Exploring compressed nuclear matter with HADES

A. Kugler

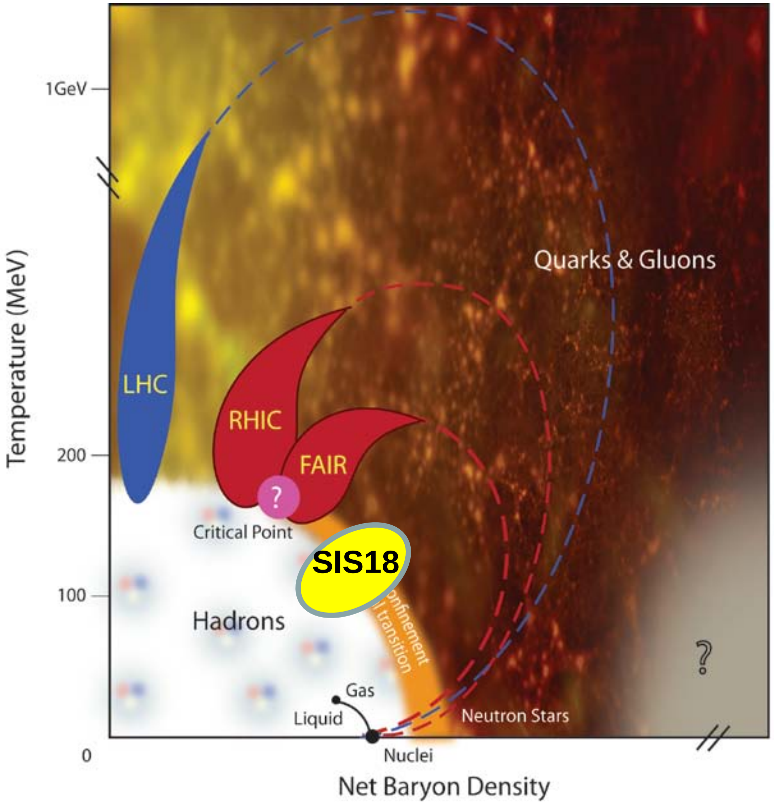
ÚJF AV ČR Řež

for the HADES collaboration

- **Motivation**
- **Elementary collisions**
- **Cold nuclear matter**
- **Compressed matter**
- **Strange probes**
- **Conclusions**

Exploring the Phase Diagram at High Baryon Density

NuPECC Long Range Plan 2010

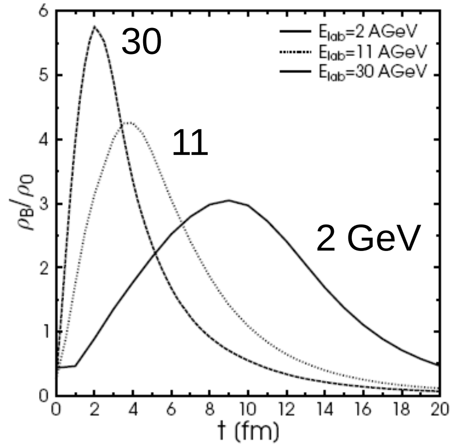


Probing nuclear matter at SIS:

- densities: $\rho_{max}/\rho_0 \cong 2 - 3$
- temperature: $T \cong 50 - 100$ MeV

→ System stays above ground state density for $\tau \cong 10 - 15$ fm/c

S. Vogel et al.
Phys. Rev. C78
044909 (2008)



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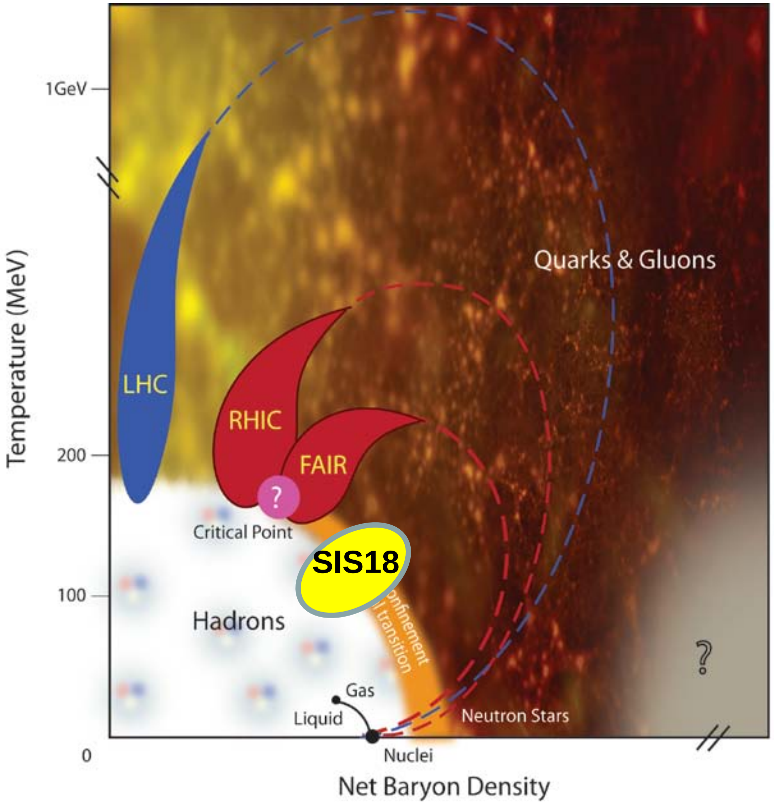

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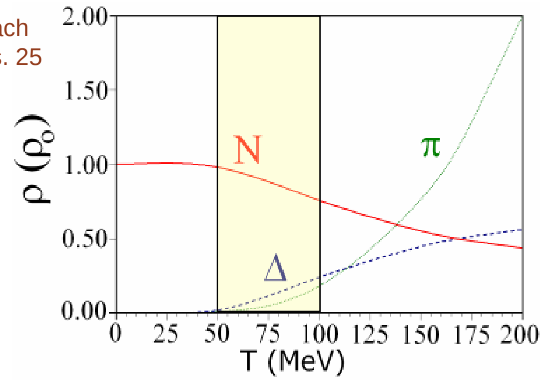
A regime of "Resonance Matter":

- matter dominated by baryons (up to 30% resonances!)
- $\tau_{fireball} \cong 10 \cdot \tau_{resonance}$

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



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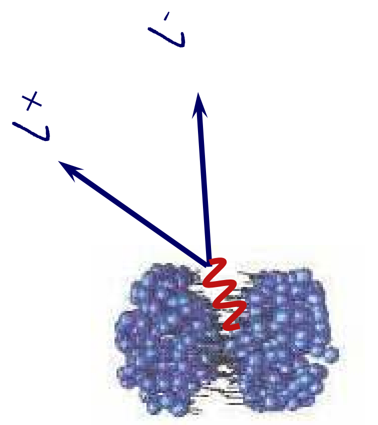
Relativistic Heavy ion collisions

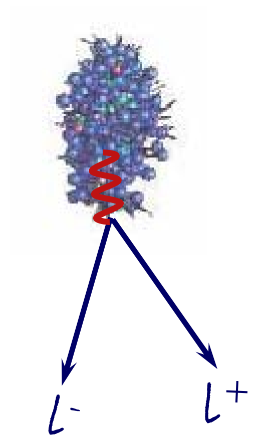
Three stages of collisions:

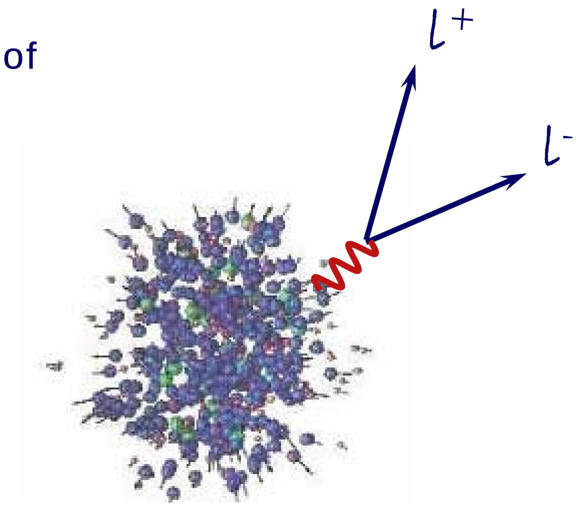
- ✓first chance collisions ~ elementary collisions of nucleons
- ✓compression ~ described by transport models
- ✓Expansion and freeze-out ~ yields given by thermal models



First chance collisions
Bremsstrahlung, hadron resonances …. **yield ~ A_{part}**

Compressed matter
Multistep non-equilibrium production of baryon resonances and of mesons → **yield ~ volume x time ~ A^{α}_{part}, $\alpha > 1$**





Freeze –out
Decays of long-lived particles (π^0, η) produced in thermal chemical equilibrium → **yield ~ volume ~ A_{part}**

High Acceptance Di-Electron Spectrometer

- GSI Darmstadt
- SIS accelerator facility. (HI beams 1-2 A GeV)

Geometry:

- full azimuthal angle, polar angle 18 – 85 deg FW polar angle 0,5-7 deg
- pair acceptance ~ 35%

