Electromagnetic baryonic transitions in the time like region with HADES

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HADES

P2IO
Physique des 2 Infinis et des Origines

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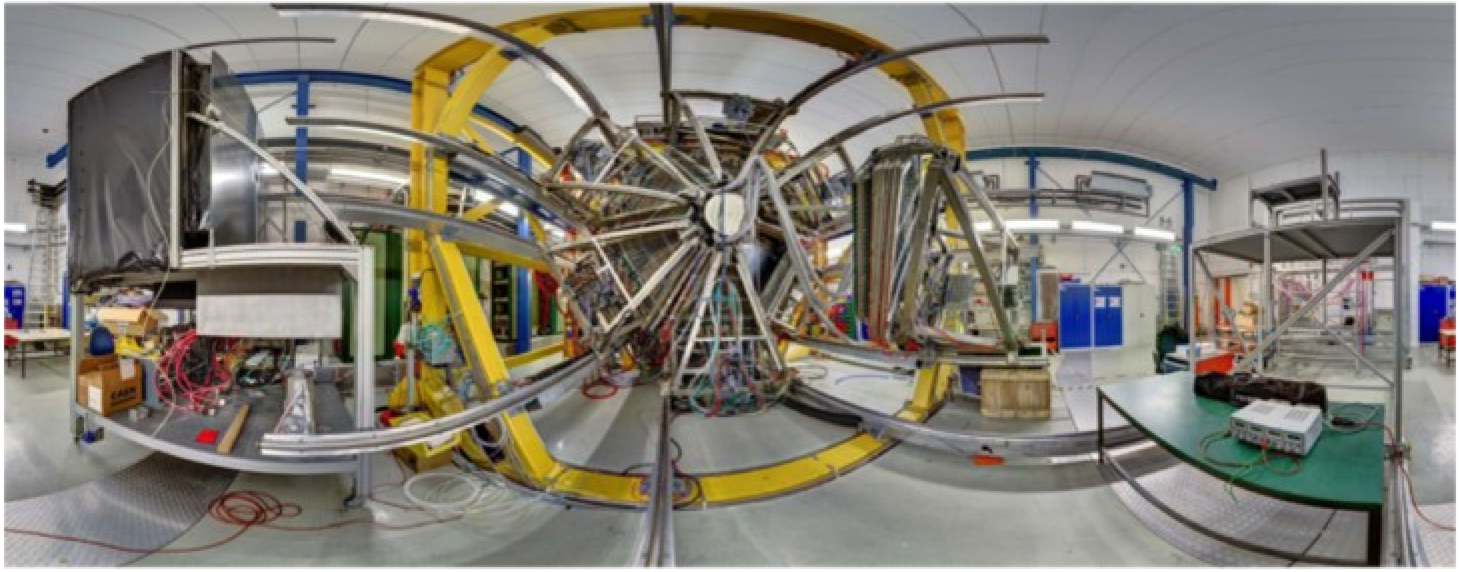
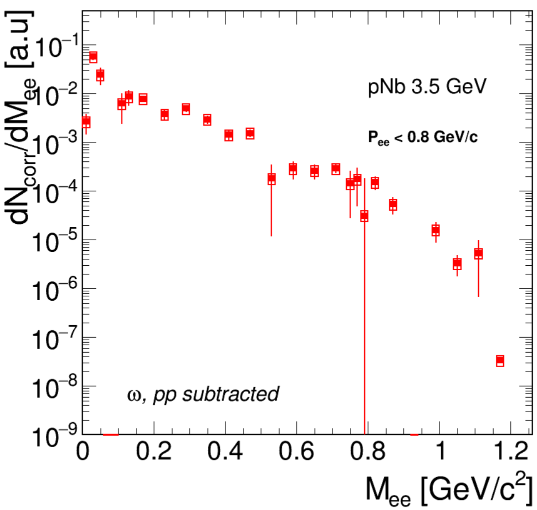
HADES detector

- Located at SIS18, GSI
- Beams: heavy-ions, protons, **pions**
- Low-mass fixed-target experiment
- Hadron and lepton identification
- Acceptance: 85% azimuthal coverage, 18-85° in polar angle
- 80.000 channels
- Fast DAQ: 50kHz event rate

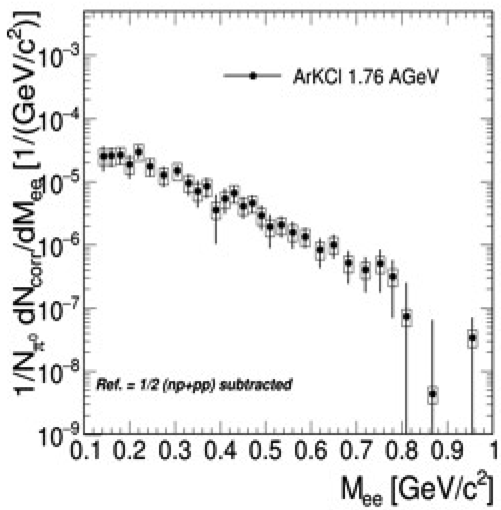


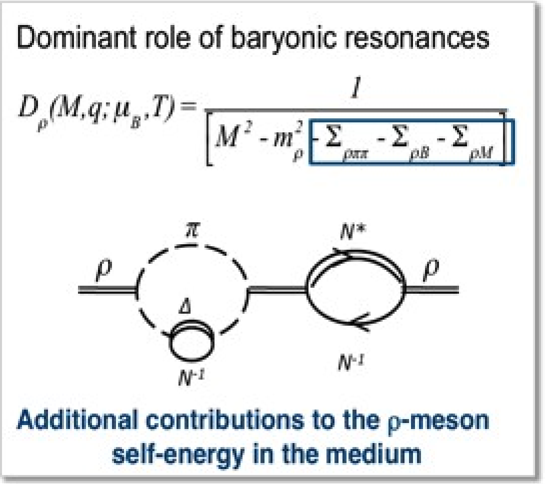
Physics motivation

HADES: Phys.Lett. B715 (2012)



Phys.Rev.C 84 (2011) 014902





- Strong broadening of in-medium states
- Significant contribution from higher (than Δ) mass resonances

- Understanding of ρ-baryon coupling mechanism
- Crucial to better control medium effects

