# Baryon electromagnetic transitions in pion induced reactions with HADES

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# Physics motivation

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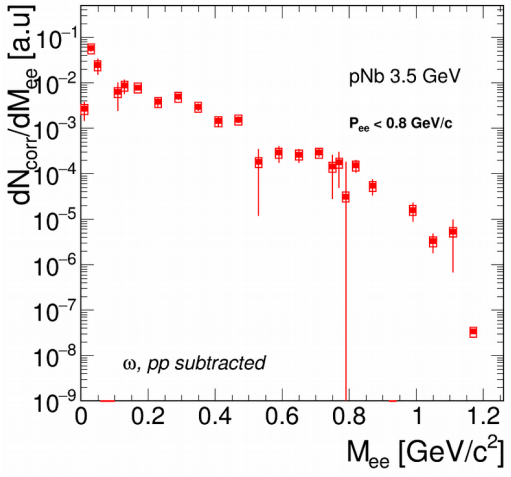
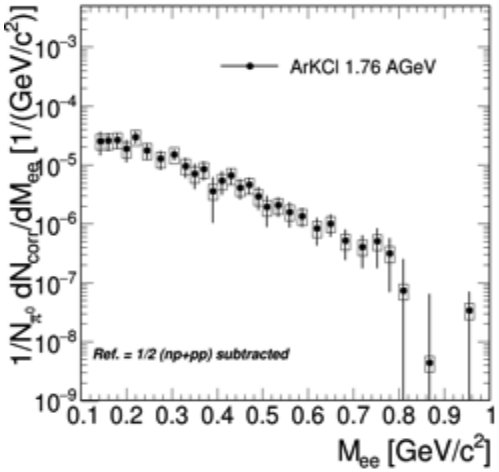
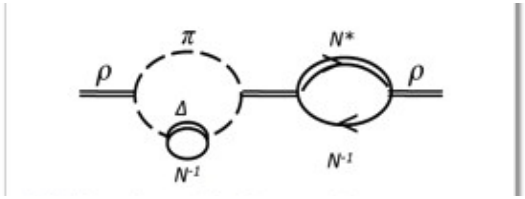
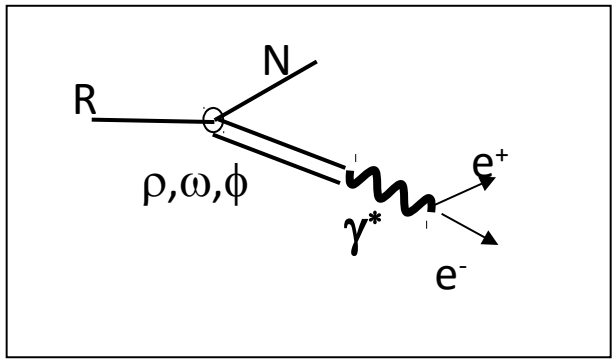
*HADES: Phys.Lett. B715 (2012)* *Phys.Rev.C 84 (2011) 014902*




- Strong broadening of in-medium ρ spectral function due to its coupling with baryonic resonances (N(1520), Δ(1620), N(1720), etc.)
- With $\pi^-$p interactions better control of medium effects
- Study of electromagnetic structure of baryons electromagnetic transition form factor



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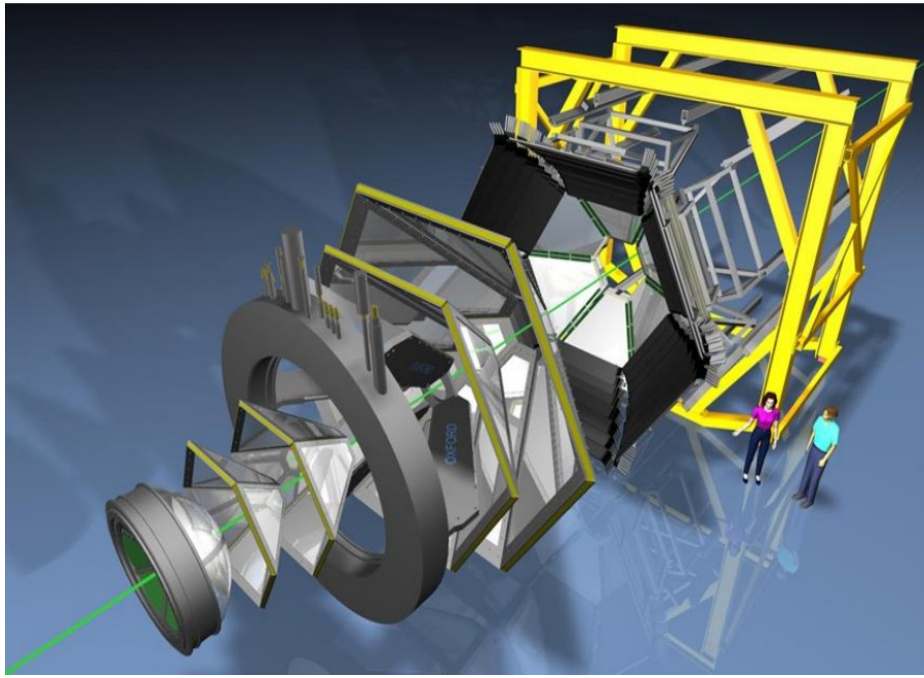
# HADES detector

- 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 $\rho/\omega$ region)
- 80.000 channels
- Fast DAQ: 50kHz event rate



