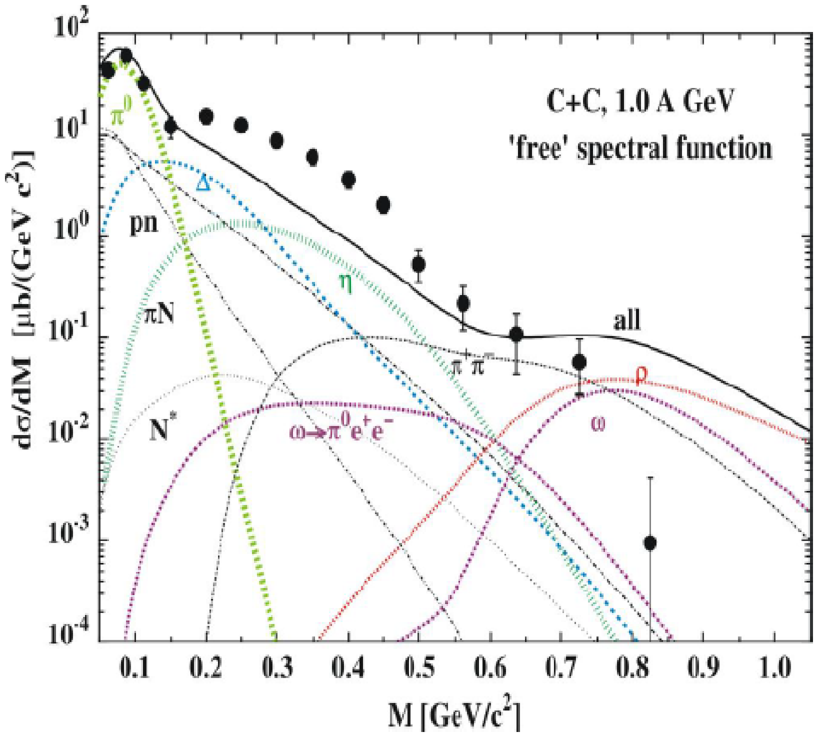
Di-electron production in dp collisions at E_{kin} =2.5 GeV

Jacek Biernat

DLS puzzle

Inclusive spectra

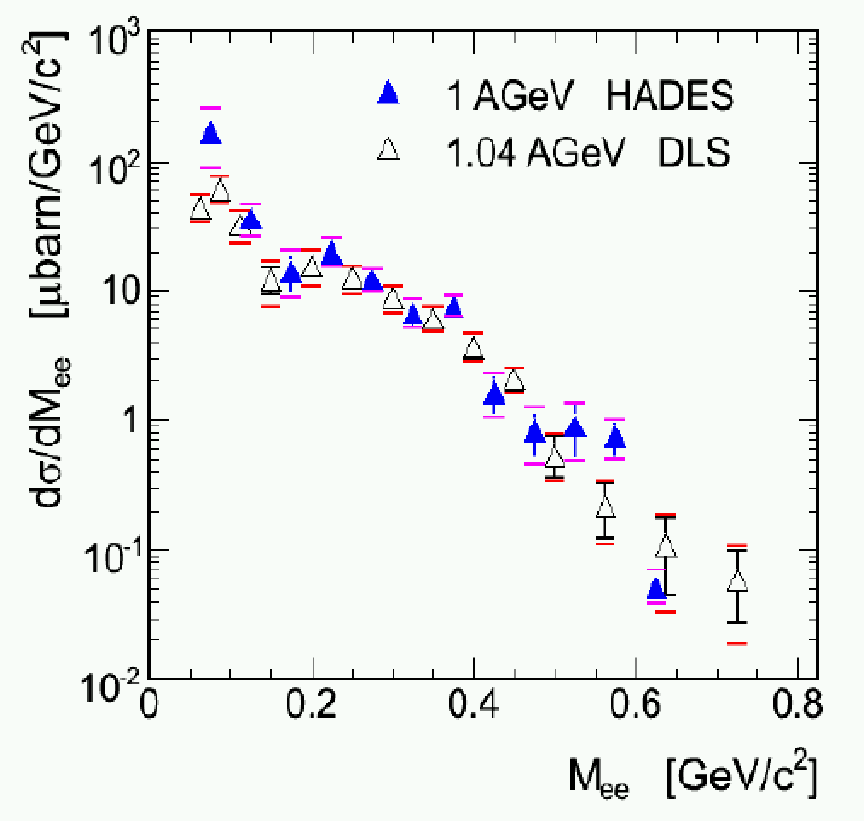
before HADES (< 2003)



DLS data: R.J. Porter et al.: PRL. 79 (1997) 1229

Calculation: E.L.Bratkovskaya et al. PLB445 (1999) 265

2004 HADES re- measures C+C collisions



HADES data: Agakishiev et al., PLB 663 (2008) 43

Main contributing sources:

- **π^0 Dalitz:**

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

- **η Dalitz:**

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

- **Δ Dalitz:**

  $\Delta \rightarrow N e^+ e^-$

- **Bremsstrahlung?**

  $NN \rightarrow NN e^+ e^-$

- **Vector meson decay $\rightarrow e^+ e^-$**

✓ HADES fully confirms DLS results

- What about „excess” ? Is it true in-medium effect ?
- or not understood elementary process?

N+N and pi-N collisions in HADES

p+p colisions @
- T_k = 1,25 GeV
- T_k = 2,2 GeV
- T_k = 3,5 GeV

quasi-free n+p collisions @
- T_k= 1,25 GeV

di-electron production

- Inclusive e+e- from pp and np

Phys.Rev. C85 (2012) 054005
Eur.Phys.J. A48 (2012) 64
Phys. Lett. B690 (2010) 118.

- **np →npe+e-**
- pp →ppe+e-

Eur.Phys.J. A50 (2014) 82

- np →de+e- H. Kuc Thesis
- π^-p→ne+e-

one-pion production

- np → npπ
- pp → ppπ

Eur.Phys.J. A50 (2014) 82
Eur.Phys.J. A48 (2012) 74

two-pion production

- np →np π+π-

Phys. Lett B 750, 12 (2015)

- pp →pp π+π-

on-going

- np→dπ+π-
- π^-p →n π+π-

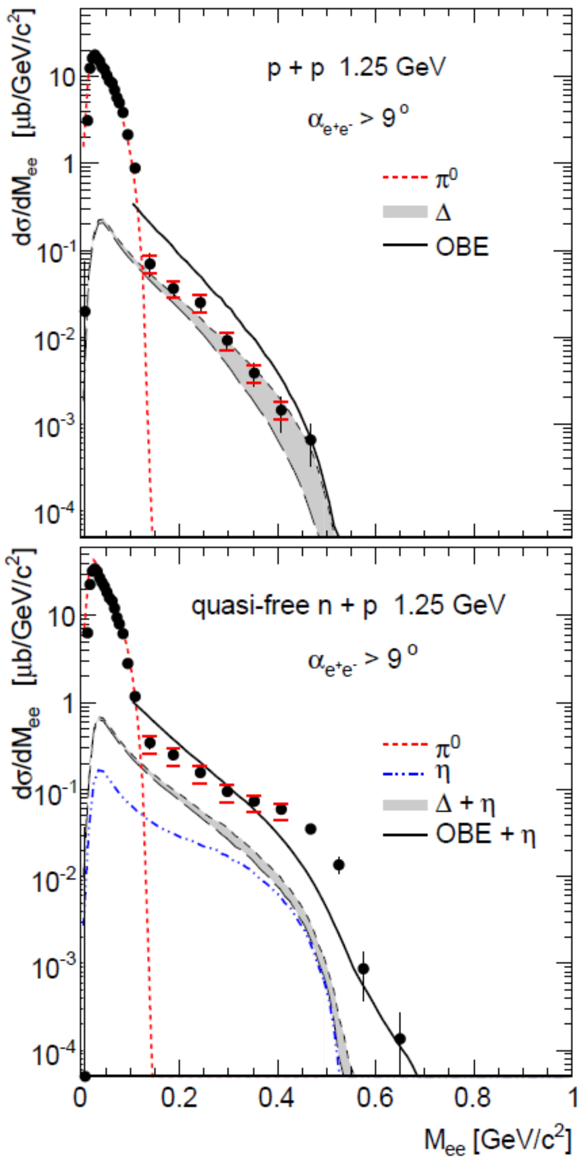
Data taken in summer 2014

What have we learnt from inclusive spectra

- **The pp spectra are well described by resonance model (N_Δ=3/2 N_π^0) based on known cross sections. NOT described by OBE with increased bremsstrahlung contribution (see next slide)**
- **pn data are underestimated by the resonance model and also not described by OBE.**
- **general difference between pp and np reactions is the different Bremsstrahlung contribution and eta contribution. (OBE + η)**
- **none of the contributions could explain the enhancement in the di-lepton yield in np.**

$p\,p \rightarrow X\, e^+\, e^-$

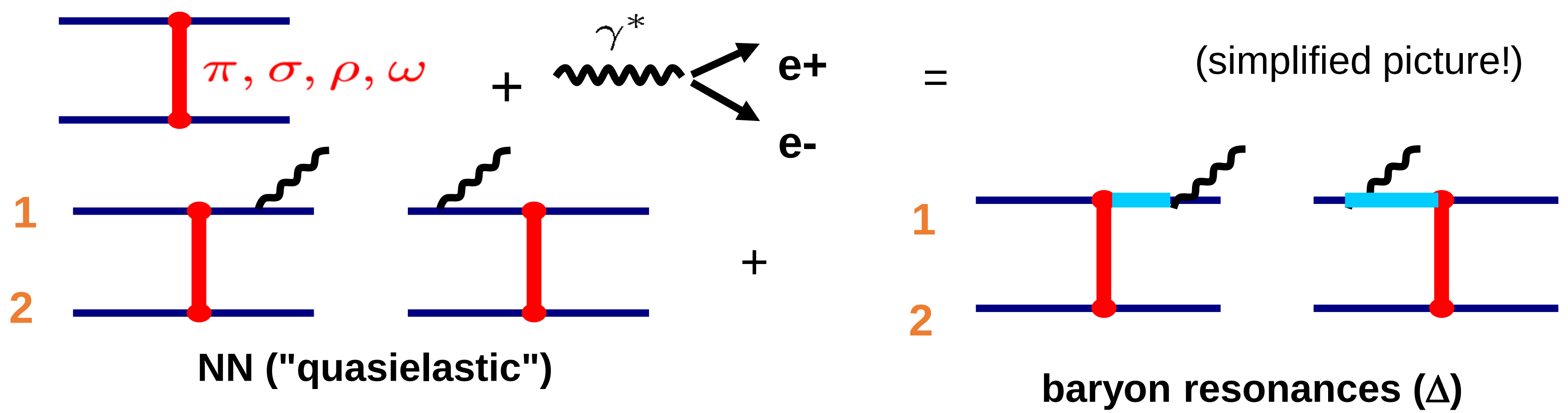
$d\,p \rightarrow X\, e^+\, e^-\, p_{spec}$

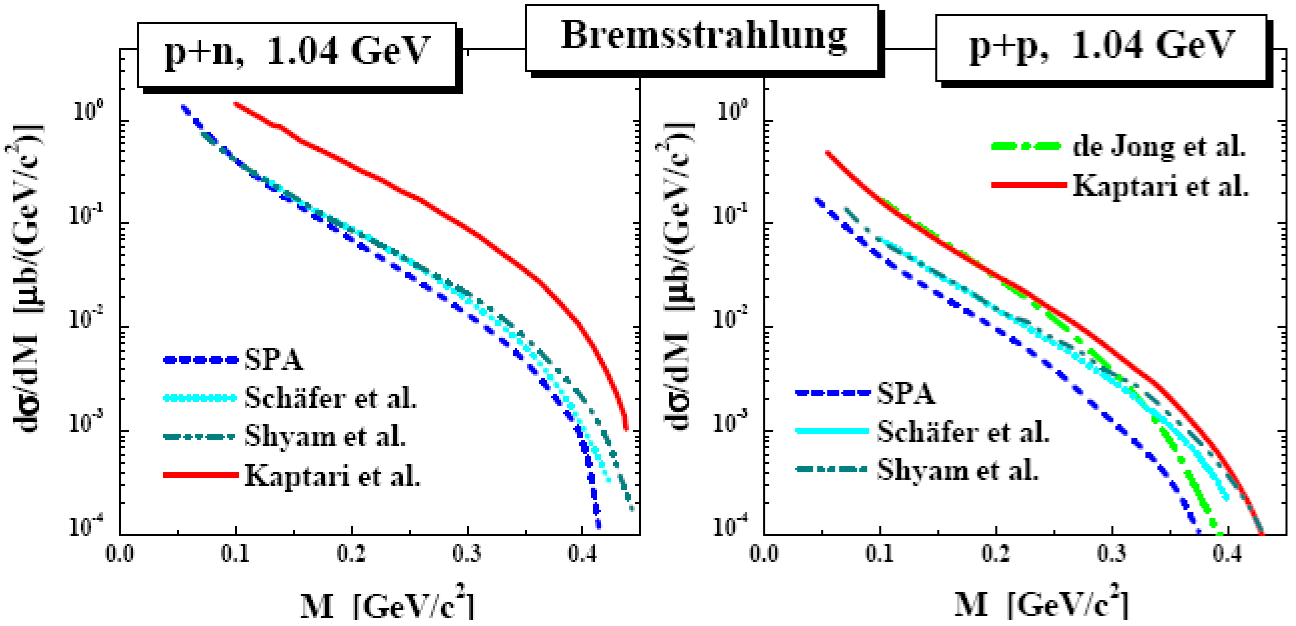


Phys. Lett B 690,118 (2010)

N-N Bremsstrahlung

- Strong + electromagnetic process (OBE models)





•E.L Bratkovskaya & W. Cassing: arXiv: 0712.0635v1

• bremsstrahlung OBE calculations:

Kaptari & Kämpfer, NPA 764 (2006) 338:

☝ **new OBE calculation:**

pn bremsstrahlung 4 larger than in earlier (<2000) calculations !

