Strange resonance production in pA and pp collisions at 3.5 GeV

Laura Fabbietti
Technische Universität Müenchen
Excellence Cluster "Universe"

SQM DUBNA 2015

Elementary reactions

Fixed Target experiments, E_{kin}~ AGeV

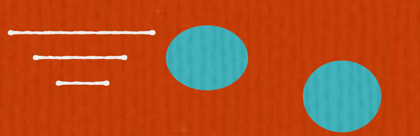
Proton Energy [GeV]	1-4	30	$\sqrt{s} = 4 - 11\,\mathrm{GeV}$
Heavy-Ion Energy [AGeV]	1-2	2-10	

HADES At SIS18

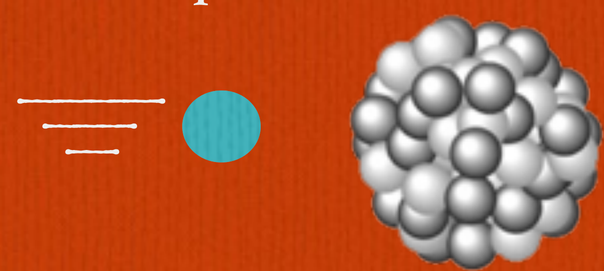
HADES + CBM

NICA

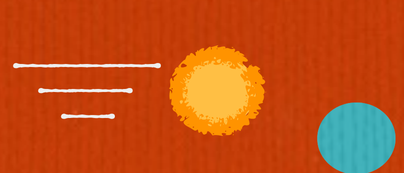
proton-proton



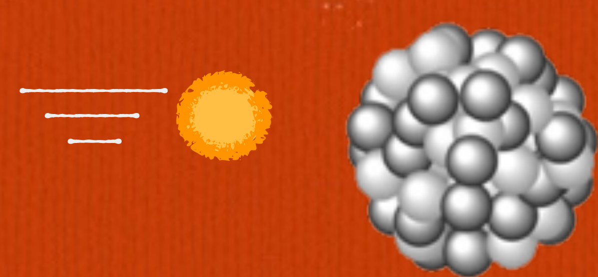
proton-nucleus



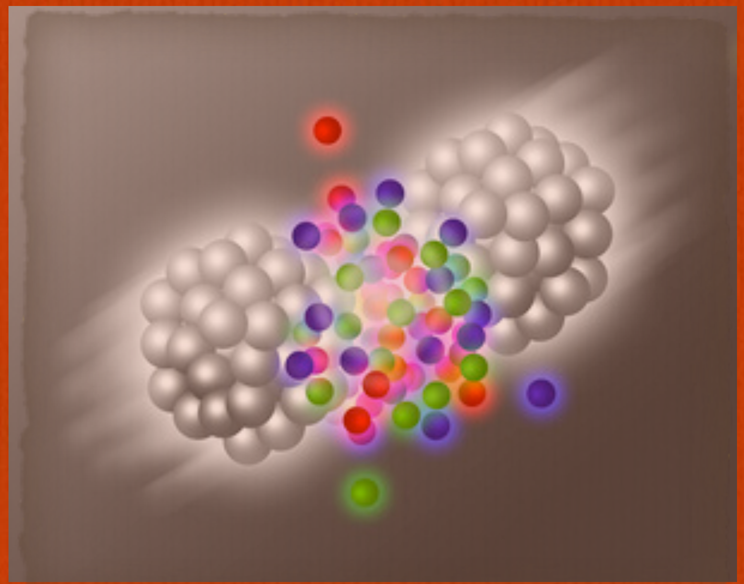
π-proton



π-nucleus



Heavy-ion Collisions ρ_B <2-3 ρ_0



Vienna University of Technology

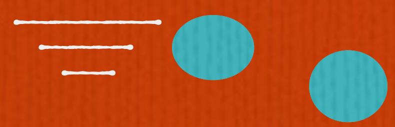
Is the contribution from resonances important in the energy regime around few GeV (up to 10-20) ?

$\rho_B \sim \rho_0$

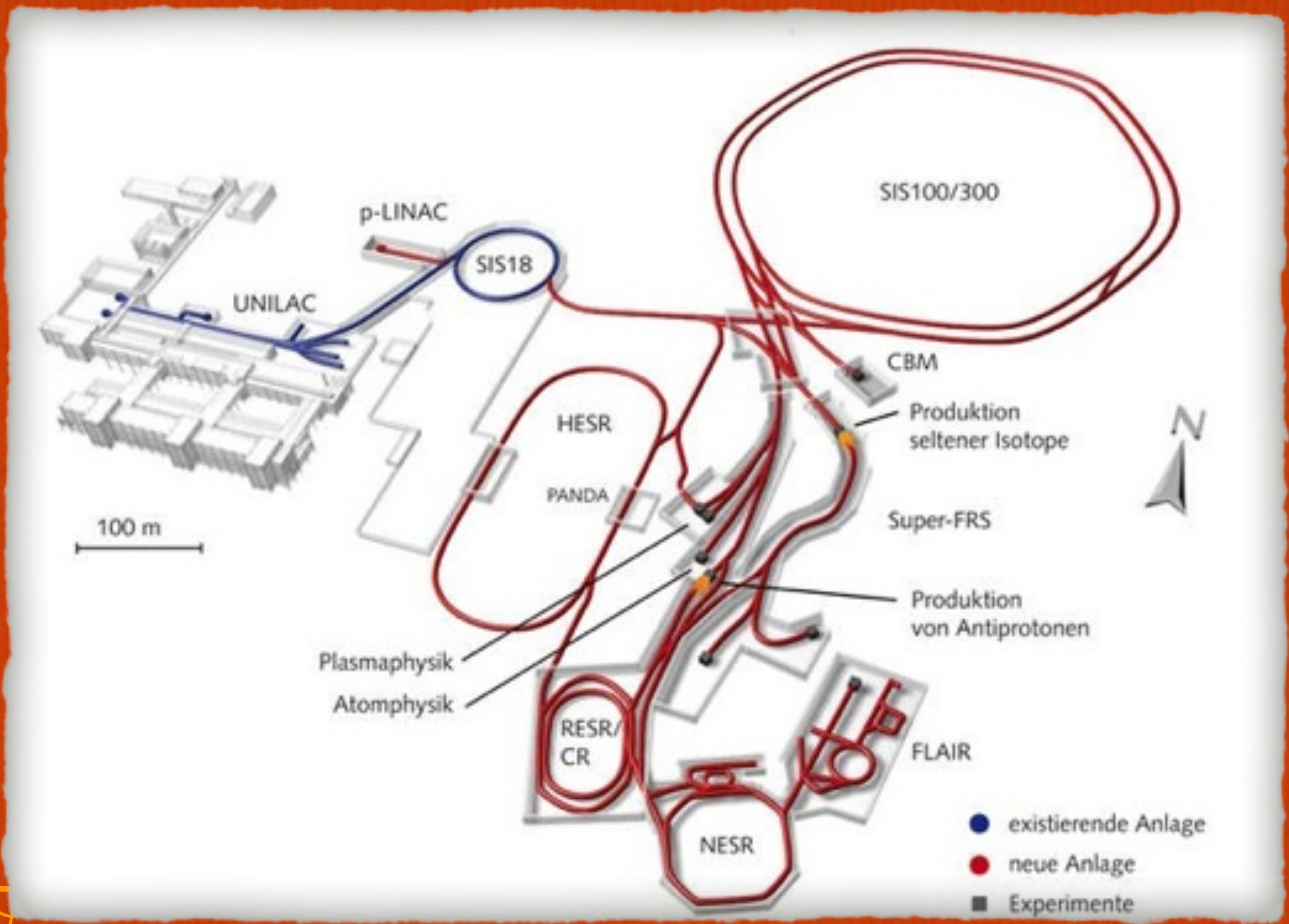
p+p in the GeV Energy Range

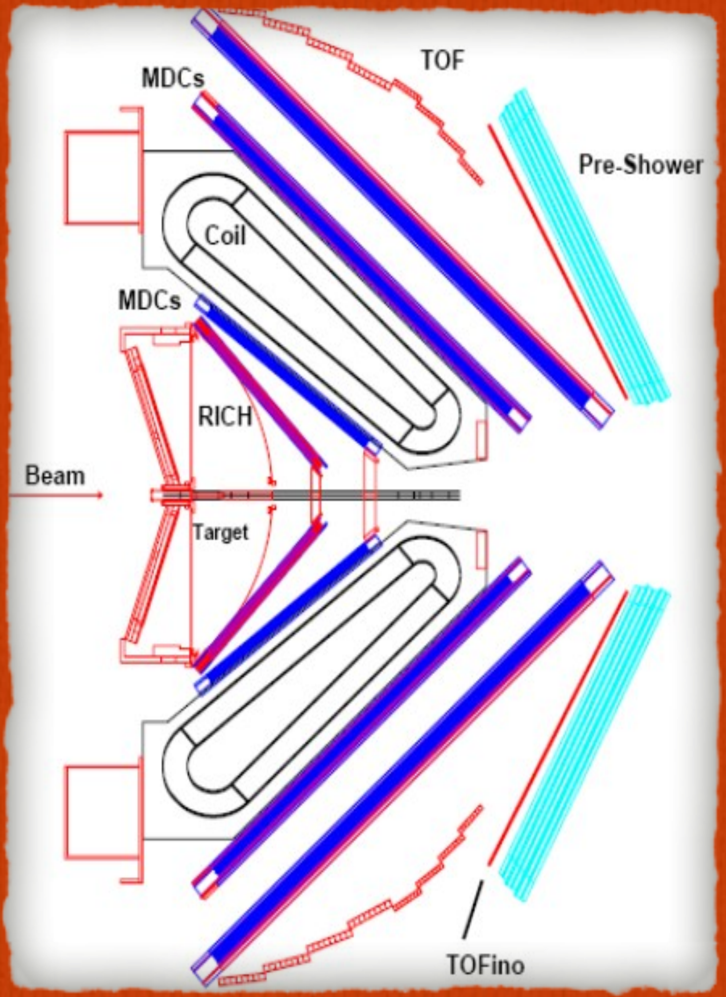
Fixed Target experiments, E_{kin}~ AGeV

proton-proton



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





Outline

Exclusive measurement of:
- Resonances accompanying Strangeness Production
- Strange Resonances
- Molecular States

Contribution by Heavy Resonances to Strangeness Production

Coherent Strangeness production

Outer Layer

K^0_S production together with Δ^+

$\Sigma^*(1385)$

$\Lambda(1405)$

Exclusive measurement of :

- Resonances accompaigning Strangeness Production
- Strange Resonances
- Molecular States

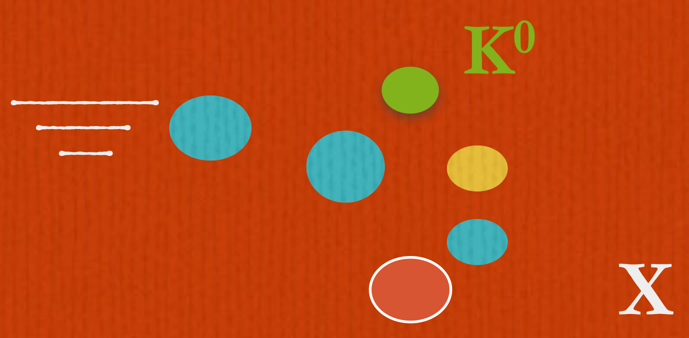
Exclusive or semi-exclusive analysis
Access to the angular distributions

Rafal Lalik talk tomorrow!

