Variety of Strangeness Physics with HADES

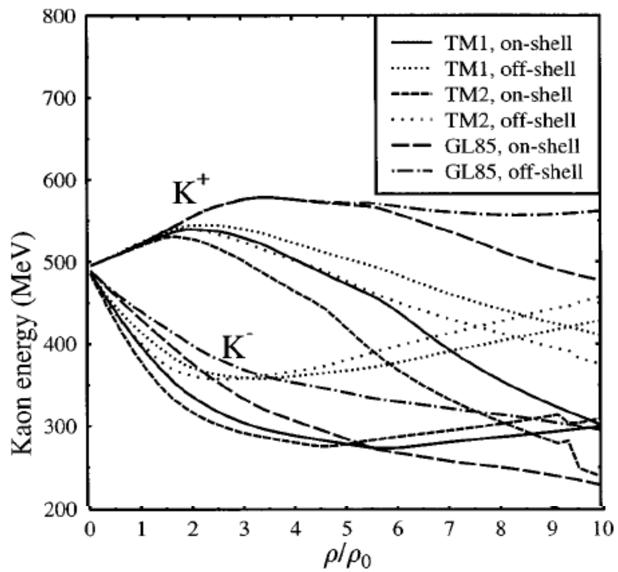
Mo., 4.3.2013

10:00 - 10:40

1. Resonances in p+p
2. Kaonic Cluster
3. Cold medium effects
4. Au+Au
5. Pion induced reactions

Strangeness in Matter

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



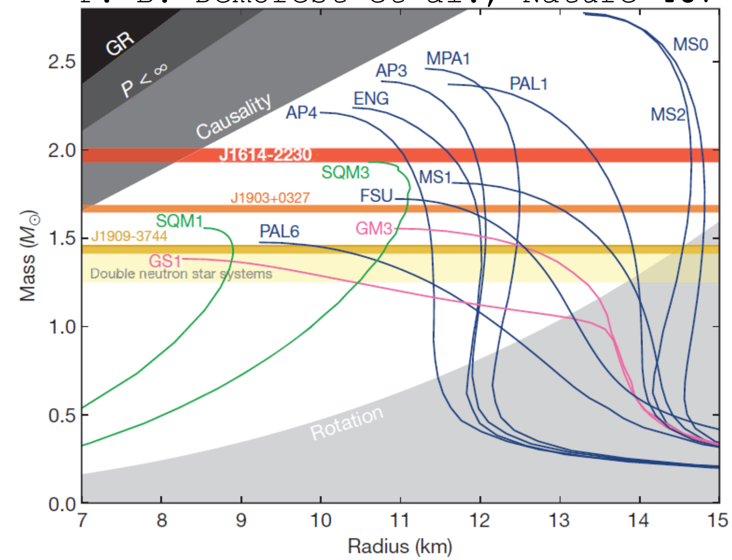
In case $m_{K^-}^* < \mu_e$

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

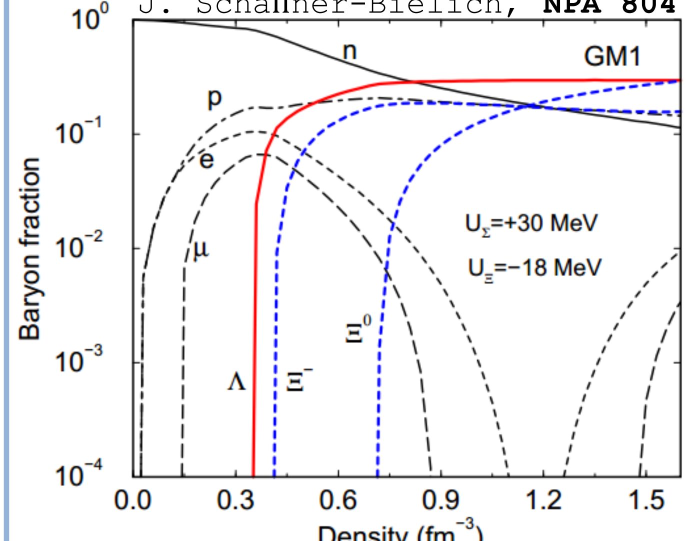
$$n \rightarrow K^- + p$$

reduces Fermi pressure and softens EOS

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

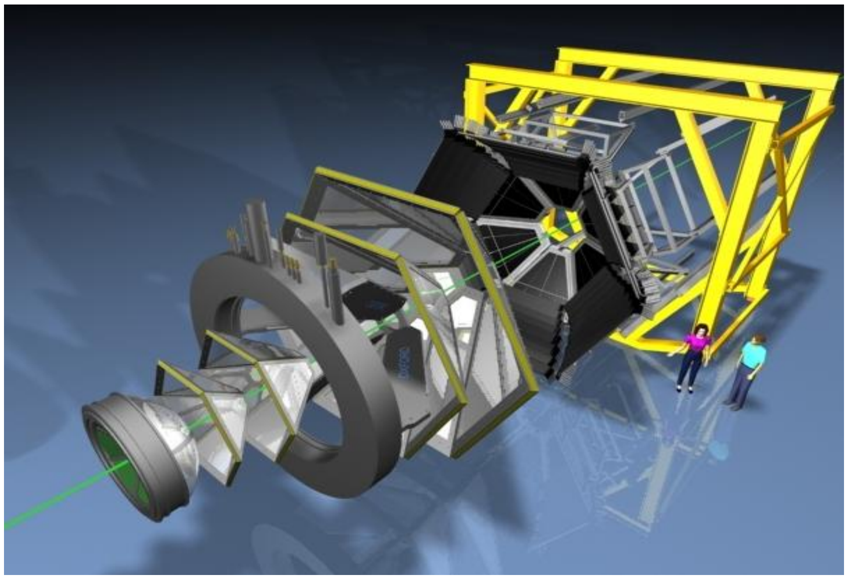


J. Schaffner-Bielich, **NPA 804** (2008)

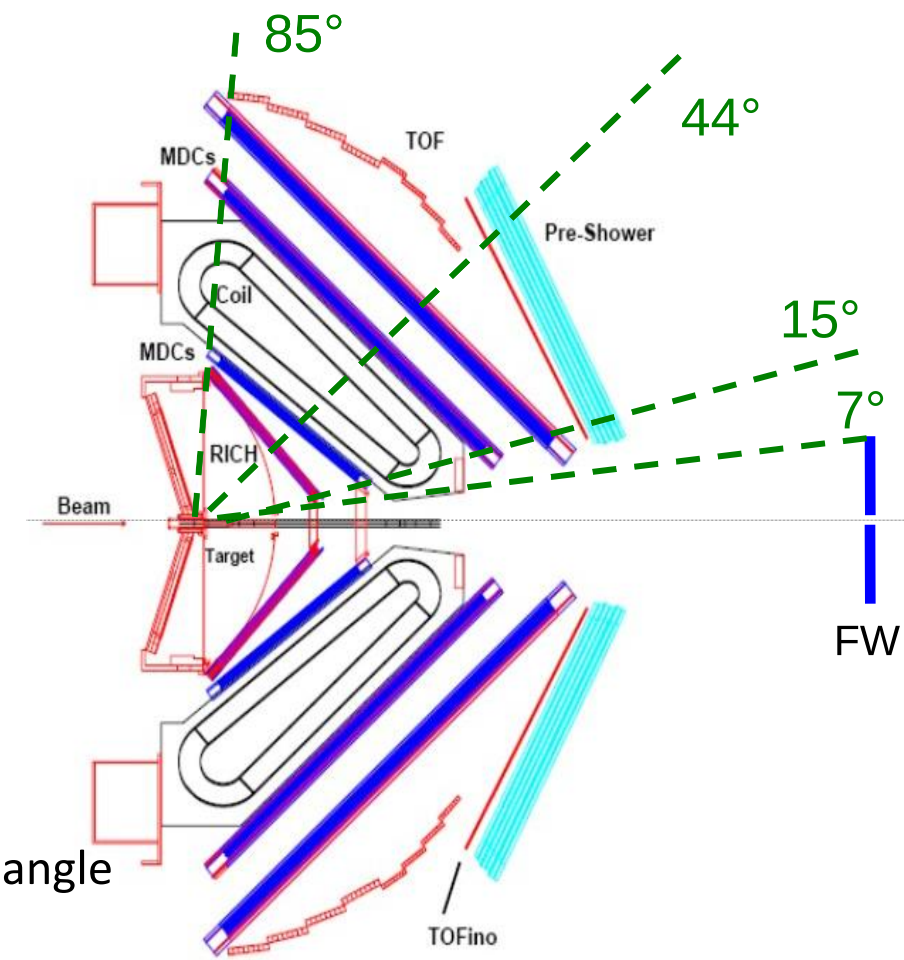


The HADES experiment

High **A**cceptance **D**i-electron **S**pectrometer
GSI, Darmstadt



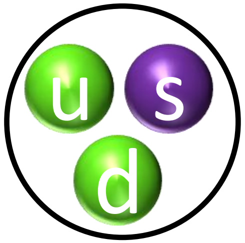
HADES Coll. (G. Agakishiev et al.),
Eur. Phys. **J. A41** (2009)



- Fixed-target experiment
- Full azimuthal coverage, 15˚- 85˚ in polar angle
- Momentum resolution ≈ 1 % - 5 %
- Particle identification via dE/dx & Tof

Strange Resonances in p+p

The $\Lambda(1405)$

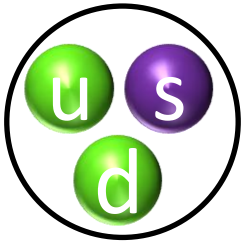


$\Lambda(1405)$

Resonance in $\Sigma\pi$

$$I(J^P) = 0(\tfrac{1}{2}^-)$$

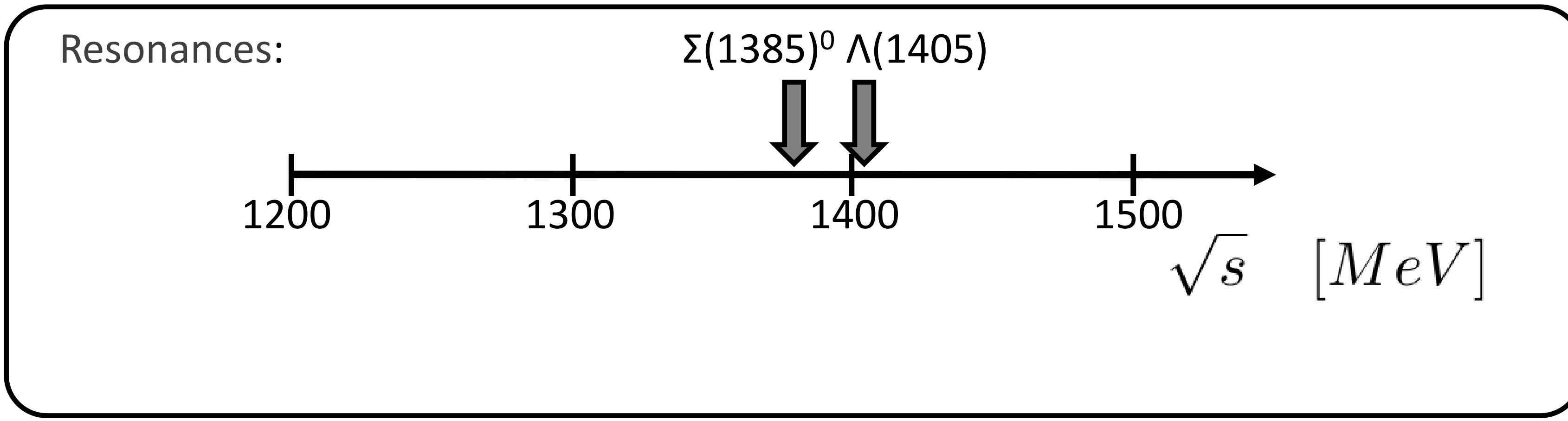
The Λ(1405)



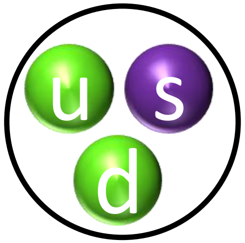
Λ(1405)

Resonance in Σπ

$$I(J^P) = 0(\tfrac{1}{2}^-)$$



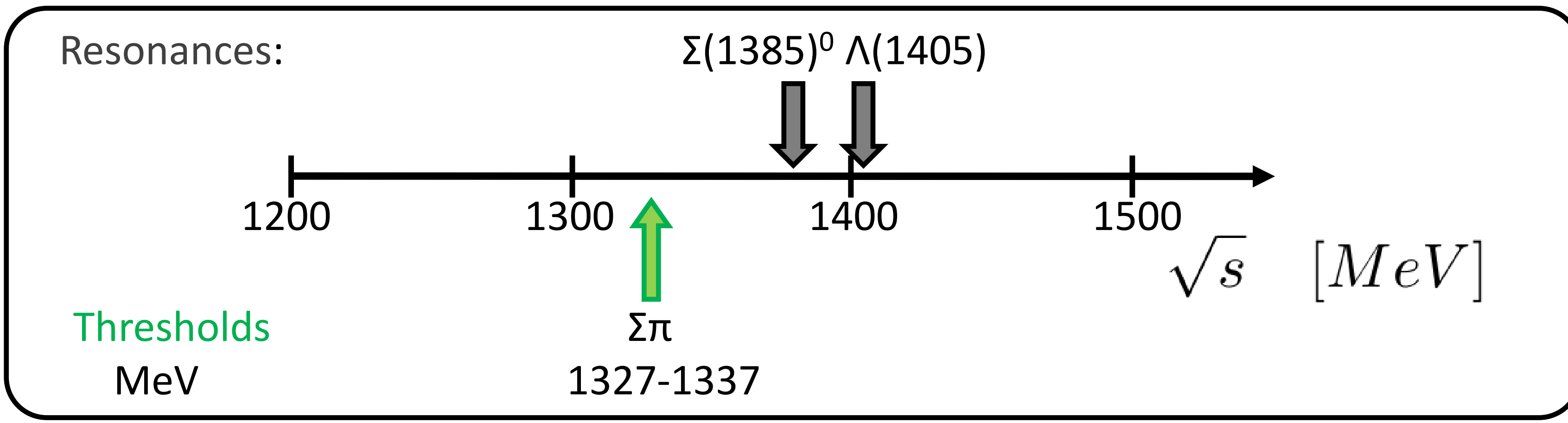
The Λ(1405)



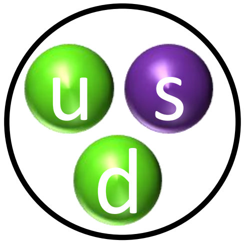
Λ(1405)

Resonance in Σπ

$$I(J^P) = 0(\tfrac{1}{2}^-)$$



The Λ(1405)

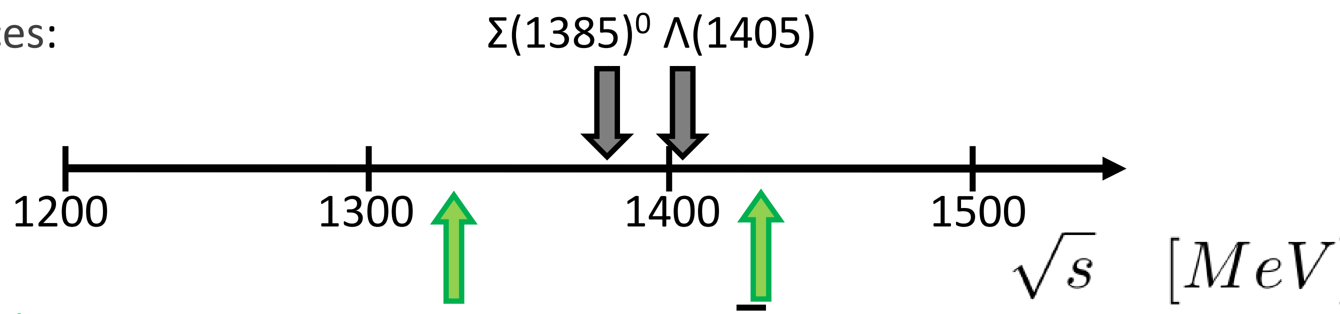


Λ(1405)

Resonance in Σπ

$I(J^P) = 0(\frac{1}{2}^-)$

Resonances:

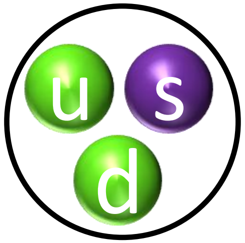


Thresholds
MeV

Σπ: 1327-1337

K̄N: 1432-1437

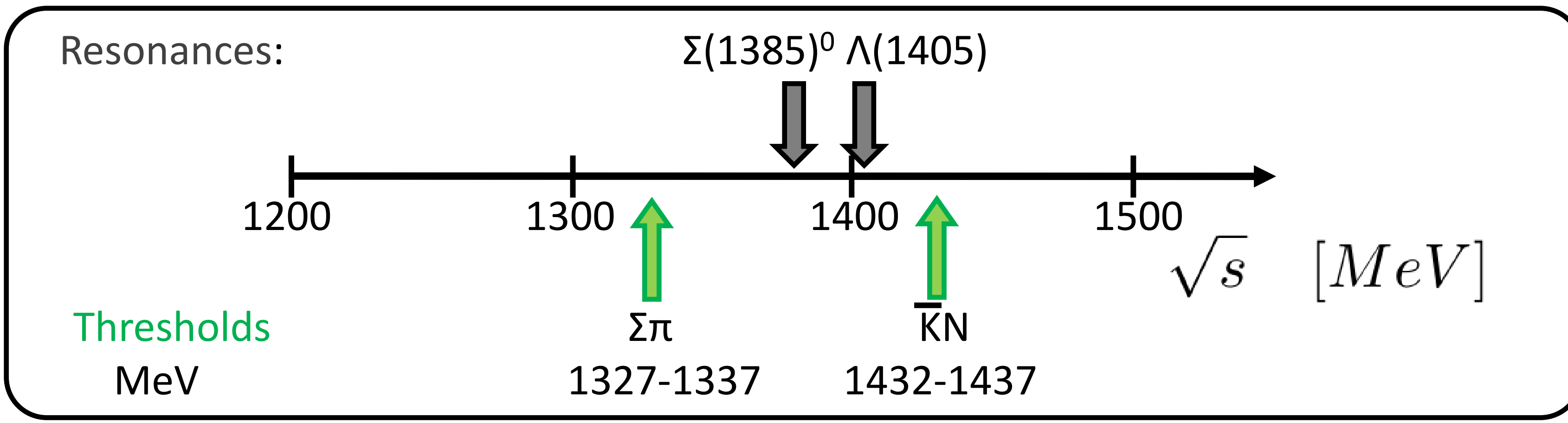
The Λ(1405)



Λ(1405)

Resonance in Σπ

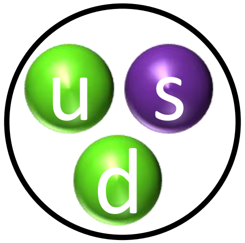
$$I(J^P) = 0(\tfrac{1}{2}^-)$$



$\bar{K}$N – interaction is attractive in the I=0 channel

- possibility of $\bar{K}$N bound states
- $\bar{K}$-N potential in the Vacuum

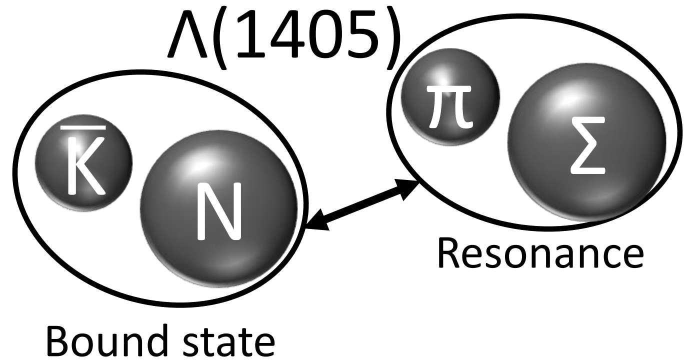
The Λ(1405)

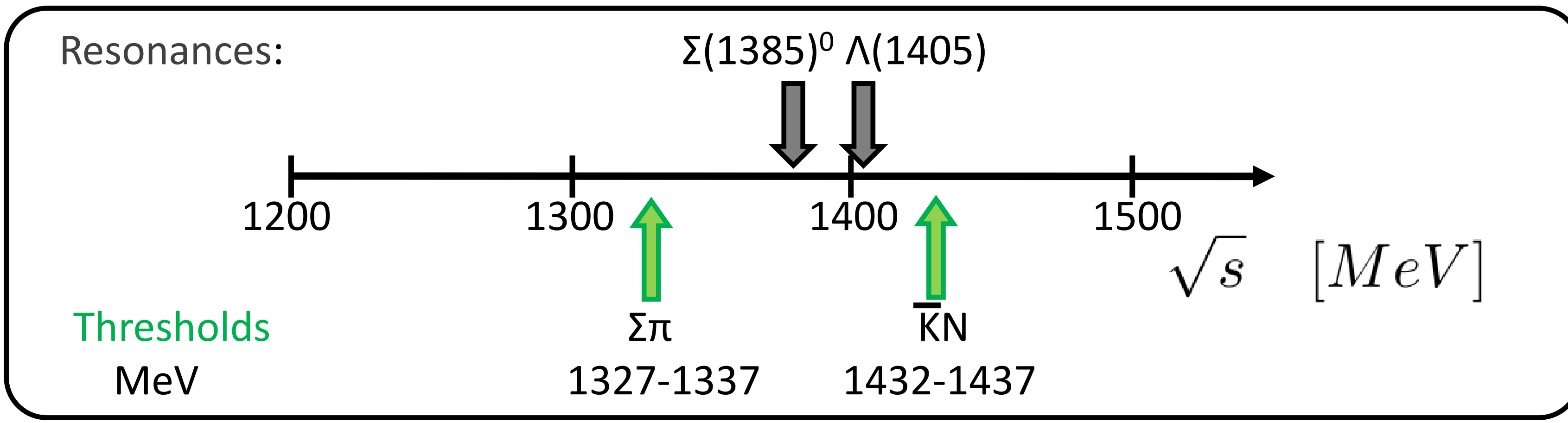


Λ(1405)

Resonance in Σπ

$$I(J^P) = 0(\tfrac{1}{2}^-)$$





K̄N – interaction is attractive in the I=0 channel

- possibility of K̄N bound states
- K̄-N potential in the Vacuum
- Coupled channel approach based on Chiral Dynamics generates the Λ(1405) dynamically

Hyodo et al., Prog.Part.Nucl.Phys. 67 (2012)
Hyodo et al., Phys.Rev. C77 (2008)
Borasoy et al., Eur.Phys.J. A25 (2005)
Magas et al., Phys.Rev.Lett. 95 (2005)
Jido et al., Nucl.Phys. A725 (2003)
Nacher et al., Phys.Lett. B455 (1999)
R.H. Dalitz et al., Phys. Rev. 153 (1967)

Reaction - Reconstruction

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

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

$\quad \hookrightarrow n + \pi^+$ — 16.11%

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

$\quad \hookrightarrow n + \pi^-$ — 33.33%

Reaction - Reconstruction

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

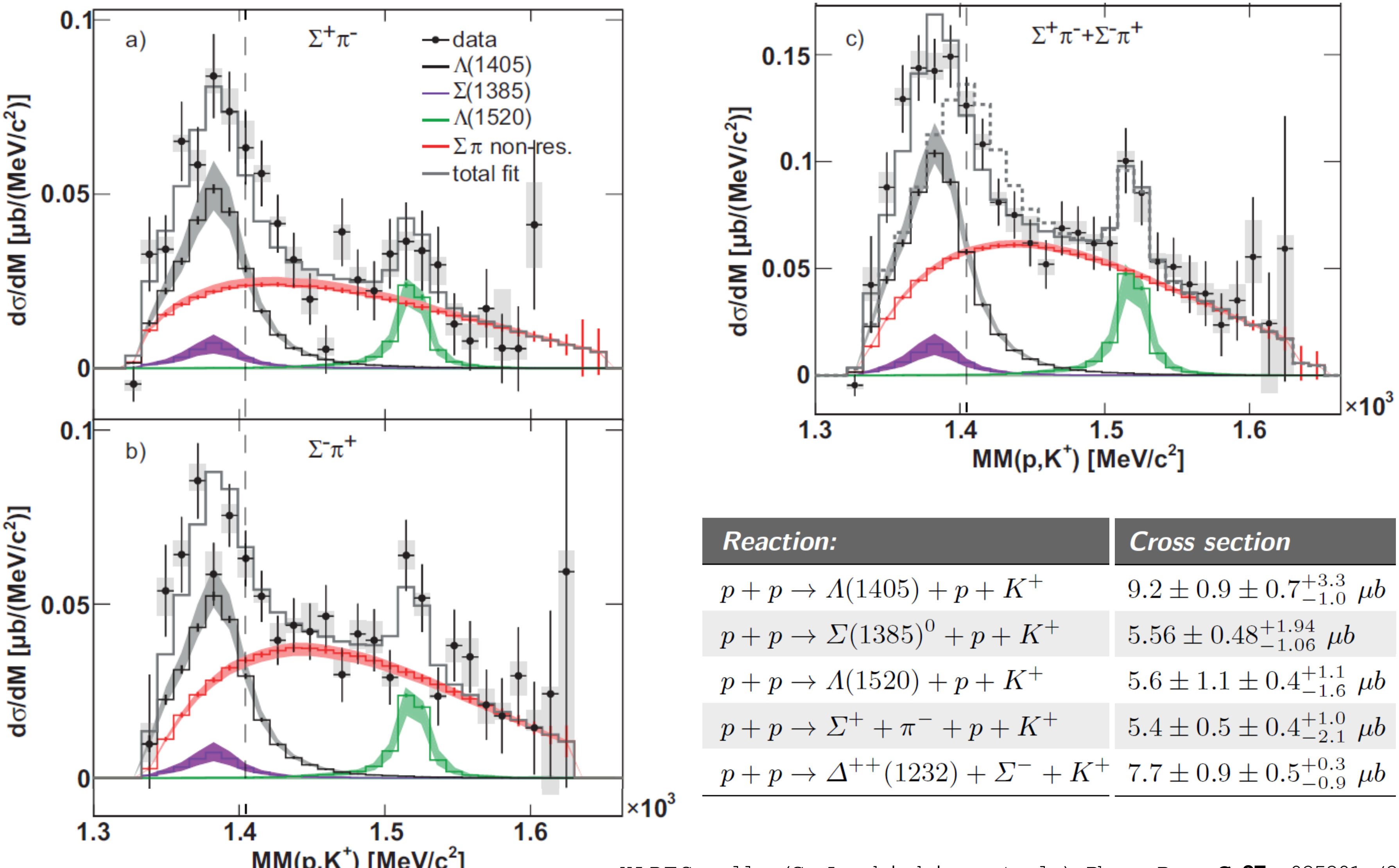
$\hookrightarrow \Sigma^+ + \pi^-$

$\quad \hookrightarrow n + \pi^+$ 16.11%

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

$\quad \hookrightarrow n + \pi^-$ 33.33%

Results

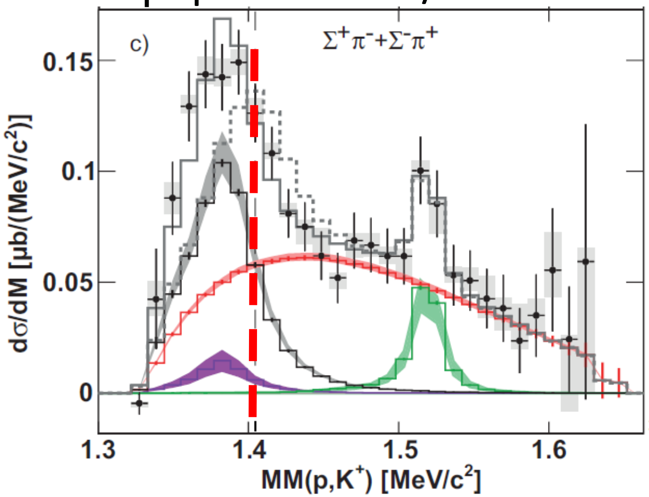


Reaction:	*Cross section*
$p+p \rightarrow \Lambda(1405)+p+K^+$	$9.2 \pm 0.9 \pm 0.7^{+3.3}_{-1.0}\ \mu b$
$p+p \rightarrow \Sigma(1385)^0+p+K^+$	$5.56 \pm 0.48^{+1.94}_{-1.06}\ \mu b$
$p+p \rightarrow \Lambda(1520)+p+K^+$	$5.6 \pm 1.1 \pm 0.4^{+1.1}_{-1.6}\ \mu b$
$p+p \rightarrow \Sigma^+ + \pi^- +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

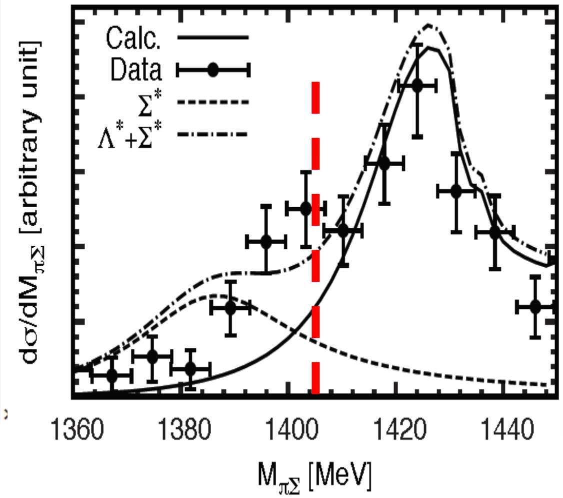
HADES coll. (G. Agakishiev et al.) Phys. Rev. **C 87**, 025201 (2013)

