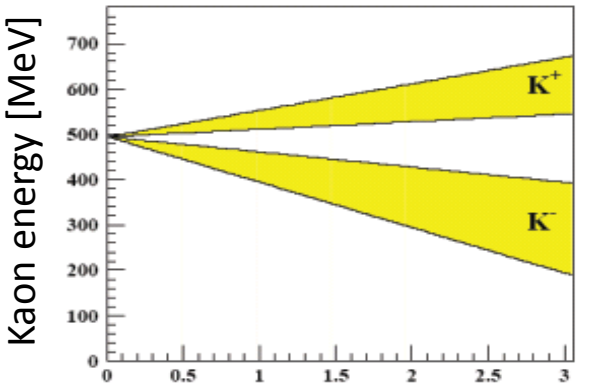
Is there a Kaonic bound state?

Outline

- Introduction
  - Interaction between K^- and Nucleon
  - The Λ(1405)
  - The Kaonic Bound state in theory and experiment
- Results for exclusive measurement in p + p
  - Λ(1405) at HADES
  - KNN with FOPI and HADES
- Summary
- Outlook

K–N Interaction

Kaons in Medium

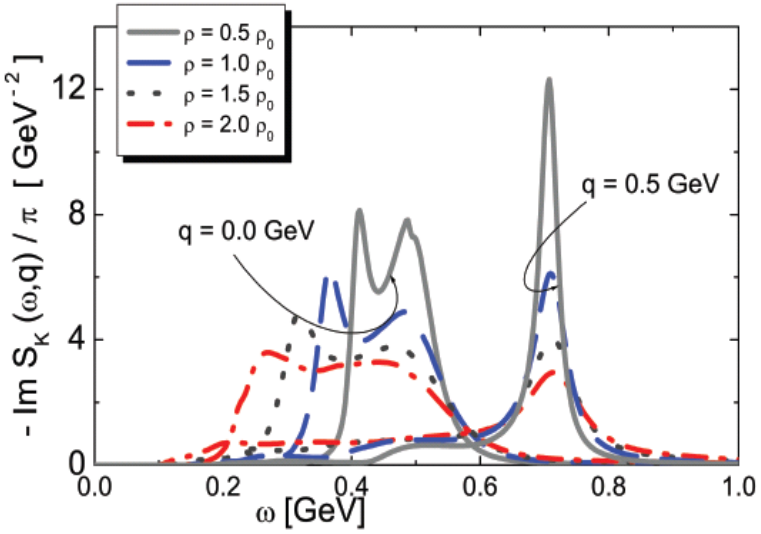


K^+ : Repulsive Interaction

K^- : Attractive Interaction

C. Sturm, Diss. TUD 2001

$\bar{K}$ Spectral Function



Lutz, Prog.Part.Nucl.Phys, 53 125-136

Coupling of $\bar{K}$ to Resonances

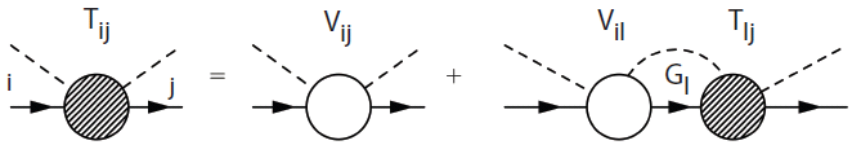
$$\Sigma + \pi \leftrightarrow \Lambda(1405) \leftrightarrow \bar{K} + N$$
$$\Lambda + \pi \leftrightarrow \Sigma(1385) \leftrightarrow \bar{K} + N$$

Resonances close to $\bar{K}$N threshold → Chiral Perturbation cannot be applied

Coupled Channel Calculation

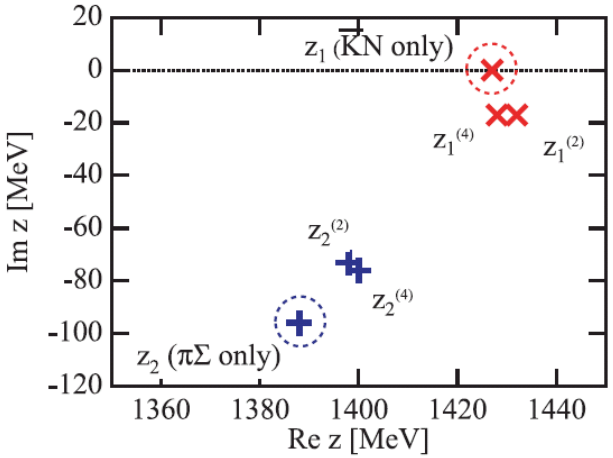
Self Consistent Bethe-Salpeter Equation

$$T_{ij}(\sqrt{s}) = V_{ij}(\sqrt{s}) + V_{il}(\sqrt{s})G_l(\sqrt{s})T_{lj}(\sqrt{s})$$



T.Hyodo,W.Weise,Phys.Rev.C77 (2008)

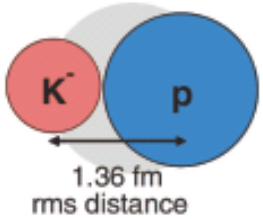
Chiral Potential



T.Hyodo,W.Weise,Phys.Rev.C77 (2008)

Phenomenological Potential

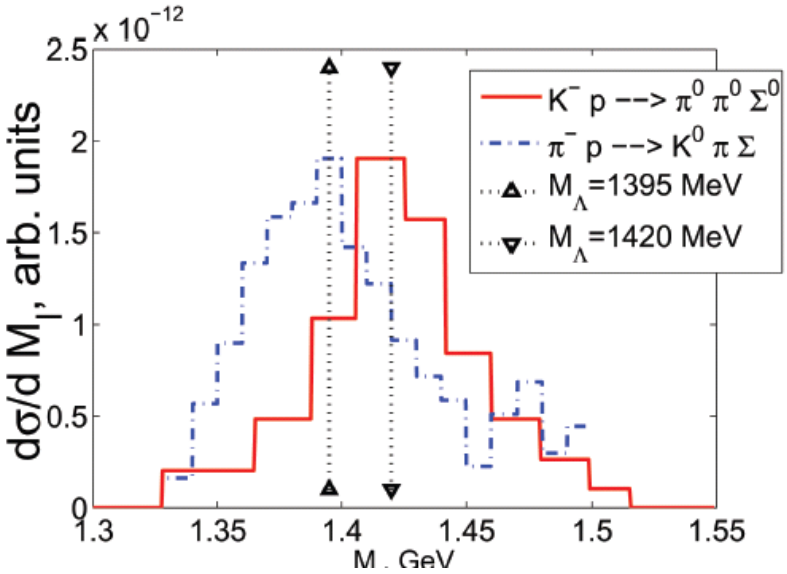
Quasi bound state of K^-p
via attractive I=0 interaction



J. Esmaili, Y.Akaishi, T. Yamazaki Phys.Lett. B 686,23
J. Esmaili, Y.Akaishi, T. Yamazaki Phys.Rev. C 83

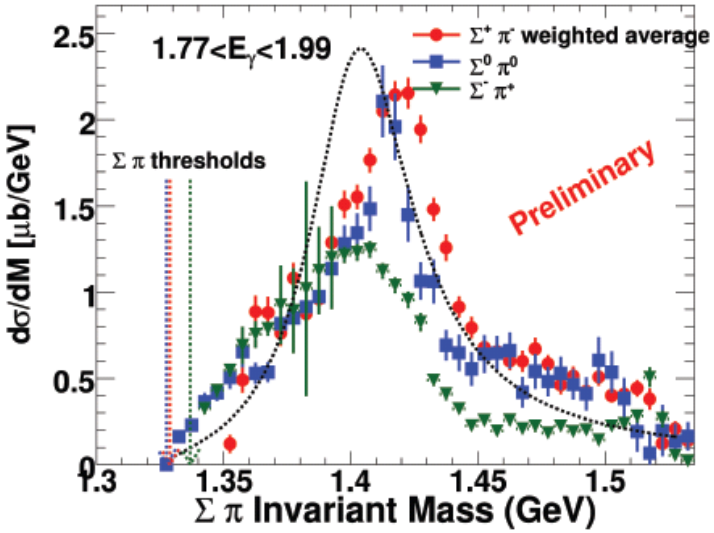
Λ(1405) Measurements

π⁻ / K⁻ induced production



Thomas et. al., Nucl.Phys. B56:15-45,1973
S.Prakhov, Phys.Rev. C79:034605,2004

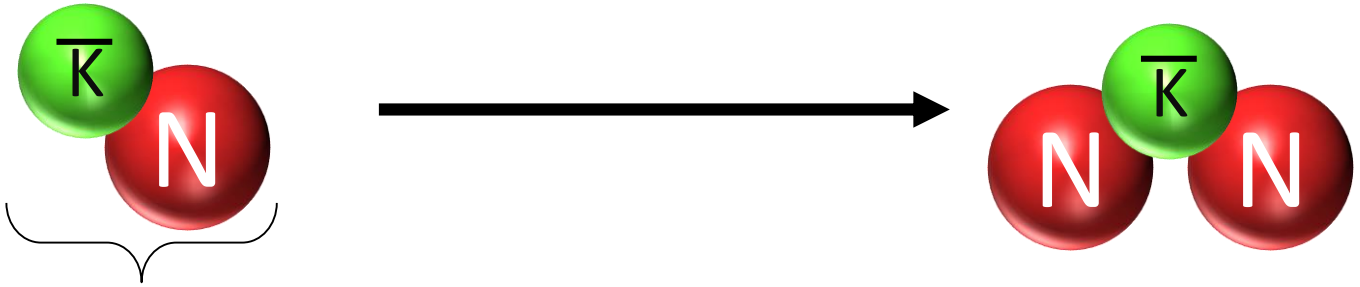
γ induced production



K.Moriya R.Schumacher
Nucl.Phys. A 835:325-328,2010

Different initial reactions may couple different to poles of Λ(1405)

Kaonic Cluster



Part of the Λ(1405) Resonance

Theoretical Predictions

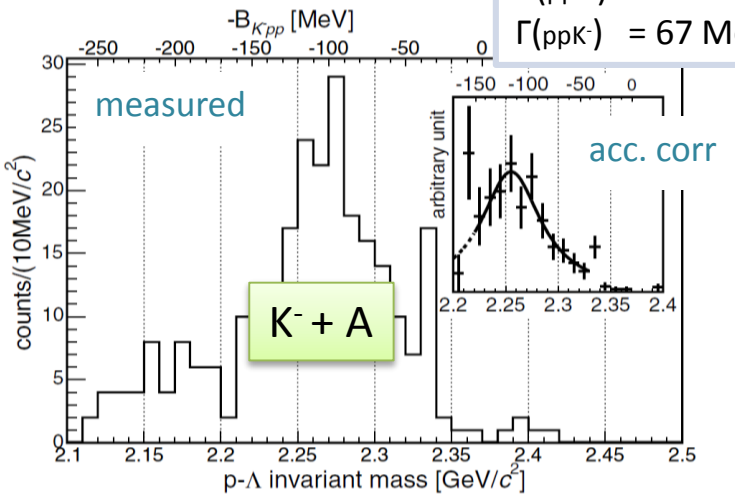
	Chiral, energy dependent				
	var. [DHW09, DHW08]	Fad. [BO12b, BO12a]	var. [BGL12]	Fad. [IKS10]	Fad. [RS14]
BE	17–23	26–35	16	9–16	32
Γ_m	40–70	50	41	34–46	49
Γ_{nm}	4–12	30			
	Non-chiral, static calculations				
	var. [YA02, AY02]	Fad. [SGM07, SGMR07]	Fad. [IS07, IS09]	var. [WG09]	var. [FIK+11]
BE	48	50–70	60–95	40–80	40
Γ_m	61	90–110	45–80	40–85	64–86
Γ_{nm}	12			~20	~21

Binding Energy (BE):
10-100 MeV
Mesonic Decay (Γ_m)
30-110 MeV
Non-Mesonic Decay (Γ_{nm})
4-30 MeV

Experimental Results on ppK$^-$

FINUDA

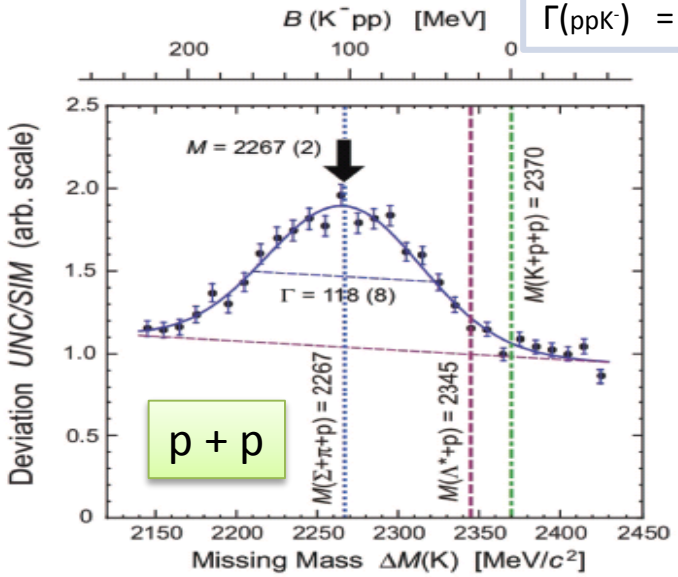
M(ppK$^-$) = 2.255 GeVc^{-2}
B(ppK$^-$) = 115 MeV
Γ(ppK$^-$) = 67 MeVc^{-2}



M. Agnello et al.
Phys.Rev.Lett.**94** (2005)

DISTO

M(ppK$^-$) = 2.267 GeVc^{-2}
B(ppK$^-$) = 103 MeV
Γ(ppK$^-$) = 118 MeVc^{-2}

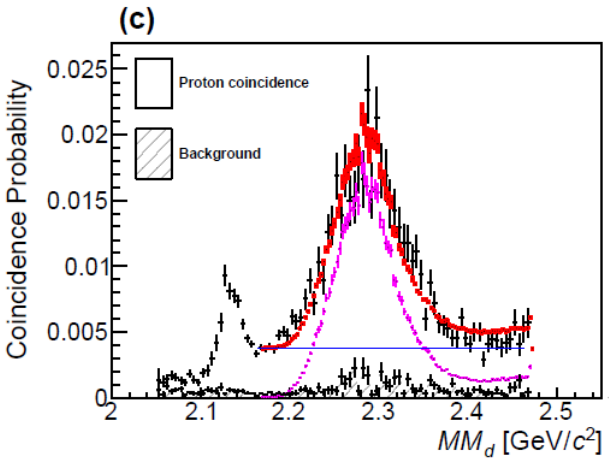


T. Yamazaki et al.
Phys.Rev.Lett.**104,** (2010)

Newest J-Parc Results

E-15 JParc

π^- + d

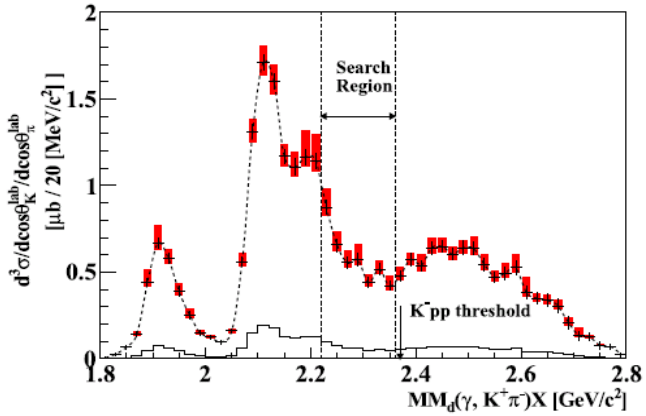


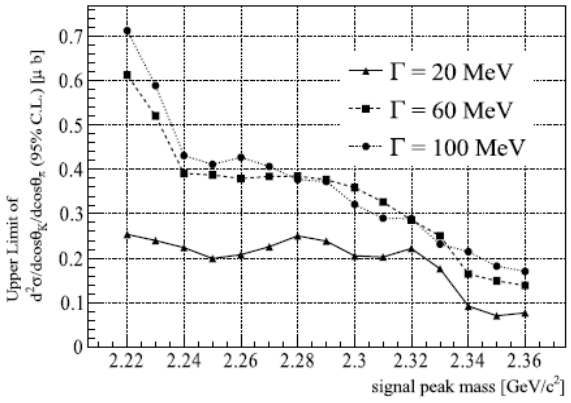
$M(ppK^-) = 2.27\ GeVc^{-2}$
$B(ppK^-) = 95\ MeV$
$\Gamma(ppK^-) = 162\ MeVc^{-2}$

Y. Ichikawa et al.
Prog. Theor. Exp. Phys. 2013

LEPS/ SPRING8

γ + d



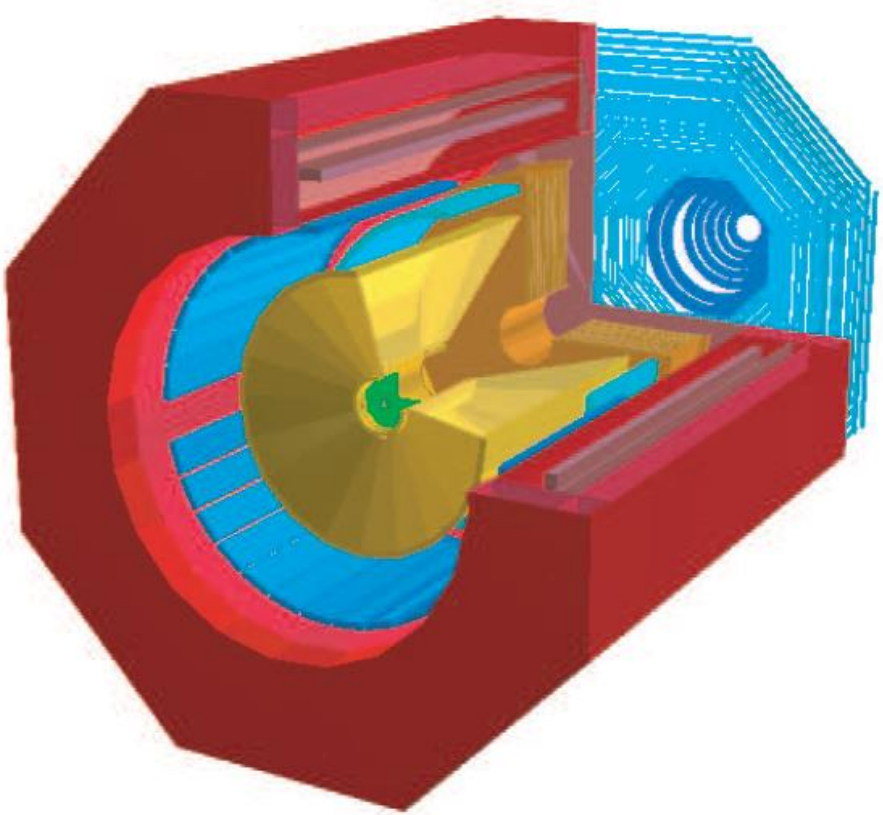


A.O. Tokayasu et al.
Phys.Lett. B728, (2014)

Experimental Data

The FOPI Experiment

SIS18 GSI Darmstadt



Beam Energy: 3.1 GeV

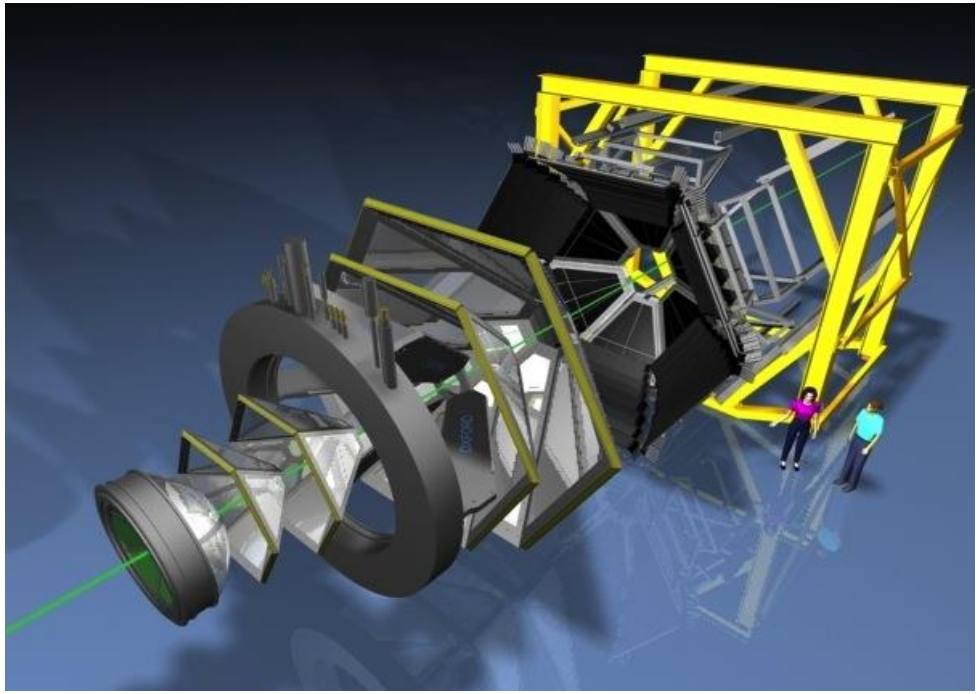
- Fixed-target Setup
- Full azimuthal coverage, 5˚- 110˚ in polar angle
- Momentum resolution ≈ 7% - 15 %
- Particle identification via dE/dx & ToF

Trigger Detector – SiΛViO:

Λ – Enhancement: $14.1 \pm 7.9(stat)^{+4.3}_{-0.6}$

The HADES experiment

High **A**cceptance **Di**-electron **S**pectrometer
GSI, Darmstadt



Beam Energy: 3.5 GeV

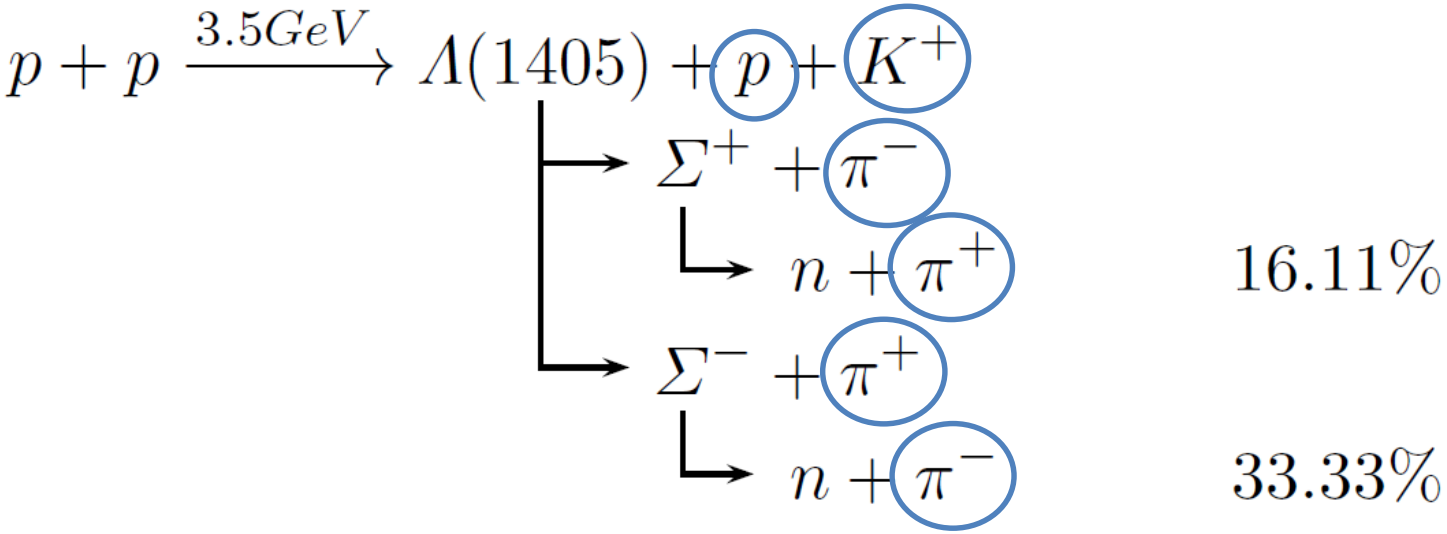
- Fixed-target Setup
- Full azimuthal coverage, 15˚- 185˚ in polar angle
- Momentum resolution ≈ 1% - 5 %
- Particle identification via dE/dx & ToF

HADES Coll. (G. Agakishiev et al.),
Eur. Phys. **J. A41** (2009)

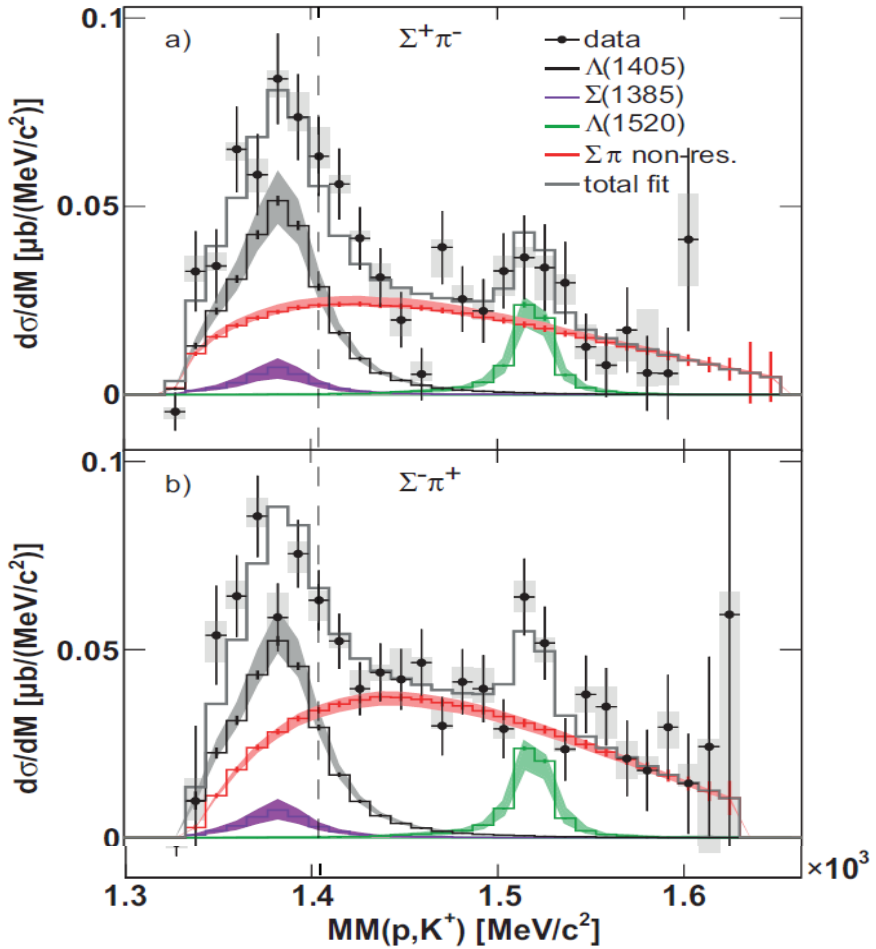
Λ(1405)

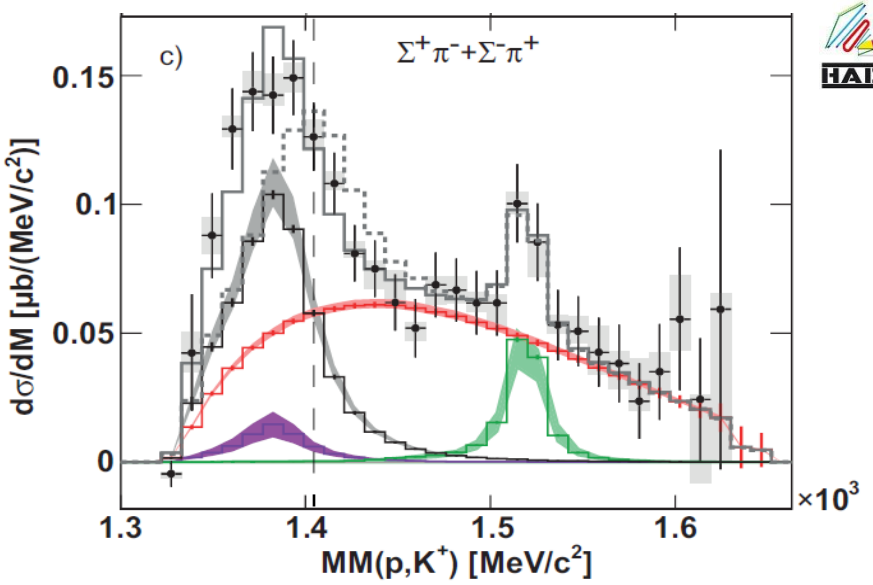
Hades reconstruction

Reaction


$p + p \xrightarrow{3.5GeV} \Lambda(1405) + p + K^+$
$\Sigma^+ + \pi^-$
$n + \pi^+$
16.11%
$\Sigma^- + \pi^+$
$n + \pi^-$
33.33%

Results

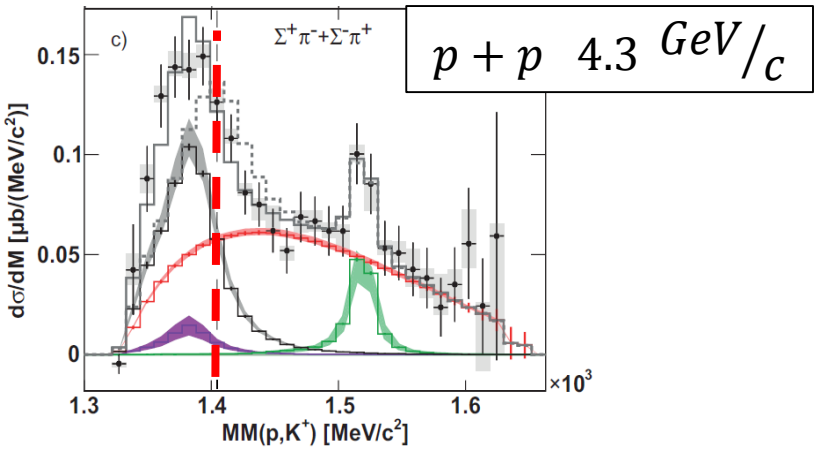


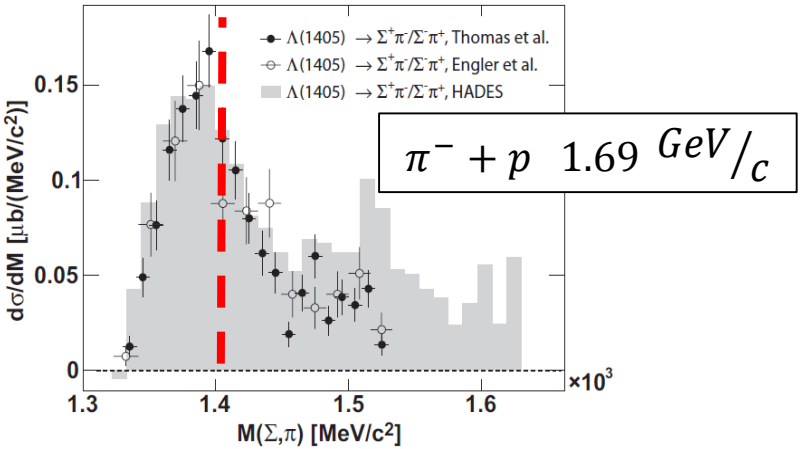


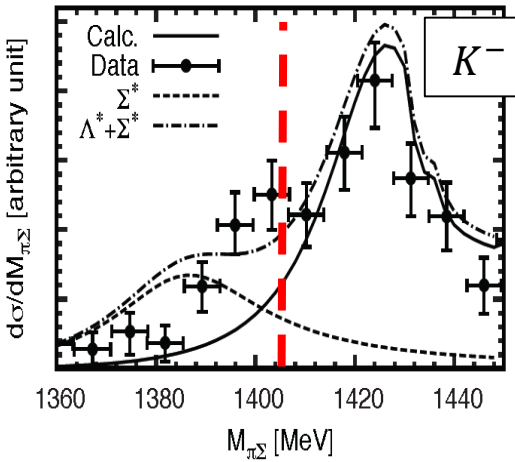
Reaction:	*Cross section*
$p+p \to \Lambda(1405)+p+K^+$	$9.2 \pm 0.9 \pm 0.7^{+3.3}_{-1.0}$ μb
$p+p \to \Sigma(1385)^0+p+K^+$	$5.56 \pm 0.48^{+1.94}_{-1.06}$ μb
$p+p \to \Lambda(1520)+p+K^+$	$5.6 \pm 1.1 \pm 0.4^{+1.1}_{-1.6}$ μb
$p+p \to \Sigma^+ + \pi^- + p + K^+$	$5.4 \pm 0.5 \pm 0.4^{+1.0}_{-2.1}$ μb
$p+p \to \Delta^{++}(1232)+\Sigma^- + K^+$	$7.7 \pm 0.9 \pm 0.5^{+0.3}_{-0.9}$ μb

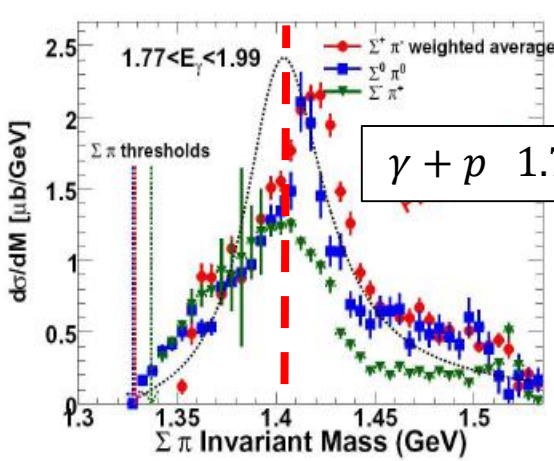
HADES coll. (G. Agakishiev et al.) Phys. Rev. **C 87,** 025201 (2013)

HADES Signal in the Context







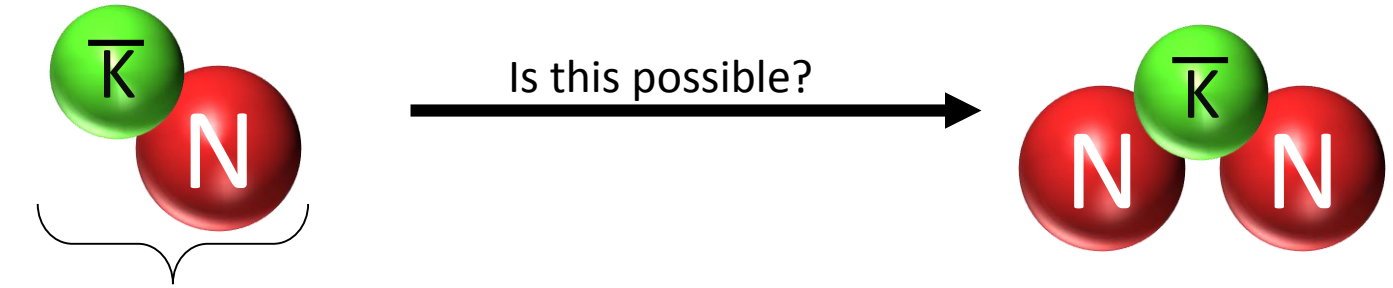


1405 MeV/c²

D.W. Thomas et al. Nuclear Physics **B56** (1973)
A. Engler et al. Phys. Rev. Lett. **15,** 5 (1965)

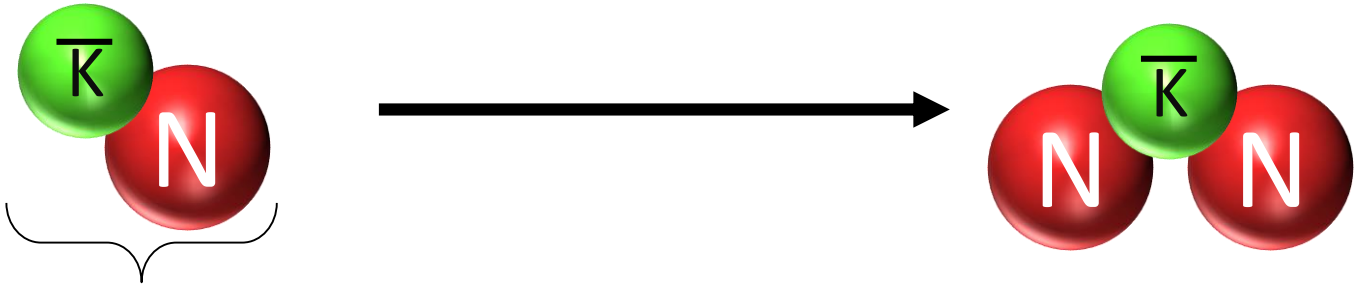
O. Braun et al. Nuclear Physics **B129** (1977)
R. Schumacher Nucl.Phys. **A835** (2010)

Kaonic Cluster



Part of the Λ(1405) Resonance

Kaonic Cluster



Part of the Λ(1405) Resonance

$$p + p \longrightarrow \underbrace{\Lambda(1405) + p}_{ppK^- + K^+} + K^+$$

$$ppK^- \longrightarrow \Lambda + p$$

Physical Background:

$$p + p \longrightarrow \Lambda + p + K^+$$

$$p + p \longrightarrow N^{*+} + p$$

$$N^{*+} \longrightarrow \Lambda + K^+$$

N^{*+} - Resonances

	Mass [GeV/c^2]	Width [GeV/c^2]	$\Gamma_{\Lambda K}/\Gamma_{All}$ %
$N(1650)S_{11}$	1.655	0.150	3-11
$N(1710)P_{11}$	1.710	0.200	5-25
$N(1720)D_{13}$	1.720	0.250	1-15
$N(1875)D_{13}$	1.875	0.220	4±2
$N(1880)P_{11}$	1.870	0.235	2±1
$N(1895)S_{11}$	1.895	0.090	18±5
$N(1900)P_{13}$	1.900	0.250	0-10

J. Beringer
Phys.Rev. D86 (2012)

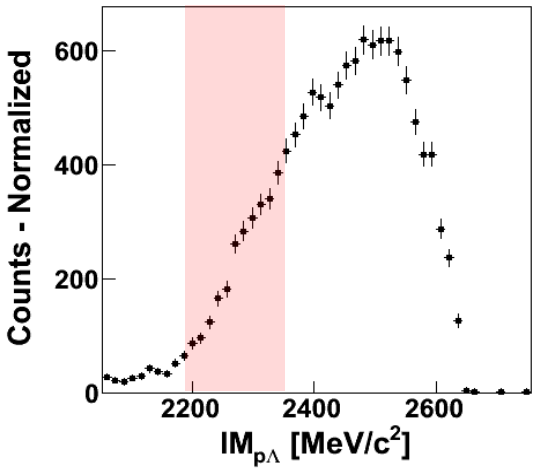
Total Data Set

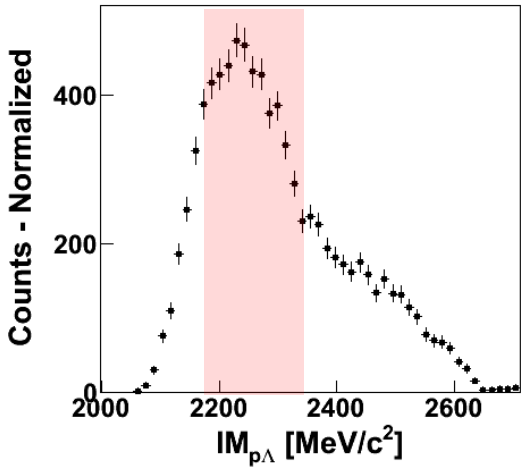
Hades Data E_{beam}=3.5 GeV

Had. Wall Data E_{beam}=3.5 GeV

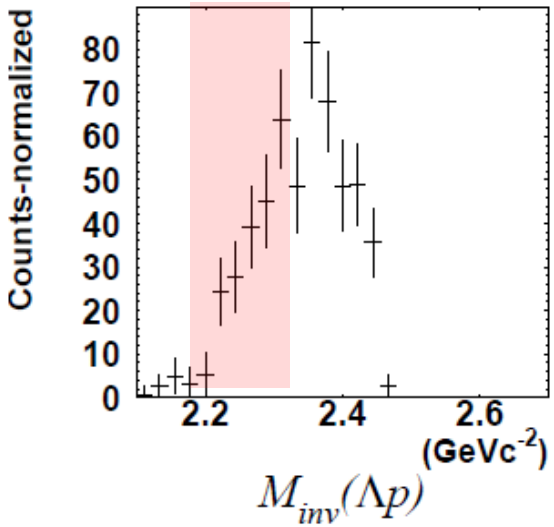
FOPI Data E_{beam}=3.1 GeV

Total Number of exclusive Events: 21000





Total Number of exclusive Events: 903



No Peak Visible
No Signal?

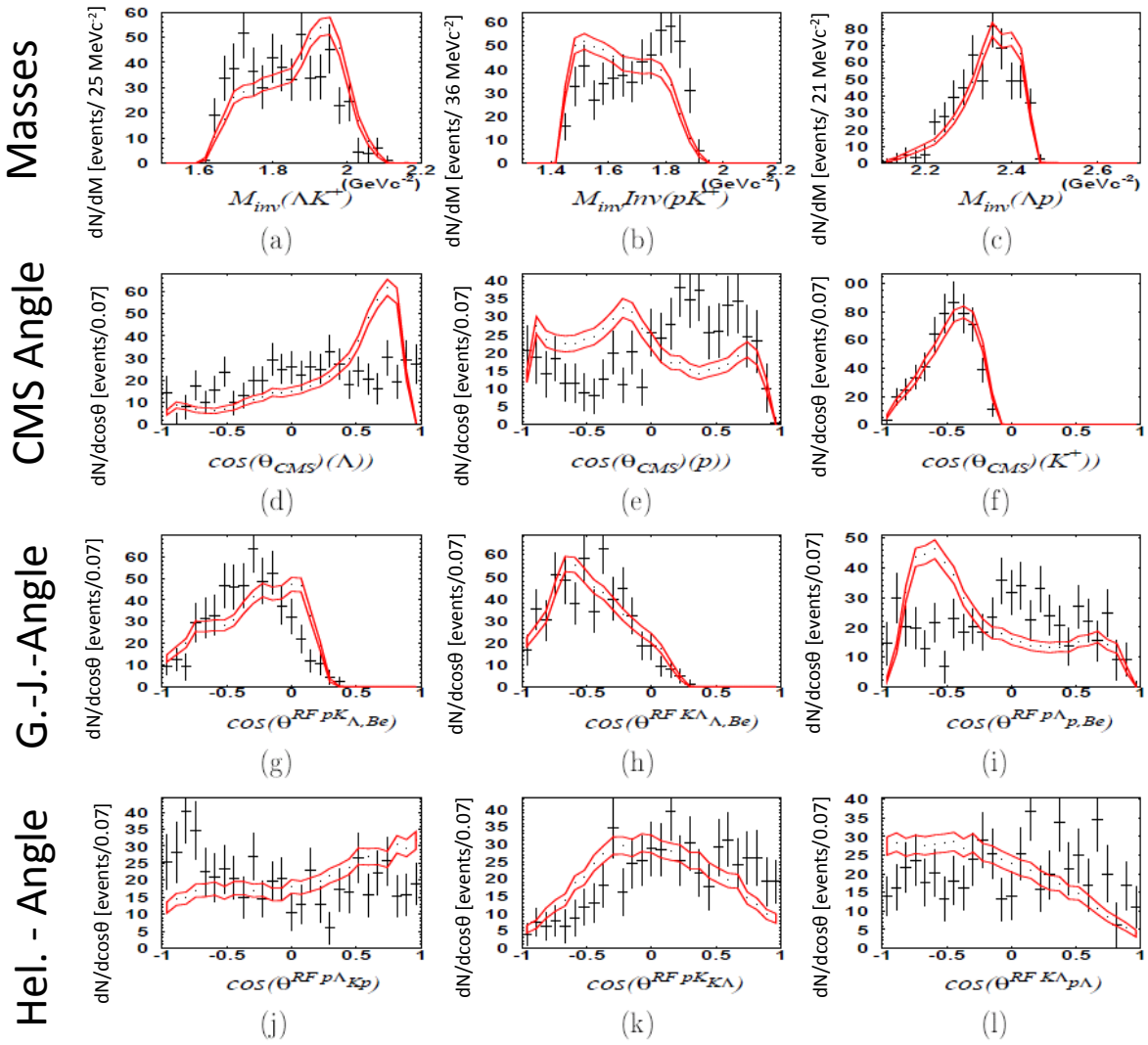
R. Münzer, Hyperfine Interaction, in print
G. Agakishiev,Phys.Lett. B742 (2015) 242-248

Model Comparison

Phase Space Simulation

Partial Wave Analysis

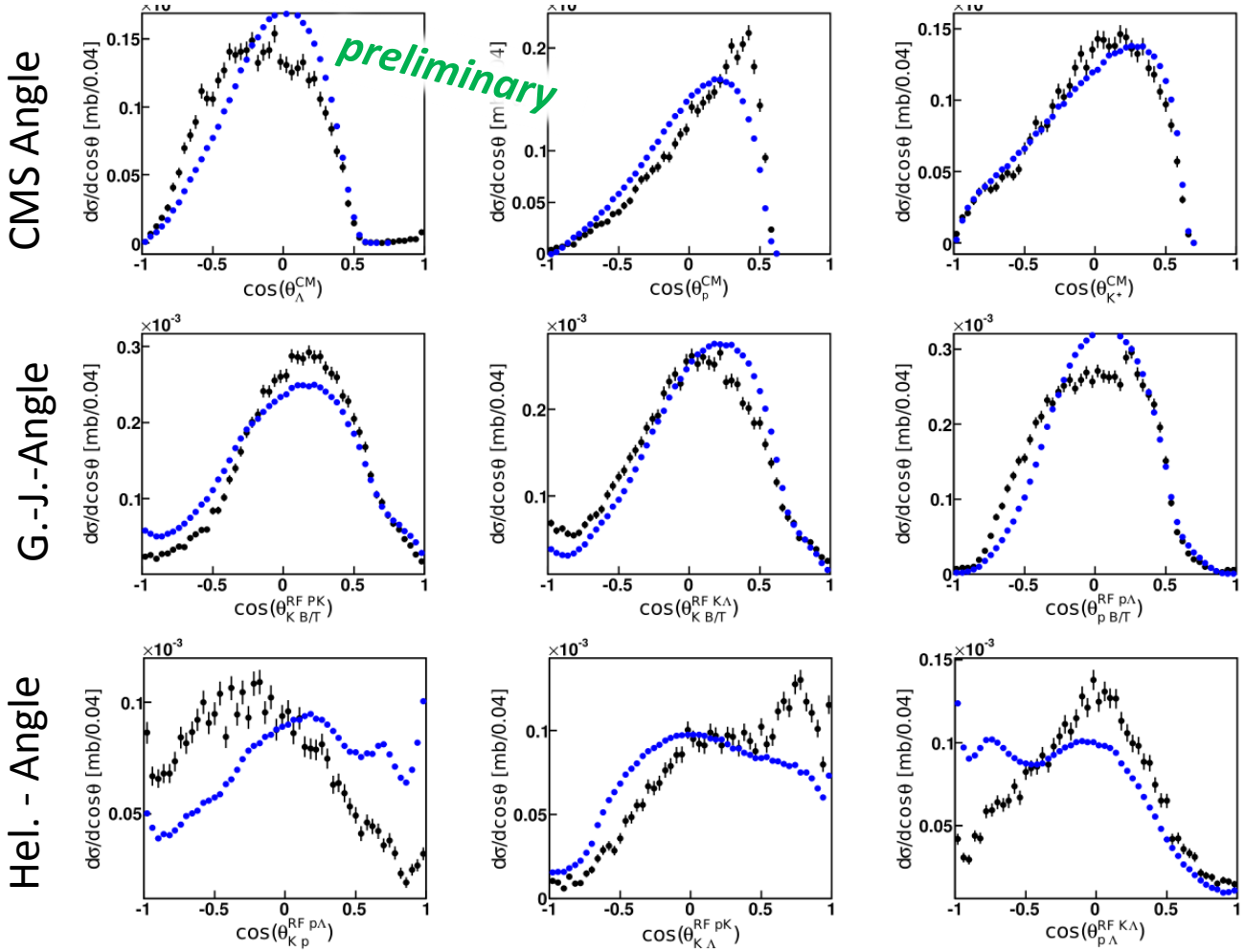
Phase Space Simulation



✚ Experimental Data

pp → p K^+ Λ Phase Space

Phase Space Model



Inside HADES acceptance

- Experimental Data
- pp→p K^+ Λ Phase Space

Partial Wave Analysis

Bonn-Gatchina PWA Framework

A. Sarantsev et.al., Eur.Phys J A 25 2005

Cross-section Decomposition

$$d\sigma = \frac{(2\pi)^4 |A|^2}{4|k|\sqrt{s}} d\phi(P, q_1, q_2, q_3), \qquad P = k_1 + k_2$$

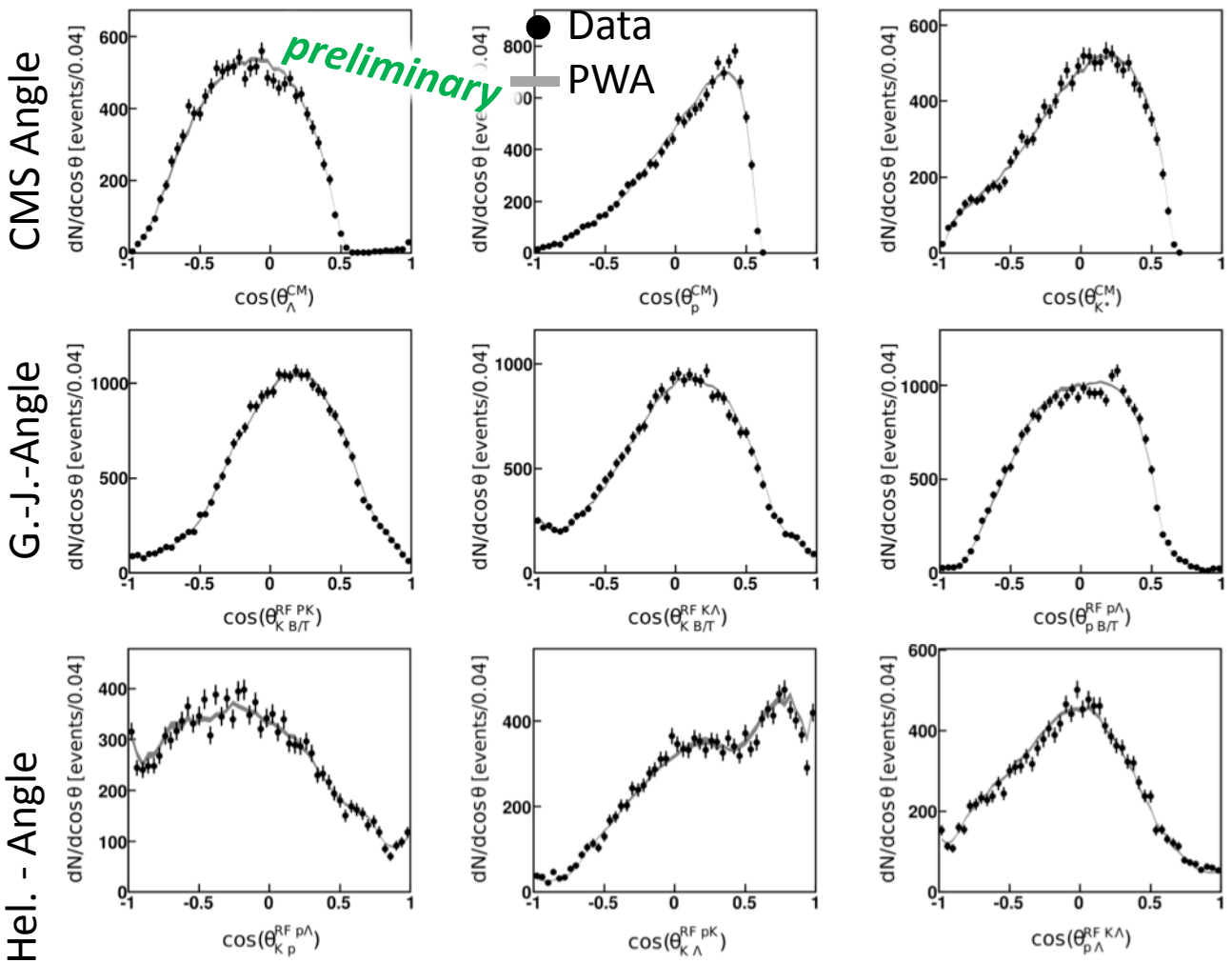
A : reaction amplitude A $\propto$ $A \propto A^{\alpha}_{tr}$ (s) (Transition amplitude of wave α)
k : 3-momentum of the initial particle in the CM
$s - P^2$: $(k_1 + k_2)^2$
$d\phi(P, q_1, q_2, q_3)$: invariant three-particle phase space

Parameterization of the Transition

$$A^{\alpha}_{tr}(s) = (a^{\alpha}_1 + a^{\alpha}_3 \sqrt{s}) e^{a^{\alpha}_2}$$

a^{α}_1 Constant amplitude
a^{α}_2 Phase
a^{α}_3 Energy dependent amp.