Inclusive Kaon production in elementary collisions

p+p @ 3.5 GeV

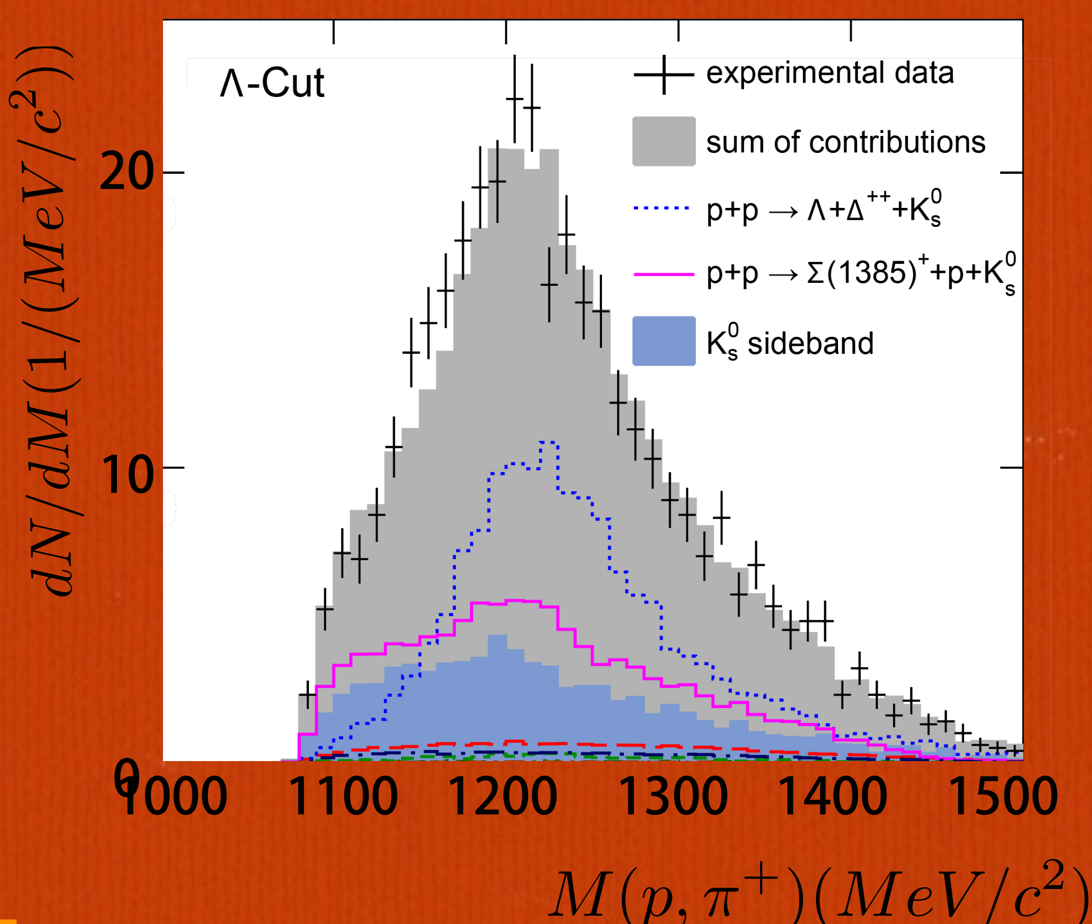
J.-C. Chen



HADES Coll.], Phys. Rev. C 90, 015202 (2014)
" Medium effects in proton-induced K^0 production at 3.5 GeV'
HADES Coll., Phys. Rev. C90 (2014) 054906

Reference Measurement of the K^0_S production in p+p to "calibrate" the interpretation of the p+A data, where the interaction between Kaons and nucleons is studied

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



New Data Base from our exclusive Measurements

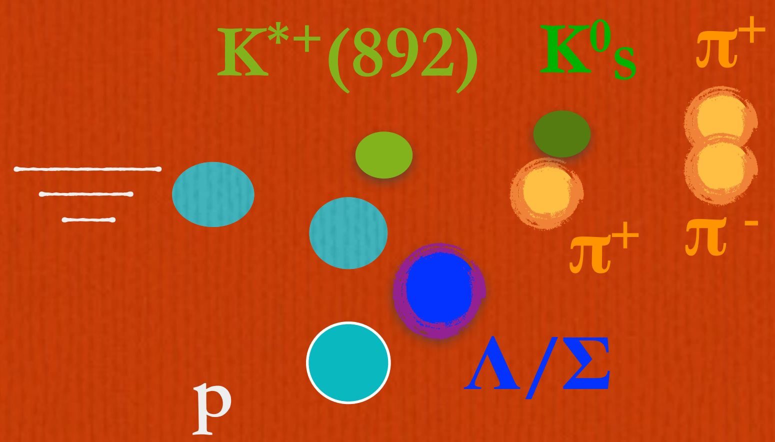
Reaction: $p + p \rightarrow$	$\sigma_{anisotropic}$ [μb]
$\Lambda + p + \pi^+ + K^0$	$\mathbf{2.57} \pm 0.02^{+0.21}_{-1.98} \pm 0.18$
$\Lambda + \Delta^{++} + K^0$	$\mathbf{29.27} \pm 0.08^{+1.67}_{-1.46} \pm 2.06$
$\Sigma^0 + p + \pi^+ + K^0$	$\mathbf{1.35} \pm 0.02^{+0.10}_{-1.35} \pm 0.09$
$\Sigma^0 + \Delta^{++} + K^0$	$\mathbf{9.26} \pm 0.05^{+1.41}_{-0.31} \pm 0.65$
$\Sigma^+ + p + K^0$	$\mathbf{26.27} \pm 0.64^{+2.57}_{-2.13} \pm 1.84$
$\Sigma(1385)^+ + p + K^0$	$\mathbf{14.35} \pm 0.05^{+1.79}_{-2.14} \pm 1.00$

K* production in p+p collisions

p+p @ 3.5 GeV

D. Mihaylov

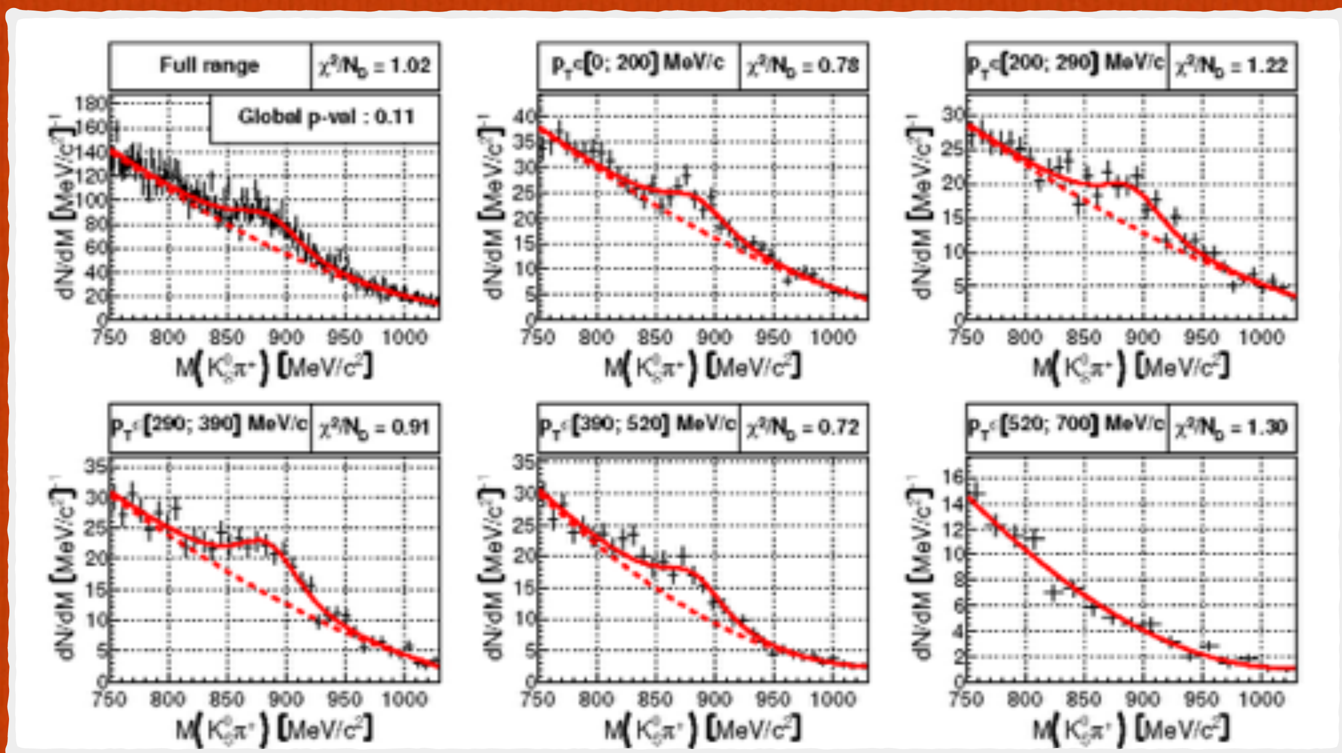
HADES Coll. arXiv:1505.06184

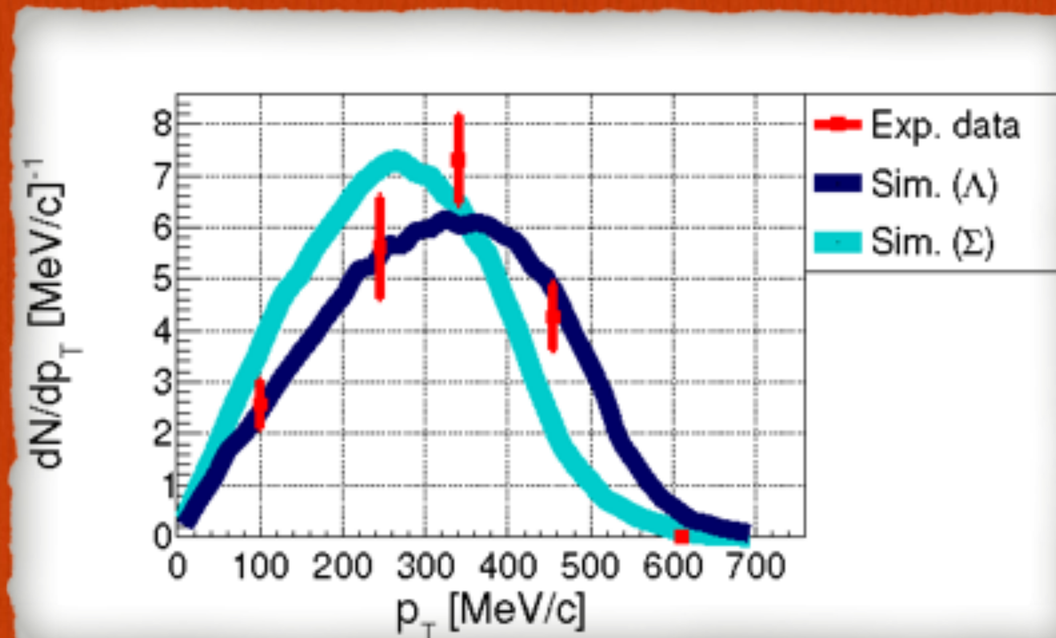


$$K^{*+}(892) \rightarrow K^0_S + \pi^+$$
$$\hookrightarrow \pi^+ + \pi^-$$

Two channels model:

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





Fit :Voigt function with fixed width (50.7 MeV)
and phase-space correction factor

