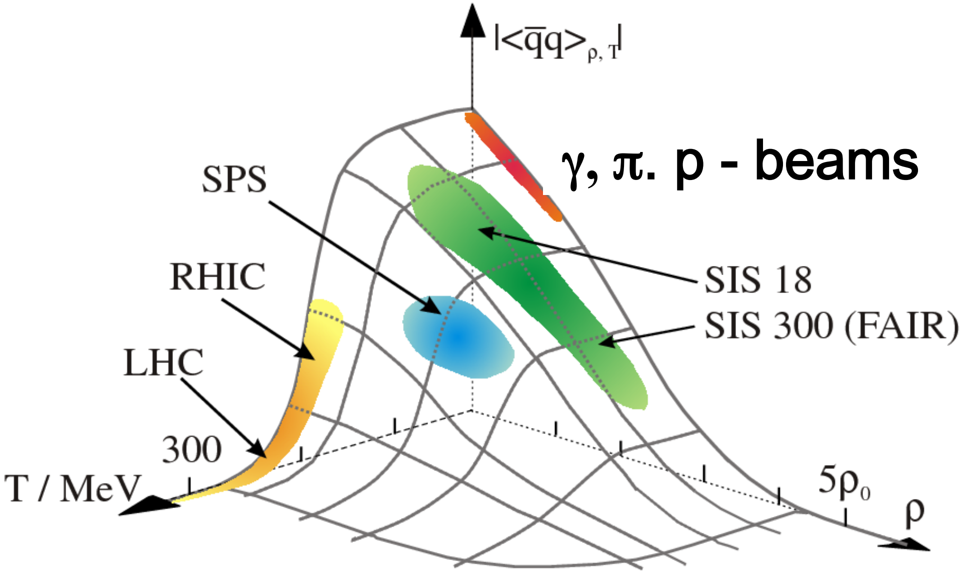
Elementary reactions studied with HADES: a hadron landscape

Laura Fabbietti for the HADES Collaboration

The Good-Old Chiral Condensate

F. Klingl, W. Weise NPA (1998)



How are the hadron properties connectected to the chiral condensate?

There are several scenarios..
2 examples:

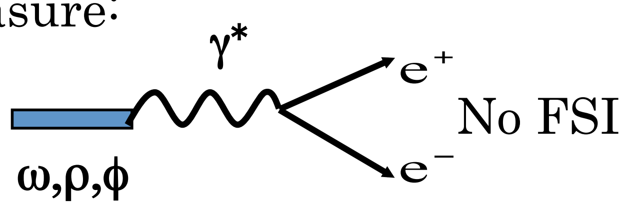
Brown-Rho scaling
PRL 1989, 1991

$$m^* \approx m\left[\langle \bar{q}q^* \rangle / \langle \bar{q}q \rangle\right]^u$$

T. Hatsuda / S. Lee: QCD sum rules
PRC46(1992)R34

$$m^* = m\left(1 - \alpha\rho^* / \rho\right)$$

Measure:



Even looking at In+In Collisions at 168 AGeV, it looks like the vector meson properties are mainly due to hadronic interaction and might not have much to do with Chiral Symmetry Restauration... ☹
What about the excesses seen in our energy regime?

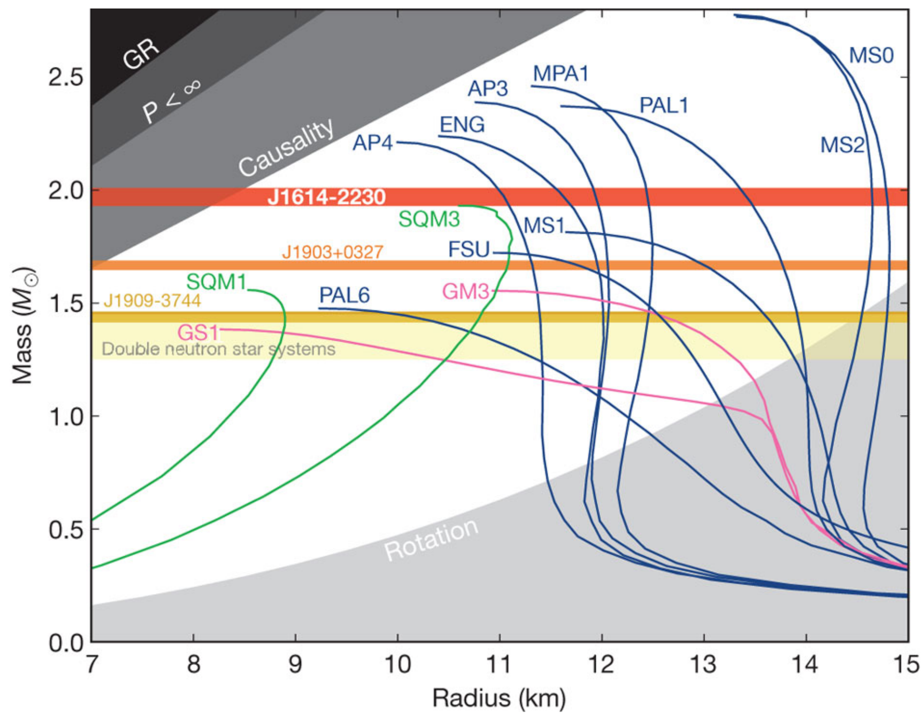
HADES PRC84(2011)014902

The Fuss with Neutron Stars

Kaon condensation in neutron stars? -> extract the K^- - Nucleus potential to test hypotheses.

Meanwhile: Neutron stars are TOO HEAVY to contemplate kaon condensate but maybe Hyperons still stand a chance?

P.B. Demorest et al., Nature 467, 1081 (2010)



Blue: Nucleons

Pink: Nucleons + exotic matter

Green: strange quark matter

Λ-Nucleus

Σ-Nucleus

Σ-Nucleus

?? At different densities?

We can start with ρ_0 for Λ (p+p, p+Nb reactions)

Then move to 2-3 ρ_0 for Λ and Ξ (Au+Au, Ag+Ag)

General Strategy

Dileptons:

Understand elementary collisions (p+p, p+n) in detail

Use the experimental data from p+p and p+n to build a cocktail and compare with C+C, Ar+KCl, Au+Au NOT TO BE completely dependent from transport models

Evaluate Excesses: Do they also have only a ‚hadronic' nature??

Strange Hadrons (K^0_S, K^+, K^-, ϕ, Λ, Σ, Ξ):

Scattering length in cold nuclear matter: compare differential distributions in p+p and p+Nb

Compare transport to elementary system and **then** move to heavier system

The "Λ(1405) puzzle"

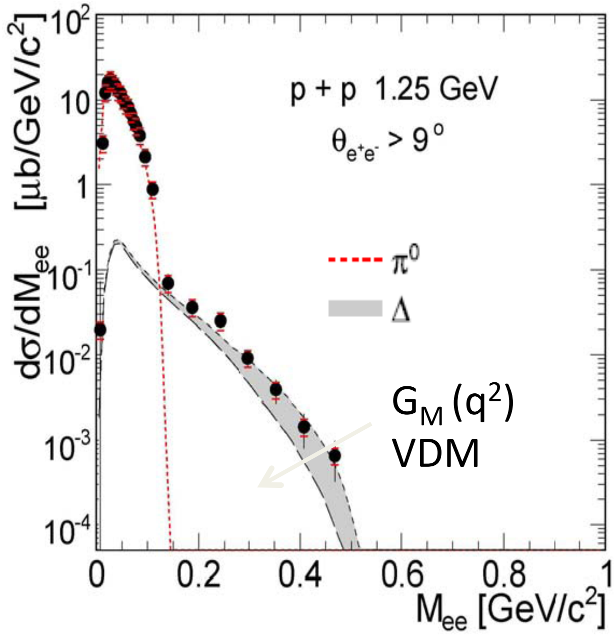
Stage:

p+p, p+n at 1.25 GeV,

p+p, p+Nb at 3.5 GeV measured with HADES at GSI, SIS18

N+N reference (I): e^+e^- in p+p

p+p@1.25 GeV



Important source: $\Delta \rightarrow pe^+e^-$ Dalitz decay

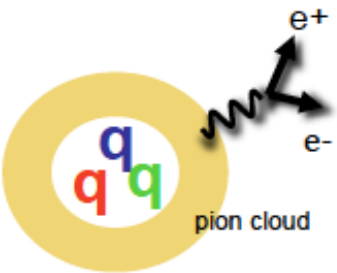
HADES: PLB690 (2010)118

Time Like ($q^2 > 0$)
Δ (J=3/2) -> N (J=1/2) γ^* transition

$$\frac{d\Gamma(\Delta \rightarrow Ne^+e^-)}{dq^2} = f\left(m_\Delta, q^2\right)\left(\left|G_M^2(q^2)\right| + 3\left|G_E^2(q^2)\right| + \frac{q^2}{2m_\Delta^2}\left|G_C^2(q^2)\right|\right)$$

G(q^2) ? el. Transition Form Factors : extented baryon structure !

Calculations: Krivoruchenko et al. PRD 65 (**2001**) 017502
G. Ramalho and T. *Pena arxiv:* 1205.2575v1 (2012)
F. Dohrmann et al., Eur. Phys. J. A 45, 401 (2010)

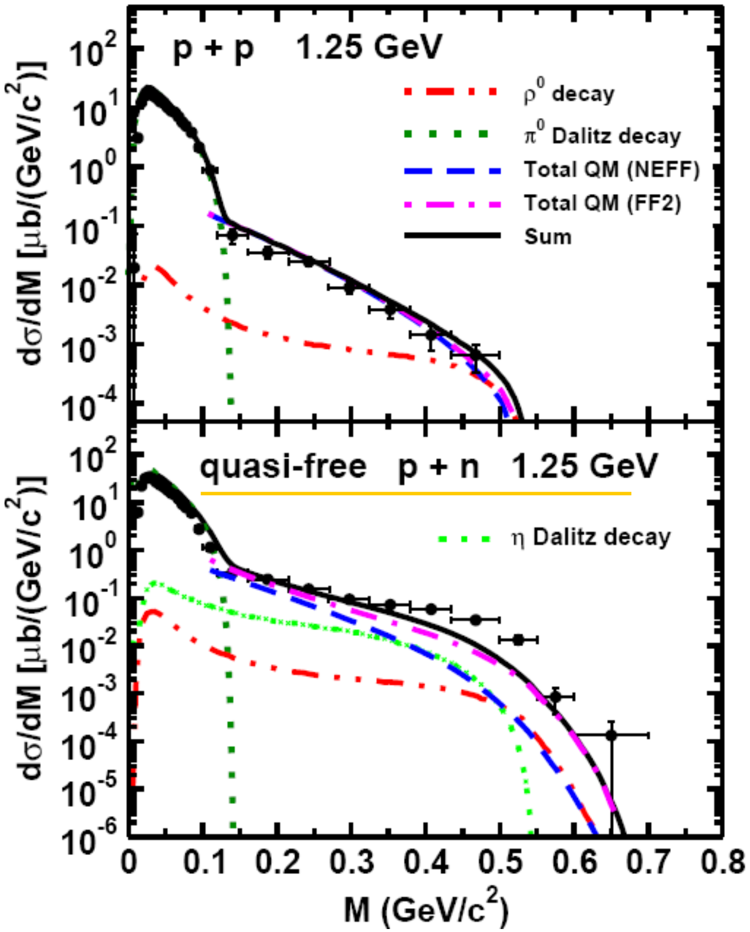


At this low energy the form factor effects do not show themselves!

