Update on one pion and two-pion production in πN reactions

GSI, November 2012, Hades collaboration meeting

B. Ramstein, IPN Orsay

In2p3

Outline

- Why are $\pi N \rightarrow \pi N$ and $\pi N \rightarrow \pi\pi N$ measurements related to the problem of mesons in-medium modification ?

- Why are new data needed?

- Can HADES provide these measurements?

acceptances, sensitive observables, count rates,…

In-medium vector meson modifications:

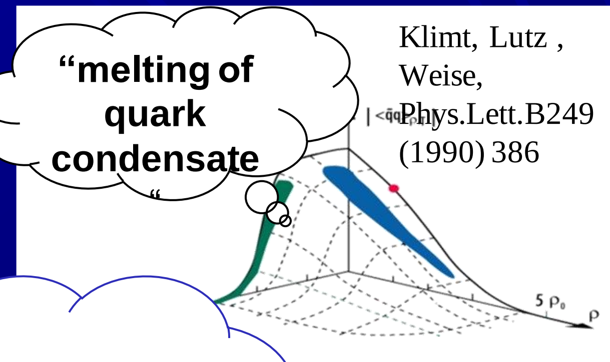
see e.g. Leupold ,Metag,Mosel Int. J. of Mod. Phys. E19 (2010) 147 for a recent review

Chiral Symetry Restoration

→ Modifications of hadron masses ?

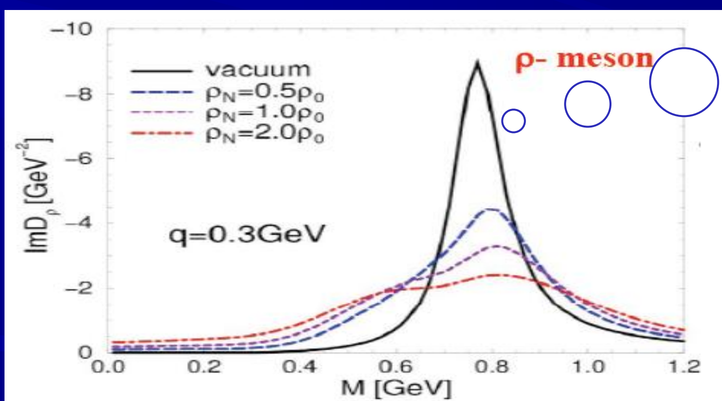
Brown-Rho PRL66(1991) 2720

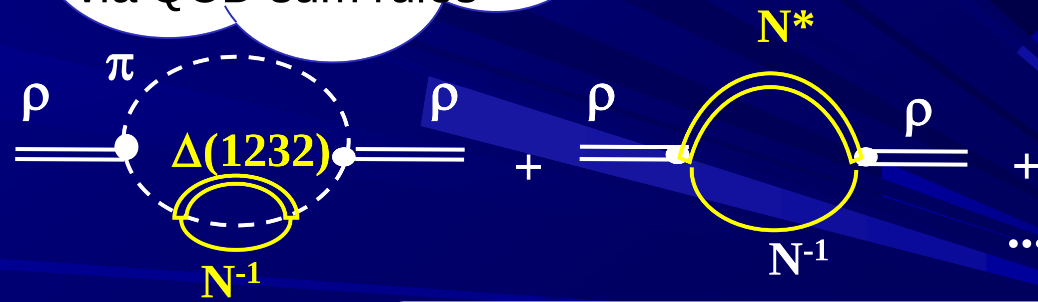
Hatsuda and Lee PRC46 (1992) ***34***



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

« in-medium broadening »

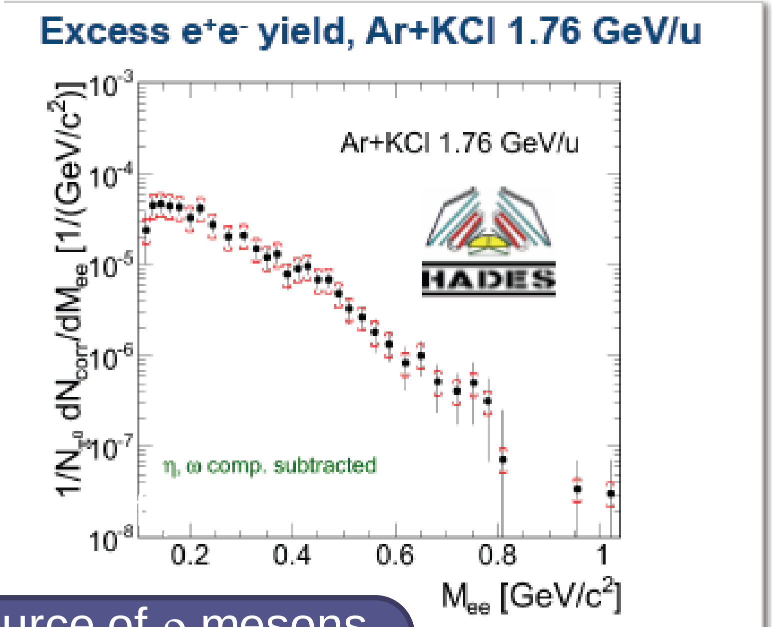


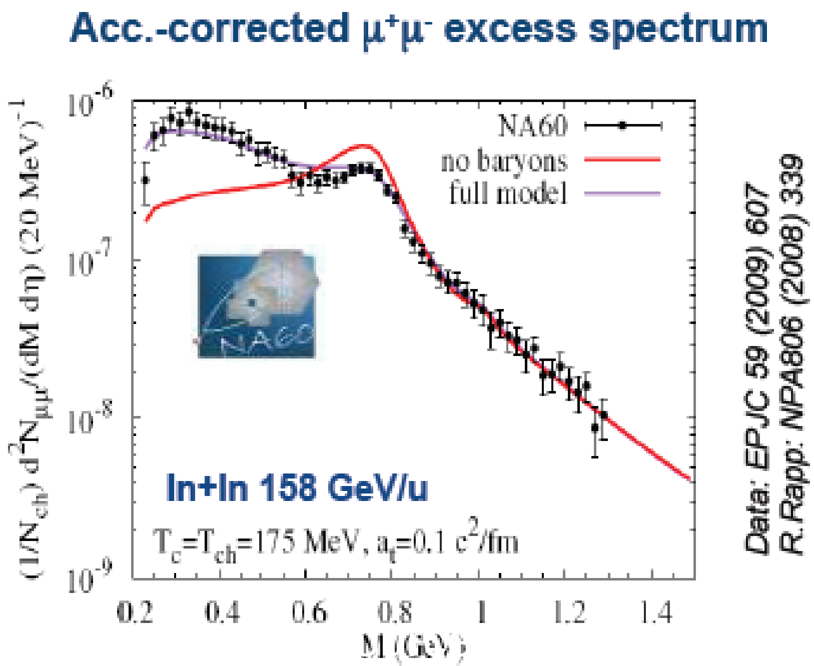


Rapp and Wambach EPJA 6 (1999) 415
Rapp, Chanfray and Wambach NPA 617, (1997) 472

In-medium spectral function depends on ρ NN* coupling

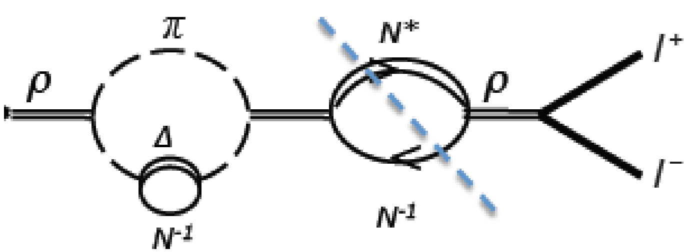
The ρ meson in hot and dense hadronic matter from SIS18 to SPS





Source of ρ mesons
NN → NR → NNρ
πN → R → Nρ

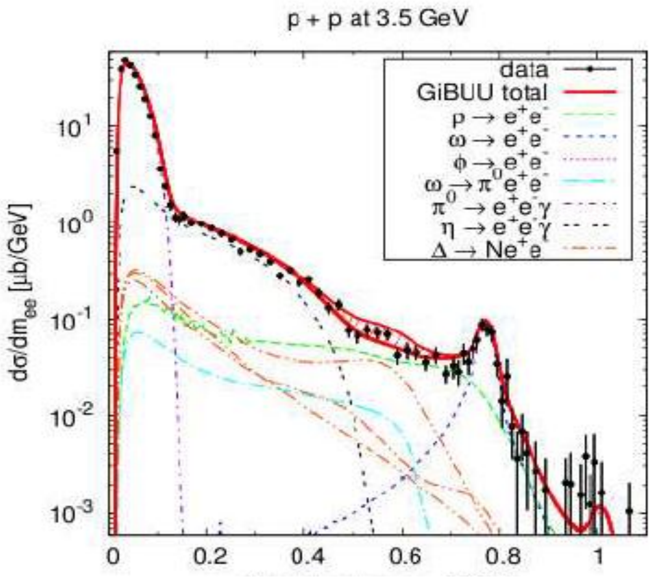
Depends on RNρ coupling



Source of ρ mesons
$\pi^+\pi^- \rightarrow \rho$

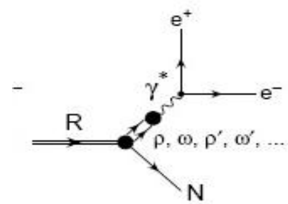
Dilepton production in pp reactions

" electromagnetic form factor approach":