Physics motivation

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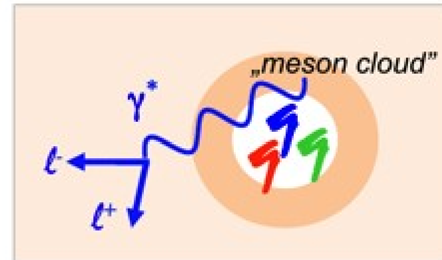
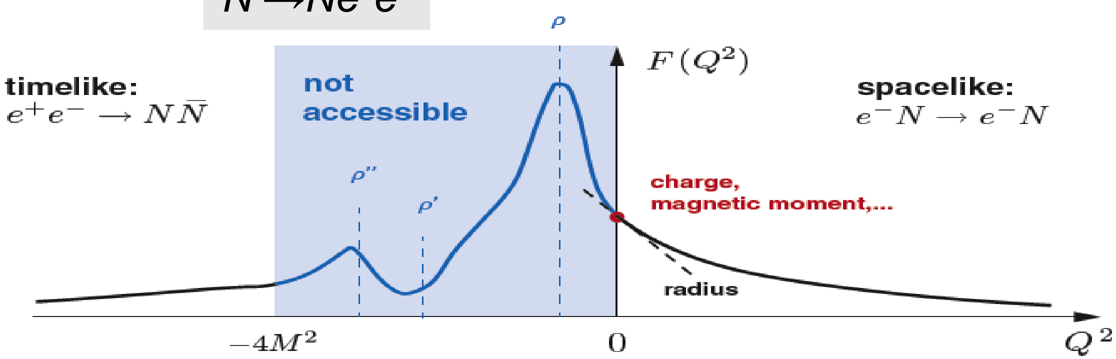
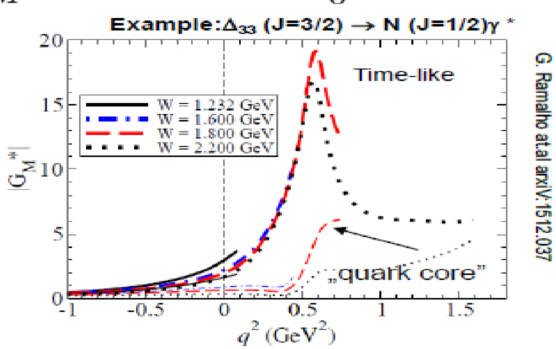
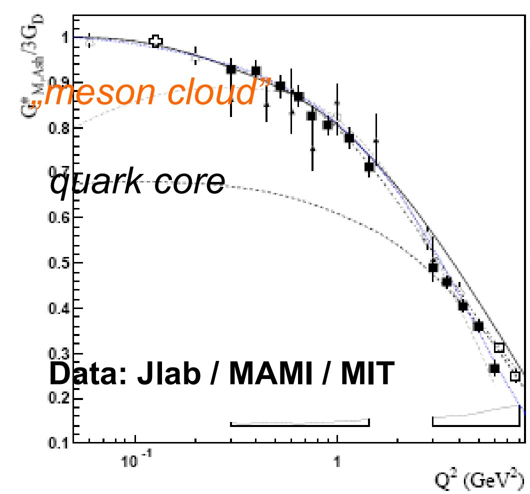
- Study of electromagnetic structure of baryons
  electromagnetic transition form factor
- Important role of pion cloud at small q^2

$N^* \to N e^+ e^-$









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

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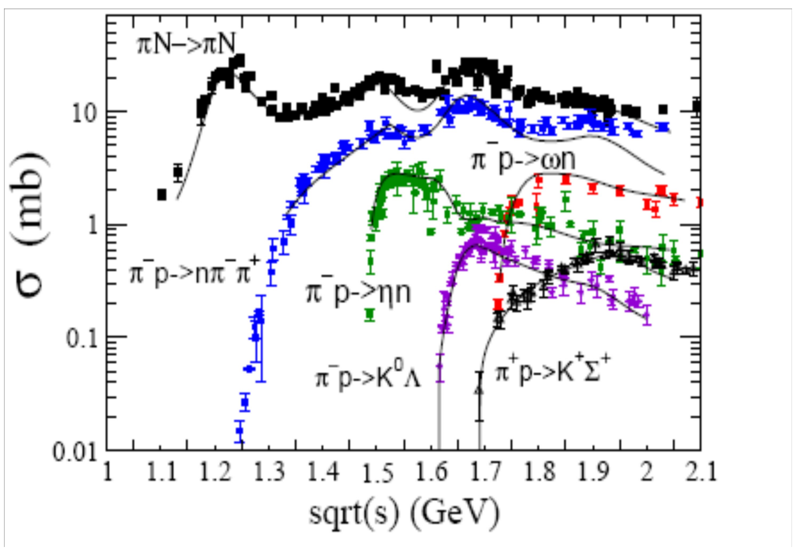
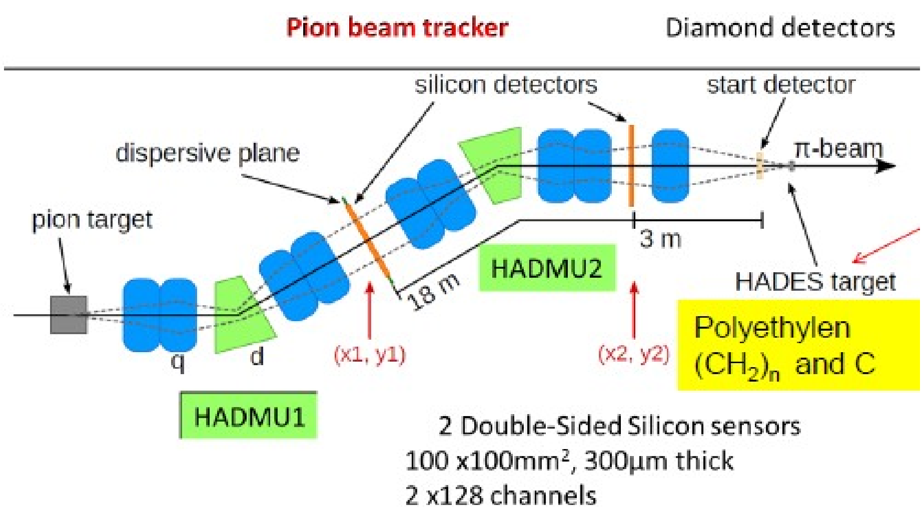
Pion beams with HADES

Secondary π momentum p_π = 0.69 GeV/c, 0.656 GeV/c, 0.748 GeV/c, 0.800 GeV/c in order to perform PWA analysis

- Excitation of the second resonance region
- Beam intensity I = 3-4 × 10^5 π/s
- Target: Polyethylene $(CH_2)_n$ and Carbon

