Partial Wave Analysis of Strangeness Production at GeV Energies

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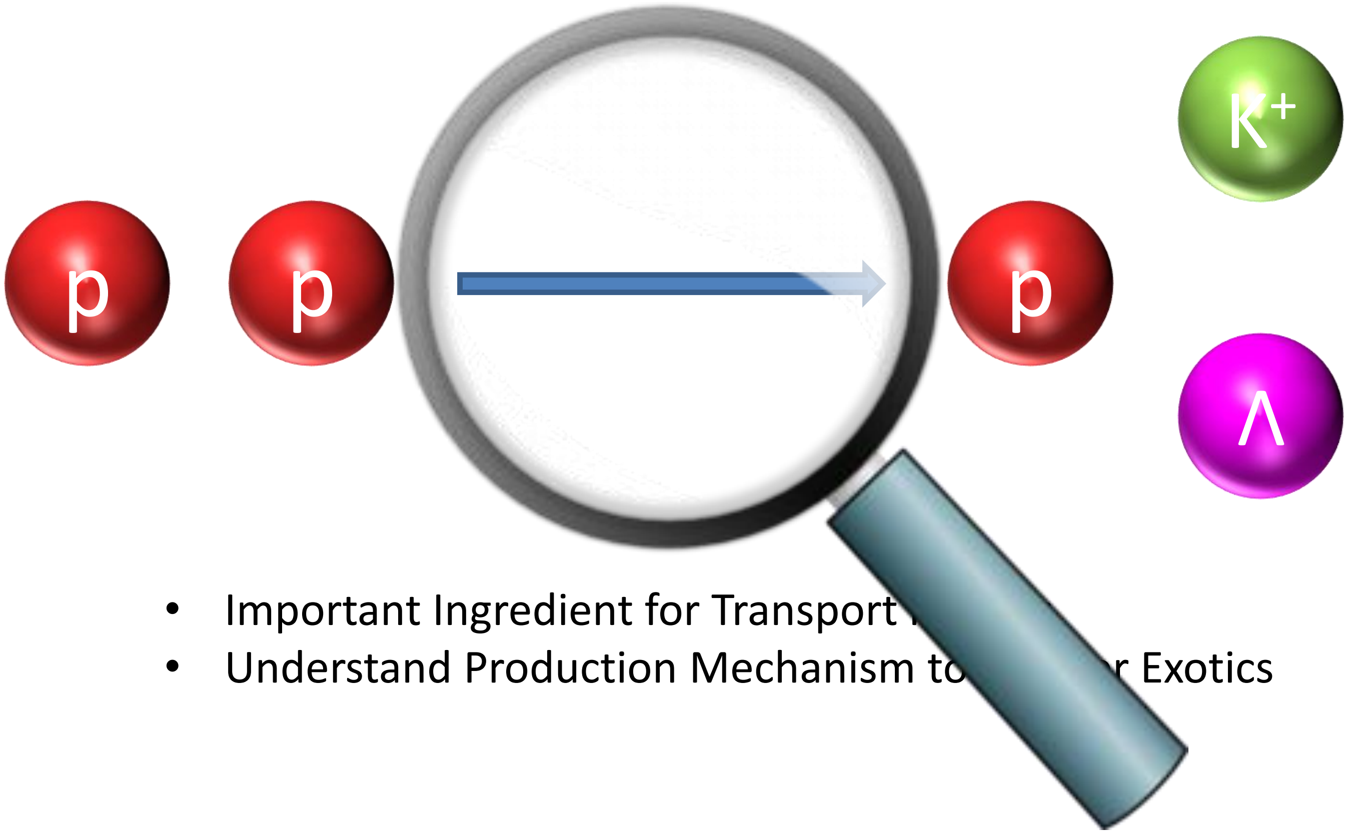
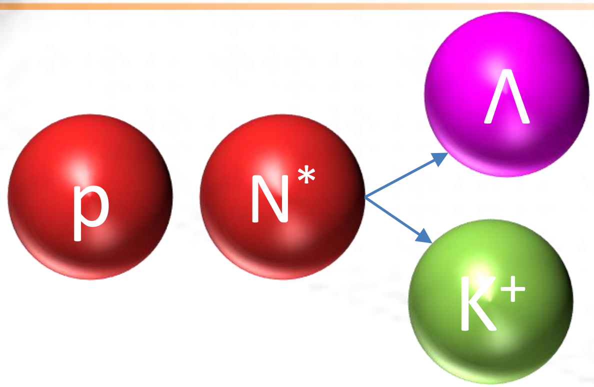
Strangeness Production



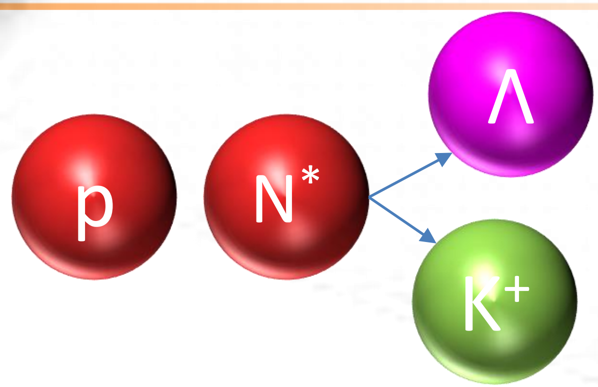
- Important Ingredient for Transport
- Understand Production Mechanism to r Exotics

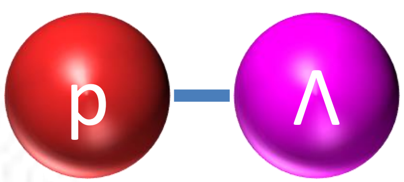
Strangeness Production



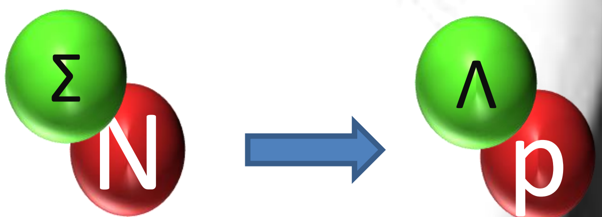
Resonance	J^P	Mass (GeV/c^2)	Γ (MeV/c^2)
N*(1650)	$1/2^-$	1.655	0.150
N*(1710)	$1/2^+$	1.710	0.100
N*(1720)	$3/2^+$	1.720	0.250
N*(1875)	$3/2^-$	1.875	0.220
N*(1880)	$1/2^+$	1.870	0.235
N*(1895)	$1/2^-$	2.090	0.090
N*(1900)	$3/2^+$	1.900	0.0250

Strangeness Production





Final State Interaction
Aka: scattering length and effective range



Conversion Processes
(Cusp Effect)

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 $A = \sum_\alpha A_{tr}^\alpha(s) \cdot Q^{in} \cdot A_{2b}(\alpha) \cdot Q^{out}$

Q^{in}, Q^{out} : spin-momentum operator of initial and final state

A_{2b} : resonant: Breit-Wigner (for N* and Cusp)

non-resonant: Effective range approximation, dependent on scattering parameters

$A_{tr}^\alpha(s) = (a_1^\alpha + a_3^\alpha \sqrt{s}) e^{i a_2^\alpha}$: a_1^α constant amplitude

a_2^α phase

a_3^α energy dependent amplitude

$d\phi(P, q_1, q_2, q_3)$: invariant three-particle phase space

Multi-PWA

Data Sets

Experiment	E_B [GeV]	$pK^+\Lambda$ Statistics	Status
COSY-TOF	1.96	~160k	In Preparation (not used in the analysis)
DISTO	2.15	121 k	Available
COSY-TOF	2.16	43 k	Available
COSY-TOF	2.16	~90k	In Preparation (not used in the analysis)
DISTO	2.5	304 k	Available
DISTO	2.85	424 k	Available
FOPI	3.1	0.9 k	Single PWA
HADES	3.5	21 k	Single PWA

HADES PLB 742 (2015) 242-248.

