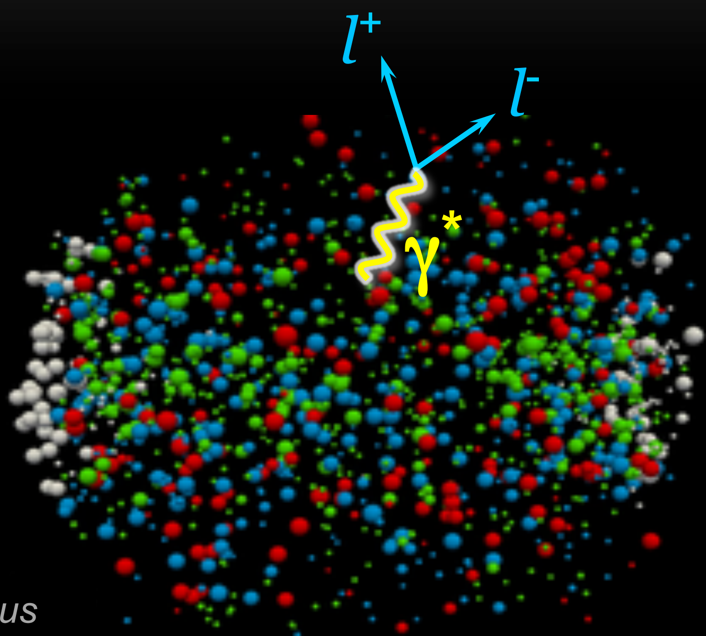


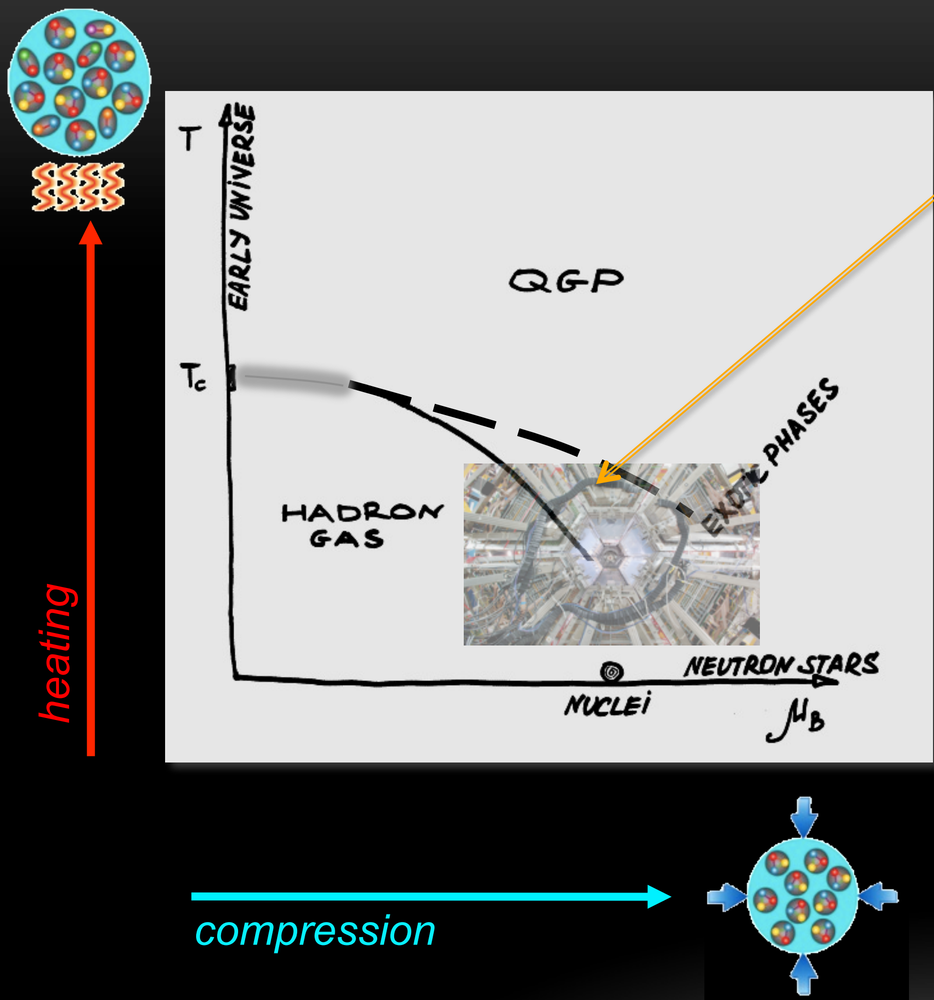
MADAI.us

RESULTS ON VIRTUAL-PHOTON PRODUCTION WITH HADES:

RESUME AND PROSPECTS

Tetyana Galatyuk for the HADES Collaboration
Technische Universität Darmstadt / GSI

THE HADES MISSION



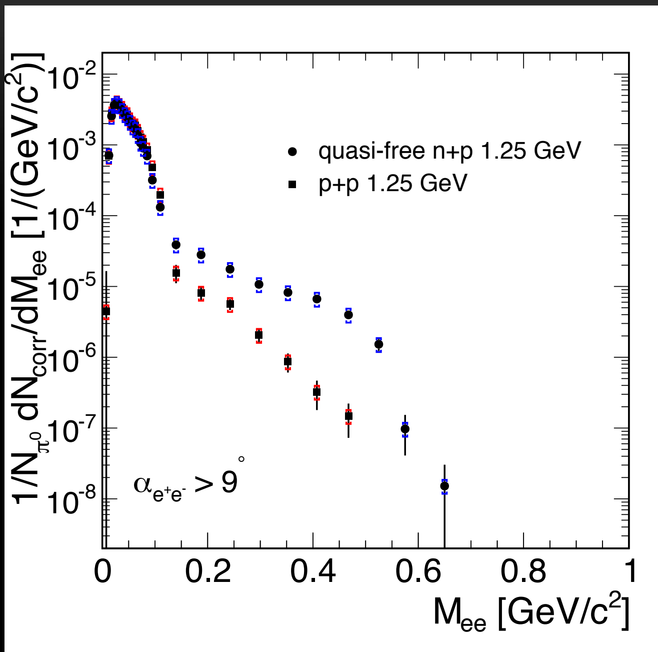
Search
(in this region)
for new states of matter with
rare and penetrating probes

- ✓ 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 (2020 - …)
  - ☐ Lepton pair excitation function up to 8 GeV/u (medium-heavy systems) and (multi-)strange particle

+ Various aspects of baryon-resonances physics

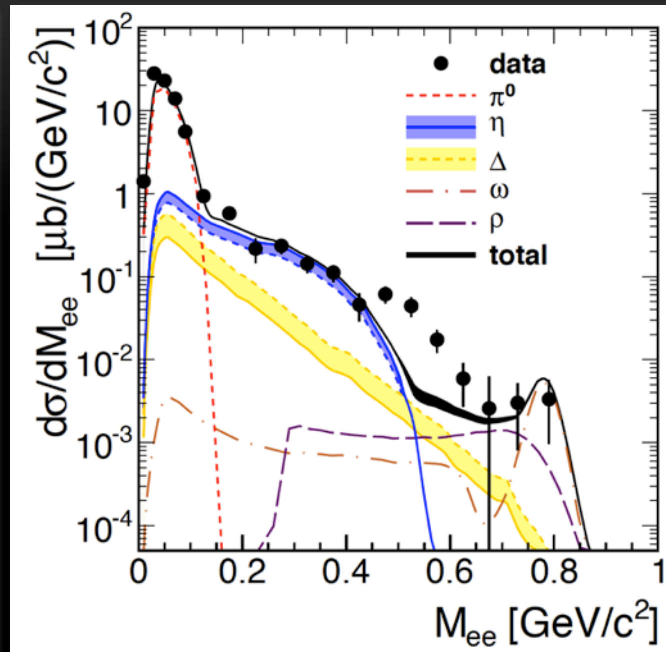
ELEMENTARY COLLISIONS

pp/np 1.25 GeV



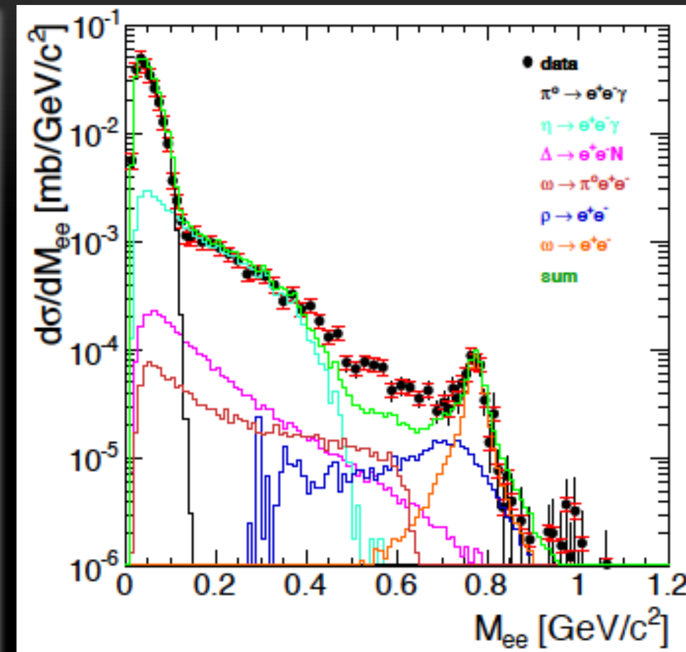
Phys.Lett. B 690 (2010) 118

pp 2.2 GeV



Phys.Rev. C85 (2012) 054005

pp 3.5 GeV

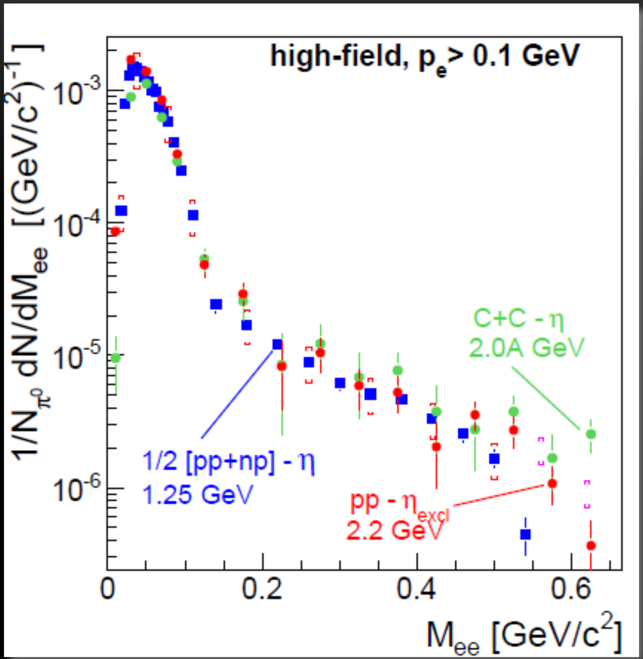


Eur.Phys.J. A48 (2012) 64

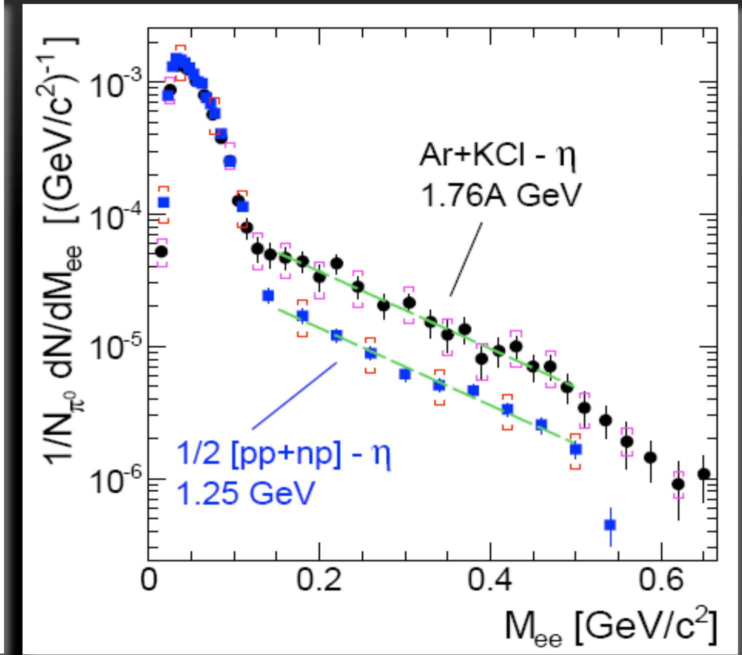
- Reference to study in-medium effects
- Probe for time-like electromagnetic structure of hadronic transitions!

- Simultaneous measurements of hadronic channels ($pp \rightarrow NN\pi$, $pp \rightarrow NN\pi\pi$) → Cross-checks on known channels, detailed information on baryonic resonance production

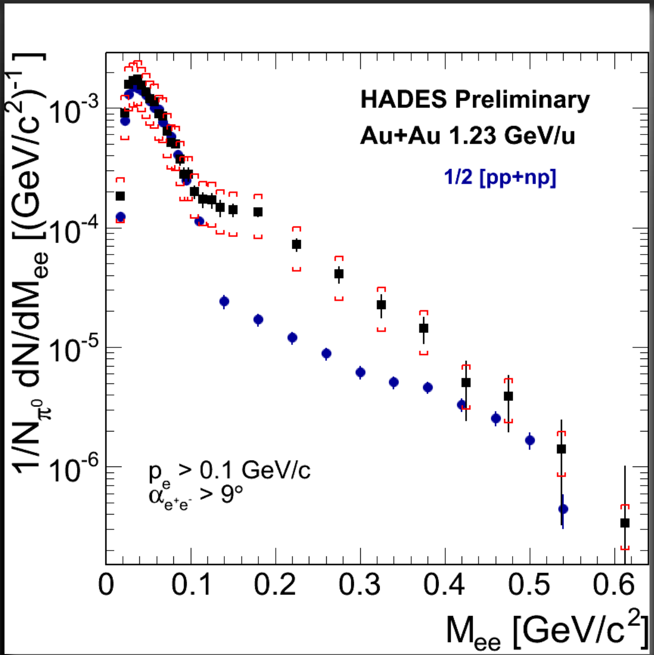
LOW-MASS DILEPTONS AT 1 – 2A GeV



Phys.Lett. B 690 (2010) 118



Phys.Rev.C 84 (2011) 014902



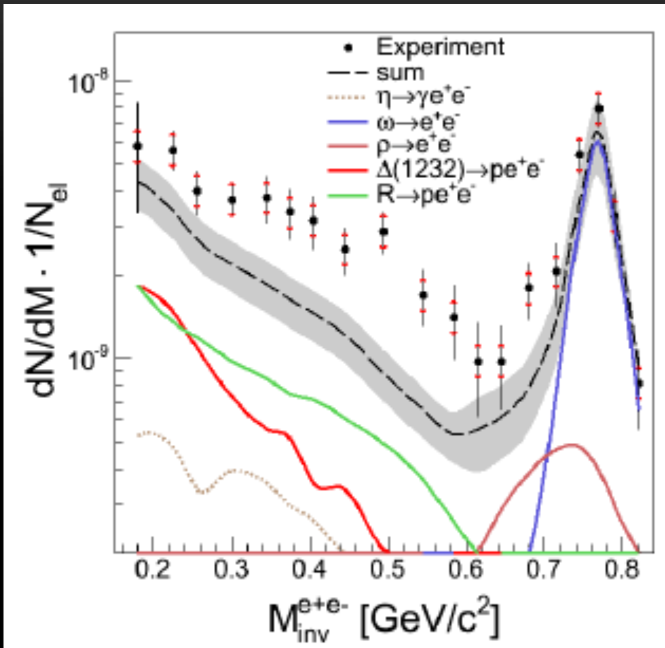
HADES PRELIMINARY

- C+C: After η subtraction, coincides with (pp+np)
- Ar+KCl: First evidence for radiation from the “medium” in this energy regime!

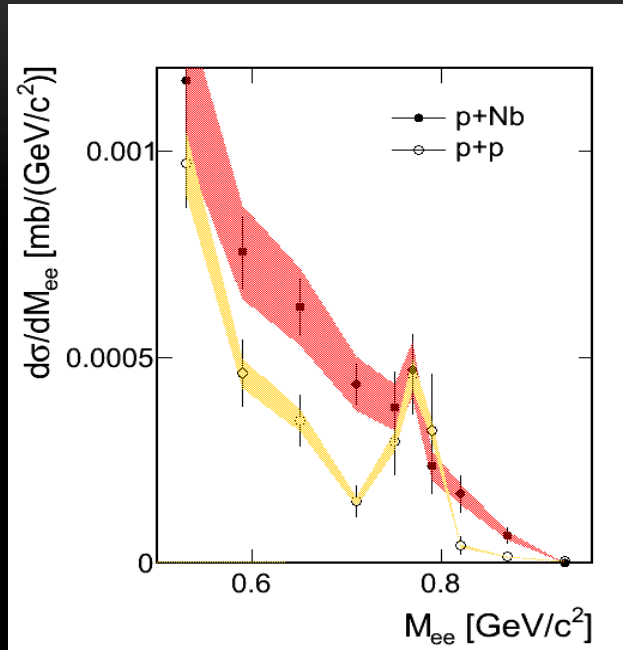
- Rapid increase of relative yield reflects the number of Δ‘s/ N*’s regenerated in fireball

REFERENCE FOR FAIR

Vacuum: p+p 3.5 GeV



Cold matter: p+Nb 3.5 GeV



Hot and dense matter: Nb+Nb 3.5 GeV

Answer at SIS100

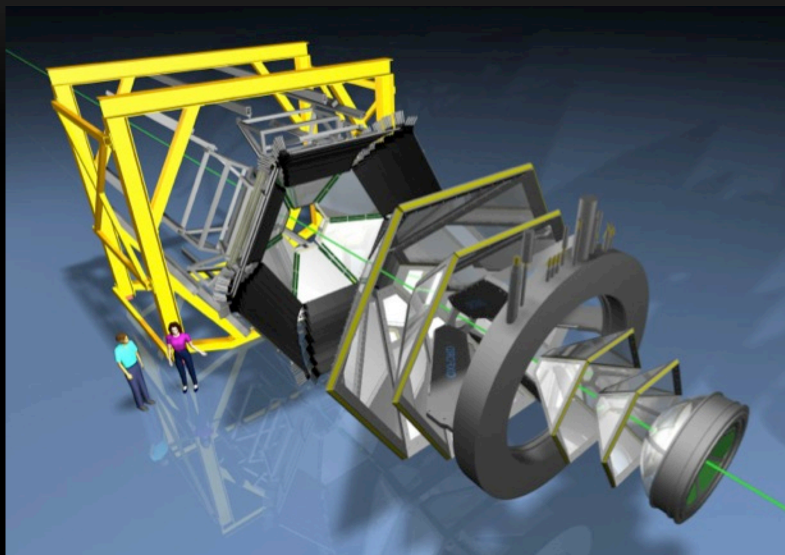
Effect of electromagnetic form factors

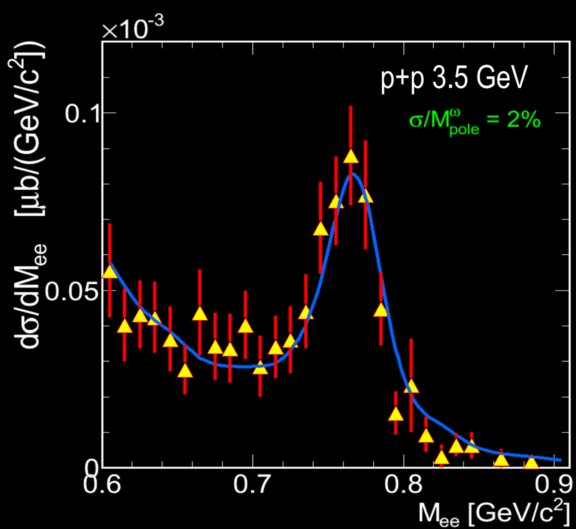
→ Treatment of Dalitz decays of broad resonances is not well understood

- Clear "excess" over p+p below VM pole
- Interplay: In-medium ρ modifications vs. secondary π reactions

→ Important constraint πN data (2014)!

