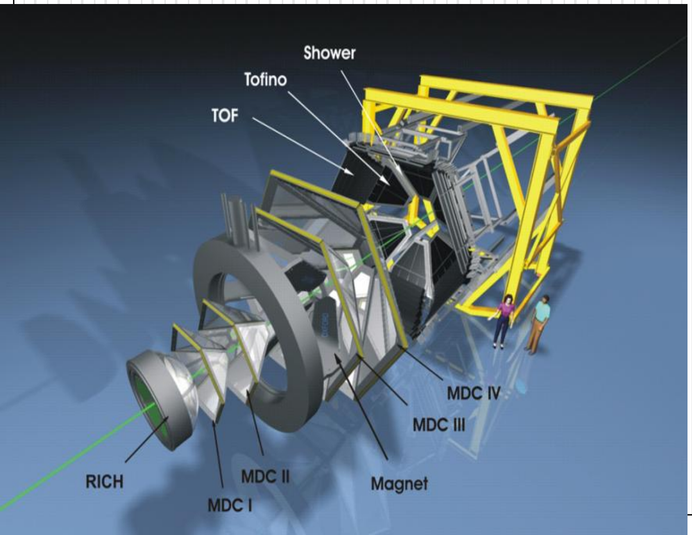
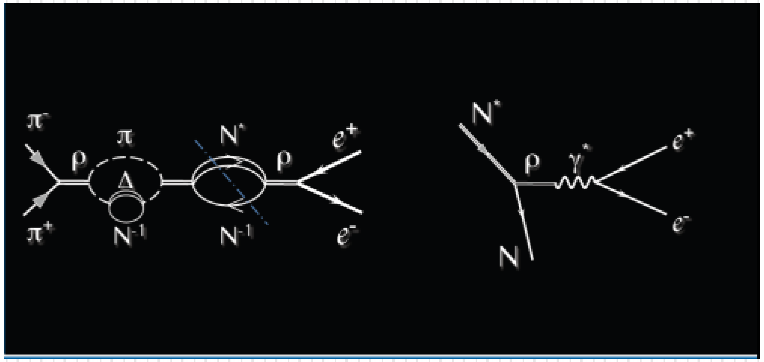
In2p3

# Study of electromagnetic processes with HADES in pion-nucleon reactions

B. Ramstein, IPN Orsay

*Pion Beam Task Force meeting, 31 October 2013*

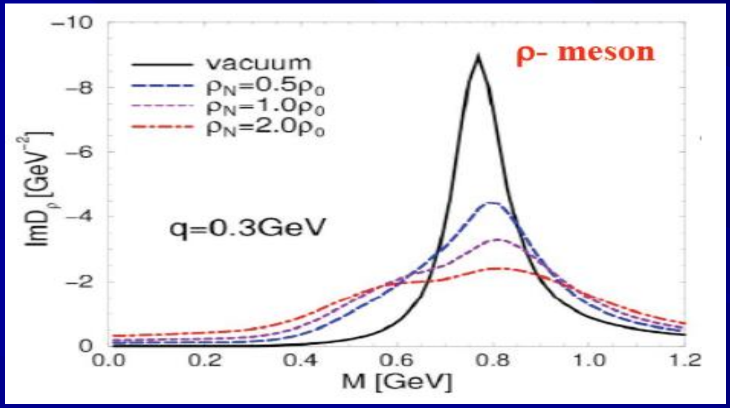


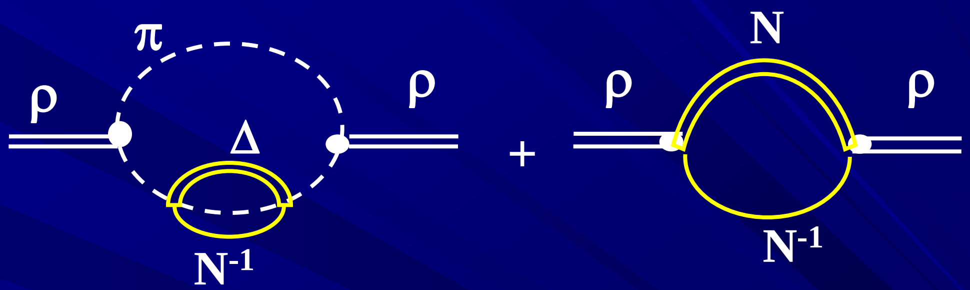



# In-medium vector meson modifications:

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

## « in-medium broadening »



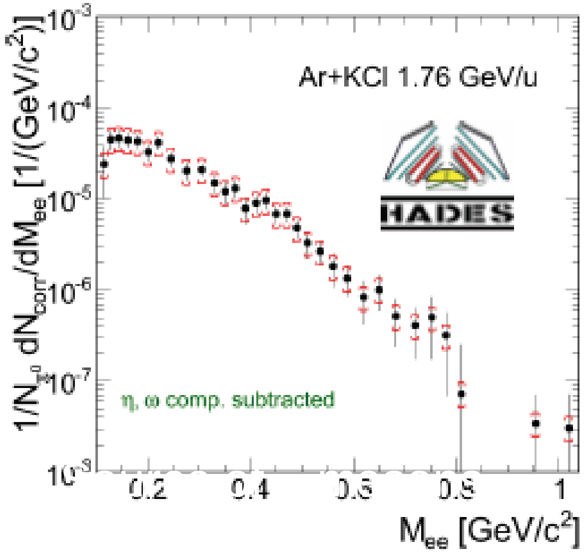




**Rapp and Wambach EPJA 6 (1999) 415**
**Rapp, Chanfray and Wambach NPA 617, (1997) 472**

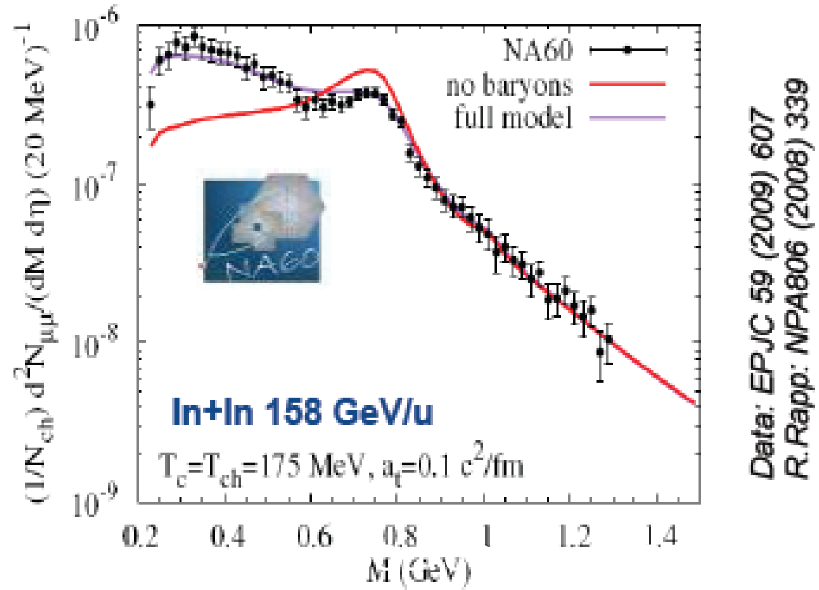
In-medium spectral function depends on ρ NN* coupling
main players: N(1520), N(1720), Δ (1910)

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

**Excess $e^+e^-$ yield, Ar+KCl 1.76 GeV/u**




**Acc.-corrected $\mu^+\mu^-$ excess spectrum**

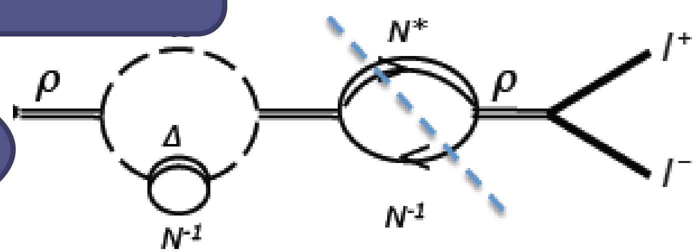



Source of ρ mesons at 1-2 AGeV

$NN \rightarrow NR \rightarrow NN\rho$

$\pi N \rightarrow R \rightarrow N\rho$

Already depends on RNρ coupling




Source of ρ mesons at ultra relativistic energies

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

Coupling of ρ to baryonic resonances: plays a crucial role in medium effects can be studied in NN and πN collisions at 1-2 GeV

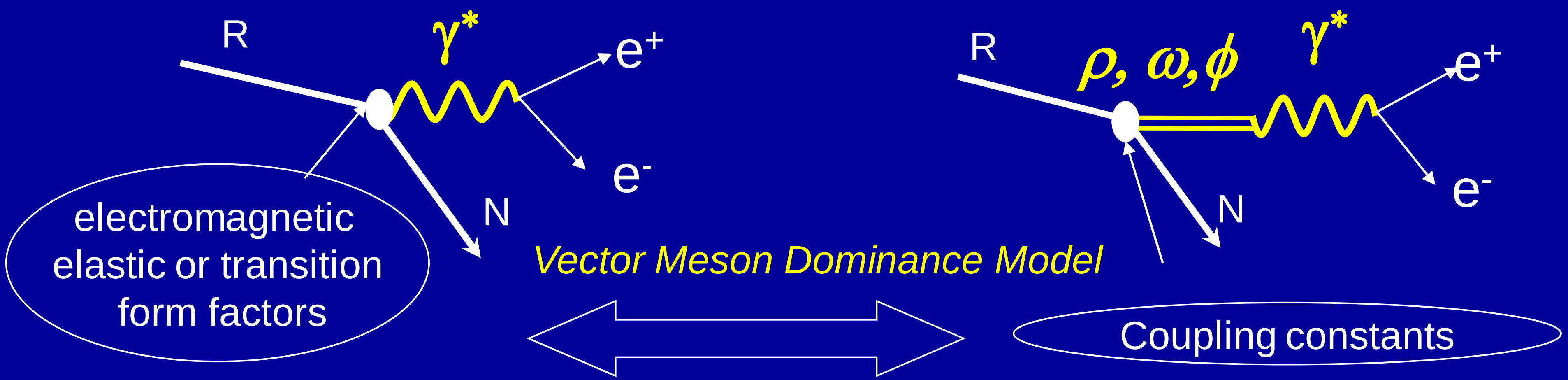
# Relation to electromagnetic structure of baryons

Dalitz decay of baryonic resonances

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

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

$\rho$ meson production and decay




**$q^2 \geq 0$ :** « Time like « region

electromagnetic form factors are unknown !

$\rightarrow$ use models fitted to Space-Like data $q^2 \leq 0$

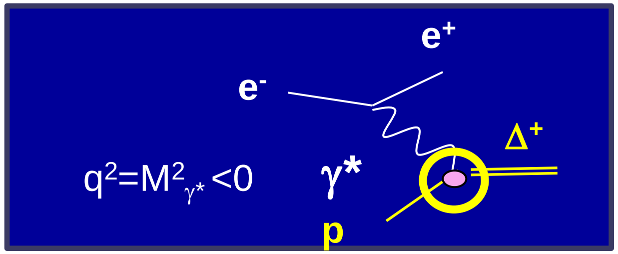
(electroproduction of baryonic resonances)

Unique way to test the vector dominance model for baryons

(not possible for elastic time-Like nucleon form factors)

# Baryonic transition electromagnetic form factors in space-Like region

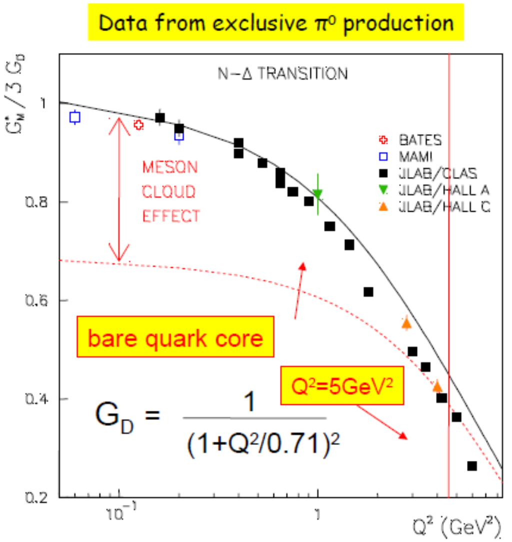
## Baryonic electromagnetic form factors are measured for $q^2 \leq 0$



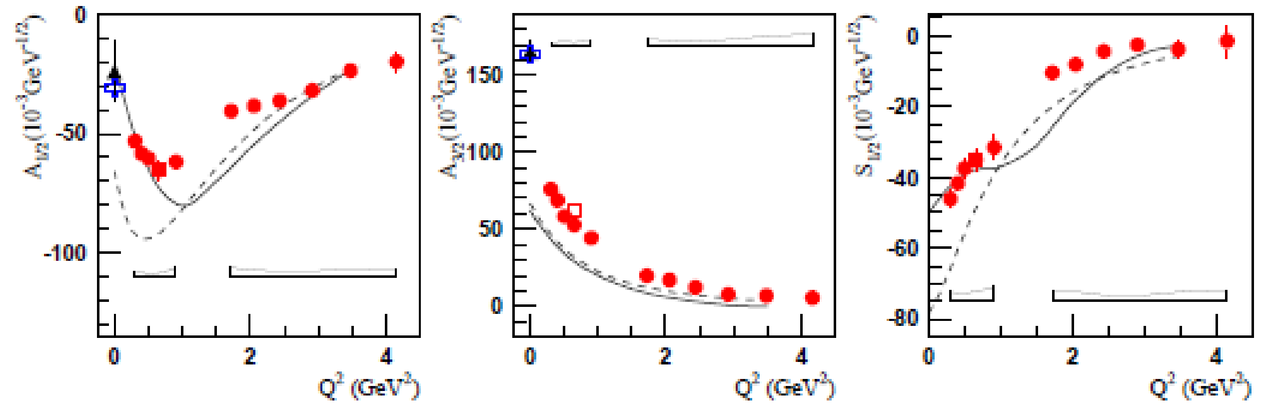

*Magnetic form factor for $\gamma^* p \to \Delta(1232)$*

Data: Mainz, Jlab

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




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




No measurement at $q^2 > 0$ → use models fitted on space like data
N.B. Time-Like transition form factors can also be calculated on the lattice