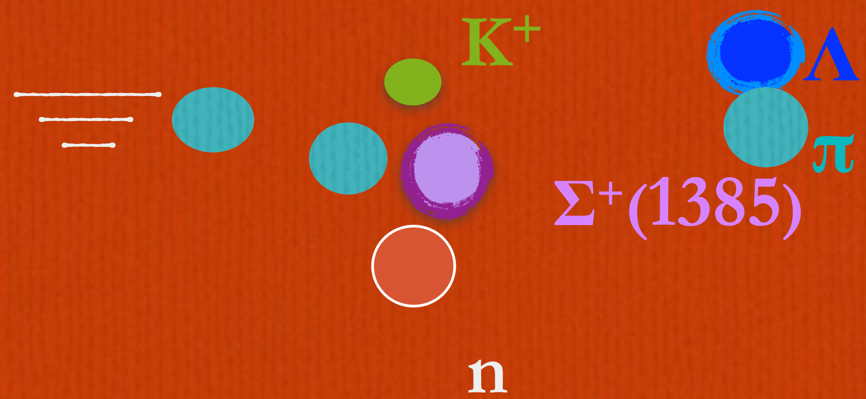
$$\sigma(p+p(3.5\,GeV) \rightarrow K^*(892)^+ + X) = 10.3 \pm 1.0^{+1.6}_{-1.2} \pm 0.7\mu b$$

Resonances measured in elementary collisions

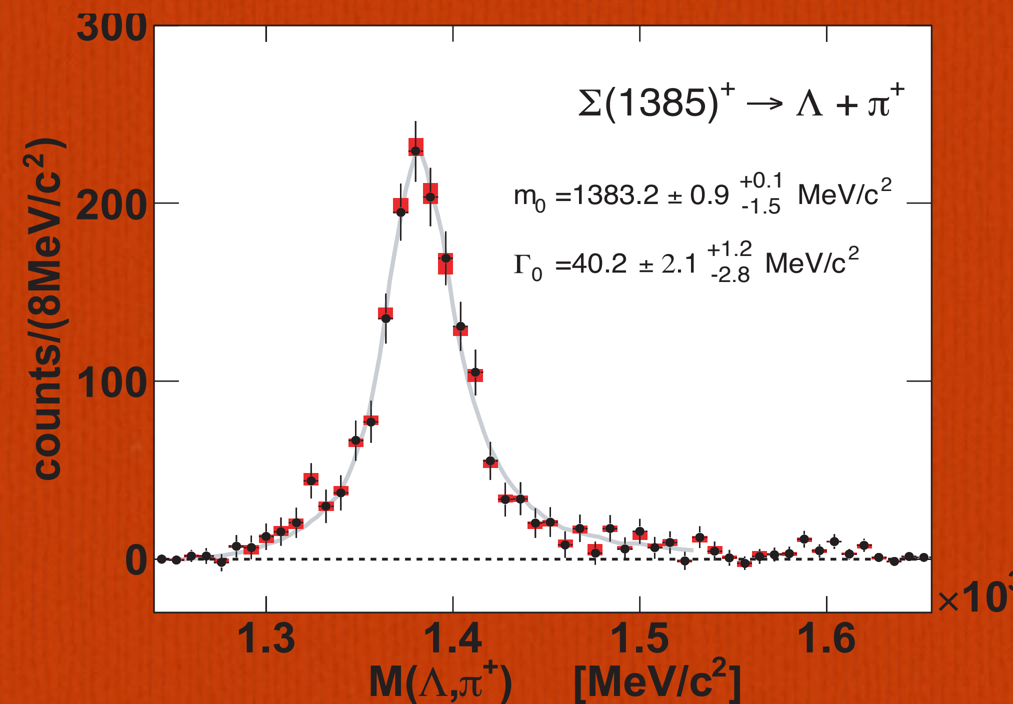
p+p @ 3.5 GeV

J. Siebenson

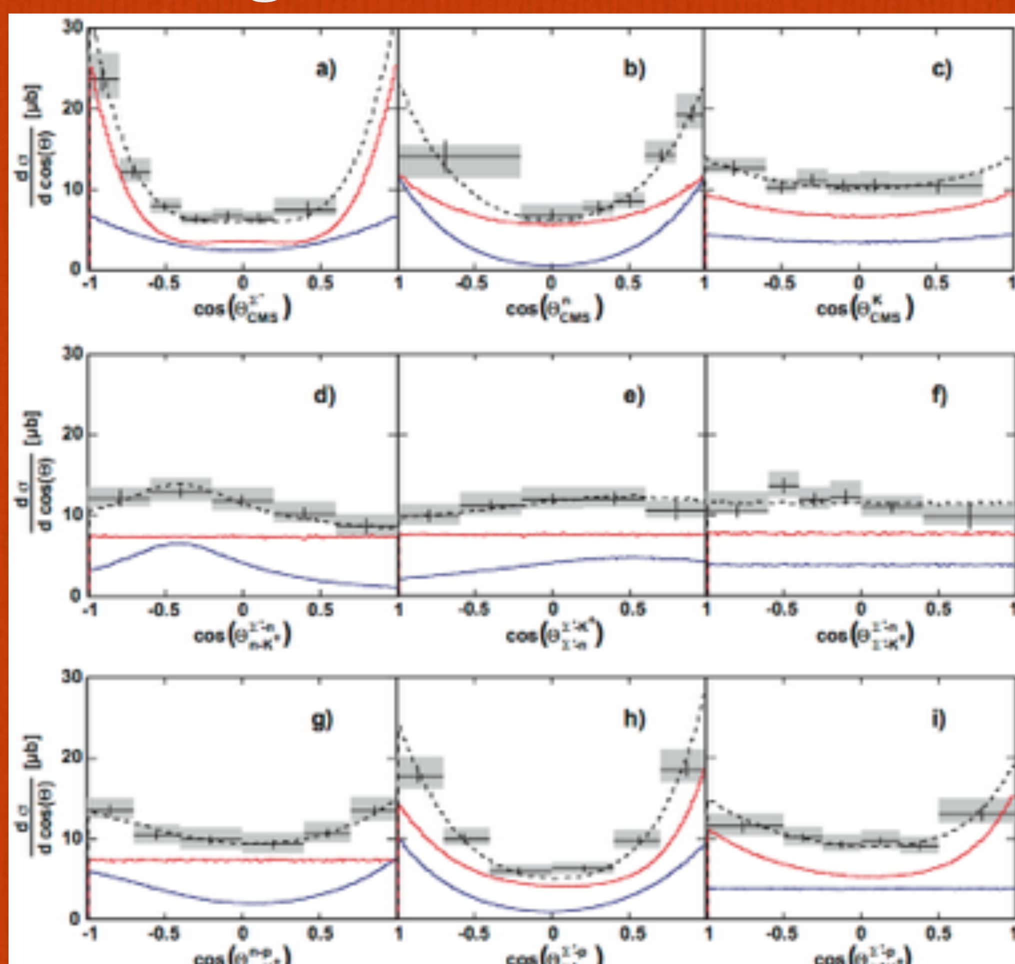
HADES Coll. Phys. Rev. C85 (2012) 035203
PDG Entry 2012



Resonance production
Coupling to different final states



Angular Distributions

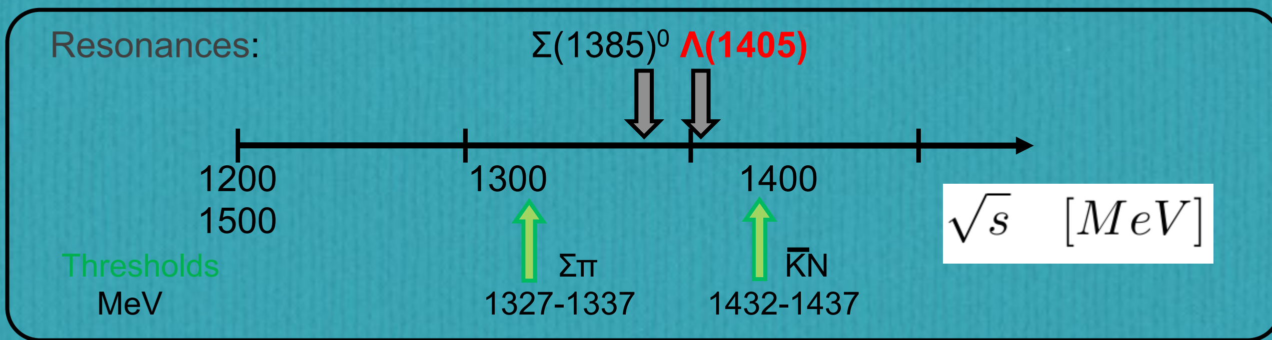


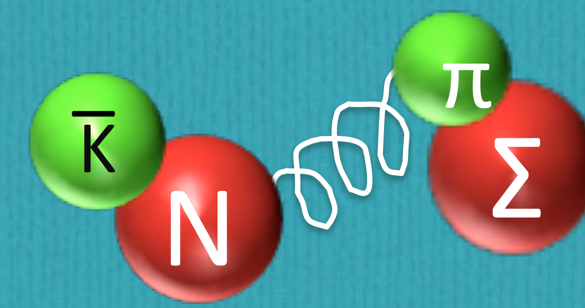
Non-isotropic angular distribution
-> has to be measured and modelled correctly to extract the total cross-section

$$\sigma_{\Sigma(1385)^+} = 22.42 \pm 0.88 \pm 1.57^{+3.04}_{-2.23}\,\mu b$$

Our Special Resonance

J. Siebenson, E. Epple





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

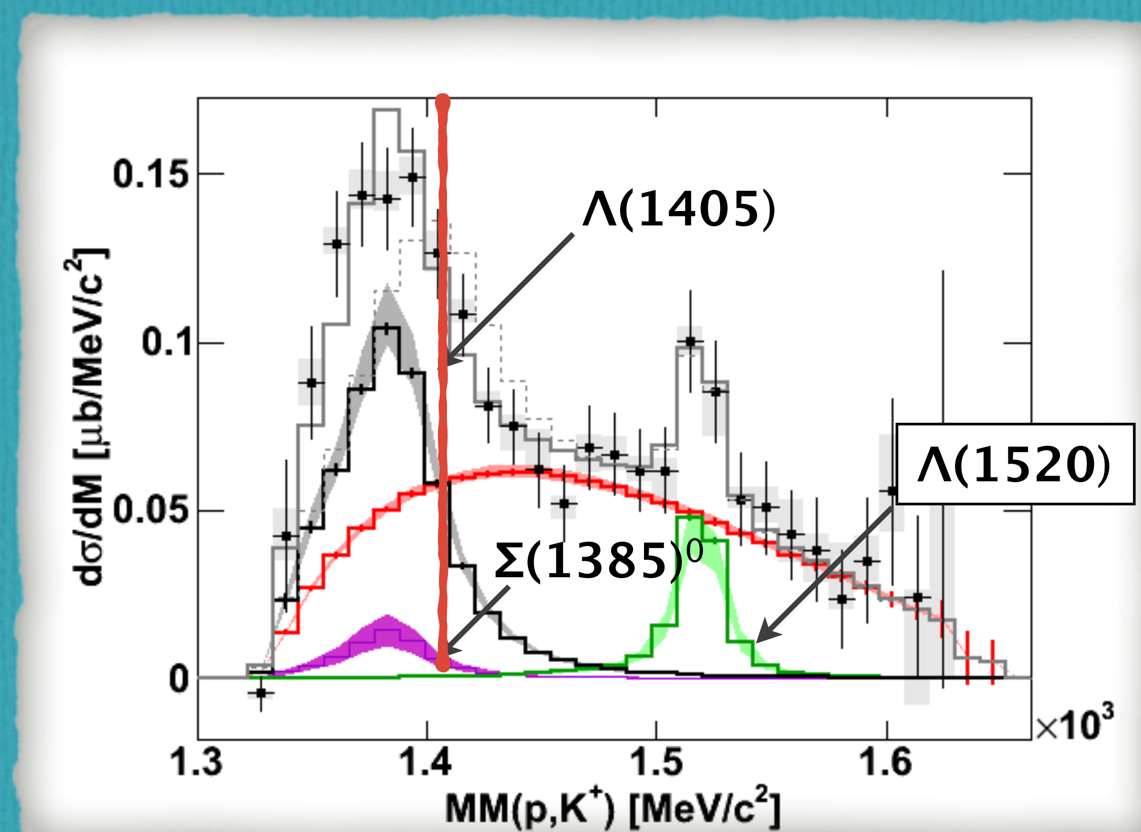
G. Agakishiev et al. [HADES] Phys. Rev. C 87 (2013) 025201.
G. Agakishiev et al. [HADES] Nucl. Phys. A 881 (2012) 178–186.

