Experimental study of the π-p$\rightarrow$ne+e-

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Hades strategy

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- Study dilepton emission in dense and hot matter (cf. DLS/Berkeley)
  A+A reactions in the 1-2 AGeV energy range C+C, Ar+KCl, Au+Au (2012)
- Cold matter at normal nuclear density p+Nb 3.5 GeV
  (cf KEK, Jlab, CBELSA/TAPS)
- Elementary collisions pp, dp and π-p (2014)
  reference to heavy-ion spectra
  study different dilepton sources (exclusive channels)
  dilepton emission is probing time-like electromagnetic structure of hadronic transitions!

- Simultaneous measurements of hadronic channels (pp $\rightarrow$NNπ, pp $\rightarrow$NN$\pi\pi$)
  Cross-checks on known channels, detailed information on baryonic resonance production
- Strangeness measurement program: K^-, K^0,ϕ, $\Sigma(1385)$, $\Lambda(1405)$ to be investigated also in π-p and π-A
- HADES@FAIR (2017): pp, pA, AA E/A<8 AGeV

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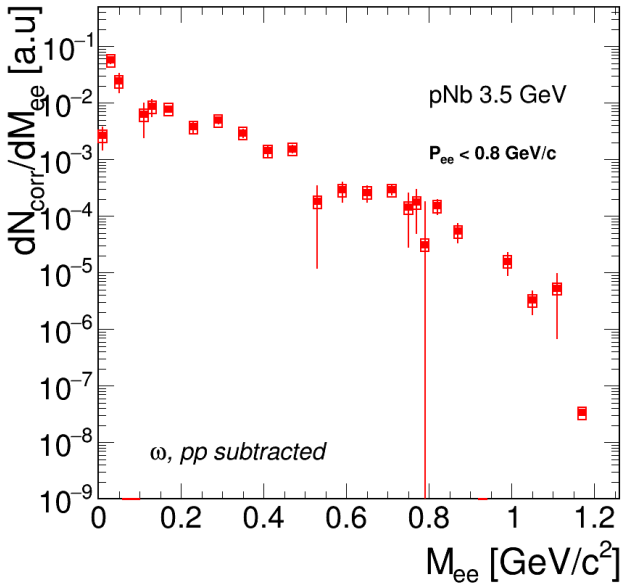
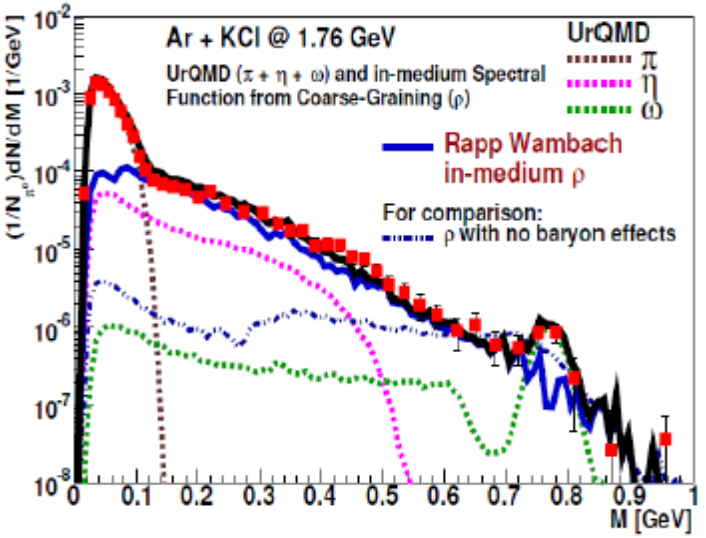
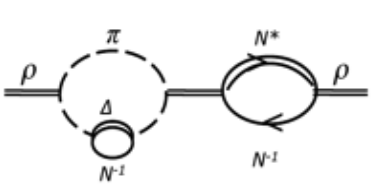
In medium modifications
Experimental results

HADES: Phys.Lett. B715 (2012)







- Strong broadening of in-medium ρ spectral function due to its coupling with baryonic resonances (N(1520), Δ(1620), N(1720), etc.)
- **The coupling of ρ to baryonic resonances can be studied directly in π^--N interactions**

Electromagnetic form factors

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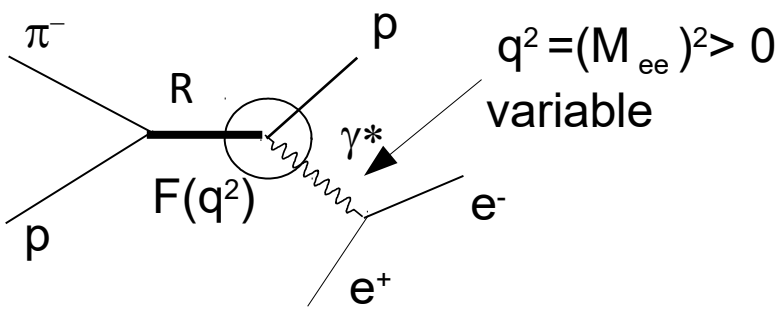
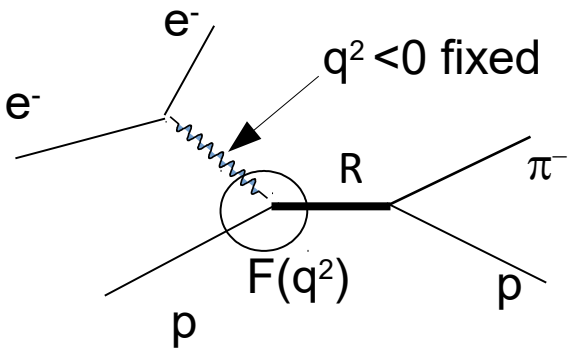
Time-like electromagnetic form factors