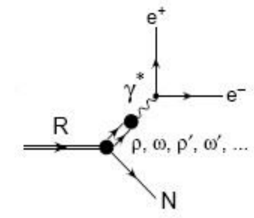
# Studies of baryonic Time-Like electromagnetic transitions in pp reactions

$pp \rightarrow ppe^+e^-$   1.25 GeV   $\Delta$ resonance Dalitz decay

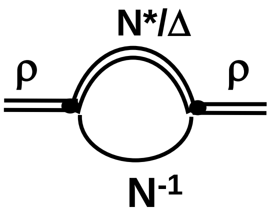
2.2 and 3.5 GeV higher lying resonances

# From proton-proton to pion-nucleon experiments

**dilepton emission in pp**




✓sensitivity to the coupling of vector mesons to baryonic resonances / Time-Like electromagnetic structure
✓complementary information in hadronic channels
✓ useful constraints for medium effects



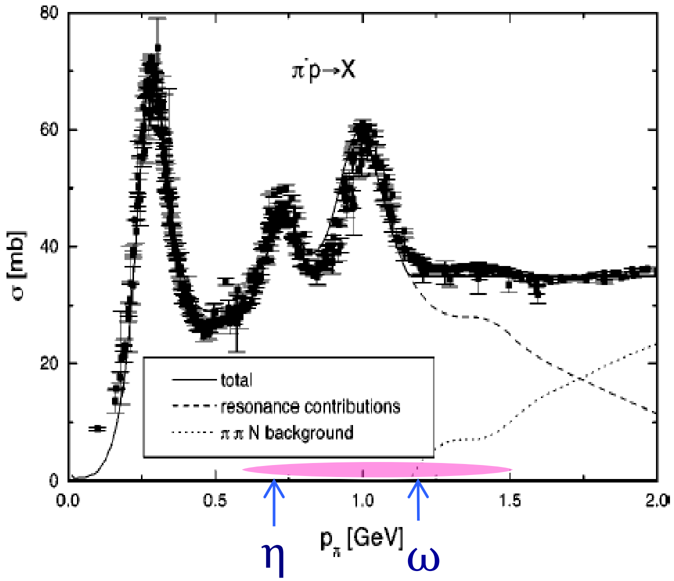

Limitations:
✓ uncertainties due to pp interaction
✓ many resonances contributing with broad mass distributions
✓ small acceptance for exclusive channels

**$\pi^- p \rightarrow n e^+ e^-$ below ρ/ω production threshold**

***Advantages:*** ***interaction better known***
***fixed mass of the resonance in s channel***
***much larger acceptance for exclusive channels***
***electromagnetic $\pi^- p \rightarrow n e^+ e^-$***
***hadronic $\pi^- p \rightarrow p\pi^-, n\pi^+\pi^-, p\pi^0\pi^-$***

# Project of pion beam experiments with HADES

**pion momentum 0.6 < p <1.5 GeV/c**
**average pion flux ~ 4 $10^5$/s**




Belongs since the very beginning to the HADES experimental program

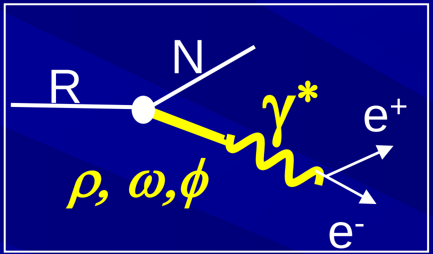
updated 2013 program:

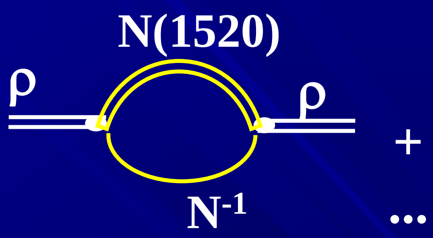
- ✓ Based on HADES results
- ✓ Limited by constraints of beam time at GSI

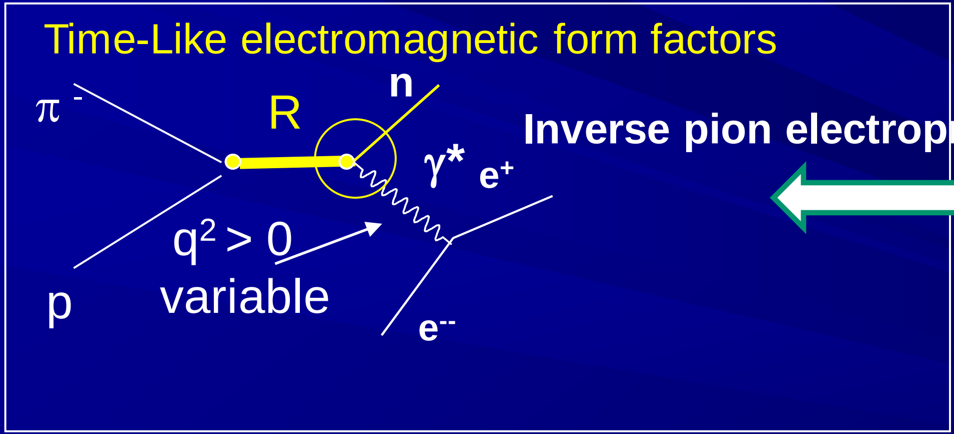
- **Strangeness production ($K^+$,$K^-$,$K^0_S$,$\phi$) in $\pi$+A**
- **$\pi^- p \to n e^+ e^-$ below ρ/ω production threshold**
- **One pion, two pion, one kaon production from an energy scan in $\pi^- p$ reactions**

# Motivations of $\pi^- p \to n e^+ e^-$ experiments with HADES

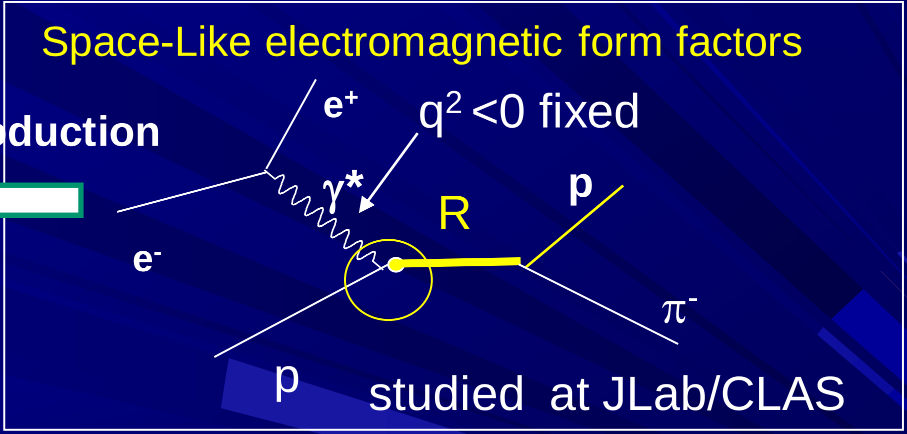
## "off-shell ρ production"




**Inverse pion electroproduction**




**$\pi^- p \to n e^+ e^-$ below ρ/ω production threshold at $\sqrt{s}$=1.52 GeV/c²**

unique chance

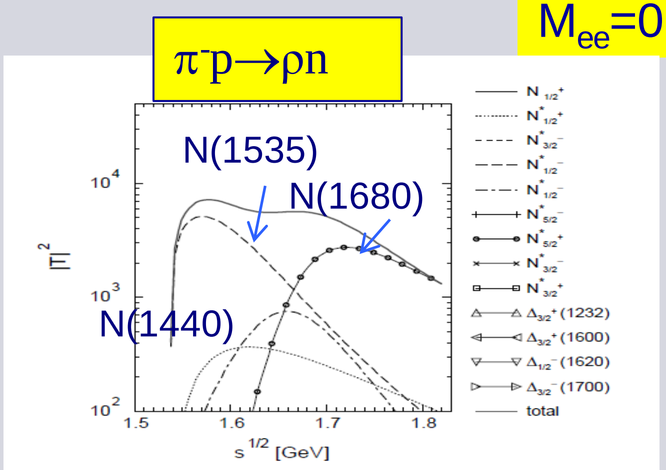
- ✓ to study the Time-Like electromagnetic structure of N*(1520)
- ✓ to constrain the in-medium modifications of the ρ meson spectral function

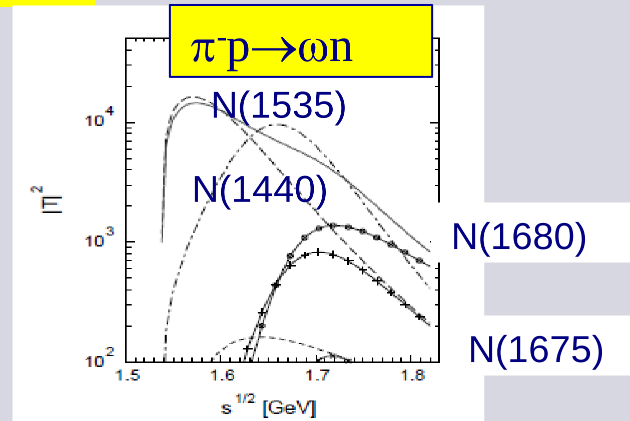
# Predictions for $\pi^- p \to n e^+ e^-$

*B. Kaempfer , A Titov , R.Reznik Nucl. Phys. A721(2003)583*
*A. Titov, B.Kaempfer EPJA 12(2001)217*

Coupling constants from quark models or derived from $R \to N\rho/\omega$ branching ratios

$M_{ee}$=0.6 GeV/c$^2$

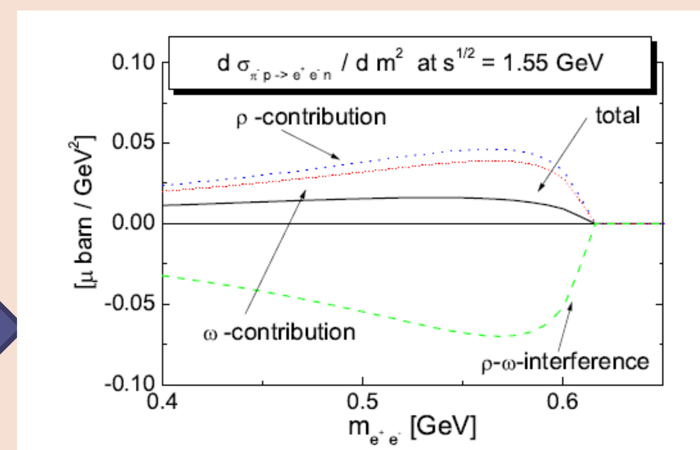



*M.F.M. Lutz , B. Friman, M. Soyeur Nuclear Physics A 713 (2003) 97–118*

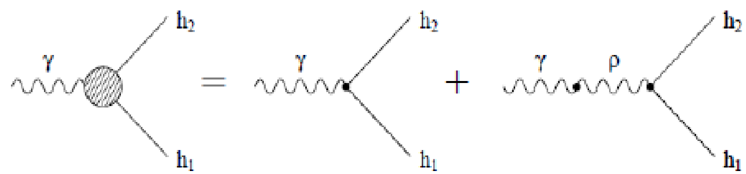
Coupling constants from hadronic coupled channel model fitted to $\gamma p \to \rho/\omega$ p and $\pi^- p \to \rho/\omega$ n data

- ✓ overall smaller amplitudes
- ✓ $D_{13}$(1520) has a larger contribution
- ✓ Very large destructive interference between I=0 ($\omega$) and I=1 ($\rho$) contributions

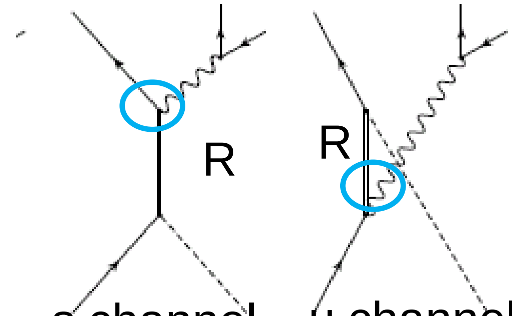


# Electromagnetic form factors approach

- ***M. Zetenyi and G. Wolf, Phys.Rev. C86 (2012) 065209***
- **ρ production is embedded in the em form factor**




$$\mathcal{L}_{\mathrm{VMD}} = -\frac{e}{2g_\rho} F^{\mu\nu} \rho^0_{\mu\nu}$$



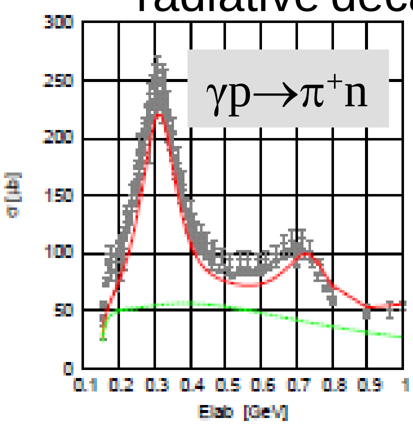

s channel u channel

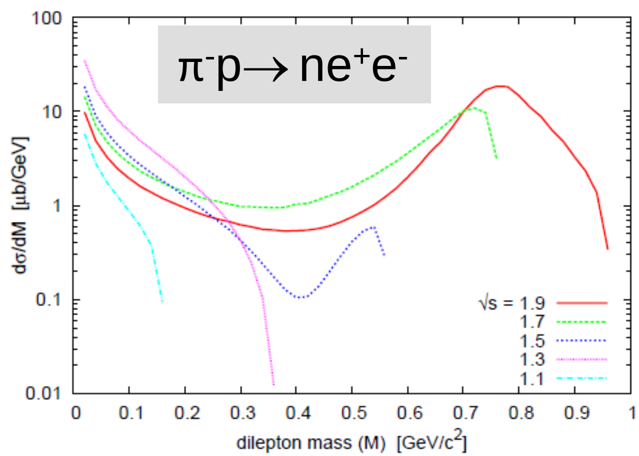
+ Born term

+ ρ meson exchange

adjustment to pion photoproduction cross sections of

- signs and strength of RNγ couplings (within the range allowed by the radiative decay widths)

