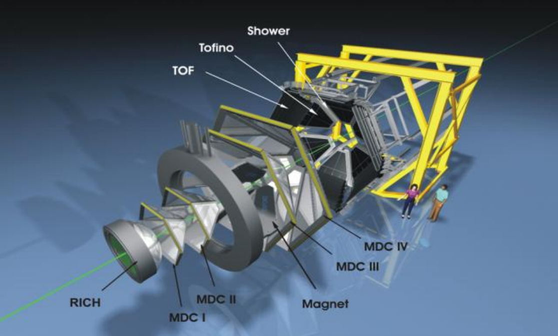

HADES

Study of elementary reactions with the High Acceptance Di-Electron Spectrometer at GSI

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Institut de Physique Nucléaire d'Orsay

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**

- **Results from pp and dp reactions with HADES**
  - **inclusive/exclusive dilepton channels**

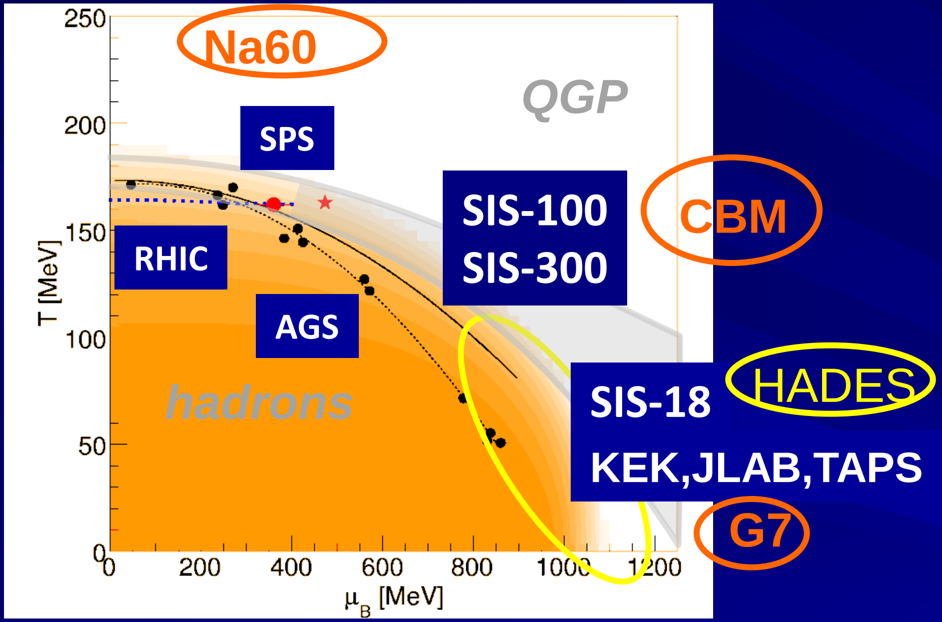
  Sensitivity to electromagnetic Time-Like form factors
  - **exclusive hadronic channels**

- **Perspectives with the GSI pion beam**

- **Conclusions**

Motivations of the HADES experiment

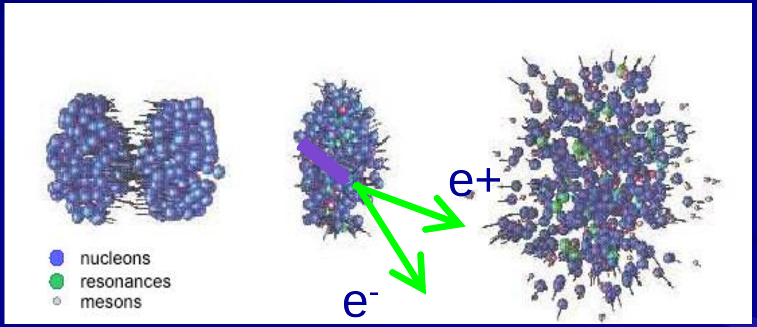
Exploring the phase diagram of hadronic matter…..



E/A=1-2 AGeV

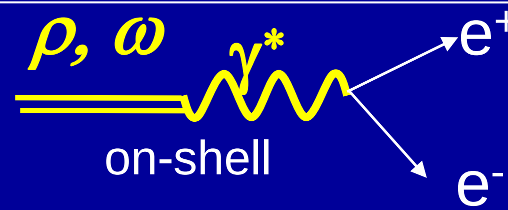
- ρ/ρ_o ~ 1-3, T < 100 MeV
- $N_\pi/A_{part} \approx 10\%$

….. using dilepton emission: rare but undistorted probe

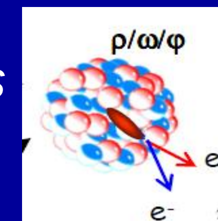


Dileptons and vector mesons

- $V \rightarrow \ell^+\ell^-$ $J^P=1^-$

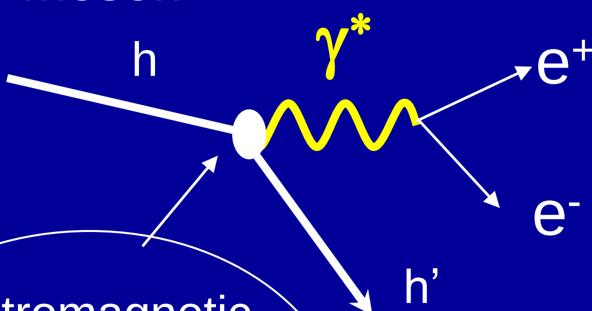


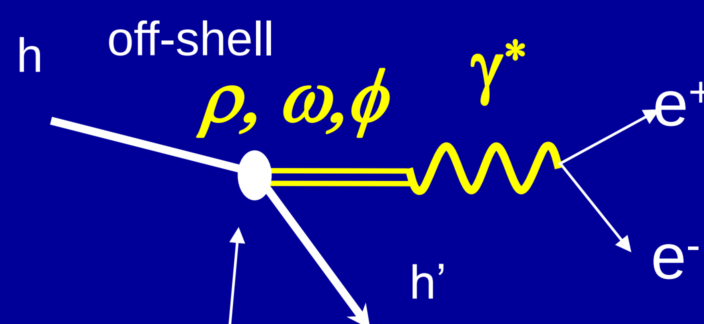
$BR_{\rho}= 4\,10^{-5}$
$BR_{\omega}= 7\,10^{-5}$



Undistorted access to in-medium vector meson spectral functions
→ Test predictions of medium modifications

- Vector Dominance Model: coupling of a virtual or real photon to *any* electromagnetic hadronic current is mediated by a vector meson

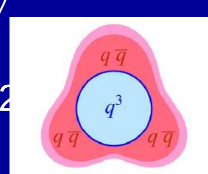




electromagnetic elastic or transition form factors
Meson cloud structure

⟺

Coupling constants



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?)

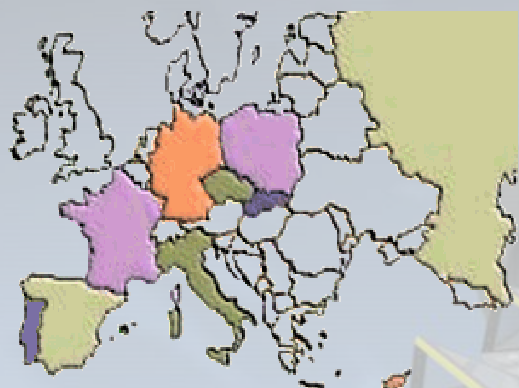
- ✓ **cold matter at normal nuclear density p+Nb 3.5 GeV**
  (cf KEK, Jlab, CBELSA/TAPS)

- ✓ **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!

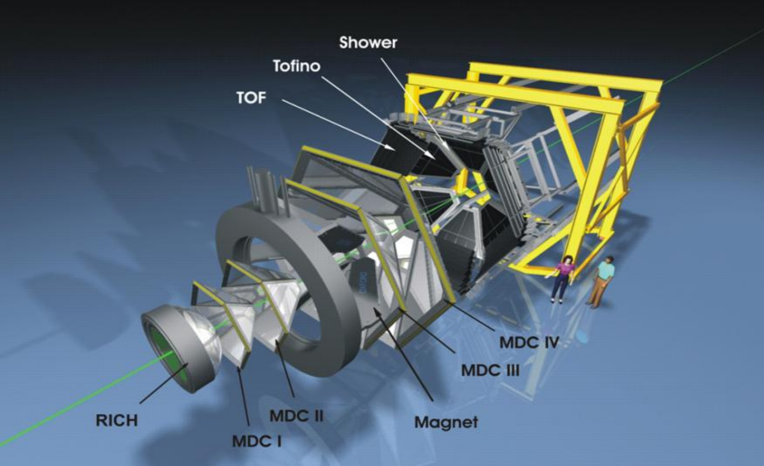
- ✓ **Simultaneous measurements of hadronic channels (pp $\rightarrow$NNπ, pp $\rightarrow$NN$\pi\pi$)**
  Cross-checks on known channels, detailed information on baryonic resonance production

- ✓ **…. strangeness measurement program: K^-, K^0,ϕ, Σ(1385), Λ(1405)**

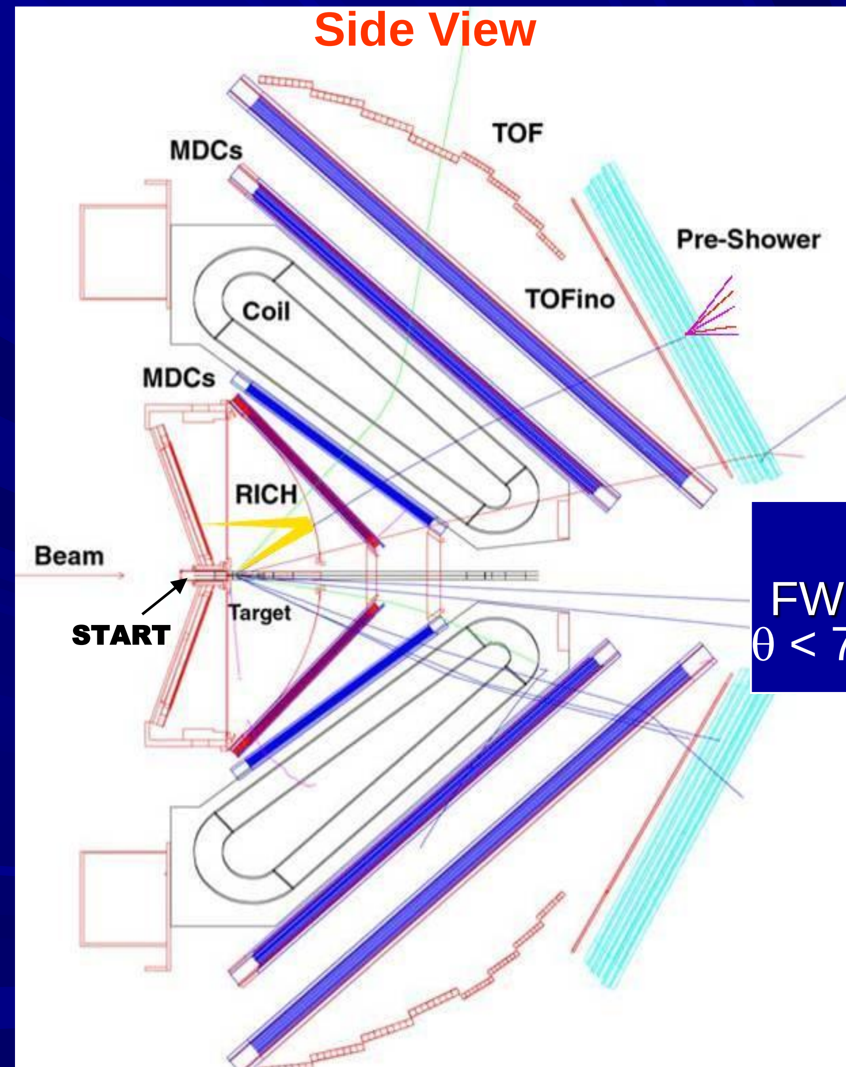
The Collaboration



- 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



FW
θ < 7

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

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

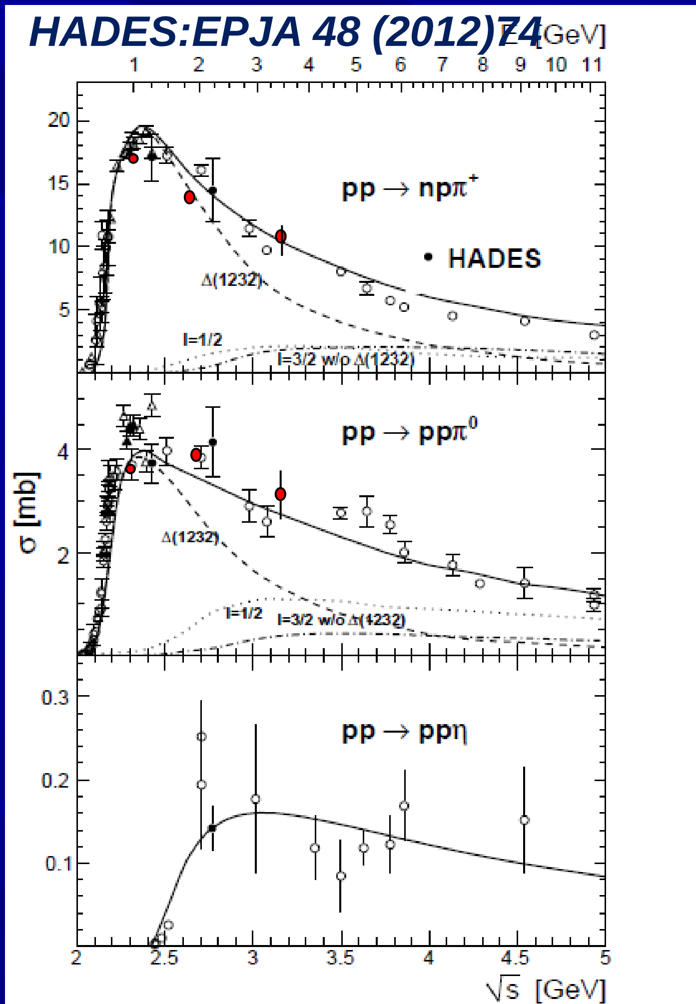
Trigger:
1st Level: ch ... 0 kHz)
2nd Level: single electron trigger (~2.5 kHz)

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

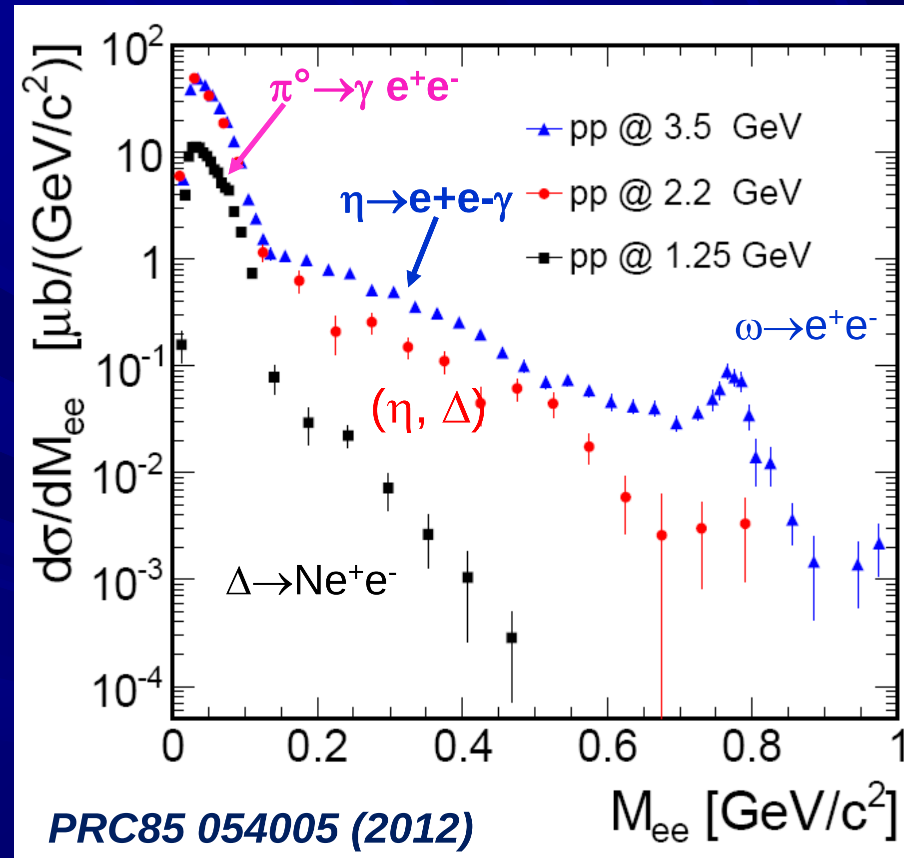
Momentum measurement
Magnet: ∫Bdl = 0.1- 0.34 Tm
MDC: 24 Mini Drift Chambers
Leptons: Δx~ 140 μ per cell, Δp/p ~ 1-2 %
ΔM/M ~ 2% at ω peak

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

Exclusive meson production in hadronic channels



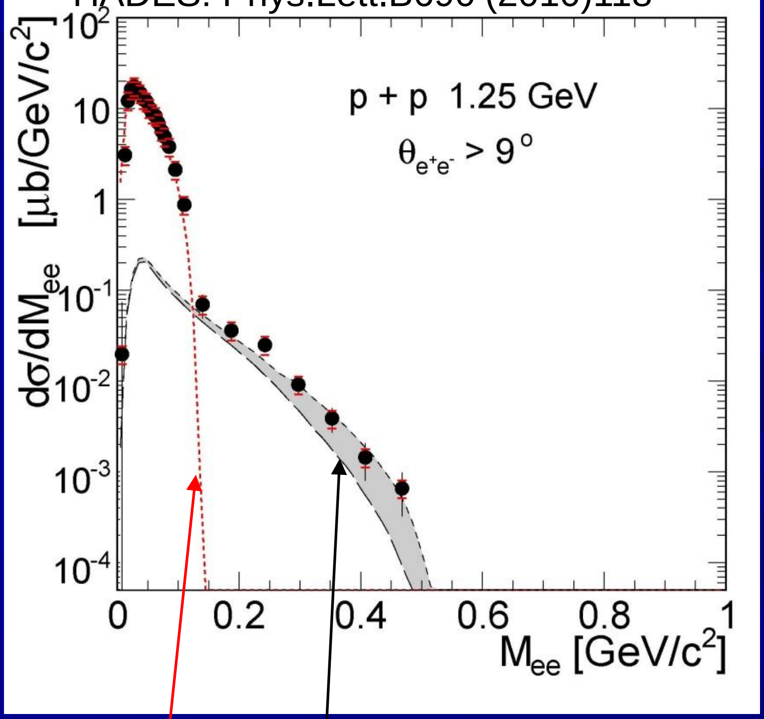
Inclusive dilepton production



Dominance of $pp \to N\Delta$ 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

HADES: Phys.Lett.B690 (2010)118



Resonance model results:
π° Dalitz
Δ Dalitz + effect of Iachello FF

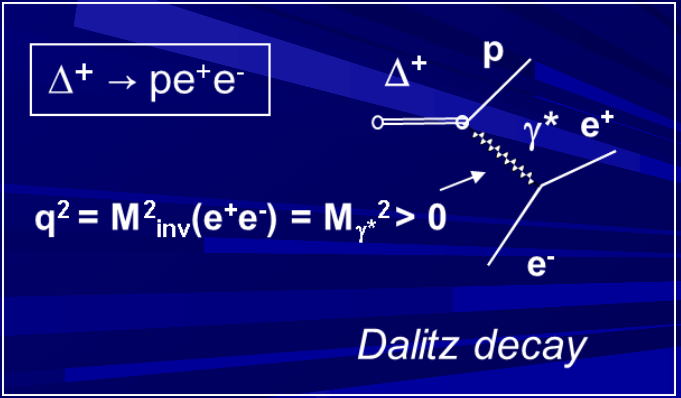
- below η threshold
- only 2 dilepton sources

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

❑ non resonant contribution expected to be small

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

Time-like N- Δ transition electromagnetic form factors ?



