Dilepton production in elementary reactions

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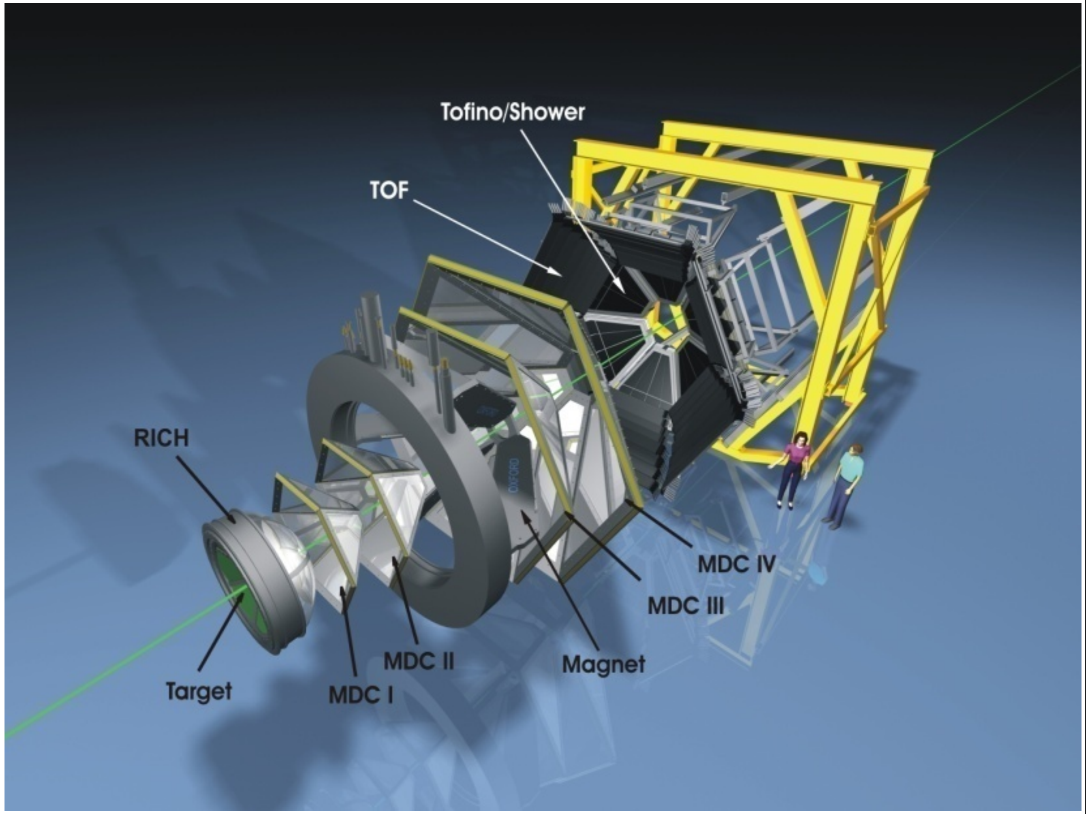
Outline

- Introduction
- The HADES experiment
- Experimental data
  - p+p data at 3.5 GeV
  - p+p and n+p data at 1.25 GeV
- Summary

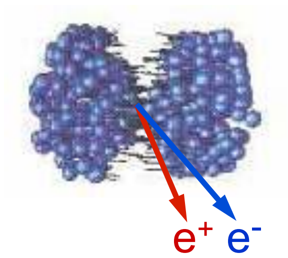
HADES spectrometer

- **Acceptance**
  - φ ~ 2π
  - $15^o < \theta < 85^o$
  - pair ~ 30%
- **Momentum resolution**
  - Magnet: 0.1-0.34 Tm
  - MDC: 24 drift chambers
  - σ_m~ 2% at ρ/ω region
- **Particle identification**
  - RICH
  - Time of flight
  - Pre-Shower
  - MDC (for hadrons)
- **Trigger**
  - LVL1- charged particle mult.
  - LVL2- single electron trigger

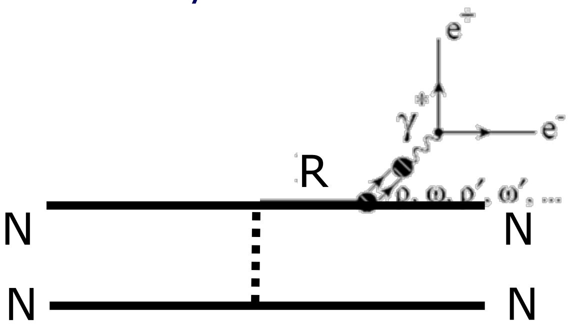


Motivation

Dilepton sources at 1-2A GeV



first chance collisions
elementary collision of nucleons

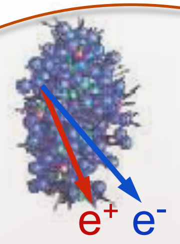


PRL 98, 052302 (2008)

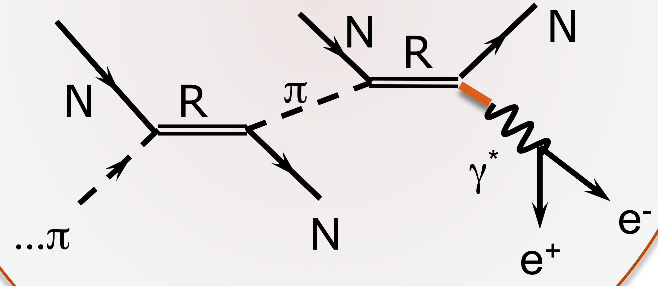
PLB 663 (2008) 43-48

PLB 690 (2010)118

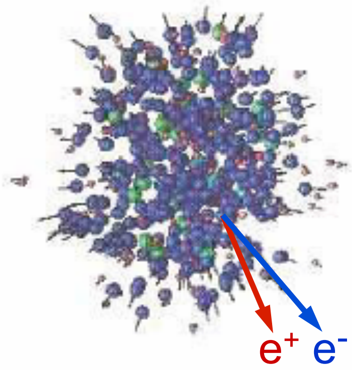
PRC 84 (2011) 014902



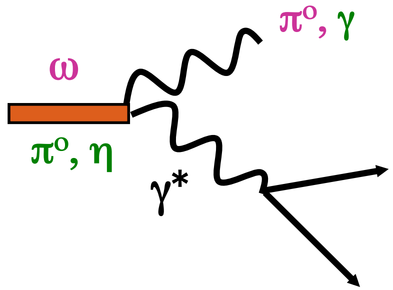
hot and dense phase
multistep production
of resonances and mesons

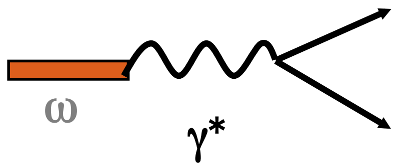


need for the elementary reactions!



freeze –out
decays of (long-lived)
states (π^0, η, ω)

