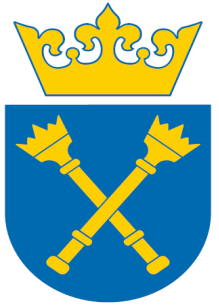



Di-pion and di-electron production in NN reactions with HADES at 1.25GeV incident beam energy.

Hubert Kuc – UJ Krakow, IPN Orsay
hubertkuc@gmail.com

List of content

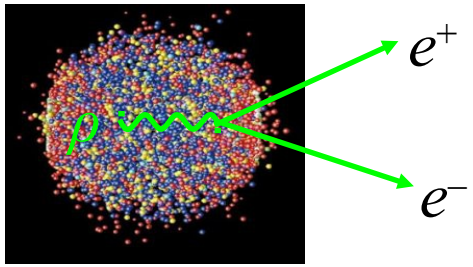
- Physics motivation
- Analysis procedure: particle identification
- Comparison to theoretical models
- Summary and Outlook

Motivation

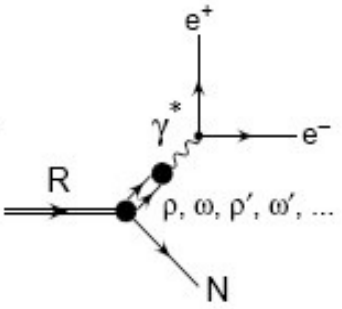
Main goal of HADES experiments:

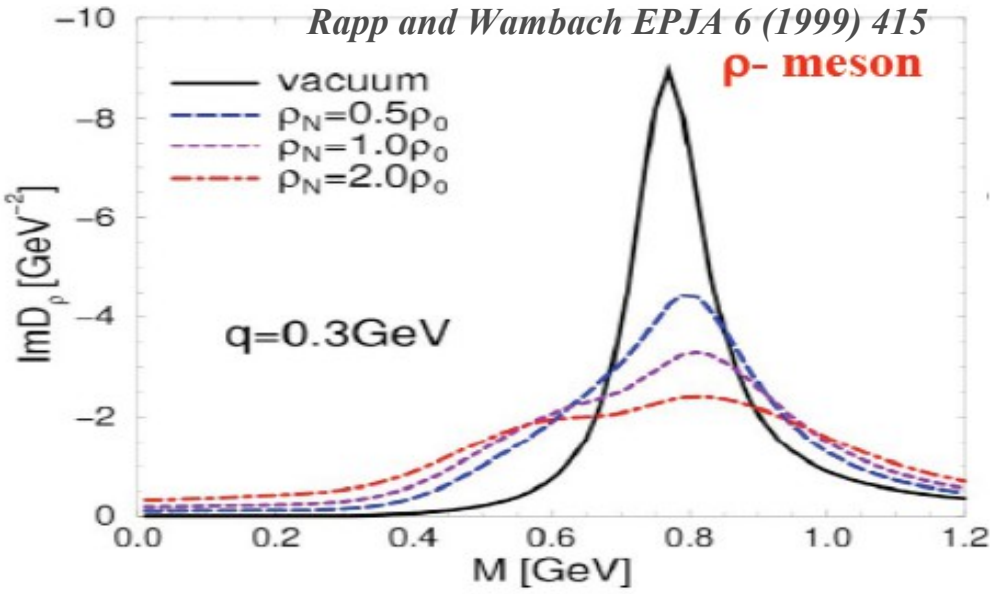
- Study in-medium vector meson via their decay in e^+e^- in the 1-2 AGeV energy range

Modification of spectral functions of vector mesons (ρ,ω,ϕ)



probes the medium
without strong interaction



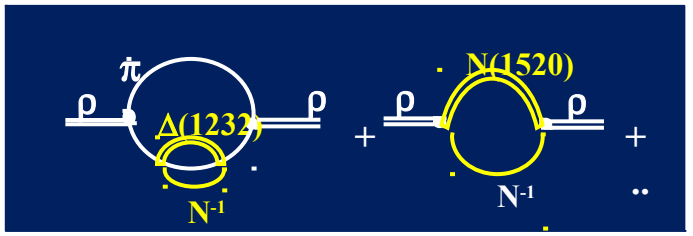


Coupling of vector mesons to baryonic resonances is driving in-medium modifications

- Elementary reactions:

✓ Reference for medium effects

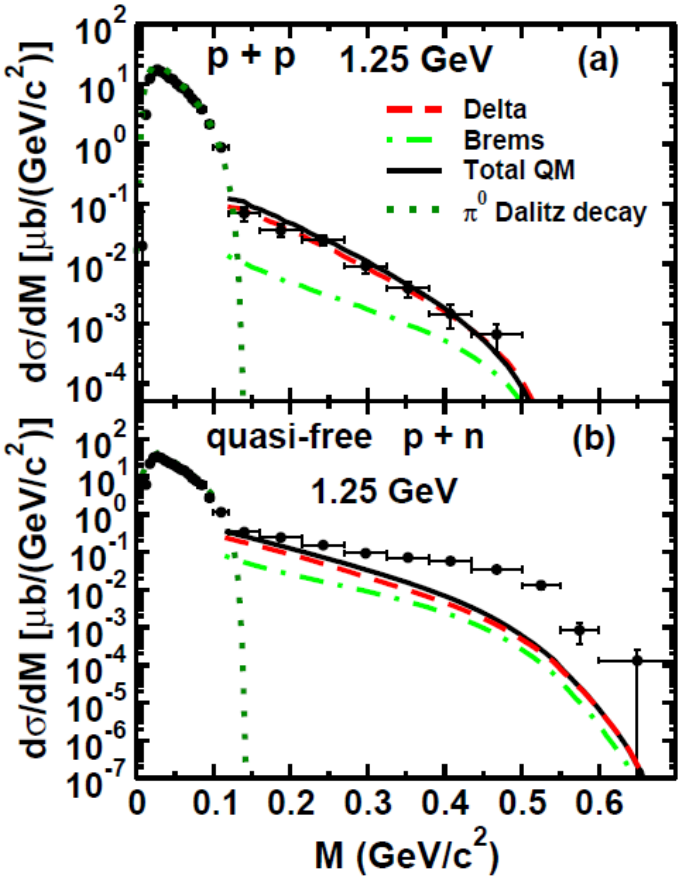
✓Do we understand e^+e^- elementary sources in N+N at 1-2 GeV ?



Motivation - elementary reactions HADES

Results from inclusive e^+e^-:

- ✓ pp well described by one boson exchange (OBE) models
- ✓ Delta dalitz decay dominating in pp
- ✓ np data are underestimated at high M_{ee}



Motivation - elementary reactions HADES

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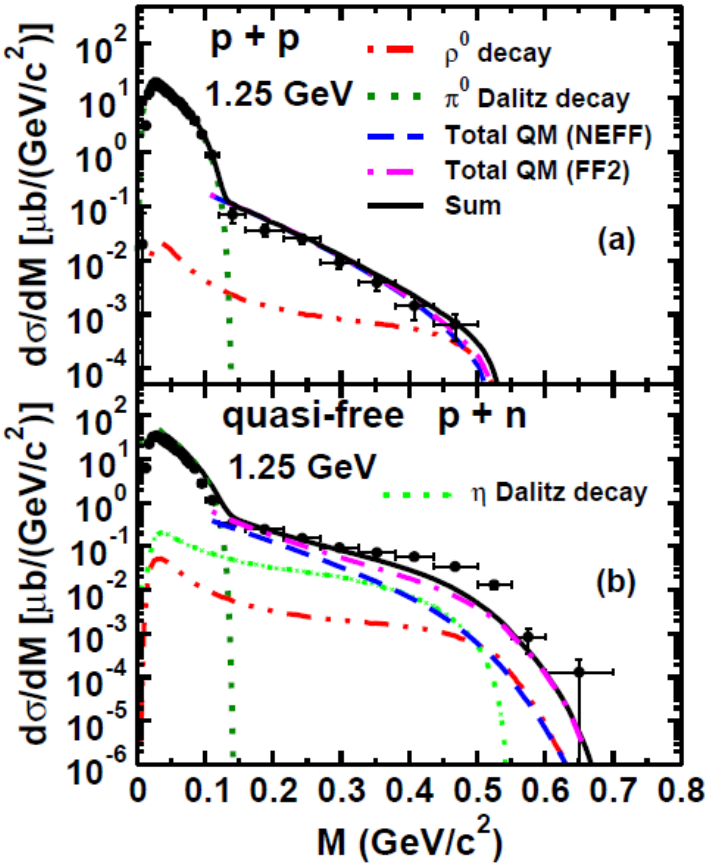
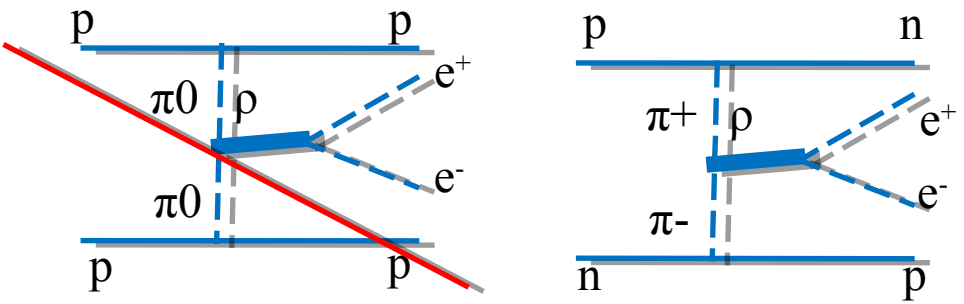


Possible explanation:
e^+e^- exces in np

off-shell ρ contribution

R. Shyam , U. Mosel, Phys.Rev. C82 (2010) 062201



Motivation - elementary reactions HADES

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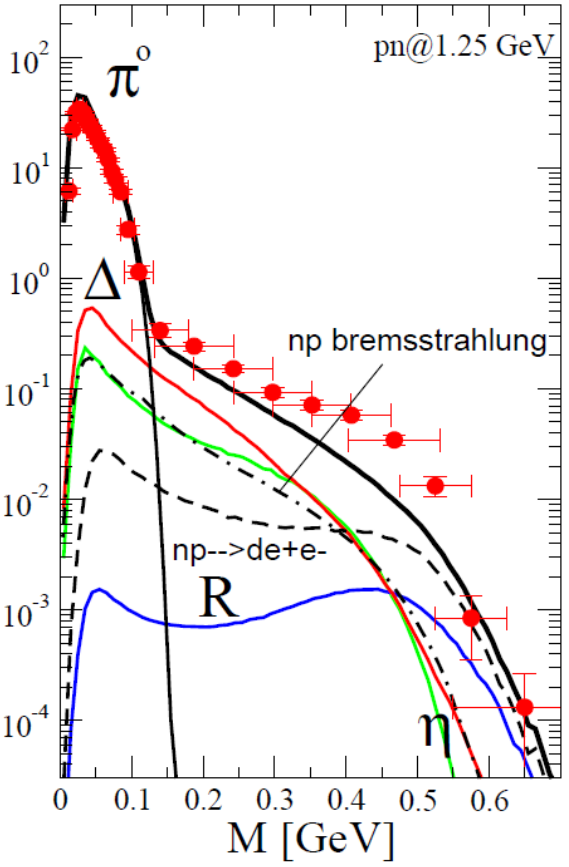


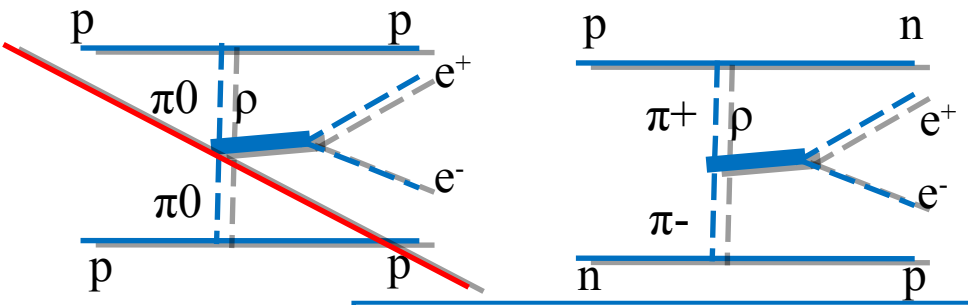
Possible explanation:
e^+e^- exces in np

off-shell ρ contribution

R. Shyam , U. Mosel, Phys.Rev. C82 (2010) 062201

$n+p \rightarrow d\ e^+e^-$

B.V. Martemyanov, et al. Phys.Rev. C84 (2011) 047601



- Can be checked by exclusive e^+e^- channels with HADES:

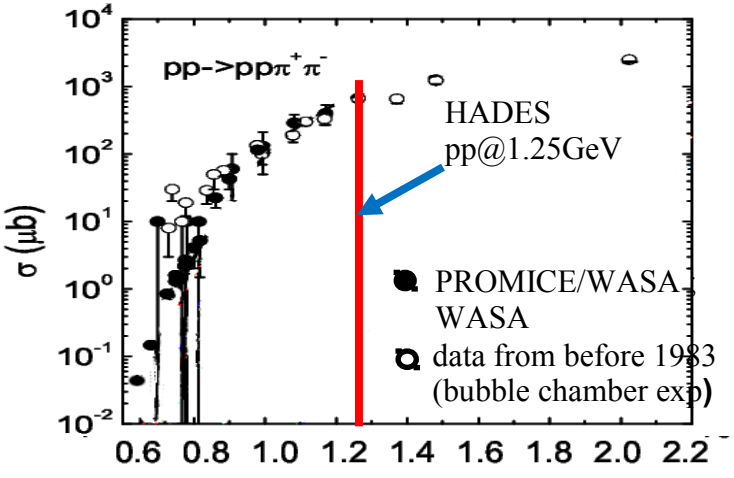
$pp \rightarrow pp\ e^+e^-$, $np \rightarrow np\ e^+e^-$, $np \rightarrow d\ e^+e^-$

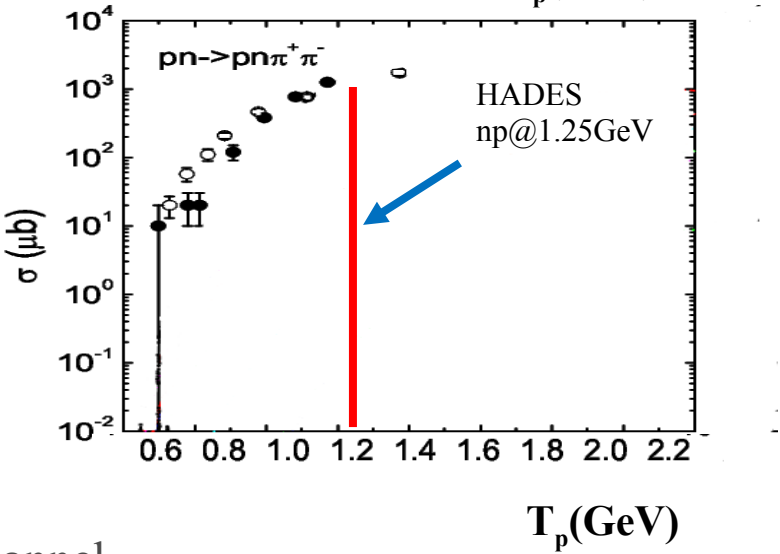
- Can be constrained by exclusive $\pi^+\pi^-$ channels with HADES:

$pp \rightarrow pp\ \pi^+\pi^-$, $np \rightarrow np\ \pi^+\pi^-$, $np \rightarrow d\ \pi^+\pi^-$

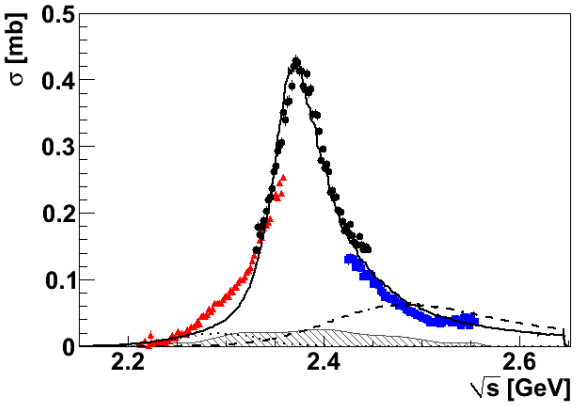
Other reasons to look into $\pi^+\pi^-$

- Specific interest in systematic study of 2-charged π channels in pp and pn
  - **$p+p \rightarrow p\ p\ \pi^+\pi^-$**
  - **$n+p \rightarrow n\ p\ \pi^+\pi^-$**
  - **$n+p \rightarrow d\ \pi^+\pi^-$**
- Main contributions
  - $N^*(1440) \rightarrow \Delta\pi$,
  - $N^*(1440) \rightarrow N\ (\pi\pi)$s-wave,
  - $\Delta\Delta$ excitation





