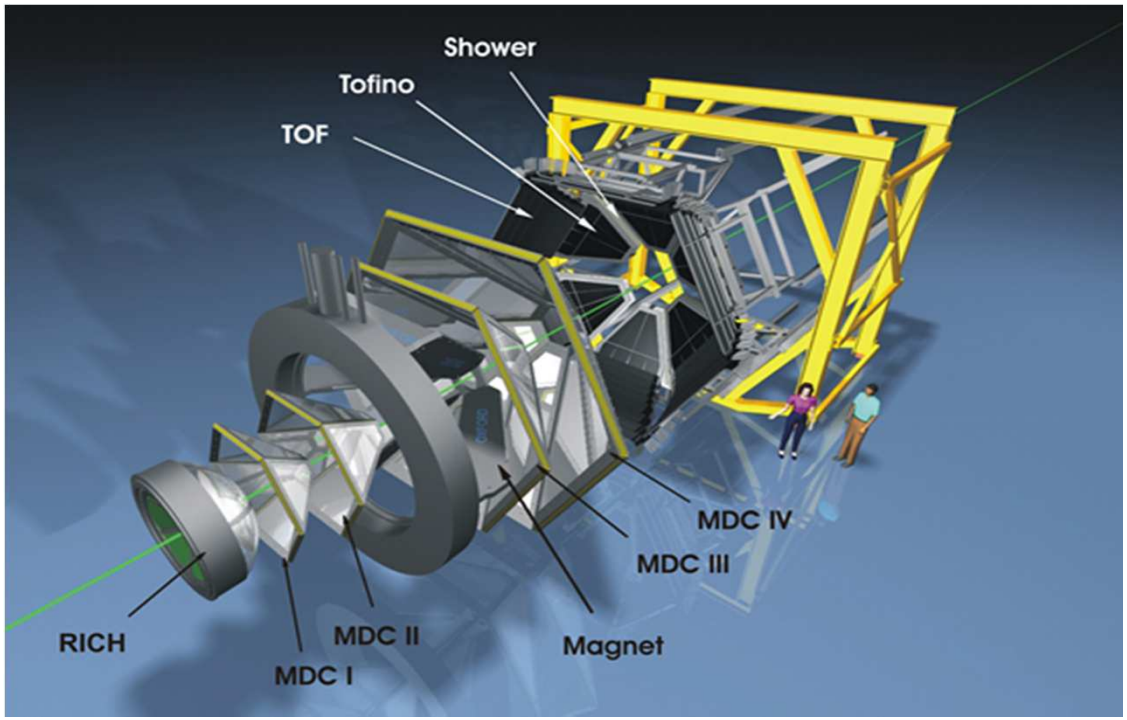
Double pion production in np and pp collisions at 1.25 GeV with HADES



Aleksey Kurilkin for the HADES collaboration

JINR, Dubna, Russia

ISHEPP2012

13 September, Dubna, Russia.

Outline

- Introduction:

  motivation, world data

- HADES experiment and Data analysis
- Results
  - double pion production, comparison with the models
- Conclusion

Motivation

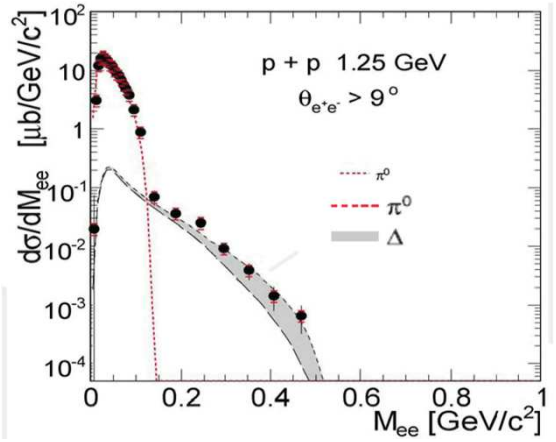
➢ Double pion production in NN collisions is one way to obtain information about the NN, πN and ππ interactions.

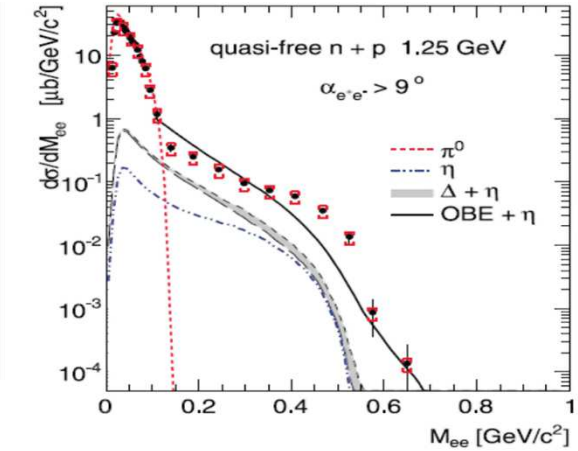
➢ Specific interest in pp and pn collisions is the study of excitation of baryons and their subsequent decays :

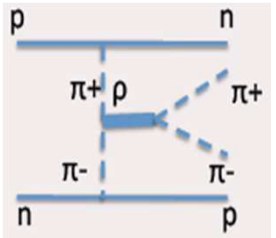
N*(1440)→ Δπ, N*(1440)→ Nσ, N*(1440)→ρN, ΔΔ excitation.

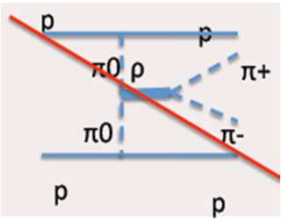
➢ Important to look in parallel to $\pi^+\pi^-$ production in pp and np collision in order to learn more and understand difference in inclusive spectra of e^+e^-

➡ in connection to HADES dilepton results.



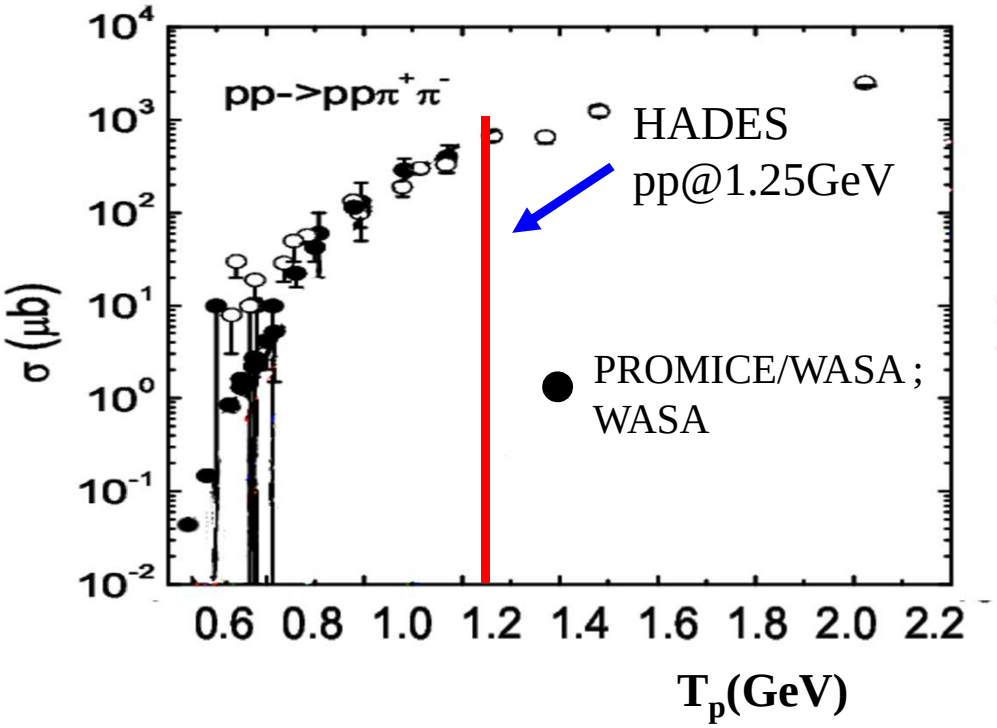


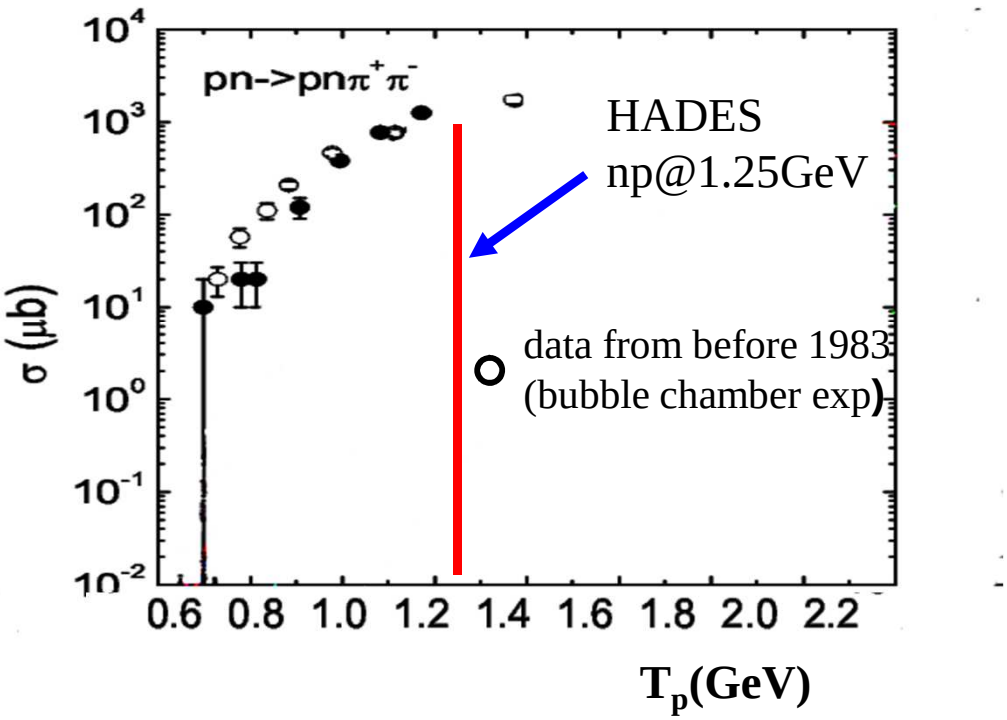




mesons and resonances are dilepton sources!