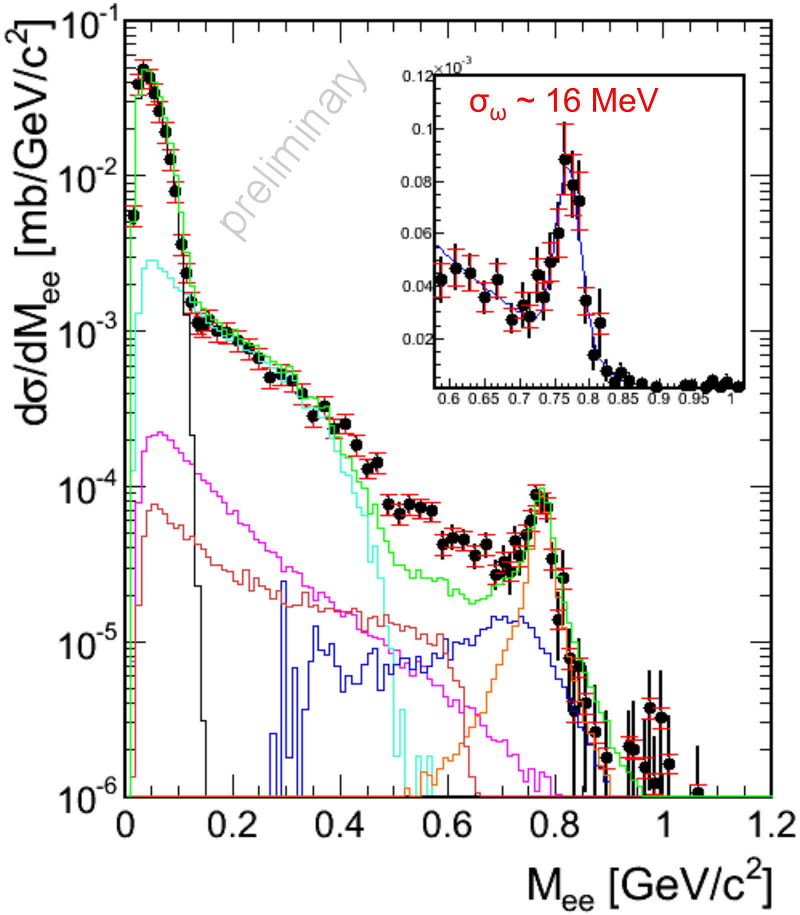




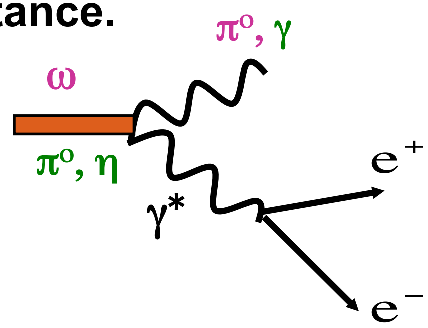
pp data at E_{kin}= 3.5 GeV

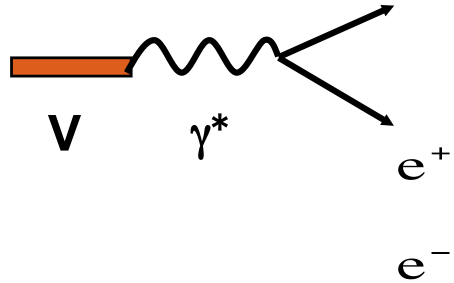
Invariant mass spectra

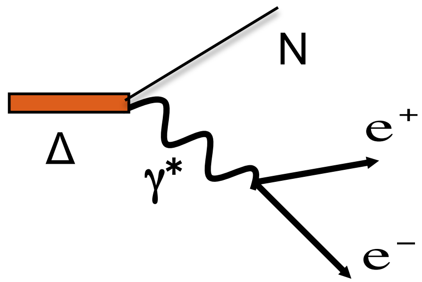
efficiency corrected. Inside HADES acceptance.
normalized to the p+p elastic scattering



pp → $e^+ e^-$ +X (inclusive spectrum)



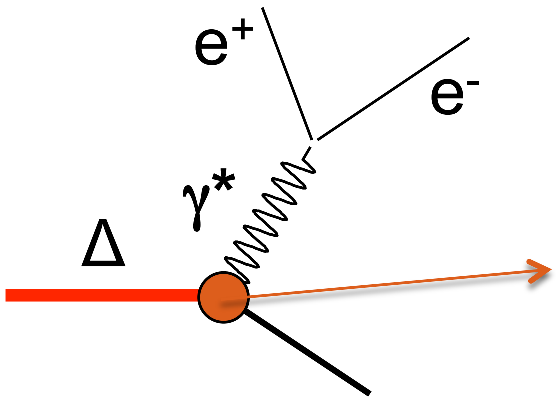




QED calculations
+
transition form factors
(known for mesons)

- What about production part?
  - inclusive cross sections
    - not known
  - production mechanism
    - **different models**

N-Delta transition form factors



$$q^2 = q_\mu(E,-\vec{q})q^\mu(E,\vec{q}) = E^2 - |\vec{q}|^2$$

$$q^2_{\gamma*} = M^2_{e^+e^-} = M^2_{\gamma*} > 0 \text{ (time like photon)}$$

$$\langle J_\Delta \lambda_\Delta | S | \lambda_N \lambda_{\gamma*} \rangle, \quad \lambda_\Delta = \lambda_{\gamma*} - \lambda_N, \quad \lambda_{\gamma*} = 0, \pm 1, \quad \lambda_N = \pm\frac{1}{2}$$

$$\left\langle J_\Delta \frac{3}{2} \middle| S \middle| -\frac{1}{2} 1 \right\rangle, \left\langle J_\Delta \frac{1}{2} \middle| S \middle| +\frac{1}{2} 1 \right\rangle, \left\langle J_\Delta \frac{1}{2} \middle| S \middle| -\frac{1}{2} 0 \right\rangle$$

$$\frac{d\Gamma(\Delta \to Ne^+e^-)}{dq^2} = \frac{\alpha^2}{48\pi} \frac{(m_\Delta + m_N)^2}{q^2 m_\Delta^3 m_N^2} \left[(m_\Delta + m_N)^2 - q^2\right]^{\frac{1}{2}} \left[(m_\Delta - m_N)^2 - q^2\right]^{\frac{3}{2}} |F(q^2)|^2$$

$$|F(q^2)|^2 = |G_M(q^2)|^2 + 3|G_E(q^2)|^2 + \frac{q^2}{2m_\Delta^2}|G_C(q^2)|^2$$

- ✧ only model calculations for q^2 dependance is known!
- ✧ from measured radiative decay width: $G_M(0) \approx 3$, $G_E(0) = 0$, $G_C(0)$ – not defined