Charge hadrons identification

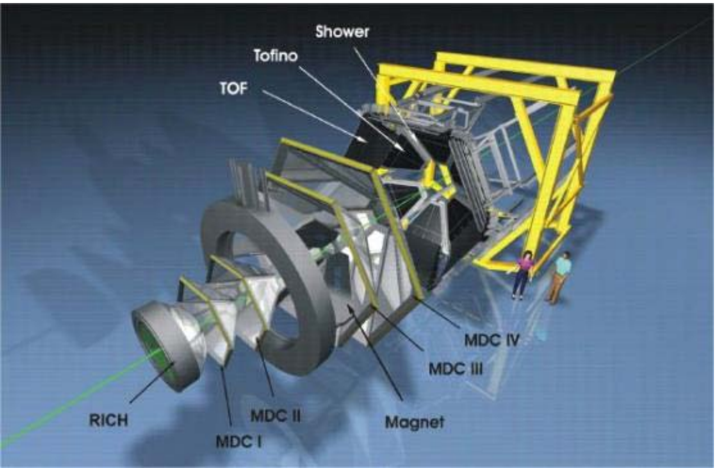
•Momentum measurement by superconducting toroidal magnet &tracking in multi-wire drift chambers

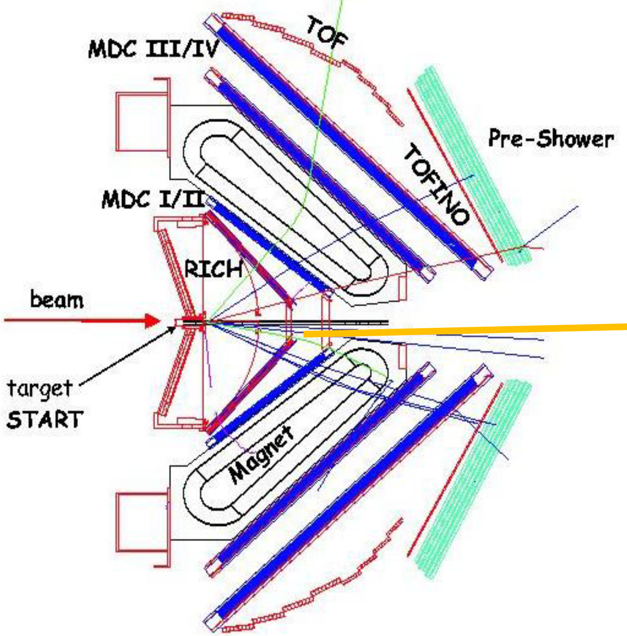
ΔM/M in ω region ~ 2.5%

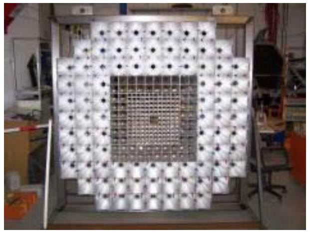
- velocity: tof ≥7ns δt ~ 100ps in TOF
- charge: dE/dx in TOF and/or in MDC

Lepton identification:

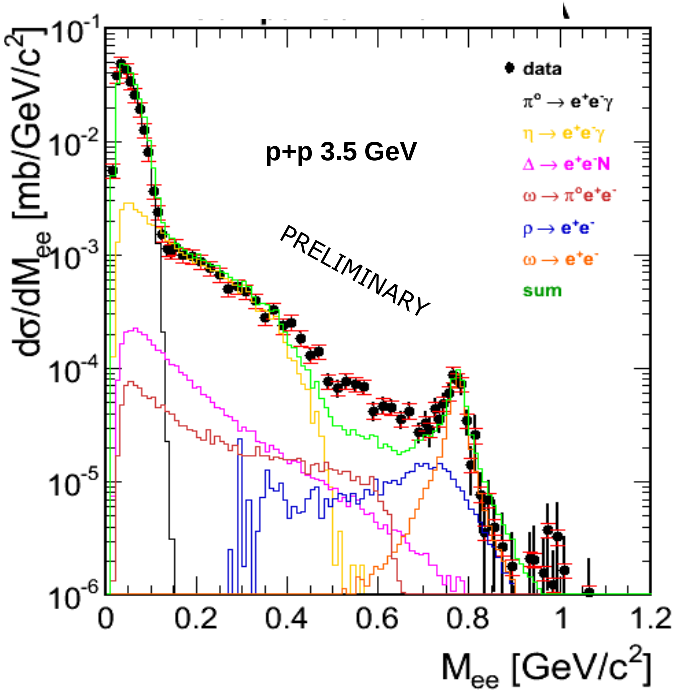
- hadron blind RICH (γ_{thr} > 18.3).
- Pre-Shower







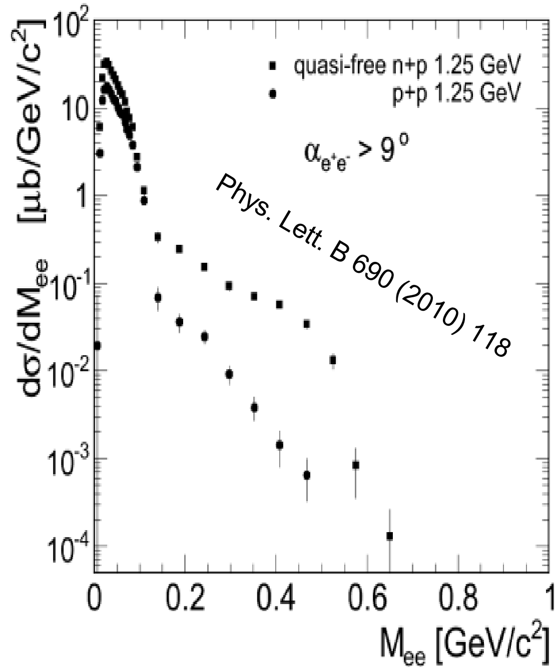
Elementary collisions of nucleons



@3.5 GeV nice description of data by set of sources

PYTHIA
- production cross sections in 4π [mb]
  - π: 18 ± 2.7
  - Δ: 7.5 ± 1.3
  - η: 1.14 ± 0.2
  - ω: 0.233 ± 0.06
  - ρ: 0.273 ± 0.07

PLUTO
decay simulation



p+p 3.5 GeV

normalization by $\sigma_{pp,elastic}$

Isospin:
$\sigma_{pd} = 2\ \sigma_{pp}$ (DLS data for E> 2 GeV)

Tagging quasi-free np reactions with spectator proton with $\sim p_d/2$
This is in contrast to inclusive dp (DLS) !!!

- π^0 yield in *n+p* larger by factor ~2 as known from isospin selection rules!
- Not trivial isospin dependence for M_{ee}>0.14GeV/c² (goes far beyond factor 2)
- Very different mass shape above π^0 Dalitz decay

Large excess in *n+p* compared to *p+p* reactions:

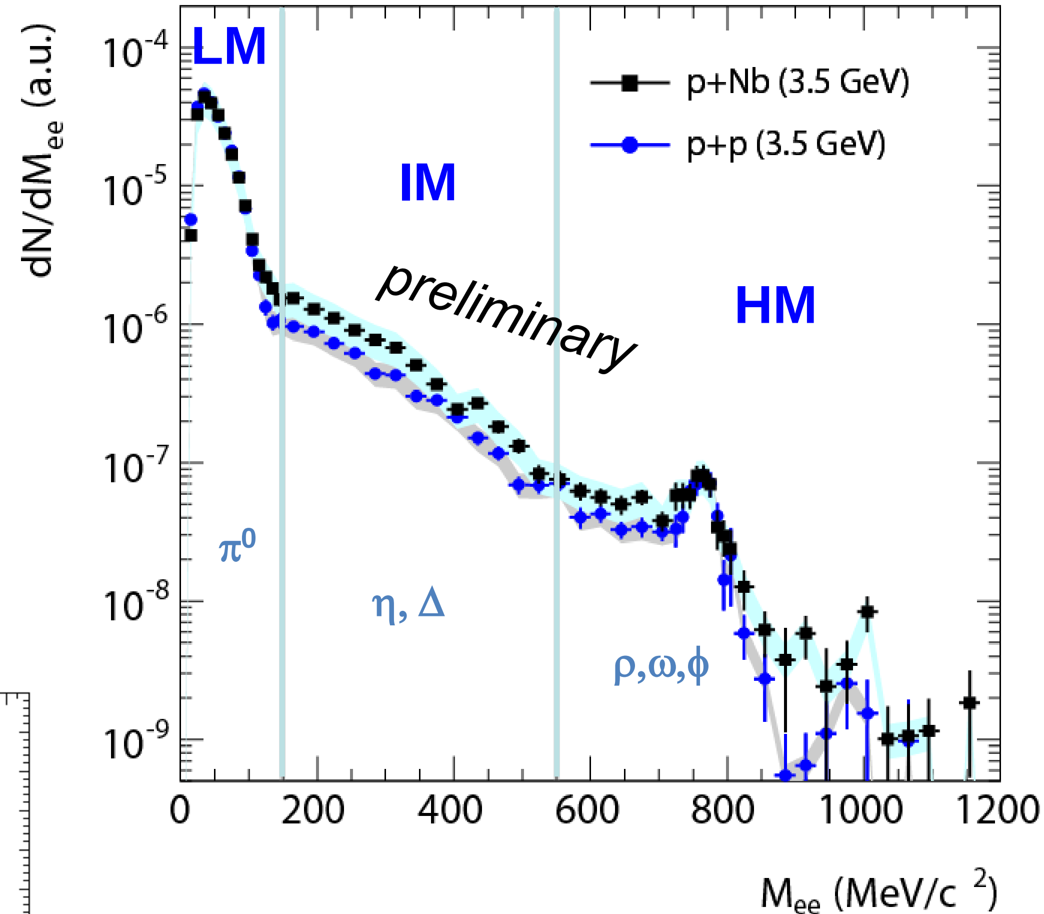
- role of Fermi momentum (off-shell propagation of VM)?
- NN Bremsstrahlung?
- Δ production?