World data on the double pion production in NN collisions



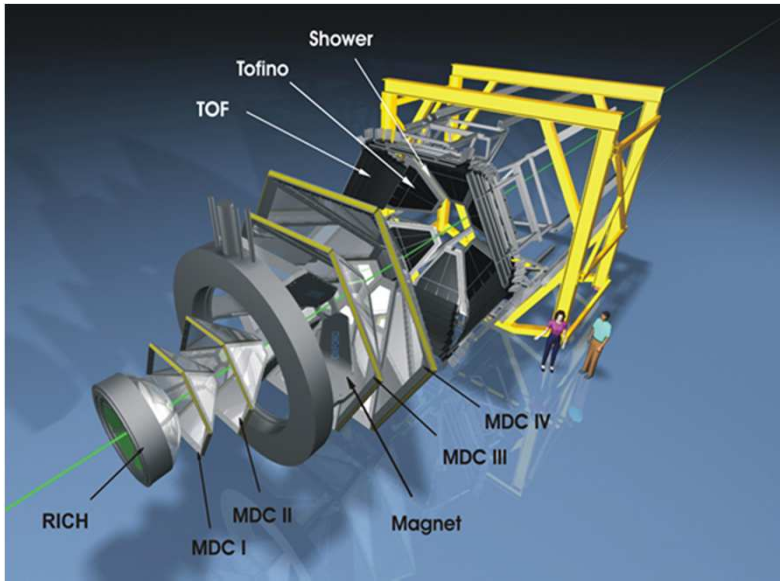


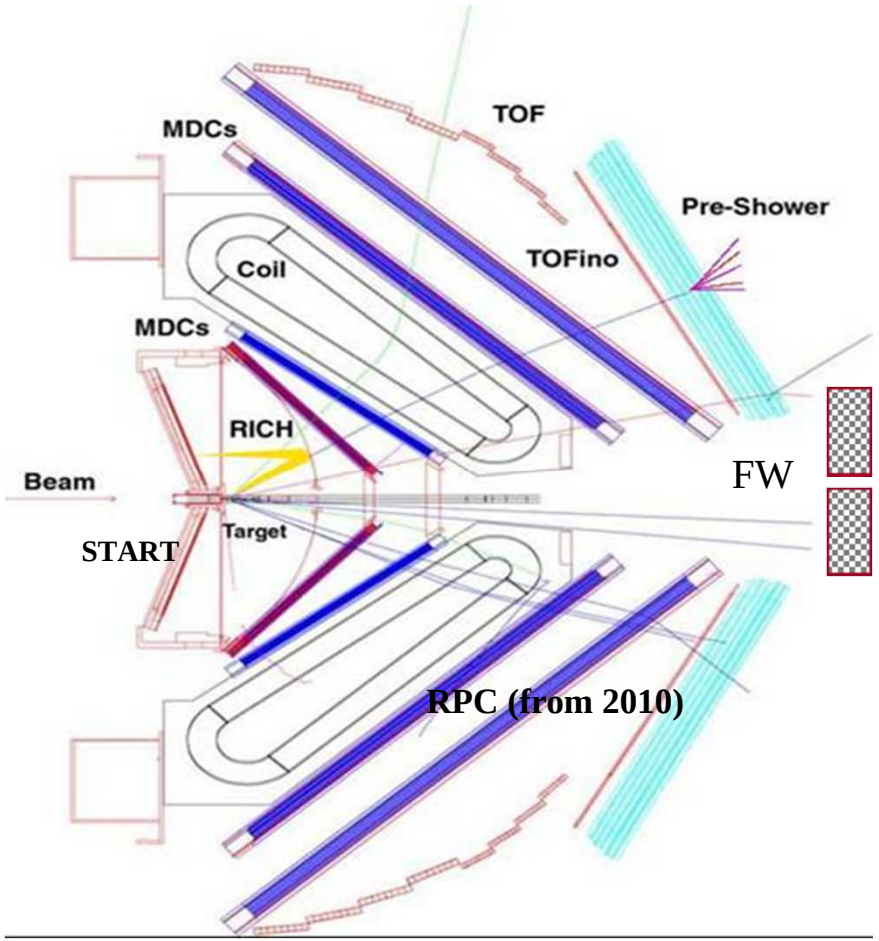
Facilities : CELSIUS, COSY, KEK, PNPI-Gatchina ⟺ two-pion production in NN collisions (after the year 2000; T_p : 650–1300 MeV)

HADES data allow to test pion production mechanisms and the contribution of baryonic resonances with a high statistical precision at large pT.

HADES experiment at SIS18, GSI

Beams from SIS18: pions, protons, nuclei
Spectrometer with high invariant
mass resolution - 2% at ρ/ω
Versatile detector for rare particle decays :
dielectrons (e^+,e^-)
strangeness: Λ, $K^{\pm,0}$, Ξ$^-$ φ
Upgrade(2010): new DAQ, Tof-RPC
(~20 KHz), (σ_{tof} ~80 ps)



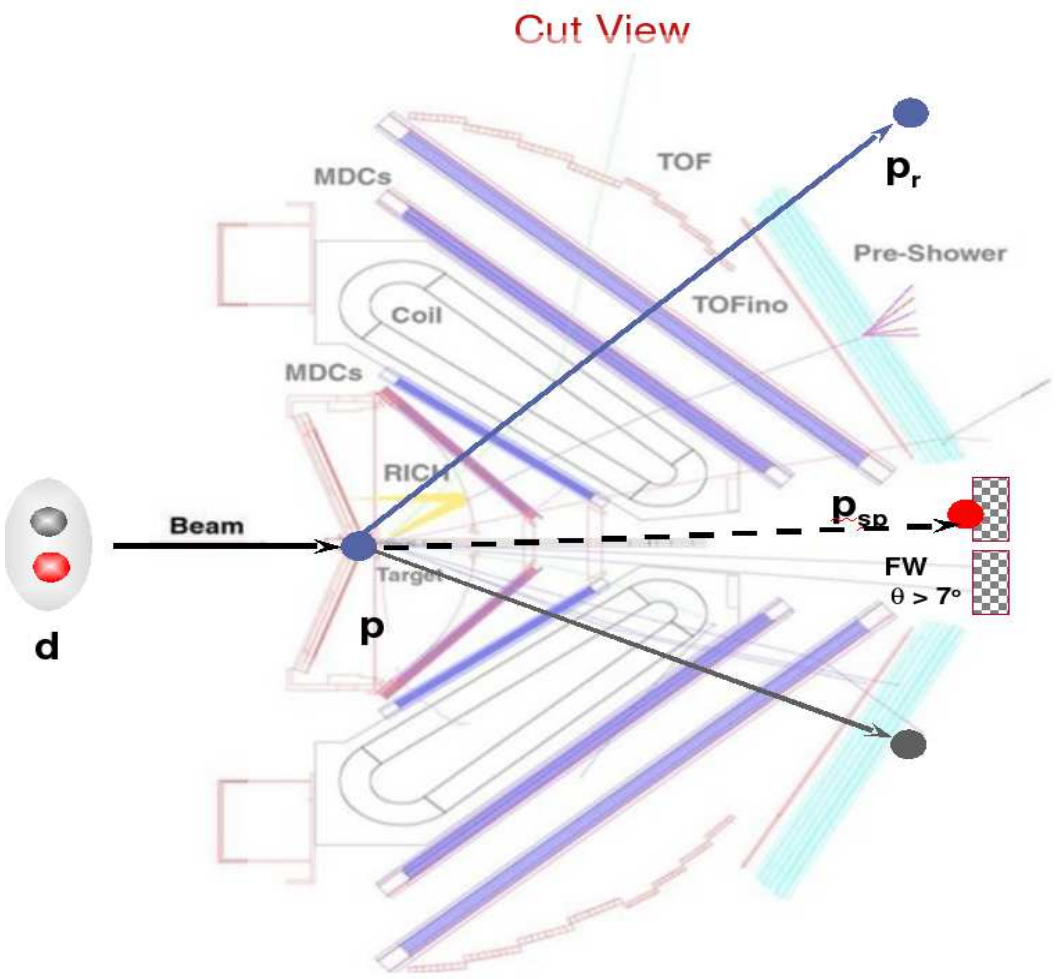


Geometry
Full azimuth, polar angles 18° - 85°
e+e- pair acceptance ≈ 0.35
~ 80.000 channels, segmented solid or LH2 targets

Experiment conditions for pp and dp reactions

- p+p reactions, Apr 2006:
- Detector set-up:
  - LH2 target
  - 21 MDC
  - No Start detector
- Kinematics for pp:
  - Kinetic Energy = 1.25 GeV

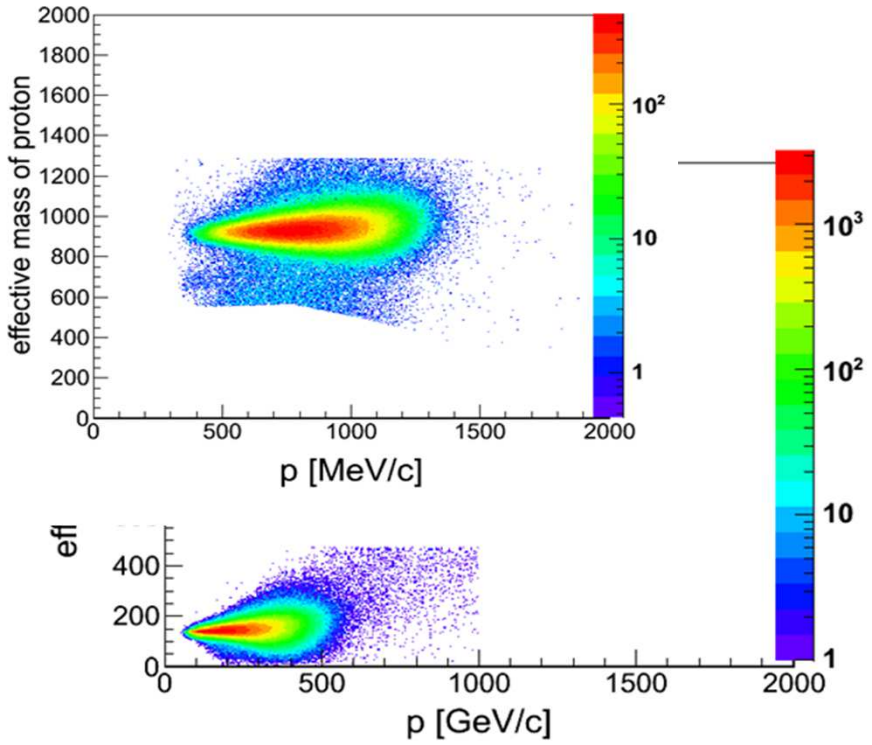
- d+p reactions, May 2007:
- Detector set-up:
  - LH2 target
  - 24 MDC
  - No Start detector
  - Forward Wall
- Kinematics for np:
  - Kinetic Energy = 1.25 GeV
  - np selection by detecting Proton-spectator in FW



PID and selection of the reaction channels

Time of flight is relative (no START detector). Time of flight reconstruction was based on tracking information + hypothesis. Each combination must fit into PID cuts. The best combination (the lowest $\chi 2$) wins.

$pp \rightarrow pp\ \pi^+\pi^-$ @ 1.25 GeV/u

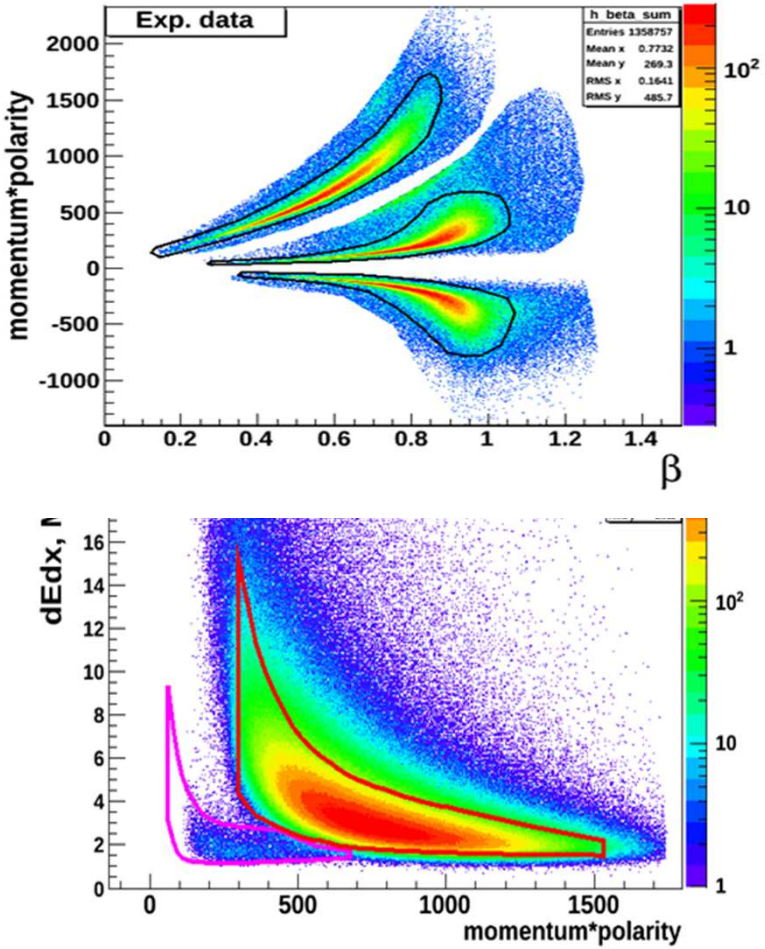


Additionally cut on:

4 particles ($pp\pi^+\pi^-$) missing mass

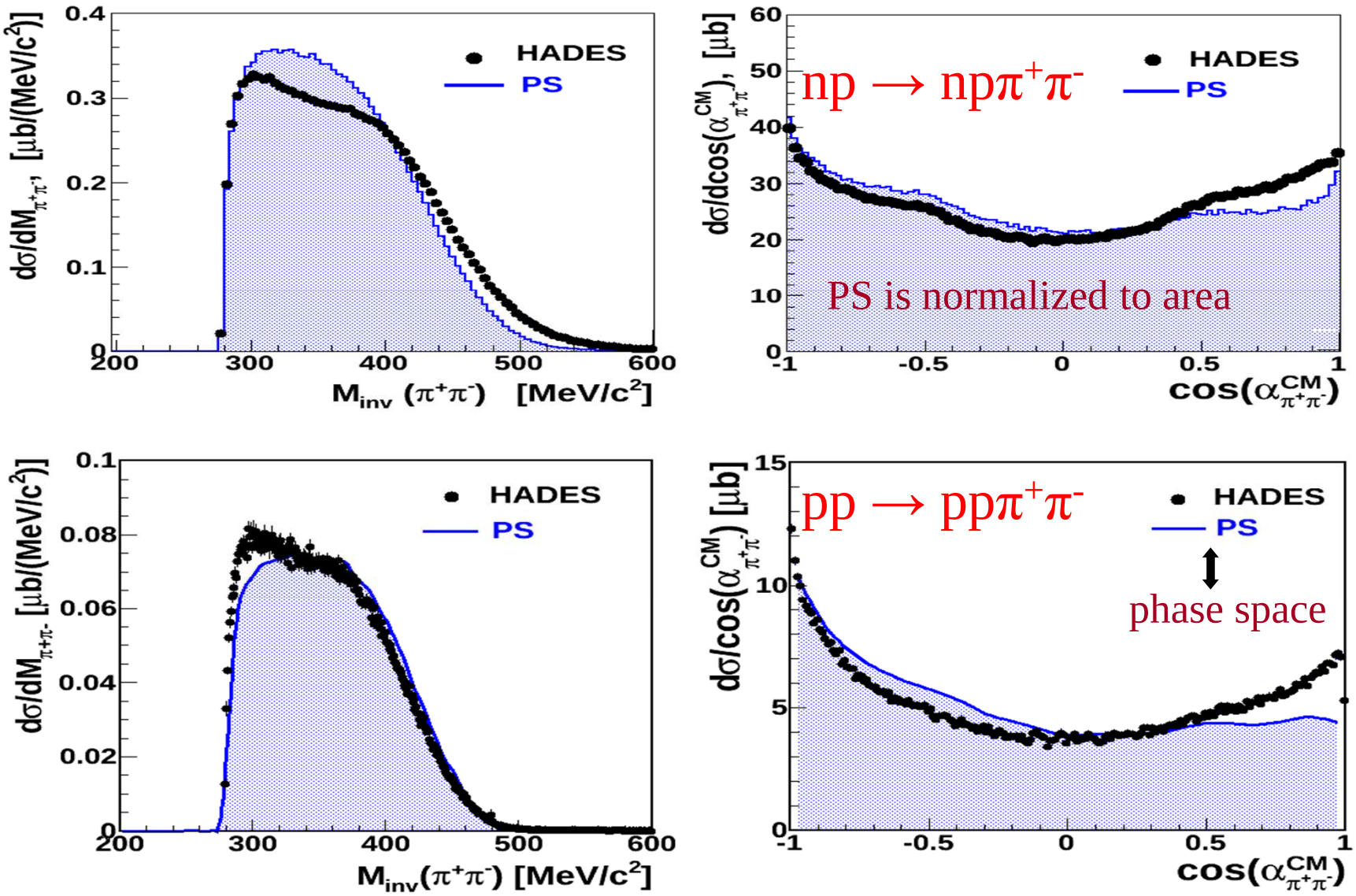
4 degree opening angle between π^+ π^-

$dp \rightarrow np\ \pi^+\pi^- + (p_{spec})$ @ 1.25 GeV/u



& proton spectator in Forward Wall

Double pion production in np and pp collisions at 1.25 GeV



$M_{\pi+\pi-}$ and angular distributions for np → np $\pi^+\pi^-$ and pp → pp $\pi^+\pi^-$ reactions.
Black points are HADES data. *Comparison in HADES acceptance*.

Existing models for the NN→NNππ reactions

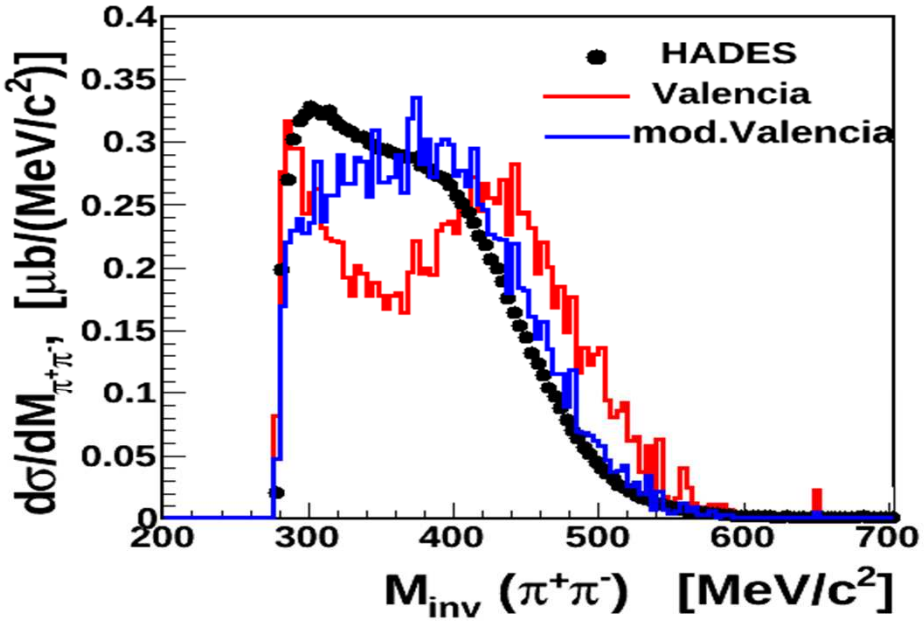
- **OPER, OPER-2 models :** *A. Jerusalimov, arXiv:1203.3330 [nucl-th] arXiv:1208.3982[nucl-ex] (reggeized π exchange model, includes one pion + one baryon exchange diagrams, all possible resonances)*

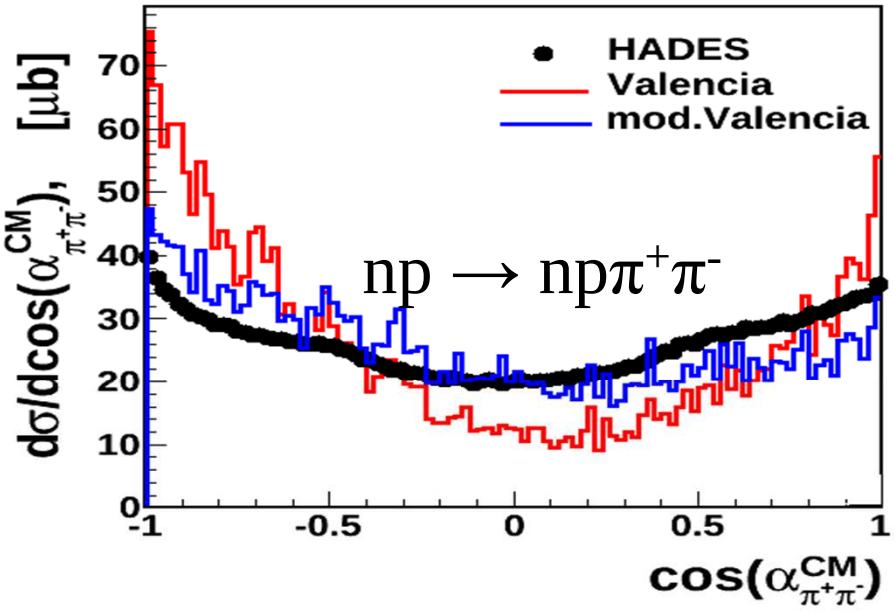
- **Valencia model :** *L. Alvarez-Ruso, E. Oset et al. Nucl. Phys. A 633 (1998) 519-543*
(Effective lagrangian model, interference between diagrams, N*(1440), Δ(1232))

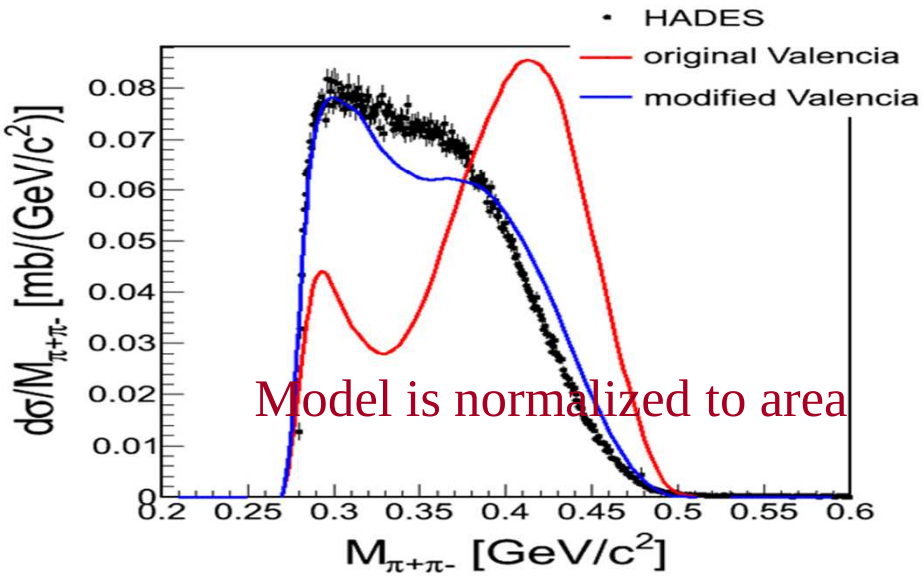
- **XuCao model :** *Xu Cao et al. Phys Rev C81, 065201 (2010)*
(Effective lagrangian model with less number of diagrams, no interference, resonances up to 1.72 GeV)