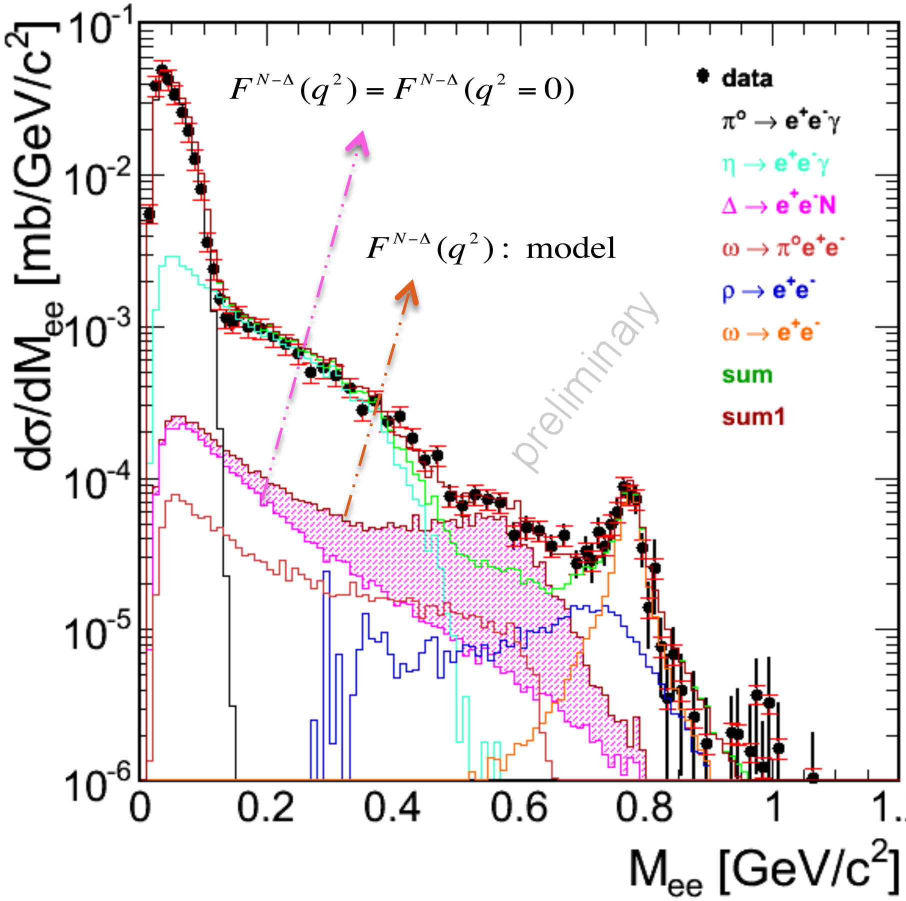
Coulomb gauge: (**εq**)=0

- ➢ different options
  - ➢ $F(q^2) = F(0)$
  - ➢ use model calculations

M. Krivoruchenko et al. Phys.Rev.D 65, 017502, M. Zetenyi and Gy. Wolf, Heavy Ion Phys.17:27-39,2003

Invariant Mass

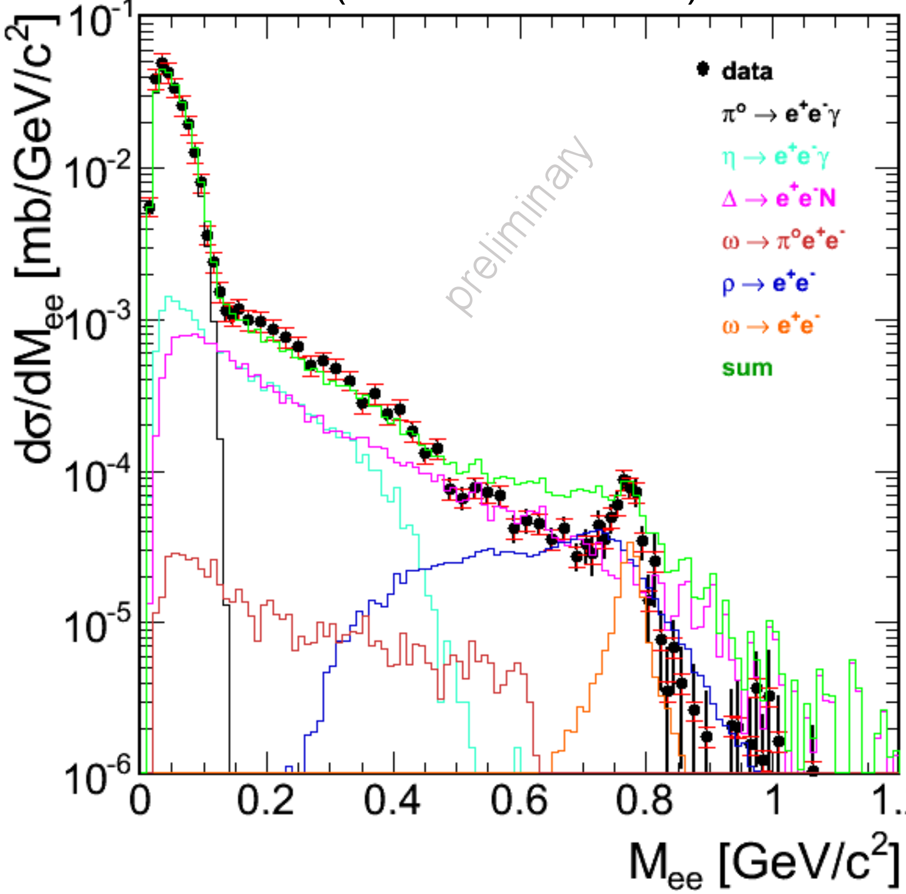
PYTHIA (production) + PLUTO (decay part)



$F^{N-\Delta}(q^2)$ model : Q. Wan and F. Iachello, Int. J. Mod. Phys. A20, 1846 (2005)

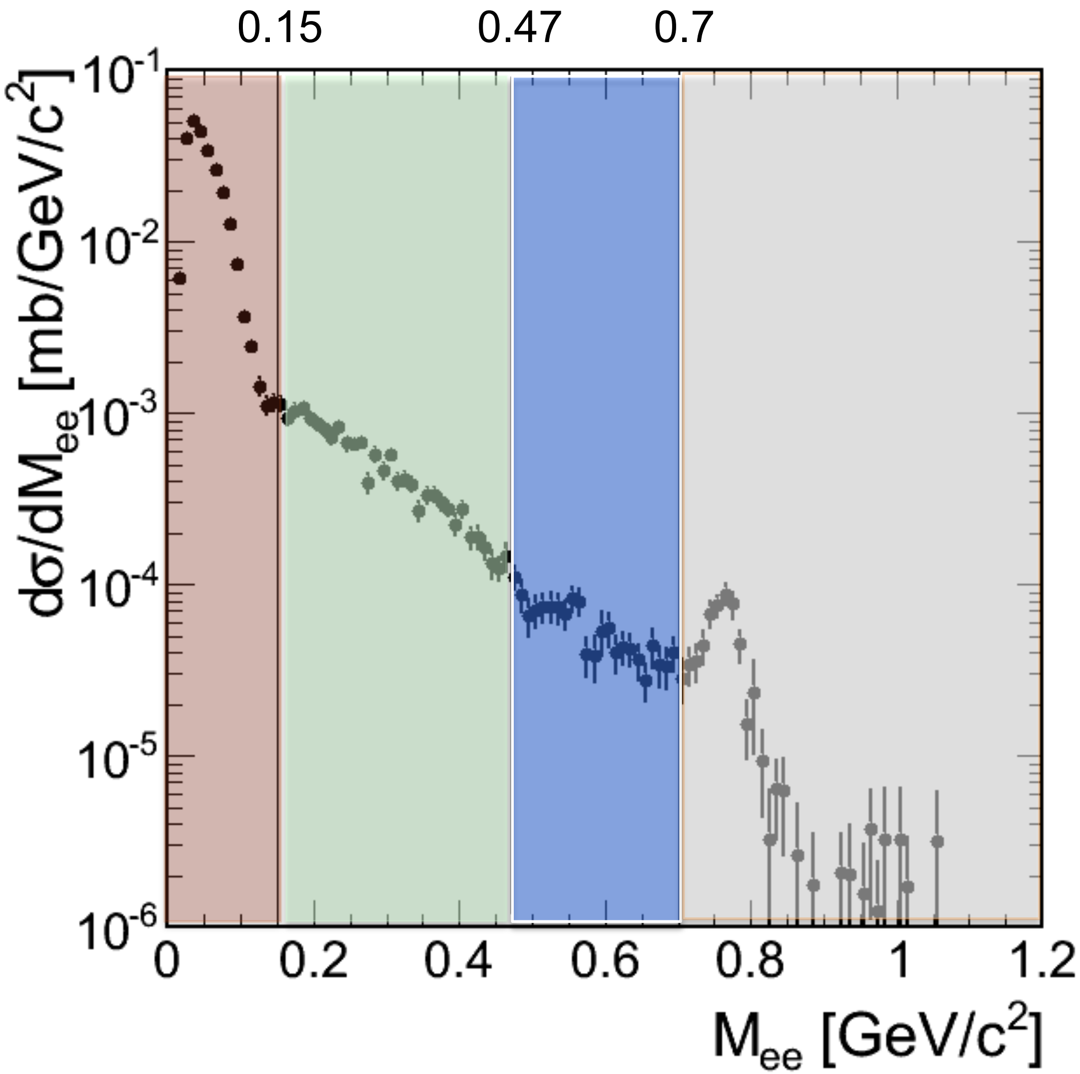
PLUTO: I. Fröhlich et al, arxiv:0708.2382

UrQMD
(resonance model)



UrQMD: K. Schmidt, et al.
Phys. Rev. C **79**, 064908 (2009)

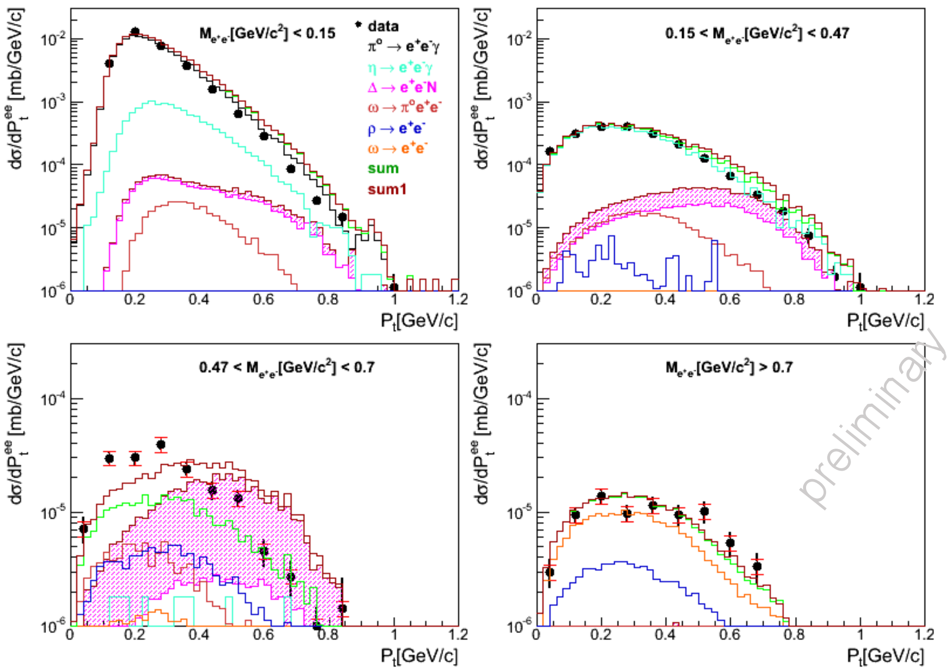
Mass bin selections



Transverse momentum

PYTHIA+PLUTO

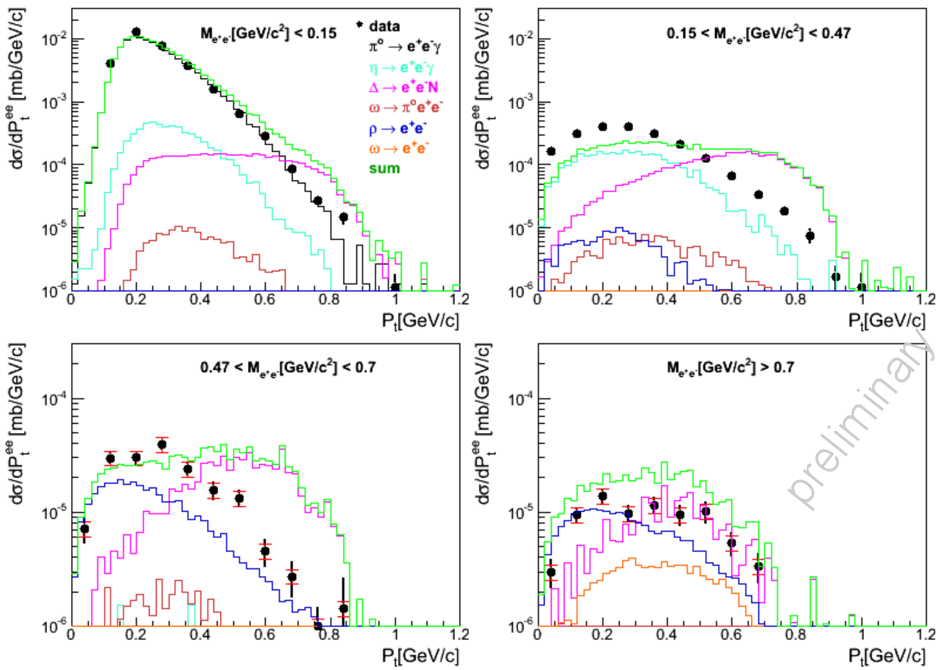
$M_{e^+e^-}[GeV/c^2] < 0.15$ $0.15 < M_{e^+e^-}[GeV/c^2] < 0.47$



