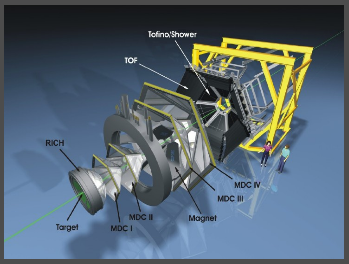
Investigating cold nuclear matter with virtual photons

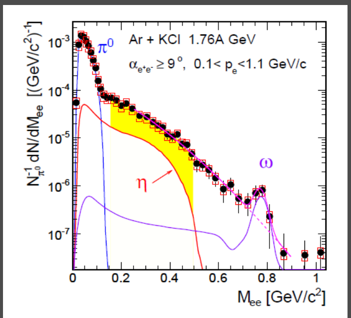
Manuel Lorenz
for the HADES collaboration

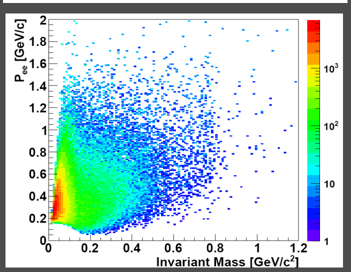
Meson 2012,
Krakow

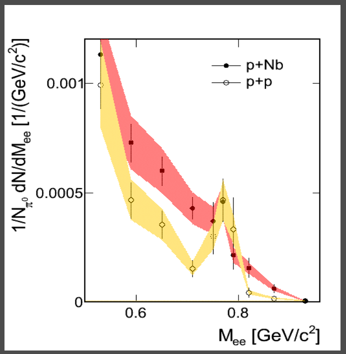
Outline

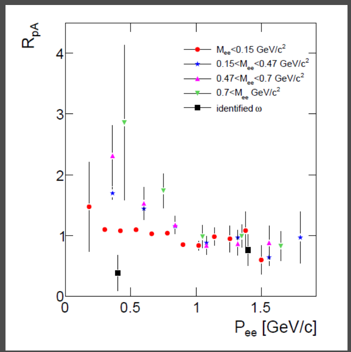
- **Introduction**
  - Experimental access to medium modications
  - The HADES spectrometer
- **Dilepton radiation**
  - State of the art modeling of baryonic contributions in elementary reactions
  - Nuclear modifcation in cold nuclear matter
- **Summary and outlook**





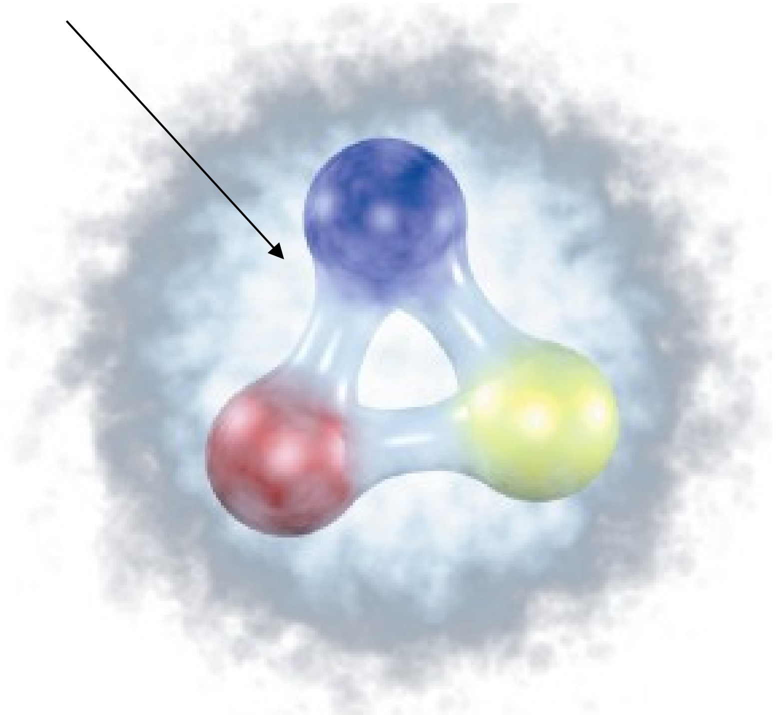






The origin of mass

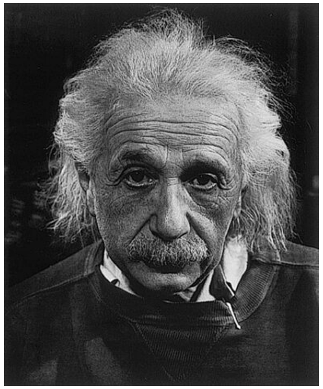
Distorted vacuum:
No color neutrality



$M >> \sum m_i$

$\Delta x \Delta p \geq \hbar$

Localization “costs” energy!



$E^2=(pc)^2+(mc^2)^2$

Dynamical generation of mass

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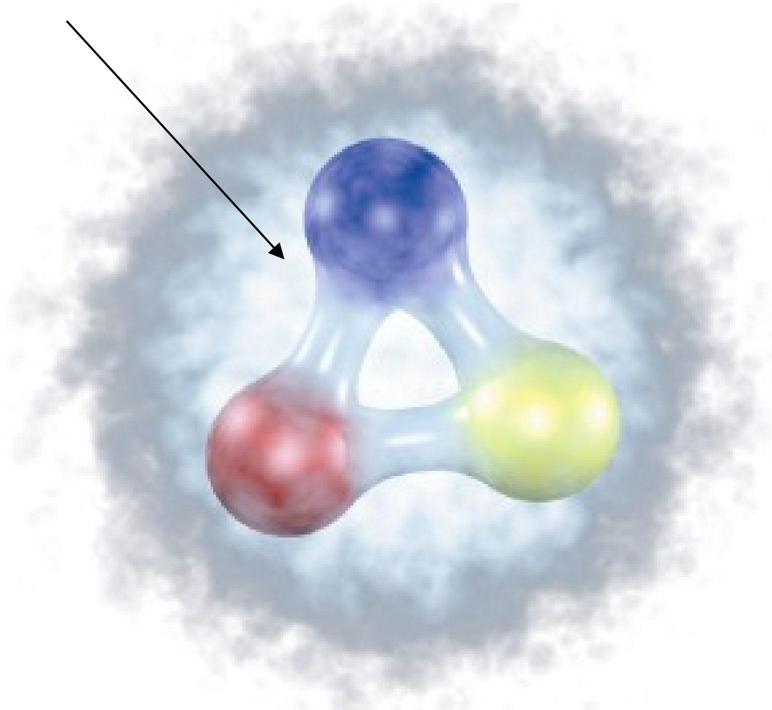

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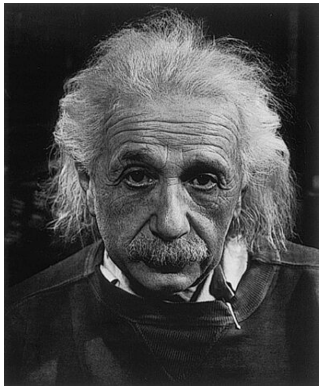

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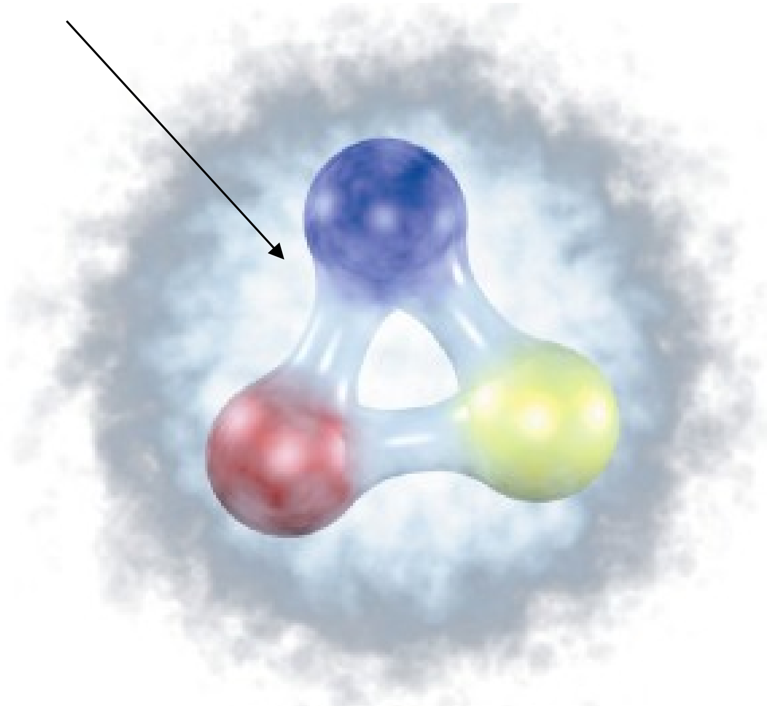

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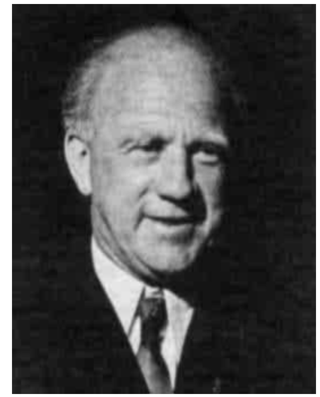

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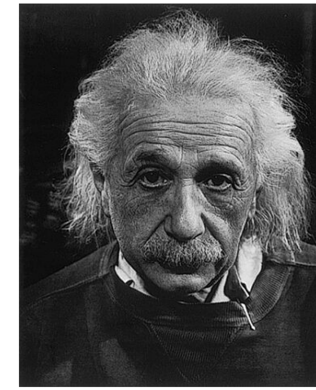

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Dynamical generation of mass

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The QCD vacuum is not empty but rather filled with condensates which must be displaced by particles and are related to particle properties:

Change vacuum, change particle properties!

Hadronic models

Chiral condensates can only be related to the integral over hadronic spectral functions by QCD sum rules: → spectral function constrained but not determined

Hadronic models needed to predict hadron properties inside the medium

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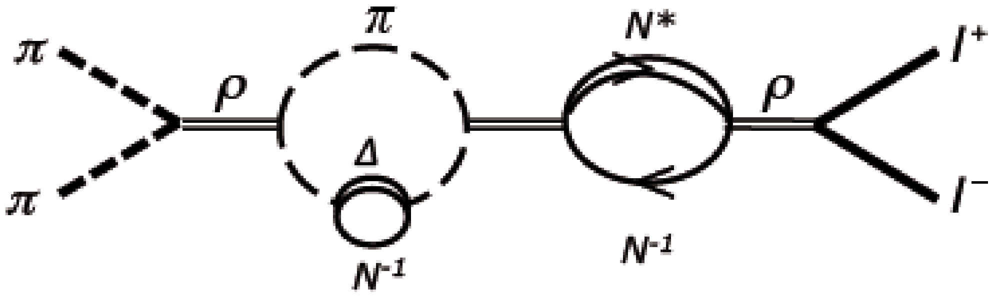
Additional contributions to particle self energy by coupling to resonances inside the medium:



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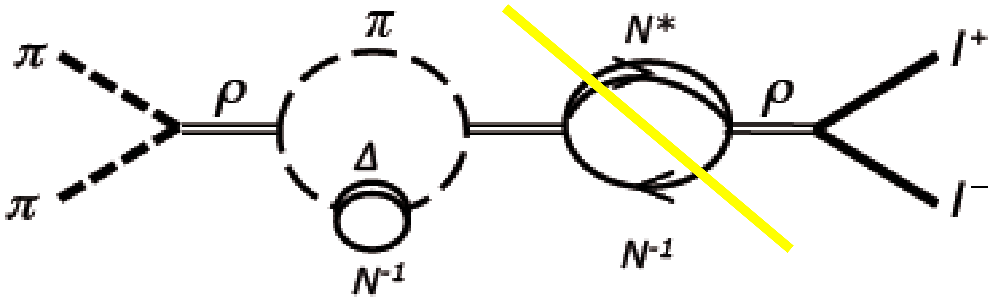
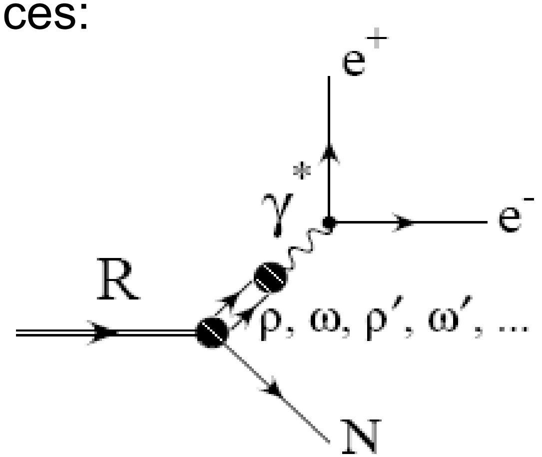


Note the similarity to Dalitz decays of baryonic resonances:



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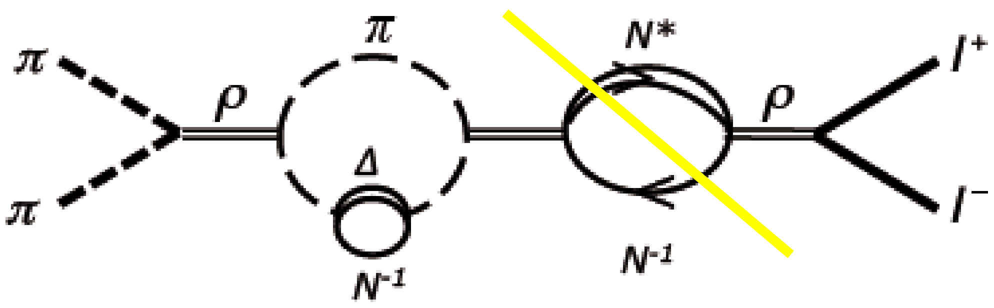
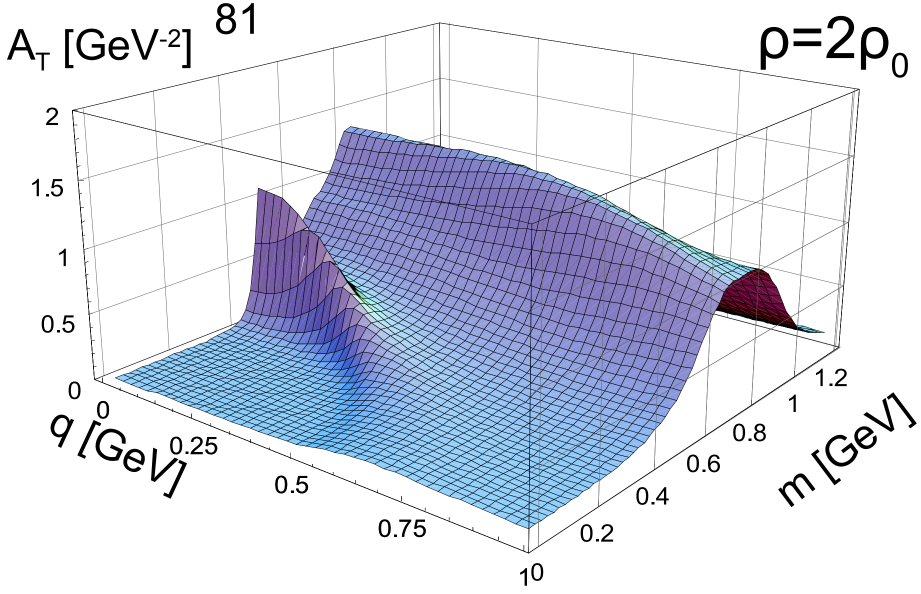


M. Post et al., NPA 741 (2004) 81



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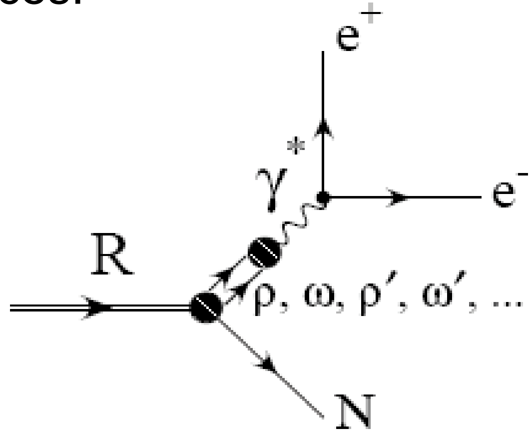
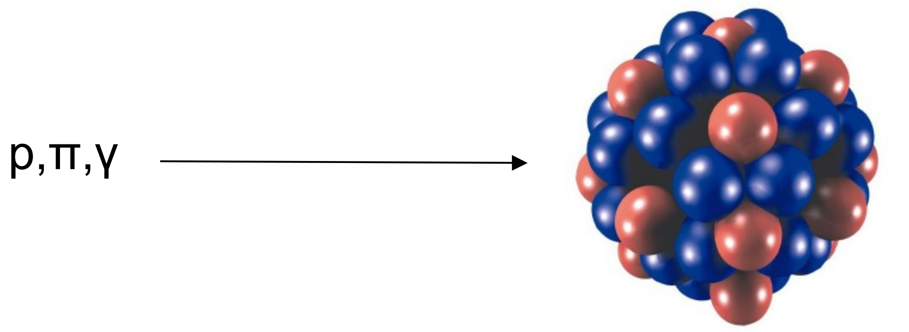


Effects restricted to momenta smaller 0.8 GeV
→ ensure acceptance

Experimental access

Distort the vacuum



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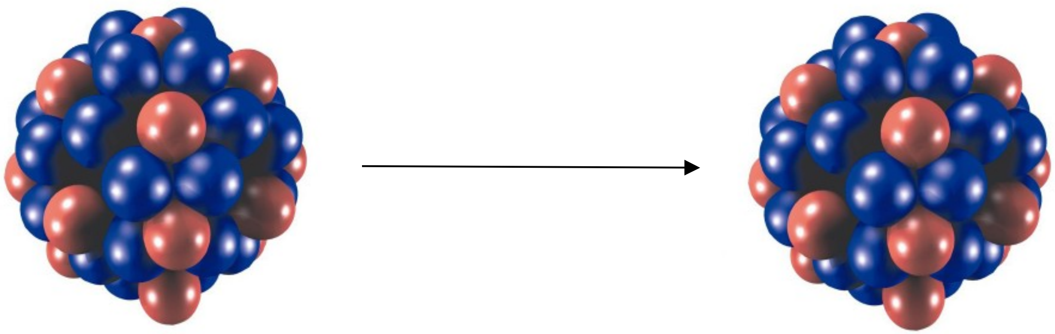
Distort the vacuum



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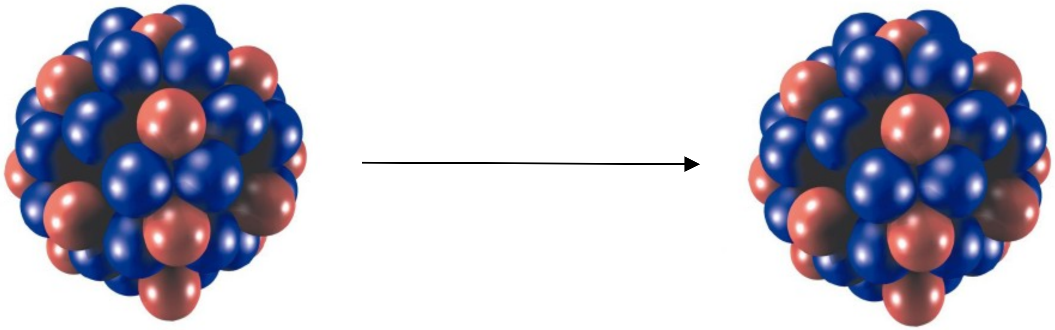

Stronger effects in HIC
More controlled conditions in cold nuclear matter, no time evolution of the density

Observable:
- **Direct line shape measurements: undistorted** information needed (dileptons)
  Short lived in order to enhance the fraction of decays inside the medium (ρ,ω)

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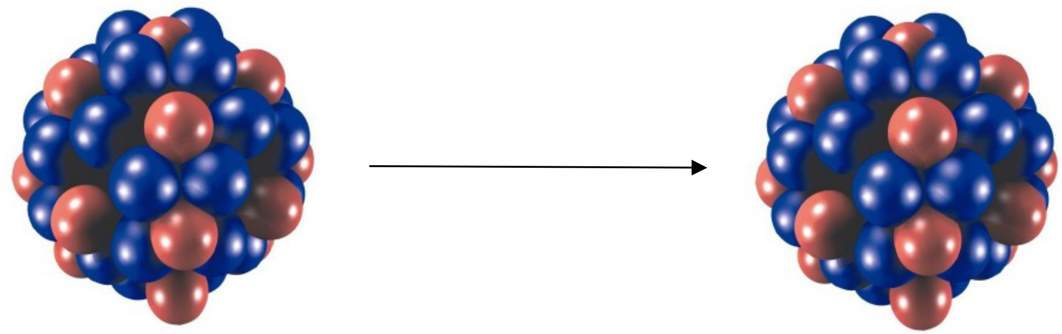

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- **Direct line shape measurements: undistorted** information needed (dileptons)
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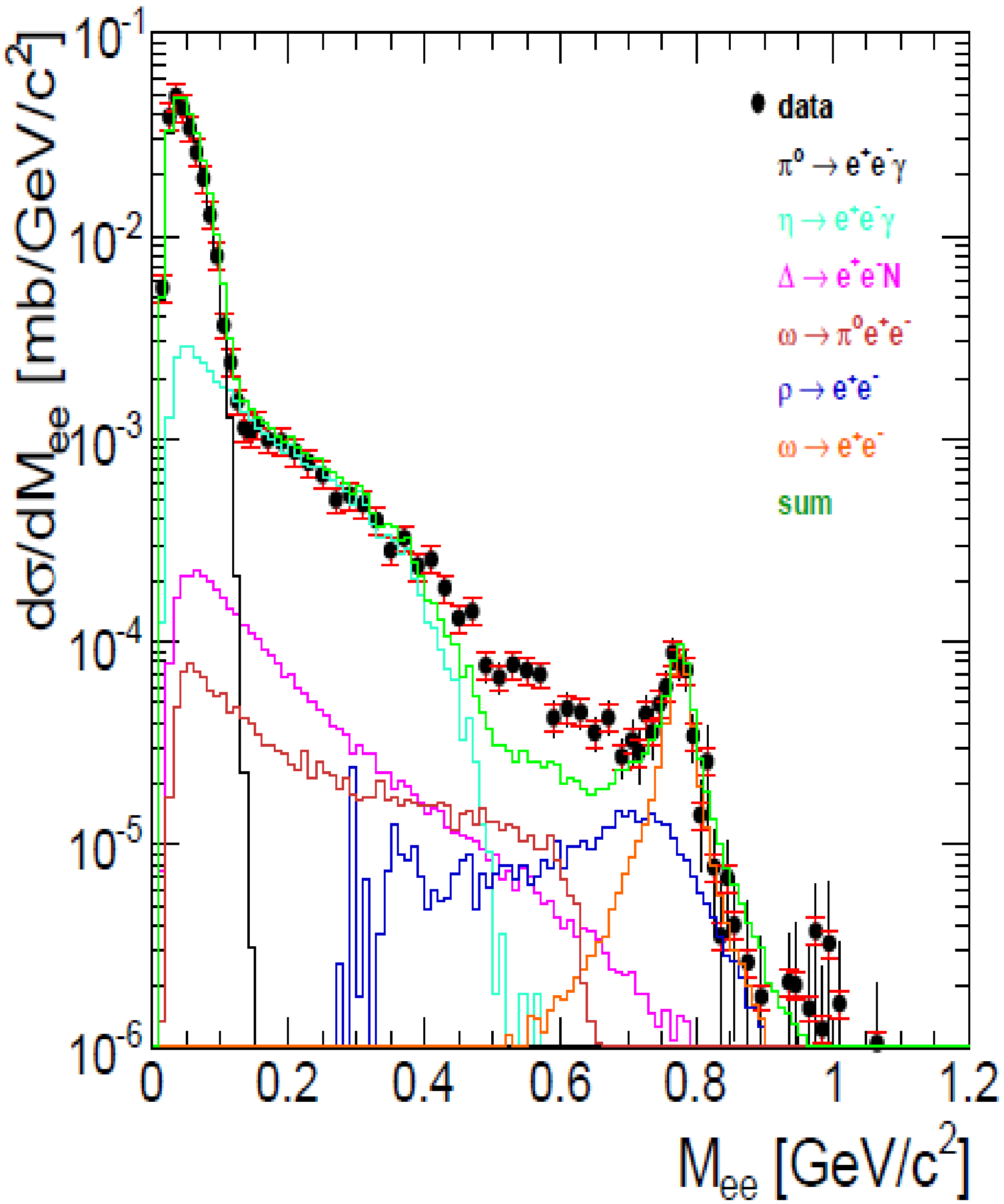
Cold nuclear matter:

- Partial decay branch might be suppressed by collisional broadening:

$$N_{e^+e^-} \propto \Gamma_{e^+e^-}\tau_{meson} \propto \frac{\Gamma_{e^+e^-}}{\Gamma_{tot}} \qquad \Gamma_{tot} = \Gamma_{vac} + \Gamma_{coll}$$

→ **nuclear suppression and line shape modifications are two aspects of medium modification!**

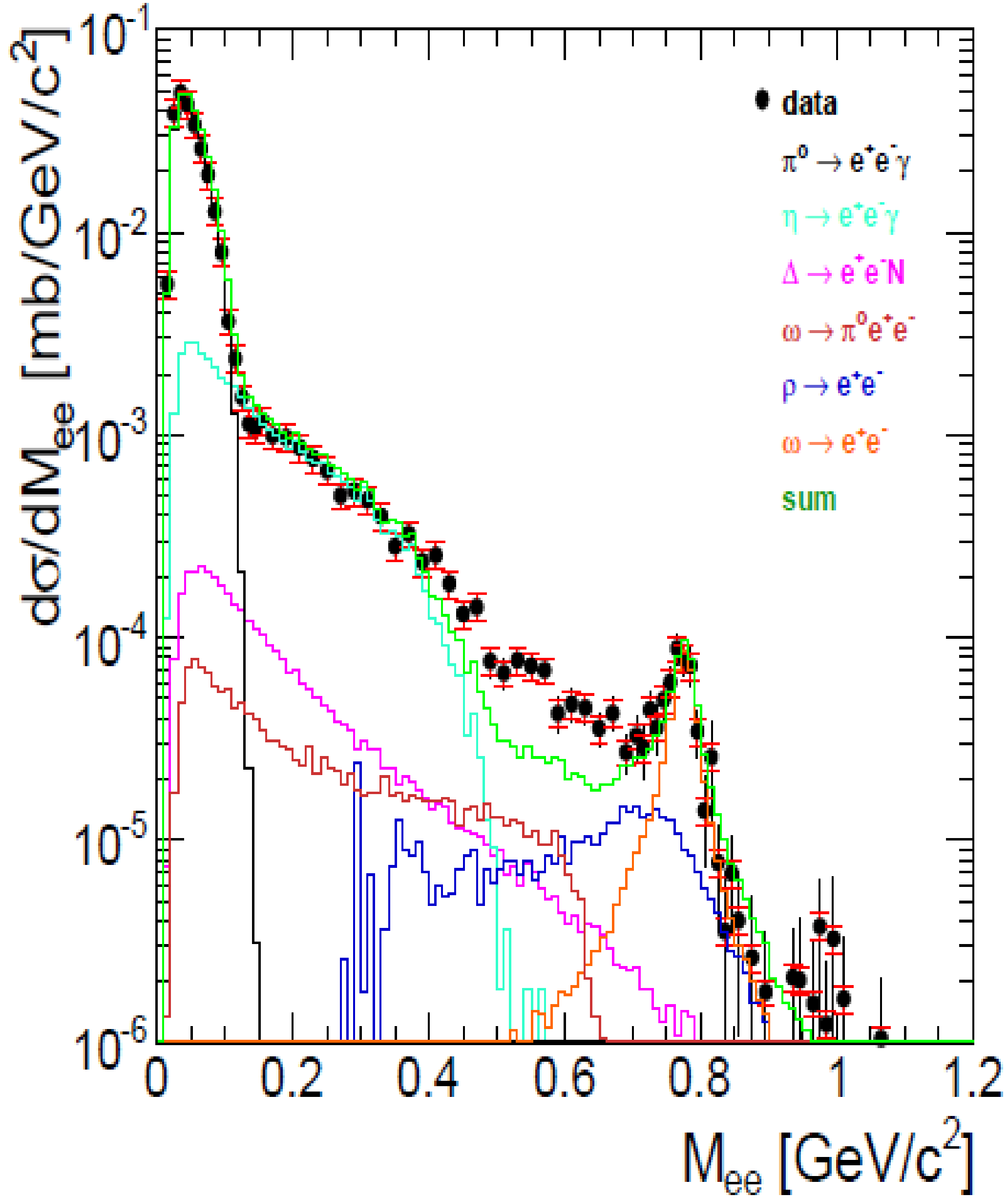
Experimental access



- dilepton spectra:
several overlapping contributions

- **combinatorial background**
Achieved precision of signal 10%
S/B =0.1 accuracy of background 1%
S/B =0.01 accuracy of background 0.1%

Experimental access



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Achieved precision of signal 10%
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Accurate and systematic extraction of different contributions in p+p, p+A and A+A collisions needed in order to make solid statements about medium modifications of the different contributions!

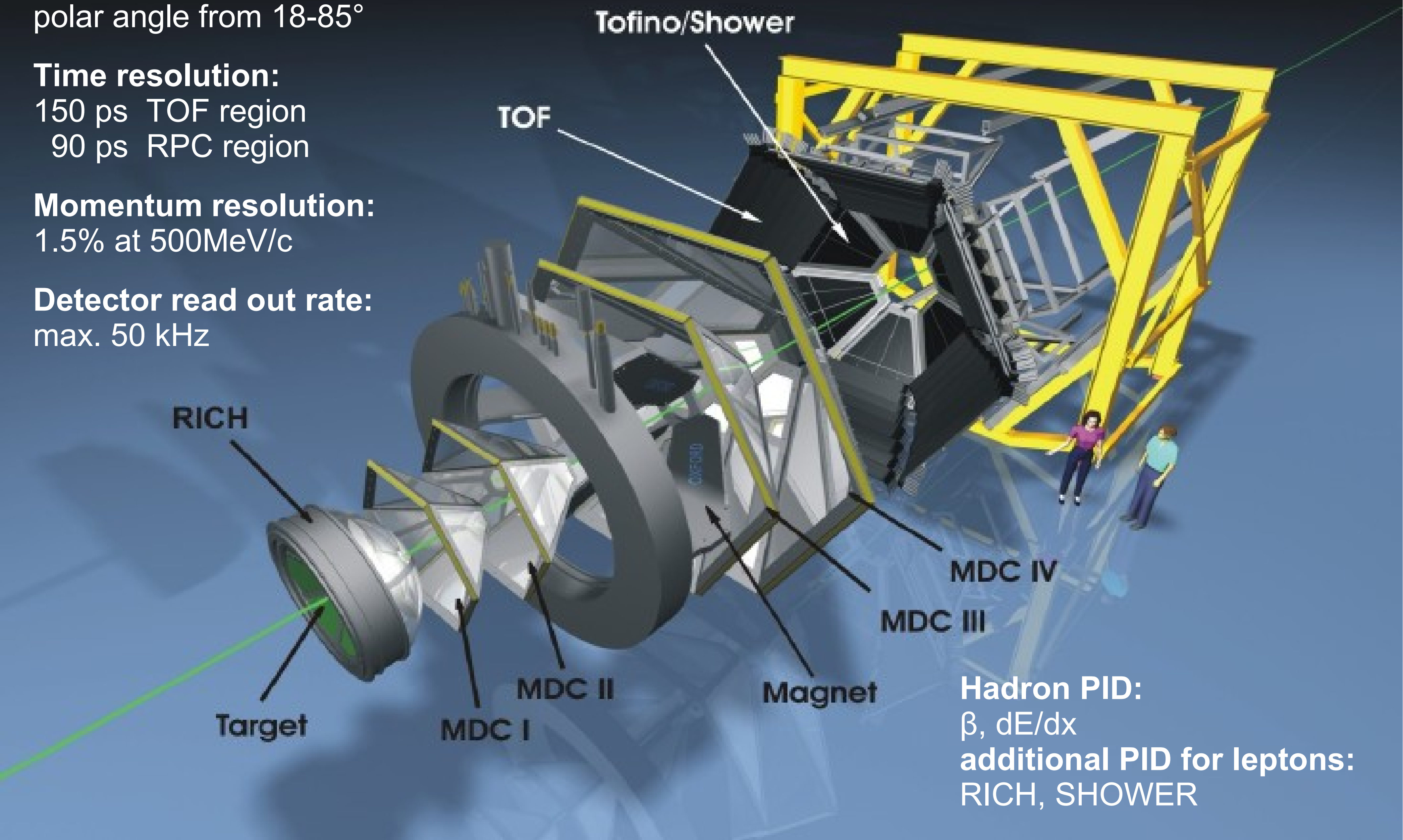
HADES

Acceptance:
full azimuthal angle
polar angle from 18-85°

Time resolution:
150 ps TOF region
90 ps RPC region

Momentum resolution:
1.5% at 500MeV/c

Detector read out rate:
max. 50 kHz

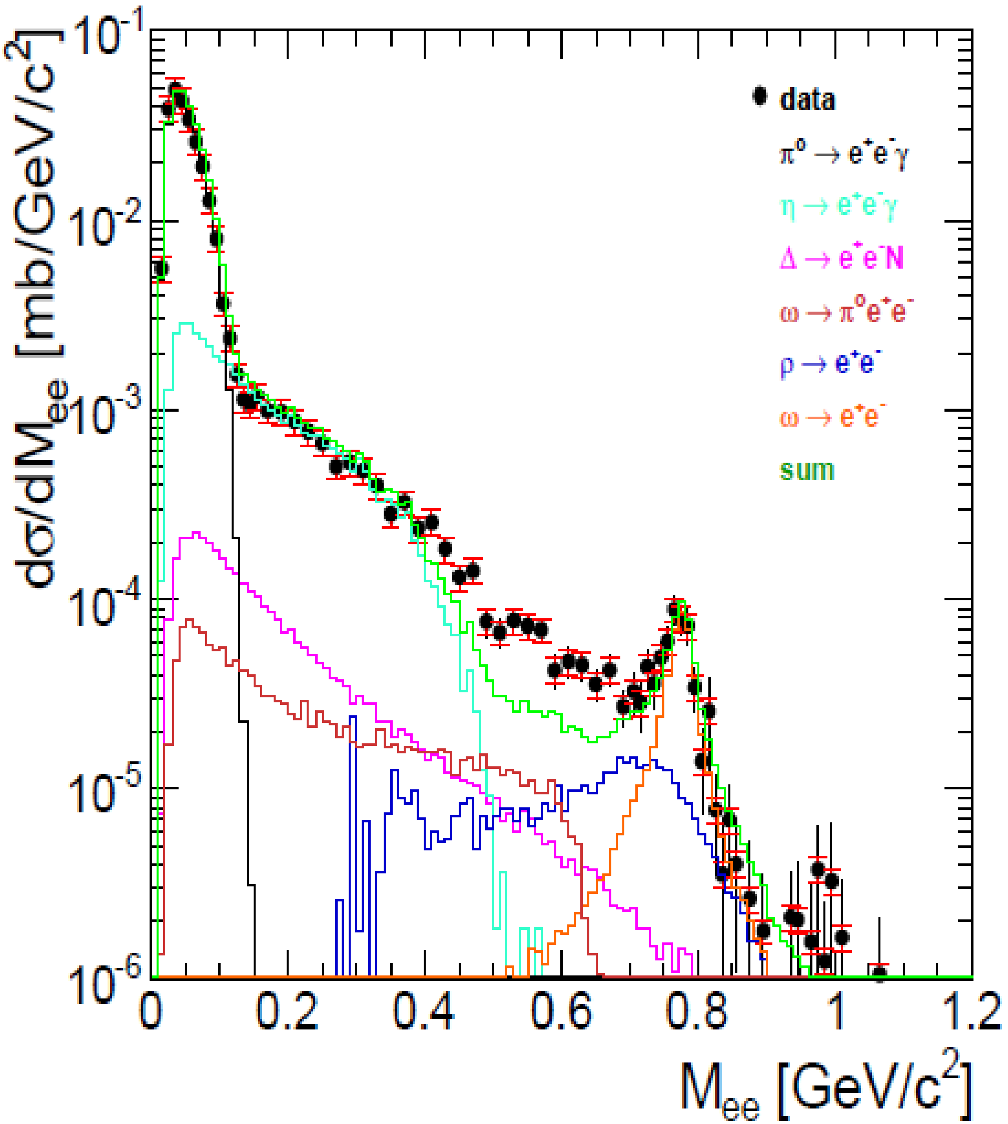


Hadron PID:
β, dE/dx
additional PID for leptons:
RICH, SHOWER

Dilepton production in elementary
and
cold nuclear matter reactions

Dilepton Cocktail contributions: p+p @ 3.5 GeV

arXiv:112.3607[nucl-ex]



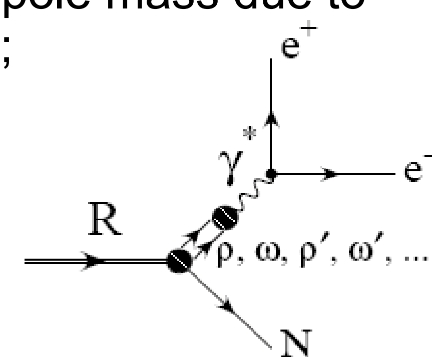
Dielectron Cocktail:
Particle generation: (tuned) PYTHIA

Particle Decay: PLUTO
Including electromagnetic transition form factors
Mass dependent branching ratios

Cross sections:
For π,η and ω contribution constrained by fits to the invariant mass spectra
Δ by p_t distributions
No ρ contribution visible!

Missing yield between 0.5 and 0.7 GeV/c²

ρ baryon-resonance coupling:
enhance yield below ρ pole mass due to kinematical constraints;



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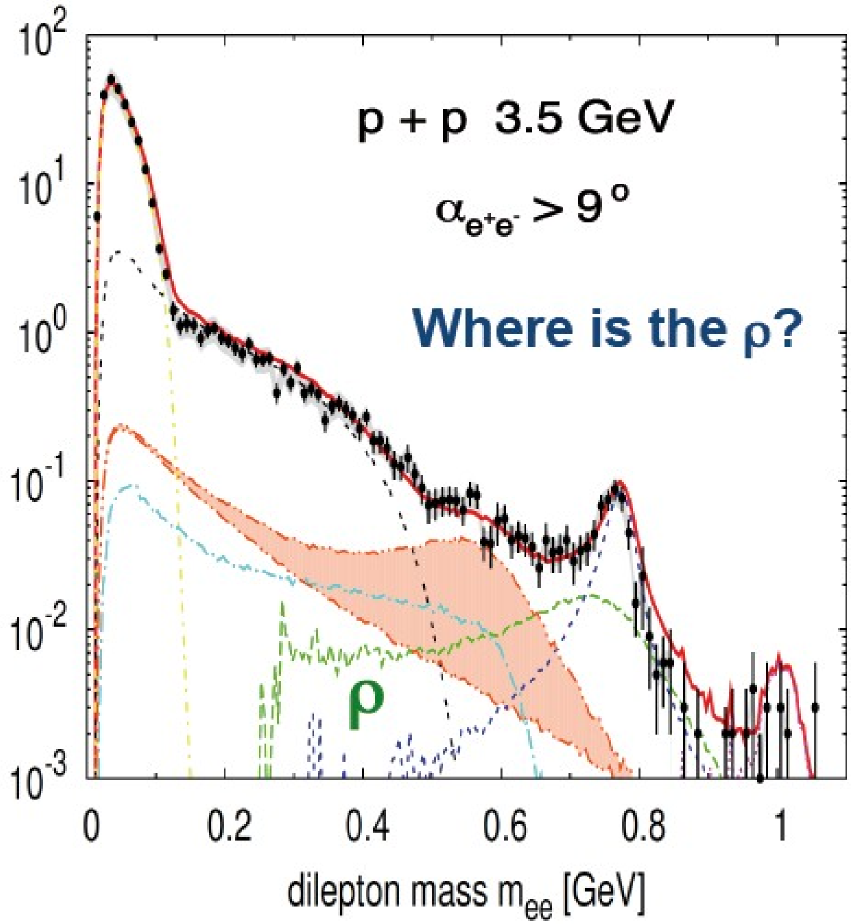
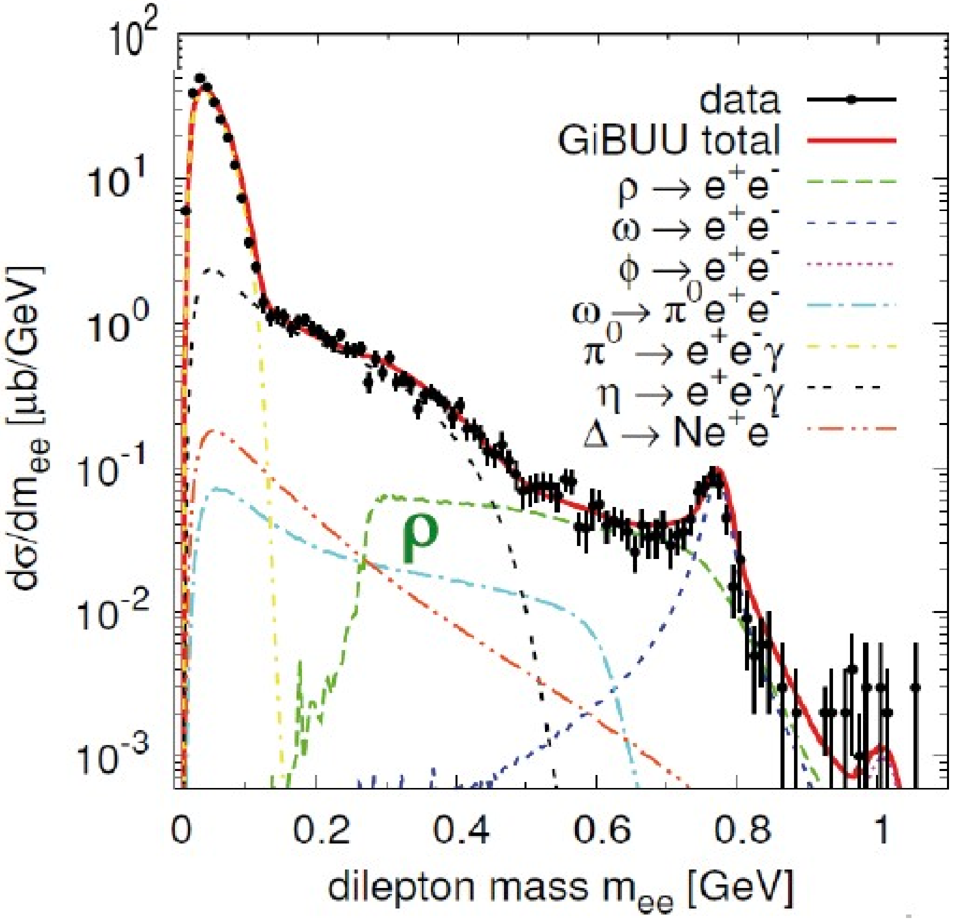
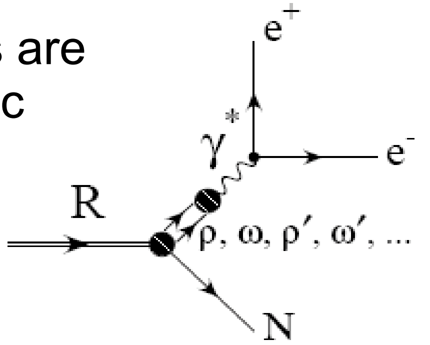




Better description when introducing
→ Δ-N EM transition form factor

→ or when all ρ mesons are produced via baryonic resonances



GiBUU simulation: by J.Weil arXiv:1106.1344v1[hep-ph]

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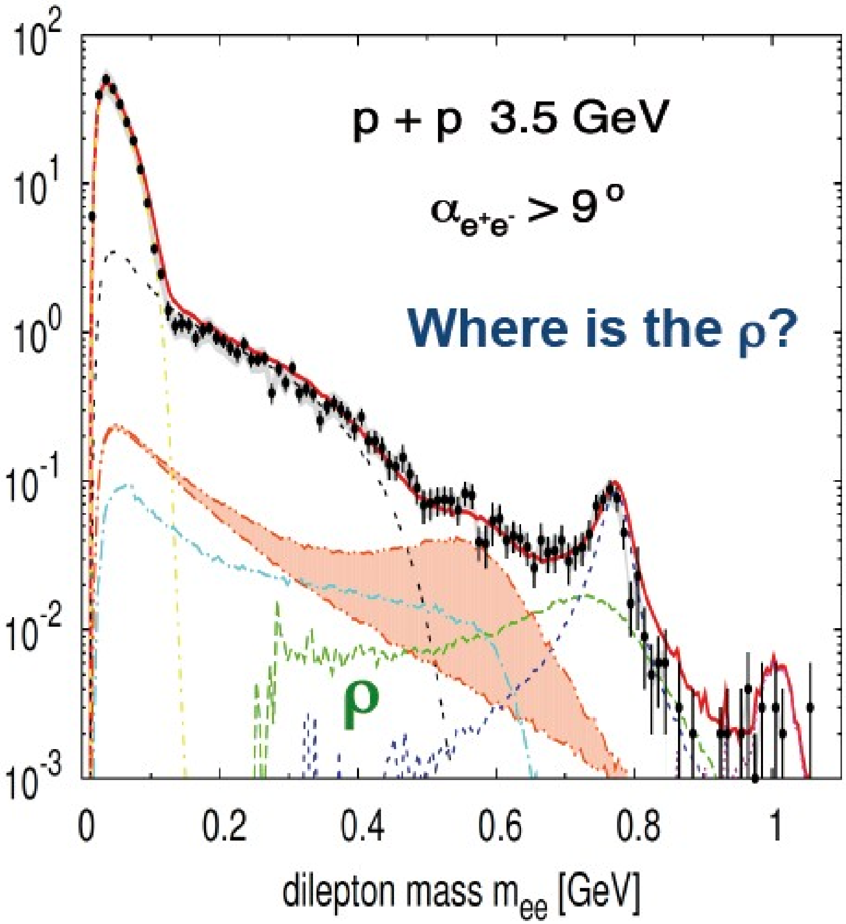

