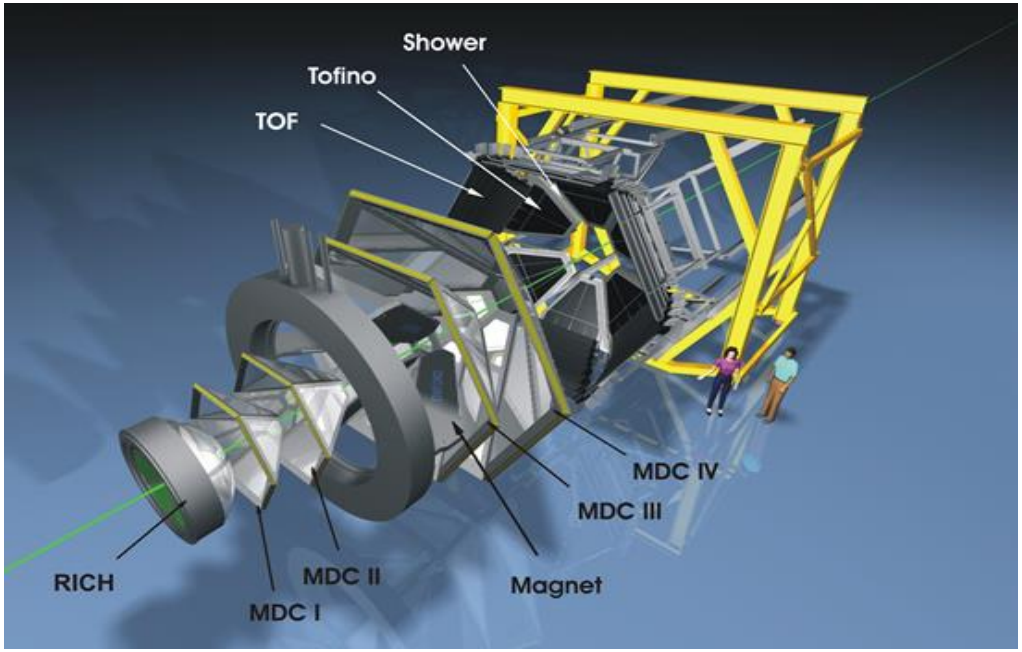
Measurement of the quasi free $np \rightarrow np\pi^+\pi^-$ and $np \rightarrow pp\pi^-\pi^0$ reactions at 1.25 GeV with HADES



Aleksey Kurilkin for the HADES collaboration
JINR, Dubna, Russia

MESON-2014

29th May - 3rd June, Krakow, Poland.

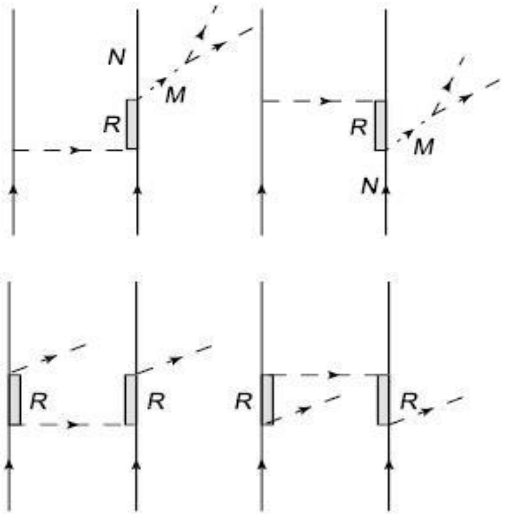
Outline

- Introduction:
  motivation, world data
- HADES experiment and Data analysis
- Results
  two-pion production, comparison with the models
- Conclusion

Motivation

➢ Two-π production in NN collisions is a very rich source of information about the baryon excitation spectrum and the baryon-baryon interaction properties.

➢ The particular interest of ππ production studies in comparison with the πN→ππN and γN → ππN reactions is the simultaneous excitation of the two baryons and their subsequent decays.

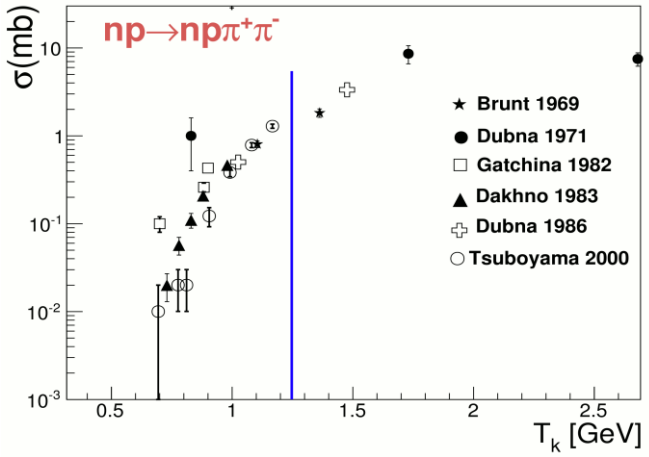


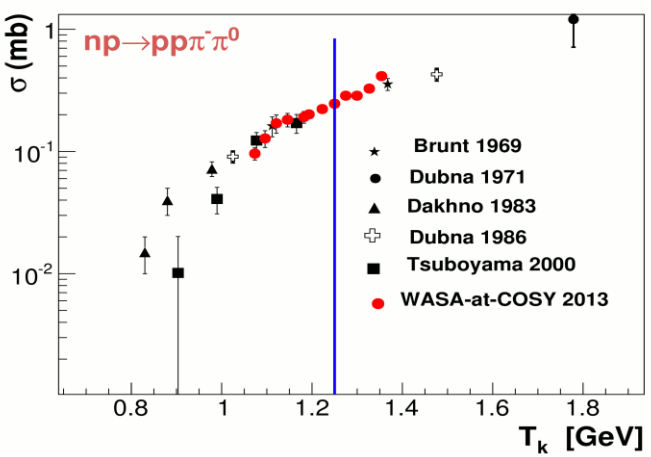
The data of NN collisions measured after the year of 2000 :

Channel	**Facilities (Tp)**
$pp \rightarrow pp\pi^+\pi^-$	CELSIUS, Gatchina, COSY, KEK (650 – 1360 MeV)
$pp \rightarrow pp\pi^0\pi^0$	CELSIUS(650 – 1400 MeV)
$pp \rightarrow nn\pi^+\pi^+$	CELSIUS(800 – 1100 MeV)
$pp \rightarrow pn\pi^+\pi^0$	CELSIUS(725 – 1100 MeV)
$pn \rightarrow pn\pi^+\pi^-$	KEK(698 – 1172 MeV)
$pn \rightarrow pp\pi^-\pi^0$	KEK, COSY (698 – 1357 MeV)

Studies ππ production from np collisions provide the information on the reaction amplitudes with the isospin zero NN initial state necessary for isospin decomposition.

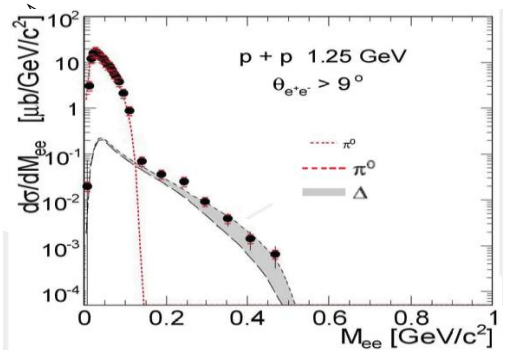
Motivation

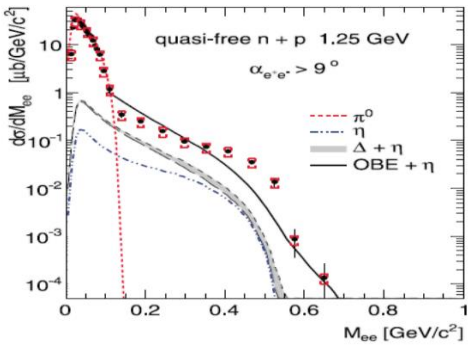


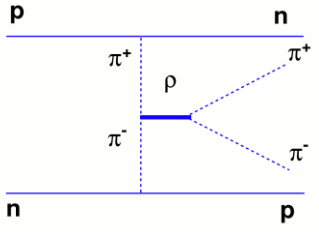


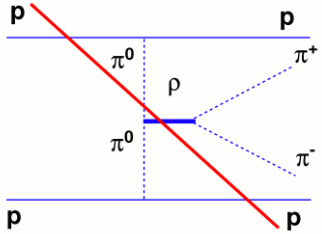
➢ Specific interest in np collisions at 1.25 GeV is the study of Δ(1232) →Nπ, N*(1440)→ Δπ, N*(1440)→ Nσ, N*(1440) → ρN, ΔΔ excitation, high-lying resonances.