HADES Signal in the Context

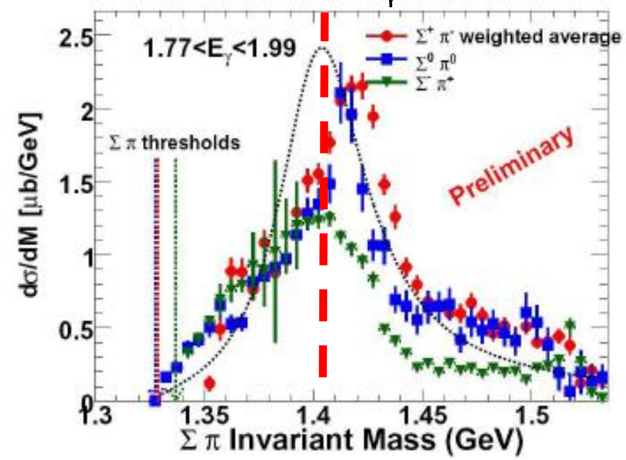
p+p 4.3 GeV/c



K^-+d 0. 68 – 0.84 GeV/c



γ+p 1.77<E_γ<1.99

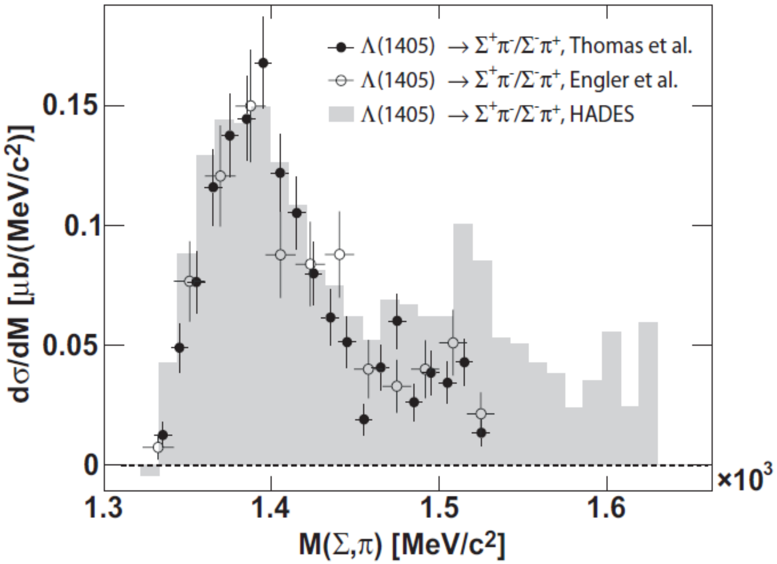


-- 1405 MeV/c^2

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

Agreement with π-Experiments

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

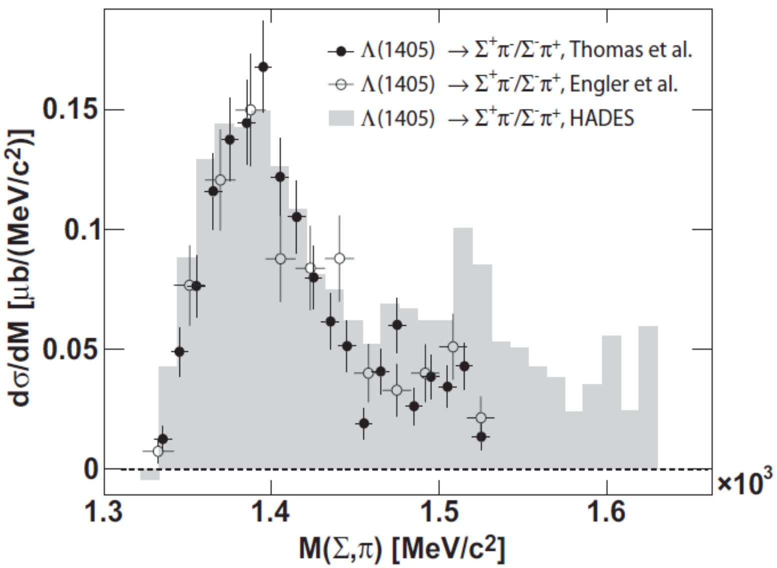


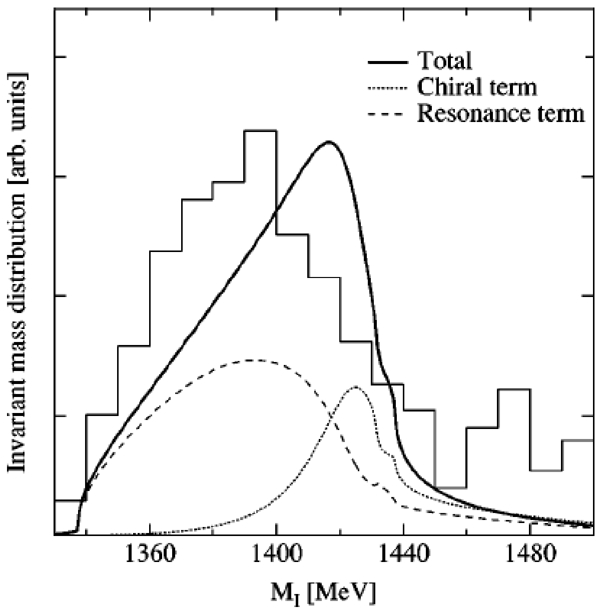
Thomas: π^-+p, p(π^-)= 1.69 GeV/c
Engler: π^-+p, p(π^-)= 1.69 GeV/c

Theory vs. experiment

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

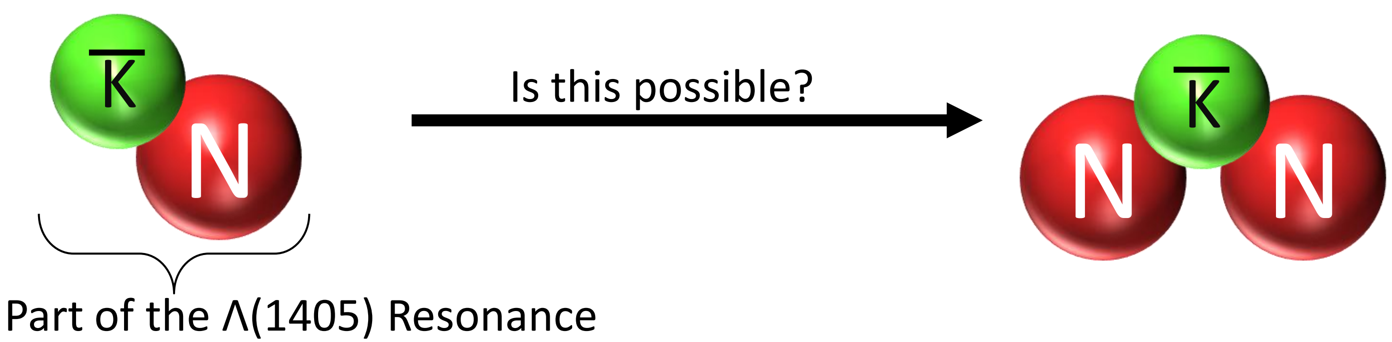
Hyodo et al., Phys.Rev. **C68** (2003) 065203





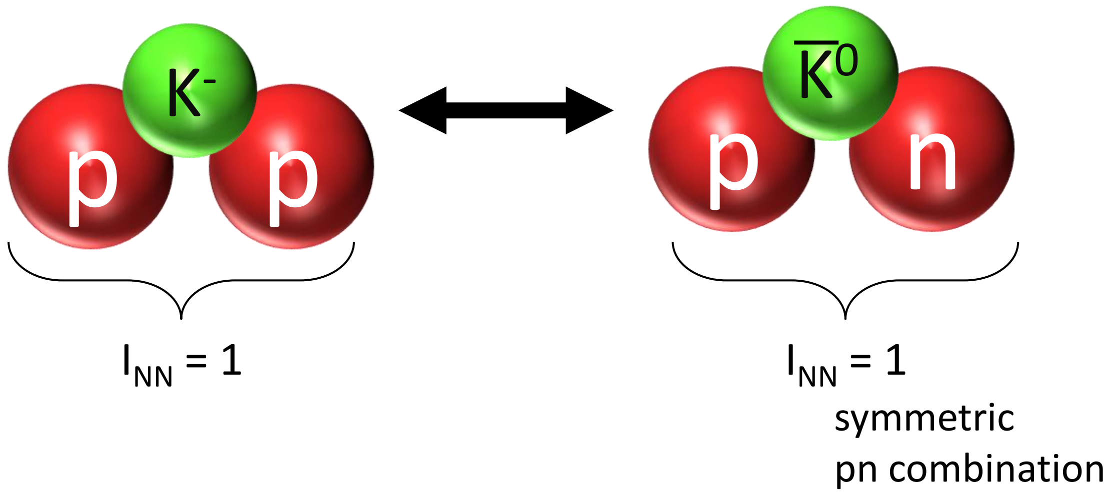
Thomas: π^-+p, p(π^-)= 1.69 GeV/c
Engler: π^-+p, p(π^-)= 1.69 GeV/c

Kaonic Cluster



The Kaonic Cluster

Property	Value
Charge	+1
Strangeness	-1
Configurations	ppK^-, $pn\overline{K}^0$
Baryon Number	2
I_{NN}	1
S	0
$\|I, I_z>$	$\|1/2,+1/2>$
J^P	0^-



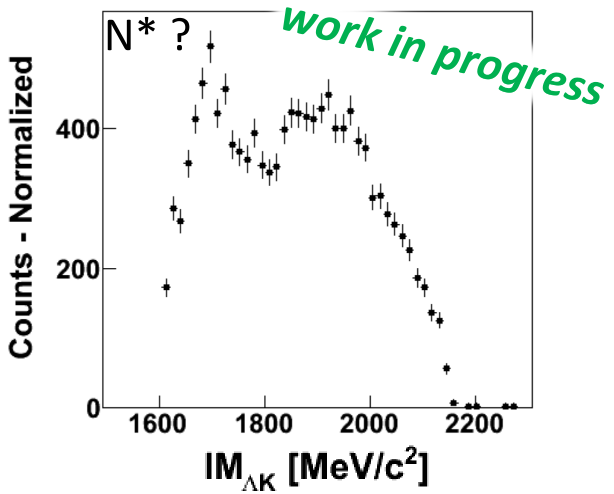
Range of predictions for
binding energy (B) and width (Γ)

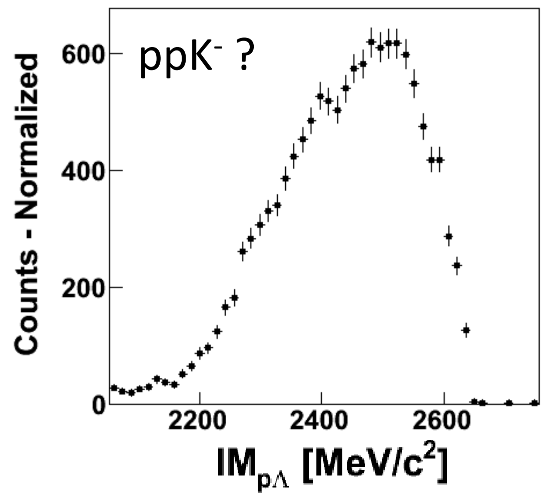
$B(ppK^-) \approx$ 14-80 MeV
$\Gamma(ppK^-) \approx$ 40-110 MeV/c^2

$$p + p \xrightarrow{3.5GeV} "ppK^-" + K^+$$
$$\to \Lambda + p$$
$$\to \Sigma^0 + p$$

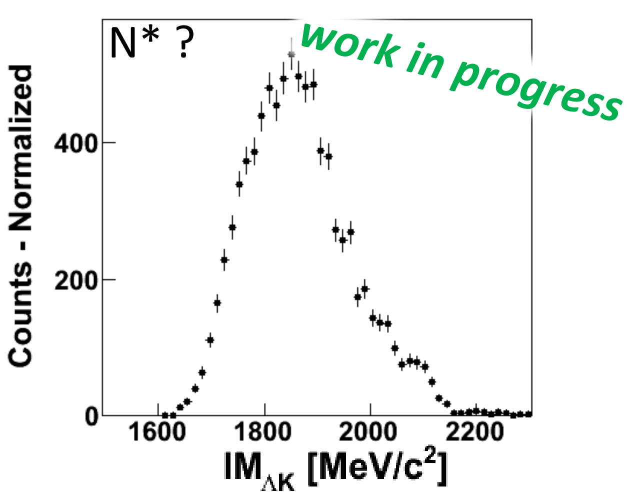
Mass observables

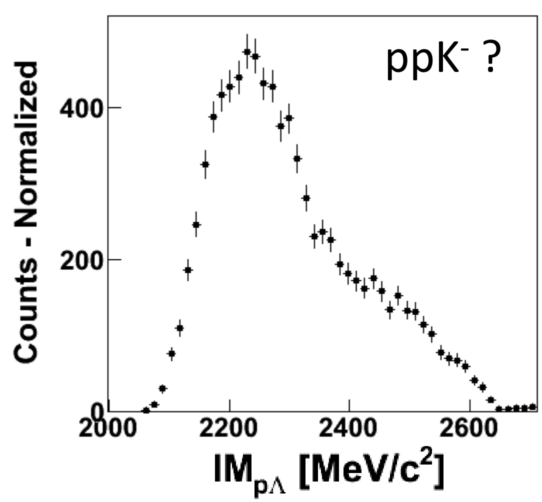
Inside HADES acceptance





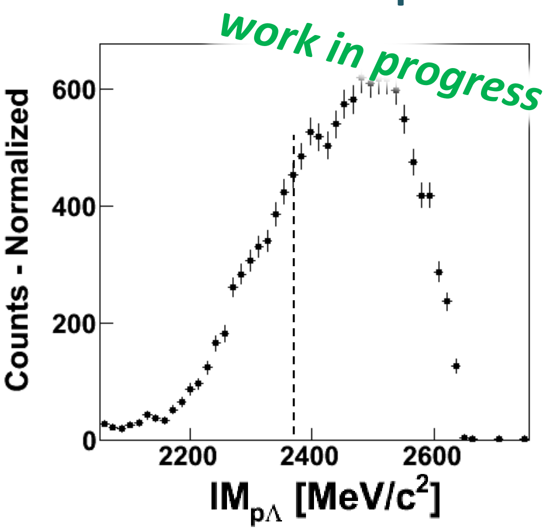
Inside WALL acceptance





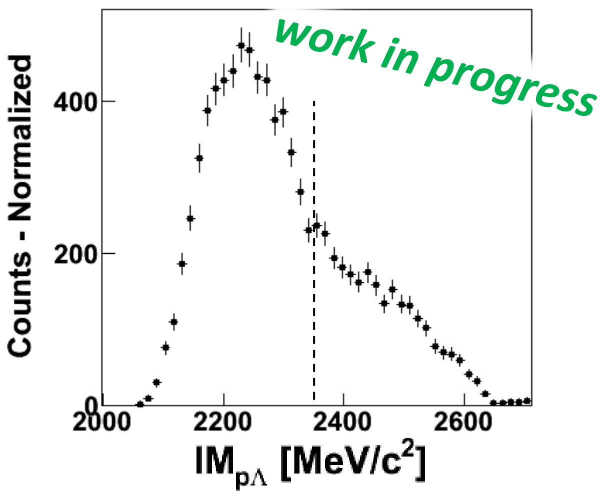
Mass observables

Inside HADES acceptance



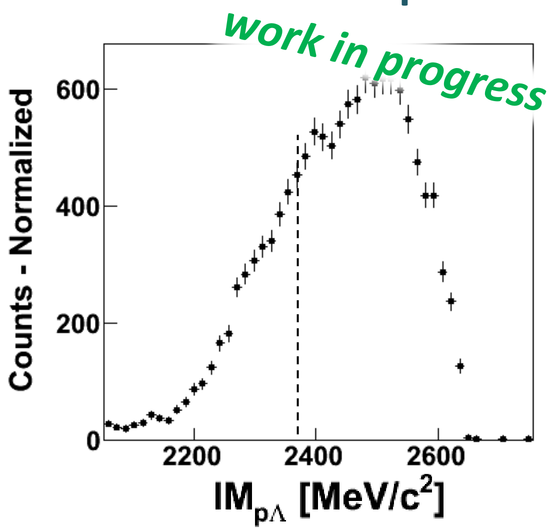
mass of Λ+p = 2053.96 MeV/c^2
mass of Σ^0+p = 2130.82 MeV/c^2
mass of p+p+K^- = 2370.22 MeV/c^2

Inside WALL acceptance



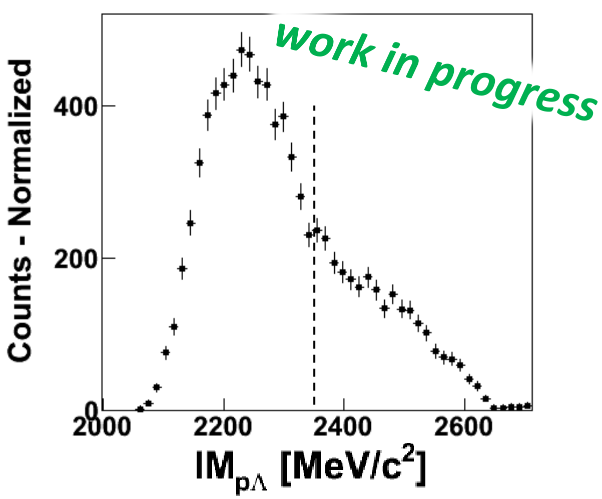
Mass observables

Inside HADES acceptance



mass of Λ+p = 2053.96 MeV/c^2
mass of Σ^0+p = 2130.82 MeV/c^2
mass of p+p+K^- = 2370.22 MeV/c^2

Inside WALL acceptance



What are the background sources that obscure the signal?

Sources for p+K$^+$+Λ

Searched Signal

$$p + p \xrightarrow{3.5GeV} \text{"}ppK^-\text{"} + K^+$$
$$\hookrightarrow \Lambda + p$$
$$\hookrightarrow \Sigma^0 + p$$

Expected background process

$$p + p \xrightarrow{3.5GeV} N^{*+} + p$$
$$\hookrightarrow \Lambda + K^+$$

Sources for p+K$^+$+Λ

Searched Signal

$$p + p \xrightarrow{3.5GeV} \text{"}ppK^-\text{"} + K^+$$
$$\hookrightarrow \Lambda + p$$
$$\hookrightarrow \Sigma^0 + p$$

Expected background process

$$p + p \xrightarrow{3.5GeV} N^{*+} + p$$
$$\hookrightarrow \Lambda + K^+$$

Sources for p+K⁺+Λ

Searched Signal

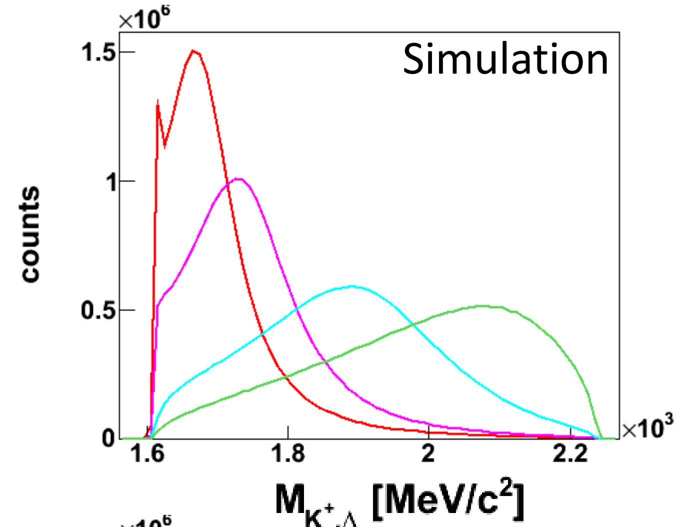
$$p + p \xrightarrow{3.5GeV} \text{"}ppK^-\text{"} + K^+$$
$$\text{"}ppK^-\text{"} \rightarrow \Lambda + p$$
$$\text{"}ppK^-\text{"} \rightarrow \Sigma^0 + p$$

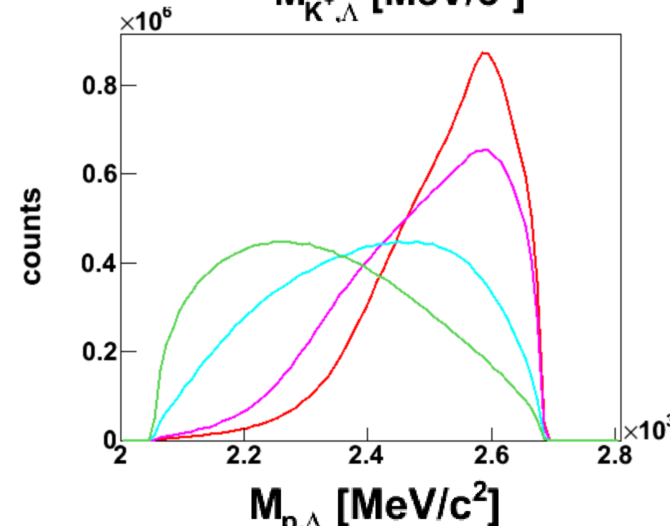
Expected background process

$$p + p \xrightarrow{3.5GeV} N^{*+} + p$$
$$N^{*+} \rightarrow \Lambda + K^+$$

$N^{*+}(1650)$
$N^{*+}(1720)$
$N^{*+}(1900)$
$N^{*+}(2190)$

Observables 4π





Bonn-Gatchina PWA

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

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

What we included to model the PK⁺Λ process:

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

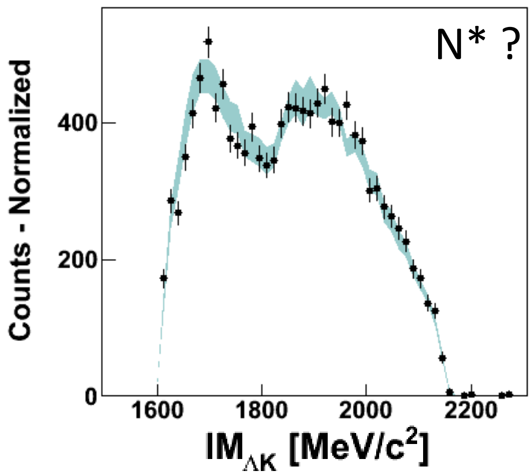
Notation in PDG	old	Mass GeV/c^2	Width GeV/c^2	$\Gamma_{\Lambda K}/\Gamma_{All}$
N(1650) $\frac{1}{2}^-$	N(1650)S_{11}	1.655	0.150	3-11%
N(1710) $\frac{1}{2}^+$	N(1710)P_{11}	1.710	0.200	5-25%
N(1720) $\frac{3}{2}^+$	N(1720)D_{13}	1.720	0.250	1-15%
N(1875) $\frac{3}{2}^-$	N(1875)D_{13}	1.875	0.220	?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

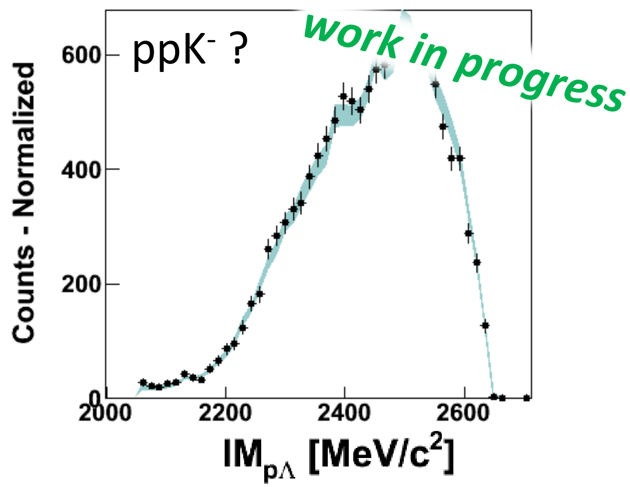
And the production of $pK^+\Lambda$ via non resonant waves