3.5 GeV

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

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

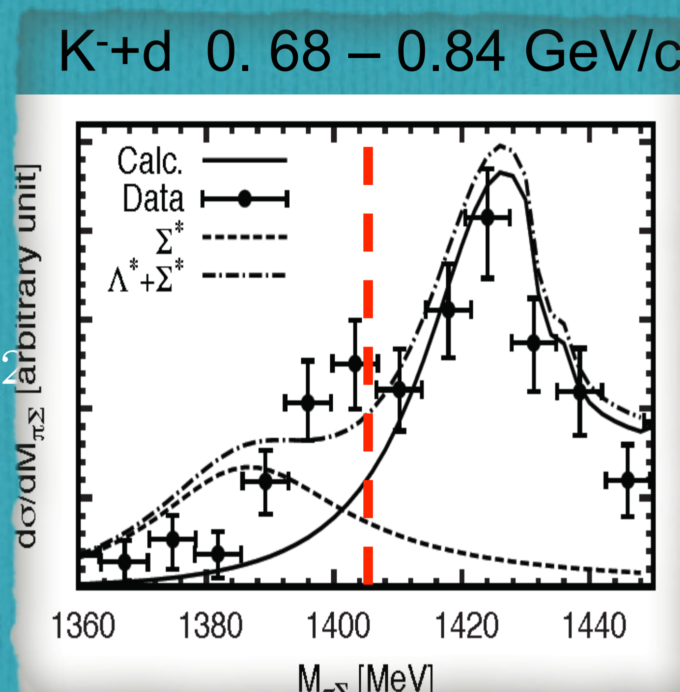
$$\searrow \pi^\pm + n$$



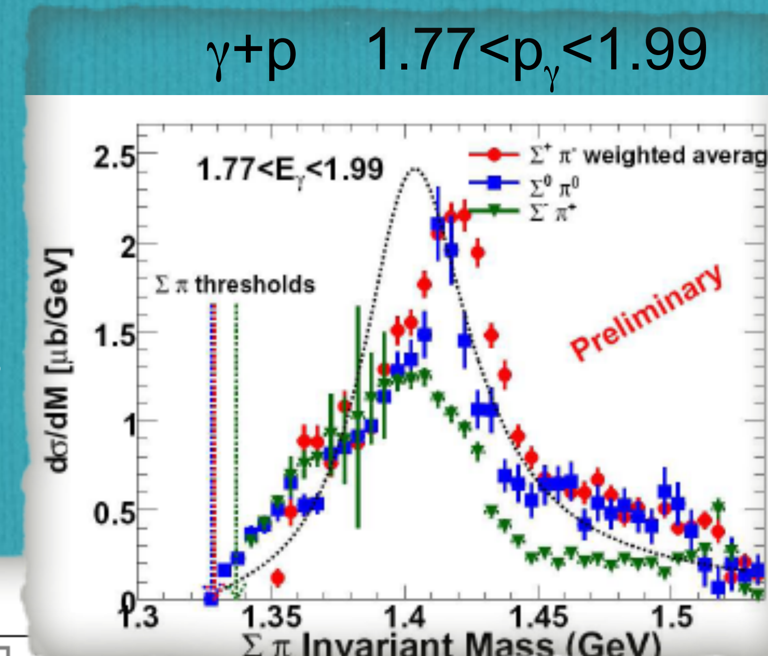
Our Special Resonance

J. Siebenson, E. Epple

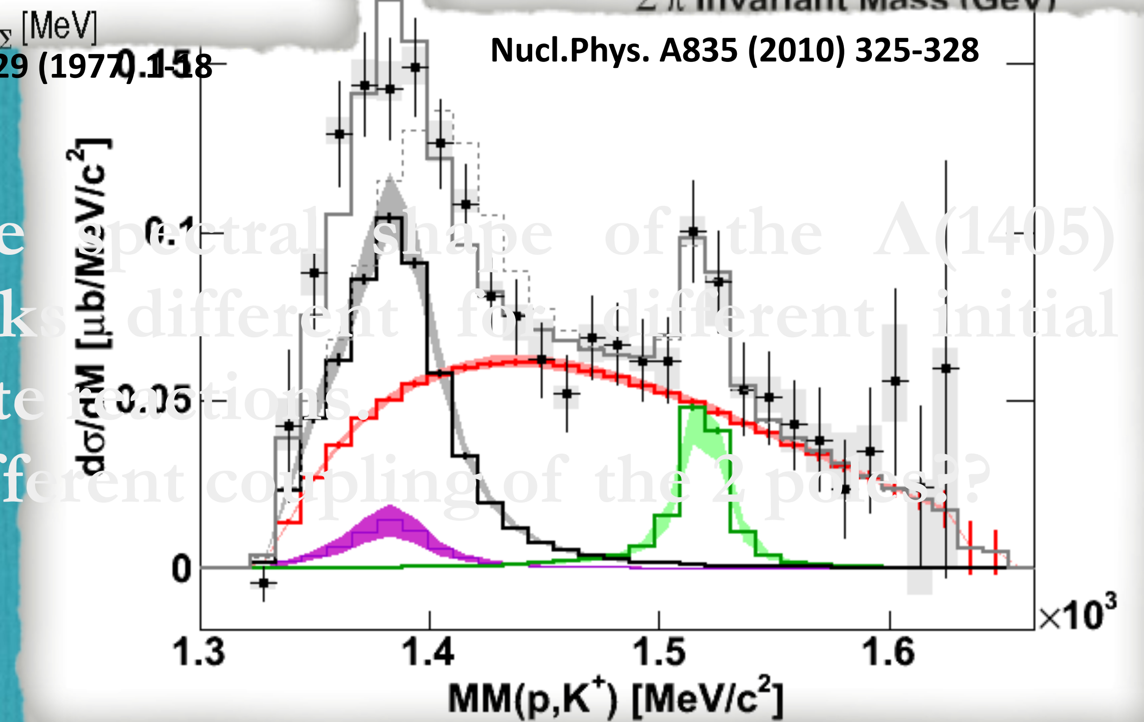
$\Lambda(1405):\ M = 1405\,MeV/c^2$ … B …)



Nuclear Physics B129 (1977) 1-18



Nucl.Phys. A835 (2010) 325-328



3.5 GeV

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

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

$$\pi^\pm + n$$

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

Different coupling of the 2 poles?

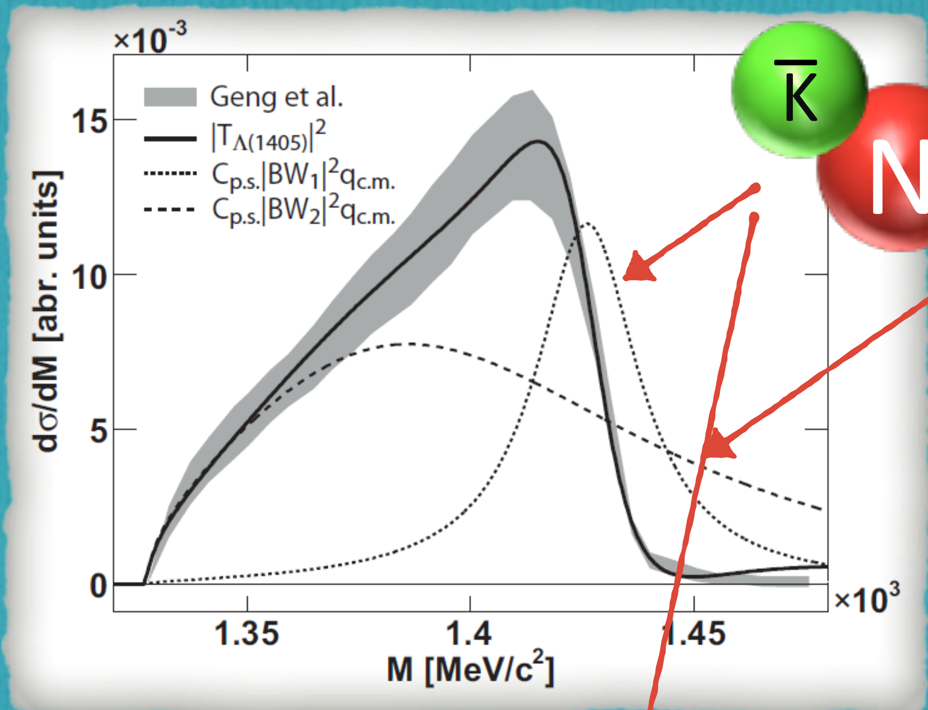
Our Special Resonance

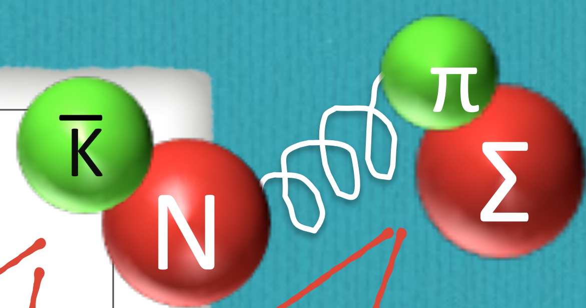
J. Siebenson, L. Fabbietti

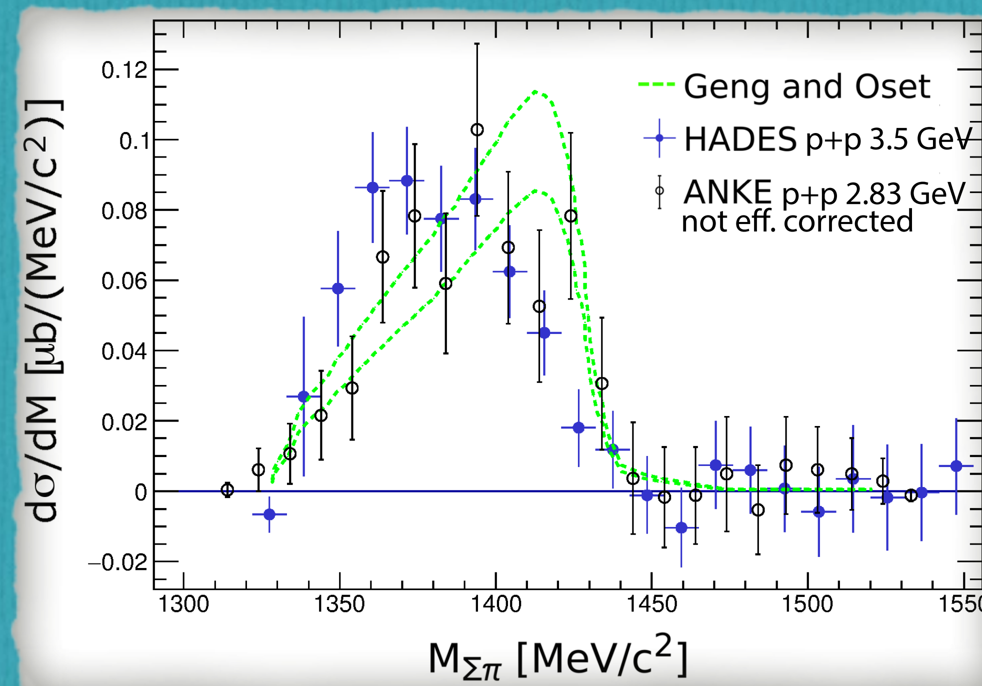
J. Siebenson and L. Fabbietti, Phys. Rev. C 88 (2013) 055201