N+N reference (II): e^+e^- in n+p

p+p/n@1.25 GeV

calculations: R. Shyam and U. Mosel *Phys. Rev. C 82:062201, 2010* ***data***: *HADES*

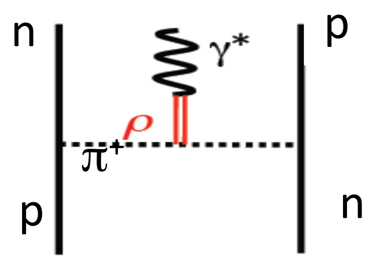


- η production – fixed by COSY, WASA data
- Bremsstrahlung pn→pne+e- (non resonant), why it is so much different from pp?

R. Shyam and U. Mosel Phys. Rev. C 82:062201, 2010

charge pion exchange & pion eFormFactor

for example:



PWA Analysis

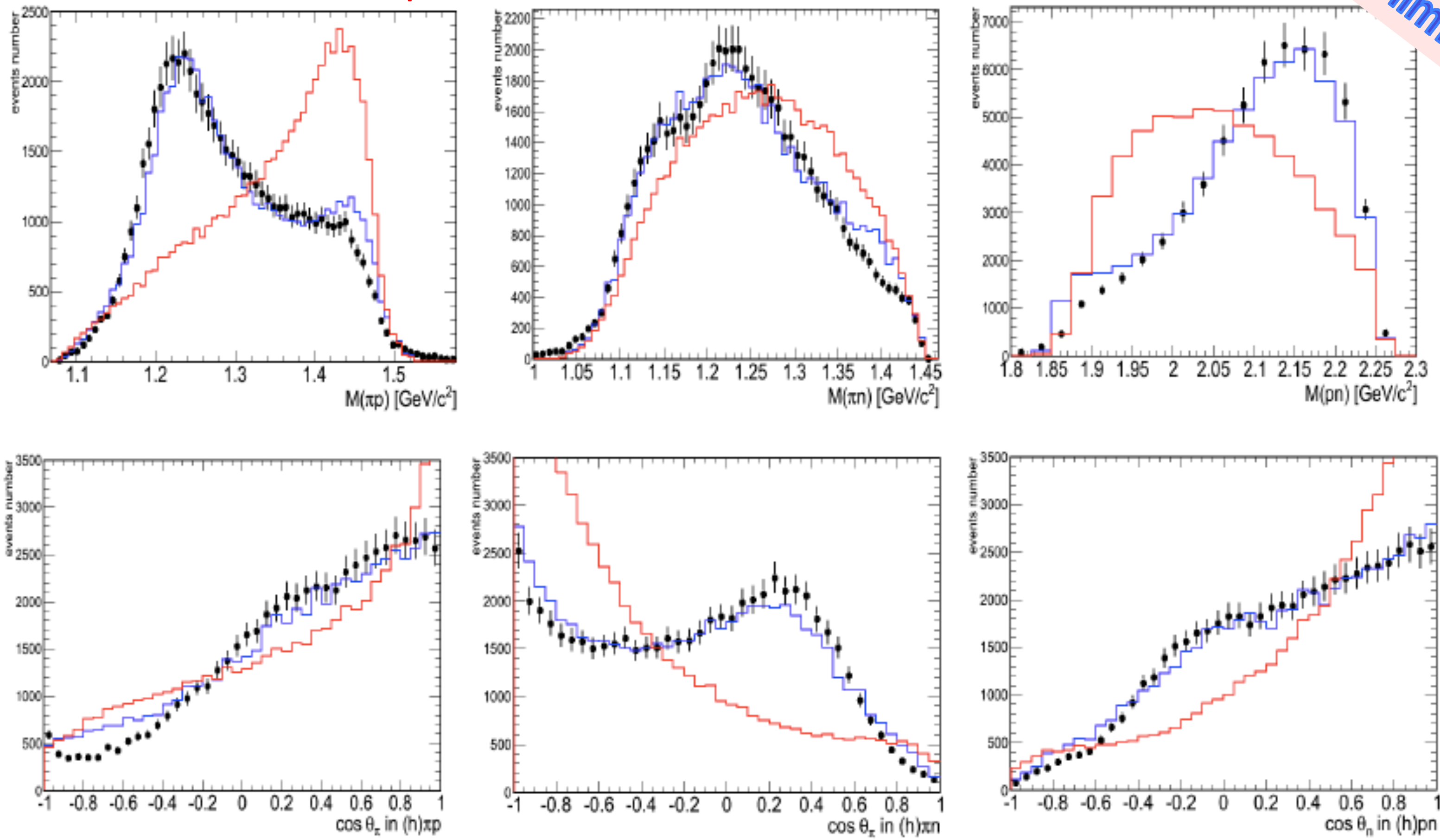
M. Gumberidze
Freitag B1

K.N. Ermakov et al. Eur. Phys. J. A47 (2011) 159

$$p + p \xrightarrow{1.25GeV} n + p + \pi^{+}$$

$\Delta(1232)N$, $P11(1440)N$, $\pi(NN)$

Blue: PWA Fit Red. Phase Space



Fixing resonance contribution via exclusive channels

p+p@3.5 GeV

$$p + p \rightarrow \Delta^{+} / N^{*+} + p, \quad \Delta^{++} + n$$

$$n + \pi^{+} + p \qquad p + \pi^{+} + n$$

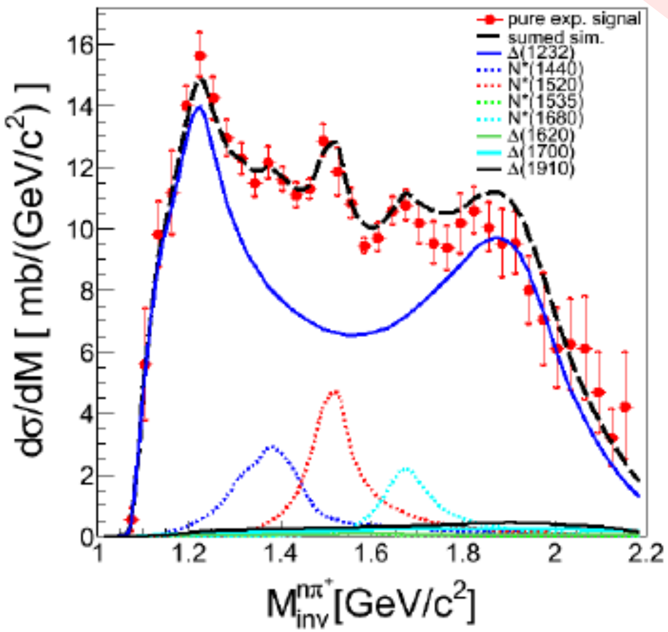
$$p + \pi^{0} + p$$

$$p + e^{+} + e^{-}$$

Incoherent Sum of 14 Resonances

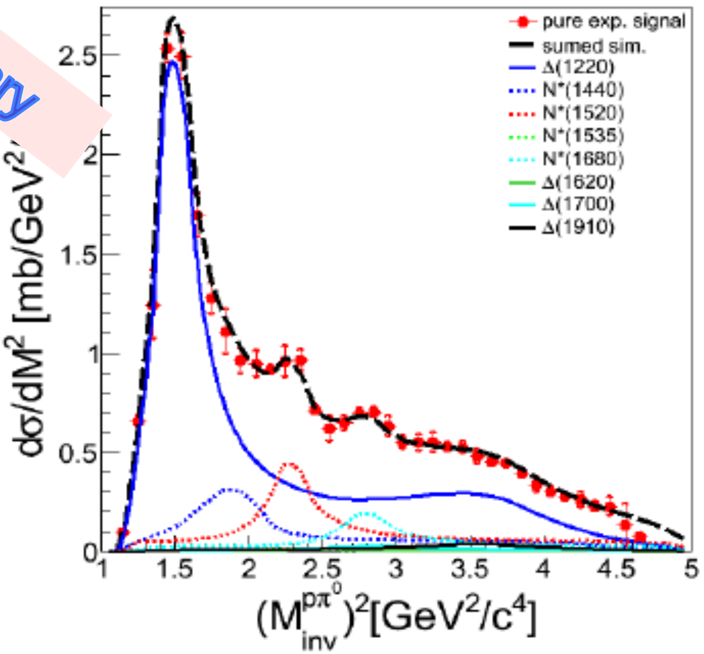
A. Dybczak : Monday B4

$pn\pi^{+}$



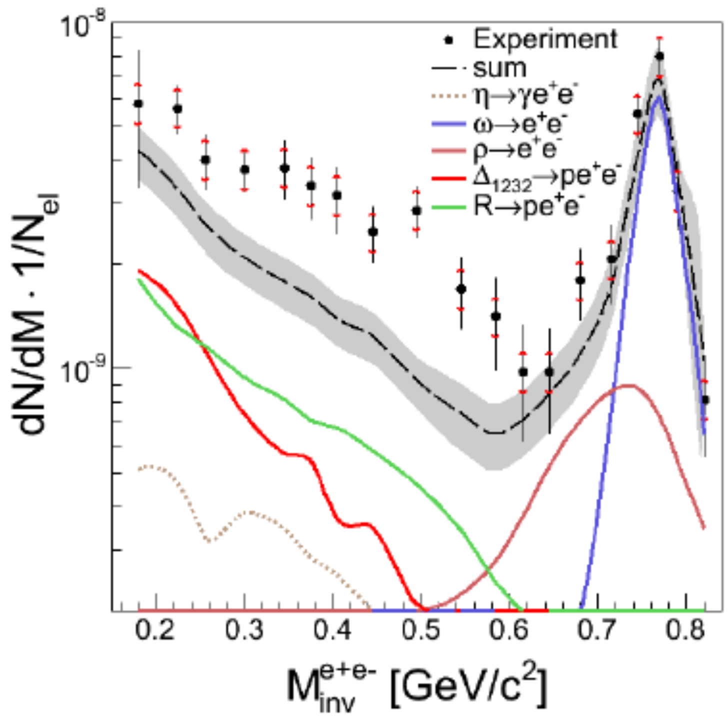
Preliminary

$pp\pi^{0}$

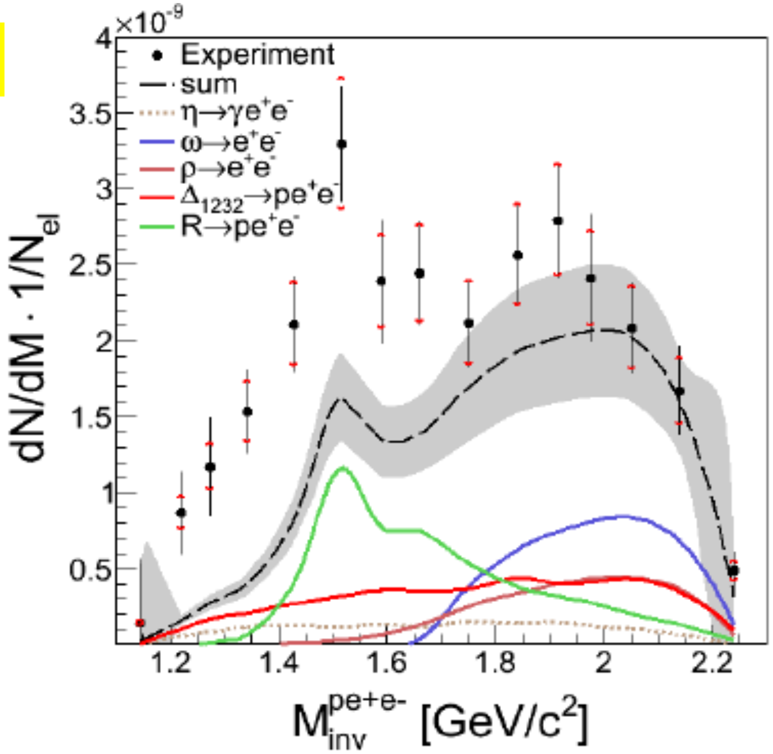


Cross-chek on Dilepton Spectra

p+p@3.5 GeV



ppe+ e-

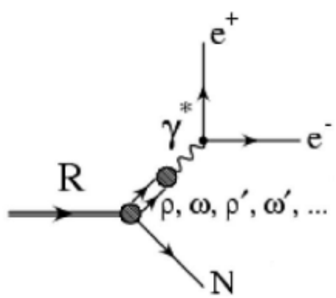


