Workshop on Two-Pion and e+e- Production in Hadronic Reactions

Event Generator for e+e- Production in π^- p Reactions

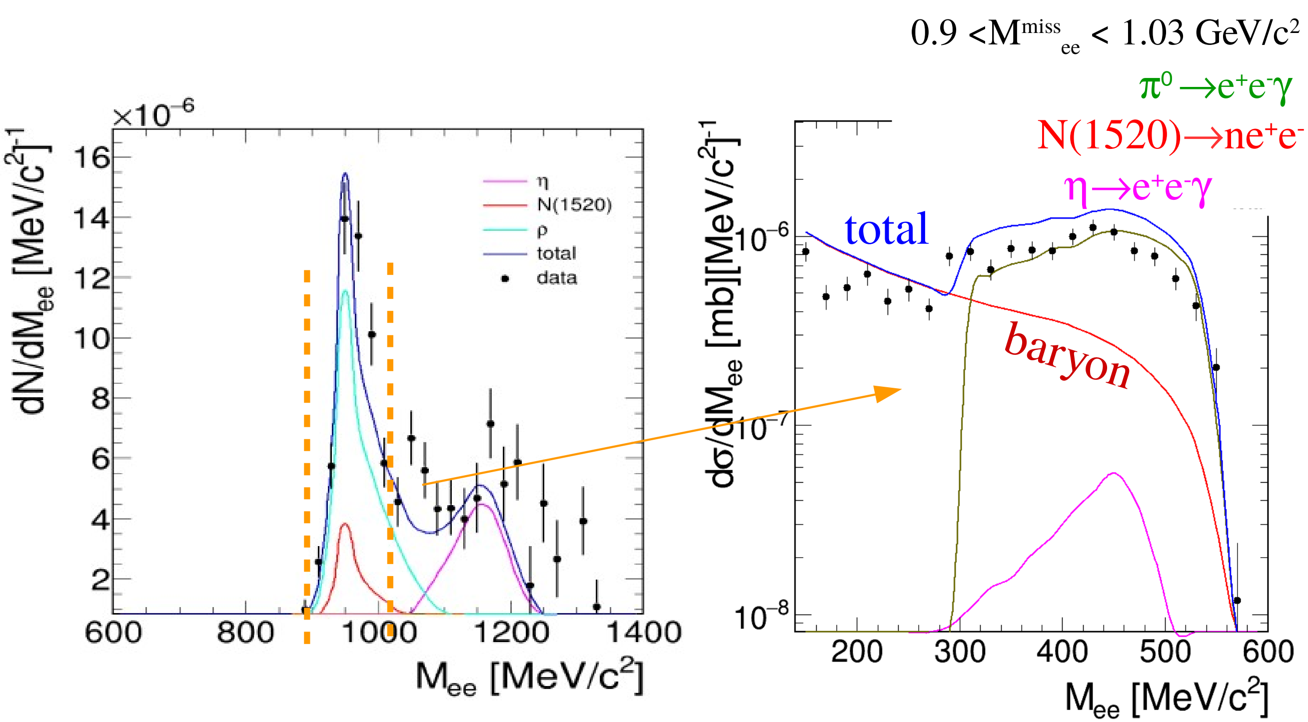
Outline:

1. Motivations.
2. Coctail simulations.
3. New event generator: assumptions and results.
4. SDME formalism and new microscopic model by E. Speranza and Collaborators.
5. Comparison to the data.

I. Denisenko, A. Sarantsev (Bonn-Gatchina)
Izabela Ciepał (IFJ PAS)
Piotr Salabura (JU)

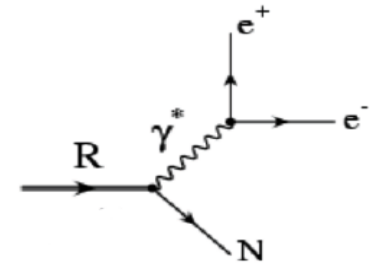
Motivations

exclusive $\pi^- p \rightarrow e^+e^- n$ @ $\sqrt{s} \sim 1.5$ GeV

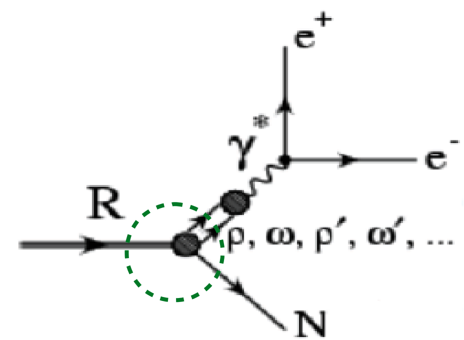


B. Ramstein contribution from Hades CM GSI

F. Scozzi Orsay



QED:
point-like R-γ^* vertex
M. Zetenyi/M. I. Krivoruchenko



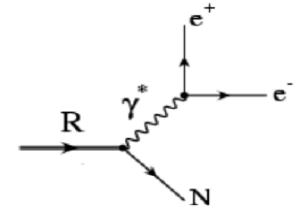
VMD:
em. transition FF (M_{ee})

Models - “simple” coctail simulations:

baryon (?) – “QED” calculated as only D13(1520) Dalitz (with σ of $\pi^- p \rightarrow n\gamma$),

Motivations

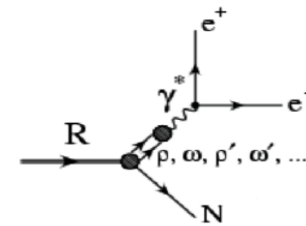
exclusive $\pi^- p \rightarrow e^+e^- n$ @ $\sqrt{s}\sim 1.5$ GeV



QED:
point-like R-γ^* vertex
M. Zetenyi/M. I. Krivoruchenko

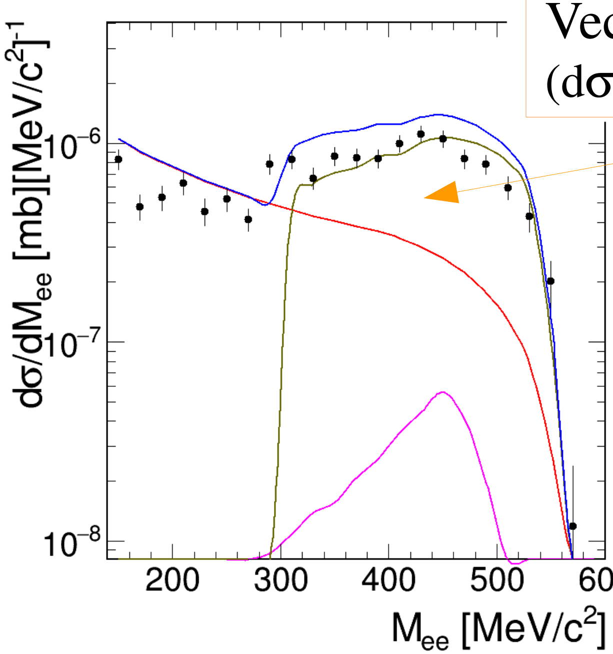
Models - "simple" coctail simulations:

- very strong contribution from **ρ** (**using strict VDM**), ρ-meson contribution derived from PWA of 2 pion channels ($n\pi^+\pi^-$, $p\pi^-\pi^0$)
  (W. Przygoda contribution from CM Frankfurt)



VMD:
em. transition FF (M_{ee})

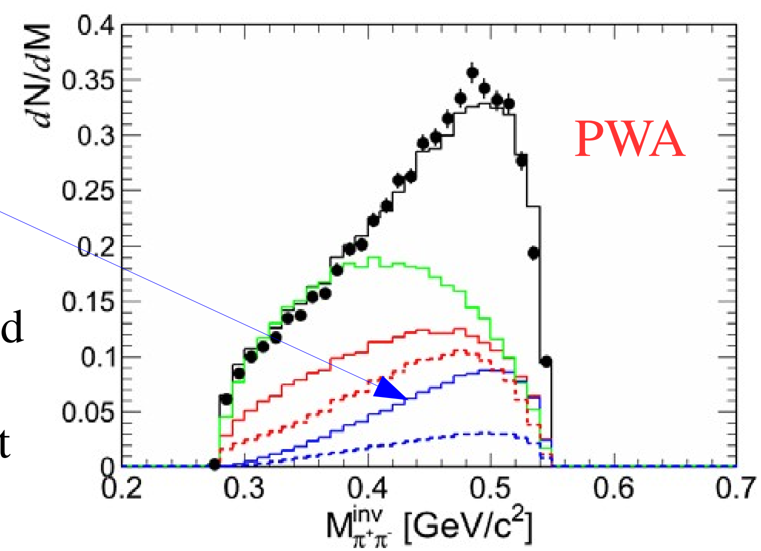
Vector Dominance Model
$(d\sigma/dM_{ee}) = (d\sigma/dM_{\pi\pi}) * BR(M_{ee}=M_\rho) * (M_\rho/M_{ee})^3$



off-shell $\rho \rightarrow e^+e^-$

off-shell $\rho \rightarrow \pi^+\pi^-$

ρ cross section obtained from $\pi^- p \rightarrow \pi^+\pi^- n$ in the same experiment



