Strangeness Nuclear Physics with HADES

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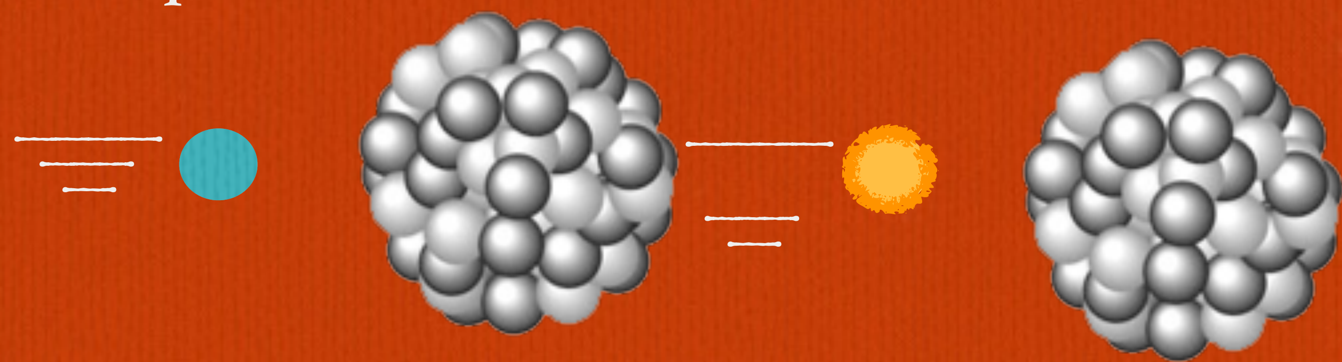
- Motivation
- Measured Kaon and Antikaon properties in nuclear matter
- Cascade Excess within nuclear matter

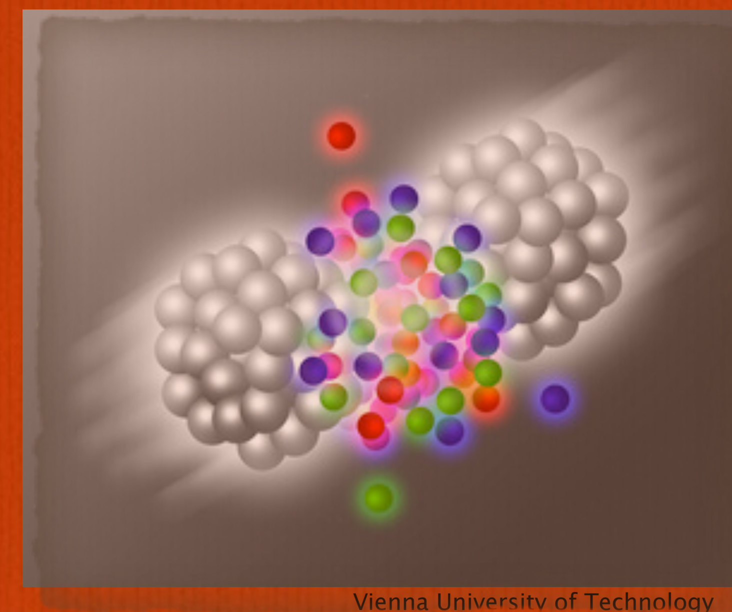
GSI, SIS18 and HADES

Fixed Target experiments, E_{kin}~ AGeV

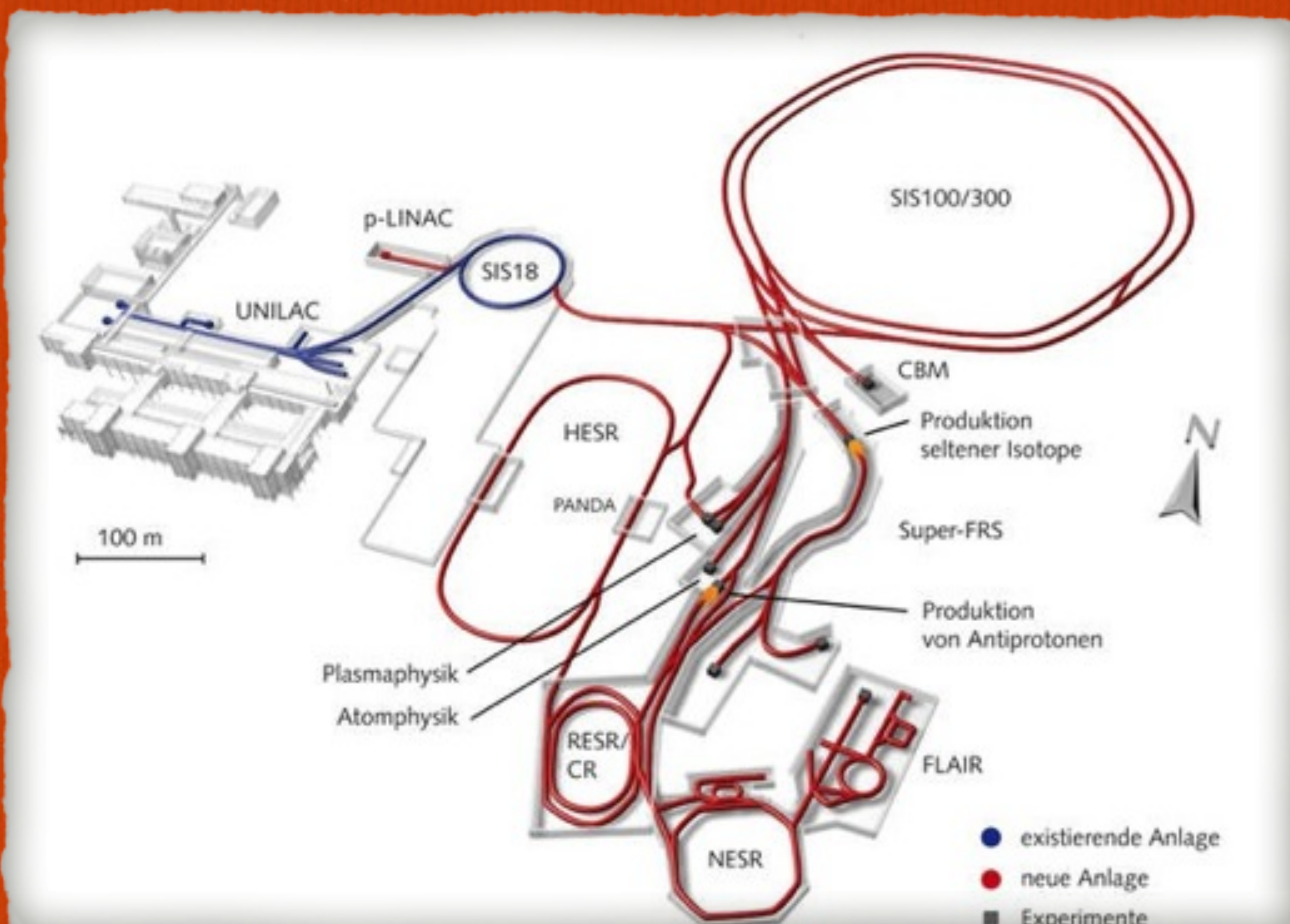
proton-nucleus π-nucleus



Elementary Reactions $\varrho_B < \varrho_0$



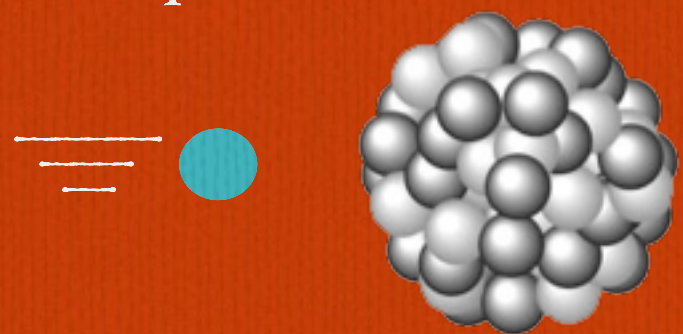
Heavy-ion Collisions ϱ_B <2-3 ϱ_0



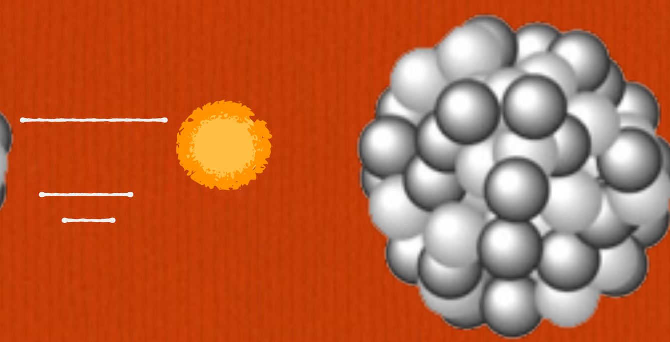
GSI, SIS18 and HADES

Fixed Target experiments, $E_{kin}\sim$ AGeV

proton-nucleus

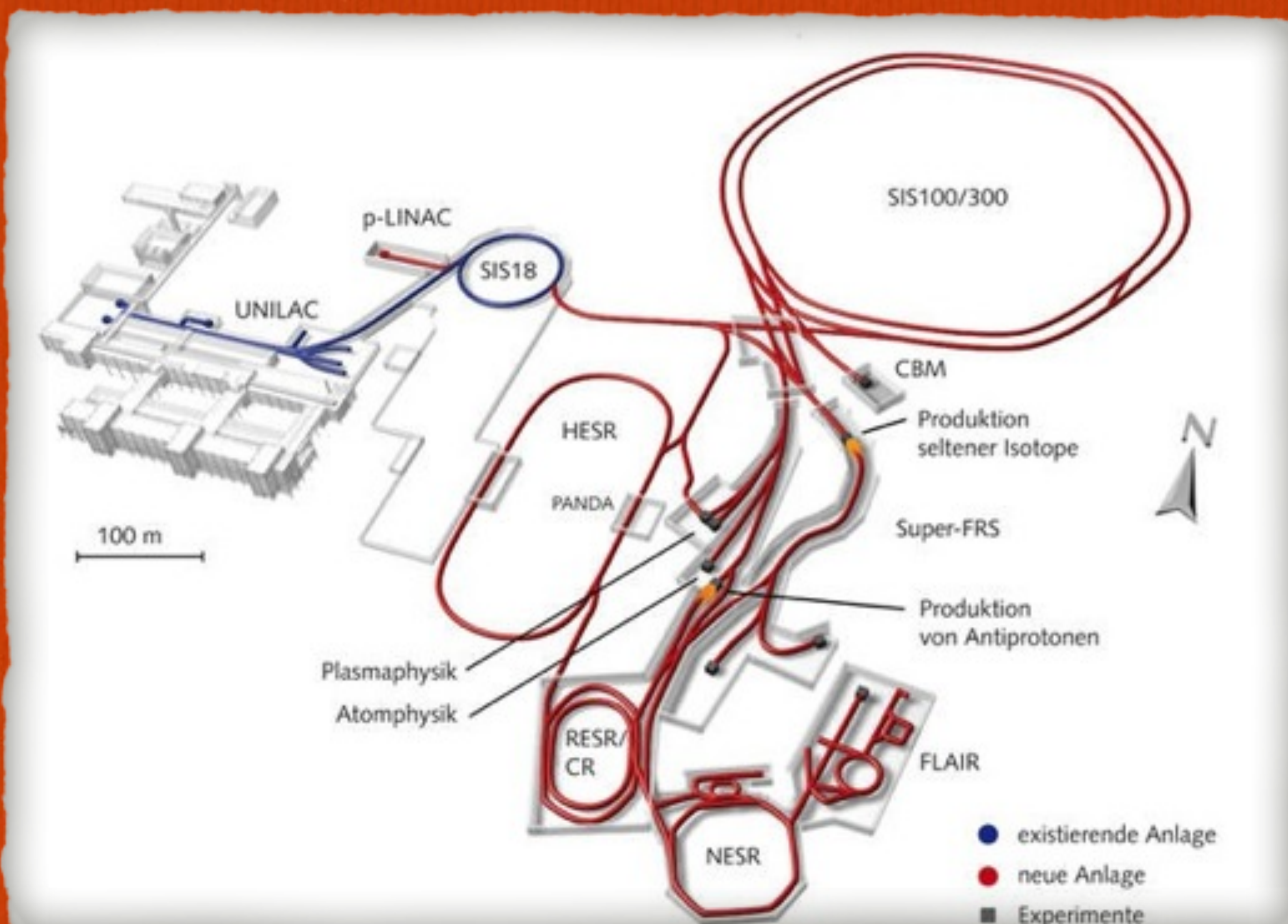


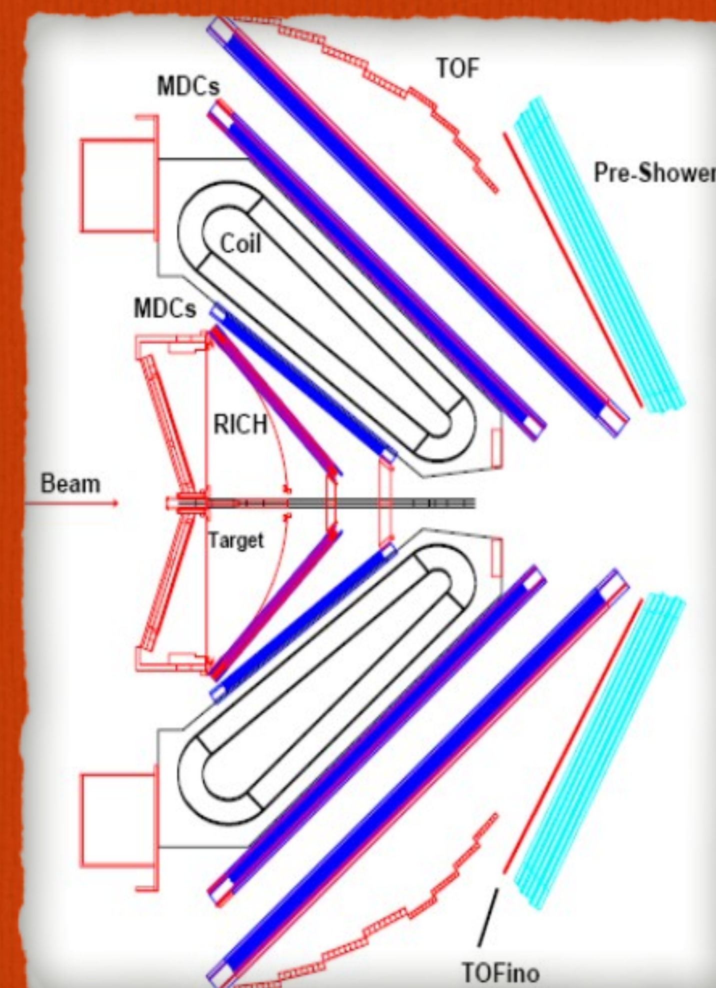
π-nucleus



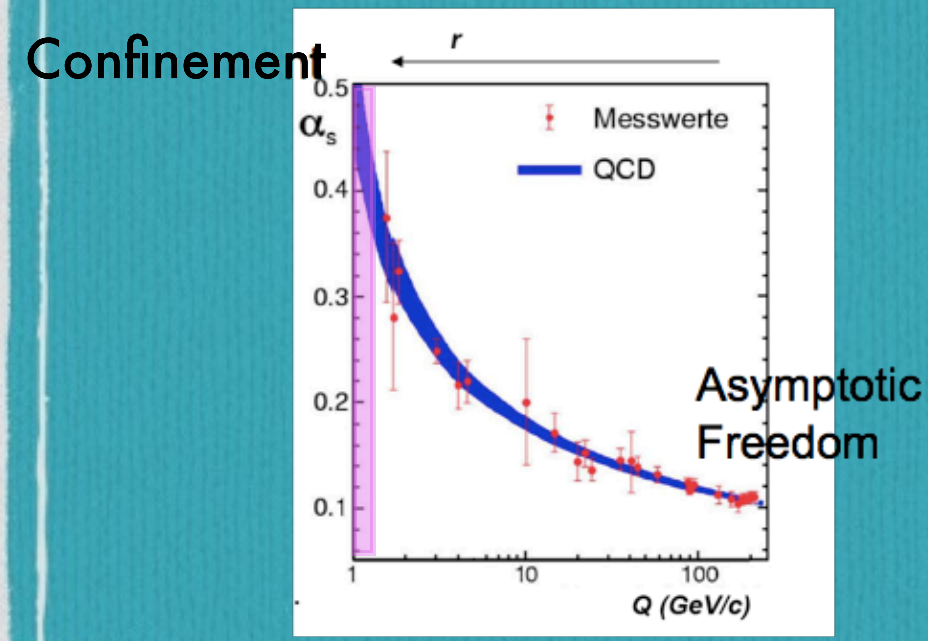
HADES
High Acceptance Di-Electron Spectrometer
Fixed Target Experiment
SIS18, Ekin=1-3 GeV/nucl
Full azimuthal coverage, 18°-85° in polar angle
$\delta p/p \sim 1\text{-}3\ \%$