- Investigation of possible evidence for ABC effect in $np \rightarrow d\pi^-\pi^+$ channel as seen by WASA in $np \rightarrow d\pi^0\pi^0$



Explained by di-baryon resonance
$\Gamma \approx 70\ MeV \ll 2*\Gamma_\Delta$
$M \approx 2380\ MeV = 2*M_\Delta - 80\ MeV$

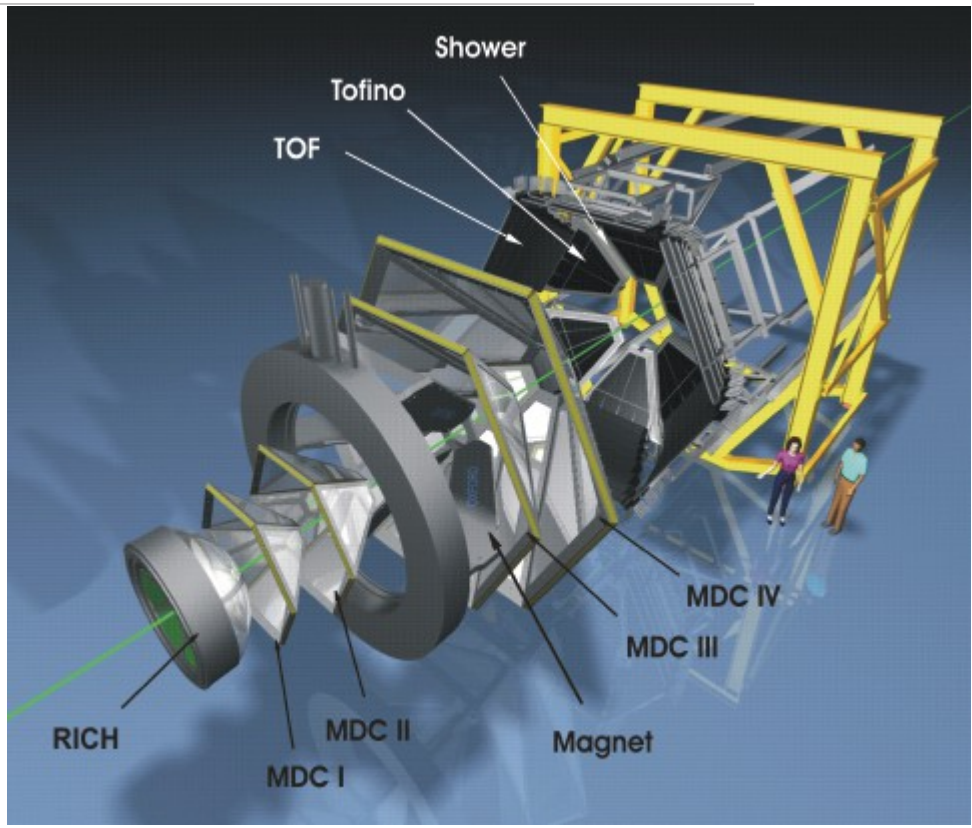
The HADES spectometer

• **Detector geometry**
full azimuthal range covered, 6 sectors
polar angle: $16^{o}<\theta<84^{o}$

•**Tracking**
Superconducting coils, toroidal field
24 Mini Drift Chambers

•**Particle identification (e, p, K, p)**
RICH, MDC, TOF, TOFINO, Shower (RPC)

•**Resolutions**
$\Delta M\omega/M\omega \sim 2.1\%$ at ω peak
$\Delta p/p \sim 2\text{-}3\%$ for proton and π



The HADES spectometer –Forward WAll

• **Detector geometry**
full azimuthal range covered, 6 sectors
polar angle: $16^o<\theta<84^o$

•**Tracking**
Superconducting coils, toroidal field
24 Mini Drift Chambers

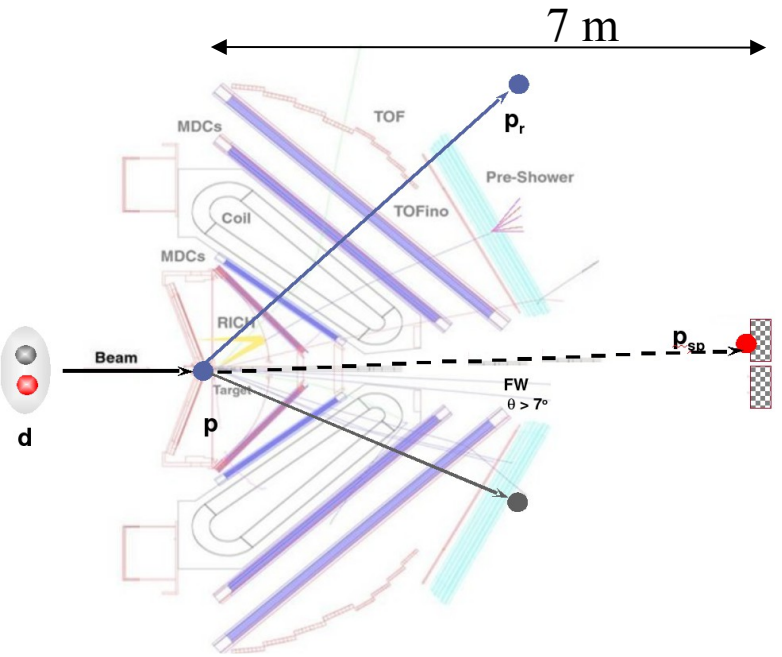
•**Particle identification (e, p, K, p)**
RICH, MDC, TOF, TOFINO, Shower (RPC)

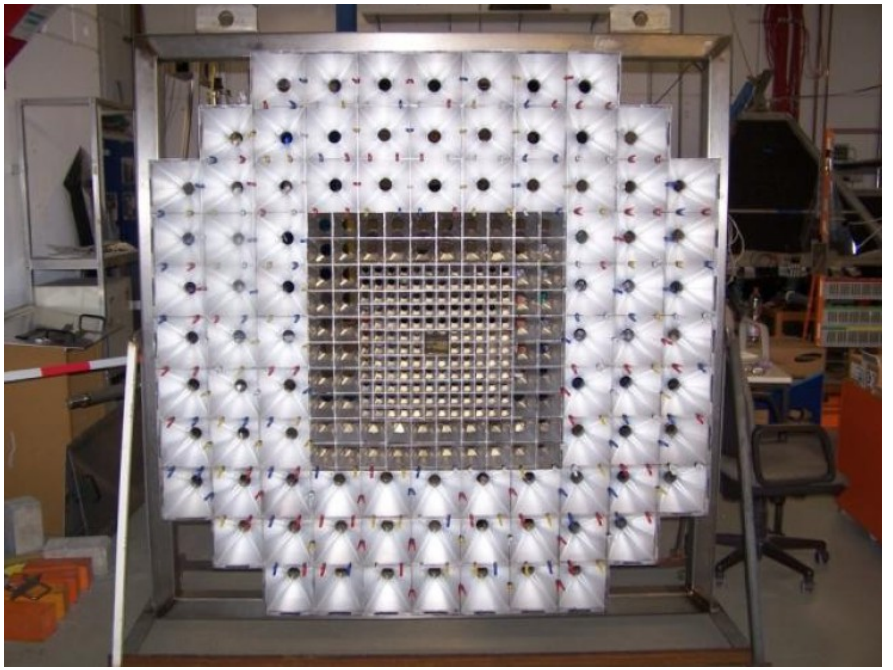
•**Resolutions**
$\Delta M\omega/M\omega \sim 2.1\%$ at ω peak
$\Delta p/p \sim 2$-3% for proton and π

• **Forward Wall:**
Plastic scintillators covering θ angles up to 7^o
Detector dedicated to tag proton spectator

• **Cells in FW:**
140 small 4x4cm → $(0^o< \theta <2^o)$
64 middle 8x8cm → $(2^o < \theta <3.3^o)$
84 large 16x16cm → $(3.3^o < \theta <7.2^o)$

**Designed for di-electron spectroscopy,
also suited for the charged hadron detection**



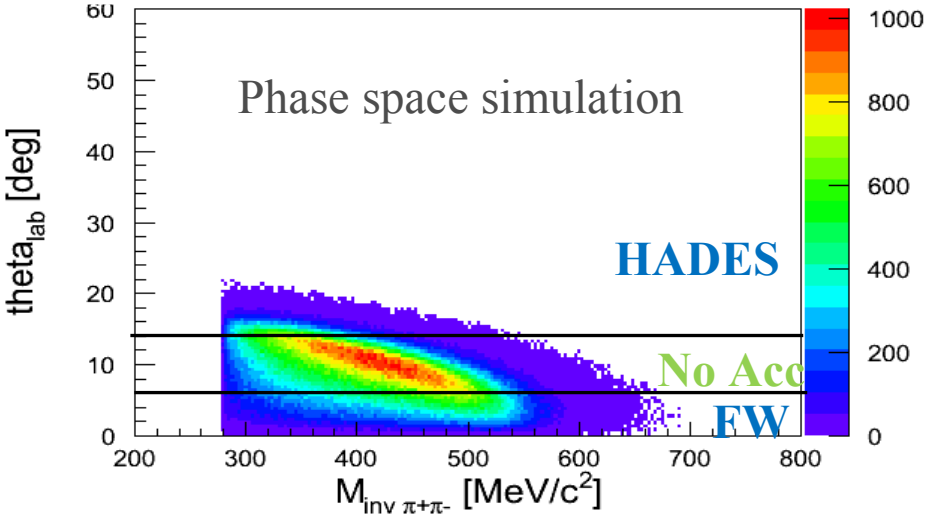


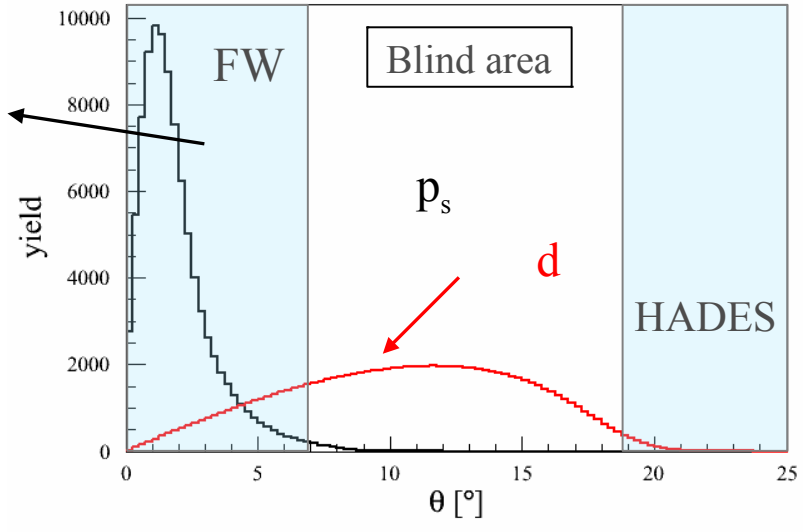
HADES acceptance for exclusive channels

All particles in HADES:

- n+p →**n** p $e^+ e^-$
- p+p →**p** p $e^+ e^-$
- n+p →d $e^+ e^-$
- n+p →n p $\pi^+ \pi^-$
- p+p →p p $\pi^+ \pi^-$
- n+p →d $\pi^+ \pi^-$

$$d(n+p_s) + p \rightarrow d\,\pi^+\pi^- + p_s$$

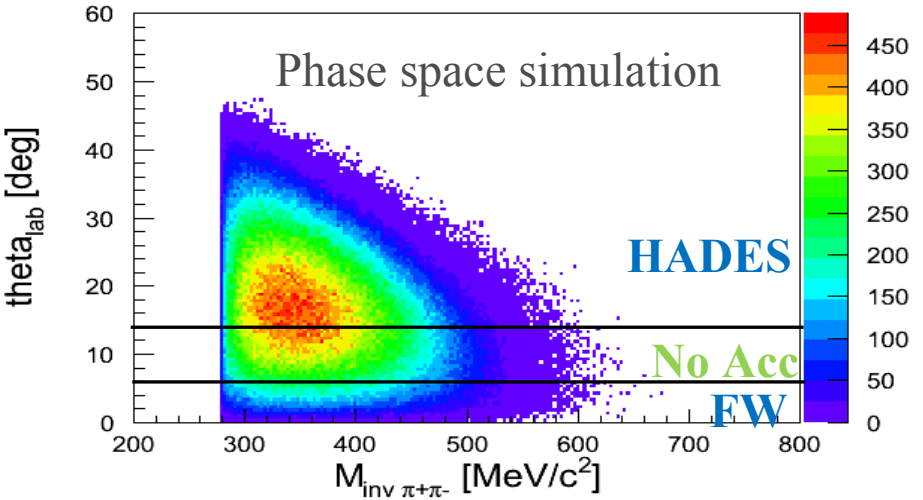


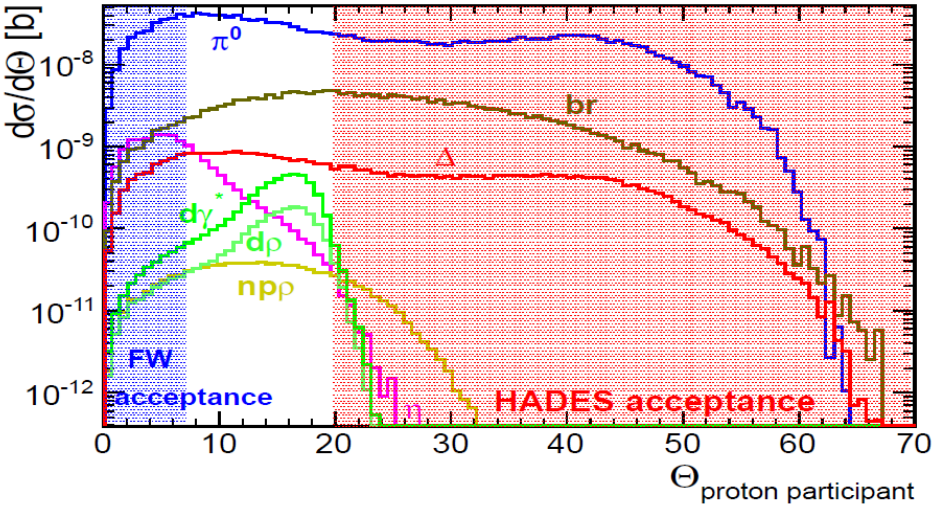


(**$e^+ e^-$ / $\pi^+ \pi^-$**) in HADES,
(**p/d**) in FW:

- n+p →**n** p $e^+ e^-$
- n+p →d $e^+ e^-$
- n+p →d $\pi^+ \pi^-$
- n+p →n p $\pi^+ \pi^-$

$$d(n+p_s) + p \rightarrow np\,\pi^+\pi^- + p_s$$

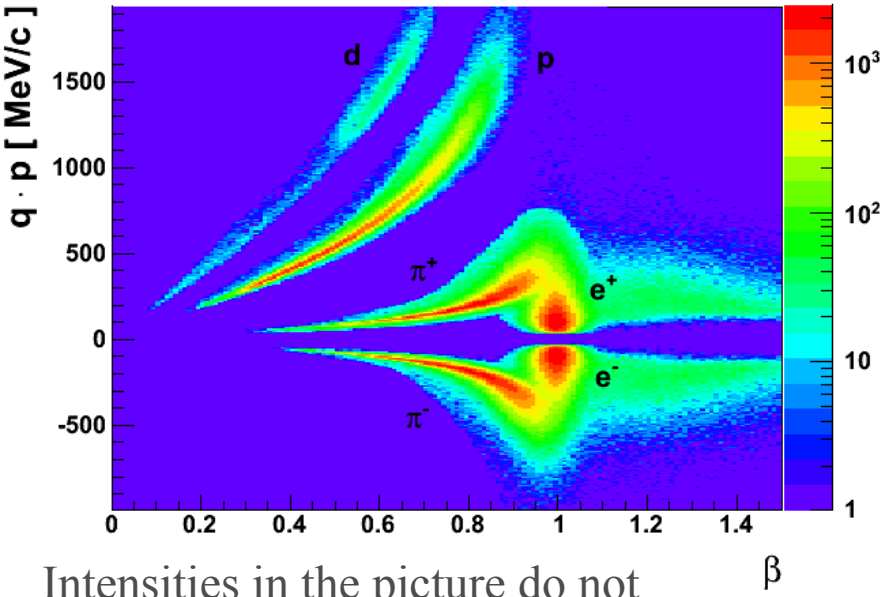




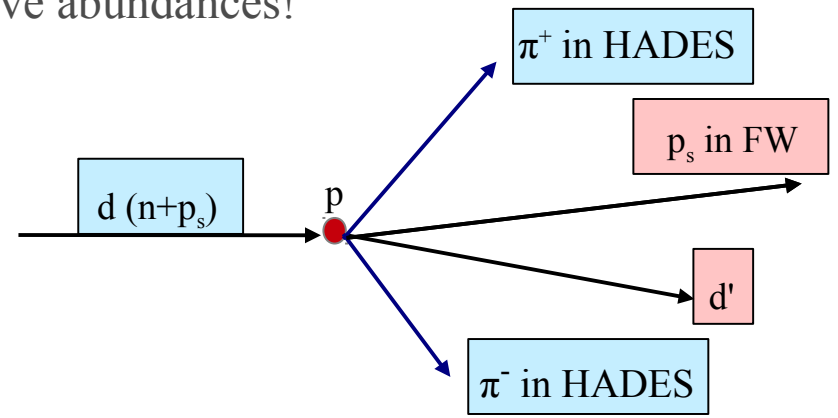
Particle identification.