Coctail @ p=0.69 GeV/c, $\sqrt{s}$~1.5 GeV

Landolt-Börnstein, Crystal Ball

$N(1520) \to n\, e^+e^-$	20.5 mb
$\Delta(1232) \to n\, e^+e^-$	8.4 mb
$\eta \to \gamma\, e^+e^-$	1 mb
$\rho \to e^+e^-$	2.3 mb

$\pi^- p \to n\, \pi^0$ (π^0 Dalitz)	9.2 mb
$\pi^- p \to n\, \pi^0 \pi^0$ (single π^0 Dalitz)	2*1.88 = 3.8 mb
$\pi^- p \to n\, \pi^- \pi^0$	3.72 mb

Branching Ratios:

π^0 : 0.012

$\Delta(1232)$: $4*10^{-5}$

N(1232): $4*10^{-5}$

η: 0.006

N* contribution **does not** include coherent contributions from various resonances

→ alternative way is to use PWA decomposition of $\pi^- p$ and event generator from Bonn-Gatchina

New Event Generator

→ based on Partial Wave Solutions of the Bonn-Gatchina group

Code in two parts, to generate:

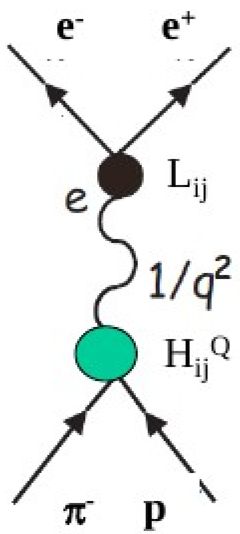
1. **signal:**

   assumptions:

   - $\boldsymbol{\pi^- p \rightarrow N^* \rightarrow \gamma^* N \rightarrow e^+e^- n}$ and $\boldsymbol{\pi^- p \rightarrow N^* \rightarrow \gamma N}$ (VMD), real and virtual photon are produced by the same "hadronic" part of the amplitude (no FF),
   - use known **γn** cross section and description of **γn** final state (PWA),
   - only transvers virtual photon polarization (as for real photon),

2. **background:** n π^0, n π^0 π^0, p π^0 π^-
   - use angular distributions provided by PWA from fits to world data

$\pi^- p \to e^+ e^- n$ – Formula for Lepton Production



$$d\sigma = \frac{(2\pi)^4}{4|k|\sqrt{s}} \left(H_{\mu\nu} \frac{e^2}{Q^4} L^{\mu\nu} \right) d\Phi^3_{ne+e-},$$

$H_{\mu\nu}$ (hadronic tensor) - hadron production and decay to γ^* (dependence on spin and parity of the transition FF):
input either from theory or from data (PWA), ..

$L_{\mu\nu}$ (lepton tensor) - transition $\gamma^* \to$e+e- (**known from QED**)

dΦ - phase space factor

E. Speranza et al., Phys.Lett.B764 (2017) 282-288

$$d\sigma \sim \sum_{pol} |A|^2 = \sum_{\lambda,\lambda'} \rho^{had}_{\lambda,\lambda'} \rho^{lep}_{\lambda,\lambda'}$$

Spin Density Matrix Elements (SDME):

$\rho^{had}_{\lambda,\lambda'} = \epsilon^{\mu}(k,\lambda) H_{\mu\nu} \epsilon^{\nu}(k,\lambda')^*$ hadron decay to γ^*

$\rho^{lep}_{\lambda,\lambda'} = \epsilon^{\mu}(k,\lambda) L^{\mu\nu} \epsilon^{\nu}(k,\lambda')^*$ γ^* decay to e+e- (QED)

virtual photon polarization (in the helicity basis):

transverse $\epsilon^{\mu}(k,-1) = \frac{1}{\sqrt{2}}(0,1,-i,0)$

longitudinal $\epsilon^{\mu}(k,0) = (0,0,0,1)$

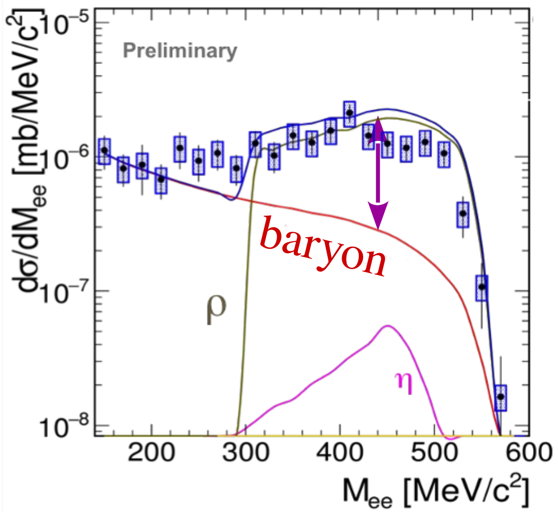
transverse $\epsilon^{\mu}(k,+1) = \frac{1}{\sqrt{2}}(0,1,i,0)$

$\pi^- p \rightarrow e^+ e^- n$ – Angular Distributions

additional information on the electromagnetic structure of the transition

known from QED

$$\frac{d\sigma}{dM d\cos\theta_{\gamma^*} d\cos\theta_e} \sim \sum_{\lambda,\lambda'} \rho^{had}_{\lambda,\lambda'} \rho^{lep}_{\lambda,\lambda'}$$



- invariant mass shows deviation from point-like baryon transitions
- additional information on the electromagnetic transitions can be provided by the angular distribution
- SDME depend on m_{γ^*}, $z = \cos\theta^{\gamma^*}_{CM}$

the amplitude for the decay of a vector particle in two fermions:

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

4 parameters: $\theta_{e+,e-}, \varphi_{e+,e-}, m_{\gamma^*}, z = \cos\theta^{\gamma^*}_{CM}$

→ SDME can be extracted from fit to the angular distributions

F. Scozzi contribution from CM Frankfurt, Trento

B. Ramstein contribution from Hades CM GSI

Separation of Resonance Contributions

→ microscopic model including N(1440) and N(1520) excitations in s and u-channels and VDM electromagnetic form factors

E. Speranza et al., Phys.Lett.B764 (2017) 282-288

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

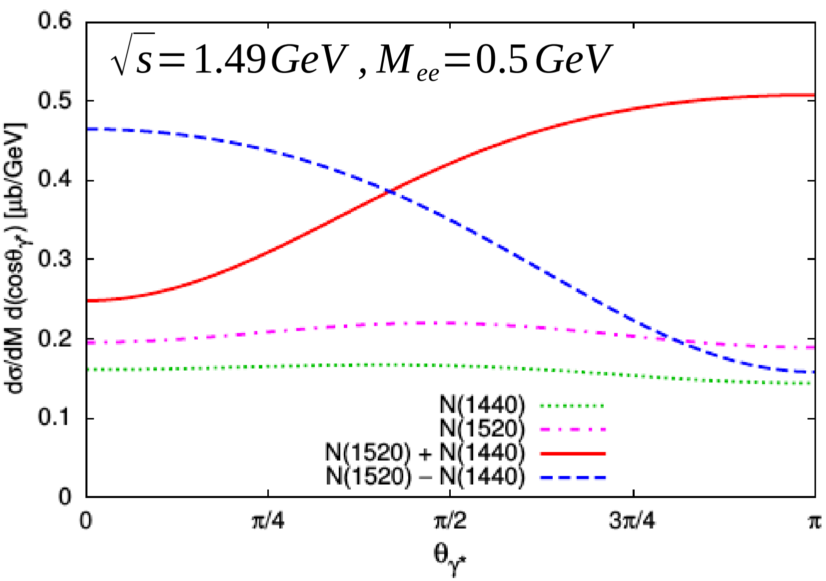
anisotropy coefficient

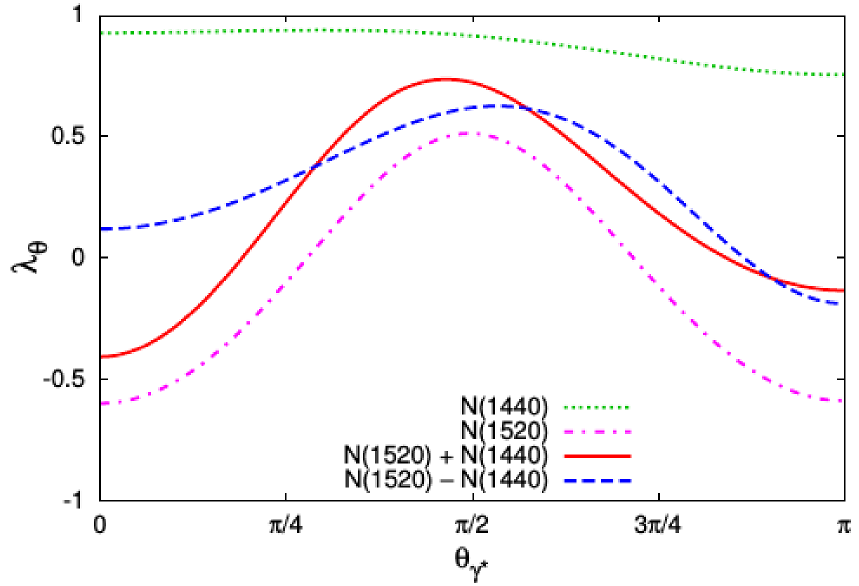
→ info on the virtual photon polarization