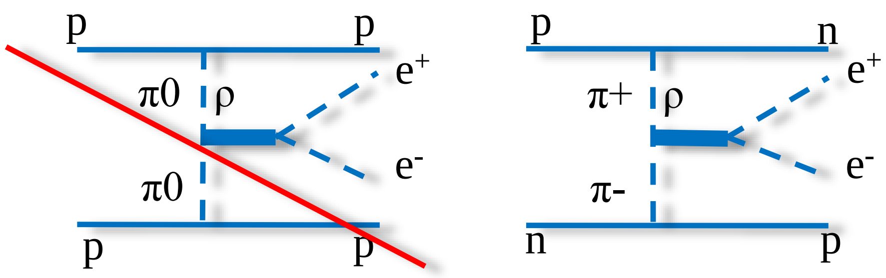
Possible explanation of e+e- excess in np (I)

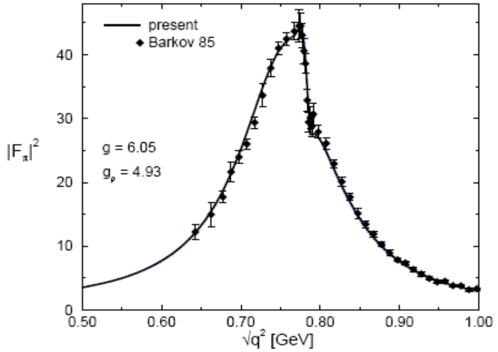
Possible explanation:

e^+e^- excess in np

Introducing charged pion FF ?

R. Shyam , U. Mosel, Phys.Rev. C82 (2010) 062201

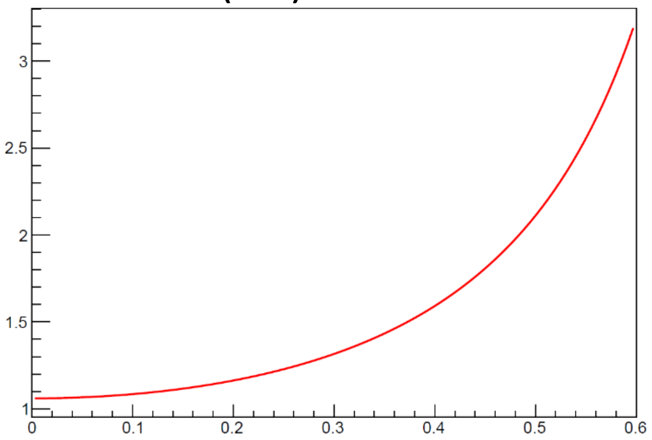


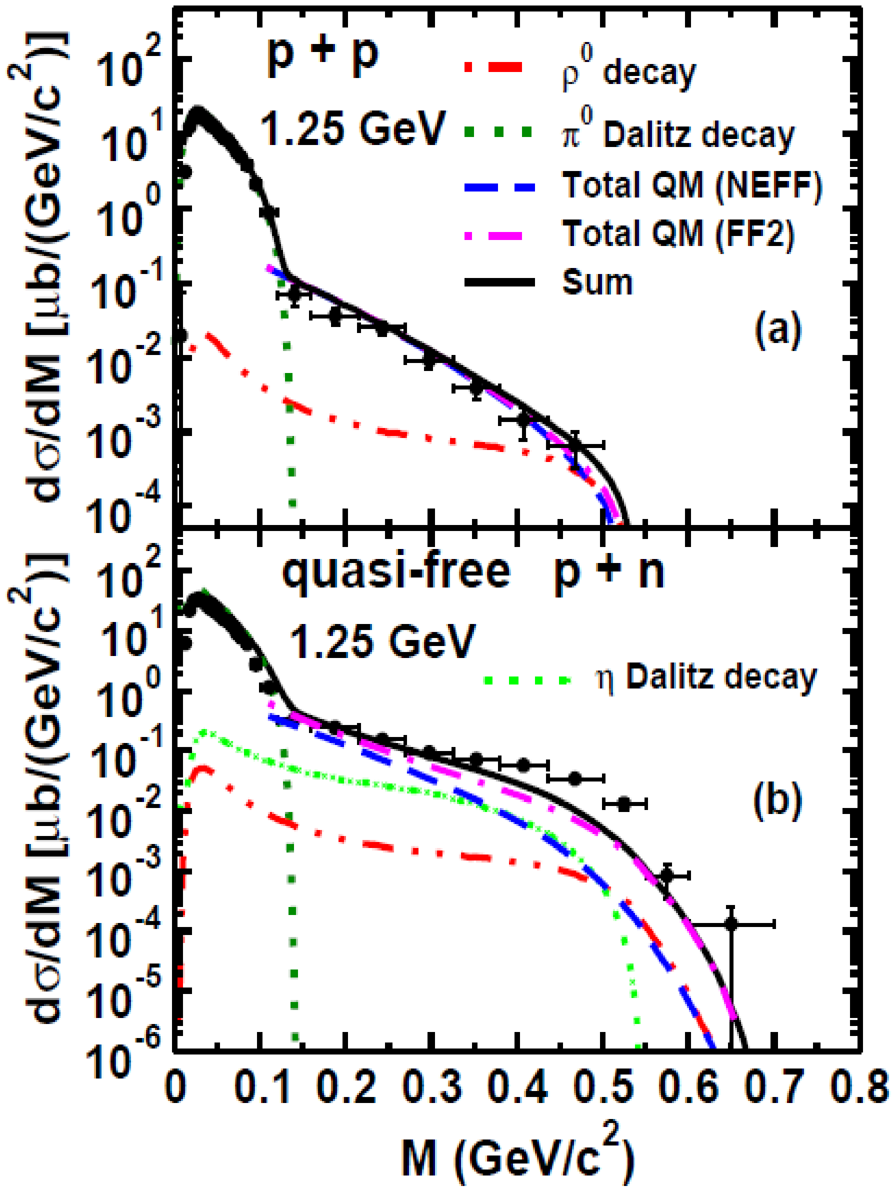


FF2 $F_\pi(M^2) = \frac{0.4}{1 - M^2/\lambda^2} + \left(\frac{0.6}{1 - M^2/2m_\rho^2}\right)\left(\frac{m_\rho^2}{m_\rho^2 - M^2 - i m_\rho \Gamma_\rho(M^2)}\right)$

$m_\rho = 0.760\ GeV/c^2$
$\lambda = 1.9\ GeV/c^2$

FF2(M²)

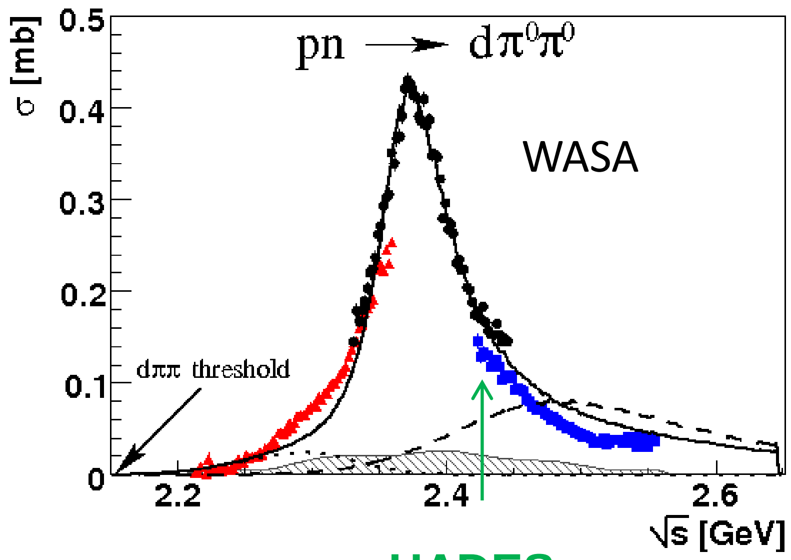


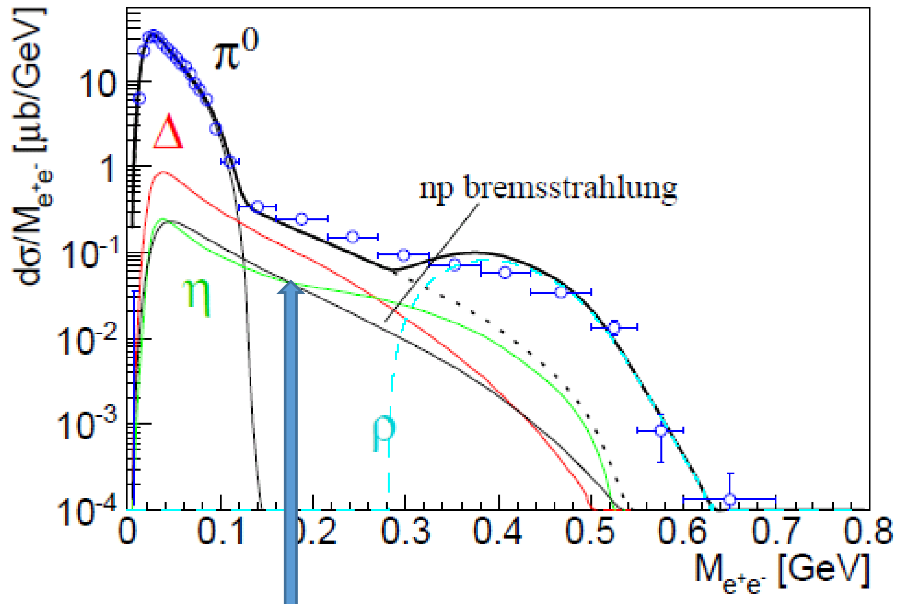


Possible explanation of e+e- excess in np (II)

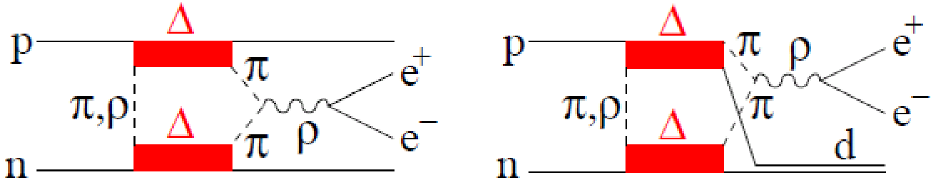
off-shell ρ contribution in ΔΔ interactions

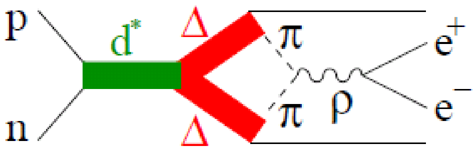
M. Bashkanov and H. Clement
Eur.Phys.J. A50 (2014) 107





$$pn \rightarrow \Delta\Delta \rightarrow pn[\pi^+\pi^-]_{I=L=1} \rightarrow pn\rho^0 \rightarrow pne^+e^-,$$





d* info:

$I(J^P) = 0(3^+)$

$M = 2.37\ \mathrm{GeV/c^2}$

$\Gamma = 70\ \mathrm{MeV}$

0.15 GeV < M_{e+e-} < 0.3 GeV
still a slightly underestimated region maybe due to

$$pn \rightarrow d^* \rightarrow [pn]_{I=0}e^+e^-$$

$$pn \rightarrow d^* \rightarrow de^+e^-$$

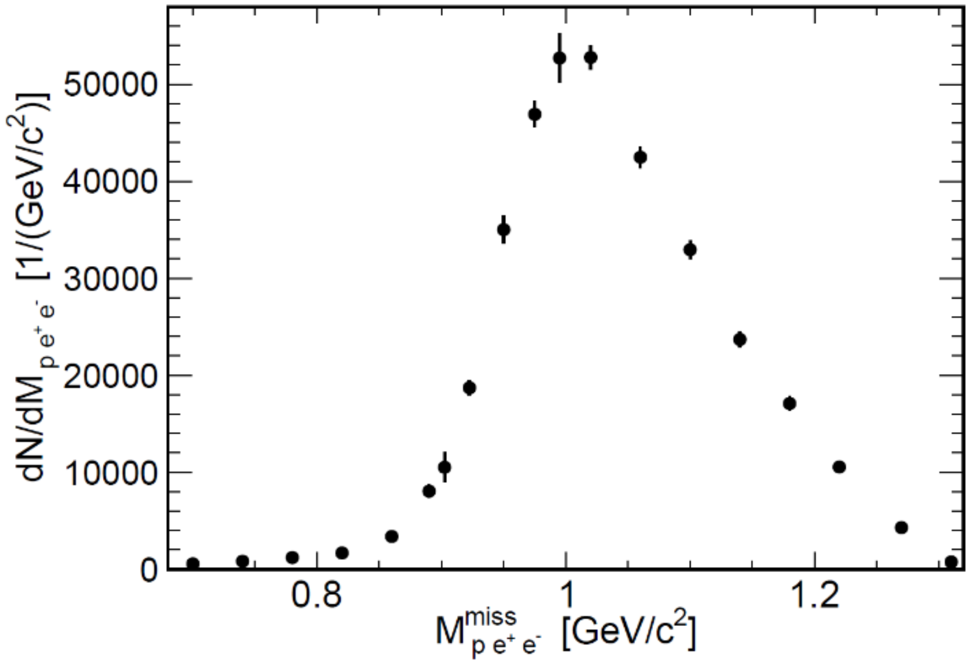
$$|\mathcal{M}(\pi^+\pi^- \rightarrow \rho^0 \rightarrow e^+e^-)|^2 = \frac{m_\rho^2\Gamma_{\pi^+\pi^-}\Gamma_{e^+e^-}}{(s-m_\rho^2)^2 + m_\rho^2\Gamma_\rho^2}.$$

