Studying in-medium hadron properties in baryonic matter with HADES

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for the HADES collaboration

Strangeness in NN and nuclear matter:
•Λ(1405) production and search for ppK$^-$ in pp reactions
•kaons (K0) , Ξ(1321), ϕ production in A+A

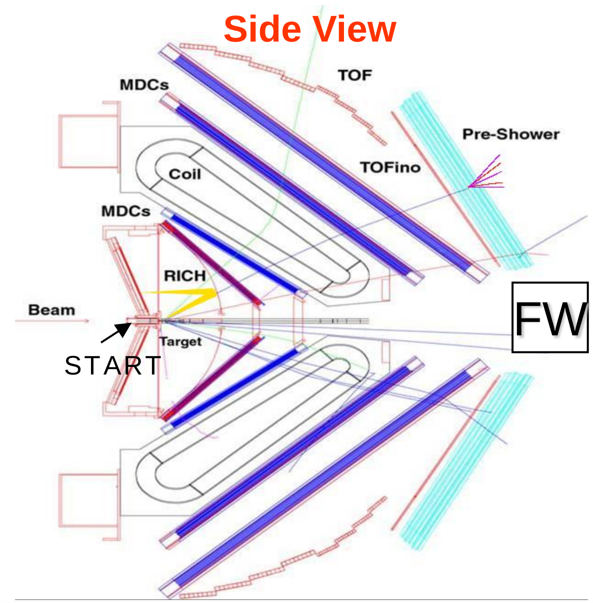
ρ/ω mesons in NN and p+A

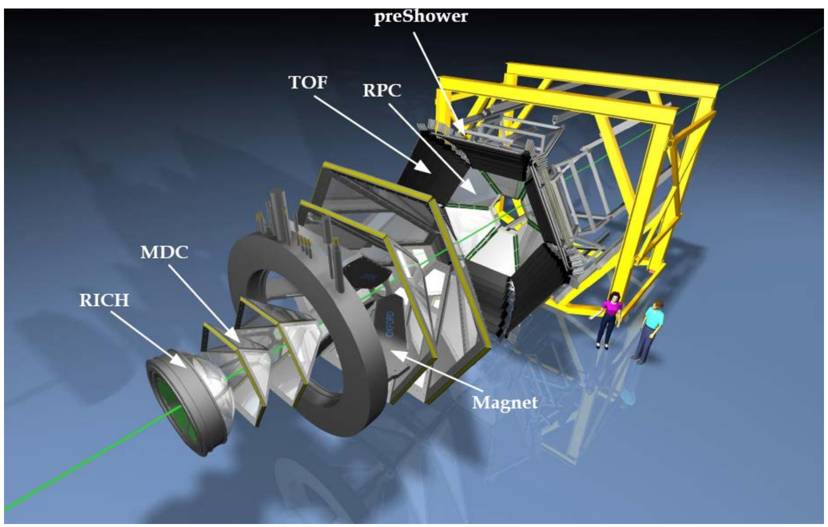
High Acceptance Di-Electron Spectrometer

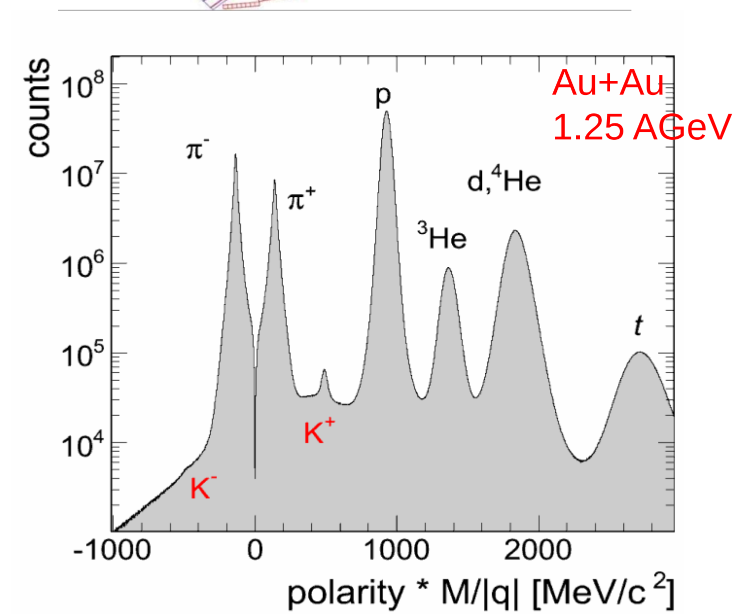
- Beams from SIS18: protons, nuclei , pions

2.0 GeV<√s<3.2 GeV

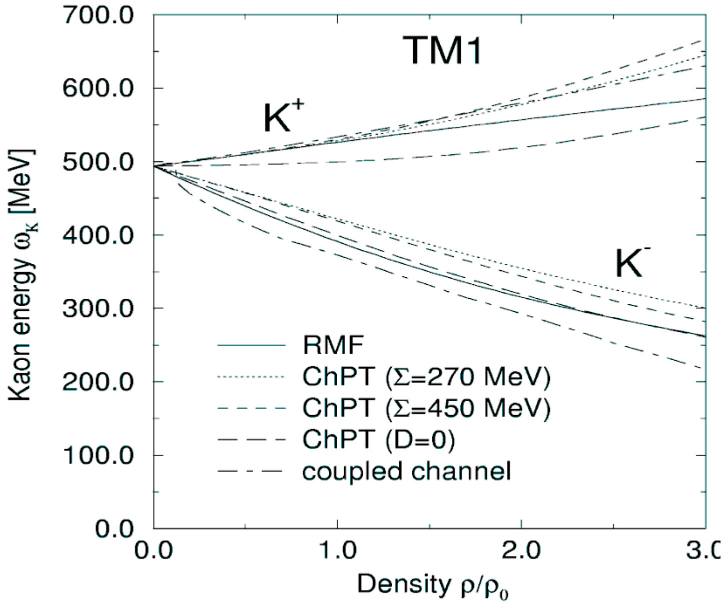
- Spectrometer with high invariant mass resolution - 2% at ρ/ω
- Versatile detector for rear probes :
- dielectrons (e+,e-)
- strangeness: Λ, $K^{\pm,0}$, Σ(1385), Ξ^- , φ







Kaons in nuclear matter



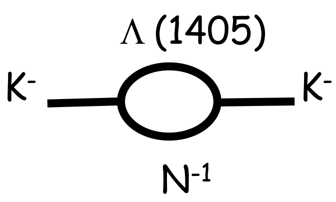
G.E Brown et.al NPA 567 (1994) 937, T. Waas, e al. PLB 379 (1996) 34
J. Schaffner-Bielich, et al.. NPA 625 (1997),..

K^0 / K^+:

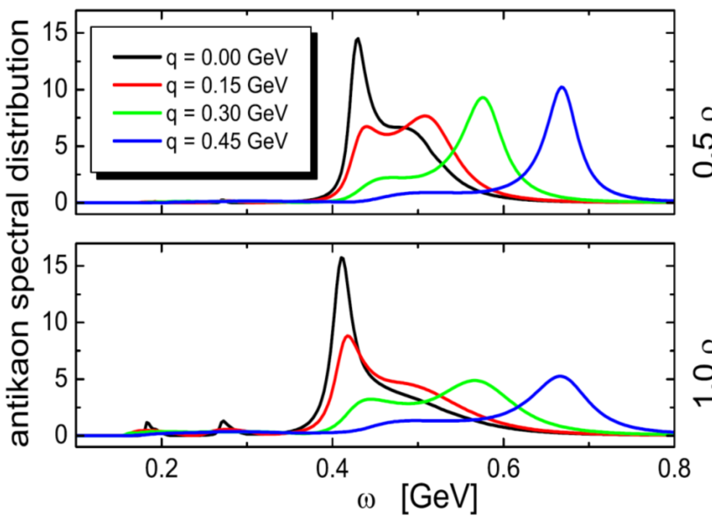
K^+/K^0 considered as good quasiparticle

✓ at SIS18 (p_K <1 GeV/c) $\lambda_{K+} \cong 5$ fm (weak absorption)

K^- in medium: more complicated → spectral function



M.F.M. Lutz, C.L. Korpa, M. Möller, nucl-th/07071283



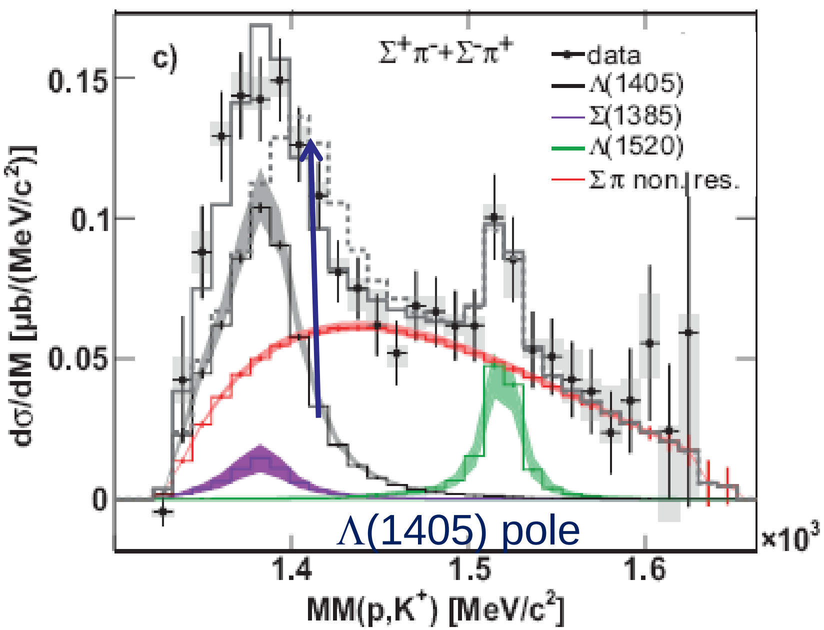
✓ Λ(1405) physics : entry to K^- in medium properties , kaonic clusters ppK^- ..,

Λ (1405) doorway into bound K^- N

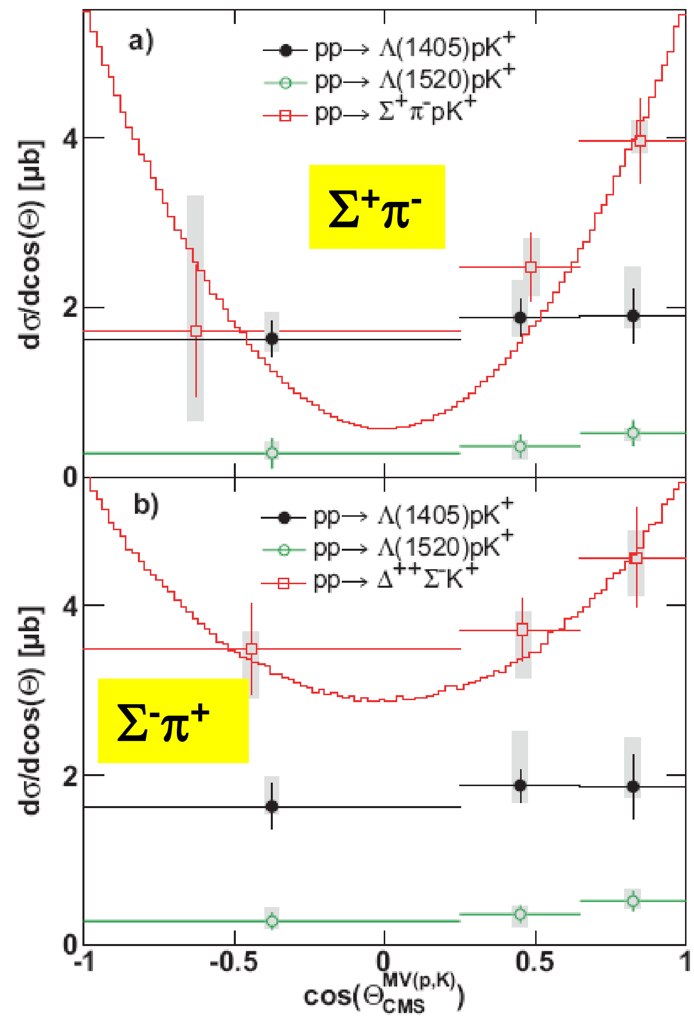
$$p + p \rightarrow \Lambda(1405) + p + K^+$$

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

$$\hookrightarrow n + \pi^{+/-}$$



HADES : PRC87(2012)025201



- pole shift? intereference with non. res Σπ lower pole stronger, Λ(1405)-N FSI?