Chiral Ansatz

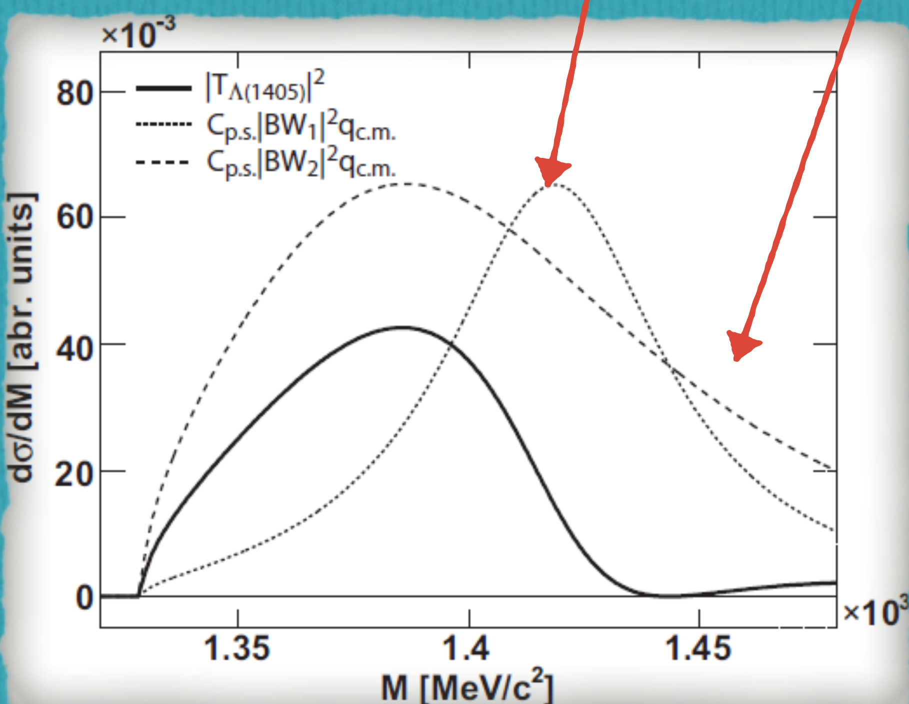
Nucl.Phys. A881 (2012) 98-114

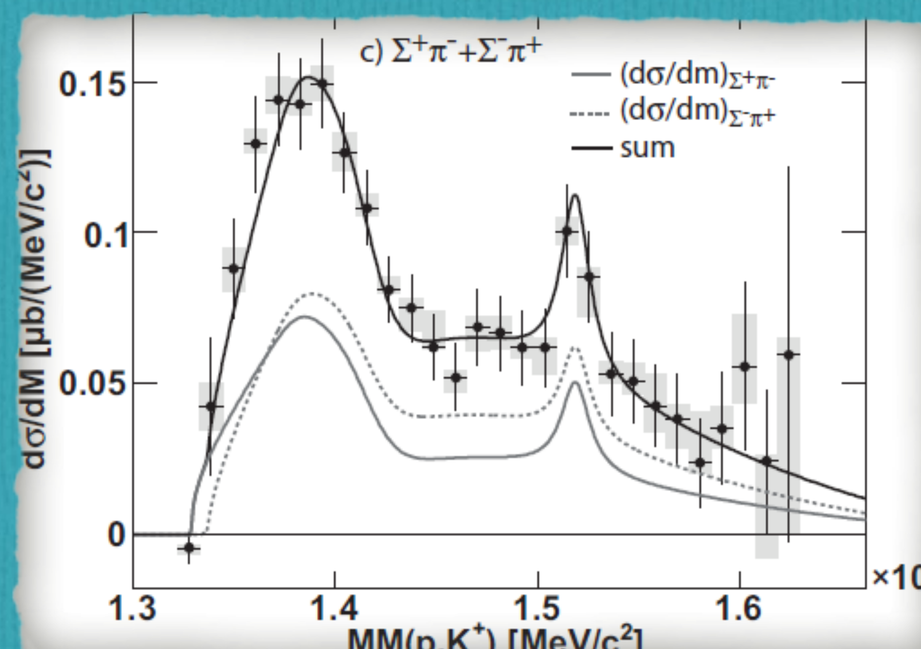






Our Ansatz





Intermediate Layer

Exclusive measurement of :

- Resonances accompaigning Strangeness Production
- Strange Resonances
- Molecular States

Contribution by Heavy Resonances to Strangeness Production

Intermediate Layer

$$\Delta^{++}(2000) \rightarrow \Sigma(1385)^{+} + K^{+}$$
$$N^{+}(2300) \rightarrow \Xi^{-} + K^{+} + K^{+}$$

.. and possible implications for Dileptons too?

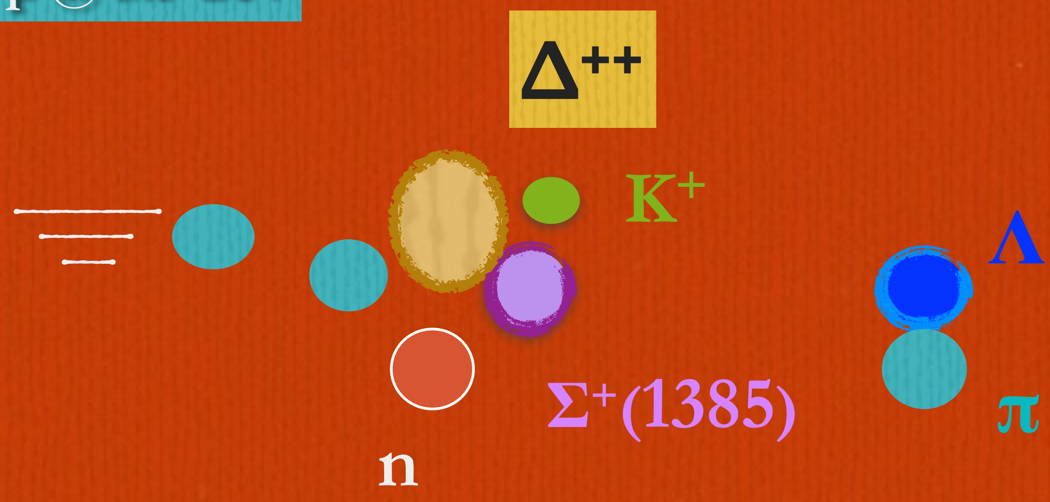
Manuel Lorenz talk tomorrow!

