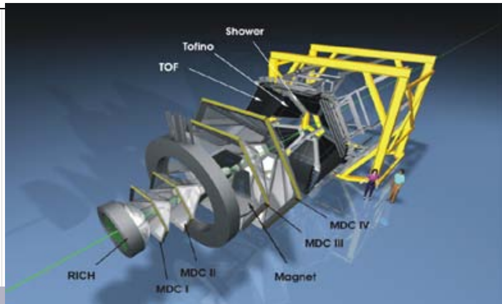
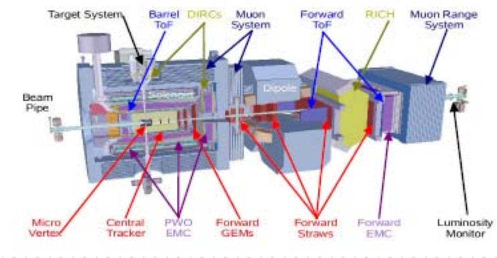




Recent results from HADES and projections for PANDA

Baryon electromagnetic structure studies in the Time-Like region with HADES and PANDA.

B. Ramstein, IPN Orsay

Clermont-Ferrand, 25/01/2013

IPN ORSAY

UNIVERSITÉ PARIS-SUD 11

cnrs dépasser les frontières

In2p3

Outline

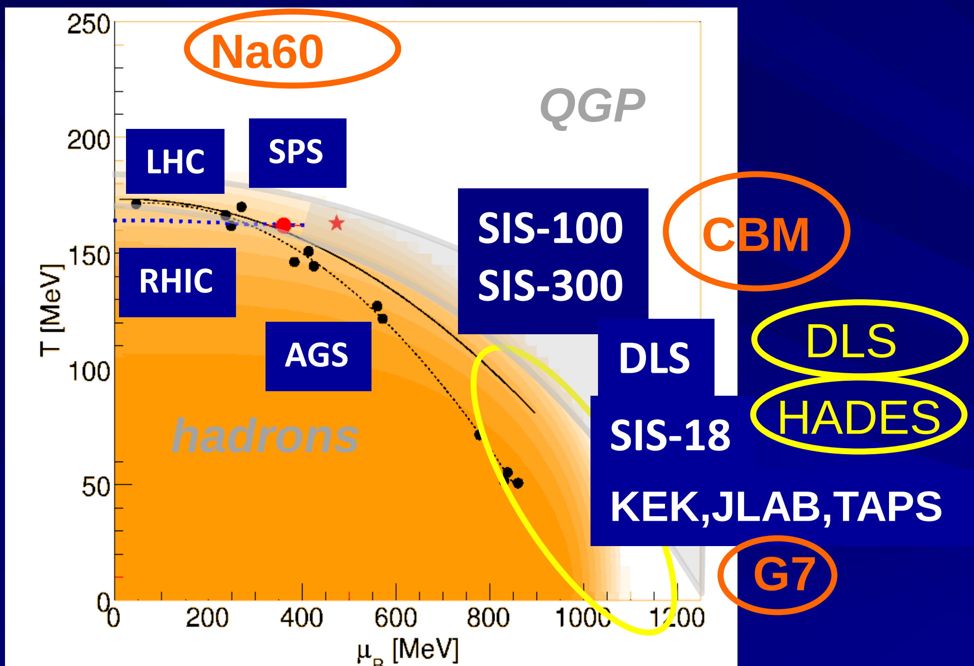
- **Introduction:**
  - **General context of HADES experiments**
  - ***In-medium modifications of vector mesons***
  - **Interest of elementary reactions**

  Sensitivity to electromagnetic Time-Like form factors

- **Results from pp and dp reactions with HADES and a glance at heavy-ion results**
- **Perspectives with the GSI pion beam**
- **Time-Like nucleon Form factor measurements with PANDA**
- **Conclusions**

Motivations of the HADES experiment

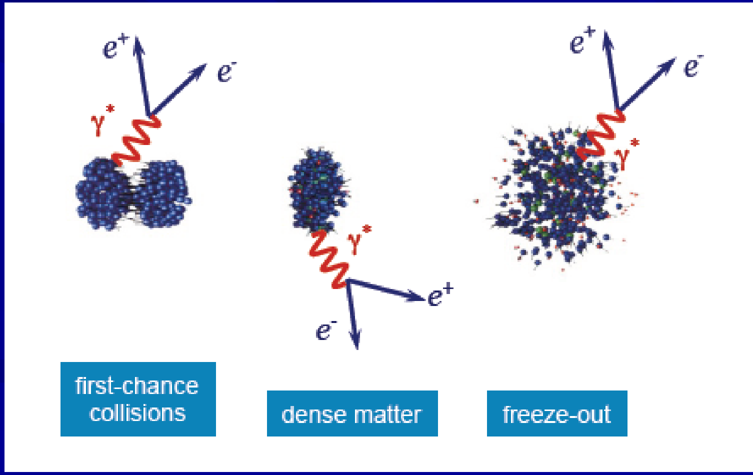
Exploring the phase diagram of hadronic matter…..



E/A=1-2 AGeV

- $\rho/\rho_o \sim$ 1-3, T < 100 MeV
- $N_\pi/A_{part} \approx 10\%$

….. using dilepton emission: rare but undistorted probe



In-medium vector meson modifications:

see e.g. Leupold ,Metag,Mosel Int. J. of Mod. Phys. E19 (2010) 147 for a recent review

Chiral Symetry Restoration

$\rightarrow$ Modifications of hadron masses ?

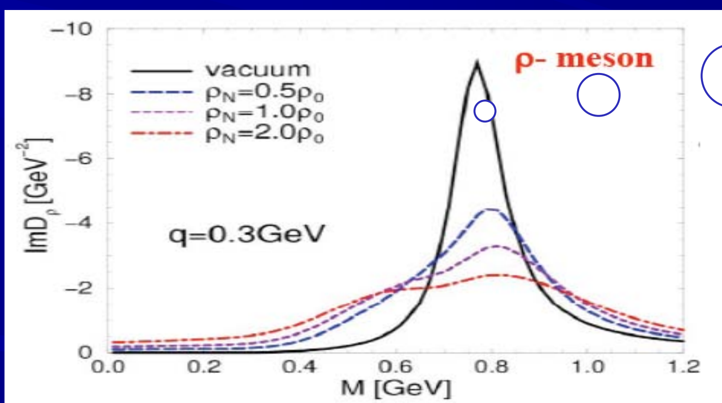
Brown-Rho PRL66(1991) 2720

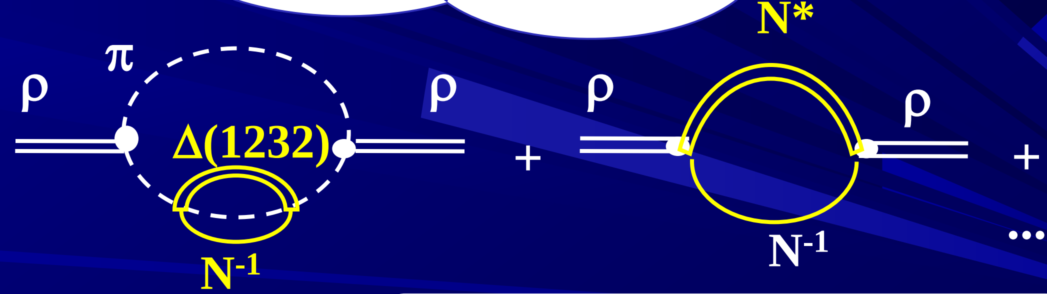
Hatsuda and Lee PRC46 (1992) ***34***

Brown-Rho scaling: $m_V^* = m_V(1 - 0.2\rho/\rho_0)$

« in-medium broadening »

Link to **chiral symetry restoration**
Connexion of vector meson spectral function to quark condensates via **QCD sum rules**





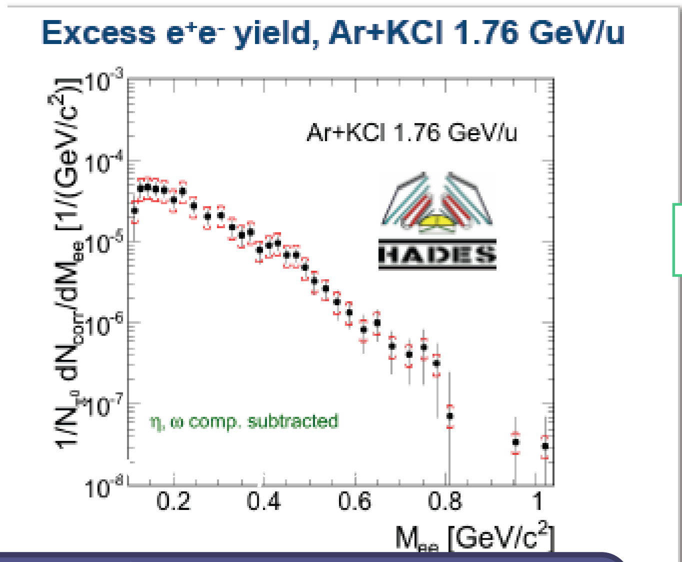
Rapp and Wambach EPJA 6 (1999) 415
Rapp, Chanfray and Wambach NPA 617, (1997) 472

In-medium spectral function depends on ρ NN* coupling

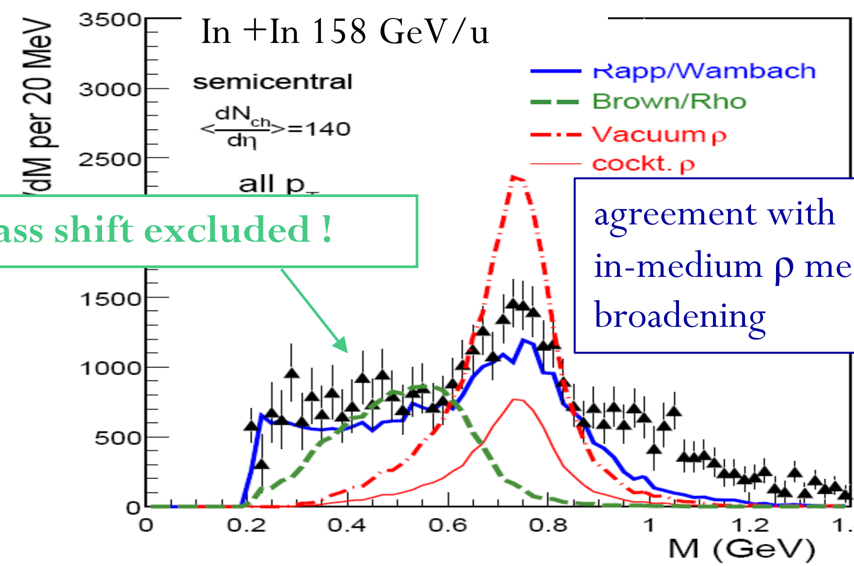
The ρ meson in hot and dense hadronic matter from SIS18 to SPS

Dilepton excess over long-lived sources

G. Agakishiev et al. Phys.Rev. C84 (2011) 014902



Arnaldi et al., PRL 100,022302 (2008)

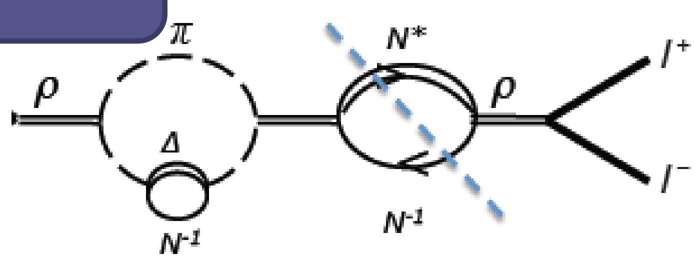


mass shift excluded !

