Measurements with pion beams in HADES- what are they good for ?- results(preliminary) and perspectives

✓ Motivation:

vector meson(ρ) in-medium mass modification

- electromagnetic structure of baryons
- e+e- results from NN - exclusive channels

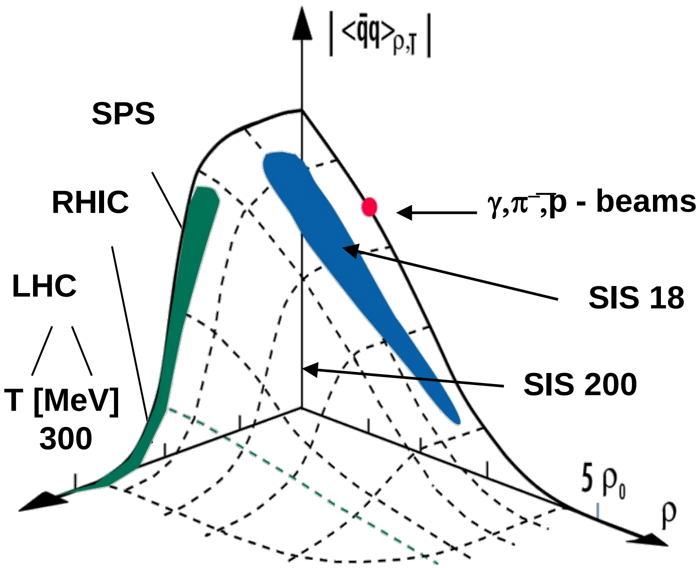
role of of $\rho \leftrightarrow$ baryon couplings, Vector Dominance Model

✓Experiment : preliminary results from run in 2014

- 2pion production
- e+e-
- Strangeness in cold nuclear matter

P. Salabura
M. Smoluchowski Institute of Physcis
Jagiellonian University, Kraków
Poland

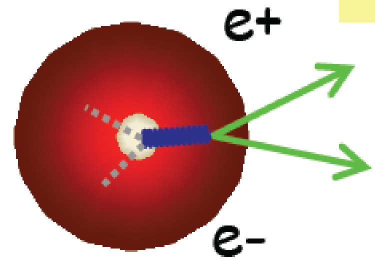
Vector mesons in medium



Measurement of the mass of short-lived mesons embbeded in nuclear matter

p/π/γ/A + A

$$m_{e+e-} = \sqrt{p_{e+}p_{e-}} \sin\frac{\vartheta_{e+e-}}{2}$$



<u>best candidate</u>

$\rho(770)\ 1^{--}\ c\tau = 1.3$ fm/c

$\Gamma = 150$ MeV

G.E. Brown / M. Rho: Scaling of masses with quark condensate - order parameter of Chiral Symmetry restoration (PRL 1989, 1991)

$$m^* \approx m\left[\langle \bar{q}q^* \rangle / \langle \bar{q}q \rangle\right]^{\mu}$$

T. Hatsuda / S. Lee: QCD sum rules PRC46(1992)R34

$$m^* = m\left(1 - \alpha\rho^* / \rho\right)$$

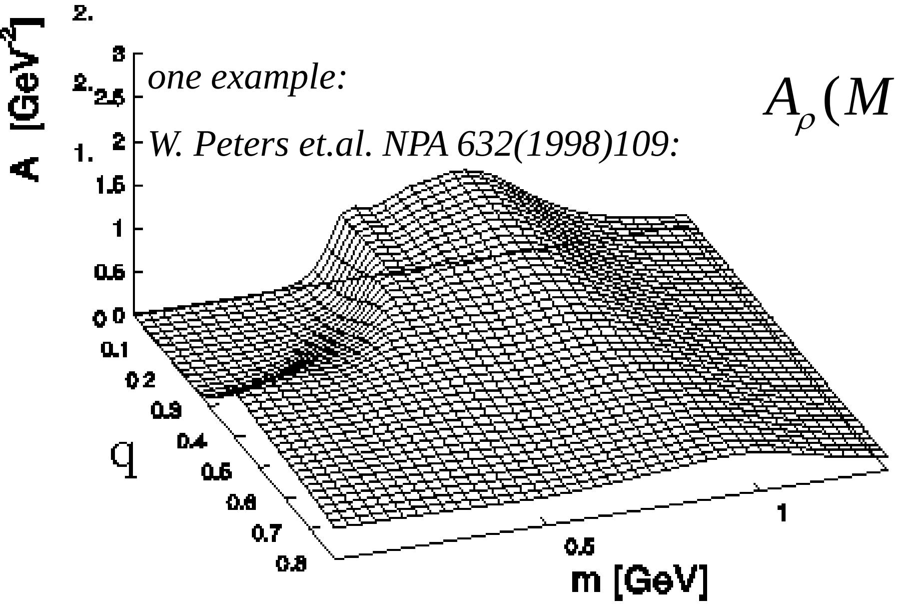
$$N_{e^+e^-} \sim \Gamma_{V \to e^+e^-} \cdot T_m = \frac{\Gamma_{e^+e^-}}{\Gamma_{tot}}$$

- low e+e- rates (~10^{-5})
- e+e- are not interacting with nuclear matter : IT IS NOT the case for hadronic decays

ρ-in medium: cold nuclear matter

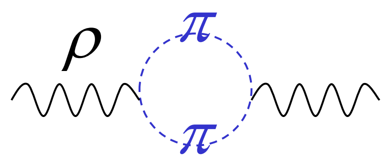
one example:

W. Peters et.al. NPA 632(1998)109:



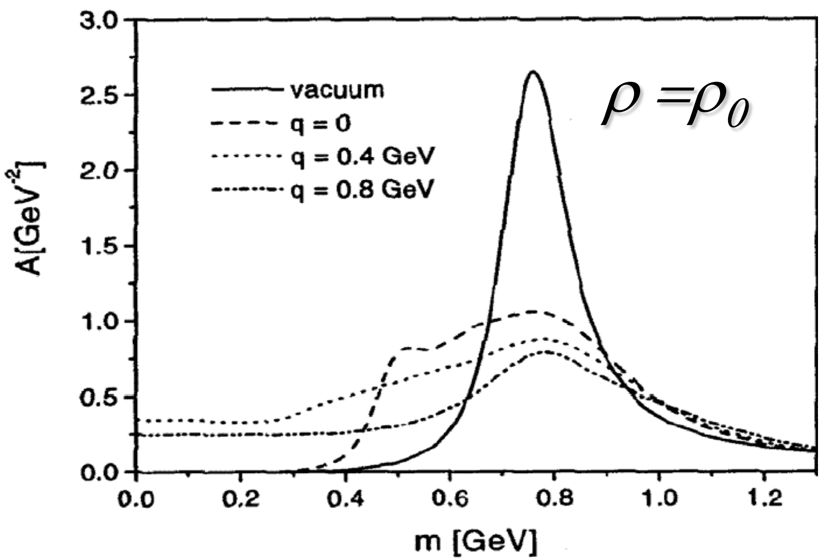
$$A_\rho(M) = -\frac{2 Im\Sigma_\rho(M)}{[M^2 - m_\rho^2 - \mathrm{Re}\,\Sigma_\rho(M)]^2 + [Im\Sigma_\rho(M)]^2}$$

Vacuum:

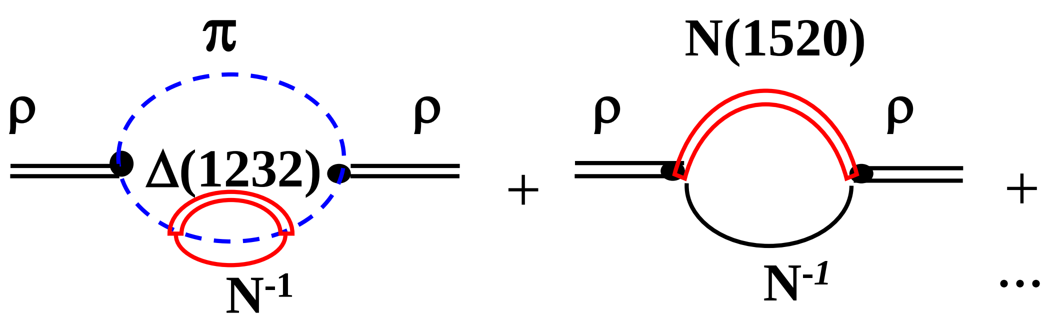


$$\Sigma_\rho(M) = -i m_\rho \Gamma_{\pi\pi}(m)$$

$$m_\rho = 0.77 GeV$$



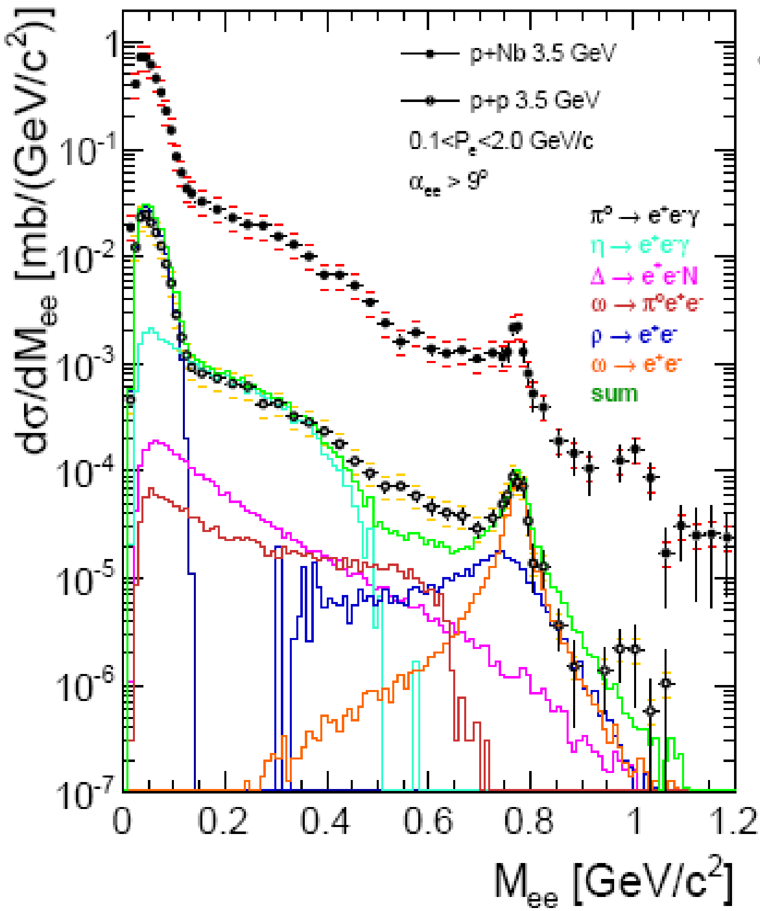
Nuclear matter: additional terms



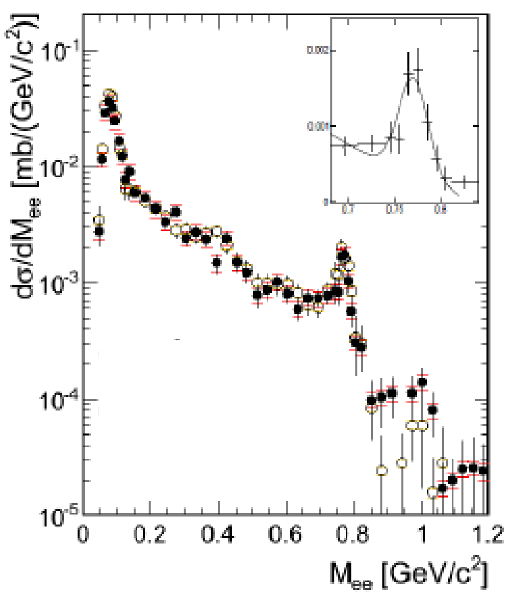
dominant role of baryonic resonances

p+p vs p+Nb @ 3.5 GeV

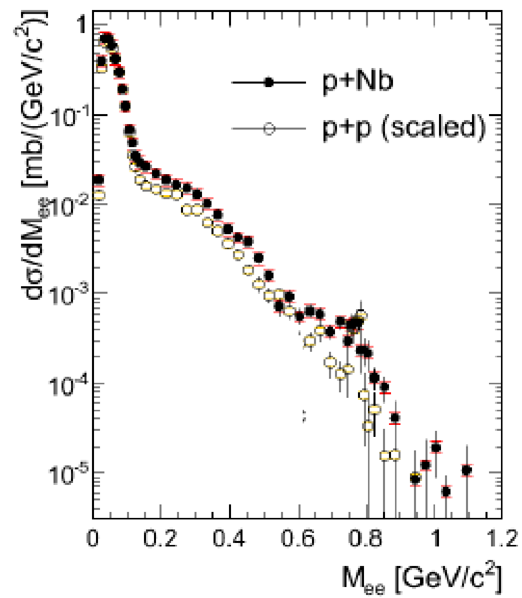
data: HADES PLB715 (2012) 304



„fast" p_{e+e-}>0.8 GeV/c



„fast" p_{e+e-}< 0.8 GeV/c



pp data scaled by „A_{part}" scaling

$$R_{pA} = \frac{d\sigma^{pNb}/dp}{d\sigma^{pp}/dp} \times \frac{\langle A^{pp}_{part}\rangle}{\langle A^{pNb}_{part}\rangle} \times \frac{\sigma^{pp}_{reaction}}{\sigma^{pNb}_{reaction}}.$$

Nuclear modification factor

- p+p cockail : based on known sources fixed to data π^0 /η/ ω/ ρ , Δ

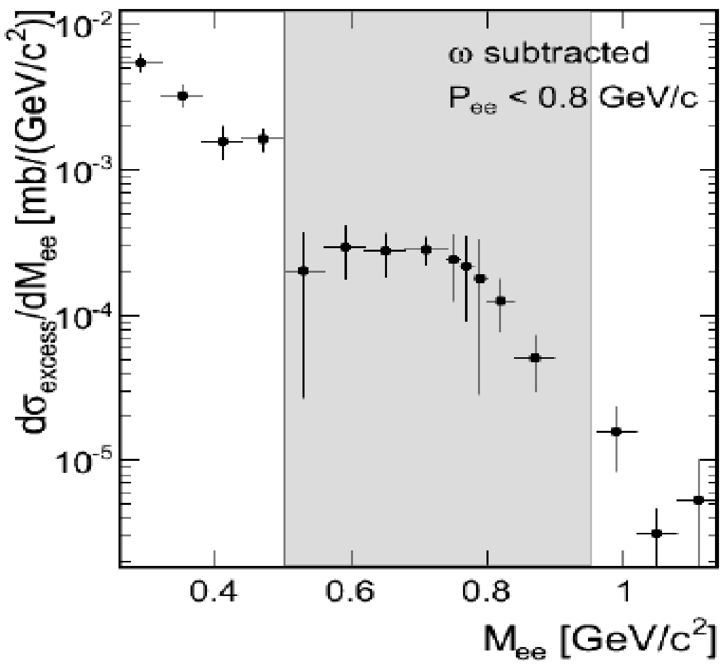
underestimeted e+e- yield below VM pole → missing component -> higher resonances (Δ, N*)->Ne+e- ?

- remarkable difference between spectra from „fast" and „slow" sources

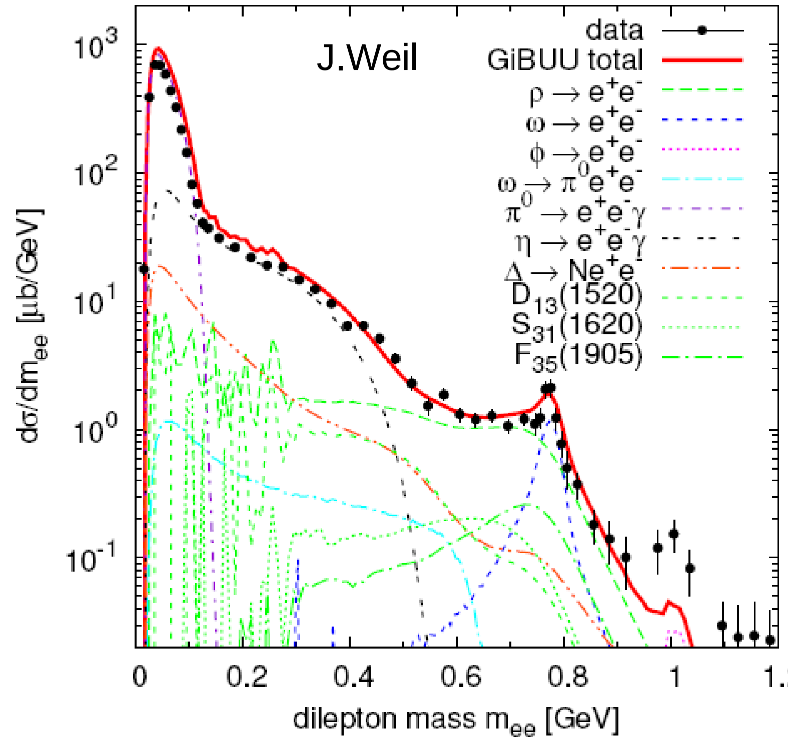
e+e- excess in p+Nb

HADES

„slow” (p<0.8 GeV/c) pairs „excess over pp reference”



Comparison to transport model



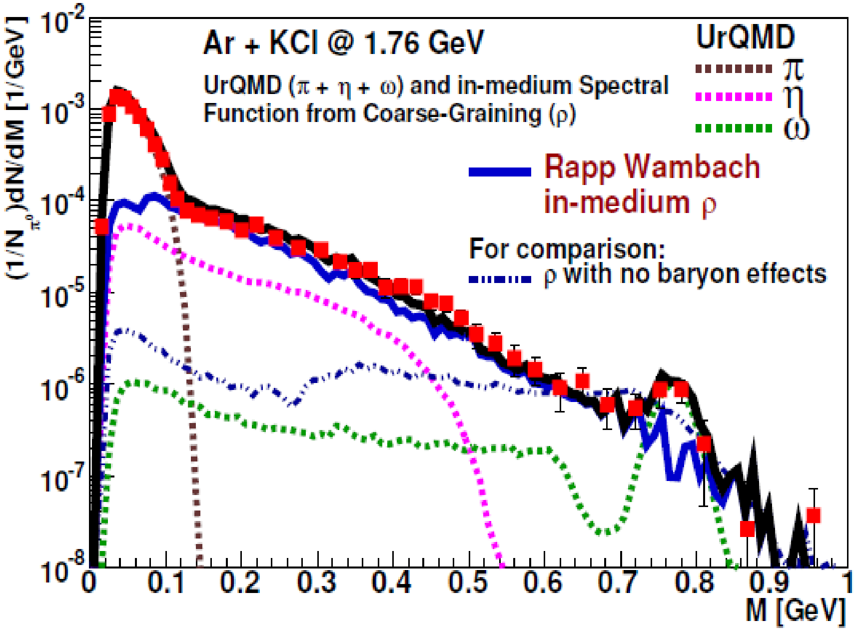
☝ clear excess in p+A below VM pole → „ρ- meson” line shape from cold nuclear matter

- modified (in-medium) spectral function ?
- GiBUU: secondary reactions π+N → N* (1520),.. →Nρ→Ne+e-

→ **HADES pion beam programme !**

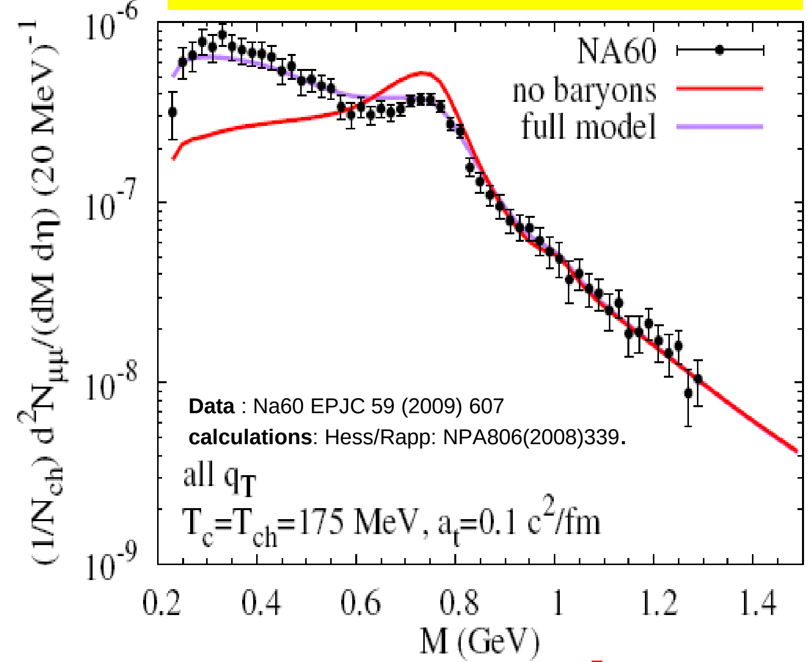
dileptons from HI from SIS18 - RHIC

HADES @ SIS18



Na60 @ SPS In+In

μ+μ- with subtracted coctail

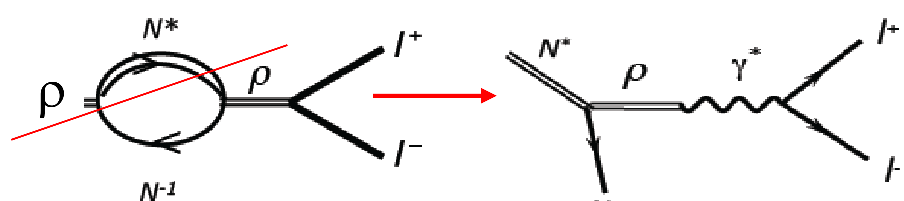


☝General conclusion:

baryons are driving force for observed melting of the ρ meson over all energy range; RHIC (STAR,PHENIX), SPS(CERES,NA60), SIS18 HADES