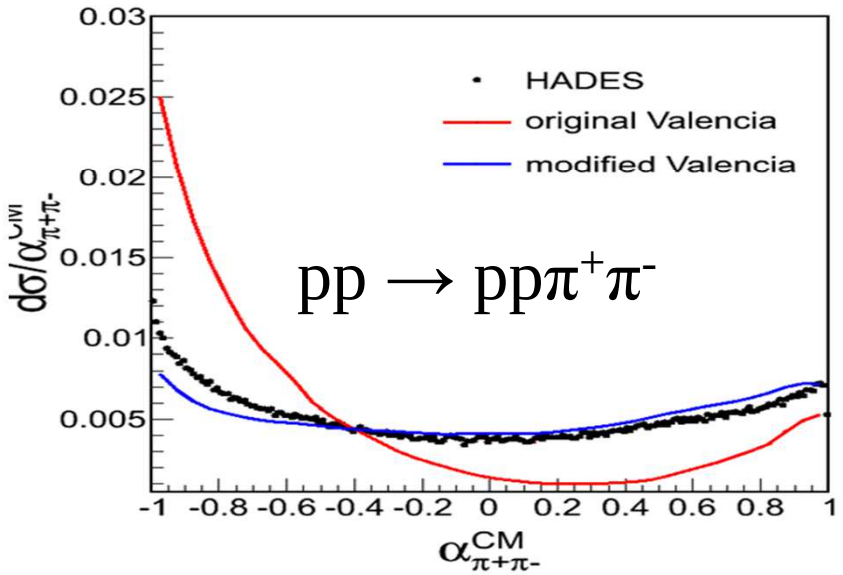
- **modified Valencia model :** *T. Skorodko*, et al., *Physics Letters B 679 (2009)30, Phys.Lett.B695:115-123,2011*
(Modification of the partial decay width between the decay N → Nσ via Δ and direct, Strength of N*(1440), ρ exchange in double Δ excitation was suppressed by factor of 12)*

Comparison HADES data with Valencia model



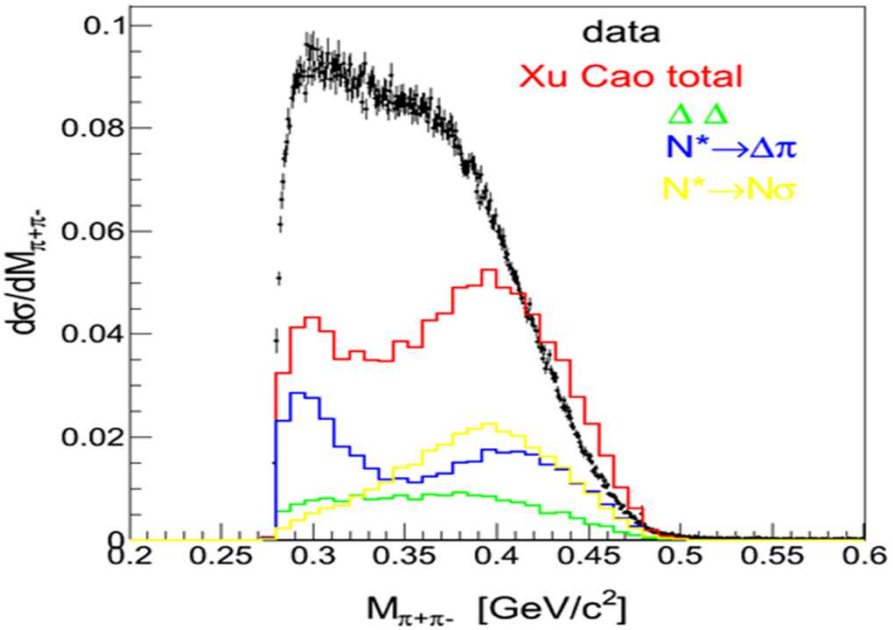


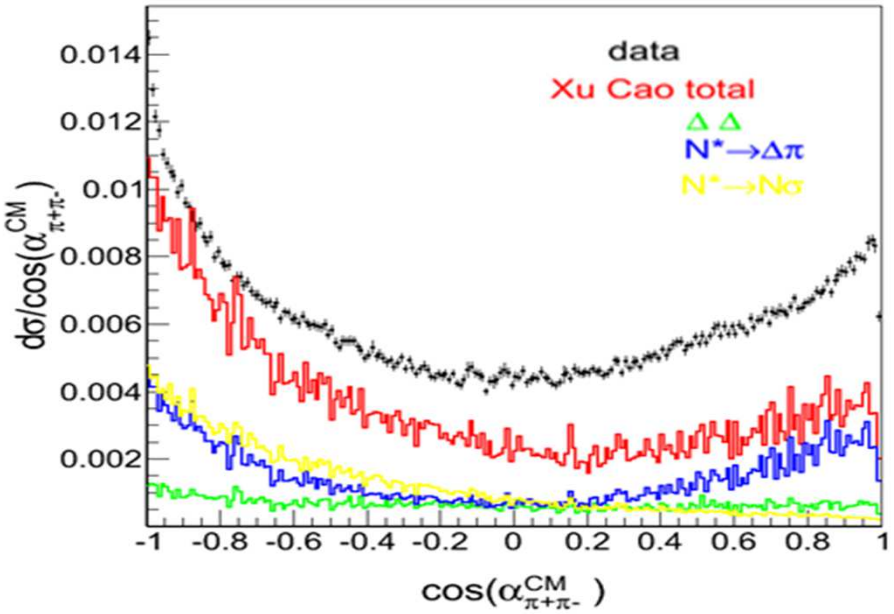




M$_{π^+π^-}$ and angular distributions for np → np π$^+$π$^-$ and pp → pp π$^+$π$^-$ reactions.
Black points are HADES data. *Comparison in HADES acceptance*.

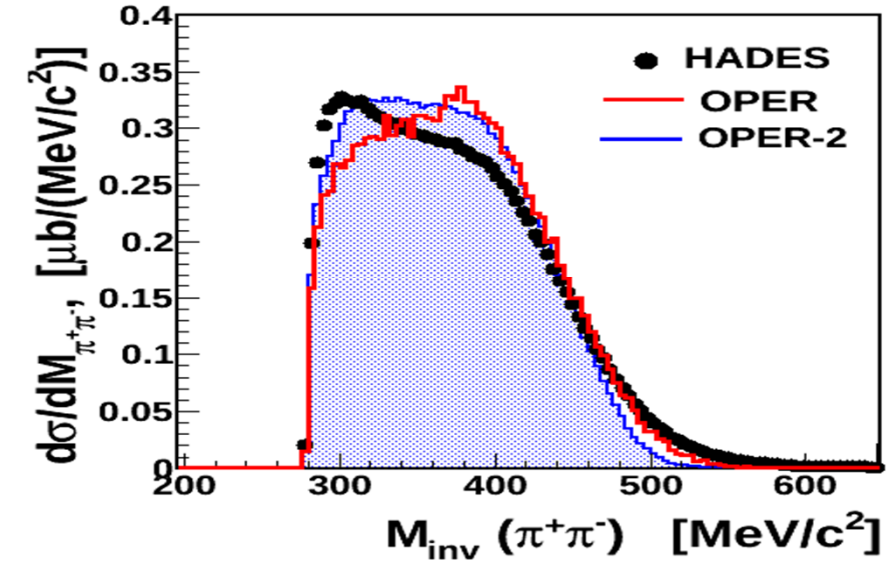
Comparison HADES data with XuCao model

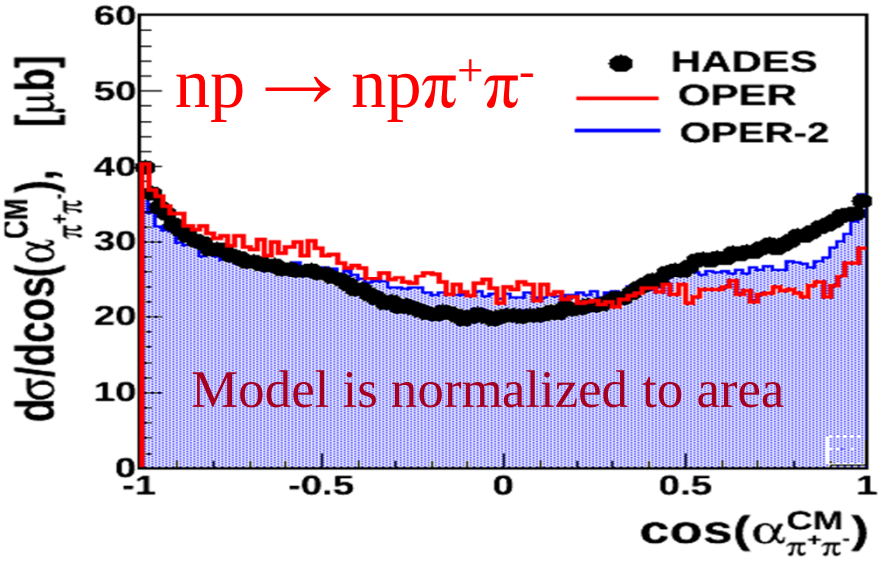


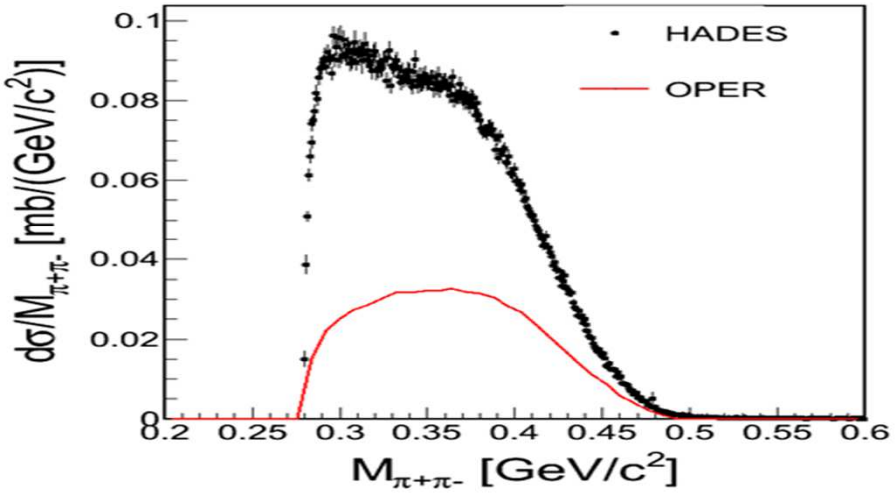


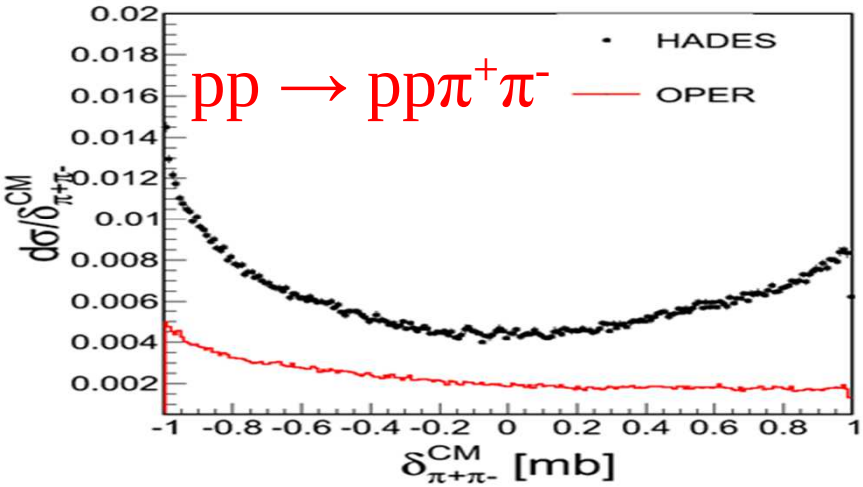
$M_{\pi+\pi-}$ and angular distributions for pp → pp $\pi^+\pi^-$ reaction.
Black points are HADES data. *Comparison in HADES acceptance*.

Comparison HADES data with OPER model









$M_{\pi+\pi-}$ and angular distributions for np → np $\pi^+\pi^-$ and pp → pp $\pi^+\pi^-$ reactions.
Black points are HADES data. *Comparison in HADES acceptance*.
OPER-2 takes into account 'hanged' diagrams (π and P exchange).

A.P.Jerusalimov arXiv:1208.3982[nucl-ex]

Summary and outlook

- HADES provides high statistics data for double pion production in pp and np @ 1.25 GeV

- New data on double pion production are important for investigations of the reaction mechanisms and development the theoretical models.