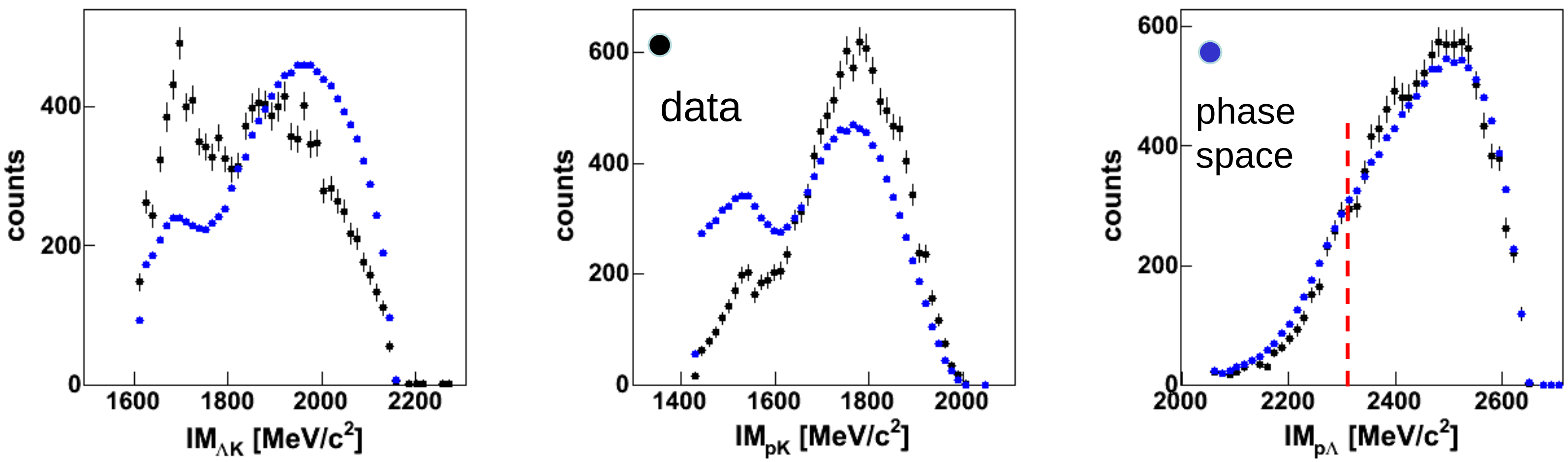
Search for ppK$^-$ bound state in p+p @ 3.5 GeV

HADES

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

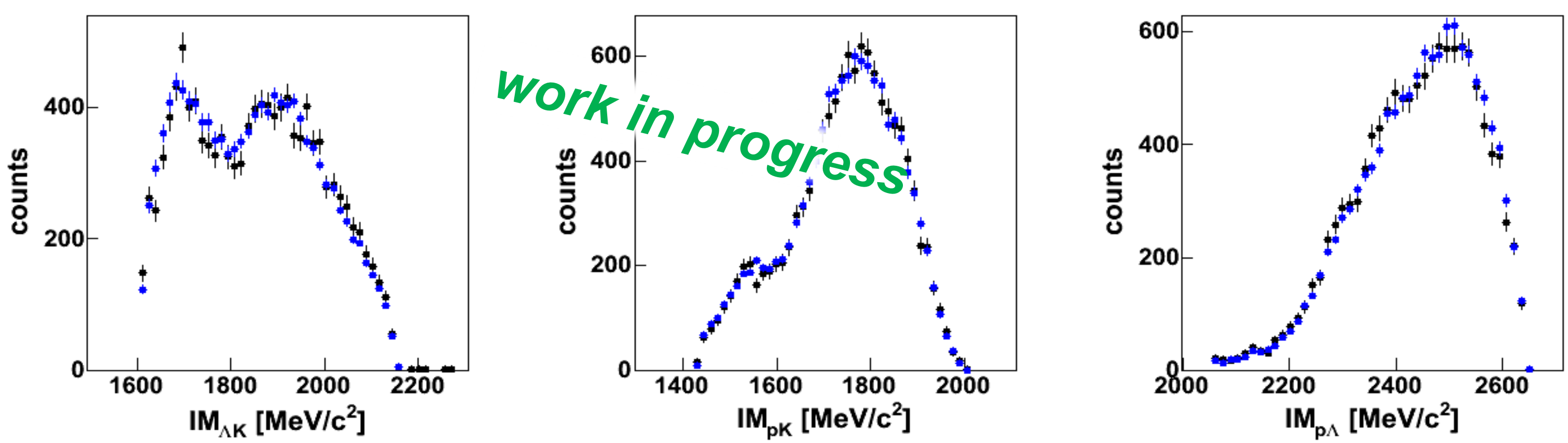
Λp

pK$^+\Lambda$ final state



--DISTO signal (M~2.27GeV)

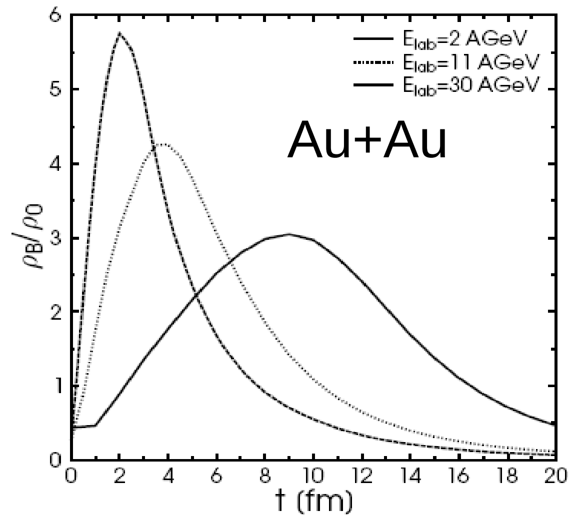
PWA (Bonn-Gatchina) –(one example) N*(1650)$^+$/N*(1710)$^+$/N*(1720)$^+$/N*(1875)$^+$ /N*(1900)$^+$+non resonant



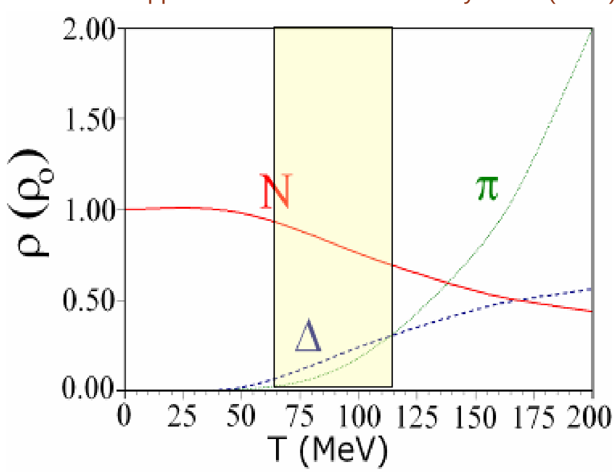
aim: global analysis of HADES/DISTO/COSY-TOF data

Case of A+A @ 1-2AGeV

S.Vogel et al. (URQMD) arXiv:0710.4463v2



Rapp & Wambach Adv. Nucl. Phys. 25 (2000)



1-2 AGeV : moderate densities but long system life time

Baryonic matter:

- ρ/ρ_N = 1-3, T< 80 MeV, τ ~12-14 fm/c

  nucleons, baryonic resonances (~30%) Δ_{33}

  mesons(π^0) ~10% "**resonance (Δ, N*) matter**"

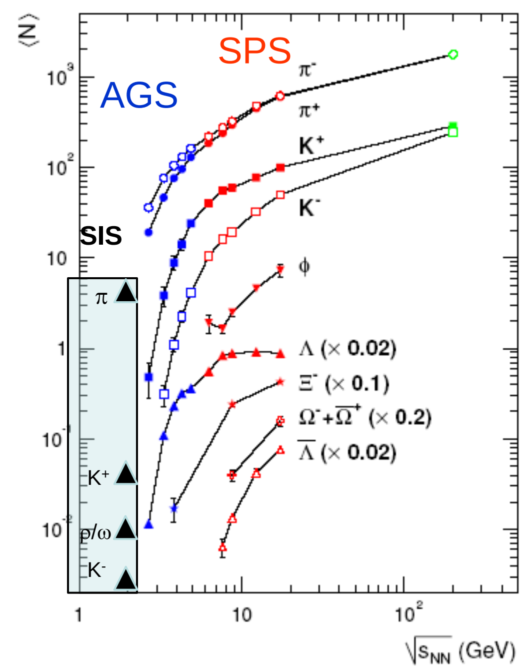
- **Sub-threshold** production of (ω, ϕ, K^- K+, Ξ) :
- confined to high density zone
- Multi-step processes ~ Apart $^{\alpha>1}$

  ex:

  N+N->NΔ , Δ+N→N +N + ϕ

  N+N>NKΛ , $\pi\Lambda\rightarrow\overline{K}$N

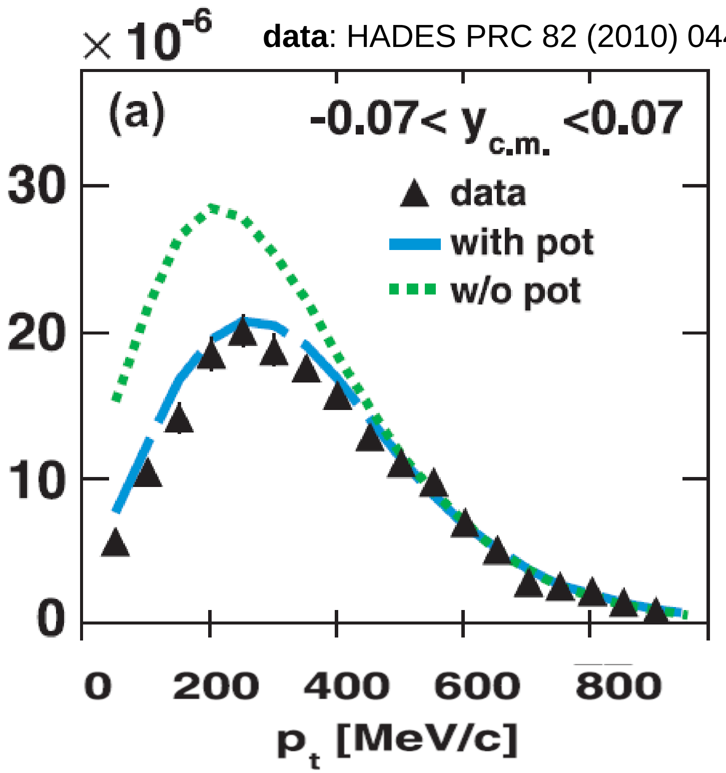
$$P_{\rho/\omega\rightarrow e+e-} \cong 10^{-6} \; !$$



K^0_s and K^+ production in A+A

K^0_s in Ar+KCl @ 1.756 GeV

data: HADES PRC 82 (2010) 044907

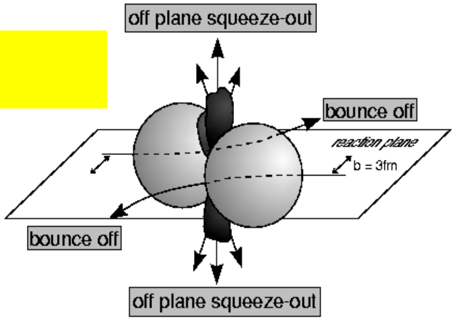


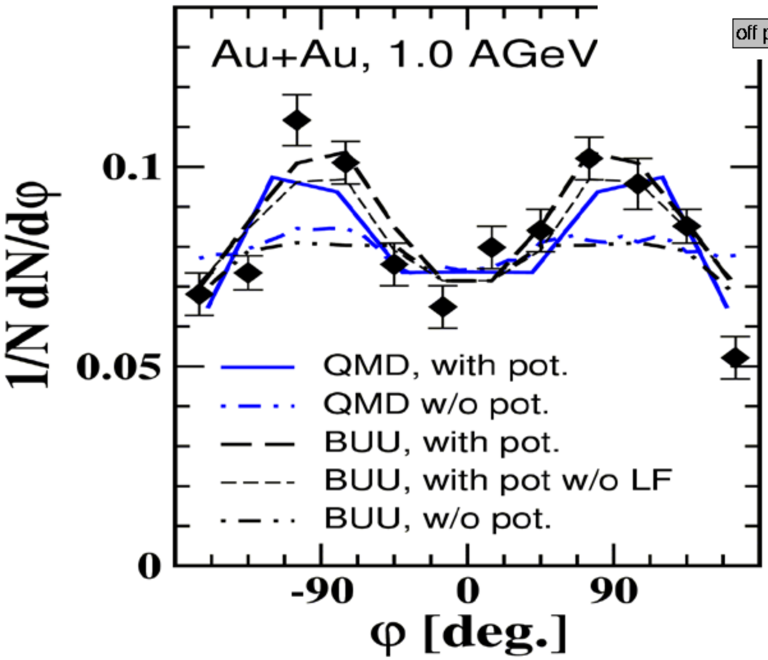
Transport models: $U_{KN} \cong$ 20-40 MeV