$0.47 < M_{e^+e^-}[GeV/c^2] < 0.7$ $M_{e^+e^-}[GeV/c^2] > 0.7$

UrQMD (resonance model)

$M_{e^+e^-}[GeV/c^2] < 0.15$ $0.15 < M_{e^+e^-}[GeV/c^2] < 0.47$

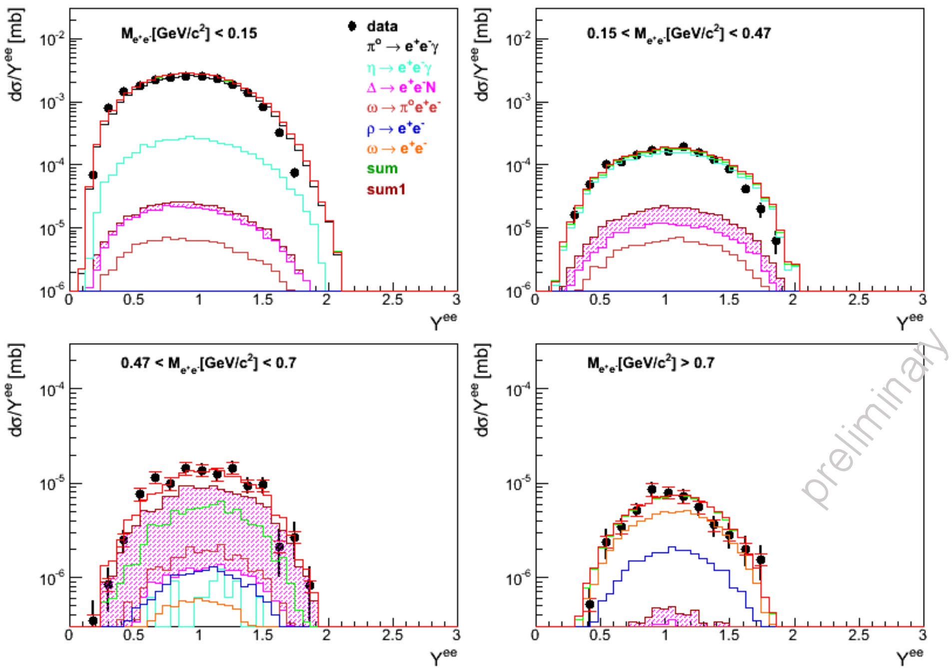


$0.47 < M_{e^+e^-}[GeV/c^2] < 0.7$ $M_{e^+e^-}[GeV/c^2] > 0.7$

Rapidity

PYTHIA+PLUTO

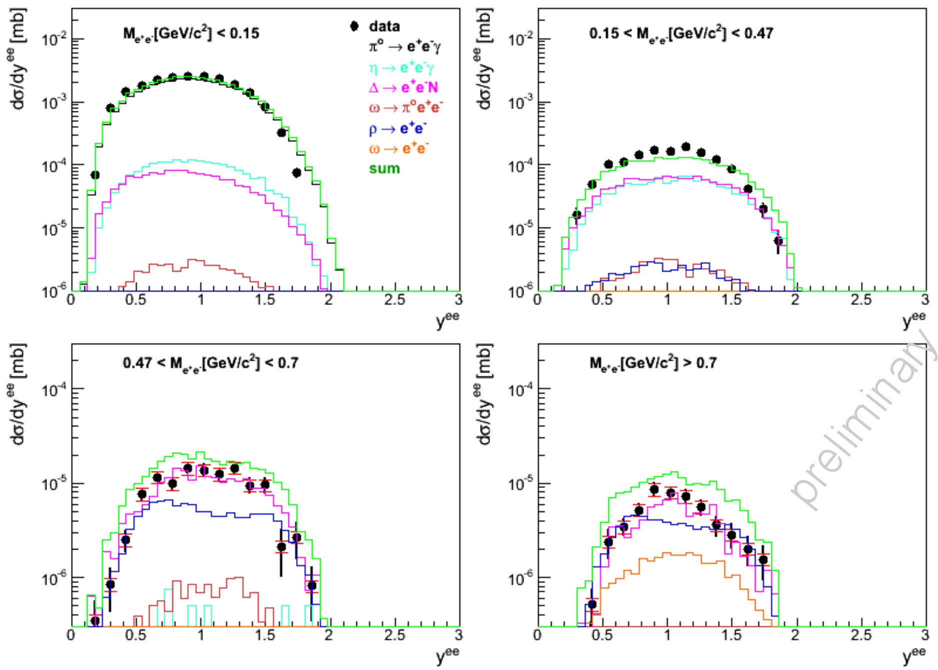
$M_{e^+e^-}[GeV/c^2] < 0.15$ | $0.15 < M_{e^+e^-}[GeV/c^2] < 0.47$



$0.47 < M_{e^+e^-}[GeV/c^2] < 0.7$ | $M_{e^+e^-}[GeV/c^2] > 0.7$

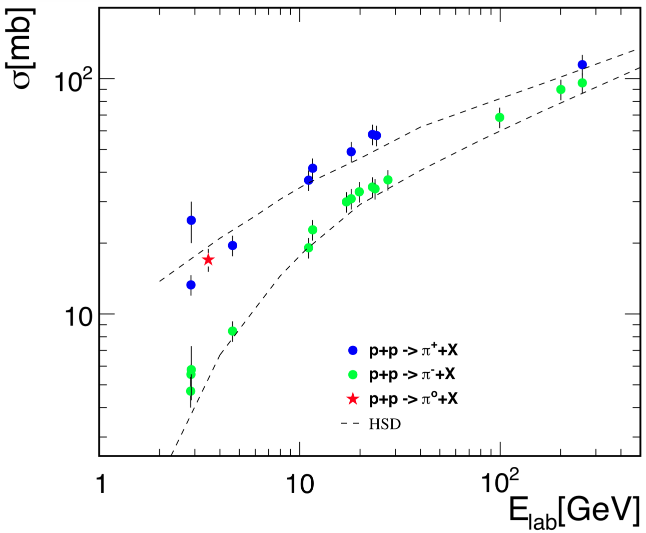
UrQMD (resonance model)

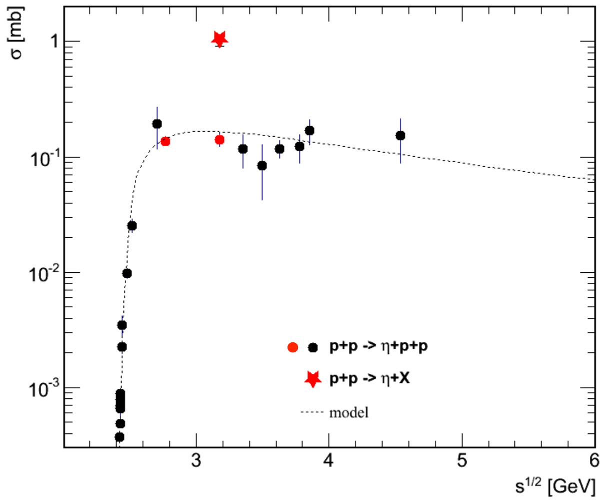
$M_{e^+e^-}[GeV/c^2] < 0.15$ | $0.15 < M_{e^+e^-}[GeV/c^2] < 0.47$

