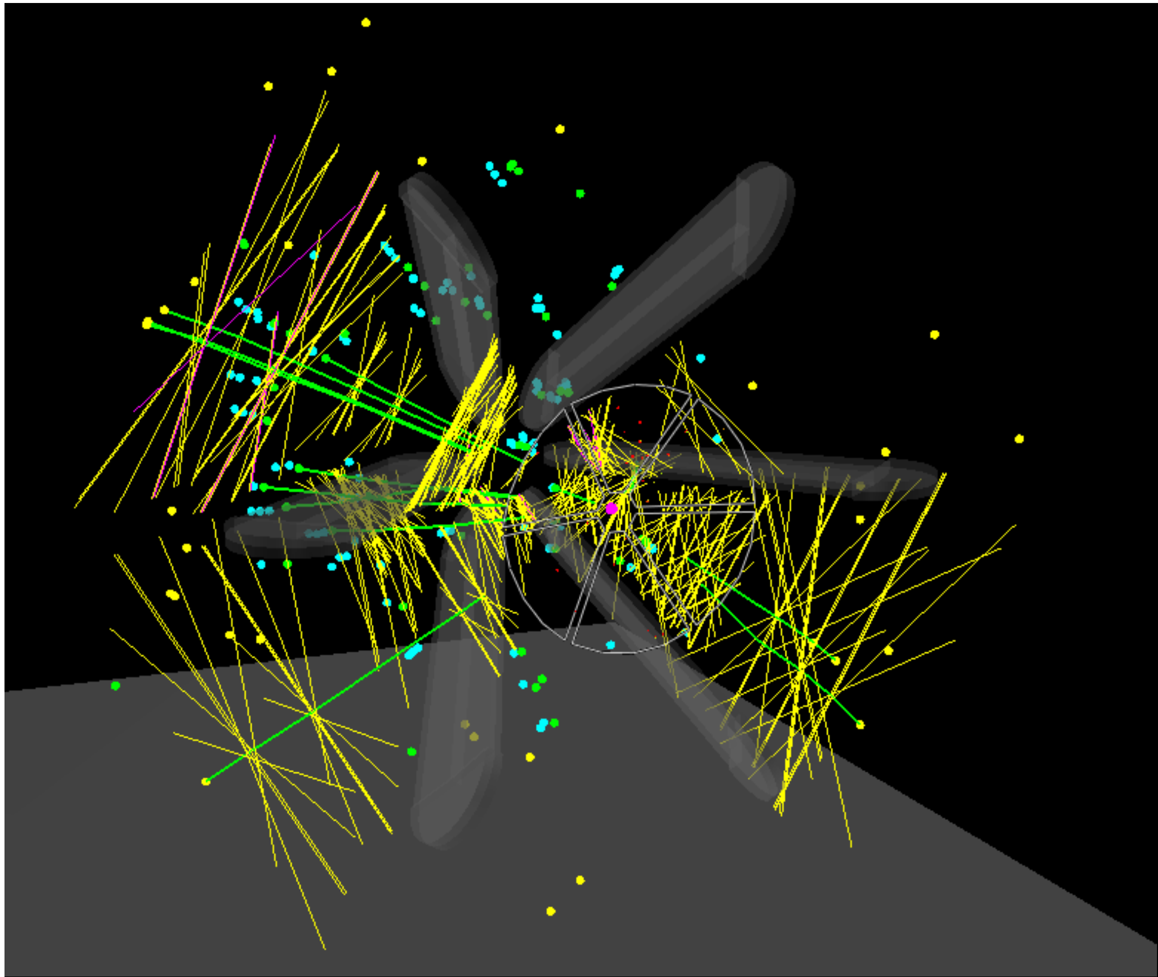


Exploring compressed nuclear matter with HADES

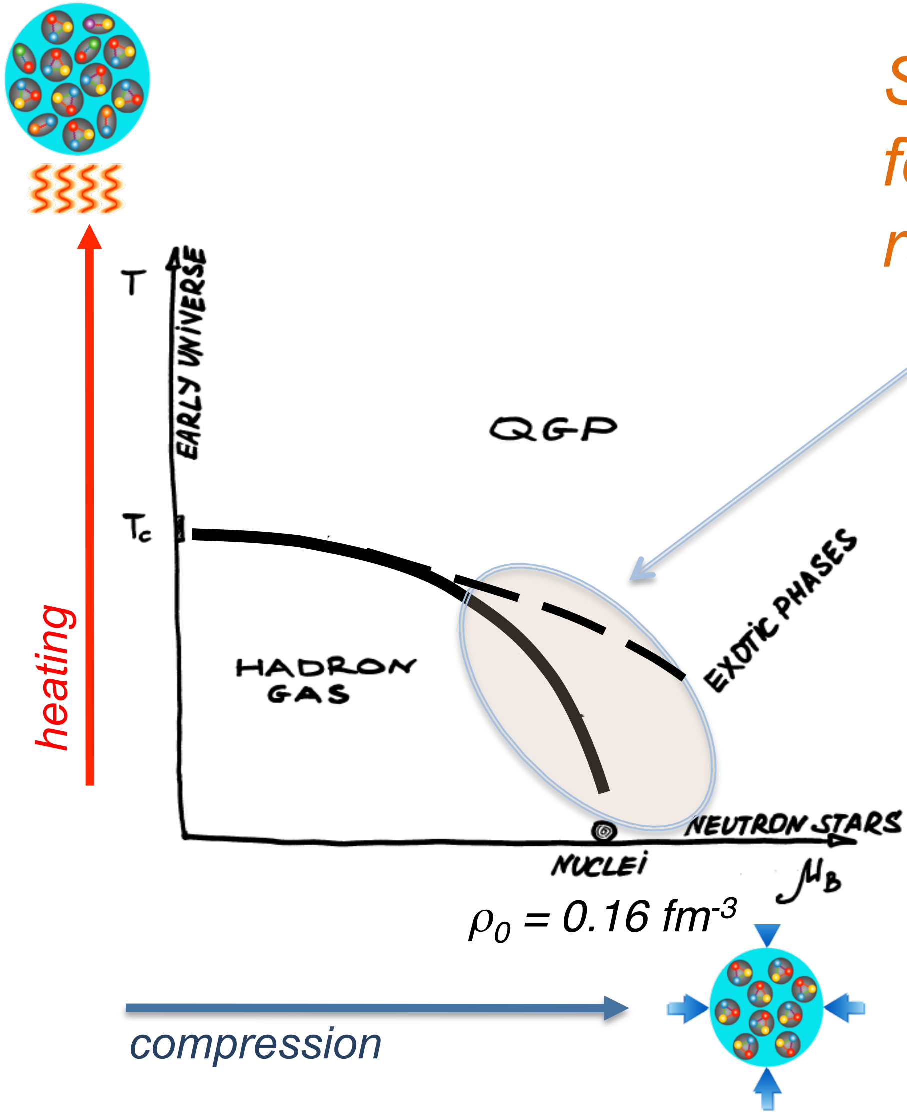
Hirschegg, January 15-21, 2012

Tetyana Galatyuk
Goethe-Univertsität Frankfurt / EMMI

for the HADES Collaboration

High Acceptance DiElectron Spectrometer

The HADES mission



Search (in this region) for new states of matter with rare and penetrating probes

- Stage I (2002 - 2008)
  - Light collision systems → limited granularity of time-of-flight system
- Stage II (2012 - 2015)
  - Heavy collision systems
  - π-induced reactions
- Stage III (2018 - …)
  - Lepton pair excitation function up to 8 GeV/u (medium-heavy systems) and (multi-)strange particle

+ Various aspects of baryon-resonances physics

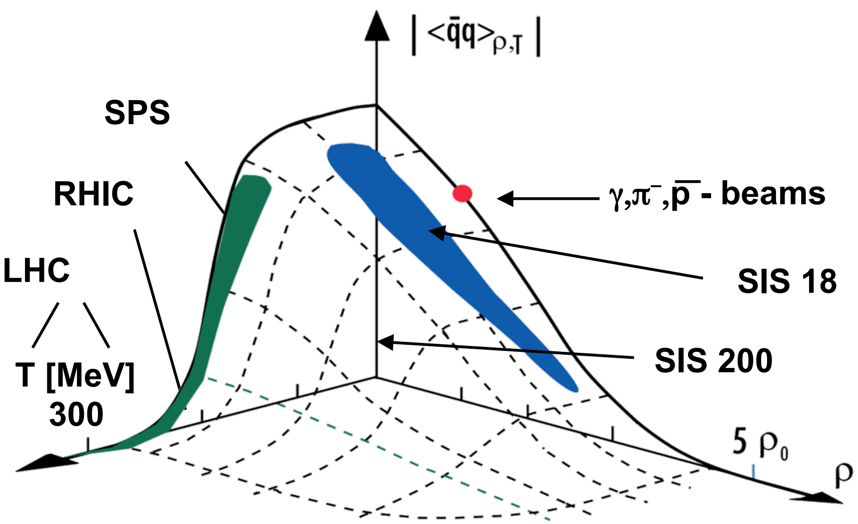
Outline

- Introduction
- Reference measurements (p+p, n+p, C+C)
- Ar+KCl collisions at 1.67 GeV/u
  - Dileptons
  - Strangeness
- Perspectives and challenges at SIS18 and SIS100
- Summary

Motivation

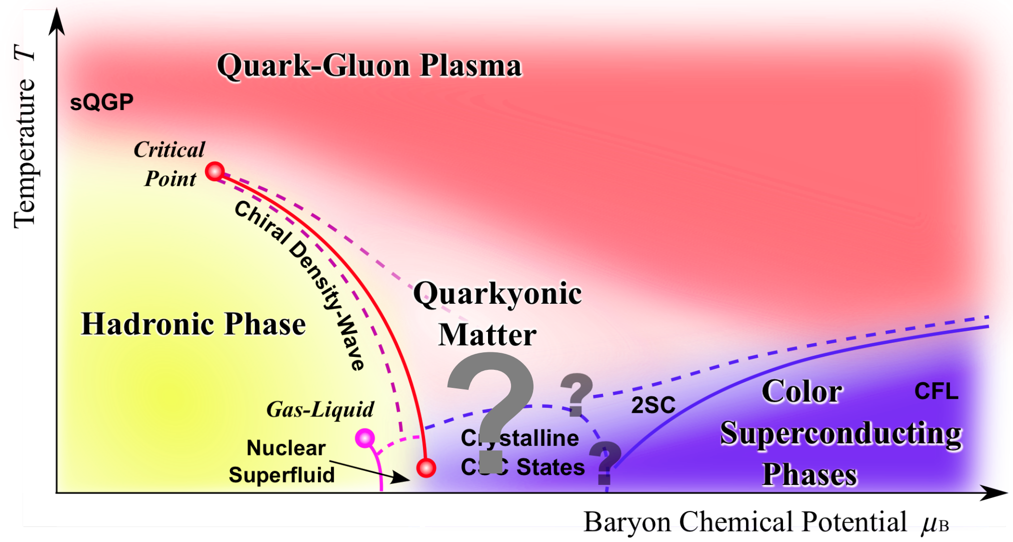
„I wonder if it finally will turn into a bluff...“

Partial restoration of chiral symmetry



Y. Nambu 1960,
R.D. Pisarski 1982,
W. Weise 1992,
…

Exotic phases

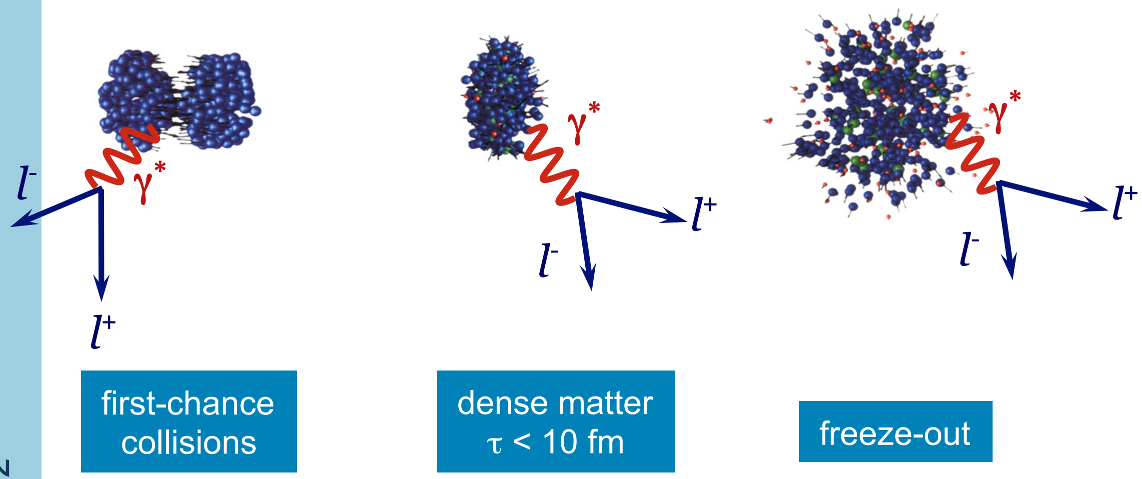


L. McLerran, R.D. Pisarski 2007,
…

→ *Experimental test*

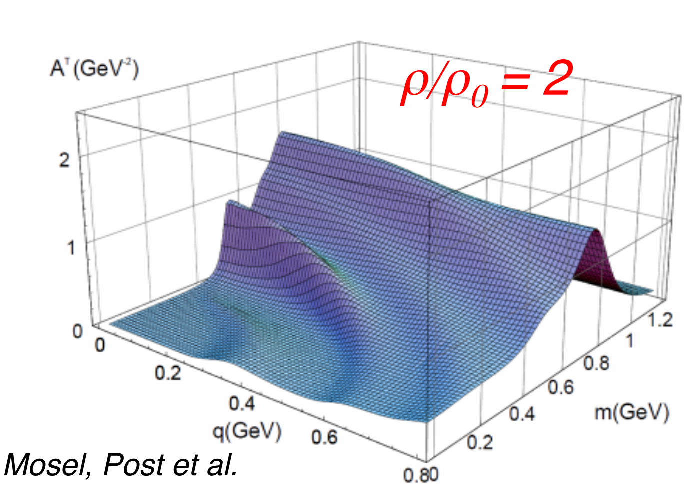
Searching for landmarks of the phase diagram of matter

$\pi, \eta, K, \phi, \Lambda, \Xi, \Omega, \ldots$



Bulk observables:

- Equation of state
- Collective flow patterns of the most abundant particles (π, K, p)
- Hadron-chemistry



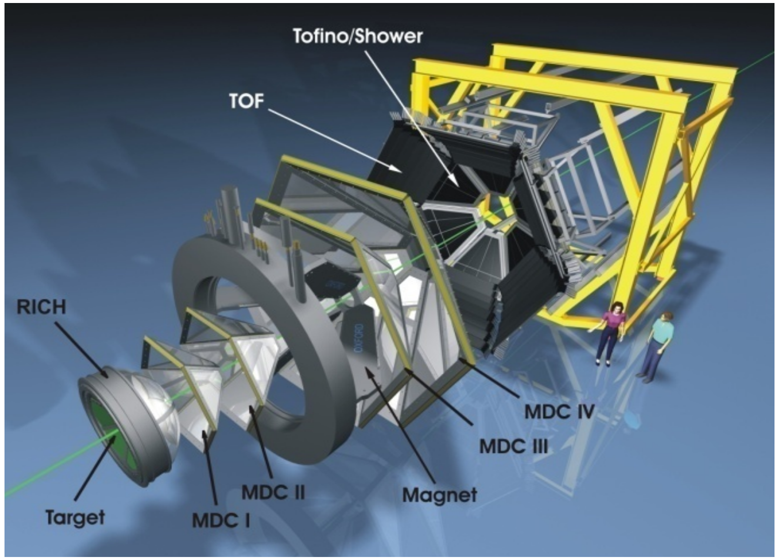
S. Leupold, U. Mosel, Post et al.
NPA 741 (2004) 81, NPA 780 (2006) 187

"Microscopic" probes:

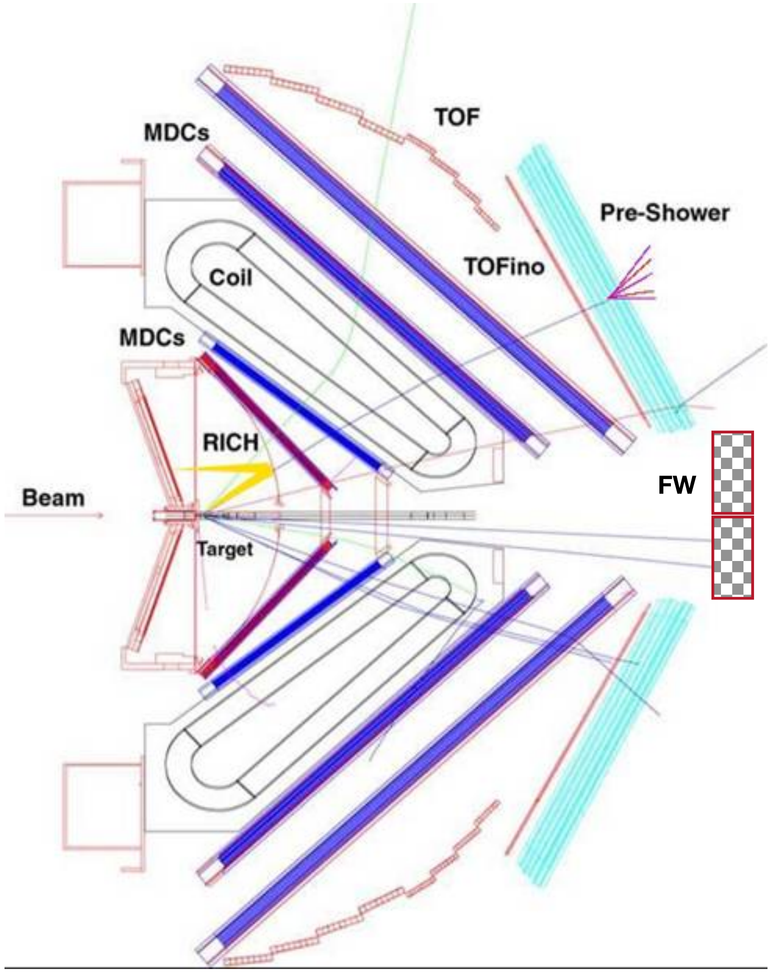
- Vector current coupling to photons (and dileptons)
  - **Emissivity of hadronic matter**
  - **In-medium spectral functions**

High Acceptance Di-Electron Spectrometer

HADES



HADES strategy:
Systematic di-electron and strangeness measurements in NN, AA, pA, πN and πA collisions



- Beams provided by SIS18: π, p, nuclei

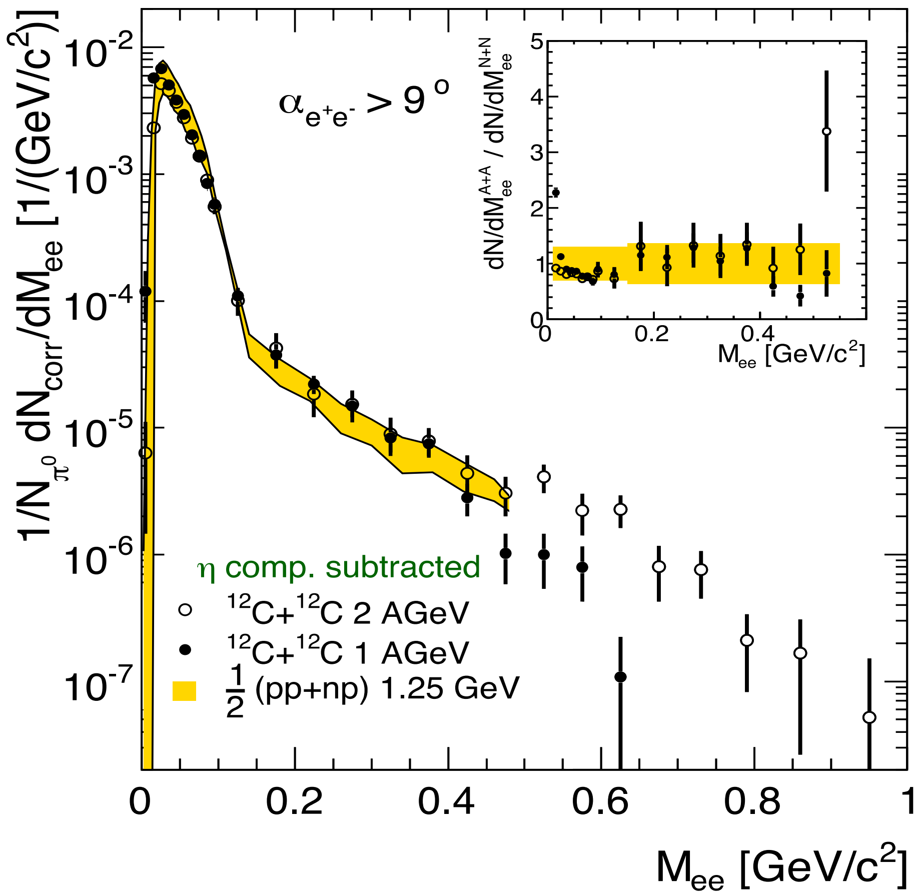
- Full azimuthal coverage
- Hadron and lepton identification

- e^+e^- pair acceptance 0.35
- **Mass resolution 2 % (ρ/ω region)**

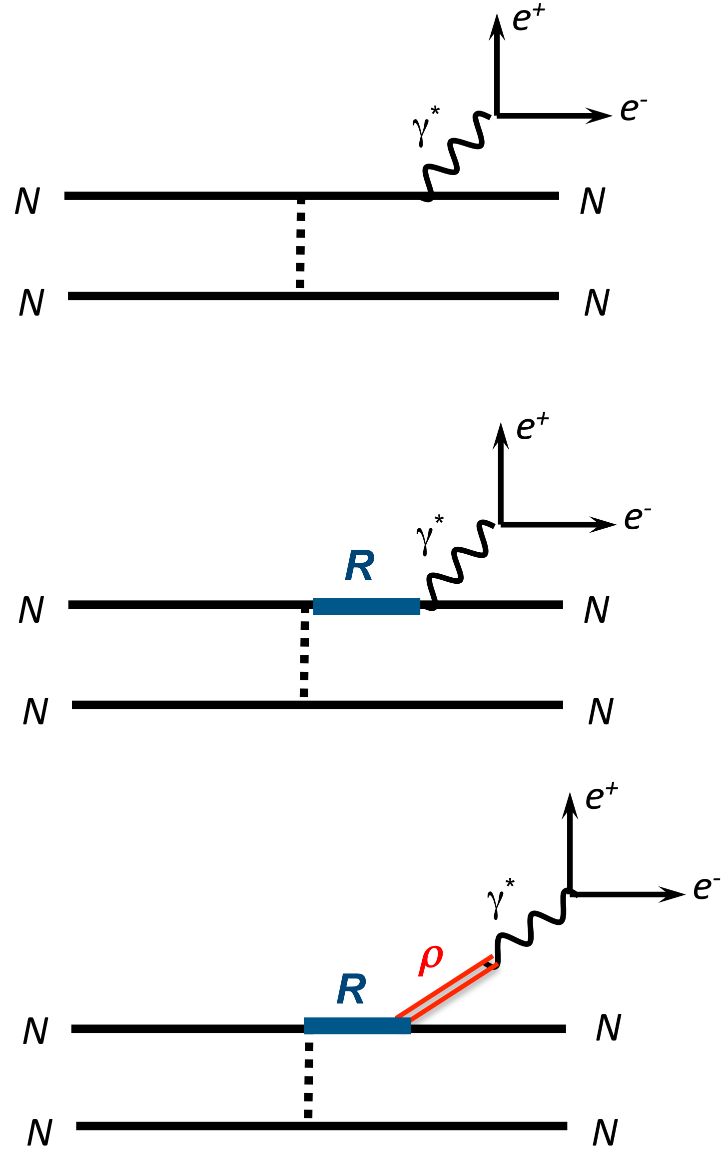
- ~ 80.000 channels
- now: **50 kHz event rate (400 Mbyte/s peak data rate)**

Origin of the low-mass pair excess in C+C collisions

Baryonic contributions from NN "reference"



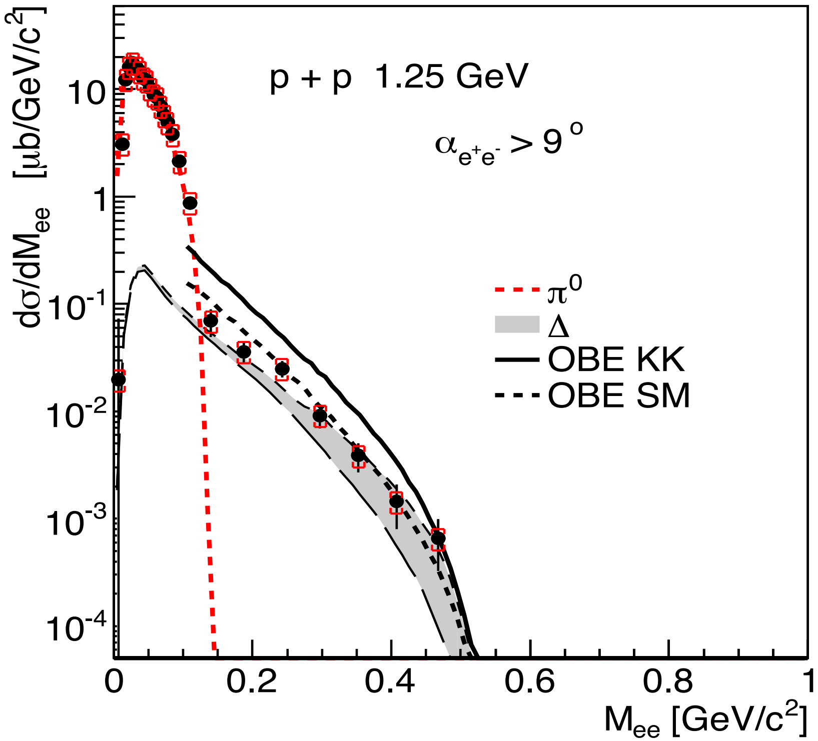
HADES: Phys. Lett. B 690 (2010) 118

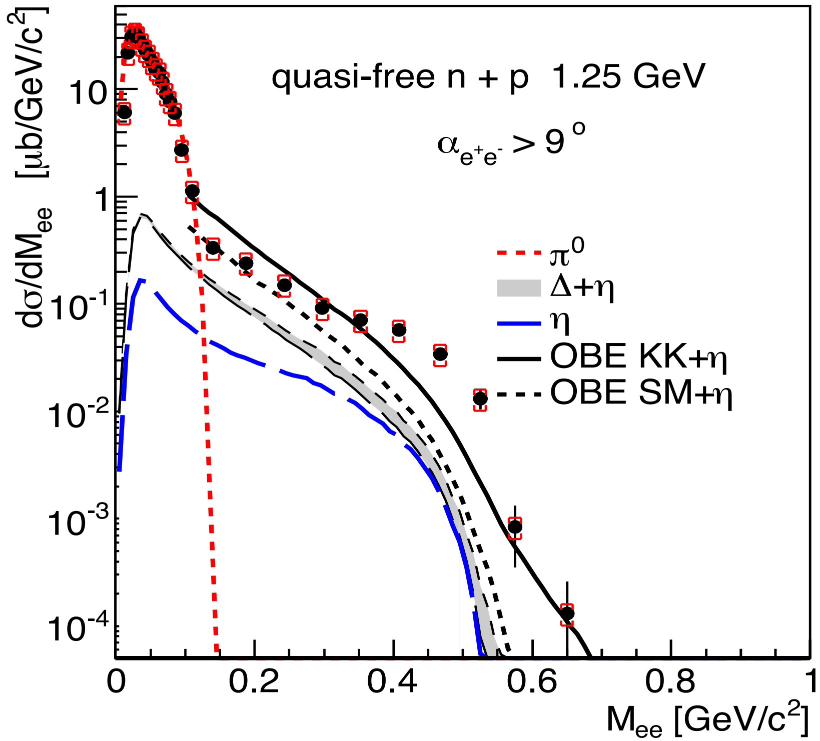


Dilepton "excess" scales with beam energy like π production

R = Δ, N*

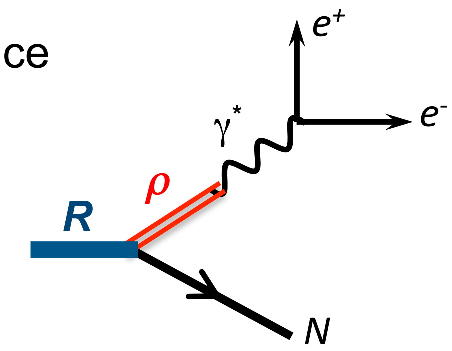
HADES pp and dp (tagged n) data vs. models