K^+ in Au+Au @ 1.0 GeV

flow:

Kaos PRLett. 95(2005) 012301





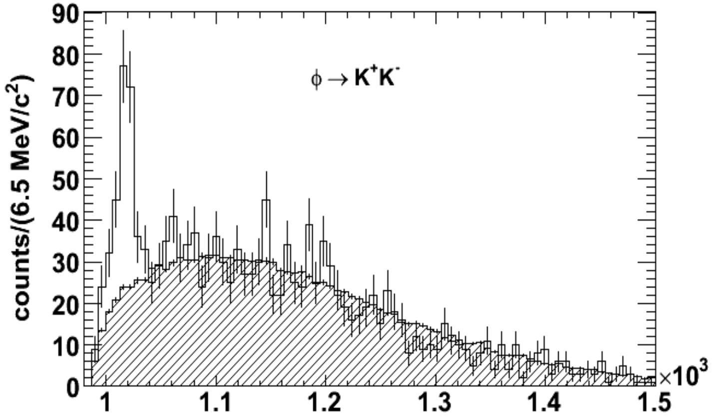
Kaons are repealed from nuclear matter:

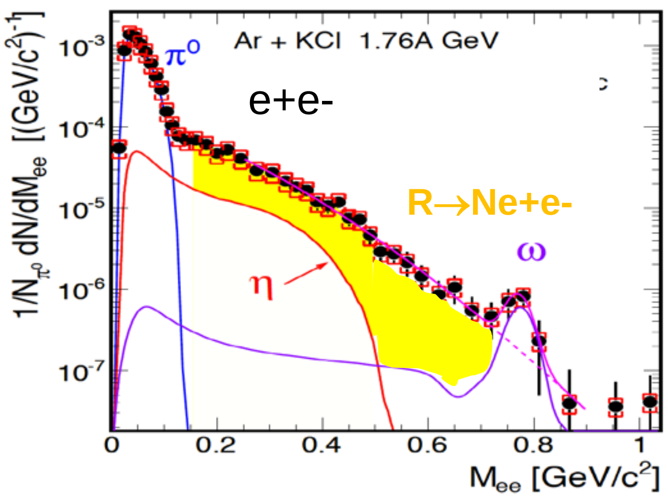
- flow out of plane : KAOS, FOPI
- reduced yield at low p_t (p): FOPI, ANKE

…but usually assumed $m^* = m(1- \alpha\, \rho_B / \rho_0)$ far too simple…

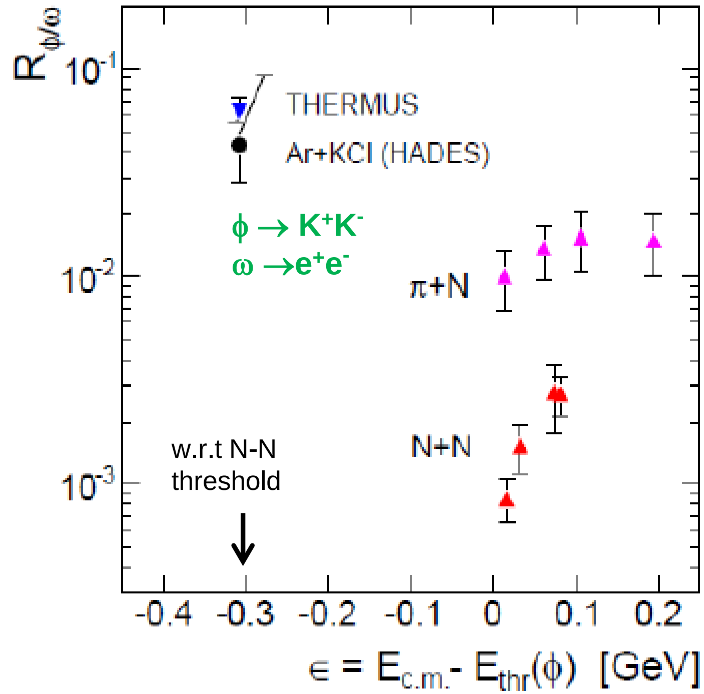
- Results for K^- are not yet conclusive…

ϕ and ϕ/ω ratio in Ar + KCl





$R_{\phi/\omega}$ $^{A+A}$ >> $R_{\phi/\omega}$ in NN and πN reactions

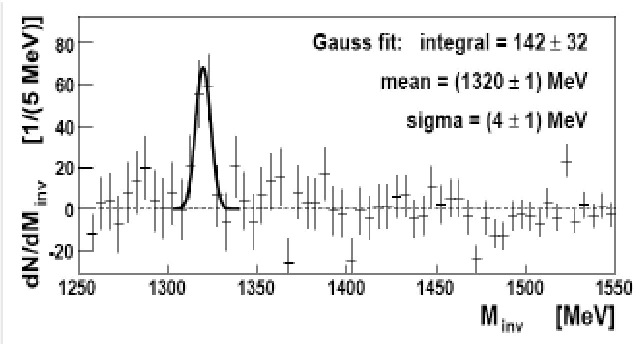


$$OZI : \phi/\omega \quad = \tan^2 \delta \cong 4.2 \cdot 10^{-3}$$

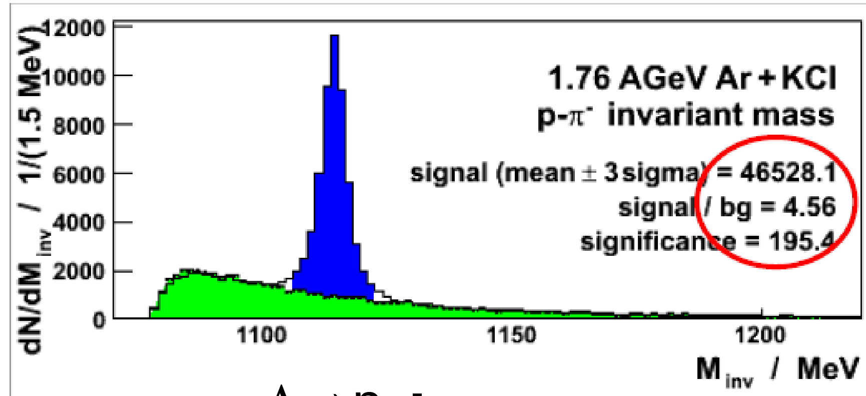
- $R_{\phi/\omega}$ $^{A+A}$: enhanced vs NN and πN
- ϕ and ω rates described by statistical hadronization models ; no suppression for $s\bar{s}$

Double strange Ξ^- (1321) in Ar+KCl

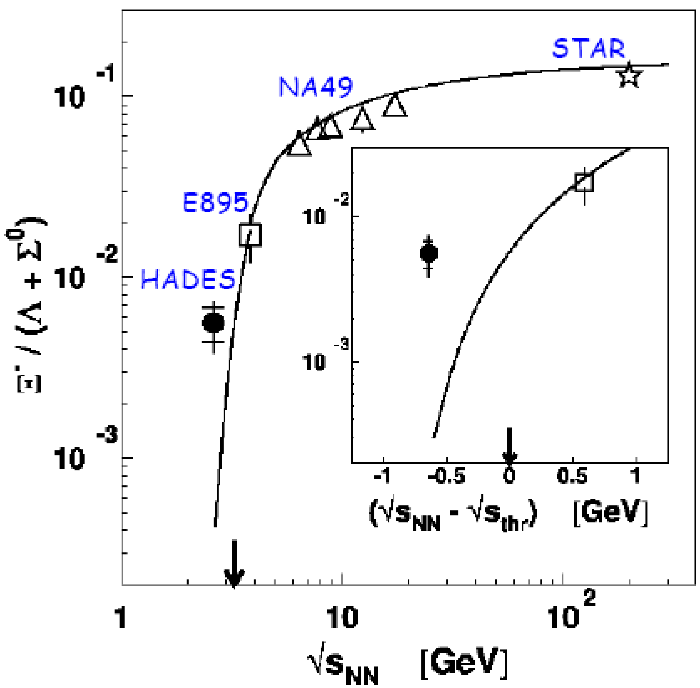
data: PRL 103 (2009) 132310



$\Xi^- \rightarrow \Lambda\pi^-$



$\Lambda \rightarrow p\pi^-$



first measurement 640 MeV below NN threshold !

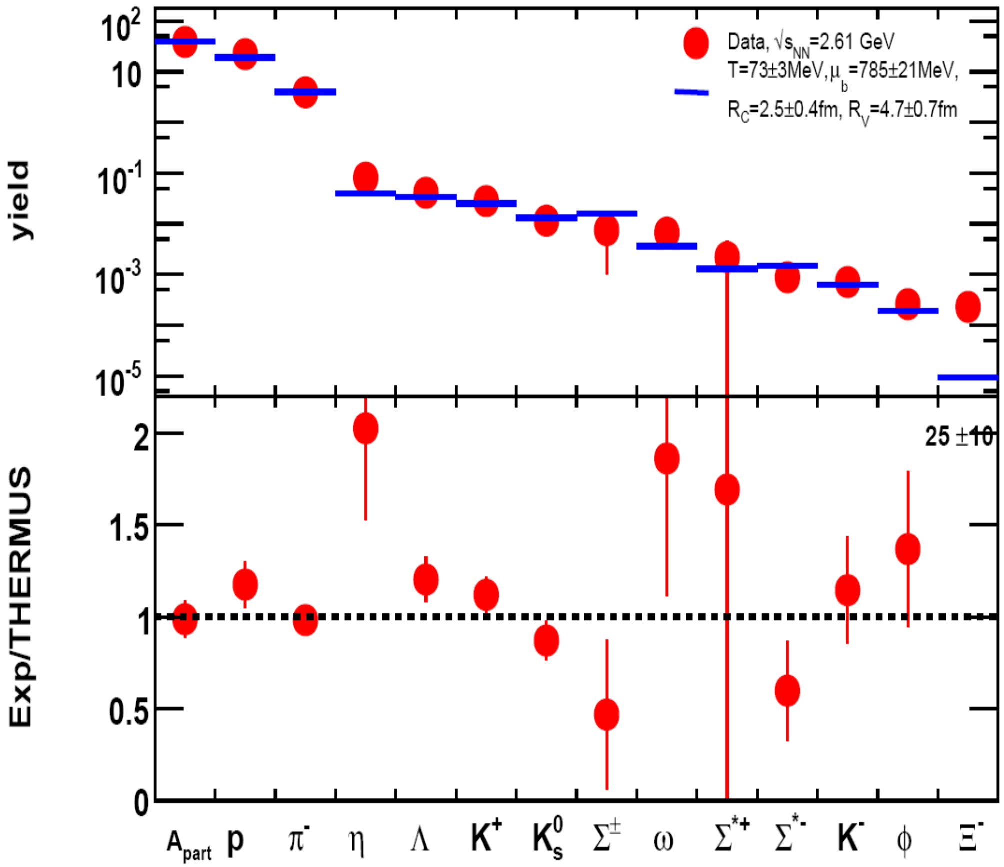
what is the production process?
strangeness exchange
$K^- Y \rightarrow \pi \, \Xi^-$?