PID in HADES

- Hadron: Hypothesis, Time (β) reconstruction, Tracking, graphical selection β vs p
- Lepton: Hypothesis, Time (β) reconstruction, Tracking, RICH and Shower correlation, graphical selection β vs p



Intensities in the picture do not reflect the relative abundances!

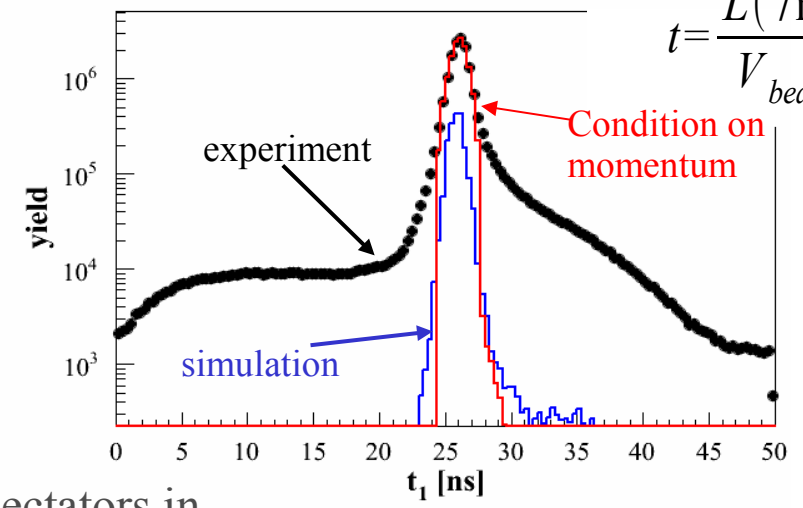


PID in Forward Wall

- Particle identification based on time of flight

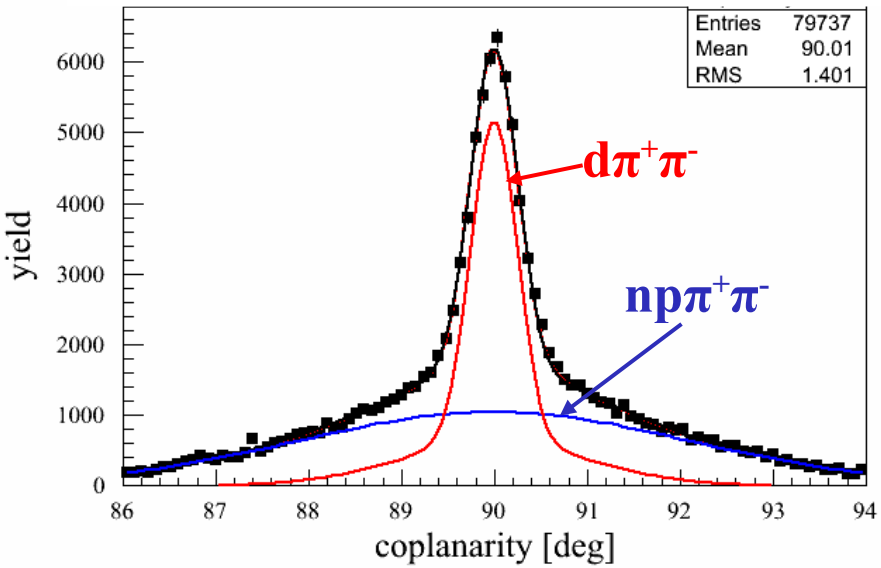
Spectator selection

$$t = \frac{L(7\text{m})}{V_{beam}} \approx 26\,ns$$



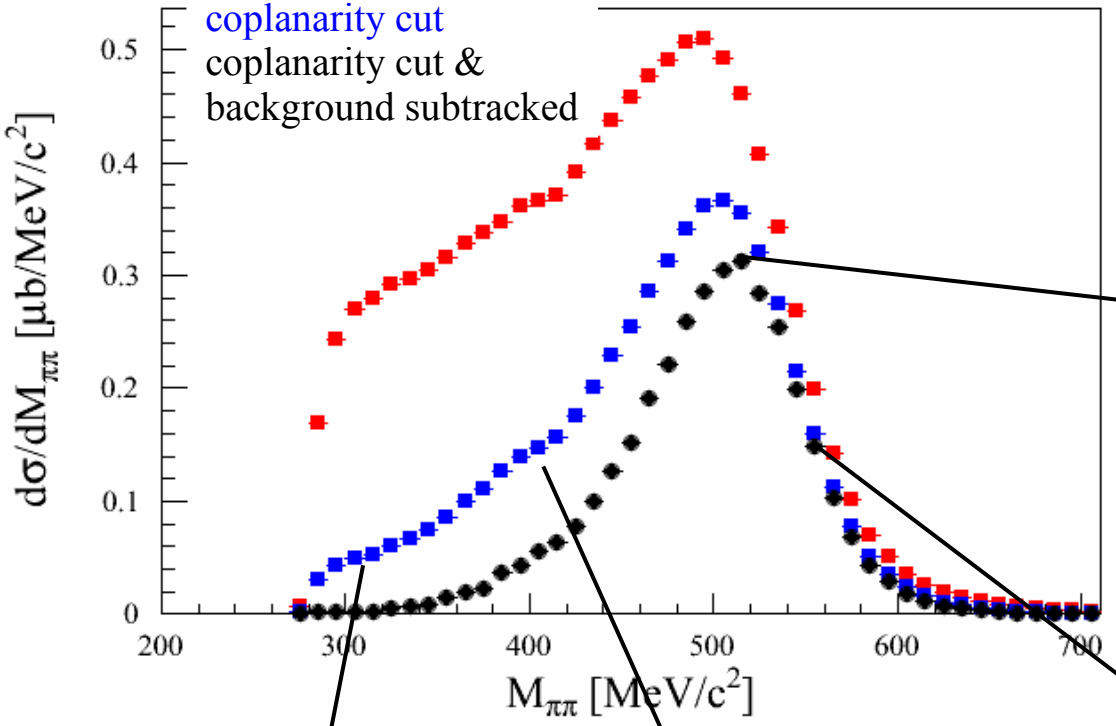
86% spectators in FWall acceptance

reaction channel separation: coplanarity



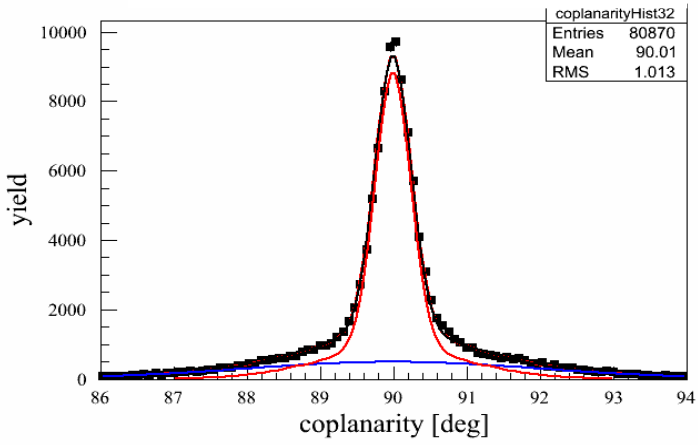
Analysis procedure for n+p->d π^+ π^- (III) : Background subtraction

full
coplanarity cut
coplanarity cut &
background subtracked

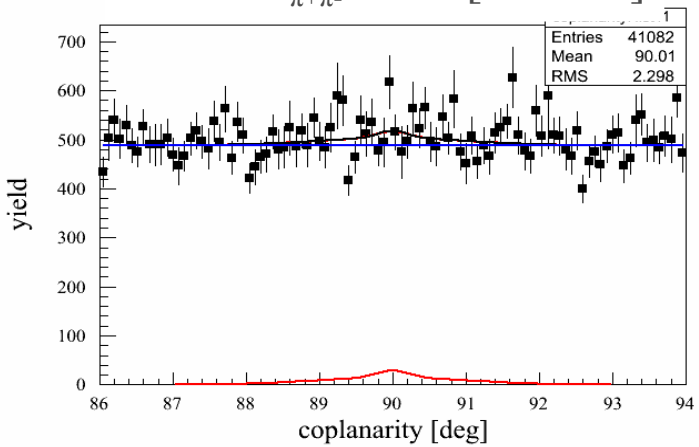


Coplanarity cut 90° ±1°

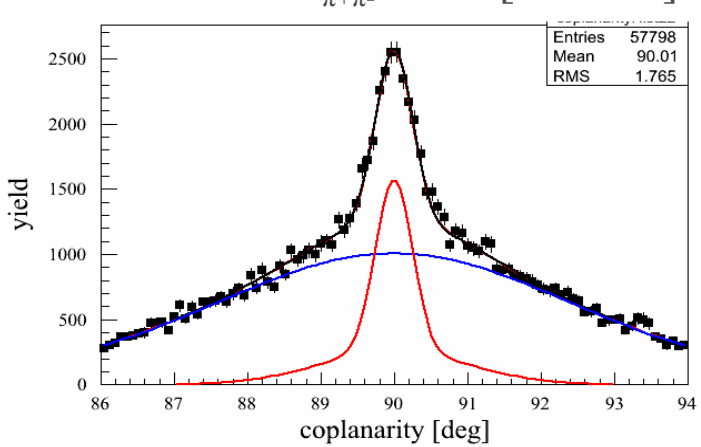
510 < M$_{π+π-}$ < 520 [MeV/c^2]



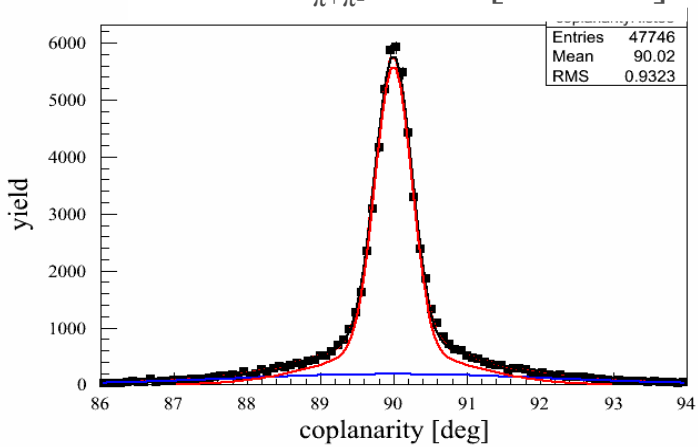
300 < M$_{π+π-}$ < 310 [MeV/c^2]



410 < M$_{π+π-}$ < 420 [MeV/c^2]

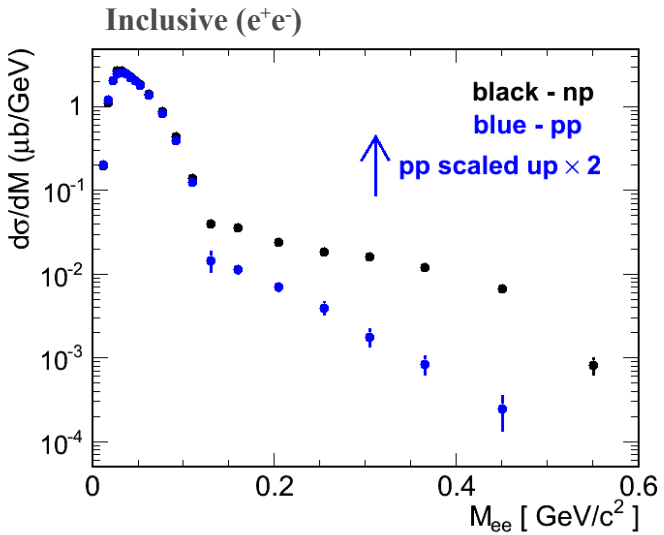


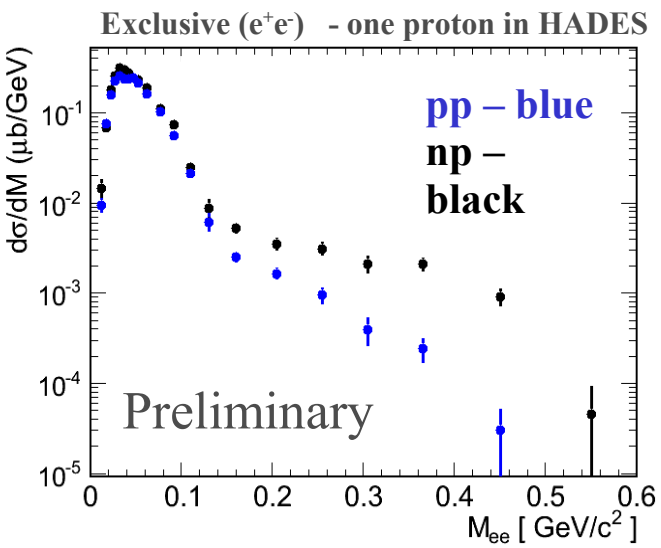
540 < M$_{π+π-}$ < 550 [MeV/c^2]



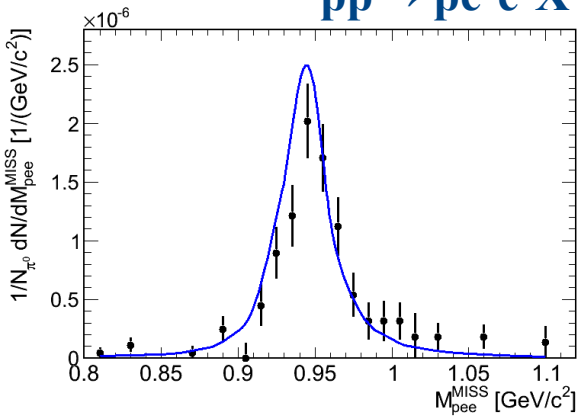
e^+e^- production in n+p & p+p @1.25GeV

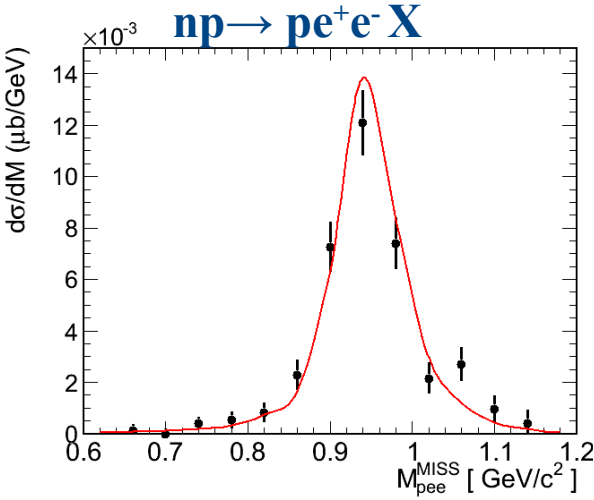
Dilepton exclusive production in pp and np@1.25GeV - HADES