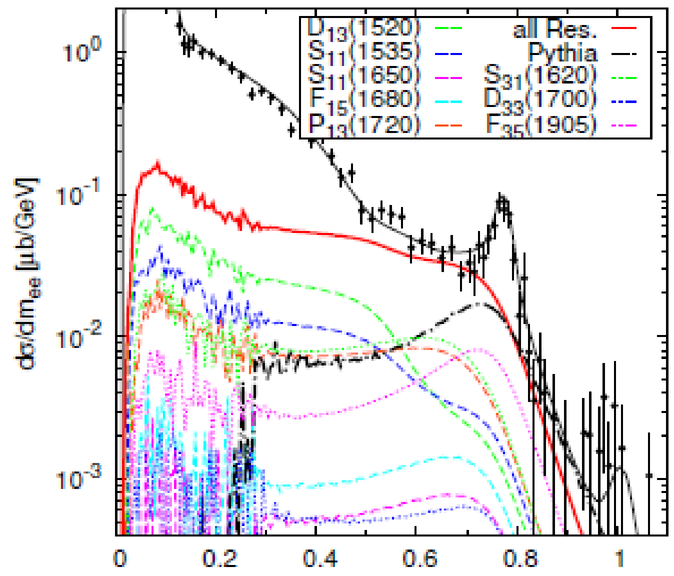
Courtesy of Janus Weil

VDM



pp 3.5 GeV

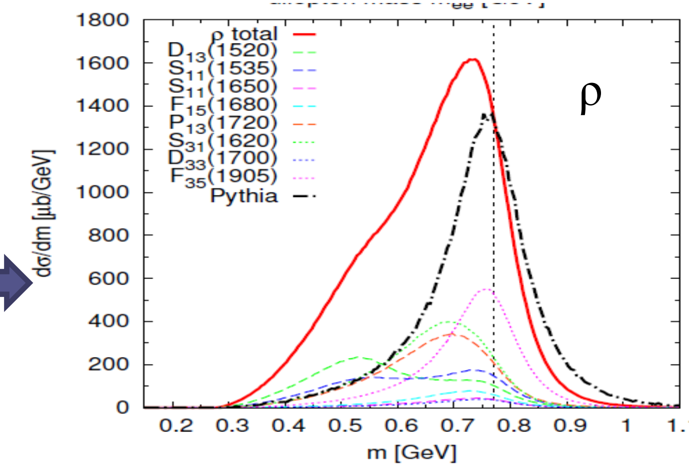
"ρ production approach":
ρNR couplings $\rho \to e^+e^-$



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

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

ρ mass distribution strongly modified in pp due to the coupling to baryonic resonances



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

In the context of dielectron measurements constraints on the coupling of ρ/ω mesons to baryonic resonances are important for

- ✓ The description of NN collisions
- ✓ The interpretation of medium effects

Why are new $\pi N \rightarrow \pi N$ and $\pi N \rightarrow \pi\pi N$ data needed?

From discussions at many meetings with A. Sarantsev, V. Shklyar, I. Strakowski,……

Partial Wave Analysis

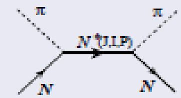
The scattering amplitude can be decomposed into different $^{2S+1}L_J$ partial waves in entrance or exit channels

Also taking care of acceptance, resolution, efficiency

Experiment

- derive scattering amplitudes from experimental data
- partial and isospin decompositions

Theory

- construct a model
- resonant + nonresonant contributions 
- calculate PW amplitudes

Compare results, fix resonance properties

Using all available channels in γN and πN reactions

On-going collaborations with different groups of PWA

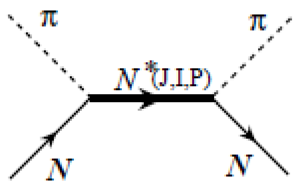
- **Giessen (V. Shklyar et al.)**
- **GWU (I. Strakowsky)**
- **BONN-Gatchina (A. Sarantsev et al.)**$\rightarrow$ ***code was provided to us and tested on pp data (W.Przygoda's talk for pp$\rightarrow$ppπ and Eliane's for pp$\rightarrow$pΛK)***

Present situation : elastic channels

- Knowledge on baryonic resonances M_R , $\Gamma(R\rightarrow\pi N)$ mainly based on Partial Wave Analysis of $\pi N\rightarrow\pi N$ and $\gamma N\rightarrow\pi N$

Mainly three main analysis of the πN scattering data so far:

- Carnegi-Mellon (Cutkosky)
- KHU (Höler)
- SAID/GWU(now absolute) (Arndt, Workman, Strakovsky, Briscoe)



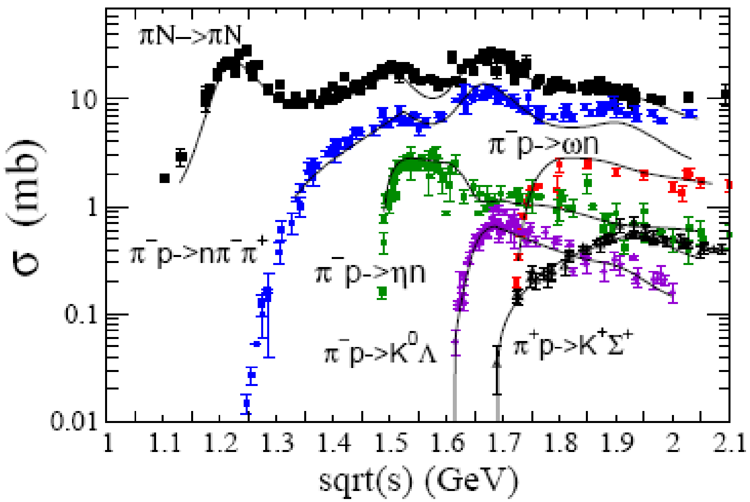
→ PDG

Dynamical models are now available (Giessen, GWU)

Problems for BR ($N^*\rightarrow N\pi$) < 20% (different analyses become incompatible)

ways to improve the situation….
✓ more precise data for $\pi N\rightarrow\pi N$ (and elastic channels…)
✓ updated analysis of elastic AND inelastic channels