agreement with in-medium ρ meson broadening

Source of ρ mesons at 1-2 AGeV
NN → NR → NNρ
πN → R → Nρ

Depends on RNρ coupling

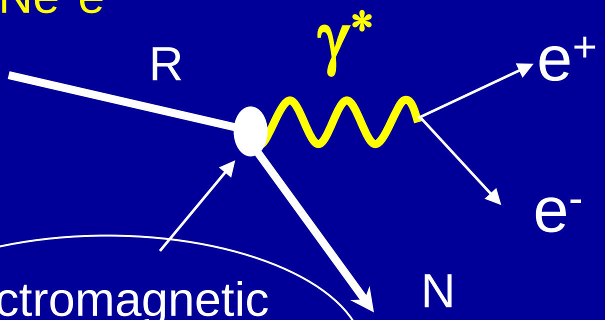


Dominant source of ρ mesons at ultra relativistic energies
$\pi^+\pi^- \rightarrow \rho$

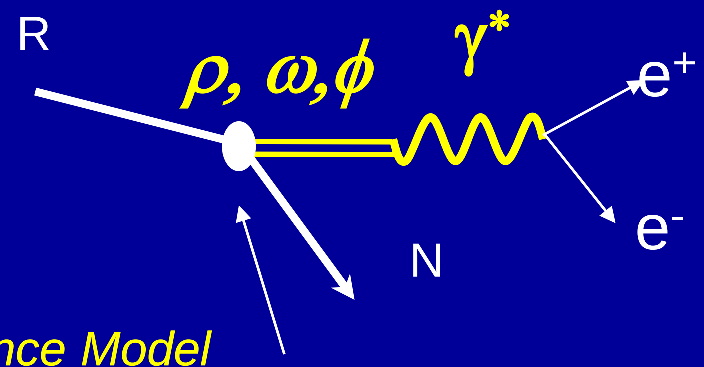
Coupling of ρ to baryonic resonances can be studied in NN collisions at 1-2 GeV

Relation to electromagnetic structure of baryons

Dalitz decay of baryonic resonances
$R \rightarrow N e^+ e^-$



ρ meson production and decay



electromagnetic elastic or transition form factors

Vector Meson Dominance Model

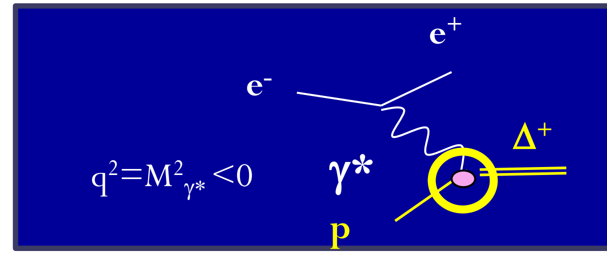
Coupling constants

$q^2 = M^2_{inv}(e^+e^-) = M^2_{\gamma^*} > 0$

q^2 ≥ 0 ***:*** « Time like « region
electromagnetic form factors are unknown !

Baryonic transition electromagnetic form factors in space-Like region

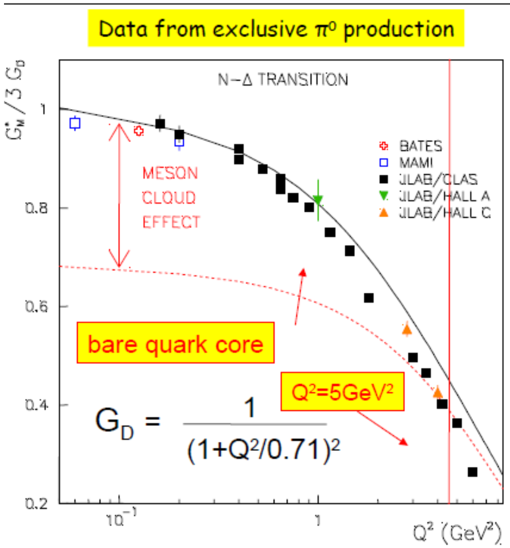
Baryonic electromagnetic form factors are measured for $q^2 \leq 0$



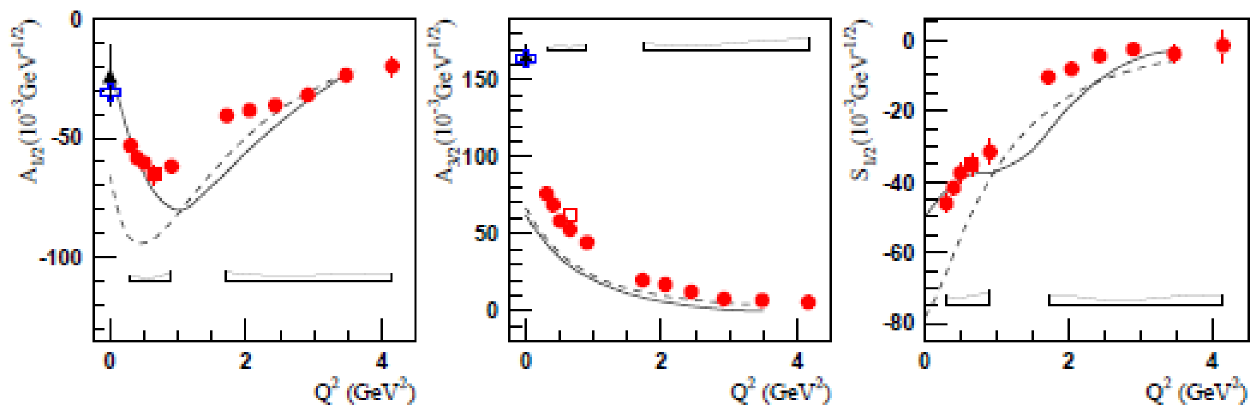
Magnetic form factor for $\gamma^* p \rightarrow \Delta(1232)$

Data: Mainz, Jlab

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



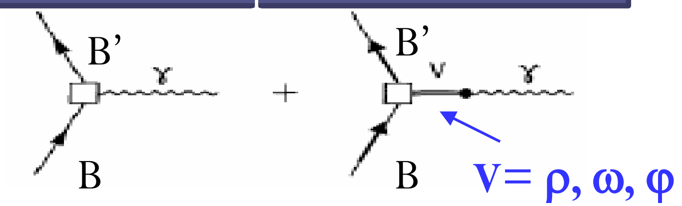
Helicity amplitudes for $\gamma^* p \rightarrow N(1520)$ D_{13} *compared to quark models*



No measurement at $q^2 > 0$ $\rightarrow$ use models fitted on space like data

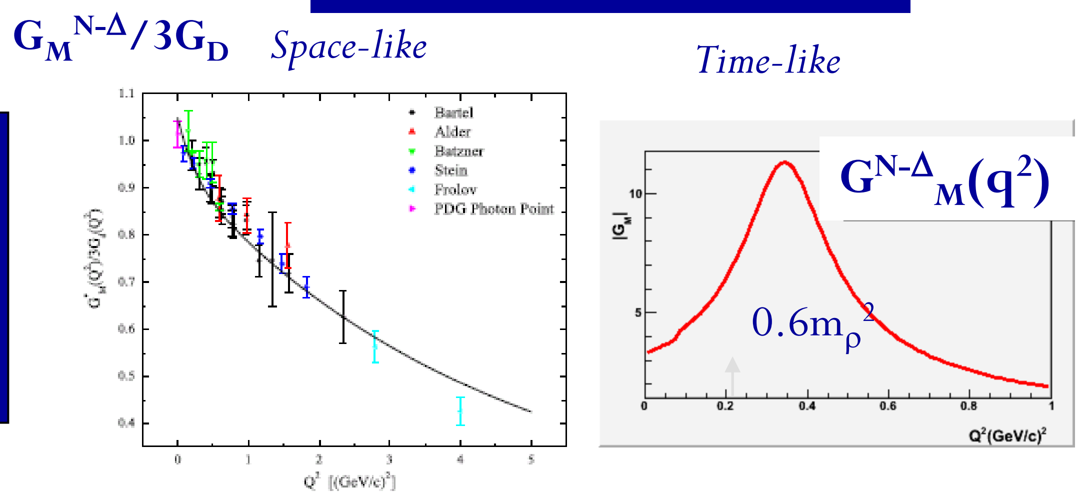
Models for N-Δ magnetic transition form factor in Time-Like region

Two component models



Wan & Iachello, int. J. Mod. Phys. A20(2005) 1846

Emilie Moriniere PHD, Orsay
F. Dorhmann et al , EPJA 45,401(2001)



- ✓ derivation of form factor starting from wave functions
- ✓ analytical continuation to **Time-Like region**
- → **to be tested with HADES**

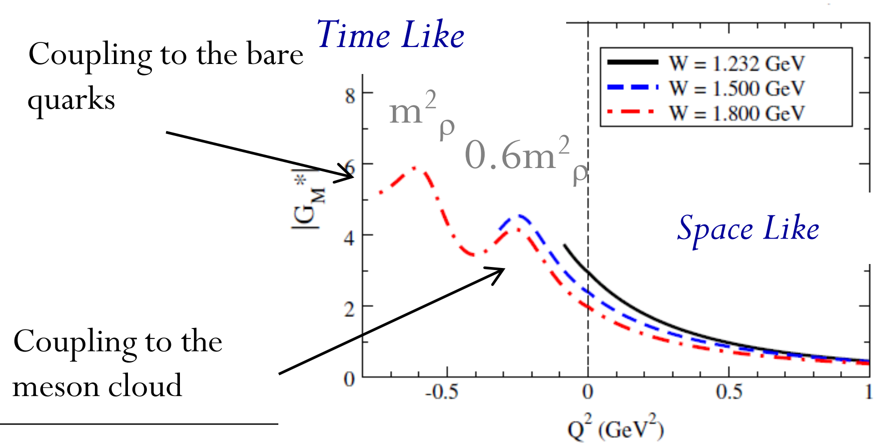
G.Ramalho and T. Pena Phys. ReV. D85,113014 (2012)

Extension to Time-Like region

- ✓ exists for **elastic nucleon form factors**

(to be measured with PANDA)

- ✓ In progress **for higher resonances**



Hades « strategy »

- ✓ **Study dilepton emission in dense and hot matter (cf. DLS/Berkeley)**
  A+A reactions in the 1-2 AGeV energy range
  C+C, Ar+KCl, Au+Au (2012), Ag+Ag(2013?)

- ✓ **cold matter at normal nuclear density p+Nb 3.5 GeV**
  (cf KEK, Jlab, CBELSA/TAPS)

- ✓ **Elementary collisions pp, dp and (in future) π^-p**
  - reference to heavy-ion spectra
  - understand dilepton production mechanism (exclusive channels)
  - dilepton emission is probing time-like electromagnetic structure of hadronic transitions!