- Preliminary comparison double-pion production in pp and np @ 1.25 GeV with the theoretical models has been performed
  - ✓ Valencia model, modified Valencia model
  - ✓ Xu Cao et al. model, OPER model

- HADES data for $pp \rightarrow pp\pi^+\pi^-$ and $np \rightarrow np\pi^+\pi^-$ reactions require further development of theoretical descriptions of the experimental data.

Thank you for your attention!

- Catania (INFN - LNS), Italy
- Cracow (Univ.), Poland
- Darmstadt (GSI, EMMI), Germany
- München (TUM, Excellence Cluster Universe), Germany
- Dresden (FZD), Germany
- Frankfurt (Univ., EMMI, HIC for FAIR), Germany
- Giessen (Univ., HIC for FAIR), Germany
- Darmstadt (TUD, EMMI), Germany
- Dubna (JINR), Russia
- Moscow (ITEP,RAS), Russia
- Nicosia (Univ.), Cyprus
- Orsay (IPN), France
- Rez (CAS, NPI), Czech Rep.
- Santiago de C. (Univ.), Spain
- Coimbra (Univ.), LIP, Portugal

The HADES Collaboration includes 17 Institutes from 9 European countries.

http://www-hades.gsi.de/

Thank you for your attention!

Comparison of the models with HADES data

- Data corrected for the tracking and PID efficiency.
  - only statistical errors presented
  - systematical errors on the order of 10 % (normalization, eff correction)

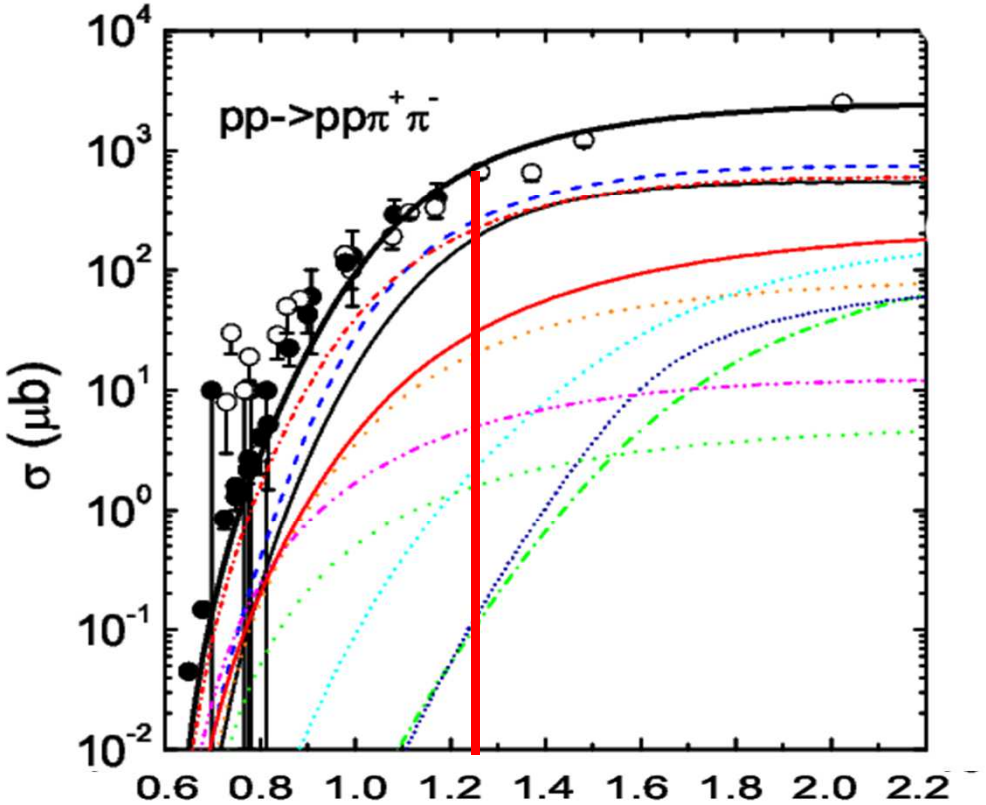
- Models filtered by the acceptance, normalized to the corresponding cross-sections.

Several distributions can be presented, according to the models most sensitive one are:

- invariant mass of $\pi^+\pi^-$ ($M_{\pi^+\pi^-}$)
- cos of opening angle in CM between $\pi^+\pi^-$ ($\cos(\alpha_{\pi^+\pi^-}\text{CM})$)

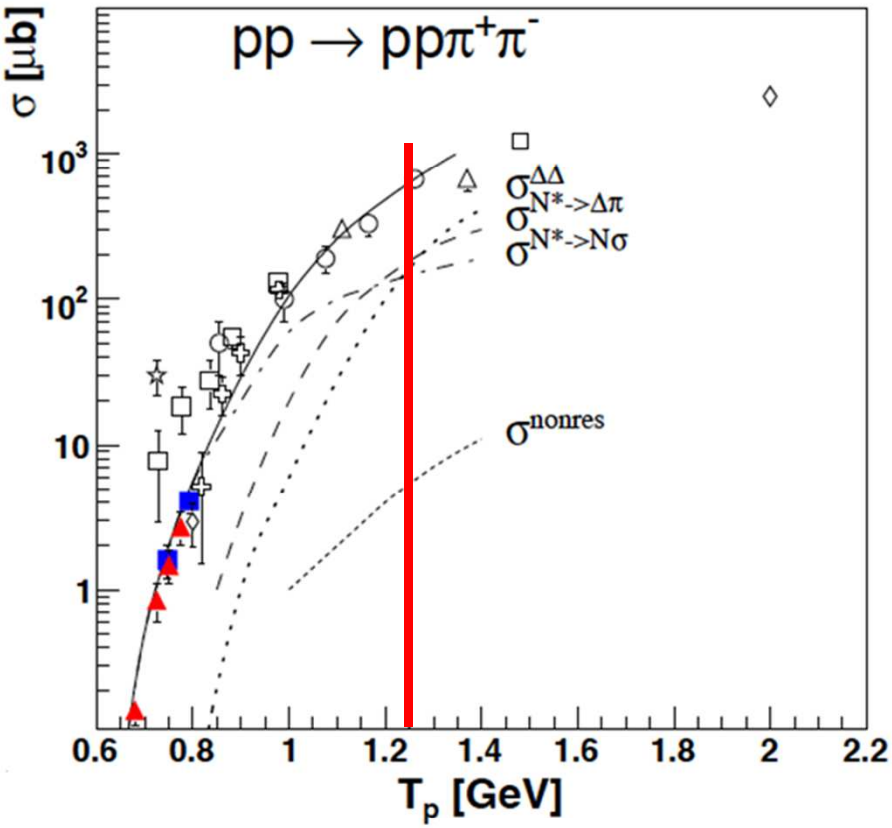
Predictions of models for the $pp \rightarrow pp\pi^+\pi^-$ reactions

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



full model	713,2 μb
N*(1440) -> Δπ	266.2 μb
N*(1440) -> Nσ	219.7 μb
double-Δ	183.7 μb

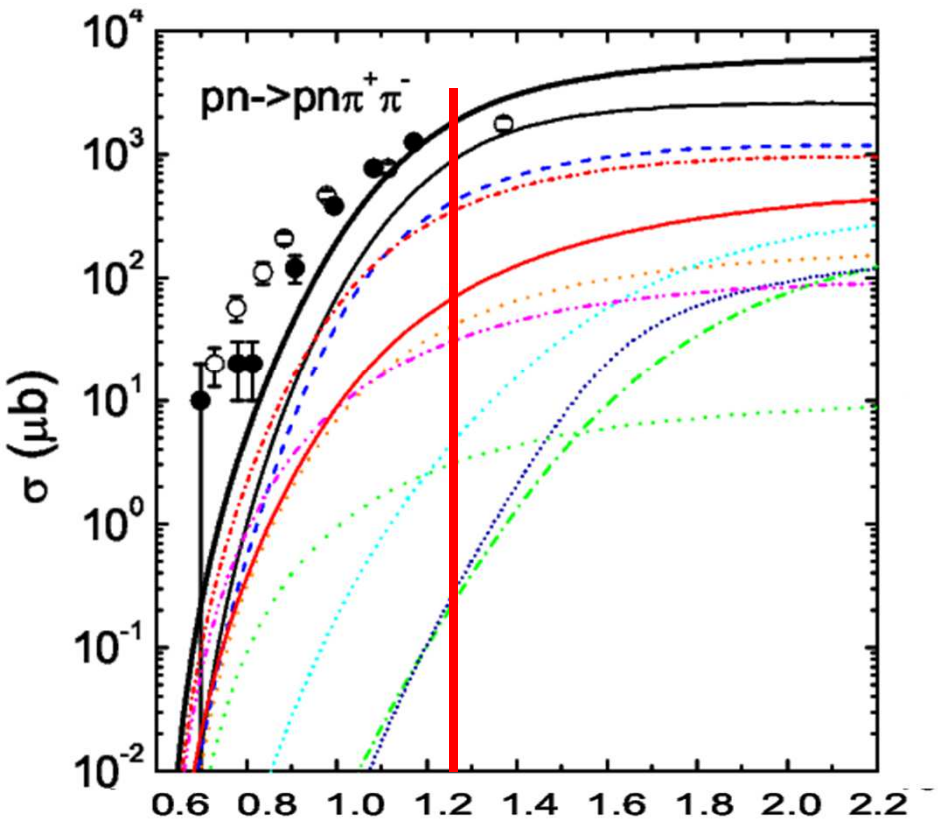
L. Alvarez-Ruso, E. Oset et al. Nucl. Phys. A 633 (1998) 519-543



full model	728.86 μb
N*(1440)->πΔ	210.60 μb
N*(1440)->Nσ	170.61 μb
$\Delta_{S\text{-wave}}$ & ΔΔ	180.08 μb
non-resonant part	5.66 μb

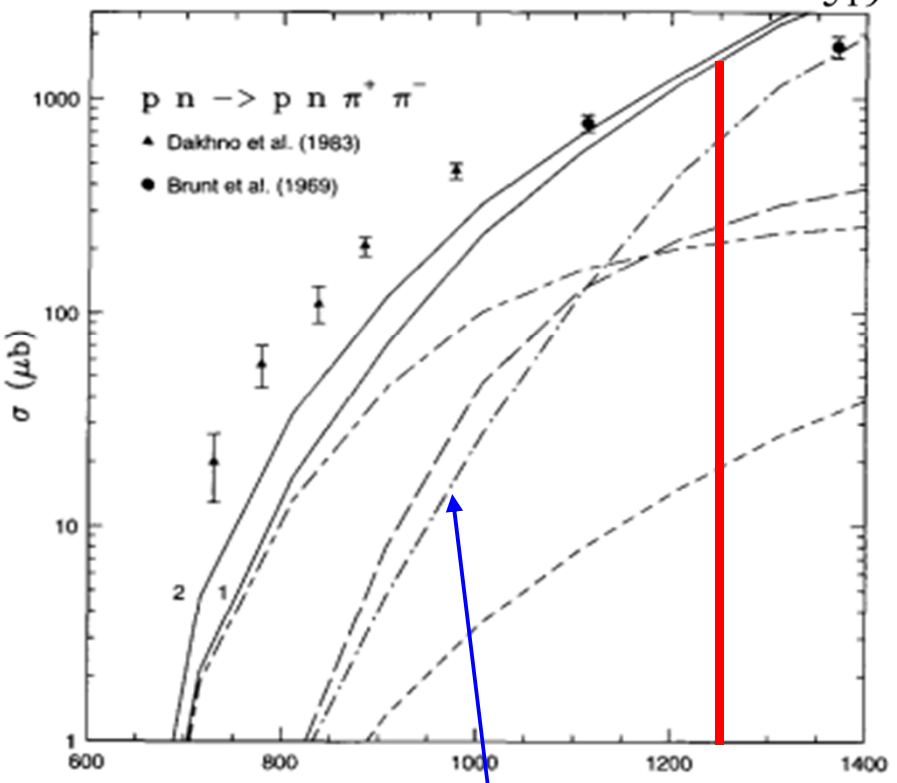
Predictions of models for the $np \to np\pi^+\pi^-$ reactions