➢ Since the $\pi^+\pi^-$ pair in np reaction can be produced in the ρ channel, the comparison $\pi^+\pi^-$ production in np and pp collisions could shed some light on the origin of the very large isospin dependence of the dilepton emission observed by the HADES experiment. *(G. Agakishiev et al. Phys. Lett.B690, (2010) 118)*





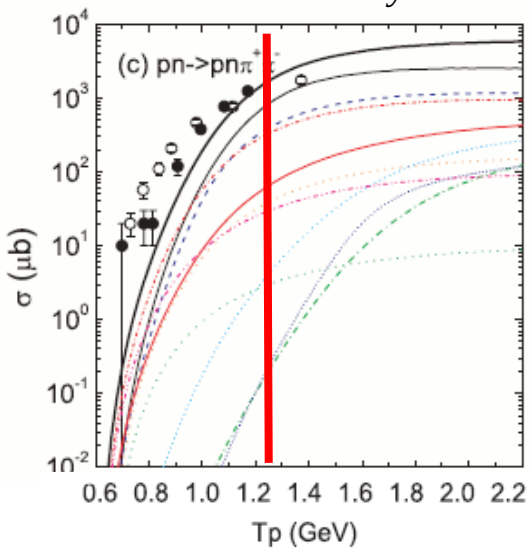


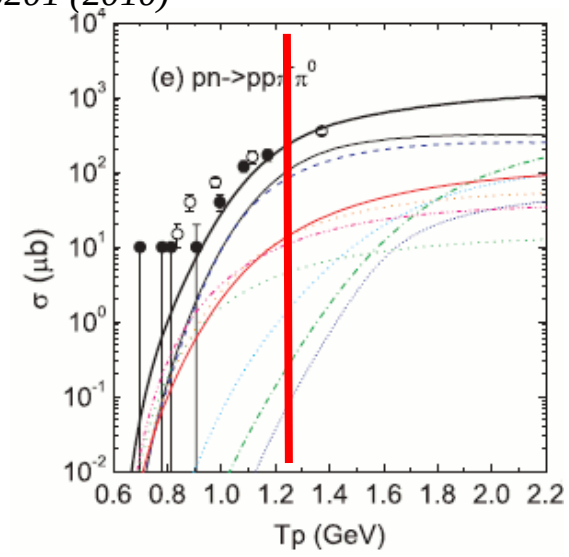


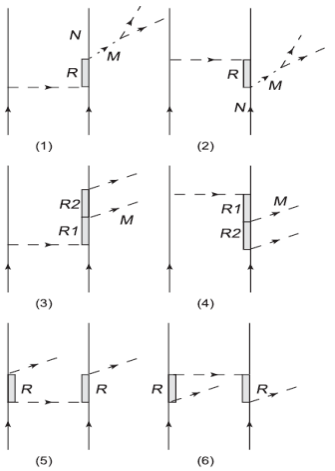
mesons and resonances are dilepton sources!

Existing experimental data and theoretical models

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







ΔΔ — **N*(1440) → Nππ** — N*(1440) → Δπ

Main contributions at 1.25 GeV

np→npπ⁺π⁻ : ΔΔ

np→ppπ⁻π⁰ : ΔΔ, N*(1440) → Δπ

Existing models for the NN→NNππ reactions

- **OPER model :** *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))

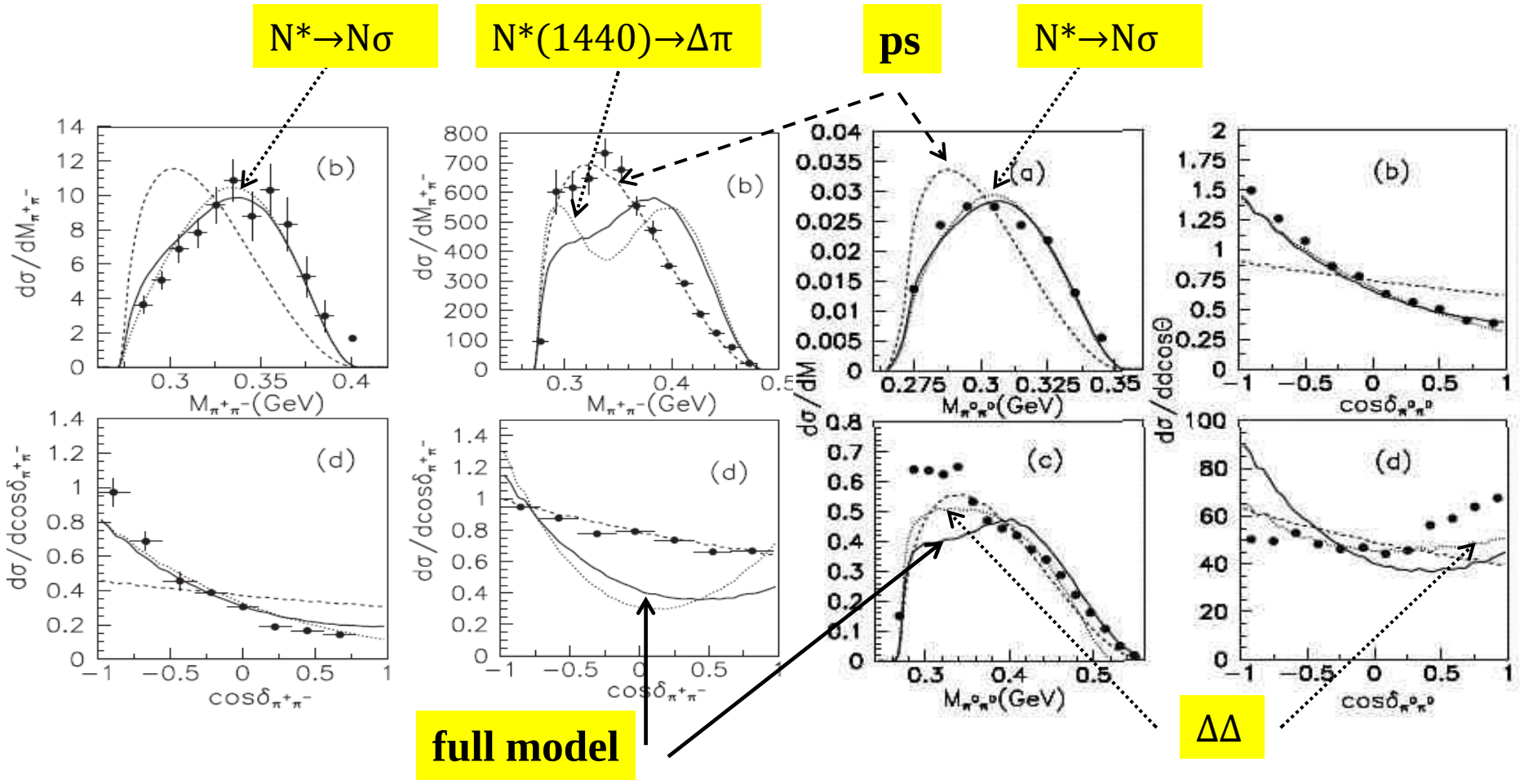
- **XuCao model :** *Xu Cao et al. Phys Rev C81, 065201 (2010)*

(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)*

Existing experimental data and Xu Cao model :



pp→ppπ⁺π⁻ : 0.895, 1.1 GeV

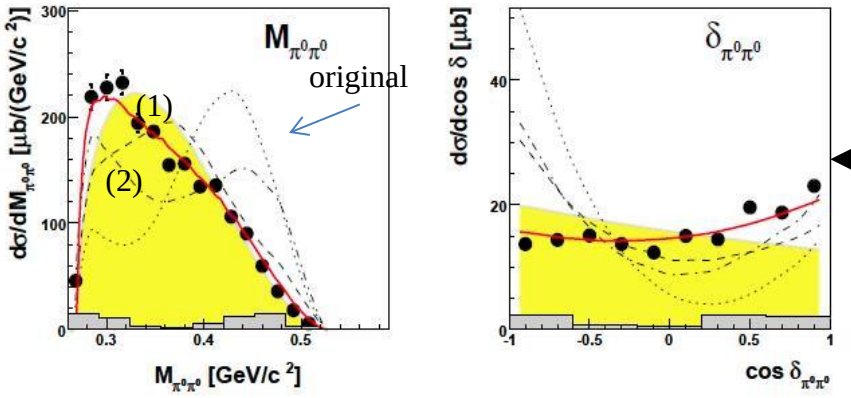
Xu Cao et al. Phys Rev C81, 065201 (2010)

pp→ppπ⁰π⁰ : 0.795, 1.3 GeV

Xu Cao et al. Int.J.Mod.Phys. A26 (2011)

Model well describes the measured differential cross sections of various isospin channels of double pion production in nucleon-nucleon collisions up to 2.2 GeV except some ππ spectra at energies above 1.1 GeV which are left as an open problem.