Contribution by Heavy Resonances to Strangeness Production

Resonances measured in elementary collisions

p+p @ 3.5 GeV

J. Siebenson



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

$$\Delta(1900-2000)^{++} \rightarrow \Sigma^{+}(1385) + K^{+}$$

$$\Gamma = 150 - 200\,\mathrm{MeV/c^2}$$

~ 30%

Chinowsky, W. *et al.* Phys.Rev. 165 (1968) 1466-1478

Role of the Δ*(1940) in the π+p→K+Σ+(1385) and pp→nK+Σ+(1385) reactions

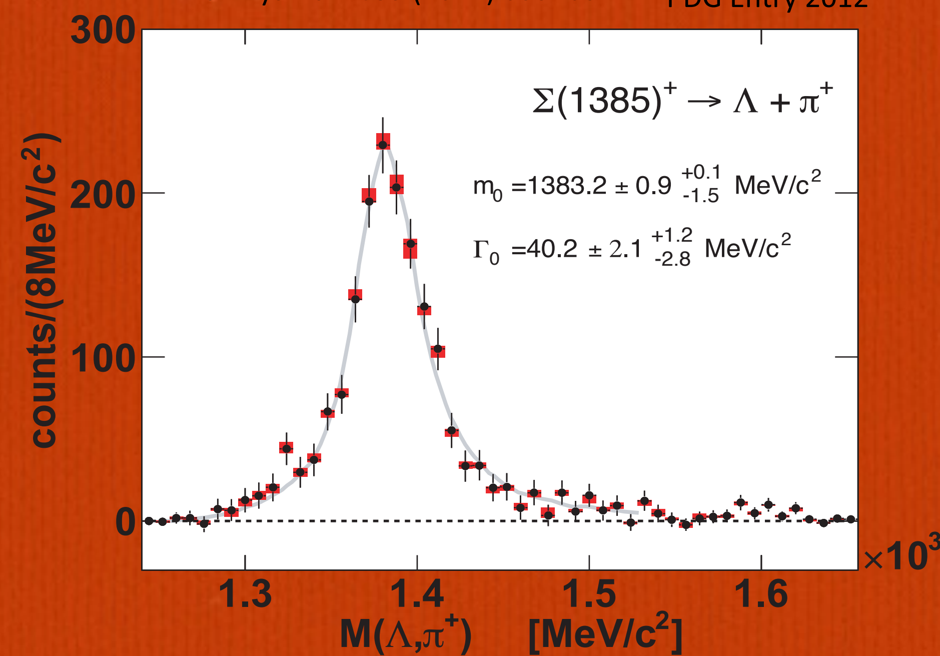
Ju-Jun Xie, En Wang, Bing-Song Zou

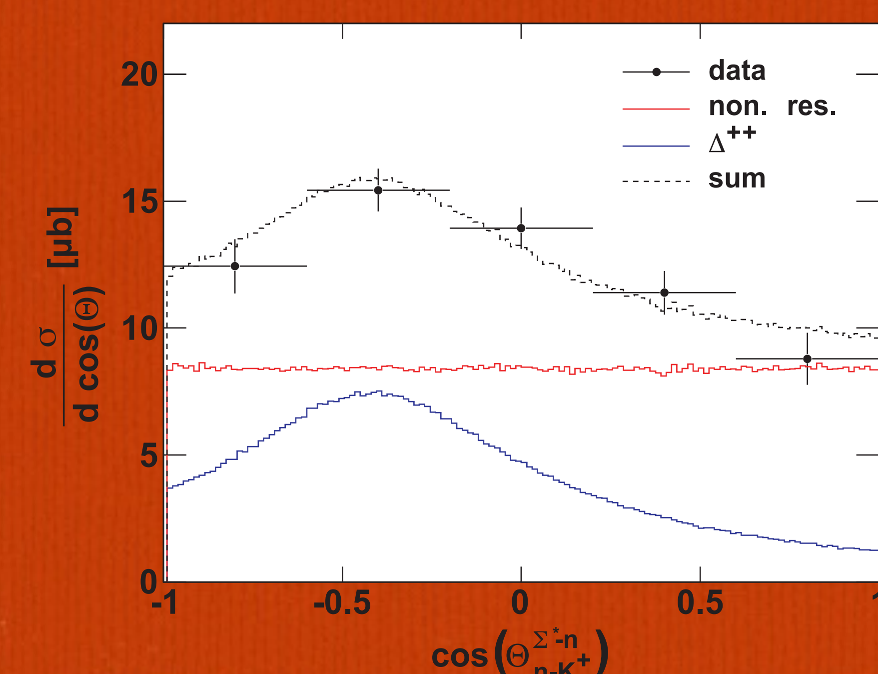
arxiv.1405.5586

Resonance production

Coupling to different final states

HADES Phys.Rev. C85 (2012) 035203 PDG Entry 2012



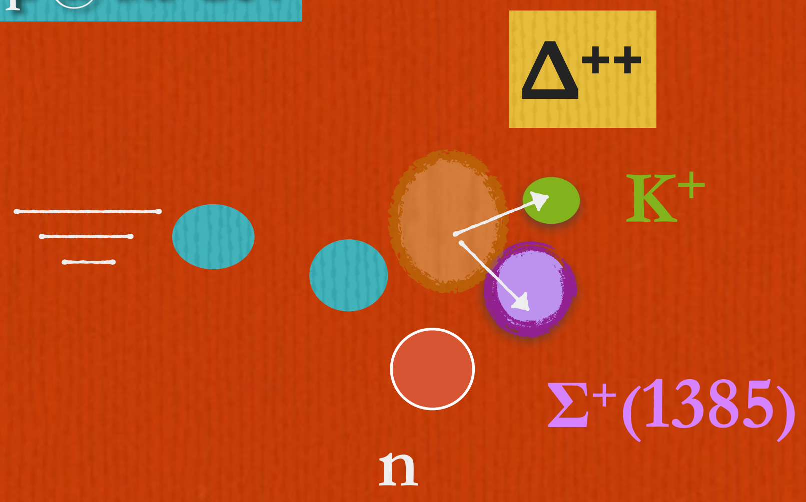


Resonances measured in elementary collisions

p+p @ 3.5 GeV

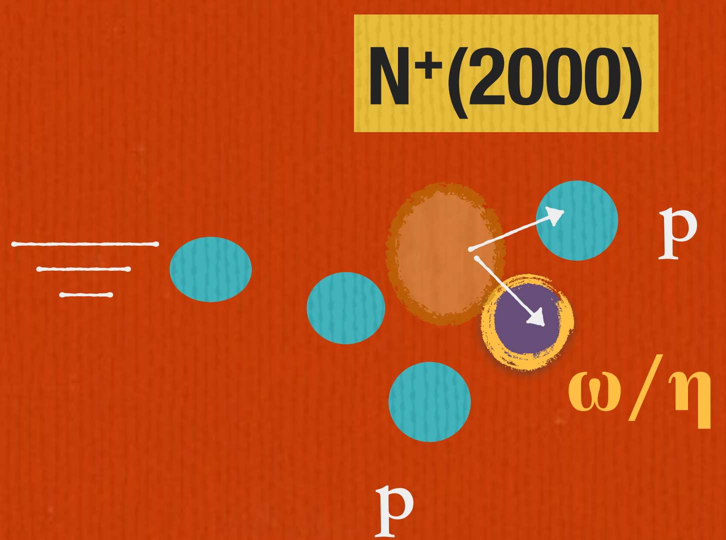
L. Fabbietti C14-09-08.1
e-Print: arXiv:1503.00616

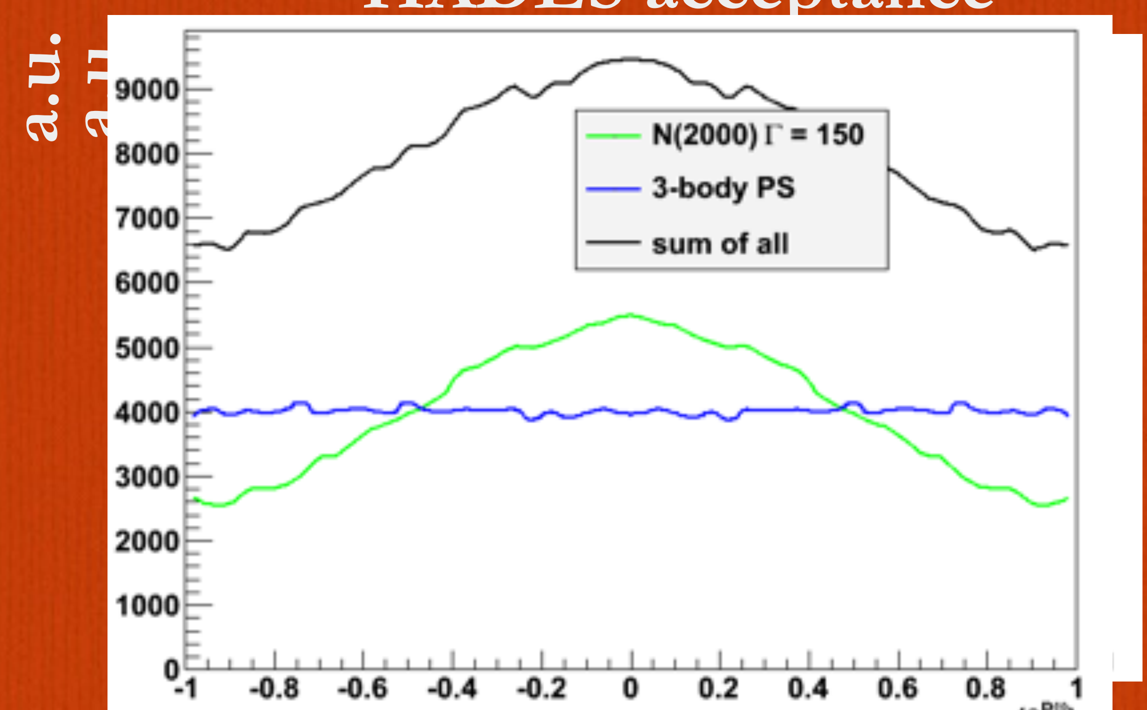
Resonance production
Coupling to different final states



Experimental data (not corrected) within the HADES acceptance

Simulation in 4π (Phase-space simulation without detector response)





$\cos\theta^{p\omega}_{pp}$

No evidence for a heavy resonance contributing to the η or ω production…. yet.. :)

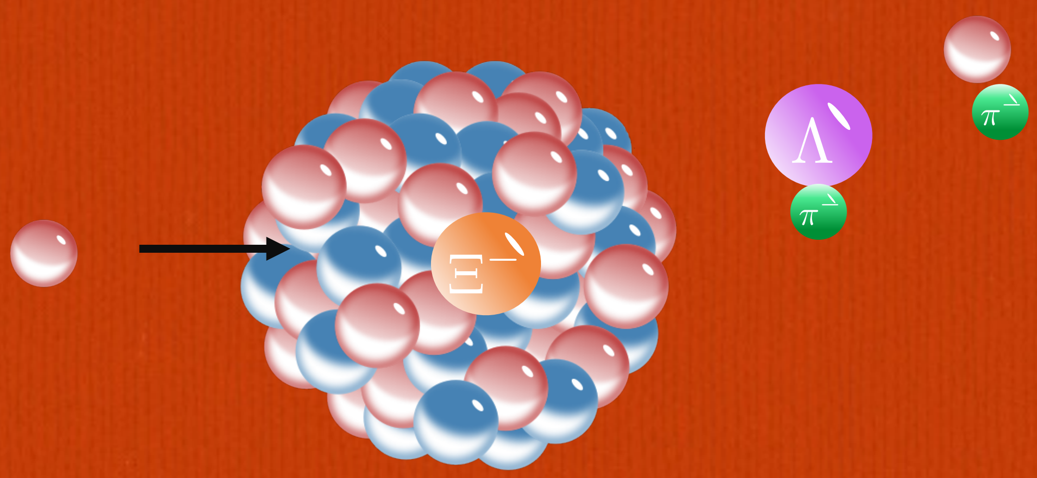
Ξ^- Production in p+A collisions

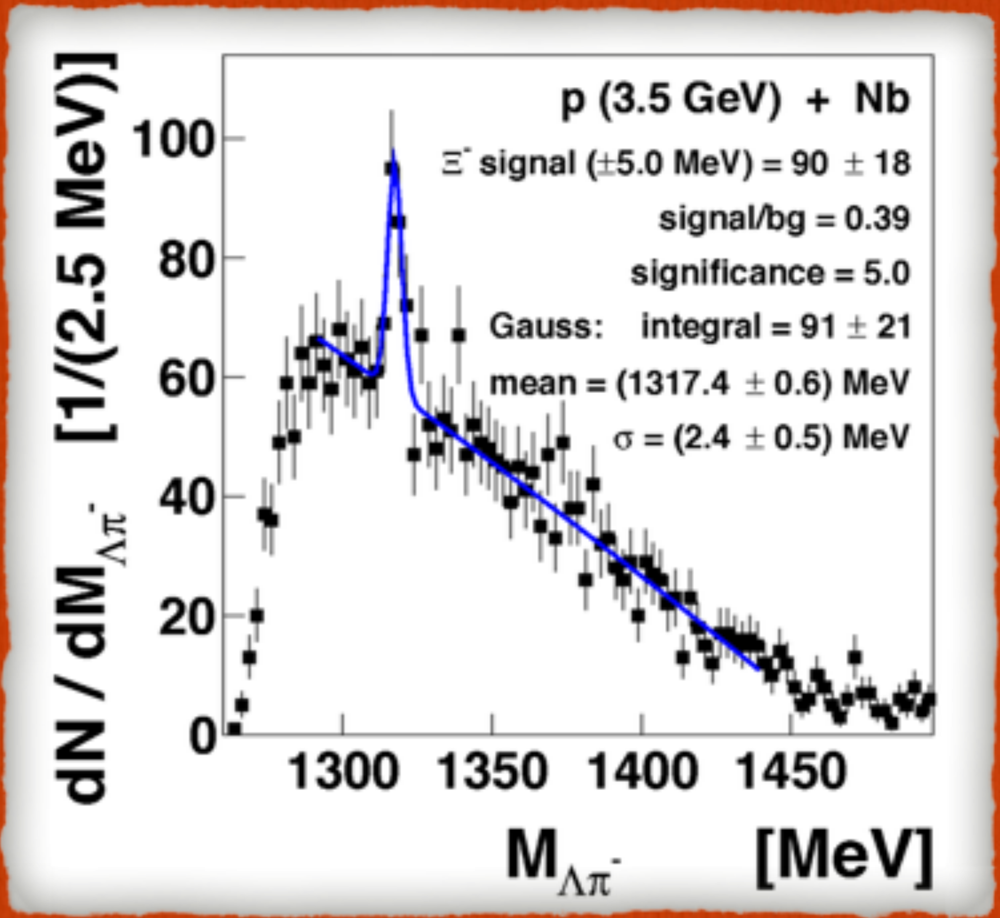
p+Nb @ 3.5 GeV

R. Kotte, C. Wendisch

Phys.Rev.Lett. 114 (2015) 21, 212301

$\Xi^- = (ssd),\ BR(\rightarrow \Lambda\pi) = 99\%,\ c\tau = 4.91\mathrm{cm}$





How to produce Ξ ?