Ξ production significantly larger then transport & statistical hadronization models

Statistical hadronization model at work

data : Ar+KCl HADES:
EPJA 47 (2011) 21

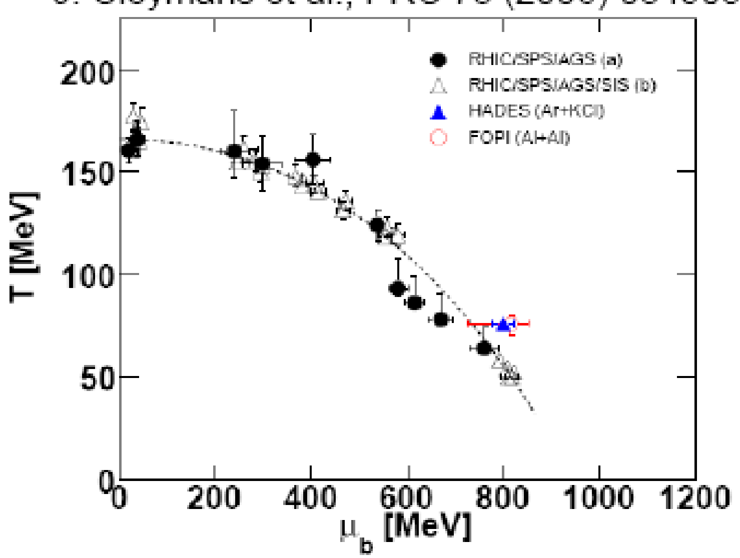
SHM: S. Wheaton, J. Cleymans,
Comp. Phys. Comm. 180 (2009) 84



calculation with Thermus (SHM): strangeness: canonical ensamble with suppression induced via strangeness conservation colume (R_C)

- enhanced η (2), ϕ (hidden strangeness)
- enhanced Ξ (~25)
- overal χ^2/n.d.f ~2.3

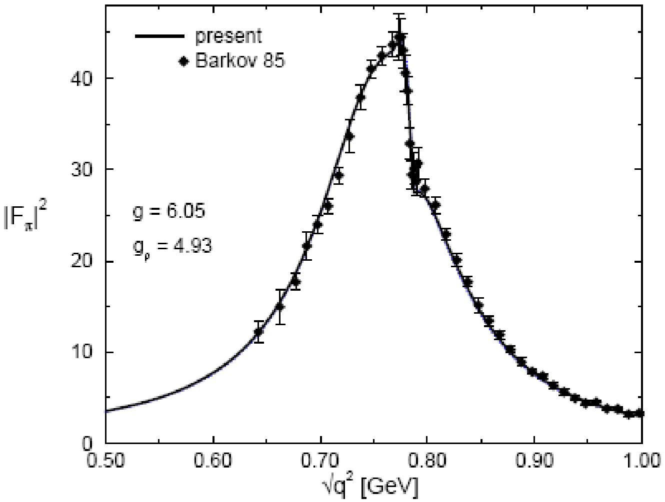
J. Cleymans et al., PRC 73 (2006) 034905

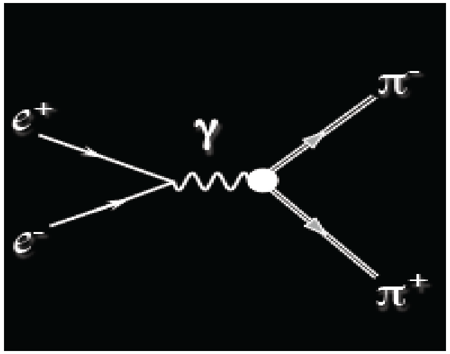


- what is the mechanism of thermalization?

ρ -meson in vacumm and nuclear matter

e+e- annihilation into 2 pions: charged pion form factor

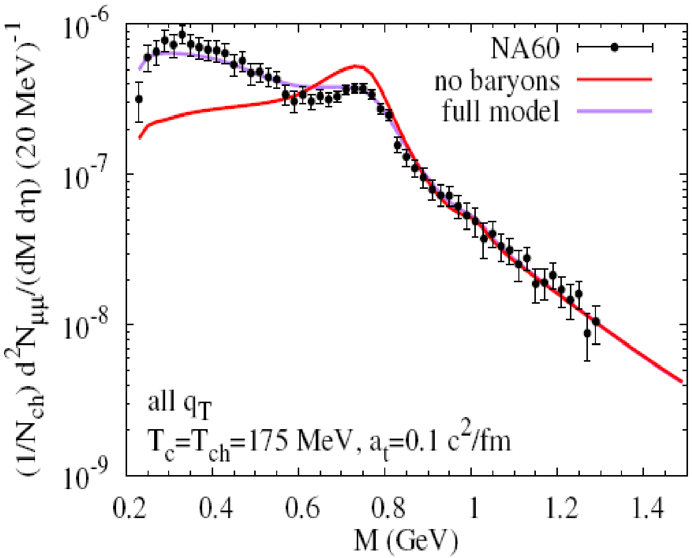




ρ meson dominance

1967: Sakurai
Vector Meson Dominance

$\pi^+ \pi^-$ annihilation into e+e- in hot nuclear matter (HI collisions)

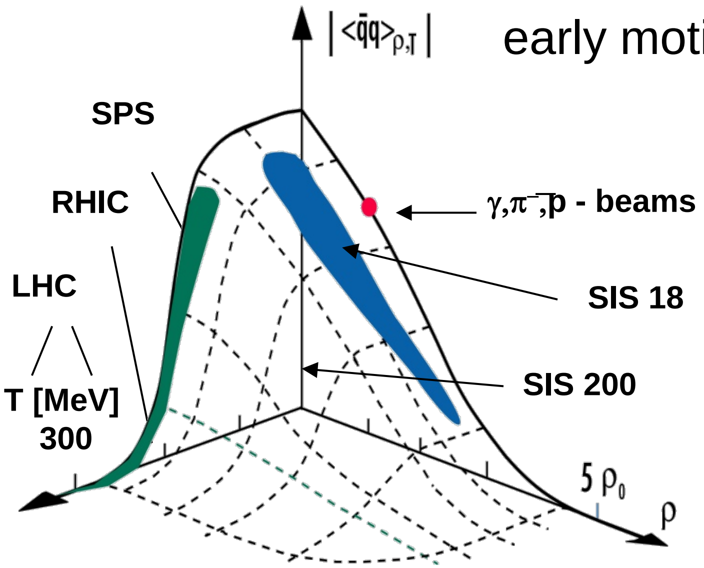


ρ meson gets very broad !

Melting of the meson in nuclear matter

Vector mesons in medium & ChS restoration..

early motivation



G.E. Brown / M. Rho: Scaling of masses with χ-condensate (PRL 1989, 1991)

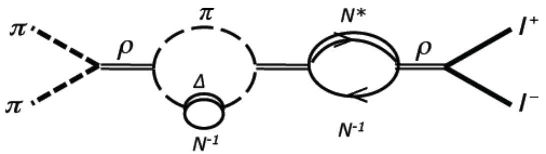
$$m^* \approx m\left[\langle\bar{q}q^*\rangle / \langle\bar{q}q\rangle\right]^u$$

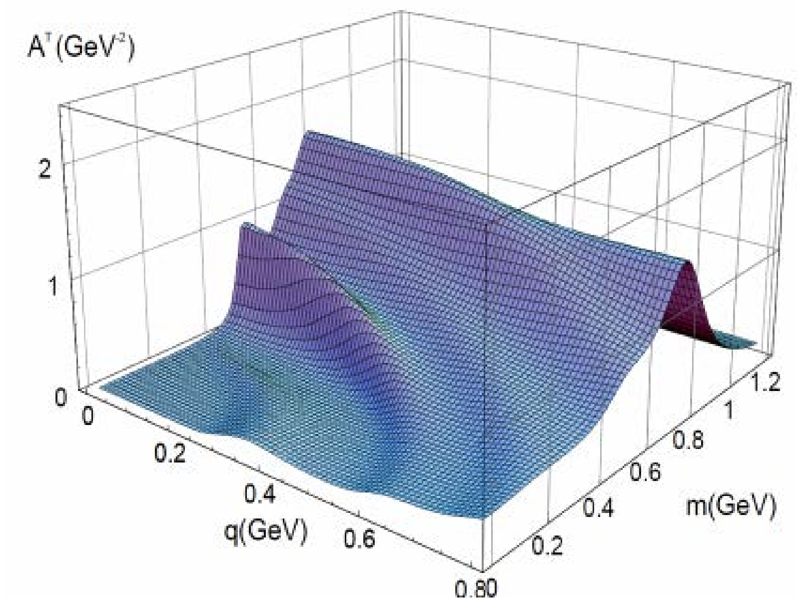
T. Hatsuda /S. Lee: QCD sum rules
PRC46(1992)R34

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

hadronic many body interactions-
ρ spectral functions..

ρ- meson at 2 x ρ_N

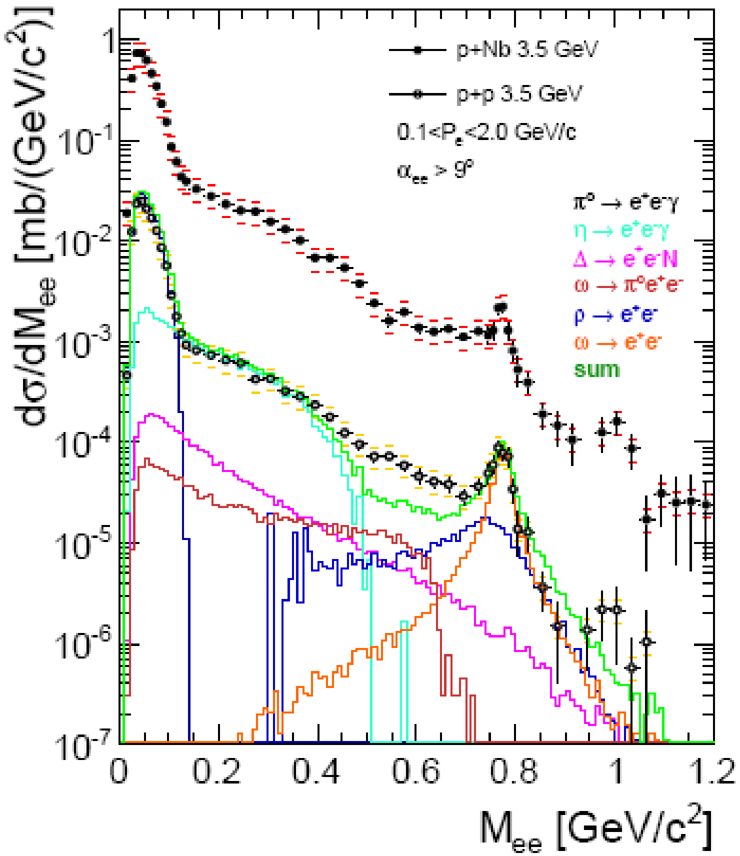




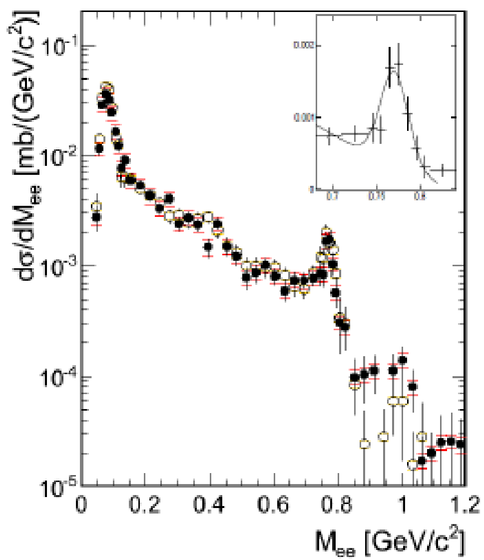
S. Leupold et al.
NPA 741 (2004) 81, NPA 780 (2006) 187