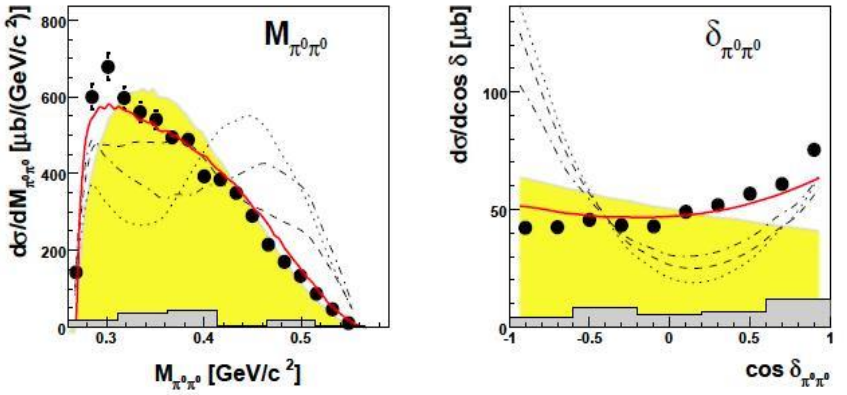
Existing experimental data and modified Valencia model

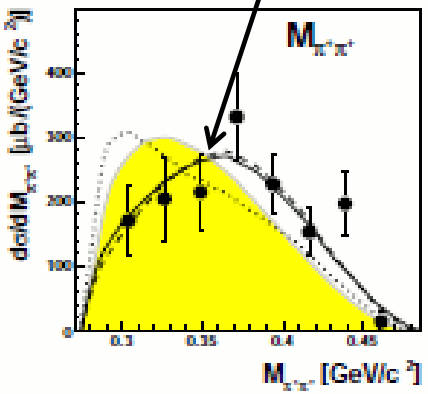


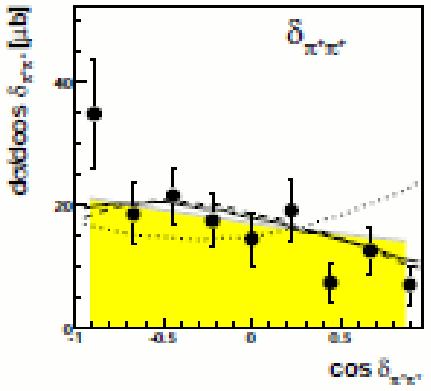
Influence of modifications of the model :

dotted : original Valencia model
dashed : (1) N*→Δπ and N*→Nσ branching ratio
dashed-dotted : (2) readjustment of strength of the N*(1440)
red : ρ exchange in ΔΔ excitation

… + Δ(1600) → Δπ







pp→pp$\pi^0\pi^0$: 1.2, 1.3 GeV

T.Skorodko et al. Phys.Lett. B695 (2011) 115-123

pp→nn$\pi^+\pi^+$: 1.1 GeV

T.Skorodko et al. Eur.Phys.J. A47 (2011) 108

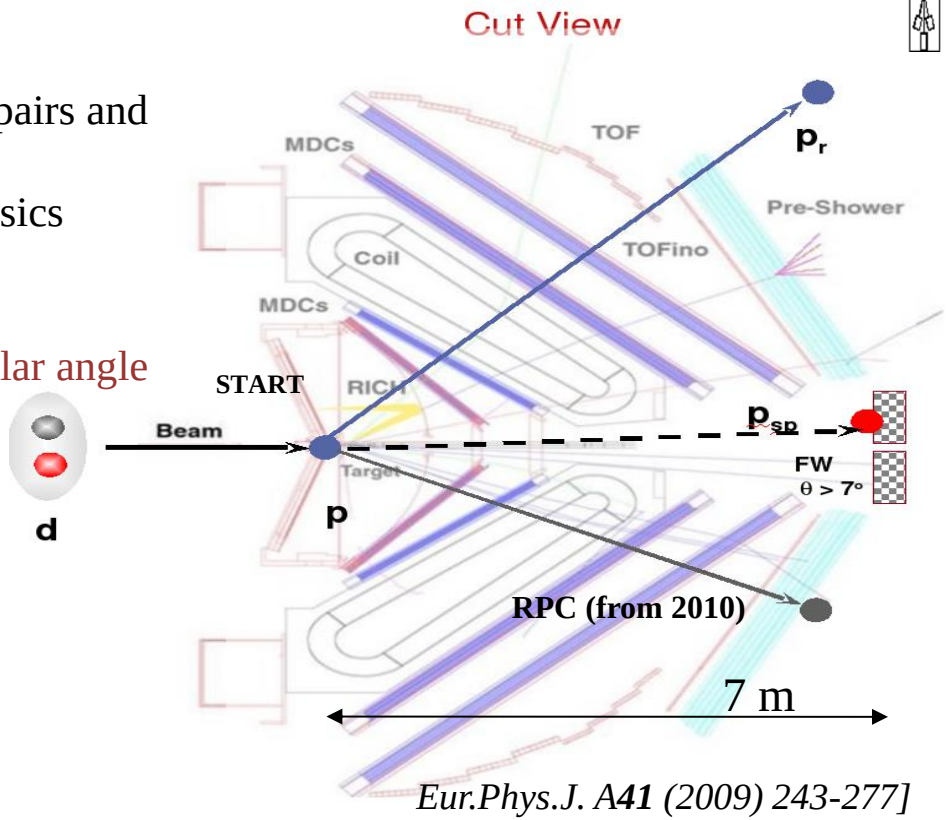
HADES data allow to test pion production mechanisms and the contribution of baryonic resonances with a high statistical precision at large Pt of secondary particles.

HADES experiment at SIS18, GSI

- **HADES strategy:**
  - ✓ Excitation function for low-mass lepton pairs and (multi-)strange baryons and mesons
  - ✓ Various aspects of baryon-resonance physics

- Beams provided by SIS18: π, proton, nuclei
- Full azimuthal coverage, 18 to 85 degree in polar angle
- Hadron and lepton identification
- Event-plane reconstruction

- e+e- pair acceptance 35%
- Mass resolution 2 % (ρ/ω region)



*Eur.Phys.J. A**41** (2009) 243-277]*

Detector components :

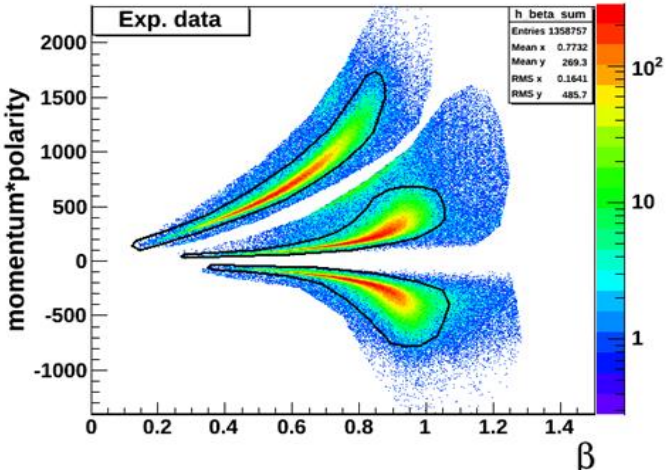
- ✓ RICH and SHOWER detector for lepton identification
- ✓ Multi-wire drift chambers(MDC) with magnetic field for momentum measurement and tracking information
- ✓ Time of flight detectors(TOF, TOFINO(RPC from 2010)) for timing and energy loss information
- ✓ Forward Wall(FW) detector to tagging proton spectator

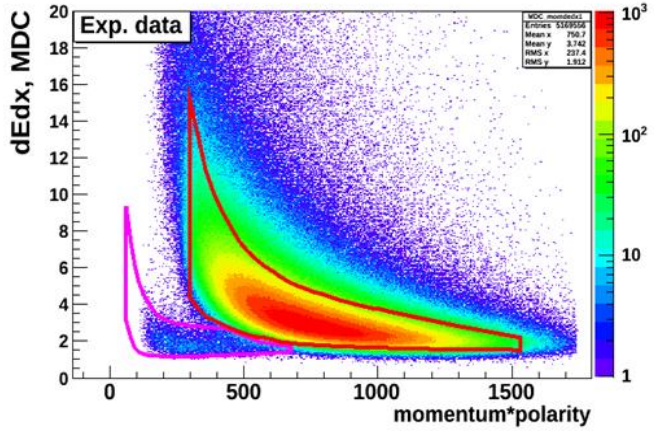
Kinematics for np :

- ✓ Kinetic Energy = 1.25 GeV
- ✓ Momentum = 1.97 GeV/c
- ✓ np selection by detecting Proton-spectator in FW

PID and selection of the reaction channel : $np \rightarrow np\pi^+\pi^-$

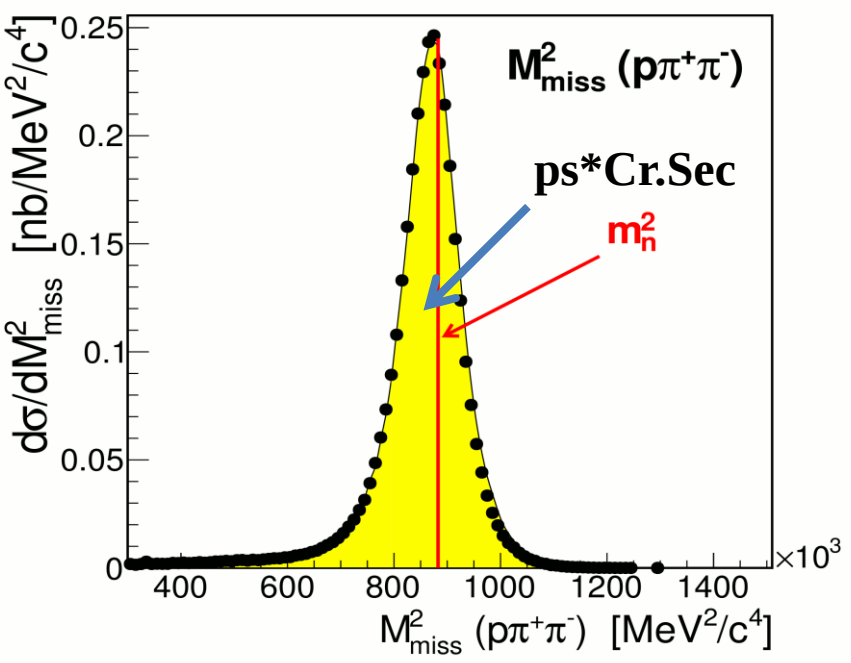
Time of flight is relative (no START detector). Time of flight reconstruction was based on tracking information + hypothesis.