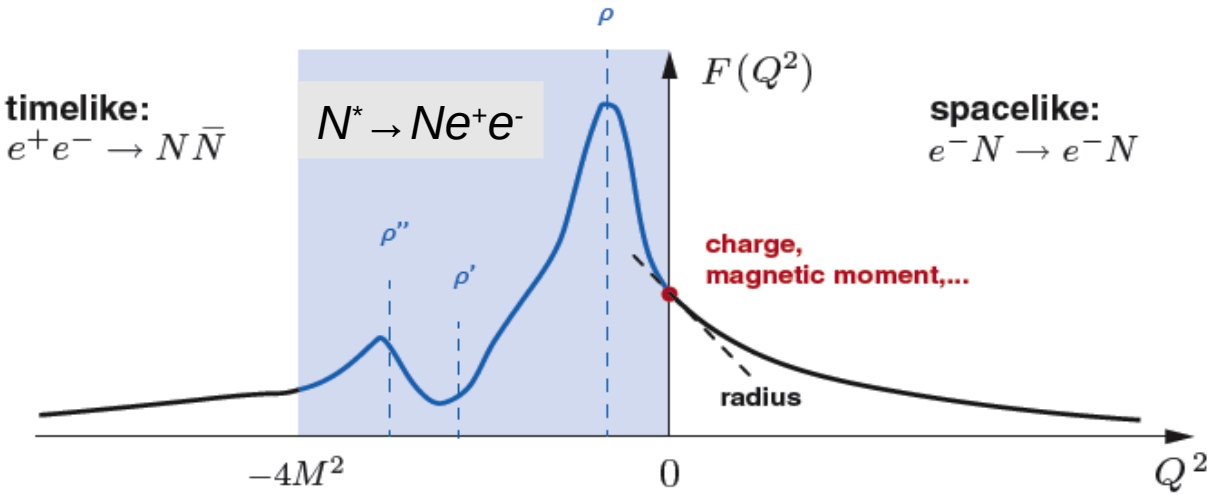


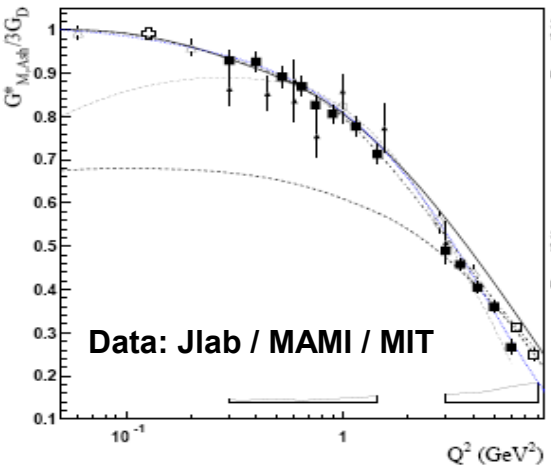
No data are available

Space-like electromagnetic form factors



Data from Jlab (CLAS) up to $-q^2 = 4$ GeV^2





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

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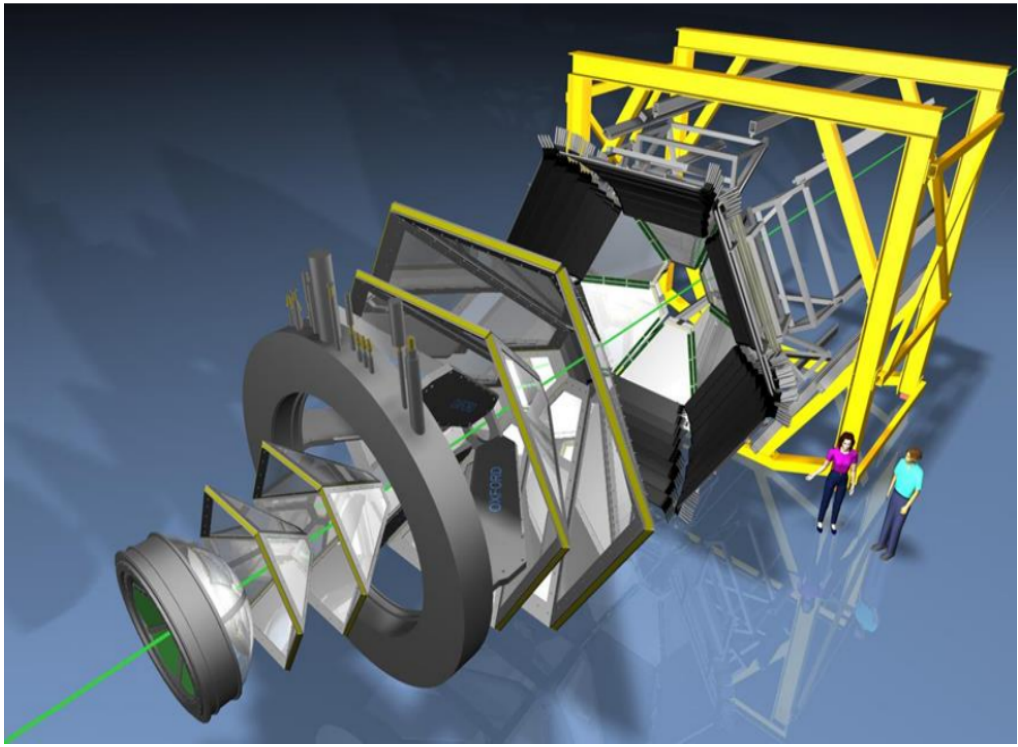
HADES detector

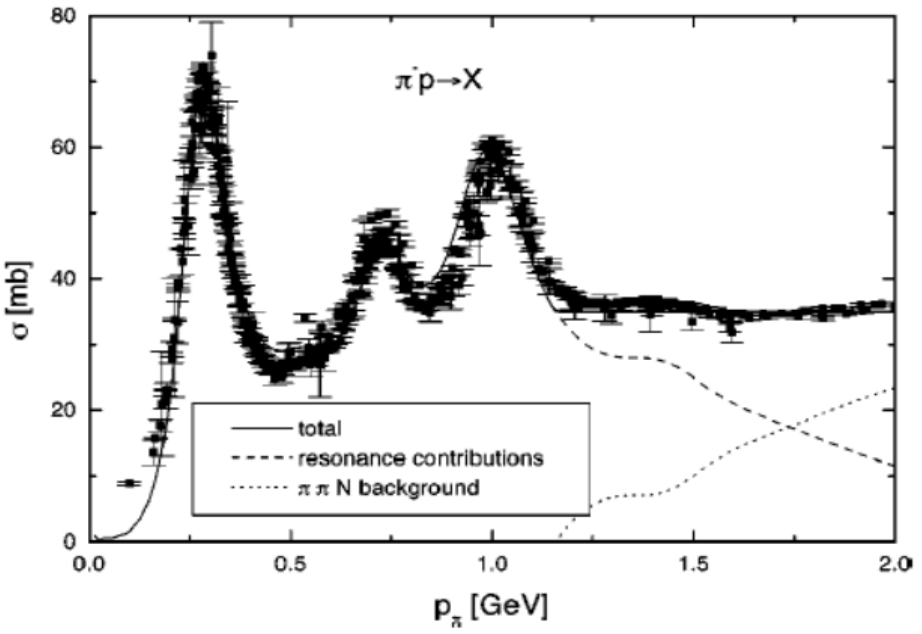
- Located at SIS18, GSI
- Beams: heavy-ions, protons, **pions**
- Fixed-target experiment
- Hadron and lepton identification
- Acceptance: 85% azimuthal coverage, 18-85° in polar angle
- Mass resolution 2 % (in ρ/ω region)
- 80.000 channels
- Fast DAQ: 50kHz event rate

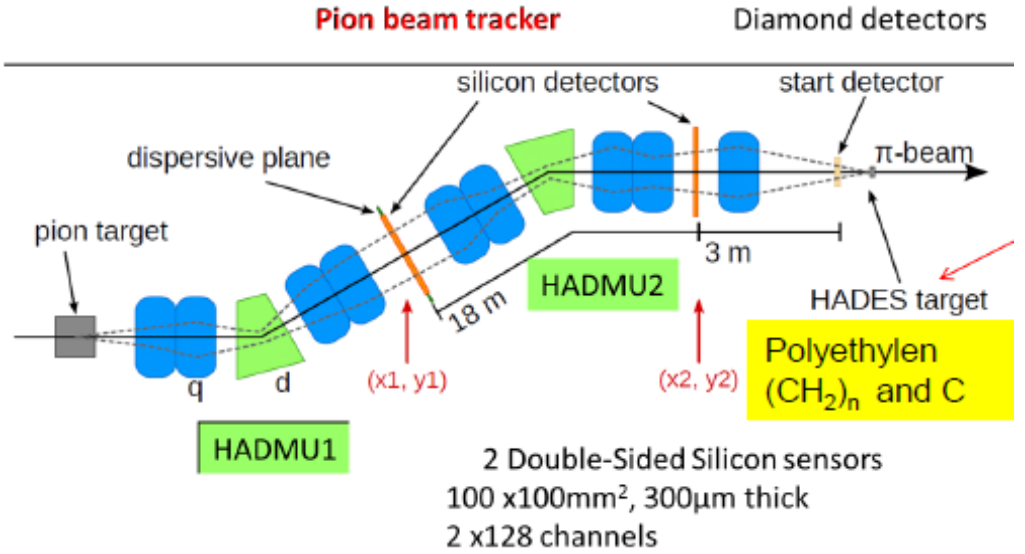


Pion beams with HADES

Secondary π momentum p_π = 0.69 GeV/c

- Access to the "second resonance region"
- Beam intensity I = 3-4 × 10^5 π/s
- σ_p = 2 %
- Target: Polyethylene $(CH_2)_n$ and Carbon





- Primary beam:
  8 × 10^{10} N_2 ions/spill
- E = 2 AGeV
- Spill: 4s cycle
- Total ~15 days of effective measurements

HADES programme for pion beam

Scan of N(1520) resonance region :

- **$\pi^+\pi^-$ production**

  Improve very poor $\pi^+\pi^-$ database. Manley analysis is based on only 240000 events (no differential distributions)