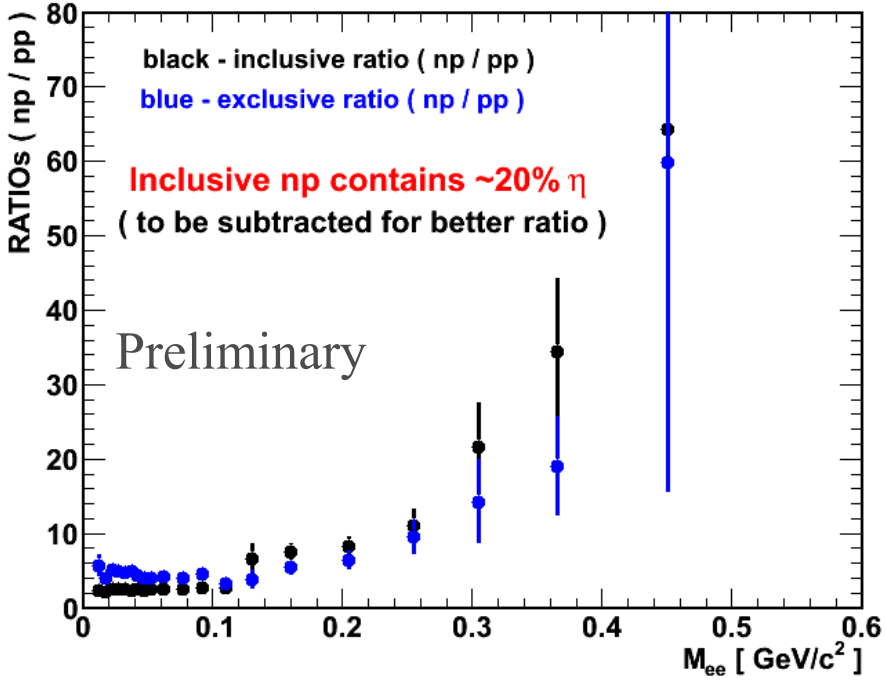




Missing mass selection







Exclusive channels

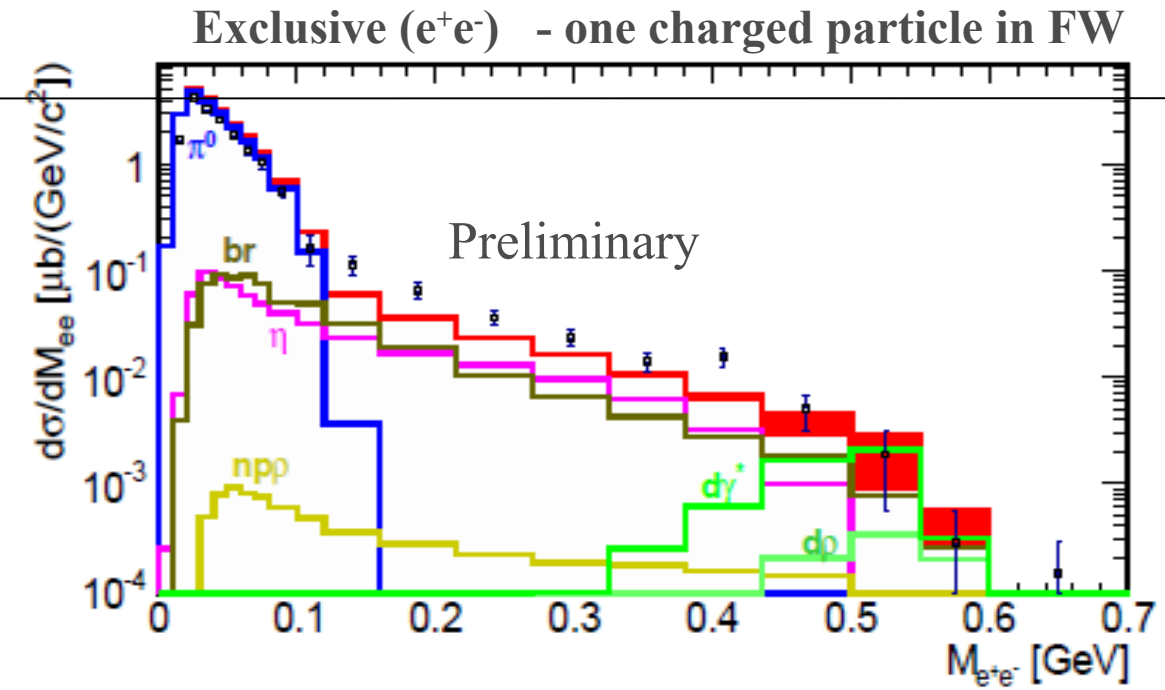
p+p →p p e^+ e^-

n+p →n p e^+ e^-

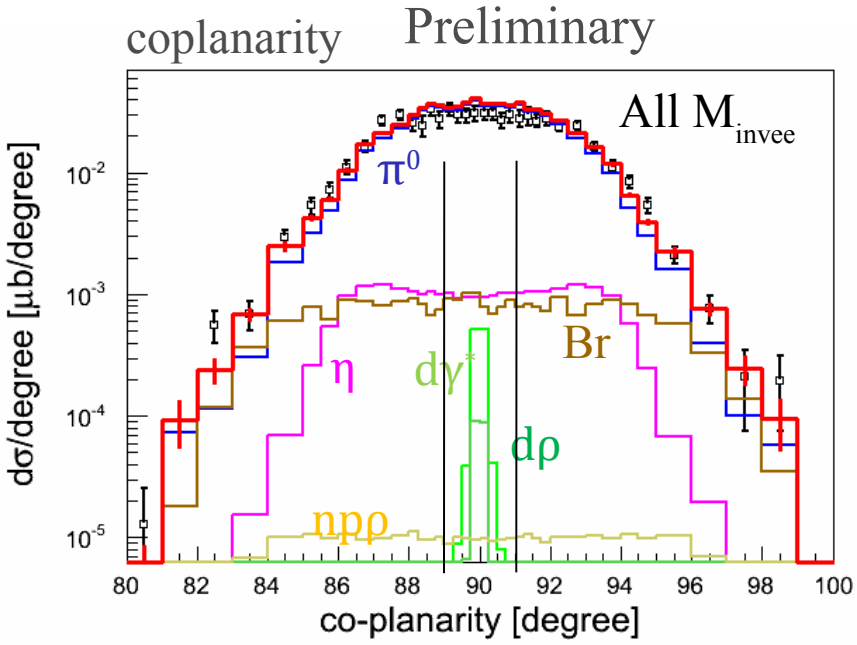
The same excess, once eta is removed in inclusive and exclusive channels. Excess is related to np → npe⁺e⁻

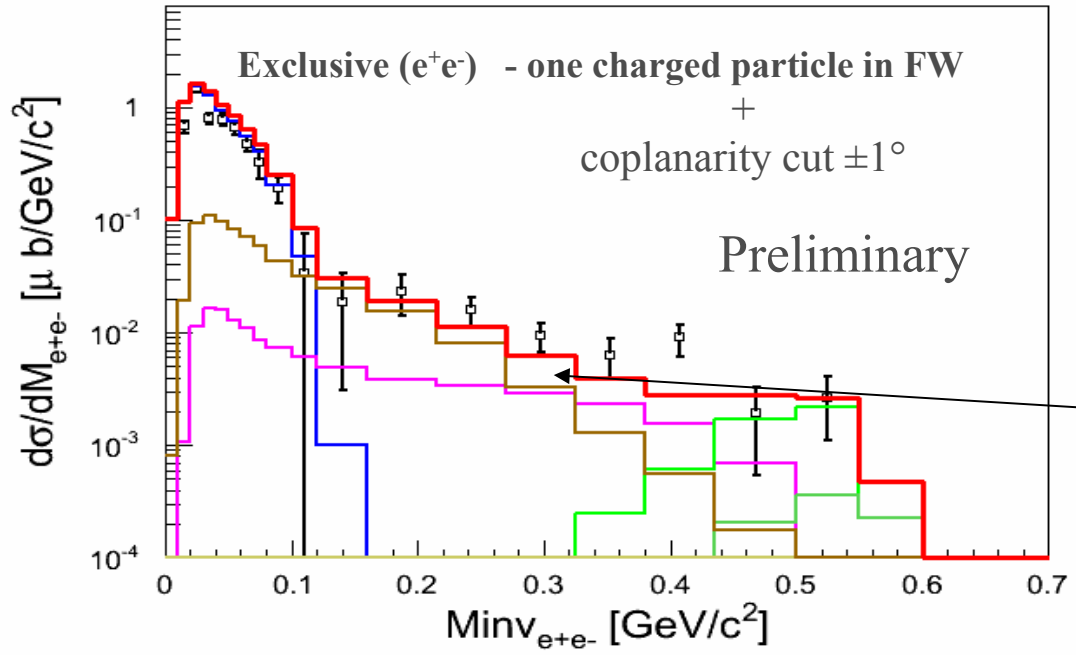
Difference should be seen in $\pi^+\pi^-$ production! if related to ρ production

Dilepton exclusive production in np@1.25GeV – Forward Wall



Excess reduced due to enhancement of η contribution (acceptance effect)





Applying **Feldman-Cousins** method to coplanarity, Upper limit for cross section of channels with deuteron in final state can be estimated

Yield at high invariant mass well explained by de+e- model (B.V. Martemyanov, et al.)

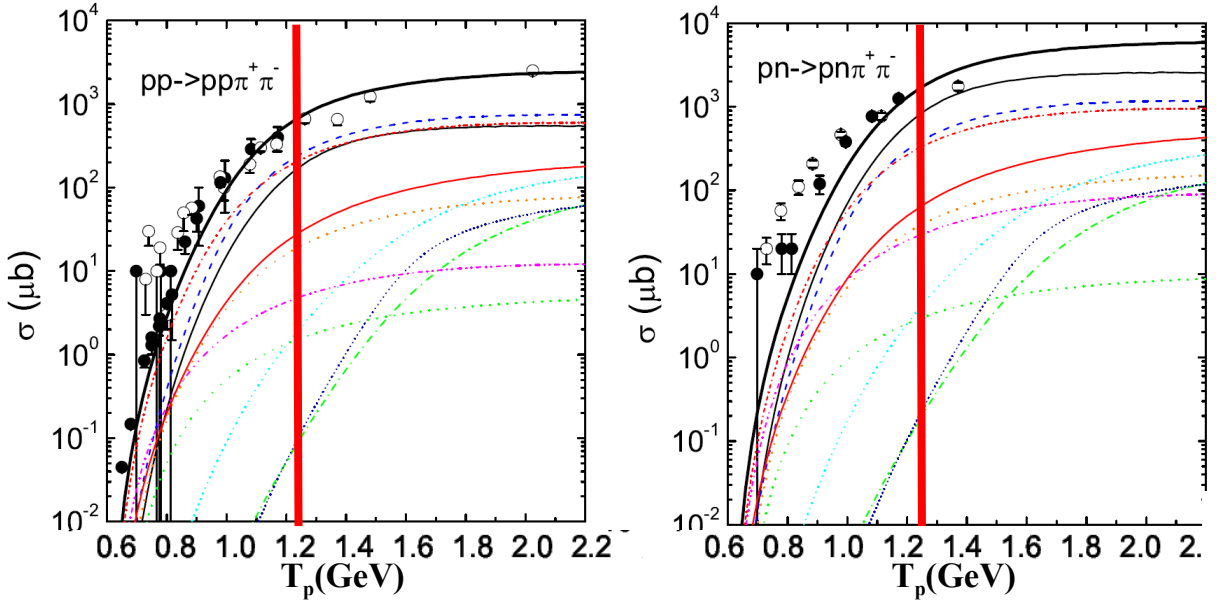
$$n + p \rightarrow n p \, \pi^{+} \pi^{-}$$

&

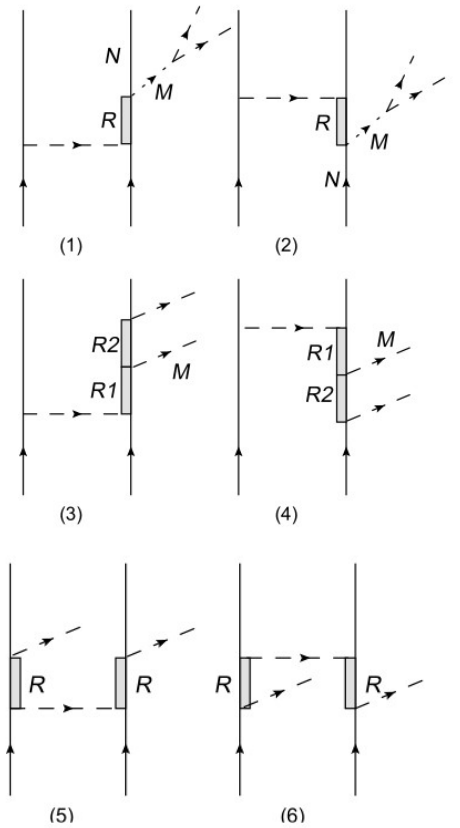
$$p + p \rightarrow p p \, \pi^{+} \pi^{-}$$

Existing experimental data and theoretical models

Xu Cao et al. Phys Rev C81, 065201 (2010)



Existing models for the NN→NNππ reactions



Main contributions at HADES energies:

N*(1440) -> Nσ

N*(1440) -> Δπ

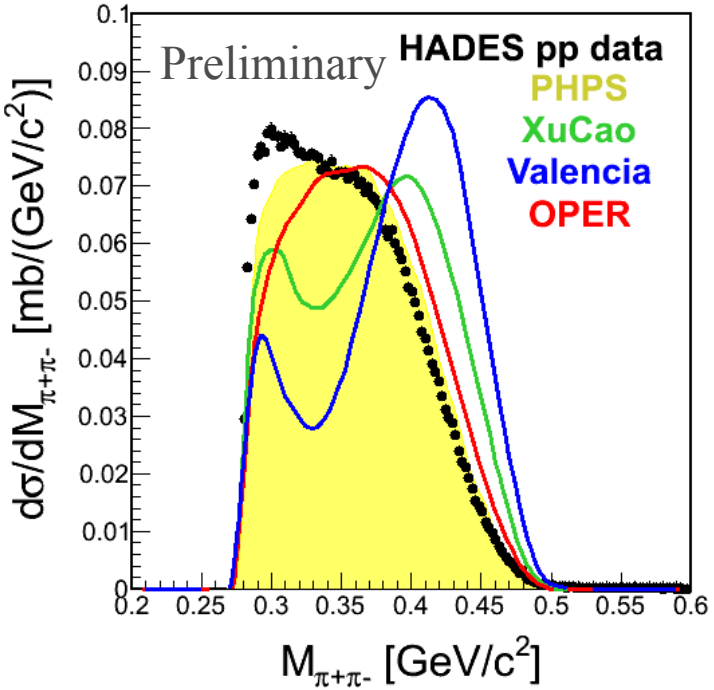
double-Δ

- **OPER, OPER-2 models :** *A. Jerusalimov, arXiv:1203.3330 [nucl-th] , arXiv:1208.3982[nucl-ex]*
  (reggeized π exchange model, includes one pion + one baryon exchange diagrams, all possible resonances)
- **Valencia model :** *L. Alvarez-Ruso, E. Oset et al. Nucl. Phys. A 633 (1998) 519-543*
  (Effective lagrangian model, interference between diagrams, N*(1440), Δ(1232))
- **XuCao model :** *Xu Cao et al. Phys Rev C81, 065201 (2010)*
  (Effective lagrangian model with less number of diagrams, no interference, resonances up to 1.72 GeV)
- **modified Valencia model :** *T. Skorodko*, et al., *Physics Letters B 679 (2009)30, Phys.Lett.B695:115-123,2011*
  (Modification of the partial decay width between the decay N → Nσ via Δ and direct, Strength of N*(1440), ρ exchange in double Δ excitation was suppressed by factor of 12)*