Δ Dalitz decay differential width

exact QED calculation :

3 amplitudes: e.g. Magnetic, Electric and Coulomb

$$\frac{d\Gamma(\Delta \to Ne^+e^-)}{dq^2} = f\left(m_\Delta, q^2\right)\left(\left|G_M^2\left(q^2\right)\right| + 3\left|G_E^2\left(q^2\right)\right| + \frac{q^2}{2m_\Delta^2}\left|G_C^2\left(q^2\right)\right|\right)$$

Inconsistencies in the litterature, see *Krivoruchenko et al. Phys. Rev. D 65 (**2001**) 017502*
Froehlich et al EPJA45:401-411,2010

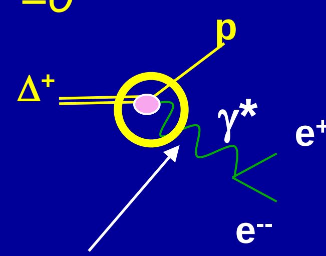
Form factors $G_M(q^2)$, $G_E(q^2)$, $G_C(q^2)$

$q^2 \geq 0$: « Time like « electromagnetic structure of N - Δ transition

complex functions known only at $q^2=0$

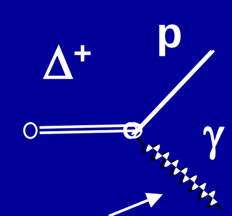
from $\gamma N \to \Delta \to \pi N$

$G_M(0)=3$, $G_E(0)=0.04$, $G_C(0)=0.2$



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

$\Delta^+ \longrightarrow \gamma p$

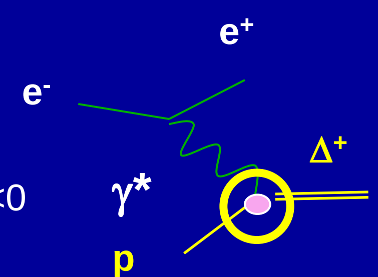


$q^2 = 0$

Radiative decay

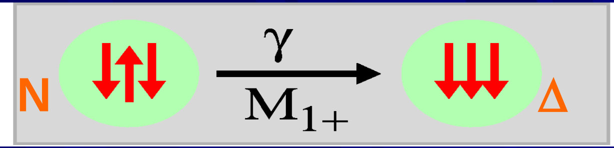
BR=0.56%±0.04%

Complementary to Space-Like region:



$q^2=M^2_{\gamma^*}<0$

N-Δ em transition : what do we know?



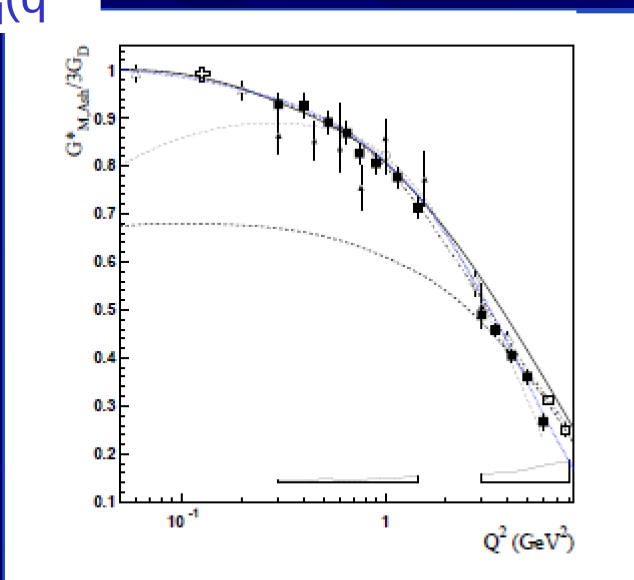
- **at $q^2=0$, mainly M_{1+} (magnetic) transition**

« Photon point » : $q^2=0$
$G_M(0)\sim3$, $G_E(0)\sim0.04$

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

- ***At finite q^2, many recent data points* from Mainz, Jlab:**
  multipole analysis of π° or π^+ electroproduction

$G_M(q^2$



$$R_{EM} \approx \frac{\mathrm{Im}(E_{1+})}{\mathrm{Im}(M_{1+})}$$

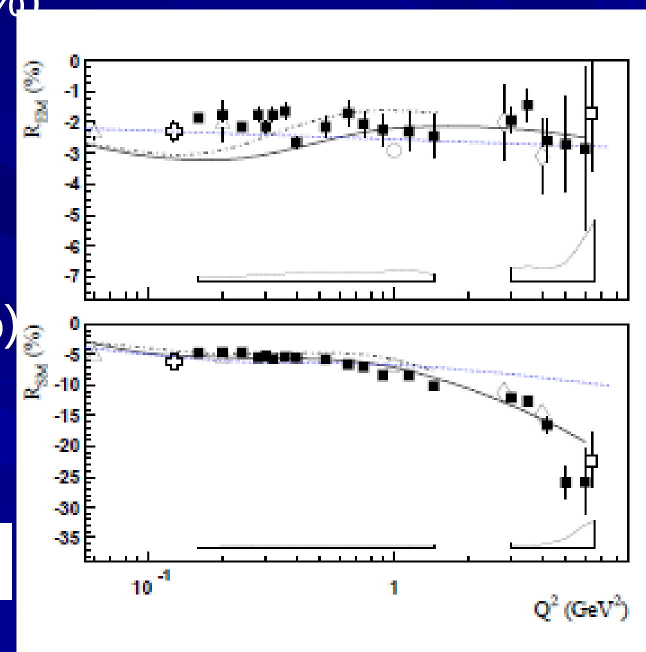
related to $G_E(q^2)$

$$R_{SM} \approx \frac{\mathrm{Im}(S_{1+})}{\mathrm{Im}(M_{1+})}$$

related to $G_C(q^2)$

(%)

(%)



Many models: dynamical models (Sato,Lee), EFT (Pascalutsa and Vanderhaeghen), Lattice QCD, two component quark model *Q. Wan and F. Iachello*, *bare quarks+meson cloud model* *T. Pena and Ramalho*

What about time-like region ?

Time-like electromagnetic N-Δ transition

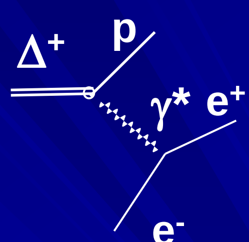
Space Like: $q^2<0$

real $G^{SL}(q2)$
Models constrained by data

Analytic continuation

Time Like: $q^2>0$

complex $G^{TL}(q2)$



However, in the Δ decay process:

q^2 stays small , $q^2 < (M_\Delta - M_p)^2$

at M_Δ =1232 MeV/c², $q^2 < 0.09$ GeV/c²

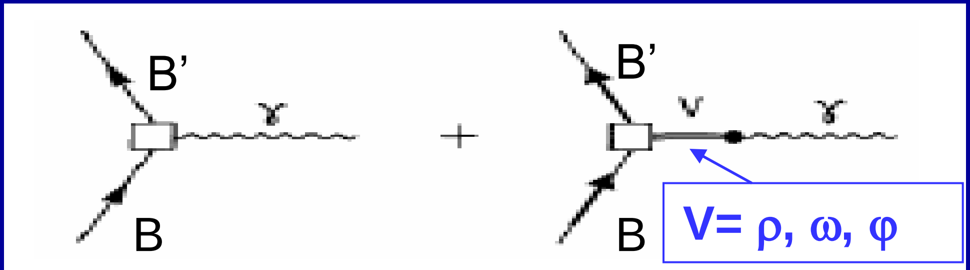
$$\frac{d\Gamma(\Delta \to Ne^+e^-)}{dq^2} = f\left(m_\Delta, q^2\right)\left(\left|G_M^2(q^2)\right| + 3\left|G_E^2(q^2)\right| + \frac{q^2}{2m_\Delta^2}\left|G_C^2(q^2)\right|\right)$$

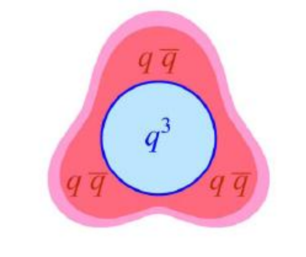
2 options:

- ✓ take **constant form factors (photon point value)**
  HSD, UrQMD, IQMD (transport models)
- ✓ use models **for form factors $G_E(q^2), G_M(q^2), G_C(q^2)$:**
  VDM,eVDM, (RQMD) *two component Iachello model,*
  Bare quark+meson cloud (T.Pena and G. Ramalho)

Iachello two-component quark model

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

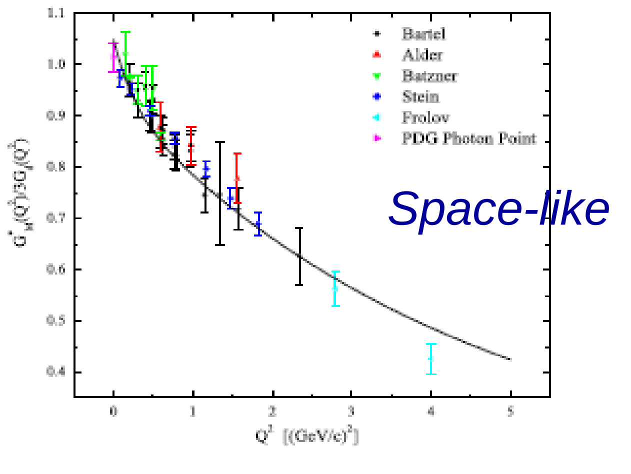




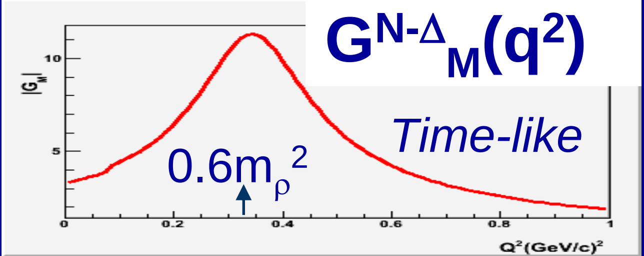
Direct coupling **Coupling mediated by vector mesons**

- ✓ **unified description of baryonic form factors**
- ✓ **analytical derivation of form factor starting from wave functions**
- ✓ **N-Δ transition: 4 parameters fitted on**
  - **elastic nucleon FF (SL+TL)**
  - **SL N-Δ transition G_M**
- ✓ **analytical continuation to Time-Like region**

$G_M^{N\text{-}\Delta}/3G_D$



$G^{N\text{-}\Delta}{}_M(q^2)$



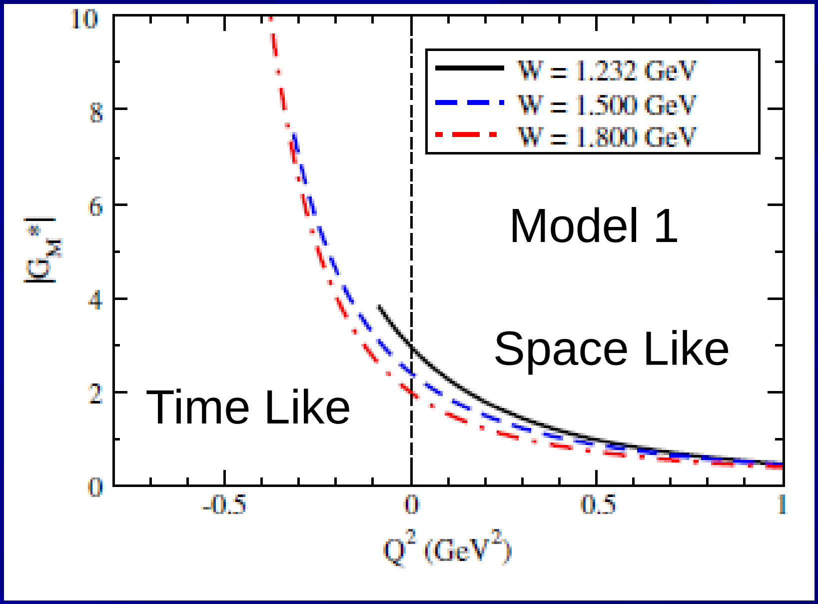
Emilie Moriniere PHD, Orsay
F. Dorhmann et al , EPJA 45,401(2001)

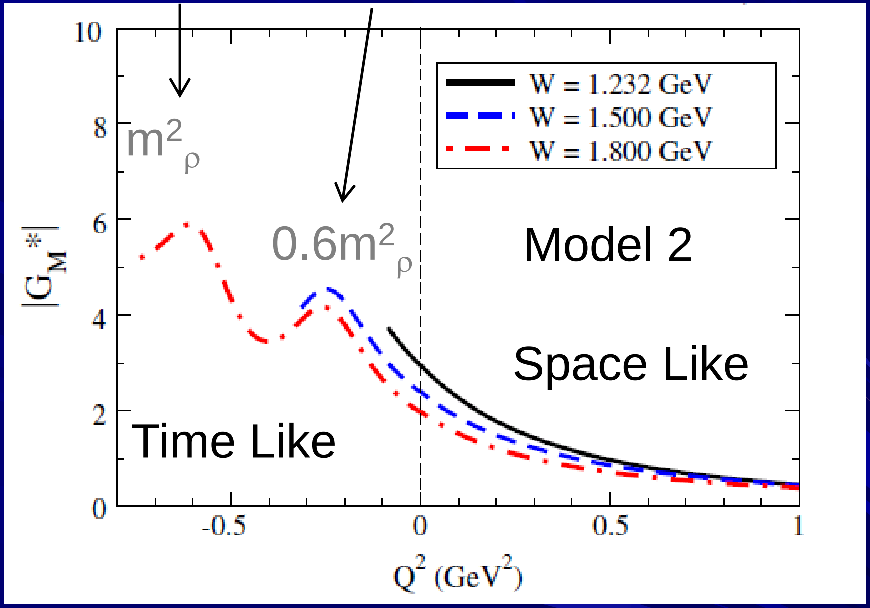
Bare quark+meson cloud model for N-Δ transition em form factor

see G. Ramalho's talk

- ✓ VDM coupling to bare quarks + pion cloud
- ✓ 2 different models for the meson cloud (doing equally well for the Space-Like!)

Coupling to the bare quarks Coupling to the meson cloud

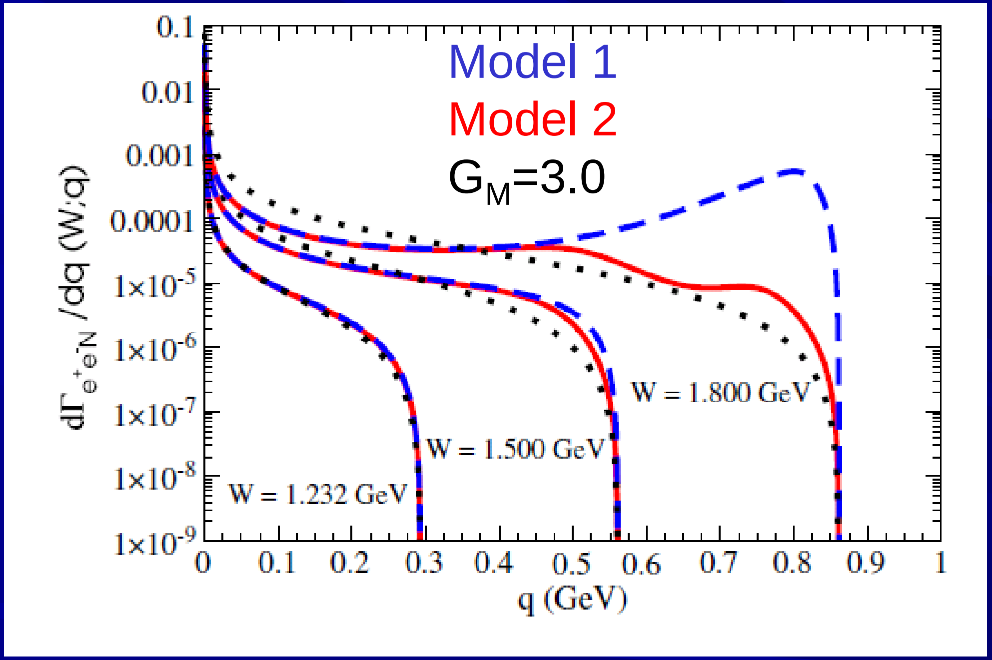




G.Ramalho and T. Pena Phys. ReV. D85,113014 (2012)