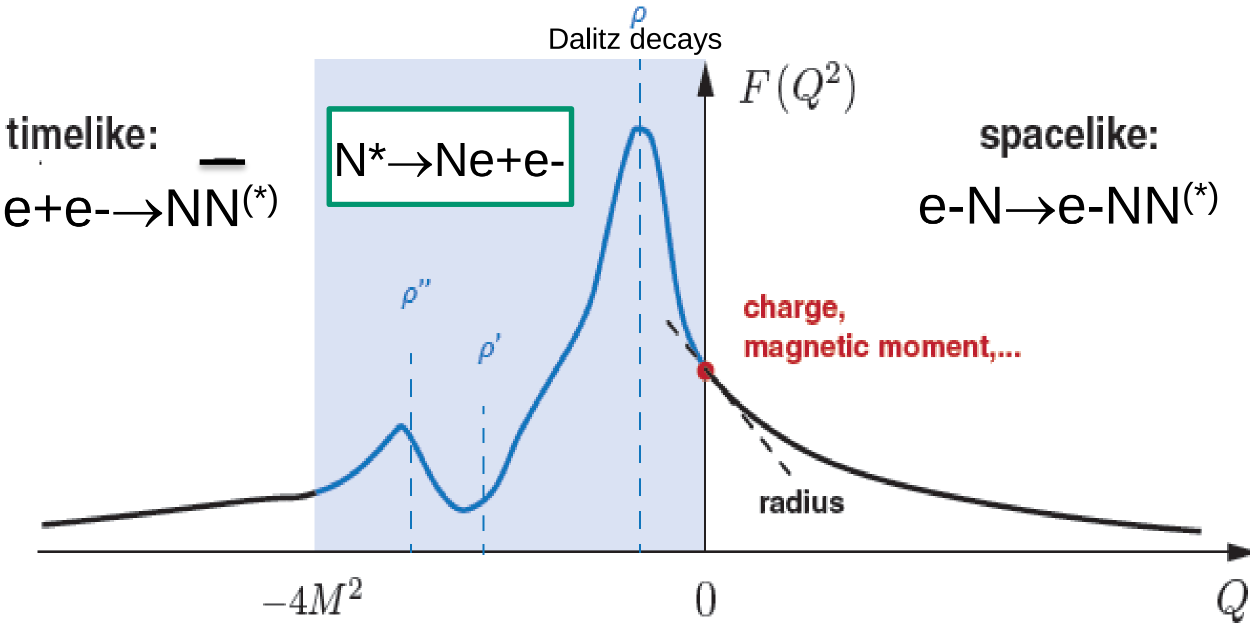
baryonic loops directly related to :

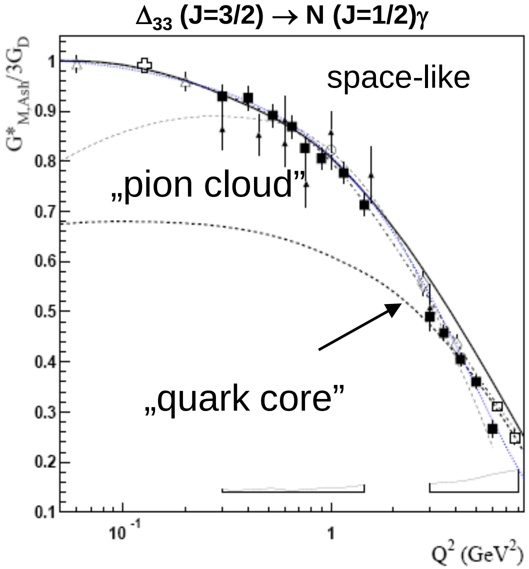
N* Dalitz decay



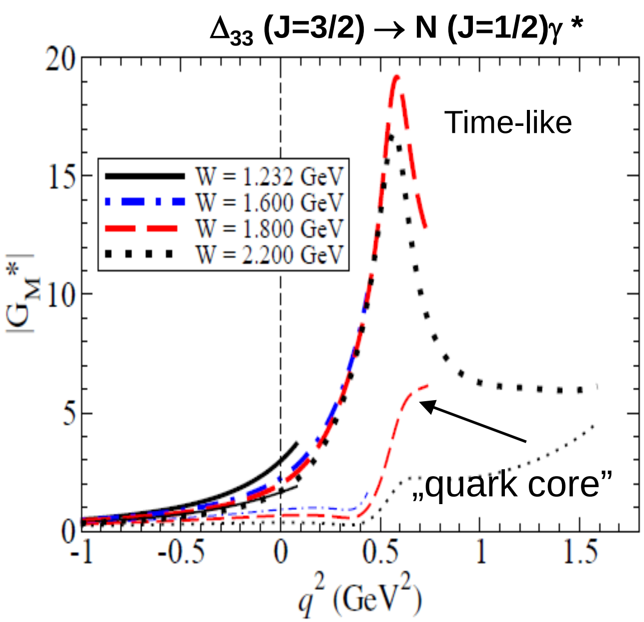
NOT measured ..!

Electromagnetic structure of baryons





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



G. Ramalho at.al arxiV:1512.037

- Resonance → Nucleon tranistions :

  em. Transition Form Factors

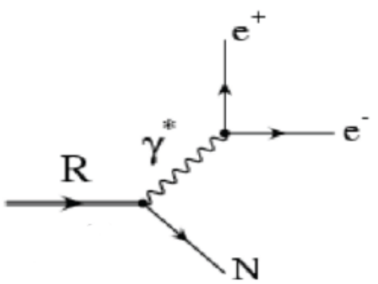
Δ : G_M (q^2), G_E (q^2) , G_C (q^2)

- Important role of pion cloud at small q^2

Models for Dalitz decays

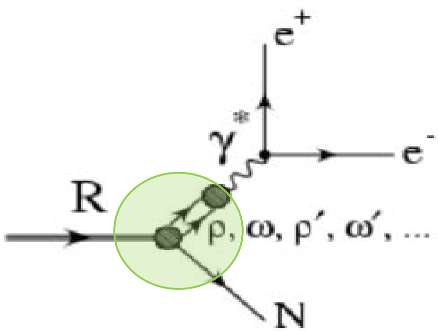
QED: point-like R-γ^* vertex
Coupling constants fixed from R->Nγ
Strong dependence on spin, parity

M. Zetenyi et al. PRC 67, 044002 (2003).
M. I. Krivoruchenko et al. Ann. Phys. 296, 299 (2002).



extended VDM1:

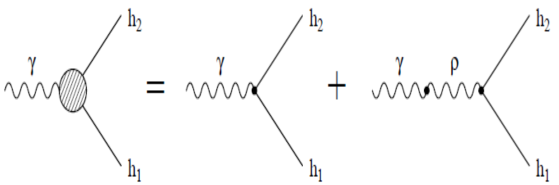
M. I. Krivoruchenko et al.
Ann. Phys. 296, 299 (2002).

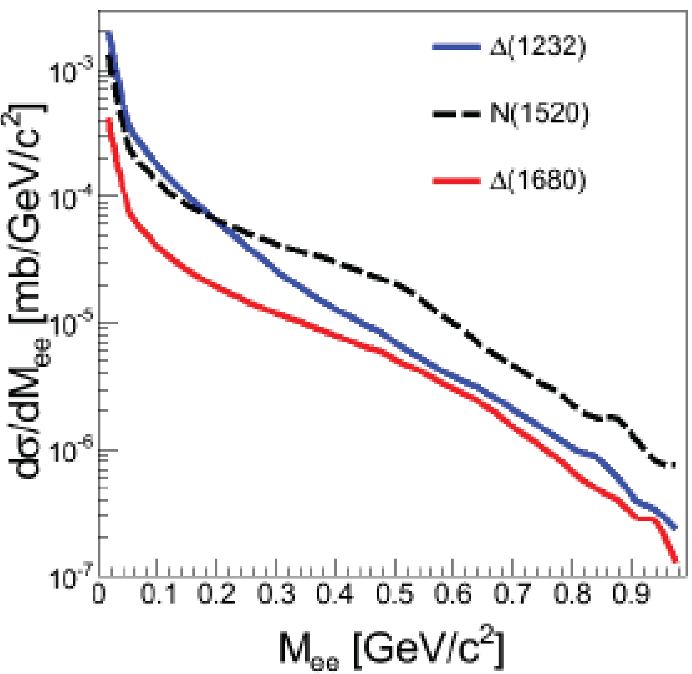


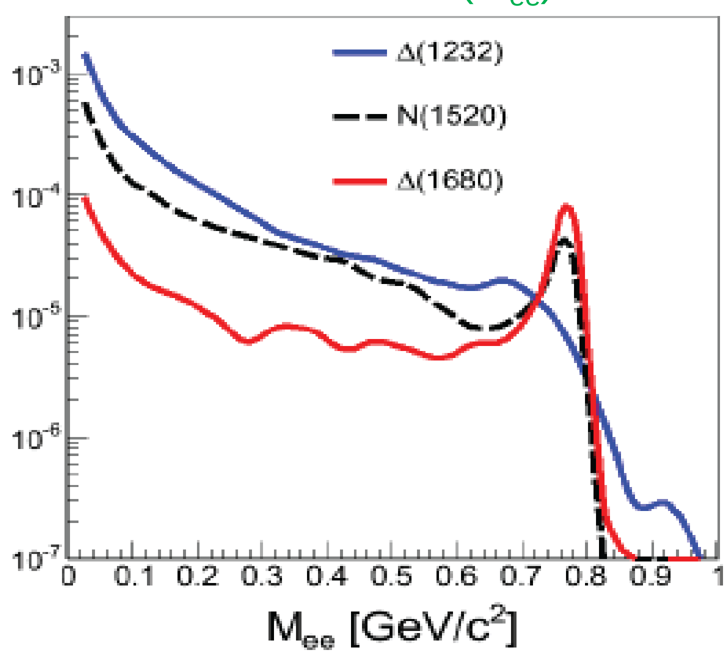
el. Transition FF (M_{ee})

extended VDM2:

H.B. O'Connell, et al.
Prog. Part. Nucl. Phys. 39, 201 (1997).
M. Zetenyi, G. Wolf PRC86(2012) 065209







„2 coupling"

vanishes at $q^2=0$

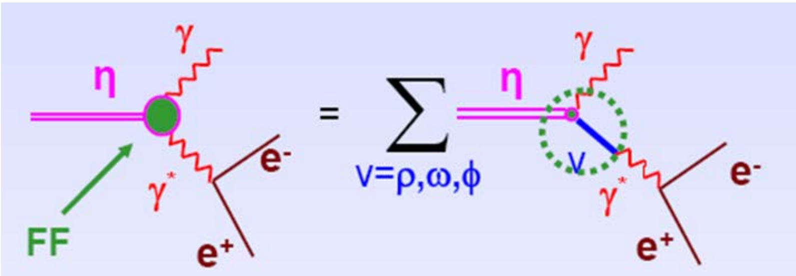
Does not provide

„standard VDM "

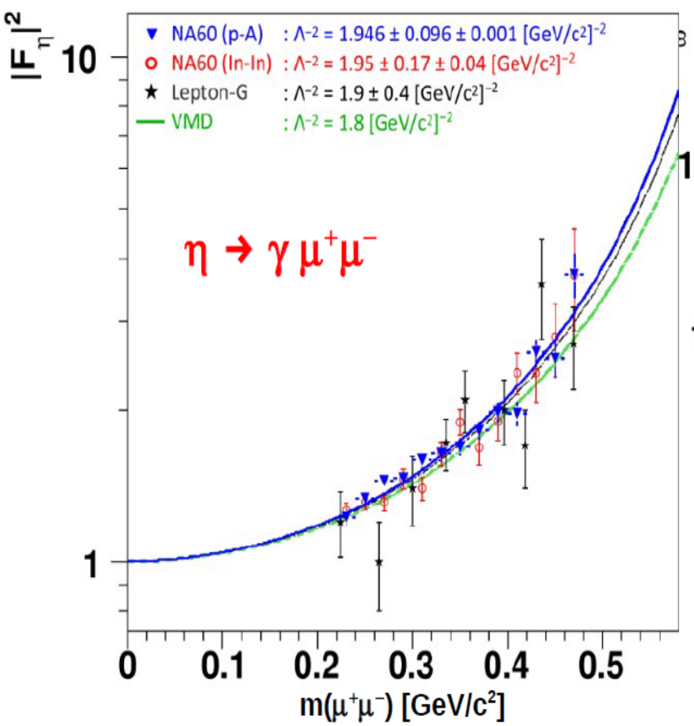
$Br(m) \sim 1/M^3$

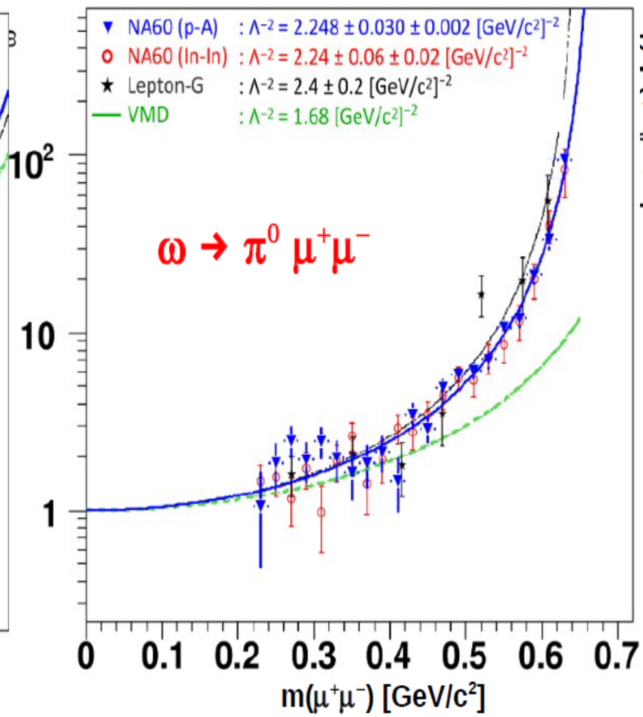
Vector Meson Dominance in work for mesons..

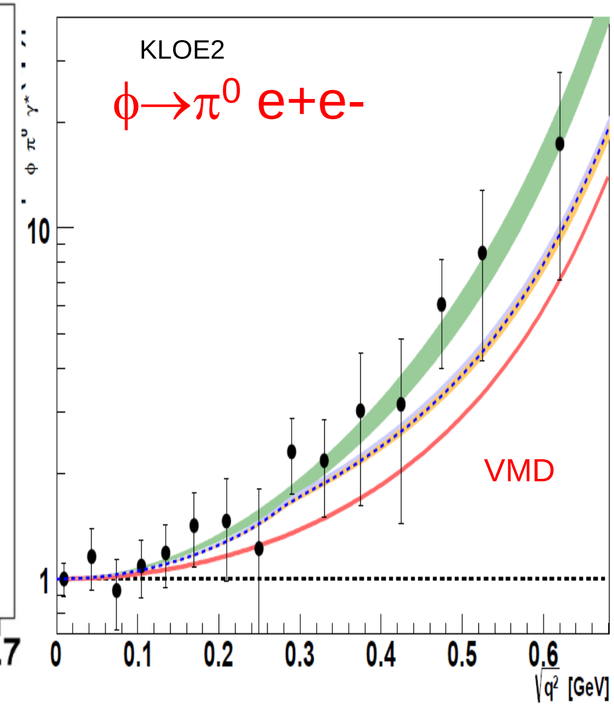
example: η decay



$$\frac{d\Gamma(\eta \to e^+e^-\gamma)}{dq^2\Gamma(\eta \to \gamma\gamma)} = \underbrace{\boxed{\frac{2\alpha}{3\pi}\left[1-\frac{4m_e^2}{q^2}\right]^{1/2}\left[1+2\frac{m_e^2}{q^2}\right]\frac{1}{q^2}\left[1-\frac{q^2}{m_\eta^2}\right]^3}}_{\text{QED}}\ \underbrace{\boxed{\left|F_\eta(q^2)\right|^2}}_{\text{FF}}$$







very important for hadronic corrections in muon g-2 ..

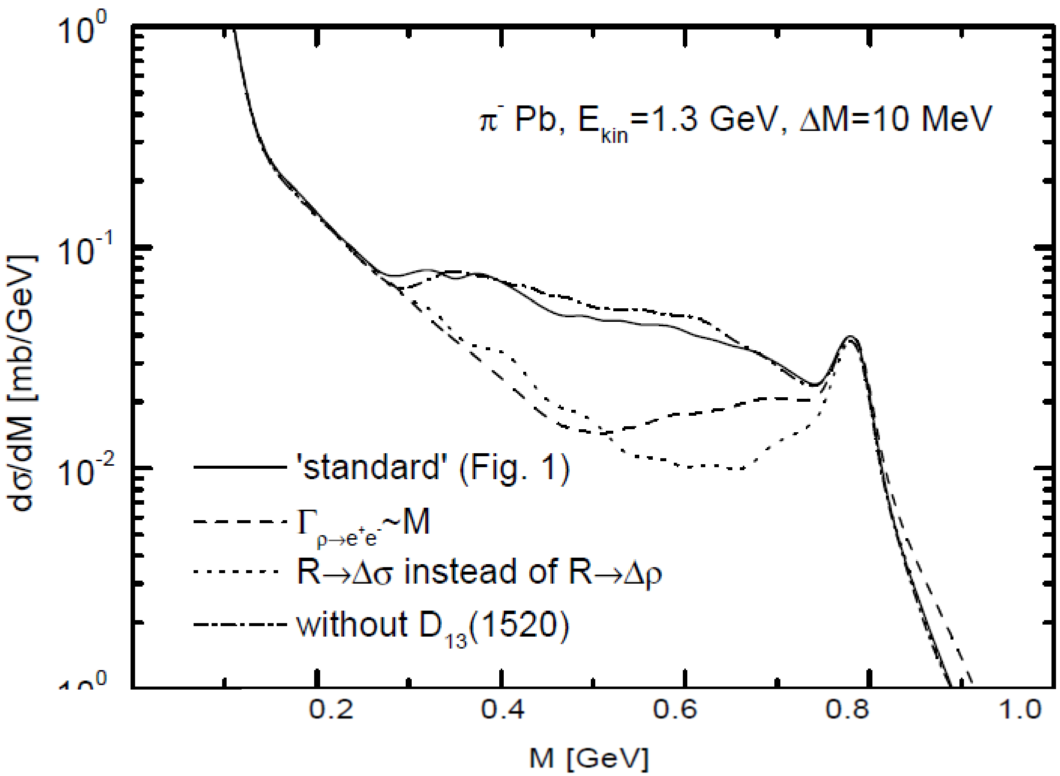
Theory

Terschlusen and Leupold [Phys. Lett. B 691 191 (2009)]
Ivashyn S. [Prob. Atom. Sci. Tech. 2012N1 179 (2012)]
Schneider, Kubis, Nieking [Phys. Rev. D86 054013 (2012)]

VDM for Baryons?

- For the electromagnetic decay of the ρ-meson to e^+e^- we use now a width proportional to M^{-3}, as resulting from vector meson dominance (VMD) [9], instead of one proportional to M from extended VMD [10], with M being the invariant mass of the ρ-meson. For our calculations this is more appropriate since we neglect a direct coupling of the virtual photon and can not treat the resulting interference terms properly within a semi-classical transport approach.

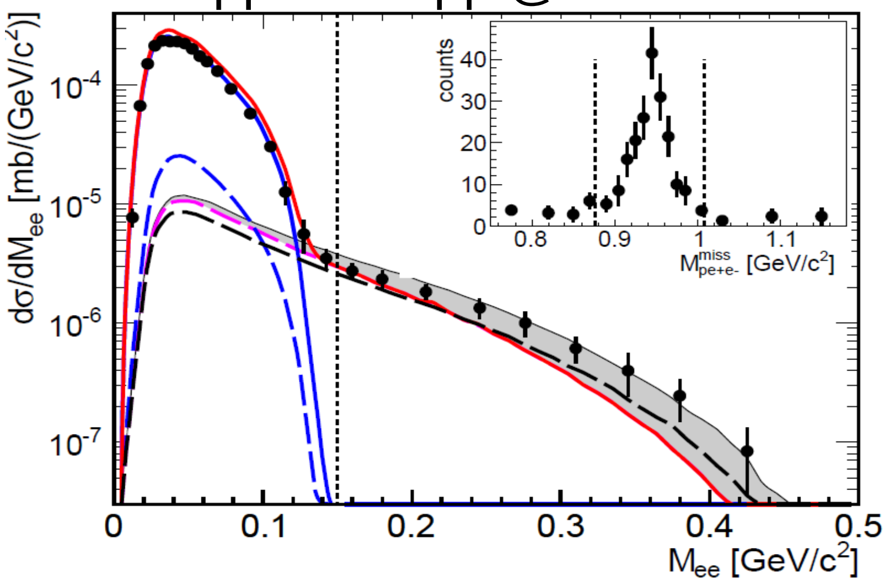
e+ e- pairs from pi- A reactions: Comment
M. Effenberger, E.L. Bratkovskaya, W. Cassing, U. Mosel (Giessen U.). Jan 1999. 9 pp.
Published in **Phys.Rev. C60 (1999) 027601**



Δ^+ Dalitz decay via $\Delta^+ \{ \to pe^+e^- \}$

HADES

pp→e+e-pp @ 1.25 GeV



red line – total
blue – π^0 Dalitz
magenta – Δ Dalitz
grey band– (VMD)
dashed – Ramalho/Peña