Transition form π+π- to e+ e-

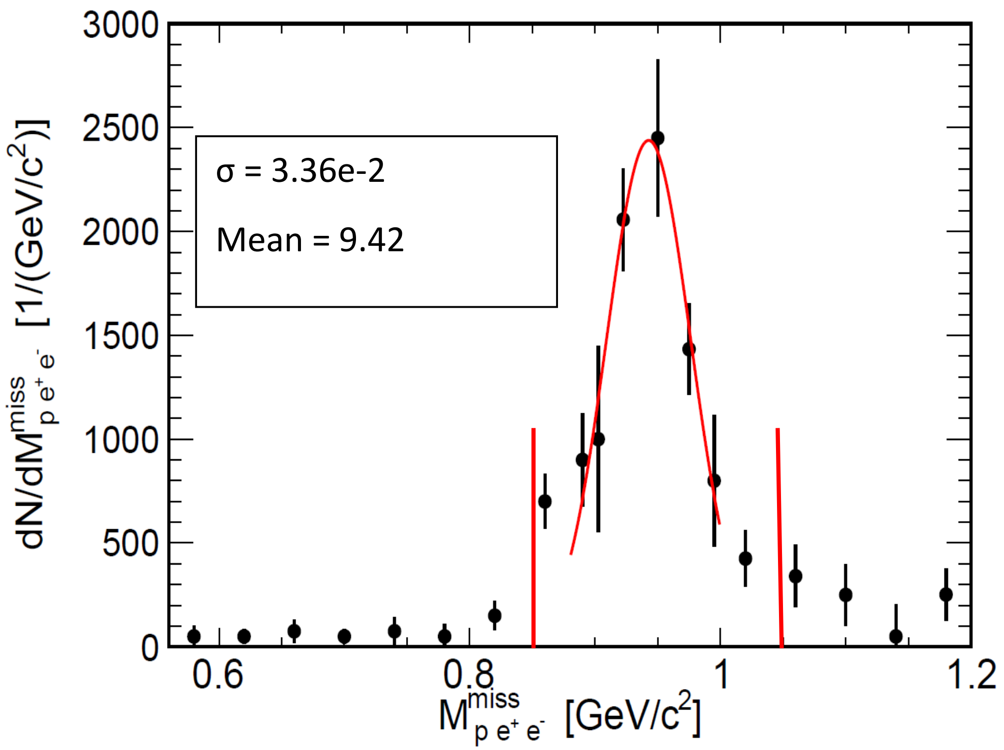
Identification of exclusive channel $(np)_{p\_spec} \to (npe^+e^-)_{p\_spec}$

- Three particle trigger selected (in case of np)
- Tagged proton in Forward Wall detector (spectator)
- 3 particles (proton ,e^+e^-) identified in HADES
- selection via missing mass window

All e^+e^- masses



$M_{inv}(e^+e^-) > 140$ MeV/c^2

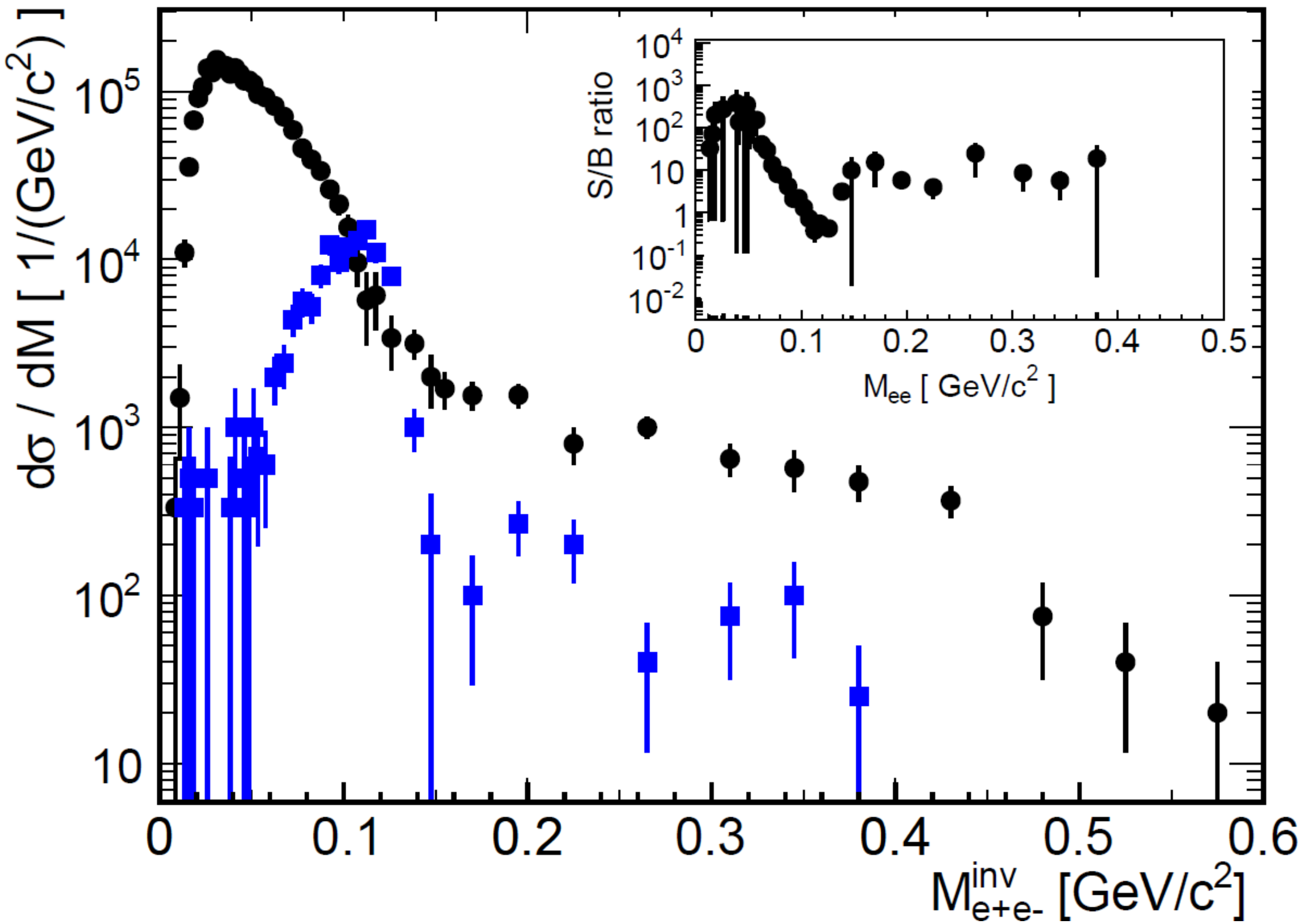


Unlike-sign combinatorial background estimation

The unlike-sign combinatorial background can be estimated by the reconstructed like-sign distribution.

$$N_{CB} = 2 * \sqrt{N_{++} * N_{--}}$$

$$N_{sig\_reco} = N_{sig} - N_{CB}$$



Above 140 MeV/c^2 background is negligible

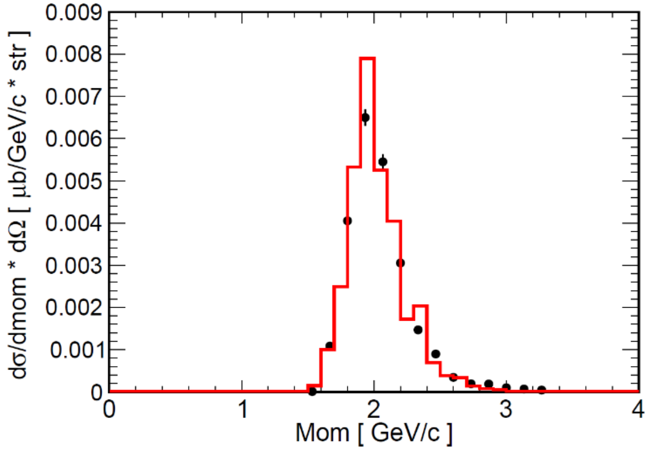
Comparison of spectator momentum distributions with simulation

