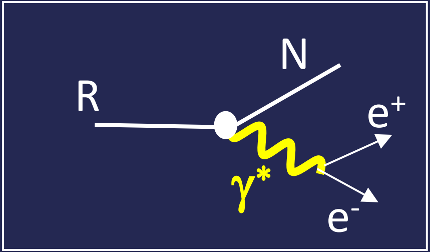
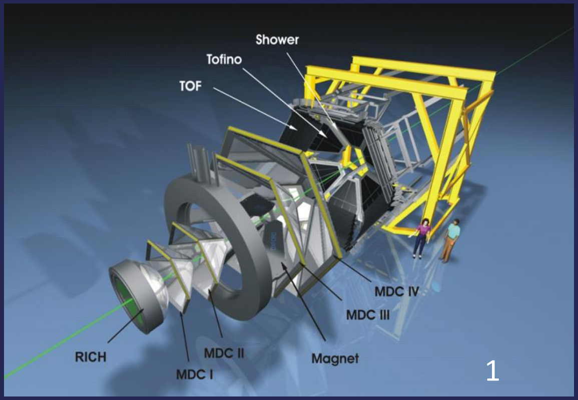
Studying Time-like electromagnetic Baryonic Transitions with HADES

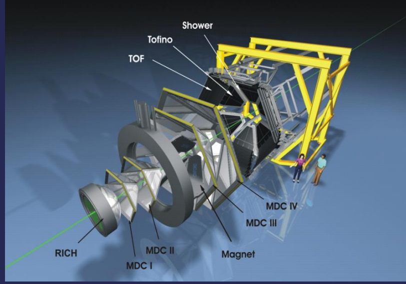
Béatrice Ramstein, IPN Orsay, France
for the HADES collaboration

Workshop of the APS Group on Hadronic Physics, Washington DC



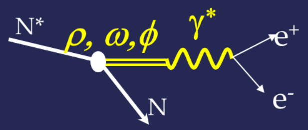


Outline



- **Introduction:**
  Motivations of measuring e^+e^- emission with HADES at GSI

- **Results from pp reactions**
  Sensitivity of e^+e^- emission to the electromagnetic structure of baryonic resonances

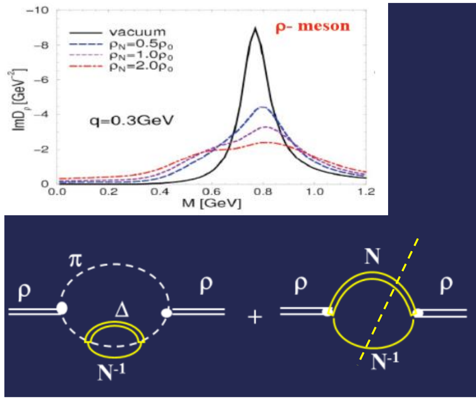


- **Results obtained with the GSI pion beam**
  $\pi^+\pi^-$, e^+e^- production

- **Conclusions**

HADES experimental program: e^+e^- production

Constrain interpretation of in-medium dilepton spectra by elementary processes



hadronic matter studies:

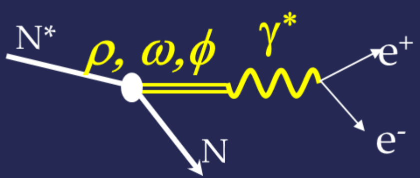
- A+A (E/A<2 GeV), p+A (E<3.5 GeV), π+A (0.5<E<1.6 GeV) (SIS18)
- Study modifications of in-medium vector meson spectral functions
- depends on ρNN* coupling - main players: N(1520), Δ (1620), N(1720)

Elementary reactions: p+p, d(n)+p, π+p

Inclusive e^+e^- production: reference spectra

Dilepton exclusive channels e.g. $pp \rightarrow ppe^+e^-$, $\pi^-p \rightarrow ne^+e^-$

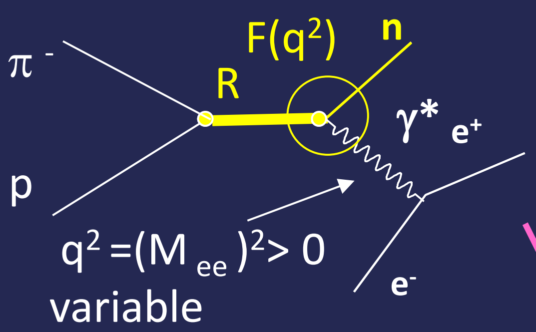
- Dalitz decay of baryonic resonances $R \rightarrow Ne^+e^-$
- Sensitivity to Time-like electromagnetic structure
- Role of Vector Meson Dominance

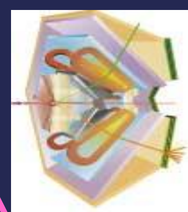


Electromagnetic baryonic transitions in Time-Like and Space-Like region:
towards a global picture ?

Time-Like electromagnetic form factors

No data

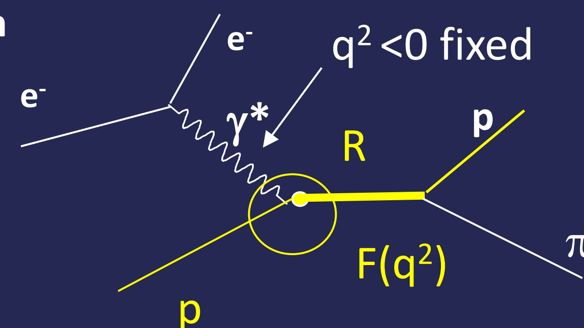


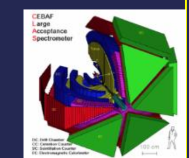


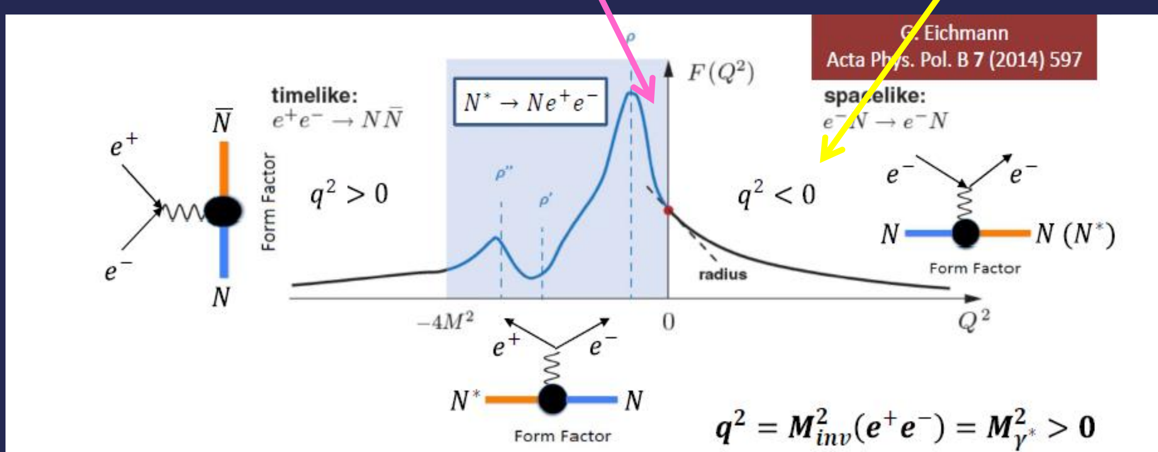
Inverse pion electroproduction

Space-Like electromagnetic form factors

Precise data from JLab/CLAS up to $-q^2=4$ GeV^2



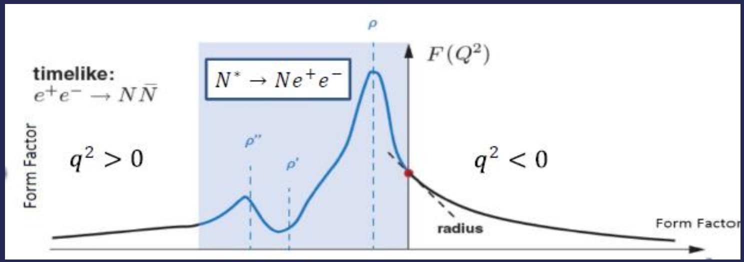




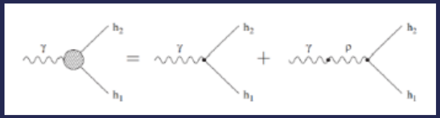
Workshop
« Space-Like and Time-like electromagnetic baryonic transitions »
8-12 May 2017, Trento
P. Cole, B. R., A. Sarantsev

