The Production of K^0's in p+p Reactions

for the HADES collaboration

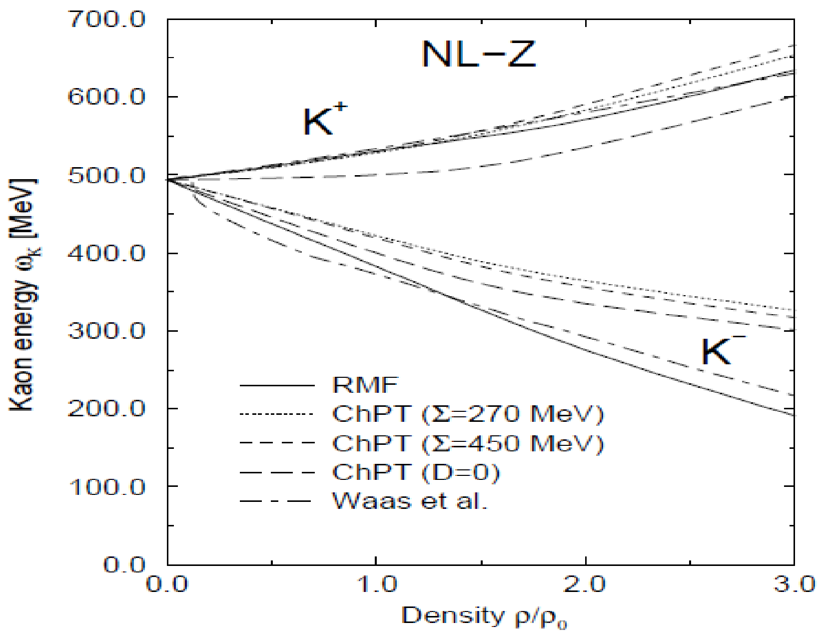
07/23/2013 – Jia-Chii Berger-Chen

TU München, Excellence Cluster Universe

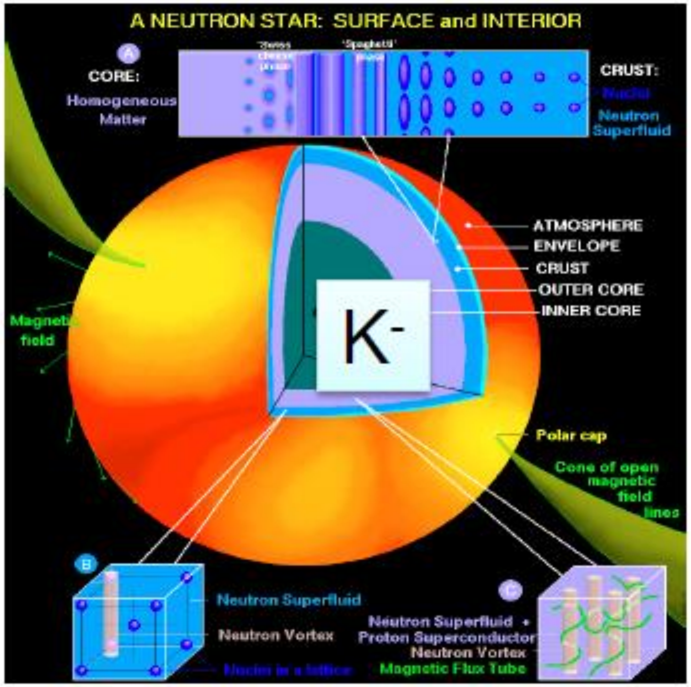
SQM 2013 Birmingham

Kaons in Medium

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



Kaplan and Nelson Phys.Lett. B 175, 57-63 (1986)



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

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

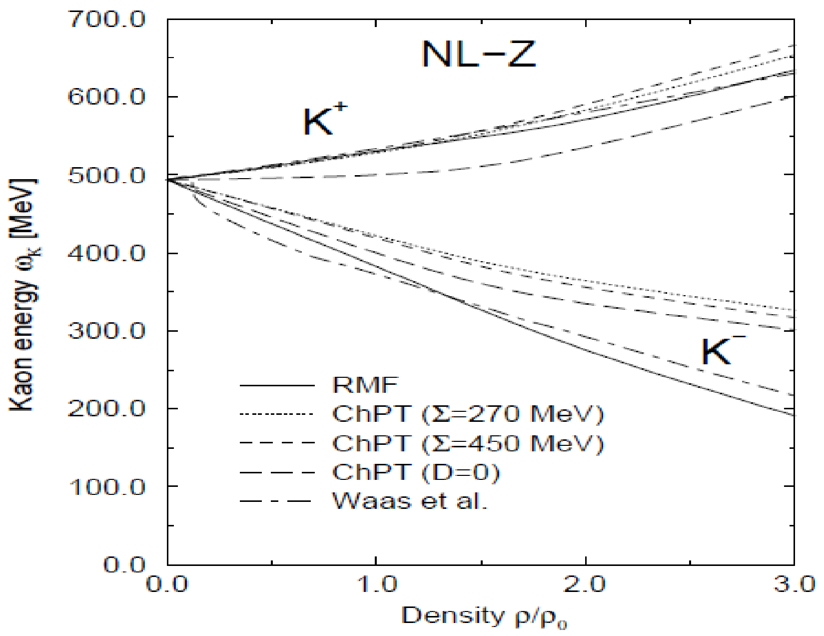
  $n \rightarrow p + K^-$

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

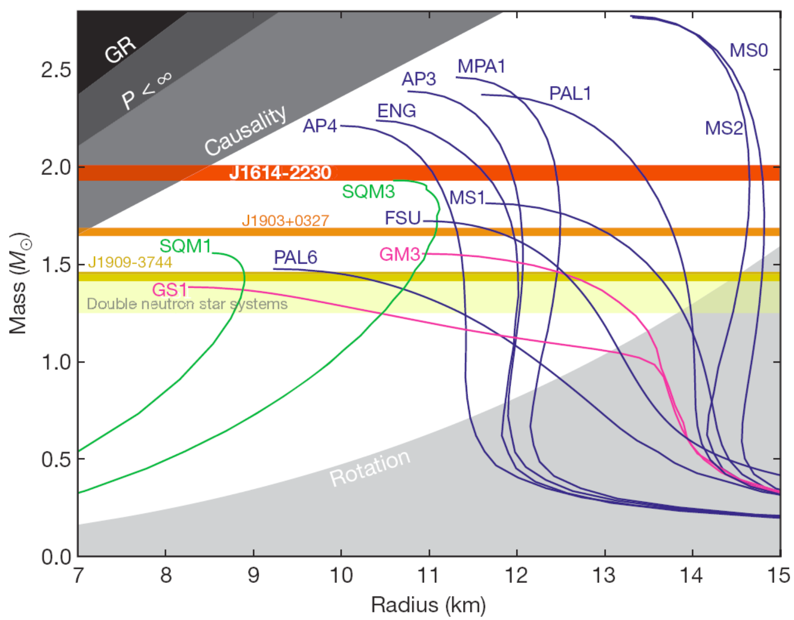
Anti-kaons in neutron stars !?

Kaons in Medium

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



Demorest et al., Nature 467 (2010)



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- High density (8-10ρ_0) in neutron stars!

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

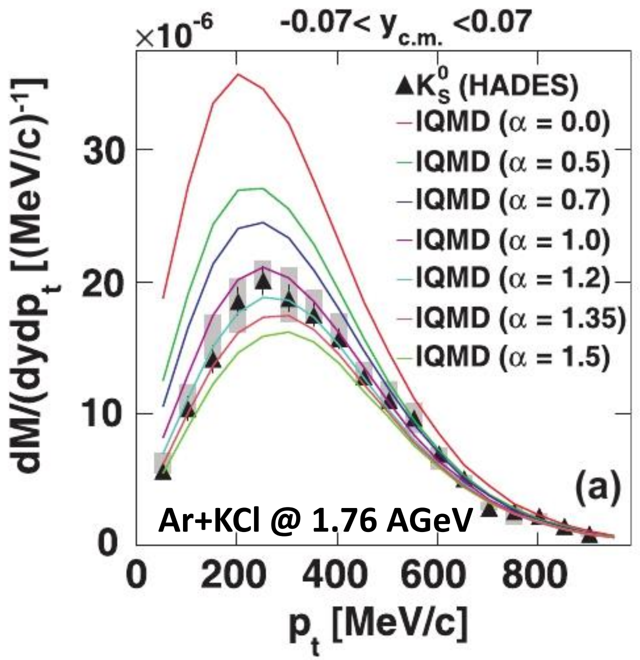
  $n \rightarrow p + K^-$

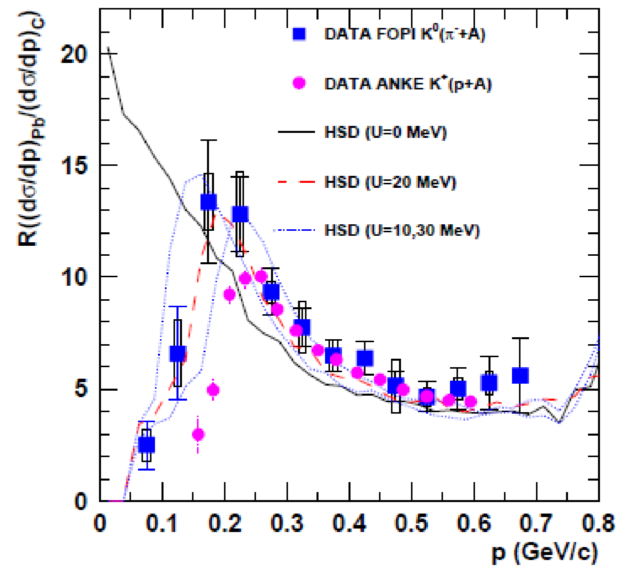
  $e^- \rightarrow K^- + \nu_e$

→ Constraint for possible EOS

Strangeness content softens EOS

Kaon Nucleon Potential

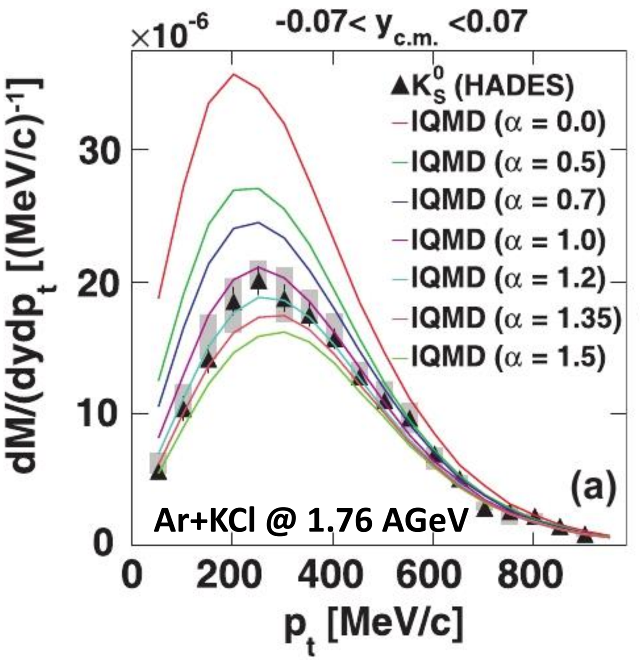


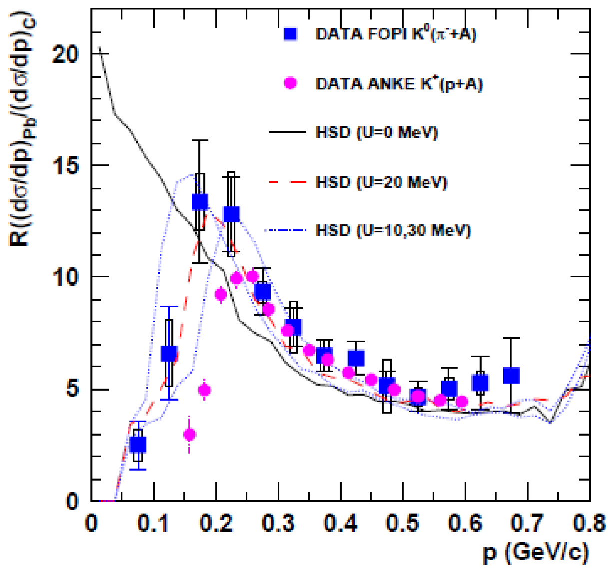


Agakishiev et al. Phys. Rev. C 82, 044907 (2010) | Büscher et al. Eur. Phys. J. A 22, 301-317 (2004)
Benabderrahmane et al. Phys. Rev. Lett. 102, 182501 (2009)

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

Kaon Nucleon Potential





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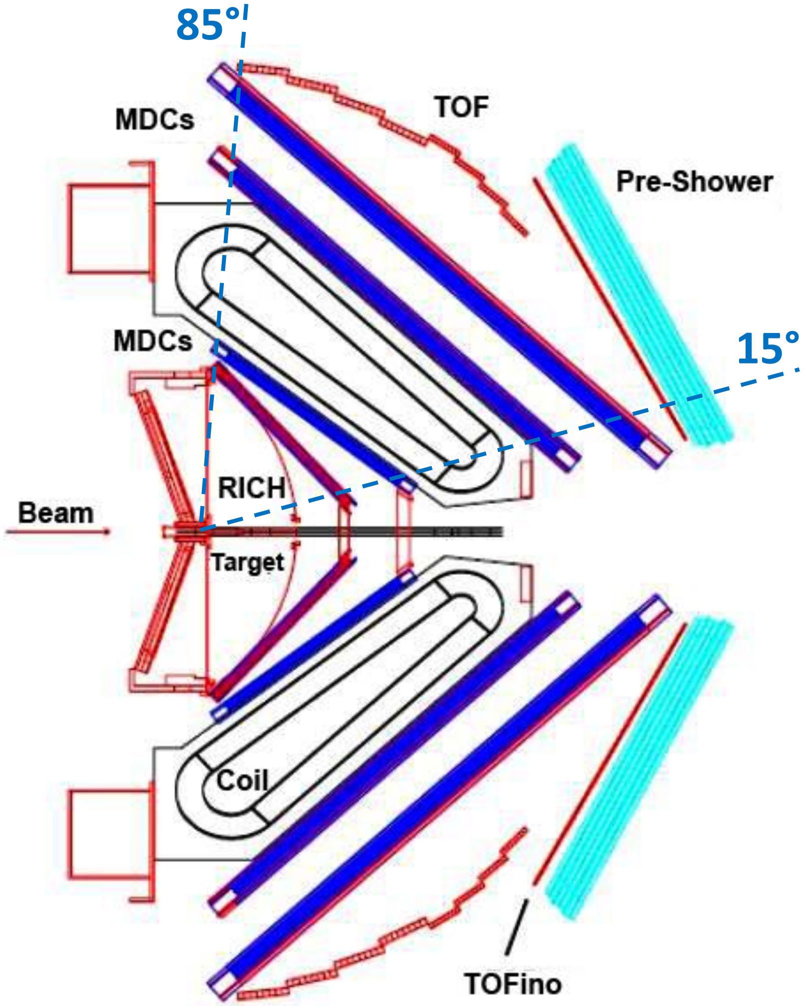
	Ar+KCl - HADES	π^-+A - FOPI	p+A - ANKE
KN potential [MeV]	39^{+8}_{-2}	20 ± 5	20 ± 3

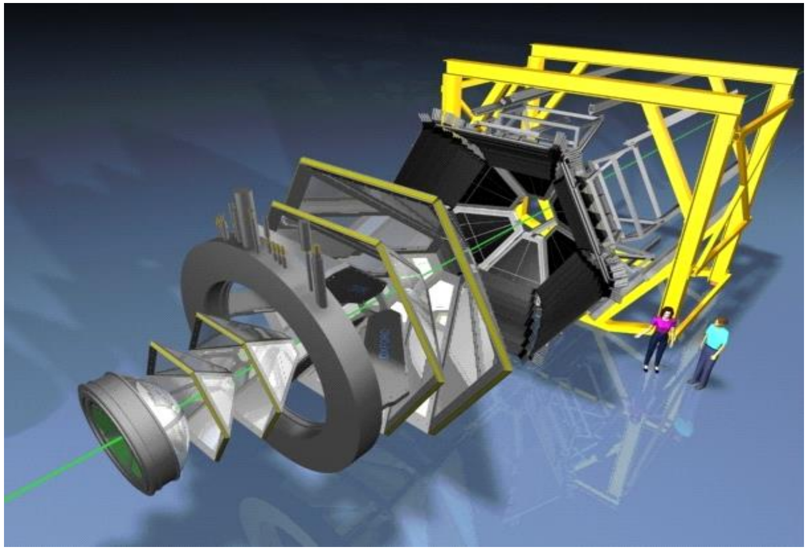
First understand elementary reactions!