COSY-TOF Spectrometer

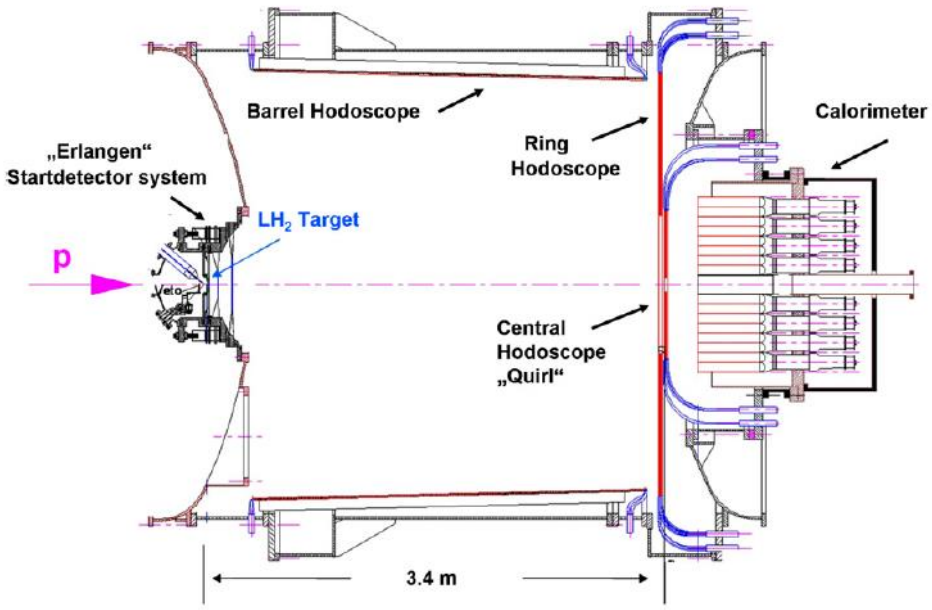
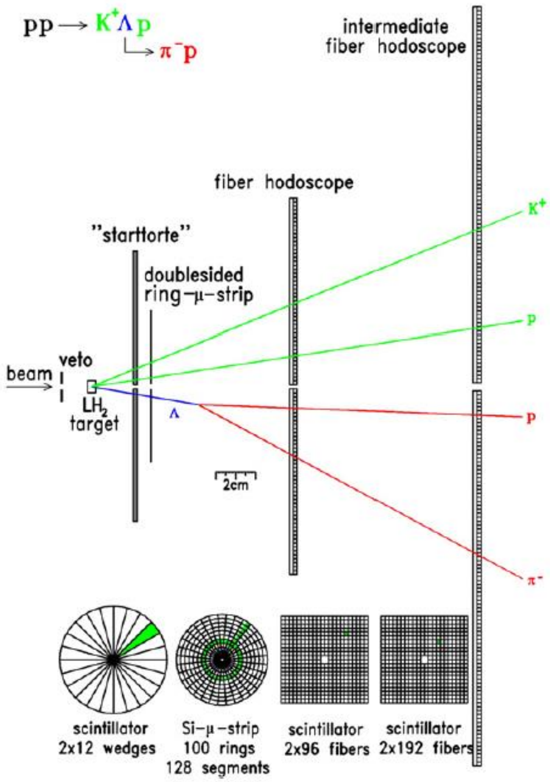


Fig. 1. Schematic view of the COSY-TOF detector.



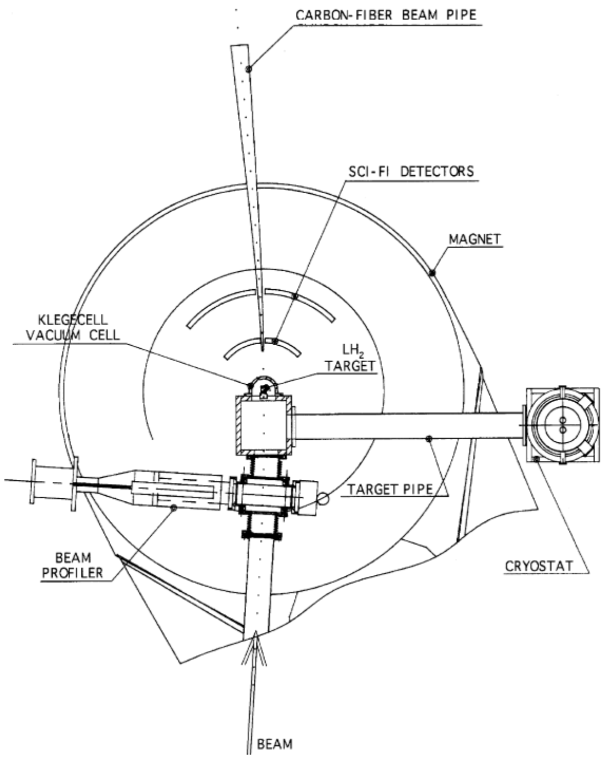
Acceptance: 1°-60° (polar), 2π (azimuthal)

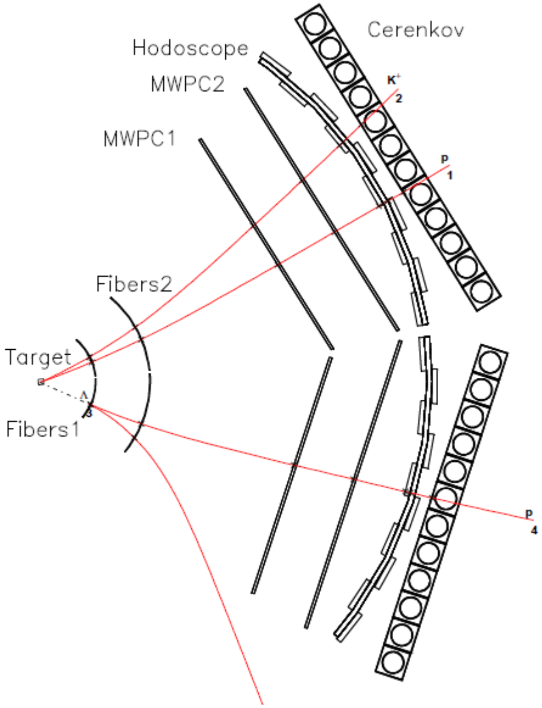
Sec. Vertex: $\sigma_{x,y} < 1mm, \sigma_z < 3mm$

$$\sigma_{TOF} = 300ps$$

$$\sigma_{MM(pK)} = 16\ MeV/c^2$$

DISTO Spectrometer





Acceptance: 23°-43° (polar), 2π (azimuthal)

$$\sigma_p = 5\%$$

$$\sigma_{MM(pK)} = 30\ MeV/c^2$$

Combined Analysis

1. Solution for HADES+FOPI+DISTO25
   - Start values for the global fit
   - Energy Range wide enough for energy dependence
   - High energy for higher N*-Resonances
2. Include Stepwise further data sample
   - Cosy216 / DISTO21 / DISTO28

