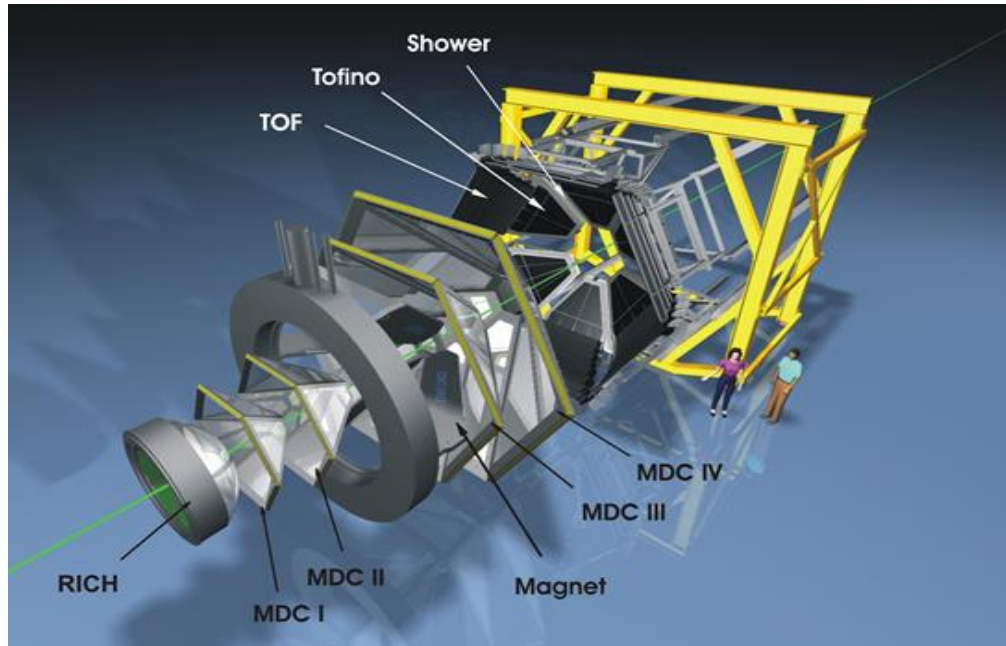
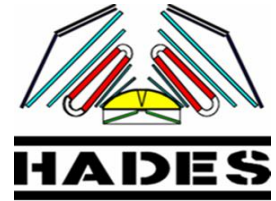


Measurement of the quasi-free $np \rightarrow np\pi^+\pi^-$ and $np \rightarrow pp\pi^-\pi^0$ reactions at 1.25 GeV with HADES



Aleksey Kurilkin for the HADES collaboration
JINR, Dubna, Russia

ISHEPP-2014

15th - 20th September, Dubna, Russia.

Outline

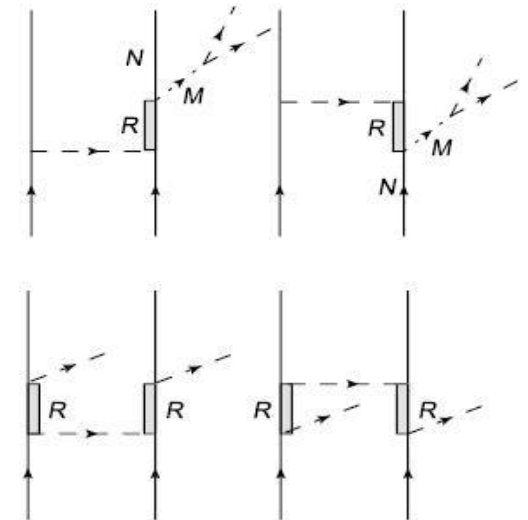
- Introduction:
motivation, world data
- HADES experiment and Data analysis
- Results
two-pion production, comparison with the models
- Conclusion