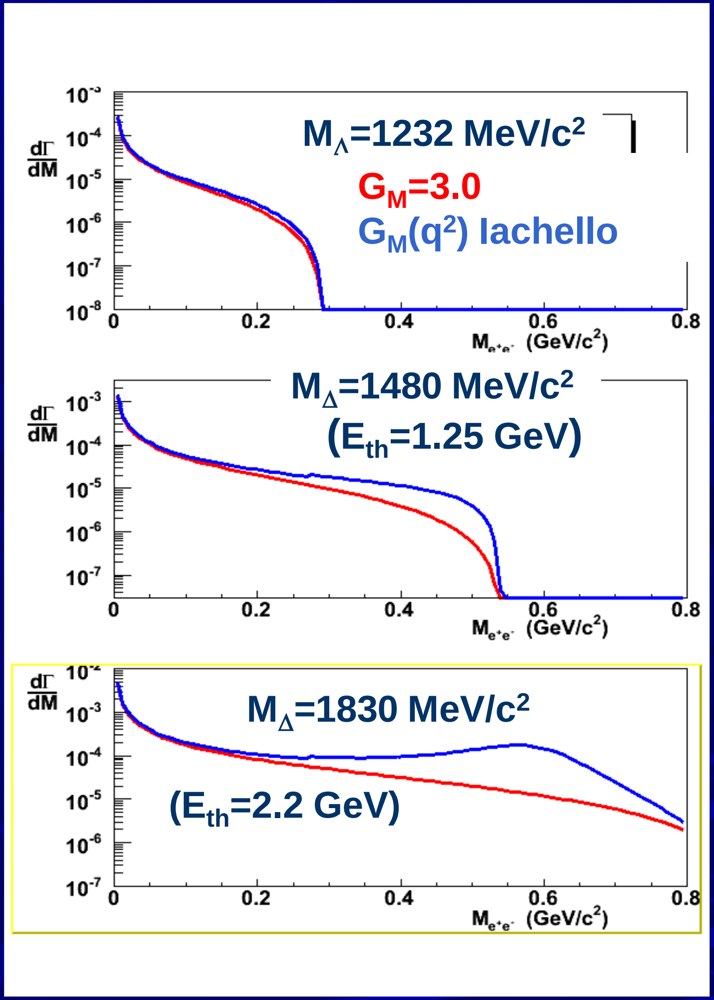
Effect of N-Δ transition form factor on dielectron yields

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



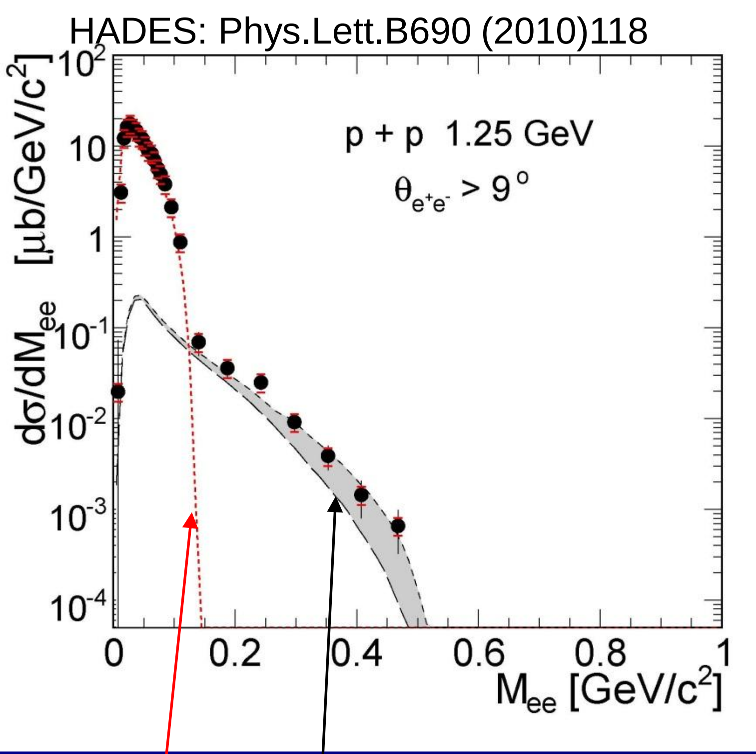
Iachello's model

F. Dorhmann et al , EPJA 45,401(2001)



smaller overall effect on dilepton yield in Ramalho's model

Dilepton production in pp reaction at 1.25 GeV



Resonance model results:
π° Dalitz
Δ Dalitz + effect of Iachello FF

- below η threshold
- only 2 dilepton sources

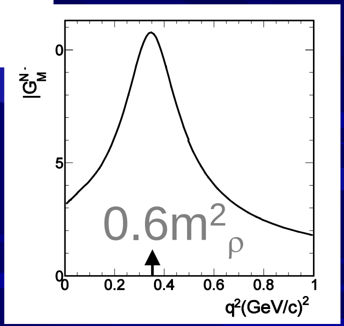
❑ π° Dalitz decay σ_{π° =4.5 mb
branching ratio $\pi^\circ \rightarrow \gamma e^+e^-$ 1.2 %

❑ 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

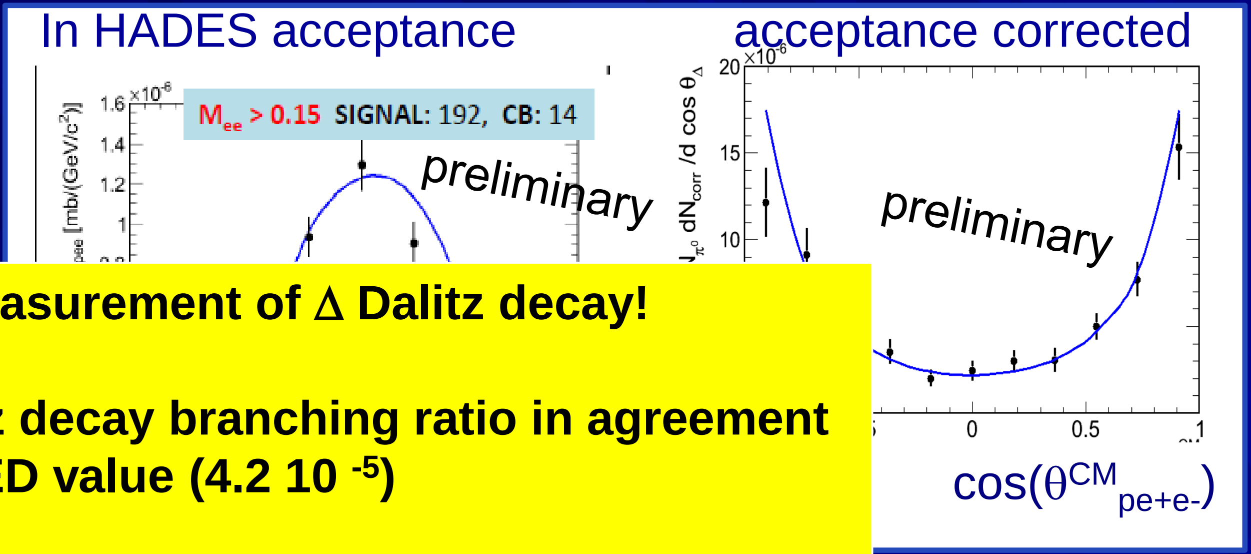
$G_M(q^2)$

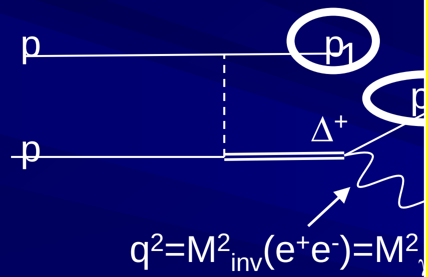


Wan and Iachello Int. J Mod. Phys. A20 (2005) 1846
G. Ramalho and T. *Pena arxiv:* 1205.2575v1 (2012)

exclusive analysis : $pp \to pp e^+e^-$ at 1.25 GeV using pe^+e^- events

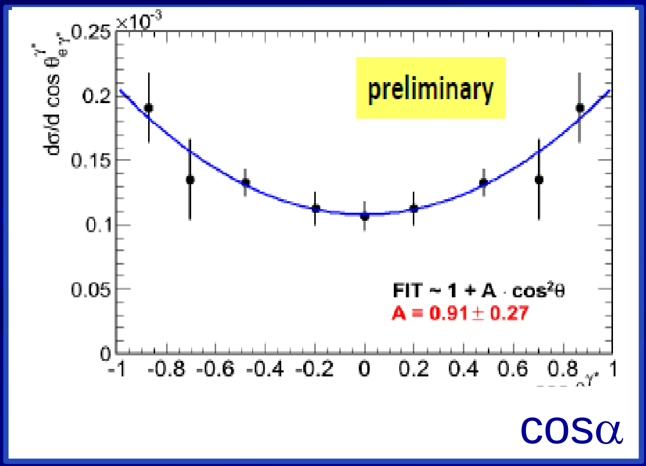
Good agreement with simulation of
Δ production + Dalitz decay
(cf hadronic channels)



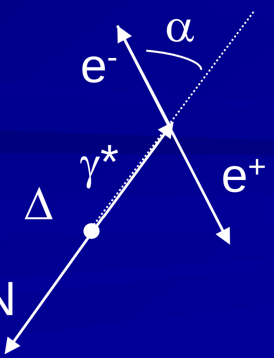


First measurement of Δ Dalitz decay!

- **Dalitz decay branching ratio in agreement with QED value (4.2 10^{-5})**



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



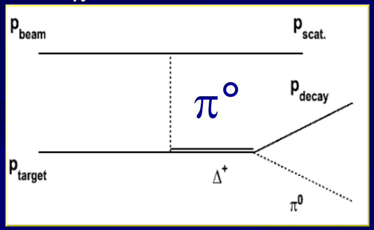
W. Przygoda's analysis
Cracow

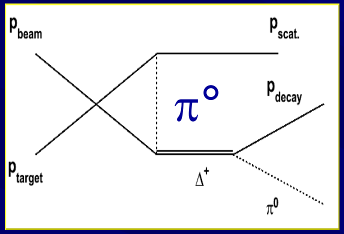
Constrains on Δ production by hadronic channels $pp \to pn\pi^+$, $pp\pi^0$ at E=1.25 GeV

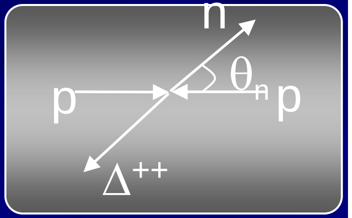
one pion exchange model

(Dmitriev et al., Nucl. Phys. A459, 503 (1986))

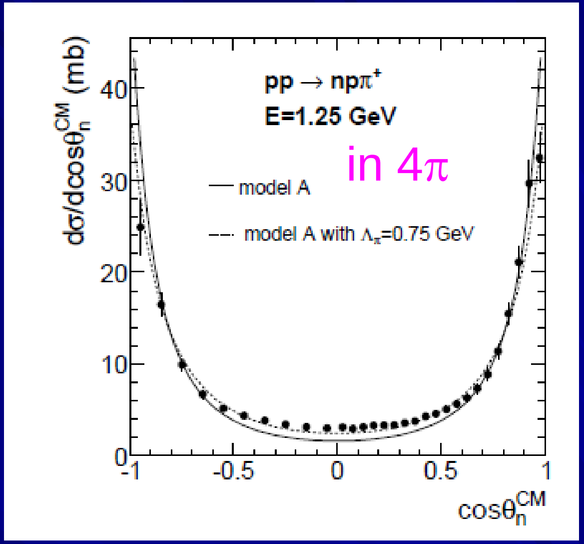
Λ_π=0.63 GeV







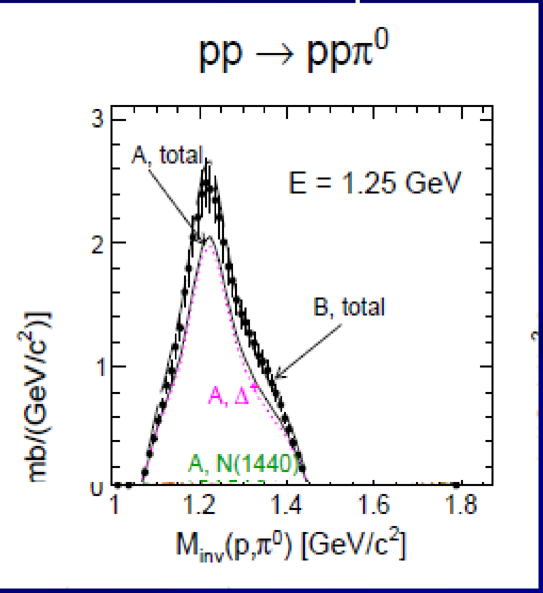
$$F(t) = \frac{\Lambda_\pi^2 - m_\pi^2}{\Lambda_\pi^2 - t}$$



T. Liu's PHD, Orsay

Λ_π= 0.75 GeV gives better description also for $pp \to pp\pi^0$

In HADES acceptance



HADES data EPJA 48 (2012)74

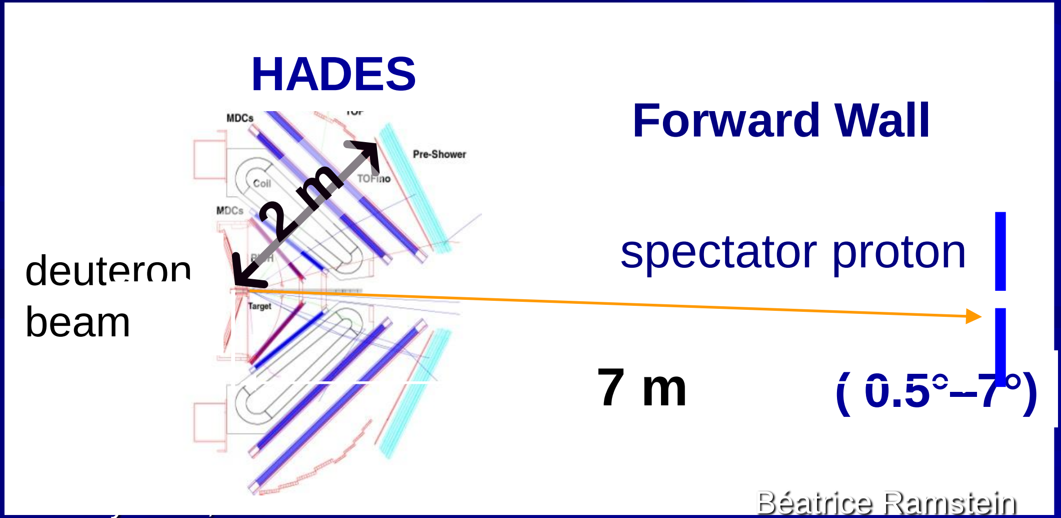
Model A:
original resonance model +N* angular distribution + NN FSI

Model B: taking into account the experimental Δ angular distribution

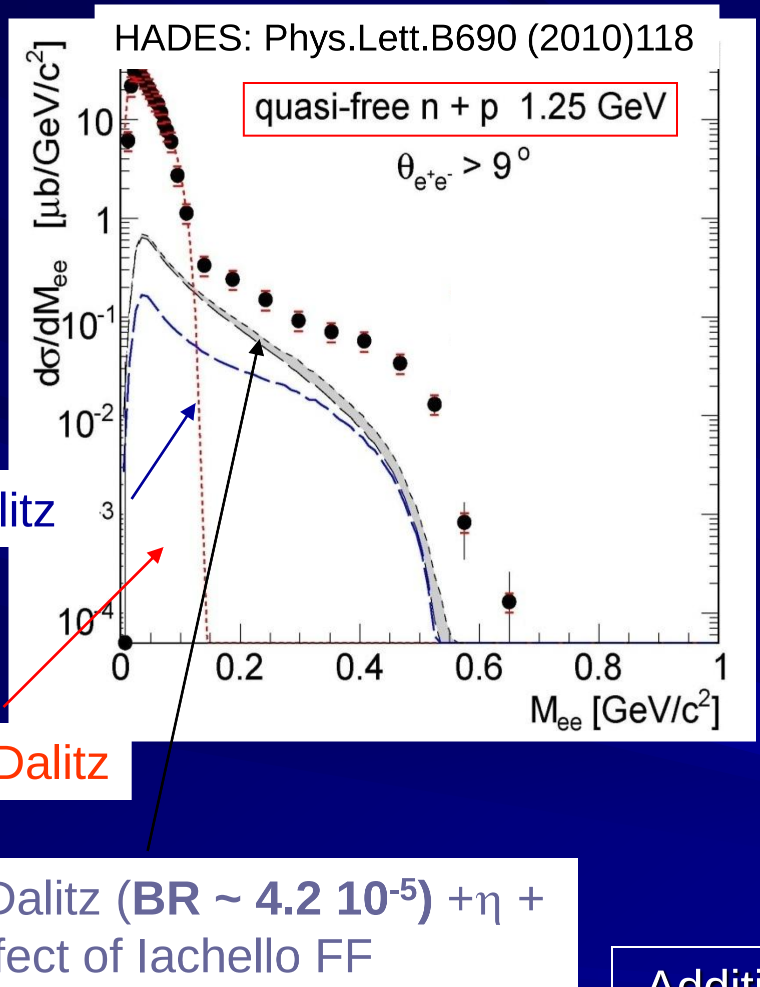
Partial Wave Analysis on-going collaboration with A. Sarantsev (Bonn-Gatchina)

isospin effects in dilepton production ?

→ Comparison of pp and quasi-free pn reactions (from dp experiments)



Quasi-free « pn » dilepton spectra



Comparison to resonance model

- ❑ π° Dalitz decay $\sigma_{\pi°}$ = 8.6 mb
  branching ratio π° →γe+e- 1.2 %
- ❑ Δ Dalitz decay :

New features with respect to pp reactions:

✓ participant neutron Fermi momentum (Paris potential)

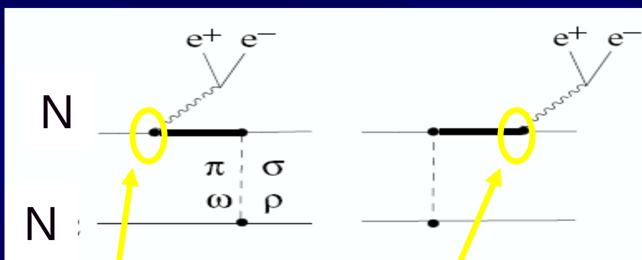
✓ η contribution (due to Fermi motion)

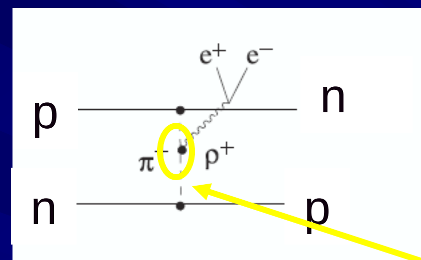
Additionnal sources with respect to pp?
NN Bremsstrahlung is absent !!
→ Check with full One Boson Exchange calculations

NN Bremsstrahlung:

Full OBE: covariant and gauge invariant

meson exchange currents





pn bremsstrahlung larger than pp

Half-off-shell electromagnetic nucleon form factors

Pion form factor ?