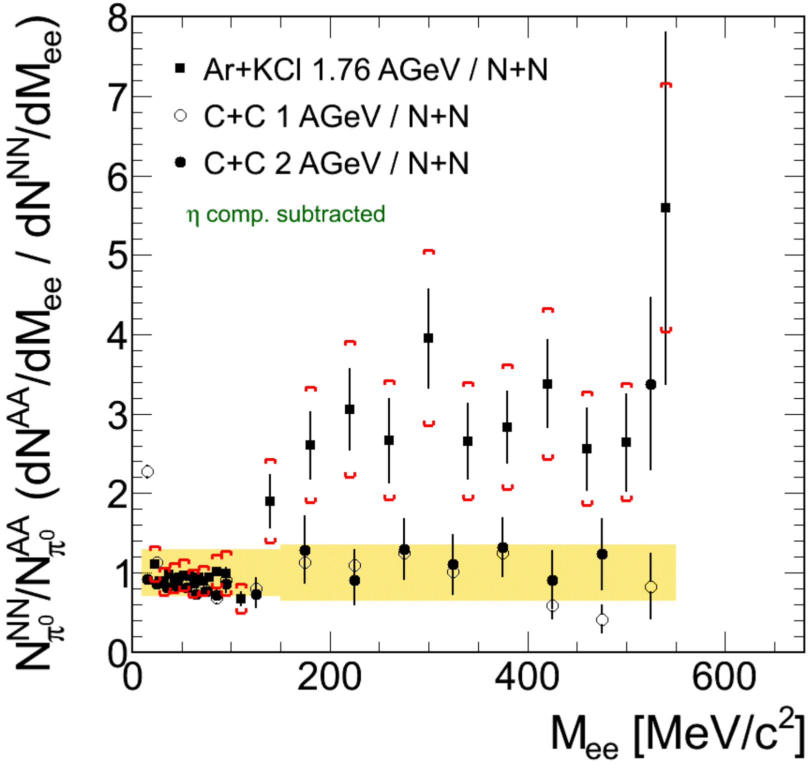


HADES: Phys. Lett. B 690 (2010) 118
Model: Pluto - ROOT based event generator

- n+p case: Different schemes for implementing gauge invariance
- OBE effective models reproduce p+p, but not (yet) n+p
- Coupling of the γ^* to Δ via intermediate ρ might play a role



Virtual photon emission in A+A collisions



HADES: Phys.Rev.C84:014902,2011

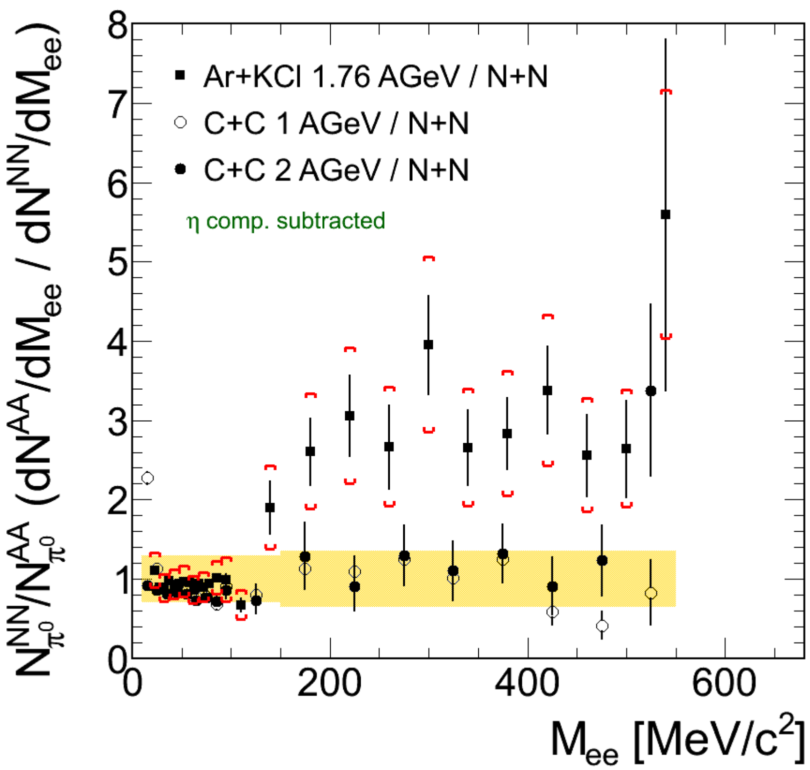
- Isolation of excess by a comparison with a **measured** "reference" spectrum
- **First evidence for radiation from the "medium"!**
- Excess yield scales with system size like $A_{part}^{1.4}$

→ multi-step processes or multi-particle correlation

Quest for heavier systems!

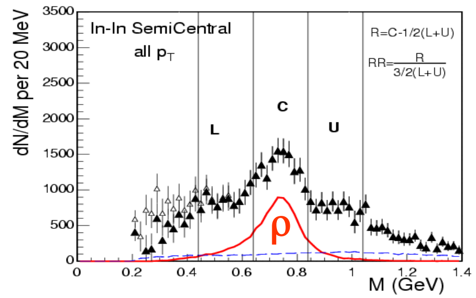
Centrality dependence of spectral shape

HADES "Δ clock"

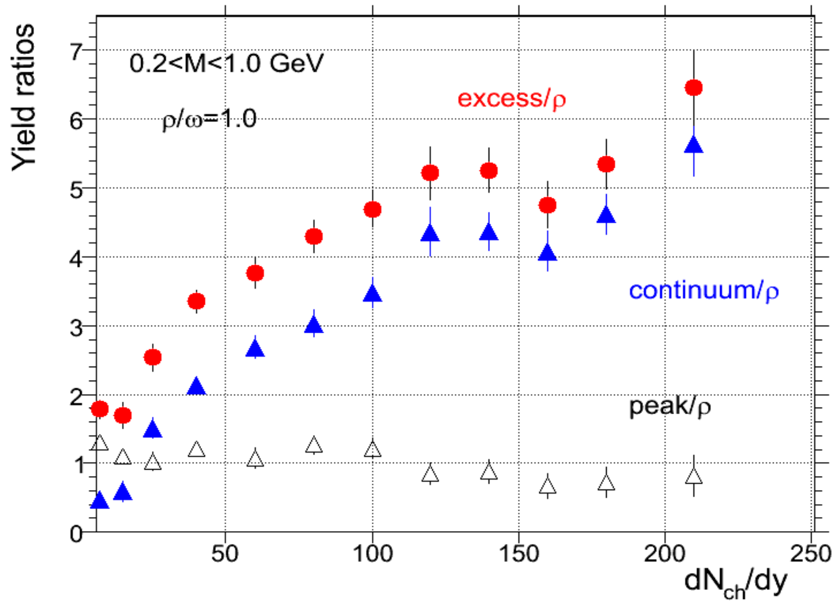


HADES: Phys.Rev.C84:014902,2011

- 34% most central collisions (A_{part}=38)
- Δ regeneration



NA60's "ρ clock"



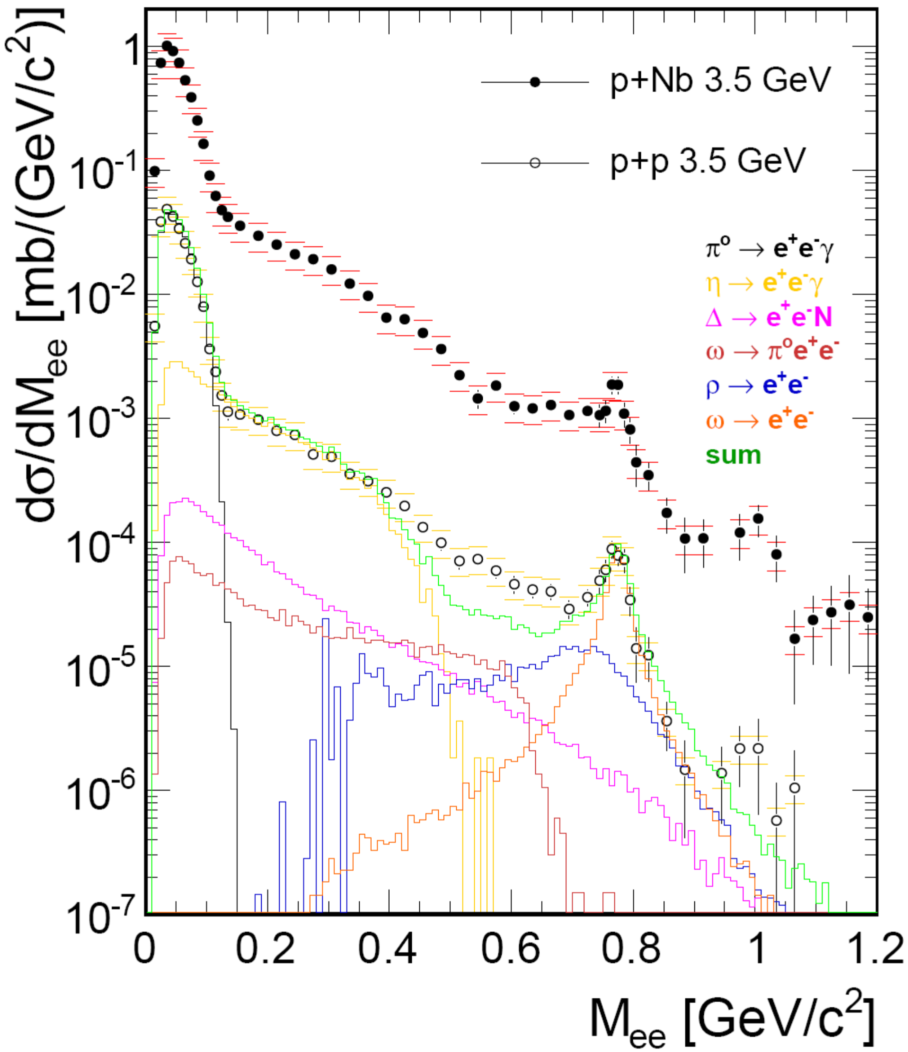
- Rapid increase of relative yield reflects the number of ρ's regenerated in fireball

Na60 data: EPJC 61 (2009) 711

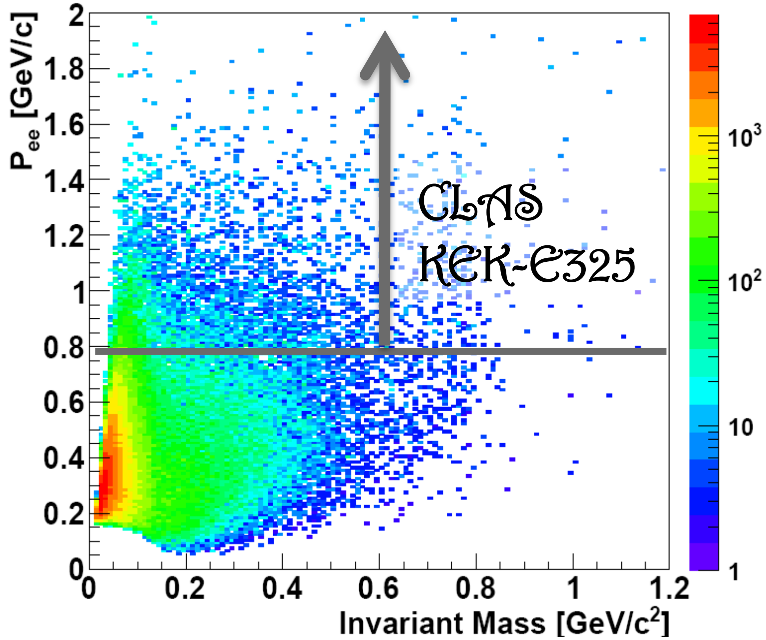
Electron pairs from cold nuclear matter

"if you are out to describe the truth, leave elegance to the tailor" (A. Einstein)

cocktail: PYTHIA +Pluto



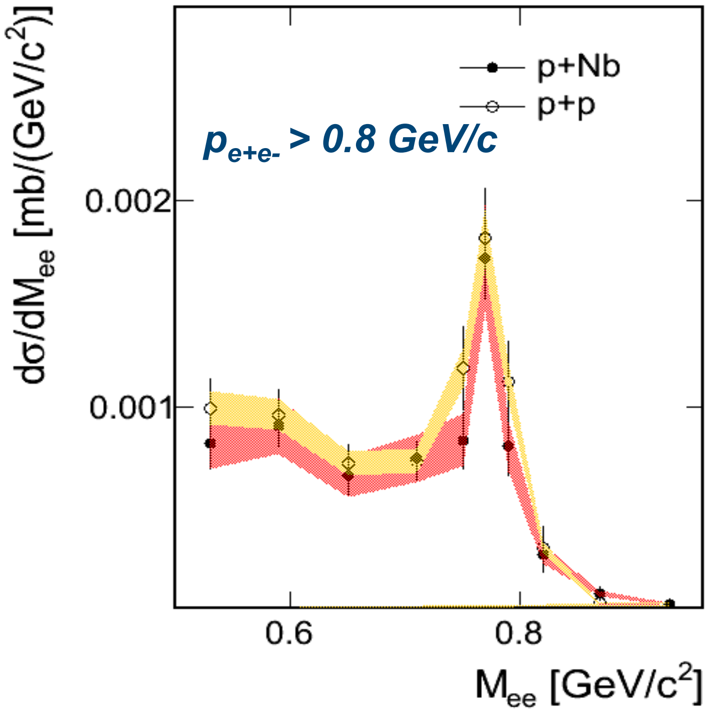
- **First measurement of lepton pairs with p_{e+e-} < 0.8 GeV/c radiated from cold matter**
  → not measured by CLAS, KEK-E325
- Mass resolution: σ_ω = **16 MeV/c²**

