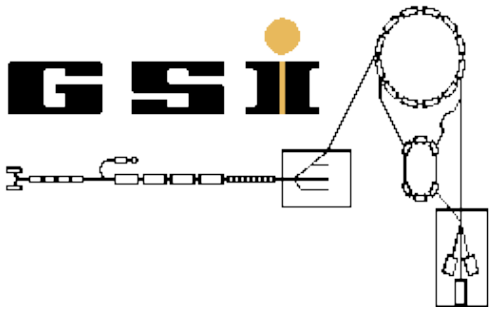
Probing Electromagnetic Form Factors with HADES

Anar Rustamov for the HADES collaboration

GSI Helmholtzzentrum für Schwerionenforschung

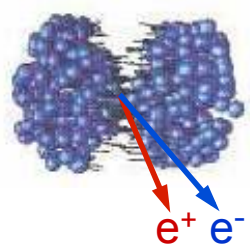


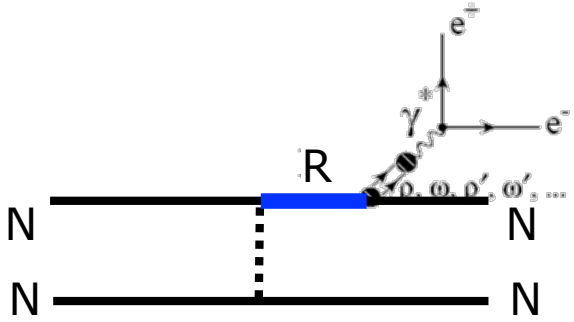
Outline

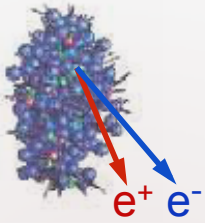
- Introduction
- Baryon Dalitz Decays
  - Form factors
  - Two – component model
- Experimental results
  - p+p and n+p data at 1.25 GeV
  - p+p data at 3.5 GeV
- Future plans
- summary

Introduction

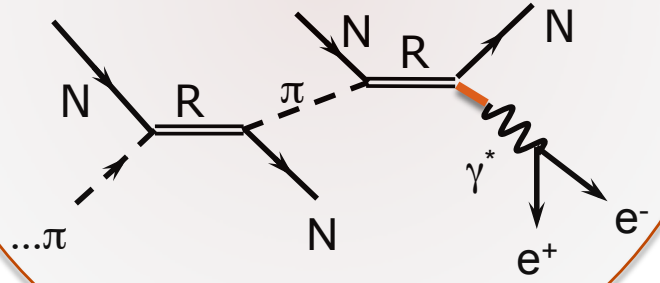
Dilepton sources at 1-2A GeV

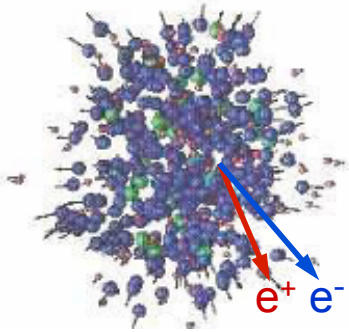




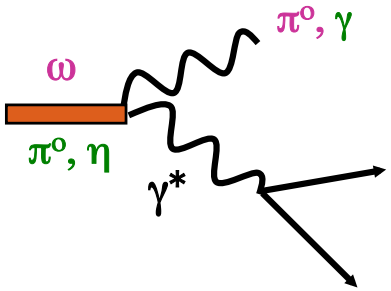


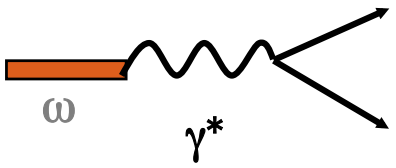
hot and dense phase
multistep production
of resonances and mesons





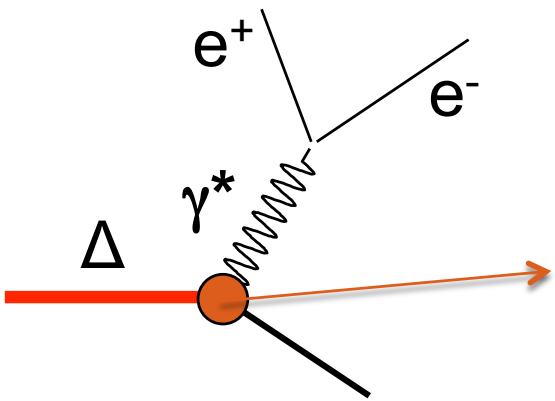
freeze –out
decays of (long-lived)
states (π^0, η, ω)





form factors in time-like domain are important for all 3 stages

N-Delta transition vertex



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

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

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

3 different form factors (analogous to Sachs form factors for the nucleon)

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

M. Krivoruchenko et al. Phys.Rev.D 65, 017502

- ✧ no data available for the time like form factors
- ✧ the branching ratio is not measured

at the photon point ($q^2 = 0$)

$G_M(0) = 3$

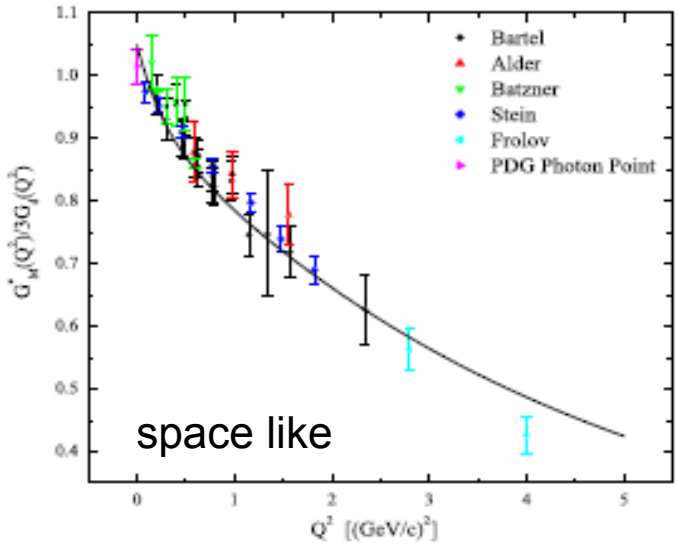
$G_E(0) \approx 0$

$C_C(0) = 0$ (current conservation)