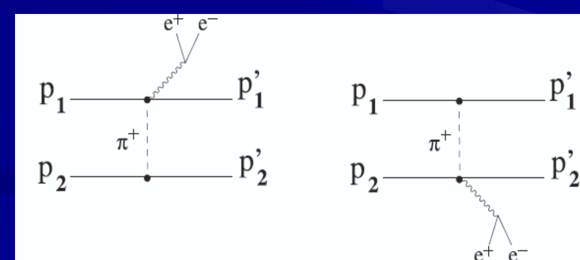
- NNπ PS coupling

R. Shyam & U.Mosel, PRC67 (2003) 065202

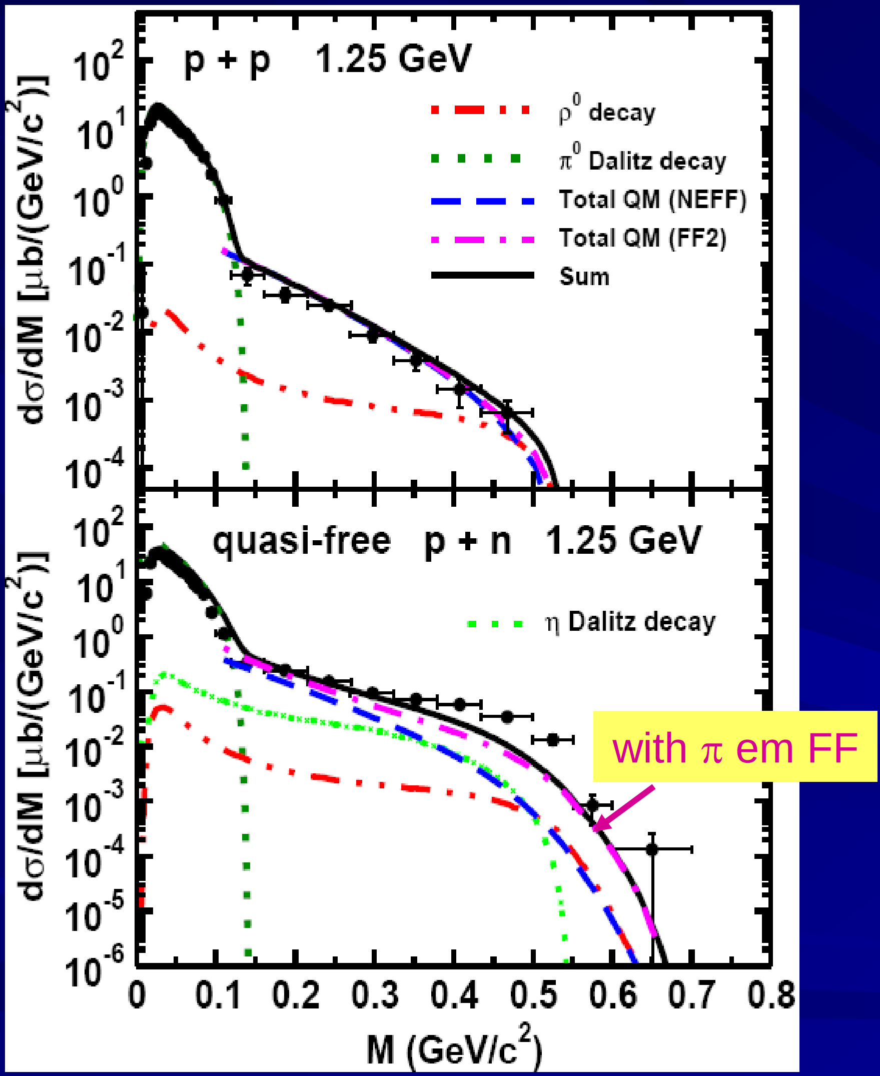
- NNπ PV coupling

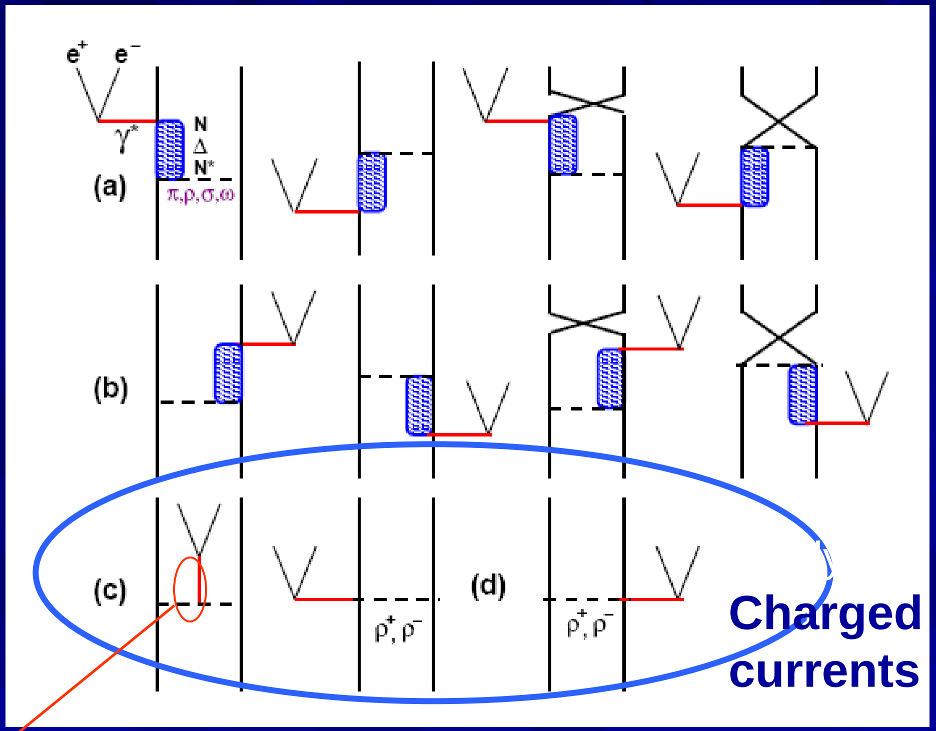
Kaptari&Kämpfer, NPA 764 (2006) 338

Gauge invariance → contact terms needed



New (2010) OBE calculations for pn→pne+e-





R. Shyam and U. Mosel **arXiv:1006.3873**

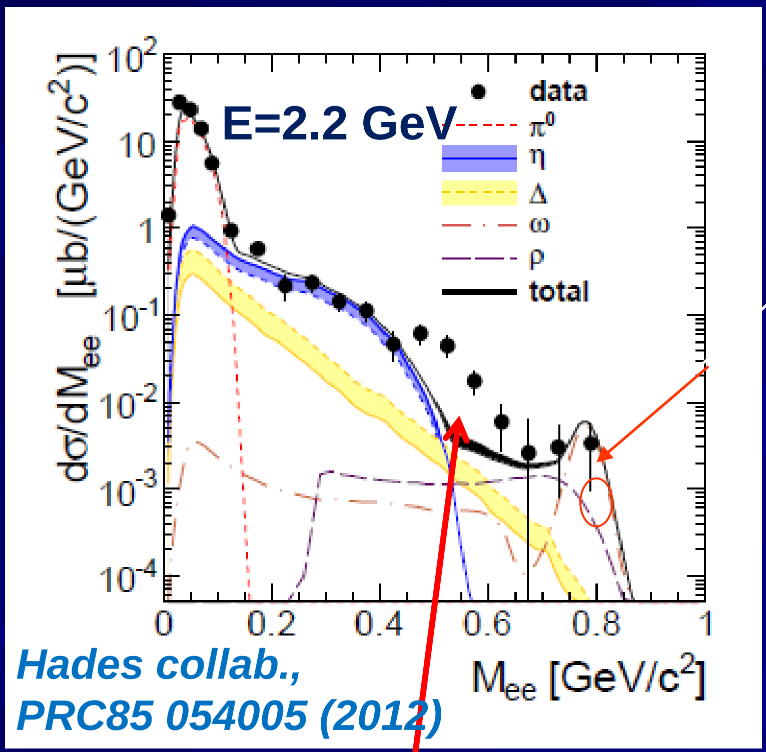
- much better agreement with data !
- sensitivity to hadronic electromagnetic structure

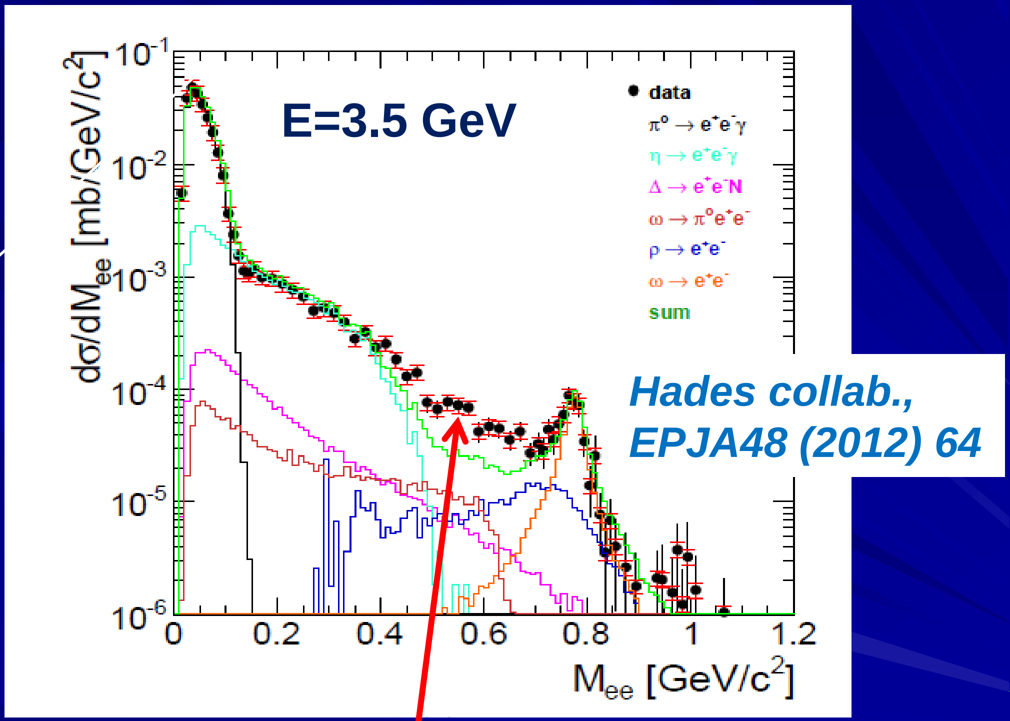
also studied in quasi-free pn reactions:

- ➢ pionic channels
- ➢ exclusive pn→pne$^+$e$^-$

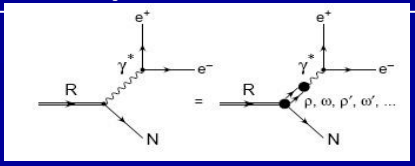
pp→e^+e^-X E=2.2 GeV,3.5 GeV

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





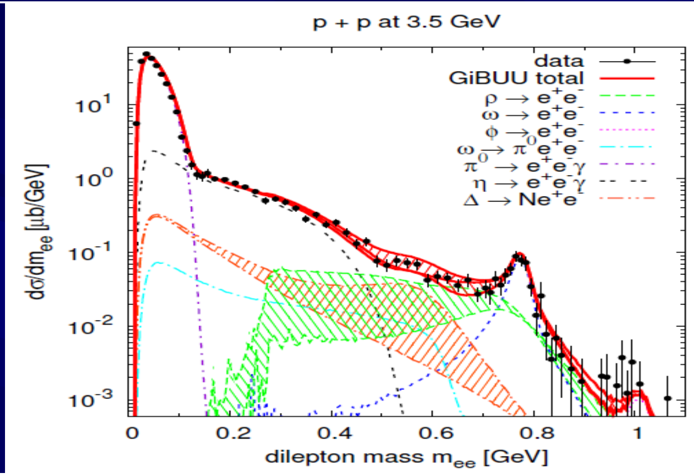
Effect of electromagnetic form factors / Coupling of ρ to baryonic resonances ?



Orsay GDR, 03/10/2012 Béatrice Ramstein

pp→e⁺e⁻X E=3.5 GeV GiBUU model

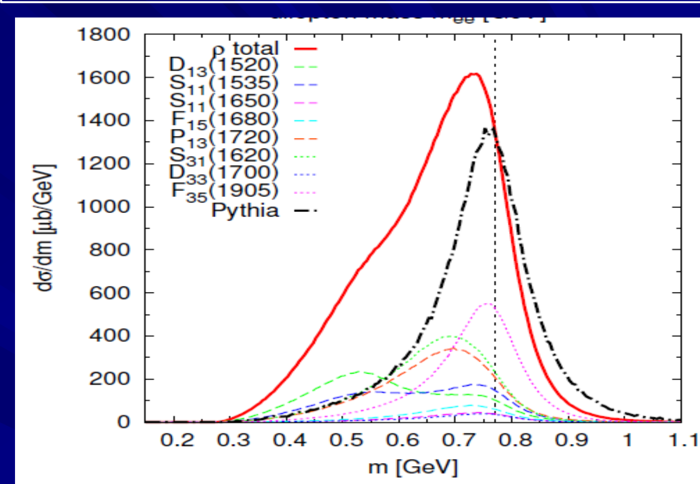
Effect of N-Δ form factor and of ρ coupling to baryonic resonances



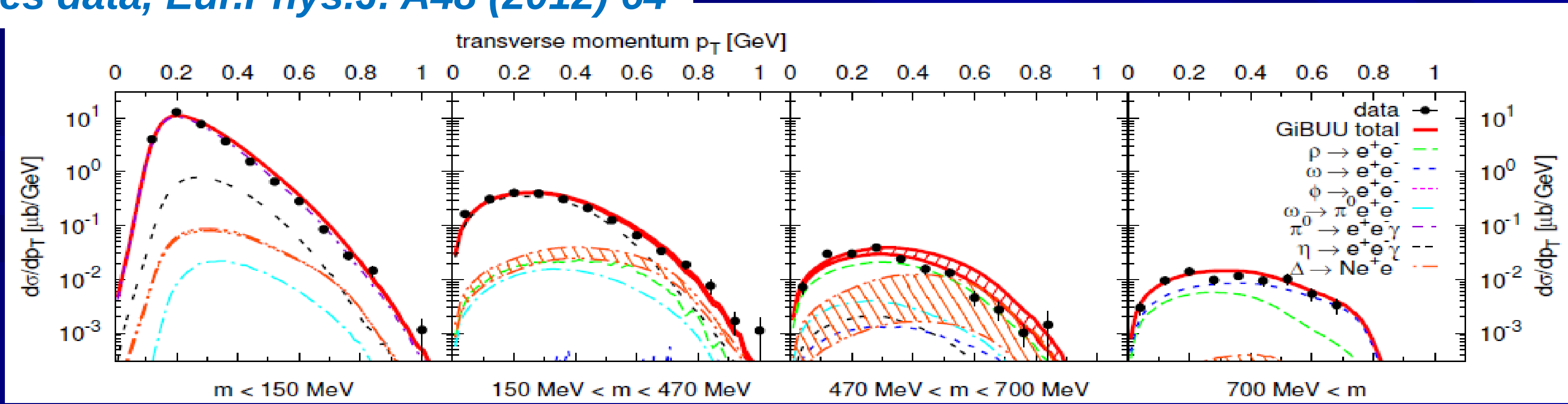
J. Weil, H. van Hees, U. Mosel arxiv:1203.3557v1

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

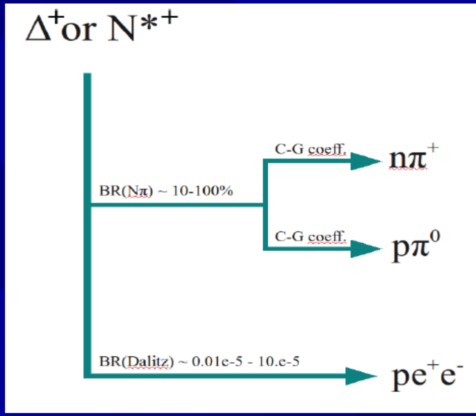
ρ mass distribution strongly modified (in pp !)



Transverse momentum distributions
→ constrains for the different contributions



Fixing resonance contribution : exclusive hadronic channels in p+p @ 3.5 GeV

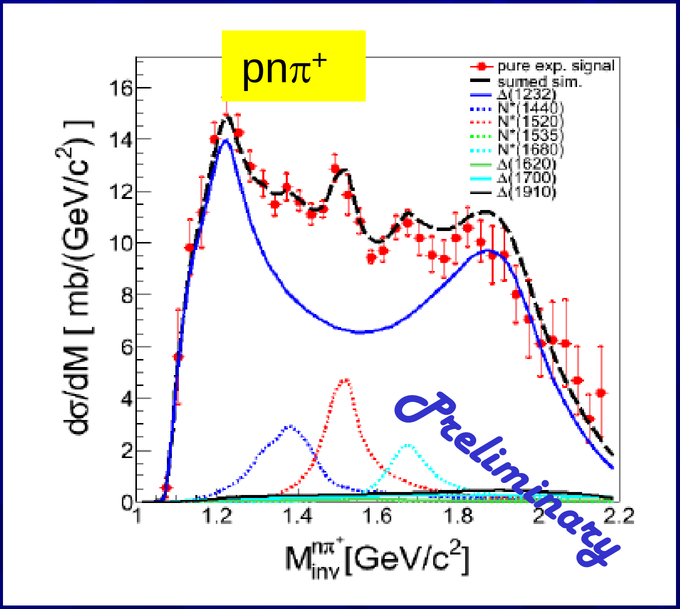


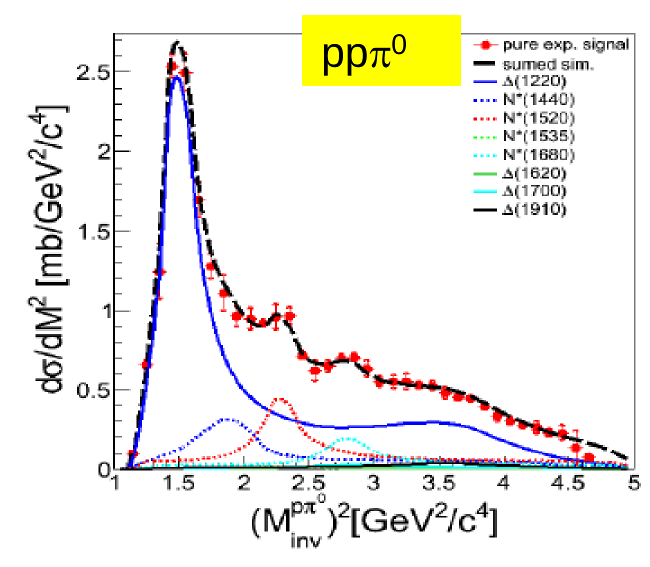
Many differential distributions studied for $pp\pi^0$, $pn\pi^+$, $pp\eta$, $pp\omega$

A. Dybczak, Cracow

J^P	Resonance	σ_{Res} [mb]	$\sigma_{\pi+}$ [mb]	σ_{π^0} [mb]
3/2+	$\Delta(1232)^{++}$	7.60±0.92	7.60±0.92	—
3/2+	$\Delta(1232)^{+}$	2.53±0.31	0.85±0.10	1.69±0.20
1/2-	$\Delta(1620)^{++}$	0.30±0.07	0.08±0.02	—
1/2-	$\Delta(1620)^{+}$	0.10±0.03	0.01±0.01	0.02±0.01
3/2-	$\Delta(1700)^{++}$	1.35±0.47	0.20±0.07	—
3/2-	$\Delta(1700)^{+}$	0.45±0.16	0.02±0.01	0.05±0.02
1/2+	$\Delta(1910)^{++}$	1.15±0.32	0.29±0.08	—
1/2+	$\Delta(1910)^{+}$	0.38±0.25	0.03±0.01	0.07±0.02
1/2+	$N^*(1440)^{+}$	1.50±0.27	0.65±0.12	0.39±0.07
3/2-	$N^*(1520)^{+}$	2.10±0.34	0.77±0.12	0.39±0.06
1/2-	$N^*(1535)^{+}$	0.12±0.04	0.04±0.01	0.02±0.01
5/2+	$N^*(1680)^{+}$	0.90±0.15	0.39±0.06	0.20±0.03

† - N*1535 constarinted by $pp \rightarrow pp\eta$ channel (Khaled Teilab Phd thesis).