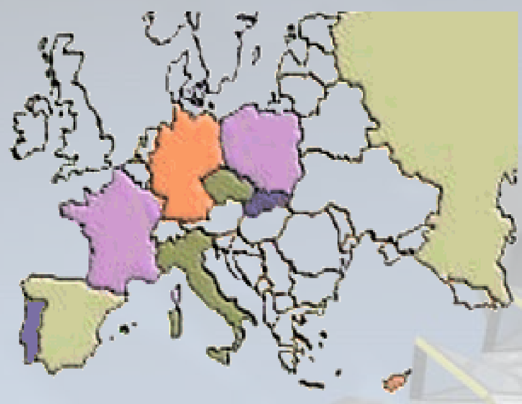
- ✓ **Simultaneous measurements of hadronic channels (pp $\rightarrow NN\pi$, pp $\rightarrow NN\pi\pi$)**
  Cross-checks on known channels, detailed information on baryonic resonance production

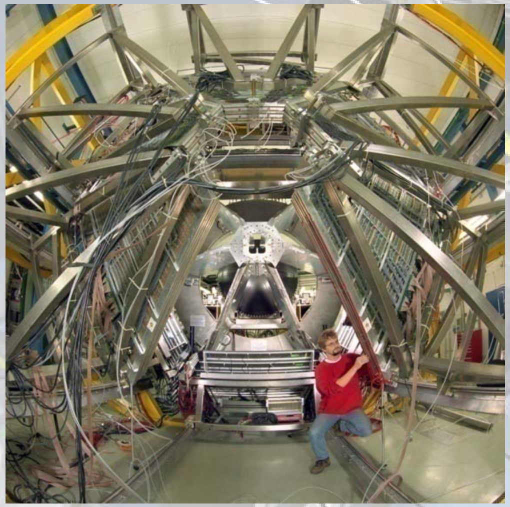
- ✓ **…. strangeness measurement program: K^-, K^0, ϕ, $\Sigma(1385)$, $\Lambda(1405)$**

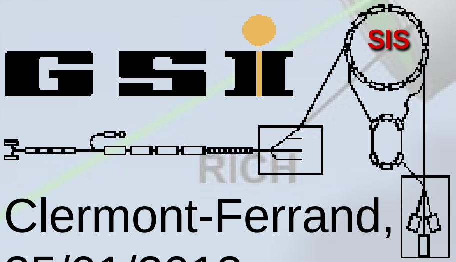
The Collaboration

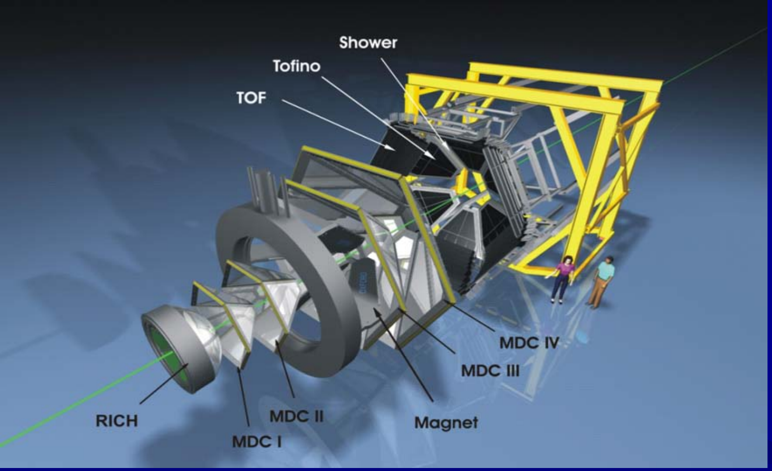
bmb+f - Förderschwerpunkt
HADES
Großgeräte der physikalischen Grundlagenforschung

- Catania (INFN - LNS), Italy
- Cracow (Univ.), Poland
- Darmstadt (GSI), Germany
- Dresden (FZD), Germany
- Dubna (JINR), Russia
- Frankfurt (Univ.), Germany
- Giessen (Univ.), 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
- Valencia (Univ.), Spain
- Coimbra (Univ.), LIP, Portugal









HADES
2nd generation dilepton spectrometer

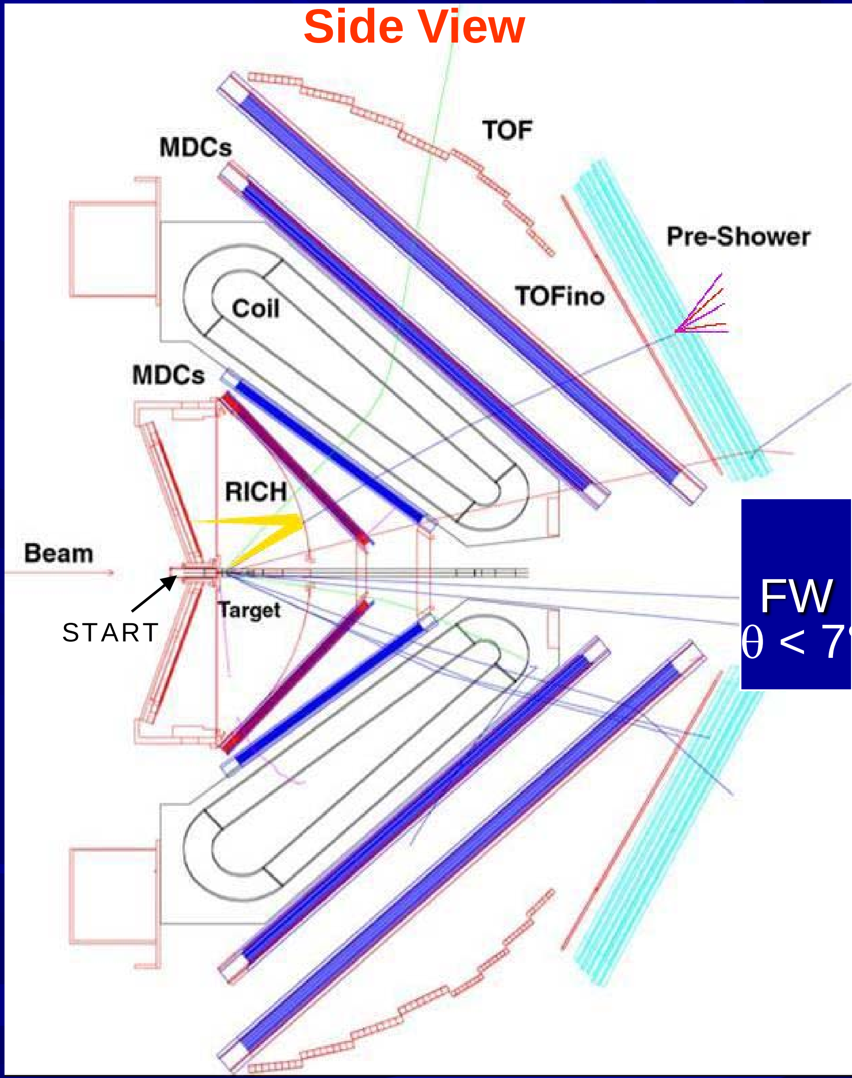
Acceptance: **Full azimuth, polar angles 18º - 85º**
Pair acceptance ≈ 0.35

Particle identification:
RICH, Time Of Flight, Pre-Shower (pad chambers & le...

Upgrade (2010)
✓New DAQ ~20 kHz
✓ new MDCs for plane 1
✓RPC θ <45°

Trigger:
1st Level: ch... ...0 kHz)
2nd Level: single electron trigger (~2.5 kHz)

Momentum measurement
Magnet: ∫Bdl = 0.1- 0.34 Tm
MDC: 24 Mini Drift Chambers
Leptons: Δx~ 140 μ per cell, Δp/p ~ 1-2 %
ΔM/M ~ 2% at ω peak

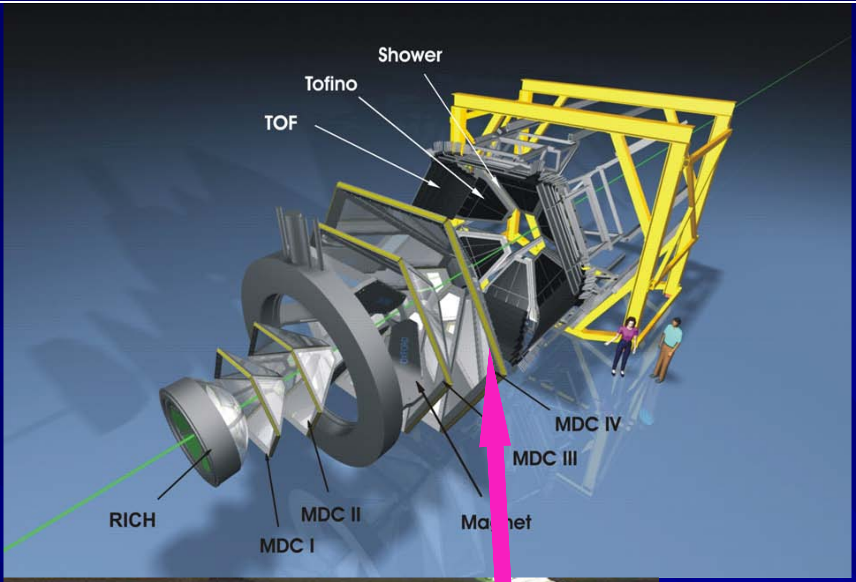


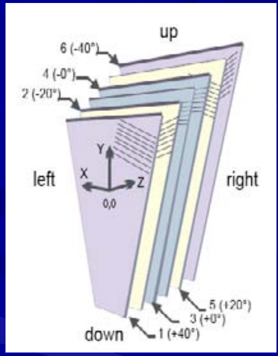
FW
θ < 7°

IPN contribution

French group:

G. Roche (Clermont-Ferrand)
IPN Orsay:
Jean-Louis Boyard (retired 2008)
Jean-Claude Jourdain (retired 2001)
Thierry Hennino
Malgorzata Gumberidze (post-doc)
Hubert Kuc (PhD 2010-2013)
Tingting Liu (PhD 2010)
Emilie Morinière (PhD 2008)
Béatrice Ramstein
Michèle Roy-Stephan (retired 2006)
…+Jacques Van de Wiele (phenomenology)

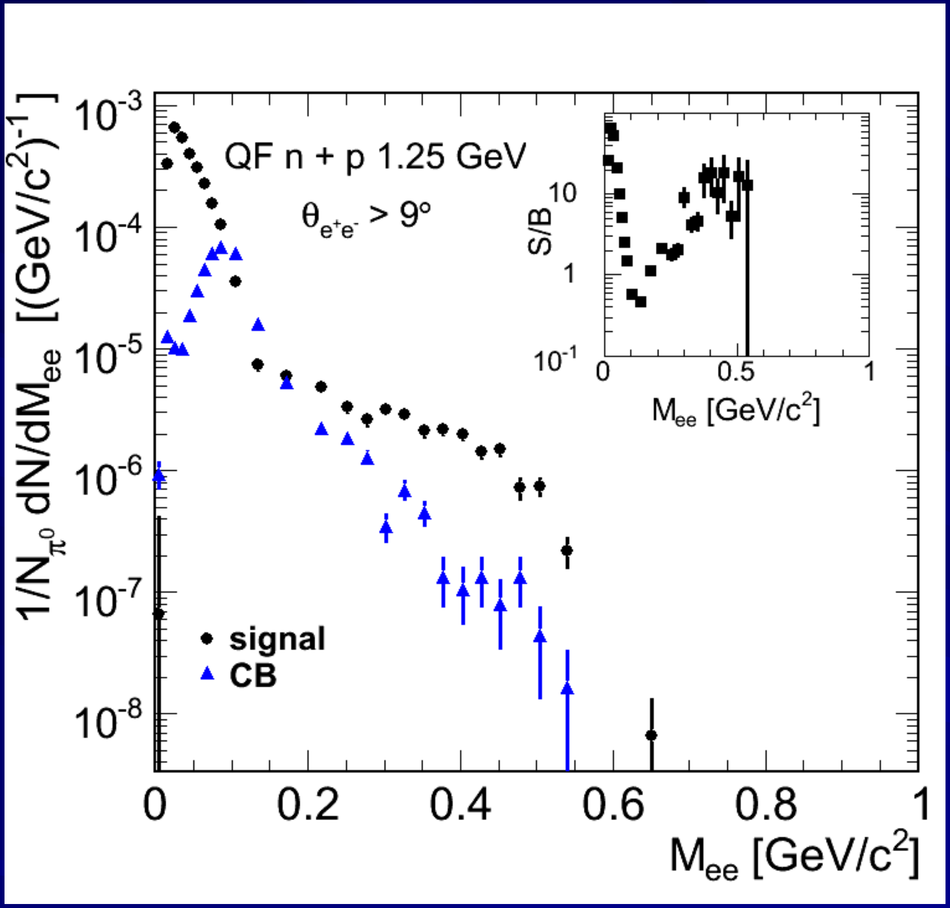




R&D détecteurs,
B. Genolini, M. Imre, J.P. Le Normand,
A. Maroni, T. Nguyen Trung,
J. Pouthas, V. Poux, P. Rosier
C. Théneau,

4th plane of 6 drift chambers
drift cell (14x10 mm^2)
active area 3.5 m^2

Analysis steps : one example



<u>Forward Wall (np selection)</u>:

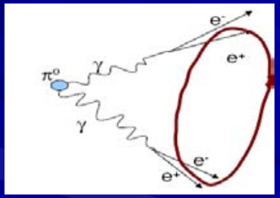
1. **Mult > 0**
2. **search for particle with 1.6 GeV < p < 2.6 GeV**