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

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

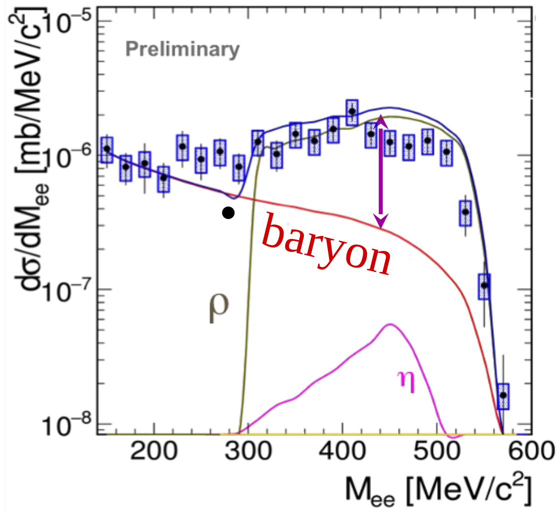
angular distributions depends on spin and parity of resonance state (λ_θ from the model):





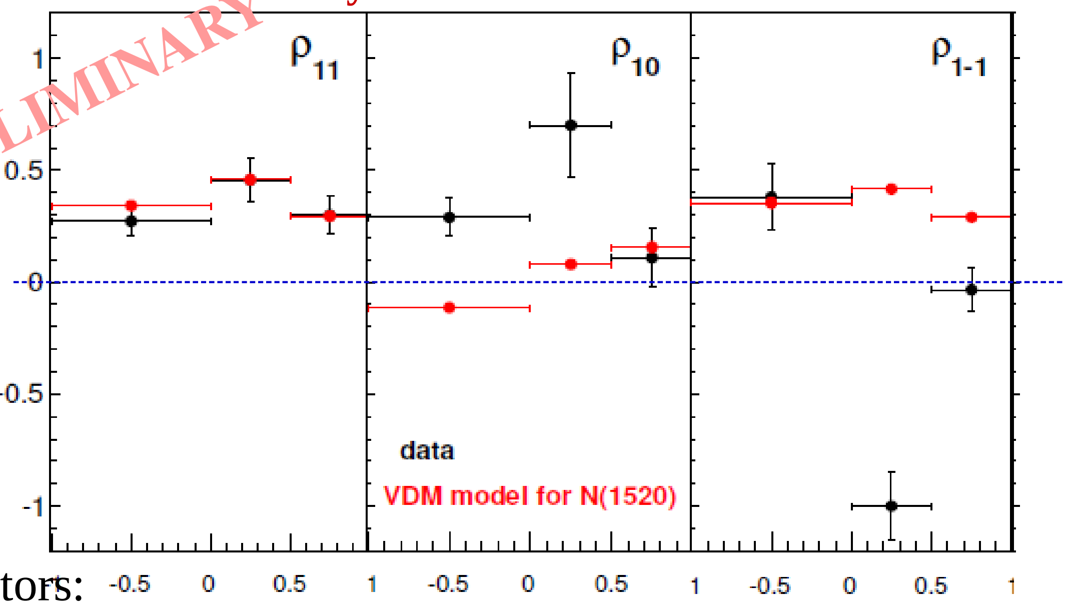
$\pi^- p \rightarrow e^+e^- n$ – Angular Distributions

additional information on the electromagnetic structure of the transition



M_{ee}> 400 MeV/c²

B. Ramstein contribution from Hades CM GSI
F. Scozzi Orsay



Cos θ_γ CM

For real γ, ρ_{11}=1/2, ρ_{10}=0

Microscopic model s and u channels:
N(1440) and N(1520) with VDM form factors:

E. Speranza et al, Phys.Lett. B764 (2017) 282-288

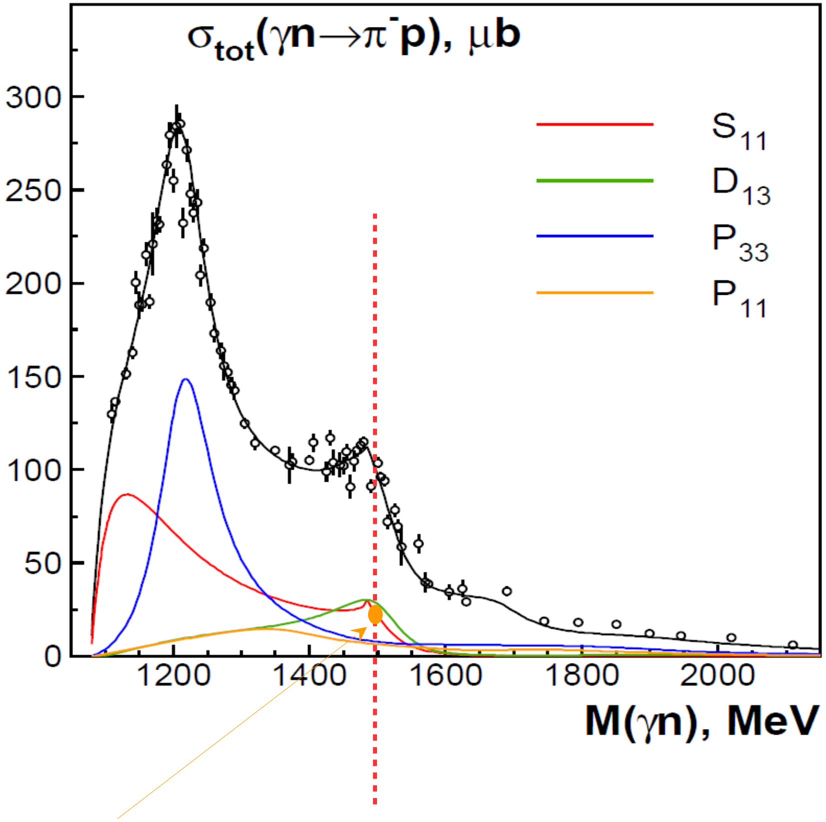
➔ low statistics but still valid information on the electromagnetic structure of the transition can be drawn:
- presence of longitudinal contribution
- data are consistent with pure N(1520) in VDM model

New Event Generator

- **virtual photon**

  → real photon estimation (no longitudinal polarization, no FF), total cross section from experimental data:

$$\sigma_{\pi p \to \gamma n} \approx 2\sigma_{\gamma n \to \pi p}$$ (related via detailed balance)



60 μb

+ Partial Wave Analysis

separation into resonances: @ √s ~1.5 GeV: dominance of **D_{13} and S_{11}**

coherent sum of s, t, u channels is taken

→ the production cross section for **S11** and **D13** in π-p is **7.6** and **18.7 mb**, respectively (PWA)

→ **σ(π-p→nγ)** can be calculated as:

S11: 7.6*0.0034 (BR) = **26 μb**

D13: 18.7*0.022 (BR) = **43 μb**

Remaining part of 60 μb comes from non-resonant background contribution (~ 17 and 34 mb, respectively)

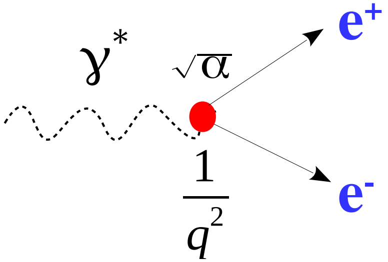
→ **σ(e+e-): factor 1/137**

New Event Generator

- **virtual photon**
  → real photon estimation :

α/q^4 - photon propagator

$z = \cos\theta_{\gamma^*}$



= 1

$$\frac{d\sigma^{\perp}_{\pi p\to ne^+e^-}}{dz} = \frac{d\sigma_{\pi p\to\gamma n}}{dz}\frac{\alpha}{3\pi q^4}\left[\frac{h_{xx}(q^2,z)+h_{yy}(q^2,z)}{h_{xx}(0,z)+h_{yy}(0,z)}\right]\left(1-\frac{2m_n^2}{s}+\frac{m_n^4}{s^2}\right)^{-\frac{1}{2}}\times$$

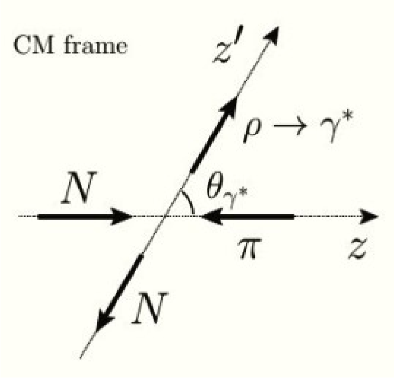
$$(2m_e^2+q^2)\sqrt{1-\frac{2(m_n^2+q^2)}{s}+\frac{(m_n^2-q^2)^2}{s^2}}\sqrt{1-\frac{4m_e^2}{q^2}}dq^2dz.$$