- **e^+e^- production**

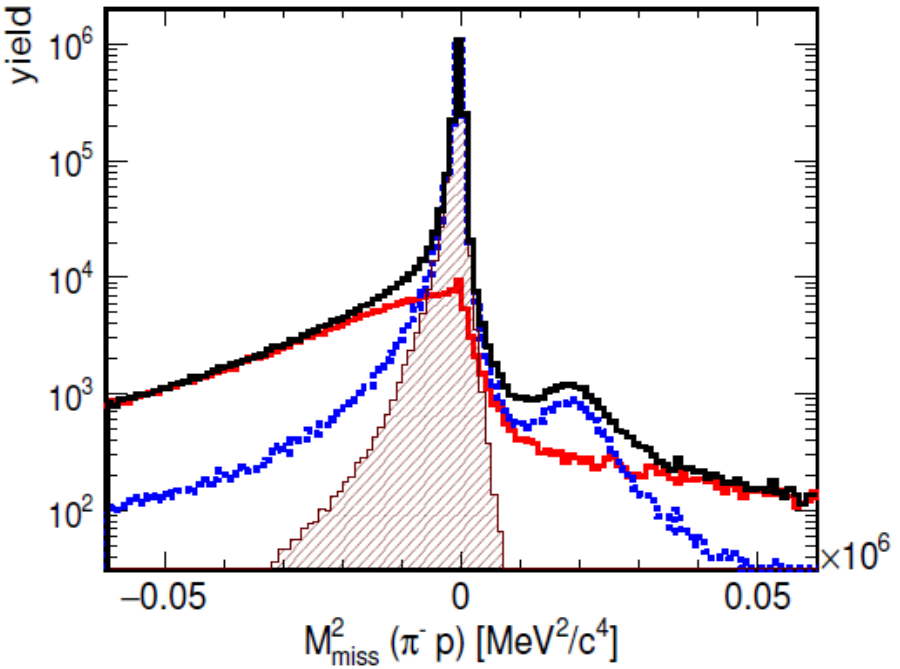
  No data are available

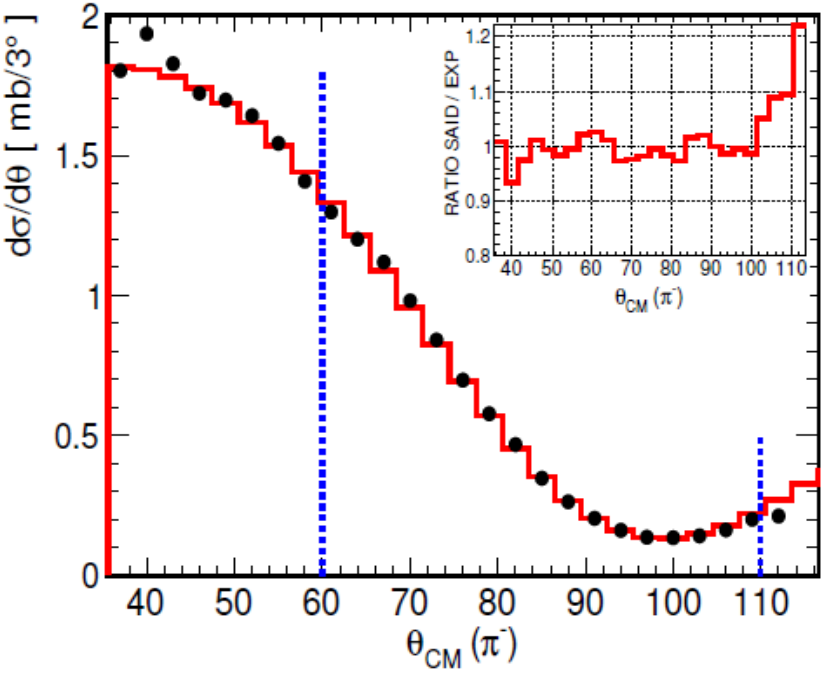
  Resonance Dalitz decays $R \rightarrow Ne^+e^-$

  (Link to time-like transition electromagnetic structure)

Elastic scattering

W. Przygoda, MESON 2016, EPJ Web of Conferences Vol. 130 (2016)

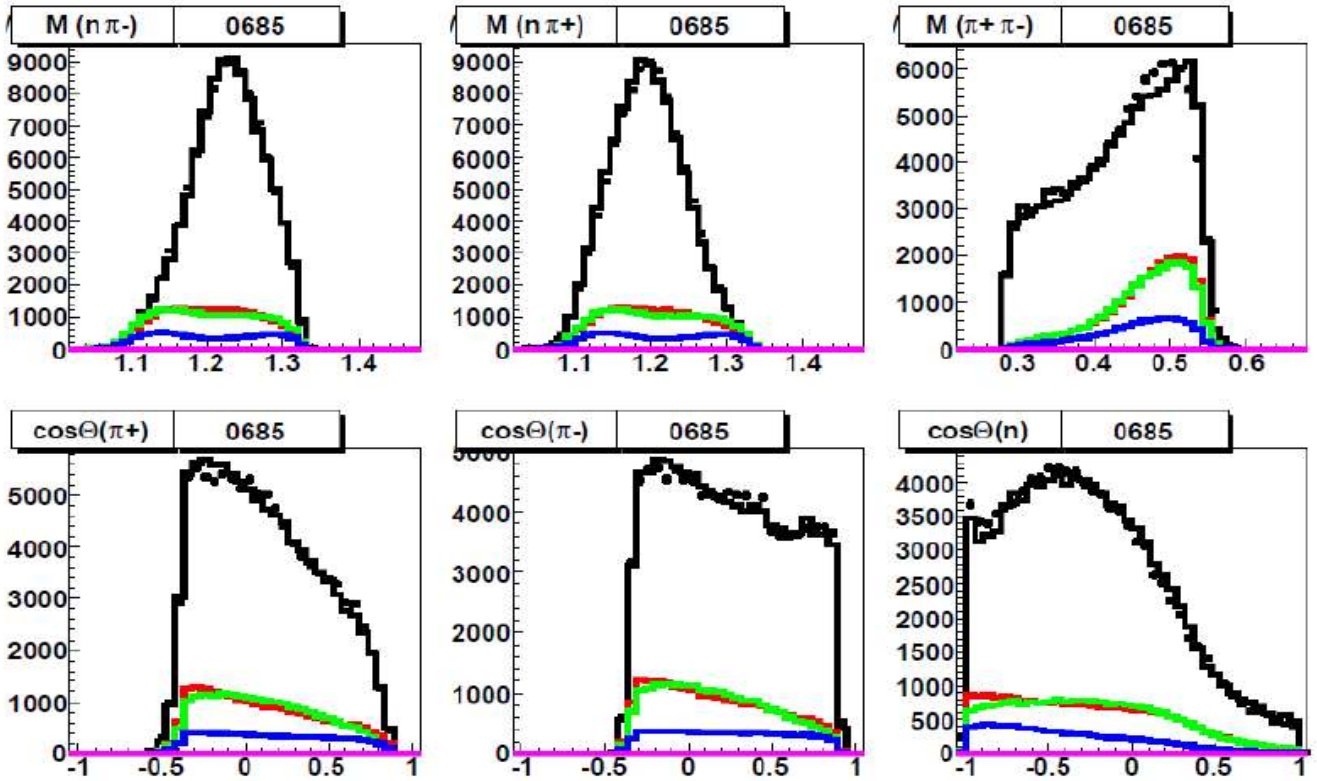




- $\pi^- p \rightarrow \pi^- p$ (after C subtraction)
- Normalization via measured $\pi^- p$ elastic scattering of known σ (SAID partial wave solution)

PWA results (one example)

Bonn-Gatchina partial wave analysis (PWA) including
- HADES data (4 energies $\pi^+\pi^-$ and $\pi^-\pi^0$)
- π and γ database



HADES preliminary

ρ total

ρ s-channel

ρ $D_{13}(1520)$ (N(1520)–> Nρ)

PWA $\pi^+\pi^-$ inv. mass ρ contribution

$\pi^-p \rightarrow \pi^+\pi^-n$ at 0.69 GeV/c

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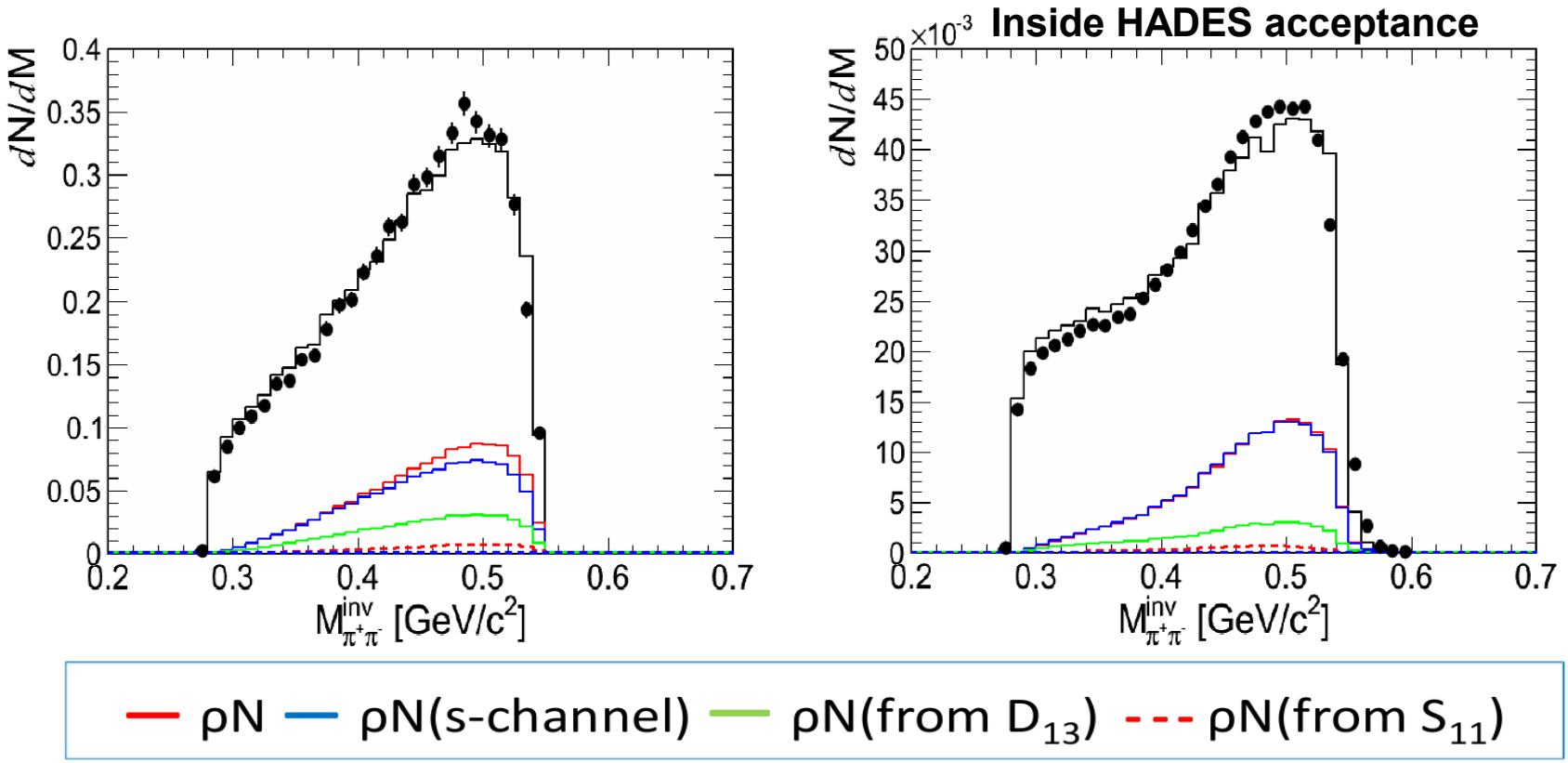