The HADES Experiment @ GSI, Darmstadt



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

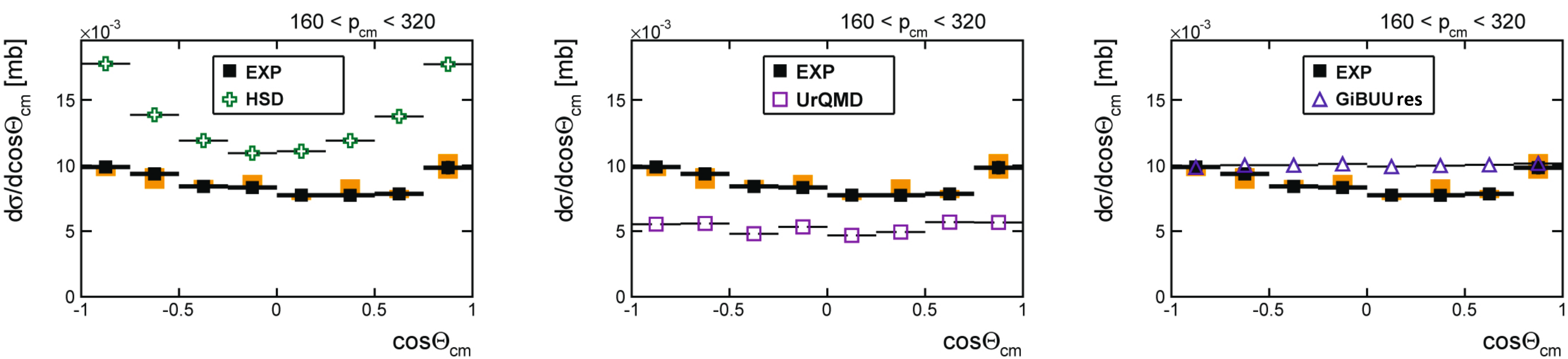
- High acceptance for dilepton pairs
- Momentum resolution ≈ 3 %
- Particle identification via dE/dx
- $1.2 \cdot 10^9$ events in p+p @ 3.5 GeV



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**

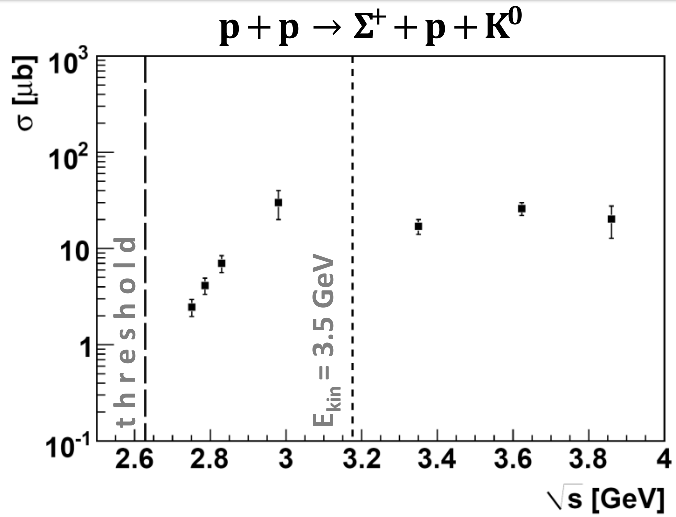
E.g. p+p @ 3.5 GeV – Inclusive K^0_S production

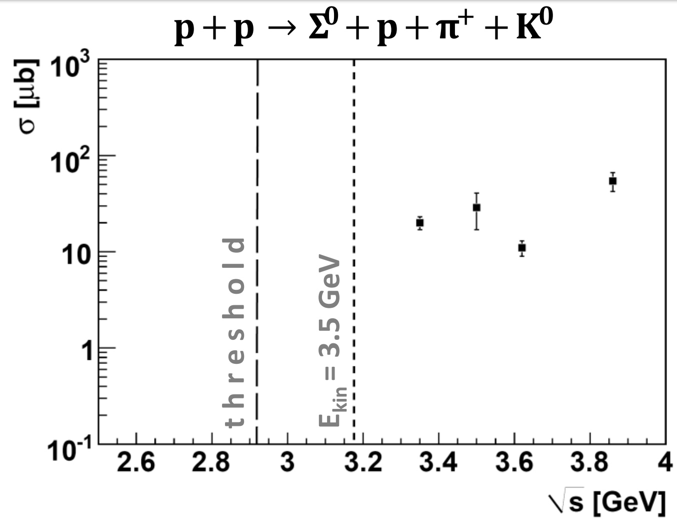


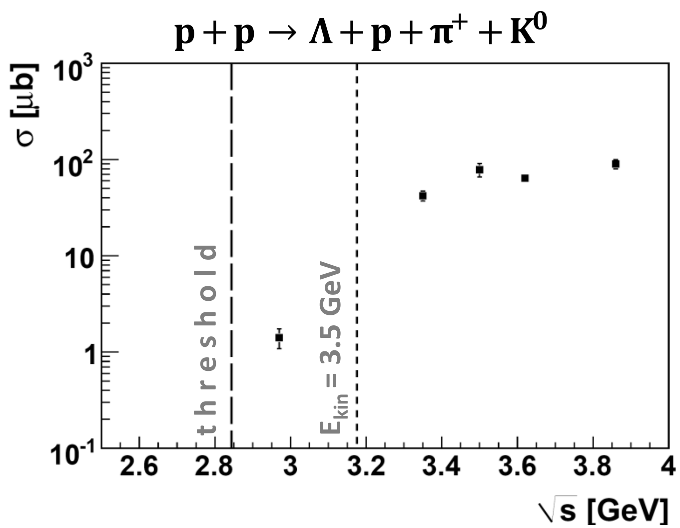
→ Neither cross sections nor angular distributions are described!

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)

Measured Exclusive Cross Sections

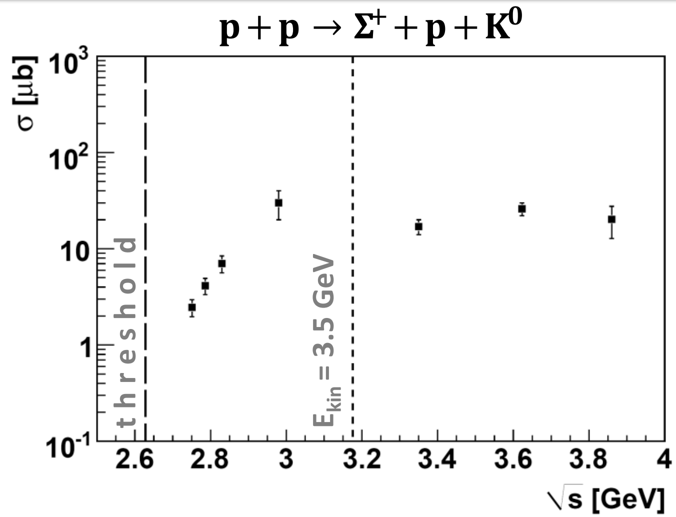


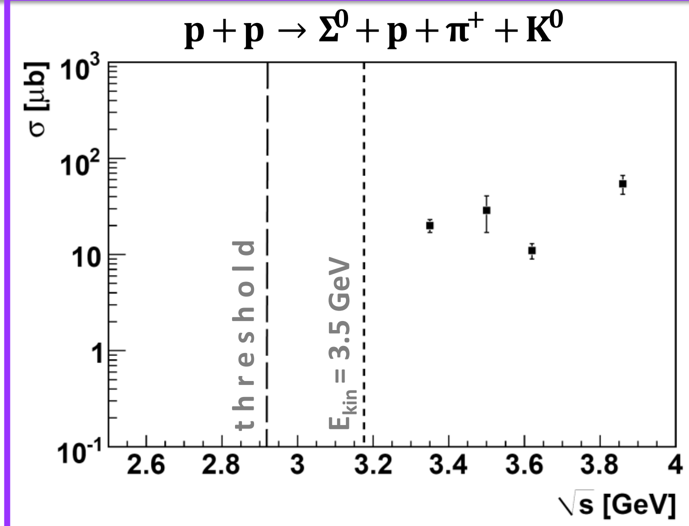


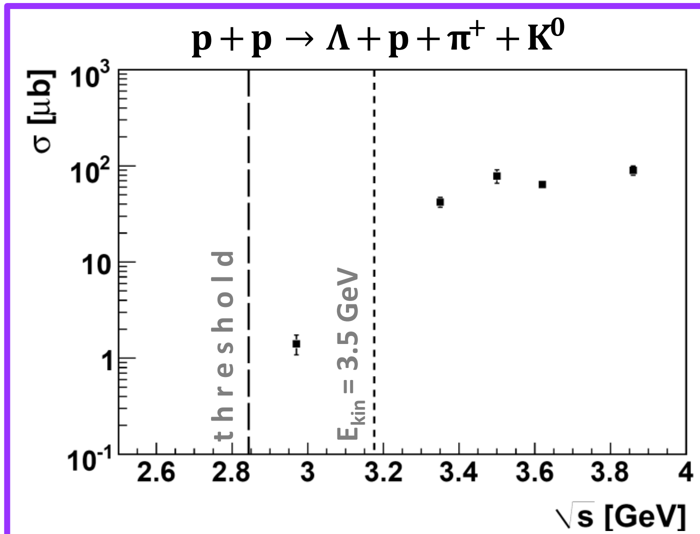


Lack of data in the region of E_{kin} = 3.5 GeV

Measured Exclusive Cross Sections







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

Contribution from resonance channels:

$p+p \rightarrow \Lambda/\Sigma^{0}+\Delta^{++}+K^{0}$

$p+p \rightarrow \Sigma(1385)^{+}+p+K^{0}$

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%

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

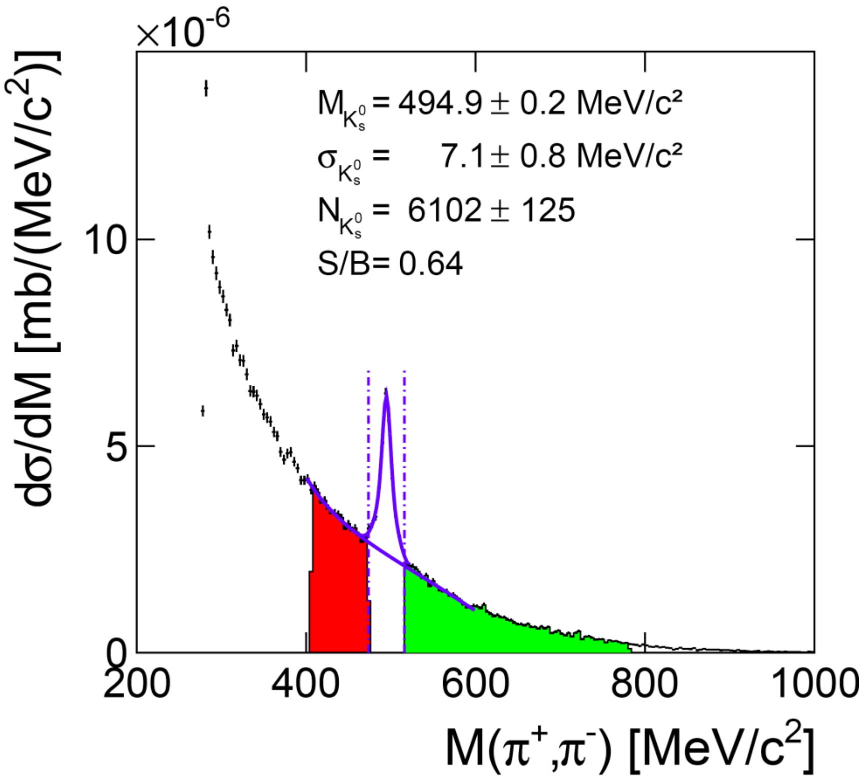
$$p + p \rightarrow \Lambda/\Sigma^0 + p + \pi^+ + K^0$$
$K^0 \rightarrow \pi^+ + \pi^-$

$$p + p \rightarrow \Sigma^+ + p + K^0$$
$K^0 \rightarrow \pi^+ + \pi^-$
$\Sigma^+ \rightarrow n + \pi^+$ 48.3%

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

$\rightarrow$ Background (non-strange channels and combinatorics) described by K^0 sideband sample

Invariant Mass (π^+, π^-)



Data sample:
events with 4 particles (p, π^+, π^+, π^-)
and applied secondary vertex cuts

→ Interesting events within
3σ-region around the K^0_S peak

Low mass and high mass sideband events used for background description.

→ Same kinematics as the background in the K^0_S mass region required for the events within the sideband sample!