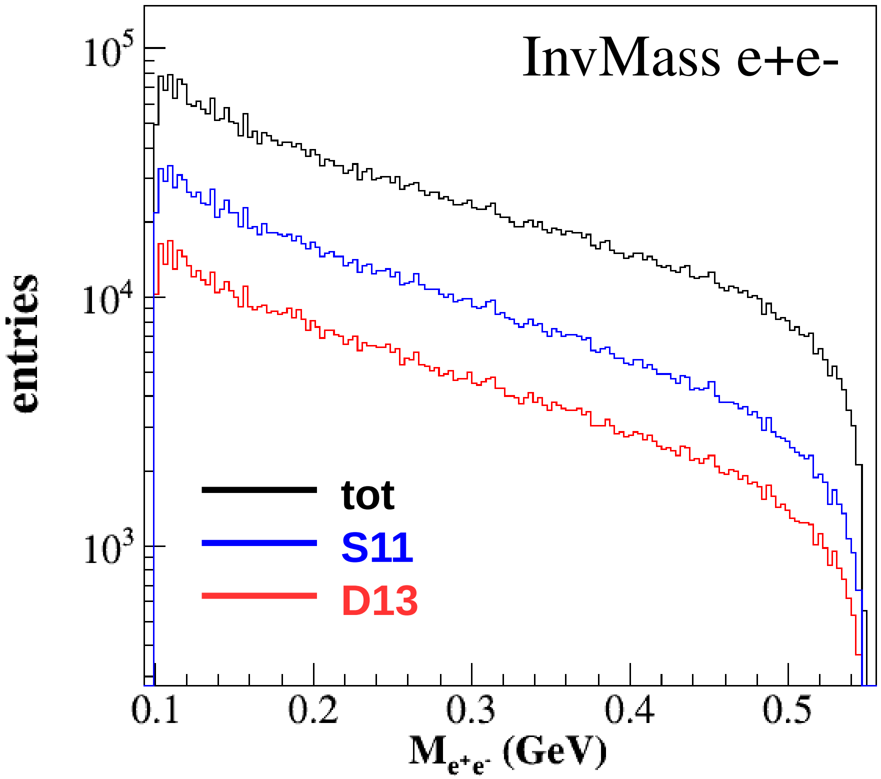
$$\frac{\phi^{(3)}_{ne+e}}{\phi^{(2)}_{n\gamma}}$$

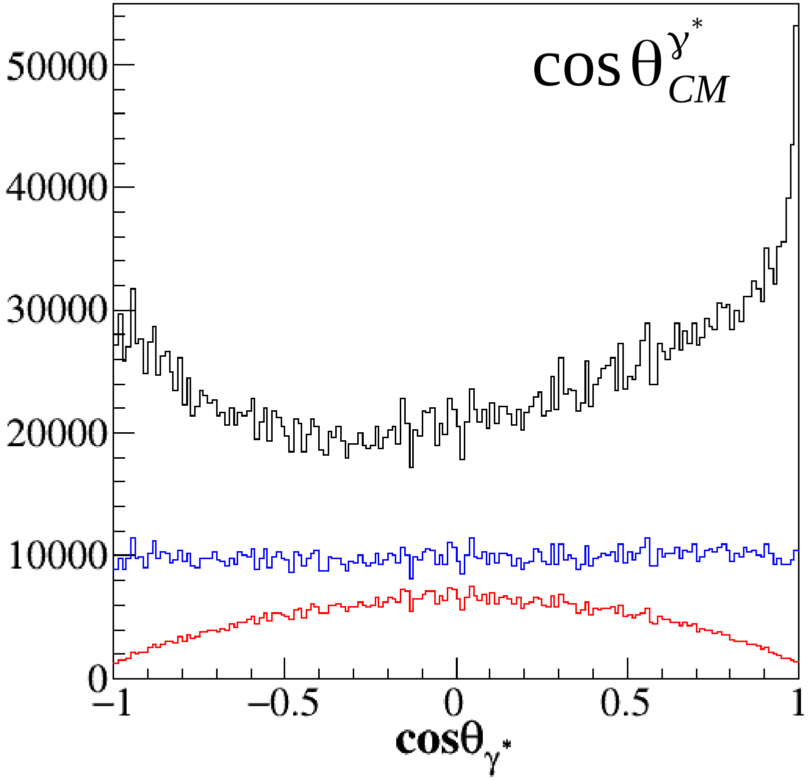
3- and 2-body phase space difference

integration of the lepton tensor over the lepton angles

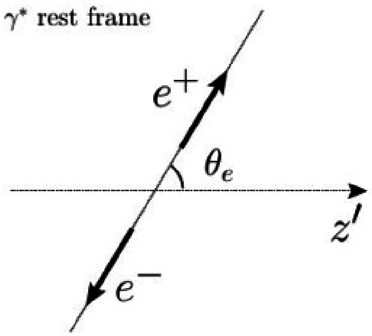
Signal Simulations

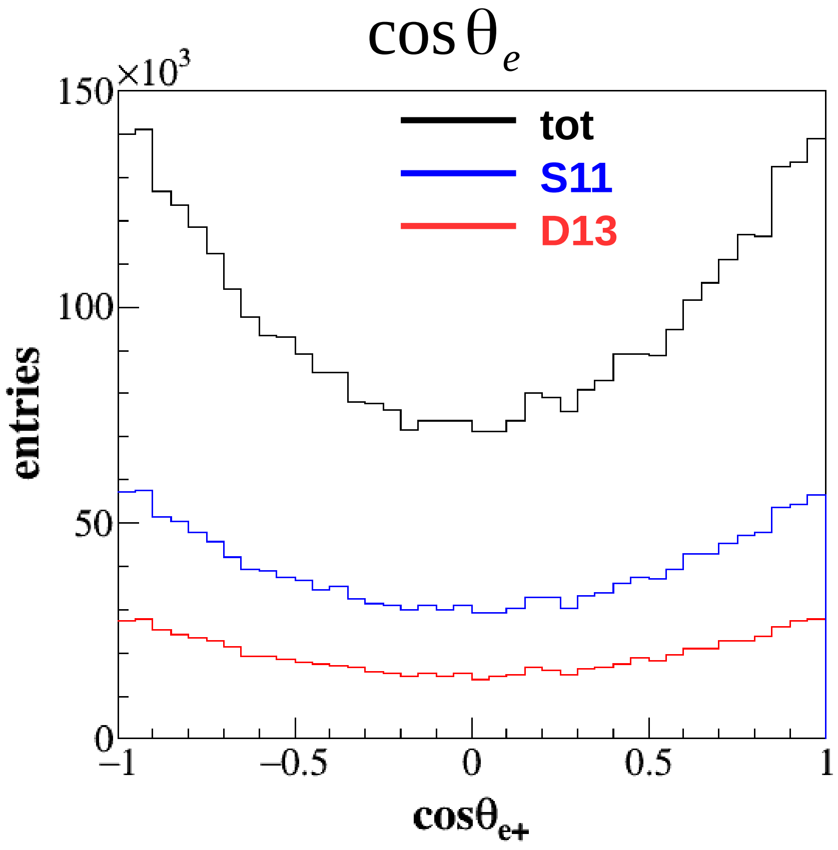


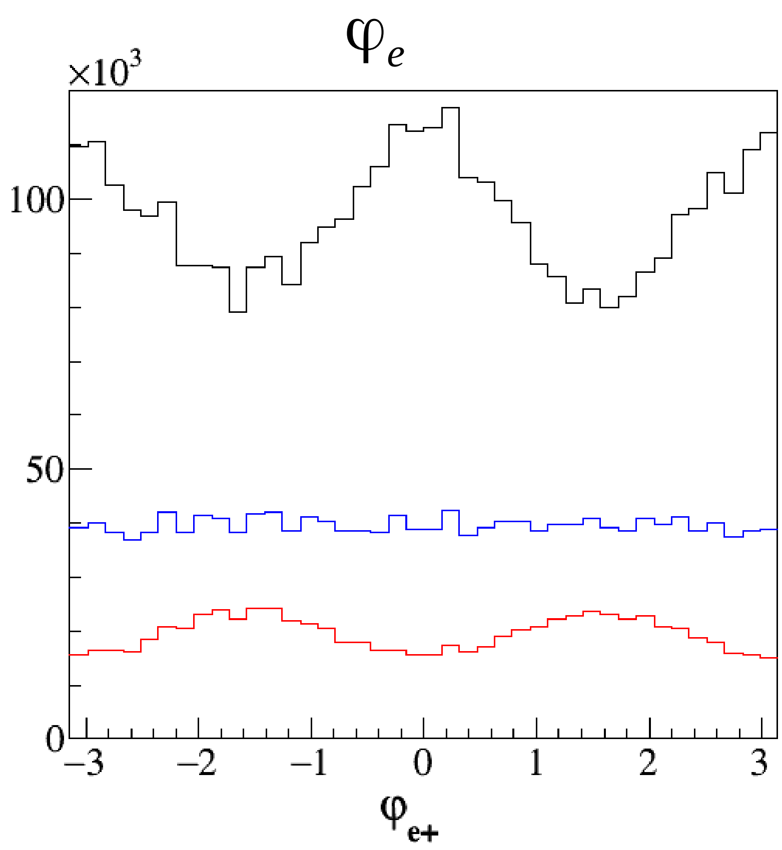




Signal Simulations



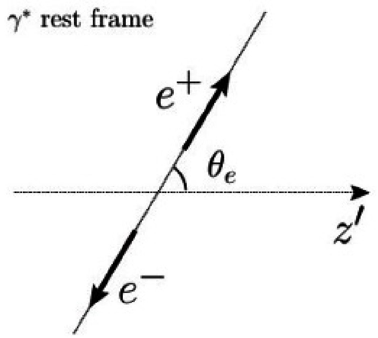




$\pi^0 \rightarrow \gamma\gamma^* \rightarrow \gamma\ e^+e^-$

1. photon virtuality q^2 is randomized (according to VDM):