N(1520)D_{13} coupling to ρN: 12 %

Total ρN : 1.3 mb

- **Dominated by s-channel**
- **Resonant D13(1520) production**
- **Strong interferences between 1/2 $^-$ states with isospin 1/2 and 3/2**

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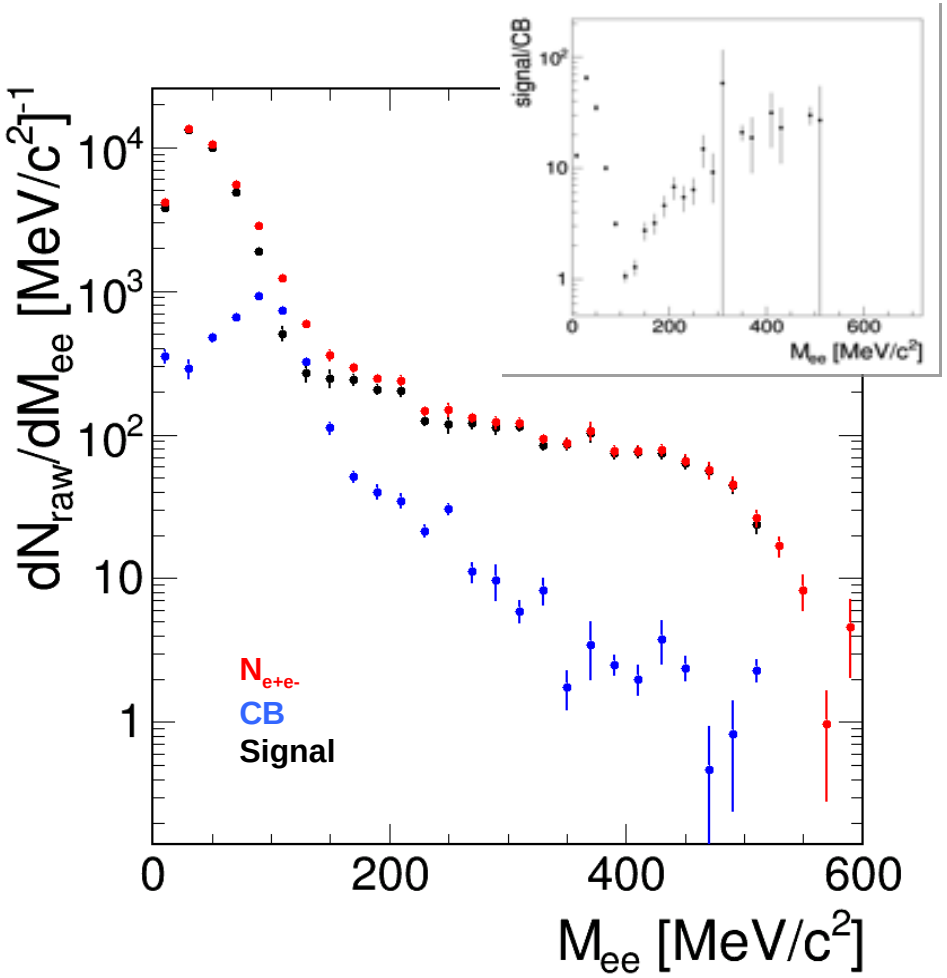
Inclusive invariant mass spectrum (raw)



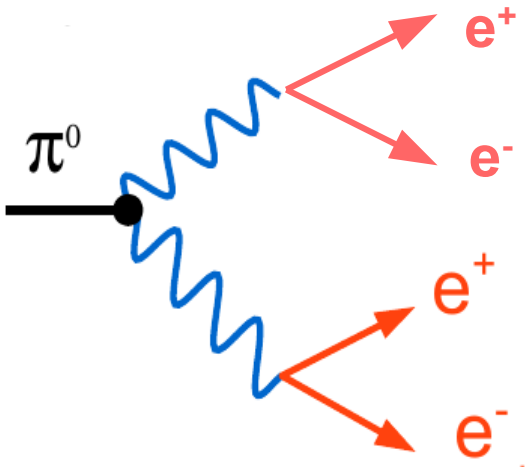
- Signal = N_{e+e-} - CB
- Same-event like-sign CB geometric and/or arithmetic mean

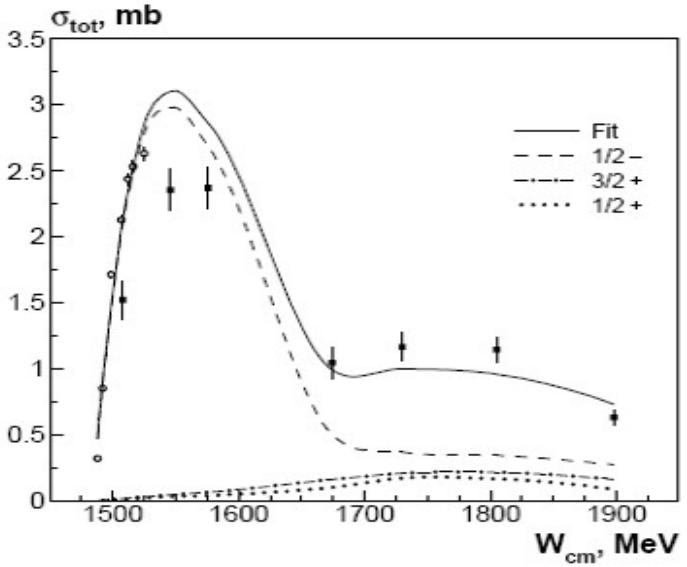
- **CB rejection cuts:**
  - Opening angle > 9°
  - Tracks with a not fitted track in the vicinity of 4° are excluded from further analysis

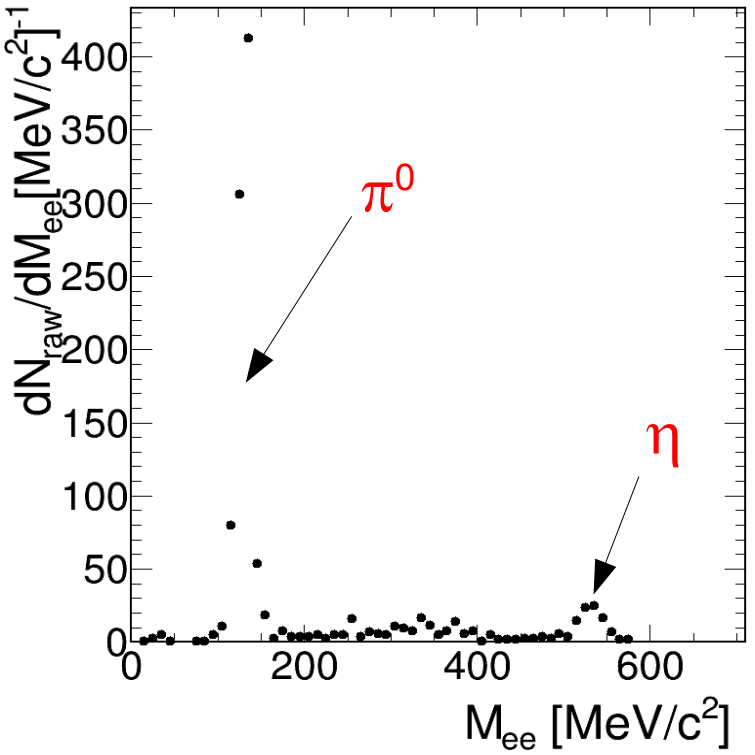
- Signal (M<140 MeV/c^2) = **37450**
- Signal (M>140 MeV/c^2) = **3350**