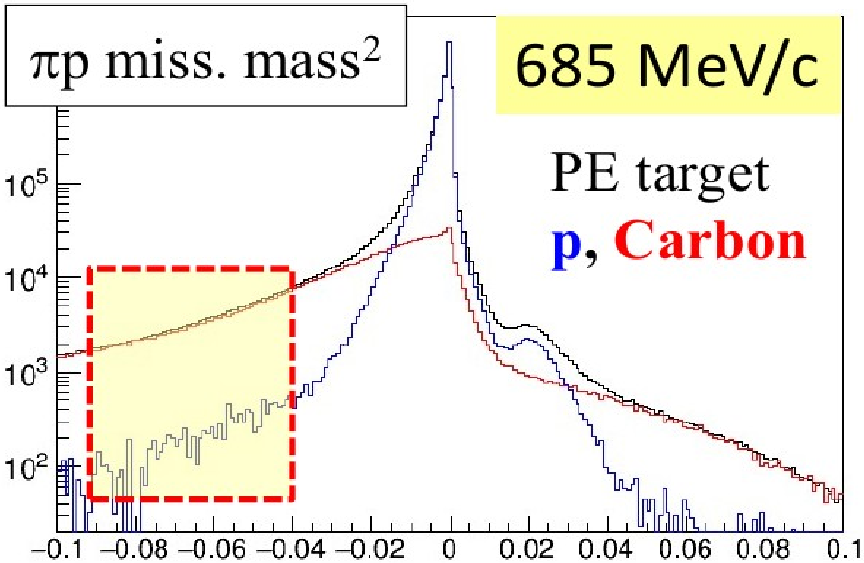


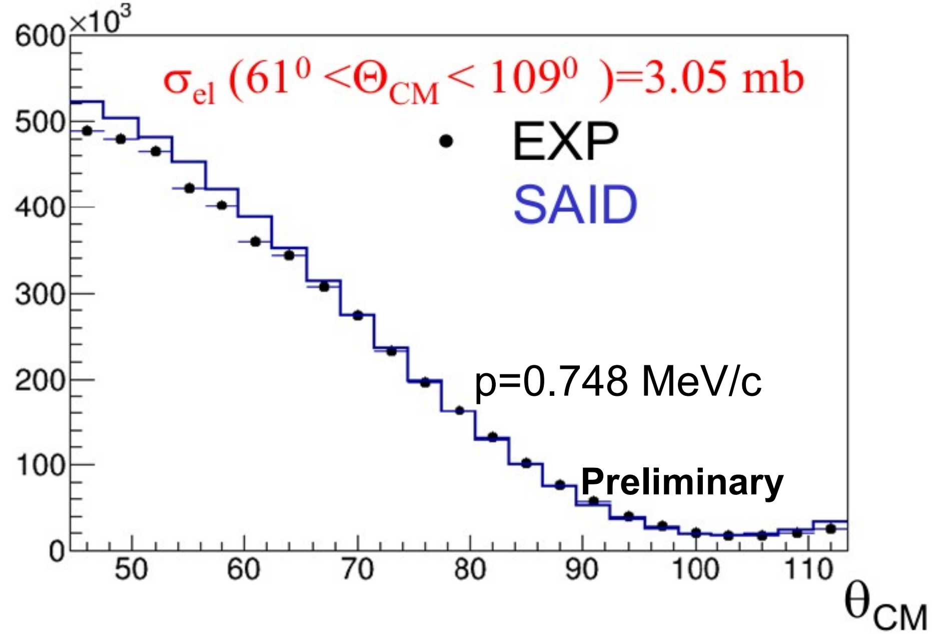


- Primary beam: 8 × 10^{10} N_2 ions/spill
- E = 2 AGeV
- Spill: 4s cycle
- Total ~15 days of effective measurements

Normalization factor

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





HADES programme for pion beam

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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)

- Strangeness production ($K^{\pm}$, K0, ϕ)

  Absorption of mesons in cold nuclear matter

Manley et al. PRD30(1984), 904

Total cross sections from PWA

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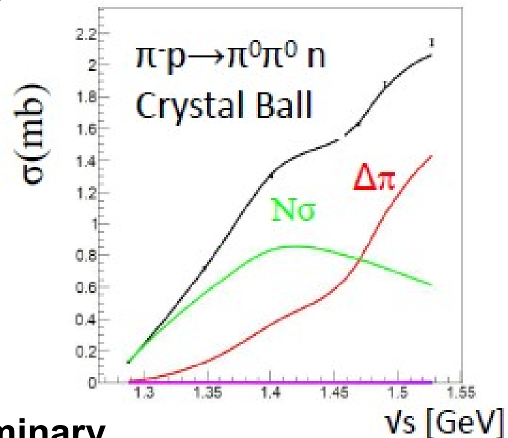
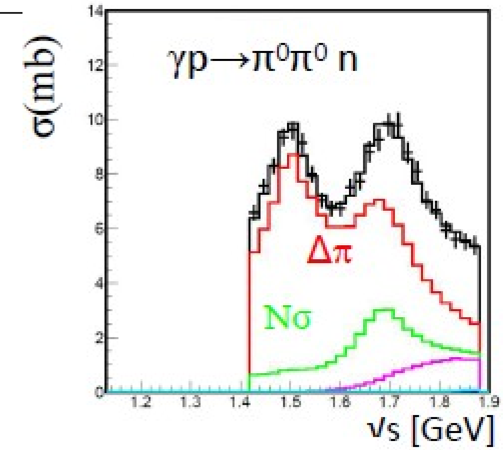
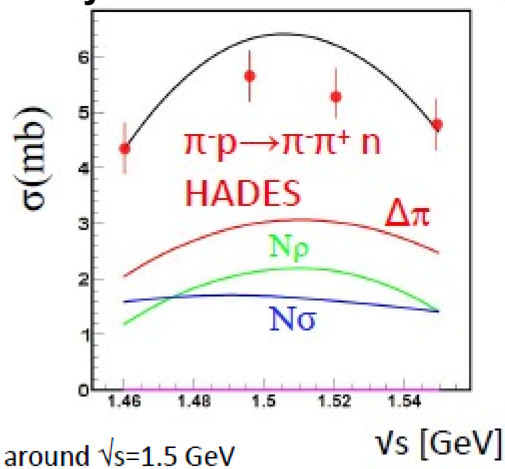
$2\pi^0$ channels:
Dominant contributions are $\Delta\pi$ and $N\sigma$ ($2\pi^0$ in I=0)
ρ (I=1) does not contribute

