The Role of Resonances in p+p Reactions associated with Strangeness Production

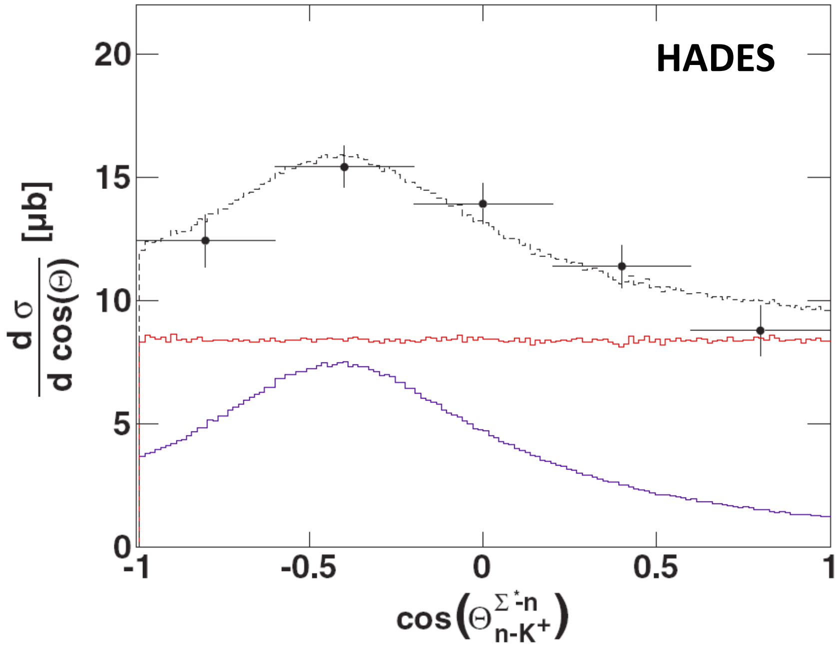
08/25/2014 – Jia-Chii Berger-Chen

TU München, Excellence Cluster Universe

PANIC 2014 Hamburg

The Role of $\Delta(2035)^{++}$ in $p+p \longrightarrow \Sigma(1385)^{+}+n+K^{+}$

Agakishiev et al. Phys. Rev. C 85, 035203 (2012)

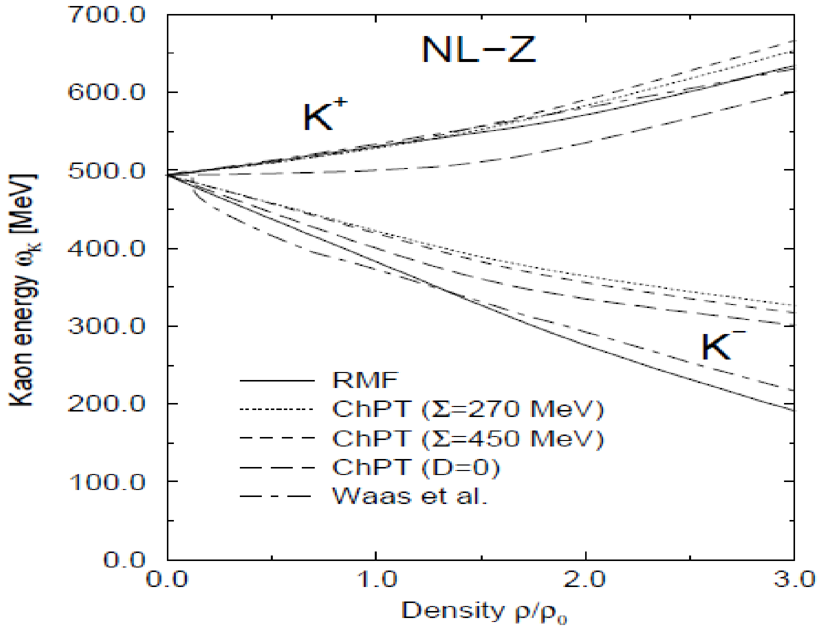


- data @ 3.5 GeV
- sim. $\Sigma(1385)^{+}+n+K^{+}$
- sim. $\Delta(2035)^{++}+n \rightarrow \Sigma(1385)^{+}+n+K^{+}$
- sum of simulations

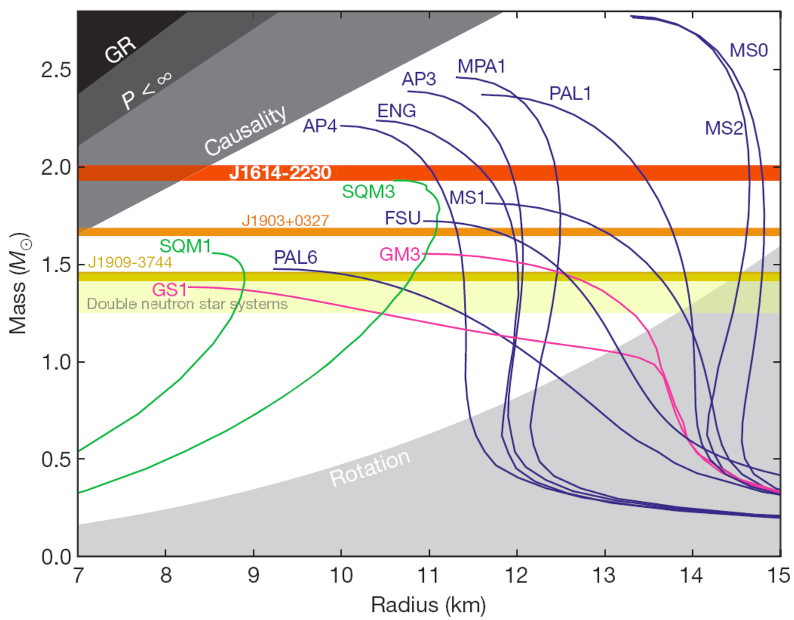
33% contribution of $\Delta(2035)^{++}$

Kaons in Medium

Schaffner et al. Nucl. Phys. A 625, 325-346 (1997)



Demorest et al., Nature 467 (2010)



- K^+ / K^- mass in-/decreases in nuclear medium
- High density (8-10ρ_0) in neutron stars!

  if $E_{K^-} < \mu_e$:

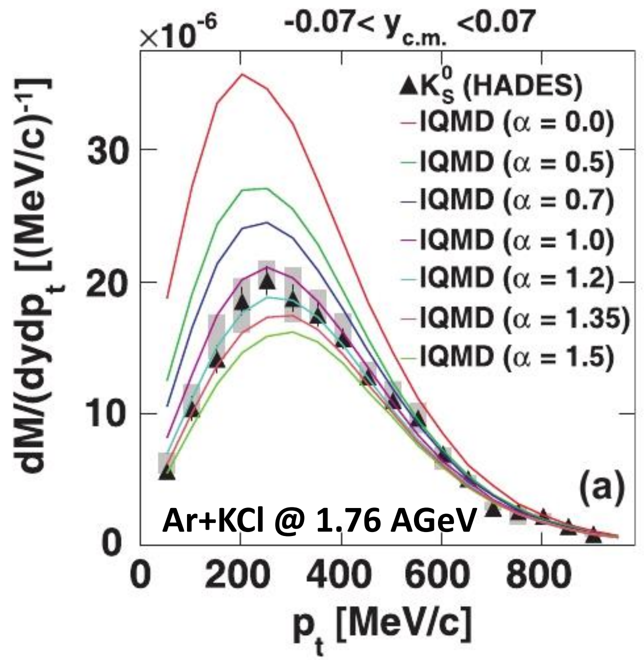
  n $\longrightarrow$ p + K^-

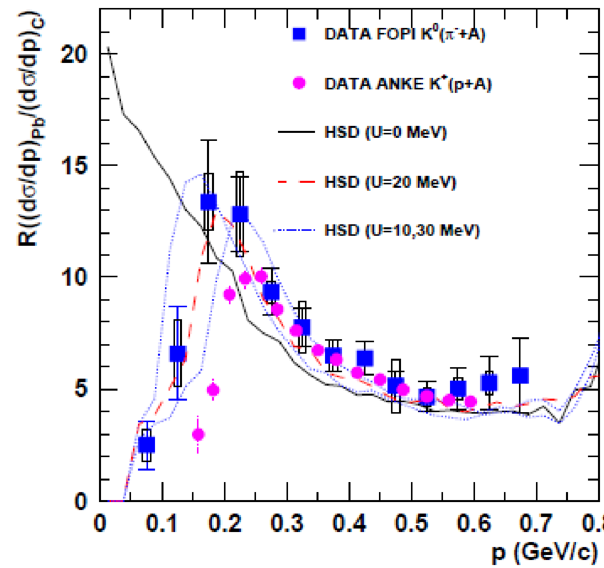
  $e^- \longrightarrow K^- + \nu_e$

$\longrightarrow$ Constraint for possible EOS

Strangeness content softens EOS

Kaon Nucleon Potential

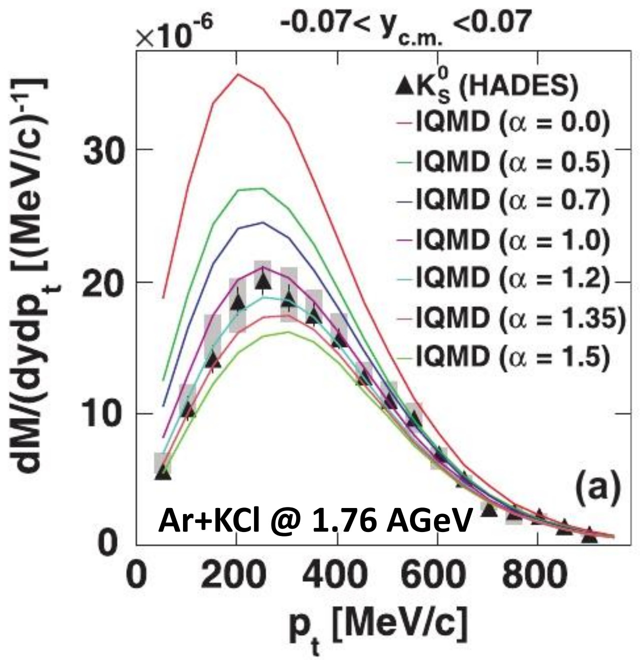


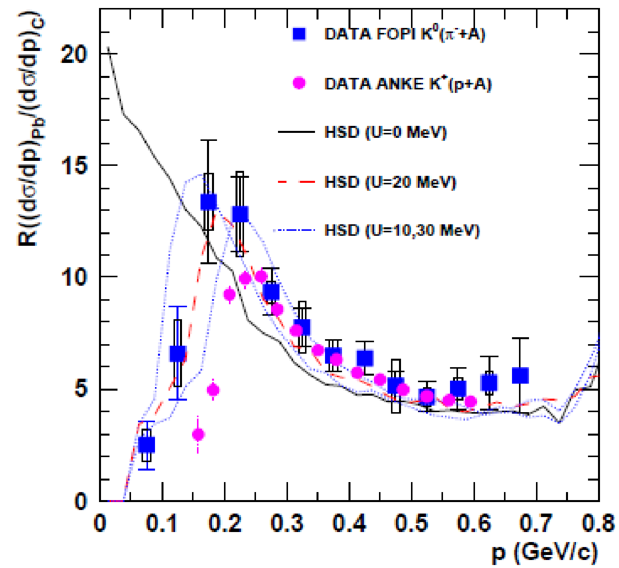


Agakishiev et al. Phys. Rev. C 82, 044907 (2010) | Büscher et al. Eur. Phys. J. A 22, 301-317 (2004)
Benabderrahmane et al. Phys. Rev. Lett. 102, 182501 (2009)

	Ar+KCl - HADES	π^-+A - FOPI	p+A - ANKE
KN potential [MeV]	39^{+8}_{-2}	20 ± 5	20 ± 3

Kaon Nucleon Potential





Agakishiev et al. Phys. Rev. C 82, 044907 (2010) | Büscher et al. Eur. Phys. J. A 22, 301-317 (2004)
Benabderrahmane et al. Phys. Rev. Lett. 102, 182501 (2009)

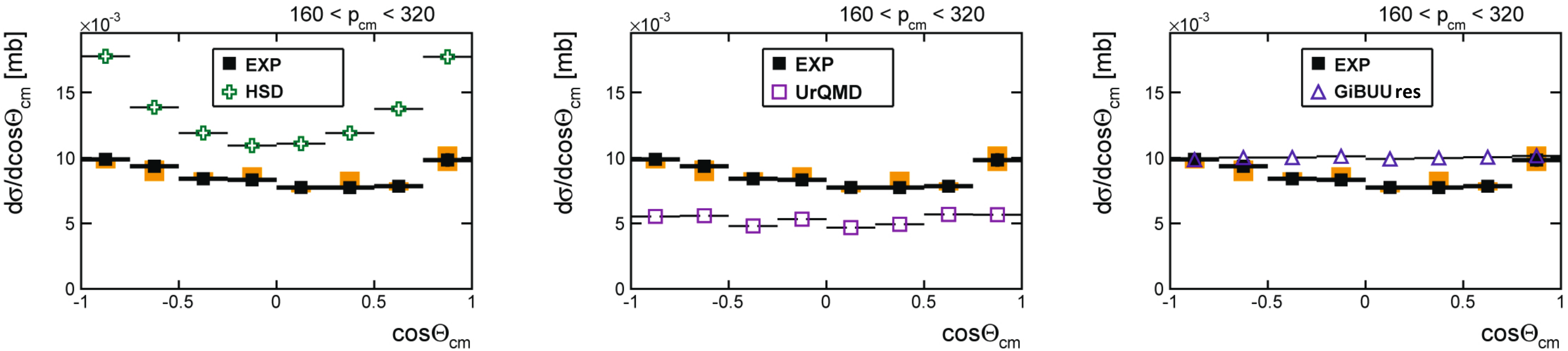
	Ar+KCl - HADES	π^-+A - FOPI	p+A - ANKE
KN potential [MeV]	39^{+8}_{-2}	20 ± 5	20 ± 3

First understand elementary reactions!