Elementary Reactions $\varrho_B < \varrho_0$





Effective (Strange) Hadron-Hadron Interaction



Small Q (~1 GeV)

Large Distances (1 fm)

Effective Field Theory of interacting Bosons

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

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

- Testing ground: K-N and $\bar{K}$-N interactions
- In-medium behaviour of these interactions and implications for humanity

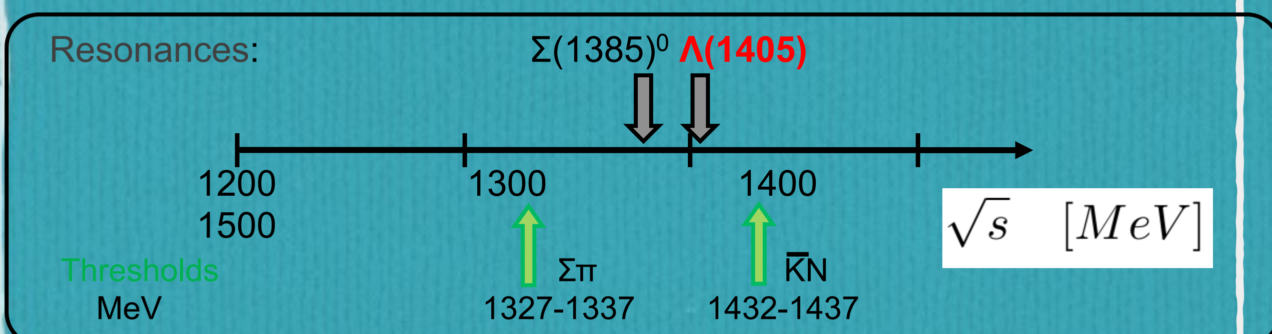
Effective Strange Hadron-Hadron Interaction

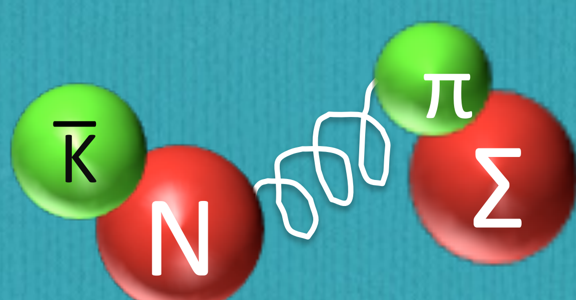
Antikaon

ChPT in SU(3) (exact Theory) does not work for the $\bar{K}N$ system
-> Coupled-Channel Ansatz based on Chiral Dynamics

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

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





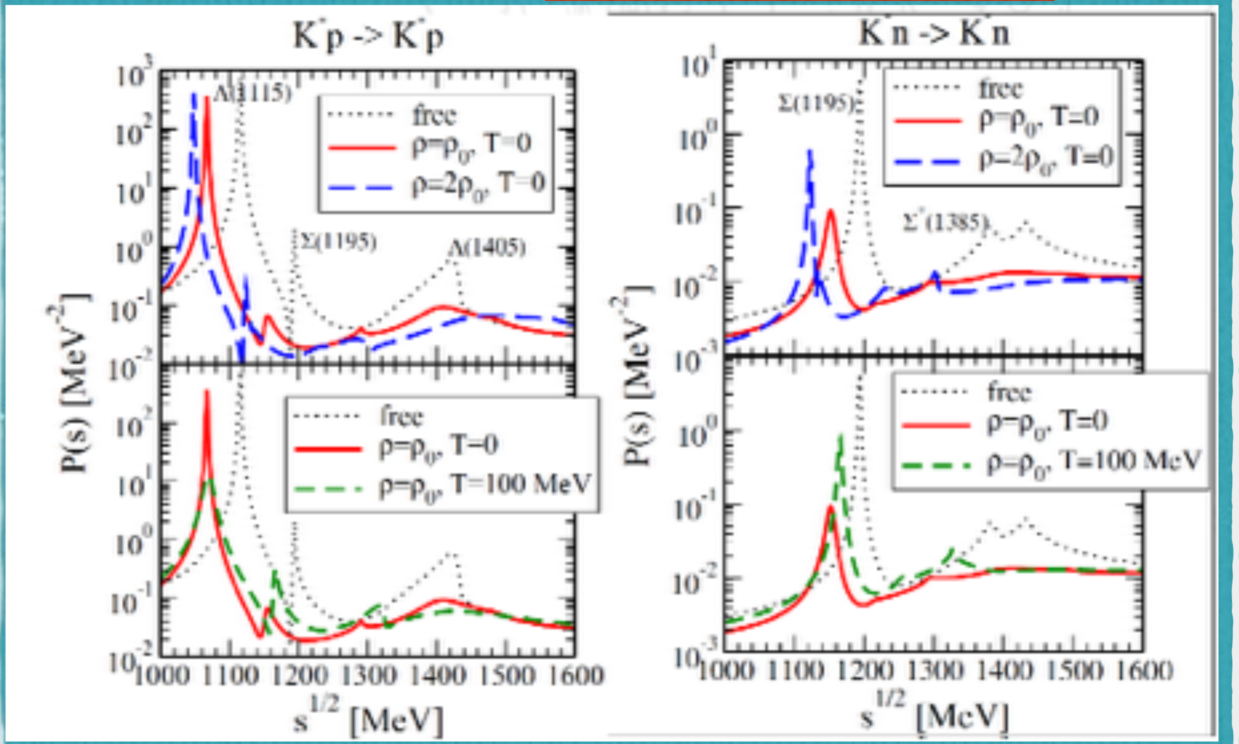
Kaon

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

Effective Strange Hadron-Hadron Interaction

Antikaon

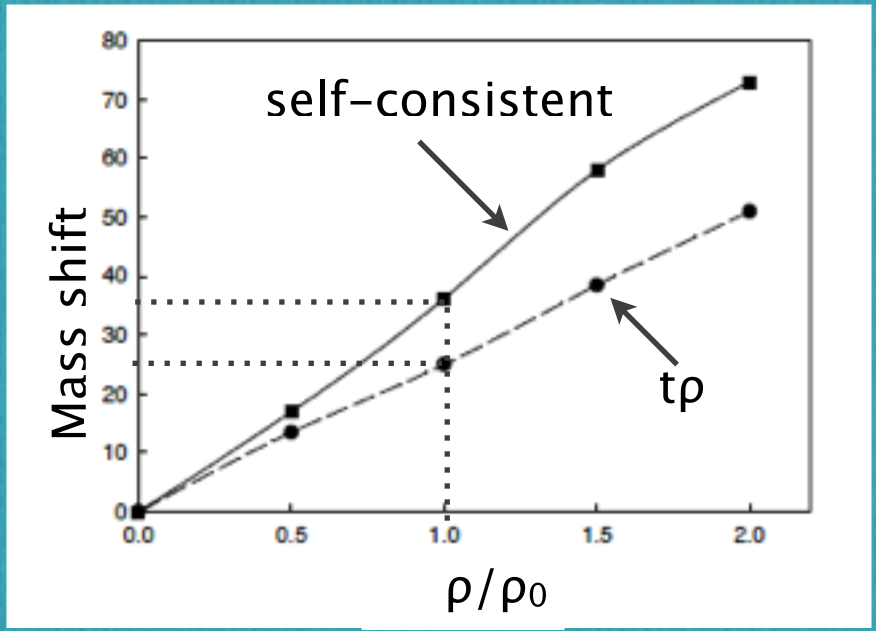
L. Tolos talk: 5a



D. Cabrera, L. Tolos et al., PRC90 (2014) 055207

- Attractive in-medium interaction, strong decrease of the effective mass, major broadening
- Complicated in-medium spectral function due to strong coupling to resonances

Kaon



C.L. Korpa, M.F.M. Lutz Acta Phys. Hung. A22 2005 21.

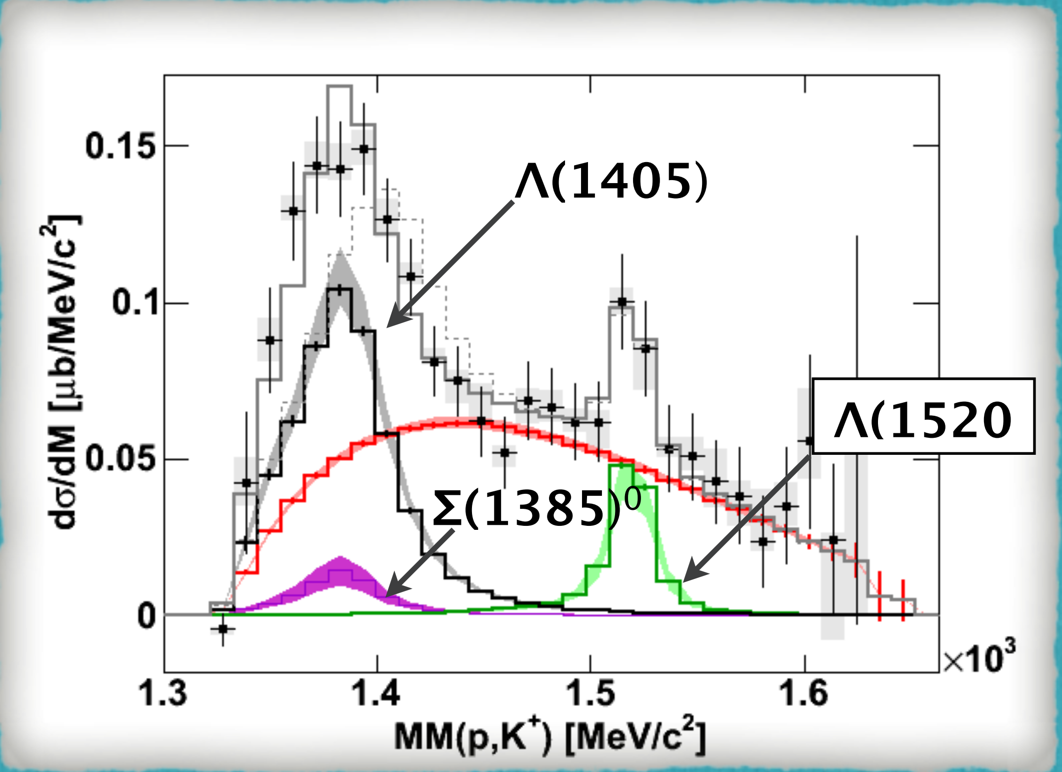
- Repulsive in-medium interaction, moderate increase of the effective mass

K⁻: Vacuum Properties

$\bar{K}N$

measured Λ(1405) in p+p collisions @ 3.5 GeV

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

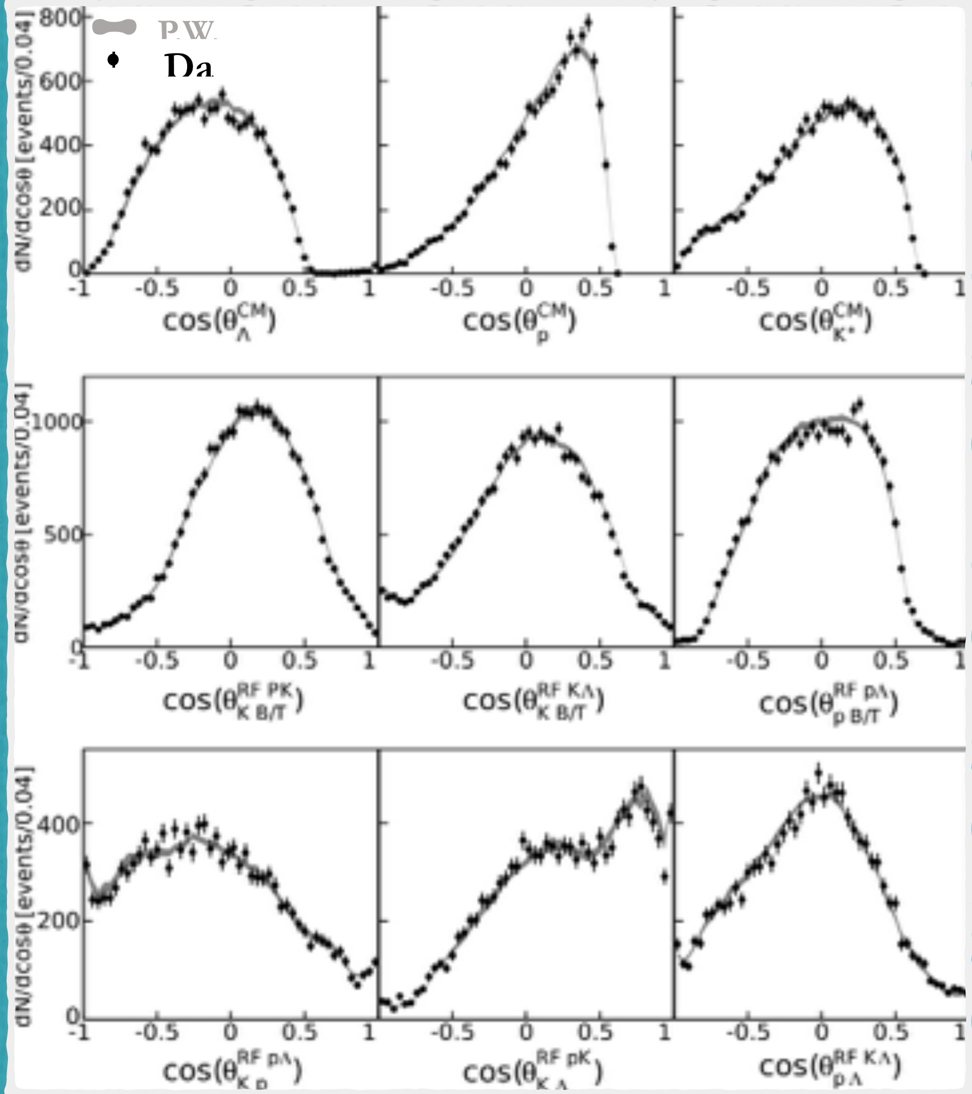


Shift in the Λ(1405) mass

$\bar{K}NN$

Upper limit determined for ppK- in the reaction $p + p(@3.5GeV) \rightarrow p + K^{+} + \Lambda$

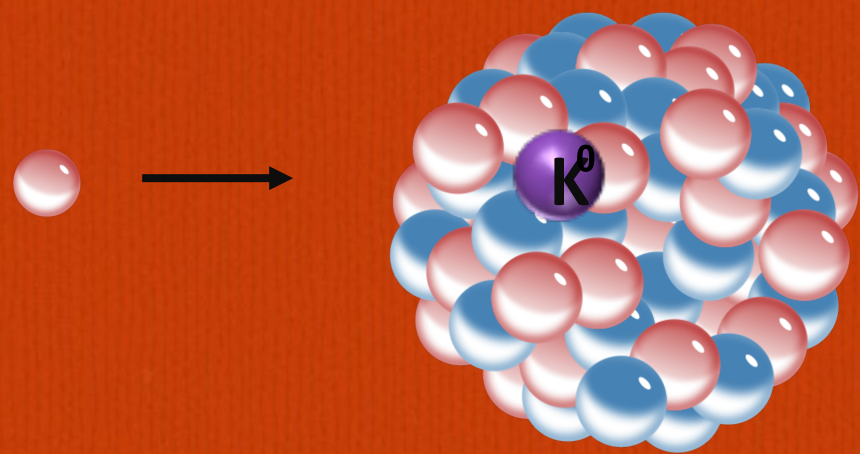
HADES Coll., Phys.Lett. B742 (2015) 242-248