THE HADES AT GSI, DARMSTADT, GERMANY

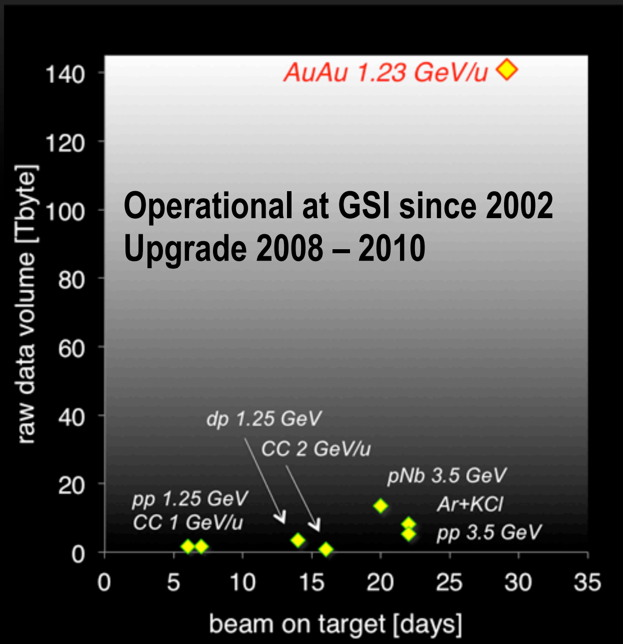




- HADES strategy:
  - Excitation function for low-mass lepton pairs and (multi-)strange baryons and mesons
  - Various aspects of baryon-resonance physics
- Beams provided by SIS18: π, proton, nuclei
- Full azimuthal coverage, 18 to 85 degree in polar angle
- Hadron and lepton identification
- Event-plane reconstruction
- e^+e^- pair acceptance 35%
- Mass resolution 2 % (ρ/ω region)
- ~ 80.000 channels
- 50 kHz event rate (400 Mbyte/s peak data rate)

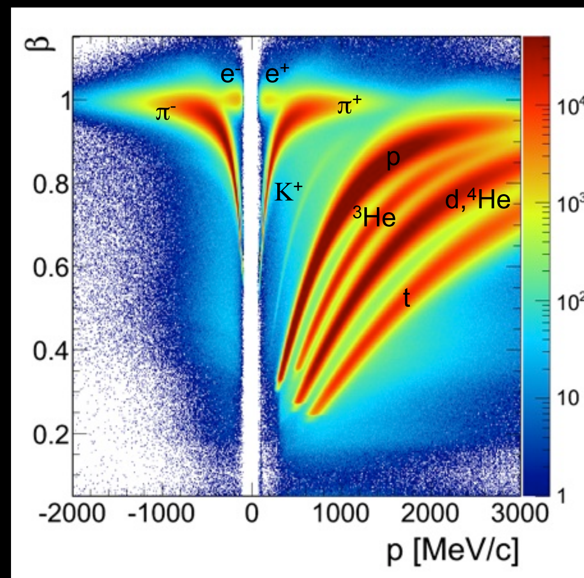
HADES EVENT RECONSTRUCTION

Recorded data sets

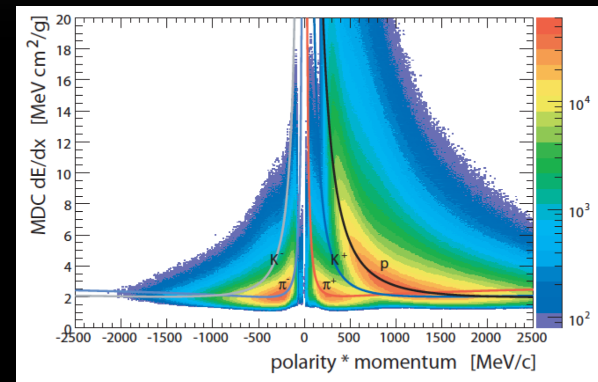


Particle identification by means of:

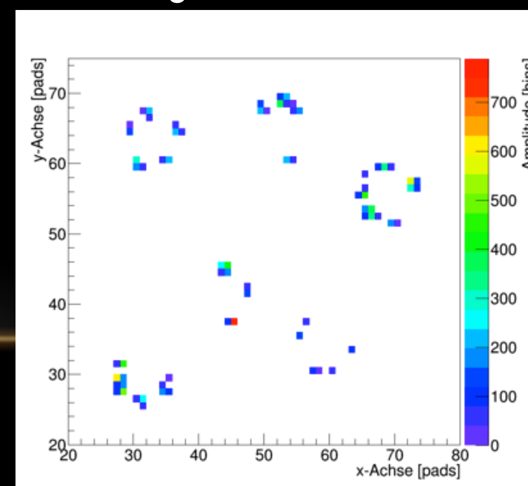
Velocity vs. momentum



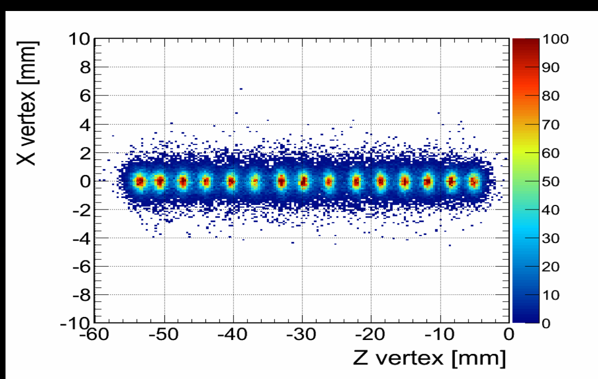
dE/dx in the MDC and ToF



RICH rings

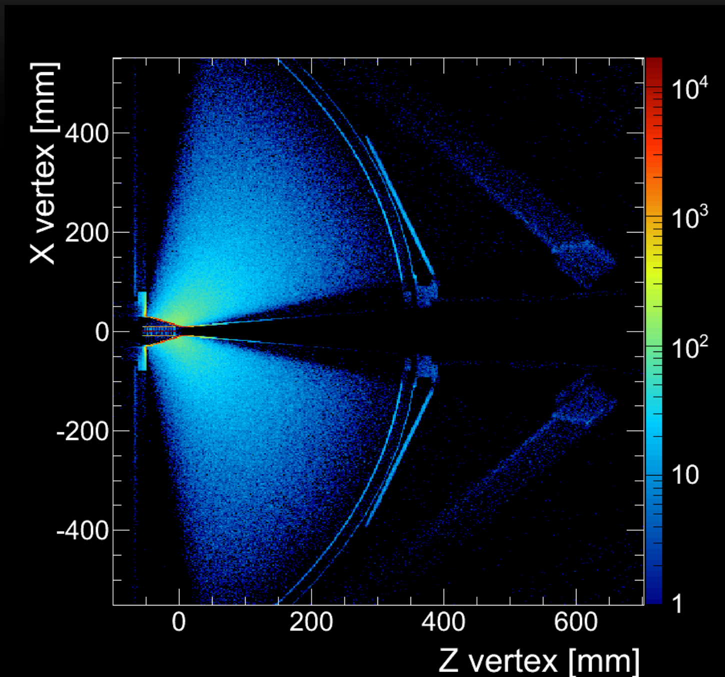


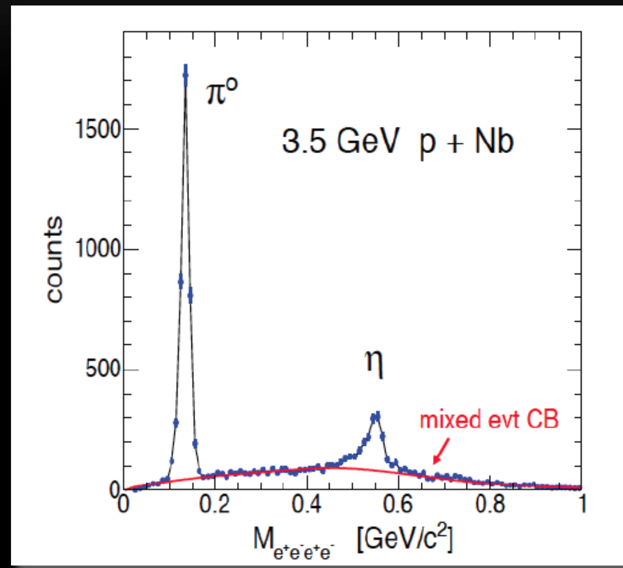
Vertex reconstruction



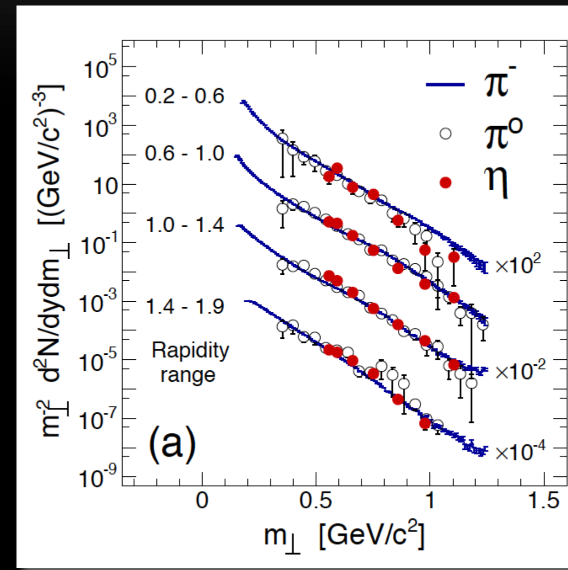
FIXING IMPORTANT COMPONENTS OF THE HADRONIC COCKTAIL

π^0 and η from full conversion method





meson $\mathbf{m_T}$-scaling



- HADES low mass spectrometer
  - Segmented target
  - RICH: $X/X_0 < 1\%$!
  - MDC: $X/X_0 \approx 0.42\%$

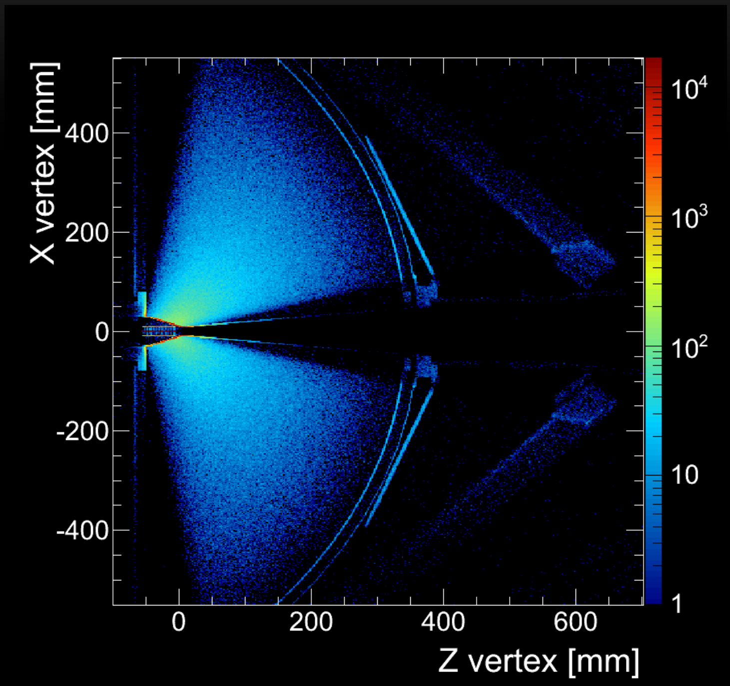
→ specially optimized to minimize conversion and multiple scattering

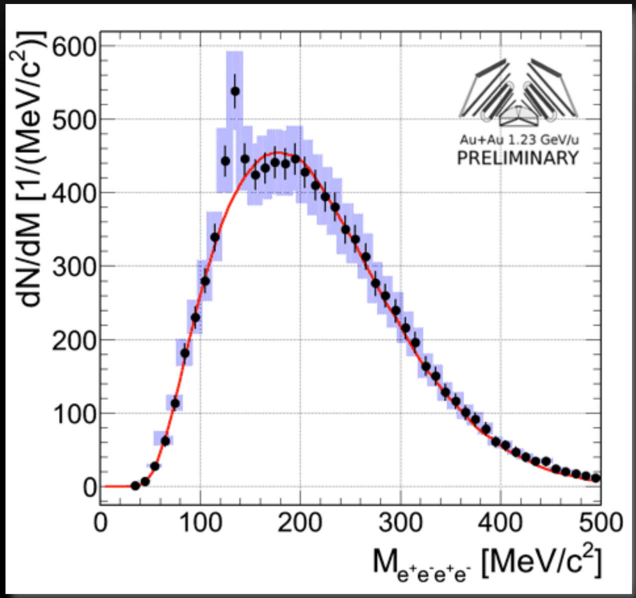
HADES p+Nb *Phys. Rev. C 88, 024904 (2013)*

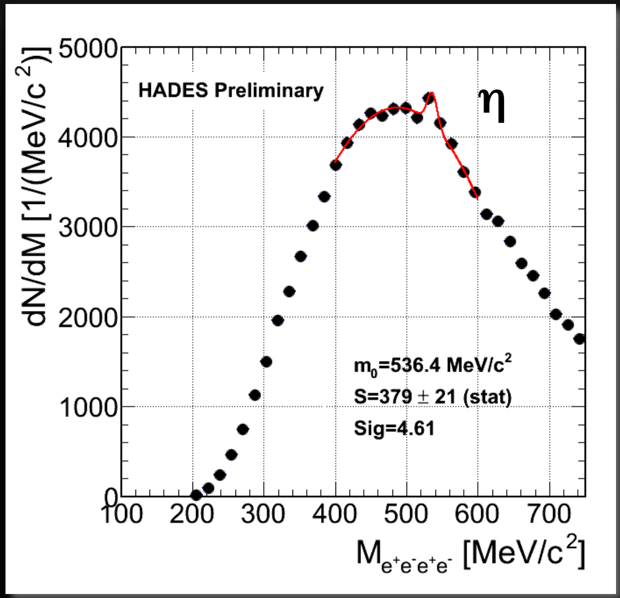
- Crucial component of the cocktail
- η cross section provides constraint on Δ and N* contributions

FIXING IMPORTANT COMPONENTS OF THE HADRONIC COCKTAIL

π^0 and η from full conversion method







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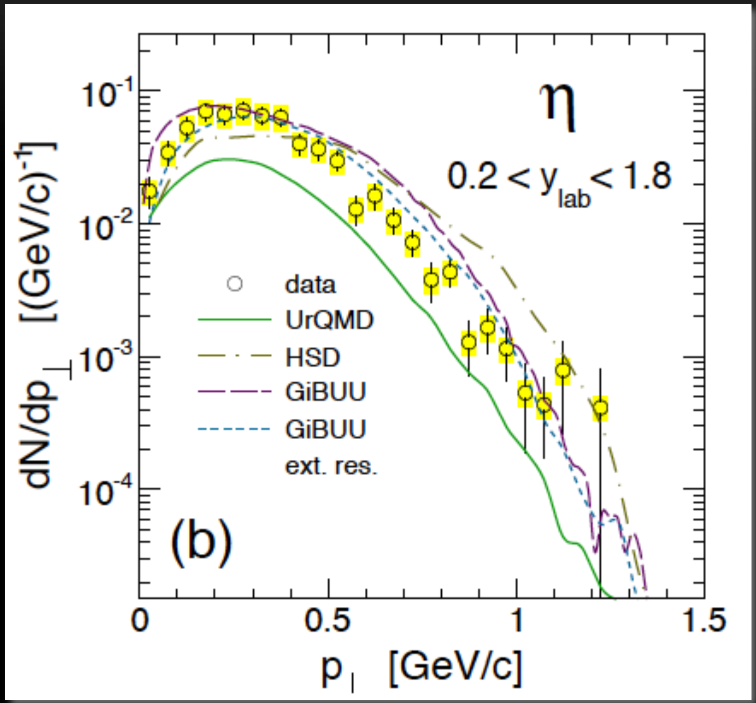
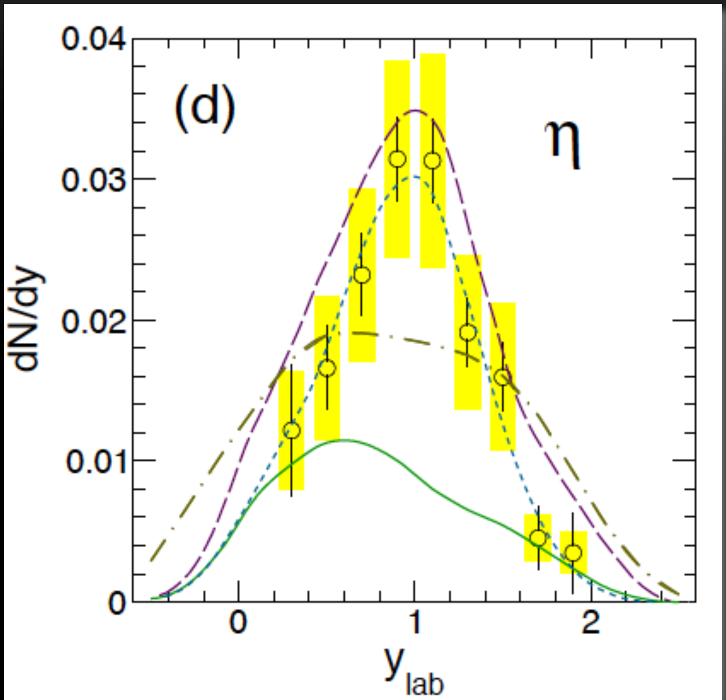
HADES p+Nb *Phys. Rev. C 88, 024904 (2013)*

- Crucial component of the cocktail
- η cross section provides constraint on Δ and N* contributions

π^0/η p_T DISTRIBUTION / YIELDS COMPARED TO TRANSPORT





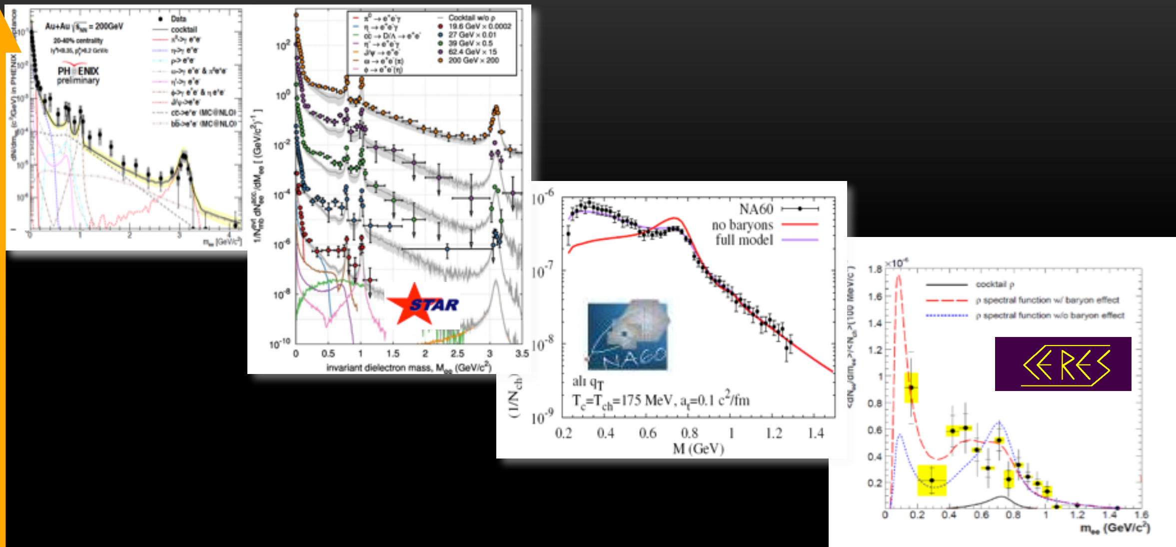
HADES p+Nb 3.5 GeV:

π^0	$0.69 \pm 0.09\ (stat)\ \pm 0.17\ (sys)$
η	$0.034 \pm 0.002\ (stat)\ \pm 0.008\ (sys)$

	N_{π^0}		N_η	
Model	$0.2 < y < 1.8$	4π	$0.2 < y < 1.8$	4π
UrQMD v3.3p1	0.38	0.66	0.013	0.016
HSD v2.7	0.38	0.69	0.028	0.038
GiBUU v1.5	0.39	0.64	0.039	0.046
GiBUU ext res	0.32	0.49	0.031	0.034