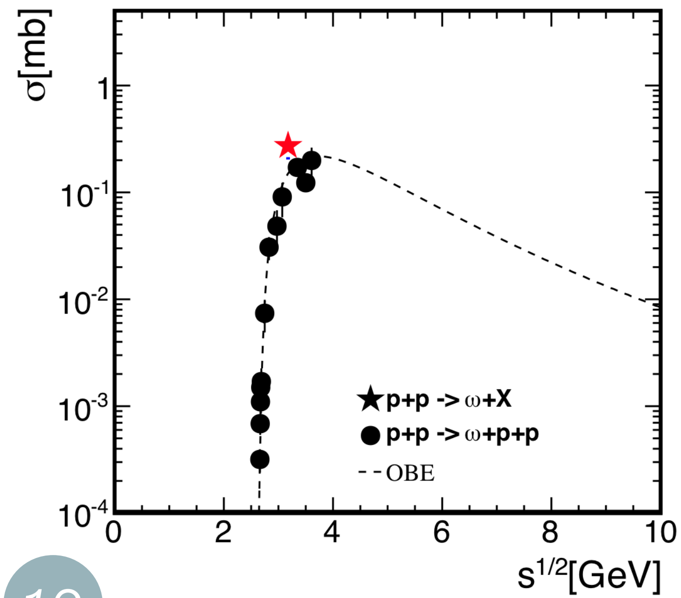


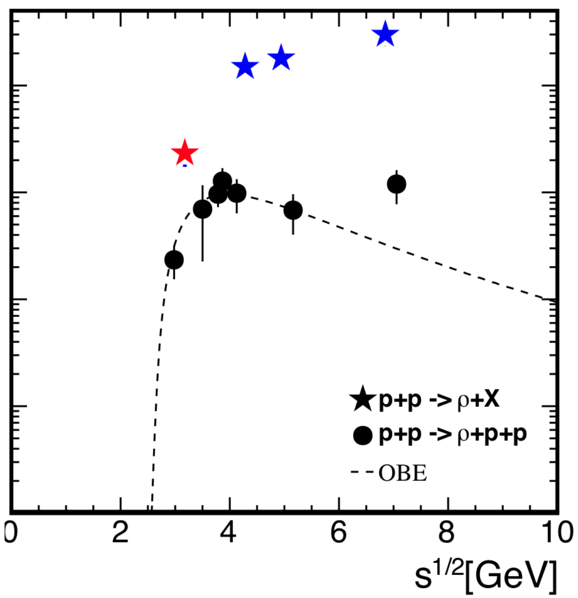
$0.47 < M_{e^+e^-}[GeV/c^2] < 0.7$ | $M_{e^+e^-}[GeV/c^2] > 0.7$

Inclusive cross sections



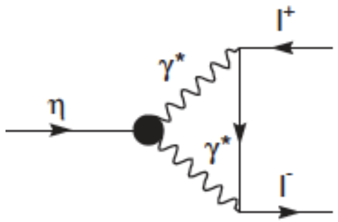






● ★ Measured by HADES

η direct decays

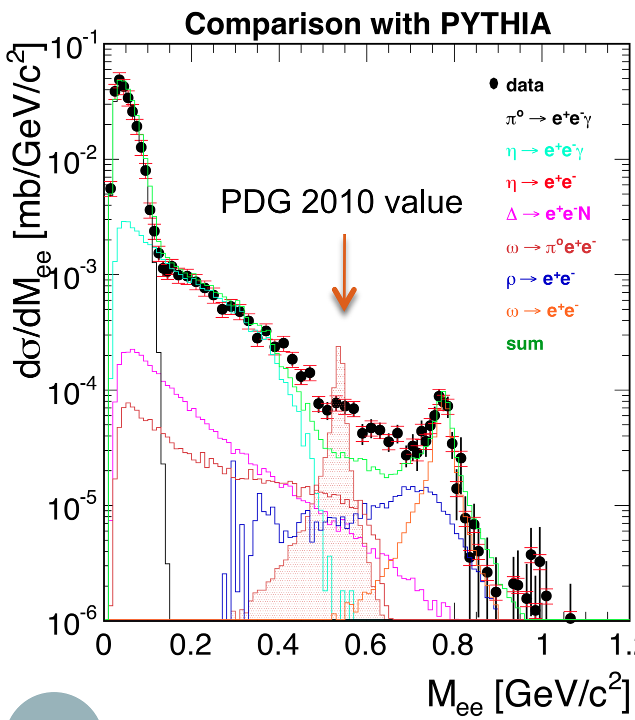


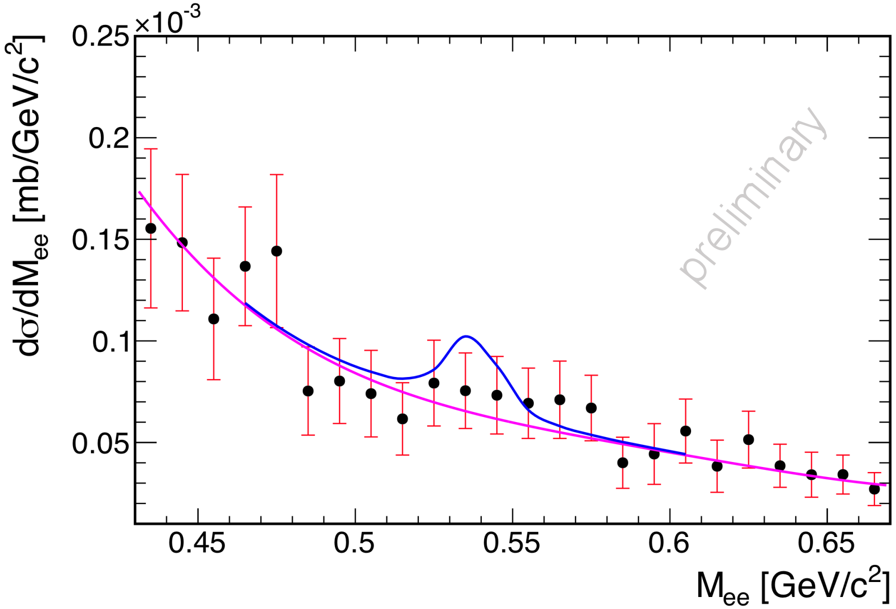
Unitarity limit:

$$Br(\eta \to \mu^+\mu^-) = 4.3\times10^{-6}$$
$$Br(\eta \to e^+e^-) = 1.77\times10^{-9}$$

PDG (2010) values:

$$Br(\eta \to \mu^+\mu^-) = 5.8\times10^{-6}$$
$$Br(\eta \to e^+e^-) < 2.7\times10^{-5}$$





Hypothetical η direct peak using improved upper limit for its branching ratio from our data

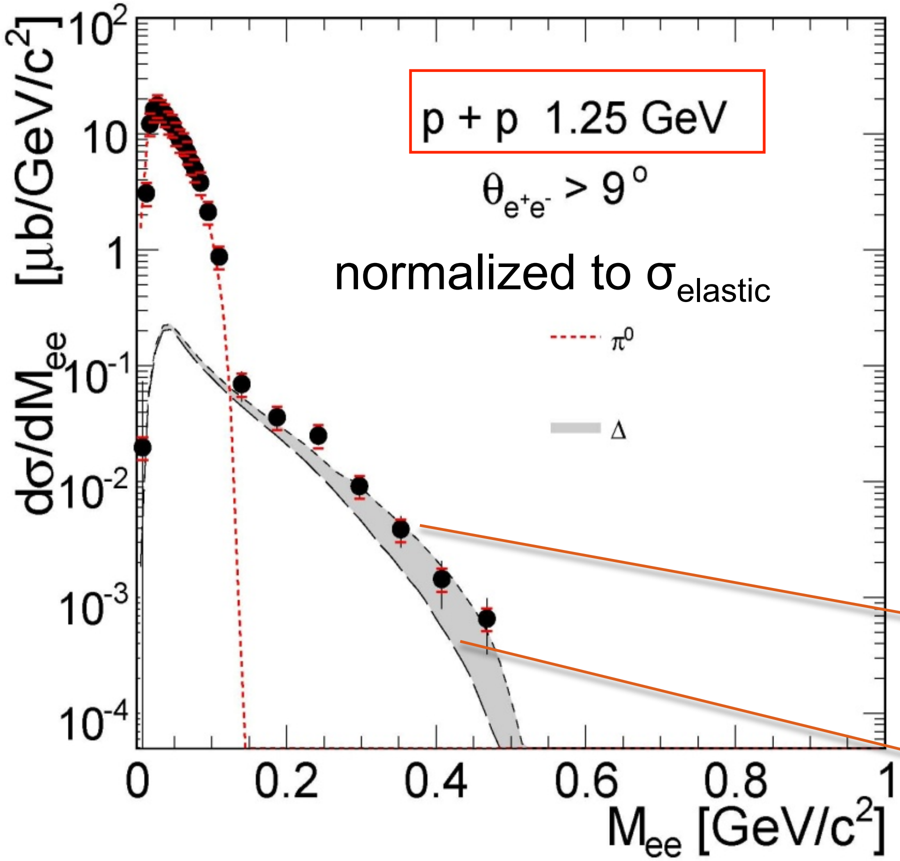
- Kolmogorov-Smirnov test:
  - no evident peak!
- Feldman and Cousins method:
  - Improved upper limit: $Br(\eta \to e^+e^-) < 4.86^{+0.7}_{-1.2}\times10^{-6}$

pp and np data at 1.25 GeV

p+p data at 1.25 GeV

pp → $e^+ e^-$ +X (inclusive spectrum) compared to simulation

Phys.Lett.B690 (2010)118



$\sqrt{s} = 2.422 GeV, \quad 2m_p + m_\eta \approx 2.424$

below η production threshold

particle productions:

π^0 - through Δ isobar, $\sigma_{\pi^0} = \frac{2}{3}\sigma_\Delta + \frac{1}{3}\sum \sigma_{N^*}$

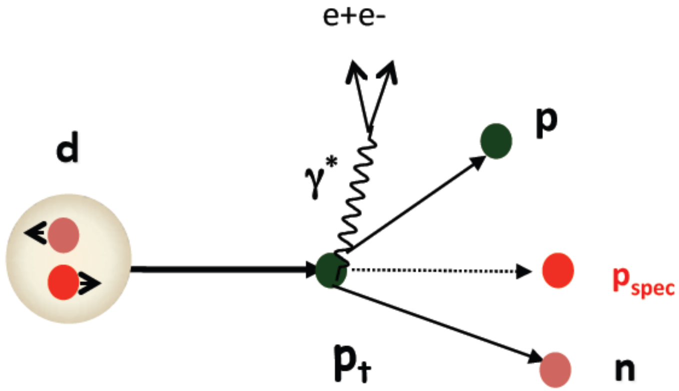
Δ – matrix elements from OPE calculations

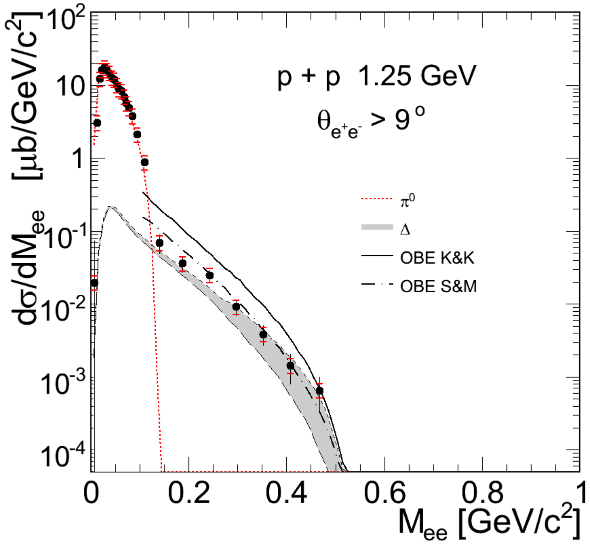
different types of N-Δ FF

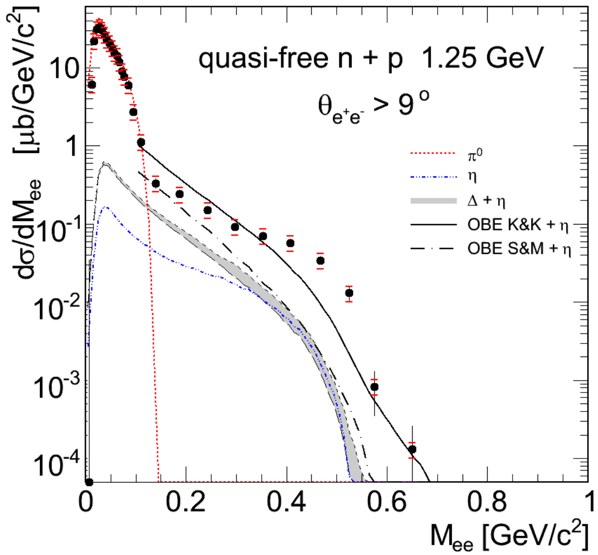
- $F^{N-\Delta}(q^2)$:from model
- $F^{N-\Delta}(q^2) = F^{N-\Delta}(q^2 = 0)$

sensitivity to the N-Δ electromagnetic vertex structure is observed !

n+p data at 1.25 GeV







Phys.Lett.B690 (2010)118

in intermediate mass range, n+p data is enhanced by a factor of ~10

(not only Δ contributes)

NN bremsstrahlung and more?

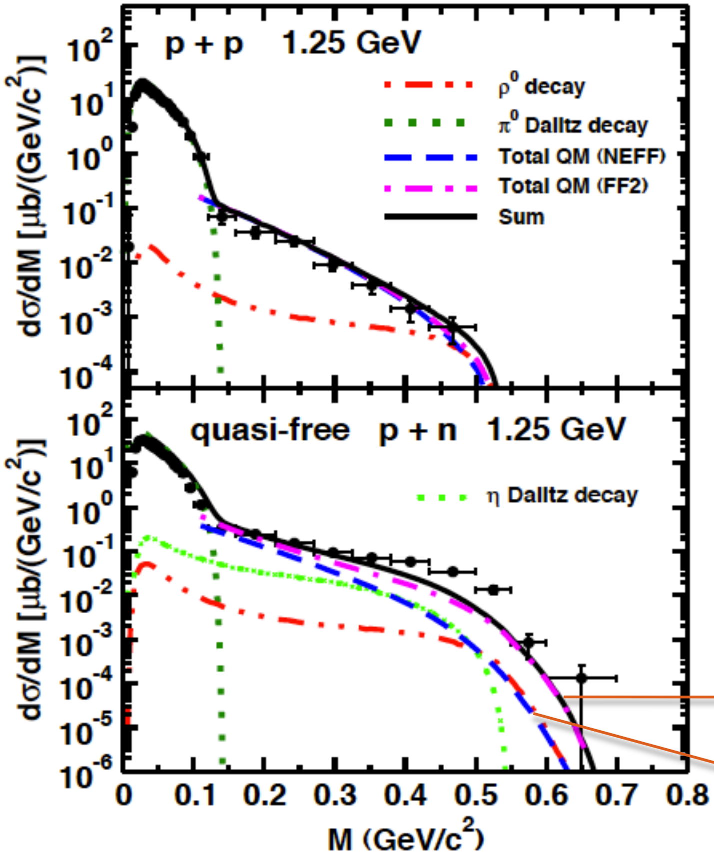
Two Eff. Lagrangian based approaches

diagrams are added-up coherently!

L. Kaptary and B. Kämpfer, NPA 764 (2006), 338

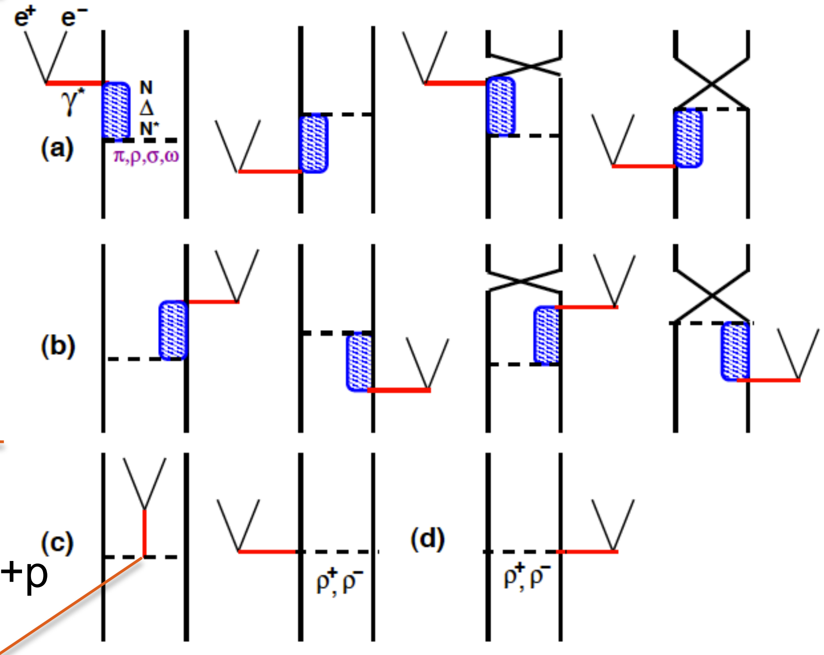
R. Shyam and U. Mosel, PRC 67 (2003), 065202