Cold matter: dilepton sources @ 3.5 GeV

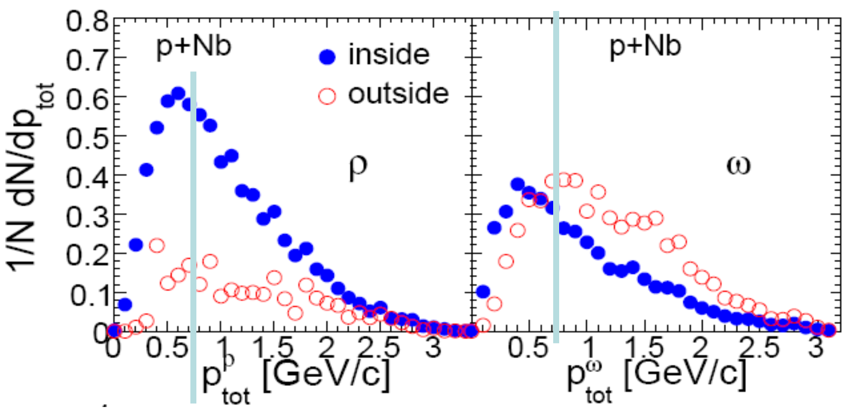
- The p+Nb spectrum is scaled down by a factor of $R = A^{\alpha}$ to fit the yield in the π0 mass region (α=0.69).

- The yield in the intermediate mass region is significantly enhanced by about 50%

- To enrich in-medium decay cut at p~ 800 [MeV/c] can be used



HSD simulation of sources



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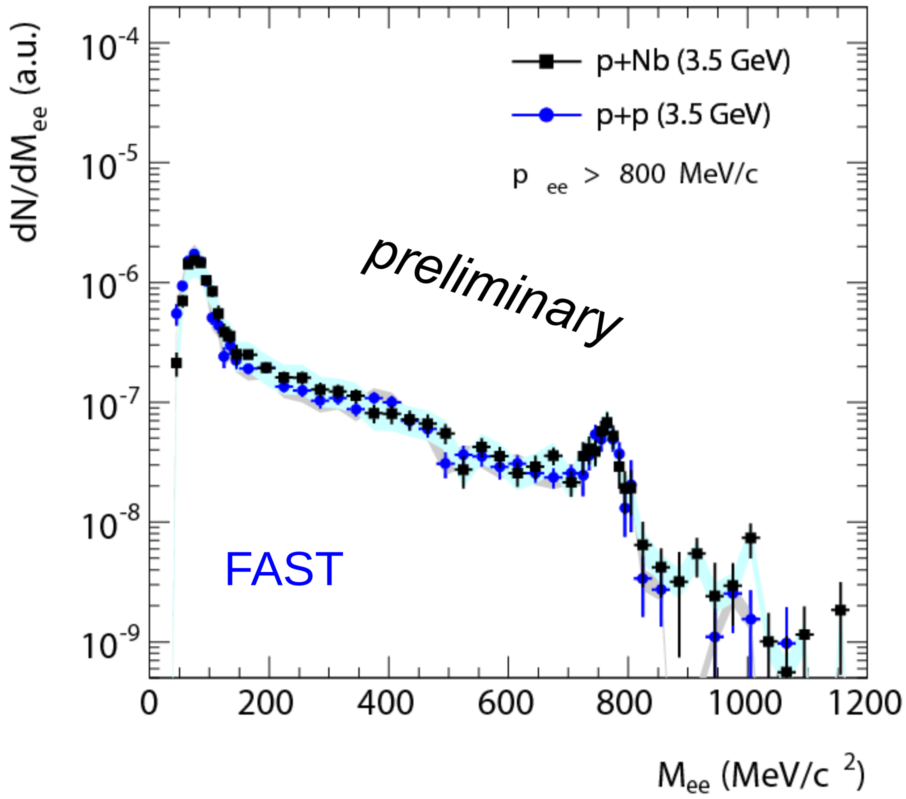
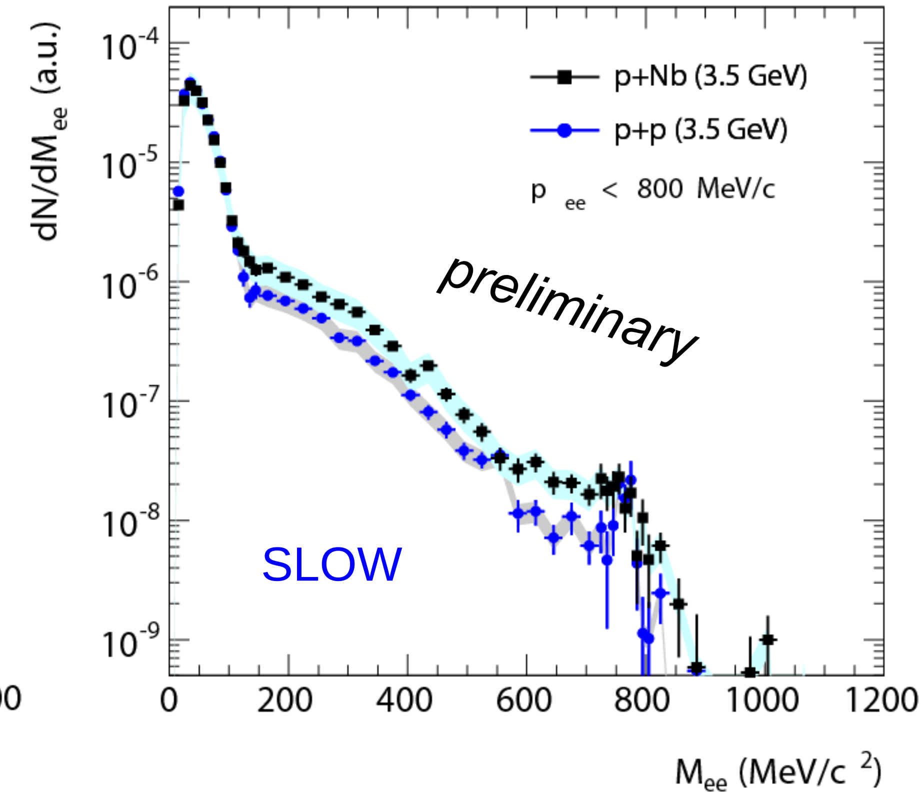
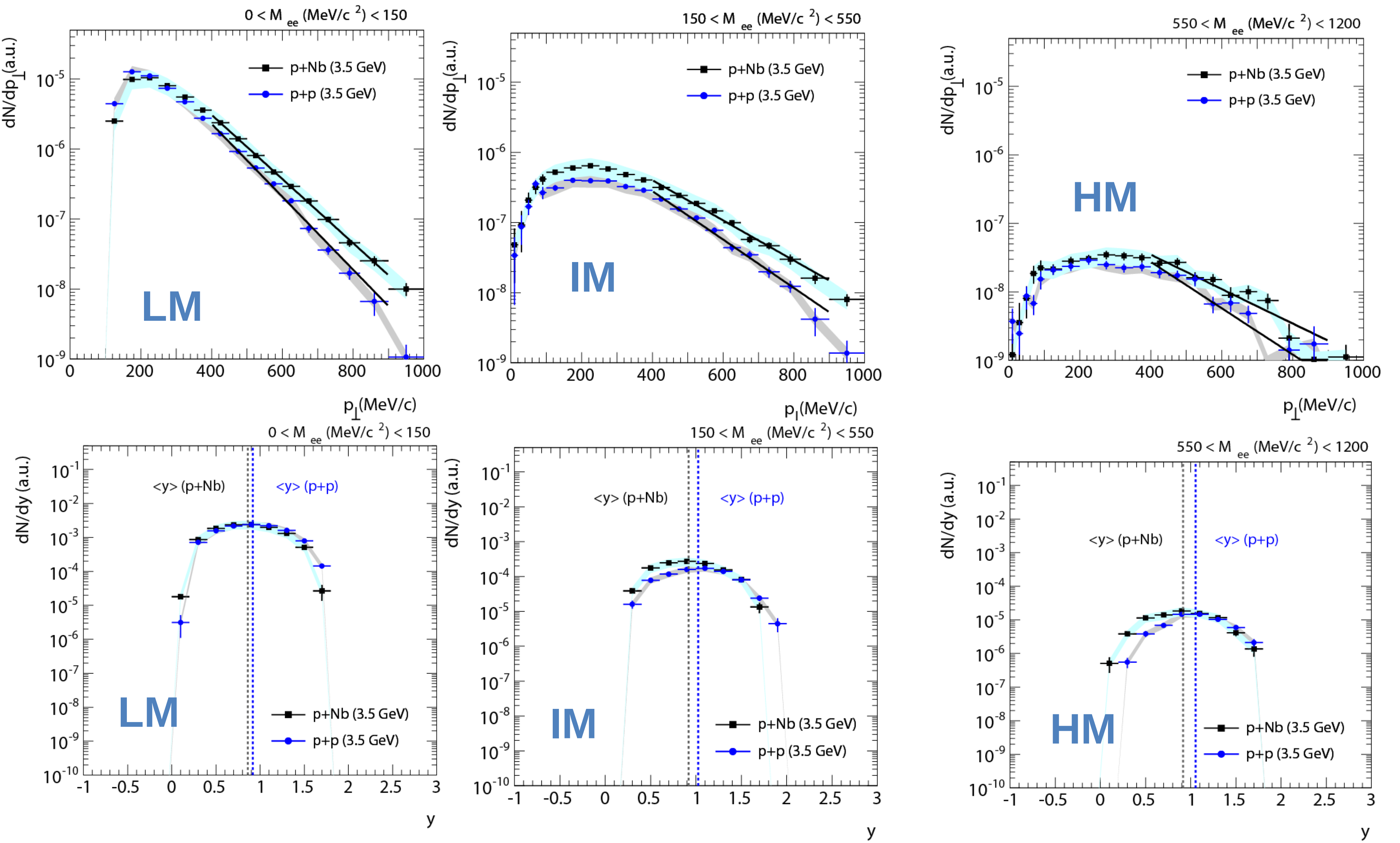
Fast and slow lepton pairs