- ✓ Resonances cross-sections taken from the fit the hadron spectra
- ✓ R→Ne$^+$e$^-$ constant eTFF

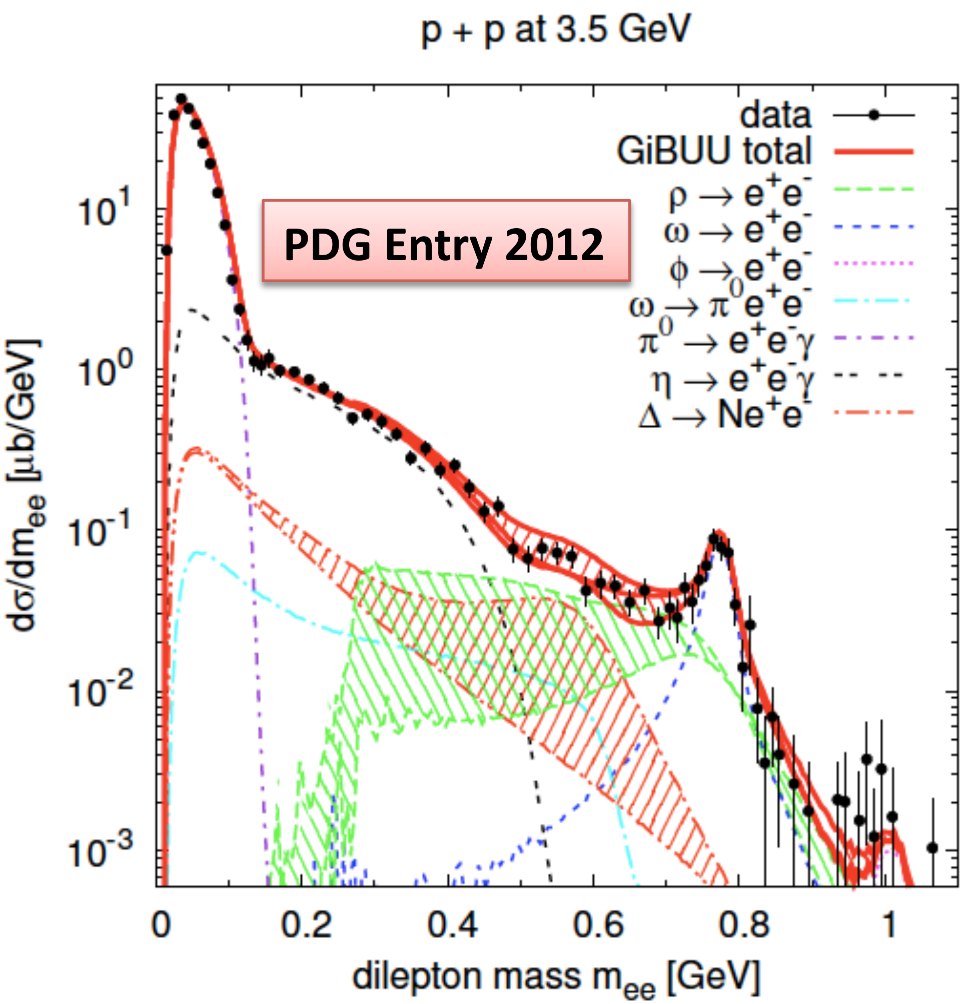
M. Zetenyi et. al. Heavy Ion Phys. 17 (2003) 27

- ✓ no off shell coupling to VM → lower limit for e$^+$e$^-$ emission
- ✓ experimental σ for ω/ρ used

missing yield related to low mass resonances and off shell VM !



p+p@ 3.5 GeV and GiBUU



J. Weil, H. van Hees, U. Mosel arxiv:1203.3557v1

Δ Form factor

Baryon-resonances contributing to ρ production

But p+p and p+n at 1.25 GeV are not reproduced

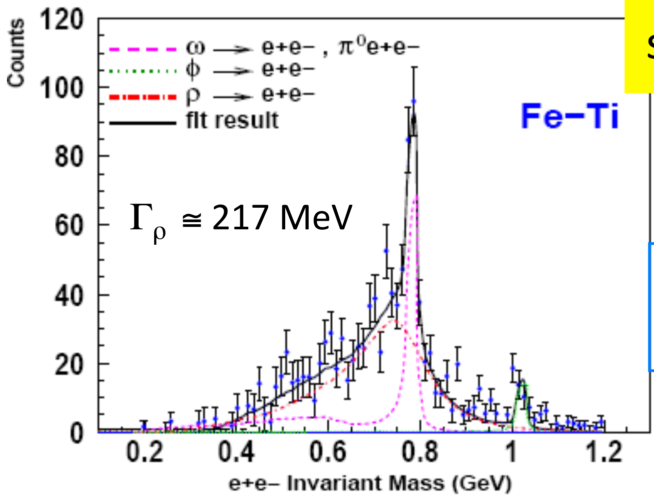
PDG Entry 2012:

BR($\eta \to e^+e^-$) < (4.9 + 0.7 - 1.2)x10^{-6} with 90% CL

Vector mesons in cold matter- experiments

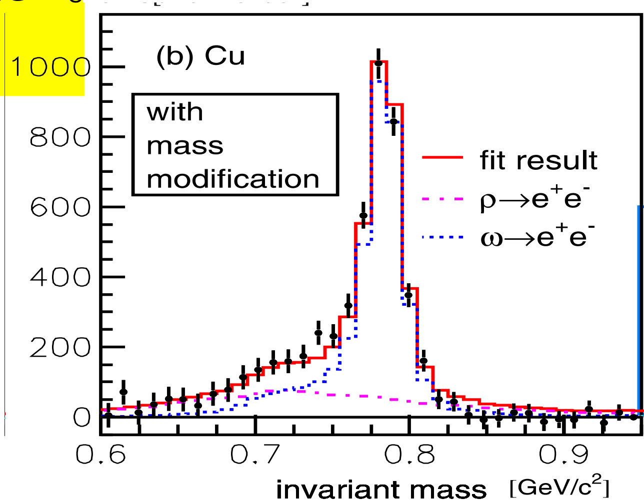
direct : ρ meson line shape

CLAS PRL 99 (2007) 262302



- no mass shift
- ρ broadenning

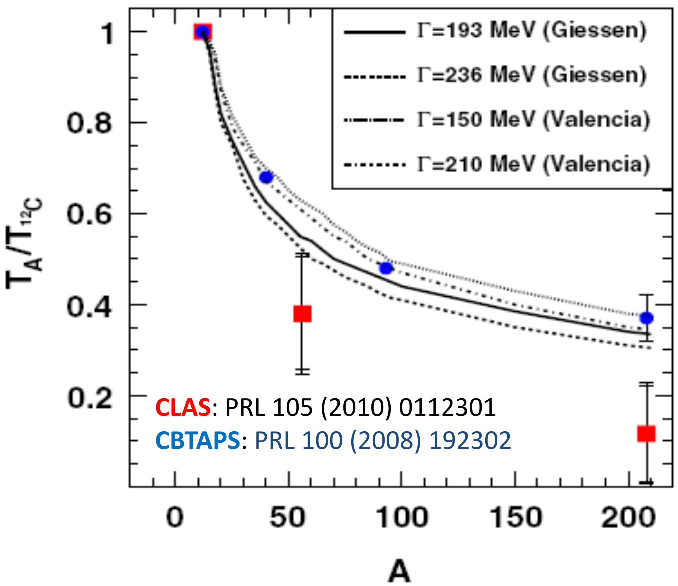
KEK-E325 PRL 96 (2006) 092301



- ρ mass shift $m^*/m_0 = 1 - 0.09\rho_N/\rho_0$

indirect: transparency

ω absorption



$$T_A = \frac{\sigma_{\gamma A \to VX}}{A \cdot \sigma_{\gamma N \to VX}}$$

$$N_{e+e-} \propto \Gamma_{e+e-} \tau_{meson} = \frac{\Gamma_{e+e-}}{\Gamma_{tot}}$$

$\Gamma_{\omega,tot}$ = 8 MeV

- large ω absorption →

  $\Gamma^*_{tot,\omega} \cong$ 210 MeV !