Updated version



R. Shyam and U. Mosel, arXiv:1006.3873 [hep-ph]

p+p and n+p



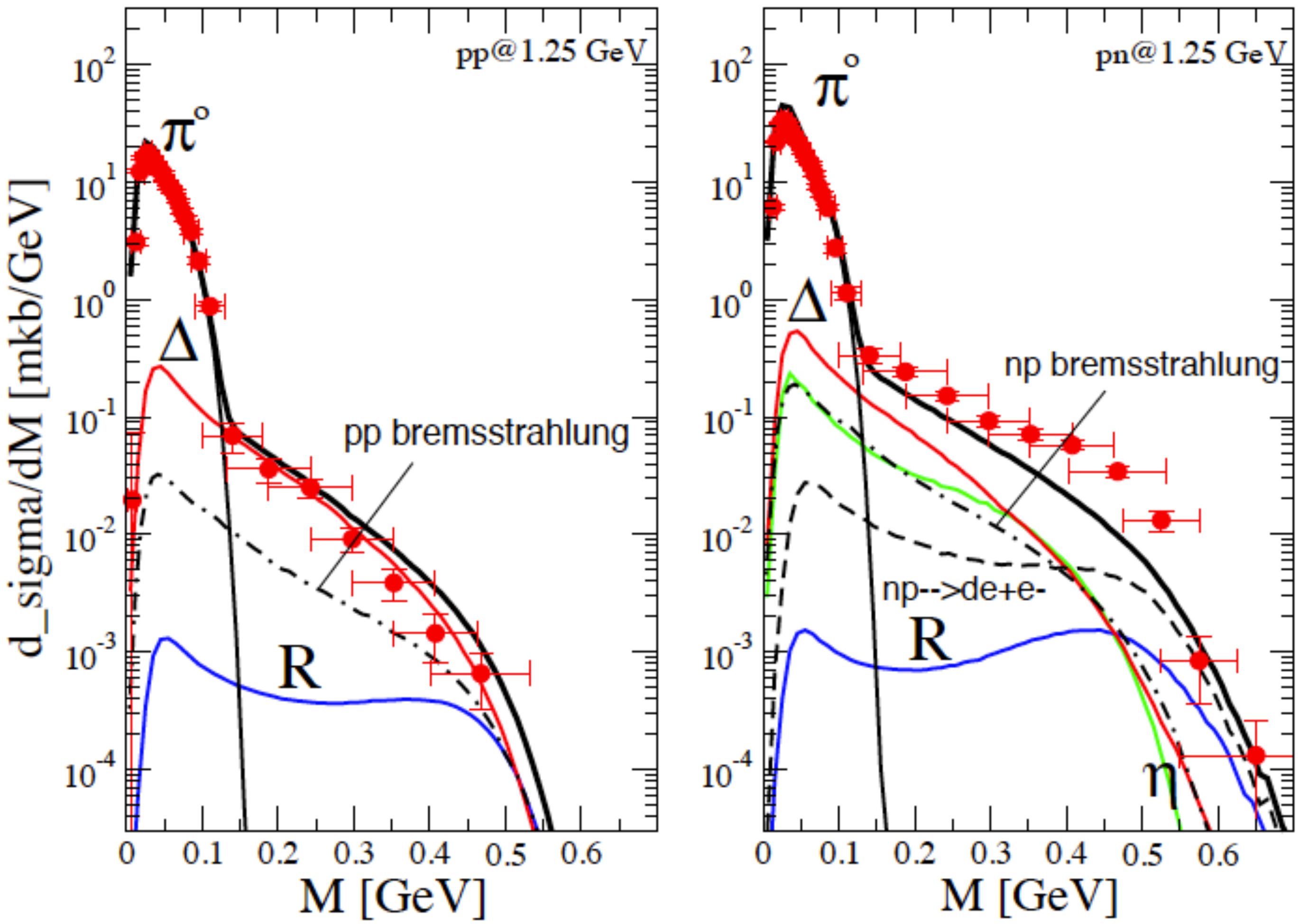
emission from internal line for n+p

with pion em. transition form factor

without pion em. transition form factor

again, sensitivity to em. form factors is observed !

New calculations

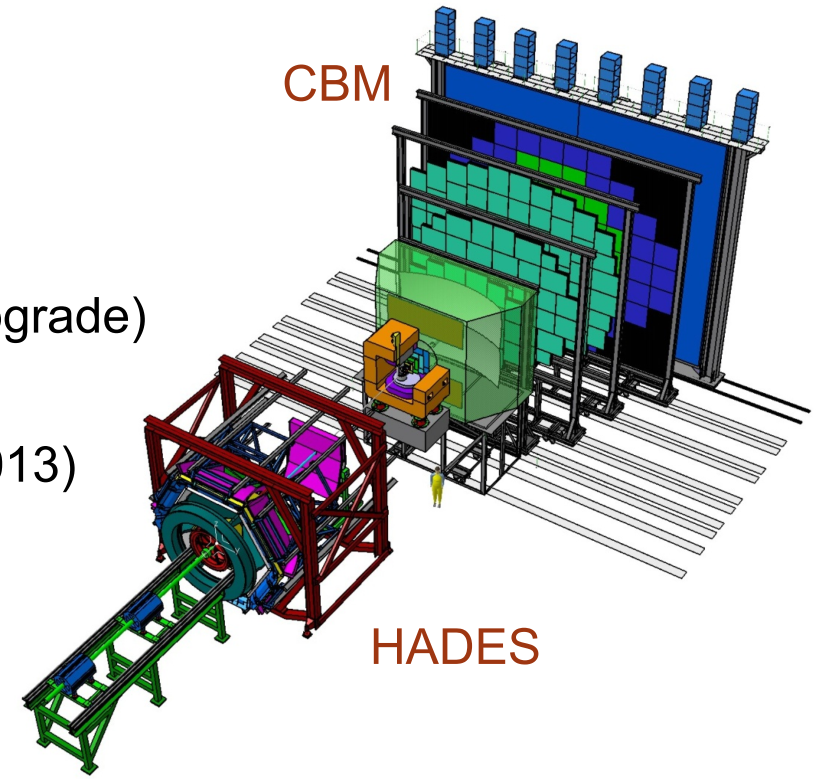


Additional contribution, np → de^+e^-, is taken into account!

B. V. Martemyanov, M. I. Krivoruchenko and Amand Faessler: arXiv:1108.4265v1

HADES future experiments

- Upgraded HADES
  - new RPC detectors (50-80ps time res.)
  - new MDCI detectors
  - forward wall
  - ~20 kHz event rates for Au+Au (DAQ upgrade)
    - Au+Au at 1.25 AGeV } (2012-2013)
    - Ag+Ag at 1.65 AGeV } (2012-2013)
    - pion induced reactions (2014)
- HADES moves to FAIR/SIS100 (after 2016)



Conclusion

- With some minor tunes PYTHIA describes the measured data in a better way compared to the UrQMD version of resonance model
- For the first time the inclusive production cross sections for π, η, ρ and ω mesons are determined
- An improved upper bound for the direct dielectron decays of the η meson is obtained
- At 3.5 GeV the data exhibits a clear structure below the ρ meson pole mass
- This structure is satisfactorily described by using the form factor model for the N-Delta transition vertex
- However, this approach contradicts the measured P_t distributions
- Already at 1.25 GeV p+p data the sensitivity to the Δ-N transition structure is observed
- Still no consistent theory for the n+p data at 1.25 GeV

The HADES collaboration

Cyprus:
Department of Physics, University of Cyprus

Czech Republic:
Nuclear Physics Institute, Academy of Sciences of Czech Republic

France:
IPN (UMR 8608), Université Paris Sud

Germany:
GSI, Darmstadt
FZ Dresden-Rossendorf
IKF, Goethe-Universität Frankfurt
II.PI, Justus Liebig Universität Giessen
PD E12, Technische Universität München

Italy:
Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Sud
Istituto Nazionale di Fisica Nucleare, Sezione di Milano

Poland:
Smoluchowski Institute of Physics, Jagiellonian University of Cracow

Portugal:
LIP-Laboratório de Instrumentação e Física Experimental de Partículas

Russia:
INR, Russian Academy of Science
Joint Institute of Nuclear Research
ITEP

Spain:
Departamento de Física de Partículas, University of Santiago de Compostela
Instituto de Física Corpuscular, Universidad de Valencia-CSIC

17 institutions
120+ members

Thank you !

