Λ(1405) Observations in p+p and K^--induced reactions

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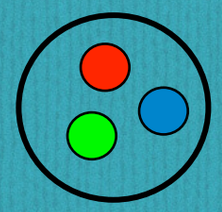
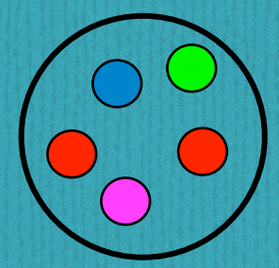
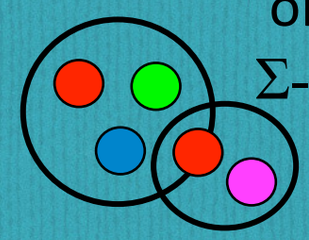
Λ(1405)



q^3 baryon ?



Pentaquark?



Molecular State?

$M \approx 1406\ MeV/c^2$

$\Gamma \approx 50\ MeV/c^2$

$I(J^P)=0\ (1/2^+)$

Decay Channels:

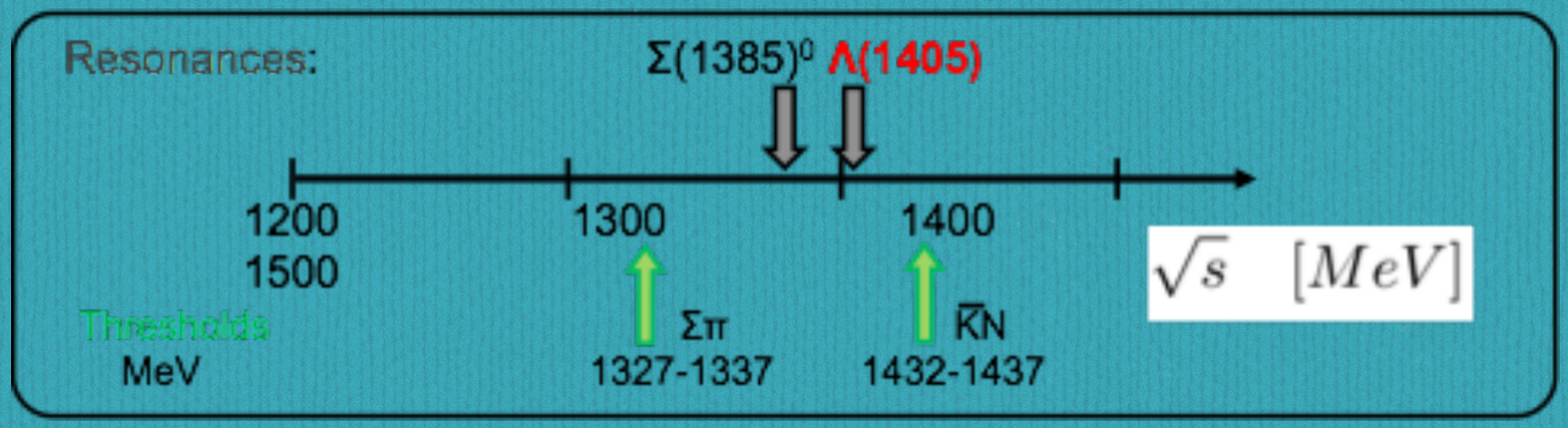
$\Sigma^0\pi^0,\ \Sigma^+\pi^-,\ \Sigma^-\pi^+$

q^3:

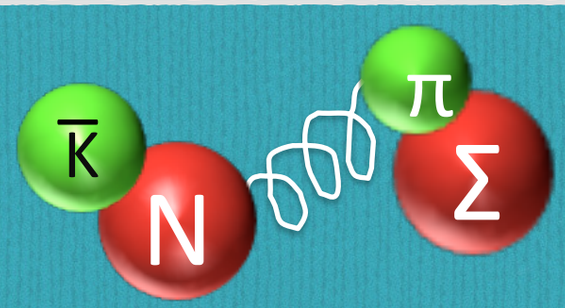
Expected Mass ~ $1700\ MeV/c^2$

Pentaquark:

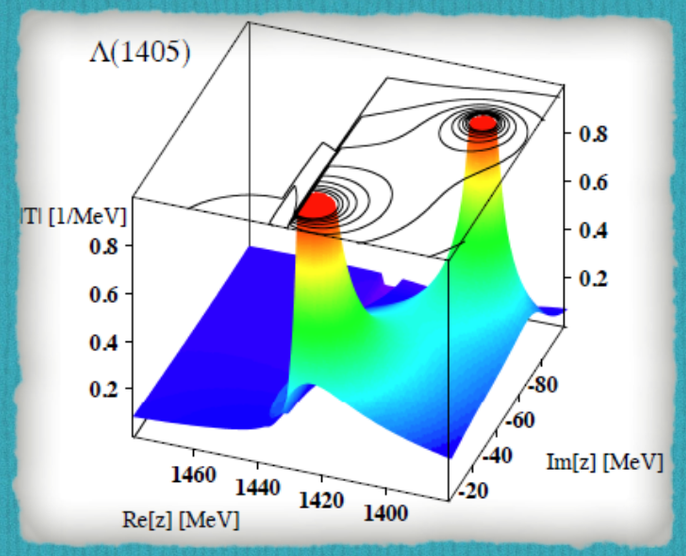
more observed excited baryons



Double Pole Structure



Prog.Part.Nucl.Phys. 67 (2012) 55-98



From calculation constrained by scattering data and kaonic atoms:

Nucl.Phys. A881 (2012) 98-114

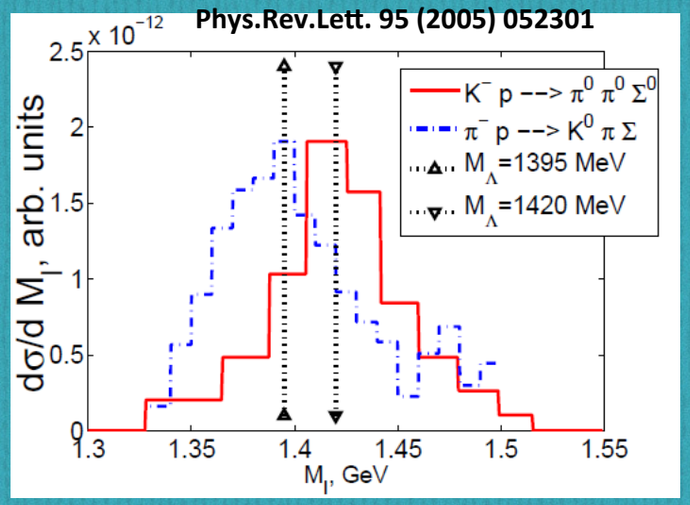
$m_{0,1}=Re(z_1)=1424^{+7}_{-23}$ MeV
$\Gamma_{0,1}=2*Im(z_1)=52^{+6}_{-28}$ MeV
$m_{0,2}=Re(z_2)=1381^{+18}_{-6}$ MeV
$\Gamma_{0,2}=2*Im(z_2)162^{+38}_{-16}$ MeV

Nucl.Phys. A900 (2013) 51 - 64

$m_{0,1}=Re(z_1)=1428^{+2}_{-1}$ MeV
$\Gamma_{0,1}=2*Im(z_1)=16^{+4}_{-4}$ MeV
$m_{0,2}=Re(z_2)=1497^{+11}_{-7}$ MeV
$\Gamma_{0,2}=2*Im(z_2)150^{+18}_{-18}$ MeV

Experimental Λ(1405) in Σπ spectrum:

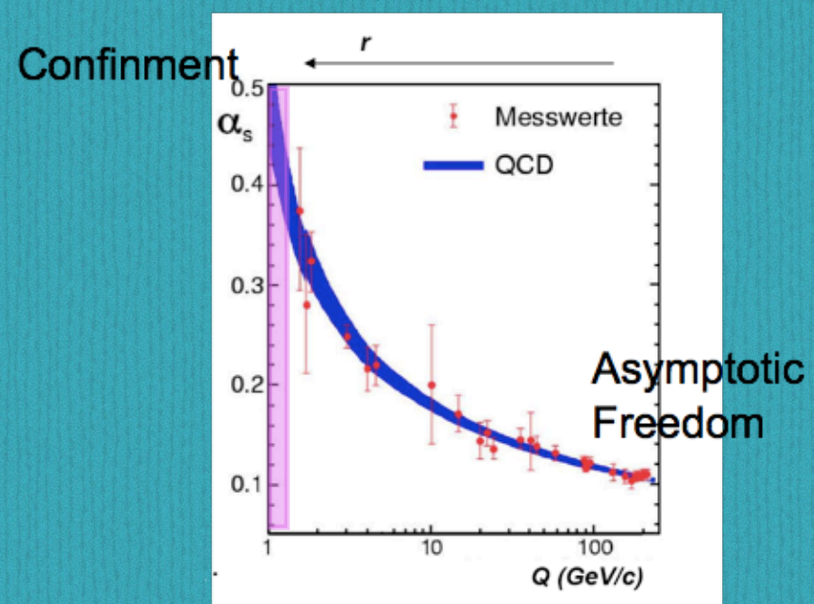
Phys.Rev.Lett. 95 (2005) 052301



* K^-+p reactions excite mainly 1420 pole
* π^-+p reactions excite mainly 1390 pole

→ Λ(1405) correlated with KN dynamics!

Effective Hadron-Hadron Interaction



Small Q (~1 GeV)

Large Distances (1 fm)

Effective Field Theory of interacting Bosons

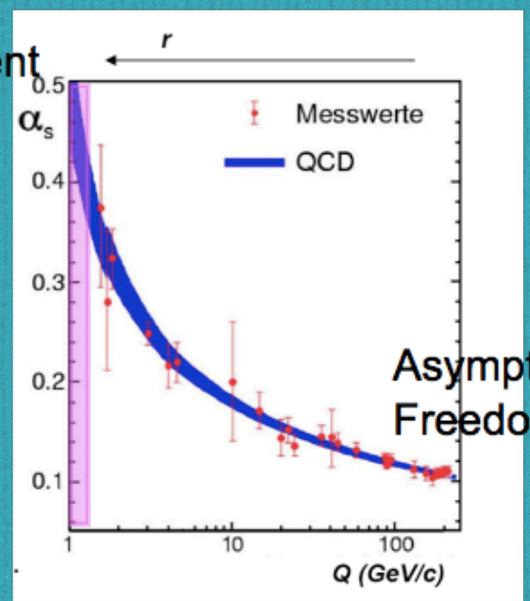
- Test-bed of the strong interaction in few body systems
- Strange quarks are intermediate between “light” and “heavy”

-> Interplay between spontaneous and explicit chiral symmetry breaking in low energy QCD.

- Testing ground: K-N and $\bar{K}$-N interactions

Strange Effective Hadron-Hadron Interaction

Confinement



Asymptotic Freedom

Small Q (~1 GeV)

Large Distances (1 fm)

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Strange Effective Hadron-Hadron Interaction

Antikaon

ChPT in SU(3) (exact Theory) does not work for the KN system
-> Coupled-Channel Ansatz based on Chiral Dynamics

Kaon

Strange Effective Hadron-Hadron Interaction

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Ex: Λ(1405) dynamically generated like a QUASI-BOUND K^-p (I=0) State

R.H. Dalitz et al.; Phys. Rev. 153 (1967) 1617

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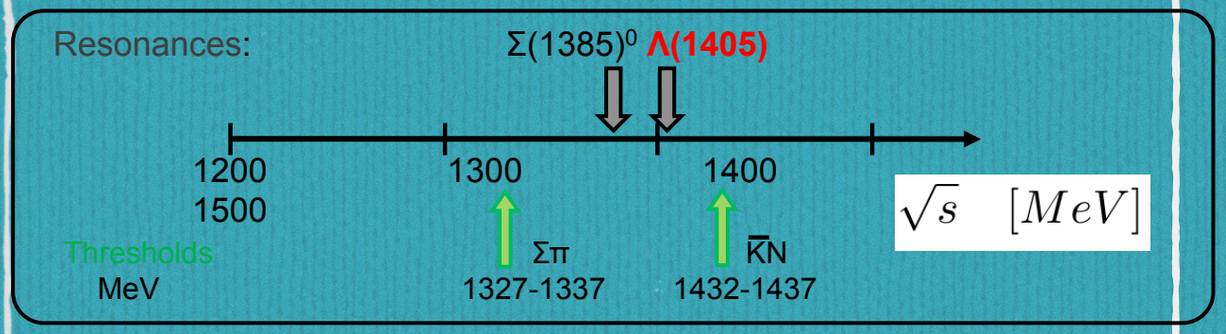

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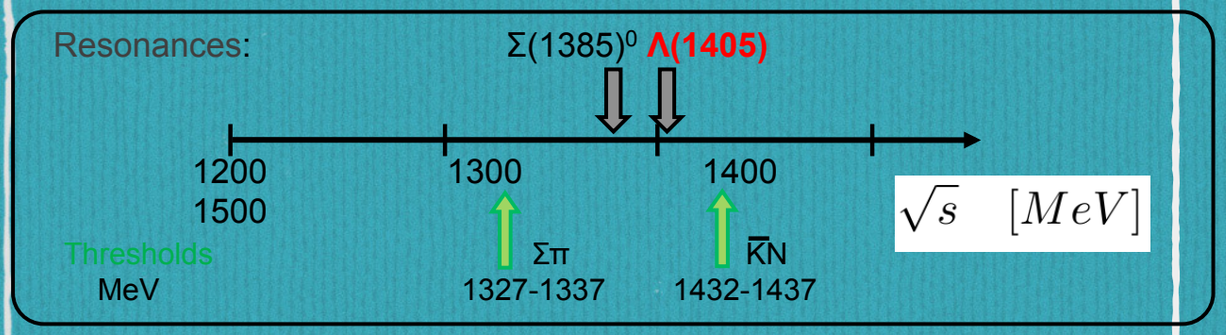

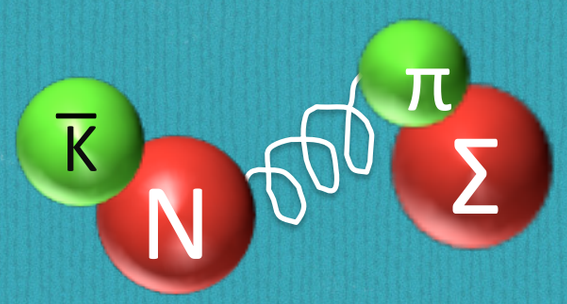

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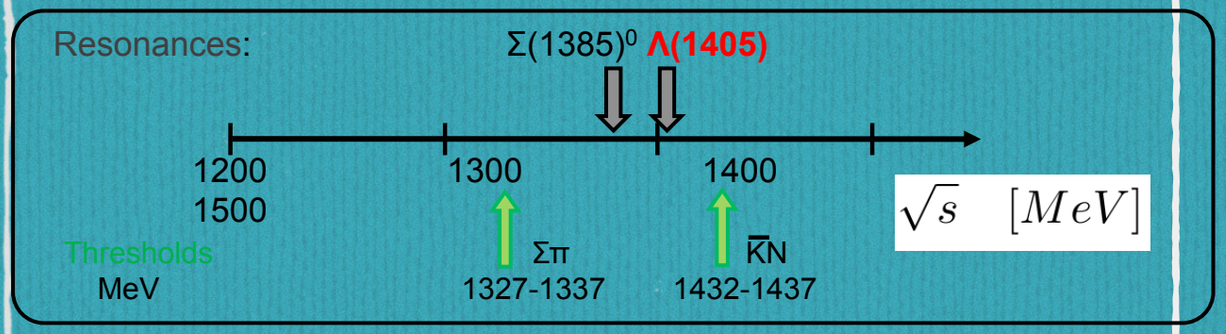
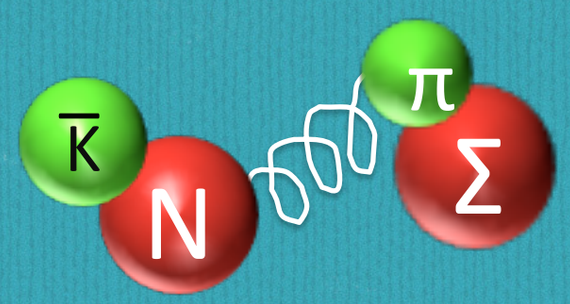




Kaon

ChPT is used to describe K-N interaction since Kaons do not get absorbed generating resonances