p+p vs p+Nb @ 3.5 GeV

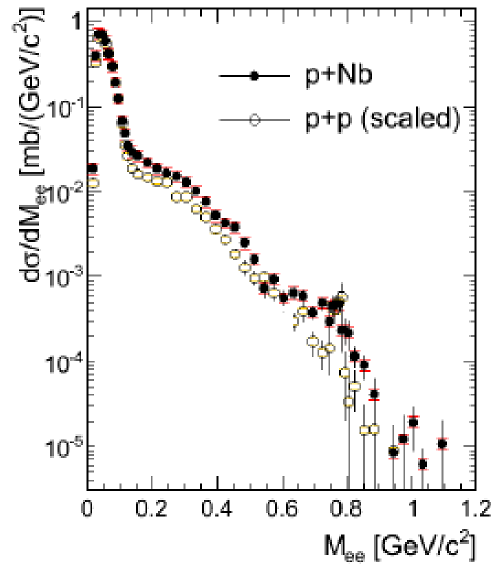
data: arXiv:1205.1918 submitted to PRL



„fast" p_{e+e-}>0.8 GeV/c



„fast" p_{e+e-}< 0.8 GeV/c



pp data scaled by „A_{part}" scaling

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

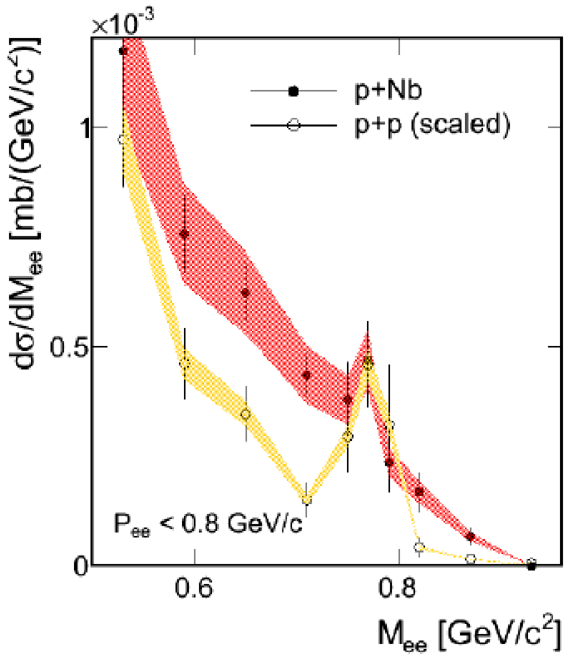
Nuclear modification factor

- large acceptance at small M_{e+e-} and p (<1 GeV/c) **(first measurement at low p !)**
- p+p cockail : based on known sources fixed to data π^0 /η/ ω/ ρ

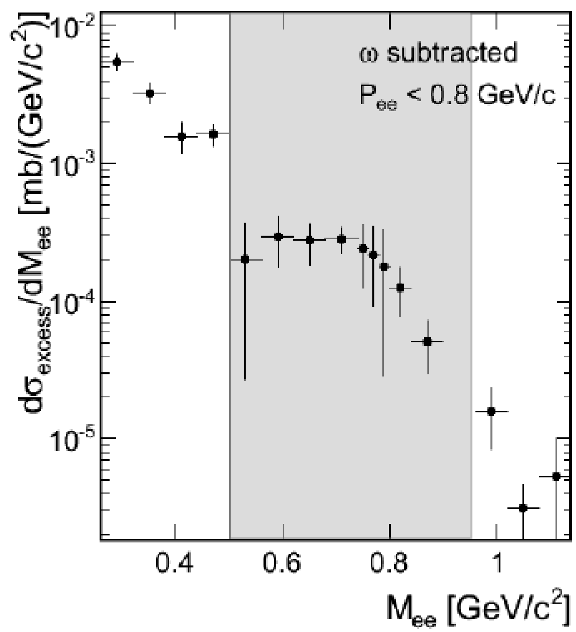
underestimated e+e- yield below VM pole → missing component? -> higher resonances (Δ, N*)

e+e- excess in p+Nb

„slow” (p<0.8 GeV/c) pairs



„excess over pp reference”



☝ clear excess in p+A below VM pole & absorption of ω **(observed also in γ+A exp)**

↓

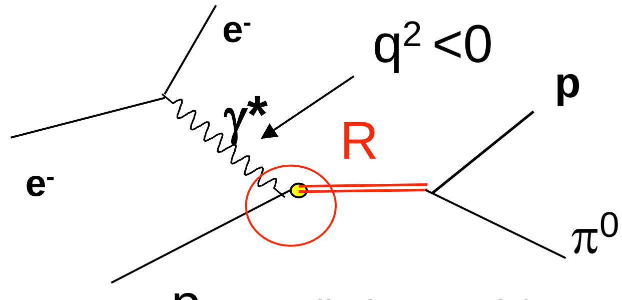
secondary reactions : π+N → N* (1520),N*(1720), Δ(1620)→Nρ→Ne+e- (i.e transport models)

or/and in medium ρ modification ?

first **R→pe+e- decay process must be understood !**

Baryon resonance structure

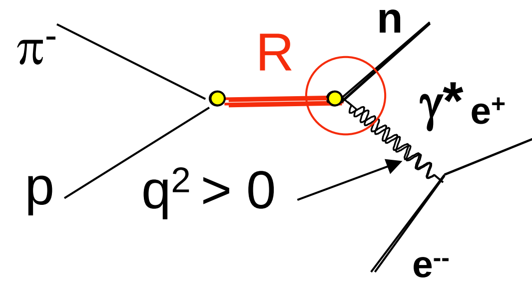
Space-Like el.Transition Form Factors



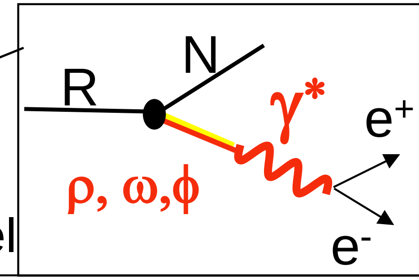
studied at JLab/CLAS/MAMI,..

pion electroproduction

Time-Like el.Transition Form Factors : Dalitz decays

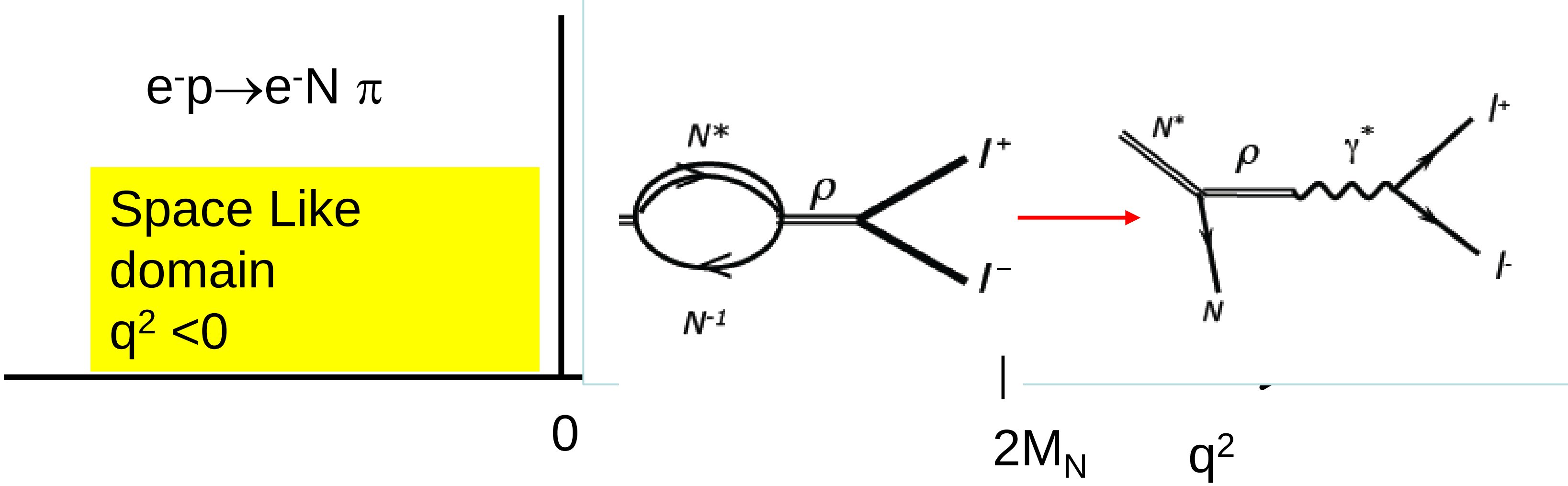


Vector **D**ominance **M**odel



Dalitz Decays: poorly known !

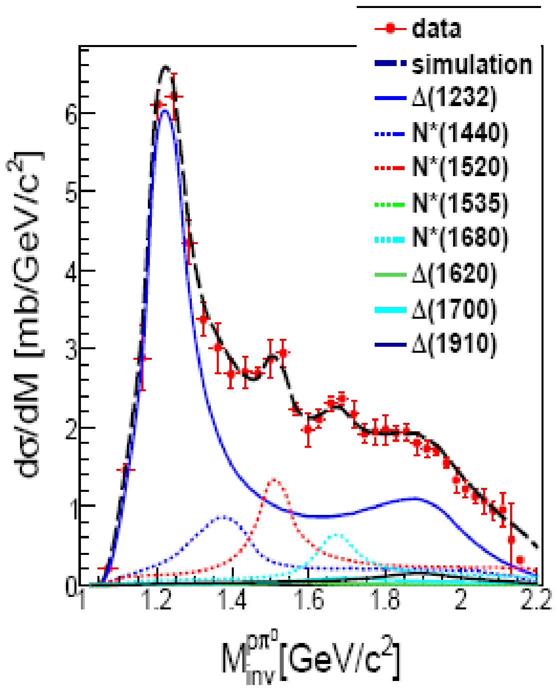
☝ directly related to :



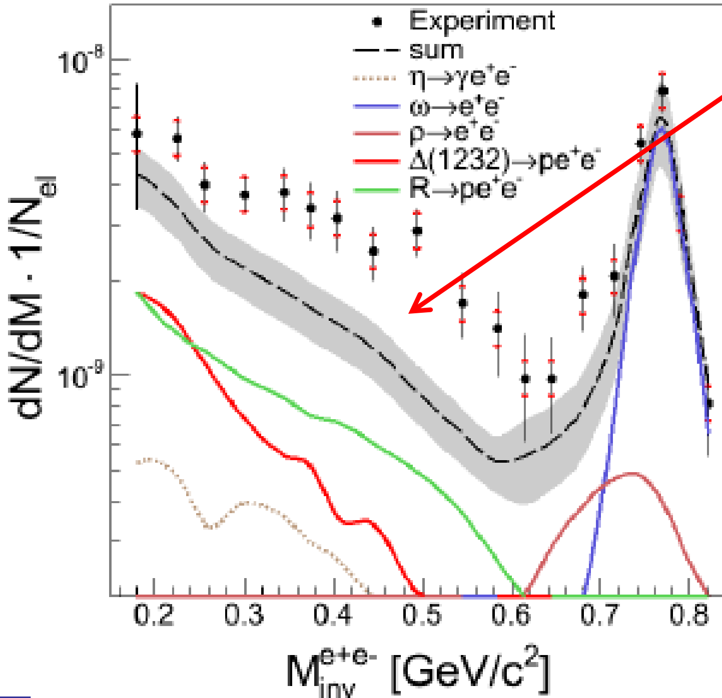
e+e- from Baryon Resonances in vacuum

HADES

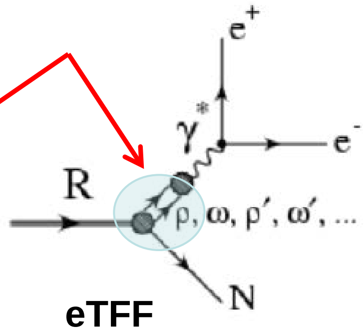
pp->ppπ^0 @3.5 GeV



pp->ppe+e- @3.5 GeV



eTFF-em. Transition Form Factors



eTFF

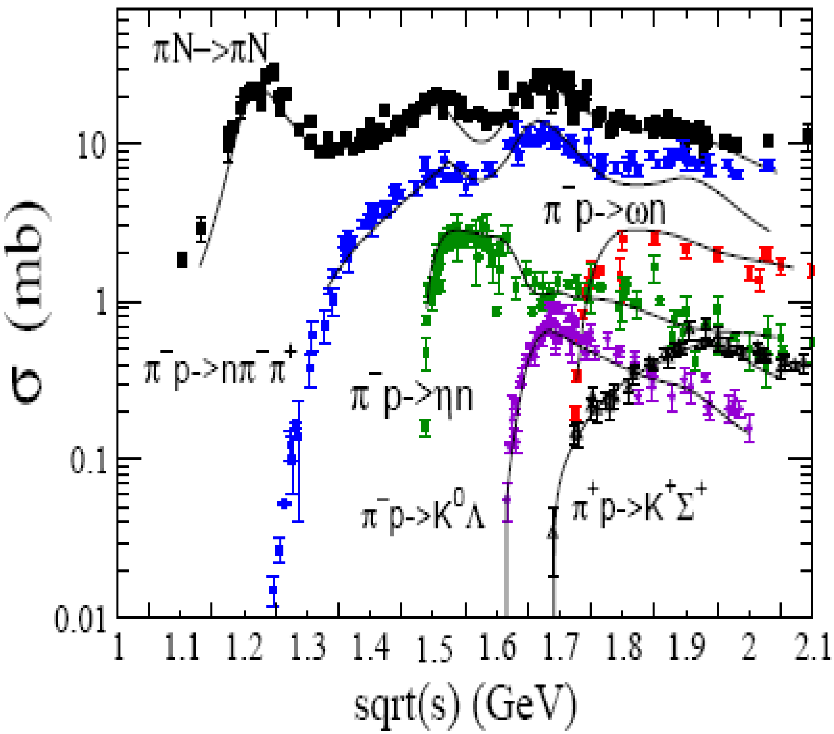
- Resonance contribution estimated from ppπ^0 and pnπ^+ channels