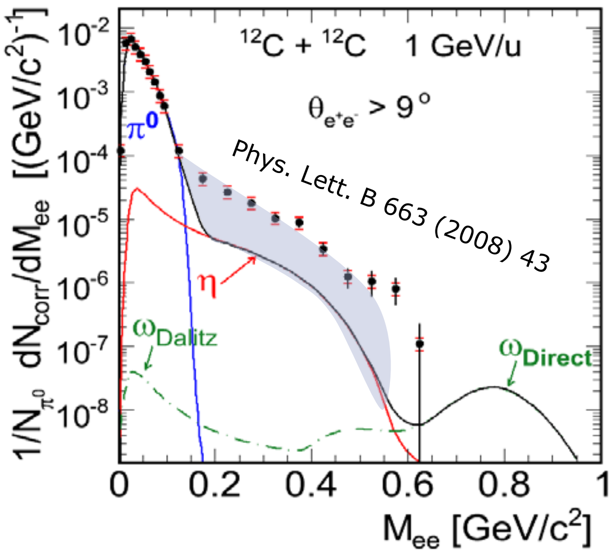
- High p: free p+p production
- Low p: overshoot over p+p different for ρ, ω, and ϕ
- Absorption of ω ?
- Production in secondary processes?

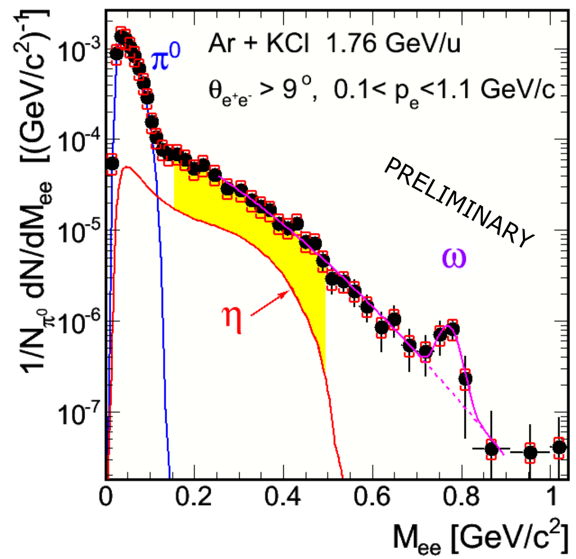
p_T and y of lepton pairs (preliminary!)

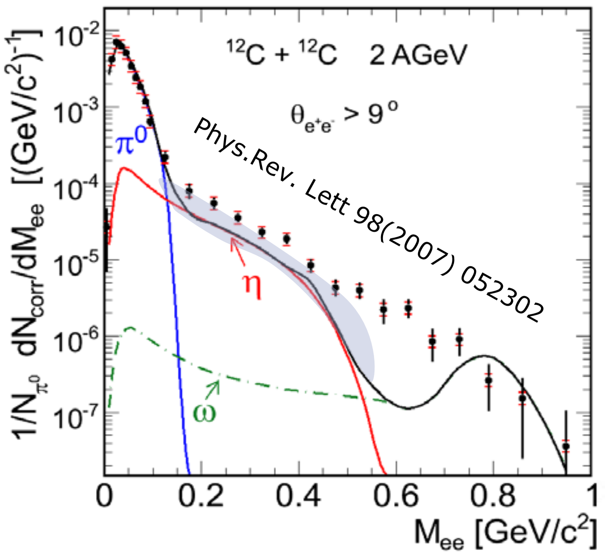


Shift to target rapidity and slightly harder spectra for pNb system

Compressed matter: Excess above eta contribution

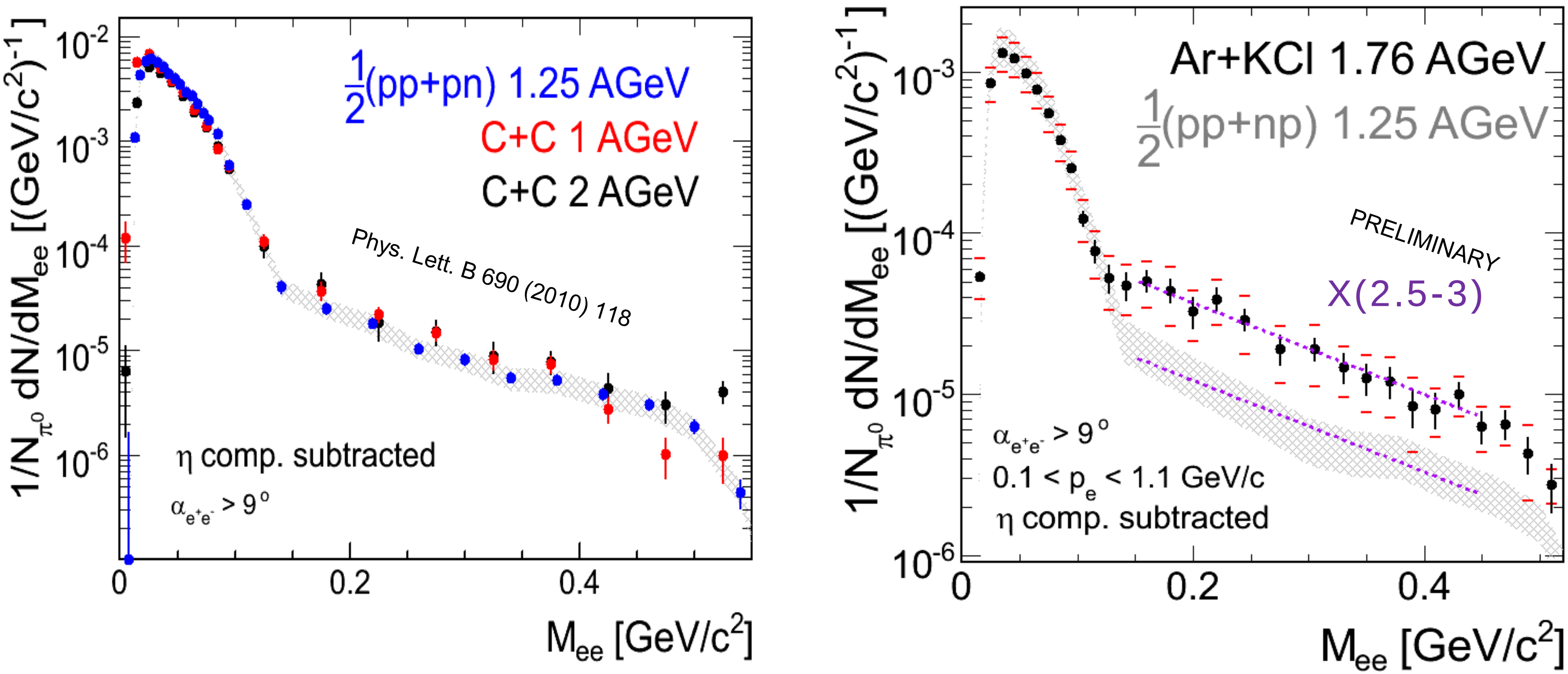






- Normalization: $N_{\pi 0} = ½ (N_{\pi+} + N_{\pi-})$, $\pi^{\pm}$ from the same data sample
  [HADES:EuroPhys.Journal A40, 45 (2009)]
- Systematic errors: ~25%, $\sigma_M(\omega)$ = 9%
- "hadronic cocktail": thermal source, only long-lived components included, i.e. π^0, η: TAPS data, ω: $m_{\perp}$ scaling.
  R. Averbeck et. al. PRC 67 (2003) 024903
  I. Froehlich et al.,arXiv:0708.2382