Constraints for Transport Models

Transport models often used for physics interpretation
Need of calibration on elementary reactions (e.g. p+p)
→ cross sections, angular distributions, **resonance contributions**

E.g. p+p @ 3.5 GeV – Inclusive K^0_S production

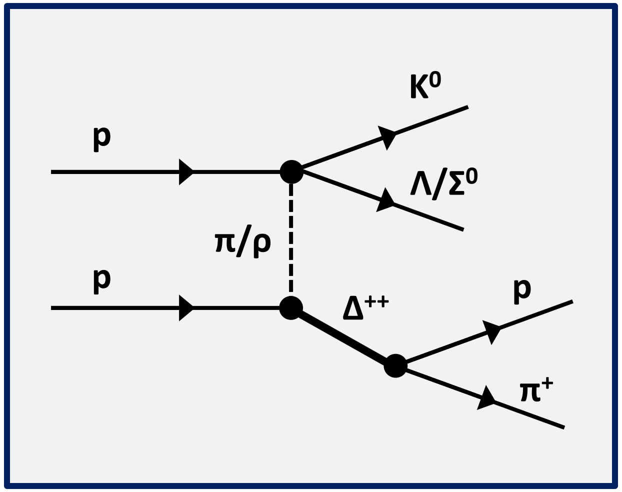


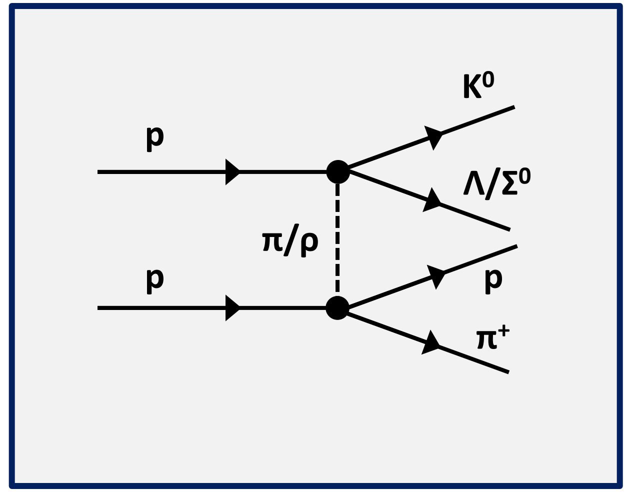
→ Neither cross sections nor angular distributions are described!

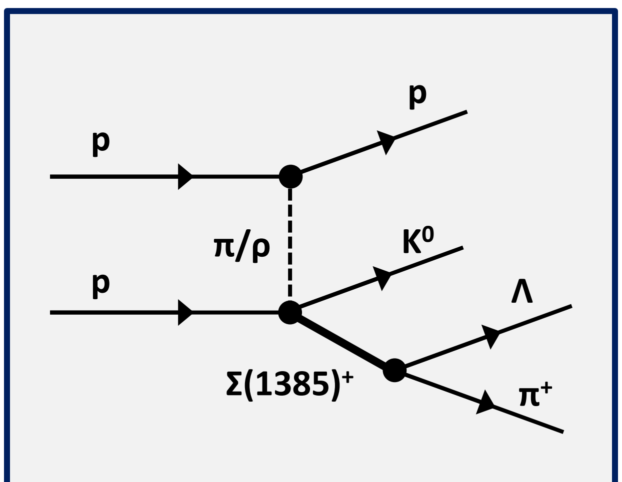
HSD: Cassing et al., Phys. Rep. 308, 65 (1999) |UrQMD: Bass et al., Prog. Part. Nucl. Phys. 41, 255 (1998)
GiBUU: Buss et al., Phys. Rept. 512, 1-124 (2012)