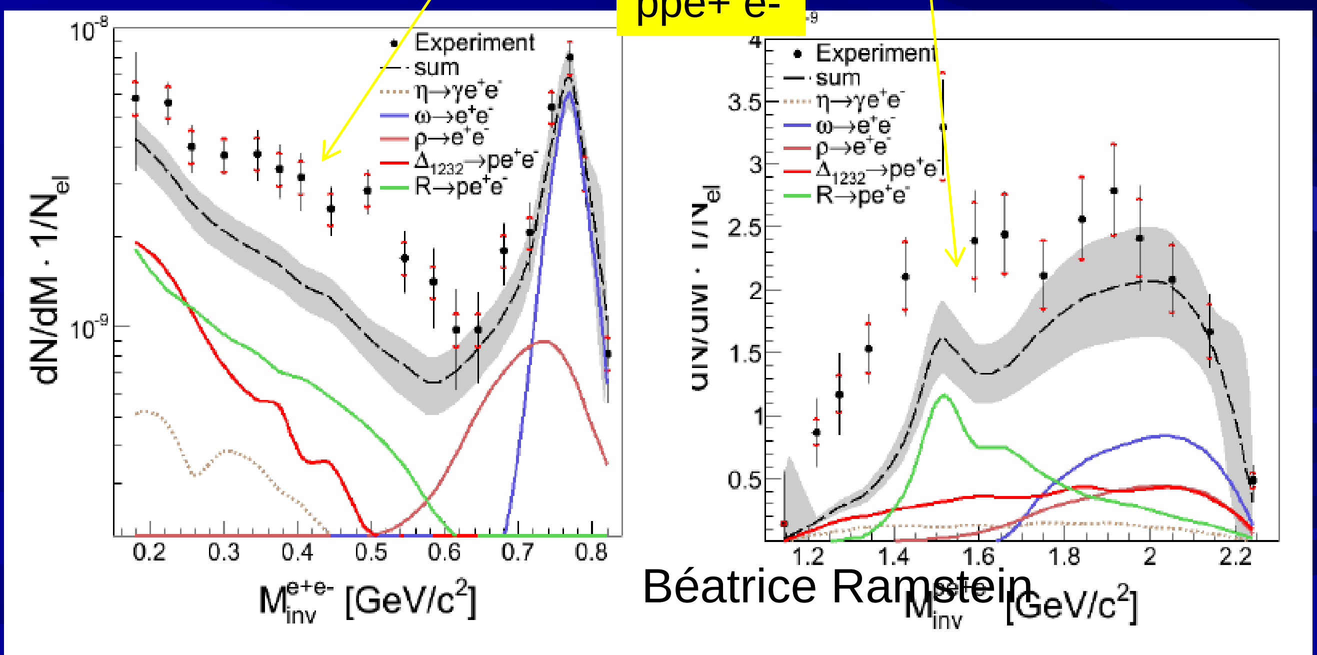


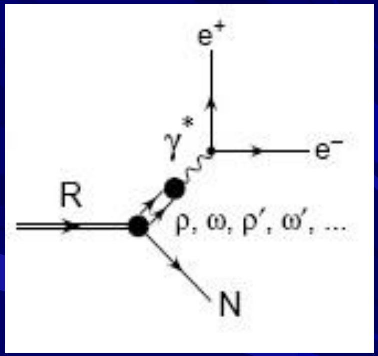
Exclusive pe^+e^- channel

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*

Missing yield related to off-shell coupling of baryonic resonances to vector mesons

ppe+ e-





A. Dybczak, Cracow

Béatrice Ramstein

More results in pp reactions…

✓ π^0 and η Dalitz decay reconstruction in pp reactions

✓Exclusive dilepton production in $pn \rightarrow pne^+e^-$, $pn \rightarrow pde^+e^-$

✓Strange channels: $\Sigma(1385)$,$\Lambda(1405)$,…
Phys.Rev. C85 (2012) 035203
Nucl.Phys. A881 (2012) 178-186

✓Partial wave analysis for $pp \rightarrow NN\pi$ and $pp \rightarrow pK\Lambda$: *collaboration with A. Sarantsev (Bonn-Gatchina)*

✓2π production in $pp \rightarrow pp\pi^+\pi^-$, $pn \rightarrow pn\pi^+\pi^-$, $pn \rightarrow d\pi^+\pi^-$
$\Gamma(N^* \rightarrow \Delta\pi)/\Gamma(N^* \rightarrow N\sigma)$ and sensitivity to N* and double Δ production mechanisms

……

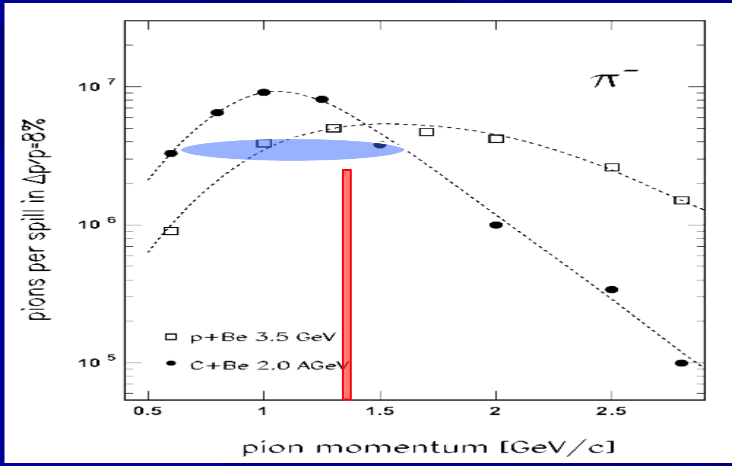
Perspectives of pion beam experiments

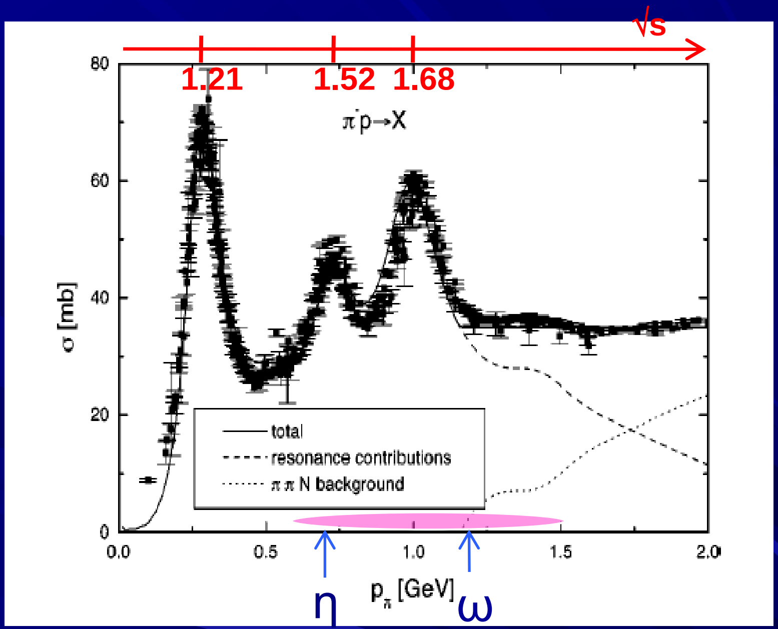
GSI pion beam

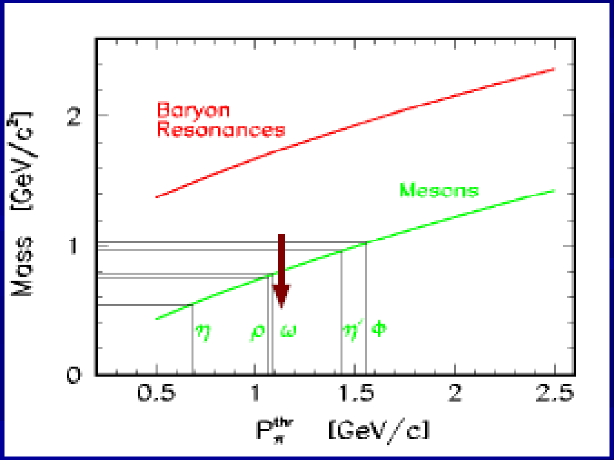
Expected Intensities for Space Charge Limit and 100% extraction efficiency

I ~ 10^6/s

Pion momentum 0.6 < p <1.5 GeV/c



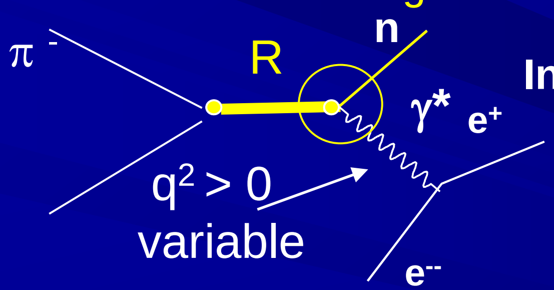




Motivations of πN experiments with HADES: Dilepton channels

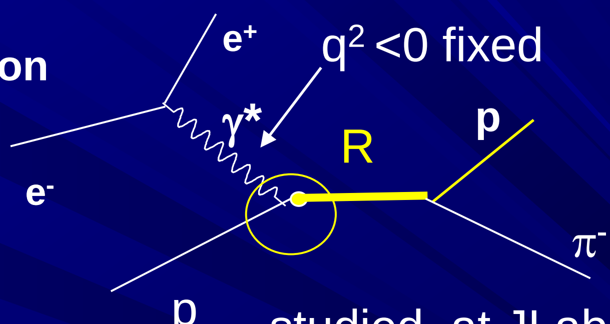
- **well-known production mechanism**
- **fixed resonance mass M_R=sqrt(s)**
- **exclusive** $\pi^- p \rightarrow n\, e^+e^-$ **channels** (η contribution can be rejected)

Time-Like electromagnetic form factors



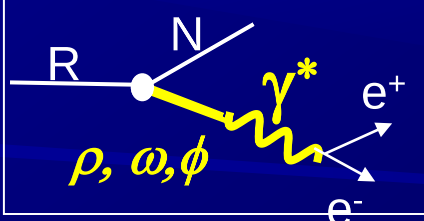
Inverse pion electroproduction

Space-Like electromagnetic form factors



studied at JLab/CLAS

03/10/2012



Vector Dominance Model

$\rightarrow$ ρ/ω coupling

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

Simulations for dilepton production below ω threshold

(omega threshold p_{th}=1.03 GeV/c)

Simple resonance model:
Incoherent sum of Dalitz decay of different baryonic resonances with constant form factors
+ meson contribution

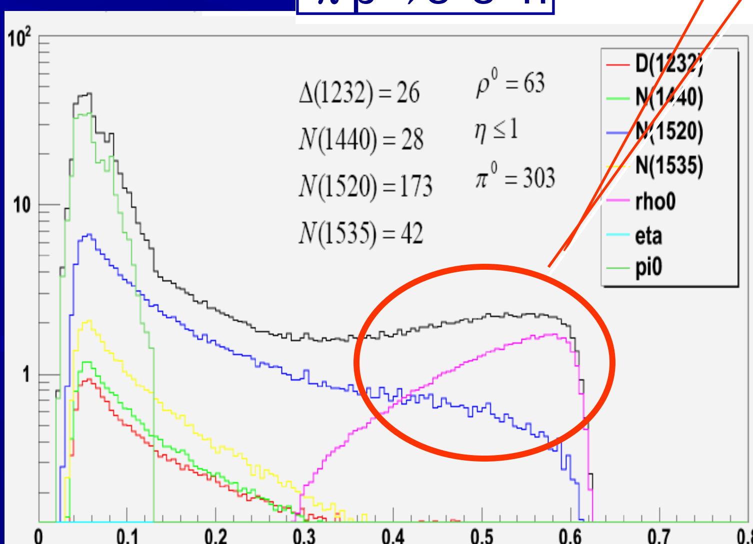
H. Kuc PhD Orsay/Cracovie

Efects of electromagnetic form factors ?

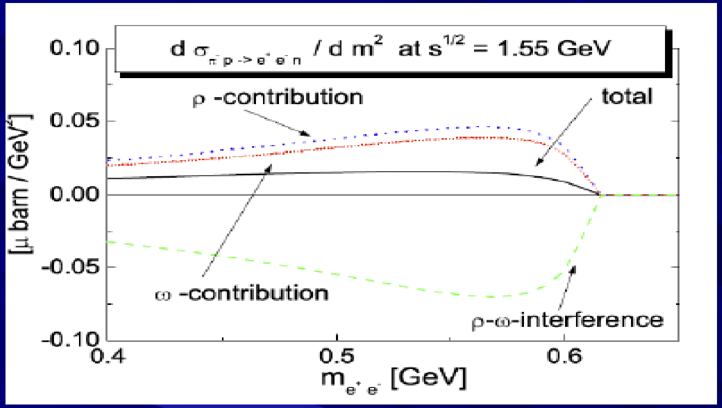
Important interference effects expected between I=0 (ω) and I=1 (ρ) channels
Linked to coupling to baryonic resonances

P=0.8 GeV/c

after missing mass cut
$\pi^- p \rightarrow e^+ e^- n$



M_{ee}(GeV/c²)



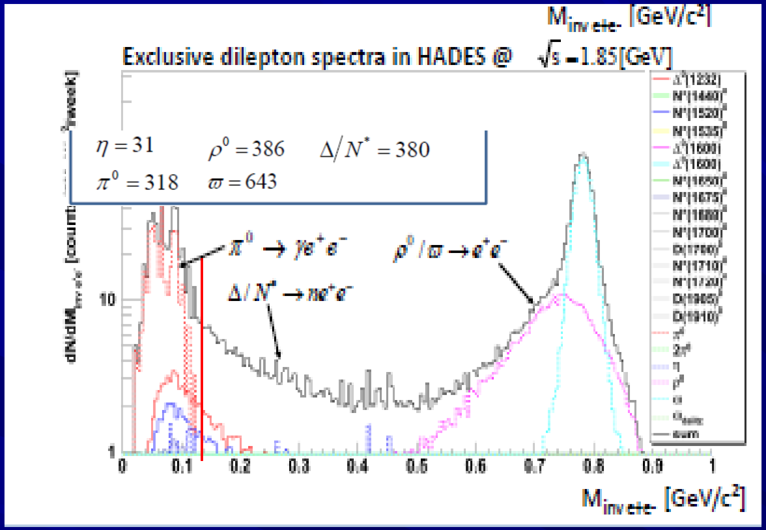
Calculations based on hadronic couplings
M. Lutz, B. Friman, M. Soyeur, NPA 713 (2003) 9
Titov and Kämpfer EPJA 12 (2001) 217

Very new calculation based on VDM transition form factors by Zetenyi and Wolf
arXiv:1208.5671v1 [nucl-th]

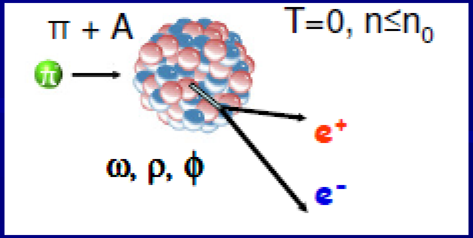
ρ/ω production in $\pi^- p \rightarrow e^+e^- n$ reaction

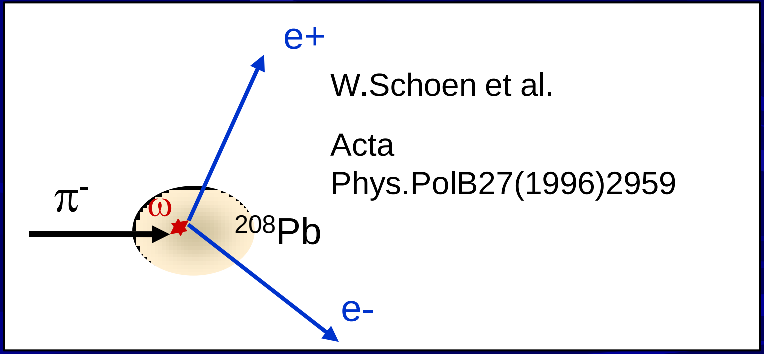
p=1.3 GeV/c √s=1.85 GeV/c

In HADES acceptance
after missing mass cut
$\pi^- p \rightarrow e^+e^- n$
1 week beam time