Motivation

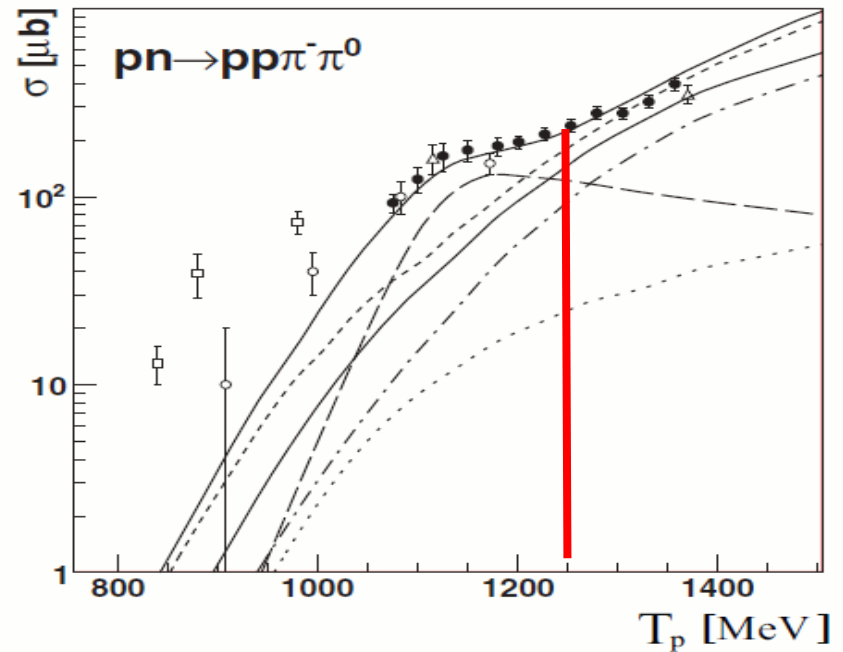
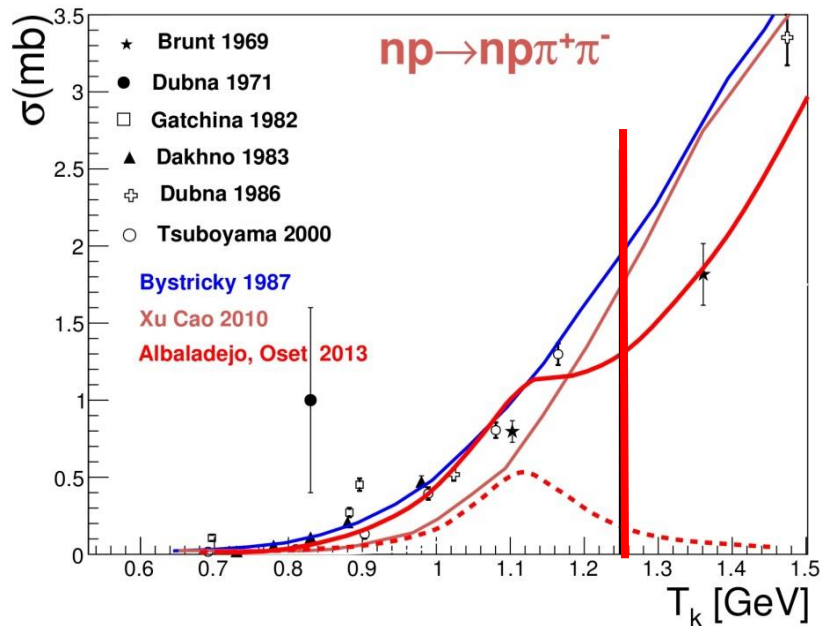
- Two- π production in NN collisions is a very rich source of information about the baryon excitation spectrum and the baryon-baryon interaction properties.
- The particular interest of $\pi\pi$ production studies in comparison with the $\pi N \rightarrow \pi\pi N$ and $\gamma N \rightarrow \pi\pi N$ 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)