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

Systematic uncertainty

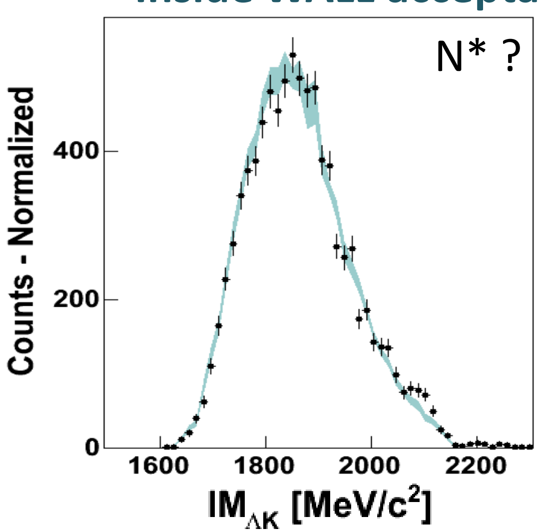
Inside HADES acceptance

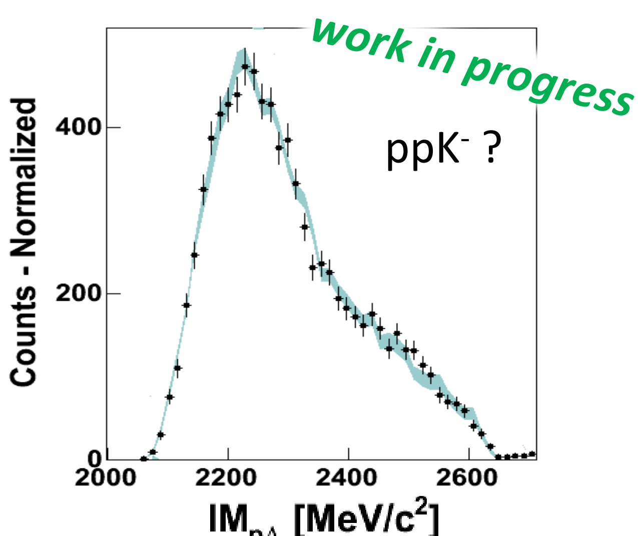




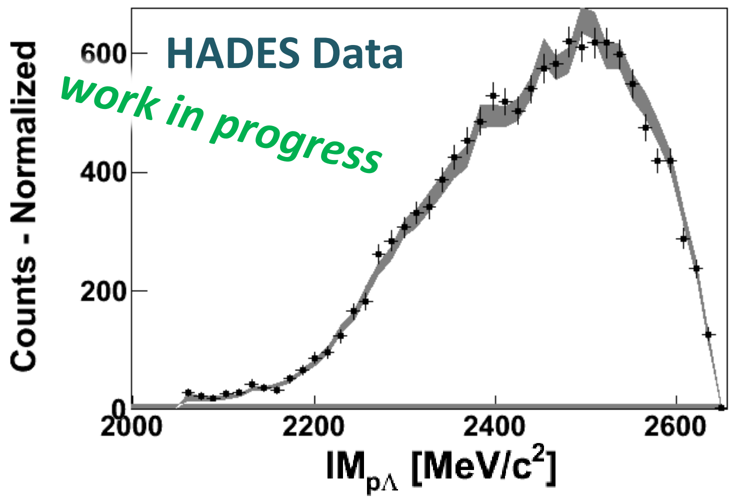
Data
Systematic of best PWA solutions

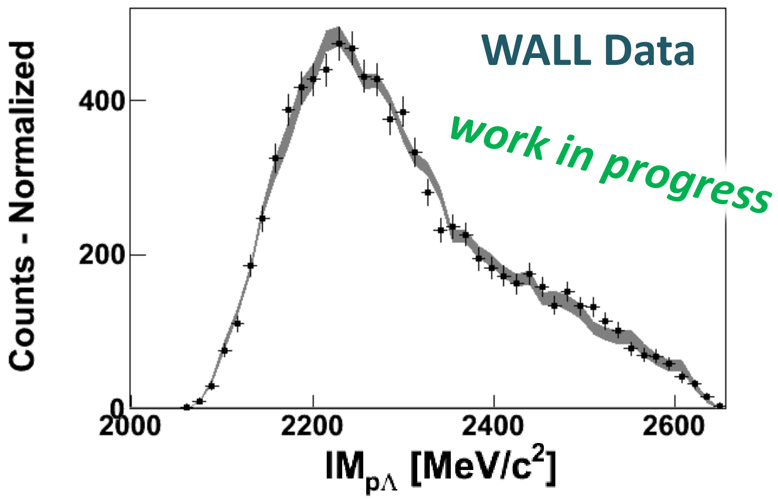
Inside WALL acceptance



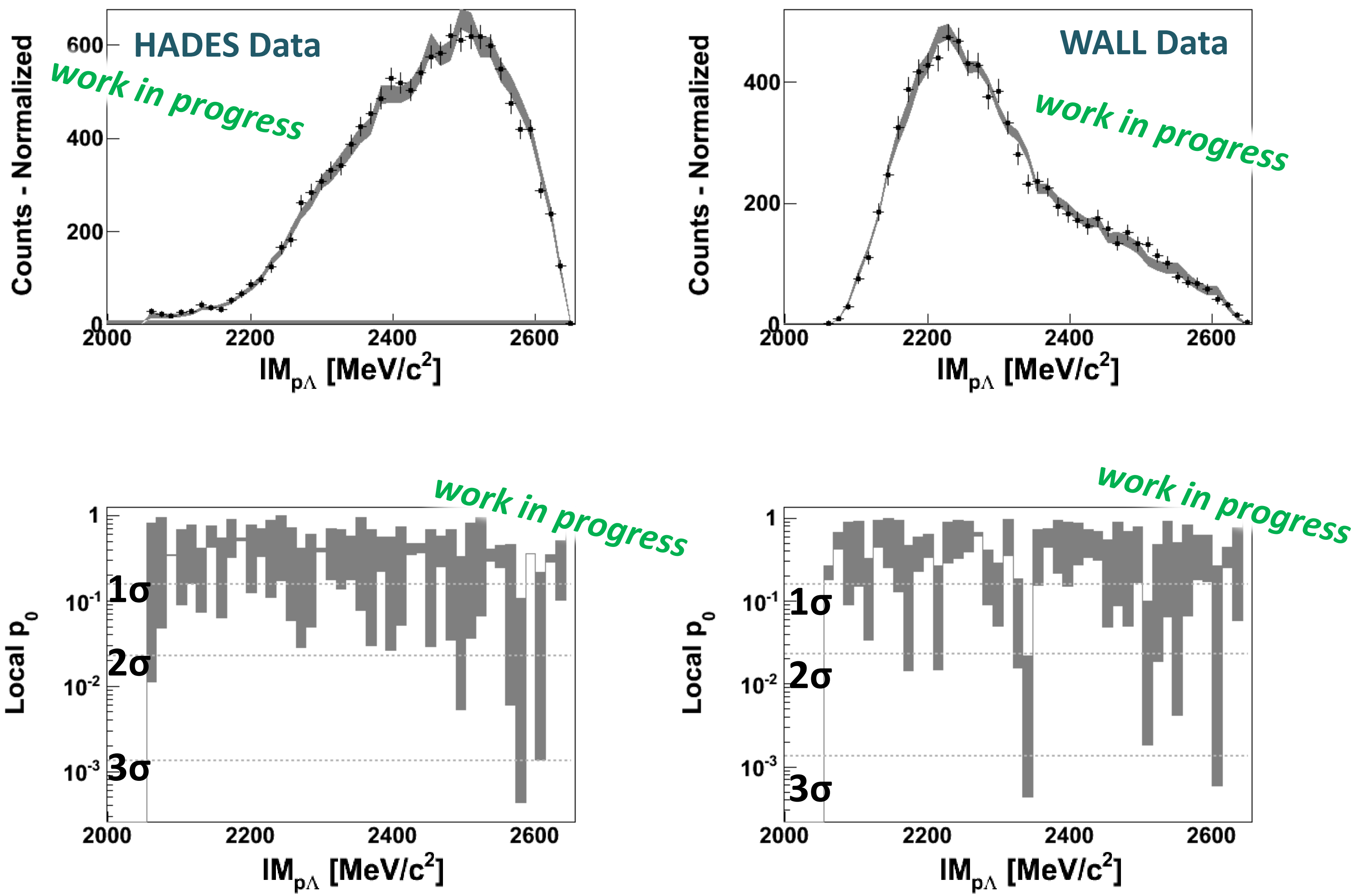


Local-p-value

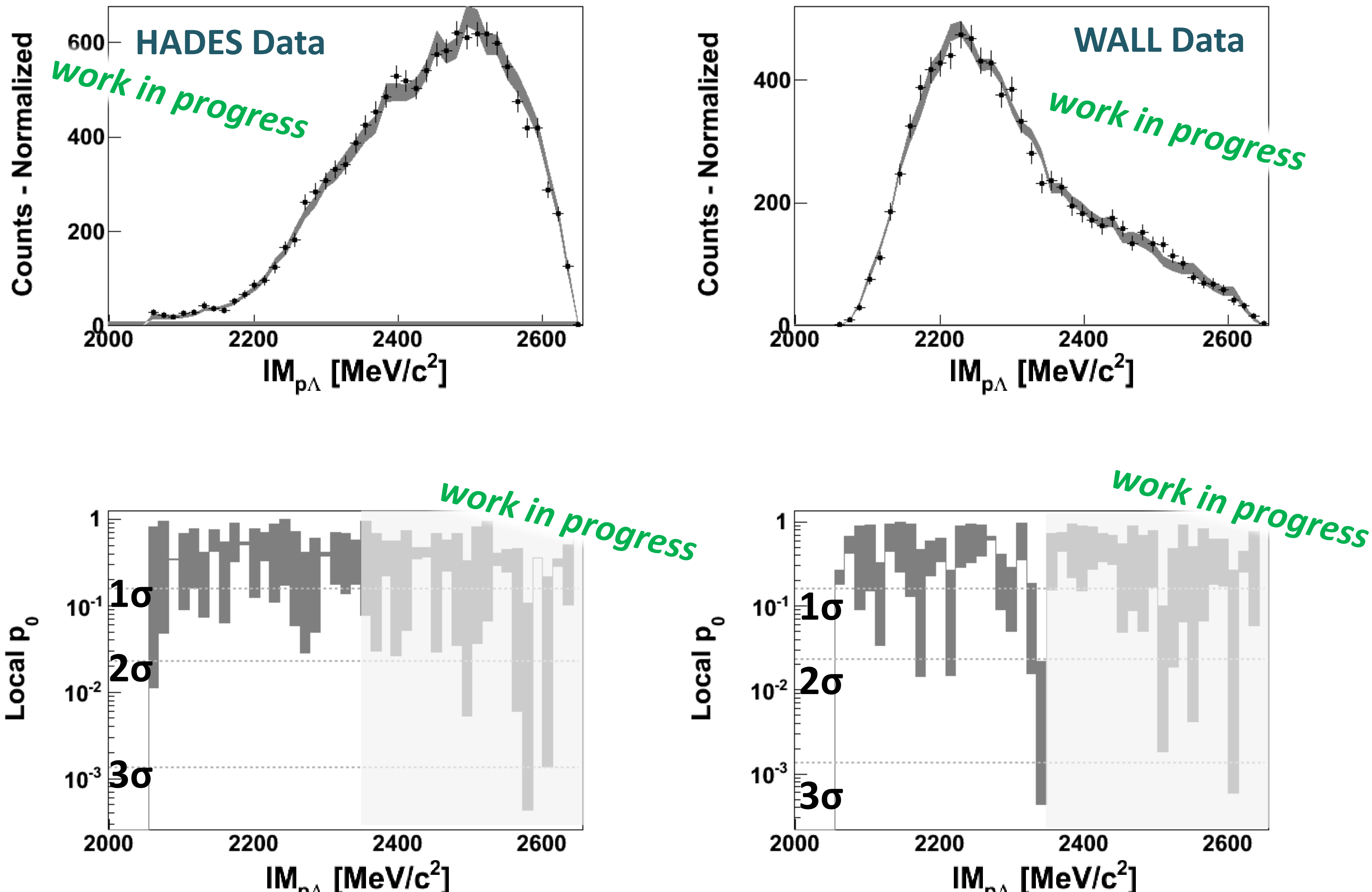




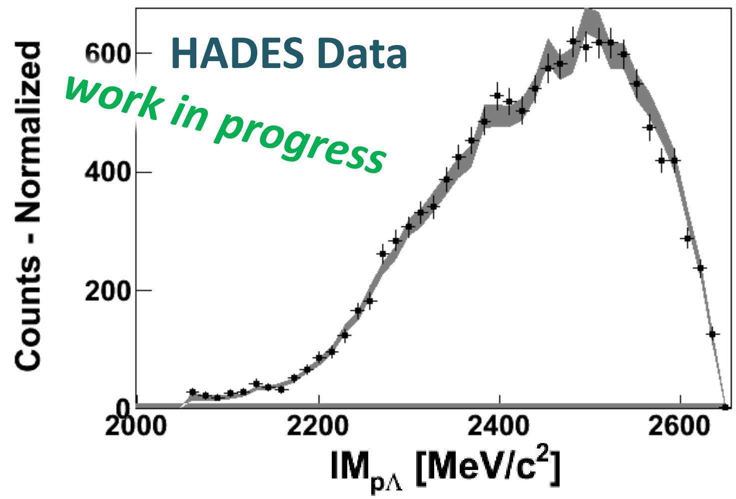
Local-p-value

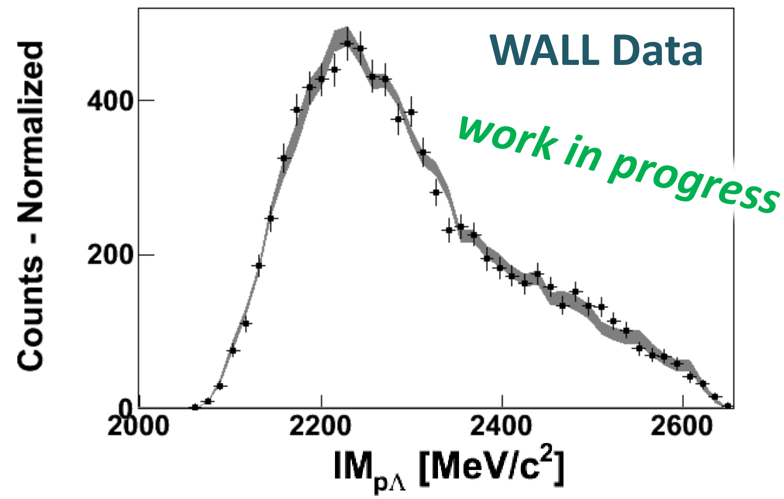


Local-p-value

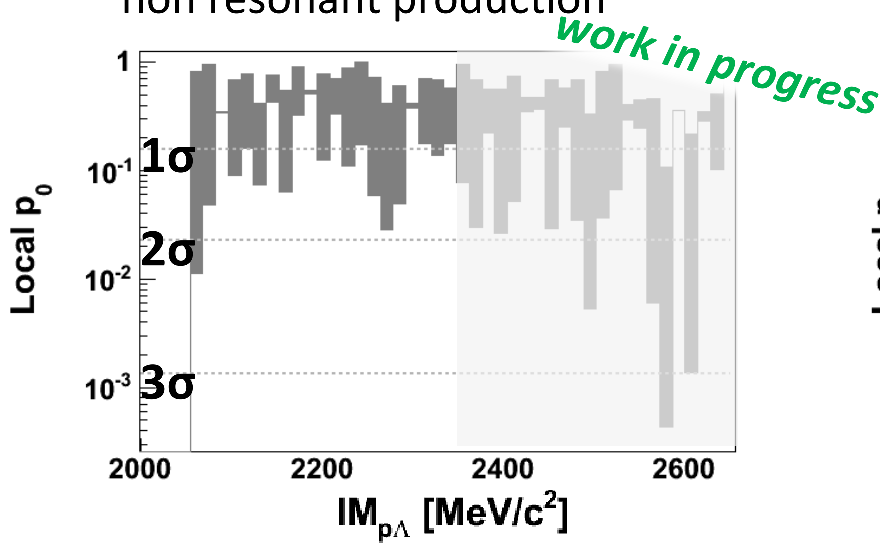


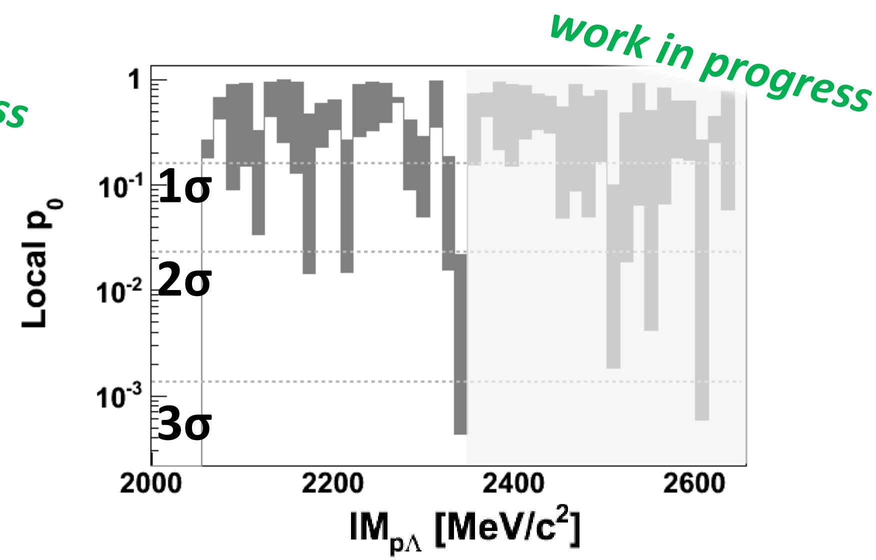
Local-p-value





Data are consistent with a model containing only N* resonances and non resonant production

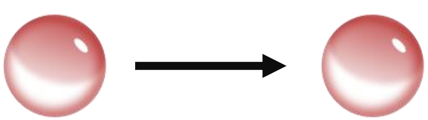




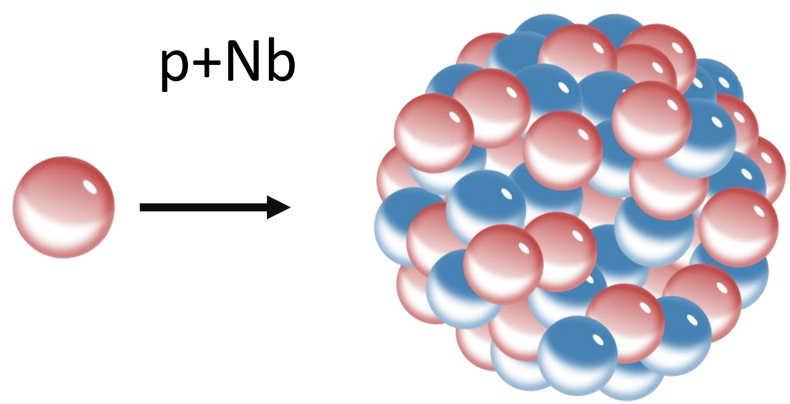
Cold medium effects

S=+1

p+p

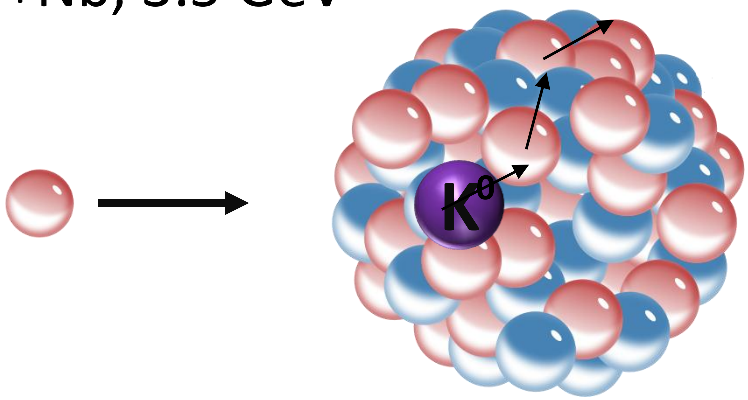


p+Nb



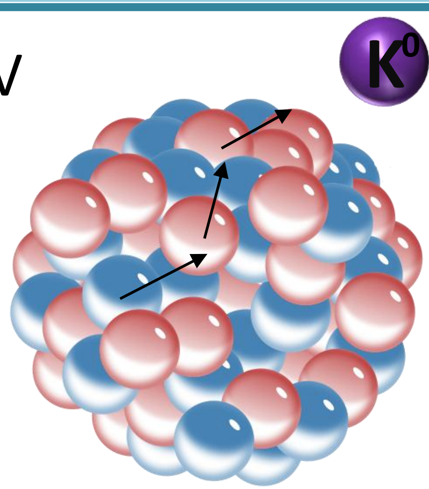
Reaction

p+Nb, 3.5 GeV



K-Nucleus Potential

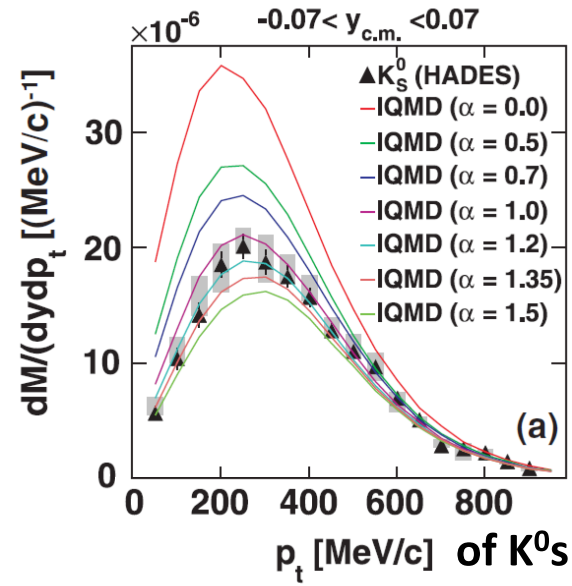
p+Nb, 3.5 GeV



Inside the Nucleus:
The K^0 experiences a potential due to the surrounding nucleons.

HADES Ar+KCl 1.76 A GeV

HADES Collaboration (G. Agakishiev et al.), Phys. Rev. **C 82**, 044907 (2010)



of K^0s

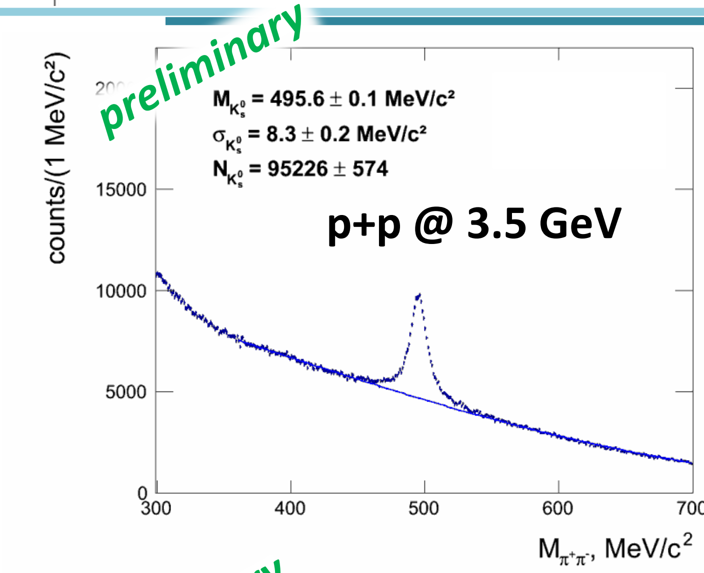
Transport simulations with U_{opt} = +39 MeV fit the data best

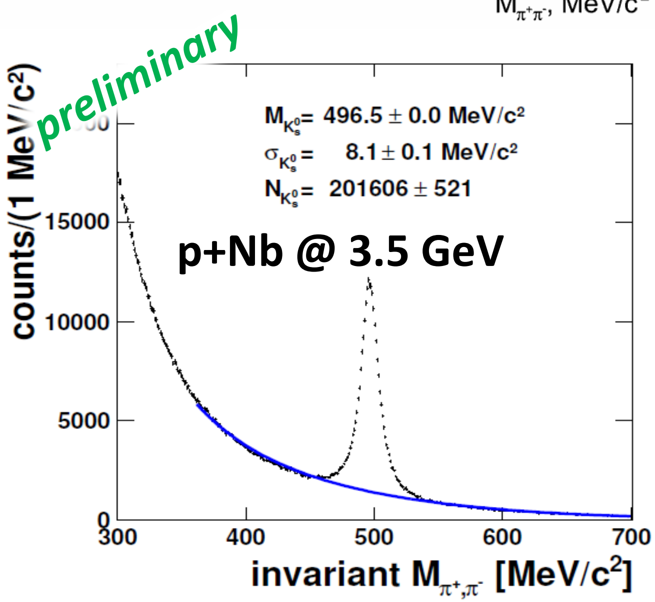
FOPI π^-+A, ANKE p+A

Benabderrahmane et al.
Phys. Rev. Lett. **102**, 182501 (2009)
Büscher et al.
Eur. Phys. J. **A 22**, 301 (2004)

U_{opt} = +20±5 MeV extracted from comparison with transport-model calculations

Reconstructed Signal

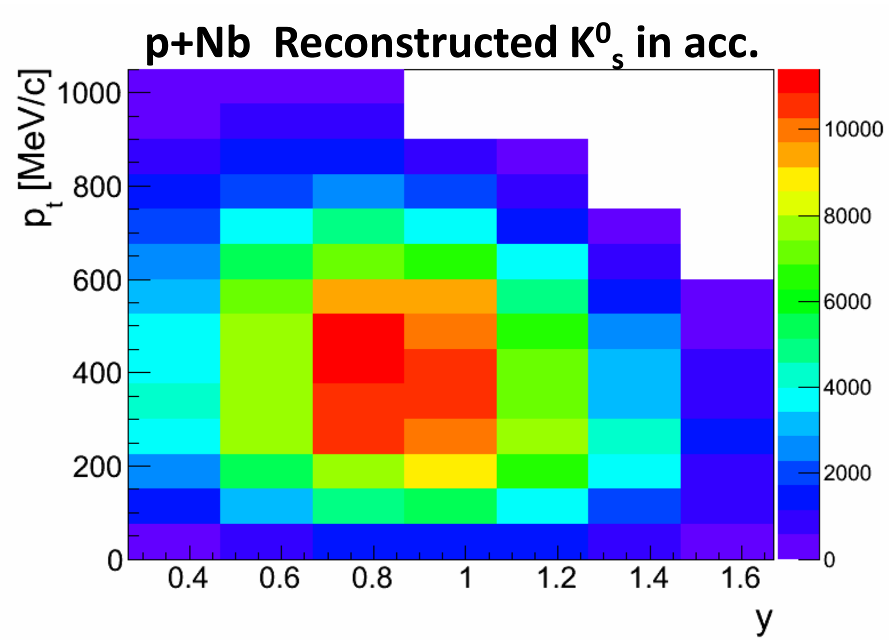




The K^0 is identified by its short-lived component K^0_S

$K^0_S \rightarrow \pi^+ \pi^-$ 69.2%.

Double differential analysis in p_t-y

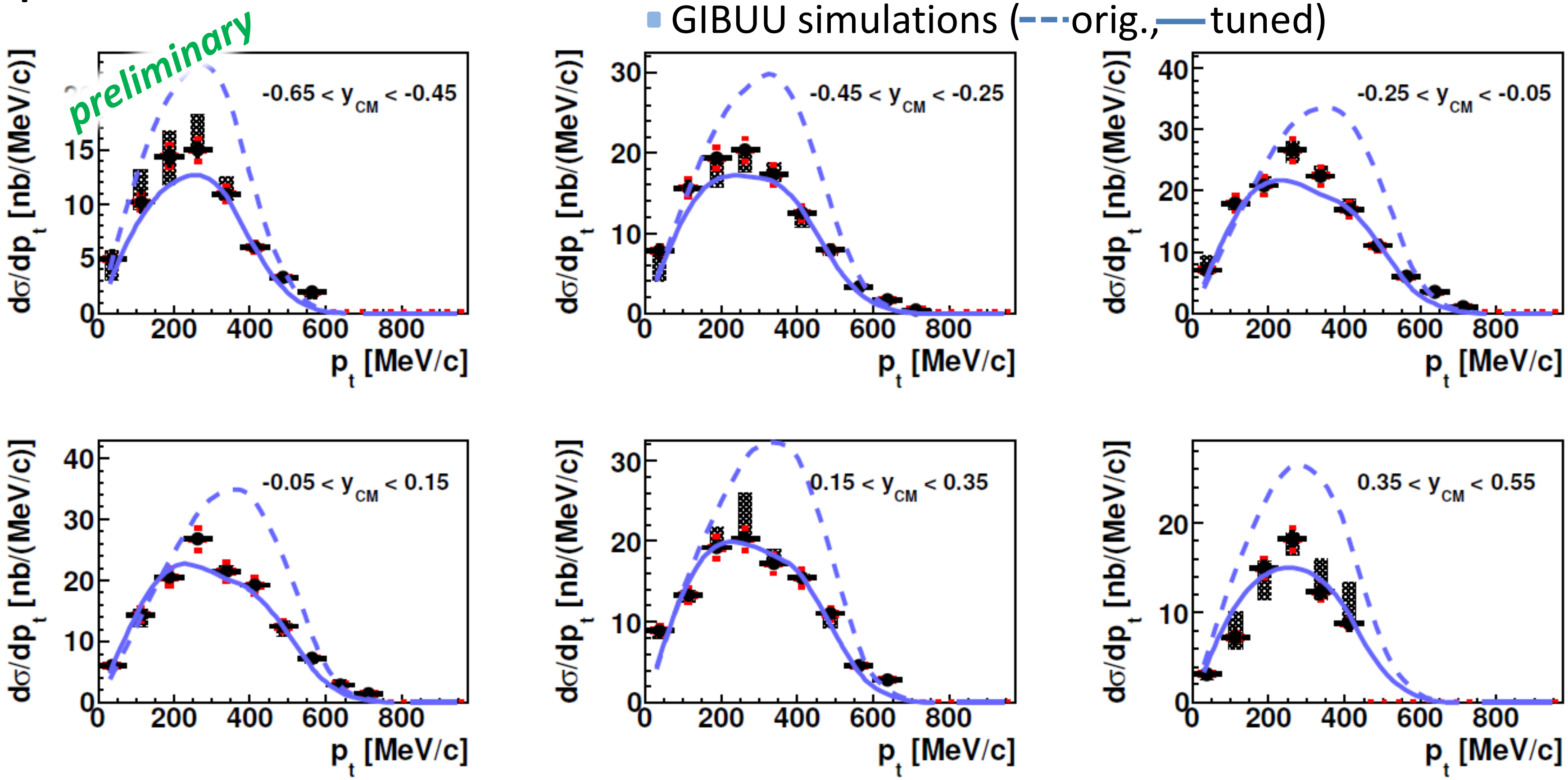


Tuned GIBUU

p+p @ 3.5 GeV

■ acc. and eff. corrected data

■ GIBUU simulations (- - - orig., —— tuned)



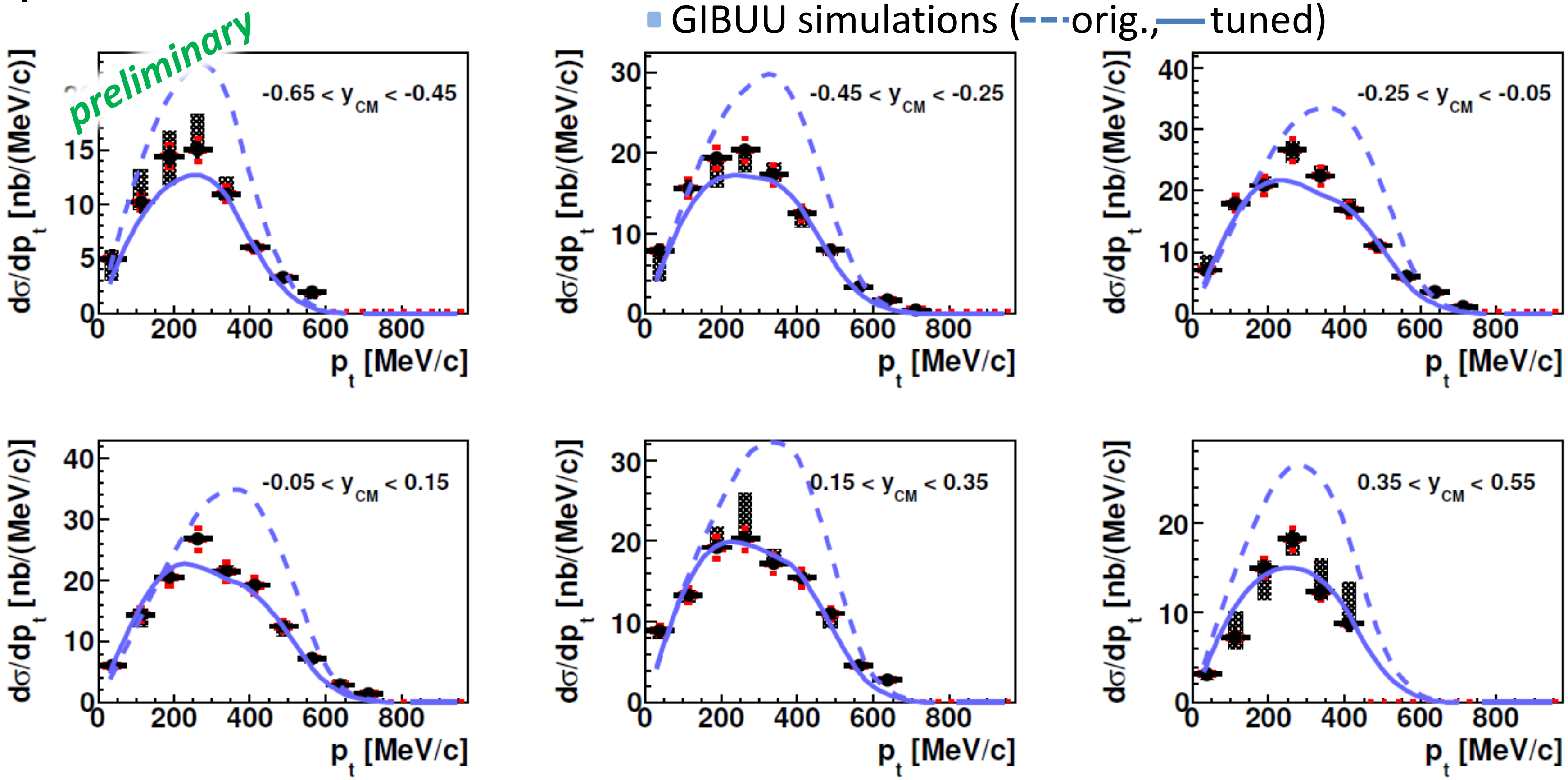
Tsushima Model:
K. Tsushima, A. Sibirtsev, and A. W. Thomas,
Phys.Rev. **C 59**, 369 (1999)

$p+p \rightarrow \Sigma^{+} + p + K^{0}$	x 0.7
$p+p \rightarrow \Delta^{++} + \Lambda + K^{0}$	x 0.4
$p+p \rightarrow \Delta^{++}/\Delta^{+} + \Sigma^{0/+} + K^{0}$	x 0.7
$p+p \rightarrow \Delta^{++} + Y^{*} + K^{0}$	implemented

Tuned GIBUU

p+p @ 3.5 GeV

■ acc. and eff. corrected data
■ GIBUU simulations (- - - orig., —— tuned)



Tsushima Model:
K. Tsushima, A. Sibirtsev, and A. W. Thomas,
Phys.Rev. **C 59**, 369 (1999)

Exclusive measurement on the way

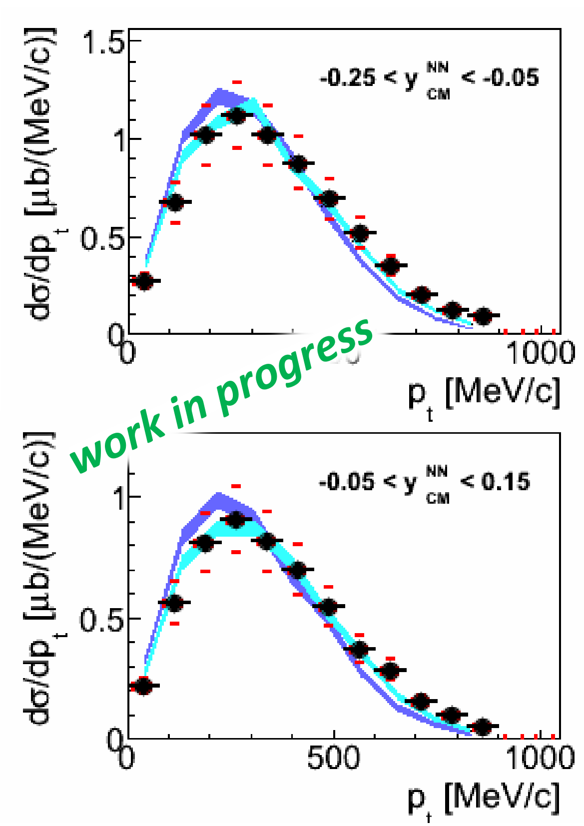
$p + p \rightarrow \Sigma^{+} + p + K^{0}$	x 0.7
$p + p \rightarrow \Delta^{++} + \Lambda + K^{0}$	x 0.4
$p + p \rightarrow \Delta^{++}/\Delta^{+} + \Sigma^{0/+} + K^{0}$	x 0.7
$p + p \rightarrow \Delta^{++} + Y^{*} + K^{0}$	implemented

P_t distributions in p+Nb

p+Nb @ 3.5 GeV $Z_{Nb} = 41$, $N_{Nb} = 52$

Things to be aware of:

1. p+p could be tuned to the data
2. Some p+n cross sections are not constrained by experiment



- acc. and eff. corrected data
- GIBUU simulations - absolutely normalized!
  (with pot., w/o pot.)