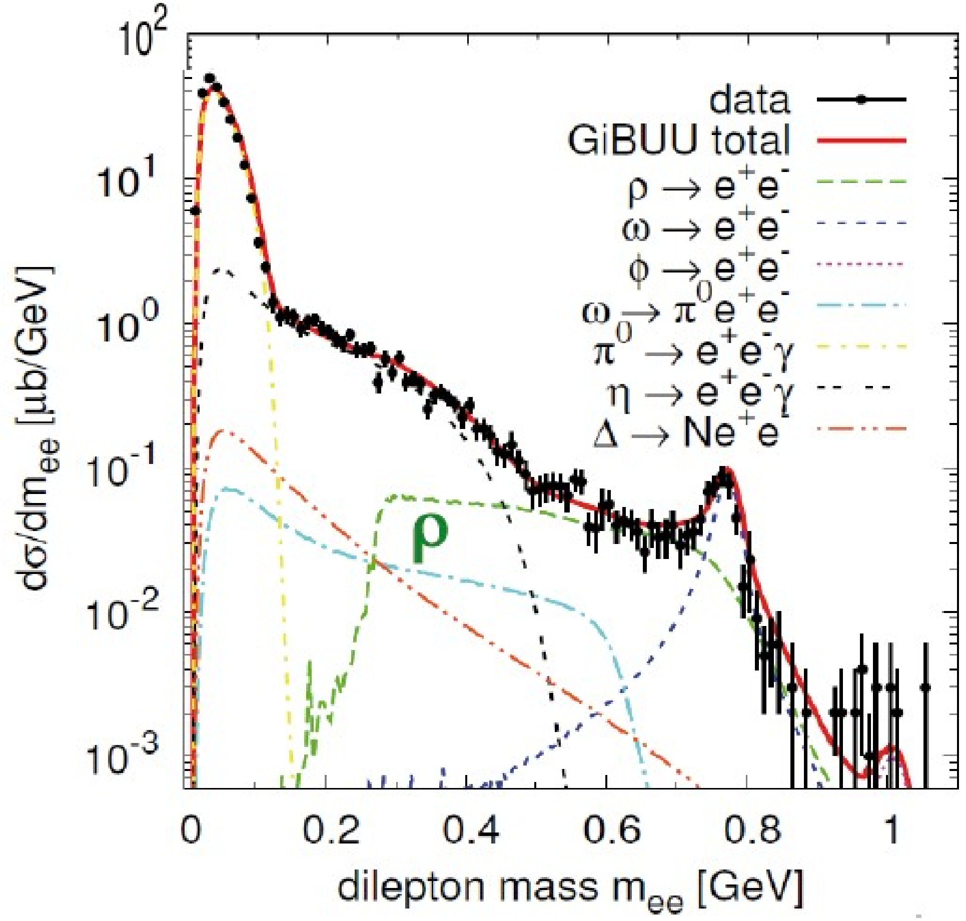

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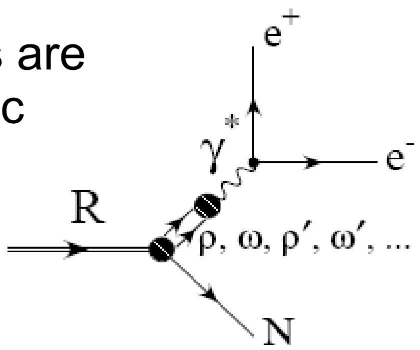
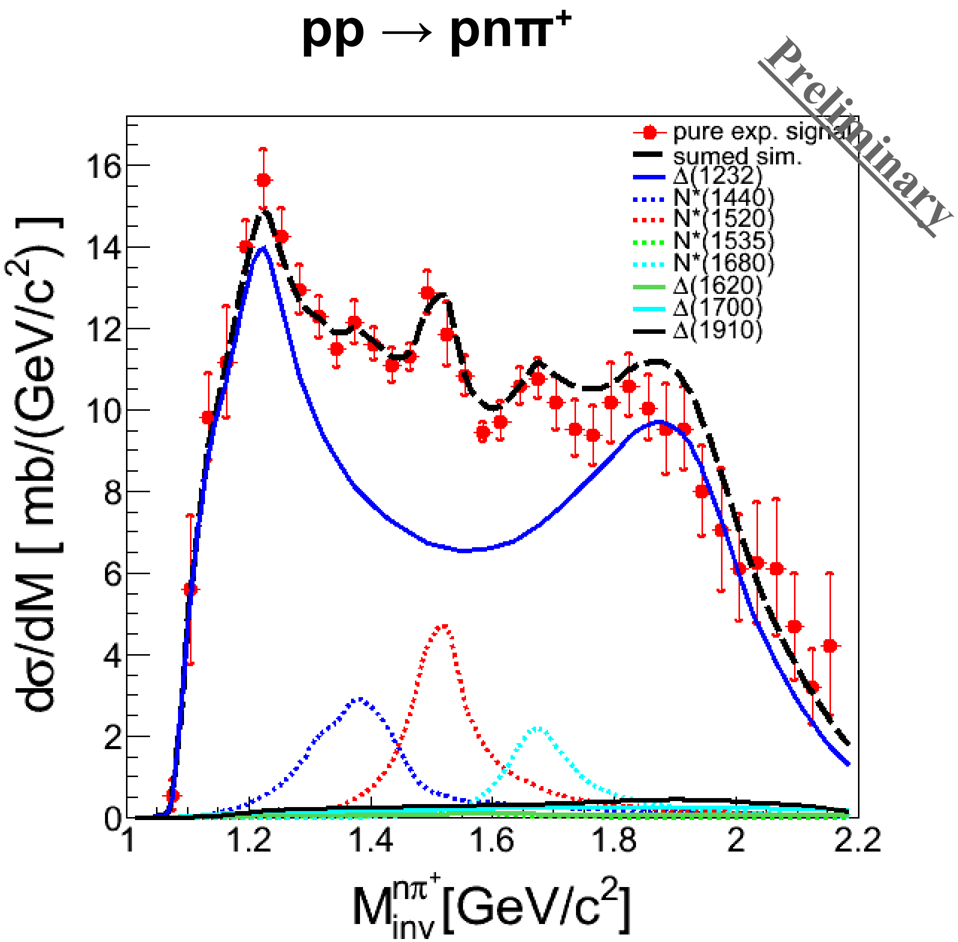
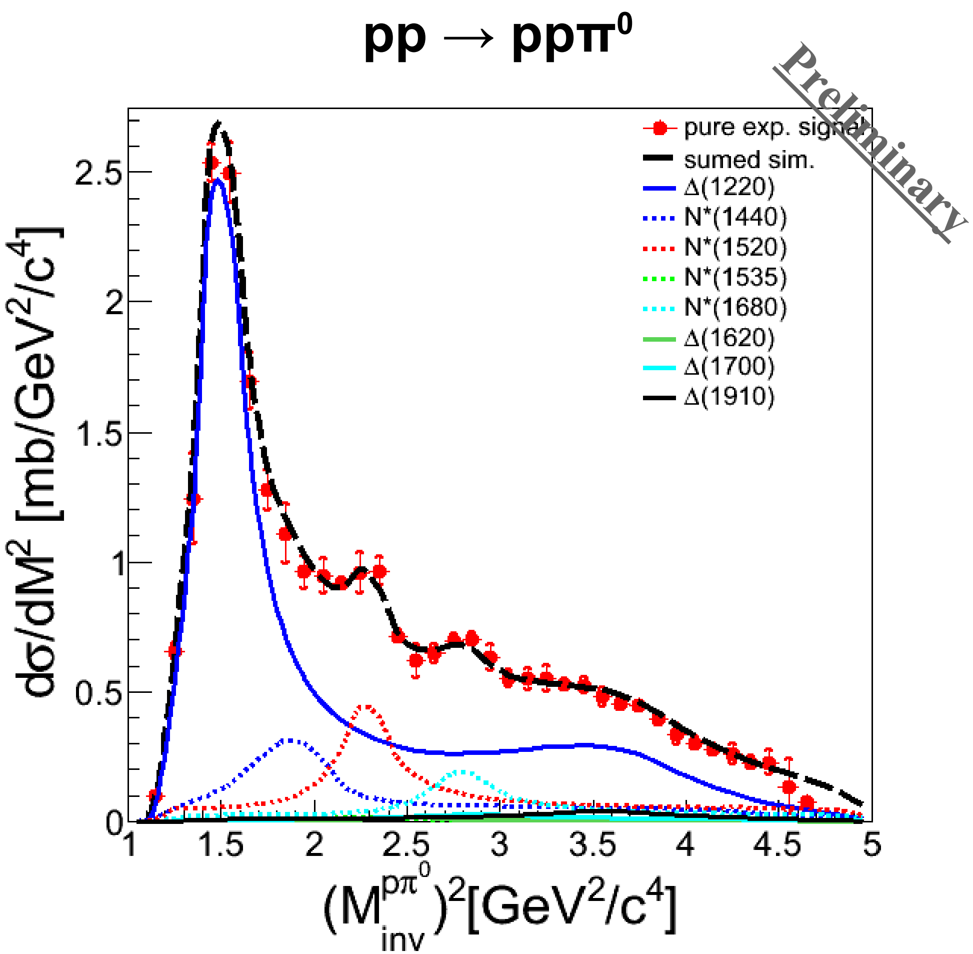


To which extent is it meaningful to distinguish between baryon resonance and ρ contribution? → baryonic contributions

GiBUU simulation: by J.Weil arXiv:1106.1344v1[hep-ph]

Constrain the resonance contributions: exclusive analysis $pp \to pn\pi^+/pp\pi^0$

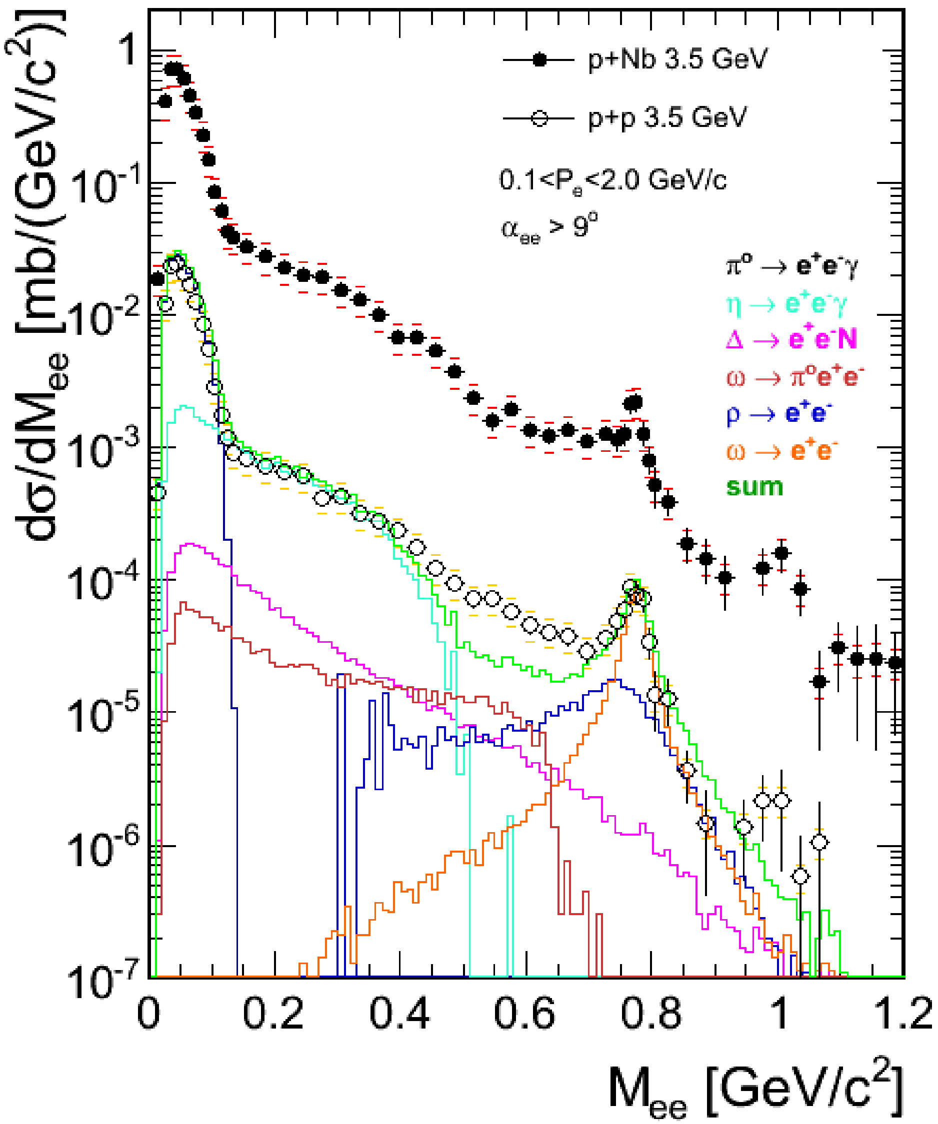




14 resonance included in the analysis
N*(1535) constrained by $pp \to pp\eta$
→ constrain relative contributions

See talk on Monday by A.Dybczak in session B4 for more details

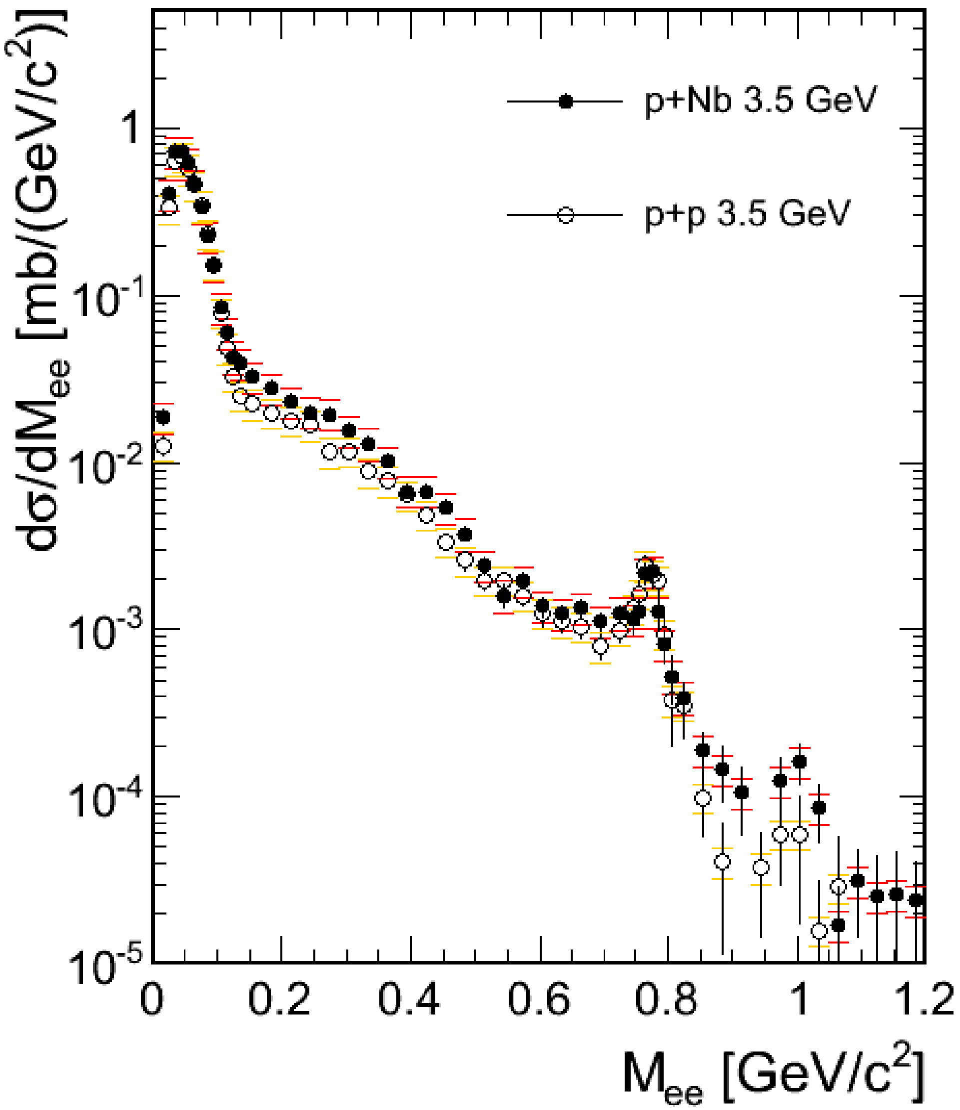
Nuclear modification in p+Nb collisions



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

arXiv:1205.1918 [nucl-ex]

Nuclear modification in p+Nb collisions



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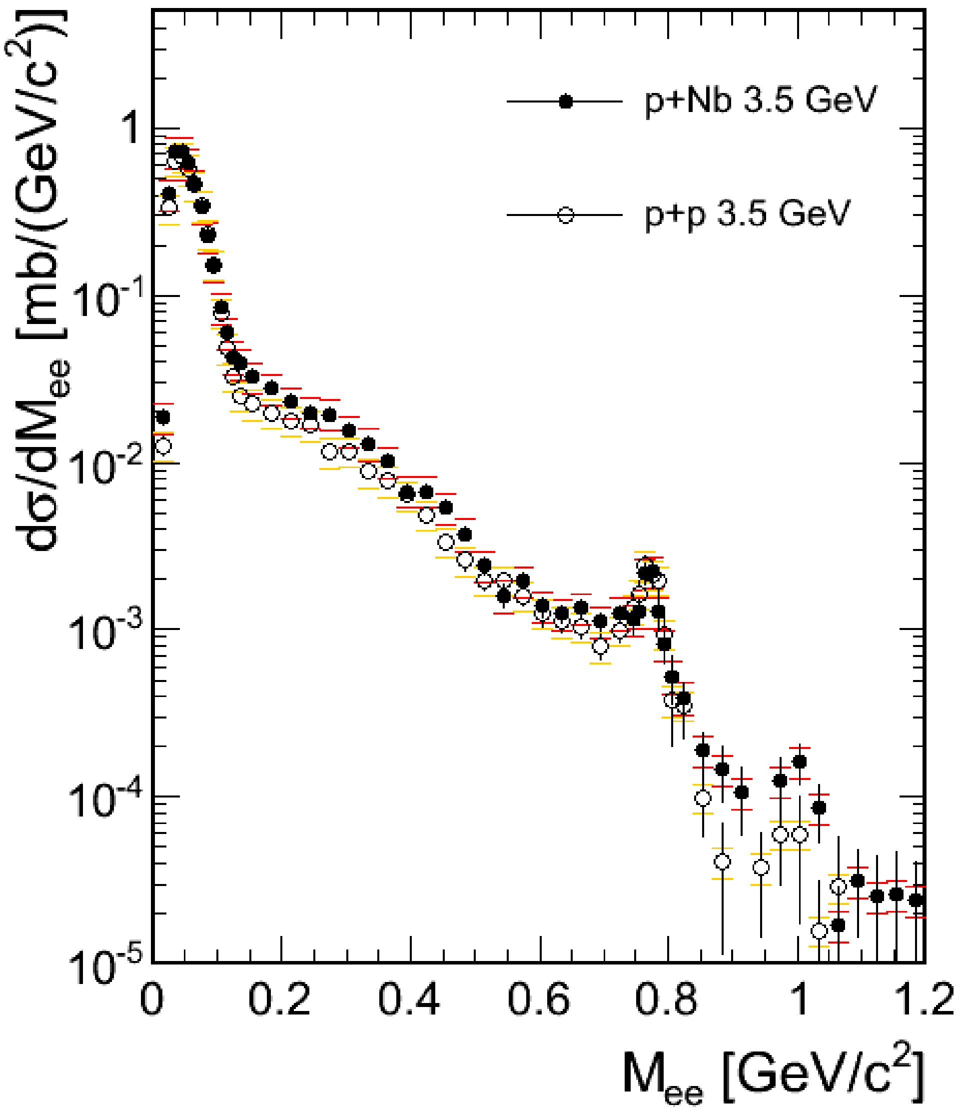

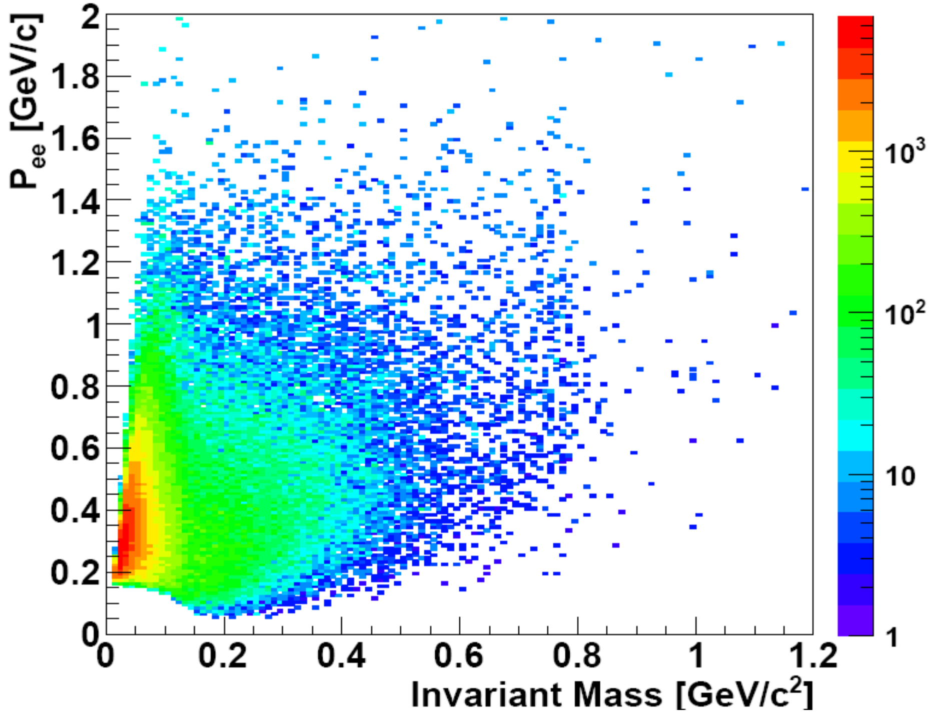

First measurements of dielectron pairs radiated from cold nuclear matter with $P_{ee} < 0.8$ GeV/c

→ not covered by CLAS and KEK-E325

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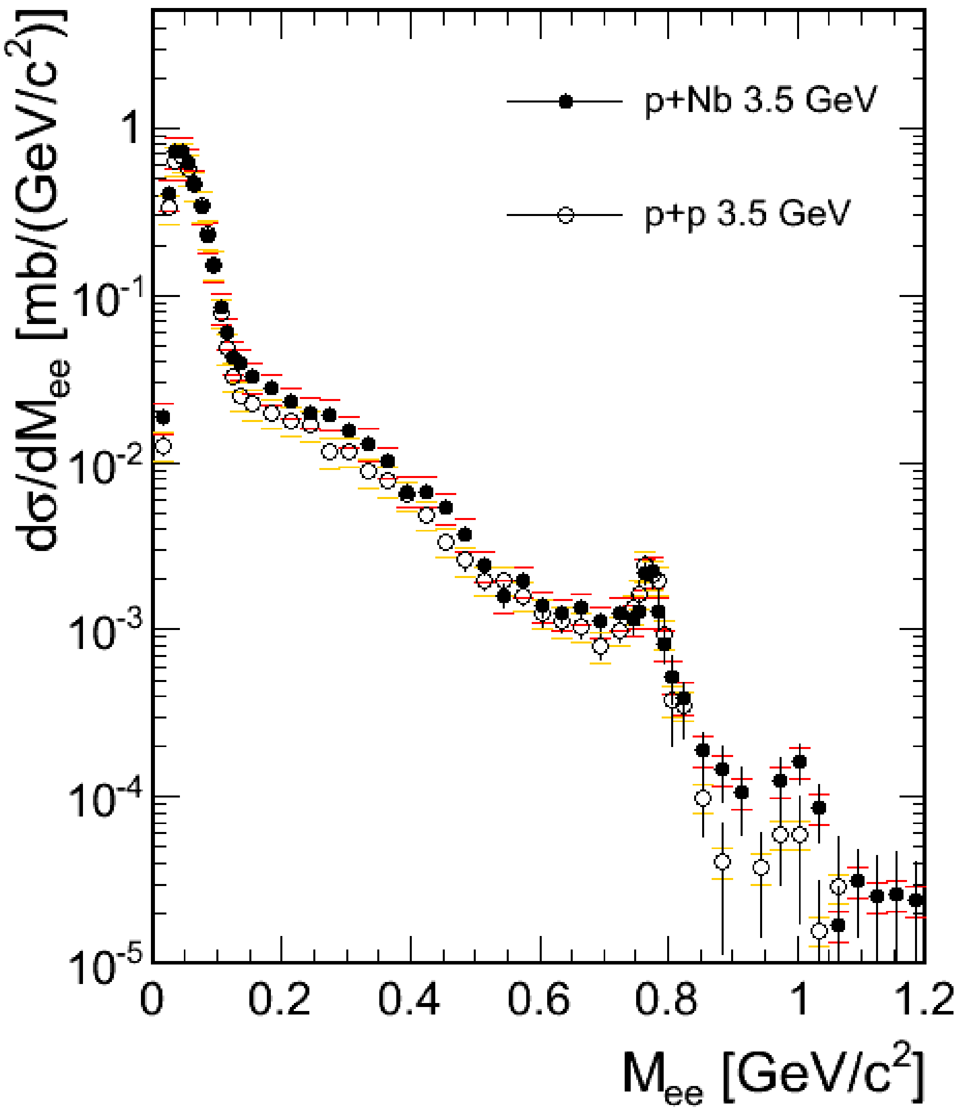