VIRTUAL PHOTON RADIATION FROM HOT AND DENSE QCD MATTER

T



Model: Ralf Rapp

STAR: QM2014,

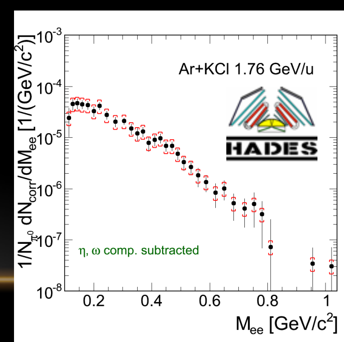
NA60: EPJC 59 (2009) 607,

CERES: Phys. Lett. B 666 (2006) 425,

HADES: Phys.Rev.C84 (2011) 014902

The HADES mission:

verify the ρ-baryon coupling mechanism

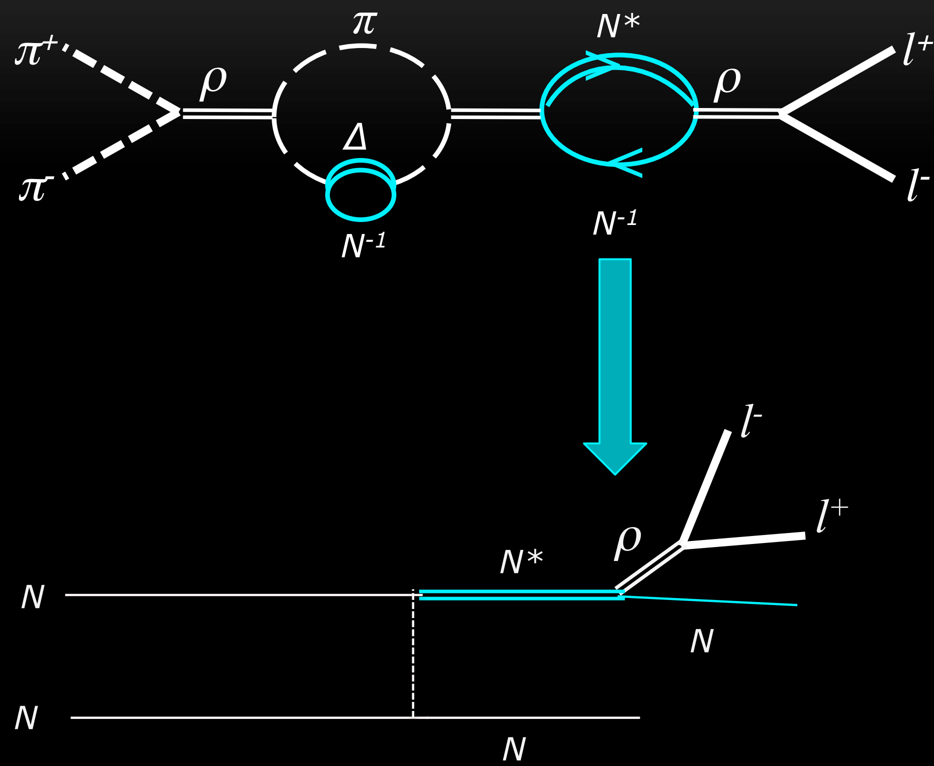


μ_B

IN-MEDIUM SELF ENERGY OF THE RHO

SPS, RHIC, LHC

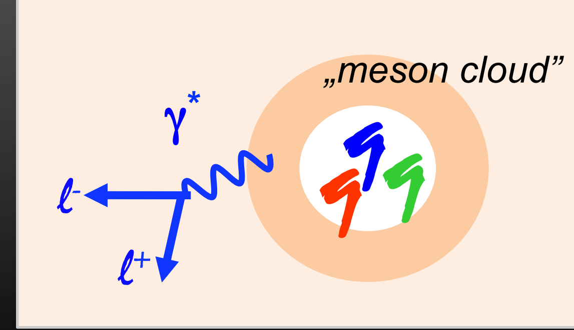
SIS18

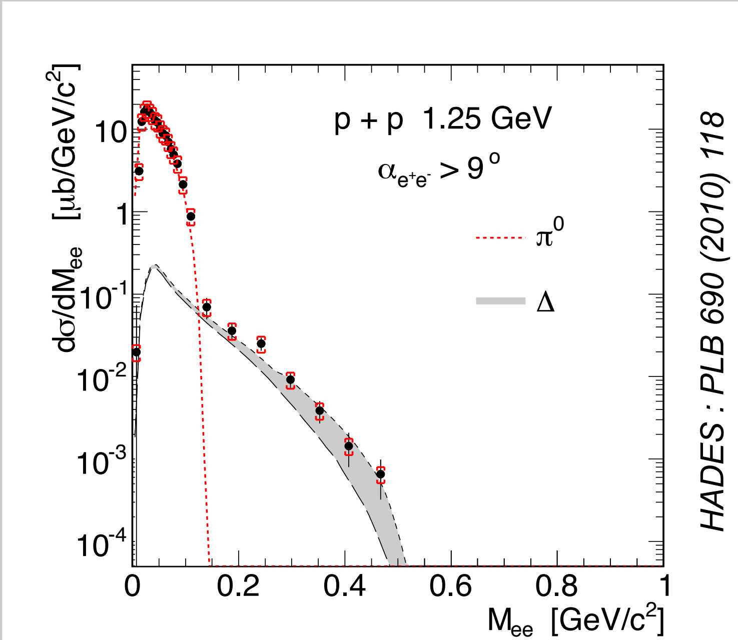


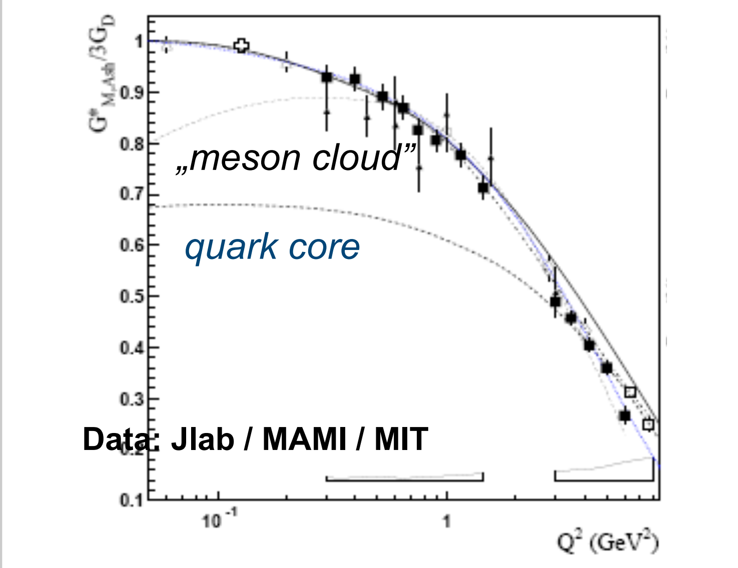
Resonance Dalitz-decays
NN bremsstrahlung

ρ - Δ/N* couplings play substantial role in ρ melting observed in UrHIC
→ connection to elementary process of baryon-resonance Dalitz-decays

NN REFERENCE: e^+e^- IN p+p COLLISIONS AT 1.25 GeV







time-like region $q^2 > 0$

Goal

- Understand $\Delta \rightarrow N\gamma^*$ transition
  - **Known from $\gamma N \rightarrow \Delta \rightarrow \pi N$**

    (exact QED calculation, Krivoruchenko et al. PRD 65 (2001) 017502)
  - **Unknown at $q^2 > 0$!**

→ use models fitted to the space like data

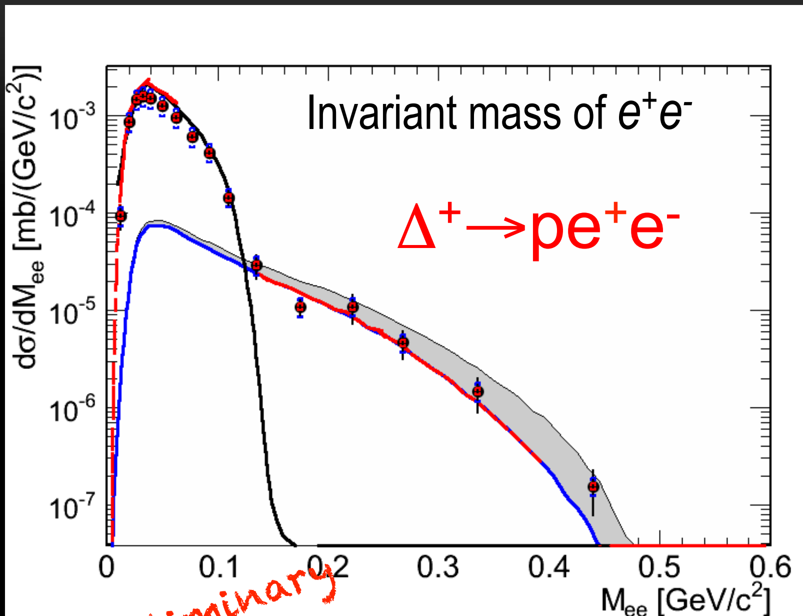
G. Ramalho and T. Pena arxiv: 1205.2575v1 (2012)

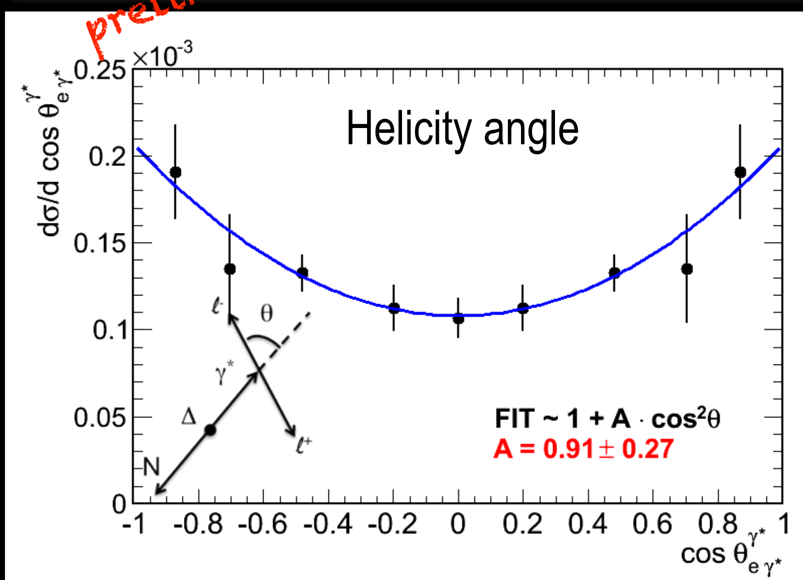
space-like region $q^2 < 0$

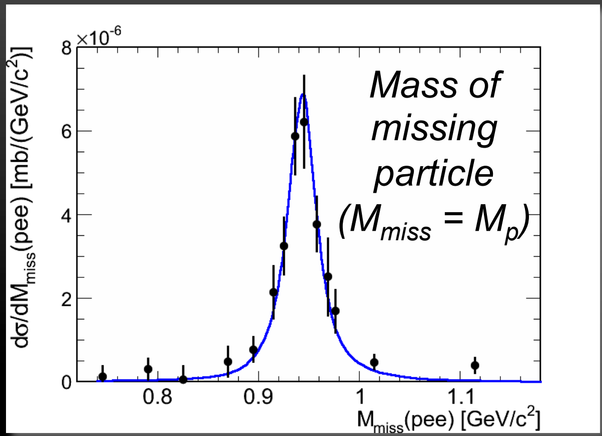
- Excitation of a baryon can be carried by the meson cloud
  - Precise data from Jlab / MAMI / MIT
  - Strong hint for dominant contribution to the $G_M(Q^2)$ from the meson cloud (30% at $G_M(0)$)

I.G. Aznauryan, V.D. Burkert Prog. Part. Nucl. Phys. 67, 1 (2012)) 1846

NN REFERENCE: pp→ppe$^+$e$^-$ COLLISIONS AT 1.25 GEV

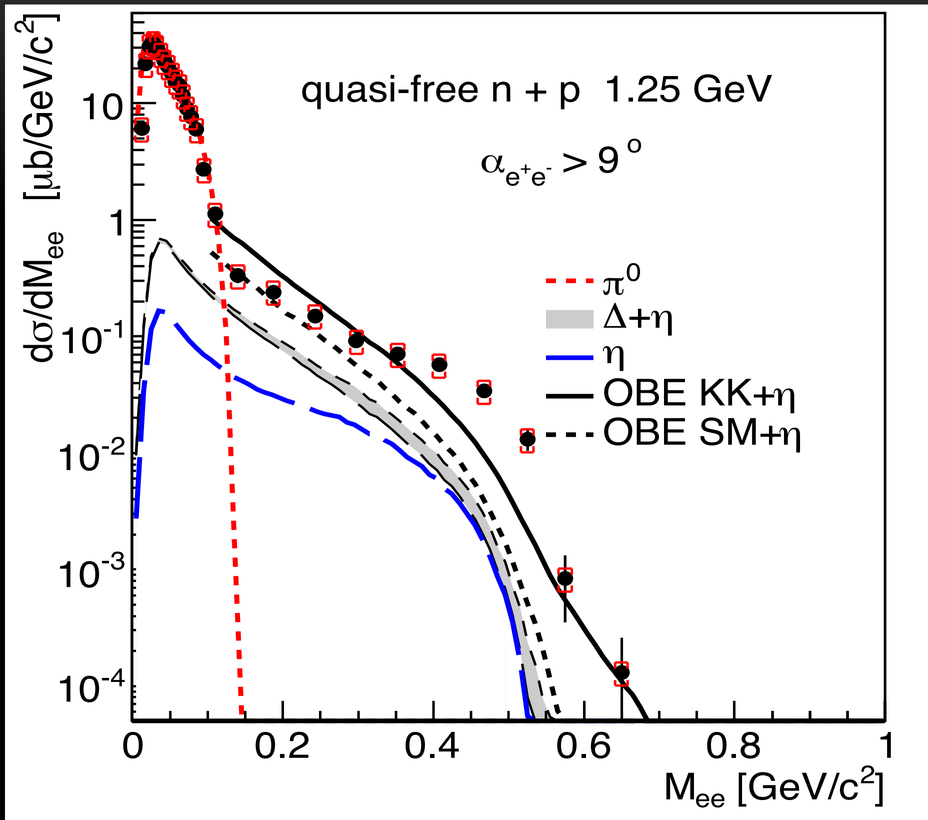




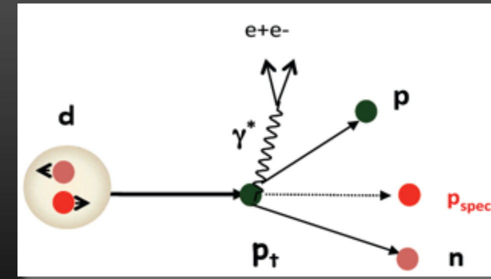


- First direct access to the Δ transition form factor in the time-like region
  - Data agree with QED calculation!
  - Branching ratio (Δ$^+$→pe$^+$e$^-$) = 4.42×10^{-5}

ELEMENTARY REACTIONS VS. OBE MODEL



HADES : PLB 690 (2010) 118



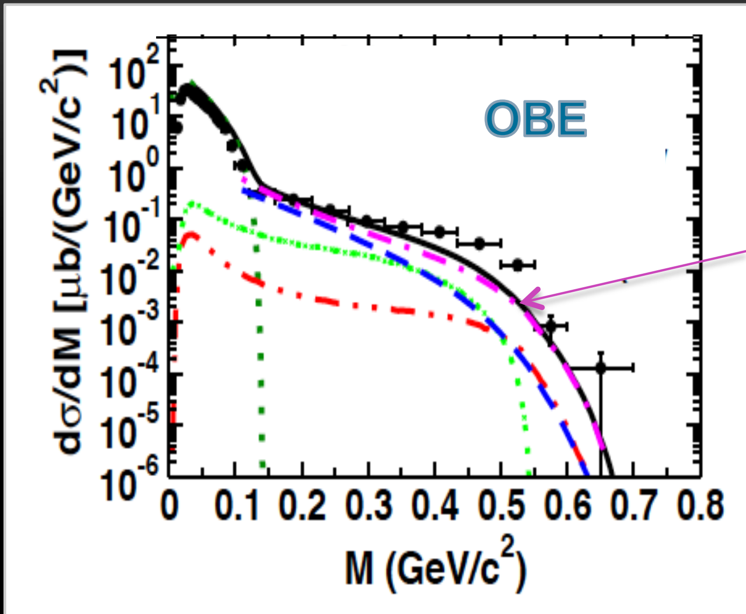
- Remarkable isospin effects
  - Role of the momentum distribution of the neutron inside the deuteron?
  - NN bremsstrahlung

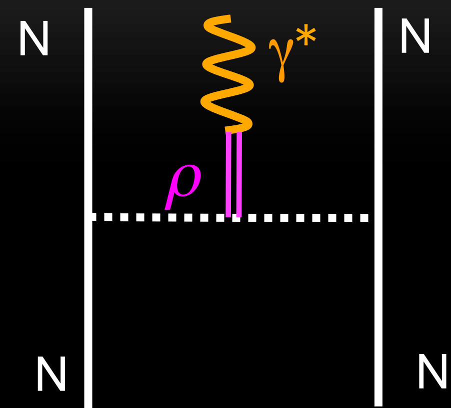
OBE models: different approaches to restore the gauge invariance
→ different types of the FF
→ different results

L.P. Kaptari and B. Kampfer, Phys. Rev. C 80 (2009) 064003;
R. Shyam and U. Mosel, Phys. Rev. C 82 (2010) 062201

One Boson Exchange calculations reproduce p+p, but not (yet) n+p !

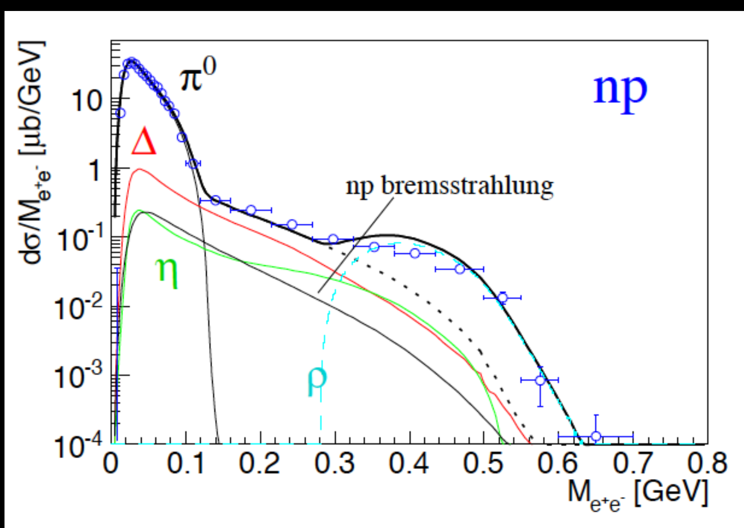
NN REFERENCE: e^+e^- IN QF n+p COLLISIONS $\sqrt{s} - 2m_N \approx m_\eta$

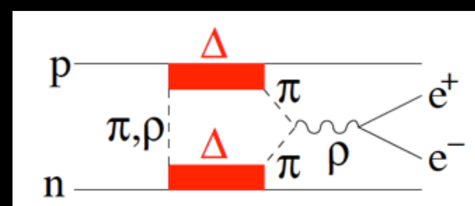




Much better agreement with data when including π EM form factor →
Sensitivity to hadronic electromagnetic structure

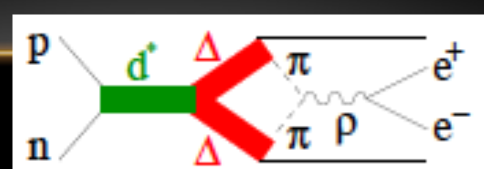
R. Shyam and U. Mosel, PRC 82:062201, 2010