Reference for cold matter effect : dilepton production in π^-A reactions

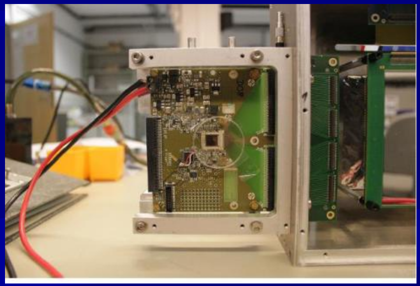


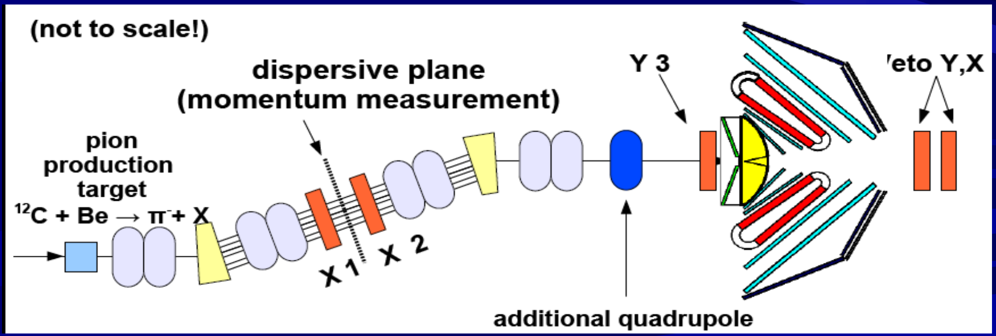


More to be done with the π beam…

- ✓ white book on physics program being written……
- ✓ $\pi^- p \to N\pi\pi$: improve the very poor existing data base needed for baryonic resonance characterization in modern Partial Wave Analysis
- ✓ $\pi^- p \to \omega n$
- ✓ strangeness channels : $\pi^- p \to K\Sigma$, $\pi^- p \to \phi N$, $\pi^- + p \to \Lambda K^0$
  $\Lambda(1405)$ structure issues:
- ✓ $\Lambda(1405) \to K^- p$ and $\Lambda(1405) \to \pi\Sigma(1194)$ *B. Saghai (Saclay), E. Oset (Valencia)*
- ✓ *πA: medium effects in dilepton and strangeness production*

✓ technical issues: **in beam, position sensitive detectors *being developped in Munich***





Conclusions: HADES experiments

- **Elementary reaction program**
  - **reference for medium effects**
  - **Selective study of dilepton processes, cross section measurements**
  - **Time-like electromagnetic structure of baryonic resonances/coupling to vector mesons**
  - **hadronic channels (Partial Wave analysis)**

- **perspectives of pion beam experiments (→ 2013)**
  - **Cold nuclear matter : π^-A dilepton production**
  - **Dilepton channels in πN→ Unique chance to study Time-Like electromagnetic structure of higher lying resonances (complementary to pion electroproduction)**
  - **two pion production, new data (differential spectra) highly needed for Partial wave Analysis → baryonic resonance properties**
  - **strangeness channels Σ(1385), Λ(1405),…**
  - **Electromagnetic calorimeter → photon and neutral meson detection (radiative decays, eta production, strangeness channels)**

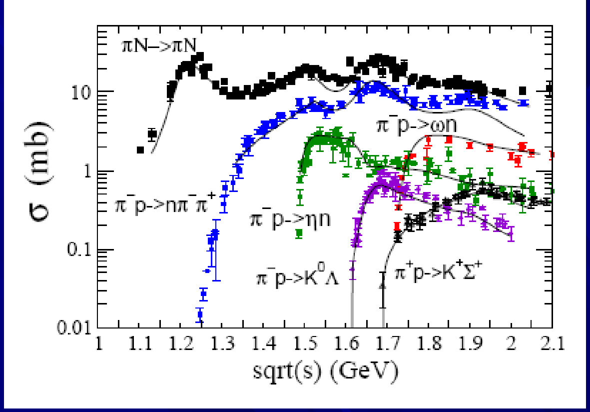
- **Before HADES moves to FAIR !**

Béatrice Ramstein 34

Thank you for your attention

Béatrice Ramstein 35

$\pi^- p \rightarrow N\pi\,\pi$



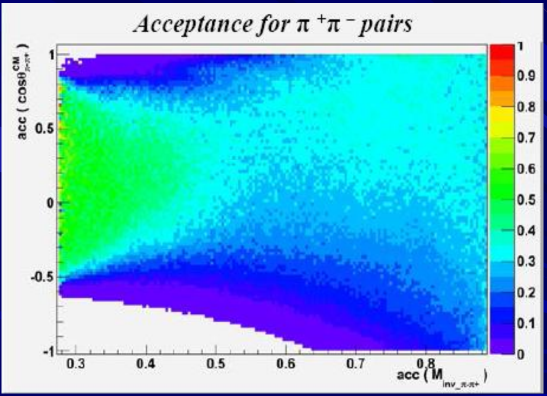
A paradoxical situation:

- modern Partial Wave Analysis recently allows more powerful analysis
- The low statistics old data are not available anymore
- Most $\pi\,\pi$ decay branching ratios for baryonic resonances in PDG are based on

D.M. Manley, R. Arndt, Y. Goradia, V.Teplitz, Phys Rev D 30, 904 (1984)

- More recent data (TRIUMF,LAMPF,BNL) do not cover the region between 1.32 and 1.9 GeV

$\rightarrow$ high statistics differential distributions are needed



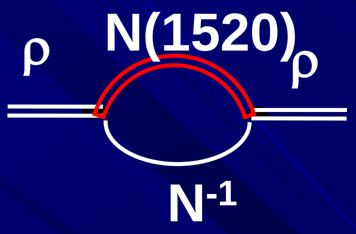
and can be provided by HADES !

$\pi^- p \rightarrow N\pi\,\pi$

Regions of interest:/open issues:

N(1440) P_{11} — Branching ratios to $\pi\Delta$ and $(\pi\,\pi)_s$ N

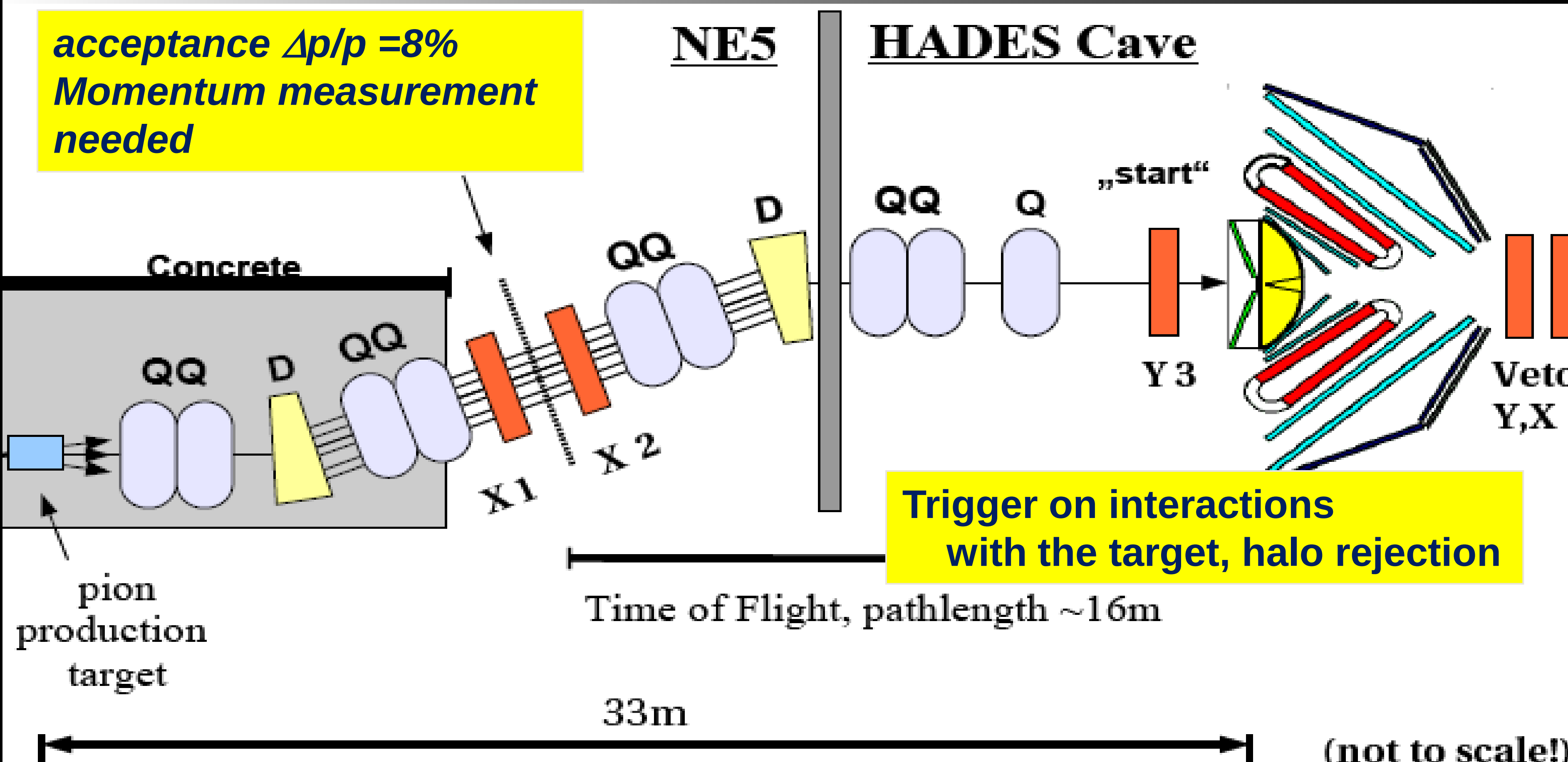
N(1520) D_{13} — Branching ratios to $\pi\Delta$ and ρN, important for ρ in-medium calculations



N(1710) P_{11} — Not seen in the latest PWA analysis
BR(2π) =40 to 90 % (PDG 2010)

Beam Line Setup (sketch)

acceptance Δp/p =8%
Momentum measurement needed



Trigger on interactions with the target, halo rejection

in beam, position sensitive detectors
- **optimization of pion production yield (duty cycle, primary beam intensity)**
- **optimization of beam line acceptance and extension at the target**

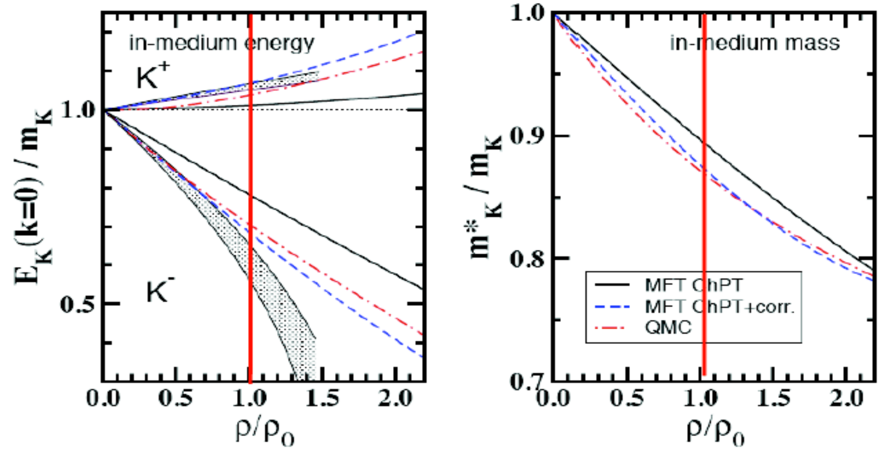
Strangeness channels with pion beams

- In $\pi^- A$ reactions:

  $\phi \to K^+ K^-$ in-medium modifications

- Kaons in medium: $K^\pm$

KN potential



C.J. Batty, E. Friedmann, A. Gal, Nucl. Rep. 287 (1997) 385.
K. Tsushima, K. Saito, A.W. Thomas, S.V. Wright, Phys. Lett. B 429 (1998) 239.
G.E. Brown and M. Rho, Nucl. Phys. A 596 (1996) 503.

- Λ (1405) in $\pi^- p \to K^0 \Lambda(1405)$

  $K^0 \to \pi^+ \pi^-$

  $\Lambda(1405) \to \pi^+\Sigma^-$ (1194) or $\pi^-\Sigma^+$ (1194)

- $\pi^- + p \to \Lambda K^0$

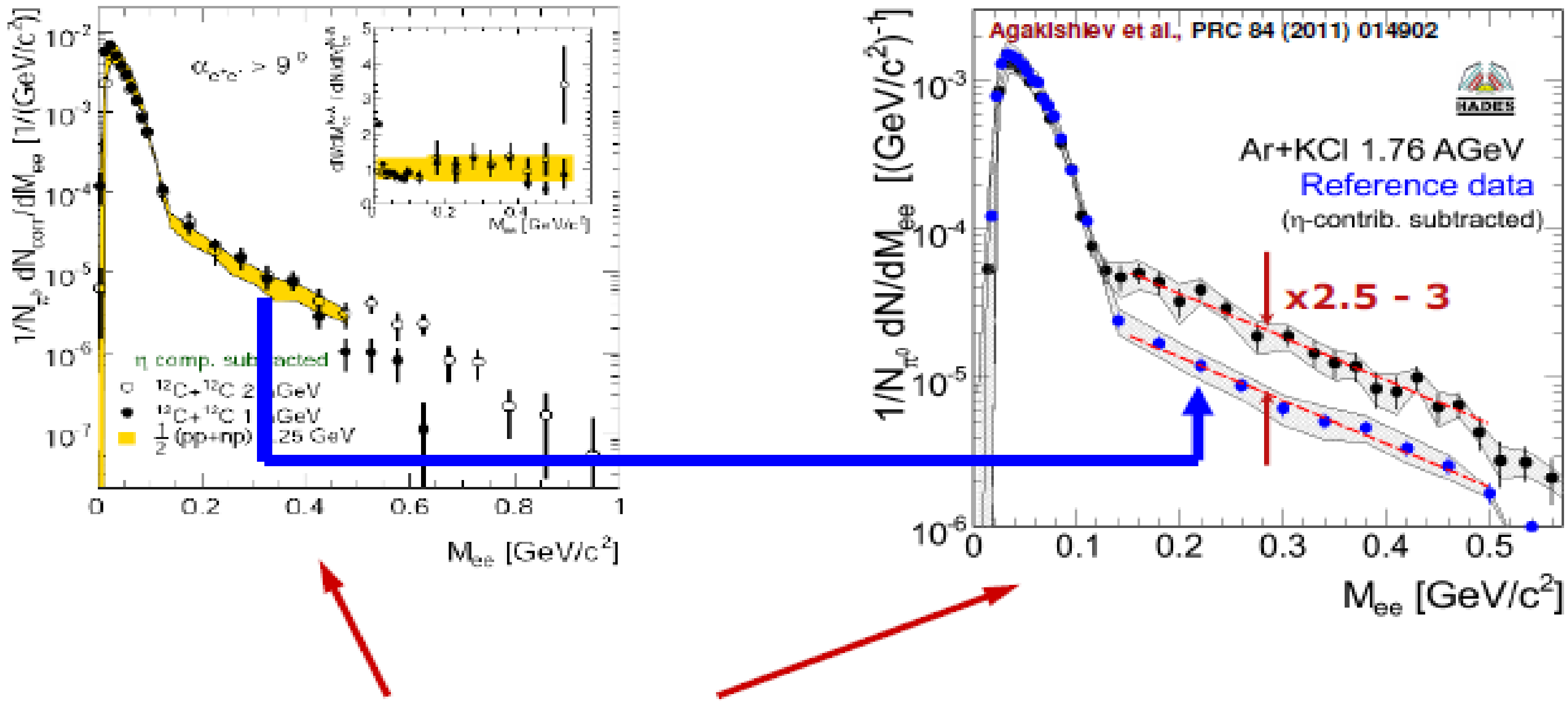
  $\Lambda \to p\,\pi^-$; $K^0 \to \pi^+ \pi^-$

$\to$ sensitive test for the resonance contribution

pp/pn as a reference to in-medium dilepton excess :

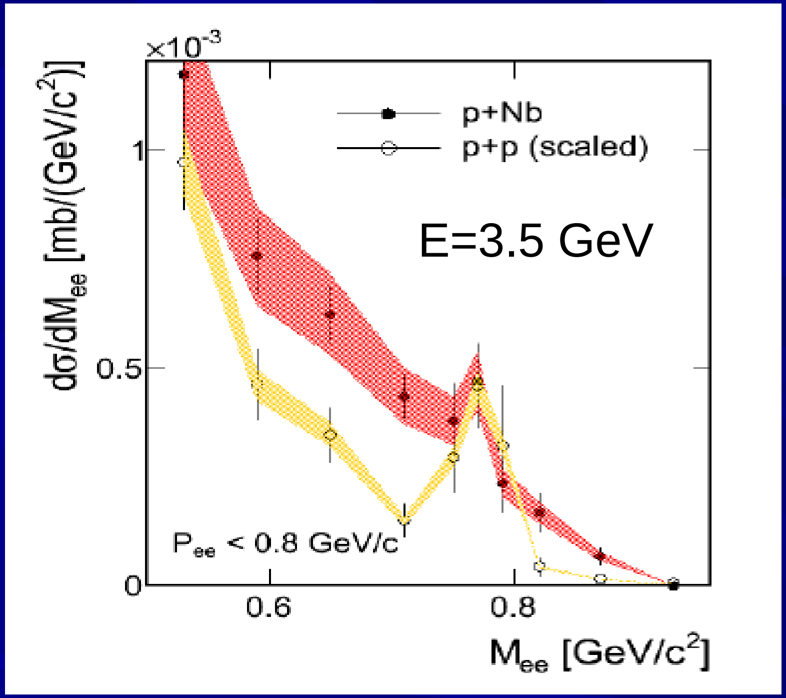
Definition of a **"reference"** based on pp and np data:

Compare excess over η in Ar+KCl with excess over η in reference



- **η contributions subtracted !**
- **yield normalized to M(π^0)** ►► **Strong excess over free NN!**

pp as a reference to cold nuclear matter effects:



Cold nuclear matter effect:

- strong ω absorption

- excess below the vector meson poles
ρ meson modifications ?

Or secondary pion induced reactions
π+N → Δ (1720,..)(N* (1520),..) →Ne+e- ?

can be constrained by pp analysis !