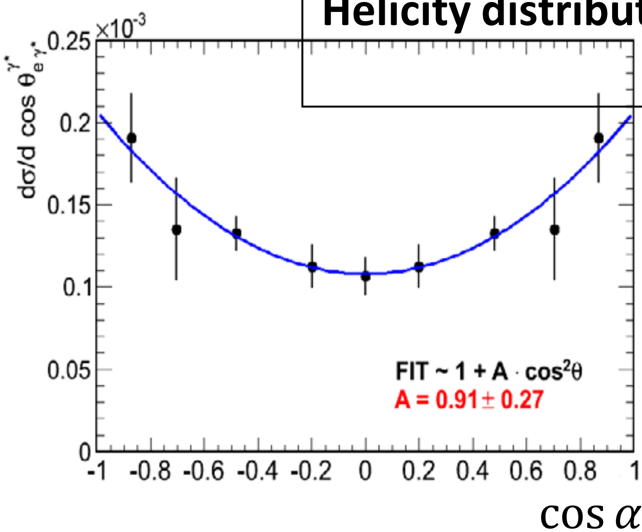
Δ Dalitz decay BR

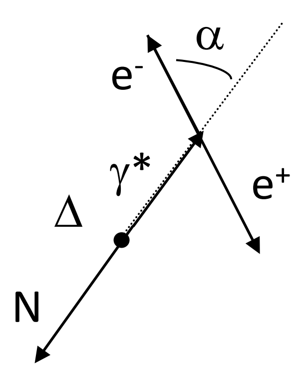
$G_M(0)$~3
$G_E(0)$~0
$G_C(0)$~0

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

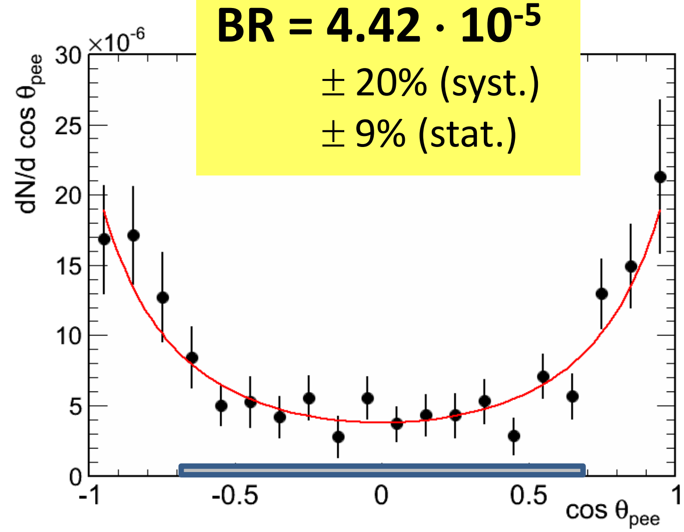
Consistent with $\Delta \to p\pi^0$

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

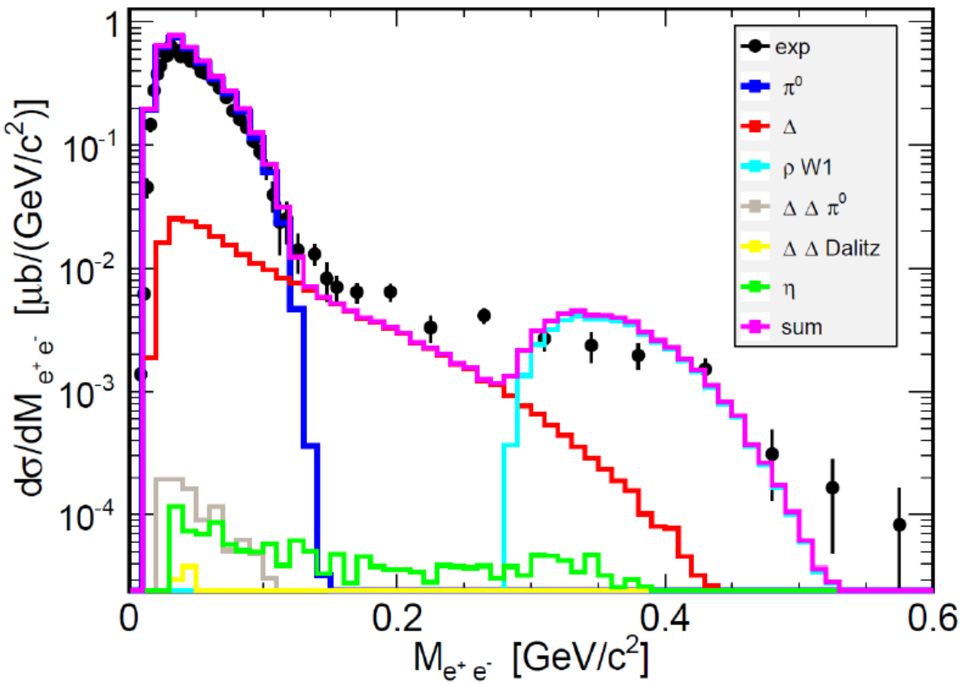


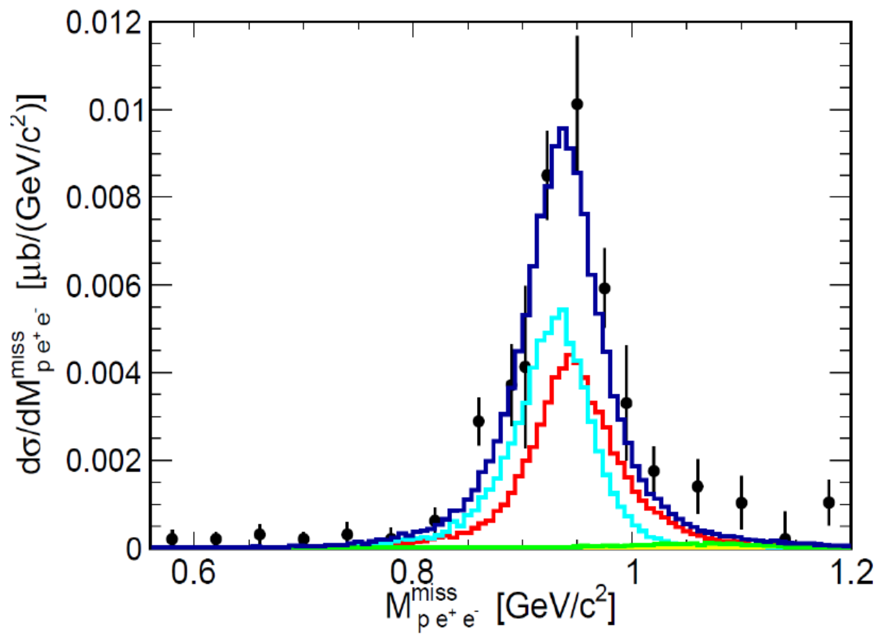


BR = 4.42 · 10^{-5}
± 20% (syst.)
± 9% (stat.)

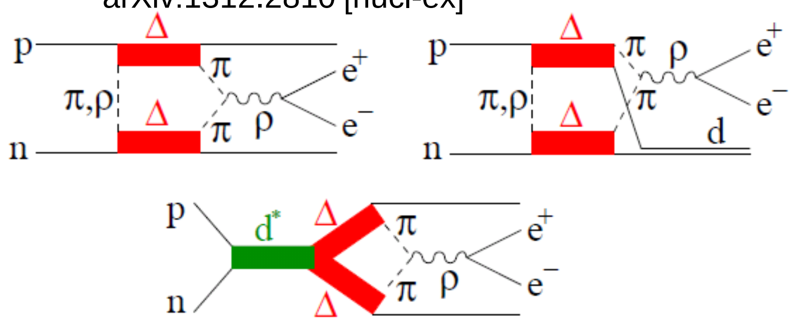


exclusive pn→pne+e-





M. Bashkanov and Clement, arXiv:1312.2810 [nucl-ex]



Strong off –shell ρ contribution

- Charged pion exchange Schyam at al.

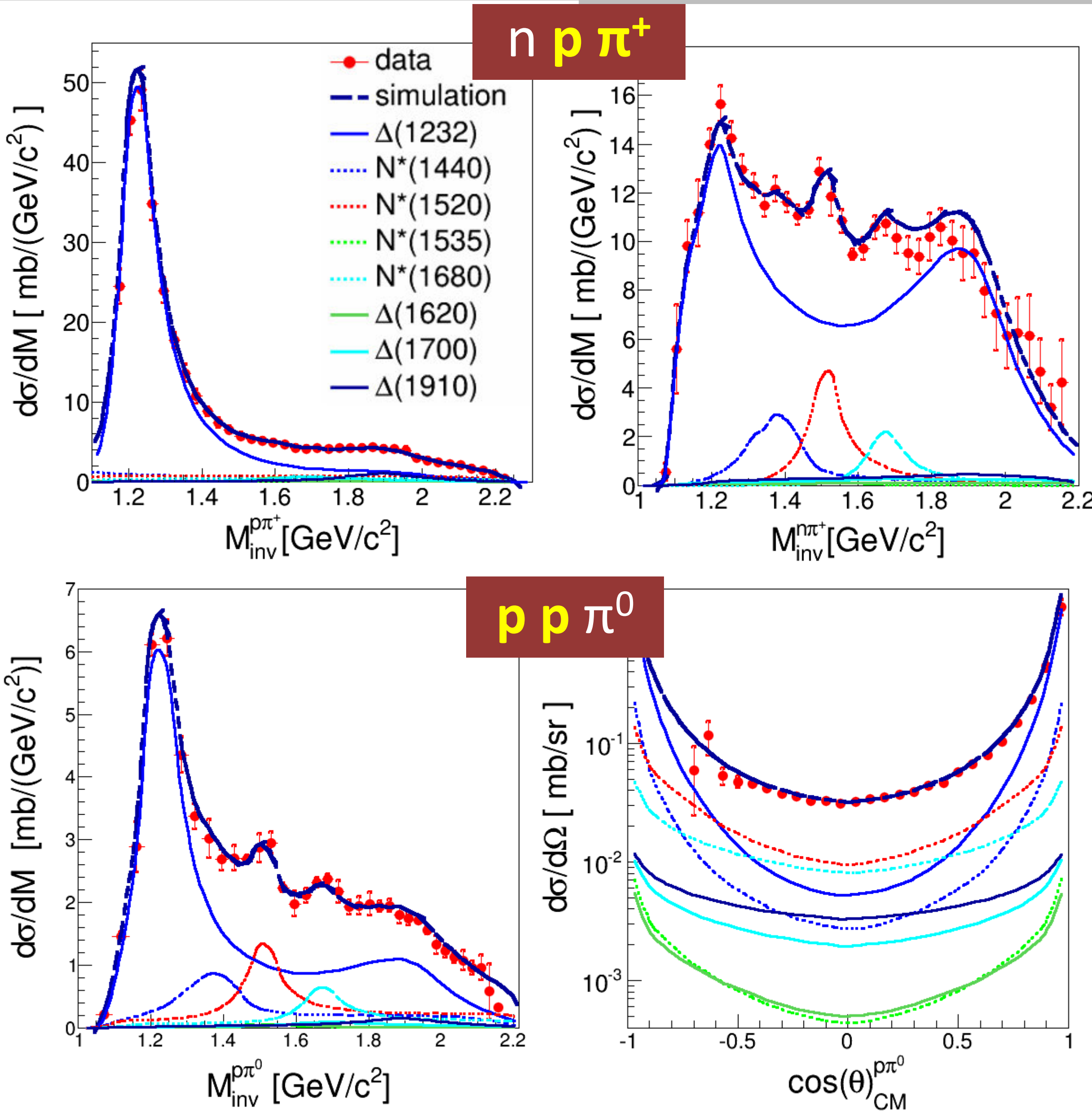
R. Shyam and U. Mosel *Phys. Rev. C 82:062201, 2010*

- Or/and double Δ fusion ala'

  Clement/Bashkanov

Higher mass resonances @3.5 GeV

HADES

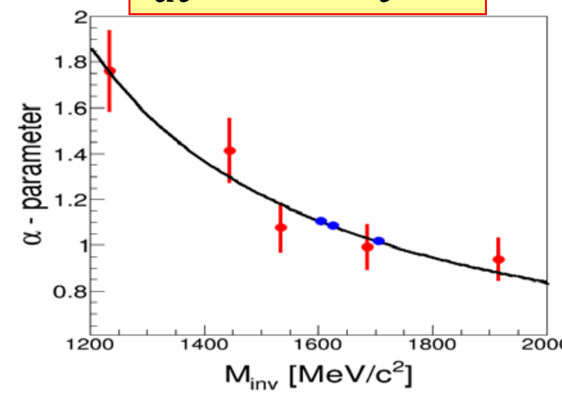


Resonance model:

Z. Teis et al.,
Z. Phys. A356 (1997) 421
J. Weil et al. (GiBUU)
Eur. Phys. J. A48 (2012) 111

Many Δ, N* states contributing..

$$\frac{d\sigma}{dt}(M_R) \propto \frac{A}{t^{\alpha(M)}}$$

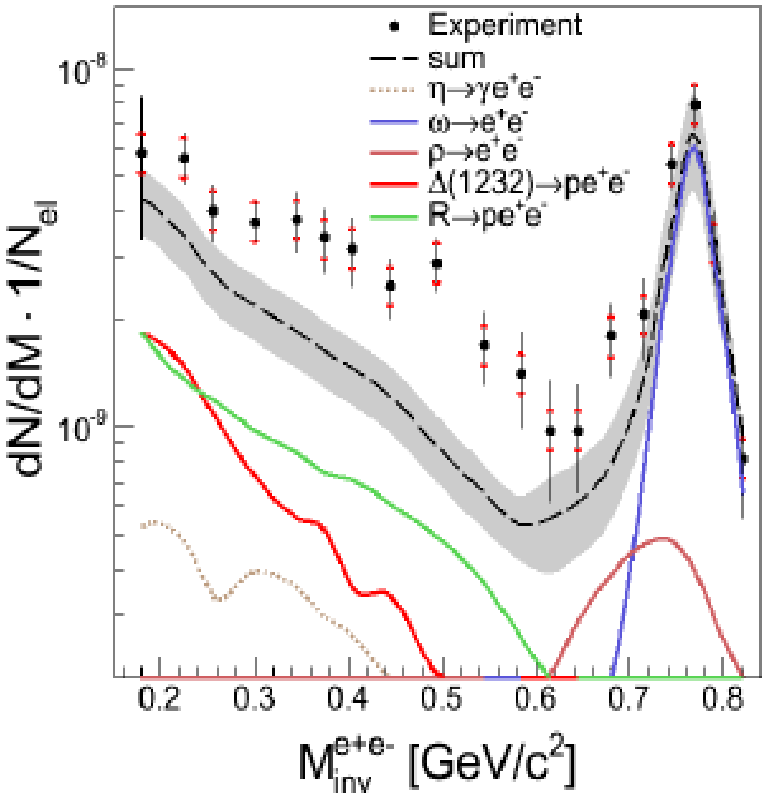


angular parametrisation as a function of ***t*** for **all resonances**

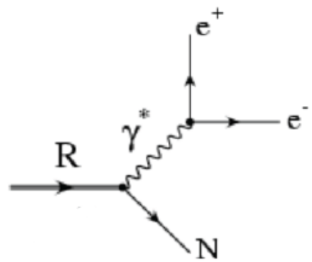
Eur. Phys. J. A (2014) **50**: 82

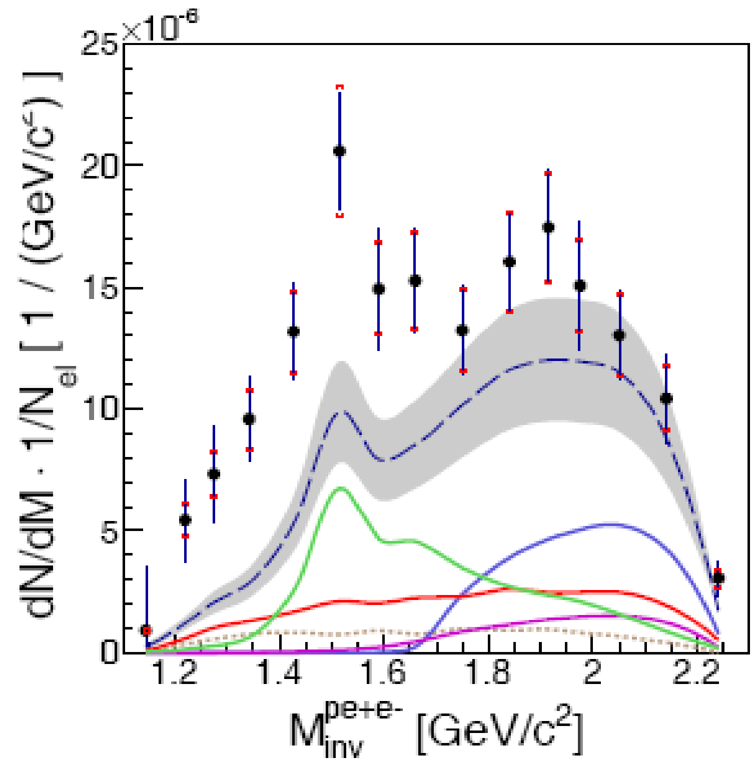
$p+p \rightarrow ppe^+e^-$ @ 3.5 GeV

Eur. Phys. J. A (2014) 50: 82



„QED" cocktail





- Several contributing resonances : N*(1520), N*(1720), Δ(1620), Δ(1905)
- ambiguites in resonance contributions (R) covered by grey band

☝ Clear excess above expected yield from the point-like coupling seems to originate from N*(1520) region

Pion beam facility at GSI

- Proposed middle of 90'es (H. Bokemeyer, W.Koenig,V. Metag, A. Schroter). Comissioned end of 90'es–first paper with results in 1999 (Progr. In Part. and Nucl. Physics 42(1999)247

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Nuclear Instruments and Methods in Physics Research A 478 (2002) 511–526

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Design and commissioning of the GSI pion beam

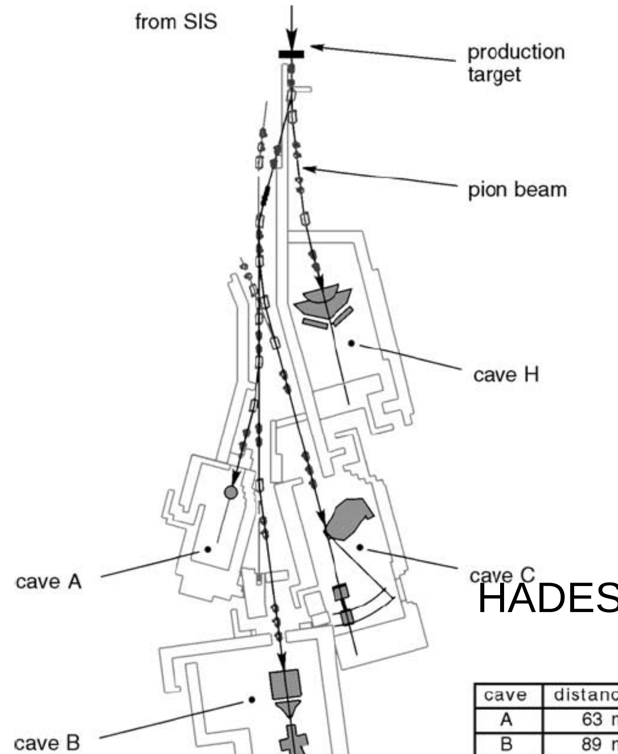
J. Díaz[a,*], N. Yahlali[a], M. Ardid[a], M. Álvarez[a], V. Avdeichikov[d], H. Bokemeyer[b], L. Carlén[d], B. Franczak[b], O. Hartmann[c,b], B. Jakobsson[d], W. Koenig[b], U. Leinberger[b], B. Lommel[a], V. Metag[b,c], Yu.A. Murin[d], W. Mittig[e], W. Niebur[b], R. Novotny[c], R. Schicker[b], R.S. Simon[b], A. Schröter[b], W. Schön[b]

First data from HADES 2014

Nuclear Physics News, Vol. 25, No. 2, 2015

facilities and methods

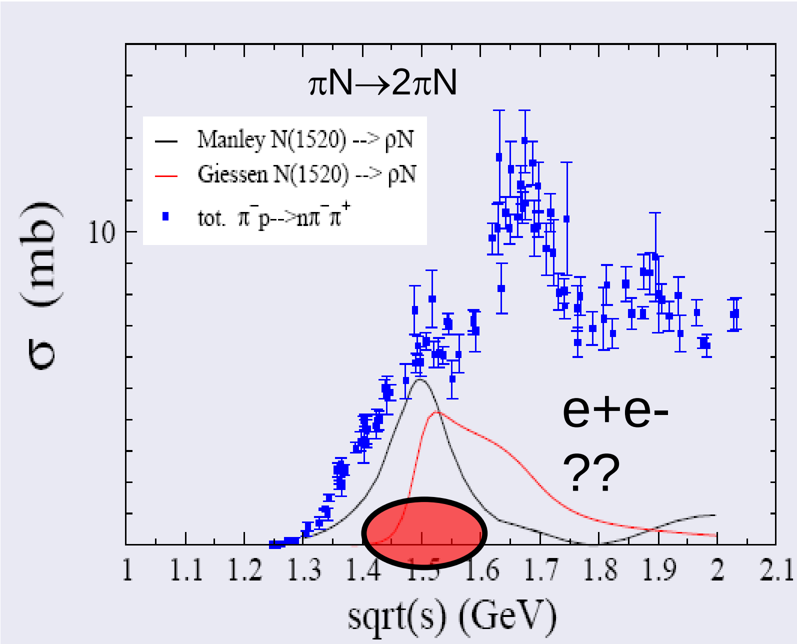
The HADES Pion Beam Facility

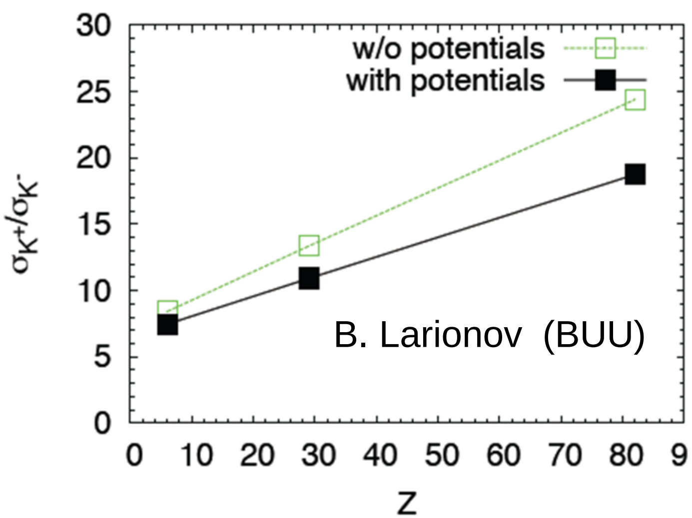


cave	distance
A	63 m
B	89 m
C	69 m
H	33 m

30 m

HADES Physics progarmme'2014 with pion beams





Main advantage of pion induced reactions

Resonance excitation can be selected by the chosen beam (pion) momentum

HADES starts with$\sqrt{s}$ =(1.46-1.55) GeV – N*(1520) resonance region

1) π+ π- production : off-shell coupling of ρ to resonance

$\rho \rightarrow \pi$+ π- (~100%) „golden channel"

Most of π+π- data 1.3 <$\sqrt{s}$ <2 come from Manley et.al PRD30,(1984) 904 based on 240 000 events (differential; distributions not available)