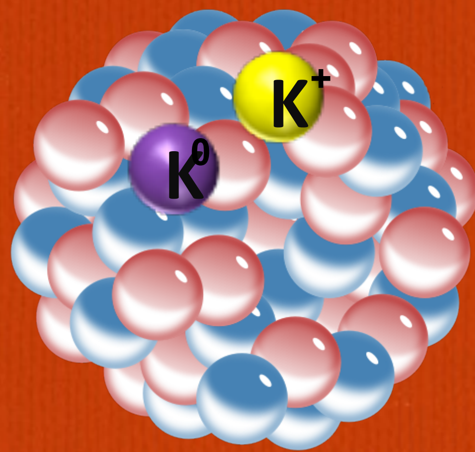


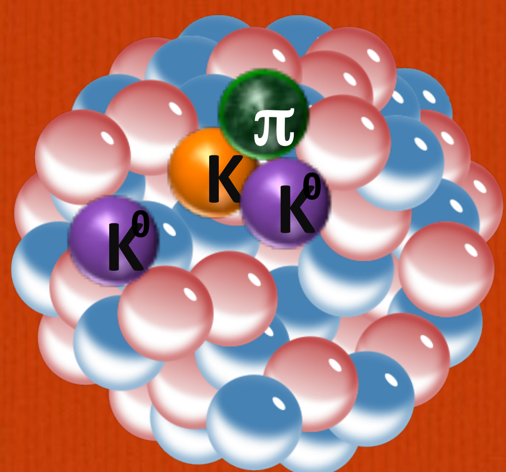
R. Muenzer talk: 3b

Kaons in cold nuclear matter

p+Nb, 3.5 GeV







Kaon interactions in nuclear medium:

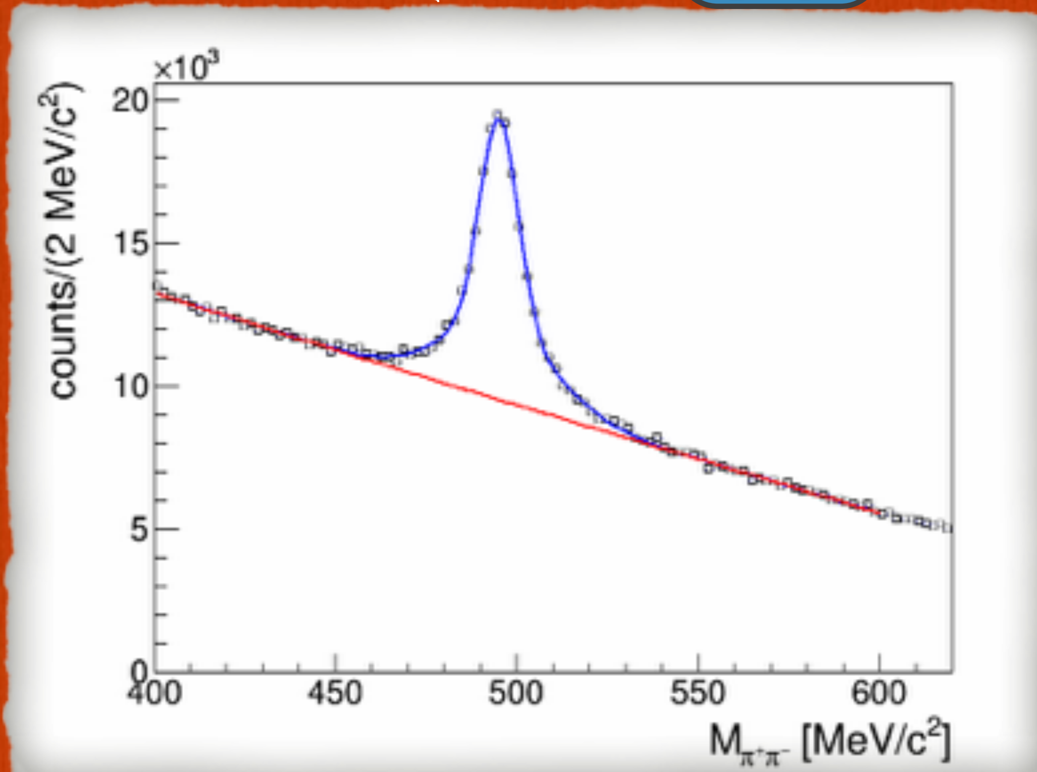
- Elastic scattering
- Charge Exchange
- Inelastic reactions
- π-induced secondary reactions…

K^0 Signal

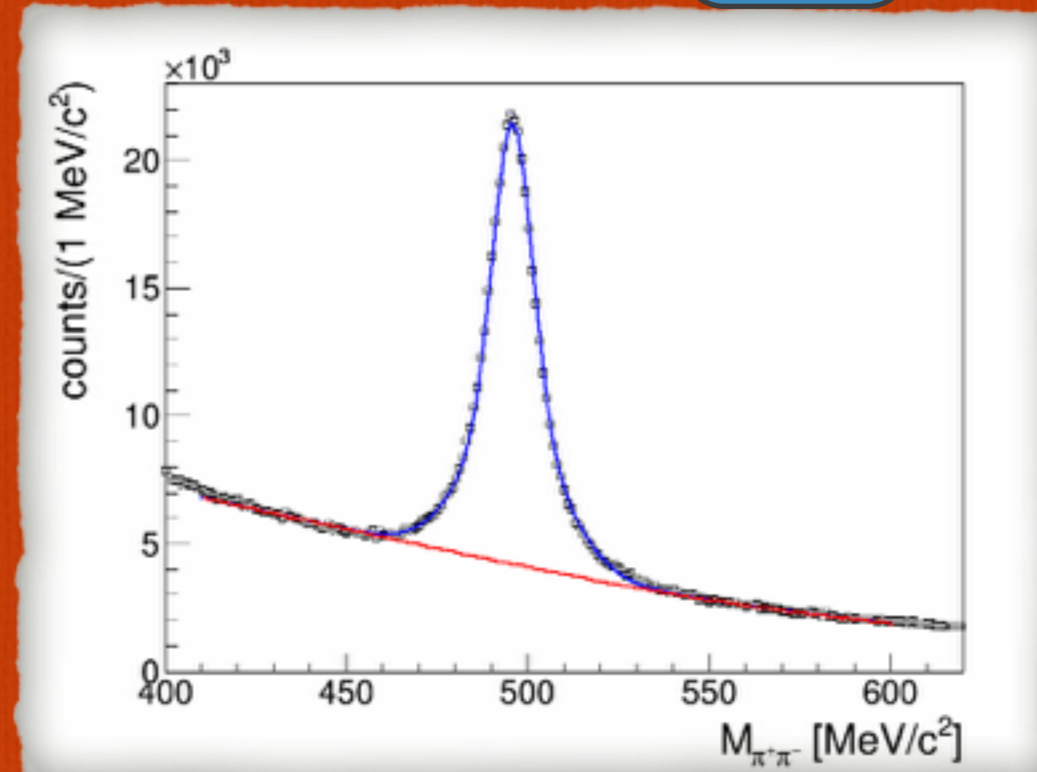
Neutral kaons measured by HADES in p+p and $p+^{93}Nb$ collisions at 3.5 GeV:

$K^0 \rightarrow \pi^+\pi^-$

vacuum $\varrho_B = 0$ p+p



in-medium $\varrho_B \leq \varrho_0$ p+Nb



Data are interpreted with the GiBUU transport model

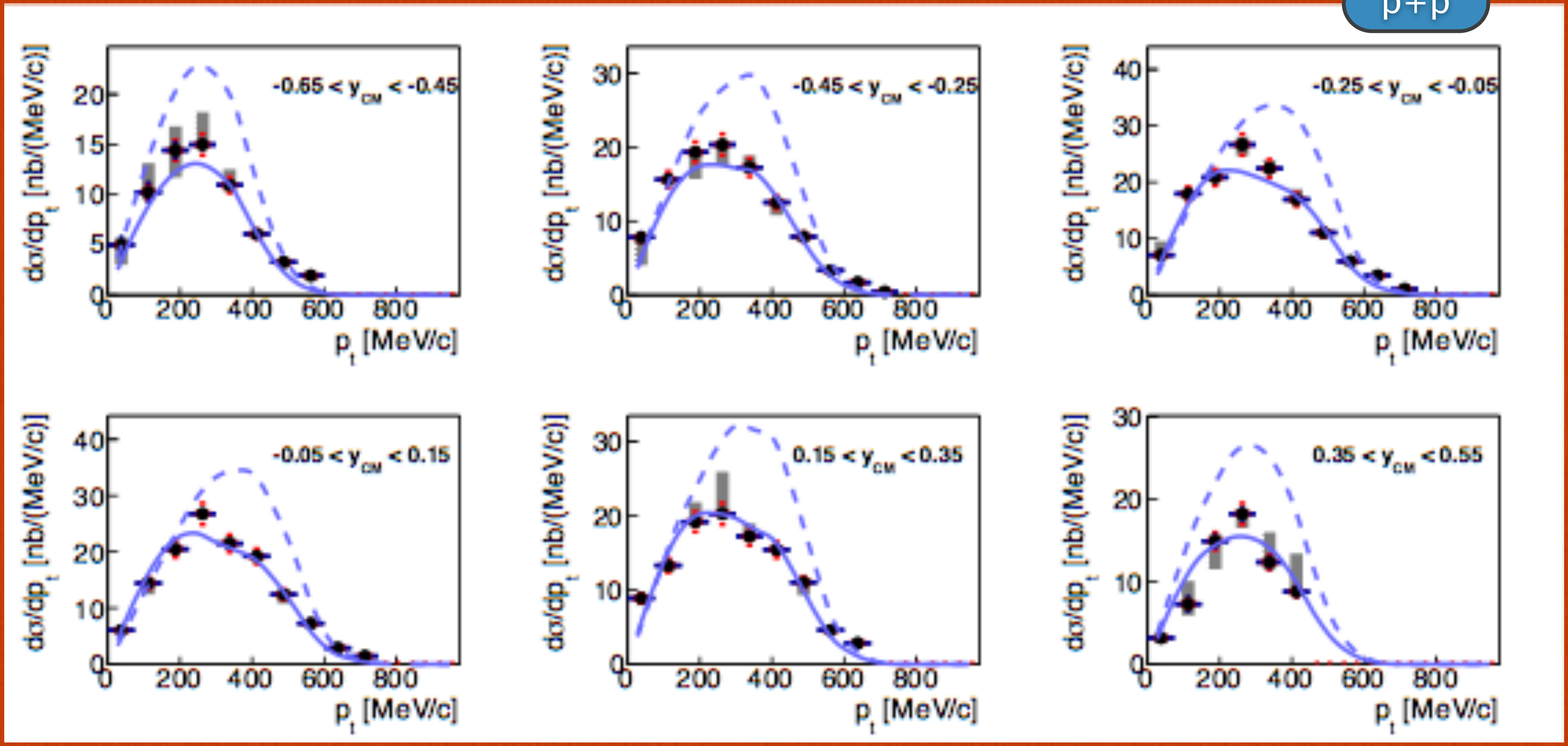
O. Buss et al., Phys. Rept. 512, 1 (2012)
http://gibuu.physik.uni-giessen.de/GiBUU/

K^0 in p+p: reference measurement

- - - - Tsushima
—— Tsushima improved

HADES Coll.], Phys. Rev. C 90, 015202 (2014)

p+p



- 4-body states produced via Δ-resonances
- Final states with two pions (5-body) added to the model via NN → Δ^{++} Y* K, Y* is Σ(1385) or Λ(1405).
- Good description of the elementary reference.

In-medium kaon potential

ChPT potential, ~35 MeV (ϱ=ϱ0, k=0) implemented in the GiBUU transport code for p/π+A

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

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

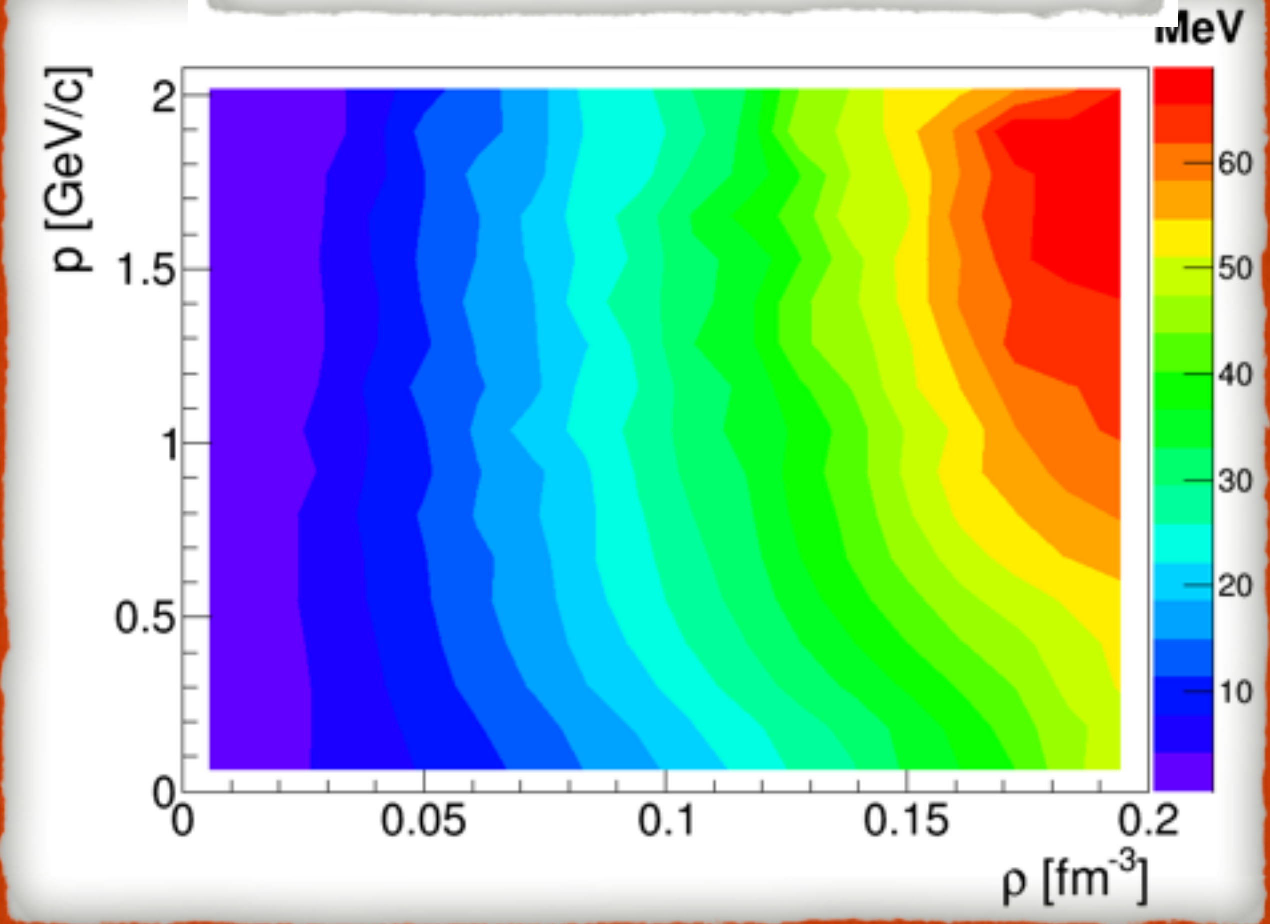
$$E^* = \sqrt{\mathbf{k}^{*2} + m_K^{*2}} + V_0$$