<u>(e^+,e^-) pair cuts</u>:

1. **track and ring quality**
2. **identification**
3. **background rejection cuts**
4. **opening angle > 9°.**

<u>Combinatorial background</u>:

like sign pairs



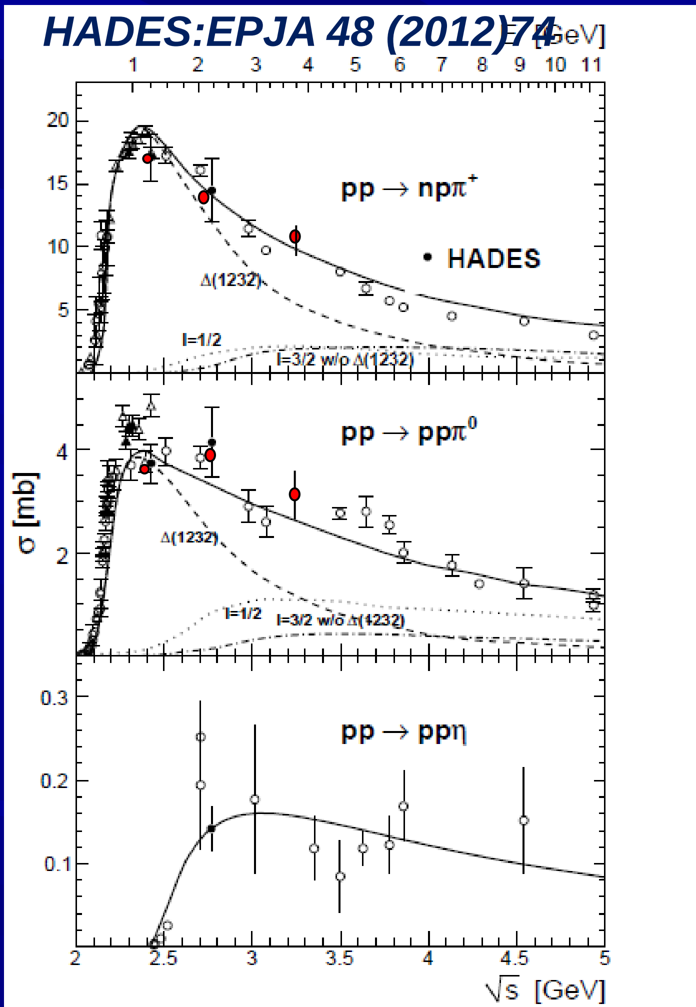
<u>efficiency corrections</u>:

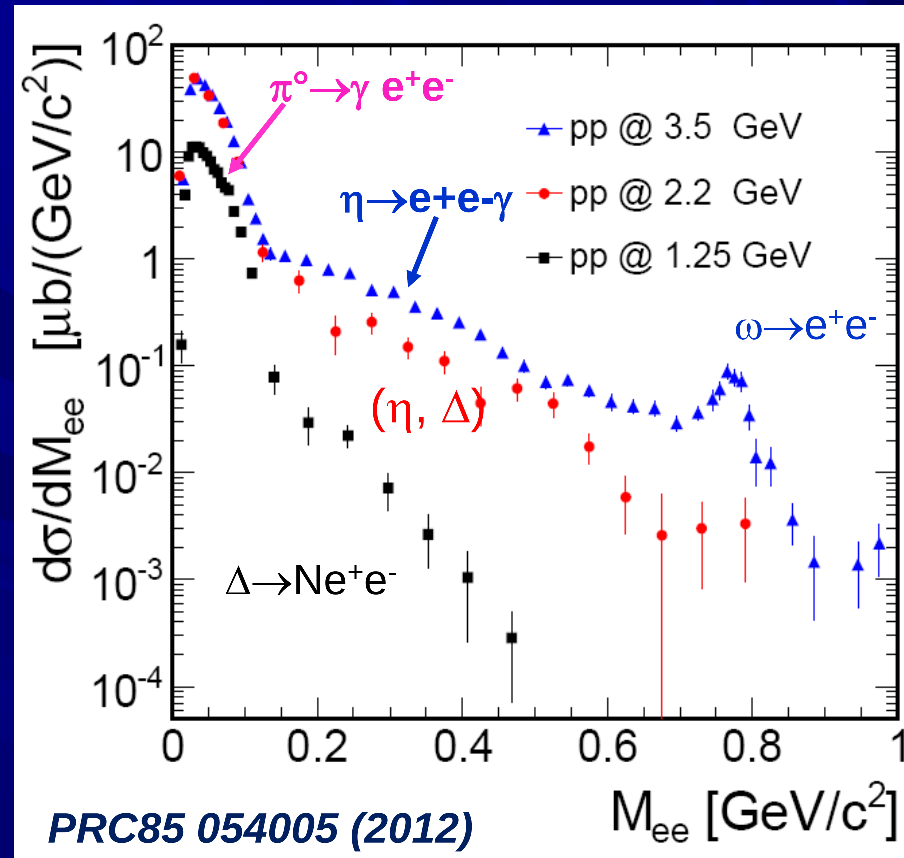
normalisation by elastic scattering measurement (syst.error ~ 11 %)

HADES measurements in pp E=1.25 GeV, 2.2 GeV ,3.5 GeV

Exclusive meson production in hadronic channels

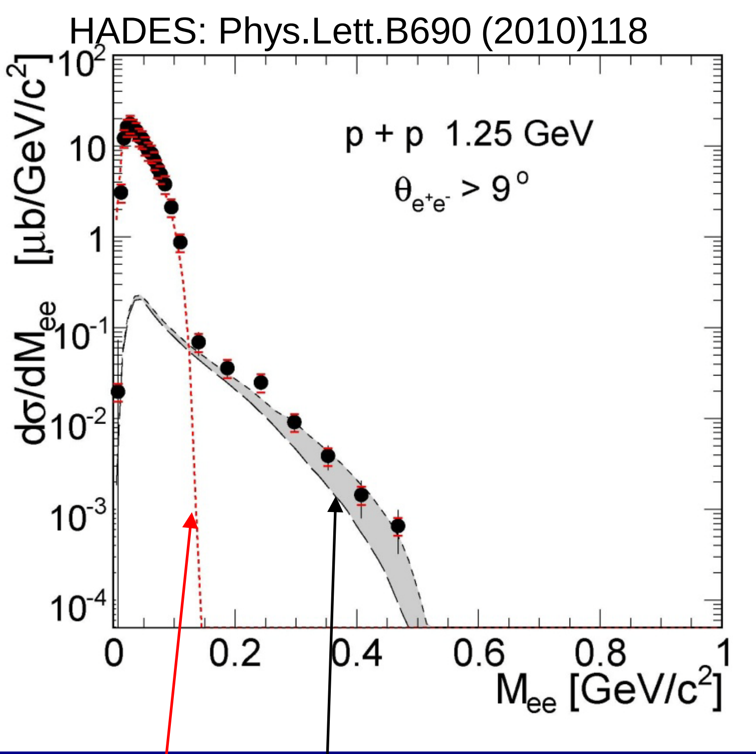
Inclusive dilepton production





Dominance of pp→NΔ below 2 GeV
η and higher resonances above 2 GeV
ρ/ω production at 3.5 GeV

Dilepton production in pp reaction at 1.25 GeV



- below η threshold
- only 2 dilepton sources

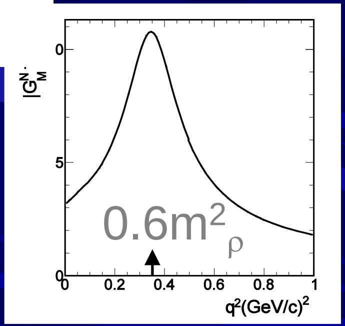
❑ $\pi°$ Dalitz decay $\sigma_{\pi°}$ =4.5 mb
branching ratio $\pi° \rightarrow \gamma e^+e^-$ 1.2 %

❑ Δ Dalitz decay :
branching ratio $\Delta \rightarrow Ne^+e^-$ (QED :4.2 10^{-5})

❑ non resonant contribution expected to be small

Time-like N- Δ transition electromagnetic form factors

$G_M(q^2)$



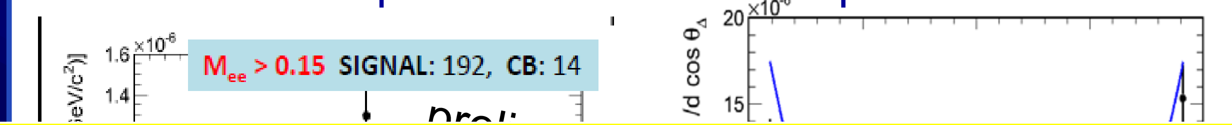
Resonance model results:
$\pi°$ Dalitz
Δ Dalitz + effect of Iachello FF

Wan and Iachello Int. J Mod. Phys. A20 (2005) 1846
G. Ramalho and T. *Pena arxiv:* 1205.2575v1 (2012)

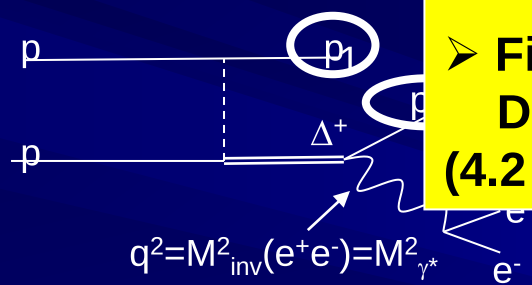
Exclusive analysis : pp→ppe$^+$e$^-$ at 1.25 GeV using pe$^+$e$^-$ events

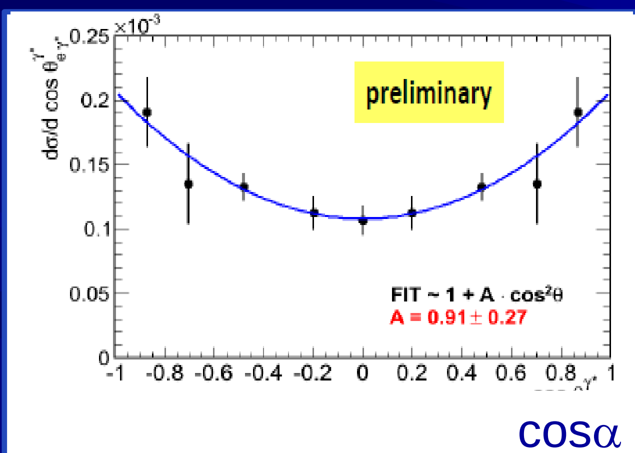
Good agreement with simulation of
Δ production + Dalitz decay
(cf hadronic channe

In HADES acceptance   acceptance corrected

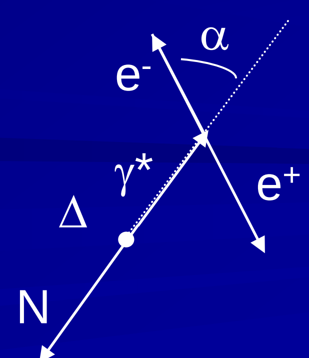


- **Exclusive channels confirm the dominance of Δ Dalitz decay**
- **First measurement of Δ Dalitz decay!**
  Dalitz decay branching ratio in agreement with QED value (4.2 10 $^{-5}$)





Helicity distributions $\gamma^* \to e^+e^-$
$d\sigma/d\Omega_e \sim 1+\cos^2\alpha$

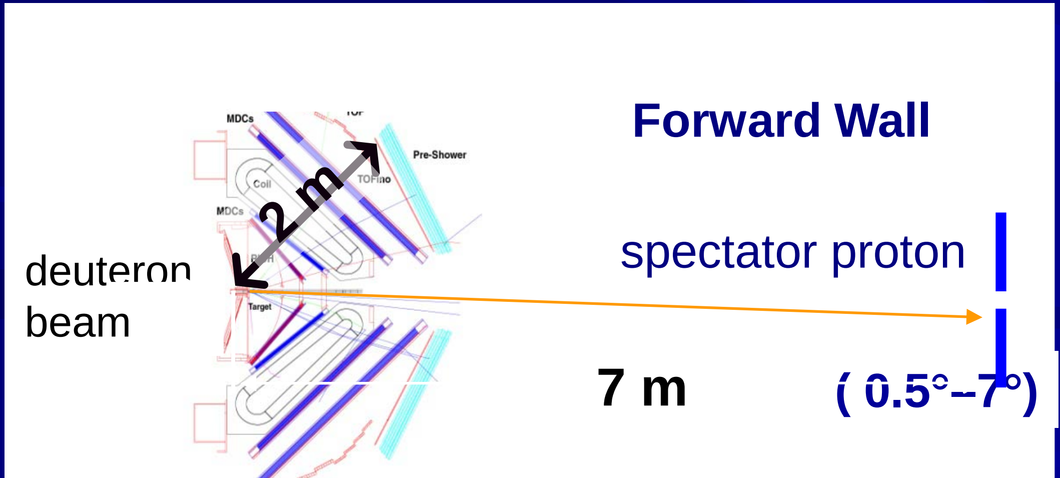


W. Przygoda's analysis Cracow

isospin effects in dilepton production ?