& proton spectator in Forward Wall

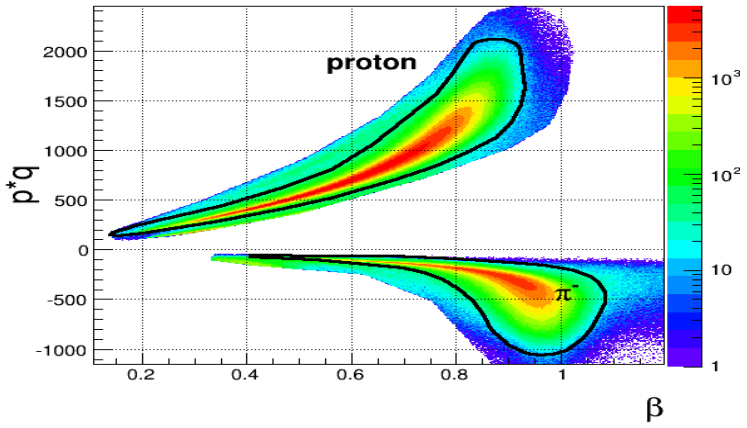
Each combination($p\pi^+\pi^-$) must fit into PID cuts. The best combination (the lowest $\chi 2$) wins.



Simulation : phase space with taking into account the energy dependence of the total cross section according to :
J.Bystricky J.Physique 48 (1987)

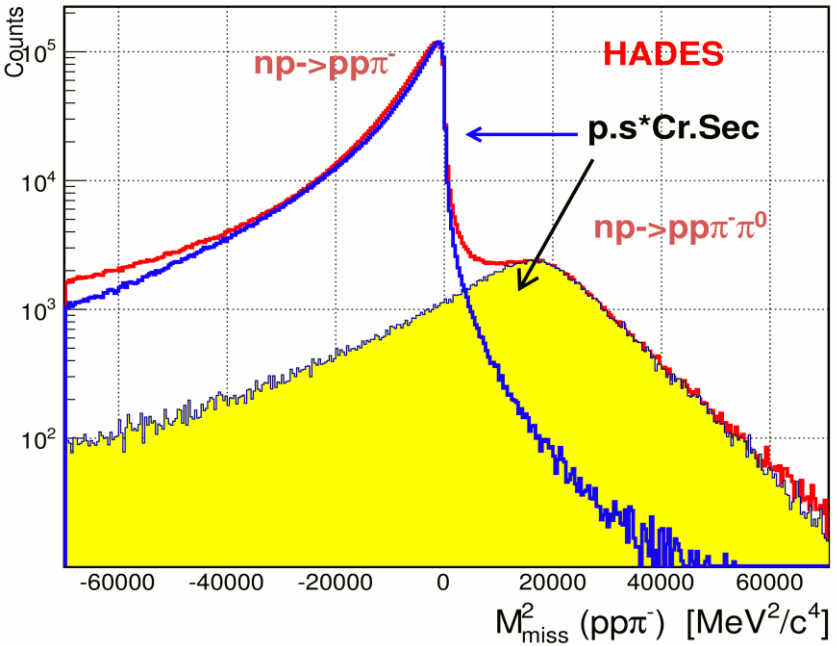
PID and selection of the reaction channel : $np \rightarrow pp\pi^-\pi^0$

Time of flight is relative (no START detector). Time of flight reconstruction was based on tracking information + hypothesis.



& proton spectator in Forward Wall

Each combination($pp\pi^-$) must fit into PID cuts. The best combination (the lowest $\chi 2$) wins.



Additional criteria : M^2_{miss} >=20000

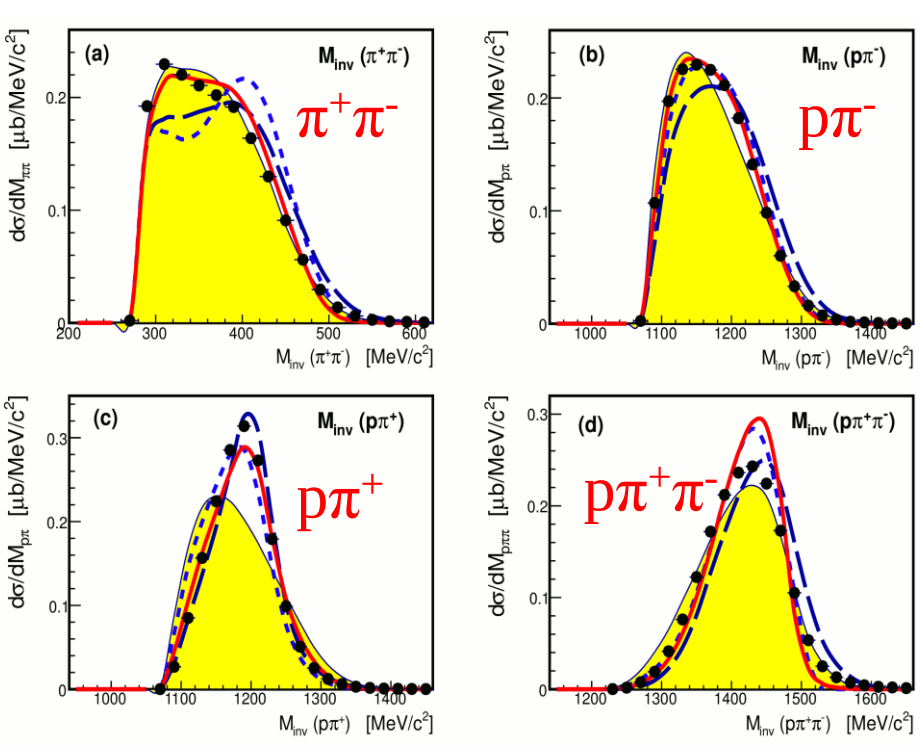
Simulation : phase space with taking into account the energy dependence of the total cross section according to :
J.Bystricky J.Physique 48 (1987)

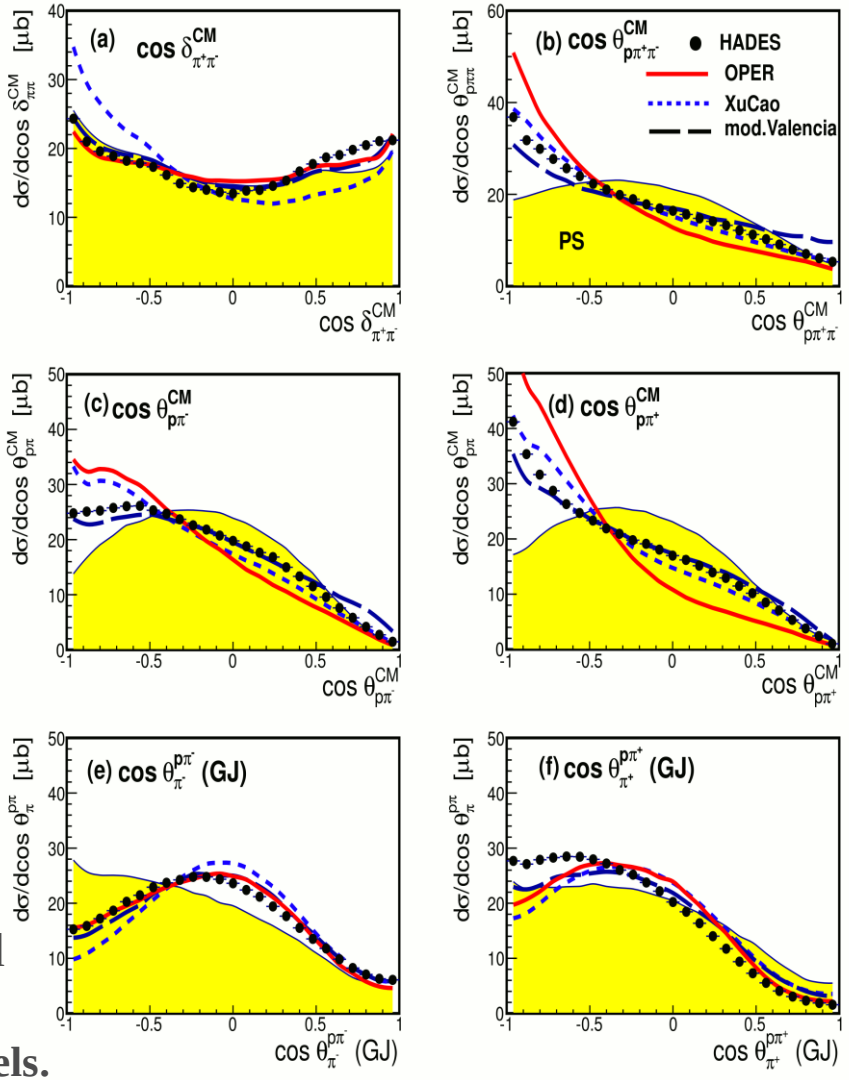
Results : comparison of the models with HADES data

- Data corrected for the tracking and PID efficiency.

- Models filtered by the acceptance, normalized to the area of experimental data.

