Meson and Di-Electron Production: Recent Results from HADES

Ingo Fröhlich for the HADES collaboration

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Motivation

- Hadrons (ηαδροσ, heavy objects)
  - Possible mechanism for mass generation: chiral symmetry breaking (as explained by C. Djalali)
  - Approach: determine properties of hadronic matter
- at:
  - Different temperatures and/or densities
- Examples
  - Normal ("cold") nuclear matter: ρ_0, T=0
  - Heavy ion reactions,
    - either <u>dense</u> ($\rho>\rho_0$, T>0) or <u>hot</u> ($\rho<\rho_0$, T>>)
  - Neutron stars

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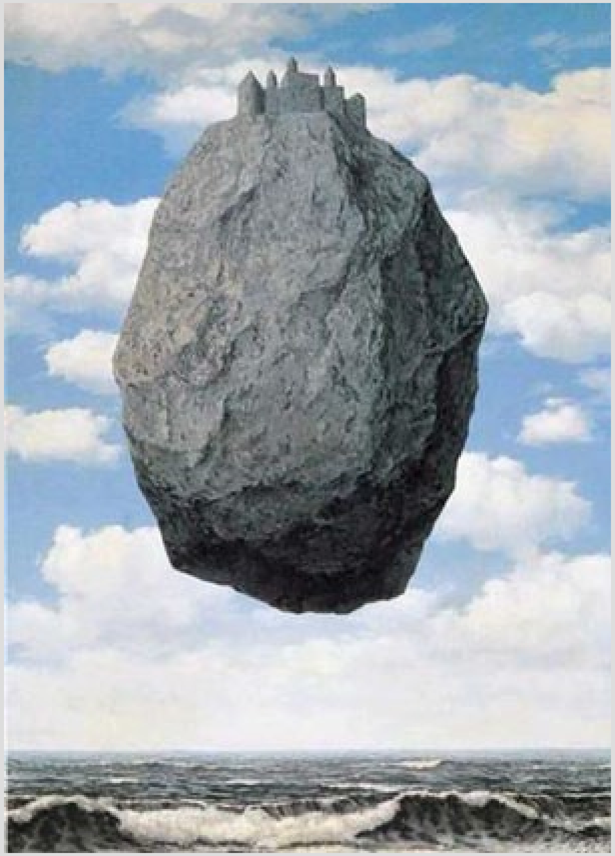
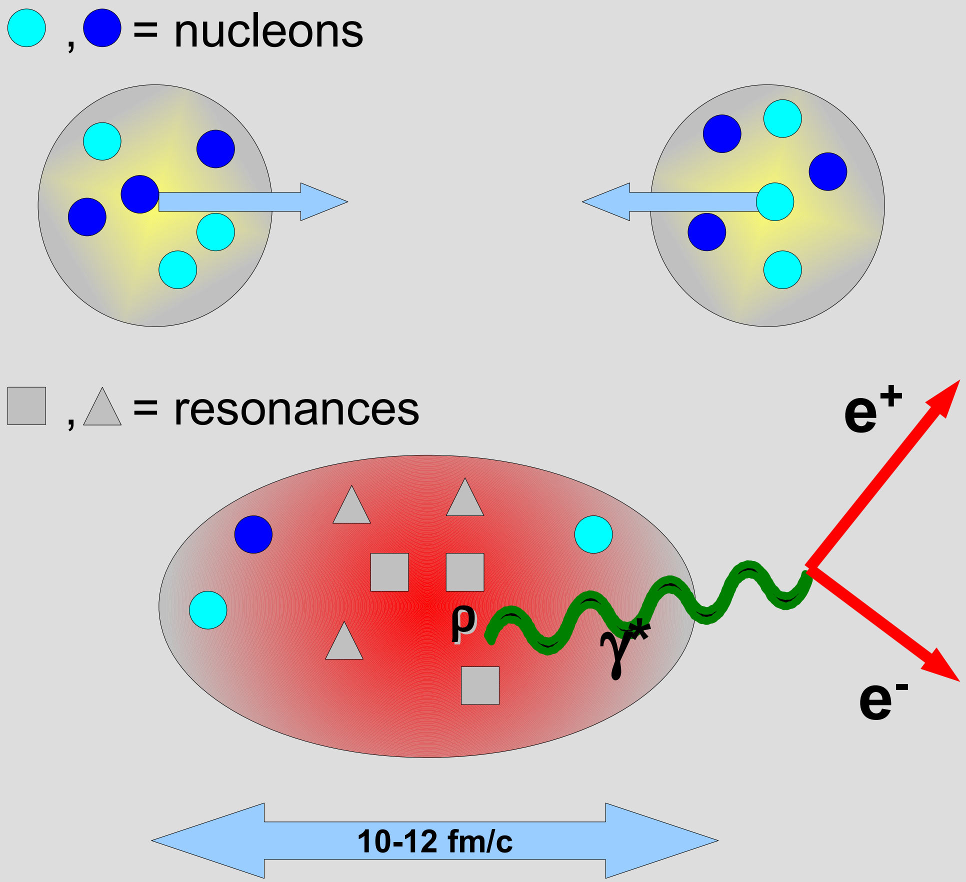
Outline

- Introduction (cont.)
- The detector setup & performance
- C+C at 1 and 2 AGeV
- p+p and p+n at 1.25 GeV
- Vector meson production
- Outlook



René Magritte:
Le Château des Pyrenées, 1959

The „Light“ from Dense Matter



- Heavy ion reactions
  - SIS18/GSI: 1-2 AGeV
  - Dense matter
  - Dominated by resonances
  - ρ produced & decayed inside dense phase

<u>multi step processes</u>: i.e.

$$NN \rightarrow N\Delta \searrow \pi N \searrow \pi N \rightarrow \rho N$$

Di-leptons are ideal probes (already outlined by C. Djalali)

Contributions to Cocktail

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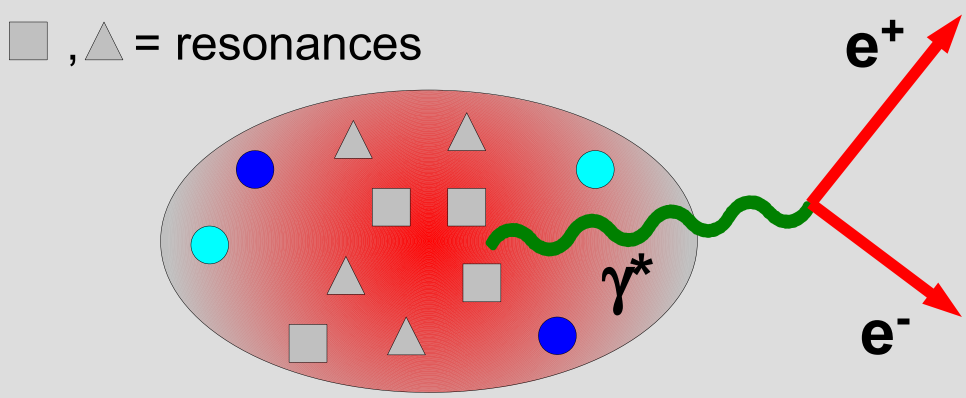
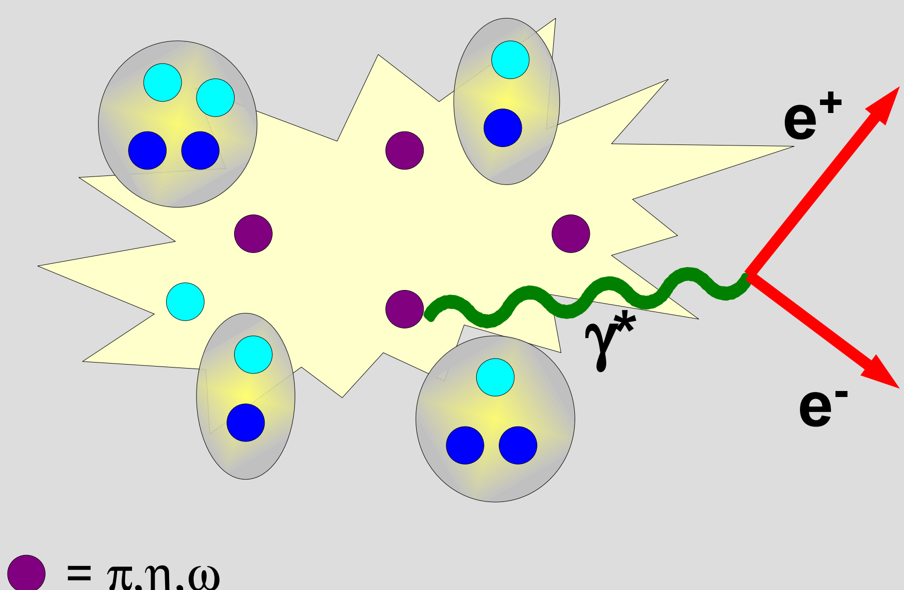




- Short-lived components
  - $\rho \rightarrow e^+e^-$
  - $\Delta, N^* \rightarrow Ne^+e^-$

  } to be studied
- Long-lived components:
  - $\pi^0/\eta \rightarrow \gamma e^+e^-$
  - $\omega \rightarrow (\pi^0)e^+e^-$

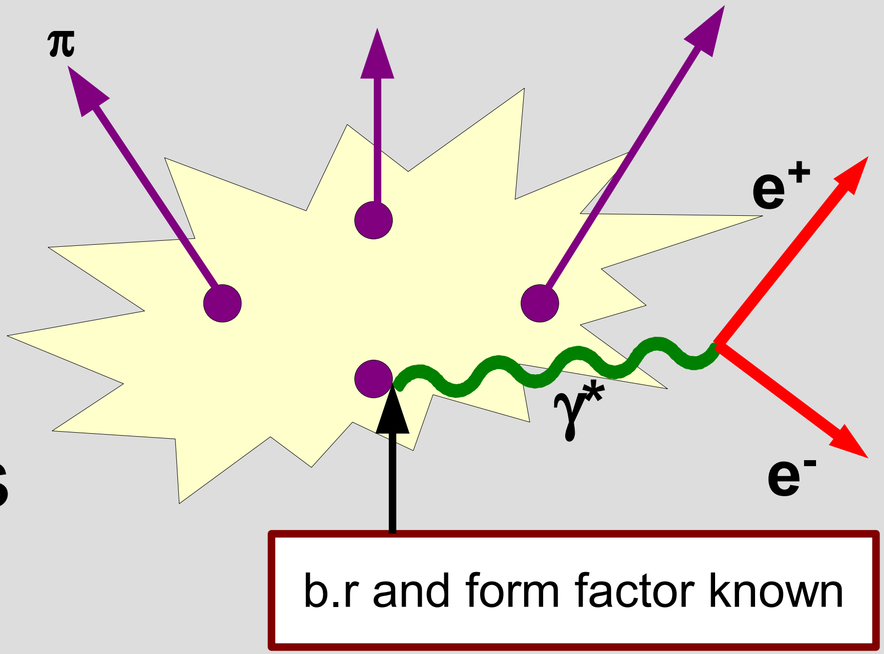
  } known properties
- Strategy:
  - Subtract long-lived components

➔ Key to electromagnetic structure of dense matter

Detector Features

- Normalization:
  - <u>Independent</u> measurement of hadronic products
- Large pair acceptance over (almost) full mass range

➔ Fixes π^0 contribution

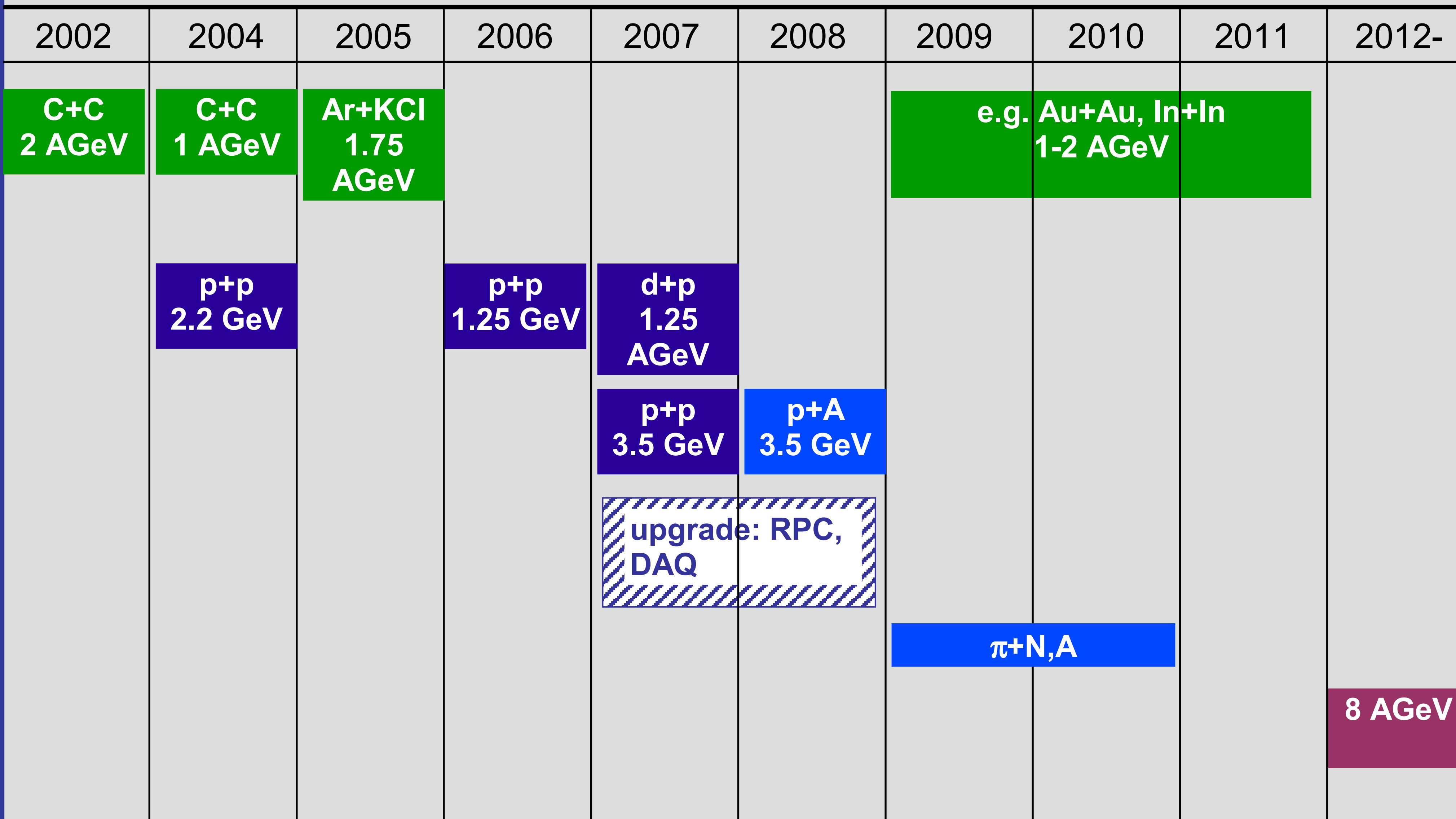


HADES: The <u>H</u>igh <u>A</u>cceptance <u>D</u>i-<u>E</u>lectron <u>S</u>pectrometer

or

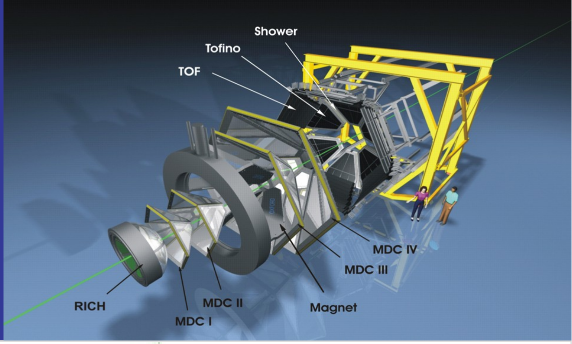
<u>H</u>adron <u>A</u>nd **<u>D</u>i-<u>E</u>lectron <u>S</u>pectrometer**

Schedule

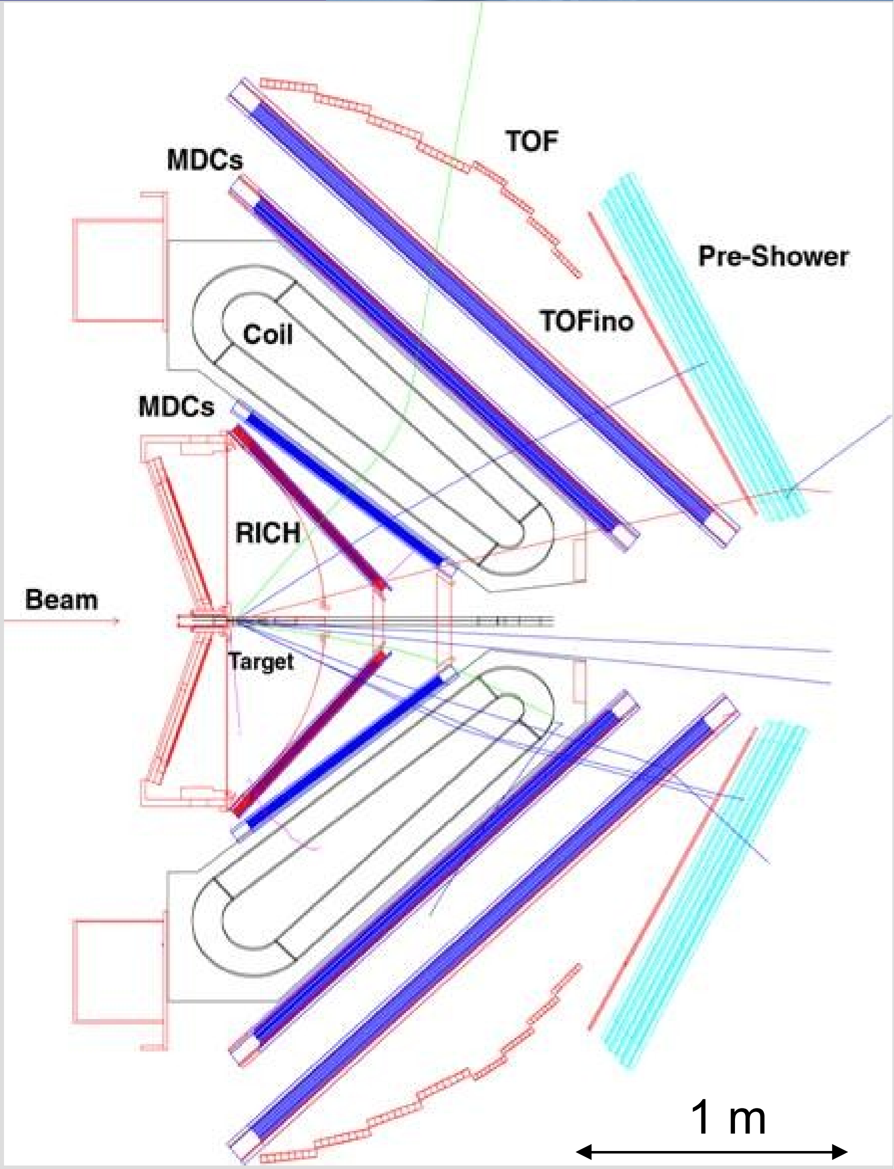

2002
2004
2005
2006
2007
2008
2009
2010
2011
2012-
C+C 2 AGeV
C+C 1 AGeV
Ar+KCl 1.75 AGeV
e.g. Au+Au, In+In 1-2 AGeV
p+p 2.2 GeV
p+p 1.25 GeV
d+p 1.25 AGeV
p+p 3.5 GeV
p+A 3.5 GeV
upgrade: RPC, DAQ
π+N,A
8 AGeV