→ **Efficiency corrections based on Monte Carlo simulations**

Searching for π^0 and η with full conversion method



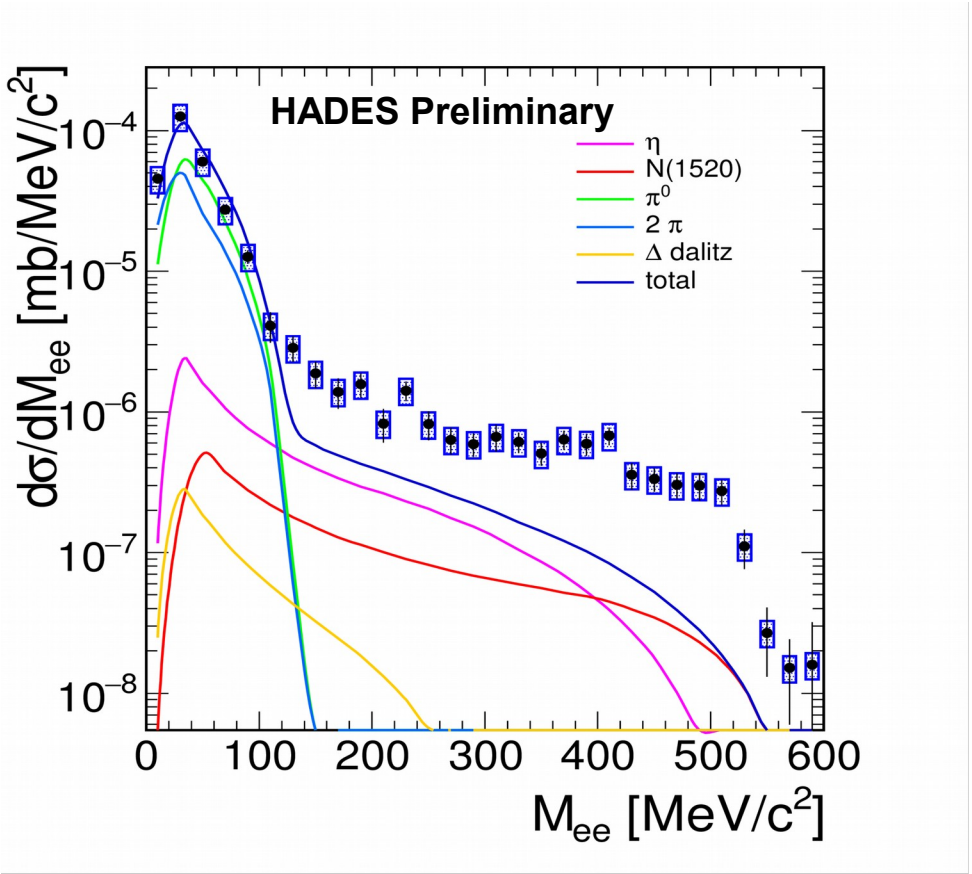




Large uncertainties on experiment and theory side

Inclusive invariant mass spectrum

Comparison with simulation



Sources:

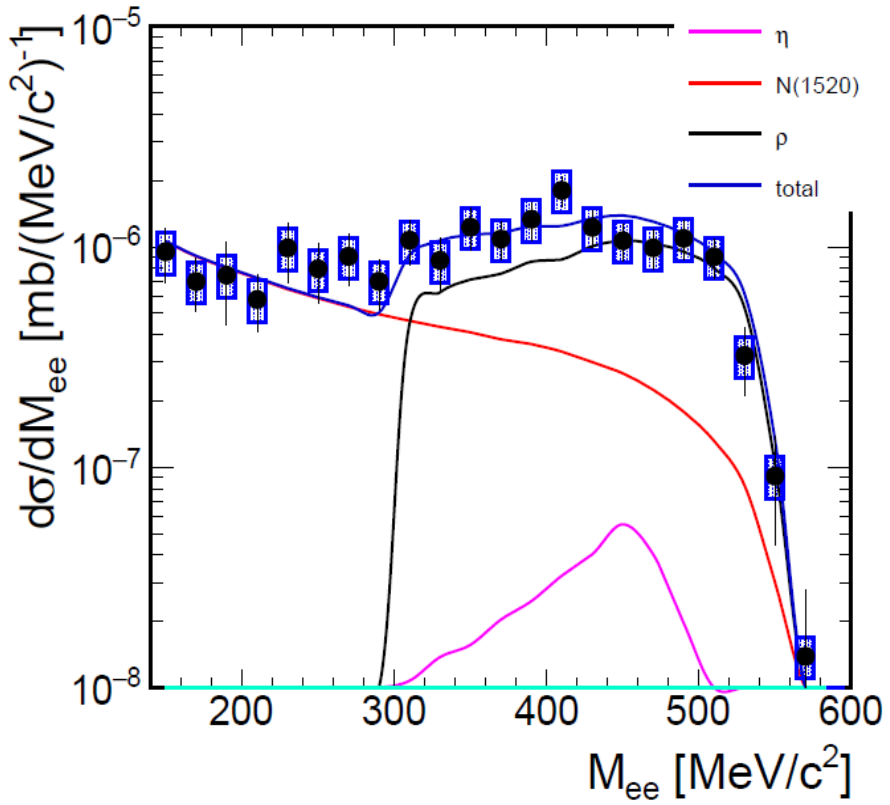
- $\sigma(\pi^- p \rightarrow \pi^0 X)$
  $\pi^0 \rightarrow e^+e^-\gamma$
- $\pi^- p \rightarrow N(1520)$
  Dalitz decay with a constant form factor
- $\sigma(\pi^- p \rightarrow \eta X)$
  $\eta \rightarrow e^+e^-\gamma$

- π^-+C treated as a quasi-free process
- Cross sections taken from database (Landolt-Bornstein)

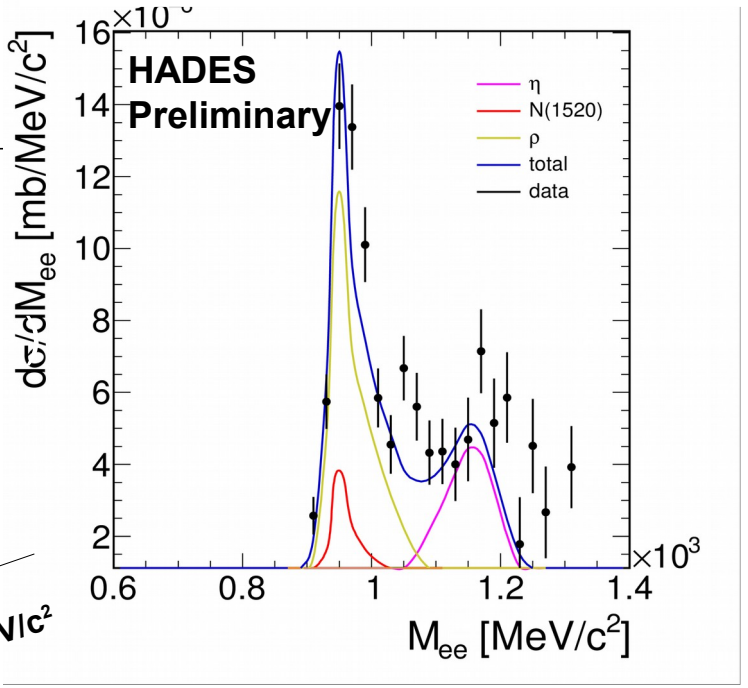
- Simulations filtered through the HADES acceptance

- **Cocktail without ρ contribution does not describe measured data!**

Exclusive channel: $\pi^- p \rightarrow n e^+ e^-$



Missing mass with M_{ee}>140 MeV/c^2



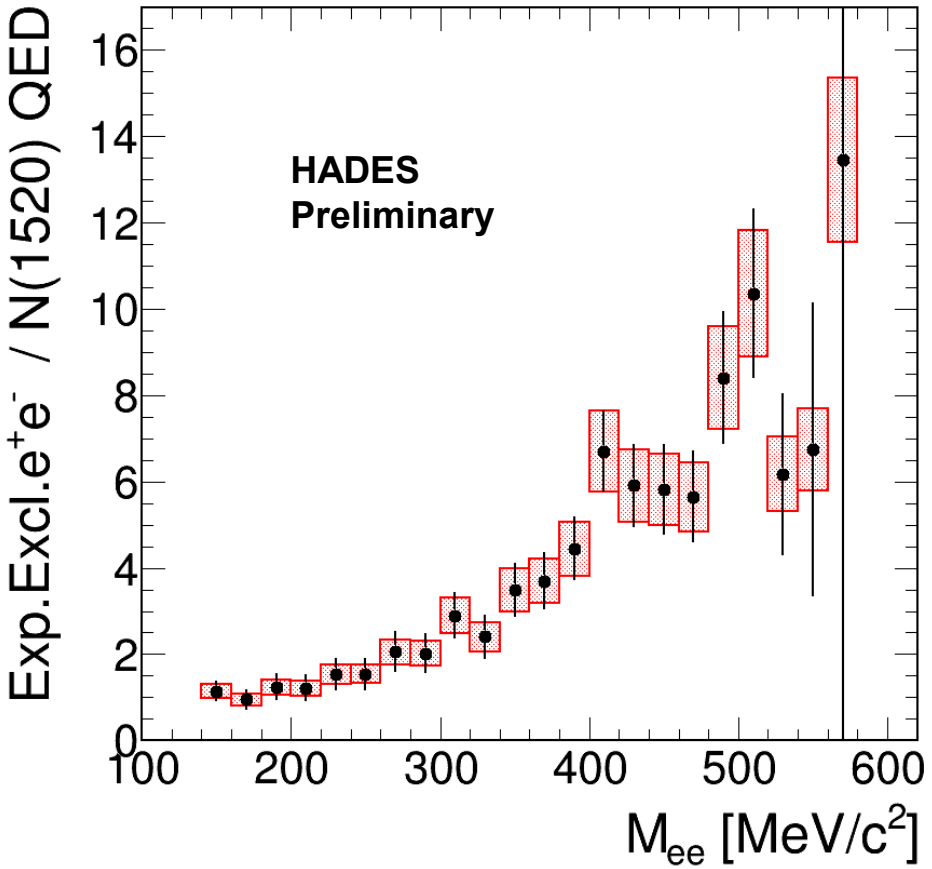
900 < Miss.Mass < 1020 MeV/c^2

ρ contribution from PWA (partial wave analysis) of $\pi^+\pi^-$ HADES data and using the **Strict Vector Dominance Model (VDM)**