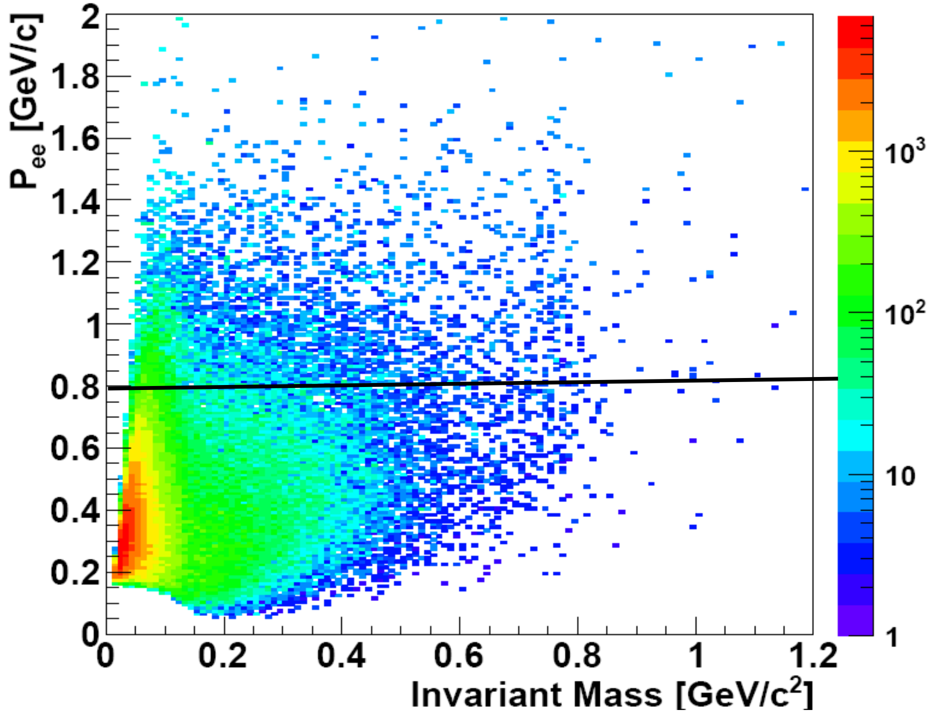

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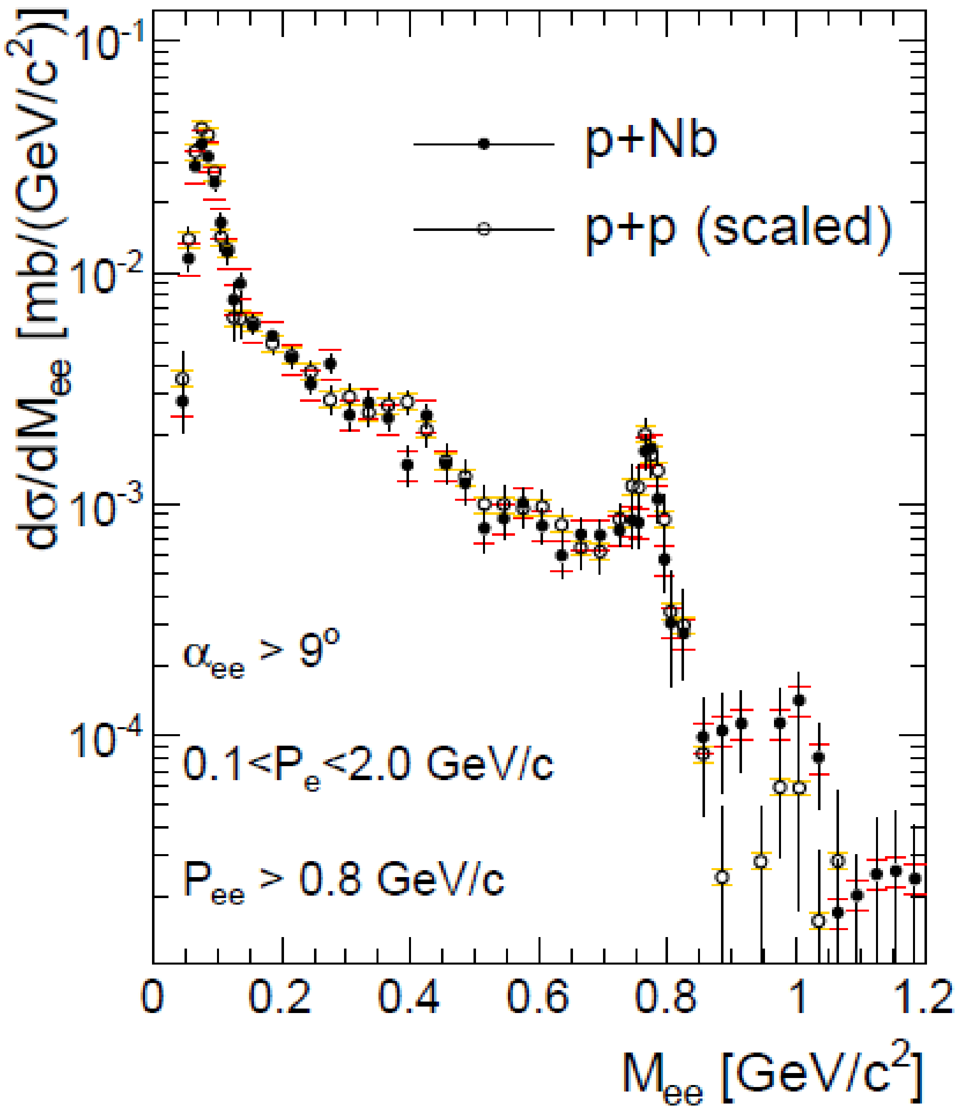
Slow and fast vector mesons



Scaled p+p data agree with p+Nb data

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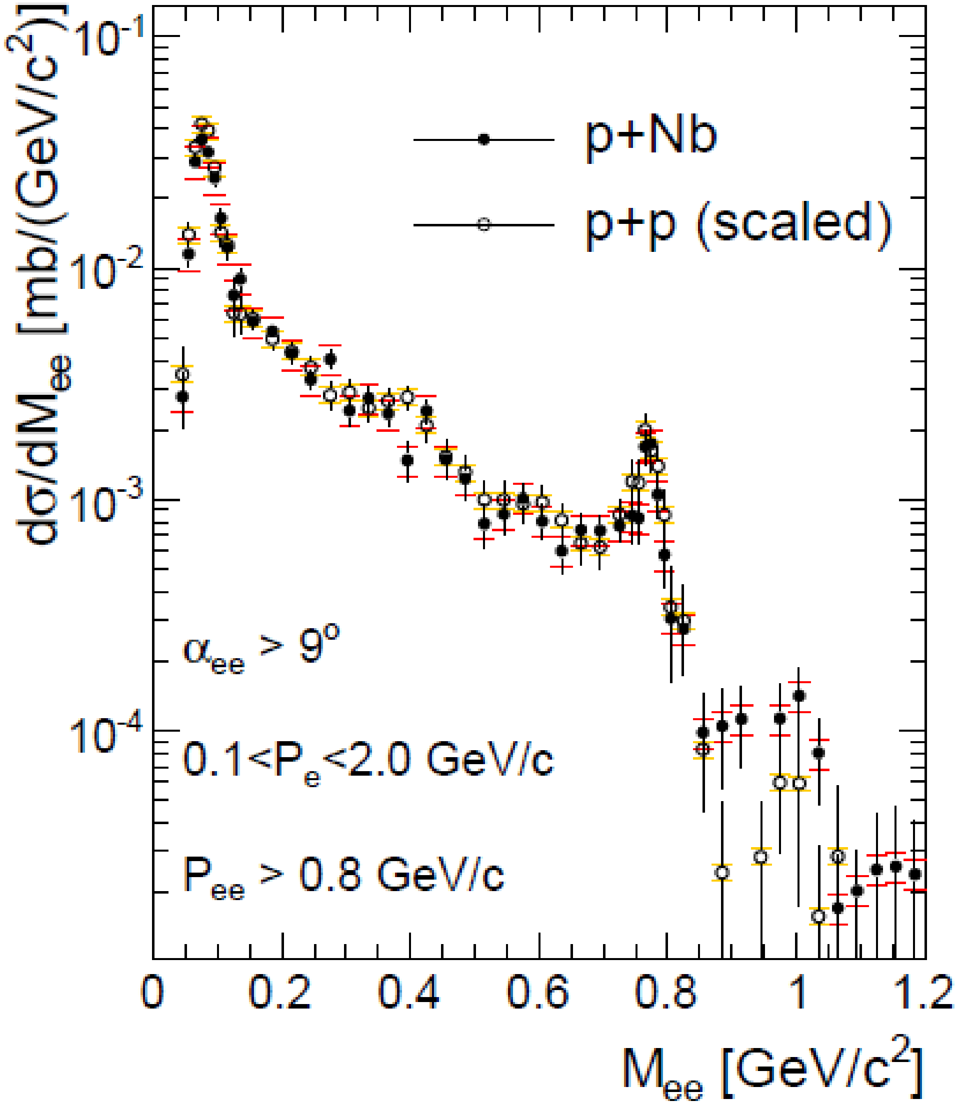

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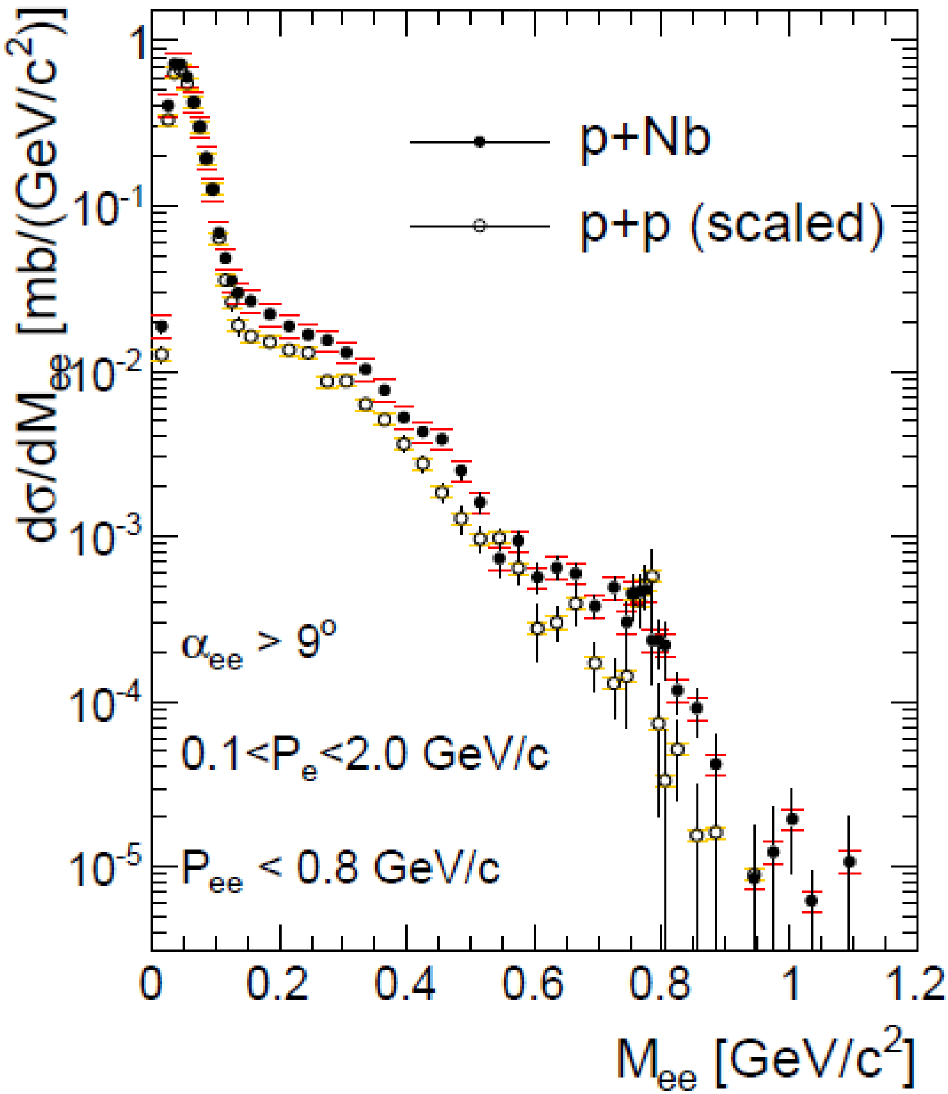
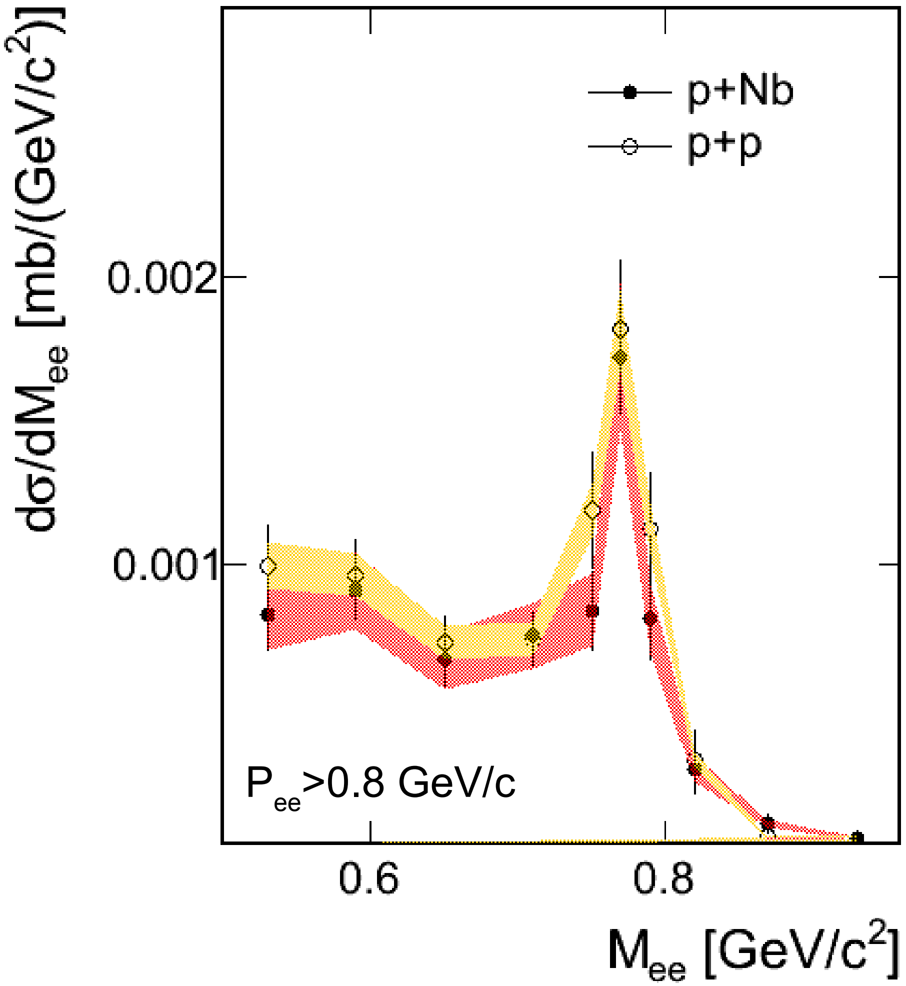


Excess in low and vector meson mass region

Slow and fast vector mesons



High momentum: pairs no significant difference in line shape of dielectrons and ω mesons

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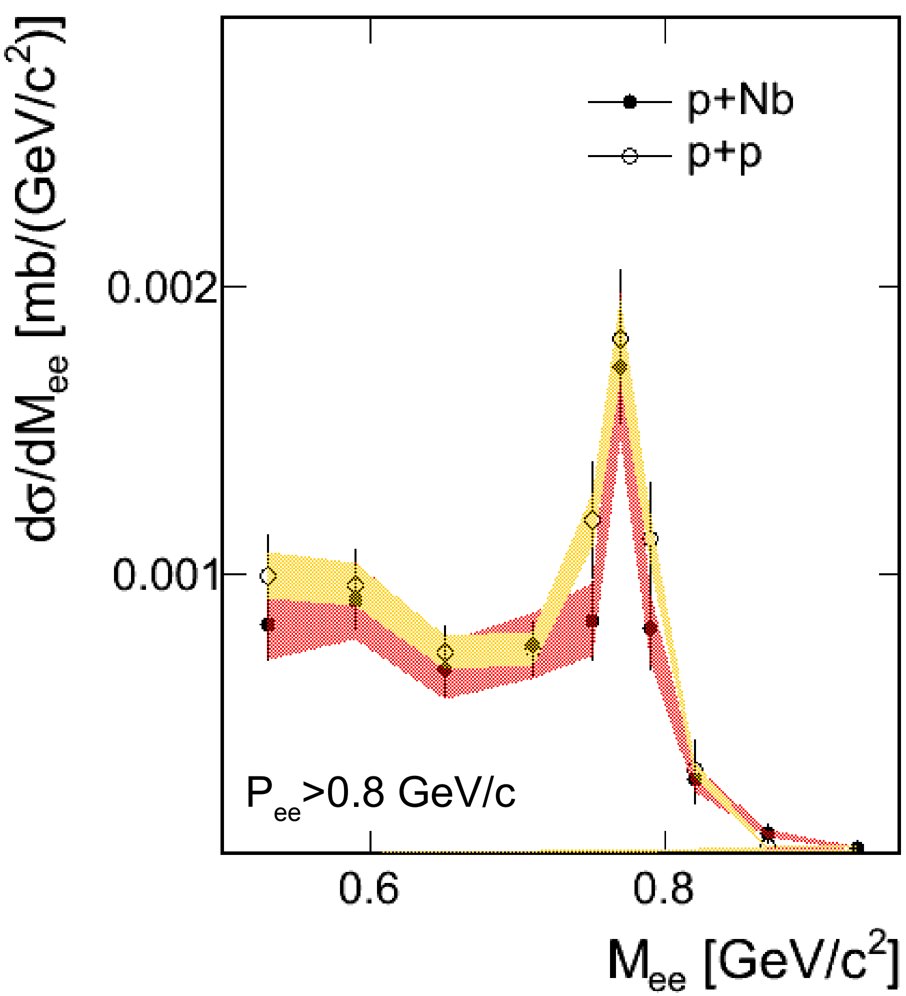
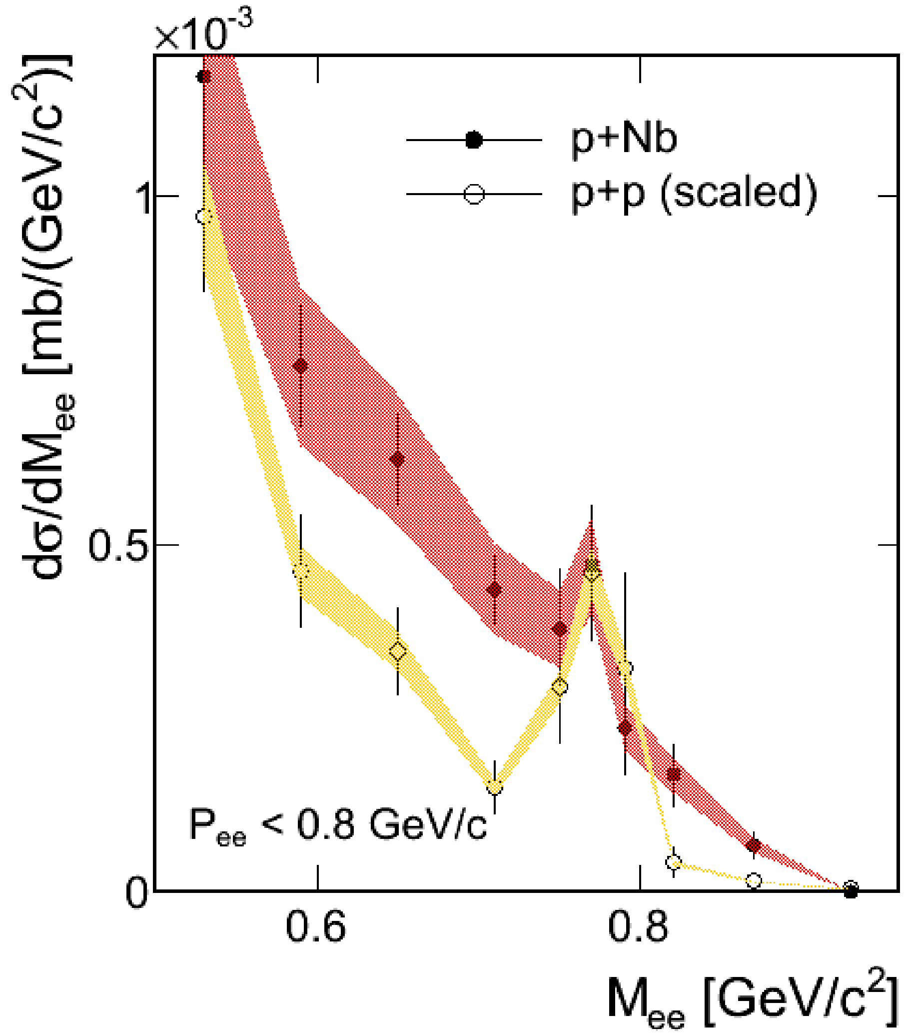
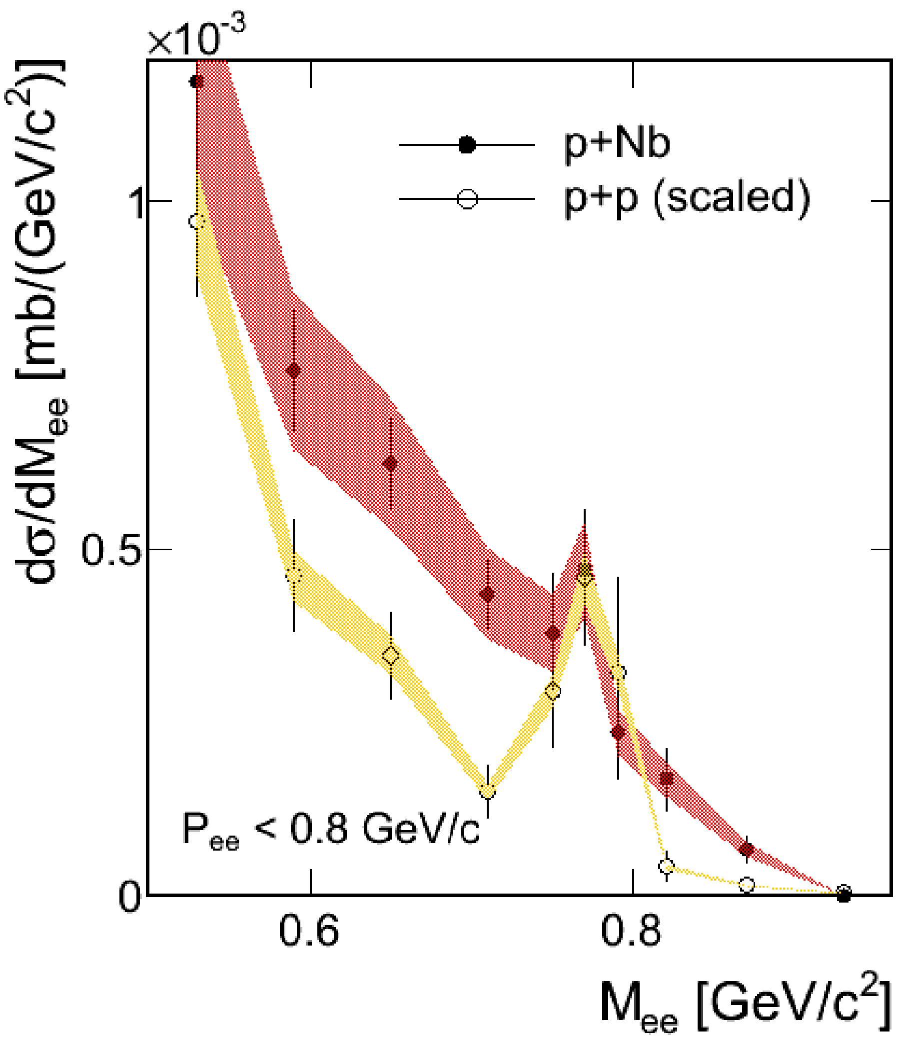