# Pion beams with HADES

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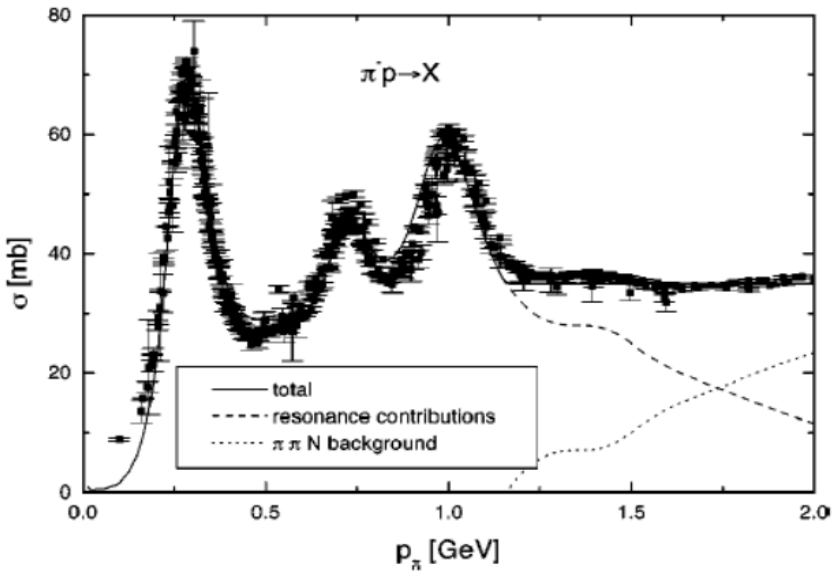
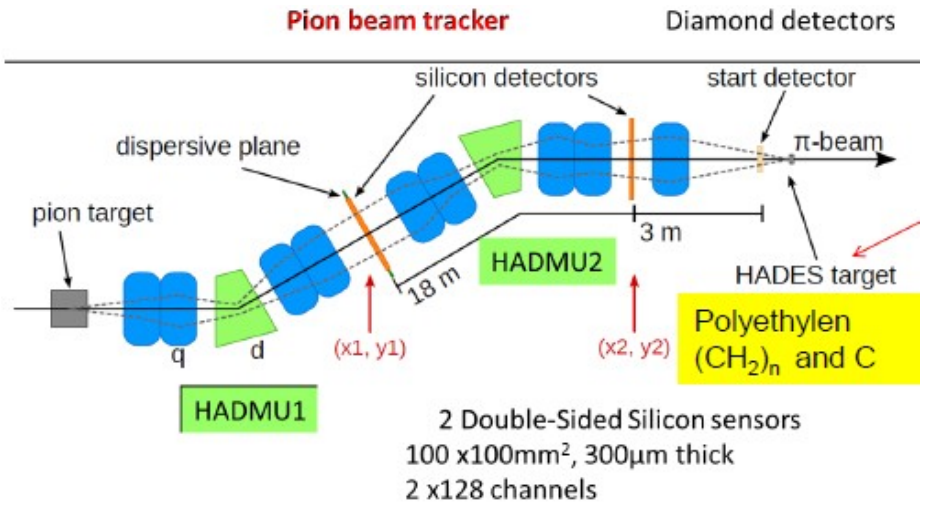
**Secondary π momentum $p_\pi$ = 0.69 GeV/c**

- Access to 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



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# 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)

  *Manley et al. PRD30(1984), 904*

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

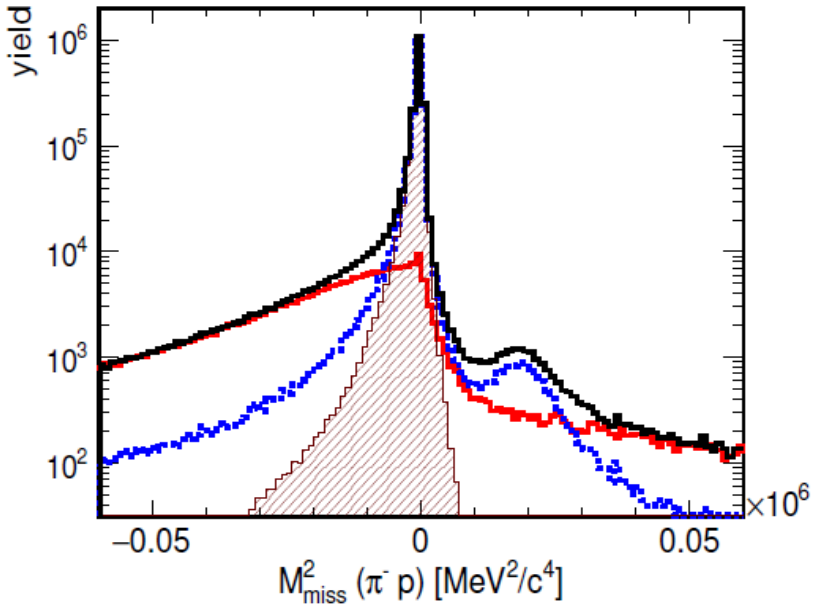
  **No data are available**

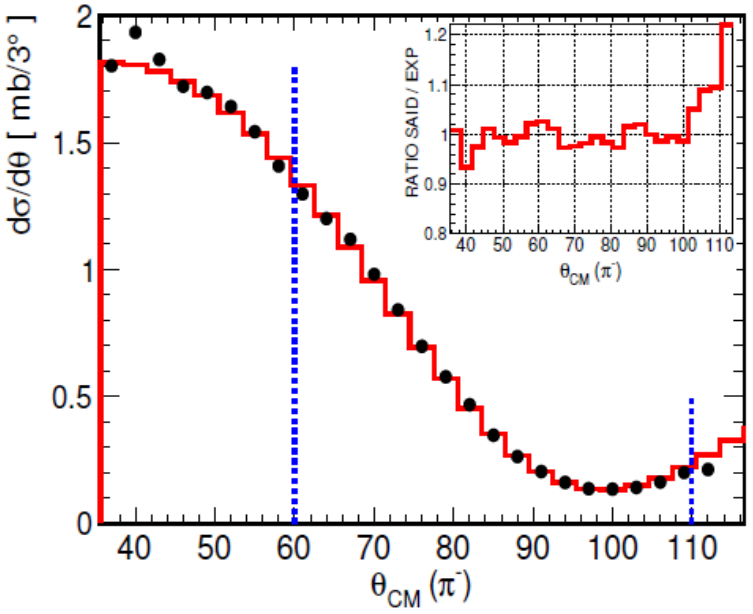
  Resonance Dalitz decays $R \rightarrow Ne^+e^-$