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



total
ΔΔ
N(1440)→Nσ*
N(1440)→Δπ*

L. Alvarez-Ruso, E. Oset et al. Nucl. Phys. A 633 (1998) 519-543



total
N(1440)→Δπ*
N(1440)→Nσ*
ΔS-wave & ΔΔ
Non - resonant

HADES PROGRAM (SO FAR)

- pp reactions

(1.25, 2.2, 3.5 GeV)

dp reactions (1.25 GeV)

- nucleus + nucleus

C+C, Ar+KCl

Au+Au (2012)

- **p + nucleus**

(Nb @ 3.5 GeV)

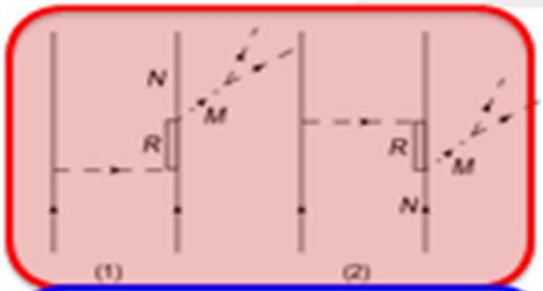
- *e+e- production in N+N – reference reactions for A+A*
- *single and double π production (barion resonances in N+N)*
- *η, ω, ϕ production- hadr.channels and rear $\eta \rightarrow$e+e- decays (new UL in PDG)*
- *Λ (1405), Σ(1385) (new PDG entry)*
- *K^0 production*

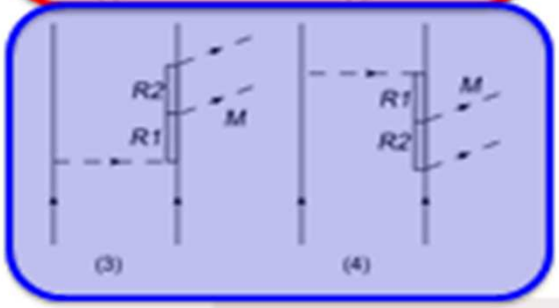
- *low mas e+e- „excess" : (DLS puzzle, emissivity,..)*
- *kaon production : K^0_s*
- *Hyperon production; Λ, Σ, Ξ(1321)*
- *ϕ production*
- *Λ-p, p-p, $\pi\pi$, correlations*

- *ρ/ω mesons in cold nuclear matter*
- *strangeness production K, ϕ*

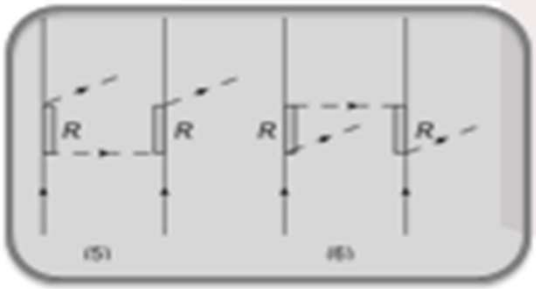
Existing models for the pp->pp$\pi^+\pi^-$ reactions

N*(1440) -> Nσ





double-Δ N*(1440) -> Δπ

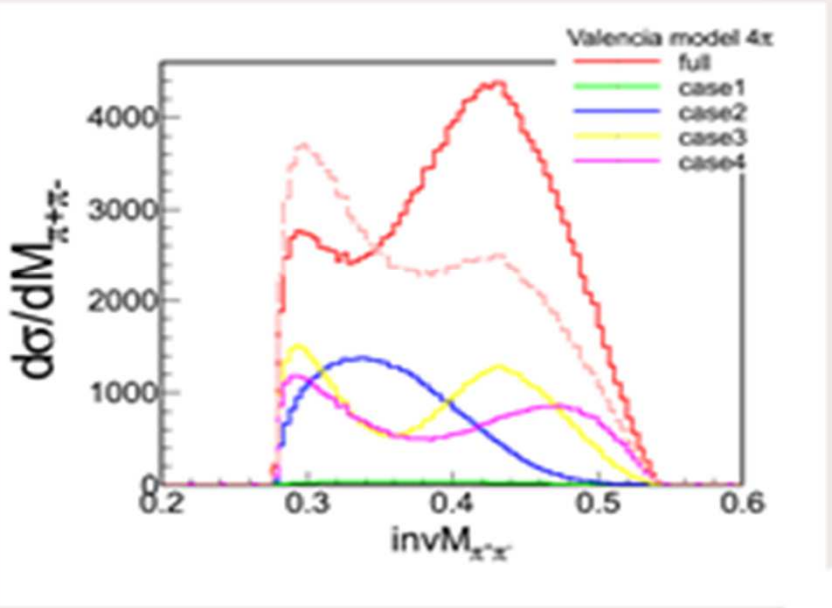


& exchange diagrams

In Valencial model in addition we have:

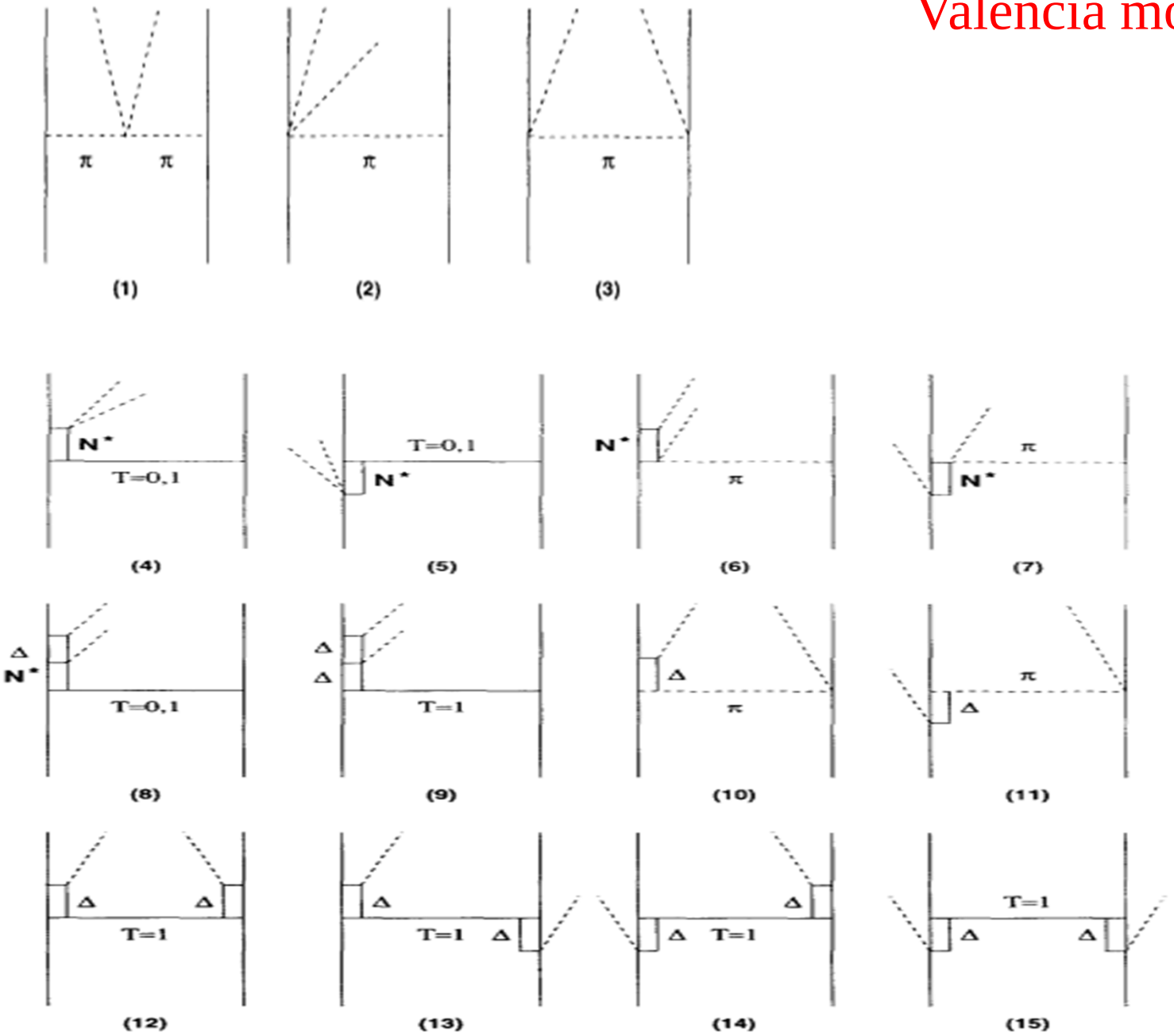
- ✓non-resonant component
- ✓interferences between different diagrams
- ✓pre-emition diagrams

Interferences between different diagrams included in the Valencia model



7

Valencia model



Modifications introduced to the Valencia model

in collaboration with Tatiana Skorodko

Following modifications have been done to the Valencia code. These changes are based on WASA analysis of channel $pp \to pp\pi^0\pi^0$. Events including modifications have been provided by T. Skorodko.

1. Modification of the partial decay width between the decay N* -> Nσ via Δ and direct

$$\frac{\Gamma(N^* \to \Delta\pi)}{\Gamma(N^* \to N\sigma)} = 1.$$

PDG	Bonn-Gatchina PWA	WASA analysis
4	0.9(1)	1.0(1)

(1): T. Skorotko et al. EPJA35,317 (2008)

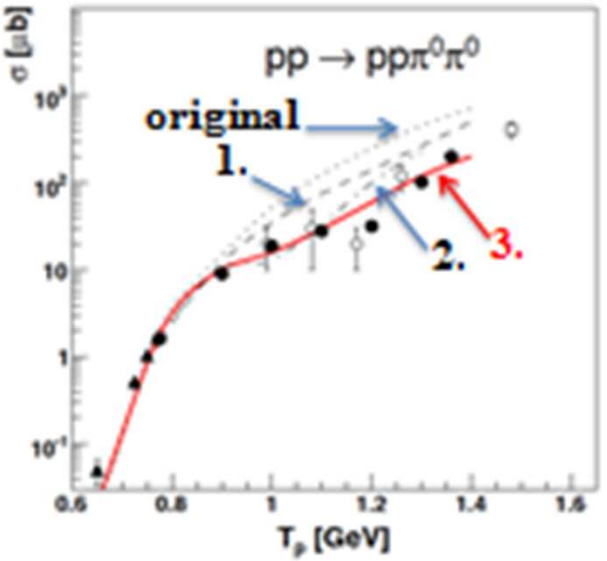
2. Strength of N*(1440)

After 'modification' the Roper behaves as s-channel resonance: rises in beginning and decreases later

3. ρ exchange in double Δ excitation

Amplitude for the Double-Δ excitation, consists of two parts: one for π-exchange and second for ρ. The ρ part hasbeen suppress by fact of 12.

(ρ-exchange is not as wel fixed by exp. observables as π-exchange.)