Comparison HADES data with models : $np \rightarrow np\pi^+\pi^-$ at 1.25 GeV





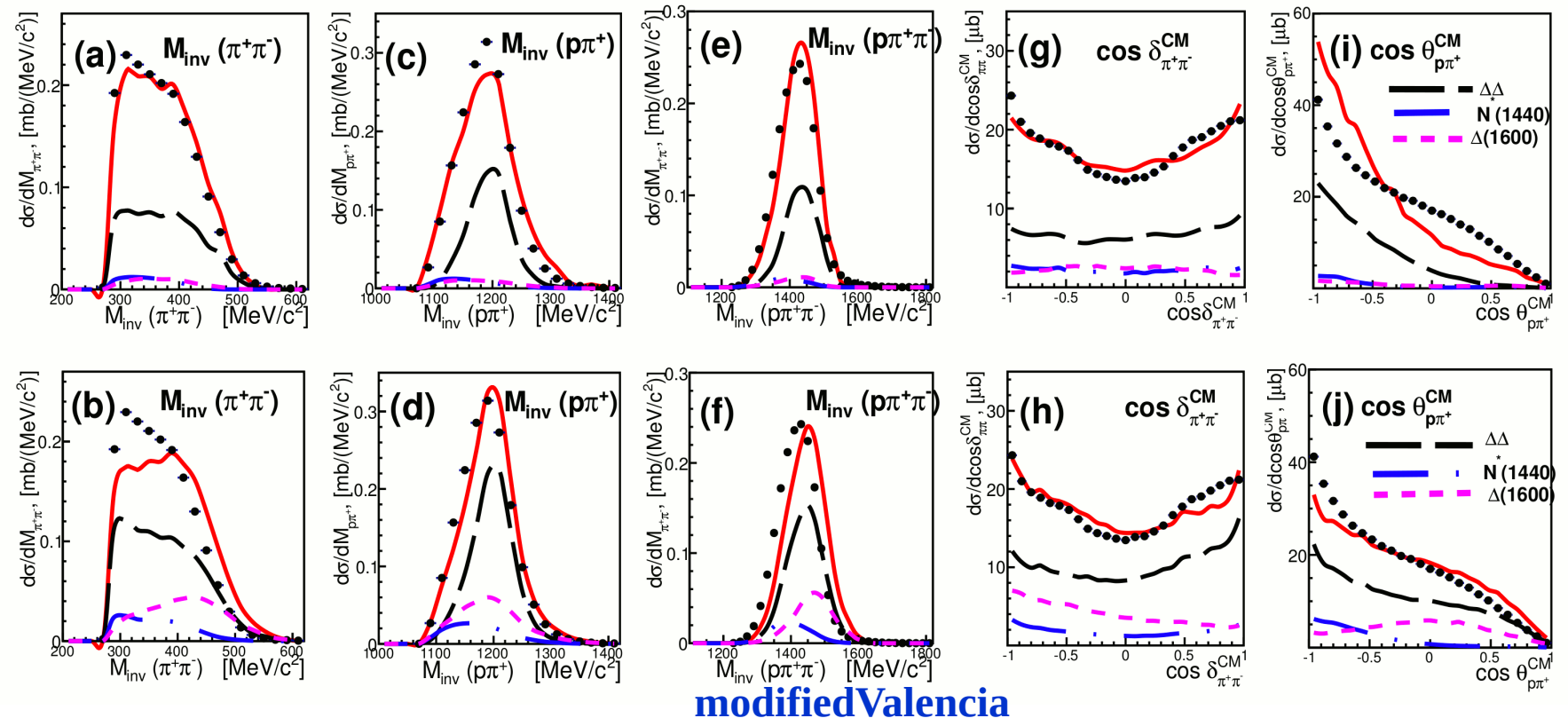
Models : OPER, XuCao, modified Valencia

- ✓ Models are filtered by acceptance and normalized to area of experimental yield.
- ✓ **Data shows sensitivity to different inputs of the models.**
- ✓ None of the models is able to explain all experimental distributions simultaneously.
- ✓ OPER and Valencia models work generally better

Comparison HADES data with models : $np \to np\pi^+\pi^-$ at 1.25 GeV

Resonances contributions in OPER(*upper panels*) and modified Valencia (*lower panels*)

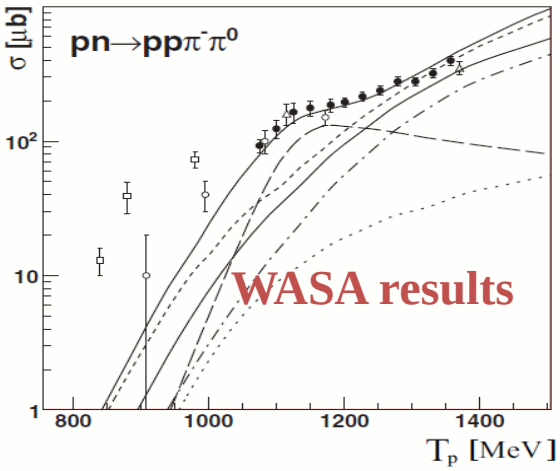
ΔΔ, N*(1440) , Δ(1600)

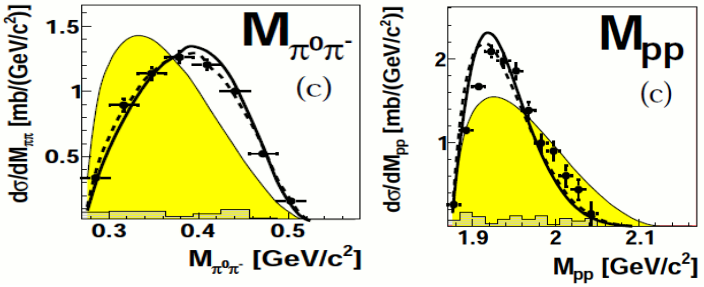


OPER : ΔΔ excitation dominates, contributions of N*(1440) and Δ(1600) is small.

Modified Valencia : ΔΔ excitation dominates, large Δ (1600) contribution is not favoured by data.

Comparison HADES data with models : $np \rightarrow pp\pi^-\pi^0$ at 1.25 GeV

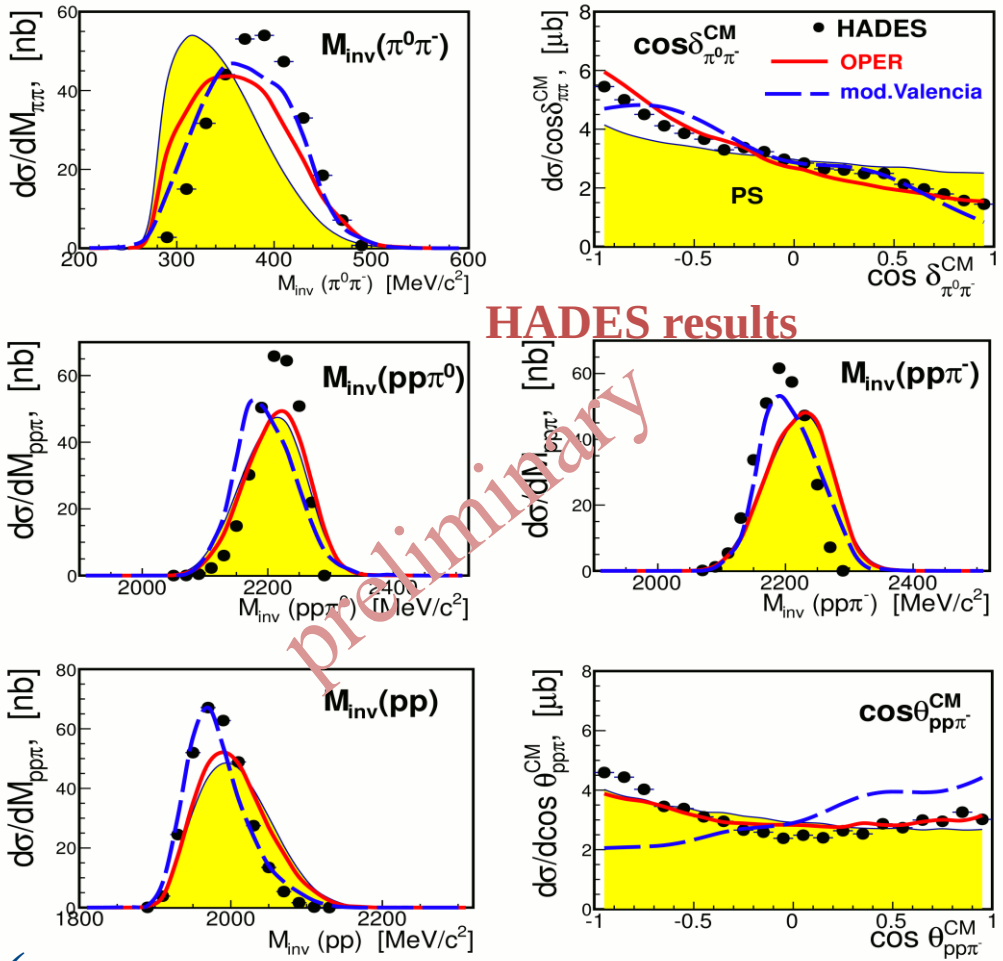




P.Adlarson et al, Phys.Rev. C88 (2013)

$np \rightarrow pp\pi^-\pi^0$ channel is consistent with d* hypothesis (m= 2.37 GeV with Γ = 70 MeV and $I(J^P) = 0(3^+)$)

P. Adlarson et. al. Phys. Rev. Lett 106, (2011)



- ✓ Models are filtered by acceptance and normalized to area of experimental yield.
- ✓ **Data shows sensitivity to different inputs of the models.**
- ✓ None of the models is able to explain all experimental distributions simultaneously.