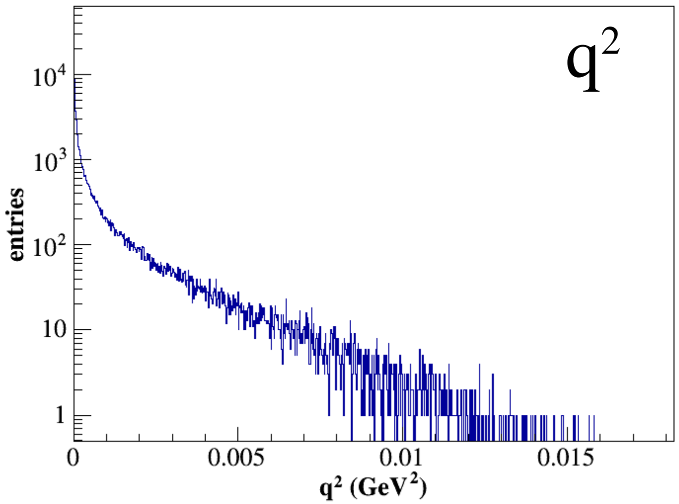
$$\frac{d\Gamma(\pi^0 \to \gamma e^+ e^-)}{dq^2 \Gamma(\pi^0 \to \gamma\gamma)} = \frac{2\alpha}{3\pi}\left[1 - \frac{4m_e^2}{q^2}\right]^{1/2}\left[q^2 + 2m_e^2\right]\frac{1}{q^4}\left[1 - \frac{q^2}{m_{\pi^0}}\right]^3 |F(q^2)|^2$$

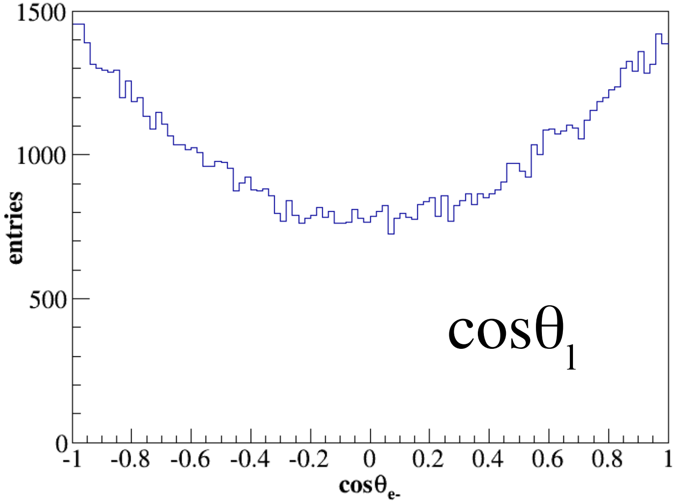


2. angular distributions are generated

$$(q^2 + 2m_e^2) \rightarrow \frac{3}{2}\left(|k|^2(1 + \cos^2\theta_l) + 2m_e^2\right)$$