Dilepton spectra with η component subtracted

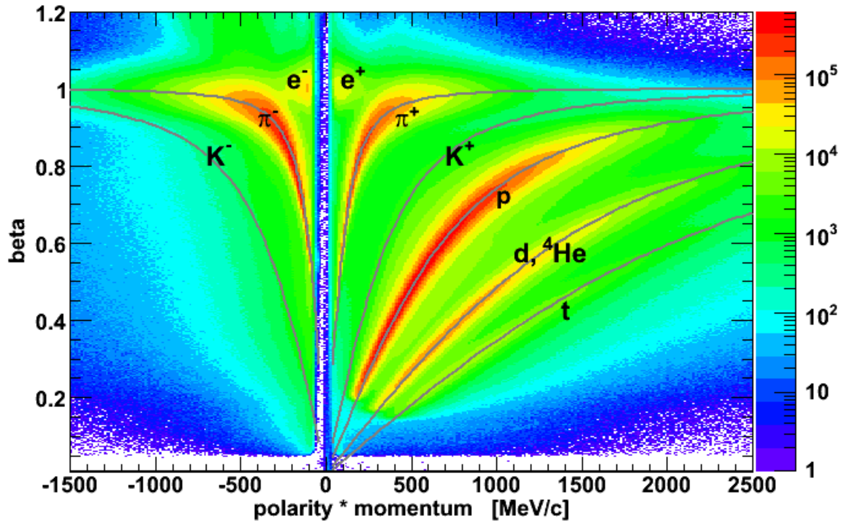


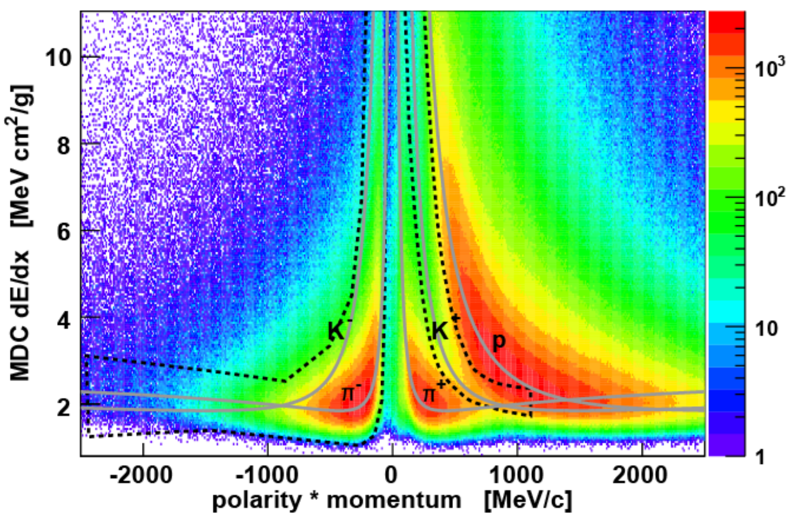
- Excess of pair yield above η-contribution established
- Excess in CC scales with E_{beam} like π production! ~ A_{part}
- Excess in First chance collision is very slightly below CC
- Significant increase of excess in ArKCl ~ $(A_{part})^{1.4}$
- Hinting at Δ resonance decays

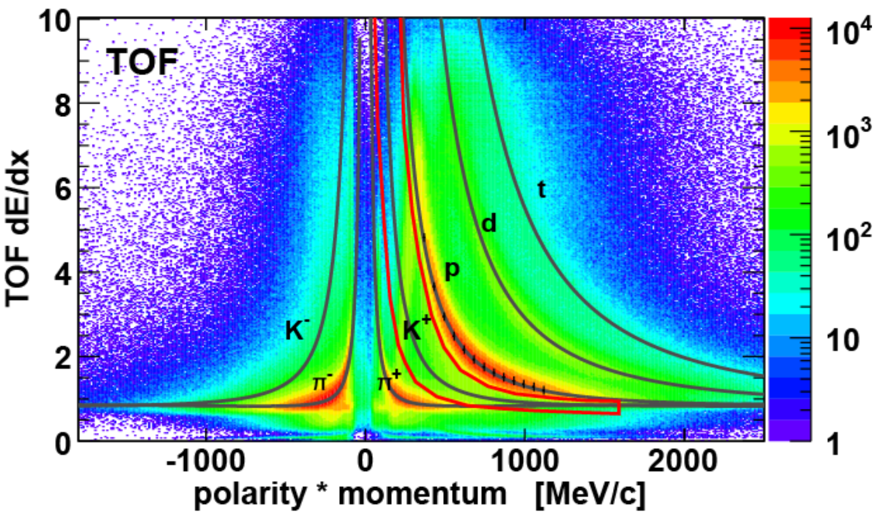
HADES as High Acceptance Hadron Spectrometer (velocity, dE/dx, momentum)

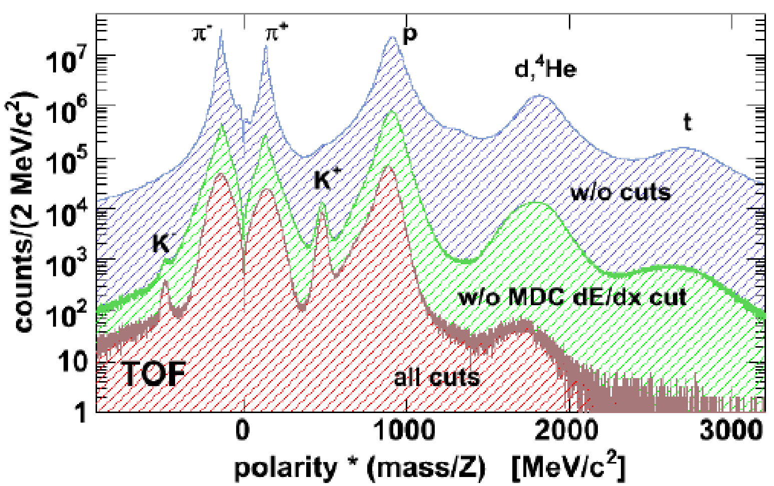
TOF (44° < Θ < 88°)

MDC



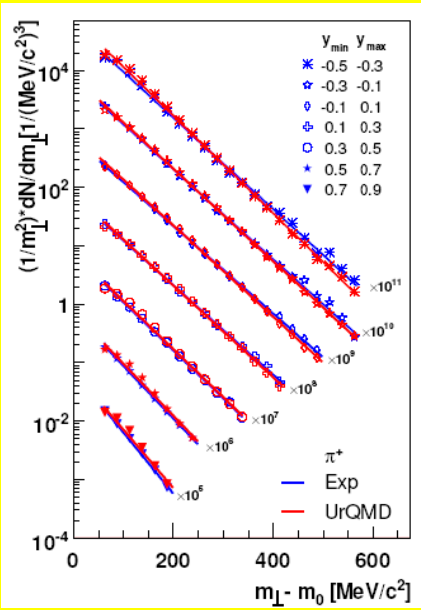


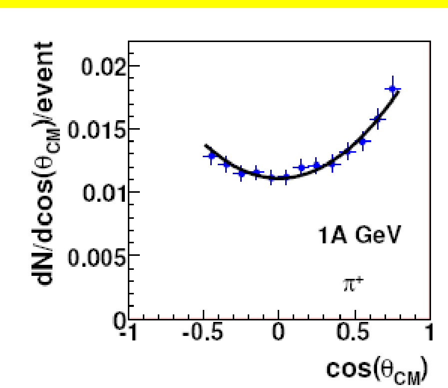




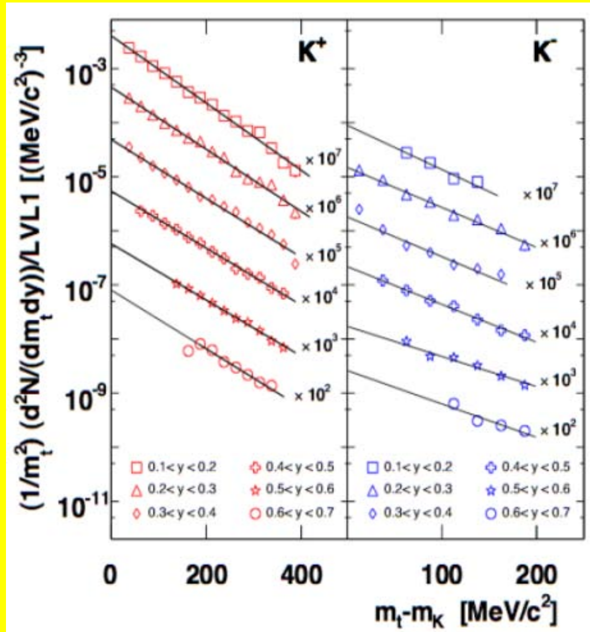
Charged hadrons: pions, Kaons ….