Detector Setup and Performance

HADES Layout



- **Geometry**
  - Full azimuthal coverage, polar angles 18º - 85º
- **Particle identification**
  - RICH: CsI solid photo cathode, C_4F_{10} radiator
  - TOF
  - TOFino, (RPC in future)
  - Pre-Shower
- **Momentum measurement**
  - Superconducting toroid
  - MDCs: 24 multi-wire drift chambers (*C+C: Only 12 MDCs*)
- **Online event selection (level-2 trigger)**



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Performance: Pions

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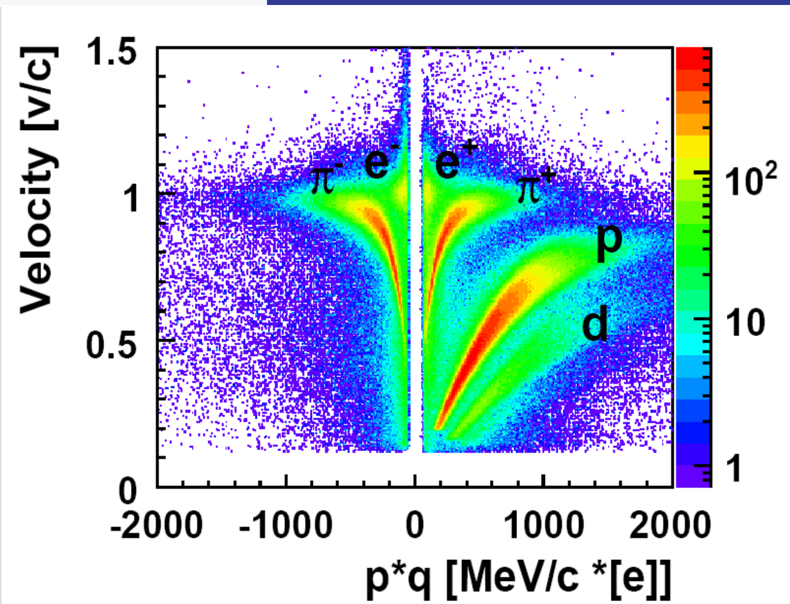
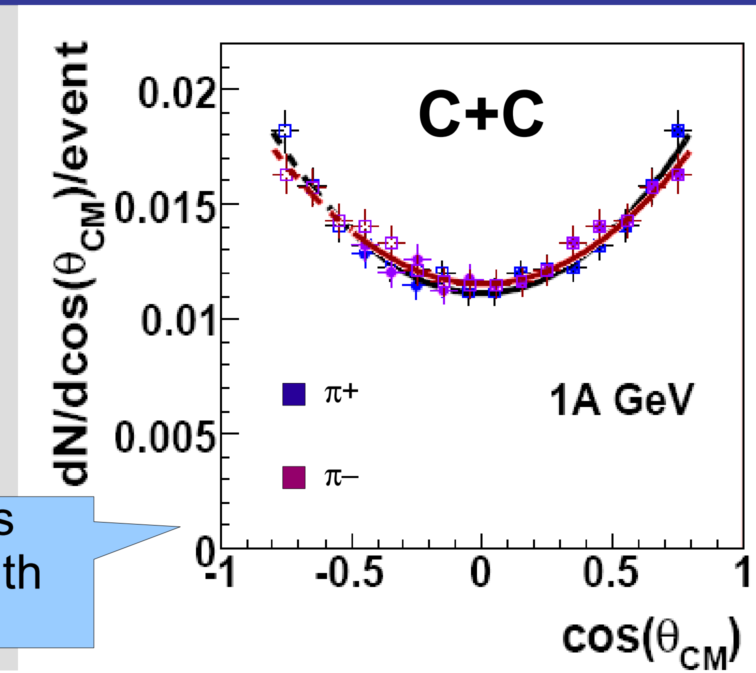




anisotropies consistent with UrQMD

- Charged pion production under control
- NB for C+C
  - $\pi^0 = ½ (\pi^+ + \pi^-)$

Beam energy = 1 AGeV

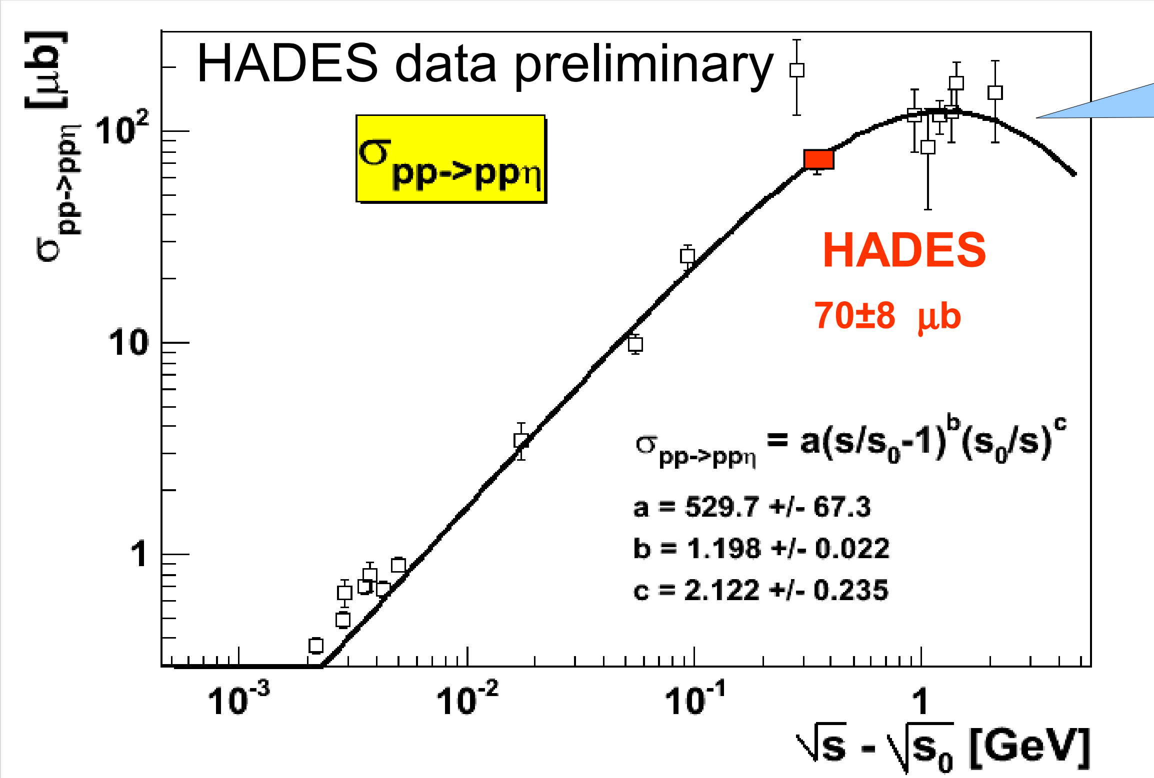
Particle	this work	KAOS [20]	TAPS [18]	UrQMD
π^+		0.061 ± 0.009		
$1/2(\pi^+ + \pi^-)$	0.061 ± 0.007			0.059
π^0			0.059 ± 0.005	0.067

Beam energy = 2 AGeV

Particle	this work	KAOS [20]	TAPS [18]	UrQMD
π^+		0.158 ± 0.014		
$1/2(\pi^+ + \pi^-)$	0.158 ± 0.017			0.137
π^0			0.154 ± 0.015	0.159

Performance: Exclusive Reactions

- Performance studied in (**exclusive**) pp reactions (here: 2.2 GeV)
- $pp \rightarrow pp\eta \rightarrow \mathbf{pp\pi^+\pi^-}\pi^0$



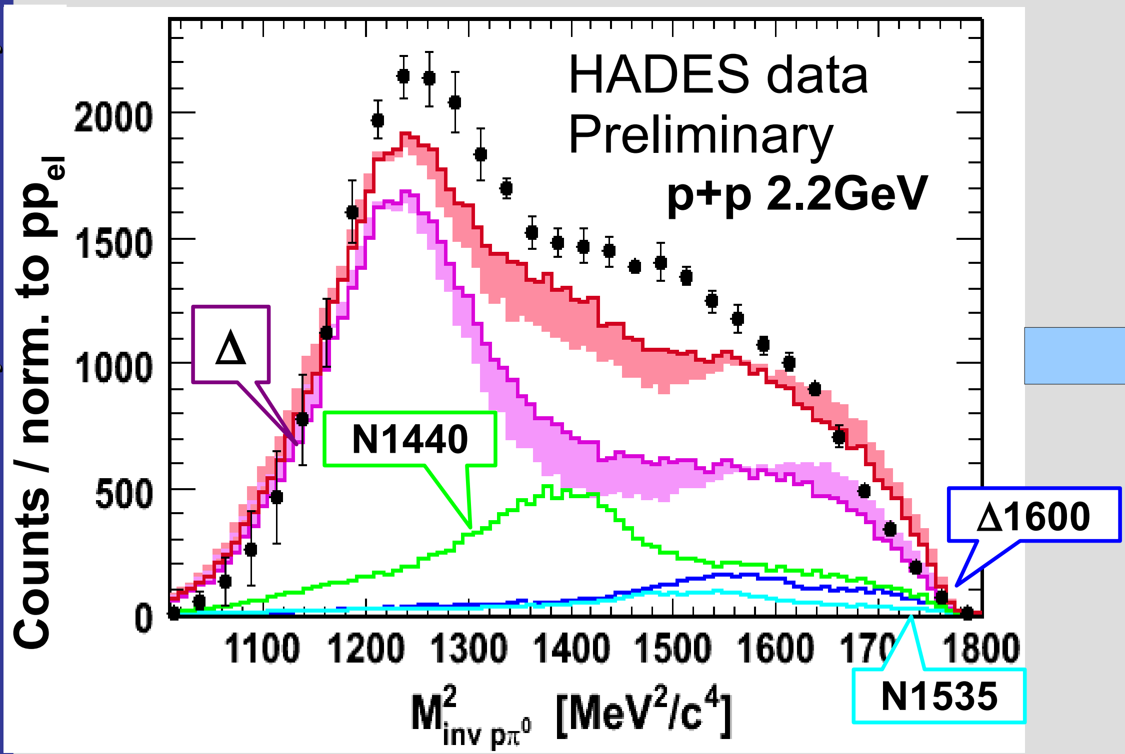
Refinement of older data set

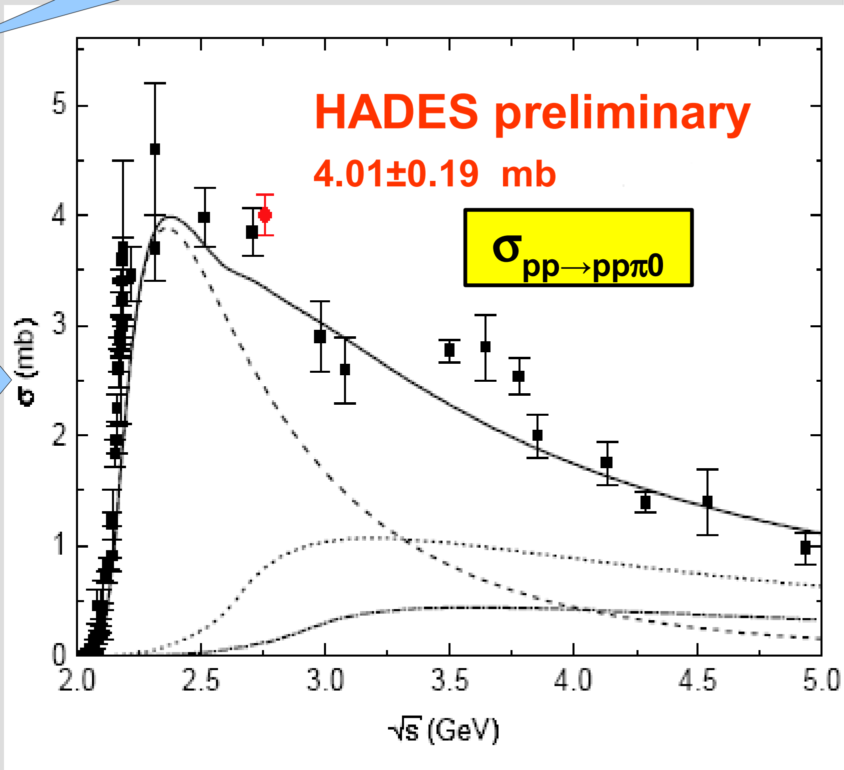
Also important for heavy ion transport models

Exclusive Reaction: $pp \rightarrow \underline{pp}\pi^0$

- π^0 simulation via resonance model [1-4]
- Cross section consistent with [1]

Absolute scale (via pp elastic)



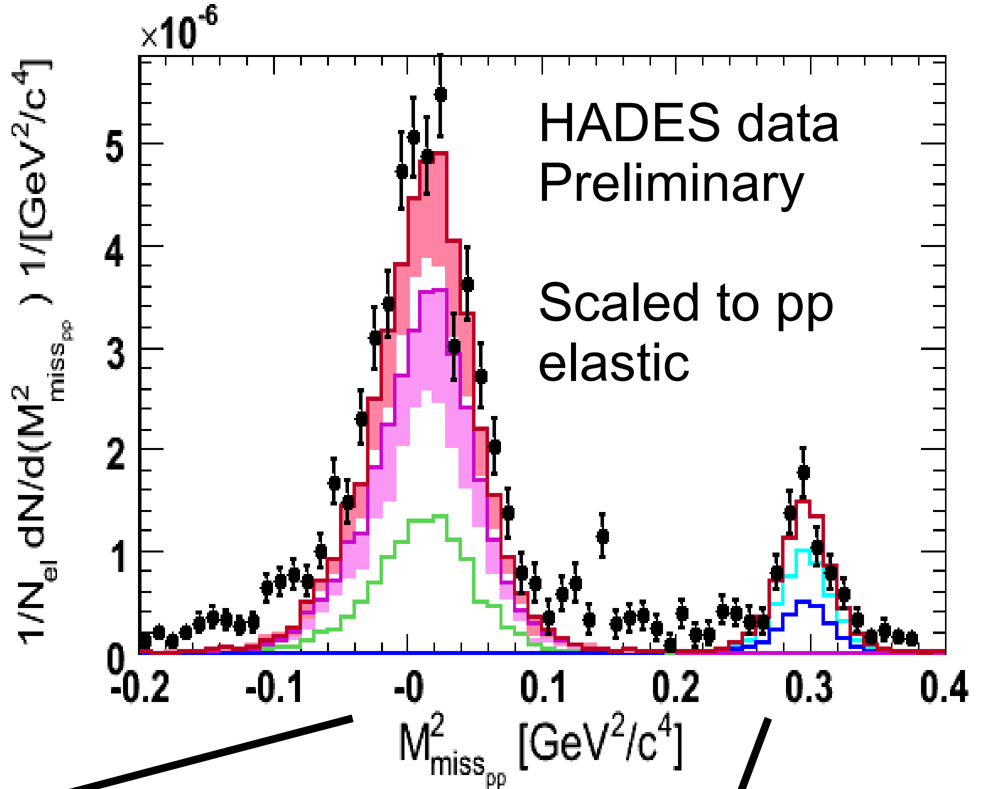


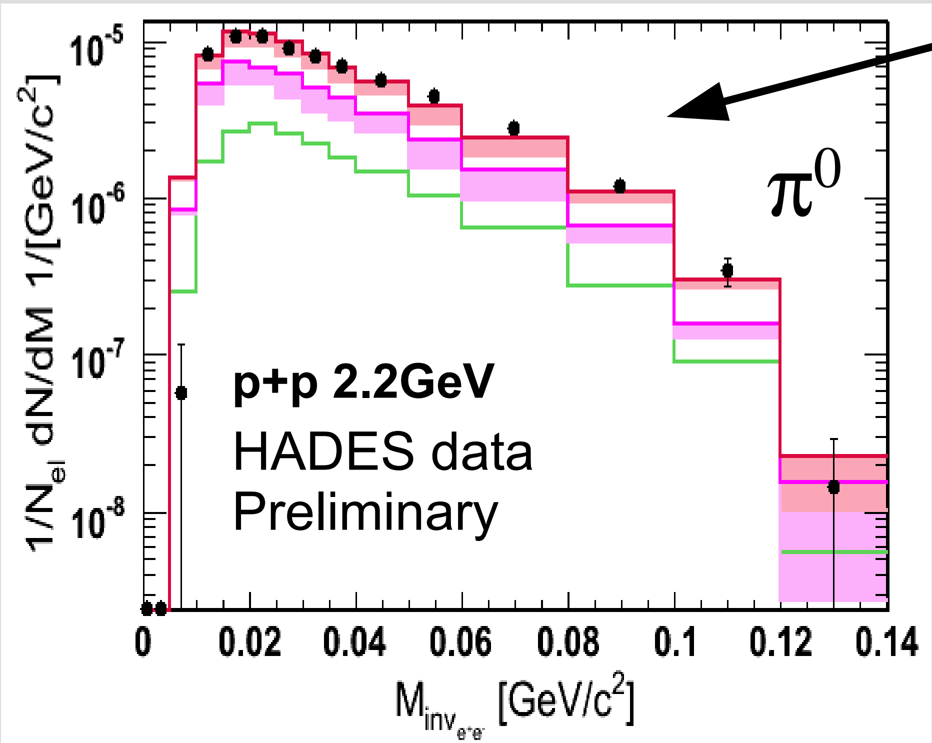
[1] Teis et al, ZPA356 (97) 421
[2] Δ angular distrib. from Dmitriev et al, NPA459 (86) 503
[3] N1440 ang. distr. from Aichelin, priv. comm.
[4] Δ decay angle varied from 1+0.6cos² (Wicklund et al. PRD 35 (87) 2670) to 1-3cos²