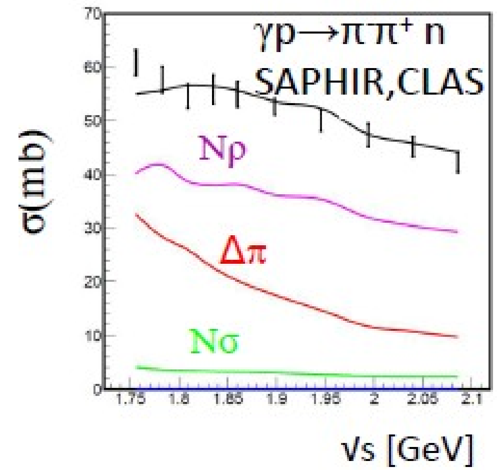




Preliminary

$\pi^+\pi^-$ channels:
Important $N\rho$ contribution



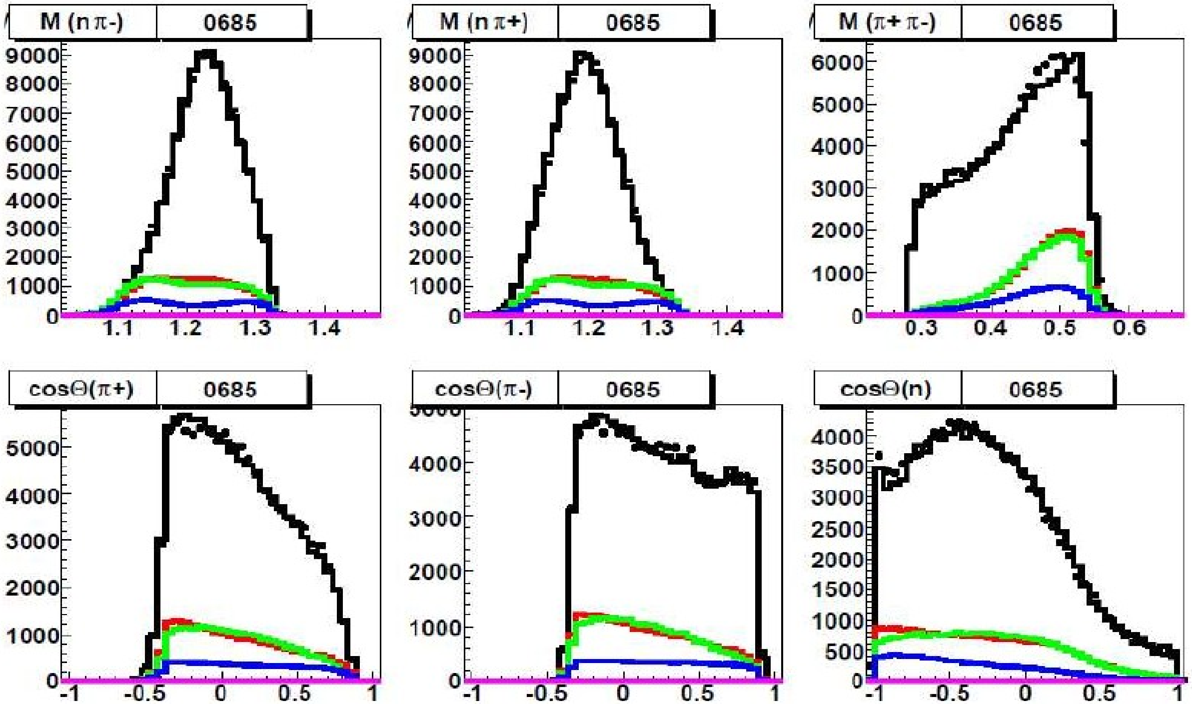


- Only N(1520) and P11(1440) play a significant role around $\sqrt{s}$=1.5 GeV
- New HADES data are crucial for the determination of the ρ contribution
- Still no data on ρ between 1.54 and 1.75 GeV (part of HADES future program)

PWA results (one example)

Bonn-Gatchina PWA including

- HADES data (4 energies $\pi^+\pi^-$ and $\pi^-\pi^0$)
- π and γ database



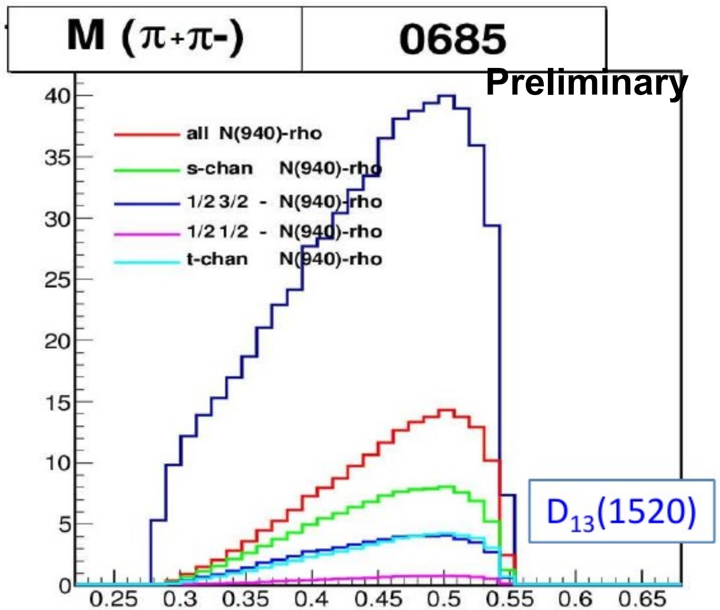
Preliminary

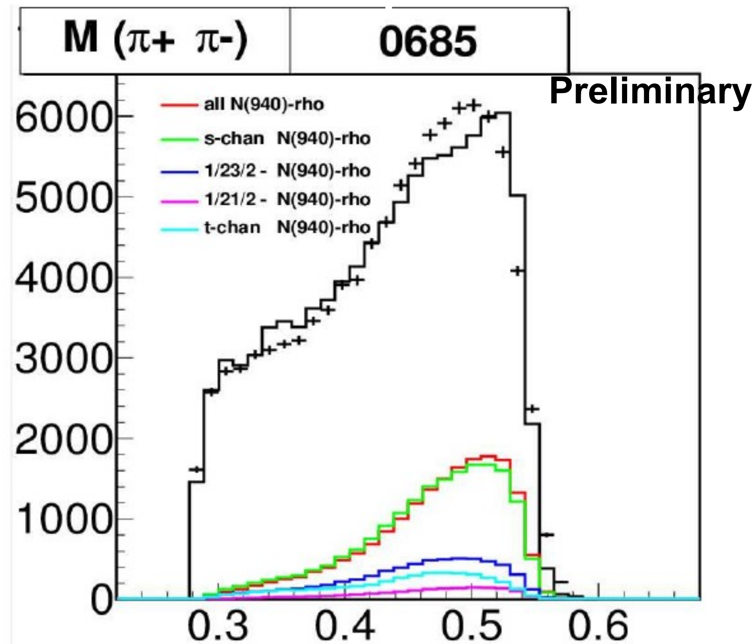
ρ total

ρ s-channel

ρ $D_{13}(1520)$

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





Important non-resonant t-channel contribution

$N(1520)D_{13}$ coupling to ρN: 17 %

Total ρN : 2.3 mb

Dominated by s-channel resonant D13(1520) production

Strong interferences between $1/2^-$ states with isospin 1/2 and 3/2

Inclusive invariant mass spectrum (raw)