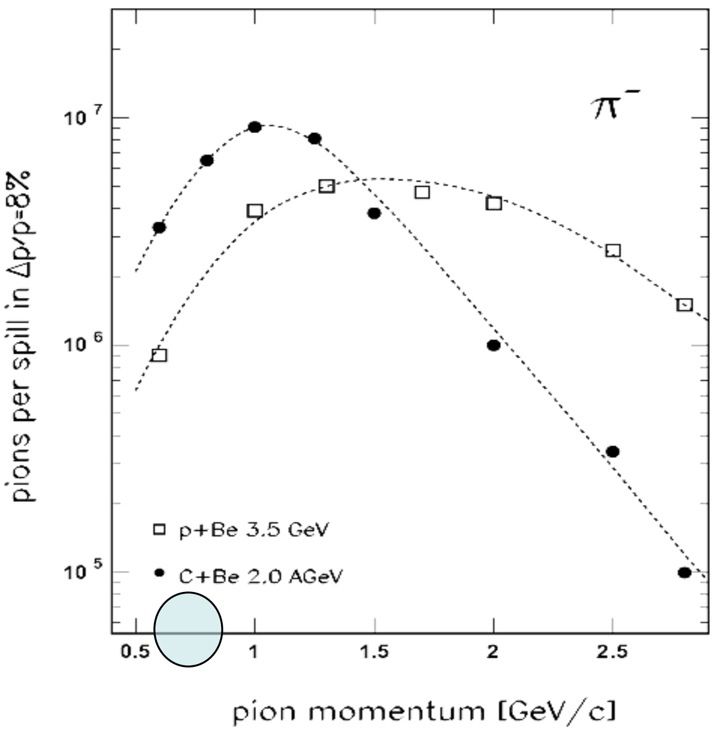
2) e+e- : never measured from pion induced reactions

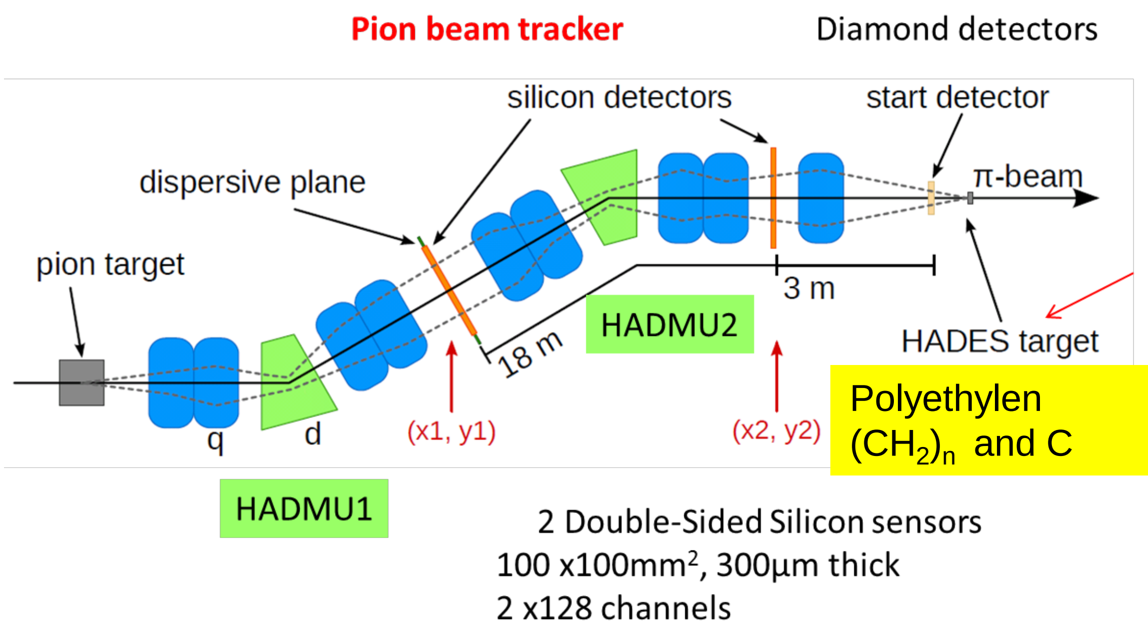
Resonance Dalitz decays R$\rightarrow$Ne+e-
Reference for p+Nb result

3) strangeness production of nucleus : $K^{\pm}$, K^0 , ϕ

Absorption of mesons in cold nuclear matter.

pion beam in HADES 2014





- Reaction N+Be 8-10* 10^{10} N_2 ions/spill (4s)
- secondary π^- with I ~ 3-4 10^5/spill @ 0.7 GeV/c - limited by primary beam Intensity
- Total ~15 days of continus measurement.
- Pion momentum $\Delta p/p$ =2.2% (σ) and ~50% acceptance @ central momentum
- in beam tracking system: (X1,X2/Y1/Y2) for pion mometum determination : $\Delta p/p$ =0.1%

Strategy for analysis of pion data

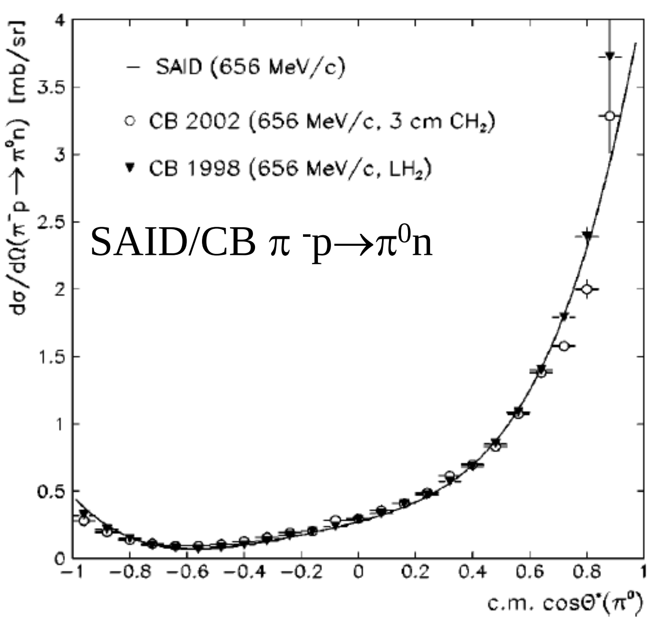
- Normalization via measured $\pi^- p$ elastic scattering of known σ (SAID Partial Wave Solution)
- Extract contributions (ρ) from $\pi^- p \to \pi^+\pi^- n$ (HADES), $\pi^- p \to \pi^0\pi^0 n$ (Cristall Ball) @

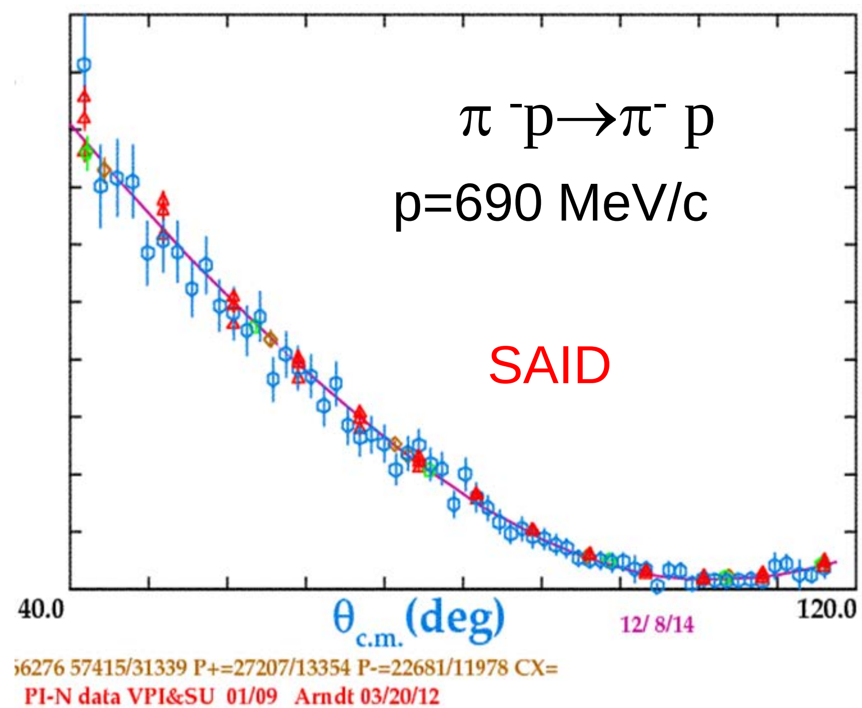
p=656 ($\sqrt{s}$=1.468), **p=690 (1.489),** p=748 (1.526) , p=800(1.556) , $\gamma p \to \pi^0\pi^0 p$ (Bonn)

& $\gamma p \to \pi^+\pi^- p$ (SAPHIR, CLAS) ($\sqrt{s}$>1.75) using Partial Wave Analysis (Bonn-Gatchina framework)

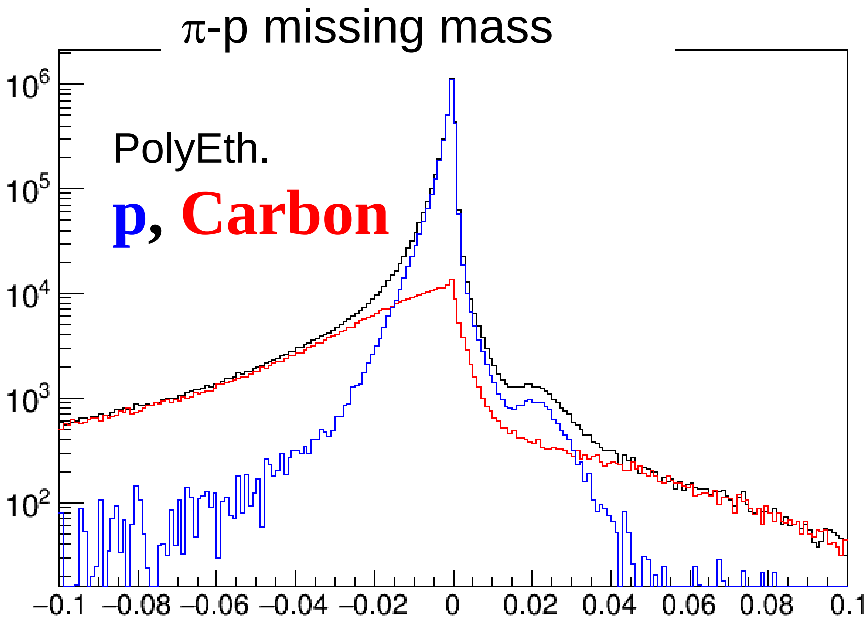
- compare to π- p -> e+e- n @ **690 MeV/c** exclusive channel

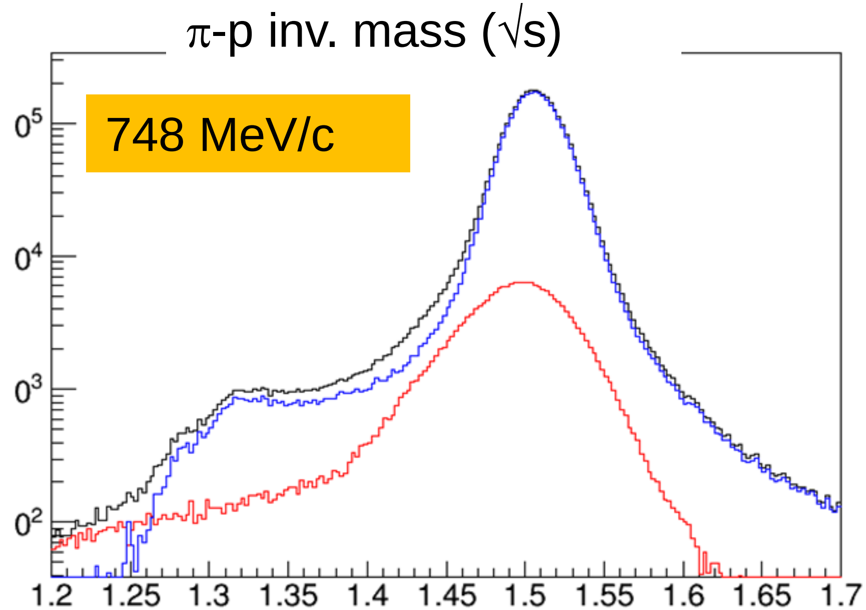
elastic channels

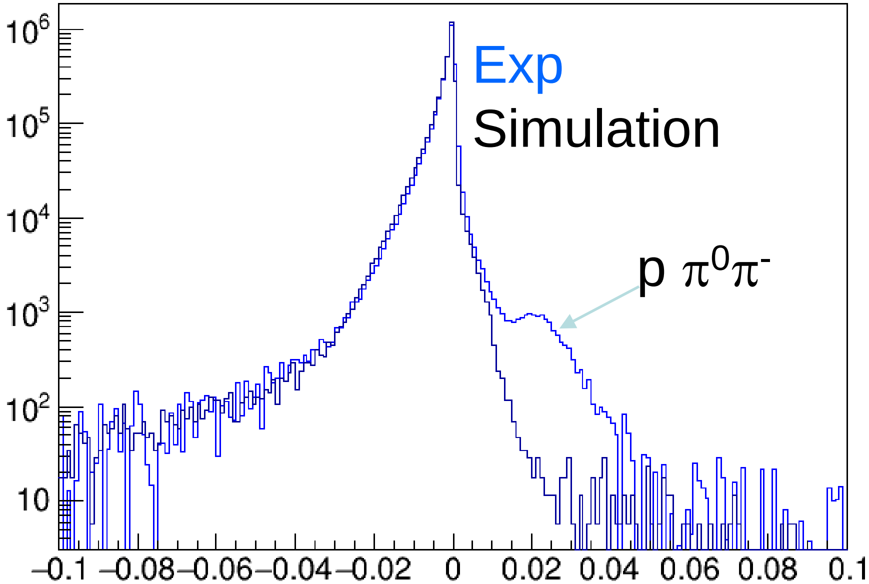


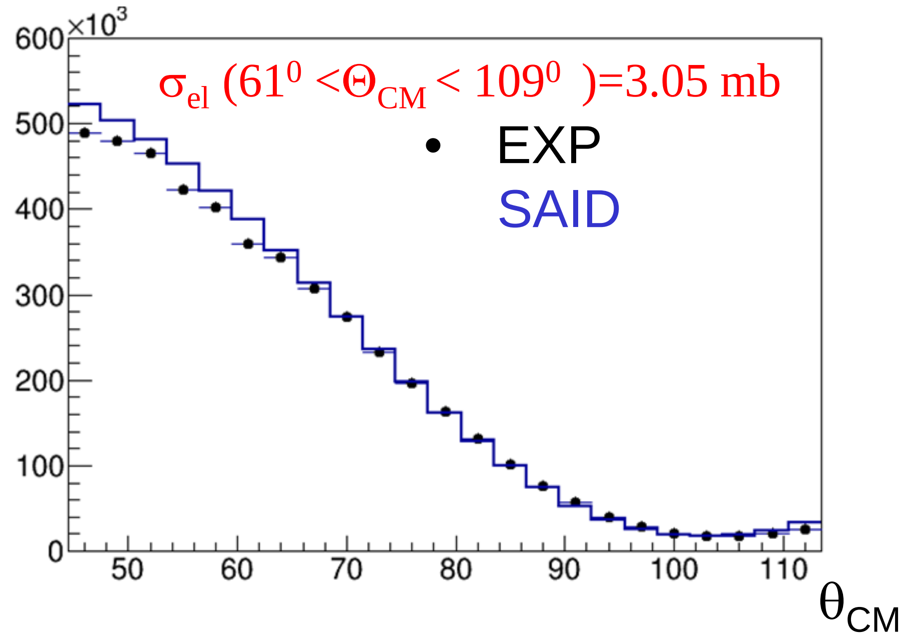


Elastic events: example 748 MeV/c





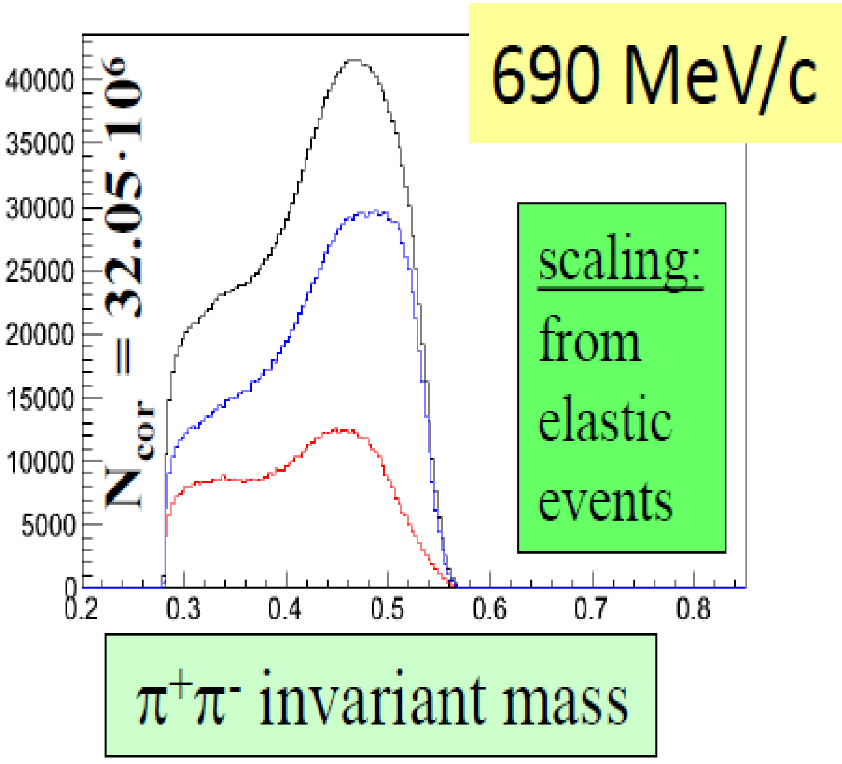


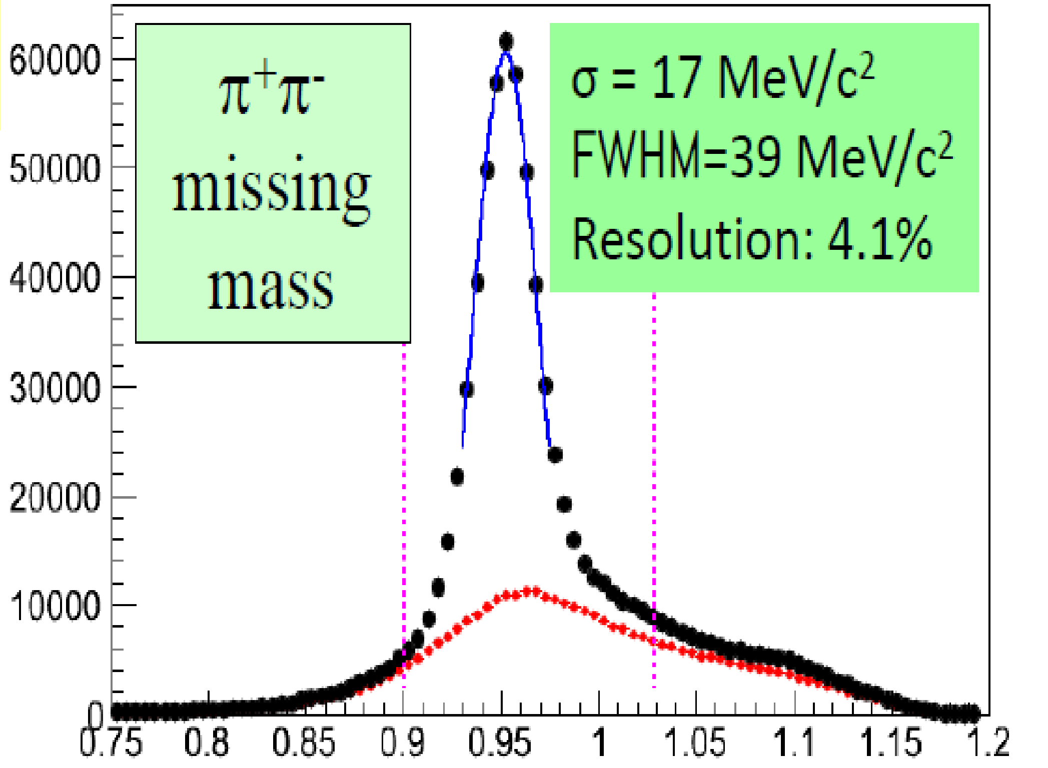


$\pi^- p \to \pi^+ \pi^- n$

- Clean Separation of proton and Carbon contributions

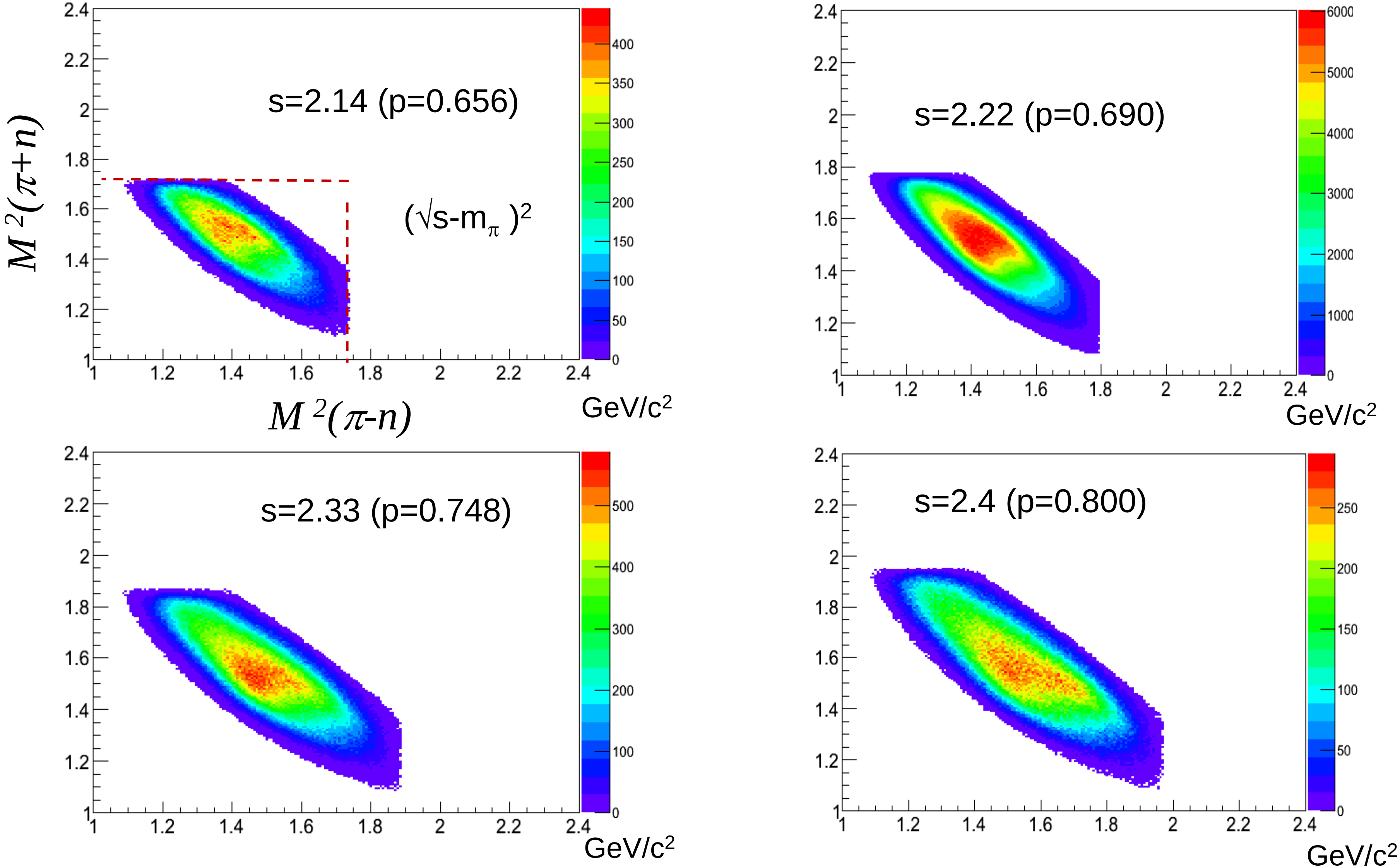
(by scaling factors derived from π-p eastic scattering)





Dalitz plots: all information is inside…

HADES acceptance : covers all dalitz area



Partial Wave Analysis (Bonn/Gatchina)

A.Saranstev et al..