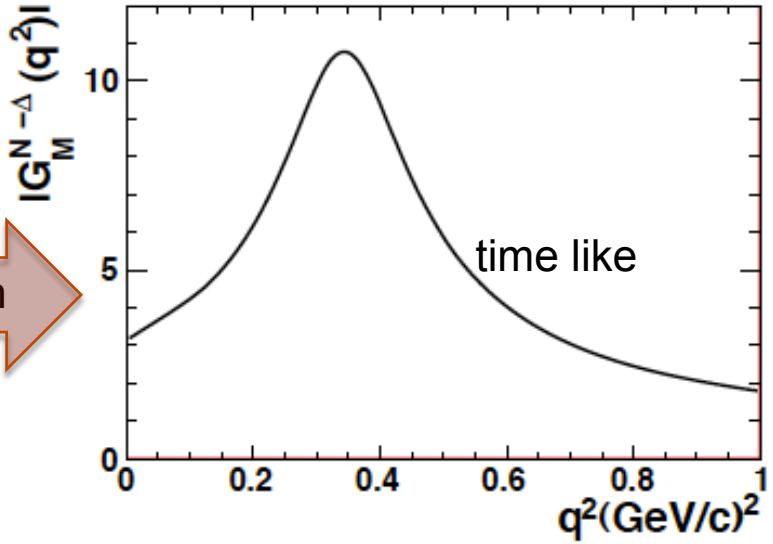
Two–component VDM type model

$$F(Q^2) = (1+\gamma Q^2)^{-2}\left[\alpha_0 + \sum_i \alpha_i \frac{M_V^2}{M_V^2 + Q^2}\right]$$

- ✧ only ground states (ρ, ω, ϕ) vector mesons are used
- ✧ reproduces simultaneously nucleon space-like and time-like as well as N-Δ space like form factors.



analytic continuation



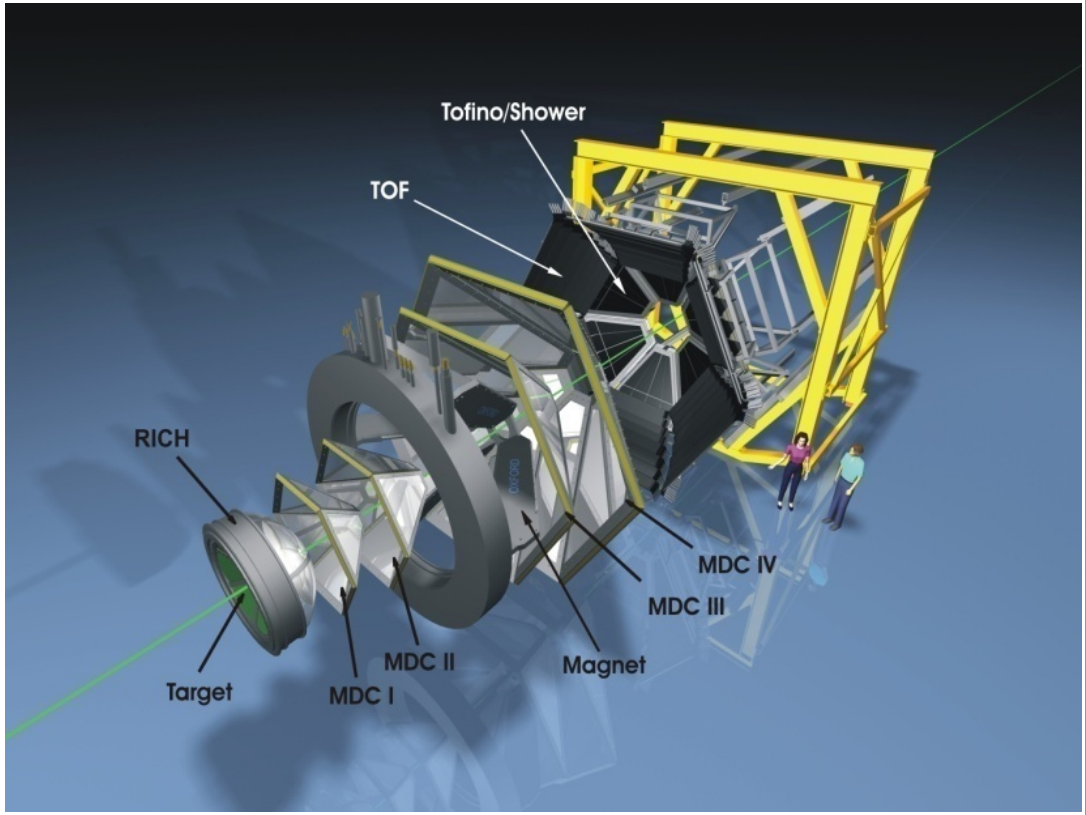
Q. Wan and F. Iachello, Int. J. Mode. Phys. A20, 1846 (2005)

alternatively one could use Extended Vector Dominance Model

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

HADES spectrometer

- **Acceptance**
  - $\varphi \sim 2\pi$
  - $15^o < \theta < 85^o$
  - 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