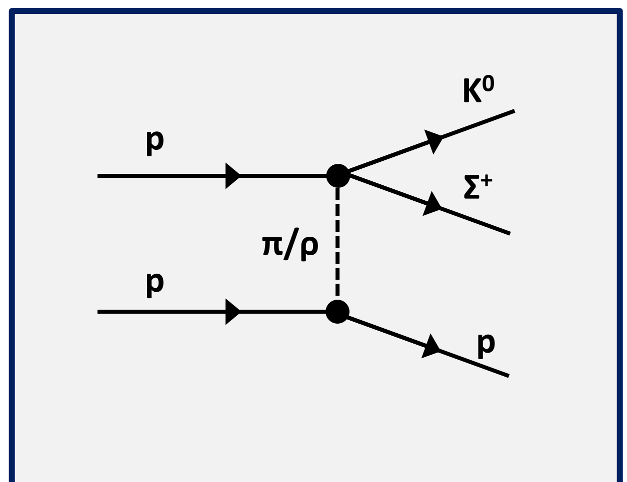
p+p Reactions associated with K^0

- Examples -

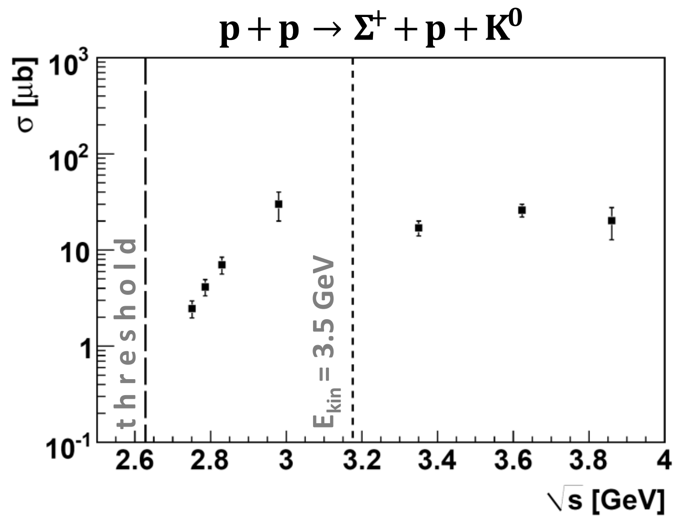


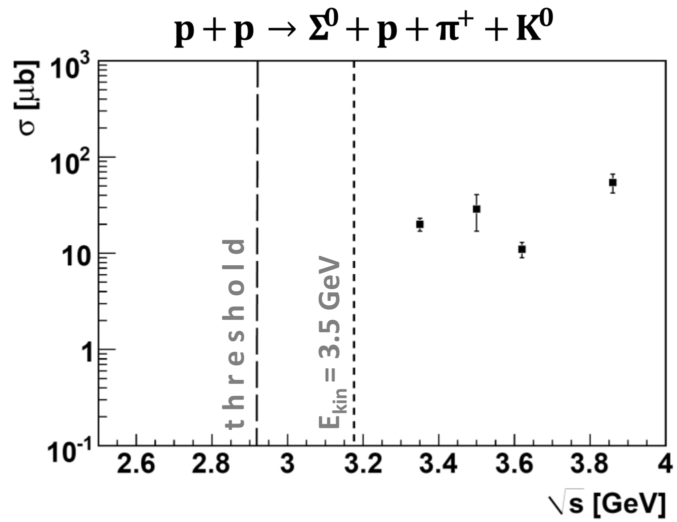


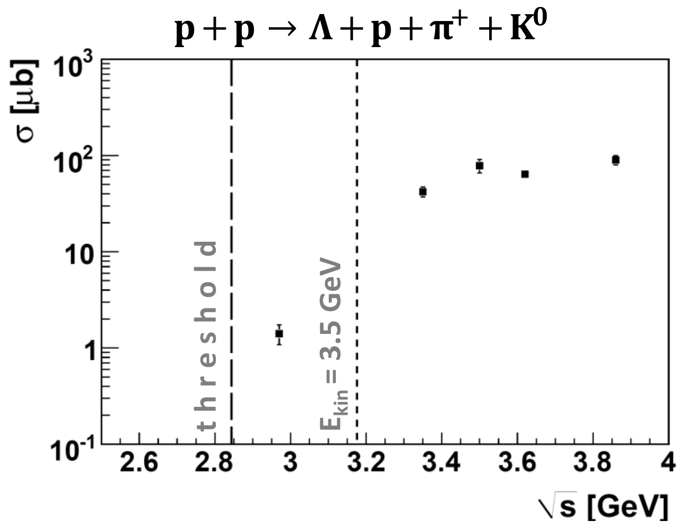




Measured Exclusive Cross Sections

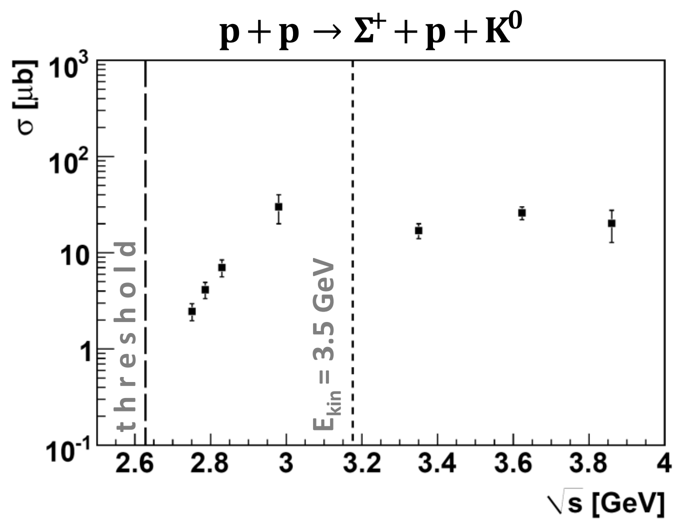


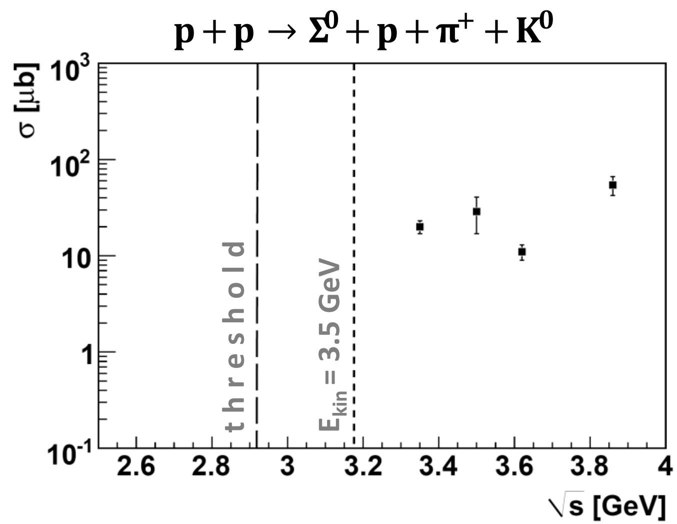


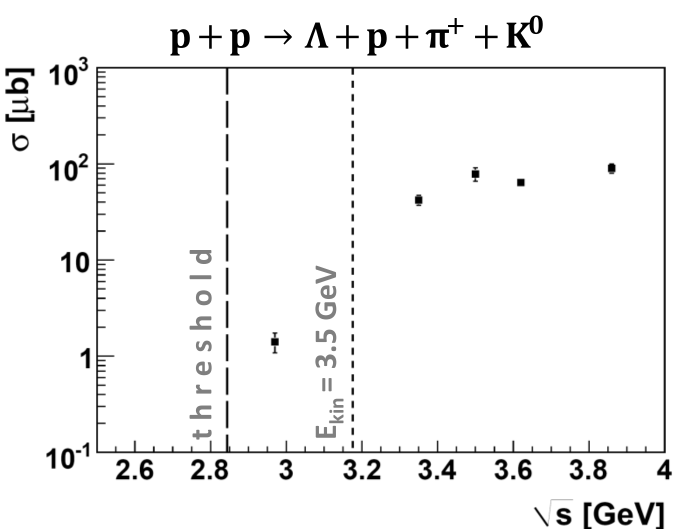


Lack of data in the region of E_{kin} = 3.5 GeV

Measured Exclusive Cross Sections





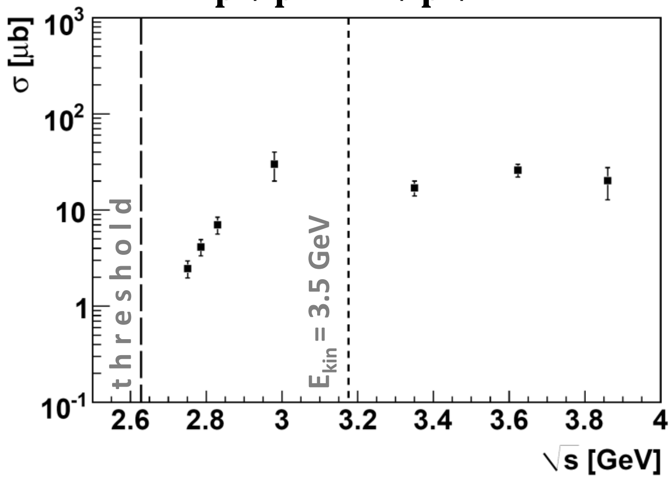


Lack of data in the region of E_{kin} = 3.5 GeV

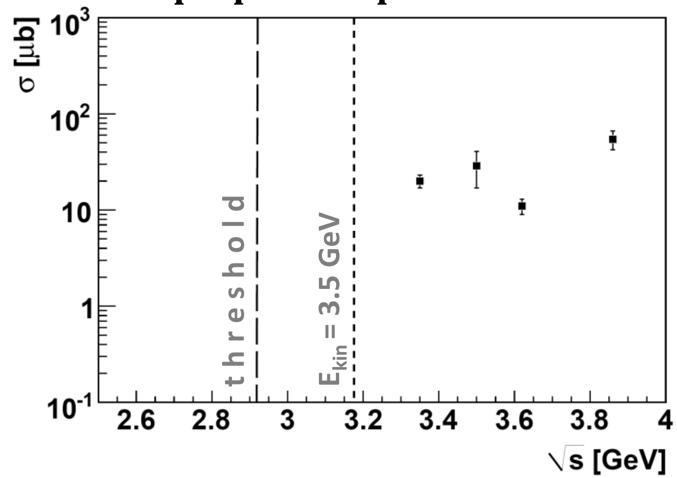
Only 2 measurements of $p + p \rightarrow \Lambda + \Delta^{++} + K^0$

Measured Exclusive Cross Sections

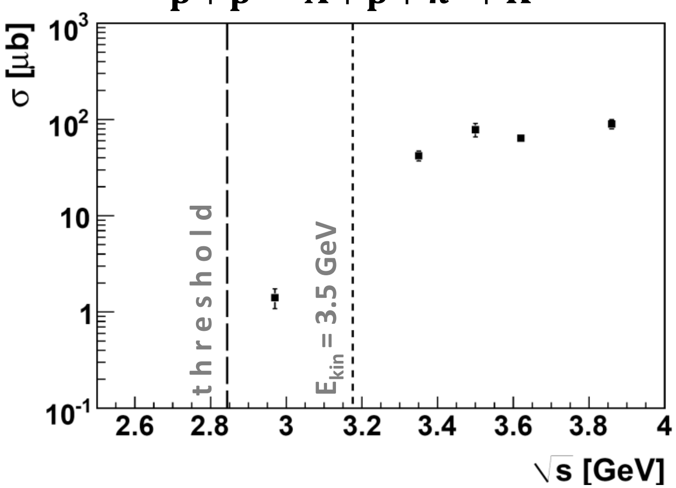
$p + p \rightarrow \Sigma^+ + p + K^0$



$p + p \rightarrow \Sigma^0 + p + \pi^+ + K^0$



$p + p \rightarrow \Lambda + p + \pi^+ + K^0$

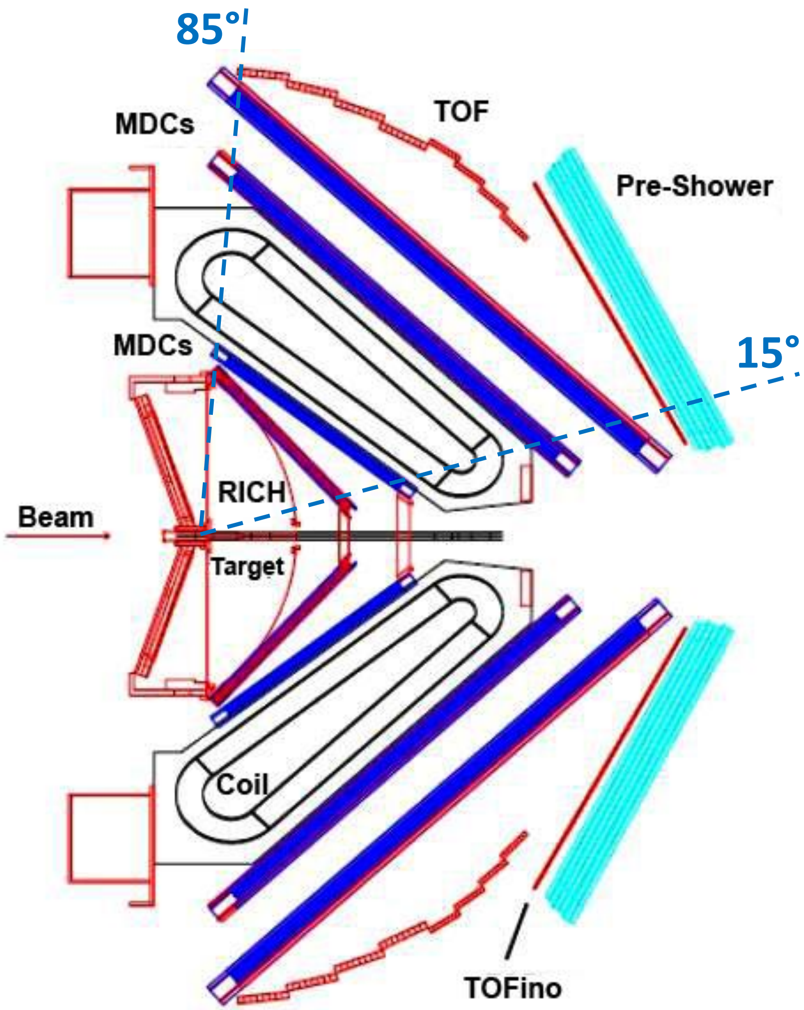


No measurement of
$p + p \rightarrow \Sigma^0 + \Delta^{++} + K^0$

Lack of data in the region of E_{kin} = 3.5 GeV

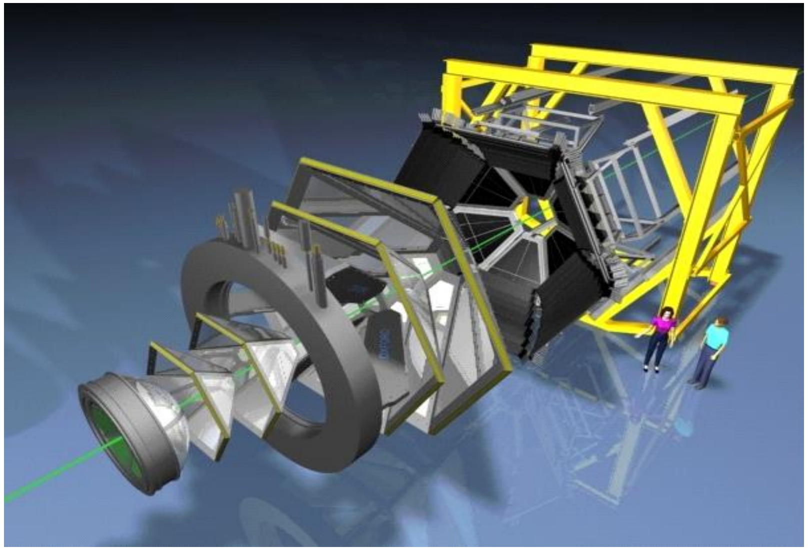
Only 2 measurements of
$p + p \rightarrow \Lambda + \Delta^{++} + K^0$

The HADES Experiment @ GSI, Darmstadt



High **A**cceptance **D**i-**E**lectron **S**pectrometer:

- High acceptance for dilepton pairs
- Momentum resolution ≈ 3 %
- Particle identification via dE/dx
- $1.2 \cdot 10^9$ events in p+p @ 3.5 GeV



Data Sample

Events with the 4 charged particles **p, π⁺, π⁺, π⁻**

Considered contributing channels:

$$p + p \rightarrow \Lambda/\Sigma^0 + \Delta^{++} + K^0$$
$K^0 \rightarrow \pi^+ + \pi^-$ 69.2%
$\Delta^{++} \rightarrow p + \pi^+$ 100%
ε = 331/254 MeV

$$p + p \rightarrow \Sigma(1385)^+ + p + K^0$$
$K^0 \rightarrow \pi^+ + \pi^-$
$\Sigma(1385)^+ \rightarrow \Lambda + \pi^+$ 87.0%
ε = 385 MeV

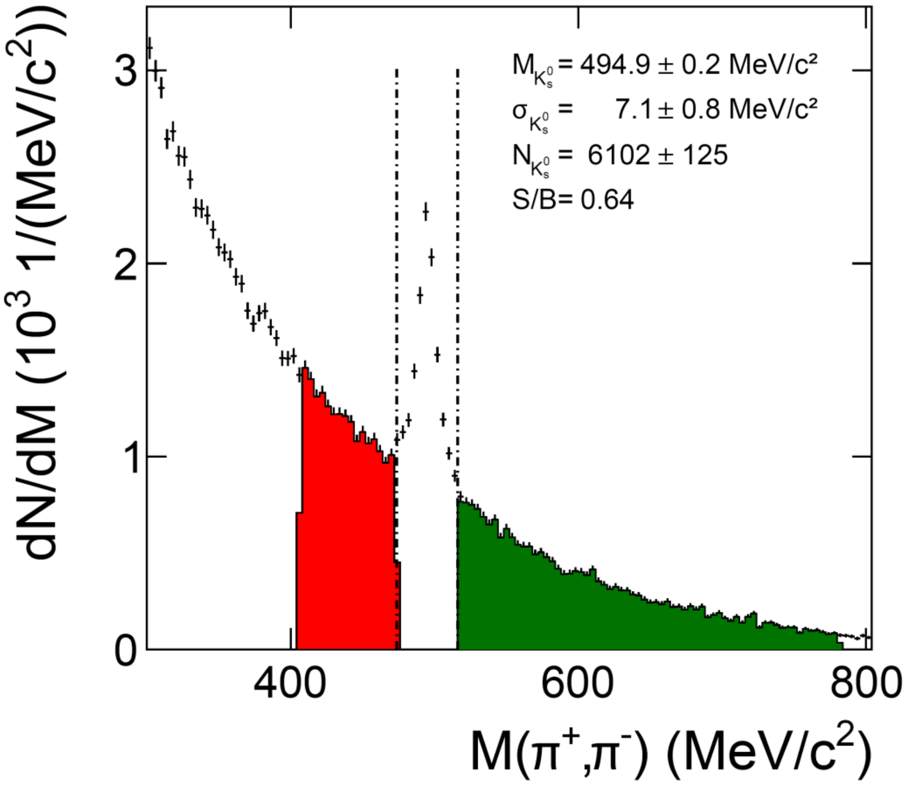
$$p + p \rightarrow \Lambda/\Sigma^0 + p + \pi^+ + K^0$$
$K^0 \rightarrow \pi^+ + \pi^-$
ε = 485/408 MeV

$$p + p \rightarrow \Sigma^+ + p + K^0$$
ε = 551 MeV
$K^0 \rightarrow \pi^+ + \pi^-$
$\Sigma^+ \rightarrow n + \pi^+$ 48.3%

& other K^0 production channels each with rather small contribution

⟶ All reactions simulated with a Monte Carlo event generator

Invariant Mass (π^+, π^-)



Data sample:
events with 4 particles (p, π^+, π^+, π^-) with cuts on the K^0_S decay topology.

Low mass and high mass sideband used to emulate the kinematics of the background.