In-medium Vector Meson spectroscopy

The advent of **high-resolution** & **high-statistics** experiments:

- **NA60** at the CERN SPS: $In+In \rightarrow \mu^+\mu^-$
- **HADES** at GSI: $p+p$, $p+A$, $A+A \rightarrow e^+e^-$
- **E325** at the KEK PS: $p+Cu \rightarrow e^+e^-$
- **CLAS** at JLAB: $\gamma+A \rightarrow e^+e^-$
- **CB/TAPS** at ELSA: $\gamma+A \rightarrow \omega \rightarrow \pi^0\gamma \rightarrow 3\gamma$
- **LEPS** at SPring-8: $\gamma+A \rightarrow \phi \rightarrow K^+K^-$
- **ANKE** at COSY: $p+A \rightarrow \phi \rightarrow K^+K^-$

Have to deal with final state interactions of VM decay products

And, of course

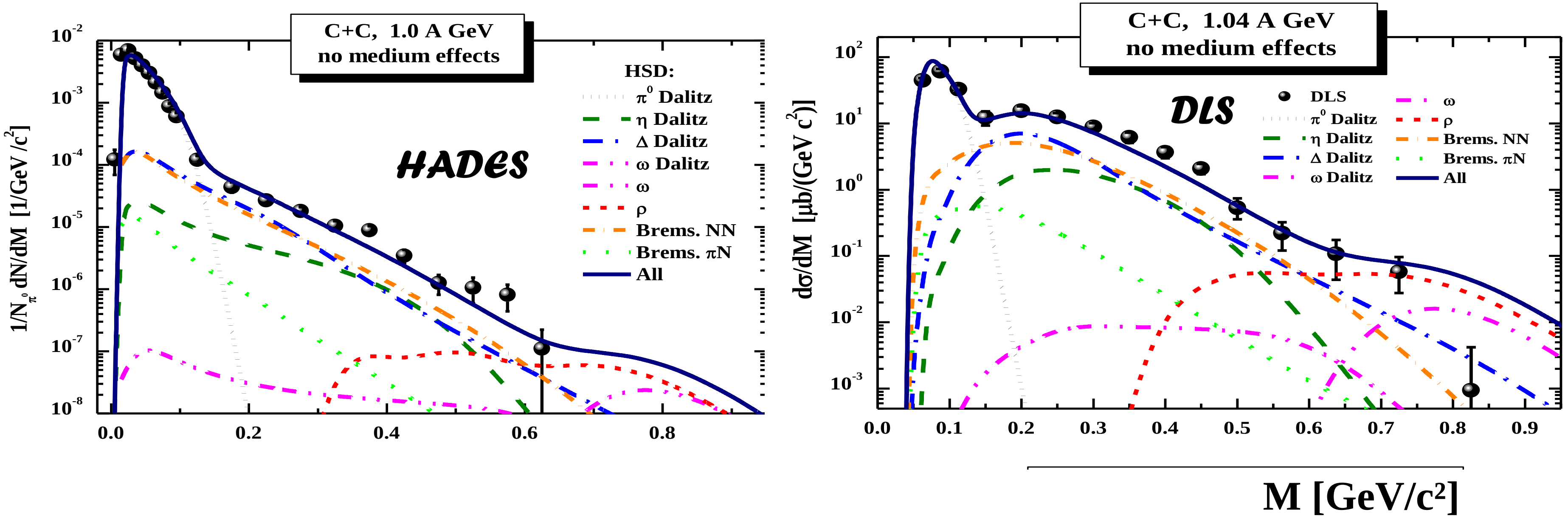
- PHENIX & STAR at RHIC
- ALICE, ATLAS & CMS at LHC

first HADES data put an end to the DLS puzzle

1997: transport models failed to explain DiLeptonSpectrometer (Berkeley) data

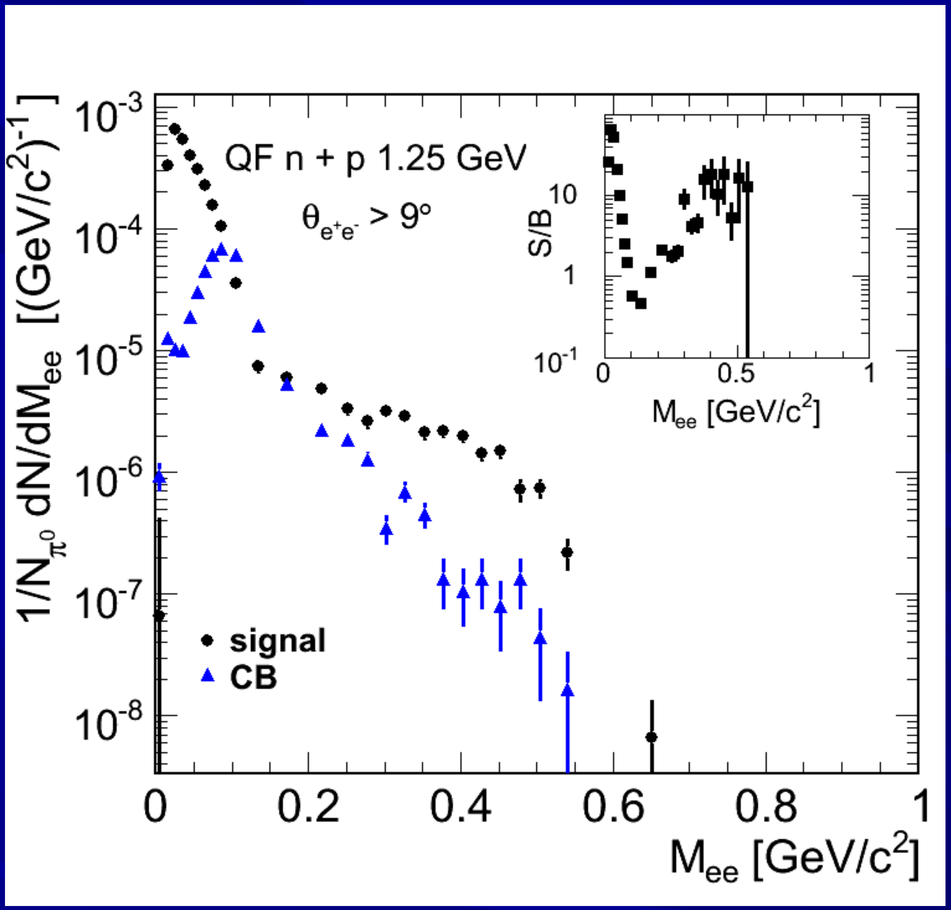
2007: DLS and HADES agree and are compatible with new transport model calculations ***G.Agakichiev et al. Phys. Lett. B 663,43 (2008)***

Hadron String Dynamics
E. Bratkovskaya and W.Cassing, nucl-th/0712.0635



Improved theoretical treatment of elementary dilepton sources

Analysis steps : one example



Forward Wall (np selection):

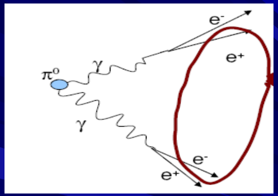
1. Mult > 0
2. search for particle with 1.6 GeV < p < 2.6 GeV

(e^+,e^-) pair cuts:

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

Combinatorial background:
like sign pairs

$$N^{CB}=2sqrt(N^{++}N^{--})$$



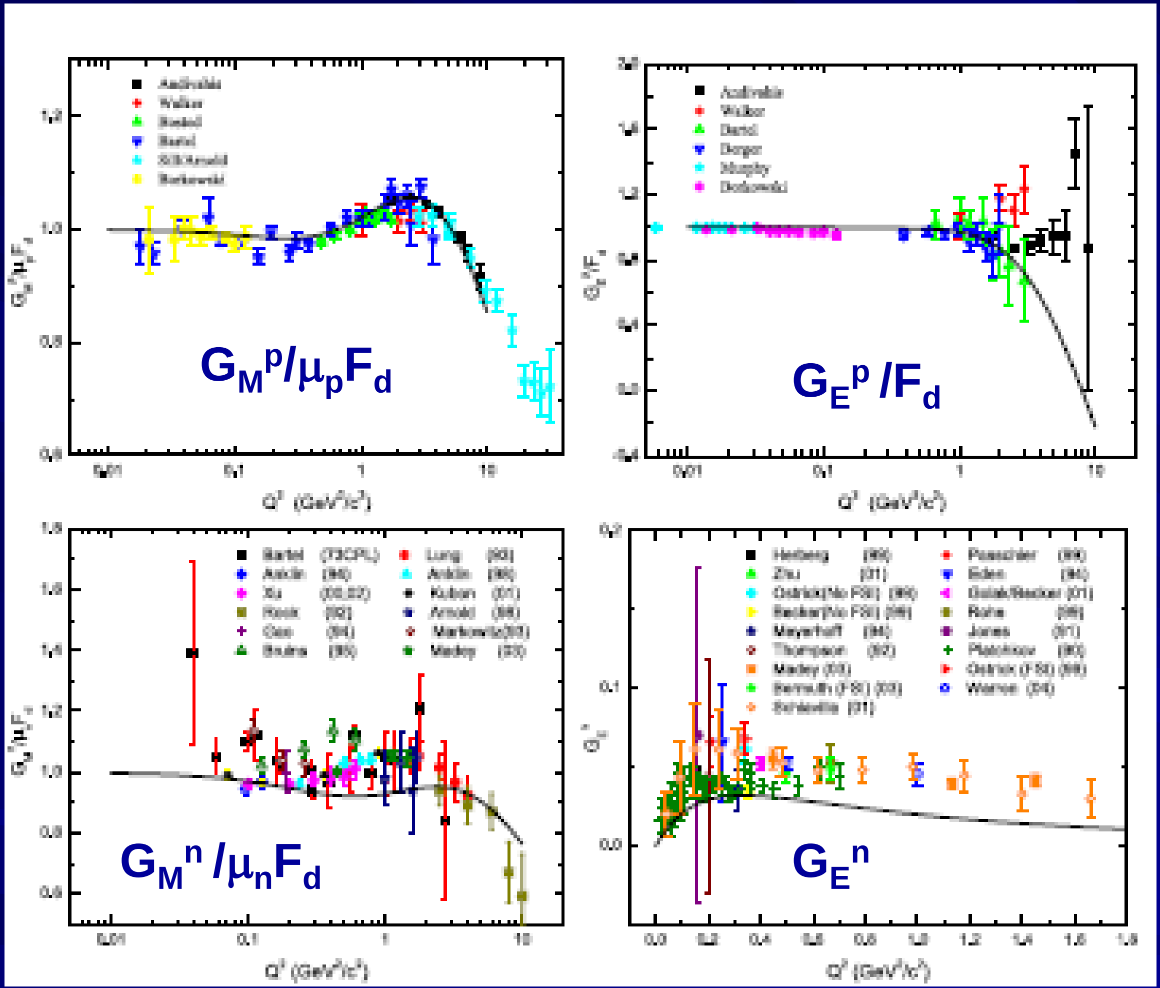
efficiency corrections:

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

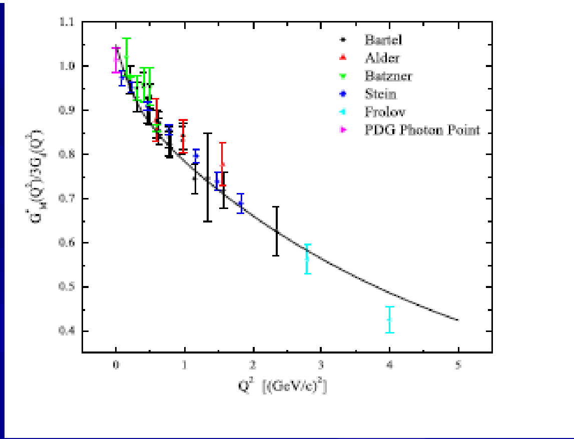
two component model: fit of parameters to existing data

elastic nucleon form factors
4 parameters a^2, γ, g_8 ,v

N-Δ magnetic transition form factors
2 additionnal parameters: a',g_{10}



best fit
$a'/a = 1.27$
$g_{10}/g_8 = 1.28$



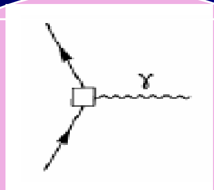
$$F_d(Q^2) = \frac{1}{\left(1 + {Q^2}/{0.71}\right)^2}$$

Iachello's two-component model:

Space-like N-Δ transition magnetic form factor

Proton magnetic moment μ_p=2.793

Intrinsic form factor
$$g(k^2)=\frac{1}{(1+a^2k^2)^2}$$



Direct coupling

$$G_M^{N-\Delta}=\mu_p\left(\frac{4}{3\sqrt{2}}\right)\sqrt{\frac{M}{M_\Delta}}\left(\frac{k}{k_{CM}}\right)g(k^2)\left[\beta'+\beta_\rho\frac{m_\rho^2}{m_\rho^2+Q^2}\right]$$

$$\vec{k}=\vec{p}_\Delta-\vec{p}_N$$

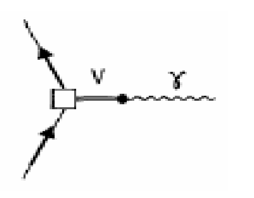
Breit Frame:

$$k^2=Q^2+\frac{(M_\Delta^2-M^2)^2}{2(M_\Delta^2+M^2)+Q^2}$$

$$k^2\approx Q^2$$

Center of mass:

$$k_{CM}^2=Q^2+\frac{(M_\Delta^2-M^2-Q^2)^2}{4M_\Delta^2}$$



coupling mediated by ρ

ρ width
$$\frac{m_\rho^2}{m_\rho^2+Q^2}\rightarrow\frac{m_\rho^2+8\Gamma_\rho m_\pi/\pi}{m_\rho^2+Q^2+(4m_\pi^2+Q^2)\Gamma_\rho\alpha(Q^2)/m_\pi}$$

$$\alpha(Q^2)=\frac{2}{\pi}\left[\frac{4m_\pi^2+Q^2}{Q^2}\right]^{1/2}\ln\left(\frac{\sqrt{4m_\pi^2+Q^2}+\sqrt{Q^2}}{2m_\pi}\right)$$

Iachello's two-component model for baryonic form factors

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

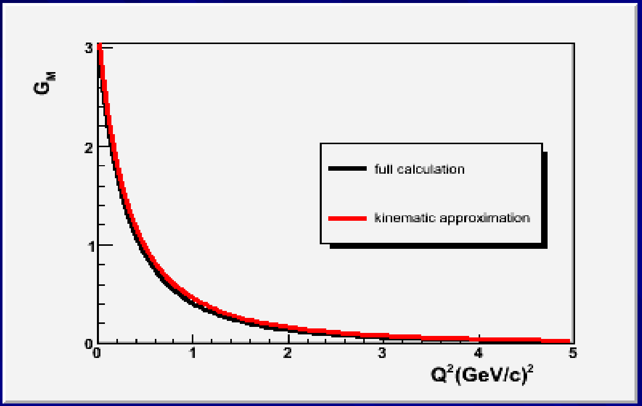
- ✓ **Unified description of all baryonic transition form factors**
- ✓ **two-component: Direct coupling to quarks + coupling mediated by vector mesons**
- ✓ **analytic continuation to time-like region**
- ✓ **Version of model with SUsf(6) symmetry**

➡ **« justification » of previous phenomenological parametrisations**

- ✓ **F. Iachello, A.D. Jackson and A. Lande Phys. Lett. 43B 191 (1973)**
- ✓ **F. Iachello EPJA 19(2004) 29 fits to more recent data**

analytic continuation to Time-Like region

1) **Kinematical singularity in Breit Frame kinematics in Time-Like region →use approximate SL form factors**

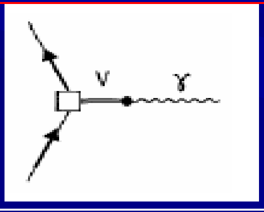


2) **ρ coupling term:**

Space Like:

$$\frac{m_\rho^2}{m_\rho^2 + Q^2}$$

$Q^2 \rightarrow - q^2$



Time Like:

$$\frac{m_\rho^2}{m_\rho^2 - q^2}$$

real ρ width term → complex ρ width term

ρ width for Time-Like transition:
- **→ essential to remove singularity at $q^2 = m_\rho^2$**
- **→ induces a large negative phase**
- **→ real for $q^2 < 4\ m_\pi^2$**

analytic continuation to Time-Like region:

3) Intrinsic form factor:

Space Like:

$$g(Q^2) = \frac{1}{(1+a^2Q^2)^2}$$

Analytic continuation : $Q^2 \rightarrow -q^2 e^{i\theta}$

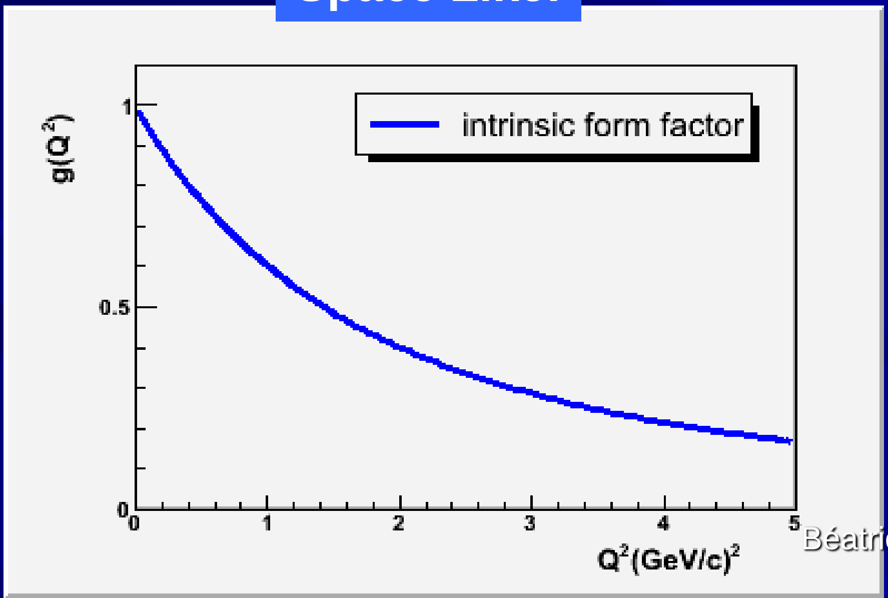
Time Like:

$$g(q^2) = \frac{1}{(1-a^2 e^{i\theta} q^2)^2}$$

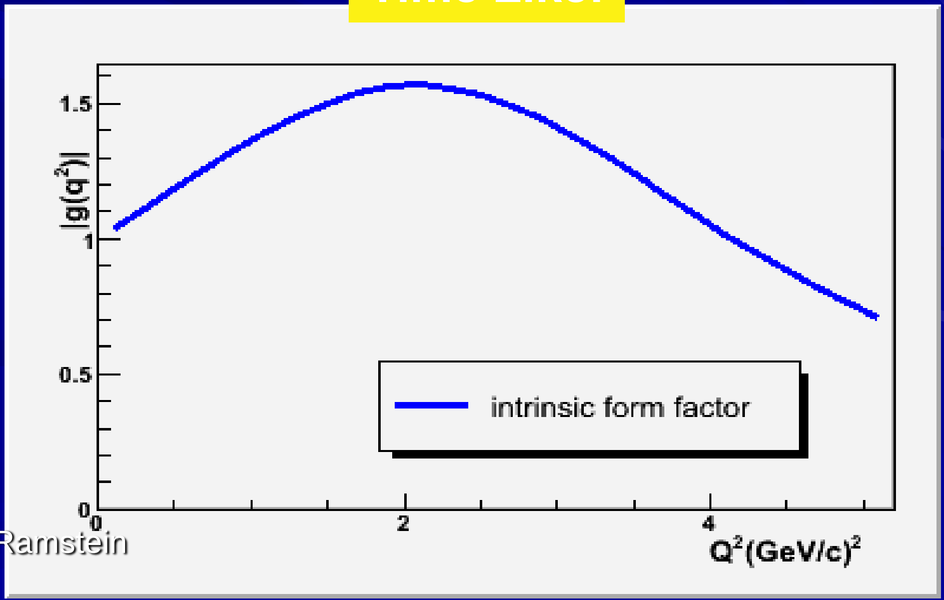
phase θ:

- ✓ **removes singularity at $q^2=1/a^2$ (~ 3.45 $(GeV/c)^2$)**
- ✓ **θ =53° fitted to elastic nucleon form factors Time Like data**
- ✓ **same value taken for N - Δ transition**

Space Like:

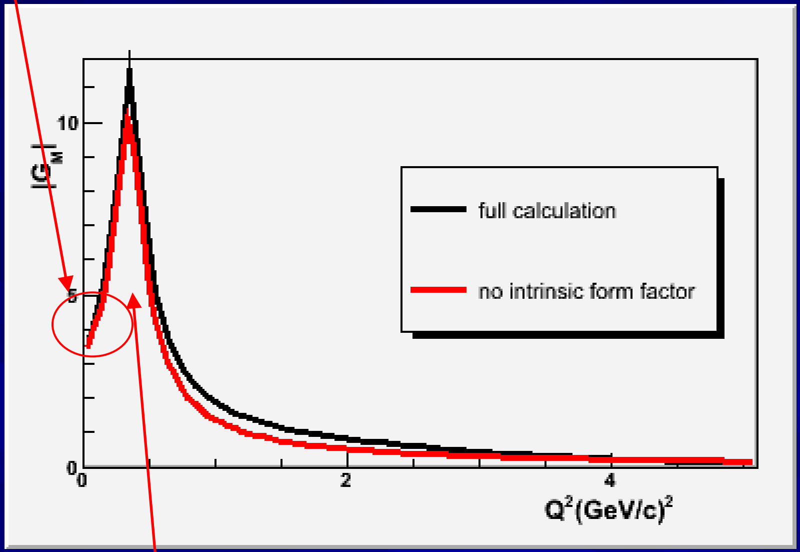


Time Like:



Time-Like N-Δ form factor in two component model : results

$G_M(0)$=3. ~1.1 μ_p



Maximum at q^2~ 0.34 $(GeV/c)^2$ ~ $0.6 m_\rho^2$

ρ propagator

Vector meson modifications:

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

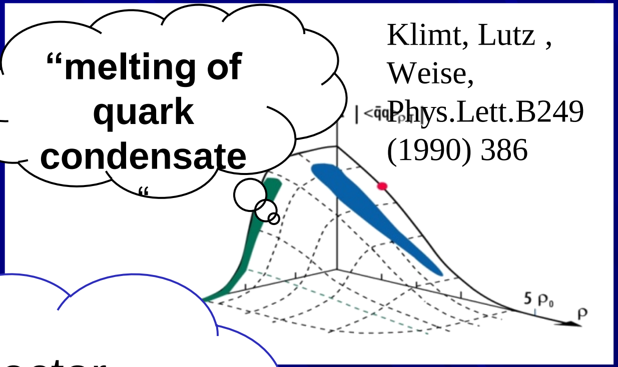
Chiral Symetry Restoration

modifications of chiral <$\bar{q}q$> condensates with ρ and T

$\rightarrow$ Modifications of hadron masses ?

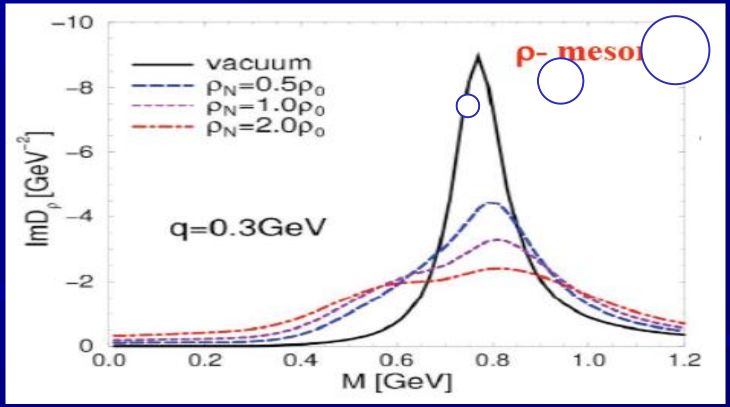
Brown-Rho PRL66(1991) 2720

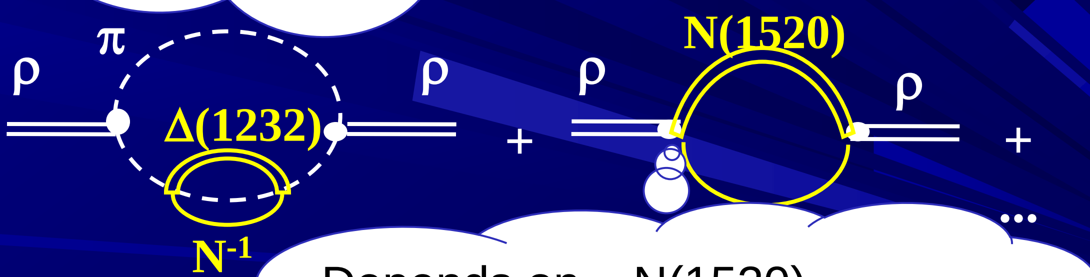
Hatsuda and Lee PRC46 (1992) ***34***



Connexion of vector meson spectral function to quark condensates via QCD sum rules

« in-medium broadening





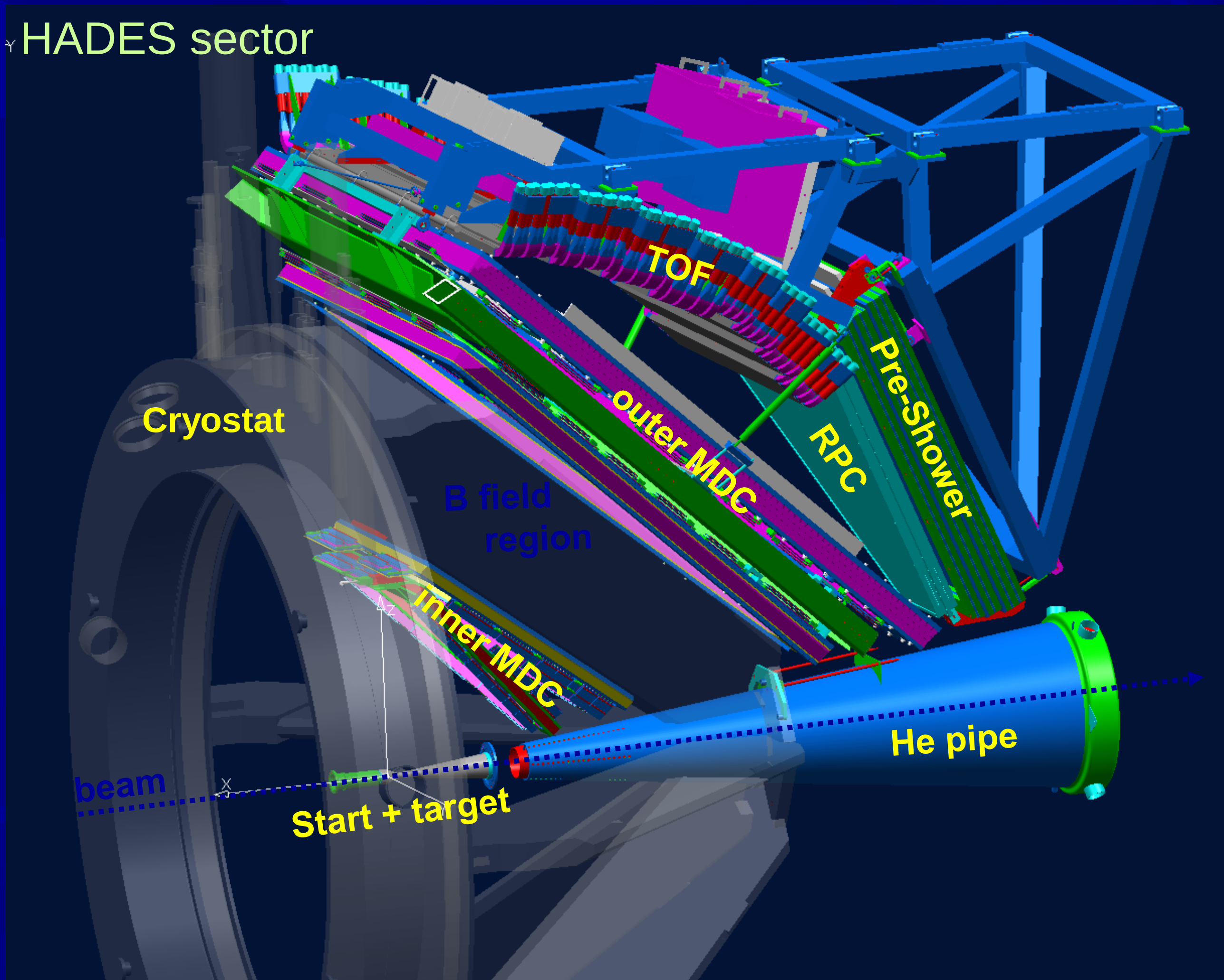
Depends on ρ N(1520) coupling

Rapp and Wambach EPJA 6 (1999) 415

Rapp, Chanfray and Wambach NPA 617, (1997) 472

Béatrice Ramstein 51

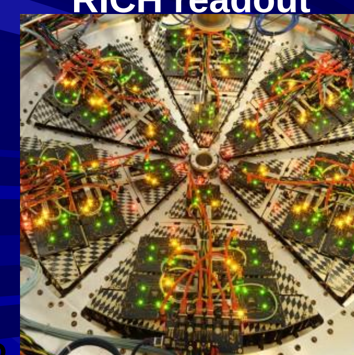
Technical layout of HADES



HADES cave

inner MDC

RICH readout



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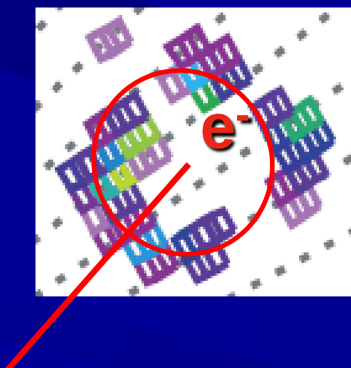
52

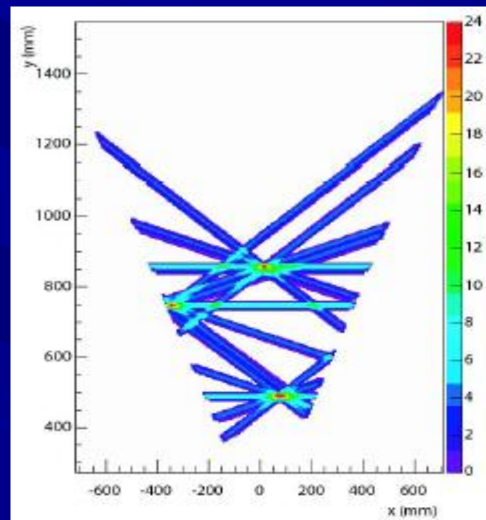
Lepton Identification with HADES

RICH pattern



+

Drift Chamber: Track reconstruction



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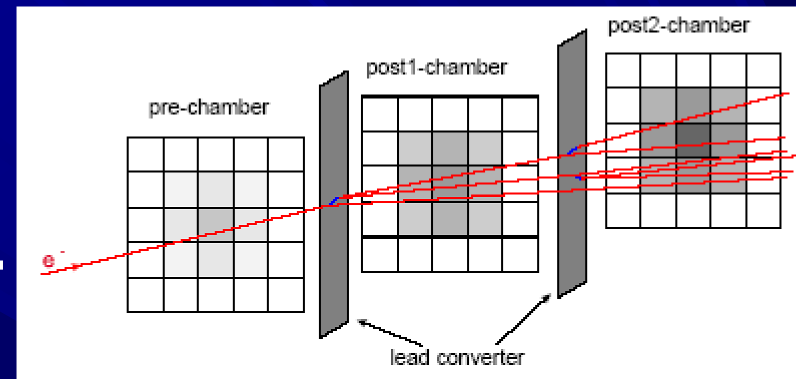
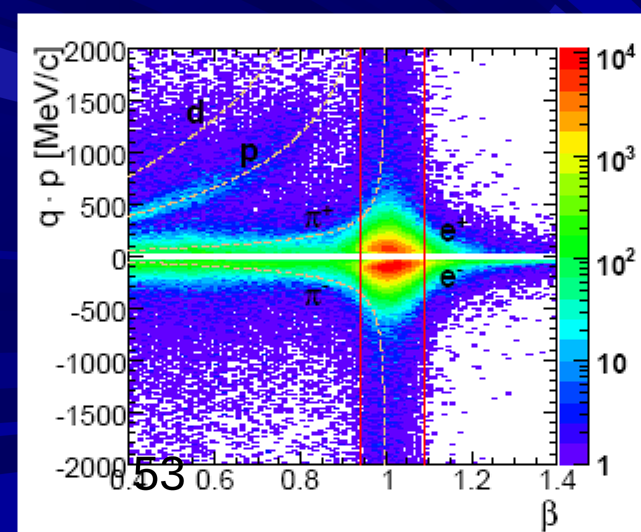
Pre-Shower condition



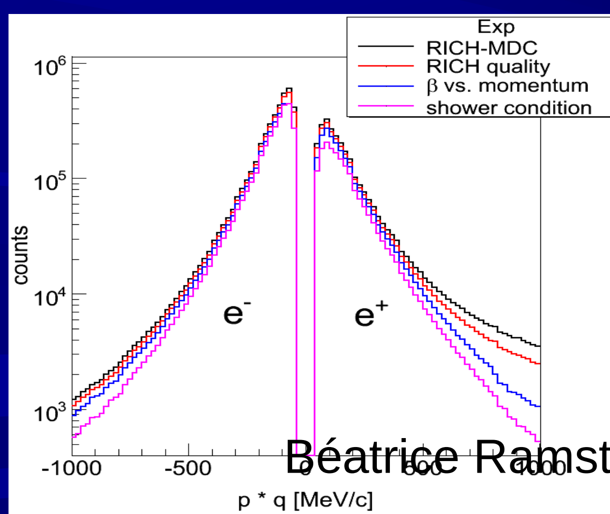
+

momentum % velocity



momentum · charge

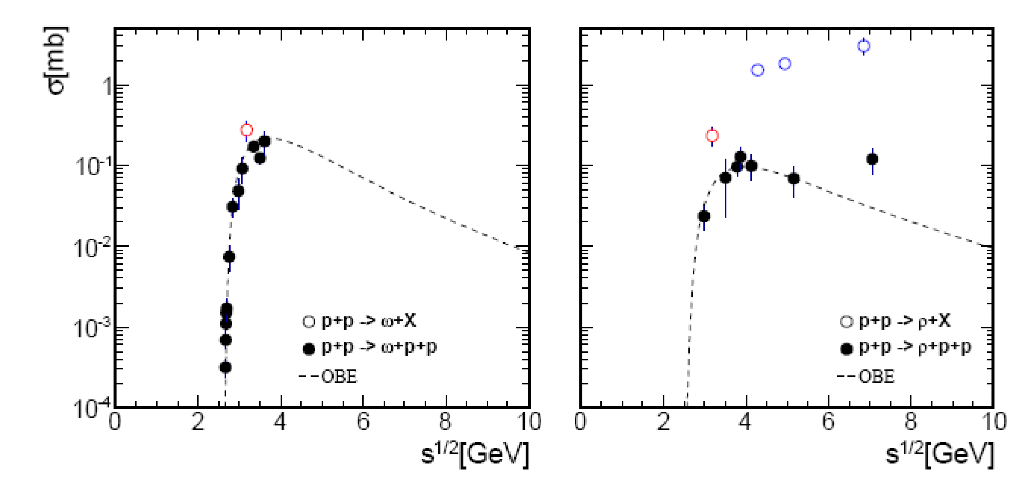
C+C 2 AGeV



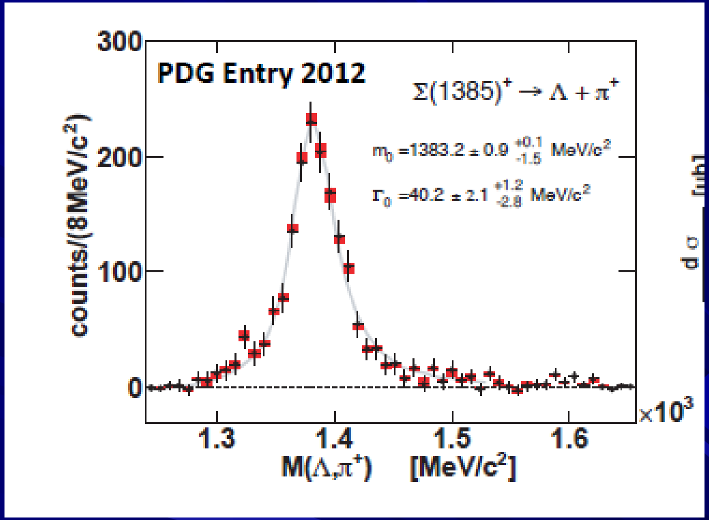
Data base entries from HADES measurements

Using both leptonic and hadronic channels

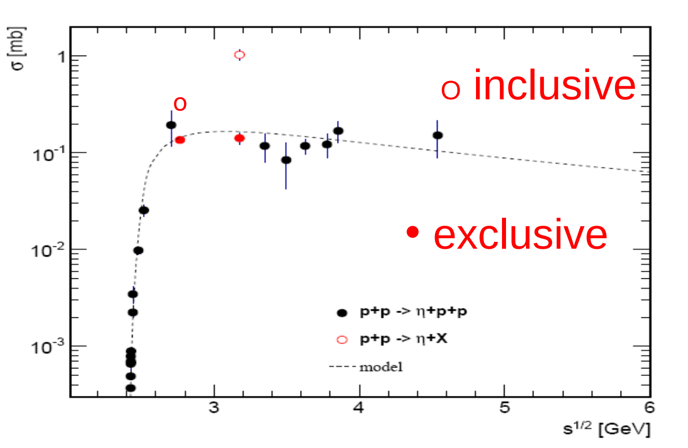
ρ/ω inclusive cross sections pp→ppρX and pp→ppωX E=3.5 GeV



pp E=3.5 GeV



η inclusive/exclusive cross sections



pp E=2.2 and 3.5 GeV

PDG Entry 2012:
BR(η->e^+e^-) < $(4.9 + 0.7 - 1.2)\times10^{-6}$
with 90% CL