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%

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

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- $K^0 \rightarrow \pi^+ + \pi^-$
- $\Sigma^+ \rightarrow n + \pi^+$ 48.3%

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

$\longrightarrow$ Background (non-strange channels and combinatorics) described by K^0 sideband sample

Simultaneous Fit of all Contributions over 5 Observables

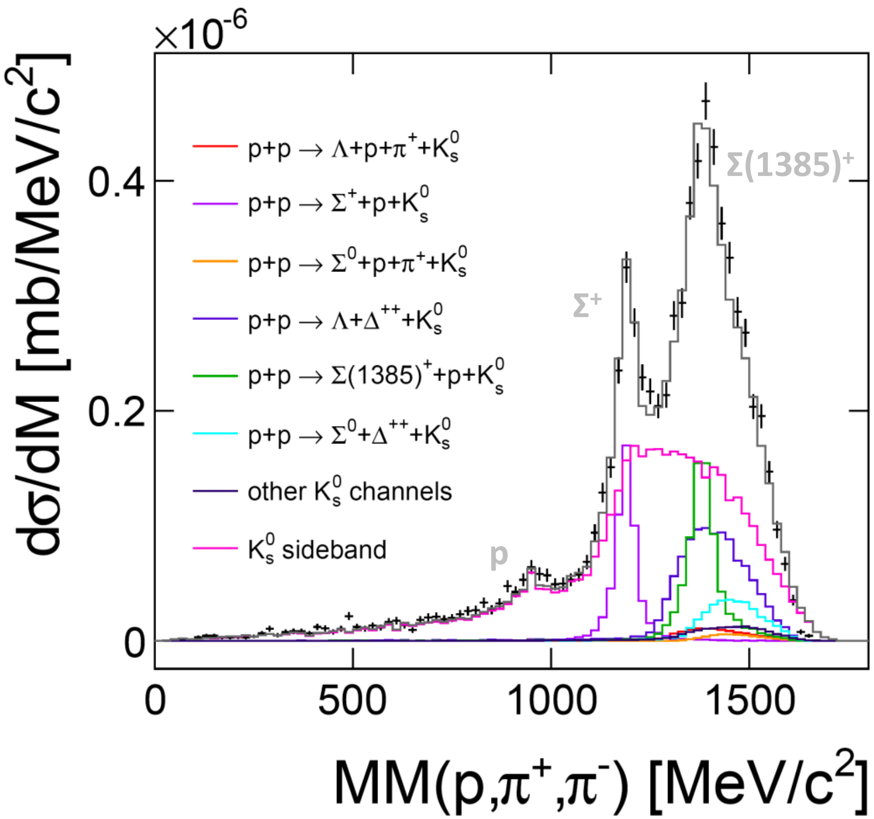
(3 missing mass, 2 invariant mass)

Constraint to the fit: sideband sample allowed to vary within ± 30%
→ X^2/NDF = 2.57

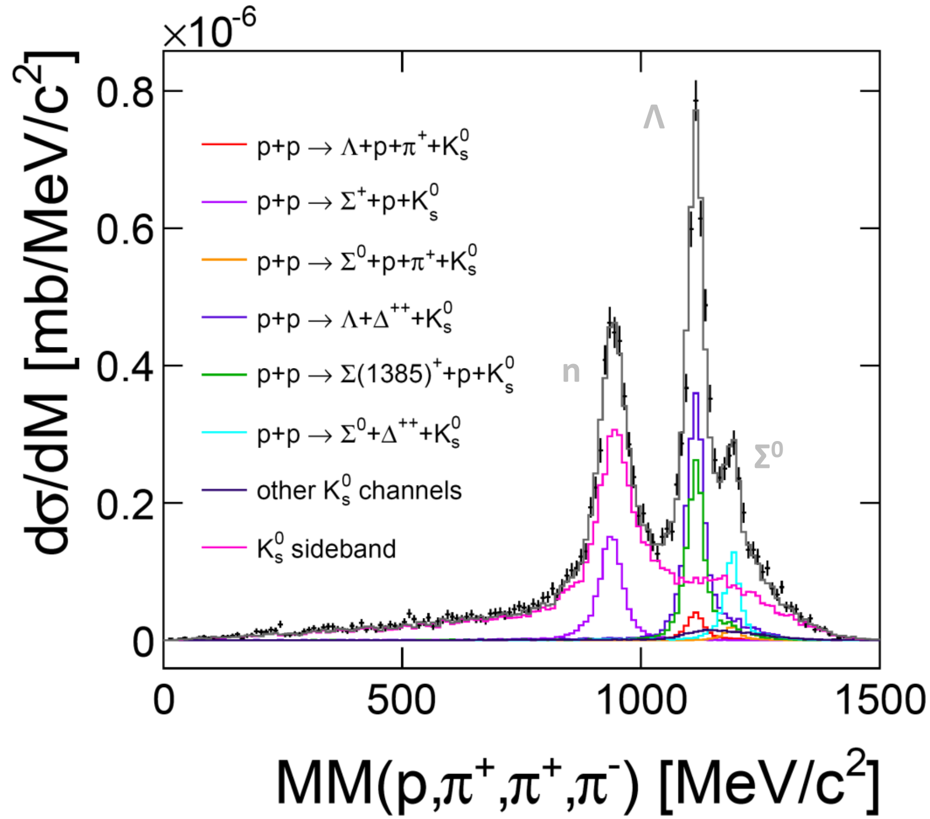
MM(p,π⁺,π⁻) and MM(p,π⁺,π⁺,π⁻)

- in ACCEPTANCE -

1st fitted observable

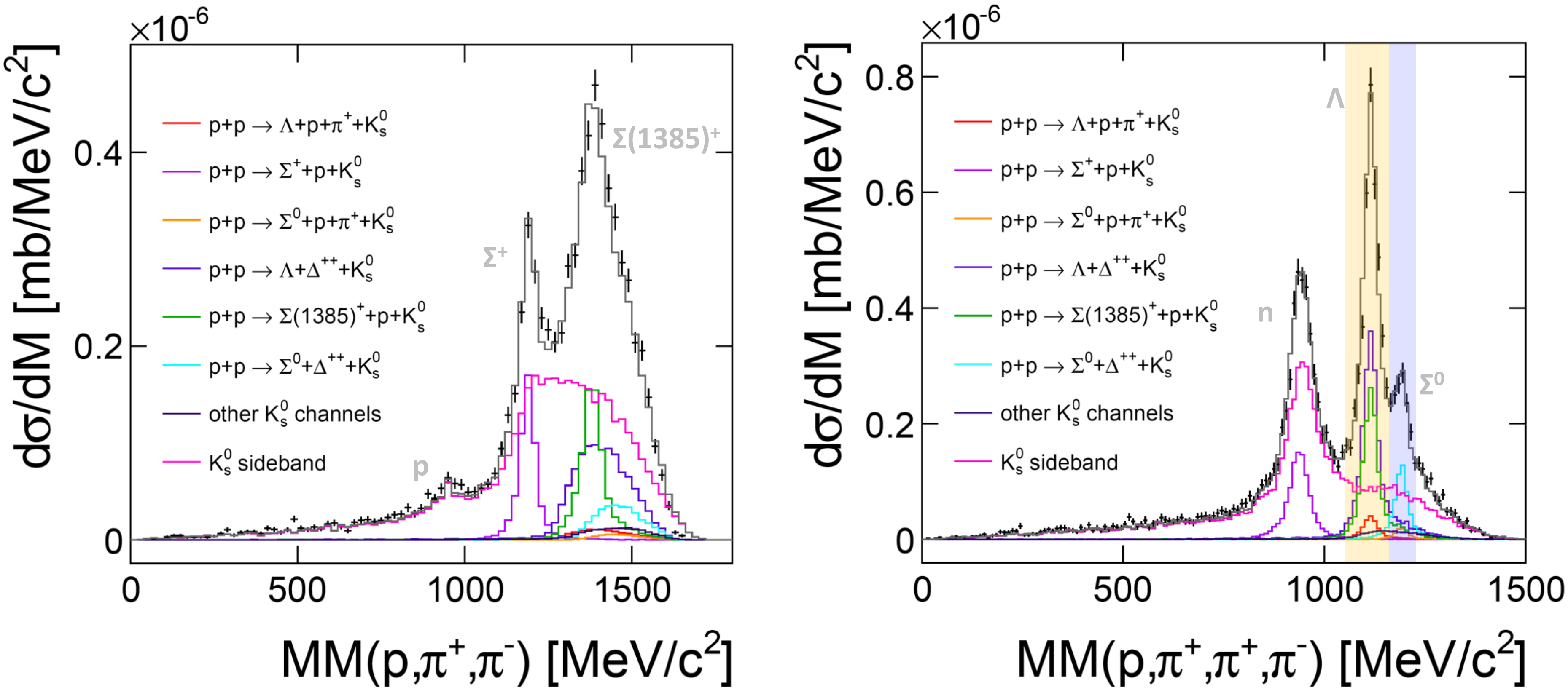


2nd fitted observable



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

MM(p,π⁺,π⁻) and MM(p,π⁺,π⁺,π⁻)
- in ACCEPTANCE -

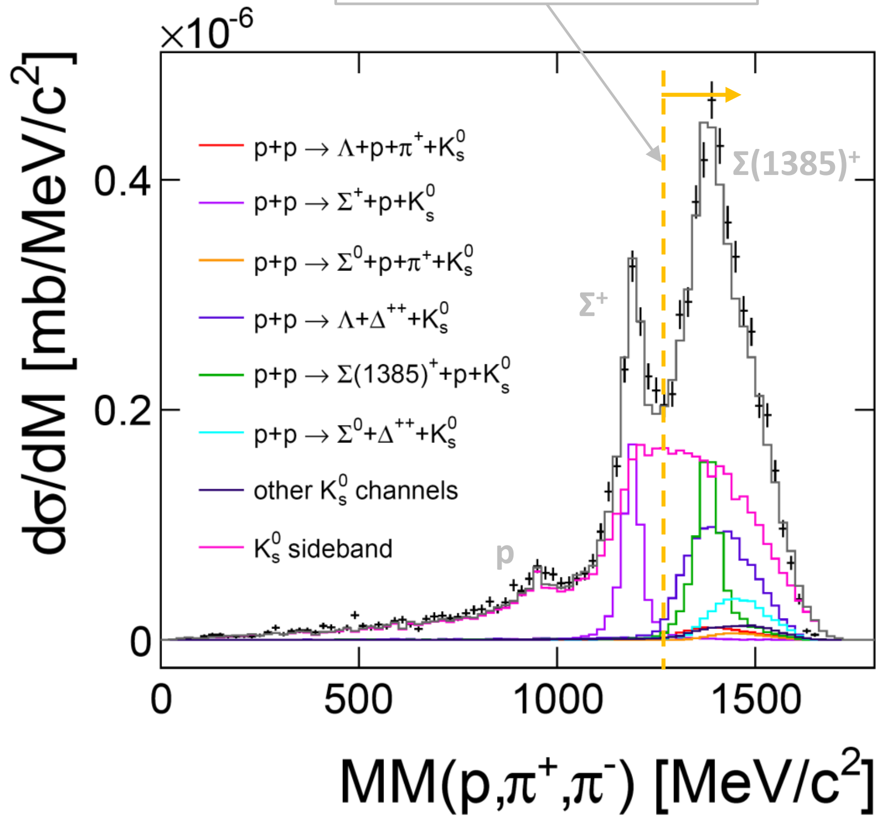


with primary vertex cut, K_S^0 secondary vertex cuts & 3σ K_S^0 mass cut

MM(p,π⁺,π⁺,π⁻) with cut on MM(p,π⁺,π⁻)