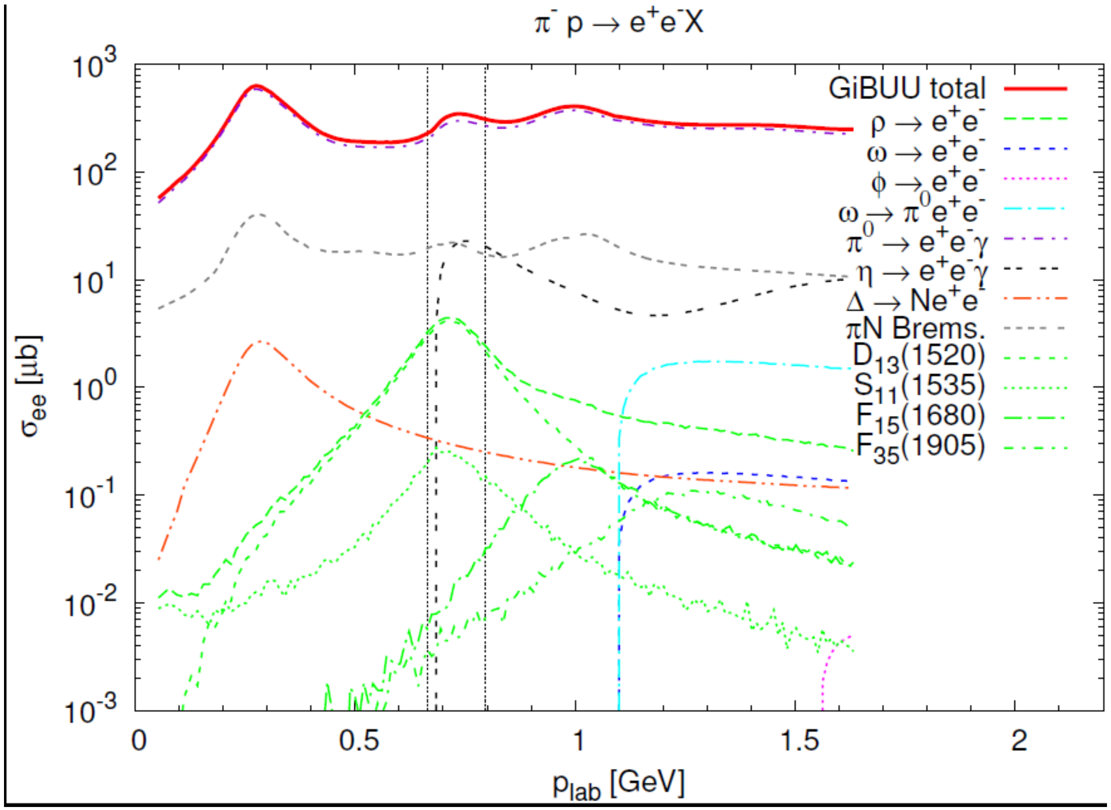


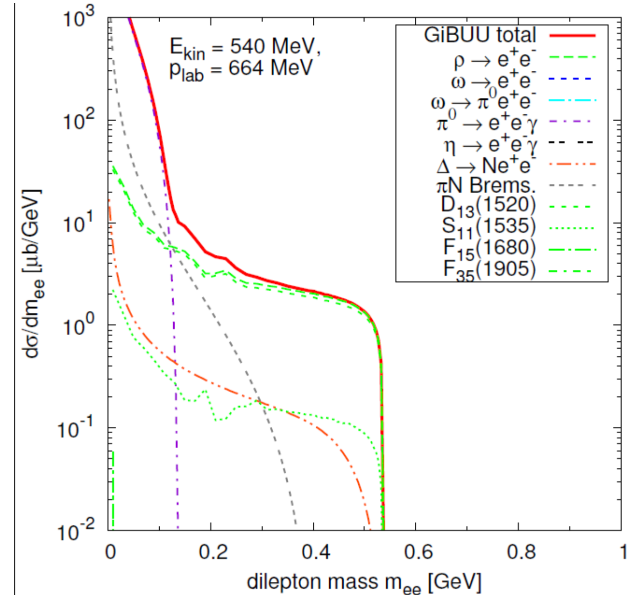



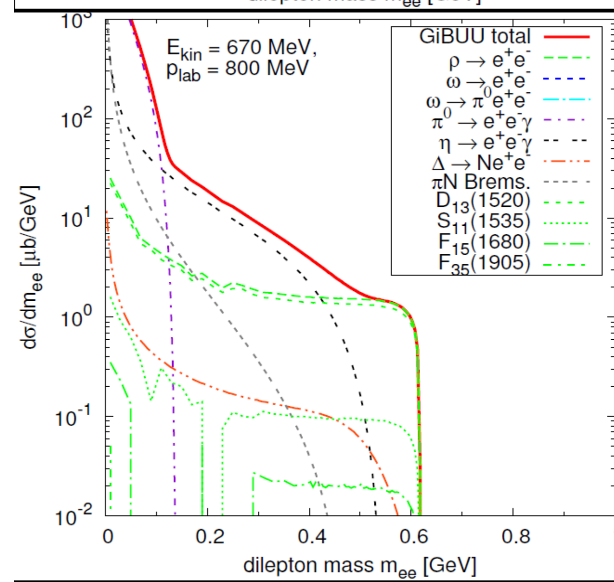

Further studies needed:
✓Inclusion of ω contribution
✓Too large cross sections for ρ production

# Very recent GiBUU calculations

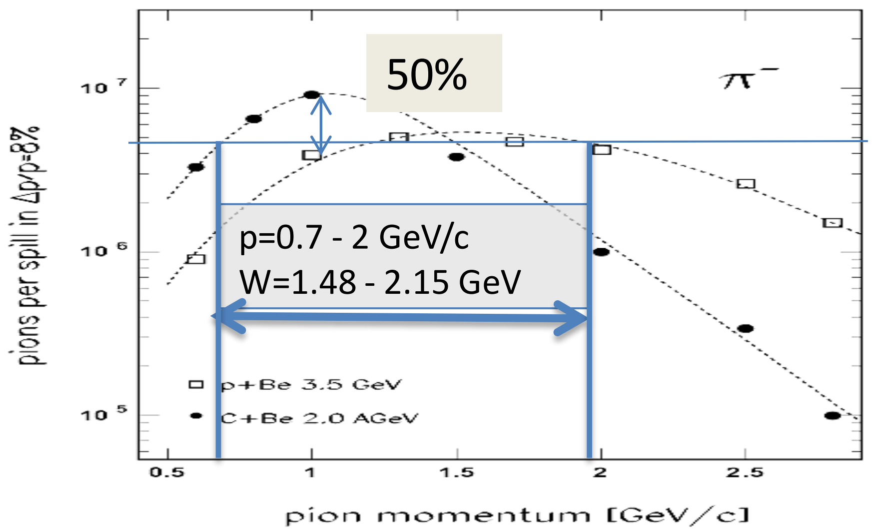
Janus Weil



# Inputs for feasibility studies: update 2013




- **measured in 2005**:
  - $2.7\ 10^{-5}\ \pi^-$/ion at 1.17 GeV/c in front of the RICH
  - max: $6.5\ 10^{10}\ N_2$ ions=0.5 xSCL
  - 4s extraction time

  → $4.5\ 10^5\ \pi^-$/s in spill

  → $2.3\ 10^5\ \pi^-$/s in average

- **Expected in 2013 :**
  - primary beam intensity: $8\ 10^{10}\ N_2$ ions/spill (measured by FOPI, 0.6 xSCL)

  → lower limit of pions at the exit of Q9: $2.2\ 10^6\ \pi^-$/spill (using the measurement in scintillator hodoscope)
  - Extraction time 2s, total spill length 4s (chosen to reduce dead time and load on the detectors)
  - Fraction of beam after Q9 inside the 6mm LH2 target radius: 2/3, see Thierry's simulations

  → $1.5\ 10^6\ \pi^-$/s in spill $3.7\ 10^5\ \pi^-$/s in average

Estimates for the 5 cm long LH2 target at 1.1 GeV/c, 80% data taking efficiency, 30% dead time

in $4\pi$, 100 % efficiency

N/ hour ~ 150 000 σ (mb) N/week ~ 25 x σ (nb)

# Existing simulations

“home made” resonance model

Madeleine Soyeur’s model

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# Baryon resonance cross sections

Baryon resonance cross sections calculated like in

- S. Teis et al. Z. Phys. A 356, 421–435 (1997)

cross section calculated via the Breit-Wigner formula:

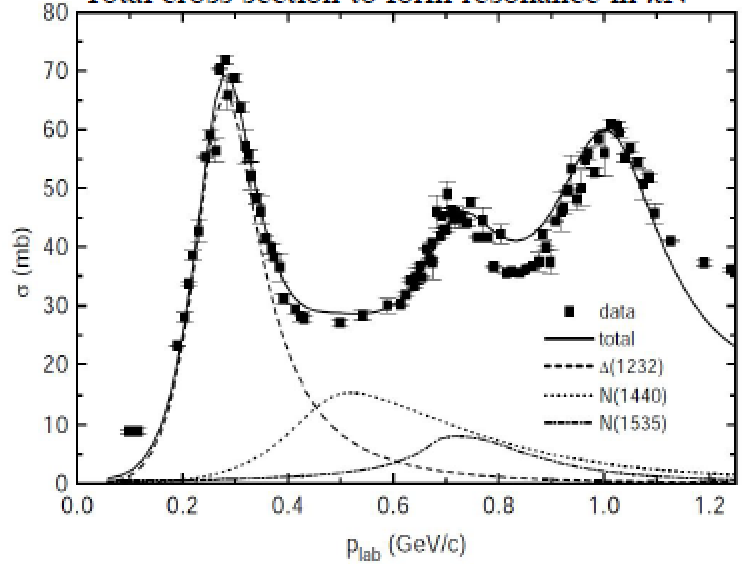
$$\sigma_{\pi\text{-}p\to R\to cd} = \frac{2J_R+1}{(2S_{\pi^-}+1)(2S_p+1)} \frac{4\pi}{p_i^2} \frac{s\Gamma_{R\to\pi-p}\Gamma_{R\to cd}}{(s-M_R^2)^2+s\Gamma_{tot}^2}$$

$$\Gamma_{tot}(q) = \Gamma_R \frac{M_\Delta}{M}\left(\frac{q}{q_r}\right)^3\left(\frac{q_r^2+\delta^2}{q^2+\delta^2}\right)^2 \quad \Delta(1232)$$

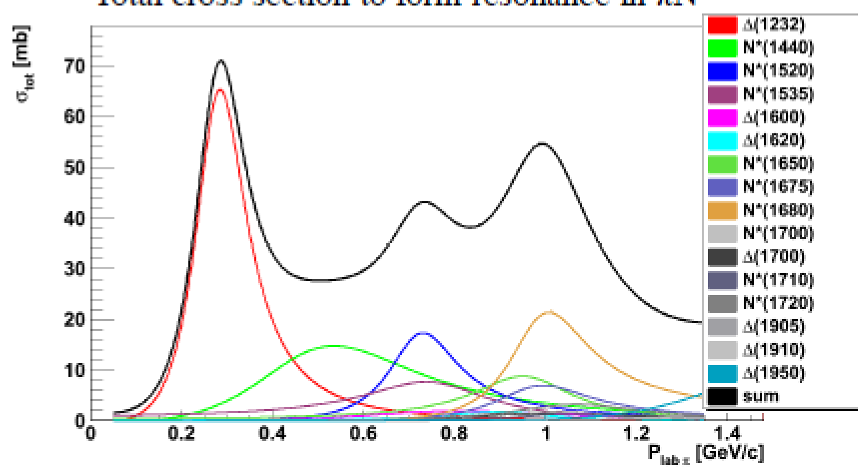
$$\Gamma_{tot}(q) = \Gamma_R\left(\frac{q}{q_r}\right)^{2l+1}\left(\frac{q_r^2+\delta^2}{q^2+\delta^2}\right)^{l+1} \quad \text{higher resonances}$$

- for total cross section $\Gamma_{R\to cd}$ replaced with $\Gamma_{tot}$

Total cross section to form resonance in πN




Total cross section to form resonance in πN



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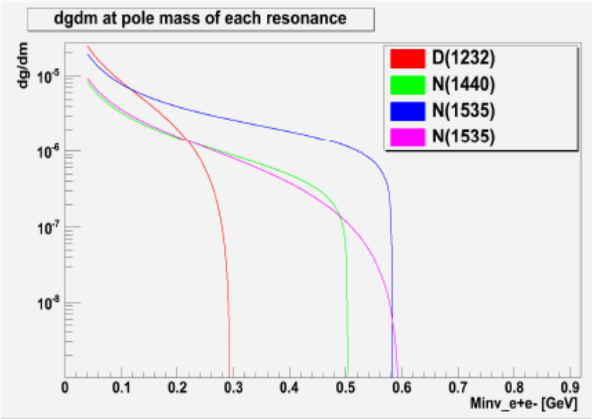
# Baryon resonance dalitz decay widths

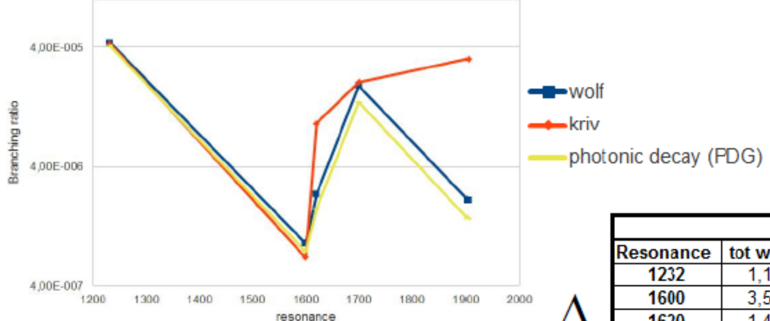
- Decay width and branching ratio for resonance dalitz decay calculations based on two models
- M. Zetenyi, Gy. Wolf arXiv:nucl-th/0202047v1 14 Feb 2002
- M. I. Krivoruchenko et al. Annals of Physics 296, 299–346 (2002)

$$\frac{d\Gamma_{R\to Ne^+e^-}}{dM^2} = \frac{\alpha}{3\pi}\frac{1}{M^2}\Gamma_{R\to N\gamma}(M)$$

$$\Gamma_{R\to N\gamma}(M) = \frac{\sqrt{\lambda(m_*^2, m^2, M^2)}}{16\pi m_*^3}\frac{1}{n_{pol,R}}\sum_{pol}|\langle N\gamma|T|R\rangle|^2$$