$NN \rightarrow N\Xi KK$

$\sqrt{s_{thr}} = 3.25\,\mathrm{GeV},\ E_{thr} = 3.74\,\mathrm{GeV}$

$\bar{K}Y \rightarrow \pi\Xi$

$YY \rightarrow \Xi N$

low cross-section

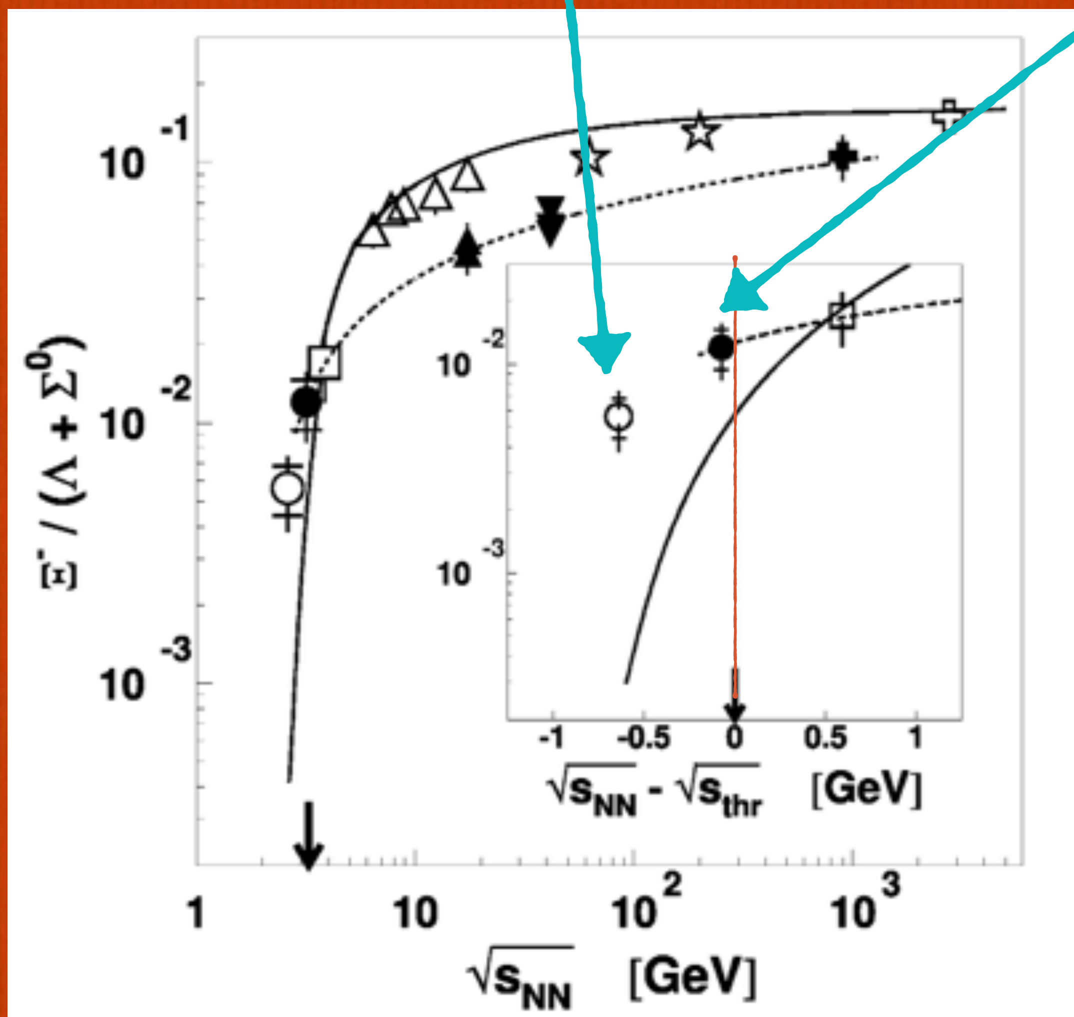
also below threshold, not enough to explain the measured Ξ/Λ yield

Ξ^- Excess

R. Kotte, C. Wendisch

Phys.Rev.Lett. 114 (2015) 21, 212301

Findings in Ar+KCl at 1.76 AGeV and p+Nb at 3.5 GeV
subthreshold production

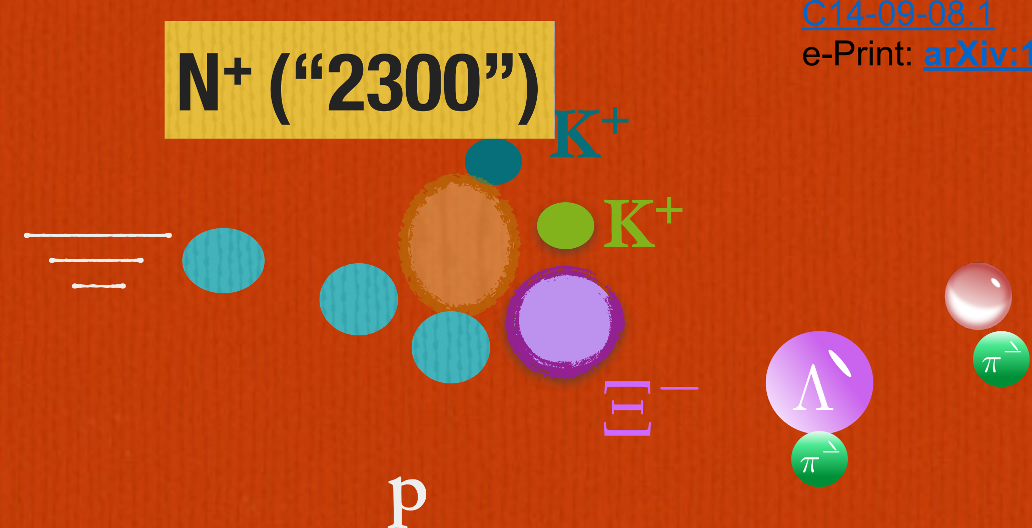


$$P_{\Xi^-} = (2.0 \pm 0.4(\text{stat}) \pm 0.3(\text{norm}) \pm 0.6(\text{syst})) \times 10^{-4}$$

$$\frac{P_{\Xi^-}}{P_{\Lambda+\Sigma^0}} = (1.2 \pm 0.3(\text{stat} \pm 0.4(\text{syst})) \times 10^{-2}$$

Excess w.r.t. Thermal hadronization model for Ar+KCl

C14-09-08.1
e-Print: arXiv:1503.00616



The possible contribution of a very heavy resonance produced in p+A reactions exploring the energy "reservoir" provided by the tail of the Fermi-Momentum distribution.
This might explain also the excess in Ar+KCl ! J. Steinheimer and M. Bleicher arXiv:1503.07305

Inner Layer

Exclusive measurement of :

- Resonances accompaigning Strangeness Production
- Strange Resonances
- Molecular States

Contribution by Heavy Resonances to Strangeness Production

Coherent Strangeness production

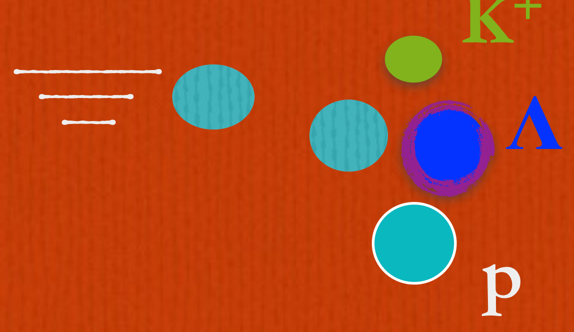
Inner Layer

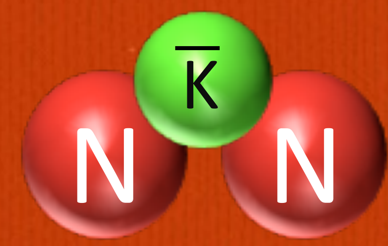
Interference of N* resonances coupling to Strangeness and Partial Wave Analysis

Coherent Strangeness production

Interferences among Resonances

proton-proton



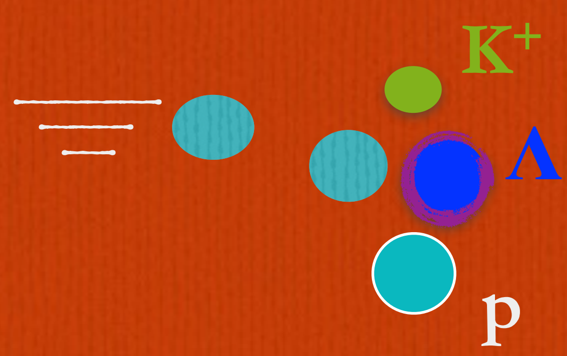


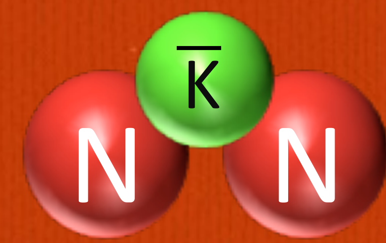
Property	Value
charge	+1
strangeness	-1
participants	ppK^-, $pn\bar{K}^0$
J^P	0^-

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

Interferences among Resonances

proton-proton

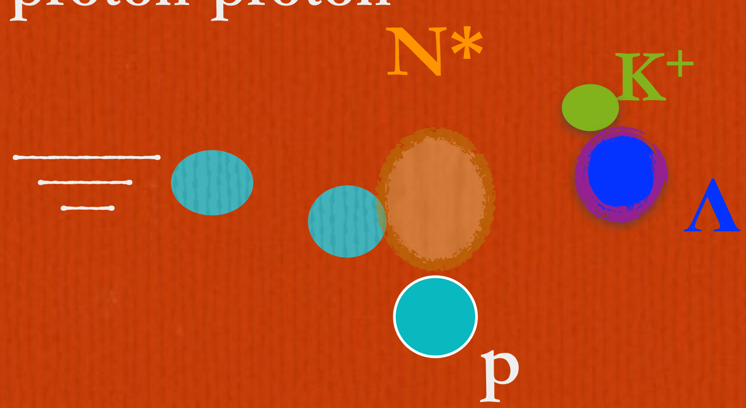




Property	Value
charge	+1
strangeness	-1
participants	ppK^-, $pn\overline{K}^0$
J^P	0^-

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

proton-proton

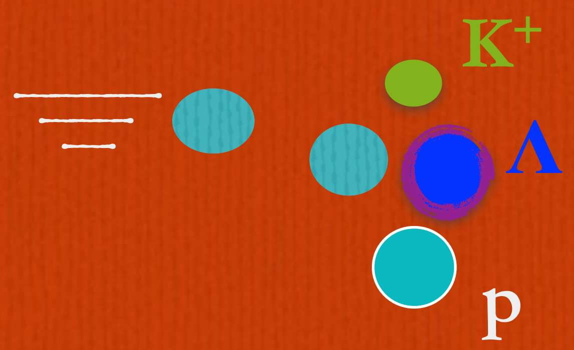


How many N* do exist?
Can these interfere with each others?
Interference: Coherent some of the different amplitudes contributing to the same final state

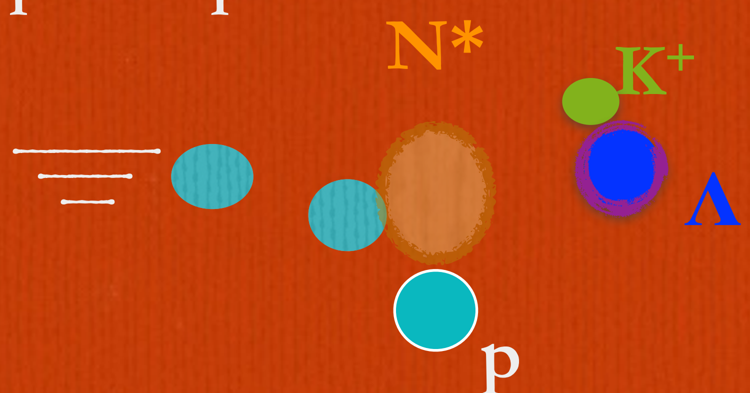
Interferences among Resonances

E. Epple, R. Muenzer

proton-proton



proton-proton



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

Notation in PDG	Old notation	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	4±2
N(1880) $\frac{1}{2}^+$	N(1880)P_{11}	1.870	0.235	2±1
N(1895) $\frac{1}{2}^-$	N(1895)S_{11}	1.895	0.090	18±5
N(1900) $\frac{3}{2}^+$	N(1900)P_{13}	1.900	0.250	0-10

Non Resonant final states

$(p\Lambda)(^{2S+1}L_J)$-K+

Given the transition amplitude for 1 possible wave

$$A^{\alpha}_{tr}(s) = \left(a^{\alpha}_1 + a^{\alpha}_3\sqrt{s}\right) e^{ia^{\alpha}_2}$$

One has to sum all the possible contributing waves to get the total amplitude

The Partial Wave Analysis Framework

E. Epple, R. Muenzer

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, 129152 (2007)

A total Amplitude is fitted event-by-event to the data and it includes:

N(1650), N(1710), N(1720), N(1875), N(1880), N(1895), N(1900)