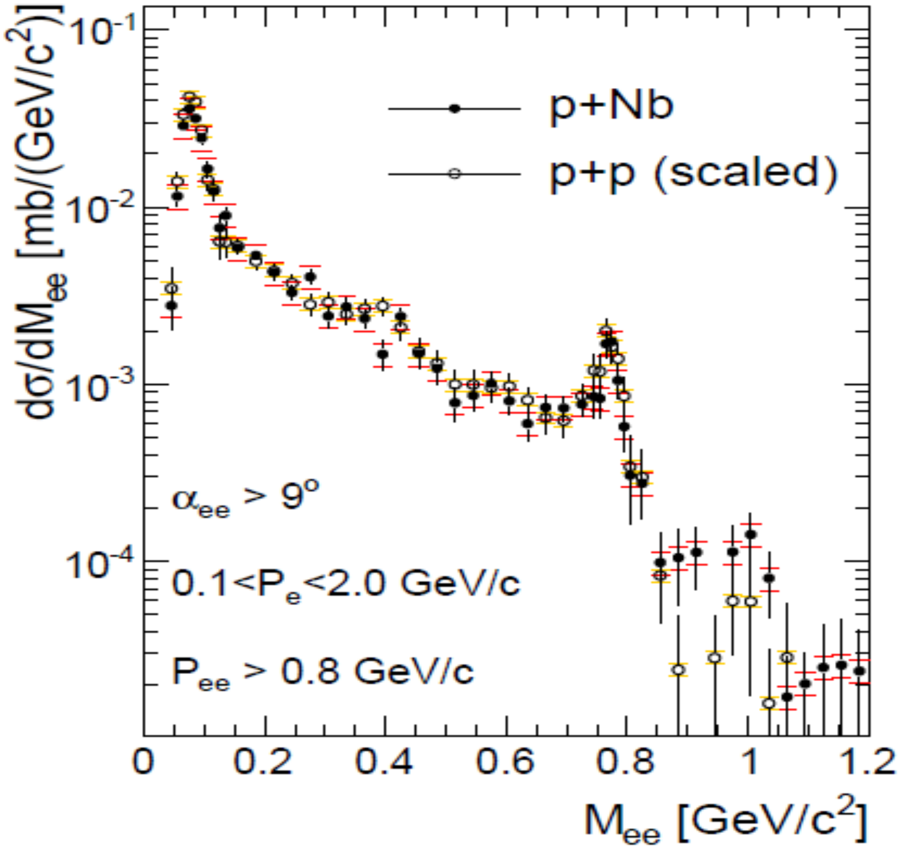
- ϕ meson (SPRING8, ANKE)

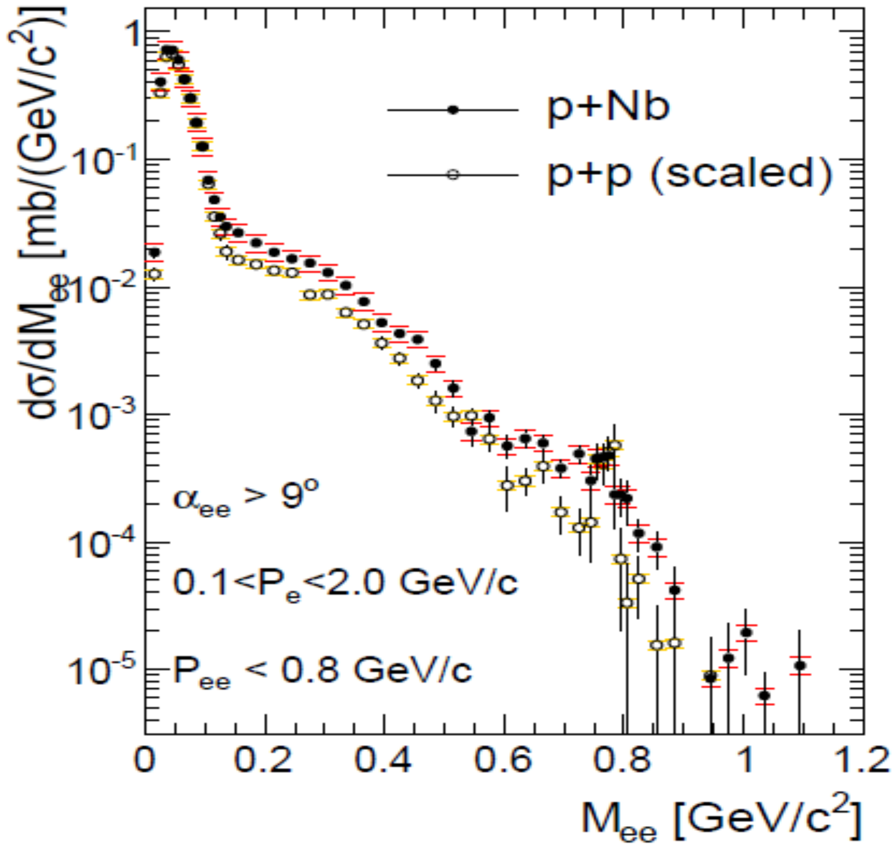
  Γ_ϕ^* ~ 33 - 50 MeV

Fast and Slow vector mesons

p+p/Nb@3.5 GeV

arXiv:1205.1918





Scaled p+p data agree with p+Nb data for momenta larger 0.8 GeV/c

First measurement of momenta smaller 0.8 GeV/c

Excess below the VM pole

Transition Form Factors?

Secondary reactions? $\pi + N \rightarrow \Delta(1720,..) N^*(1520,..) \rightarrow Ne^+e^-$

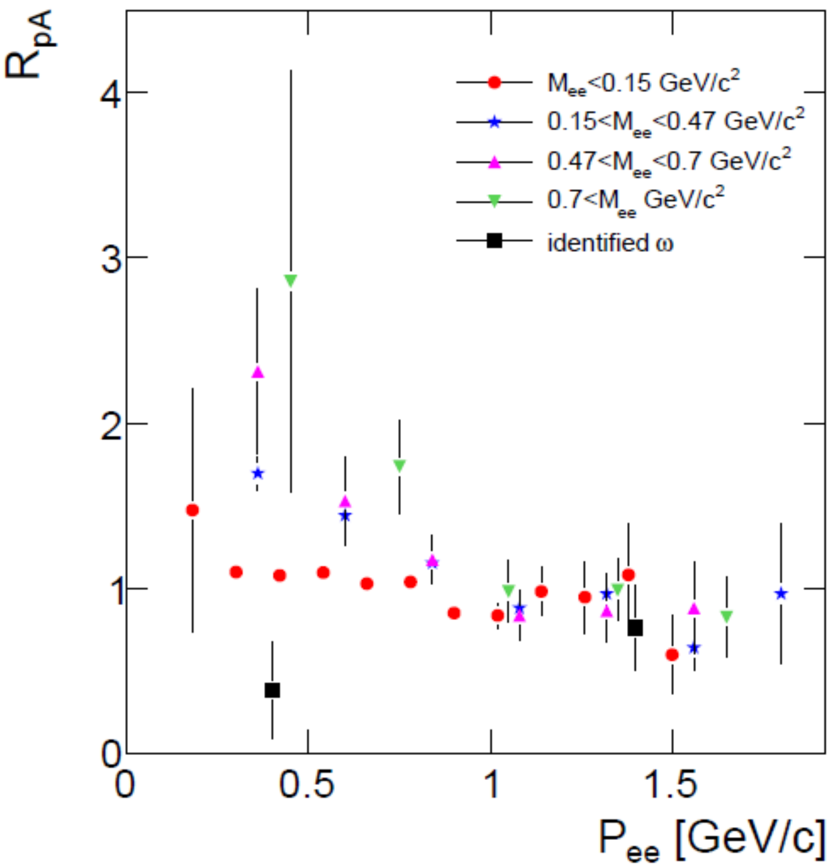
In medium modification of the ρ?

Nuclear Modification Factor

p+p/Nb@3.5 GeV

$$R_{pA} = \frac{d\sigma^{pNb}/dp}{d\sigma^{pp}/dp} \times \frac{\langle A^{pp}_{part}\rangle}{\langle A^{pNb}_{part}\rangle} \times \frac{\sigma^{pp}_{reaction}}{\sigma^{pNb}_{reaction}}$$

arXiv:1205.1918



Rise in all invariant mass regions for low P_{ee}: ->Secondary particle production

Absorption stronger than feeding from secondary collisions for ω mesons

$$N_{e^+e^-} \propto \Gamma_{e^+e^-}\tau_{meson} \propto \frac{\Gamma_{e^+e^-}}{\Gamma_{tot}}$$

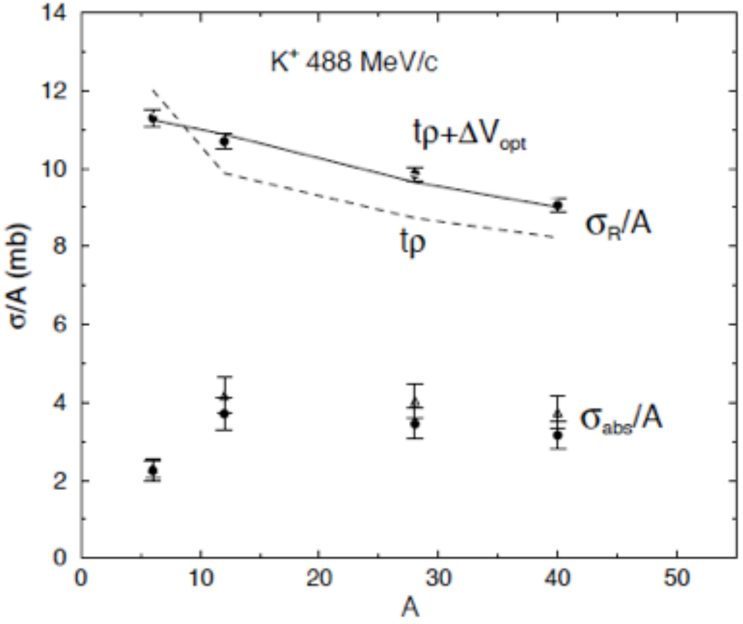
$$\Gamma_{tot} = \Gamma_{vac} + \Gamma_{coll}$$