  (Link to time-like transition electromagnetic structure)

# Elastic scattering

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

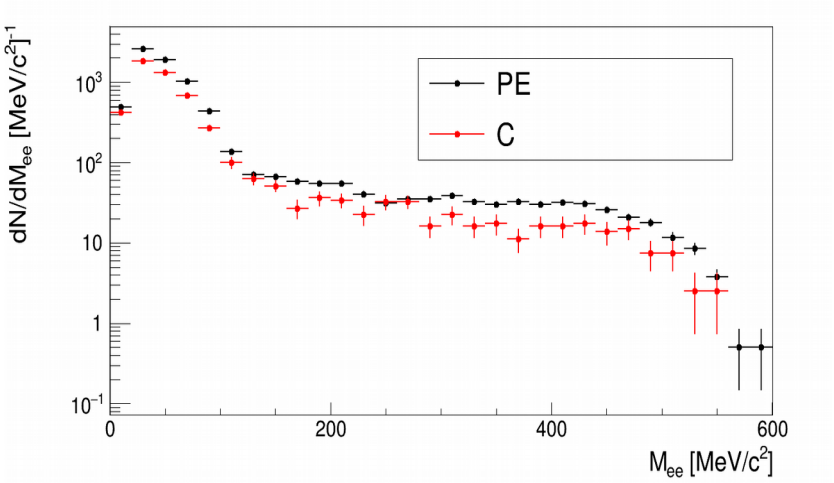


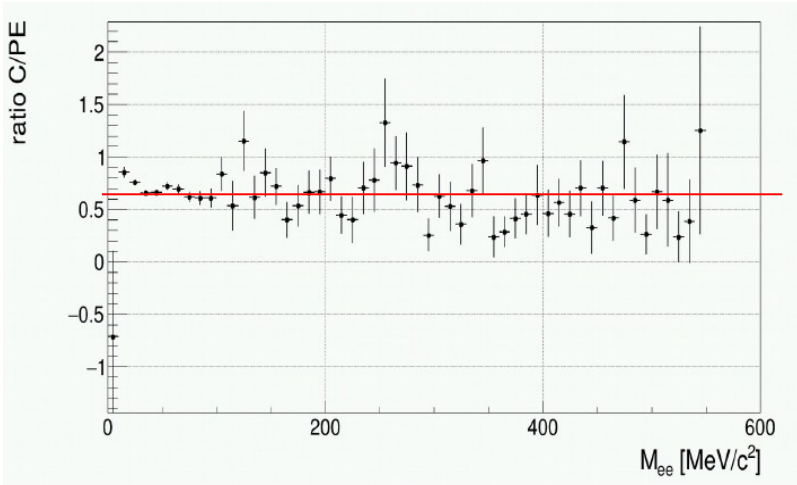




- $\pi^- p \rightarrow \pi^- p$ (after C subtraction)
- Normalization via measured $\pi^- p$ elastic scattering of known σ (SAID partial wave solution)

# Carbon contribution

Normalisation carbon/polyethylene using ⫽p elastic scattering
Using full statistics: for polyethylene: 0.84 $10^{-7}$ mb/event
for C: 4.2 $10^{-7}$ mb/event



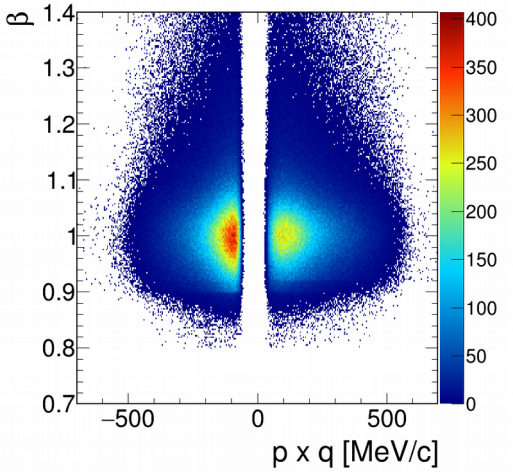




Global fraction of carbon contribution in polyethylene target : 0.68 ± 2% (stat)± 10% (syst)

Consistent with previous estimate: C/PE=2/3 i.e. $\sigma_C = 4\,\sigma_p$

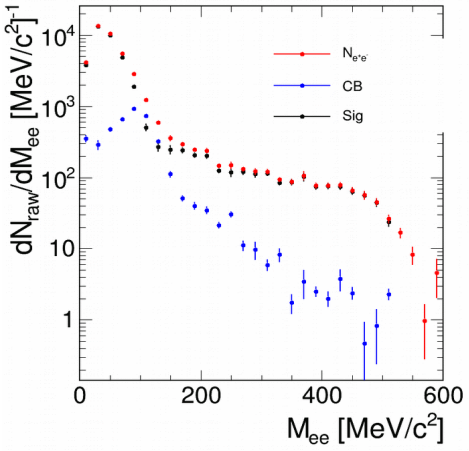
# How to get dilepton spectrum ?

1) Lepton identification
   - Velocity vs momentum
   - Track has to be detected in RICH detector (two different algorithms are used in the analysis)




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

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



# PLUTO cocktail for $e^+e^-$ production

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*$\pi^- p$:*

- $\pi^0 \rightarrow \gamma e^+e^-$

$\pi^- + p \rightarrow n\ \pi^0$ 9.2 mb (Landolt-Börnstein (LB))

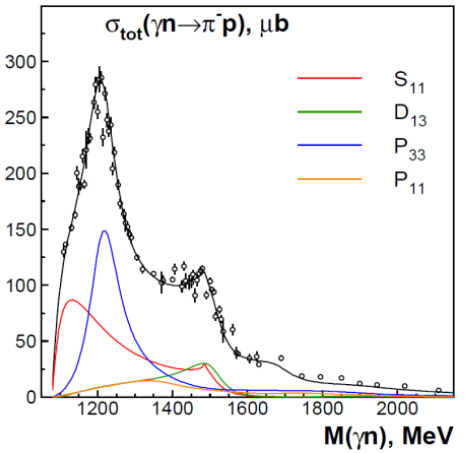
$\pi^- + p \rightarrow n\ \pi^0\ \pi^0$ 2x 1.8 mb (Crystal Ball)