p+p in the GeV Energy Range

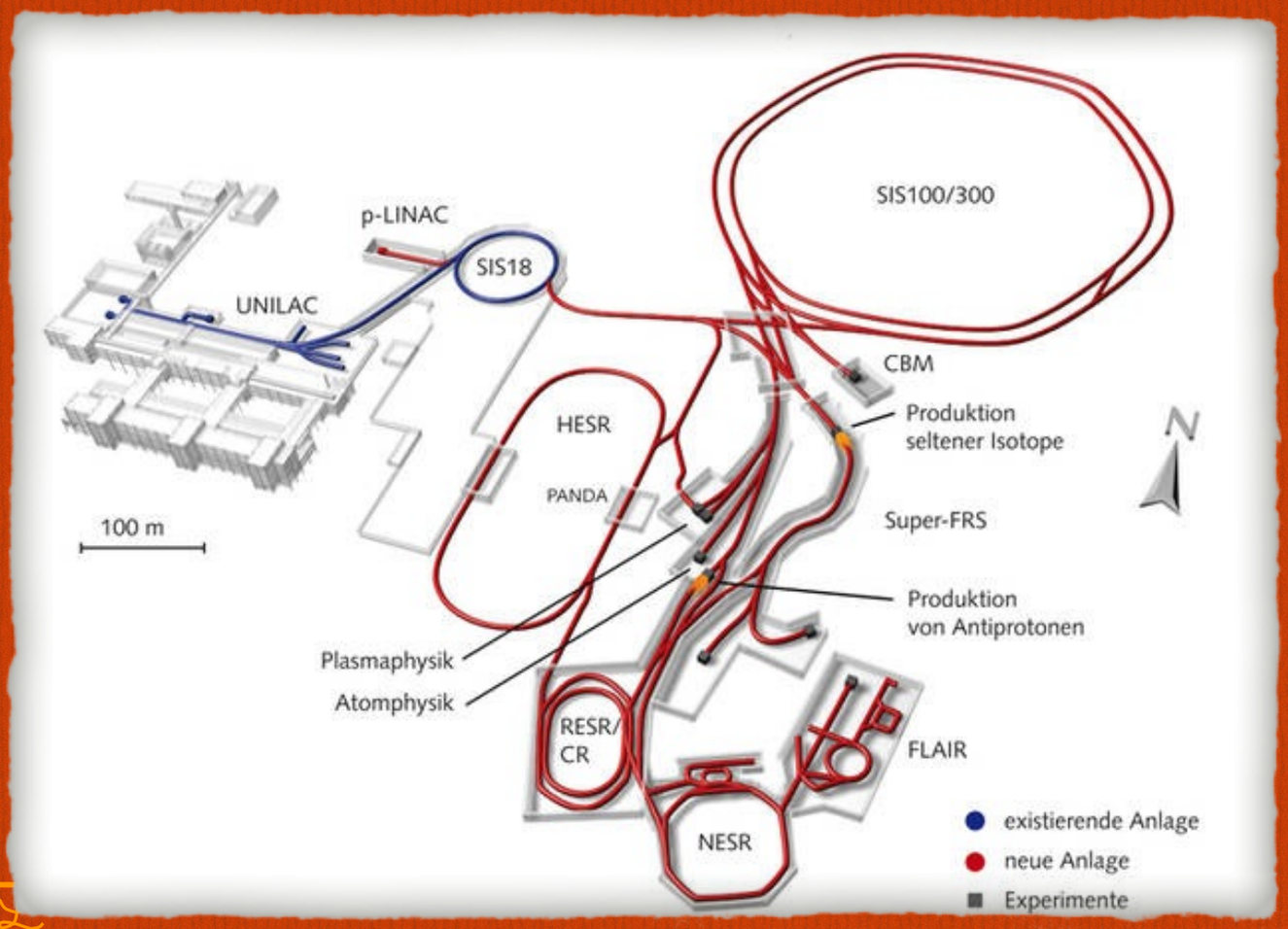
Fixed Target experiments, E_{kin}~ AGeV

proton-proton

p+p in the GeV Energy Range

Fixed Target experiments, E_{kin}~ AGeV

proton-proton

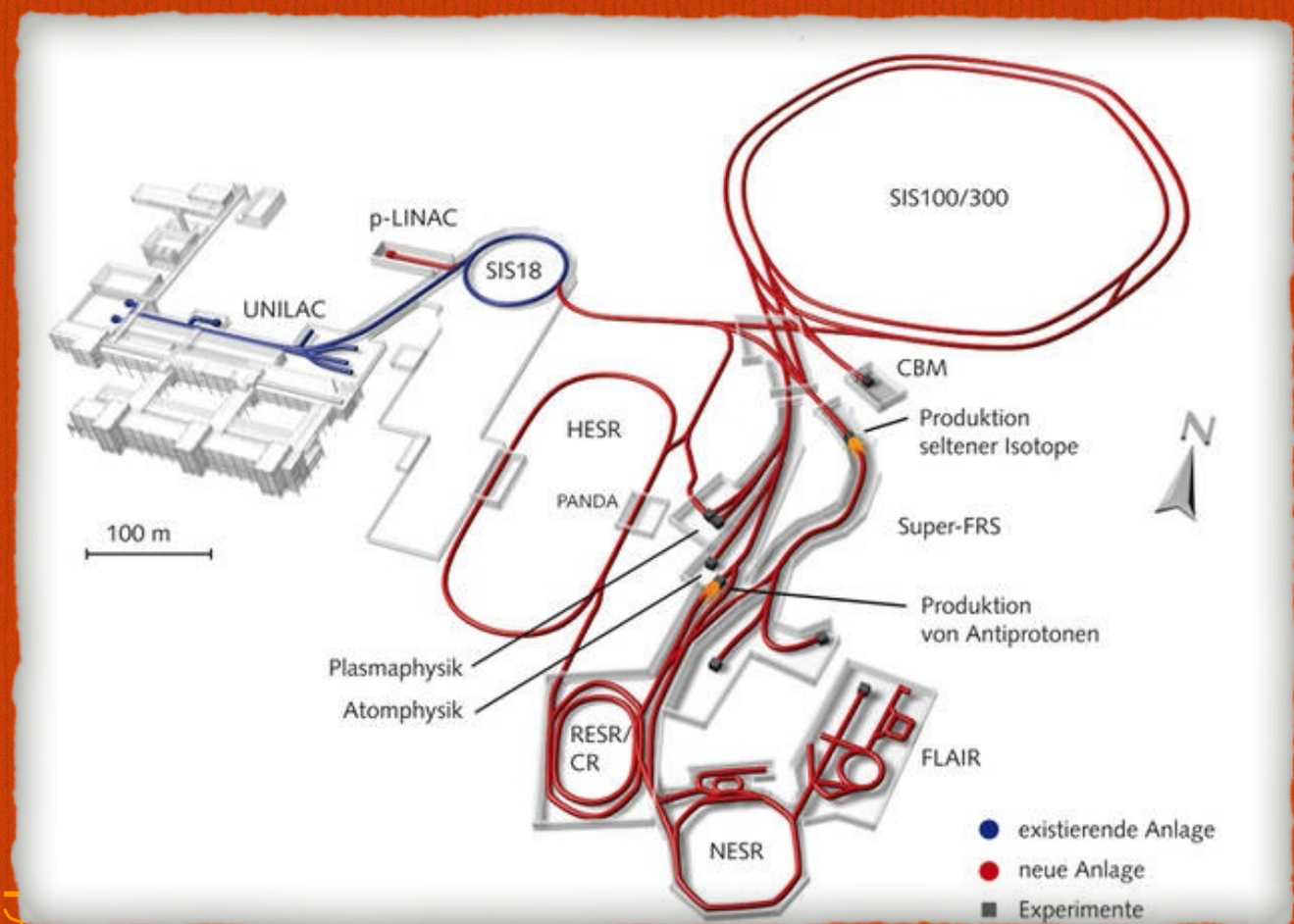


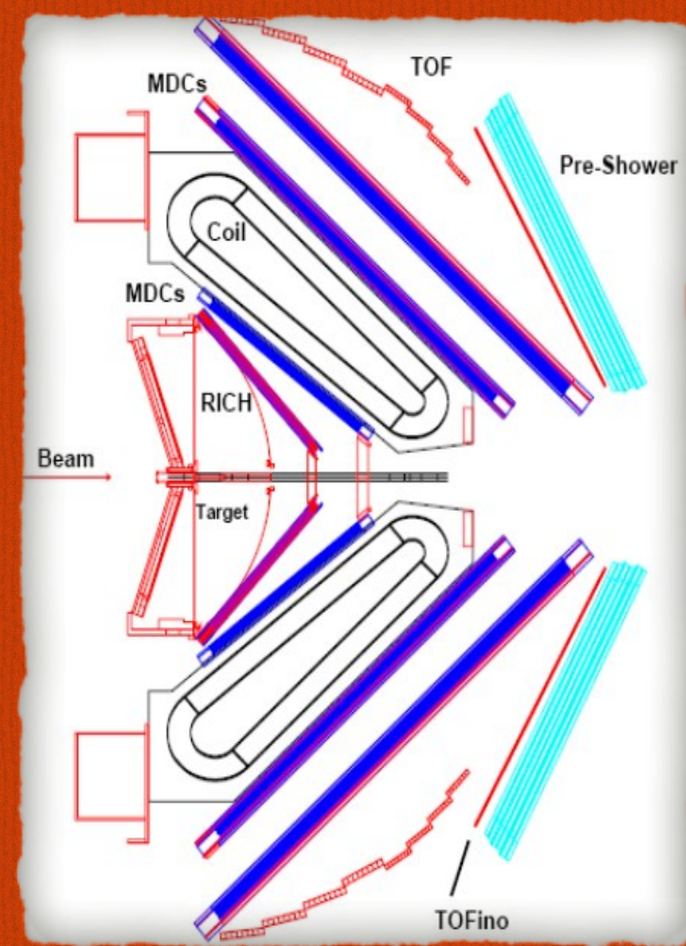
p+p in the GeV Energy Range

Fixed Target experiments, E_{kin}~ AGeV

proton-proton

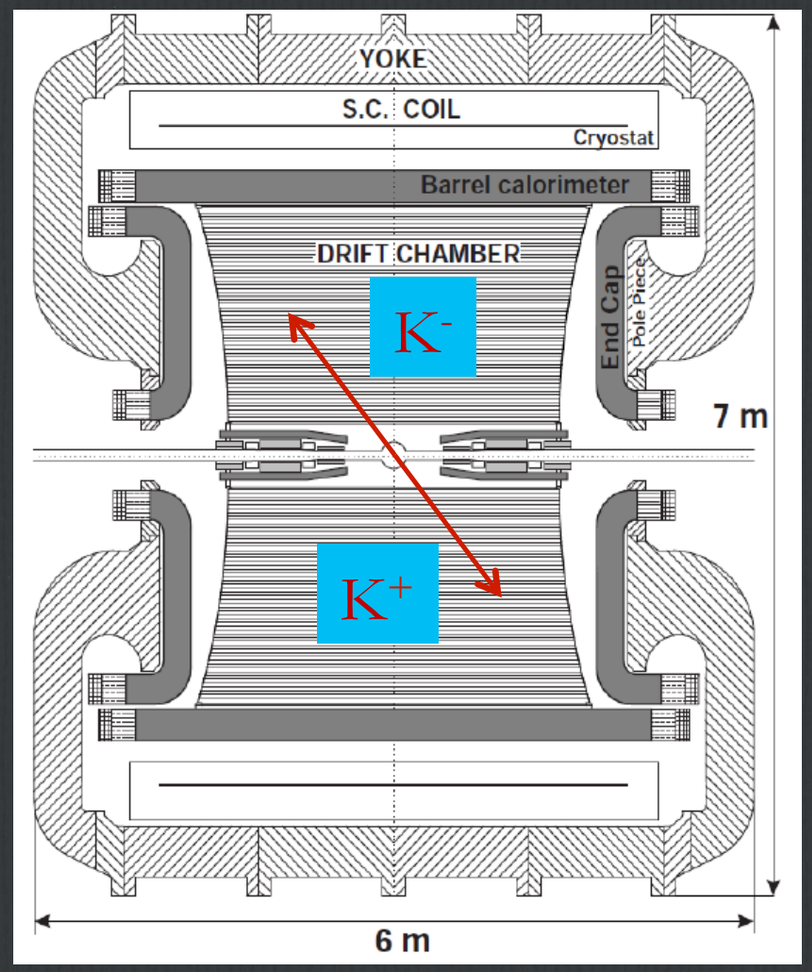
HADES
High Acceptance Di-Electron Spectrometer
Fixed Target Experiment
SIS18, Ekin=1-3 GeV/nucl
Full azimuthal coverage, 18°-85° in polar angle
$\delta p/p$ ~ 1-3 %





K- ^{4}He reactions at Daφne

KLOE Experiment



- K- Momentum = 127 MeV/c
- $\sigma p/p \sim 0.4$ MeV/c
- 96% geometrical acceptance
- Calorimeter for γs: $\sigma_m \sim 18$ MeV/c^2
- Vertex resolution: 1 mm
- Gas: 90% He, 10% C_4H_{10}

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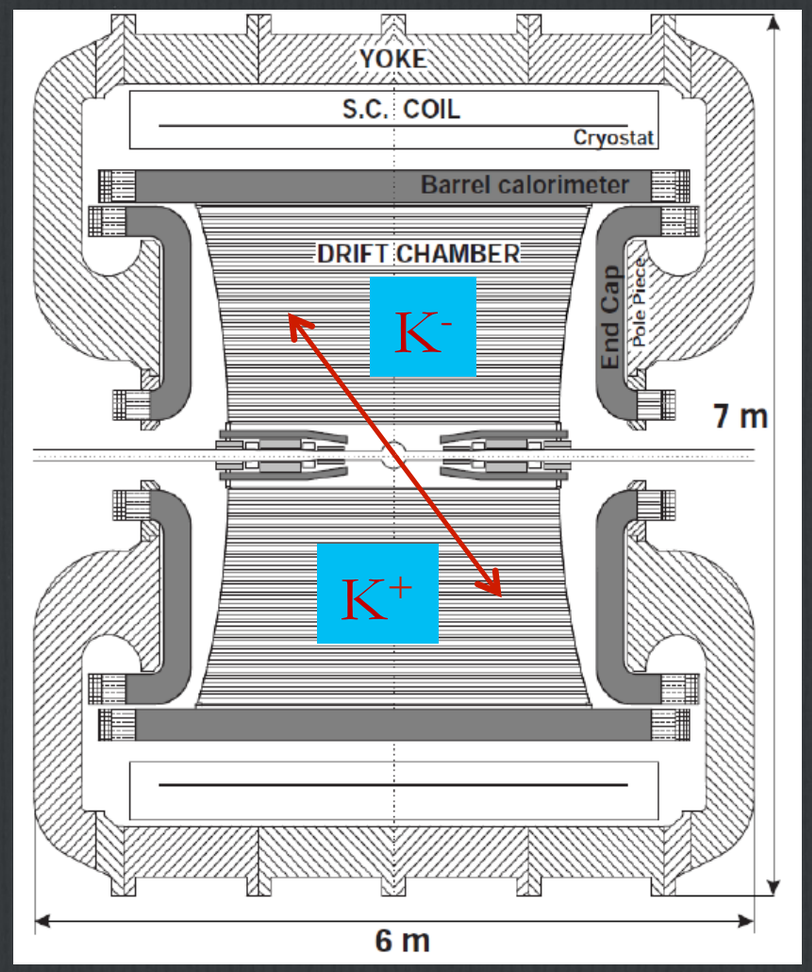

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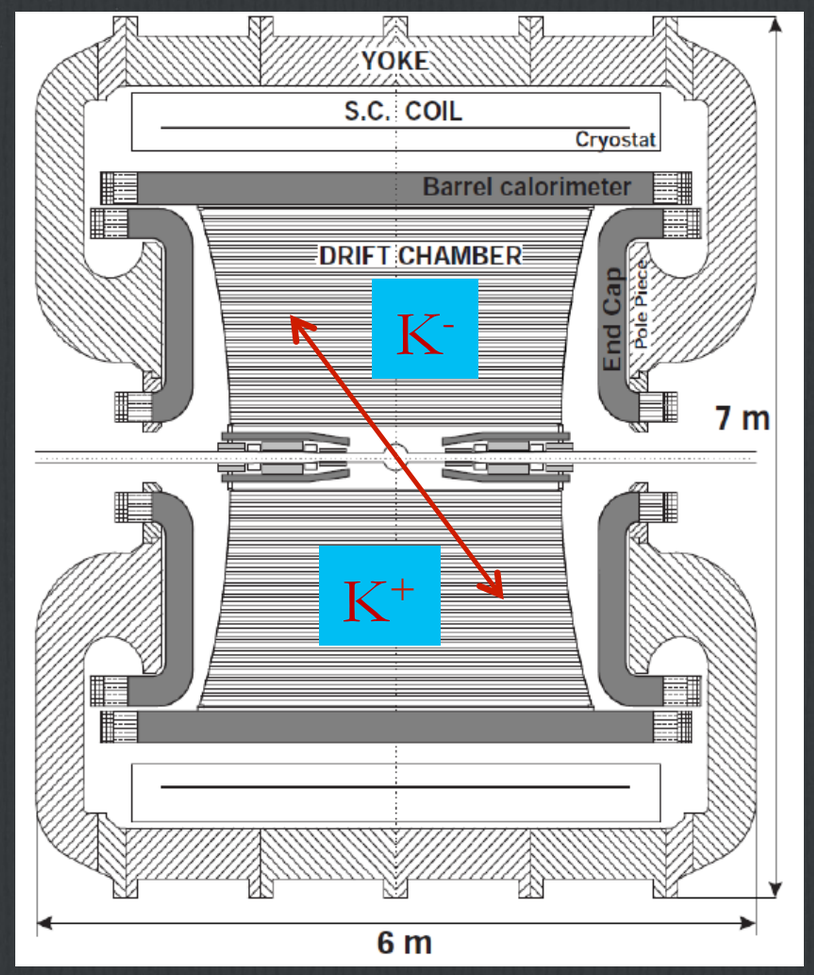

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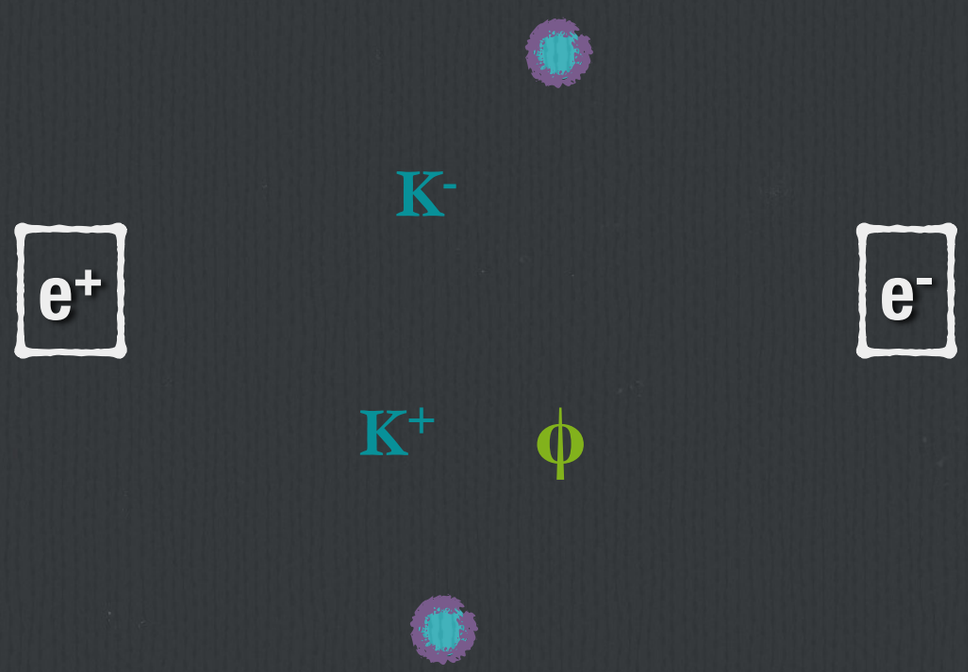

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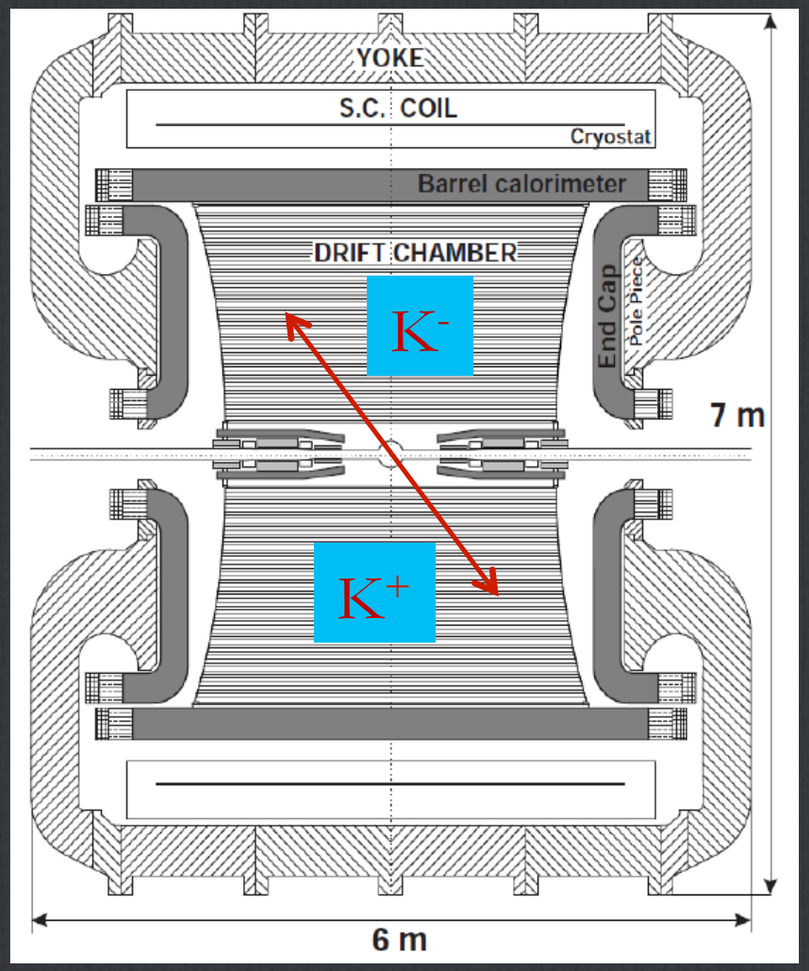


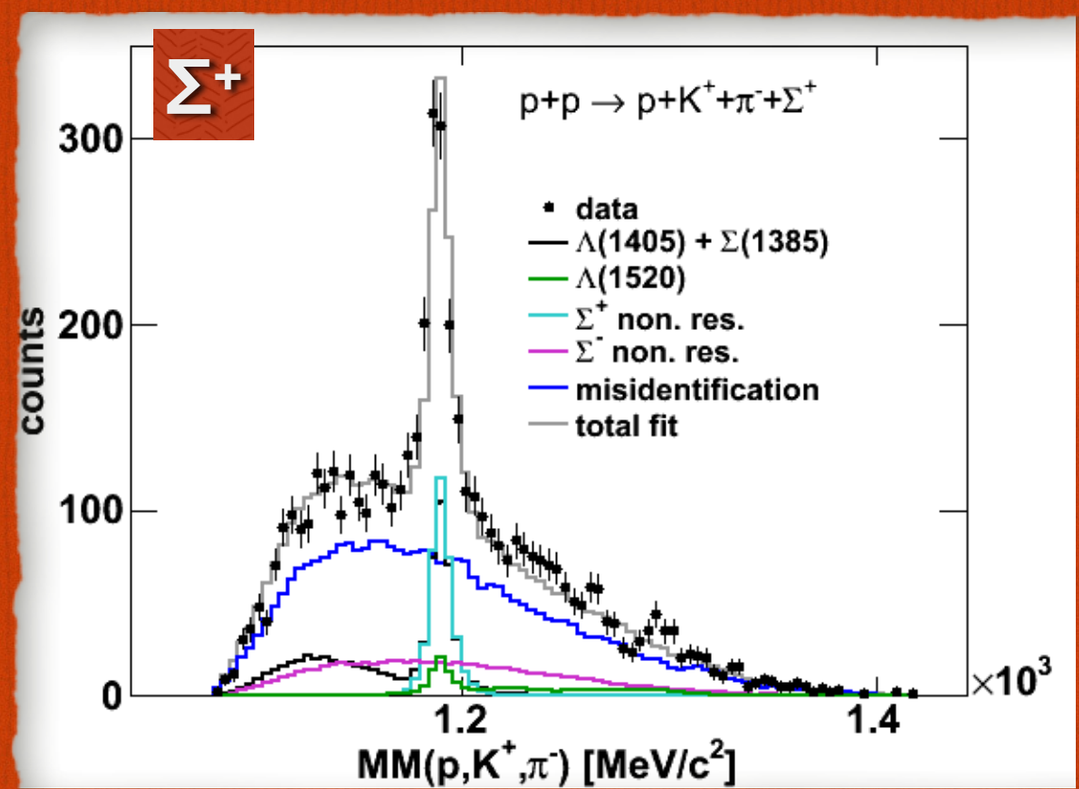
p+p collisions

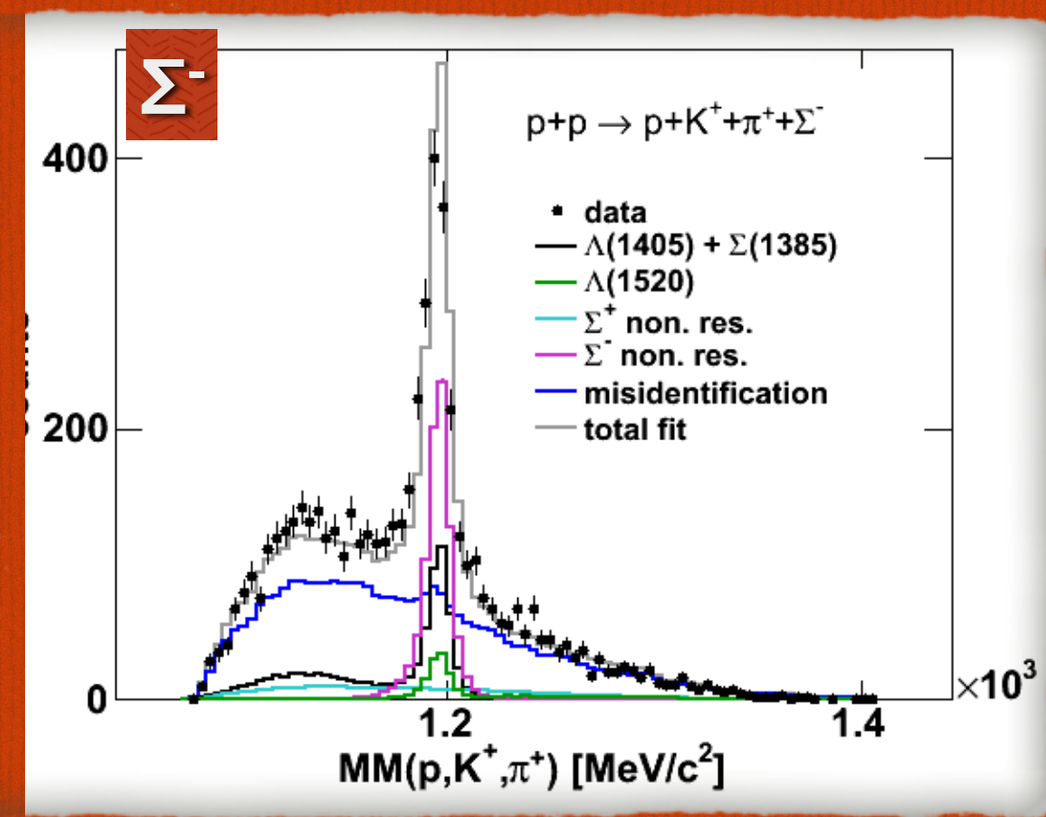
proton-proton

$\sigma(\Lambda(1405))/\sigma(\Sigma(1385)^0) \approx 2.8$, known from analysis of neutral decay channels