Time-like form factor models

Models: fitted to space-like ($q^2 \leq 0$) form factors data analytically continued to time-like region ($q^2>0$)



- Two-component model (direct coupling+VDM)



Zetenyi and Wolf, Phys. Rev. C 86 (2012) 065209

- e-VDM model *M. Krivoruchenko, Ann. Phys. 296 (2002) 299*

Currently being extended (work in progress) to recent
- SL transition FF data (CLAS)
- ρ/ωNN* couplings (PWA)

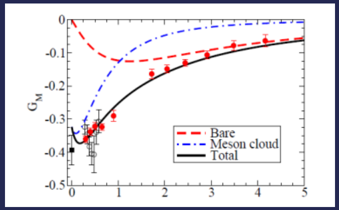
- constituent quark-core+ meson cloud

existing for N-Δ(1232) and N-N(1520)

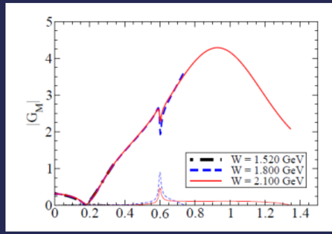
G. Ramalho, T. Pena Phys.Rev. D85 (2012), 113014

G. Ramalho, T. Pena Phys.Rev. D95 (2017), 014003

Space Like



Time Like



HADES

High Acceptance DiElectron Spectrometer at GSI, Darmstadt

Acceptance: **Full azimuth, polar angles 18° - 85°**

Particle identification: e^+/e^-, π^+/π^-, K^+/K^-, p

RICH, Time Of Flight, Pre-Shower (pad chambers & lead converter) (also MDC ($K^\pm$))

Trigger:

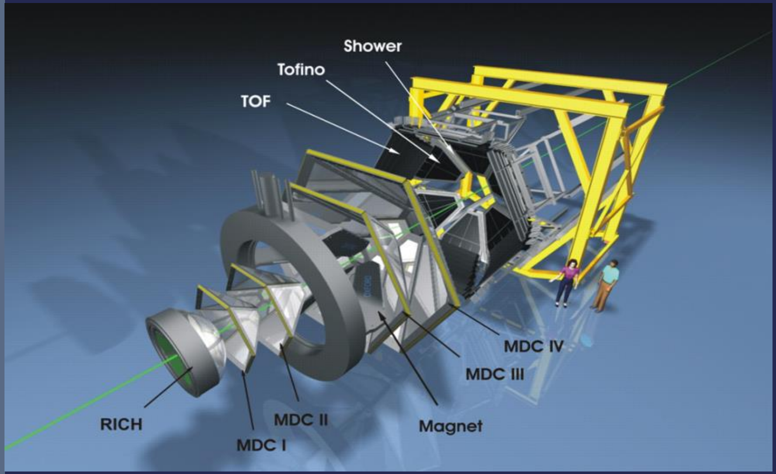
~ 50 kHz

Momentum measurement

Magnet: $\int Bdl$ = 0.1- 0.34 Tm

MDC: 24 Mini Drift Chambers

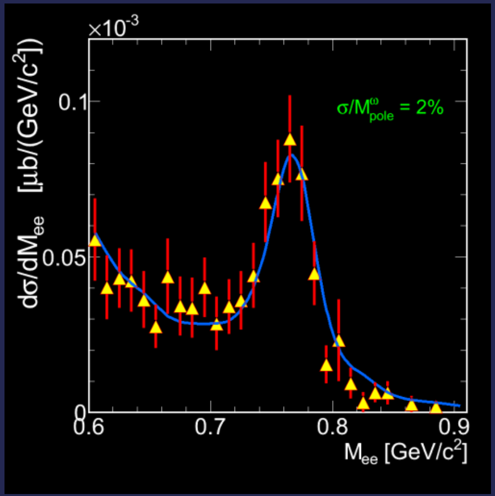
Leptons: Δx~ 140 μ per cell, $\Delta p/p$ ~ 1-2 %



$\Delta M/M$ ~ 2% at ω peak

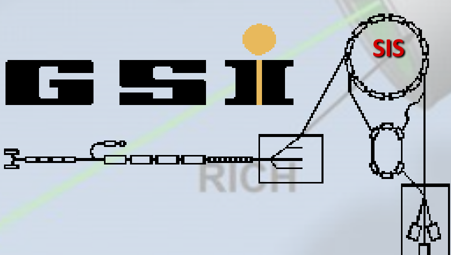
- ✓ **Electromagnetic Calorimeter**
- ✓ **Forward Detector (0.5-7°)**

to be ready in 2018



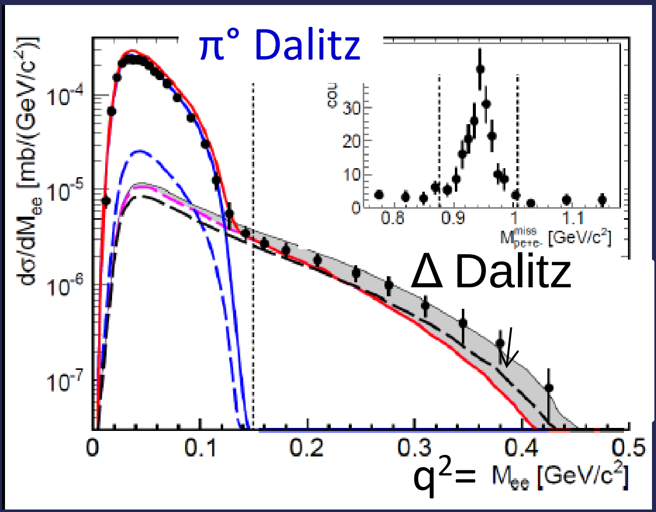
The Collaboration

- Cracow (Univ.), Poland
- Darmstadt (GSI), Germany
- Dresden (FZD), Germany
- Dubna (JINR), Russia
- Frankfurt (Univ.), Germany
- Giessen (Univ.), Germany
- Jülich (FZJ), Germany
- Milano (INFN, Univ.), Italy
- München (TUM), Germany
- Moscow (ITEP,MEPhI,RAS), Russia
- Nicosia (Univ.), Cyprus
- Orsay (IPN), France
- Rez (CAS, NPI), Czech Rep.
- Sant. de Compostela (Univ.), Spain
- Wuppertal (BUG), Germany
- Coimbra (Univ.), LIP, Portugal



Time like baryon electromagnetic transitions in pp reactions

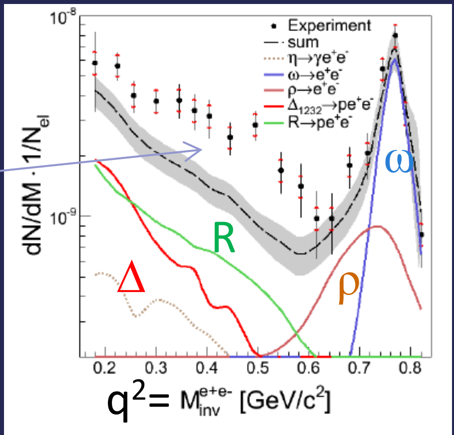
- pp$\rightarrow$ppe$^+$e$^-$ E=1.25 GeV

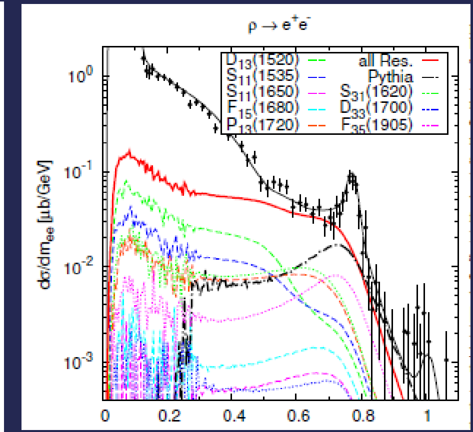


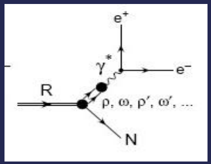
✓ Δ production cross section deduced from PWA of one pion production channels
G. Agakishiev et al., Eur. Phys. J. A 51 (2015) 137.
✓ first measurement of Δ(1232) Dalitz decay branching ratio BR($\Delta \rightarrow$ pe$^+$e$^-$) =
(4.19 $\pm$ 0.42 (model) $\pm$ 0.46 (syst.) $\pm$ 0.34 (stat.)) 10^{-5}.