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

pp and np data at 1.25 GeV

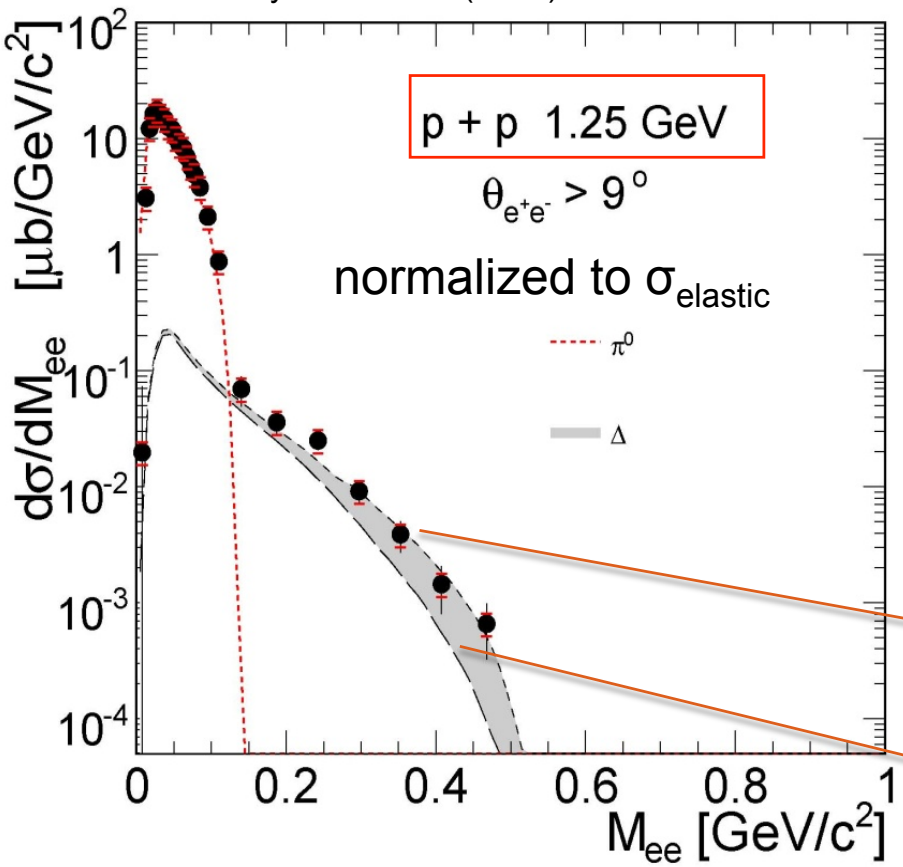
p+p data at 1.25 GeV

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

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

below η production threshold

Phys.Lett.B690 (2010)118



particle productions:

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

Δ – matrix elements from OPE calculations

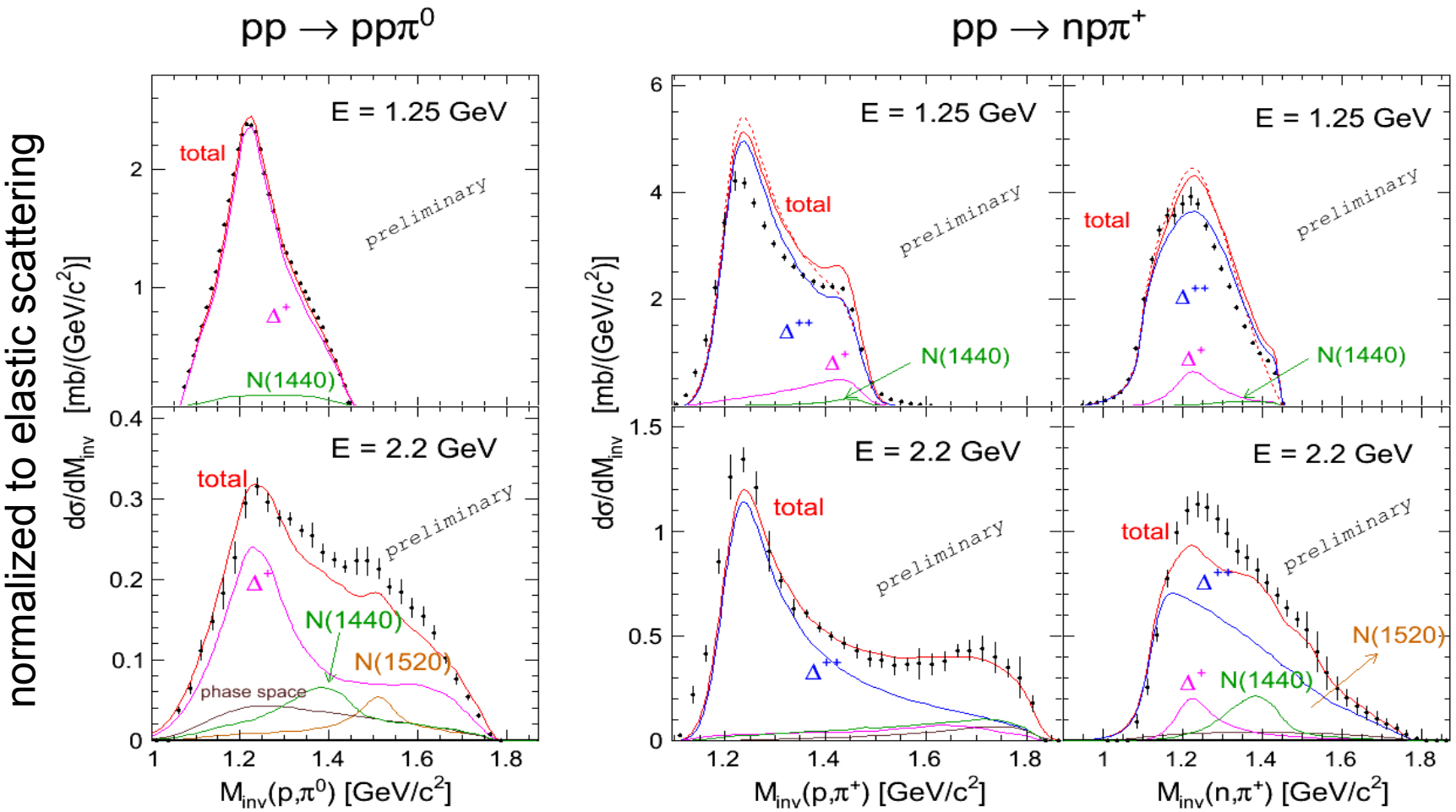
different types of N-Δ FF

✧ 2 – component model

✧ fixed at the photon point

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

Exclusive pion production



- ✧ nice agreement with a resonance model (shape and yield)
- ✧ confirms an assumption in the previous slide on π^0 production