Summary and outlook

- HADES provides high statistics data on ππ production in np@1.25 GeV

- Comparison of ππ production in np @ 1.25 GeV with the theoretical models has been performed inside HADES acceptance :
  - ✓ modified Valencia model
  - ✓ Xu Cao et al. model
  - ✓OPER model

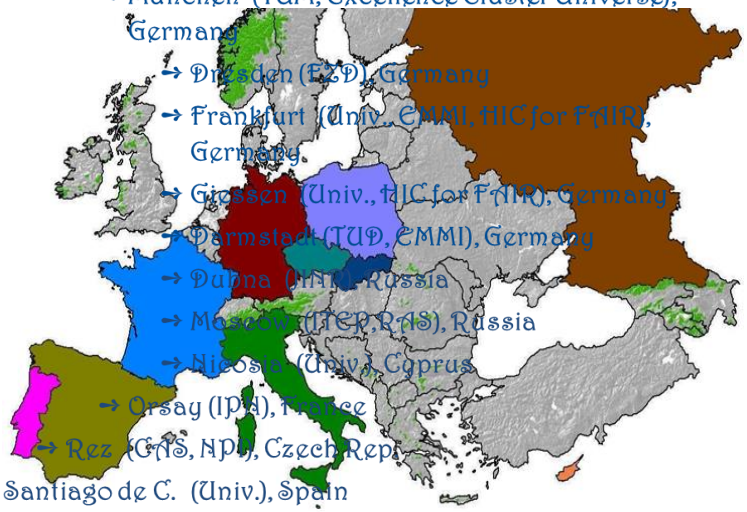
$np \rightarrow np\pi^+\pi^-$ channel :
- ✓ dominance of Δ Δ excitation
- ✓ contributions of N*(1440) and Δ (1600) are small

$np \rightarrow np\pi^+\pi^-$ and $np \rightarrow pp\pi^-\pi^0$ channels :
- ✓ strong constraints for existing models.

Impact:
- better description of the contribution of baryonic resonances to meson and dilepton production in NN and heavy-ion production
- independent checks for existence of $I(J^P) = 0(3^+)$ dibaryon (WASA results)

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



• 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)

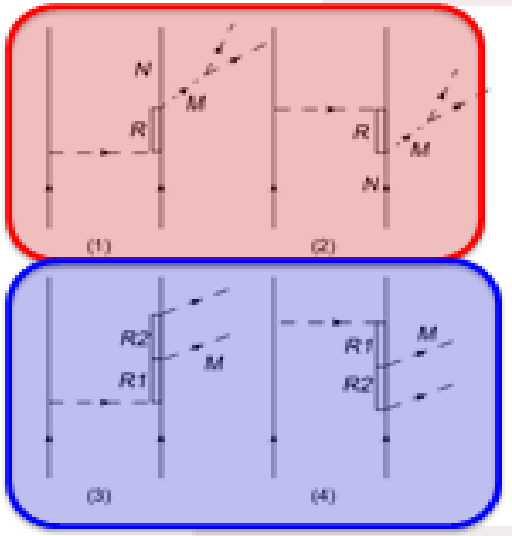
- *e+e- production in N+N – reference reactions for A+A*
- *single and double π production (barion resonances in N+N)*
- *η, ω, ϕ production- hadr.channels and rear $\eta \rightarrow$e+e- decays (new UL in PDG)*
- *Λ (1405), Σ(1385) (new PDG entry)*
- *K^0 production*

- *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*

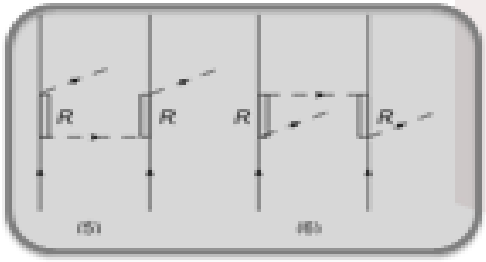
- *ρ/ω mesons in cold nuclear matter*
- *strangeness production K, ϕ*

Existing models for the pp->ppπ+π- reactions

N*(1440) -> Nσ



double-Δ N*(1440) -> Δπ

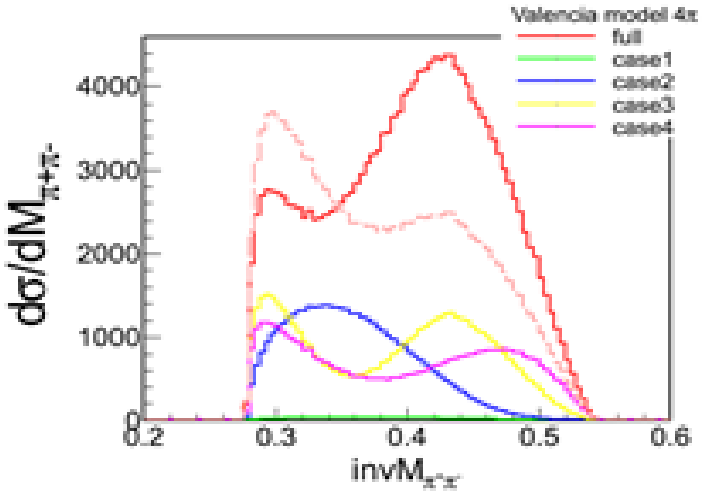


& exchange diagrams

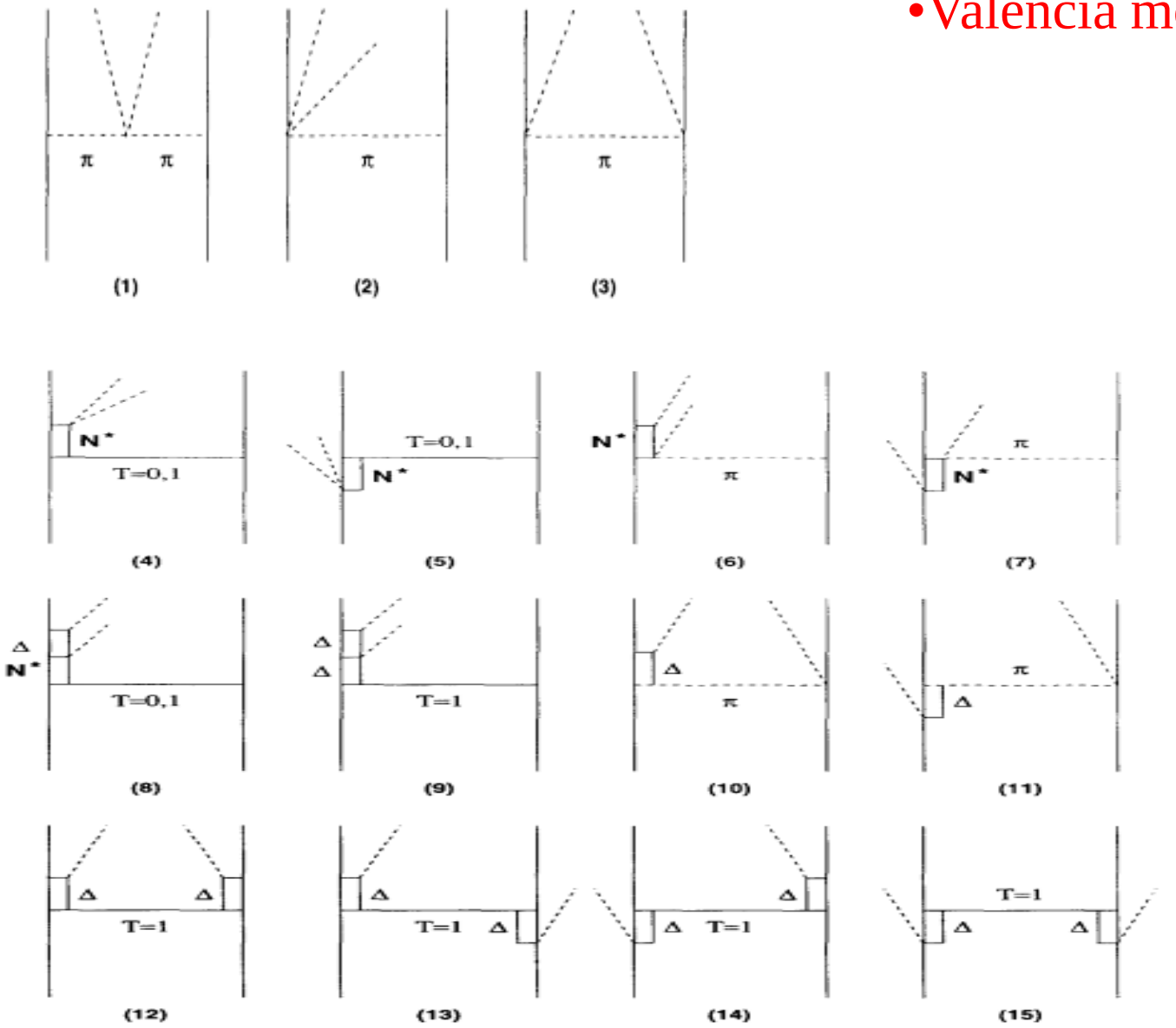
In Valencial model in addition we have:

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

Interferences between different diagrams included in the Valencia model



•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 -> 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)

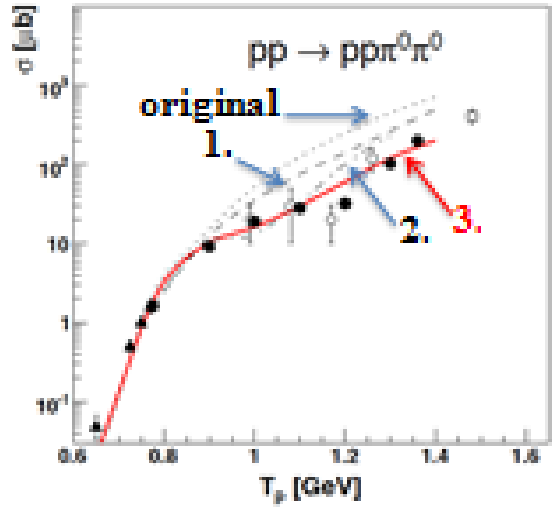
2. Strength of N*(1440)

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.