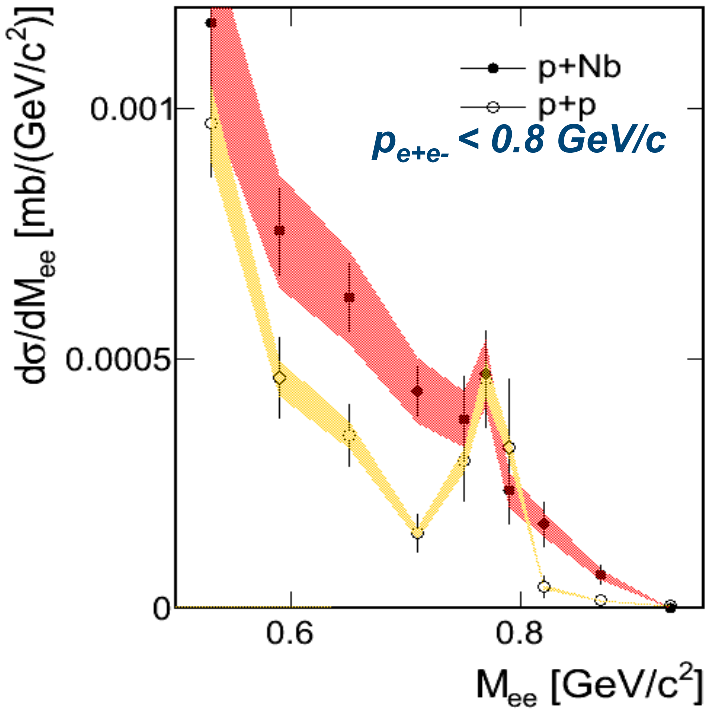


HADES p+p data: arXiv:1112.3607 [nucl-ex]
HADES p+Nb data: in preparation

Electron pairs from cold nuclear matter

HADES p+Nb data (M. Weber, M. Lorenz), publication in preparation

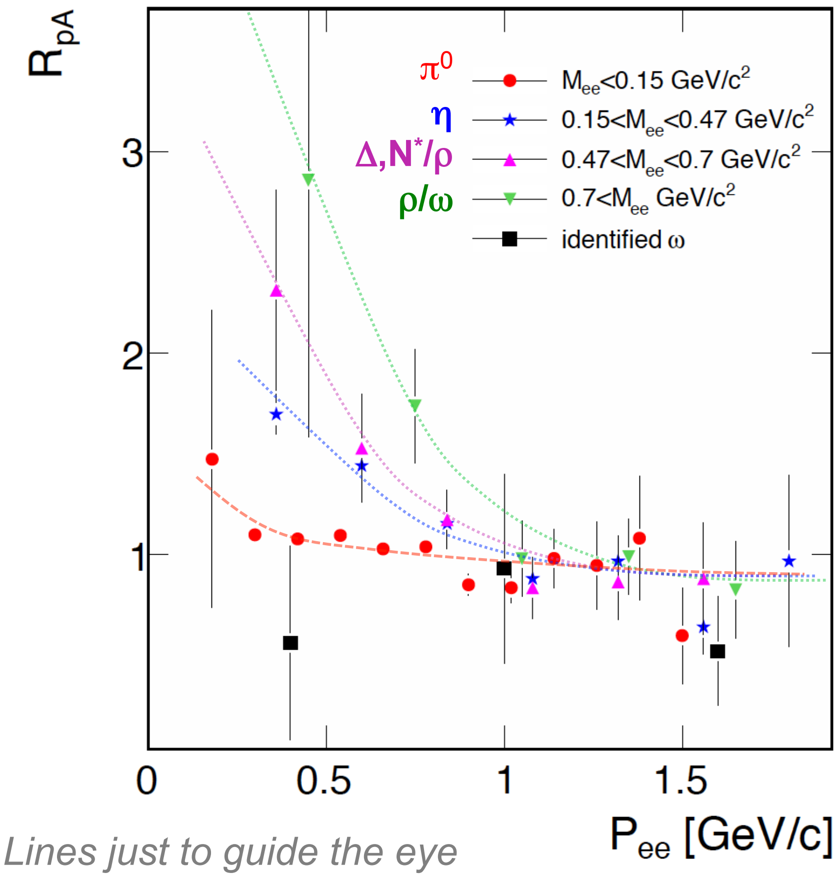




- No ω line shape modification is observed
- For p_{e+e-}< 0.8 GeV/c clear **excess over p+p**
  → role of the secondary ρ from N(1520), Δ (1700),…?
- **Reduced ω yield** → strong broadening?

Origin of the excess in p+Nb system?

Nuclear modification factor: $R_{pA} = \frac{d\sigma/dp^{pNb}}{d\sigma/dp^{pp}} \cdot \frac{A_{part}^{pp}}{A_{part}^{pNb}} \cdot \frac{\sigma_{reaction}^{pp}}{\sigma_{reaction}^{pNb}}$



Lines just to guide the eye

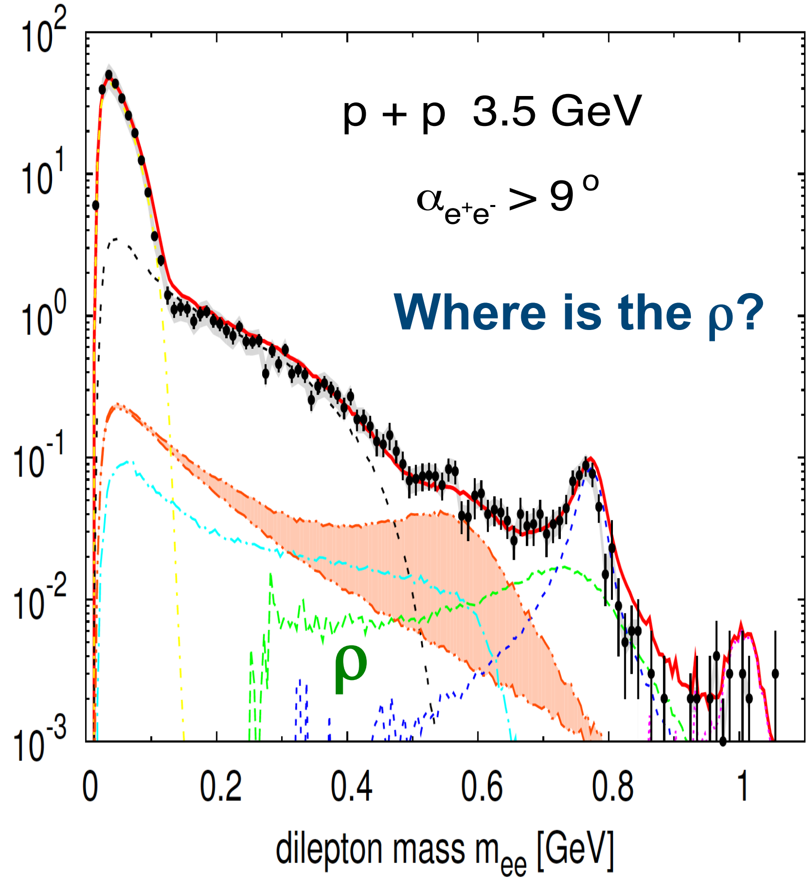
- **R_{pA} grows significantly when p_{e+e-} decreases** (max for ρ) → role of secondary reactions?
- **Identified ω do not show momentum dependence!**

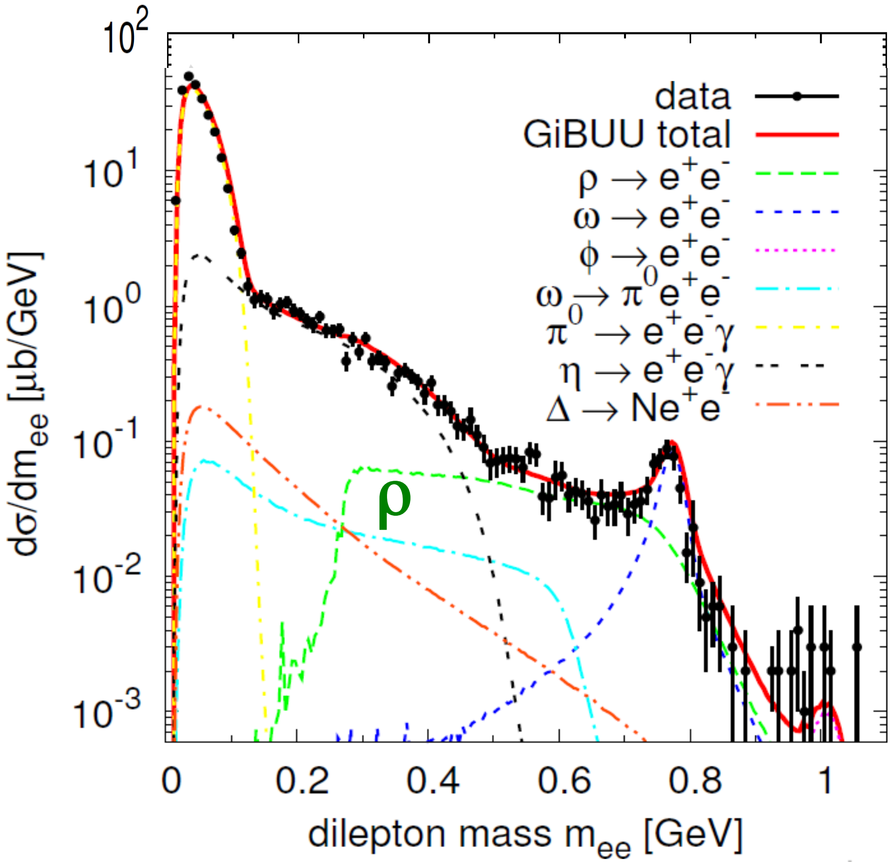
From T_A to ω absorption,
like in γA reactions (see talk V. Metag)?

→ not straightforward in pA collisions

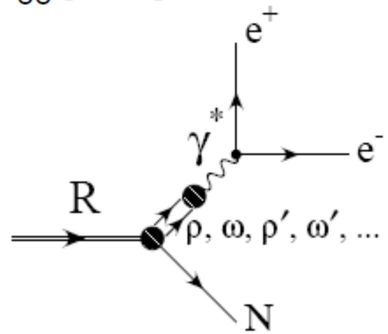
GiBUU calculations : p+p at 3.5 GeV

J. Weil at al., arXiv:1106.1344v1 [hep-ph] 7 Jun 2011

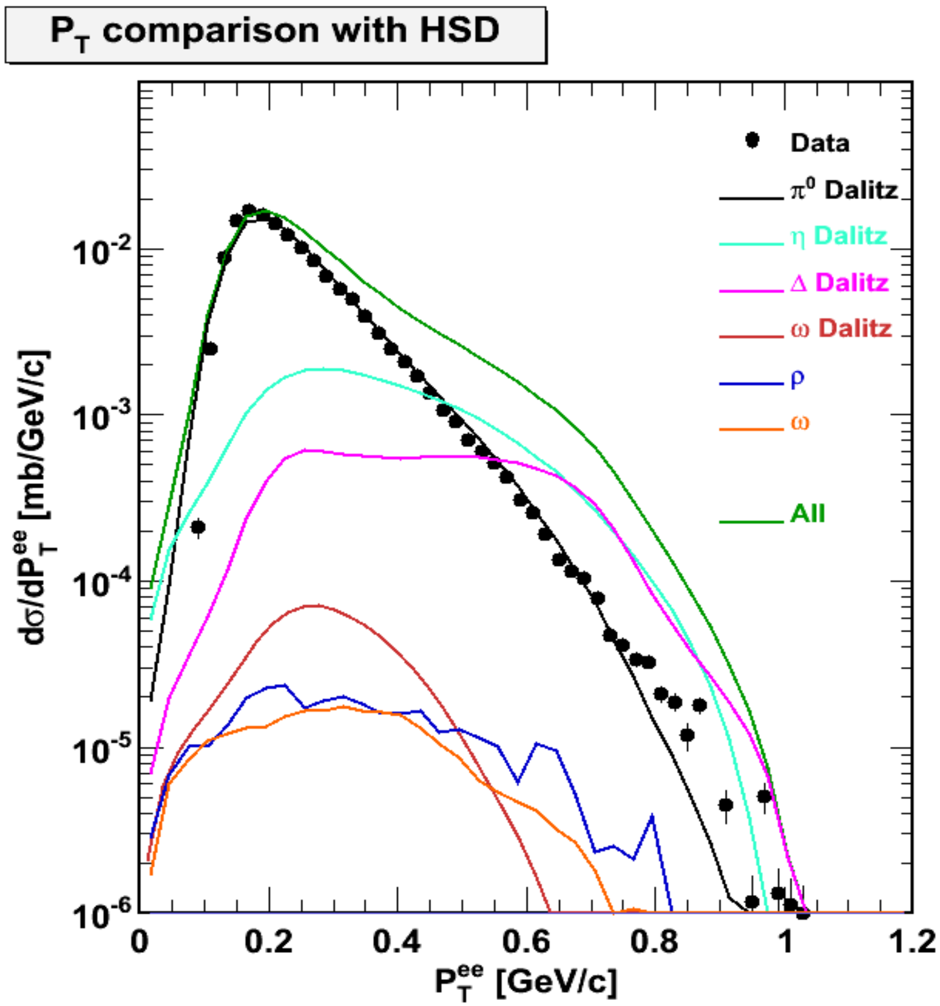


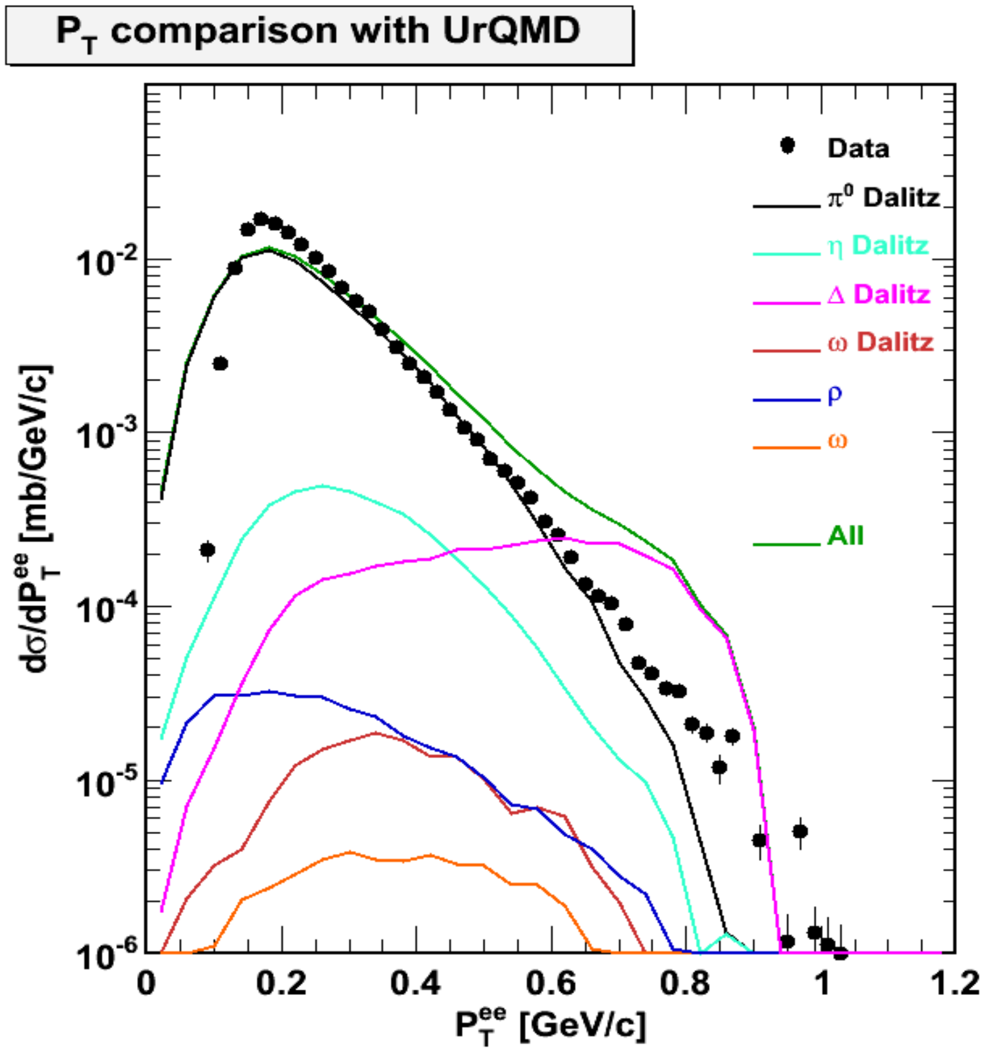


- Better description when introducing Δ-N transition EM form factor
- or when producing all ρ via baryonic resonances →