Other double-π results from HADES

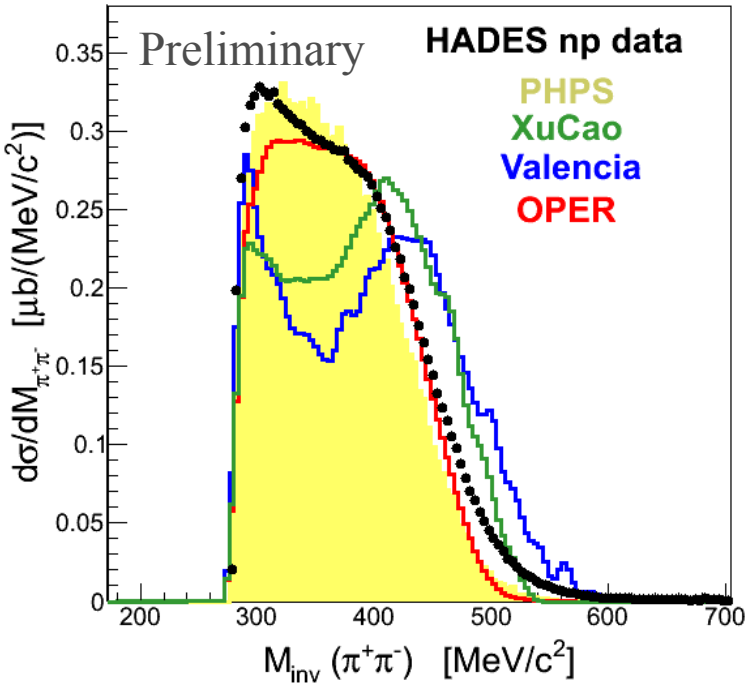
$pp \rightarrow pp\pi^+\pi^-$

M. Gumberidze (TU Darmstadt)



$np \rightarrow np\pi^+\pi^-$

A. Kurilkin (Dubna)

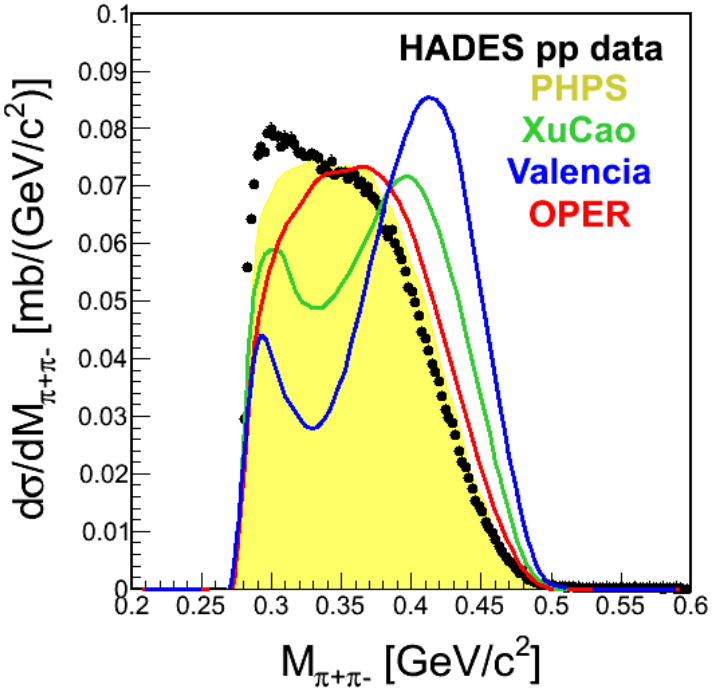


- Models normalized to area of experimental yield.
- Data shows sensitivity to different inputs of the models.
- None of the models is able to explain experimental data
- Investigations with modified models is ongoing

Other double-π results from HADES

$pp \rightarrow pp\pi^+\pi^-$

M. Gumberidze (TU Darmstadt)



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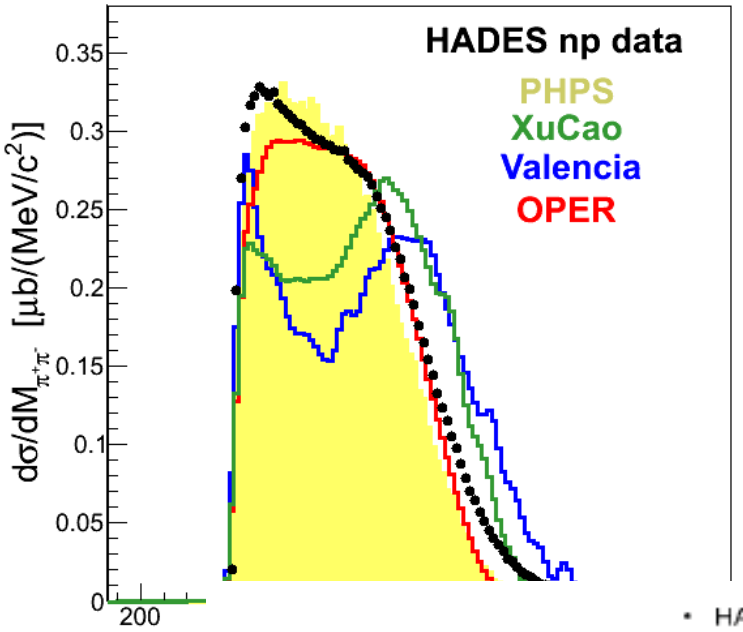

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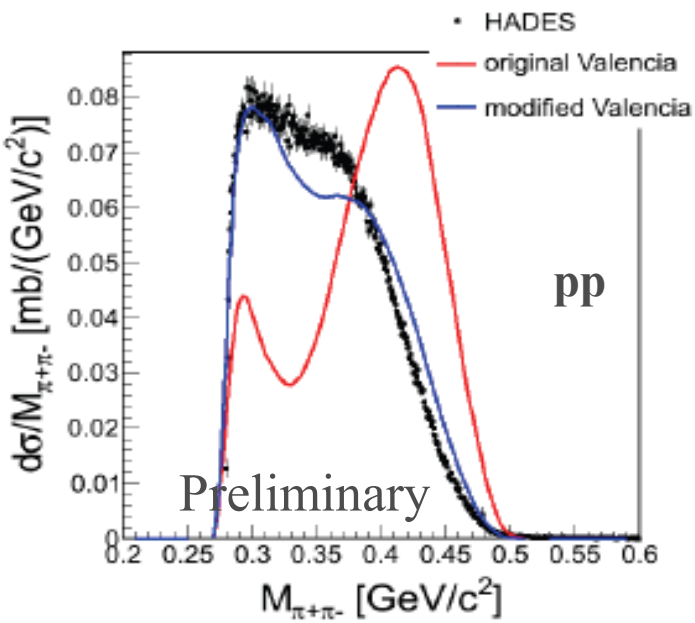
- Data shows sensitivity to different inputs of the models.
- None of the models is able to explain experimental data
- Investigations with modified models is ongoing



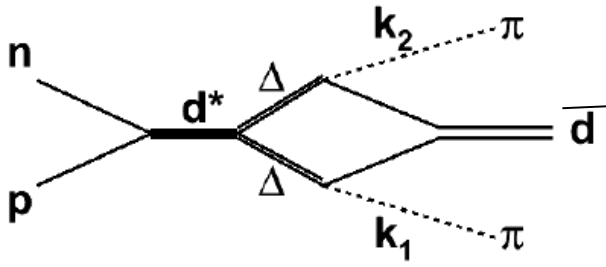
Modified model
- reduced ratio beatween Δπ/Nσ
- readjustment of strenght of the N*(1440)
- reduced ρ exchange in ΔΔ excitation

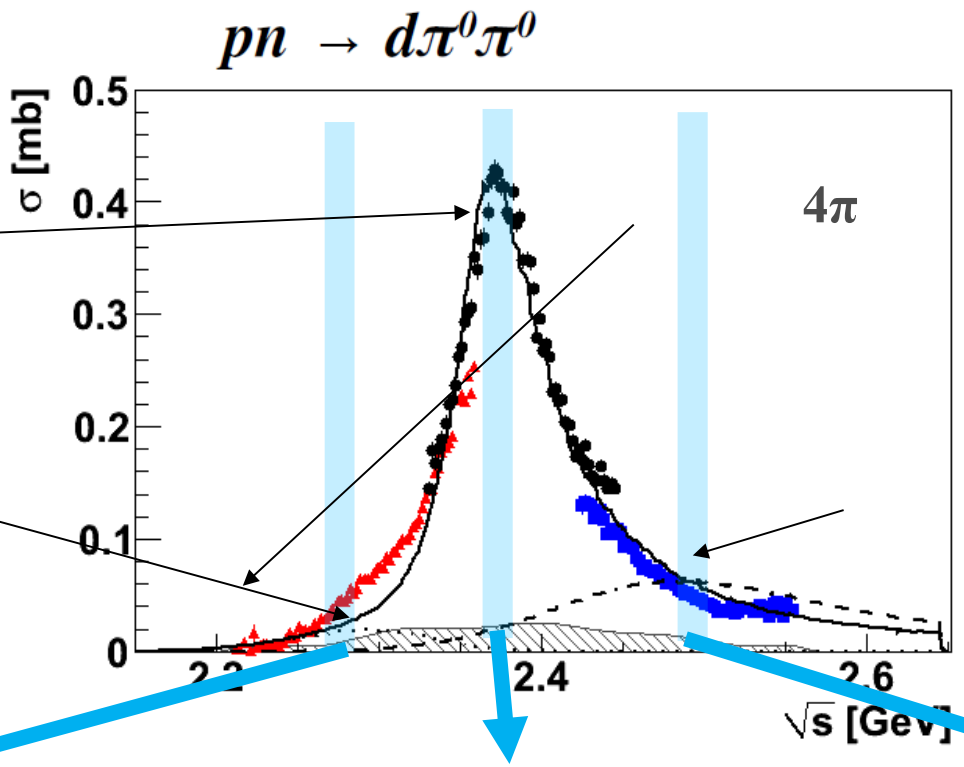
$$n + p \rightarrow d\ \pi^{+}\ \pi^{-}$$

ABC effect – presentation of Annette Pricking (WASA-at-COSY coll.) from MESON2012

di-baryon resonance model
$\Gamma \approx 70\ MeV \ll 2*\Gamma_\Delta$
$M \approx 2380\ MeV$
$= 2*M_\Delta - 80\ MeV$

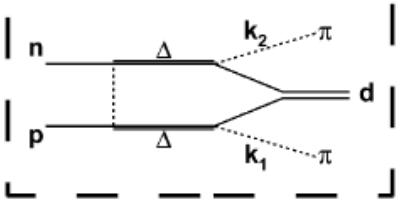
ABC Effect - (Enhancement in M$\pi\pi$) related to peak in total cross section !



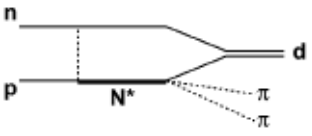


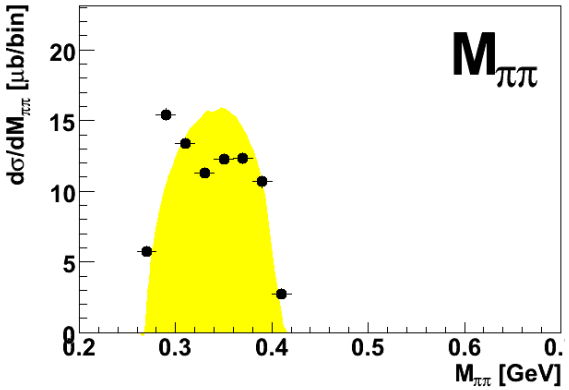
systematic uncertainties

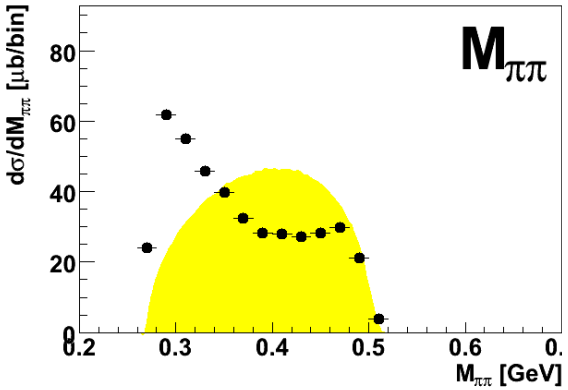
t-channel ΔΔ

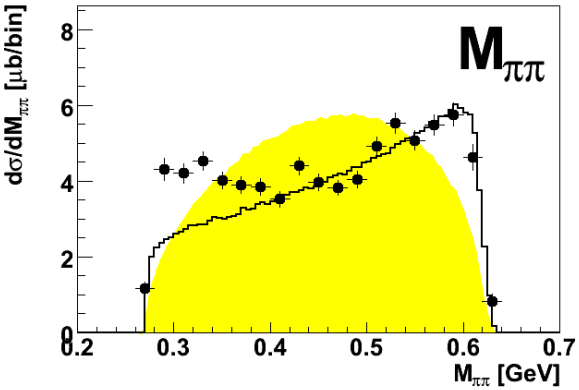


Roper excitation





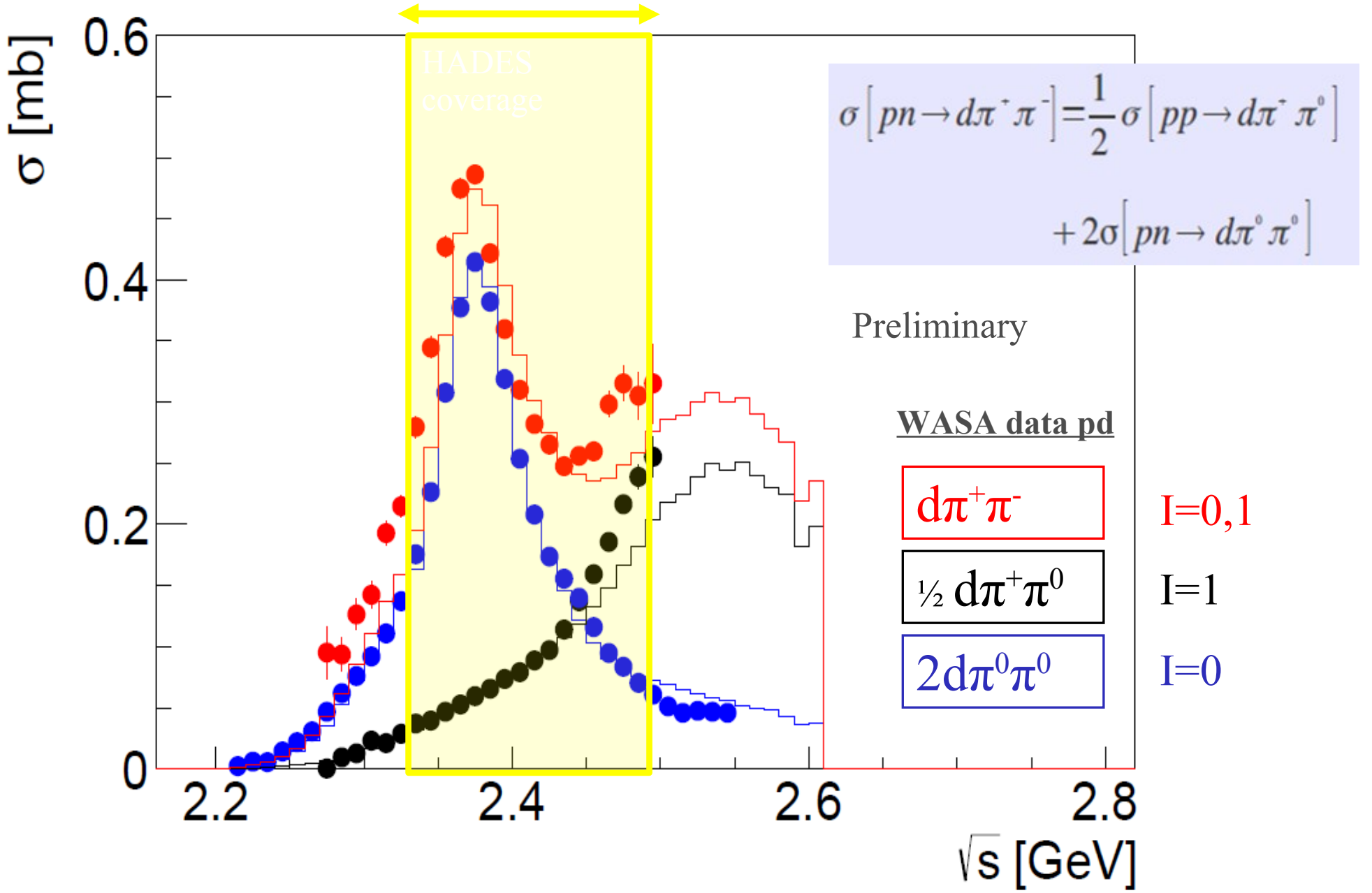




P. Adlarson et. al Phys. Rev. Lett. 106:242302, 2011

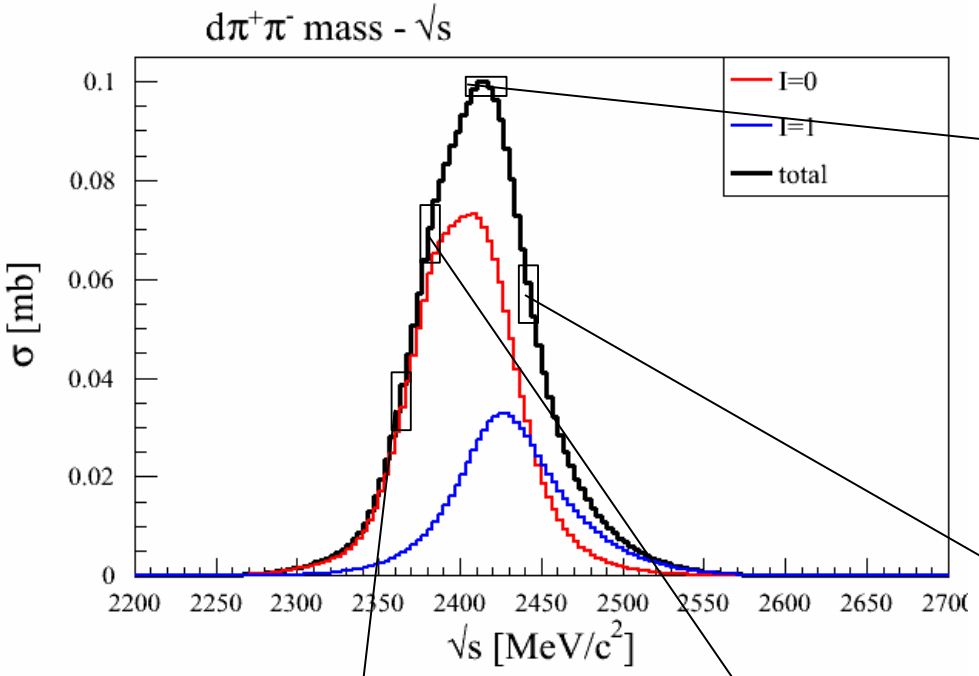
Model of the di-baryon resonance - M. Bashkanov (WASA-at-COSY coll.)