Four Best PWA Solutions

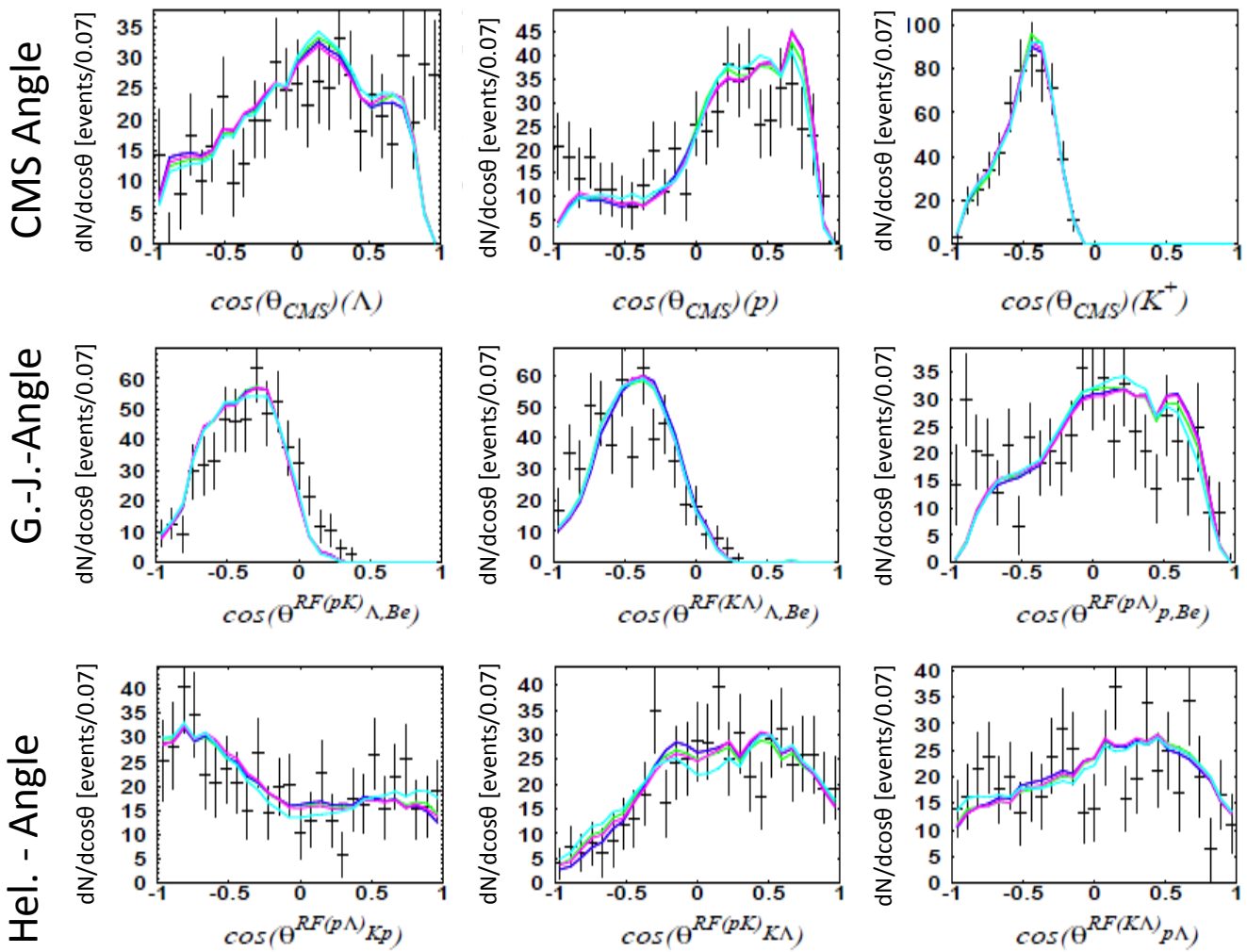


Inside HADES acceptance

Measured Data

PWA solutions

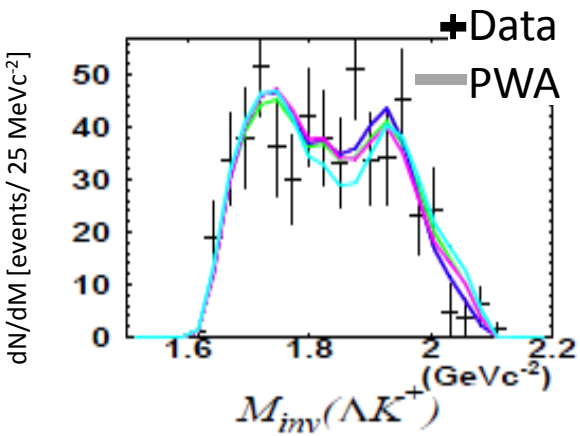
PWA Results

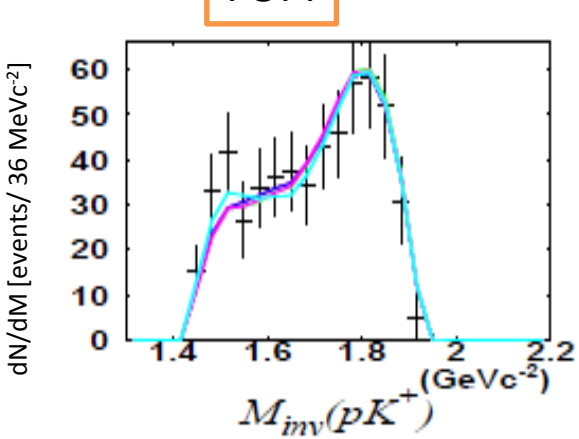


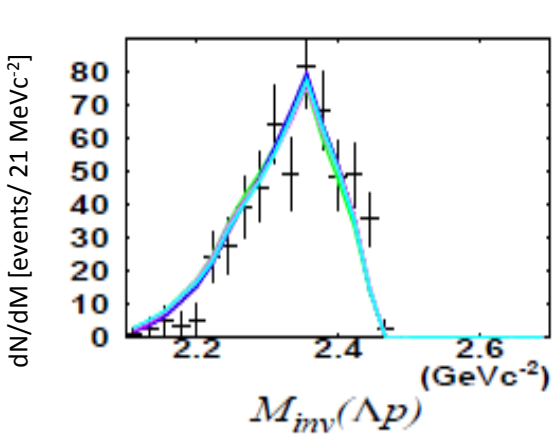
- Experimental Data
- Solution A
- Solution B
- Solution C
- Solution D
- Solution E

Four Best PWA Solutions

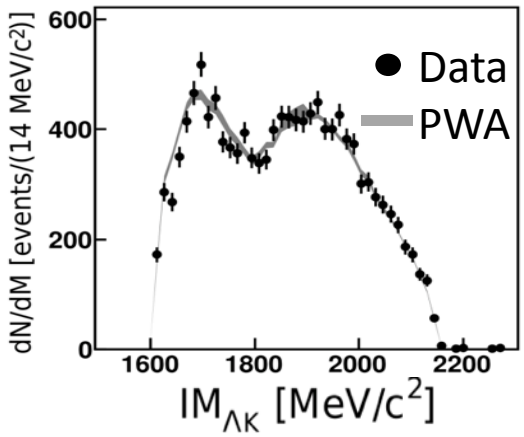
FOPI

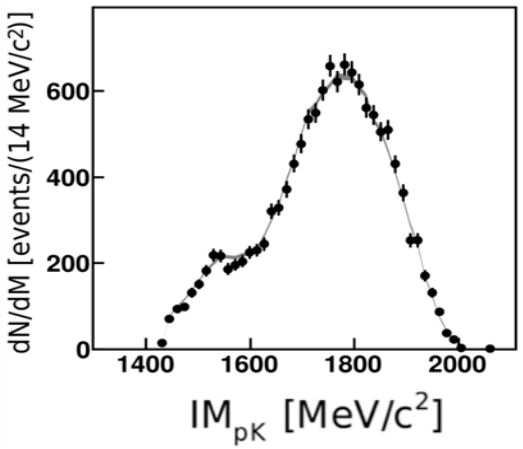


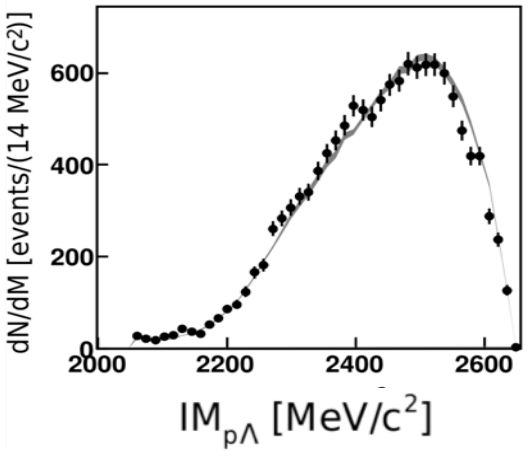




HADES







Upper Limit of ppK^- Contribution

ppK^- Upper Limit Determination

-> ppK^- Waves include in BG-PWA

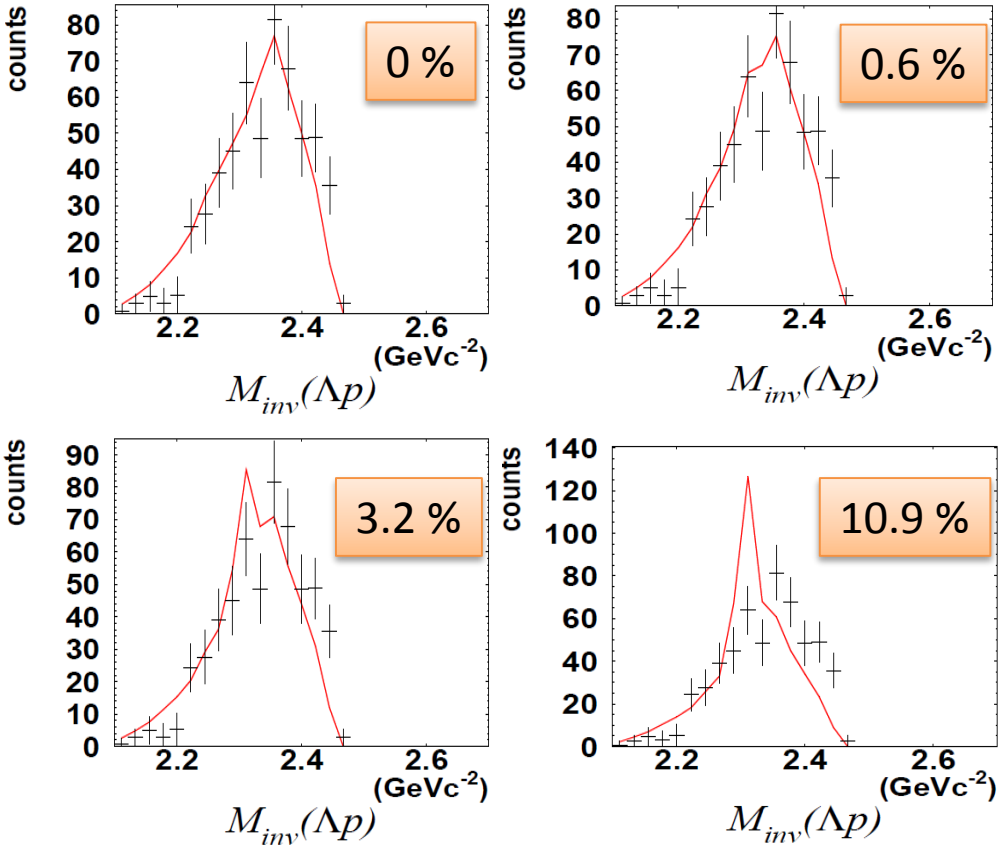
-> Mass and Width fixed

-> Background for 5 best solution without ppK^-

-> Stepwise increase of Amplitude (a_1)

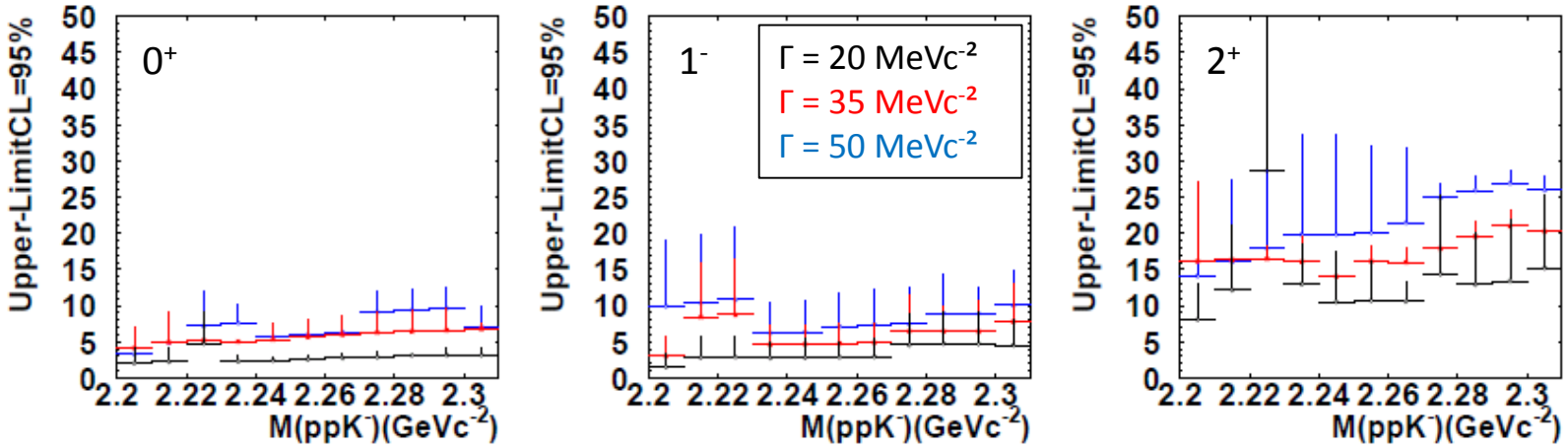
-> Phase Parameter free (a_2)
=> Optimal amount of Interference

Exclusion limit:
Confidence Level (95%) (CL_s)



M(ppK^-) = 2.305 GeVc^{-2} Γ(ppK^-)=20 MeVc^{-2}

ppK^- Upper Limit Determination



$p + p \rightarrow p + K^+ + \Lambda$
Total Cross Section

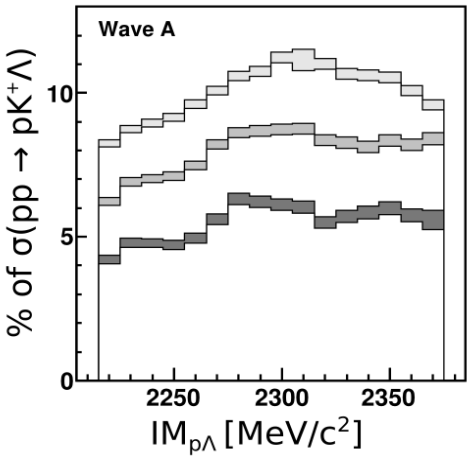
$$\sigma_{pK^+\Lambda} = 41.0 \pm 12.8 \mu b$$

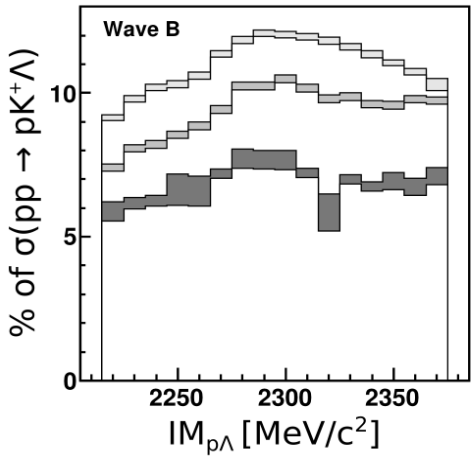
Interpolated from literature

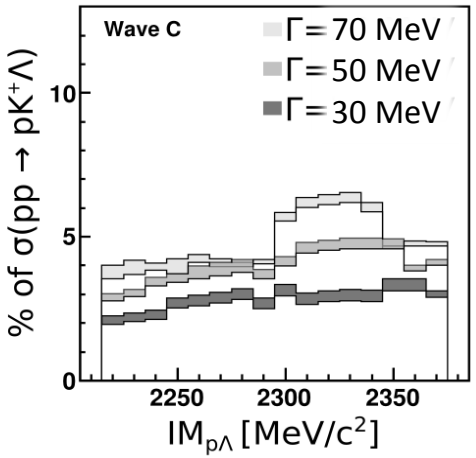
Upper Limit Cross Section

Γ (MeVc^{-2})	Cross Section (μb)
20	$7.6 \pm 1.2^{-3.5}$ - $22.4 \pm 3.6^{-10.7}$
35	$6.3 \pm 1.7^{-0.6}$ - $9.5 \pm 2.6^{-0.9}$
50	$10.2 \pm 1.8^{-4.5}$ - $11.6 \pm 3.4^{-0.6}$
60	$11.2 \pm 1.9^{-5.0}$ - $33.8 \pm 5.2^{-16.9}$
80	$11.4 \pm 2.7^{-3.8}$ - $35.9 \pm 5.7^{-17.4}$

Upper Limit







Measured total cross-section: $\sigma_{pK^+\Lambda} = 38.12 \pm 0.43^{+3.55}_{-2.83} \pm 2.67(p+p\text{-}error) - 2.9(background)\ \mu b$

Upper limit of ppK^- Cross Section:

Γ ($MeVc^{-2}$)	Cross Section (μb)
0^+	1.9 – 3.9
1^-	2.1 – 4.2
2^+	0.7 – 2.1

Production Cross Section Λ(1405)

$9.2 \pm 0.9 \pm 0.7\ ^{+3.3}_{-1.0}\ \mu b$

HADES coll. (G. Agakishiev et al.)
Phys. Rev. **C 87,** 025201 (2013)

Summary Λ(1405)

- Λ(1405)
  - Coupling between Σπ and K^-p: Different Coupling to final state.
  - First reconstruction of charged decay channel of Λ(1405) in p + p with HADES
  - Peak position at 1385 GeV/c^2(Best description by according simulation input)
  - Position comparable to π production, different to K^-/γ production

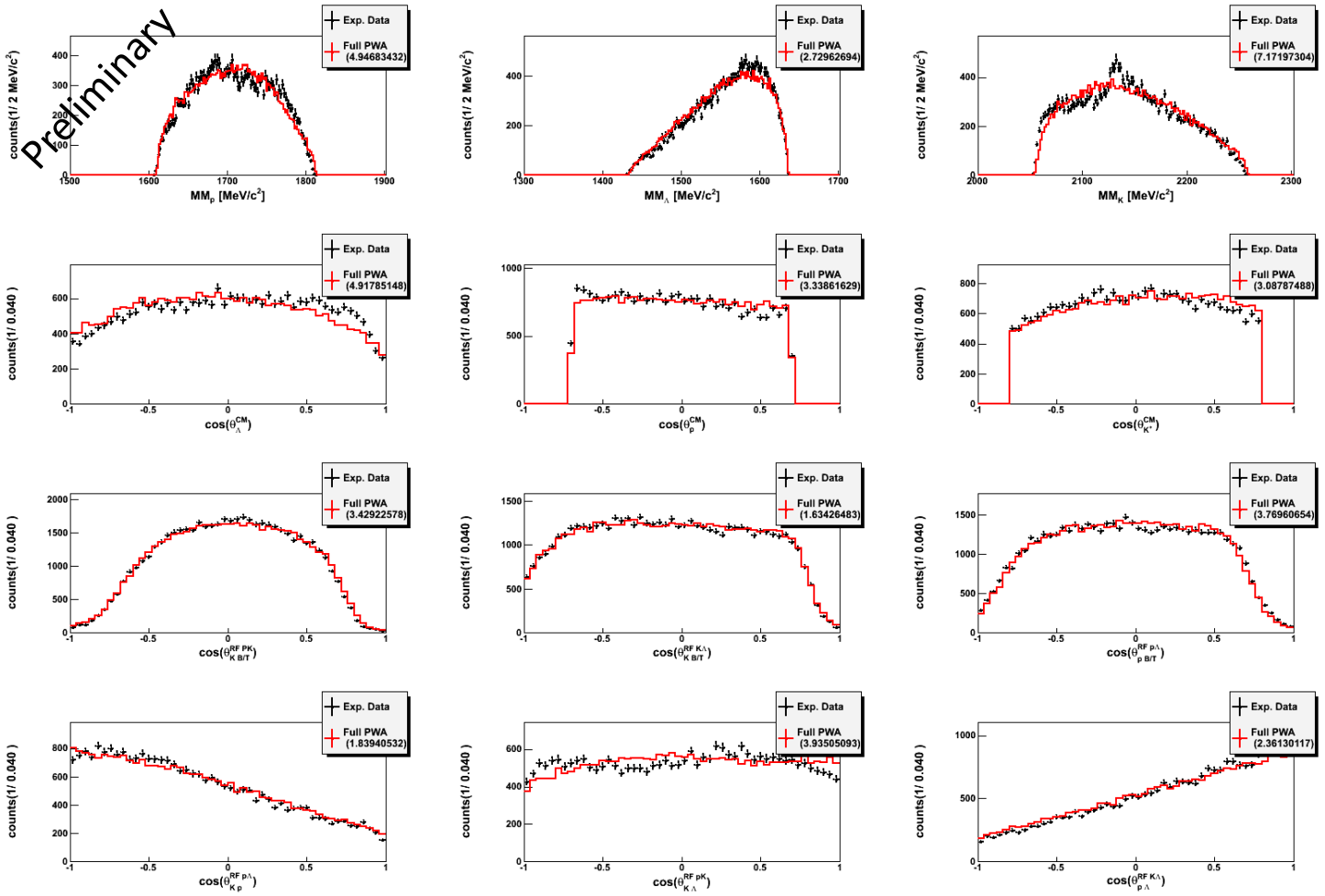
- Kaonic Bound State
  - Kaon Nucleon Bound States -> Predicted by Theory but not conclusive Properties
  - Experimental Results show different behavior
  - No Signal Visible in p + p Reaction data measured at FOPI and HADES
  - Production Mechanism has to be described by Partial Wave Analysis including Interference
  - Extraction of Upper Limit: 0.7 - 4.1 µb (HADES) 7.1 - 35.7 µb (FOPI)

Outlook

- Improvement of description Background description
- Combined Analysis

Experiment	E_B [GeV]	$pK^+\Lambda$ Statistics	ε_{ppK^-} [MeV]	Status
COSY-TOF	1.96	~160k	-104	In Preparation
DISTO	2.15	120 k	-114	Available
COSY-TOF	2.16	3.6 k	-104	Available
COSY-TOF	2.16	40 k	-104	Available
COSY-TOF	2.16	~90k	-104	In Preparation
COSY-TOF	2.25	36 k	-83	Available
COSY-TOF	2.40	1.6 k	-24	Available
DISTO	2.5	304 k	26	Available
DISTO	2.85	424 k	116	Available
FOPI	3.1	0.9 k	196	Single PWA
HADES	3.5	21 k	315	Single PWA

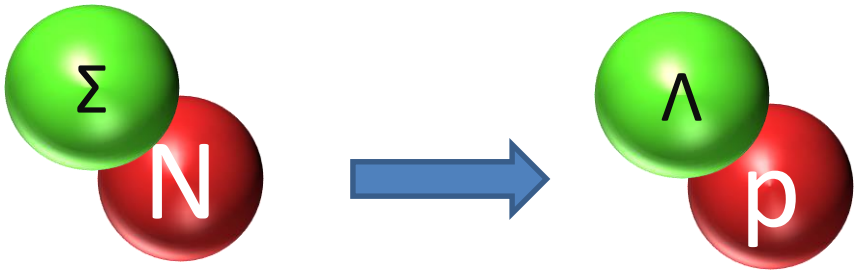
PWA Results – COSY@2.16 GeV

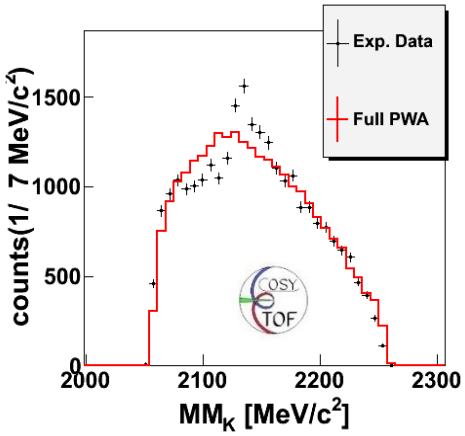


M. Roeder et al., Eur. Phys. J. A49, 157 (2013)

The ΣN Cusp Effect

Coupled Channel:





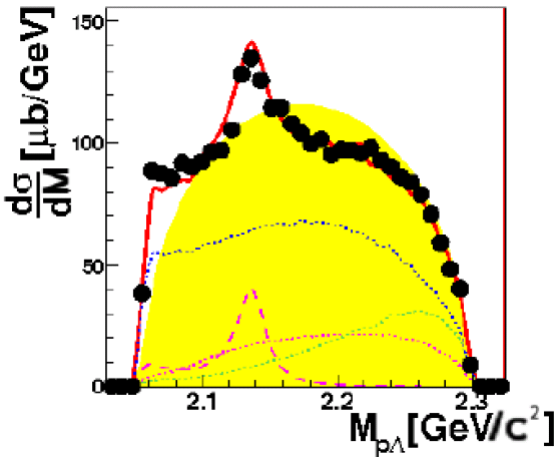
At Threshold : 2130 MeVc^{-2}

Quantum Number of Cusp: 0^+ / 1^+ (L=0,2)

Spectral Function:

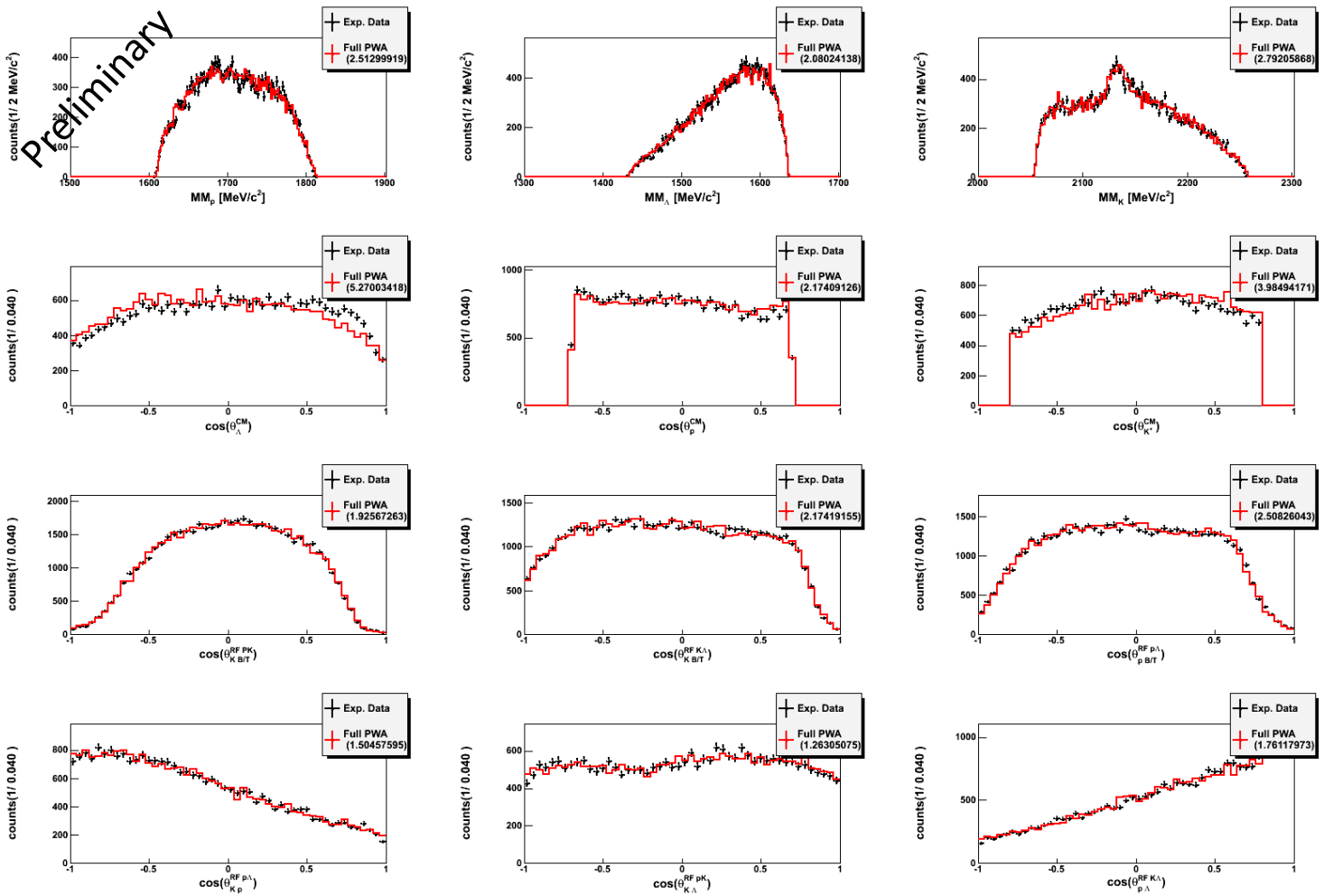
Breit Wigner

Flatté



S.Abd El-Samad, Eur.Phys.J A49(2013)

PWA Results with Cusp – COSY@2.16 GeV



M. Roeder et al., Eur. Phys. J. A49, 157 (2013)

Data Sets

Experiment	E_B [GeV]	$pK^+\Lambda$ Statistics	ε_{ppK^-} [MeV]	Status
COSY-TOF	1.96	~160k	-104	In Preparation
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FOPI	3.1	0.9 k	196	Combined PWA
HADES	3.5	21 k	315	Combined PWA

Thank You

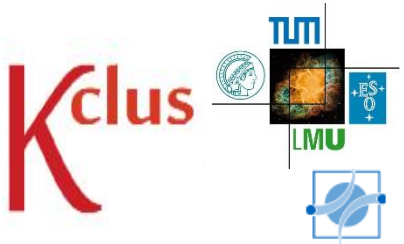
HADES Collaboration

FOPI Collaboration

DISTO Collaboration
M. Maggiora

COSY-TOF Collaboration
J. Ritman, E. Roderburg
F. Hauenstein, D. Gronzka

Bonn Gatchina Group
A. Sarantsev



K-Cluster – Excellence Cluster Universe – TU Munich
L. Fabbietti, E. Epple, P. Klose, S.Lu, J. Siebenson, D. Soliman

Backup

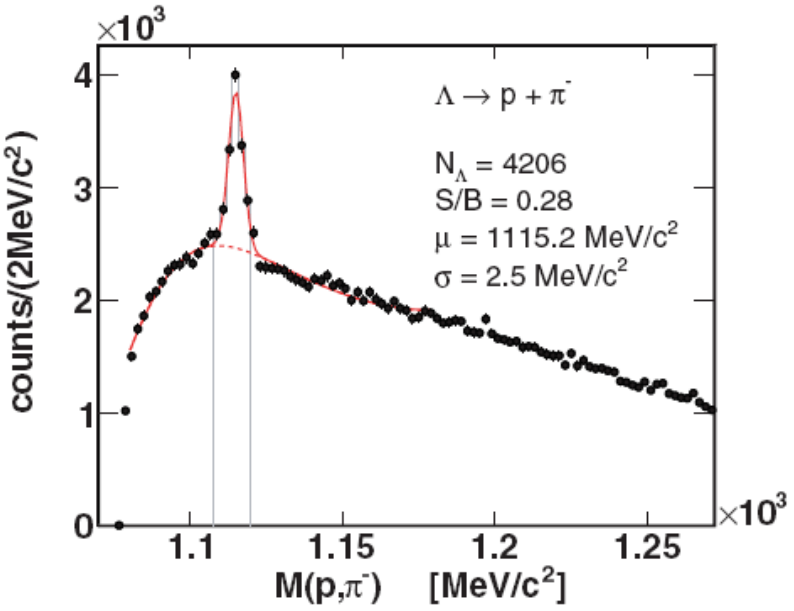
$\Sigma(1385)^{+}$

Hades reconstruction

Reconstruction

$$p(3.5\mathrm{GeV}) + p \rightarrow \Sigma(1385)^{+} + K^{+} + n$$
$$\hookrightarrow \Lambda + \pi^{+}$$
$$\hookrightarrow p + \pi^{-}.$$

1. Reconstrcut charge Particles
2. Reconstrcut Lambda Signal
3. Identify Neutron Signal via Missing Mass
4. Precise Kaon Selection



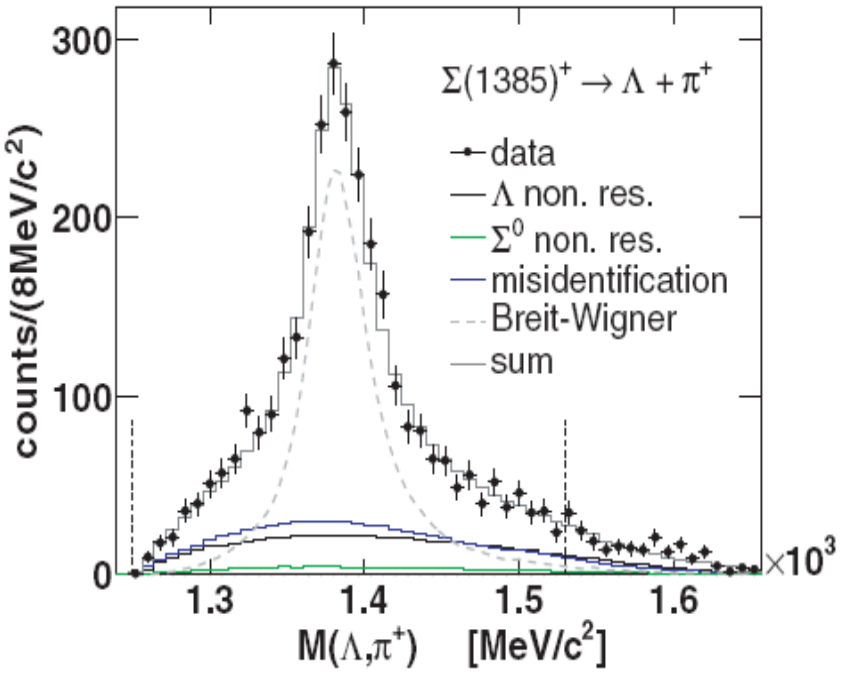
$\Sigma(1385)^+$ Signal

Reaction

$$p(3.5\mathrm{GeV}) + p \rightarrow \Sigma(1385)^+ + K^+ + n$$
$$\hookrightarrow \Lambda + \pi^+$$
$$\hookrightarrow p + \pi^-.$$

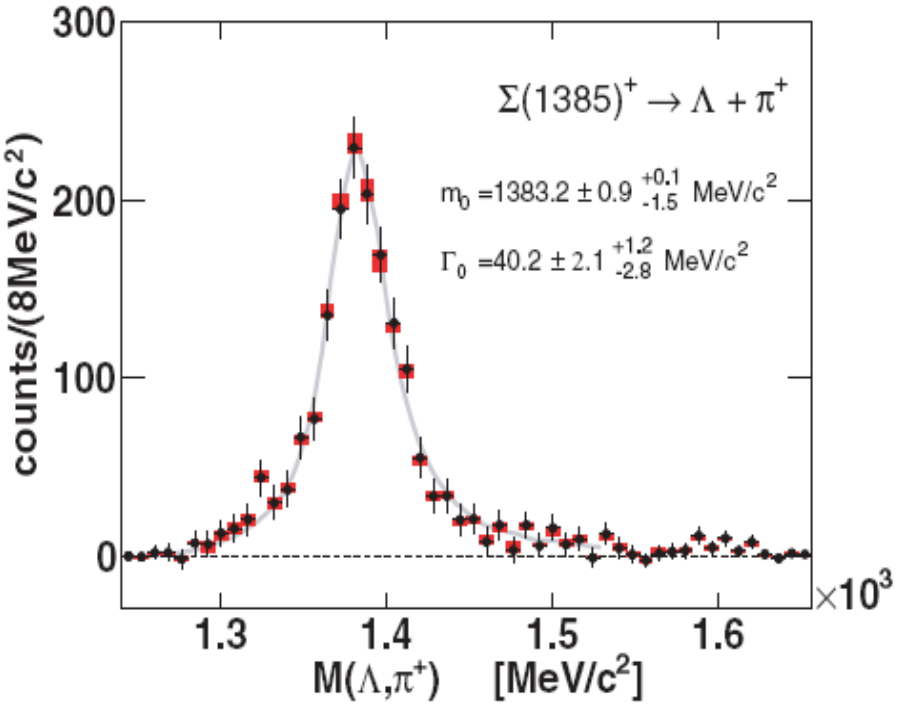
Background Contribution

- Misidentification
  Fixed by K^+ sideband analysis
- Non resonant background
  simultaneous fit



G. Agakishiev et al., Phys. Rev. C 85, 2013

$\Sigma(1385)^+$ Signal



$$\sigma_{\Sigma(1385)^+} = 22.42 \pm 0.99 \pm 1.57^{+3.04}_{-2.23}\ \mu b$$

G. Agakishiev et al., Phys. Rev. C 85, 2013

Relativistic p-wave Breit – Wigner

$$\text{Breit-Wigner} \propto \frac{q^2}{q_0^2} \frac{m_0^2 \Gamma_0^2}{\left(m_0^2 - m^2\right)^2 + m_0^2 \Gamma^2},$$

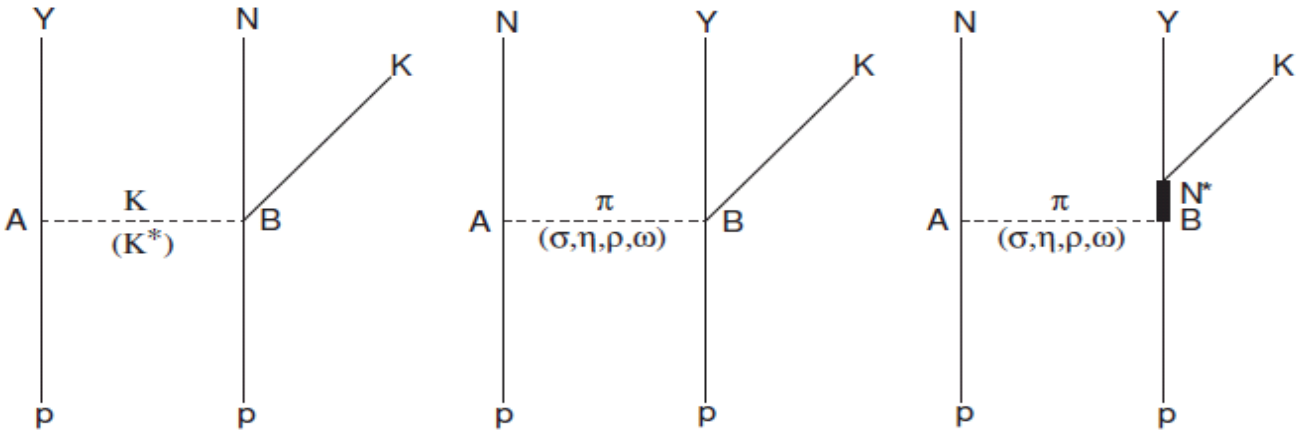
$$\Gamma = \Gamma_0 \frac{m_0 q^3}{m q_0^3} F_1(q),$$

$$F_1(q) = \frac{1 + (q_0 R)^2}{1 + (q R)^2},$$

PDG Entry

Production Mechanism

One Boson Exchange (OBE) Model



Strange boson exchange

Non strange boson exchange

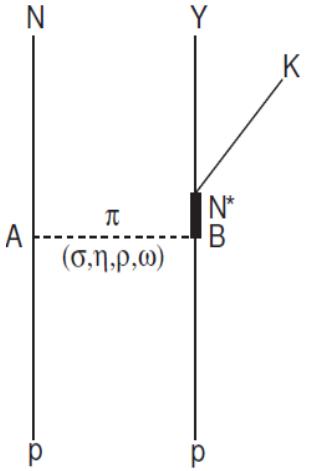
Non strange boson resonance production

E.Ferrari,S.Serio Phys.Rev. 167:1298-1308

Production Mechanism

Intermediate Resonance

$$p + p \xrightarrow{3.5GeV} \Delta^{++} + n$$
$$\hookrightarrow \Sigma(1385)^{+} + K^{+}$$
$$\hookrightarrow \Lambda + \pi^{+}$$
$$\hookrightarrow p + \pi^{-}$$



Production Mechanism

Intermediate Resonance

$$p + p \xrightarrow{3.5GeV} \Delta^{++} + n$$
$$\hookrightarrow \Sigma(1385)^{+} + K^{+}$$
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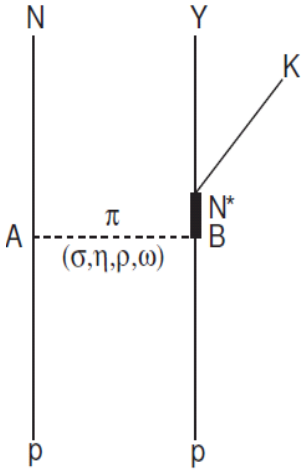
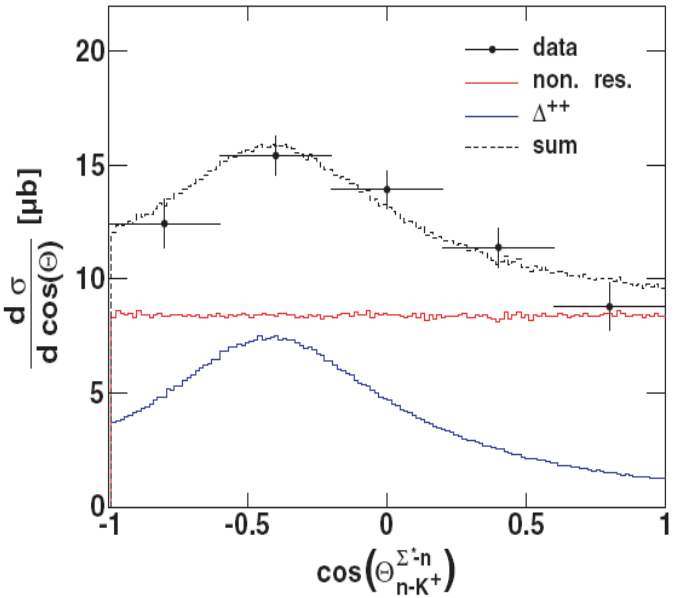