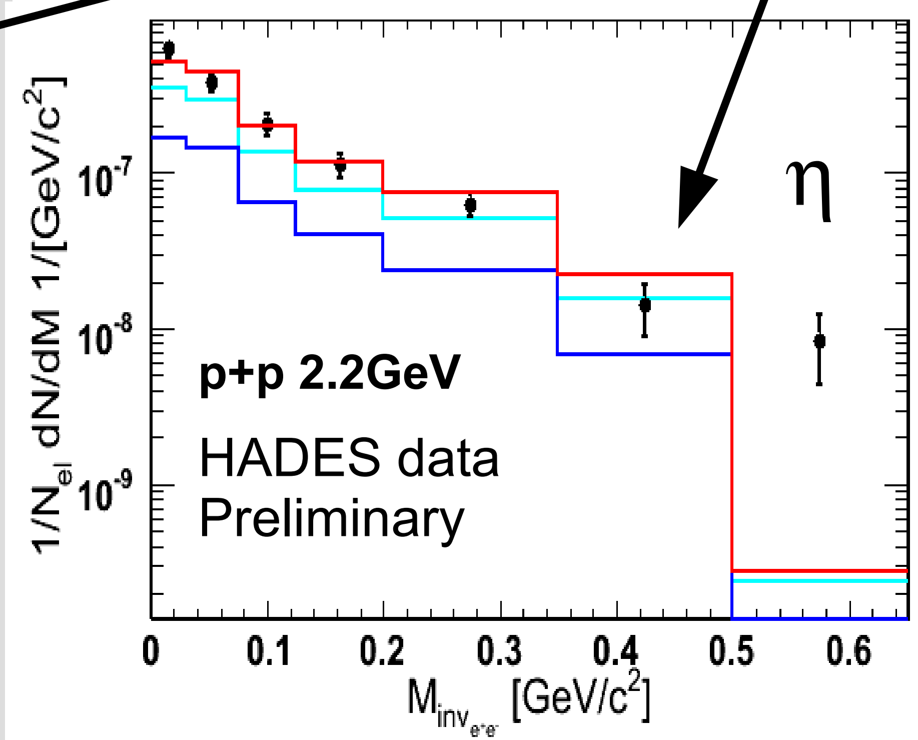
η/π^0 Dalitz Decay

- $pp \rightarrow pp\eta/\pi^0$
  $\rightarrow$ **ppe⁺e⁻**γ

→ Efficiency under control







Virtual Photon Polarization

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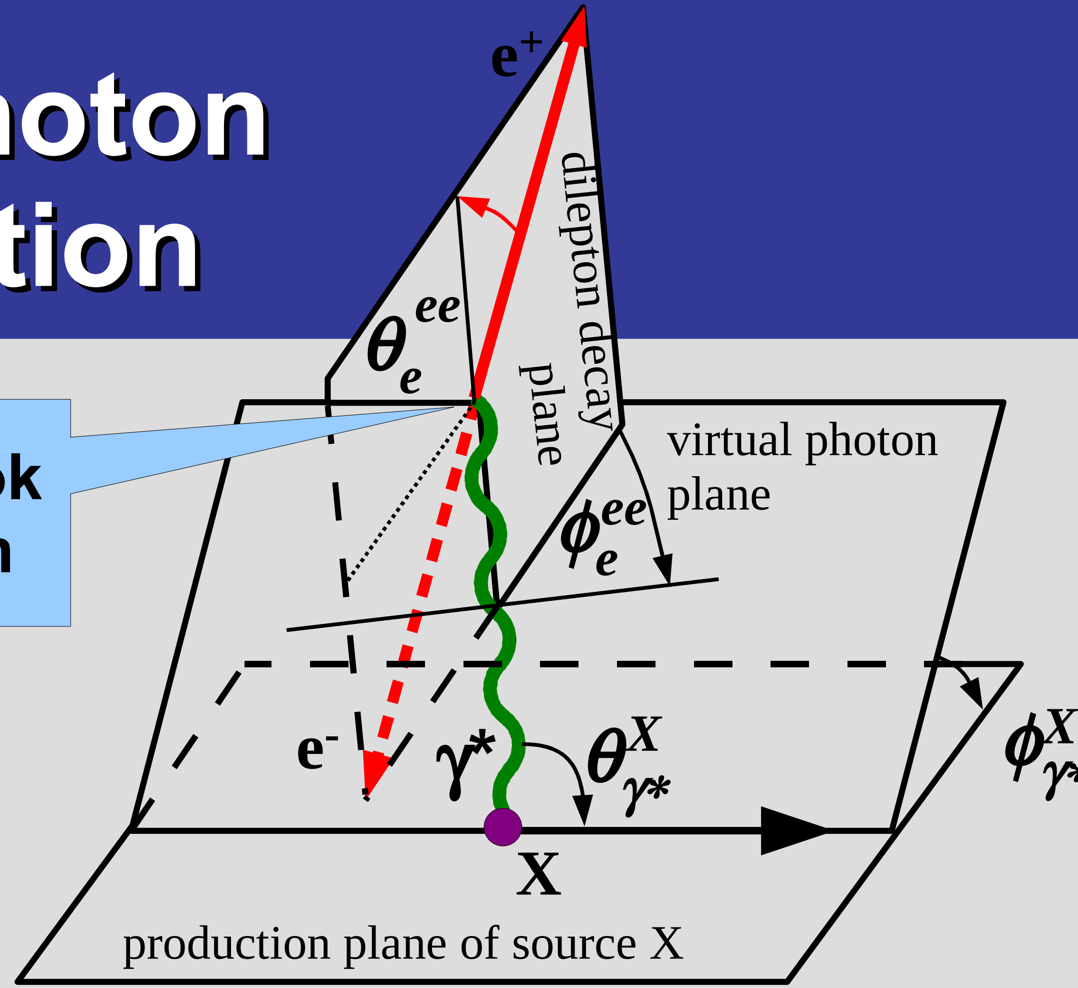
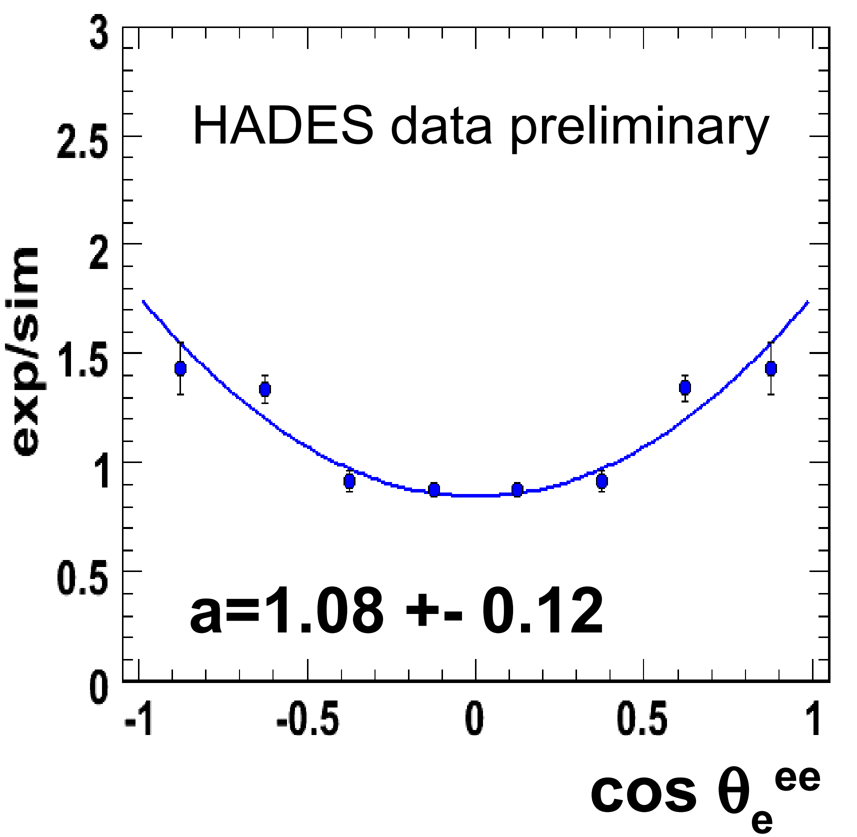
Additional observable to look into production mechanism





- Di-Lepton decay angles
  - → Polarizations
- e.g. helicity angle distribution ~1+a·cos²θ
- η: a=-1 [1]

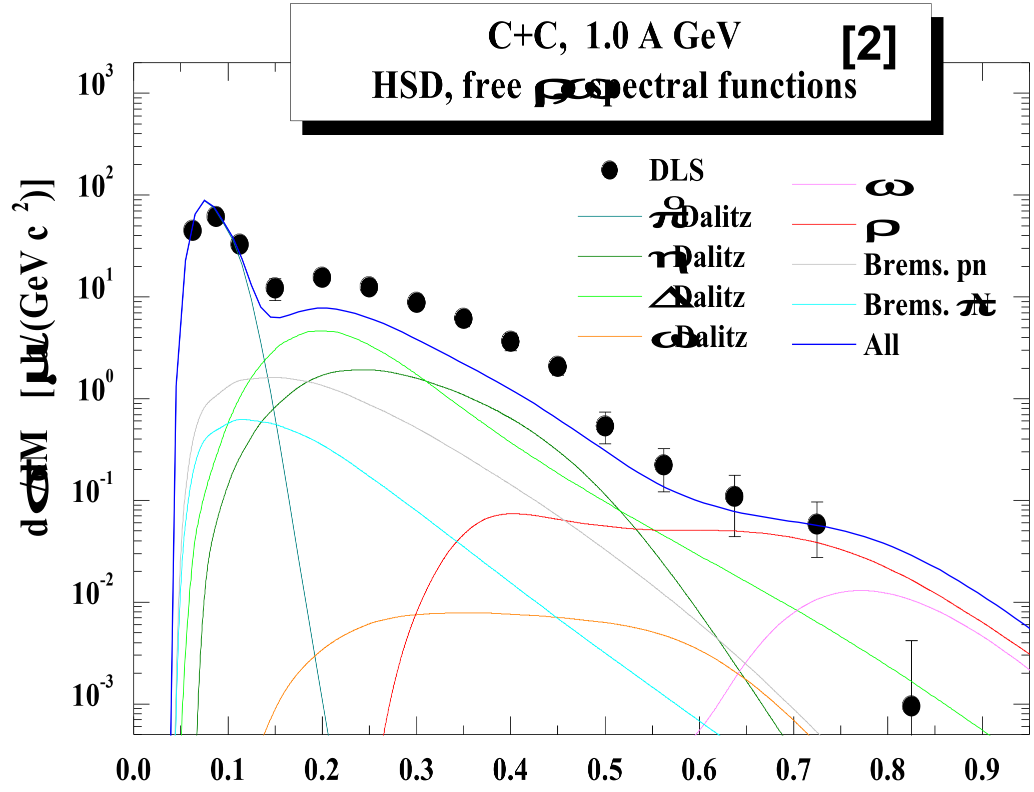
[1] E.L. Bratkovskaya, et al., Phys.Lett. B348 (1995) 283.

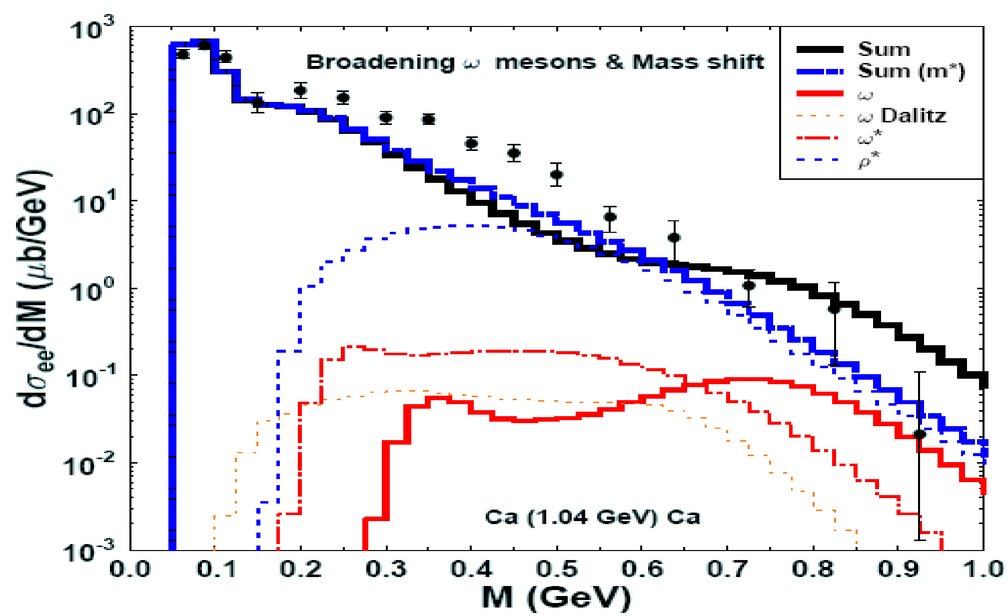
C+C @ 1 and 2 AGeV
The DLS puzzle

„DLS puzzle"

- DLS heavy ion data
- Enhancement
  - Remained unexplained for a long time
  - Triggered speculations

➔ HADES: C+C at 1/2 AGeV



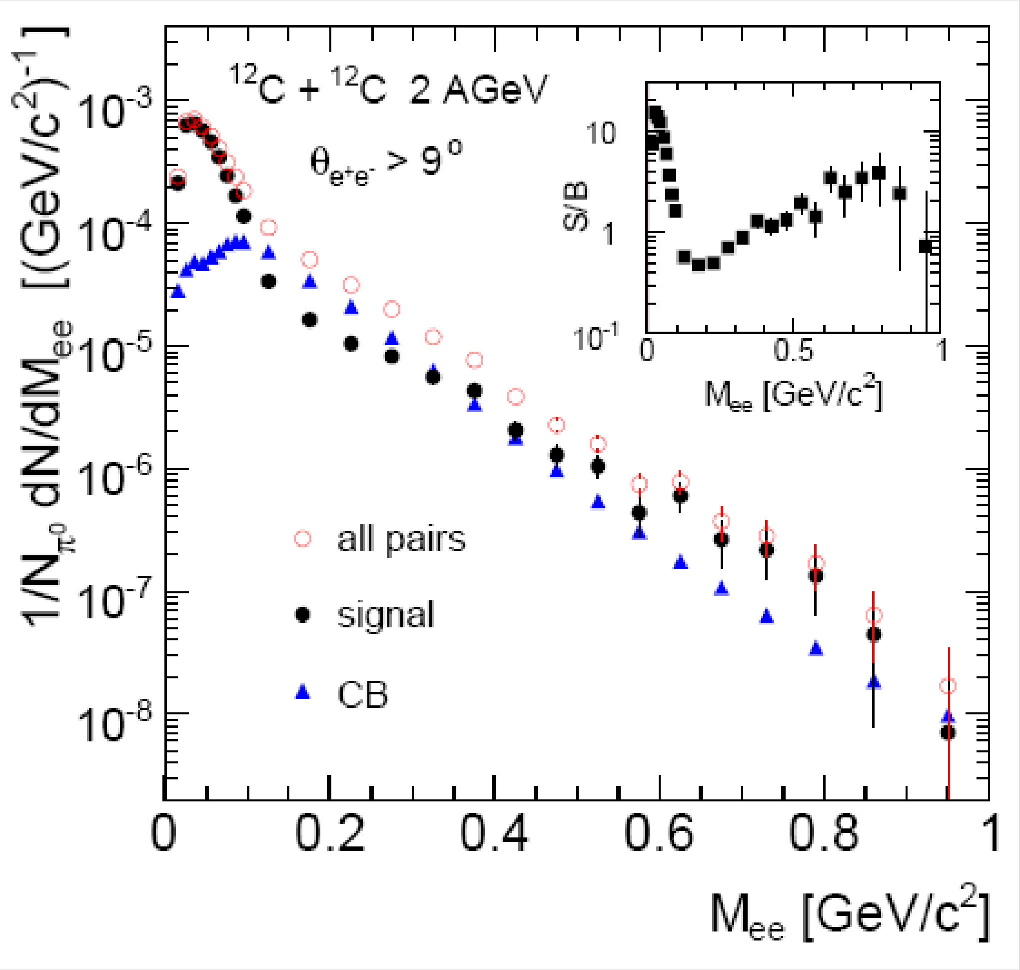


[3]

[1] DLS Data: R.J. Porter et al.: PRL 79 (1997) 1229
[2] E.L. Bratkovkaya, Trento workshop
[3] C. Ernst et al., PRC 58 (1998) 447

HADES Pair Analysis

- C+C at 2AGeV
  - Lepton & pair selections
  - (e.g. >9° opening angle)
- Subtract combinatorial background
- Efficiency correction



details: see talk of F. Krizek, Mon. session C

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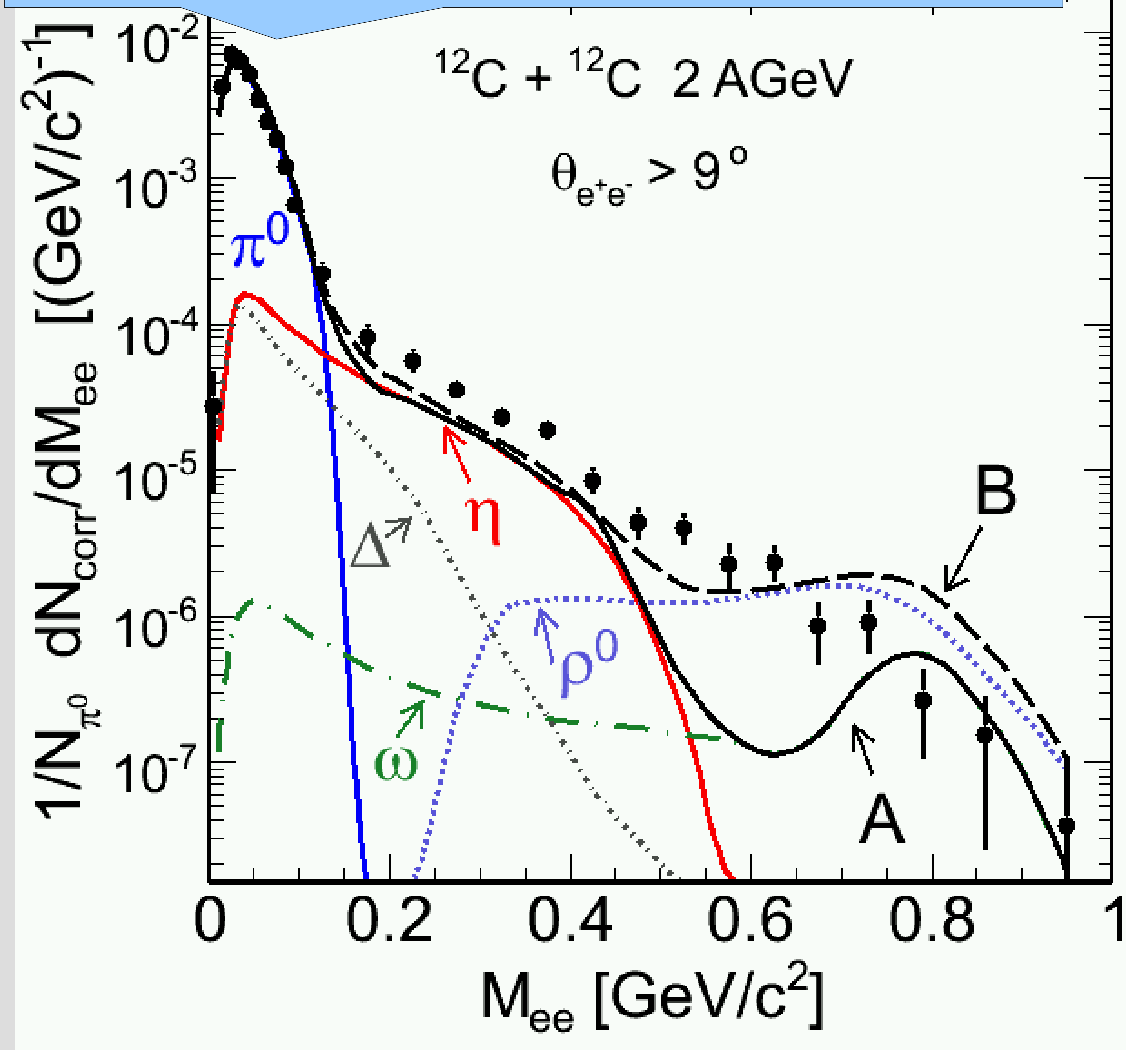
C+C @ 2AGeV [1]