$k = k(q^2)$ – momentum of a lepton in a γ^* reference frame

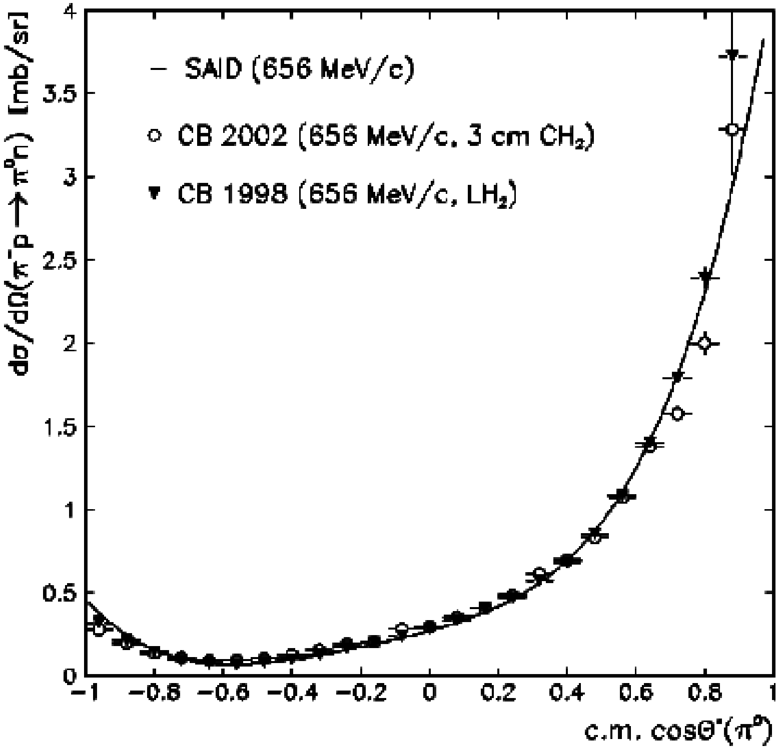


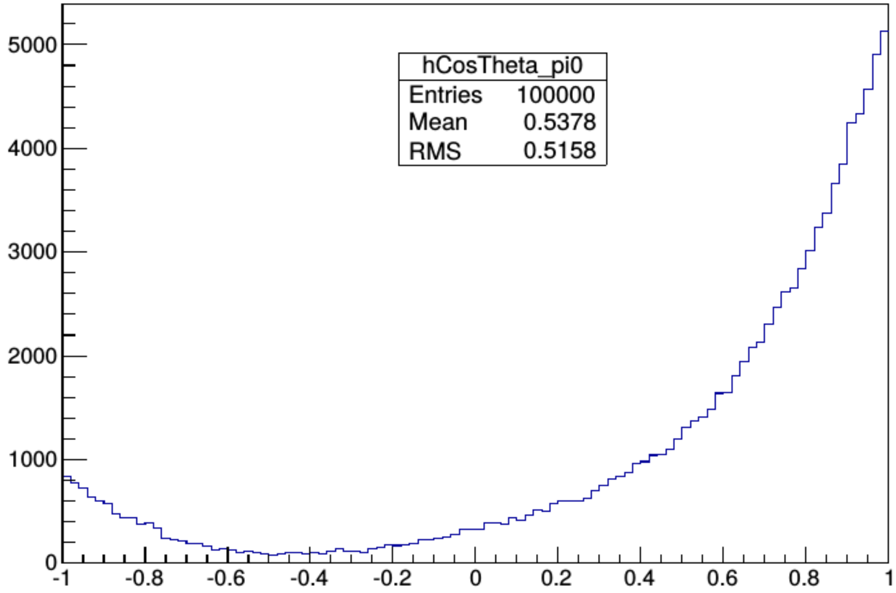


1. $\pi^- p \rightarrow \pi^0 n$ @ 690 MeV/c

Generated events vs SAID PWA

Total cross section: $\sigma_{\pi n}$ =8.33 +/-0.41 mb, p=690 MeV/c

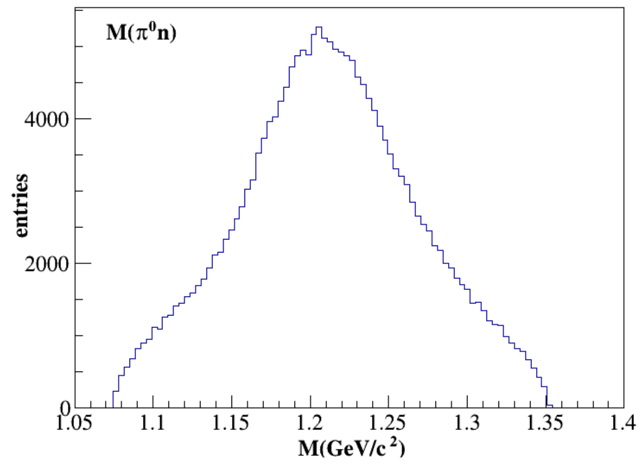


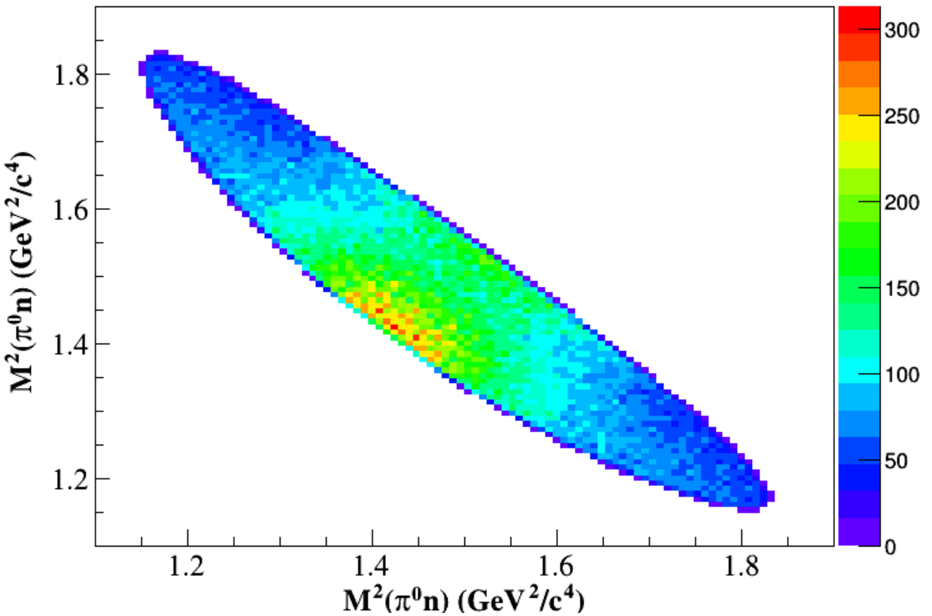


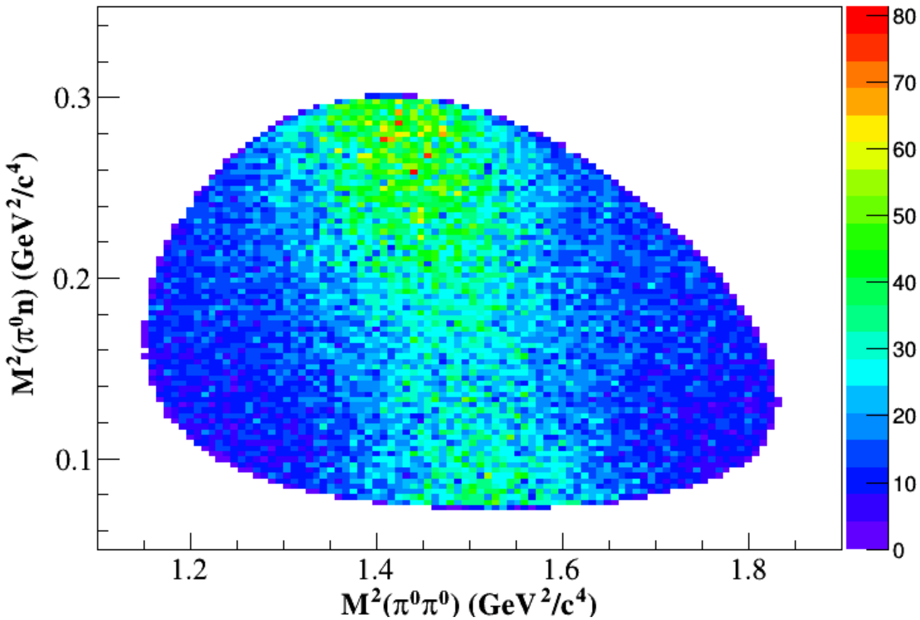
$\cos\theta_{CM}$

$\pi^- p \rightarrow \pi^0 \pi^0 n$

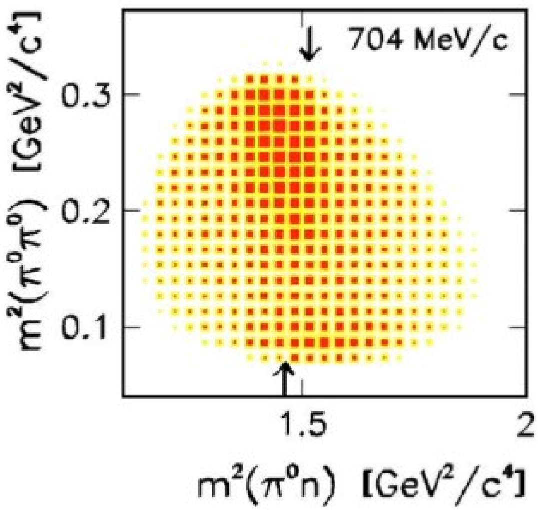
1. the phase space is weighted according to Bonn-Gatchina PWA solution,
2. random π^0 is chosen,
3. its decay to γ e+e- is simulated

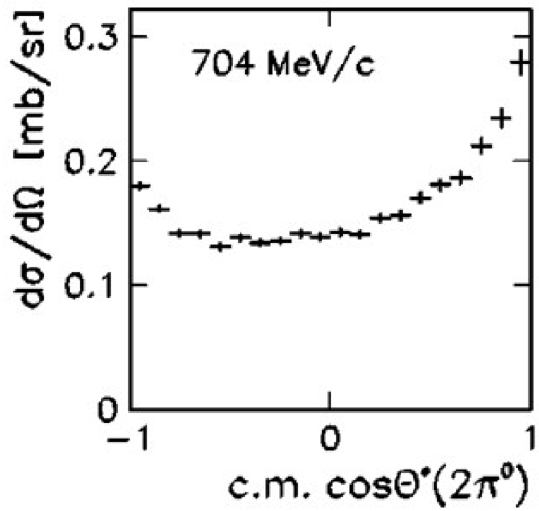




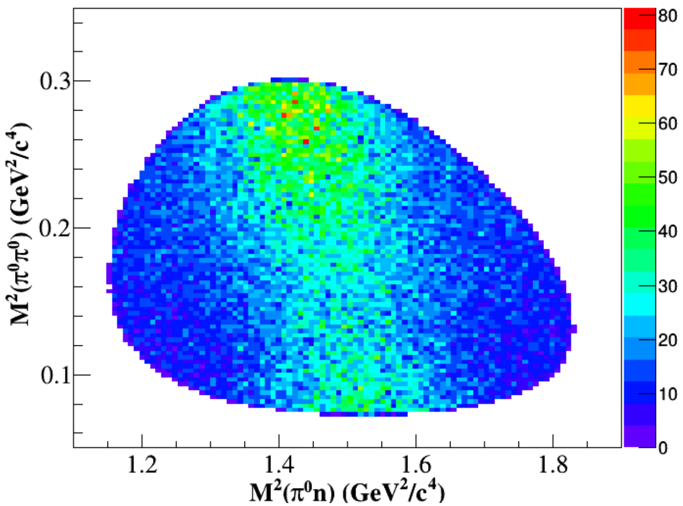


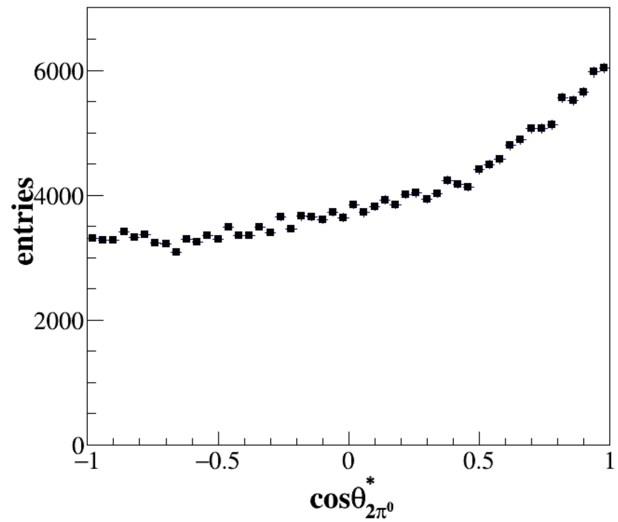
$\pi^- p \rightarrow \pi^0\pi^0 n$ in comparison to data





Crystal Ball data
@ p = 704 MeV/c
Phys. Rev. C 69, 045202(2004)