Conservative estimation: $\sigma(\Sigma(1385)^0) = 0.5\sigma(\Sigma(1385)^+$

$\rightarrow \sigma(\Lambda(1405))/\sigma(\Sigma(1385)^0)\ ) \approx 1.0 \rightarrow$ no influence on pole mass or line shape of $\Lambda(1405)$





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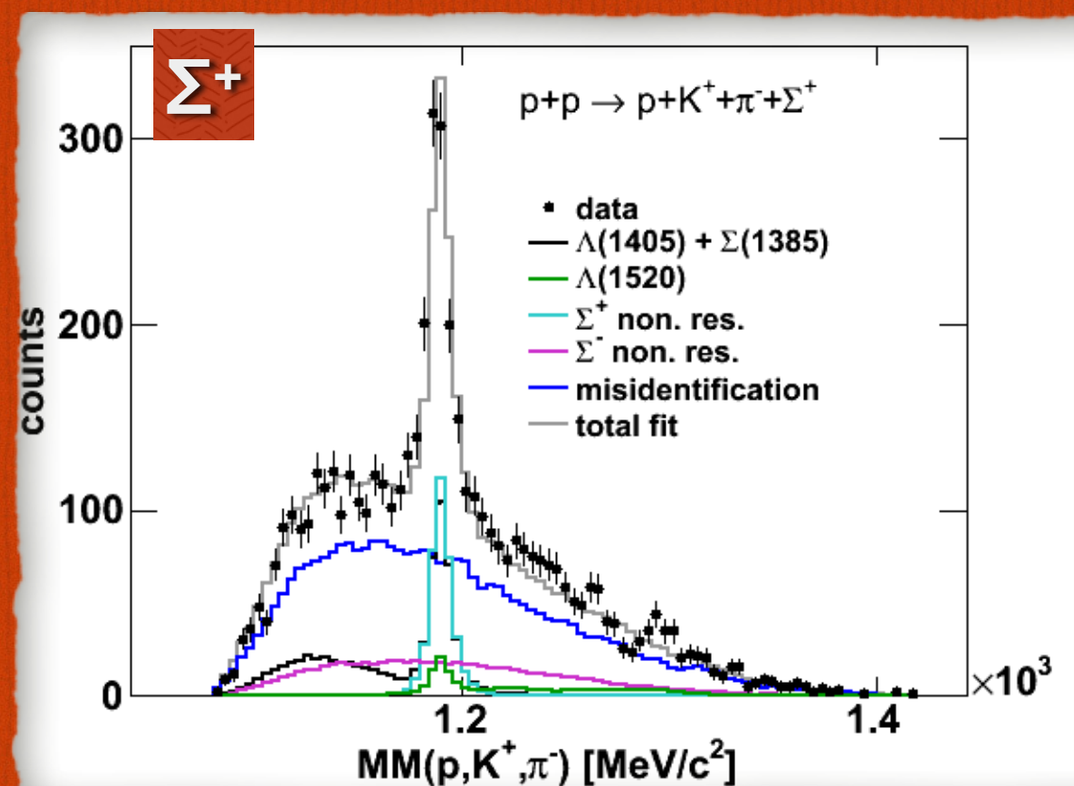

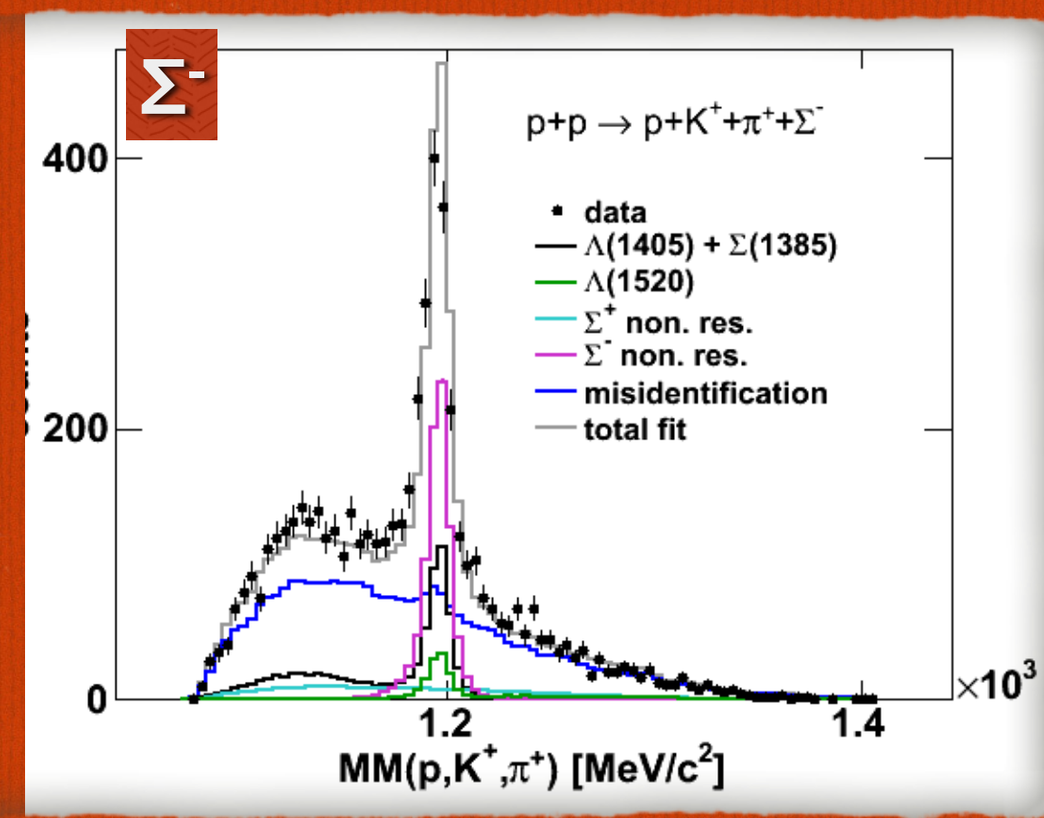

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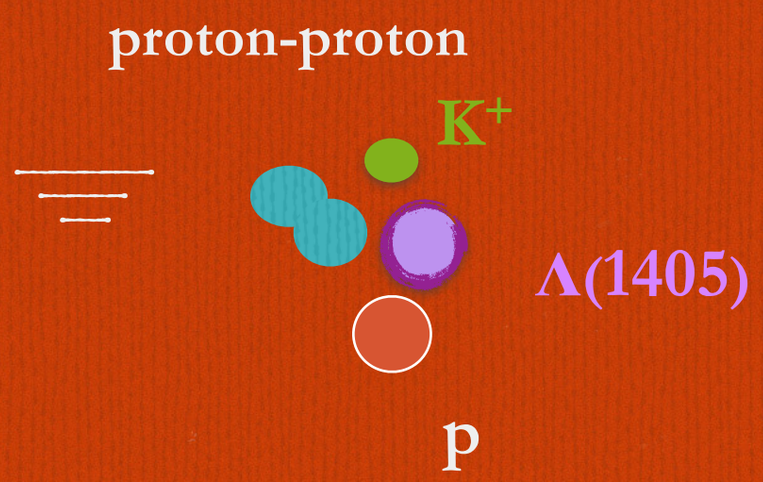

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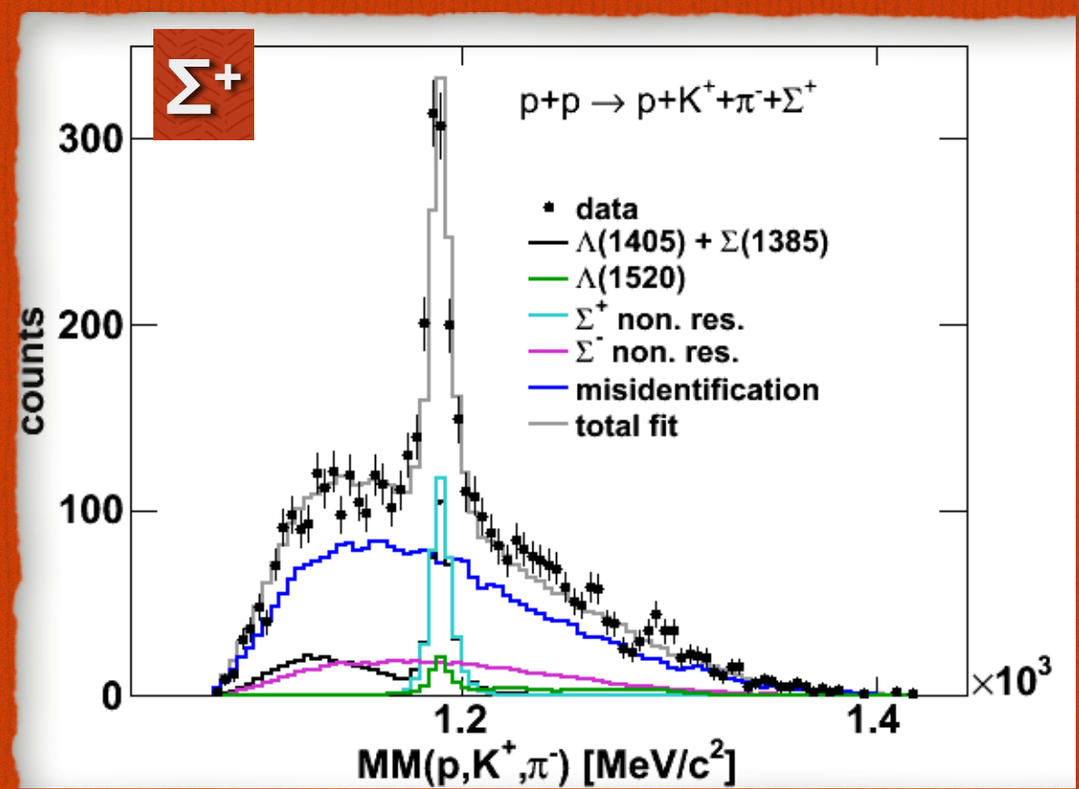

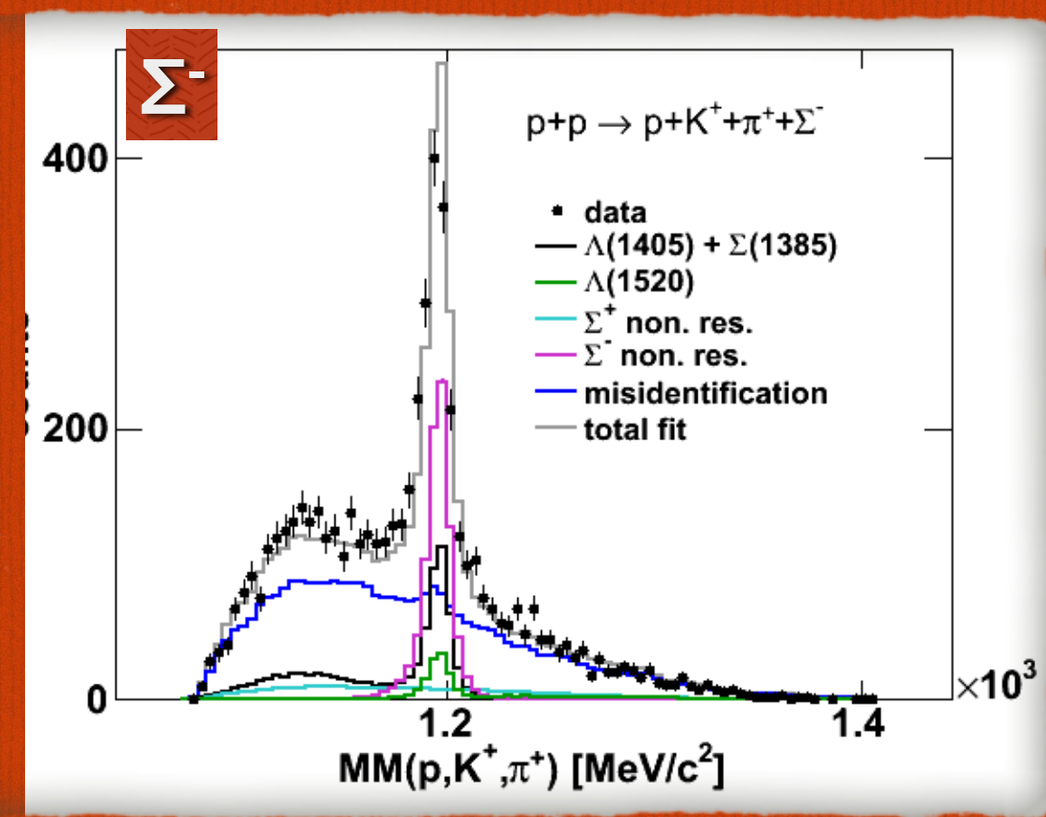

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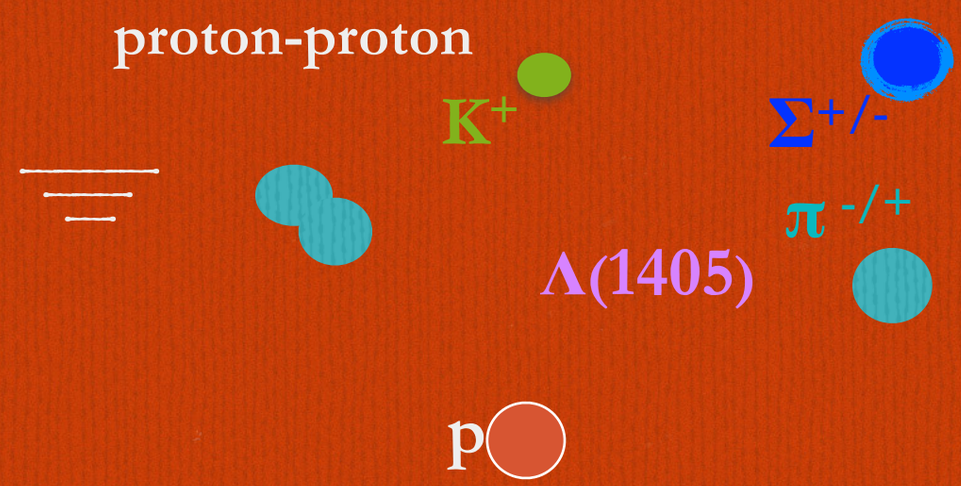

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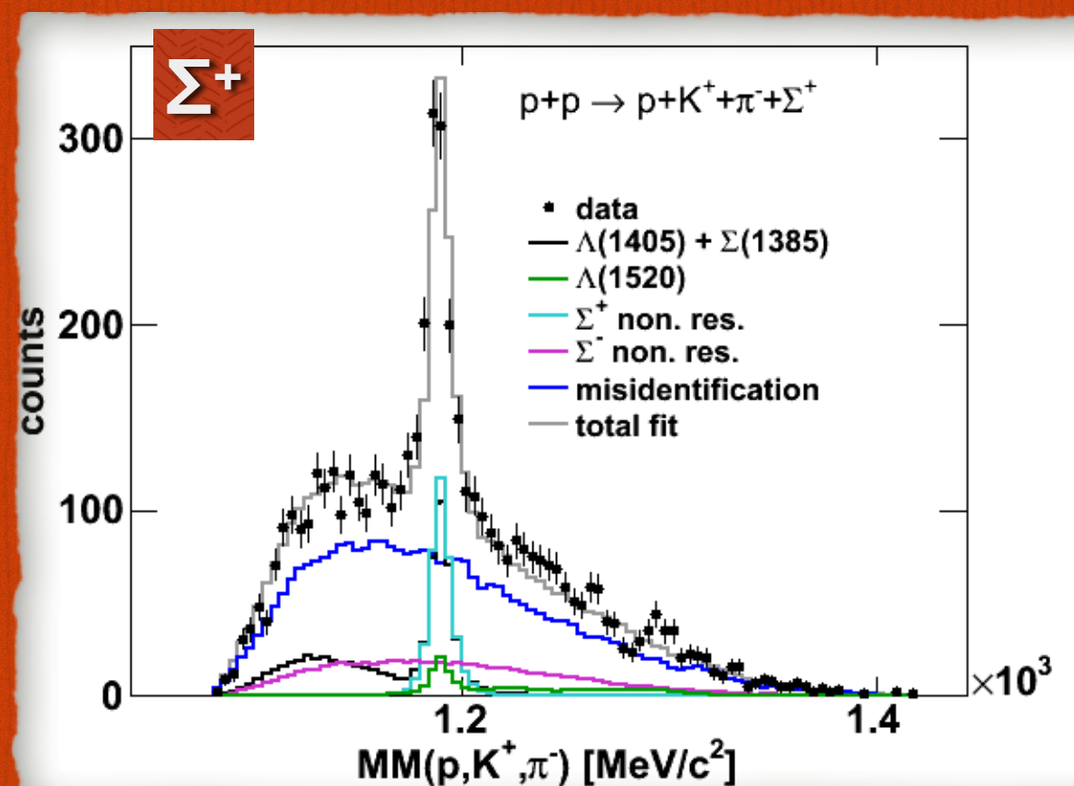

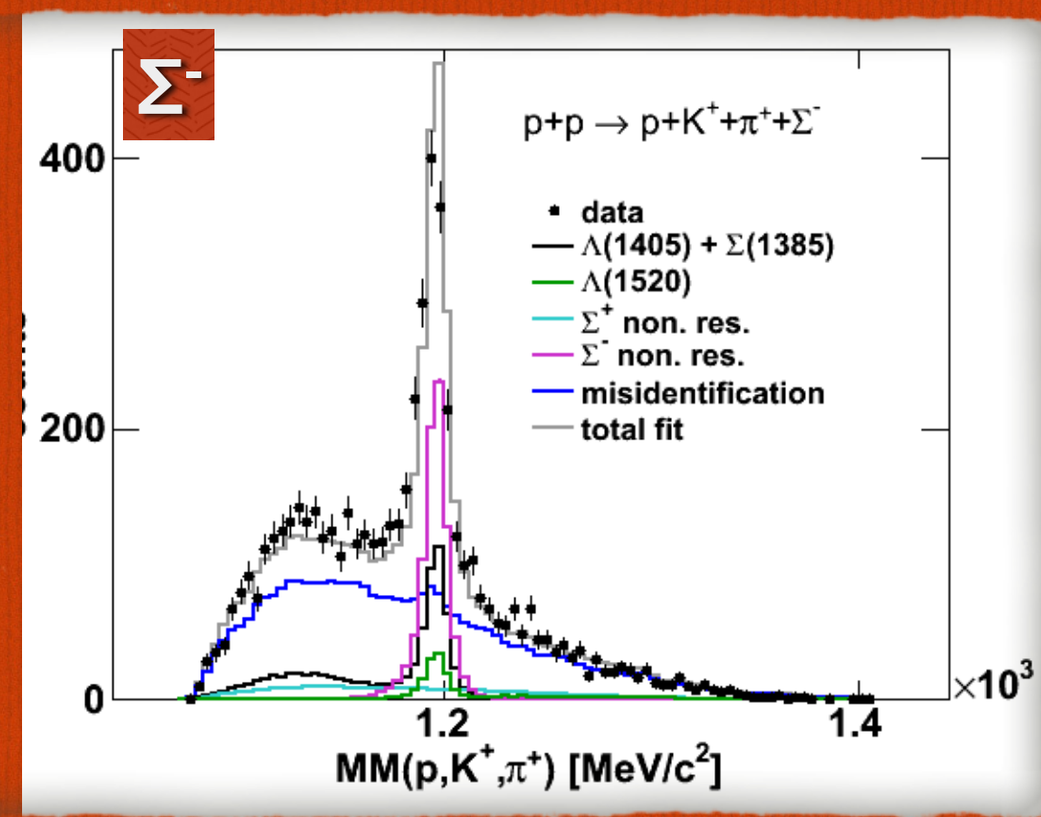

Our Special Resonance

J. Siebenson, E. Epple

Efficiency and Acceptance Corrected data

Channel	Cross section
$p+p \rightarrow \Lambda(1405)+p+K^+$	$9.2 \pm 0.9 \pm 0.7^{+3.3}_{-1.0}$ μb
$p+p \rightarrow \Sigma(1385)^0+p+K^+$	$5.6 \pm 0.5^{+2.0}_{-1.1}$ μb
$p+p \rightarrow \Lambda(1520)+p+K^+$	$5.6 \pm 1.1 \pm 0.4^{+1.1}_{-1.6}$ μb
$p+p \rightarrow \Sigma^-+\Delta^{++}(1232)+K^+$	$7.7 \pm 0.9 \pm 0.5^{+0.3}_{-0.9}$ μb
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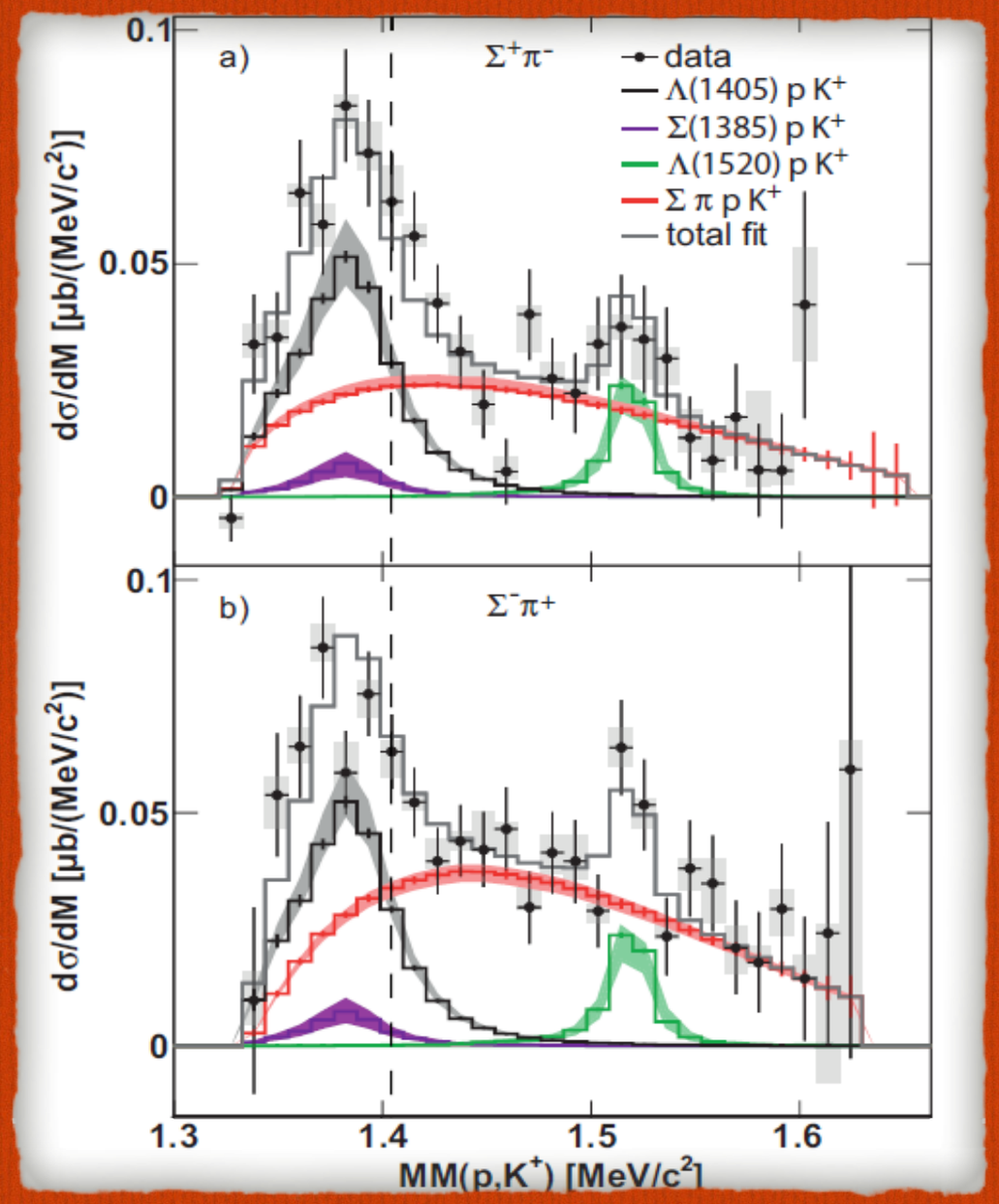
Phys. Rev. C 87, 025201 (2013)