Helicity Angle



66% free production
33% resonant production via Δ(2050)*++

G. Agakishiev et al., Phys. Rev. C 85, 2013

Summary $\Sigma(1385)^+$

- Reconstructed $\Sigma(1385)^+$ signal
  - $\mathrm{m} = 1383.2 \pm 0.9^{+0.1}_{-1.5}\, MeV/c^2$
  - $\Gamma = 40.2 \pm 2.1^{+1.2}_{-2.8}\, MeV/c^2$
  - $\sigma_{\Sigma(1385)^+} = 22.42 \pm 0.99 \pm 1.57^{+3.04}_{-2.23}\, \mu b$
- Important role of resonances: 33% from $\Delta(2050)^{++}$
- Angular distribution extracted
  - Input for transport model
- Benchmark for $\Lambda(1405)$ analysis

Spectral Function

Relativistic BW distribution $\frac{d\sigma}{dm} \approx \frac{1}{(M^2 - s - i\Gamma M)}$

$\Sigma N\ CUSP : \Lambda N, \Sigma N\ coupled\ channel\ interaction$

Flatté approach: $\frac{d\sigma}{dm} \approx \frac{\sqrt{(\Gamma_{p\Lambda})}}{(M^2 - s - i(\Gamma_{p\Lambda} + \Gamma_{p\Sigma})M)}$

$\Rightarrow$ Separate Analysis By Shuna Lu

$\Gamma_{p\Lambda} = g_{p\Lambda} * q_{p\Lambda} \qquad \Gamma_{p\Sigma} = g_{p\Sigma} * q_{p\Sigma}$

$$q_{p\Lambda} = \frac{\sqrt{((s + (m_\Lambda^2 + m_p^2)) * (s - (m_p - m_\Lambda)^2))}}{2\sqrt{(s)}} \qquad q_{p\Sigma} = i\frac{\sqrt{((s + (m_\Lambda^2 + m_p^2)) * (s - (m_p - m_\Lambda)^2))}}{2\sqrt{(s)}}$$

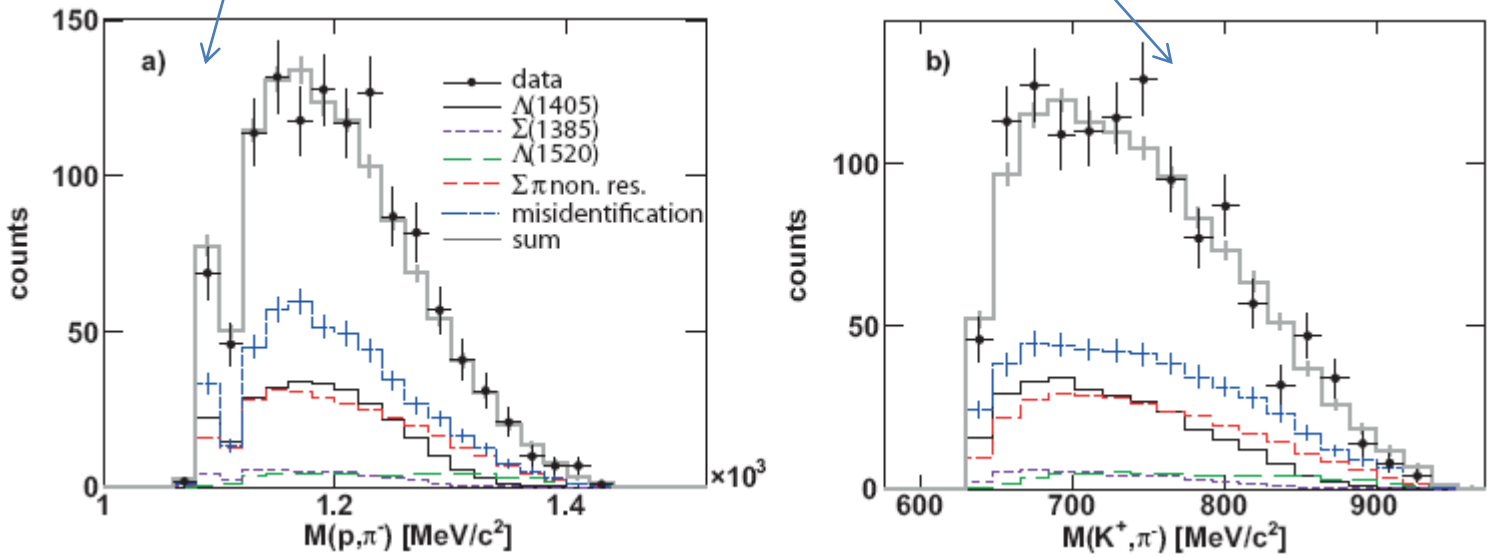
$g_{p\Lambda}, g_{p\Sigma}$ is coupling constant squared . $q_{p\Lambda}, q_{p\Sigma}$ is c.m.momentum

Background Discussion Sigma-

$$\Sigma^+ + \pi^- + p + K^+$$

$$\Sigma^+ + K^+ + \Delta^0(1232)/N(1440) \rightarrow \Sigma^+ + K^+ + (p\pi^-)$$

$$\Sigma^+ + p + K^{*0} \rightarrow \Sigma^+ + p + (K^+\pi^-)$$



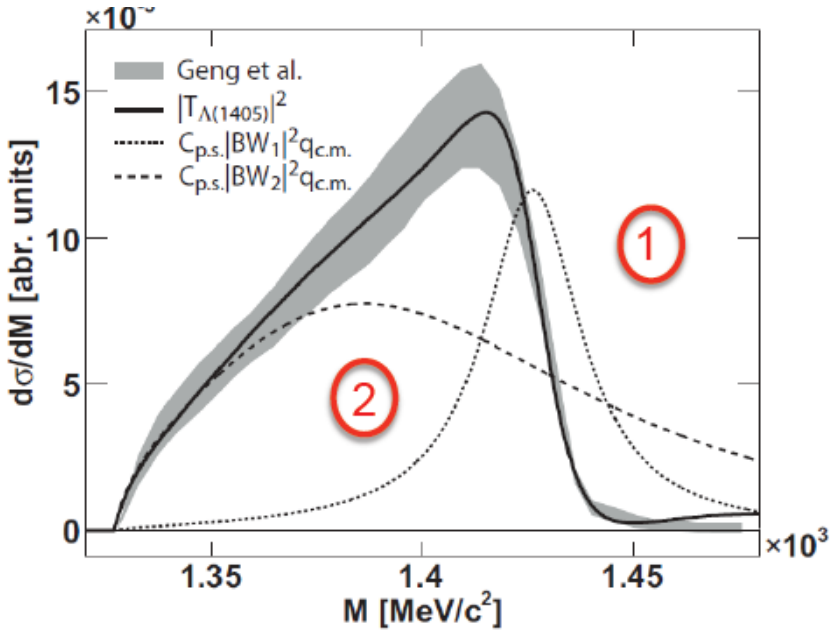
No Signature of Intermediate Resonance Visible
=> Background can be described by Free production

Interference

Double pole nature of Λ(1405) and include interference effects with non-resonant channels

Assumption:

- Parameterize Λ(1405) as coherent sum of two Breit-Wigner functions with
- $C_{p.s.}$ the available phase space
- $q_{c.m.}$ the decay momentum for πΣ
- Constrain $m_{0,i}$ and $\Gamma_{0,i}$ from latest Weise calculations (**Nucl.Phys. A881 (2012) 98-114**)



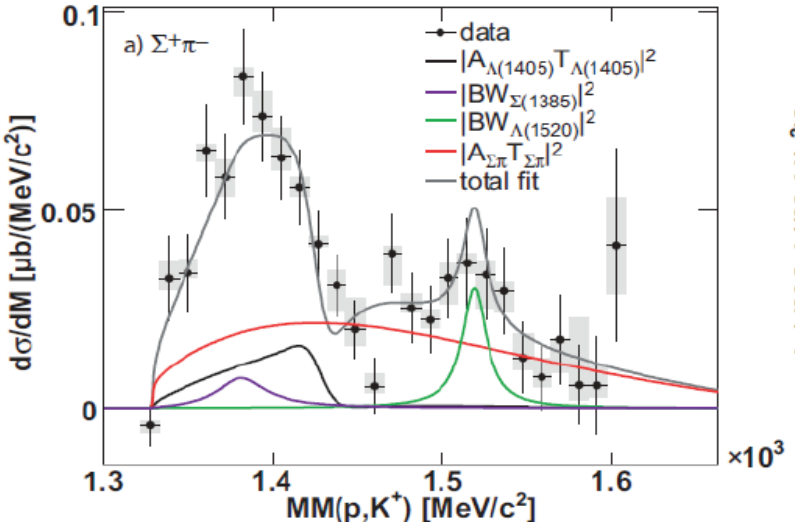
m_1	Γ_1	m_2	Γ_2	A_1/A_2	φ_1
1426	28	1375	147	0.23	206

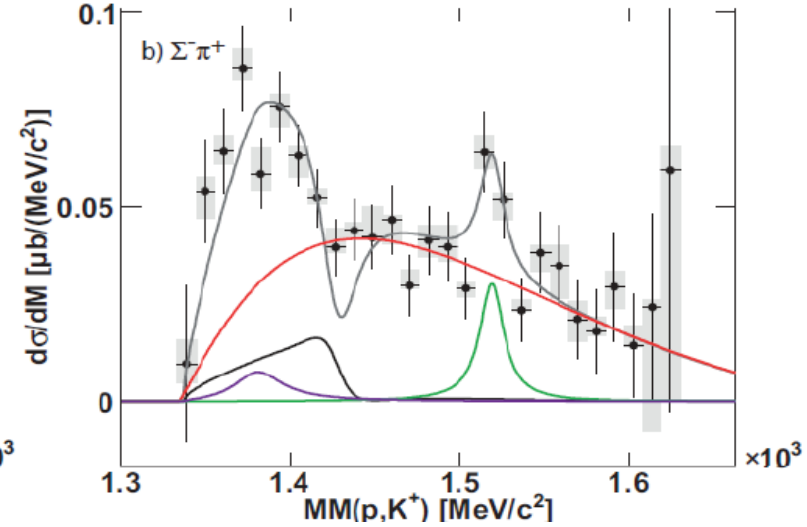
Nucl.Phys. A881 (2012) 98-114

Interference with Background

$$\left(\frac{d\sigma}{dm}\right)_{\Sigma^+\pi^-} = \left|A_{\Lambda(1405)}T_{\Lambda(1405)} + e^{i\alpha}A_{\Sigma^+\pi^-}T_{\Sigma^+\pi^-}\right|^2 + \left|BW_{\Sigma(1385)^0}\right|^2 + \left|BW_{\Lambda(1520)}\right|^2$$

$$\left(\frac{d\sigma}{dm}\right)_{\Sigma^-\pi^+} = \left|A_{\Lambda(1405)}T_{\Lambda(1405)} + e^{i\beta}A_{\Sigma^-\pi^+}T_{\Sigma^-\pi^+}\right|^2 + \left|BW_{\Sigma(1385)^0}\right|^2 + \left|BW_{\Lambda(1520)}\right|^2$$





$A_{\Lambda(1405)}$	$A_{\Sigma^+\pi^-}$	$A_{\Sigma^-\pi^+}$	α	β
1.06	0.93	1.04	67°	109°

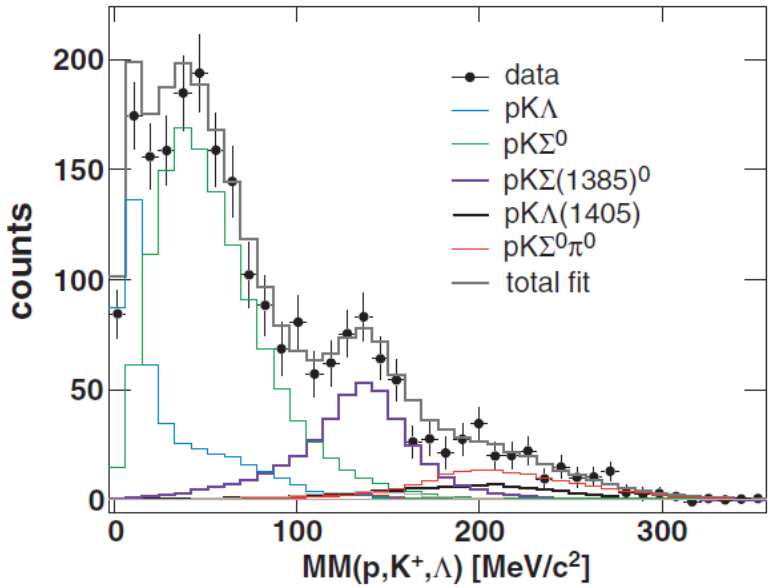
arXive - Referene

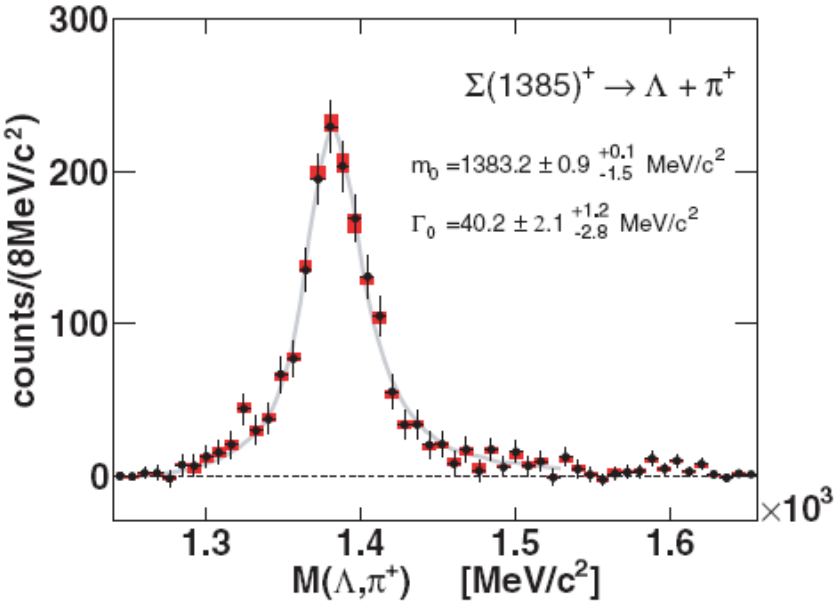
Could the Signal be Sigma (1385)

$\Sigma(1385)^0 \rightarrow \Lambda\pi^0$

Slides => backup

$\Sigma(1385)^+$





$\sigma_{\Sigma(1385)^0} = 5.56 \pm 0.48^{+1.94}_{-1.06}\ \mu b$

G. Agakishiev et al., Phys Rev C 87, 2013

$\sigma_{\Sigma(1385)^+} = 22.42 \pm 0.99 \pm 1.57^{+3.04}_{-2.23}\ \mu b$

G. Agakishiev et al., Phys Rev C 85, 2013

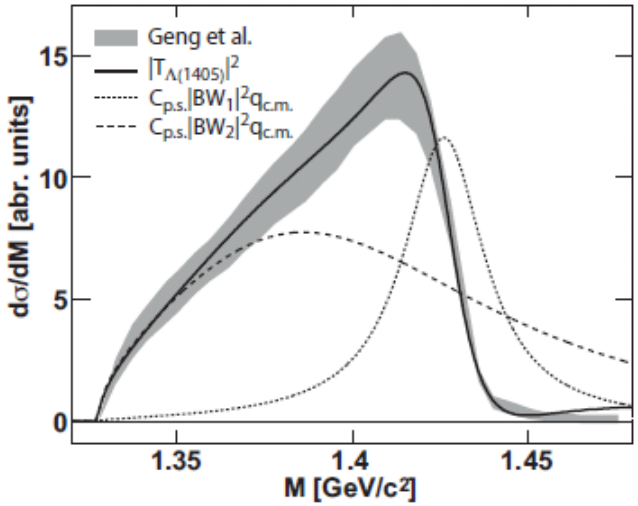
Assumption: Peak Dominated by $\Sigma(1385)^0$ → $\sigma_{\Sigma(1385)^0} \cong 50$ µb

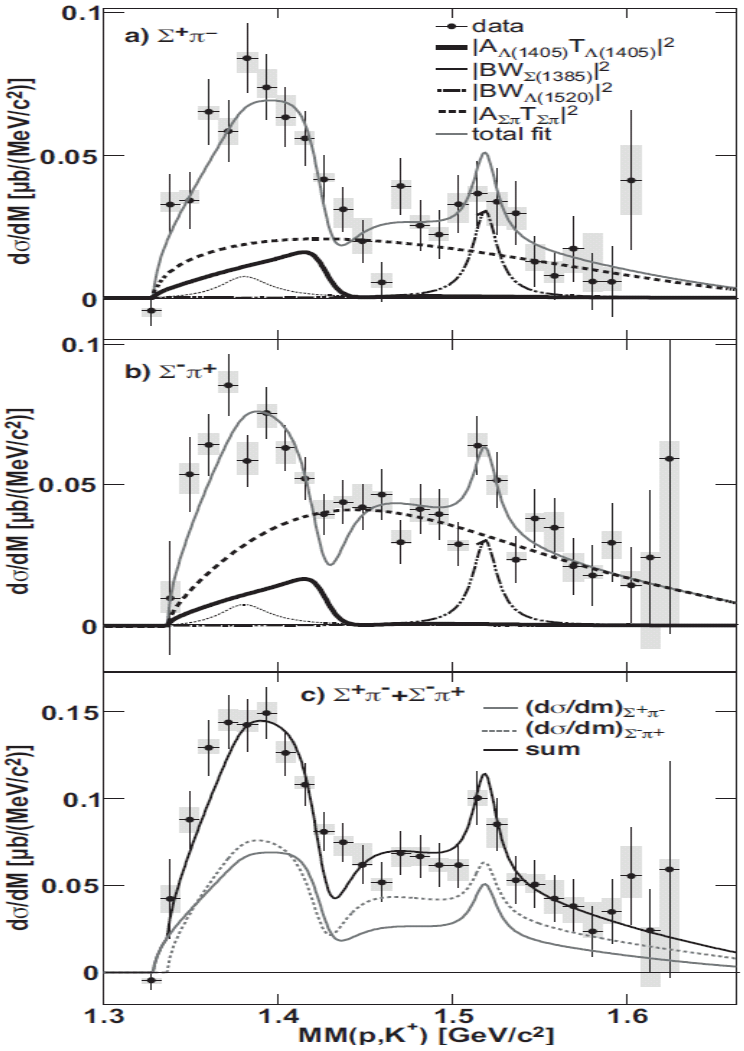
Interference with Background

$$\left(\frac{d\sigma}{dm}\right)_{\Sigma^+\pi^-} = \left|A_{\Lambda(1405)}T_{\Lambda(1405)} + e^{i\alpha}A_{\Sigma^+\pi^-}T_{\Sigma^+\pi^-}\right|^2 + \left|BW_{\Sigma(1385)^0}\right|^2 + \left|BW_{\Lambda(1520)}\right|^2$$

$$\left(\frac{d\sigma}{dm}\right)_{\Sigma^-\pi^+} = \left|A_{\Lambda(1405)}T_{\Lambda(1405)} + e^{i\beta}A_{\Sigma^-\pi^+}T_{\Sigma^-\pi^+}\right|^2 + \left|BW_{\Sigma(1385)^0}\right|^2 + \left|BW_{\Lambda(1520)}\right|^2$$

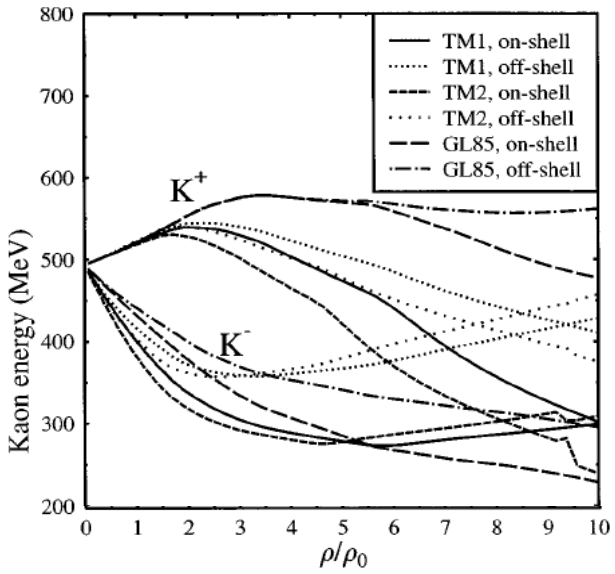
$A_{\Lambda(1405)}$	$A_{\Sigma^+\pi^-}$	$A_{\Sigma^-\pi^+}$	α	β
1.06	0.93	1.04	67°	109°





Strangeness in Matter

J. Schaffner and I. N. Mishustin
Phys. Rev. **C 53,** 3 (1996)



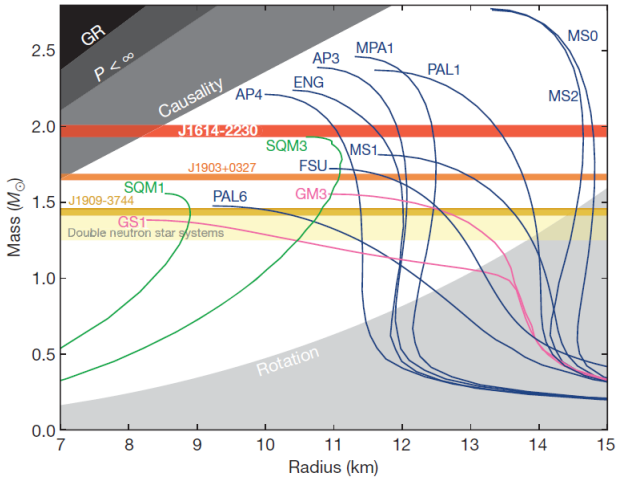
In case $m_{K^-}{}^* < \mu_e$

$$e^- \rightarrow K^- + \nu_e$$

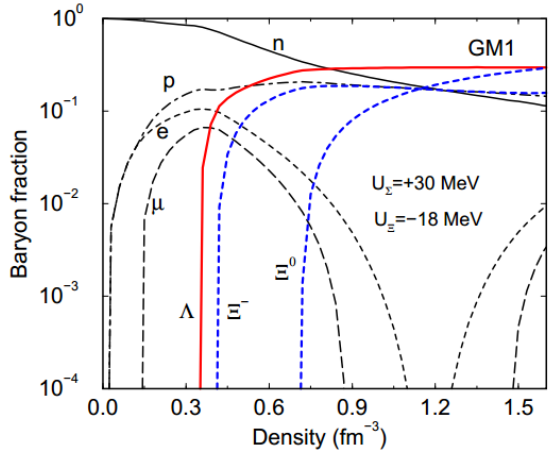
$$n \rightarrow K^- + p$$

reduces Fermi pressure and softens EOS

P. B. Demorest et al., Nature **467** (2010)



J. Schaffner-Bielich, **NPA 804** (2008)

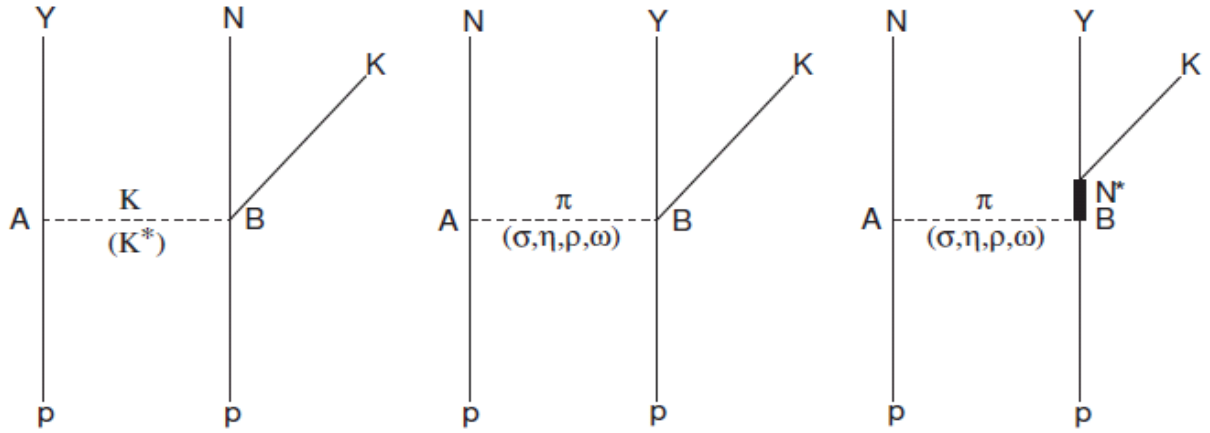


Current Data Set

- Photoproduction D.Keller (CLAS) Phys.Rev. D78
- K^-p Baubilier - Z.Phys.C (1984) / Agulier Benitz - Ann.Fis A 77 (1981)
- pp S.Klein Phys. Rec D1

<u>Production Mechanismus in p-p</u>

One Boson Exchange Model



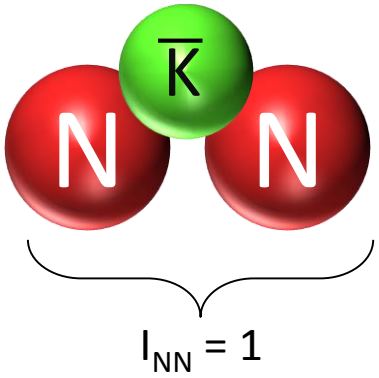
Strange Boson Exchange

Non strange Boson Exchange

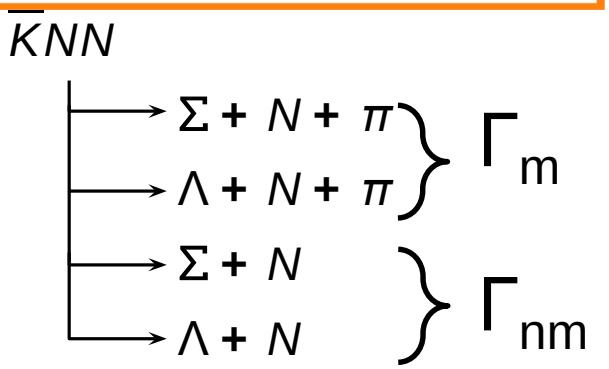
Non strange Boson Resonance Production

E.Ferrari,S.Serio Phys.Rev. 167:1298-1308

The Smallest Cluster



Property	Value
charge	+1
strangeness	-1
participants	ppK^-, $pn\overline{K}^0$
J^P	0^-

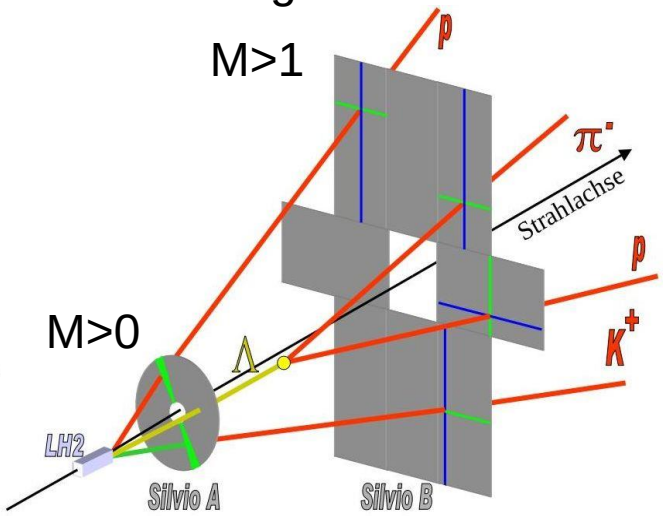


	Chiral, energy dependent				
	var. [DHW09, DHW08]	Fad. [BO12b, BO12a]	var. [BGL12]	Fad. [IKS10]	Fad. [RS14]
BE	17–23	26–35	16	9–16	32
Γ_m	40–70	50	41	34–46	49
Γ_{nm}	4–12	30			
	Non-chiral, static calculations				
	var. [YA02, AY02]	Fad. [SGM07, SGMR07]	Fad. [IS07, IS09]	var. [WG09]	var. [FIK+11]
BE	48	50–70	60–95	40–80	40
Γ_m	61	90–110	45–80	40–85	64–86
Γ_{nm}	12			~20	~21

Binding Energy (BE):
10-100 MeV
Mesonic Decay (Γ_m)
30-110 MeV
Non-Mesonic Decay (Γ_{nm})
4-30 MeV

Trigger Detector - SiΛViO

Silicon Λ-Vertexing and **I**dentification **O**nline

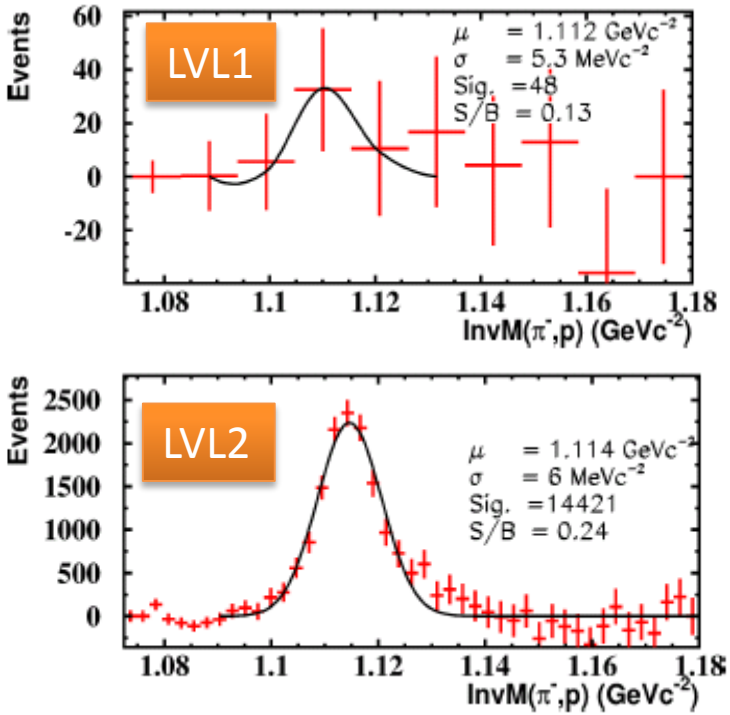


Trigger conditions:

LVL1 : Multiplicty(ToF) > 1

LVL2 : LVL1 + SiΛViO

Inclusive Λ Reconstruction



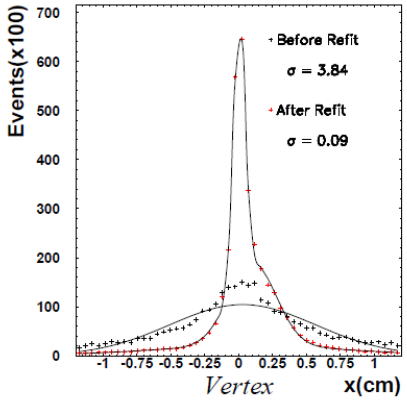
Λ – Enhancement: $14.1 \pm 7.9(stat)^{+4.3}_{-0.6}$

R. Münzer et. al. NIM A 745 (2014) 38-49

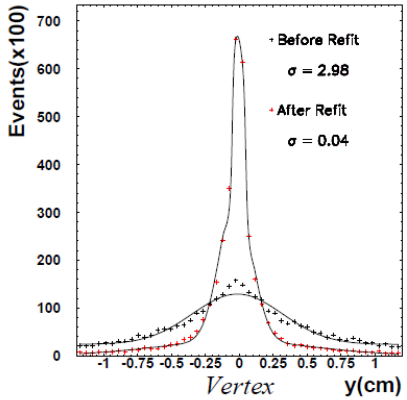
Reconstruction of exclusive Reactions

$p + p \rightarrow p + K^{+} + \Lambda$

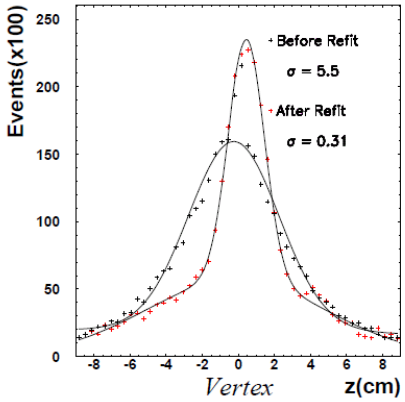
Inclusive Reconstruction



(a)



(b)

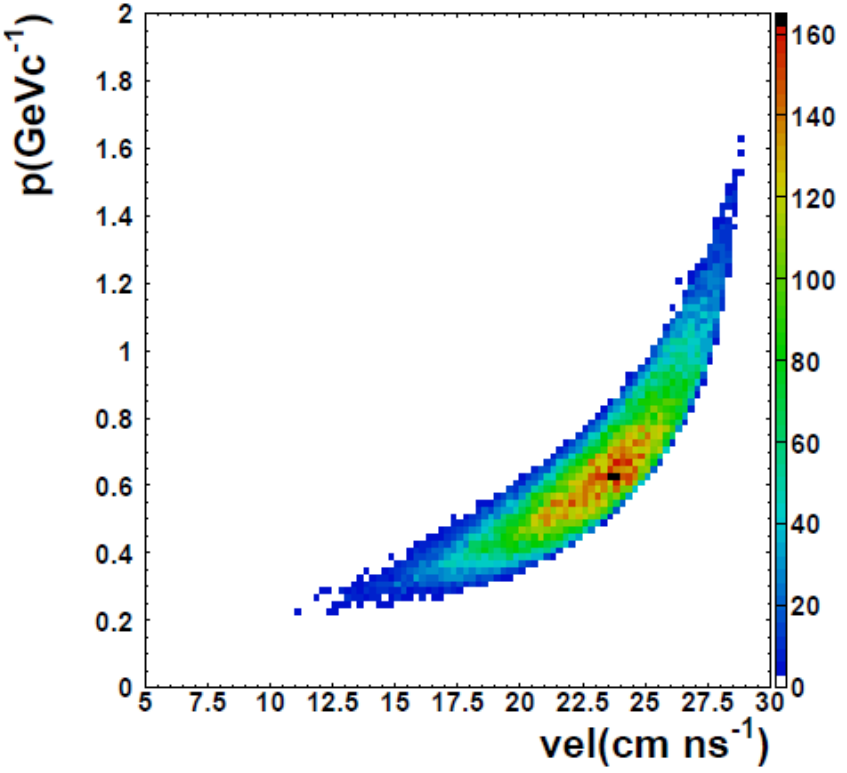


	Before Refit [cm]	After Refit [cm]
σ_x	3.84	0.09
σ_y	2.98	0.04
σ_z	5.50	0.31

Exclusive Data Sample

Primary K^+ Selection

Kaon Candidates in RPC and CDC



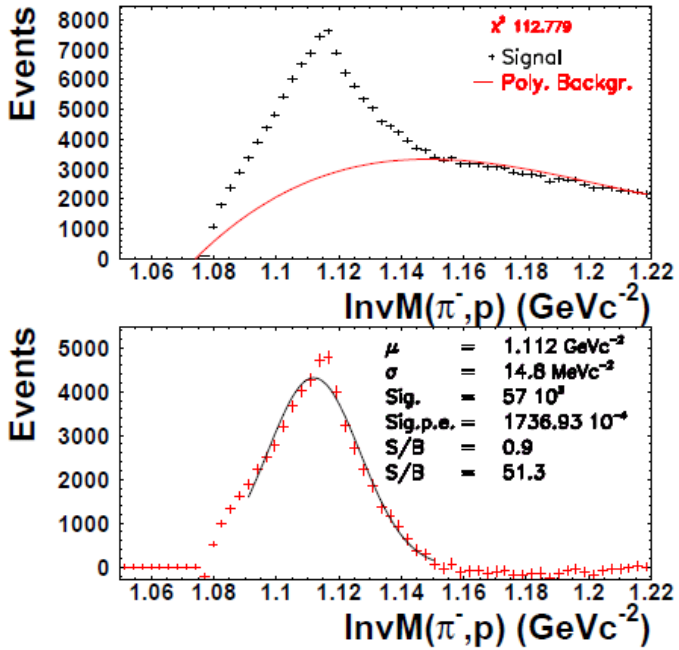
Exclusive Data Sample

Primary K^+ Selection

Λ Selection

Λ Candidates in all sub detector Combinations

Λ -> p + π^-



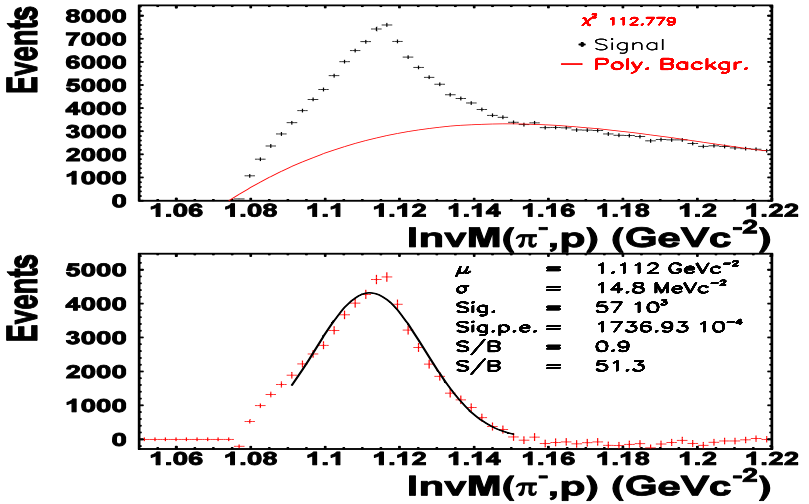
Exclusive Reconstruction

$$p + p \xrightarrow{3.1GeV} \Lambda + p + K^+$$
$$\Lambda \rightarrow p + \pi^-$$

Primary K^+ Selection

↓

Λ Identification



Exclusive Reconstruction

$$p + p \xrightarrow{3.1GeV} \Lambda + p + K^+$$
$$\Lambda \rightarrow p + \pi^-$$

Primary K^+ Selection

↓

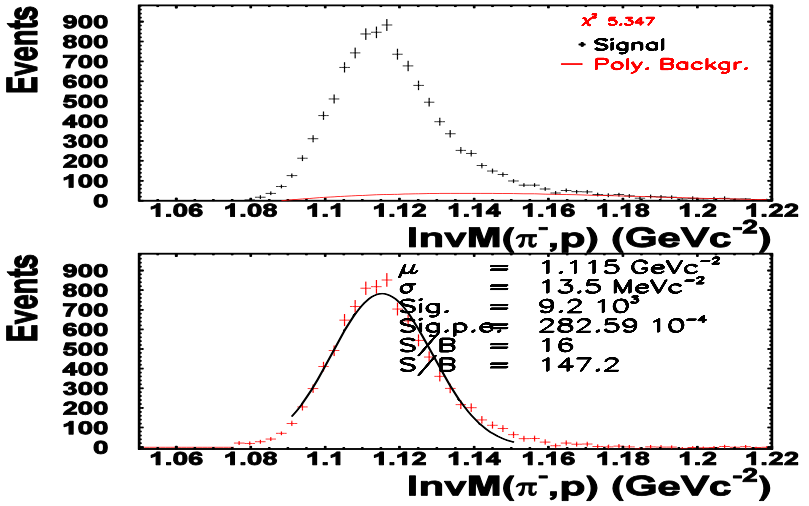
Λ Identification

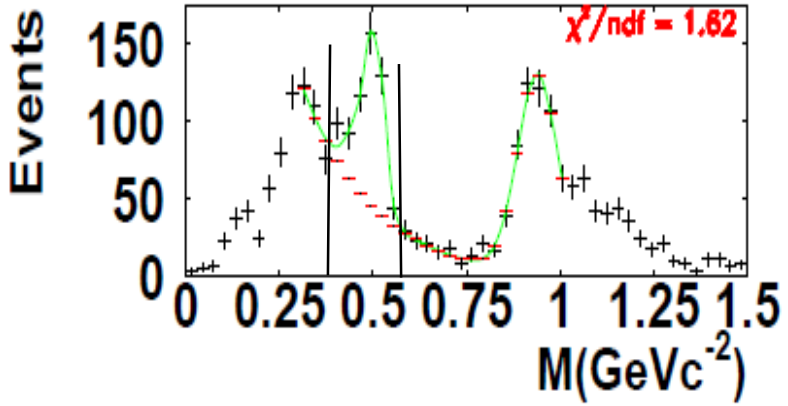
↓

Exclusive Selection by Kinematical Refit

↓

Secondary K^+ Selection Sideband Analysis





Exclusive Data Sample

Primary K^+ Selection

↓

Λ Selection

↓

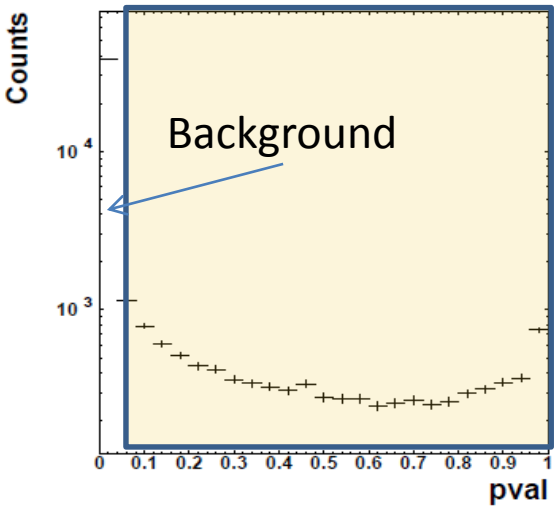
Exclusive Selection by kinemetical refit

Kinematical Refit

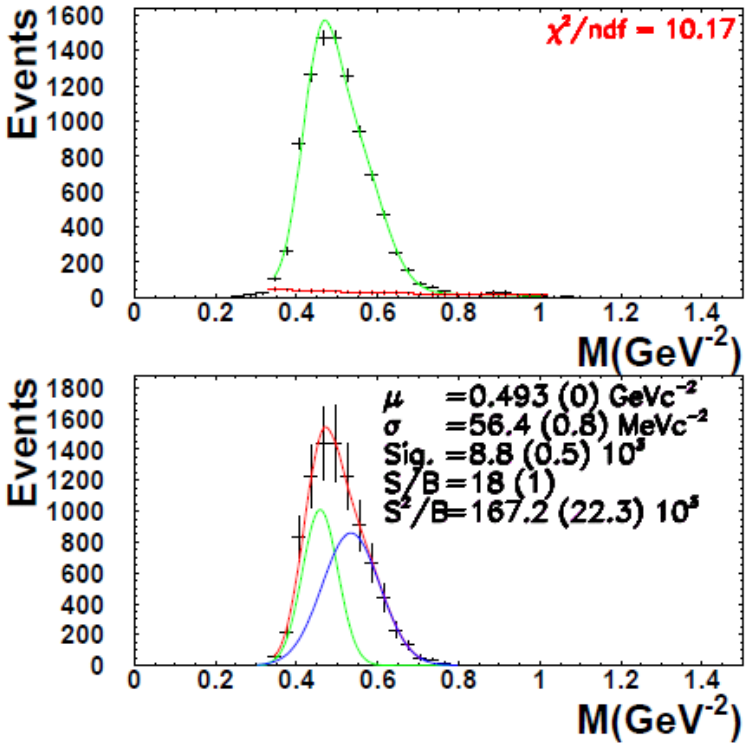
Variation of Track parameters with error