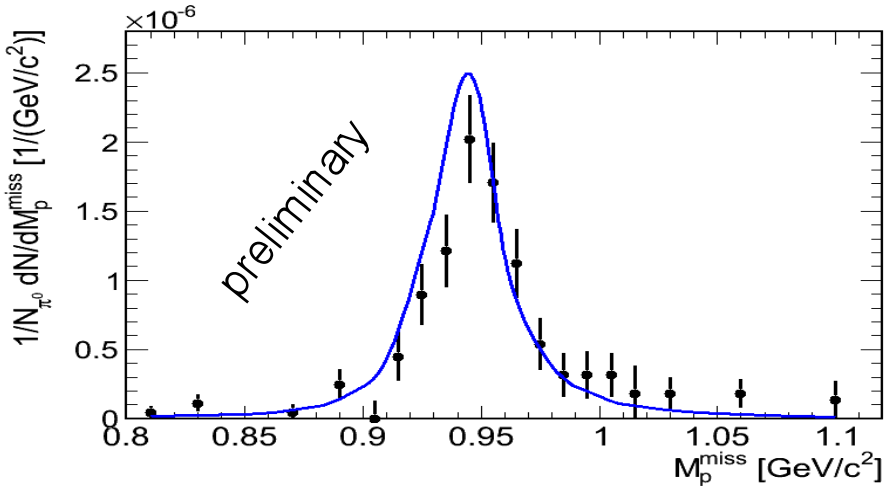
S. Teis et., al, Z. Phys. A 356, 421–435 (1997)

Exclusive ppe^+e^- channel (1)

Do we really measure p p → p Δ^+ → ppe^+e^-
Let's check by detecting 3 particles in final state: p, e^+, e^- !

mass of missing particle (M_{miss})

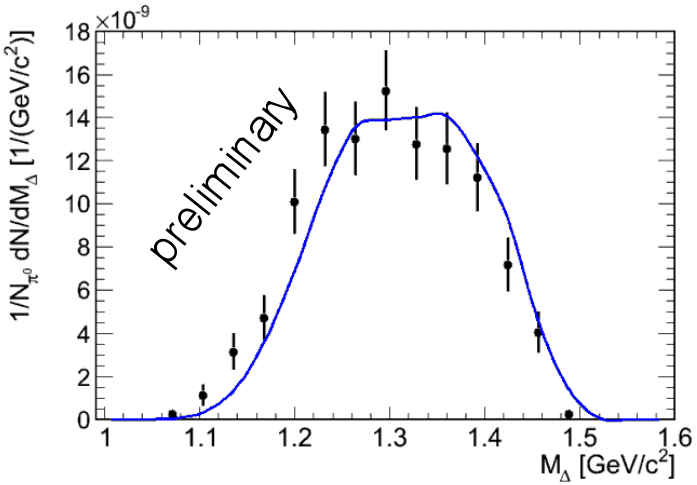
M_{ee}> 140 GeV/c^2



● data points
— simulated Δ Dalitz decay

invariant mass distribution of pe^+e^-

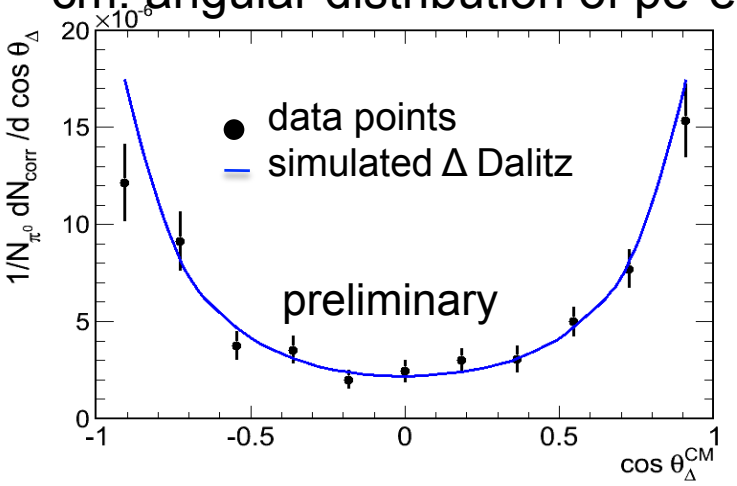
M_{ee}> 140 GeV/c^2



● data points
— simulated Δ Dalitz decay

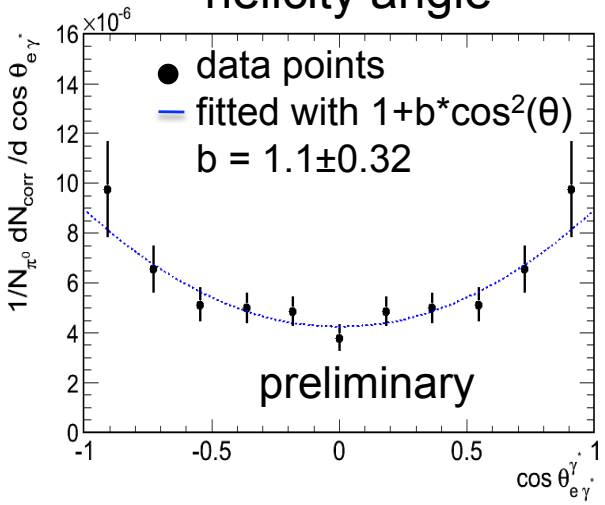
Exclusive ppe⁺e⁻ channel (2)