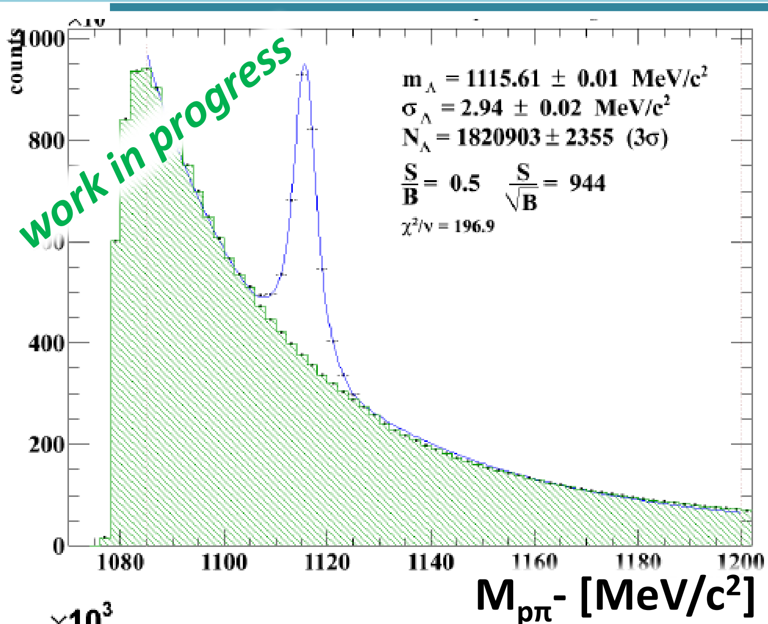
Chiral potential for K^0 implemented in GIBUU

$$m_K^* = \sqrt{m_K^2 - \frac{\Sigma_{KN}}{f_\pi^2}\rho_s + V_\mu V^\mu}$$

$$V_\mu = \frac{3}{8 f_\pi^{*2}} j_\mu$$

Kirill Lapidus, HK 17.6, Mo 18:00

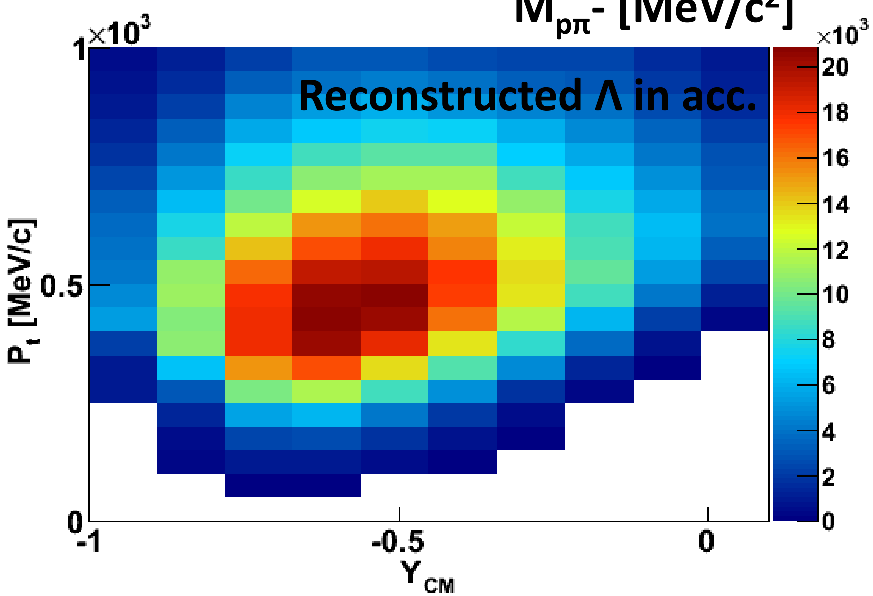
An Outlook on Λ's

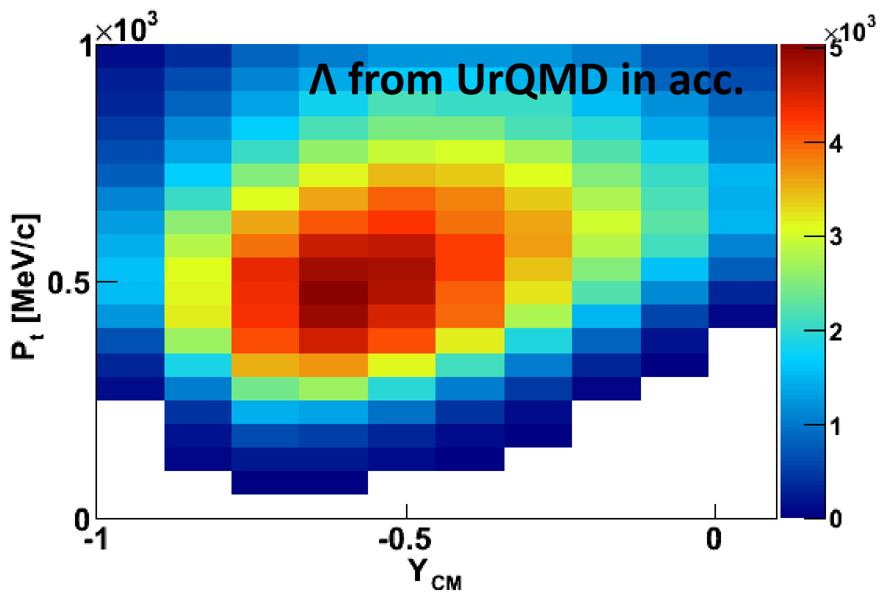


p+Nb @ 3.5 GeV

N_Λ reconstructed ≈ 2 Mio

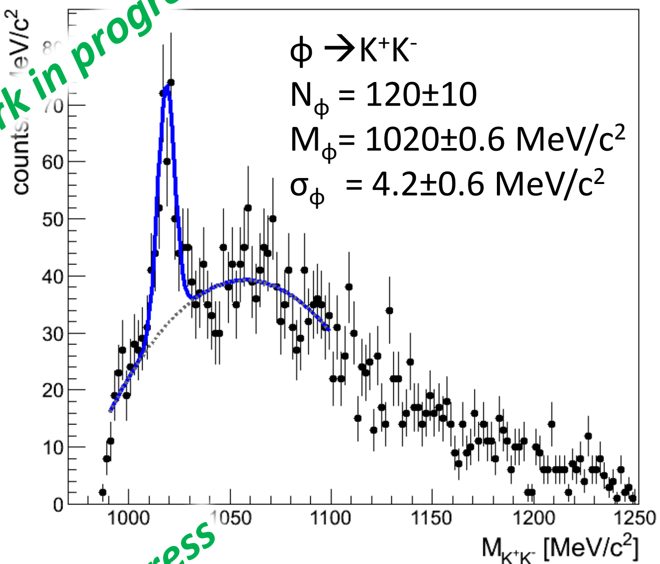
Christian Wendisch, HK 17.5, Mo 17:45
Poster
Oliver Arnold, HK 54.11, Mi 16:45

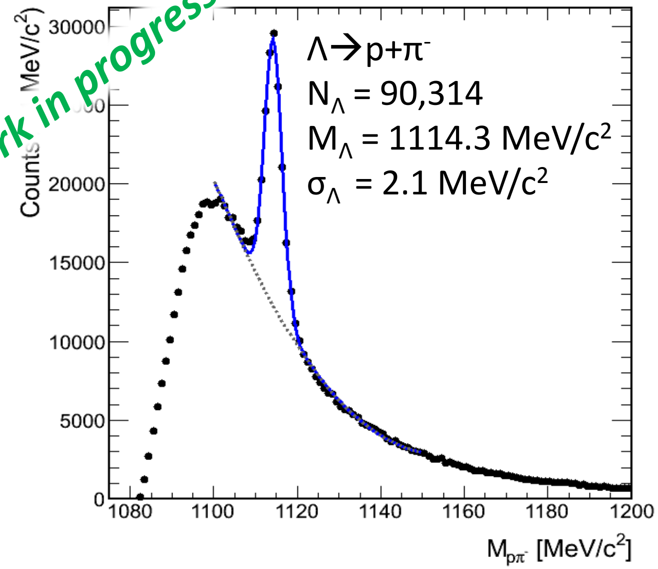


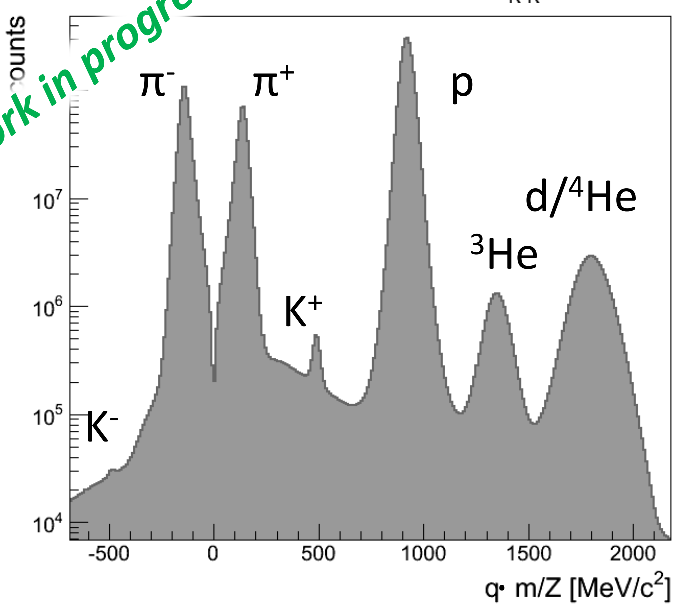


Au+Au
Work in progress

Strangeness in Au+Au 1.25 AGeV





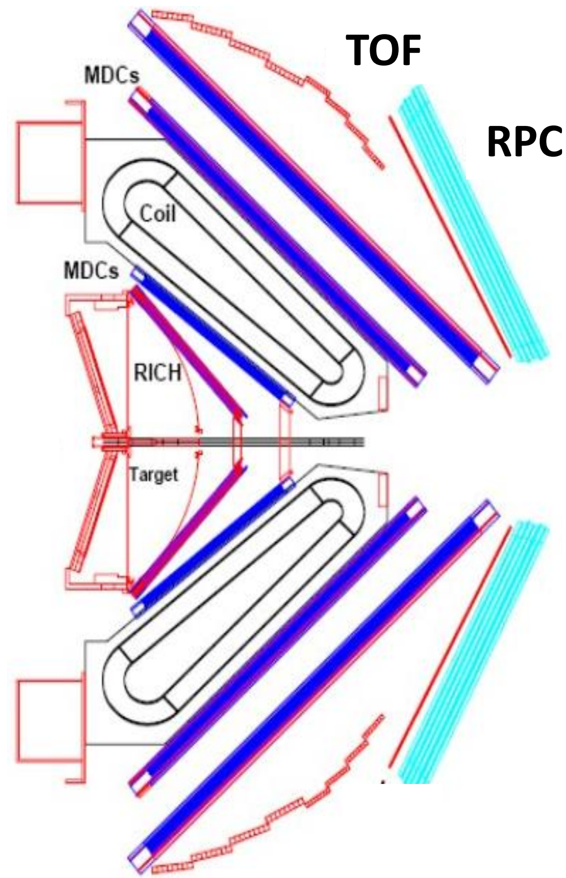


First time manifold strangeness reconstruction; all produced sub-threshold of free NN collision

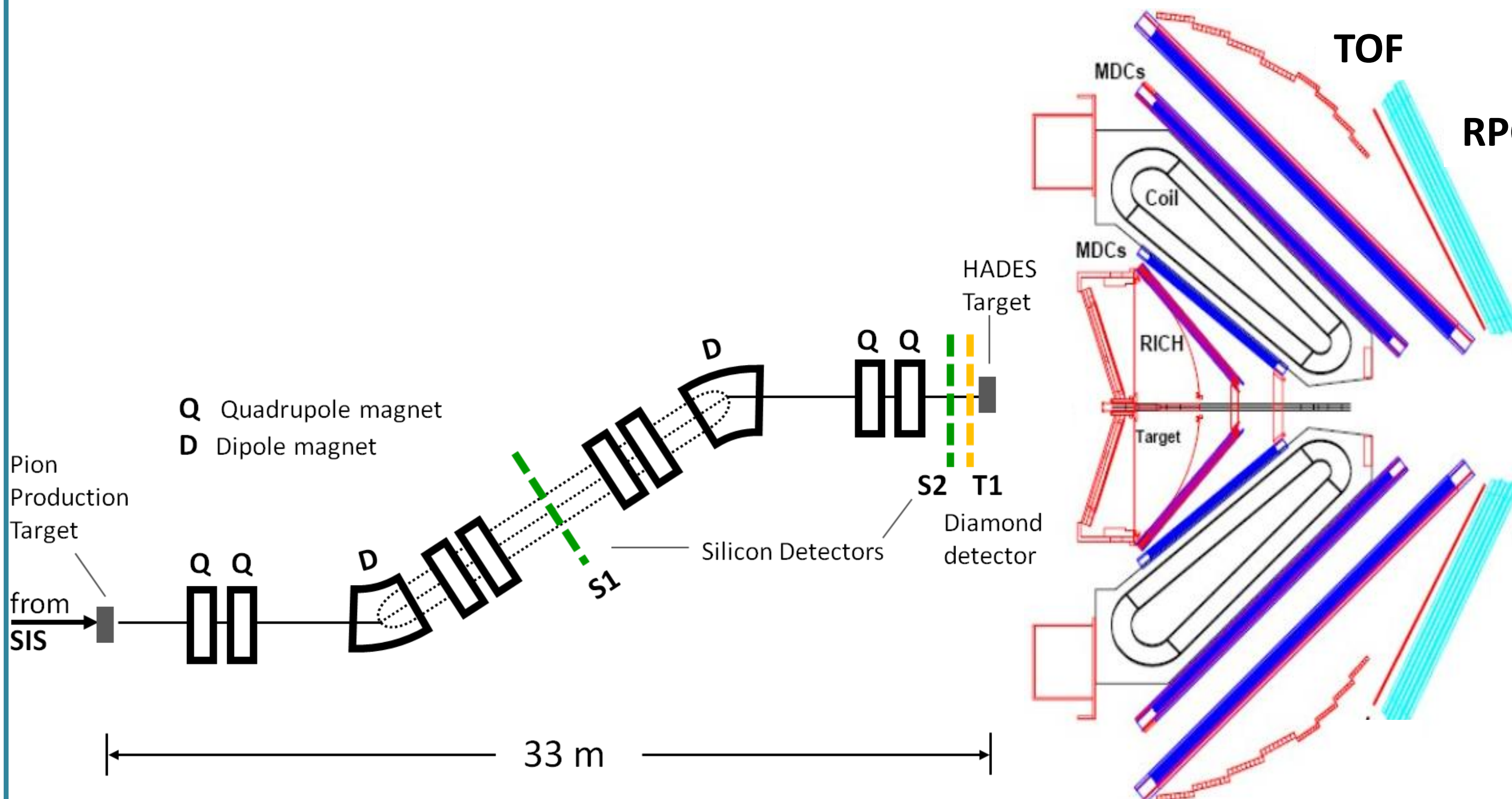
Manuel Lorenz, HK 4.5 Mo 12:15

Pion induced reactions

Tracker for the π-Beam



Tracker for the π-Beam



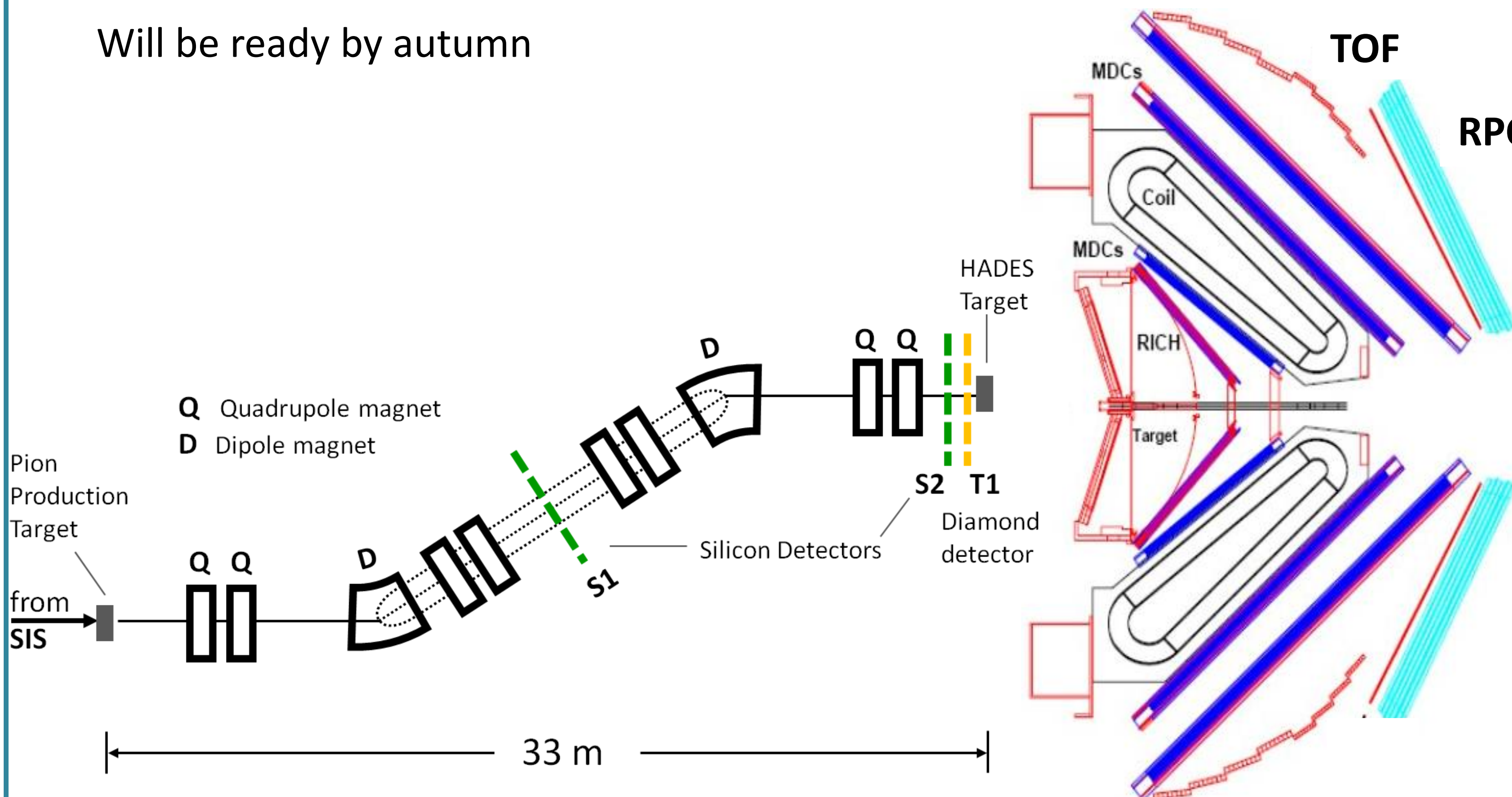
Rafal Lalik, HK 35.3, Di 14:45

Poster

Joana Wirth, HK 52.21, Mi 16:45

Tracker for the π-Beam

Will be ready by autumn

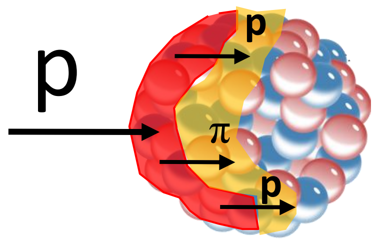


Rafal Lalik, HK 35.3, Di 14:45

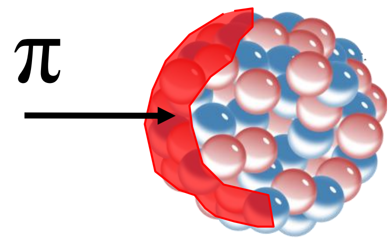
Poster

Joana Wirth, HK 52.21, Mi 16:45

Physics with Pion Beams

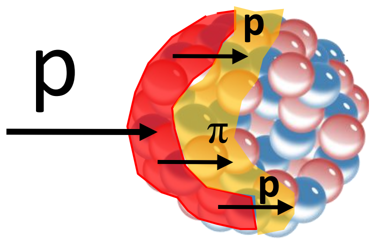


p + Nb

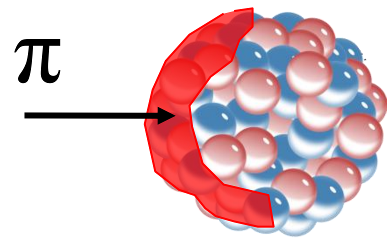


π^- + C/Cu/Pb

Physics with Pion Beams



p + Nb



π^- + C/Cu/Pb

$$U_{opt} = U_R(r) + i\, U_I(r)$$

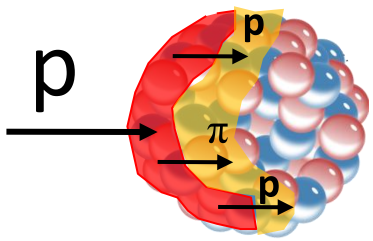
Takes into account the modified energy of a particle inside a nucleus

- Modified production rates
- Modified momentum distributions

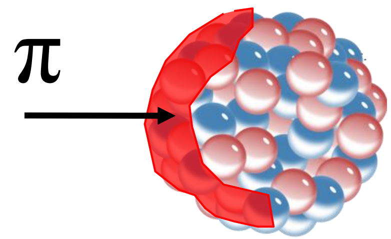
Takes into account the presence of more than one open channel.

- Inelastic scattering
- Absorption by formation of a resonance

Physics with Pion Beams



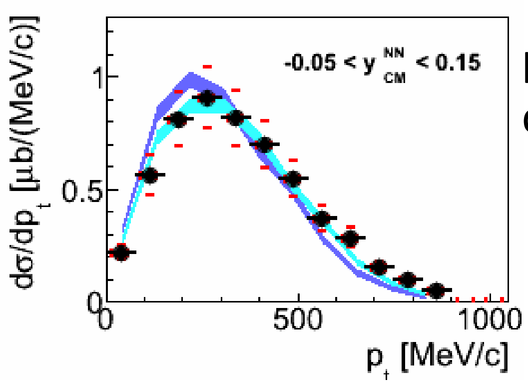
p + Nb



π^- + C/Cu/Pb

$$U_{opt} = U_R(r) + i\, U_I(r)$$

How to measure?



p_t distributions

How to measure?