High momentum: pairs no significant difference in line shape of dielectrons and ω mesons

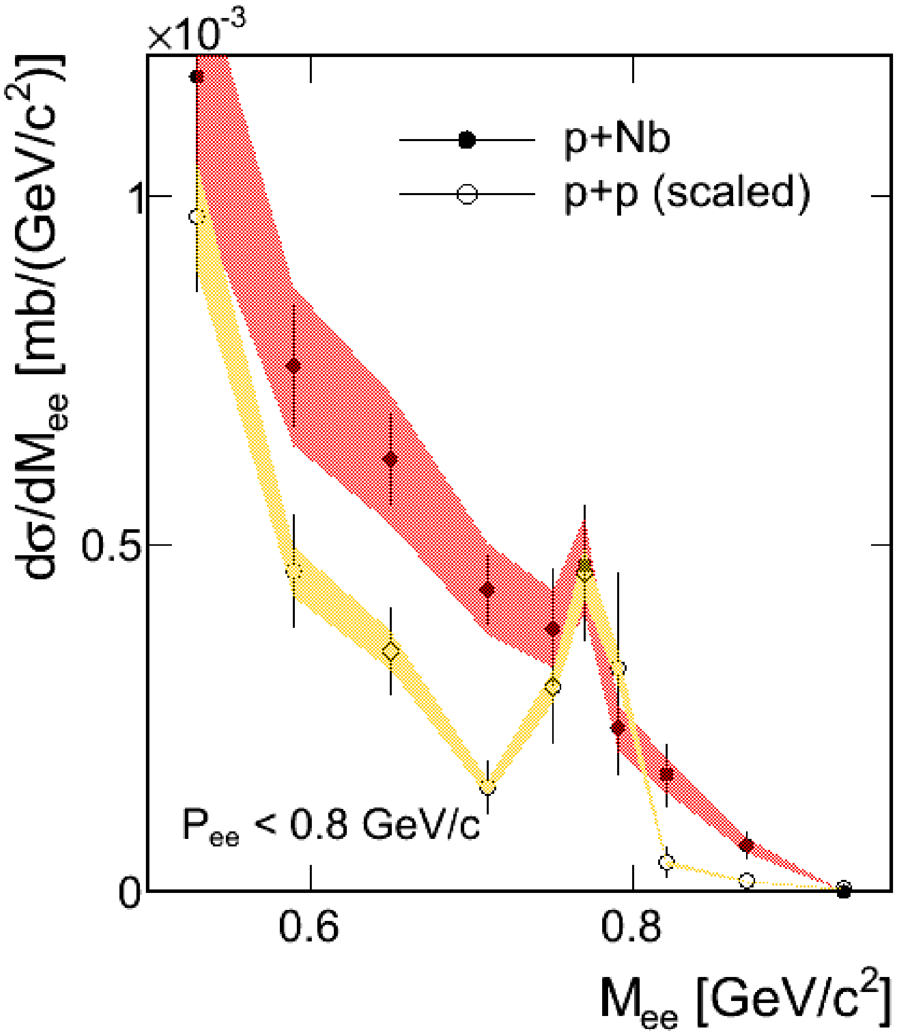
Low momentum: strong difference due to additional ρ-like contribution and suppression of ω's

Low momentum excess



Subtract the ω peak contribution

Low momentum excess



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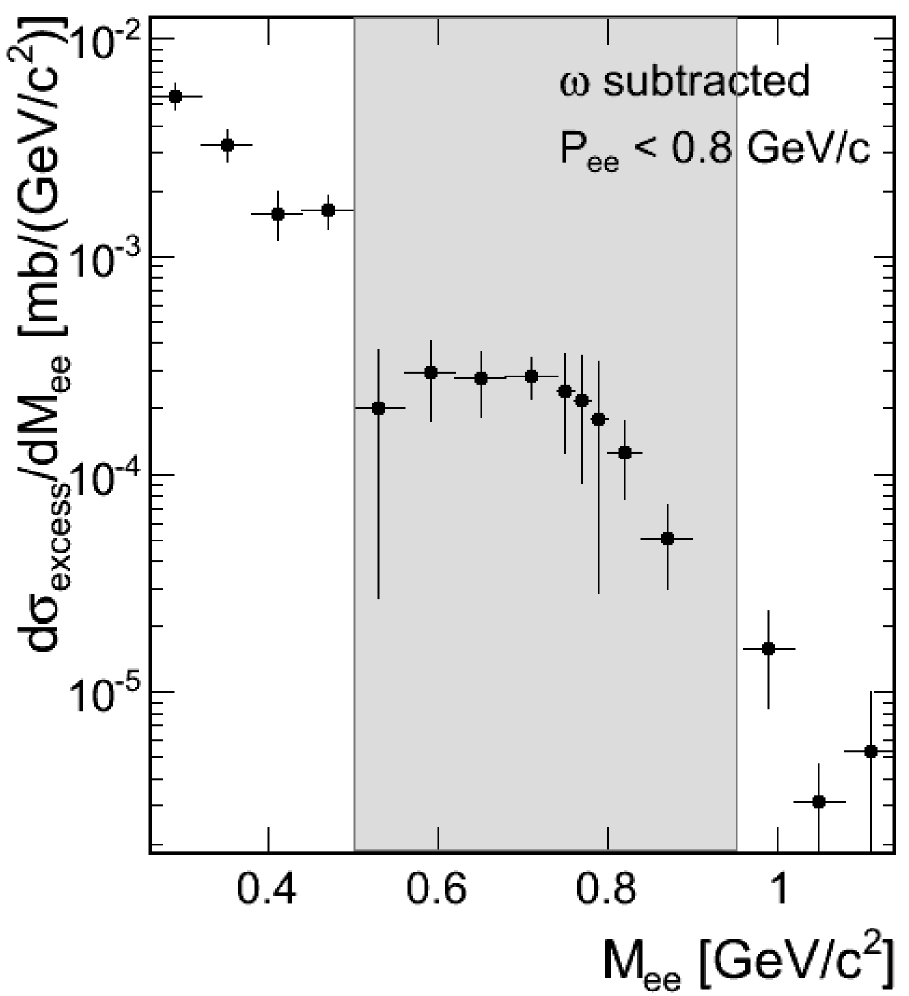
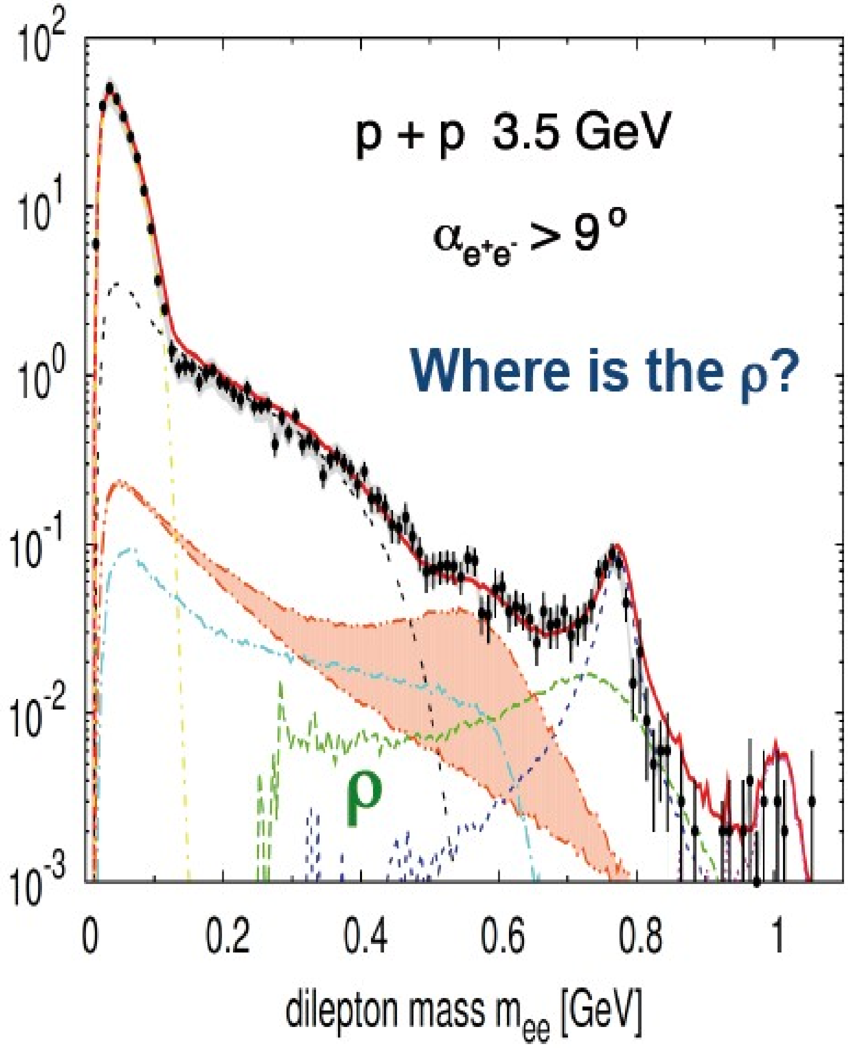
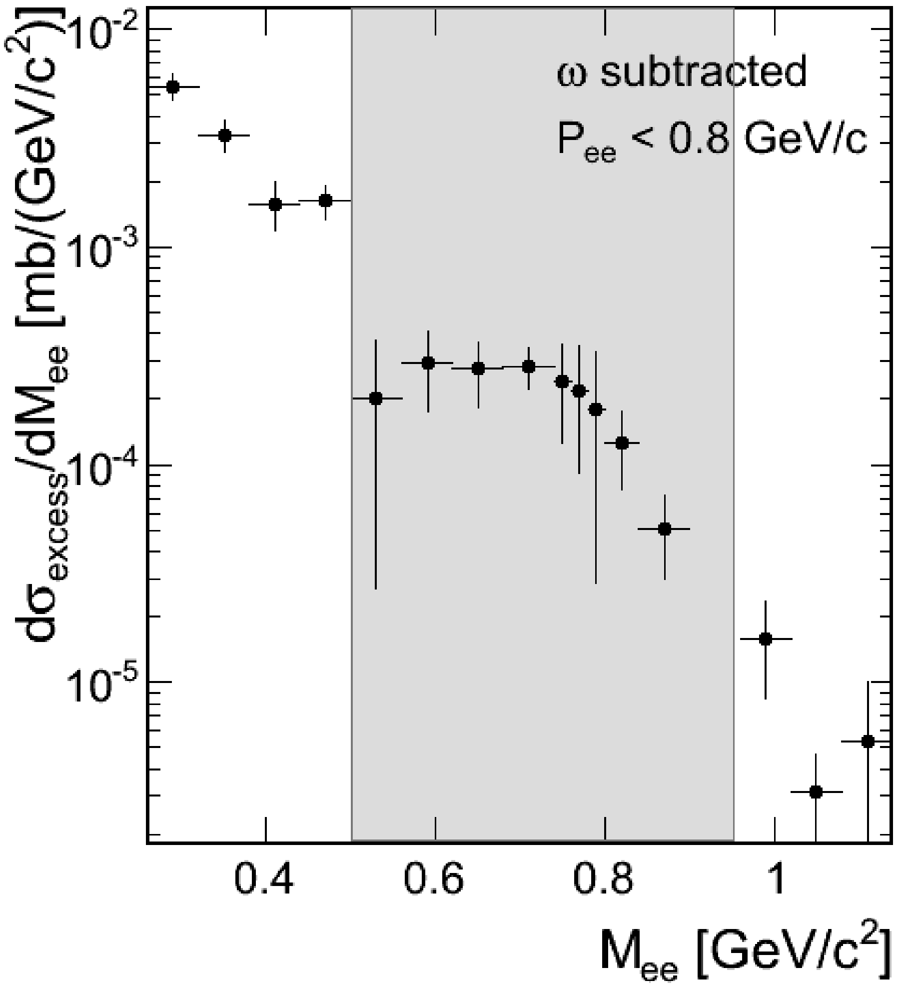


Excess due to “baryonic contributions”

Low momentum excess

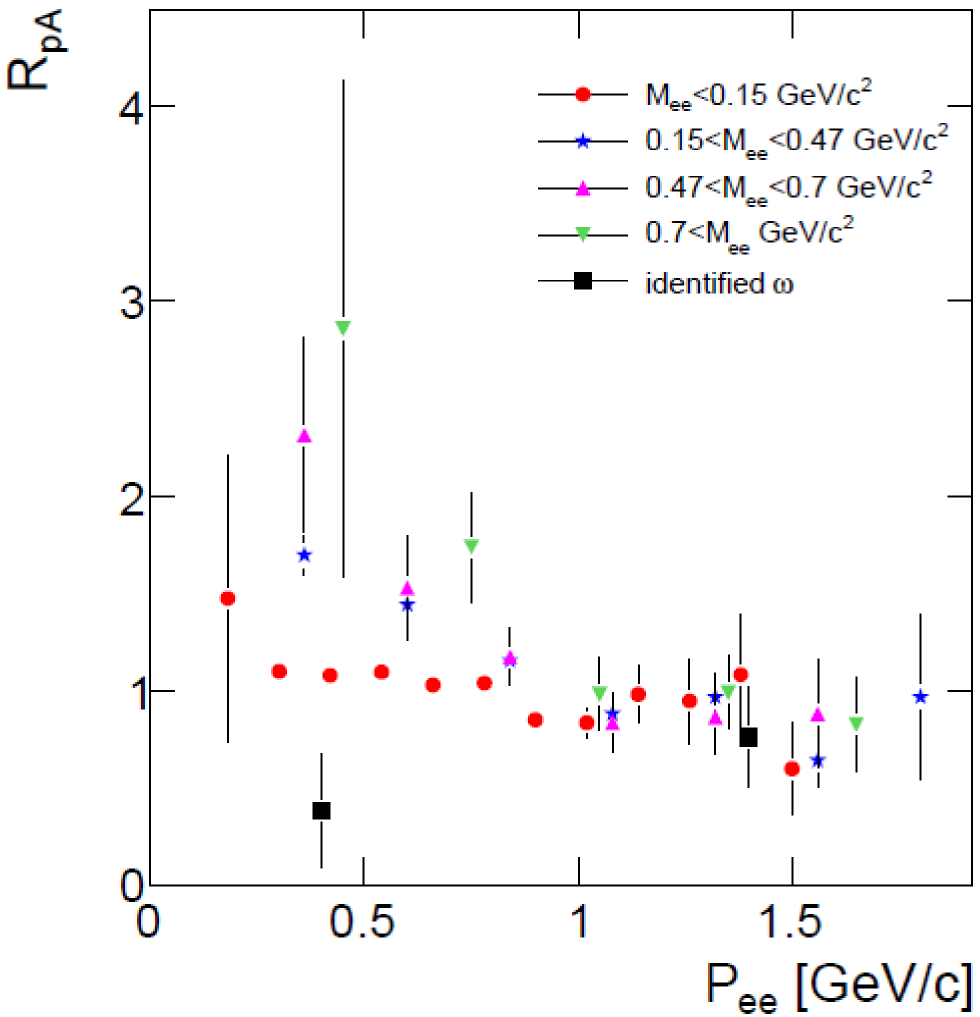


Similar shape to Δ with EM formfactor



Excess due to “baryonic contributions”

Nuclear modification factor as function of the momentum



Rise in all invariant mass regions for low P_{ee}:
Importance of secondary particle production

Opposite trends for ω and ρ-like contribution!

Absorption stronger than feeding from secondary collisions for ω mesons
→ reduced partial branching ratio due to strong broadening inside the medium

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

$$\Gamma_{tot} = \Gamma_{vac} + \Gamma_{coll}$$

Two aspects of in medium modifications: Absorption of particle like states (ω) and modification of the remaining dielectron shape in the invariant mass spectra!

Summary and Outlook

Elementary reactions:

• Better description of e^+e^- cocktail by introducing

ρ baryon-resonance coupling: “baryonic contribution“

• Different resonance contributions can be constrained in exclusive channels

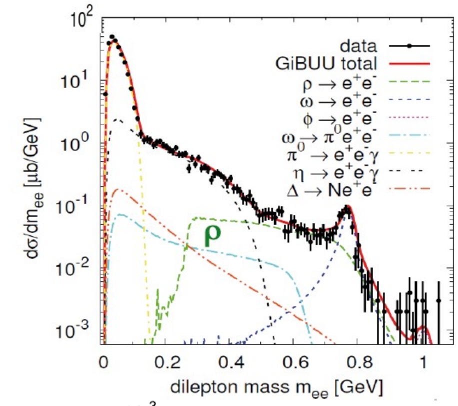
Cold nuclear matter:

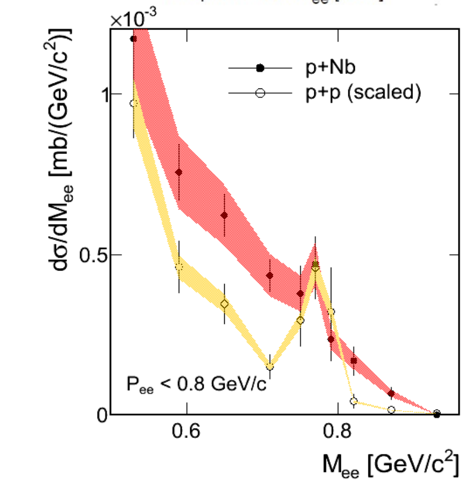
• Strong nuclear modification for slow dilepton pairs in cold nuclear matter

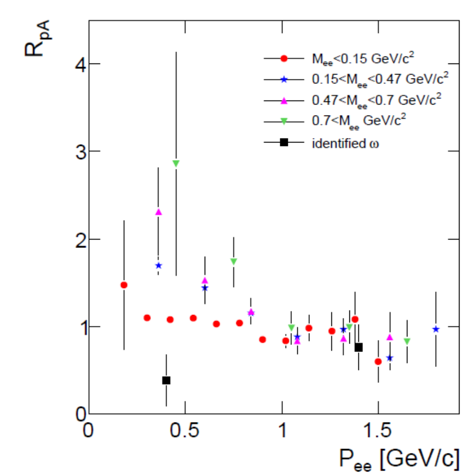
- Two aspects of medium modifications: additional “baryonic contribution” and absorption of ω mesons

Outlook:

• Additional systematics can be gained by π-beam program at GSI







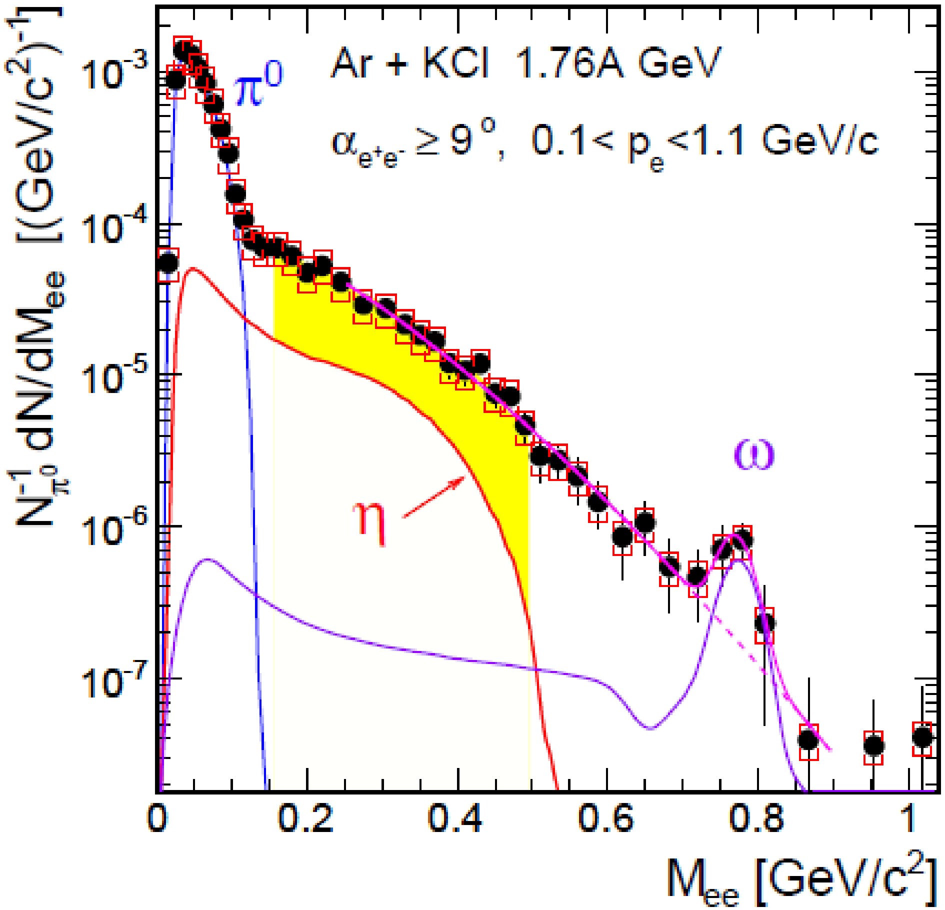
The HADES Collaboration

Jörn Adamczewski-Musch, Geydar Agakishiev, Claudia Behnke, Alexander Belyaev, Jia-Chii Berger-Chen, Alberto Blanco, Christoph Blume, Michael Böhmer, Pablo Cabanelas, Nuno Carolino, Sergey Chernenko, Jose Díaz, Adrian Dybczak, Eliane Epple, Laura Fabbietti, Oleg Fateev, Paulo Fonte, Jürgen Friese, Ingo Fröhlich, Tetyana Galatyuk, Juan A. Garzón, Roman Gernhäuser, Alejandro Gil, Marina Golubeva, Fedor Guber, Malgorzata Gumberidze, Szymon Harabasz, Klaus Heidel, Thorsten Heinz, Thierry Hennino, Romain Holzmann, Jochen Hutsch, Claudia Höhne, Alexander Ierusalimov, Alexander Ivashkin, Burkhard Kämpfer, Marcin Kajetanowicz, Tatiana Karavicheva, Vladimir Khomyakov, Ilse Koenig, Wolfgang Koenig, Burkhard W. Kolb, Vladimir Kolganov, Grzegorz Korcyl, Georgy Kornakov, Roland Kotte, Erik Krebs, Hubert Kuc, Wolfgang Kühn, Andrej Kugler, Alexei Kurepin, Alexei Kurilkin, Pavel Kurilkin, Vladimir Ladygin, Rafal Lalik, Kirill Lapidus, Alexander Lebedev, Ming Liu, Luís Lopes, Manuel Lorenz, Gennady Lykasov, Ludwig Maier, Alexander Malakhov, Alessio Mangiarotti, Jochen Markert, Volker Metag, Jan Michel, Christian Müntz, Rober Münzer, Lothar Naumann, Marek Palka, Vladimir Pechenov, Olga Pechenova, Americo Pereira, Jerzy Pietraszko, Witold Przygoda, Nicolay Rabin, Béatrice Ramstein, Andrei Reshetin, Laura Rehnisch, Philippe Rosier, Anar Rustamov, Alexander Sadovsky, Piotr Salabura, Timo Scheib, Alexander Schmah, Heidi Schuldes, Erwin Schwab, Johannes Siebenson, Vladimir Smolyankin, Manfred Sobiella, Yuri Sobolev, Stefano Spataro, Herbert Ströbele, Joachim Stroth, Christian Sturm, Khaled Teilab, Vladimir Tiflov, Pavel Tlusty, Michael Traxler, Alexander Troyan, Haralabos Tsertos, Evgeny Usenko, Taras Vasiliev, Vladimir Wagner, Christian Wendisch, Jörn Wüstenfeld, Yuri Zanevsky