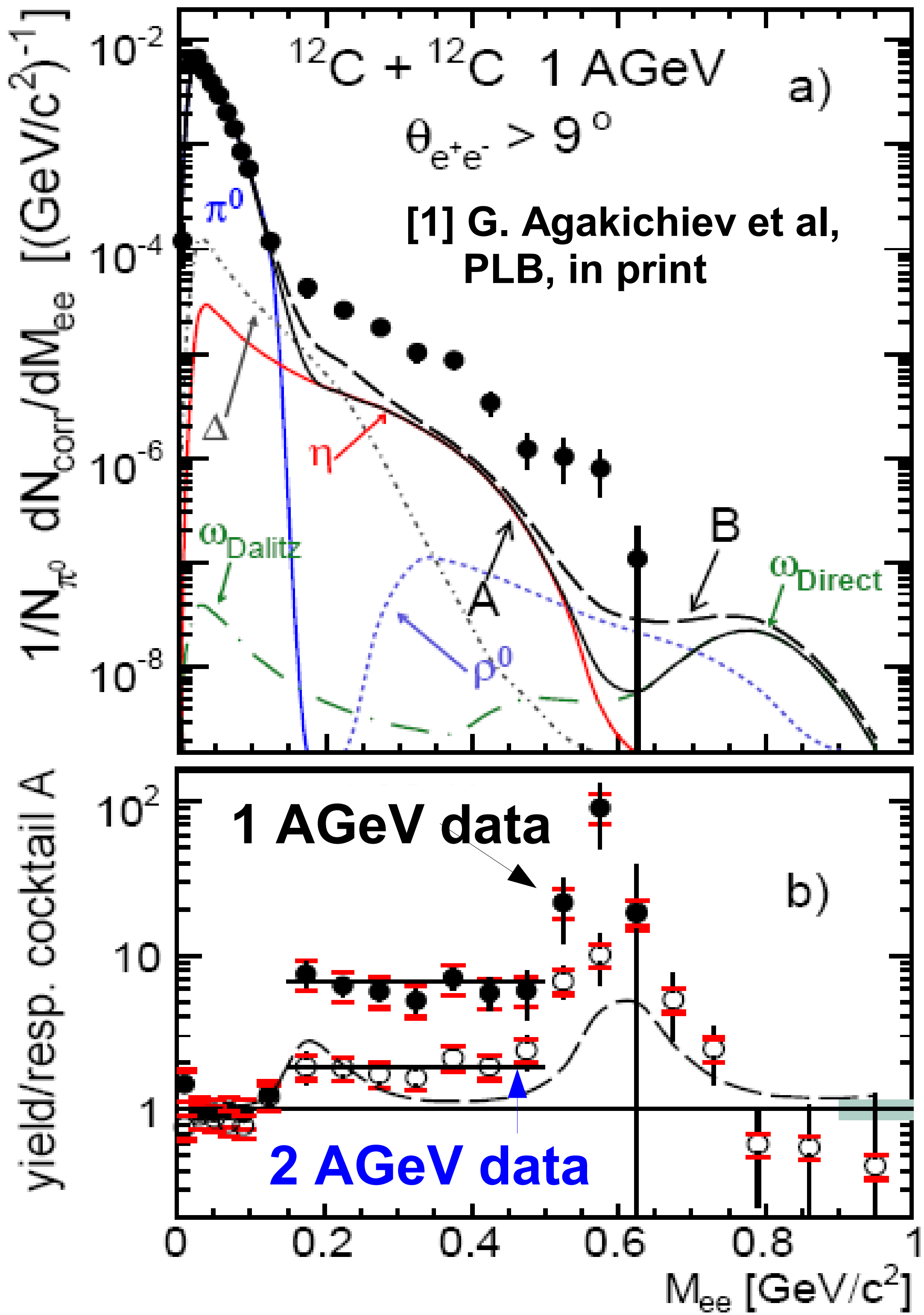
Normalization via *charged* pions



- Simulation **Pluto**
  - Thermal emission of particles
  - ➔ No „bremsstrahlung“
- Model A: long-lived sources: π^0, η, ω
- Model B: with short-lived resonances ρ,Δ

[1] G. Agakichiev et al, PRL 98, 052302 (2007)

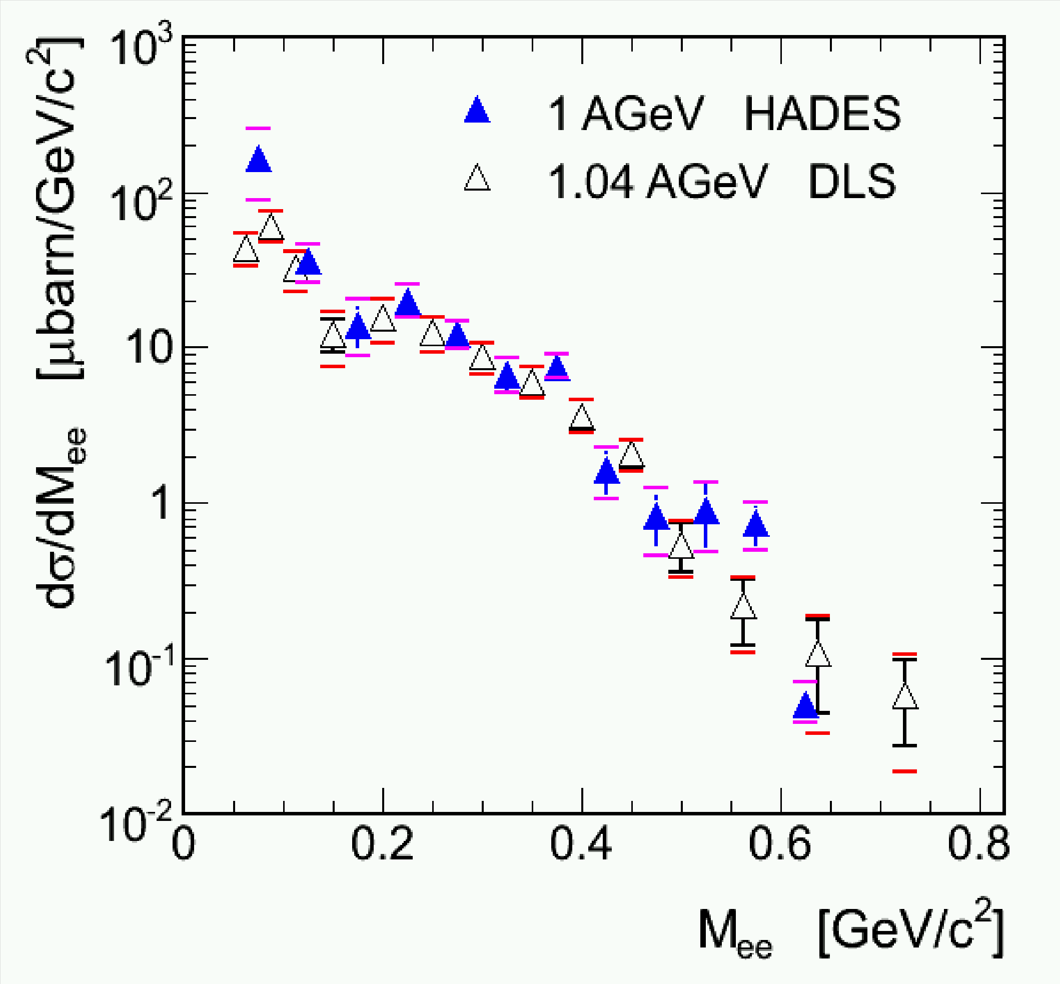
2AGeV vs. 1AGeV



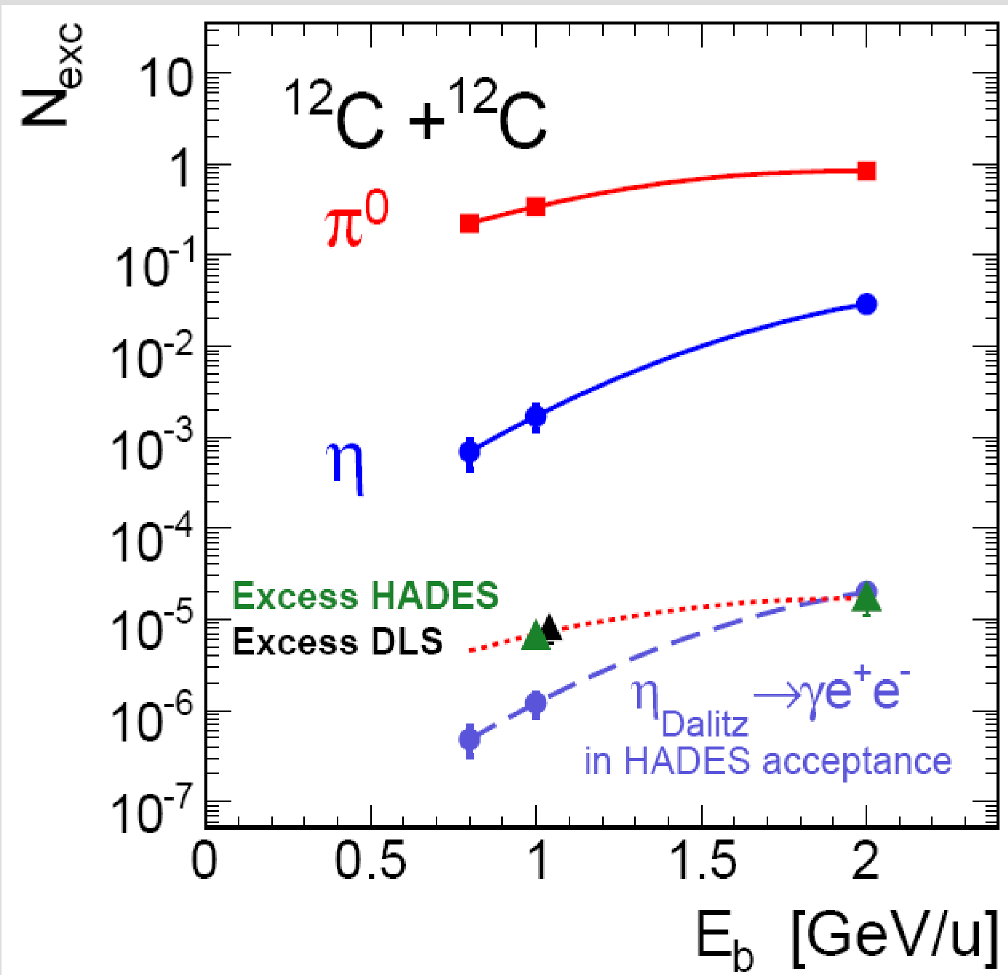
- 1 AGeV data [1] analyzed by same methods
- π^0 region well under control
- Enhancement in η region
  - 6.8 at 1AGeV
  - (DLS: 6.5 at 1.04 AGeV)
  - 1.9 at 2AGeV

HADES vs DLS

- DLS data confirmed by HADES
- Conclusion: No „*DLS*“ puzzle
- What else could explain the enhancement?



HADES „Scaling Law“

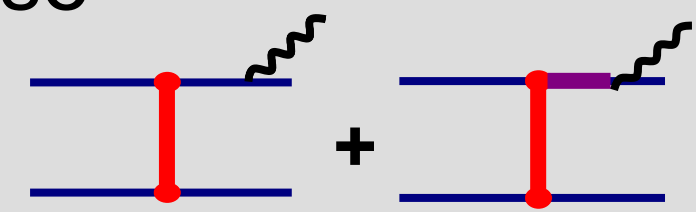


- Enhancement scales like π^0 production
- Pions are produced via (mainly Δ) resonances
- → Additional radiation stems from resonances
- → Would underline the role of „resonant matter“

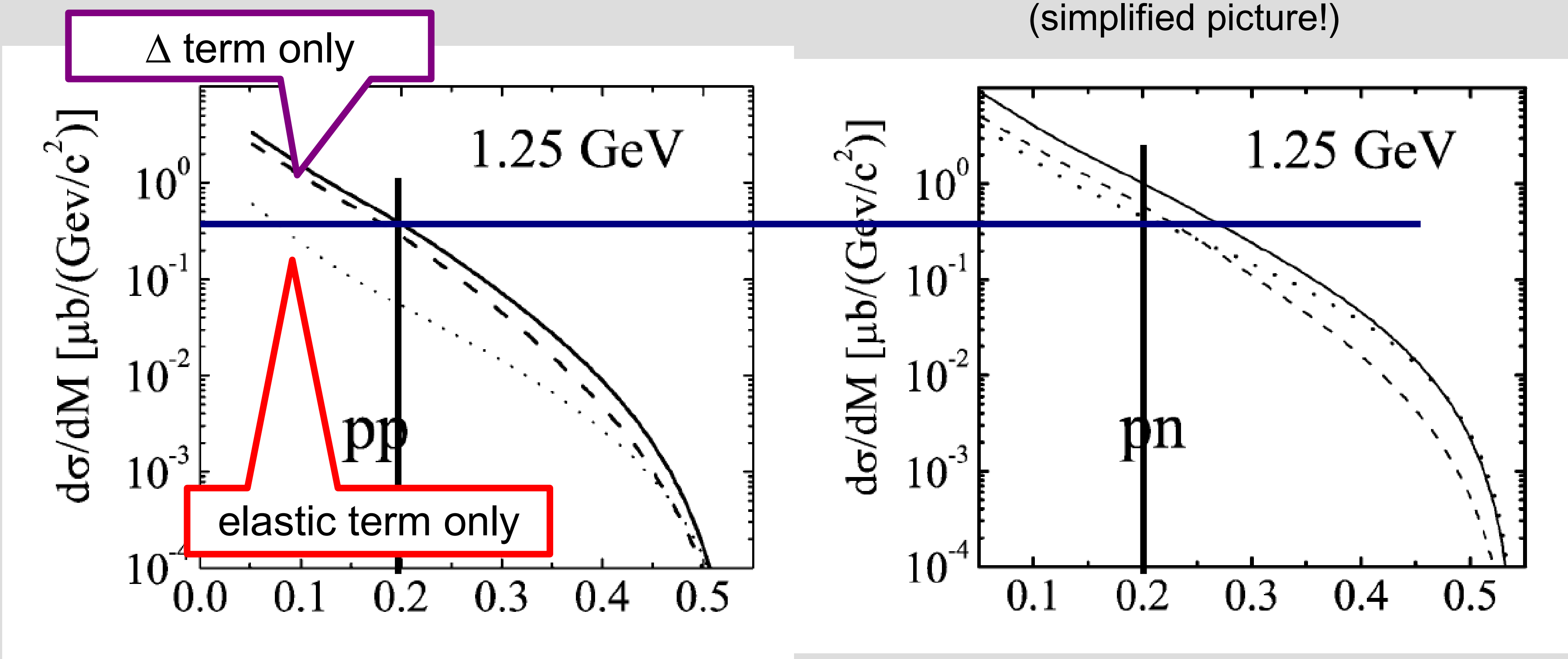
pn + Δ treatment

- Recent calculation [1] of NN bremsstrahlung + Δ
- Enhancement in the pn case

[1] Kaptari, Kämpfer, NPA 764 (2006) 338



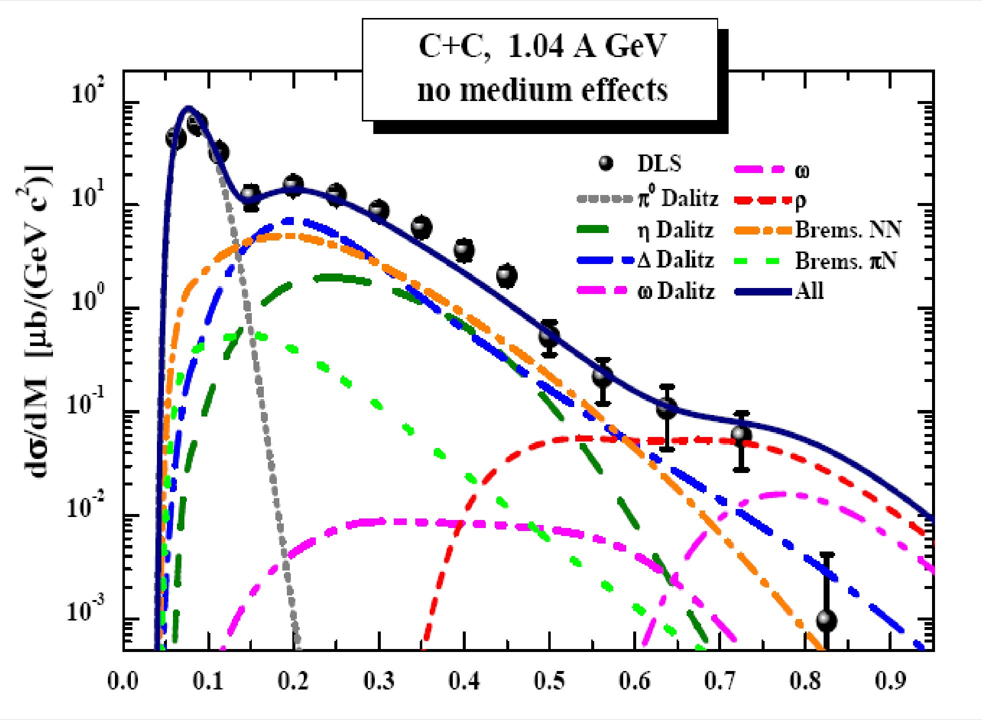
(simplified picture!)