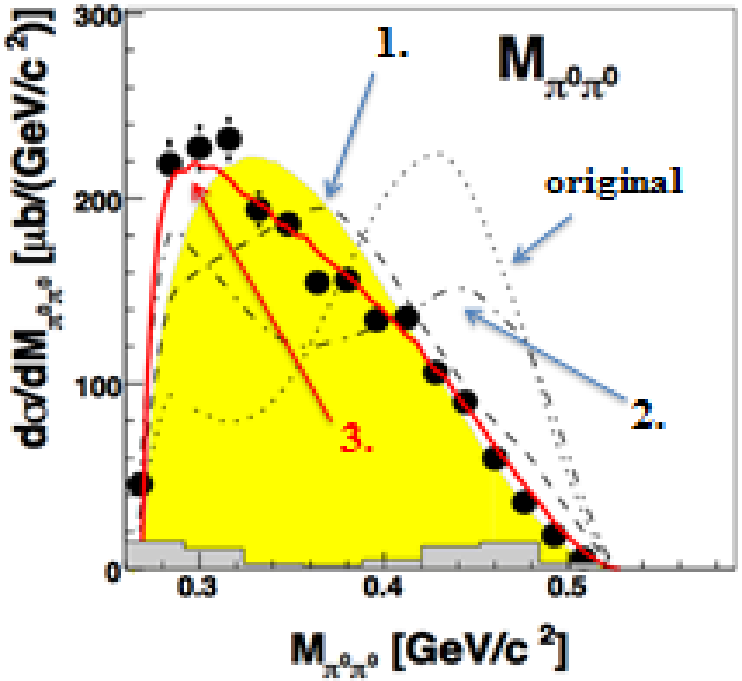
(ρ-exchange is not as wel fixed by exp. observables as π-exchange.)

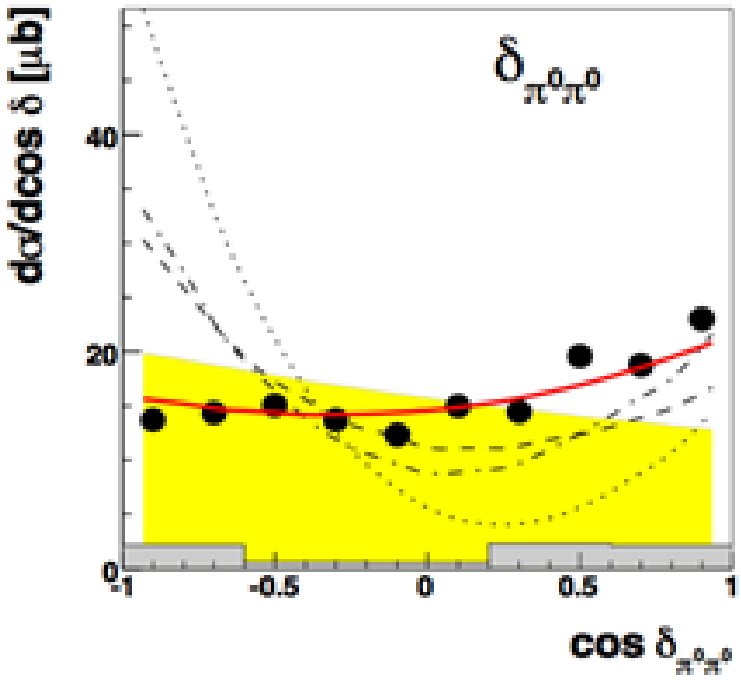


More details about the changes to the model can be found here:
Physics Letters B 679 (2009)30, Phys.Lett.B695: 115-123,2011

Influence of the modifications of the model

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





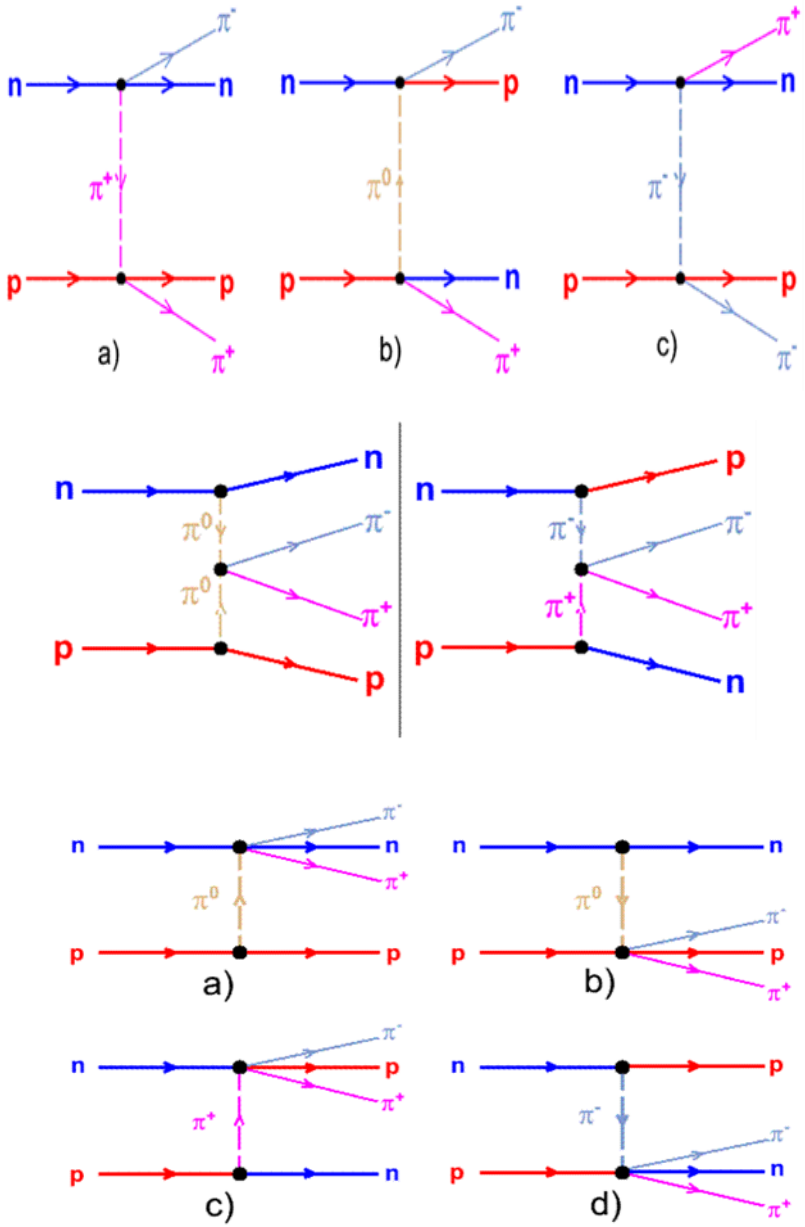
dotted : original model

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

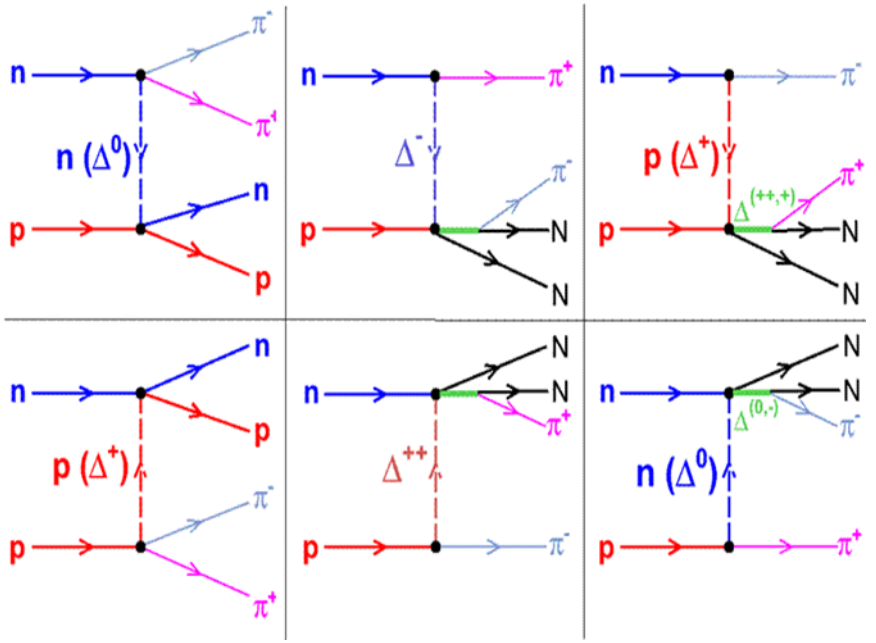
dashed-dotted : (2) readjustment of strength of the N*(1440)

red: (3) ρ exchange in double Δ excitation

•Model : OPER (A.P.Jerusalimov)