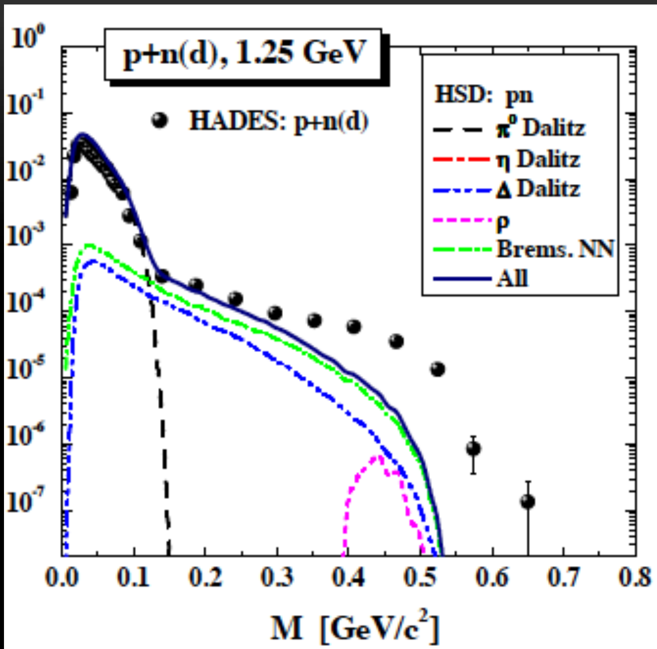


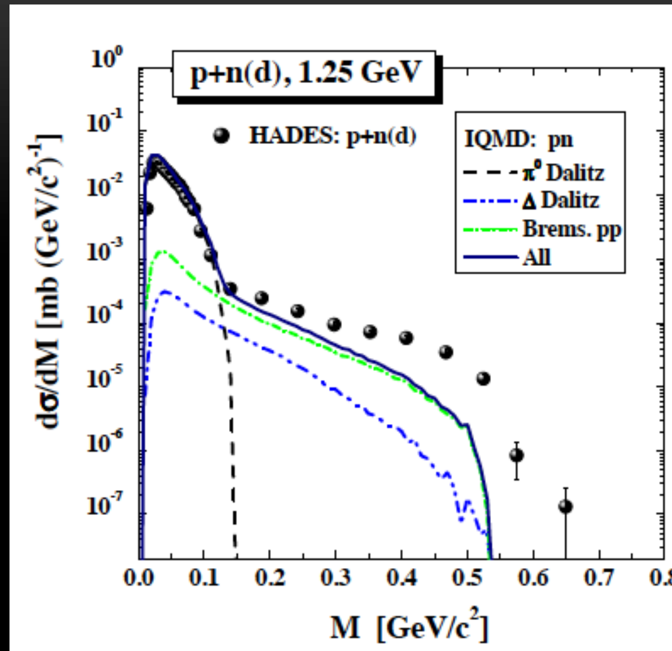
Double Δ excitation plus "final state" interaction

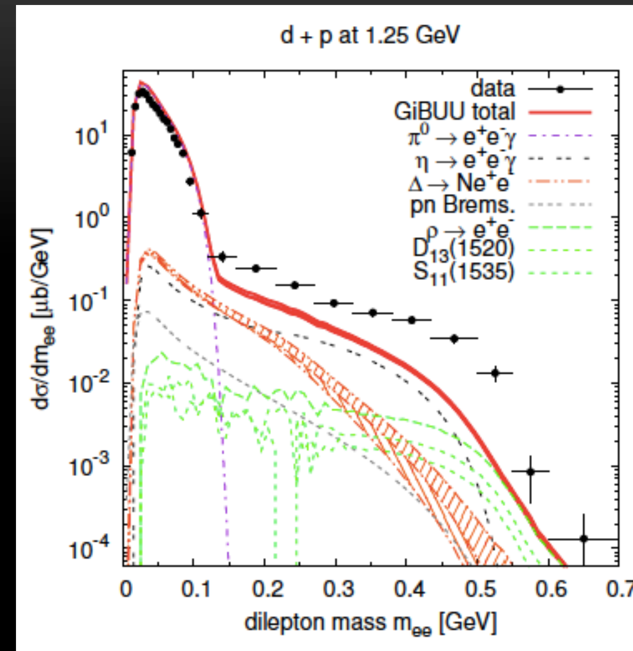
M. Bashkanov, H. Clement, Eur. Phys. J. A50, 107, (2014)



ELEMENTARY REACTIONS IN TRANSPORT MODELS

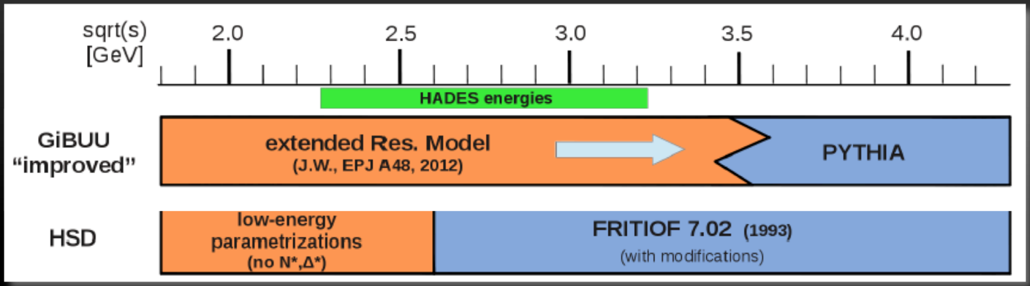






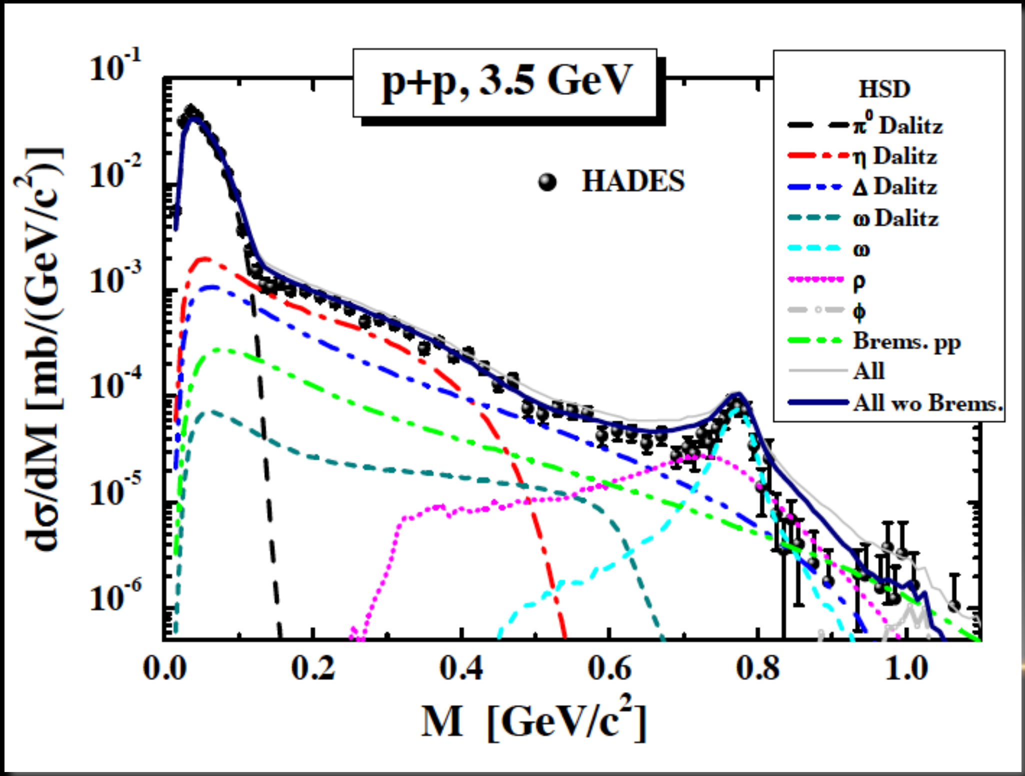
- NN bremsstrahlung are calculated within the SPA model, restricting the emission process to elastic NN collisions (appr. is valid if $E_\gamma < \tau^{-1}_{NN} \approx 100$ - 200 MeV)
- Δ contribution is treated explicitly by producing and decaying the resonance within a Dalitz-decay model in inelastic collisions
- The interference of elastic and inelastic channels is neglected.

ELEMENTARY REACTIONS IN TRANSPORT MODELS pp 3.5 GeV

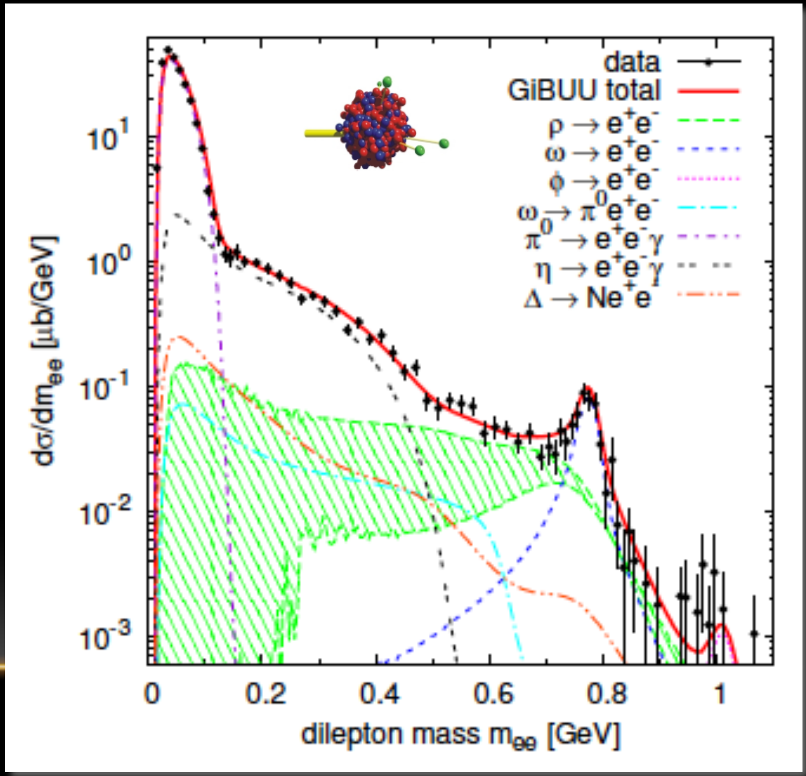


HADES energy range is clearly in the resonance regime!

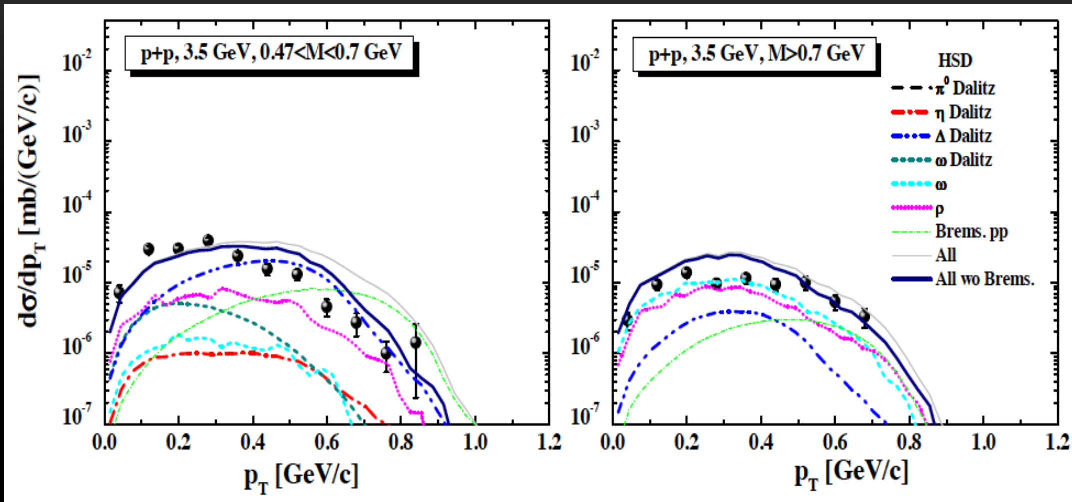
E.L. Bratkovskaya et al., Phys. Rev. C 87 (2013) 6, 064907

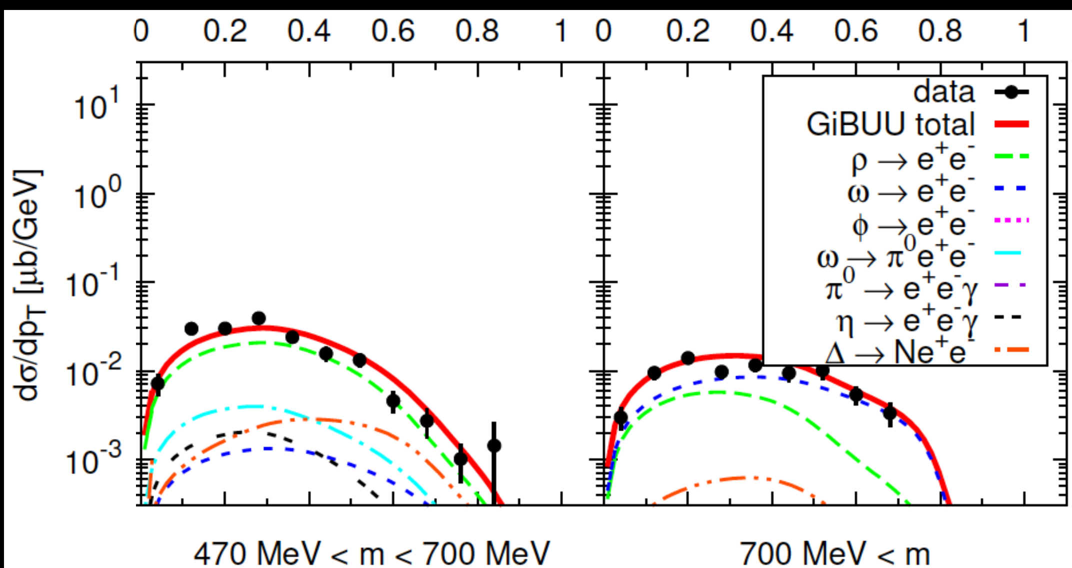


J. Weil et al., Eur. Phys. J. A 48 (2012) 111



ELEMENTARY REACTIONS IN TRANSPORT MODELS pp 3.5 GeV



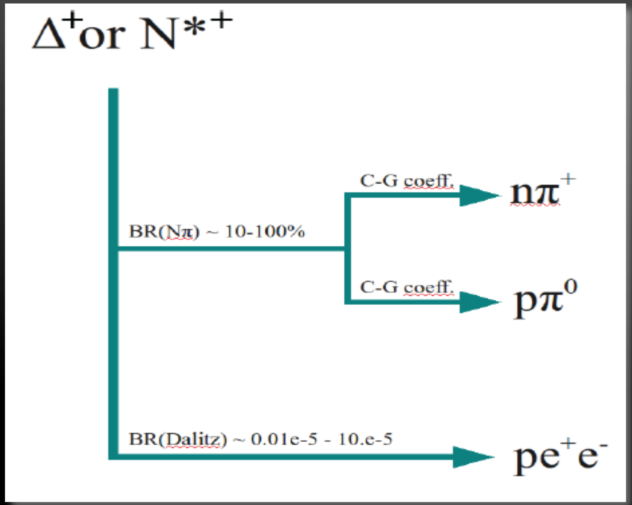


Many uncertainties:

- inclusive cross sections π, Δ, η, ω/ρ (fixed now by HADES)
- Δ → pe^+e^- transition (Dalitz decay), rates, EM transition form factors
- ρ - spectral function

Check resonance contribution with πN data

BARYON RESONANCES IN pp AT 3.5 GeV



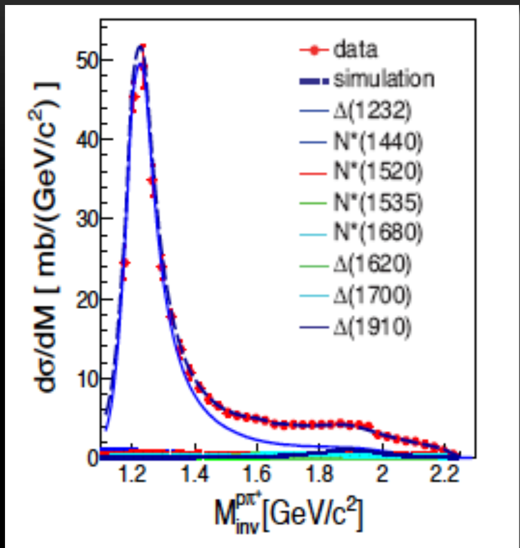
HADES Collab.: Eur. Phys. J. 50 A (2014) 82

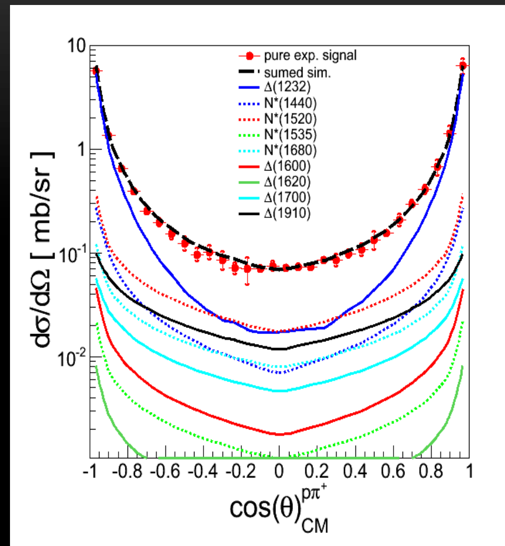
J^P	Resonances	Γ_R [MeV]	$BR(N\pi)$	$BR(pe^+e^-)$
$3/2^+$	**Δ(1232)**	120	1	4.2e-5
$1/2^+$	**N*(1440)**	350	0.65	3.06e-6
$3/2^-$	**N*(1520)**	120	0.55	3.72e-5
$1/2^-$	**N*(1535)**	150	0.46	1.45e-5
$3/2^+$	*Δ*(1600)	350	0.15	0.73e-6
$1/2^-$	**Δ(1620)**	150	0.25	1.73e-6
$1/2^-$	*N**(1650)	150	0.8	8.03e-6
$5/2^-$	*N**(1675)	150	0.45	1.02e-6
$5/2^+$	**N*(1680)**	130	0.65	1.97e-5
$3/2^+$	*N**(1720)	150	0.2	3.65e-6
$3/2^-$	**Δ**(1700)	300	0.15	1.38e-5
$5/2^+$	*Δ*(1905)	350	0.15	1.46e-6
$1/2^+$	**Δ(1910)**	280	0.25	0.73e-5
$7/2^+$	*Δ*(1950)	285	0.4	3.06e-6

Recepie:

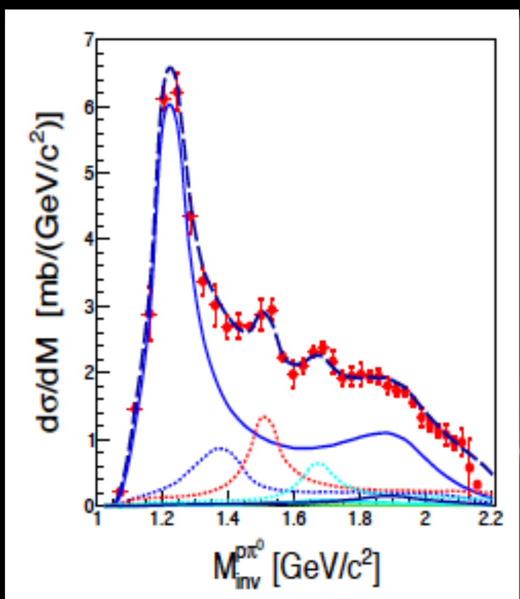
- Resonance model: production amplitude is given by incoherent sum of R contributions, isospin relations
- Starting point: R parametrization
  S. Teis et al., Z. Phys. A356 (1997) 421
- Take 4* resonances + empirical angular distributions
- BR(R→pe^+e^-): point-like R-γ^* vertex
  M. Zetenyi and Gy. Wolf., Heavy Ion Phys. 17 (2003) 27
- For the overlaping R only one R with largest BR(Nπ) selected

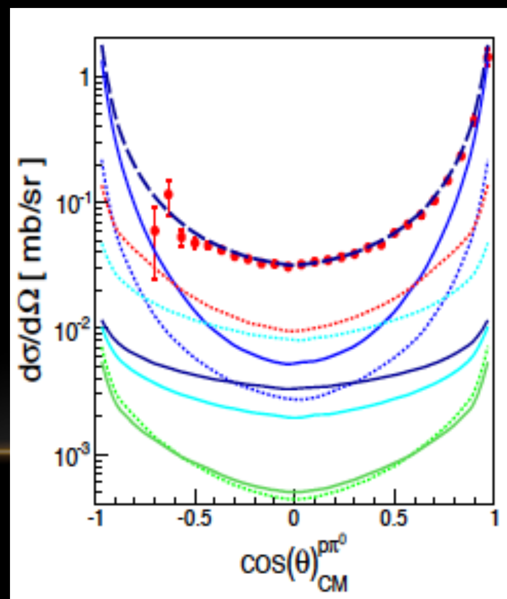
EXCLUSIVE ANALYSIS OF pp → pnπ^+ AND pp → ppπ^0





- Δ^{++} (1232) dominates
- Excelent description of Δ-line shape („Moniz" FF)