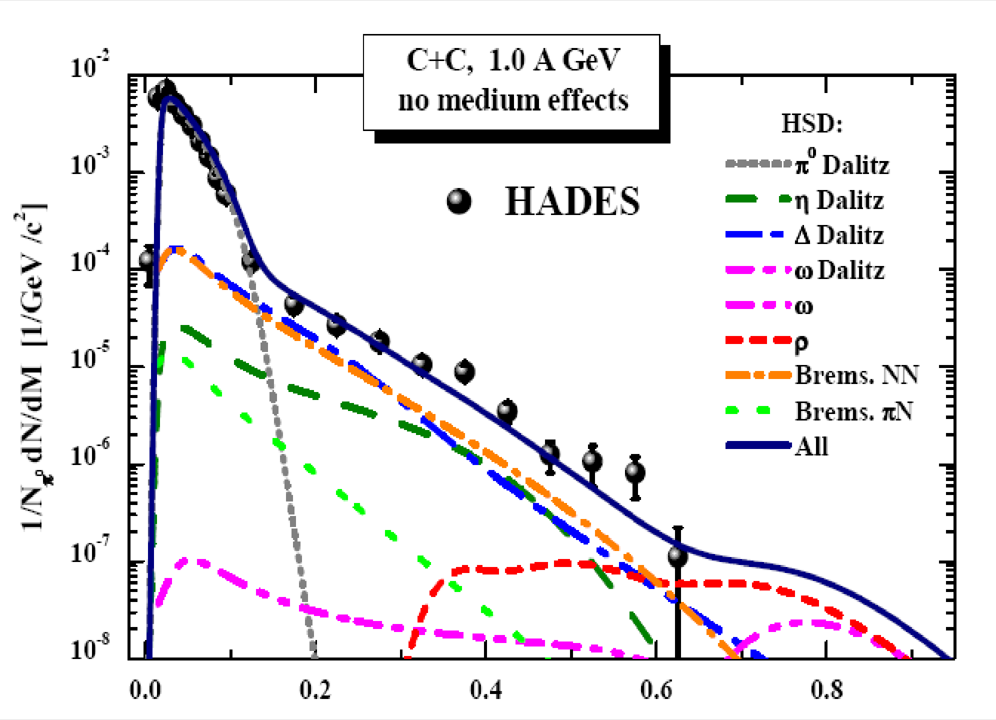


Up-to date Transport [1] for 1 AGeV

- Does larger pn Bremsstrahlung [2] explain excess?

[1] HSD: E.L. Bratkovskaya and W. Cassing arXiv:0712.0635v1 and private communication
[2] L.P. Kaptari and B. Kämpfer, Nucl.Phys. A 764 (2006) 338
[3] DLS Data: R.J. Porter et al. Phys.Rev.Lett. 79 (1997) 1229





- Needs verification in NN collisions!

Elementary collisions with HADES
The „Low-Mass“ Puzzle

Di-Leptons from pp/dp at 1.25(A)GeV

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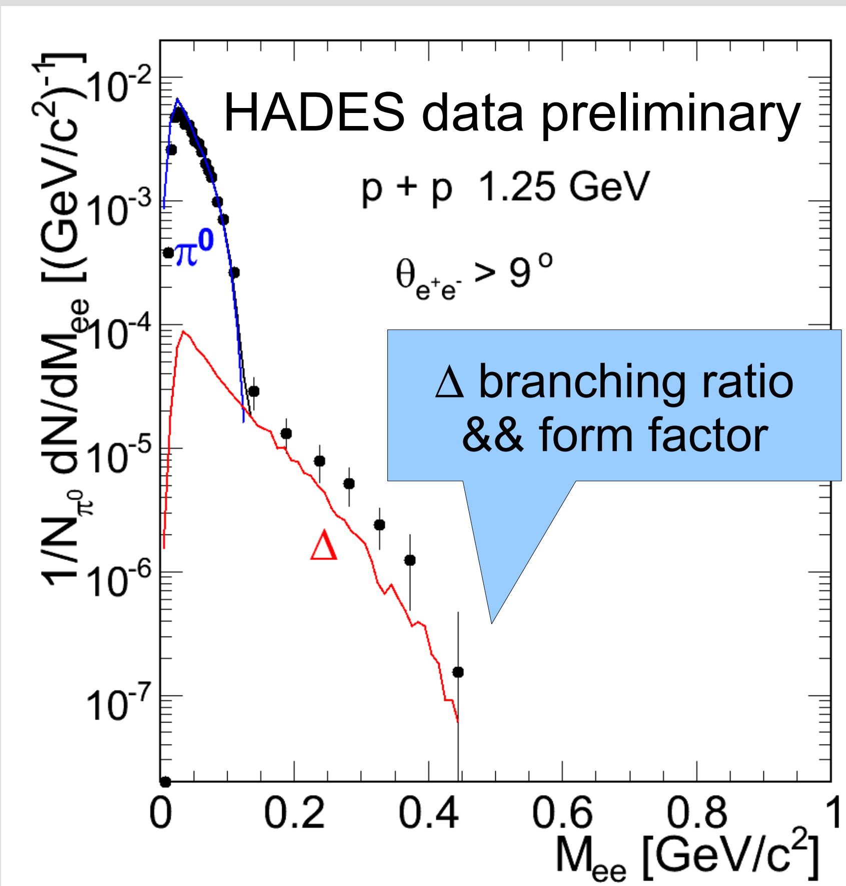
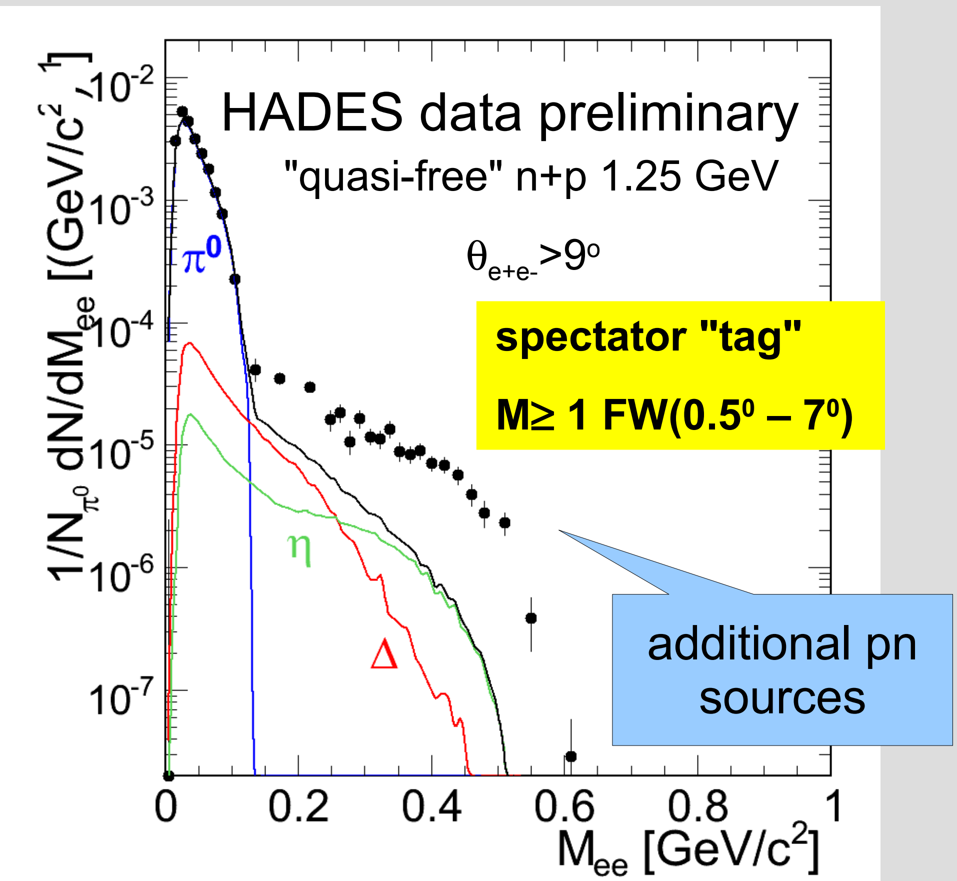
- Δ fixed by isospin (assuming π^0 via Δ only)
- pp case: below η threshold
- pn: η contribution est. by COSY/Saturne data





Ratio pp/pn

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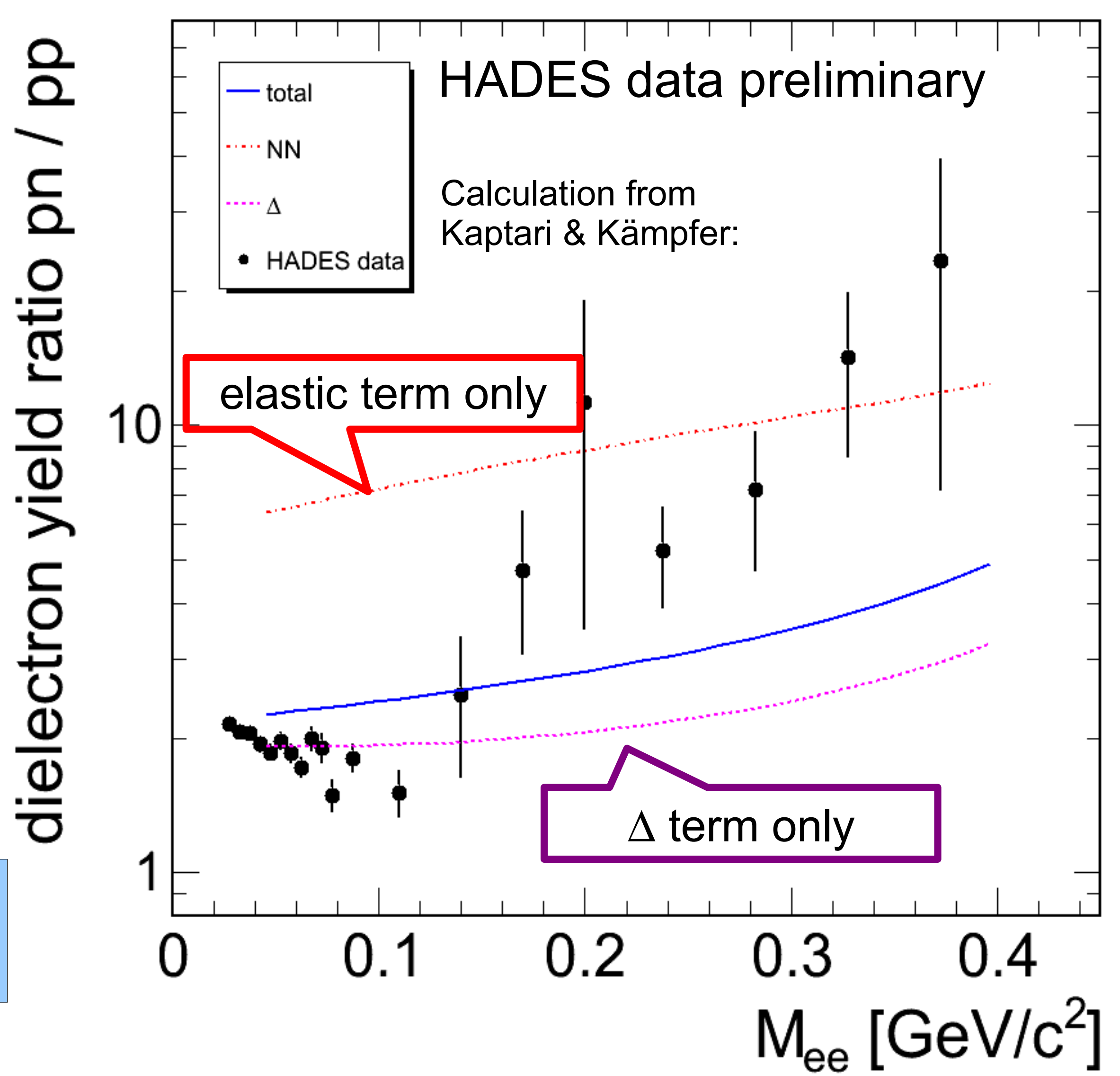
- OBE calculation from Kaptari is not sufficient
- Hint for additional off-shell resonances?

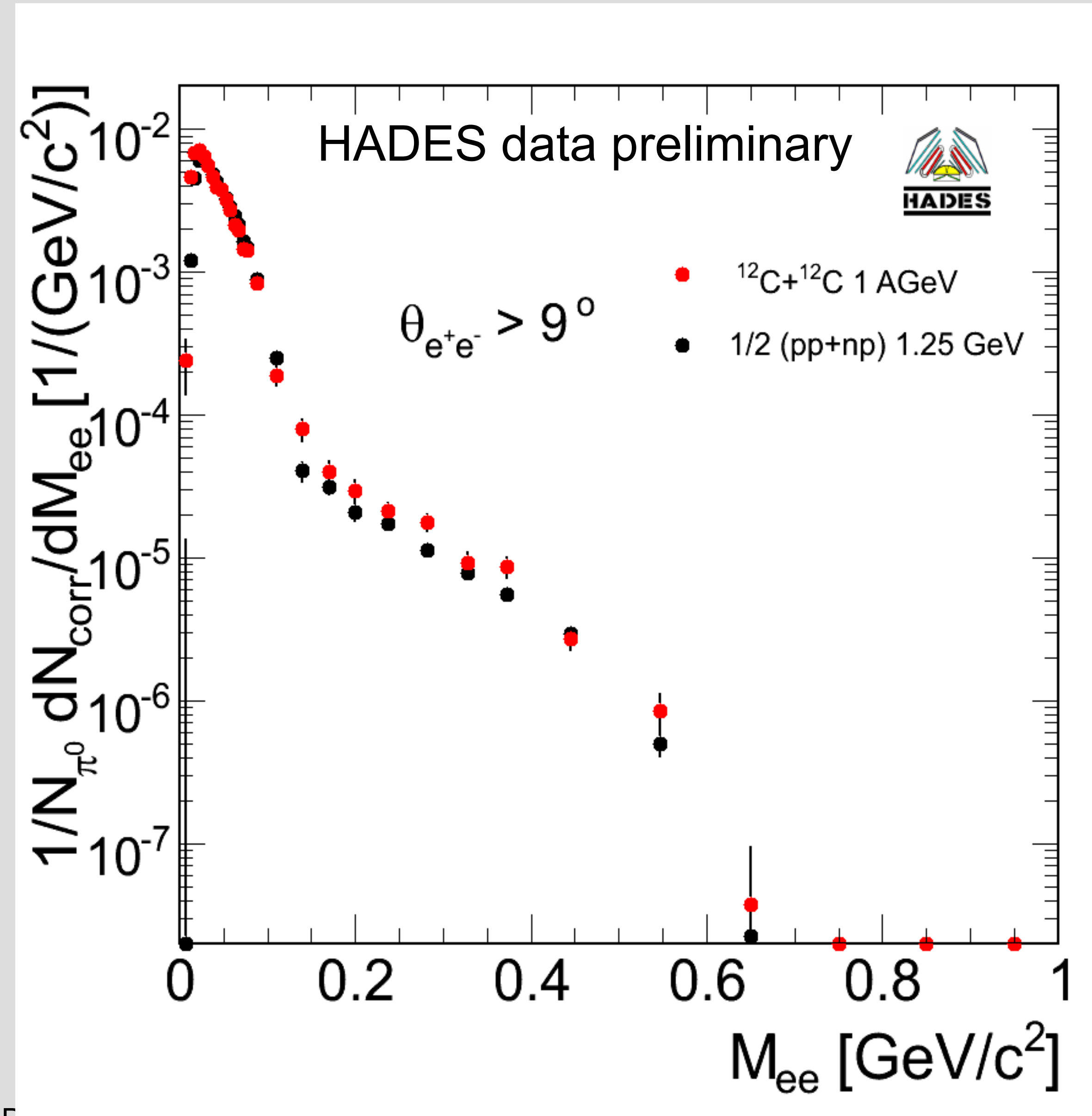
see talk of T. Galatyuk, Mon C, 17:10



C+C vs. pp/pn

- Elementary reactions (1.25GeV)
- Compared to C+C data at 1 AGeV

➔ C+C data almost explained by pure NN interactions



Vector Meson Production with HADES (High-Mass Resolution)