More details about the changes to the model can be found here:
Physics Letters B 679 (2009)30, Phys.Lett.B695: 115-123,2011

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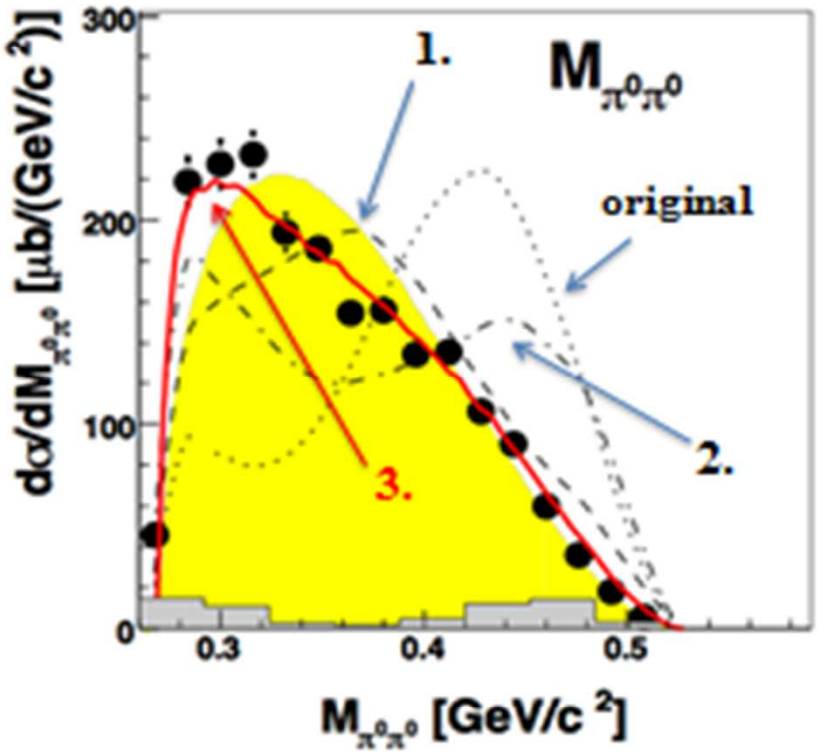
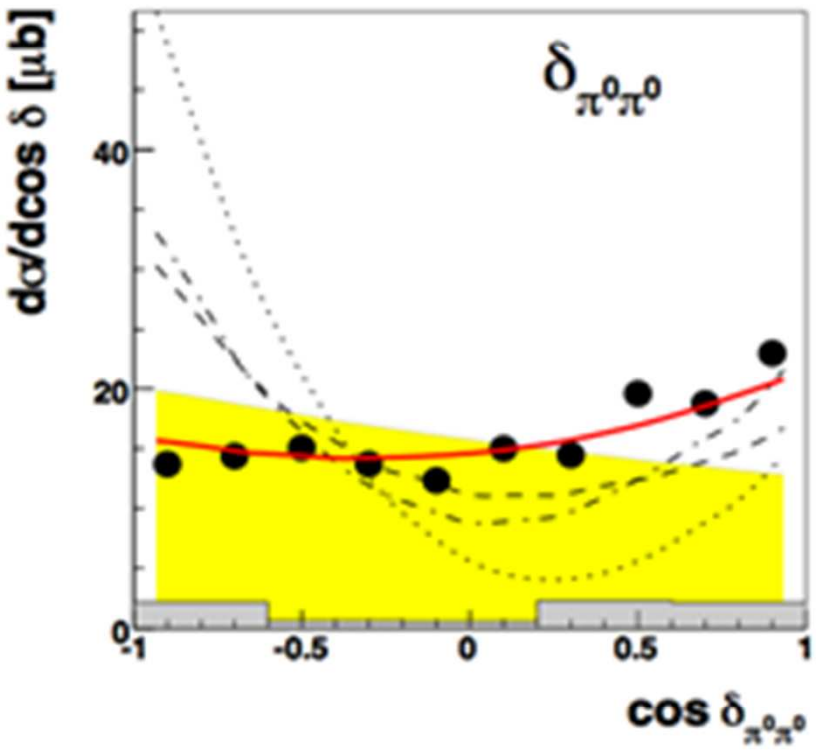
Influence of the modifications of the model

pp -> pp$\pi^0\pi^0$ at T_p = 1.2 GeV WASA





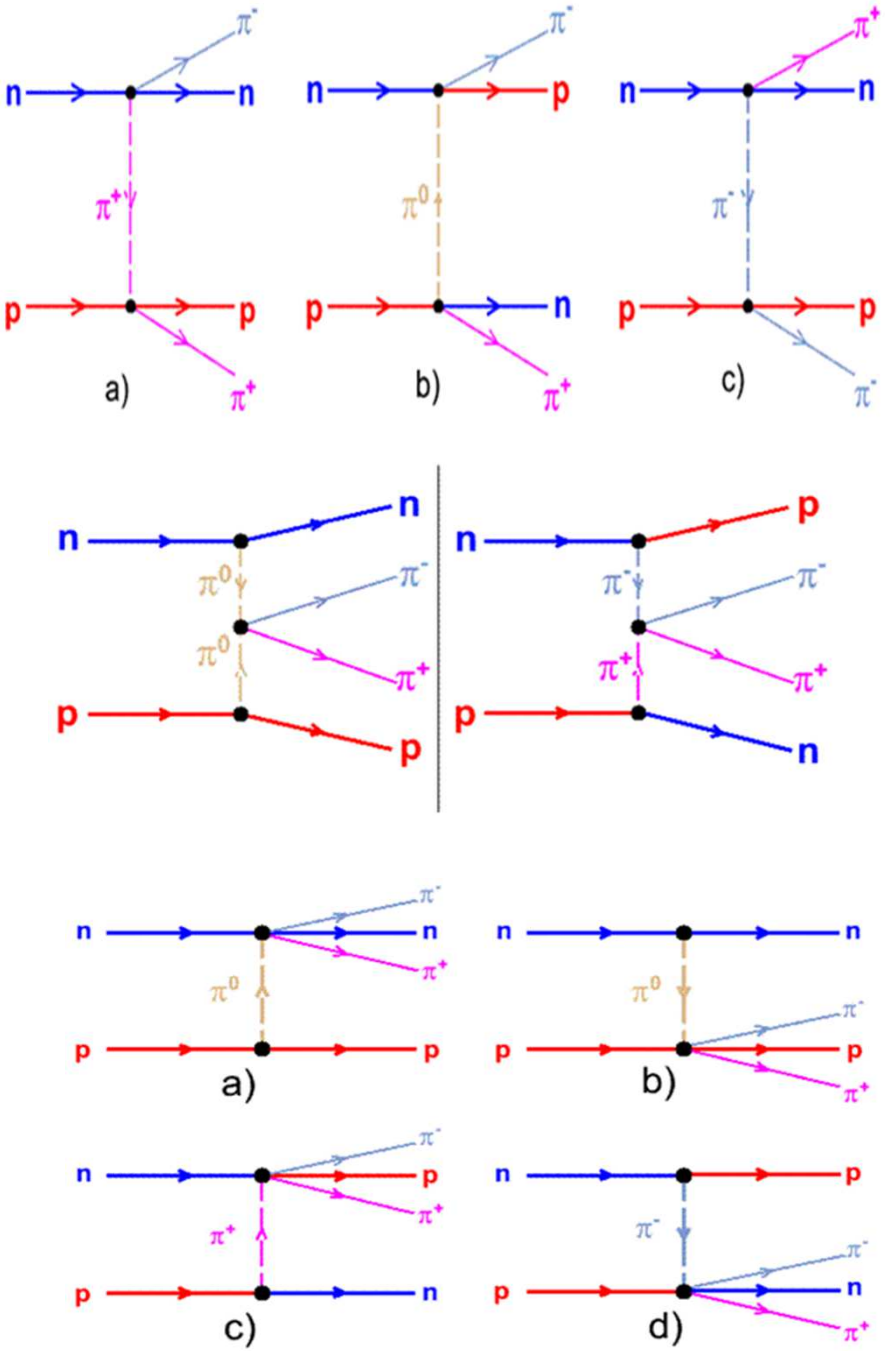
dotted : original model

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

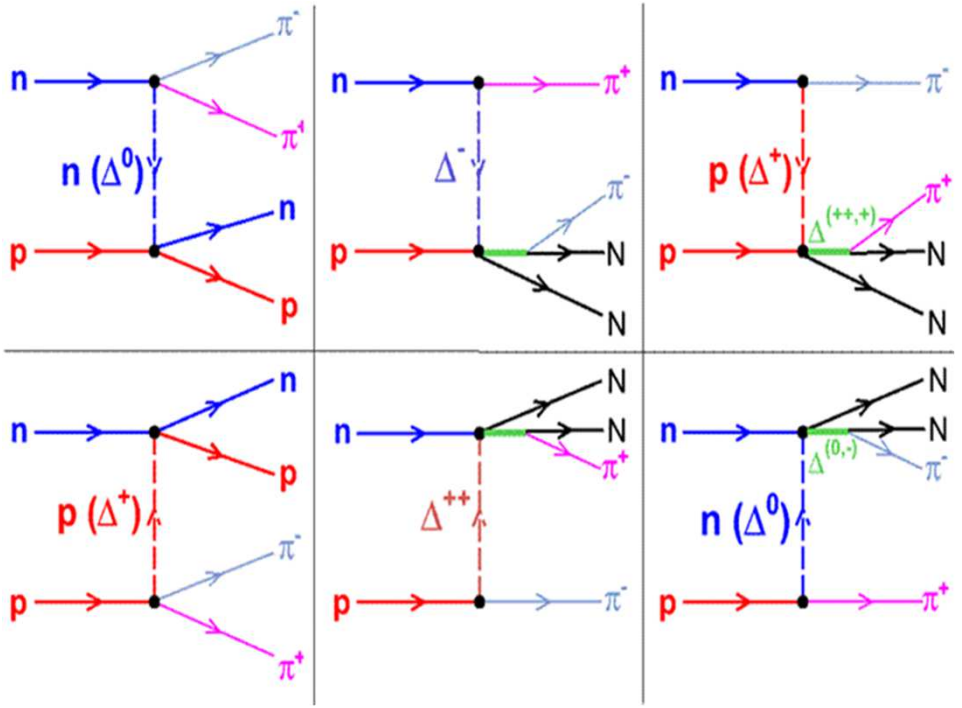
dashed-dotted : (2) readjustment of strength of the N*(1440)

red: (3) ρ exchange in double Δ excitation

Model : OPER (A.P.Jerusalimov)