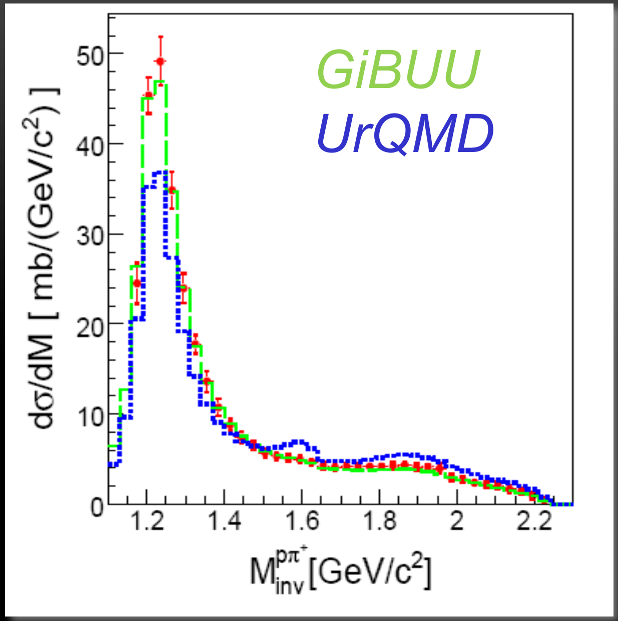


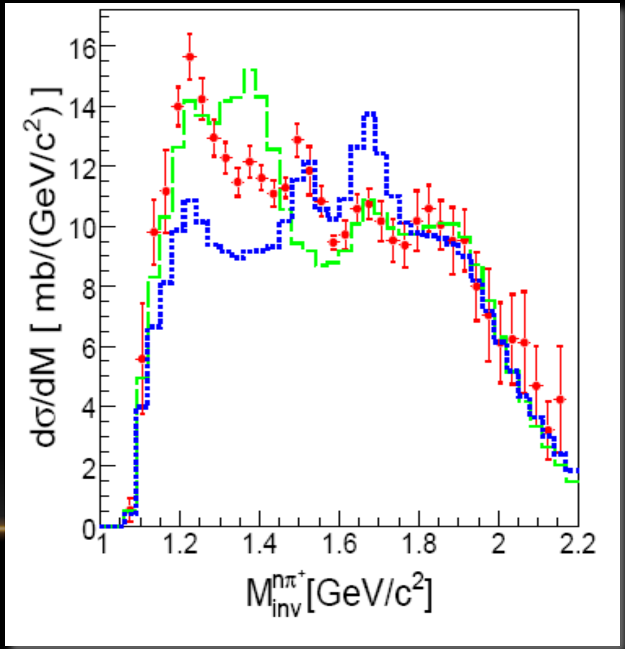
- Δ^+(1232), N*(1440), N*(1520),…
- N*1535: independent estimate by analysis of the pp → ppη Dalitz plot *(K. Teilab Int.J.Mod.Phys.A26 (2011) 694-696)*

RESONANCE MODEL DECOMPOSITION

HADES Collab.: Eur. Phys. J. 50 A (2014) 82

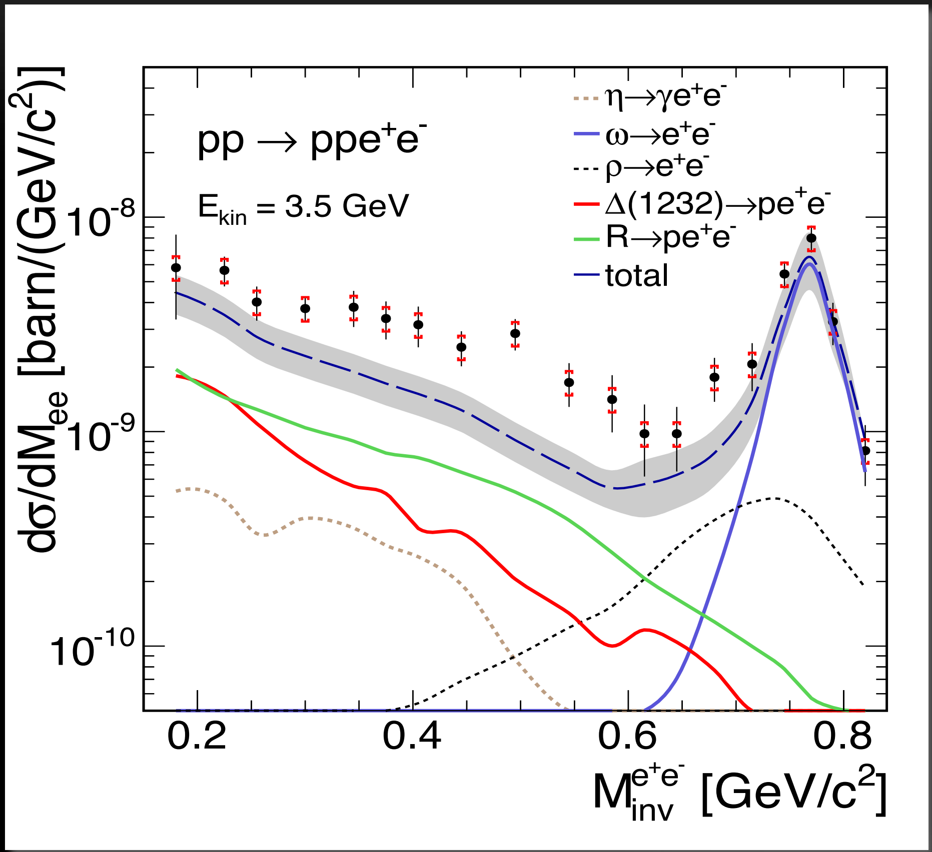
Resonances	σ_R	$\sigma_R^{Teis}(\sigma_R^{GiBUU})$	σ_R^{UrQMD}
Δ(1232)	2.53 ± 0.31	2.0 (2.2)	1.7
N(1440)	1.50 ± 0.37	0.83 (3.63)	1.15
N(1520)	1.8 ± 0.3	0.22 (0.27)	1.7
N(1535)	0.152 ± 0.015	0.53 (0.53)	0.8
Δ(1600)	$< 0.24 \pm 0.10$	0.70 (0.14)	0.4
Δ(1620)	$< 0.10 \pm 0.03$	0.60 (0.10)	0.2
N(1650)	$< 0.81 \pm 0.13$	0.23 (0.24)	0.4
N(1675)	$< 1.65 \pm 0.27$	2.26 (0.94)	1.2
N(1680)	$< 0.90 \pm 0.15$	0.21 (0.22)	1.2
N(1720)	$< 4.41 \pm 0.72$	0.15 (0.14)	0.68
Δ(1700)	0.45 ± 0.16	0.10 (0.06)	0.35
Δ(1905)	$< 0.85 \pm 0.53$	0.10 (0.06)	0.25
Δ(1910)	$< 0.38 \pm 0.11$	0.71 (0.14)	0.08
Δ(1950)	$< 0.10 \pm 0.06$	0.08 (0.10)	0.25





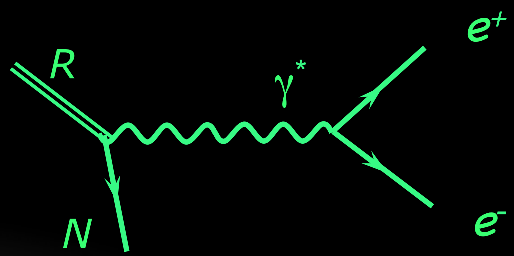
EXCLUSIVE DILEPTON PRODUCTION pp → pp e^+e^-

HADES Collab.: Eur. Phys. J. A (2014) 50: 82



- Significant contribution from higher (than Δ) mass resonances („QED": point like R→Nγ^* vertex)

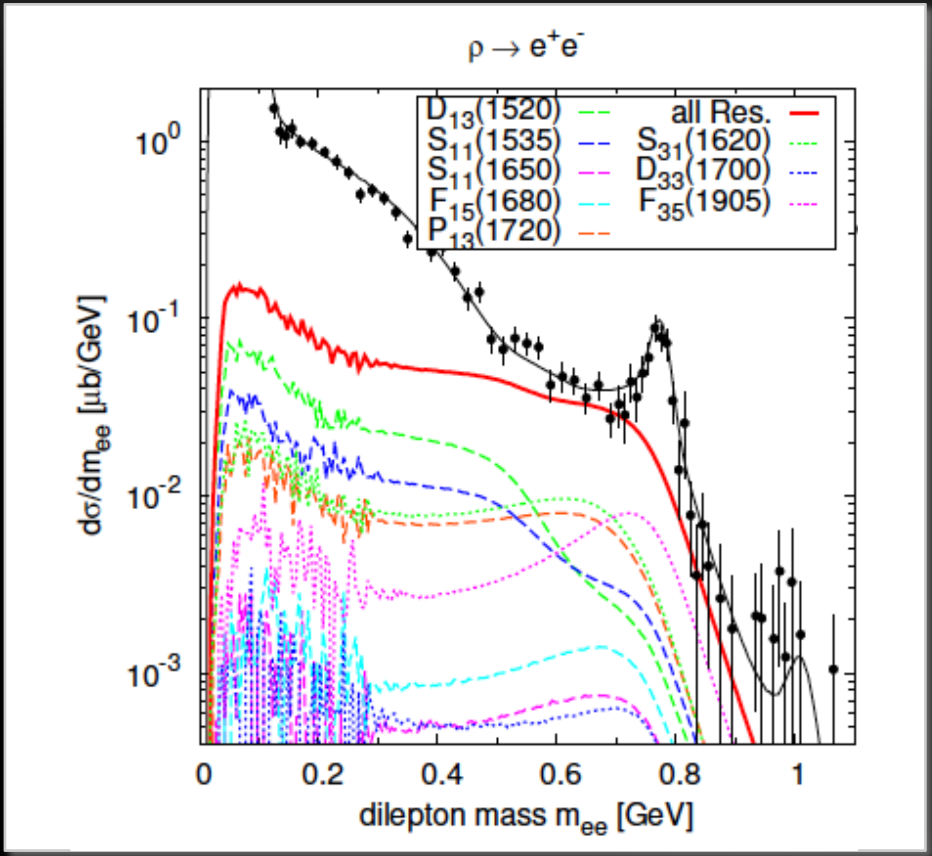
→ Fixed through decomposition of the exclusive π production: pp→ppπ^0 and pp→npπ^+



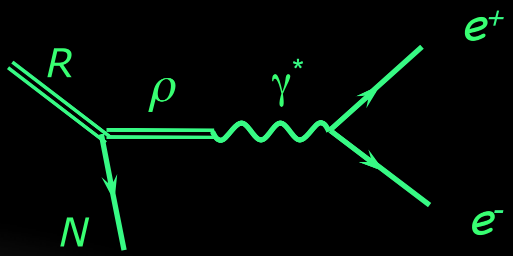
R assumes no ρ contribution

INCLUSIVE DILEPTON PRODUCTION

J. Weil et al., Eur. Phys. J. A 48 (2012) 111

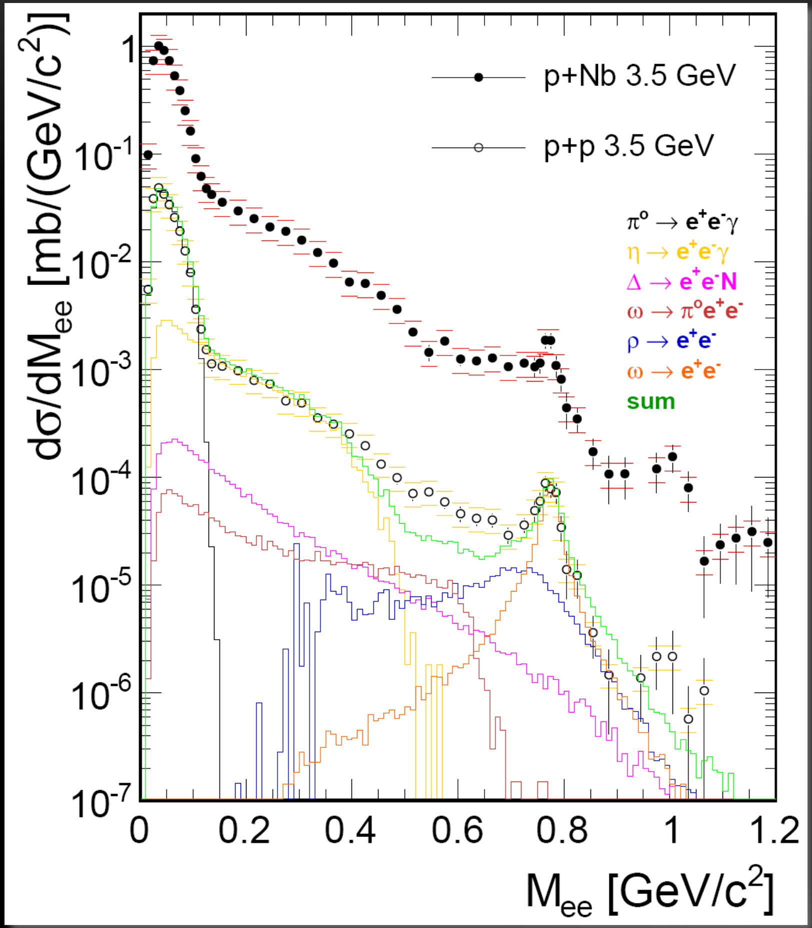


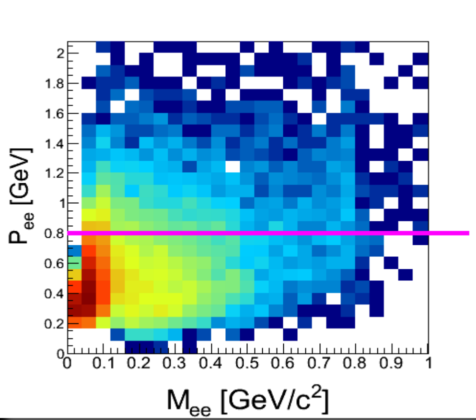
- Supported by GiBUU (Janus Weil)
  - → large contributions from several $\mathbf{N}^*$ and Δ^* resonances



COLD MATTER EFFECTS

pp AND pNb REACTIONS AT 3.5 GeV





- First measurement of in-medium vector meson decays in the relevant momentum region (P_{ee} down to 200 MeV/c)

PDG Entry 2012, 2014
BR($\eta \to e^+e^-$) < 2.5x10^{-6} (90% CL)

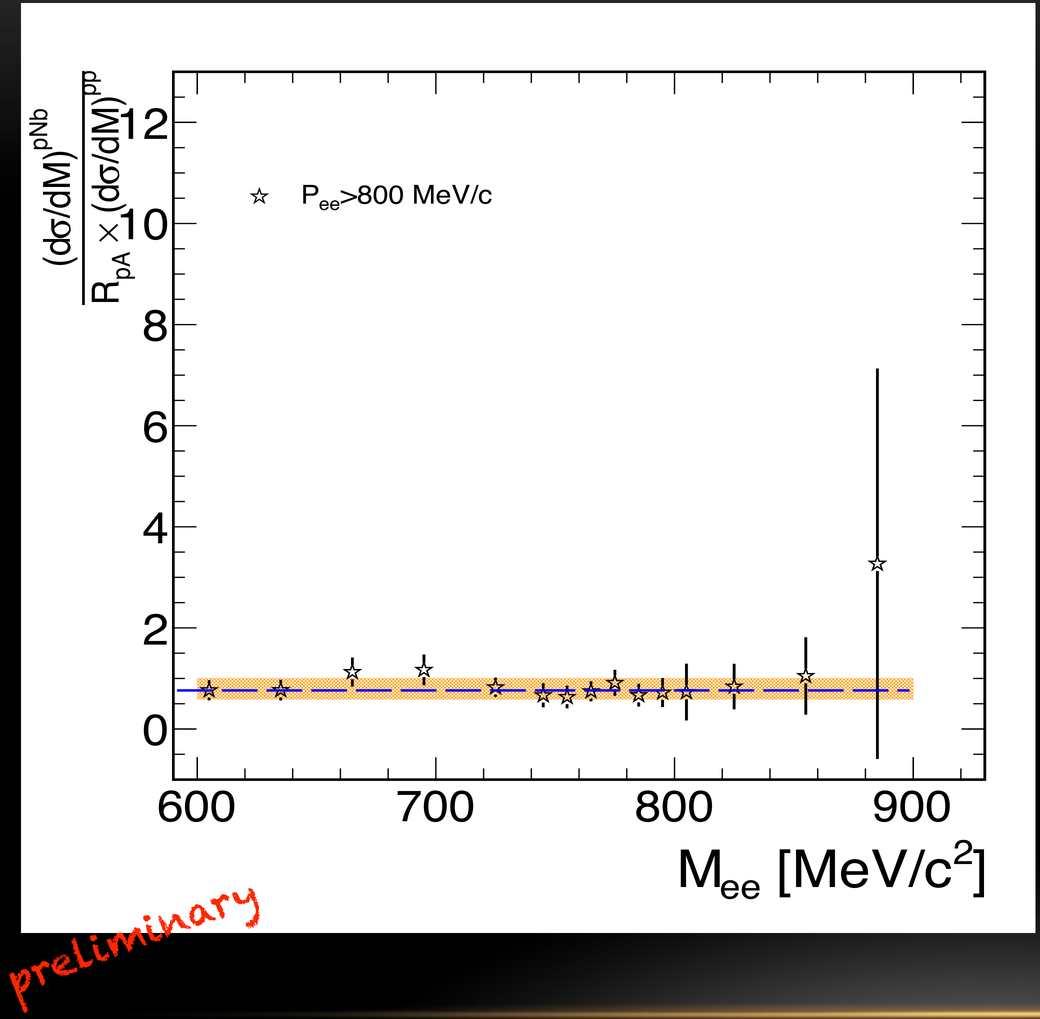
Still far above theoretical expectations: BR ≃ 5x10^{-9}