Two aspects of in medium modifications: Absorption of particle like states (ω) and modification of the remaining dielectron shape in the invariant mass spectra!cent

M. Lorenz
Friday A2

K-N Scattering in nuclear matter

Free KN amplitudes underestimate the K+-nucleus reaction c.s. by ~15%



E. Friedman, A. Gal. Phys. Rept. 452 (2007) 89.

Number of mechanisms proposed to explain the difference:

- Swelling of nucleons in nuclear matter.
  P.B. Siegel et al. Phys. Rev. C 31 (1985) 2184.
- Modification of exchanged vector mesons.
  G.E. Brown et al. Phys. Rev. Lett. 60 (1988) 2723.
- Meson exchange-current contribution. M.F. Jiang et al. Phys. Rev. C. 46 (1992) 6.
- In-medium formation of the Θ^+ pentaquark: $KNN \rightarrow \Theta^+ N$. A. Gal et al. Phys. Rev. Lett. 94 (2005) 072301. L. Tolos et al. Phys. Lett. B 632 (2006) 219.

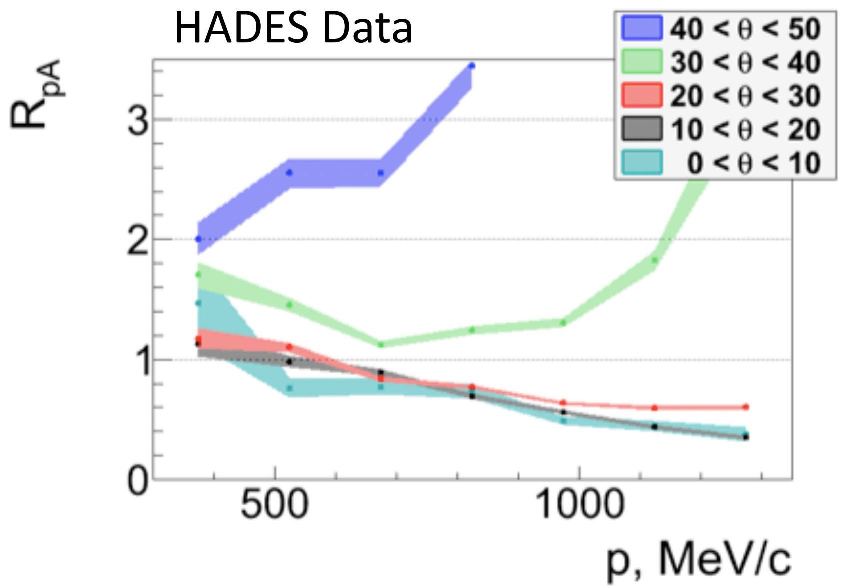
Nuclear Modification Factor for K^0_S

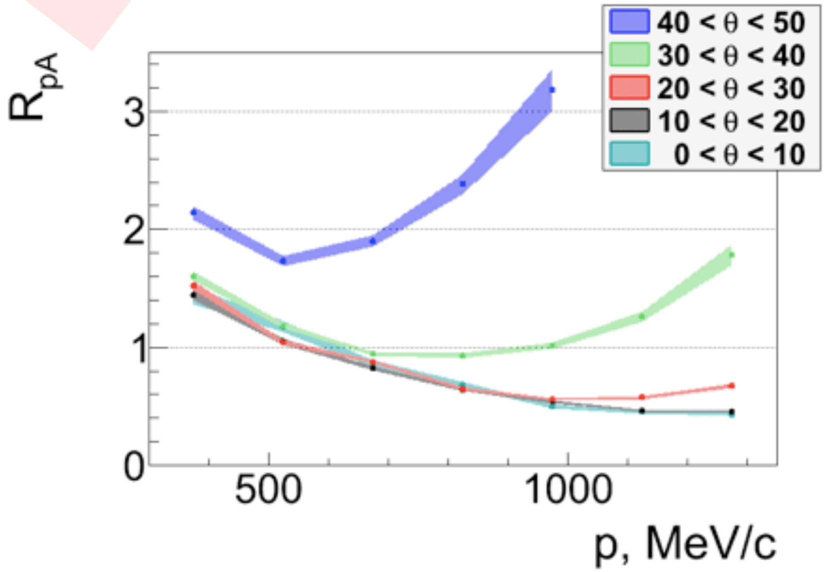
$$R_{pA}(p) = \frac{d\sigma_{pA}/dp}{d\sigma_{pp}/dp} \cdot \frac{N^{pp}_{part}}{N^{pA}_{part}} \cdot \frac{\sigma^{pp}_{tot}}{\sigma^{pA}_{tot}}$$

Preliminary

p+Nb@3.5 GeV

Transport simulations (GiBUU)
with free KN cross sections

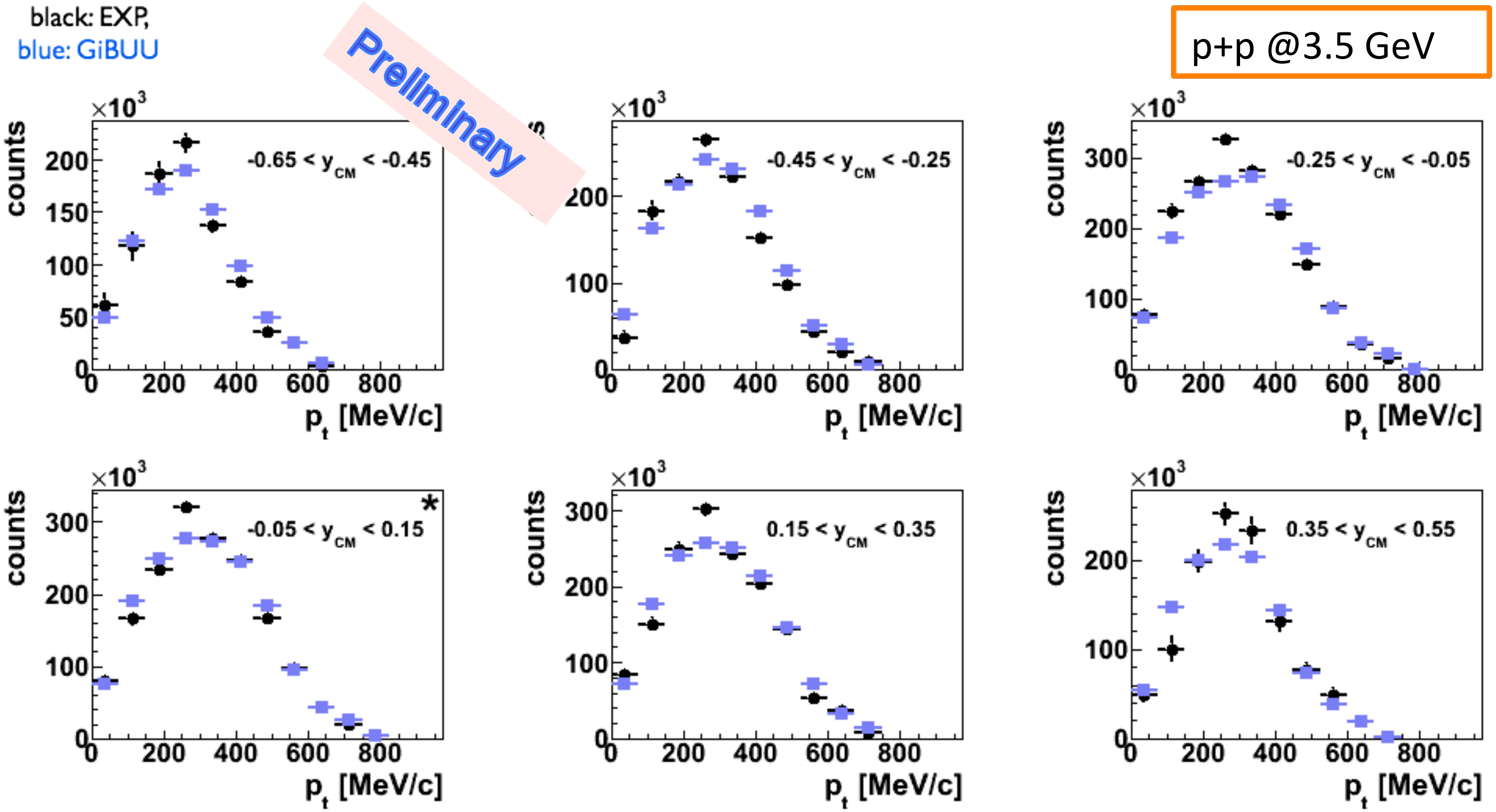




GiBUU: O. Buss et al. Phys. Rept. 512 (2012) 1-124.