Backup

Dilepton production in HIC

Dileptons: low mass enhancement

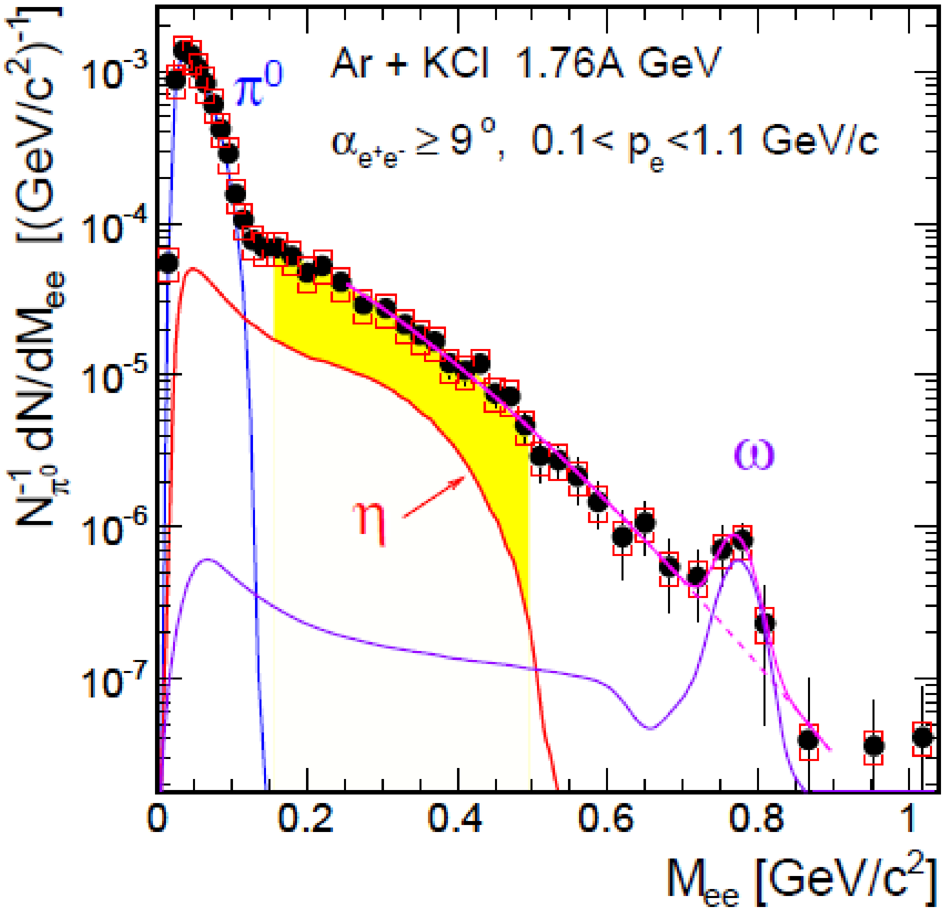


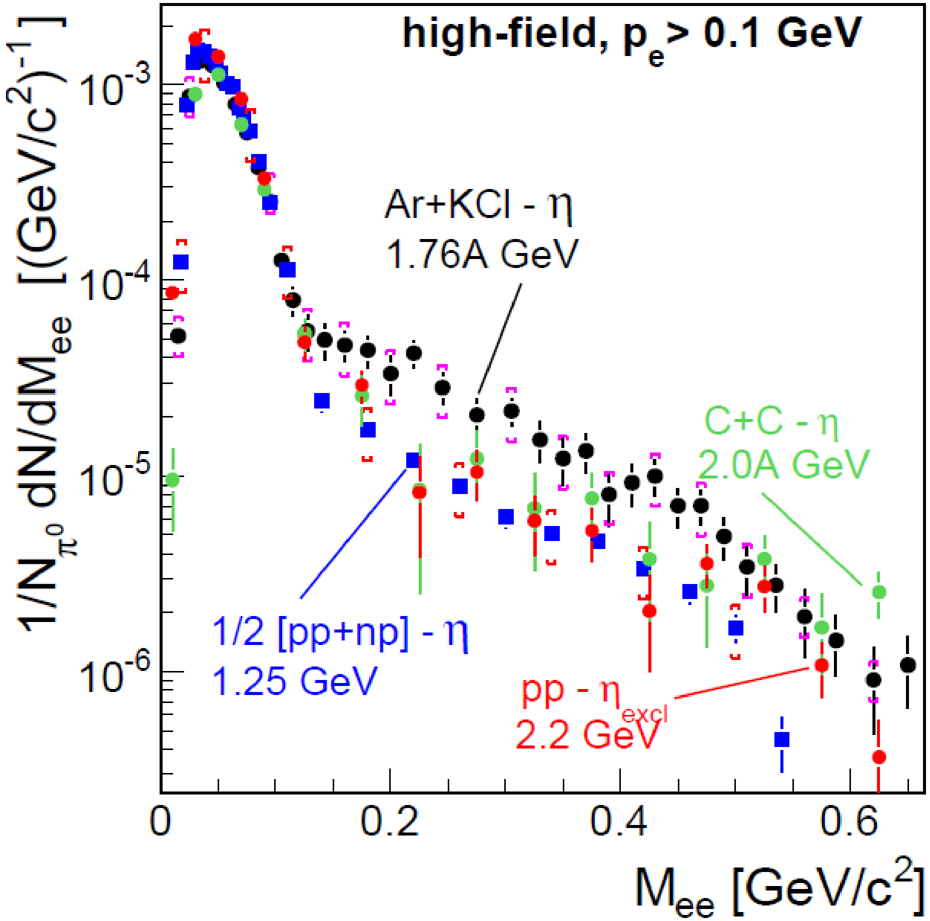
First measurements of ω's at these energies
subthreshold + electromagnetic decay channel:
→ **50 million events for one ω!**

Excess over long-lived cocktail components

Phys.RevC84:014902, 2011

Dileptons: low mass enhancement





First measurements of ω's at these energies
subthreshold + electromagnetic decay channel:
→ **50 million events for one ω!**

Excess over long-lived cocktail components

First evidence for radiation from the medium

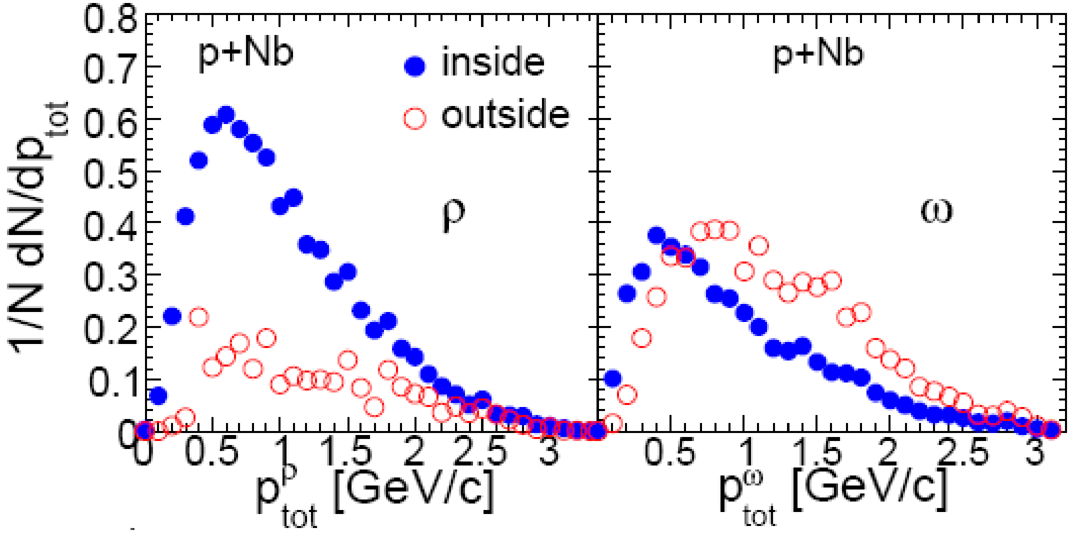
Due to enhanced contributions of baryonic resonances or modification of the ρ meson?

→ **Measure ρ in p+p, p+Nb and Au+Au**

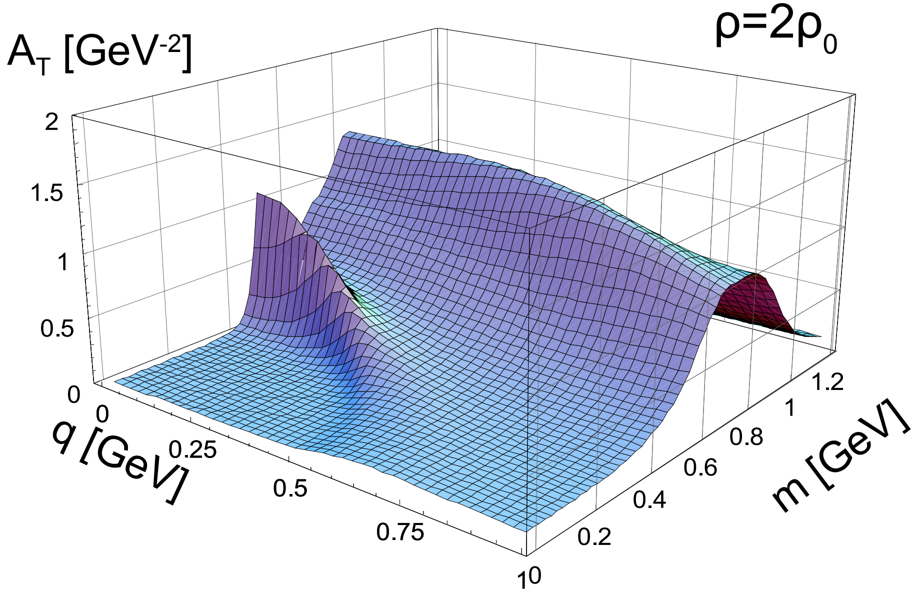
Phys.RevC84:014902, 2011

Momentum dependence

HSD calculation from beam time proposal



M. Post et al., NPA 741 (2004) 81



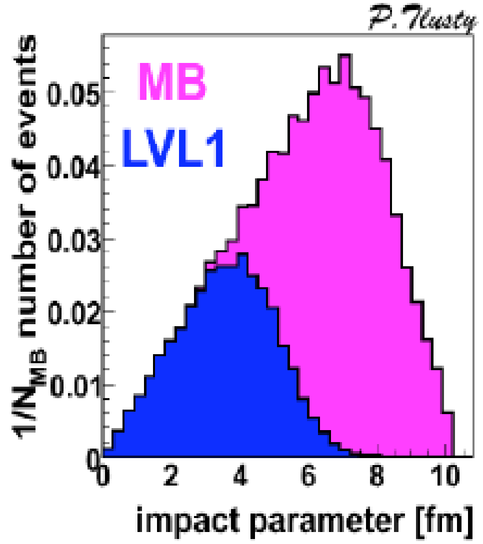
Change in line shape:
decay inside the medium,
→ short-lived,
→ initial momentum as low as possible

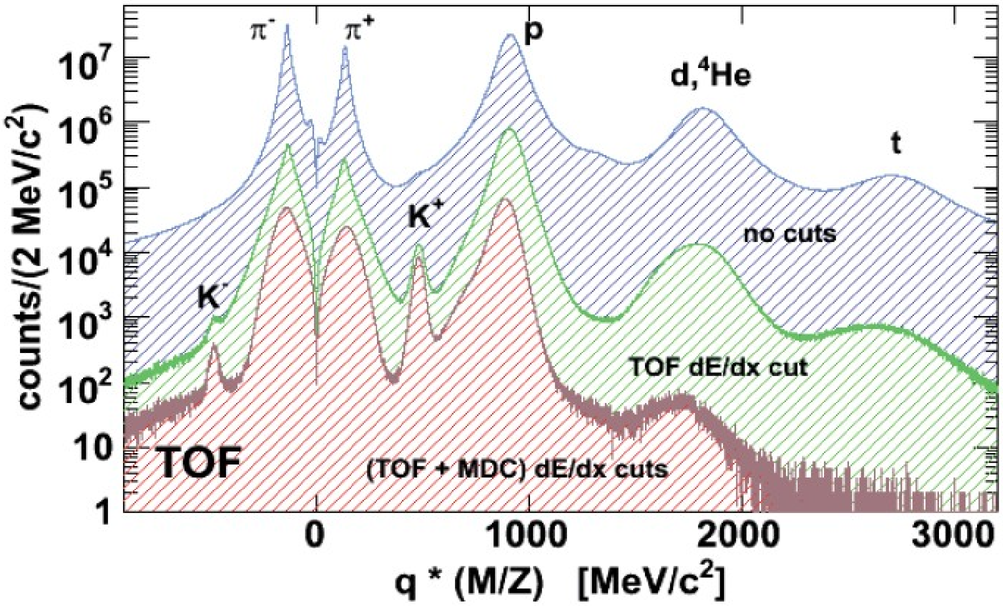
Hadronic models:
Effects restricted to momenta smaller 0.8 GeV
→ ensure acceptance

Results HIC: hadrons

Ar+KCl 1.76 AGeV

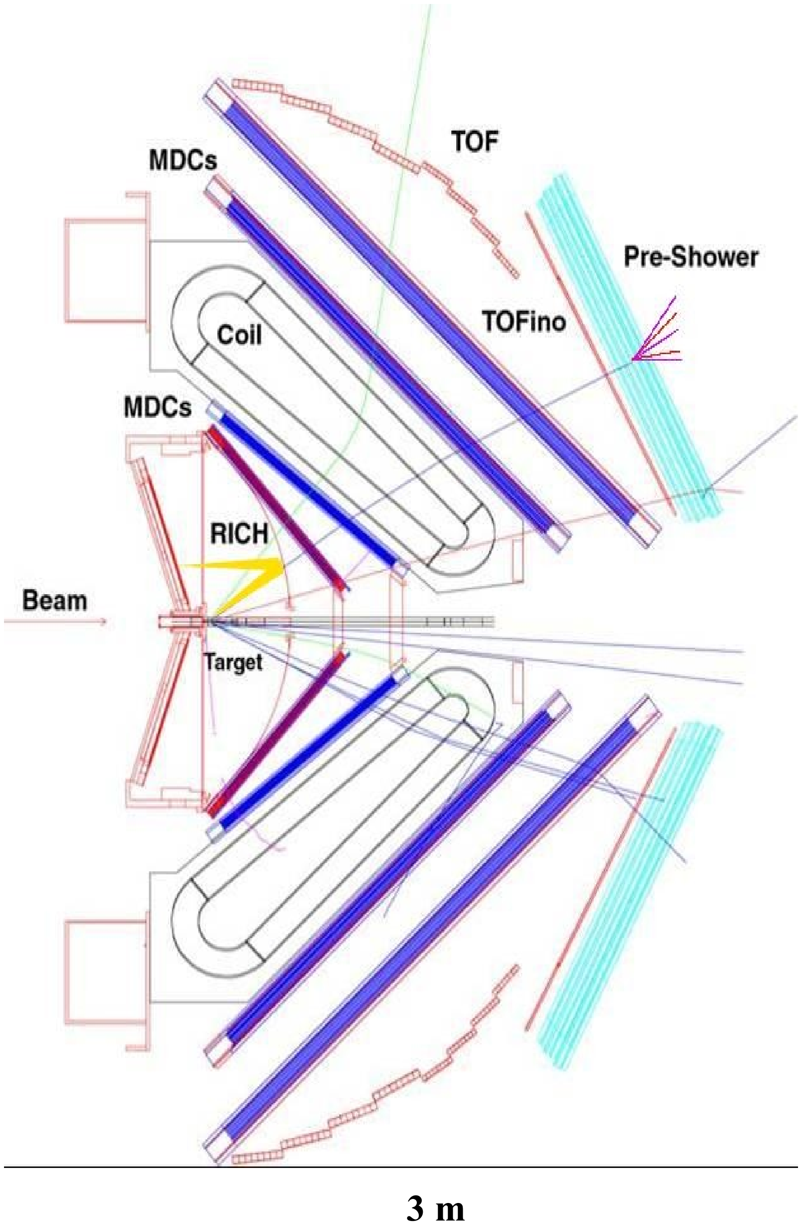
LVL1 Trigger – centrality selection estimated based on UrQMD simulations





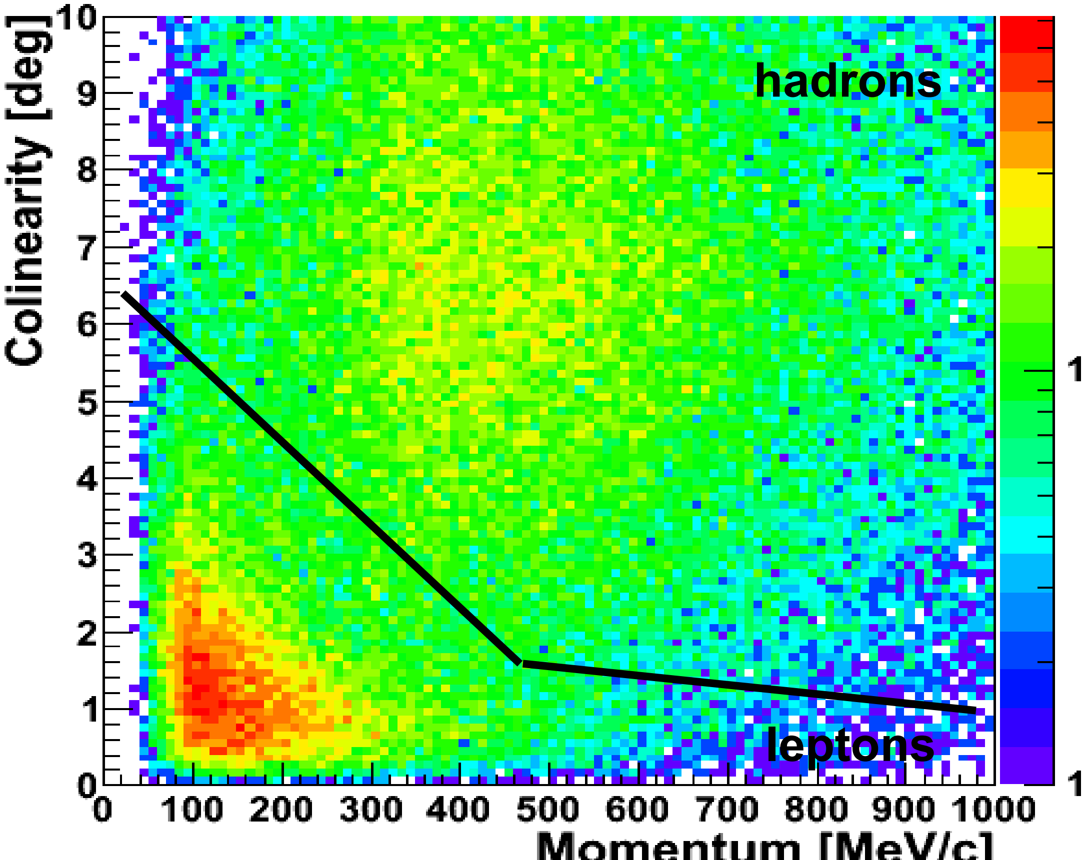
	<b> (fm)	$\langle N_{part.} \rangle$
min. bias	5.83	19.25
LVL1	3.54	38.5

Electron identifcation

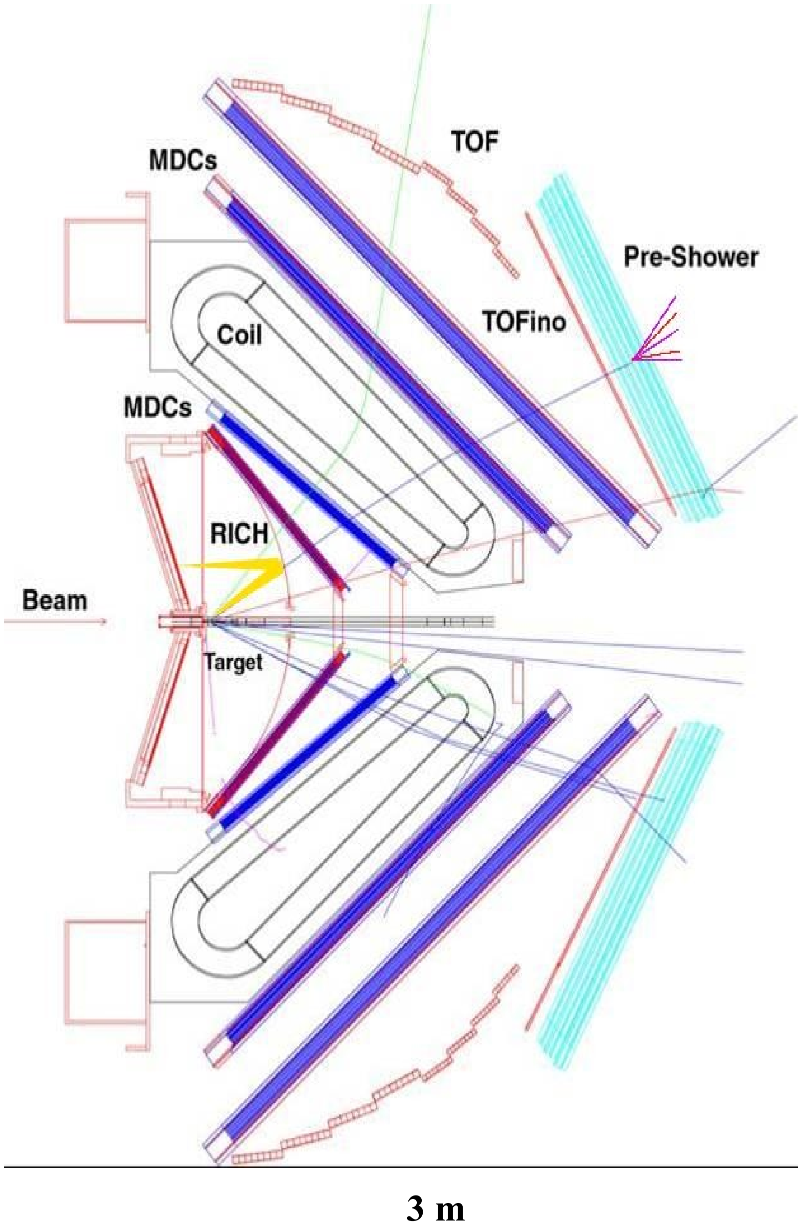


Electron identification:
- RICH
- SHOWER
- dEdx (MDC + TOF-walls)