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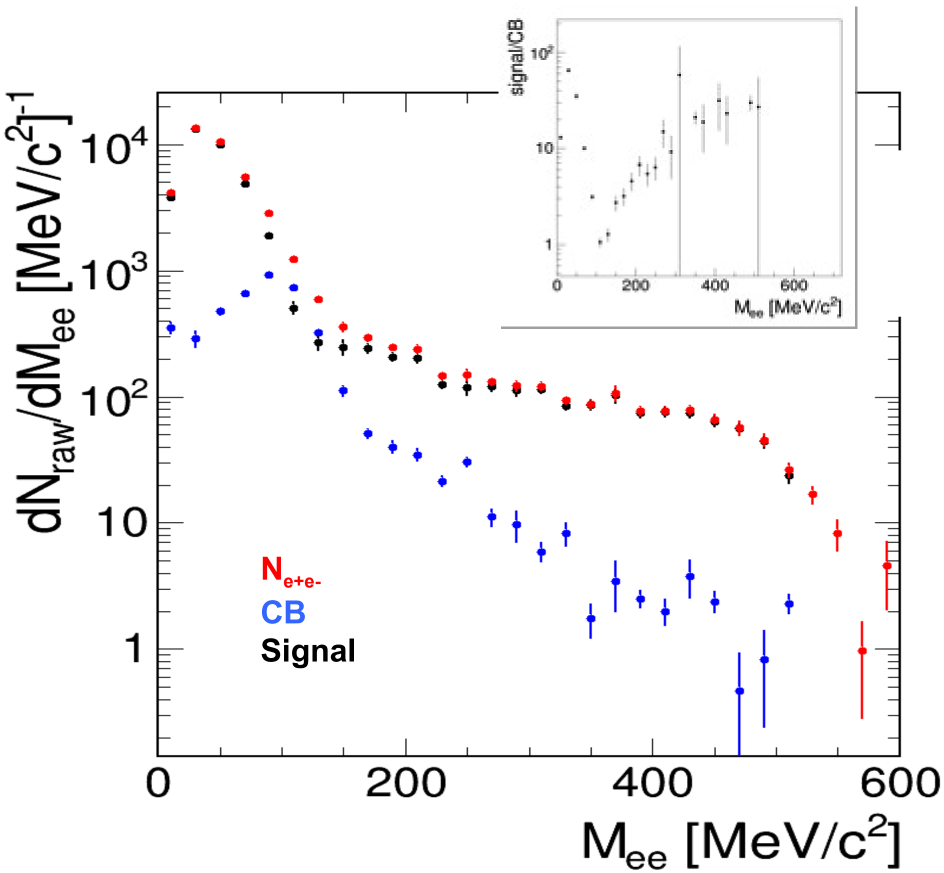

Signal = N_{e+e-} - CB

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/c²) = **13138**

Signal (M>140 MeV/c²) = **2209**

Efficiency corrections based on Monte Carlo simulations

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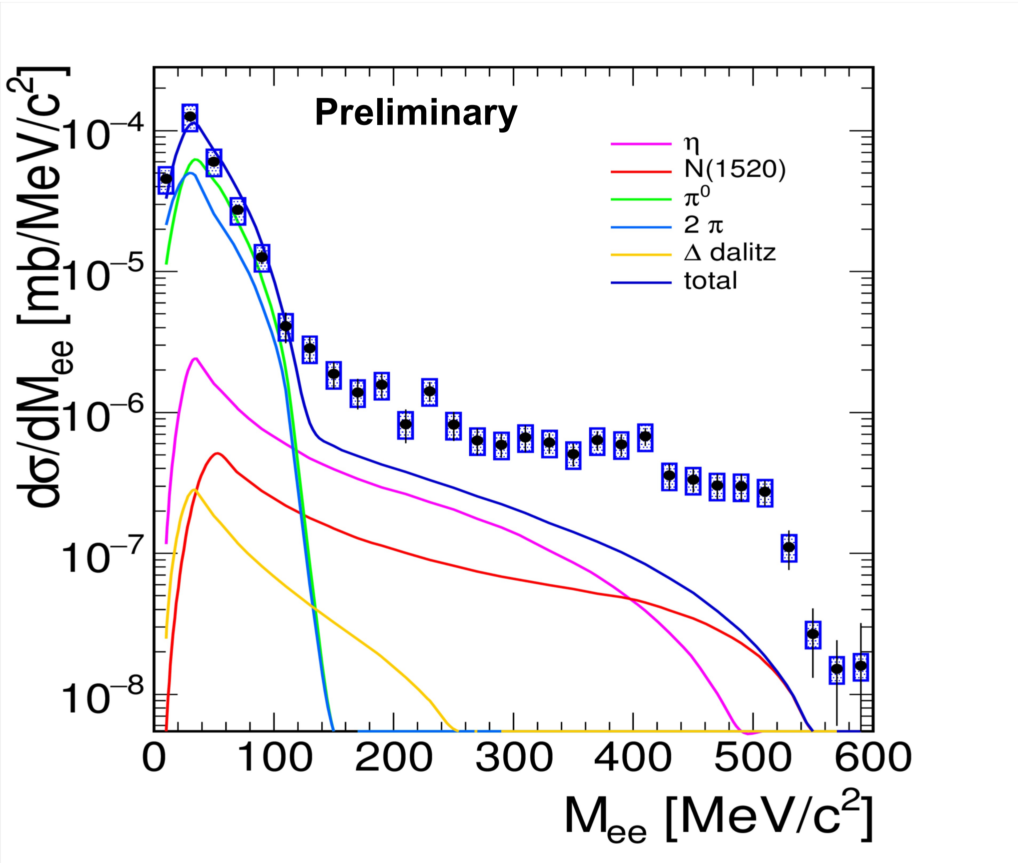
Comparison with simulation



- π^-+C treated as a quasi-free process
- Simulation results are combined according to the ratio p/C 1:2

Sources:

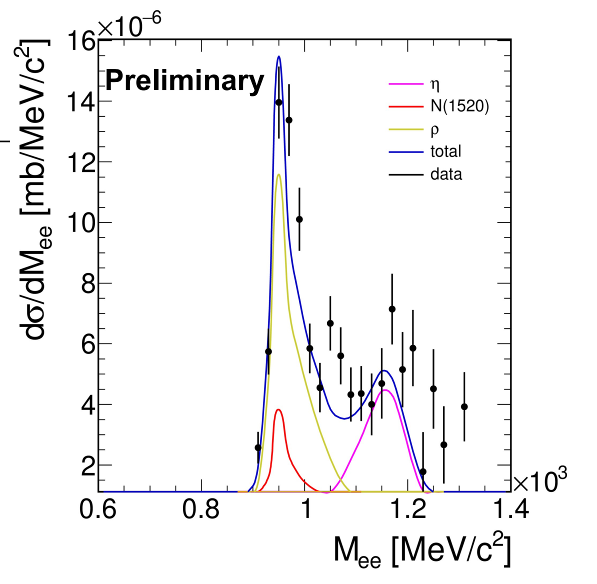
- $\sigma(\pi^- p \rightarrow \pi^0 X)$ = 16.1 mb $\pi^0 \rightarrow e^+e^-\gamma$
- $\pi^- p \rightarrow N(1520)$ = 20.4 mb
  Wolf / Zetenyi „QED" model (no FF)
  with BR = 4 × $10^{-5} \rightarrow n e^+e^-$
- $\sigma(\eta)$ = 0.3 mb (p); 0.7 (C) mb
  $\eta \rightarrow e^+e^-\gamma$

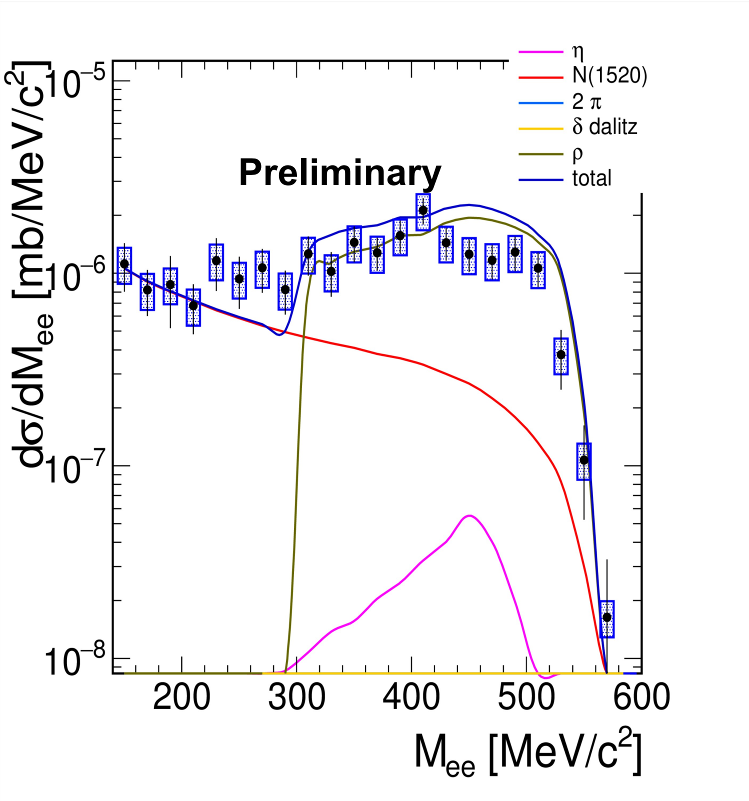
- Efficiency corrected data
- Simulations filtered through the HADES acceptance

- Cocktail without ρ contribution does not describe measured data!

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

Missing mass with M>140 MeV/c²





900 < Miss.Mass < 1020 MeV/c²

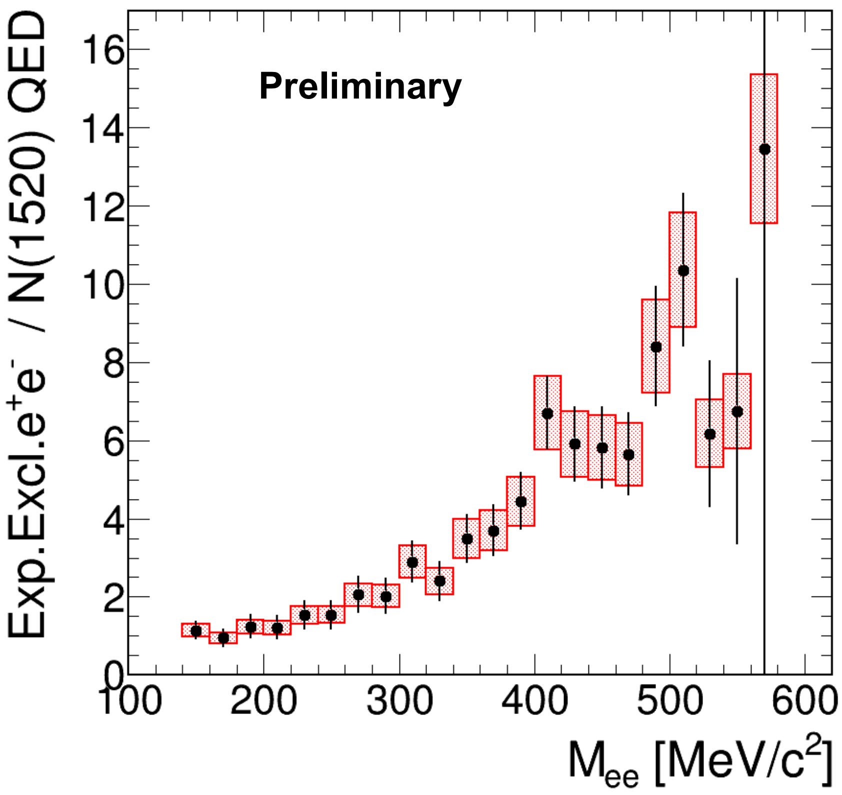
Good description using a cocktail of point-like baryons+ρ contribution

ρ contribution from PWA and using the **Strict Vector Dominance Model**

$$\frac{d\sigma}{dM_{ee}} = \frac{d\sigma}{dM_{\pi\pi}} c_p \left(\frac{m_\rho}{m_{ee}}\right)^3$$