Qualitative agreement. Hints of larger rescattering in data.
The comparison of the experimental data with the transport model should deliver info about the K-N scattering at ρ0

Momentum Distribution of K^0_S in p+p



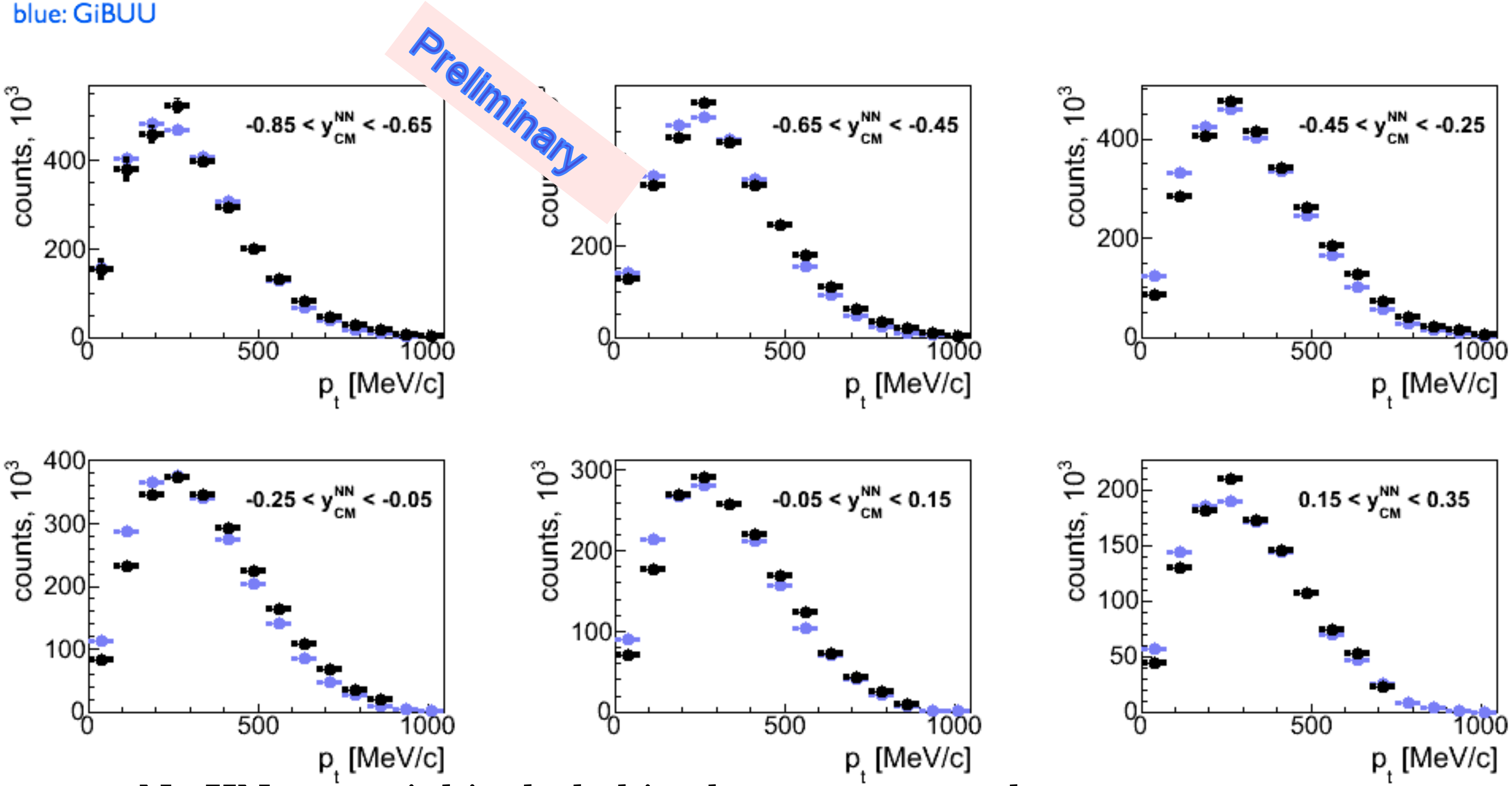
GiBUU Code tuned on the p+p reaction to have a reference

Momentum Distribution of K^0_S in p+Nb

Idea: Repulsive K^0_S-Nucleus Potential should be visible in the momentum distribution as a shift tolarger momenta

p+Nb@3.5 GeV

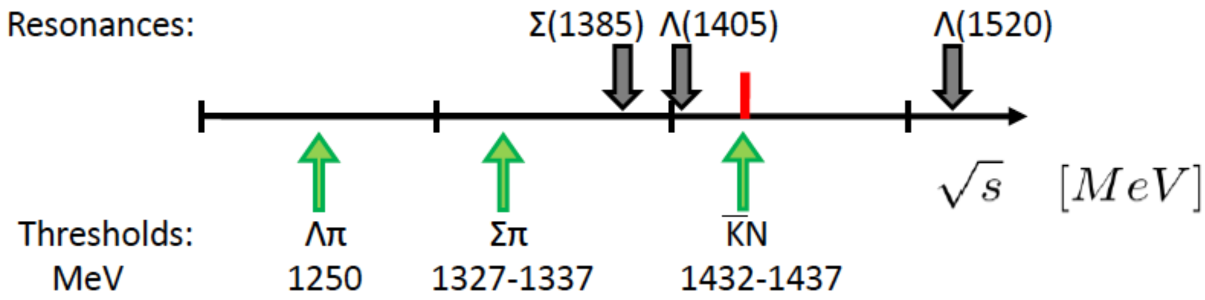
black: EXP,
blue: GiBUU



No KN potential included in the transport code

Systematic Overshoot of the GiBUU at low p_t ->? Effect of the potential

Antikaon-Nucleon Interaction

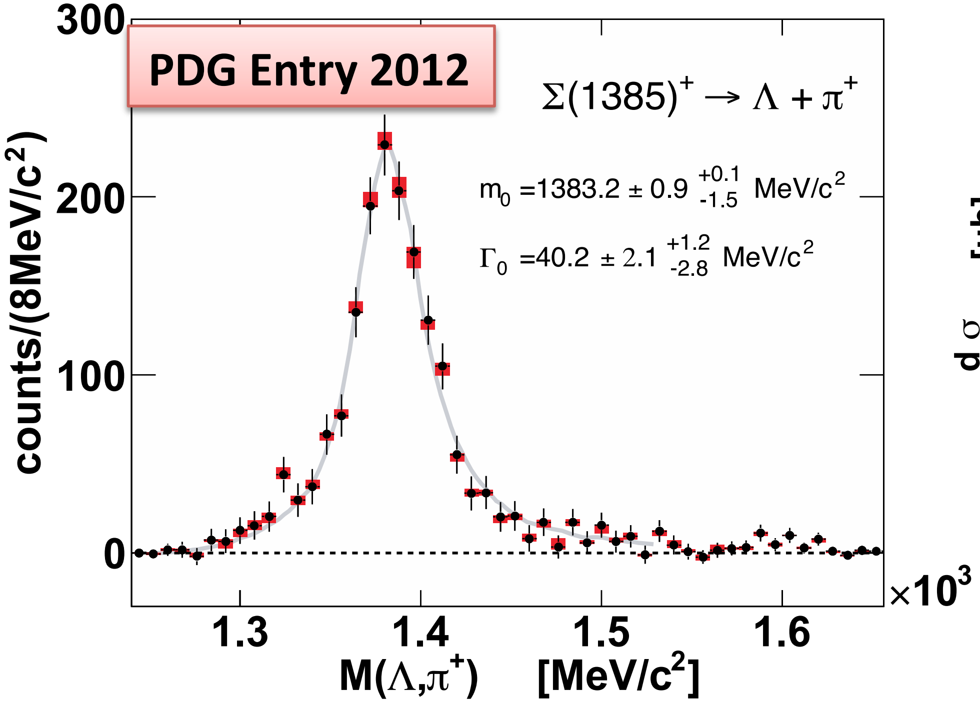


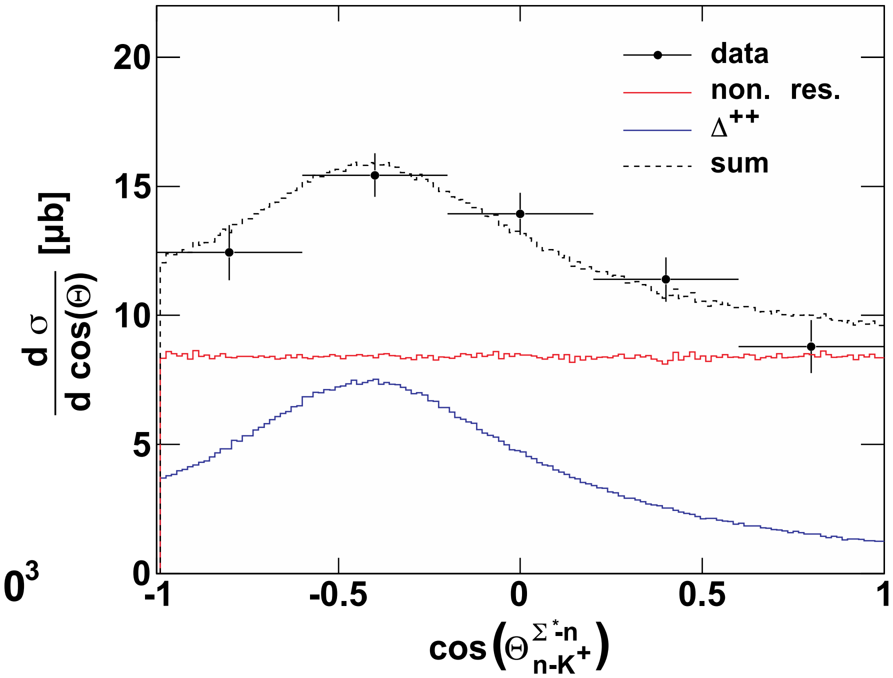
- Λ(1405) is crucial for understanding of the free and in-medium KN interaction.
- Predicted as a KN bound state.
- Within coupled channel approach generated as a KN bound state and a Σπ resonance.

Strategy in p+p 3.5 GeV:
1. Analyse the $\Sigma(1385)^{+}$.
2. Find the $\Sigma(1385)^{0}$ contribution.
3. Extract the Λ(1405) signal.

$\Sigma(1385)^+$ in p+p Collisions

Phys. Rev. C 85, 035203 (2012).



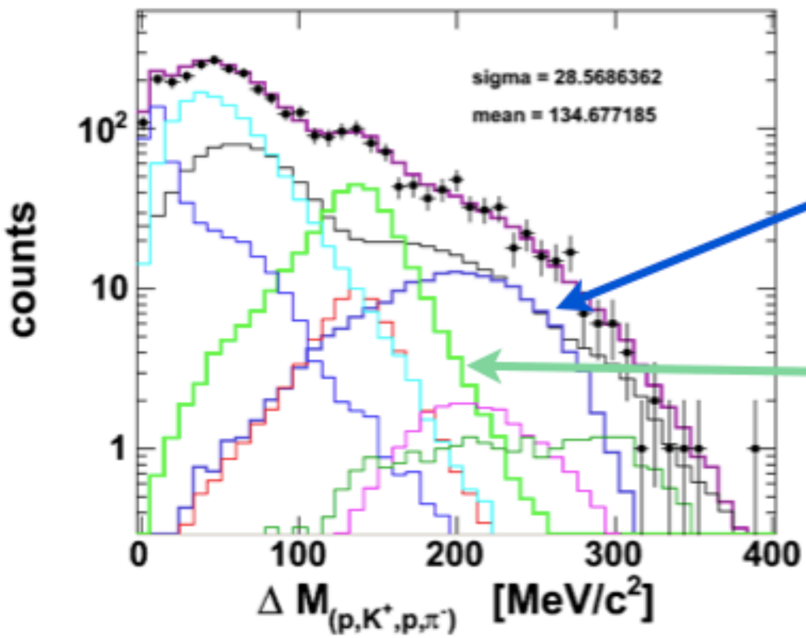


Extraction of the precise line shape for the first time in p+p reactions

The angular distributions suggest that around 30% of the $\Sigma(1385)$ yields stems from the decay of a Δ++

$\Sigma(1385)^0$ Contribution

Hyperfine Interaction 210, (2012) 45.