cm. angular distribution of pe⁺e⁻



consistent with OPE calculations

helicity angle

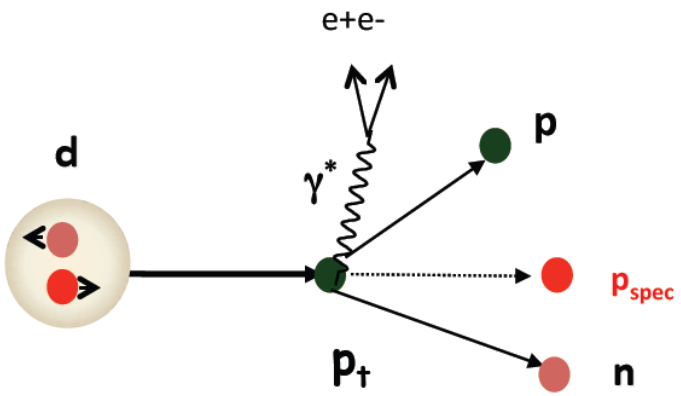


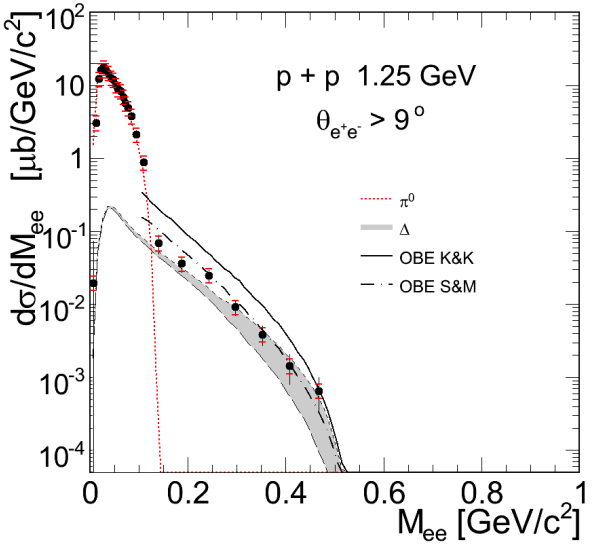
consistent with QED calculations
(negelcting Coulomb form factor)

helicity angle: angle between a lepton in the γ* rest frame, and a γ* in the Δ rest frame.

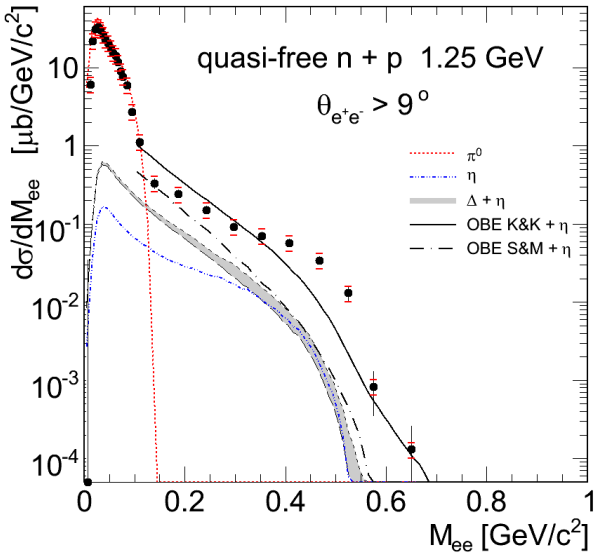
- ✧ indeed pp data at high e⁺e⁻ masses is dominated by Delta Dalitz decay
- ✧ first measurement of Δ Dalitz branching ratio
- ✧ in agreement within 20% with QED value of $4.2*10^{-5}$

Quasi-free n+p data at 1.25 GeV





in intermediate mass range, n+p data is enhanced by a factor of ~10
(not only Δ contributes), NN bremsstrahlung ?

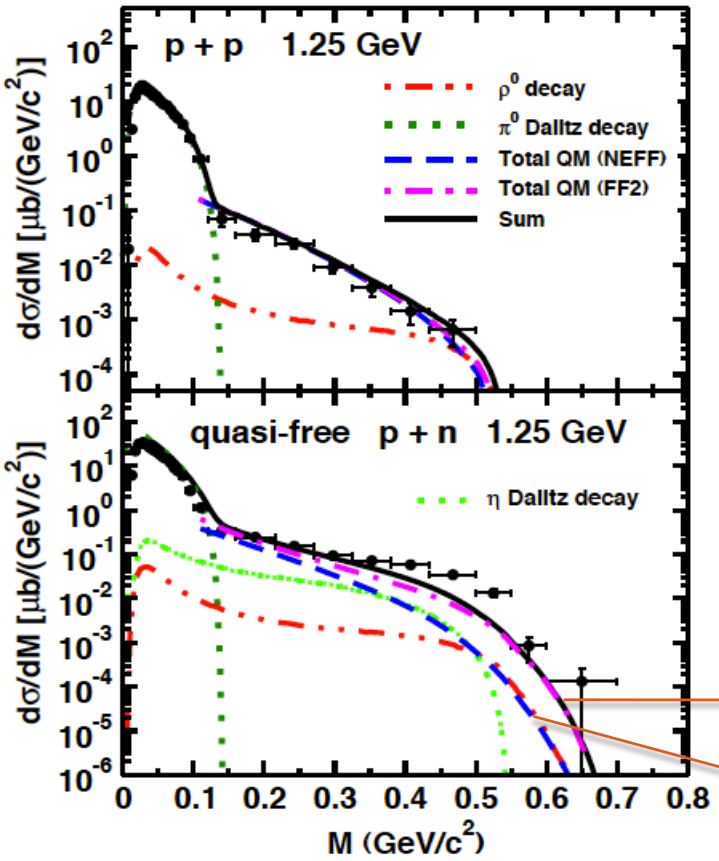


Two Eff. Lagrangian based approaches
diagrams are added-up coherently!

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

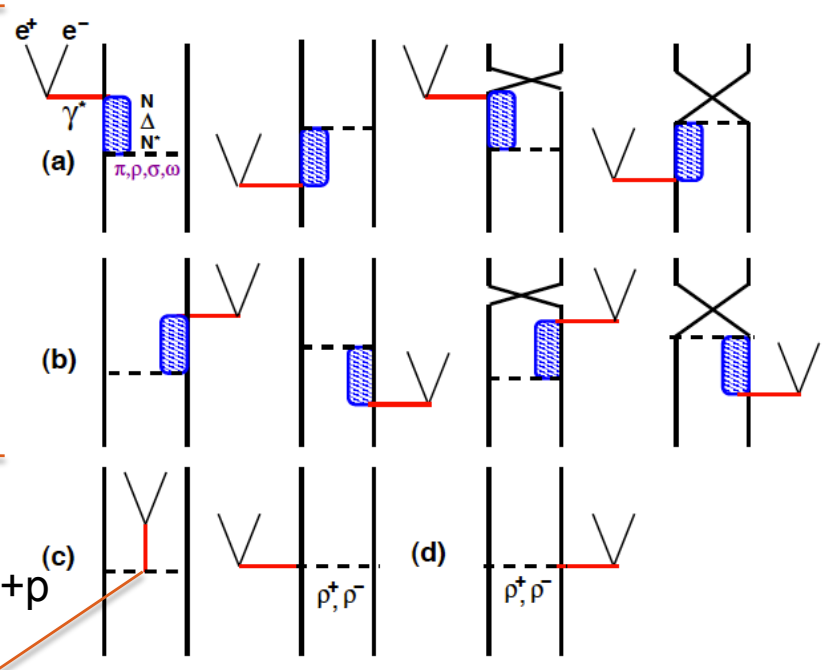
R. Shyam and U. Mosel, PRC 67 (2003), 065202

New calculations



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 !