HSD and UrQMD calculations : p+p at 3.5 GeV



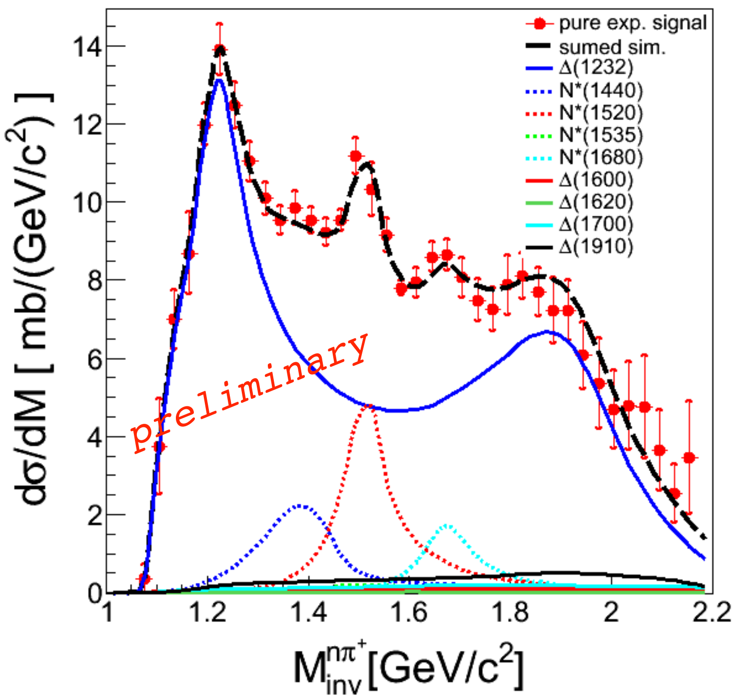


Particle production by LUND string fragmentation

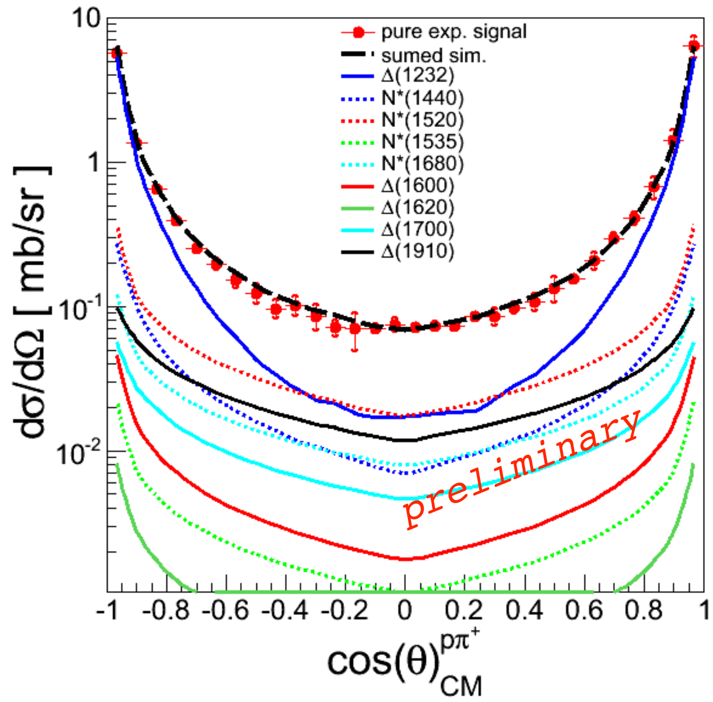
Particle production through baryonic resonances

Reconstruction of the baryonic resonances: exclusive analysis of pp → pnπ^+ ans pp → ppπ^0

nπ^+ invariant mass



pπ^+ angular distribution

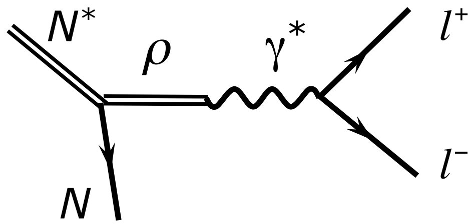


Data: in preparation, A. Dybczak

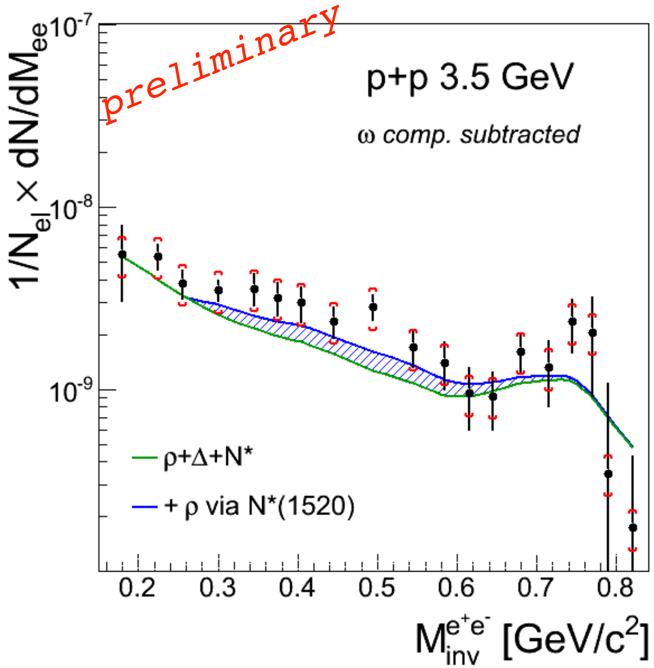
- 14 baryonic resonances are included in the analysis (N*1535 constrained by pp → ppη channel)
  K. Teilab Int.J.Mod.Phys.A26:694-696,2011
- Cross section for resonance production via exclusive analysis of pp → pnπ^+ and pp → ppπ^0

pp → ppe$^+$e$^-$

Dileptons: from SIS to SPS...



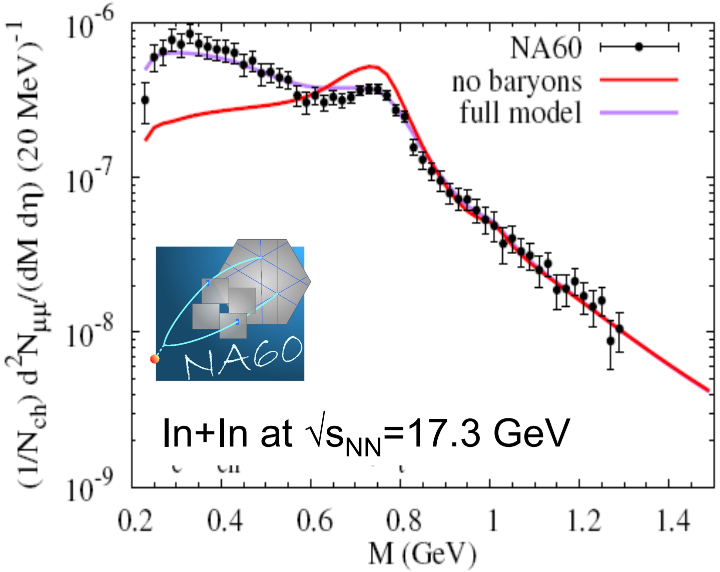
Exclusive analysis: pp → ppe⁺e⁻



Data: in preparation, A. Dybczak
Model: M. Zetenyi and Gy. Wolf
Phys. Rev. C 67, 044002 (2003).

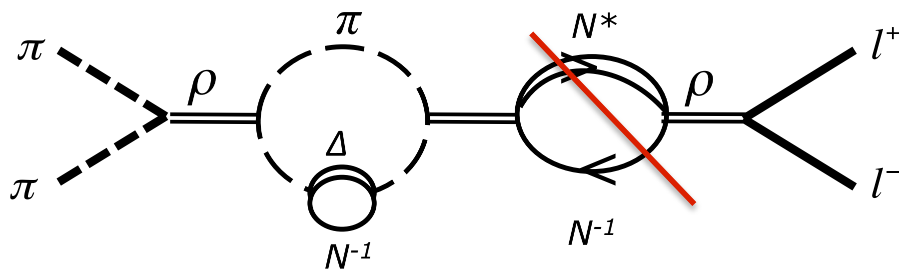
- Dalitz decays of baryonic resonances - dominant source at low beam energies.
- Relative contribution reconstructed from the hadronic channels

Acceptance corrected dimuon excess yield



Data: EPJC 59 (2009) 607
R.Rapp: NPA806 (2008) 339

In-medium ρ spectral function:
strength of dilepton yield at low masses is **due to coupling to baryons**!

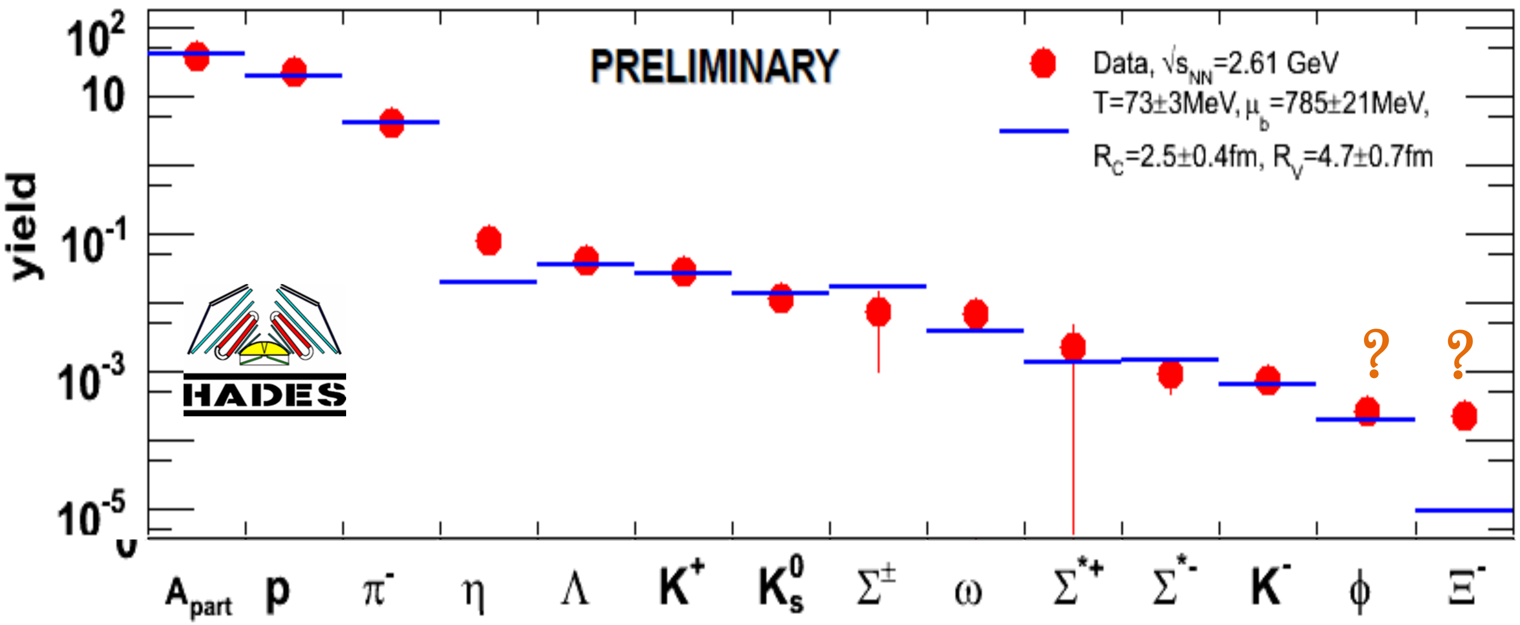


Friman et al., 1993 Nucl. Phys. A 560 411

strangeness

Strangeness production in Ar+KCl collisions

Final state "hadron-chemistry"