$$\mathbf{k}^* = \mathbf{k} - \mathbf{V}$$

$$\Sigma_{KN} = 250 - 450\,\mathrm{MeV}$$

$$f_\pi = 93\,\mathrm{MeV},\ f_\pi^{*2} = 0.6 f_\pi^2$$

$$U = E^* - E_{vac.} = E^* - \sqrt{p^2 + m^2}$$



For nuclear matter at rest $\langle V_{1,2,3} \rangle = 0 \Rightarrow k^* = k$

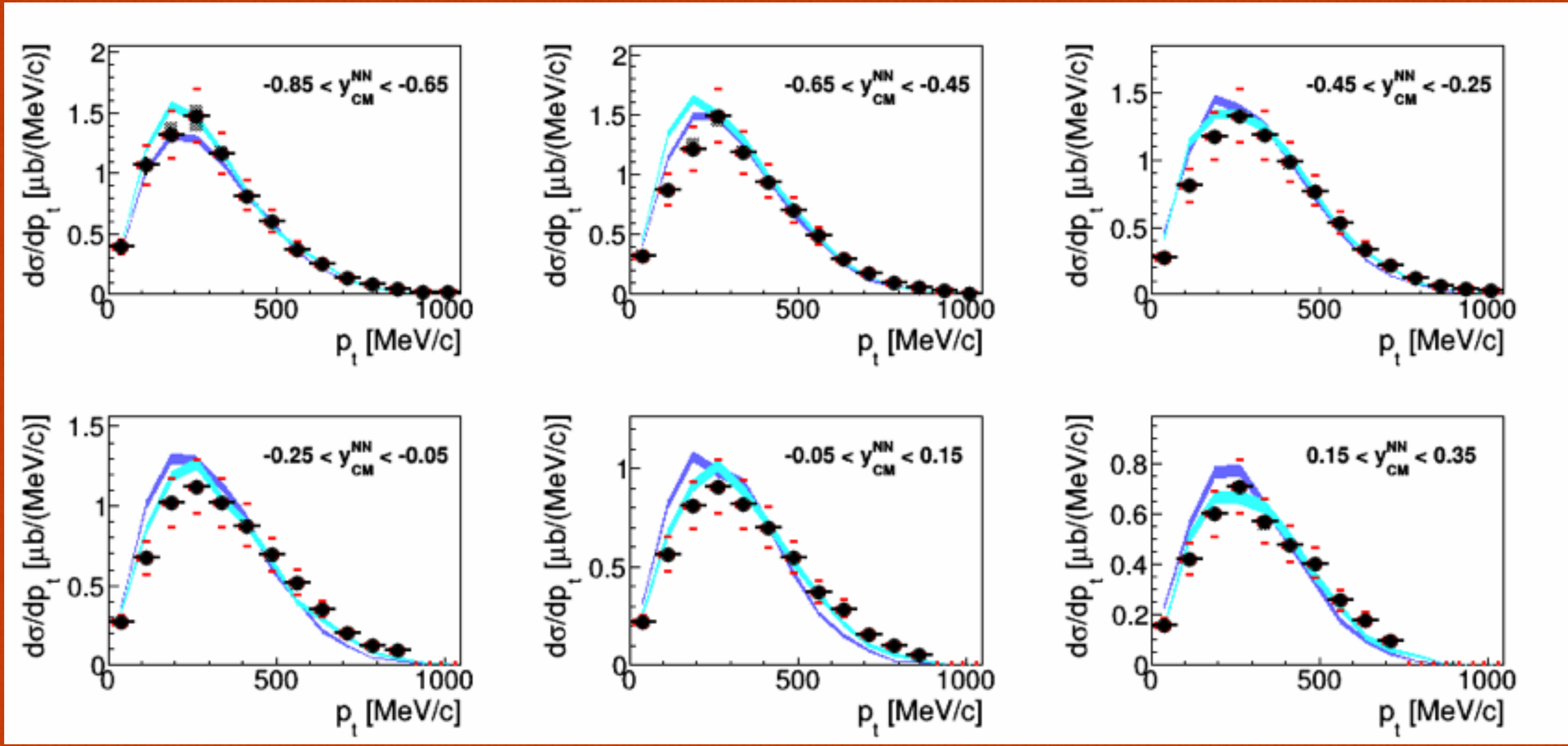
$$U = \sqrt{\mathbf{k}^{*2} + m^{*2}} + V_0 - \sqrt{\mathbf{k}^2 + m_{vac.}^2},\ m* < m$$

Effect of the potential in p+Nb: p_t-y

GiBUU w/o pot.
GiBUU w. pot.

“ Medium effects in proton-induced K^0 production at 3.5 GeV”
HADES Coll., Phys. Rev. C90 (2014) 054906

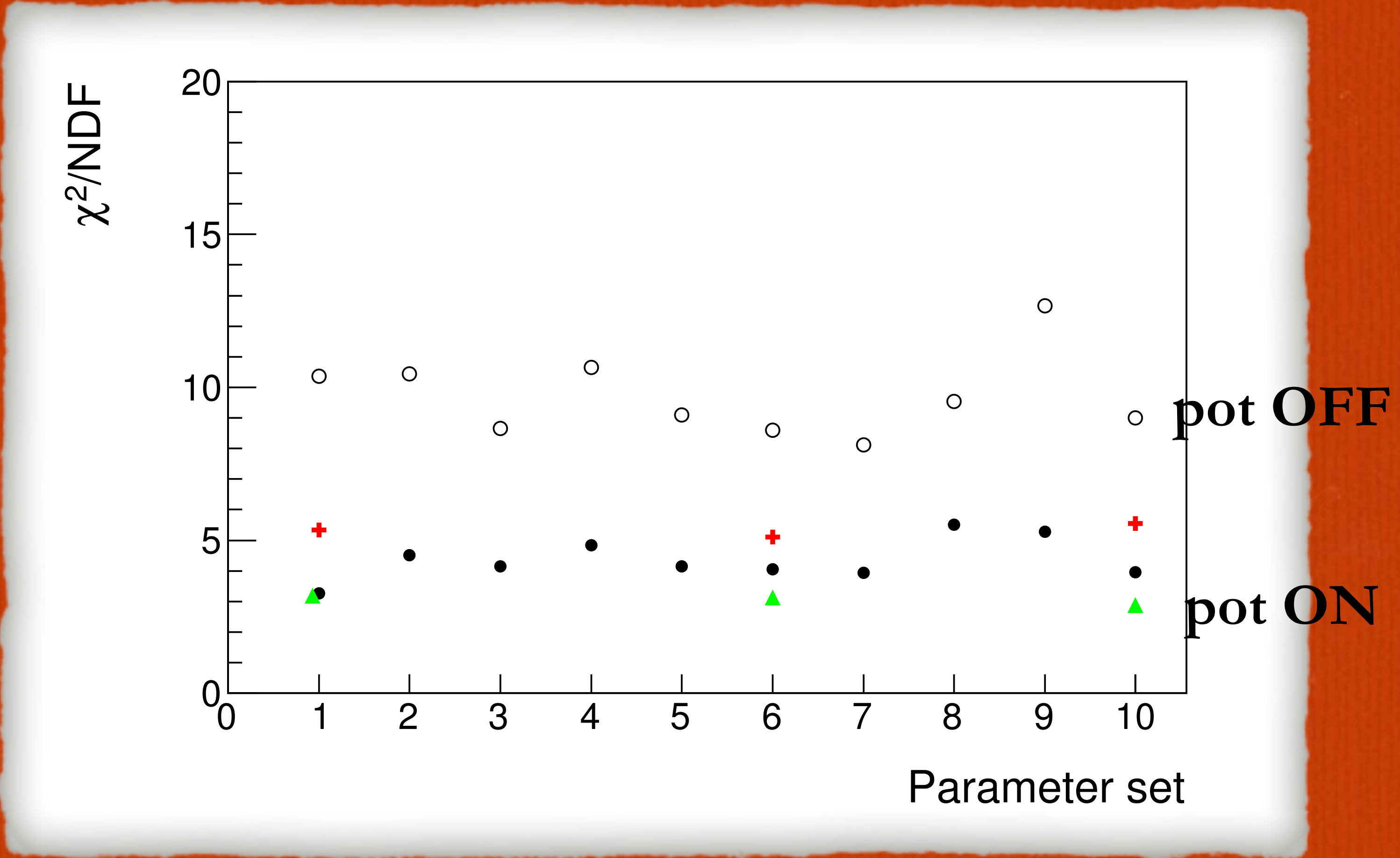
p+Nb



- Systematical modification of p_t-spectra owe to the repulsive potential.
- Uncertainties in the model parameters (np cross sections, …).

χ^2 Analysis

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



Set	Meaning
1	"standard"
2	ΔN +25%
3	ΔN −25%
4	πN +25%
5	πN −25%
6	np3 +25%
7	np3 −25%
8	KN +25%
9	KN −25%
10	np3 +30% & 5b −30%

χ^2 Analysis

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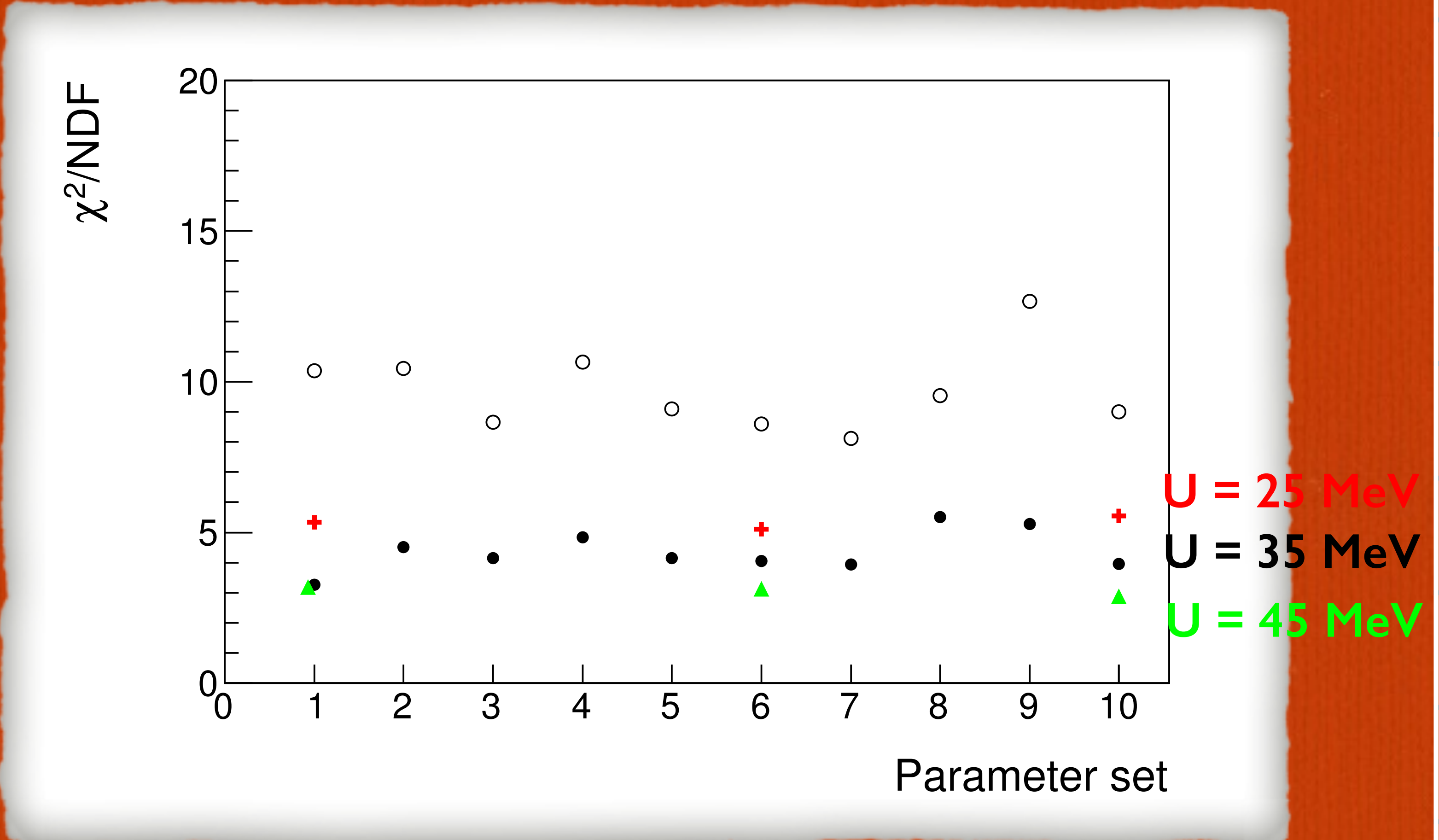

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8	KN +25%
9	KN −25%
10	np3 +30% & 5b −30%

Potential strength is adjusted by changing:

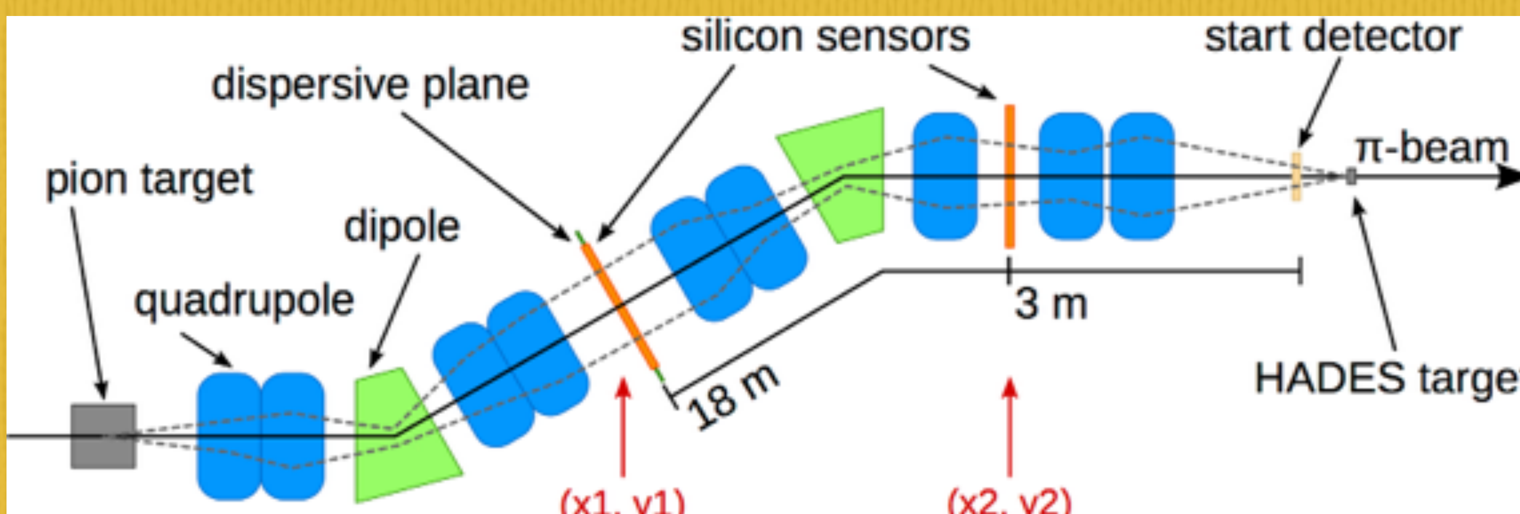
$$V_\mu = \frac{3}{8 f_\pi^*} j_\mu$$

$$U = \sqrt{\mathbf{k}^{*2} + m^{*2}} + V_0 - \sqrt{\mathbf{k}^2 + m_{vac.}^2}, \quad m* < m$$

π-induced Reactions

High Statistics pion beams (10^6 part/sec)
Measured for the first time at GSI in **2014** with HADES
Primary Beam: N 10^{12} part/s on Be Target
Momentum Spread: 8%
Beam envelope ∅: 6 cm