$\pi^- + p \rightarrow p\ \pi^-\ \pi^0$ 3.72 mb (Crystal Ball)

$\pi^- + p \rightarrow X\ \pi^0$ 16.6 mb

« N(1520) »: stands for full point-like baryon transition

- 40.8 mb deduced from $\gamma n \rightarrow \pi^- p$ using detailed balance $e^+e^-$ distribution as $N(1520)^0 \rightarrow n e^+e^-$ with BR=4 $10^{-5}$




$\pi^- p: \rightarrow \pi^+\pi^- n$

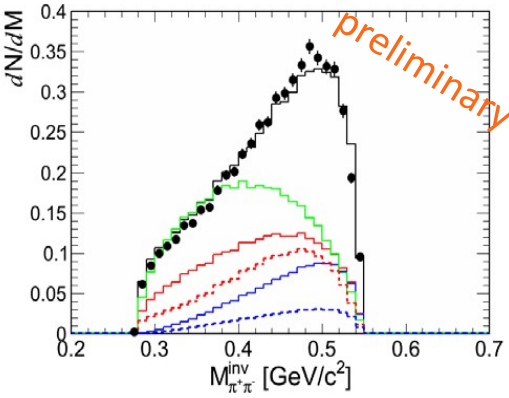
- $\rho \rightarrow e^+e^-$ : cross section deduced from PWA of pionic channels

$\sigma$=1.3 mb , two options for $\rho$ mass distribution

- « PLUTO $\rho$ » : simple BW
- « PWA $\rho$ »: contribution in HADES $\pi^+\pi^-$ mass distribution

$e^+e^-$ yield deduced from Vector Dominance Model

$(d\sigma/dM_{ee}) = (d\sigma/dM_{\pi\pi}) * BR(M_{ee}=M_\rho) * (M_\rho/M_{ee})^3$



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# PLUTO cocktail : carbon contribution

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$\pi^-C$: quasi-free process

$\pi^0$ , N(1520) and $\rho$ production: (momentum distr. of nucleons taken into account) scaled to $\sigma_C/\sigma_H = 4$

$\eta \rightarrow \gamma e^+e^-$

Interactions with proton: beam smearing

Interactions with carbon: beam smearing+Fermi momentum

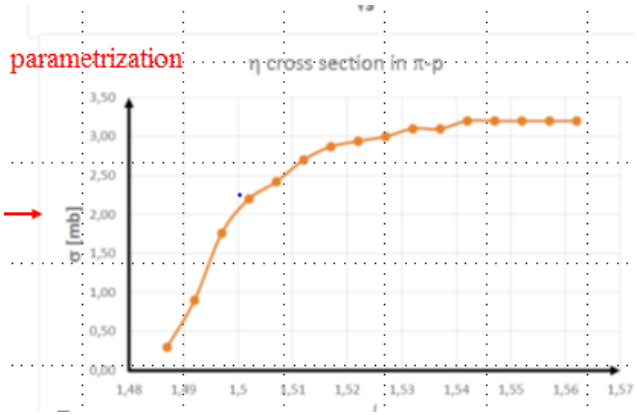
**Participant-spectator model in PLUTO**

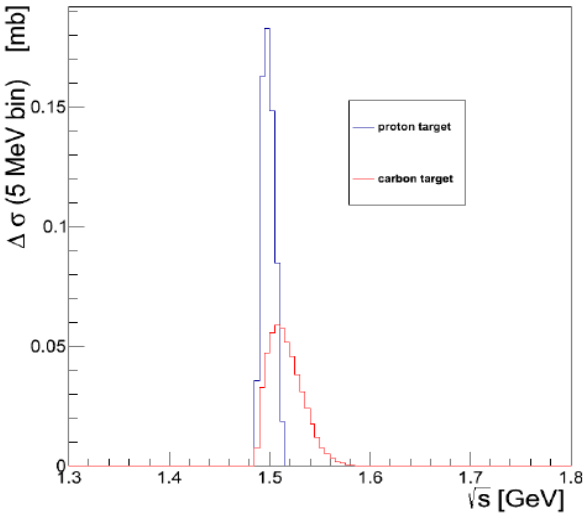
Integrated cross section:

Proton: 0.63 mb

Carbon: 0.50 mb

Total 1.63 mb



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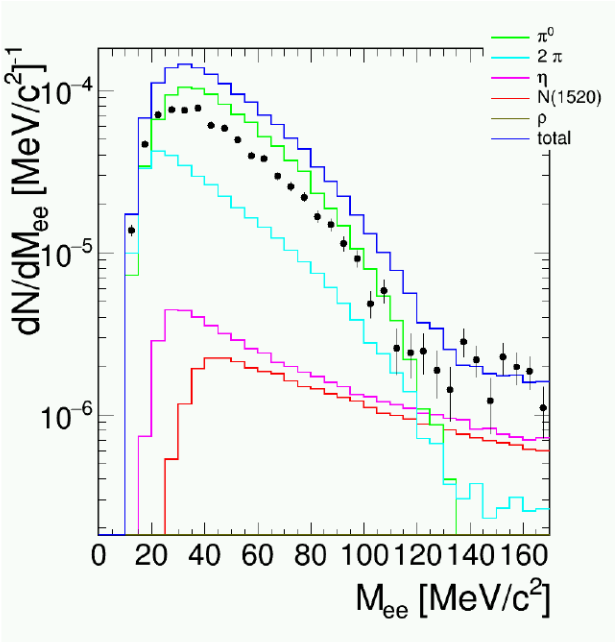
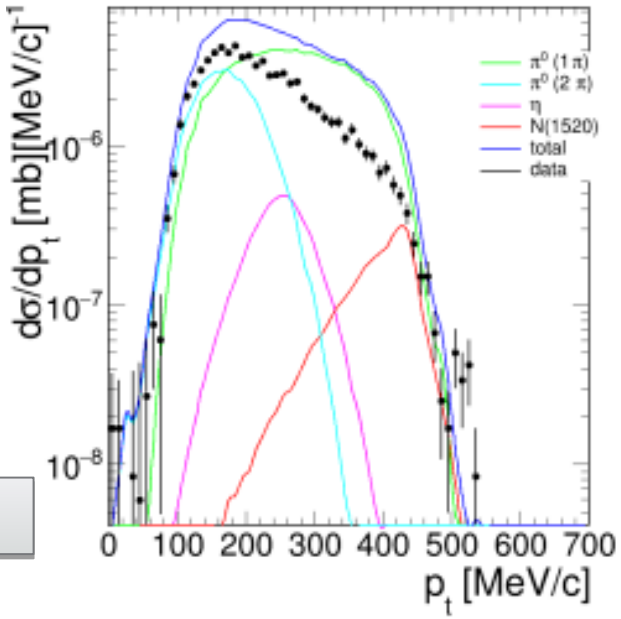
# Raw data compared to the cocktail: $\pi^0$ peak