Differential ratios of particle yield

K^0,K^+,K^-, ϕ and Λ

Transparency measurement

$$T_A = \frac{\sigma_{\pi^- A \to K^- + X}}{f(A) \cdot \sigma_{\pi^- C \to K^- + X}}$$

What you should take home

- $\Lambda(1405)$ measured for the first time produced in p+p in the $\Sigma^{+/-}\pi^{-/+}$ decay channels
  Anomalous mass shift similar to pion induced reactions
- A search for kaonic nuclear bound states has revealed no signal at 3.5 GeV

- A large statistic of K^0s is analyzed in p+p and p+Nb
- Data are compatible with GIBUU including a potential
- Measurement of elementary production cross sections is on the way and essential for the description of nuclear systems

- First signals from Au+Au yield a lot of prospect for future physics results

- Pion-beam experiment – planned for this year
- Measurement of real and imaginary part for $\bar{K}N$ potential

The HADES Collaboration

Jörn Adamczewski-Musch, Geydar Agakishiev, Claudia Behnke, Alexander Belyaev, Jia-Chii Berger-Chen, Alberto Blanco, Christoph Blume, Michael Böhmer, Pablo Cabanelas, Nuno Carolino, Sergey Chernenko, Jose Díaz, Adrian Dybczak, Eliane Epple, Laura Fabbietti, Oleg Fateev, Paulo Fonte, Jürgen Friese, Ingo Fröhlich, Tetyana Galatyuk, Juan A. Garzón, Roman Gernhäuser, Alejandro Gil, Katharina Gil, Marina Golubeva, Fedor Guber, Malgorzata Gumberidze, Szymon Harabasz, Klaus Heidel, Thorsten Heinz, Thierry Hennino, Romain Holzmann, Jochen Hutsch, Claudia Höhne, Alexander Ierusalimov, Alexander Ivashkin, Burkhard Kämpfer, Marcin Kajetanowicz, Tatiana Karavicheva, Vladimir Khomyakov, Ilse Koenig, Wolfgang Koenig, Burkhard W. Kolb, Vladimir Kolganov, Grzegorz Korcyl, Georgy Kornakov, Roland Kotte, Erik Krebs, Hubert Kuc, Wolfgang Kühn, Andrej Kugler, Alexei Kurepin, Alexei Kurilkin, Pavel Kurilkin, Vladimir Ladygin, Rafal Lalik, Kirill Lapidus, Alexander Lebedev, Ming Liu, Luís Lopes, Manuel Lorenz, Gennady Lykasov, Ludwig Maier, Alexander Malakhov, Alessio Mangiarotti, Jochen Markert, Volker Metag, Jan Michel, Christian Müntz, Rober Münzer, Lothar Naumann, Marek Palka, Vladimir Pechenov, Olga Pechenova, Americo Pereira, Jerzy Pietraszko, Witold Przygoda, Nicolay Rabin, Béatrice Ramstein, Andrei Reshetin, Laura Rehnisch, Philippe Rosier, Anar Rustamov, Alexander Sadovsky, Piotr Salabura, Timo Scheib, Alexander Schmah, Heidi Schuldes, Erwin Schwab, Johannes Siebenson, Vladimir Smolyankin, Manfred Sobiella, Yuri Sobolev, Stefano Spataro, Herbert Ströbele, Joachim Stroth, Christian Sturm, Khaled Teilab, Vladimir Tiflov, Pavel Tlusty, Michael Traxler, Alexander Troyan, Haralabos Tsertos, Evgeny Usenko, Taras Vasiliev, Vladimir Wagner, Christian Wendisch, Jörn Wüstenfeld, Yuri Zanevsky

Backup

HADES Talks 1

- HK 17.3 Mo 17:15 HSZ-204
  π^0 and η production in proton-induced reactions measured with HADES
  Malgorzata Gumberidze
- HK 52.32 Mi 16:45 HSZ 2.OG
  General readout scheme for the HADES Electromagnetic Calorimeter: status and perspectives
  Behruz Kardan
- HK 35.3 Di 14:45 WIL-A221
  Development of the Pion Tracker for HADES spectrometer
  Rafal Lalik
- HK 4.5 Mo 12:15 HSZ-204
  Reconstruction of rare hadronic signals in Au+Au at 1.23A GeV with HADES
  Manuel Lorenz
- HK 4.2 Mo 11:30 HSZ-204
  HADES at SIS-100
  Jerzy Pietraszko
- HK 54.5 Mi 16:45 HSZ 3.OG
  Upper limit of the Hypertriton production in the Ar+KCl collision system at 1.76 AGeV with HADES
  Timo Scheib

HADES Talks 2

- HK 10.6 Mo 12:15 WIL-A221
  Performance of the HADES DAQ in Au+Au
  Jan Michel
- HK 17.5 Mo 17:45 HSZ-204
  Produktion von Λ-Hyperonen und φ-Mesonen in Reaktionen von p (@3.5 GeV)+Nb.
  Christian Wendisch
- HK 17.6 Mo 18:00 HSZ-204
  Production and interaction of neutral kaons in proton proton and proton-nucleus reactions at 3.5 GeV beam energy
  Kirill Lapidus

HADES Poster

- HK 55.1 Mi 16:45 HSZ 3.OG
  Production of p, d and t in Ar+KCl-Collisions at 1.76AGeV
  Heidi Schuldes
- HK 55.2 Mi 16:45 HSZ 3.OG
  Leptonenidentifikation in Au+Au bei 1,23 GeV/u
  Patrick Sellheim
- HK 55.4 Mi 16:45 HSZ 3.OG
  Systematics of pi^0 and eta Dalitz decays in the Gold on Gold beam time of HADES
  Claudia Behnke
- HK 55.3 Mi 16:45 HSZ 3.OG
  How I found high momentum leptons in HADES
  Szymon Harabasz
- HK 54.11 Mi 16:45 HSZ 3.OG
  Study of the Λ(1116) interaction with the cold nuclear environment
  Oliver Arnold
- HK 52.21 Mi 16:45 HSZ 2.OG
  Development of a cooling system and vacuum chamber for the pion tracker for HADES
  Joana Wirth
- HK 52.22 Mi 16:45 HSZ 2.OG
  Data-driven calibration proceedure for the HADES electromagnetic calorimeter
  Dimitar Mihaylov

Reaction Systems

Year	System	Energy
2002	C+C	2 AGeV
2004	C+C	1 AGeV
2005	Ar+KCl	1.756 AGeV
2006	p+p	1.25 GeV
2007	p+p	3.5 GeV
2007	d+p	1.25 AGeV
2008	p+Nb	3.5 GeV
2012	Au+Au	1.25 AGeV

Reaction Systems

Year	System	Energy
2002	C+C	2 AGeV
2004	C+C	1 AGeV
2005	Ar+KCl	1.756 AGeV
2006	p+p	1.25 GeV
2007	p+p	3.5 GeV
2007	d+p	1.25 AGeV
2008	p+Nb	3.5 GeV
2012	Au+Au	1.25 AGeV
>2013	π+p, π+A	p = 0.8÷1.7 GeV/c
>2015, FAIR	C+C, Ni+Ni	up to 8 AGeV

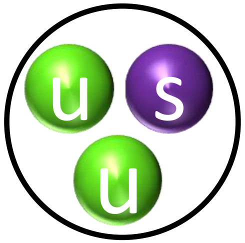
Reaction Systems

Year	System	Energy
2002	C+C	2 AGeV
2004	C+C	1 AGeV
2005	Ar+KCl	1.756 AGeV
2006	p+p	1.25 GeV
2007	p+p	3.5 GeV
2007	d+p	1.25 AGeV
2008	p+Nb	3.5 GeV
2012	Au+Au	1.25 AGeV
>2013	π+p, π+A	p = 0.8÷1.7 GeV/c
>2015, FAIR	C+C, Ni+Ni	up to 8 AGeV

Backup

Resonances in p+p

The $\Sigma(1385)^+$



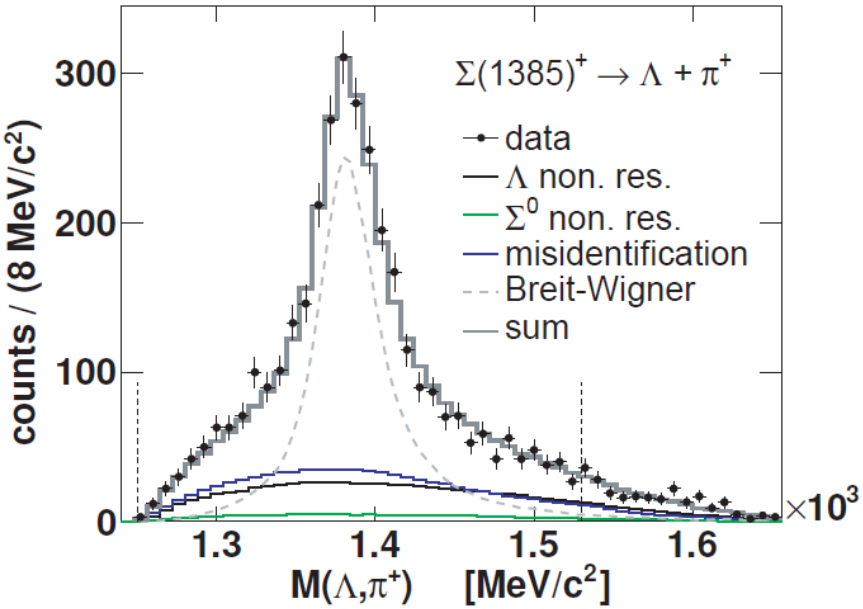
$\Sigma(1385)^+$

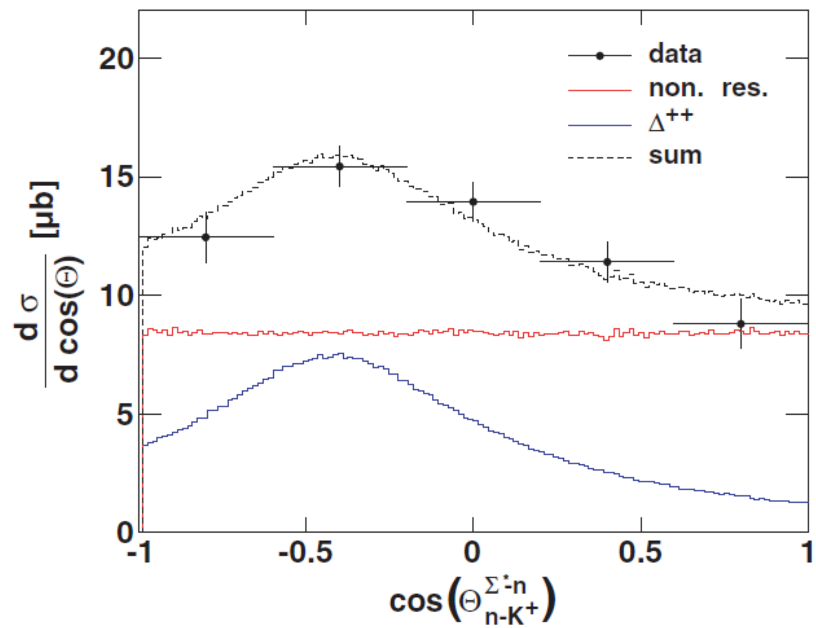
Resonance in $\Sigma\pi$

$$I(J^P) = 1(\tfrac{3}{2}^+)$$

$$p(3.5GeV) + p \rightarrow \Sigma(1385)^+ + K^+ + n$$
$$\quad \hookrightarrow \Lambda + \pi^+$$
$$\qquad \hookrightarrow p + \pi^- .$$

HADES coll. (G. Agakishiev et al.) Phys. Rev. **C 85,** 035203 (2012)





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

Total cross section

$$\sigma = 22.42 \pm 0.99 \pm 1.57^{+3.04}_{-2.23}\ \mu b$$

Reaction - Reconstruction

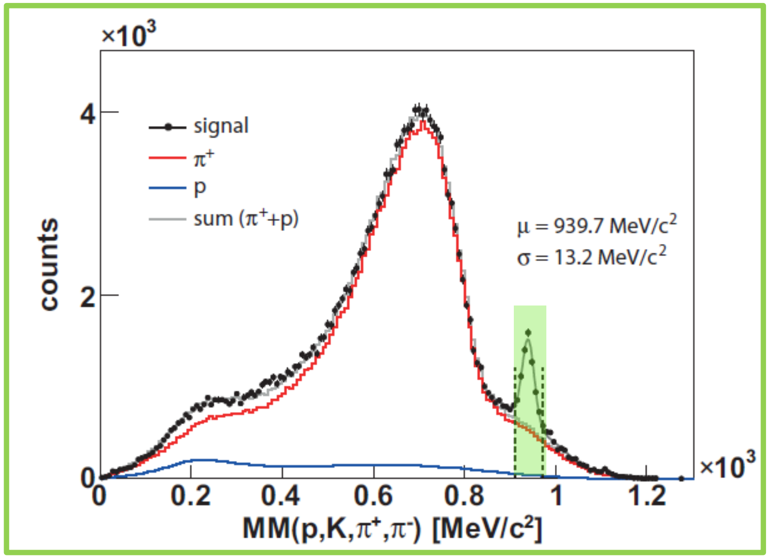
$$p + p \xrightarrow{3.5GeV} \Lambda(1405) + p + K^{+}$$

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

$$\hookrightarrow n + \pi^{+} \qquad 16.11\%$$

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

$$\hookrightarrow n + \pi^{-} \qquad 33.33\%$$

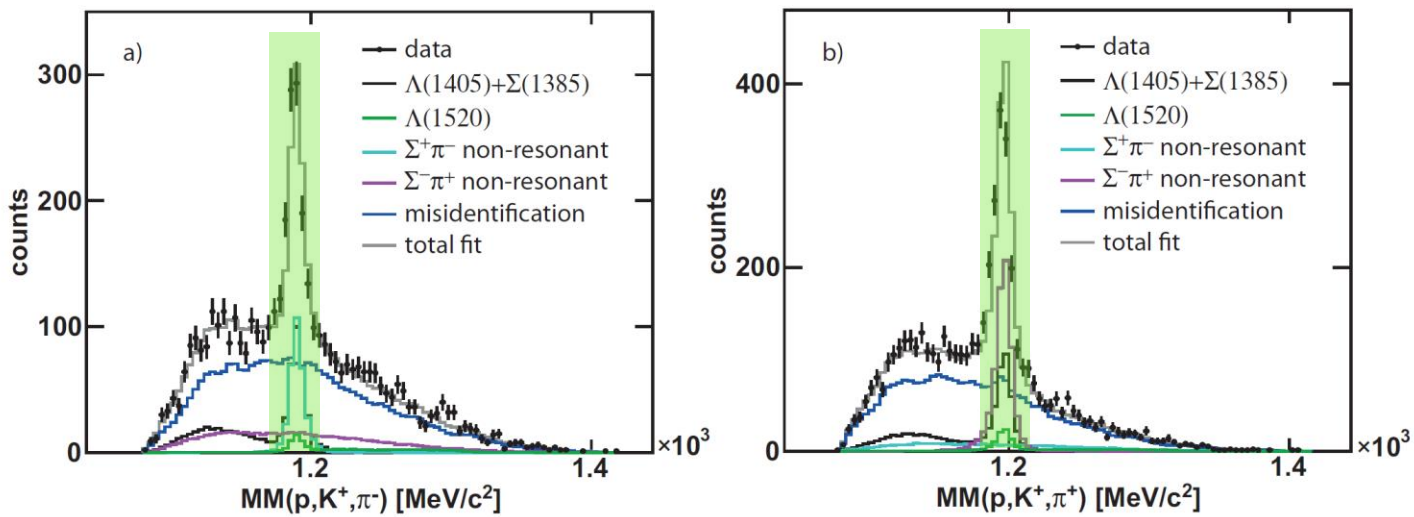


Reaction - Reconstruction

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

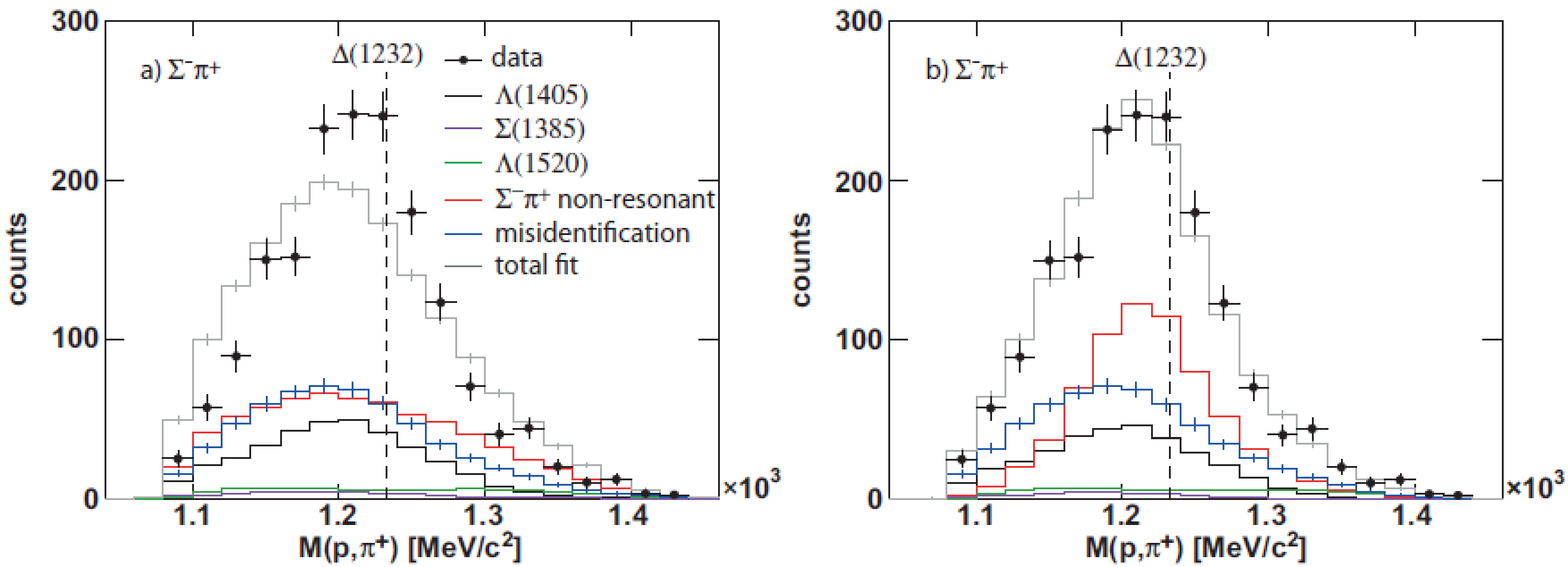
$$\Lambda(1405) \rightarrow \Sigma^+ + \pi^-, \quad \Sigma^+ \rightarrow n + \pi^+ \qquad 16.11\%$$

$$\Lambda(1405) \rightarrow \Sigma^- + \pi^+, \quad \Sigma^- \rightarrow n + \pi^- \qquad 33.33\%$$



Δ^{++} contribution

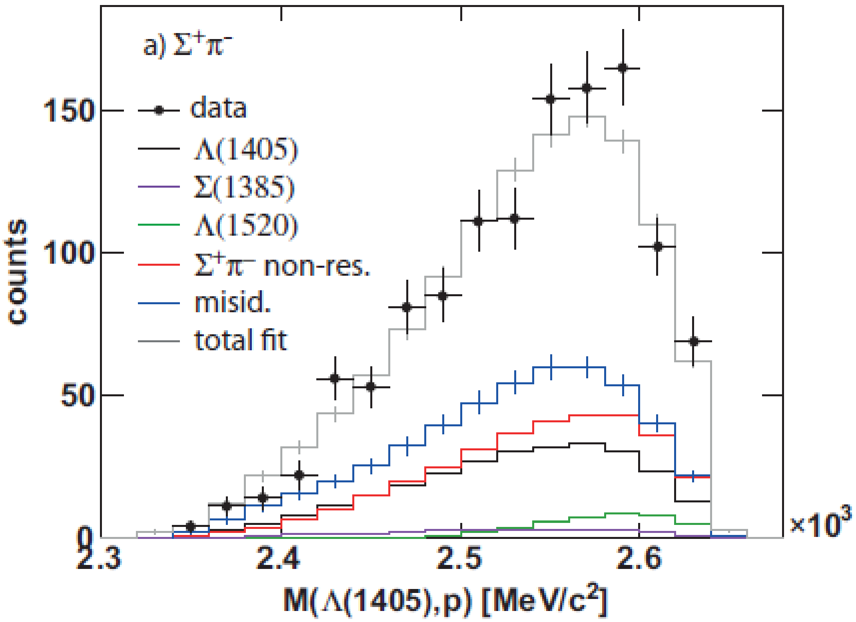
G. Agakishiev (HADES Coll.), Nuclear Physics **A 881** (2012)

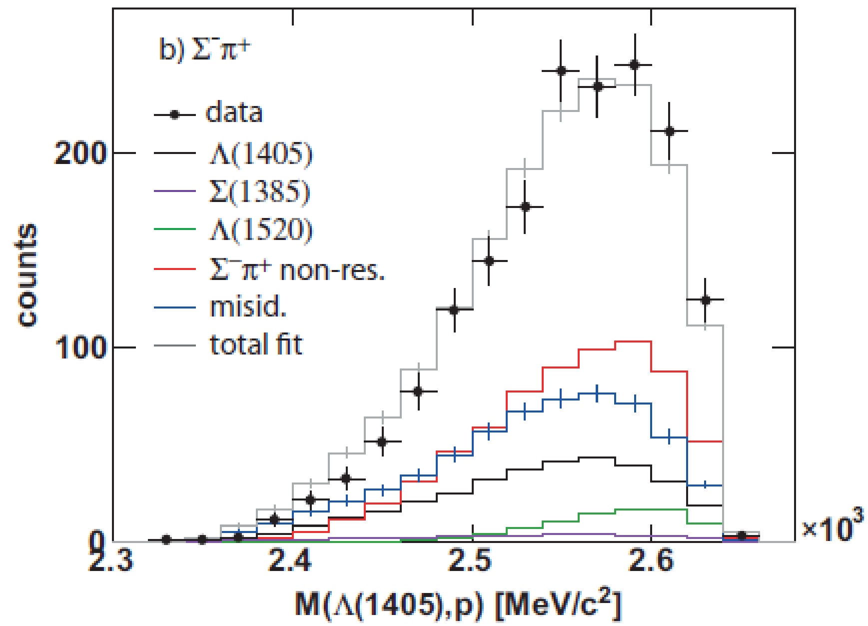


p+p → Σ⁻+**p+π⁺**+K⁺ or p+p → Σ⁻ +**Δ⁺⁺**+K⁺

Reaction:	***Cross section***
$p+p \rightarrow \Delta^{++}(1232) + \Sigma^- + K^+$	$7.7 \pm 0.9 \pm 0.5^{+0.3}_{-0.9}\ \mu b$

More Observables





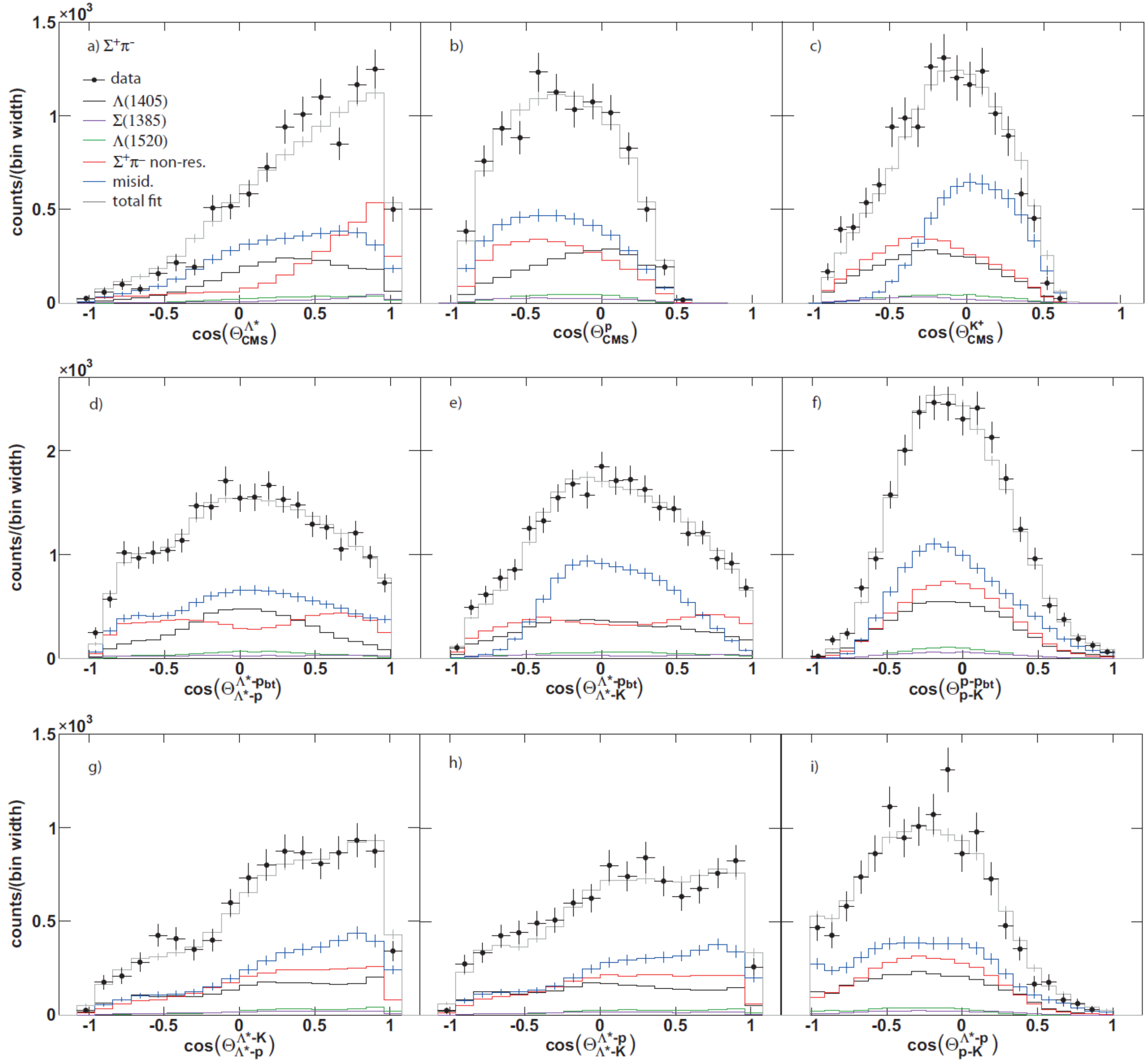


Figure 1.9: Angular distributions for the $\Sigma^+\pi^-$ data sample. First row shows the production angles of the $\Lambda(1405)$ candidate, the proton and the K^+ in the CMS. Second row displays the three possible G-J angles. In the third row the three helicity angles are plotted.

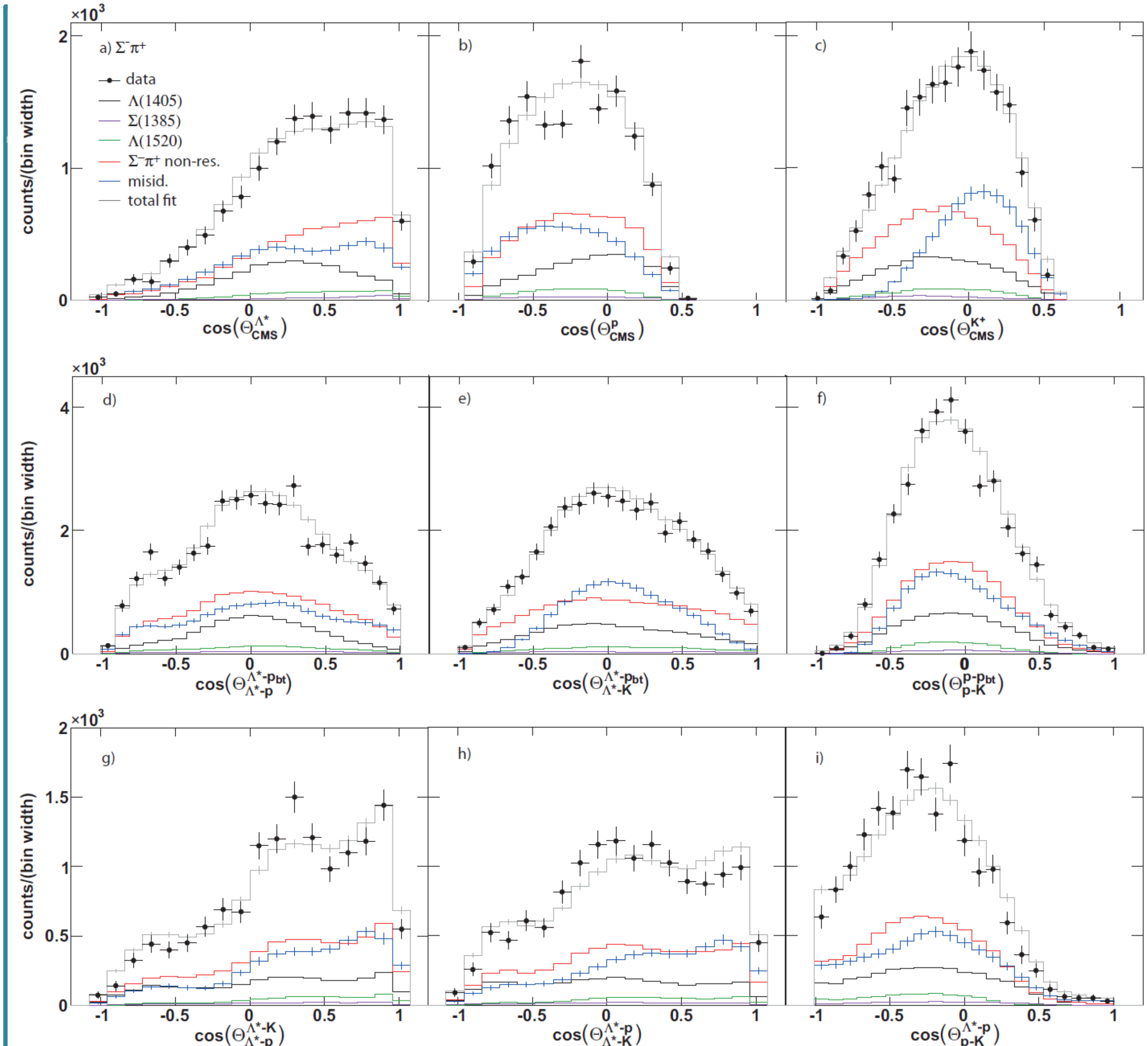
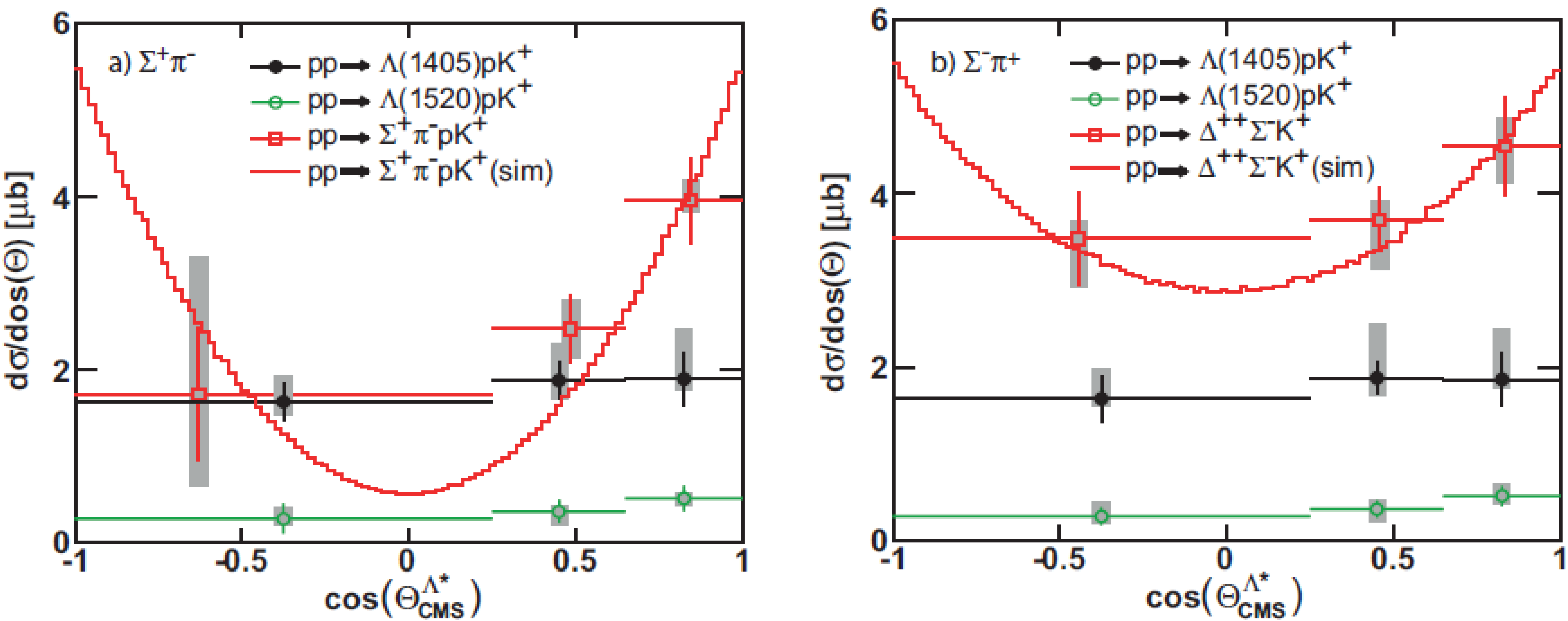


Figure 1.10: Angular distributions for the $\Sigma^-\pi^+$ data sample. First row shows the production angles of the $\Lambda(1405)$ candidate, the proton and the K^+ in the CMS. Second row displays the three possible G-J angles. In the third row the three helicity angles are plotted.