Pion-Tracker



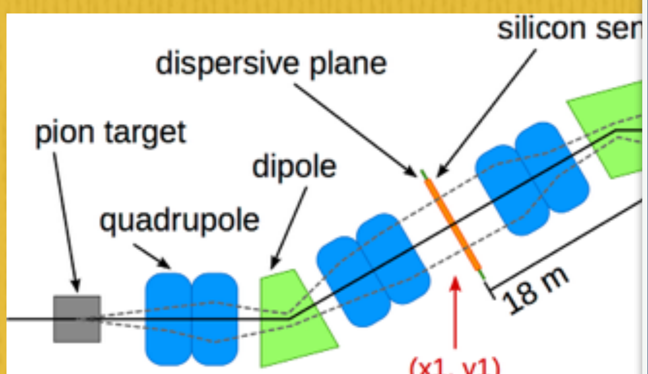
Cerberos

Double sided Silicon Device ($10x10\ cm^2$)
with self triggering read out based on n-XYTER ⟹ 32 MHz
Mono-Crystallin Diamond as Start Detector $\Delta\tau$<50 ps

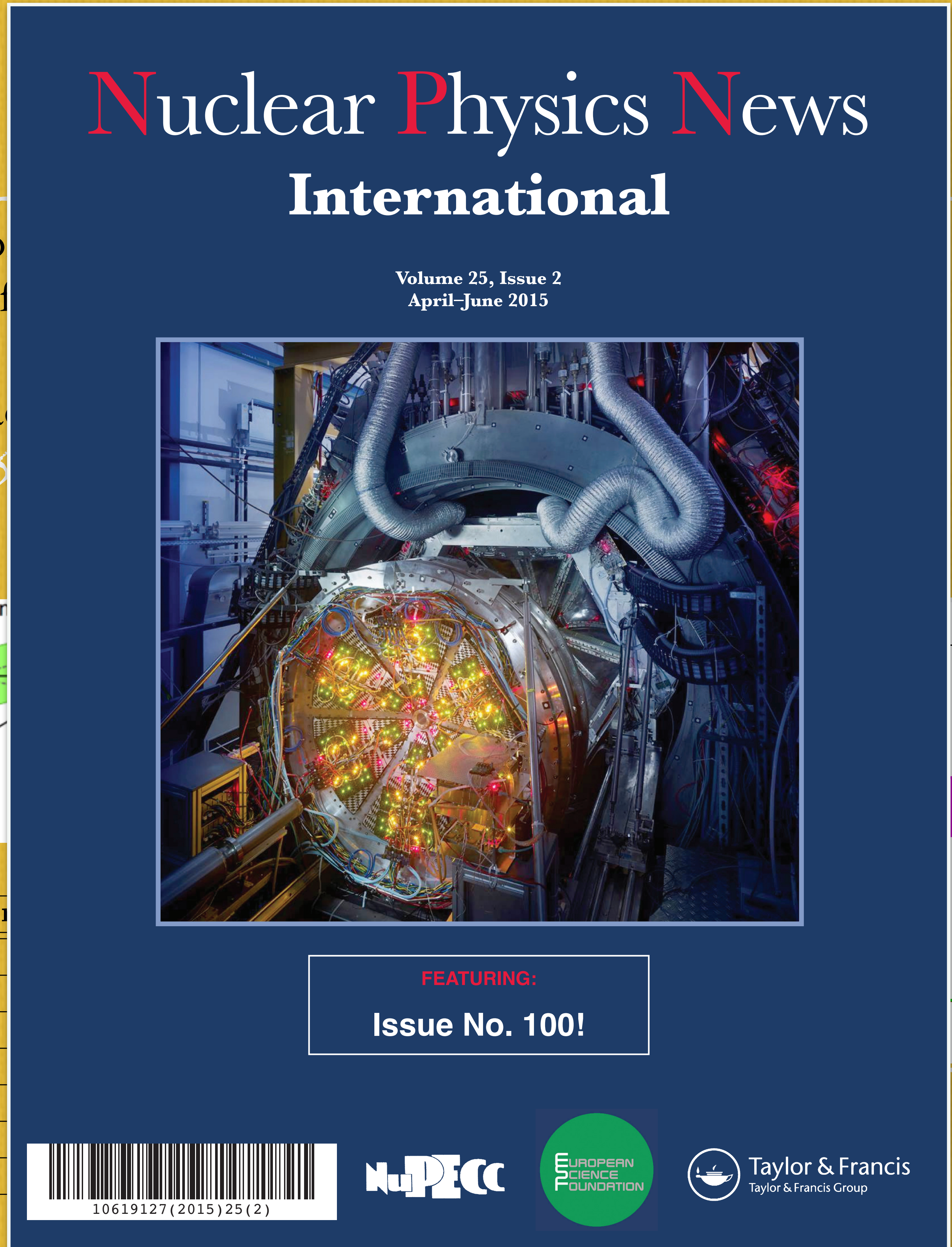
Very precise (0.1%) reconstruction of the beam momentum

High Statistics pio
Measured for the f
Primary Beam: N
Momentum Sprea
Beam envelope ∅

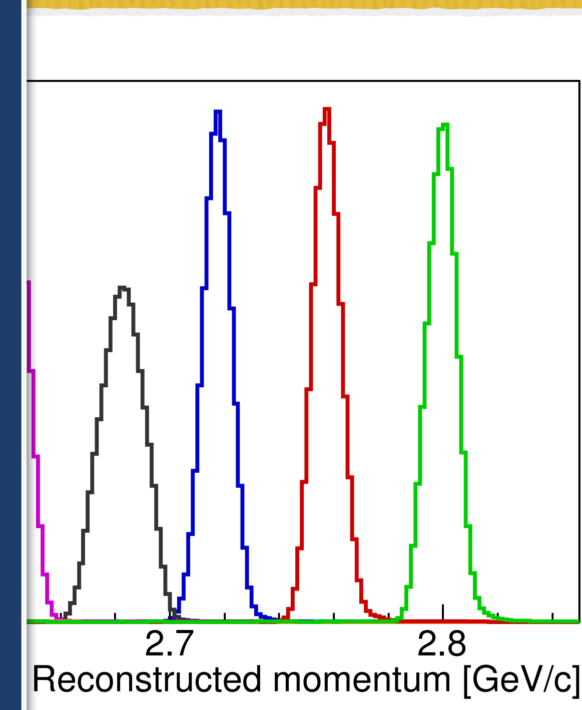
Pion-Tracker



RefMom [GeV/c]	RecMo
2.56	2.58
2.60	2.61
2.64	2.64
2.68	2.68
2.72	2.72
2.76	2.76
2.80	2.80



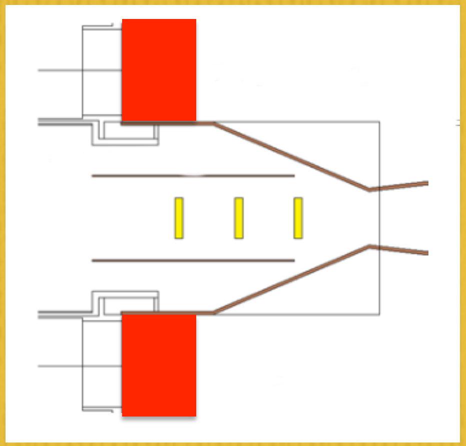
solution



Kaon Production in π-induced Experiments

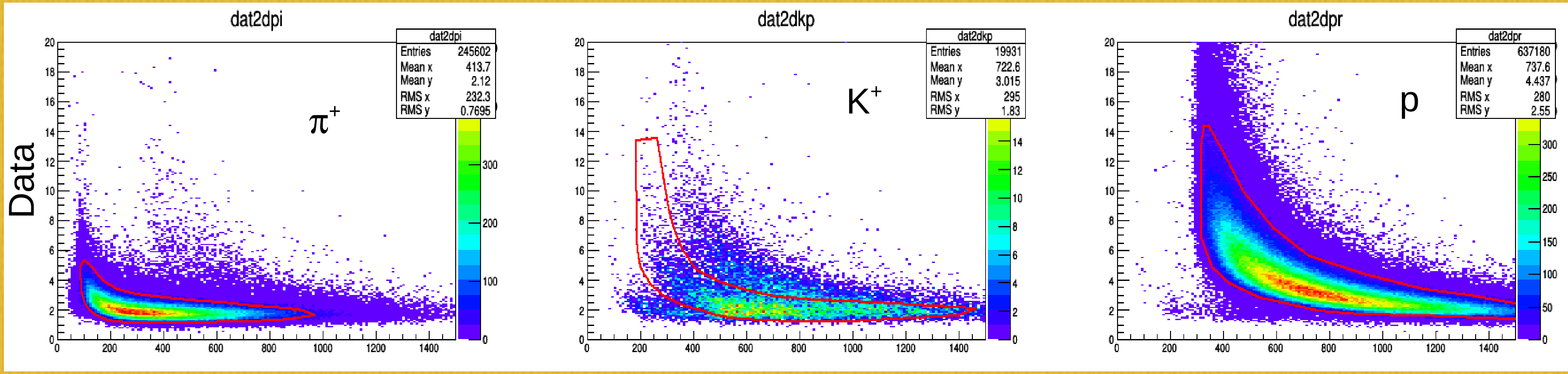
$\pi^- + C,\ \pi^- + ^{184}_{74}W$ **@ 1.7 GeV/c**
M2 Trigger: Mult $_{\mathrm{RPC+TOF}}$>1

W(C): 3 targets, ∅12 mm,
2.4(7.2) mm thick



Kaon Identification via dE/dx in the MDC

dE/dx with mass cut



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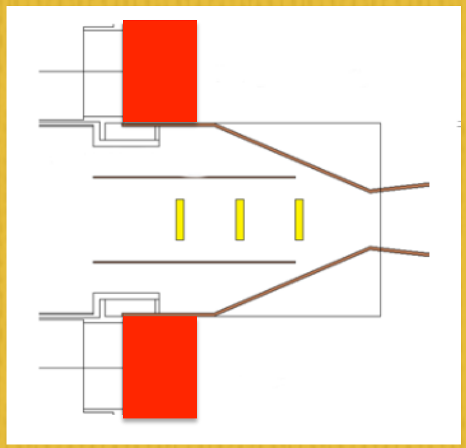
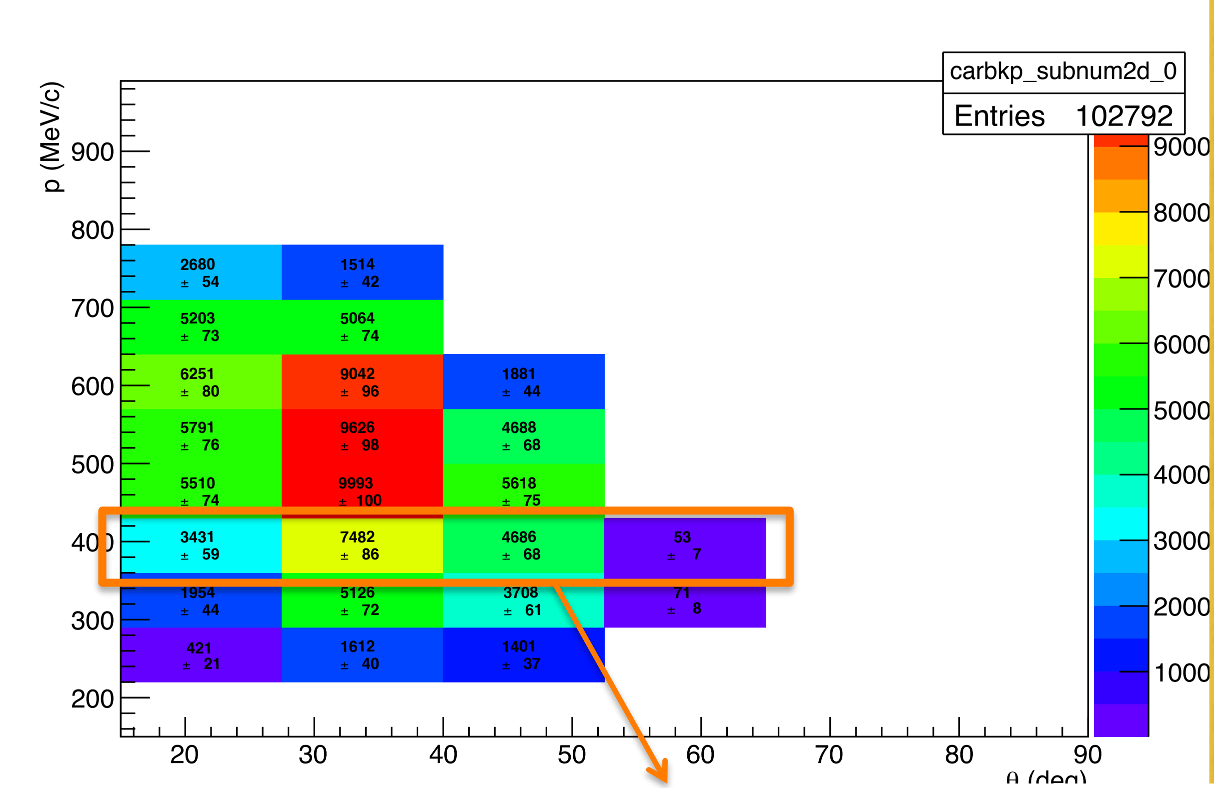
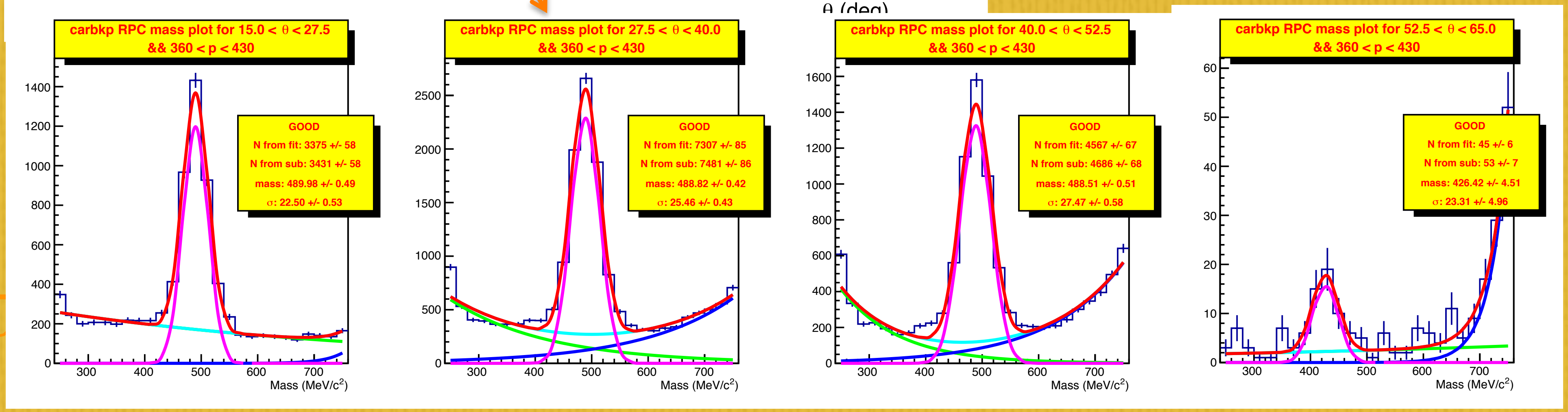


K$^+$ mass fits, typical resolution in mass 20-30 MeV/c^2



RPC Acceptance



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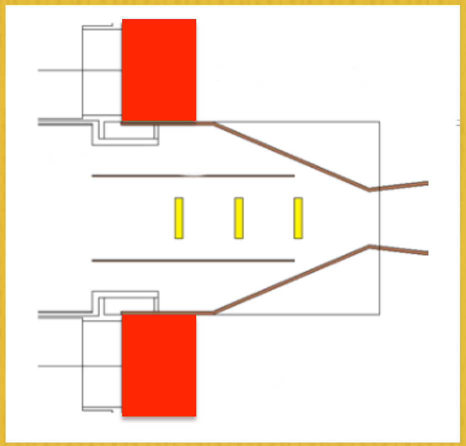