- pp$\rightarrow$ppe$^+$e$^-$ E=3.5 GeV

✓ Cocktail of point-like baryonic resonances from 1π production
✓ Evidence of VDM-type form factors (coupling to ρ)
G. Agakishiev et al. Eur.Phys.J. A50 (2014) 8

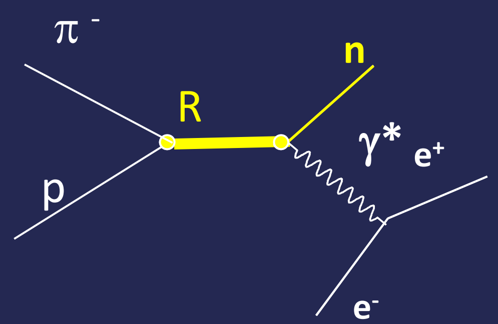






J. Weil, et al., EPJA 48, 111 (2012)

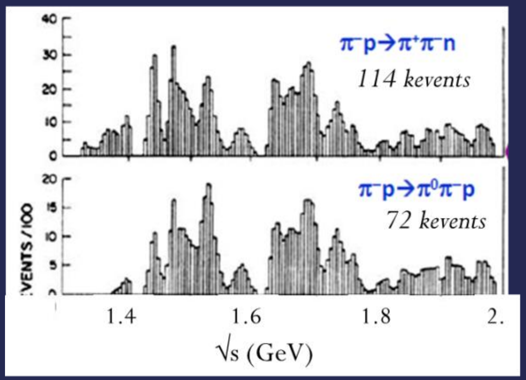
Interest of πN reaction study



Electromagnetic channels

- Exclusive $\pi^- p \rightarrow n\, e^+e^-$ can be easily selected
- Resonance produced in s-channel with fixed mass $=\sqrt{s}$
  (less overlapping contributions then in pp)
- πN interaction better controlled than pp
- Imputs from pion photo/electro-production can be used

SAID, data base, CNS, GWU http://gwdac.phys.gwu.edu



Hadronic channels:

- Very poor data base for pion beam data
- New data needed to advance knowledge in baryon

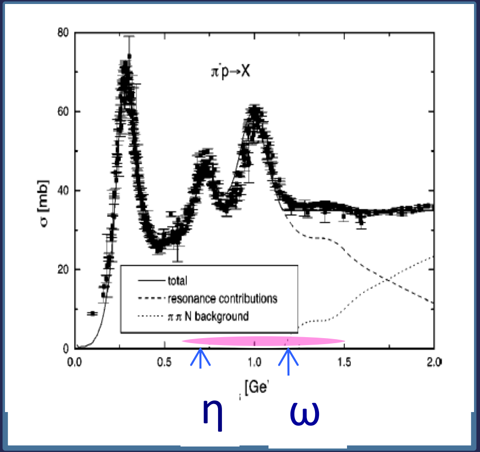
and meson spectroscopy (J-PARC, projects of meson beam Facilities *W. J. Briscoe et al., Eur. Phys. J. A51 (2015) no.10, 129*)

Pion beam at GSI

GSI pion beam

momentum 0.6 < p <1.5 GeV/c

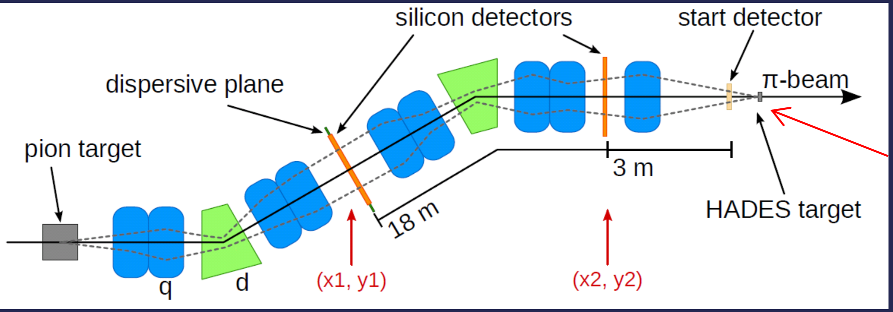
pion flux ~ 10^6/s at 1 GeV/c

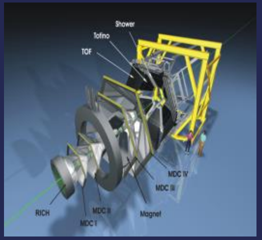


Pion beam tracker

Diamond detectors

HADES





2 Double-Sided Silicon sensors

100 x100mm², 300µm thick

2 x128 channels

Pion momentum acceptance σ=2%

Resolution $\Delta p/p < 0.3\%$

Pion beam experiment with HADES

2014 experiment: Limited beam time +intensity

Use of Polyethylene $(CH_2)_n$ and Carbon targets

Motivations: investigate the N(1520) region

- ✓ $\pi^+ \pi^-$ and $\pi^- \pi^\circ$ production in an energy scan (4 measurements $\sqrt{s}$ =1.46-1.55 GeV/c^2)

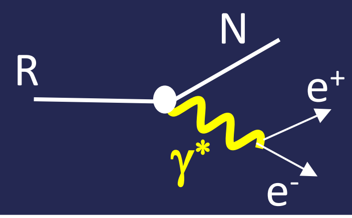
  Improve database for baryon spectroscopy: $2\pi N = \rho N, \sigma N, \pi\Delta$ branchings

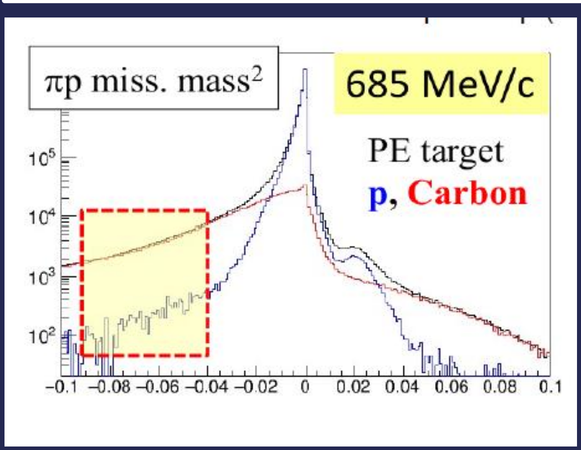
- ✓ e^+e^- production $\sqrt{s}$ =1.49 GeV/c^2

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

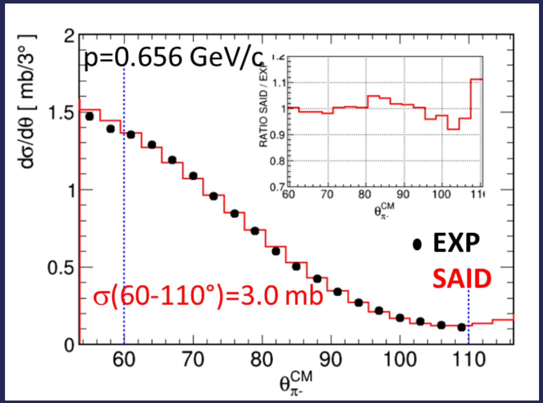
  (Link to time-like transition electromagnetic structure)