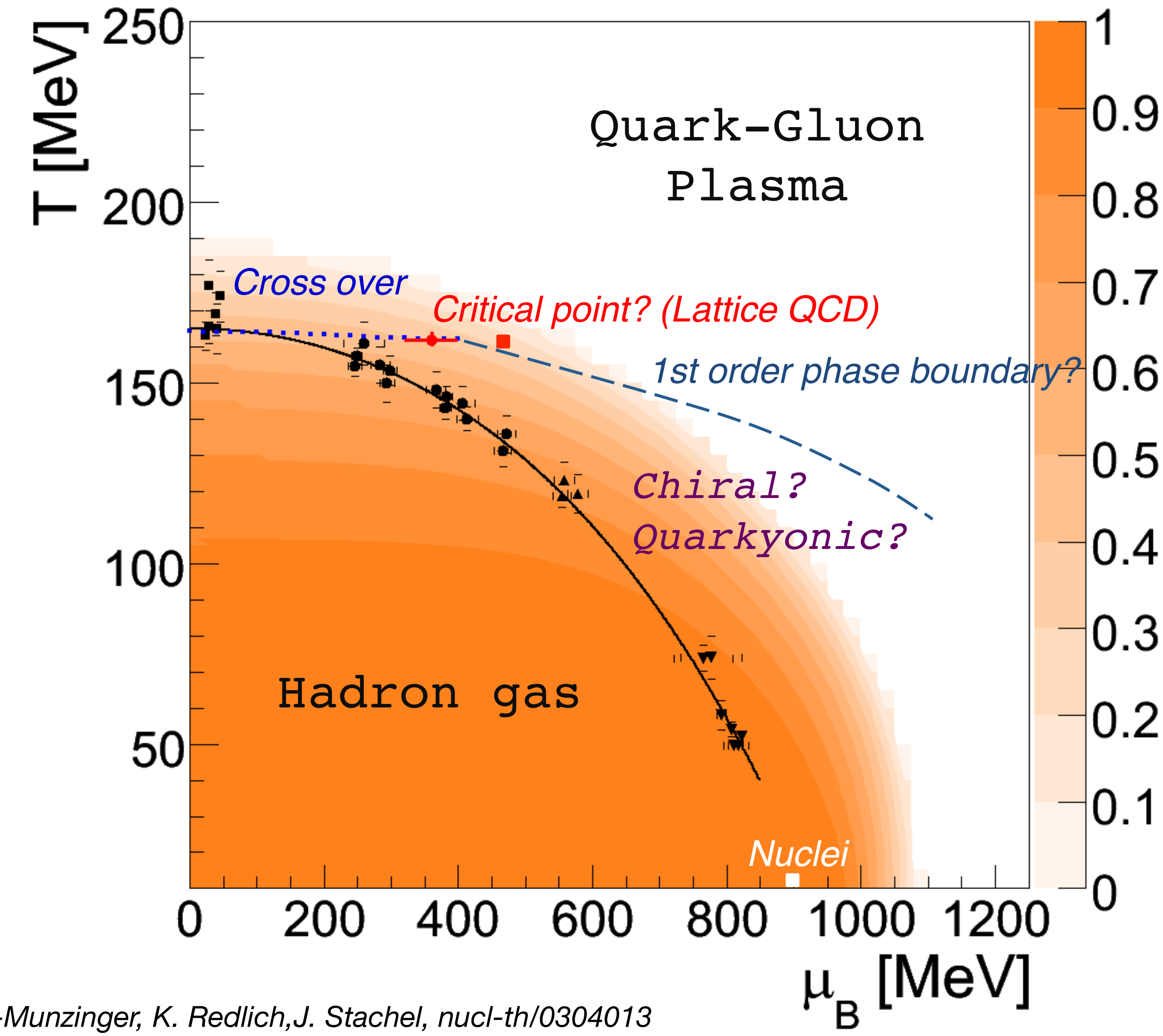
— *THERMUS fit: J.Cleymans, J.Phys.G31(2005)S1069*

● *HADES Ar+KCl data at 1.76 GeV/u: Eur. Phys. J. A 47:21, 2011*

- Statistical Hadronization Model describes hadron abundances except in case of large Ξ^- yield
- Thermal equilibrium also at low energies (high μ_B)?
- Production mechanism of **multi-strange baryons**?

Quest for higher statistics!

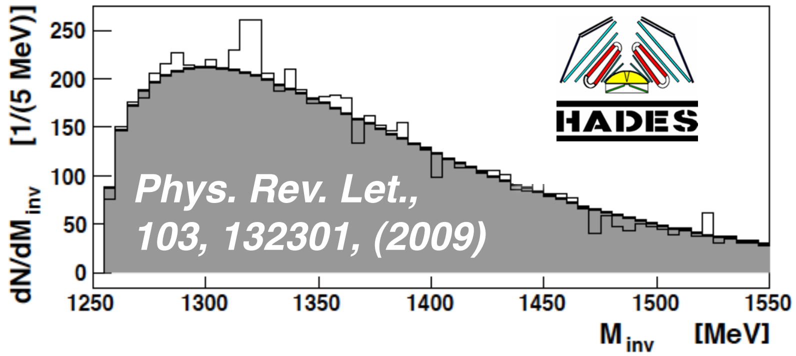
HADES and the Phase Diagram of Matter

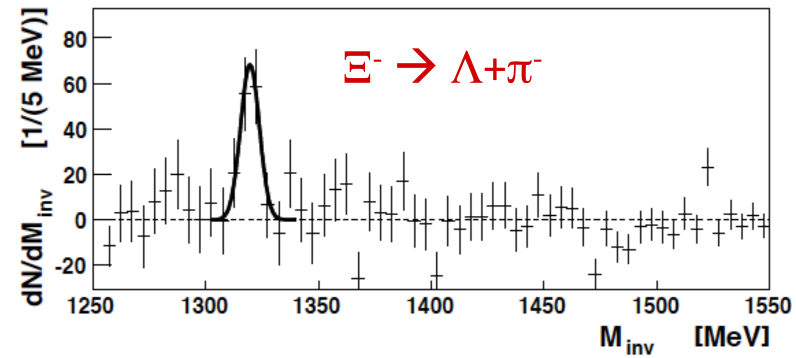


$$\frac{\langle q\bar{q} \rangle_{T,\mu_B}}{\langle q\bar{q} \rangle_{T=0,\mu_B=0}}$$

SHM : P. Braun-Munzinger, K. Redlich, J. Stachel, nucl-th/0304013
J. Cleymans, K. Redlich, PRC 60 054908
lQCD : Z. Fodor et al., hep-lat/0402006, F. Karsch, QM04
<qqbar> : Schäfer, Wambach (priv. communication)

Multi-strange baryons



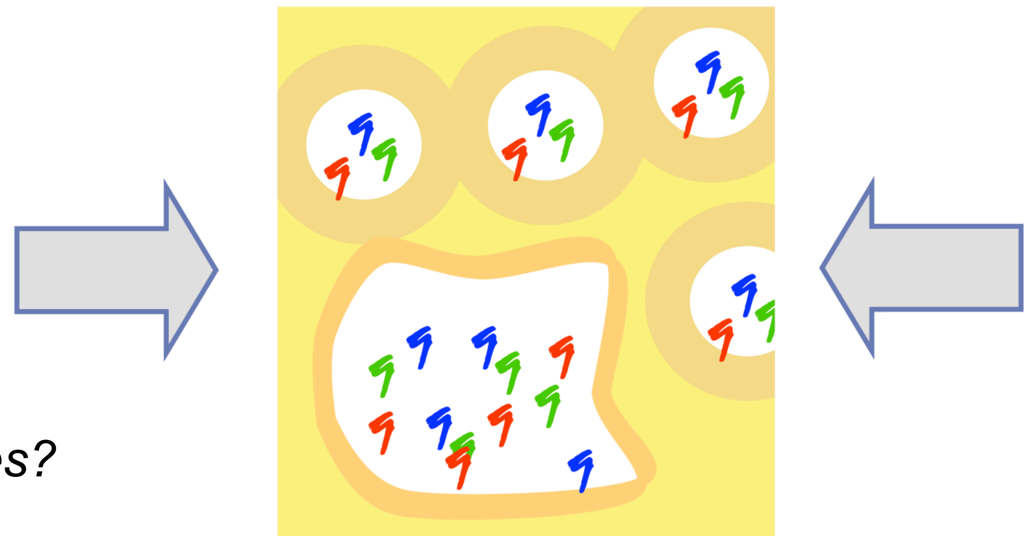


Probability ($M_{s\bar{s}}$) to produce in Ar+KCl collisions a strange quark pair is ≈ 5 × 10^{-2}

$$M_{\Xi^-} \approx 0.1 \times M_{s\bar{s}}^2$$

Bag fussion → Quarkyonic matter?

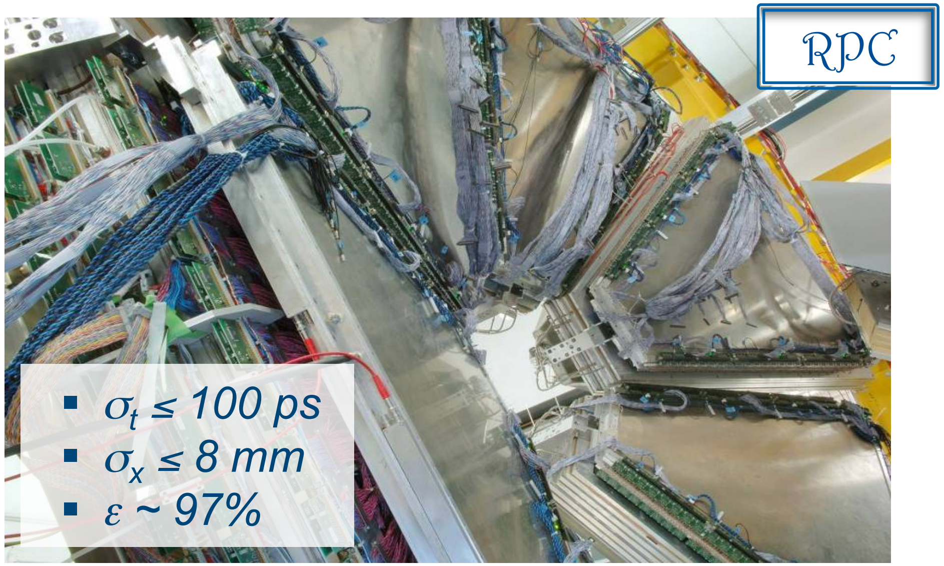
Strange quarks "trapped" in bubbles?



$T << T_c$, finite μ_B

The HADES upgrade

HADES upgrade: the RPC time-of-flight system

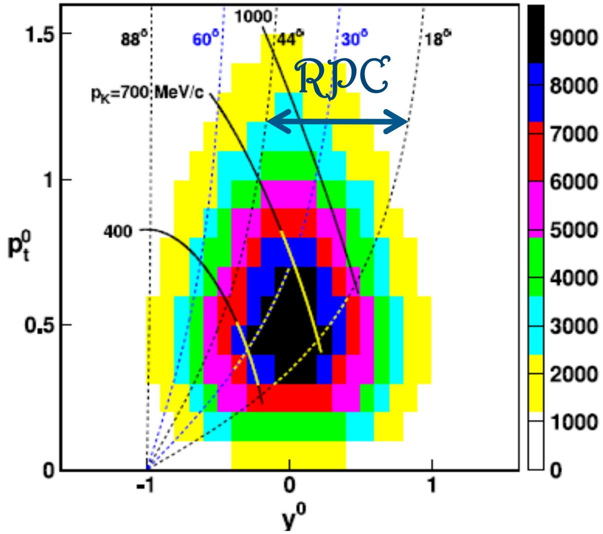


- $\sigma_t \leq 100$ ps
- $\sigma_x \leq 8$ mm
- $\varepsilon \sim 97\%$

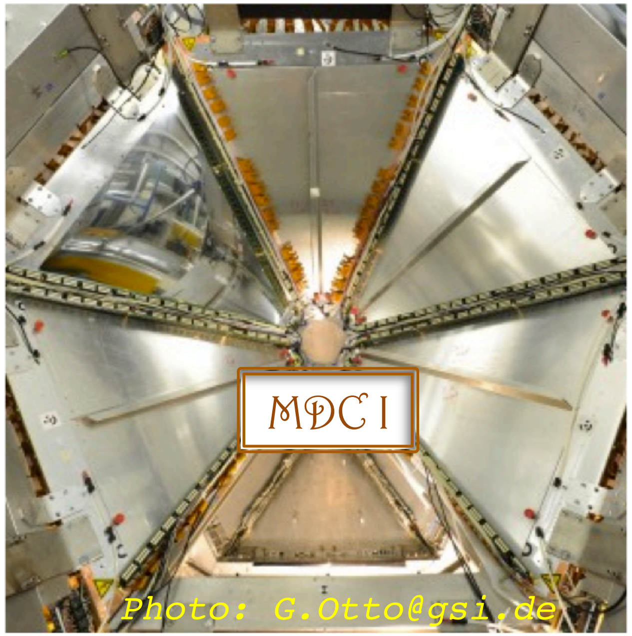
D. Belver et al . NIM A602(2008) 687, 788
E. Blanco et al. NIM A602(2008) 691

Leading institute: Coimbra, Portugal

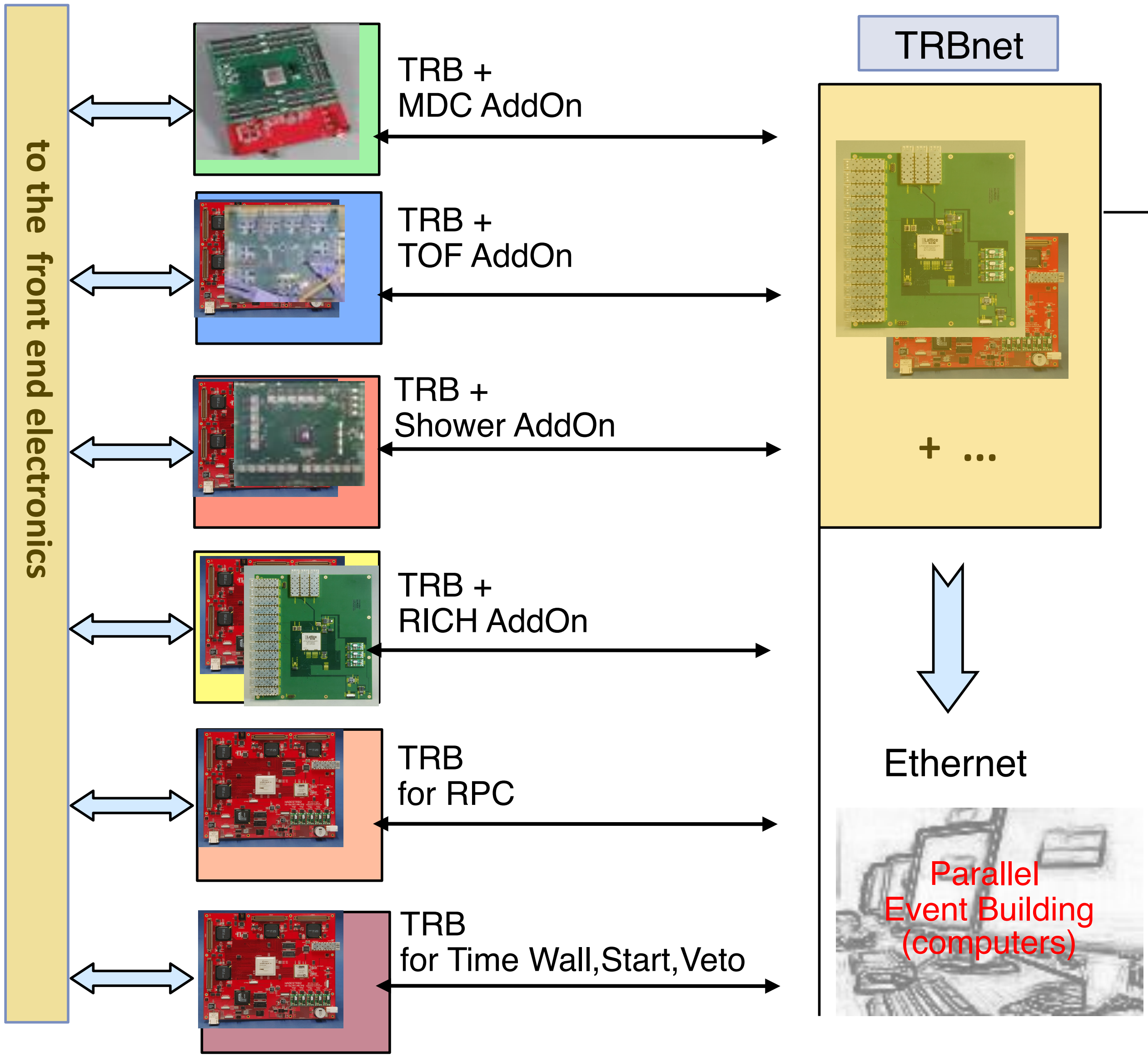
K^- acceptance (nice rapidity coverage!)