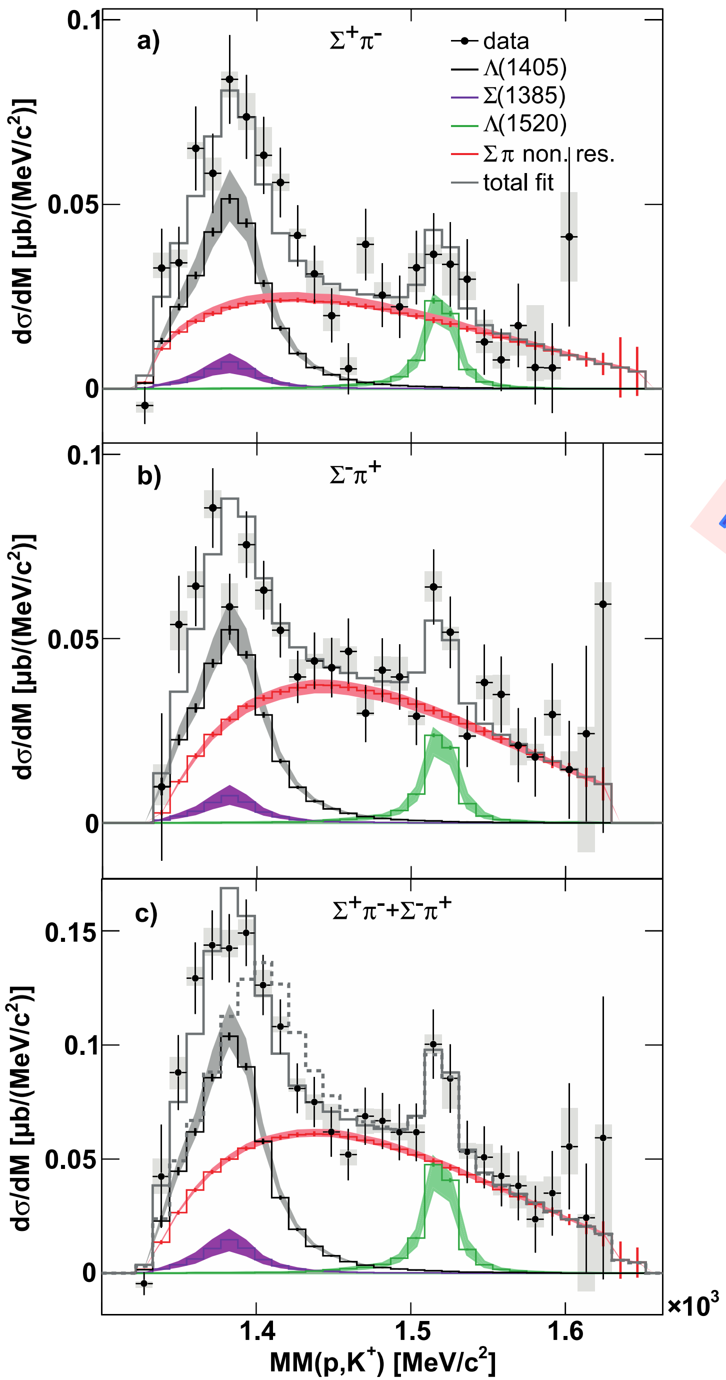


$$p + p \xrightarrow{3.5GeV} \Lambda(1405) + K^+ + p$$
$$\hookrightarrow \Sigma^0 + \pi^0$$
$$\hookrightarrow \Lambda + \gamma$$
$$\hookrightarrow p + \pi^-$$

$$p + p \xrightarrow{3.5GeV} \Sigma(1385)^0 + K^+ + p$$
$$\hookrightarrow \Lambda + \pi^0$$
$$\hookrightarrow p + \pi^-$$

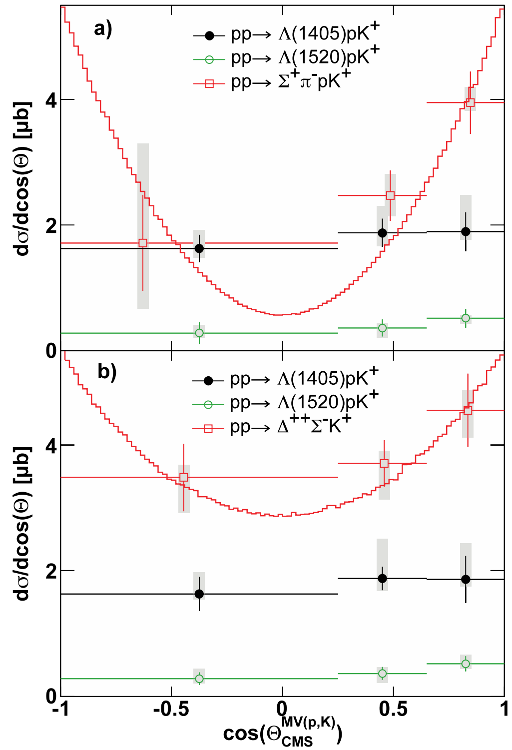
Separation of $\Sigma^0(1385)$ and $\Lambda(1405)$ possible.
$\Sigma^0(1385)$ cross section is found to be 6±2 μb.

Λ(1405) in p+p Collisions



Efficiency and Acceptance corrected data
Example of incoherent sum of different channels that can reproduce the data assuming a SHIFT of the pole Mass for the Λ(1405) to 1385 MeV/c^2

Preliminary



Isotropic angular distribution in CMS for Λ(1405)
Anisotropy observed for the contributing channels

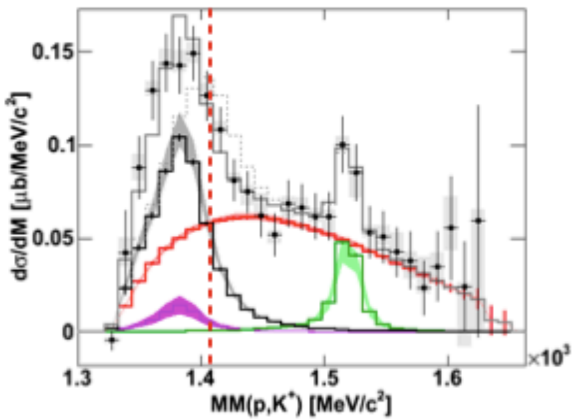
$$p + p \rightarrow \Sigma^+ + \pi^- + p + K^+$$

$$\rightarrow \Delta^{++} + K^+ + \Sigma^- \rightarrow \Sigma^- + \pi^+ + p + K^+$$

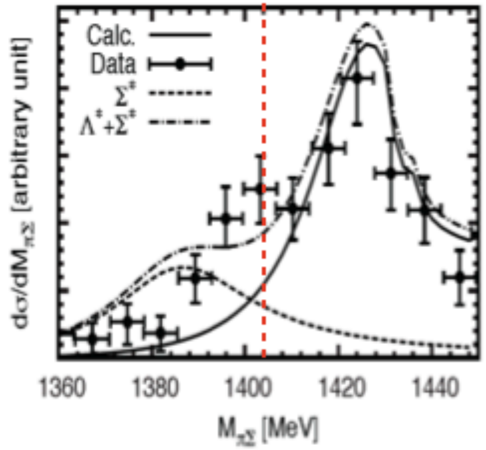
Nucl. Phys. A. 881, 178 (2012)

Striking: different reaction<->different line-shapes

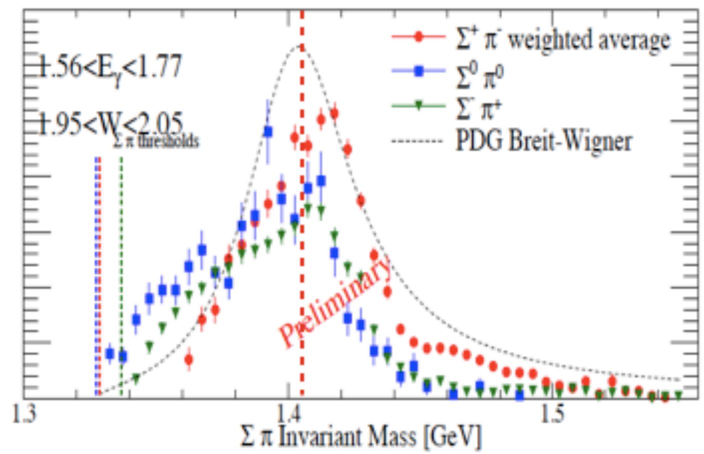
p+p at 4.3 GeV/c



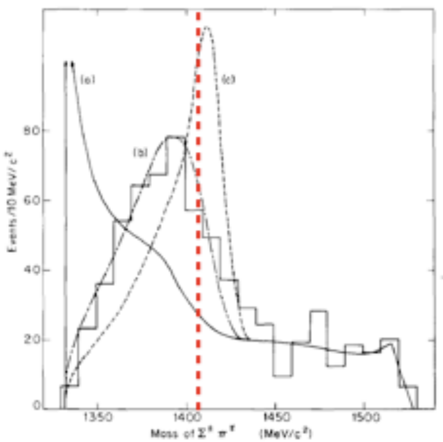
K⁻+d at 0.7–0.85 GeV/c



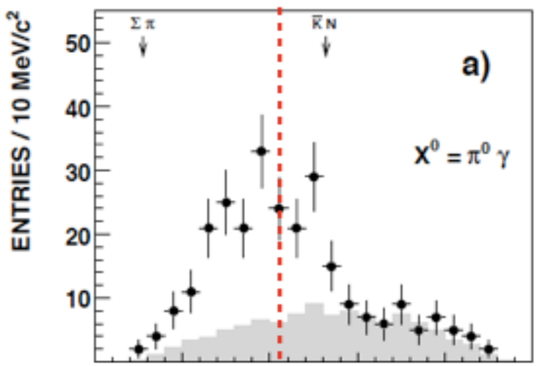
γ+p at 1.6–1.8 GeV/c



π⁻+p at 1.69 GeV/c



p+p at 3.65 GeV/c



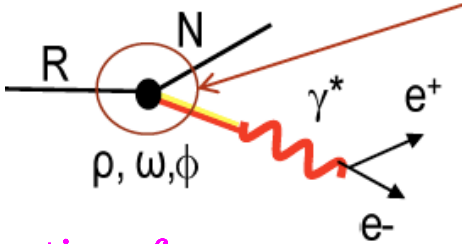
O. Braun et al. Nucl. Phys. B129 (1977) 1.
K. Moriya et al. arXiv:1110.0469 [nucl-ex].
D.W. Thomas et al. Nucl. Phys. B56 (1973) 15.
I. Zychor et al. Phys. Lett. B660 (2008) 167-171.