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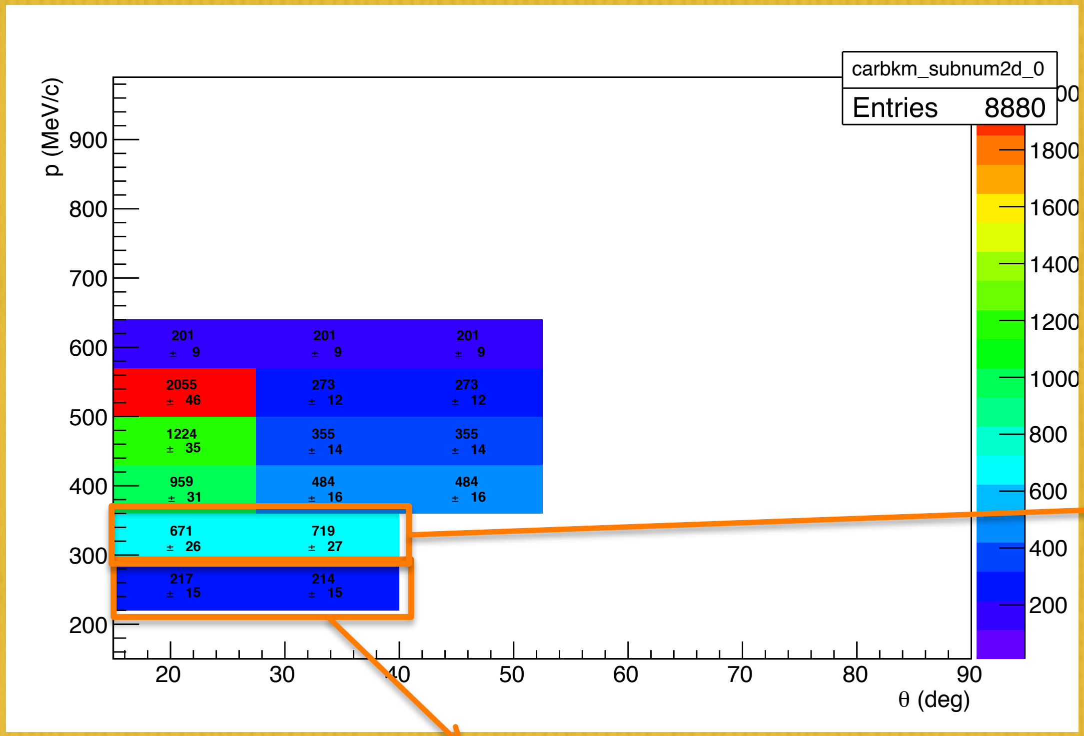

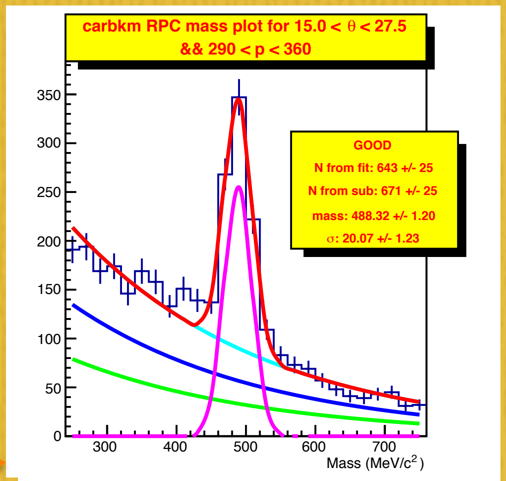

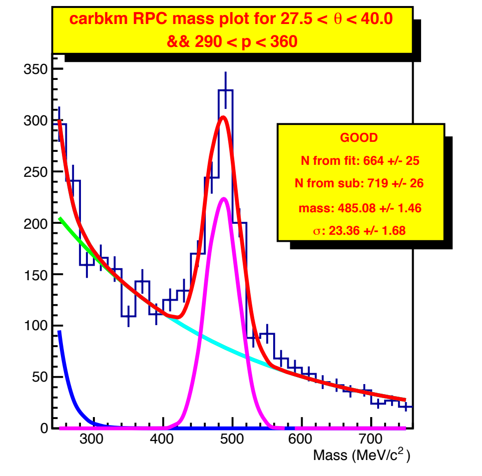

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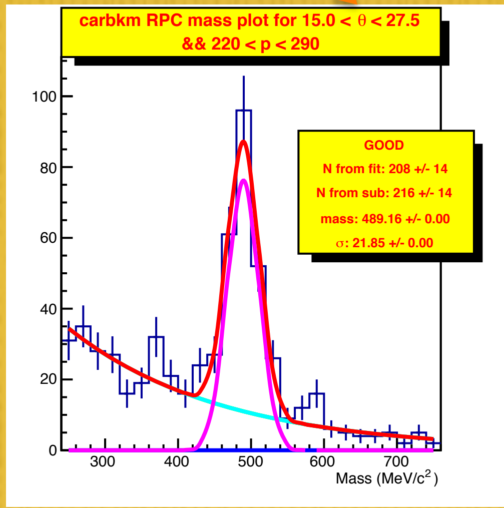
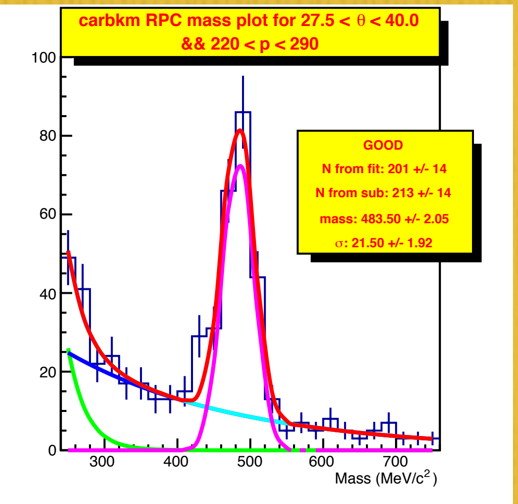




K^- Disappearance

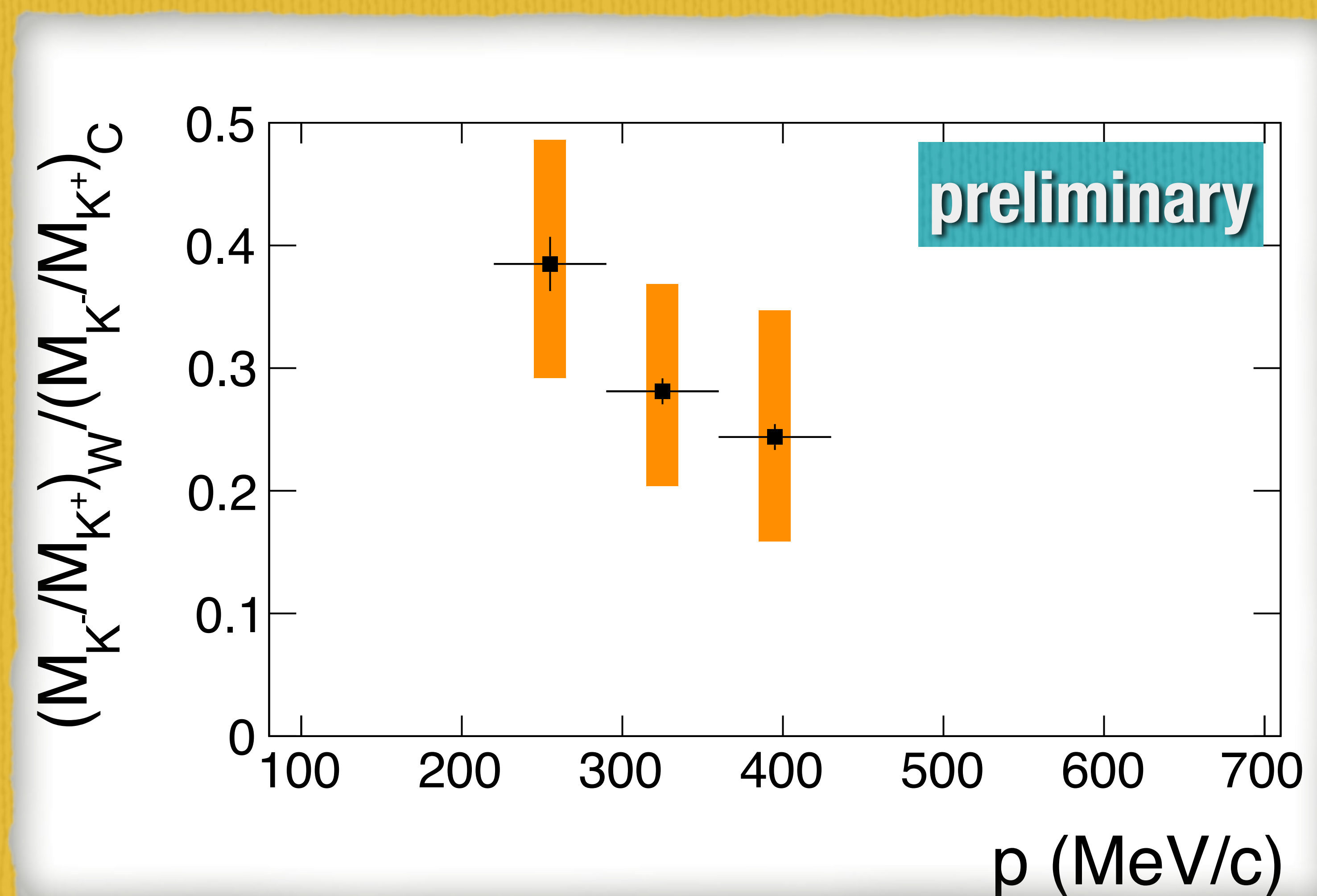
- π-absorption mostly on the nucleus surface
- less model dependent

Disappearance of K^- wrt to K^+ when comparing π+C and π+W

Average measured in the two TOF and RPC detector systems

Remarks:

- Multi-nucleon absorption negligible
- K^-Nucleon Absorption: Dominant?
- Check In-medium calculation!!



O. Vasquez Doce: 3a

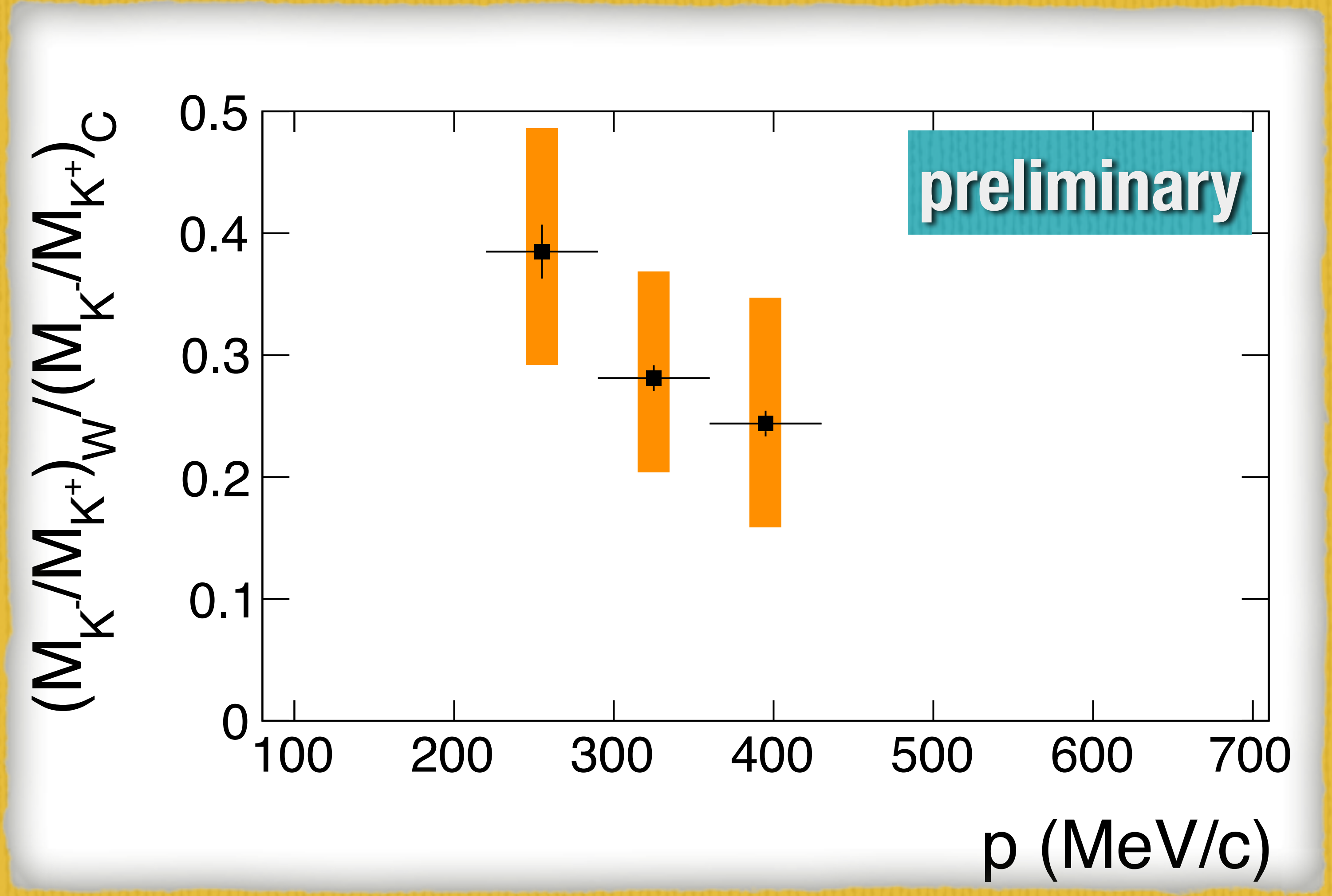
K^- Disappearance

- π-absorption mostly on the nucleus surface
- less model dependent

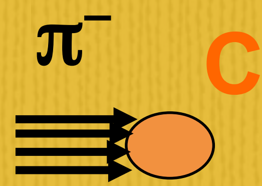
Disappearance of K^- wrt to K^+ when comparing π+C and π+W

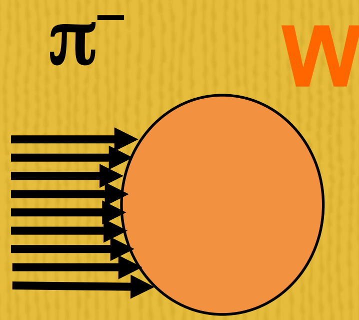
Average measured in the two TOF and RPC detector systems

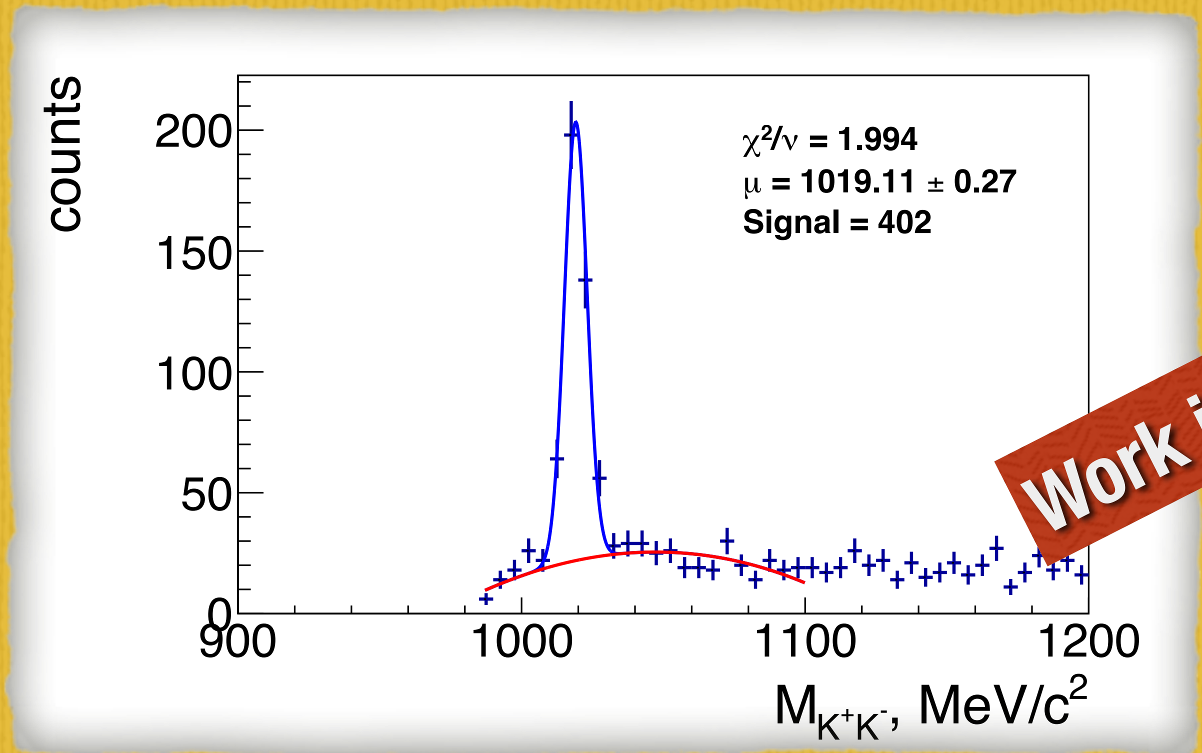
Remarks:
- K^+ shifted to larger momenta due to repulsive potential
- Ratio could be even smaller
- Extend the study to 600 MeV/c