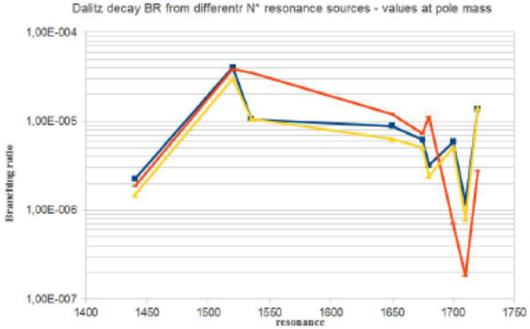



$$BR_{R\to ne^+e^-} = \frac{\Gamma_{R\to ne^+e^-}}{\Gamma_{tot}}$$ - at the pole mass




$\Delta$

| | | wolf | | kriv | | photonic decay (PDG) | |
|---|---|---|---|---|---|---|---|
| Resonance | tot width PDG | BR e+e- | width e+e- | BR e+e- | width e+e- | BR e+e- | BR nγ |
| 1232 | 1,18E-001 | 4,34E-005 | 5,21E-006 | 4,25E-005 | 5,02E-006 | 4,09E-005 | 5,60E-003 |
| 1600 | 3,50E-001 | 9,01E-007 | 3,15E-007 | 6,86E-007 | 2,40E-007 | 7,66E-007 | 1,05E-004 |
| 1620 | 1,45E-001 | 2,33E-006 | 3,50E-007 | 9,17E-006 | 1,33E-006 | 1,75E-006 | 2,40E-004 |
| 1700 | 3,00E-001 | 1,91E-005 | 5,73E-006 | 2,03E-005 | 6,10E-006 | 1,39E-005 | 1,90E-003 |
| 1905 | 3,30E-001 | 2,09E-006 | 6,88E-007 | 3,18E-005 | 1,05E-005 | 1,46E-006 | 2,00E-004 |



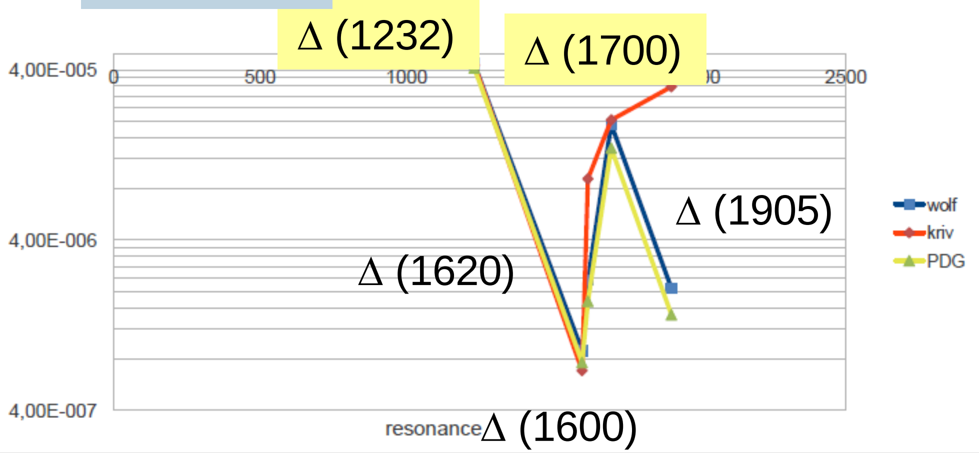

$N_0^*$

| | | wolf | | kriv | | photonic decay (PDG) | |
|---|---|---|---|---|---|---|---|
| Resonance | tot width PDG | BR e+e- | width e+e- | BR e+e- | width e+e- | BR e+e- | BR nγ |
| 1440 | 3,00E-001 | 2,25E-006 | 6,76E-007 | 1,87E-006 | 5,60E-007 | 1,50E-006 | 2,05E-004 |
| 1520 | 1,15E-001 | 4,05E-005 | 4,86E-006 | 3,84E-005 | 4,42E-006 | 3,03E-005 | 4,15E-003 |
| 1535 | 1,50E-001 | 1,06E-005 | 2,14E-006 | 3,53E-005 | 5,30E-006 | 1,07E-005 | 1,47E-003 |
| 1650 | 1,65E-001 | 8,82E-006 | 1,32E-006 | 1,21E-005 | 2,00E-006 | 6,31E-006 | 8,65E-004 |
| 1675 | 1,50E-001 | 6,20E-006 | 9,30E-007 | 7,27E-006 | 1,09E-006 | 5,11E-006 | 7,00E-004 |
| 1680 | 1,30E-001 | 3,21E-006 | 4,17E-007 | 1,13E-005 | 1,47E-006 | 2,45E-006 | 3,35E-004 |
| 1700 | 1,00E-001 | 5,90E-006 | 5,90E-006 | 7,08E-007 | 2,86E-006 | 5,11E-006 | 7,00E-004 |
| 1710 | 1,00E-001 | 1,21E-006 | 1,21E-006 | 1,82E-007 | 6,00E-007 | 8,03E-007 | 1,10E-004 |
| 1720 | 2,00E-001 | 1,39E-005 | 2,77E-006 | 2,77E-006 | 3,14E-006 | 1,43E-005 | 1,96E-003 |

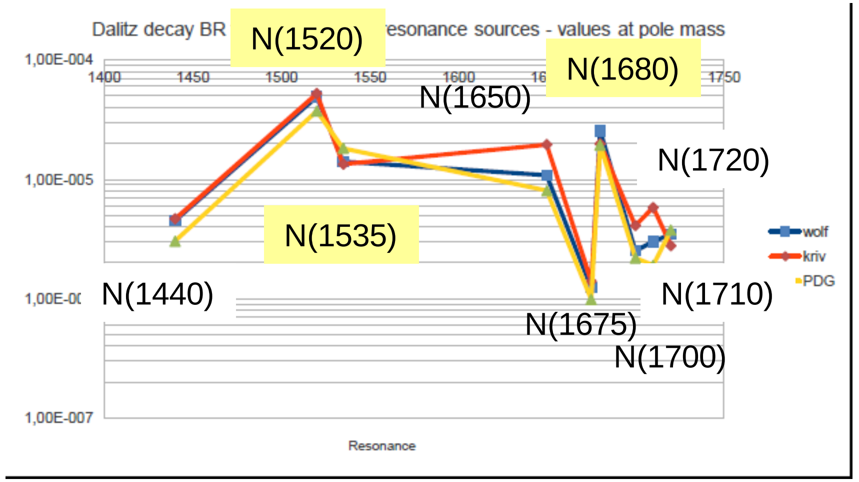
# Coupling to photons: who are the main players ?

Comparison Wolf/Krivoruchenko/ scaling to PDG photocoupling*

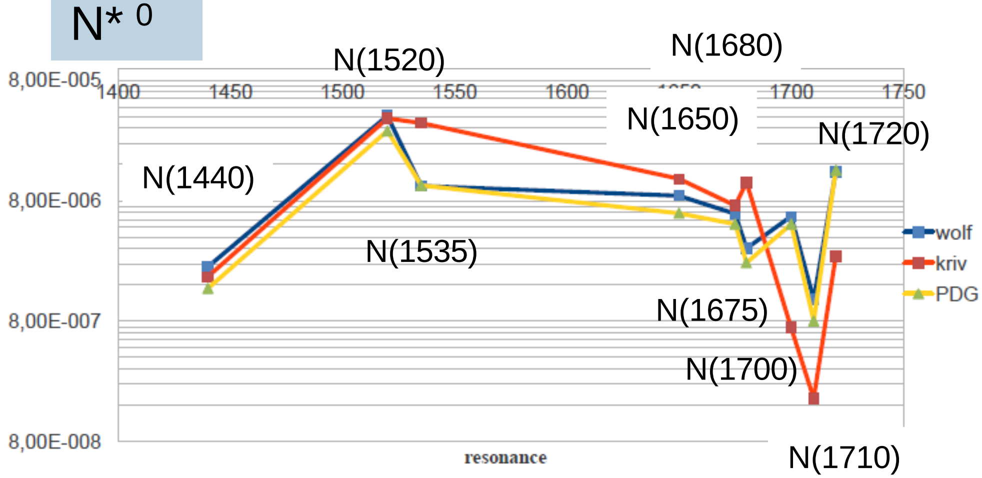
$\Delta^0$ and $\Delta^+$




N*+




N* 0

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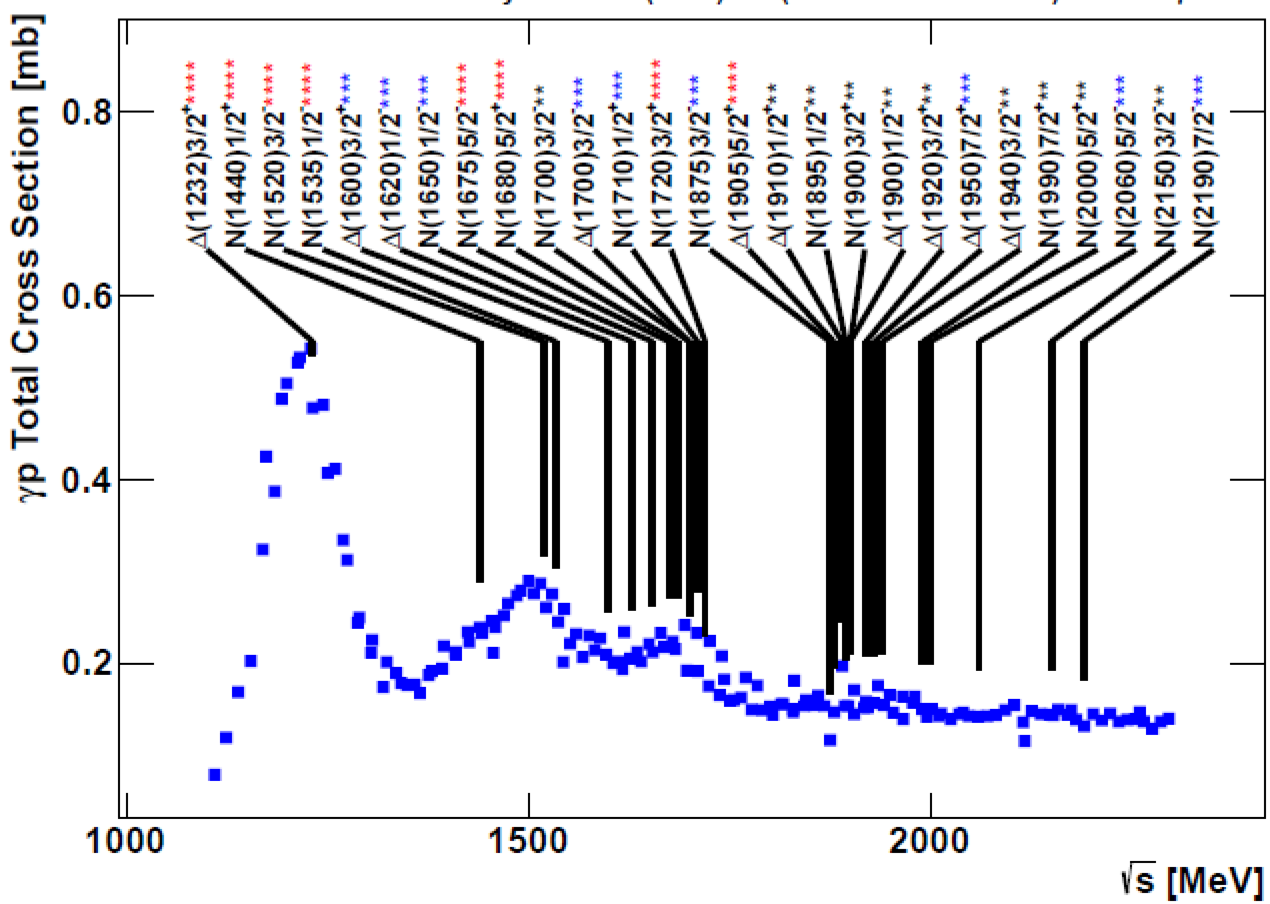
# Baryon Resonance Coupling to the Photon

A. V. Anisovich *et al.* Eur. Phys. J. A 48 (2012) 15. (Solution BG2011-02) Seen in γ N

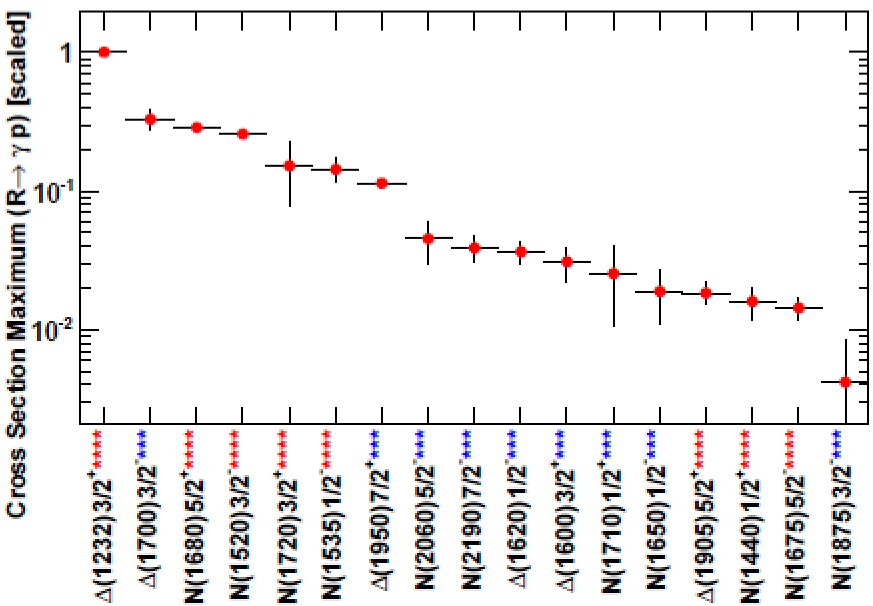


# Baryon Resonance Coupling to the Photon

Bonn-Gatchina PWA solution

A. V. Anisovich, *et al.*, Eur. Phys. J. A **48** (2012) 15.

Cross section maximum assuming a Breit-Wigner shape and no interference.




results from fits to:

$\pi N$ Production

$\pi N$, $K^0\Lambda$, $K^+\Sigma^+$, $K^0\Sigma^0$, $\pi^0\pi^0 n$

$\gamma N$ Production

$p\pi^0$, $p\eta$, $n\pi^+$, $K^+\Lambda$, $K^+\Sigma$, $K^0\Sigma^+$, $p\pi^0\pi^0$, $p\pi^0\eta$

Only coupling uncertainties are propagated.