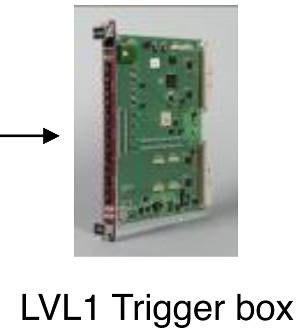


- New set of Plane I drift chambers: HZDR, Germany
- Stable operation of 4 modules in Au+Au environment in Aug. 2011!



HADES DAQ upgrade

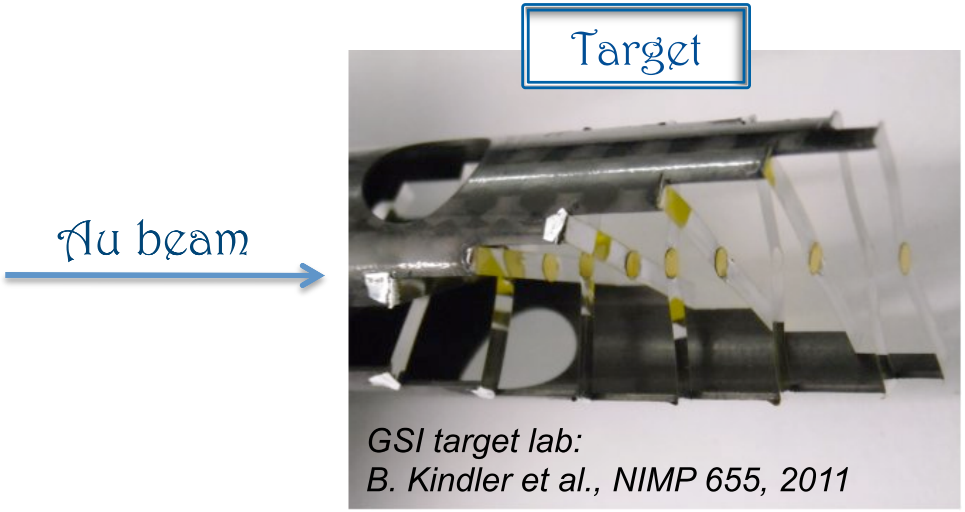




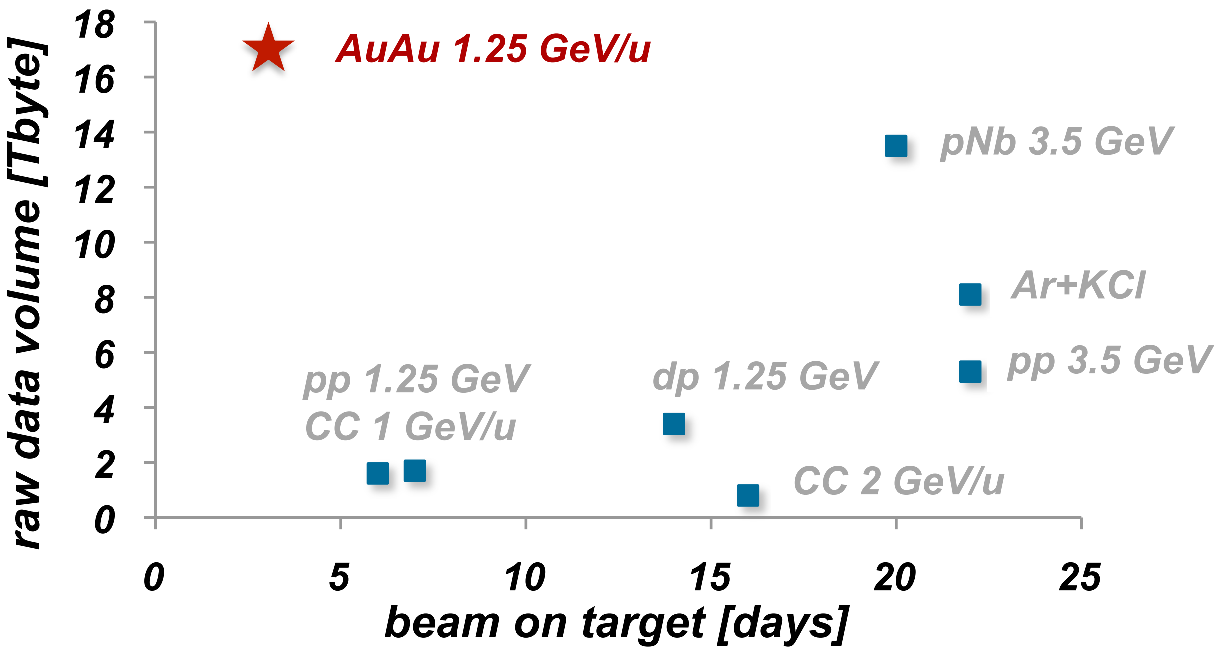
- Versatile, FPGA board based system using dedicated add-on boards and data/trigger/slow-control transport via serial optical links (TRBnet)
- Event rate up to 100 kHz (p+p), 20 kHz (Au+Au)
- Data rate up to 500 Mbyte/s (peak)

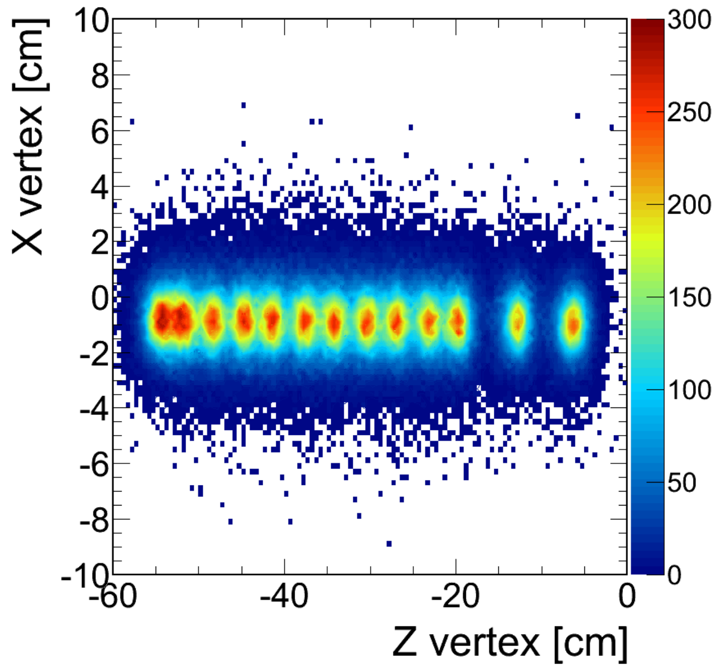
Au+Au at 1.25 GeV/u (commissioning beam time Aug'2011)

- 64 hours beam Au on Au target
- 1.3 x 10^7 ions per second
- 8 kHz trigger rate
- 200 Mbyte/s data rate
- 0.84 x 10^9 events
- 17 x 10^{12} Byte of data

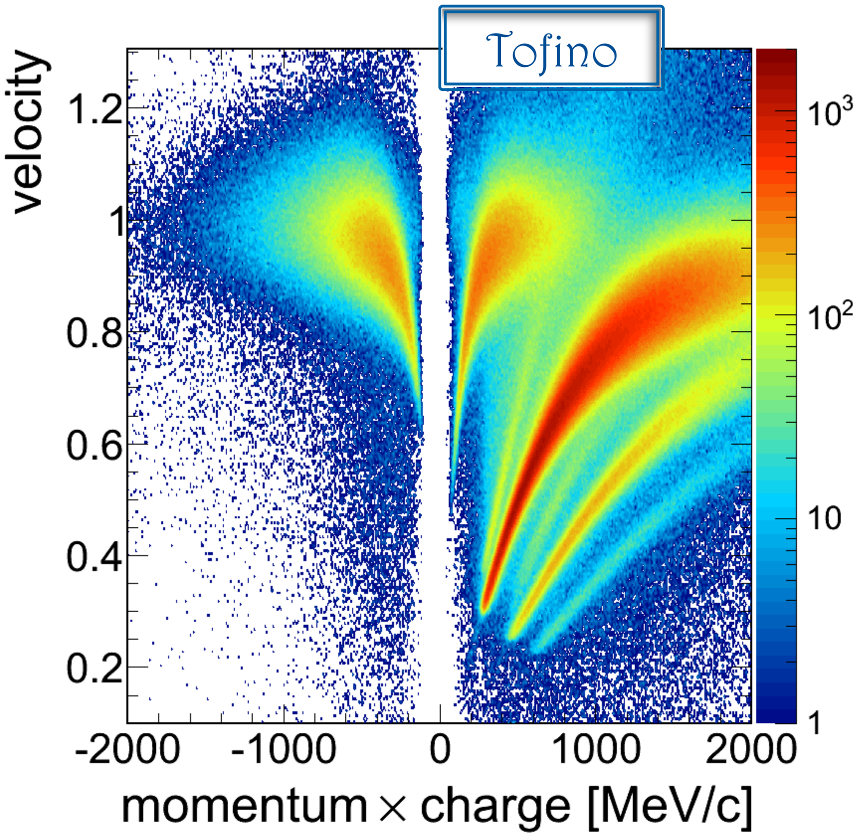


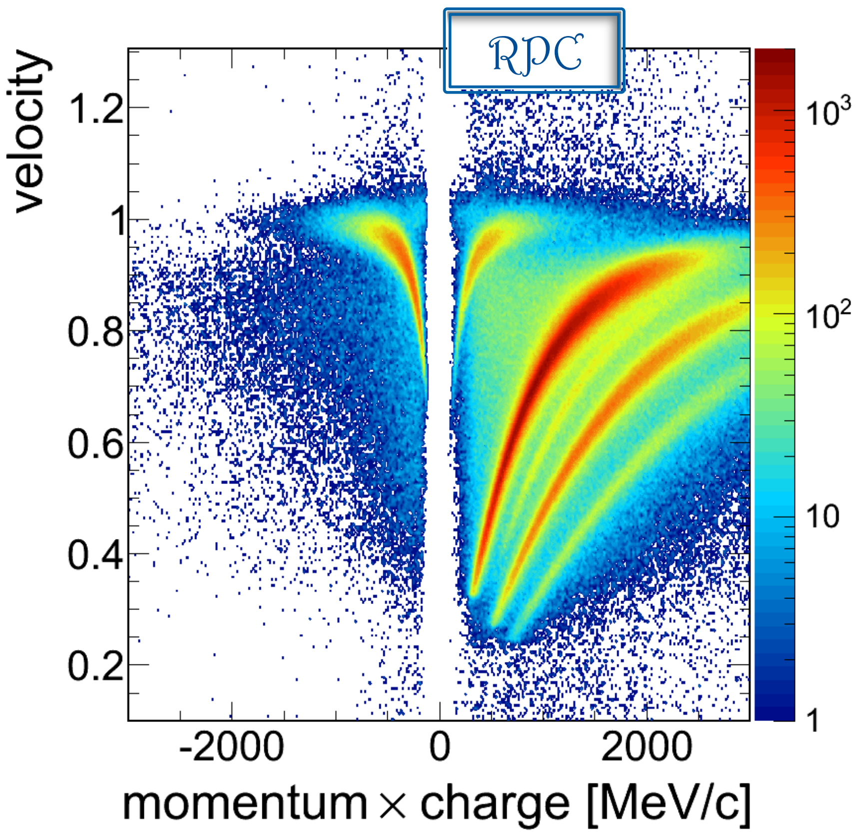
GSI target lab:
B. Kindler et al., NIMP 655, 2011





Particle identification: then and now …



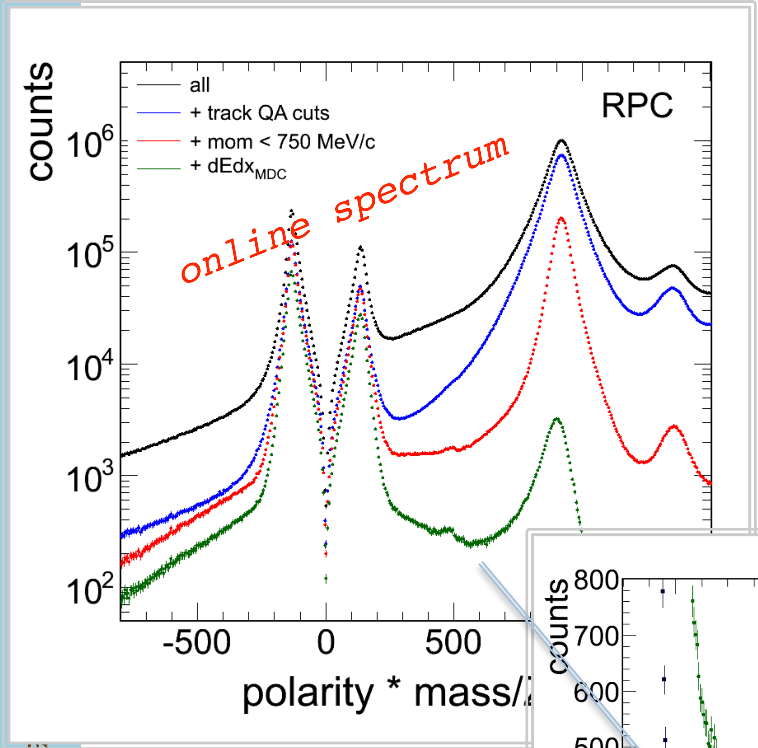


The Coimbra team (P. Fonte, A. Blanco et al.), detector modules
GSI/HADES (M. Traxler, W. Koenig et al.), FEE and read-out