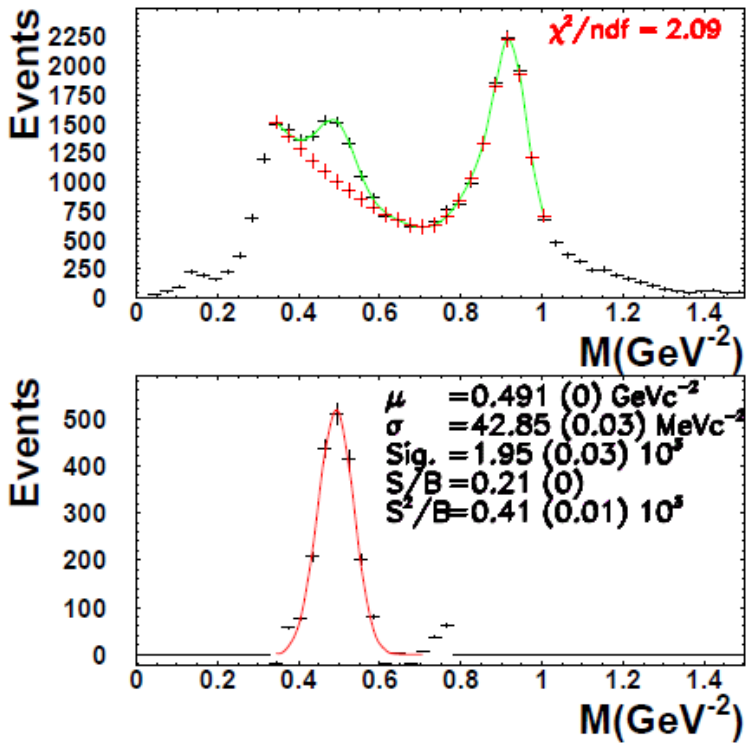
$$\chi^2 = (\vec{\alpha} - \vec{\alpha}_0)^T V_{\vec{\alpha}_0}^{-1} (\vec{\alpha} - \vec{\alpha}_0)$$

$$pvalue = \int_{\chi^2_{fit}}^{\infty} f_\nu(\chi^2) d\chi^2.$$



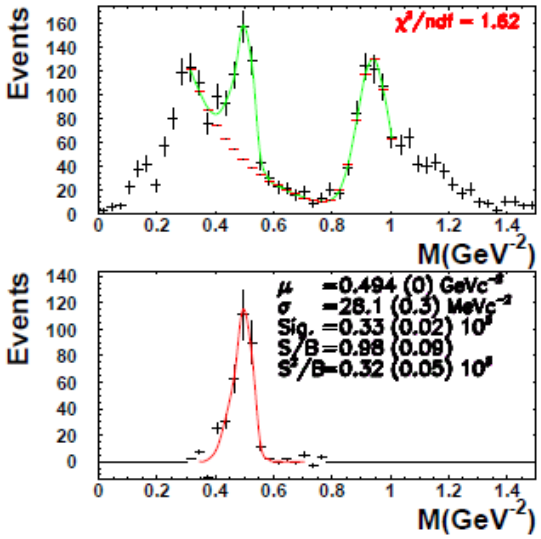
Different Kaon selection



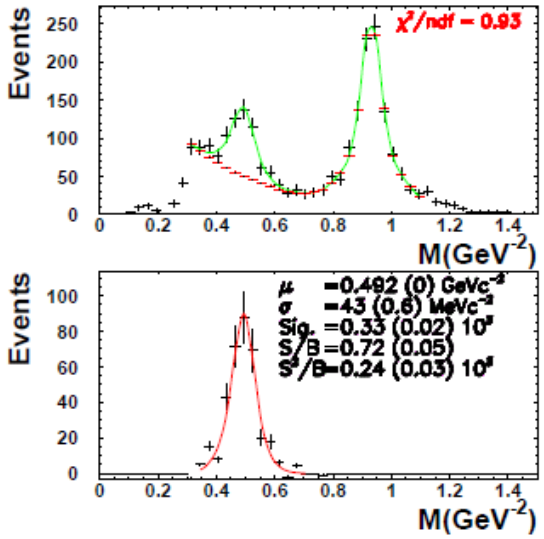


Backup

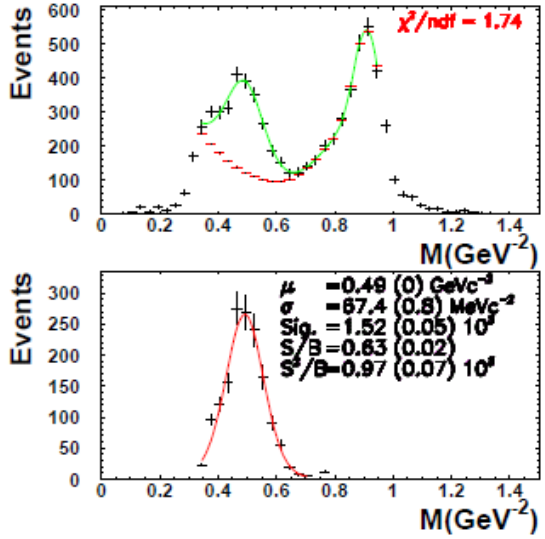
p < 0.5 GeV/c



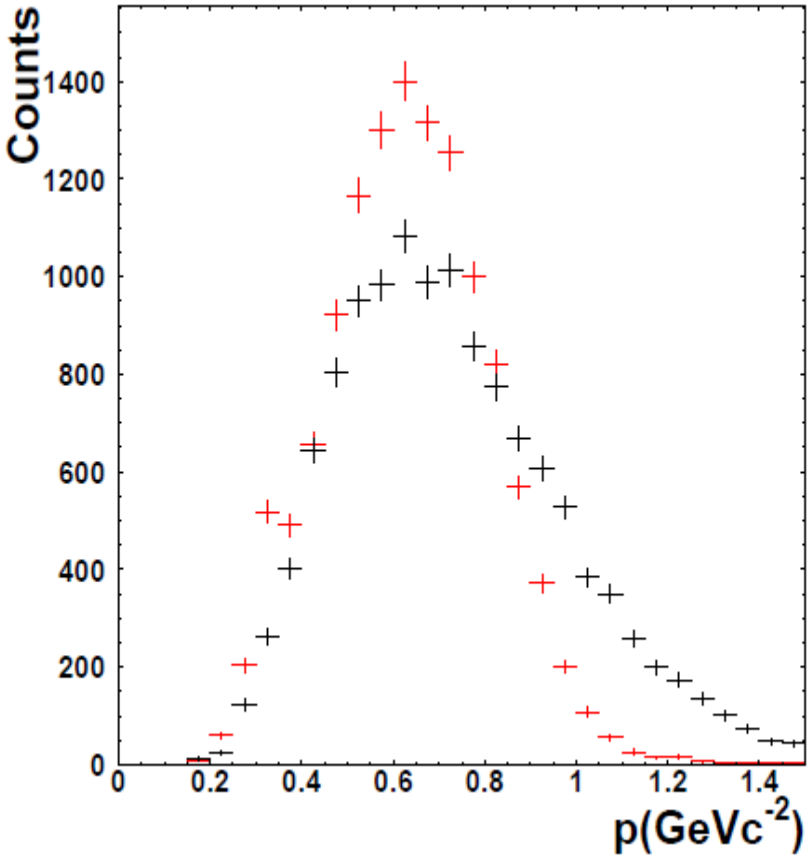
0.5 GeV/c < p < 0.6 GeV/c

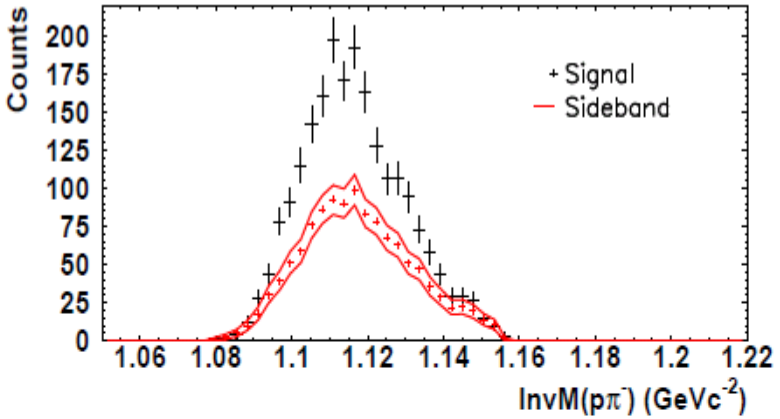


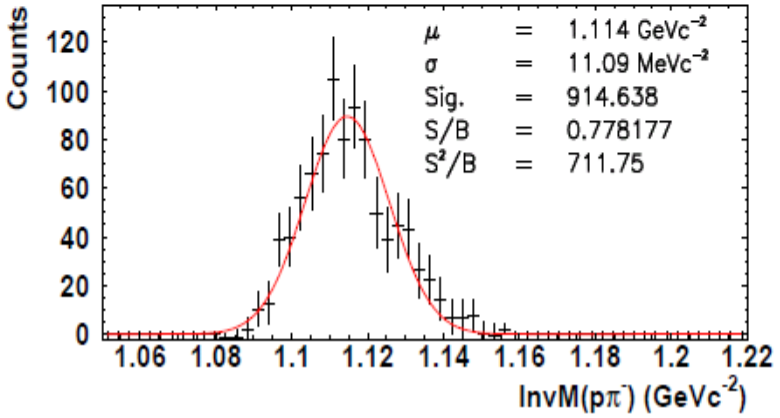
p > 0.6 GeV/c



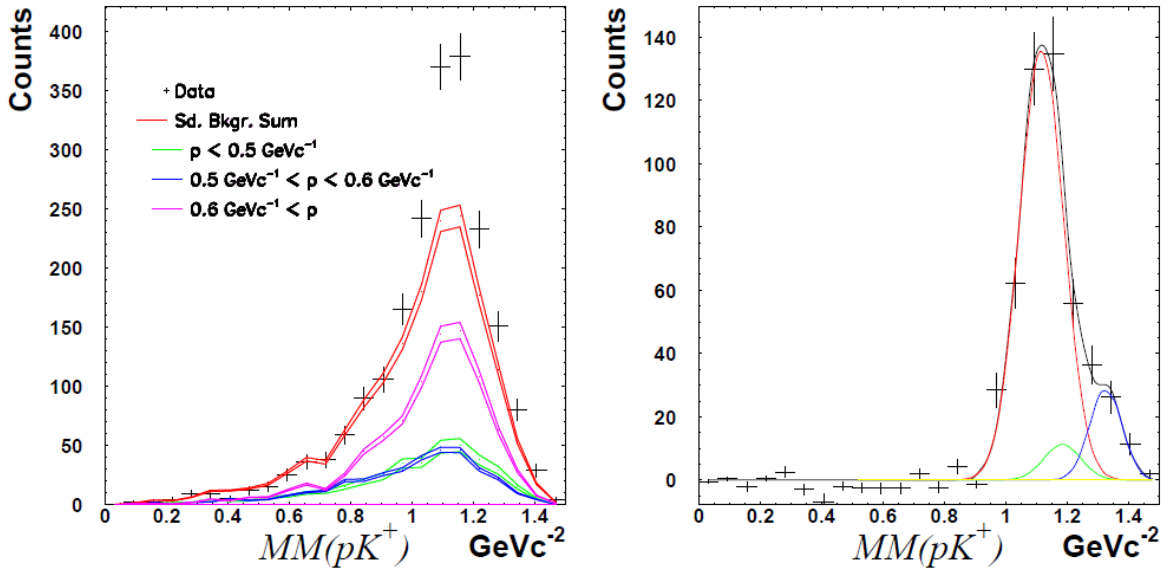
Sideband Analysis







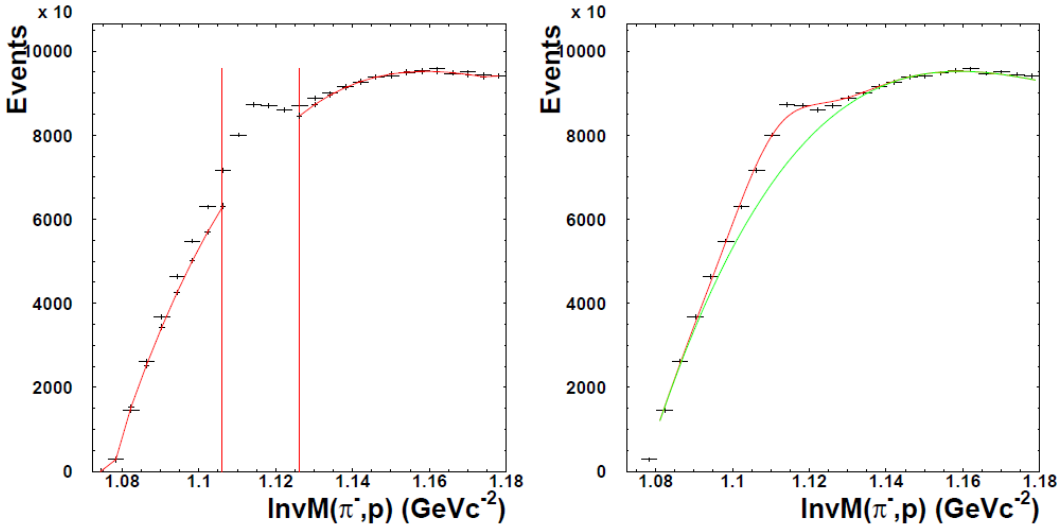
Λ / Σ Separation

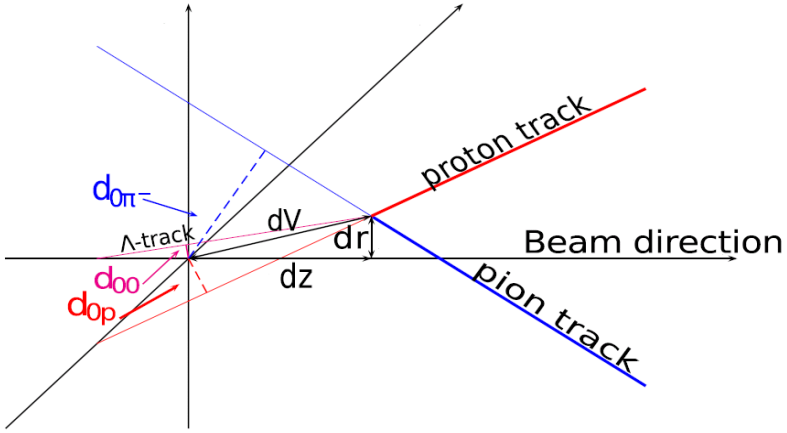


Particle	Mass	Fit μ	Fit σ	Fit Amplitude
Λ	1115.8	1.1171	0.07	136.35
Σ^0	1192.1	1.185	0.06	11.277
higher Resonance contribution		1.32	0.05	28.8

Remaining Background

$1/14.8.$

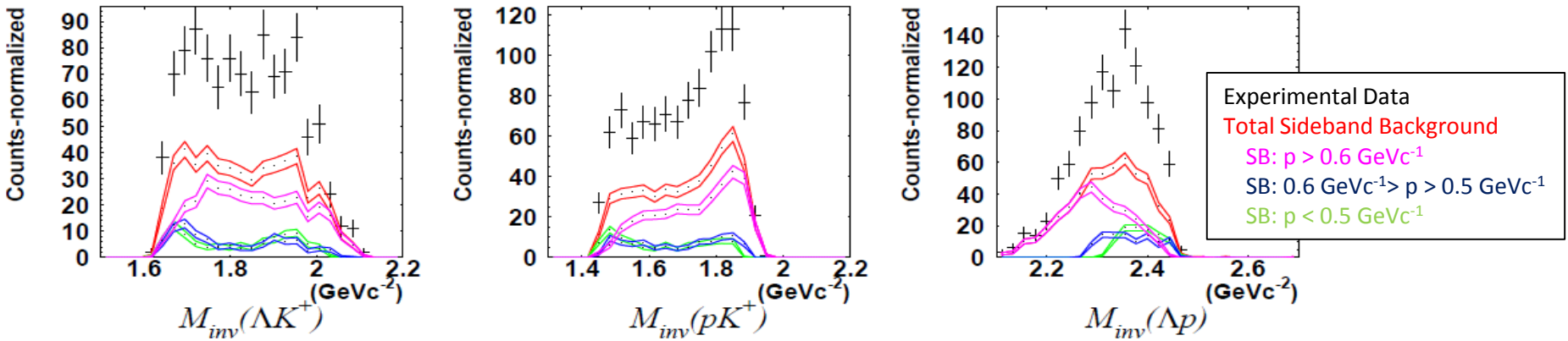




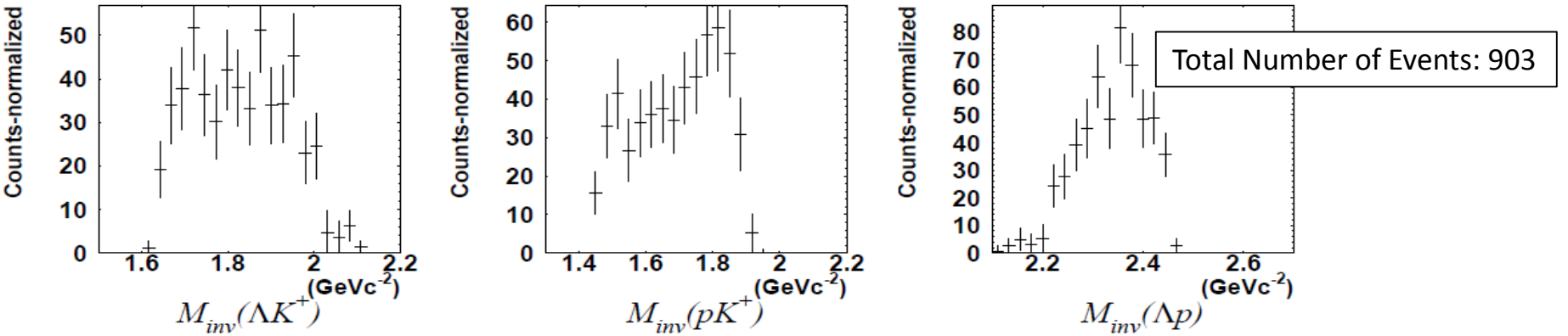
value	minimal value [cm]	maximal value [cm]
$primvertex_x$	-1.0	1.0
$primvertex_y$	-1.0	1.0
$primvertex_z$	-2.0	2.0
dr	3.0	∞

Exclusive Data Sample

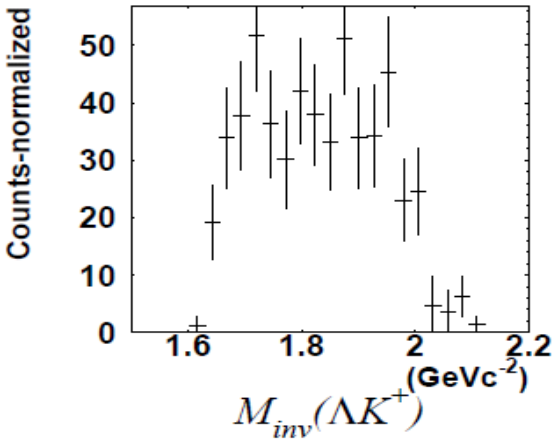
Sideband Background

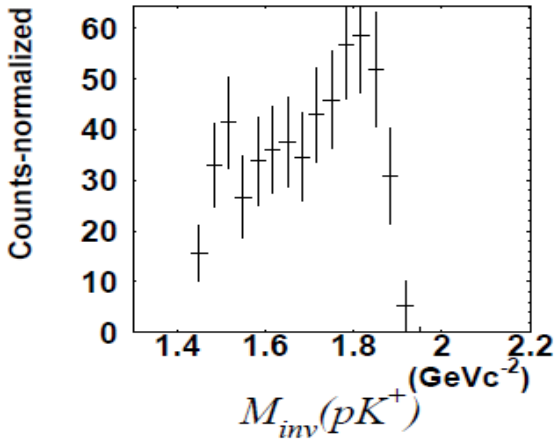


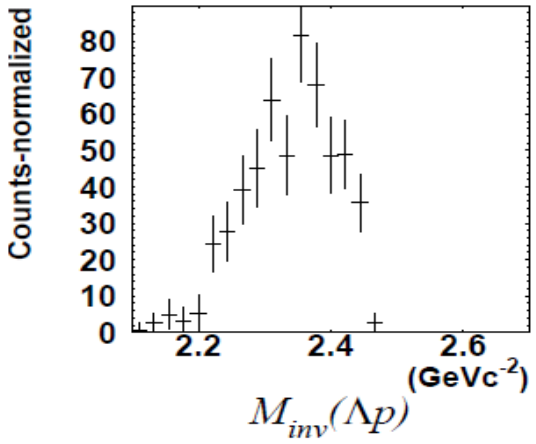
Background Subtracted



Exclusive Data Sample



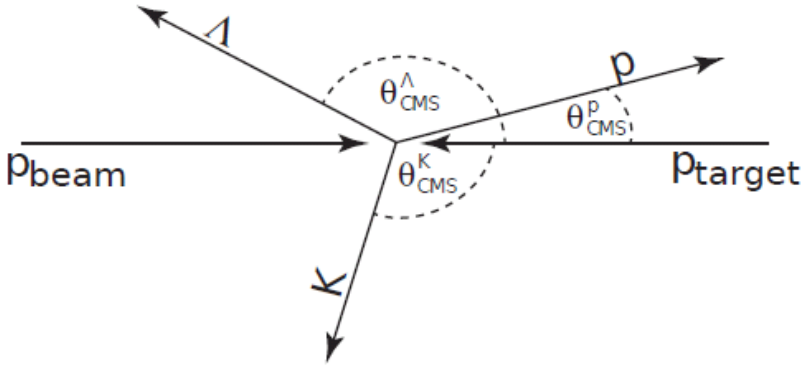




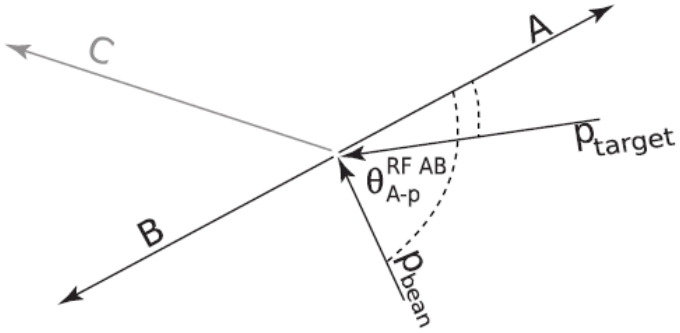
Momentum Region	Signal Events	Background Events
0.0 - 0.5 GeV/c	177	146
0.5 - 0.6 GeV/c	150	136
0.6 - GeV/c	577	577
Total	903	859

Angular Distributions

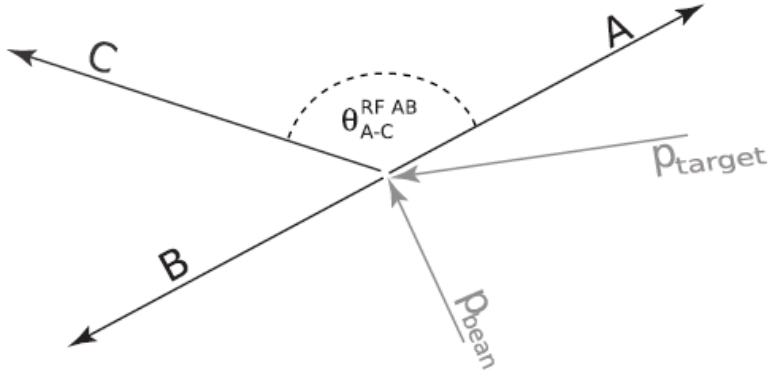
Center-of-mass angle



Gottfried-Jackson Angle



Helicity Angle



Simulation Packages

Phase Space Simulation

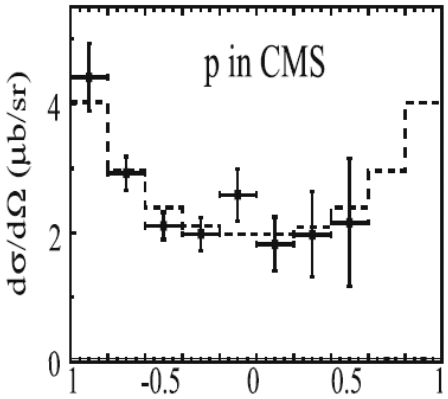
Incoherent Cocktail

$$p + p \rightarrow p + K^{+} + \Lambda$$

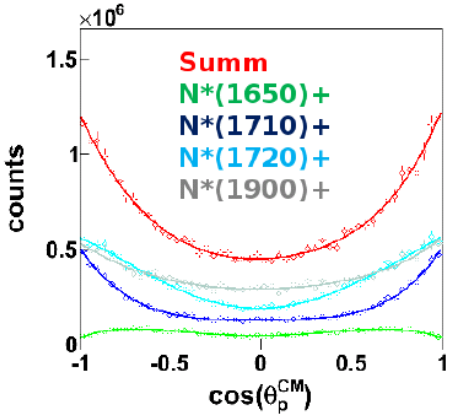
$$p + p \rightarrow p + N^{+*}(\rightarrow K^{+} + \Lambda)$$

Angular Distribution

Fröhlich et al.
PoS ACAT2007 (2007)



M. Abdel-Bary et al.,
Eur.Phys.J A46(2010)



E. Epple,
Diss. TUM (2014)

Transport Modell - UrQMD

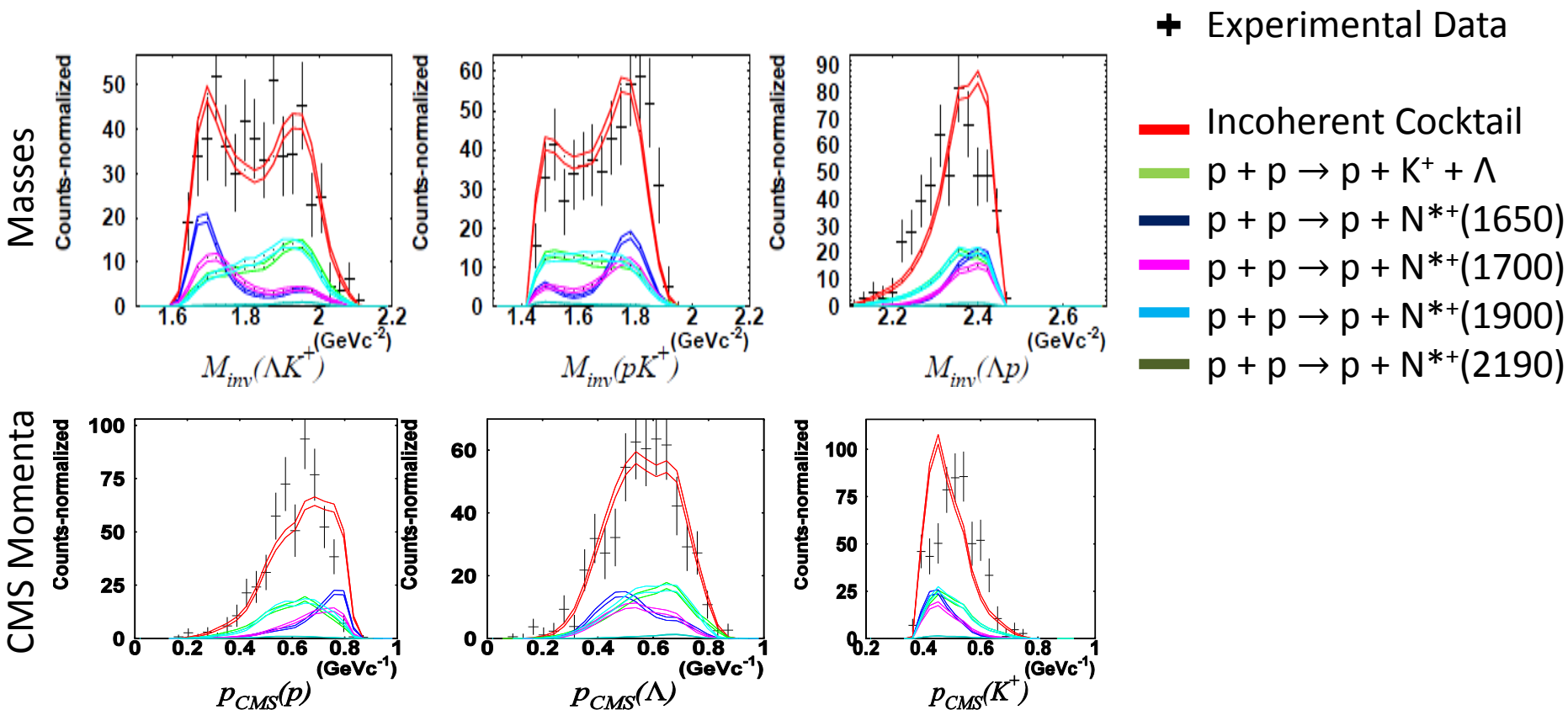
Quantum Molecular Dynamics

Description of all particle correlations

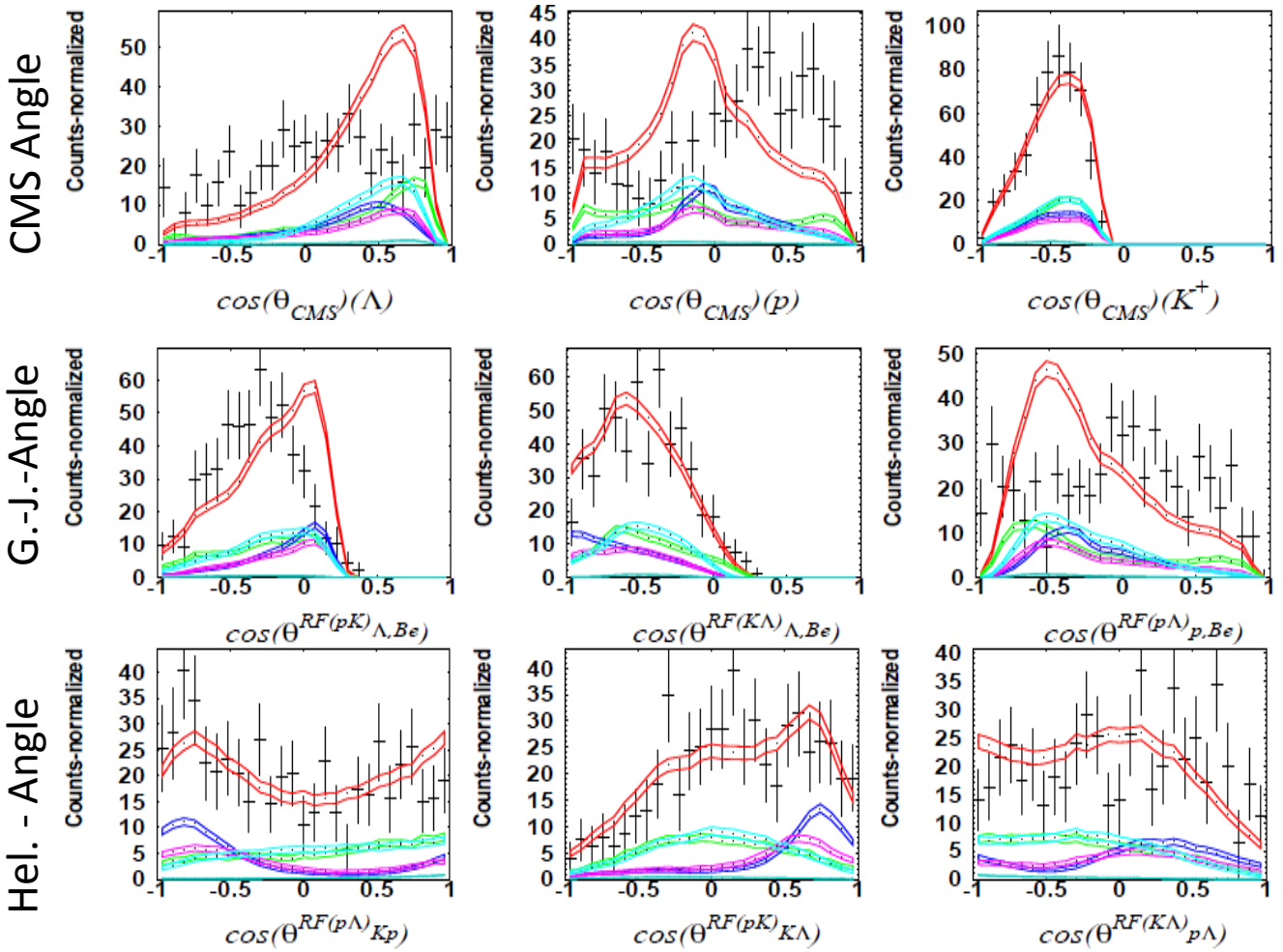
Production of p K^{+} Λ via Resonances (N^{+*})

The UrQMD Model,
http://urqmd.org/ 2013

Phase Space Simulation

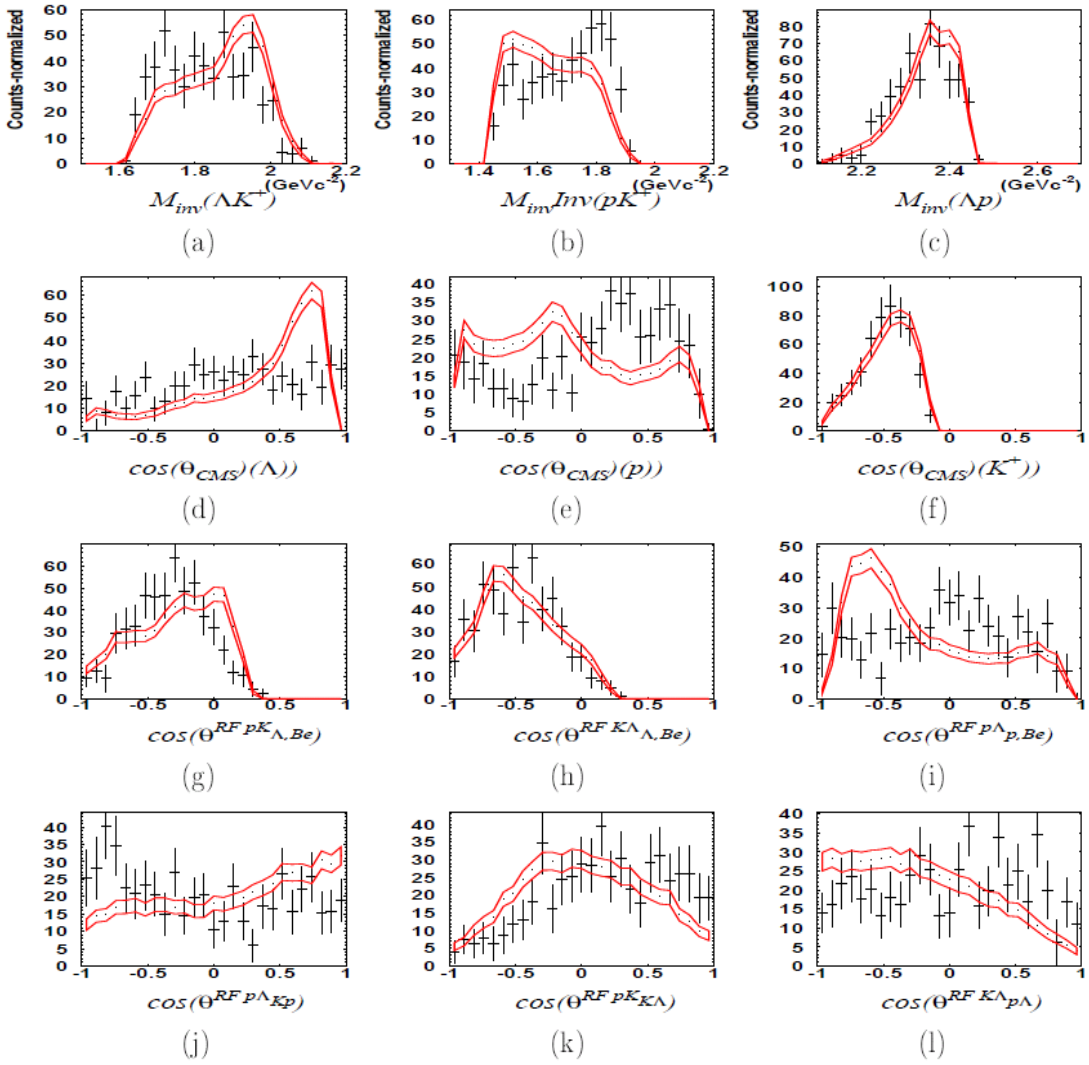


Phase Space Simulation



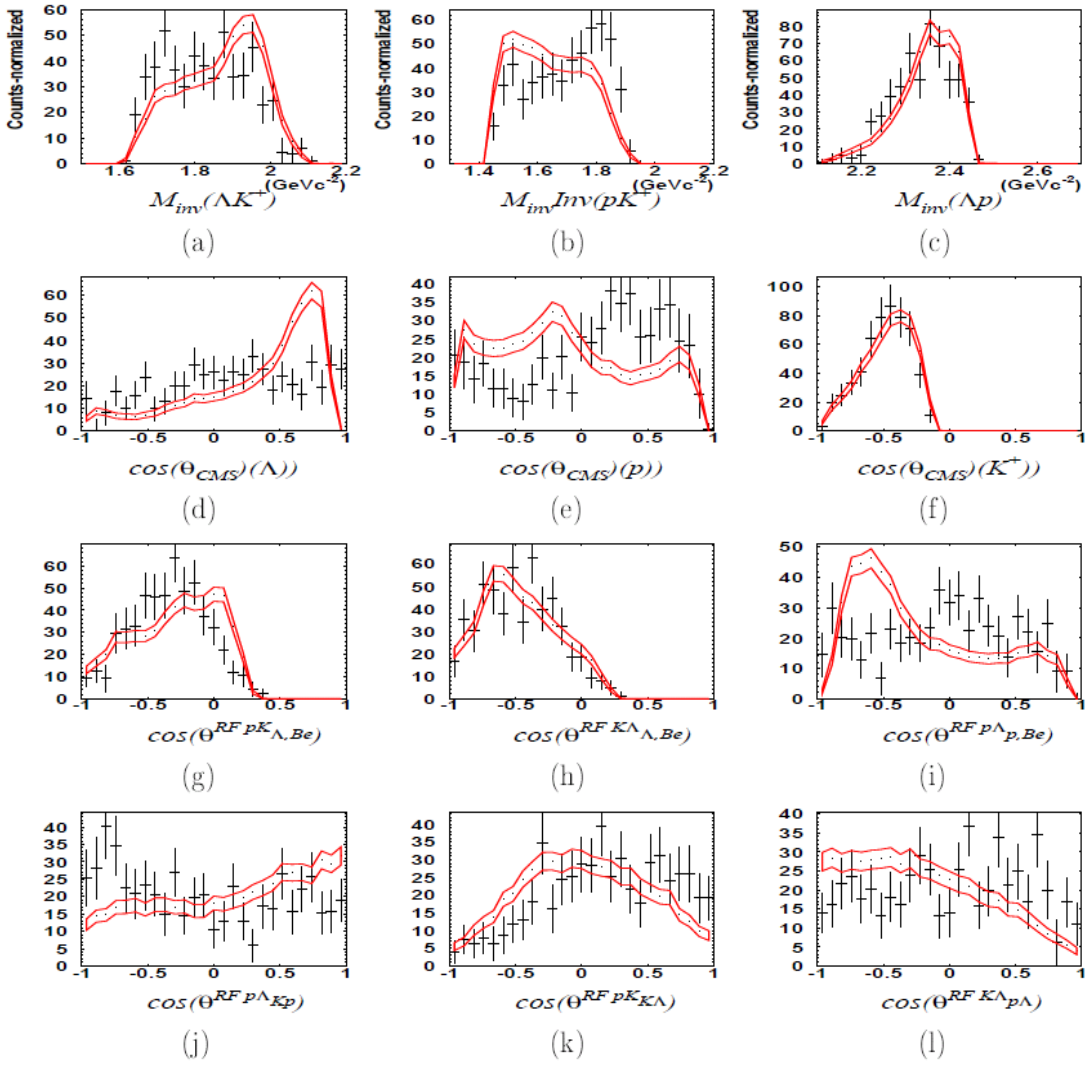
- Experimental Data
- Incoherent Cocktail
- p + p → p + K^+ + Λ
- p + p → p + N^{*+}(1650)
- p + p → p + N^{*+}(1700)
- p + p → p + N^{*+}(1900)
- p + p → p + N^{*+}(2190)

Phase Space Simulation



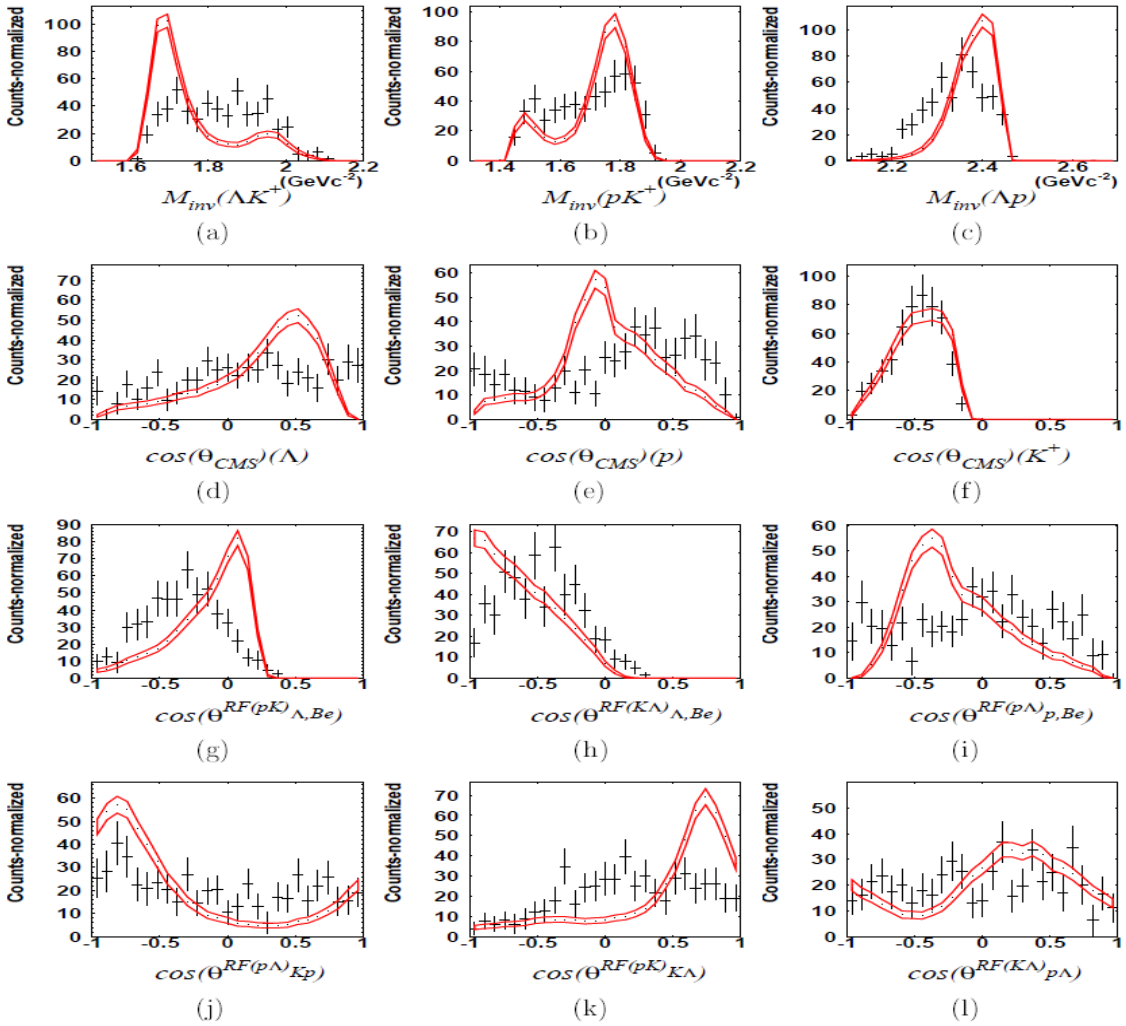
- Experimental Data
- pp -> p K^+ Λ Phase Space Simulation

Phase Space Simulation



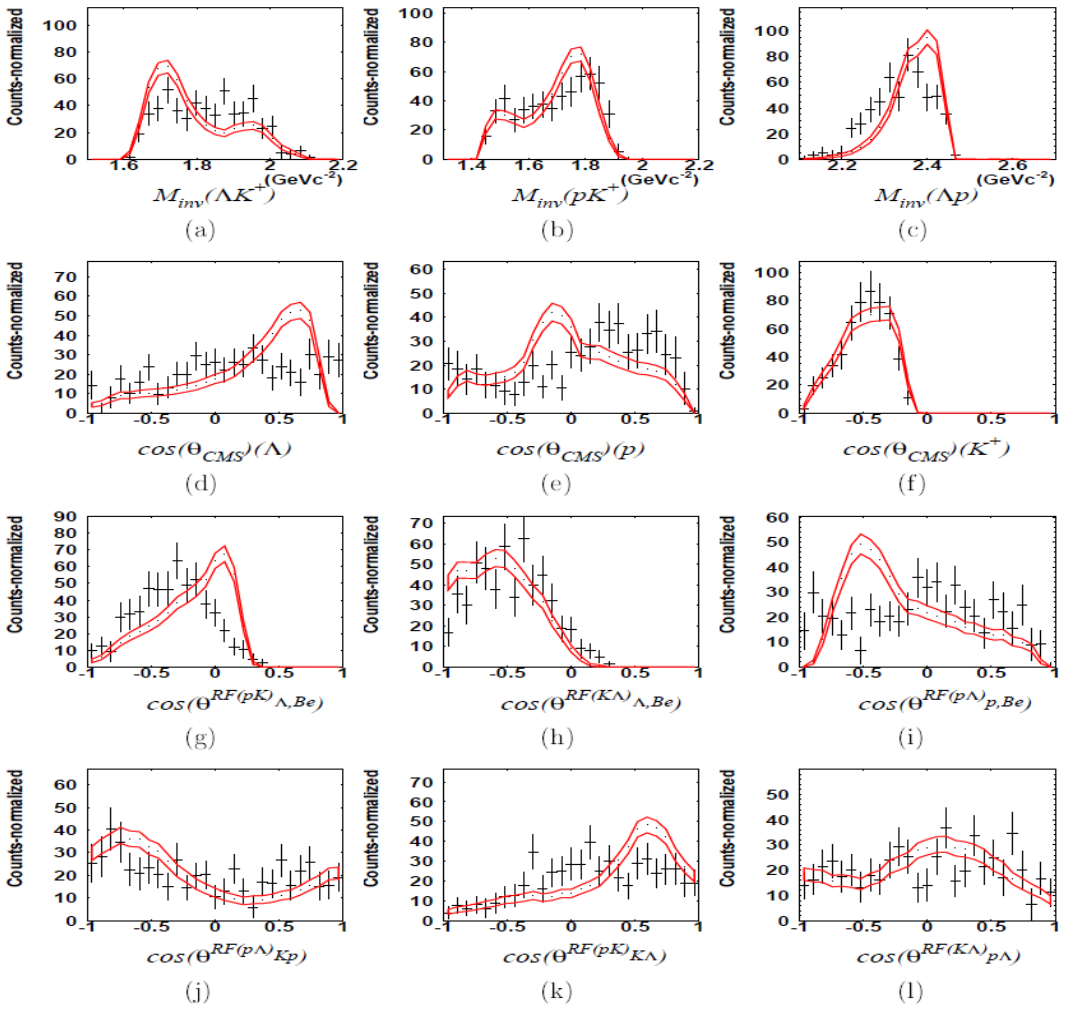
- Experimental Data
- pp -> p K^+ Λ Phase Space Simulation

Phase Space Simulation



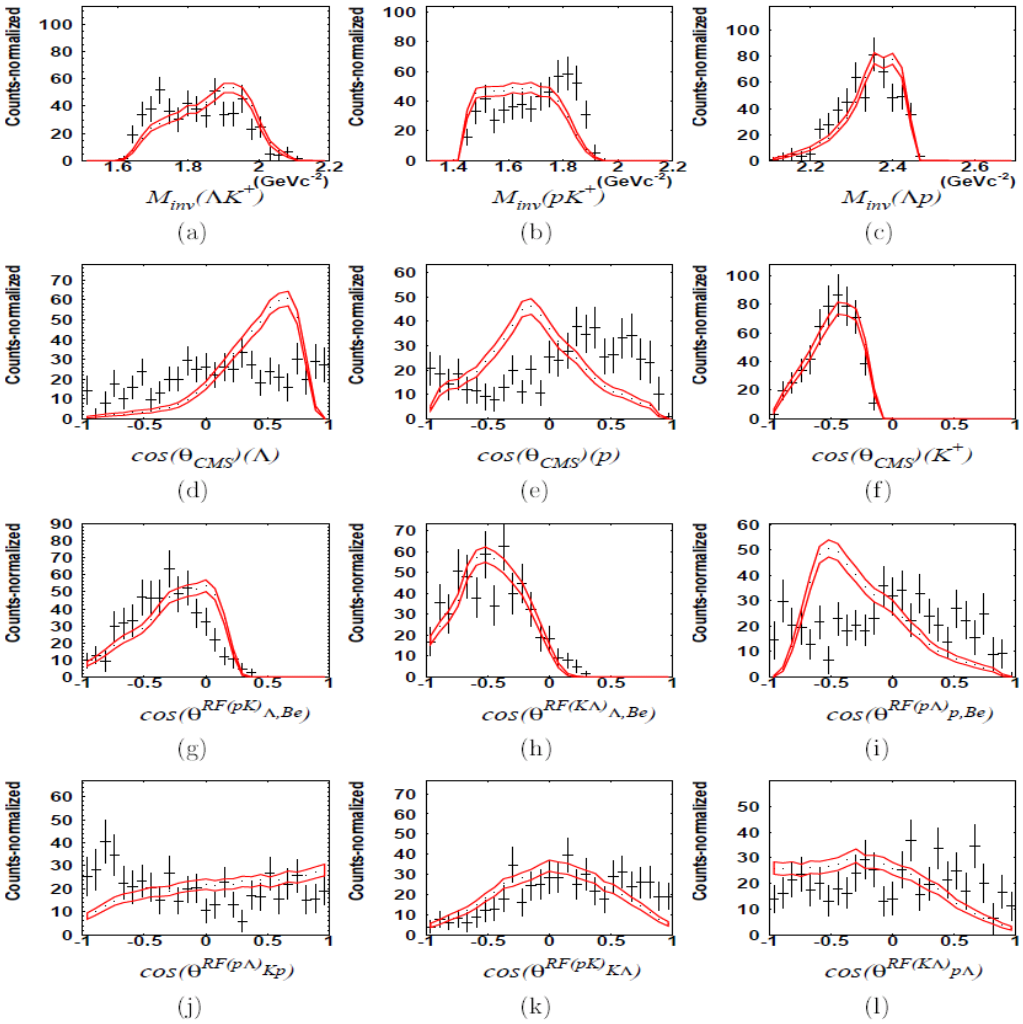
- Experimental Data
- pp -> p N*$^+$(1650) Phase Space Simulation