Ar+KCl @ 1.756 AGeV

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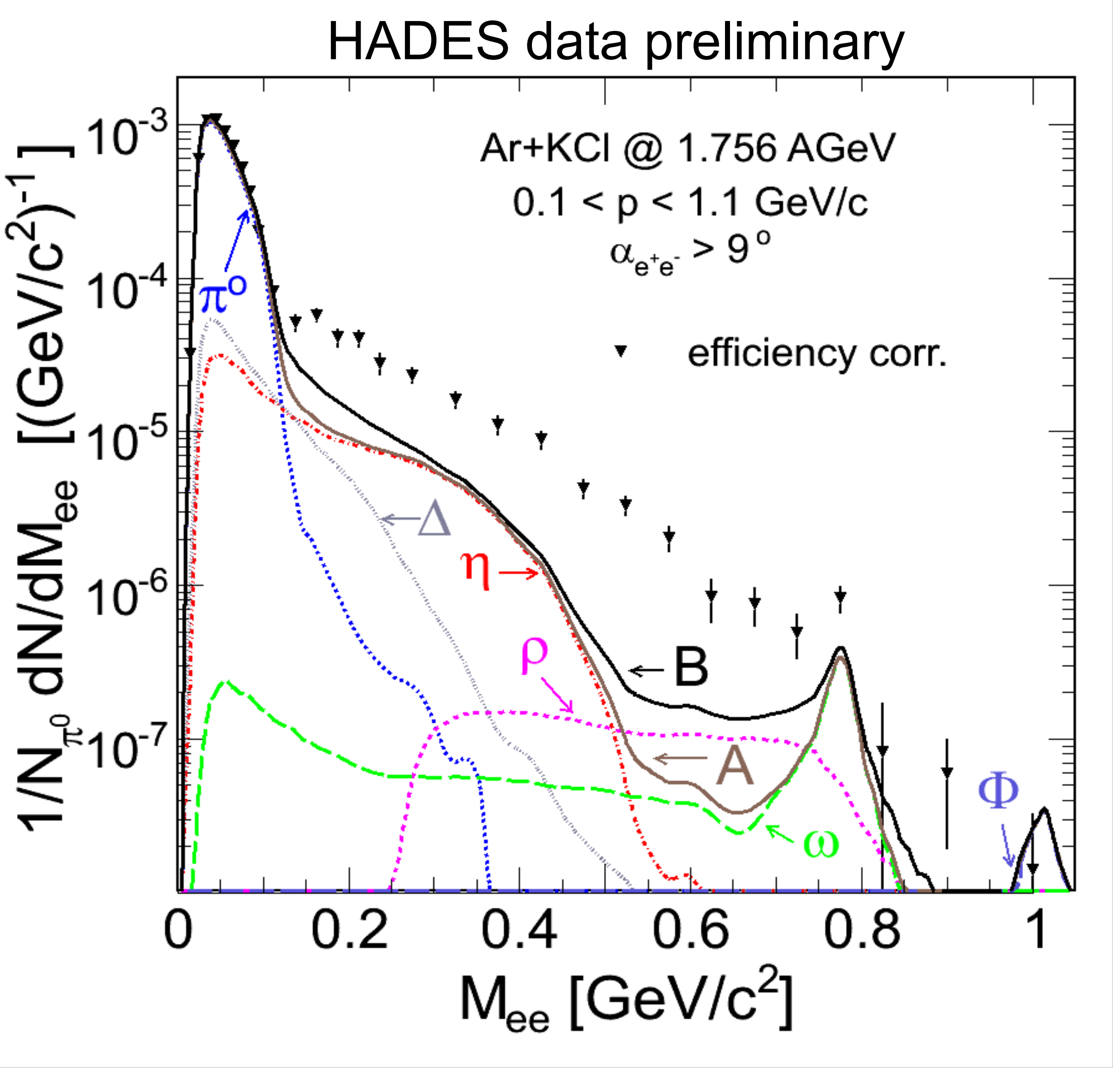
- Higher mass resolution
- Good statistics of pairs above 0.5 GeV
- Large excess over Pluto cocktail in the mass region 0.15-0.6 GeV
- ω peak
  - ➔ first time at SIS/ Bevalac energy regime



pp @ 3.5 GeV (Apr 07)

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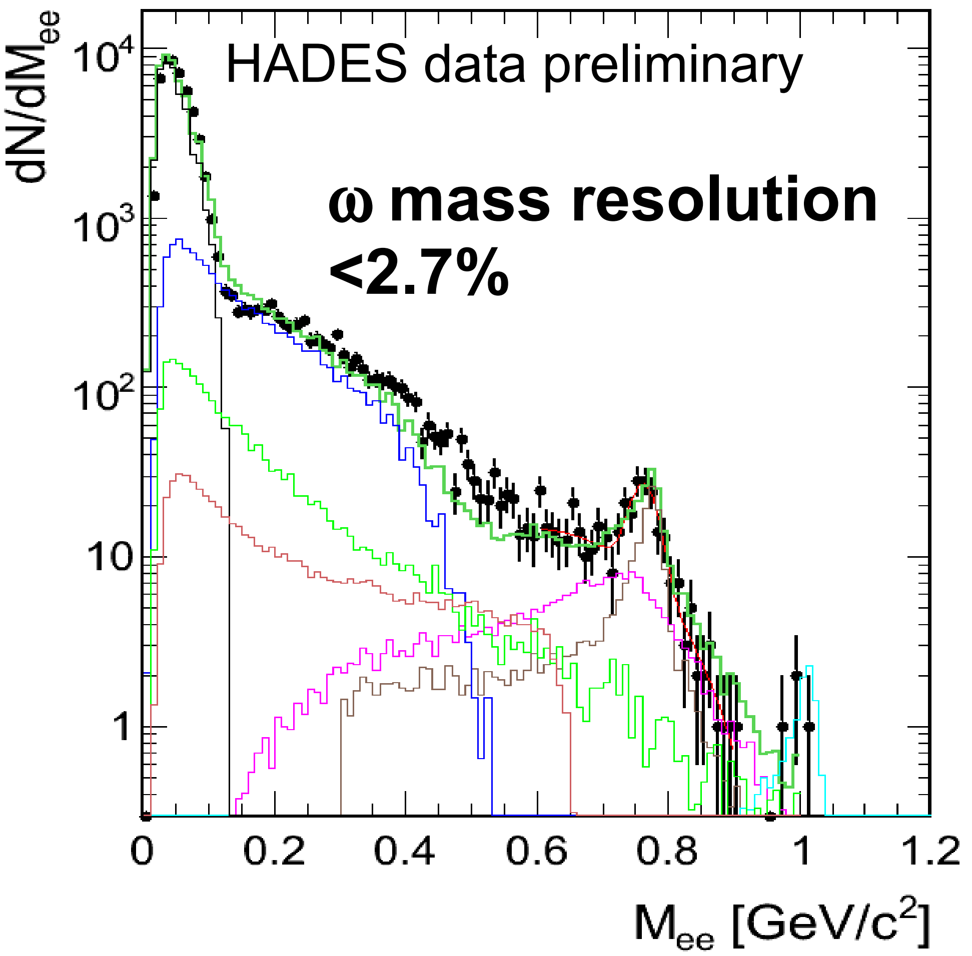


- ρ mass shape
  - Production mechanisms
  - Resonance model
- ω line shape
  - Reference to p+Nb done at the same energy
- Inclusive vector meson production
  - ω factor 2 lower then prediction [1]

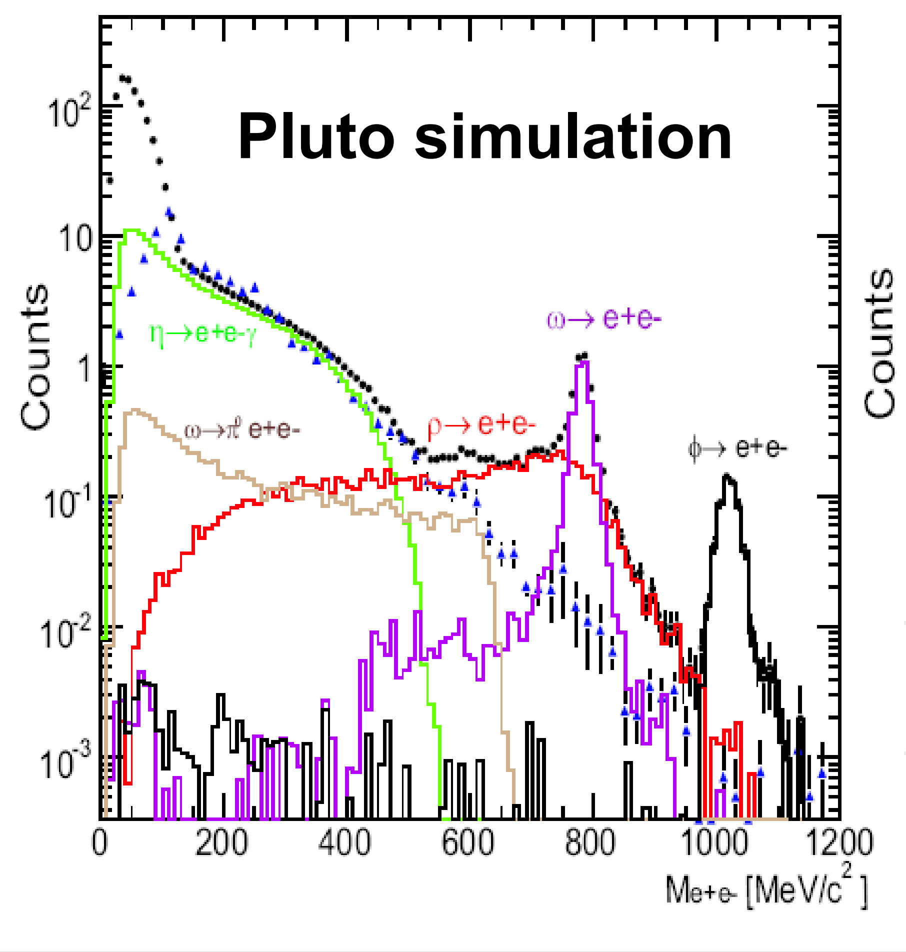
[1] see: E.L. Bratkovskaya and W. Cassing P.Rpt. 308 (1999) 65

Outlook

p + Nb Experiment

...coming soon...

- Sep/Oct 2008
- Exp. situation at normal nuclear density
  - Not conclusive
  - Verification needed
- Same target as CB/Taps (Nb)
- Same energy as HADES pp (3.5 GeV)
  - Model-independent extraction of modifications



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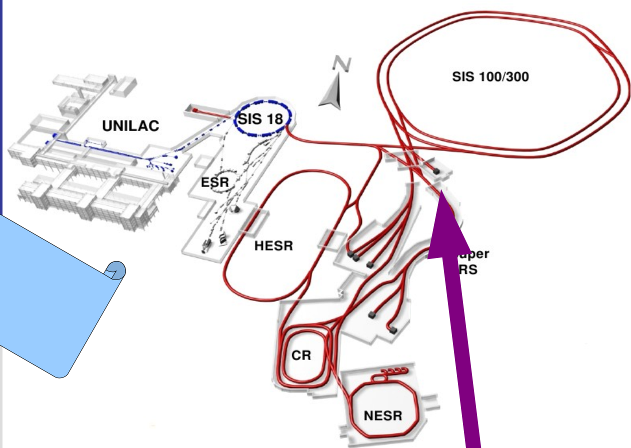
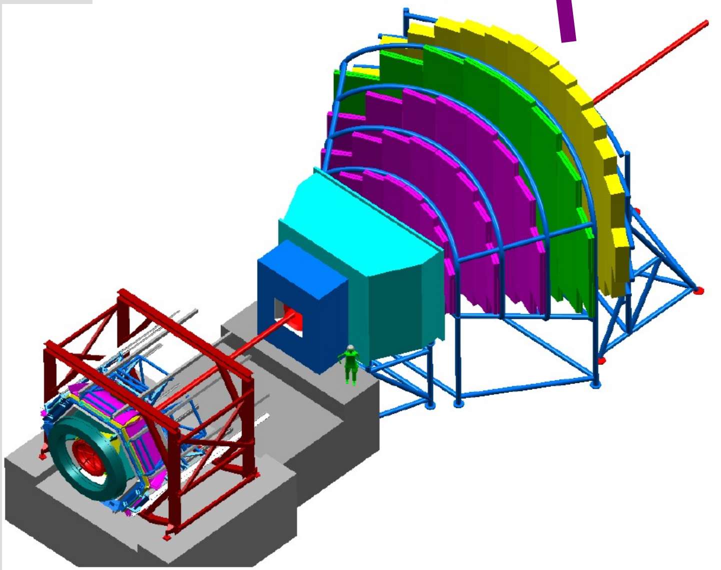
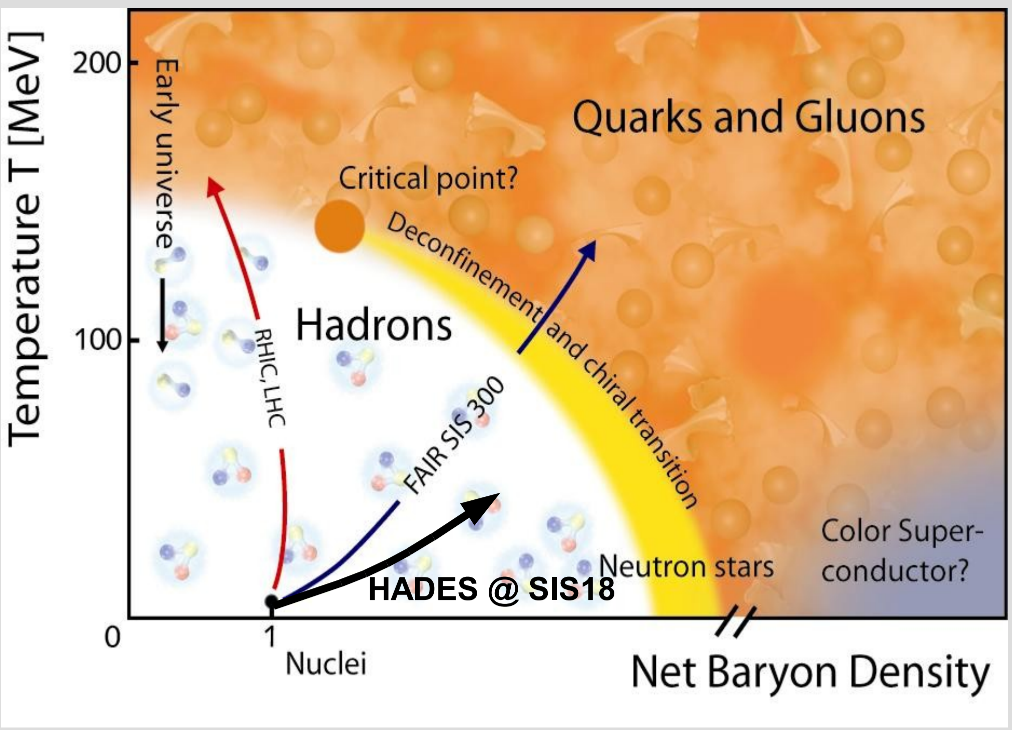
HADES @ FAIR

...future...





- 2-40 GeV: terra incognita (>8AGeV covered by CBM)
- Transition from resonance matter to pionic environment

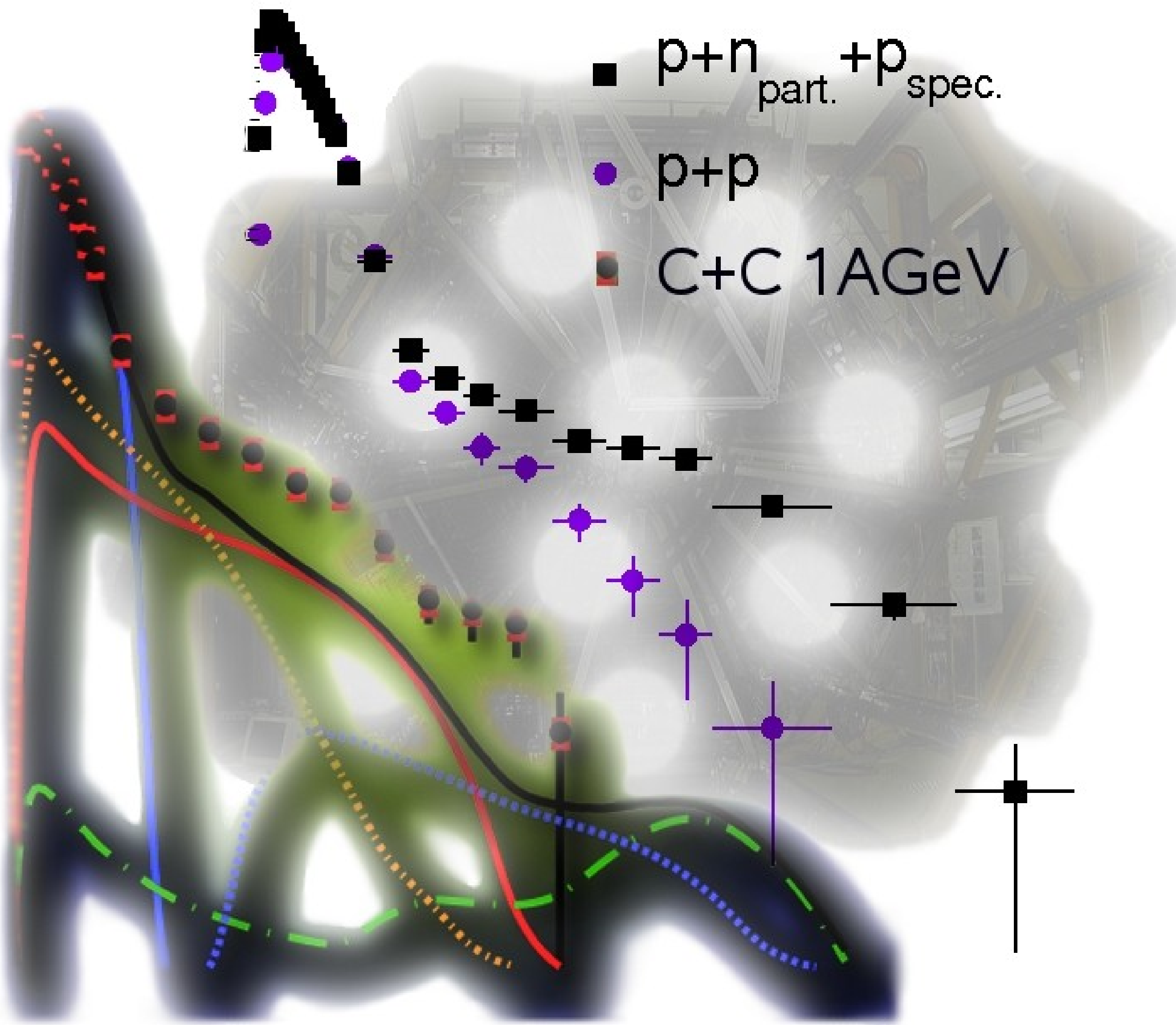


- HADES upgrade:
  - Forward wall
  - Data acquisition
  - High granularity RPC replaces Tofino
  - RICH modification

Summary

- Di-Lepton spectroscopy with HADES
- Comprehensive program:
- Heavy ion reactions
  - C+C (low resolution) at 1/2AGeV
  - Ar+KCl (high resolution) at 1.756AGeV: ω clearly seen
- Elementary reactions
  - p+p and n+p at 1.25 GeV
    - Sufficient to describe C+C at 1AGeV
  - p+p at 3.5 GeV (ω mass shape)
- Outlook:
  - p+A at 3.5 GeV (vector meson modifications)
  - Heavier systems (Au+Au, Ni+Ni)

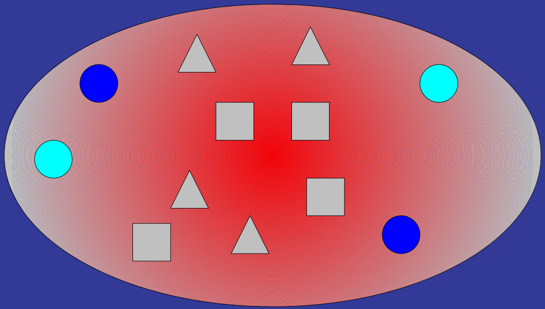
The Collaboration



- Bratislava (SAS, PI), Slovakia
- Catania (INFN - LNS), Italy
- Cracow (Univ.), Poland
- **Darmstadt (GSI), Germany**
- Dresden (FZR), Germany
- Dubna (JINR), Russia
- Frankfurt (Univ.), Germany
- Giessen (Univ.), Germany
- Milano (INFN, Univ.), Italy
- Munich (TUM), Germany
- Moscow (ITEP,MEPhI,RAS), Russia
- Nicosia (Univ.), Cyprus
- Orsay (IPN), France
- Rez (CAS, NPI), Czech Rep.
- Sant. de Compostela (Univ.), Spain
- Valencia (Univ.), Spain
- Coimbra (Univ.), Portugal

Backup

High Density Phase



multi step processes: i.e.