- An excellent tool widely used in hadron spectroscopy (γN, πN, pp reactions)
- Based on K-Matrix approach (coupled channels): allows to fit several reactions channels at the same time with strong unitarity constraints
- Take into account specific detector acceptances and efficiencies

(data are analysed together with phase space Monte Carlo passed through detector response)

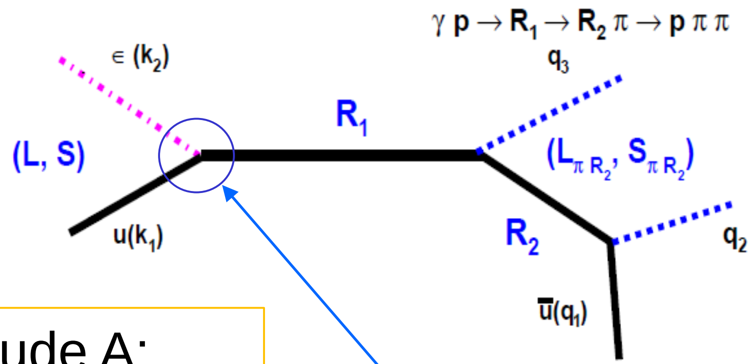
- Fit is done on event by event basis with maximum likehood method (correlation in multidimensional space following are taken into account!)

At present ~0.34 mln data points taken in global fit with χ^2 /DOF= 1.6

In HADES we use Energy dependent extraction of amplitudes: several energy points are analysed together with different final states. Resonance properties (masses, widths are not subject to fit)

Already several channels analysed and published (pp$\rightarrow$pkΛ, pp $\rightarrow$pnπ+, ppπ^0)

Double pion Production in pion and photo -induced



R_1 has well defined J, P

for example for pion-nucleon

S-wave $J^P = 1/2^-$ (pion neg.parity)

$L_{2I,\,2J} = S_{11}$ or S_{31}

P-wave $J^P = 1/2^+$ or $3/2^+$

P_{11} , P_{13} or P_{31} , P_{33}

Reaction amplitude A:

Pion induced reactions:

$$A_{1i} = K_{1j}(I - i\rho K)^{-1}_{ji}$$

$$K_{ij} = \sum_\alpha \frac{g_i^\alpha g_j^\alpha}{M_\alpha^2 - s} + f_{ij}(s) \qquad f_{ij} = \frac{f_{ij}^{(1)} + f_{ij}^{(2)}\surd}{s - s_0^{ij}}$$

Photon induced reactions:

$$A_k = P_j(I - i\rho K)^{-1}_{jk}$$

The vector of the initial interaction has the form:

$$P_j = \sum_\alpha \frac{\Lambda^\alpha g_j^\alpha}{M_\alpha^2 - s} + F_j(s)$$

Λ -helicity ampl

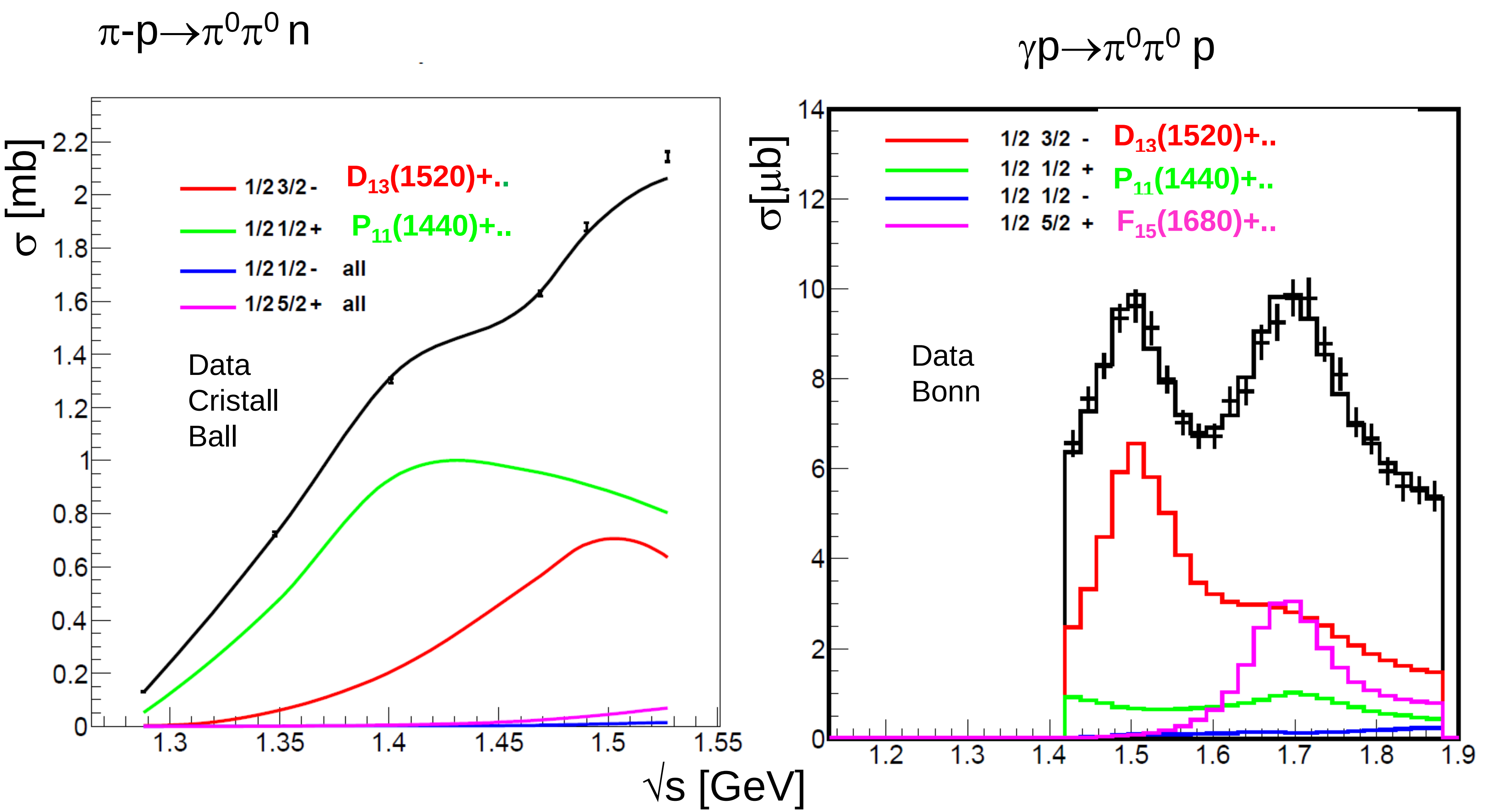
In both same K matrix accounts for hadronic part : resonances with masses M_α, coupling to channels g(i,j), phase space for decay ρ and background terms f_{ij}

Baryon data base

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

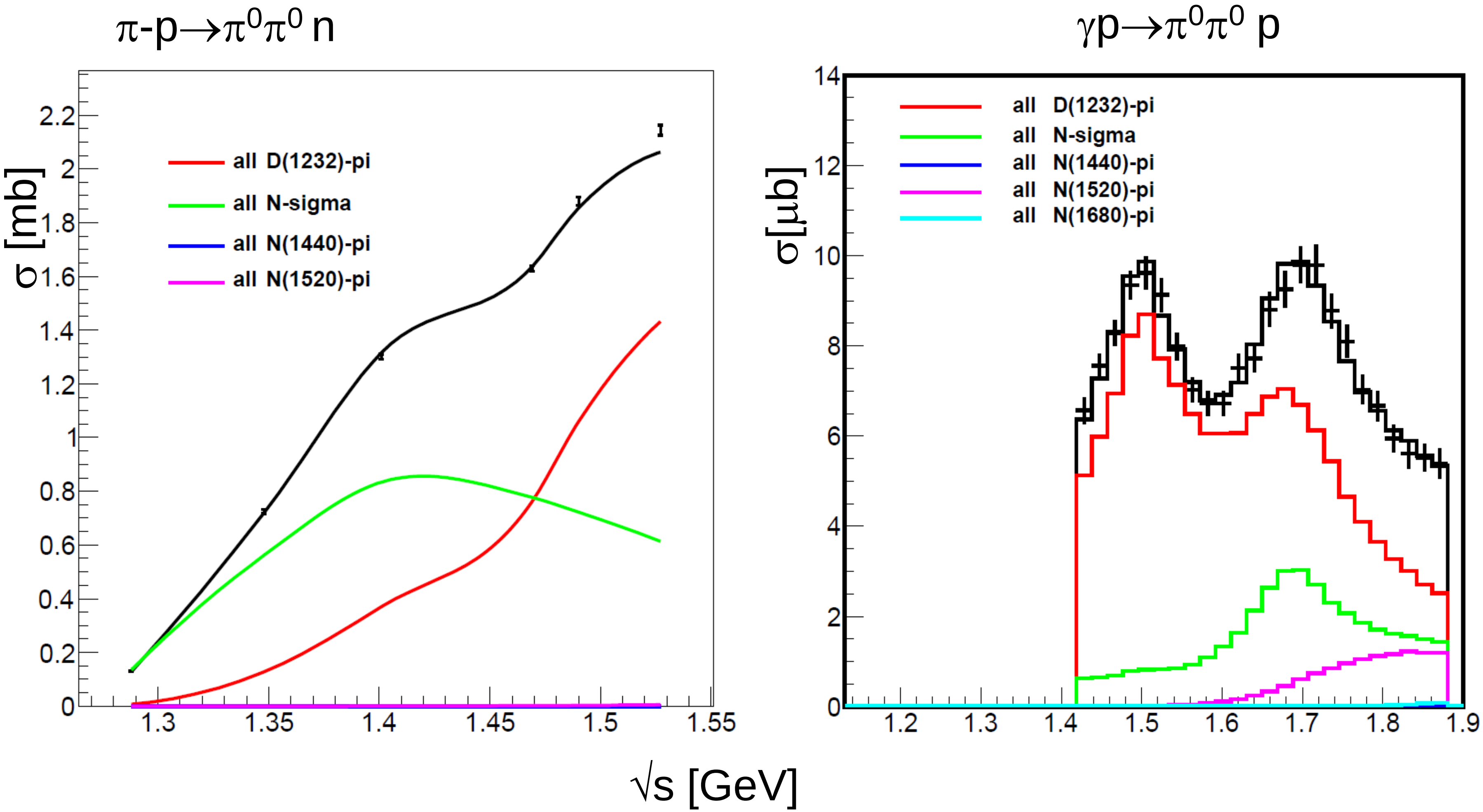
Separation into initial states (waves)

A.Saranstev



In the Energy range of 1.45-1.55 GeV in 2 pion production only few resonances matters D13(1520), P11(1440)

Separation into final states

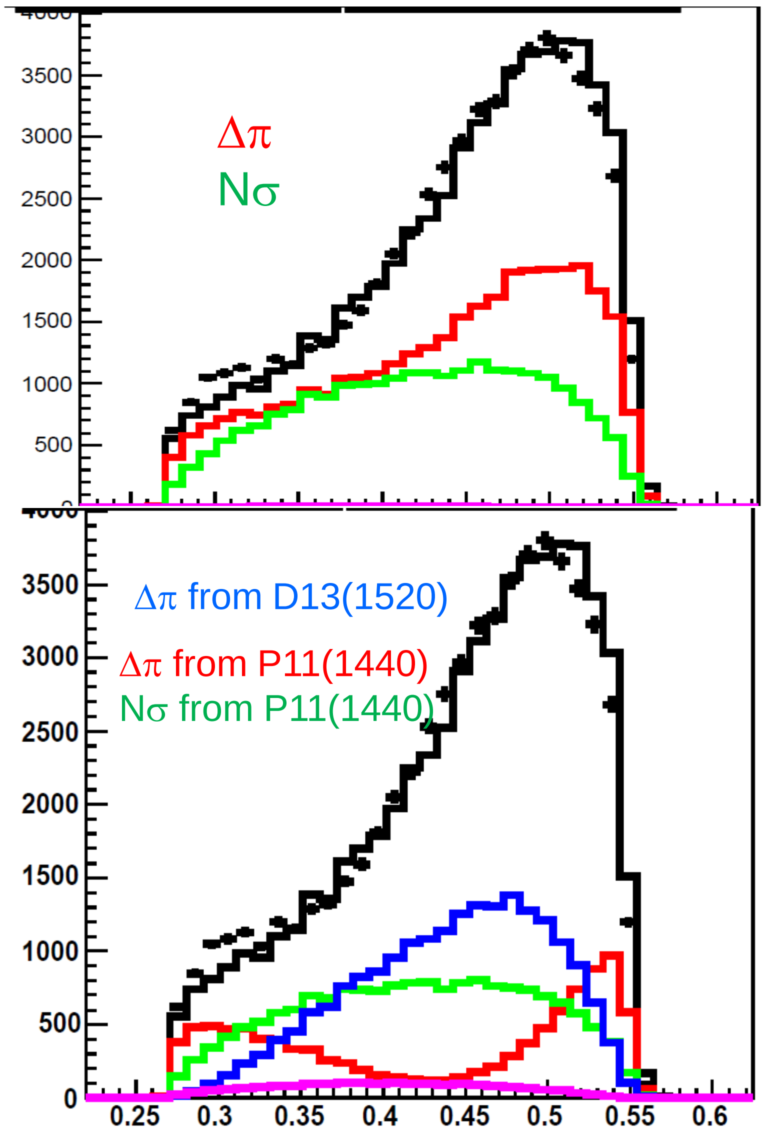


Dominat channels in $2\pi^0$ are $\Delta\pi$ and $N\sigma$ ($2\pi^0$ in I=0)

ρ Does Not contribute because it is I=1, hence does not decay to 2 π^0

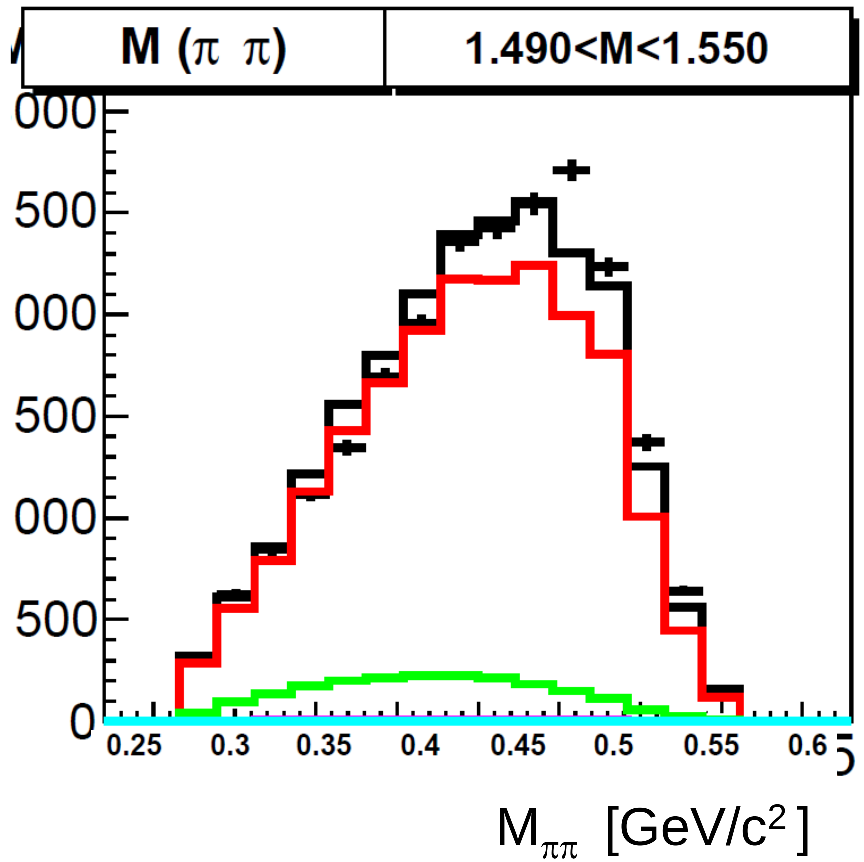
Complementary character of reactions..

π-p$\to\pi^0\pi^0$ n @ 0.691 ($\sqrt{s}$=1.49)



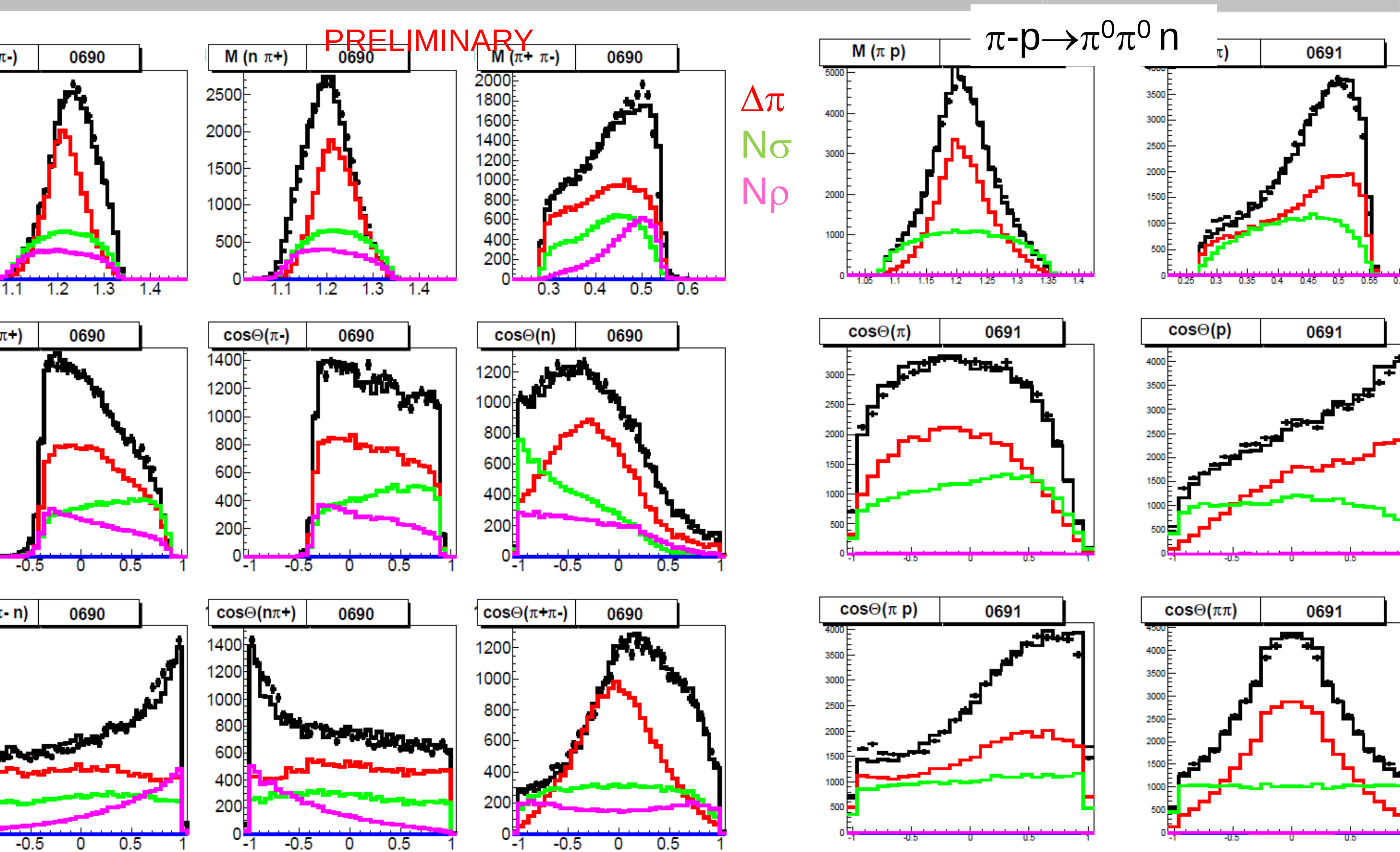
Exmple 2 pion mass

γp$\to\pi^0\pi^0$ p



Different shapes are due to different resonance contributions P11(1440) and D13(1520)