Phase Space Simulation



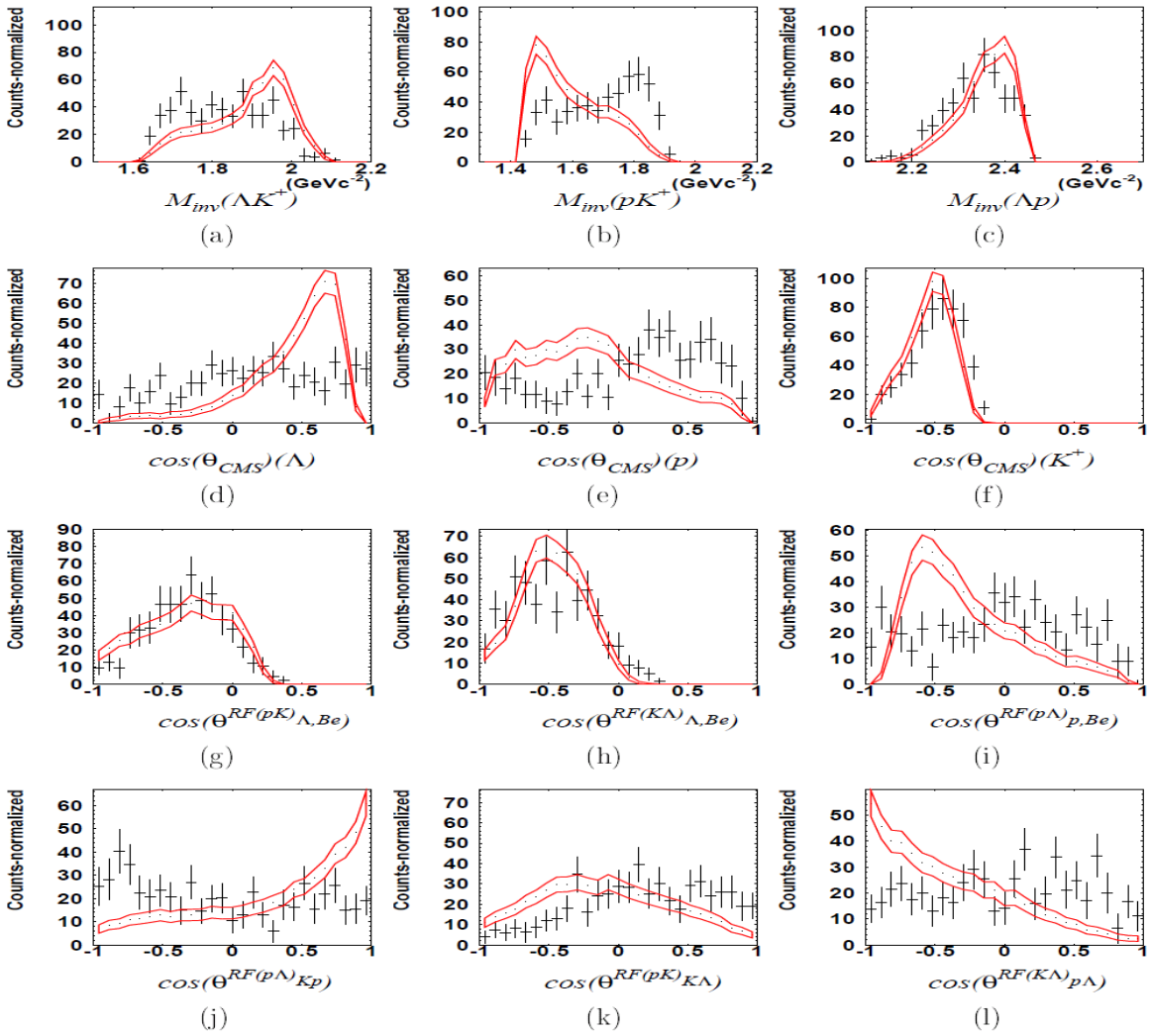
- Experimental Data
- pp -> p N*$^+$(1700) Phase Space Simulation

Phase Space Simulation



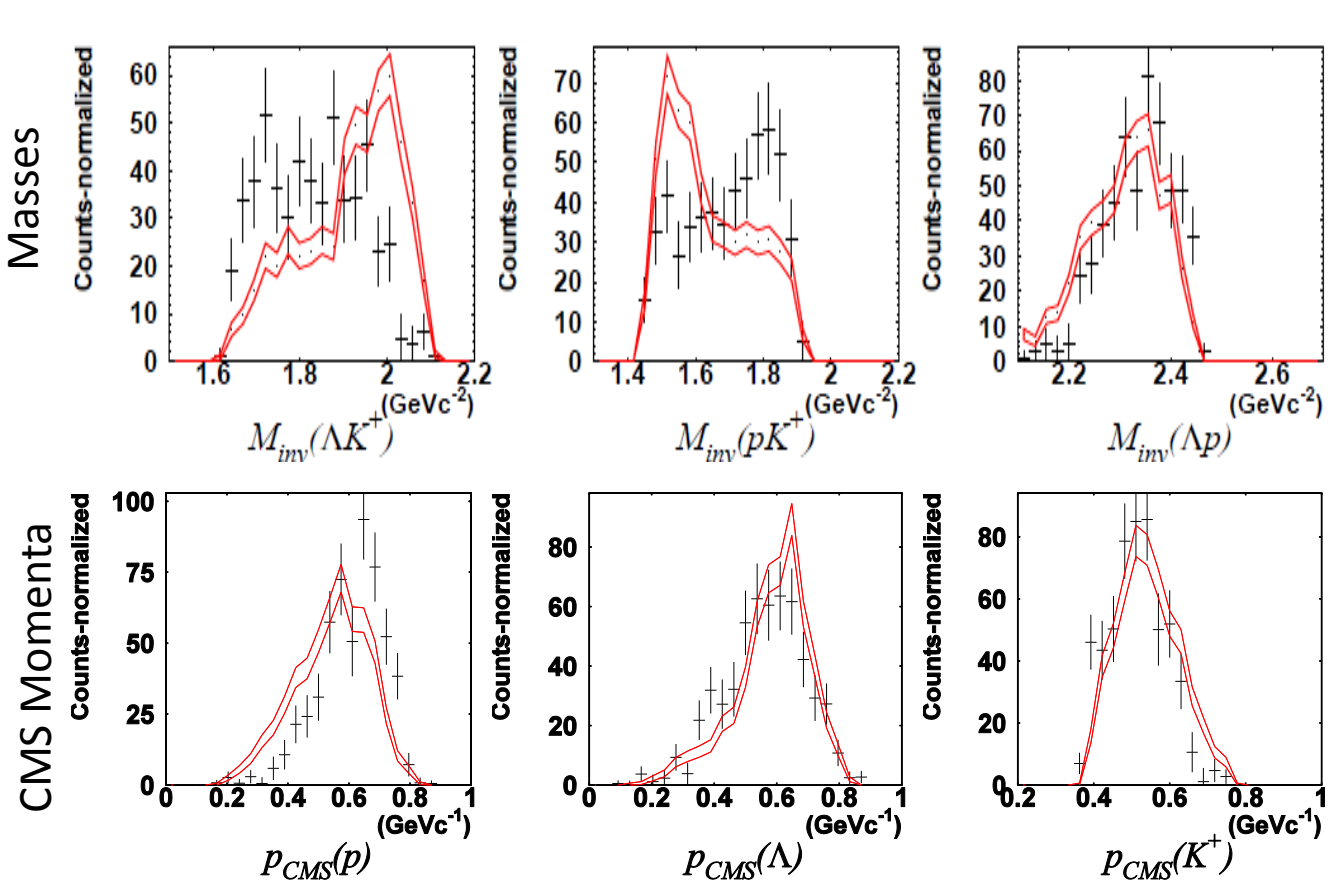
- Experimental Data
- pp -> p N*$^+$(1900) Phase Space Simulation

Phase Space Simulation



- Experimental Data
- pp -> p N*$^+$(2190) Phase Space Simulation

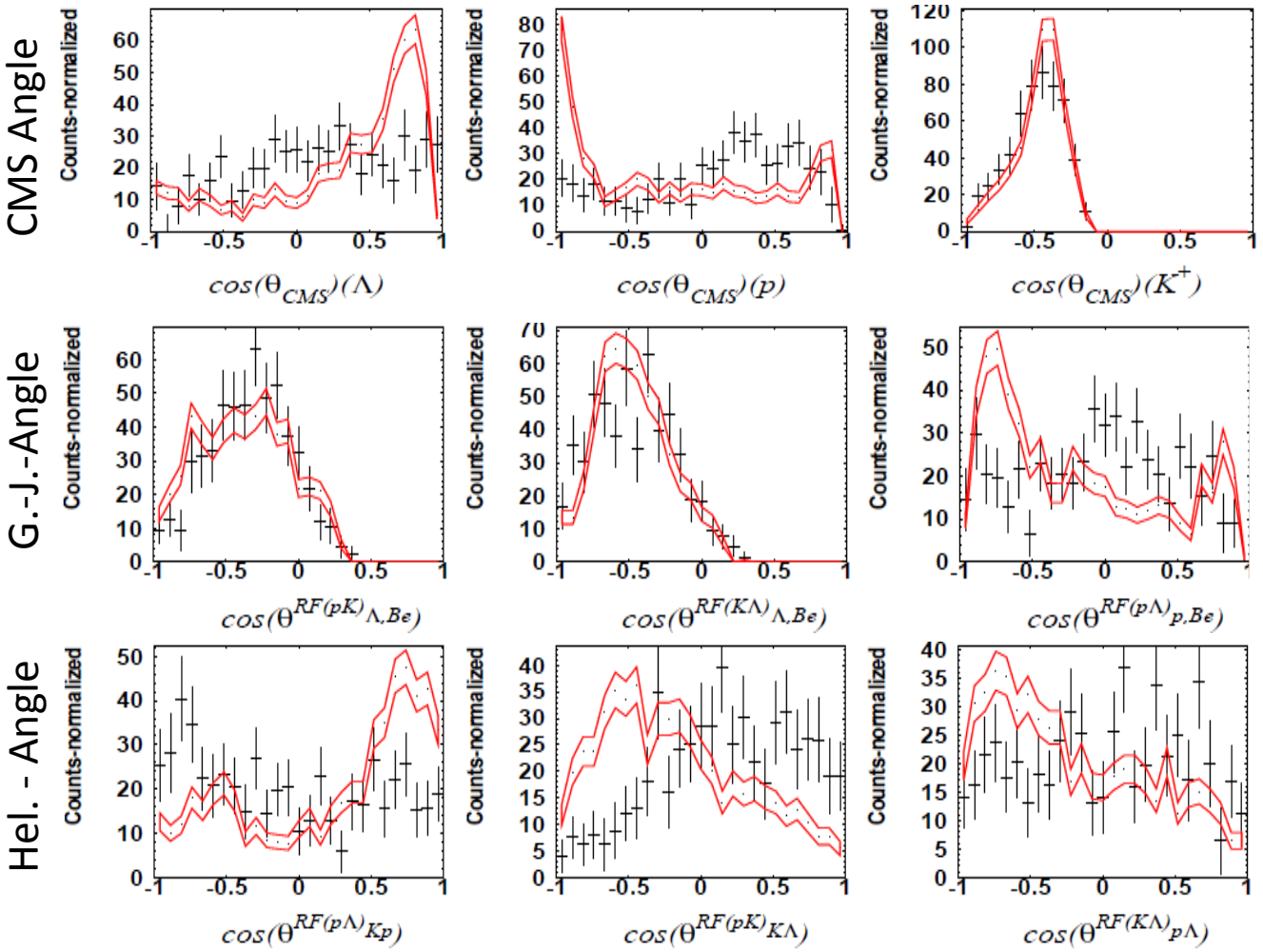
UrQMD Simulation



+ Experimental Data

UrQMD Simulations

UrQMD Simulation



+ Experimental Data

— UrQMD Simulations

$A =$ $N^*(1875)$ waves enabled (1) / disabled (0)

$B =$ $N^*(1880)$ waves enabled (1) / disabled (0)

$C =$ $N^*(1895)$ waves enabled (1) / disabled (0)

$D =$ $N^*(1900)$ waves enabled (1) / disabled (0)

$E =$ $pK^+\Lambda$ non resonant waves enabled (1) / disabled (0)

$F = 5$ Initial proton states: ${}^1S_0, {}^1D_2, {}^3P_0, {}^3P_1, {}^3P_2, {}^3F_3$

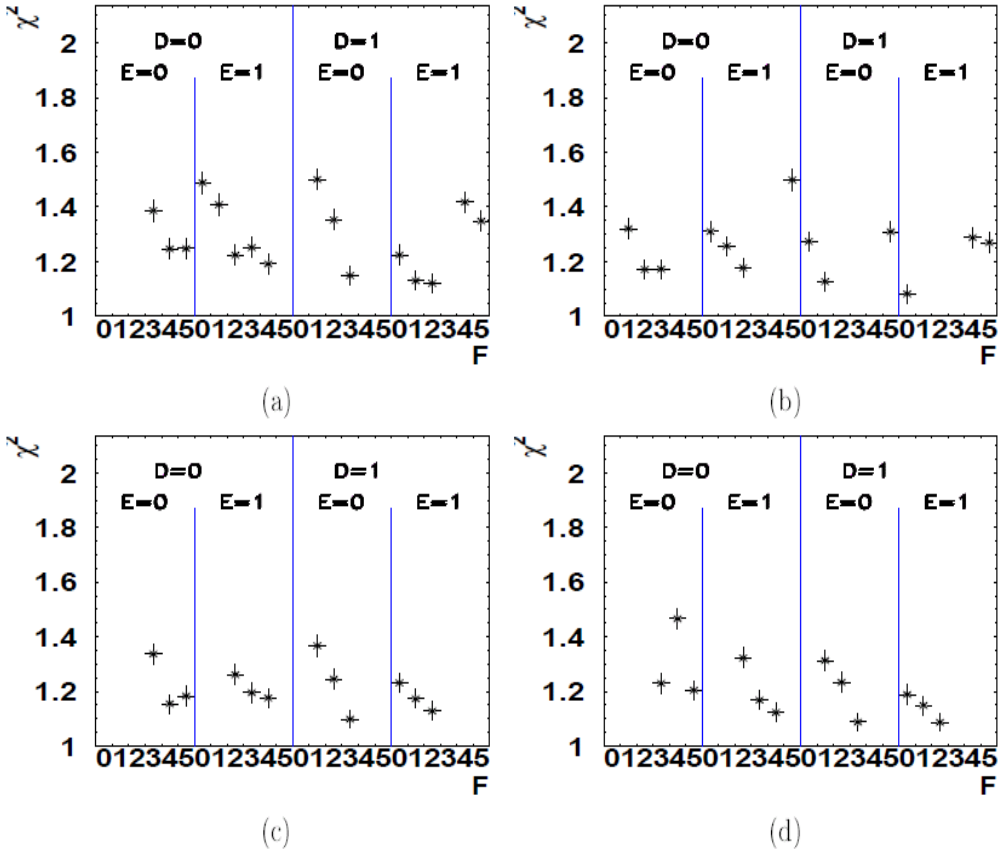
$= 4$ Initial proton states: ${}^1S_0, {}^1D_2, {}^3P_0, {}^3P_1, {}^3P_2$

$= 3$ Initial proton states: ${}^1S_0, {}^1D_2, {}^3P_0, {}^3P_1$

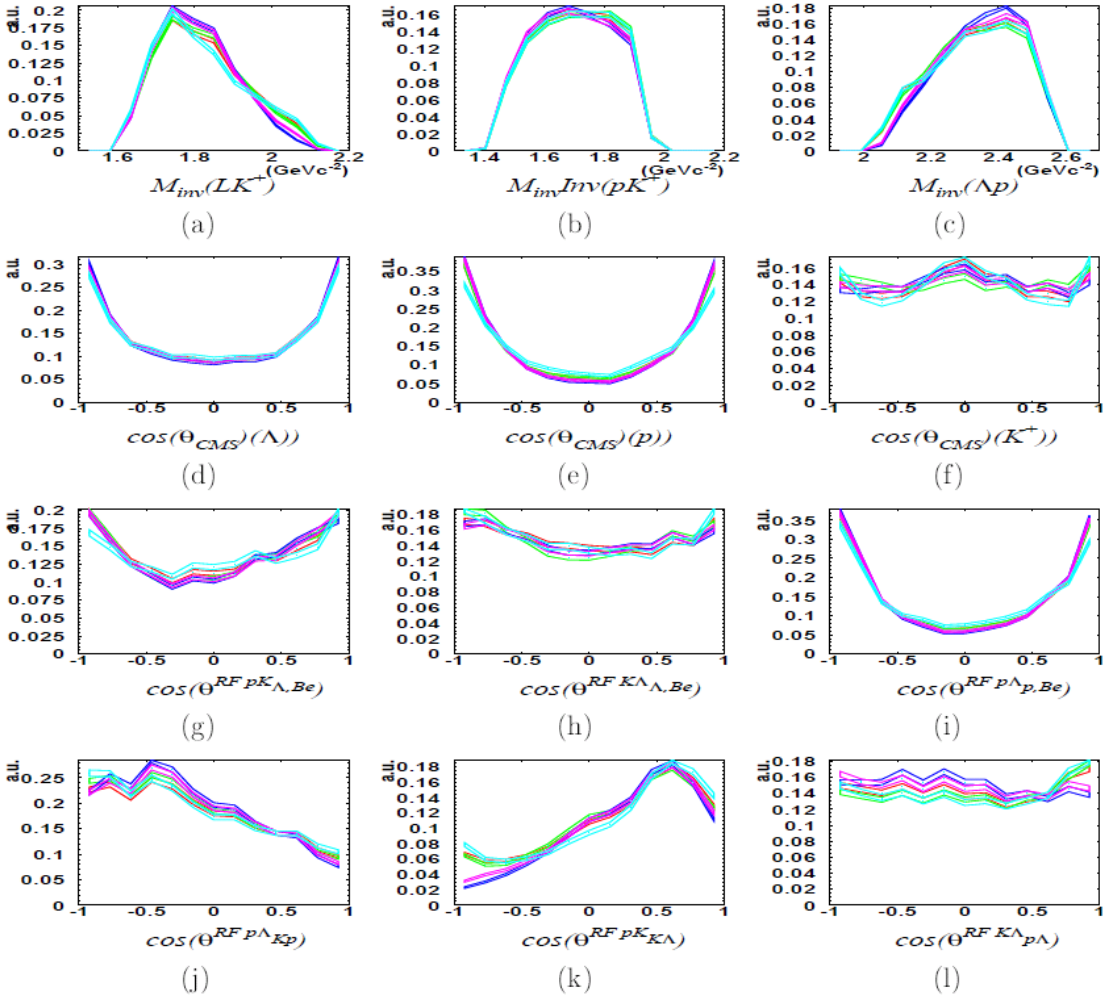
$= 2$ Initial proton states: ${}^1S_0, {}^1D_2, {}^3P_0$

$= 1$ Initial proton states: ${}^1S_0, {}^1D_2$

$= 0$ Initial proton states: ${}^1S_0$



PWA Results in 4π



ppK^- Upper Limit Determination

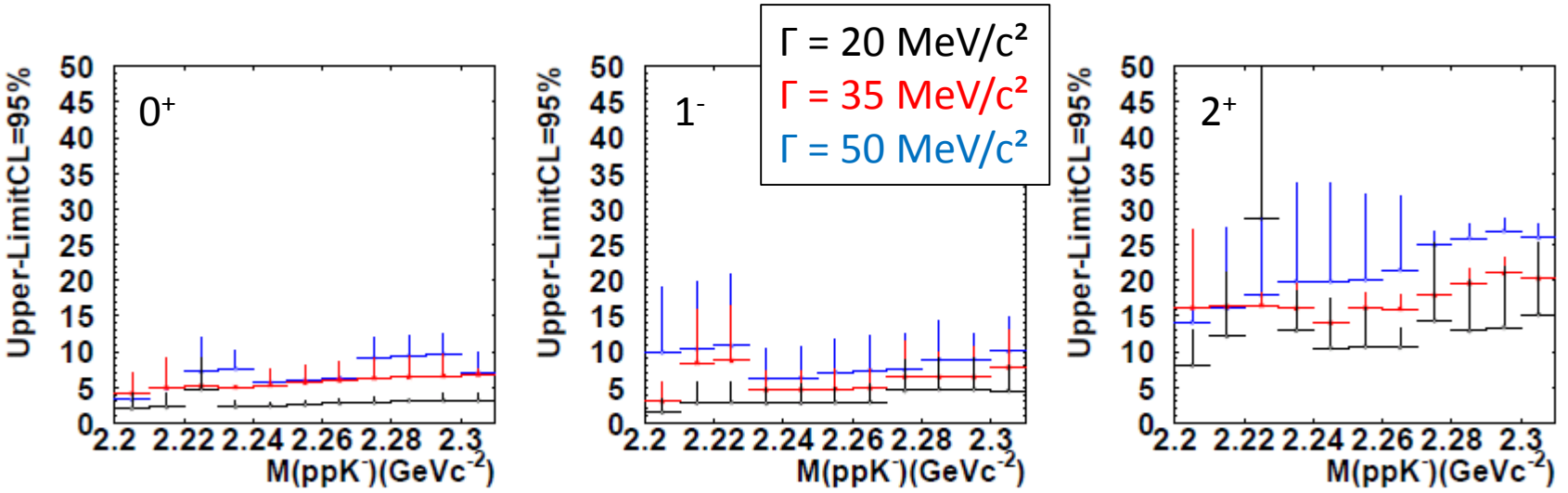
Exclusion limit:

$$p_\mu > \alpha\,(1 - p_0)$$

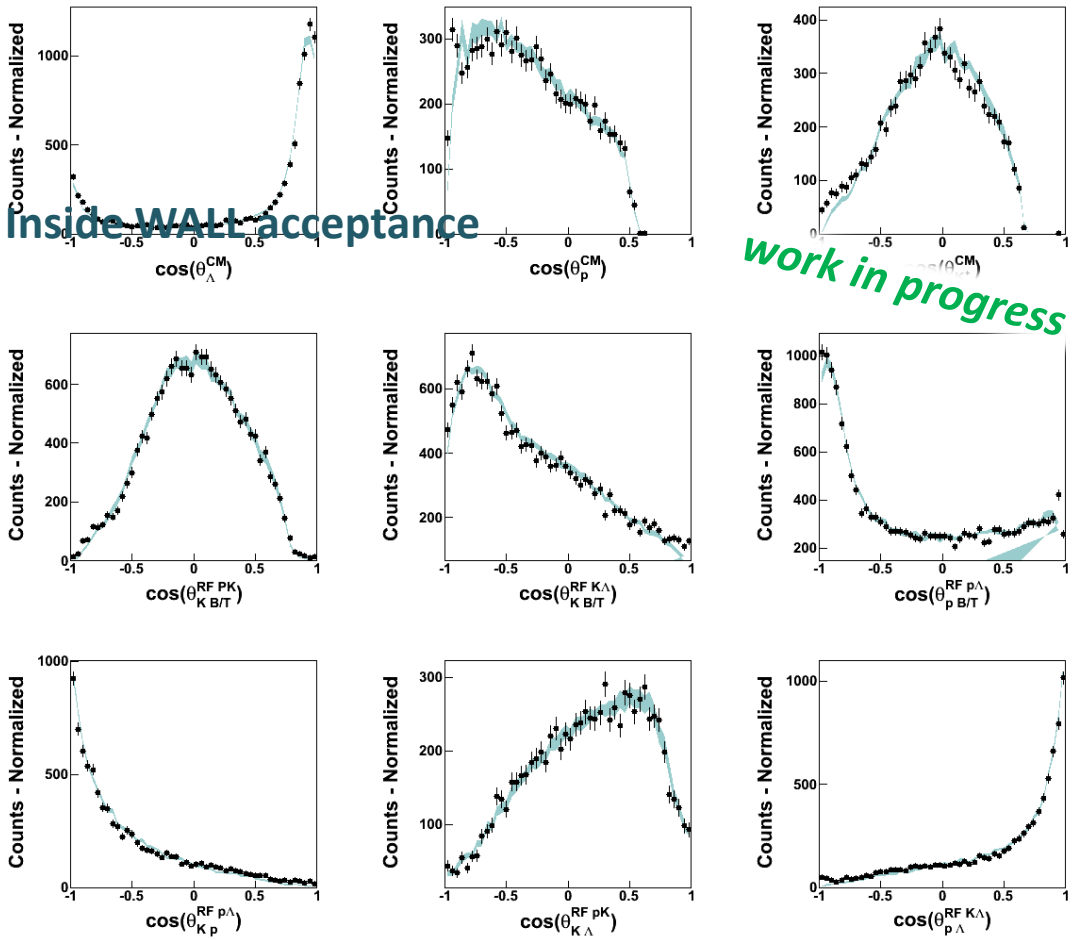
$$p_\mu = \int_{\chi^2_{signal}}^{\infty} f_\nu(\chi^2)\,d\chi^2$$

Scan of different mass and width
M(ppK^-) = 2.205-2.305 GeV/c^2
Γ(ppK^-) = 20-80 MeV/c^2
And 5 best solution of PWA w/o ppK^-

Background Solution: 000113



Hades Wall Data



Inside WALL acceptance

work in progress

Data
Systematic of best PWA solutions

Bonn-Gatchina PWA

Cross Section for the production of three particles out of a collision of two particle

$$d\sigma = \frac{(2\pi)^4 |A|^2}{4|\boldsymbol{k}|\sqrt{s}}\, d\Phi_3(P, q_1, q_2, q_3)\ , \qquad P = k_1 + k_2$$

A - reaction amplitude
k – 3-momentum of the initial particle in the CM
s – $P^2=(k_1+k_2)^2$
$d\Phi_3(P,q_1,q_2,q_3)$ – invariant three-particles phase space

http://pwa.hiskp.uni-bonn.de/

A.V. Anisovich, V.V. Anisovich, E. Klempt, V.A. Nikonov and A.V. Sarantsev
Eur. Phys. J. A 34, 129152 (2007)

The decomposition of the scattering amplitude into partial waves can be written as follows:

$$A = \sum A^{\alpha}_{tr}(s) Q^{in}_{\mu_1 \ldots \mu_J}(SLJ) A_{2b}(i, S_2 L_2 J_2)(s_i) \times\ Q^{fin}_{\mu_1 \ldots \mu_J}(i, S_2 L_2 J_2 S' L' J)\ . \quad (2)$$

S,L,J – spin, orbital mom. and total angular momentum of the pp system
S_2,L_2,J_2 – spin, orbital mom. and total angular momentum of the two particle system in fin. state
S',L' – spin, orbital mom. between the two particle system and the third particle with four mom. q_i
multiindex α – possible combinations of the S, L,J, S_2, L_2, J_2, S', L' and i
A_{tr}^{α} (s) - transition Amplitude
A_{2b}^{α} (i,S_2,L_2,J_2) – rescattering process in he final two-particle channel (e.g. production of Δ)

Fitting Procedure

The transition Amplitude is parameterized as follows

$$A^{\alpha}_{tr}(s) = \left(a^{\alpha}_{1} + a^{\alpha}_{3}\sqrt{s}\right) e^{i a^{\alpha}_{2}}$$

This is a log-likelihood minimization on an event-by-event base

What we included to model the $pK^+\Lambda$ process:

N* Resonances in the PDG with measured decay into $K^+\Lambda$

Notation in PDG	Old notation	Mass [GeV/c^2]	Width [GeV/c^2]	$\Gamma_{\Lambda K}/\Gamma_{All}$ %
N(1650) $\frac{1}{2}^-$	N(1650)S_{11}	1.655	0.150	3-11
N(1710) $\frac{1}{2}^+$	N(1710)P_{11}	1.710	0.200	5-25
N(1720) $\frac{3}{2}^+$	N(1720)D_{13}	1.720	0.250	1-15
N(1875) $\frac{3}{2}^-$	N(1875)D_{13}	1.875	0.220	4± 2
N(1880) $\frac{1}{2}^+$	N(1880)P_{11}	1.870	0.235	2± 1
N(1895) $\frac{1}{2}^-$	N(1895)S_{11}	1.895	0.090	18± 5
N(1900) $\frac{3}{2}^+$	N(1900)P_{13}	1.900	0.250	0-10

And the production of $pK^+\Lambda$ via non resonant waves

Systematic

N* content

No.	Combination
0	N(1650), N(1710), N(1720)
1	N(1650), N(1710), N(1720), N(1900)
2	N(1650), N(1710), N(1720), N(1895)
3	N(1650), N(1710), N(1720), N(1880)
4	N(1650), N(1710), N(1720), N(1875)
5	N(1650), N(1710), N(1720), N(1900), N(1880)
6	N(1650), N(1710), N(1720), N(1900), N(1895)
7	N(1650), N(1710), N(1720), N(1900), N(1875)
8	N(1650), N(1710), N(1720), N(1895), N(1880)
9	N(1650), N(1710), N(1720), N(1895), N(1875)
10	N(1650), N(1710), N(1720), N(1880), N(1875)

non-resonant content

No.	Combination
0	no non-resonant waves
1	$(pL)(^1S_0) - K$
2	previous wave + $(pL)(^3S_1) - K$
3	previous waves + $(pL)(^1P_1) - K$
4	previous waves + $(pL)(^3P_0) - K$
5	previous waves + $(pL)(^3P_1) - K$
6	previous waves + $(pL)(^3P_2) - K$
7	previous waves + $(pL)(^1D_2) - K$
8	previous waves + $(pL)(^3D_1) - K$
9	previous waves + $(pL)(^3D_2) - K$

Best Solutions

No. of N* combination	No. of non-res. waves	Log-likelih.
0	7	-2415.74
1	**8**	**-2708.49**
2	8	-2524.59
3	**8**	**-2712.49**
4	4	-2671.05
5	8	-2310.4
6	**9**	**-2754.37**
7	8	-2657.77
8	**8**	**-2734.97**
9	6	-2698.86
10	4	-2642.58

Solution inside WALL acceptance

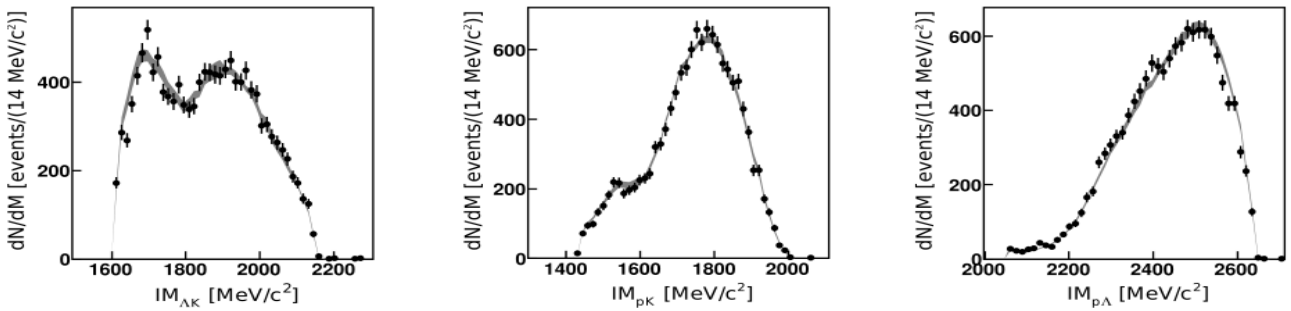


Figure 2.18: Two-particle masses for the **HADES data set** (black points) shown with the **four best PWA solutions** (gray band), obtained by a ?t to the HADES and WALL data.

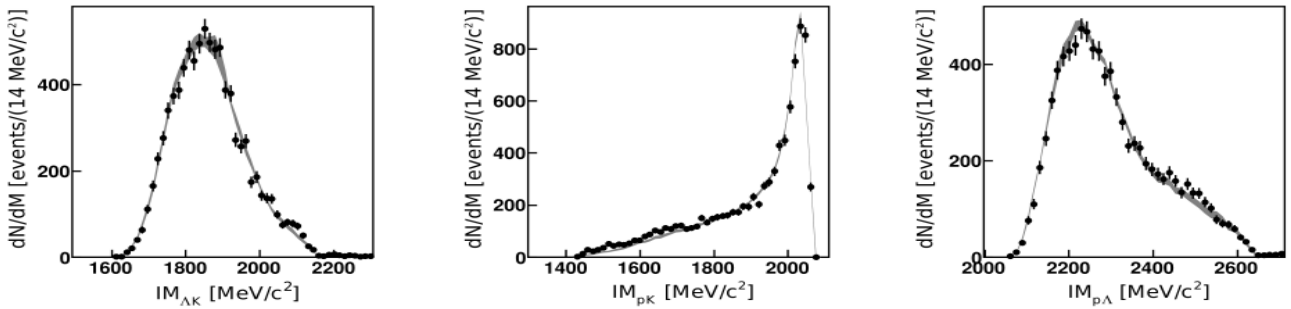
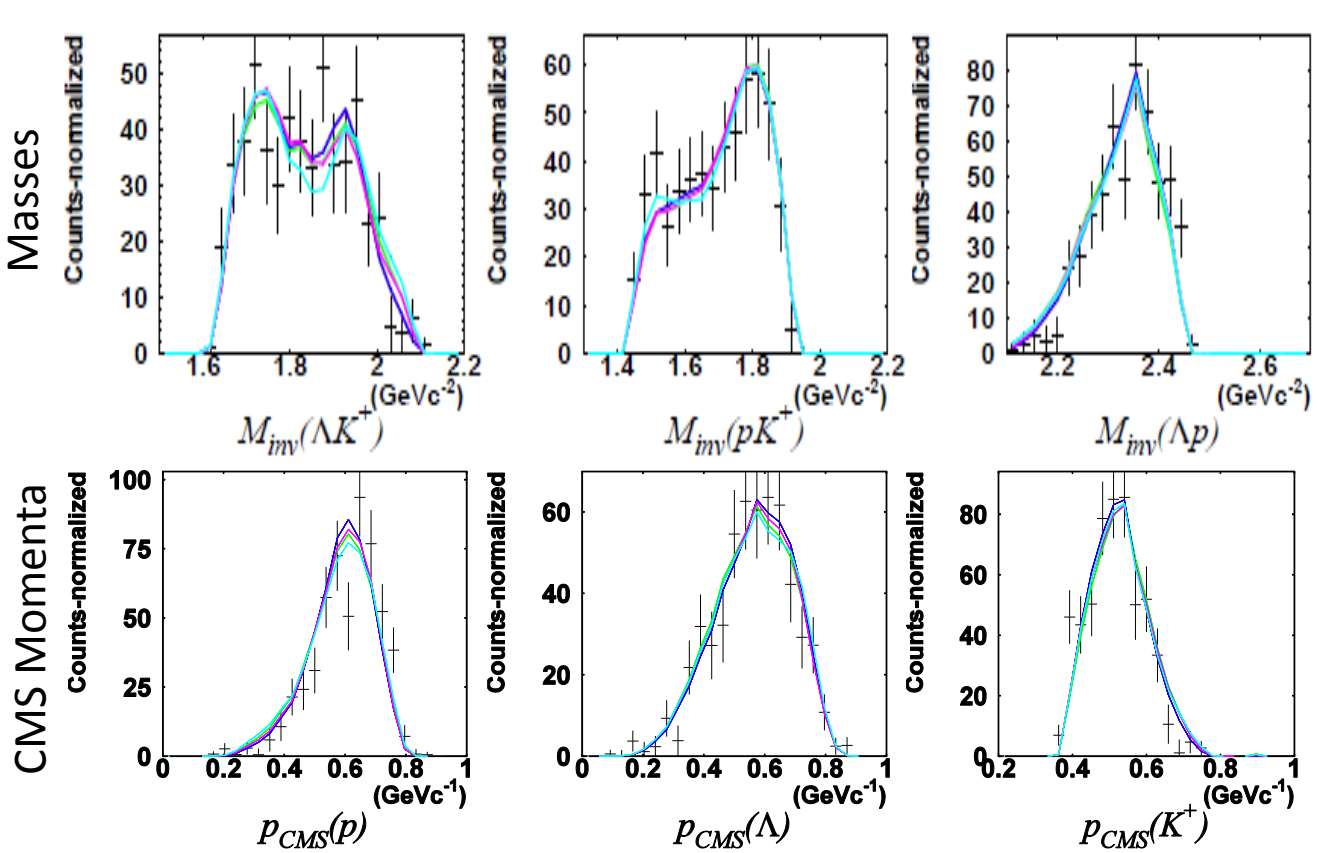


Figure 2.19: Two-particle masses for the **WALL data set** (black points) shown with the **four best PWA solutions** (gray band), obtained by a ?t to the HADES and WALL data.

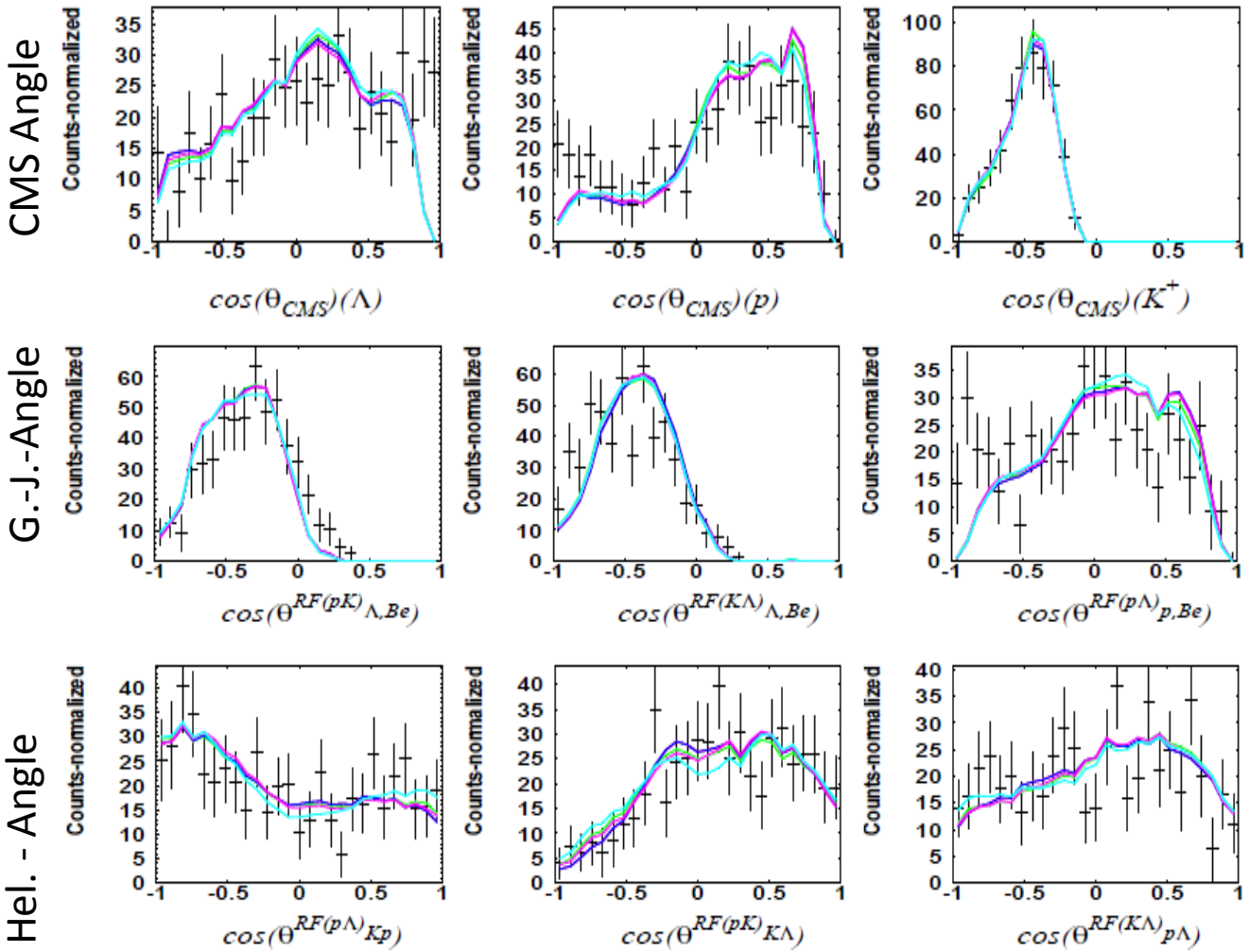
PWA Results



✚ Experimental Data

Solution A
Solution B
Solution C
Solution D
Solution E

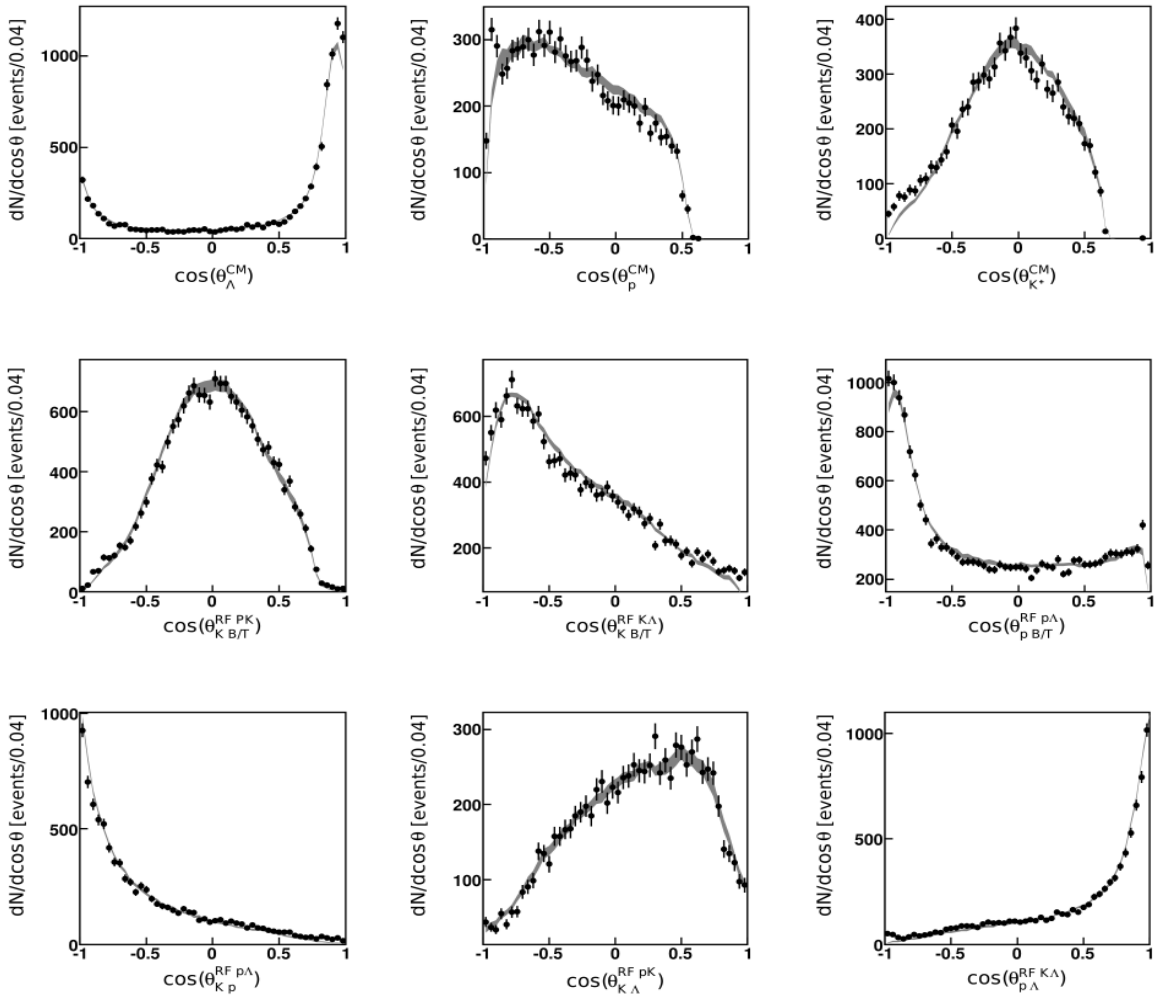
PWA Results



✚ Experimental Data

Solution A
Solution B
Solution C
Solution D
Solution E

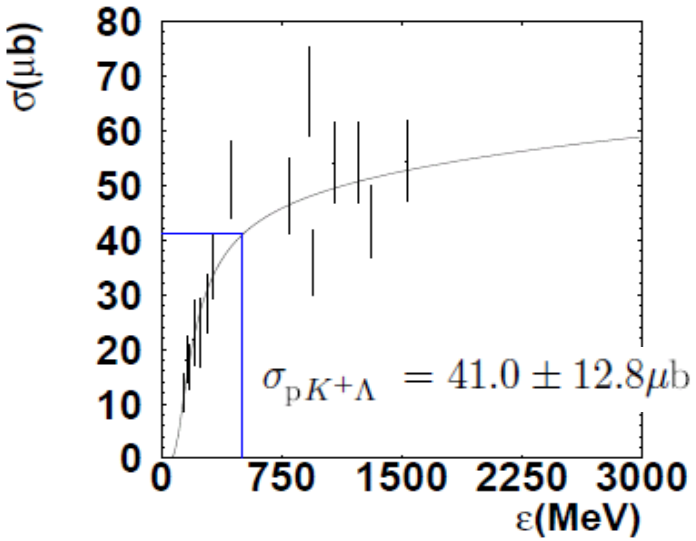
Solution inside WALL acceptance



ppK$^-$ Upper Limit

p + p -> p + K^+ + Λ
Total Cross Section

$$\sigma(\epsilon) = a\left(1 - \frac{s_0}{(\sqrt{s_0}+\epsilon)^2}\right)^b \left(\frac{s_0}{(\sqrt{s_0}+\epsilon)^2}\right)^c$$



S. Abd El-Samad et al. Phys.Lett B688 (2010)
S. Abd El-Samad et al. Phys.Lett B632 (2007)
M. Abdel-Bary et al., Eur.Phys.J A46(2010)
S. Abd El-Samad et al., Eur.Phys.J A49(2013)
K.Fuchs et al., Springer Verlag 1985