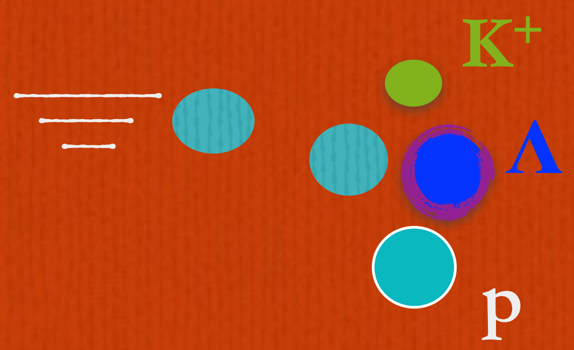
Non-resonant $PK^{+}\Lambda$ production waves

Interferences

110 different solutions have been tested to the p+p at 3.5 GeV data
4 best solutions are identified on the base of the likelihood of the fit

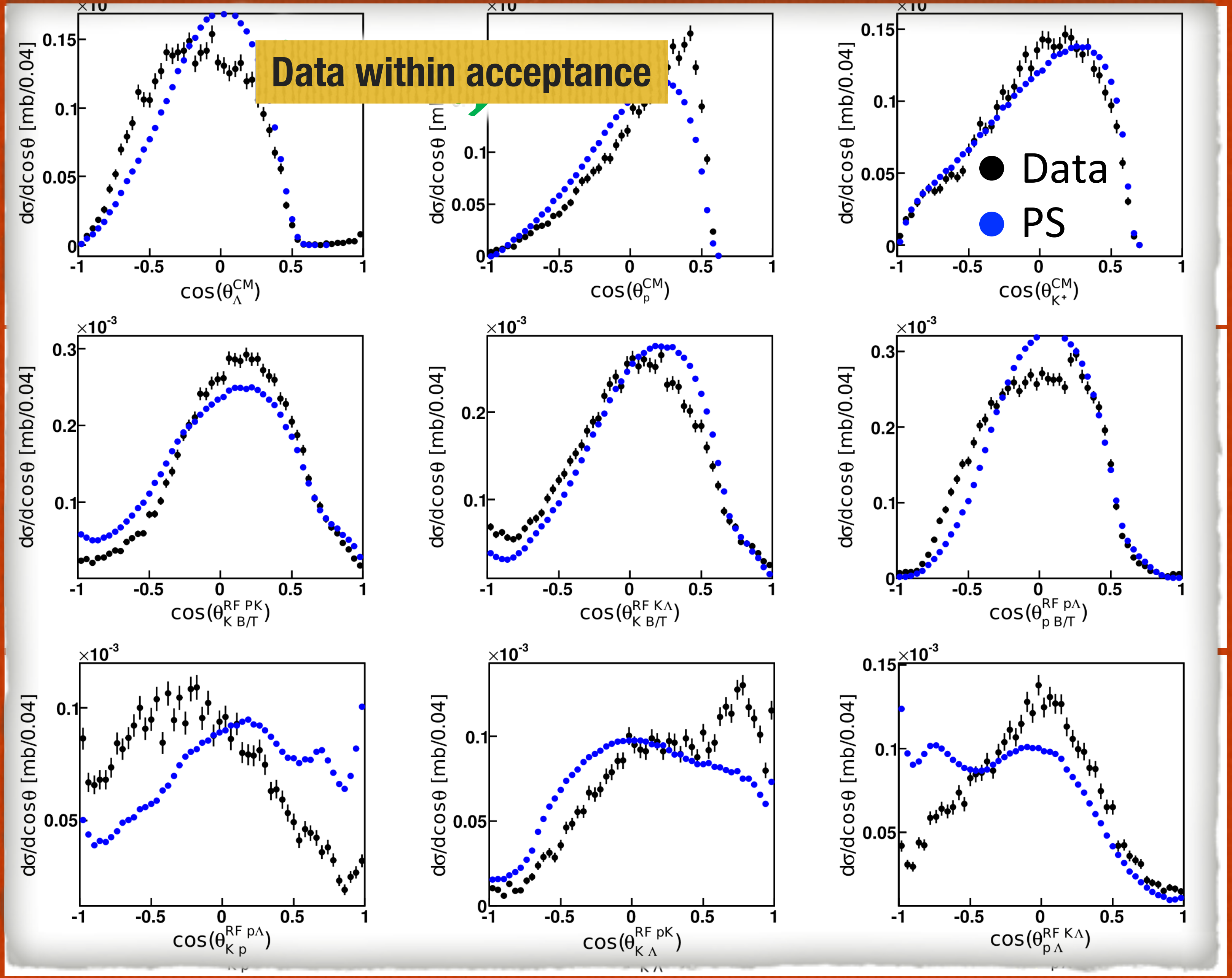
PWA Results

proton-proton



Angular Distributions of the $pK^+\Lambda$ final state

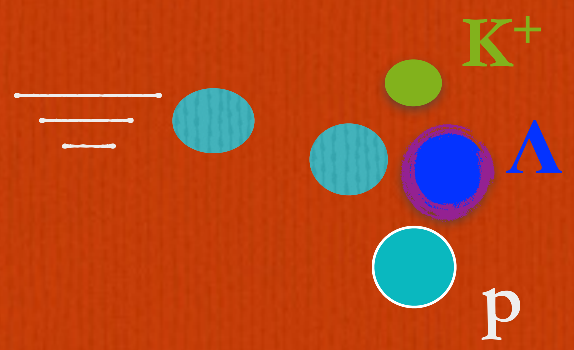
HADES Coll., Phys.Lett. B742 (2015) 242-248



PWA Results

E. Epple, R. Muenzer

proton-proton



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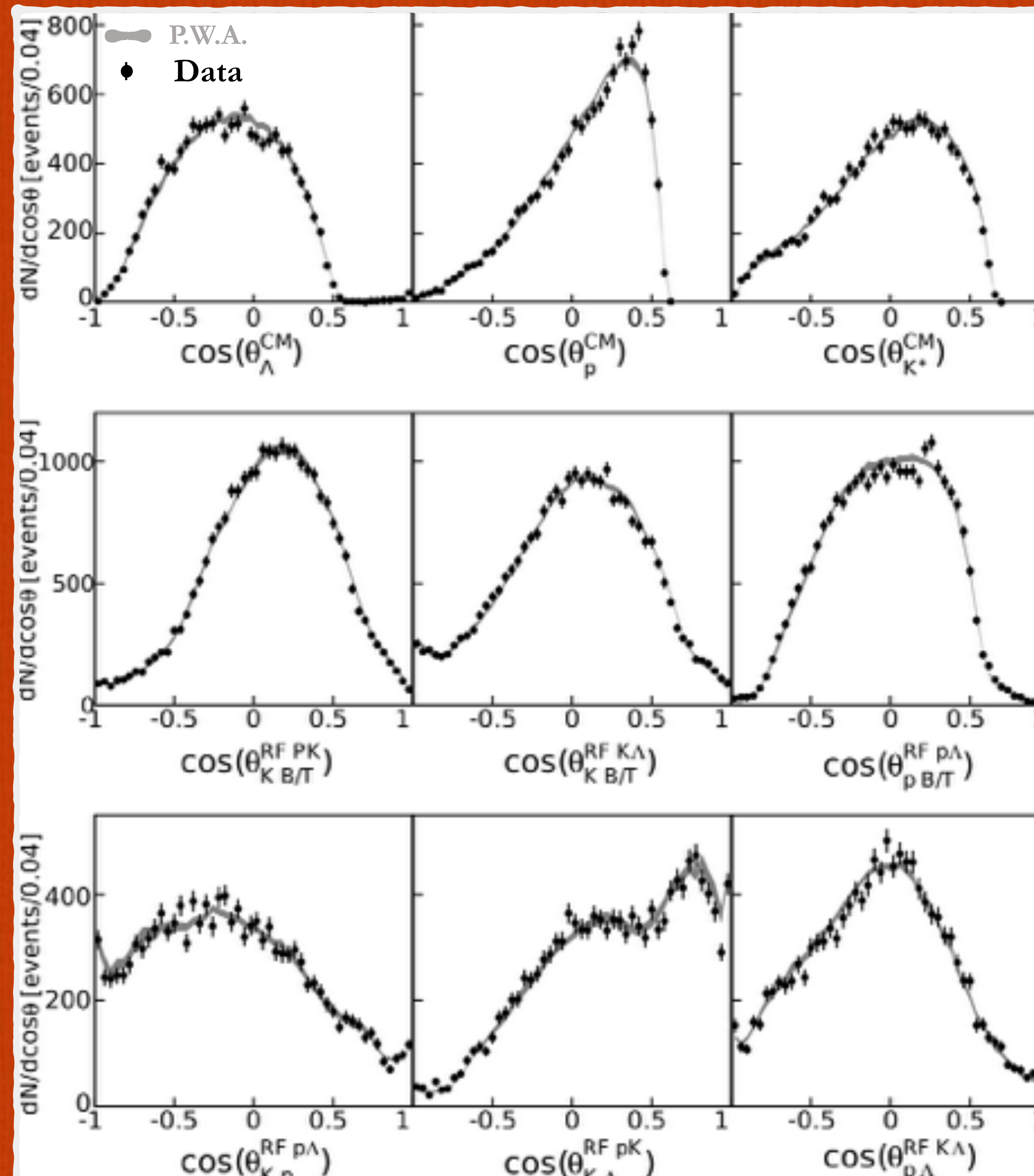


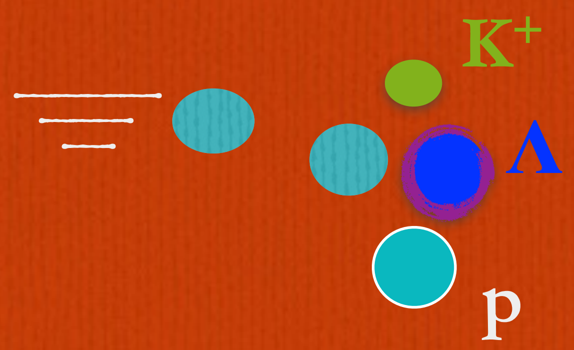
Name	N* combination
1/8	N(1650), N(1710), N(1720), N(1900)
3/8	N(1650), N(1710), N(1720), N(1880)
6/9	N(1650), N(1710), N(1720), N(1900), N(1895)
8/8	N(1650), N(1710), N(1720), N(1895), N(1880)

Ambiguity in the determination of the N* contribution
Currently a global PWA analysis of all the available data for p+p -> pKΛ is carried out !!

PWA Results

R. Muenzer, S. Lu

proton-proton



DFG FA 898/2-1: Global PWA Analysis, TUM

Experiment	E_B [GeV]	$pK^+\Lambda$ Statistics	ε_{ppK^-} [MeV]	Status
COSY-TOF	1.96	~160k	-104	
DISTO	2.15	120 k	-114	
COSY-TOF	2.16	3.6 k	-104	Single PWA
COSY-TOF	2.16	40 k	-104	Single PWA
COSY-TOF	2.16	~90k	-104	
COSY-TOF	2.25	36 k	-83	Single PWA
COSY-TOF	2.40	1.6 k	-24	Single PWA
DISTO	2.5	304 k	26	Single PWA
DISTO	2.85	424 k	116	
FOPI	3.1	0.9 k	196	Single PWA
HADES	3.5	21 k	315	Single PWA

Ambiguity in the determination of the N* contribution
Currently a global PWA analysis of all the available data for p+p -> pKΛ is going on!!

Summary

* Exclusive analysis of p+p to extract resonances
1.Yield
2.Angular Distributions
3.Decay Chains from heavy resonances to lighter one
4.Possible implications for “Excesses” seen in the strange and non-strange sector
5.Molecular states

* Partial Wave Analysis to evaluate interferences among resonances
1.How this all effects the interpretation of heavy ion collisions in the GeV energy range?

<u>pp, pd measurements needed for FAIR and NICA as a reference</u>