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3.5 GeV

$$p + p \rightarrow \Lambda(1405) + K^+ + p$$

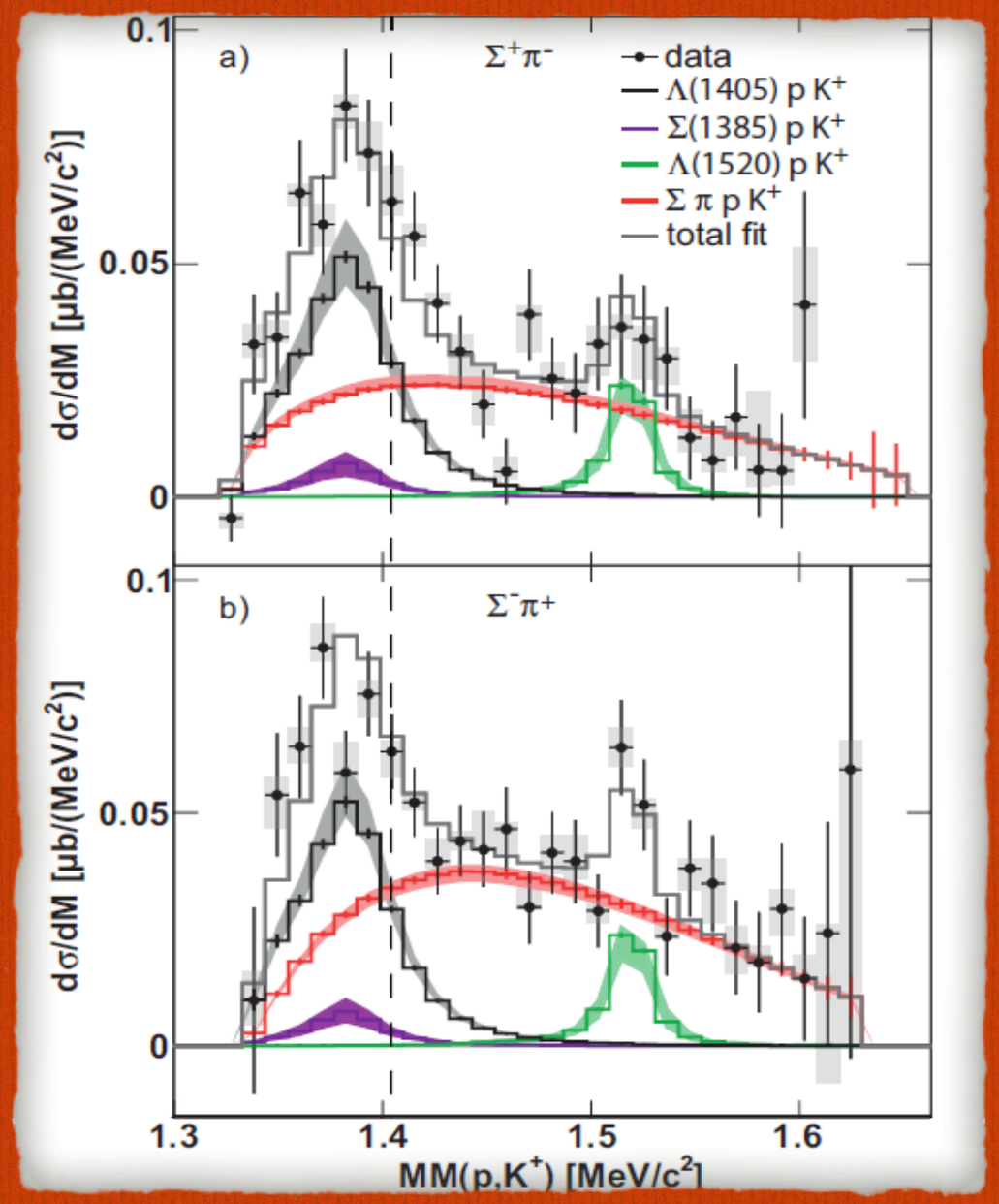
$$\searrow$$

$$\Sigma^\pm + \pi^\mp$$

$$\searrow$$

$$\pi^\pm + n$$

Phys. Rev. C 87, 025201 (2013)



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3.5 GeV

$$p + p \rightarrow \Lambda(1405) + K^+ + p$$

$$\searrow$$

$$\Sigma^{\pm} + \pi^{\mp}$$

$$\searrow$$

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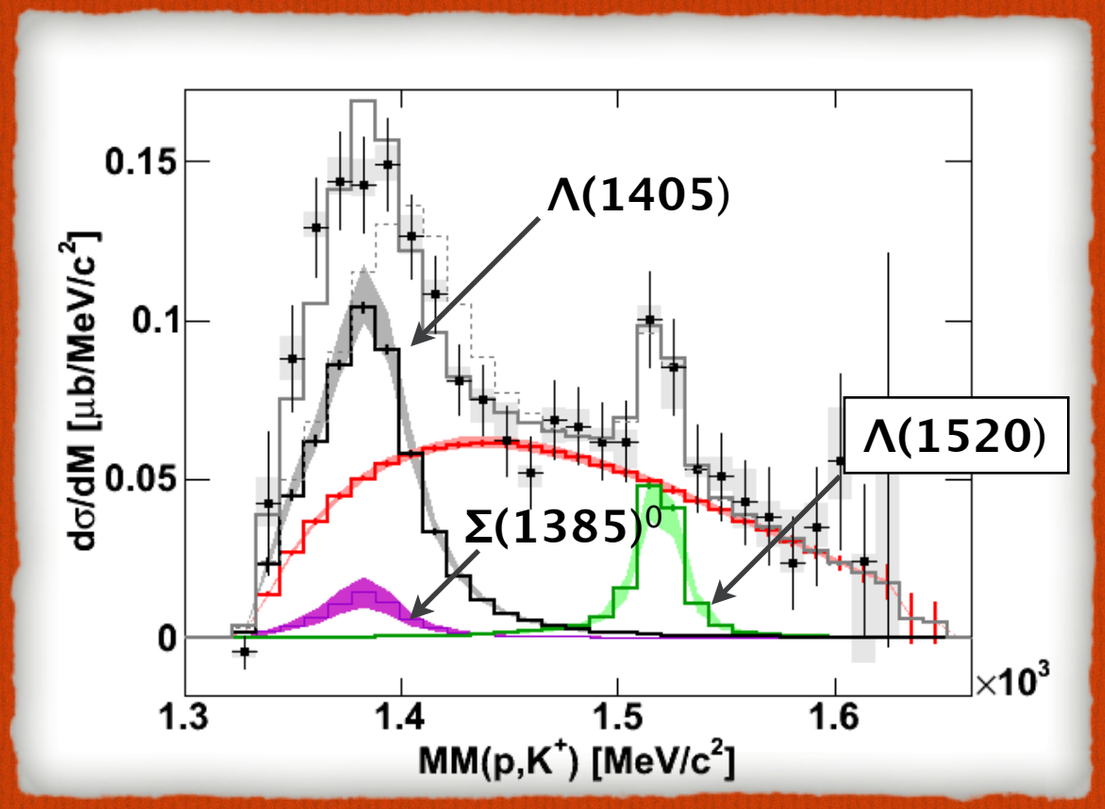
$$\searrow$$

$$\Sigma^{\pm} + \pi^{\mp}$$

$$\searrow$$

$$\pi^{\pm} + n$$

G. Agakishiev et al. [HADES] Phys. Rev. C 87 (2013) 025201.
G. Agakishiev et al. [HADES] Nucl. Phys. A 881 (2012) 178–186.



Our Special Resonance

J. Siebenson, E. Epple

Efficiency and Acceptance Corrected data

Channel	Cross section
p+p → Λ(1405)+p+K⁺	$9.2 \pm 0.9 \pm 0.7^{+3.3}_{-1.0}$ μb
p+p → Σ(1385)⁰+p+K⁺	$5.6 \pm 0.5^{+2.0}_{-1.1}$ μb
p+p → Λ(1520)+p+K⁺	$5.6 \pm 1.1 \pm 0.4^{+1.1}_{-1.6}$ μb
p+p → Σ⁻+Δ⁺⁺(1232)+K⁺	$7.7 \pm 0.9 \pm 0.5^{+0.3}_{-0.9}$ μb
p+p → Σ⁺+π⁻+p+K⁺	$5.4 \pm 0.5 \pm 0.4^{+1.0}_{-2.1}$ μb

3.5 GeV

$$p + p \rightarrow \Lambda(1405) + K^+ + p$$

$$\searrow$$

$$\Sigma^{\pm} + \pi^{\mp}$$

$$\searrow$$

$$\pi^{\pm} + n$$

G. Agakishiev et al. [HADES] Phys. Rev. C 87 (2013) 025201.
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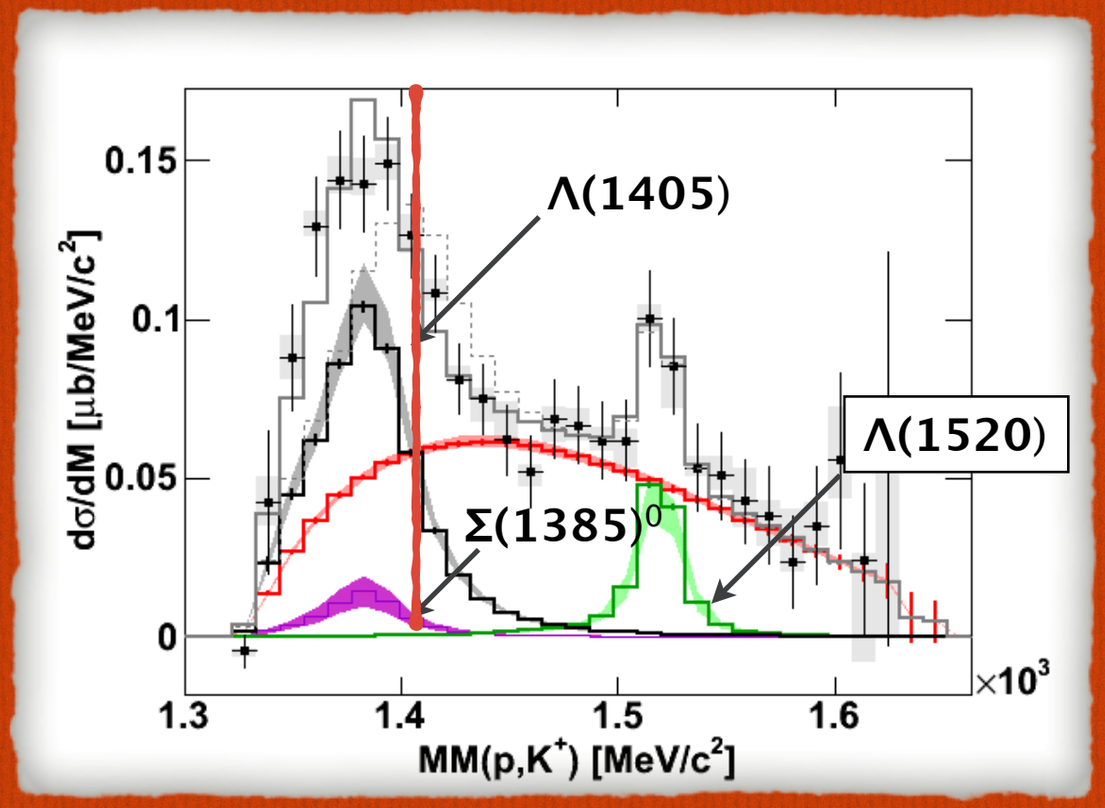

Our Special Resonance

J. Siebenson, E. Epple

$$\Lambda(1405): \; M = 1405\, MeV/c^2 (?)\, \Gamma = 50\, MeV/c^2 \; (B = 1,\; S = -1\; J^P = 1/2^-)$$

3.5 GeV

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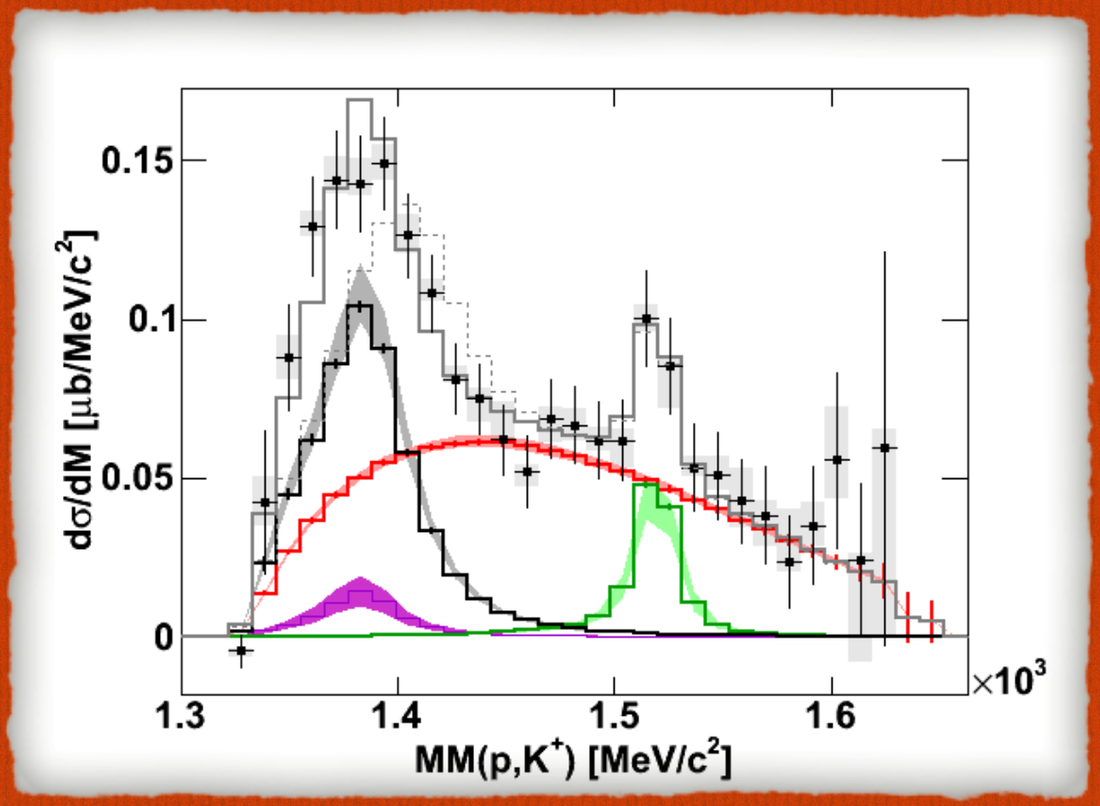

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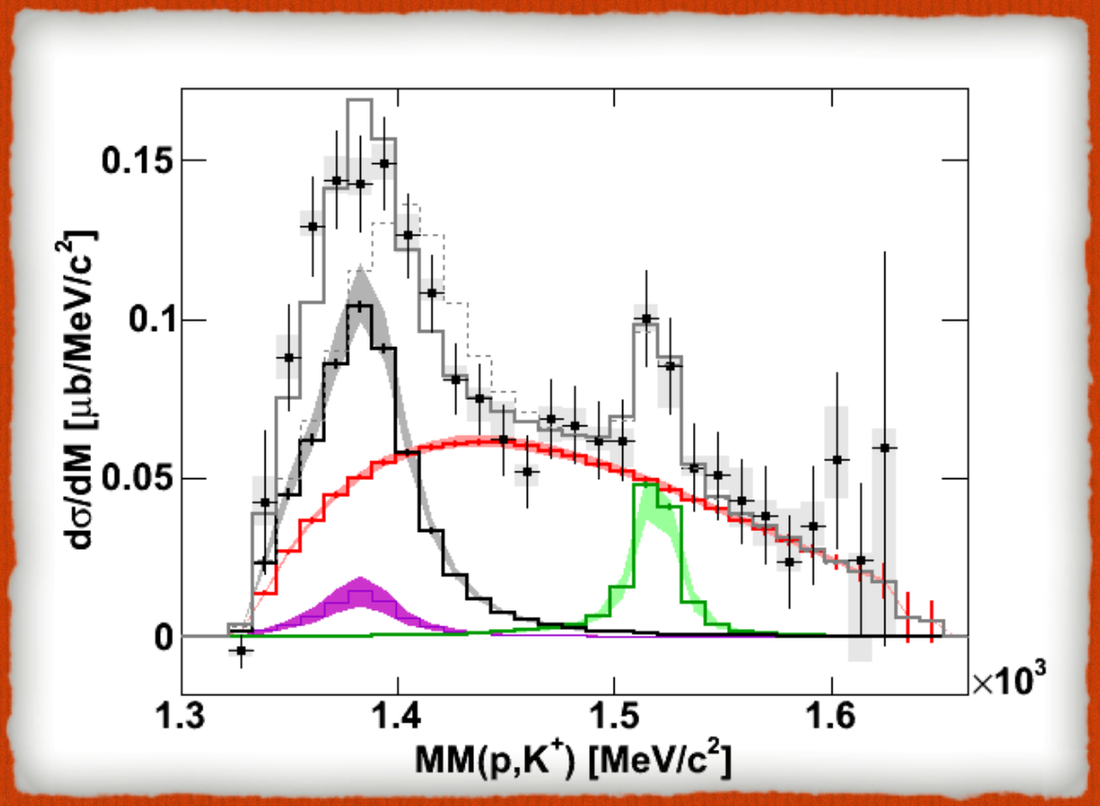
$$p + p \xrightarrow{3.5\,\text{GeV}} \Lambda(1405) + K^+ + p$$

$$\searrow \Sigma^\pm + \pi^\mp$$

$$\searrow \pi^\pm + n$$



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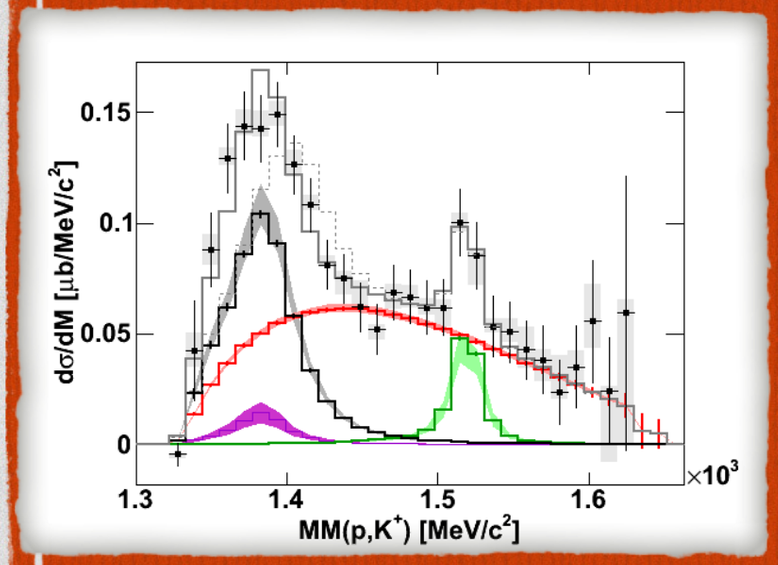

3.5 GeV

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$$\Sigma^{\pm} + \pi^{\mp}$$