decision based on a neural network



Electron identifcation



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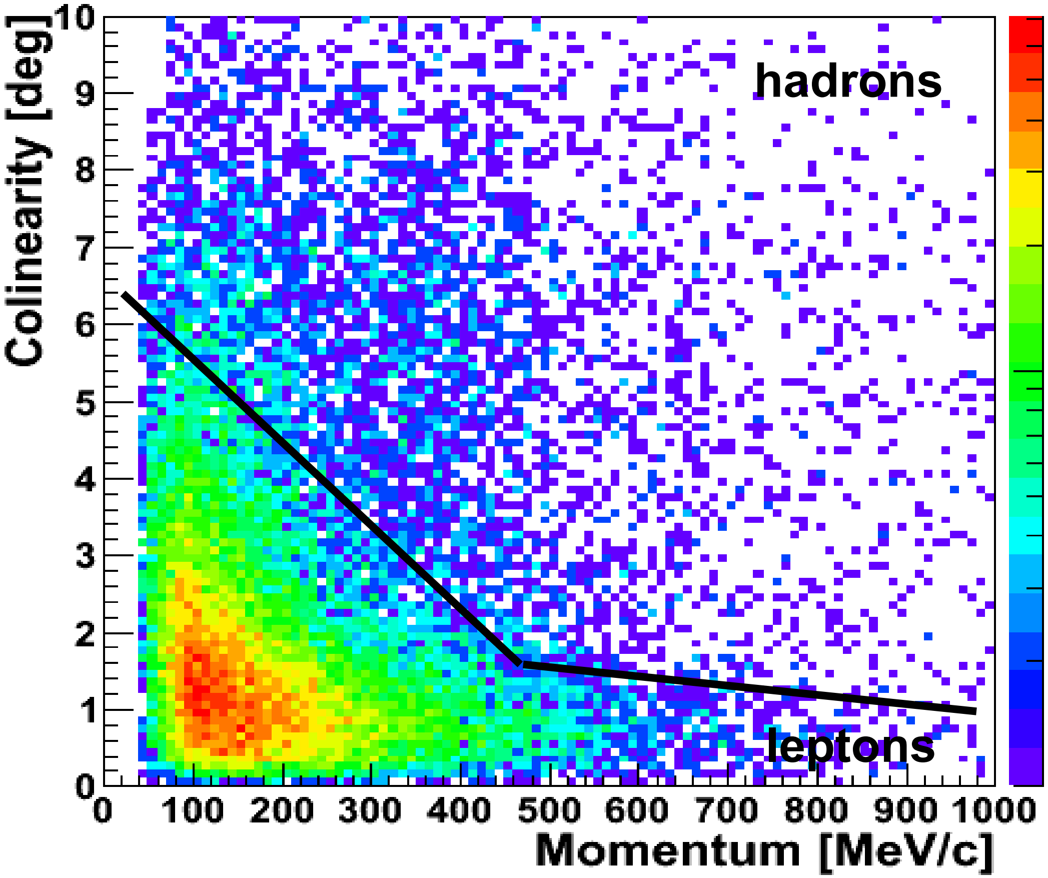
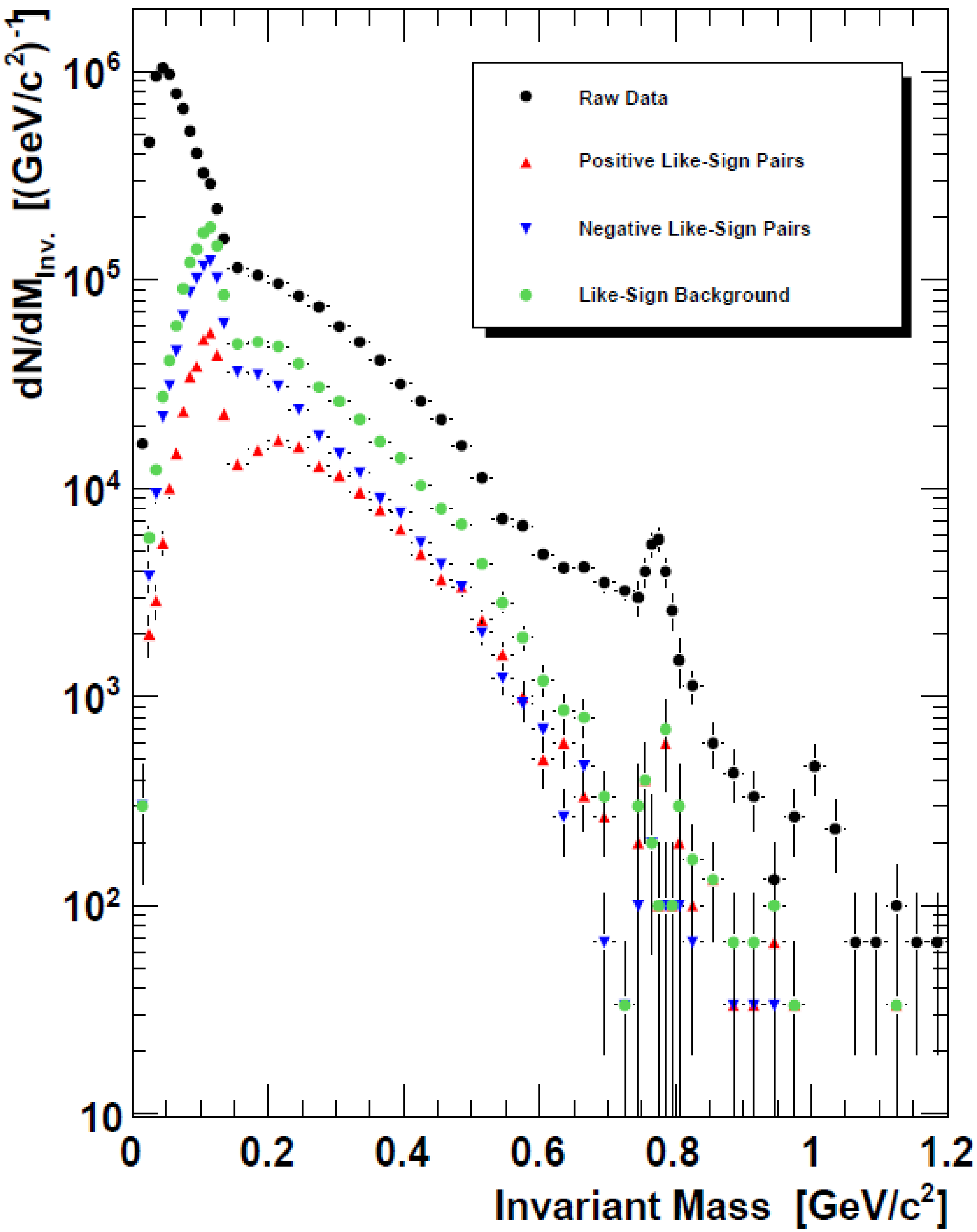
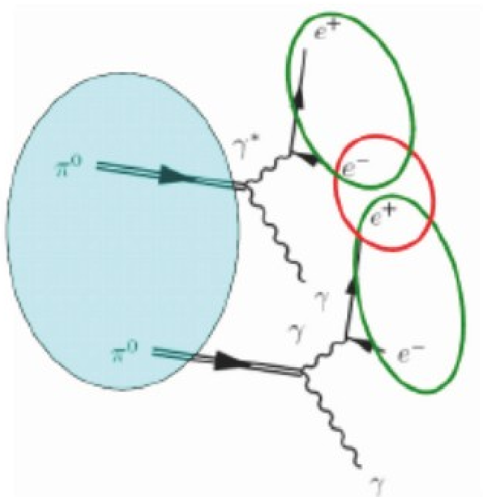


e^+e^- pair reconstruction

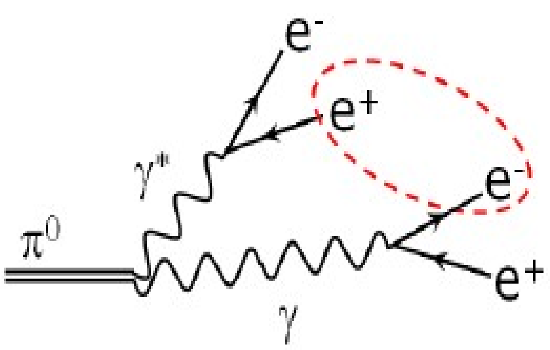


Background sources:

uncorrelated

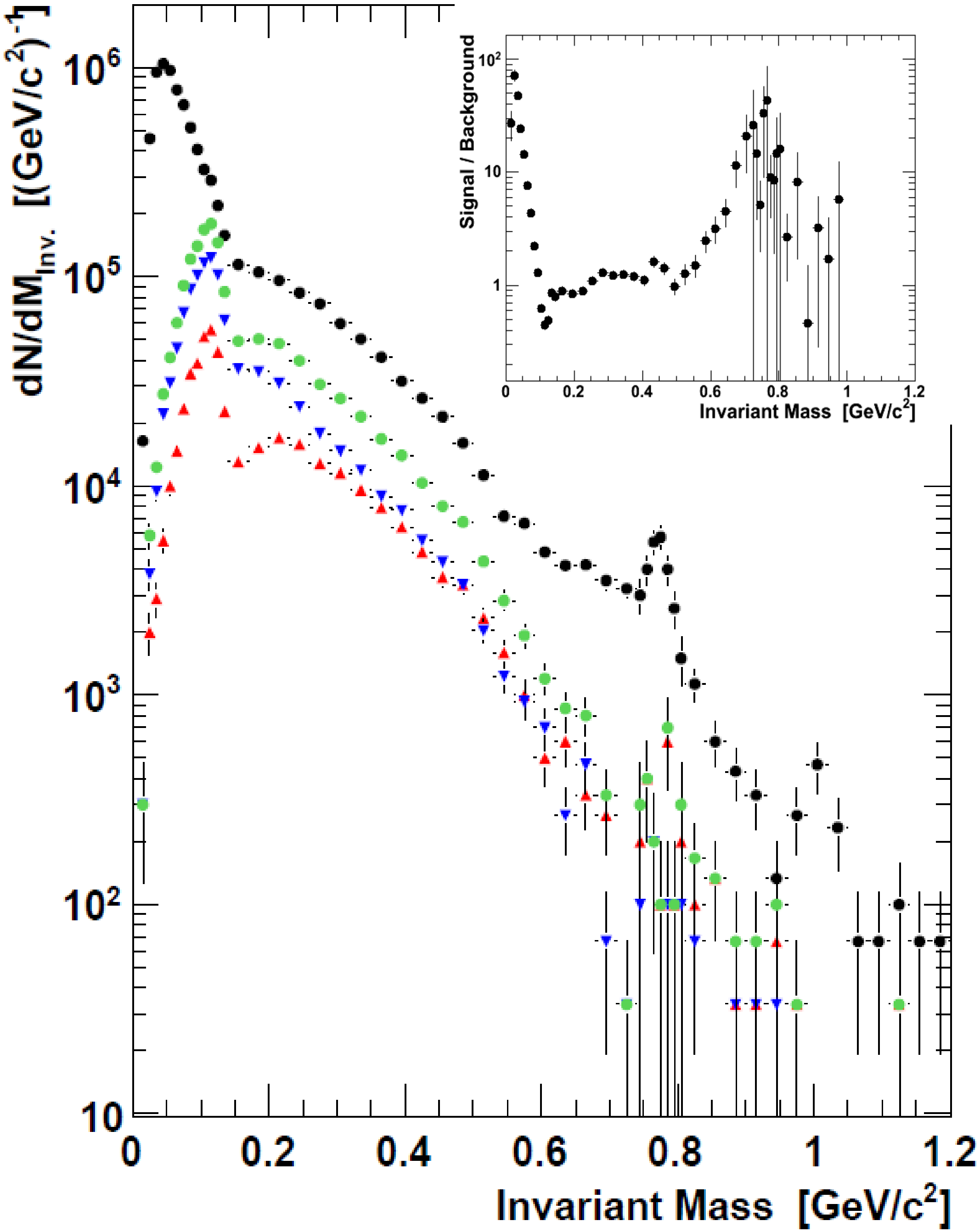


correlated



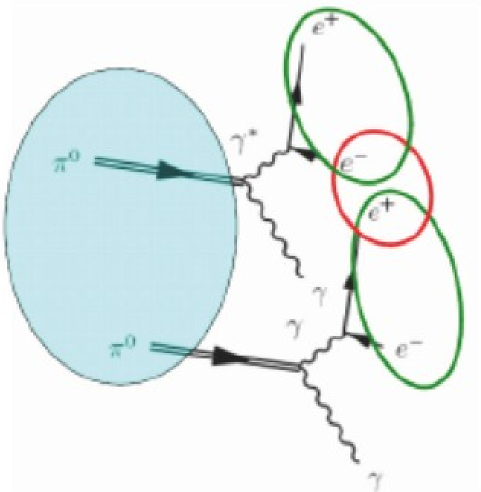
$$U = N_{++} + N_{--}$$

e$^+$e$^-$ pair reconstruction

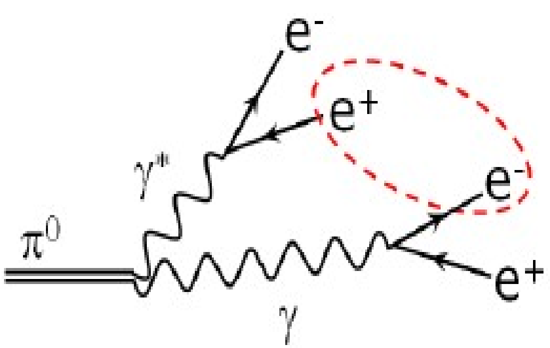


Background sources:

uncorrelated



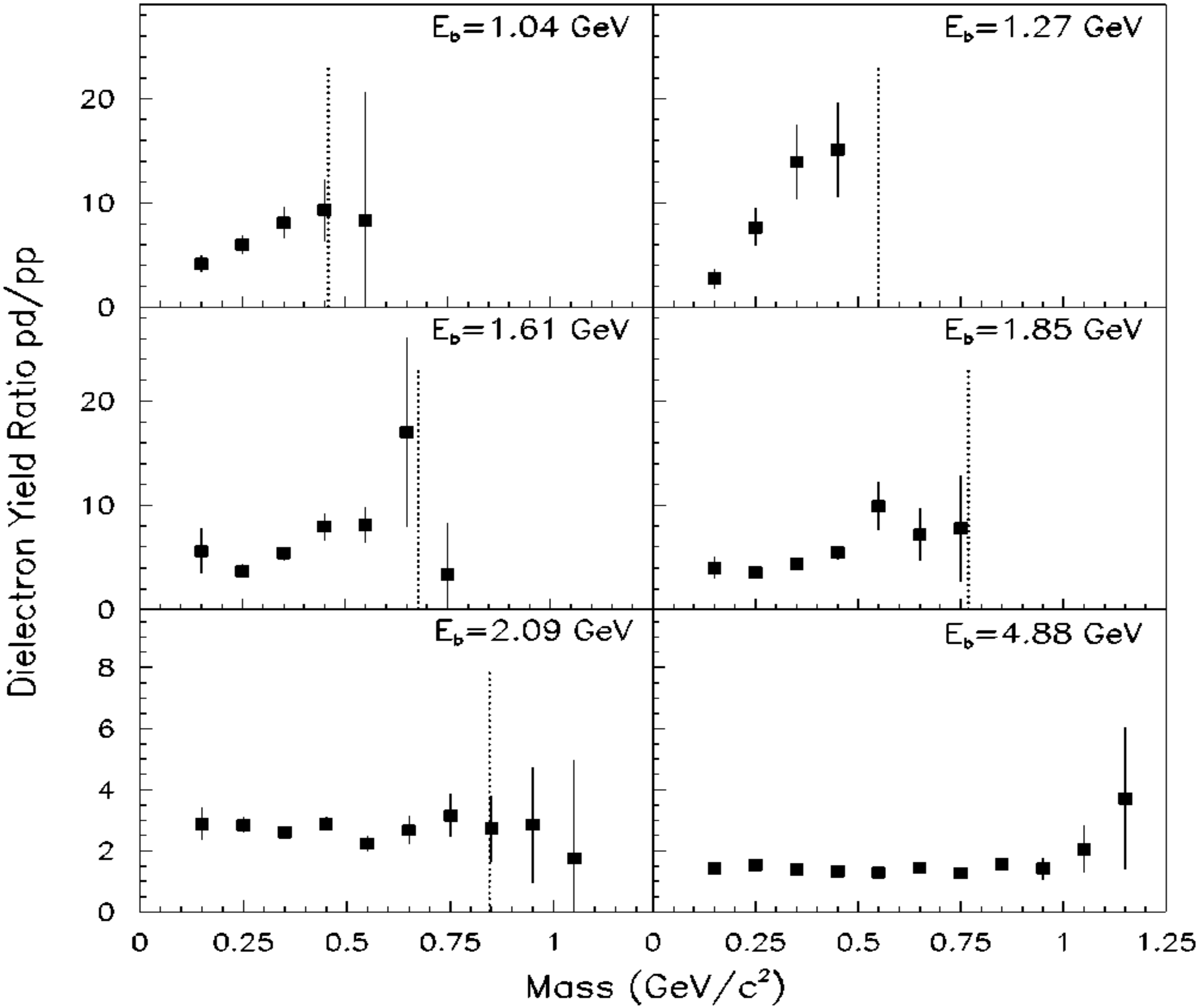
correlated



U = N$_{++}$+N$_{--}$

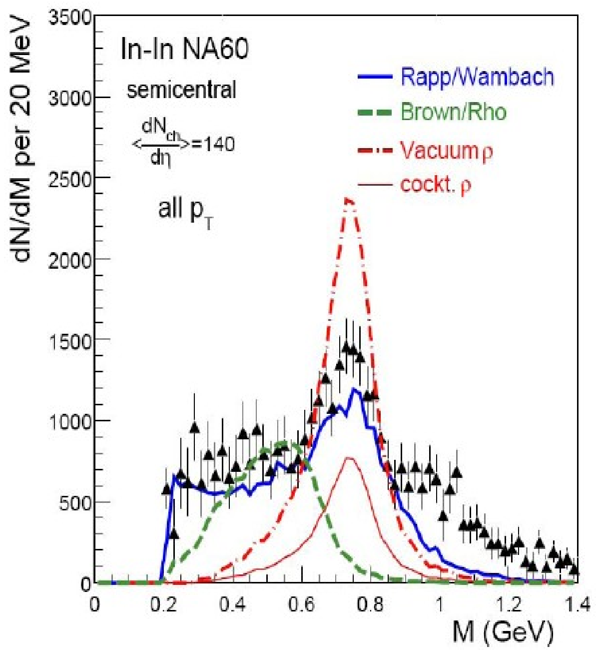
How good is the reference: Isospin effects

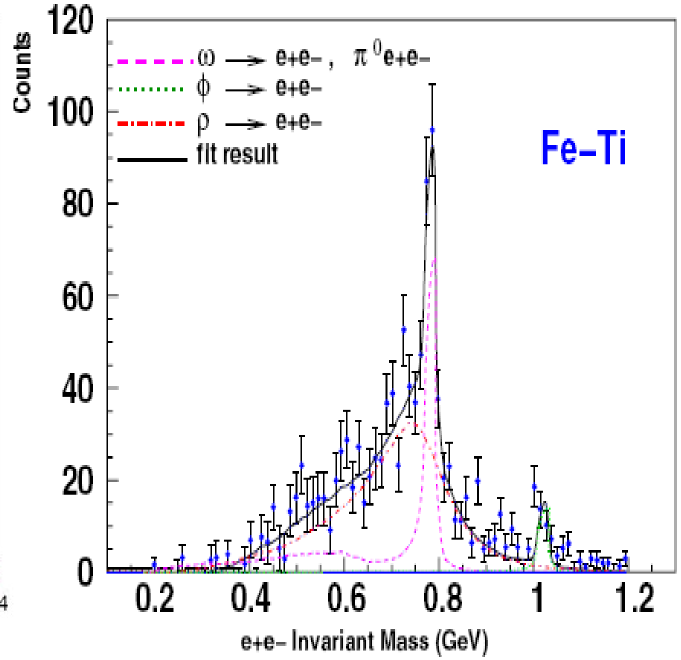
DLS PRC 57 (1998)

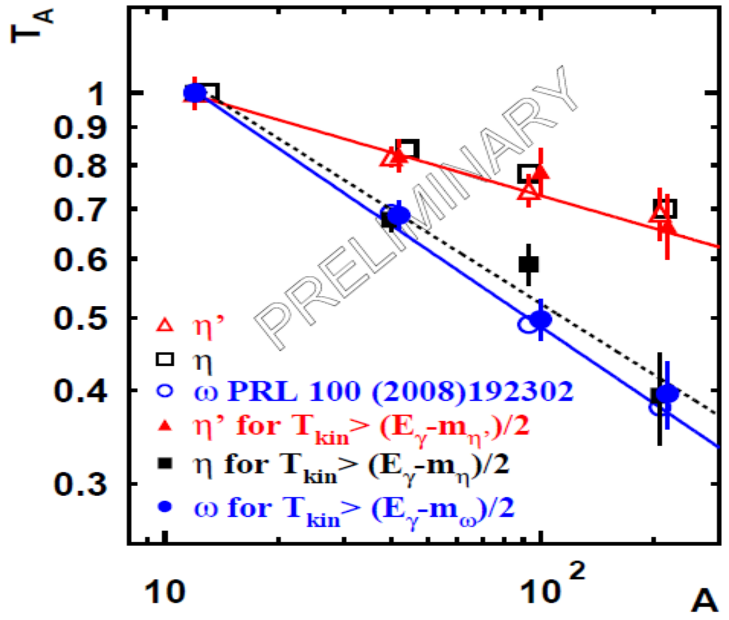


@3.5 GeV apart from the factor 2 due to isospin coefficients no strong effects expected

Data on medium modifications







Direct measurements of the ρ:

HIC

NA60: centrality dependent broadening, no shift

R.Arnaldi et. Al PRL 96 (2006)

Photon induced reactions

Clas: some broadening no shift

Nasseripour et. al., PRL 99 (2007)

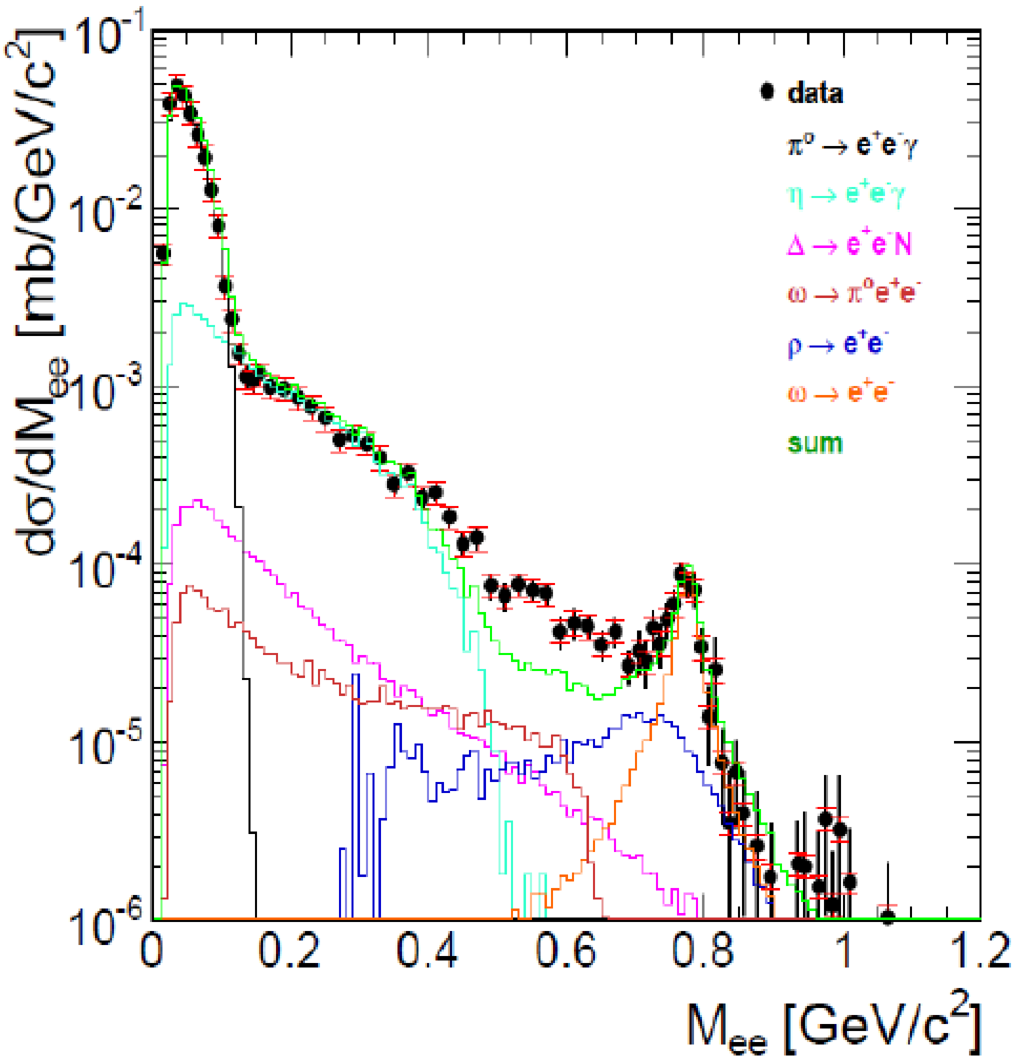
In direct measurements of ω-width:

CBELSA/TAPS: strong broadening (factor ≈16)

M.Nanova private communication

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

Theorectical dielectron cocktail



Problems in treating broad resonances:

- Mass dependent branching ratio

$$\Gamma_{tot}(m) \simeq \Gamma_{\Delta\to\pi N} = \Gamma_{pole}\frac{m_{pole}}{m}\left(\frac{q}{q_{pole}}\right)^{2L+1} \cdot F_{cutoff}$$