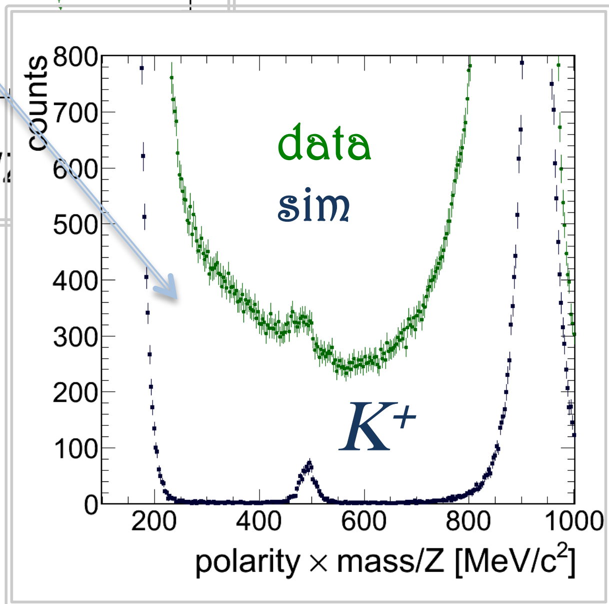
Online spectra from Au+Au collisions at 1.24 GeV/u

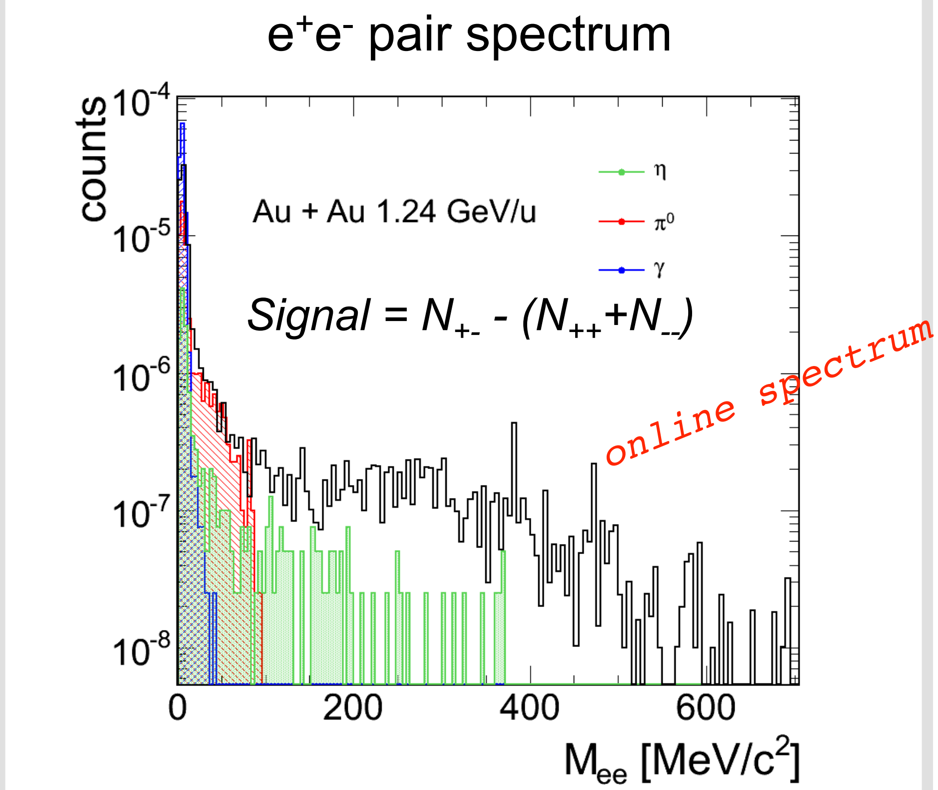
Online analysis: preliminary alignment and calibration.

New tracking with improved performance in high track density environment



5×10^7 *events*





- Only three active sectors
- 1/8 of the total statistic

Still to come...

π beam experiments with HADES

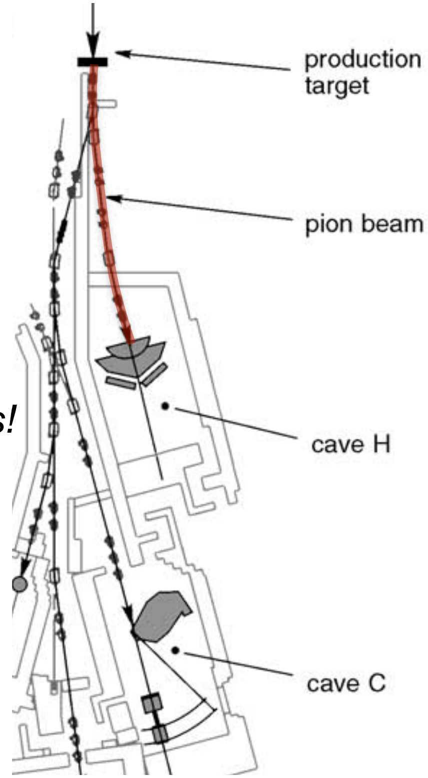
- **Physics with πN experiments:**
  - New precision data are of enormous importance for understanding of baryon resonance physics
  - Special interest to sub-threshold production
- **Challenges:**
  - Determine π momentum with Δp/p ~1-5%
  - Beam spot of 6x6 cm^2 at dispersive plane
    → detector with sufficient active area
  - Beam intensity ~10^8 part./s
    → radiation hard detector
    → fast readout electronics

Primary beam:
10^{11} N (2 AGeV) /spill

SIS fast ramping

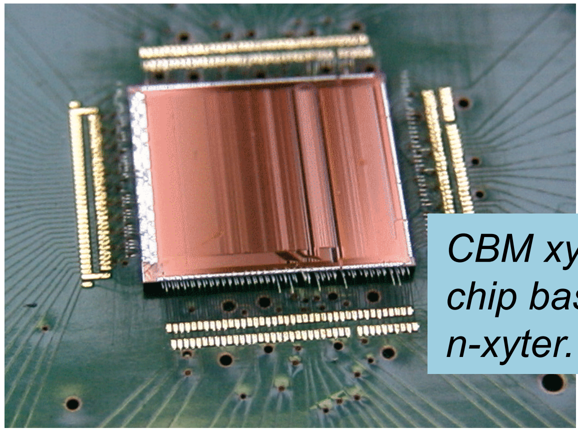
Spill: 4s cycle

Stable run for 3 weeks!



ZEUS at DESY

- **Strategy:**
  - Use 10×10cm^2 silicon strip detector
  - 2×128 channels - double sided
  - Radiation hard
  - Profit from n-xyter developments for CBM
    - ✓ Self-triggered architecture
    - ✓ 128 channels
    - ✓ Average hit per channel rate 160 kHz



CBM xyter FE chip based on n-xyter.

Summary

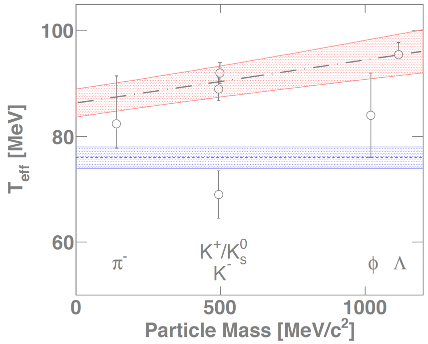
HADES provides high-quality data for understanding di-electron and strangeness production in elementary and heavy-ion collisions at SIS energy regime.

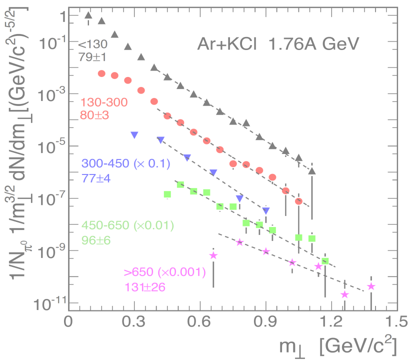
- Long-lived states of compressed nuclear matter are produced in heavy-ion collisions at few GeV energy regime
- This state of matter might be much more exotic than a hadron gas
- Observations:
  - "Thermal" hadron production (with some exceptions)
  - Strong broadening of in-medium states
  - High Ξ^- production cross section

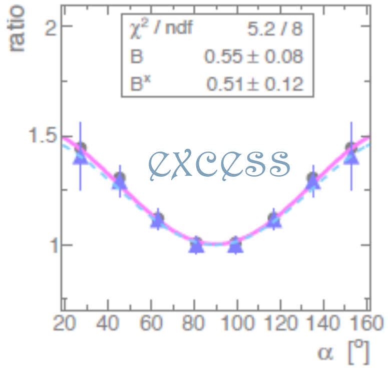
Many more results from elementary collisions!

Au+Au at 1.25 GeV/u commissioning beam time

- New HADES took off!
  Performance goals reached and partly exceeded
- Detector is ready for the production beam time in April - May 2012







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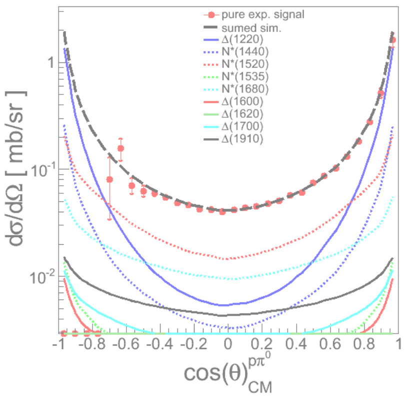
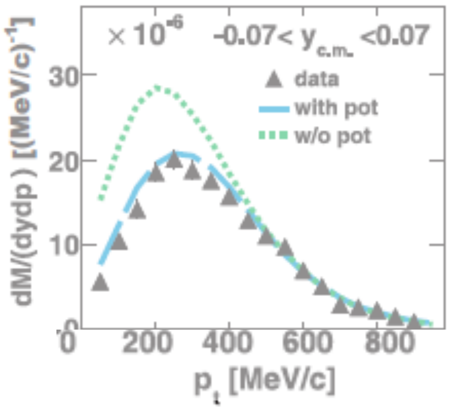
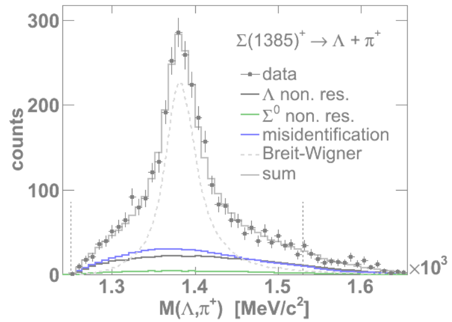
Thank you!







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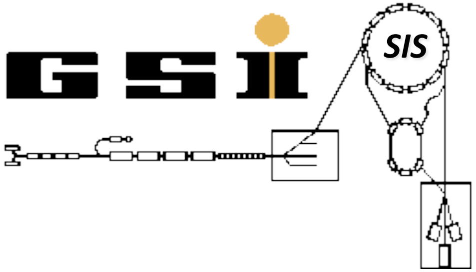
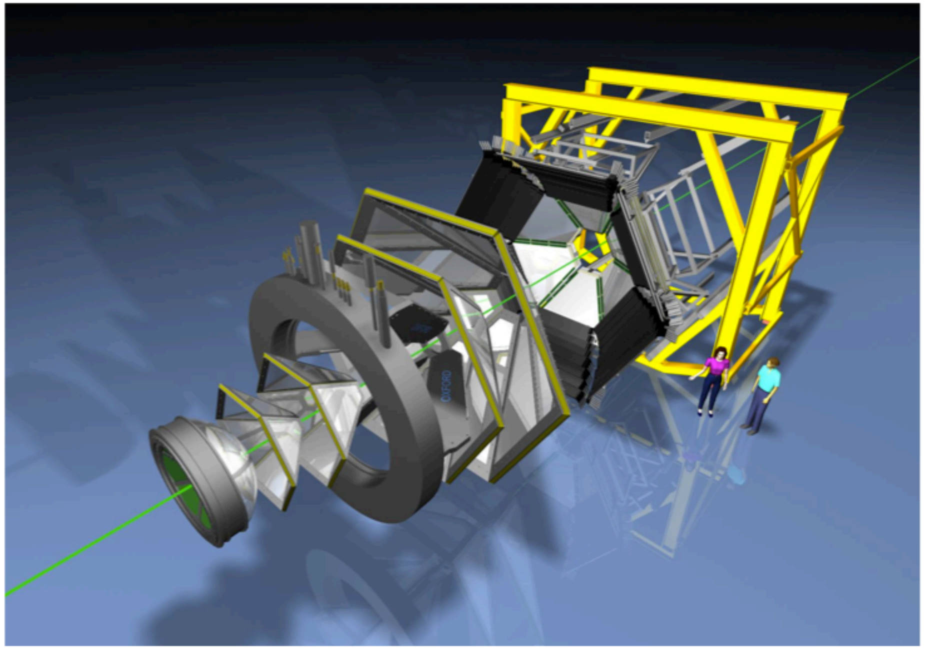
The HADES Collaboration





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- München (TUM, Excellence Cluster Universe), Germany
- Dresden (FZD), Germany
- Frankfurt (Univ., EMMI, HIC for FAIR), Germany
- Giessen (Univ., HIC for FAIR), Germany
- Darmstadt (TUD, EMMI), Germany
- Dubna (JINR), Russia
- Moscow (ITEP,RAS), Russia
- Nicosia (Univ.), Cyprus
- Orsay (IPN), France
- Rez (CAS, NPI), Czech Rep.
- Santiago de C. (Univ.), Spain
- Coimbra (Univ.), LIP, Portugal