  No existing data





Subtraction of C contribution
and
Normalisation using
π^-+p elastic scattering

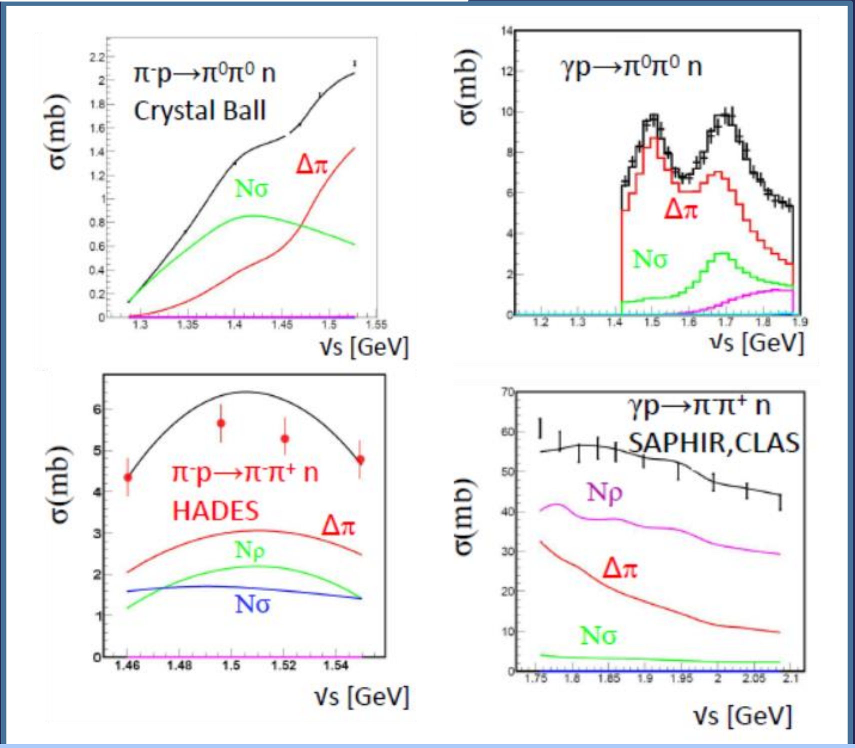


Bonn-Gatchina Partial Wave Analysis in 2π production channels

- ✓ collaboration with A. Sarantsev
- ✓ 4 data samples from HADES ($\pi^- p \to n\pi^+\pi^-$ and $\pi^- p \to p\pi^0\pi^-$)
- + photon and pion data base

$2\pi^0$ channels:
dominant contribution are $\Delta\pi$ and $N\sigma$ ($2\pi^0$ in i=0)
ρ does not contribute

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



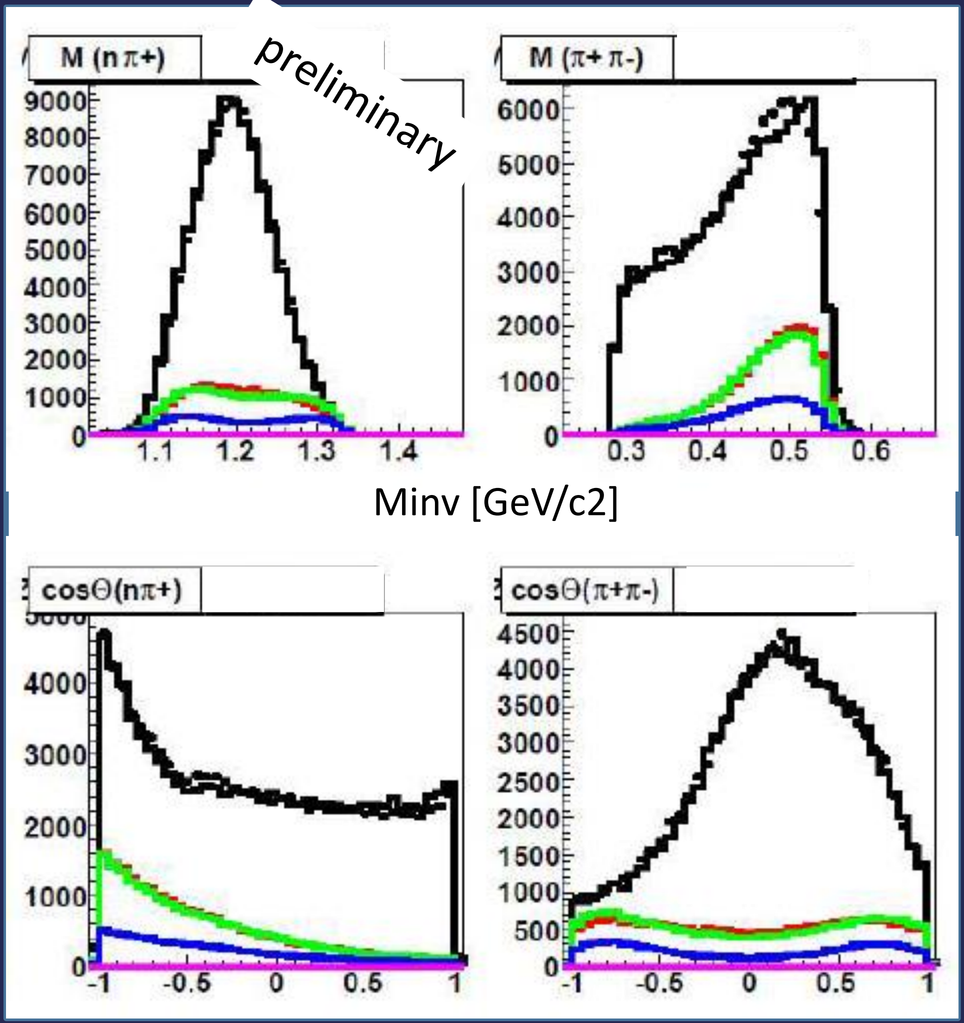
Only N(1520) and N(1440) play a significant role around $\sqrt{s}$=1.5 GeV
New HADES data are crucial for the determination of the ρ contribution
Still no data on ρ between 1.54 and 1.75 GeV/c^2 (part of HADES future program)

Bonn-Gatchina PWA: HADES data

One example for
p_{π}=685 MeV/c

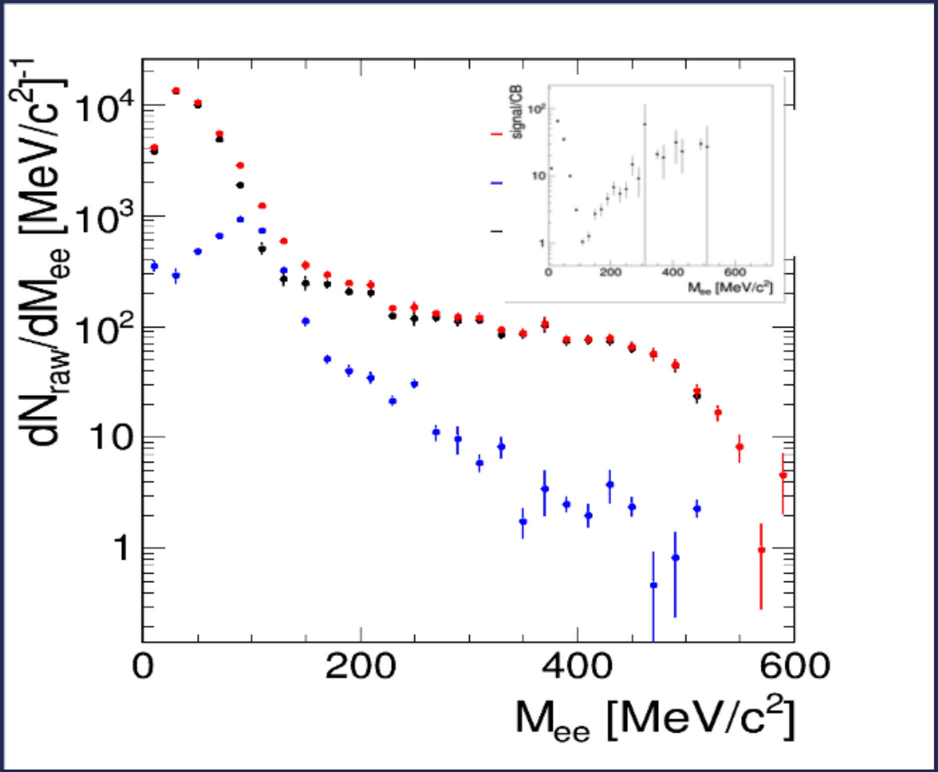
ρ **total**
ρ **in s-channel**
ρ **from D13(1520)**