πN→ππN: present status

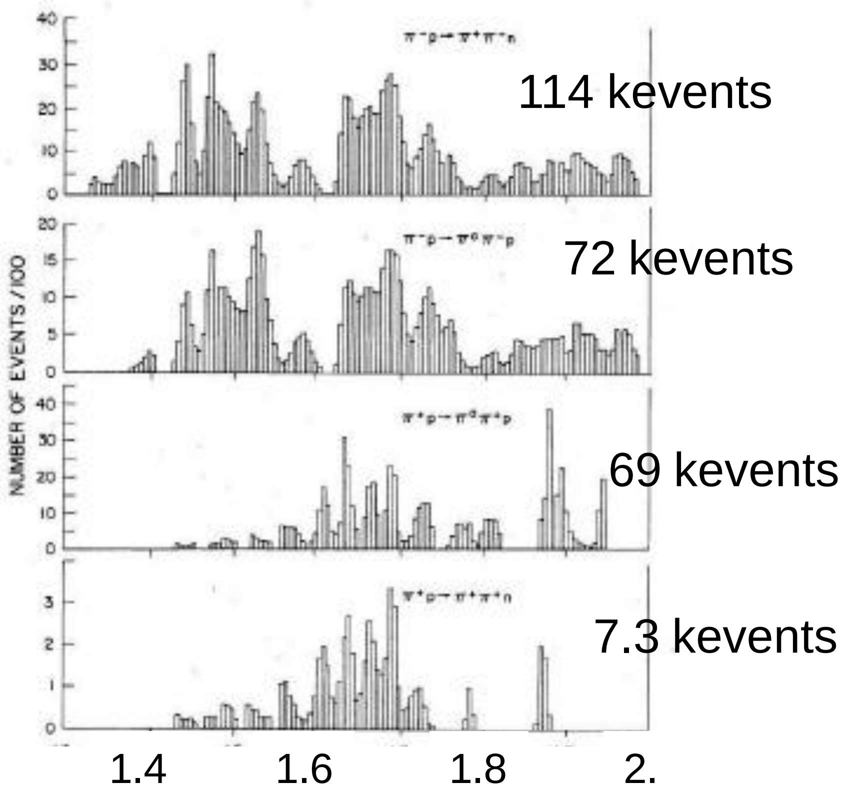


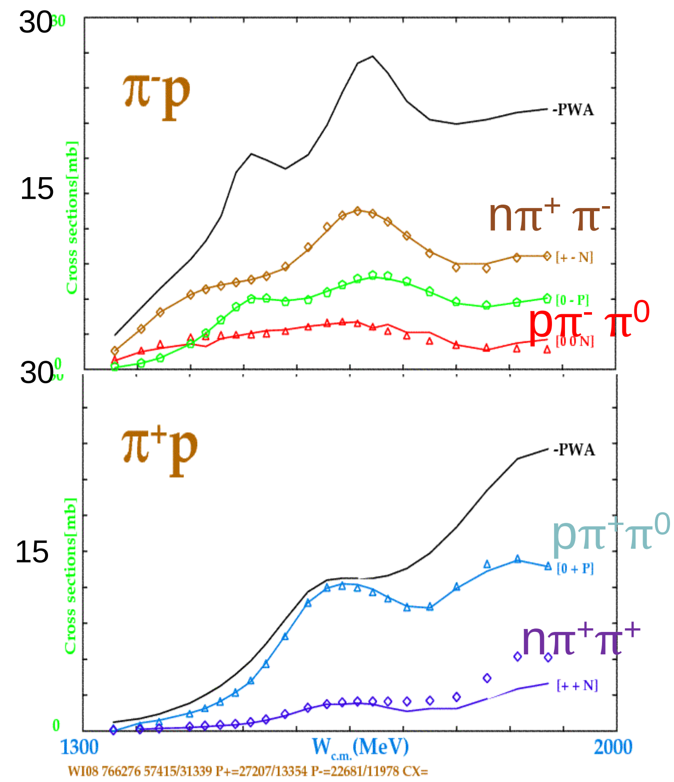
Two-pion production is the most important inelastic channel

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)

πN→ Nπ π : Existing data

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





- More recent data (TRIUMF,LAMPF,BNL) do not cover the region between 1.32 and 1.9 GeV
→ high statistics differential distributions are needed

$N(1710)$ P_{11} $\quad I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ Status: ∗∗∗

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters **111B** 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

$N(1710)$ BREIT-WIGNER MASS

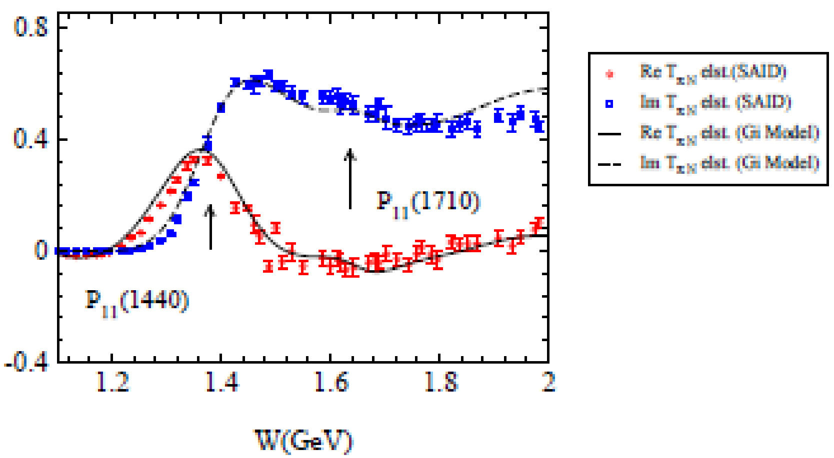
VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
1680 to 1740 (≈ 1710) OUR ESTIMATE				
1717±28	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
1700±50	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1723± 9	HOEHLER	79	IPWA	$\pi N \to \pi N$

PDG 2010:

$Br(\pi N) \approx$ 10 to 20 %

$Br(2\pi N) \approx$ 40 to 90 %

$Br(K\Lambda) \approx$ 5 to 25 %



Modern GWU (SAID) PWA:

no signal around 1710 MeV !

Giessen Model: $P_{11}(1710)$:

$Br(\pi N) \approx 3\%$

Summary: motivations for $\pi N \to \pi N$ and $\pi N \to \pi NN$ measurements

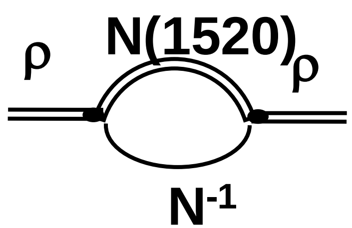
Need for a high statistics energy scan in the region W > 1.3 GeV to provide πN and πNN differential cross sections

✓ Complete existing very precise photoproduction data
✓ Improve knowledge of baryonic resonances, M_R, $\Gamma(N^* \to N\pi)$, $\Gamma(N^* \to N\pi\pi)$
✓ Important for baryonic structure issues (Constituent Quark Models, Lattice QCD)

Regions of interest/open issues:

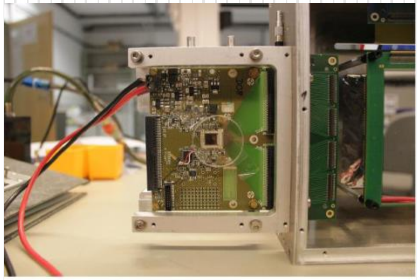
N(1440) P_{11} Branching ratios to $\pi\Delta$ and $(\pi\,\pi)_s$ N

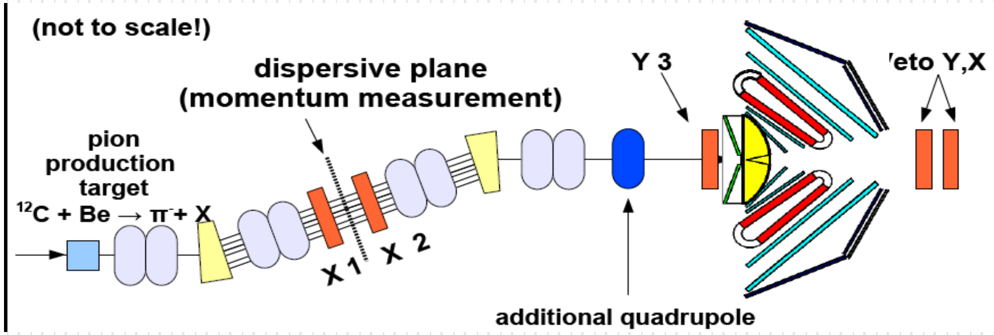
N(1520) D_{13} Branching ratios to $\pi\Delta$ and ρN, important for ρ in-medium calculations

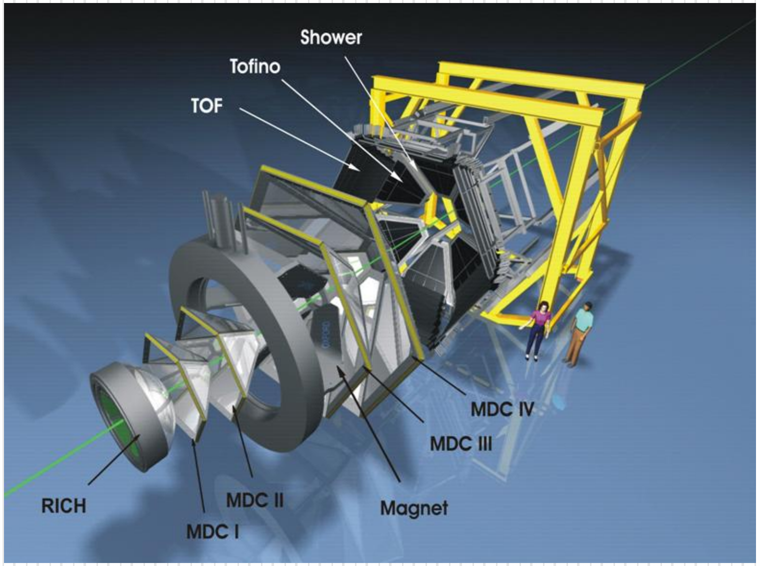


N(1710) P_{11} Not seen in the latest PWA analysis
BR(2π) =40 to 90 % (PDG 2010)

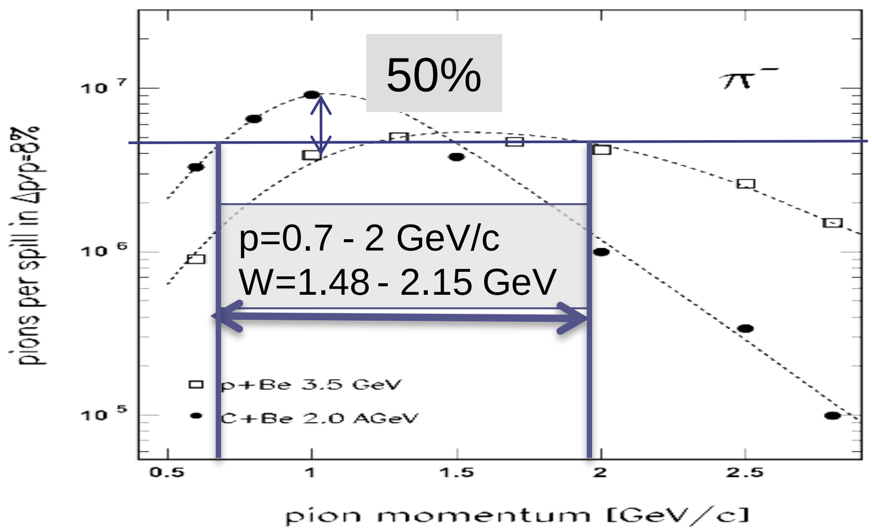
Can HADES provide these data ?