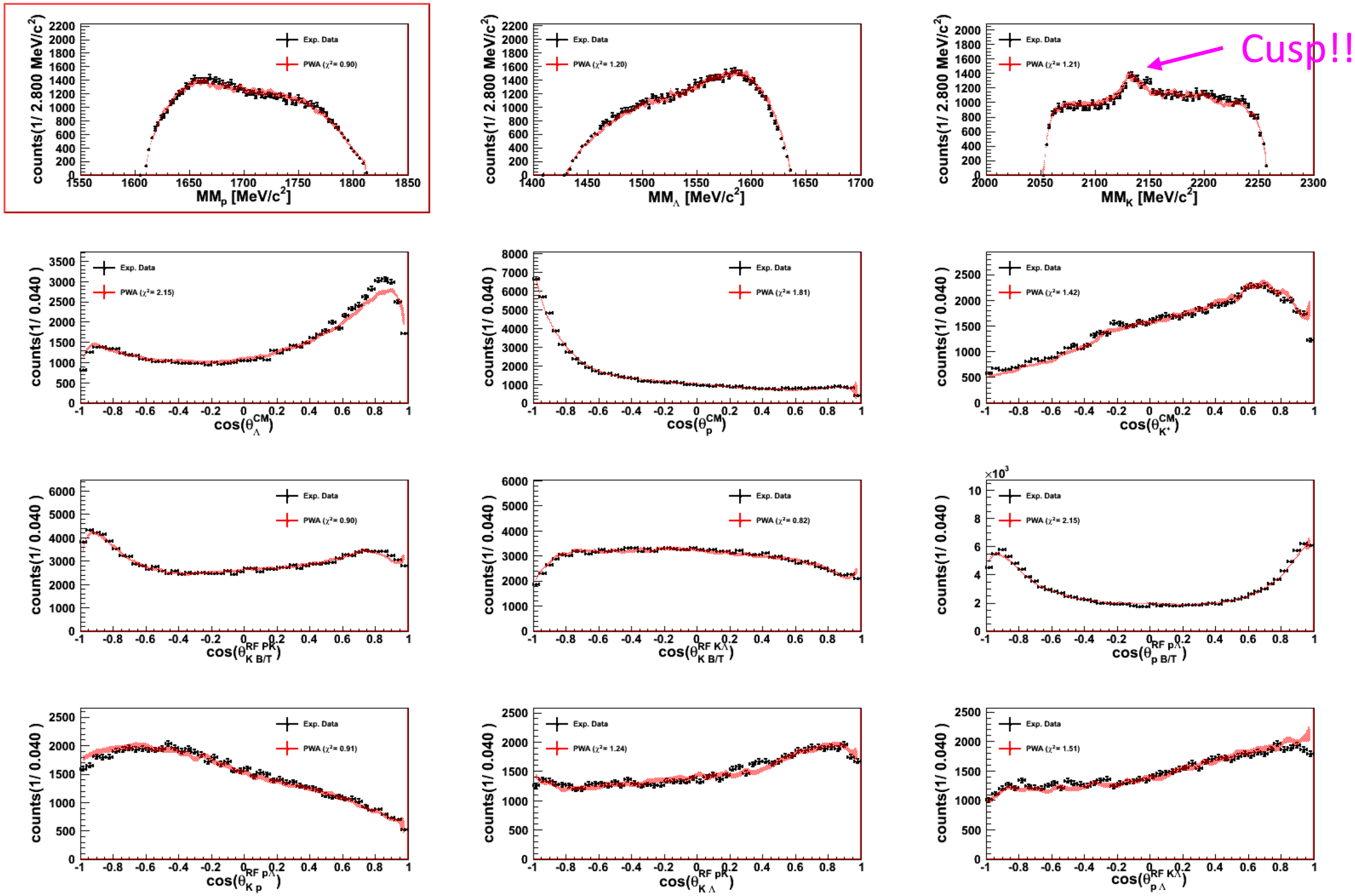
Parameter Scan

Initial pp states up to F wave
Include different N* Resonances

Solution	A	B	C	D	E
Loglike	-67142	-67018	-66878	-66504	-66405
$\frac{\chi^2}{ndf}(ndf = 4547)$	9,50	9,98	9,98	10,01	10,34
N*(1650)	+	+	+	+	+
N*(1710)	+	+	+	+	+
N*(1720)	+	+	+	+	-
N*(1875)	+	+	-	-	+
N*(1880)	+	+	+	+	+
N*(1895)	+	+	+	+	+
N*(1900)	-	+	+	-	+
Cusp Wave $\Sigma N\ (0^+, 1^+)$	+	+	+	+	+