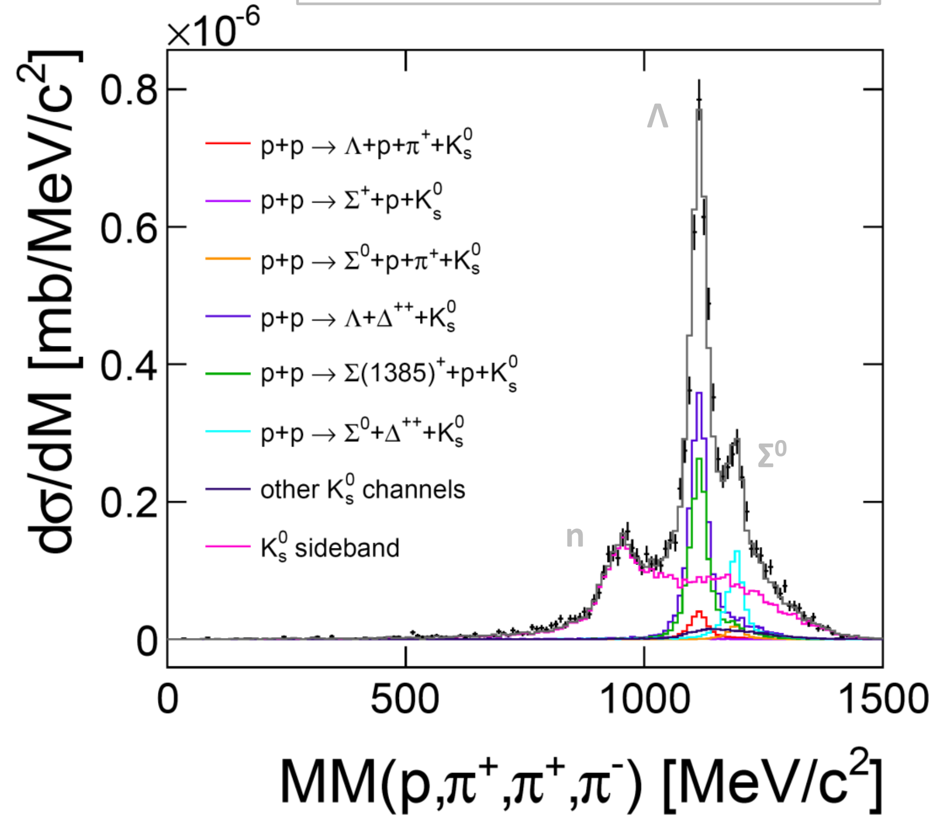
- in ACCEPTANCE -

cut @ 1270 MeV/c²



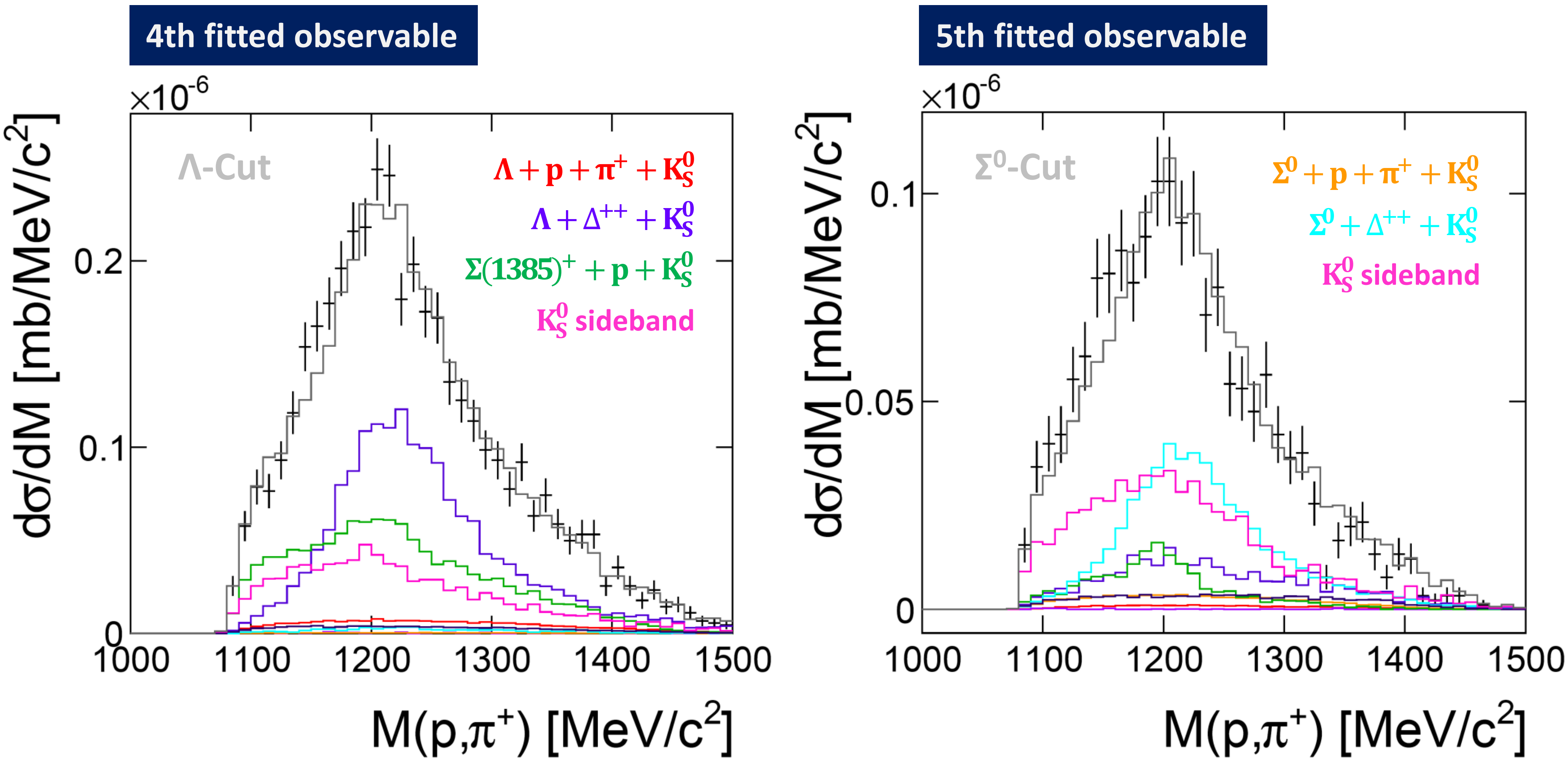
3rd

MM(p,π⁺,π⁻) > 1270 MeV/c²



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

IM(p, π^+)
- in ACCEPTANCE -



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

Angular Distributions

Scaling from simult. fit used for simulation

Including Angular Anisotropy

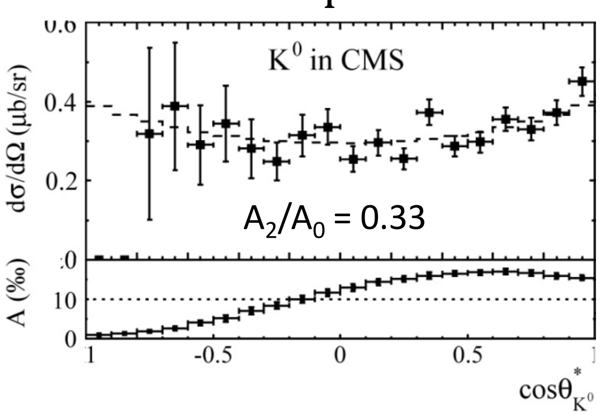
$p + p \rightarrow \Sigma^{+} + p + K^{0}$: from COSY-TOF at E_{kin} = 2.26 GeV

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

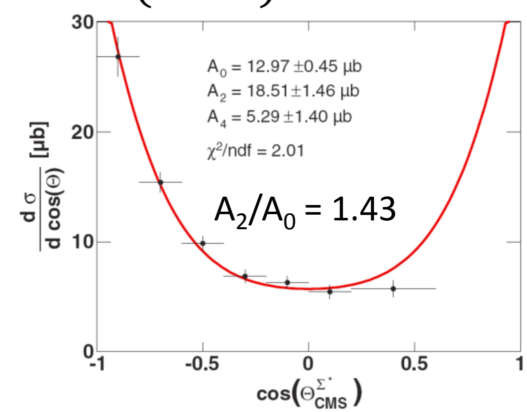
$p + p \rightarrow \Lambda + \Delta^{++} + K^{0}$: from minimization of $\cos\theta_{cm}^{p\pi^{+}}$

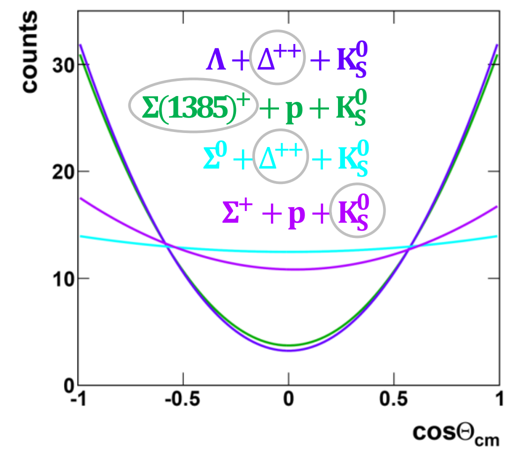
$p + p \rightarrow \Sigma^{0} + \Delta^{++} + K^{0}$: from minimization of $\cos\theta_{cm}^{p\pi^{+}}$

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



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

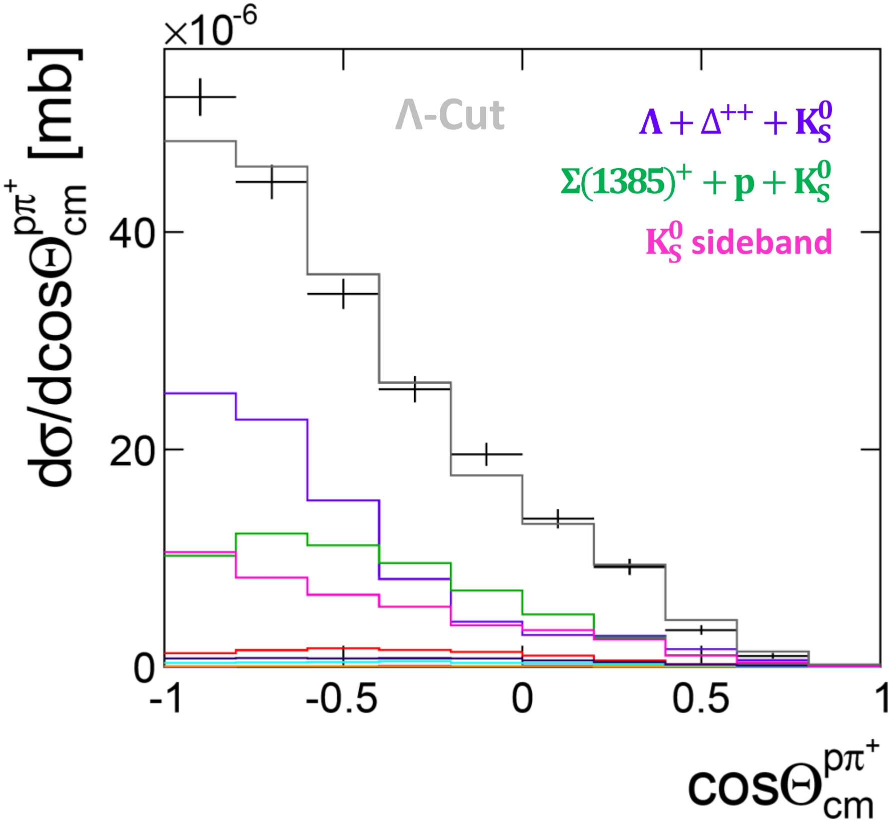


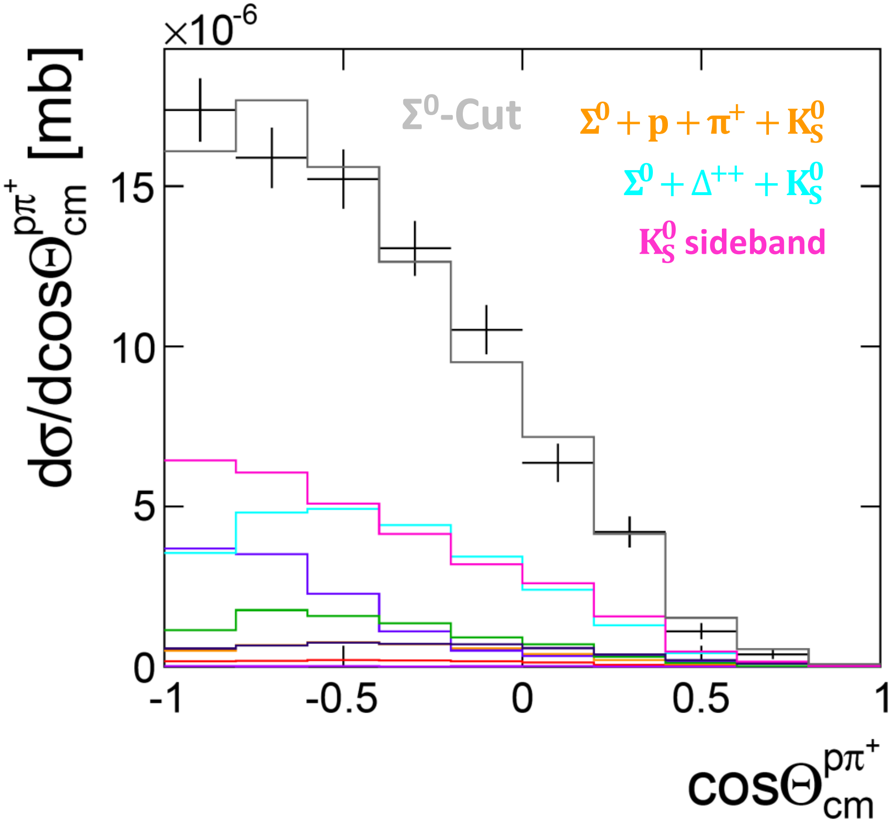


Abdel-Bary et al., arXiv:1202.4108v1 [nucl-ex] | Agakishiev et al., Phys. Rev. C 85, 035203 (2012)

Angular Distribution of Δ^{++} Candidate

- in ACCEPTANCE -





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

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 constraint on sideband contribution in simultaneous fit (±10%, ±20%, ±40%, ±50%,)

Cross Sections

Reaction: $p + p \rightarrow$	**$AV_{anisotropic}$: $\sigma_{sim.fit}$ [μb]**
$\Lambda + p + \pi^{+} + K^{0}$	$\mathbf{2.57} \pm 0.02^{+1.26}_{-1.98} \pm 0.18$
$\Lambda + \Delta^{++} + K^{0}$	$\mathbf{29.45} \pm 0.08^{+1.67}_{-1.46} \pm 2.06$
$\Sigma^{0} + p + \pi^{+} + K^{0}$	$\mathbf{1.35} \pm 0.02^{+1.64}_{-1.35} \pm 0.09$
$\Sigma^{0} + \Delta^{++} + K^{0}$	$\mathbf{9.26} \pm 0.05^{+1.41}_{-1.10} \pm 0.65$
$\Sigma^{+} + p + K^{0}$	$\mathbf{26.27} \pm 0.64^{+2.12}_{-4.41} \pm 1.84$
$\Sigma(1385)^{+} + p + K^{0}$	$\mathbf{14.35} \pm 0.05^{+1.79}_{-2.14} \pm 1.00$

systematic uncertainties from normalization to elastics

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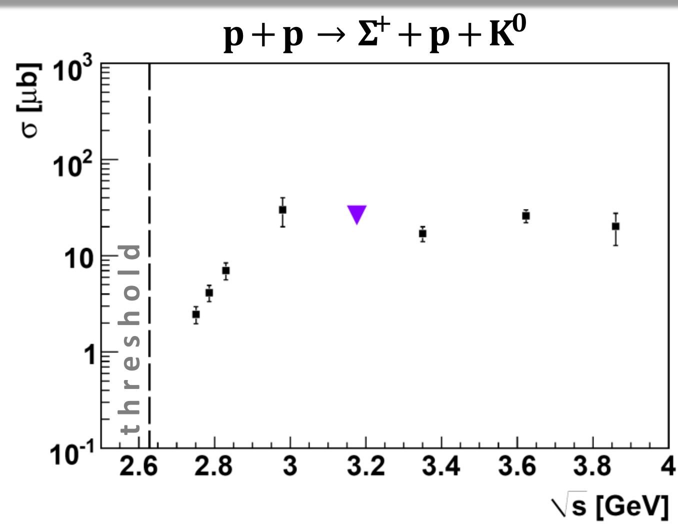
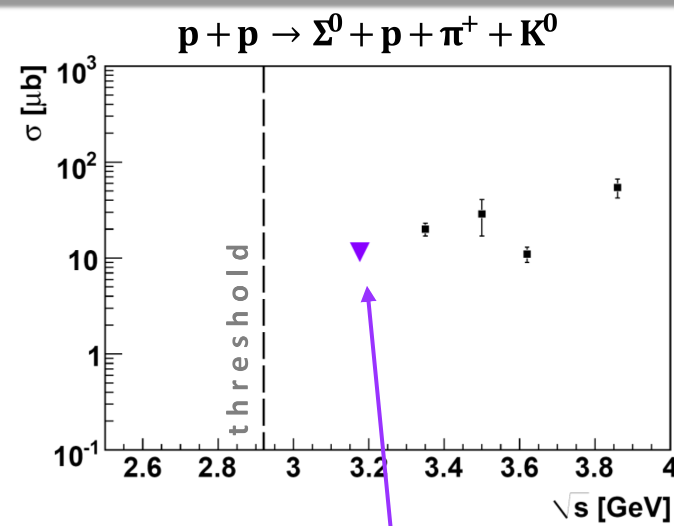
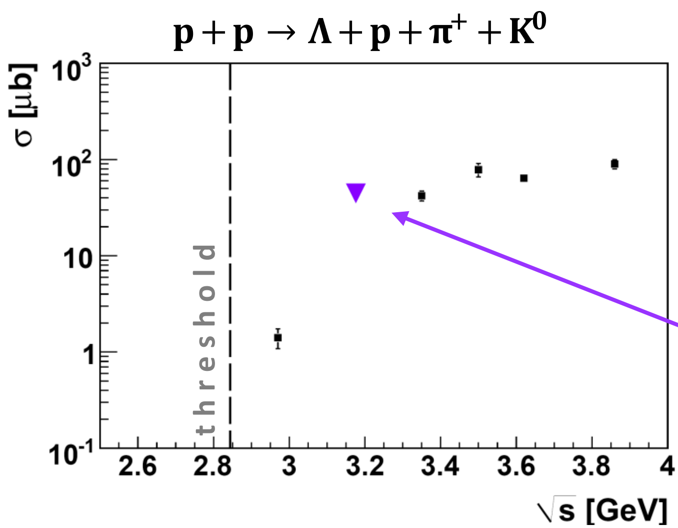
systematic uncertainties from normalization to elastics