Inputs for feasibility studies:



- **measured in 2005**:
  - 2.7 10^{-5} π^-/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 π^-/s in spill
  - → 2.3 10^5 π^-/s in average

- **Expected in 2012 :**
  - 25% target cuts, see Thierry's simulations → 2. 10^{-5} π^-/ion at 1.17 GeV/c on target
  - 8 10^{10} N_2 ions (measured by FOPI, 0.6 xSCL)
  - Extraction time 1s ,total spill length 3s
  - → 1.6 10^6 π^-/s in spill   5.3 10^5 π^-/s in average
  - Room for improvement ? beam line acceptance 25%→?, SCL 60→100% ?

Estimates for the 5 cm long LH2 target at 1.1 GeV/c, 80% data taking efficiency, 50% dead time
in 4π, 100 % efficiency
N/ hour ~ 150 000 σ (mb)   N/week ~ 25 x σ (nb)

Cross sections and counting rates

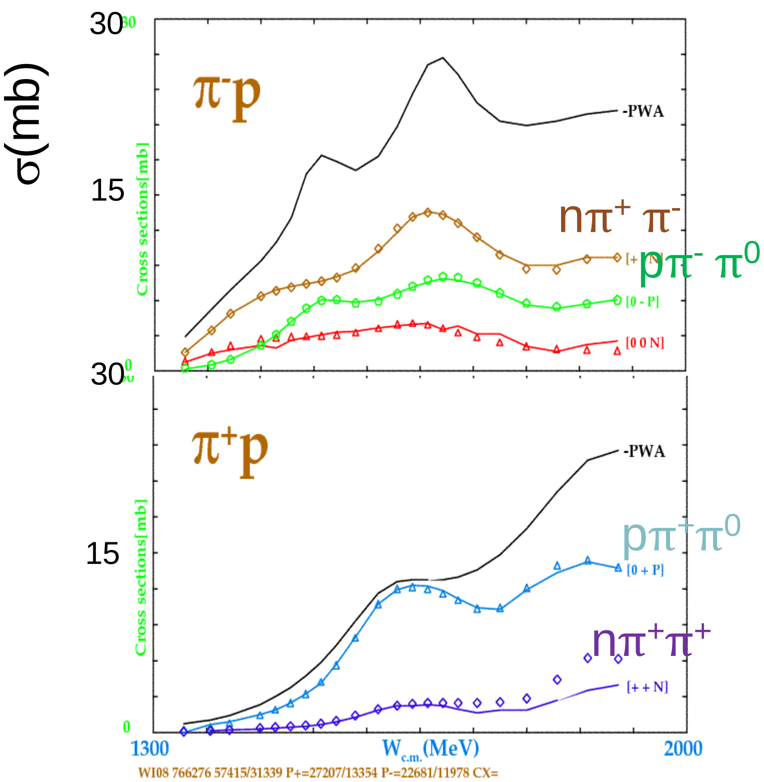
$\pi^- p / \pi^+ p \rightarrow N\pi\pi$

SAID database

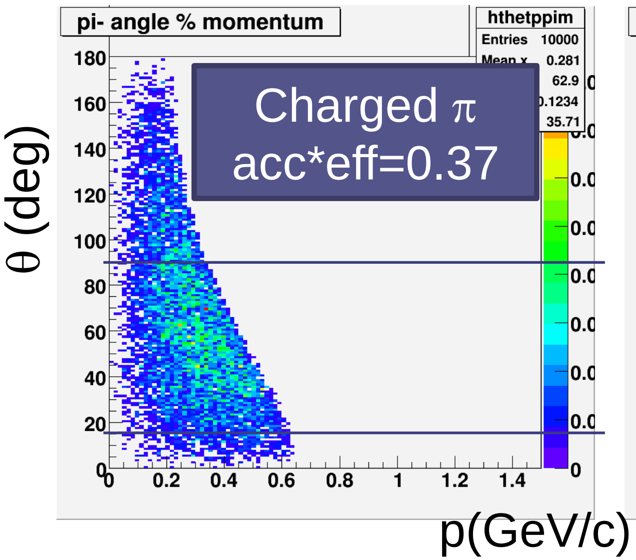
$p = 0.7$ - 2 GeV/c
$W = 1.48$ - 2.15 GeV

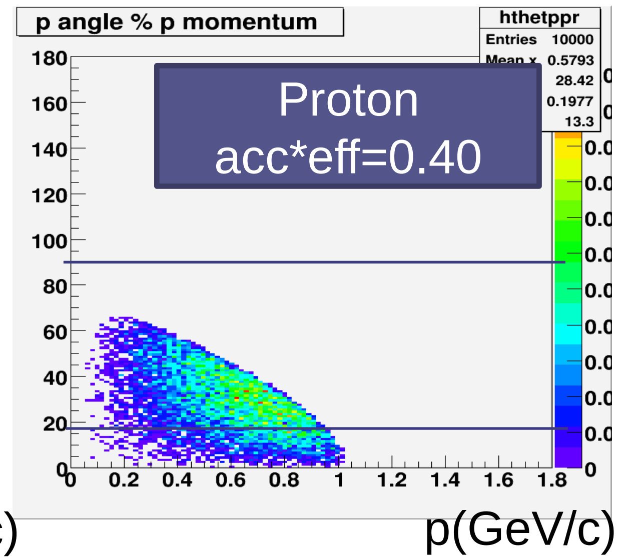
$\pi^- p \rightarrow p\pi^- \pi^0$ $\sigma = 4 - 6.3$ mb
$\pi^- p \rightarrow n\pi^+ \pi^-$ $\sigma = 6 – 11$ mb

$\pi^+ p \rightarrow p\pi^+ \pi^0$ $\sigma = 2 - 11.4$ mb
$\pi^+ p \rightarrow n\pi^+ \pi^+$ $\sigma = 0.4 – 3.3$ mb



πN→ Nπ π :acceptances

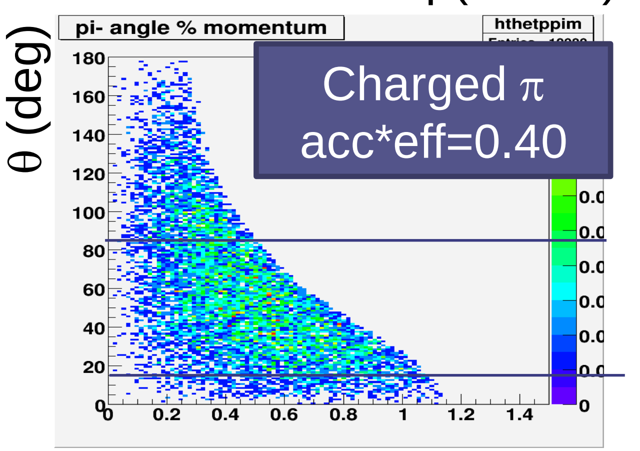


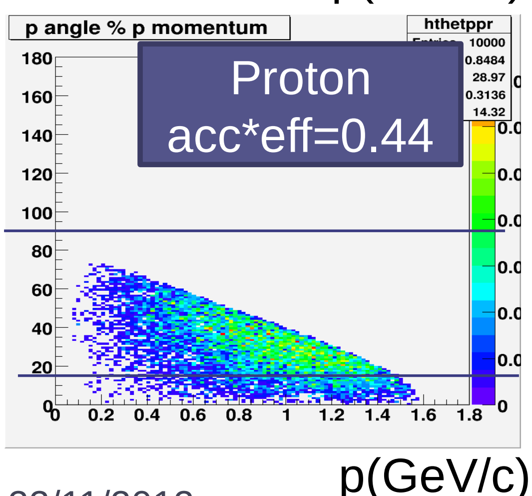


p=0.8 GeV/c

acceptance/efficiency

$\pi^- p \rightarrow p \pi^- \pi^0$	$\pi^- p \rightarrow n \pi^+ \pi^-$
0.16	0.13