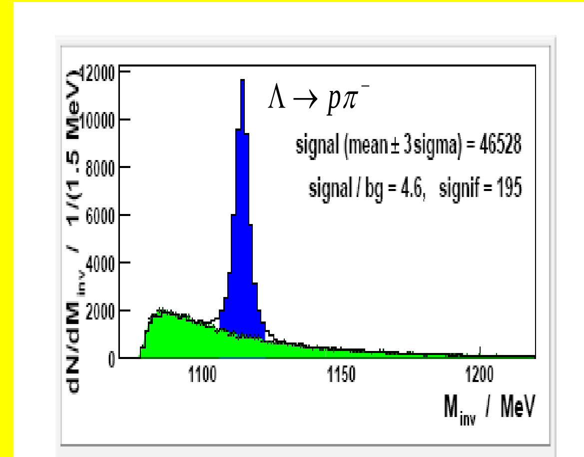
C + C 1AGeV

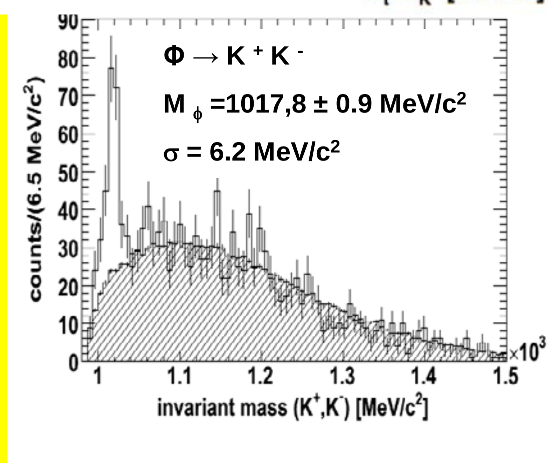


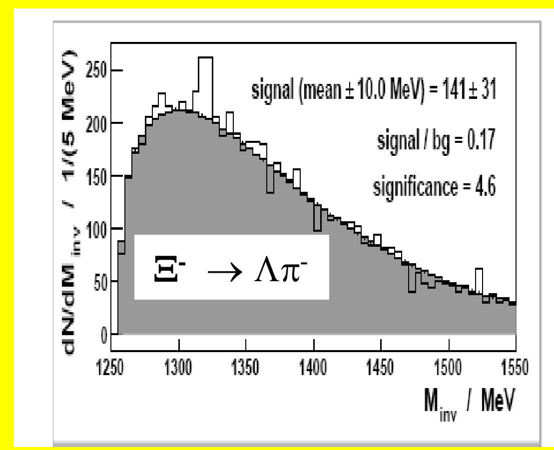


Ar+KCl 1.76 GeV/u







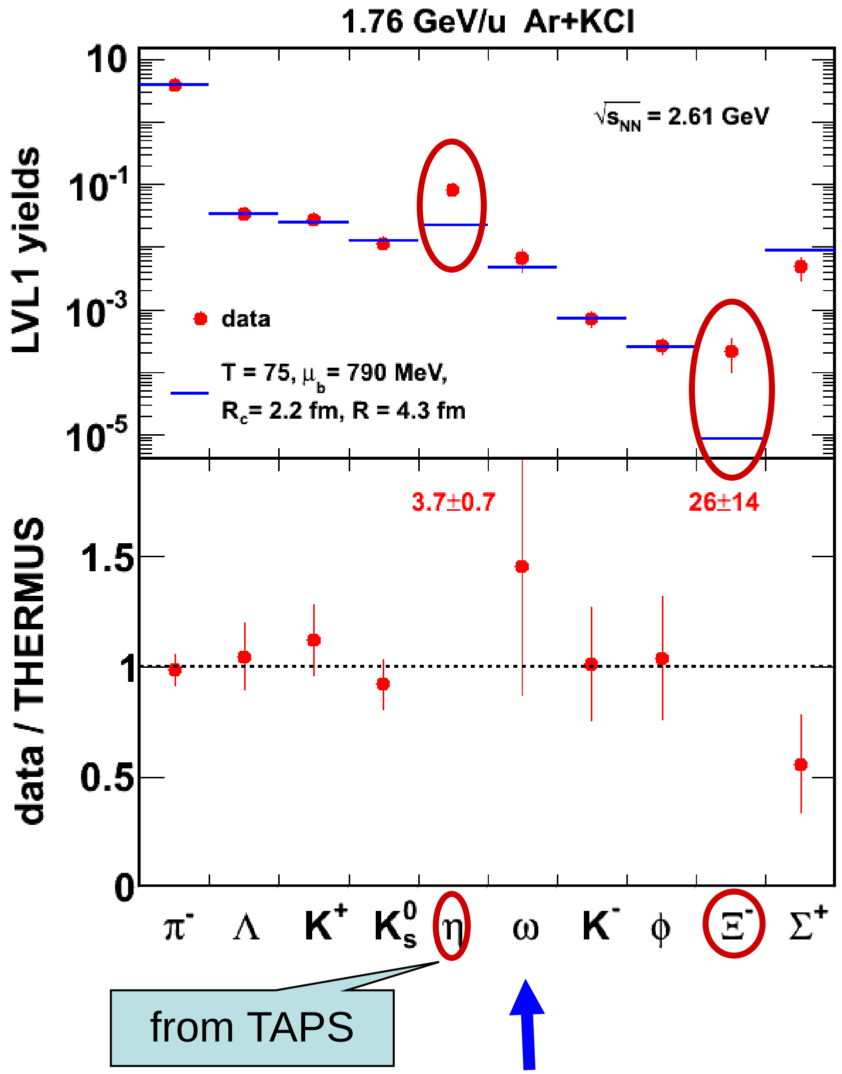


+ more strange probes

Comparison with a statistical model

THERMUS
calculation

(T, μ_B and R_C
fit to HADES data)



ω and ϕ described
in statistical model,
but…

HADES: Eur.Phys.J.A47:21,2011

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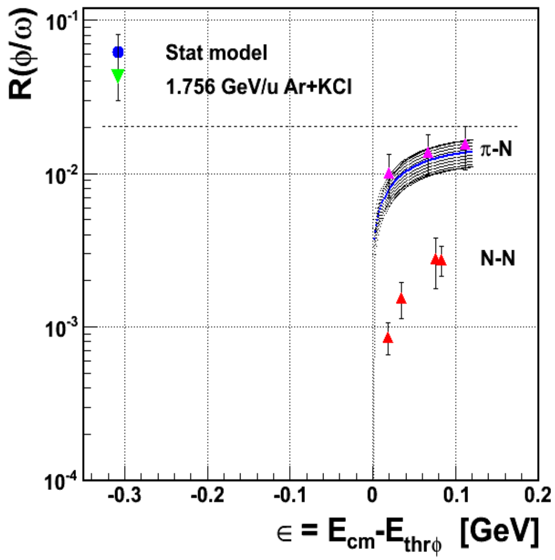
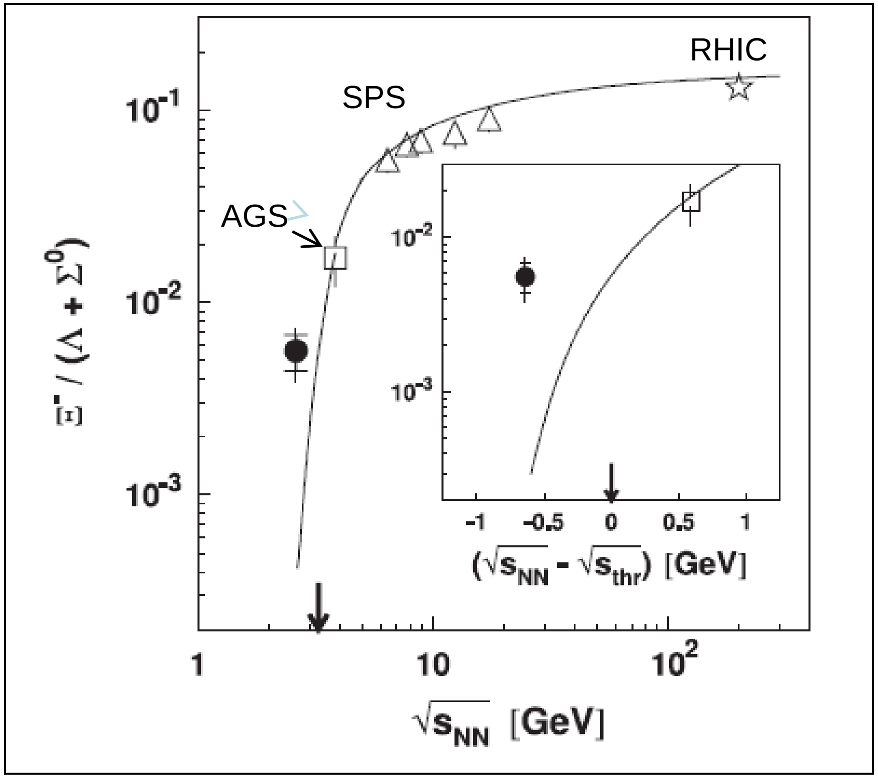
Hidden and Double Strangeness production in Ar+KCl

- $\phi \rightarrow K^+K^-$: $(2.6 \pm 0.7) \cdot 10^{-4}$
- $\omega \rightarrow e^+e^-$: $(6.7 \pm 2.7) \cdot 10^{-3}$

$$R_{\phi/\omega} = 0.043^{+0.038}_{-0.013}$$



>> OZI allowed



- First observation of deep (640 MeV) subthreshold of double-strange cascade hyperon Ξ^- (1321) production
- production yield of Ξ^- comparable to that of ϕ

$$\frac{P_{\Xi^-}}{P_{\Lambda+\Sigma^0}} = (5.6 \pm 1.2^{+1.8}_{-1.7}) \times 10^{-3}$$

- production yield underestimated by model (stat. and transport) calculations

•$R_{\phi/\omega}$ in ArKCl >> $R_{\phi/\omega}$ in NN and πN

•Yet, e.g. ϕ/K^- can be described by a statistical model (THERMUS)

HADES: Eur.Phys.J.A47:21,2011
HADES: Phys. Rev. Lett. 103(2009)132301

Conclusions

Excess of dilepton yield over "elementary collisions" observed in IM

- **in cold matter (slow dileptons) ~ 0.5**
- **in compressed matter ~ 2.5**

In AA collisions excess of dilepton yield over "η -contribution" observed in IM

- **scales with E_{beam} like π production**
- **scales with size of compressed zone like $(A_{part})^{\alpha}$, α ~1.4**

Strangeness production studied in compressed matter

- **first observation of deep (640 MeV) subthreshold production of Ξ^- (1321)**
- **production yield of Ξ^- comparable to that of ϕ**
- **production yield of Ξ^- (1321) underestimated by model (stat. and transport) calculations**

HADES experimental data indicate that:

➔ multi-step non-equilibrium processes play substantial role in production of vector mesons and strangeness particles

The HADES Collaboration

Cyprus:
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Joint Institute of Nuclear Research
ITEP