Cross Sections compared to World Data





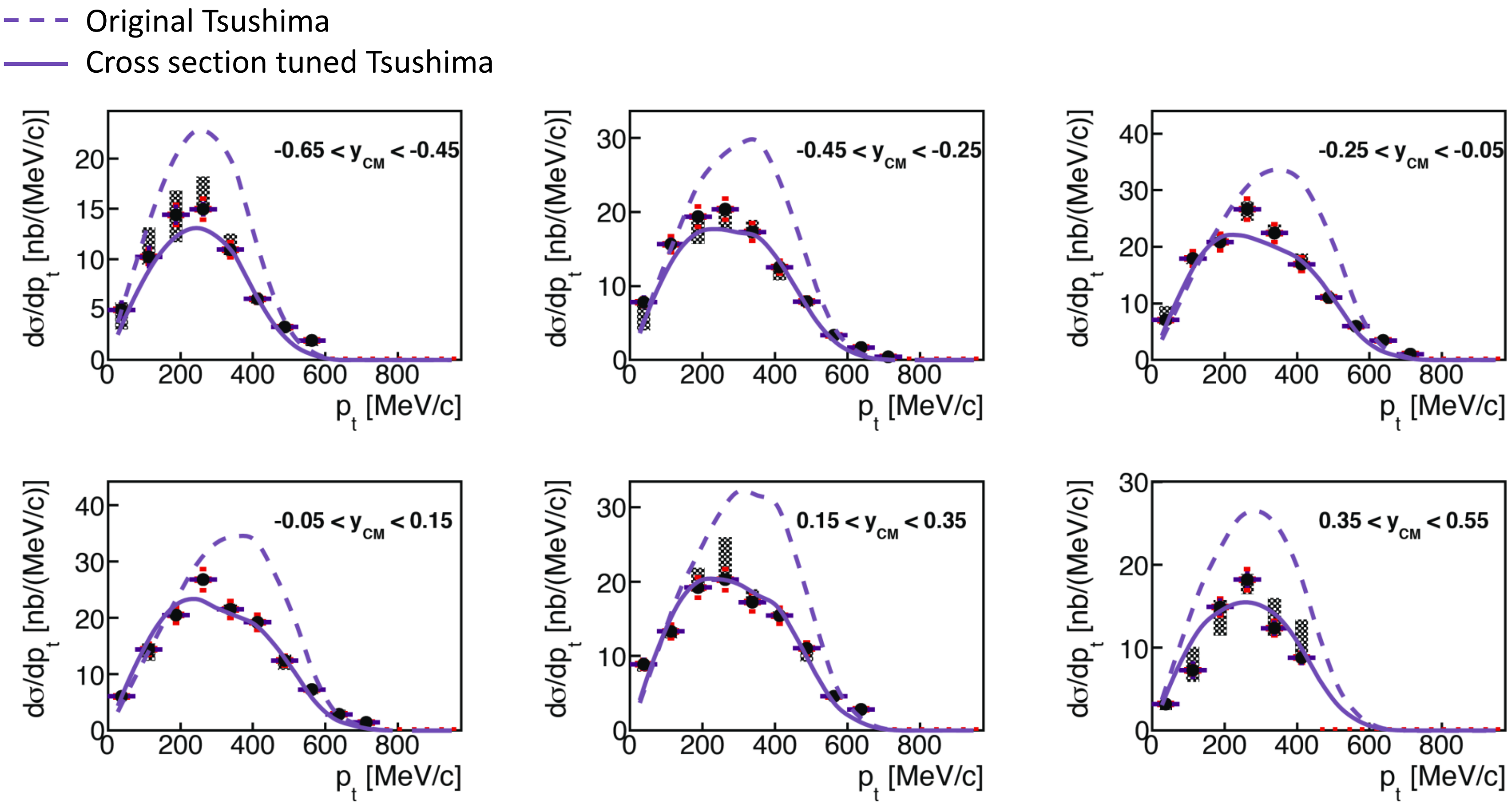


Sum of cross sections:

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

$p + p \xrightarrow{3.5\text{GeV}} K^0 + X$: Exp vs. $\text{GiBUU}_{\text{res}}$



Cross section tuned model in agreement with experimental data!

Summary & Outlook

SUMMARY:

- Contribution by Δ^{++} determined in p+p @ 3.5 GeV
- Other K^0 production channels with Σ^+ and $\Sigma(1385)^+$ can be studied
- Angular distributions are determined

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

  $\rightarrow \Sigma^0 + \Delta^{++} + K^0$ has less anisotropy
- Experimental data nicely reproduced by simulations and K^0 sideband
- Extraction of cross sections for all channels $\rightarrow$ **resonant channels dominating**
- Cross section tuned GiBUU reproduces inclusive K^0 production in p+p

OUTLOOK:

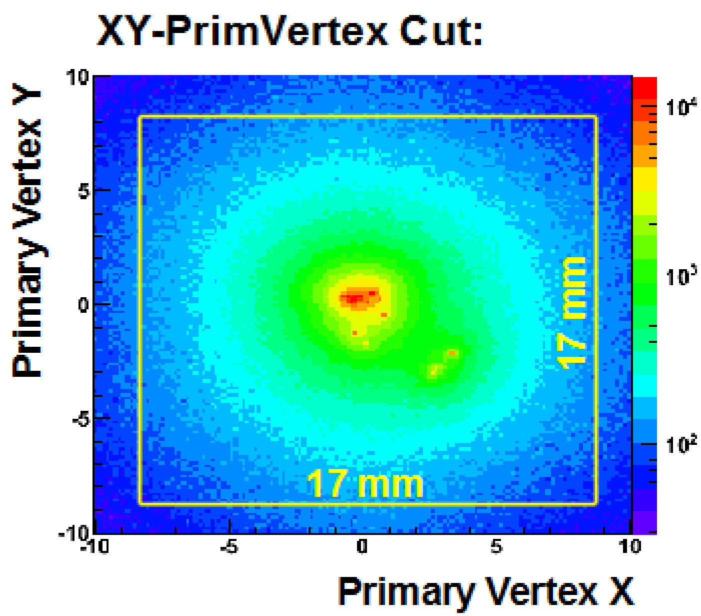
- Understand the difference of the angular anisotropy in Λ or Σ^0 production
- Publish the results

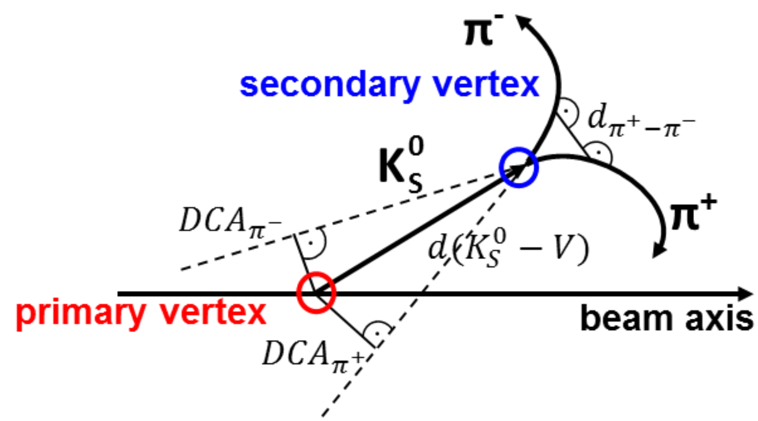
Thank you for your attention!
☺

Back Up

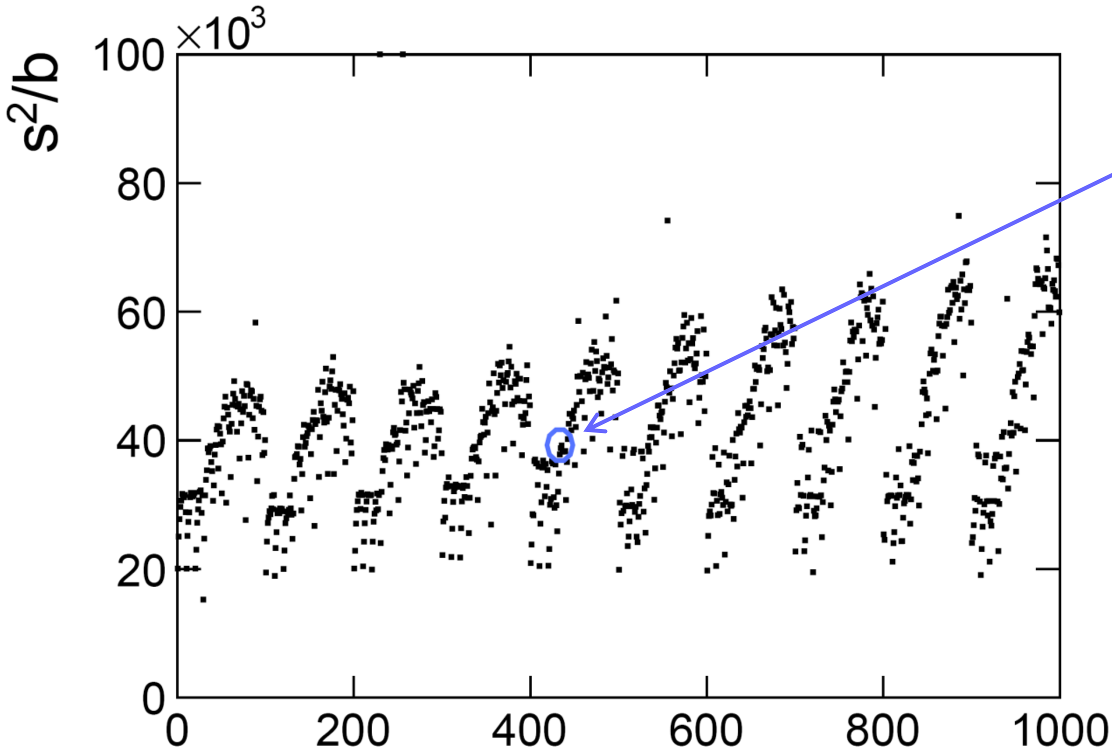
K_S^0 Analysis Steps

1. Particle identification via graphical cuts on MDC dE/dx
2. Reconstruction of the K_S^0 using $\pi^+\pi^-$ pairs
3. Application of primary vertex cuts (x,y: beam axis ± 8.5cm, z: -10…-70cm)
4. Application of secondary vertex cuts
   ($d_{\pi^+-\pi^-}$ < 7mm, $d(K_S^0 - V)$ > 25mm, DCA_{π^+} > 7mm, DCA_{π^+} > 7mm)





K_S^0 secondary vertex cut variation

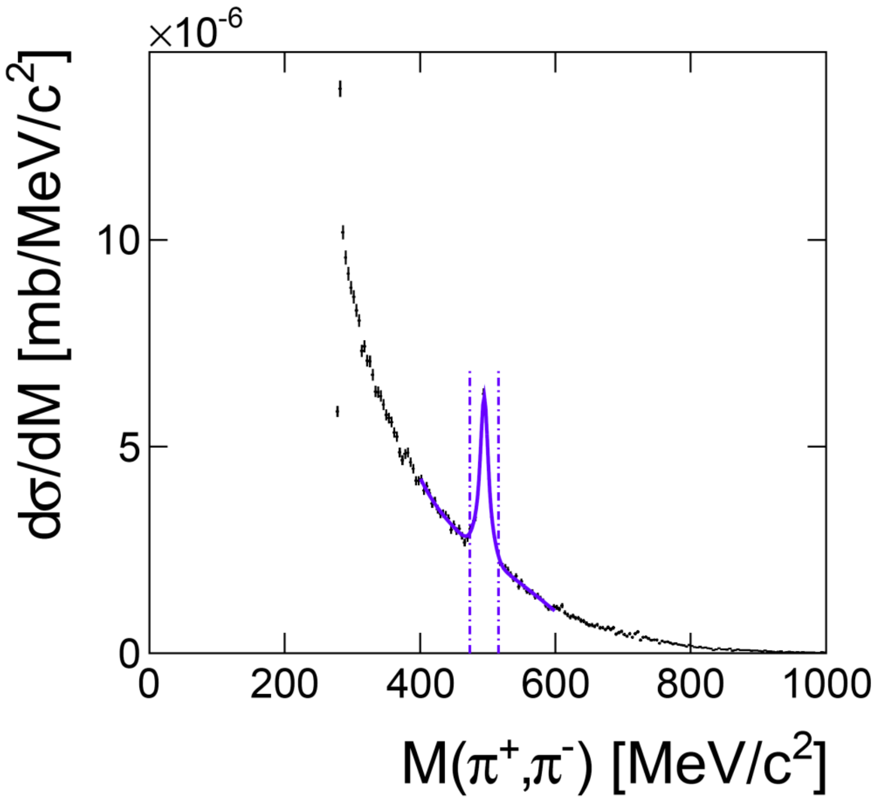


$d_{\pi^+-\pi^-}$ + 10*$d(K_S^0 - V)$ + 100*DCA_{π^+/π^-}

$d_{\pi^+-\pi^-}$ < 7mm
$d(K_S^0 - V)$ > 25mm
DCA_{π^+} > 7mm
DCA_{π^+} > 7mm)

Sideband Analysis

Invariant Mass (π^+, π^-)