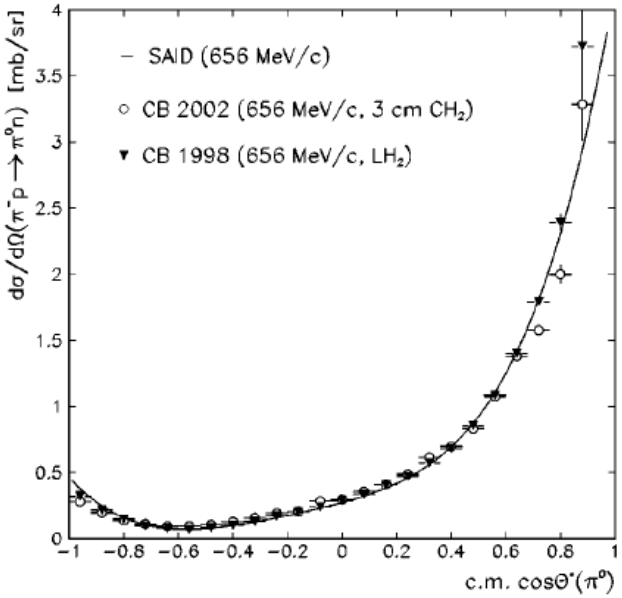



$\pi^0$ yield larger by a factor about 2 in the simulation




Simulation of $\pi^0$ with the cocktail is not satisfactory

# New event generator

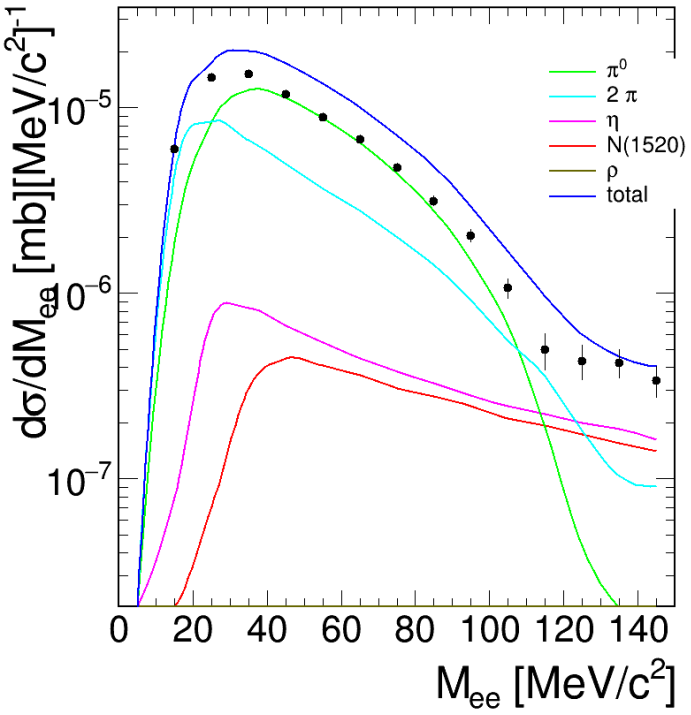


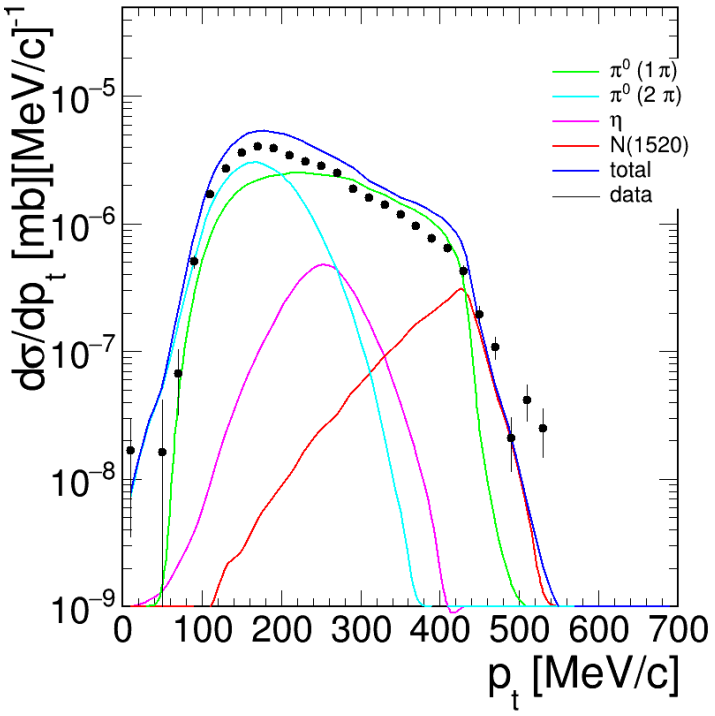

$\pi^0$ angular distribution in $\pi^-p \rightarrow n\,\pi^0$ is very forward peaked in CM ! (isotropic in PLUTO or GIBUU)