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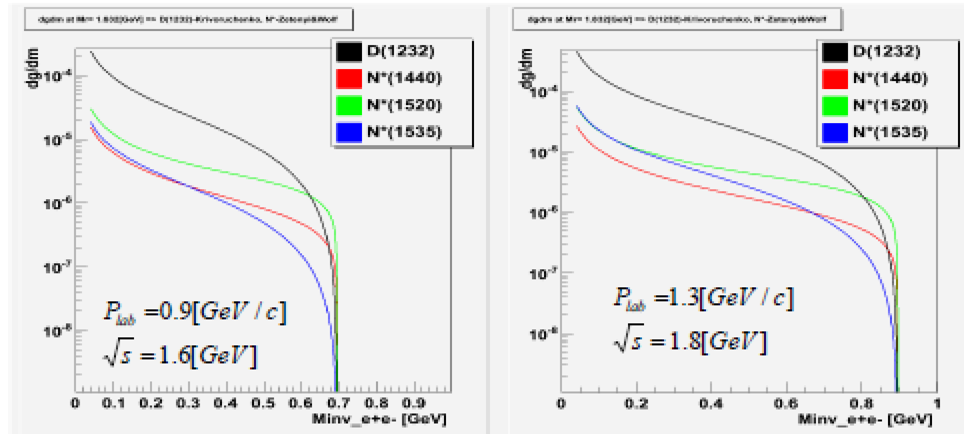
# Baryon resonance dalitz decay cross section

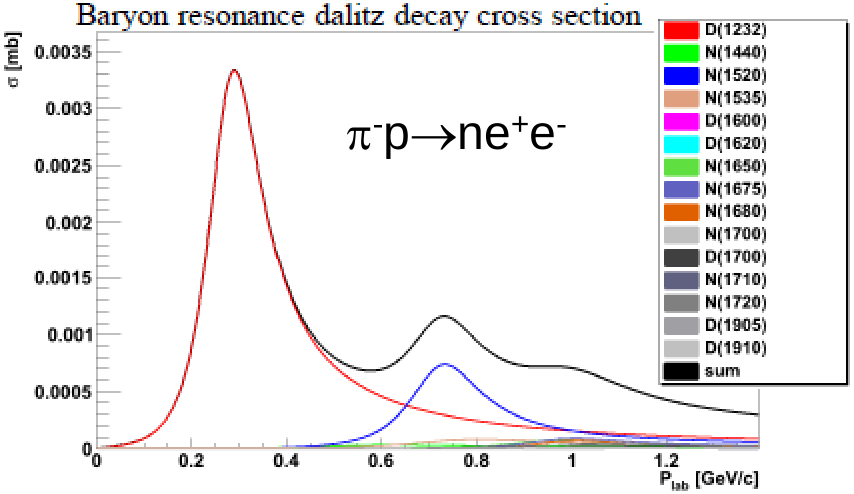
- Using Zetenyi & Wolf formula mass dependent decay widths can be calculated,
- $\Gamma_{R \to ne^+e^-}(M_R)$ used to calculate mass dependent dalitz decay cross section for baryon resonances



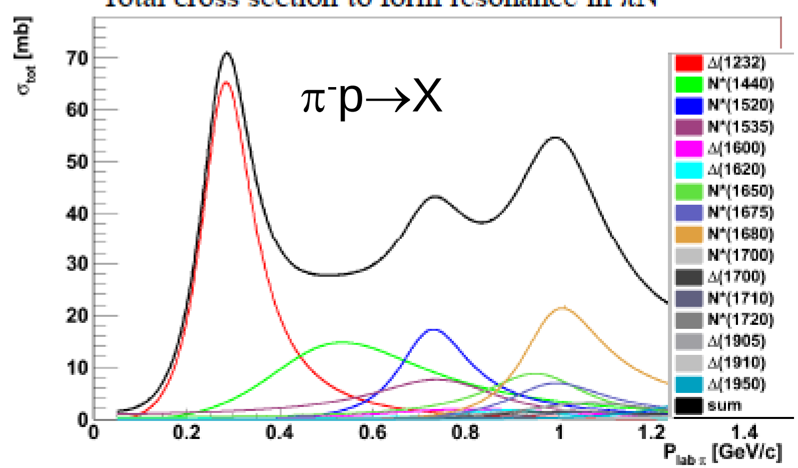

$$\sigma_{\pi\text{-}p \to R \to cd} = \frac{2J_R + 1}{(2S_{\pi^-}+1)(2S_p+1)} \frac{4\pi}{p_i^2} \frac{s\Gamma_{R\to\pi^- p}\Gamma_{R\to cd}}{(s - M_R^2)^2 + s\Gamma_{tot}^2}$$

Cross section for resonance Dalitz decay calculated by replacing $\Gamma_{R \to cd} = \Gamma_{R \to ne^+e^-}$

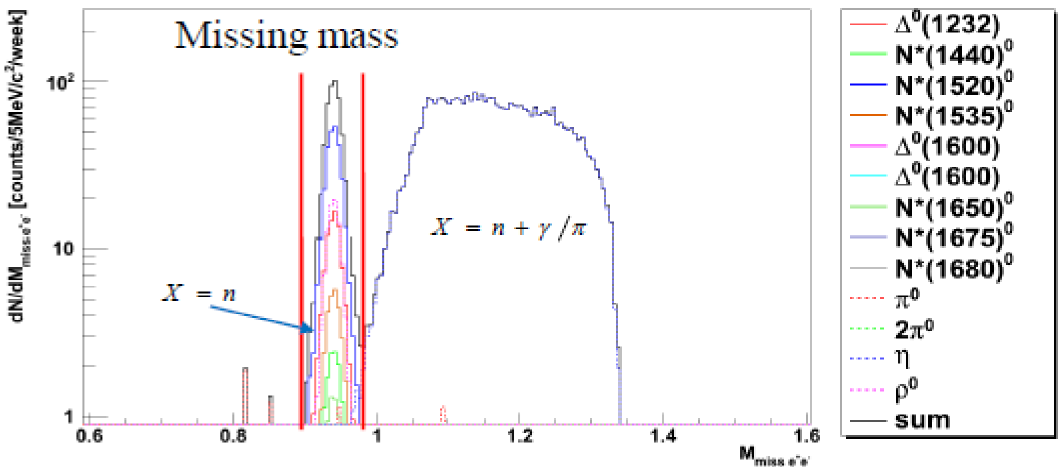
Baryon resonance dalitz decay cross section




Total cross section to form resonance in πN



# Exclusive $e^+e^-$ spectra @0.8GeV




$\pi^- + p \rightarrow X + e^+e^-$ $M_{e\text{-}e\text{+}}$>140MeV

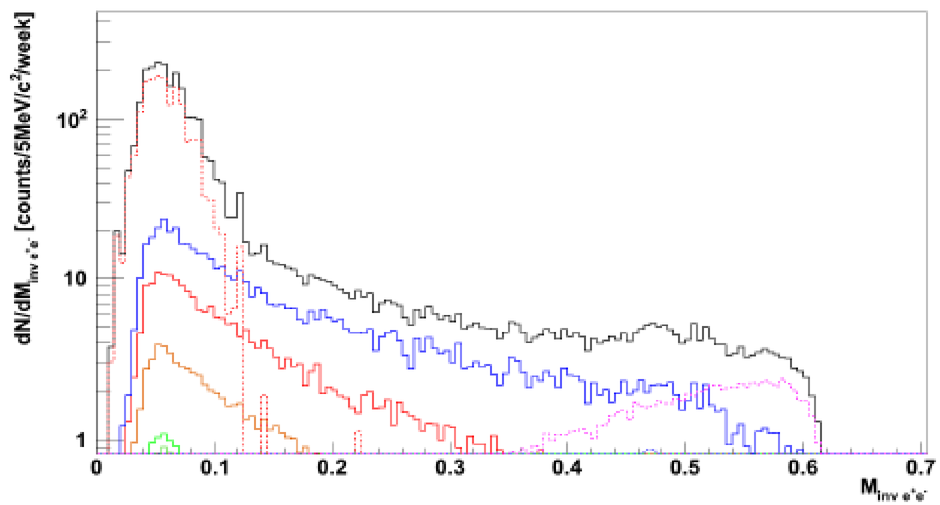
$P_{lab} = 0.8[GeV/c]$

$\sqrt{s} = 1.55[GeV]$

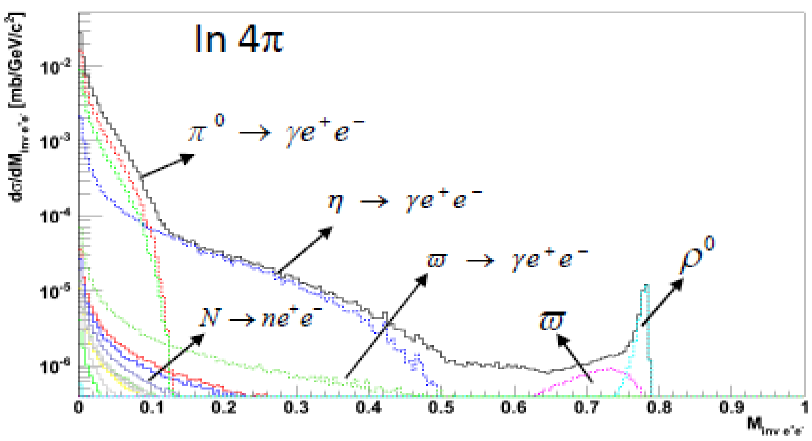
Hubert Kuc

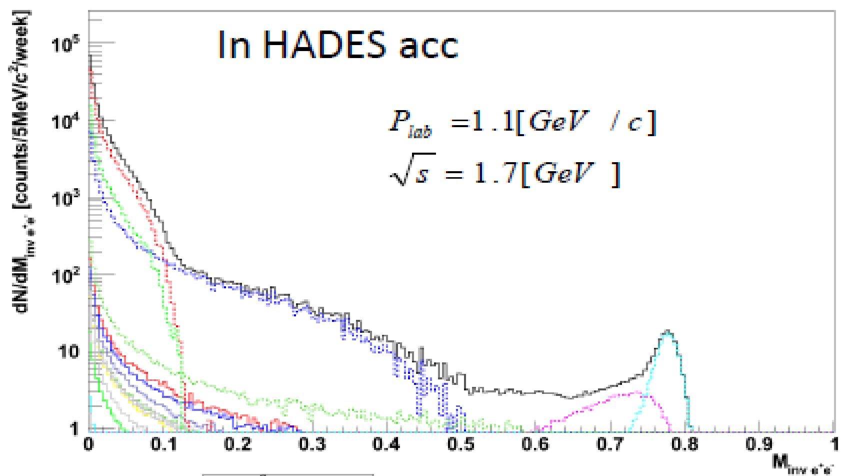
Exclusive analisis with $\pi^0$ mass cut $M_{e\text{-}e\text{+}}$>140MeV

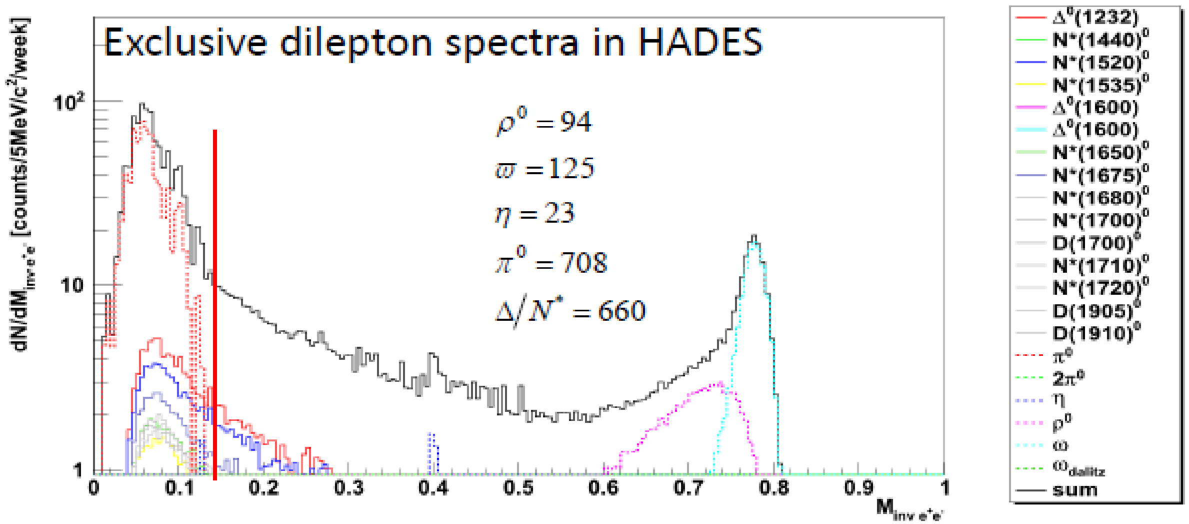
$\rho^0 = 92$ $\Delta(1232) = 89$



# $e^+e^-$ production in $\pi^- + p@1.1GeV$



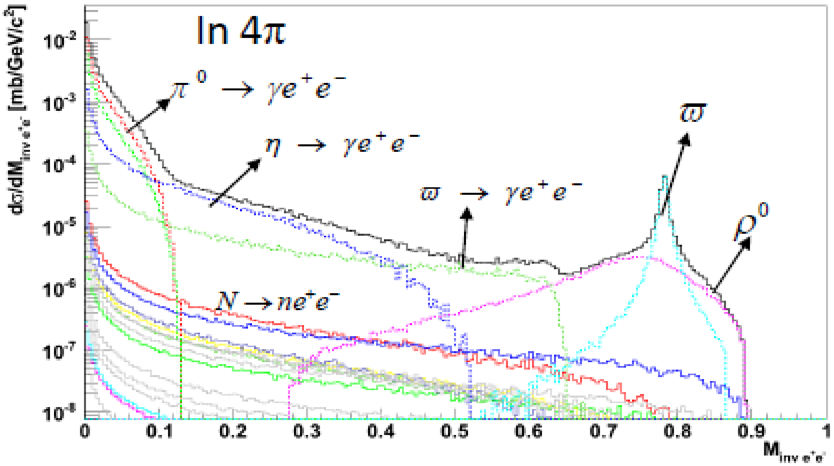

Hubert Kuc

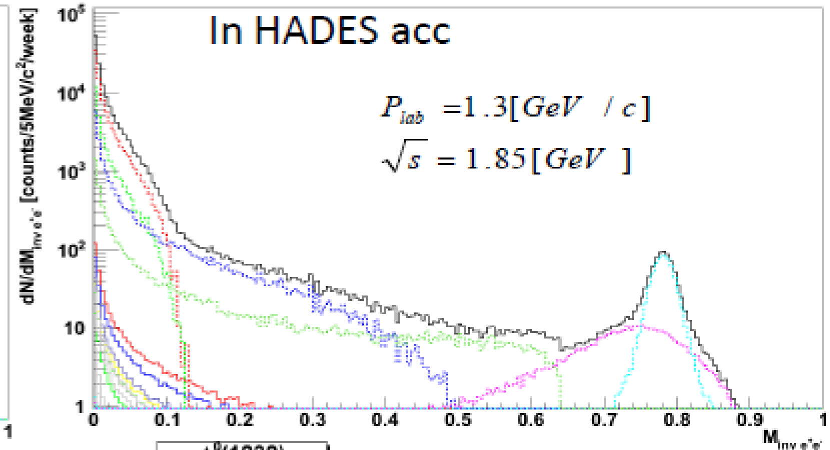
…sive analisis with $\pi^0$
…ass cut $M_{e\text{-}e\text{+}}$>140MeV