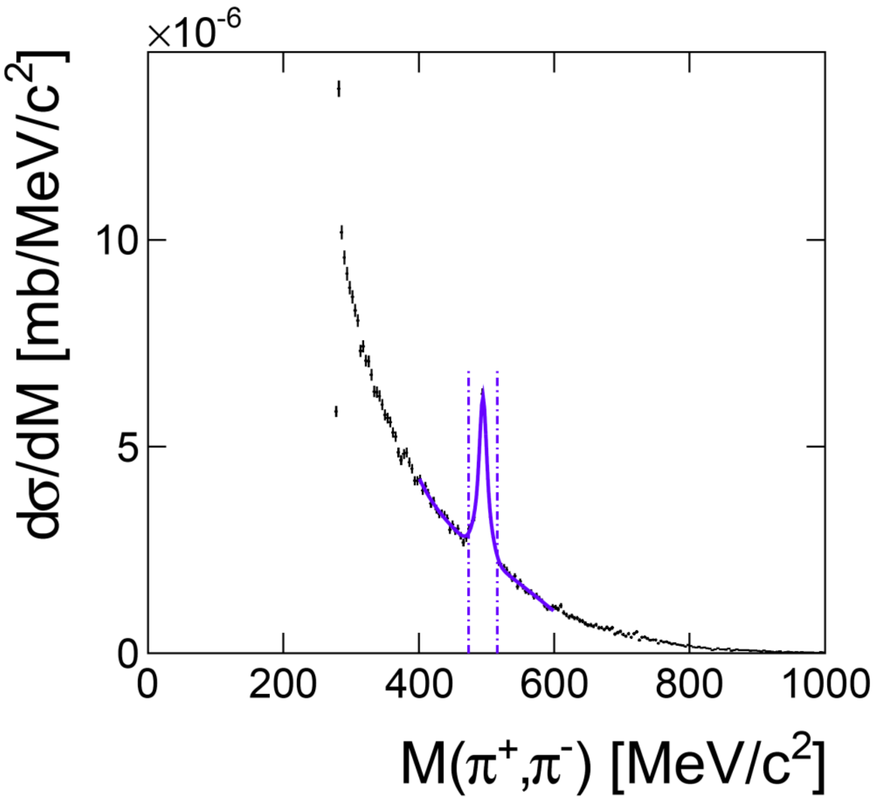


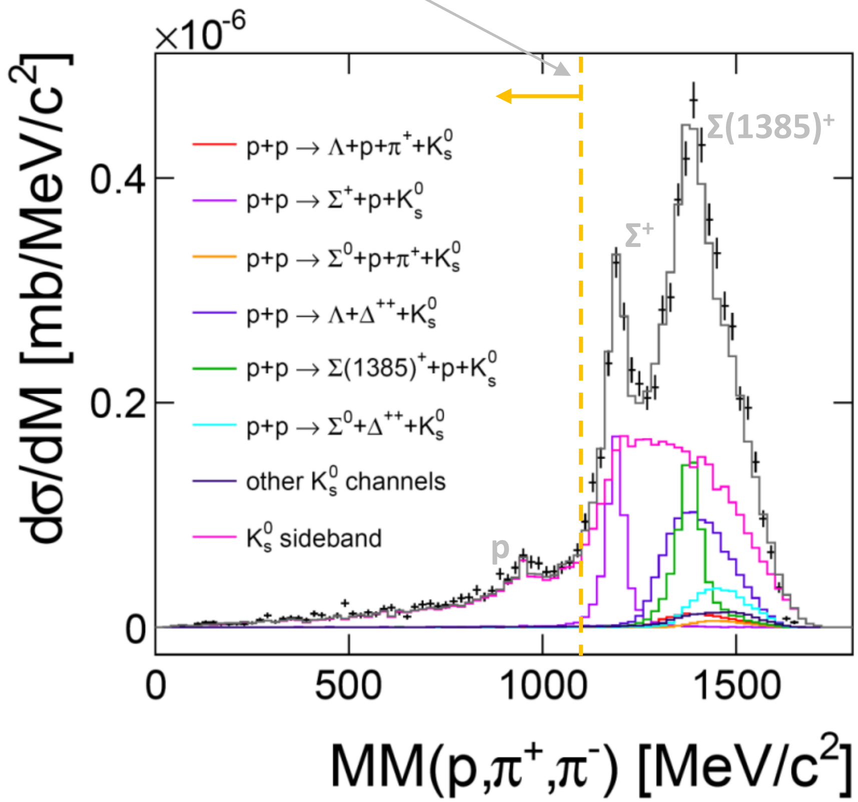
Data sample:
events with 4 particles (p, π^+, π^+, π^-)
secondary vertex cuts as usual

→ Interesting events within
3σ-region around the K_S^0 peak

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

cut @ 1100 MeV/c^2 for background selection

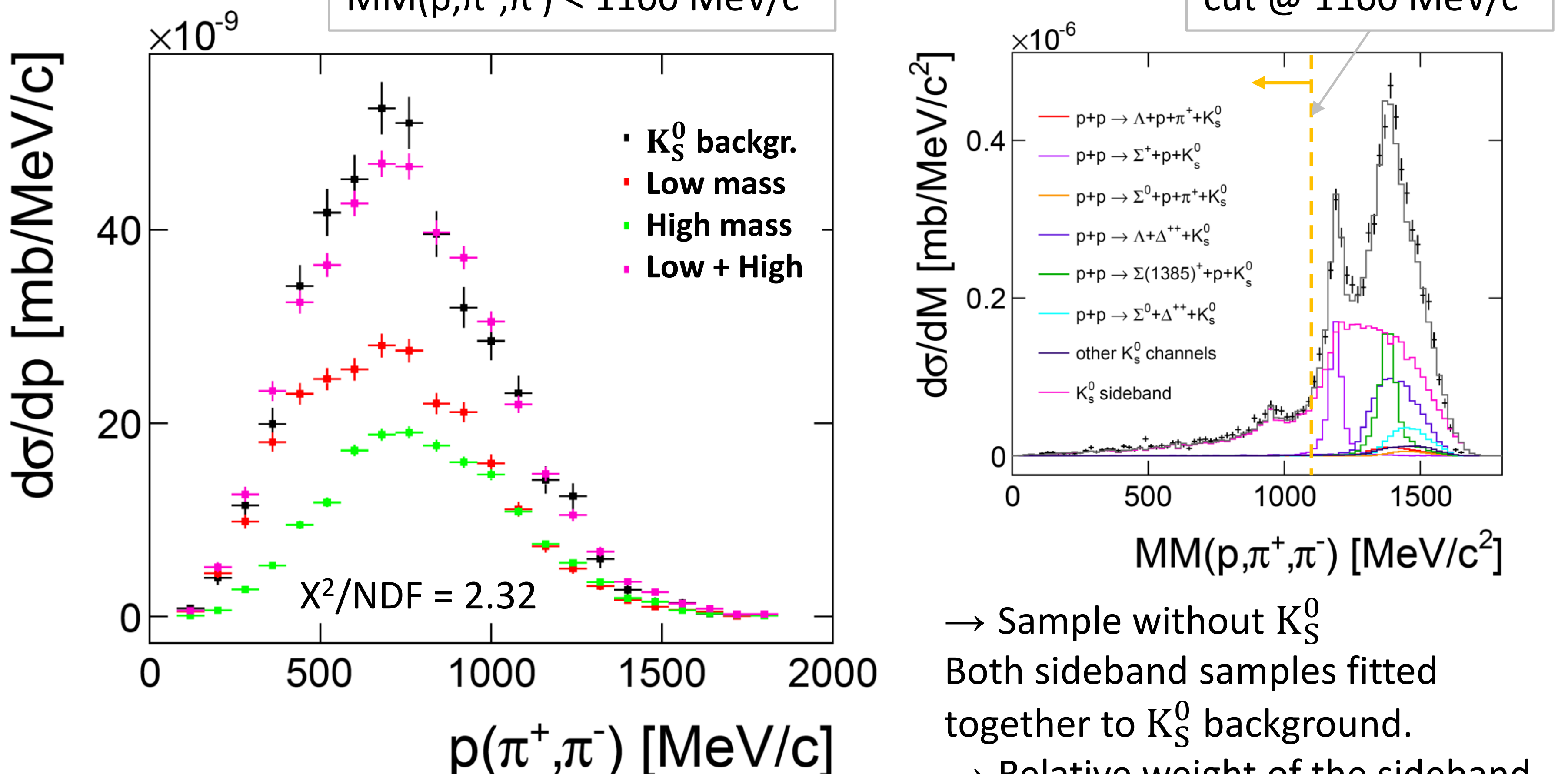




Fit Sideband Sample to Momentum of K_S^0 Background

MM(p,π+,π-) < 1100 MeV/c²

cut @ 1100 MeV/c²



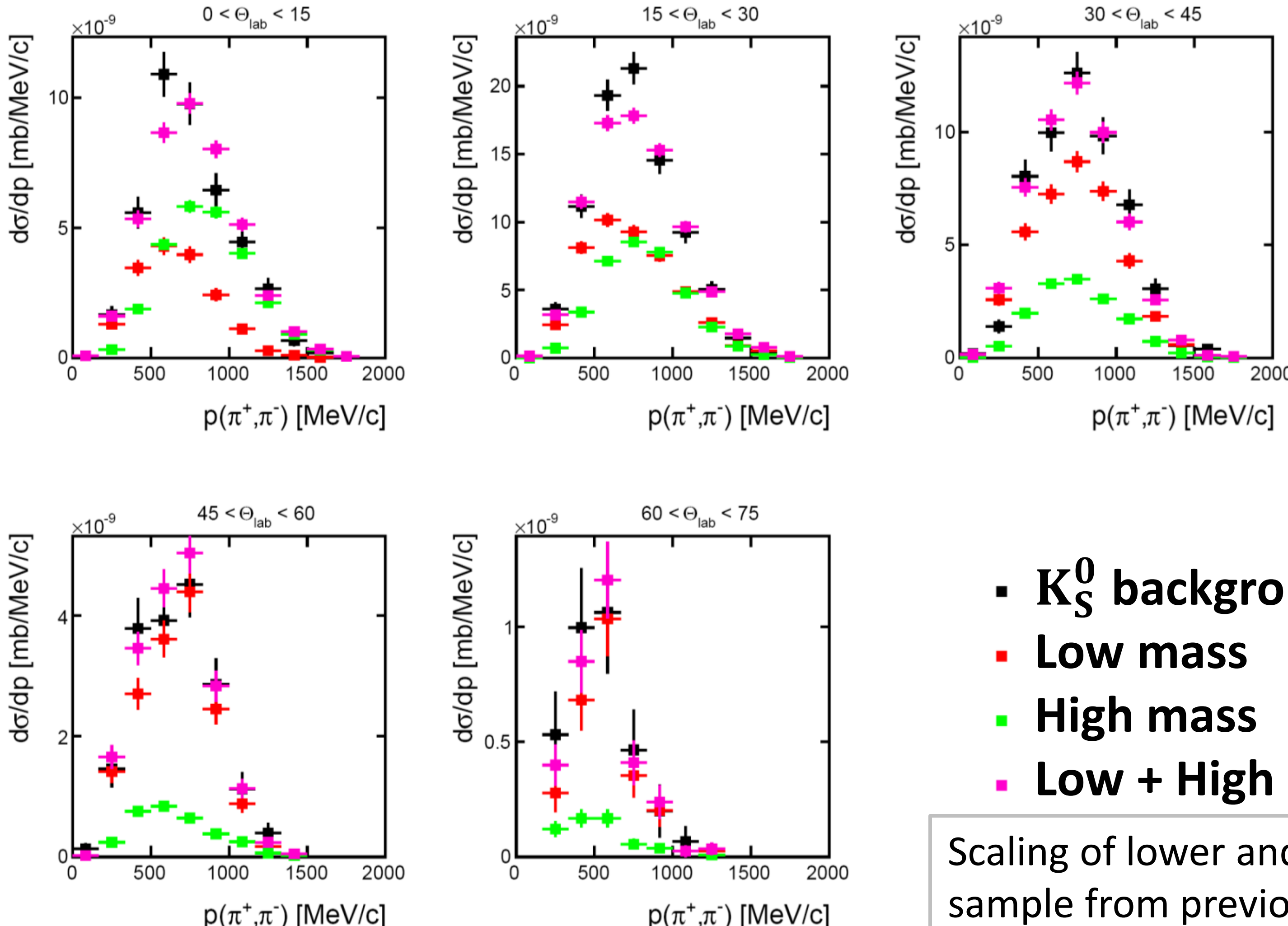
→ Sample without K_S^0

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_S^0 Background

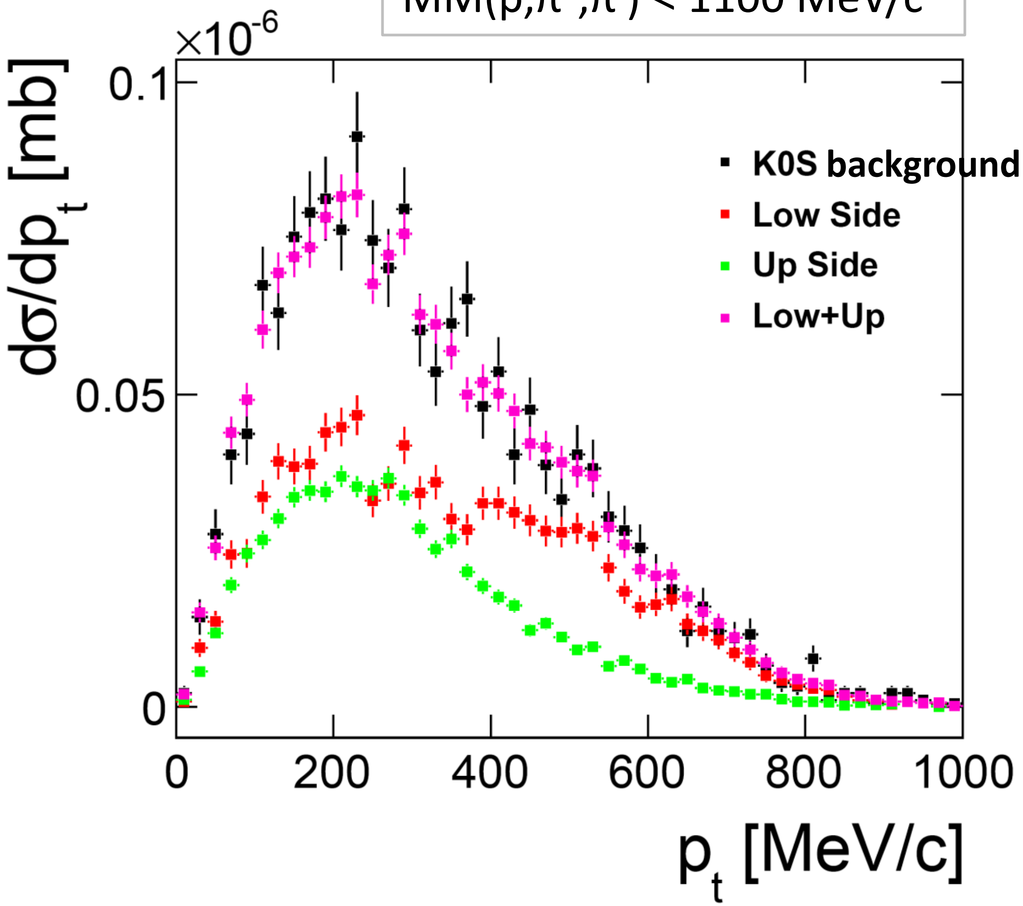


- **K_S^0 background**
- **Low mass**
- **High mass**
- **Low + High**

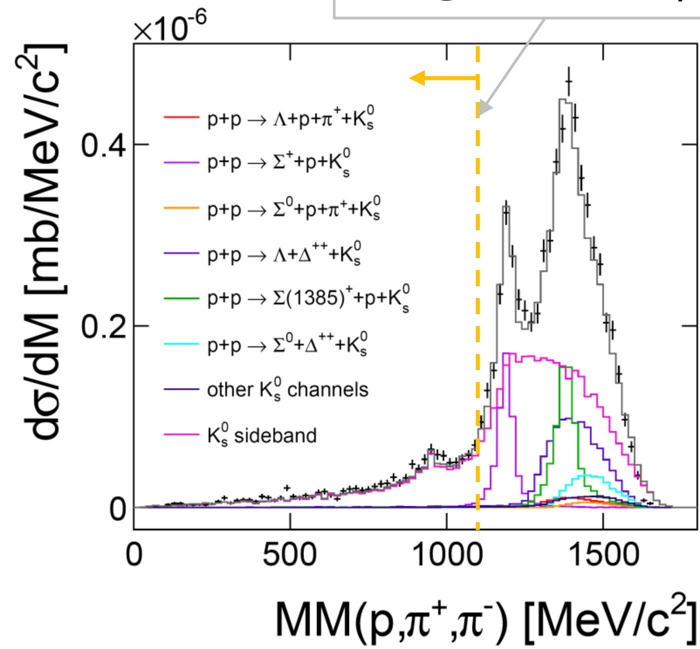
Scaling of lower and upper sample from previous fit!