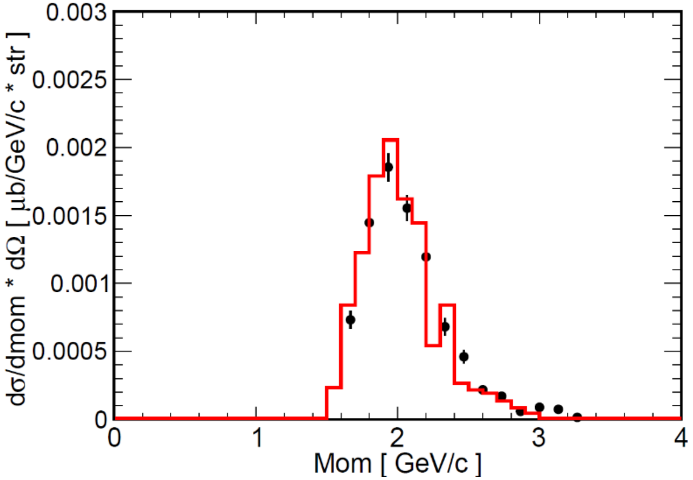
θ < 2 deg

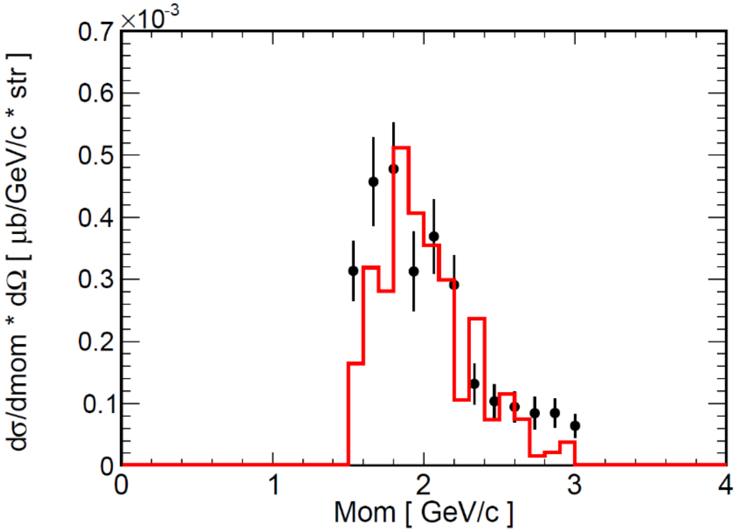
$M_{inv}(e^+e^-)$ <140 MeV/c^2

2 < θ < 4

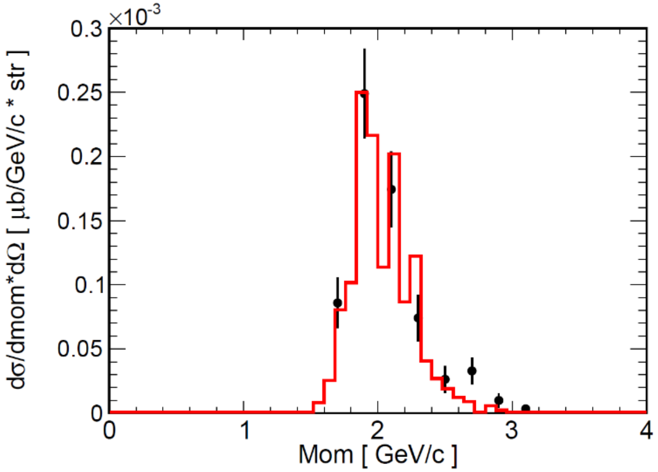
4 < θ < 6

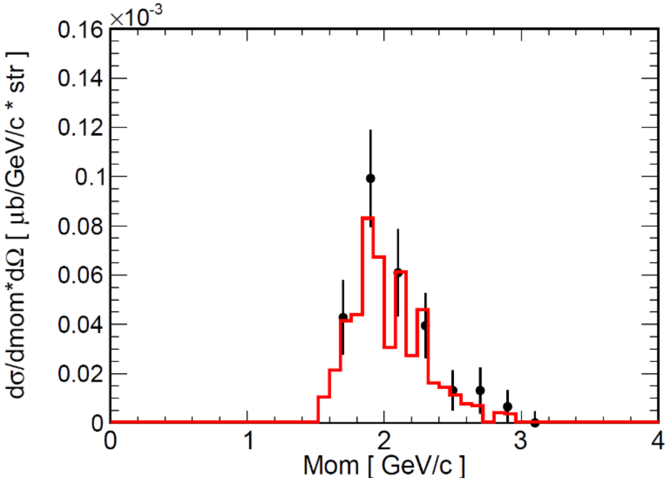


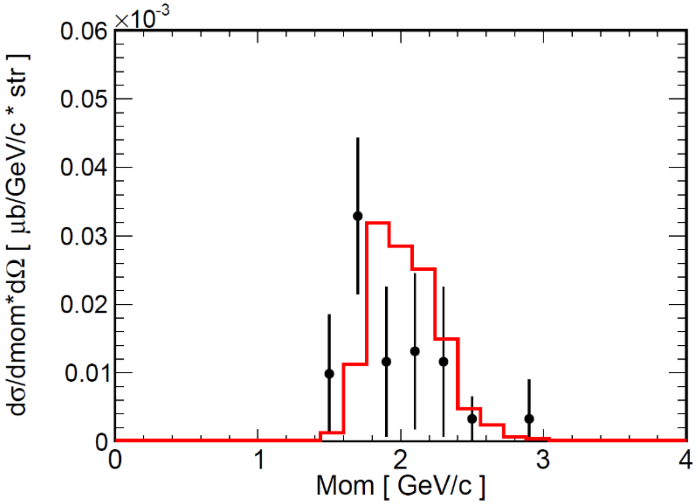




$M_{inv}(e^+e^-)$>140 MeV/c^2







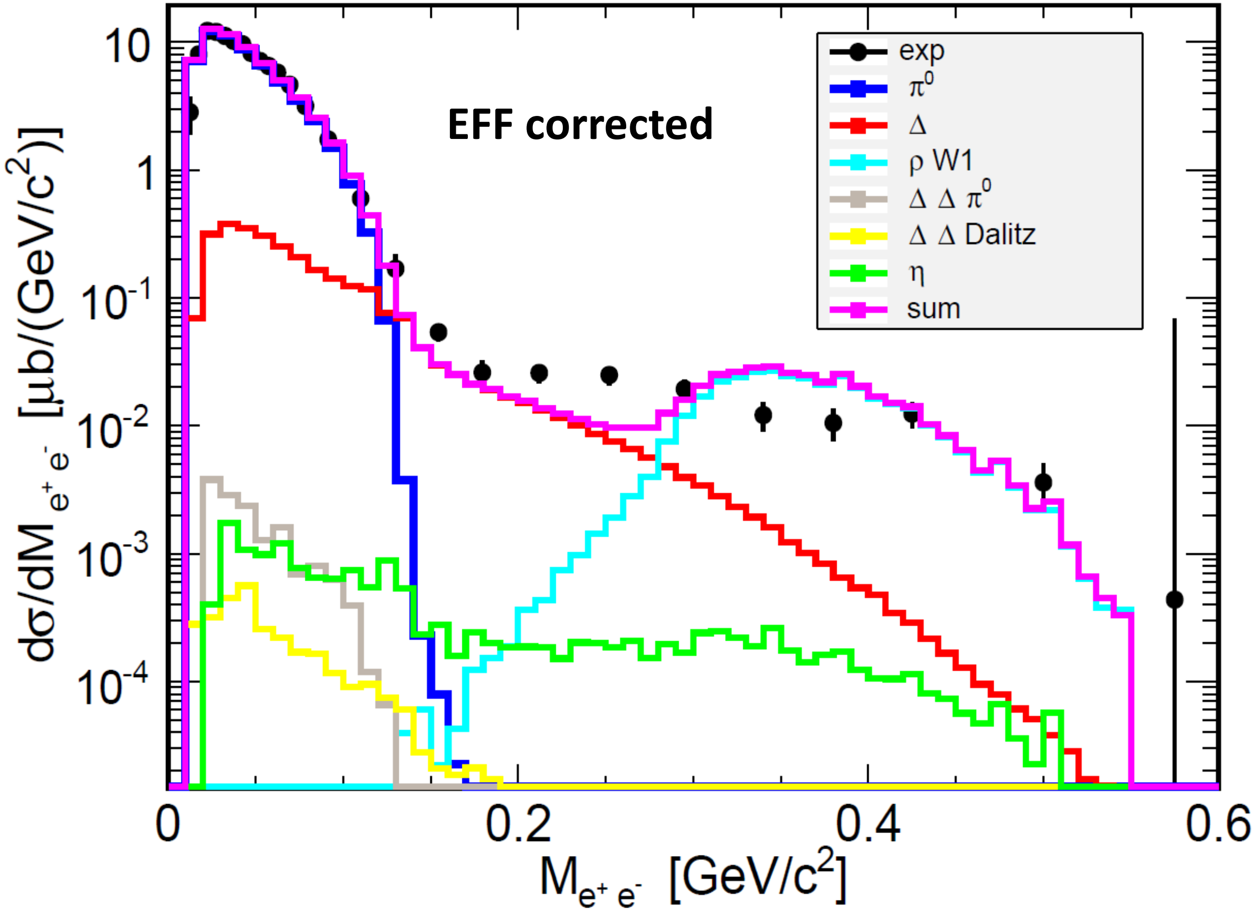
Very good agreement in all mass range !

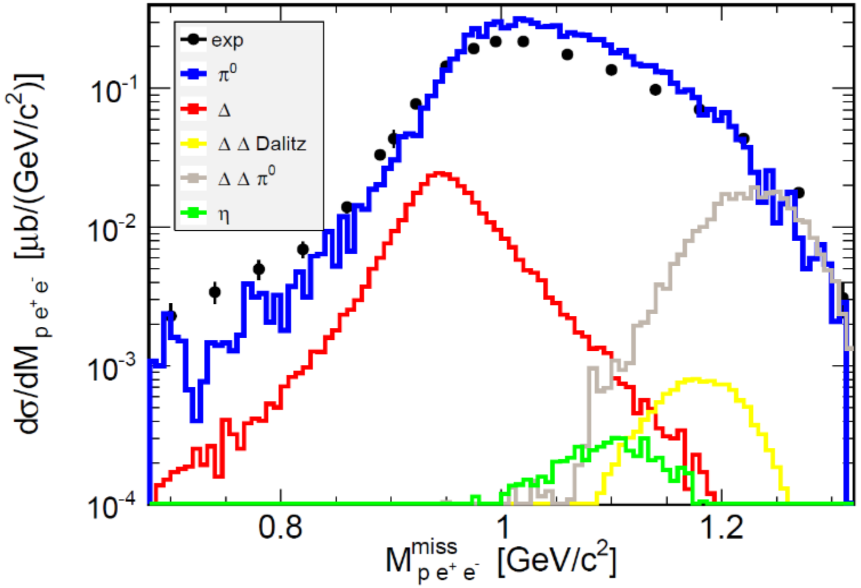
Comparison to models

Resonance model + rho contribution from Clement & Bashkanov:

Obtained form authors in a event by event form.
Total exclusive cross section is 210 μb:

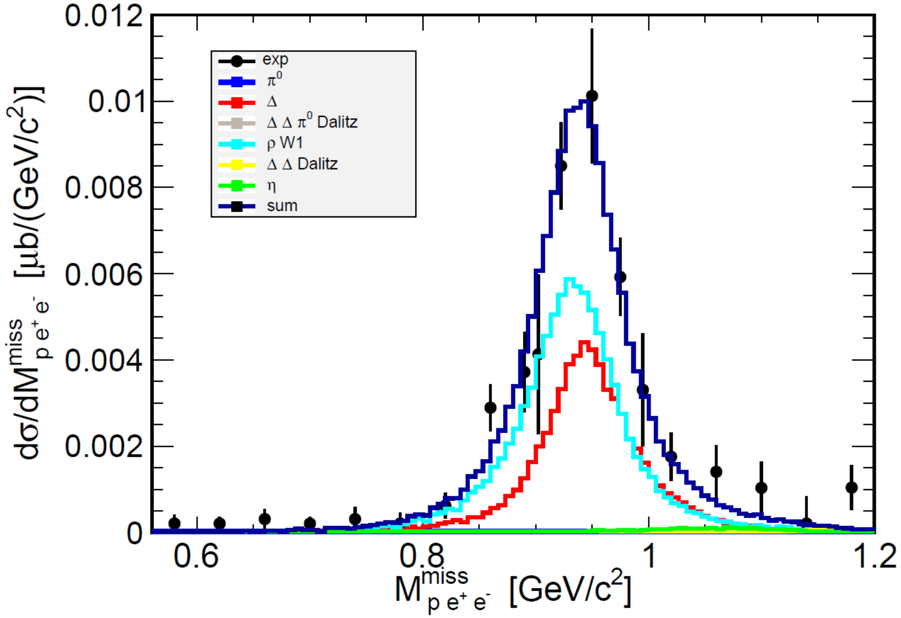
1. $np \rightarrow \Delta\Delta \rightarrow np\rho$ $\sigma = 170\ \mu b$
2. $np \rightarrow d^{*} \rightarrow np\rho$ $\sigma = 40\ \mu b$