$NN \rightarrow N\Delta$

$\searrow \pi N$

$\searrow \pi N \rightarrow \rho N$

- Particle production at or below threshold
- $\rho \rightarrow e^+e^-$ decay inside fireball
- Direct access to in-medium properties

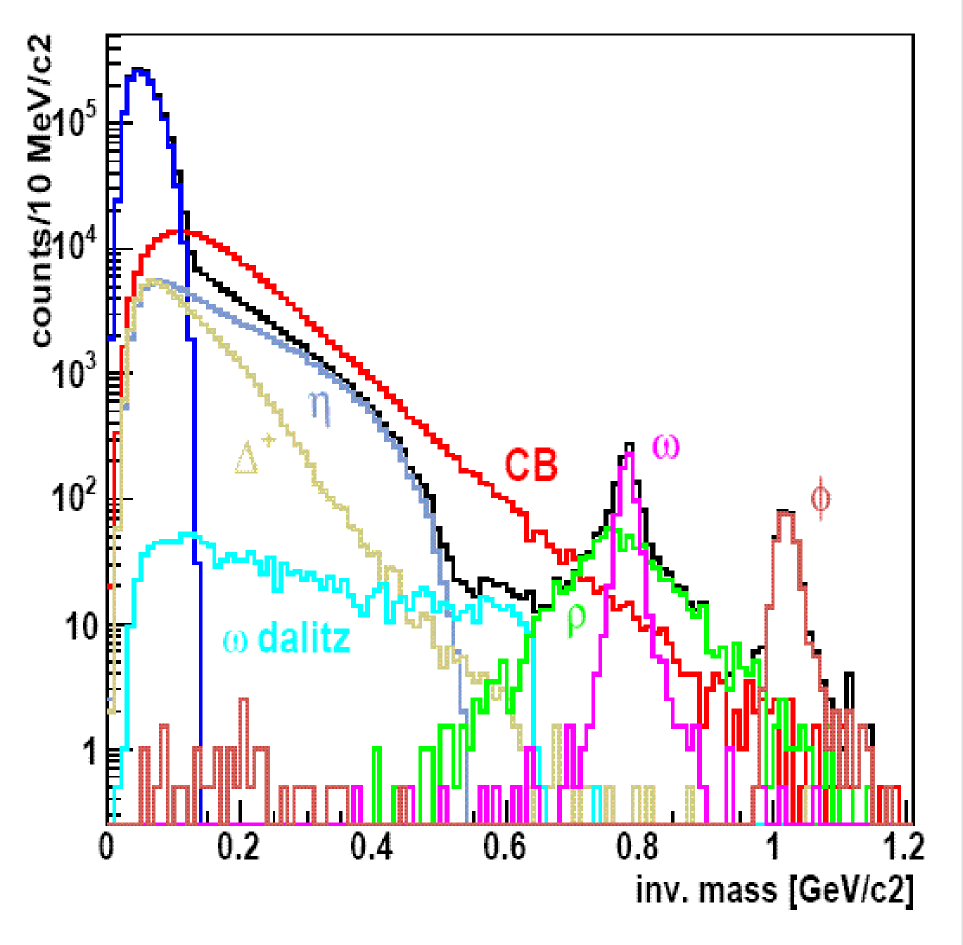
Rare probes at bombarding energies of 1 – 2 AGeV !!!

Meson	Mass (MeV/c^2)	Γ (MeV/c^2)	$c\tau$ (fm)	Main decay	e^+e^- BR
ρ	768	152	1.3	$\pi^+\pi^-$	4.4×10^{-5}
ω	782	8.43	23.4	$\pi^+\pi^-\pi^0$	7.2×10^{-5}
ϕ	1019	4.43	44.4	K^+K^-	3.1×10^{-4}

Cocktail

- Consequence:
- long-lived particles (π, η, ω) have no uncertainty

- Subtract „trivial" sources to get ρ mass shape



Vector Mesons in Medium

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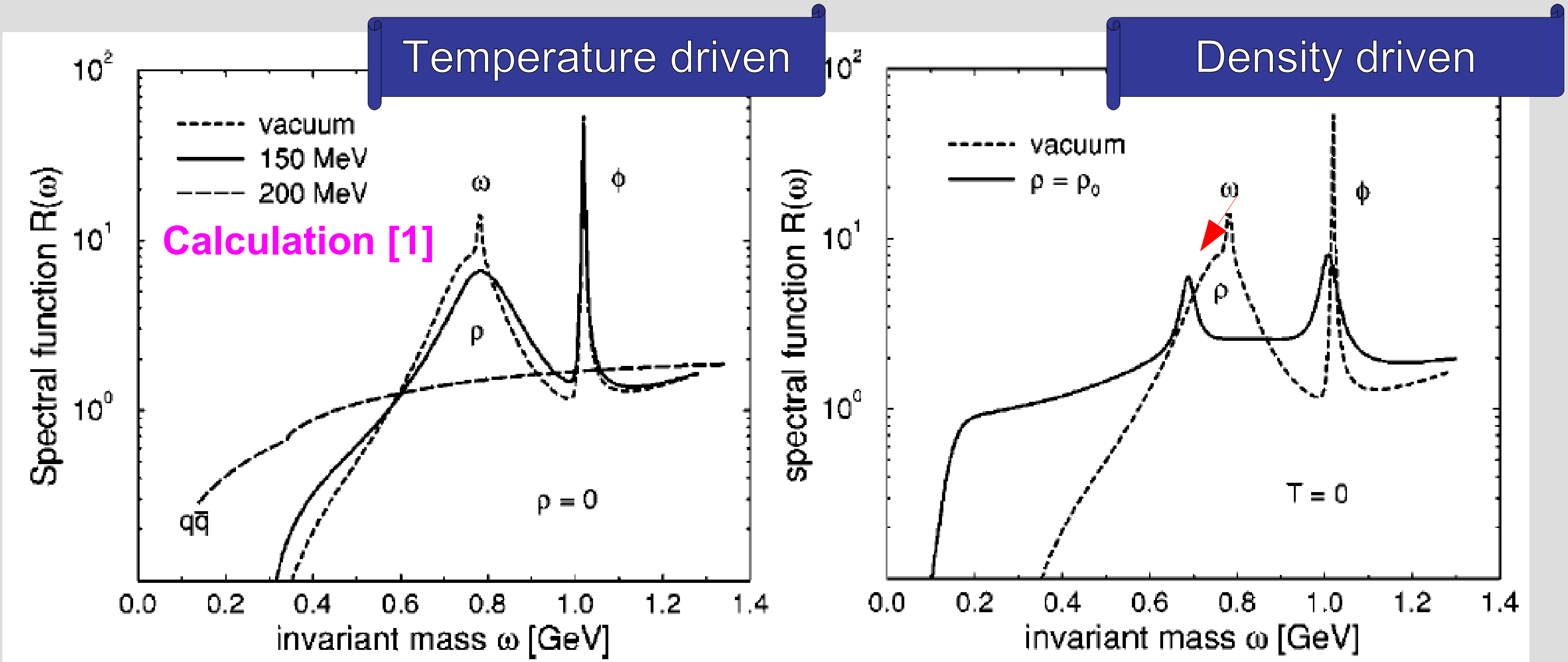
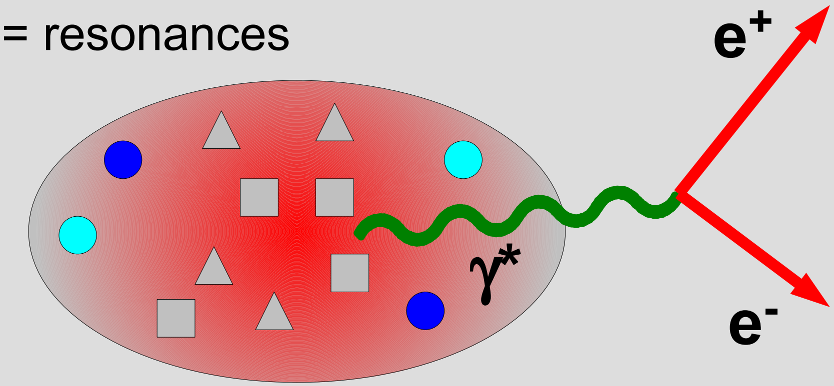
[1] T. Renk et al., PRC 66 (2002) 014902

- Hadrons
  - Expected to change properties in dense medium (e.g. mass, width)
  - Vector mesons: controversial discussion
    - Brown/Rho scaling: Dropping mass of ω,ρ

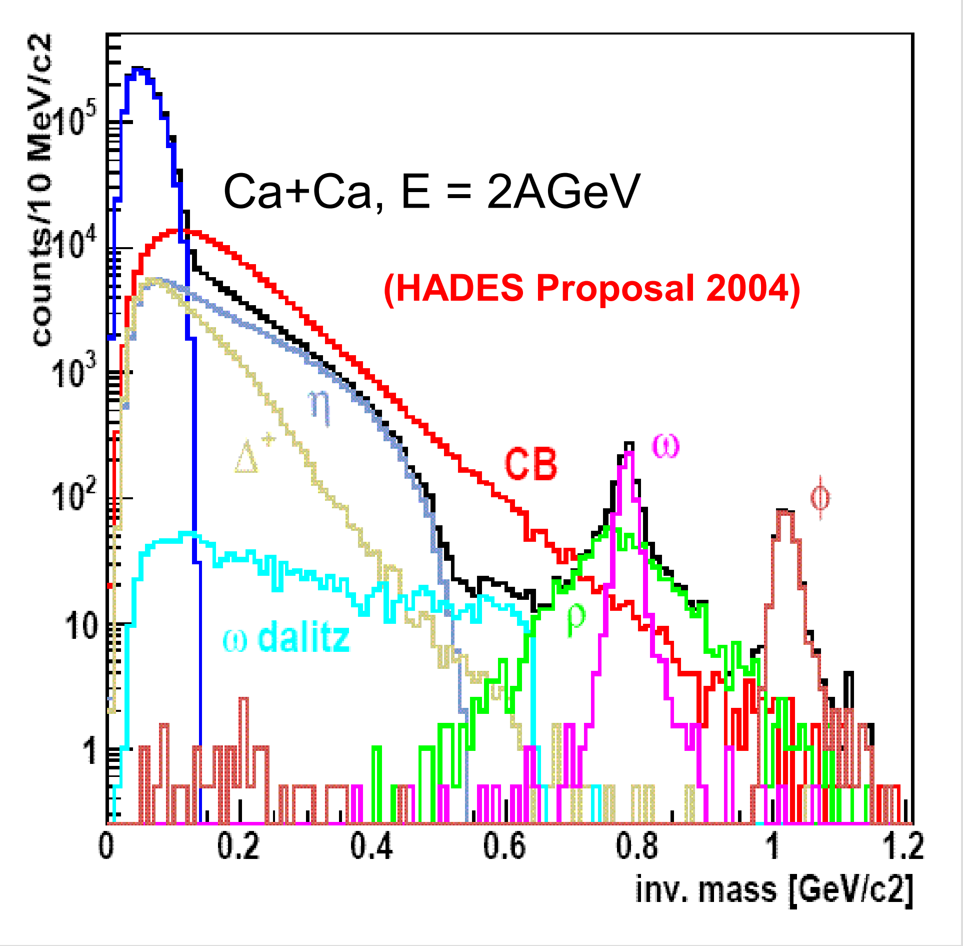


Continuum

■ , ▲ = resonances



- Continuum dilepton sources: π^0,η,ω,Δ
  - $\pi^0/\eta \rightarrow \gamma e^+e^-$
  - $\omega \rightarrow \pi^0 e^+e^-$
  - $\Delta \rightarrow N e^+e^-$



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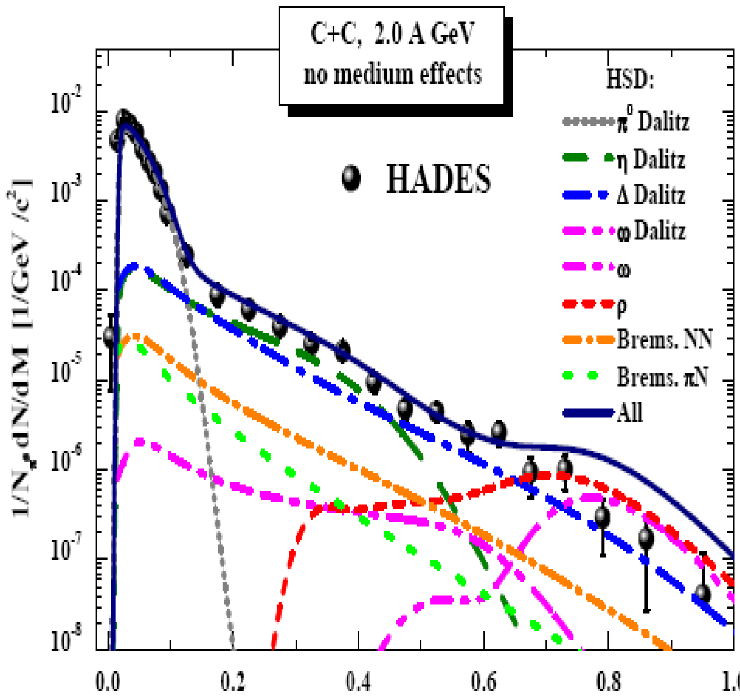
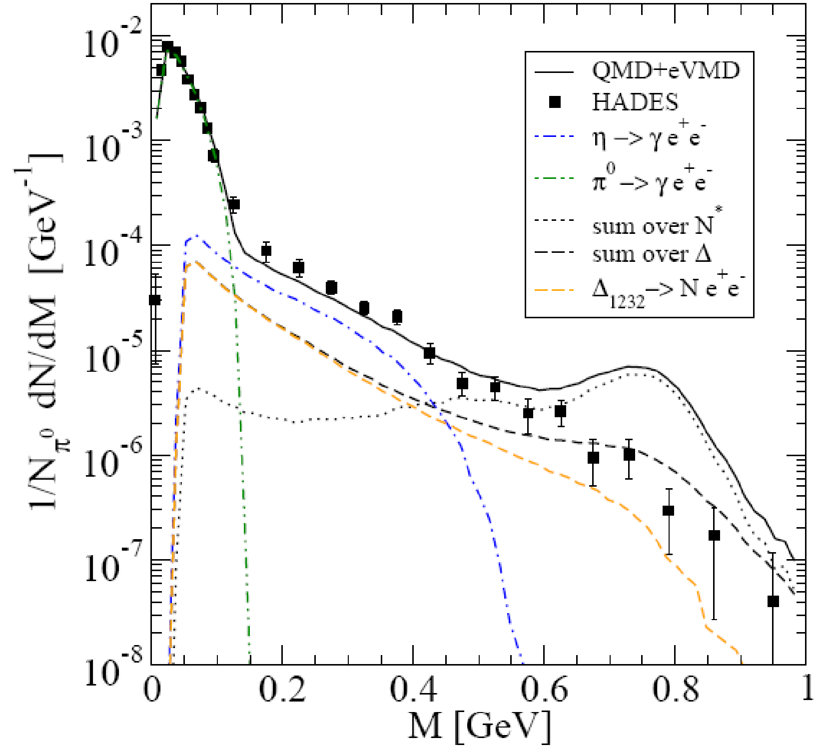
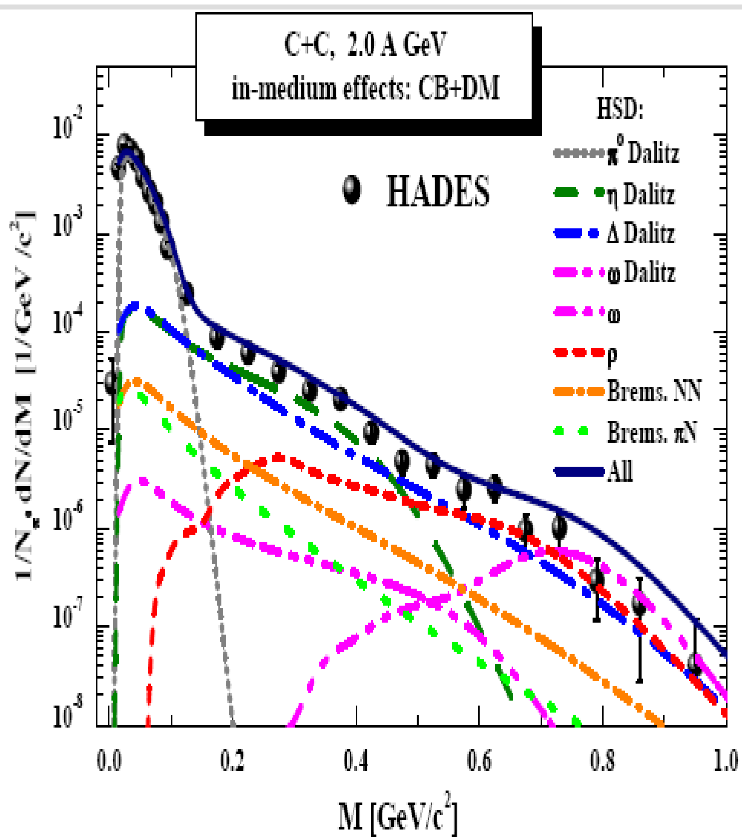
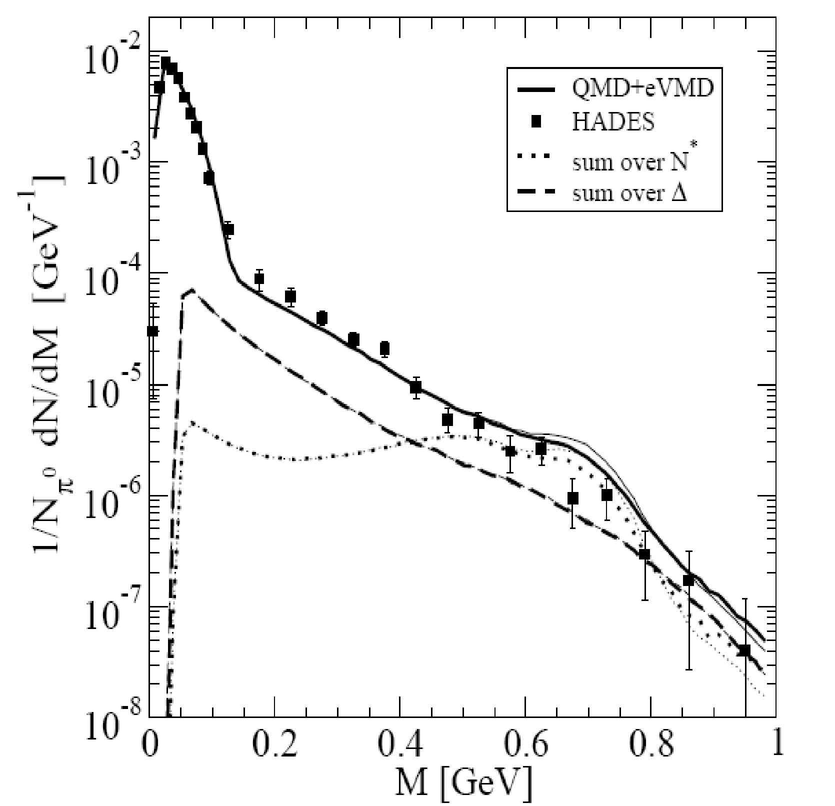
- ...