Motivation

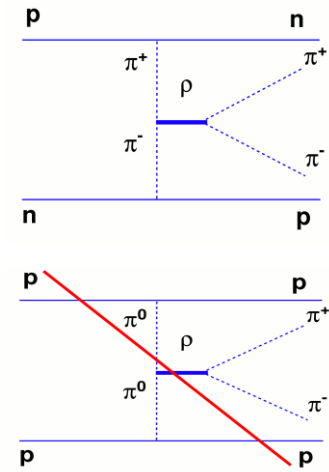
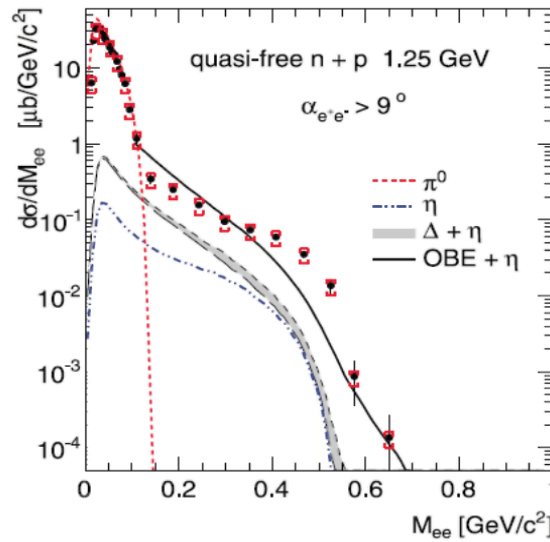
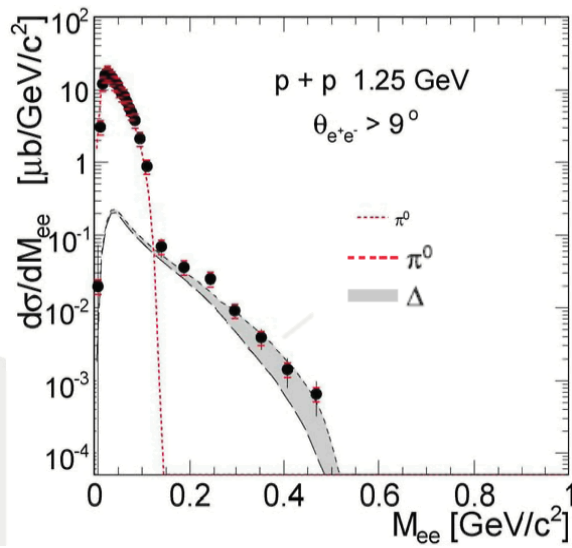


➤ Specific interest in np collisions at 1.25 GeV is the study of $\Delta(1232) \rightarrow N\pi$, $N^*(1440) \rightarrow \Delta\pi$, $N^*(1440) \rightarrow N\sigma$, $N^*(1440) \rightarrow \rho N$, $\Delta\Delta$ excitation, high-lying resonances.

➤ Independent checking for existence of d^* dibaryon (WASA results)
($m = 2.37$ GeV with $\Gamma = 70$ MeV and $I(J^P) = 0(3^+)$)

P. Adlarson et al. Phys. Rev. Lett. 106, 242302 (2011), Phys. Lett. B 721, 229 (2013), Phys. Rev. C 88 (2013) 5, 05520. M. Bashkanov et al., Phys. Rev. Lett. 102, 052301 (2009)