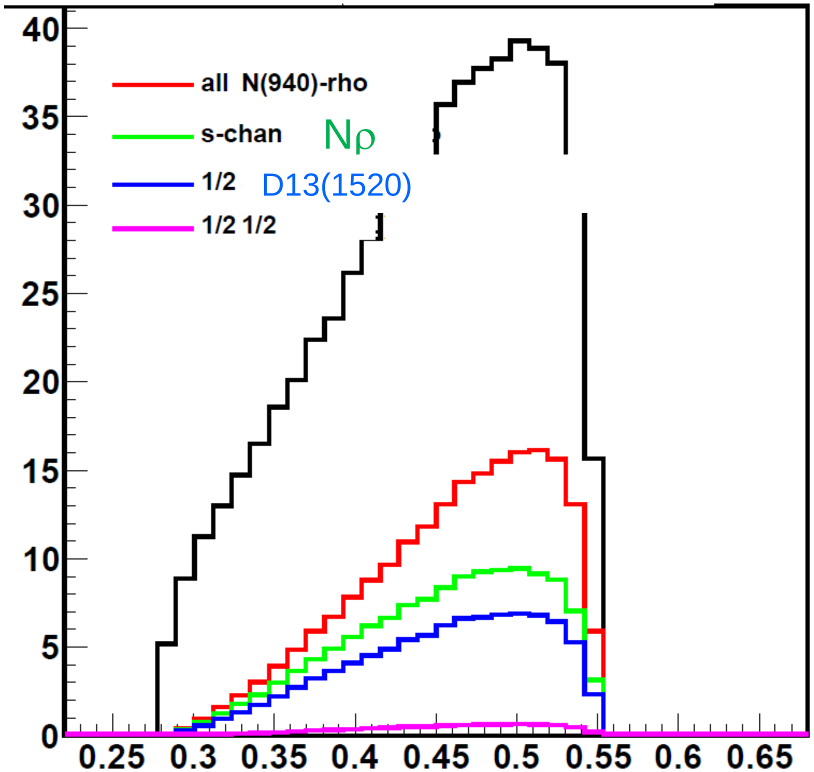
Example of fit for $\pi^- p \rightarrow \pi^+\pi^-$ p=690 MeV



2 pion invariant mass - ρ contribution

PRELIMINARY

Total cross sections
(from PWA solutions)

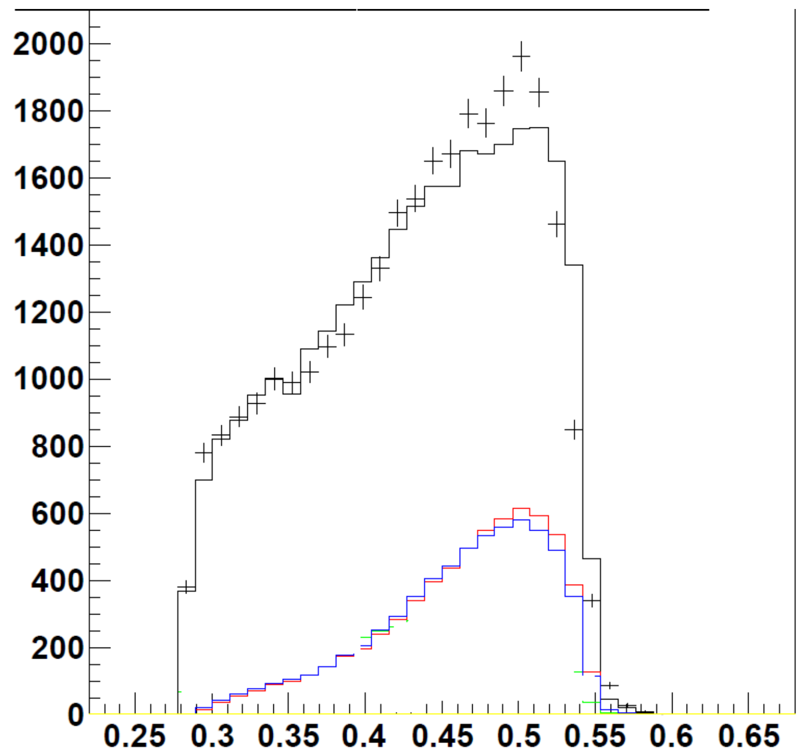


- Important non-resonant (t-channel contribution)

Total :

σ_ρ = 2.3 mb (PWA solutions)

Inside HADES acceptance

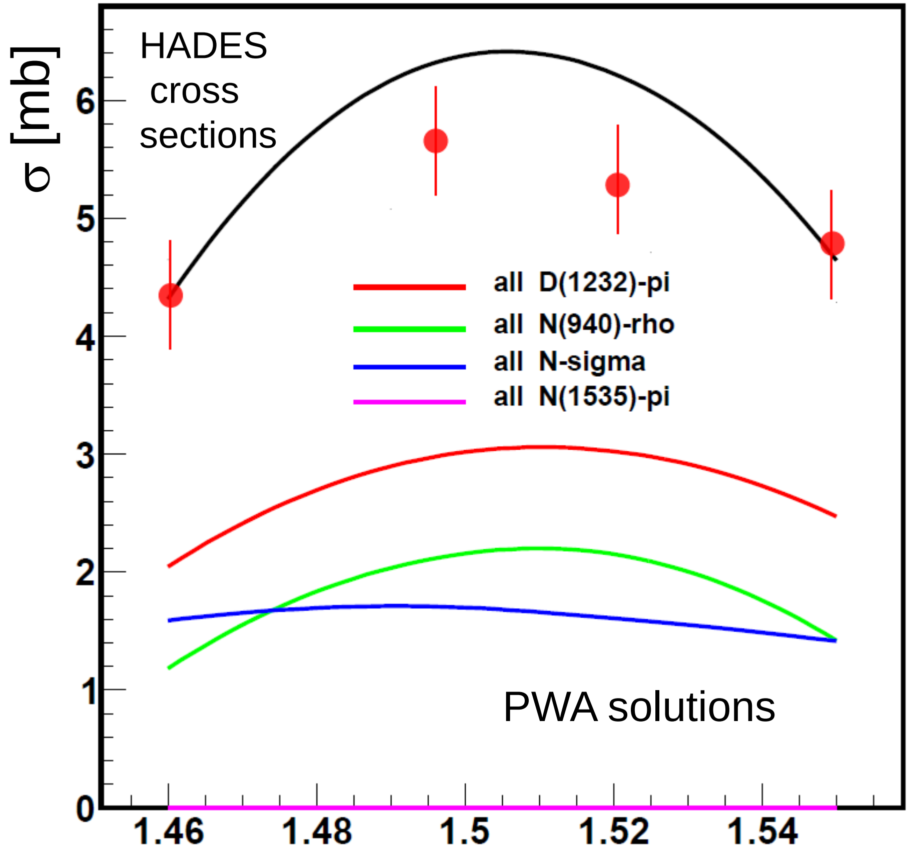


- Dominated by s-channel - resonant D13(1520) production

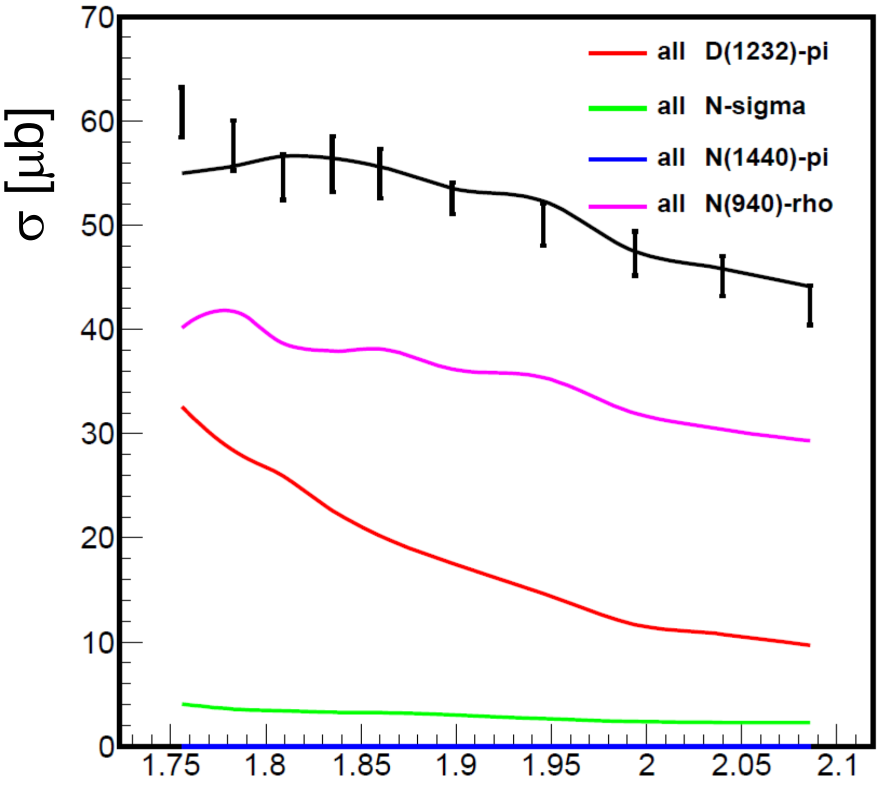
Total cross sections

PRELIMINARY

Full solid angle $\pi^- p \rightarrow \pi^+ \pi^- n$



$\gamma p \rightarrow \pi^+ \pi^- p$ (SAPHIR,CLAS)



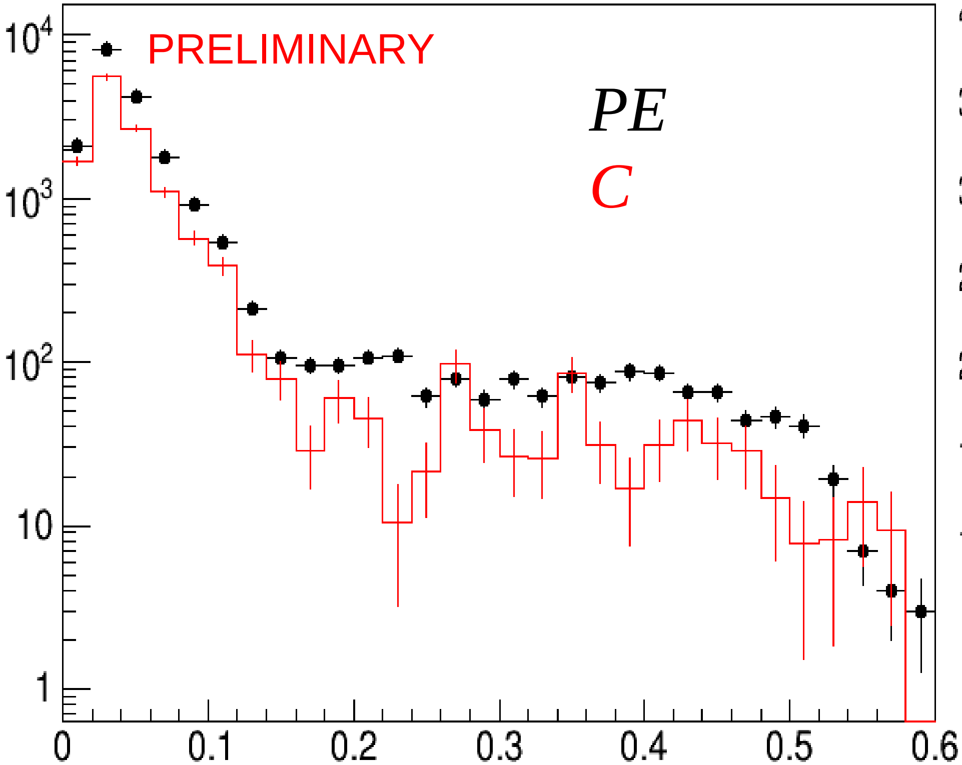
$\sqrt{s}$ [GeV]

BR(D13(1520)→Nρ (17%)

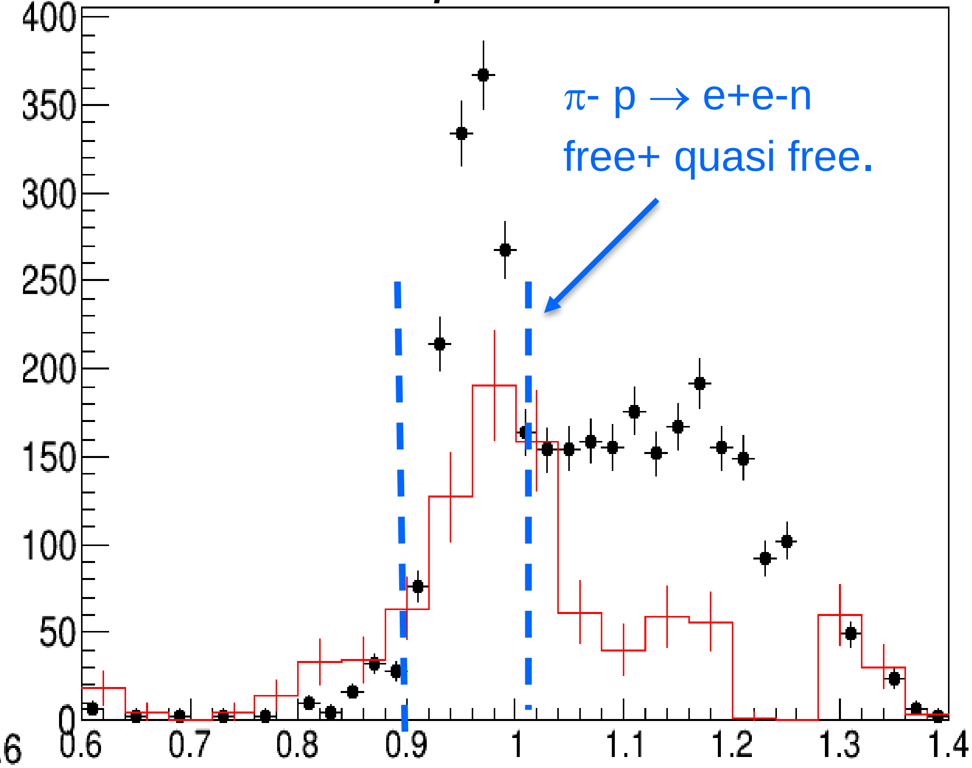
e+e- inclusive spectra @ p=690 MeV/c

PRELIMINARY

Inclusive inv. mass



Miss. Mass for M>120 MeV



- Too low statistics from carbon (scaled by 5) data for subtraction
- free+"quasi-free" π-p $\rightarrow$e+e- n events selected by missing mass cut
- e+e- yield from proton to carbon ~ 1:2 ($\pm$20%)

e+e- inclusive inv. mass vs model

HADES

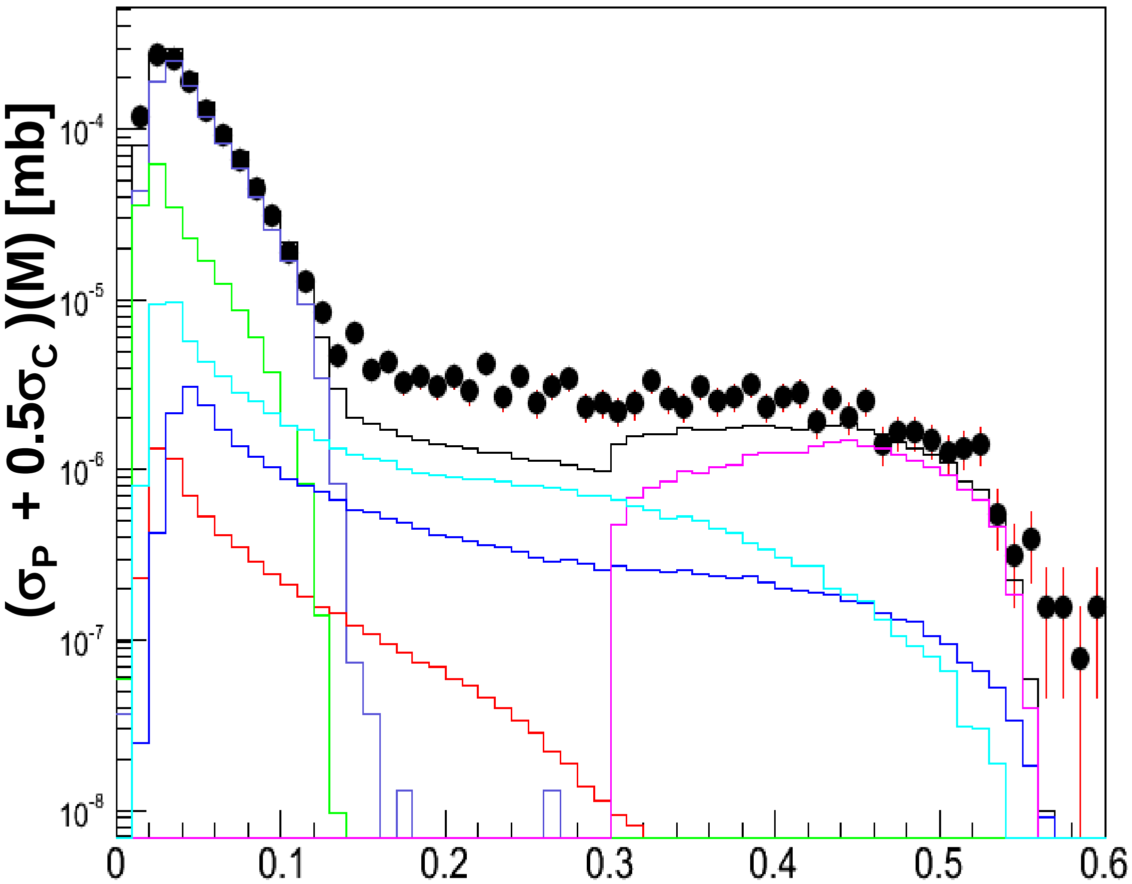
EXP

π- PE @ 690 MeV/c

SIM

PLUTO coctail
based on known σ

PRELIMINARY



$N_{beam} = N_{el} / (\sigma_{el} * \rho d)$ (target dens)

$N_{PE}^{e+e-} = N_{beam}(\sigma_P + 0.5\sigma_C)\,\rho d$

π^0 Dalitz

$2\pi^0$ Dalitz

$\eta \rightarrow \gamma e+e-$

N(1520) (PWA)$\rightarrow$ne+e- (QED)

ρ(PWA)$\rightarrow$e+e-

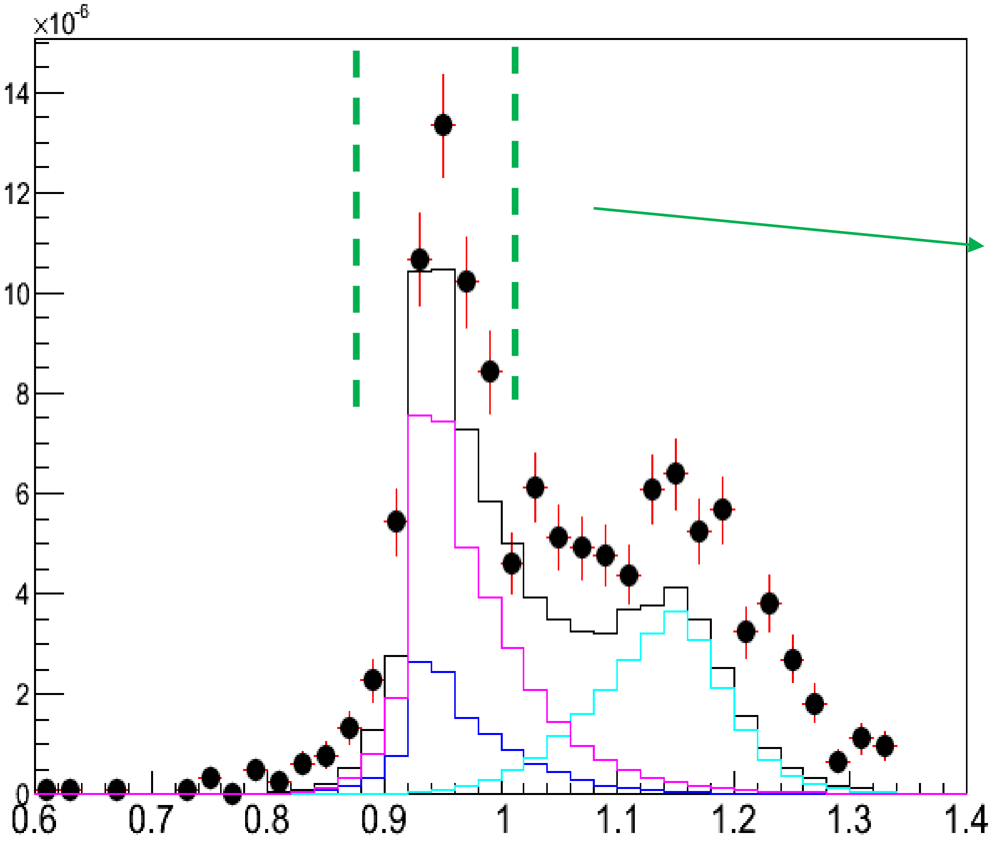
! BR(M)~ $1/M^3$ (factor 4.6!)

$\Delta \rightarrow$ne+e- (QED)

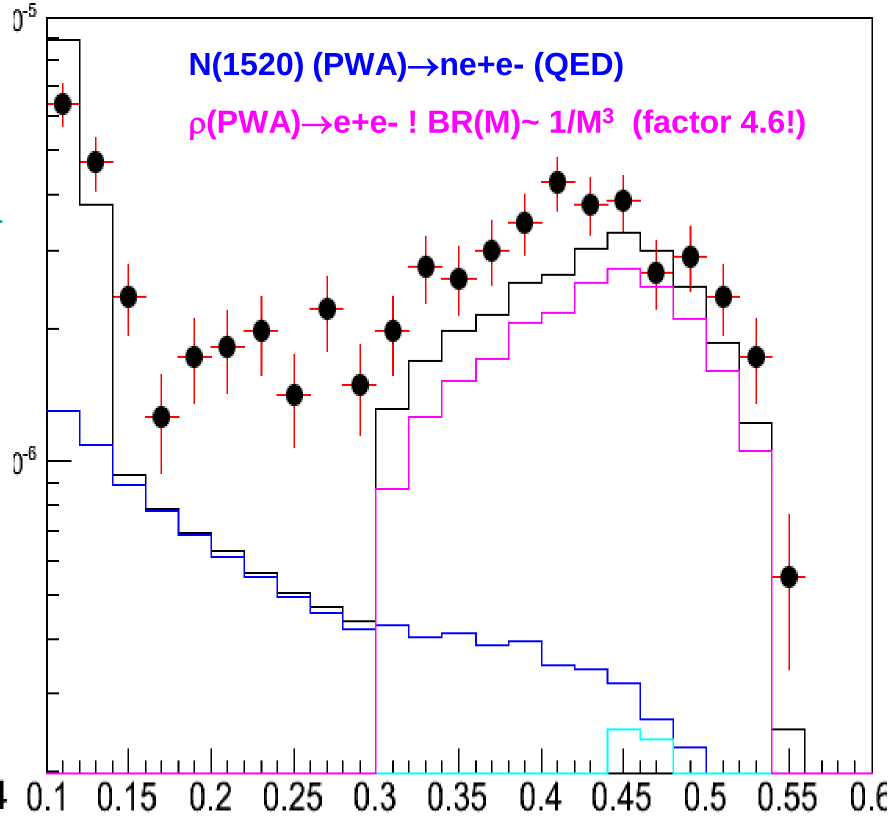
Exclusive π-p$\rightarrow$e+e- n: comparison to model

PRELIMINARY

Miss. Mass for M_{e+e-} >120 MeV



Exclusive inv. mass



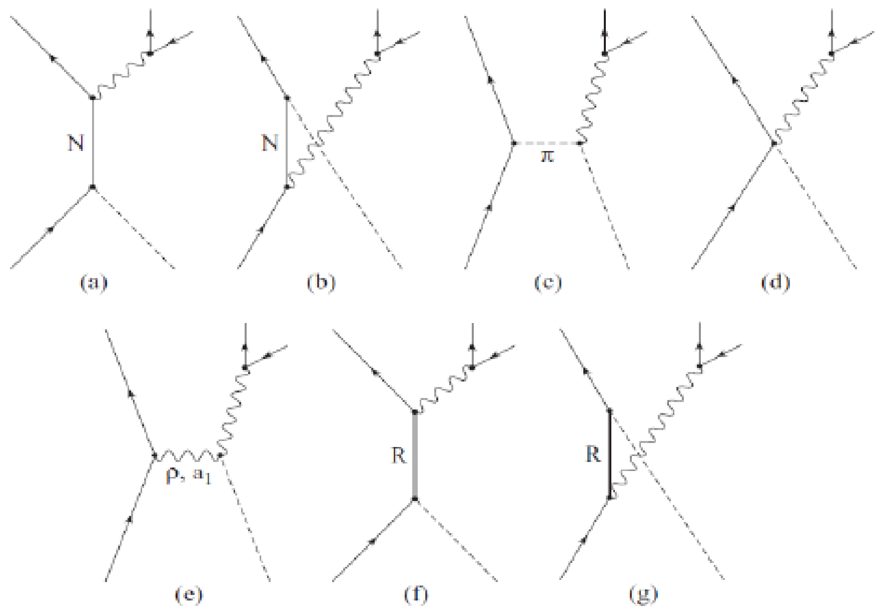
Very strong ρ contribution (along VMD) !