Additional slides

Measured reactions

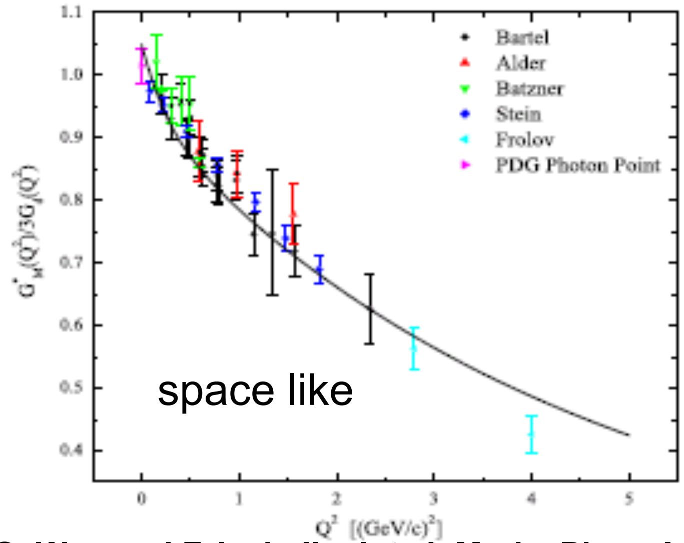
reaction (E_{kin})	year	physics goal
$^{12}C+^{12}C$ (2 A GeV) $^{12}C+^{12}C$ (1 A GeV) $^{40}Ar+^{nat}KCl$ (1.76 A GeV)	2002 2004 2005	verification of the DLS data, systematic investigation of excess yield, strangeness analysis
p+p (2.2 GeV)	2004	investigation of η meson production, transition form-factors, helicity angles. Investigation of the detector performance by elastic scattering.
p+p (1.25 GeV) d+p (1.25 GeV)	2006 2007	Investigation of NN bremstrahlung and Delta Dalitz decays
p+p (3.5 GeV)	2007	Investigation of vector meson production mechanisms. Study the experimental line shape of the omega meson
$p+^{93}Nb$ (3.5 GeV)	2008	Investigation of in medium modification of the vector mesons

Two–component VMD type model

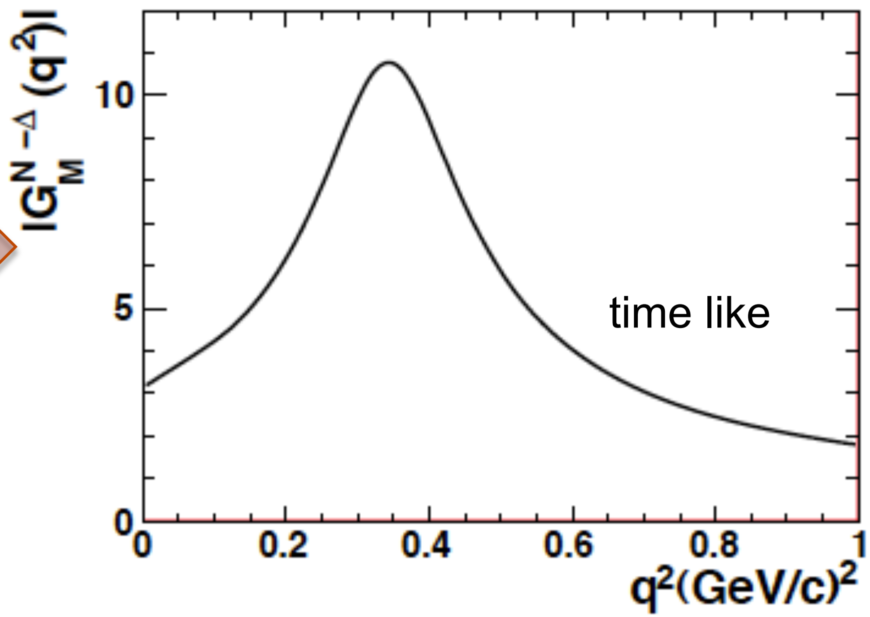
$$F(Q^2) = (1+\gamma Q^2)^{-2}\left[\alpha_0 + \alpha_\rho \frac{M_\rho^2}{M_\rho^2 + Q^2}\right]$$

✧only ρ (isovector) is relevant in case of Δ

✧ reproduces simultaneously nucleon space-like and time-like as well as N-Δ space like form factors.



Q. Wan and F. Iachello, Int. J. Mode. Phys. A20, 1846 (2005)

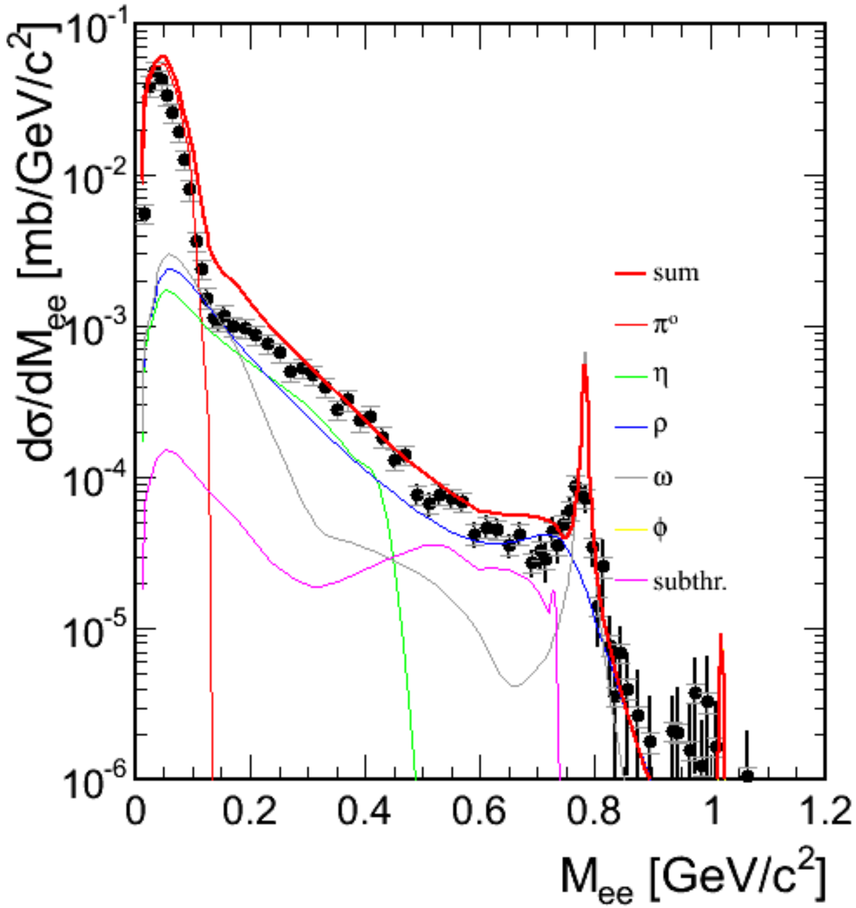


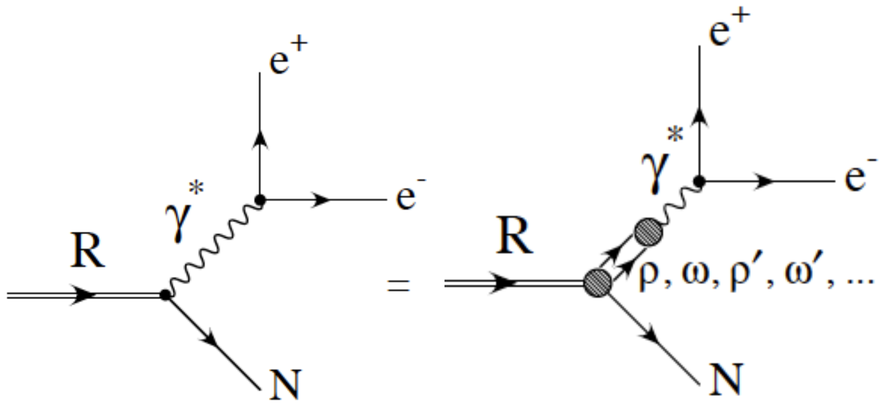
↗In our q^2 range the VDM part dominates

alternatively one could use Extended Vector Dominance Model

M. I. Krivoruchenko et. al, Ann. of Phys. 296, 299 (2002)

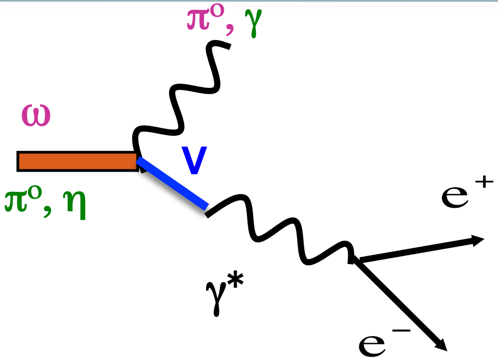
eVMD





M. I. Krivoruchenko et. al, Ann. of Phys. 296, 299 (2002)

Transition form factors



$$\frac{d\Gamma}{dM} = \left[\frac{d\Gamma}{dM}\right]_{QED} \left|F(M^2)\right|^2$$

$$F(M^2)_{\pi^o} \approx 1 + M^2 \frac{dF}{dM^2}\Big|_{M^2=0} = 1 + M^2 b_{\pi^o} \quad (b_{\pi^o} = 5.5\,\mathrm{GeV}^{-2})$$

$$\left|F(M^2)\right| = \frac{\left(d\Gamma/d\mathrm{M}\right)_{\exp}}{\left(d\Gamma/dM\right)_{QED}}$$

pole parameterization

$$\left|F(M^2)\right|^2 = \left(1 - \frac{M^2}{\Lambda^2}\right)^{-2}$$