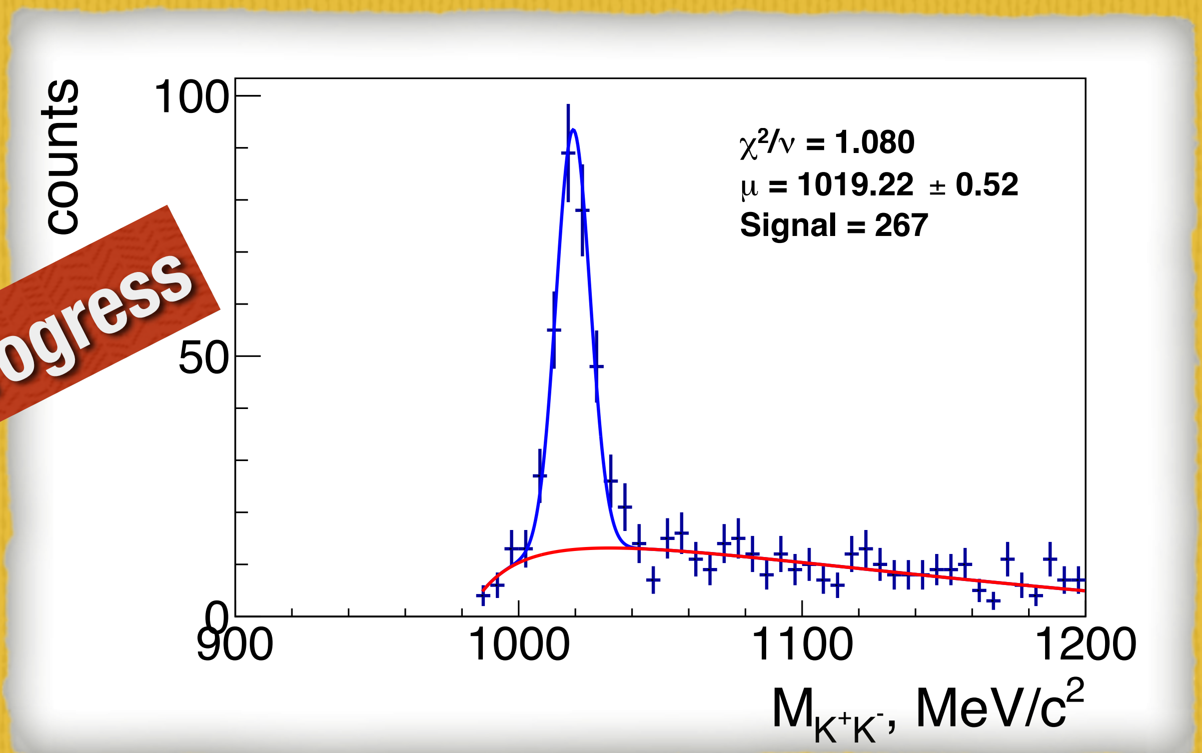
ϕ Spectra







Work in progress



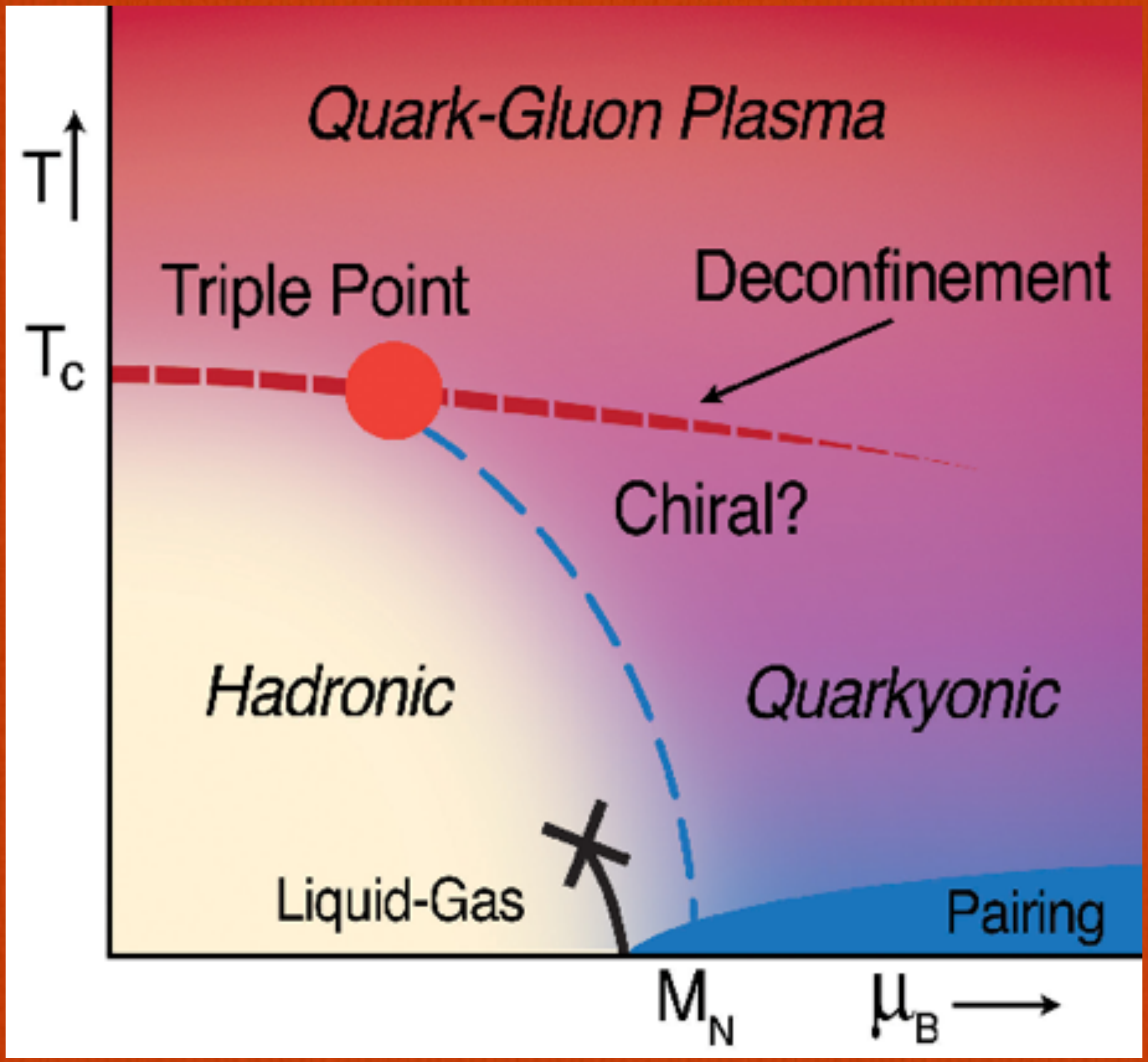
Acceptance and Efficiency corrections are needed for precise ratios
Also the K- disappearance must be taken into account properly
-> All transparency Ratio for ϕ are probably much too low!

Ξ^- Production within nuclear matter

Subthreshold production wrt N+N collisions

Andronic, A. et al. Nucl.Phys. A837 (2010) 65-86

- Why should it get easier to produce objects as (ssd)?
- Quarkyonic Matter formed?
- Look for Cascade production in A+A collisions at low kinetic energies (Ar+KCl @ 1.765 GeV)
- Check also the p+A reference

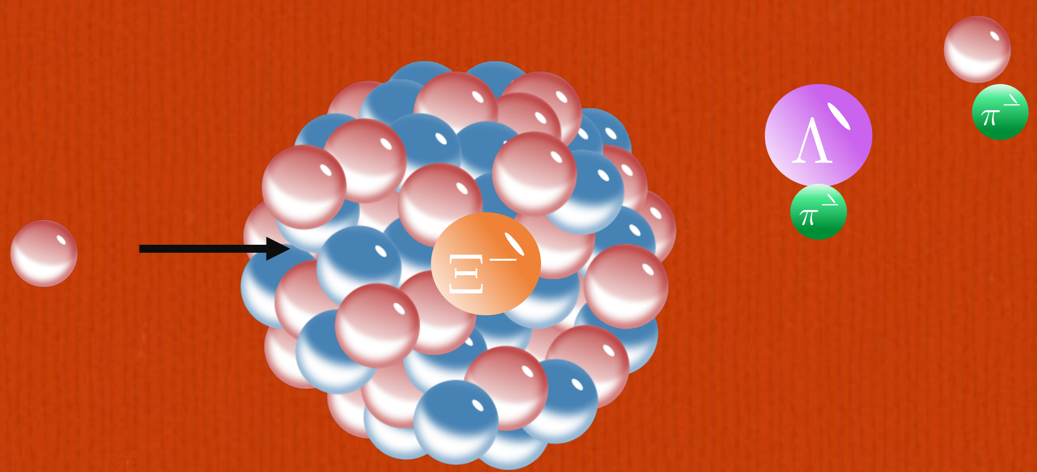


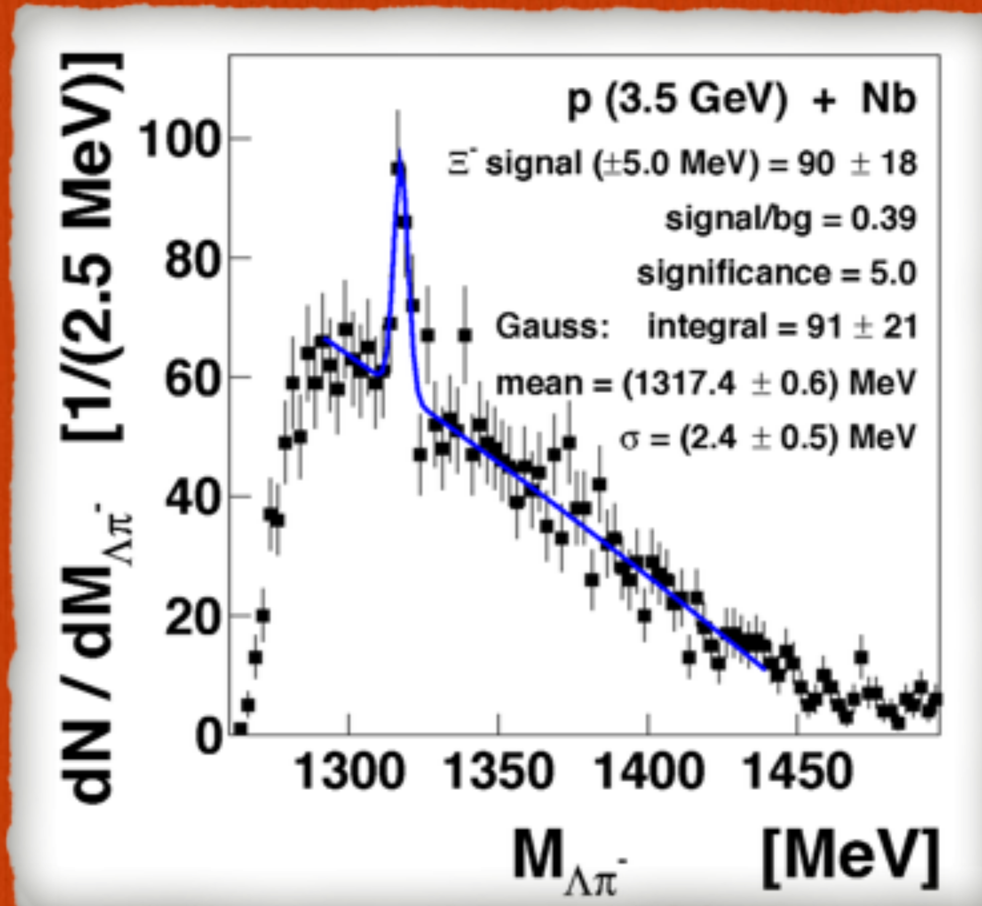
Ξ^- Production in p+A collisions

p+Nb @ 3.5 GeV

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

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





How to produce Ξ ?

$NN \rightarrow N\Xi KK$

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

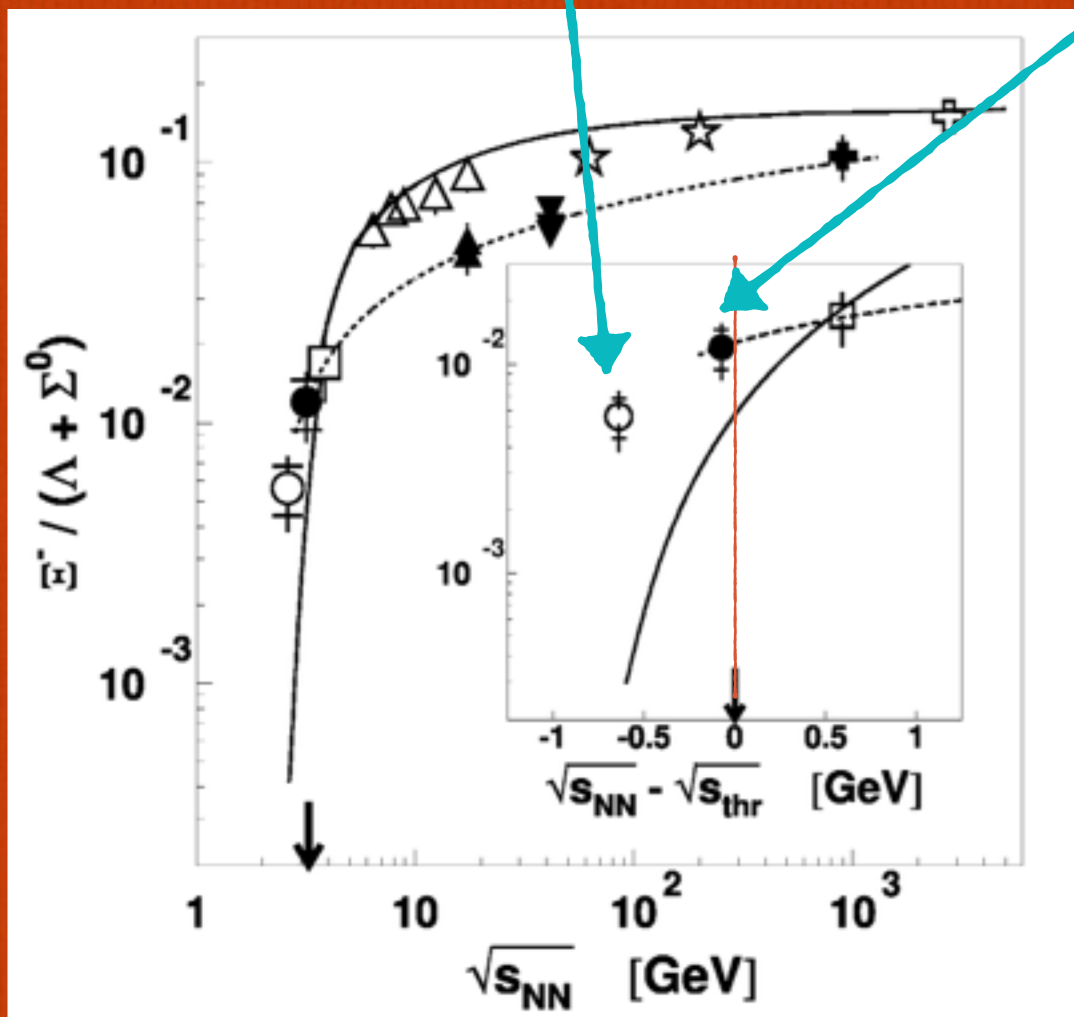
$\bar{K}Y \rightarrow \pi\Xi$ low cross-section