HADES

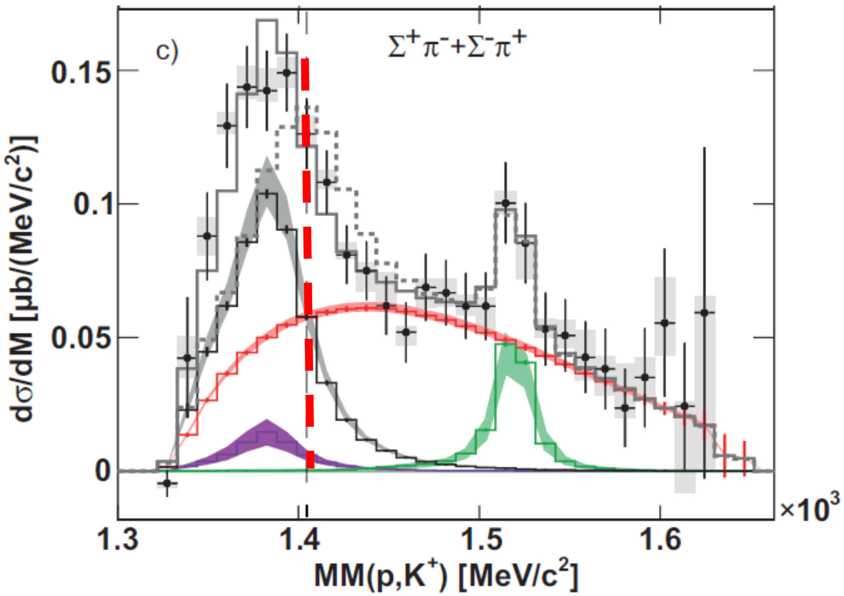


HADES coll. (G. Agakishiev et al.) Phys. Rev. **C 87**, 025201 (2013)

p+p → X + p + K^+

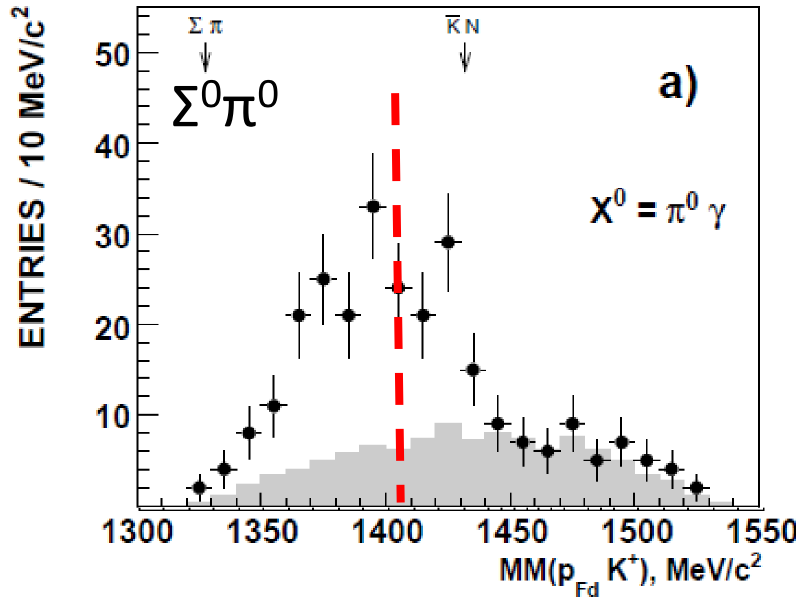
Comparison with ANKE

p+p 4.3 GeV/c



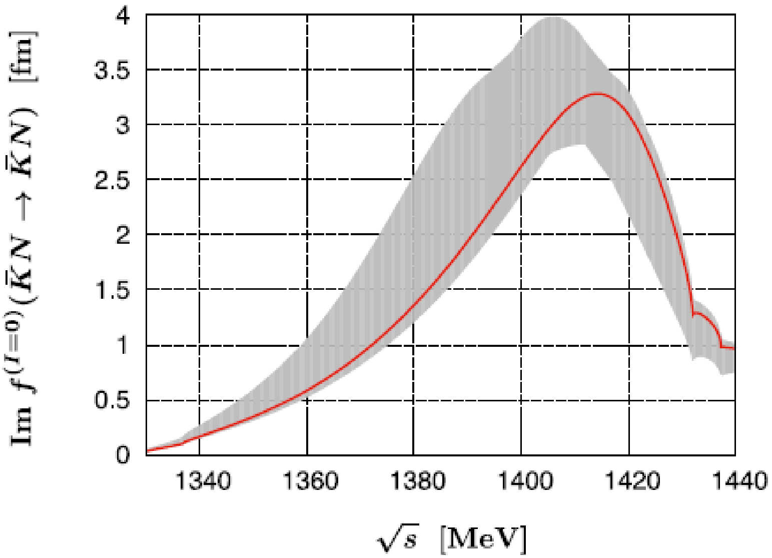
HADES coll. (G. Agakishiev et al.) Phys. Rev. **C 87,** 025201 (2013)

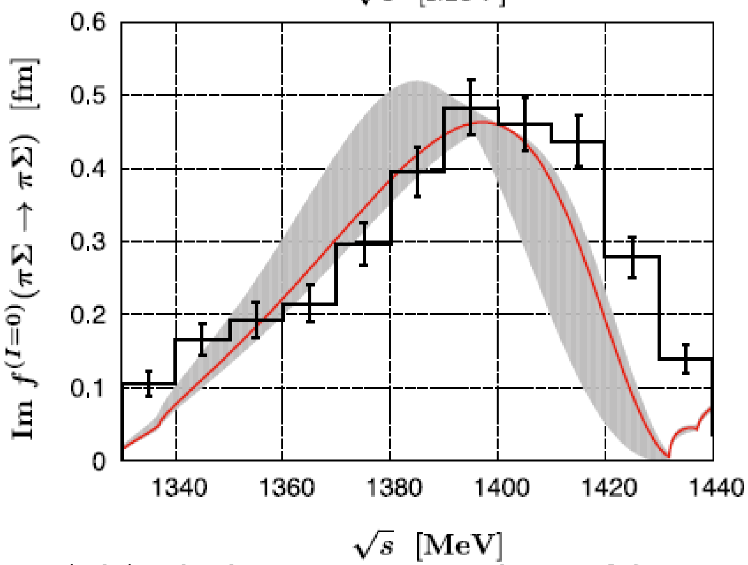
p+p 3.65GeV/c



I. Zychor et al. Physics Lett. **B660** (2008)

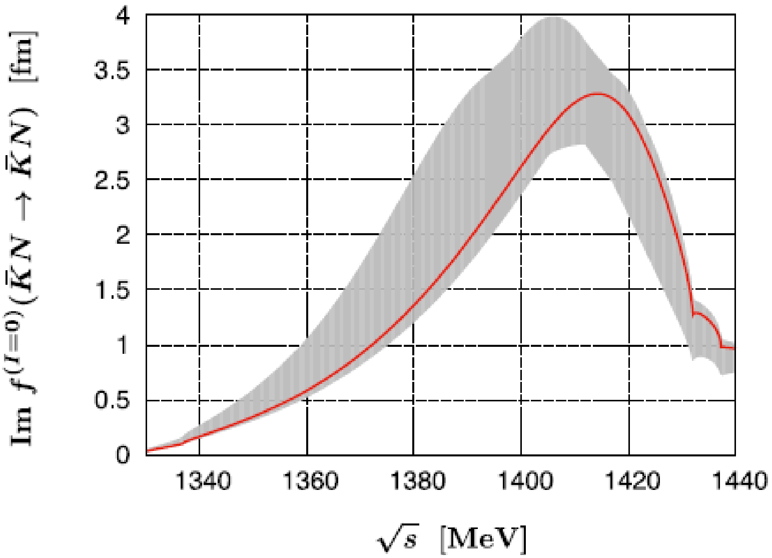
Theoretical Line Shapes

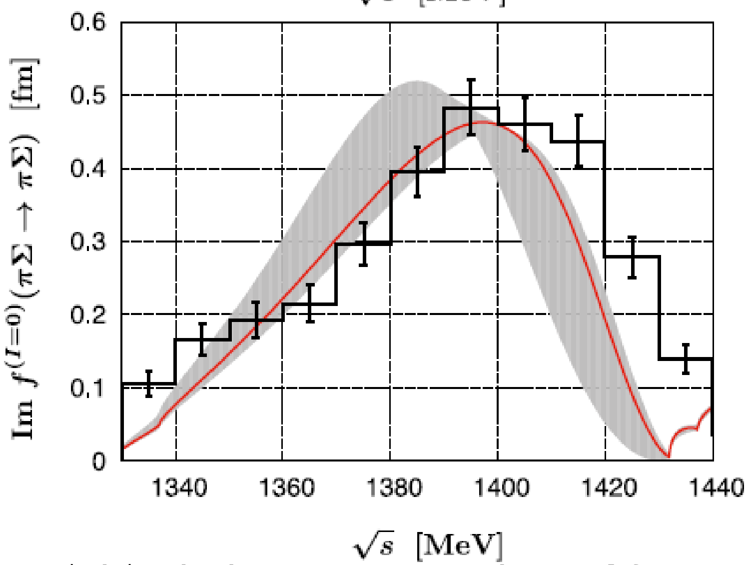




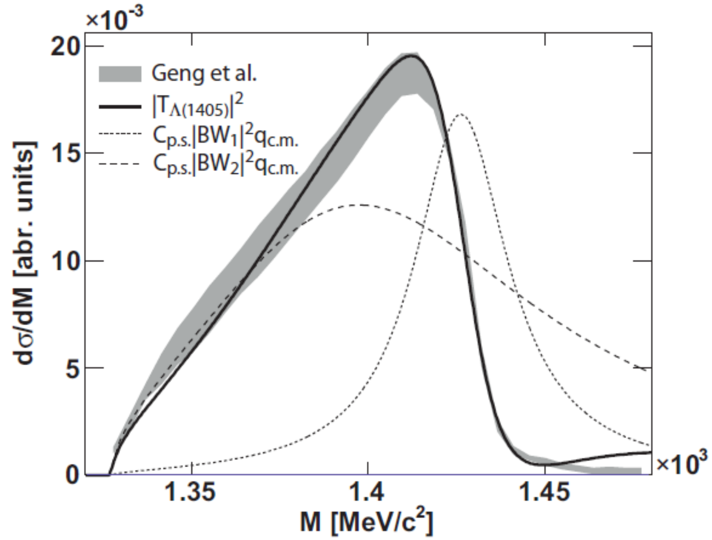
Yoichi Ikeda, Tetsuo Hyodo, Wolfram Weise
Nuclear Physics **A 881**, 98–114 (2012)

Theoretical Line Shapes





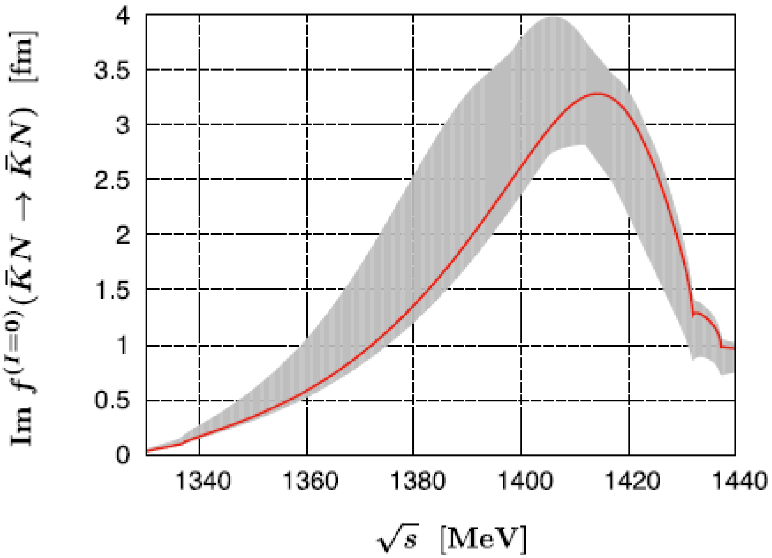
Yoichi Ikeda, Tetsuo Hyodo, Wolfram Weise
Nuclear Physics **A 881**, 98-114 (2012)

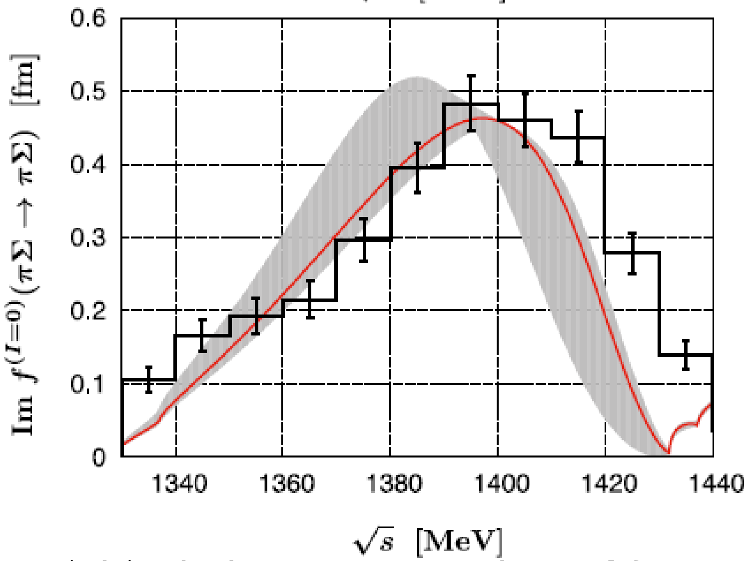


L.S. Geng and E. Oset.
Eur. Phys. J., A34, 405-412 (2007)

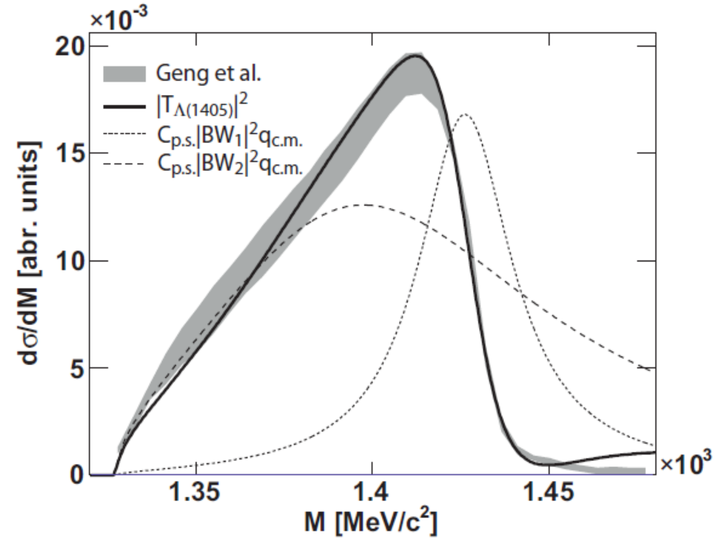
Fitted to the ANKE data

Theoretical Line Shapes





Yoichi Ikeda, Tetsuo Hyodo, Wolfram Weise
Nuclear Physics **A 881**, 98–114 (2012)



L.S. Geng and E. Oset.
Eur. Phys. J., **A34** (2007)

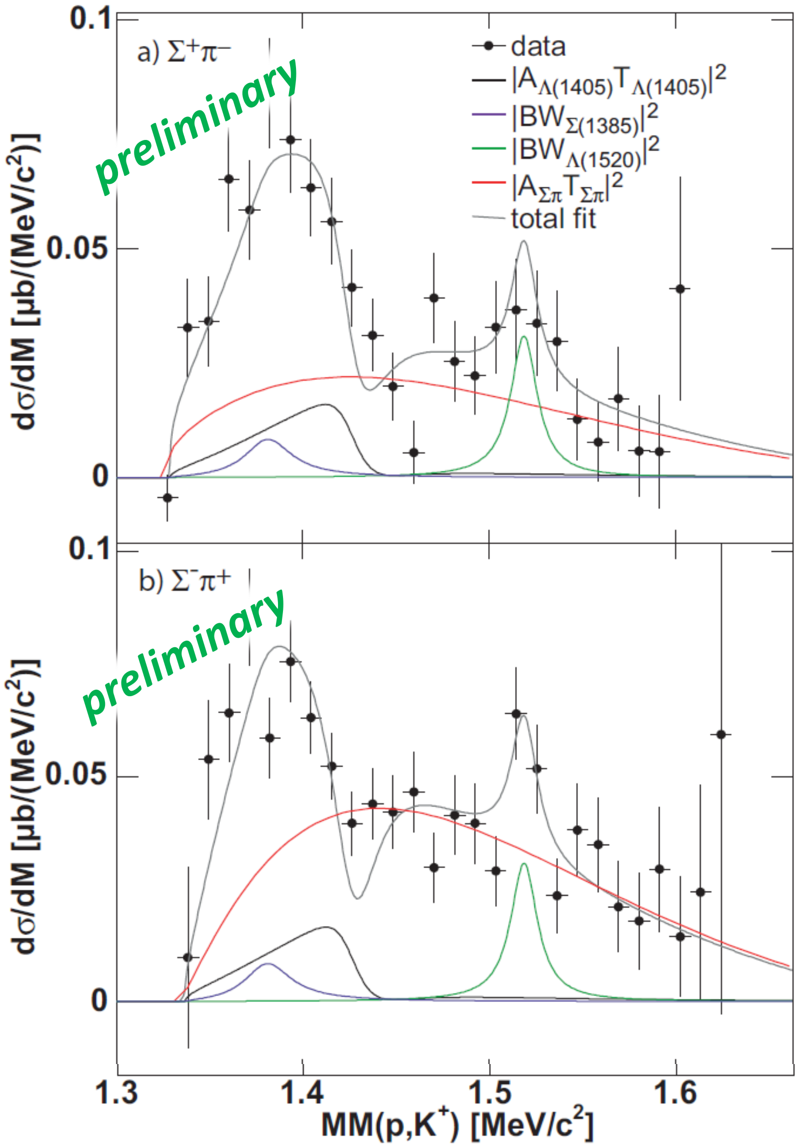
Fitted to the ANKE data

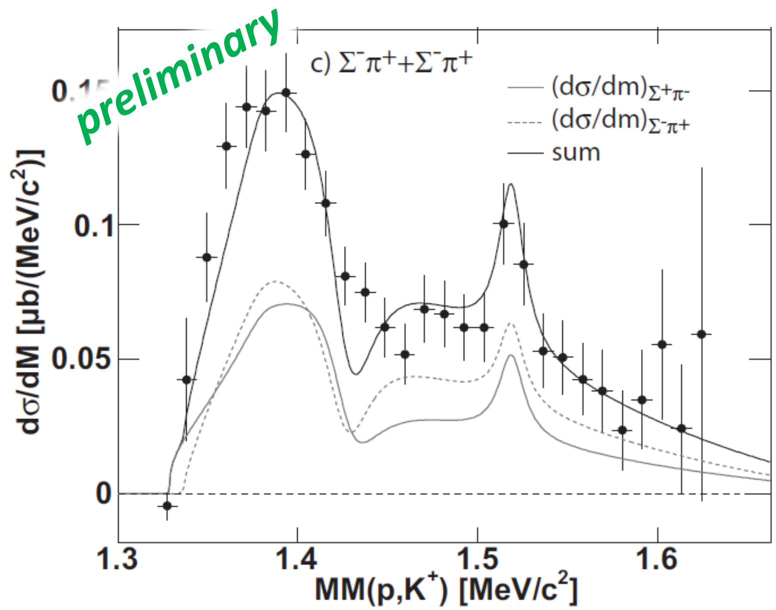
Reconstruction of the Lineshape:

$$\frac{d\sigma}{dm} = \left|T_{\Lambda(1405)}\right|^2 = C_{p.s.}(m)\left|BW_1(m) + BW_2(m)e^{i\varphi_2}\right|^2 q_{c.m.}$$

$$\text{with } BW_i = A_i \frac{1}{m - m_{0,i} + i\Gamma_{0,i}/2}$$

Interferences

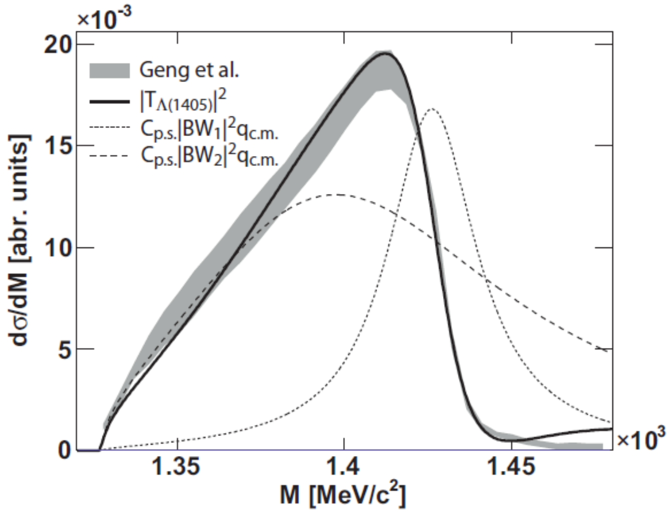




Maximum interference between Λ(1405) and the non-resonant background

-> may shift a Λ(1405) with a high pole mass to lower values

Discussion



$$\frac{d\sigma}{dm} = \left|T_{\Lambda(1405)}\right|^2 = C_{p.s.}(m)\left|BW_1(m) + BW_2(m)e^{i\varphi_2}\right|^2 q_{c.m.}$$

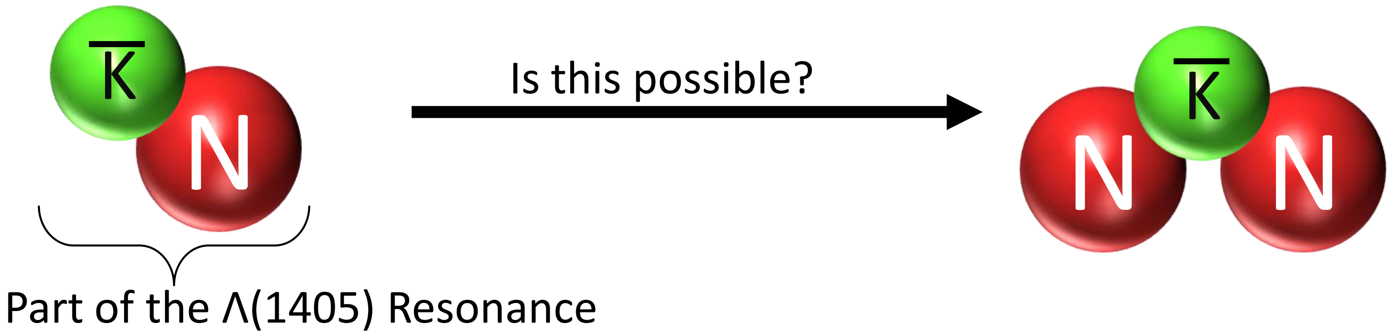
$$\text{with } BW_i = A_i \frac{1}{m - m_{0,i} + i\Gamma_{0,i}/2}$$

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

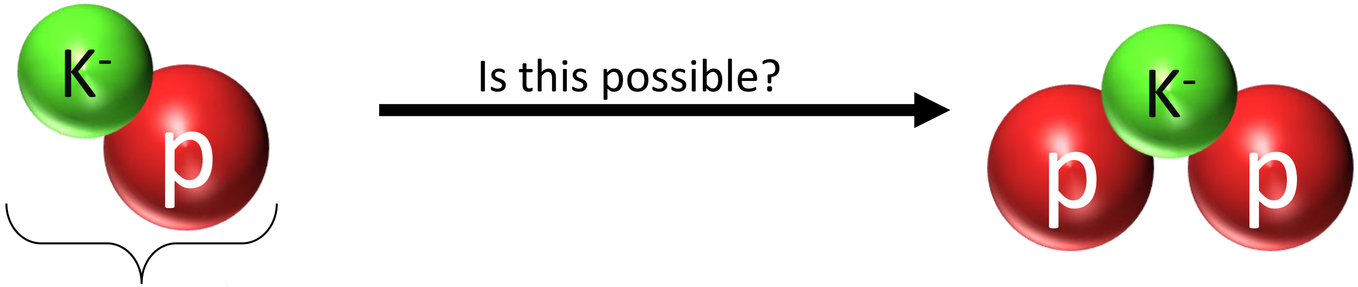
$$\left(\frac{d\sigma}{dm}\right)_{\Sigma^-\pi^+} = \left|A_{\Lambda(1405)}T_{\Lambda(1405)} + e^{i\beta}A_{\Sigma^-\pi^+}T_{\Sigma^-\pi^+}\right|^2 + \left|BW_{\Sigma(1385)^0}\right|^2 + \left|BW_{\Lambda(1520)}\right|^2$$

Backup

Kaonic Cluster



The Idea of bound kaonic-nuclear clusters



Part of the Λ(1405) resonance

Prediction of deeply bound Anti-Kaon nuclear states

S. Wycech, Nucl.Phys. A450 399 (1986)
T. Yamazaki and Y. Akaishi, Phys Lett. B 535 (2002)
T. Yamazaki and Y. Akaishi, Phys Rev. C 65 (2002)

Variational calculations

T. Yamazaki, Y. Akaishi Phys. Rev. C76 (2007)
A. Doté, T. Hyodo, W. Weise Nucl. Phys. A804 (2008)
A. Doté, T. Hyodo, W. Weise Phys. Rev. C79 (2009)
S. Wycech, A. M. Green, Phys. Rev. C79 (2009)
N. Barnea, A. Gal, E. Z. Liverts, Phys. Lett. B712 (2012)

Fadeev Calculations

N.V. Shevchenko, A. Gal, J. Mares, Phys. Rev. Lett. 98 (2007)
N.V. Shevchenko, A. Gal, J. Mares, J. Révay, Phys. Rev. C76 (2007)
Y. Ikeda, T. Sato, Phys. Rev. C76 (2007)
Y. Ikeda, T. Sato, Phys. Rev. C79 (2009)
Y. Ikeda, H. Kamano T. Sato, Prog. Theor. Phys. 124 (2010)
E. Oset et al. Nucl. Phys. A881 (2012)

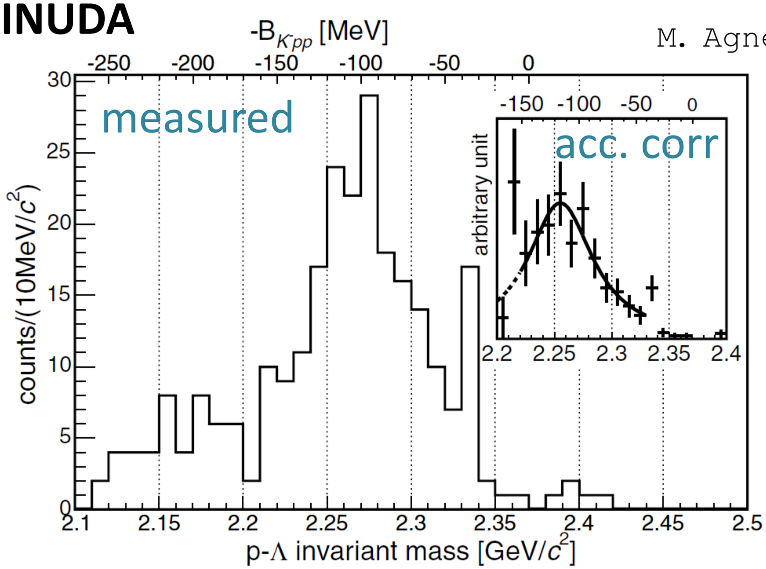
$B(ppK^-) \approx$ 14-80 MeV
$\Gamma(ppK^-) \approx$ 40-110 MeV/c^2