Preliminary results
- **ρ production: σ ~2.3 mb**
- **N(1520): ρN coupling ~ 17% (PDG 15-25%)**



Analysis of e^+e^- channels

Raw e^+e^- invariant mass spectrum



Signal = N_{e+e-} -CB
CB: same-event like-sign pairs

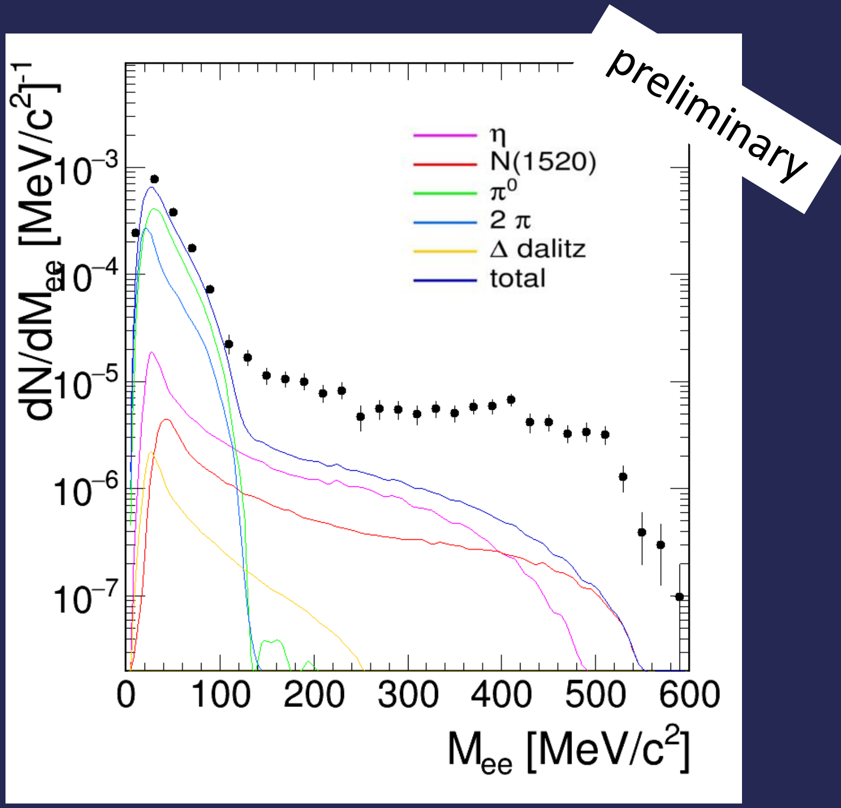
CB rejection cuts:
Tracking optimized to reject γ conversion
e^+e^- opening angle > 9°

Signal (M<140 MeV/c^2) = **13138**
Signal (M>140 MeV/c^2) = **3300**

Efficiency corrections based on GEANT simulations

Measurement on CH2 target: $(d\sigma_{/}dM)_H+0.5\ (d\sigma_{/}dM)_C$
$\sigma_C \sim 4\ \sigma_H$

Inclusive e^+e^- production



PLUTO event generator

Fröhlich et al, POS (2007) 076

π^-p:

- Meson production: Landolt-Börnstein

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

- « N(1520) »: Point-like baryonic contribution

cross section from from $\gamma n \rightarrow \pi^- p$

e^+e^- distribution as $N(1520)^0 \rightarrow Ne^+e^-$

π^-C:

- quasi-free process (momentum distr. of

nucleons taken into account) scaled to $\sigma_C/\sigma_H \sim 4$

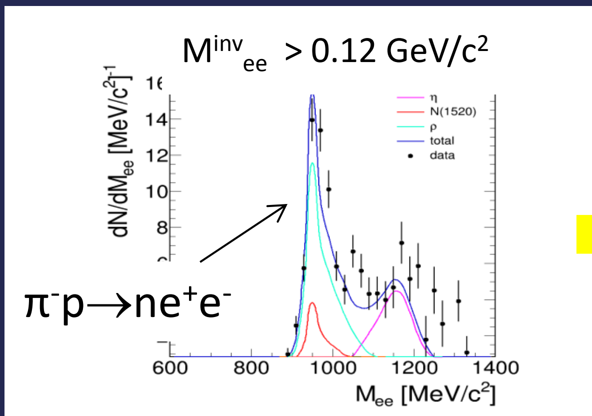
Simulations filtered by acceptance

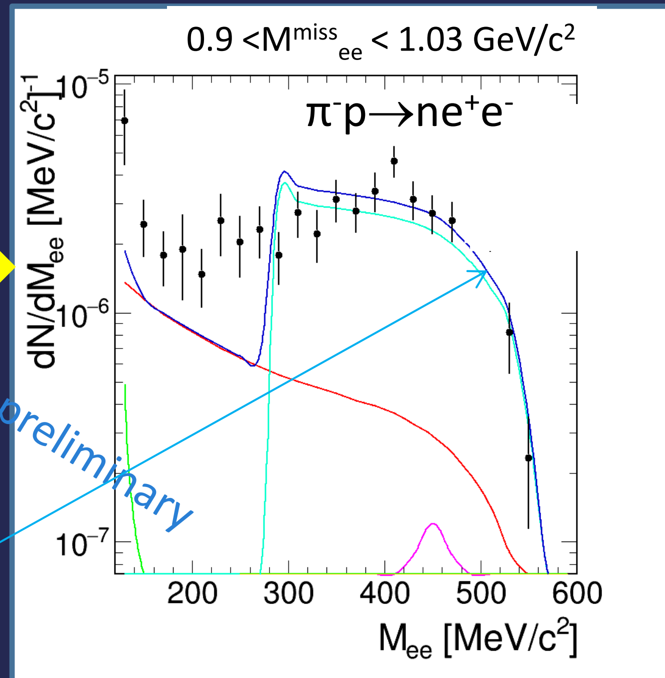
- Cocktail of point-like sources

underestimates the e^+e^- yield at high invariant mass

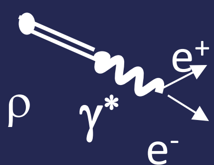
- Strong η contribution

Exclusive ne^+e^- channel with pion beams:

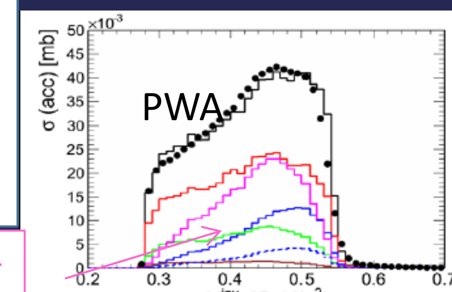




Total
$\pi^0 \to e^+e^-\gamma$
$\eta \to e^+e^-\gamma$
$N(1520) \to n e^+e^-$



$\rho \to e^+e^-$



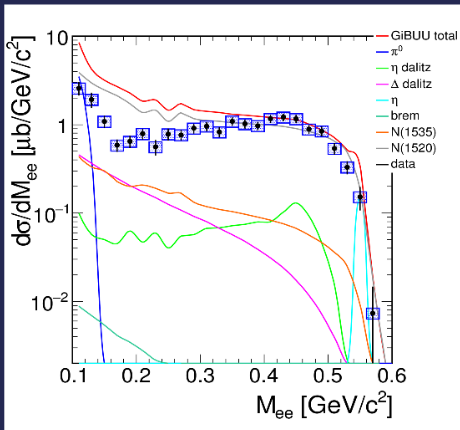
$M^{inv}_{\pi\pi}$ (GeV/c^2)