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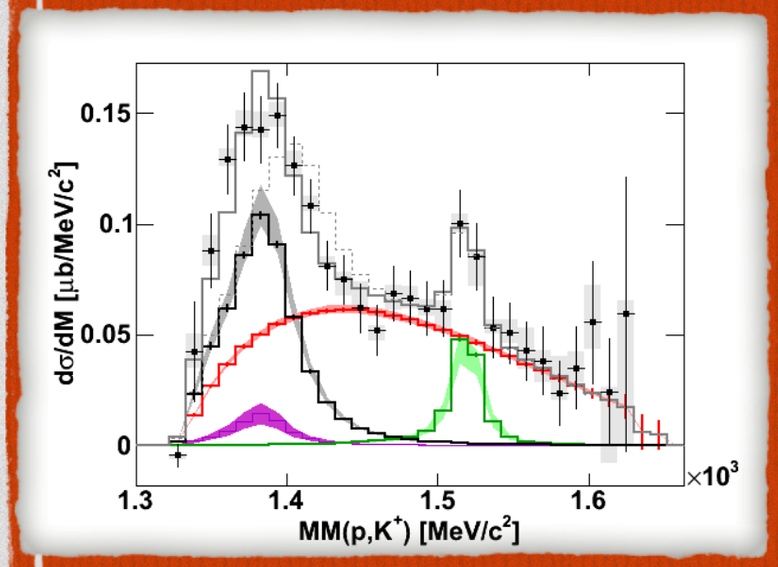
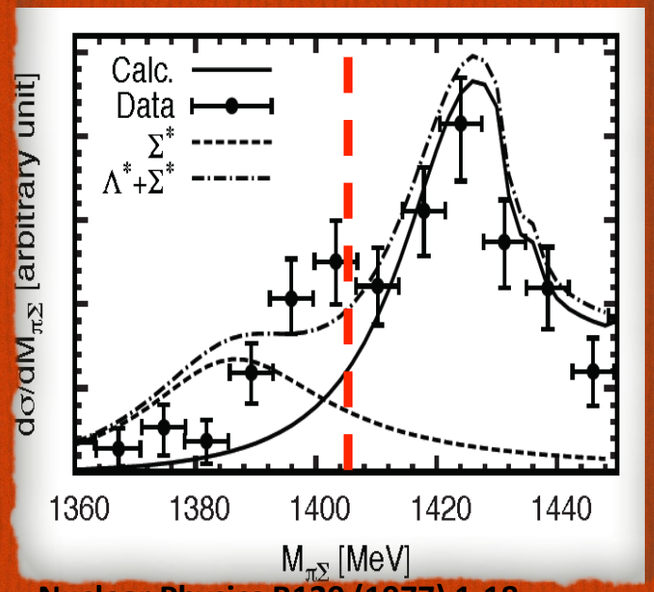


K⁻+d 0. 68 – 0.84 GeV/c



Nuclear Physics B129 (1977) 1-18

3.5 GeV

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Our Special Resonance

J. Siebenson, E. Epple

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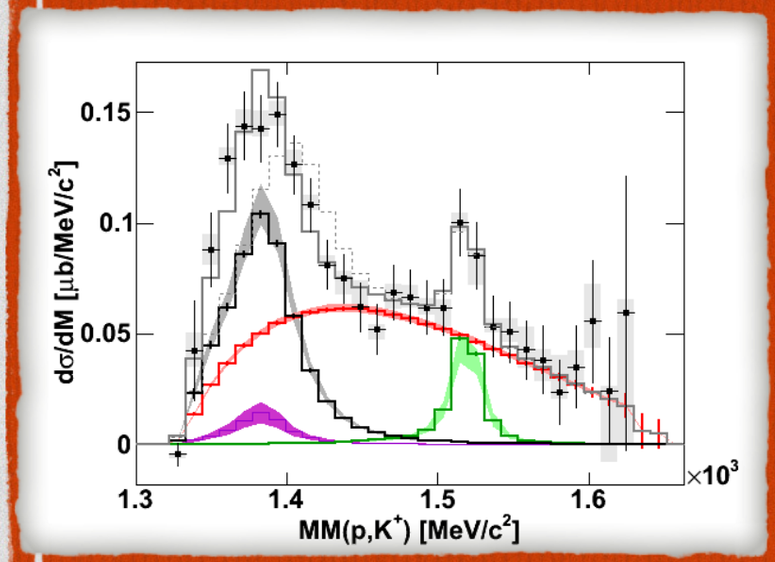

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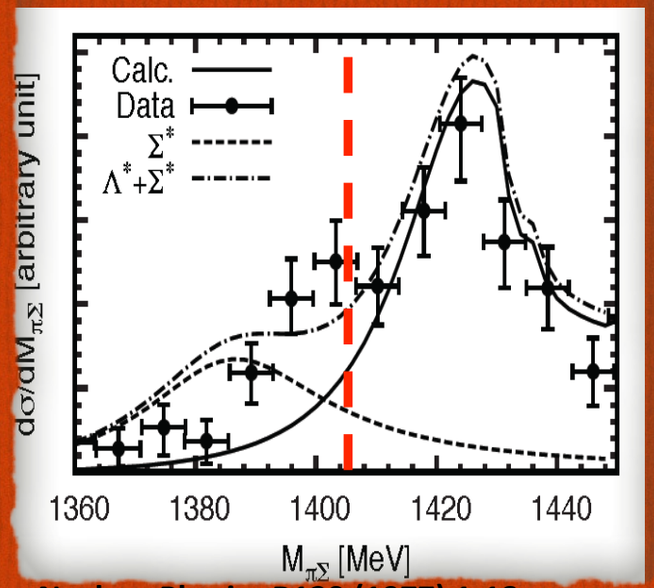
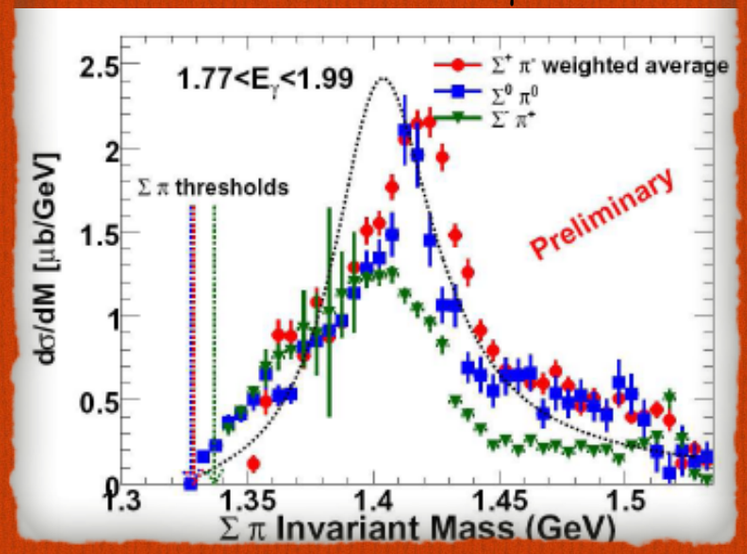


Nuclear Physics B129 (1977) 1-18

γ+p 1.77<p_γ<1.99



Nucl.Phys. A835 (2010) 325-328

3.5 GeV

$$p + p \rightarrow \Lambda(1405) + K^+ + p$$

$$\searrow$$

$$\Sigma^\pm + \pi^\mp$$

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Our Special Resonance

J. Siebenson, E. Epple

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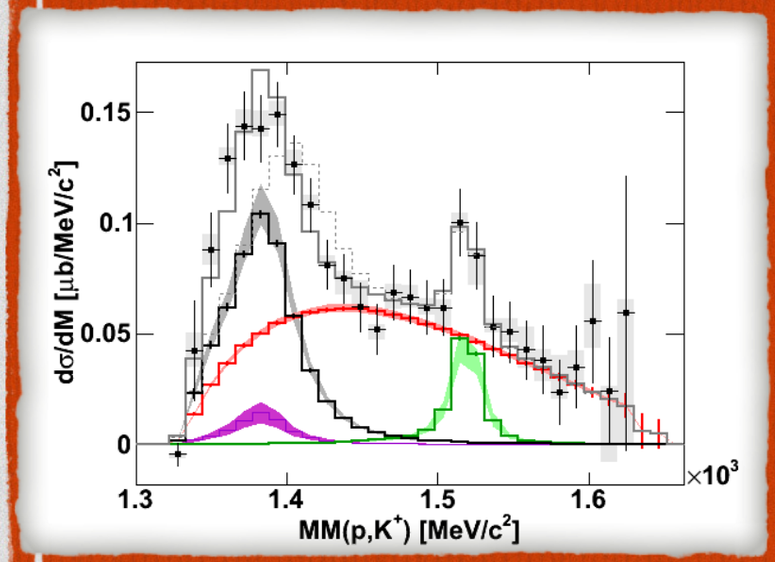

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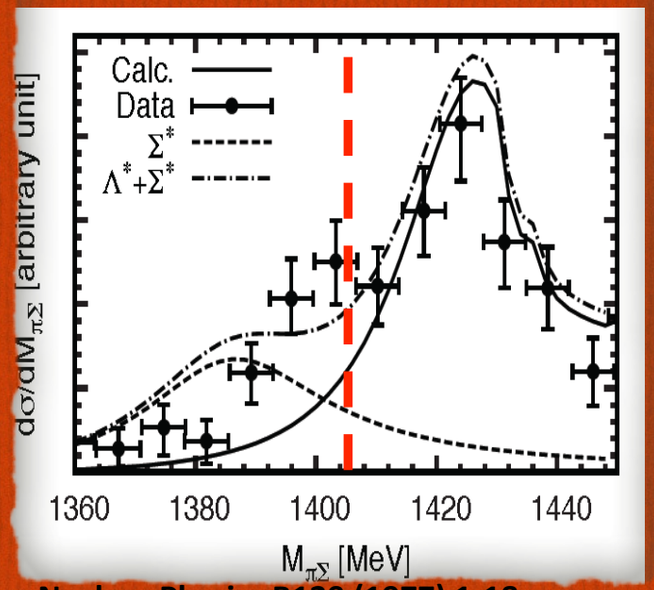

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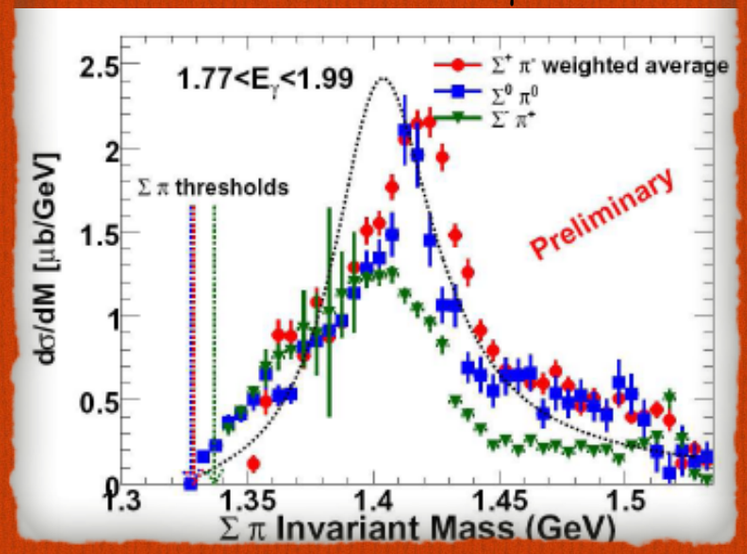

Nucl.Phys. A835 (2010) 325-328

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The spectral shape of the Λ(1405) looks different for different initial state reactions.

p+p and π+p reactions look similar
Different coupling of the 2 poles??

Our Special Resonance

J. Siebenson, E. Epple

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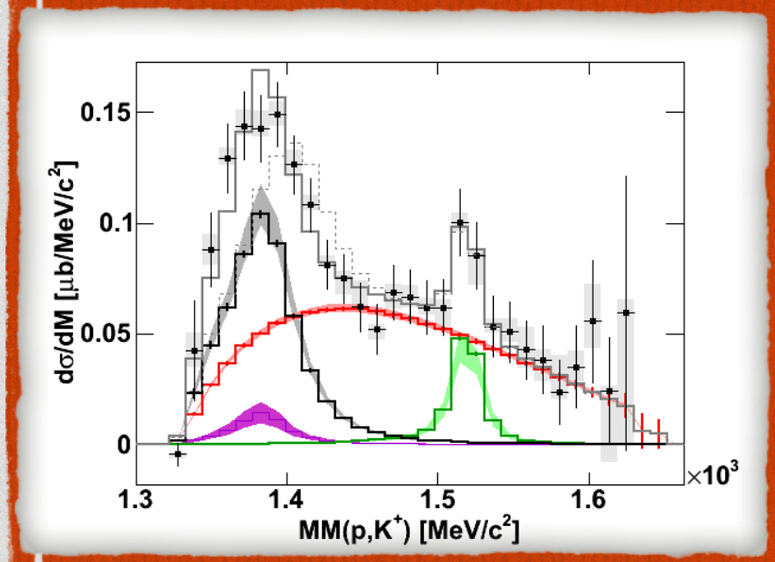

Nucl.Phys. B56 (1973) 46-51, Phys.Rev.Lett. 15 (1965) 224

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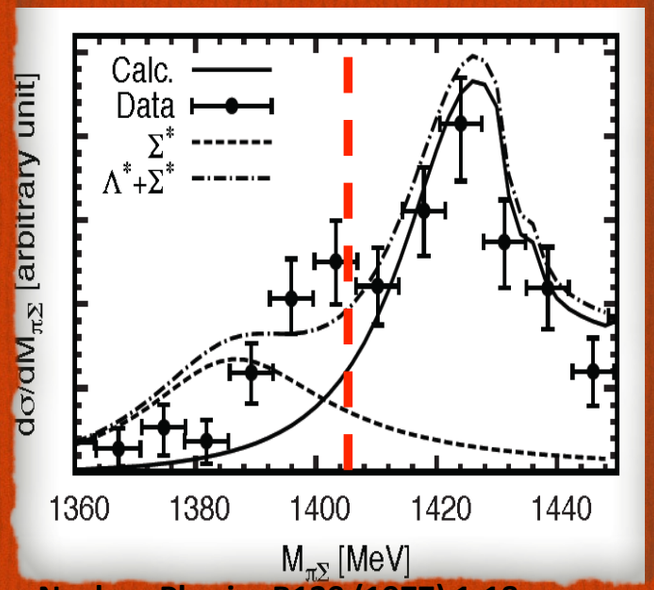

Nuclear Physics B129 (1977) 1-18

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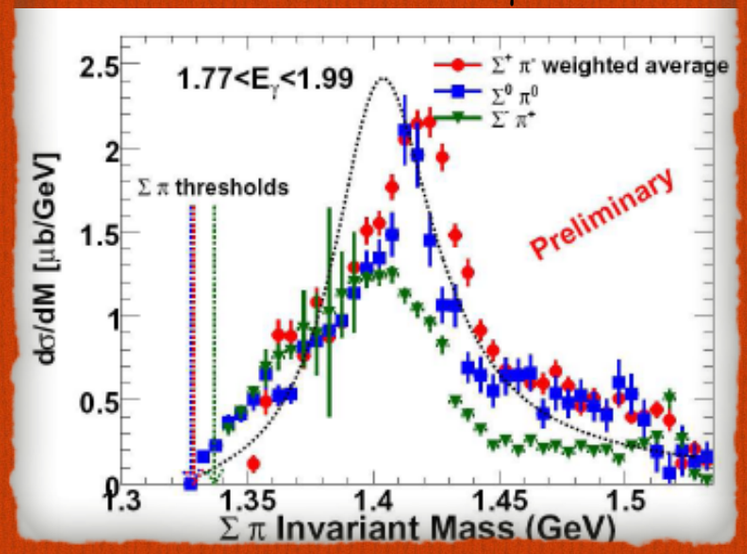
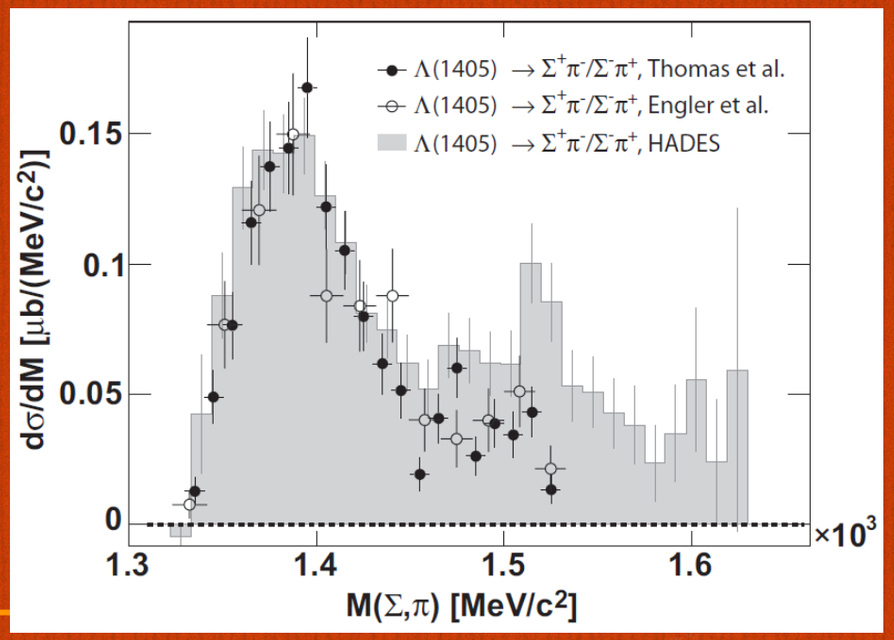


Nucl.Phys. A835 (2010) 325-328



p

The spectral shape of the Λ(1405) looks different for different initial state reactions.

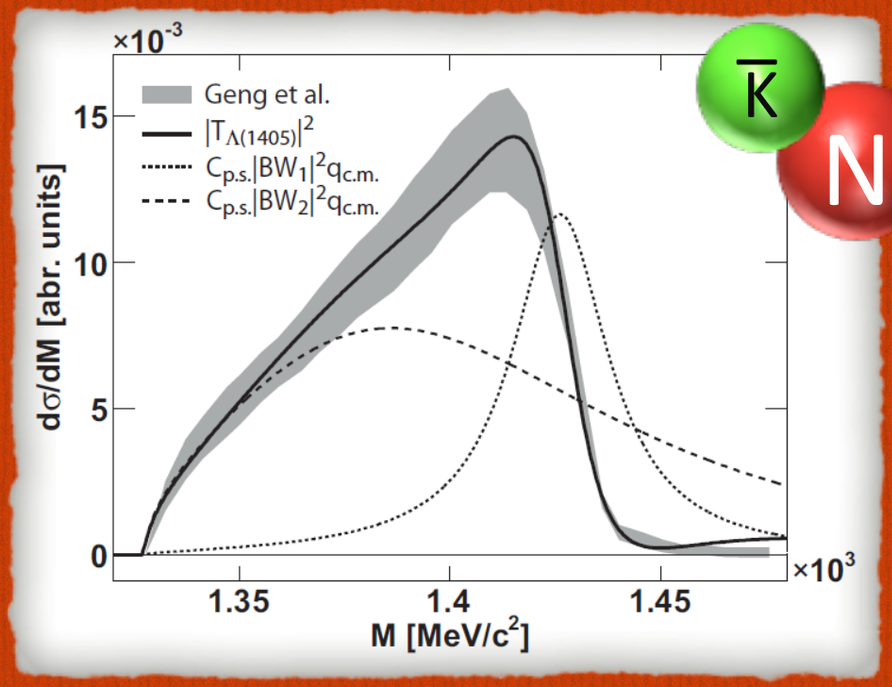
p+p and π+p reactions look similar

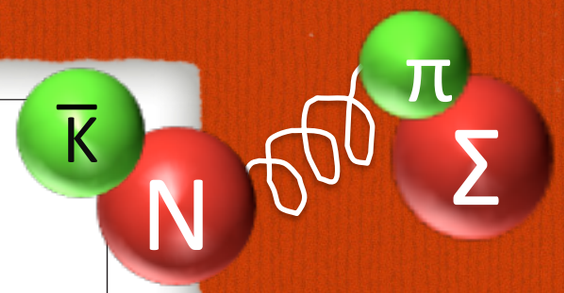
Different coupling of the 2 poles??