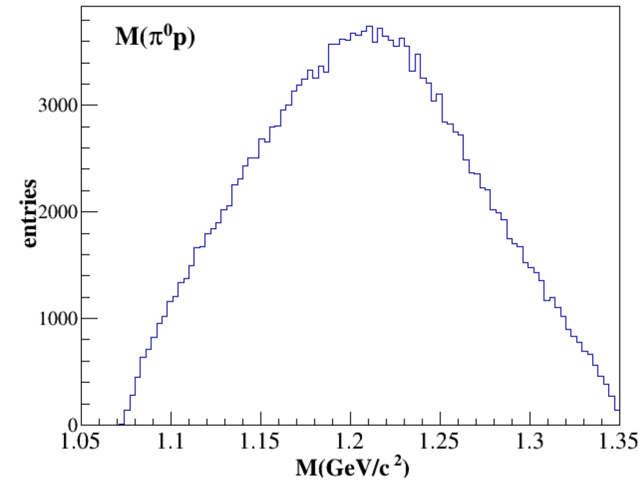


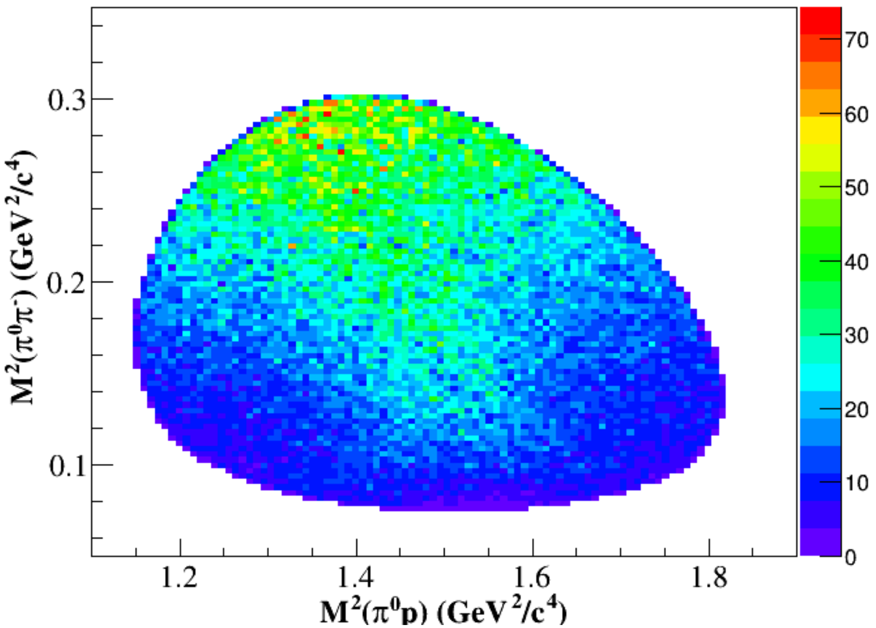


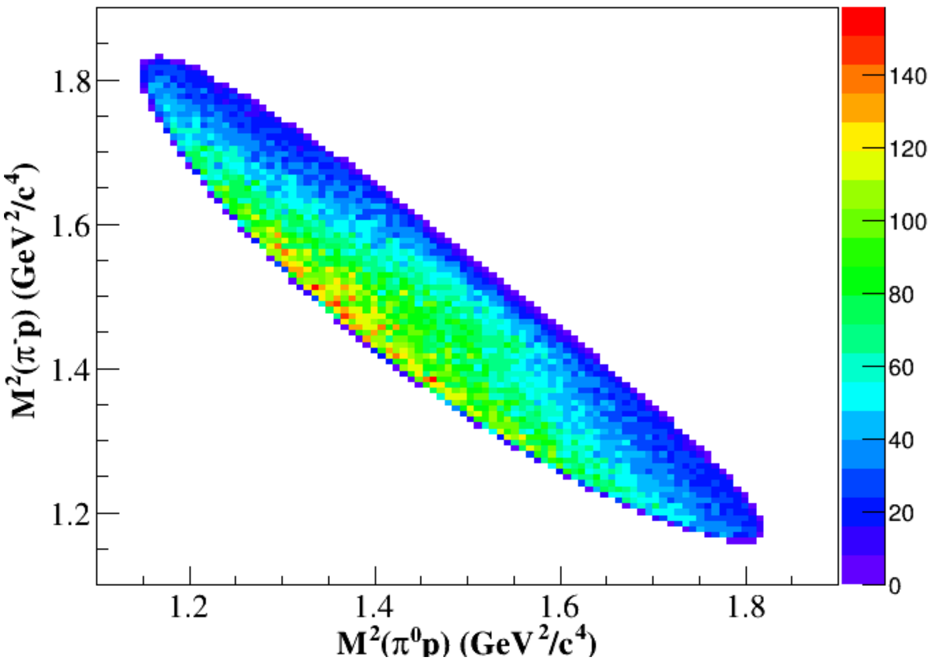
Generator
@ p =690 MeV/c

$\pi^- p \to \pi^0 \; \pi^- \; p$

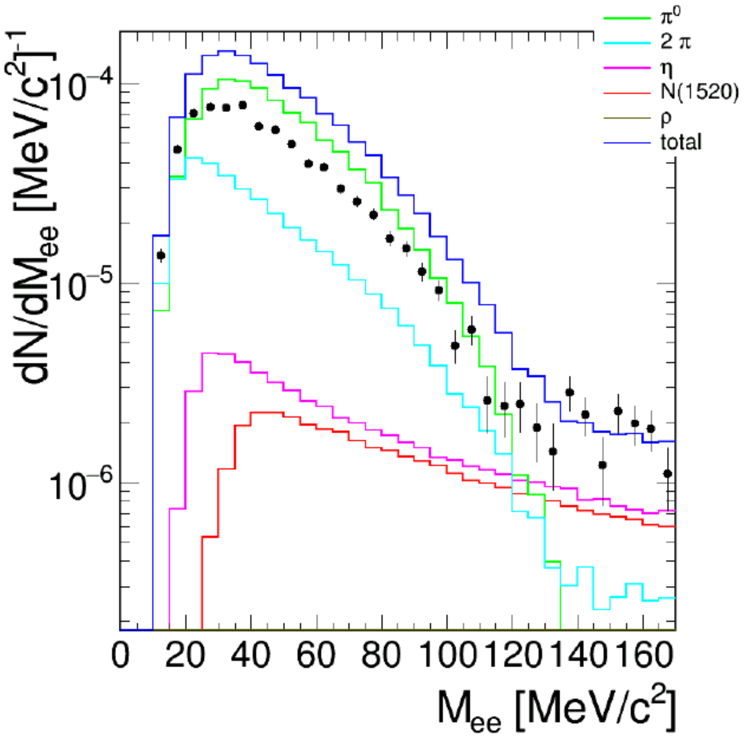
1. the phase space is weighted according to Bonn-Gatchina PWA solution,
2. random π^0 is chosen,
3. its decay to γ e+e- is simulated



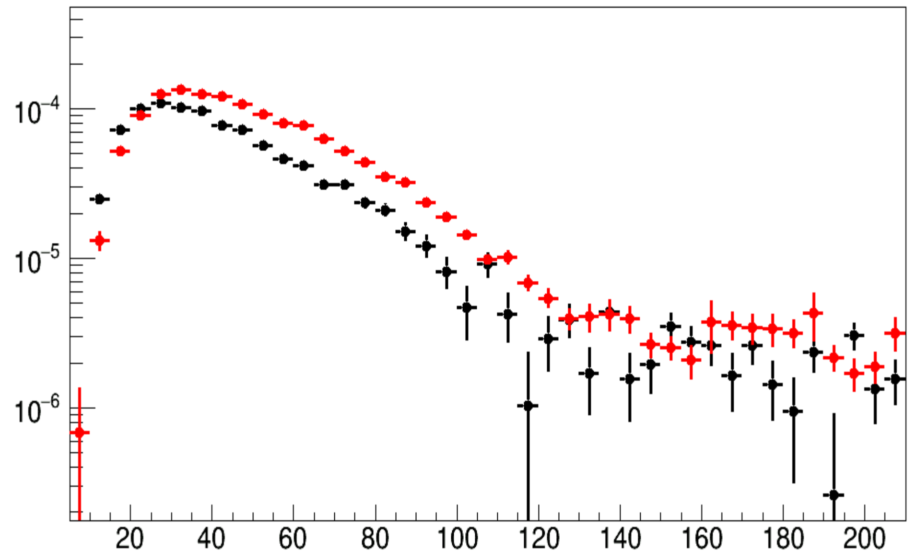




PLUTO cocktail (16.6 mb)

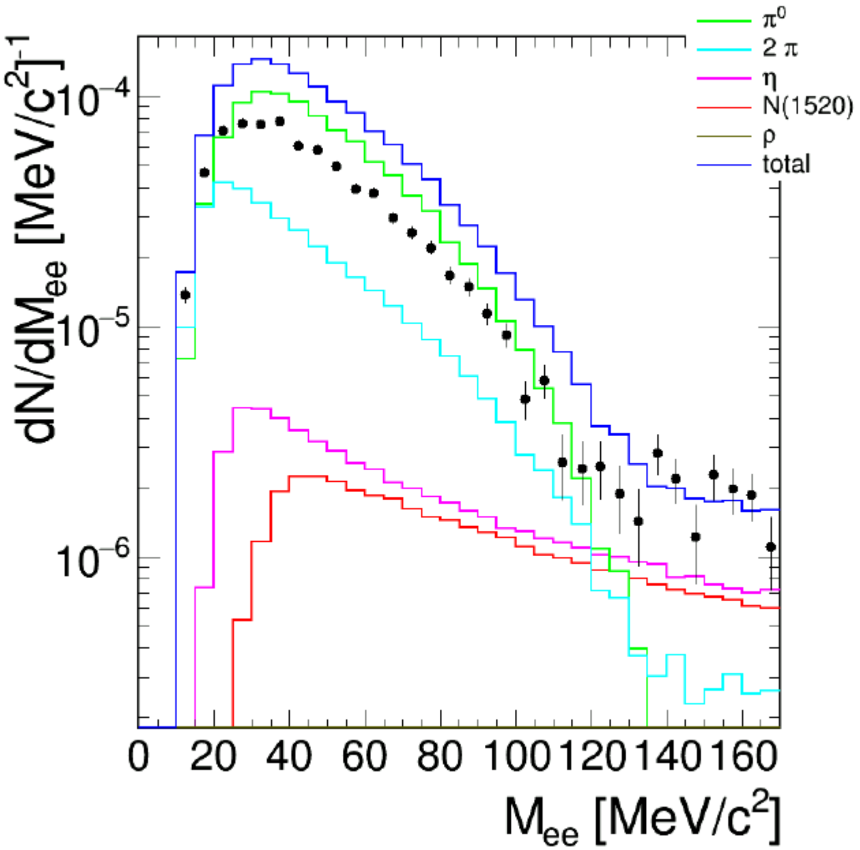


GiBUU (19 mb)