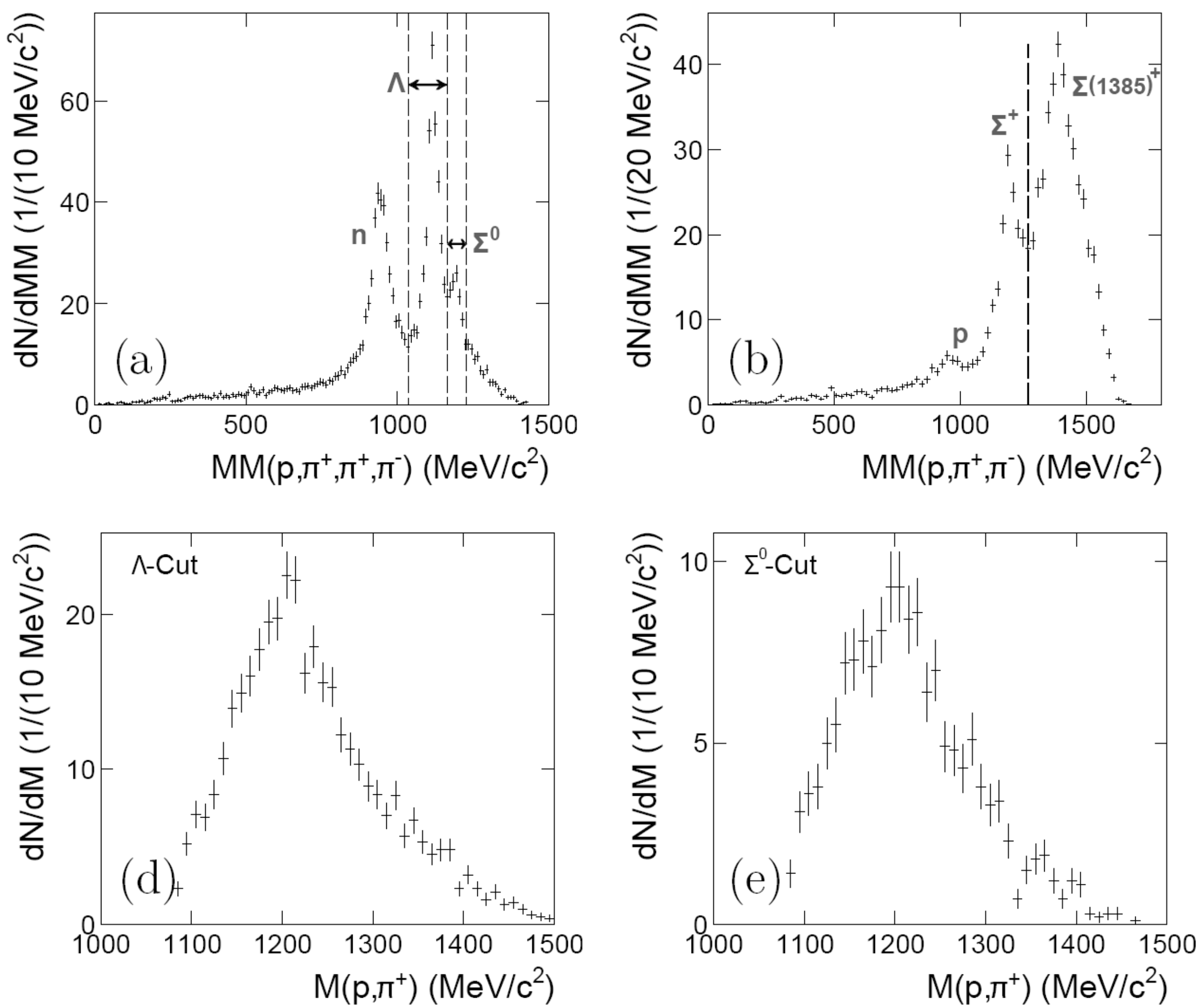
Simultaneous Fit to 5 Observables with total sideband

- sideband constraint to ± 30%

$\longrightarrow X^2/NDF = 2.57$

The 5 fitted Observables

- in ACCEPTANCE -



$p + p \rightarrow \Lambda/\Sigma^0 + \Delta^{++} + K^0$, with $K^0 \rightarrow \pi^+ + \pi^-$ and $\Delta^{++} \rightarrow p + \pi^+$

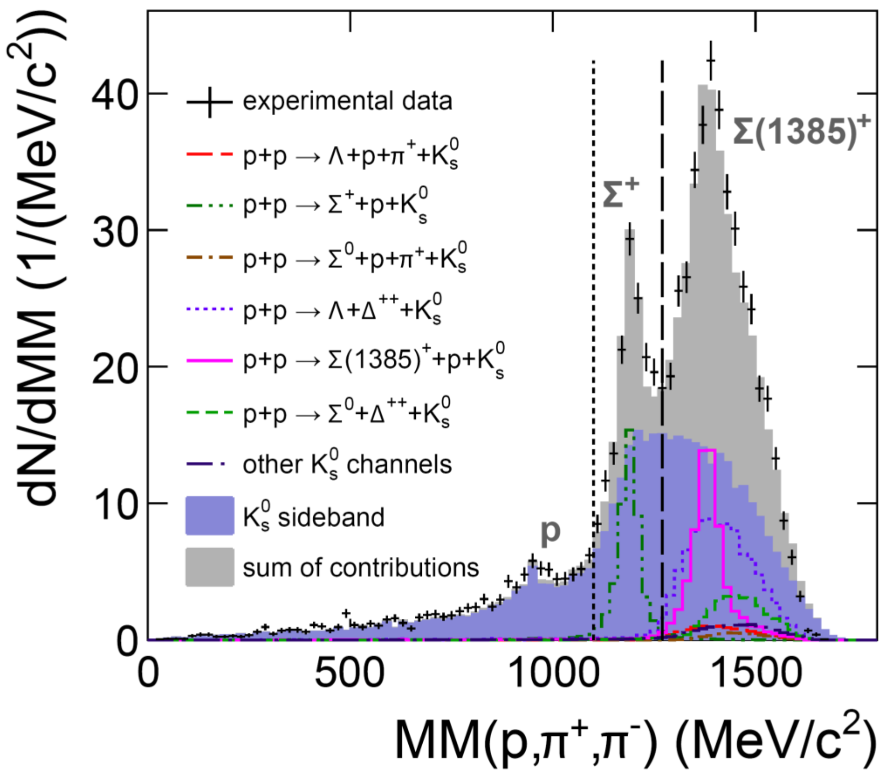
$p + p \rightarrow \Lambda/\Sigma^0 + p + \pi^+ + K^0$, with $K^0 \rightarrow \pi^+ + \pi^-$

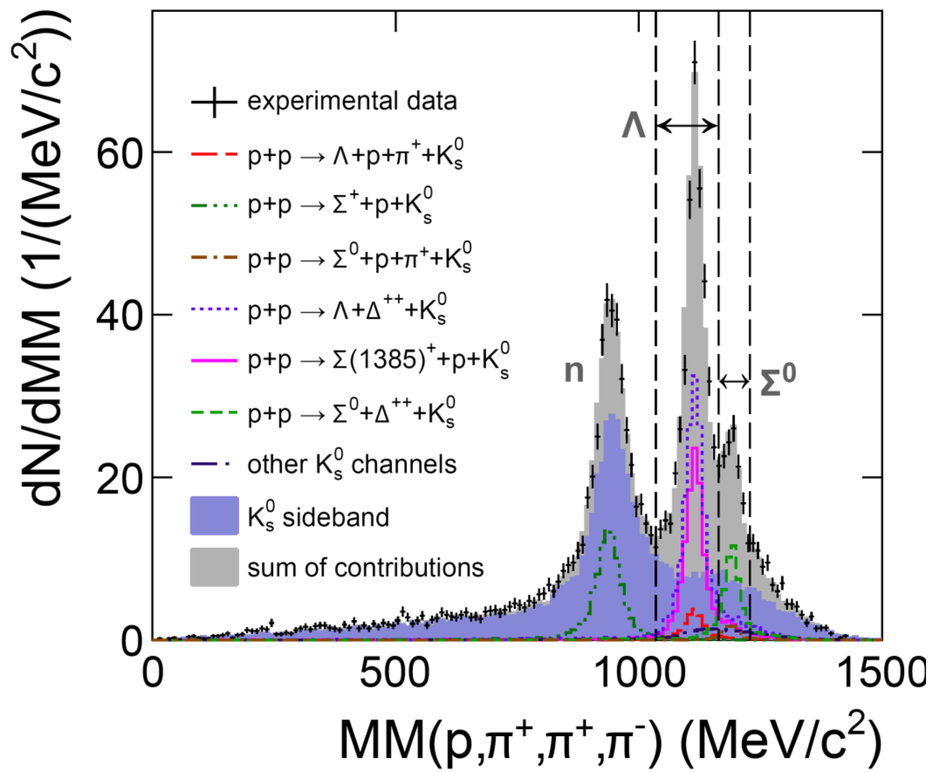
$p + p \rightarrow \Sigma(1385)^+ + p + K^0$, with $K^0 \rightarrow \pi^+ + \pi^-$ and $\Sigma(1385)^+ \rightarrow \Lambda + \pi^+$

$p + p \rightarrow \Sigma^+ + p + K^0$, with $K^0 \rightarrow \pi^+ + \pi^-$ and $\Sigma^+ \rightarrow n + \pi^+$