HADES: Phys.Lett. B715 (2012) 304-309

OMEGA IN COLD MATTER

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

Ratio of e^+e^- yield from pNb to pp

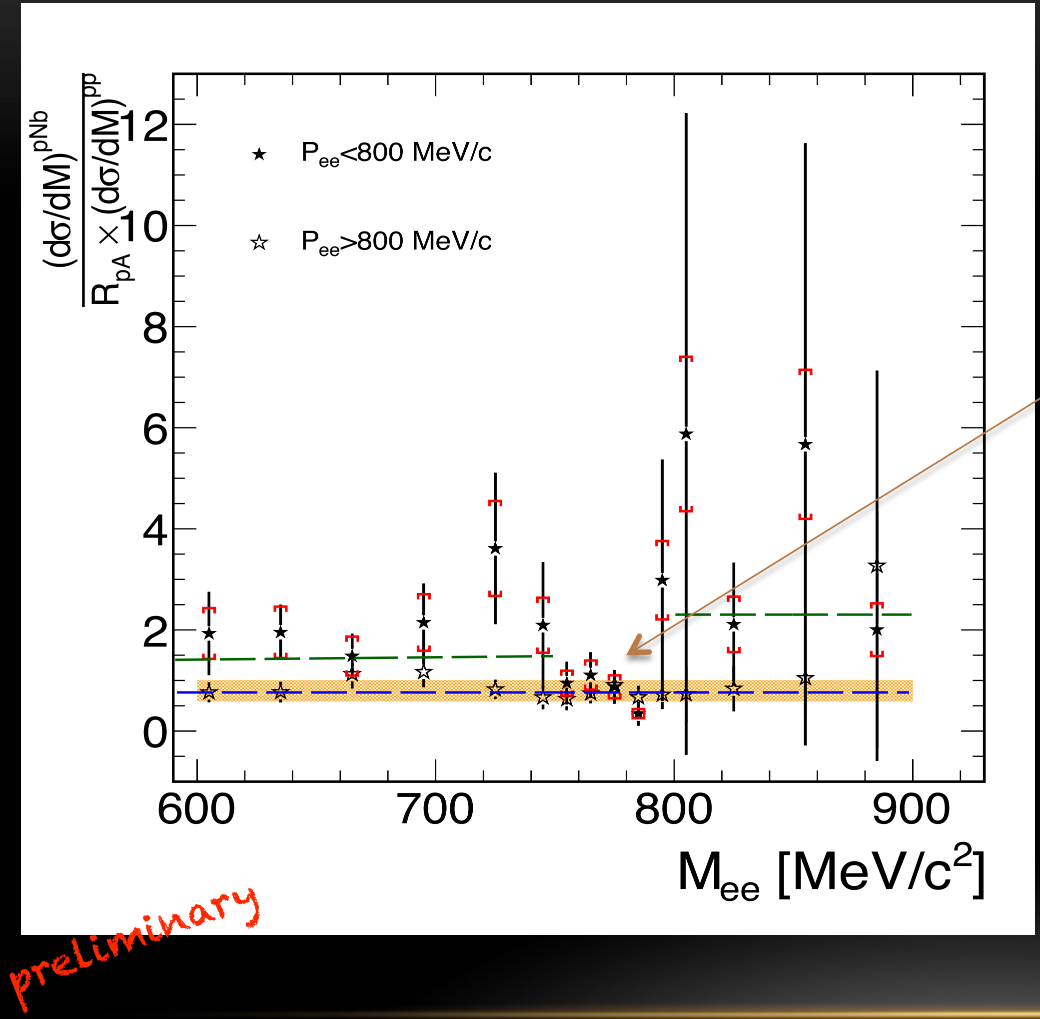


- High-momentum ω mesons "decouple" from the medium

OMEGA IN COLD MATTER

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

Ratio of e^+e^- yield from pNb to pp

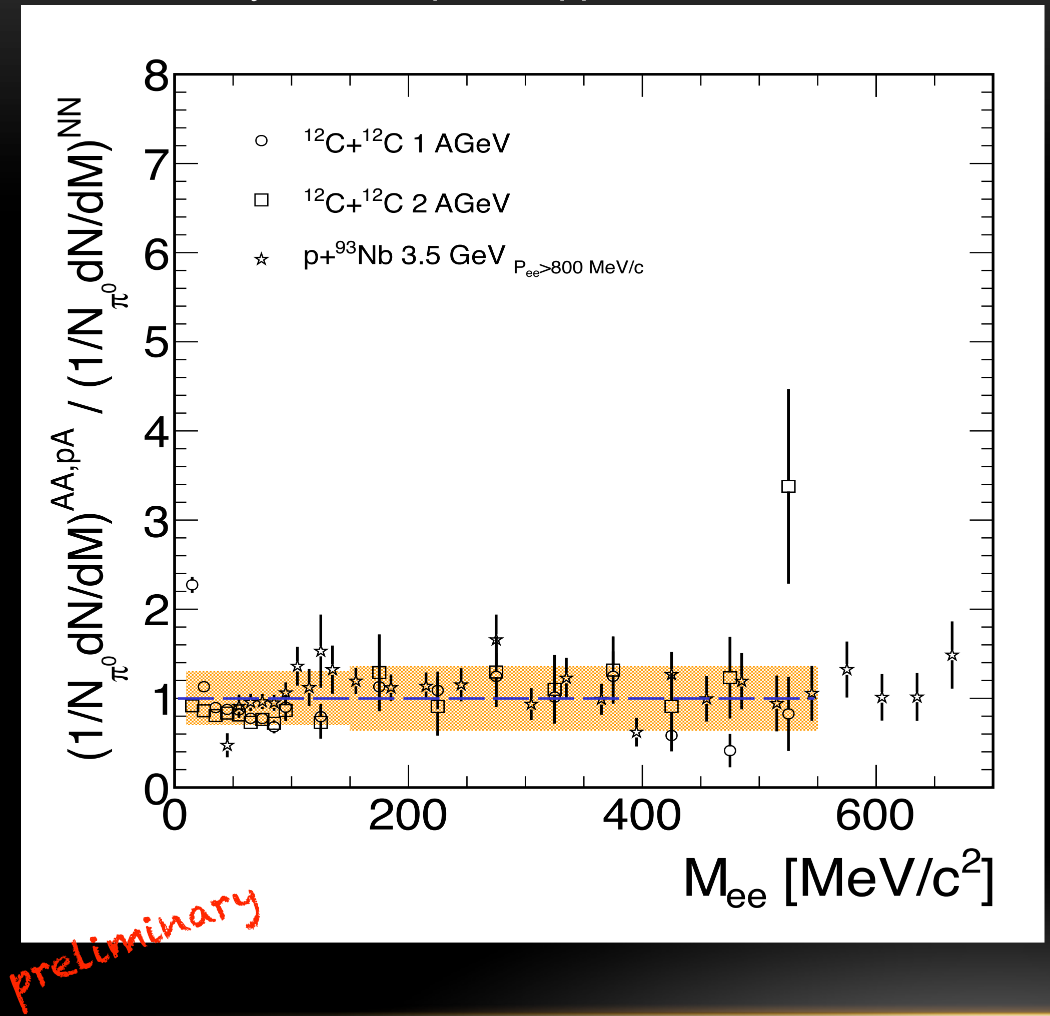


- High-momentum ω mesons "decouple" from the medium
- Reduced ω yield → strong absorption in the medium?
- Clear excess over p+p → role of the secondary ρ from N(1520), Δ(1700) → supported by transport GiBUU

FROM COLD TO
HOT AND DENSE MATTER
LOW-MASS EXCESS

SYSTEMATICS OF DILEPTON MEASUREMENTS WITH HADES

Ratio of e⁺e⁻ yield from pNb to pp

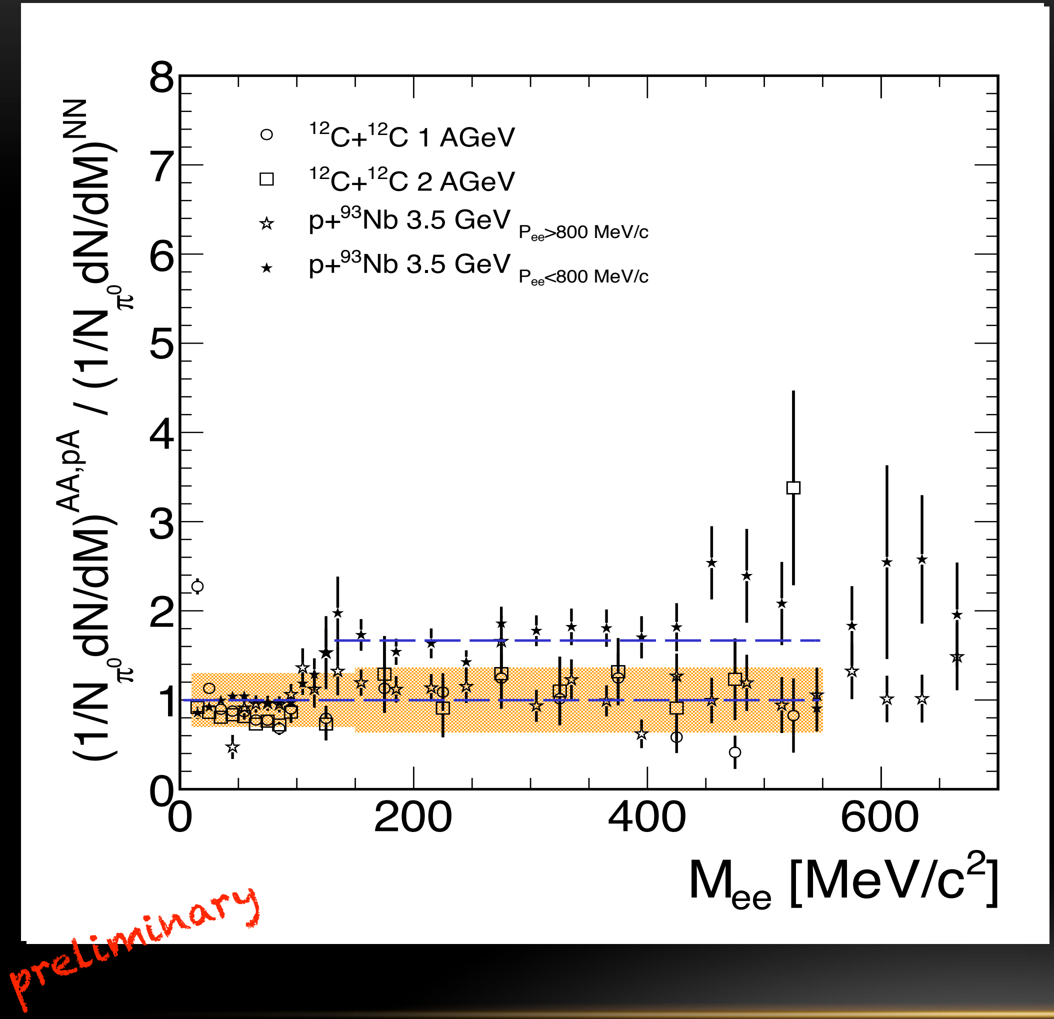


Reference spectra

- → Measurement of NN reference spectra (pn at 1.25 GeV, pp at 1.25, 2.2, 3.5 GeV)

SYSTEMATICS OF DILEPTON MEASUREMENTS WITH HADES

Ratio of e^+e^- yield from pNb to pp



Reference spectra

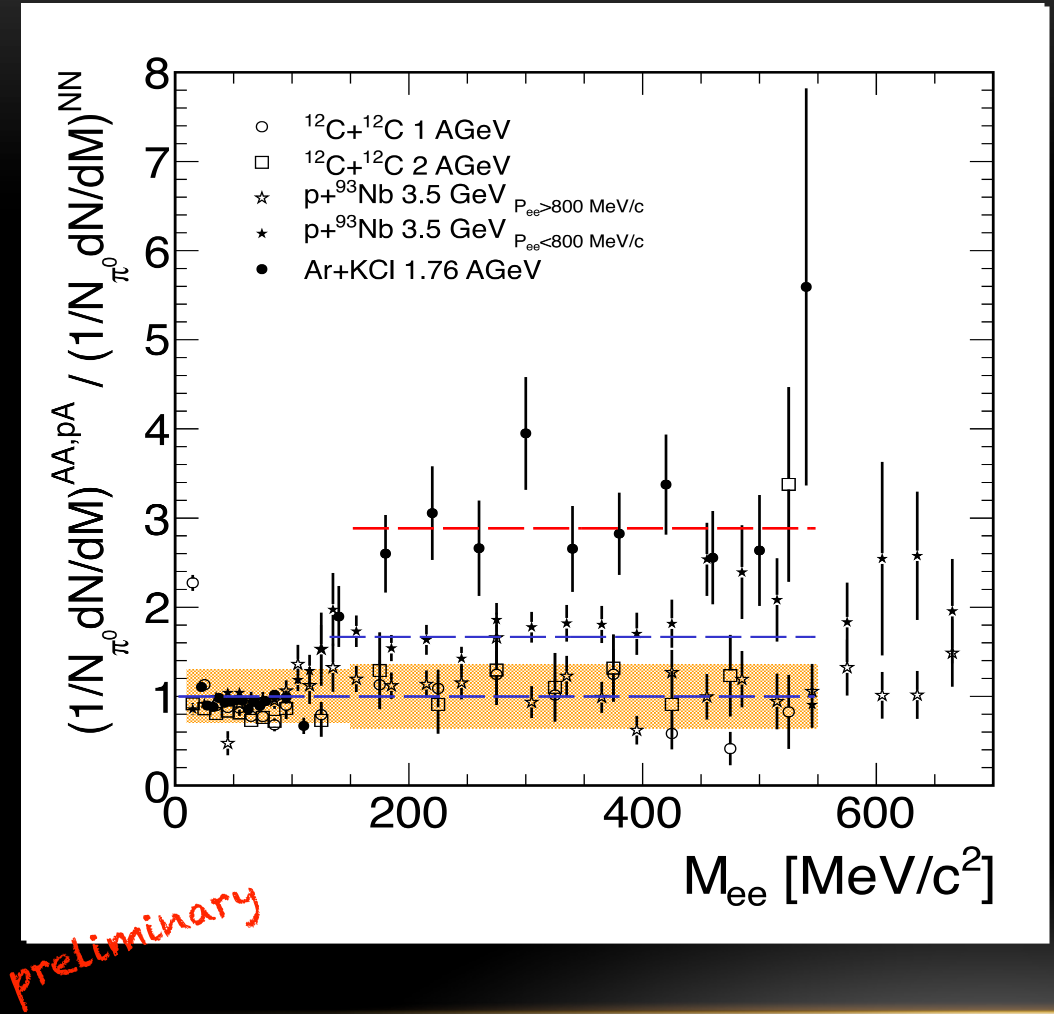
- → Measurement of NN reference spectra (pn at 1.25 GeV, pp at 1.25, 2.2, 3.5 GeV)

Cold nuclear matter

- → No differences observed for P_{ee} > 0.8 GeV/c
- → Additional e^+e^- yield for P_{ee} < 0.8 GeV/c (F = 1.7)

SYSTEMATICS OF DILEPTON MEASUREMENTS WITH HADES

Ratio of e^+e^- yield from pNb to pp



Reference spectra

- Measurement of NN reference spectra (pn at 1.25 GeV, pp at 1.25, 2.2, 3.5 GeV)

Cold nuclear matter

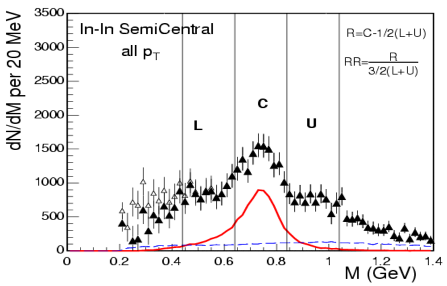
- No differences observed for P_{ee} > 0.8 GeV/c
- Additional e^+e^- yield for P_{ee} < 0.8 GeV/c (F = 1.7)

Hot and dense matter

- Excess yield scales with system size ~$A_{part}^{1.4}$
- Life time of the fireball?

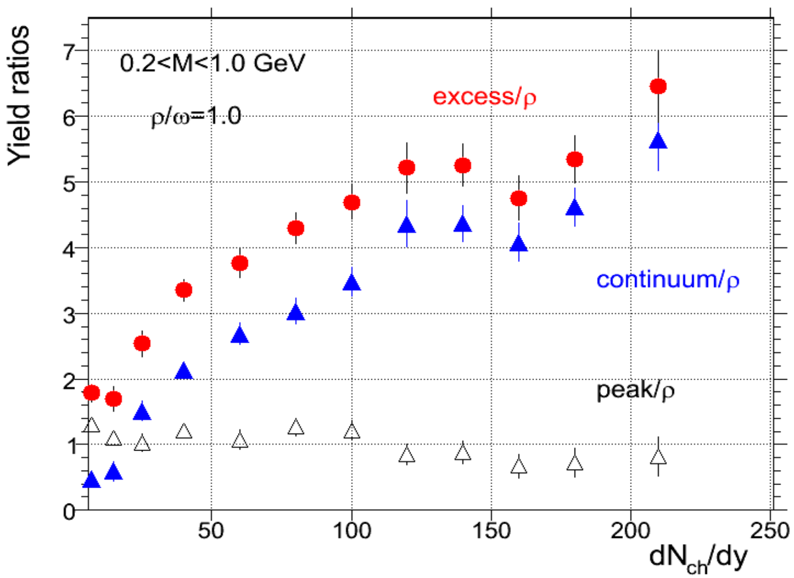
HADES “RESONANCE CLOCK”

Na60 data: EPJC 61 (2009) 711



“ρ clock”

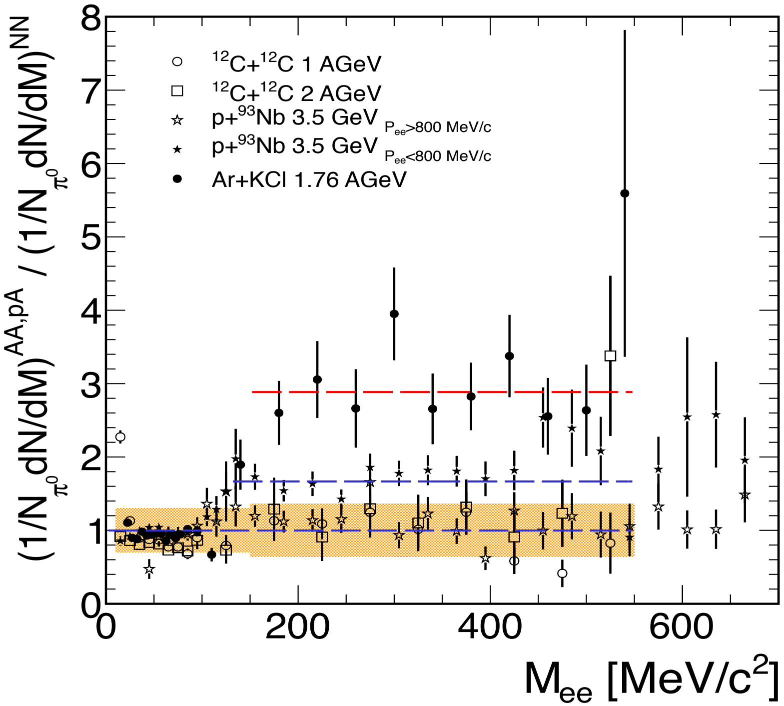
In+In 158A GeV



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

HADES: Phys.Rev.C84:014902,2011

“R clock”

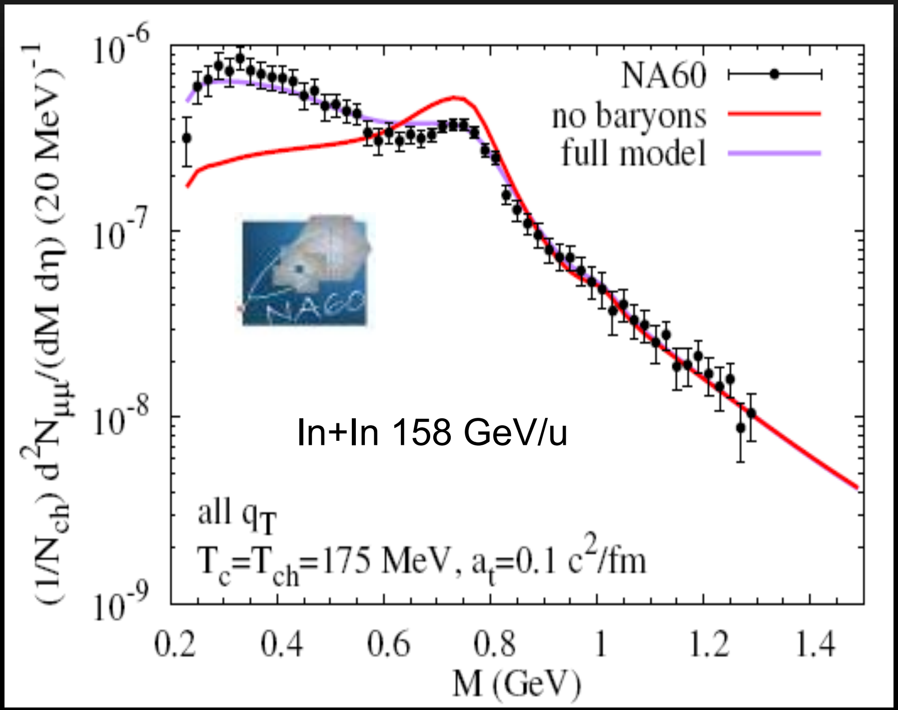


- p+Nb (A_{part}=2.7): F = 1.7
- Ar+KCl (A_{part}=38): F = 2.5 – 3
- Au+Au (*A_{part}=180): F = 8 – 10*

→ Δ/N* regeneration

ISOLATION OF EXCESS BY A COMPARISON WITH A MEASURED HADRONIC COCKTAIL

ACCEPTANCE-CORRECTED μ+μ− EXCESS SPECTRUM



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

- Isolation of excess by subtraction of measured decay cocktail (without ρ), based solely on local criteria for the major sources η, ω and ϕ

1. initial hard processes: Drell Yan
2. "core" ⇔ emission from thermal source [McLerran, Toimela 1985]

$$\frac{1}{q_T}\frac{dN^{(\text{thermal})}}{dM\,dq_T} = \int d^4x \int dy \int M d\varphi \frac{dN^{(\text{thermal})}}{d^4x d^4q}$$

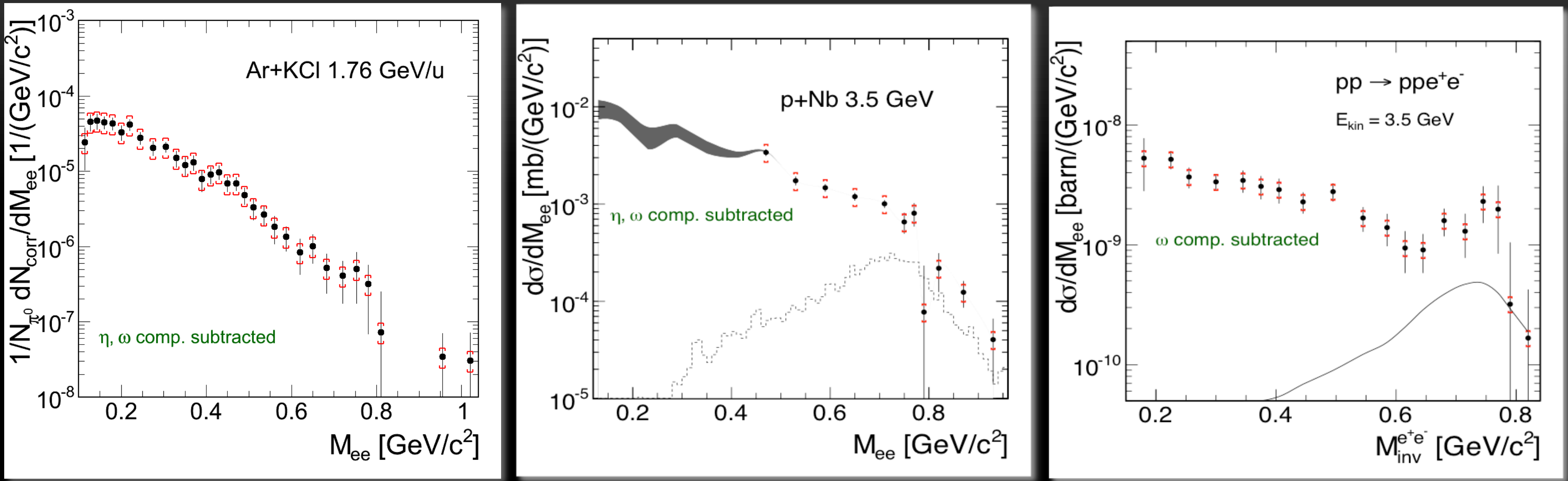
3. "corona" ⇔ emission from "primordial" mesons (jet-quenching)
4. ~~after thermal freeze-out ⇔ emission from "freeze-out" mesons~~

[Cooper, Frye 1975]

$$N^{(\text{fo})} = \int \frac{d^3q}{q_0} \int q_\mu d\sigma^\mu f_B(u_\mu q^\mu/T) \frac{\Gamma_{\text{meson}\to\ell^+\ell^-}}{\Gamma_{\text{meson}}}$$

- Strength of dilepton yield at low masses is due to coupling to baryons!