p=1.3 GeV/c

acceptance/efficiency

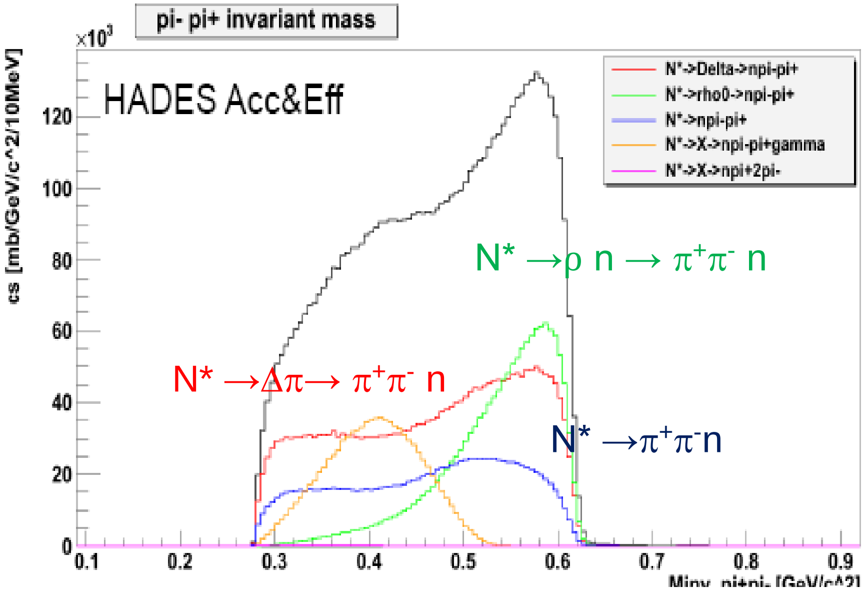
$\pi^- p \rightarrow p \pi^- \pi^0$	$\pi^- p \rightarrow n \pi^+ \pi^-$
0.19	0.16

Similar numbers for
$\pi^+ p \rightarrow p \pi^+ \pi^0$
$\pi^+ p \rightarrow n \pi^+ \pi$

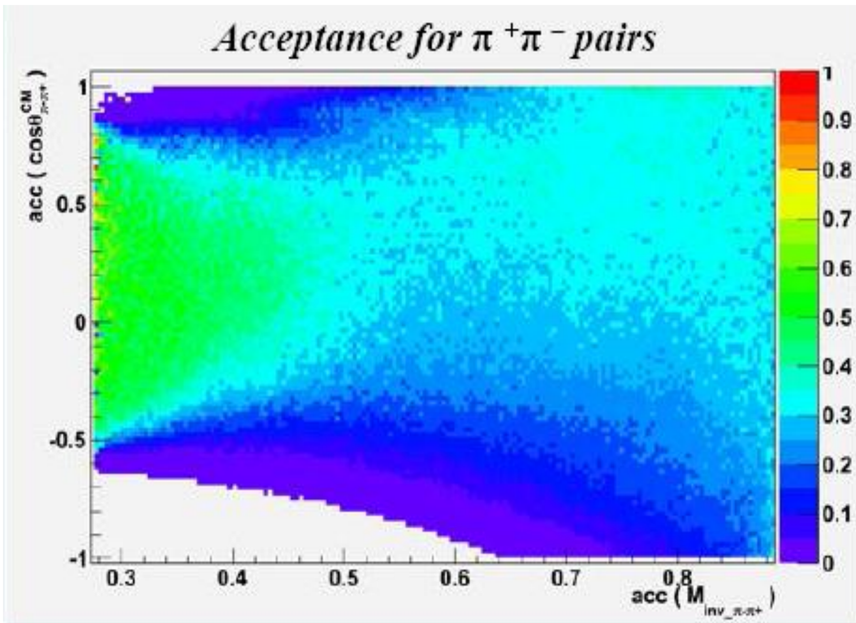
$\pi^- p / \pi^+ p \rightarrow N\pi\pi$:sensitivity

Hubert Kuc simulations

P=0.8 GeV/c $s^{1/2}$=1.56 GeV



$M_{\pi\pi}$(GeV/c^2)



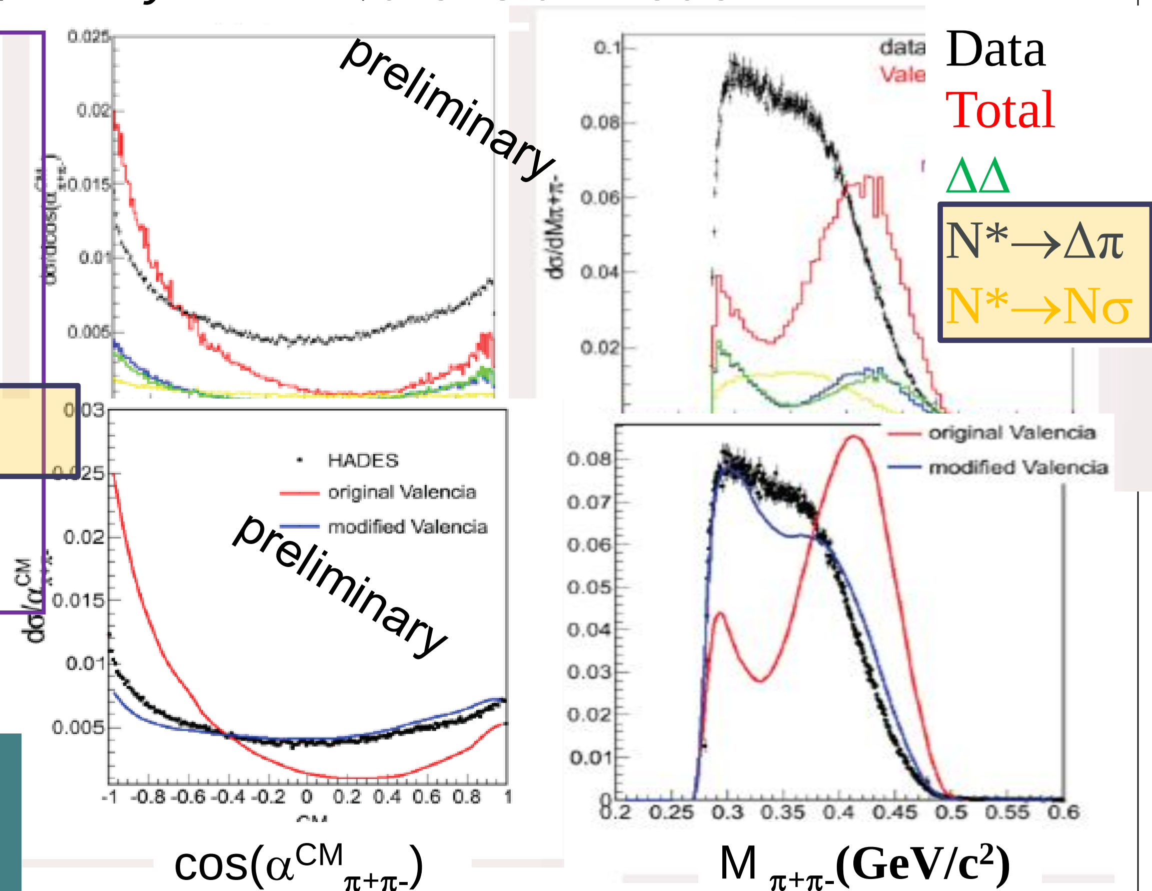
- ✓ $M_{\pi\pi}$ invariant mass in acceptance is sensitive to different N* decay channels
- ✓ Good sensitivity also for $M_{\pi+N}$, $M_{\pi-N}$

$pp \to pp\pi^+\pi^-$ 1.25 GeV sensivity of two-pion observables

M. Gumberidze, Orsay

Valencia model

High sensitivity of both observables to
- N*, Δ production mechanisms ($\sigma+\pi+\rho$ exchange)
- $\Gamma(N^* \to \Delta\pi) / \Gamma(N^* \to N\sigma)$
- Total strength of N* (1440)



much higher sensitivity expected in $\pi N \to \pi\pi N$
- Higher acceptance
- Less uncertainty on production mechanism

$\pi^- p \rightarrow N\pi\,\pi$:statistics for one point

p=0.7 - 2 GeV/c W=1.48 - 2.15 GeV
Average statistics in acceptance for one value of W