$MM(p,\pi^+,\pi^-)$ and $MM(p,\pi^+,\pi^+,\pi^-)$

- in ACCEPTANCE -

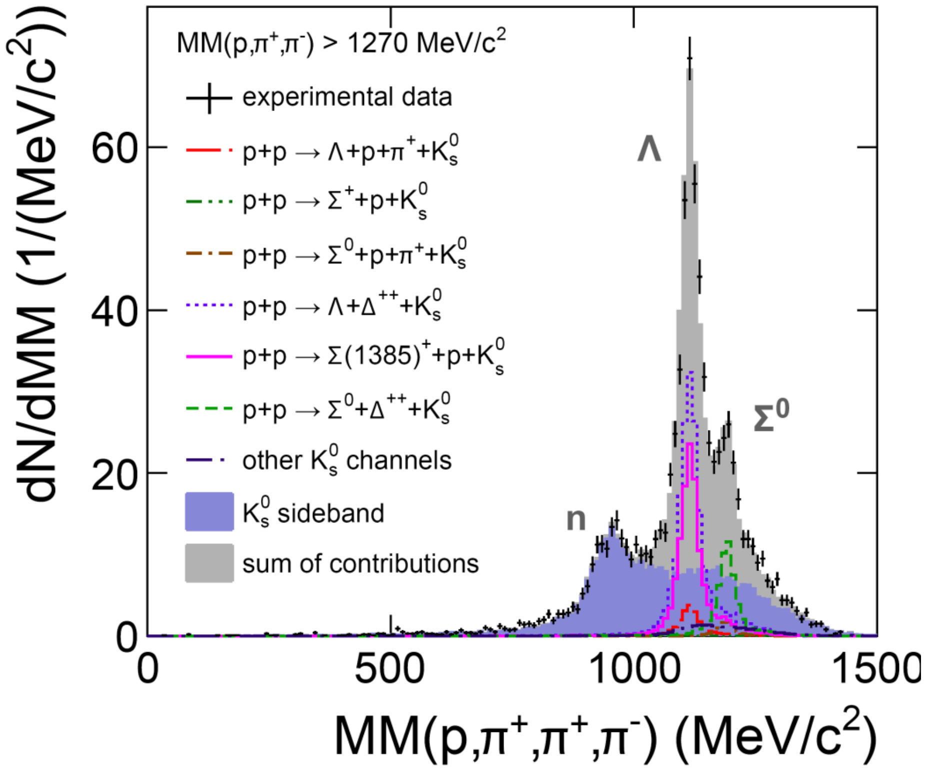




$MM(p,\pi^+,\pi^+,\pi^-)$ with cut on $MM(p,\pi^+,\pi^-)$

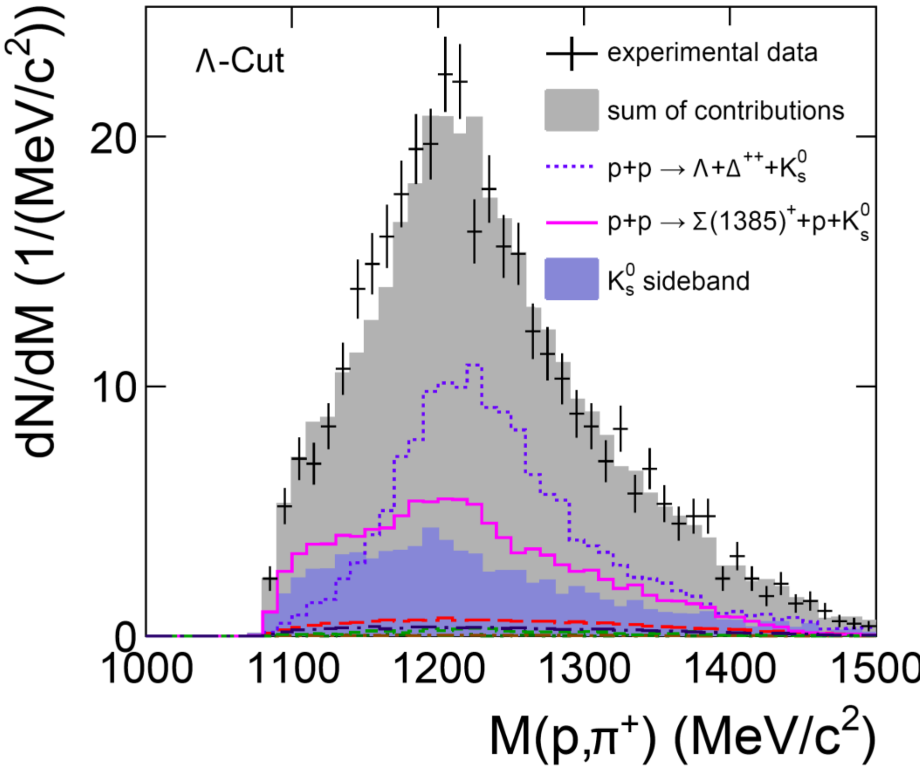
- in ACCEPTANCE -

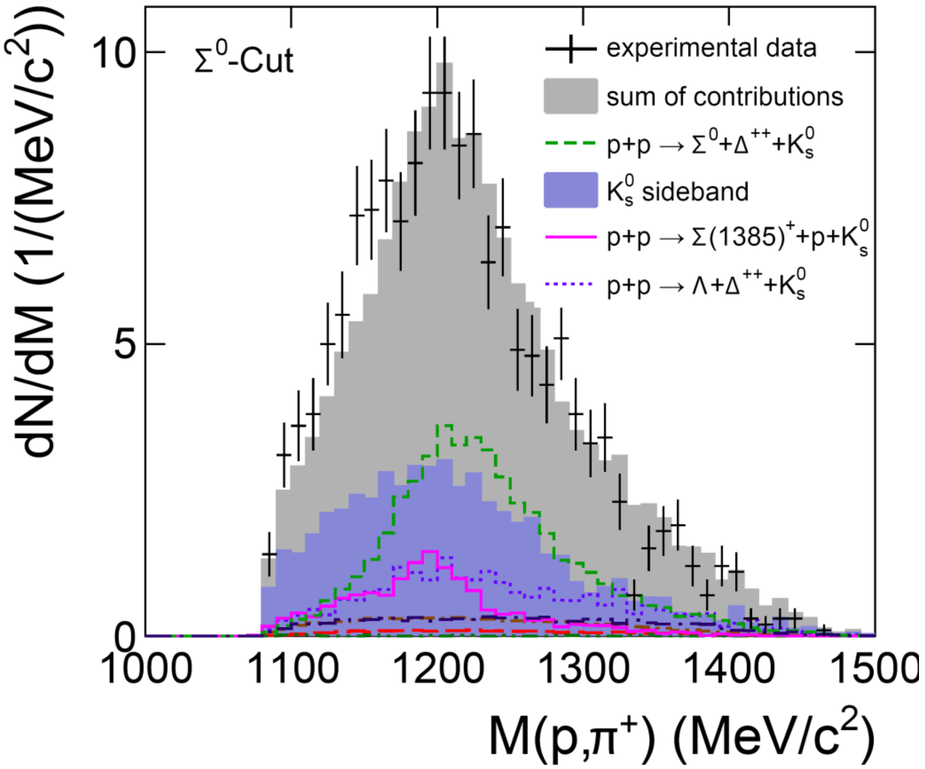
$MM(p,\pi^+,\pi^-) > 1270$ MeV/c^2



$M(p, \pi^+)$

- in ACCEPTANCE -





Angular Distributions

Scaling from simult. fit used for simulation

Including Angular Anisotropy

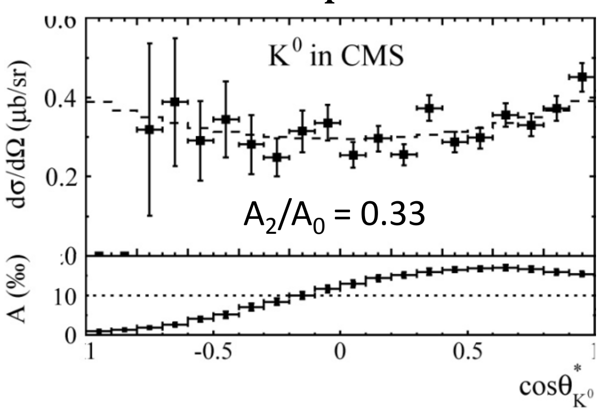
$p + p \rightarrow \Sigma^+ + p + K^0$: from COSY-TOF at E_{kin} = 2.26 GeV

$p + p \rightarrow \Sigma(1385)^+ + p + K^0$: from $\Sigma(1385)^+ + n + K^+$

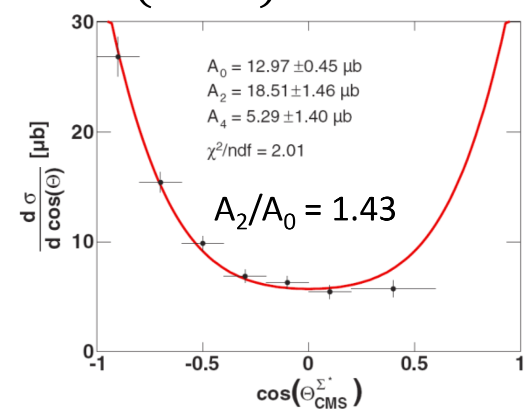
$p + p \rightarrow \Lambda + \Delta^{++} + K^0$: from X^2/ndf minimization of $\cos\theta_{cm}^{p\pi^+}$

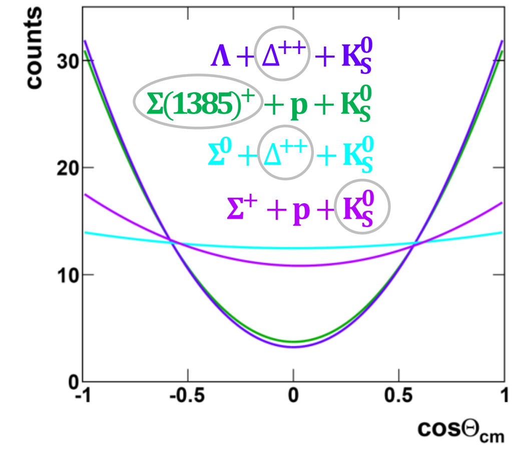
$p + p \rightarrow \Sigma^0 + \Delta^{++} + K^0$: from X^2/ndf minimization of $\cos\theta_{cm}^{p\pi^+}$

$\Sigma^+ + p + K^0$



$\Sigma(1385)^+ + n + K^+$





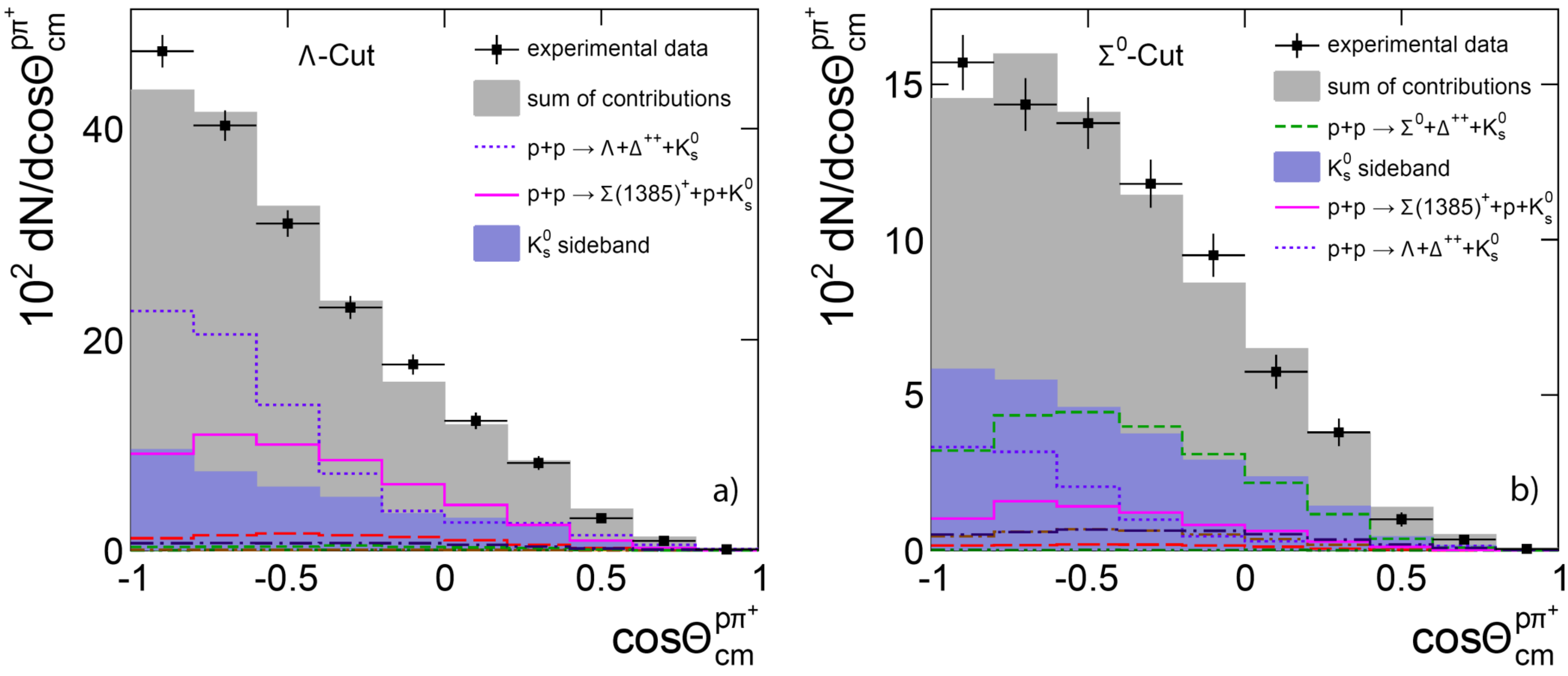
Abdel-Bary et al., arXiv:1202.4108v1 [nucl-ex] | Agakishiev et al., Phys. Rev. C 85, 035203 (2012)

Angular Distribution of Δ^{++} Candidates

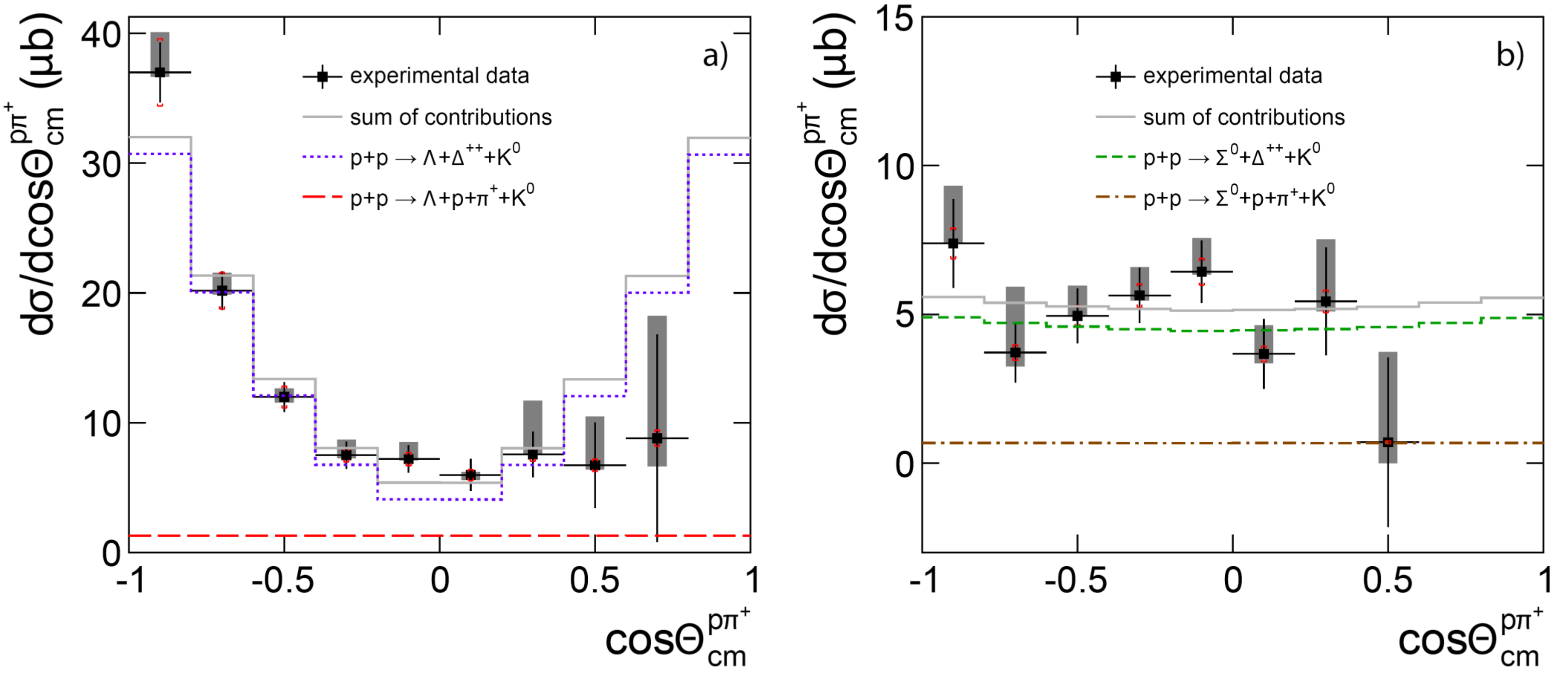
- in ACCEPTANCE -

X^2/ndf (anisotropic sim.) = 1.87

X^2/ndf (isotropic sim.) = 25.64



Corrected Angular Distribution



Cross Sections of Exclusive Channels

statistical uncertainty: relative stat. uncertainty of experimental data

systematic uncertainty:

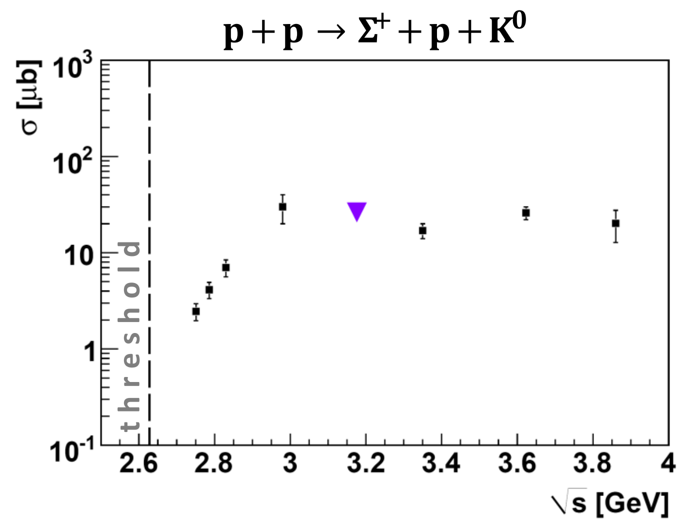
- variation of secondary vertex cuts each by ±20%
- variation of the sideband integral in $M(\pi^+, \pi^-)$ by ±20%

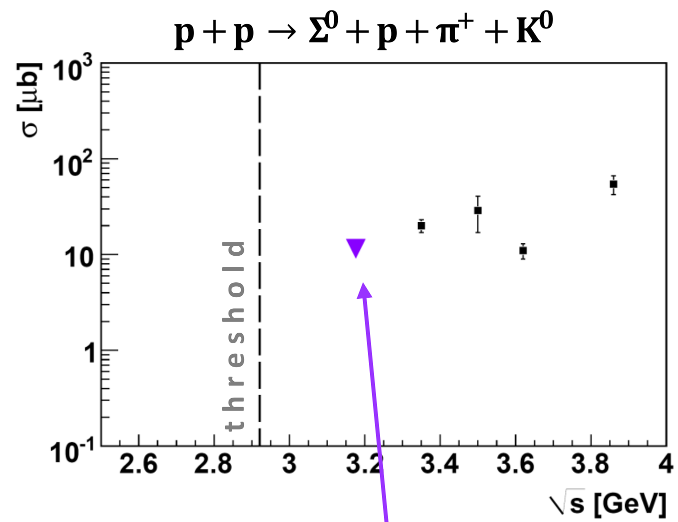
Cross Sections

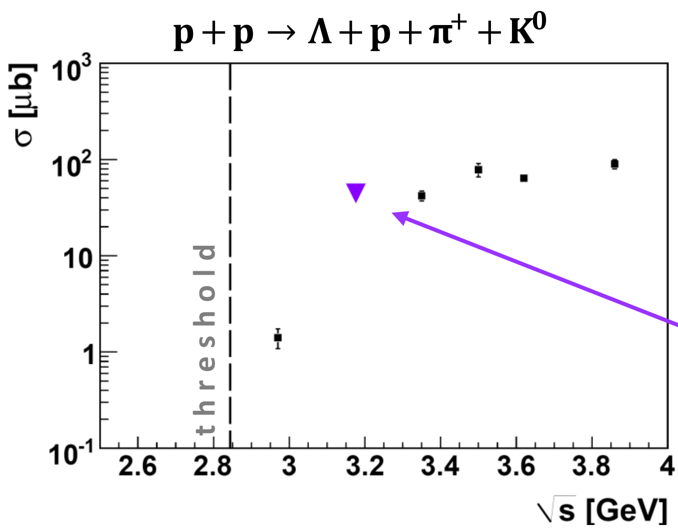
Reaction: $p + p \rightarrow$	$\sigma_{isotropic}$ [μb]	$\sigma_{anisotropic}$ [μb]
$\Lambda + p + \pi^+ + K^0$	$\mathbf{2.37} \pm 0.02^{+0.18}_{-2.35} \pm 0.17$	$\mathbf{2.57} \pm 0.02^{+0.21}_{-1.98} \pm 0.18$
$\Lambda + \Delta^{++} + K^0$	$\mathbf{25.56} \pm 0.08^{+1.85}_{-1.45} \pm 1.79$	$\mathbf{29.27} \pm 0.08^{+1.67}_{-1.46} \pm 2.06$
$\Sigma^0 + p + \pi^+ + K^0$	$\mathbf{1.40} \pm 0.02^{+0.41}_{-1.40} \pm 0.10$	$\mathbf{1.35} \pm 0.02^{+0.10}_{-1.35} \pm 0.09$
$\Sigma^0 + \Delta^{++} + K^0$	$\mathbf{9.17} \pm 0.05^{+1.45}_{-0.11} \pm 0.64$	$\mathbf{9.26} \pm 0.05^{+1.41}_{-0.31} \pm 0.65$
$\Sigma^+ + p + K^0$	$\mathbf{24.25} \pm 0.63^{+2.42}_{-1.80} \pm 1.70$	$\mathbf{26.27} \pm 0.64^{+2.57}_{-2.13} \pm 1.84$
$\Sigma(1385)^+ + p + K^0$	$\mathbf{13.15} \pm 0.05^{+1.91}_{-2.07} \pm 0.92$	$\mathbf{14.35} \pm 0.05^{+1.79}_{-2.14} \pm 1.00$

systematic uncertainties from normalization to elastics

Cross Sections compared to World Data







Sum of cross sections:

- $p\,p \longrightarrow \Sigma^0\, p\, \pi^+\, K^0$
- $p\,p \longrightarrow \Sigma^0\, \Delta^{++}\, K^0$
- $p\,p \longrightarrow \Sigma(1385)^+\, p\, K^0$ (5.85%)

- $p\,p \longrightarrow \Lambda\, p\, \pi^+\, K^0$
- $p\,p \longrightarrow \Lambda\, \Delta^{++}\, K^0$
- $p\,p \longrightarrow \Sigma(1385)^+\, p\, K^0$ (87.0%)

Summary

Agakishiev et al., Phys. Rev. C 90, 015202 (2014)

SUMMARY:

- Extraction of cross sections for K^0 channels with help of incoherent simulations
- Clear sign for angular anisotropy in the production

$\rightarrow \Lambda + \Delta^{++} + K^0$ has strong anisotropy

$\rightarrow \Sigma^0 + \Delta^{++} + K^0$ has less anisotropy

$\rightarrow$ Difference in angular distributions observed also in COSY-TOF study

of $p + p \rightarrow \Lambda/\Sigma^0 + p + K^+$ @ p_{beam} = 3059 MeV/c

Abdel-Bary et al., Eur. Phys. J. A 46, 27-44 (2010)

Thank you!

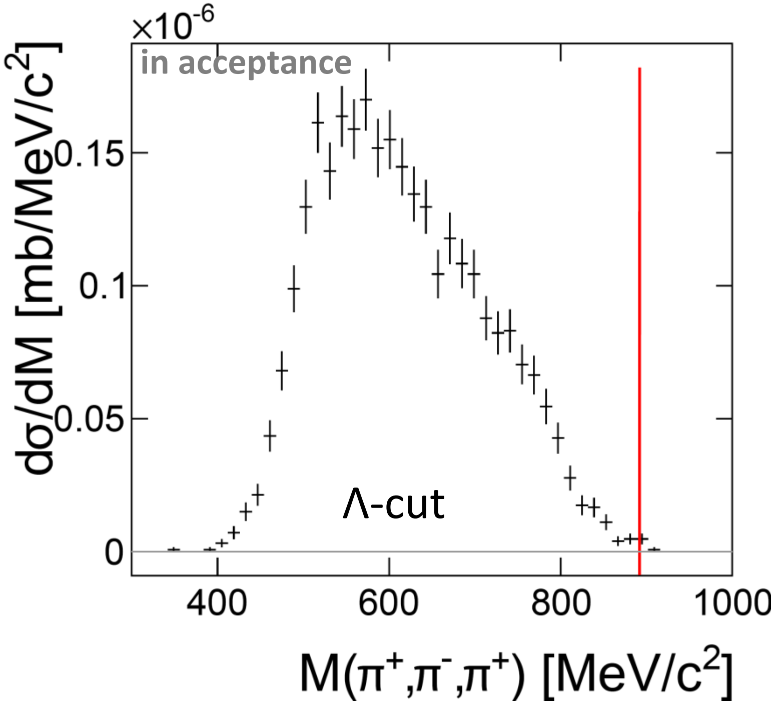
HADES Collaboration

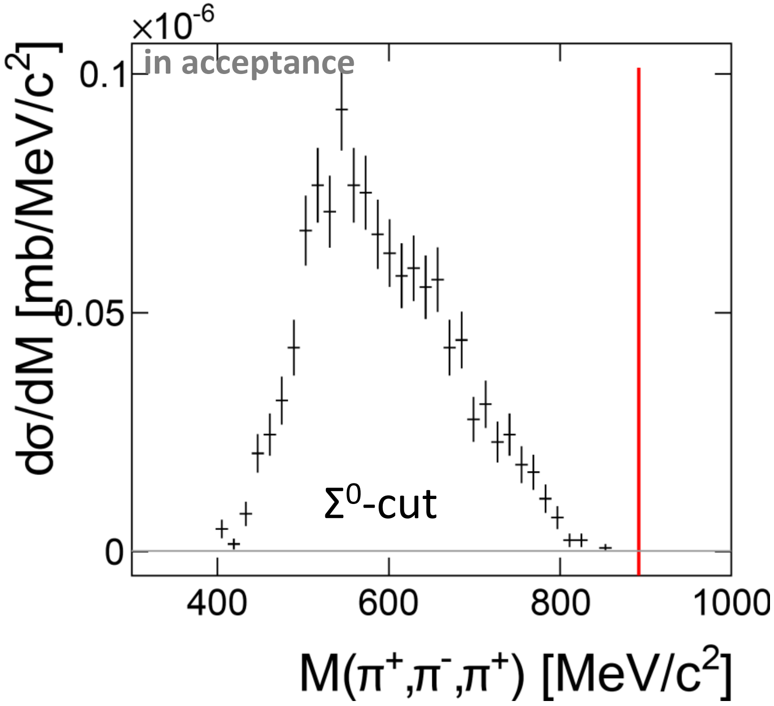
Back Up

K*(892)$^+$ Contribution?

$$p + p \rightarrow \Lambda/\Sigma^0 + p + K^*(892)^+$$
$$\hookrightarrow K^0 + \pi^+$$