Good description using a cocktail of point-like baryons+ρ contribution

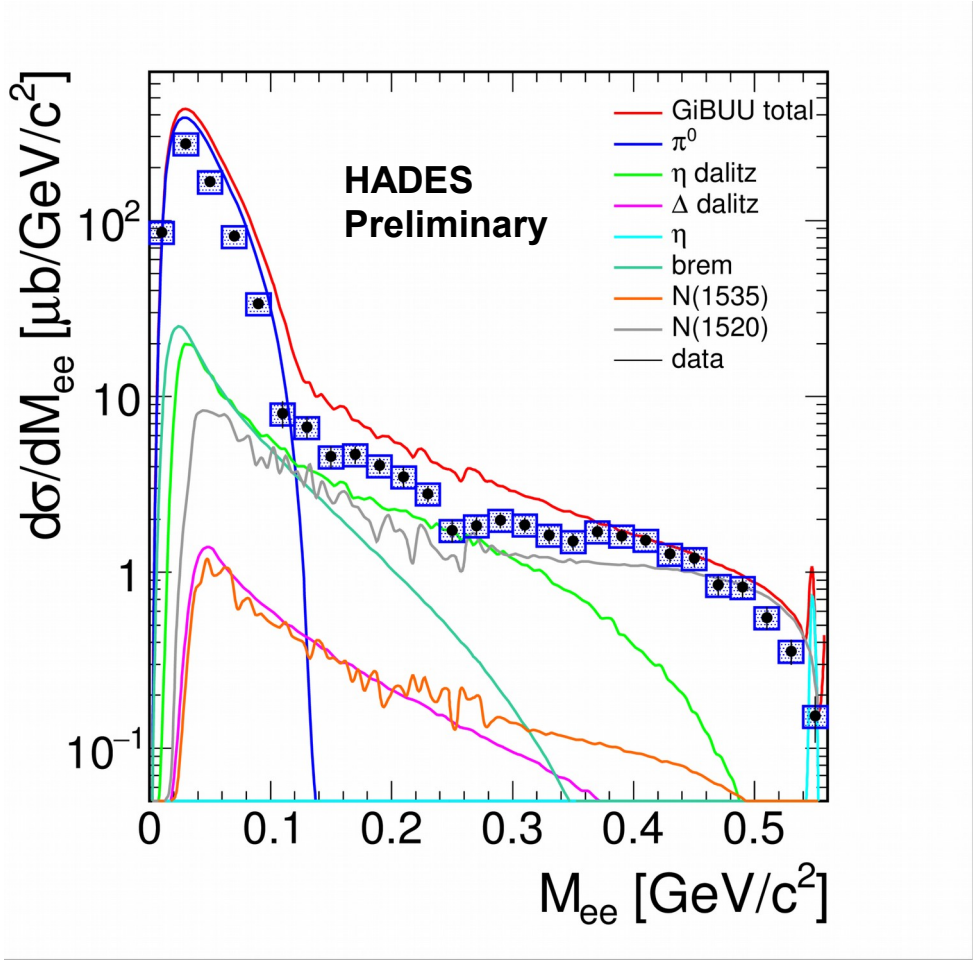
$$\frac{d\sigma}{dM_{ee}} = \frac{d\sigma}{dM_{\pi\pi}} C_p \left(\frac{m_\rho}{m_{ee}}\right)^3 \quad C_p = 4.7\text{x}10^{-5}$$

Deviation from point-like behaviour



- Ratio between:
  - Efficiency corrected exclusive e^+e^- spectra
  - N(1520) QED calculation, filtered through the HADES acceptance
- **Clear deviation from unity in the high mass region!**
- **Indication for VDM like form factors**

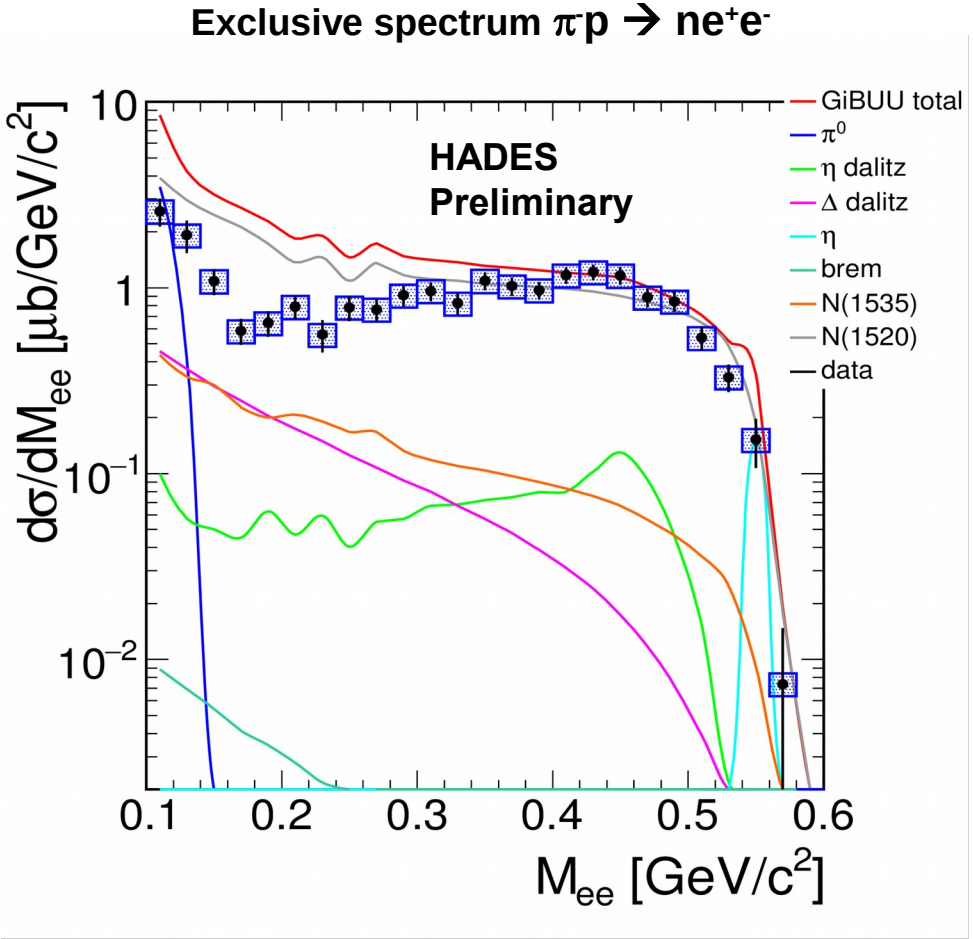
Comparison with GiBUU model



- BUU-type hadronic transport model
- Incoherent sum of the cocktail components
- σ_p (π^0) = 19 mb
- σ_p (η) = 0.9 mb
- σ_p (Δ) = 4.24 mb

- Some overestimation in π^0 region and above 140 MeV/c^2 dominated by N(1520) and η

Comparison with GiBUU model

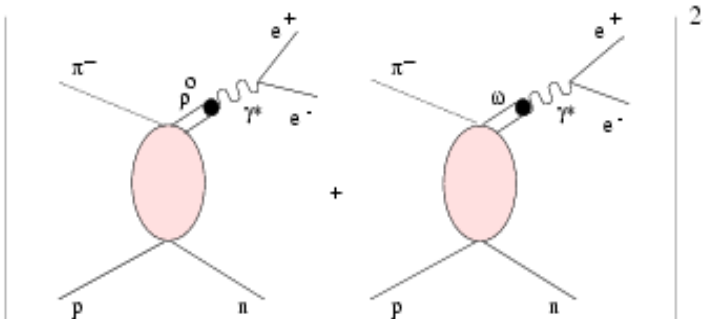


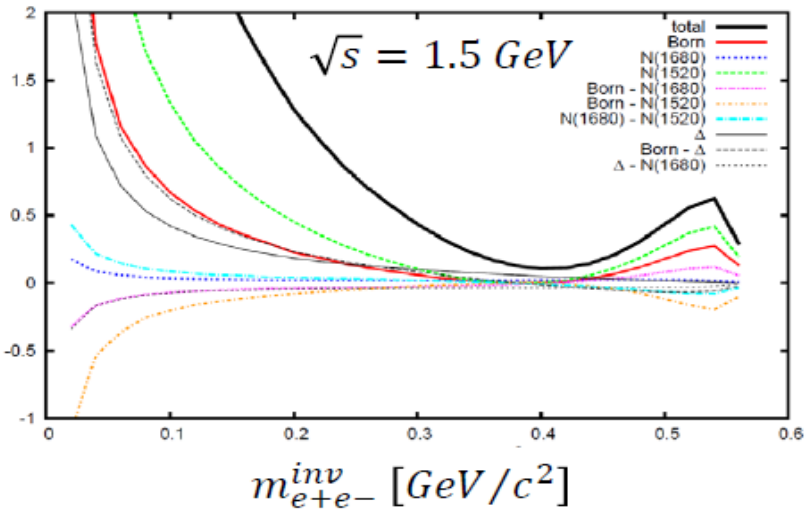
- N(1520)→Nρ→Ne⁺e⁻ with ρ→e⁺e⁻ following pure VDM form factor for N(1520)