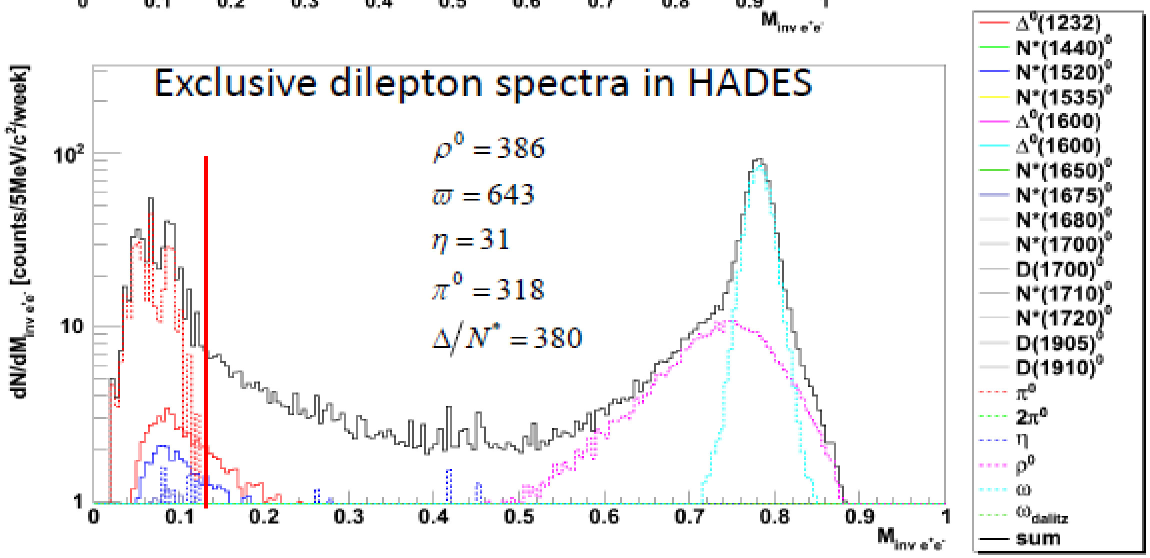
$$\rho^0 / \varpi = 219$$

$$\Delta / N^* = 263$$

# $e^+e^-$ production in $\pi^- + p@1.3GeV$




Exclusive analisis with $\pi^0$ mass cut $M_{e-e+}$>140MeV

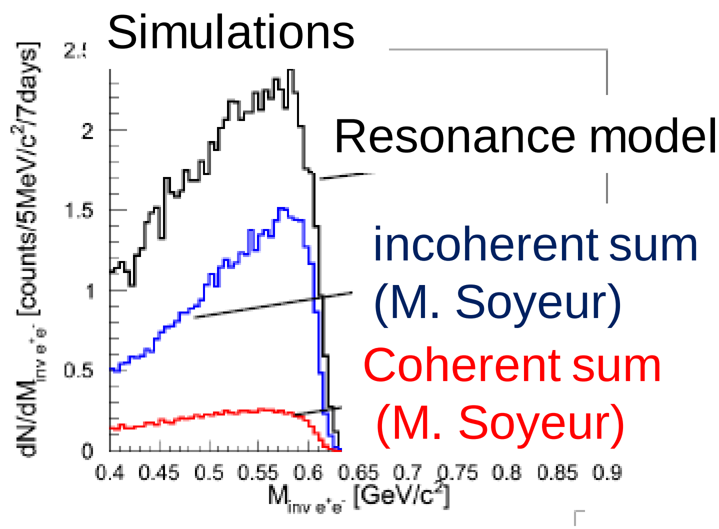
$$\rho^0/\varpi = 1029$$

$$\Delta/N^* = 182$$

# $\pi^- p \rightarrow n e^+ e^-$: count rate estimates

P=0.8 GeV/c $\sqrt{s}$=1.55 GeV/c
(below $\omega$ threshold)

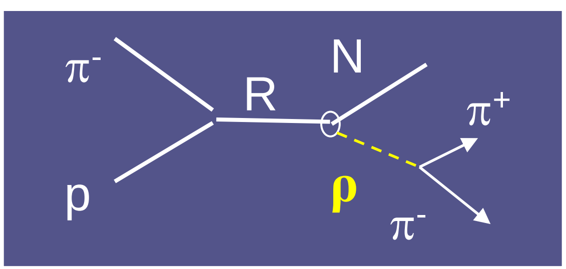
| | Resonance model | Titov et al. | M. Lutz et al. |
|---|---|---|---|
| Evts/ 2 weeks M>0.14 GeV/$c^2$ | ~ 1900<br>GiBUU~ 1400 | ~6000 | ~200 |

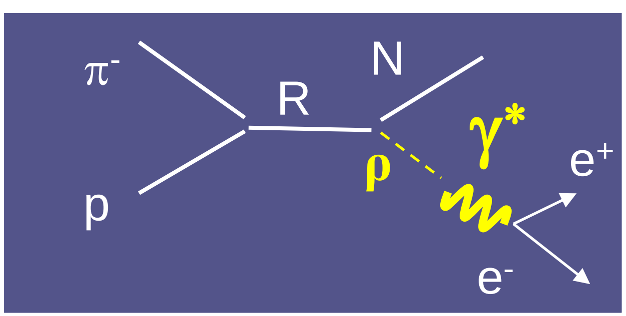



## Strategy:

1. fix the ρNN* couplings using the $\pi^- p \rightarrow \pi^+ \pi^- N$ channels in the energy scan

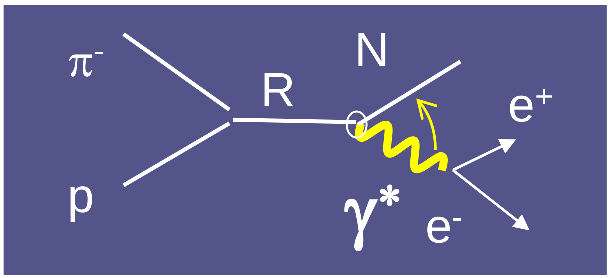
2. Measure "off-shell" ρ effects in the dielectron production at the N*(1520) energy



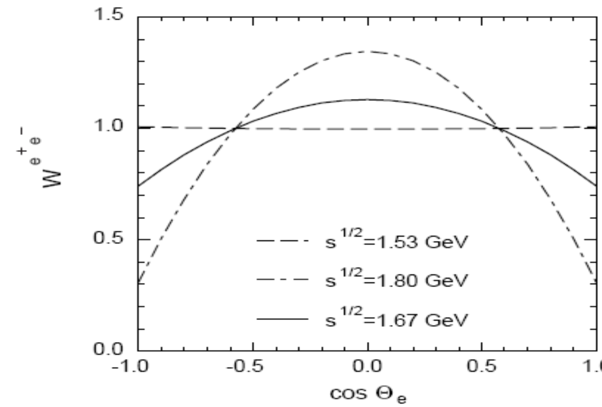



# Angular distributions in $\pi^- p \rightarrow n e^+ e^-$ :

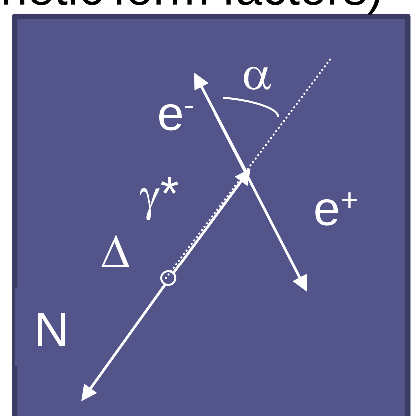
$\gamma^*$ angular distributions in CM
sensitive to the different resonance
.contributions



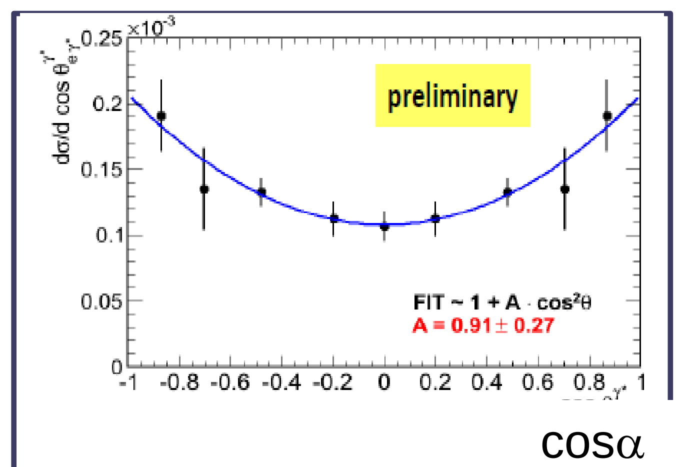

*B. Kaempfer , A Titov , R.Reznik Nucl. Phys. A721(2003)583*




$e^+/e^-$ angular distributions
in $\gamma^*$ reference frame
sensitive to helicity amplitudes
(electromagnetic form factors)




e.g distributions in $1+\cos^2\theta$ in case of purely magnetic transition $\Delta$ (1232) measured in pp reactions



# Remaining issues-ongoing studies

- Count rates will be low, (predictions are scattered), but it will give in any case the very first direct information on off-shell $\rho$ emissivity.
- Choose energy:
  - P=0.740 GeV/c ($\sqrt{s}$=1.52 GeV/$c^2$) ?
- Resume Hubert's simulations, include pion momentum reconstruction (Jacek)
- helicity angle distribution for the different resonances (M. Zetenyi ?)
- Improved lagrangian model (including $\omega$) (M. Zetenyi and G. Wolf)
- Form factor models for N-N(1520) time-like transition (T. Pena and G. Ramalho)
- Fit eVDM Form factor model (Krivoruchenko and Faessler ) to recent Space-Like data

Reminder: existing simulations for $\gamma$ detection (EMC)

# Experiments with the GSI $\pi^-$ beam : one possible scenario

- 1 week $\pi^-A$ 1.6 GeV/c 3 targets C, Cu, Pb

strangeness production (K,$\phi$) (and a few hundreds of $\rho/\omega \rightarrow e^+e^-$)

- 1 week $\pi^-p$ energy scan $\pi^-p \rightarrow n\pi^+\pi^-, p\pi^-\pi^0$

PWA (or maybe 3.5 days if we scan only the lower energy region)

- 2 weeks (or 2.5 weeks) $\pi^-p \rightarrow ne^+e^-$ 0.740 GeV/c

Electromagnetic transition form factors of baryonic resonance/ off-shell $\rho$ meson production

# Conclusion:

## perspectives of pion beam experiments with HADES ( 2014)

- Strangeness production in $\pi^- A$ at 1.7 GeV/c
- Energy scan of $\pi^- p$ reactions : one pion, two pion and kaon production

Urgent need of new data for Partial Wave Analysis → baryonic resonance properties

- $\pi^- p \rightarrow n e^+ e^-$ at 0.8 GeV/c

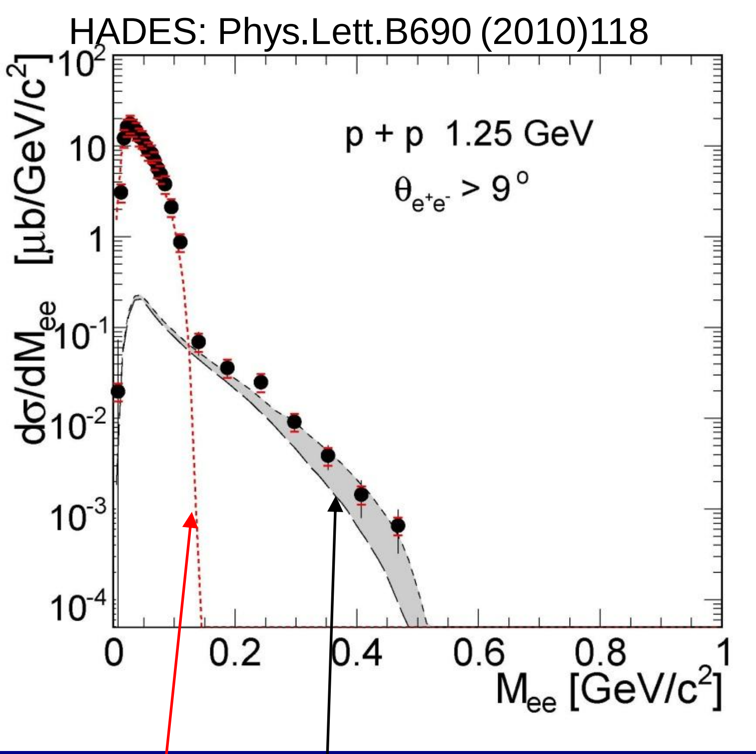
Crucial to control the interpretation of medium effects (lesson from HADES dilepton experimental program )