	$\pi^- p \rightarrow p\pi^-\,\pi^0$	$\pi^- p \rightarrow n\pi^+\,\pi^-$
σ (mb)	4.8	8
evts /hour	95 000	130 000
Evts/bin/shift	95	130
Time for PWA condition	0.8 shift	

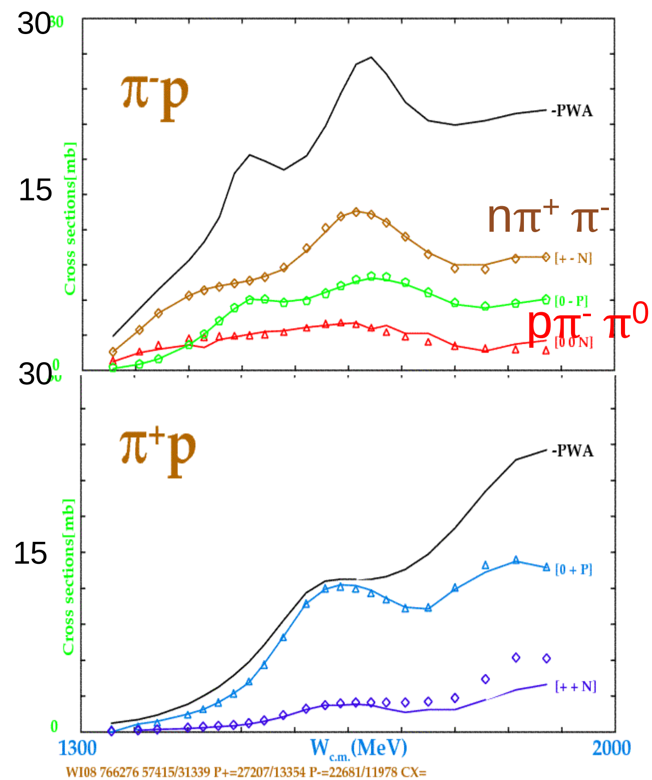
Requirements for Partial Wave Analysis
20 bins in $\cos(\theta_{\pi\pi})$, 20 bins in $M_{\pi+N}$, 20 bins $M_{\pi-N}$
80 counts /bin *(to be discussed)*

$\pi^- p \rightarrow N\pi\,\pi$ statistics for energy scan

p=0.7 - 2 GeV/c W=1.48 - 2.15 GeV
Energy scan in steps of 25 MeV (26 points)
80 evts/bin (8000 bins $\cos(\theta_{\pi\pi})$, $M_{\pi+N}$, $M_{\pi\text{-}N}$)

	$\pi^- p \rightarrow p\pi^-\pi^0$	$\pi^- p \rightarrow n\pi^+\pi^-$
Time for 26 points in W	21 shifts (~ 7 days)	

In total ~ 21 10^6 $\pi^+\pi^-$(114 000 existing)
~ 15 10^6 $\pi^0\pi^-$ (72 000 existing)

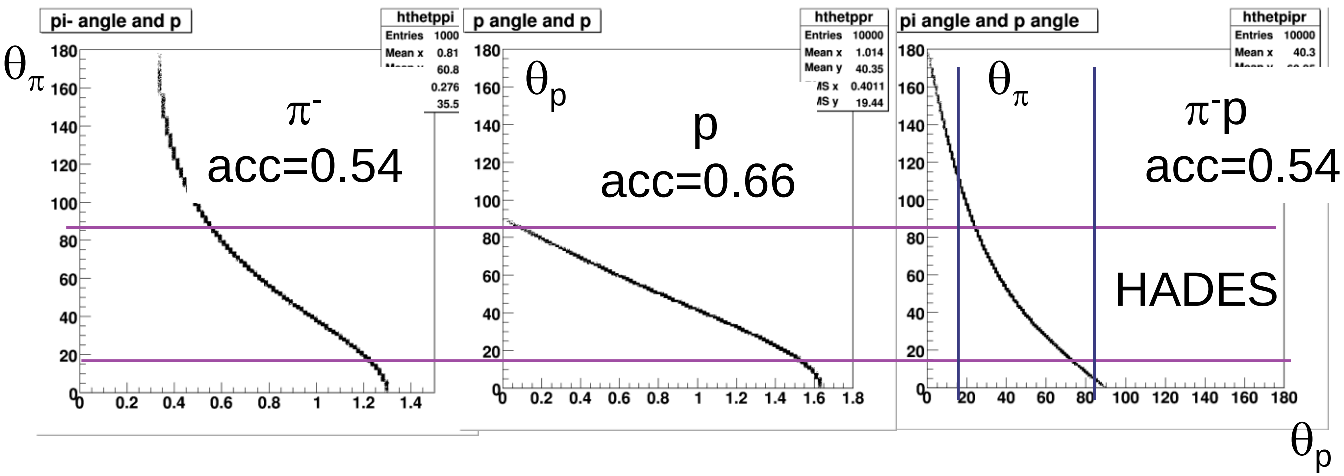


Other interesting and accessible channels
✓ϕn and other strange channels (Laura)
✓multiparticle production
e.g. $\Delta^0\eta \rightarrow p\pi^-\eta$ (missing resonances study)

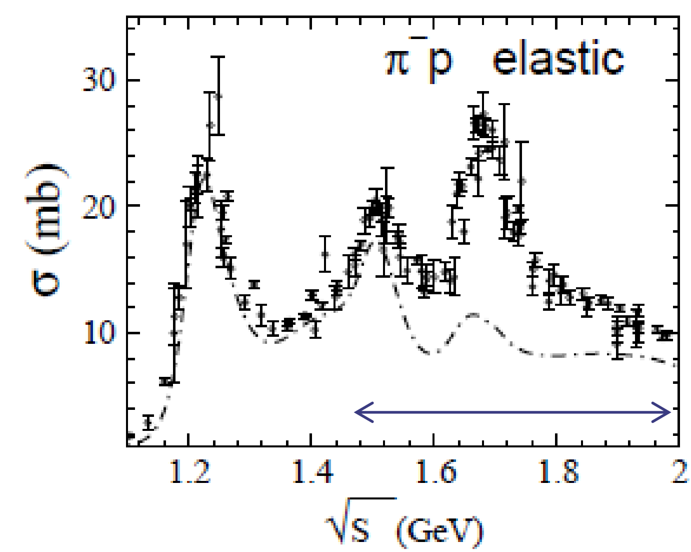
✓and with an EMC: $\pi^0\pi^0$ n, ηn, ωn,…

$\pi^- p \rightarrow \pi^- p$ statistics

P=0.8 GeV/c



σ= 10-25 mb



	P=0.8 GeV/c	P=2 GeV/c
acc π^- and p	54%	55 %
acc π^- or p	66%	66%

~ 6-15 Mevents/point (0.8 shift)

HADES can provide, within one week, the missing $\pi^- p \rightarrow \pi^- p$, $\pi^- p \rightarrow \pi^0 \pi^- p$ and $\pi^- p \rightarrow \pi^- \pi^+ n$ measurements

A new combined PWA analysis of all pion and photoproduction channels will be possible.

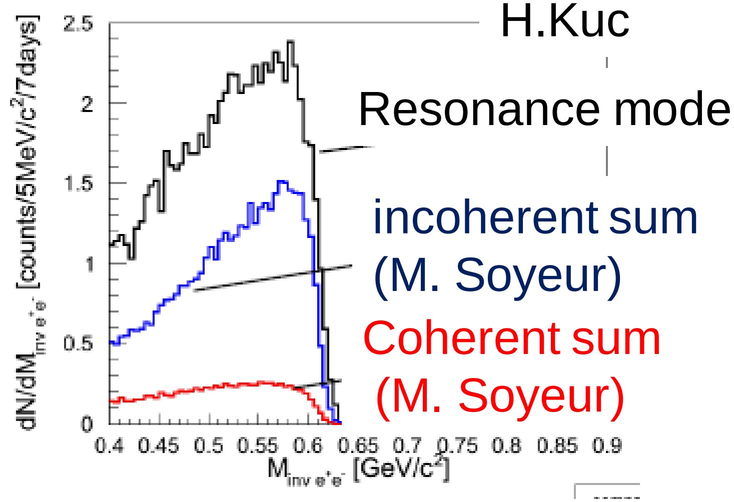
$\pi^- p \rightarrow n e^+ e^-$: an update

P=0.8 GeV/c (below ω threshold)

	Resonance model	M. Soyeur et al.
Evts/ week	970	~100

P=1.3 GeV/c (above ω threshold)