HADES

going to higher energy

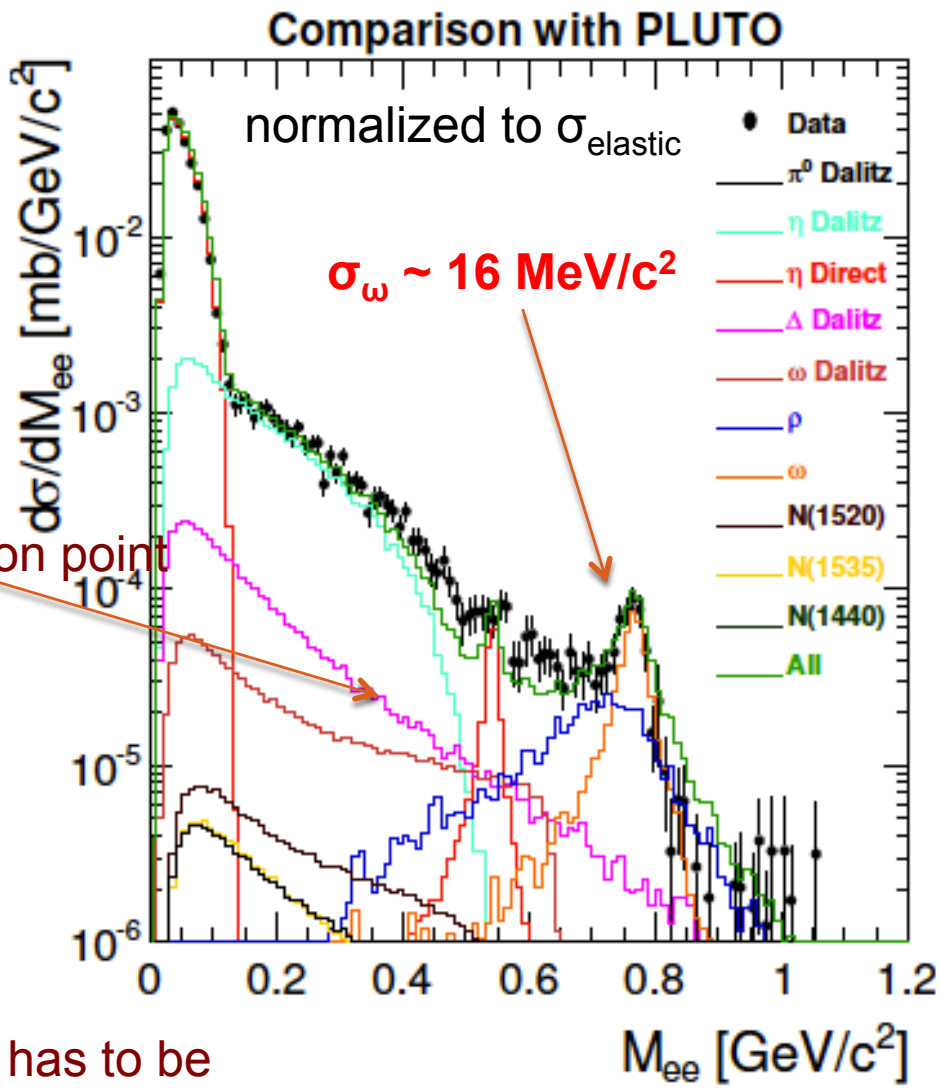
p+p data at 3.5 GeV

p+p data at 3.5 GeV (1)

- particle production
  - π multi resonance
  - η, ω, ρ via phase space
  - Δ through 1 π exchange
- particle decays
  - form factors
  - mass dep. Width
    - *Fröhlich et al, arxiv:0708.2382*

Δ form-factor is fixed at the photon point

- cross sections in 4π [mb]
  - π: 16 ± 2.6 (from data)
  - Δ: 7.5 fixed from PYTHIA
  - η: 0.93 ± 0.2 (fit to data)
  - ω: 0.25 ± 0.05 (fit to data)
  - ρ: 0.38 ± 0.07 (fit to data)



The PDG 2010 value for η → e^+e^- BR has to be scaled down by a factor of at least 3.