DISTO@2.14 GeV

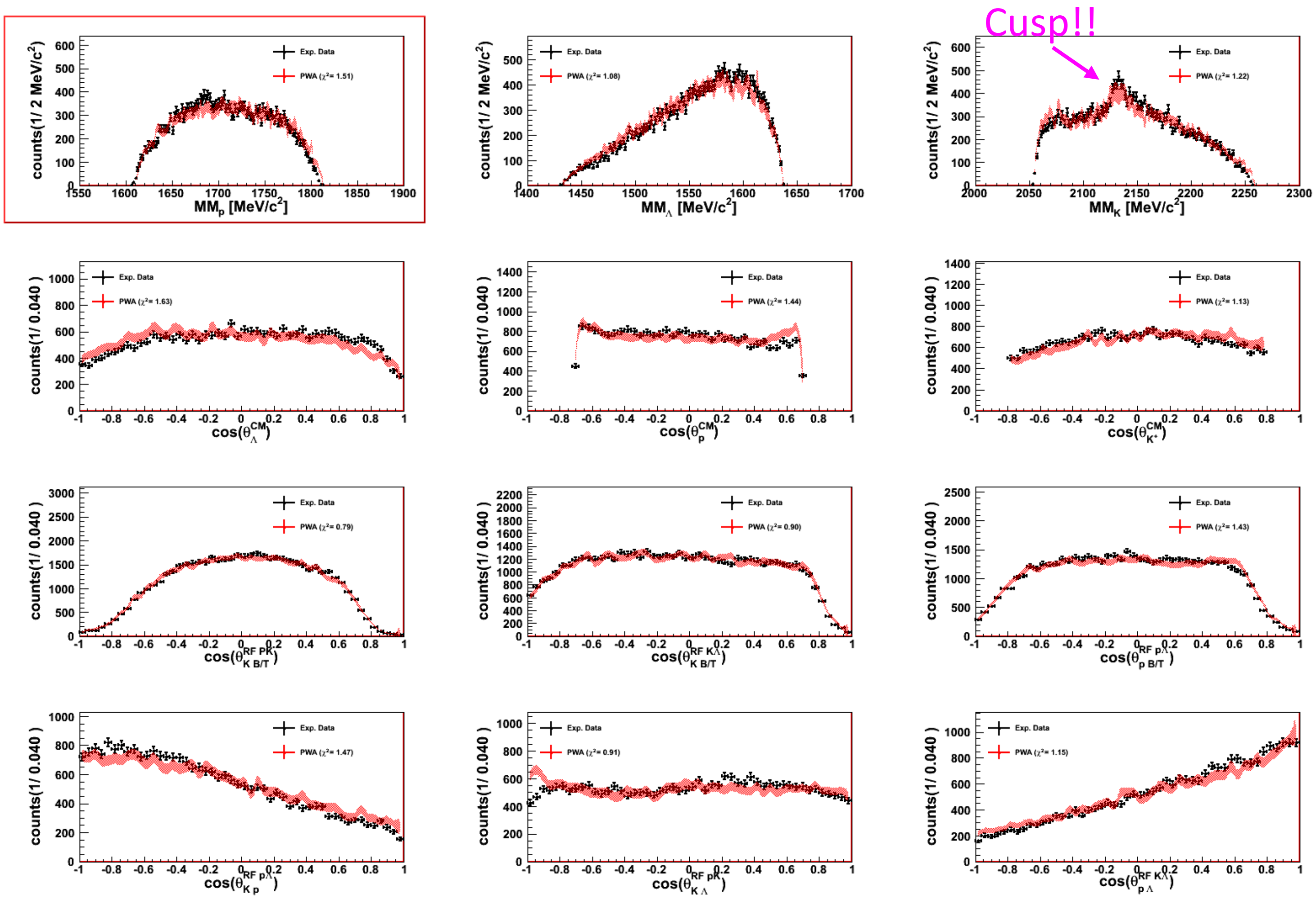
Preliminary



	X^2 / ndf (ndf=428)
PWA	1.52

COSY-TOF@2.16 GeV

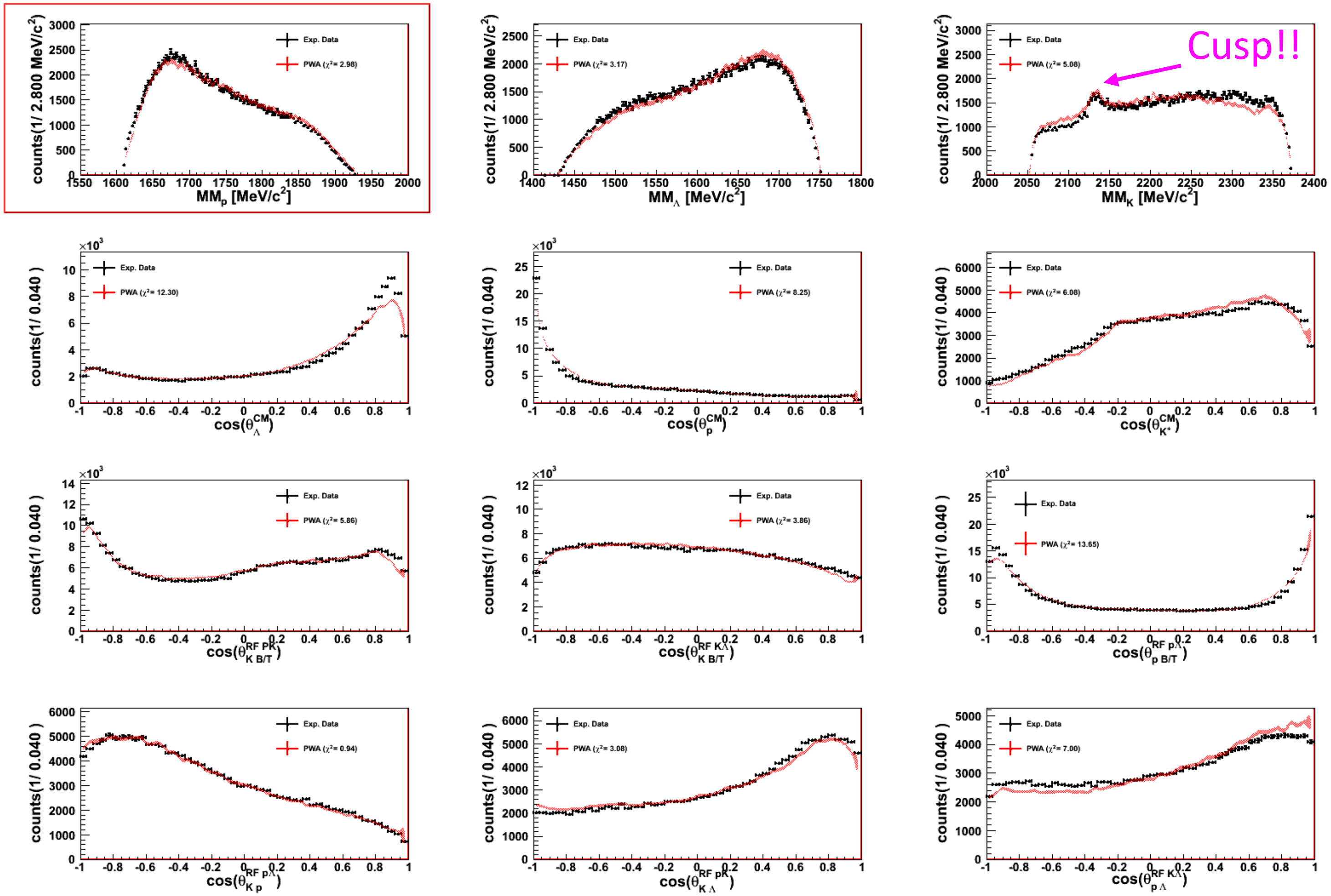
Preliminary



	X^2 / ndf (ndf=428)
PWA	0.44

DISTO@2.5 GeV

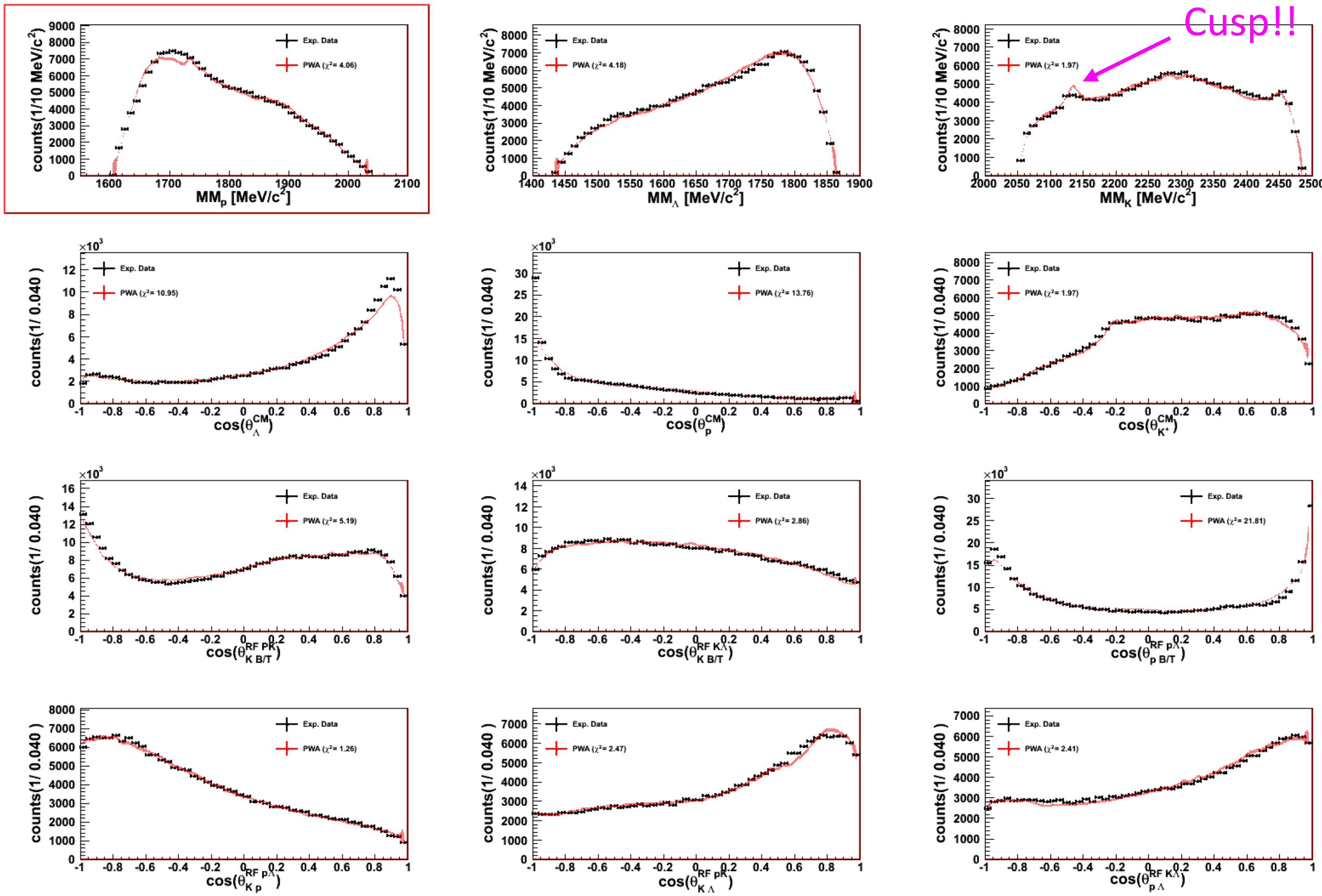
Preliminary



	X^2 / ndf (ndf=428)
PWA	2.56

DISTO@2.85 GeV

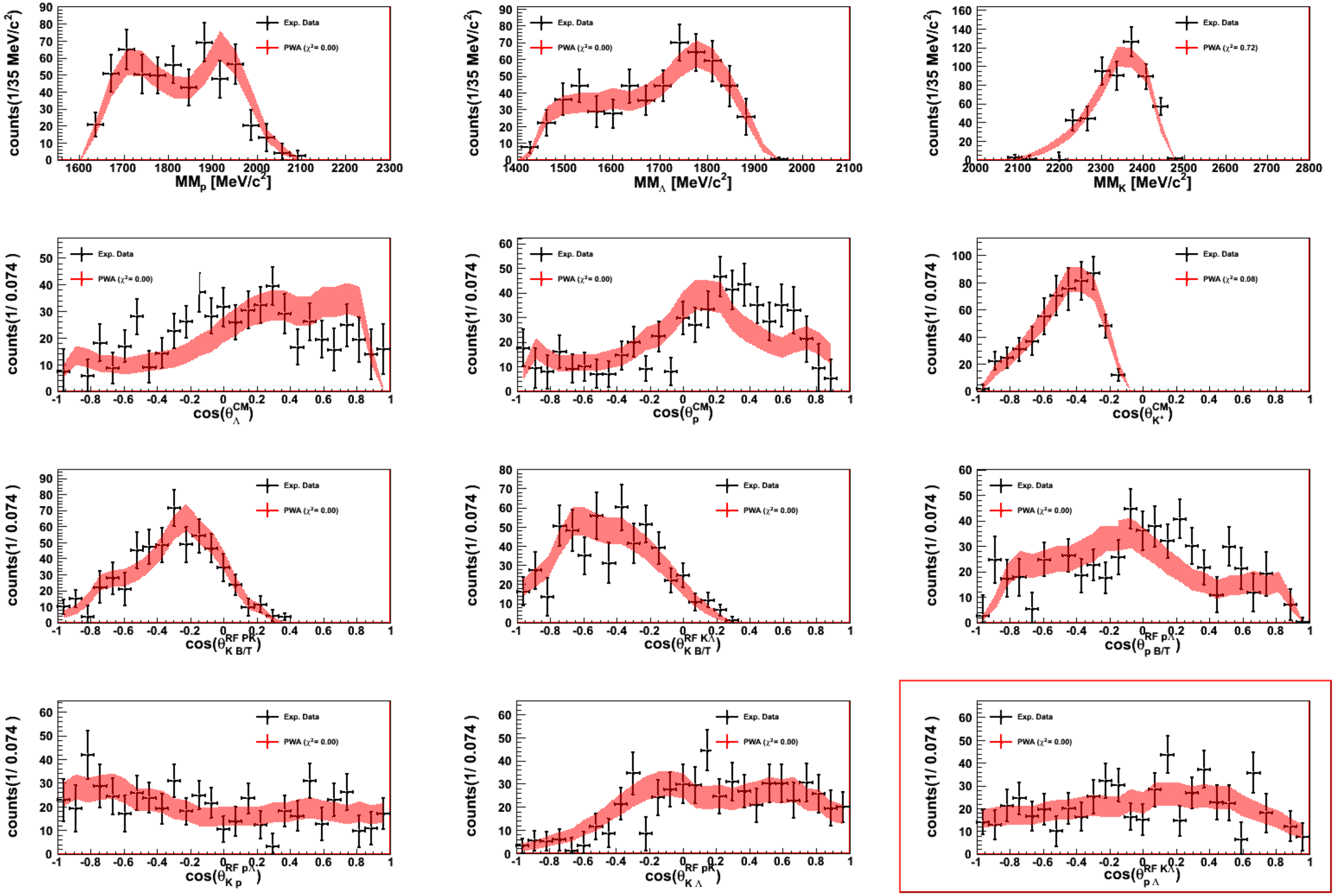
Preliminary



	X^2 / ndf (ndf=428)
PWA	3.55

FOPI

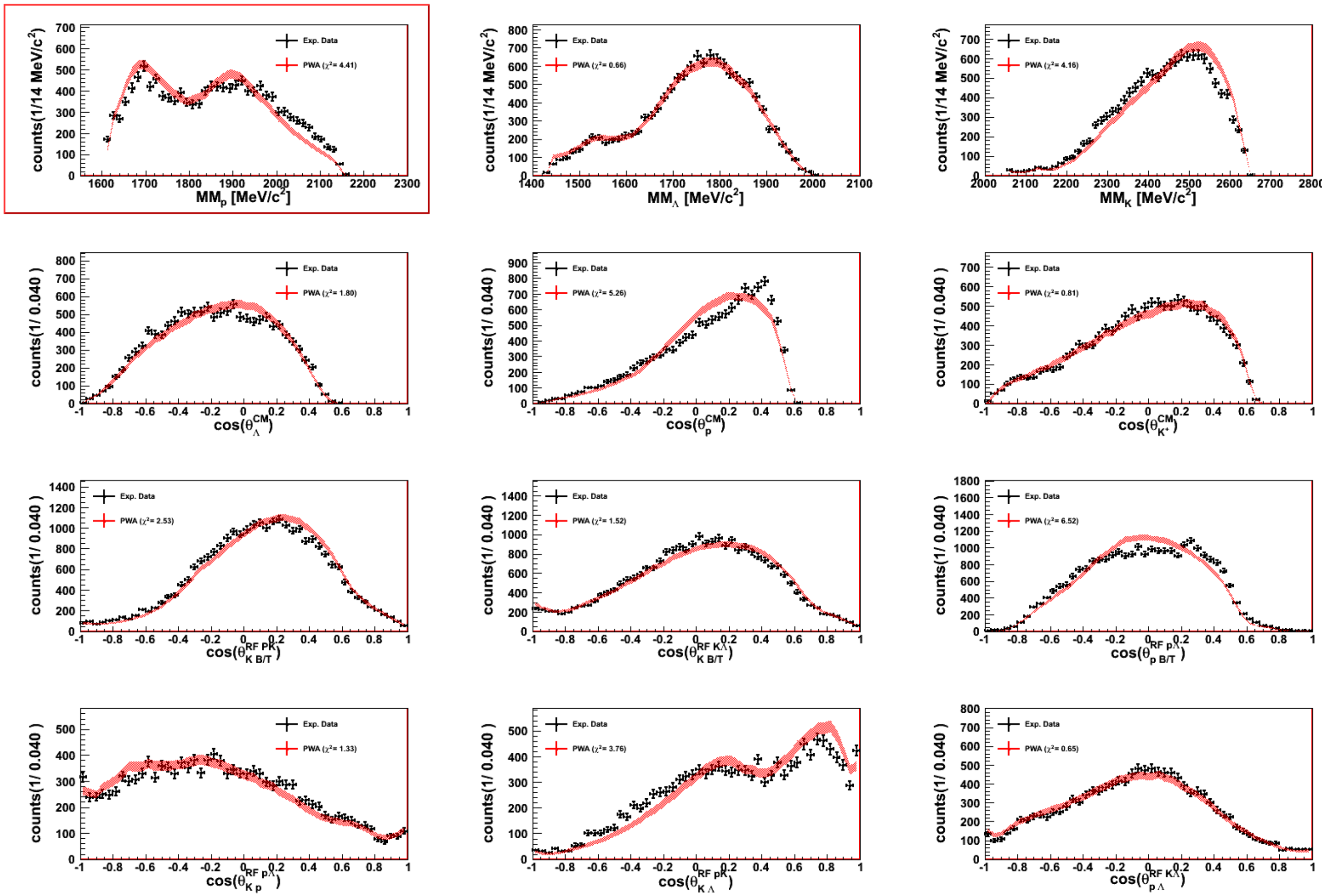
Preliminary