W. Weise, R. Hartle, Nucl.Phys. A 804 (2008) 173-185
A. Cieply, E. Friedman, A. Gal, D. Gazda, J. Mares, Phys. Rev. C 84 (2011) 045206
D. Gazda, E. Friedman, A. Gal, J. Mares, Phys.Rev. C76 (2007) 055204

Previous Results

FINUDA

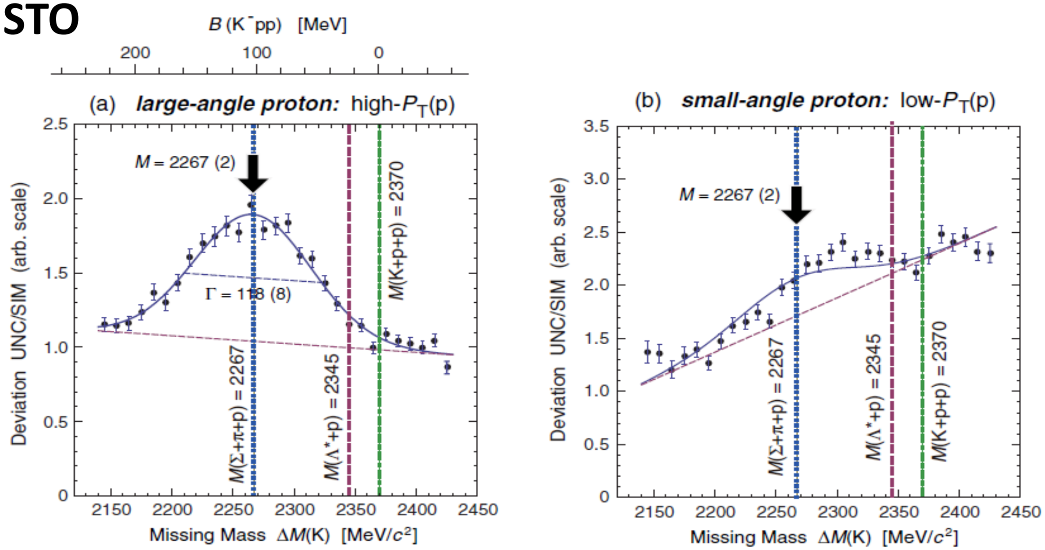
M. Agnello et al. Phys. Rev. Lett. **94** (2005)



M(ppK$^-$) = 2.255 GeV/c^2
B(ppK$^-$) = 115 MeV
Γ(ppK$^-$) = 67 MeV/c^2

DISTO

T. Yamazaki et al. Phys. Rev. Lett. **104**, (2010)
M. Maggiora et al. Nucl. Phys. **A 835** (2010)



M(ppK$^-$) = 2.267 GeV/c
B(ppK$^-$) = 103 MeV
Γ(ppK$^-$) = 118 MeV/c^2

Partial Wave analysis

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

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

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

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

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

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

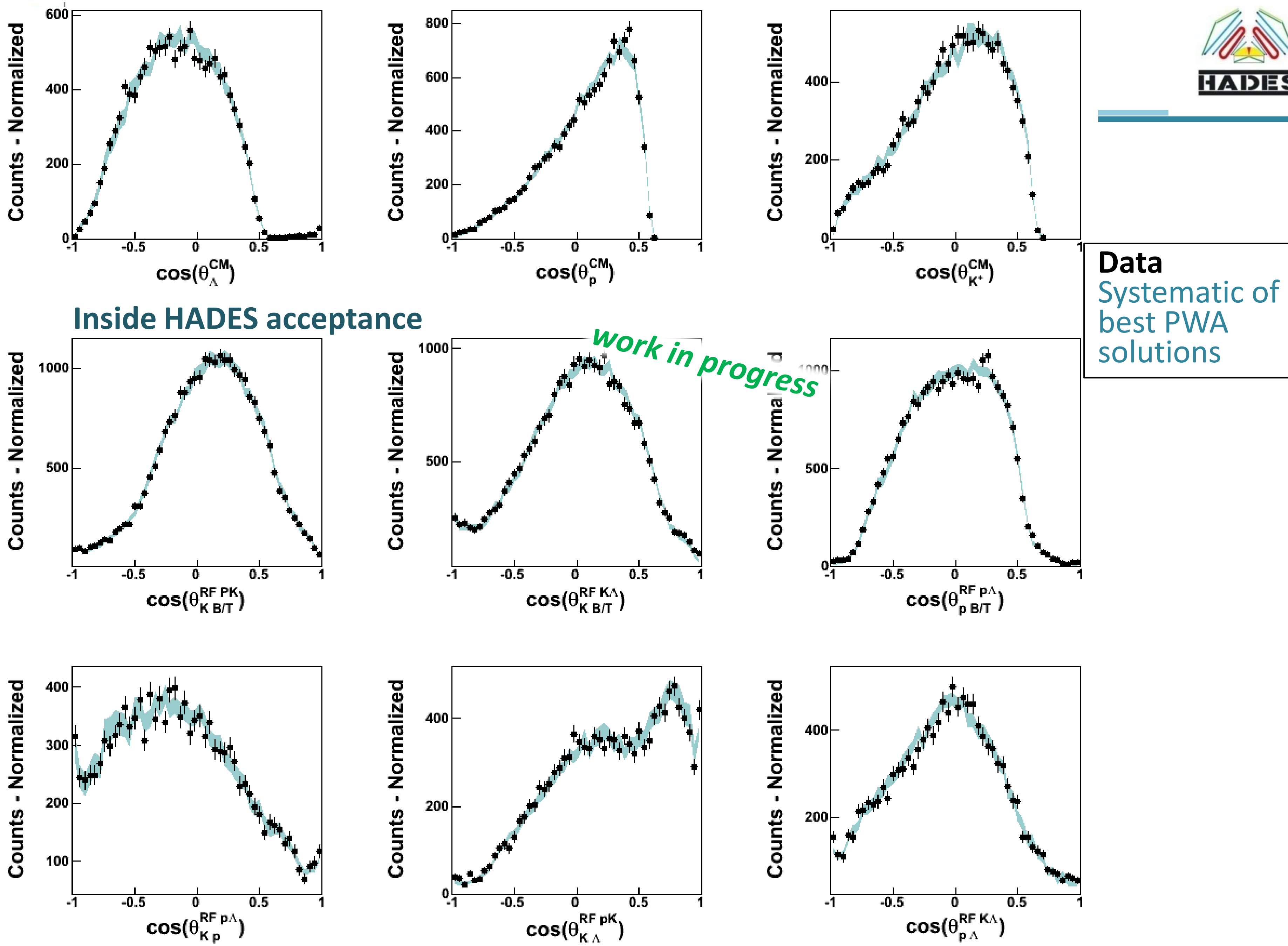
A. Sarantsev, Private communication

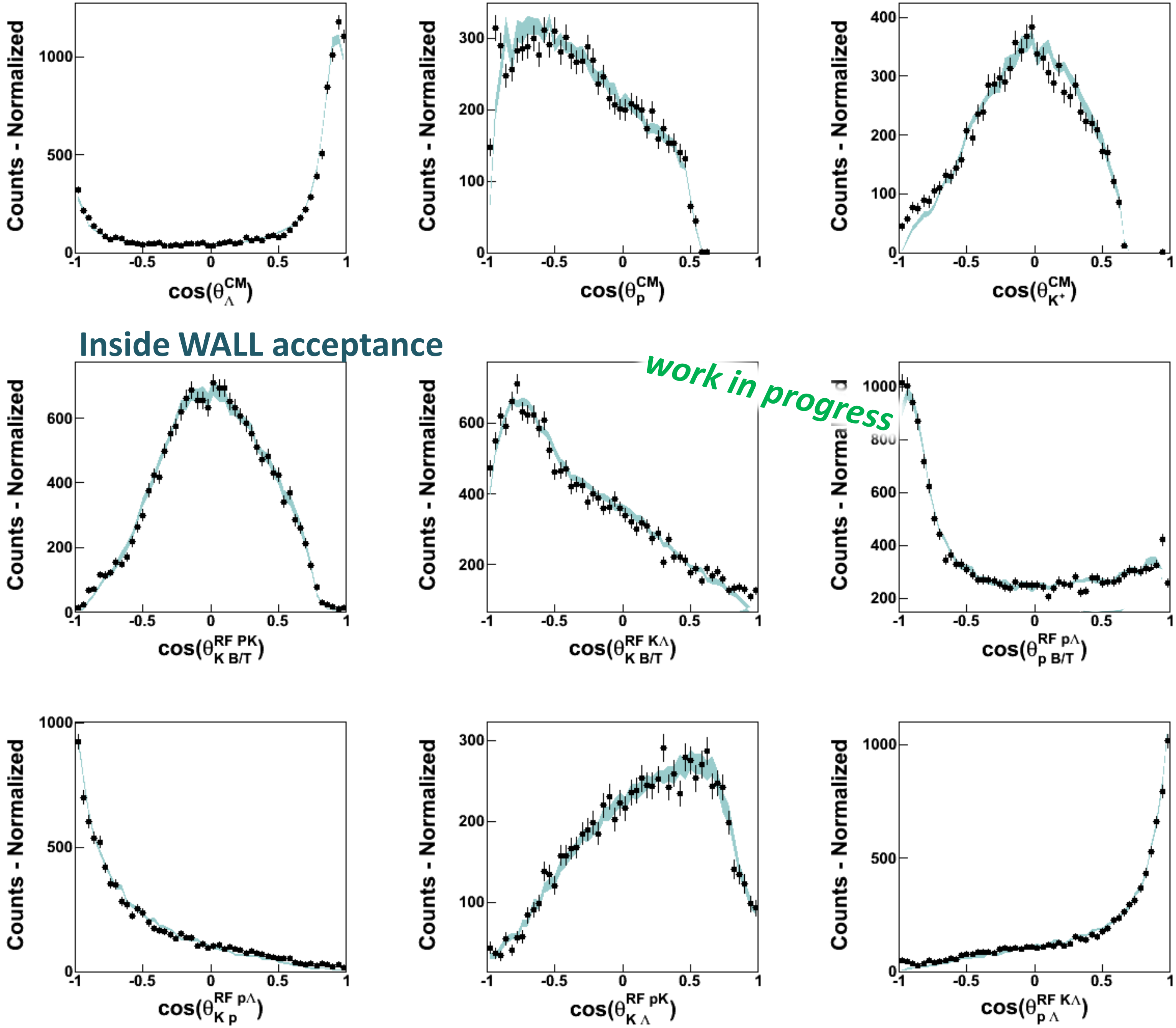
Fitting Procedure

The transition Amplitude is parameterized as follows

$$A_{tr}^{\alpha}(s) = \left(a_1^{\alpha} + a_3^{\alpha}\sqrt{s}\right) e^{i a_2^{\alpha}}$$

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

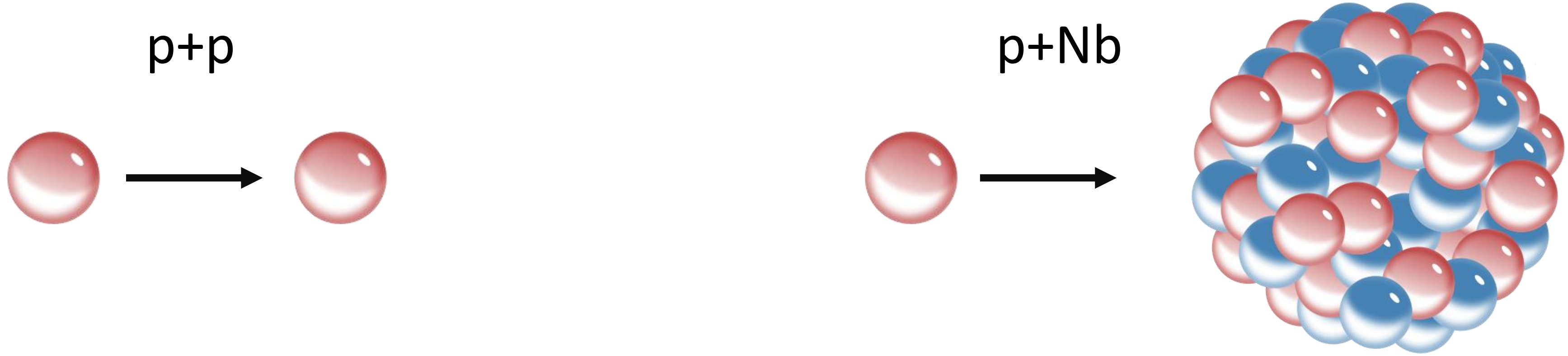

Counts - Normalized
$\cos(\theta_{\Lambda}^{CM})$
$\cos(\theta_{p}^{CM})$
$\cos(\theta_{K^+}^{CM})$
Inside HADES acceptance
work in progress
$\cos(\theta_{K\ B/T}^{RF\ PK})$
$\cos(\theta_{K\ B/T}^{RF\ K\Lambda})$
$\cos(\theta_{p\ B/T}^{RF\ p\Lambda})$
$\cos(\theta_{K\ p}^{RF\ p\Lambda})$
$\cos(\theta_{K\ \Lambda}^{RF\ pK})$
$\cos(\theta_{p\ \Lambda}^{RF\ K\Lambda})$
HADES
Data
Systematic of best PWA solutions



Data
Systematic of best PWA solutions

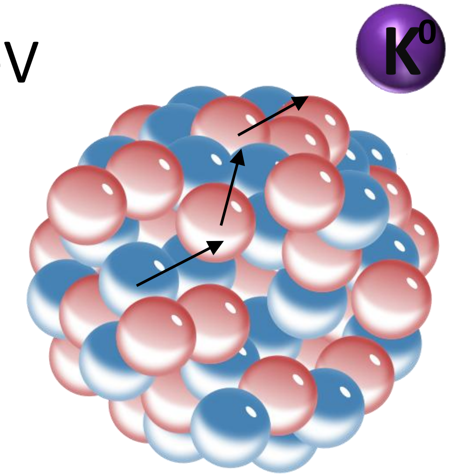
Backup

Cold medium effects



K-N scattering

p+Nb, 3.5 GeV



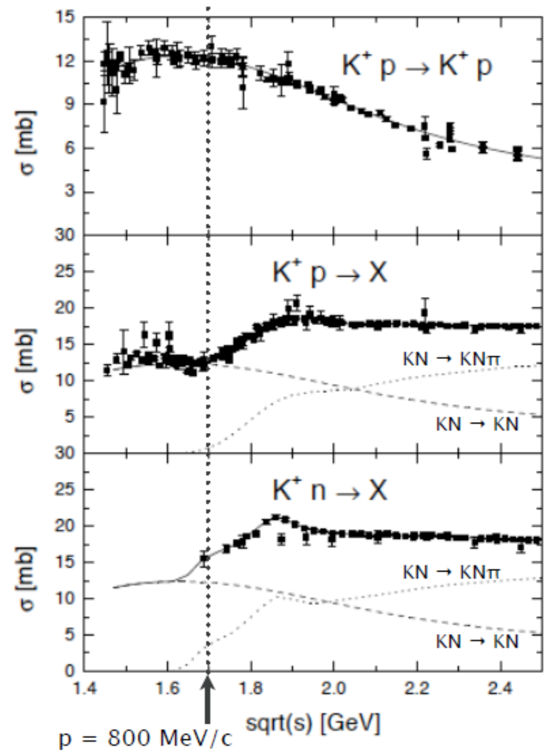
Inside the Nucleus:

The K^0 undergoes scattering processes

K^0+N → K^0 +N *Deviates the momentum*

K^0+p → K^+ +n *Disappearance of K^0*

K^0+N → K^0 +N + π *Reduces the momentum*



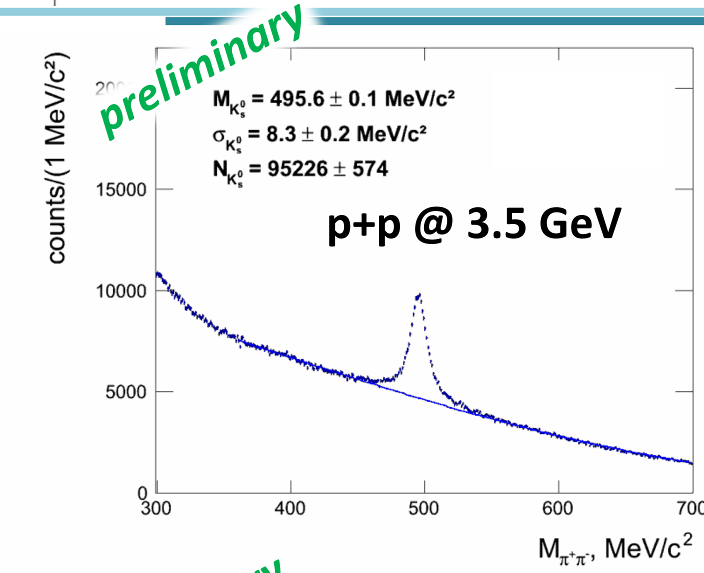
Picture: M. Effenberger, PhD. Giessen, 1999.

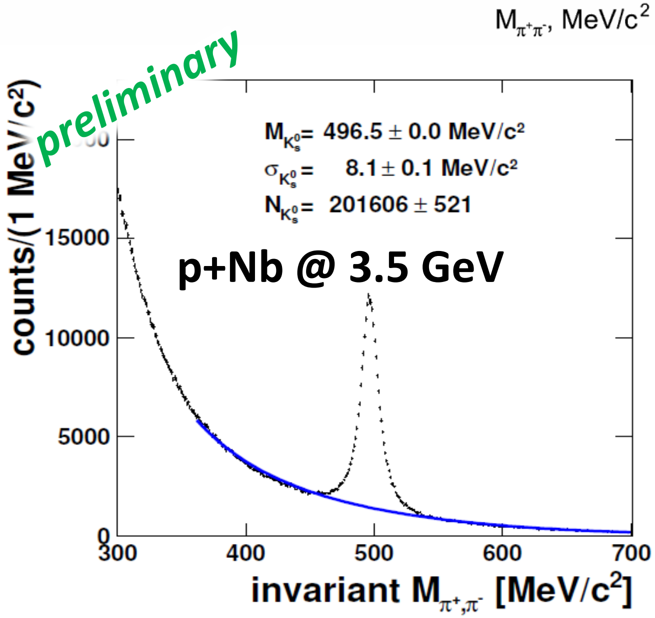
Tuning of cross sections for Resonance model

TABLE I. Reactions with the largest contributions to the K^0 production in p+p collisions at 3.5 GeV and corresponding cross sections.

Reaction	$\sigma_{\mu b}$
$p+p \rightarrow \Sigma^+ + p + K^0$	21.29
$p+p \rightarrow \Lambda + p + \pi^+ + K^0$	18.40
$p+p \rightarrow \Sigma^0 + p + \pi^+ + K^0$	12.38

Statistic

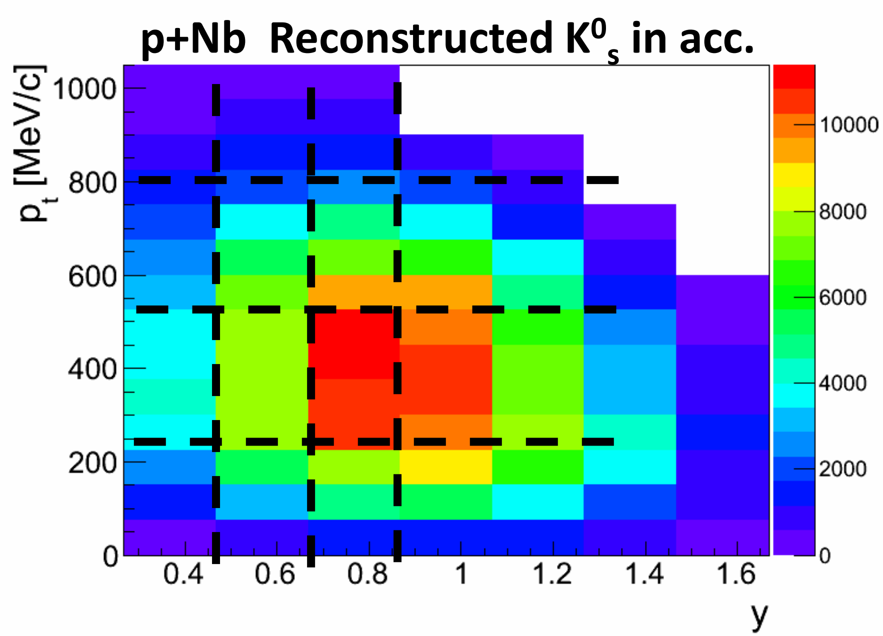




The K^0 is identified by its short-lived component K^0_S

$K^0_S \rightarrow \pi^+ \pi^-$ 69.2%.

Double differential analysis in p_t-y

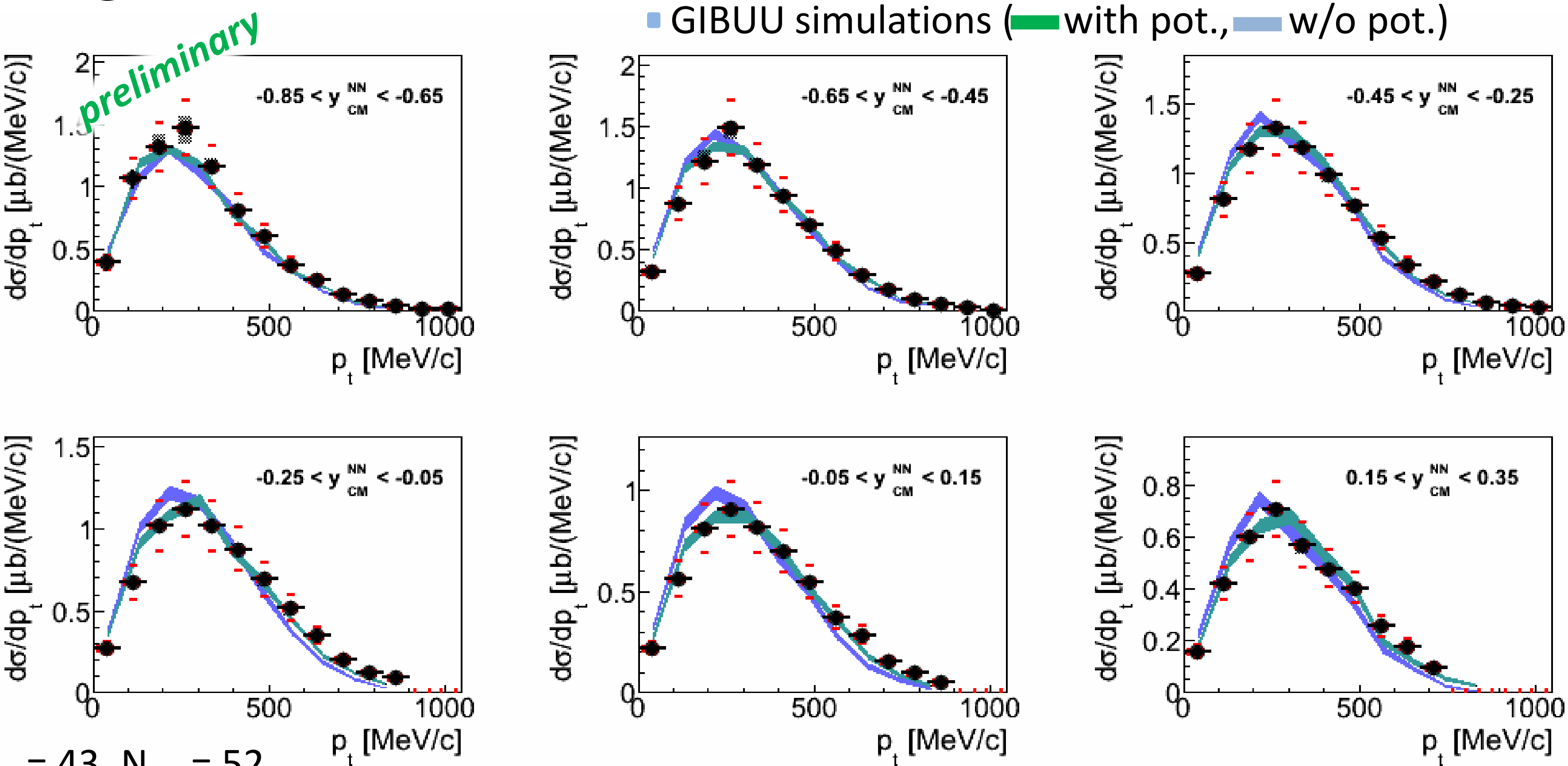


P_t distributions in p+Nb

p+Nb @ 3.5 GeV

■ acc. and eff. corrected data

■ GIBUU simulations (▬ with pot., ▬ w/o pot.)



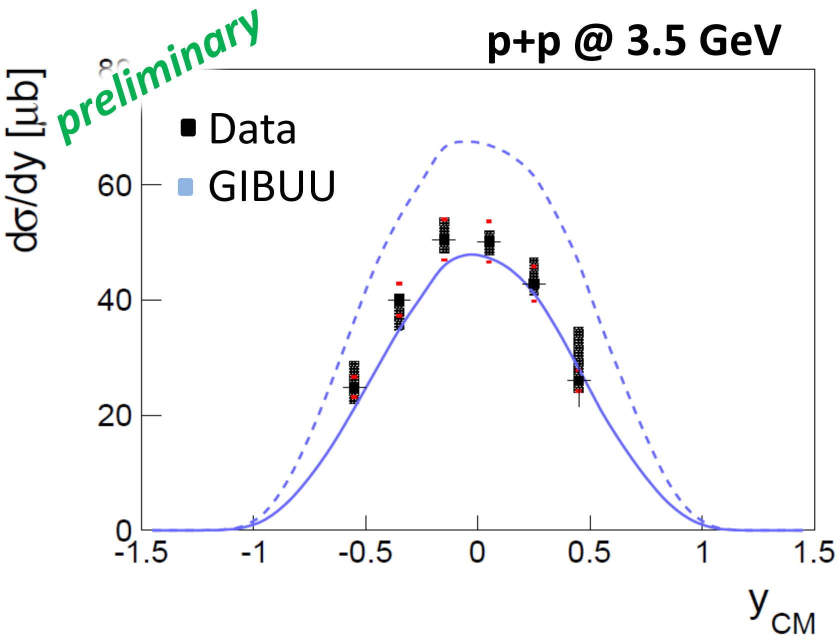
$Z_{Nb} = 43$, $N_{Nb} = 52$

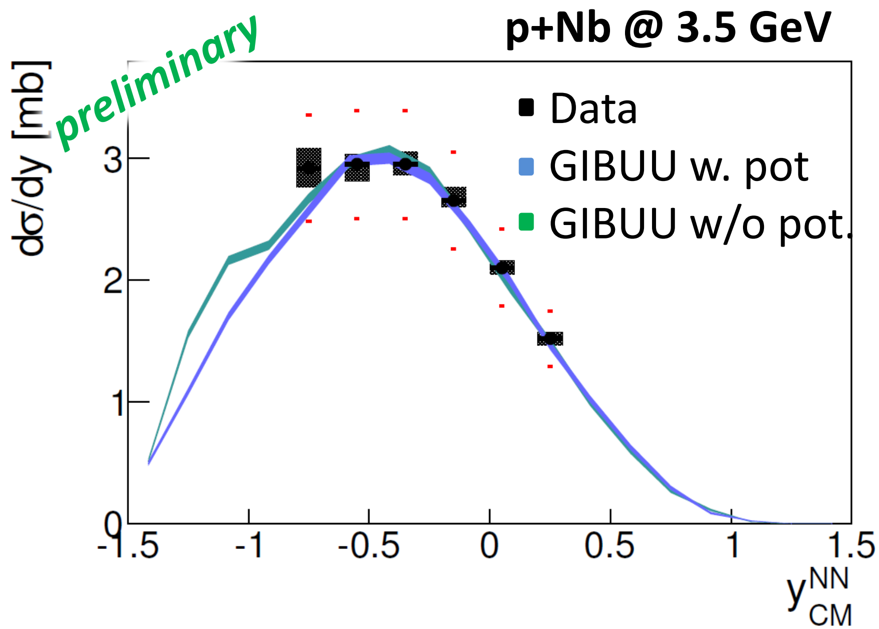
<u>Things to be aware of:</u>

1. p+p could be tuned to the data
2. Some p+n cross sections are a free parameter