Spain:
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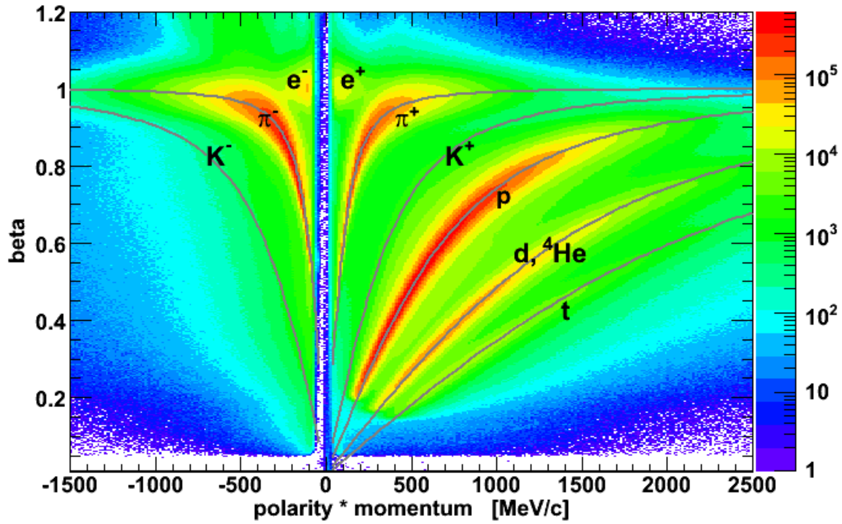
Instituto de Física Corpuscular, Universidad de Valencia-CSIC

17 institutions
120+ members

Backup Slides

HADES as High Acceptance Di-Electron Spectrometer (velocity, momentum, RICH)

TOF (44° < Θ < 88°)

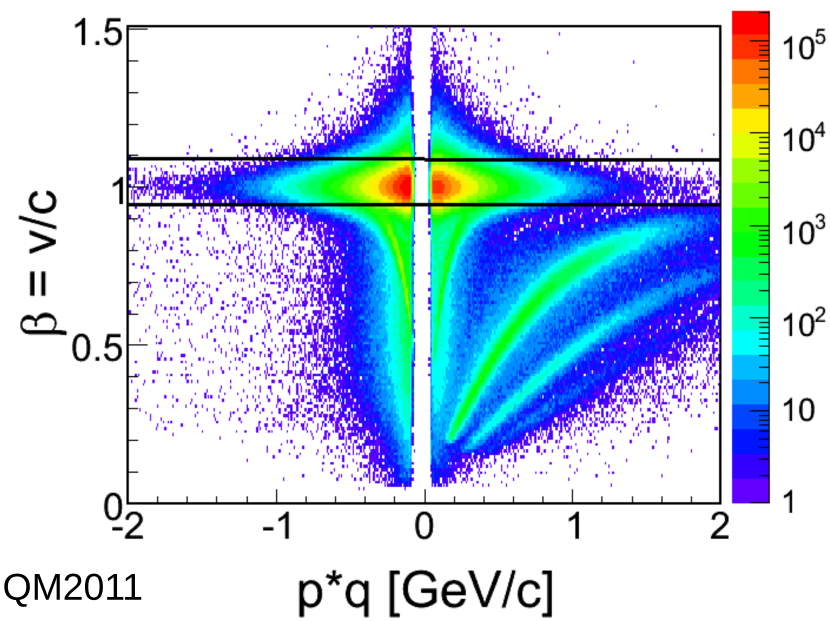


Selection criteria for single electrons/positrons:

1) track is associated with a Cherenkov ring
2) velocity constraints
3) shower condition

e+e- pair analysis :

- close pair cuts (opening angle > 9 deg)
- correction on reconstruction efficiencies



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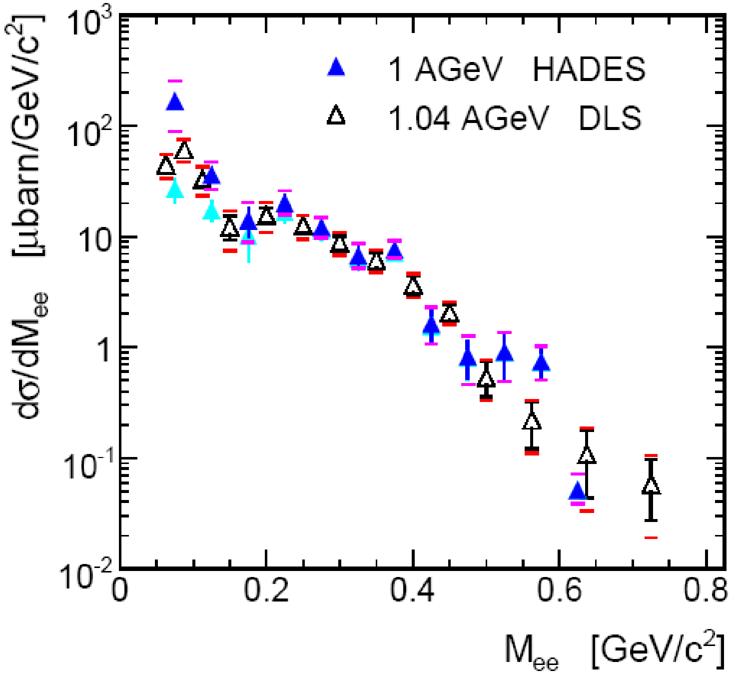
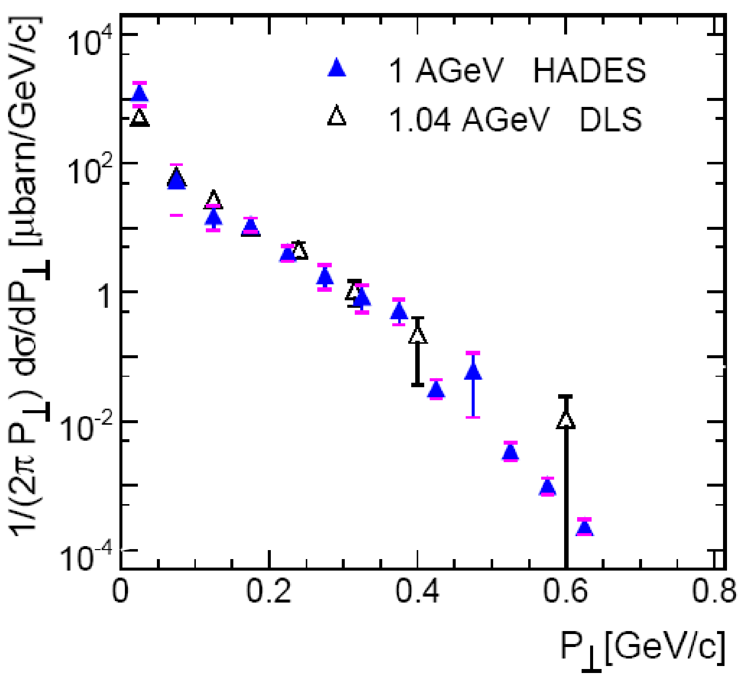
HADES vs. DLS: a direct comparison

Project HADES data into DLS acceptance and compare …





DLS Data: R.J. Porter et al.: PRL 79 (1997) 1229

J. Carroll at

International Workshop on Soft Dilepton Production
August 20-22,1997, LBNL

➔ HADES and DLS data agree !

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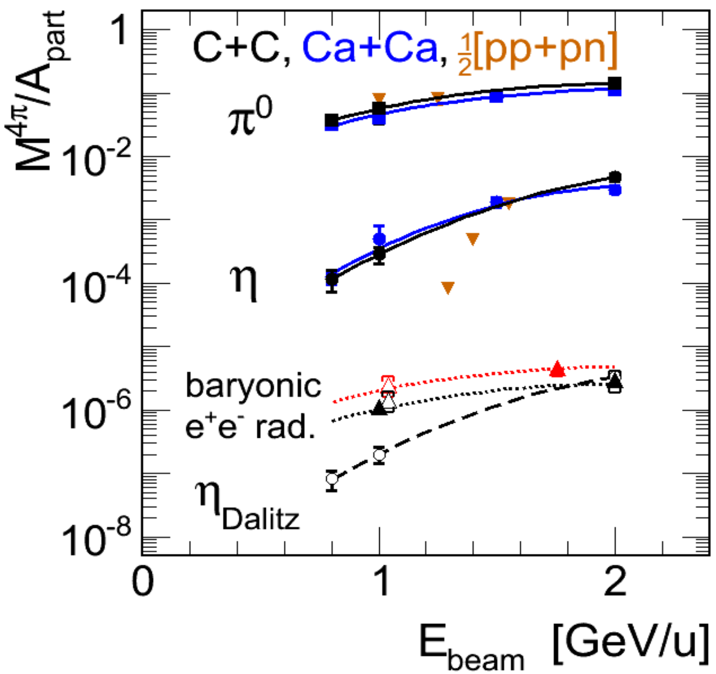
Excess above eta contribution ~ E_{beam} ~A_{part}



- π^0 and η yields have different scaling with E_{beam}
- excess scales with E_{beam} like π production
- π and η yields scales with A_{part} ~ linear
- excess scales with A_{part} stronger than linear

➔ baryon resonances involved ?
➔ multistep processes involved ?
➔ role of vector mesons ?