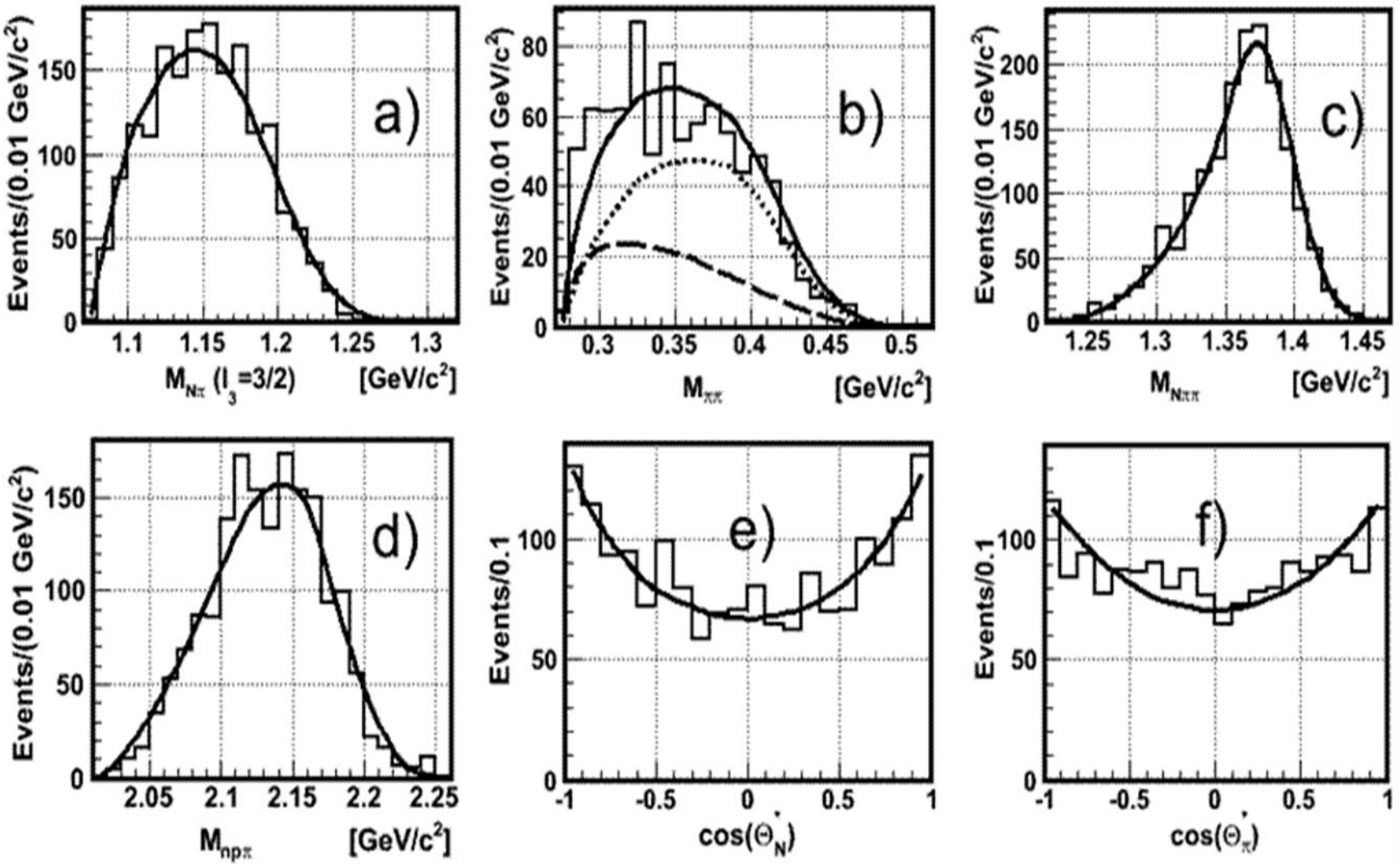


•diagrams OPE

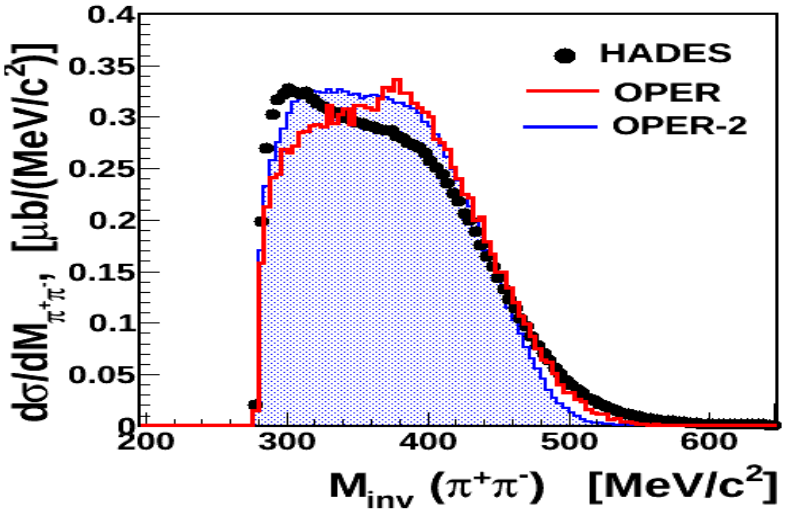


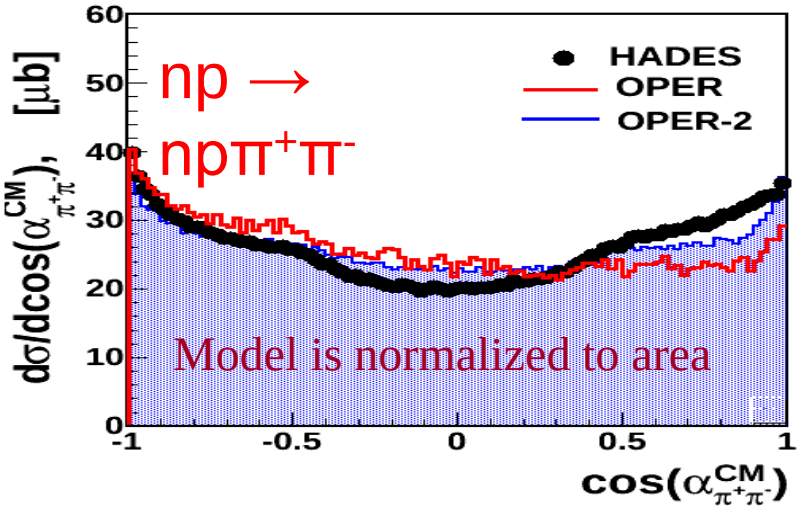
•diagrams OBE

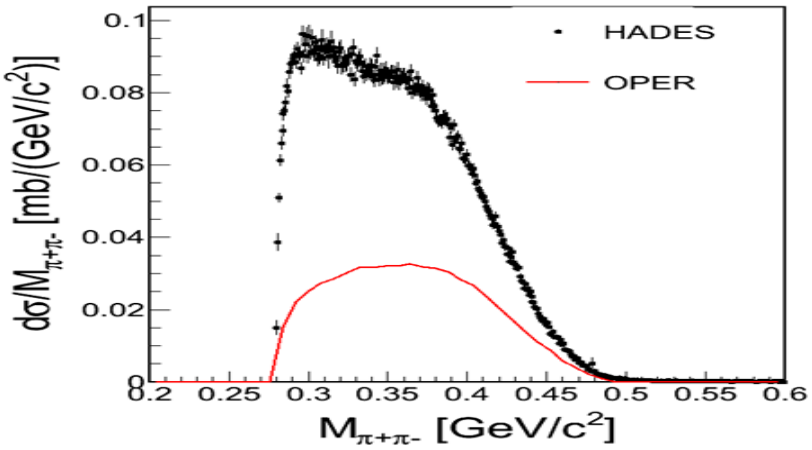
•Experimental distributions for np→npπ+π- at p 1.73 GeV/c

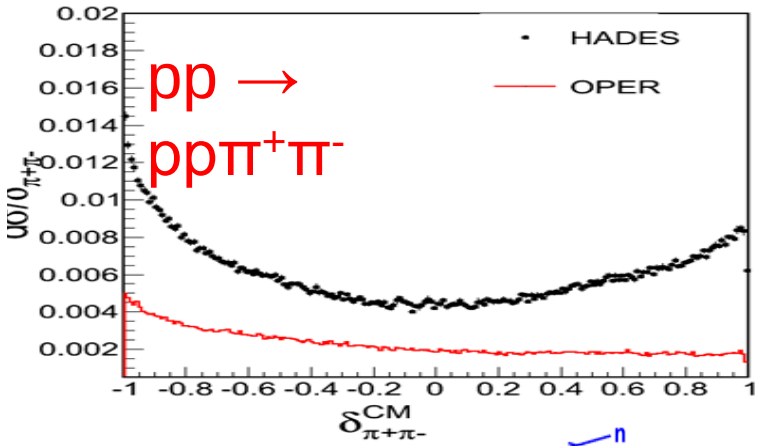


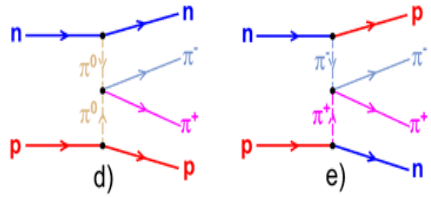
Comparison HADES data with OPER model











$M_{\pi^+\pi^-}$ and angular distributions for np → np $\pi^+\pi^-$ and pp → pp $\pi^+\pi^-$.
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]

Comparison HADES data with models : $np \rightarrow pp\pi^-\pi^0$ at 1.25 GeV