ε = 230/257 MeV

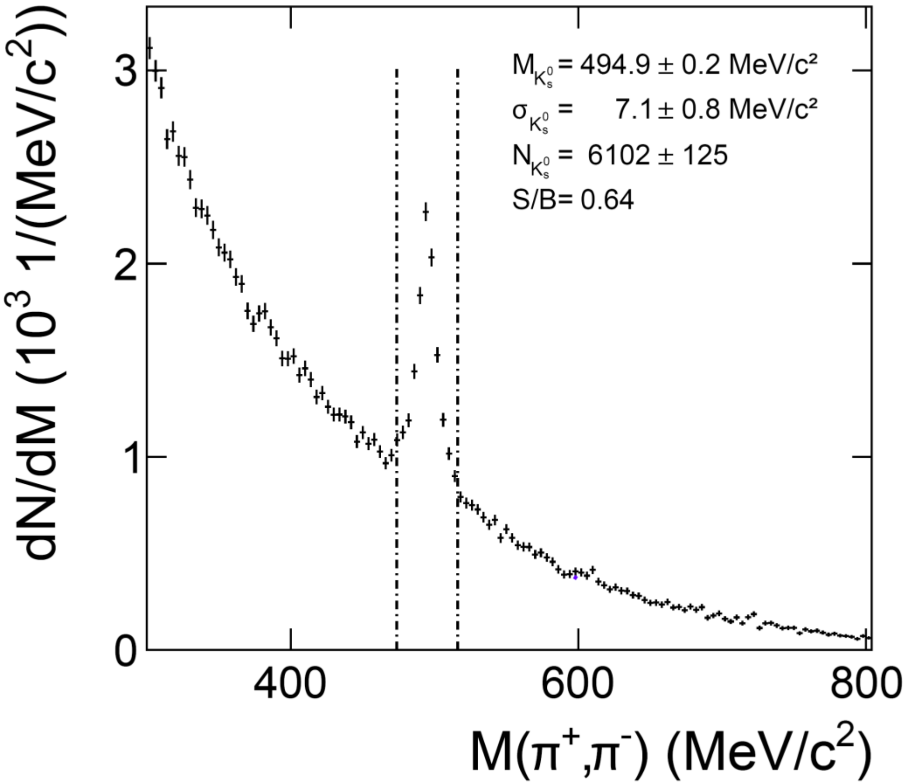


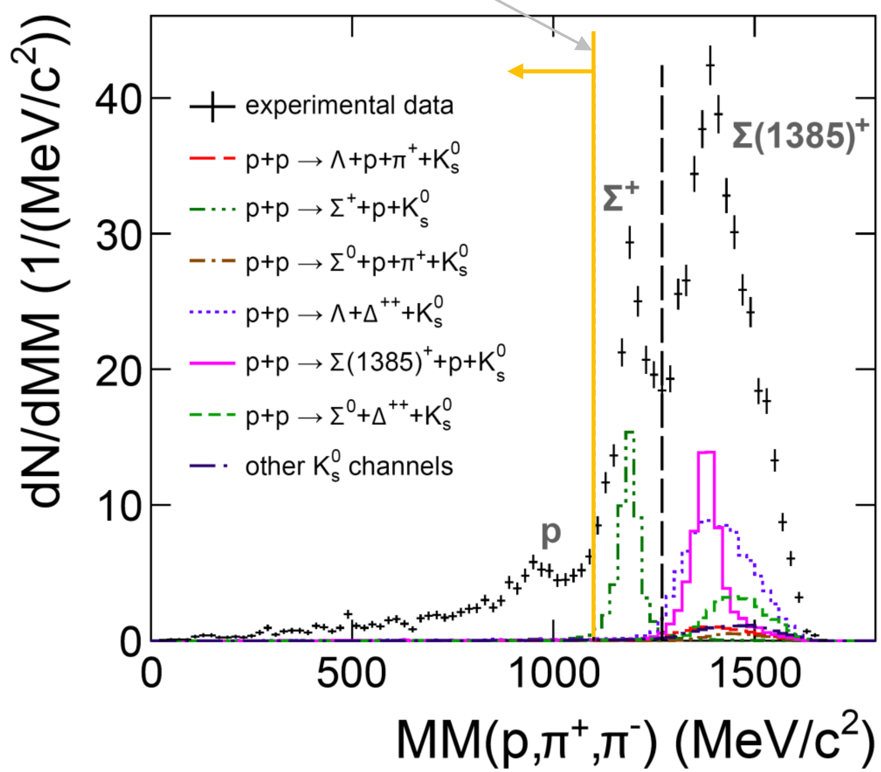


→ Not enough acceptance

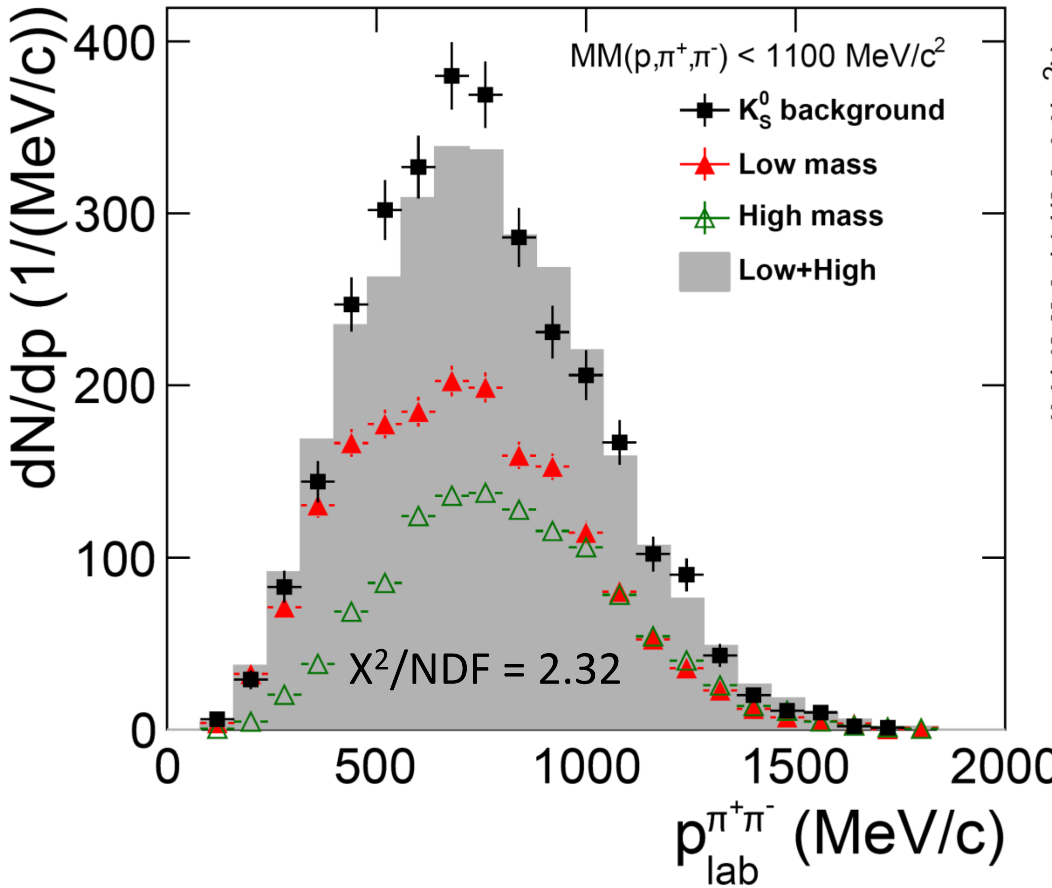
Invariant Mass (π^+, π^-) & MM(p,π^+,π^-)

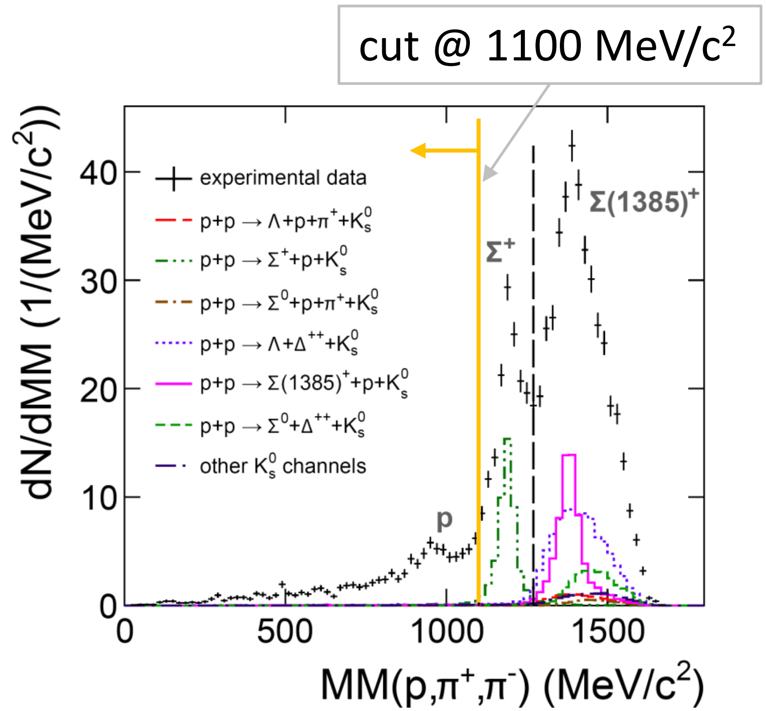
cut @ 1100 MeV/c^2 for background selection





Fit Sideband Sample to Momentum of K_S^0 Background





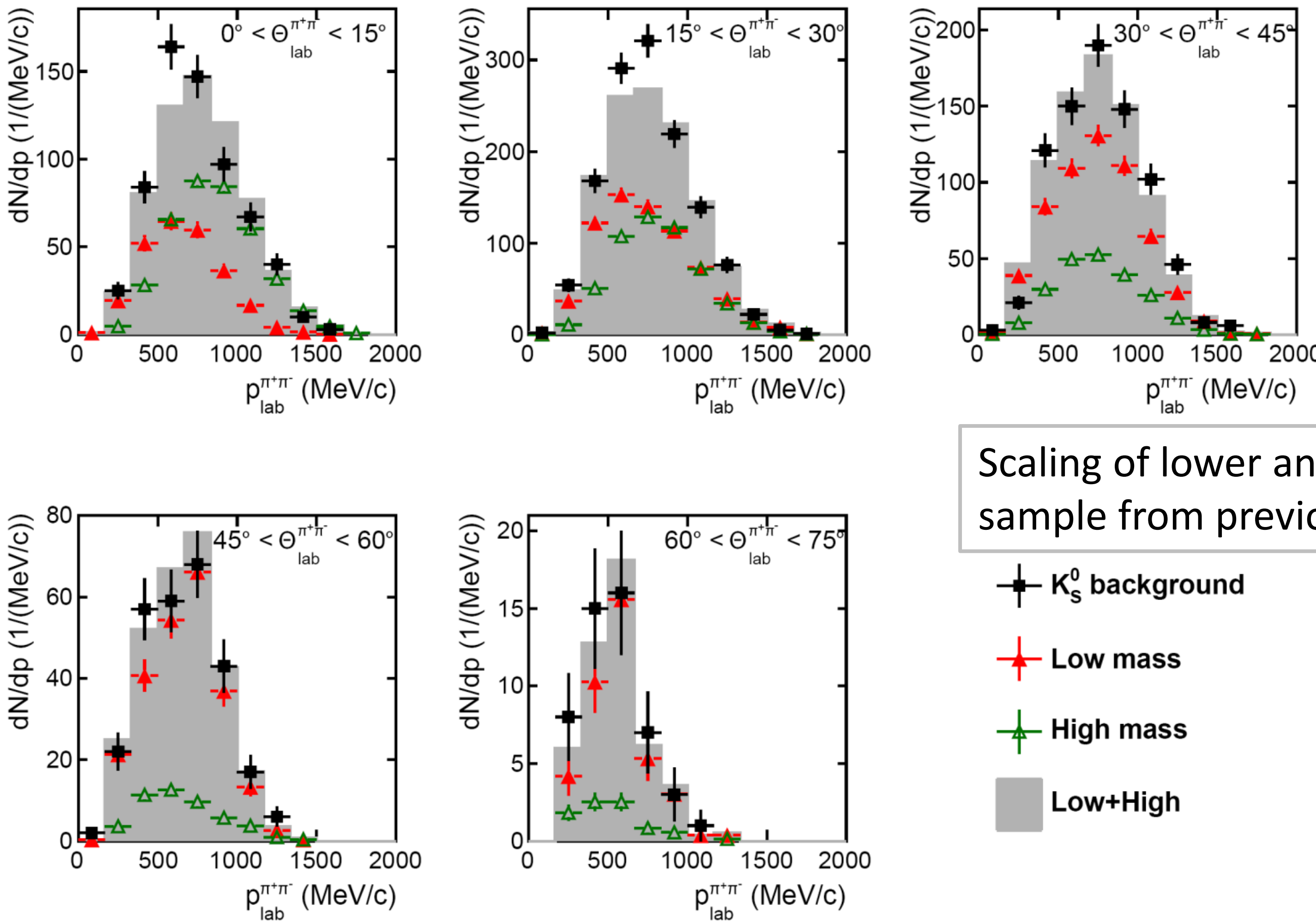
→ Sample without K_S^0

Both sideband samples fitted together to K_S^0 background.