	X^2 / ndf (ndf=428)
PWA	0.91

HADES

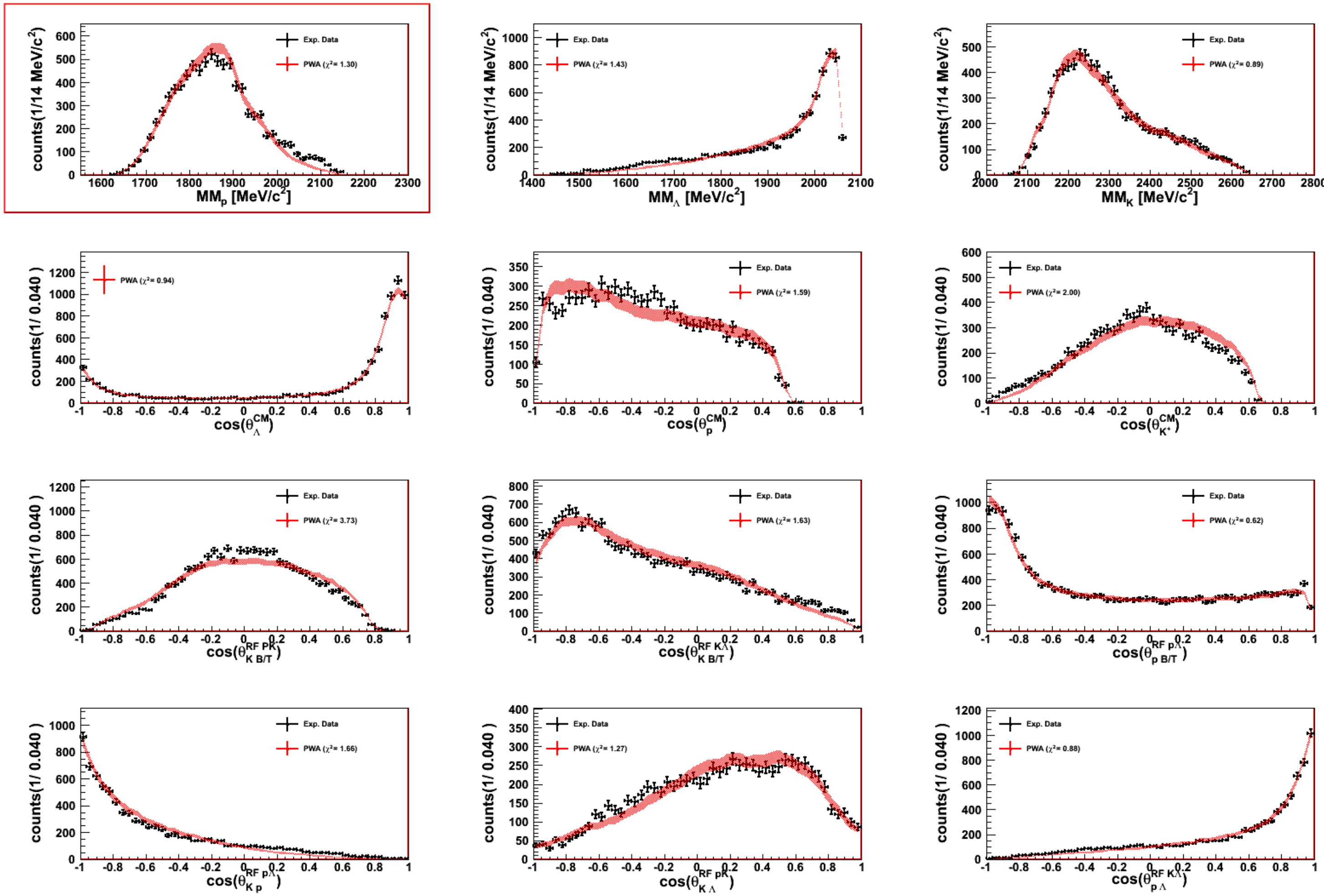
Preliminary



	X^2 / ndf (ndf=428)
PWA	2.14

HADES - WALL

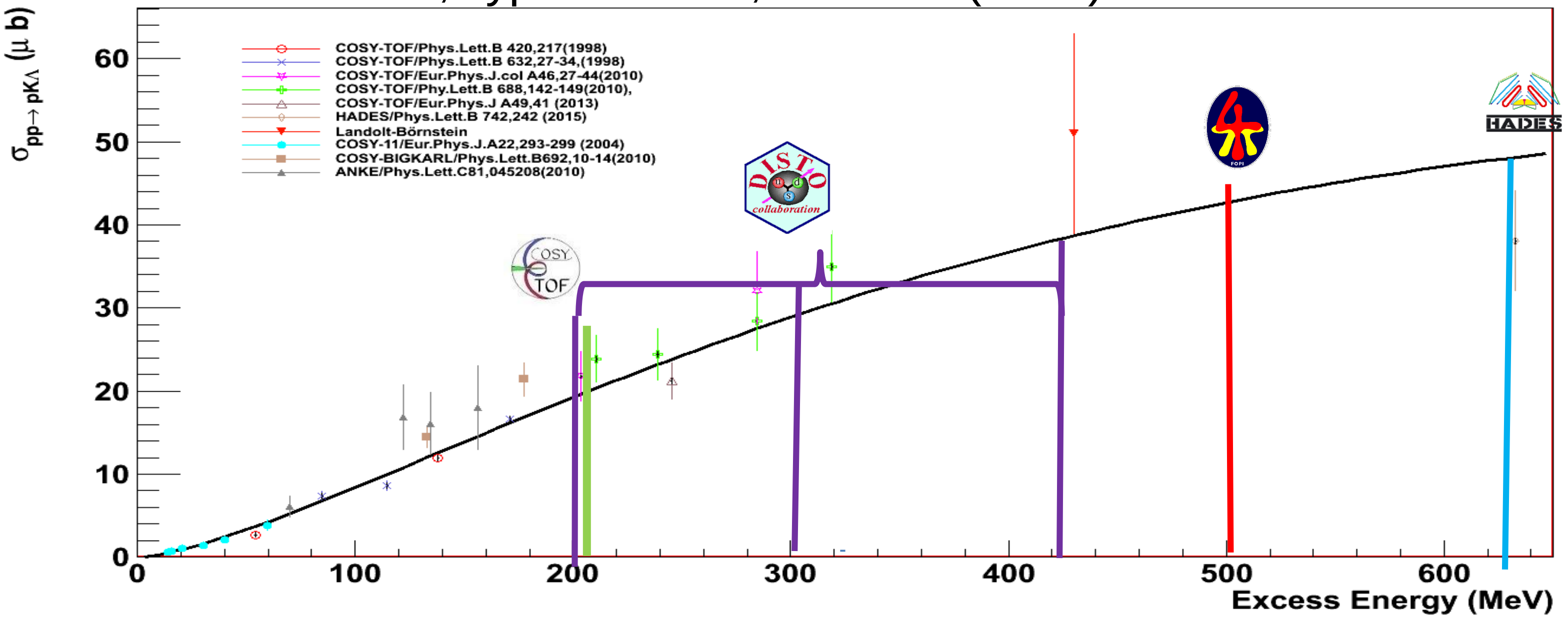
Preliminary



	X^2 / ndf (ndf=428)
PWA	1.86

Total Cross Section

R.Muenzer et al.,Hyperfine 233, 159-166 (2016)



$$\sigma_{pK\Lambda} = C_1\left(1 - \frac{s_0}{(\sqrt{s_0}+\epsilon)^2}\right)^{C_2}\left(\frac{s_0}{(\sqrt{s_0}+\epsilon)^2}\right)^{C_3}$$

Value:

$C_1 = 4.03 \pm 0.57\ 10^2$