Unique chance to study Time-Like electromagnetic structure of higher lying resonances/coupling to ρ/ω mesons (complementary to pion electroproduction)

**GSI pion beam is unique in world at present to provide these data**
**This should be exploited ,…. before HADES moves to FAIR**

Thank you

# 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 $\sigma_{\pi°}$ =4.5 mb
  branching ratio π° → $\gamma e^+e^-$ 1.2 %

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

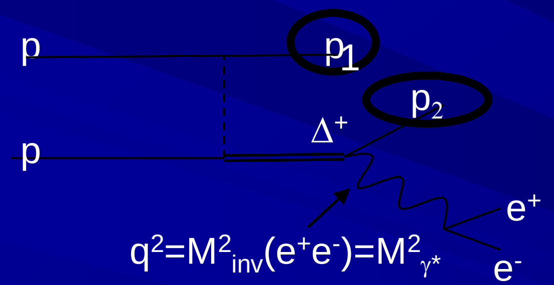
- non resonant contribution expected to be small

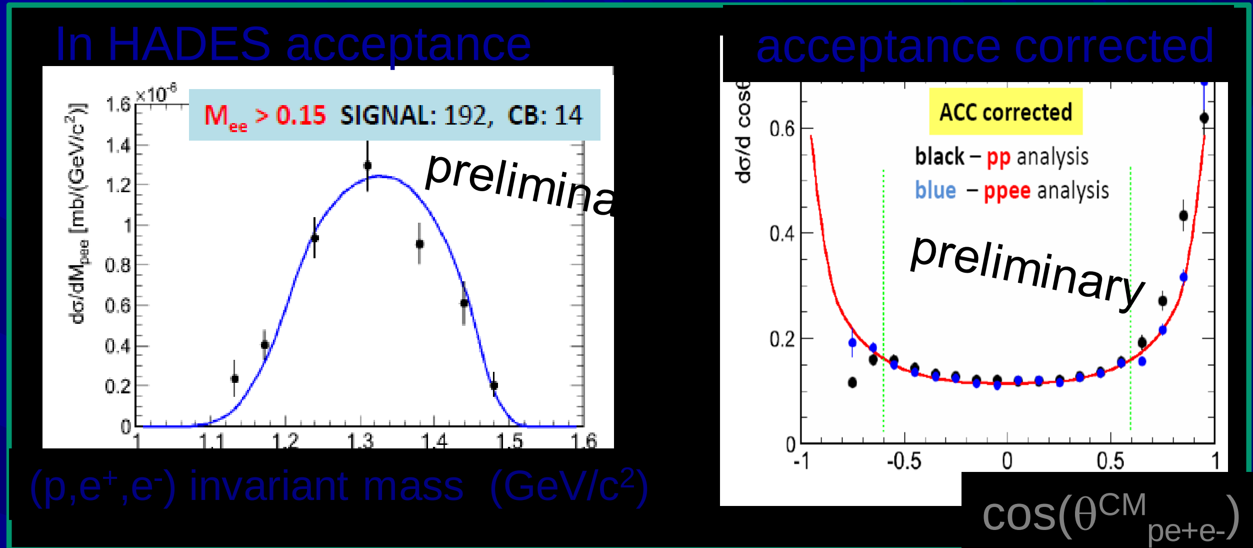
  **Time-like N- Δ transition electromagnetic form factors**

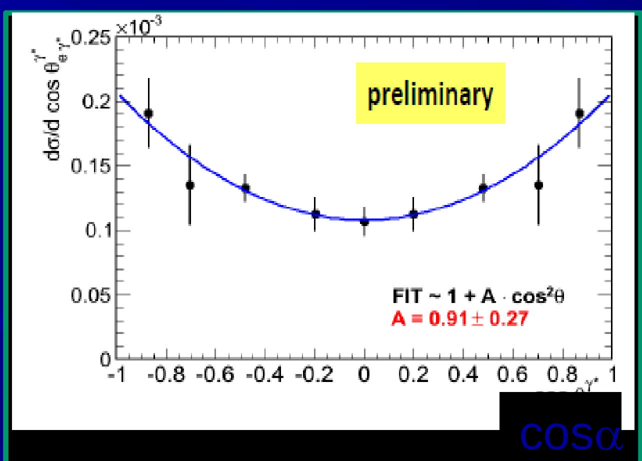
Wan and Iachello Int. J Mod. Phys. A20 (2005) 1846
G. Ramalho and T. Pena *Phys.Rev. D85 (2012) 113014*

# Exclusive analysis : $pp \rightarrow pe^+e^-$ at 1.25 GeV

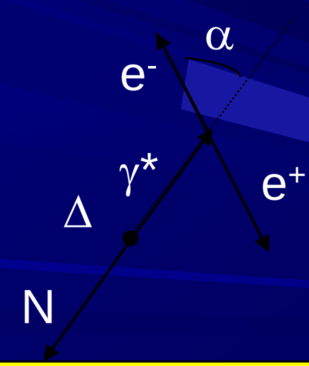
Good agreement with simulation of
$\Delta$ production + Dalitz decay
(cf hadronic channels)




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

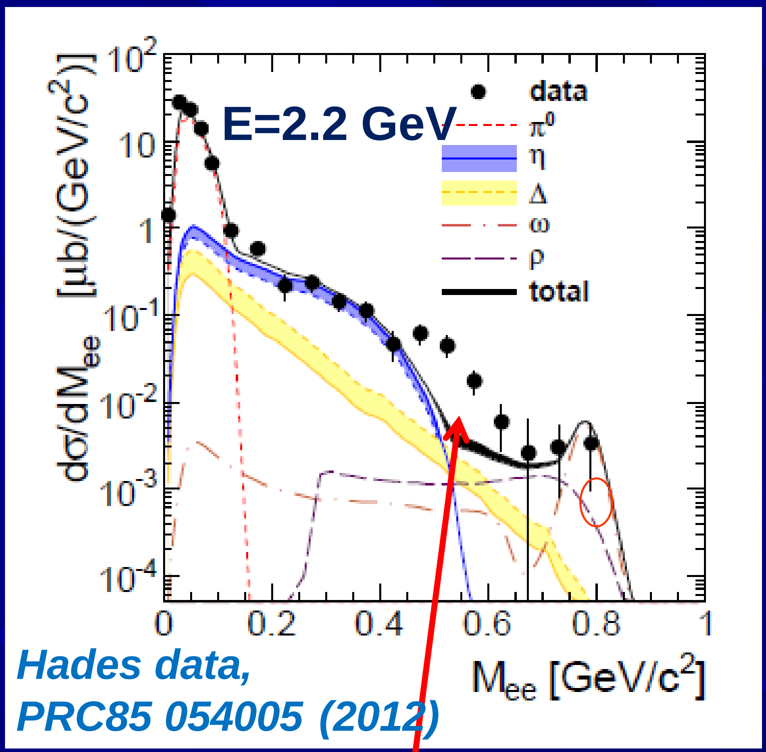



W. Przygoda's analysis
Cracow

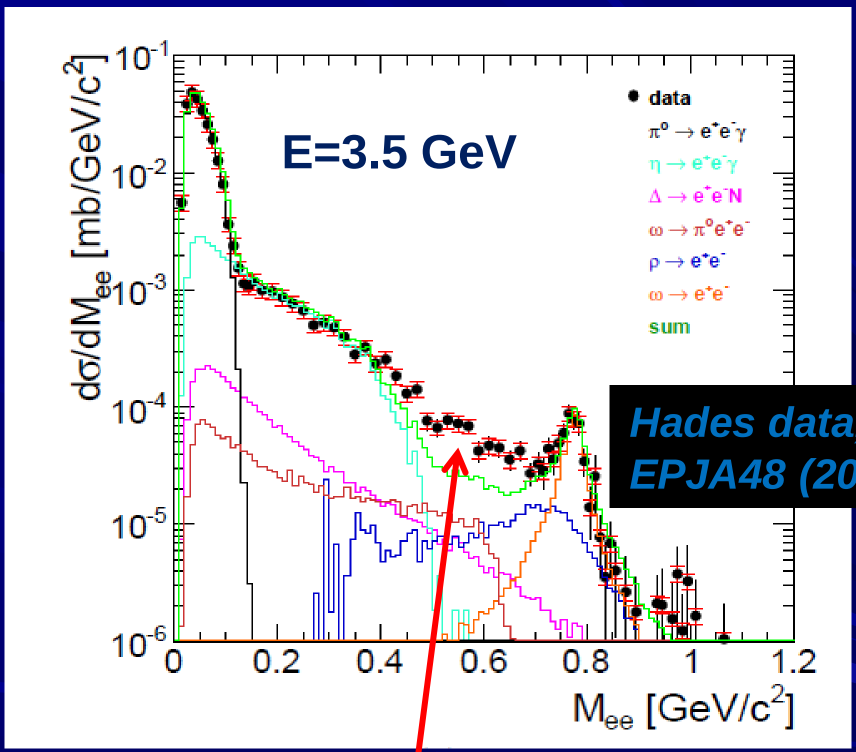
**First measurement !**
**Dalitz decay branching ratio in agreement with QED value ($4.2\ 10^{-5}$)**
**BR= $4.42\ 10^{-5}$ ±20% ( syst.) ± 9% (stat)**

# 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)

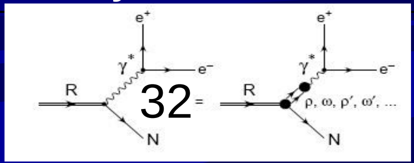



*Hades data, PRC85 054005 (2012)*




*Hades data, EPJA48 (2012) 64*

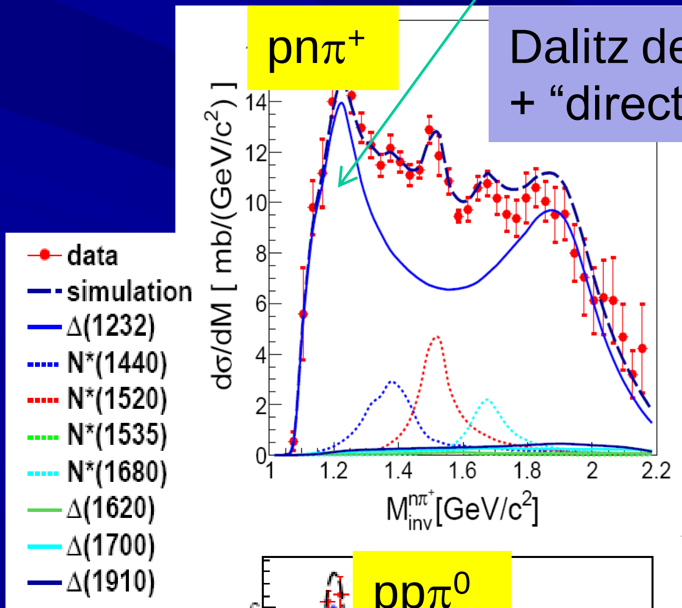
Effect of electromagnetic form factors /  Coupling of ρ to baryonic resonances ?

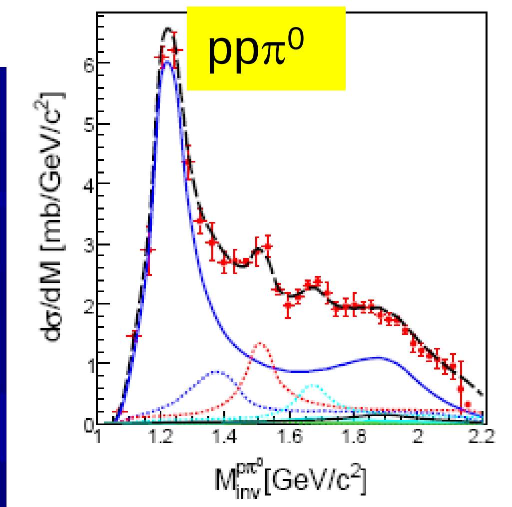


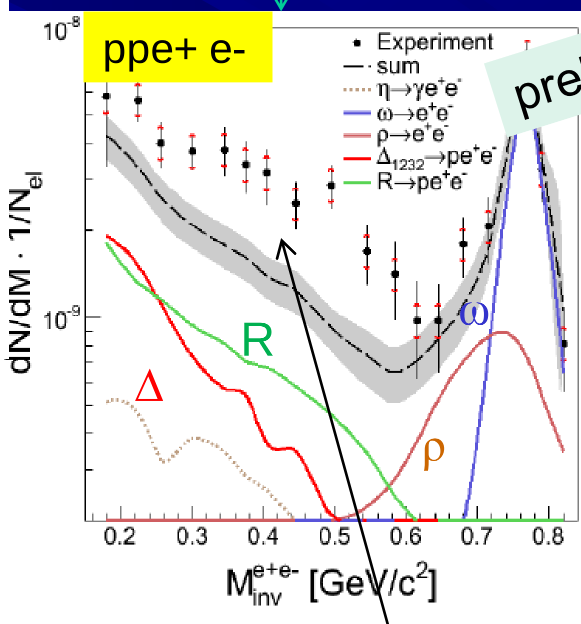
# Exclusive pp→ppe⁺e⁻ channel at 3.5 GeV