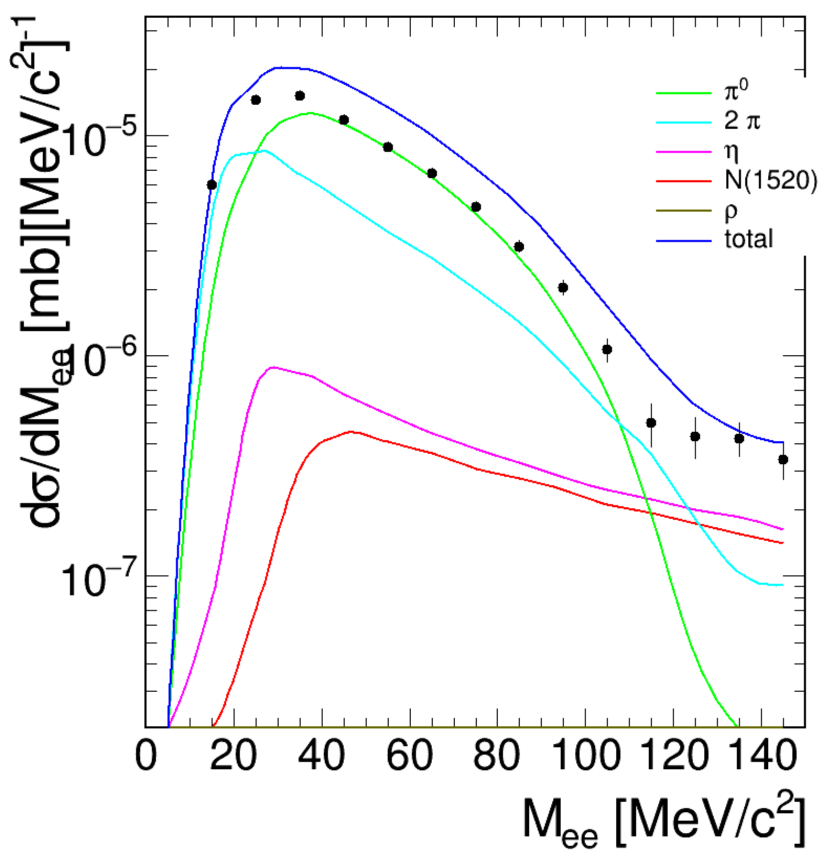


→ model dependence of the π^0 peak in acceptance

PLUTO cocktail (16.6 mb)



New event generator with proper angular distribution



Summary & Outlook

The code will be used to:

- fit Spin Density Matrix Elements (**SDME**) from data inside the HADES acceptance (based on method used by Bonn-Gatchina) evaluate the systematics of SDME extraction.

Plans:

- extract SDME from the data
- further consistency checks of the generator
- comparison with the coefficients calculated with the GSI model (Speranza et al.)
- compare with the Hades distributions in the acceptance

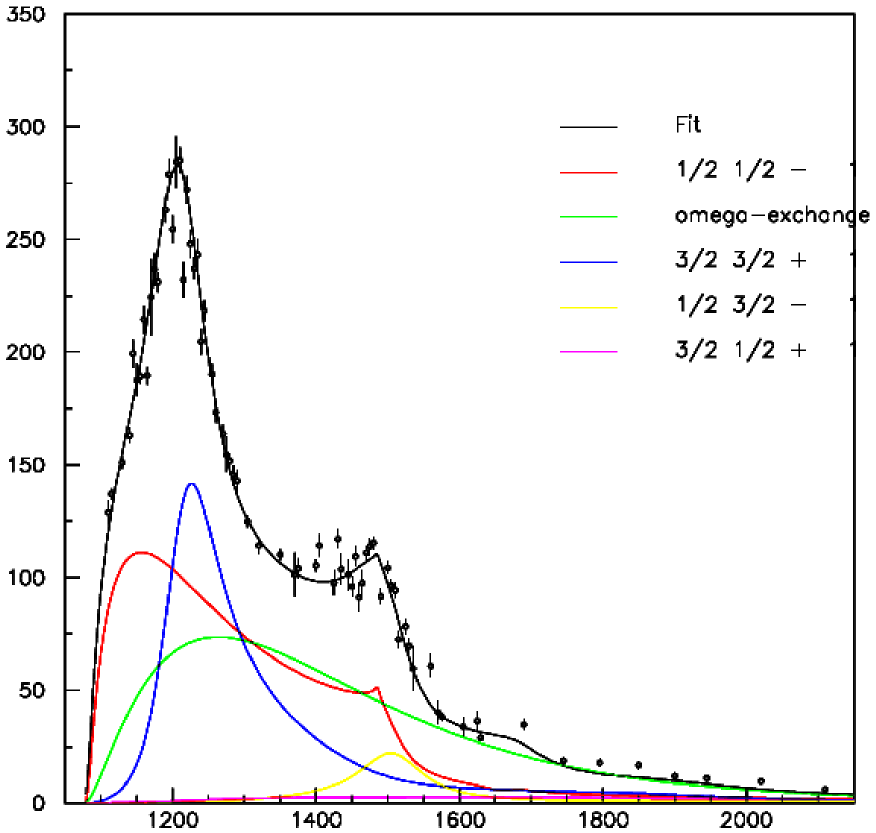
Thank You

for

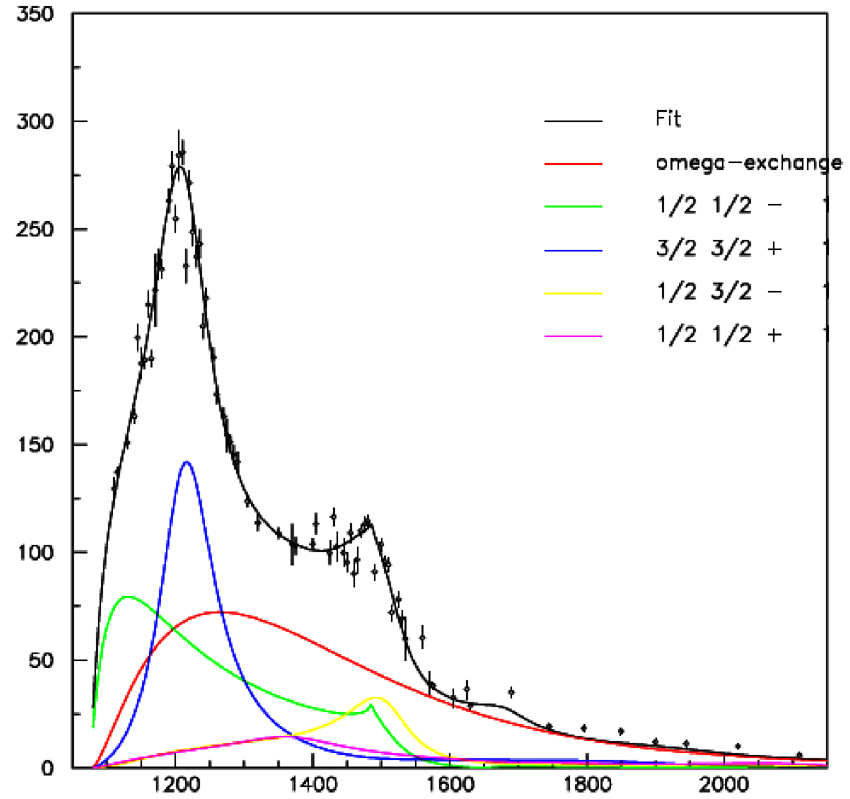
Your Attention

Backup

S11/D13 ~ 2:1
projection on s channel



S11/D13 ~ 1:1
s, t, u channels summed coherently



	D13	S11
Andrey PWA	0.23% ($BR_{n\gamma}$)	0.35% ($BR_{n\gamma}$)
Res. prop. (Andrey's PWA)-BW widths	Γ_{tot} =114 MeV $\Gamma_{n\gamma}$ = 260 keV (BR=0.23%)	Γ_{tot} =116 MeV $\Gamma_{n\gamma}$ =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%