- Use the new event generator based on PWA of Bonn-Gatchina group to produce events for $\pi^0$ production ($\pi^-p \rightarrow n\pi^0$ , $\pi^-p \rightarrow n\,\pi^0\,\pi^0$ , $\pi^-p \rightarrow p\pi^-\,\pi^0$ ) (*see Iza Ciepal's talk )*

- Other ingredients ($\eta$, N(1520), $\rho$) as in the PLUTO cocktail

# Comparison data/new cocktail




Better description of $\pi^0$ peak but still a not small discrepancy stands

# Tuning of the RICH digitizers

- Selection of a « pure «  lepton sample
  - $e^+e^-$ pairs with  (beta, momentum) cut and RICHQA<4  and Minv <140 MeV/$c^2$
  - Opening angle >9°
  - Fitted-unfitted track cut at 4°
- Data/simulation comparison for RICH observables
  - Number of pads per ring
  - Average charge per pad
- Two sets of parameters to be adjusted
  - fExpSlope[sector] : charge gain
  - CorrSec[sector][wavelength] photo-detection efficiciency. Only the sector-wise scaling factors are adjusted

  - No unique result: effect of charge gain and photo-detection  is highly correlated !
  - Data-driven efficiency method to control the results

# Lepton reconstruction efficiency

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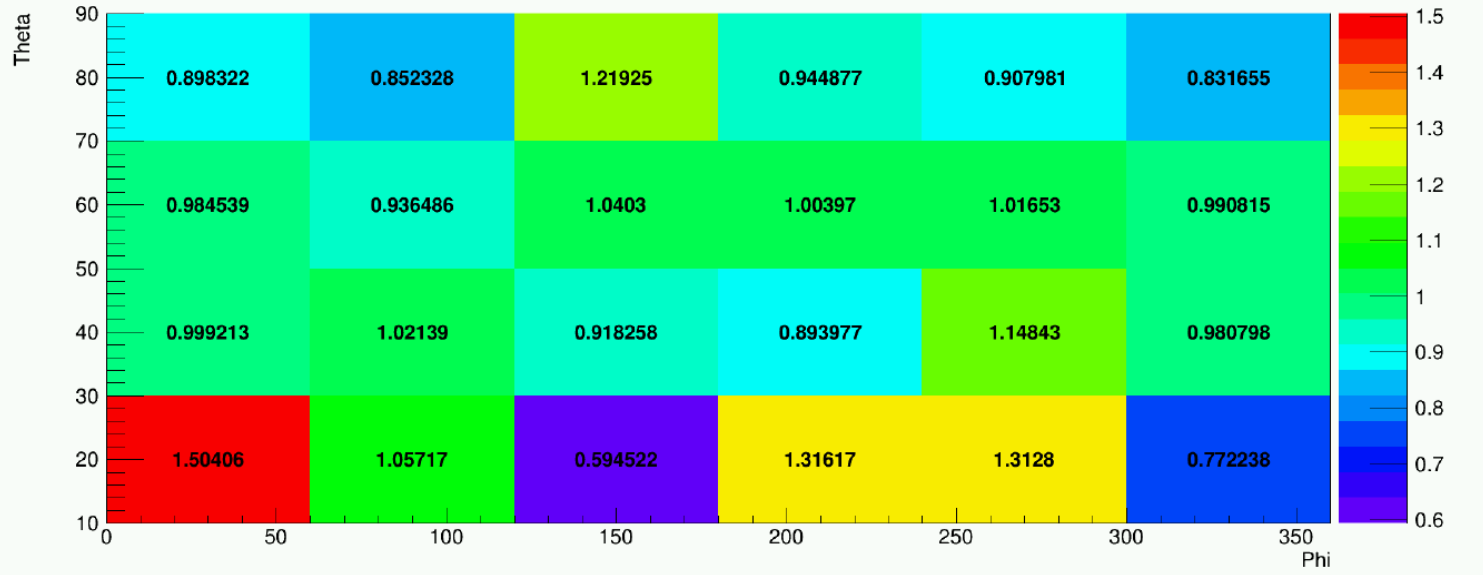
Definition of the reference sample:

- pair of tracks with opposite charge
- opening angle > 9°, p < 300 MeV/c
- beta*momentum cut
- negative track identified as an electron (ring finder or backtracking)

Efficiency= fraction of events in the reference sample with the positive track reconstructed as a positron




Very good agreement after the final tuning



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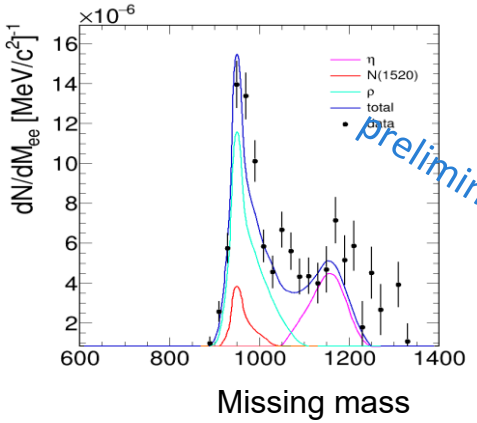
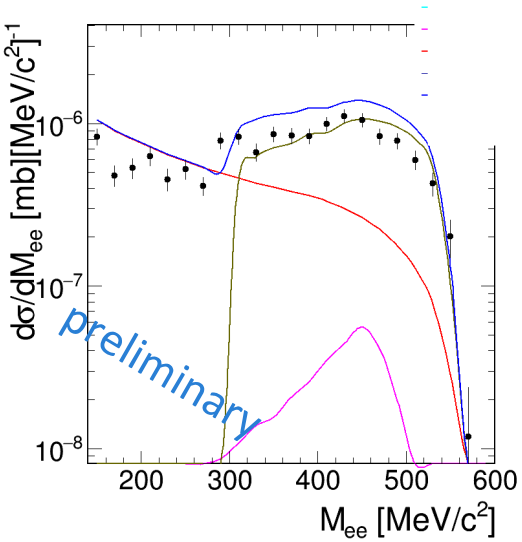
# Exclusive channel: $\pi^- p \rightarrow n e^+ e^-$