→ Comparison of pp and quasi-free pn reactions

(from dp experiments)

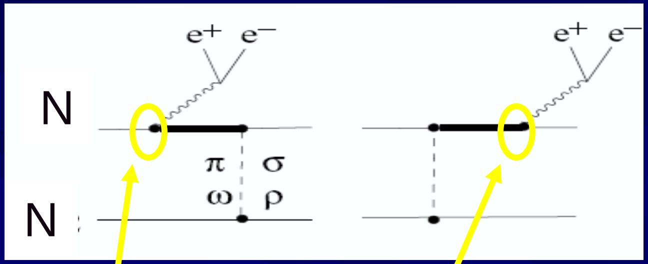


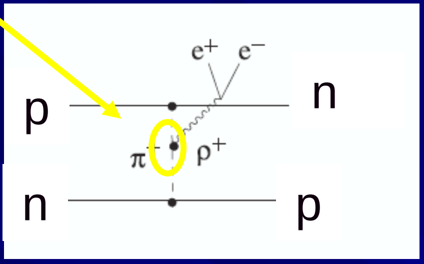
Non-resonant contributions in $NN \to NNe^+e^-$

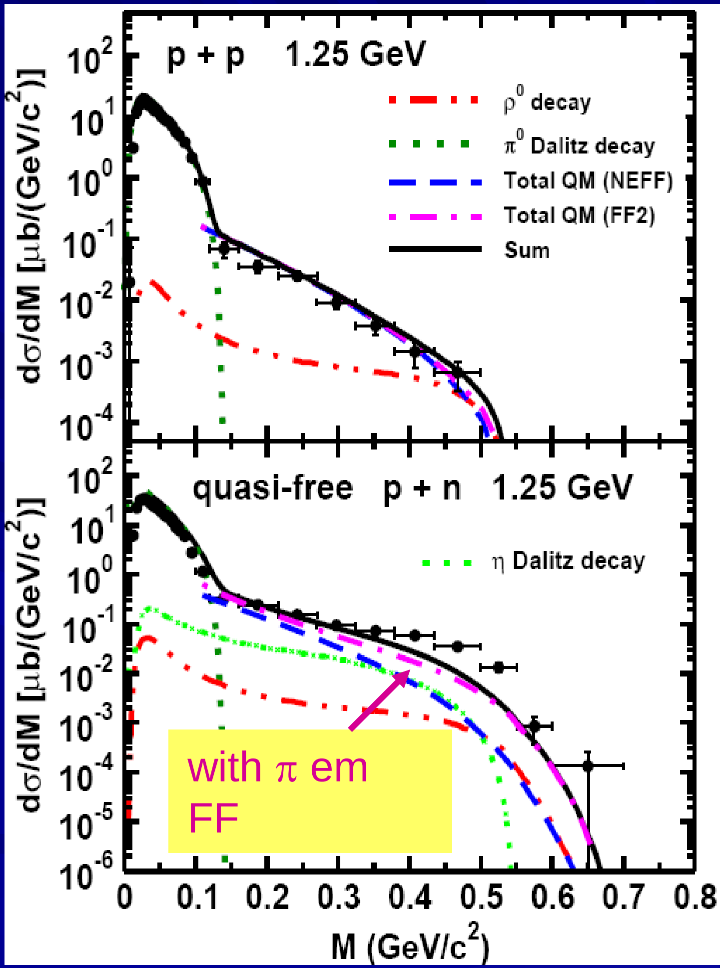
Pion form factor

meson exchange currents

HADES data: Phys.Lett.B690 (2010)118







Half-off-shell electromagnetic nucleon form factors

- sensitivity to hadronic electromagnetic structure
- much better agreement with data with π em form factor !

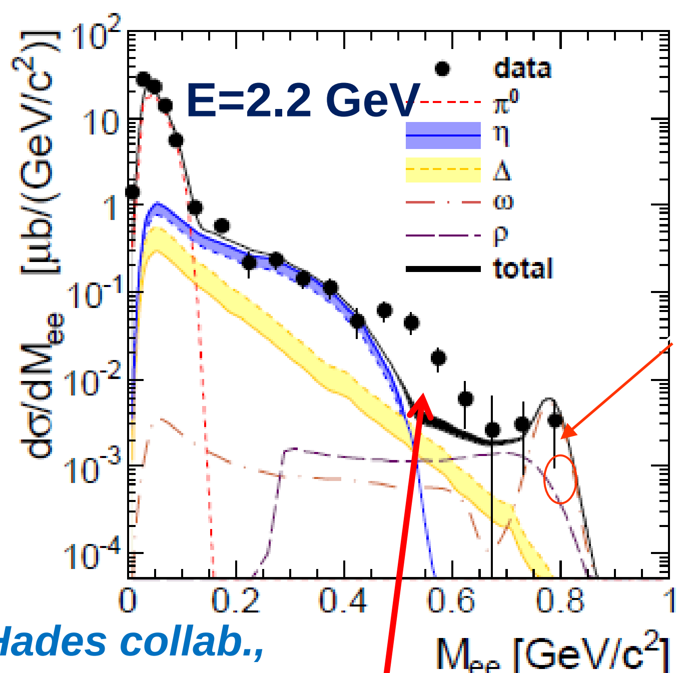
On-going analysis:

- pionic channels
- exclusive $pn \to pne^+e^-$

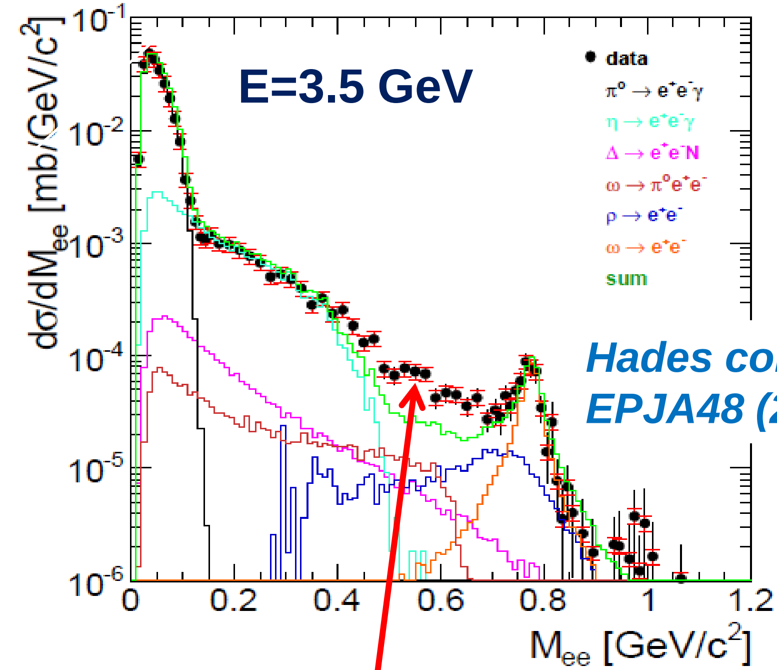
R. Shyam & U.Mosel, PRC82 (2010) 062201

pp→e⁺e⁻X E=2.2 GeV,3.5 GeV

Comparison to cocktail of dilepton sources
- Direct production of ρ/ω
- Dalitz decay of Δ resonance (point-like)

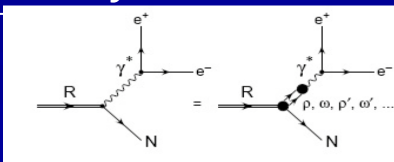


Hades collab.,
PRC85 054005 (2012)



Hades collab.,
EPJA48 (2012) 64

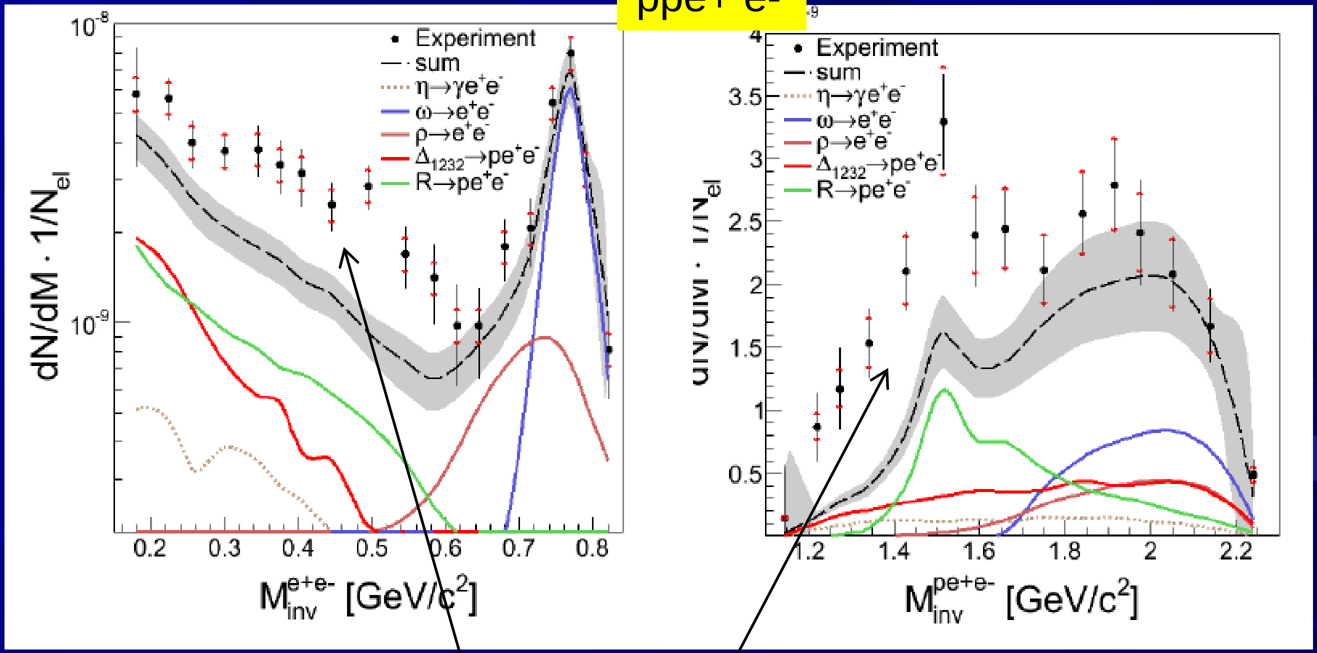
Effect of electromagnetic form factors / Coupling of ρ to baryonic resonances ?