$C_p = 4.7 \times 10^{-5}$

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

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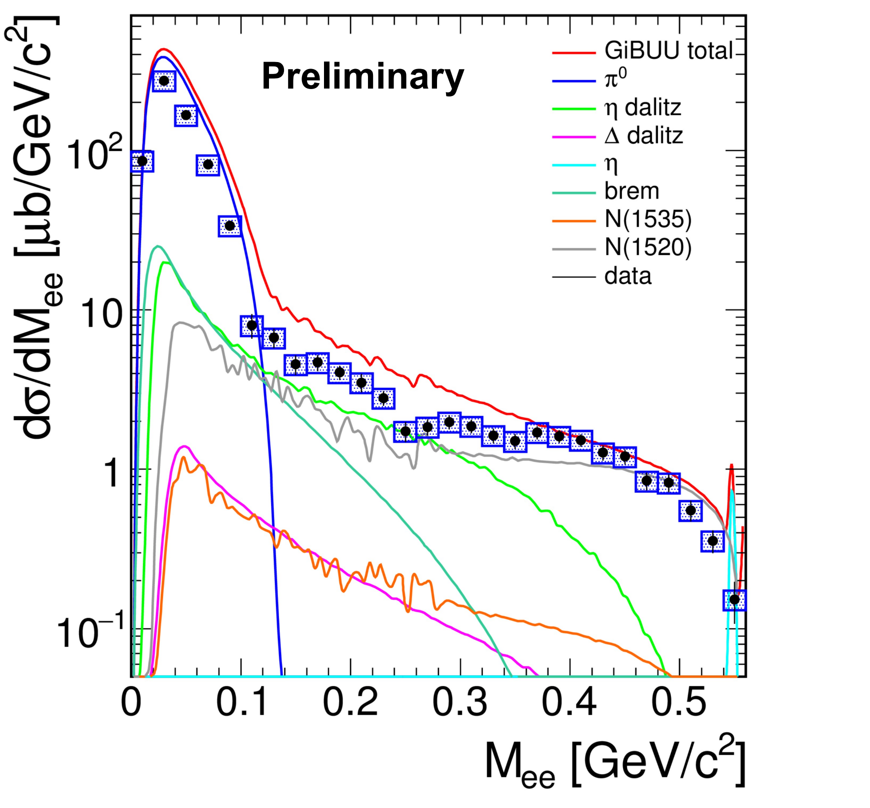
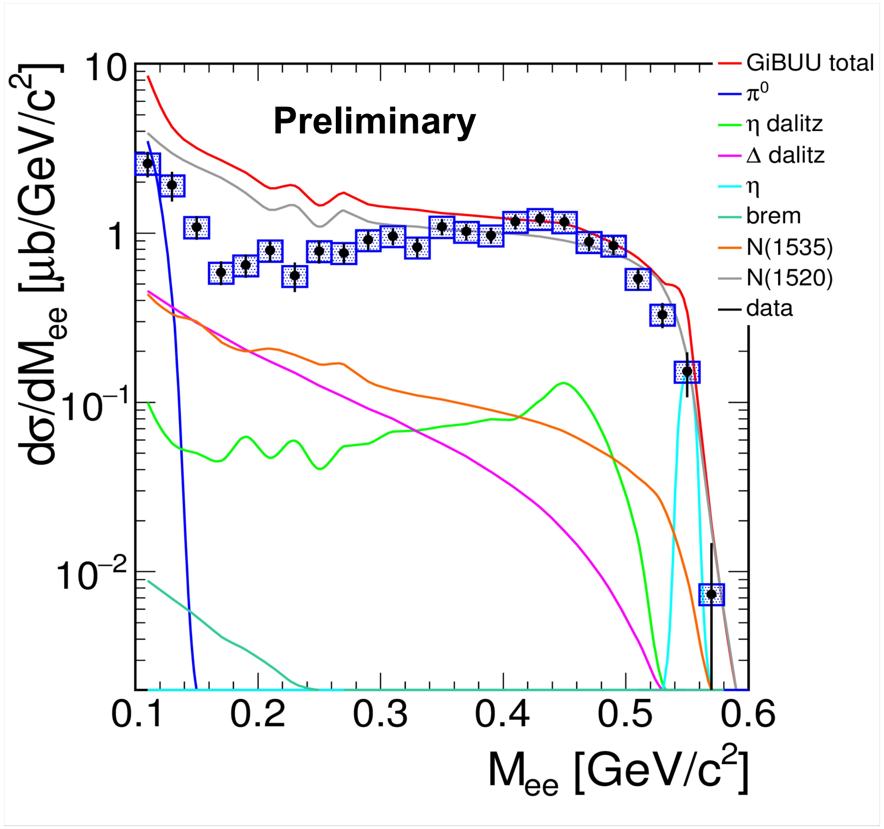
Inclusive spectrum



- BUU-type hadronic transport model
- Incoherent sum of the cocktail components
- $\sigma_p(\pi^0)$ = 19 mb
- $\sigma_p(\eta)$ = 0.9 mb
- $\sigma_p(\Delta)$ = 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

Exclusive spectrum



- Overestimation in π^0 region
- $N(1520) \rightarrow N\rho \rightarrow Ne^+e^-$ with $\rho \rightarrow e^+e^-$ following pure VDM form factor for N(1520)

→ yield excess for N(1520)->e^+e^-N at small q^2

points to known problem of too large radiative decay width : (N*/Delta->Nγ) in pure VDM model.

Outlook – exploiting γ* and e+/e- angular distributions

For a vector particle decaying in 2 fermions:

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

θ and φ are in the rest frame of the vector state,

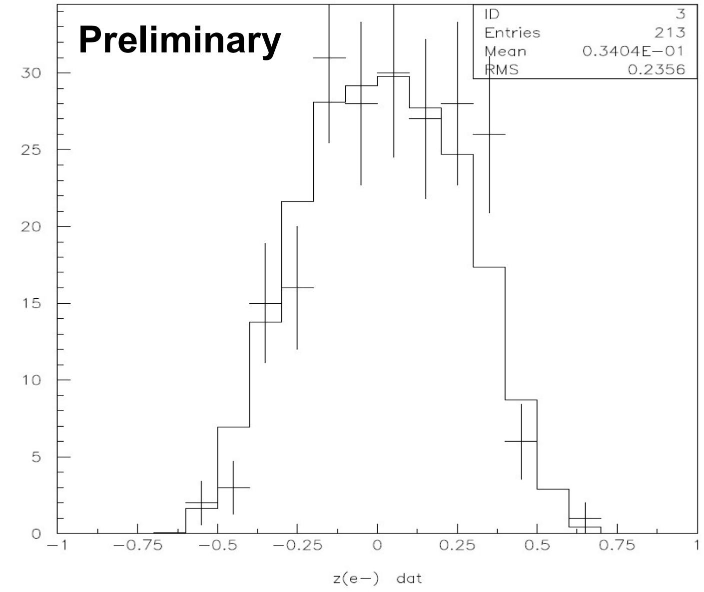
ρ_{ij}: coefficients of spin density matrix