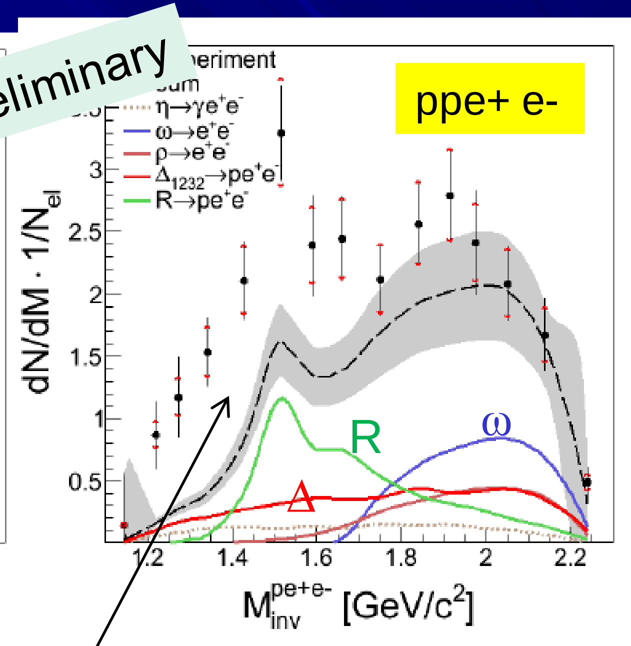
Cocktail of baryonic resonances constrained by hadronic channels

Dalitz decays of point-like baryonic resonances + "direct" ρ and ω




Excess related to light baryonic resonances (N(1520)

# Branching ratio from M. Zetenyi and Gy. Wolf formula

$$\frac{d\Gamma_{R\to Ne^+e^-}}{dM^2} = \frac{\alpha}{3\pi}\frac{1}{M^2}\Gamma_{R\to N\gamma}(M)$$

The differential width of the Dalitz-decay of a par tonic decay width to a virtual photon, $\Gamma_{R\to N\gamma}(M)$

Here the notation $M^2(=q^2)$ is used for the square of the dilepton invariant mass (= mass of the virtual photon). $\Gamma_{R\to N\gamma}(M)$ can be expressed in terms of the photonic decay matrix element $\langle N\gamma|T|R\rangle$ as

$$\Gamma_{R\to N\gamma}(M) = \frac{\sqrt{\lambda(m_*^2, m^2, M^2)}}{16\pi m_*^3}\frac{1}{n_{pol,R}}\sum_{pol}|\langle N\gamma|T|R\rangle|^2$$

$$\frac{1}{n_{pol,R}}\sum_{pol}|\langle N\gamma|T|R\rangle|^2 = 2\mathcal{M}_T + \mathcal{M}_L$$

$$\begin{aligned}
\mathcal{M}_T^{1/2+} &= 4\pi\alpha g_1^2\frac{1}{2m^4}\left(m_*^2 - m^2\right)^2\left[(m_* + m)^2 - M^2\right],\\
\mathcal{M}_L^{1/2+} &= 4\pi\alpha g_1^2\frac{M^2}{2m^4}(m_* + m)^2\left[(m_* + m)^2 - M^2\right],\\
\mathcal{M}_T^{1/2-} &= 4\pi\alpha g_1^2\frac{1}{2m^4}\left(m_*^2 - m^2\right)^2\left[(m_* - m)^2 - M^2\right],\\
\mathcal{M}_L^{1/2-} &= 4\pi\alpha g_1^2\frac{M^2}{2m^4}(m_* - m)^2\left[(m_* - m)^2 - M^2\right],\\
\mathcal{M}_T^{3/2+} &= 4\pi\alpha g_1^2\frac{1}{12m_*^2m^2}\left[(m_* - m)^2 - M^2\right]\\
&\quad\times\left(3m_*^4 + 6m_*^3m + 4m_*^2m^2 + 2m_*m^3 + m^4\right.\\
&\quad\left.-2m_*mM^2 - 2m^2M^2 + M^4\right),
\end{aligned}$$

$$\begin{aligned}
\mathcal{M}_L^{3/2+} &= 4\pi\alpha g_1^2\frac{M^2}{3m^2}\left[(m_* - m)^2 - M^2\right],\\
\mathcal{M}_T^{3/2-} &= 4\pi\alpha g_1^2\frac{1}{12m_*^2m^2}\left[(m_* + m)^2 - M^2\right]\\
&\quad\times\left(3m_*^4 - 6m_*^3m + 4m_*^2m^2 - 2m_*m^3 + m^4\right.\\
&\quad\left.+2m_*mM^2 - 2m^2M^2 + M^4\right),\\
\mathcal{M}_L^{3/2-} &= 4\pi\alpha g_1^2\frac{M^2}{3m^2}\left[(m_* + m)^2 - M^2\right],
\end{aligned}$$

$$\begin{aligned}
\mathcal{M}_T^{5/2+} &= 4\pi\alpha g_1^2\frac{1}{480m_*^4m^4}\left[(m_* - m)^2 - M^2\right]\left[(m_* + m)^2 - M^2\right]^2\\
&\quad\times\left(2m_*^4 - 4m_*^3m + 3m_*^2m^2 - 2m_*m^3 + m^4\right.\\
&\quad\left.+2m_*mM^2 - 2m^2M^2 + M^4\right),\\
\mathcal{M}_L^{5/2+} &= 4\pi\alpha g_1^2\frac{M^2}{120m_*^2m^4}\left[(m_* - m)^2 - M^2\right]\left[(m_* + m)^2 - M^2\right]^2\\
\mathcal{M}_T^{5/2-} &= 4\pi\alpha g_1^2\frac{1}{480m_*^4m^4}\left[(m_* - m)^2 - M^2\right]^2\left[(m_* + m)^2 - M^2\right]\\
&\quad\times\left(2m_*^4 + 4m_*^3m + 3m_*^2m^2 + 2m_*m^3 + m^4\right.\\
&\quad\left.-2m_*mM^2 - 2m^2M^2 + M^4\right),\\
\mathcal{M}_L^{5/2-} &= 4\pi\alpha g_1^2\frac{M^2}{120m_*^2m^4}\left[(m_* - m)^2 - M^2\right]^2\left[(m_* + m)^2 - M^2\right]
\end{aligned}$$

# Baryon Resonance Coupling to the Photon

| Resonance | Partial Width [MeV] | Total Width [MeV] |
|---|---|---|
| $N(1440)1/2^+$ **** | 0.29929+-0.078503 | 365+-35 |
| $N(1520)3/2^-$ **** | 0.9959+-0.059978 | 114+-5 |
| $N(1535)1/2^-$ **** | 1.2535+-0.23877 | 128+-14 |
| $N(1650)1/2^-$ *** | 0.19052+-0.080828 | 104+-10 |
| $N(1675)5/2^-$ **** | 0.072775+-0.0126 | 152+-7 |
| $N(1680)5/2^+$ **** | 1.1808+-0.05224 | 118+-6 |
| $N(1710)1/2^+$ *** | 0.56018+-0.32318 | 200+-18 |
| $N(1720)3/2^+$ **** | 3.3891+-1.6398 | 420+-100 |
| $N(1875)3/2^-$ *** | 0.06435+-0.063951 | 200+-25 |
| $N(2060)5/2^-$ *** | 1.1664+-0.40369 | 375+-25 |
| $N(2190)7/2^-$ *** | 0.79473+-0.17224 | 335+-40 |
| $\Delta(1232)3/2^+$ **** | 1.1111+-0.031101 | 110+-3 |
| $\Delta(1600)3/2^+$ *** | 0.2256+-0.063419 | 220+-45 |
| $\Delta(1620)1/2^-$ *** | 0.40437+-0.077764 | 130+-11 |
| $\Delta(1700)3/2^-$ *** | 5.7183+-0.98023 | 310+-40 |
| $\Delta(1905)5/2^+$ **** | 0.30669+-0.055753 | 335+-18 |
| $\Delta(1950)7/2^+$ *** | 1.1933+-0.081041 | 256+-10 |

# $e^+e^-$ production in $\pi^- + p$@1.3GeV

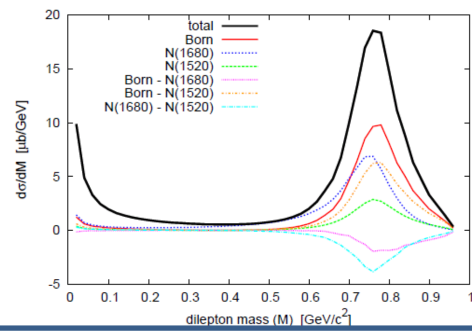
**Cross sections in different models**

Zetenyi and Wolf coherent model (only $\rho$ ?)

- ~18 μb/GeV at $\rho$ peak
- $\omega$ contribution to be added ?
- Very roughly about 3 μb for

  $\pi^- p \rightarrow n\rho \rightarrow ne+e-$ (large !!)

$\sqrt{s}$=1.9 GeV

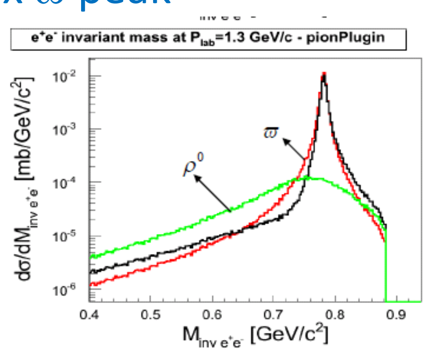



Soyeur and Lutz: coherent sum of $\rho$ and $\omega$ contributions

~0.12 μb/GeV max rho peak

~ 10 μb/GeV max $\omega$ peak

$\sqrt{s}$=1.85 GeV




Hubert's simulations are based on Incoherent sum of cross sections from data tables,

$\pi^- p \rightarrow n\rho$ is about 2.6 mb

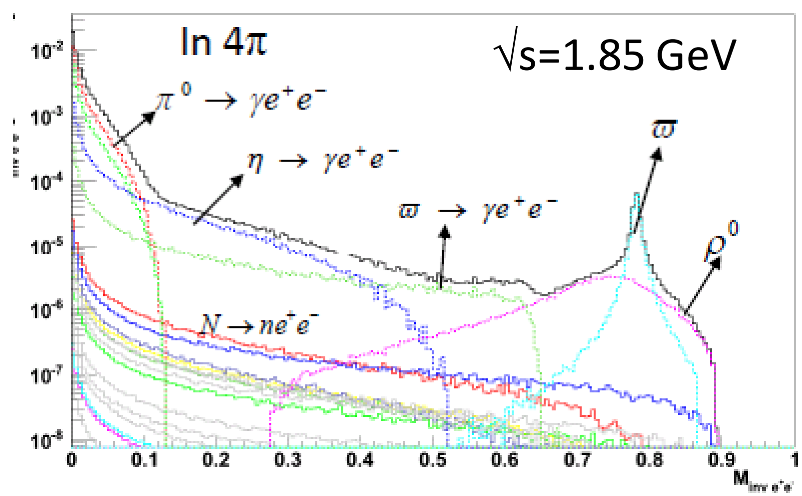
$\pi^- p \rightarrow n\omega$ is about 2.5 mb

$\pi^- p \rightarrow n\rho \rightarrow ne^+e^-$ 0.120 μb

$\pi^- p \rightarrow n\omega \rightarrow ne^+e^-$ 0.180 μb

~ 0.6 μb/GeV max $\rho$ peak

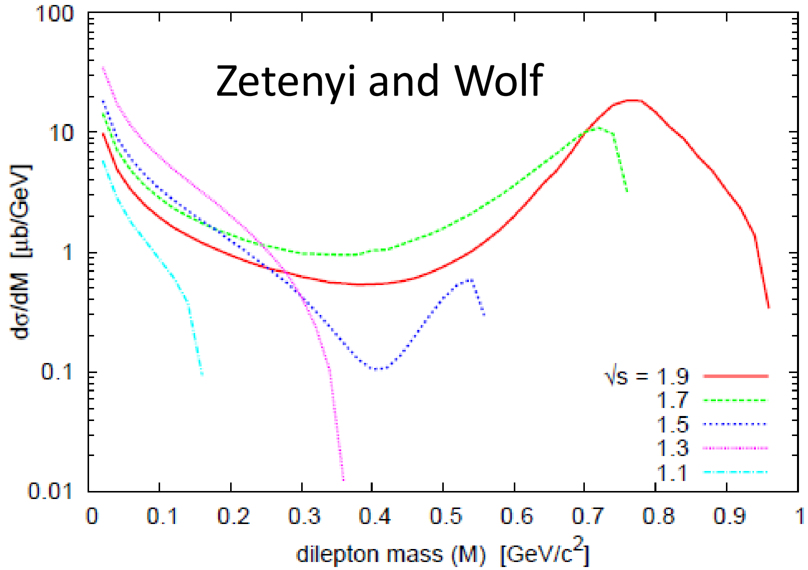
~ 16 μb/GeV max $\omega$ peak



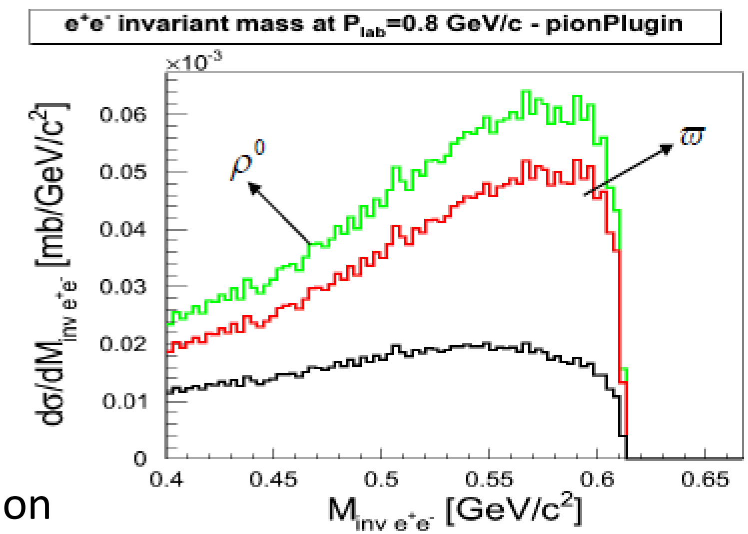
What about ower energies

sults

ρ contribution
Zetenyi at √s=1.5 GeV
~0. 6 μb/GeV
M. Soyeur at √s=1.55 GeV
0.06 μb/GeV




M. Soyeur et al
at √s=1.5 GeV




M=0.3 GeV/c2
Zetenyi's contribution at √s=1.5 GeV
~0. 6 μb/GeV
Hubert's cocktail
at √s=1.55 GeV
~ 0.2 μb/GeV
New GiBUU calculation
~ 0.15 μb/GeV

Hubert's calculation
at √s=1.5 GeV