Motivation

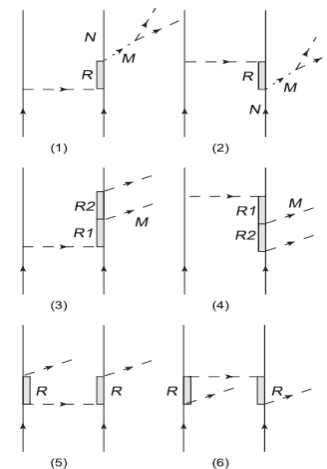
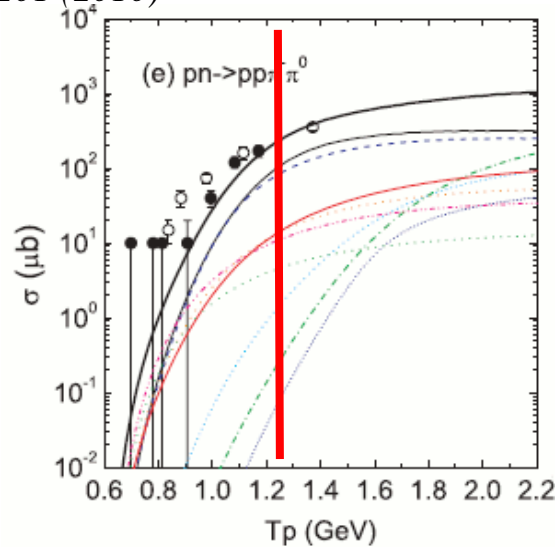
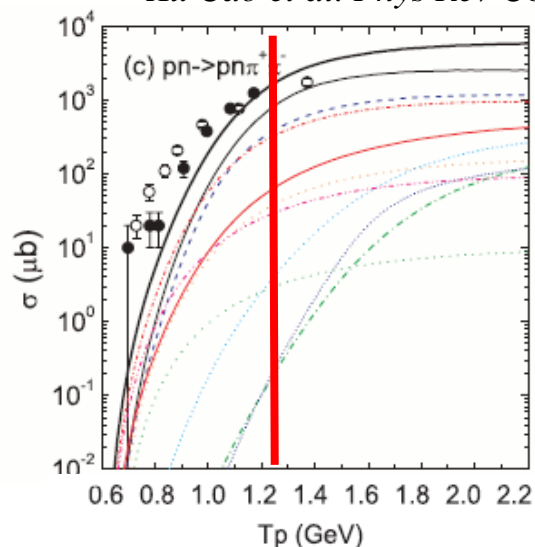


mesons and resonances are dilepton sources!

- Study of excitation of baryonic resonances coupled to the ρ meson for a better understanding of the dilepton production in NN reactions and also in nucleon matter due to the expected modifications of the meson spectral functions. (*S. Leupold et al. Int. J. Mod. Phys. E 19 (2010) 147*)
- 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*)

Existing experimental data and theoretical models

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



$\Delta\Delta$

$N^*(1440) \rightarrow N\pi\pi$

$N^*(1440) \rightarrow \Delta\pi$

Main contributions at 1.25 GeV

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

$np \rightarrow pp\pi^-\pi^0 : \Delta\Delta, N^*(1440) \rightarrow \Delta\pi$

Existing models for the $NN \rightarrow NN\pi\pi$ 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, $N^*(1440)$, $\Delta(1232)$)
- **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 $N^* \rightarrow N\sigma$ via Δ and direct, Strength of $N^*(1440)$, ρ exchange in double Δ excitation was suppressed by factor of 12)