- Resonances (R) with Mass up to 2 GeV included

calculations with point-like RNγ^* does not describe data

eTFF(Me$^+$e-) dependence very important -> Vector Meson contribution !

pion beams at SIS18: HADES in 2014



differential distributions are even more scarce (or missing)

Badly need for hadron physics to improve our undertsanding of baryon resonance properties!

For physics discussed in this talk:

- $\pi^+ \pi^-$ production : coupling of ρ to resonance

old „Manley” analysis PRD30,(1984) 904
1.3 <√s <2 was based on 240 000 events (differential; distributions not avialable)

Full excitation function can be measured with HADES within 2 weeks!

+ many others like : $\pi^- p \rightarrow \pi^- p$, $\pi^- p \rightarrow K^0 \Lambda$, $K^+ \Sigma^-$

needed for PWA and coupled channel calculations

- e+e- never measured

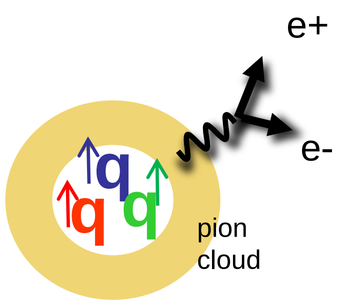
Resonance Dalitz decays R→Ne+e- (electromagnetic Transition Form Factors)

- meson production of nucleus : $K^{\pm}$, ρ, ω, ϕ

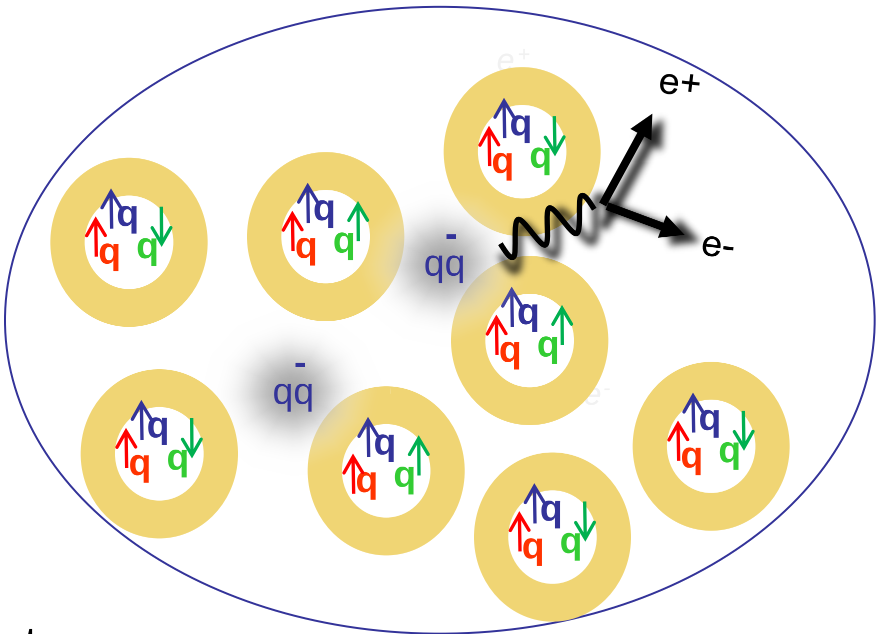
Radiation from baryonic matter

Vacumm

$\Delta(N^{*}) \rightarrow Ne+e-$



Dense matter 2-4ρ_0 :
baryon resonances + nucleons +
(20-30%) pions



1) How does the γ^{*}(e+e-) couples to resonance

1) How does the radiation from „resonance” matter look like?

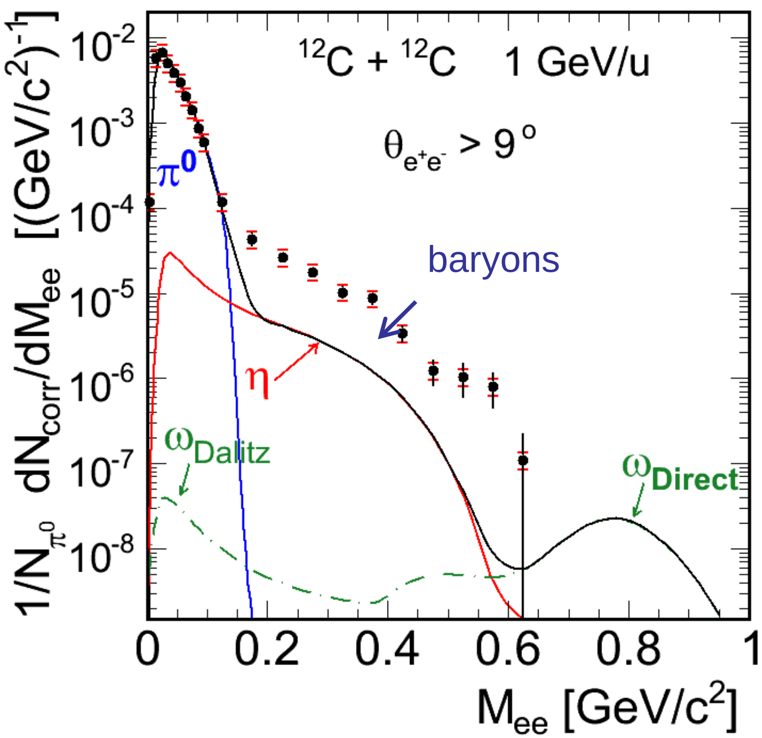
superposition of NN reactions?

multistep processes (transport) ?

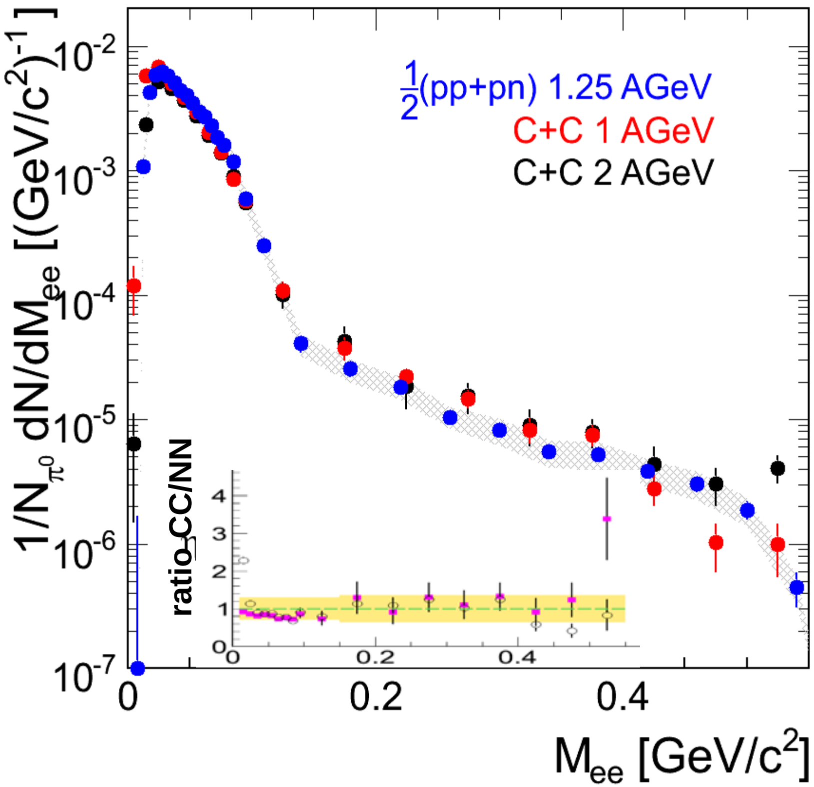
thermalized system ?

CC compared to NN reference.