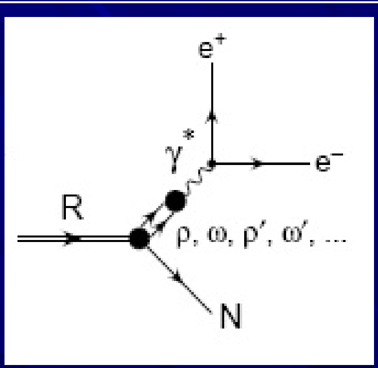


Exclusive pp→ppe$^+$e$^-$ channel at 3.5 GeV

✓ Cross sections and angular distributions for baryonic resonances from hadronic channel analysis
✓ Direct production of ρ,η,ω with cross sections from hadronic analysis (of $\eta/\omega \rightarrow \pi^+\pi^-\pi^0$) and $\sigma_\rho = 1/2\sigma_\omega$
✓ Constant form factors (taken at q^2=0) *M. Zetenyi and G. Wolf Heavy Ion Phys. 17 (2003) 27*

ppe+ e-



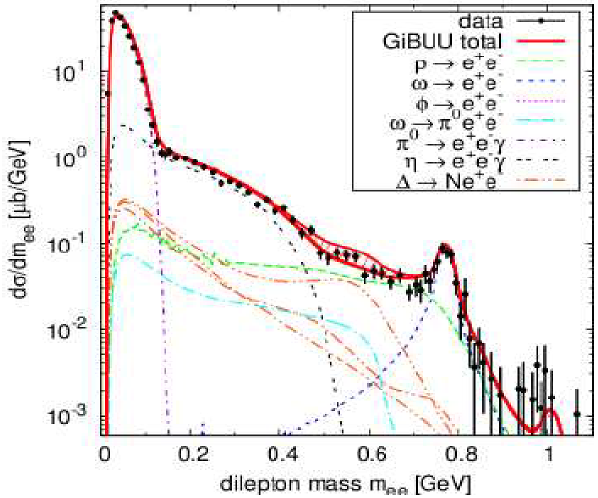


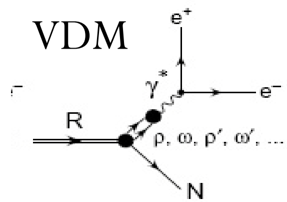
A. Dybczak, Cracow

Additional information from exclusive channels
Missing yield related to light baryonic resonances (N(1520) ,..)

Transport model calculations for inclusive e^+e^- production in pp

" electromagnetic form factor approach":





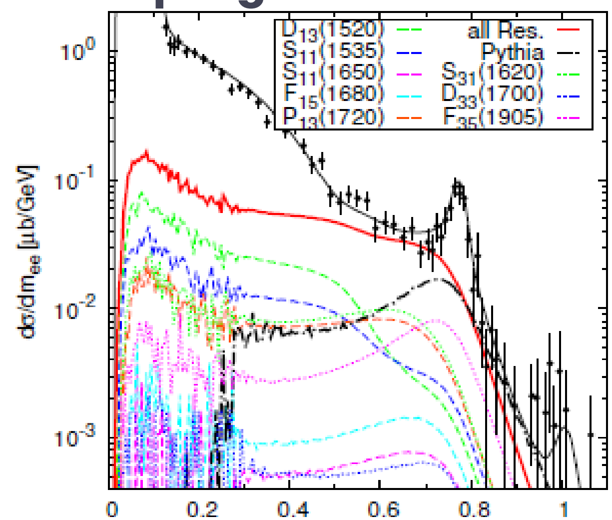
pp 3.5 GeV

Courtesy of Janus Weil

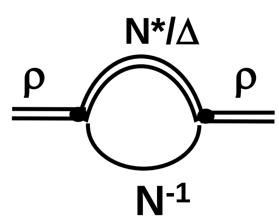
Hades data, Eur.Phys.J. A48 (2012) 64

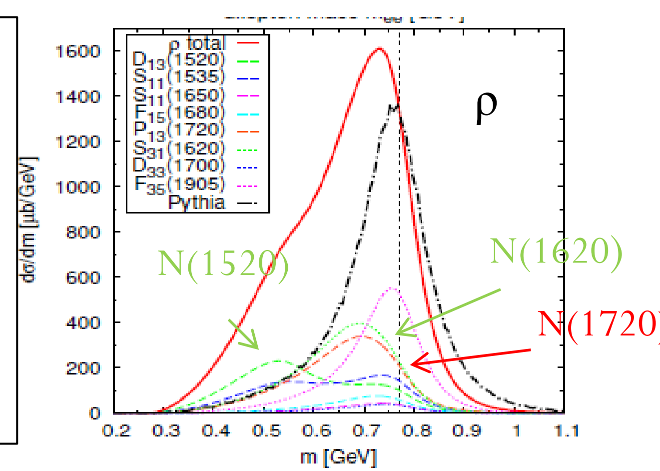
N-Δ Form Factor: G.Ramalho *and T. Pena Phys. ReV. D85, 113014 (2012)*

"ρ production approach":
ρNR couplings $\rho \to e^+e^-$



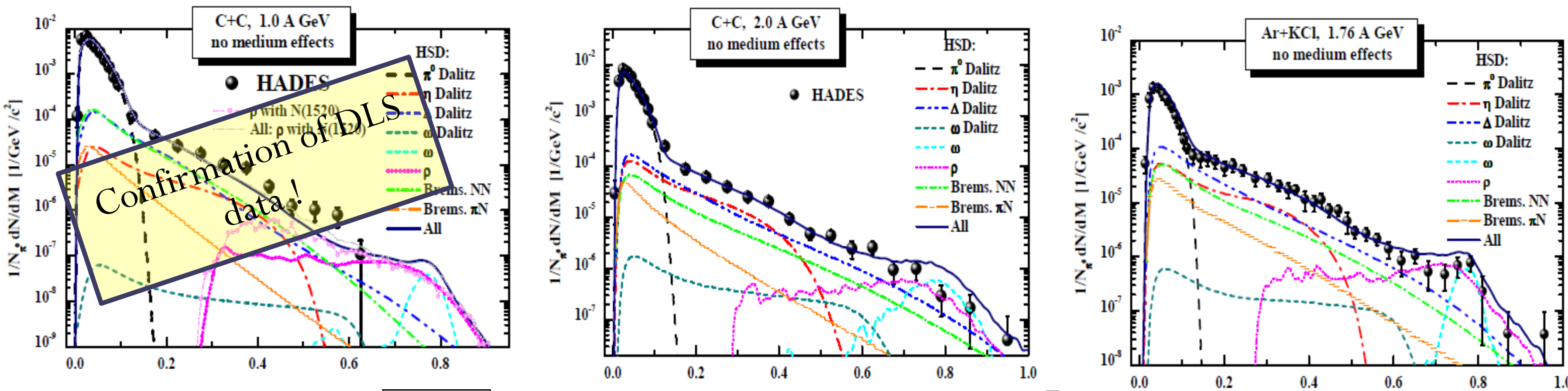
- ✓ ***ρ mass distribution strongly modified at the production level***
- ✓ *Same origin as in-medium effects (coupling to baryonic resonances)*
- ✓ *large uncertainties: production cross sections of baryonic resonances,* **ρNN* couplings** → **π beam experiment**

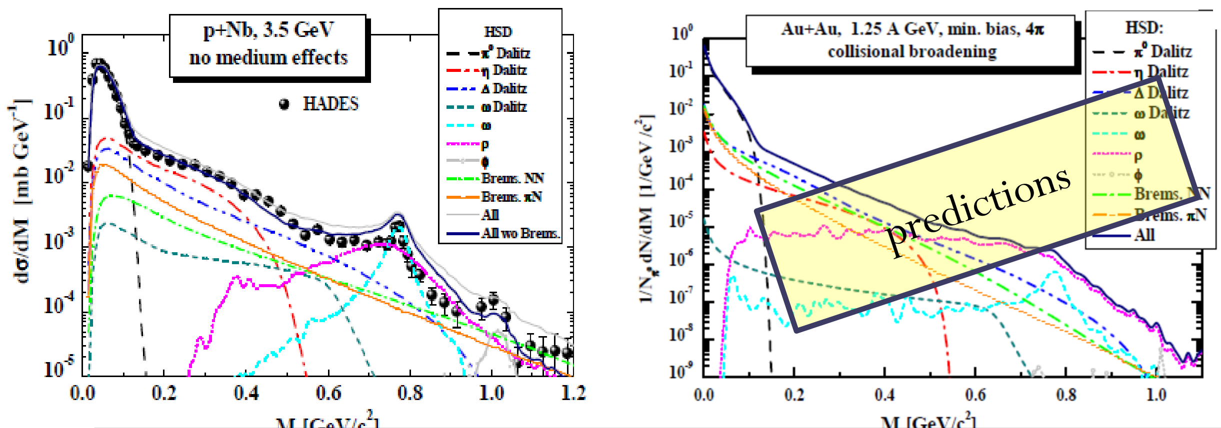




J.Weil, H. van Hees and U. Mosel, EPJA 48, 111 (2012)

Towards a consistent description of dilepton production in all systems





HSD: E. Bratkovskaya et al.
arXiv:1301.0786 [

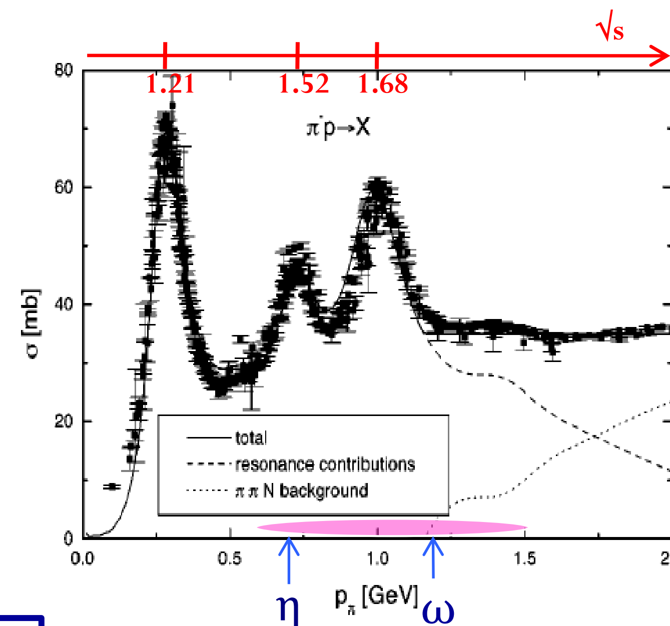
- ✓pp also rather well described, problem remains with pn data
- ✓Still contradictory predictions (UrQMD)
- ✓modifications of spectral functions are small at SIS energies (except Au+Au ?)
- ✓But HADES data are useful to study the ρN(N*/Δ) couplings (which are crucial for medium effects) and are very efficient in putting constraints to models

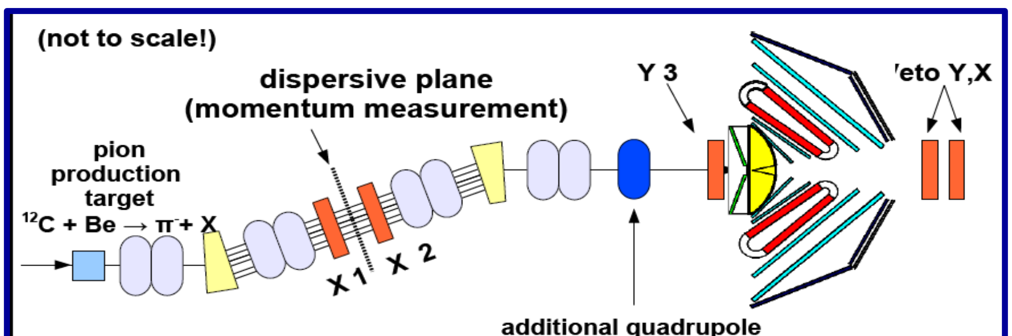
Perspectives of pion beam experiments

Future HADES experiments with the GSI pion beam

pion momentum 0.6 < p <1.5 GeV/c
I ~ 10^6/s

measurements with HADES of e^+e^-, $\pi^\pm$, $K^\pm$ in π^-p and π^-A reactions in the region of baryonic resonances with mass between 1.4 and 2.0 GeV/c2