P_t Comparison
Sideband Sample vs. K0s Background

$MM(p,\pi^+,\pi^-) < 1100\ MeV/c^2$



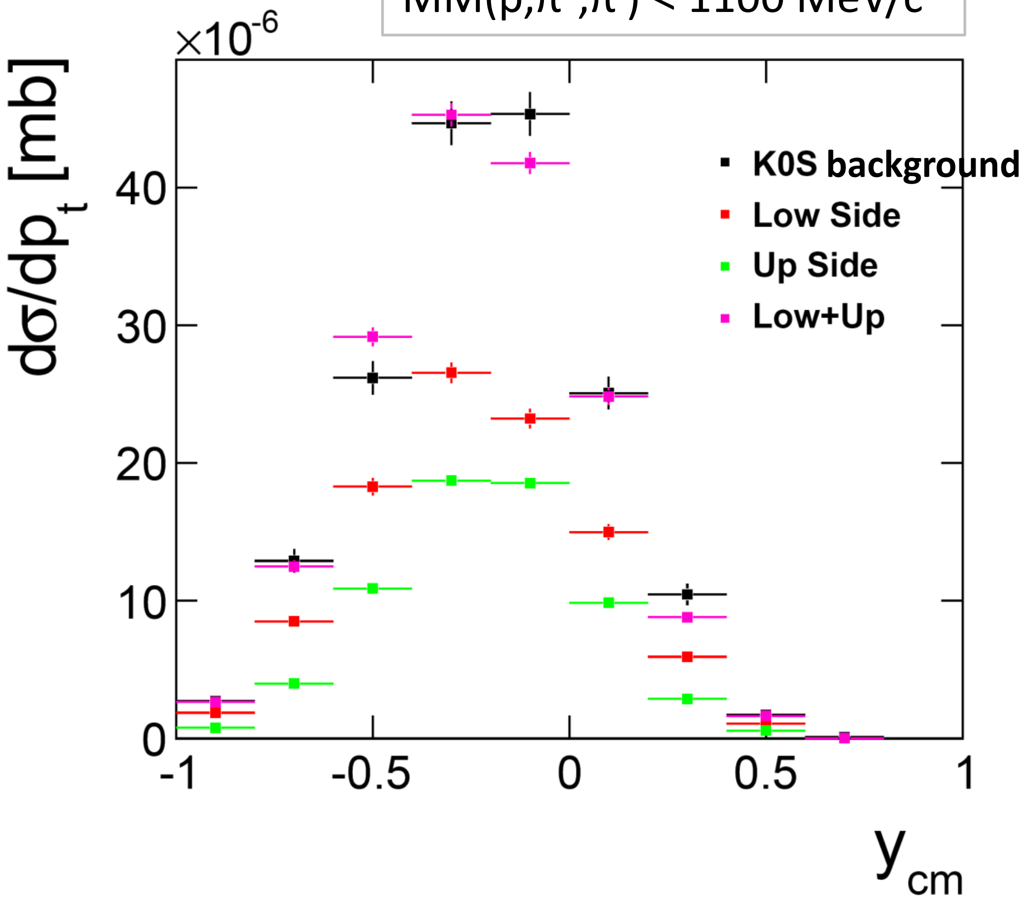
cut @ $1100\ MeV/c^2$



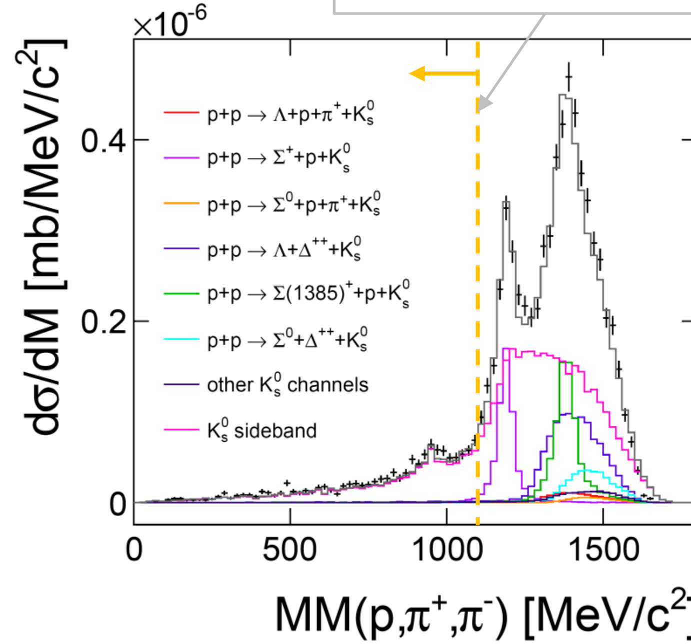
→ using the relative weight from the fit to momentum of K0s background

Rapidity Comparison
Sideband Sample vs. K0s Background

MM(p,π^+,π^-) < 1100 MeV/c^2



cut @ 1100 MeV/c^2



→ using the relative weight from the fit to momentum of K0s background

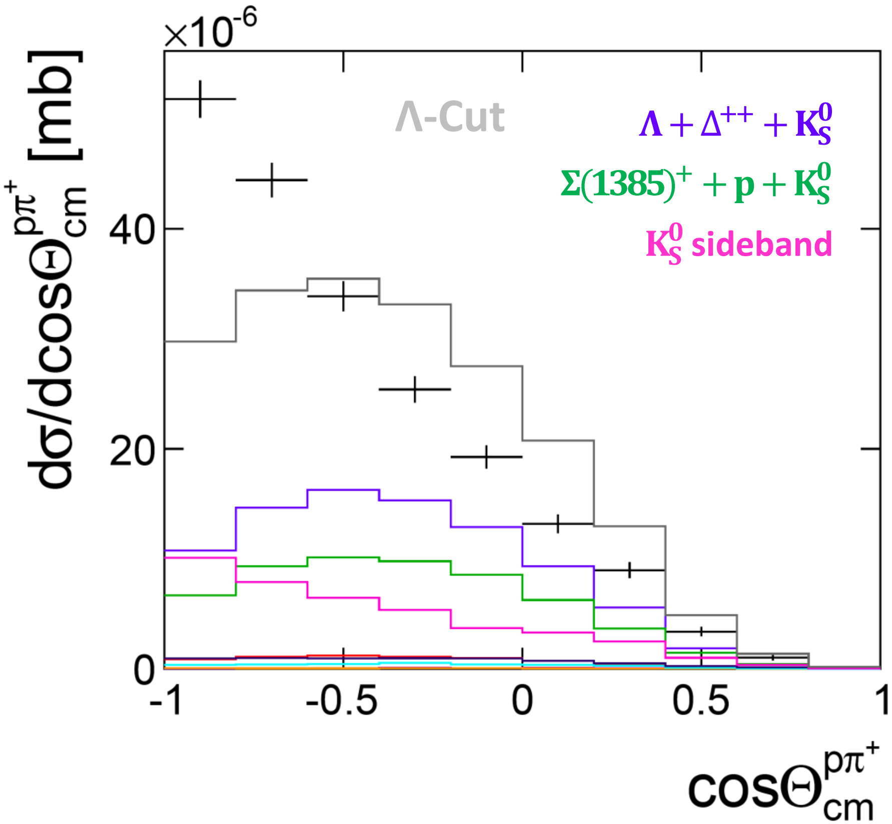
Angular Distributions

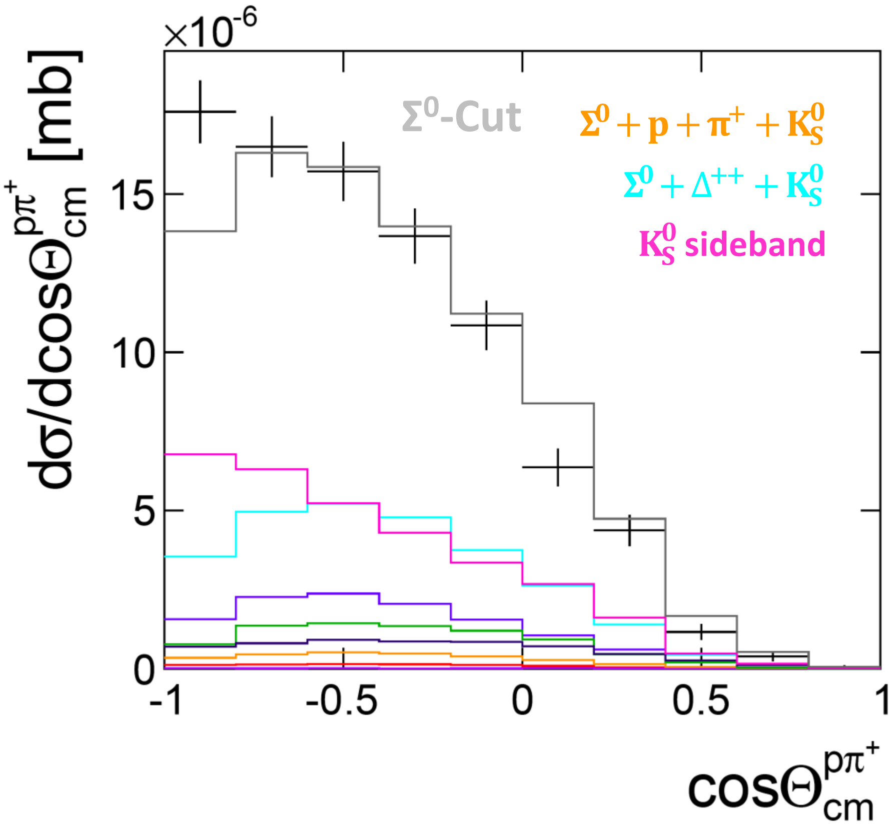
AV iso

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

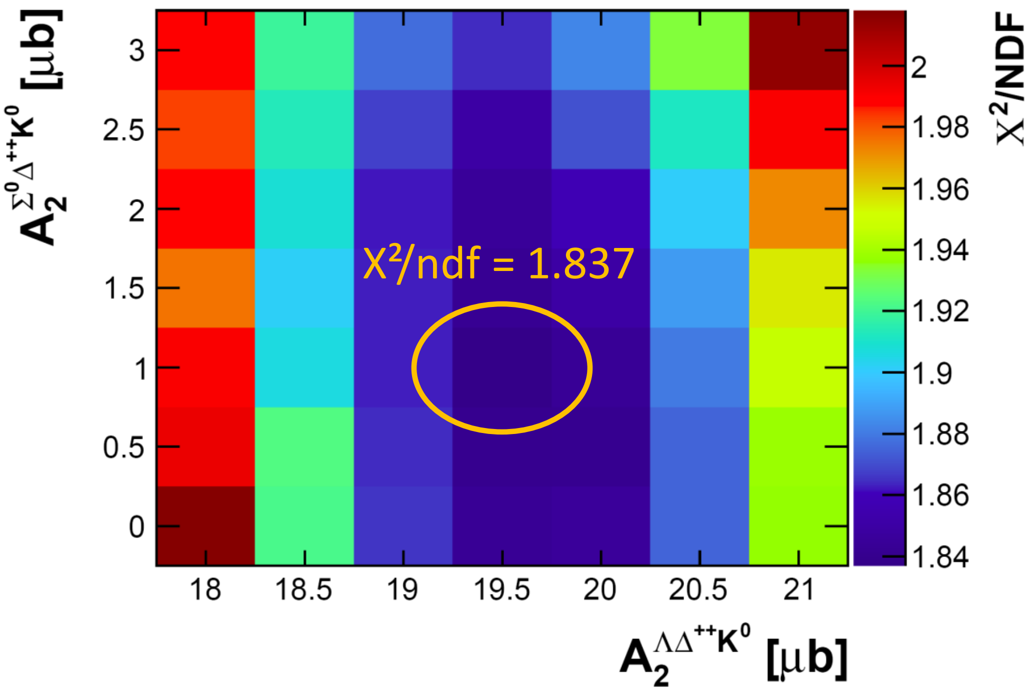
Variation of the A_2 Coefficient

Legendre polynomial:

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

A_0 → 12.97 μb

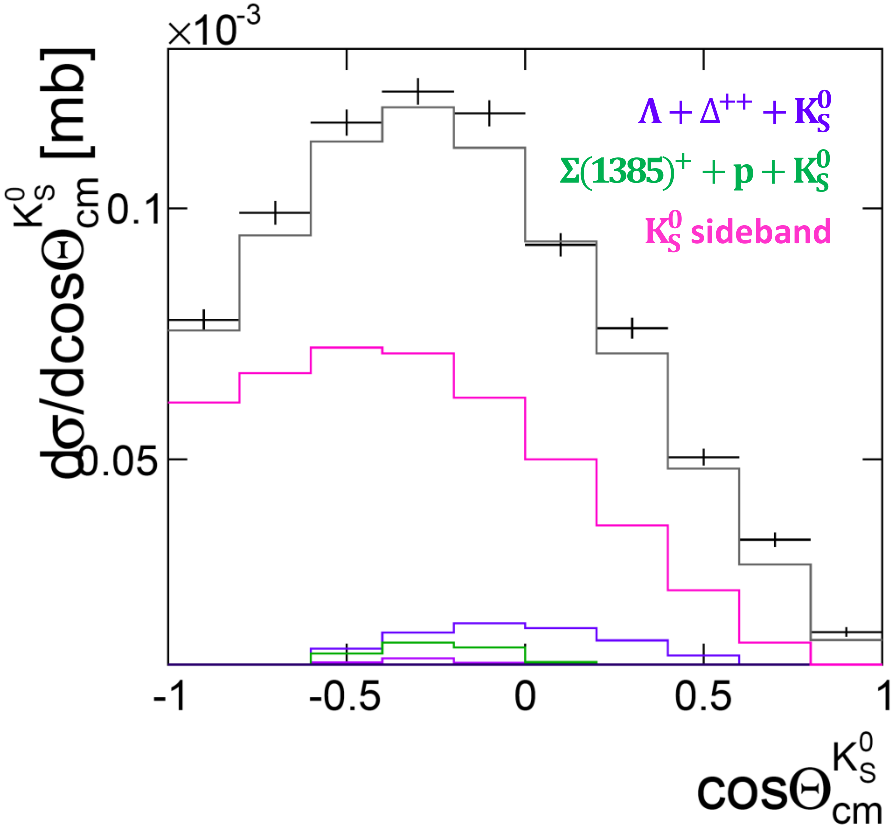
A_2 → responsible for the strength of the anisotropy