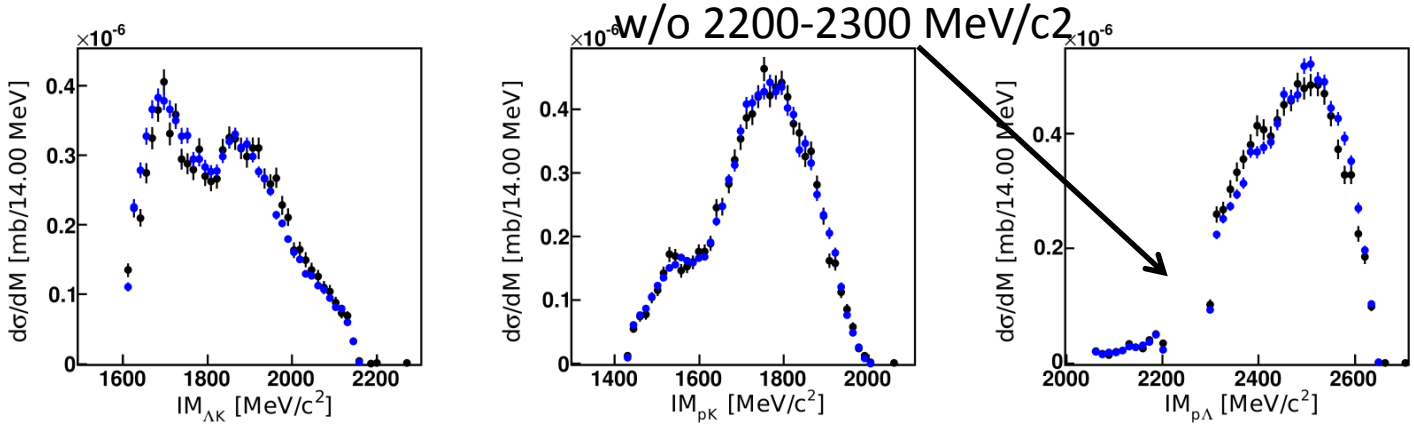
Upper Limit Cross Section

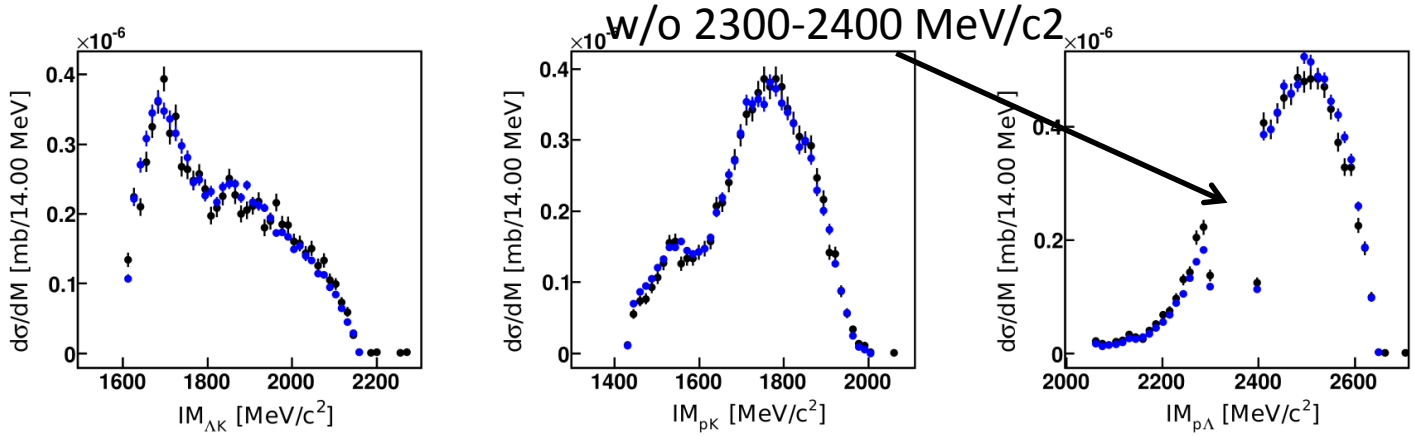
Γ (MeVc^{-2})	Cross Section (μb)
20	$7.6 \pm 1.2^{-3.5}$ - $22.4 \pm 3.6^{-10.7}$
35	$6.3 \pm 1.7^{-0.6}$ - $9.5 \pm 2.6^{-0.9}$
50	$10.2 \pm 1.8^{-4.5}$ - $11.6 \pm 3.4^{-0.6}$
60	$11.2 \pm 1.9^{-5.0}$ - $33.8 \pm 5.2^{-16.9}$
80	$11.4 \pm 2.7^{-3.8}$ - $35.9 \pm 5.7^{-17.4}$

High production cross section
even though no peak is visible

Peak structure suppressed
due to interference

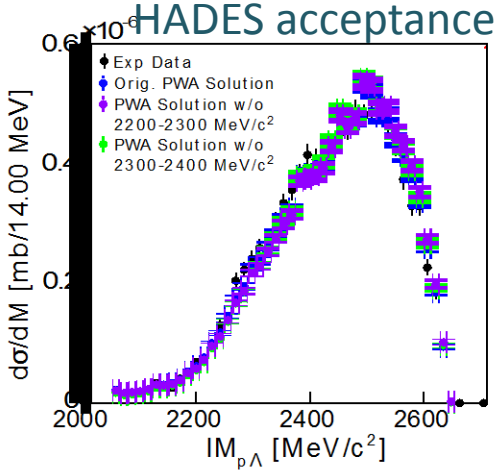
Cross Check

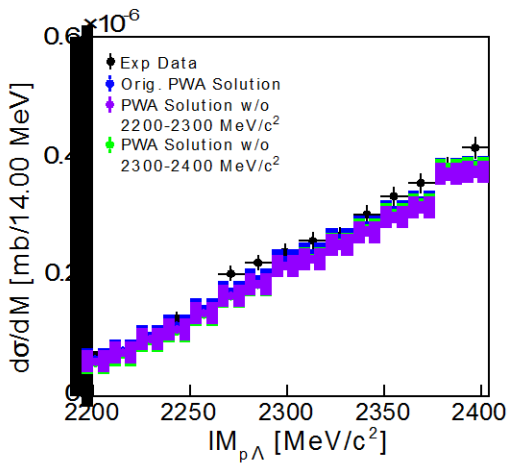

w/o 2200-2300 MeV/c2
dσ/dM [mb/14.00 MeV]
IM_ΛK [MeV/c²]
IM_pK [MeV/c²]
IM_pΛ [MeV/c²]


w/o 2300-2400 MeV/c2
dσ/dM [mb/14.00 MeV]
IM_ΛK [MeV/c²]
IM_pK [MeV/c²]
IM_pΛ [MeV/c²]

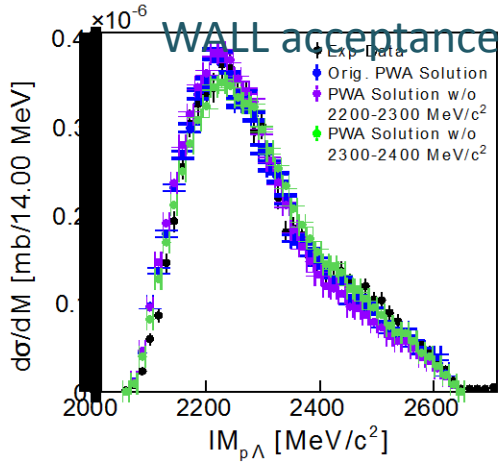
Cross Check

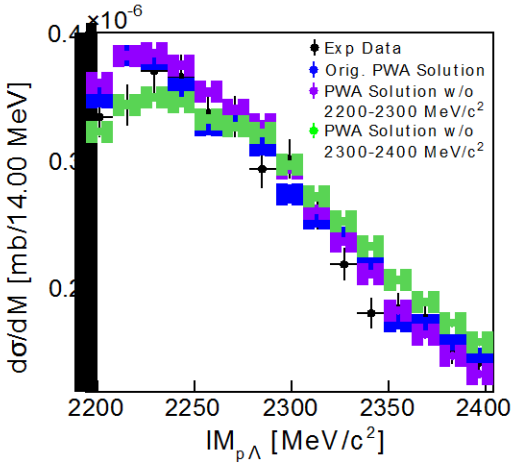
HADES acceptance





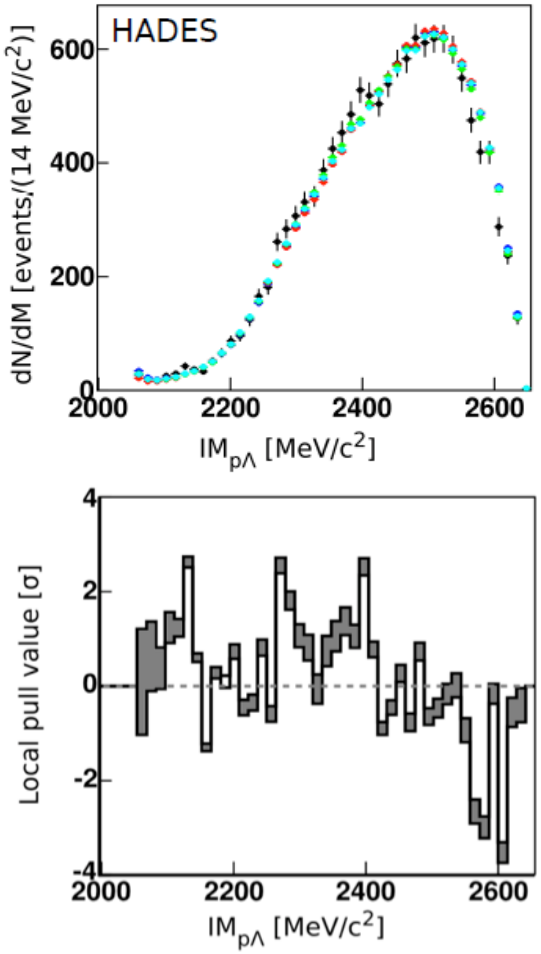
WALL acceptance





Good consistency among the results.
The solution is not biased by a possible signal in the excluded mass range

Result



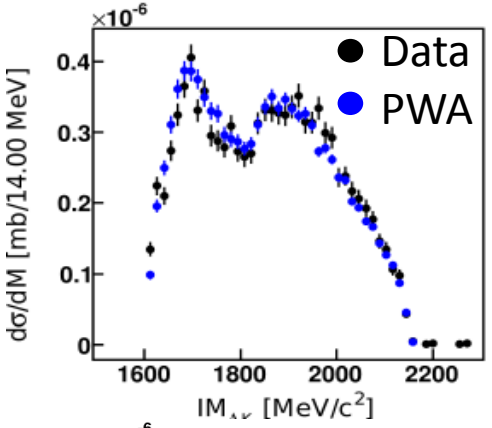
$$pull = \sum_{i=1}^{N_b} \frac{(m_i - \lambda_i)}{\lambda_i}$$

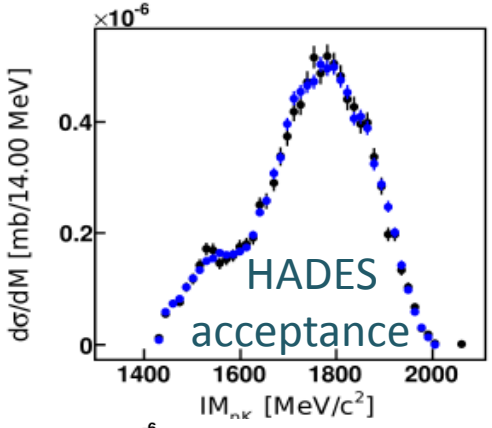
m_i are the number of measured events in the bin i
λ_i number of expected events in the bin according to the model
N_b is the number of bins

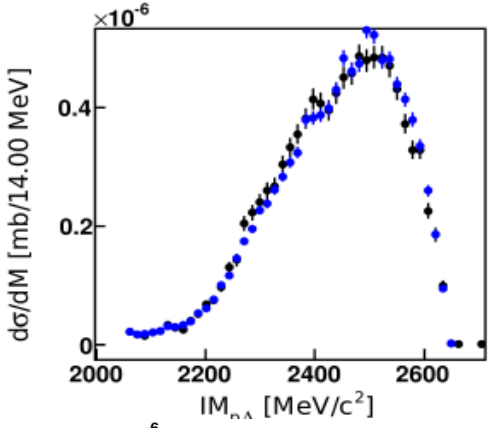
The best solution

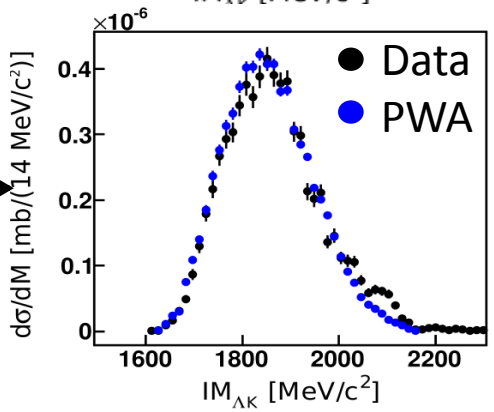
Fitted

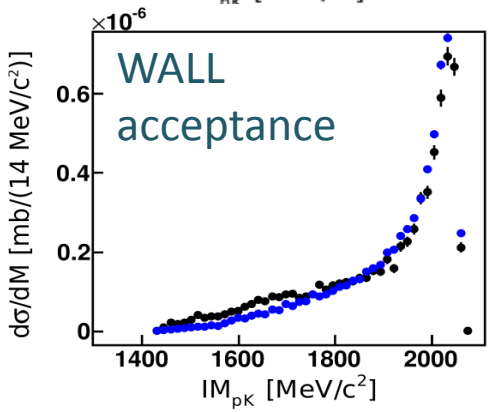
Extra-polated

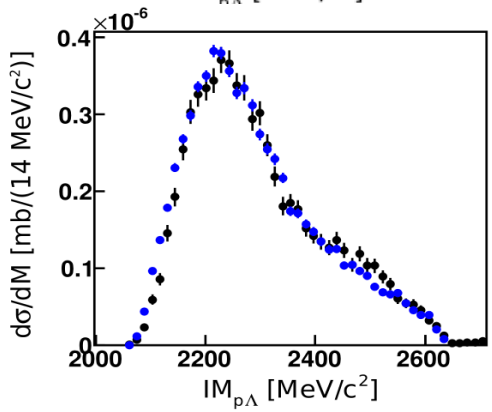












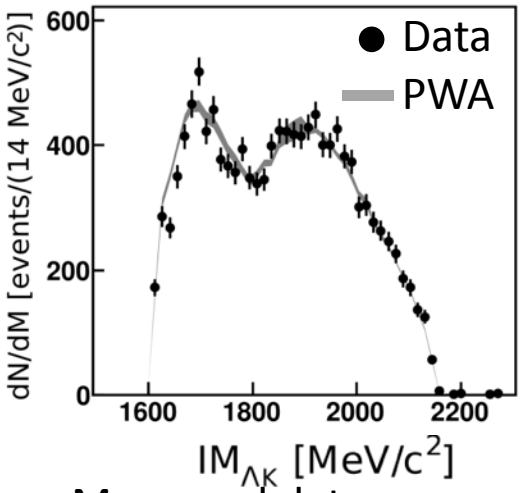
Included resonances: N(1650), N(1710), N(1720), N(1900), N(1895)

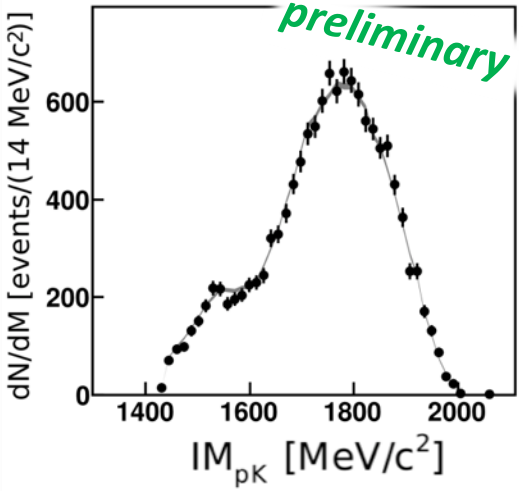
Non-resonant waves:

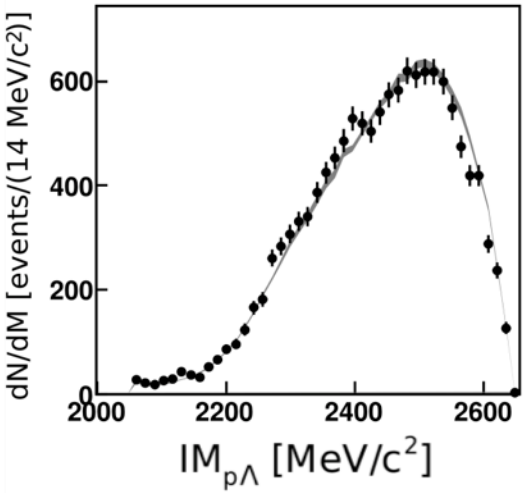
$(pL)(^1S_0) - K$ $(pL)(^3S_1) - K$ $(pL)(^1P_1) - K$
$(pL)(^3P_0) - K$ $(pL)(^3P_2) - K$ $(pL)(^3P_1) - K$
$(pL)(^3D_1) - K$ $(pL)(^1D_2) - K$ $(pL)(^3D_2) - K$

Four Best PWA Solutions

Inside HADES acceptance







Measured data

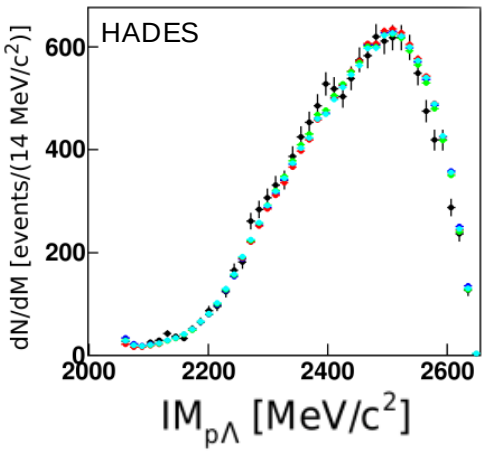
PWA solutions

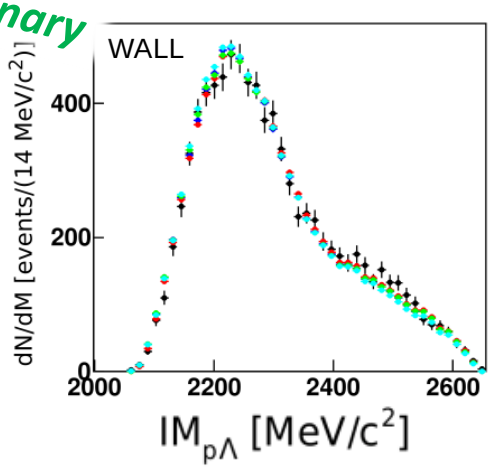
Name	N* combination
1/8	N(1650), N(1710), N(1720), N(1900)
3/8	N(1650), N(1710), N(1720), N(1880)
6/9	N(1650), N(1710), N(1720), N(1900), N(1895)
8/8	N(1650), N(1710), N(1720), N(1895), N(1880)

Test of the Null Hypothesis

Test of the Null Hypothesis

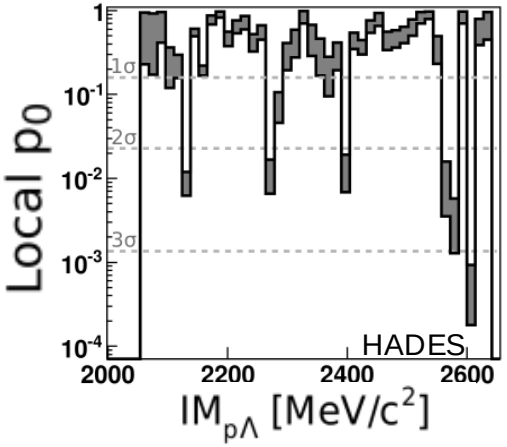
preliminary

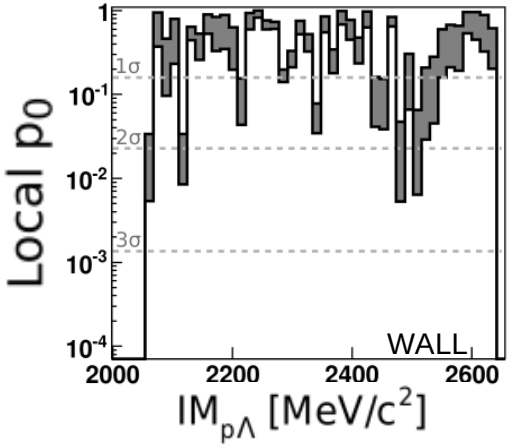




$$\chi^2_P = \frac{(m_i - \lambda_i)^2}{\lambda_i}$$

$$p - value = \int_{\chi^2_{P,d}}^{\infty} P(\chi^2, Ndf)\, d\chi^2$$

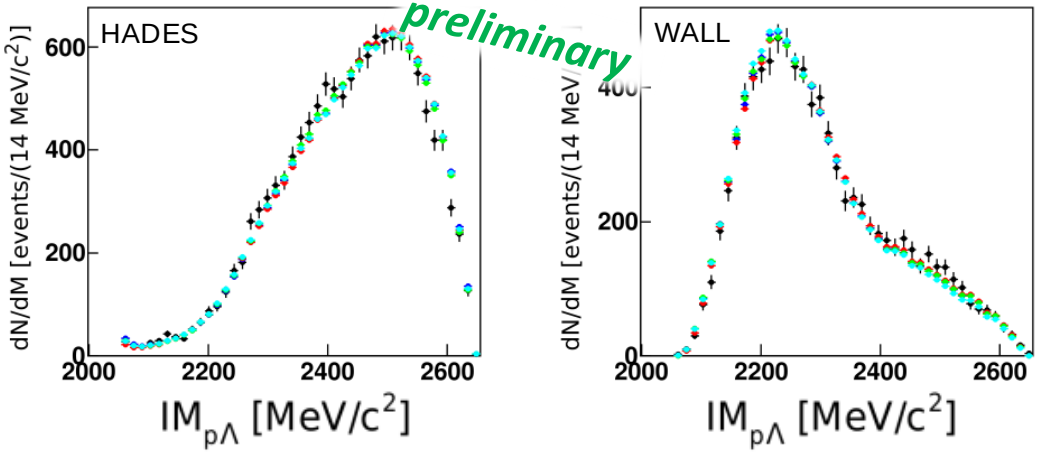


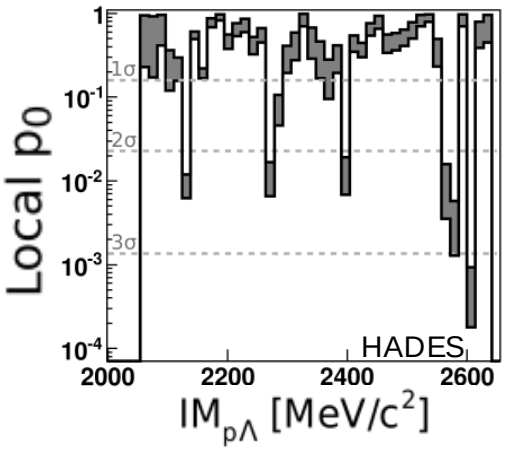


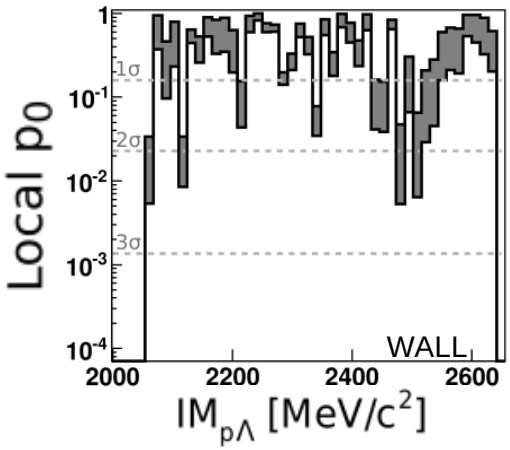
m_i measured events in bin i

λ_i expected events in bin i according to the model

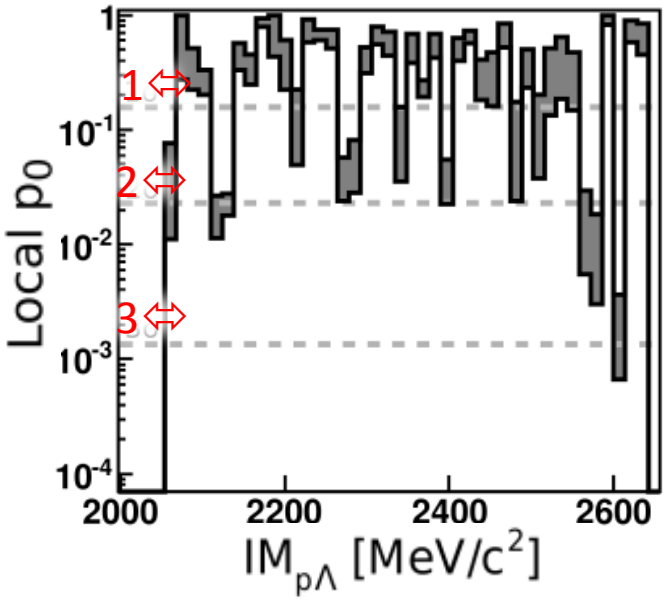
Test of the Null Hypothesis



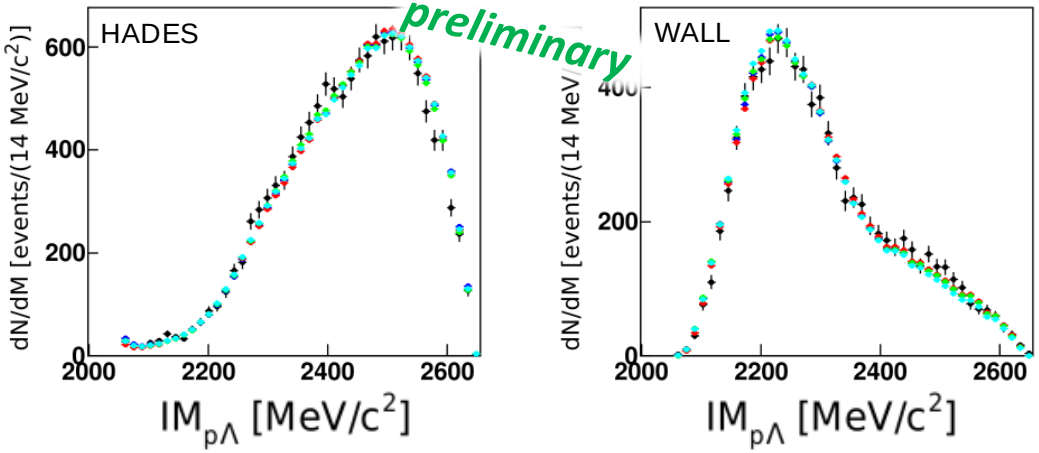


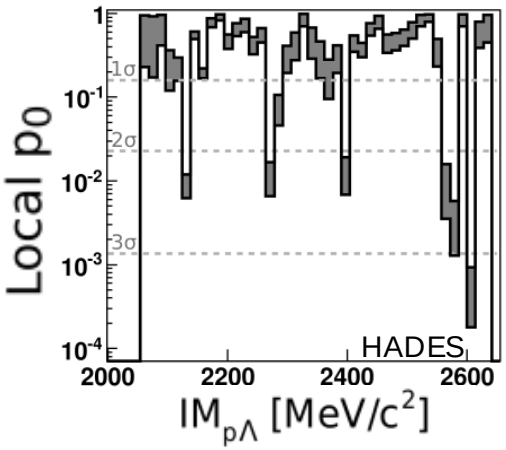


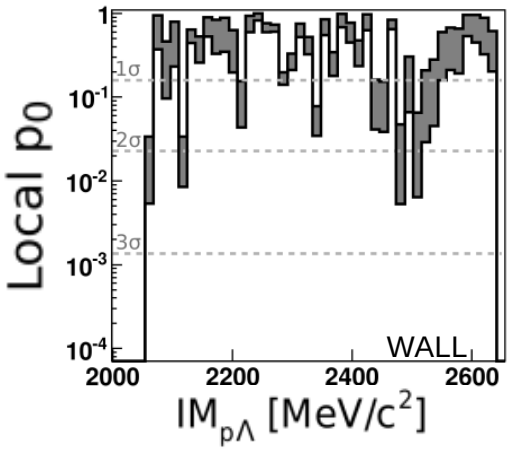
Combined result



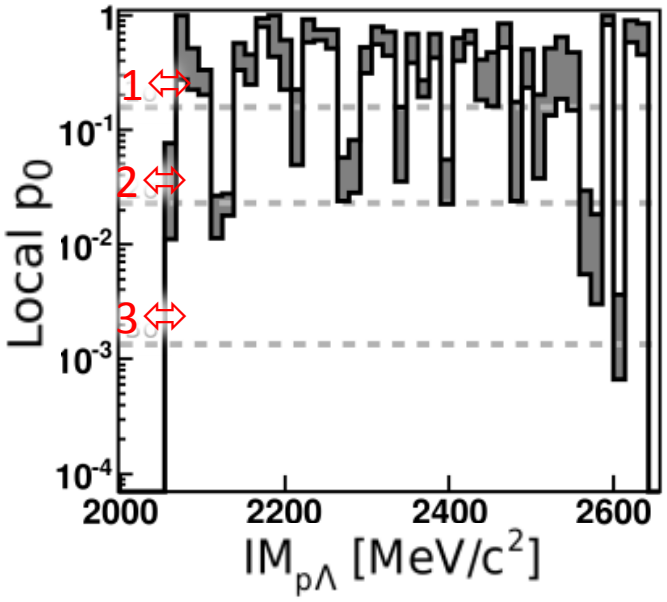
Test of the Null Hypothesis





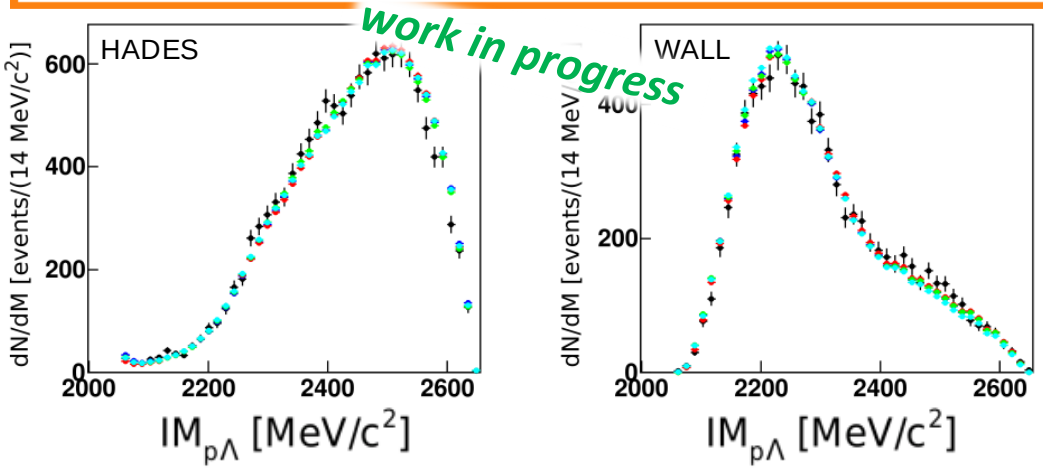


Combined result



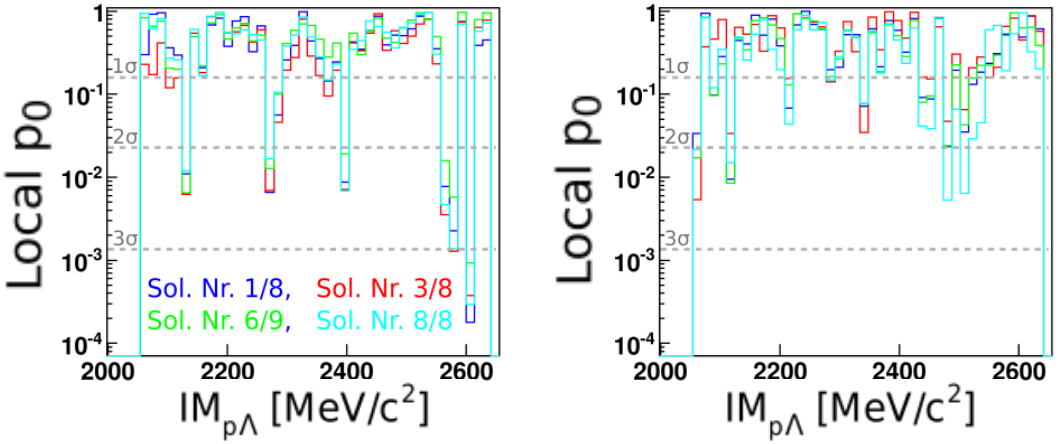
We found no new signal in the data

Test of the Null Hypothesis



$$\chi^2_P = \frac{(m - \lambda)^2}{\lambda}$$

$$p - value = \int_{\chi^2_{P,d}}^{\infty} P(\chi^2, Ndf) d\chi^2$$

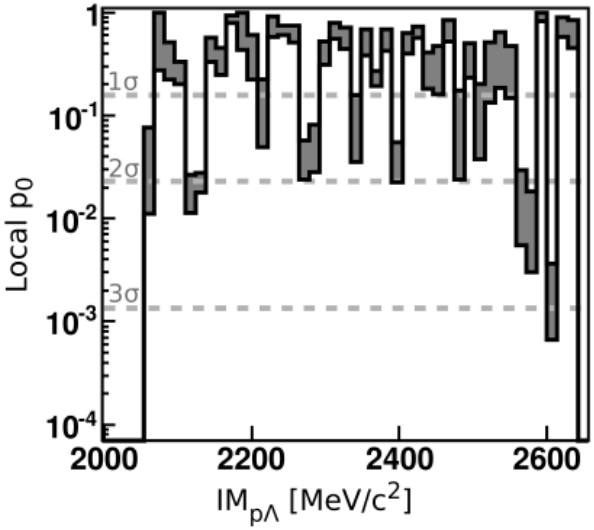


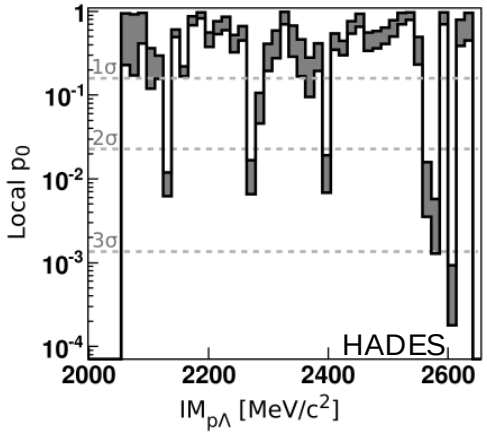
m_i measured events in bin i

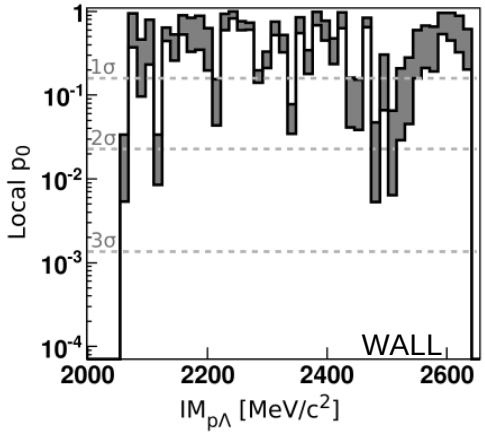
λ_i expected events in bin i according to the model

$$\chi^2_P = \frac{(m_{\cdot} - \lambda\ )^2}{\lambda} \Rightarrow \chi^2_P = \sum_{i=1}^{N_b} \frac{(m_i - \lambda_i)^2}{\lambda_i}$$

Combined result

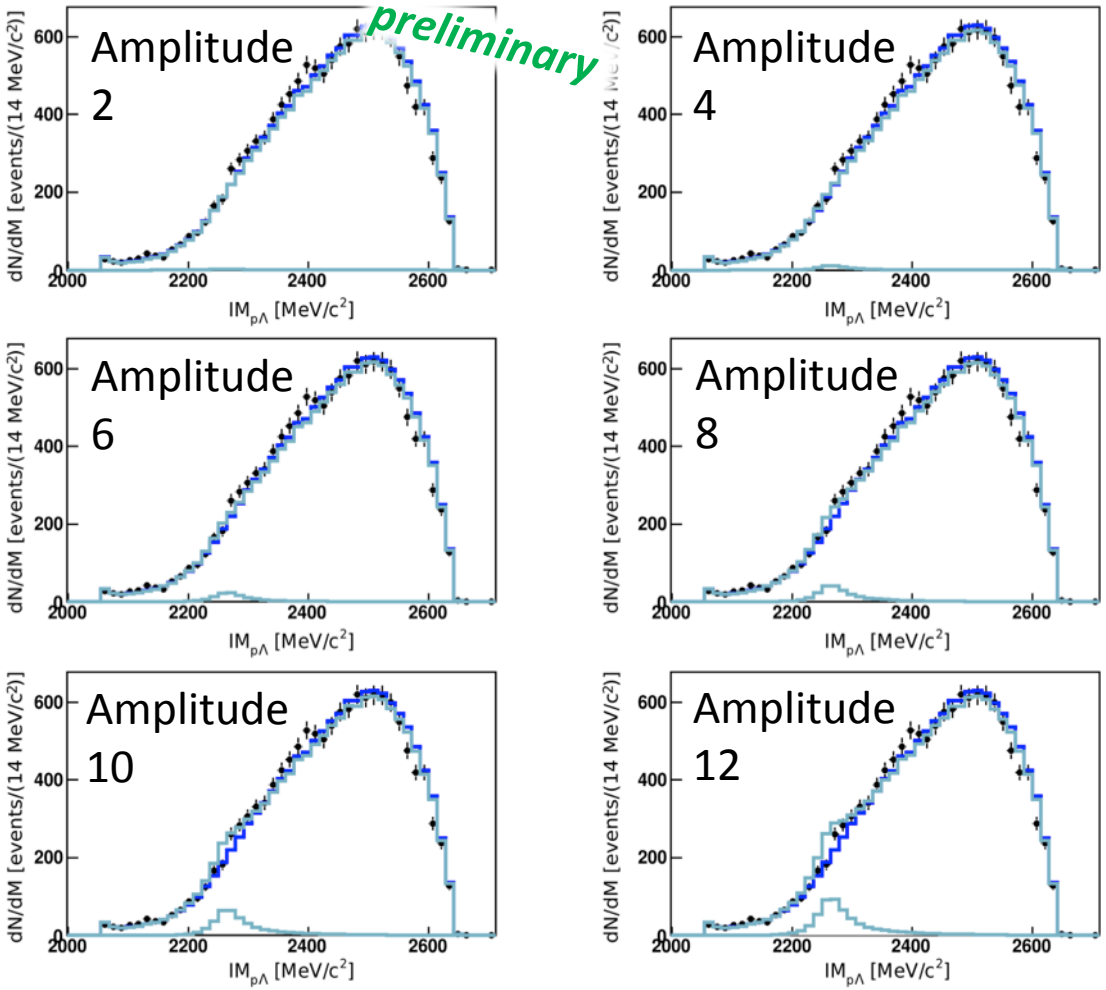






Test of the Signal Hypothesis

Inclusion of a new State



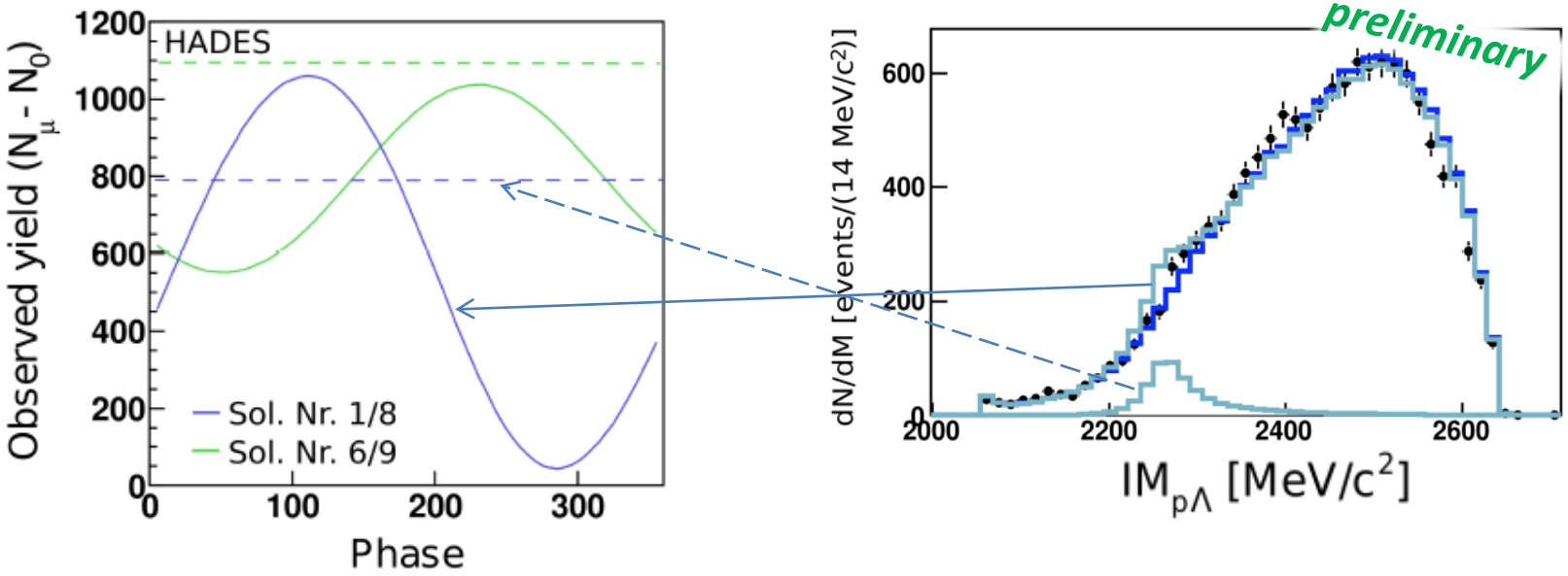
Data Points

Null Hypothesis

Hypothesis with ppK-

Feature of a PWA

… Interferences



The minimum has to be found by the fit

Upper limit at CL_s 95%

These waves are included into the four best solutions of the PWA

$^{2S+1}L_J$

$$Wave A: \ ^{'}p + p^{'} \ ^1S_0 \rightarrow \ ^{'}ppK(2250) - K^{'} \ ^1S_0$$

$$Wave B: \ ^{'}p + p^{'} \ ^3P_1 \rightarrow \ ^{'}ppK(2250) - K^{'} \ ^1P_1$$

$$Wave C: \ ^{'}p + p^{'} \ ^1D_2 \rightarrow \ ^{'}ppK(2250) - K^{'} \ ^1D_2$$

Scanned masses:
2220 – 2370 MeV/c^2 (in steps of 10 MeV/c^2)
Scanned widths:
30 MeV, 50 MeV, and 70 MeV

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N* resonances

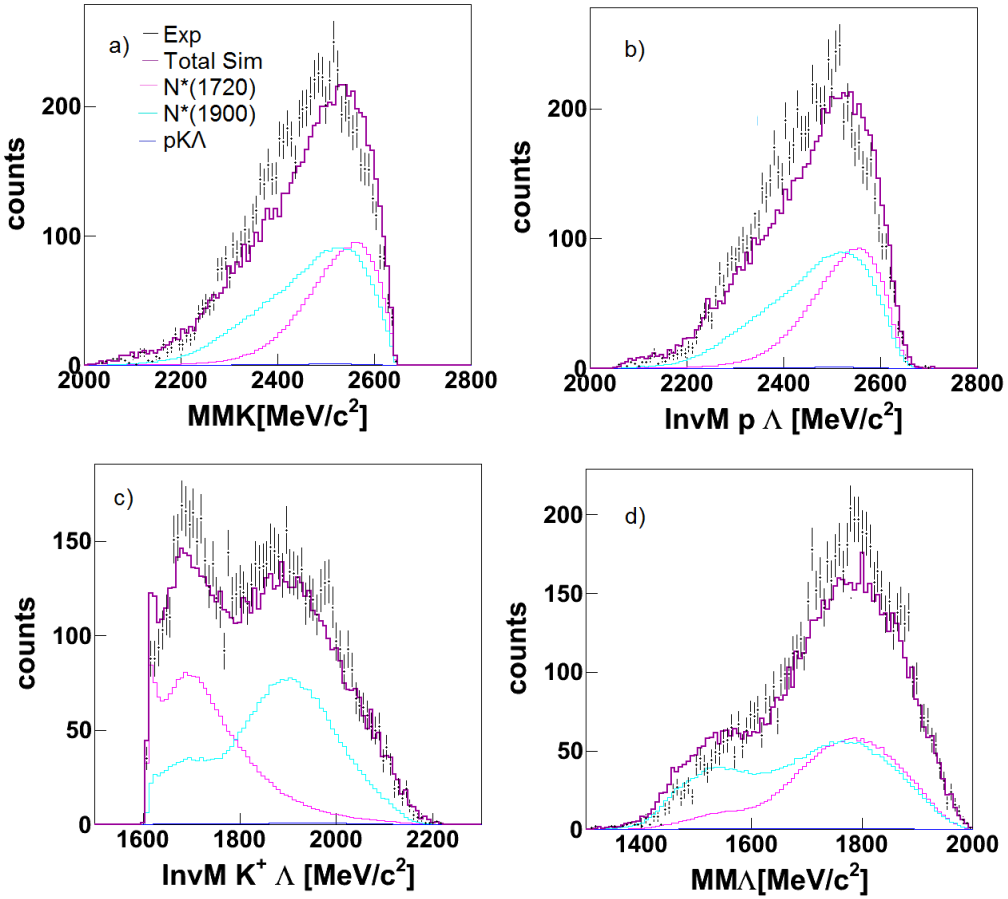
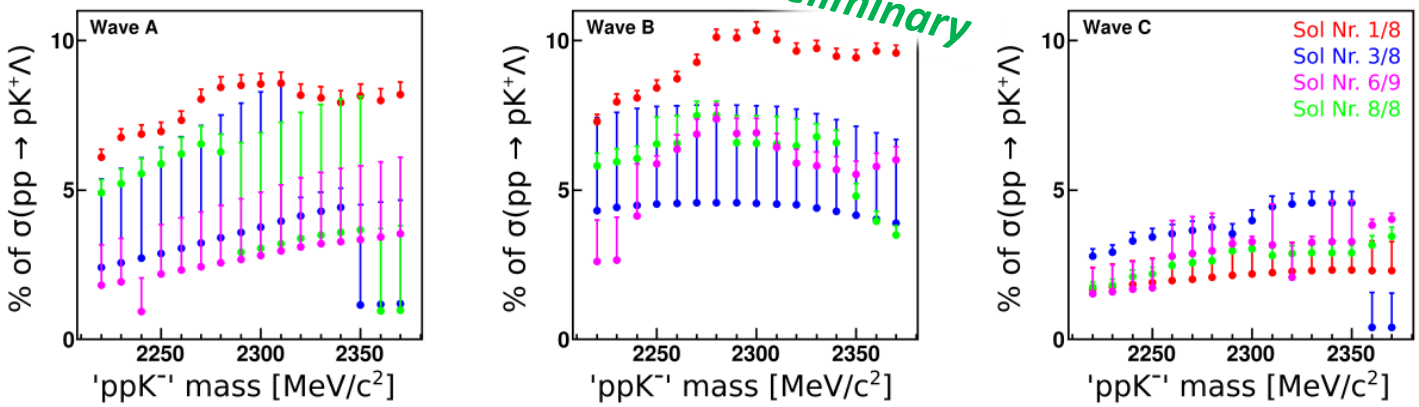


Figure 6.10: a) $IM_{K^+\Lambda}$, b) $IM_{p\Lambda}$,c) MM_{K^+} and d) MM_{Λ} fitted with the sum of the four N^{*+}-resonances from table 6.2 and the simulation of a direct $pK^+\Lambda$ production.