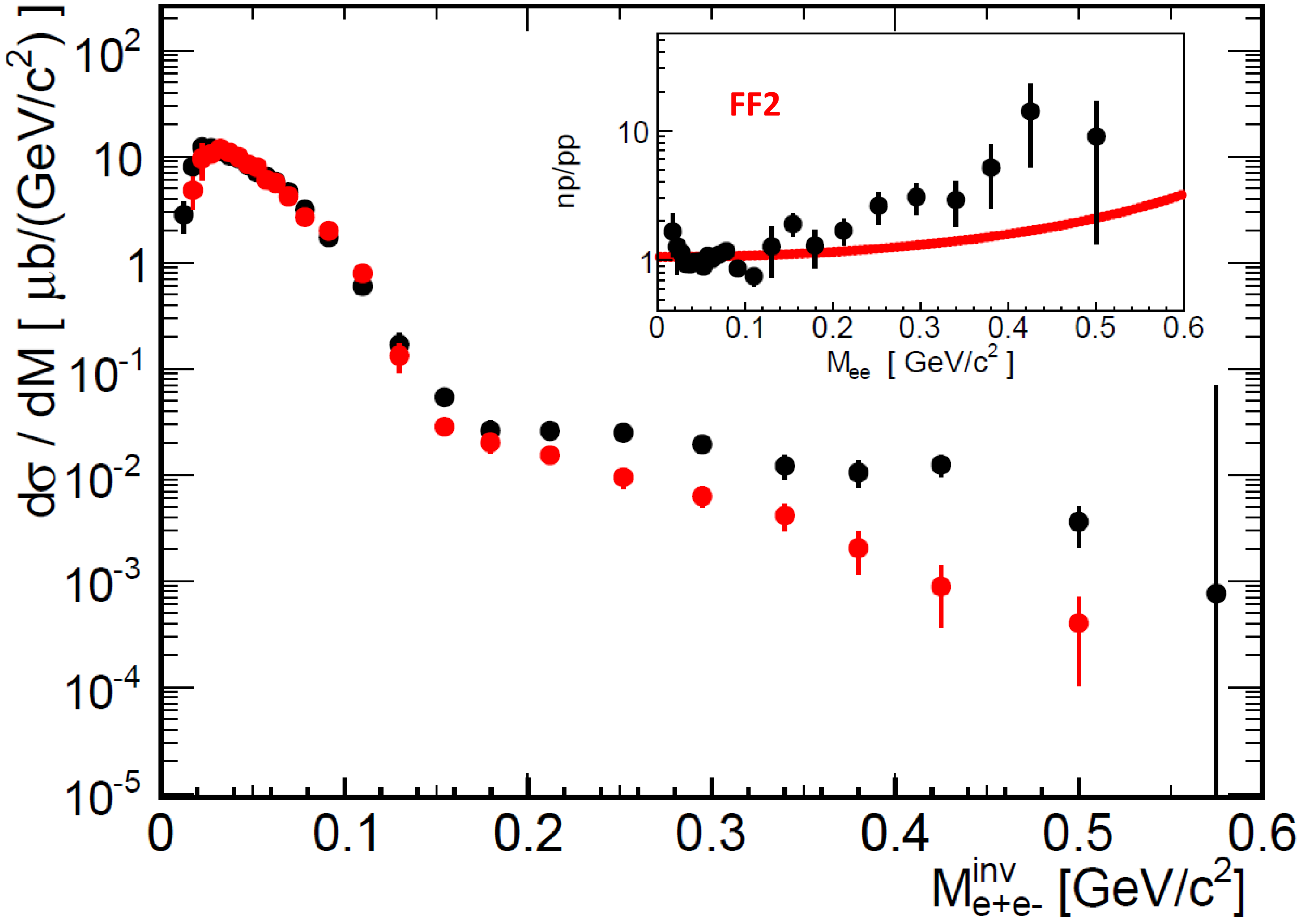


All e^+e^- masses

$M_{inv}(e^+e^-) > 140\ MeV/c^2$



pp vs np



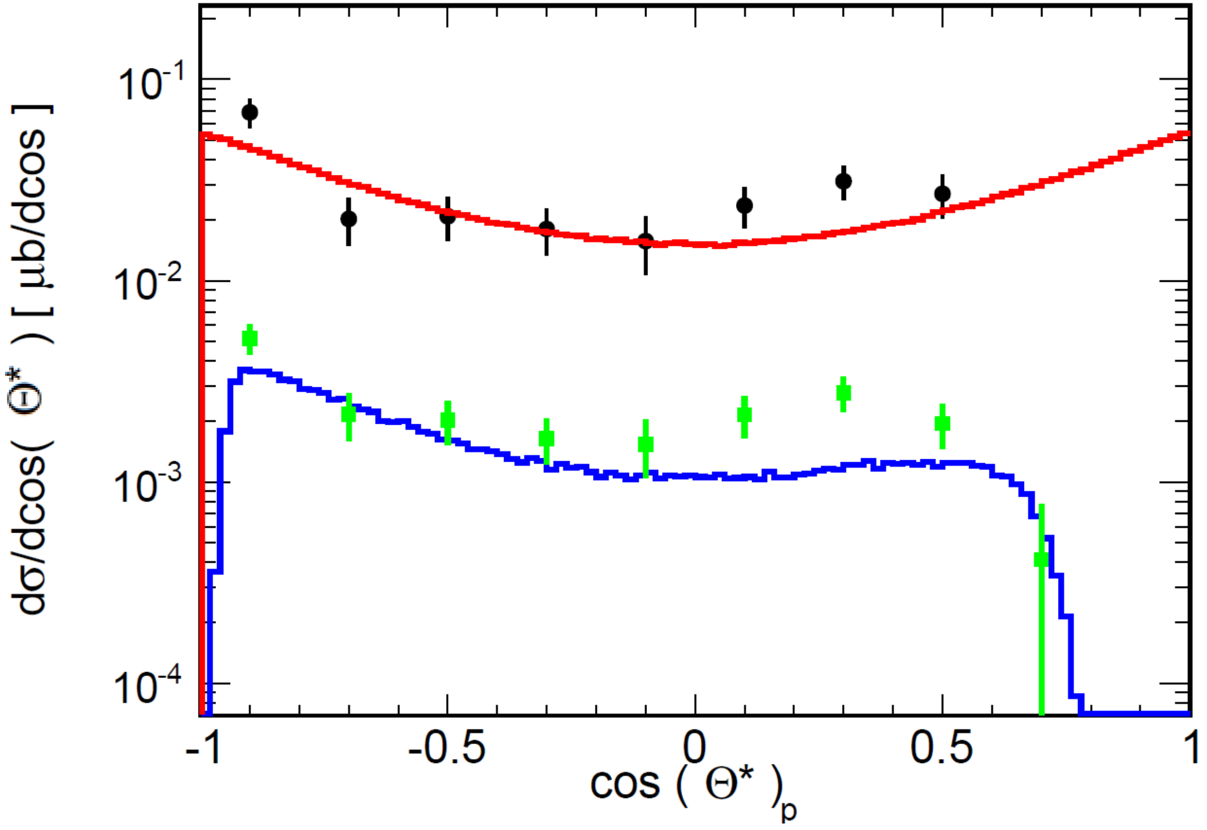
pp data scaled to the same π^0 cross section as in **np** data set.

np excess above pp higher than Shyam/Mosel calculations with charged pion FF

angular distributions of proton in the center of mass

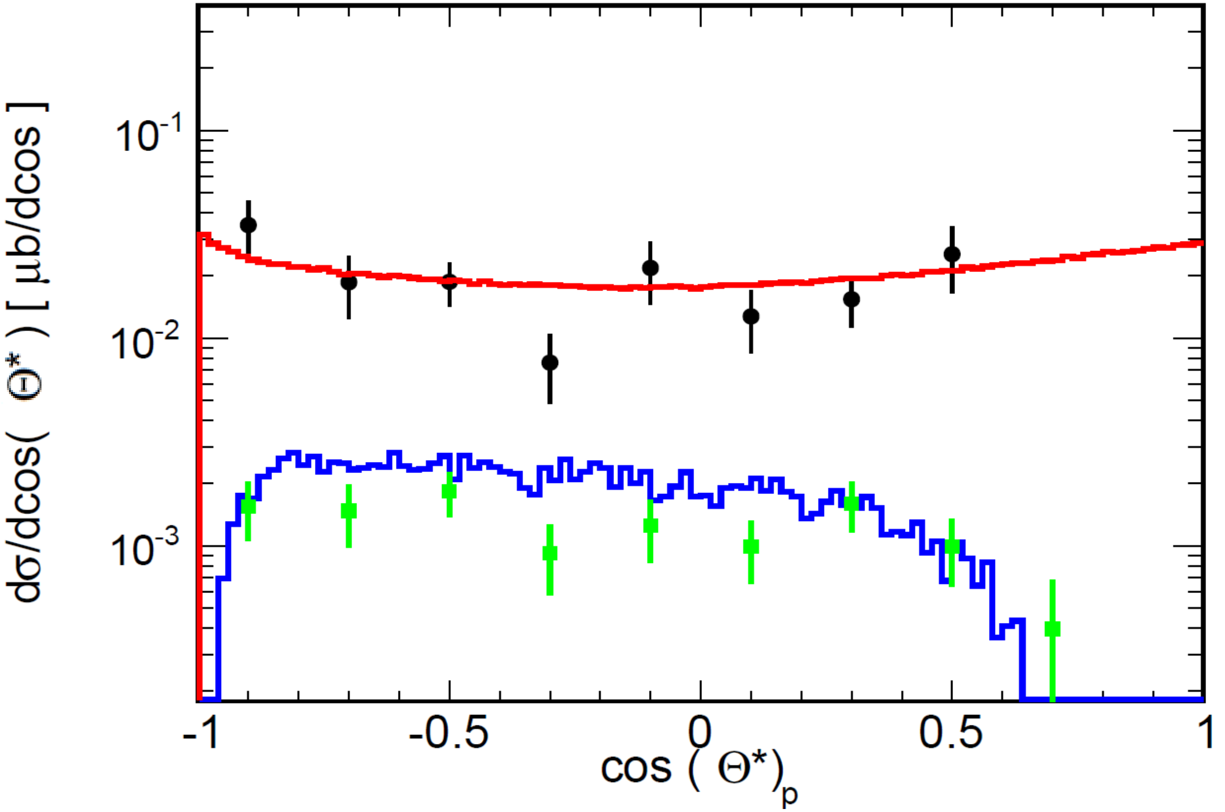
140 < $M_{inv}(e^+e^-)$ < 280 MeV/c^2

Data corrected to 4π
Pluto simulation (Δ→pe^+e^-)
Data in acceptance (EFF corrected)
Sim in acceptance (EFF corrected)



$M_{inv}(e^+e^-)$ > 280 MeV/c^2

Data corrected to 4π
Bashkanov & Clement
Data in acceptance (EFF corrected)
Sim in acceptance (EFF corrected)



angular distributions of virtual photon (γ*) in the center of mass

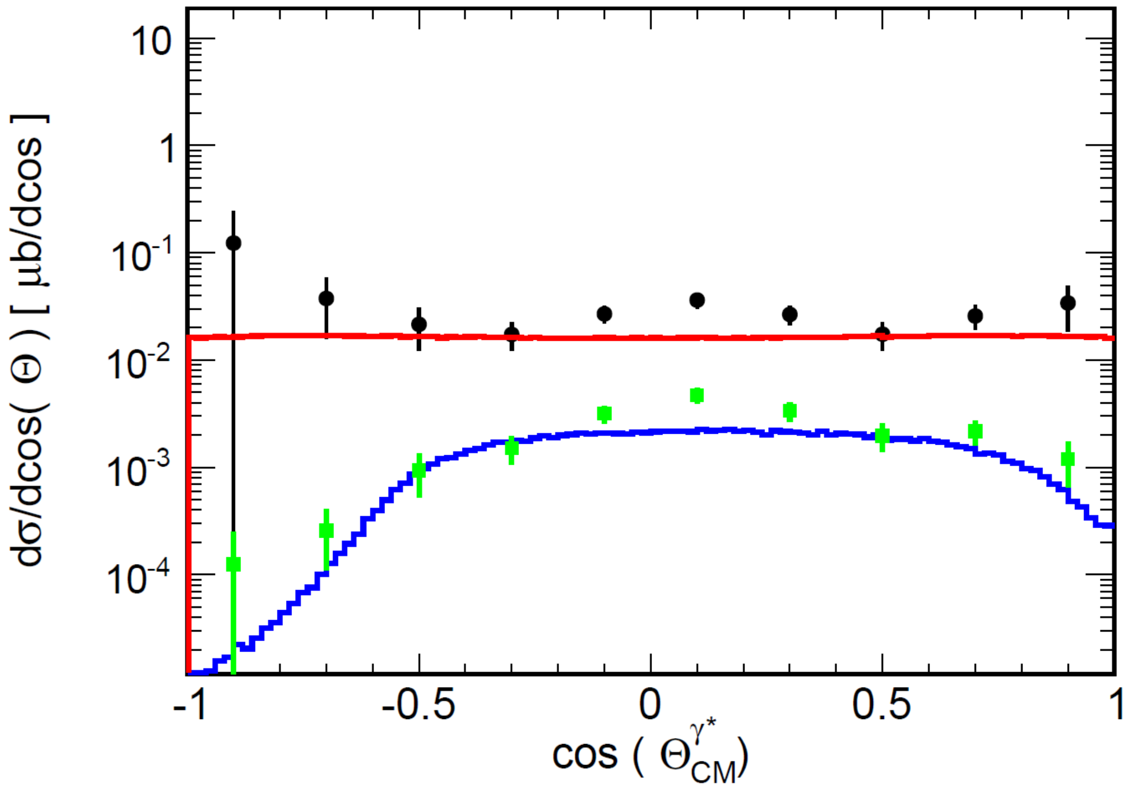
$140 < M_{inv}(e^+e^-) < 280$ MeV/c^2

Data corrected to 4π

Pluto simulation ($\Delta \rightarrow pe^+e^-$)

Data in acceptance (EFF corrected)

Sim in acceptance (EFF corrected)