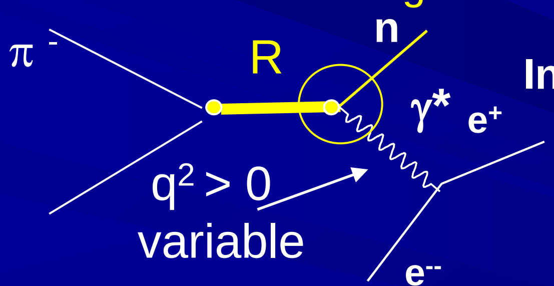


- Test in fall 2013
- Experiment April 2014

Motivations of πN experiments with HADES: Dilepton channels

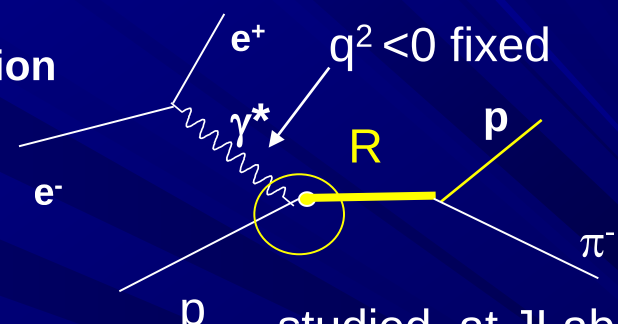
- **well-known production mechanism**
- **fixed resonance mass M_R=sqrt(s)**
- **exclusive** π^- p $\rightarrow$ n **e^+e^- channels** (η contribution can be rejected)

Time-Like electromagnetic form factors

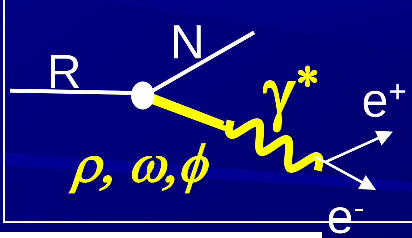


Inverse pion electroproduction

Space-Like electromagnetic form factors

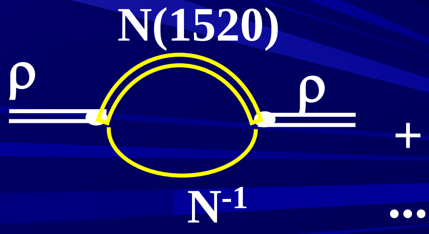


studied at JLab/CLAS



Vector Dominance Model

$\rightarrow$ ρ/ω coupling

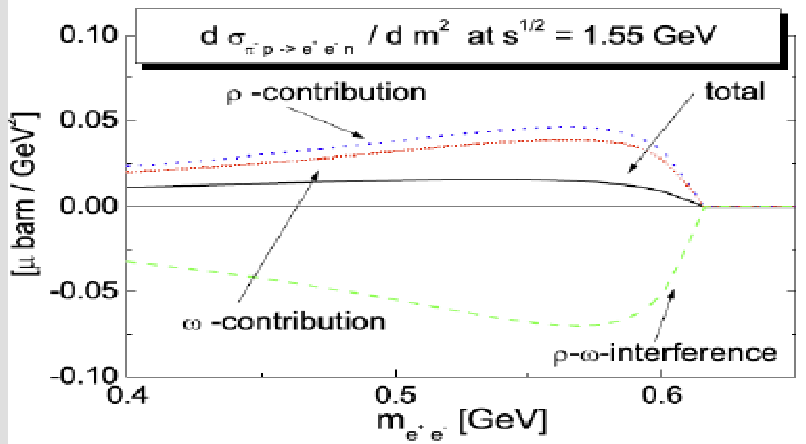


More direct access to Time-Like em transition form factors than in pp

Predictions for $\pi^- p \to e^+ e^- n$ below ω threshold

Calculations based on **hadronic couplings**
M. Lutz, B. Friman, M. Soyeur, NPA 713 (2003) 9
Titov and Kämpfer EPJA 12 (2001) 217

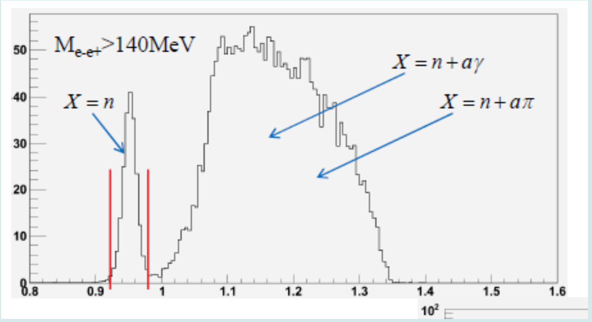
Important interference effects expected between I=0 (ω) and I=1 (ρ) channels



Very new calculation based on ***VDM transition form factors*** *by Zetenyi and Wolf* arXiv:1208.567.v1 [nucl-th]

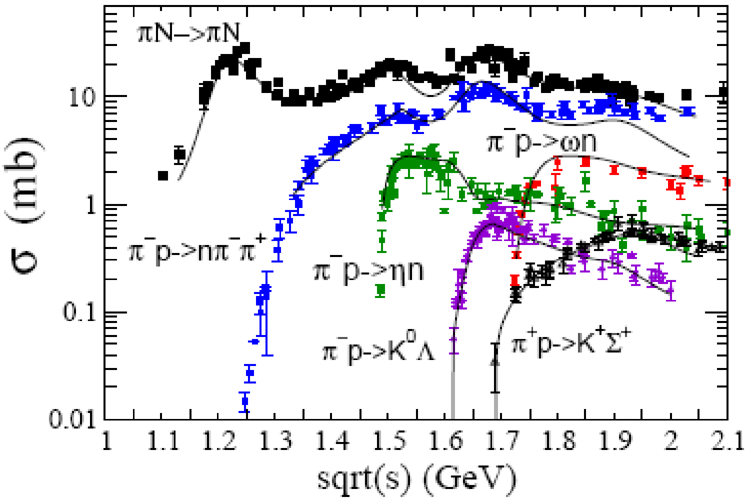
Feasibility study : H. Kuc's PhD Orsay/Cracow

Simulation of $\pi^- p \to e^+ e^- X$
Selection of $\pi^- p \to e^+ e^- n$
By missing mass



Access to unexplored Time-Like electromagnetic structure of baryonic transitions/ off-shell ρ production

πN→ππN: present status



All what we know about N* couplings to ρN, Δπ, σN is due to *Manley, Arndt, Goradia, Teplitz PRD 30 (1984) 904.*
based on the analysis of 240000 events (bubble chamber < 1980)

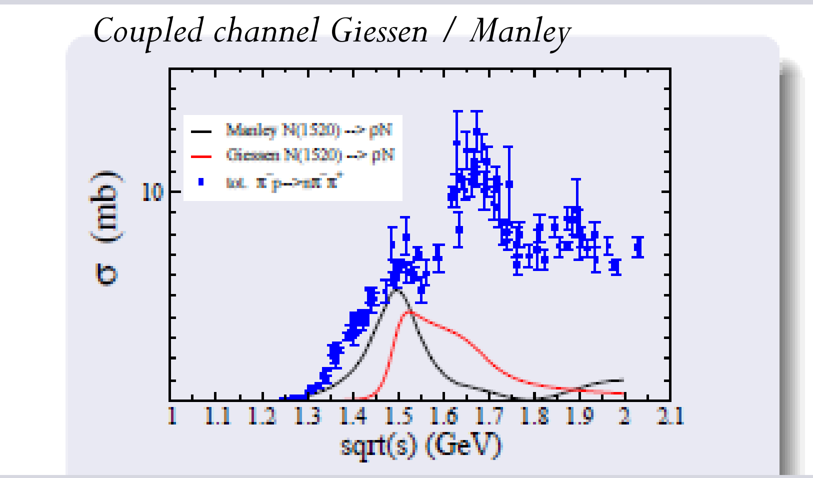
- ✓ Complete existing very precise photoproduction data
- ✓ Improve knowledge of baryonic resonances, M_R, Γ(N*→Nπ), Γ(N*→Nππ)
- ✓ Dynamical models are now available → a new combined PWA analysis of all pion and photoproduction channels will be possible.
- ✓ Important for baryonic structure issues (Constituent Quark Models, Lattice QCD)

Some open issues for $\pi N \to \pi\pi N$ and $\pi N \to \pi N$ measurements

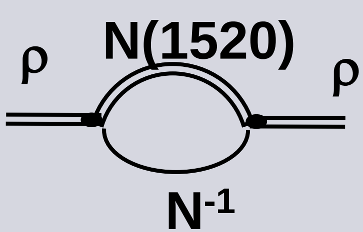
N(1520) D_{13} state

Manley et al. strong $N(1520) \to 2\pi$

$BR(\rho N) \sim 20\%$



- ✓ Important coupled channel effects
- ✓ With $BR(\rho N) \sim 20\%$, cross sections are not reproduced
- ✓ need for differential cross sections
- ✓ Important for medium effects



N(1440) P_{11}

Branching ratios to $\pi\Delta$ and $(\pi\pi)_s N$ need to be checked

N(1710) P_{11}

- ✓ Existence contradictory
- ✓ Not seen in the latest PWA analysis
- ✓ $BR(2\pi)$ =40 to 90 % (PDG 2010)

Time-Like nucleon Form Factors at PANDA

… and other electromagnetic channels

IPN Orsay: T. Hennino, R.Kunne, D. Marchand, S. Ong, B. Ramstein,
E. Tomasi-Gustafsson (CEA/IRFU), J. Van de Wiele
A. Dbeyssi (PhD), B. Ma (PhD) + post-doc (2013)
+ service R&D detecteurs

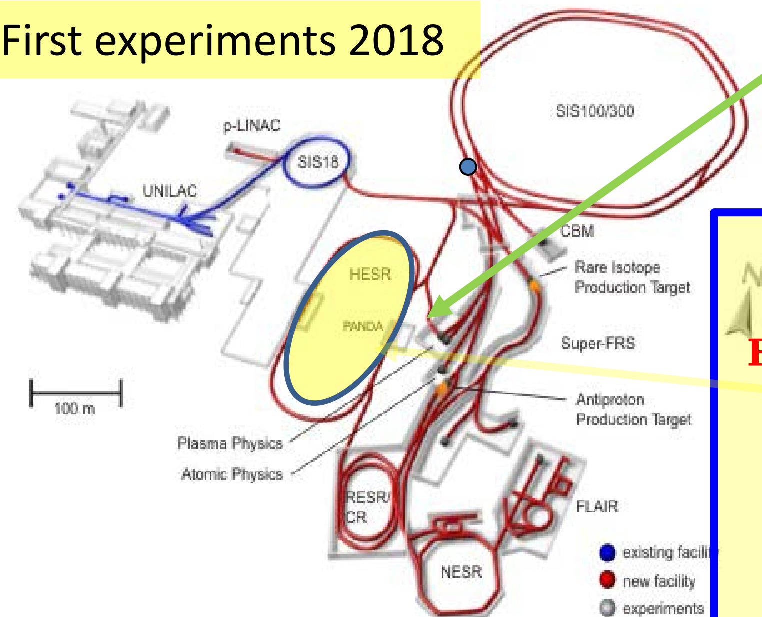
Collaboration with H. Fonvieille (Clermont-Ferrand)

The FAIR facility

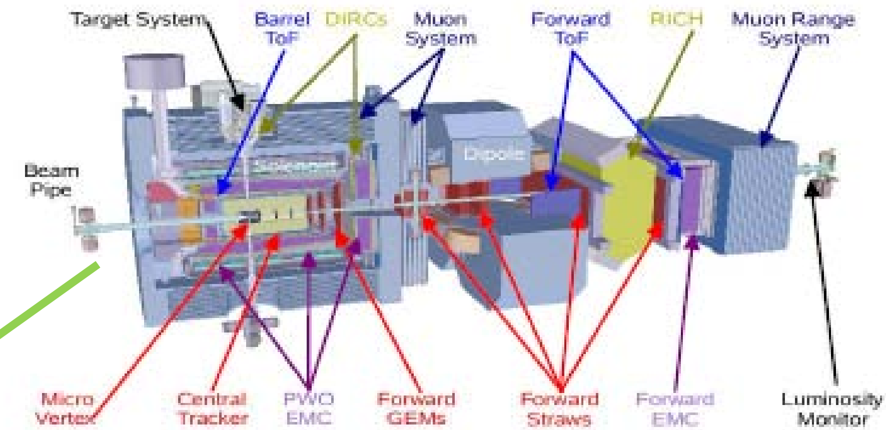
Facility for Antiproton and Ion Research