$\rho \to \pi^+\pi^-$

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

e^+e^- exclusive production: comparison to models

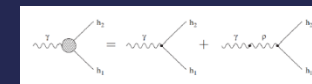


- Cocktails from resonance models (GiBUU)

$N(1520)^0 \rightarrow n\rho \rightarrow ne^+e^-$

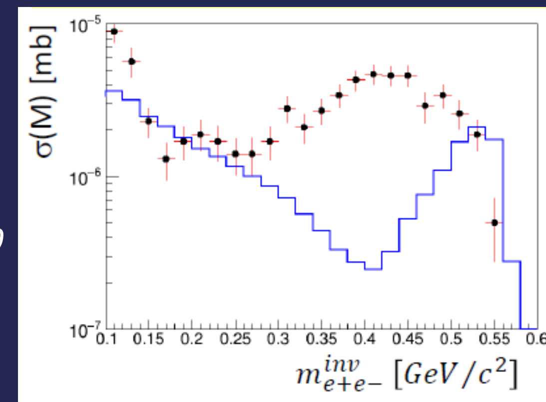
Overestimates contribution at low q^2 (related to too large radiative decay BR ($R \rightarrow N\gamma$) in pure VDM models)

- Lagrangian model : real γ + VDM coupling



Large Born term

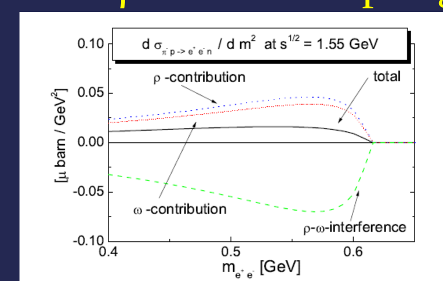
Zetenyi and Wolf
Phys. Rev. C 86 (2012) 065209



- s channel model based on $\rho/\omega NN^*$ couplings

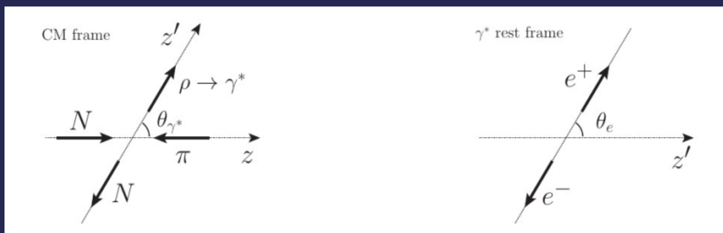
Destructive interference

too low e^+e^- yield



B. Kaempfer , A Titov , R.Reznik NPA 721(2003)583
M. Lutz , B. Friman, M. Soyeur NPA 713 (2003) 97–118

Interest of angular distributions

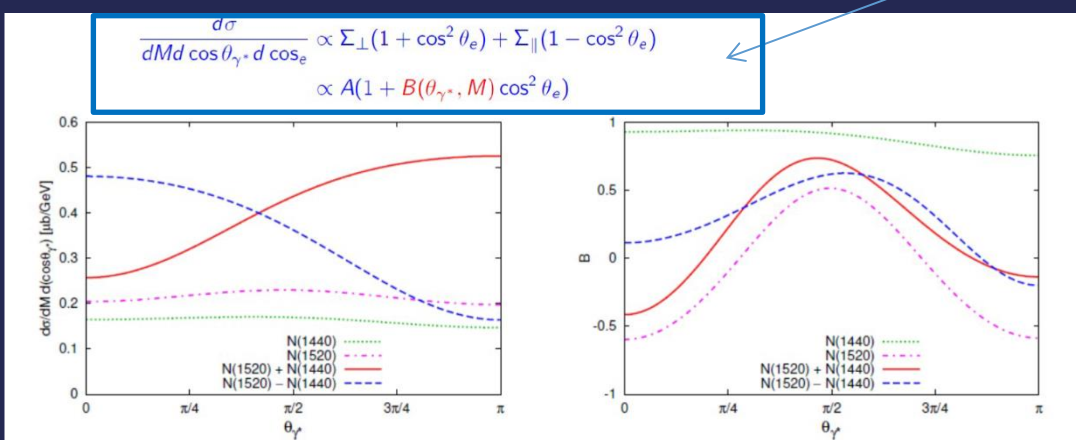


- e^+e^- invariant mass distributions are only sensitive to a linear combination of $|FF|^2$
- Additional information in angular distributions
- γ^* angle in CM: sensitive to the spin structure of the different contributions
- helicity angle: for each contribution, it reflects the electromagnetic structure of the transition

Similarly to polarization in (e,e') scattering

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

Density matrix formalism:



- on-going work to extract coefficients from data
- Low statistics but could provide a detailed information on the electromagnetic structure of the transition

Outlook-Future plans for HADES

pioneering studies with HADES and the GSI pion beam in the N(1520) region…

- ✓ e^+e^- channels : Time-like baryonic transitions
- ✓ 2π channels: baryon spectroscopy

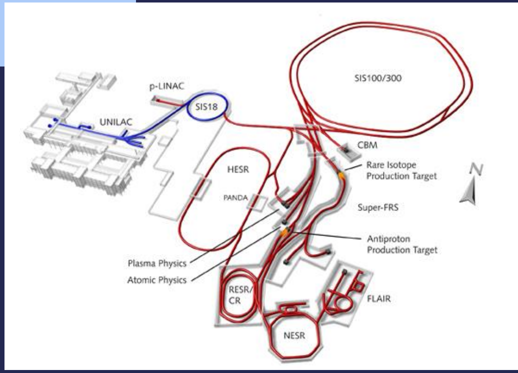
2018: 3-4 year time slot for HADES experiments with beams (p,π, A) at SIS 18 before the start of FAIR

- ✓ Higher statistics measurements + liquid hydrogen target
- ✓ Higher acceptance (Forward Detector)+ Electromagnetic Calorimeter
- ✓ Investigate heavier resonances Δ(1620), N(1720),… in e^+e^- channels and many hadronic channels, e.g. $\pi^- p \rightarrow \eta n$, $K^0\Lambda$, $K\Sigma$,….

- ✓ Electromagnetic decays of hyperons in pp reactions : $Y \rightarrow \Lambda\gamma$, $Y \rightarrow \Lambda e^+e^-$

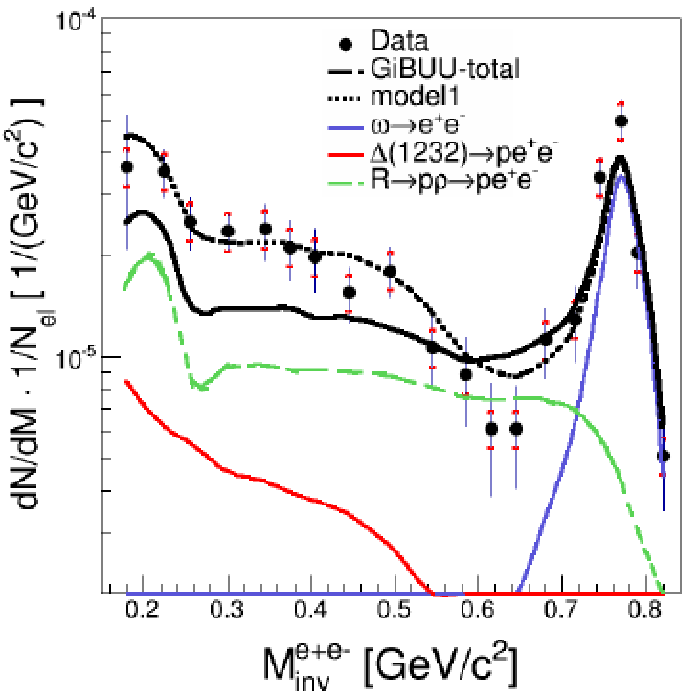
Pave the way for future meson beam facilities
W. J. Briscoe et al., Eur. Phys. J. A51 (2015) no.10, 129