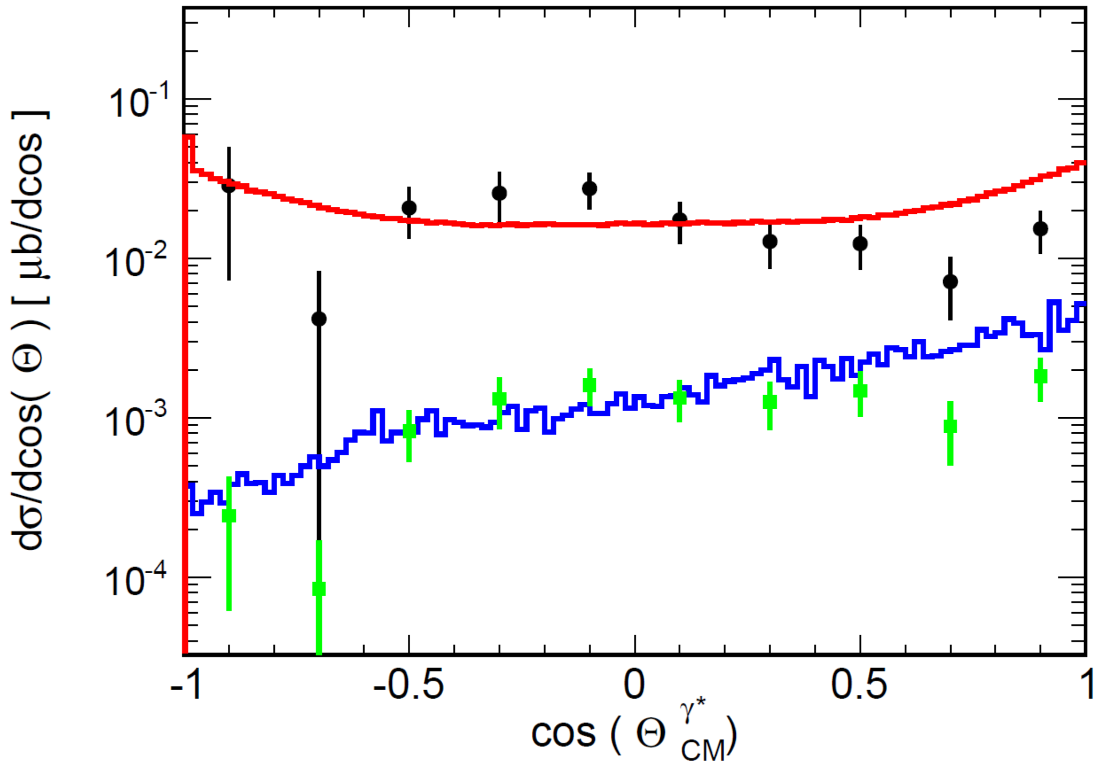
$M_{inv}(e^+e^-) > 280$ MeV/c^2

Data corrected to 4π

Bashkanov & Clement

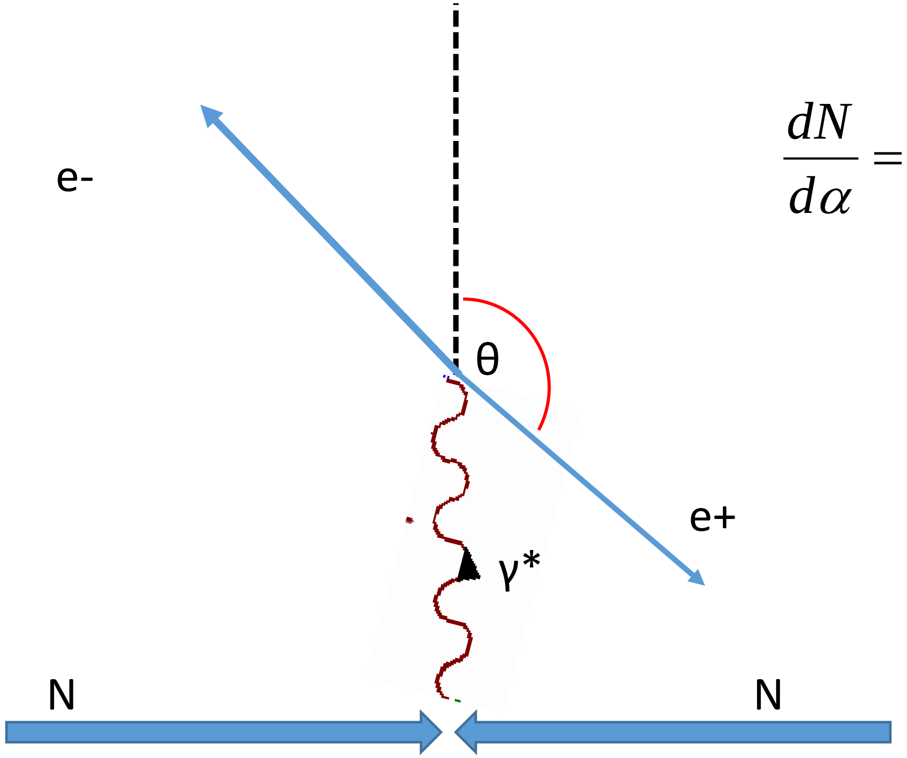
Data in acceptance (EFF corrected)

Sim in acceptance (EFF corrected)

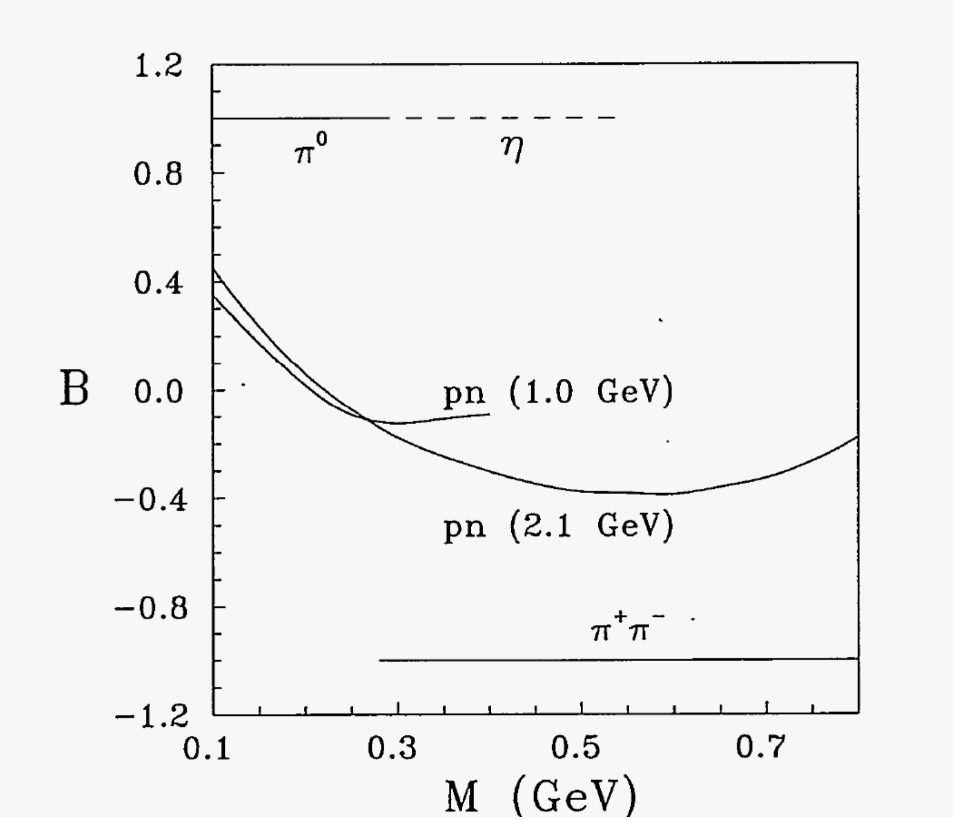


Pseudo- Helicity

- Pseudo- Helicity is defined as the angle between the lepton and the virtual photon in the virtual photon rest frame (leptons are boosted directly to γ * rest frame)
- Two regions of interest selected
- Data extrapolated to 4π



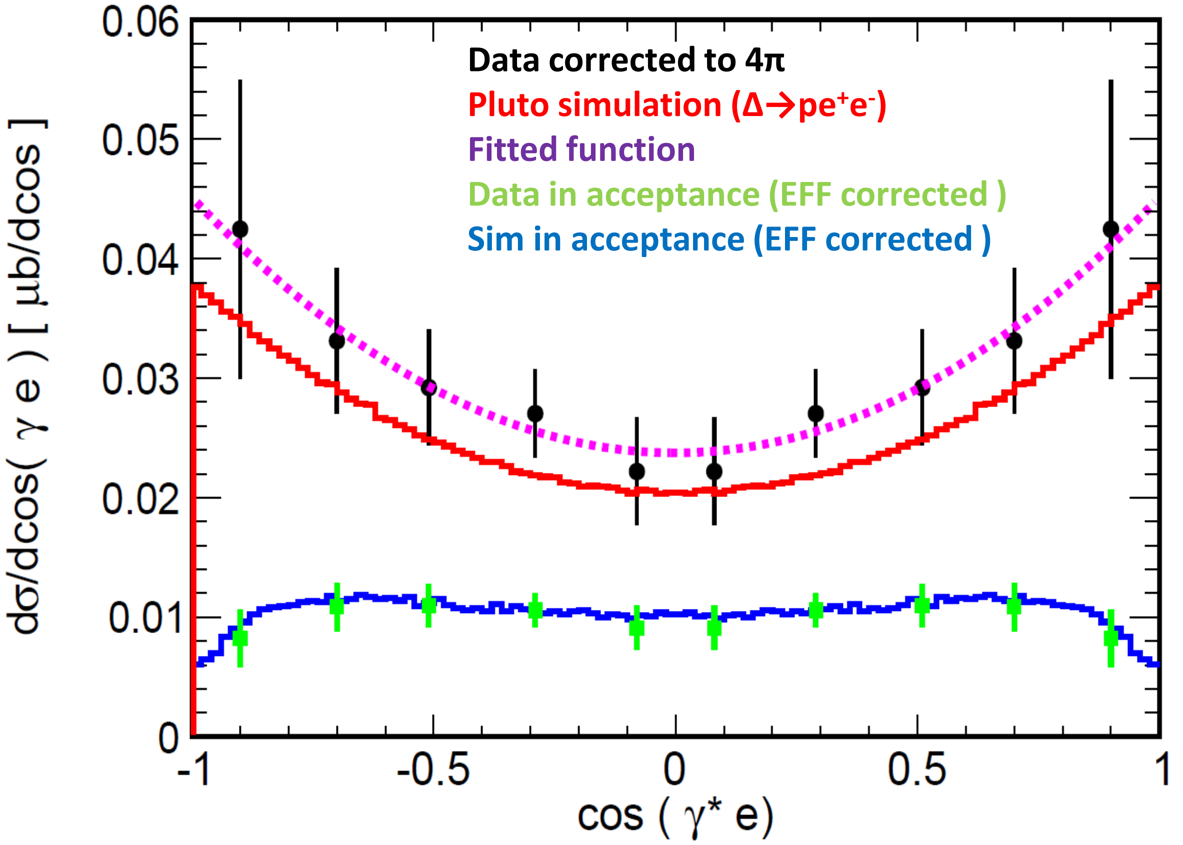
$$\frac{dN}{d\alpha} = A(1 + B\cos^2\alpha)$$