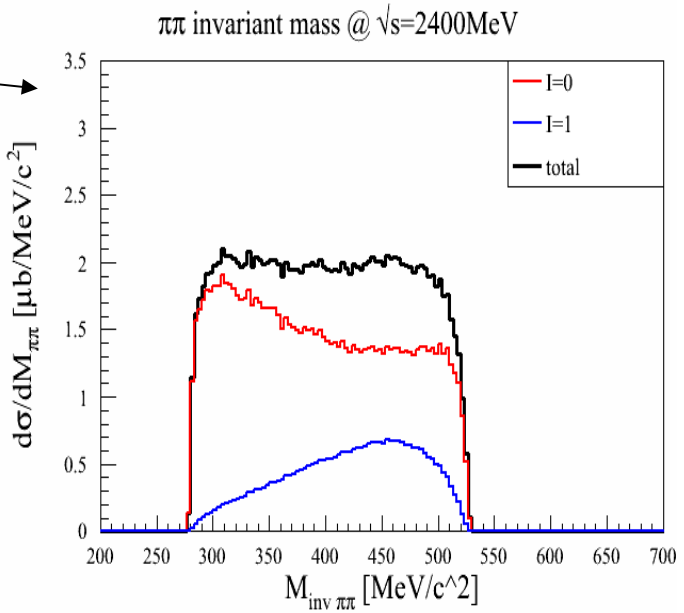
Range of √s for HADES measurement at deuton beam energy T=1.25 AGeV
(weighted by neutron momentum distribution in deuteron)

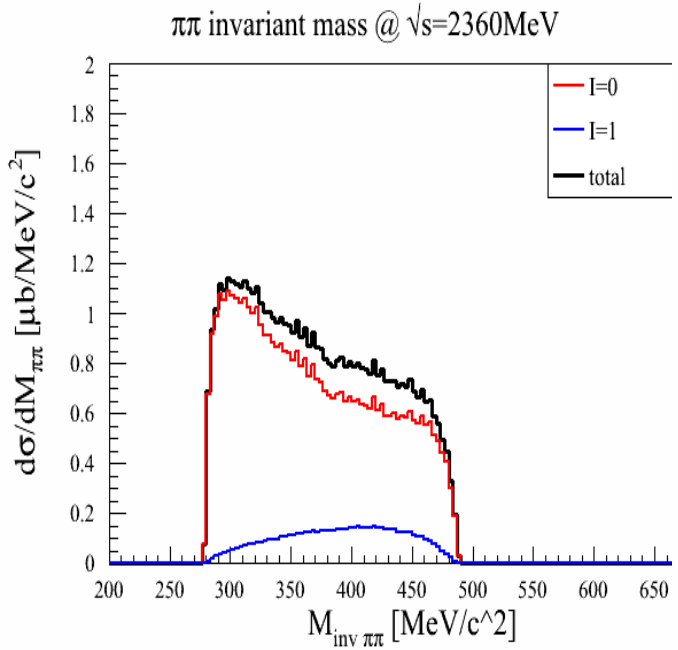


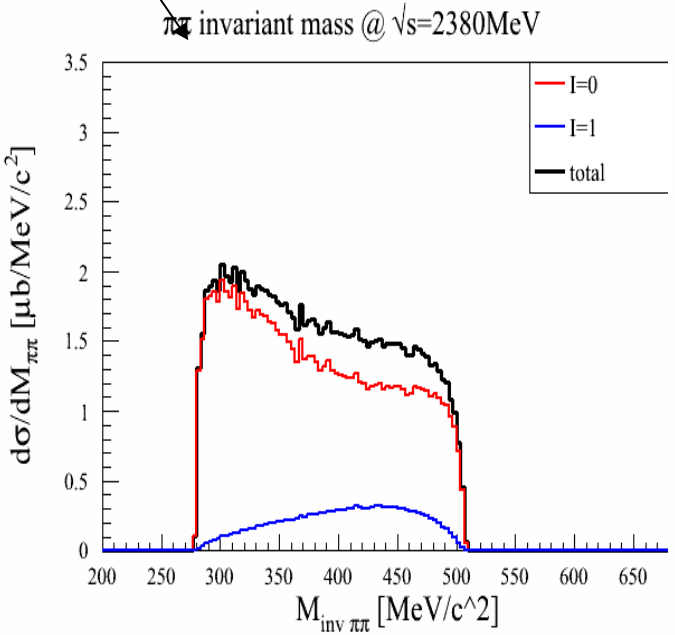
Di-pion mass changes with total energy - 4π

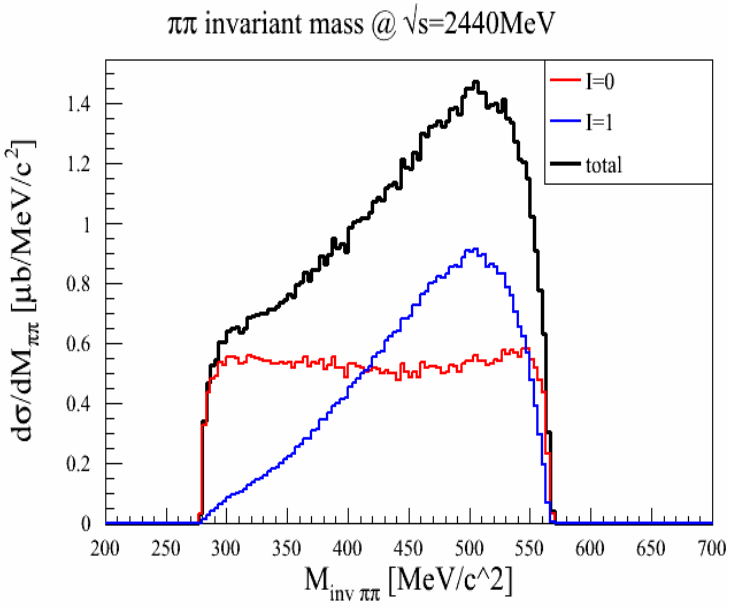
simulation



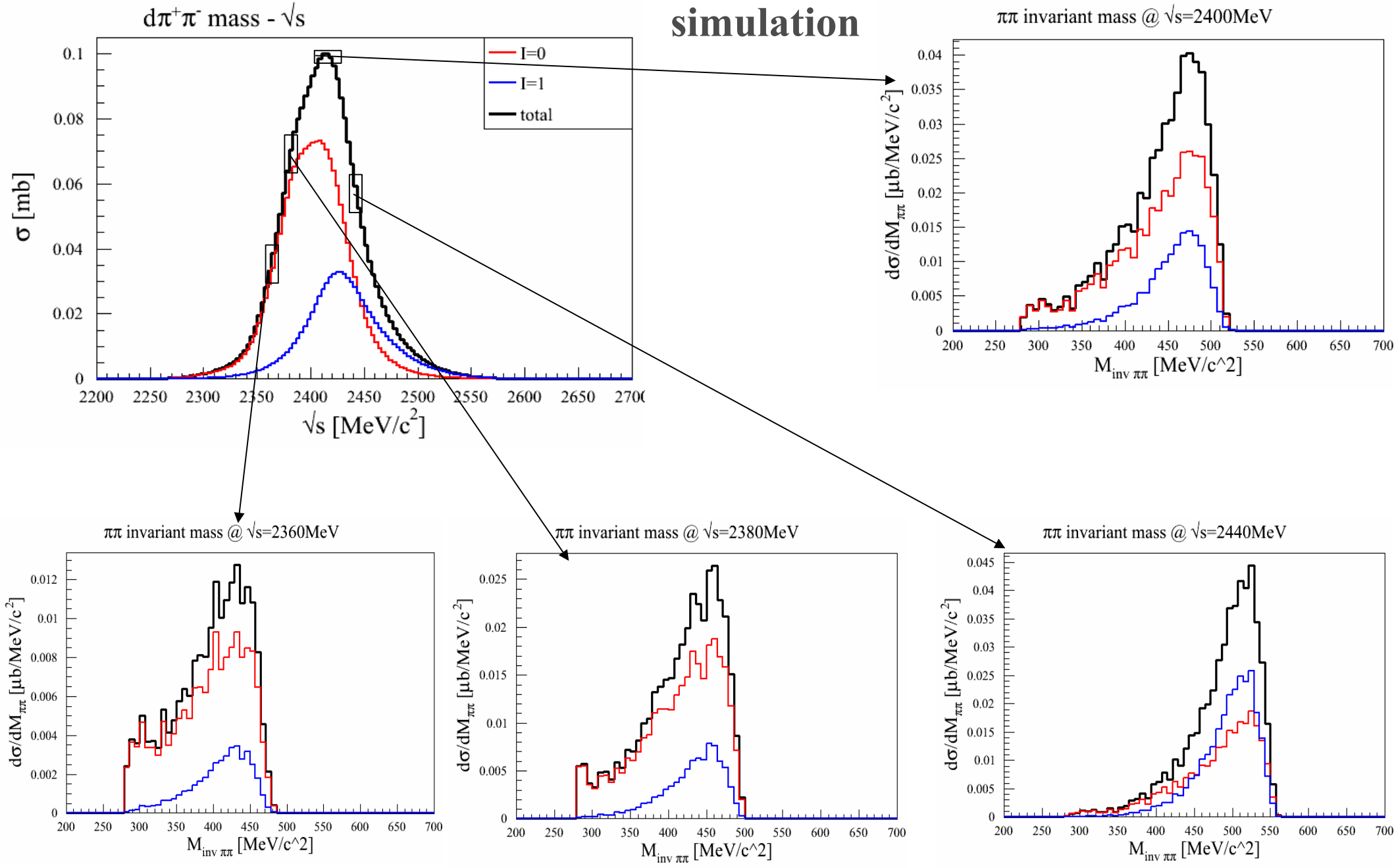






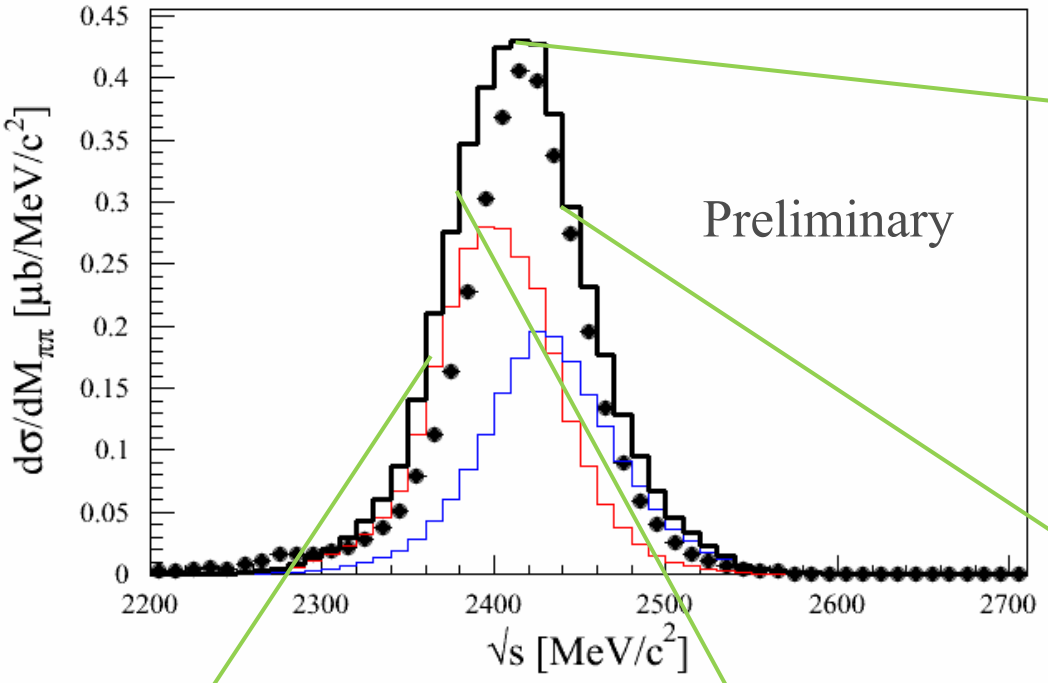


Di-pion mass changes with total energy – HADES acceptance

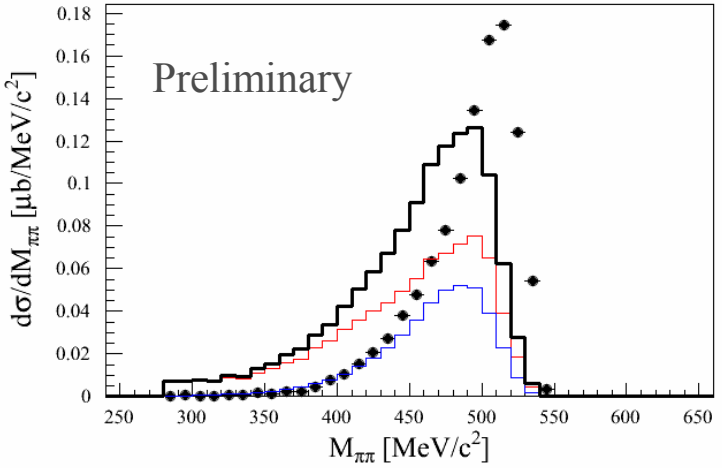


Di-pion mass changes with total energy – HADES Acceptance

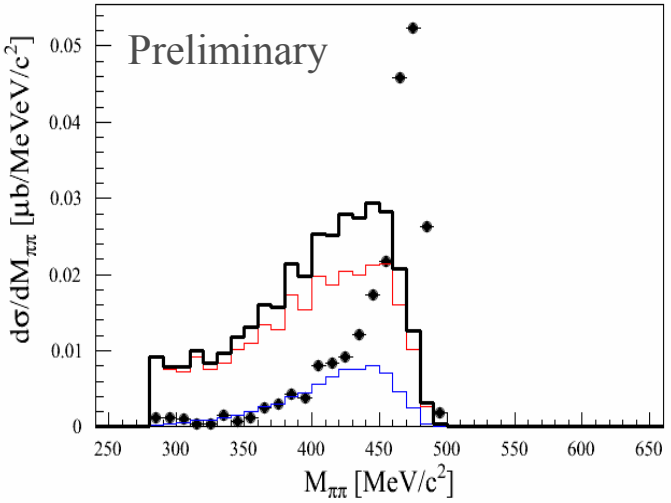
$d(n+p_s) + p \rightarrow d\,\pi^+\pi^- + p_s \qquad (\sqrt{s}=M_{inv\ d\,\pi^+\pi^-})$



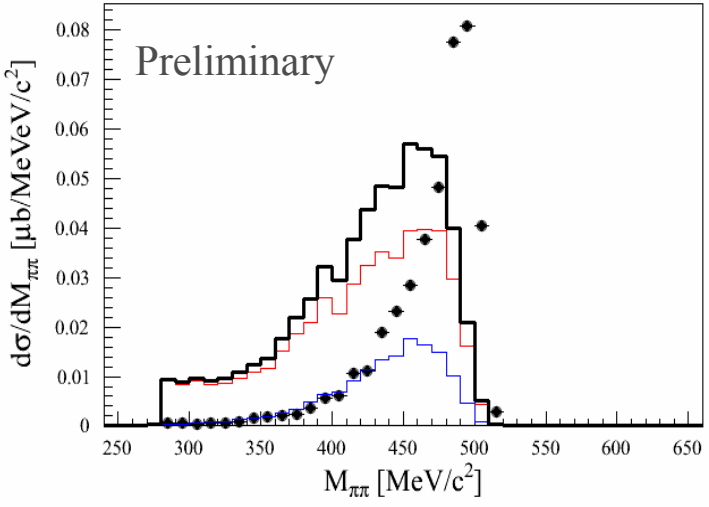
2.39<√s <2.42 [GeV/c²]