$C_2 = 1.49 \pm 0.04$

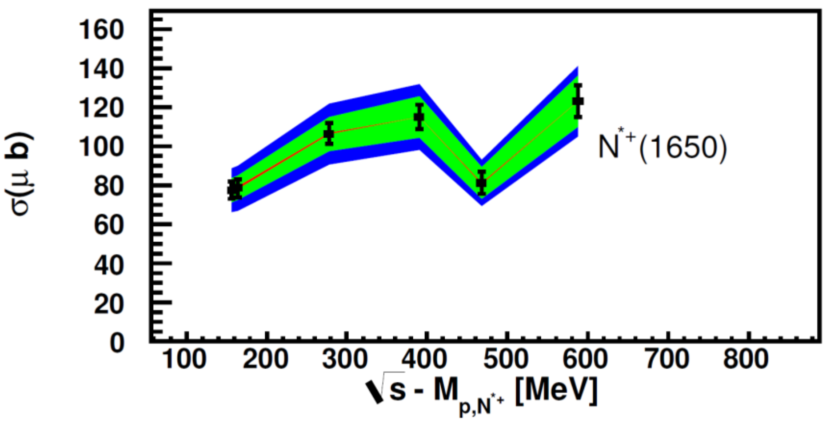
$C_3 = 1.43 \pm 0.39$

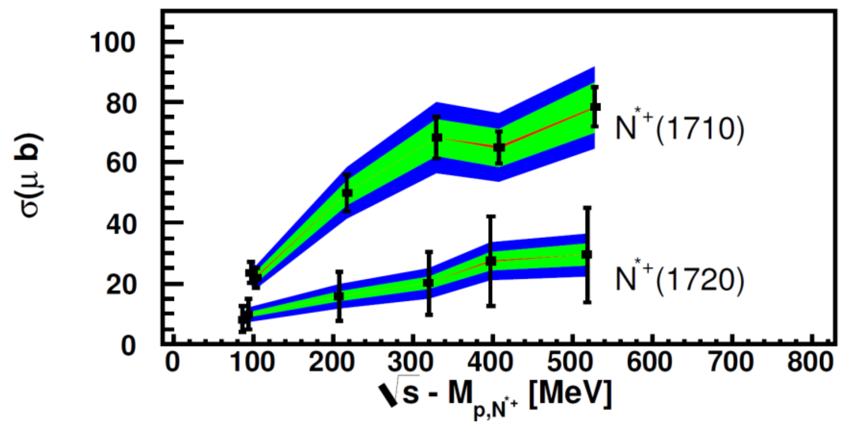
Branching Ratio

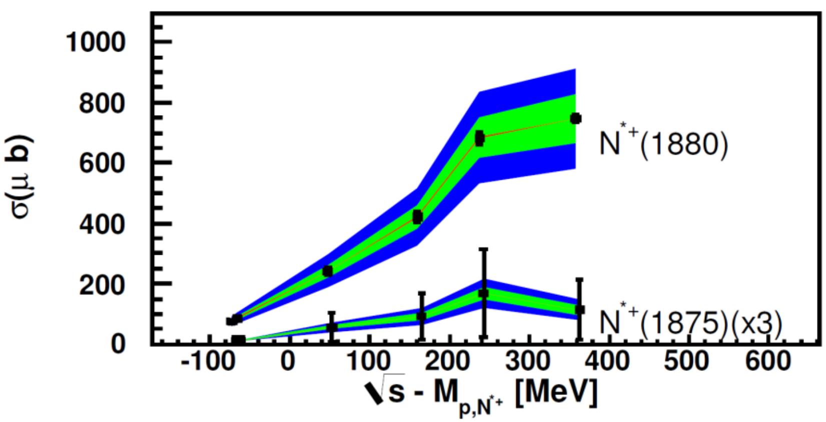
	Mass [GeV/c^2]	Width [GeV/c^2]	$\Gamma_{\Lambda K}/\Gamma_{All}$ %
N(1650)S_{11}	1.655	0.150	3-11
N(1710)P_{11}	1.710	0.200	5-25
N(1720)D_{13}	1.720	0.250	1-15
N(1875)D_{13}	1.875	0.220	4± 2
N(1880)P_{11}	1.870	0.235	2± 1
N(1895)S_{11}	1.895	0.090	18± 5
N(1900)P_{13}	1.900	0.250	0-10