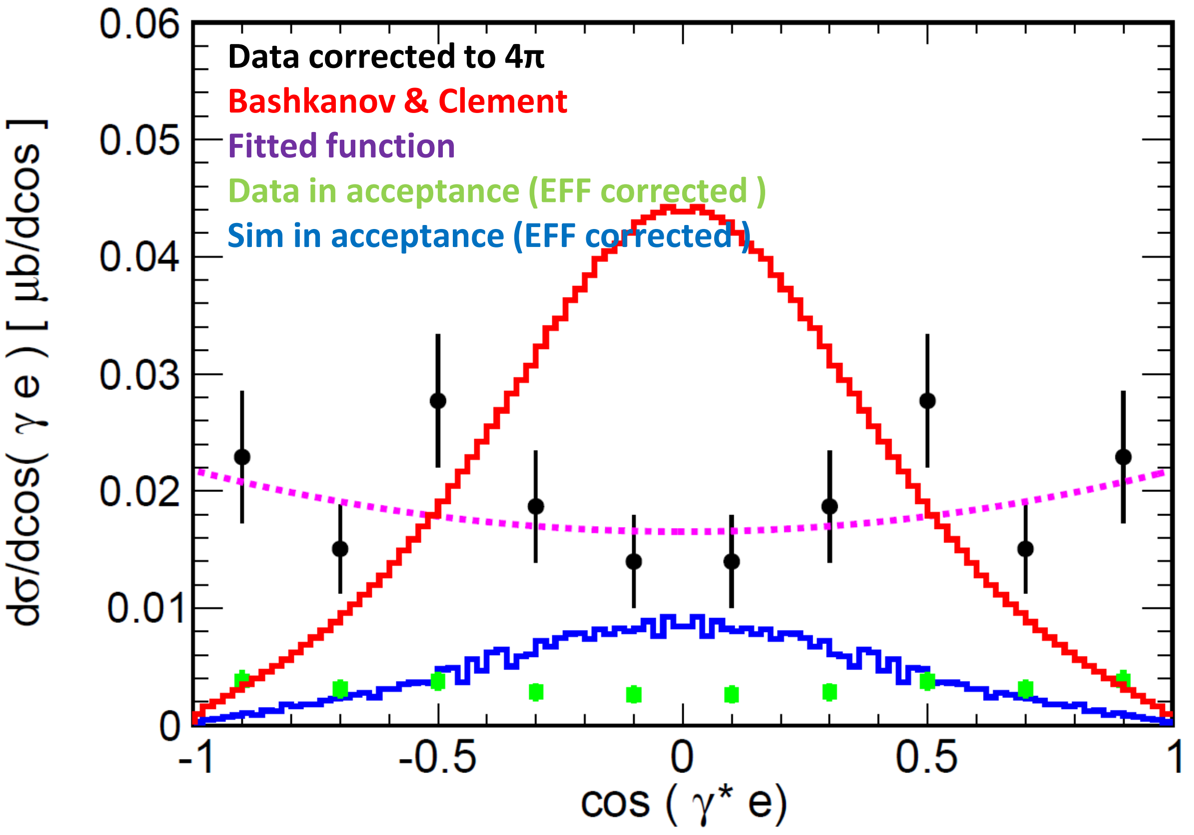
E. Batkovskaya et.al, PLB348 (1995) 283

Pseudo-Helicity

$140 < M_{inv}(e^+e^-) < 280$ MeV/c^2



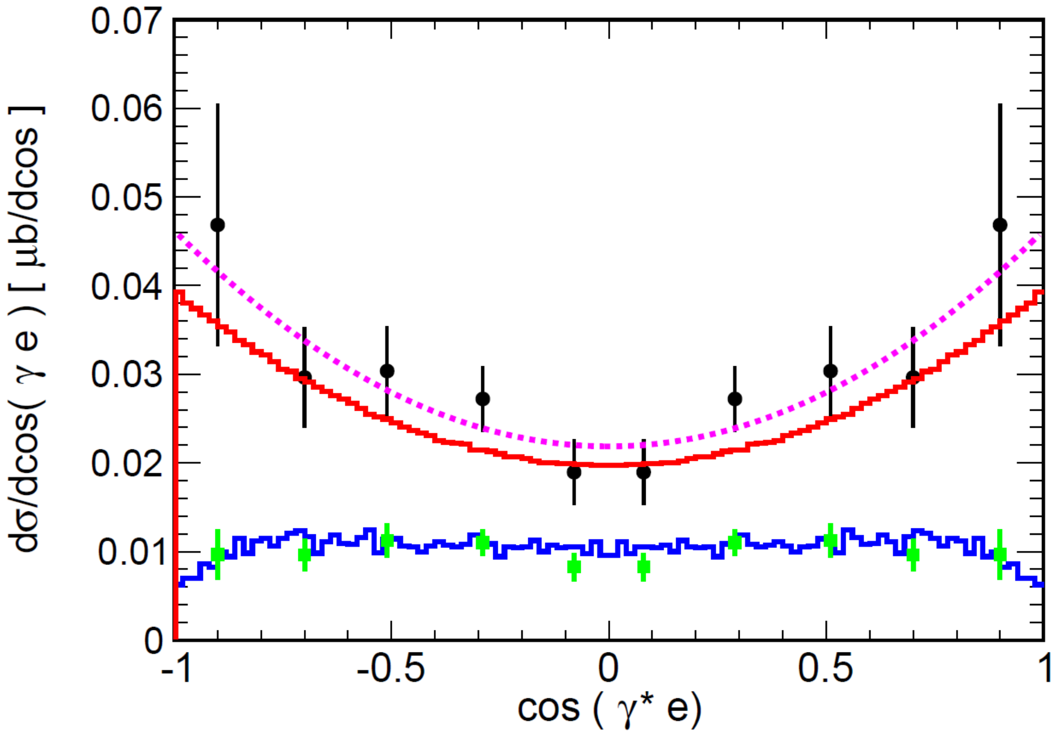
$M_{inv}(e^+e^-) > 280$ MeV/c^2



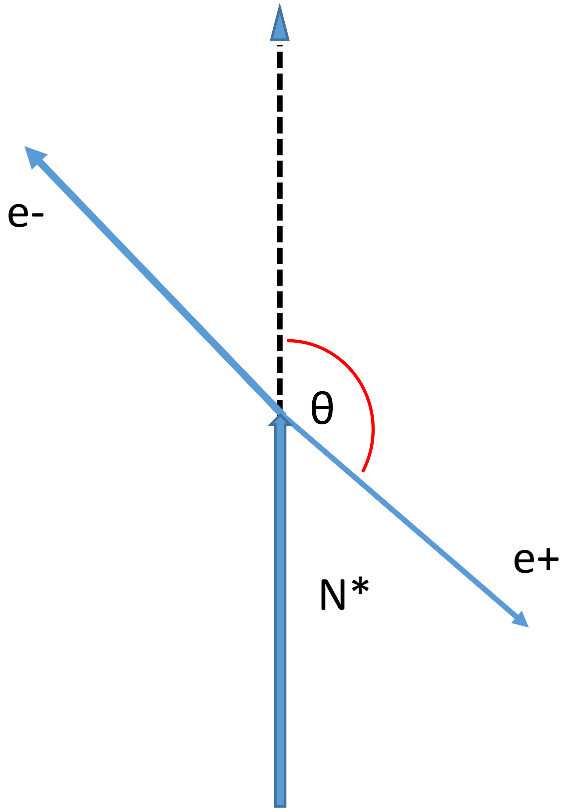
140MeV/c^2 < M < 280 MeV/c^2	Anisotropy parameter (B)
Simulation	0.77 ±0.006
Experiment	0.9 ±0.36

280 MeV/c^2 < M	Anisotropy parameter (B)
Simulation	-1.30 ±0.003
Experiment	0.15 ±0.32

Helicity



- Since there is a confirmation of the major contribution of Δ in e+ e- production in the range of 140 MeV/c^2 < M < 280 MeV/c^2 Helicity has been calculated (boost to Δ reference frame)



140MeV/c^2 < M < 280 MeV/c^2	Anisotropy parameter (B)
Simulation	1 ±0.006
Experiment	1.1 ±0.4

Conclusion

- excess of e+ e- pairs in np over pp is a genuine feature of the exclusive channel
- Helicity distributions show a interesting pattern:

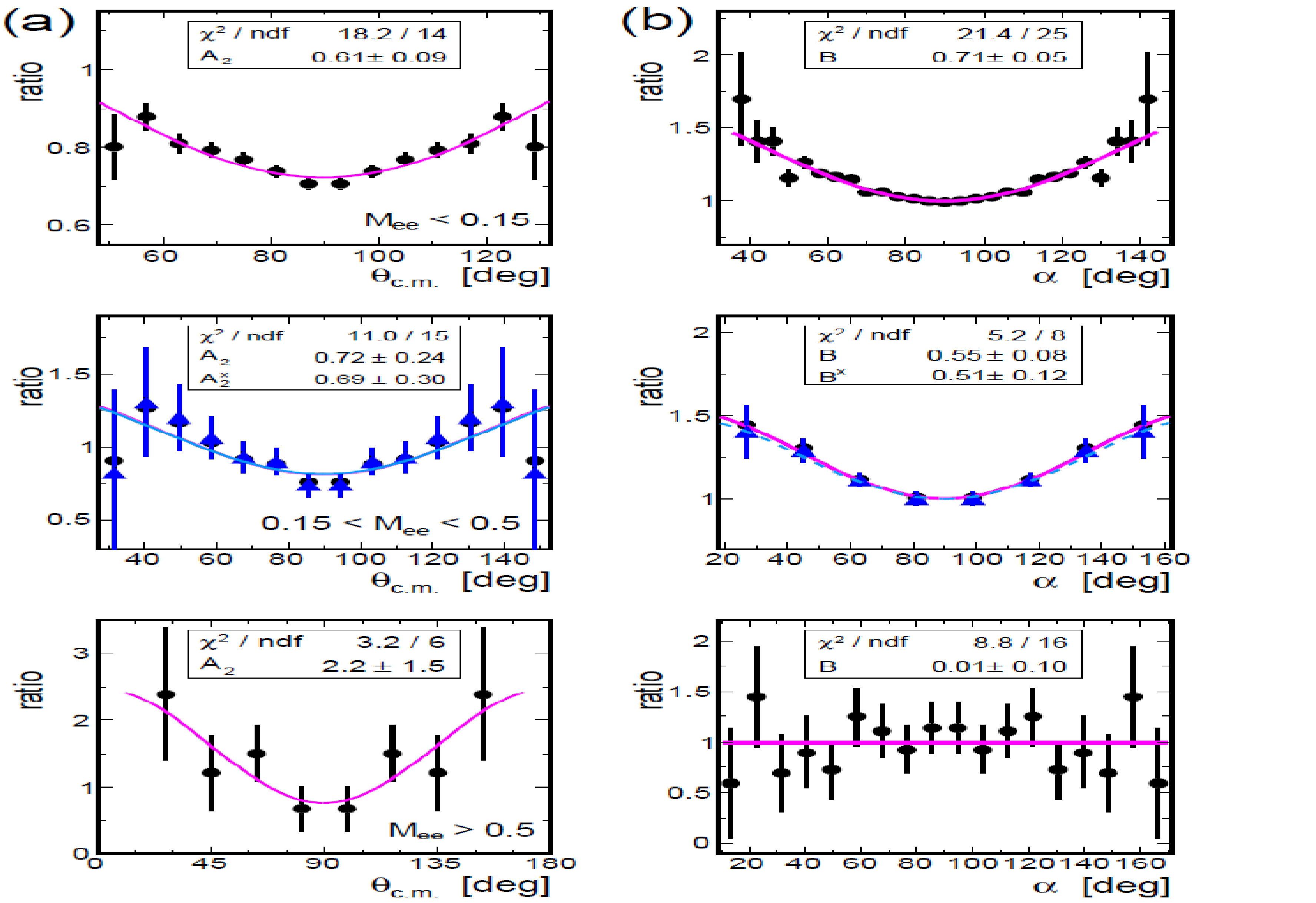
a) In mass region dominated with Δ, anisotropy is in agreement with expectation

b) In higher mass region (ρ - dominated) the distribution is isotropic→ similarity with Heavy Ion

- Model of Bashkanov overestimates the data by a factor of 2.
- Virtual photon distributions are isotropic
- Proton distributions obtained form the data are mostly described by the model
- charged pion FF in bremsstrahlung alone does not describe the ratio of np/pp

Backup

Results obtained from Ar-KCl run



The HADES spectrometer

- **Detector geometry**

full azimuthal range covered, 6 sectors
polar angle: 16°<θ<84°

- **Tracking**

Superconducting coils, toroidal field
24 Mini Drift Chambers

- **Particle identification (e, p, K, p)**

RICH, MDC, TOF, TOFINO, Shower (RPC)

- **Resolutions**

ΔMω/Mω ~ 2.1% at ω peak
Δp/p ~ 2-3% for proton and π

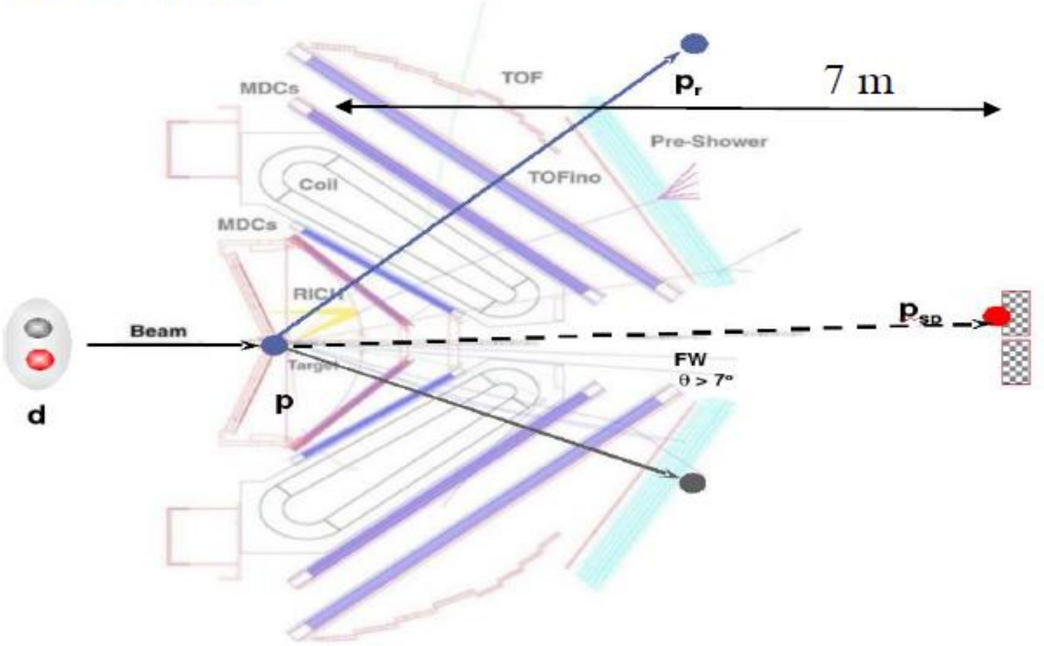
- **Forward Wall:**

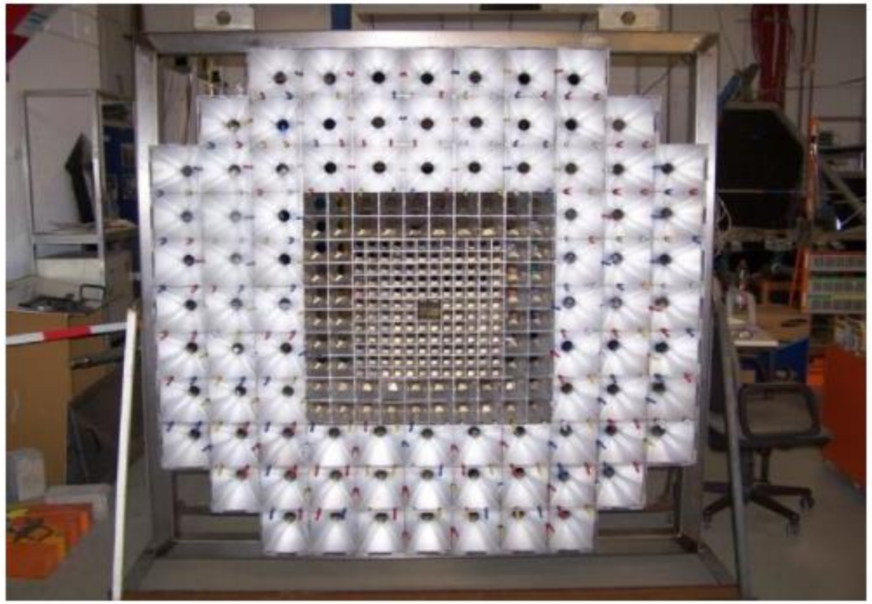
Plastic scintillators covering θ angles up to 7°
Detector dedicated to tag proton spectator