π^0 and η from TAPS ■
(min. bias)

e^+e^- pair excess:
HADES ▲ ▲
DLS △ △

Scaling at LVL1 trigger with A_{part} or with N_{coll} (Glauber)

$$\frac{\langle A_{part} \rangle_{Ar+KCl}}{\langle A_{part} \rangle_{C+C}} \approx 4.5 \qquad \frac{\langle N_{coll} \rangle_{Ar+KCl}}{\langle N_{coll} \rangle_{C+C}} \approx 6.1$$

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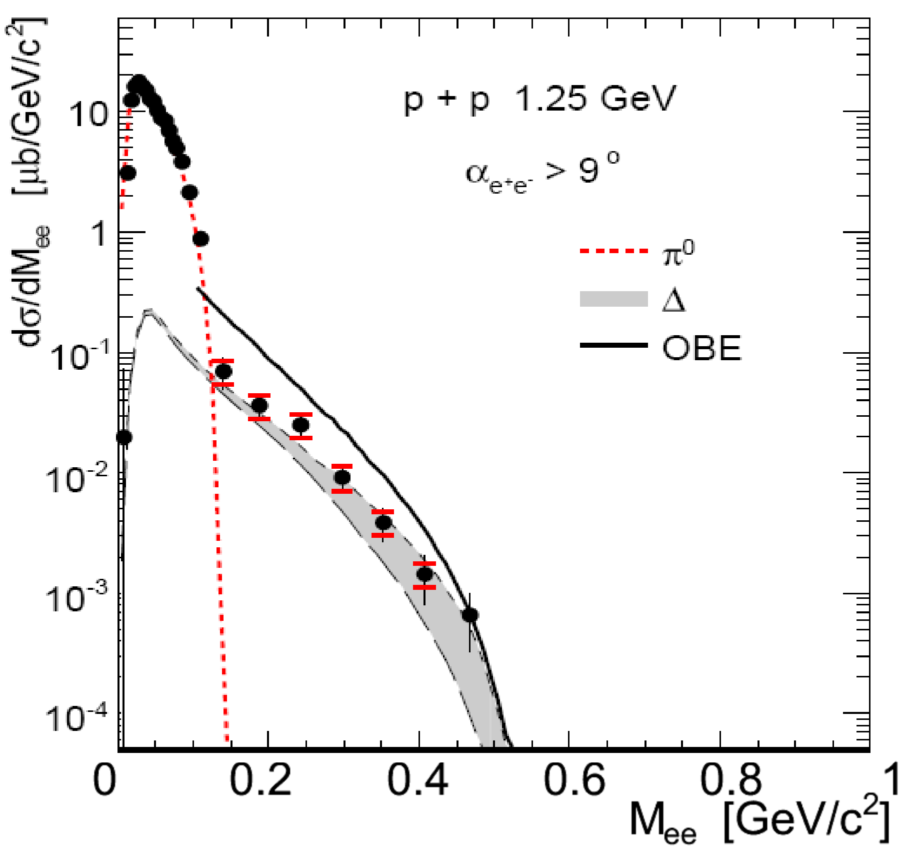
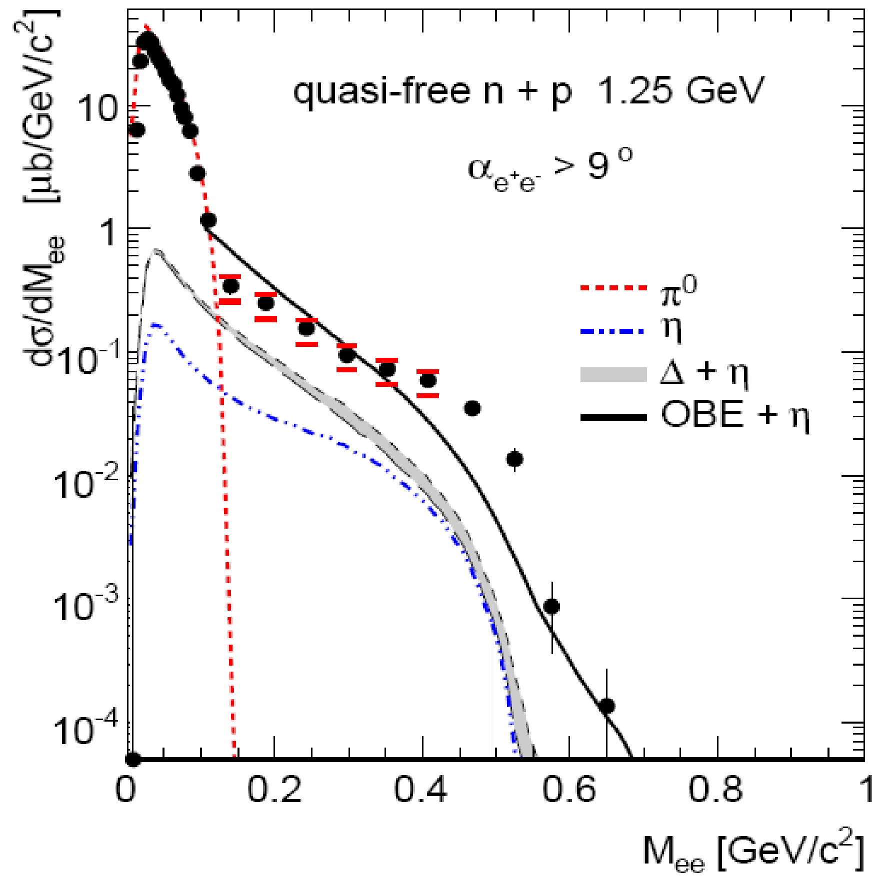
Comparison of pp and np data with model





Model Calculations:

a) NN→NNe+e- OBE calculations Kaptari & Kämpfer (K&K) NPA 764 (2006) 338

b) Δ ,η yield constraint by data. Δ Dalitz decay Krivoruchenko et al. Phys. Rev. D 65 (**2001**) 017502 **+ VMD form-factor** (Q. Wan and F. Iachello, Int. J. Mod. Phys. A 20 (2005) 1846)

pn data are not described by model calculations !

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Dileptons from cold matter
p+Nb vers. p+p @ 3.5 GeV

In p+p: absolute normalization by elastic scattering

In p+Nb:

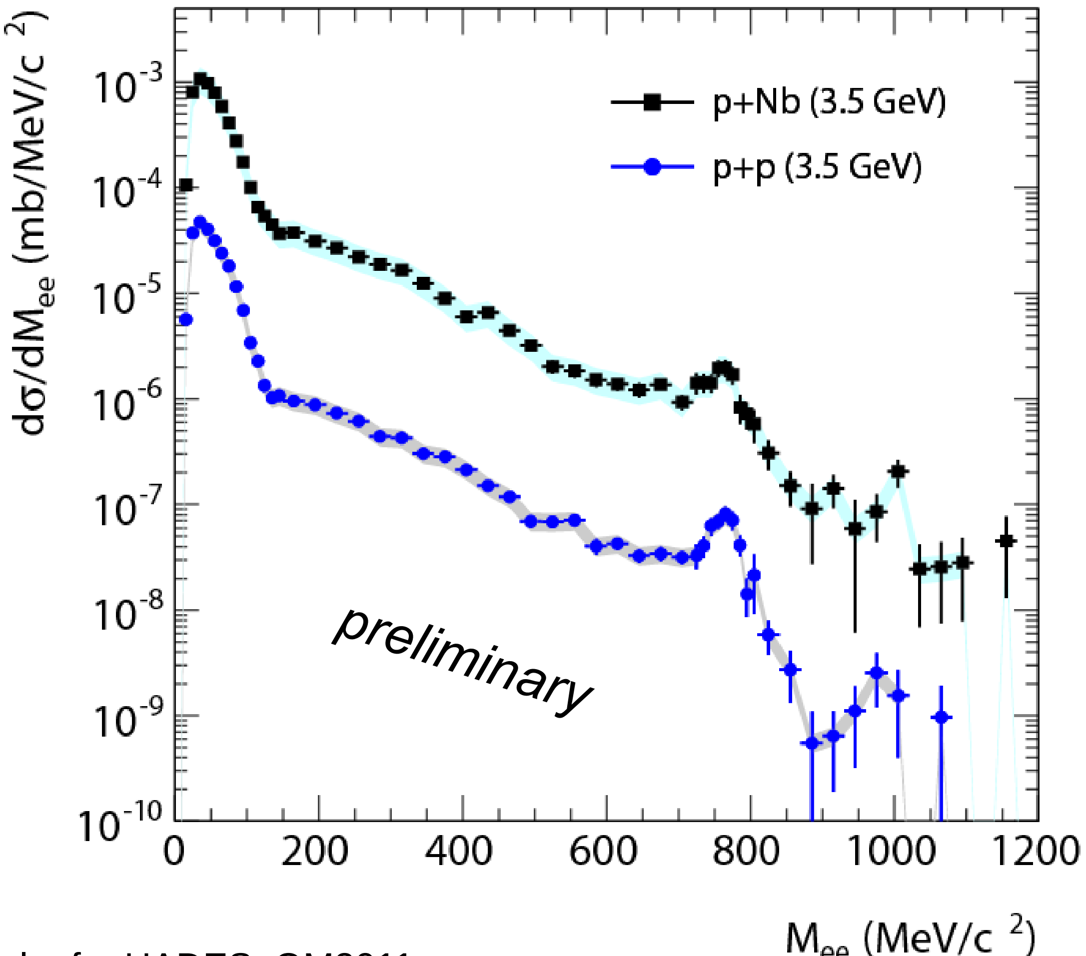
Absolute normalization of cross sections derived exploiting comparison of measured charged pion's yields (HADES) with HARP_CDP results

<u>HARP-CDP experiment</u>

- p_p = 3, 5, 8, 12 GeV/c
- A = Be, Cu, Ta, Pb

EPJ C63(2009)549-609. ;
EPJ C64 (2009) 181-241.

Systematical error ≈ 30 %



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Transparency ratio T_A

$$\frac{\sigma_{\omega/\phi(pA)}}{\sigma_{\omega/\phi(pN)}} = (A)^{\alpha}$$

Fit with Gaussians:

- High p:
  $\alpha_{pNb,\omega} = 0.69 \pm 0.27$
  $\alpha_{pNb,\phi} = 1.04 \pm 2.50$

- Low p:
  $\alpha_{pNb,\omega} = 0.62 \pm 0.36$

Black body: $\alpha \sim 2/3$

Glauber: $\alpha \sim 0.8$

W.Cassing et al., PLB 238 (1990) 25