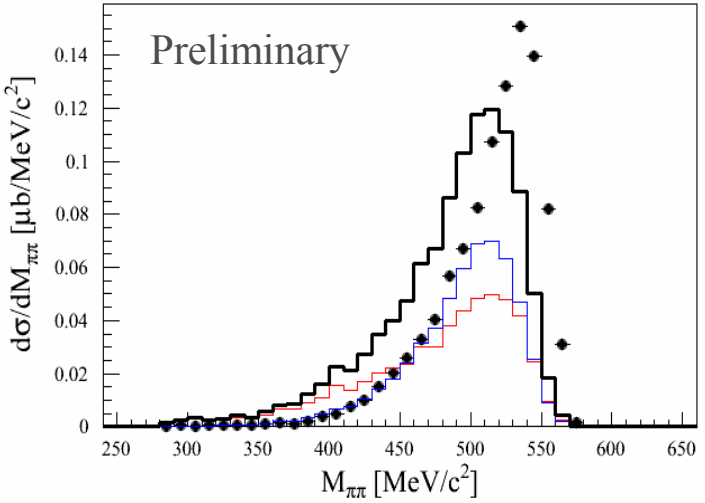
2.35<√s <2.37 [GeV/c²]



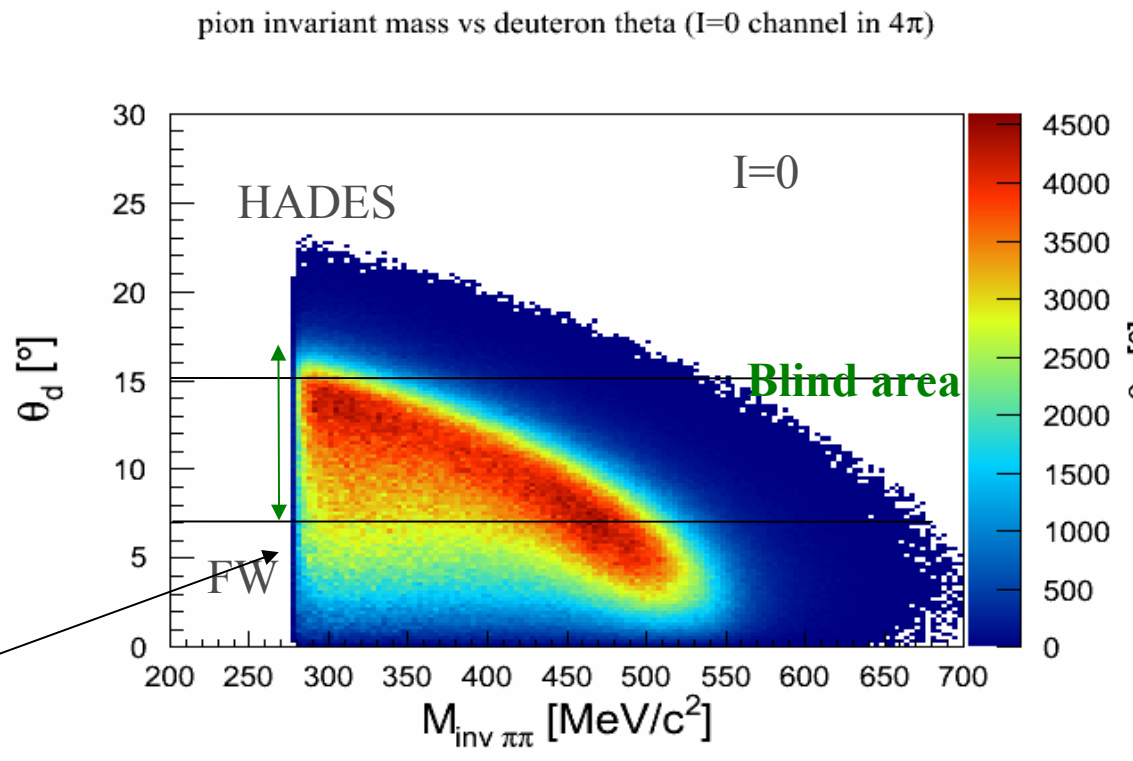
2.37<√s <2.39 [GeV/c²]

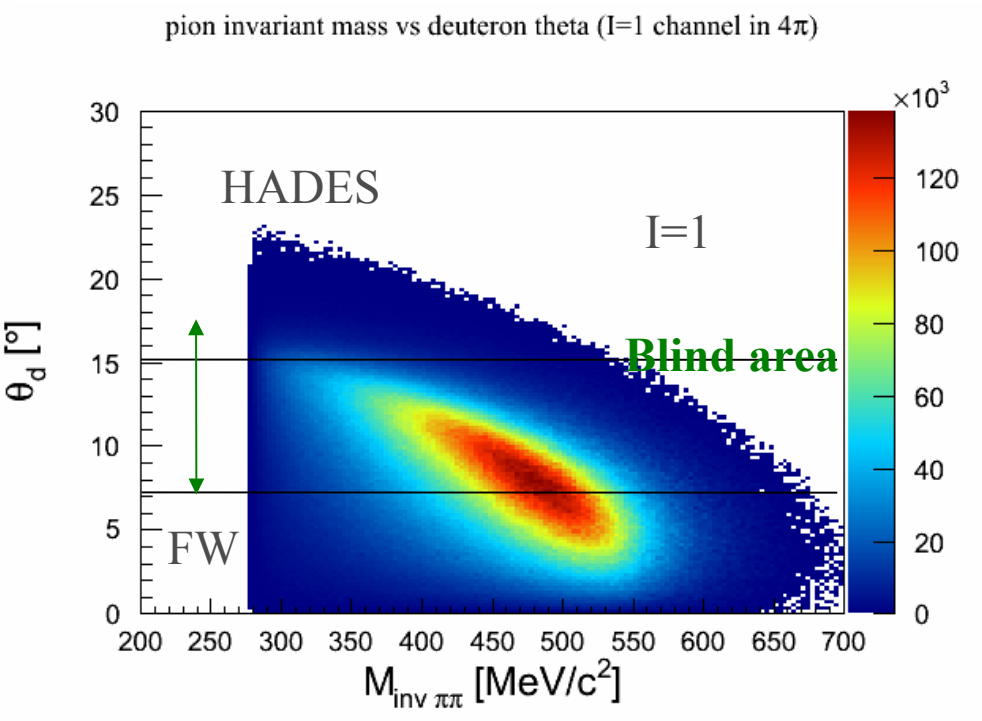


2.42<√s <2.45 [GeV/c²]



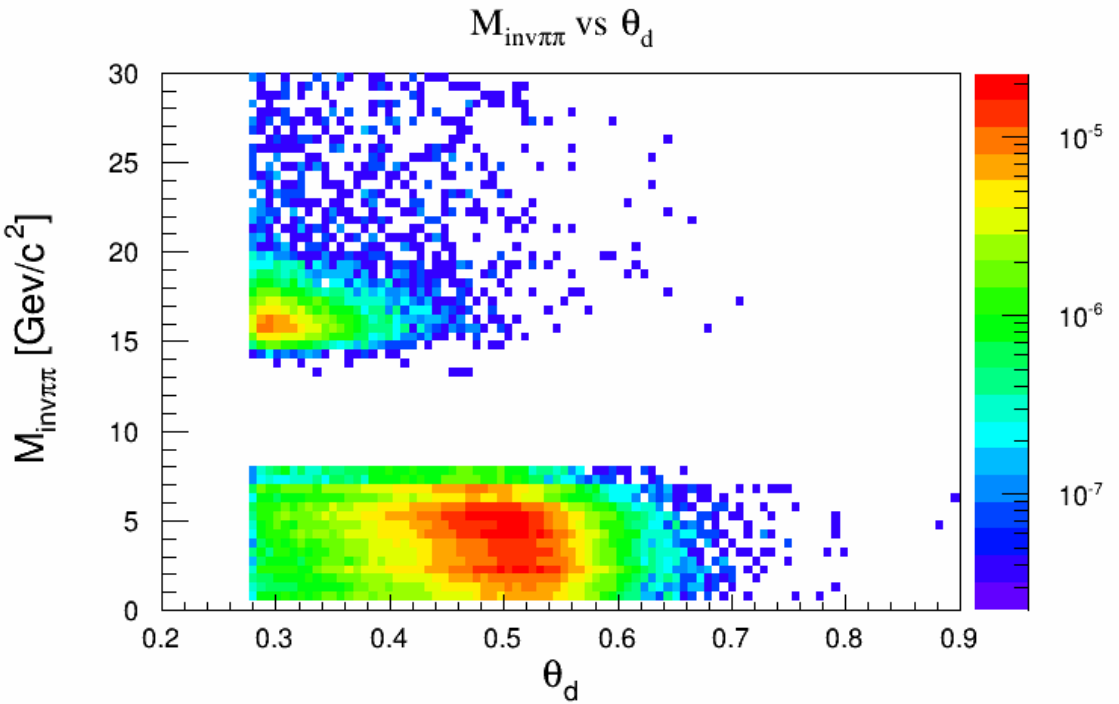
Di-baryon resonance d* – model from Mikhail Bashkanov (WASA)



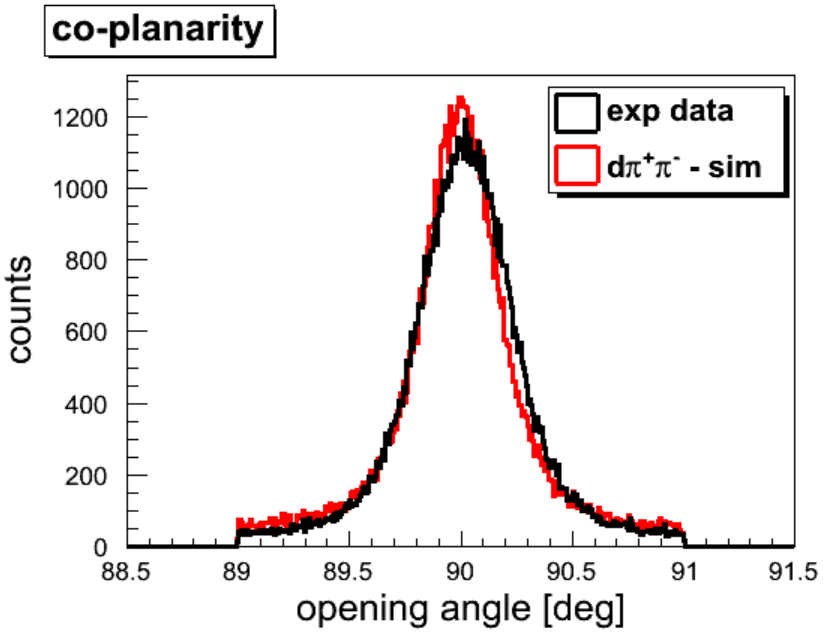


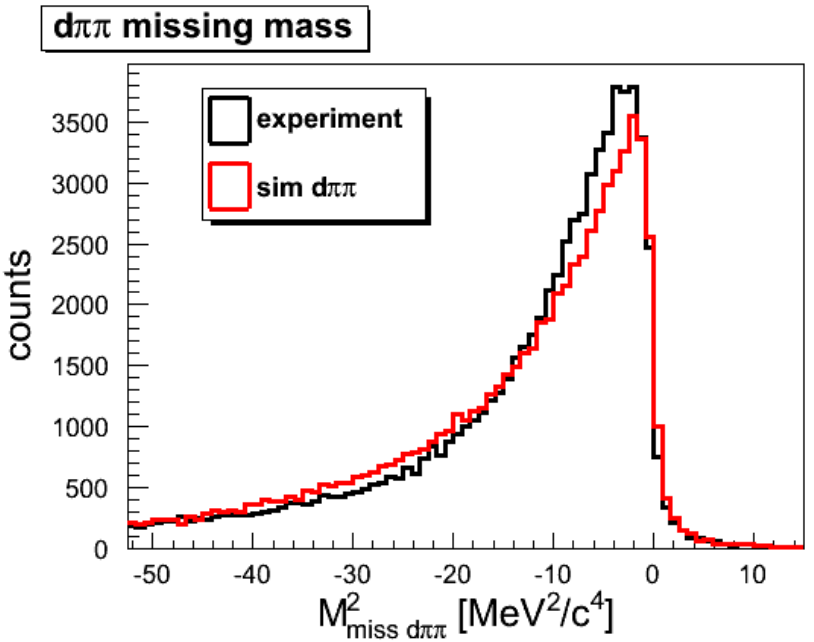
Possible explanation of overshooting HADES data is not precise angular distribution of d*

Total acceptance for the reaction~0.55%



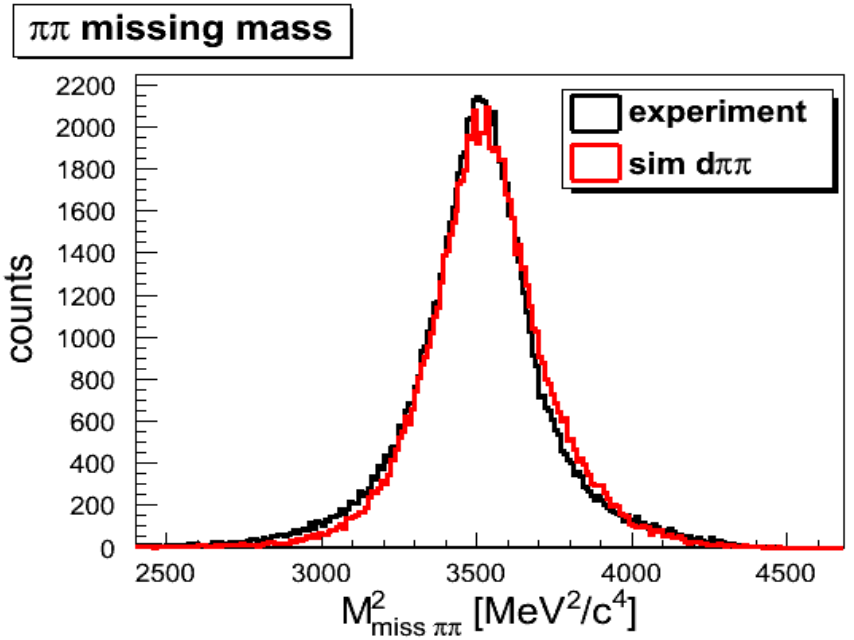
d π^+ π^- analysis with deuteron in HADES