- **Cells in FW:**

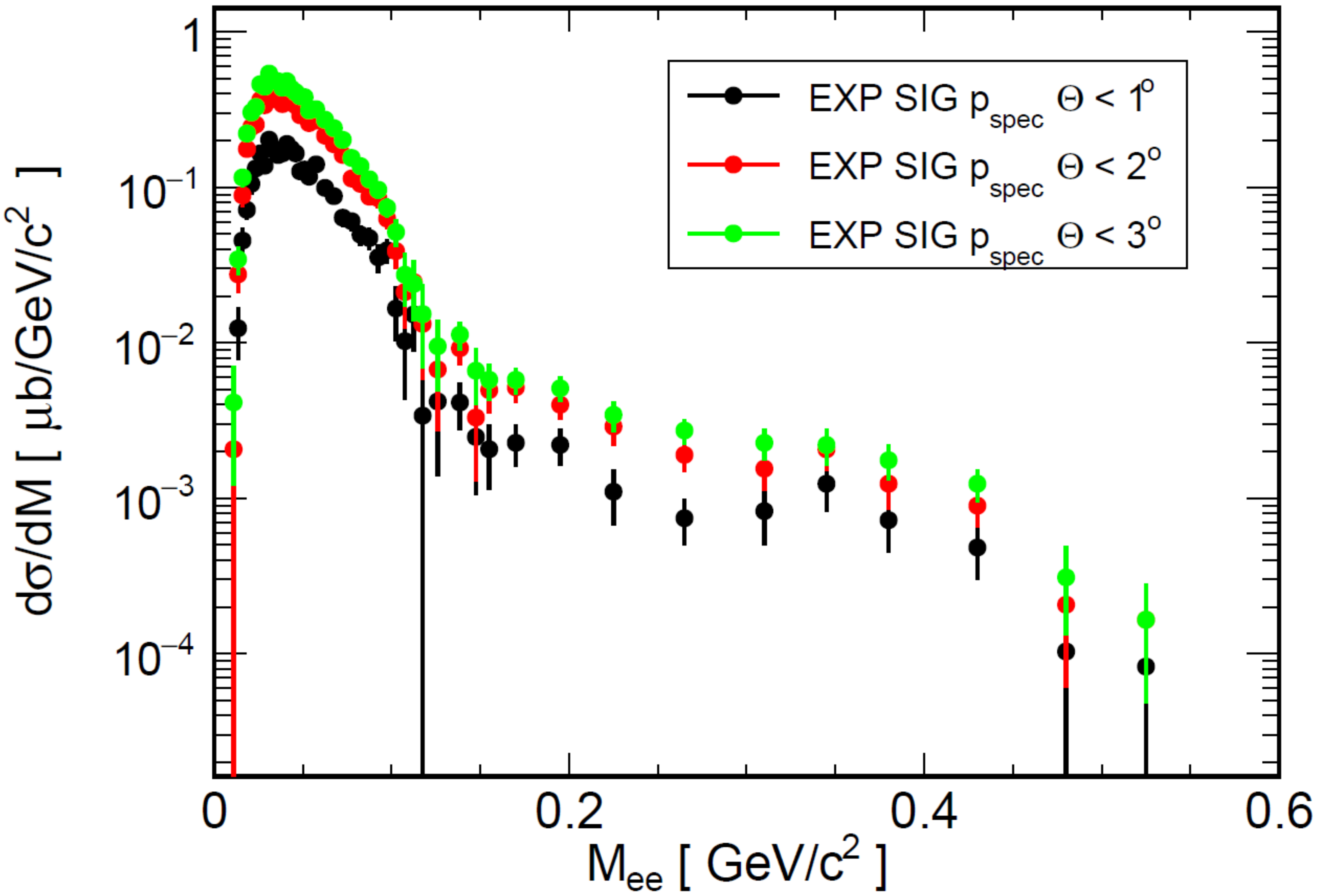
140 small 4x4cm → (0°< θ <2 °)
64 middle 8x8cm → (2 °< θ <3.3 °)
84 large 16x16cm → (3.3 °< θ <7.2 °)

Designed for di-electron spectroscopy, also suited for the charged hadron detection

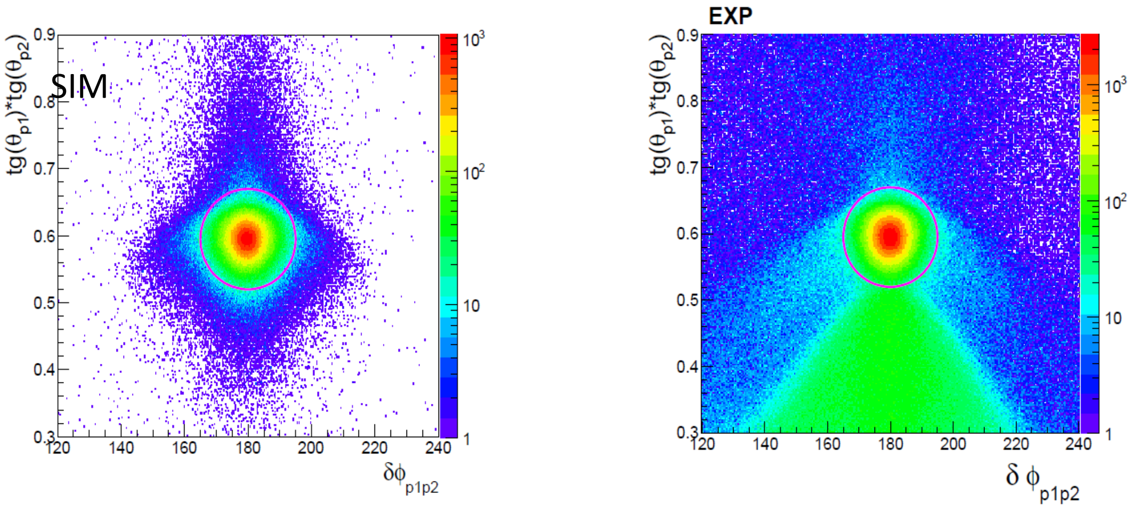




Exclusive invariant mass distributions for various p_spec angles



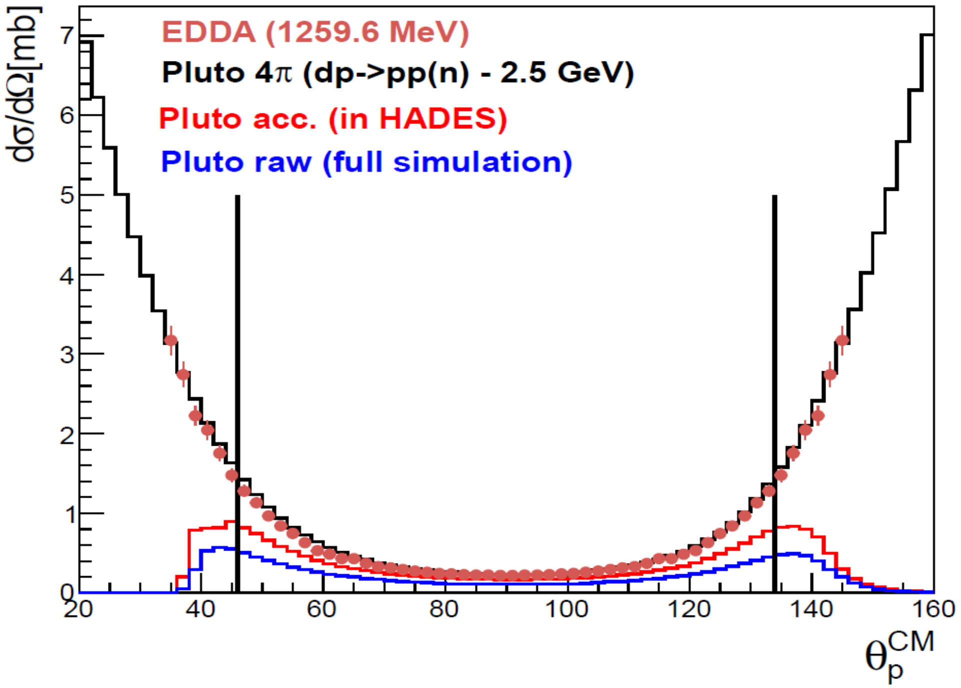
Normalization of HADES data in n-p collisions



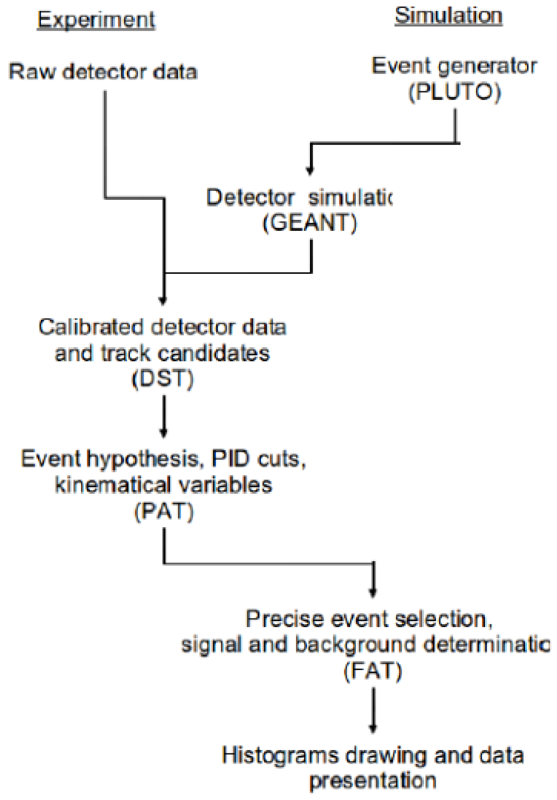
Selection of pp elastic events measured simultaneously by HADES based on angular correlation

- ✓ acceptance and efficiency corrections in the angular range 46° $<\Theta_{CM}<$134°
- ✓ normalization to the known cross section from the EDDA experiment in the same angular range

K= σ_{el}/N_{el} = (2,95 ±0,25)*10^{-9} mb/counts
normalization factor
applied to the measured yield



Selected channels for simulation : **resonance model**



lp.	channel	cr. sect.	br. ratio
1.	$d\,p \Rightarrow p_{sp}\,n\,\Delta^+ \Rightarrow p_{sp}\,n\,p\,\pi^0 \rightarrow p_{sp}\,n\,p\,\gamma\,e^+\,e^-$	$3.67mb$ [59]	0.012
2.	$d\,p \Rightarrow p_{sp}\,p\,\Delta^0 \Rightarrow p_{sp}\,p\,n\,\pi^0 \rightarrow p_{sp}\,p\,n\,\gamma\,e^+\,e^-$	$3.67mb$ [59]	0.012
3.	$d\,p \Rightarrow n_{sp}\,p\,\Delta^+ \Rightarrow n_{sp}\,p\,p\,\pi^0 \rightarrow n_{sp}\,n\,p\,\gamma\,e^+\,e^-$	$3.67mb$ [59]	0.012
4.	$d\,p \Rightarrow p_{sp}\,p\,\Delta^0 \rightarrow p_{sp}\,p\,n\,e^+\,e^-$	$5.54mb$ [59]	$4.82 \cdot 10^{-5}$
5.	$d\,p \Rightarrow p_{sp}\,n\,\Delta^+ \rightarrow p_{sp}\,n\,p\,e^+\,e^-$	$5.54mb$ [59]	$4.93 \cdot 10^{-5}$
6.	$d\,p \Rightarrow n_{sp}\,p\,\Delta^+ \rightarrow n_{sp}\,p\,p\,e^+\,e^-$	$5.54mb$ [59]	$4.94 \cdot 10^{-5}$
7.	$d\,p \Rightarrow p_{sp}\,n\,p\,\eta \rightarrow p_{sp}\,n\,p\,\gamma\,e^+\,e^-$	$13.6\mu b$ [38]	$5.86 \cdot 10^{-3}$
8.	$d\,p \Rightarrow p_{sp}\,d\,\eta \rightarrow p_{sp}\,d\,\gamma\,e^+\,e^-$	$23.9\mu b$ [38]	$5.82 \cdot 10^{-3}$
9.	$d\,p \Rightarrow n_{sp}\,p\,p\,\eta \rightarrow n_{sp}\,p\,p\,\gamma\,e^+\,e^-$	$2.33\mu b$ [38]	$5.84 \cdot 10^{-3}$
10.	$d\,p \Rightarrow p_{sp}\,n\,p\,e^+\,e^-$	$1.48\mu b$ [17]	1
11.	$d\,p \Rightarrow p_{sp}\,p\,N^0(1520) \Rightarrow p_{sp}\,p\,n\,\rho \rightarrow p_{sp}\,p\,n\,e^+\,e^-$	$8.91\mu b$ [63]	$8.12 \cdot 10^{-4}$
12.	$d\,p \Rightarrow n_{sp}\,p\,N^+(1520) \Rightarrow n_{sp}\,p\,p\,\rho \rightarrow n_{sp}\,p\,p\,e^+\,e^-$	$8.91\mu b$ [63]	$8.12 \cdot 10^{-4}$
13.	$d\,p \Rightarrow p_{sp}\,d\,\rho \rightarrow p_{sp}\,d\,e^+\,e^-$	$6.40\mu b$ [63]	$8.12 \cdot 10^{-4}$
14.	$d\,p \Rightarrow p_{sp}\,d\,\gamma^* \Rightarrow p_{sp}\,d\,e^+\,e^-$	$41.7nb$ [60]	1