Oppurtunity with the pion beam program: Λ(1405) with HADES for 2 different reactions

What comes next

Dalitz-Decay of Baryonic Res.
Above/below the ω threshold

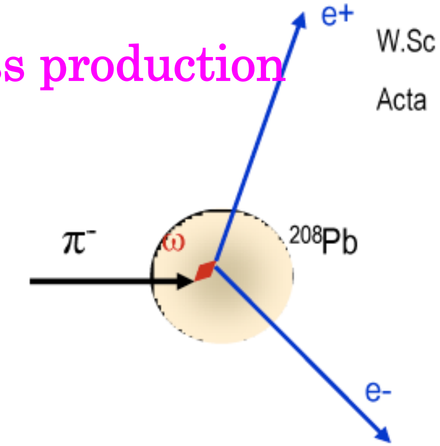
$$\pi^- + p \rightarrow R \rightarrow N e^+ e^-$$



PWA: branching ratios of baryonic resonances

$$\pi^- + p \rightarrow N + \pi + \pi$$

ω recoilless production



Λ(1405) in π-induced reactions

$$\pi + p \xrightarrow{1.62GeV} \Lambda(1405) + K_S^0$$
$$\hookrightarrow \Sigma^0 + \pi^0$$
$$\hookrightarrow \Lambda + \gamma$$
$$\hookrightarrow p + \pi^-$$

Λ(1405) Absorption in different target

$$\pi^- + Pb \rightarrow \Lambda(1405) + \ldots$$

ϕ In Medium

$$T_Z = \frac{\sigma_{\pi^- A \rightarrow \phi X}}{Z^\alpha \sigma_{\pi^- p \rightarrow \phi X}}$$

K- absorption Measurement

$$2\omega U_{K^- A} = -4\pi\left[f_{K^- p}\rho_p + f_{K^- n}\rho_n\right] + 2\omega U_{abs} + \ldots$$

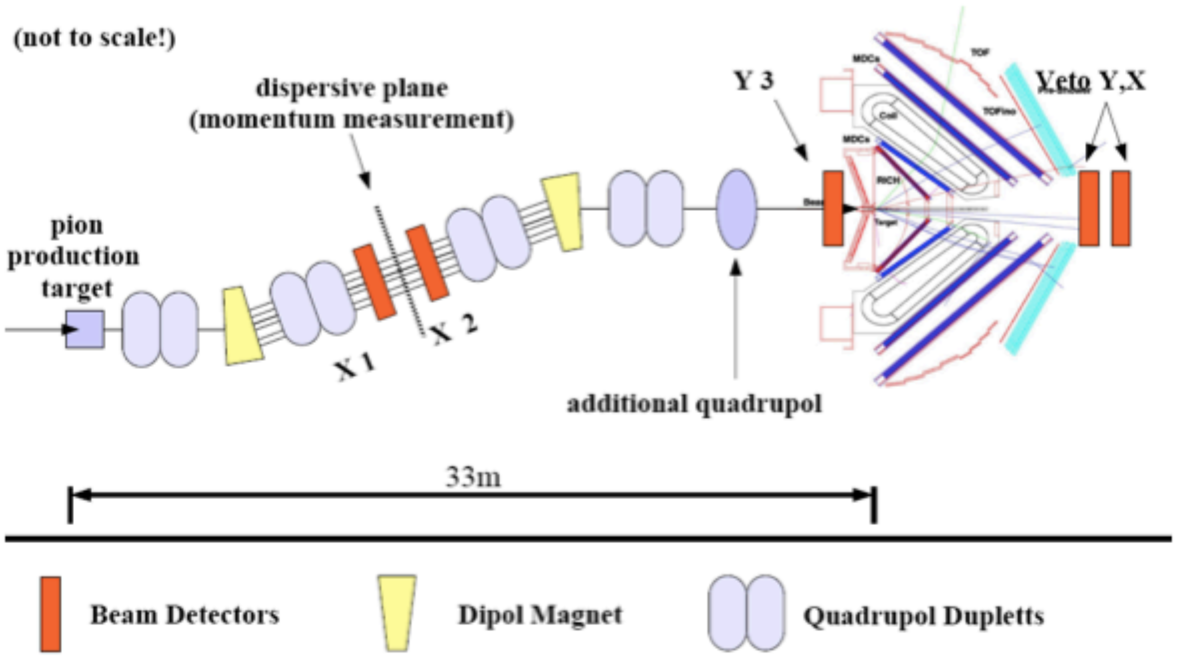
f_{K^-p} *scattering length* → *from kaonic atoms*

U_{abs} K^- *absorption potential on Nucleus*

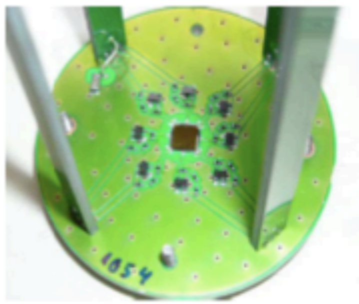
Experiments with Pions

(HADES) Nucl. Instr. Meth. A 618 121 (210)

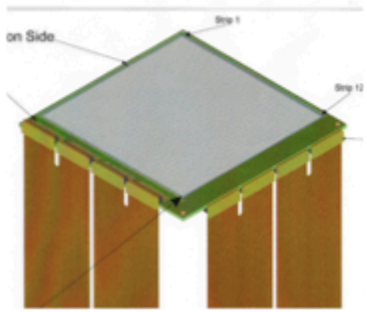
C+Be
N+Be
~10^{10} p/s



Diamant



Silicon



Pion Beam Intensity: 10^6p/s
Beam Spot: 3x3 cm^2 on Target
$\Delta p/p \sim 4\%$
⟶ Beam Trackers are necessary

Summary

p+p @1.25 GeV under control, PWA Analysis should improve the quantitative knowledge of the Resonance contribution

p+p @ 3.5 GeV: η -> PDG ☺ Excess at intermediate Masses ? D Form Factor? Resonances associated to ρ and ω production?

Extend the PWA analysis in p+p to 2pion FS

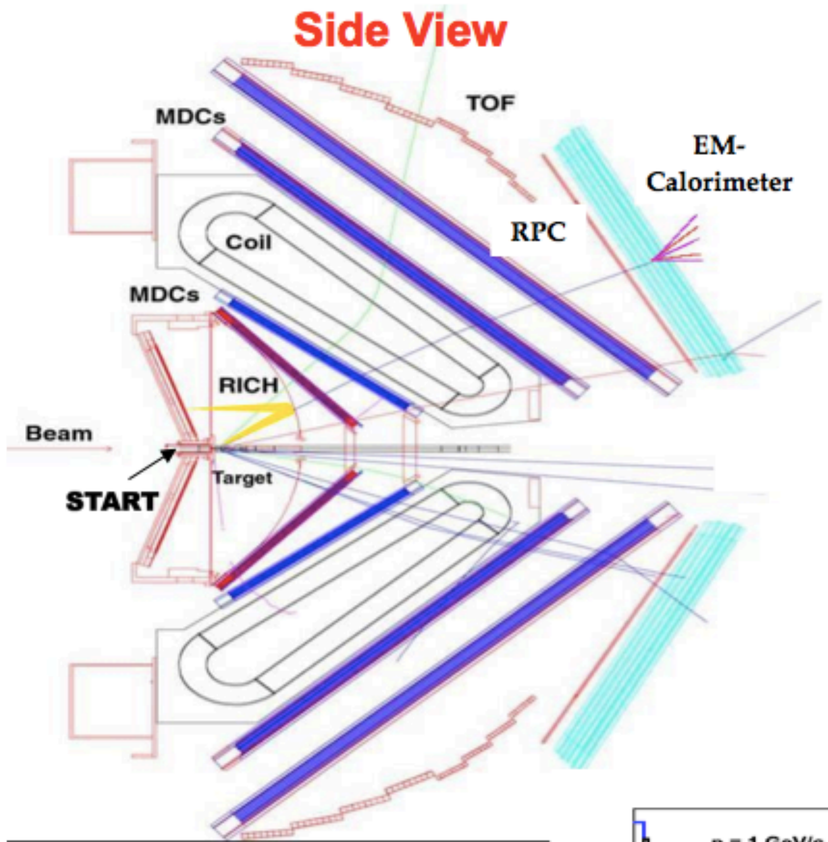
Σ(1385)+ : precise determination of the spectral shape .> PDG

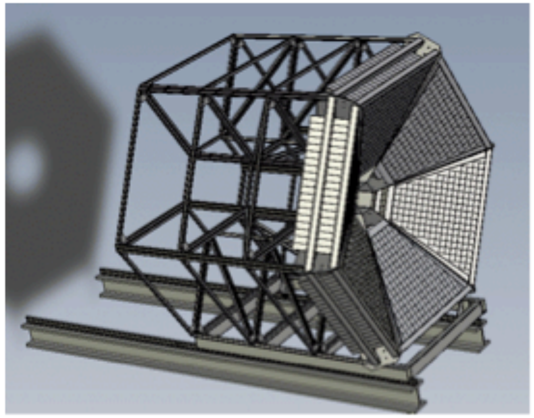
Λ(1405) in p+p @ 3.5 GeV: Pole Mass shifted to 1385 MeV/c^2 !!

p+Nb/p+p:

- slow omegas absorbed in nuclear matter: data ready for interpretation
- K0s scattering length in nuclear matter can be extracted
- Λ scatterings legnth will be studied as well
- Momentum analysis for K^0s (almost done) and Λ (in progress) can deliver info about the potential in nuclear matter.

HADES Calorimeter





PID, Simulation