DIELECTRONS FROM HADES

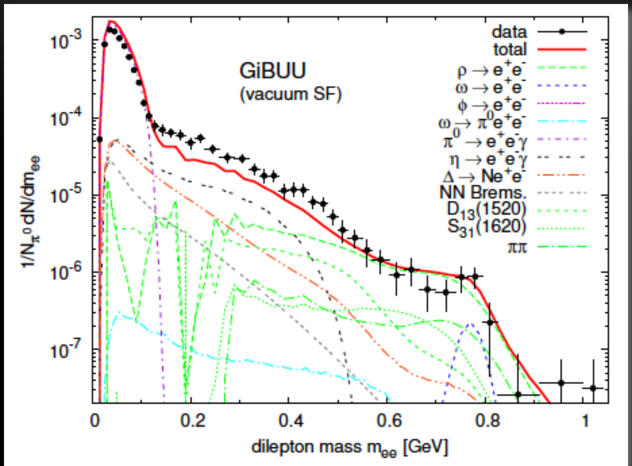


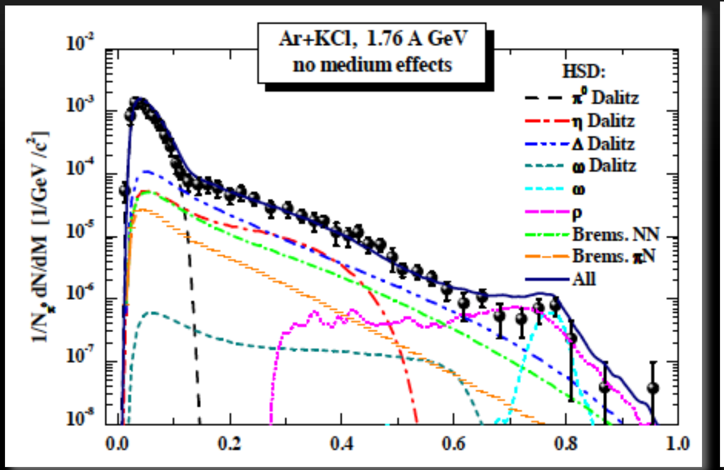
- Dilepton "excess" isolated by comparison to measured decay cocktail (same recipe as NA60)
- Systematic uncertainties due to accuracy on η multiplicities (-15%)

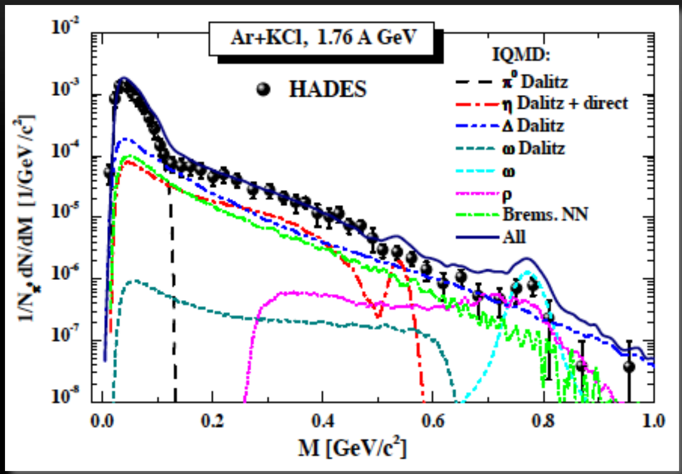
→ Coupling to baryon resonances: introduces strong deviations from Breit-Wigner shape (already in pp!)

VIRTUAL PHOTON EMISSION IN A+A COLLISIONS - TRANSPORT

J. Weil et al., Eur. Phys. J. A 48 (2012) 111







GiBUU with vac. SF misses data → room for medium modifications!

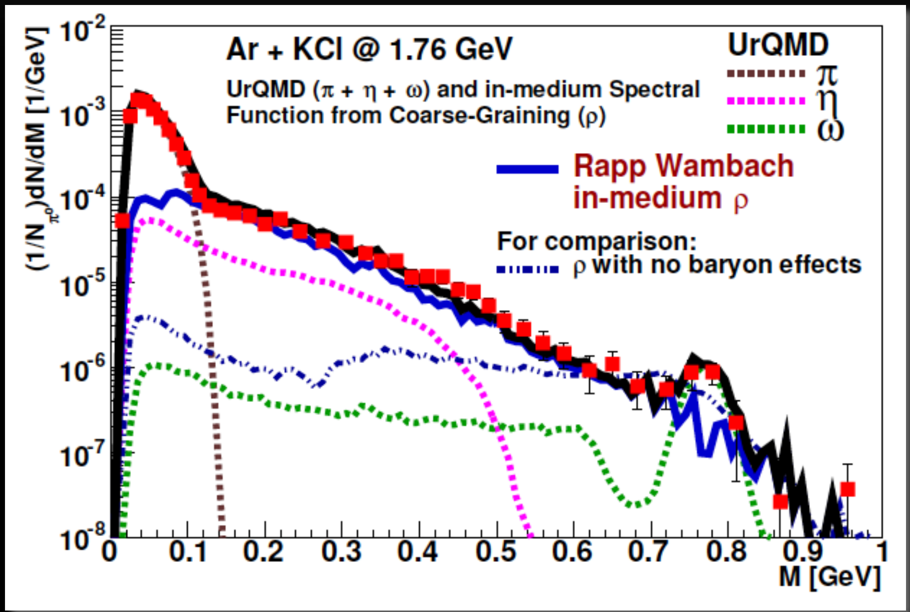
HSD & iQMD *Phys. Rev. C 87 (2013) 6, 064907*

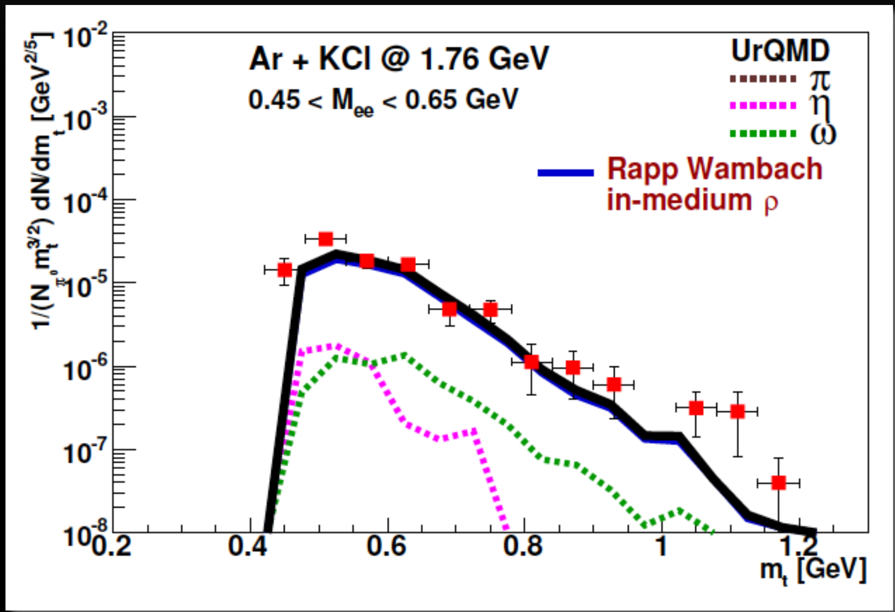
"…the dilepton enhancement observed in Fig. 32 (and hence also in the experimental spectra) is due to bremsstrahlung and due to the Δ dynamics in the medium. Both are not related to collective effects like the in-medium modifications of spectral functions but are a mere consequence of the presence of other nucleons in the nuclei". ? ? ?

IN-MEDIUM RHO FROM HADES

UrQMD-medium evolution + RW-QFT rates

S. Endres et al.

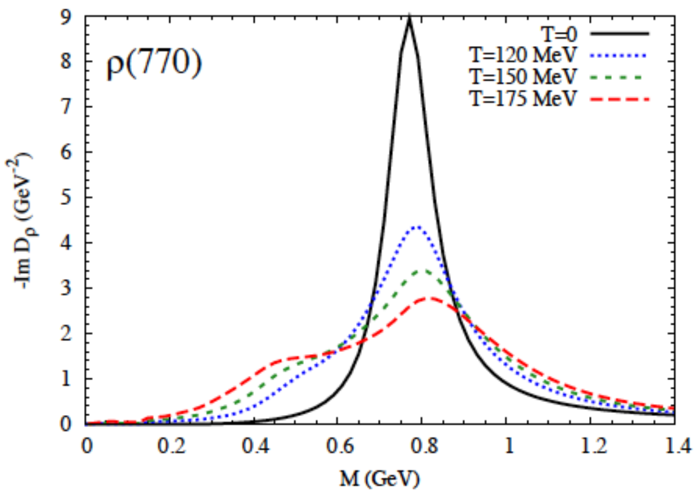




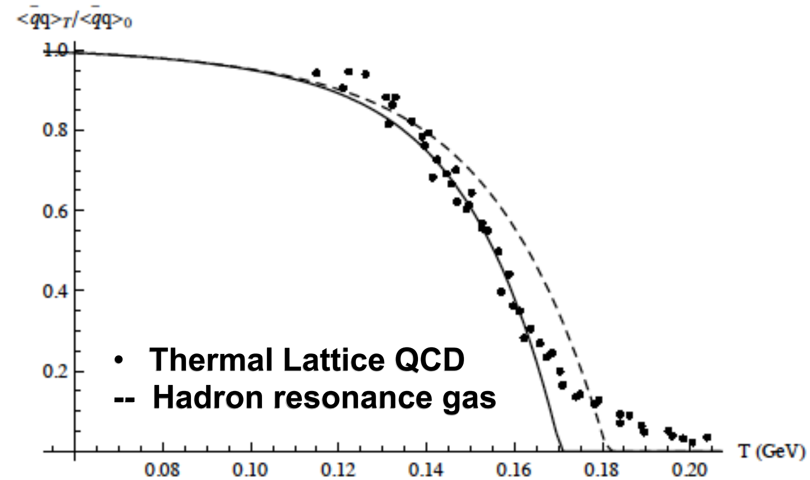
DILEPTONS, HADRONIC RESONANCES AND PHASE DIAGRAM OF MATTER

P. Hohler and R. Rapp, PLB 731 (2014) 103

In-medium ρ spectral function



Temperature dependence of the chiral quark condensate

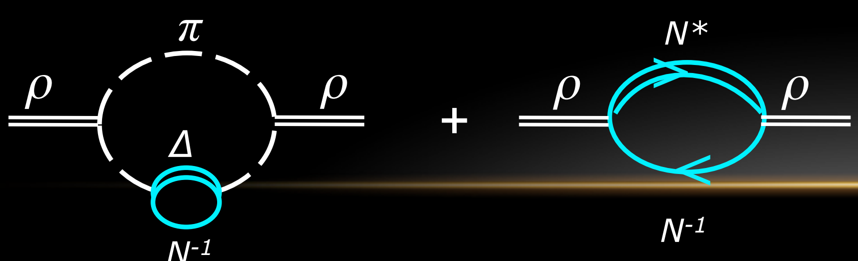


S. Borsanyi et al., JHEP 1009, 073 (2010)

effective hadronic theory

$$\frac{\langle \bar{q}q\rangle(T,\mu_B)}{\langle \bar{q}q\rangle_0} = 1 - \sum_h \frac{\varrho_h^s \Sigma_h}{m_\pi^2 f_\pi^2}$$

1. $\Sigma_h = m_q \langle h|q\bar{q}|h\rangle > 0$ contains *quark core + "pion cloud"*



2. Excitation of the vacuum (melting of condensate) matches spectral medium effects

”IF YOU ARE OUT TO DESCRIBE THE TRUTH, LEAVE ELEGANCE TO THE TAILOR”

A. EINSTEIN

PERSPECTIVES OF THE π BEAM EXPERIMENTS

FROM pp TO π^-p EXPERIMENTS

Dilepton emission in pp

- sensitivity to the coupling of vector mesons to baryonic resonances / time-like EM structure
- complementary information in hadronic channels
- useful constraints to study in-medium effects

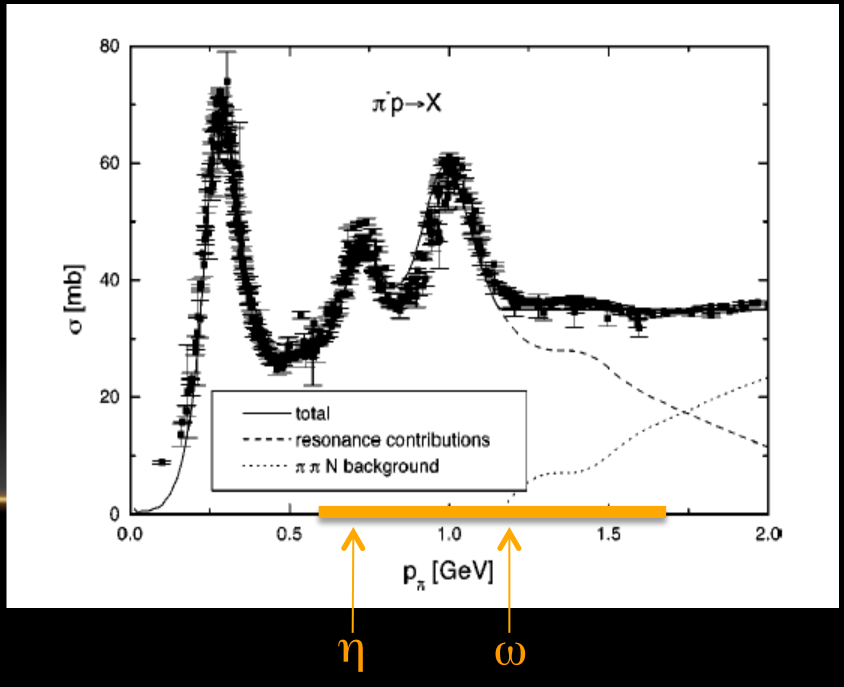
→ **Limitations:**

- uncertainties due to pp interaction
- many resonances contributing with broad mass distributions
- small acceptance for exclusive channels

$\pi^- p \rightarrow n e^+ e^-$ below ρ/ω production threshold

→ **Advantages:**

- interaction better known
- fixed mass of the resonance in s channel
- much larger acceptance for exclusive channels
  - electromagnetic $\pi^- p \rightarrow n e^+ e^-$
  - hadronic $\pi^- p \rightarrow p\pi^-$, $n\pi^+\pi^-$, $p\pi^0\pi^-$



PION BEAM RUN IN 2014

- πA experiments:
  - In-medium effects (strange and vector mesons)
- πp experiments
  - Resonance-Dalitz decays
  - Special interest to sub-threshold vector meson production

→ Crucial to control the interpretation of medium effects from SIS to LHC

→ Unique chance to study Time-Like electromagnetic structure of higher lying resonances

→ Successful test of the pion tracker and beam optics in May 2014!

→ First beam in July, p_π = 1.7 GeV
→ August-September, p_π = 0.69 GeV

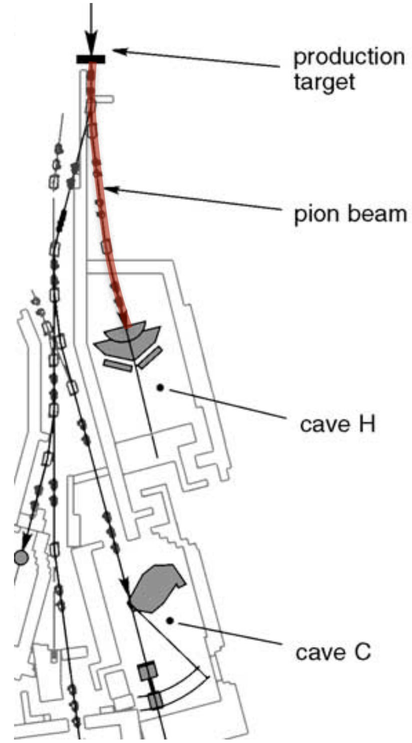
Primary beam:
10^{11} N (2A GeV) /spill

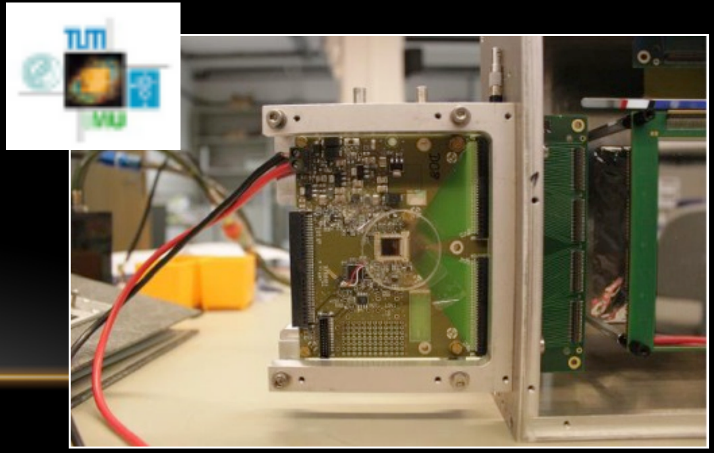
SIS fast ramping

Spill: 4s cycle

Stable run for 3 weeks!