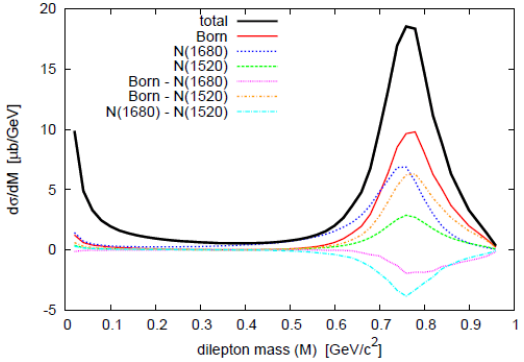
	Resonance model	M. Soyeur et al.
Evts/ week	2300	~1100



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

New calculations by Zetenyi and Wolf arXiv:1208.56 ,

- ✓ *only ρ*
- ✓ *too large cross sections*



Counting rates strangeness production

- Full GEANT simulations for p_{π}=1.7 GeV/c (above ϕ threshold)

Numbers of events per day

	C	Cu	Pb
K^0	4.7 10^5	3.0 10^5	3.7 10^5
K^+	1.4 10^6	1.2 10^6	1.1 10^6
K^-	10^5	6.3 10^4	5.9 10^4
ϕ (K^+K^-)	1260	3780	3400

π^- +p

π^- +p $\rightarrow \Sigma^-$ + K^+ (detection of all charged particles + missing neutron analysi
π^- + p $\rightarrow \Lambda$+ K^0s (detection of all charged particles)
π^- + p $\rightarrow \Sigma^0$ + K^0 (detection of all charged particles but the photon)

Numbers of events per 0.8 shift

Σ^- + K^+	Λ+ K^0_s	Σ^0 + K^0
5150	280	480

threshold for the productions:
$\Sigma^-K^+\approx$ 1.035 GeV/c
$\Lambda K^0\approx$0.896 GeV/c
$\Sigma^0K^0\approx$1.031 GeV/c

Experiments with the GSI π^- beam : one possible scenario

- 1 week π^-A 1.6 GeV/c 3 targets C, Cu, Pb
strangeness production (K,ϕ) (and a few hundreds of $\rho/\omega \rightarrow e^+e^-$)

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

- 2 weeks $\pi^-p \rightarrow ne^+e^-$ 0.8 GeV/c
Electromagnetic transition form factors of baryonic resonance/ off-shell ρ meson production

Conclusion

Measurements of differential distributions in $\pi^- p \to n \pi^+ \pi^-$ in an energy scan from 0.8 to 1.3 GeV/c (W=1.48 - 2.15 GeV)

$\rightarrow$ necessary complement to photoproduction data in order to improve the knowledge on baryonic resonances properties

$\rightarrow$ outstanding contribution for hadronic structure studies (Lattice QCD, quark models)

$\rightarrow$ These data are necessary for the interpretation of medium effects in dielectron production at SIS energies AND above

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

A scenario is proposed to measure

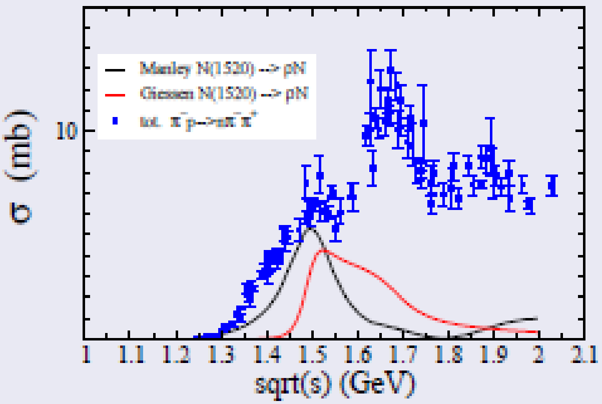
- ✓ **strangeness production in $\pi^- A$ p=1.6 GeV/c**
- ✓ **two-pion and kaon production in an energy scan in $\pi^- p$**
- ✓ **off-shell $\rho\omega$ production $\pi^- p \to n e^+ e^-$ p=0.8 GeV/c**

N(1520) D_{13} state

Manley et al: PRD(1984)

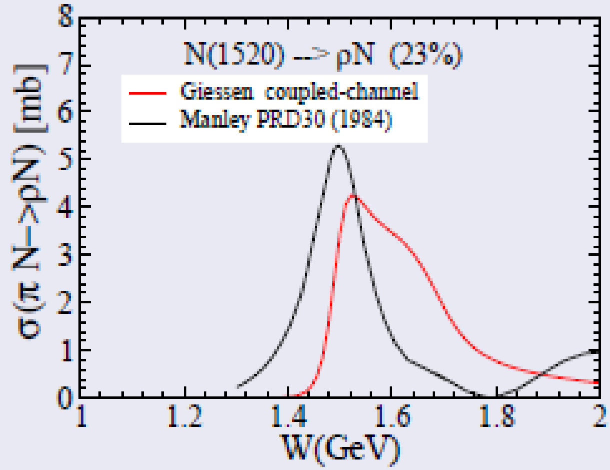
$M_R = 1.52$MeV
Γ_{tot}=120MeV

strong N(1520)$\rightarrow 2\pi N$
Br(ρN) ≈20%



- need diff. x-sections of $\pi^- p \rightarrow \pi\pi N$

Giessen Model (CC): $\pi N \rightarrow \rho N$



- Giessen : overlapping of spectral functions of $N^*(1520)$ and ρ-meson: non-symmetric
- Giessen: no effect below 1.4 GeV
- Manley: no ρ-spectral function: should be updated

Exclusive channel $\pi^- p \rightarrow n e^+ e^-$

Early motivations:

Coupling to ρ/ω channels

New approach based on transition electromagnetic form factors

New calculations: Zetenyi and Wolf

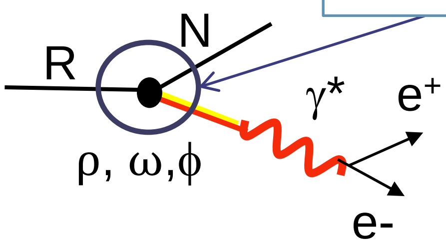
$\pi^- p \rightarrow n e^+ e^-$: *an unique tool to study the Dalitz decay of baryonic resonances:*

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

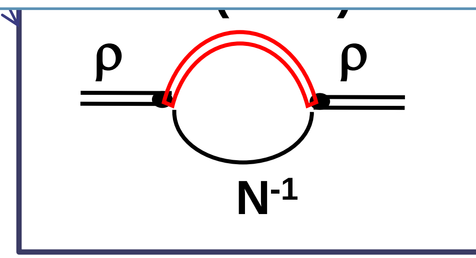
$M_R = \sqrt{s}$

- Form Factor: electromagnetic structure of the N-R transition $G_{E/M}(q^2)$ and $G_C(q^2)$
- in Vector Dominance Model, form factors depend on the ρ/ω couplings → importance also for in-medium propagation of vector mesons

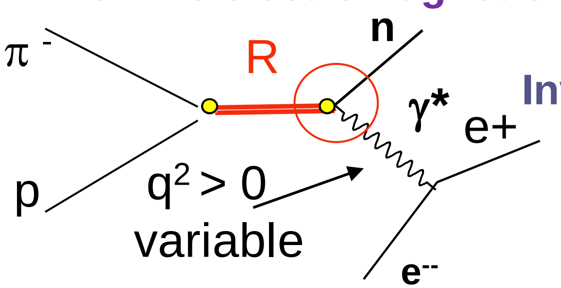
Dalitz decay: R



$q^2 = M_\gamma^2 = M_{ee}^2$

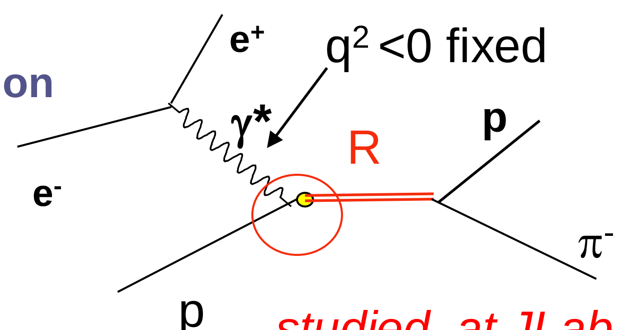


Time-Like electromagnetic form factors



Inverse pion electroproduction

Space-Like electromagnetic form factors

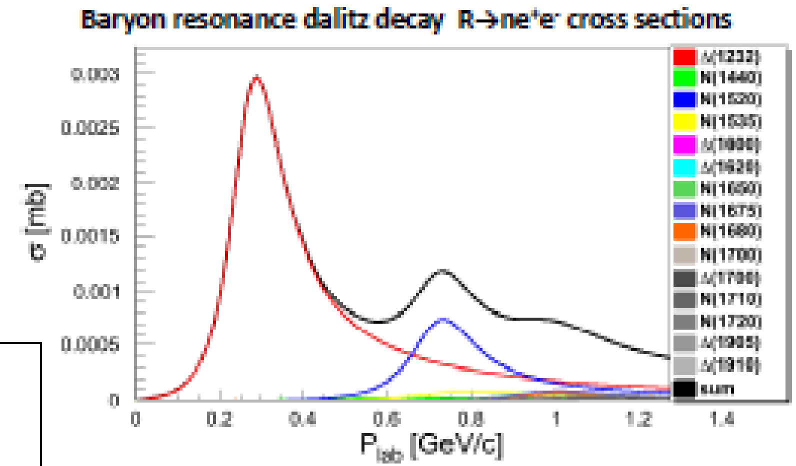


studied at JLab/CLAS

Value known only at $q^2=0$
(related to $R \rightarrow N\gamma$ decay branching ratio)