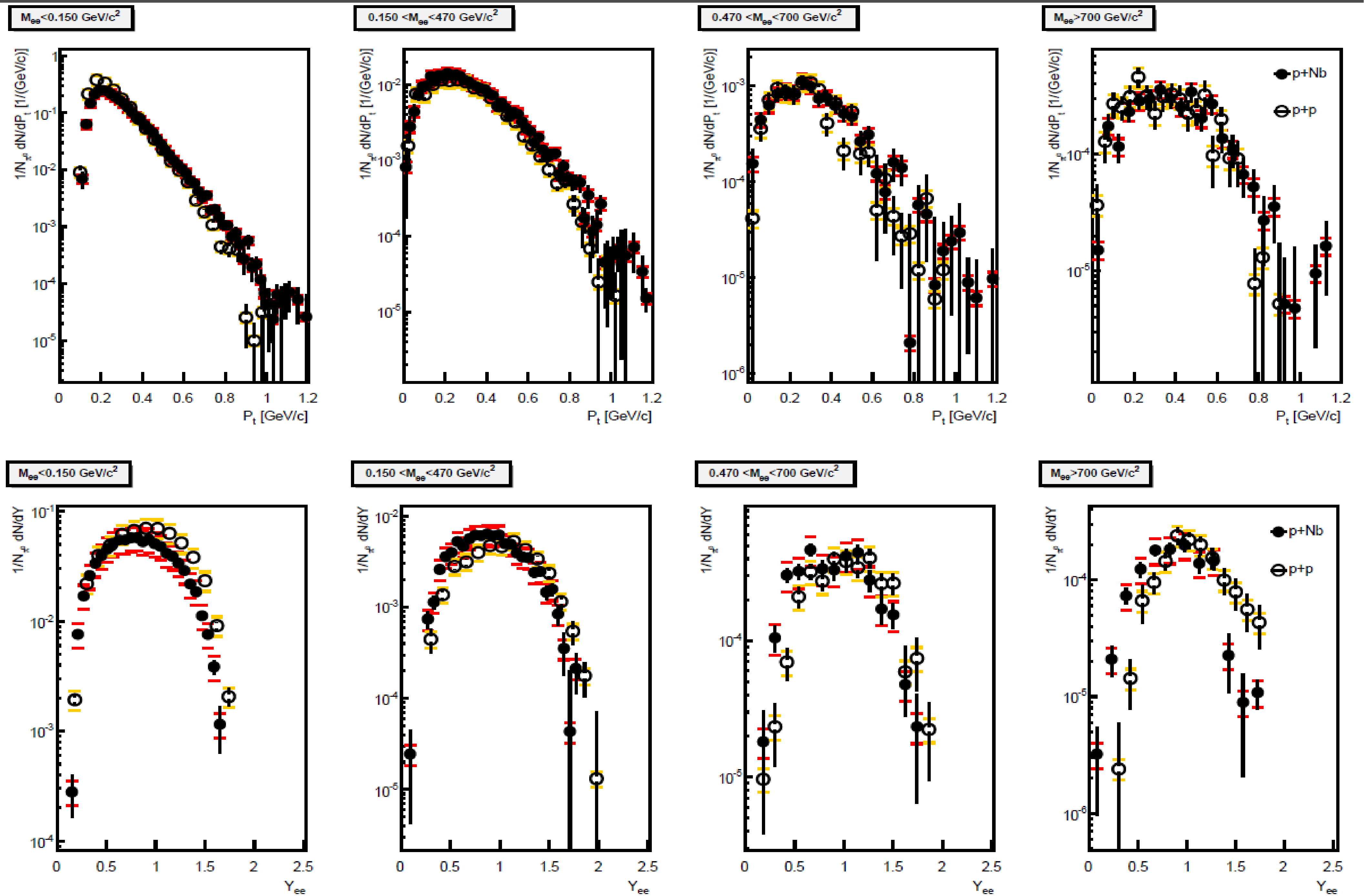
M. I. Krivoruchenko and A. Faessler. Comment on delta radiative and dalitz decays.
Phys. Rev. D, 65(017502), [arXiv:nucl-th/0104045] 2002

•Cut off parameter

$$F_{cutoff} \propto \frac{1}{q^2+\delta^2}$$

D. M. Manley and E. M. Saleski. Multichannel resonance parametrization of pi n scattering amplitudes. Phys. Rev. D, D 45(4002), 1992

•Electromagnetic formfactor:
fixed at the photon point

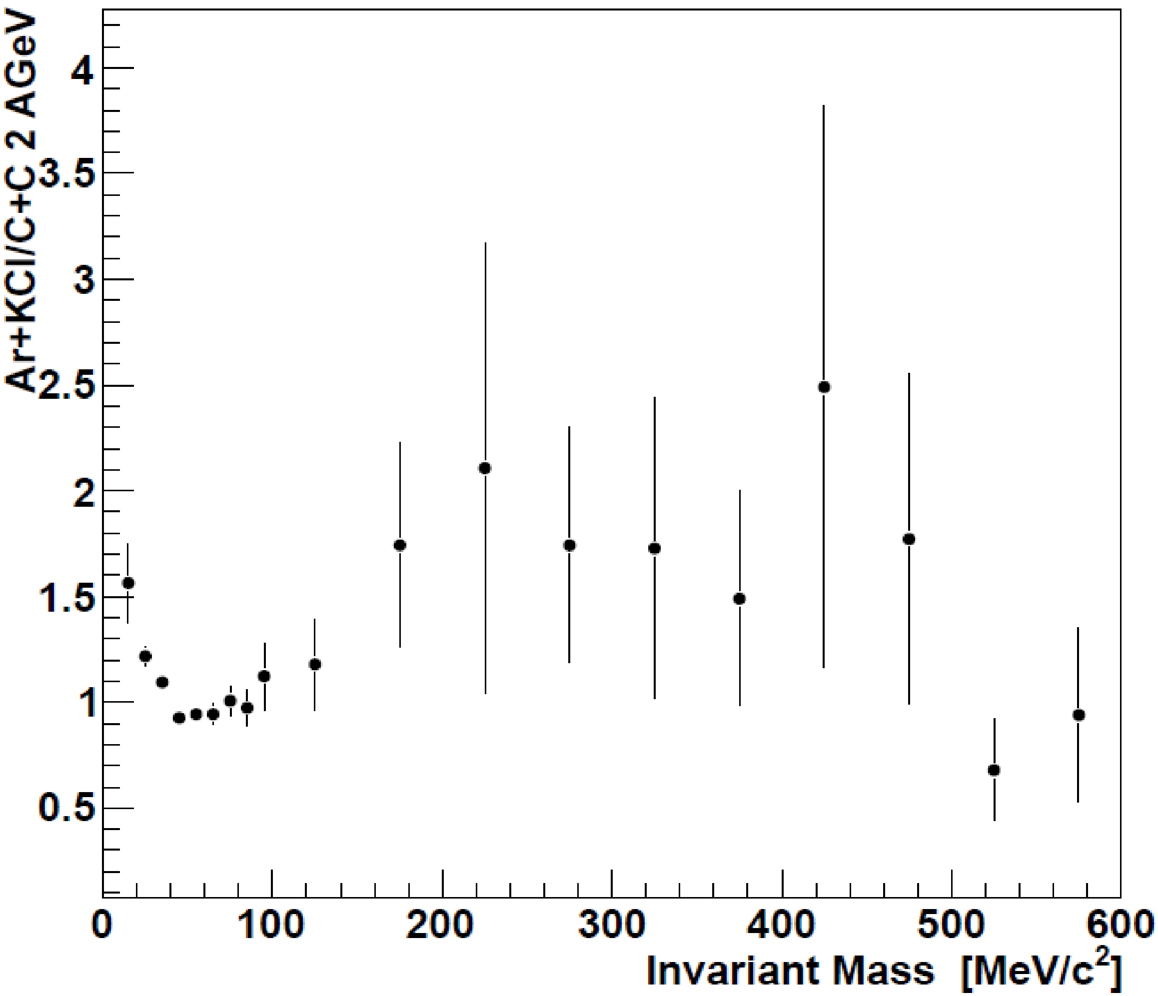


Mee<0.150 GeV/c2
0.150 <Mee<470 GeV/c2
0.470 <Mee<700 GeV/c2
Mee>700 GeV/c2
1/Nπ dN/dPt [1/(GeV/c)]
Pt [GeV/c]
1/Nπ dN/dY
Yee
p+Nb
p+p

invariant mass region	π^0	η	Δ/ρ	vector meson
$< Y >$ (pNb)	0.88	0.92	0.91	0.90
$< Y >$ (pp)	0.97	1.04	1.04	1.06
$< p_t >$ (pNb) $[MeV/c^2]$	0.29	0.26	0.32	0.4
$< p_t >$ (pp) $[MeV/c^2]$	0.28	0.30	0.30	0.34

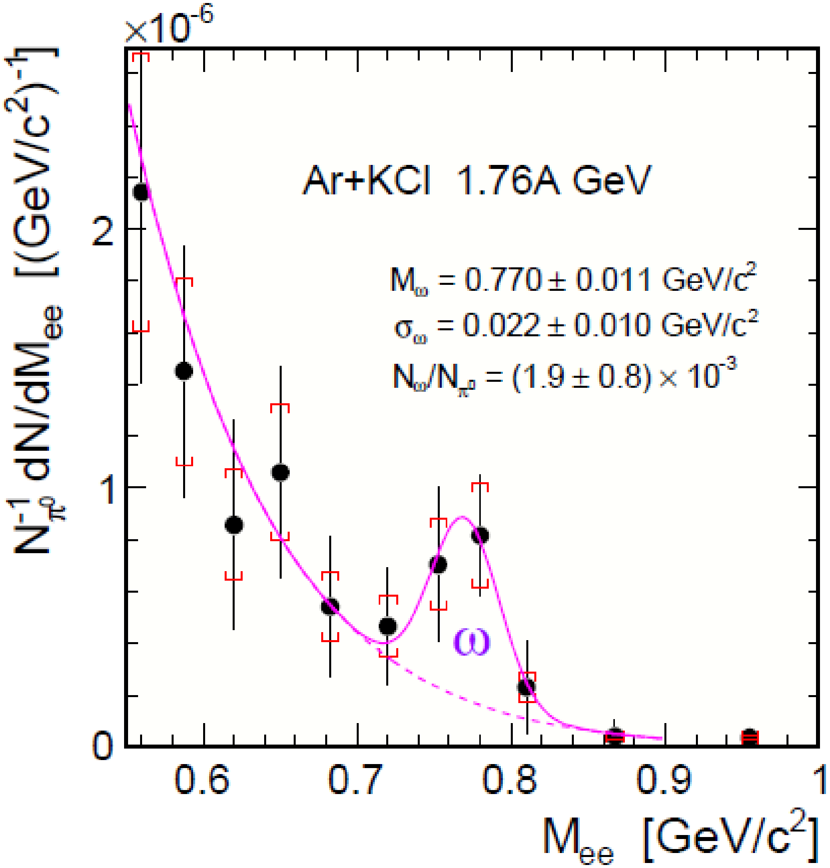
Dileptons: low mass enhancement

The DLS files:
1997: DLS reports on an excess in the low mass region which could not be explained by theory, the case remained unsolved for several years
2008: HADES confirms DLS data
2009: C+C data can be explained by superposition of elementary reactions. Excess is already present in elementary reactions.
2010: HADES Ar+KCl data show a strong excess over the C+C data, what will happen in heavier system Au+Au?



HIC: vector mesons

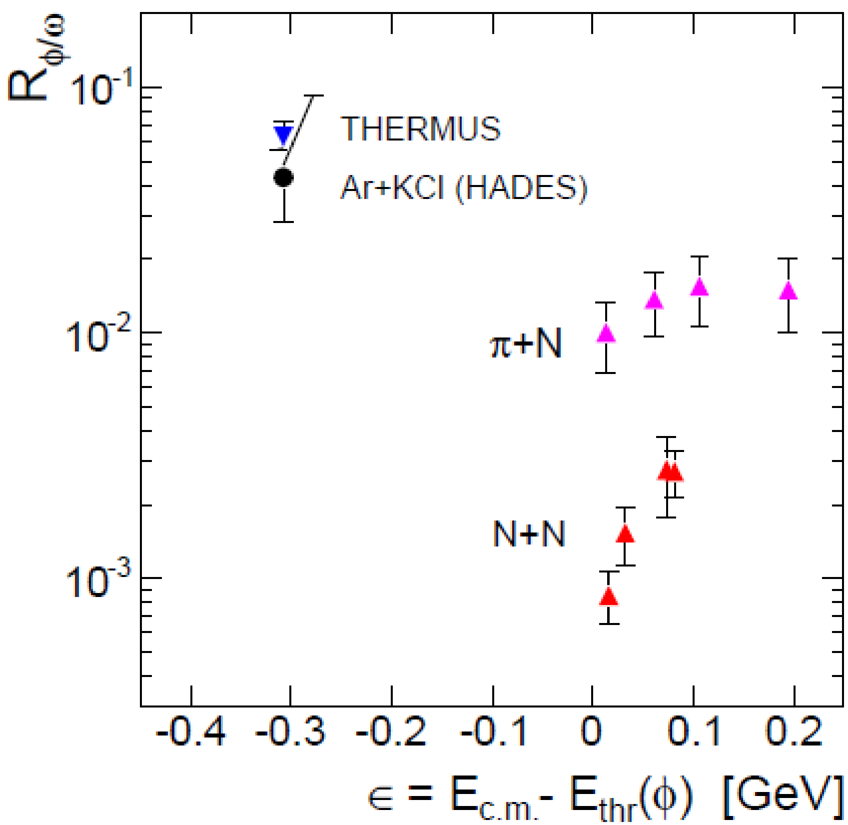
ω-meson:
subthreshold + electromagnetic decay channel: **50 million events for one ω!**



$\phi \rightarrow K^+K^-$, multiplicity: $(2.6 \pm 0.7) \cdot 10^{-4}$

$\omega \rightarrow e^+e^-$, multiplicity: $(6.7 \pm 2.8) \cdot 10^{-3}$

Φ/ω ratio:
suppressed in elementary reactions due to OZI rule



>> $R_{\phi/\omega}$ in NN and πN reactions !
Impact of other channels besides NN and πN ? (e.g. ρN, ρΔ, …) Effect of the medium?

But no indication for modification of the vector meson line shape...

G. Agakishiev et al. [HADES Collaboration]. Dielectron production in Ar+KCl collisions at 1.76A GeV. Phys. Rev., C84(014902), [arXiv:1103.0876 [nucl-ex]]. 2011

Momentum dependence

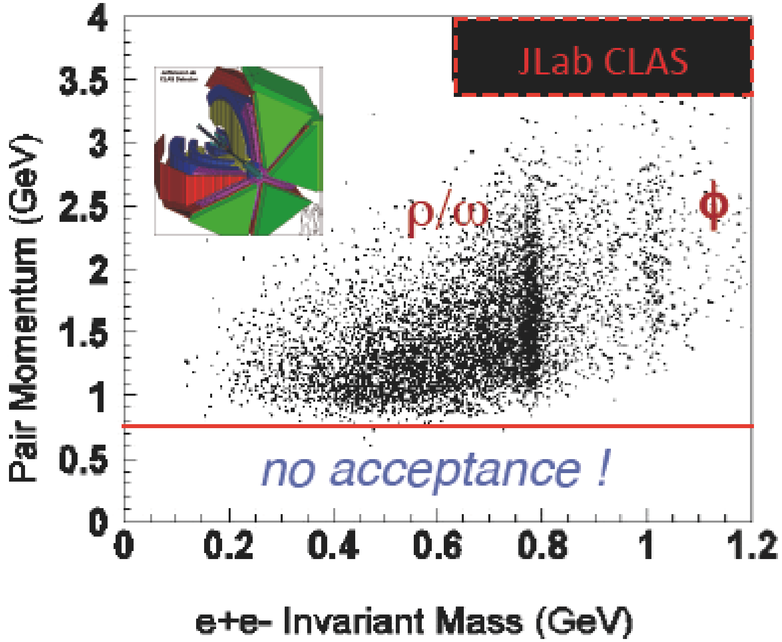
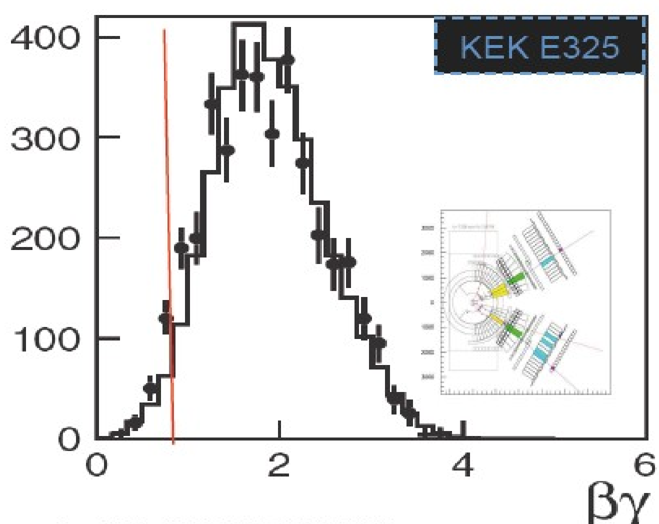
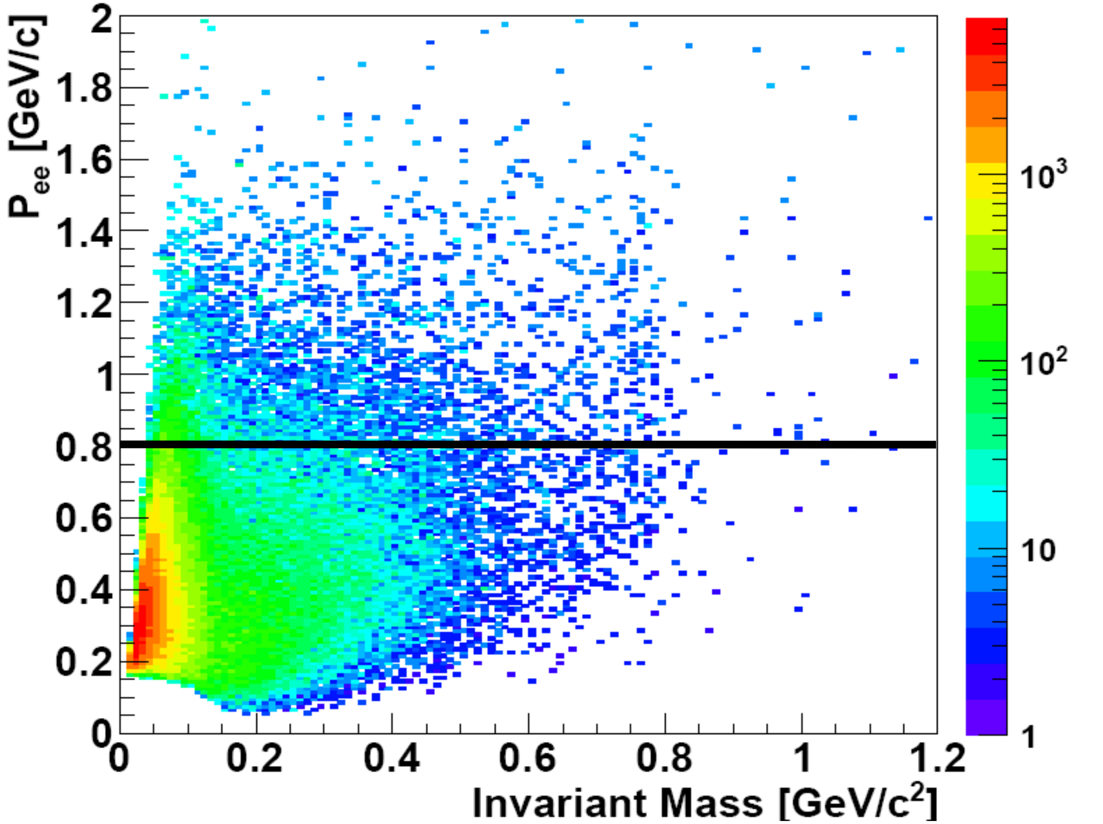


Fig. from S.Leupold et al., nucl-th 0907.2388

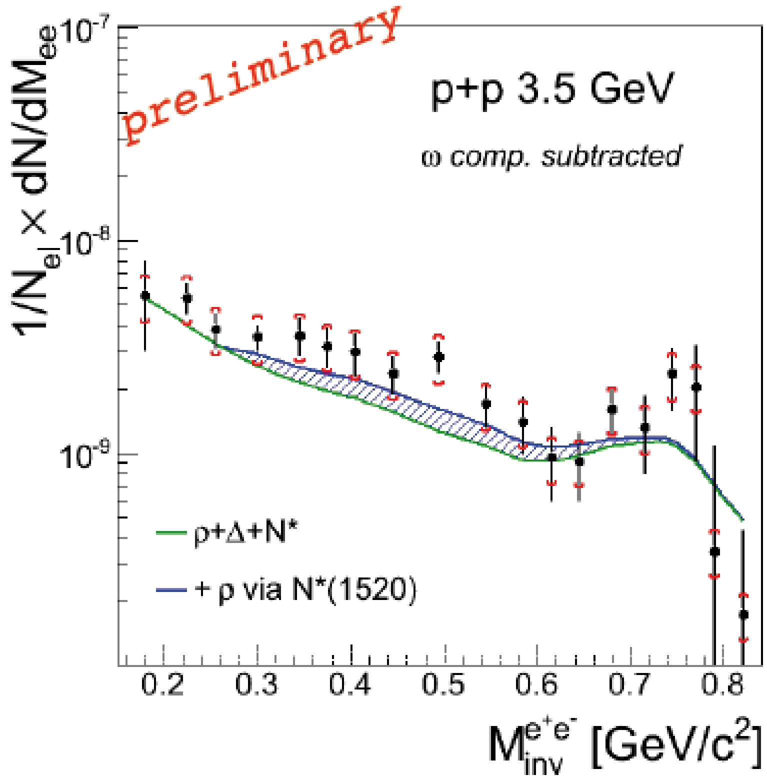


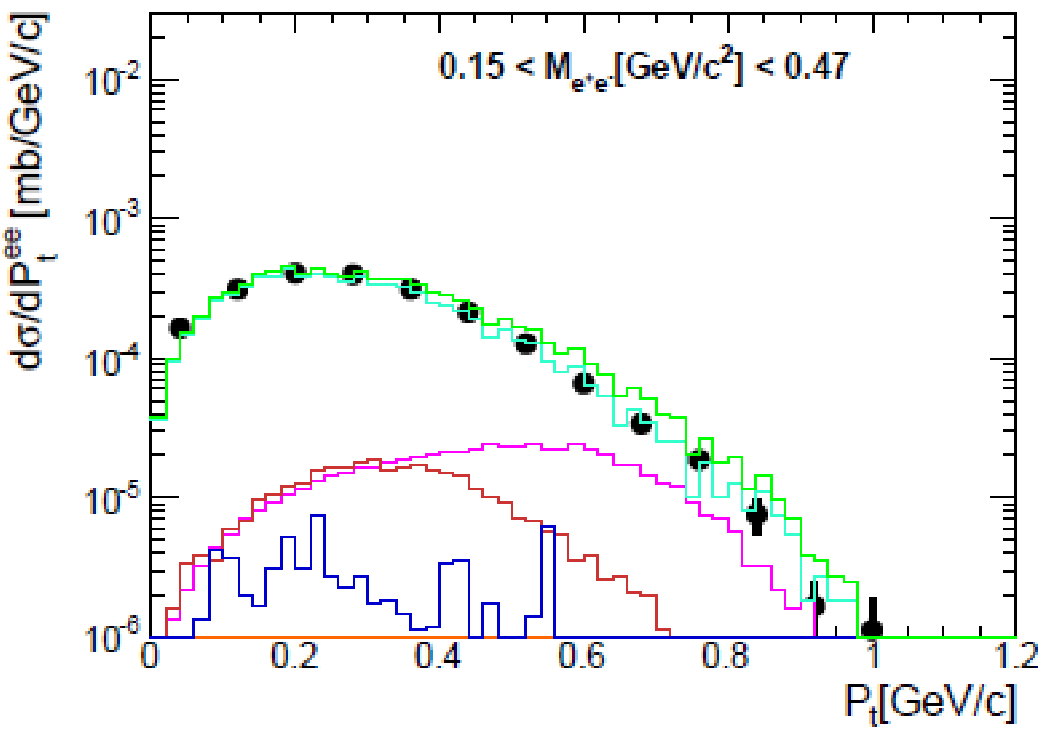
R.Muto et al., PRL 98 (2007) 042501



Compared to CLAS and KEK-E325 better coverage of slow vector mesons
→ compare slow and fast vm with pp reference

The origin of mass





0.15 < M[GeV/c2] < 0.47
dσ/dPt [mb/GeV/c]
Pt[GeV/c]