cocktail: „long lived sources”-freeze out



η contribution subtracted

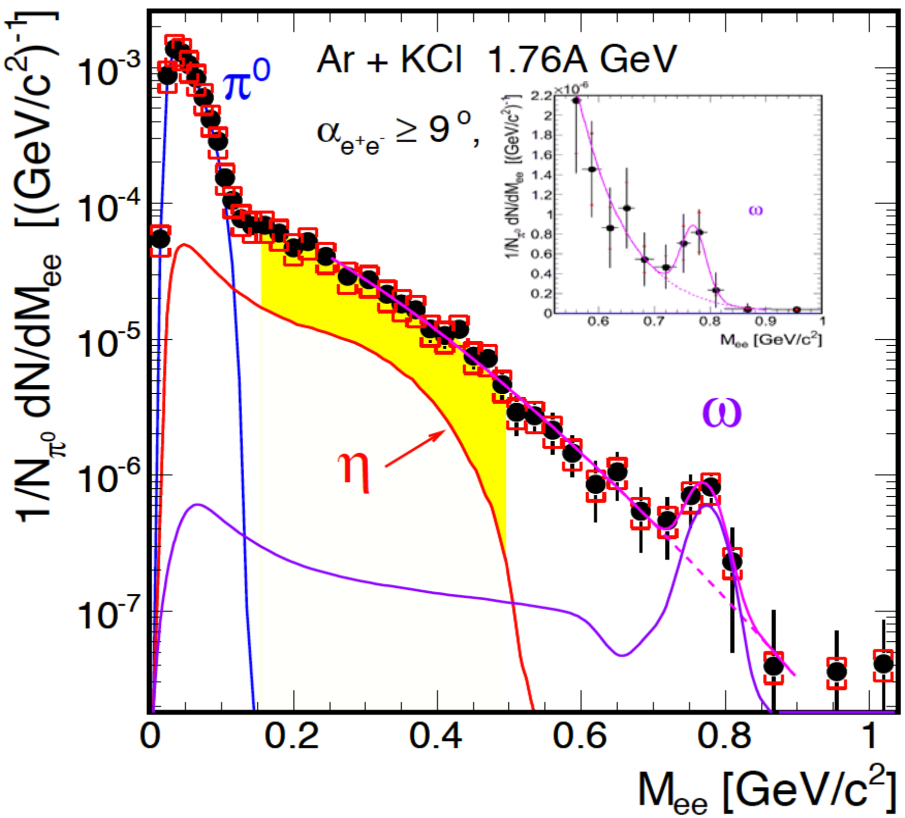


data: HADES PLB690 (2010)118 PRL98(2007) 052302

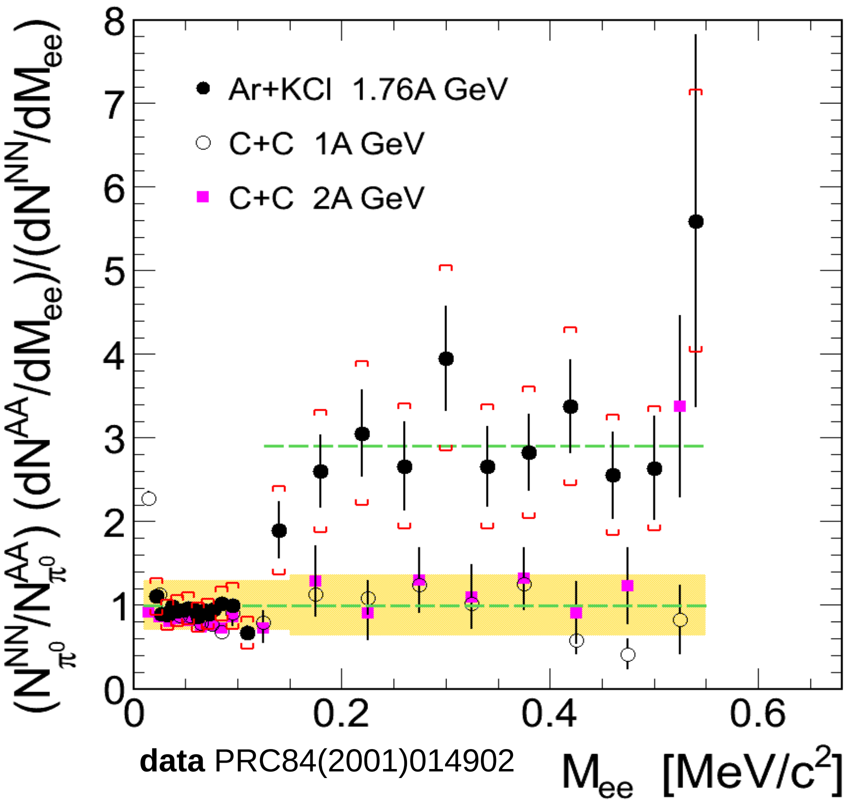
- NN and C+C normalized to the individual N(π^0)
- *C+C* data (1 and 2 AGeV !) reproduced (within 20%) by superposition of NN interactions (reference) – no room (within error bars) for in-medium effects

e+e- pairs from Ar+KCl @ 1.756

Cocktail with „freeze-out" comp.



η component subtracted



data PRC84(2001)014902

- excess related to radiation from inside of the firelball
- radiation from short lived resonance states propagating in matter ?

$\tau_{firellball}$ ~ 8-10 fm/c > τ_{Δ} ~ 1.3 fm/c → N_{e+e} ~ τ_{e+e-} Volume

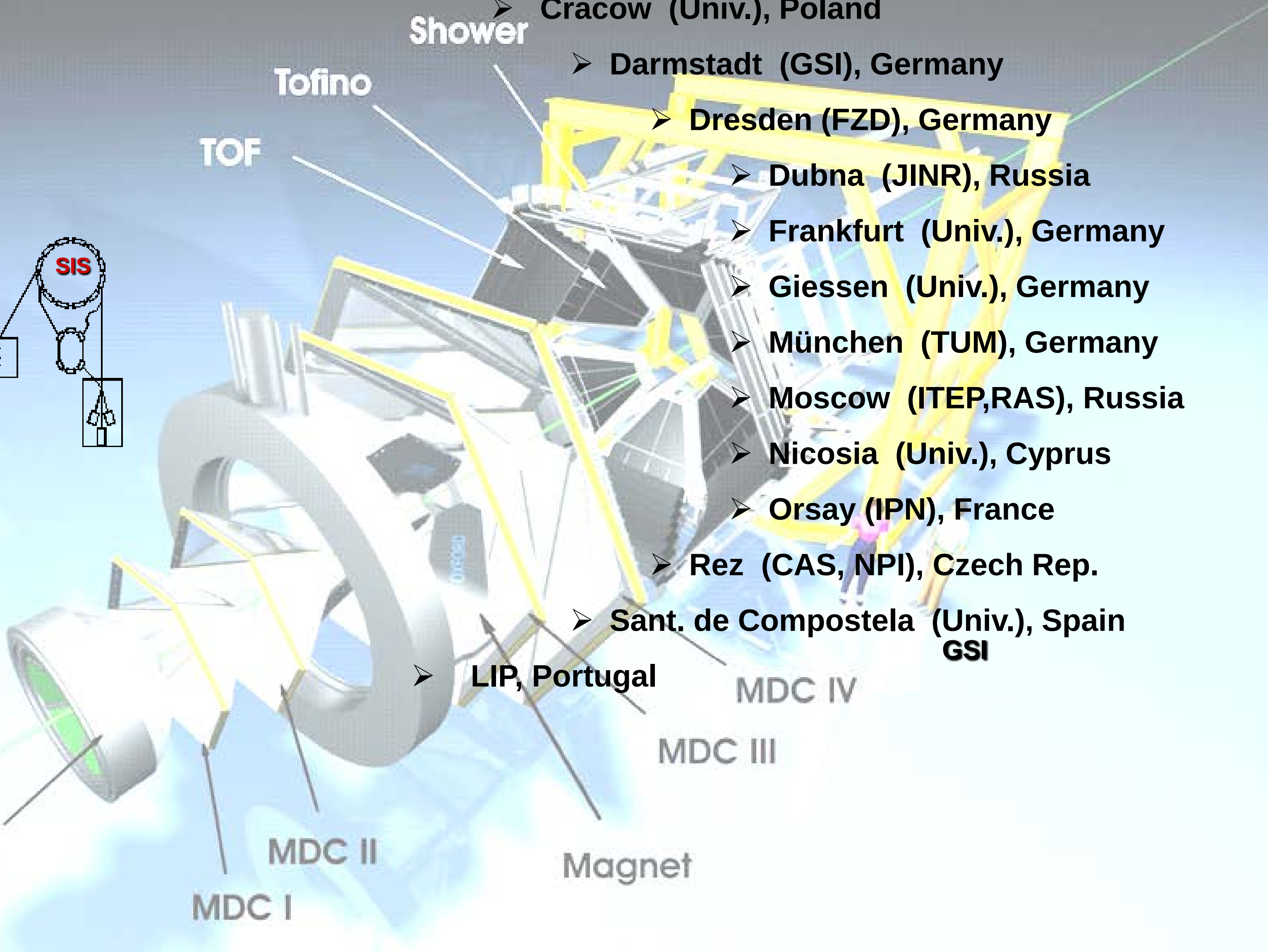
Summary:

- new K^0_S data support repulsive KN in-medium potential ; Λ(1405) is crucial for antykaon properties in nuclear matter -> pp data waits for comparison with microscopic calculations
- enhanced ϕ production w.r.t. NN/ πN data
- enhanced (above SHM predictions) production of double strange Ξ(1321)
- in-medium effects on ρ (p+A) are not clear yet :

  determination of ρ -meson shape in N-N collisions („vacumm”) is far from trivial and requires better understanding of Δ/N^* -ρ couplings $\rightarrow$ el.Transition Form Factors , work is in progress

  Properties of baryon resonances in nuclear matter are strongly related to the in medium ρ properties
- pion beam programme essential for understanding of vector meson in-medium properties & kaon production

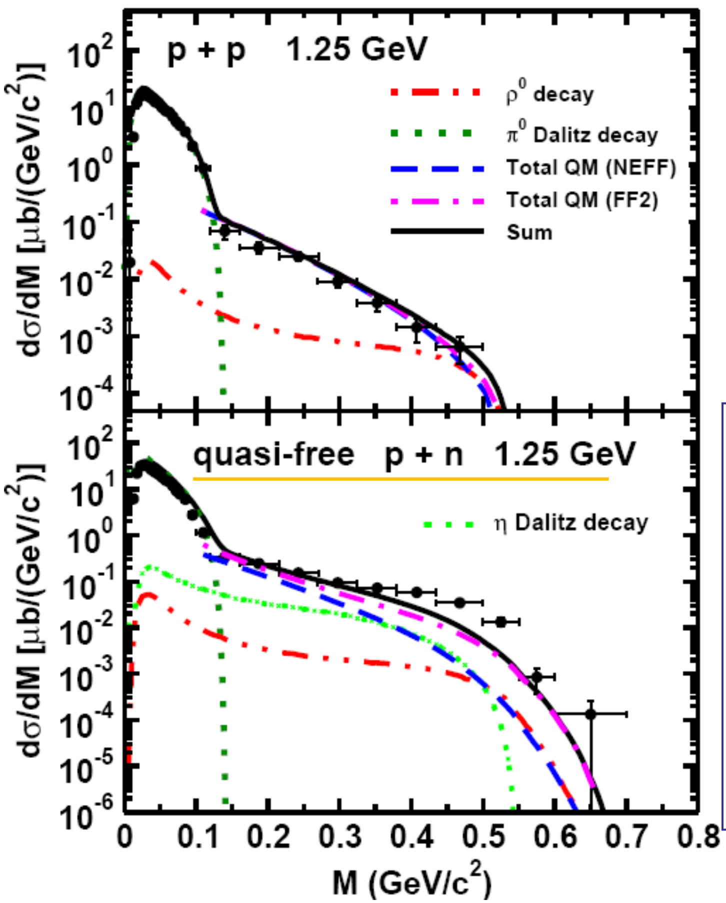
The Collaboration



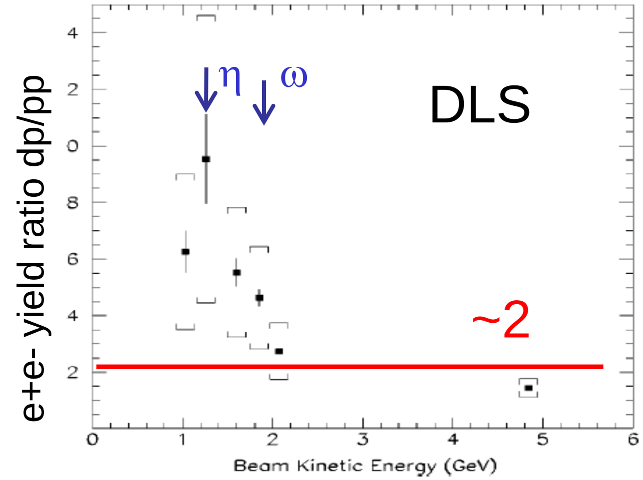
- Cracow (Univ.), Poland
- Darmstadt (GSI), Germany
- Dresden (FZD), Germany
- Dubna (JINR), Russia
- Frankfurt (Univ.), Germany
- Giessen (Univ.), Germany
- München (TUM), Germany
- Moscow (ITEP,RAS), Russia
- Nicosia (Univ.), Cyprus
- Orsay (IPN), France
- Rez (CAS, NPI), Czech Rep.
- Sant. de Compostela (Univ.), Spain
- LIP, Portugal

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

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



Large isospin effect at 1-2 AGeV!

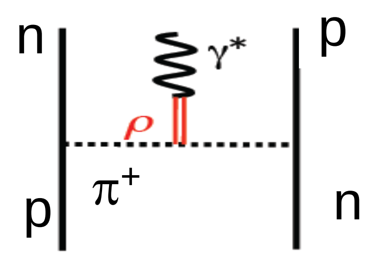


- η production – fixed by COSY, WASA data
- bremsstrahlung pn→pne+e- (non resonant), why it is so much different from pp?