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

$0.9 < M^{miss}_{ee} < 1.03$ GeV/$c^2$




Total
$\rho^0 \rightarrow e^+e^-\gamma$
$\eta \rightarrow e^+e^-\gamma$
$N(1520) \rightarrow n e^+e^-$

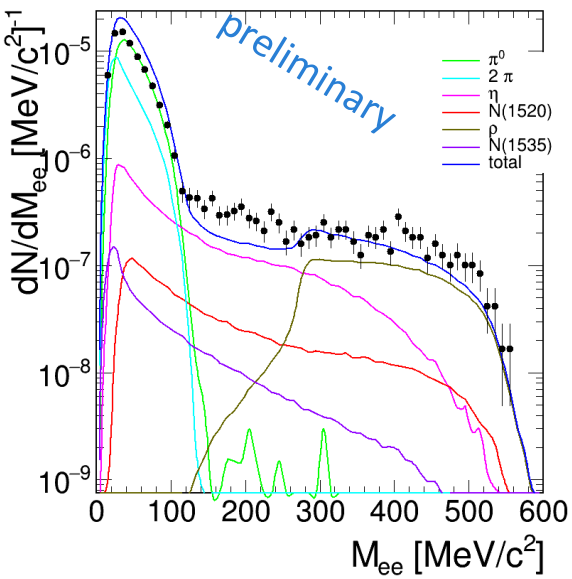
Vector Dominance Model
$(d\sigma/dM_{ee}) = (d\sigma/dM_{\pi\pi}) * BR(M_{ee}=M_\rho) * (M_\rho/M_{ee})^3$

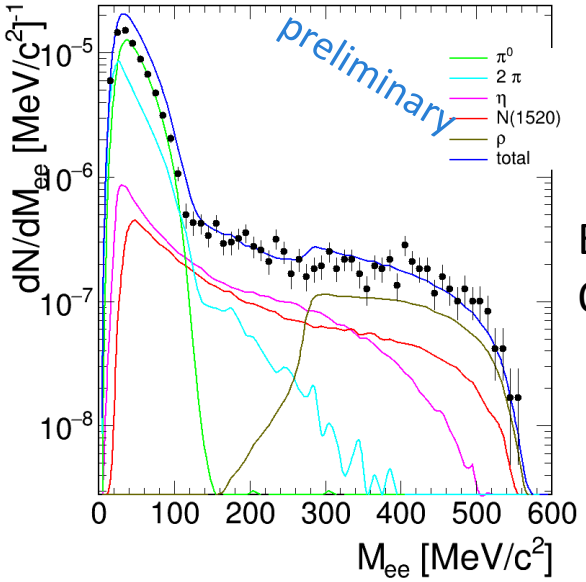
- Deviation from point-like behaviour consistent with VDM ($\rho \rightarrow e^+e^-$)
- $\rho$ cross section and mass shape derived from $\pi^- p \rightarrow \pi^+\pi^- n$ measured in the same experiment !
- Empirical way of taking into account VDM form factors for electromagnetic decays

# Introducing N(1535)

The production cross section for S11 and D13 in π-p @ √s=1.48 GeV is 7.6 and 18.7 mb , respectively (Andrey's PWA)

| | D13 | S11 |
|---|---|---|
| Andrey PWA | 0.23% ($BR_{n\gamma}$) | 0.35% ($BR_{n\gamma}$) |
| Res. prop. (Andrey's PWA)-BW widths | $\Gamma_{tot}$ =114 MeV<br>$\Gamma_{n\gamma}$ = 260 keV (BR=0.23%) | $\Gamma_{tot}$ =116 MeV<br>$\Gamma_{n\gamma}$ =400 keV (BR=0.35%) |
| PDG (2017) | $BR_{n\gamma}$ = 0.3-0.53% | $BR_{n\gamma}$ = 0.01-0.25% (!) |
| Zetenyi/Wolf | $BR_{n\gamma}$ = 0.42% | $BR_{n\gamma}$ = 0.15% |



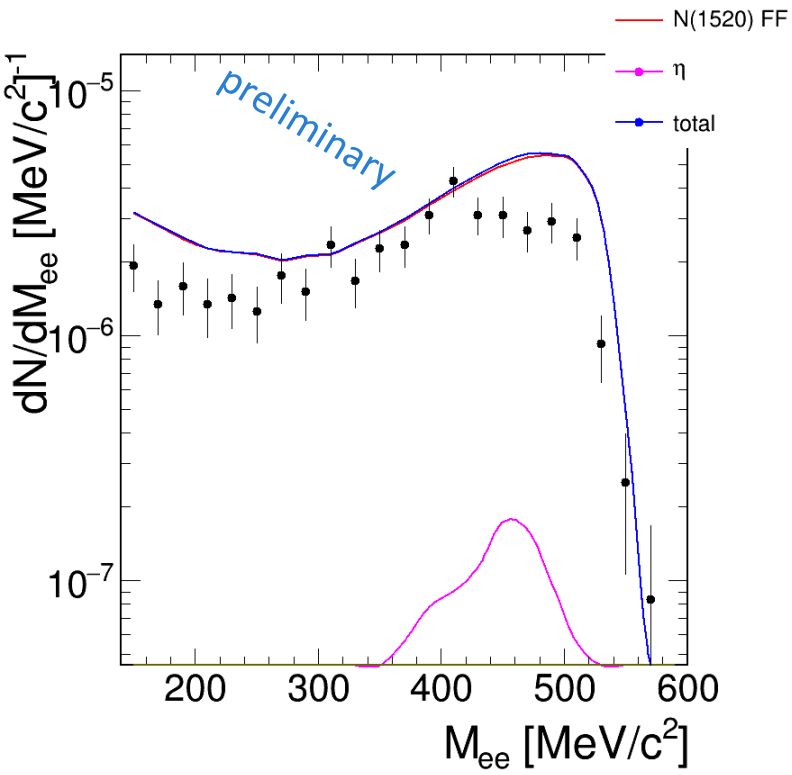




Effective way: Only N(1520)

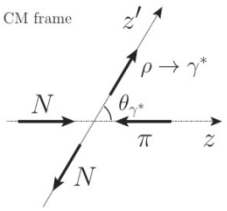
# Adding form factor to N(1520)

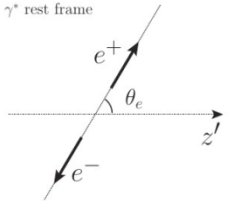
Use of the form factor for proton (provided by G. Ramalho) and renormalize using the radiative decay.