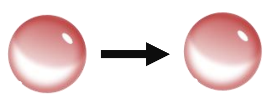
Kirill Lapidus, HK 17.6, Mo 18:00

Rapidity density distribution

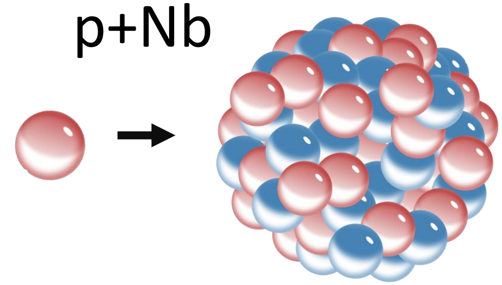




p+p



p+Nb

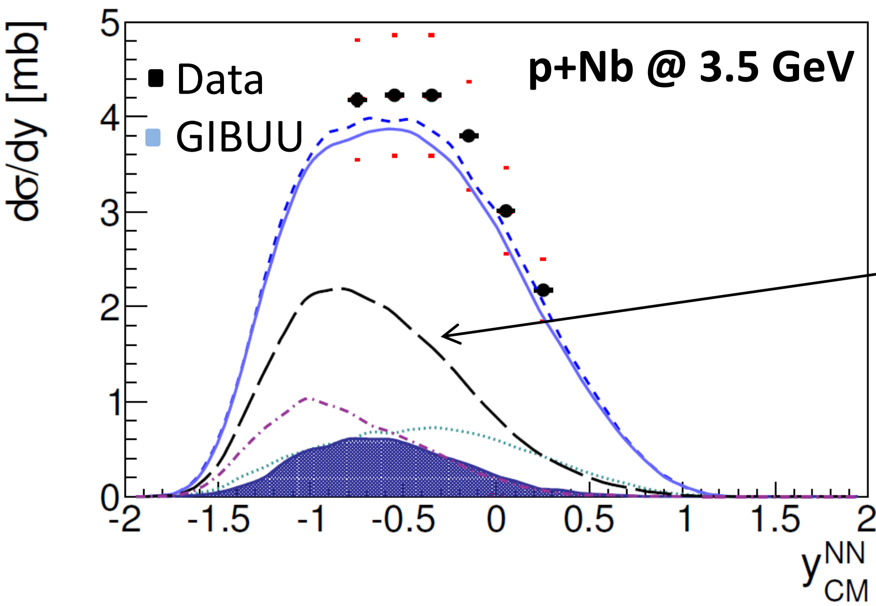


$\sigma(p+p \rightarrow K^0 + X) = 113.0 \pm 7.9\ \mu b$

Cross Section for p+Nb is model dependent

Kirill Lapidus, HK 17.6, Mo 18:00

Rapidity density distribution



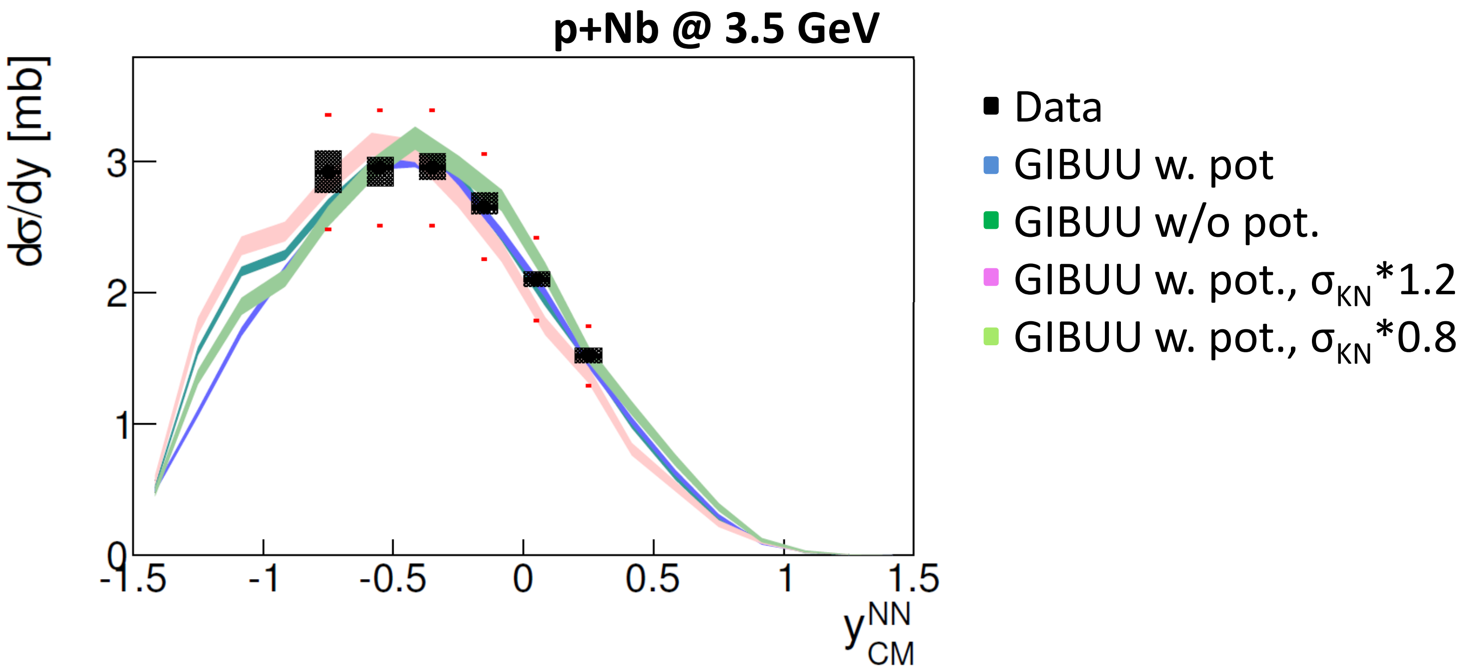
K^0 from primary reactions
p+p, p+n

K^0 from secondary reactions
ΔN, πN, K^+n

A strong shift of the rapidity distribution towards the target rapidity is to large extent influenced by the elastic scattering processes $K^0N \rightarrow K^0N$.

Rapidity distribution is influenced by KN scattering and serves as a measure of the kaon-nucleon in-medium interaction

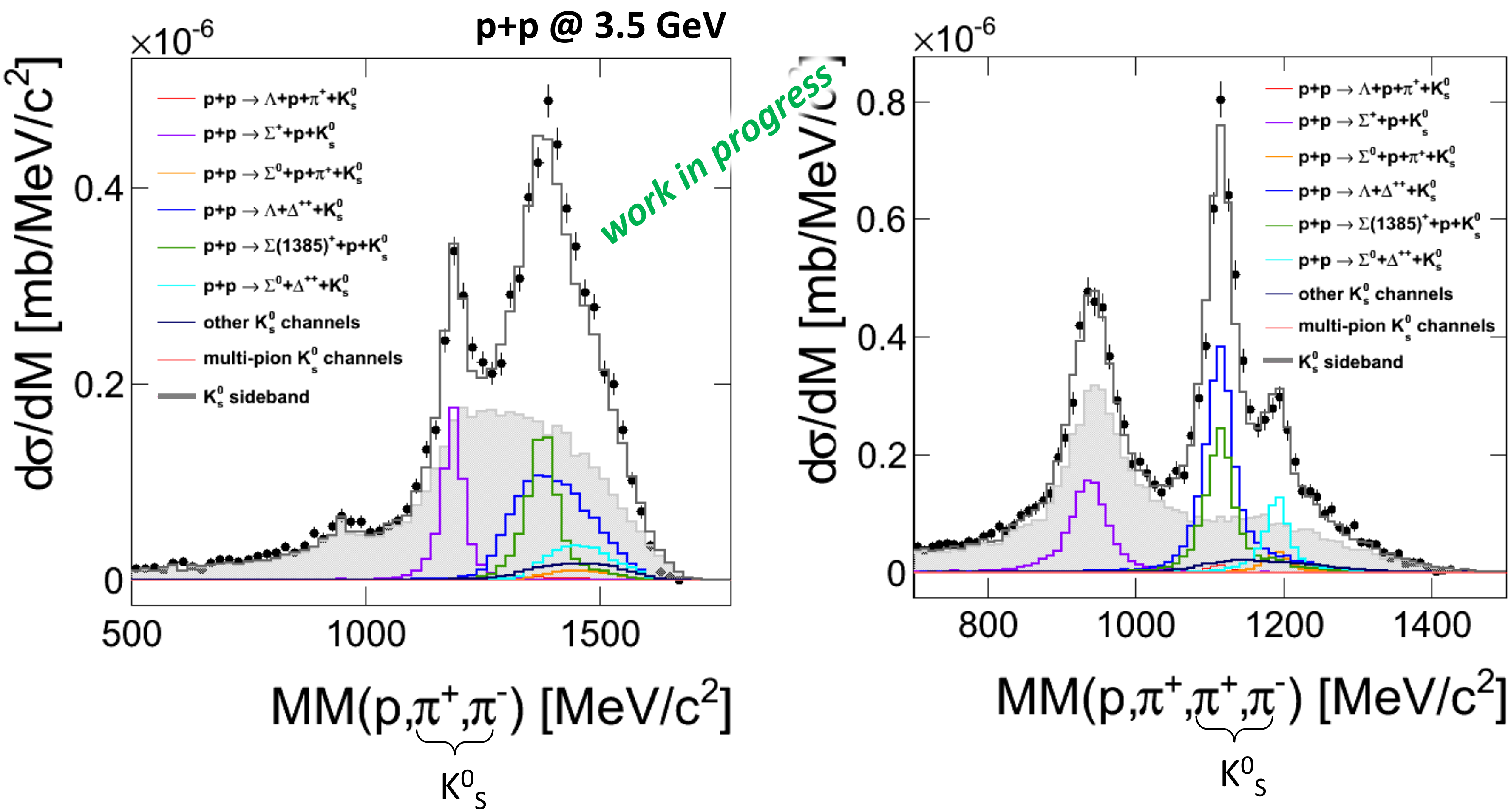
KN – in-medium scattering



Is in agreement with vacuum KN scattering cross section

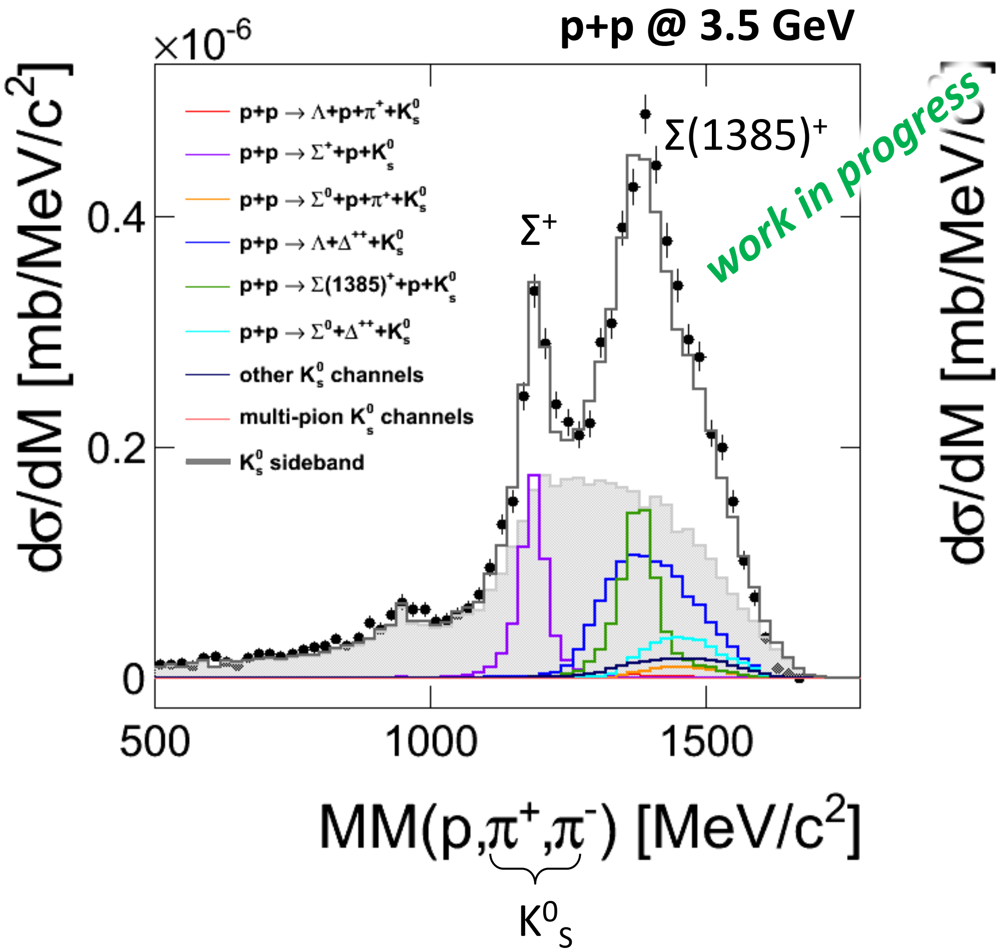
Kirill Lapidus, HK 17.6, Mo 18:00

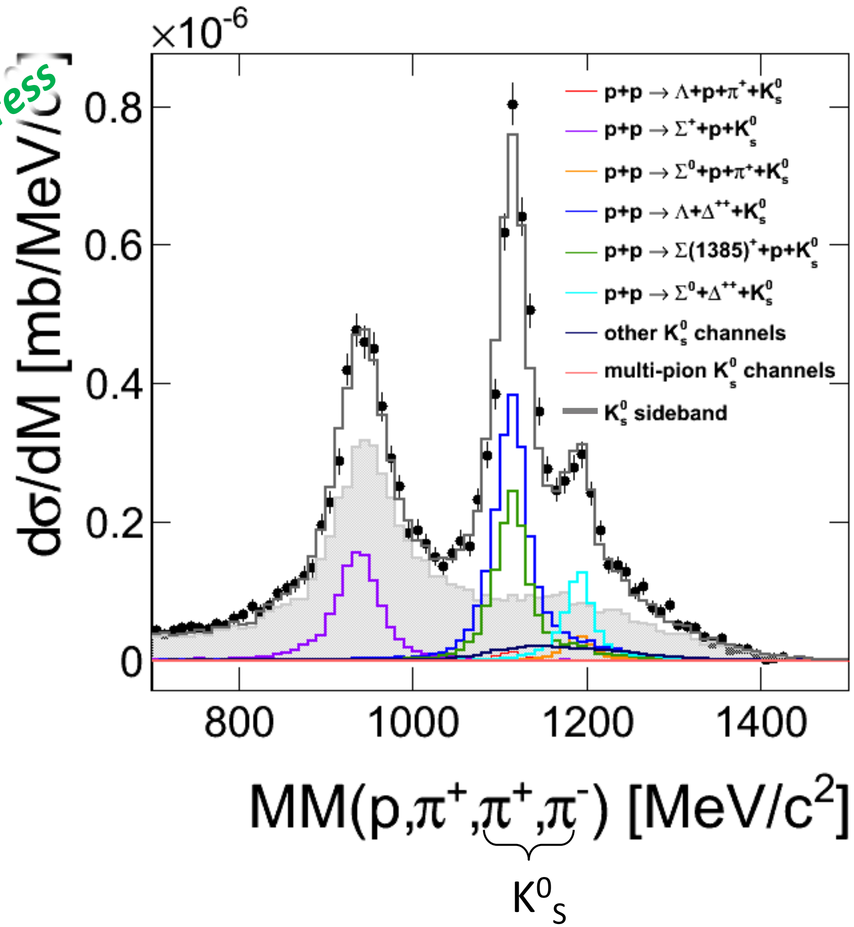
More about Cross Sections



p+p→ Λ+**p+π**$^+$+K^0_S	or	p+p→ Λ+**Δ**$^{++}$+K^0_S
p+p→ Σ^0+**p+π**$^+$+K^0_S		p+p→ Σ^0+**Δ**$^{++}$+K^0_S

More about Cross Sections

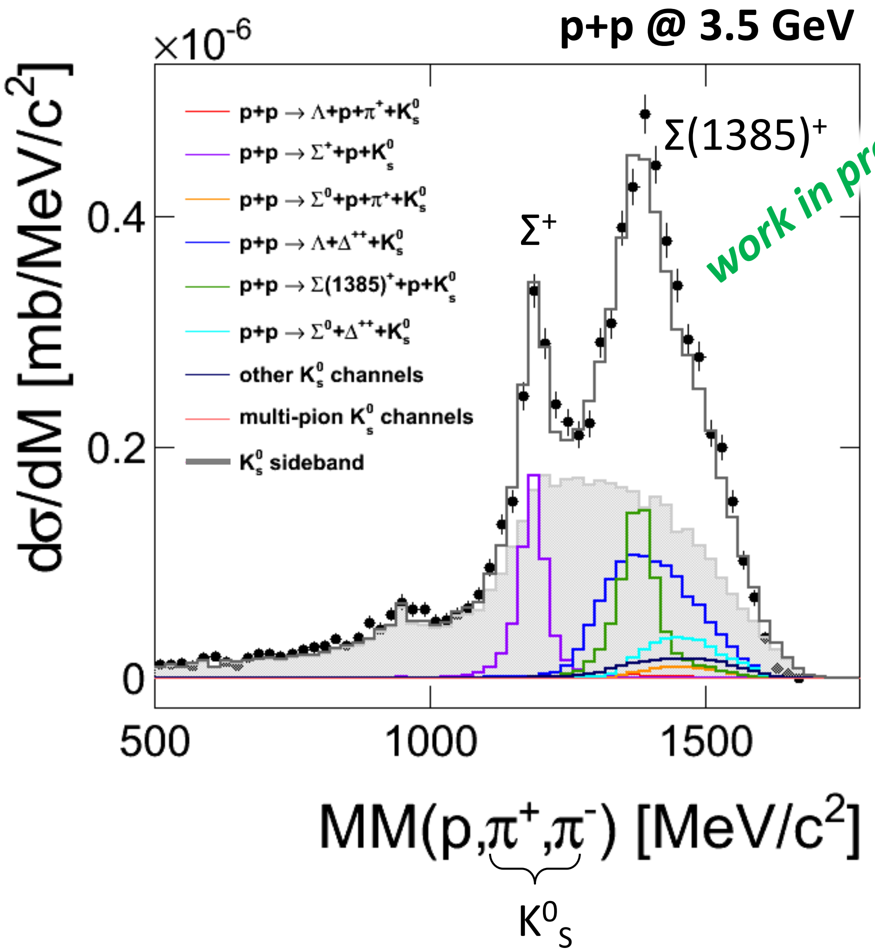


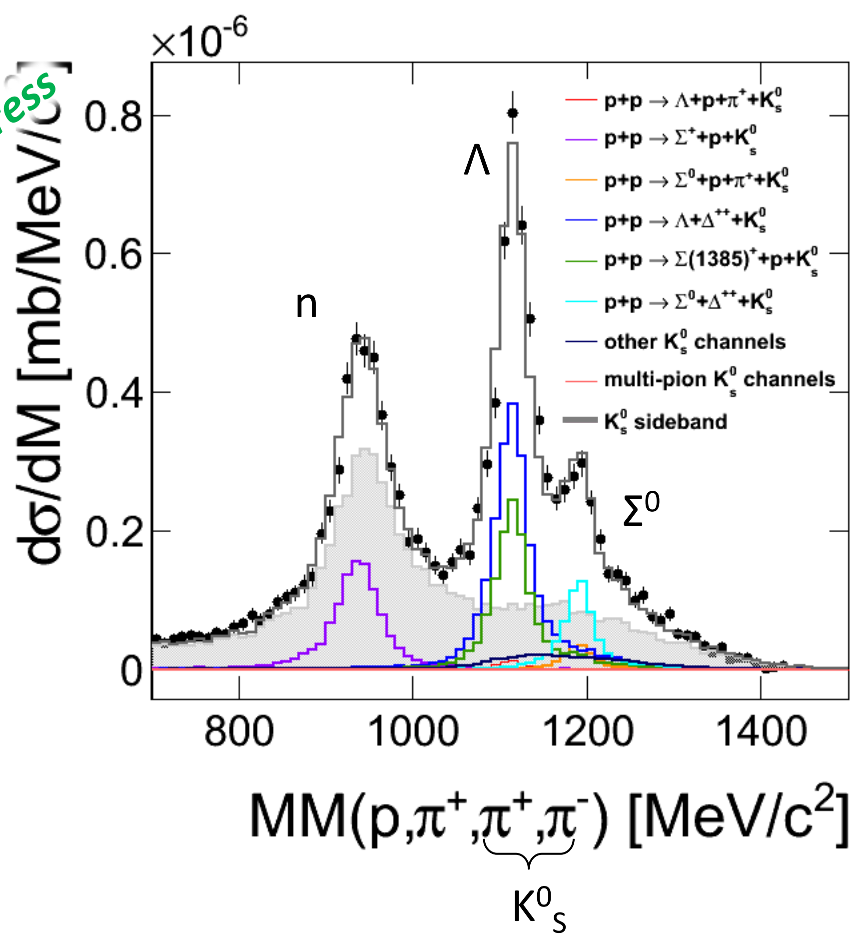


$p+p \rightarrow \Lambda+\mathbf{p}+\boldsymbol{\pi}^{+}+K^0_S$ or $p+p \rightarrow \Lambda+\boldsymbol{\Delta}^{++}+K^0_S$

$p+p \rightarrow \Sigma^0+\mathbf{p}+\boldsymbol{\pi}^{+}+K^0_S$ or $p+p \rightarrow \Sigma^0+\boldsymbol{\Delta}^{++}+K^0_S$

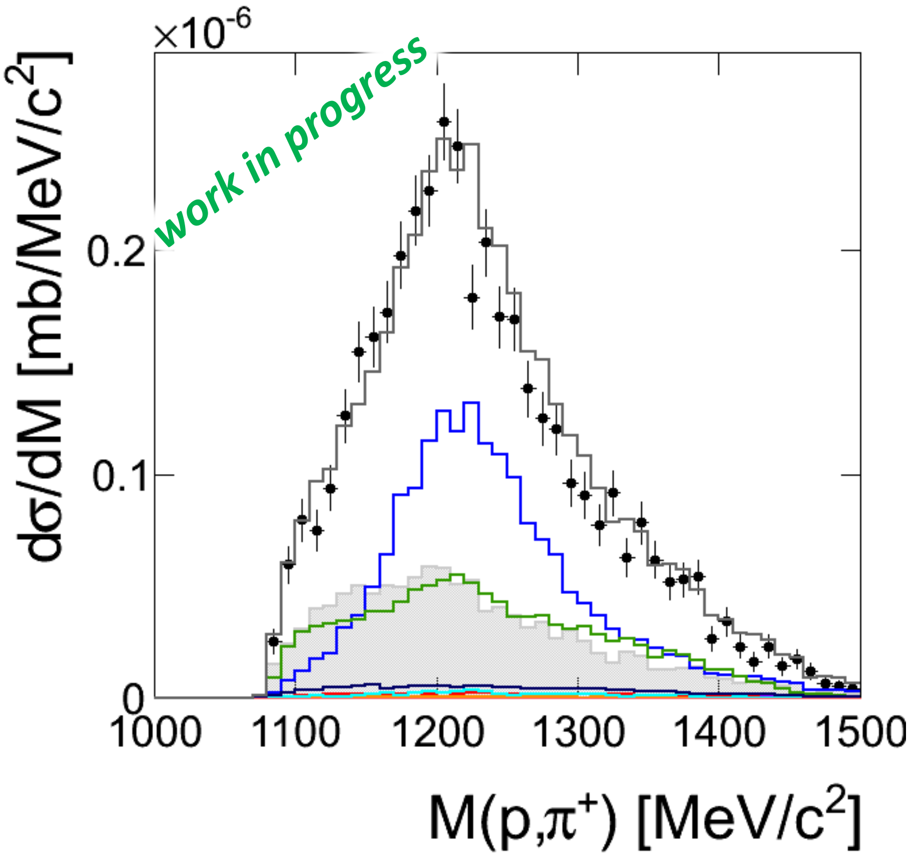
More about Cross Sections

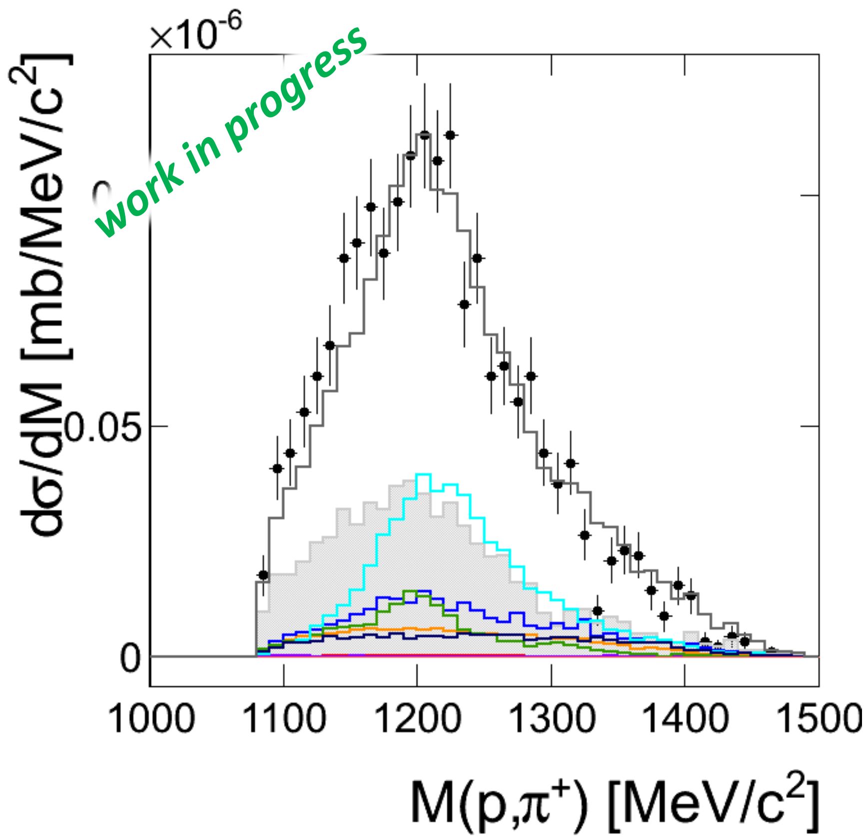




$p+p \rightarrow \Lambda + \mathbf{p} + \boldsymbol{\pi}^+ + K^0_S$ $p+p \rightarrow \Sigma^0 + \mathbf{p} + \boldsymbol{\pi}^+ + K^0_S$	or	$p+p \rightarrow \Lambda + \boldsymbol{\Delta}^{++} + K^0_S$ $p+p \rightarrow \Sigma^0 + \boldsymbol{\Delta}^{++} + K^0_S$

Signals of Δ^{++}





$p+p \rightarrow \Lambda + p + \pi^+ + K^0$ ≈0.8 μb

$p+p \rightarrow \Lambda + \Delta^{++} + K^0$ ≈26 μb

$p+p \rightarrow \Sigma(1385)^+ + p + K^0$ ≈3 μb

$p+p \rightarrow \Sigma^0 + p + \pi^+ + K^0$ ≈2.4 μb

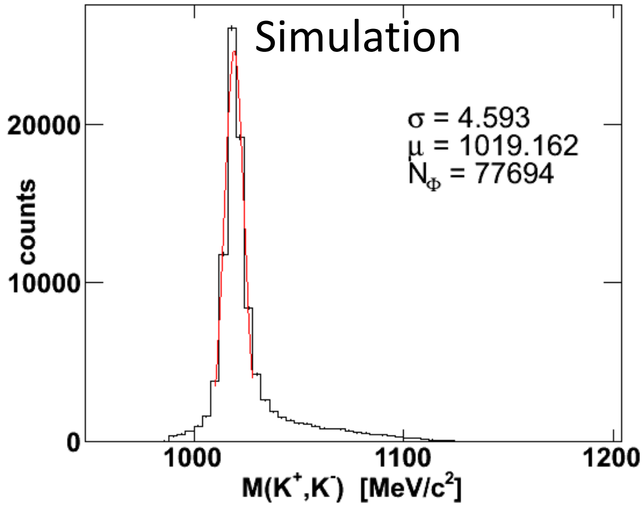
$p+p \rightarrow \Sigma^0 + \Delta^{++} + K^0$ ≈9 μb

Backup

Pion induced reactions

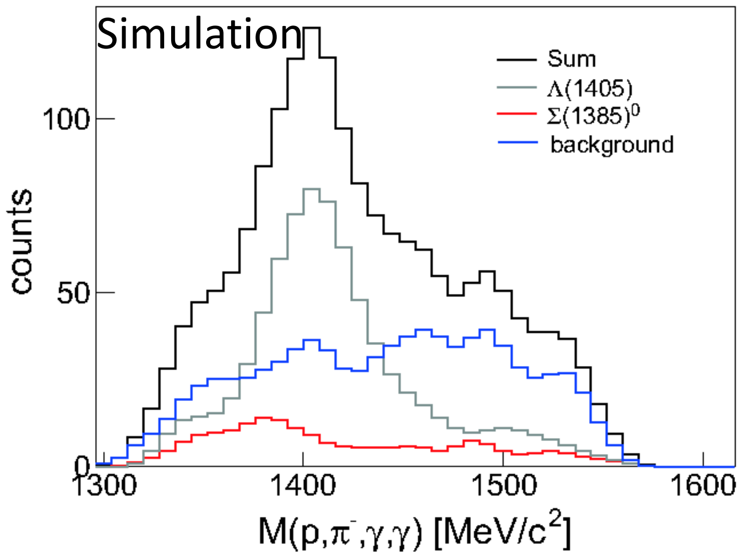
Strange physics with π-Beams

$\pi^- + p \rightarrow \phi\ n$, $\phi \rightarrow K^+ + K^-$



$\pi^- + A \rightarrow \phi\ X$, $\phi \rightarrow K^+ + K^-$

$\pi^- + p \rightarrow \Lambda(1405)\ K^0$, $\Lambda(1405) \rightarrow \Sigma^+ \pi^-$



10^6 π− / 2s, 50% daq dead time, 0.8 duty, 5% interaction target

Counts per DAY

P=1.7GeV/c	π + C	π + Cu	π + Pb
K^0_S	$6*10^5$	$3.8*10^5$	$4.4*10^5$
K+	$1.5*10^6$	$1.5*10^6$	$1.4*10^6$
K^-	$1.2*10^5$	$0.8*10^5$	$7*10^4$
ϕ	1500	4500	10.000

+ plenty of Λ