→ Overestimation points to problem with strict VDM at small invariant mass (close to real photon emission)

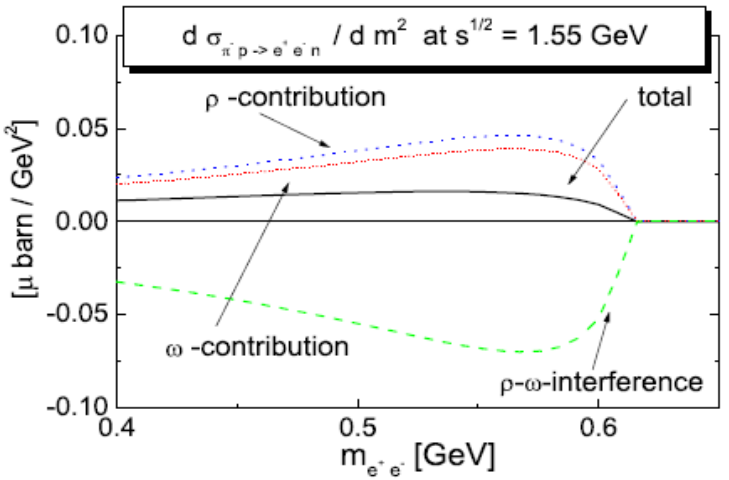
e^+e^- production in microscopic models

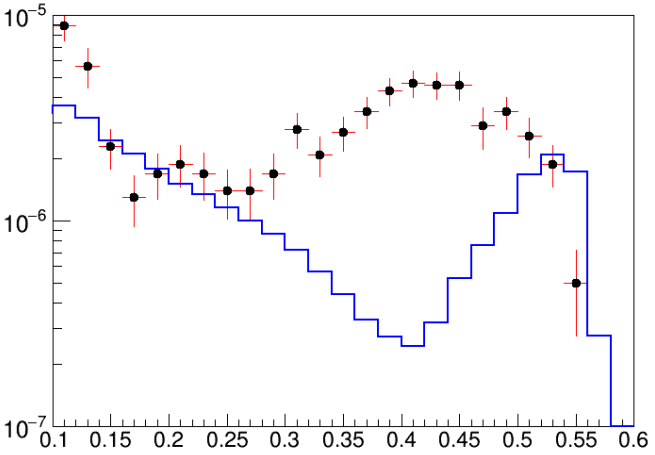
Resonance contribution N*/Δ + Interference effects (important $\leq$ ρ/ω threshold!)





M.Lutz, B.Friman, M. Souyer, NPA 713 (2003)





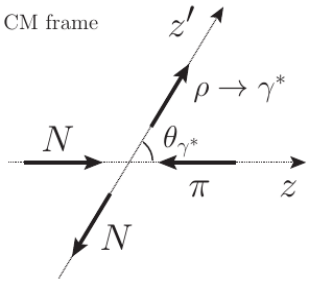
G. Wolf, M.Zetenyi, PRC86 (2012)

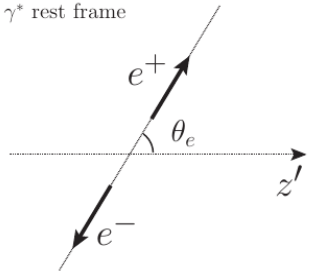
Exploiting angular distribution

- Invariant mass shows deviation from point-like baryon transitions
- Additional information on the electromagnetic transitions can be provided by the angular distribution
- General formula for $\gamma^* \rightarrow e^+e^-$ angular distribution:

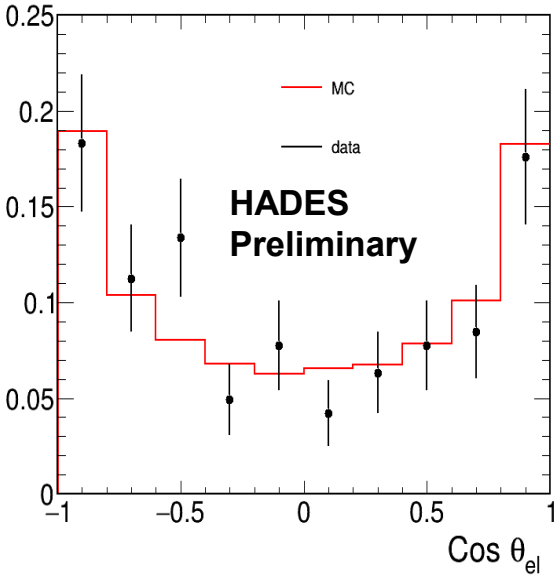
$$|A|^2 = 8|\mathbf{k}|^2\left[1 - \rho_{11}^{(H)} + \cos^2\theta(3\rho_{11}^{(H)} - 1) + \sqrt{2}\sin(2\theta)\cos\phi\,\mathbf{Re}\rho_{10}^{(H)} + \sin^2\theta\cos(2\phi)\,\mathbf{Re}\rho_{1-1}^{(H)}\right]$$

- Coefficients depend on $M_{e^+e^-}$ and γ^* angle
- The estimation of the coefficients is performed via a log-likelihood event-by-event approach

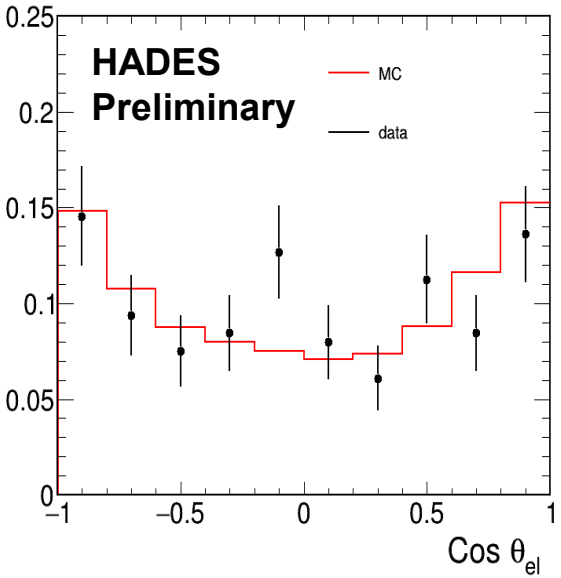




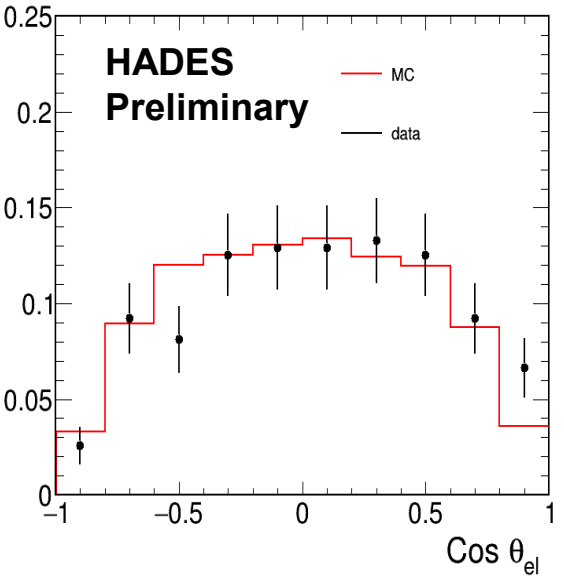
Fit results in HADES acceptance



Cos θ_{γ}^{CM} <0 and
M_{inv} >400 MeV/c^2



0< Cos θ_{γ}^{CM} <0.5 and
M_{inv} >400 MeV/c^2



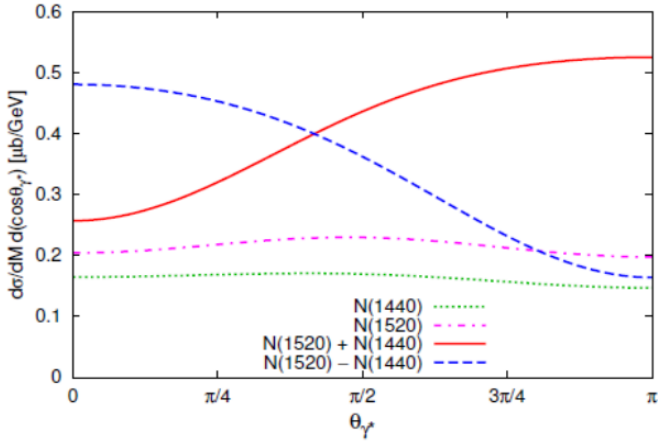
Cos θ_{γ}^{CM} >0.5 and
M_{inv} >400 MeV/c^2