Secondary π beam:
- Intensity I=10^6 π^-/s
- Momentum: 0.6 < p < 1.5 GeV/c



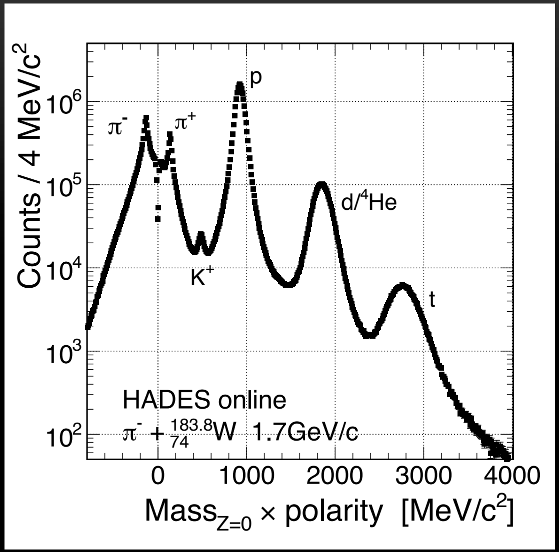


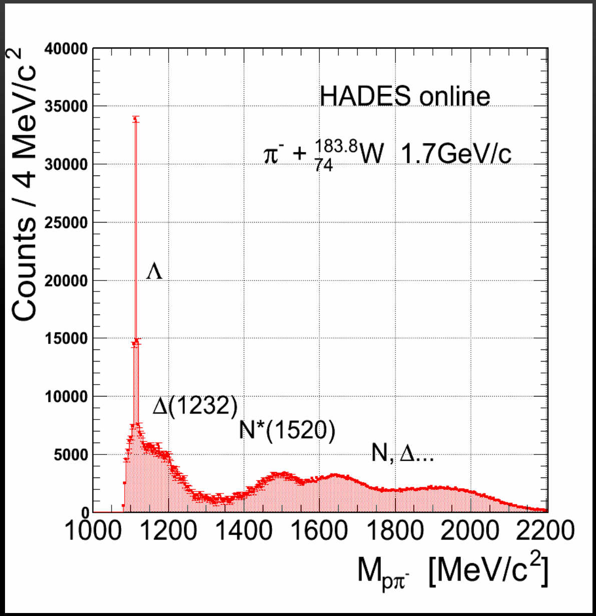
ONLINE SPECTRA FROM JULY

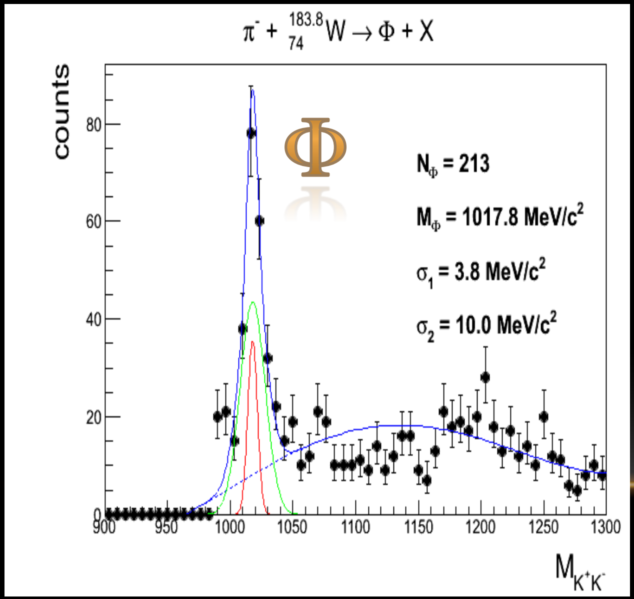
Measurement combined with

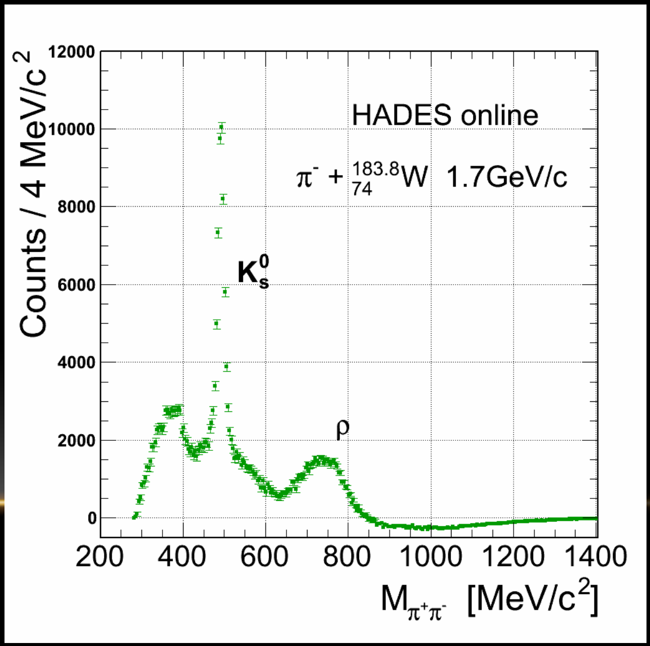
machine developments

for SIS100









THE HADES COLLABORATION

- Catania, Italy
- Coimbra, Portugal
- Cracow, Poland
- GSI Damstadt, Germany
- TU Darmstadt, Germany
- Dresden, Germany
- Dubna, Russia
- Frankfurt, Germany
- Giessen, Germany
- Lisboa, Portugal
- München, Germany
- Milano, Italy
- Moscow, Russia
- Nicosia, Cyprus
- Orsay, France
- Rez, Czech Rep.
- Santiago de Compostela, Spain

18 institution partners
~100 collaborators

SUMMARY

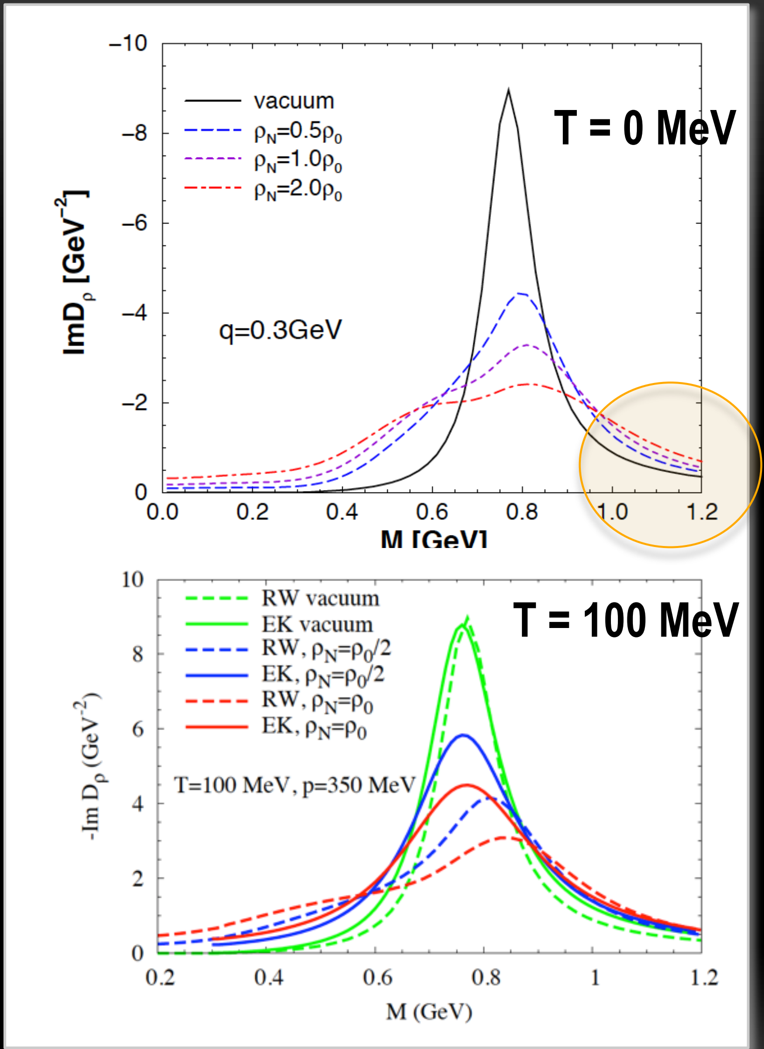
HADES provides a high-quality data on dilepton emission from A+A and elementary collisions, including exclusive analysis.

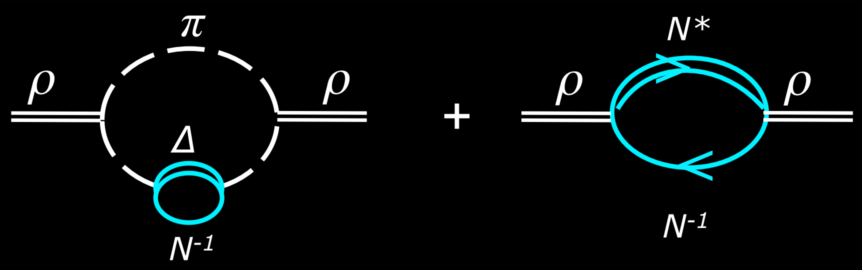
- Unique possibility of characterizing properties of baryon rich matter with rare probes:
    - Contributions from the dense/early phase a quite featureless → strong broadening of in-medium states!(?)
    - *Interesting observations in strangeness production*

- Urgent need of pion induced reactions
    - Elementary reactions are very important to control the interpretation of medium effects (lesson from HADES dilepton experimental program)
    - Unique chance to study time-like electromagnetic structure of higher lying resonances/coupling to ρ/ω mesons
    - GSI pion beam is unique in world at present to provide these data.

THANK YOU!

IN-MEDIUM VECTOR MESON MODIFICATIONS





In-medium spectra function depends on ρNN* coupling!

Main contributions: N(1520), N(1720), Δ(1910)

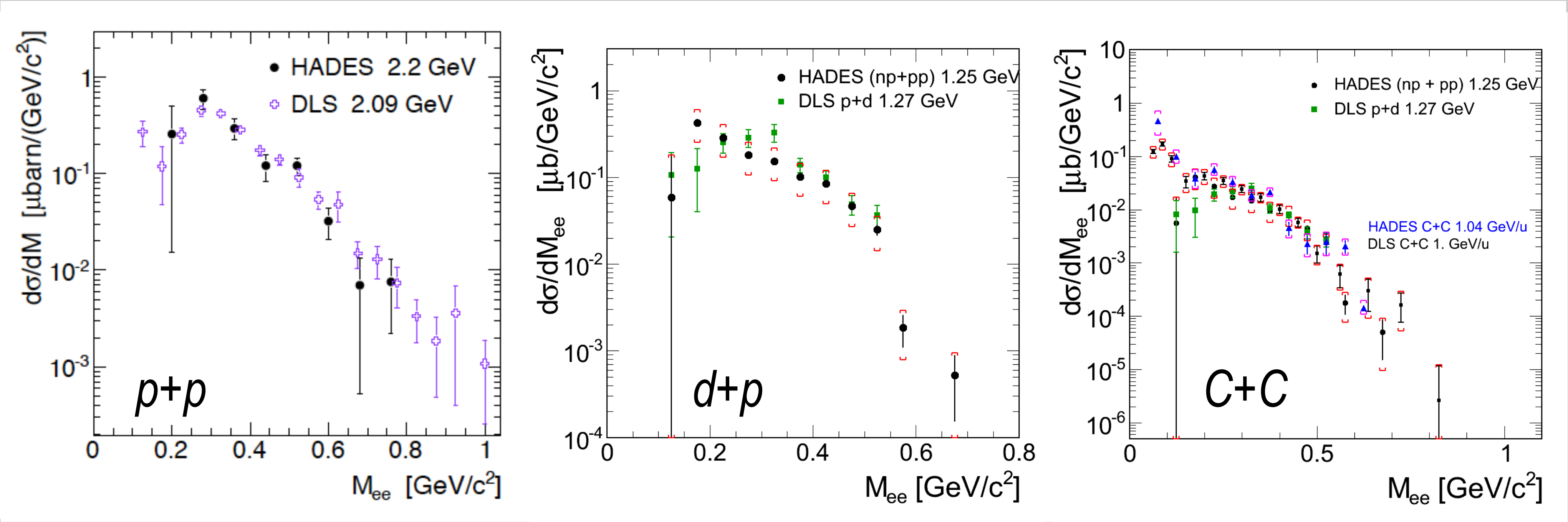
*R. Rapp, J. Wambach, Eur. Phys. J. A **6** (1999) 415*
V.L. Eletsky, M. Belkacem, P.J. Ellis, J.I. Kapusta, Phys. Rev. C 64 (2001) 035202

IS THE DLS DATA WRONG?

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

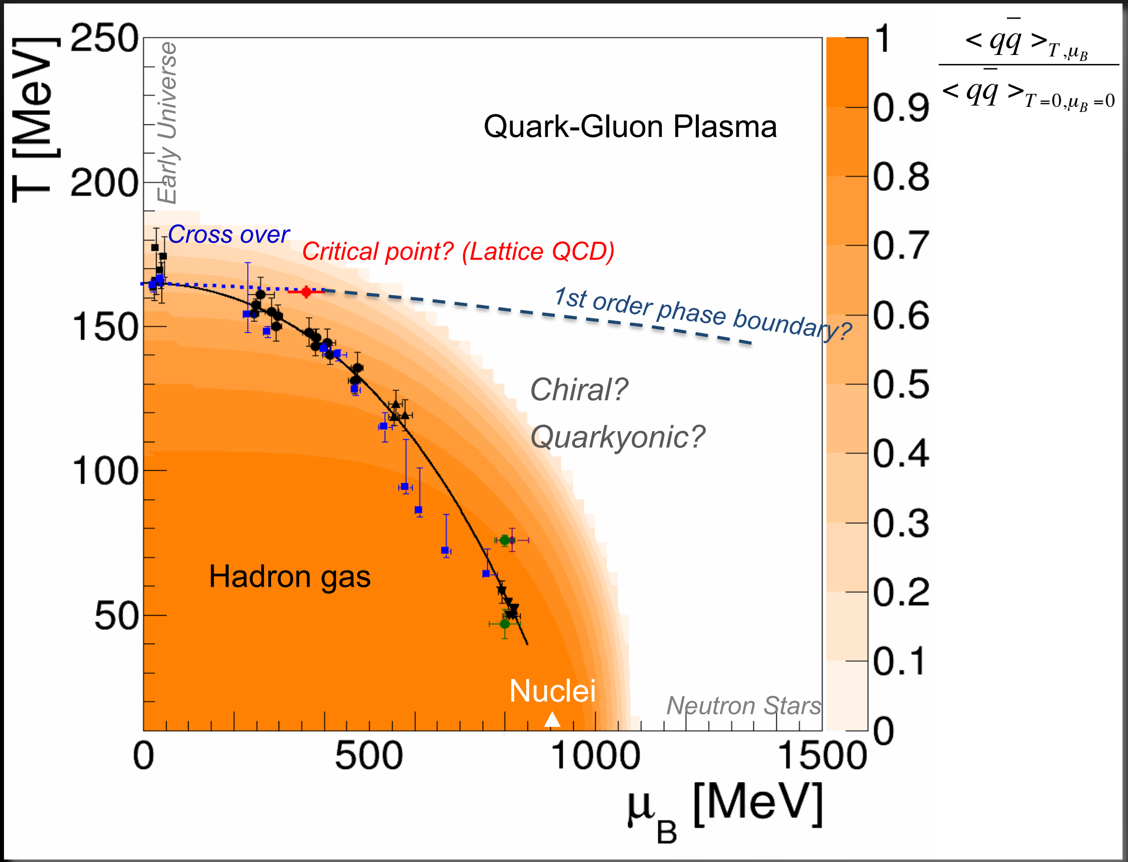
HADES data:
PLB 663 (2008) 43,
arXiv:1203.2549, PLB 690 (2010) 118

HADES data in the acceptance of DLS, compared to DLS data.



HADES and DLS data agree !

SEARCHING FOR THE LANDMARKS OF THE PHASE DIAGRAM OF MATTER



SIS18 (1 – 2A GeV):
moderate densities but long lifetime

- T < 80 MeV
- $\rho_{max}/\rho_0 \cong 1 - 3$, $\tau > 15$ fm/c
- <qq> substantially depleted
- $N_\pi/A_{part} \approx 10\%$

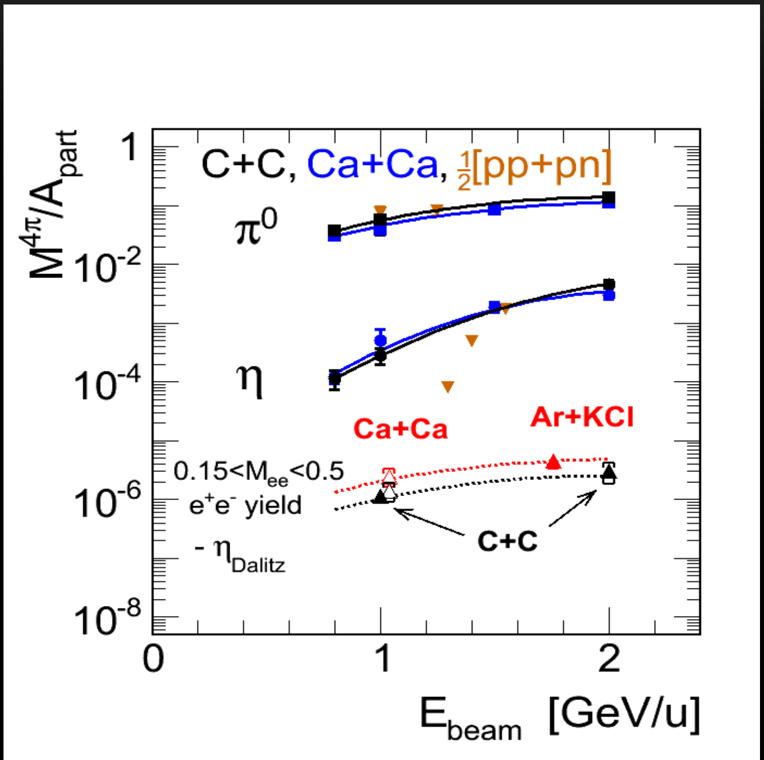
SIS18 (proton beam at 3.5 GeV):

- Reference for FAIIR

Andronic et al., Nucl. Phys. A 837 (2010) 65
J. Cleymans and K. Redlich, Phys. Rev. C 60 (1999) 054908
Condensate: B.J. Schaefer and J. Wambach
HADES data (green): M. Lorenz et al. [HADES Collaboration], Nucl. Phys. A (2014) QM14
FOPI data (lila): X. Lopez et al. [FOPI Collaboration], Phys. Rev. C 76 (2007) 052203

“EXCESS” VS. BEAM ENERGY AND SYSTEM SIZE

Yield/A_{part}



- baryonic contrib. in Ar+KCl >> C+C
- scales with E_{beam} like π production
- scales with ≈ <Apart>$^{1.4}$

π^0 and η from TAPS ■ (min. bias)

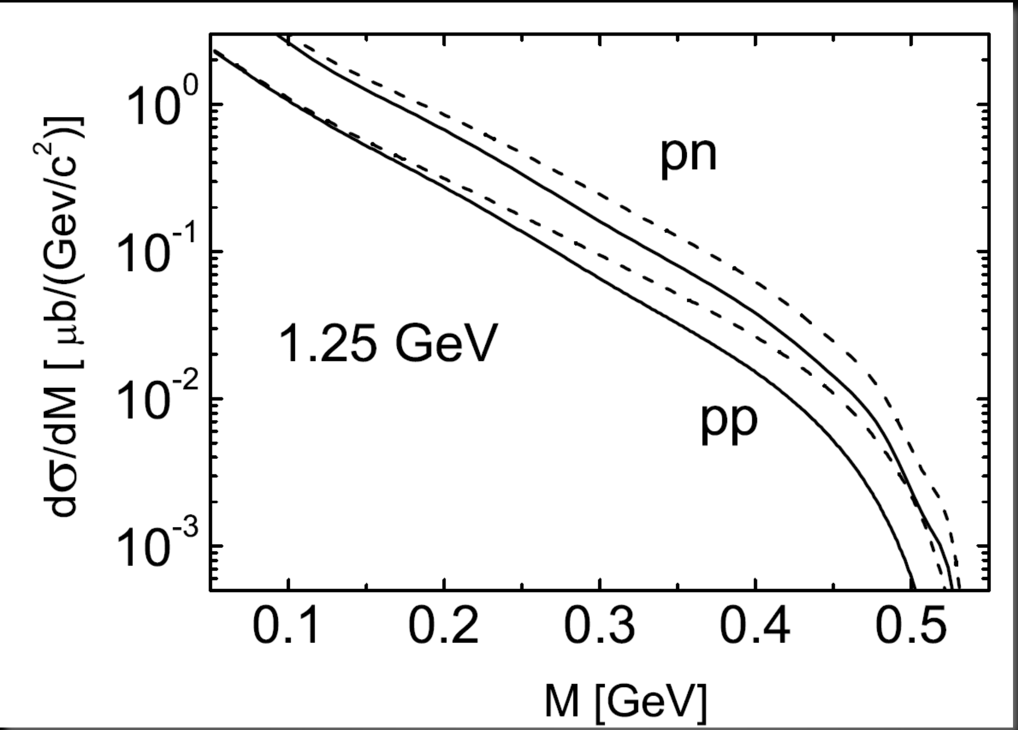
e^+e^- „excess” pairs:

HADES ▲ ▲ ▲ (LVL1)

DLS △ (min. bias)

THE INTERFERENCE EFFECS

M_{inv} distribution of e^+e^- in pp and pn collisions as a coherent sum (solid lines) vs. an incoherent summation (dashed lines)



L. Kaptari et al. arXiv:0903.2466v1 [nucl-th]

The interference effects become significant at higher values of the di-electron invariant mass and reduce the cross section by a factor of about 2 − 2.5!