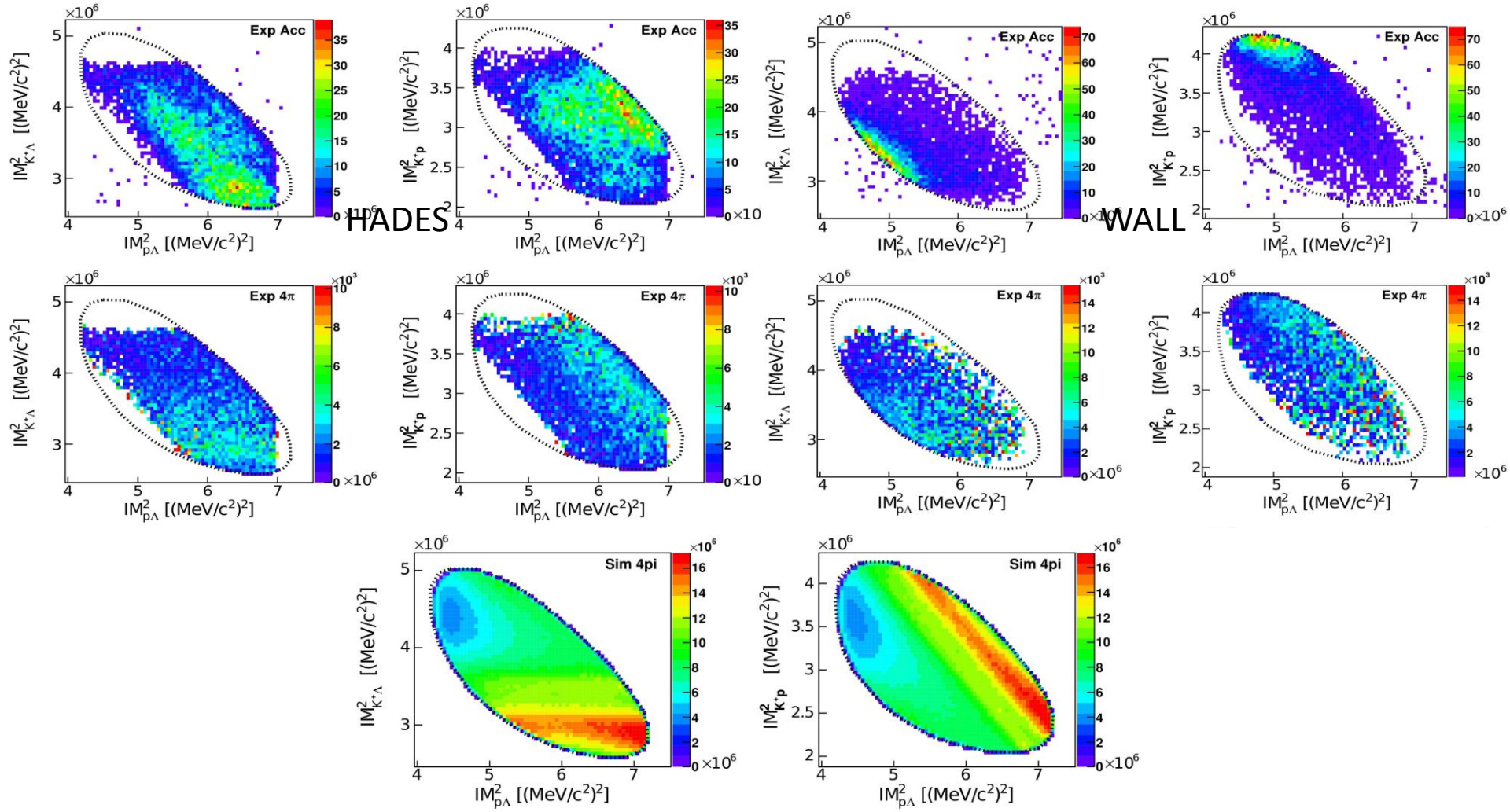
Master Thesis A. Solaguren-Beascoa Negre

Upper Limit

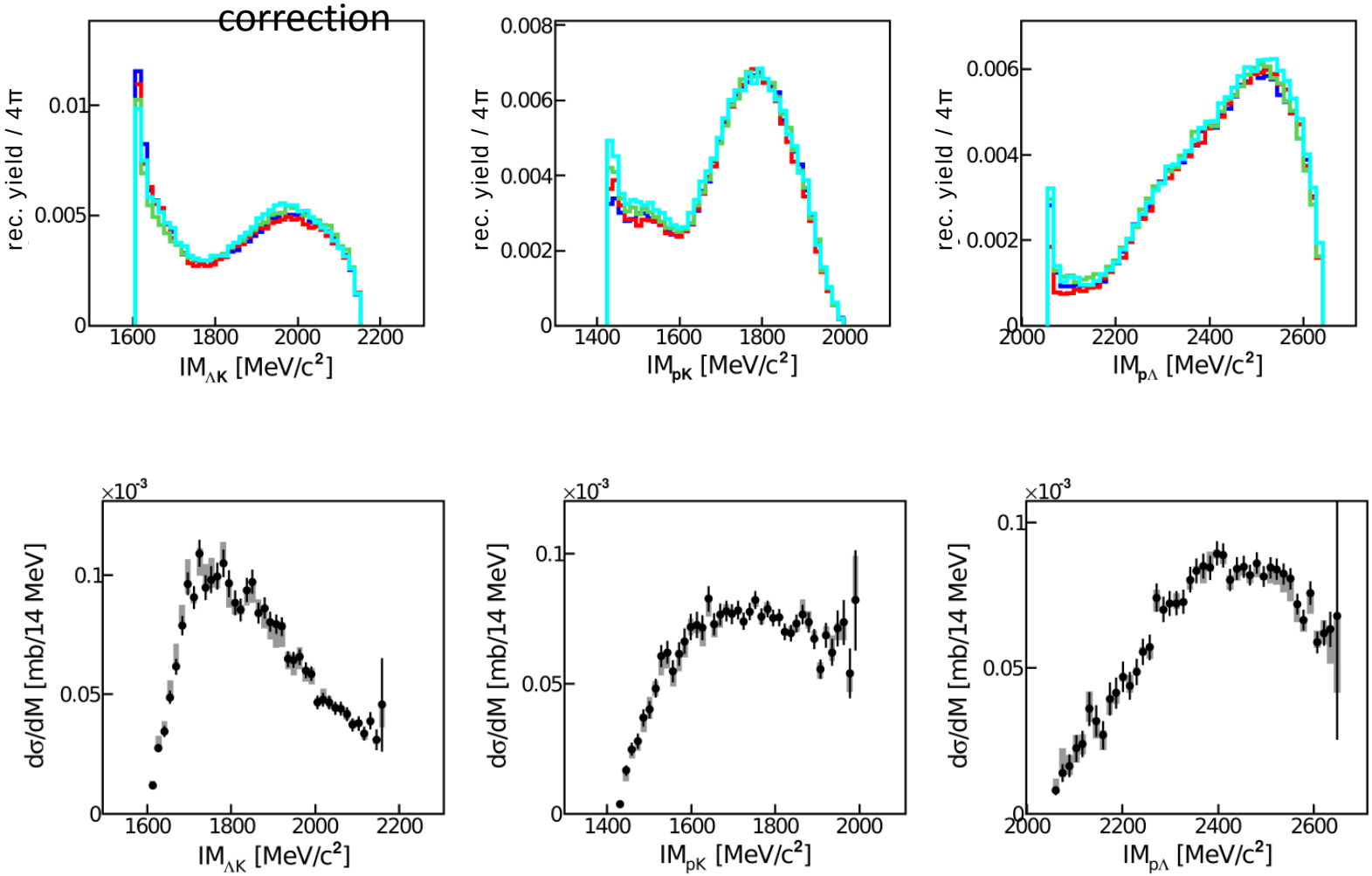


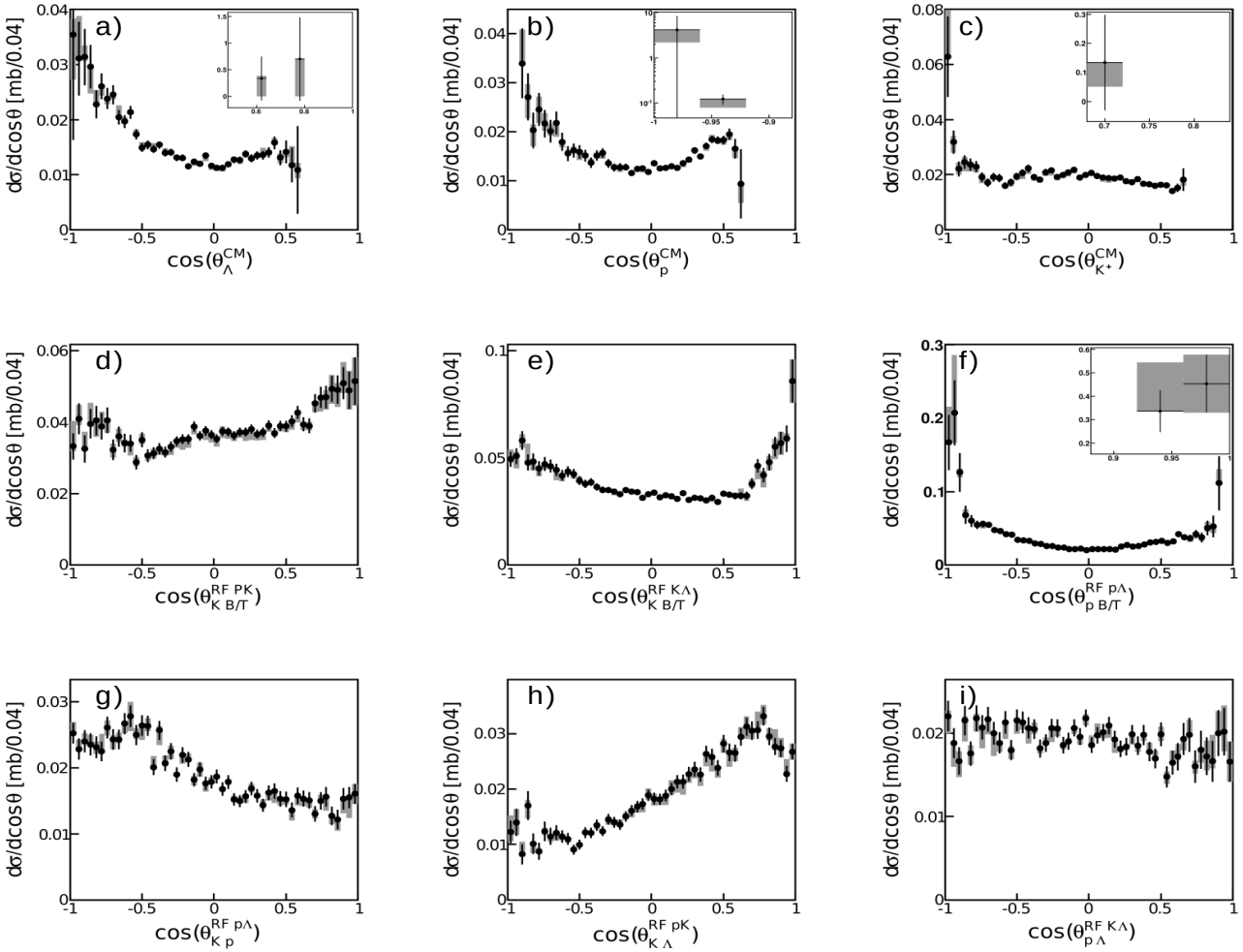
Γ(ppK$^-$)=50 MeV

Dalitz Plots



Cross Section




a)
b)
c)
d)
e)
f)
g)
h)
i)
dσ/dcosθ [mb/0.04]
cos(θ^CM_Λ)
cos(θ^CM_p)
cos(θ^CM_K+)
cos(θ^RF pK_K B/T)
cos(θ^RF KΛ_K B/T)
cos(θ^RF pΛ_p B/T)
cos(θ^RF pΛ_K p)
cos(θ^RF pK_K Λ)
cos(θ^RF KΛ_p Λ)

Multi PWA

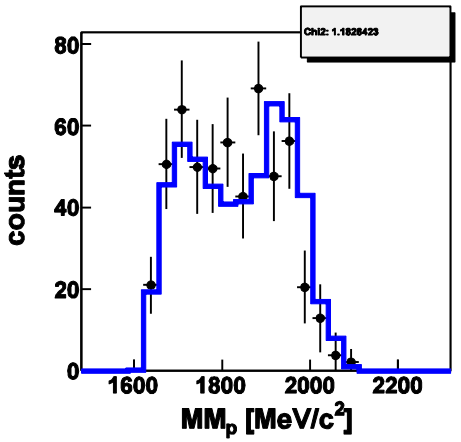
Combined Analysis of HADES and FOPI

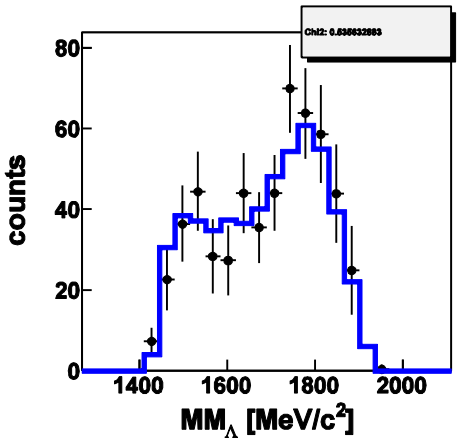
4 Best HADES Solutions HADES-only	→	4 Best HADES Solutions HADES+FOPI
1_8 (s=-0.27 10^4)		1_8 (s=-0.83 10^5)
8_8 (s=-0.27 10^4)		8_8 (s=-0.82 10^5)
3_8 (s=-0.27 10^4)		**3_8 (s=-0.98 10^5)**
6_9 (s=-0.27 10^4)		6_9 (s=-0.78 10^5)

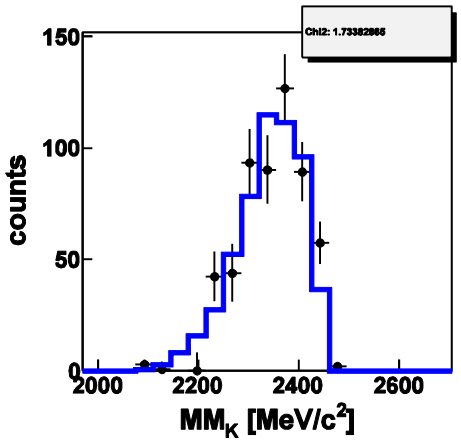
s : - (Log Likely hood) of PWA

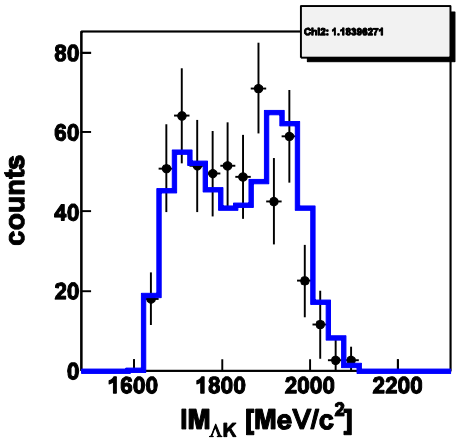
Energy dependent coefficient =0

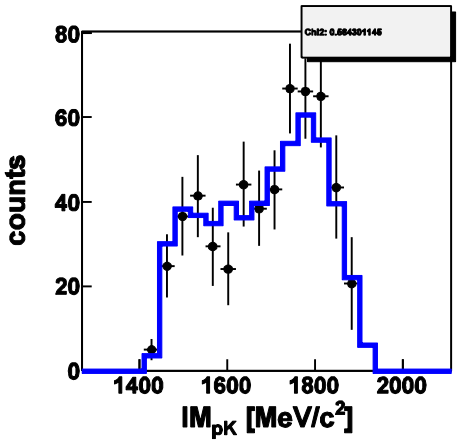
Results of 3_8

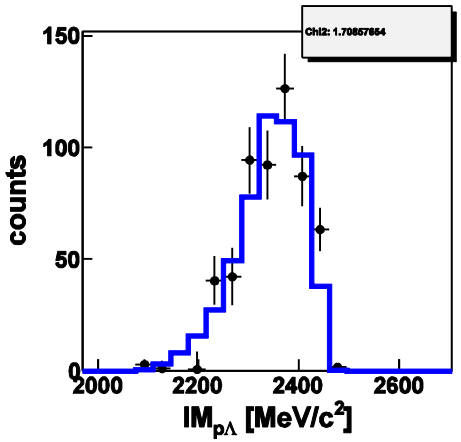




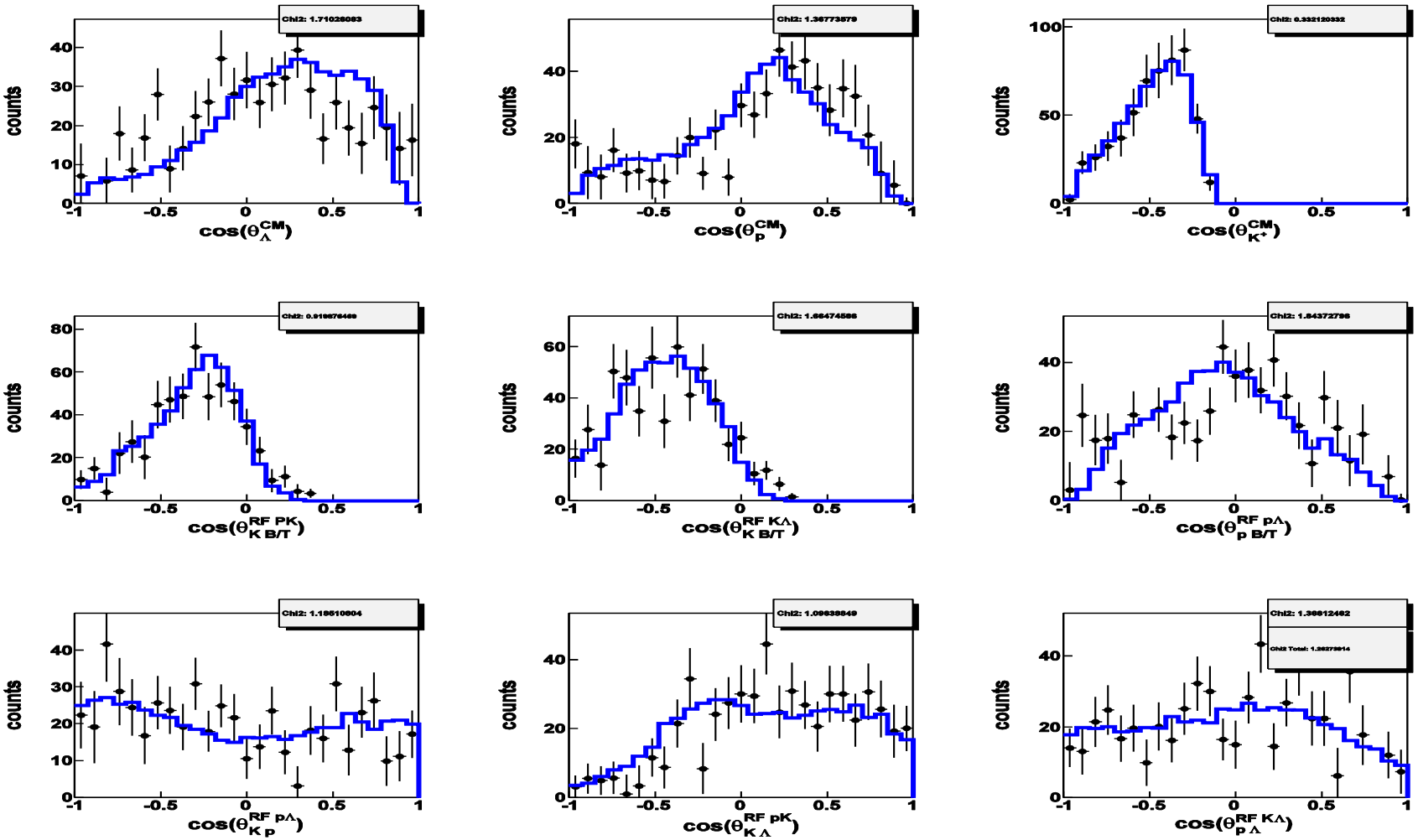




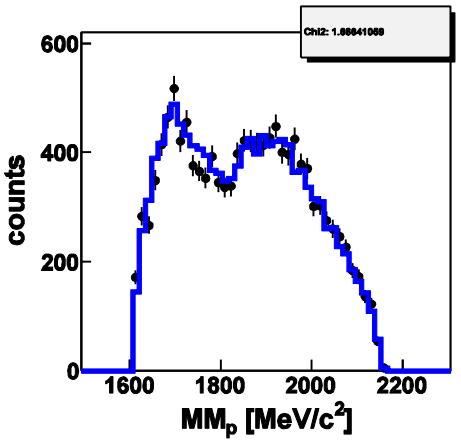


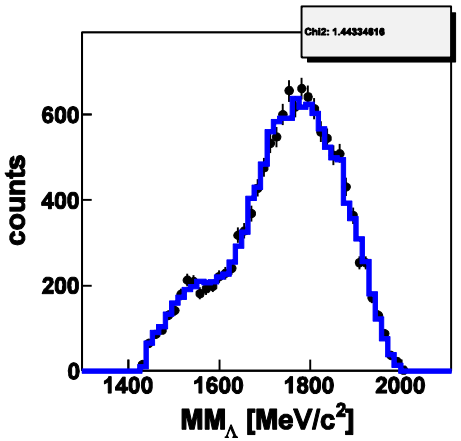


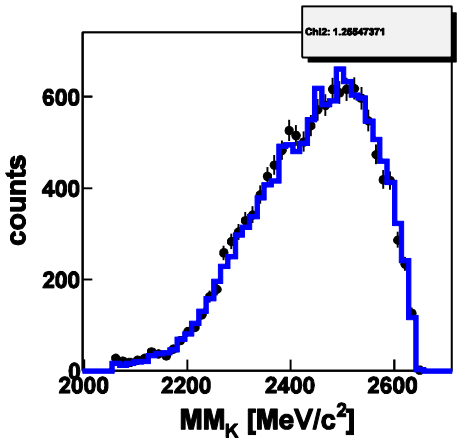
Results of 3_8

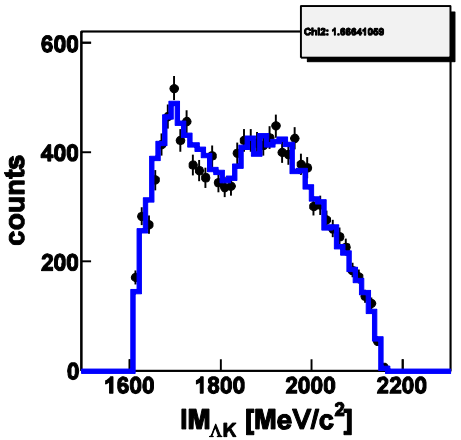


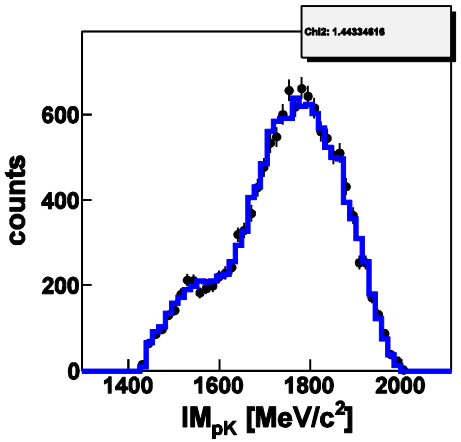
Results of 3_8

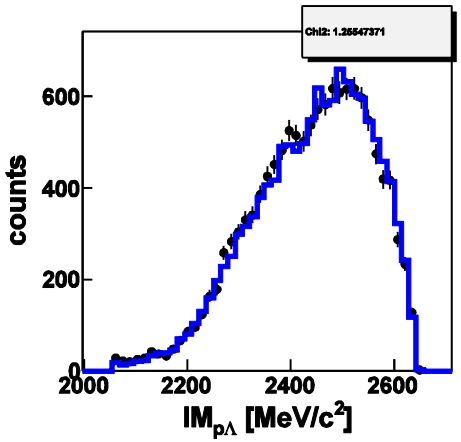




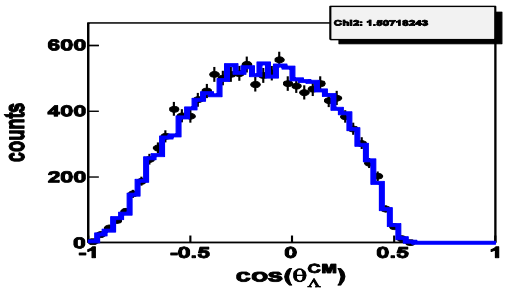


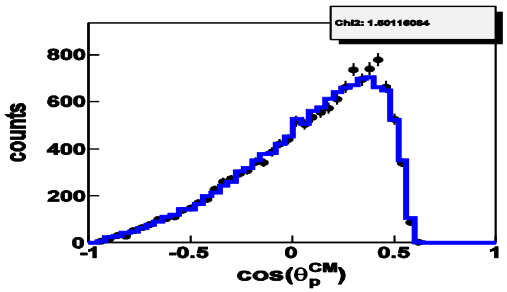


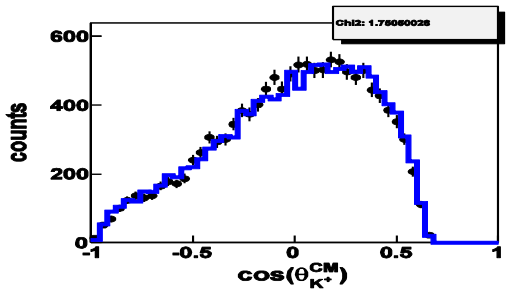


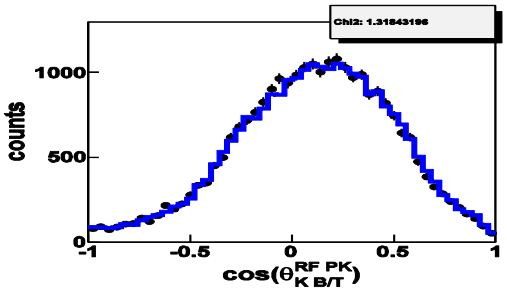


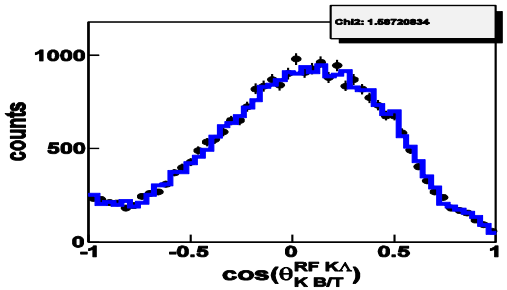
Results of 3_8

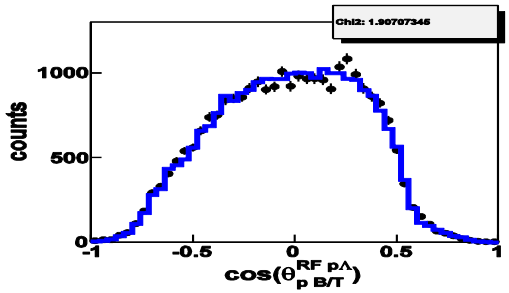


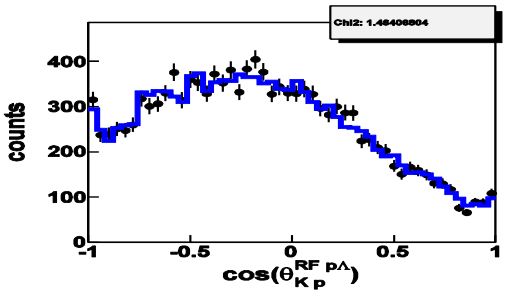


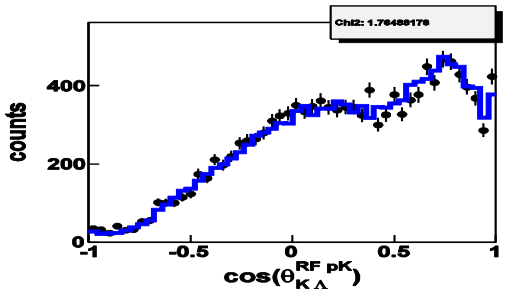


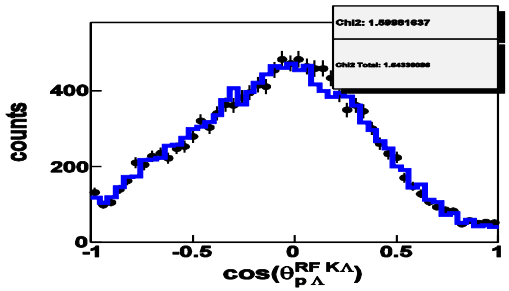












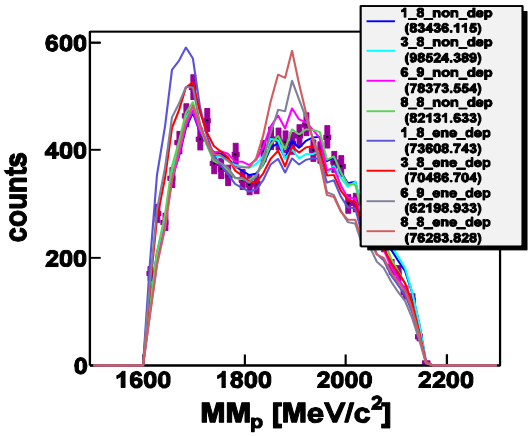
Combined Analysis of HADES and FOPI

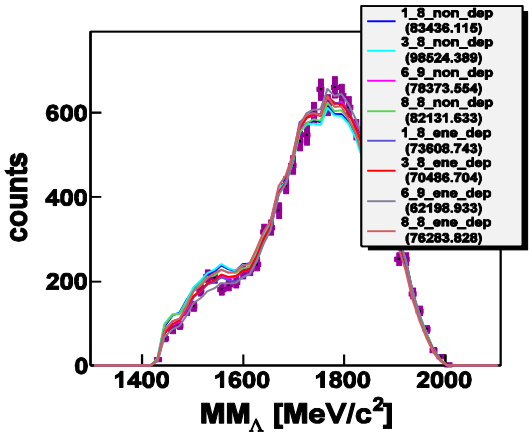
4 Best HADES Solutions HADES-FOPI (ene-fix)	→	4 Best HADES Solutions HADES+FOPI (ene_dep)
1_8 (s=-0.83 10^5)		1_8 (s=-0.73 10^5)
8_8 (s=-0.82 10^5)		8_8 (s=-0.76 10^5)
3_8 (s=-0.98 10^5)		**3_8 (s=-0.70 10^5)**
6_9 (s=-0.78 10^5)		6_9 (s=-0.62 10^5)