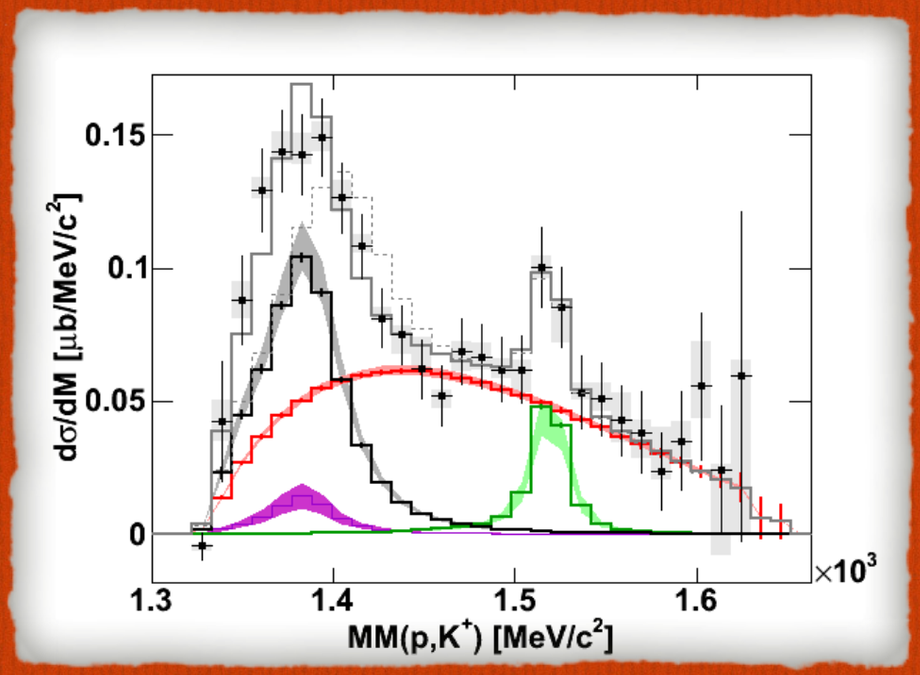
Our Special Resonance

J. Siebenson

Chiral Ansatz







Nucl.Phys. A881 (2012) 98-114

$m_{0,1}=Re(z_1)=1424^{+7}_{-23}$ MeV
$\Gamma_{0,1}=2*Im(z_1)=52^{+6}_{-28}$ MeV
$m_{0,2}=Re(z_2)=1381^{+18}_{-6}$ MeV
$\Gamma_{0,2}=2*Im(z_2)162^{+38}_{-16}$ MeV

Two poles combined such to reproduce the calculation for p+p

- S.F. for the Σ0π0 decay
- lower energy than for HADES

Calculation does not match the HADES data

Nucl.Phys. A881 (2012) 98-114

Our Special Resonance

J. Siebenson

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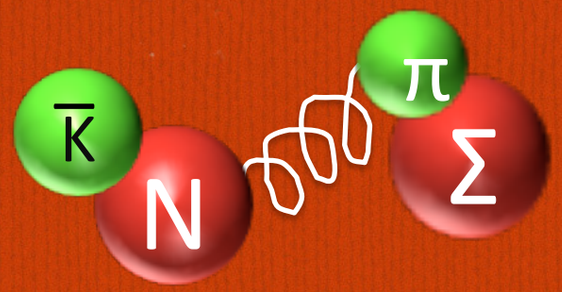

Fit to the data leaving the coupling of the two poles free and also width and mass within the error -> Broader Kp pole and larger amplitude for Σπ

Our Special Resonance

J. Siebenson

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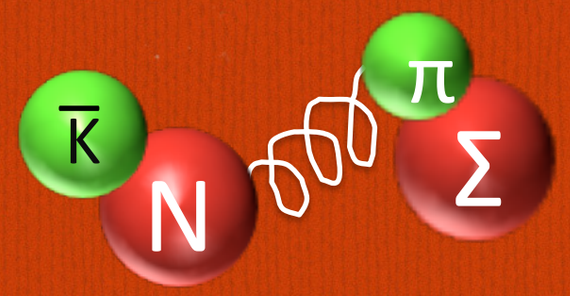

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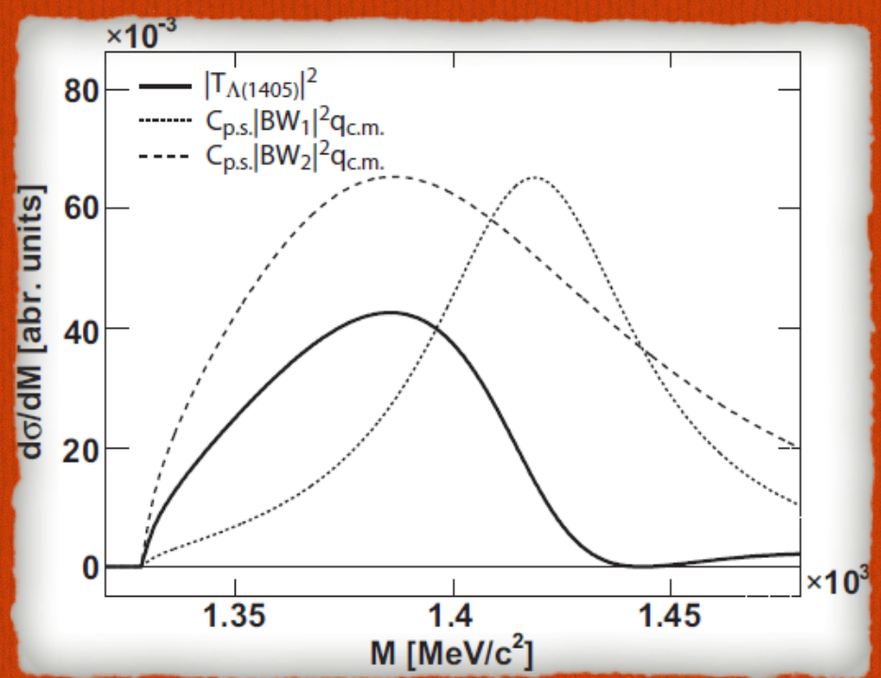
Our Ansatz



Our Special Resonance

J. Siebenson

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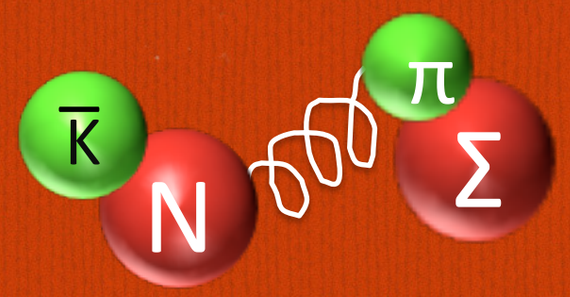
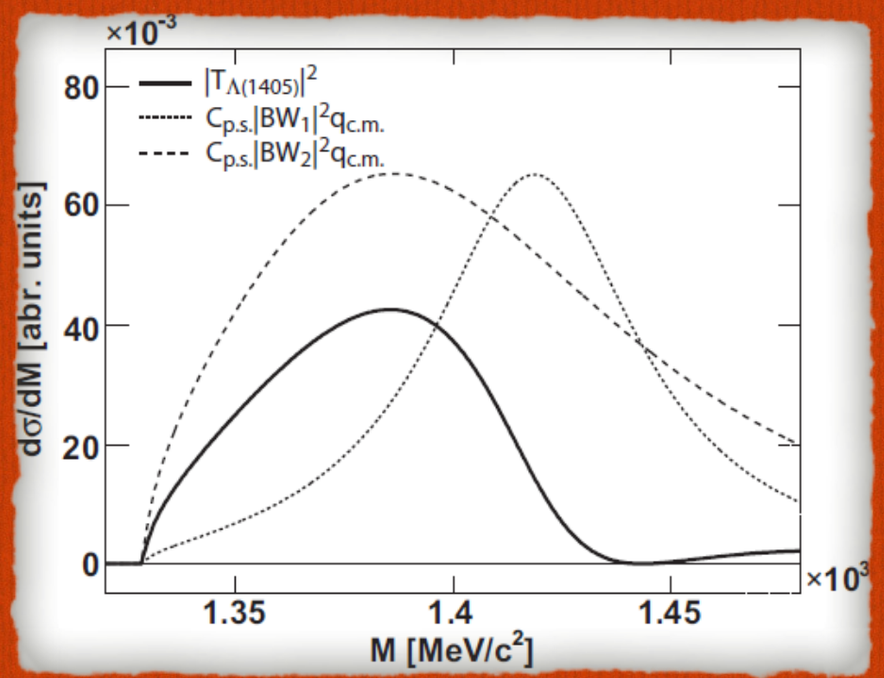
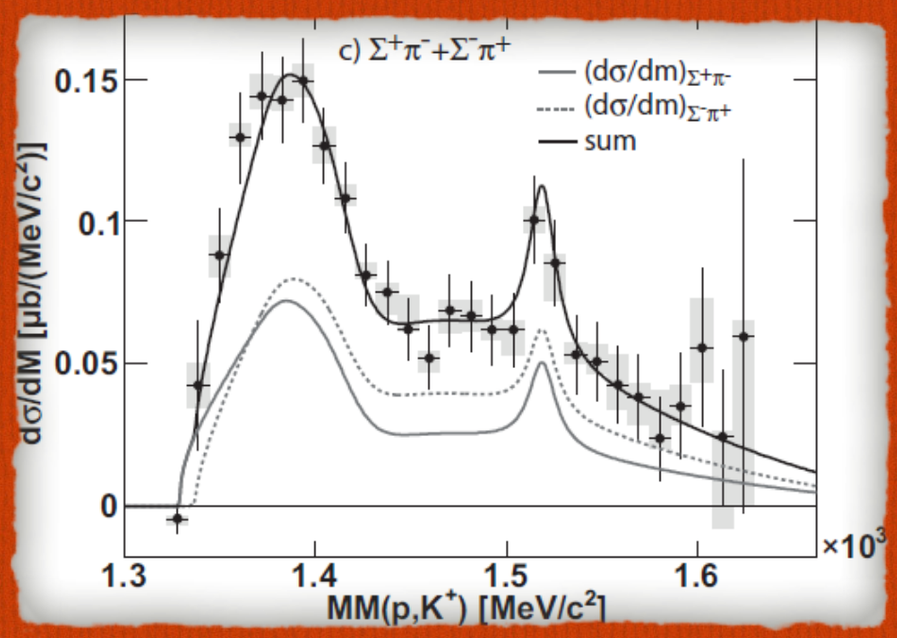


Fit to the data leaving the coupling of the two poles free and also width and mass within the error -> Broader Kp pole and larger amplitude for $\Sigma\pi$

Our Ansatz

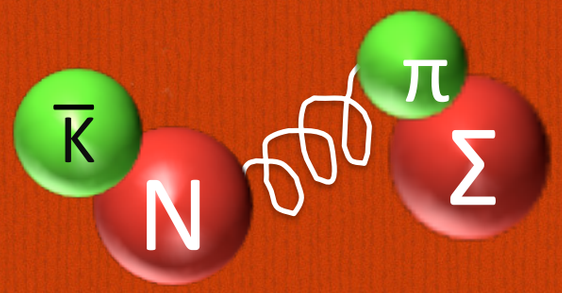


J. Siebenson, L. Fabbietti, Phys. Rev. C 88 (2013) 055201.



Our Special Resonance

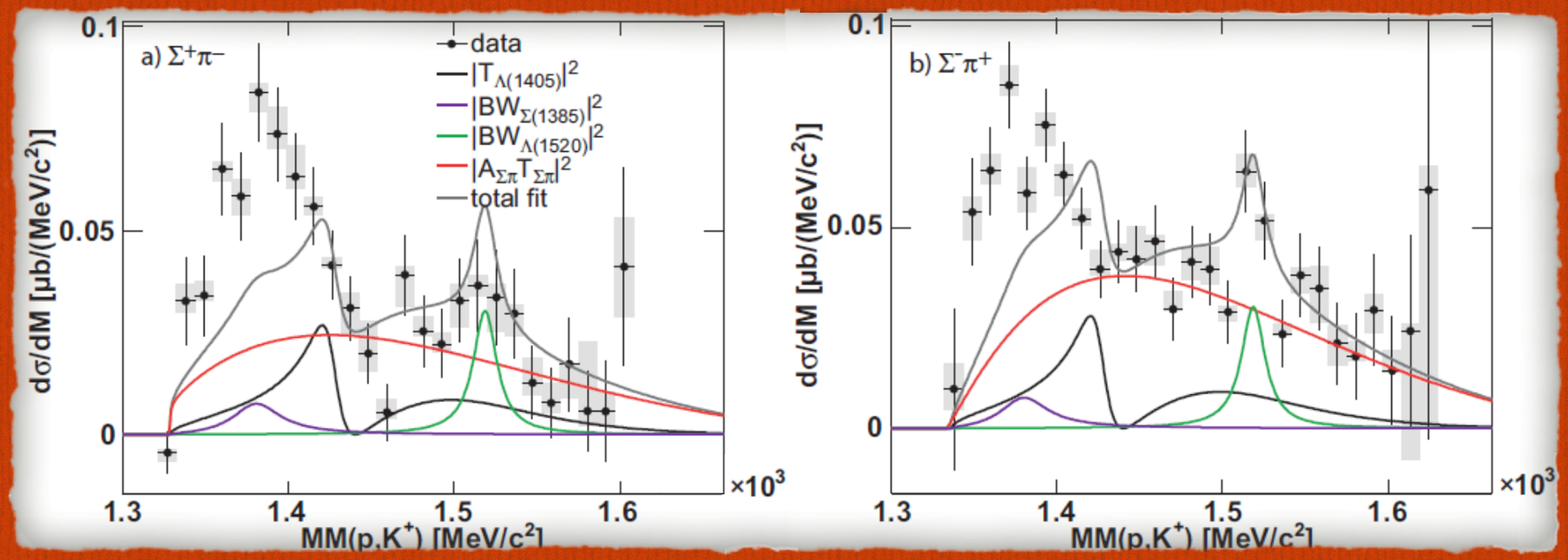
J. Siebenson



Nucl.Phys. A900 (2013) 51 - 64

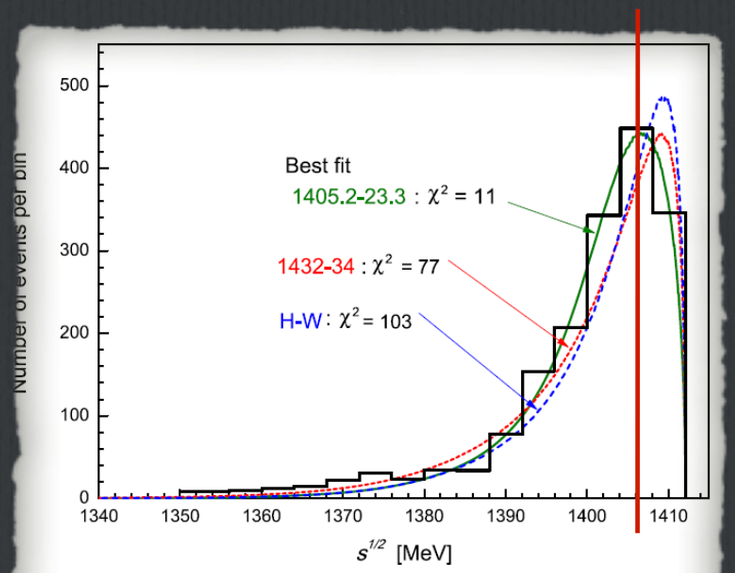
$m_{0,1}=Re(z_1)=1428^{+2}_{-1}$ MeV
$\Gamma_{0,1}=2*Im(z_1)=16^{+4}_{-4}$ MeV
$m_{0,2}=Re(z_2)=1497^{+11}_{-7}$ MeV
$\Gamma_{0,2}=2*Im(z_2)150^{+18}_{-18}$ MeV

Assuming these two poles the data cannot be reproduced even if advocating interferences with the non resonant part



K- ^{4}He

D. Riley et al., Phys. Rev. D 11(1975) 3065
Esmaili et al., Phys. Lett B686 (2010) 23-28



g. 6. Detailed differences in $M_{\Sigma\pi}$ spectra among the Hyodo–Weise prediction and e present model predictions.

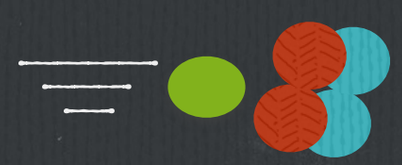
Previous data <u>at rest</u> with $\pi\Sigma$ mass below the kinematical limit

Theoretical interpretation of the $\Lambda(1405)$ as a pure K^-p pole

-> Data for <u>in-flight</u> processes have access to the high mass region

K_{mom}~ 100 MeB -> $M_{\pi\Sigma}$ up to 1425 MeV/c^2

K- ^{4}He



$$K^- +^4 He \rightarrow \Lambda(1405) + X$$

$$\hookrightarrow \Sigma^0 + \pi^0$$

$$\hookrightarrow \Lambda + \gamma + \gamma + \gamma$$

3 γs have to be detected in the calorimeter

K- ^{4}He

D. Riley et al., Phys. Rev. D 11(1975) 3065
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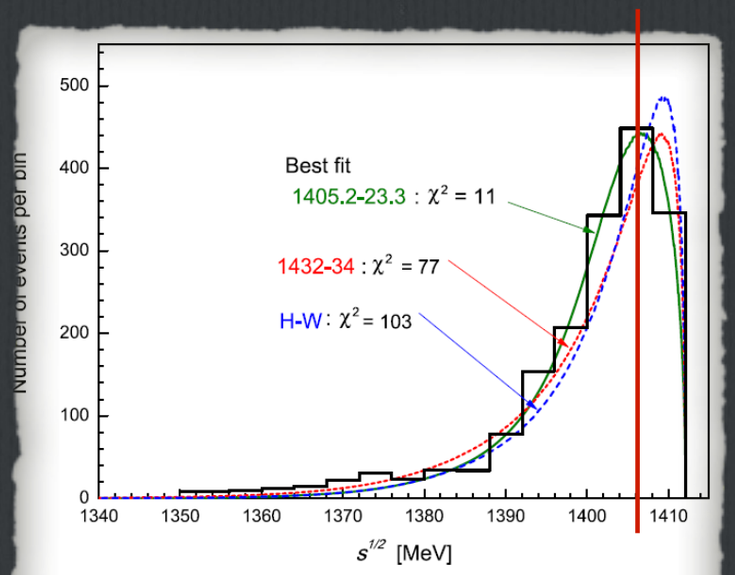

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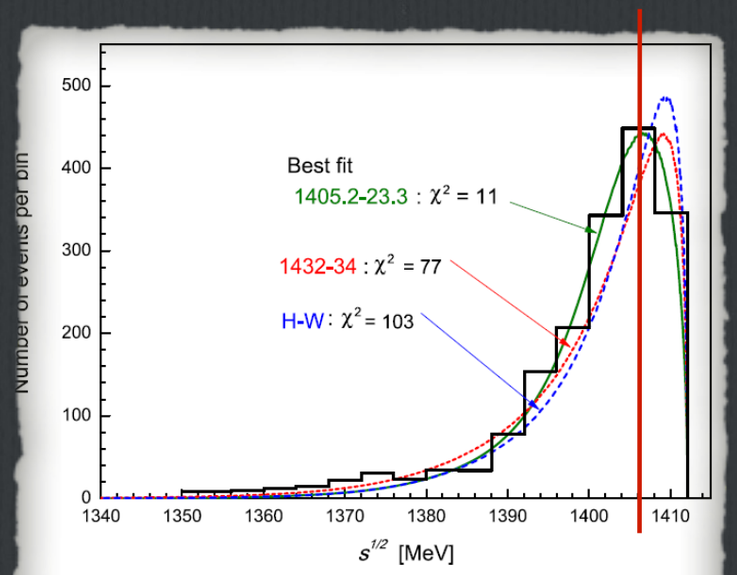

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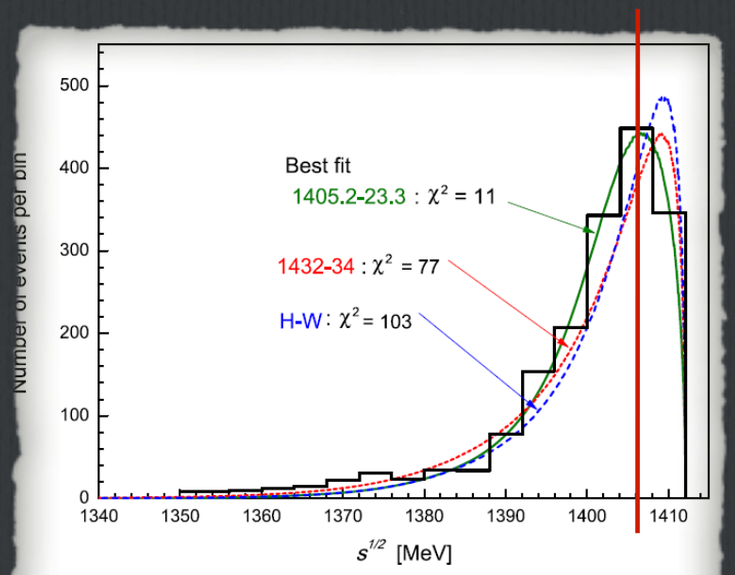

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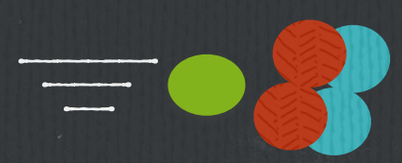
K- ^{4}He



$$K^- +^4 He \rightarrow \Lambda(1405) + X$$
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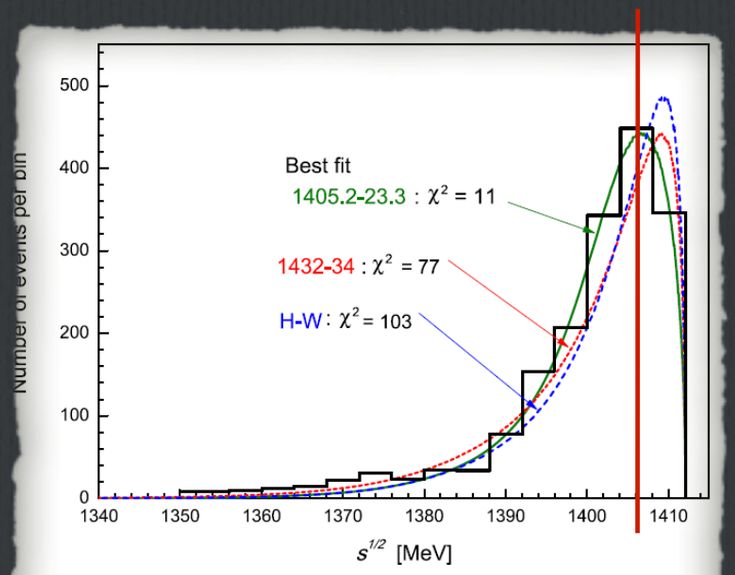
$$\hookrightarrow p + \pi^0$$

2 γs have to be detected in the calorimeter

K- ^{4}He

D. Riley et al., Phys. Rev. D 11(1975) 3065
Esmaili et al., Phys. Lett B686 (2010) 23-28



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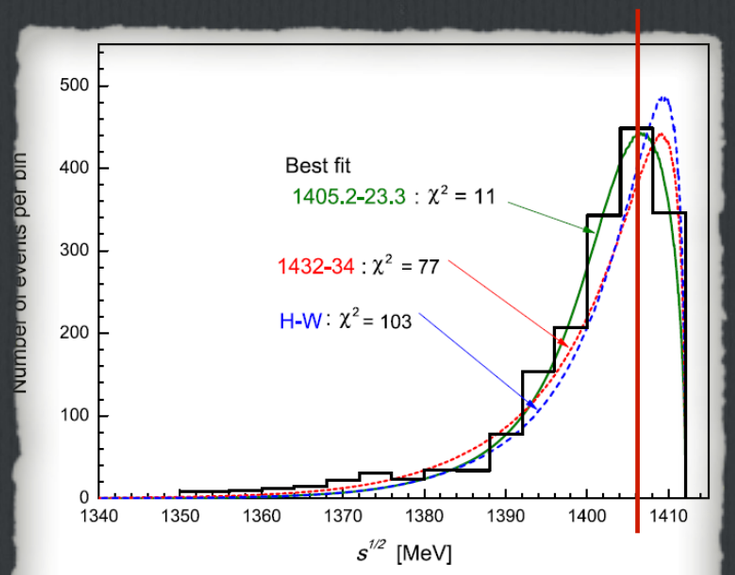
Esmaili et al., Phys. Lett B686 (2010) 23-28



g. 6. Detailed differences in $M_{\Sigma\pi}$ spectra among the Hyodo–Weise prediction and e present model predictions.