Dilepton production in pion-nucleon collisions in an effective field theory approach

Miklós Zétényi* and György Wolf†

We present a model of electron-positron pair production in pion-nucleon collisions in the exclusive reaction $\pi N \to N e^+ e^-$. The model is based on an effective field theory approach, incorporating 16 baryon resonances below 2 GeV. Parameters of the model are fitted to pion photoproduction data. We present the resulting dilepton invariant mass spectra for $\pi^- p$ collisions up to $\sqrt{s} = 1.9$ GeV center-of-mass collision energy. These results are meant to give predictions for the planned experiments at the HADES spectrometer in GSI, Darmstadt.

Phys. Rev. C **86** (2012) 065209



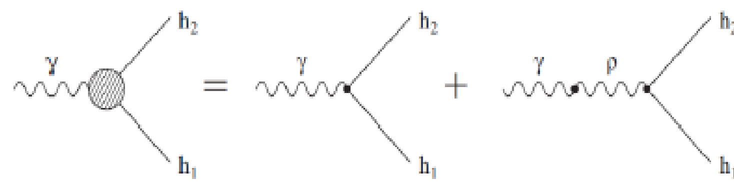
Feynman diagrams contributing to the proces

$$\pi + N \to N + e^+ + e^-$$

a) s- b) u- c) t-channel diagrams d) contact interaction term

e) vector meson exchange diagram

f) s- g) u-channel baryon resonance contributions

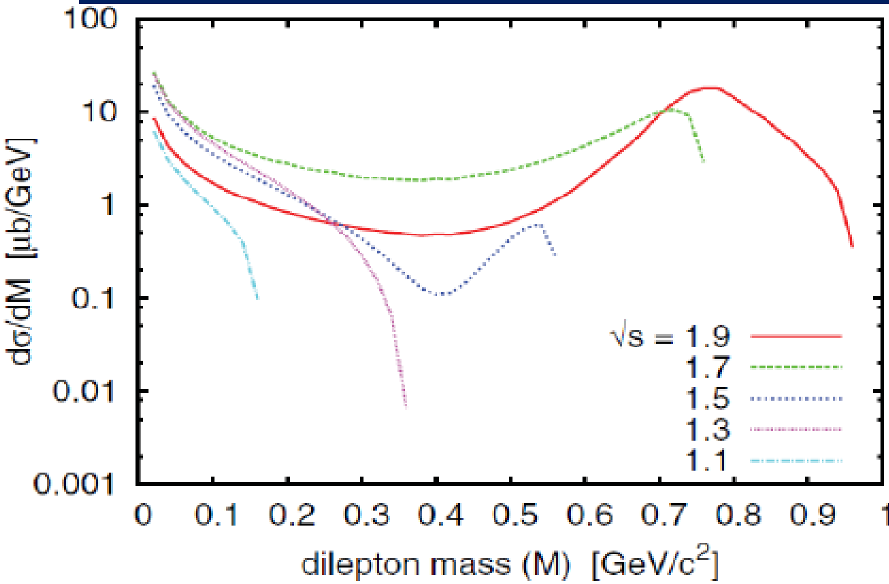


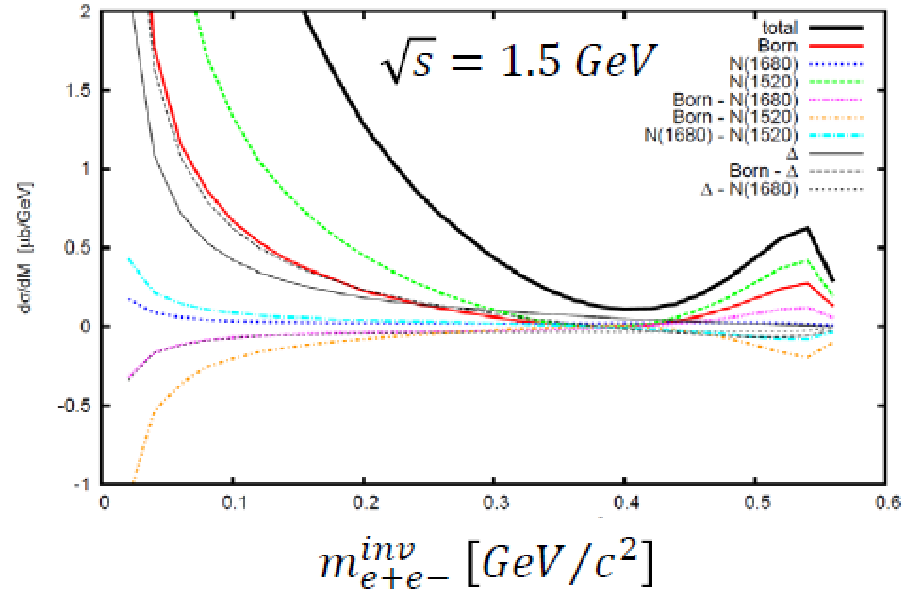
VMD form factor:

$$F_{\mathrm{VMD}}(k^2) = -\frac{e}{g_\rho}\frac{k^2}{k^2 - m_\rho^2 + i\sqrt{k^2}\Gamma_\rho(k^2)}$$

k^2 instead of m_ρ^2

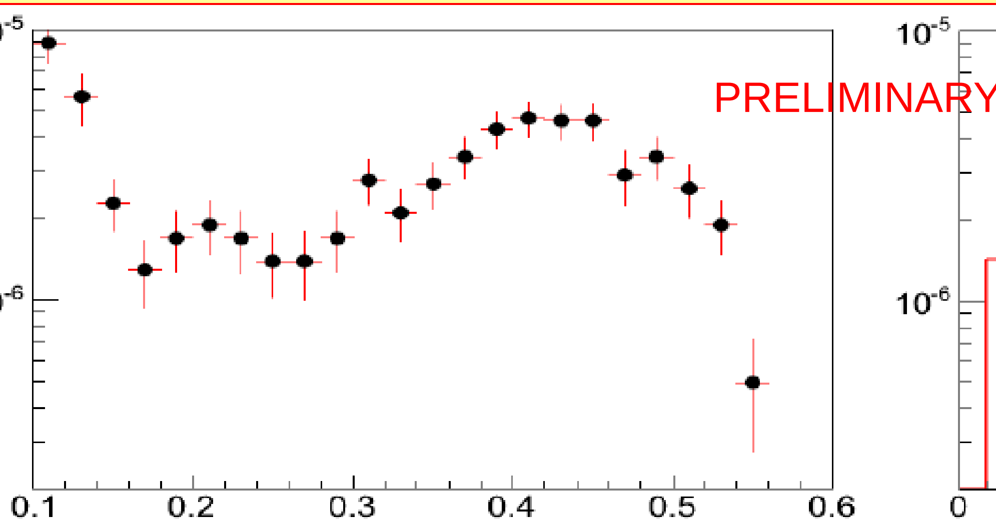
e^+e^- in effective field theory approach

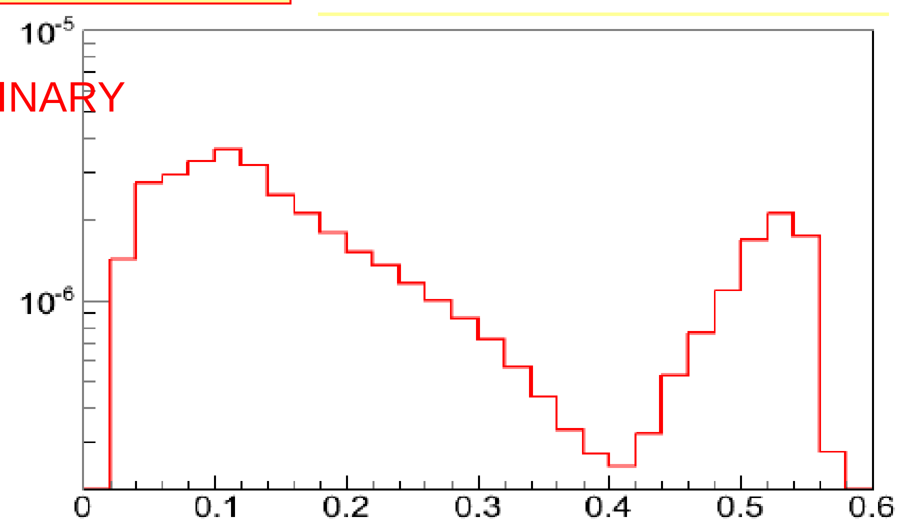




Zetenyi & Wolf: higher $\sqrt{s} = 1.5\ GeV\ (\pi^- p)$
HADES: $\sqrt{s} = 1.492\ GeV(\pi^- p)$ and $\sqrt{s} = 1.461\ GeV(\pi^- C)$

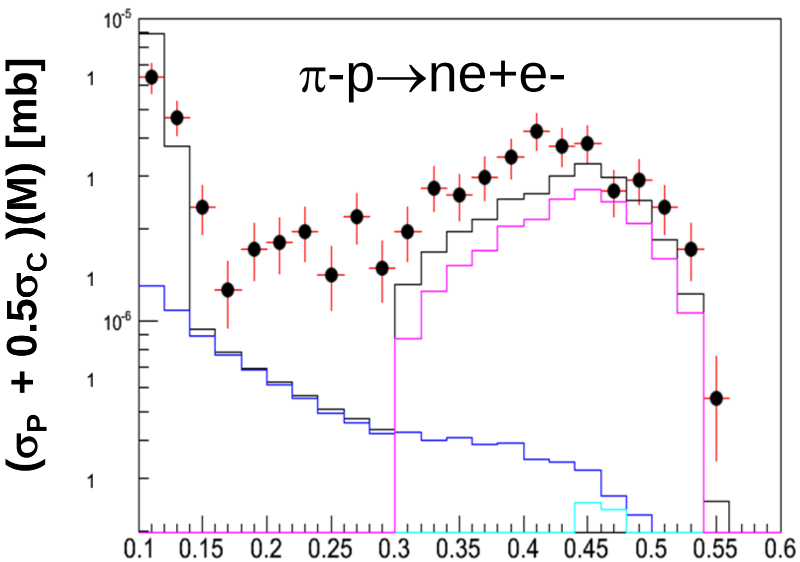
A very different pattern..



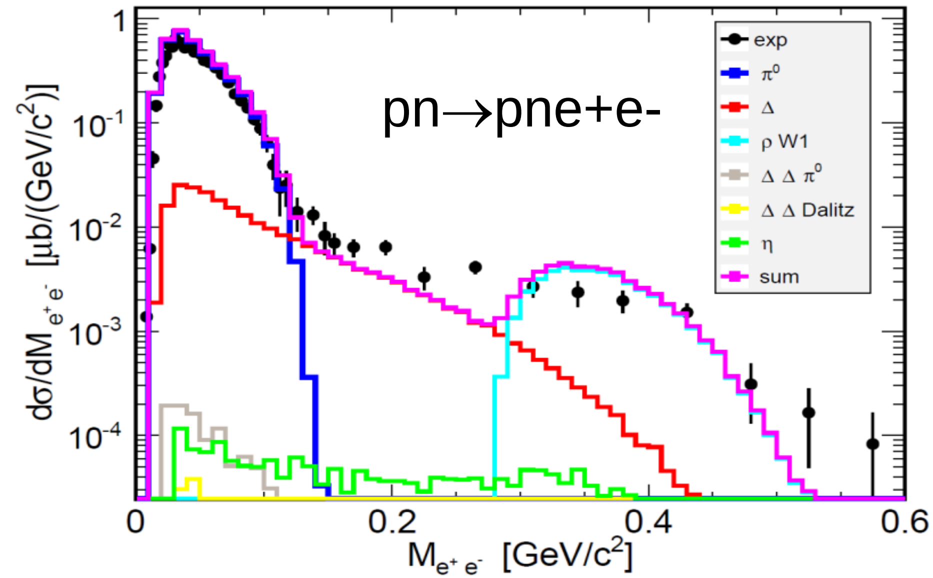


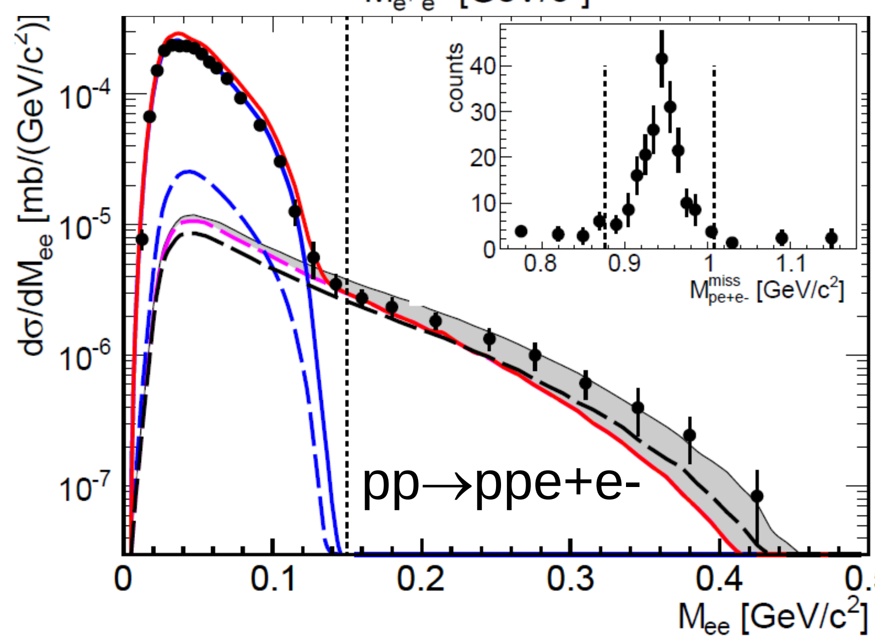
A consistent picture ....

$\sqrt{s} - M_n = 1.49 - 0.94 = 0.55$

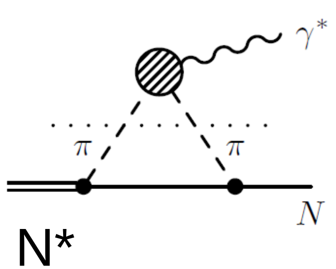


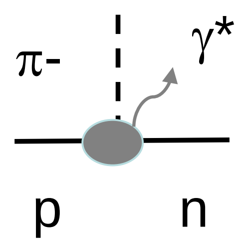
$\sqrt{s} - 2*M_n = 2.43 - 2*0.94 = 0.55$





A strong ρ signal correlated with charged pion exchange…pion cloud?

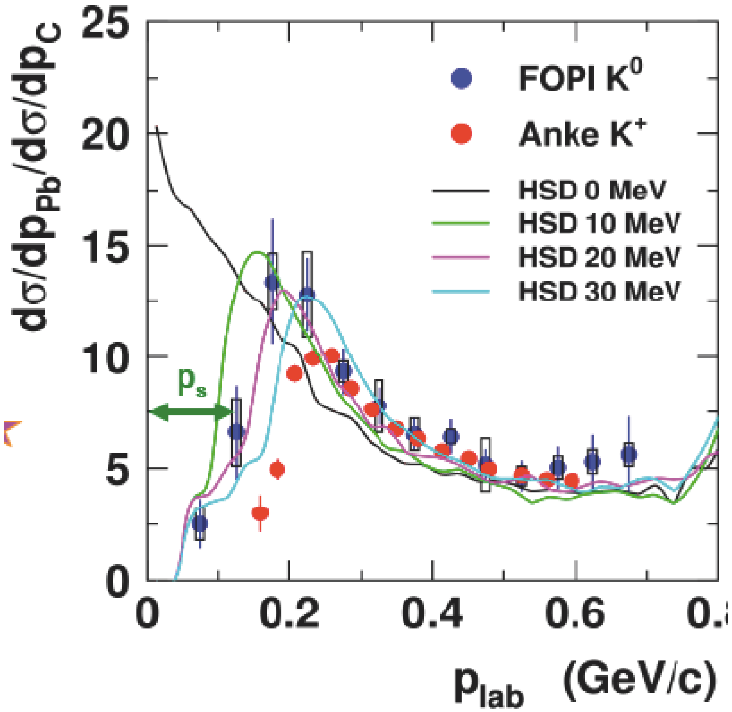




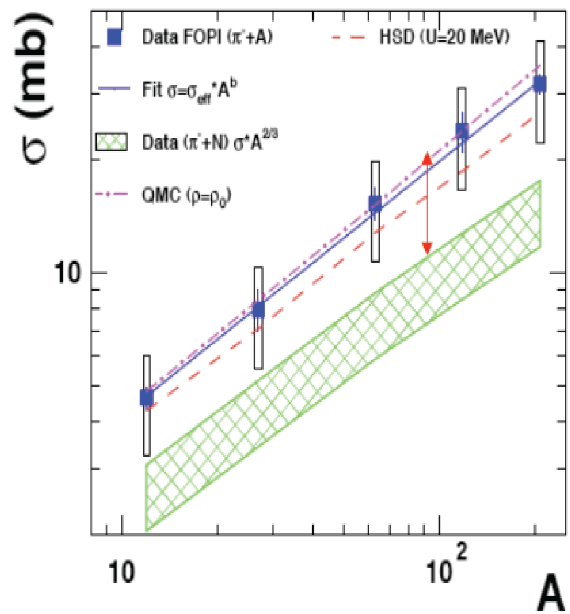
Strangeness production in π A

FOPI : K^0 production in pion induced reactions

FOPI: PRL102(2009)183591,
ANKE : EPJA22(2006) 301



K^0_s Cross-Section π+A



$$\sigma\left(\pi^- + A \rightarrow K^0 + X\right) = \sigma_{eff} \cdot A^b$$

$$\sigma_{eff} = 0.87 \pm 0.13\, mb$$

$$b = 0.67 \pm 0.03$$

Sum of elementary cross-section

Factor 2: Multiple-step processes?
Same Trend as a fc. of A

HADES goal: increase statistics, differential data

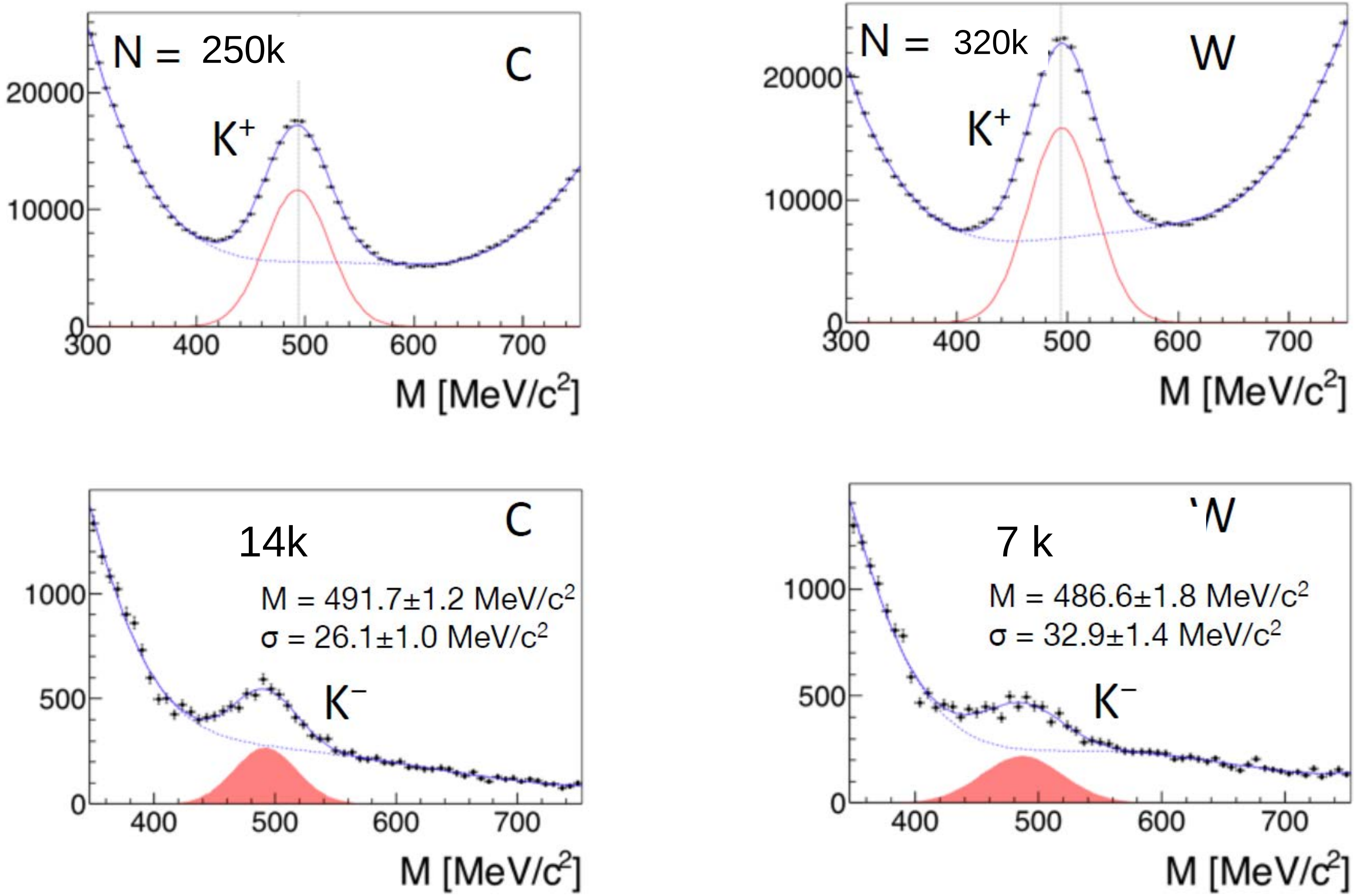
- HADES: K0/K+ (p/Nb) only rescattering, no strong absorption

What is the A dependency for K- as compared to K+ ?