→ Relative weight of the sideband samples to total sideband

dPdΘ Comparison

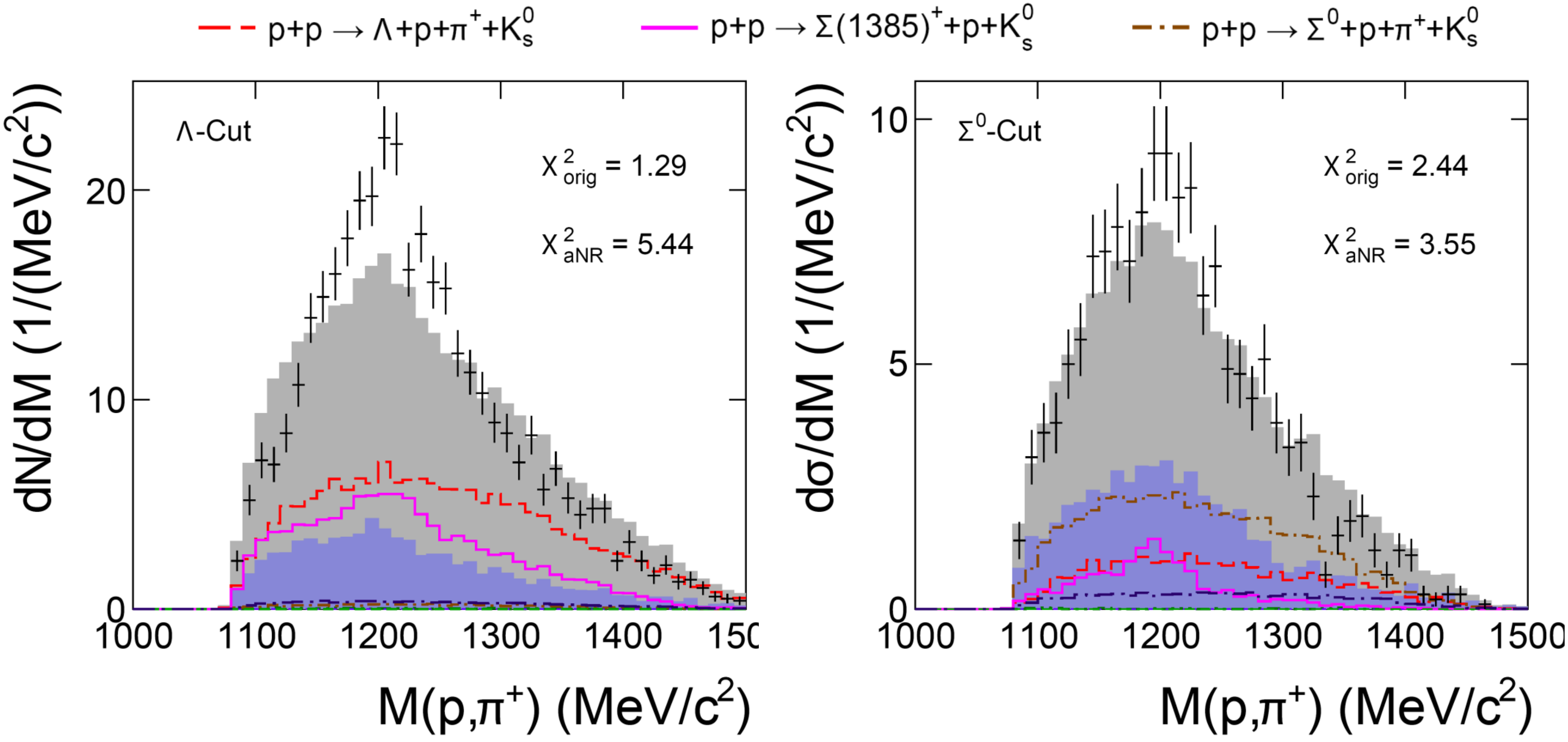
Sideband Sample vs. K^0_S Background



Scaling of lower and upper sample from previous fit!

M(p, π⁺) total strength to non-resonant

- in ACCEPTANCE -

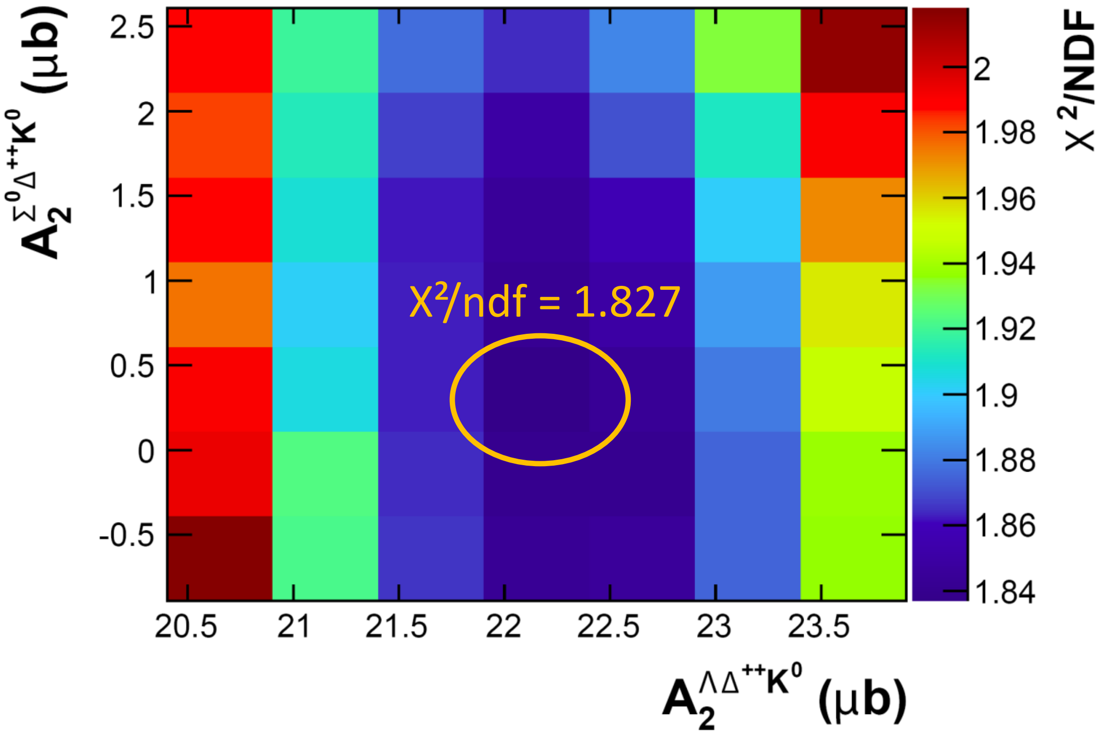


Variation of the A_2 Coefficient

Legendre polynomial:

$$y = \boldsymbol{A_0} + \boldsymbol{A_1}x + \boldsymbol{A_2}\tfrac{1}{2}(3x^2 - 1) + \boldsymbol{A_3}\tfrac{1}{2}(5x^3 - 3x) + \boldsymbol{A_4}\tfrac{1}{8}(35x^4 - 30x^2 + 3)$$

→ responsible for the strength of the anisotropy

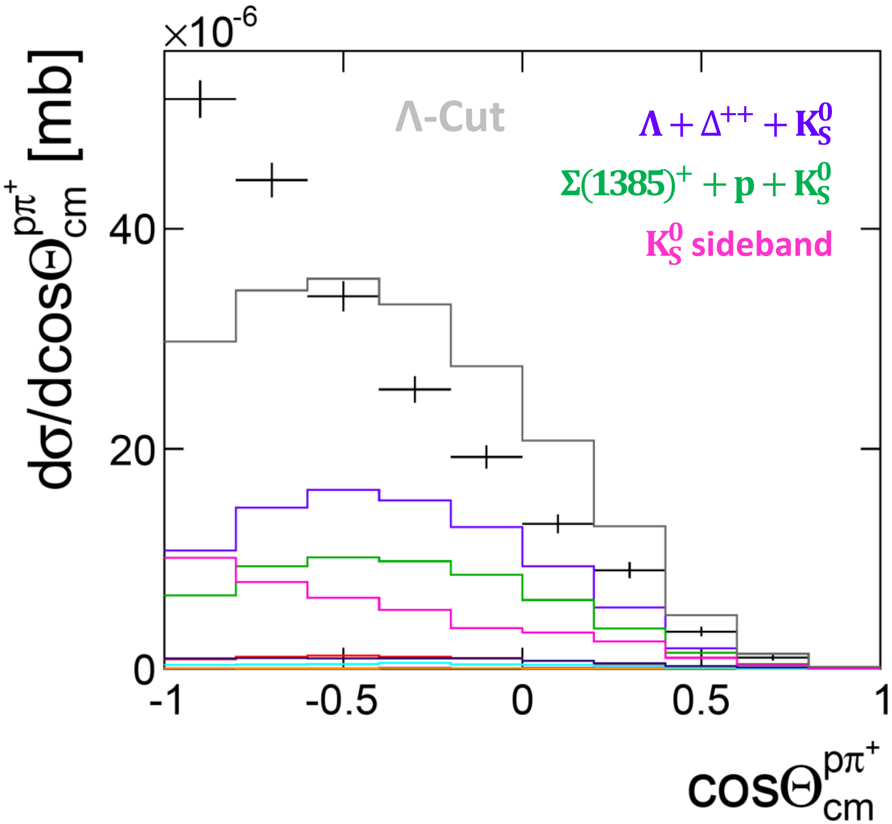


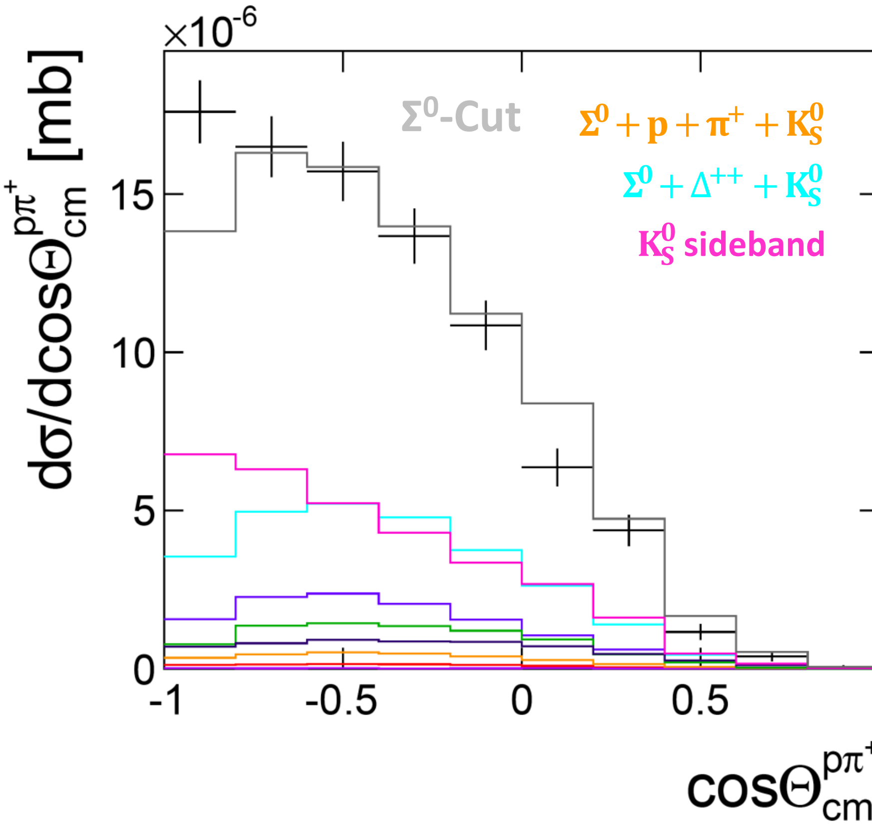
X^2/ndf for isotropic sim: 25.64

Angular Distribution of Δ^{++} Candidate

- in ACCEPTANCE -

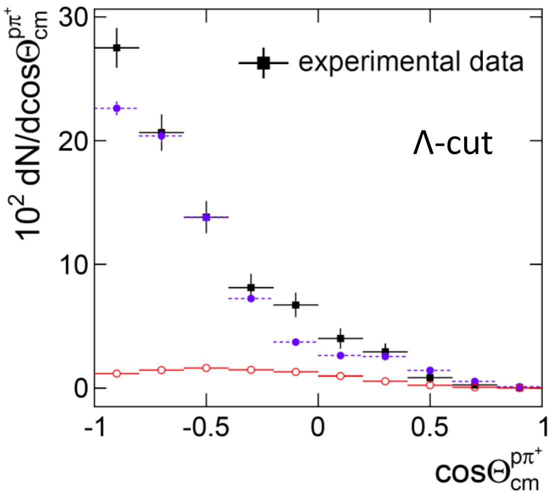
All channels simulated with **ISOTROPIC** angular distribution





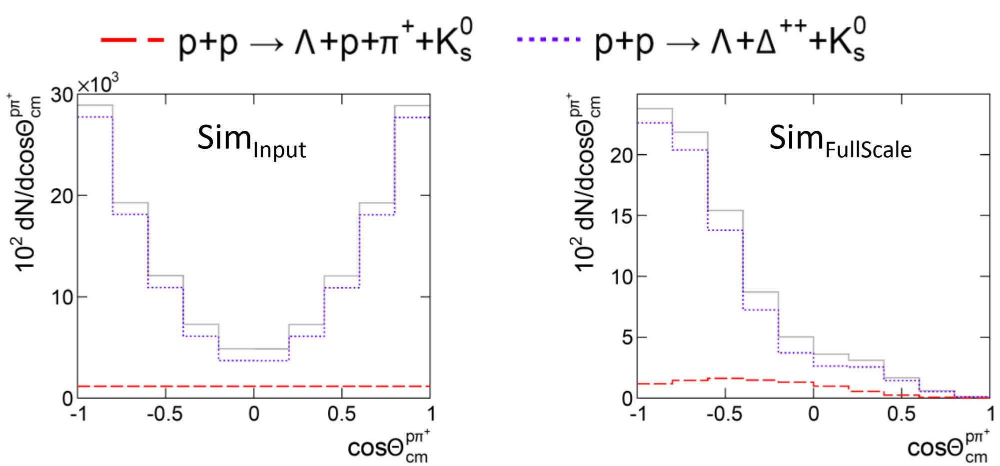
with primary vertex cut, K^0_S secondary vertex cuts & 3σ K^0_S mass cut

Correction of $\Lambda+(p+\pi^+)/\Delta^{++}+K^0$



- Subtraction of all contributions except $\Lambda+p+\pi^++K^0$ and $\Lambda+\Delta^{++}+K^0$ in experimental spectrum with Λ-selection → **assuming correct yield and angular distrubutions of subtracted channels**
- Calculating the **correction matrix from simulation** of these channels with the extracted angular distributions and cross sections

→ Analogous for Σ associated channels



Correction matrix