Previous data at rest with $\pi\Sigma$ mass below the kinematical limit

Theoretical interpretation of the $\Lambda(1405)$ as a pure K^-p pole

-> Data for in-flight processes have access to the high mass region

K_{mom}~ 100 MeB -> $M_{\pi\Sigma}$ up to 1425 MeV/c^2

$$K^- +^4 He \rightarrow \Lambda(1405) + X$$

$$\hookrightarrow \Sigma^+ + \pi^-$$

$$\hookrightarrow p + \pi^0$$

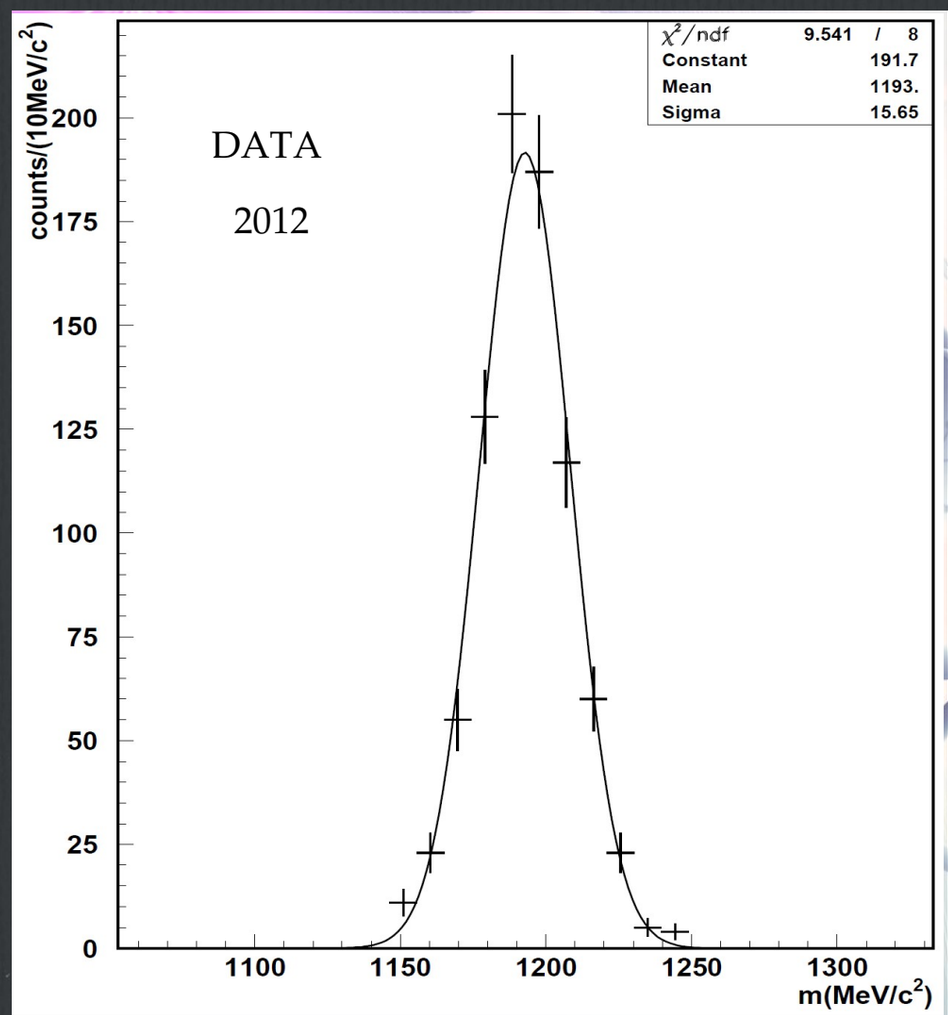
2 γs have to be detected in the calorimeter

Particle Identification in KLOE

C. Curceanu, L. Fabbietti, K. Piscicchia, A. Scordo, I. Tucakovic, O. Vasquez-Doce + KLOE

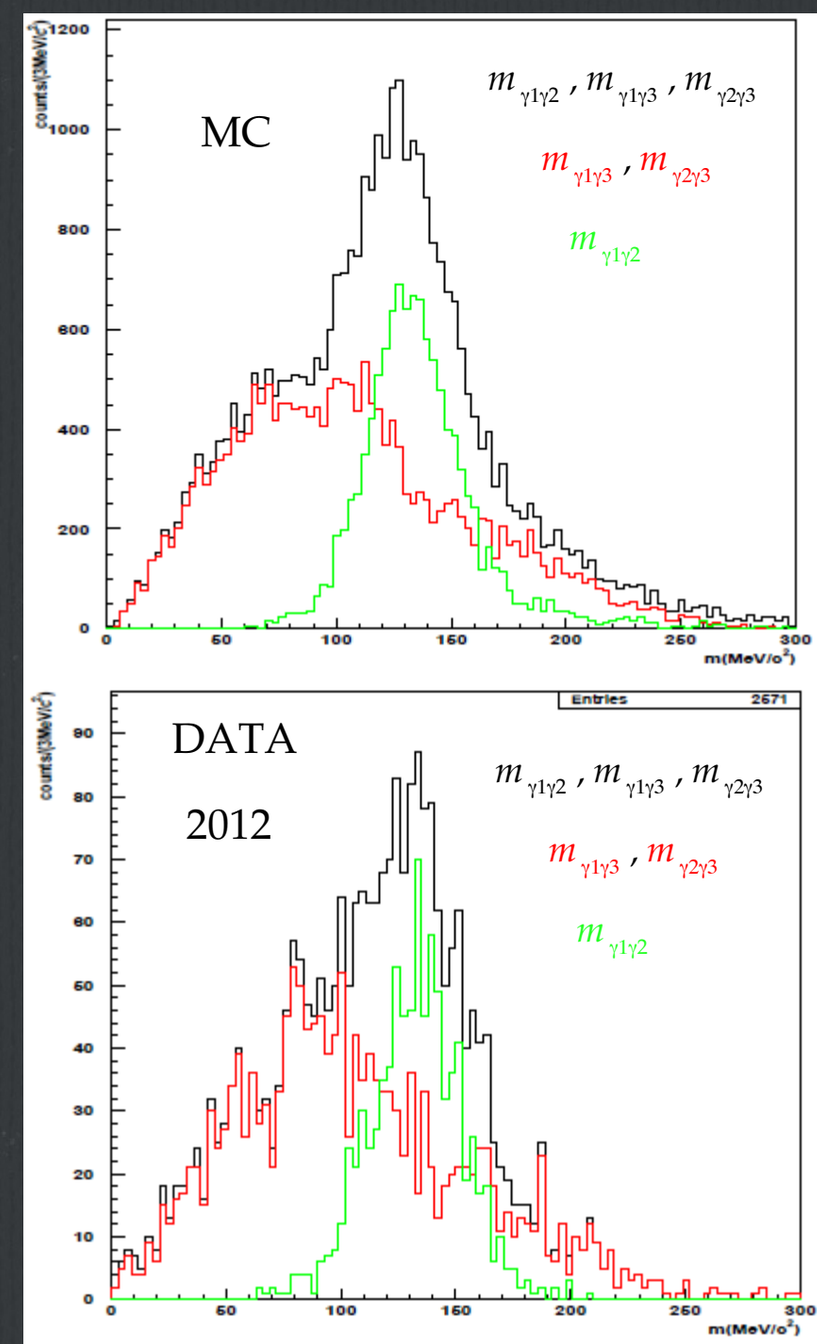
After the Λ selection..

Σ^0



$m_{\Lambda\gamma}$

π^0



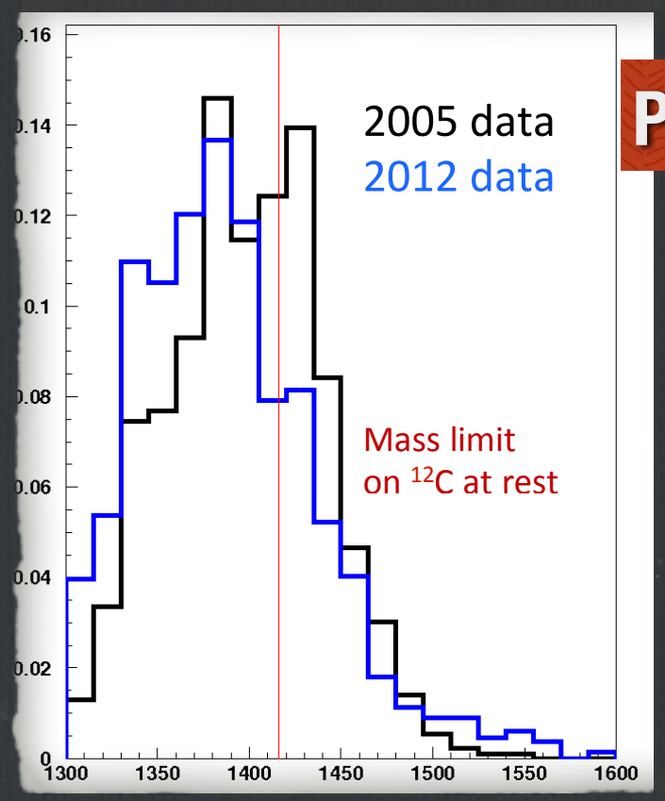
$m_{\gamma\gamma}$

80% efficiency for $\Sigma^0\pi^0$

$\Lambda(1405) \rightarrow \pi^0\Sigma^0$

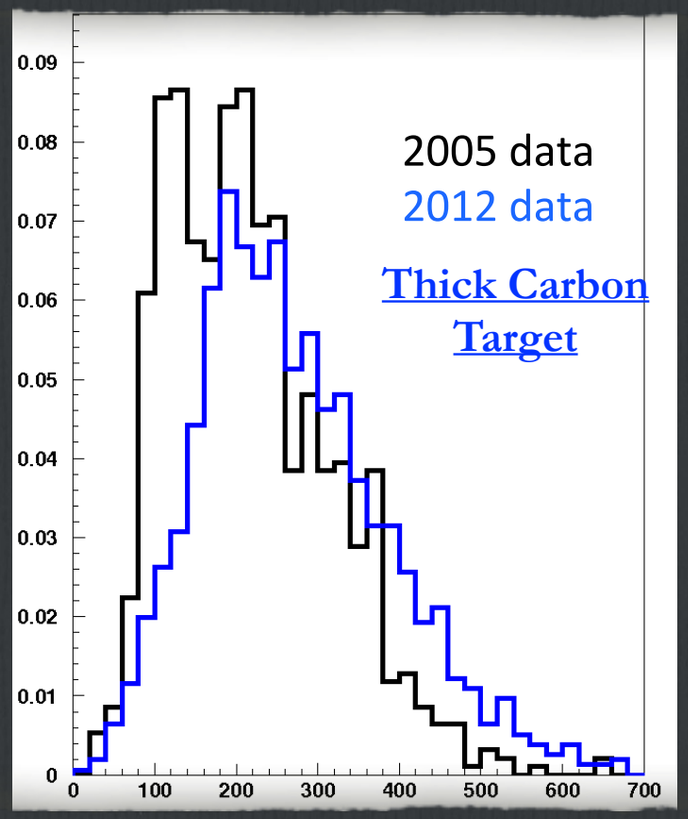
At rest Data
In-flight + at Rest Data
In-flight: larger masses are accessible

a.u.



$m_{\pi^0\Sigma^0}\,(\mathrm{MeV/c^2})$

Preliminary



$p_{\pi^0\Sigma^0}\,(\mathrm{MeV/c})$

Mass resolution $\sigma_m = 32\,\mathrm{MeV/c^2}$

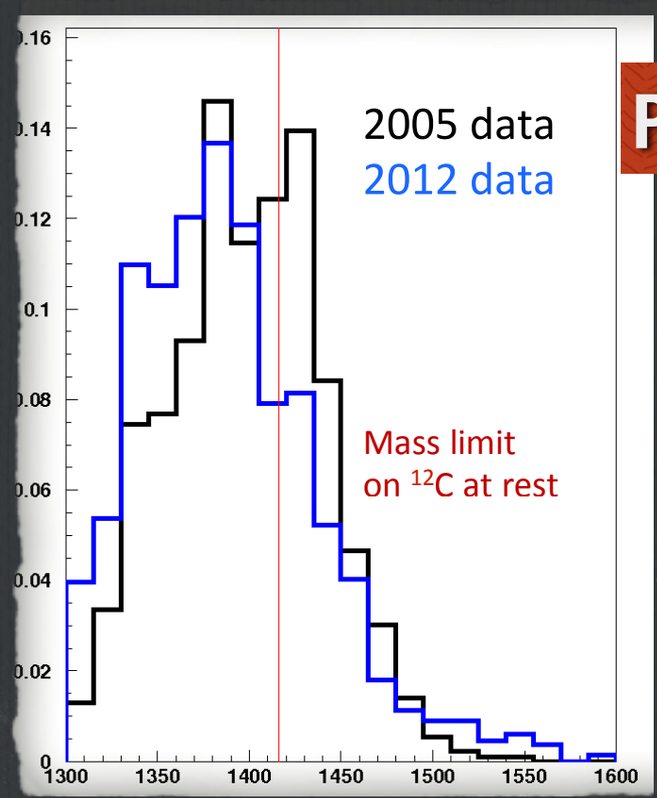
Momentum resolution $\sigma_p = 20\,\mathrm{MeV/c}$

$\Lambda(1405) \rightarrow \pi^0\Sigma^0$

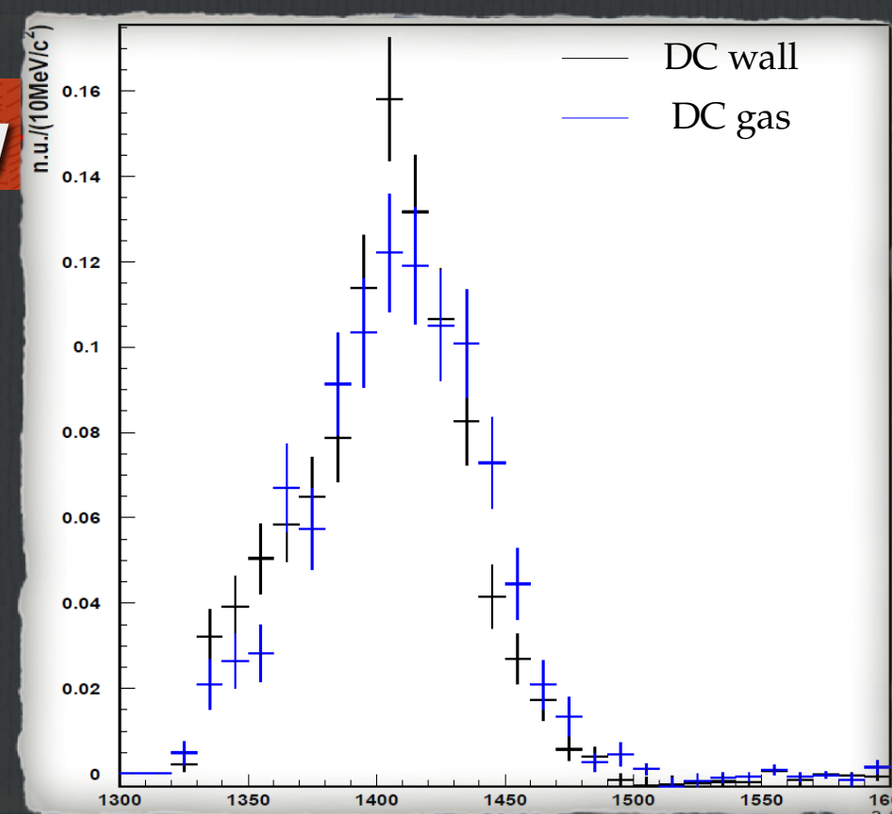
At rest Data
In-flight + at Rest Data
In-flight: larger masses are accessible

Nominal mass for Σ^0 and π^0

a.u.



Preliminary



$m_{\pi^0\Sigma^0}\,(\mathrm{MeV/c^2})$

$m_{\pi^0\Sigma^0}\,(\mathrm{MeV/c^2})$

Mass resolution $\sigma_m = 32\,\mathrm{MeV/c^2}$

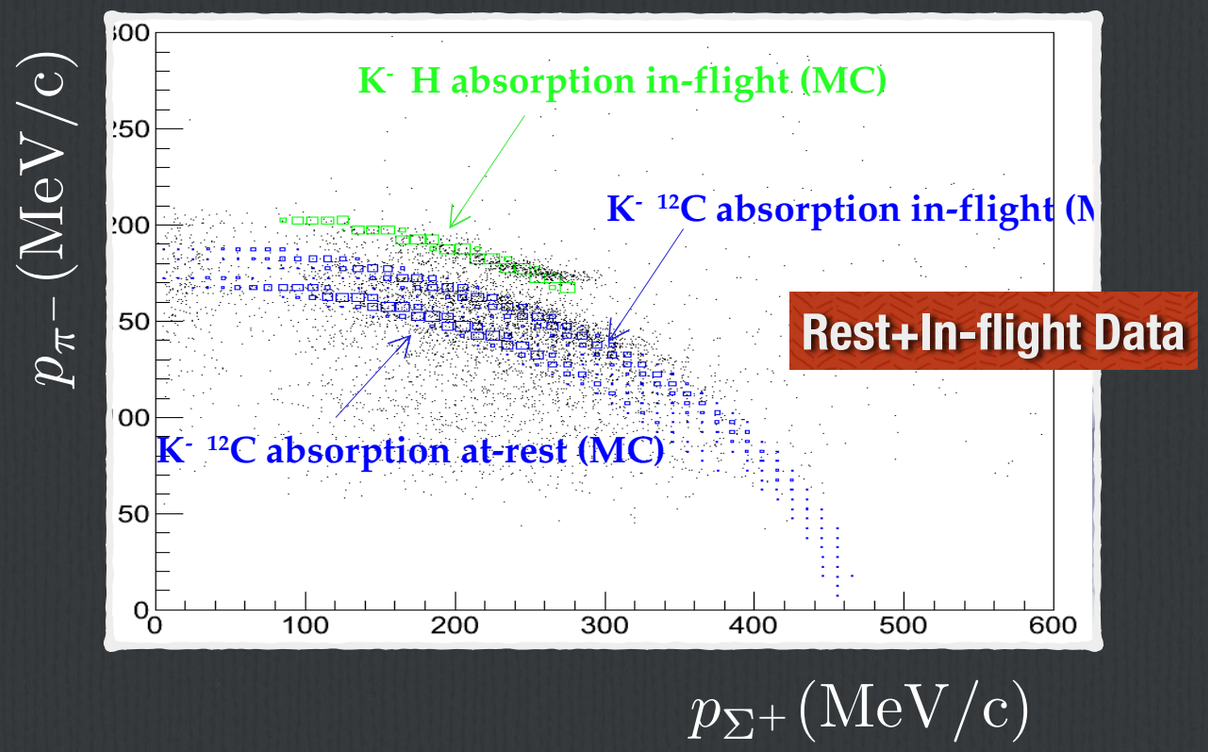
Momentum resolution $\sigma_p = 20\,\mathrm{MeV/c}$

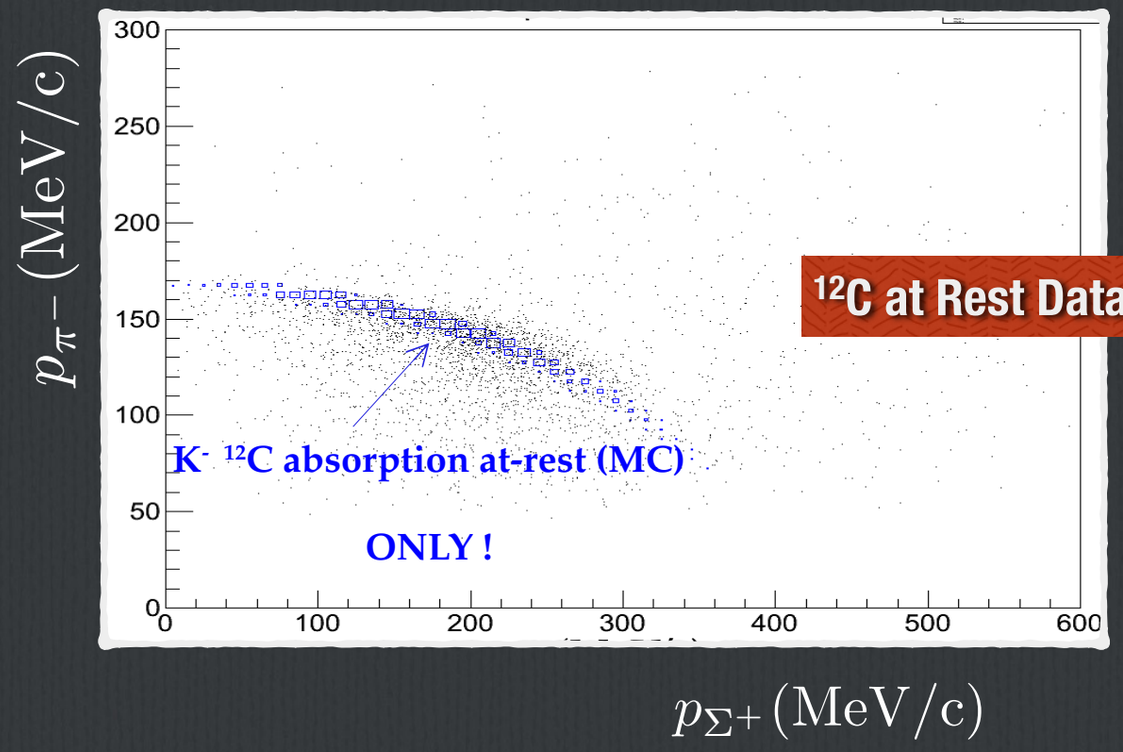
Fit Components

- Resonant component K^- +C/^{4}He at-rest/in-flight (M,Γ)= (1390- 1430, 5-52 MeV/c^2)
- Non resonant $\Sigma^0\pi^0$ K^- +H production in-flight
- Non resonant $\Sigma^0\pi^0$ K^- +C/^{4}H production at-rest/in-flight
- $\Lambda\pi^0$
- misidentification background

$\Sigma^+\pi^-$ Selection: Hydrogen Contamination

$$\Sigma^+\pi^- \rightarrow (p\pi^0)\pi^-$$

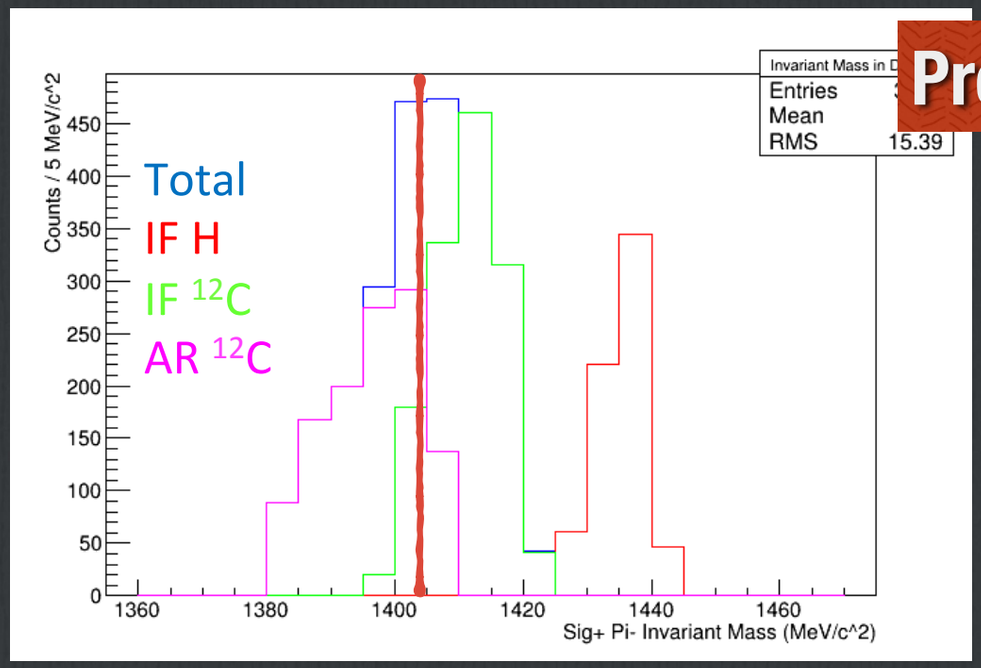




Momentum resolution π^- < 1 MeV

This channel offers a bench mark for the K^-+H contribution

Shifted-Resonance or Quasi-free?