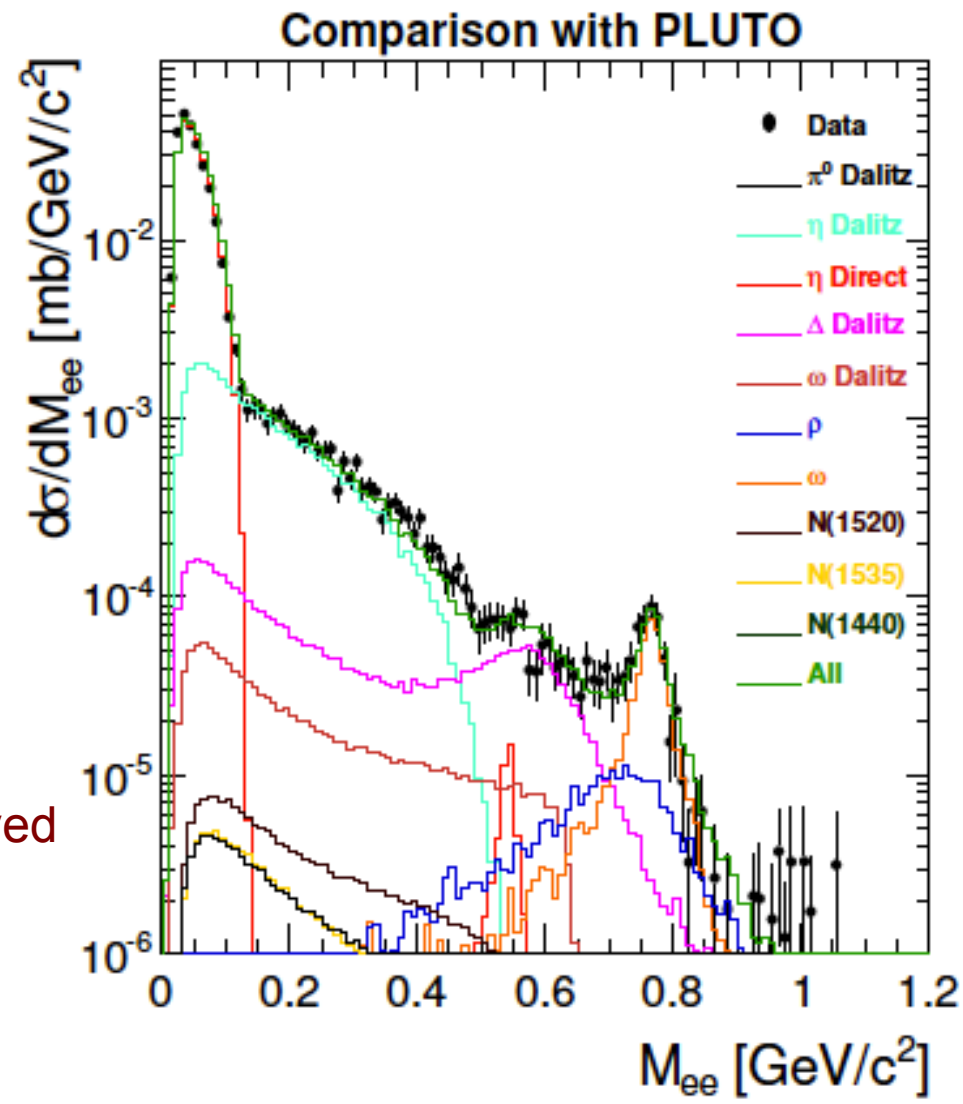
p+p data at 3.5 GeV (2)

2-component model for Δ form-factor

σ_ρ is scaled down by a factor of 2

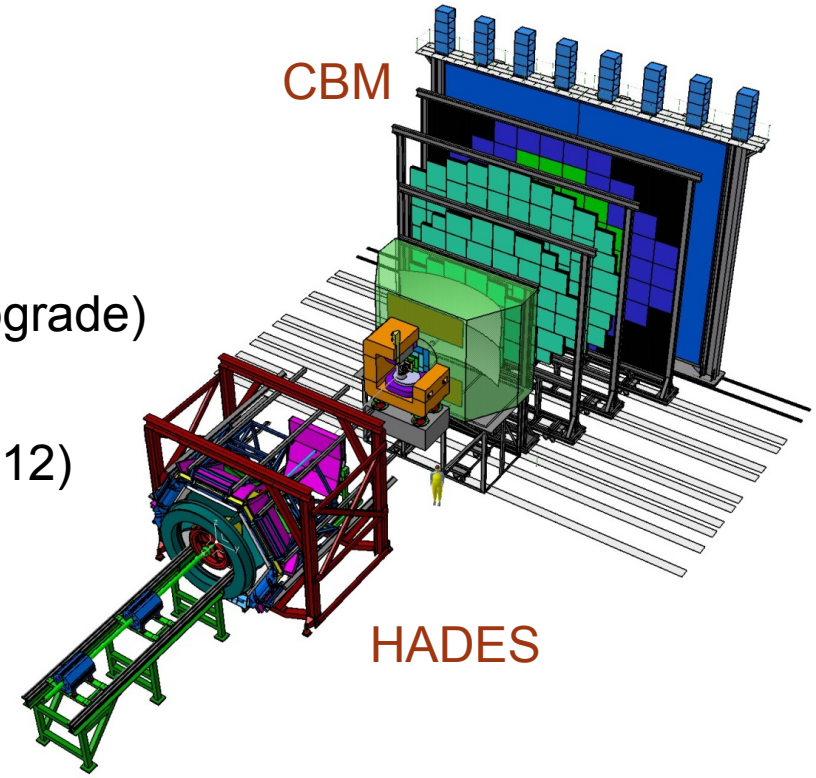
a PDG 2010 value for η → e^+e^- has to be scaled down by a factor of 12.

Inclusion of form-factors for N-Δ vertex, explains the experimentally observed structure below ρ meson pole mass.



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
    - Ag+Ag at 1.65 AGeV
    } (2011-2012)
    - pion induced reactions (2012)
- HADES moves to FAIR/SIS100 (after 2016)