Model predictions

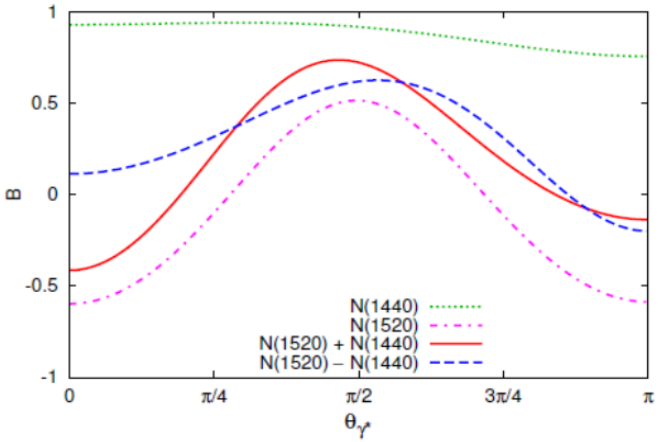
- Microscopic model including N(1440) and N(1520) excitations in s and u-channels and VDM electromagnetic form factors (E.Speranza, M. Zetenyi, B. Friman, Physics Letters B 764 (2017) 282–288)

$$\frac{d\sigma}{dM\, d\cos\theta_{\gamma^*}\, d\cos_e} \propto \Sigma_\perp(1+\cos^2\theta_e) + \Sigma_\parallel(1-\cos^2\theta_e)$$
$$\propto A(1 + B(\theta_{\gamma^*}, M)\cos^2\theta_e)$$

$$\lambda_\theta = \frac{3\rho_{11}-1}{1-\rho_{11}}$$



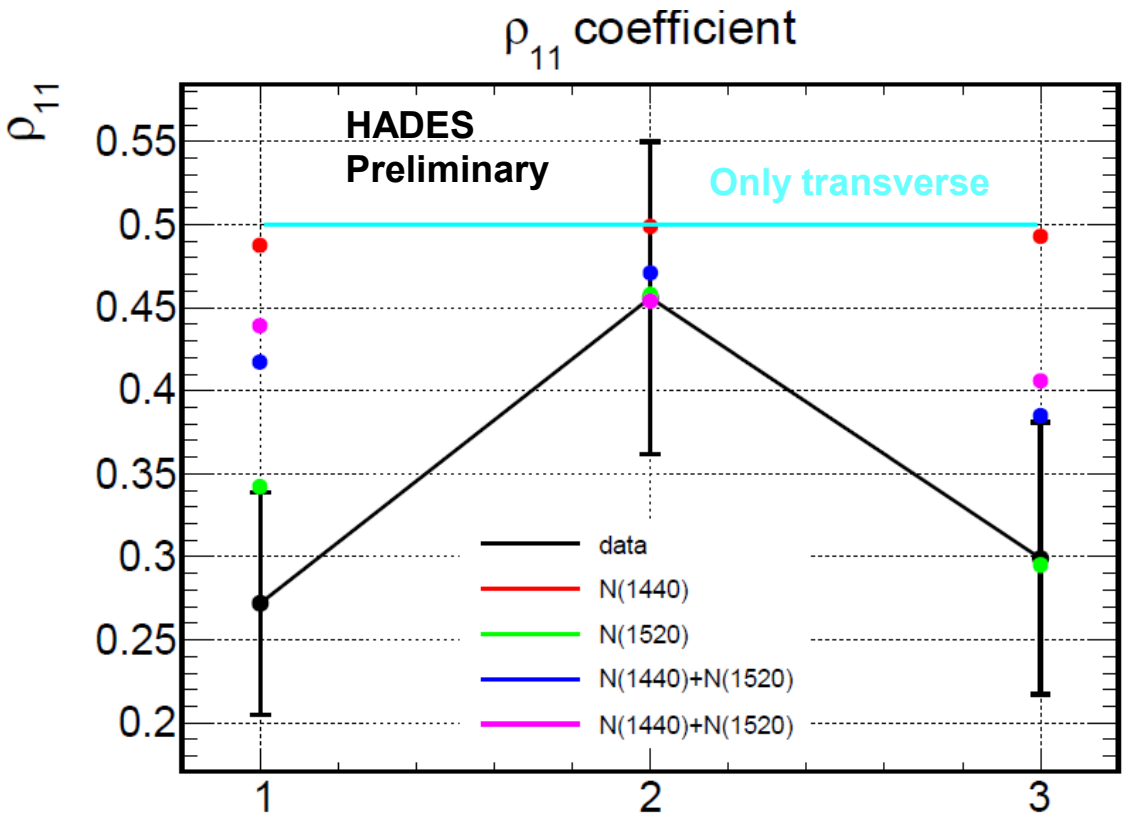
Distribution of virtual photon angle in CM: sensitive to interference between amplitudes for different contributions



Distribution of helicity angle: for each contribution, it reflects the electromagnetic structure of the transition

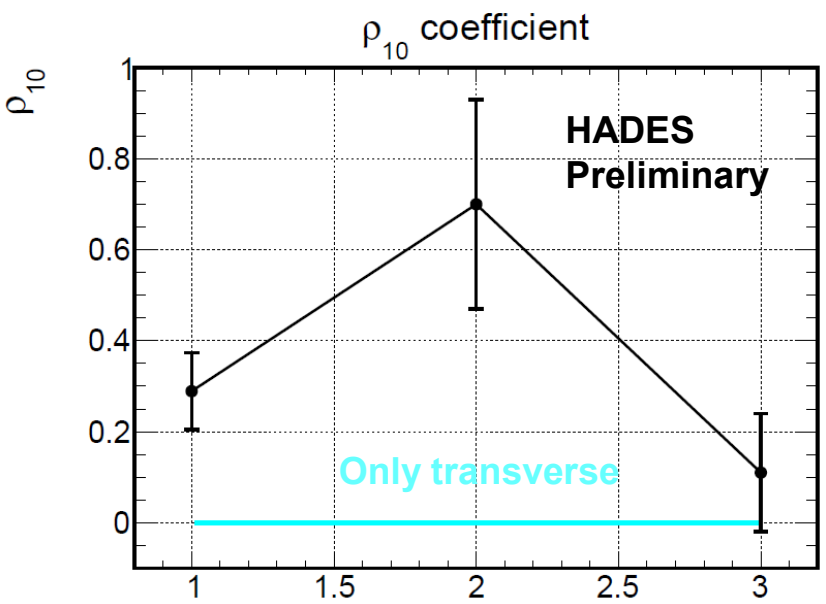
Model predictions
Comparison with data

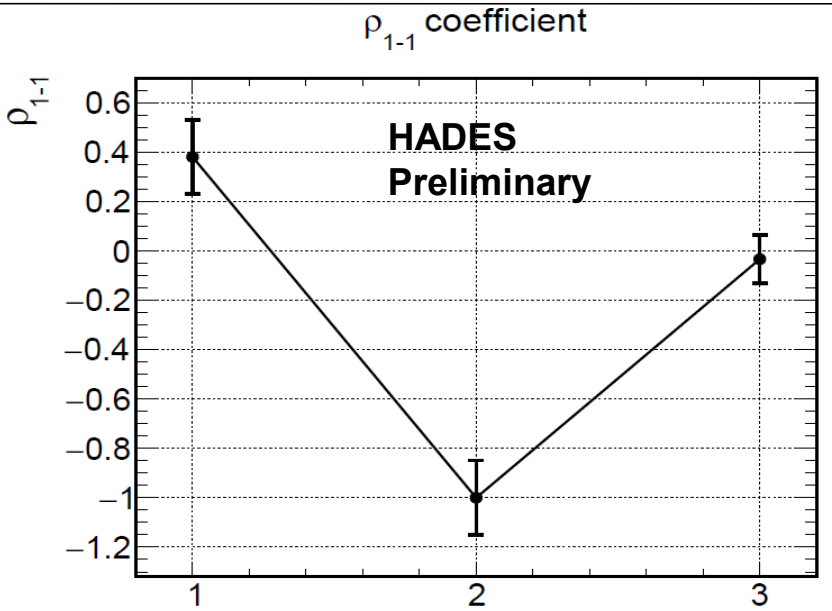
- Comparison of density matrix coefficients extracted from the data and in the microscopic model in the same M_{ee} and θ_{γ^*} ranges



1:-1<Cos θ_{cm}<0
2:0<Cos θ_{cm}<0.5
3:0.5<Cos θ_{cm}<1

Model predictions
Comparison with data





- Model independent statements: transverse photons give $\rho_{11}=1/2$, $\rho_{10}=0$
- Data indicate significant contribution of longitudinal virtual photons, especially for $\cos\theta_{cm}$ in [-1,0] and [0.5,1].
- Consistent with pure contribution of N(1520)
- Points to a too large N(1440) contribution (also supported by PWA of $\pi^- p \rightarrow n\pi^+\pi^-$ channel)
- Effects of non-resonant terms to be studied

Summary and outlook

- HADES – Di-Electron spectrometer in combination with pion beam is an unique tool to understand in details baryon-ρ couplings using both e^+e^- and $\pi^+\pi^-$ measurements
- Measurement of e^+e^- invariant mass spectra for inclusive and exclusive channels
- **Good agreement with a cocktail of point-like source + ρ contribution deduced from PWA of $\pi^+\pi^-$ data**
- Comparison to GiBUU points to too large N(1520) contributions (due to VDM model?)
- Despite low statistics, angular distributions show sensitivity to time-like electromagnetic structure of the transitions and allows for a comparison to models
- Future plan to continue pion induced reactions at higher energies with an electromagnetic calorimeter and new RICH detector