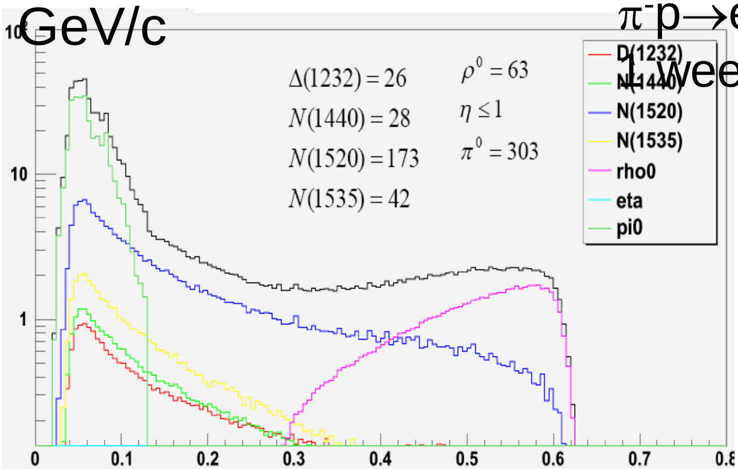
Simulations for $\pi^- p \rightarrow e^+ e^- X$

- **Simple resonance model**: *H. Kuc simulations*
Incoherent sum of Dalitz decay of different baryonic resonances with constant form factors
+ meson contribution
- **Coherent calculations** are ... *M. Zetenyi's talk on Friday*



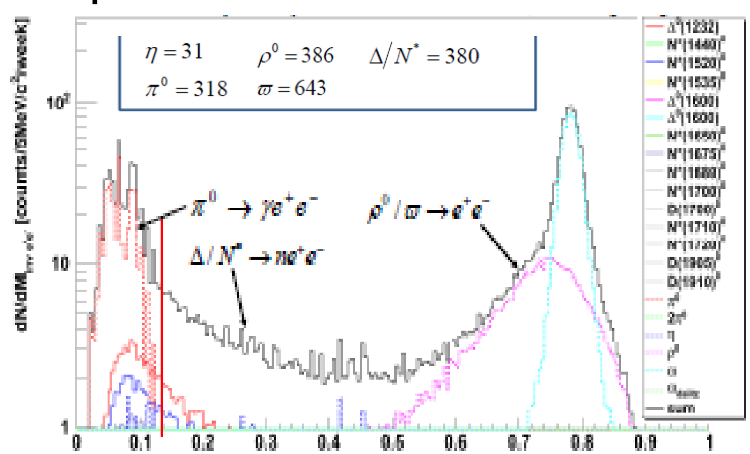
In HADES acceptance after missing mass cut
$\pi^- p \rightarrow e^+ e^- n$
1 week beam time

p=0.8 GeV/c $\sqrt{s}$=0.55 GeV/c



$M_{ee}(GeV/c^2)$

p=1.3 GeV/c $\sqrt{s}$=1.85 GeV/c



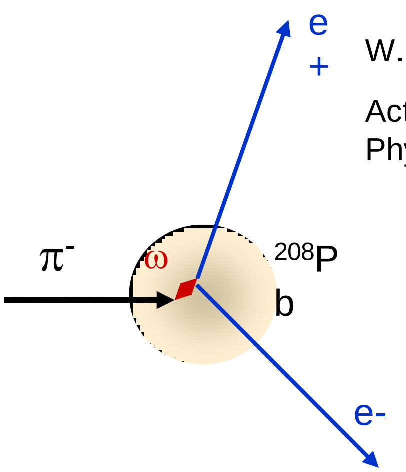
$M_{ee}(GeV/c^2)$

Dilepton spectroscopy in π^{-}A/ π^{-}p

Early motivations reinforced by HADES results in pA/pp

Dilepton spectroscopy in π^-A
Medium effets on vector mesons:

- Modifications of the vector mesons (ρ,ω,ϕ) properties in nuclear medium are predicted
- Connection with chiral symetry restoration?
- These effects are looked for by HADES using
  - Heavy-Ion reactions (hot and dense matter)
  - p+A reactions (cold nuclear matter)
- Interest of π^-A :
  - cold nuclear matter
  - mesons are produced with low momentum: probability to decay in the medium is higher



W.Schoen et al.

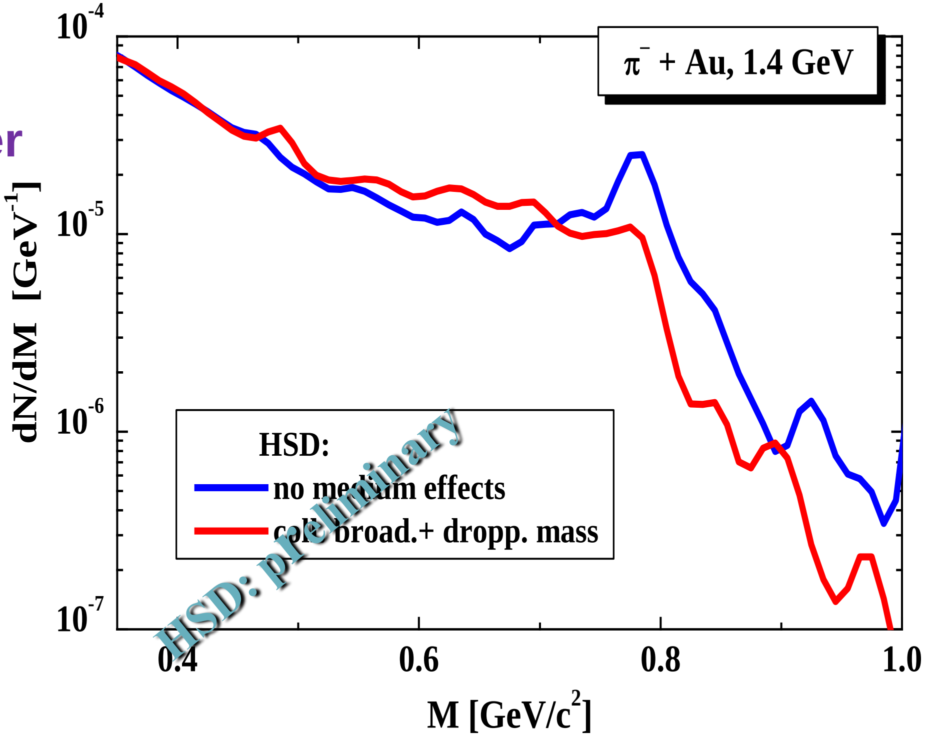
Acta Phys.PolB27(1996)2959

Dilepton spectroscopy in $\pi^{-}A$

Predictions for πA

(too) early predictions: Effenberger revisited

E. Bratkovskaya (Frankfurt) *HSD calculations*
Presented in Orsay Februry 2009



Large medium effects are expected in πA reactions

$\pi^- p / \pi^+ p \to N\pi\,\pi$:statistics for one point

p=0.7 - 2 GeV/c W=1.48 - 2.15 GeV
Average statistics in acceptance for one value of W

	$\pi^- p \to p\pi^- \pi^0$	$\pi^- p \to n\pi^+ \pi^-$	$\pi^+ p \to p\pi^+ \pi^0$	$\pi^+ p \to n\pi^+ \pi+$
σ (mb)	4.8	8	9.	1.5
evts /hour	95 000	130 000	178 000	24000
Evts/bin/shift	95	130	177	24
Time for PWA condition	1 shift		4 shifts	
Time for 26 points in W	27 shifts (~ 9 days)		108. Shifts (~ 36 days)	

Requirements for Partial Wave Analysis (from JPARC proposal)
20 bins in $\cos(\theta_{\pi\pi})$, 20 bins in $M_{\pi+N}$, 20 bins $M_{\pi-N}$
100 counts /bin *(to be discussed)*