Very tentative result, just to show the sensitivity



# Angular distributions



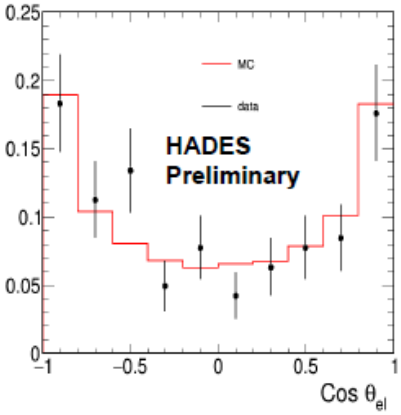

Additional information on the electromagnetic structure of the transition in angular distributions

Spin density matrix formalism

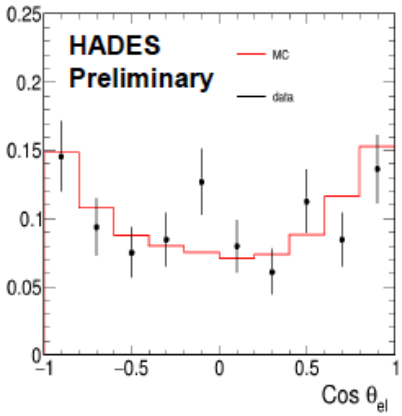
$$\frac{|A|^2}{\sigma} = \frac{1}{N}\left(8m_e^2 + 8|\mathbf{k}|^2\left[1 - \tilde{\rho}_{11}^{(H)} + \cos^2\theta(3\tilde{\rho}_{11}^{(H)} - 1) + \sqrt{2}\sin(2\theta)\cos\phi\,\mathrm{Re}\tilde{\rho}_{10}^{(H)} + \sin^2\theta\cos(2\phi)\,\mathrm{Re}\tilde{\rho}_{1-1}^{(H)}\right]\right)$$

Fitted to HADES data in acceptance : quasi-free $\pi^- p \to n e^+ e^-$ $\sqrt{s}$ =1.49 GeV/$c^2$

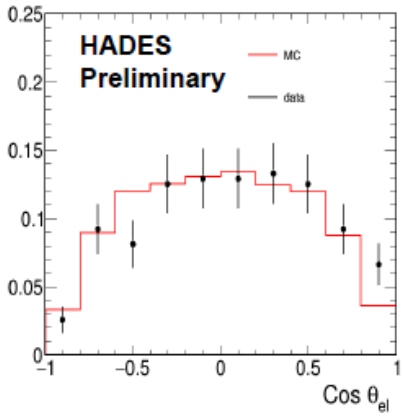
Cos $\theta_\gamma^{CM} < 0$




$0 < \cos\theta_\gamma^{CM} < 0.5$




Cos $\theta_\gamma^{CM} > 0.5$

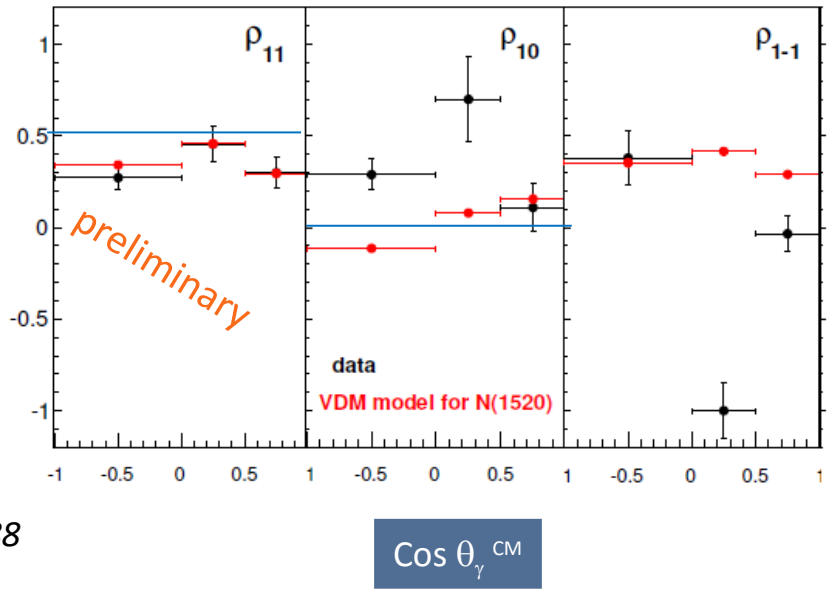


# Spin density matrix coefficients

Quasi-free $\pi^- p \rightarrow n e^+ e^-$ $\sqrt{s}$ =1.49 GeV/$c^2$

$M_{ee}$> 400 MeV/$c^2$

For real $\gamma$, $\rho_{11}=1/2$, $\rho_{10}=0$




Microscopic model s and u channels:

N(1440) and N(1520) with VDM form factors:

*B. Friman, M. Zetenyi, E. Speranza Phys.Lett. B764 (2017) 282-288*

- Despite low statistics, significant information on the electromagnetic structure of the transition
- Presence of longitudinal contribution
- Consistent with pure N(1520) in VDM model

# Summary and outlook

- Problems in the description of the $\pi^0$ peak using uniform distribution
- Implementation of a more detailed generator doesn't solve completely the discrepancy
- Yield at large invariant masses is in agreement with $\rho$ from PWA + VDM
- Despite low statistics, angular distributions show sensitivity to time-like electromagnetic structure of the transitions and allows for a comparison to models

**Thank you for you attention**