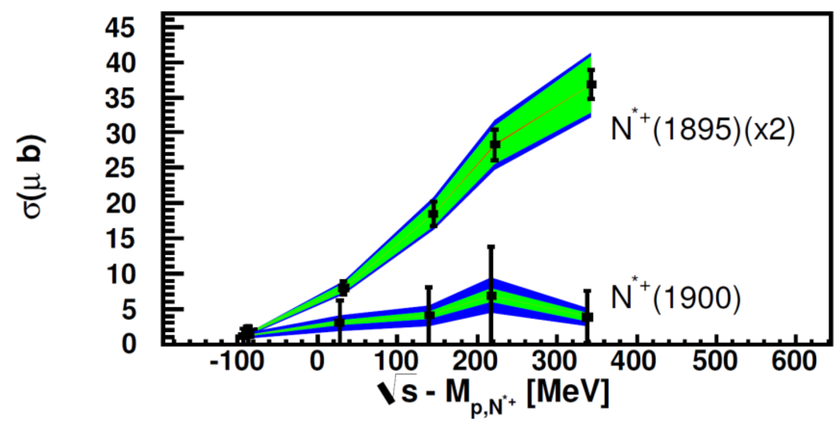
Cross Section

Preliminary





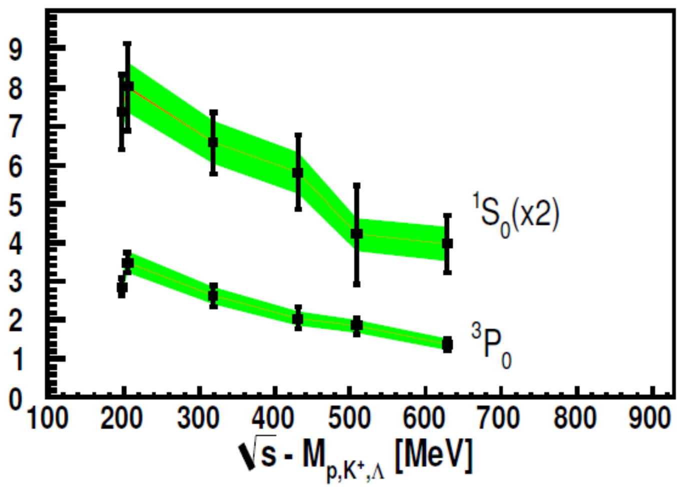


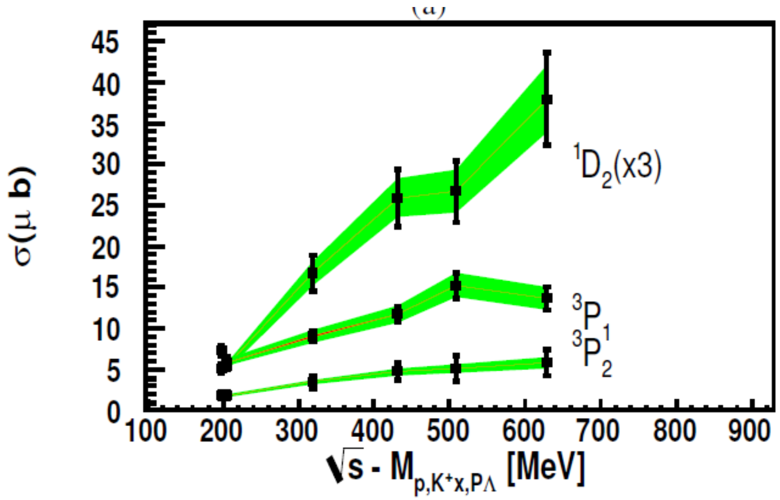


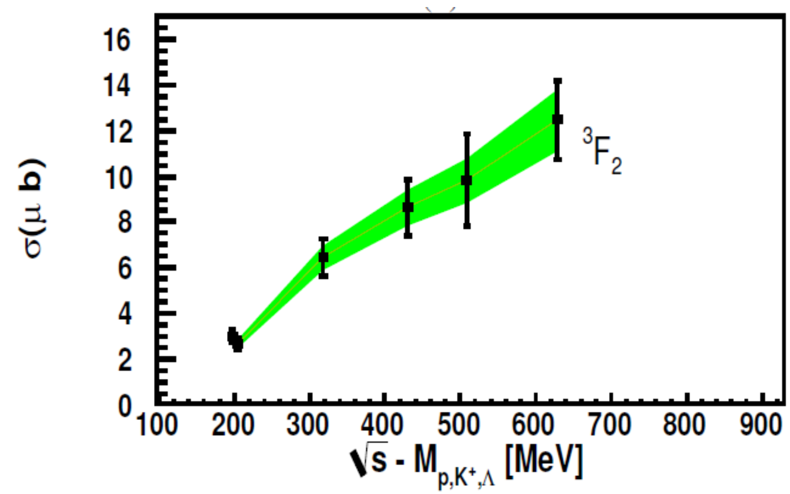
Non Resonant-Resonant: 20%-80%

Initial State

Preliminary







Final State Interaction in PWA

$$A_{2b}^{\beta} = \frac{\sqrt{s_i}}{1+\frac{1}{2}r^{\beta}q^2 a_{p\Lambda}^{\beta} + iq a_{p\Lambda}^{\beta} q^{2L}/F(q, r^{\beta}, L)}$$

$a_{p\Lambda}^{\beta}$ Scattering Length

For I=0

r^{β} Effective Range of System

$$\alpha_s = -1.43 \pm 0.36 \pm 0{,}09\ fm \qquad \alpha_t = -1{,}88 \pm 0{,}38 \pm 0.10 fm$$

$$r_s = 1.31 \pm 0.24 \pm 0{,}16\ fm \qquad r_t = 1.04 \pm 0.78 \pm 0.15 fm$$

Source	$^1S_0\ a_{\Lambda-p}$ [fm]	$^1S_0\ r_{\Lambda-p}$ [fm]	$^3S_1\ a_{\Lambda-p}$ [fm]	$^3S_1\ r_{\Lambda-p}$ [fm]	$< a_{\Lambda-p} >$ [fm]
This work	$-1.43 \pm 0.36 \pm 0.09$	$1.31 \pm 0.24 \pm 0.16$	$-1.88 \pm 0.38 \pm 0.10$	$1.04 \pm 0.78 \pm 0.15$	
NLO^2 [15]	-2.91	2.78	-1.54	2.72	-1.88^3
LO^2 [15]	-1.91	1.40	-1.23	2.13	-1.4^3
[16]	$-1.8^{+2.3}_{-4.2}$	-	$-1.6^{+1.1}_{-0.8}$	-	-
[17]	-	-	-	-	$-1.25 \pm 0.08 \pm 0.03$
[18]	-	-	$-1.31^{0.32}_{-0.49} \pm 0.3 \pm 0.16$	-	$-1.233 \pm 0.014 \pm 0.3 \pm 0.12$

[15] Haidenbauer et al.Nuclear Physics A,915,24-58 (2013)
[16] G. Alexander et a., Phys. Rev. 173,1452 (1968).
[17] M.Roeder et al., Eur. Phys. J. A49, 157 (2013)
[18] Hauenstein 2014

Data Sets for Cusp Analysis

Experiment	E_B [GeV]	$pK^+\Lambda$ Statistics	Status
COSY-TOF	1.96	~160k	In Preparation (not used in the analysis)
DISTO	2.15	121 k	Available
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Cusp Effect

Effect close to the ΣN threshold

Coupled Channel Interaction

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

$$p + p \rightarrow N\Sigma + K^+$$

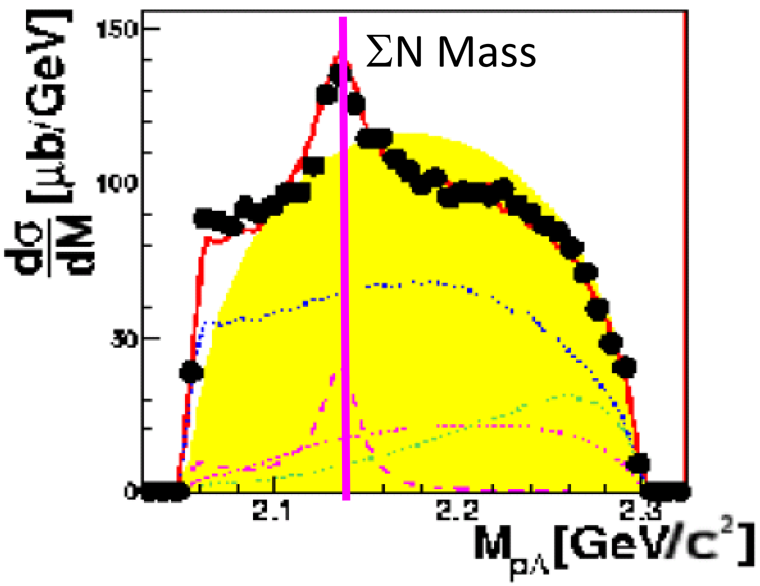
$$\rightarrow p + \Lambda + K^+$$

$N\Sigma$: $p\Sigma^0$ / $n\Sigma^+$

The Σ and N are expected to be in a relative s-wave state.
spin-parity of the N Σ system is either $J^P = 0^+$ or 1^+.