AV aniso

Angular Distribution of K^0_S

- in ACCEPTANCE -



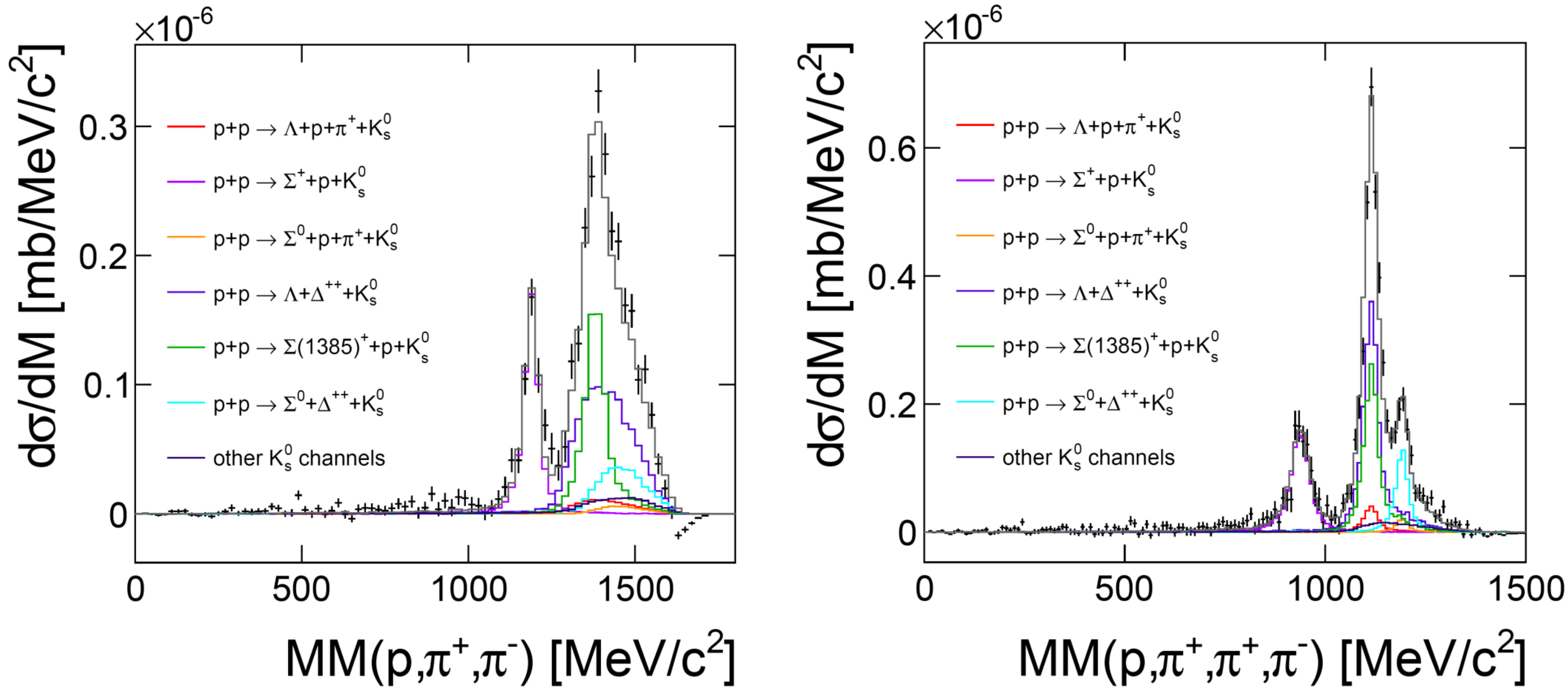
with primary vertex cut, K^0_S secondary vertex cuts & 3σ K^0_S mass cut

Plots with subtracted sideband and all relevant K0 channels

all plots are **IN ACCEPTANCE**

MM(p,π⁺,π⁻) and MM(p,π⁺,π⁺,π⁻)

- in ACCEPTANCE -



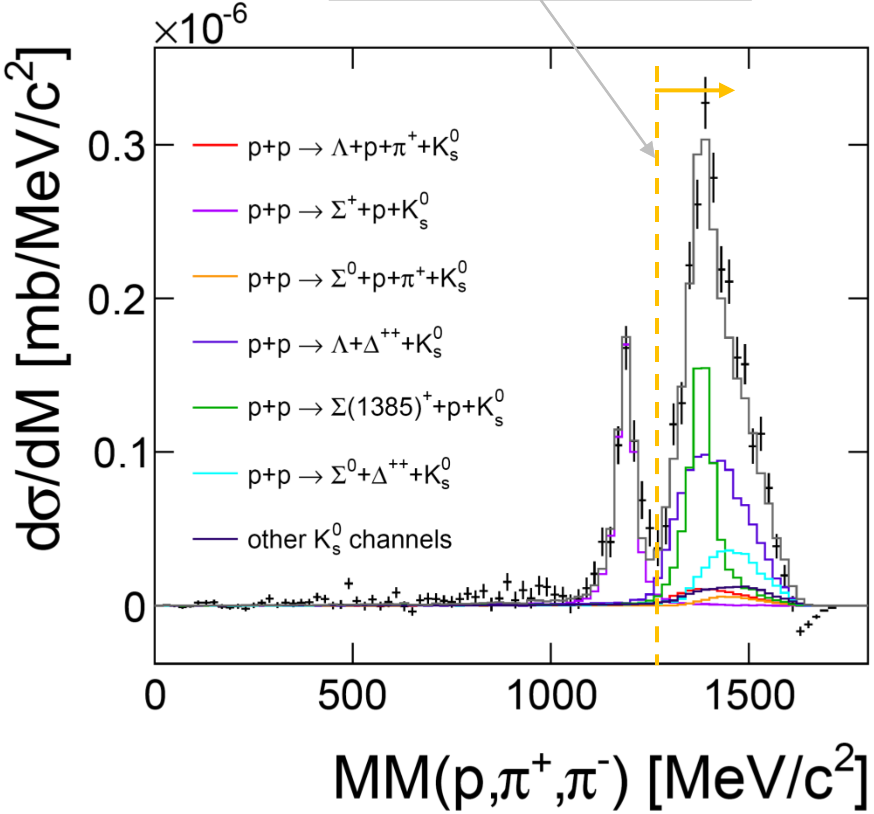
only primary vertex cut, K^0_s secondary vertex cuts & 3σ K^0_s mass cut

MM(p,π⁺,π⁺,π⁻) with cut on MM(p,π⁺,π⁻)

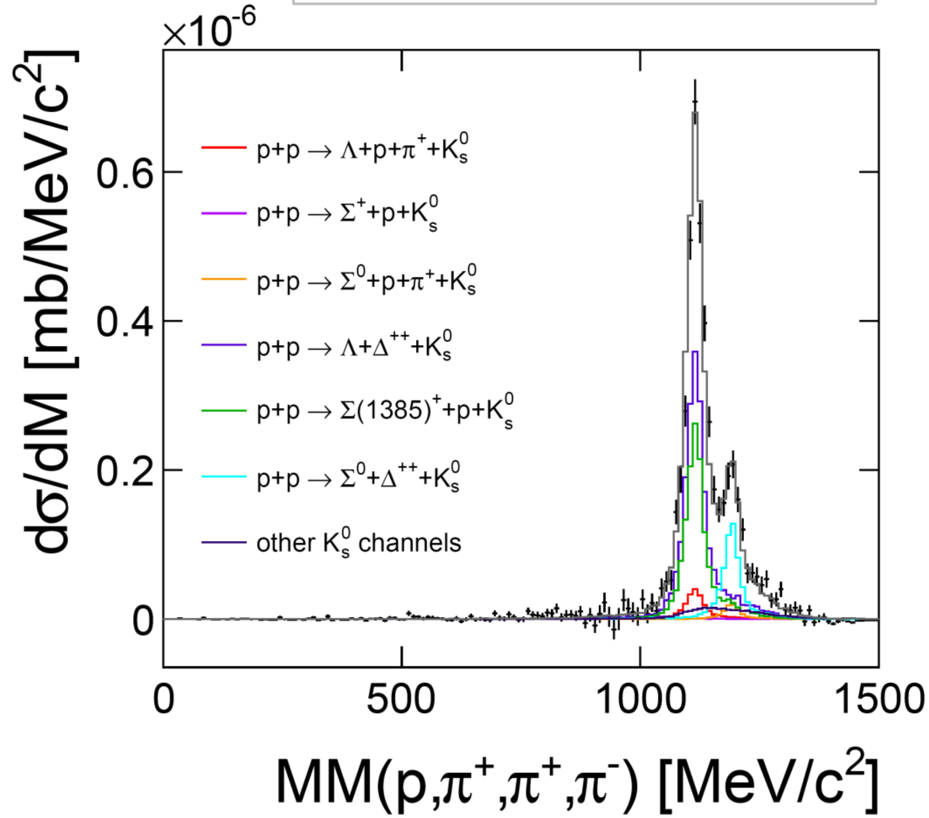
- in ACCEPTANCE -

AV aniso

cut @ 1270 MeV/c²



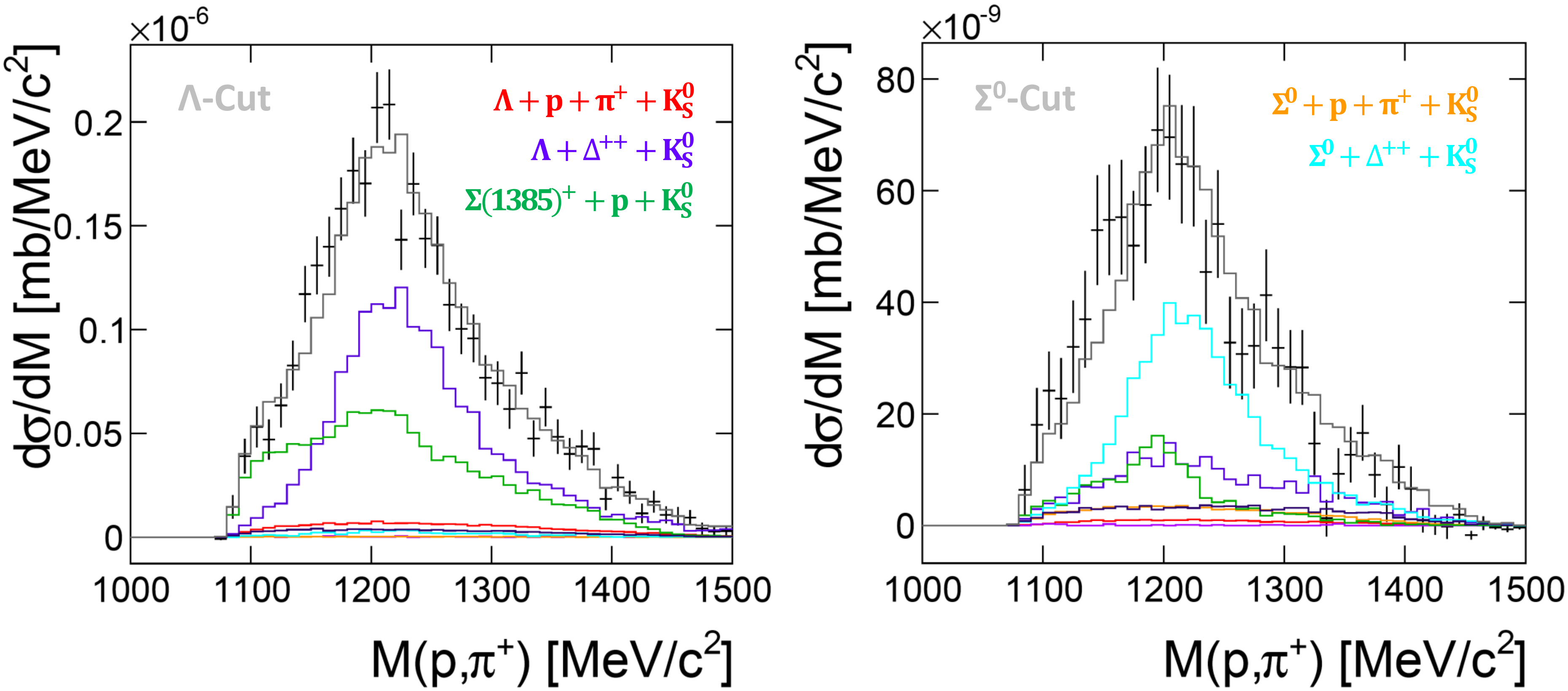
MM(p,π⁺,π⁻) > 1270 MeV/c²



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

IM(p, π⁺)

- in ACCEPTANCE -



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

Cross Sections

Reaction: $p + p \rightarrow$	**AV$_{anisotropic}$: $\sigma_{sim.fit}$ [μb]**	**AV$_{isotropic}$: $\sigma_{sim.fit}$ [μb]**
$\Lambda + p + \pi^+ + K^0$	$\mathbf{2.57} \pm 0.02^{+1.26}_{-1.98} \pm 0.18$	$\mathbf{2.90} \pm 0.03^{+0.76}_{-2.90} \pm 0.20$
$\Lambda + \Delta^{++} + K^0$	$\mathbf{29.45} \pm 0.08^{+1.67}_{-1.46} \pm 2.06$	$\mathbf{25.72} \pm 0.08^{+1.57}_{-1.59} \pm 1.80$
$\Sigma^0 + p + \pi^+ + K^0$	$\mathbf{1.35} \pm 0.02^{+1.64}_{-1.35} \pm 0.09$	$\mathbf{1.34} \pm 0.02^{+1.30}_{-1.34} \pm 0.09$
$\Sigma^0 + \Delta^{++} + K^0$	$\mathbf{9.26} \pm 0.05^{+1.41}_{-1.10} \pm 0.65$	$\mathbf{8.96} \pm 0.05^{+1.71}_{-0.96} \pm 0.63$
$\Sigma^+ + p + K^0$	$\mathbf{26.27} \pm 0.64^{+2.12}_{-4.41} \pm 1.84$	$\mathbf{24.21} \pm 0.63^{+2.00}_{-6.90} \pm 1.69$
$\Sigma(1385)^+ + p + K^0$	$\mathbf{14.35} \pm 0.05^{+1.79}_{-2.14} \pm 1.00$	$\mathbf{13.40} \pm 0.05^{+1.68}_{-2.30} \pm 0.94$

systematic uncertainties from normalization to elastics

Simulated K^0 Production channels

Reaction	σ [μb]
$p+p \to \Sigma^+ + p + K^0$	21.29
$p+p \to \Lambda + p + \pi^+ + K^0$	18.40
$p+p \to \Sigma^0 + p + \pi^+ + K^0$	12.38
$p+p \to \Lambda + \Delta^{++} + K^0$	4.47
$p+p \to p + n + K^+ + K^0$	7.58
$p+p \to \Sigma(1385)^+ + p + K^0$	5.31
$p+p \to \Lambda + n + \pi^+ + \pi^+ + K^0$	5.08
$p+p \to \Sigma^+ + n + \pi^+ + K^0$	4.53
$p+p \to \Lambda + p + \pi^+ + \pi^0 + K^0$	4.46
$p+p \to \Sigma^+ + p + \pi^0 + K^0$	4.06
$p+p \to \Sigma^- + p + \pi^+ + \pi^+ + K^0$	3.75
$p+p \to \Sigma^+ + p + \pi^+ + \pi^- + K^0$	2.26
$p+p \to p + p + \pi^+ + K^- + K^0$	2.02

- production cross sections from phasespace fits of experimental data
- cross sections used as start parameters in the simultaneous fit over 5 exp observables