Using the data for γ*->e+e- decay

to find the values of ρ_{11}, ρ_{10} and ρ_{1-1}

using log-likehood method

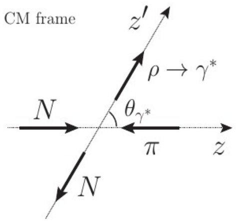
Points:data
Histogram: fitted function

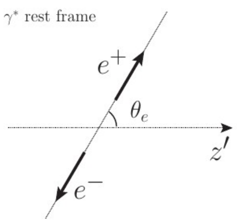


Outlook – exploiting γ* and e⁺/e⁻ angular distributions

Microscopic model(B. Friman, M. Zetenyi, E. Speranza) arxiv.org/pdf/1605.04954.pdf

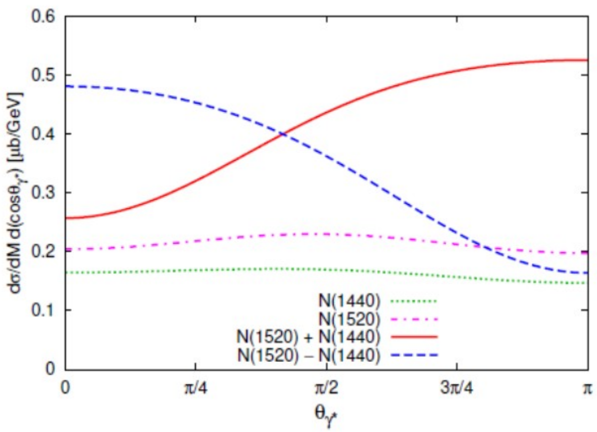
- Distribution of virtual photon angle in CM: sensitive to interference between amplitudes for different contributions
- Distribution of helicity angle: for each contribution, it reflects the electromagnetic structure of the transition

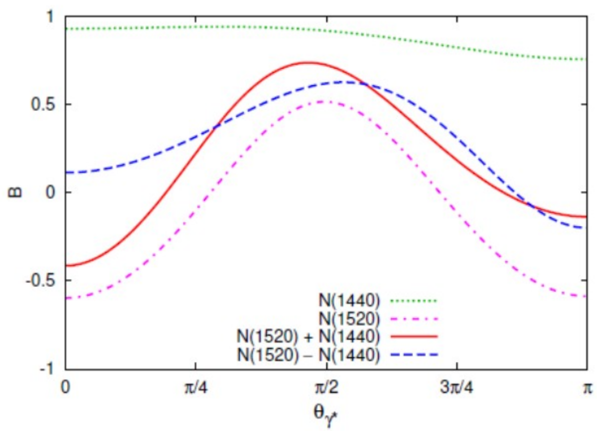




$$\frac{d\sigma}{dM\,d\cos\theta_{\gamma^*}\,d\cos_e} \propto \Sigma_\perp(1+\cos^2\theta_e) + \Sigma_\parallel(1-\cos^2\theta_e)$$

$$\propto A(1 + B(\theta_{\gamma^*}, M)\cos^2\theta_e)$$





Summary

- 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
- Very precise new data in $\pi\pi$ channels

  → Strong impact for baryon spectroscopy N(1520)
- 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?)
- Programme to be continued in 2018 (higher lying resonances, improved quality of π beam, ..)

A.Saranstev

Baryon data base

DATA	BG2013-2014	added in BG2014-2015
$\pi N \to \pi N$ ampl.	SAID or Hoehler energy fixed	
$\gamma p \to \pi N$	$\frac{d\sigma}{d\Omega}, \Sigma, T, P, E, G, H$	E, G, T, P (CB-ELSA, CLAS)
$\gamma n \to \pi N$	$\frac{d\sigma}{d\Omega}, \Sigma, T, P$	$\frac{d\sigma}{d\Omega}(MAMI)$
$\gamma n \to \eta n$	$\frac{d\sigma}{d\Omega}, \Sigma$	$\frac{d\sigma}{d\Omega}$ (MAMI)
$\gamma p \to \eta p$ $\gamma p \to \eta' p$ $\gamma p \to K^+\Lambda$ $\gamma p \to K^+\Sigma^0$ $\gamma p \to K^0\Sigma^+$	$\frac{d\sigma}{d\Omega}, \Sigma$ $\frac{d\sigma}{d\Omega}, \Sigma, P, T, C_x, C_z, O_{x'}, O_{z'}$ $\frac{d\sigma}{d\Omega}, \Sigma, P, C_x, C_z$ $\frac{d\sigma}{d\Omega}, \Sigma, P$	T, P, H, E (CB-ELSA) $\frac{d\sigma}{d\Omega}, \Sigma$ Σ, P, T, O_x, O_z (CLAS) Σ, P, T, O_x, O_z (CLAS)
$\pi^- p \to \eta n$ $\pi^- p \to K^0\Lambda$ $\pi^- p \to K^0\Sigma^0$ $\pi^+ p \to K^+\Sigma^+$	$\frac{d\sigma}{d\Omega}$ $\frac{d\sigma}{d\Omega}, P, \beta$ $\frac{d\sigma}{d\Omega}, P\ (K^0\Sigma^0)\ \frac{d\sigma}{d\Omega}\ (K^+\Sigma^-)$ $\frac{d\sigma}{d\Omega}, P, \beta$	
$\pi^- p \to \pi^0\pi^0 n$ $\pi^- p \to \pi^+\pi^- n$	$\frac{d\sigma}{d\Omega}$ (Crystal Ball)	 $\frac{d\sigma}{d\Omega}$ (HADES)
$\gamma p \to \pi^0\pi^0 p$ $\gamma p \to \pi^0\eta p$ $\gamma p \to \pi^+\pi^- p$	$\frac{d\sigma}{d\Omega}, \Sigma, E, I_c, I_s$ $\frac{d\sigma}{d\Omega}, \Sigma, I_c, I_s$ 	 $\frac{d\sigma}{d\Omega}, I_c, I_s$ (CLAS)
$\gamma p \to \omega p$ $\gamma p \to K^*(890)\Lambda$		$\frac{d\sigma}{d\Omega}, \Sigma, \rho^0_{ij}, \rho^1_{ij}, \rho^2_{ij}, E, G$ (CB-ELSA) $\frac{d\sigma}{d\Omega}, \Sigma, \rho^0_{ij}$ (CLAS)

Included in fit