- Cosy-TOF Analysis:

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



Solid line: Full MC simulation

Shaded areas: phase-space distributions

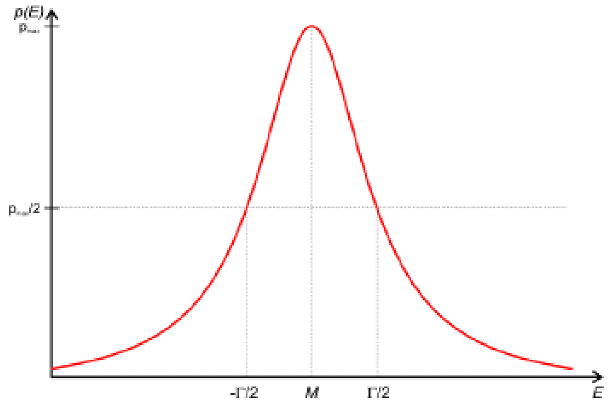
BG-PWA + Breit-Wigner approach

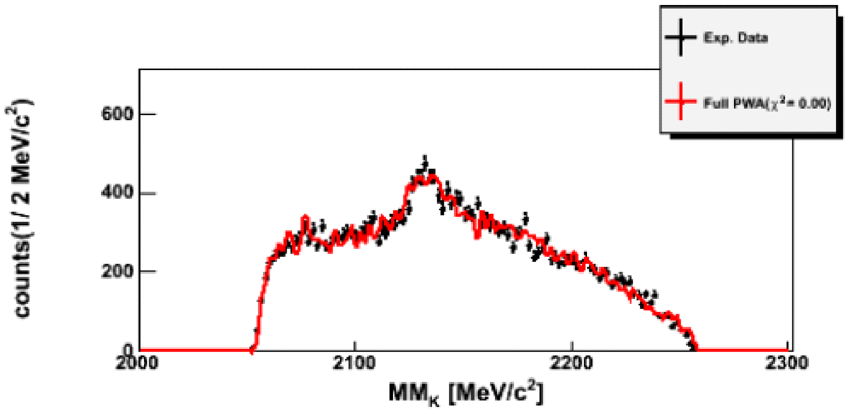
The Relativistic Breit-Wigner distribution:

$$\frac{d\sigma_{p\Lambda}}{dm_{p\Lambda}} \approx \frac{1}{m_R^2 - m_{p\Lambda}{}^2 - i\Gamma m_{p\Lambda}}$$

m_R	Mass of resonance
Γ	Width of resonance
$m_{p\Lambda}$	Invariant mass of pΛ

- COSY-TOF 2.16GeV
- Invariant Mass m_R: 2:13 GeV/c²
- Width Γ: 0.02 GeV/c²





Data from: M. Roeder et al., Eur. Phys. J. A 49, 157 (2013)

BG-PWA + Flatté approach

The Flatté parameterization:

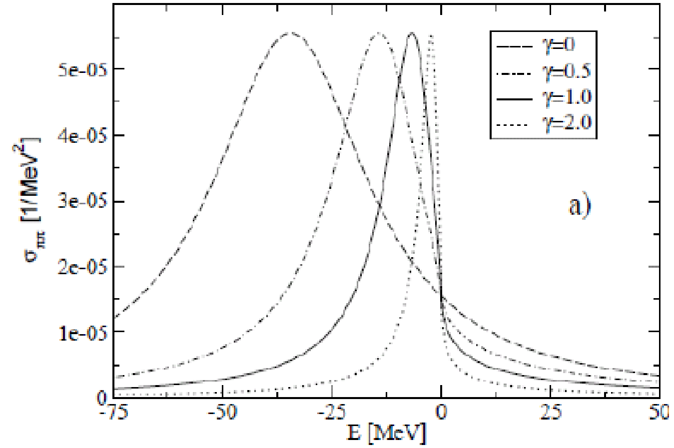
$$\frac{d\sigma_{p\Lambda}}{dm_{p\Lambda}} \approx \frac{C * m_R * \sqrt{\Gamma_{p\Lambda}\Gamma_o}}{|\, m_R^2 - m_{p\Lambda}^2 - i m_{p\Lambda}(\Gamma_{p\Lambda} + \Gamma_{p\Sigma})\,|^2}$$

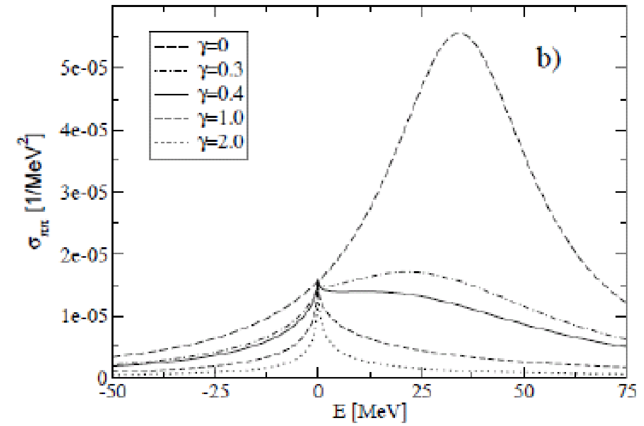
m_R	Mass of resonance
Γ	Width of resonance
$m_{p\Lambda}$	Invariant massof pΛ

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

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

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



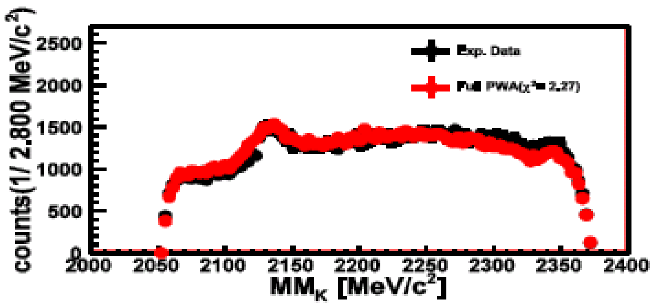


BG-PWA + Flatté approach

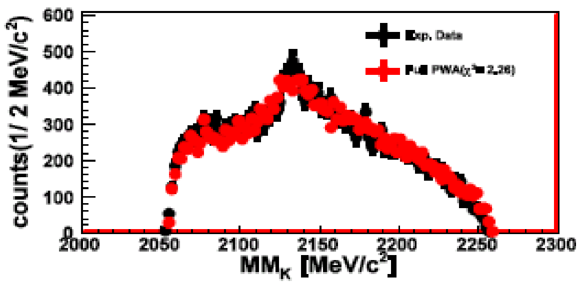
Combined data analysis

Preliminary

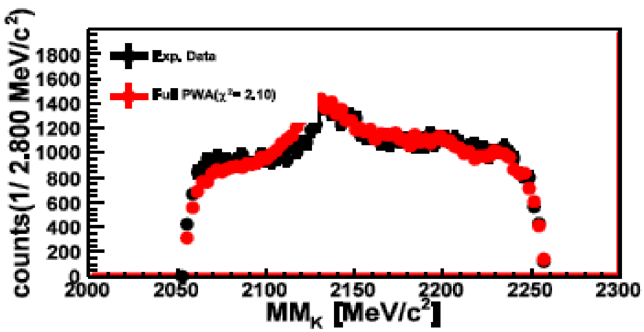
- DISTO 2.5GEV



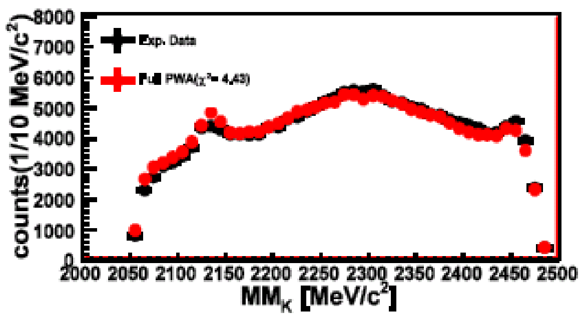
- COSY-TOF 2.16GEV



- DISTO 2.14GEV



- DISTO 2.85GEV



- **Final coupling constants:** $g_{N\Sigma}$=**1.55±0.08x10^{-2}** , $g_{p\Lambda}$ = **0.30±0.03x10^{-2}**
- **Threhold mass value from the fit:** **m_R=2.13±0.006 GeV/c^2**

Summary and Outlook

- Combined Analysis for COSY & DISTO & HADES & FOPI completed for N*
- Systematical Analysis performed
- Excitation Function for N* and pKL extracted
- Scattering Length p-Λ separate for Singlet and Triplet
- Cusp Wave: preliminary studies on 4 data set

- Paper 1) is being Finalized at the Moment (N*)
- Estimation of the global upper limit for ppK-
- Global analysis including the cusp with Flatte'