[1] E. Santini et al
arXiv:0804.3702

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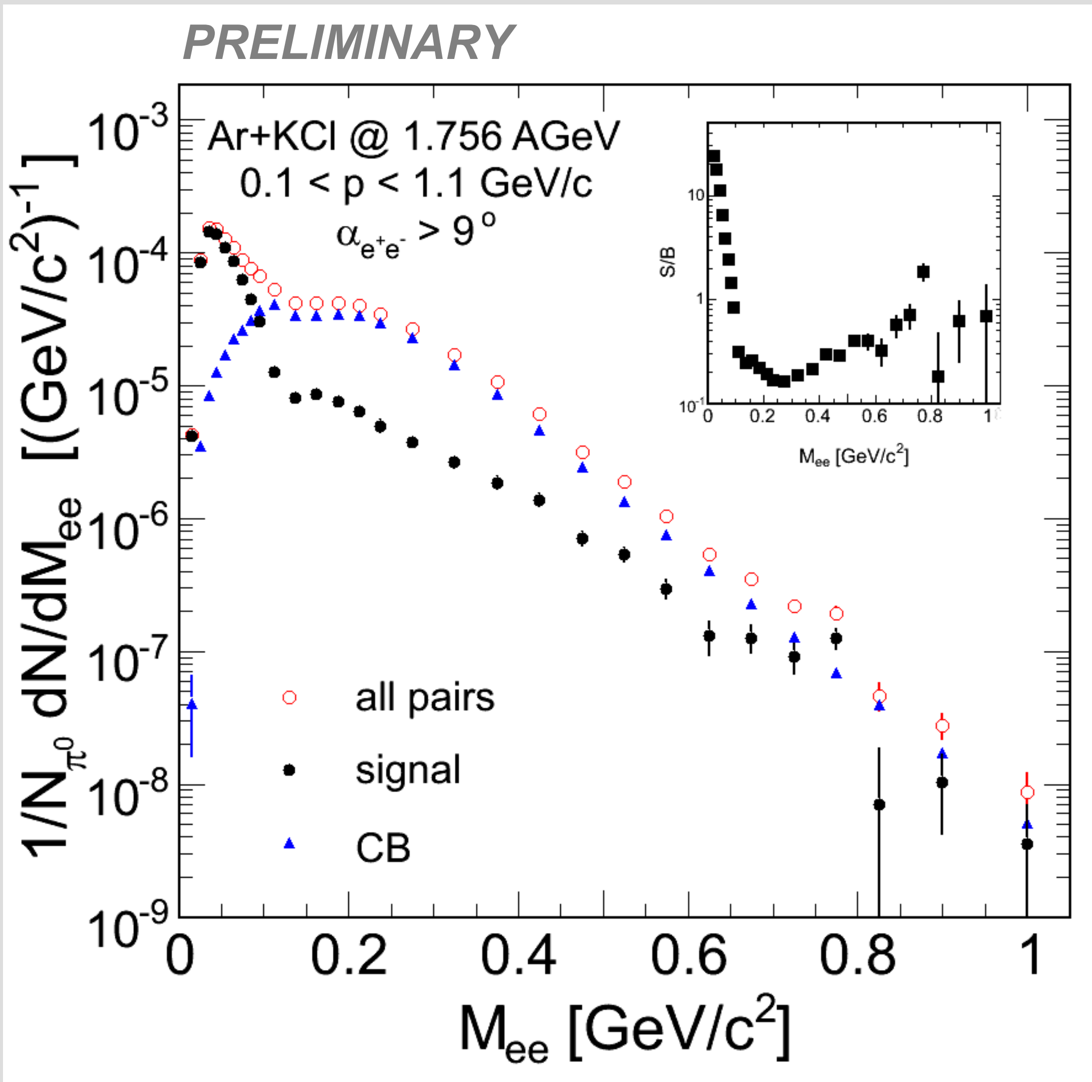


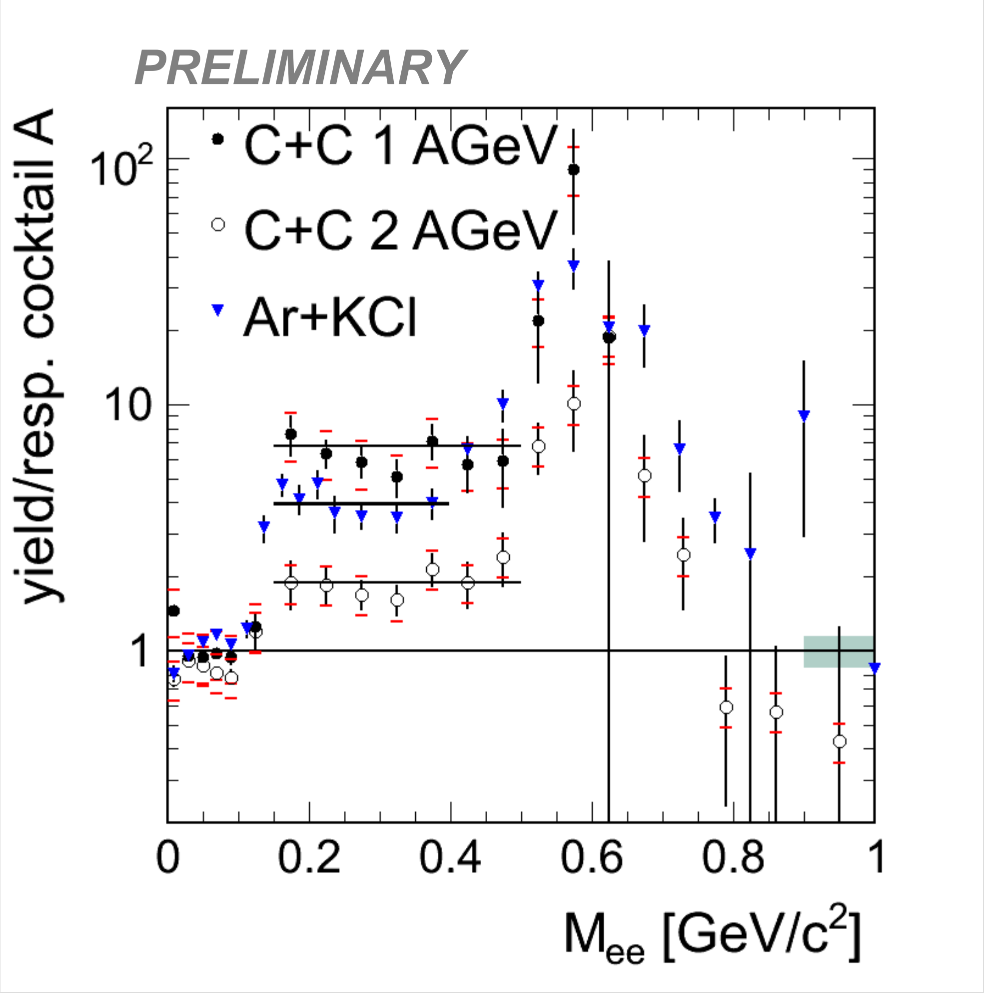
Excess above η:

$$F = \frac{Y_{tot}}{Y_{\eta}}$$

C+C @ 1 AGeV
F=6.8 ± 0.6 (stat) ± 1.3 (sys) ± 2.0 (η)

C+C @ 2 AGeV
F=1.9 ± 0.2 (stat) ± 0.3 (sys) ± 0.3 (η)

Ar+KCl @ 1.756 AGeV (prelim.)
F=4.3 ± 0.2 (stat) ± 1.3 (sys) ± 1.0 (η)



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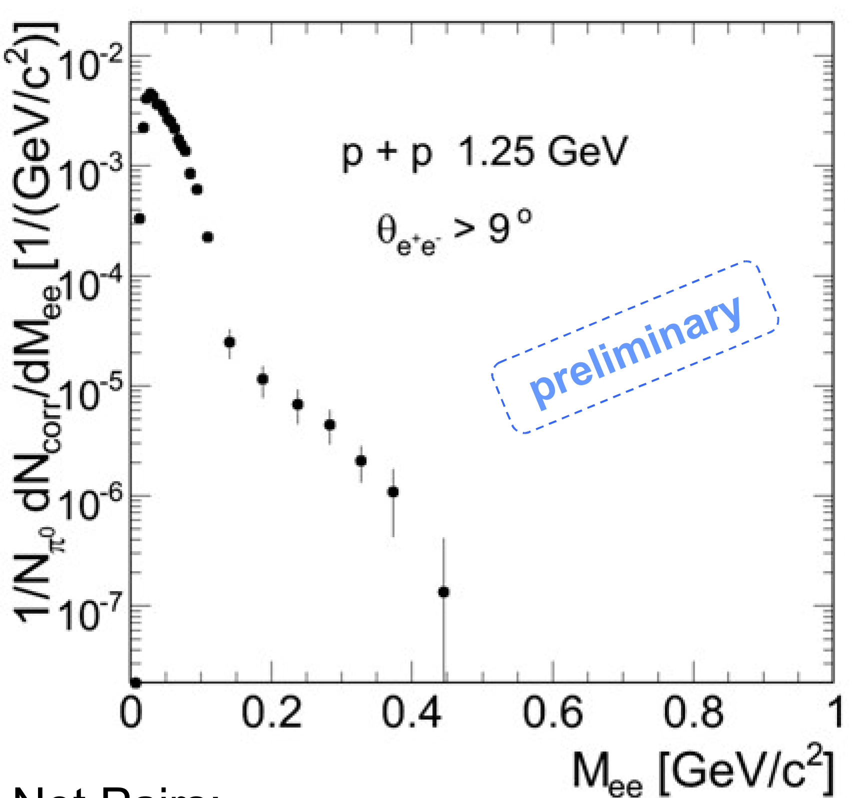
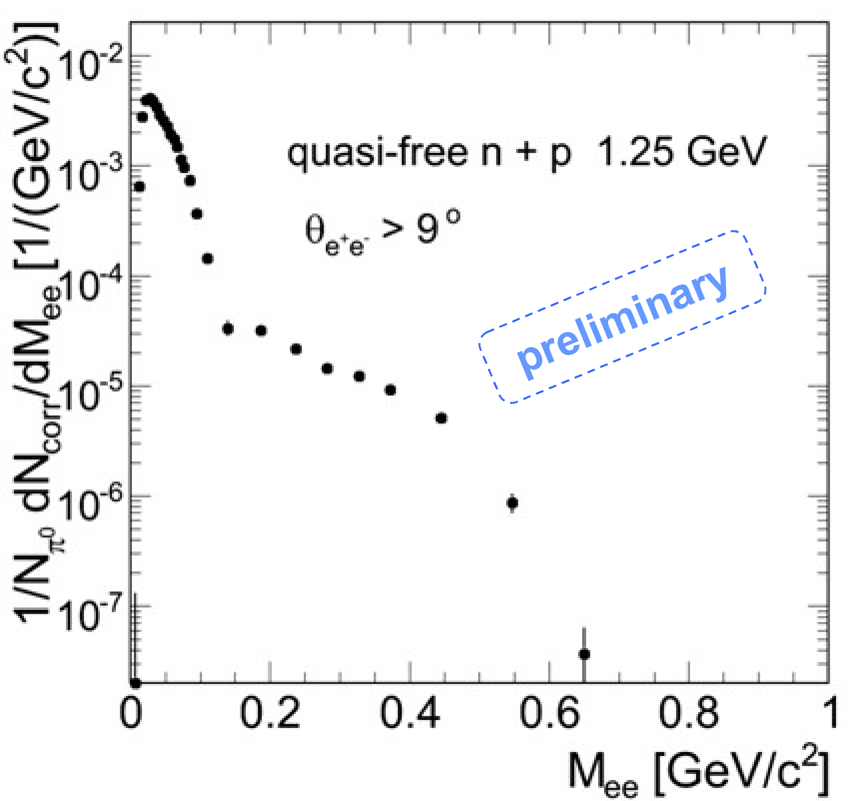
pp data



np data



Net Pairs:

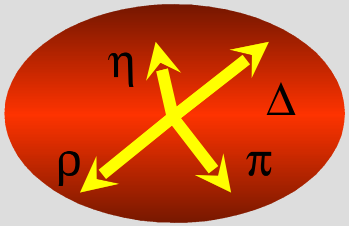
pp data : M_{ee} < 150 MeV/c²: 37156 counts, M_{ee} ≥ 150 MeV/c²: 418 counts

np data : M_{ee} < 150 MeV/c²: 61472 counts, M_{ee} ≥ 150 MeV/c²: 2207 counts

Total systematic error is about 28 %
- efficiency correction ~20%
- normalization to π^0 ~20%

Thermal model

- Elementary collisions & ***heavy ion reactions*** in one tool → Pluto



- Thermal model: Particles produced with Boltzmann distribution $\frac{dN}{dE} \propto pEe^{\frac{-E}{T}}$
  - Options: 2 temperatures, radial flow
- Anisotropic sampling

$$\frac{dN}{d\Omega} \propto 1 + A_2 \cos^2\theta_{cm} + A_4 \cos^2\theta_{cm}$$

A_1, A_2, T_1, T_2 are free parameters

- Broad mesons & resonance

$$\frac{d^2N}{dEdM} \propto Bolzmann(E) * BreitWigner(M), E \geq M$$

Mass sampling

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Mass sampling of hadrons

- Spectral shape of collision products (e.g. N*1535): Breit Wigner

$$\frac{dN}{dM} \propto \frac{M^2 \Gamma_{tot}(M)}{(M^2 - M_0^2)^2 + M^2 \Gamma_{tot}^2(M)}$$

- Decay into stable hadrons N*→pπ

Here, q, q_0 are ***fixed by m_1,m_2***

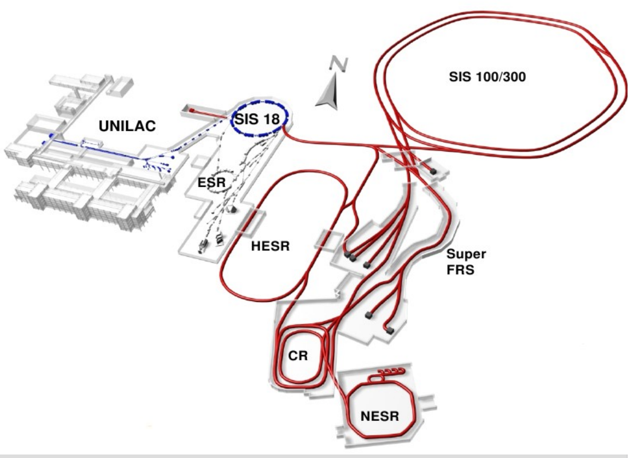
$$\Gamma_{M_0,m_1,m_2}(M) = \Gamma_0 \frac{M_0}{M} \left(\frac{q}{q_0}\right)^{2l+1} \left(\frac{q_p^2+\delta^2}{q^2+\delta^2}\right), \Gamma_{tot} = \Sigma \Gamma_i$$

- Unstable products: fold & integrate over m

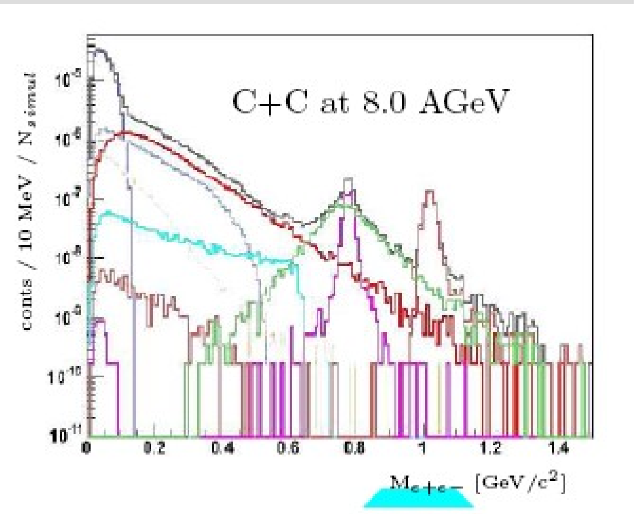
$$\Gamma_i = \int_{m_{min}}^{m-m_2} \frac{dN}{dM} p_{cm}(m, m_1, m_2) \Gamma_{m_2}(m, m_1)$$

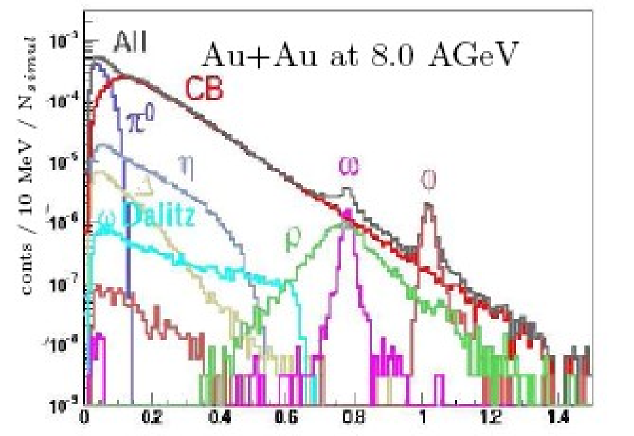
consequences:
- •have to take all BRs into account
- •recursive width calculation

HADES @ FAIR



- HADES upgrade:
- Forward wall for spectators (done)
- Data acquisition (ongoing)
- High granularity RPC replaces Tofino (ongoing)
- RICH modification to compensate boost





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