- Reduced mass -> b>2/3
- Absorption …-> b<2/3

Kaon production

PRELIMINARY

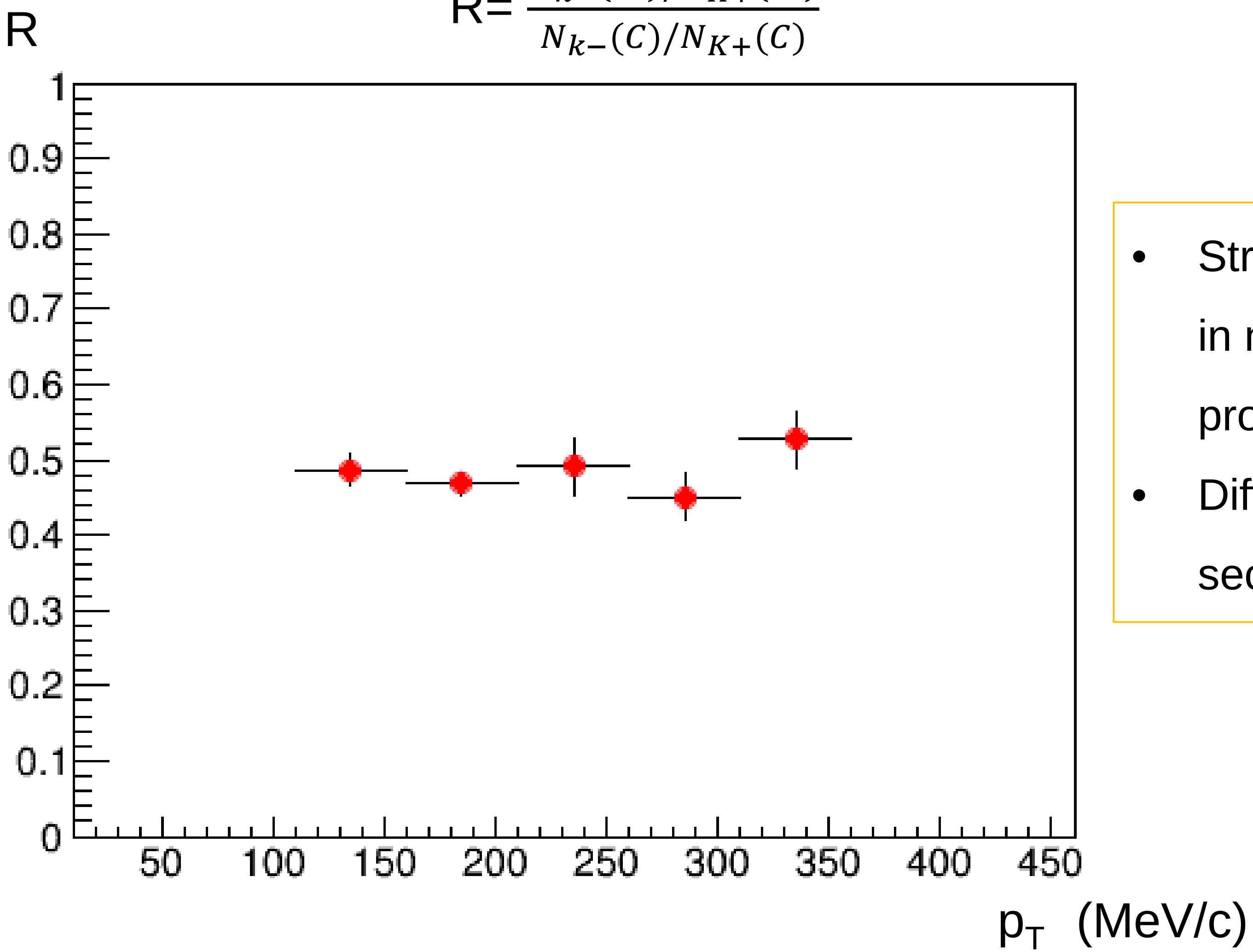


K-/K+ ratio

Double ratio;

$$R = \frac{N_{k-}(W)/N_{K+}(W)}{N_{k-}(C)/N_{K+}(C)}$$

PRELIMINARY



- Strong absorption of K- in nucleus (2N, 3N processes..?)
- Differential cross sections –in progress

Transparency ratio in „cold matter”

HADES

- „disapearance of meson in nuclear matter”

$$T_A = \frac{\sigma_{\gamma(\pi)A\to VX}}{A\cdot\sigma_{\gamma(\pi)N\to VX}}$$

Glauber Picture;

CabreraNPA733(2004)130

$$\vec{r}\,' = \vec{r} + l\frac{\vec{q}}{|\vec{q}\,|}$$

$$\sigma_{\gamma A} = \int d\Omega \int d^3 r \rho(r) \frac{d\sigma_{\gamma N}}{d\Omega} \exp\left(\frac{1}{q}\int_0^\infty dl \,\mathrm{Im}\prod\nolimits_{medium}(q,\rho(r'))\right) P(r+\delta r')$$

Production

Absorption

FSI of decay products

- ISI (not for γ), Pauli-blocking, Fermi-motion, secondary processes, shadowing ….

in-medium width

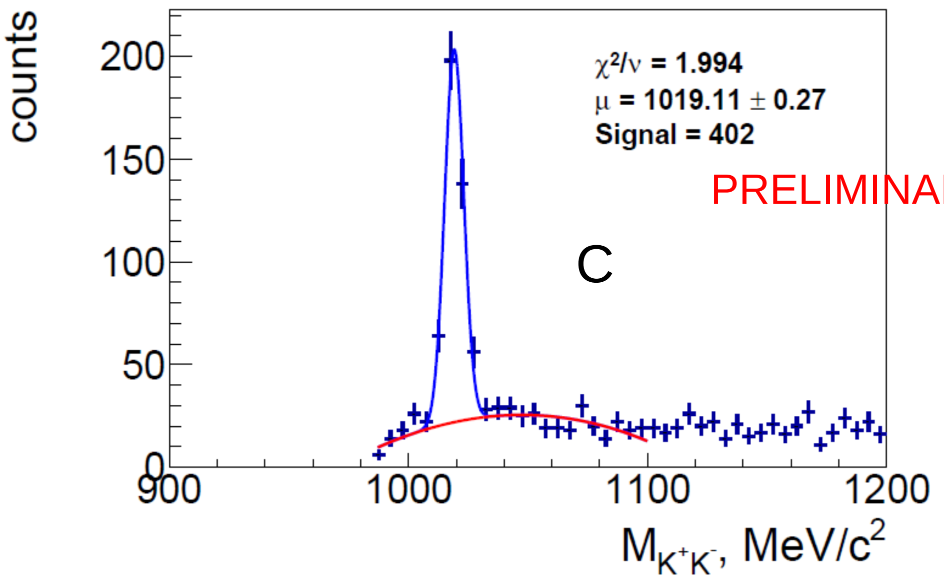
absent for e+e-

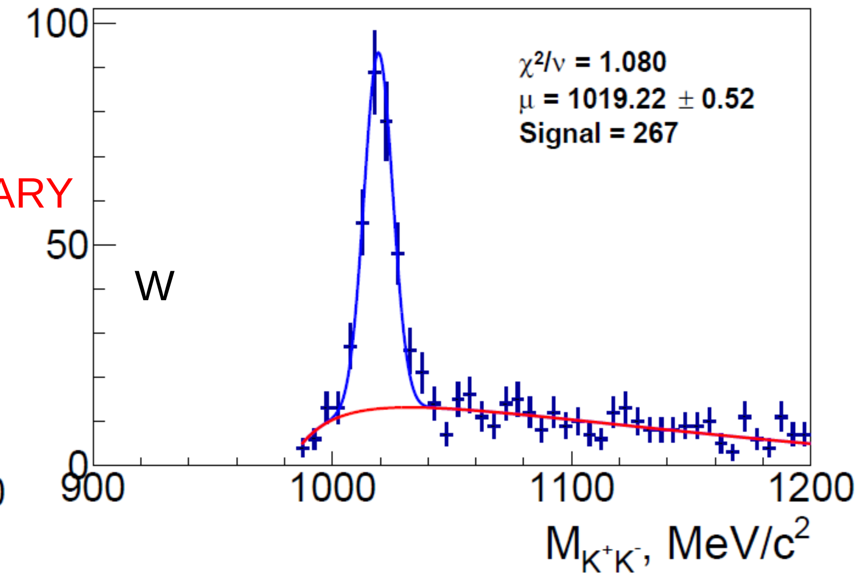
$$\Gamma_{coll}(q) = -\frac{\mathrm{Im}\prod(q)}{\omega}$$

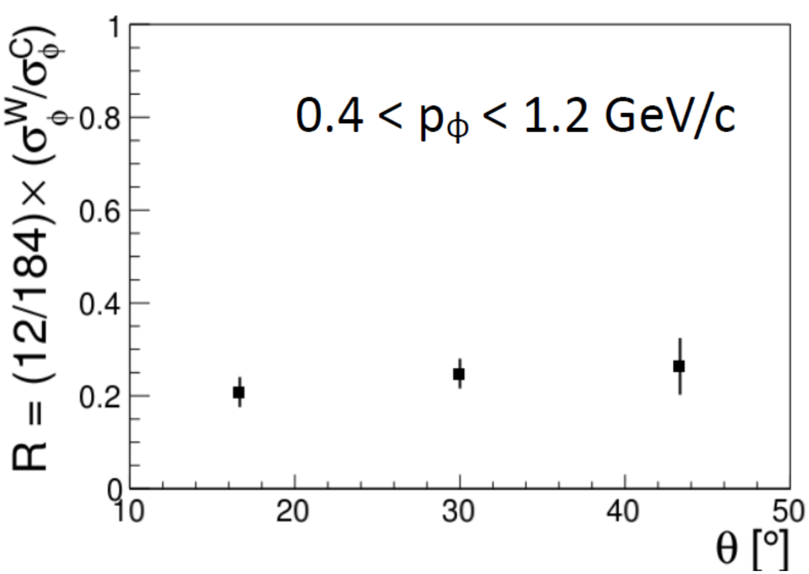
- normalization to C to reduce nuclear effects

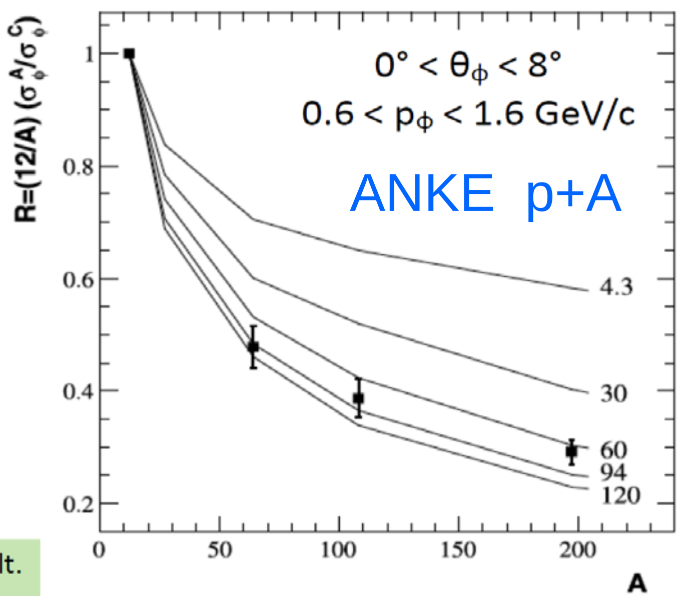
ϕ absorption in π- A collisions @ 1. 7 GeV/c

HADES



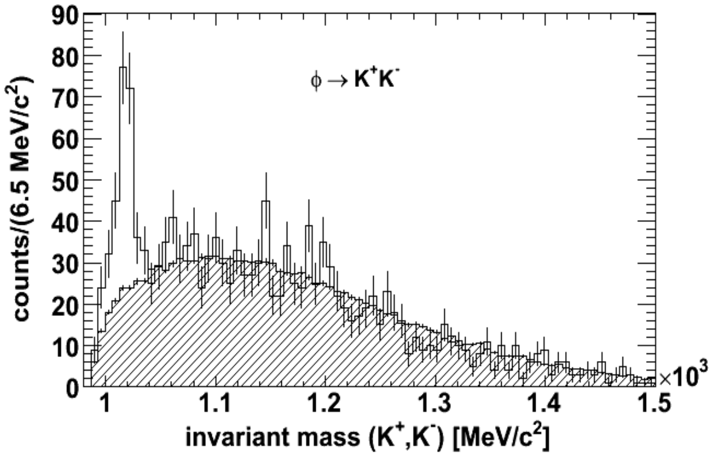




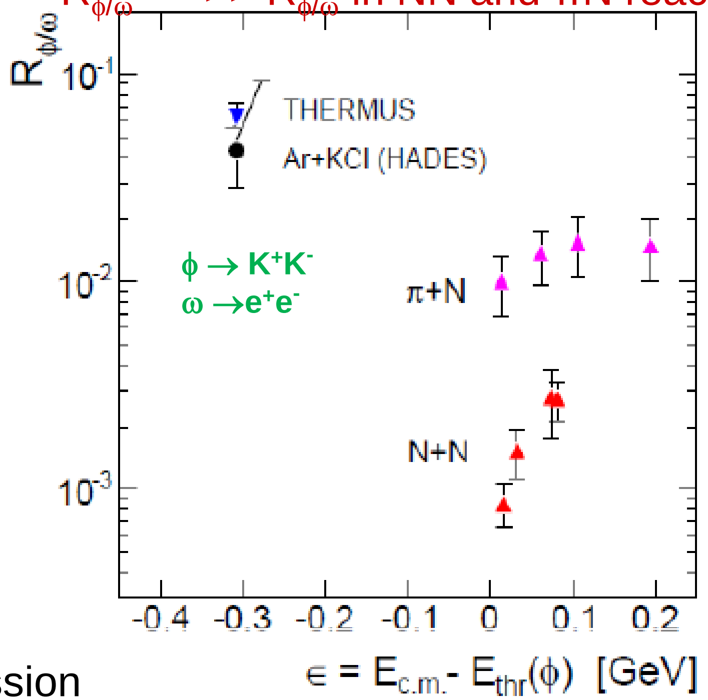


ϕ/K^- and ϕ/ω ratio in A + A

HADES: PRC80(2009)025209



$R_{\phi/\omega}^{A+A} >> R_{\phi/\omega}$ in NN and πN reactions



$$OZI: \phi/\omega = \tan^2\delta \cong 4.2 \cdot 10^{-3}$$

☝ enhanced production of ϕ in HI : no suppression w.r.t ω (i.e OZI rules)… but large absorption in cold nuclear matter?

Maybe origin is same? For example consider strong (15%) BR($\phi \rightarrow \rho\pi$) which can be increase in medium, but then also can lead to $\rho\pi \rightarrow \phi$ production

Summary and outlook

HADES

- HADES & pion beam is an unique tool to understand in details baryon<->ρ couplings
- Significant off-shell ρ contribution originating from

D13(1520) shown by combined PWA and e+e- data

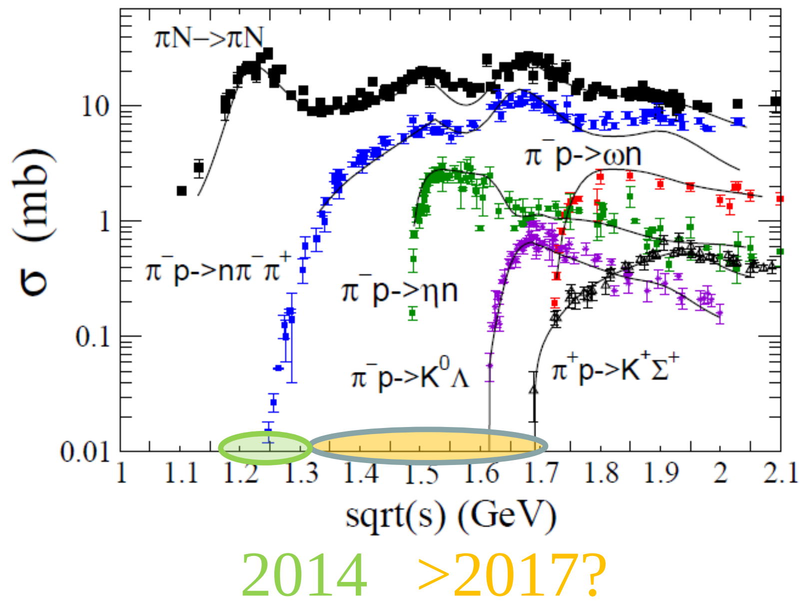
- Large impact on e+e- production !

Important for interpretation of HADES p+Nb

- New good quality data on kaon and ϕ

meson production off nucleus

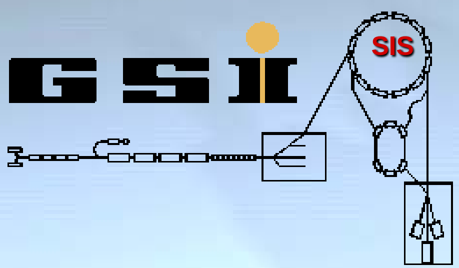
WHAT NEXT?



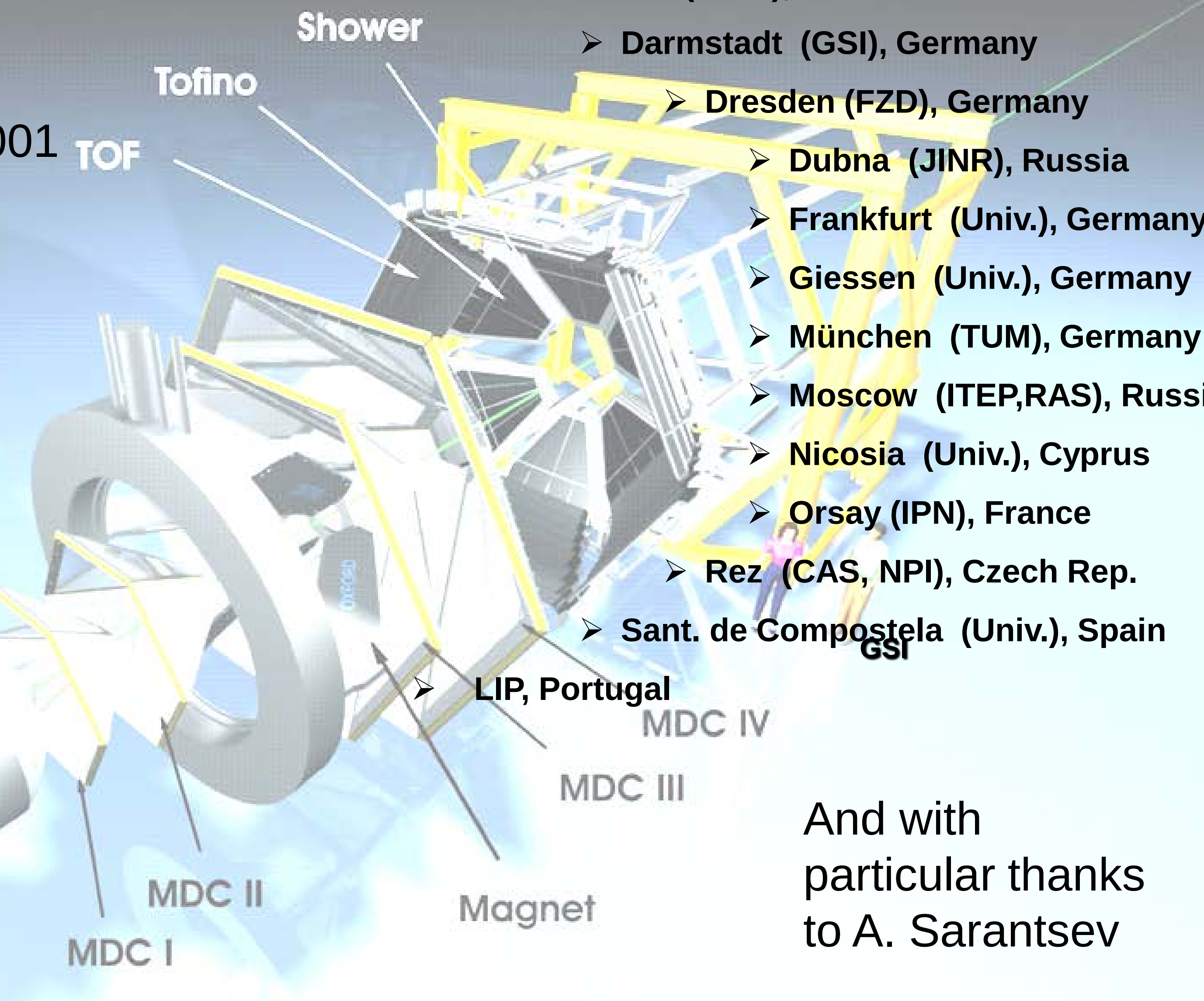
- High statistics beam energy scan : continutation and extension to third resonance region
- Hadronic final states ,one pion, 2 pion, hyperon production to control resonance excitation (HADES upgrade with el. calorimeter !- neutral final states!)
- Dielectron measurements
- Hadron and dielectron production in π+A

The HADES collaboration

13 Institutions
Technical Proposal
accepted 1995
First experiments 2001



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



And with
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