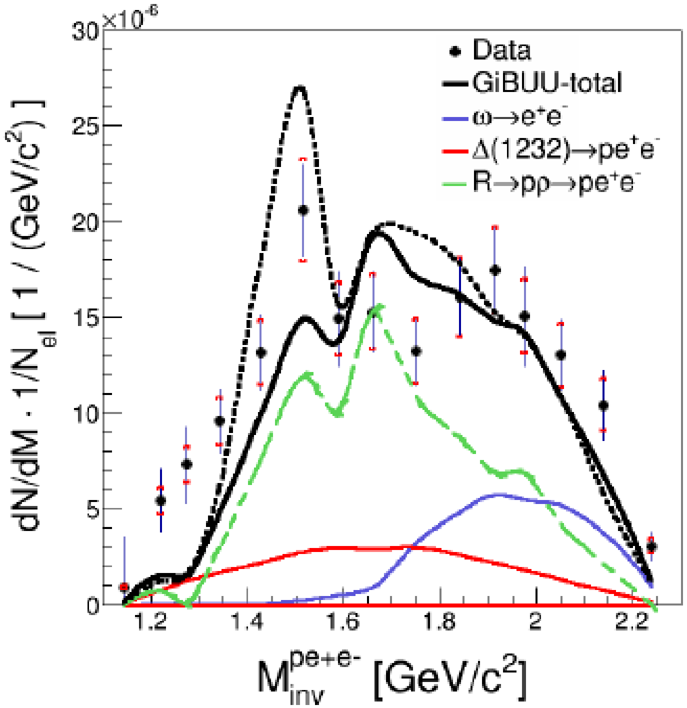
- ➢ After 2022: HADES experiments at FAIR (p and ion beams, possibly pions in future….)



Thank you

p+p @ 3.5 GeV (ρN coupling)





Branching ratios (in percent) for $R \to N\rho$

Resonances	GiBUU	UrQMD	KSU	BG	CLAS
$N^*(1520)$	21	15	20.9(7)	10(3)	13(4)
$\Delta(1620)$	29	5	26(2)	12(9)	16
$N^*(1720)$	87	73	1.4(5)	10(13)	-
$\Delta(1905)$	87	80	< 14	42(8)	-

KSU: M. Shresta, D.M. Manley
Phys. Rev. C86 (2012) 055203

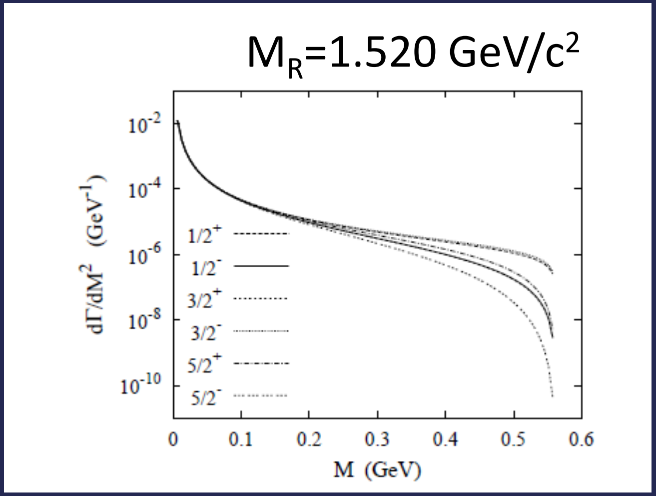
BG: A.V. Anisovich *et al.*
Eur. Phys. J. A48 (2012) 15

CLAS: V. Mokeev *et al.*
Phys. Rev. C86 (2012) 035203

Dalitz decay differential decay width:

$N(1520) \rightarrow Ne^+e^-$

$$\frac{d\Gamma}{dMee^2} = f(M_{ee}{}^2)(|G_E|^2 + 3|G_M|^2 + (M_{ee}/M_R)^2|G_C|^2)$$



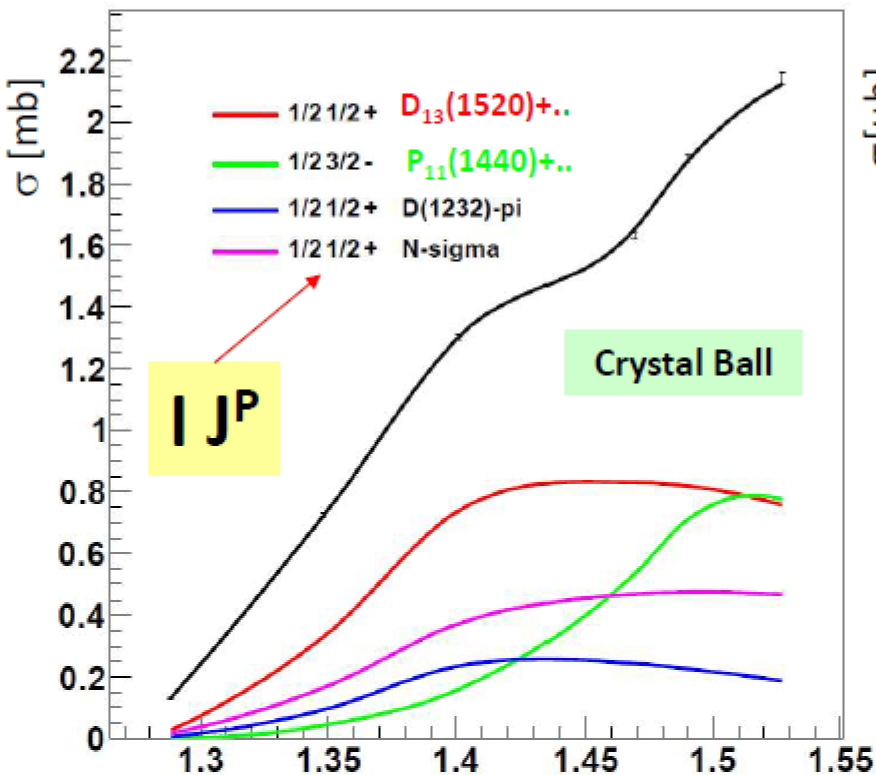
PWA coupled channel analysis

Baryon data base

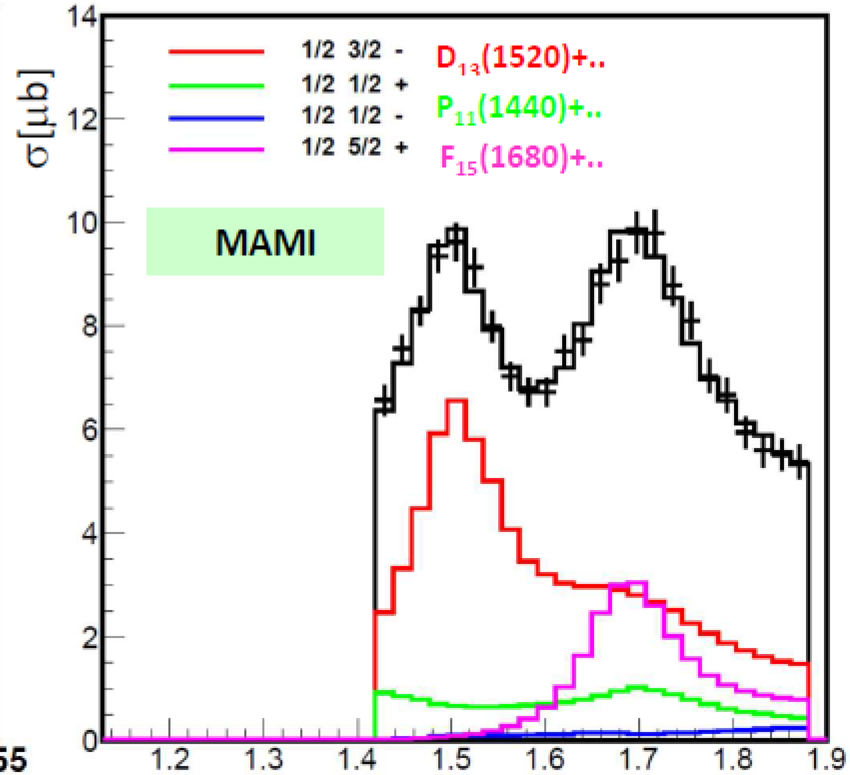
DATA	BG2013-2014	added in BG2014-2015
$\pi N \to \pi N$ ampl.	SAID or Hoehler energy fixed	
$\gamma p \to \pi N$	$\frac{d\sigma}{d\Omega}, \Sigma, T, P, E, G, H$	E, G, T, P (CB-ELSA, CLAS)
$\gamma n \to \pi N$	$\frac{d\sigma}{d\Omega}, \Sigma, T, P$	$\frac{d\sigma}{d\Omega} (MAMI)$
$\gamma n \to \eta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