- **Hadron Structure and Dynamics**
- **Nuclear and quark matter**
- **Super-heavy elements**
- **Nuclear Structure and Astrophysics**
- **Atomic, Plasma and Material Physics**
- **Radiobiology**

First experiments 2018



PANDA



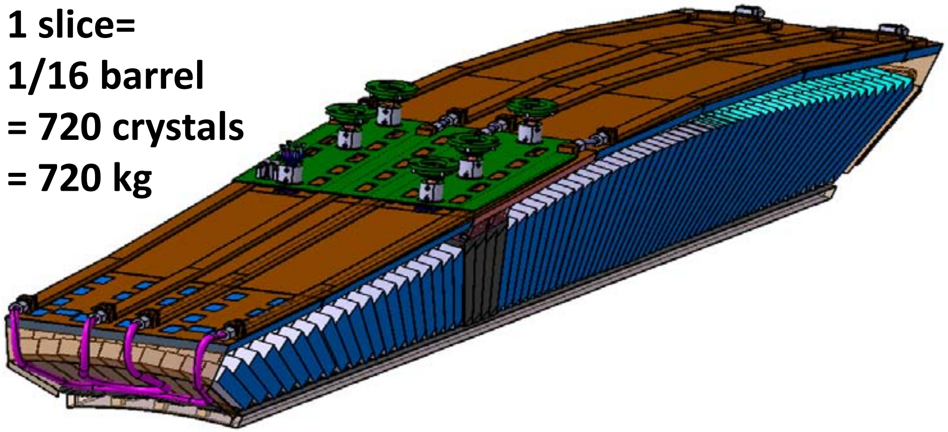
Antiproton ring
High Energy Storage Ring 1.5 – 15 GeV/c
$L = 2 \times 10^{32}\ cm^{-2}\ s^{-1}$
$\sigma_p/p = 10^{-4}$
2×10^{7} int.s^{-1}

- ✓Meson spectroscopy
  D mesons, charmonium
- ✓Glueballs, hybrids,…
  Charmed and multi-strange baryon spectroscopy
- ✓ hypernuclei (S=2)
- ✓ Hadrons in nuclear matter
- ✓ **Proton structure**

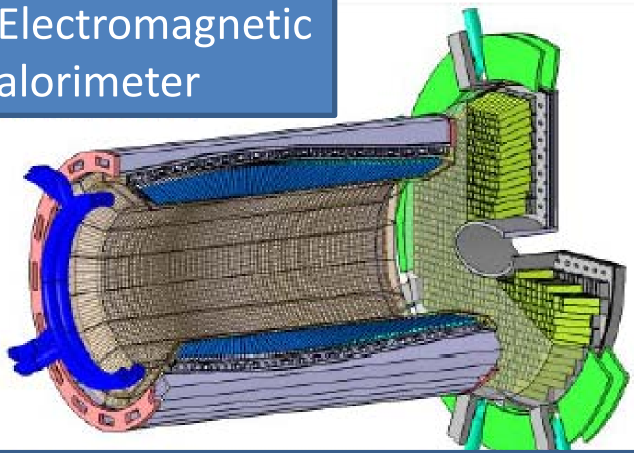
PANDA Barrel EMC

- Barrel calorimeter:

1 slice=
1/16 barrel
= 720 crystals
= 720 kg



Barrel Electromagnetic Calorimeter



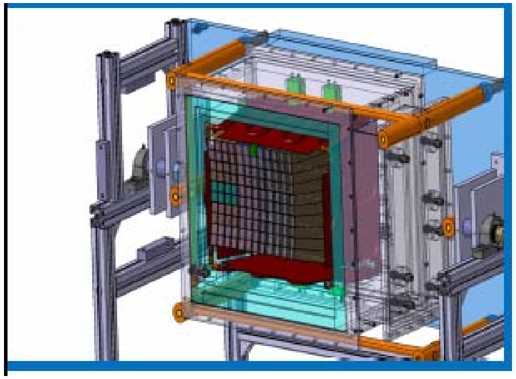
11520 crystals in 16 slices cooled to -25^{0}C

- IPN Orsay: Mechanical structure design and cooling

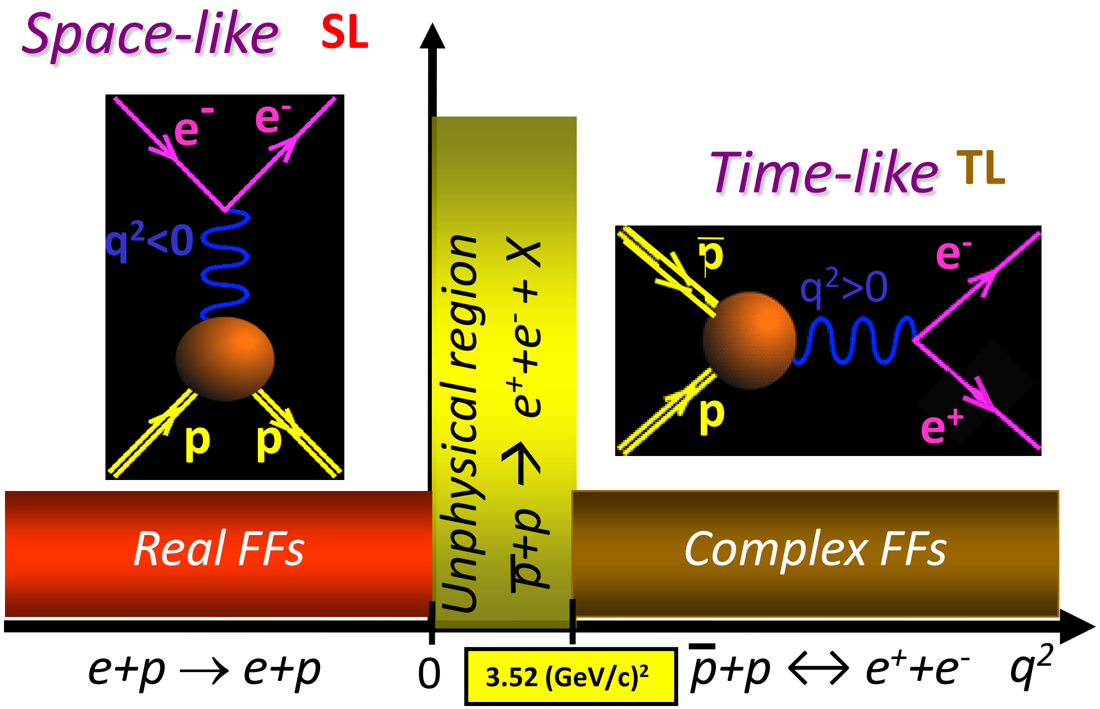
✓ Prototype of 60 crystals already tested

✓ Proto120 (120 crystals) to be tested in 2013

(cosmics, γ beams at MAMI)



Time-Like and Space-Like electromagnetic form factors



Constraints:

- $G_E^p(0)=1$
- $G_M^p(0)=\mu_p$
- $G_E^p(4m_p^2)= G_M^p(4m_p^2)$

✓ Much less data in Time-Like region

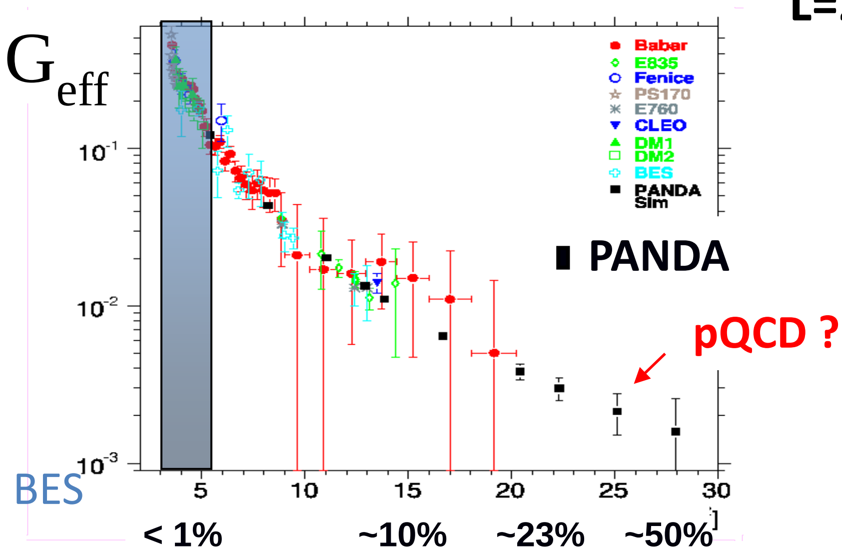
✓ Form factors in both regions are linked (dispersion relations)

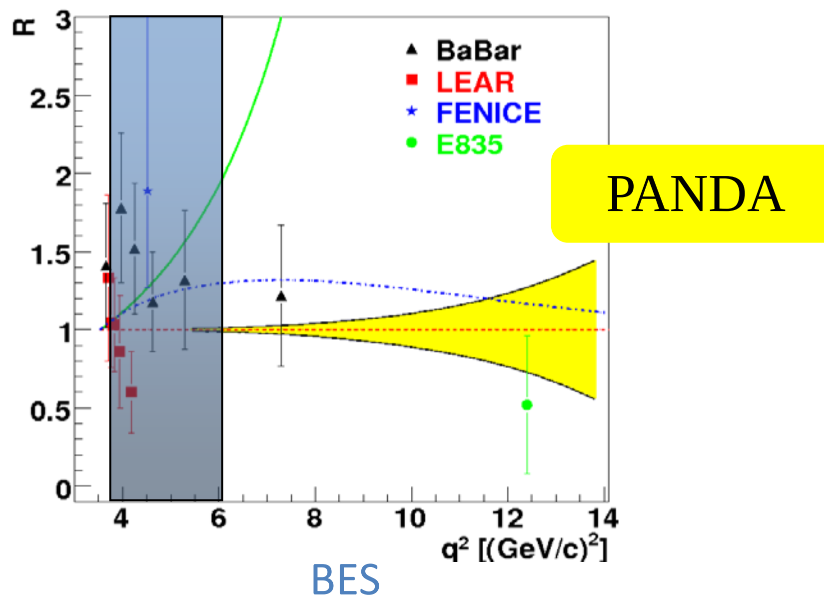
✓ Values should be the same at high q^2 (analyticity) and should follow pQCD behaviour $|G_{E,M}(q^2)| \sim (q^2)^{-2}$

Time-Like Form Factor measurement with PANDA : precision estimates

Feasibility study at IPNO: M. Sudol et al. EPJA 44 (2010) 373

L=2 fb^{-1}





PANDA will bring

Precise determination of $|G_E|$ and $|G_M|$ up to 14 (GeV/c)^2

G_{eff} up to 30 (GeV/c)^2 : transition towards perturbative QCD

Feasibility studies for form factor in the unphysical region ($q^2<4m_p^2$)

✓ in $\bar{p}p \to e^+e^-\pi^0$ (J. Boucher, PhD 2011)

✓ In $\bar{p}d \to ne^+e^-$ (H. Fonvieille and V.A. Karmanov EPJA42 (2009) 287-298)

Conclusion:

- **Elementary reaction program**
  - reference for medium effects
  - Time-like electromagnetic structure of baryonic resonances/coupling to vector mesons

    connection with PANDA !

- **perspectives of pion beam experiments** (→ oct. 2013)
  - Dilepton channels in $\pi N \rightarrow$ unique chance to study Time-Like electromagnetic structure of higher lying resonances (complementary to pion electroproduction)
  - One pion, Two pion and kaon production:new data highly needed for Partial wave Analysis → baryonic resonance properties

GSI pion beam is unique in world at present to provide the missing data

- **Before HADES moves to FAIR … and IPN HADES team moves to PANDA**