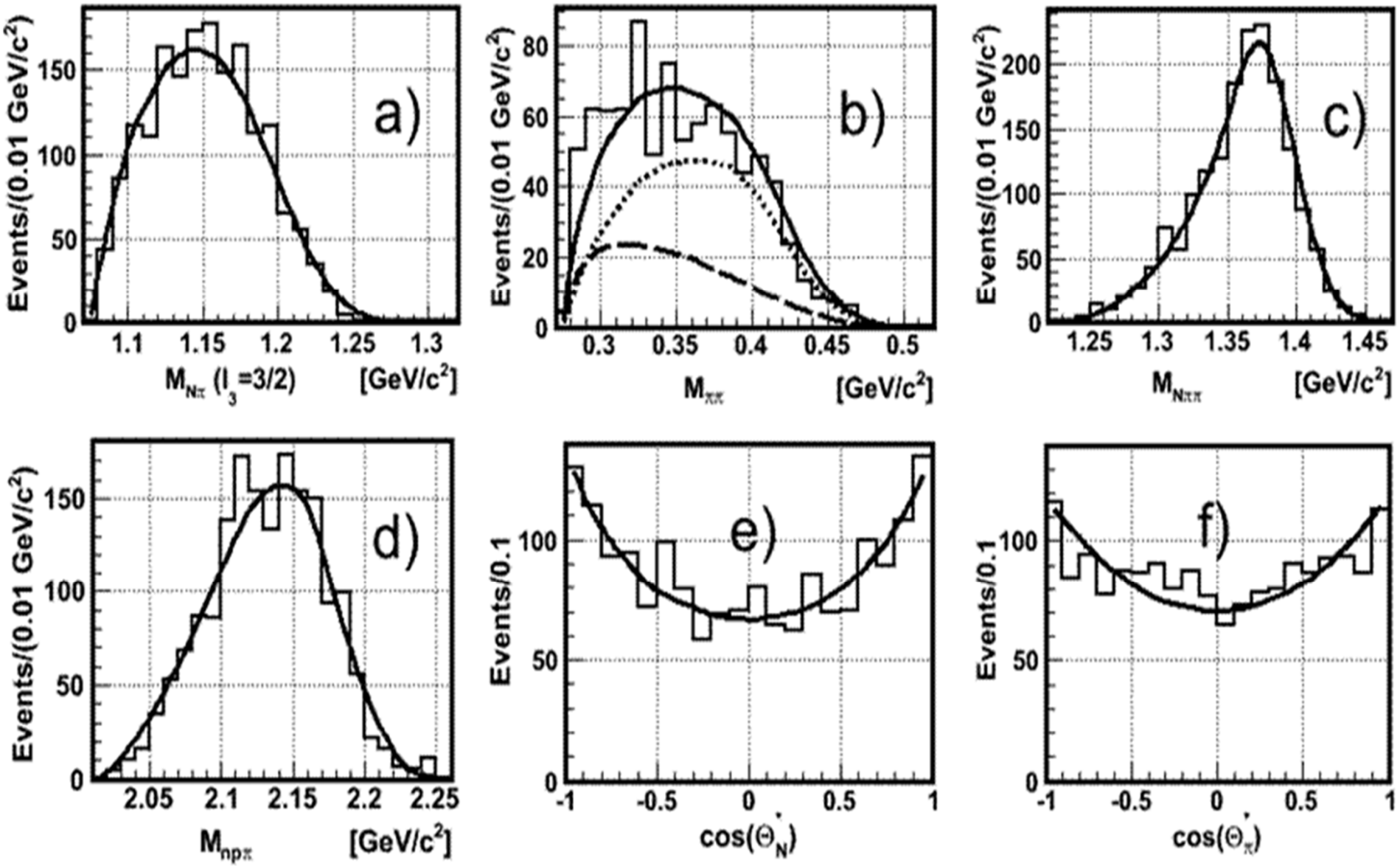


diagrams OPE



diagrams OBE

Experimental distributions for np→npπ+π- at p 1.73 GeV/c



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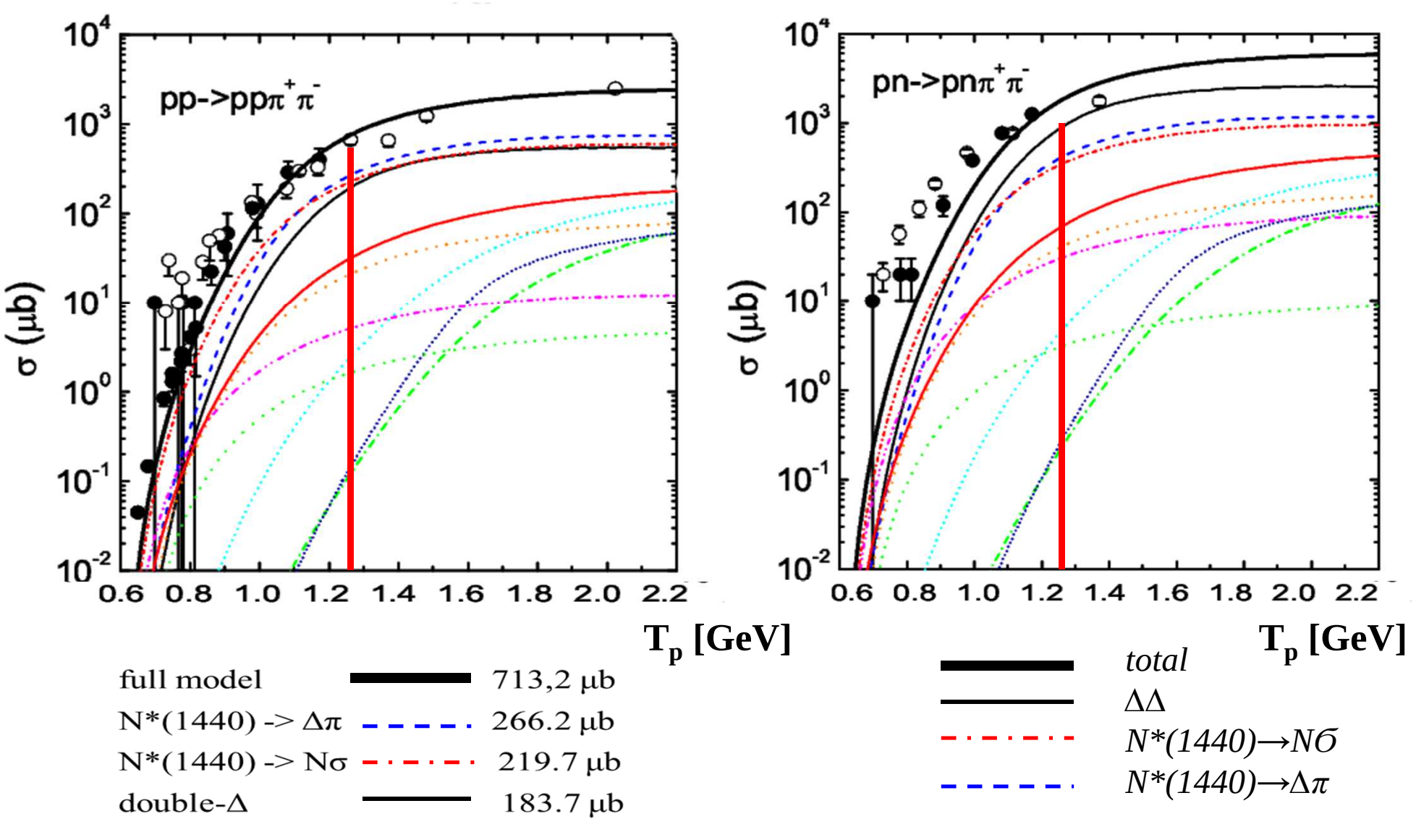
- cos of opening angle in CM between $\pi^+\pi^-$ ($\cos(\alpha_{\pi^+\pi^-}\mathrm{CM})$)

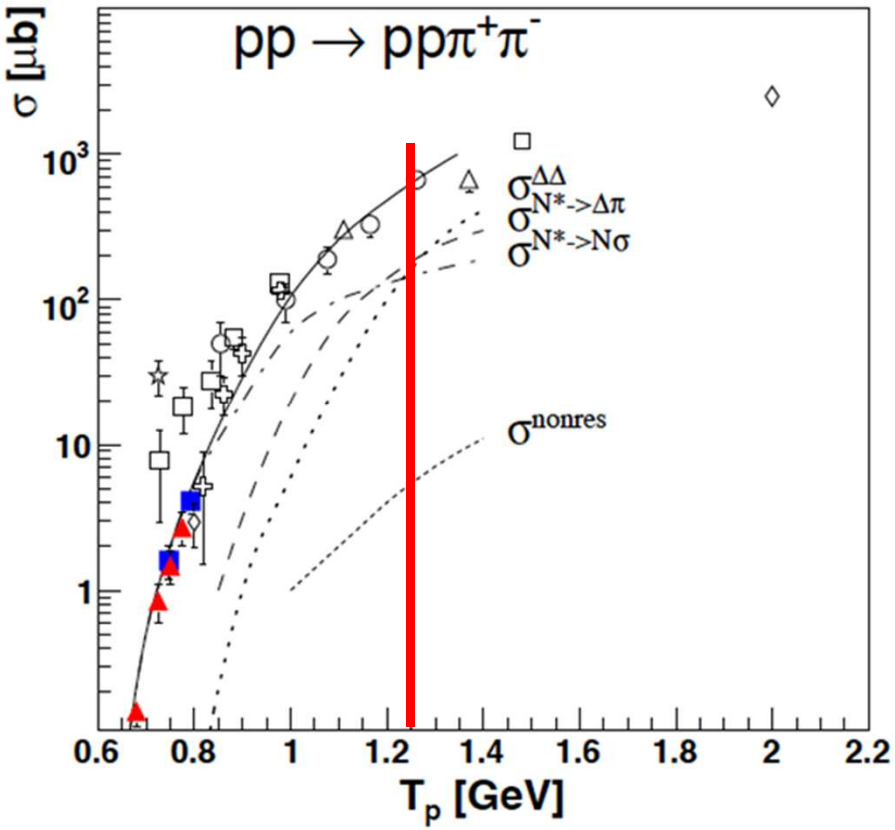
Predictions of Xu Cao model for the NN→NNπ⁺π⁻ reactions

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

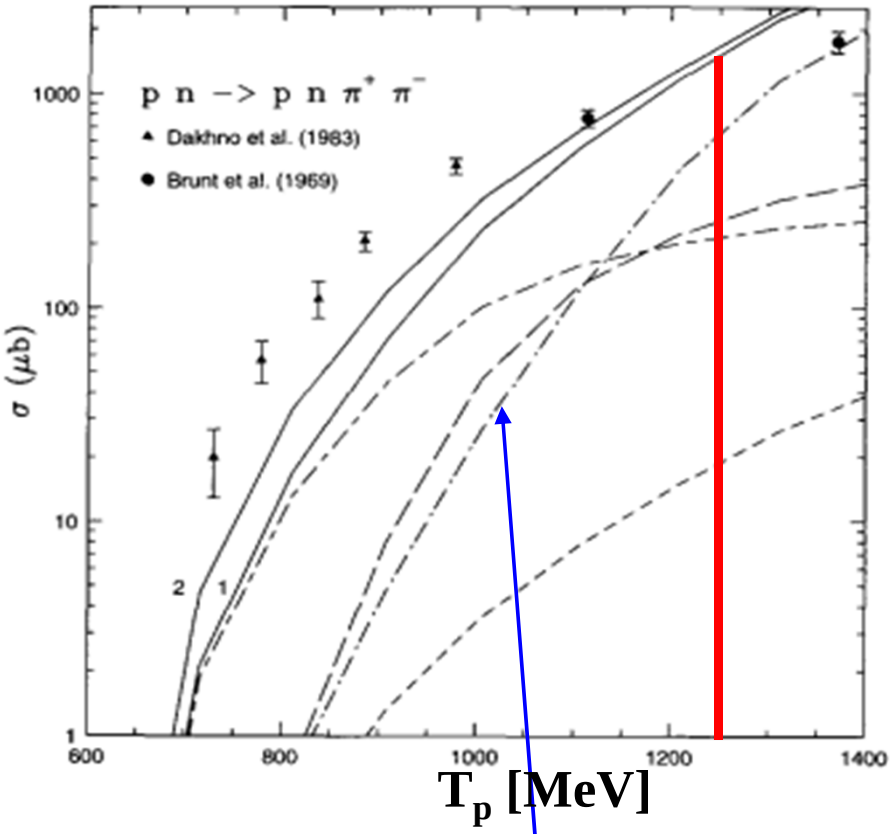


Predictions of Valencia model for the NN→NNπ⁺π⁻ reactions

L.Alvarez-Ruso, E.Oset et al., Nucl. Phys. A633(1988) 519-543



full model	728.86 μb
N*(1440)->πΔ	210.60 μb
N*(1440)->Nσ	170.61 μb
$\Delta_{S\text{-wave}}$ & ΔΔ	180.08 μb
non-resonant part	5.66 μb



full model

N(1440)→Δπ*

N(1440)→Nσ*

ΔS-wave & ΔΔ

Non - resonant