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

charge pion exchange & pion eFormFactor

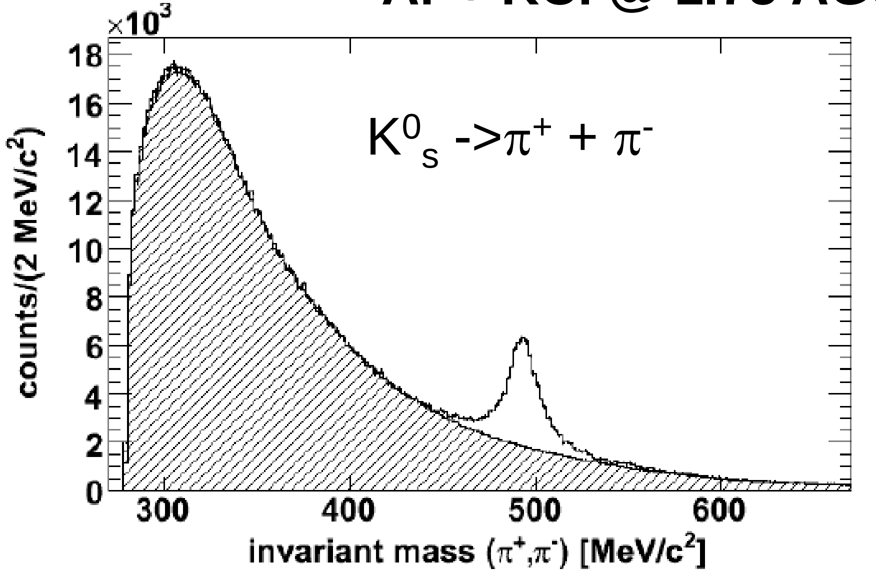
for example:

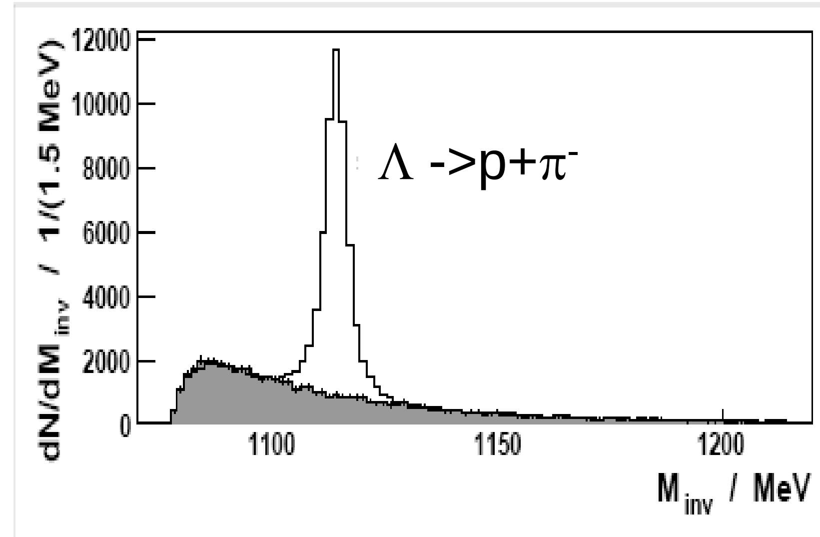


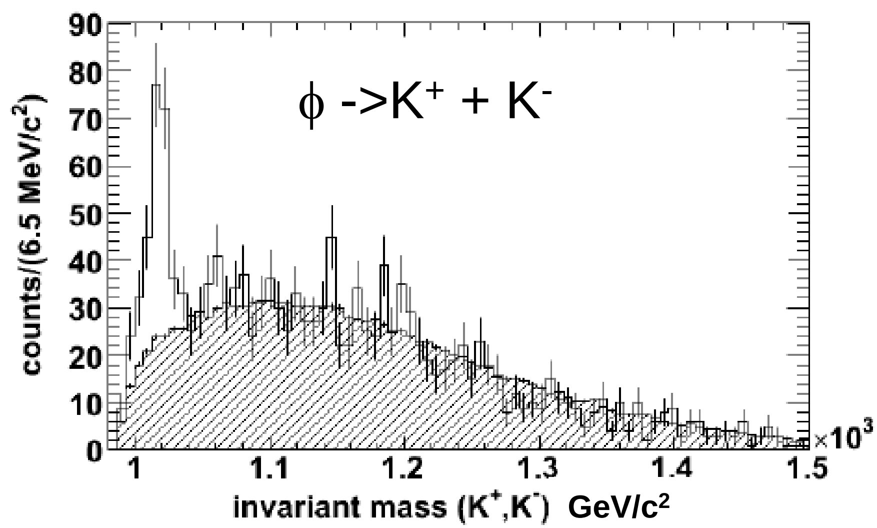
Resonance reconstruction strangeness

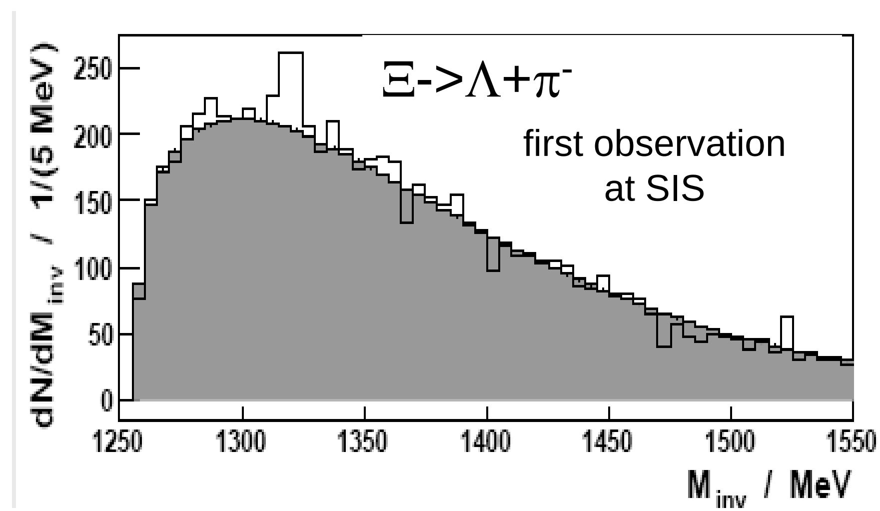
HADES

Ar + KCl @ 1.75 AGeV: excellent rec. capabilities



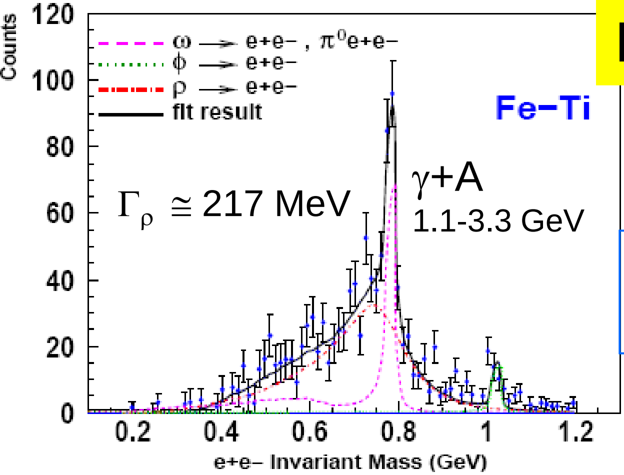






Vector mesons in cold matter- experiments

CLAS PRL 99 (2007) 262302



direct : ρ meson line shape

- no mass shift
- ρ broadenning

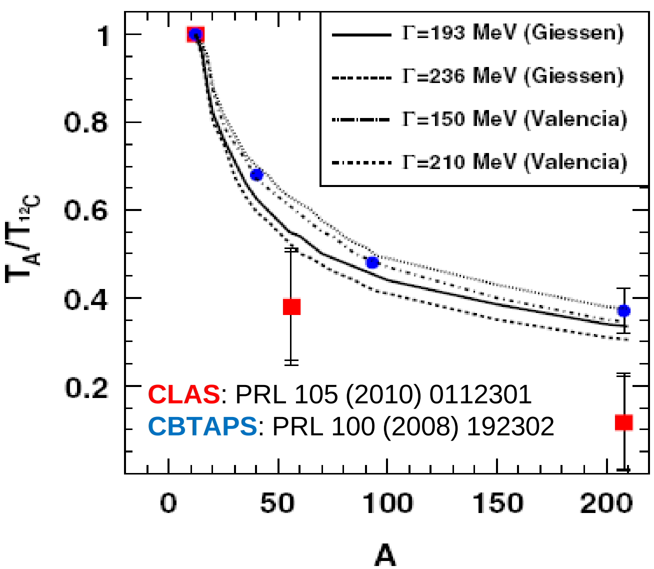
KEK-E325 PRL 96 (2006) 092301

p+Cu 12 GeV

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

indirect: transparency

ω absorption



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

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

$$\Gamma_{\omega}^{*} \sim \rho_N v_{\omega} \sigma_{VN}$$

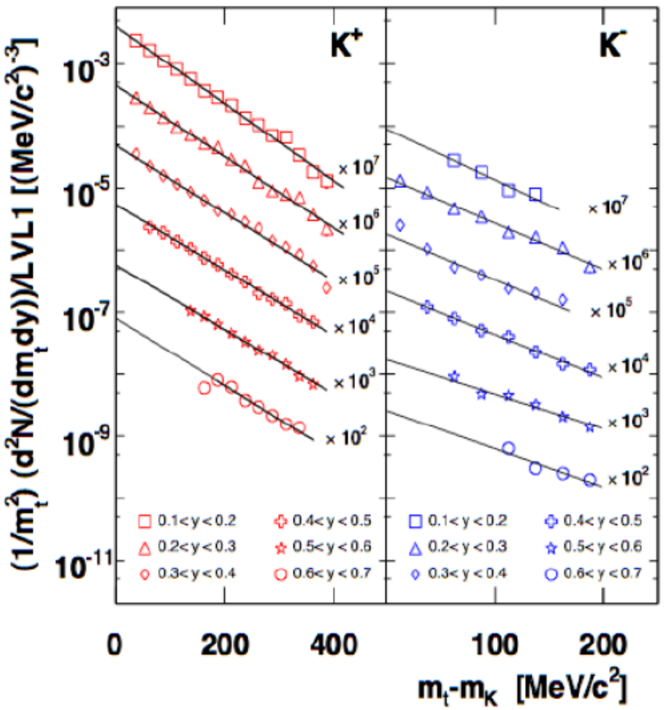
- large ω absorption →

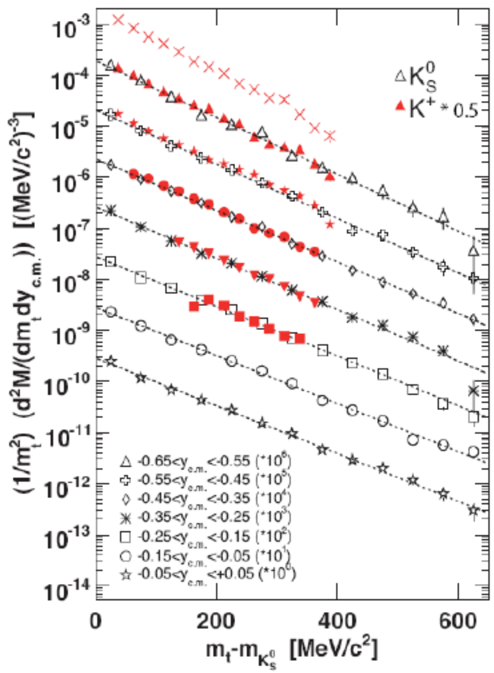
  $\Gamma^*_{tot,\omega} \cong$ 210 MeV !

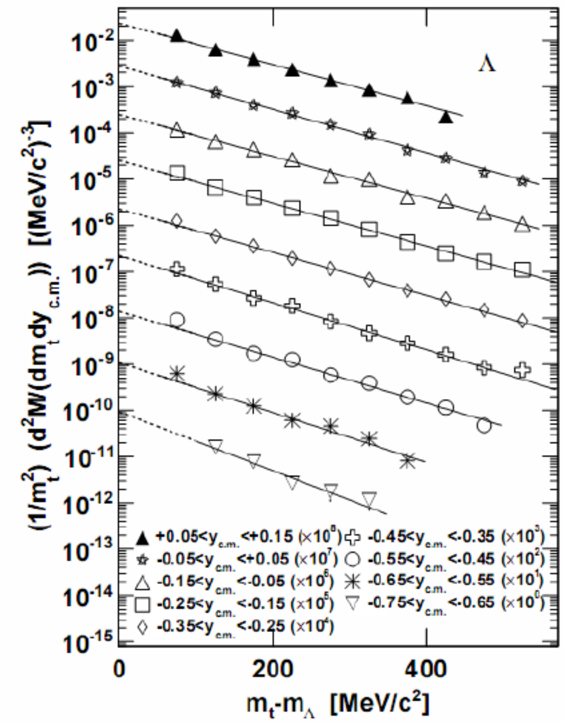
- ϕ meson (SPRING8, ANKE)

  $\Gamma_{\phi}^{*} \sim$ 33 - 50 MeV

Strangness production in ArKcl







Boltzmann fit: $$\frac{1}{m_t^2}\frac{d^2M}{dm_t dy_{cm}} = C(y_{cm}) \exp\left(-\frac{(m_t - m_0)c^2}{T_B(y_{cm})}\right).$$

→ inverse slopes $T_B(y_{cm})$