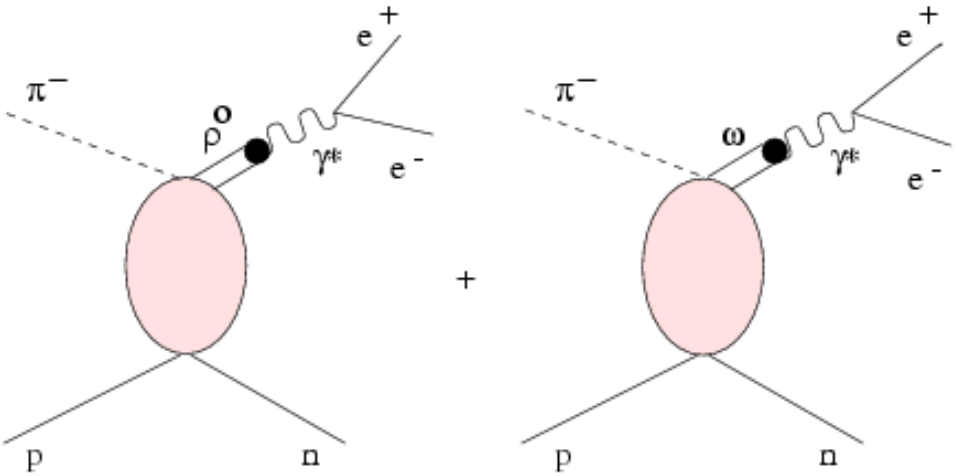
Pion beams

direct excitation of resonances

$\pi^- + p \rightarrow n\, e^+e^-$

$\pi^- + p \rightarrow n\, \rho \quad (I=1/2,\ I=3/2)$

$\pi^- + p \rightarrow n\, \omega \quad (I=1/2 \text{ only})$

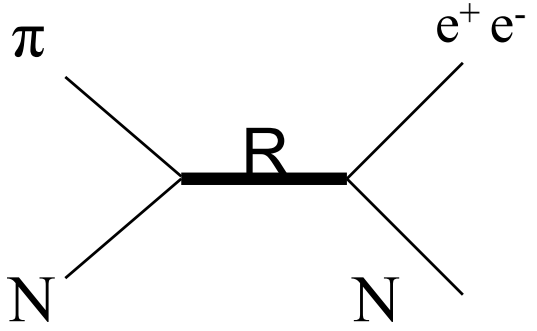


investigation of ρ/ω mixing

M.F.M. Lutz , B. Friman, M. Soyeur NPA 713 (2003) 97

A.Titov, B.Kaempfer EPJA 12(2001)217

near resonances



Access to em. time-like form factors for higher resonances!

Summary

- Baryon resonances have strong impact on dilepton spectra
- Time-like electromagnetic transition form-factors are necessary for their differential decay rate calculation
- Already at 1.25 GeV p+p data the sensitivity to the Δ-N transition structure is observed
- For the first time the Δ Dalitz decay process is measured
- The n+p data is better described by taking into account pion electromagnetic transition form factor
- 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
- Sensitivity of data to the $\eta \rightarrow e^+e^-$ branching ratio is observed

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

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

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Laboratori Nazionali del Sud
Istituto Nazionale di Fisica Nucleare
Sezione di Milano

Poland:
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Jagiellonian University Cracow

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

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

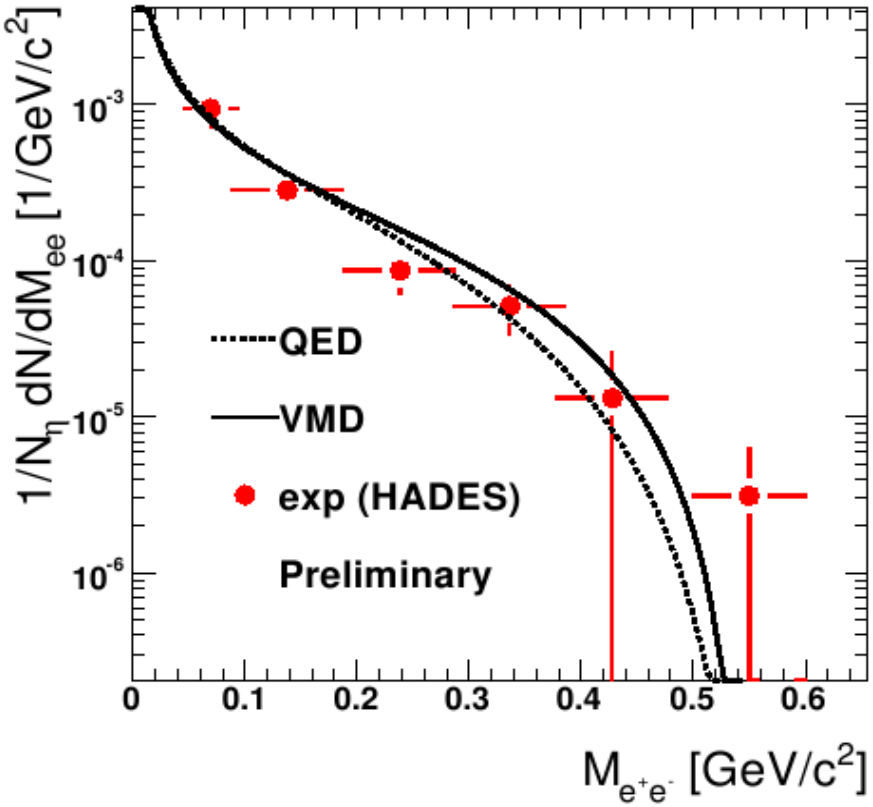
Spain:
Departamento de Física de Partículas,
University of Santiago de Compostela
Instituto de Física Corpuscular,
Universidad de Valencia-CSIC

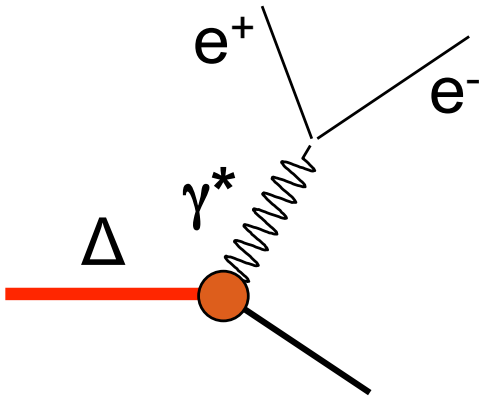
Thank you !

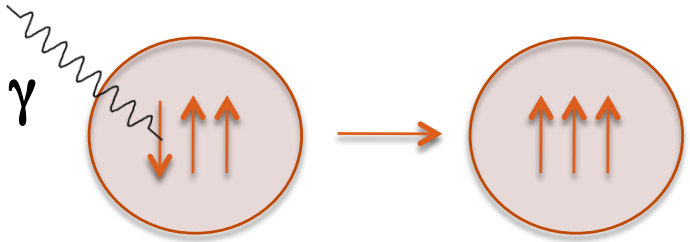
17 institutions
120+ members

Backup Slides

η Form-Factor




e+
e-
γ*
Δ


γ
N
Δ

Exclusive ppe$^+$e$^-$ channel