PWA: initial waves

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

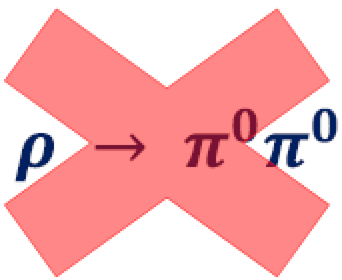


$\gamma p \rightarrow \pi^0 \pi^0 p$



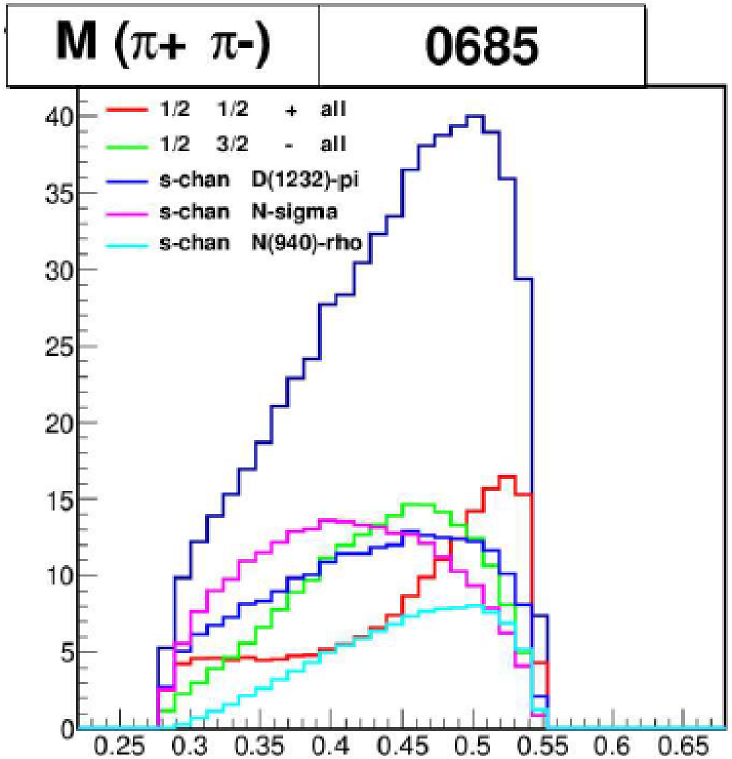
√s [GeV]

in energy range of **1.45 - 1.55 GeV**
in 2-pion production only few resonances
matter: **D_{13}(1520)**, **P_{11}(1440)**

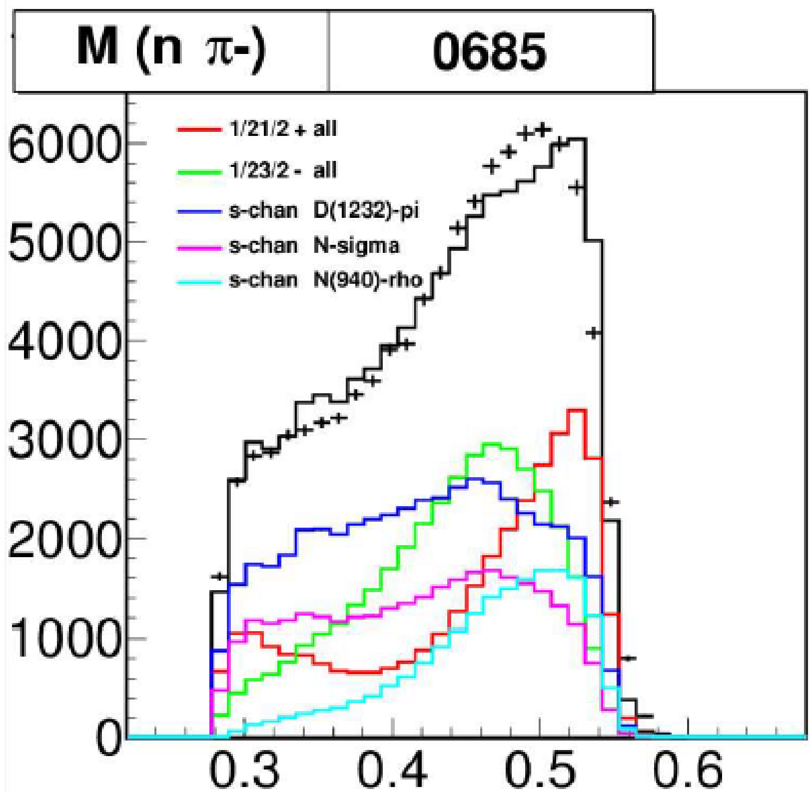


PWA $\pi^+\pi^-$ inv. mass – main contributions

Total cross section (from PWA solution)



Inside HADES acceptance:



INPUT: $D_{13}(1520)$, $P_{11}(1440)$

OUTPUT: $\Delta\pi$, $N\sigma$, $N\rho$

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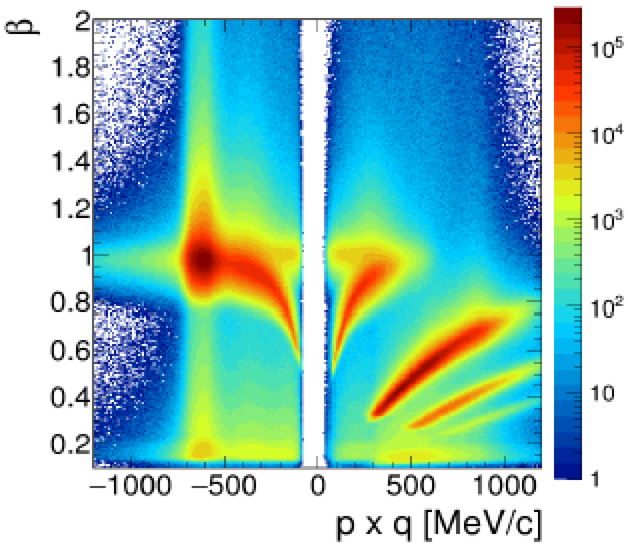
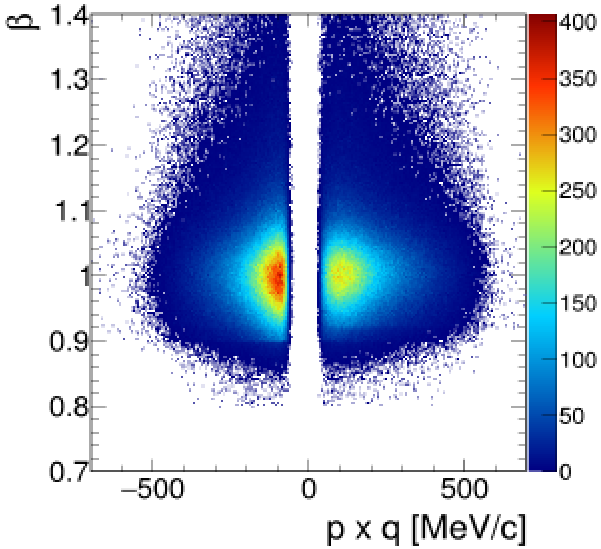
Electron ID

TECHNISCHE UNIVERSITÄT DARMSTADT

- Particle velocity vs momentum
- Track has to be detected in RICH detector





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IPN ORSAY