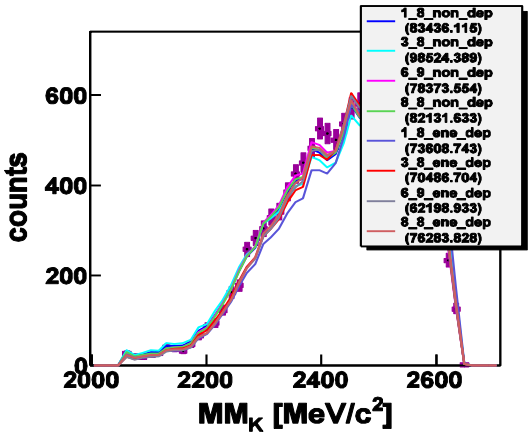
s : - (Log Likely hood) of PWA

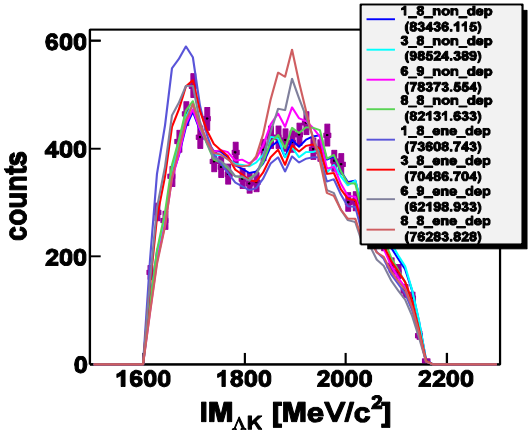
Energy dependent coefficient fitted

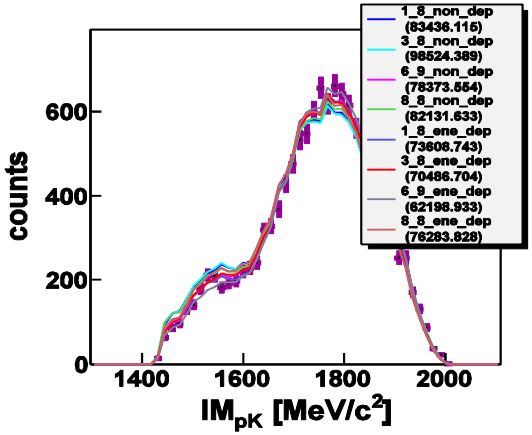
Results HADES

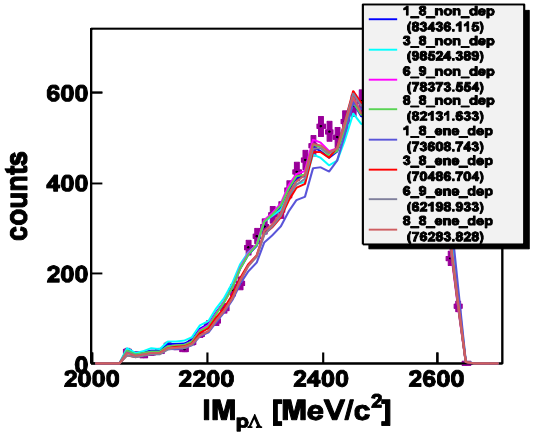




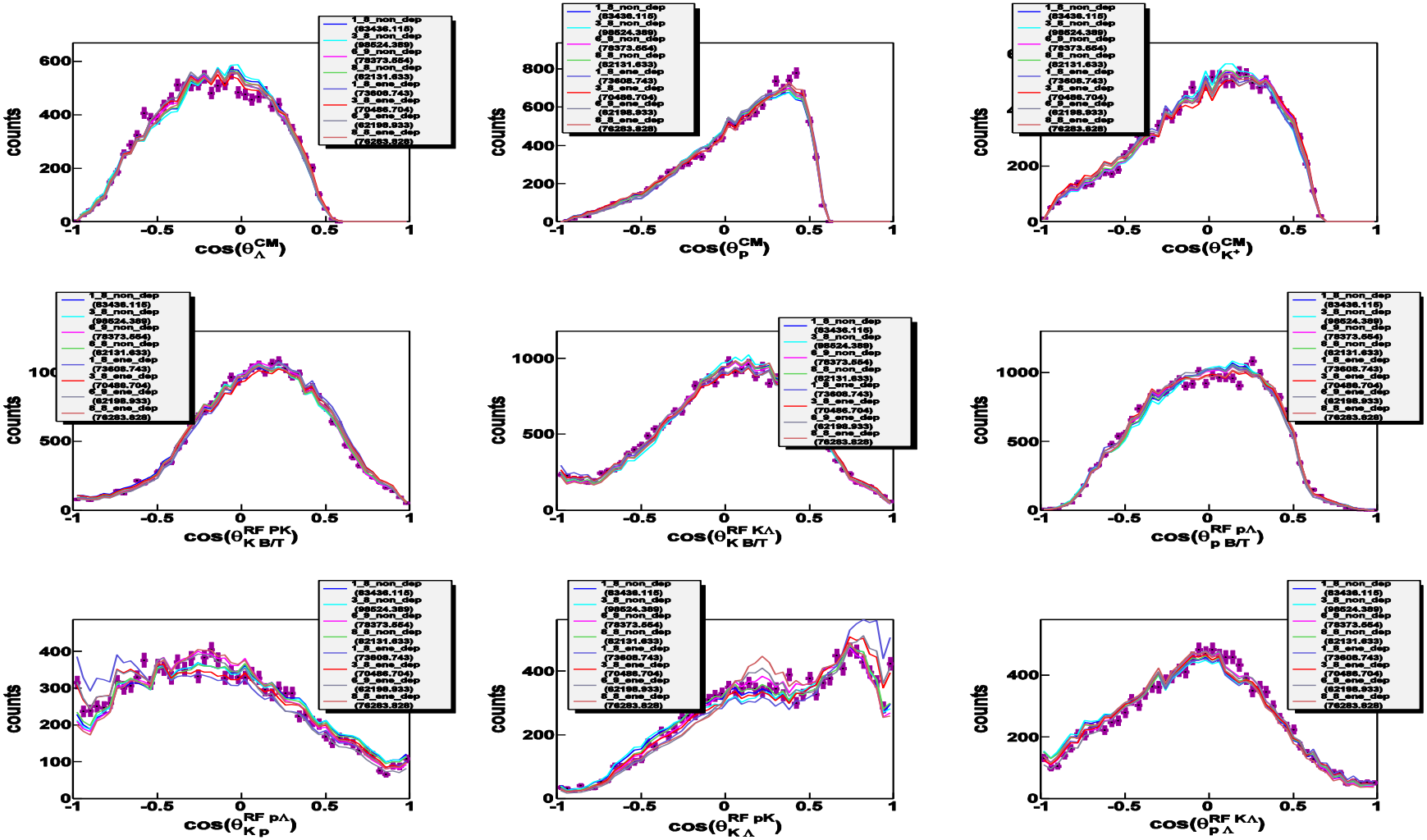




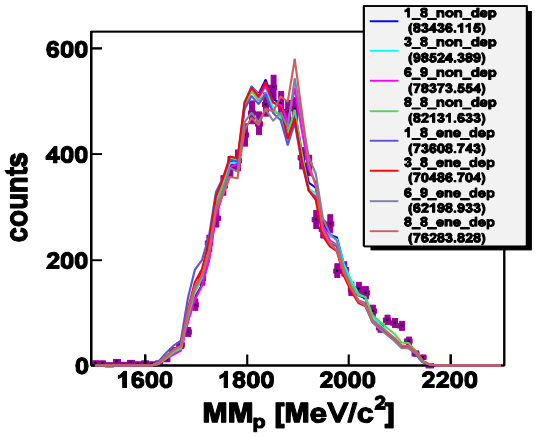


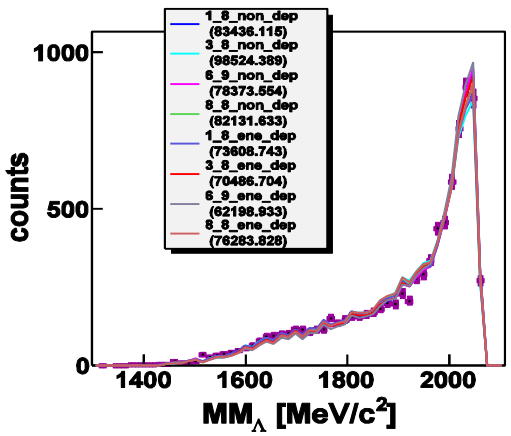


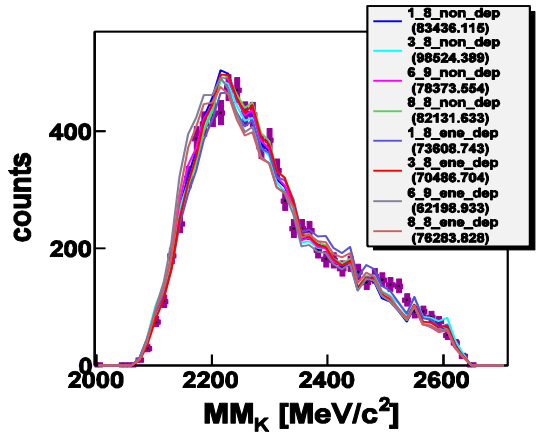
Results HADES

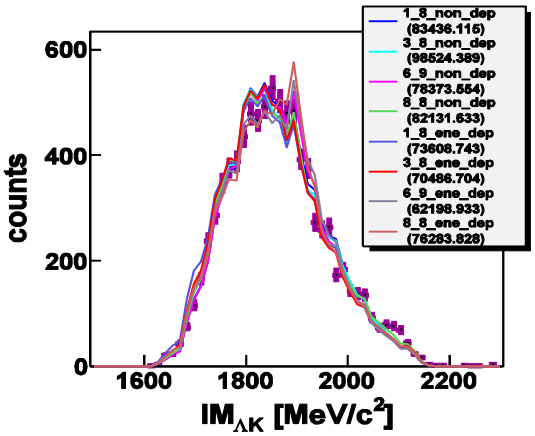


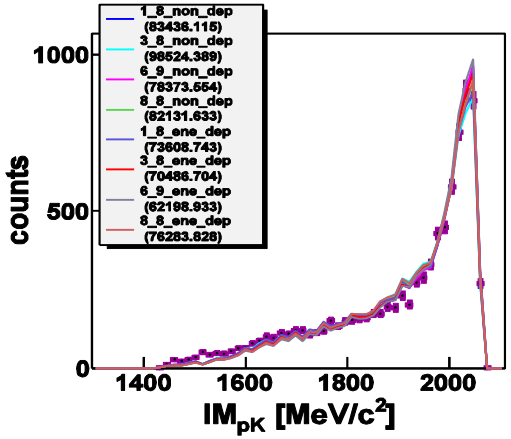
Results WALL

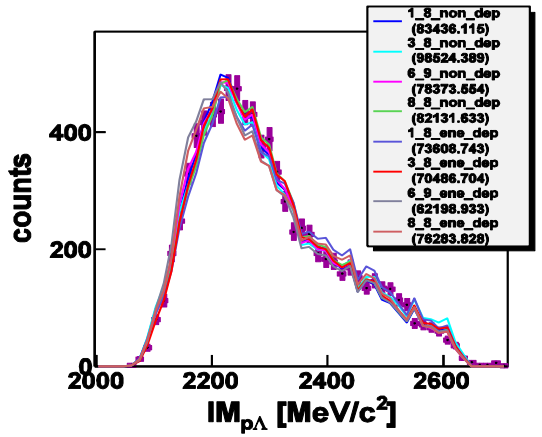




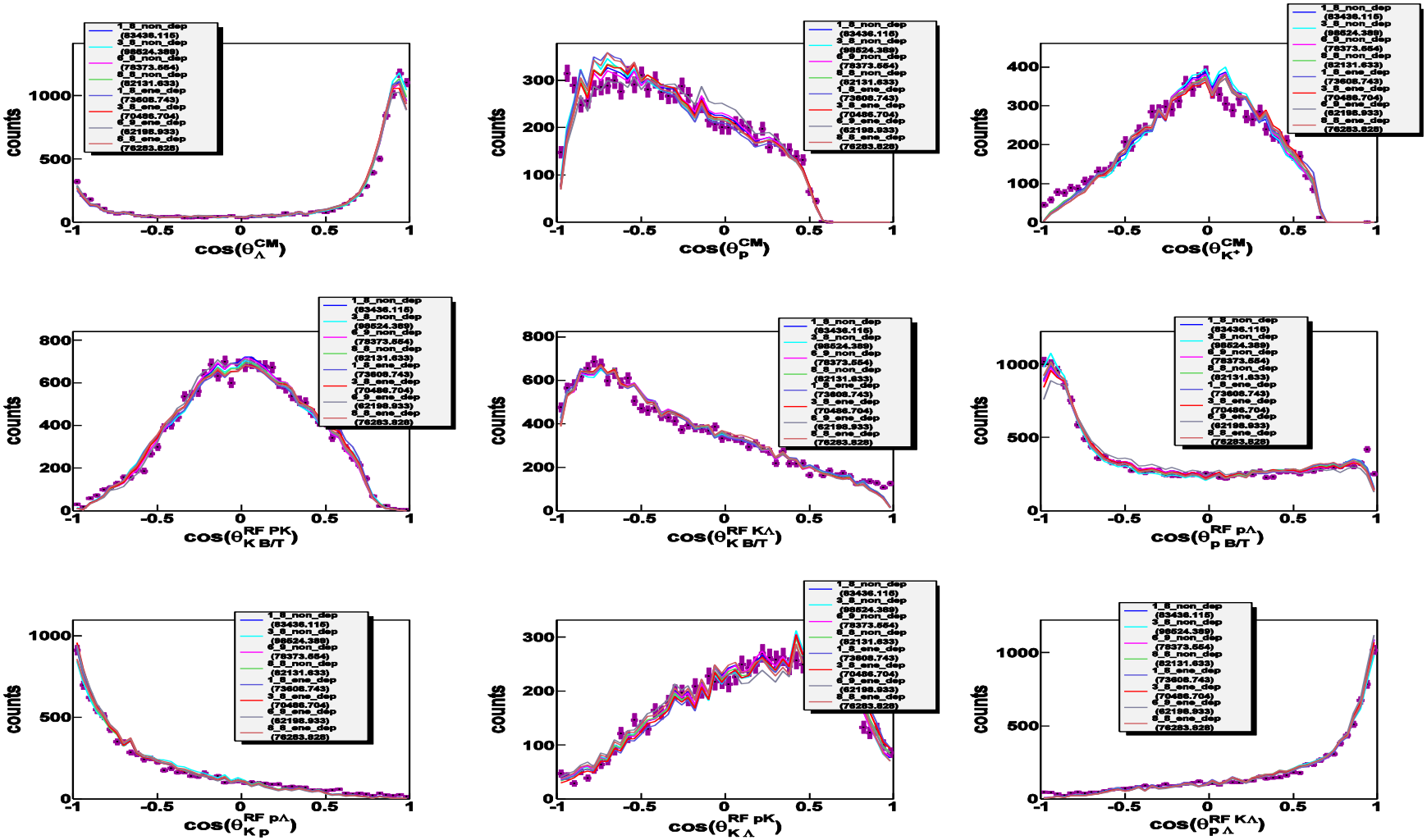




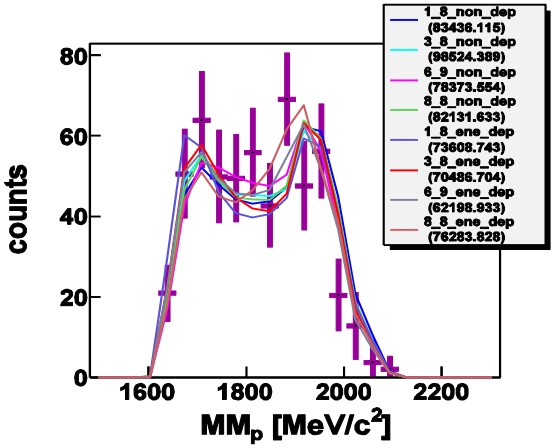


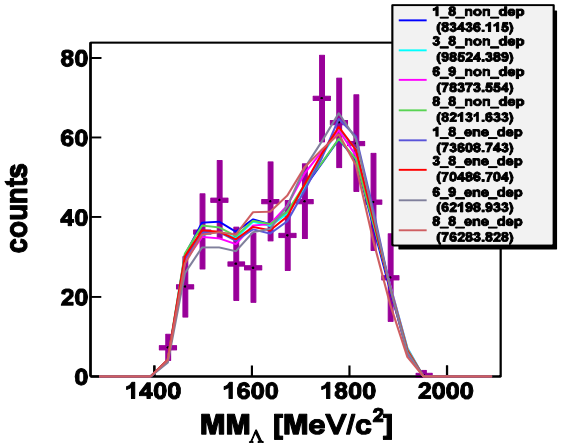


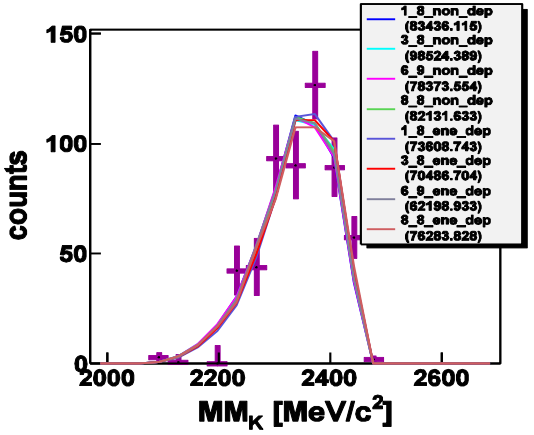
Results WALL

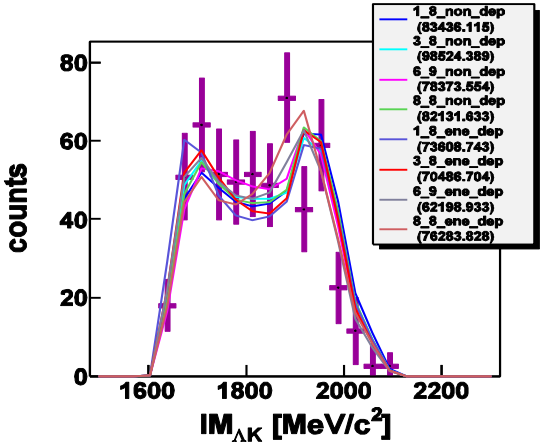


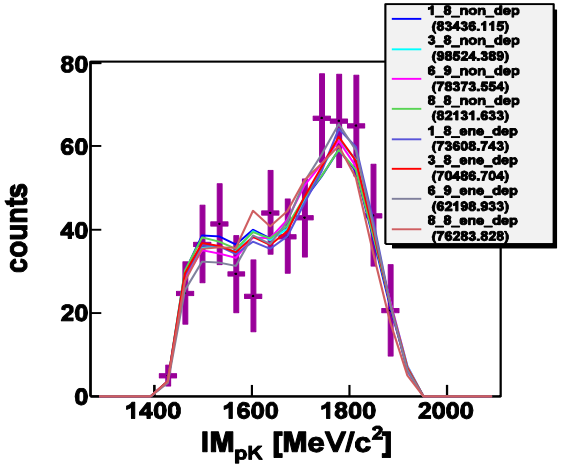
Results FOPI

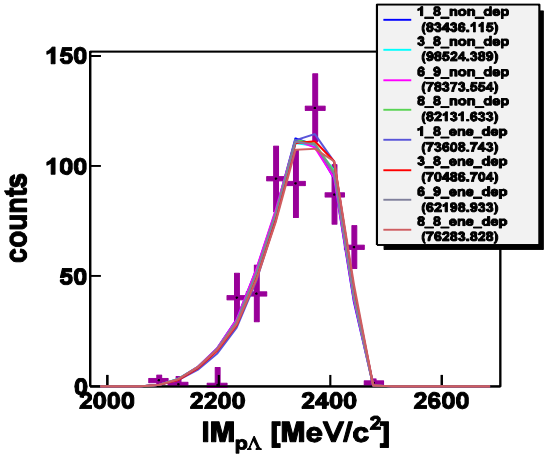




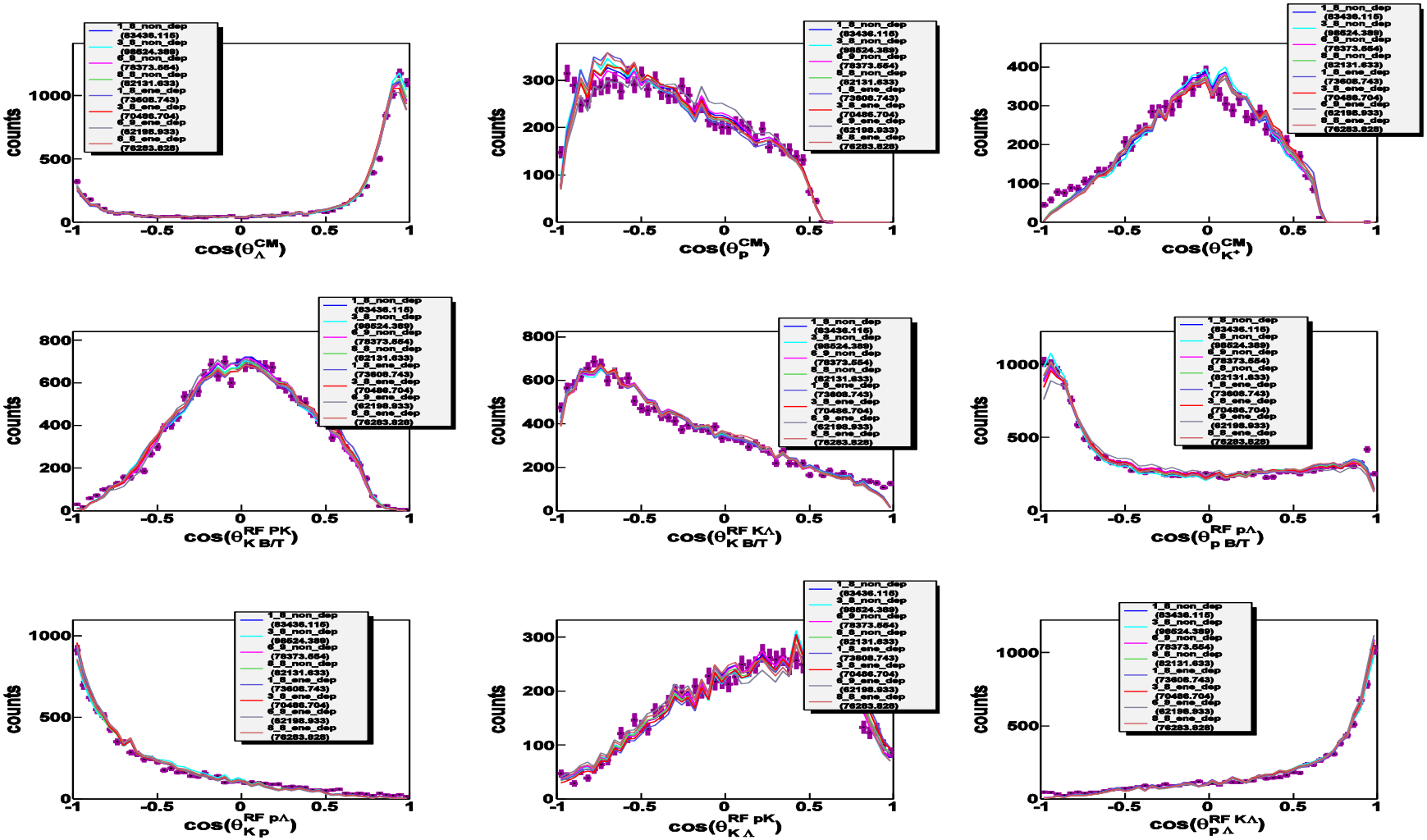




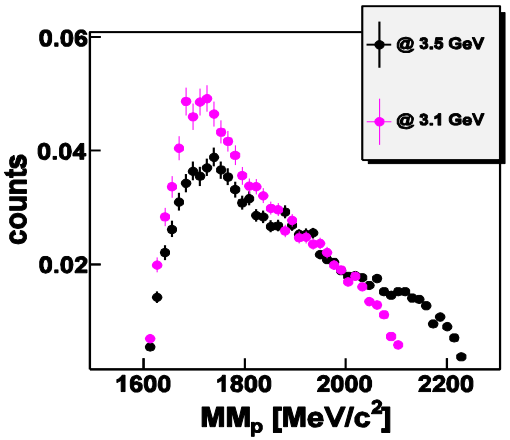


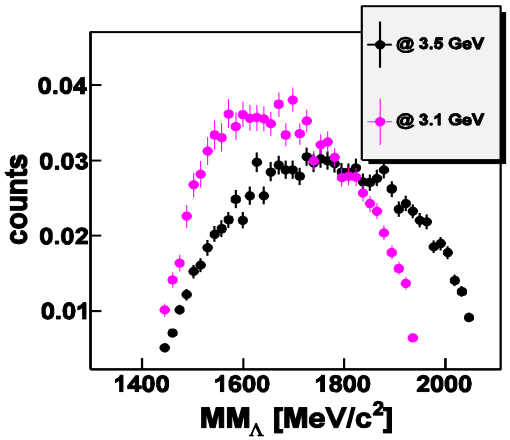


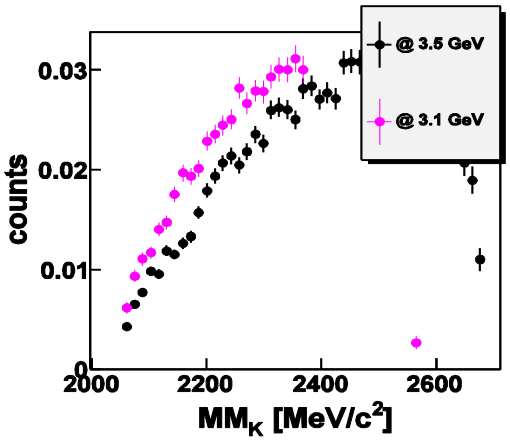
Results FOPI

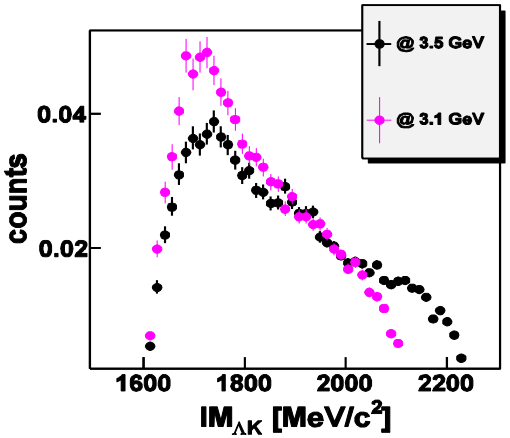


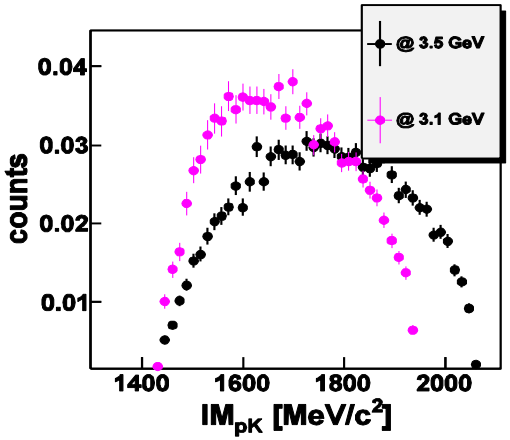
4 PI – param_3_8_ene_dep

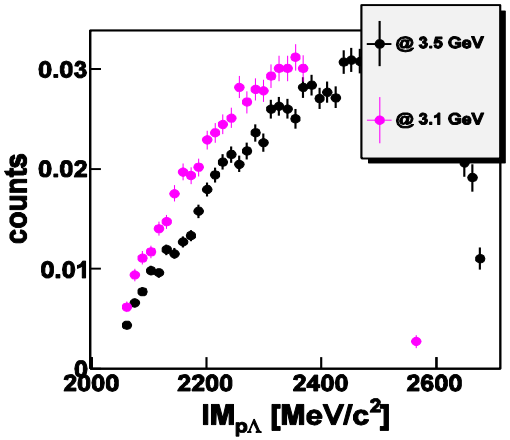












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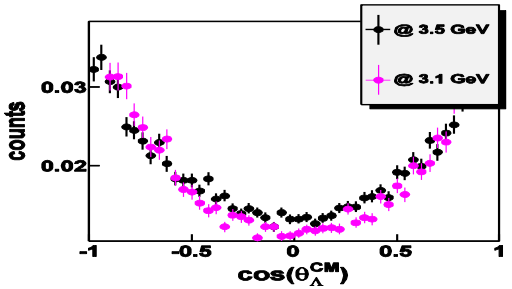
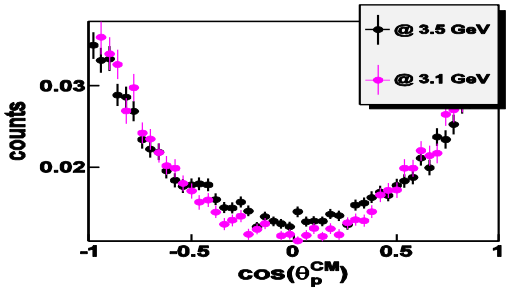
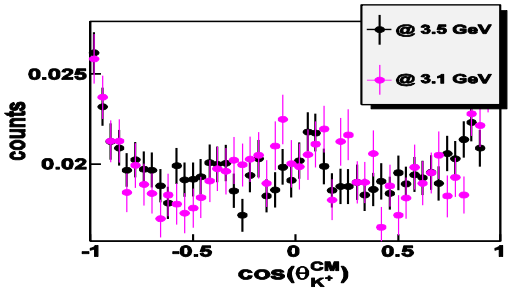
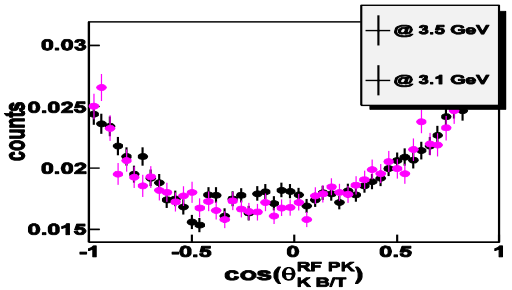
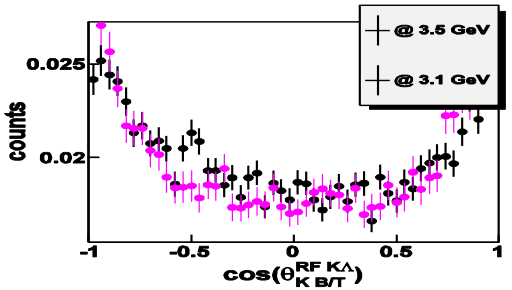
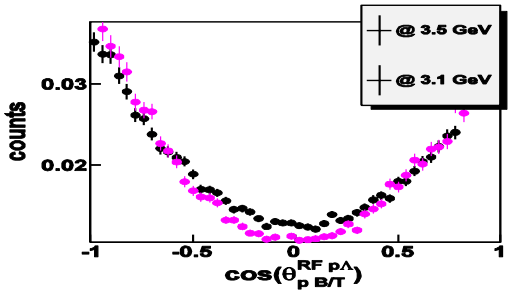


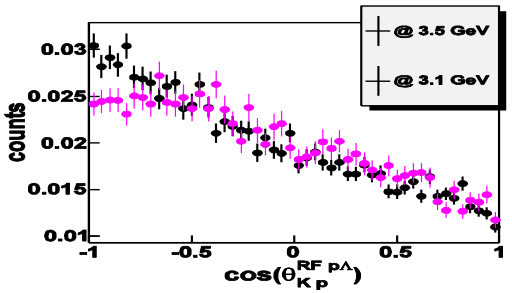


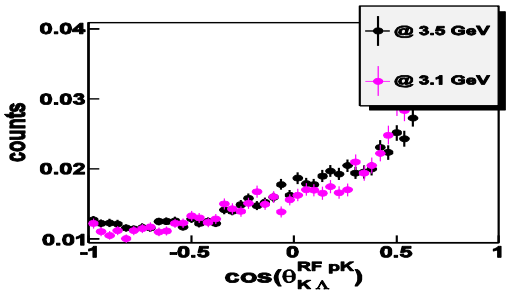


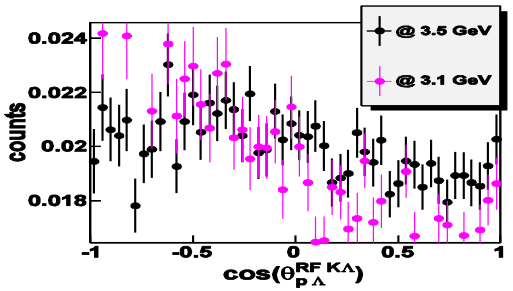






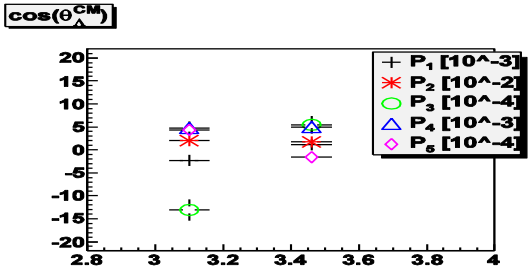


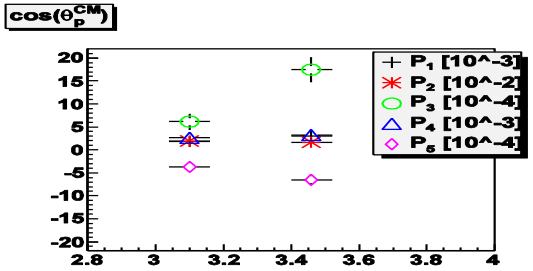


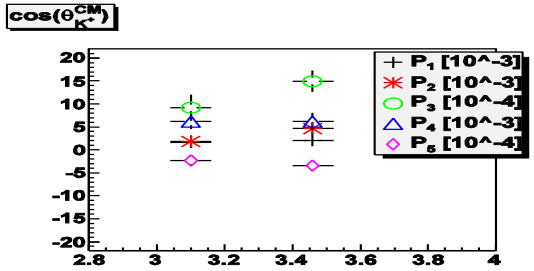


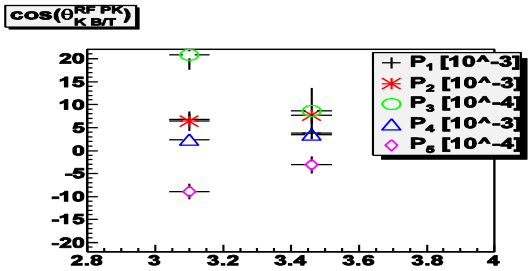
Legendre Fits

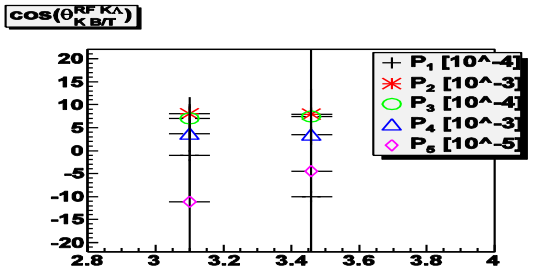
Mean of all solutions

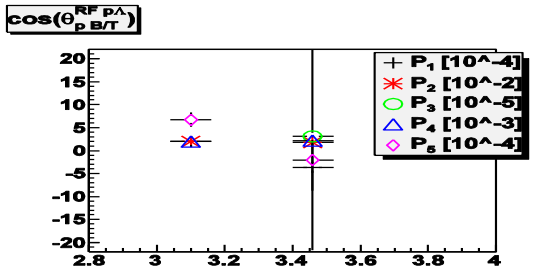


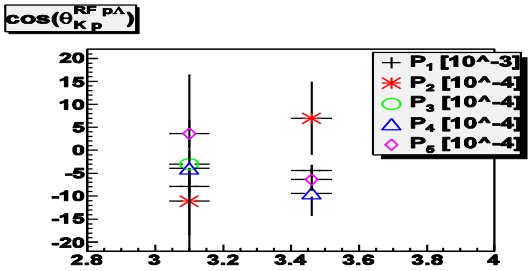


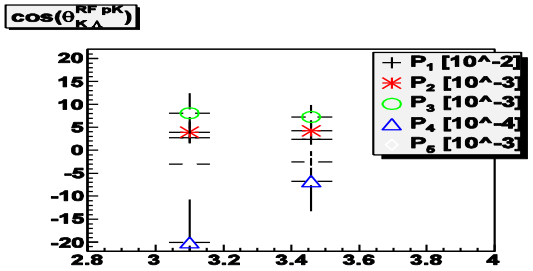


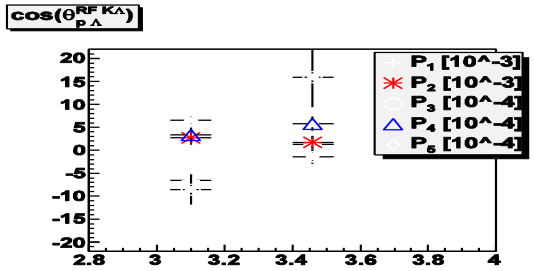




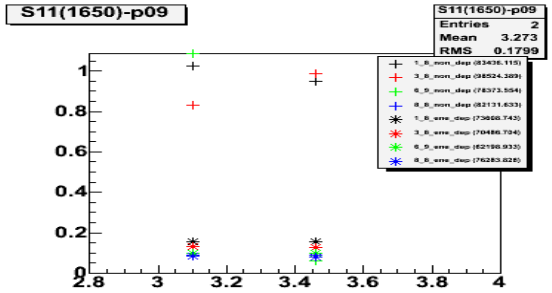


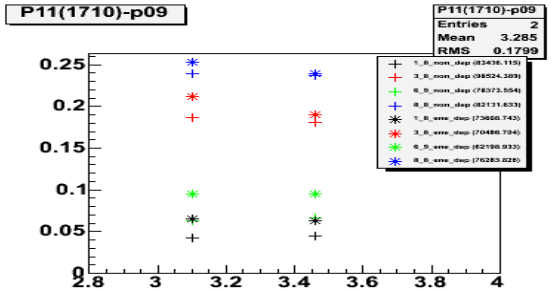


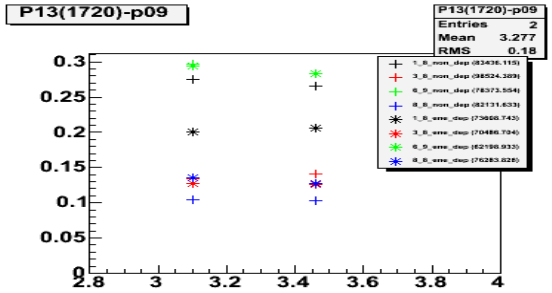


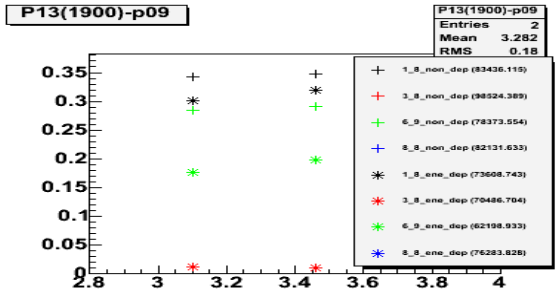


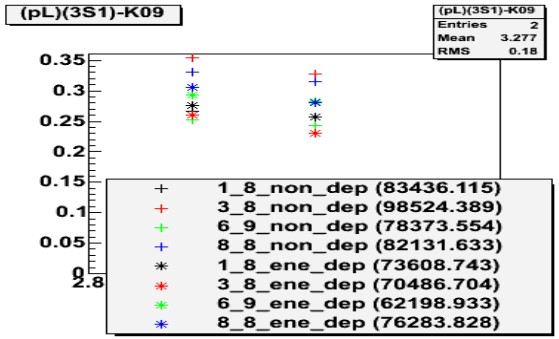
Contributions

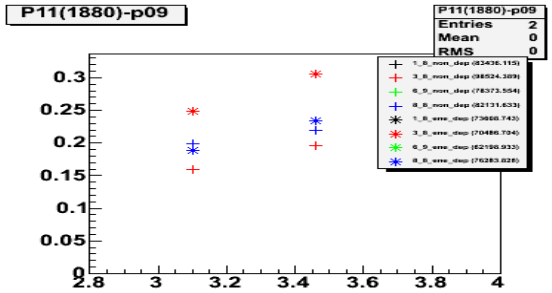


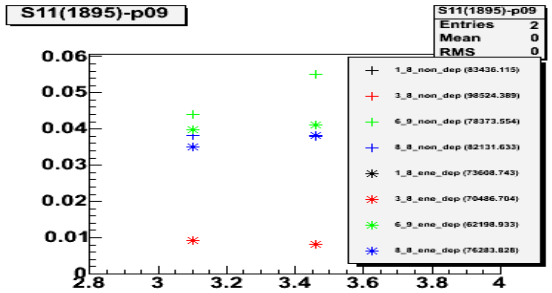












PWA without Interference

Combined Analysis of HADES and FOPI

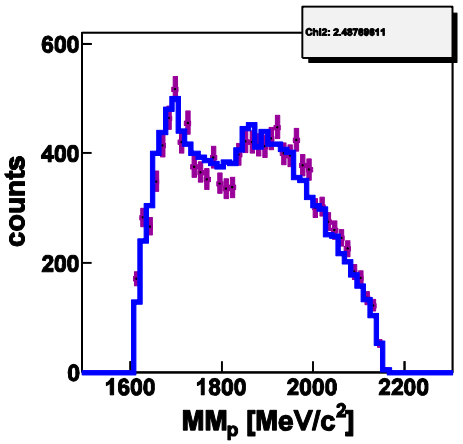
With Interference:

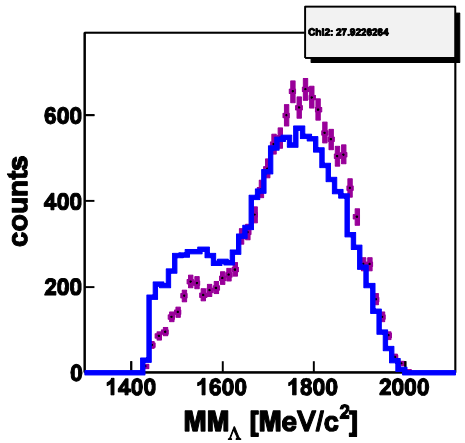
1. cfgg = Σ cp * tensor
2. Cross section = Σ cfgg * cfgg^{+}

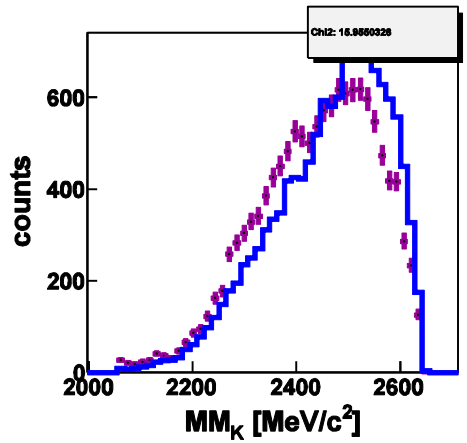
Without Interference:

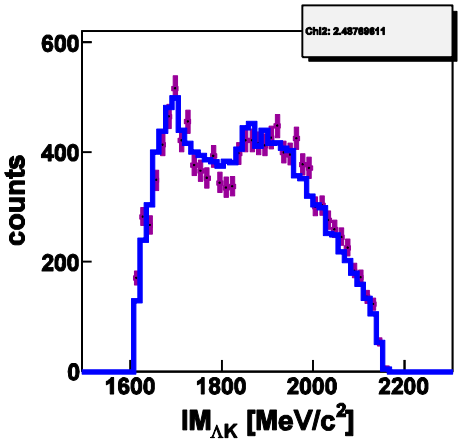
1. cfgg = Σ (cp * tensor) * (cp * tensor)$^{+}$
2. Cross section = Σ cfgg

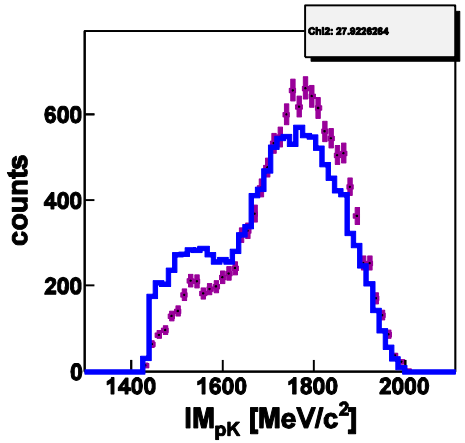
Results of 3_8_wo_int (not fitted)

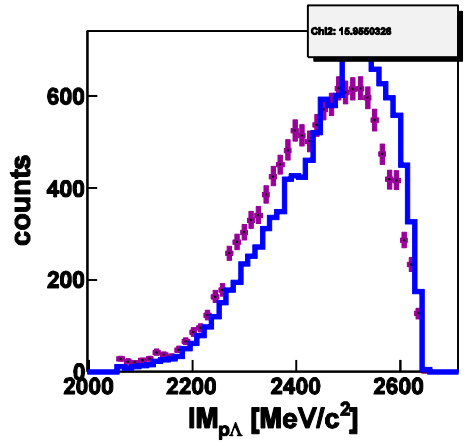




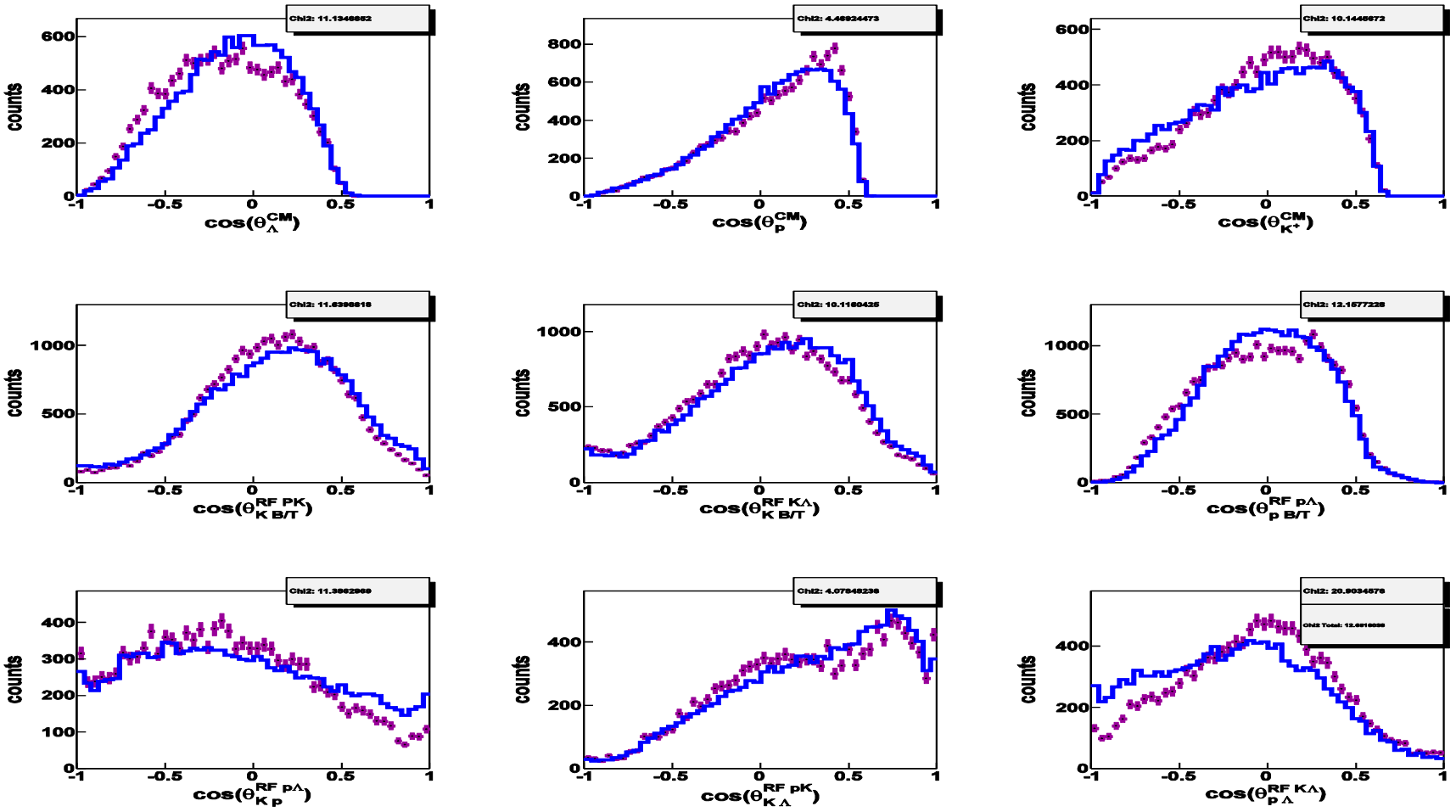




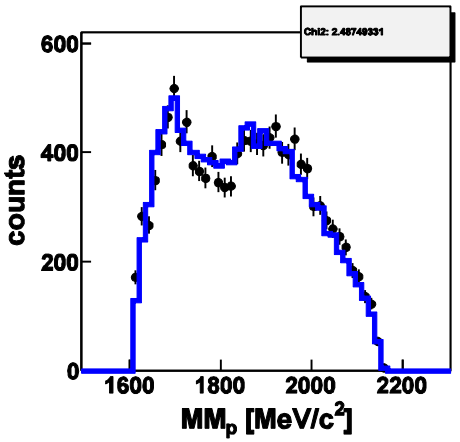


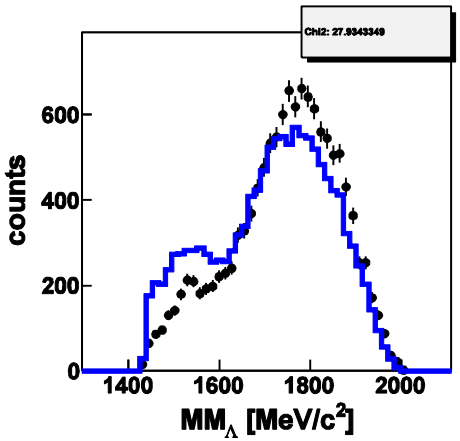


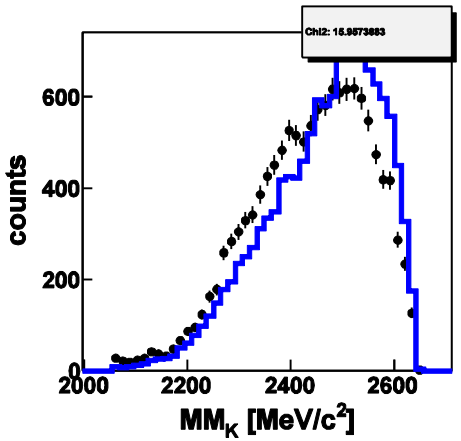
Results of 3_8_wo_int (not fitted)

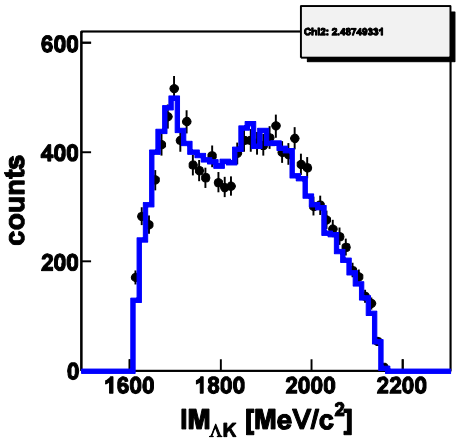


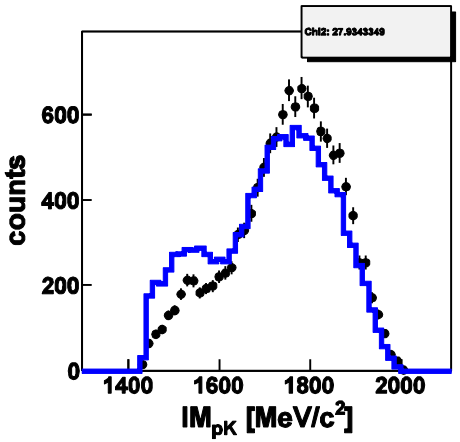
Results of 3_8_wo_int (100 iter)

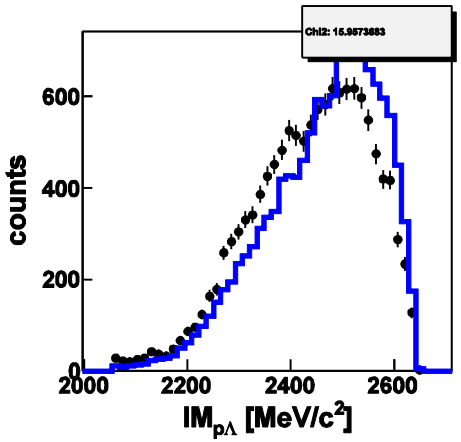




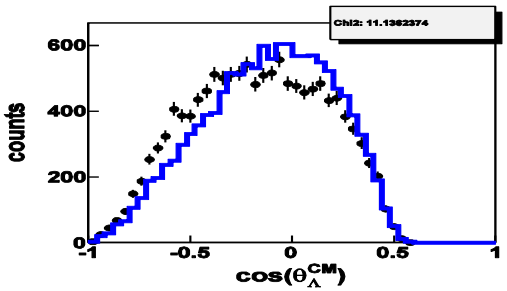


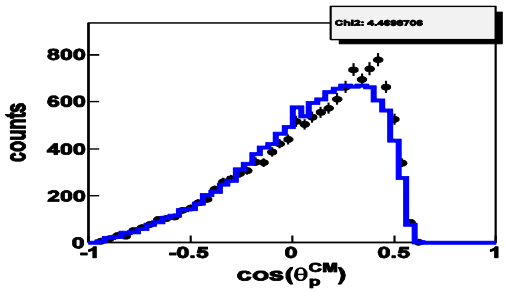


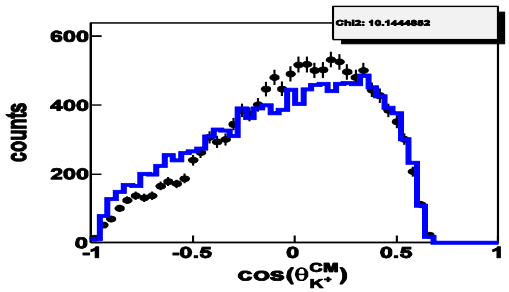


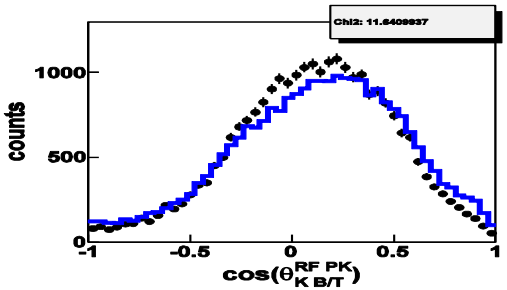


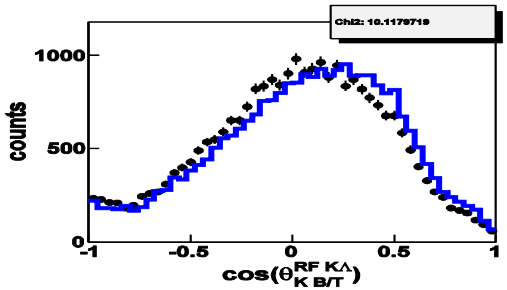
Results of 3_8_wo_int (100 iter)

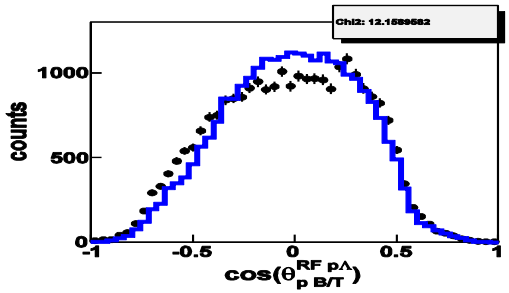


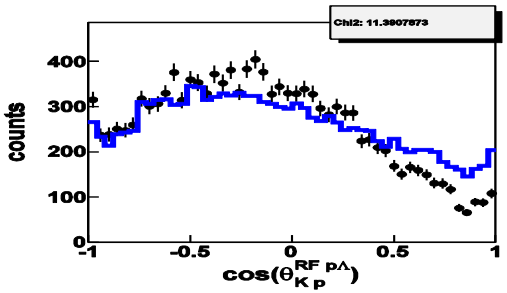


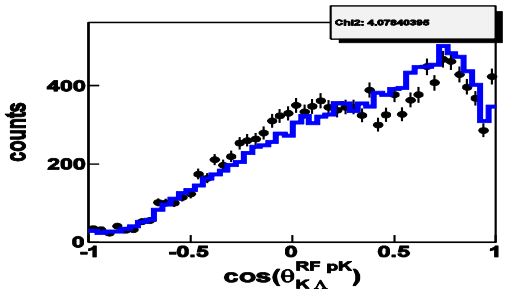


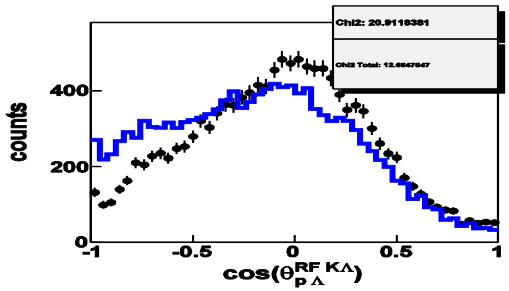












Contribution of Production Channels

PWA Results – Relative Contribution

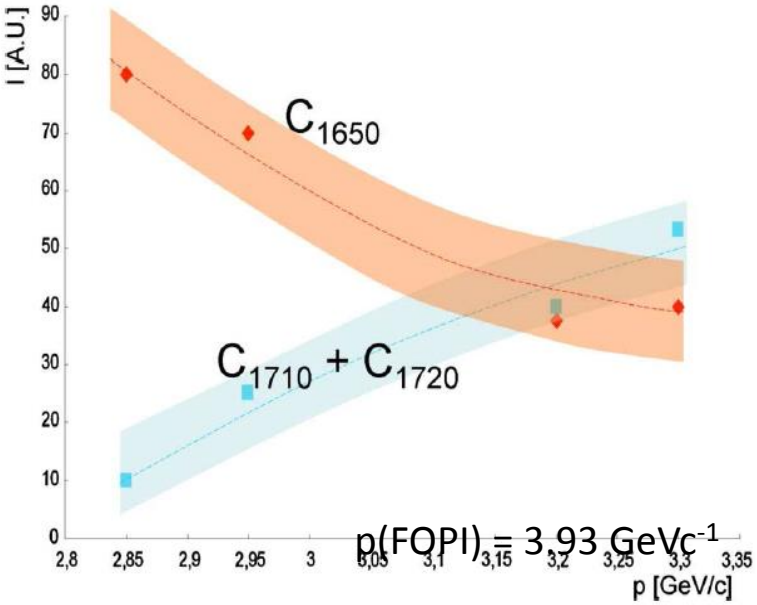
Sol.	X^2 / ndf	Direct $pK^+\Lambda$	N^{*+} (1650)	N^{*+} (1710)	N^{*+} (1720)	N^{*+} (1875)	N^{*+} (1880)	N^{*+} (1895)	N^{*+} (1900)
A	1.09	0 %	11.3 %	52.4 %	11.8 %	6.3 %	10.9 %	0 %	7.3 %
B	1.09	16.6 %	9.4 %	42.3 %	14.1 %	0 %	9.7 %	0 %	7.9 %
C	1.10	0 %	11.1 %	49.5 %	7.5 %	0 %	14.1 %	9.3 %	8.5 %
D	1.12	13.9 %	6.8 %	43.8 %	11.9 %	5.3 %	9.4 %	0 %	8.9 %
E	1.15	21.1 %	8.6 %	41.9 %	17.6 %	0 %	0 %	0 %	10.8 %

PWA Results – Relative Contribution

Sol.	X^2 / ndf	Direct $pK^+\Lambda$	N^{*+} (1650)	N^{*+} (1710)	N^{*+} (1720)	N^{*+} (1875)	N^{*+} (1880)	N^{*+} (1895)	N^{*+} (1900)
A	1.09	0 %	11.3 %	52.4 %	11.8 %	6.3 %	10.9 %	0 %	7.3 %
B	1.09	16.6 %	9.4 %	42.3 %	14.1 %	0 %	9.7 %	0 %	7.9 %
C	1.10	0 %	11.1 %	49.5 %	7.5 %	0 %	14.1 %	9.3 %	8.5 %
D	1.12	13.9 %	6.8 %	43.8 %	11.9 %	5.3 %	9.4 %	0 %	8.9 %
E	1.15	21.1 %	8.6 %	41.9 %	17.6 %	0 %	0 %	0 %	10.8 %

PWA Results – Relative Contribution

Sol.	X^2 / ndf	Direct $pK^+\Lambda$	N^{*+} (1650)	N^{*+} (1710)	N^{*+} (1720)	N^{*+} (1875)	N^{*+} (1880)	N^{*+} (1895)	N^{*+} (1900)
A	1.09	0 %	11.3 %	52.4 %	11.8 %	6.3 %	10.9 %	0 %	7.3 %
B	1.09	16.6 %	9.4 %	42.3 %	14.1 %				
C	1.10	0 %	11.1 %	49.5 %	7.5 %				
D	1.12	13.9 %	6.8 %	43.8 %	11.9 %				
E	1.15	21.1 %	8.6 %	41.9 %	17.6 %				



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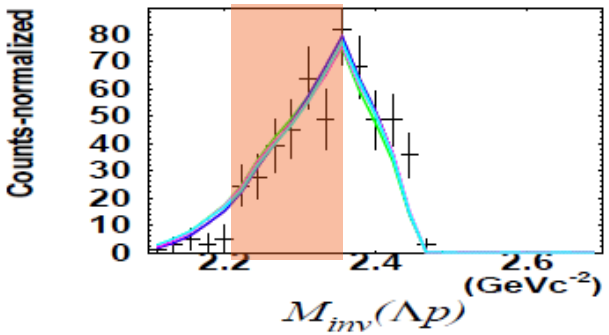
PWA Results – Relative Contribution

Sol.	X^2 / ndf	Direct $pK^+\Lambda$	N^{*+} (1650)	N^{*+} (1710)	N^{*+} (1720)	N^{*+} (1875)	N^{*+} (1880)	N^{*+} (1895)	N^{*+} (1900)
A	1.09	0 %	11.3 %	52.4 %	11.8 %	6.3 %	10.9 %	0 %	7.3 %
B	1.09	16.6 %	9.4 %	42.3 %	14.1 %	0 %	9.7 %	0 %	7.9 %
C	1.10	0 %	11.1 %	49.5 %	7.5 %	0 %	14.1 %	9.3 %	8.5 %
D	1.12	13.9 %	6.8 %	43.8 %	11.9 %	5.3 %	9.4 %	0 %	8.9 %
E	1.15	21.1 %	8.6 %	41.9 %	17.6 %	0 %	0 %	0 %	10.8 %

PWA Results – Relative Contribution

Sol.	X^2 / ndf	Direct $pK^+\Lambda$	N^{*+} (1650)	N^{*+} (1710)	N^{*+} (1720)	N^{*+} (1875)	N^{*+} (1880)	N^{*+} (1895)	N^{*+} (1900)
A	1.09	0 %	11.3 %	52.4 %	11.8 %	6.3 %	10.9 %	0 %	7.3 %
B	1.09	16.6 %	9.4 %	42.3 %	14.1 %	0 %	9.7 %	0 %	7.9 %
C	1.10	0 %	11.1 %	49.5 %	7.5 %	0 %	14.1 %	9.3 %	8.5 %
D	1.12	13.9 %	6.8 %	43.8 %	11.9 %	5.3 %	9.4 %	0 %	8.9 %
E	1.15	21.1 %	8.6 %	41.9 %	17.6 %	0 %	0 %	0 %	10.8 %



Experimental Data can be described by known sources