$YY \rightarrow \Xi N$ also below threshold, not enough to explain the measured Ξ/Λ yield

Ξ^- Excess

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

Phys.Rev.Lett. 103 (2009) 132301
Phys.Rev.Lett. 114 (2015) 21, 212301

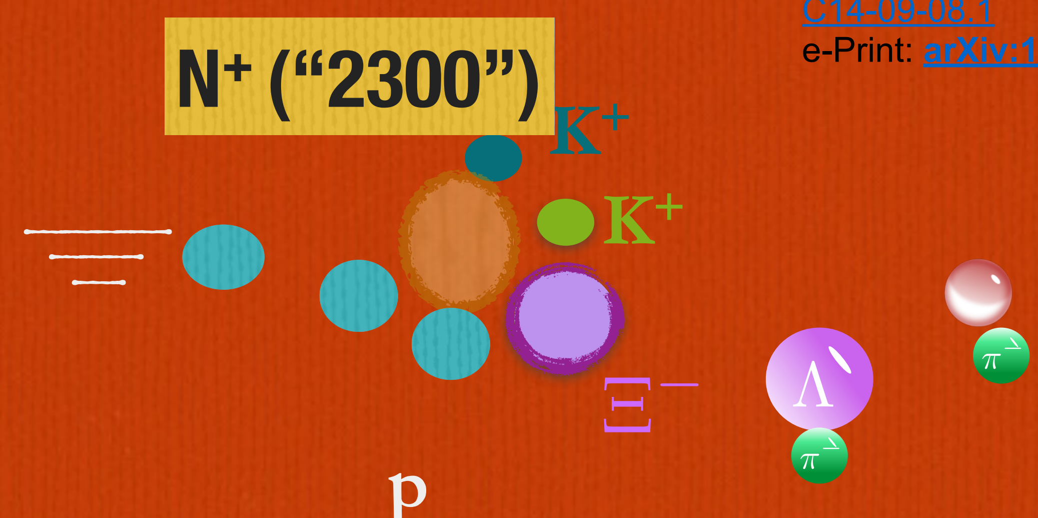


$$P_{\Xi^-} = (2.0 \pm 0.4(\text{stat}) \pm 0.3(\text{norm}) \pm 0.6(\text{syst})) \times 10^{-4}$$

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

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

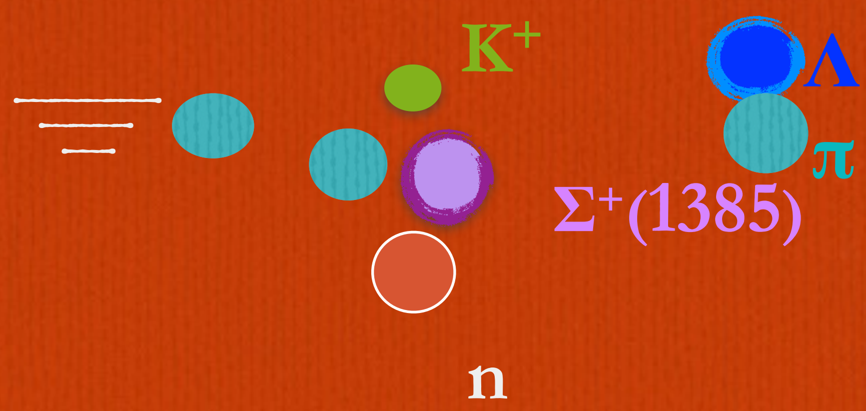
C14-09-08.1
e-Print: arXiv:1503.00616



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**

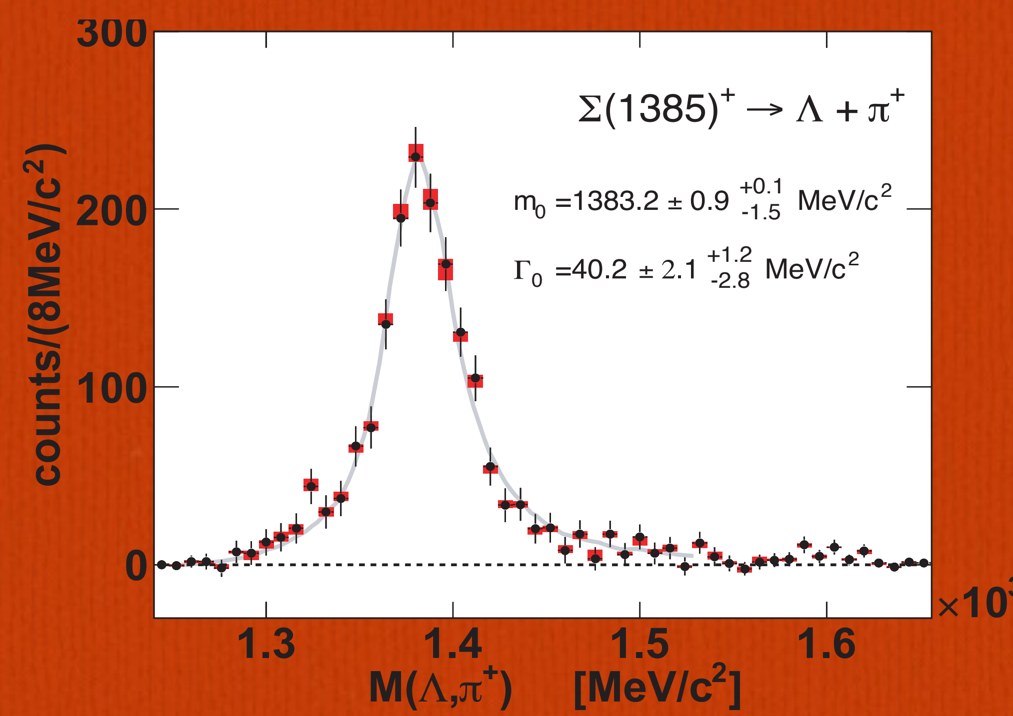
Resonances measured in elementary collisions

p+p @ 3.5 GeV

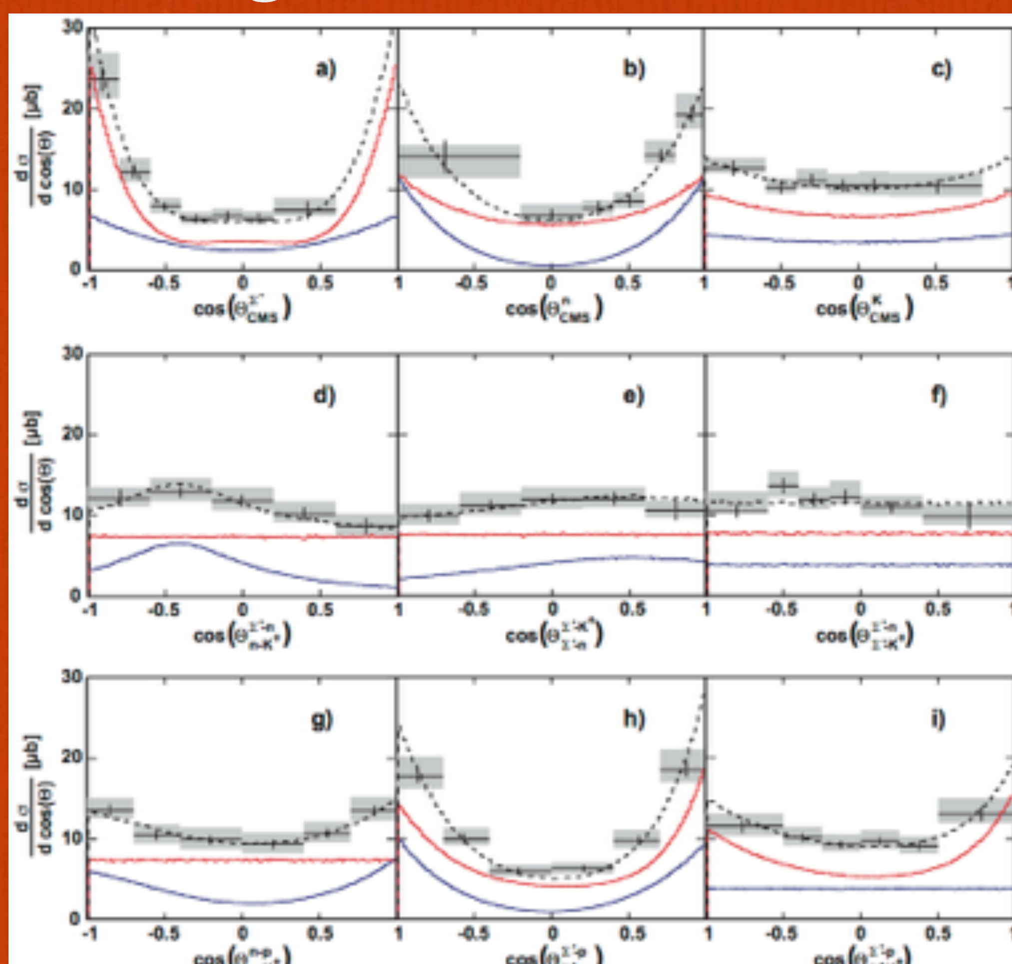


HADES Coll. Phys. Rev. C85 (2012) 035203
PDG Entry 2012

Resonance production
Coupling to different final states



Angular Distributions

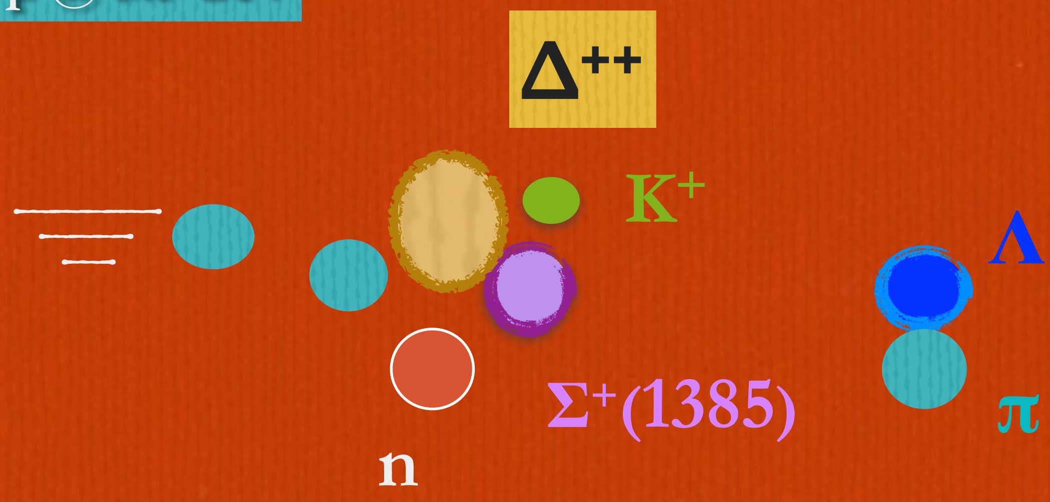


Non-isotropic angular distribution
-> has to be measured and modelled correctly to extract the total cross-section

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

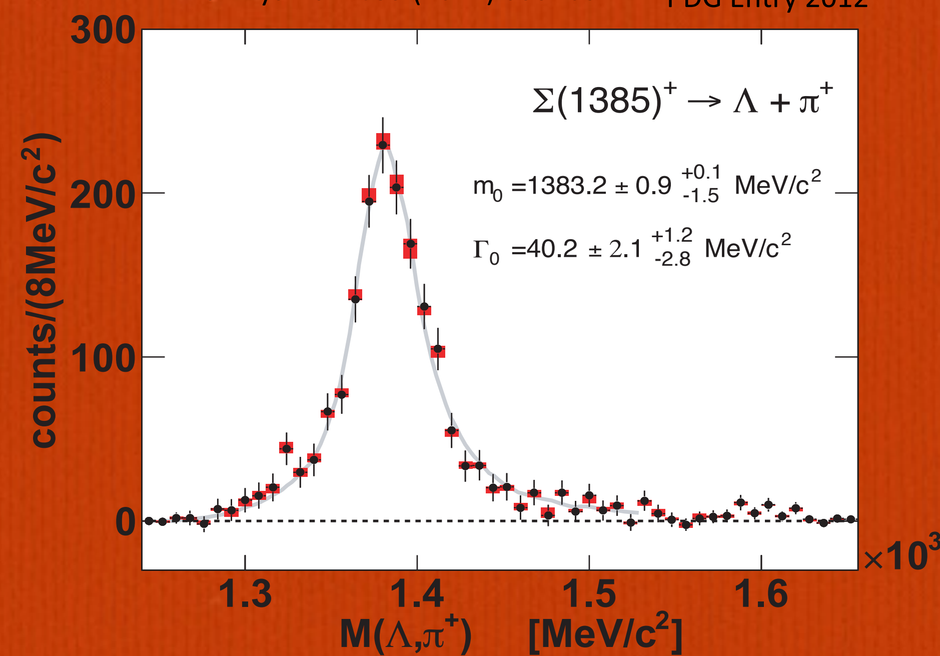
Resonances measured in elementary collisions

p+p @ 3.5 GeV



Resonance production
Coupling to different final states

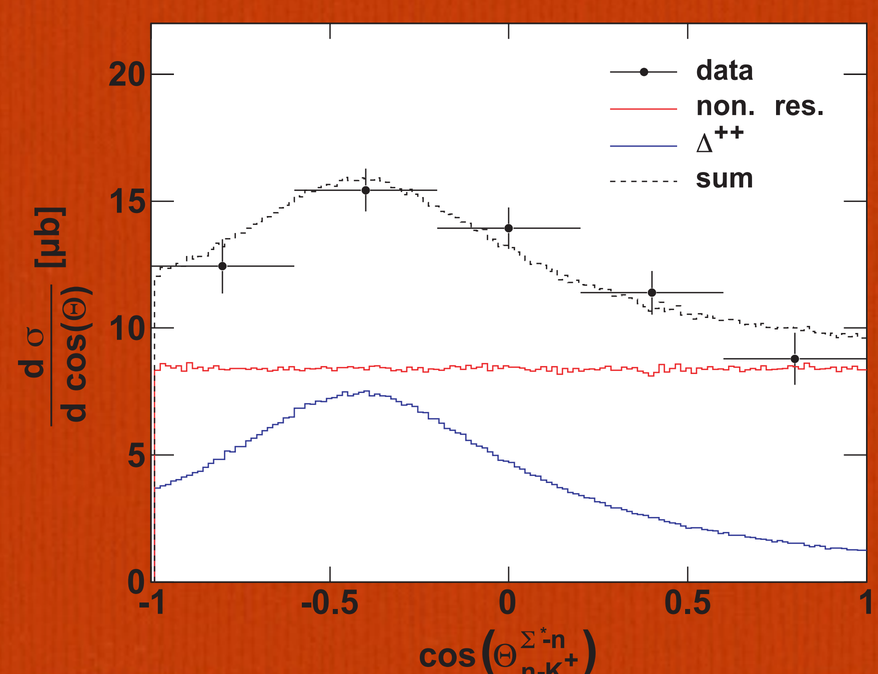
HADES Phys.Rev. C85 (2012) 035203   PDG Entry 2012



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

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

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



~ 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

Summary

* Kaon in matter: hints of a moderate repulsive potential in p +Nb@3.5GeV (40 MeV at $\varrho = \varrho_0$ and p = 0)
* Model dependent interpretation based on transport codes

* First measurement of Antikaon disappearance in π^- + nucleus reactions

* Ξ^- Measurement in Ar+KCl@1.756 AGeV and p+Nb@3.5GeV below threshold and unexpected large yields are observed.
* New experiments are needed to pin down the creation mechanism