$n + p \rightarrow X + d\pi\pi$

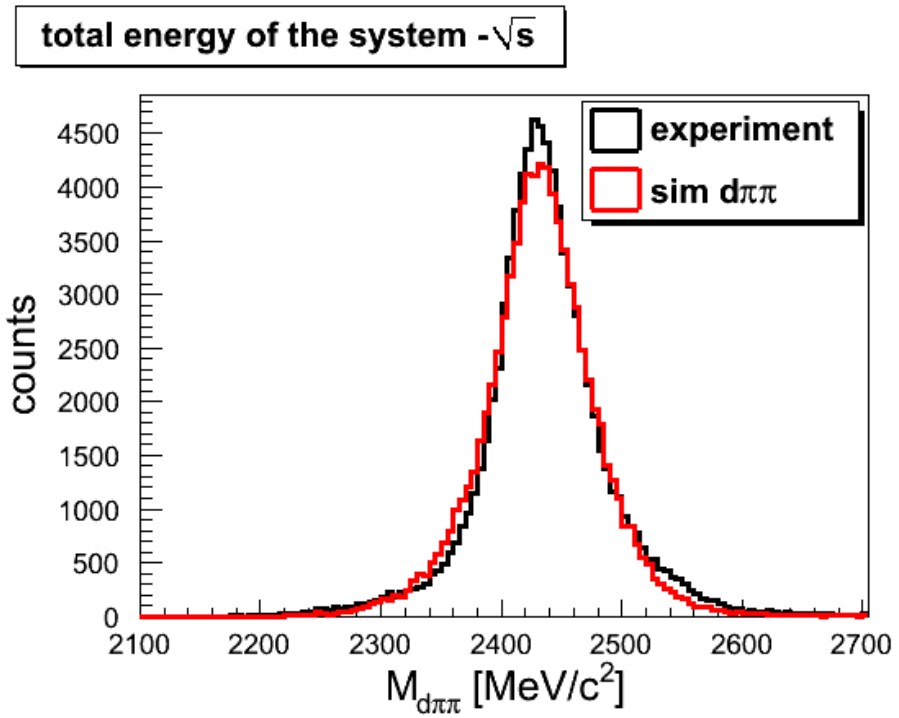
zero expected

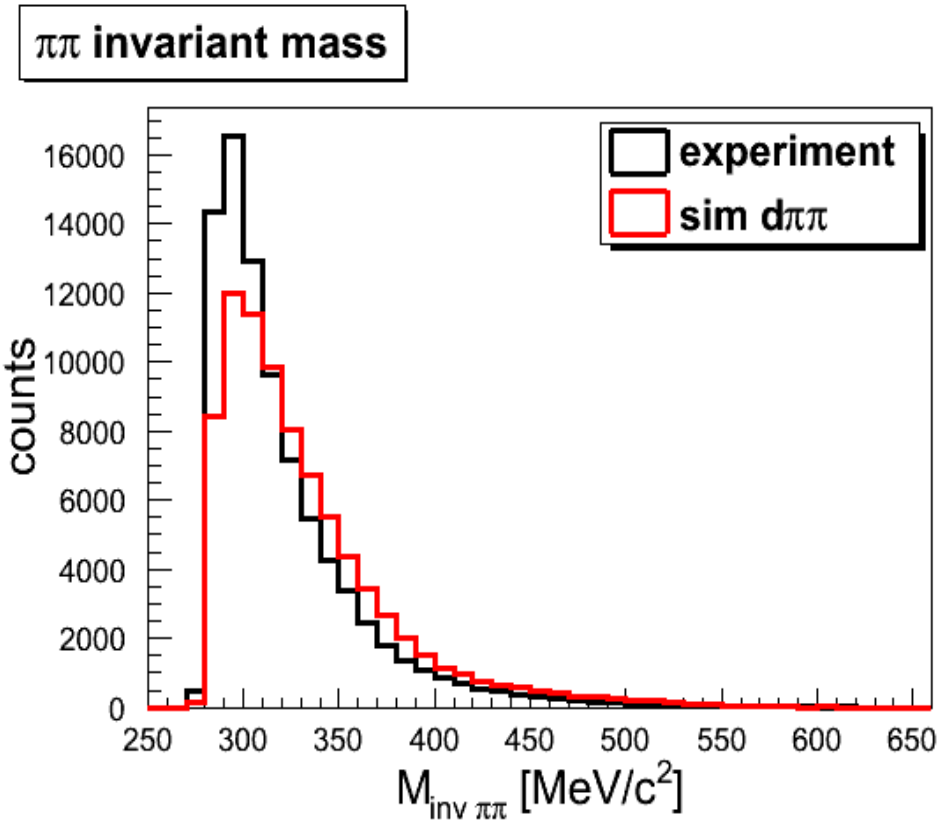


$n + p \rightarrow X + \pi\pi$

deuteron expected

d π^+ π^- analysis with deuteron in HADES





Summary and Outlook

- e^+e^- excess seen in pn/pp inclusive
- excess related to exclusive channel pn $\rightarrow$pn e^+e^- („off-shell" ρ meson production)
- pn $\rightarrow$d e^+e^- model in agreement with the data (B.V. Martemyanov, et al.)
- pp/pn $\rightarrow$pp/pn $\pi^+\pi^-$
  - Ongoing comparison with models
  - Sensitivity to $\Delta\Delta$, $N^*\rightarrow\Delta\pi$, $N^*\rightarrow N\sigma$
- pn $\rightarrow$d $\pi^+\pi^-$
  - Yield in agreement with model including d* as used by WASA
  - $M_{inv(\pi\pi)}$ do not agree

Outlook:

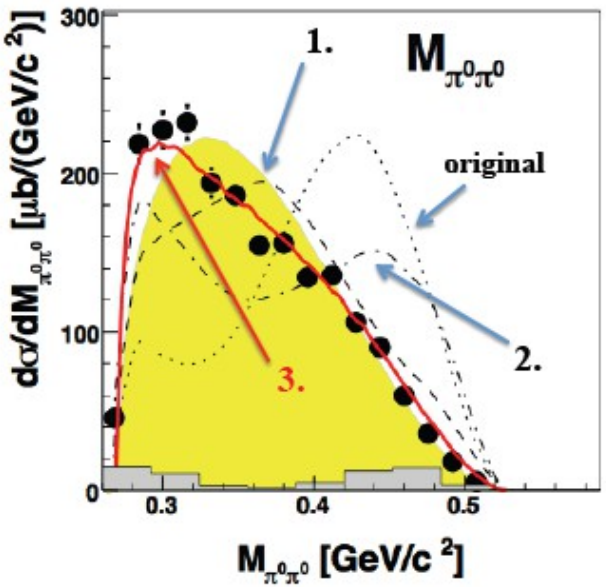
- Deuteron selection by missing mass method (pn $\rightarrow \pi^+\pi^- X$): extension to the „blind" area

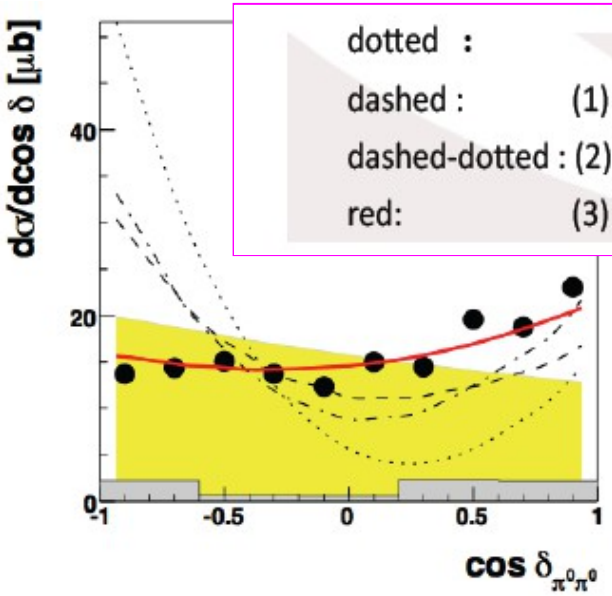
Thank you.

The end

Modifications of Valencia model

$pp \to pp\pi^0\pi^0$ E= 1.3 GeV WASA





dotted : original model

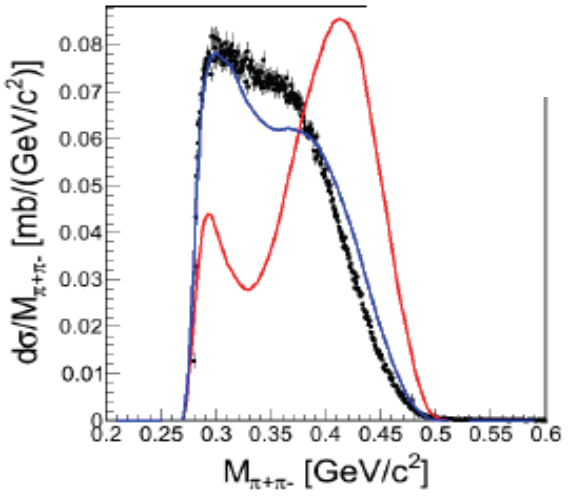
dashed : (1) N* -> Δπ and N* -> Nσ branching ratio

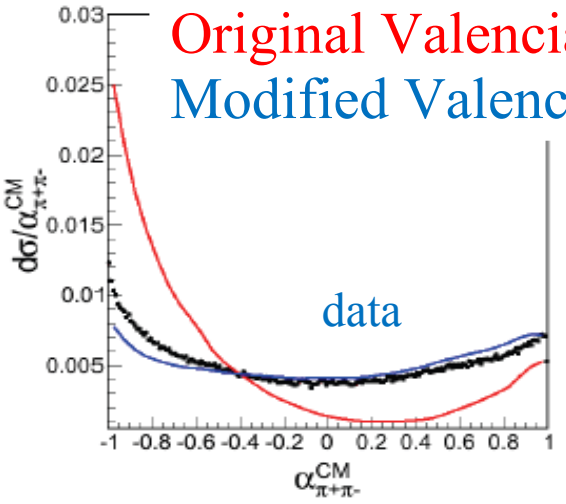
dashed-dotted : (2) readjustment of strength of the N*(1440)

red: (3) ρ exchange in double Δ excitation

Changes mostly driven by recent WASA measurements

$pp \to pp\pi^+\pi^-$ E= 1.25 GeV HADES





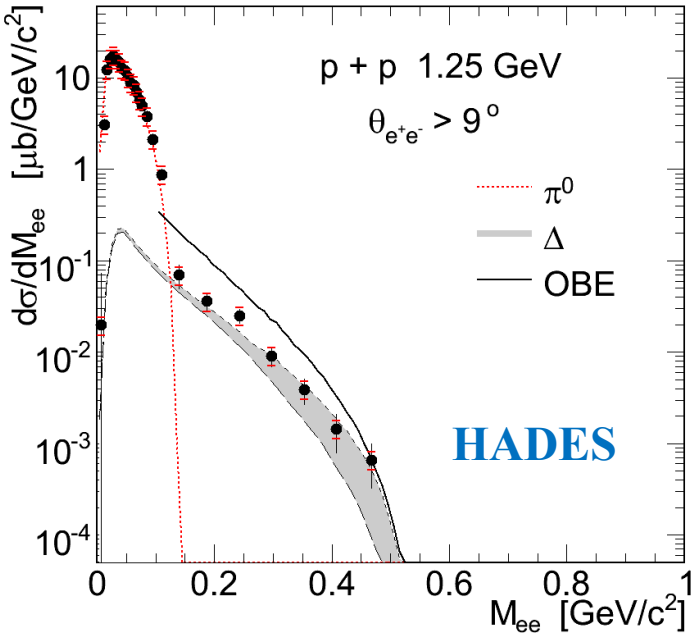
Original Valencia model

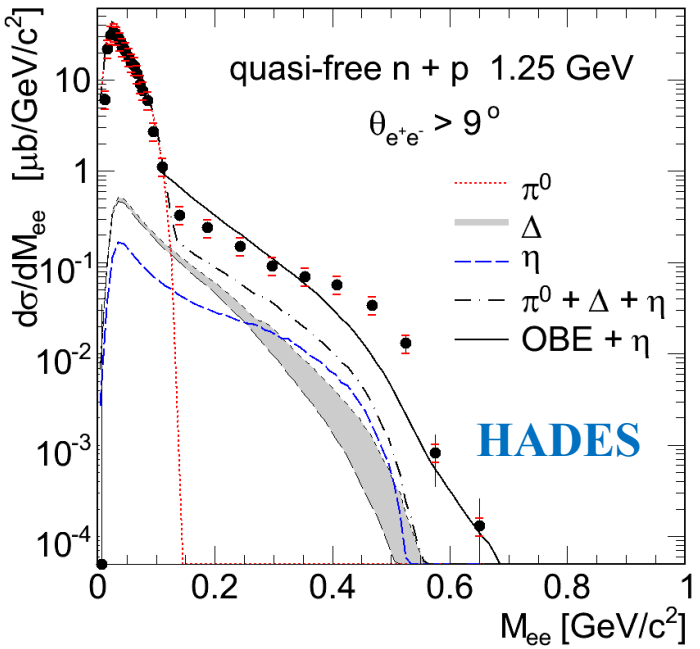
Modified Valencia model

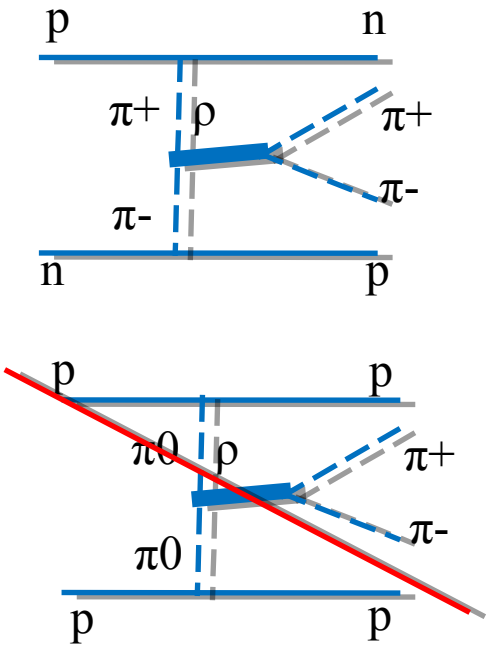
Much better description of both $\pi^+\pi^-$ and $\pi^0\pi^0$ channels with the modified model

Motivation for HADES experiment

- Main goal of HADES is studys of hadronic matter using dilepton probes
-
- Study in-medium vactor meson via their decay in e^+e^-
- Do we understand e^+e^- elementary sources in N+N at 1-2 GeV ?

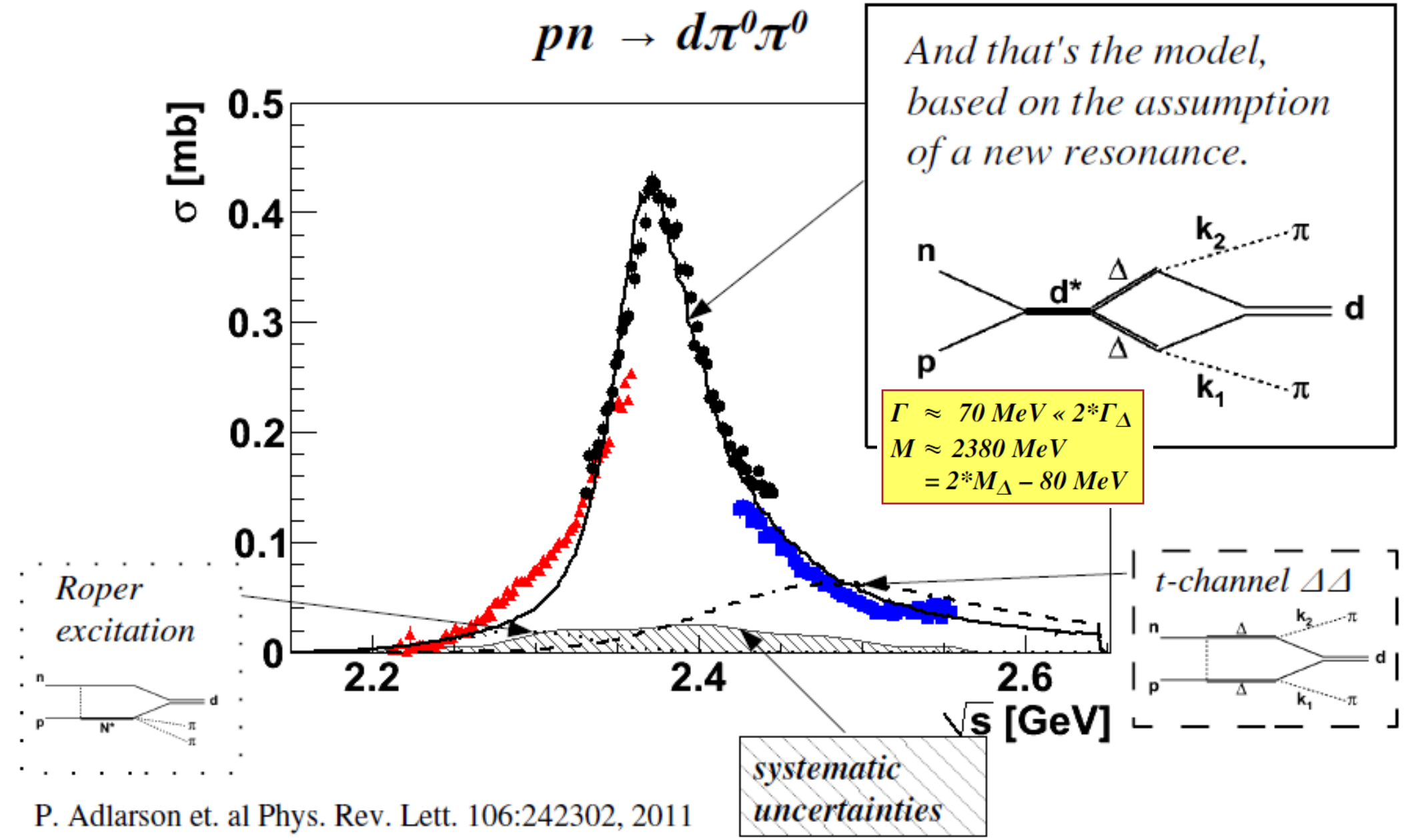






Important to look in parallel to $\pi^+\pi^-$ production in pp and np collision in order to learn more and understand difference in inclusive spectra of e^+e^-

A New Resonance: Total Cross Section $pn \rightarrow d\pi^0\pi^0$



P. Adlarson et. al Phys. Rev. Lett. 106:242302, 2011