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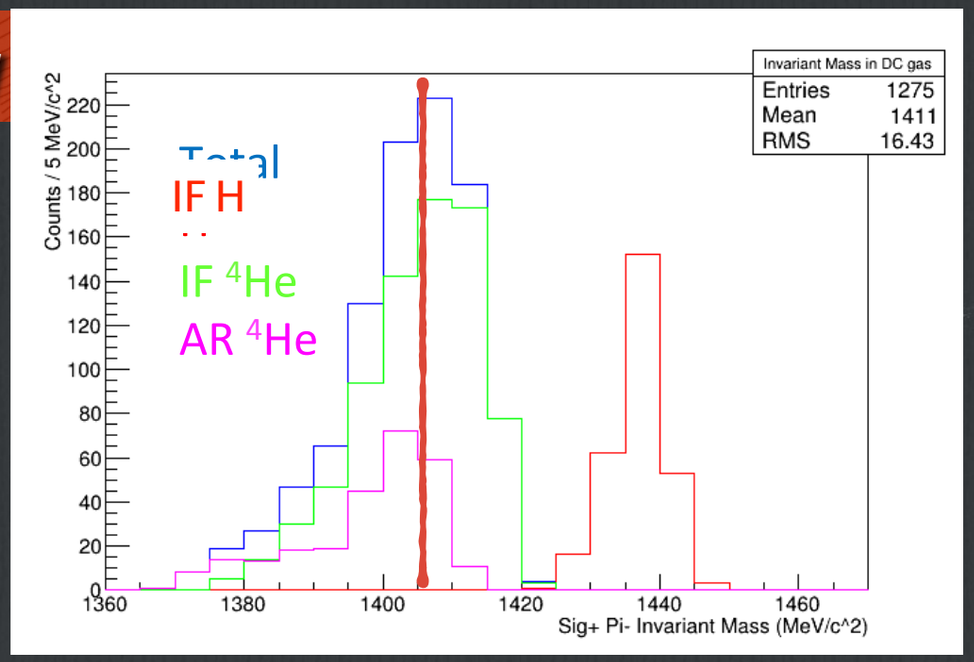


$$\mathrm{IF/AR} = 1.16 \pm 0.05$$

$$\mathrm{IF/AR} = 2.9 \pm 0.3$$

The in-flight $\Sigma^0\pi^0$ invariant mass distribution reaches out to 1420 MeV/c^2
Is that the $\Lambda(1405)$ or a quasi-free process?

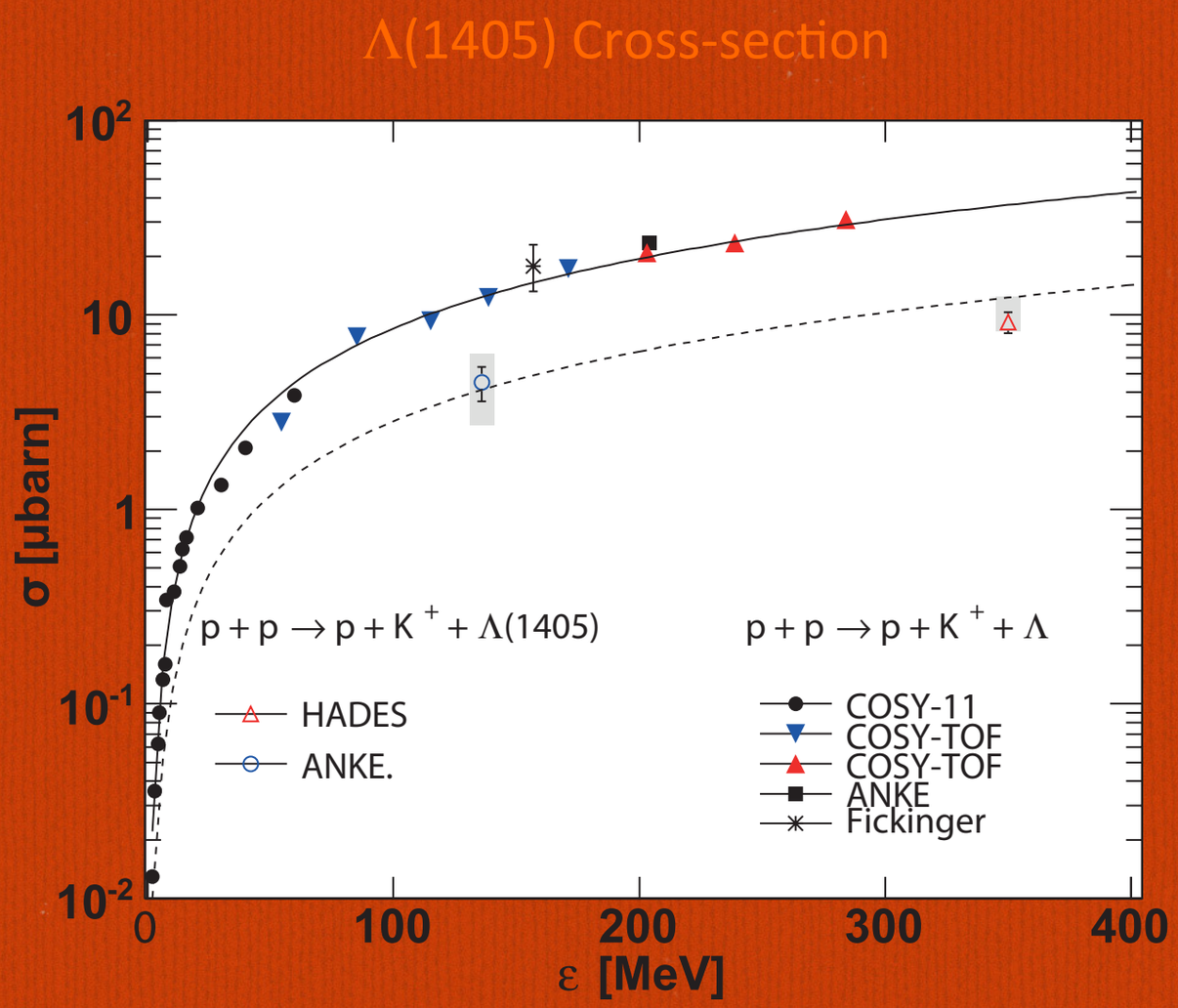
Conclusions and Summary

Λ(1405) measured in p+p at 3.5 GeV with HADES in the charged decay channel. Shift to lower masses
Theoretical calculations unable to explain this data
Interferences? Different coupling of the two poles?

Λ(1405) measured in K- + 4He/C with KLOE in the neutral and 1 charged channel
at-rest and in-flight component
Different contributions not disentangled yet
In-flight component shifted?? or Quasi-free?

<u>Calculations are needed</u>

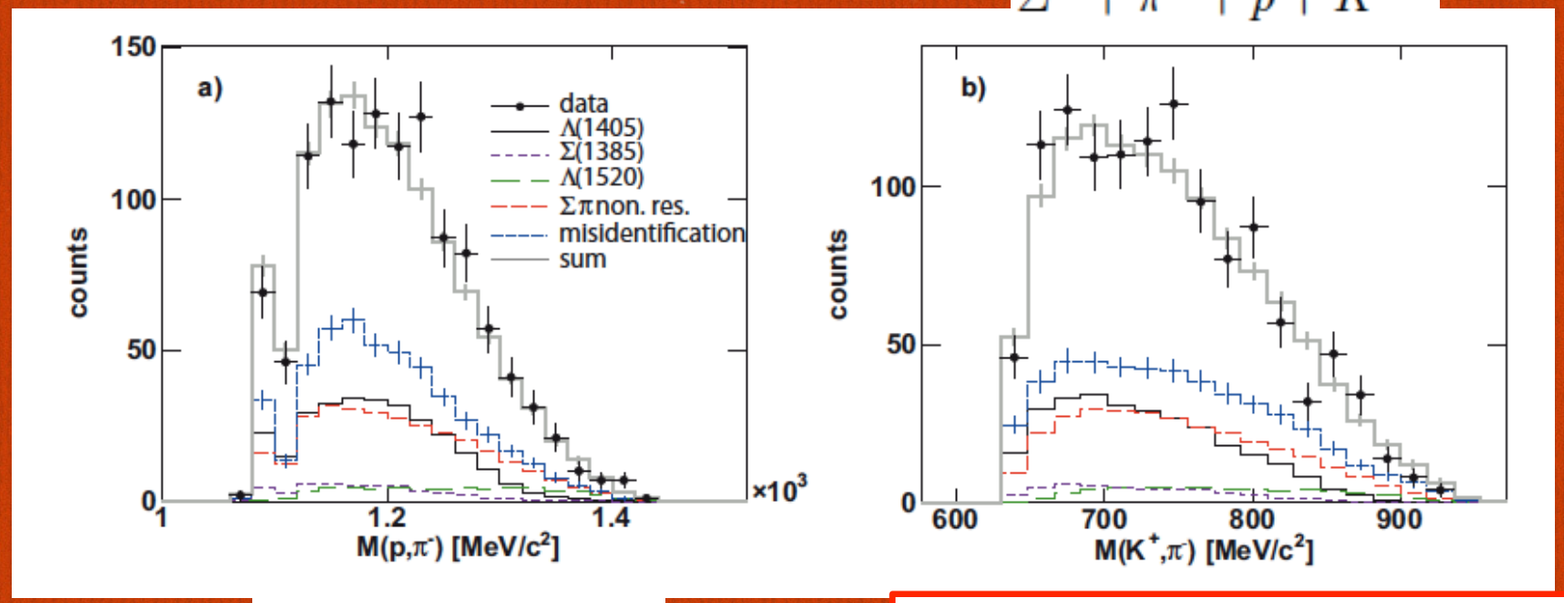
Total Cross-section



Non resonant Contribution

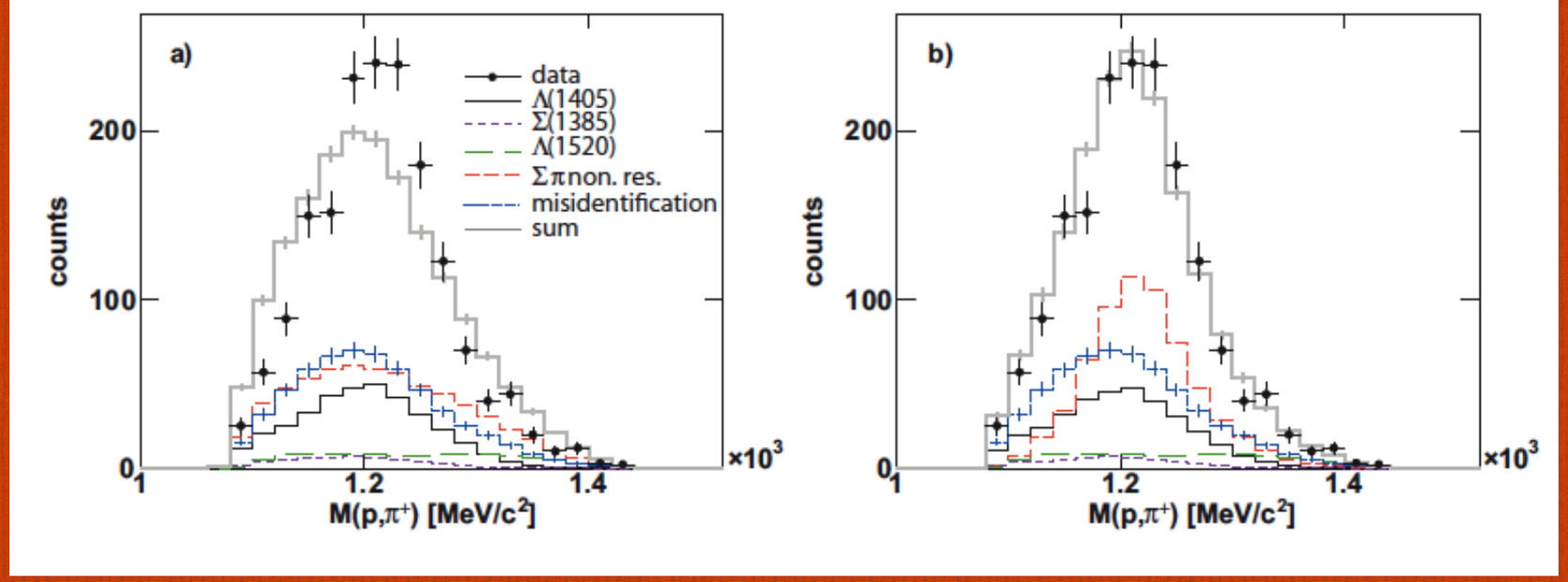
Δ^{++}

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



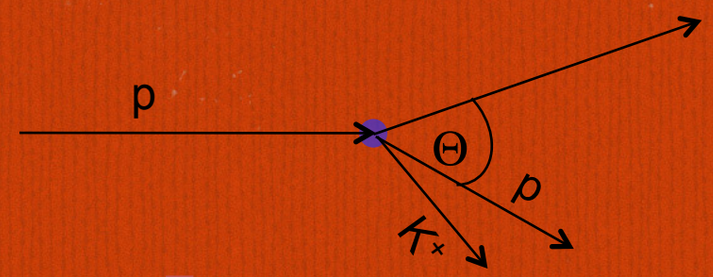
$\Sigma^{-} + \pi^{+} + p + K^{+}$

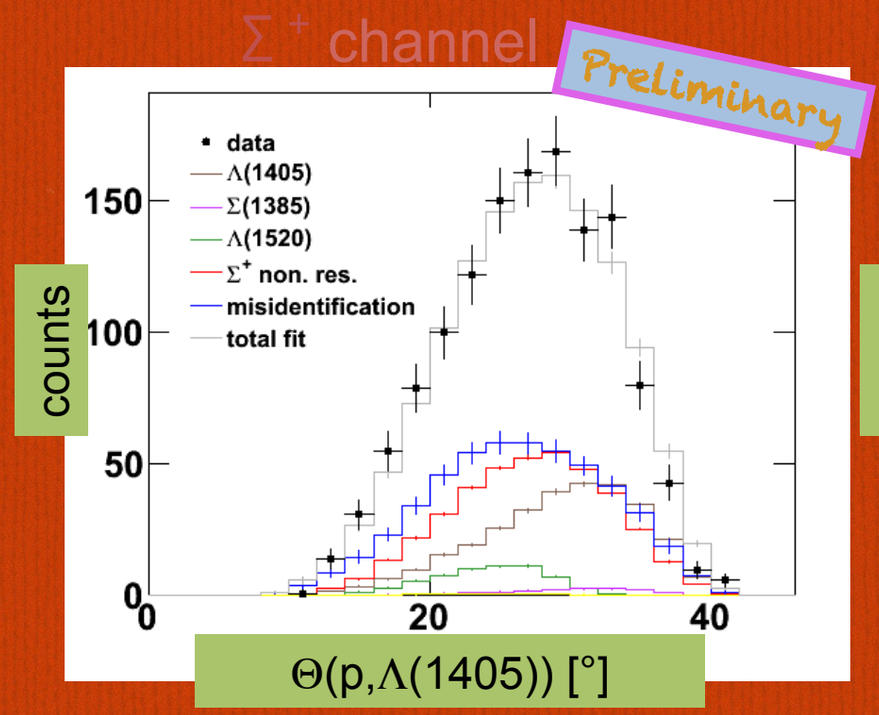
$\Sigma^{-} + K^{+} + \Delta^{++}(1232) \rightarrow \Sigma^{-} + K^{+} + (p\pi^{+})$

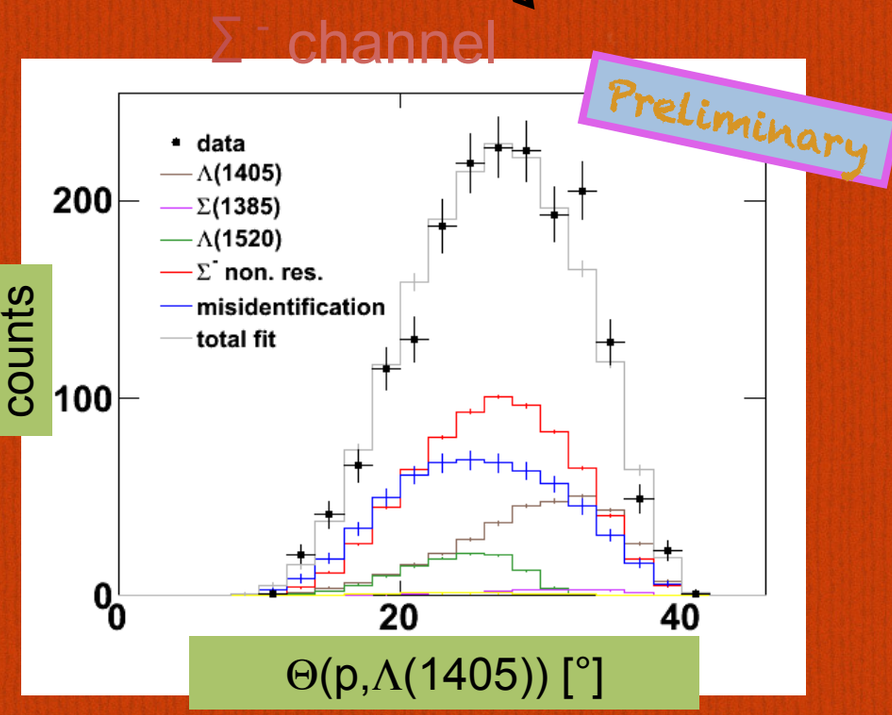


Λ(1405)-p angle

Opening angle in the laboratory system:



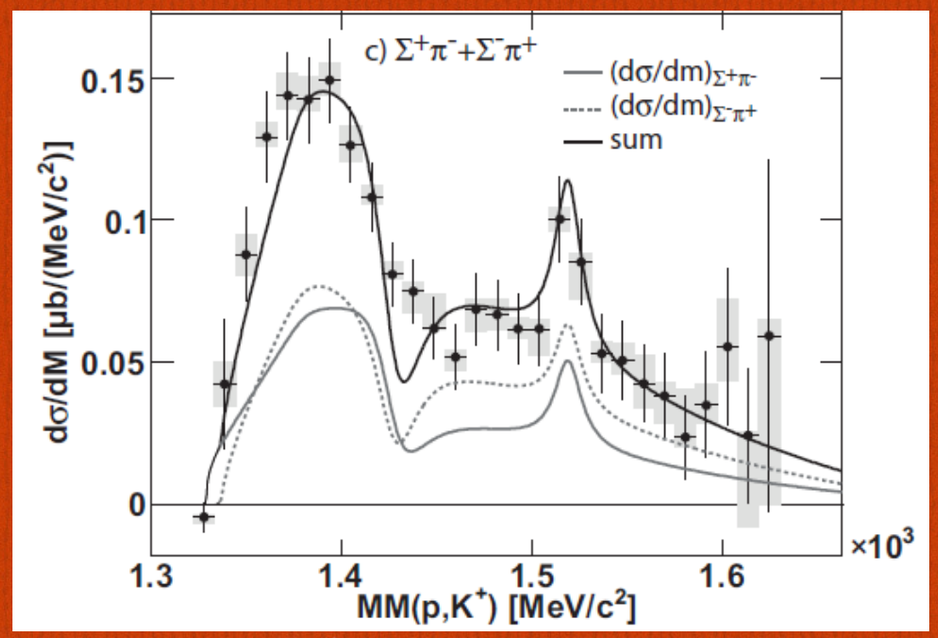




No significant deviation from phase space

Interference with non resonant

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



$A_{\Lambda(1405)}$	$A_{\Sigma^+\pi^-}$	$A_{\Sigma^-\pi^+}$	α	β
1.05	0.94	1.05	68°	111°

Interference with non resonant

* The $p+p \rightarrow \Sigma^{-}+\Delta^{++}(1232)+K^{+}$ reaction is a very probable candidate for the non-resonant part of the $\Sigma^{-} + \pi^{+} + p + K+$ spectrum and has differrent quantum numbers then the $\Lambda(1405)$ contribution. This does not lead to interferences

* Why should both charged decay channels interfere in the same way?

* Why we dont see any shift in in p+p -> $\Sigma(1385)^{+} + K^{+} + n$ or for the $\Lambda(1520)$

* p+p(@3.5GeV) ->π+p+p/π+π+p+p Incoherent analysis of 14 N* with angular distribution reproduce perfectly the data and is consistent with dilepton yield. This looks like small room for interferences..