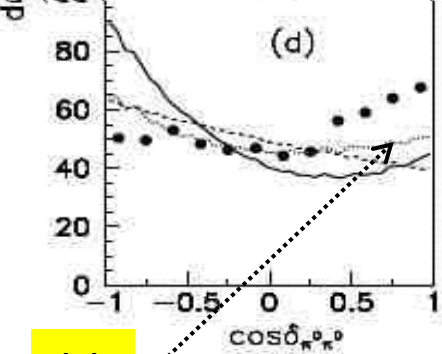
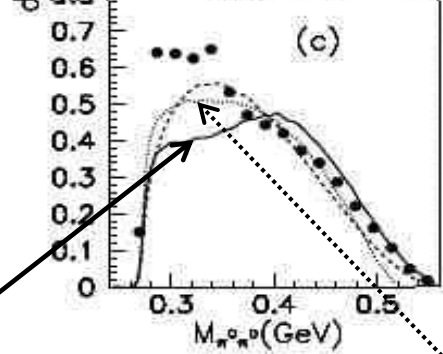
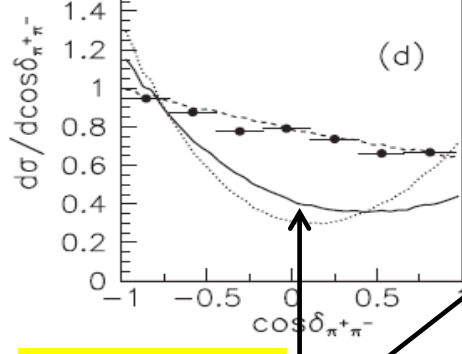
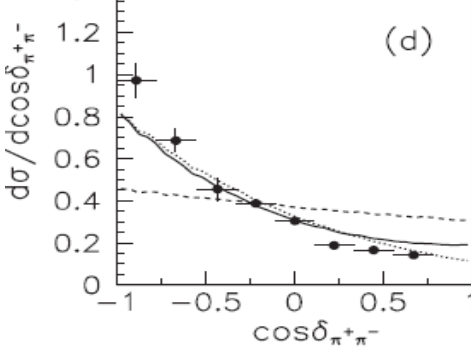
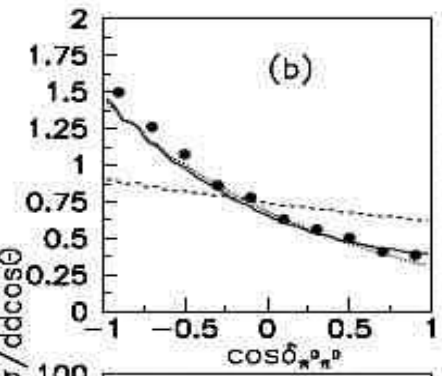
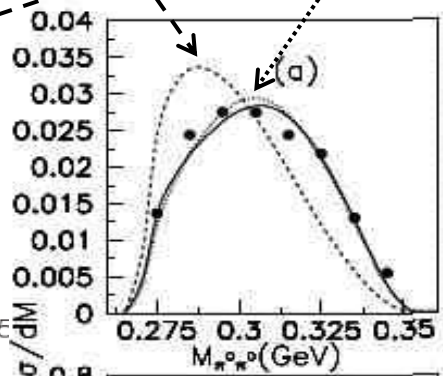
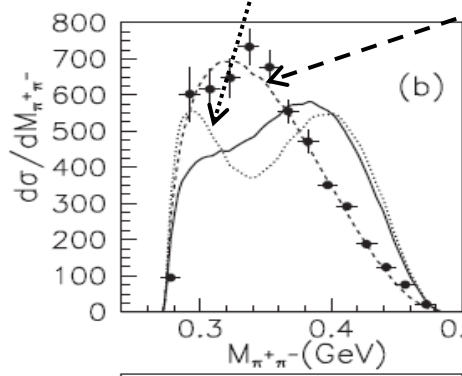
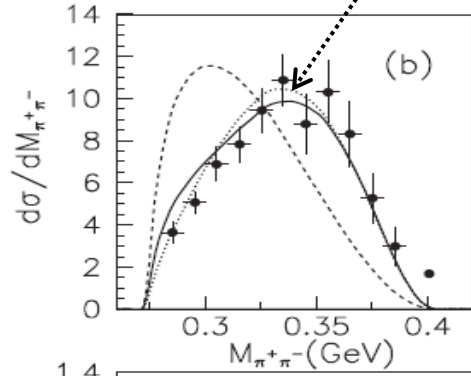
Existing experimental data and Xu Cao model :

$N^* \rightarrow N\sigma$

$N^*(1440) \rightarrow \Delta\pi$

ps

$N^* \rightarrow N\sigma$



full model

ΔΔ

$pp \rightarrow pp\pi^+\pi^- : 0.895, 1.1 \text{ GeV}$

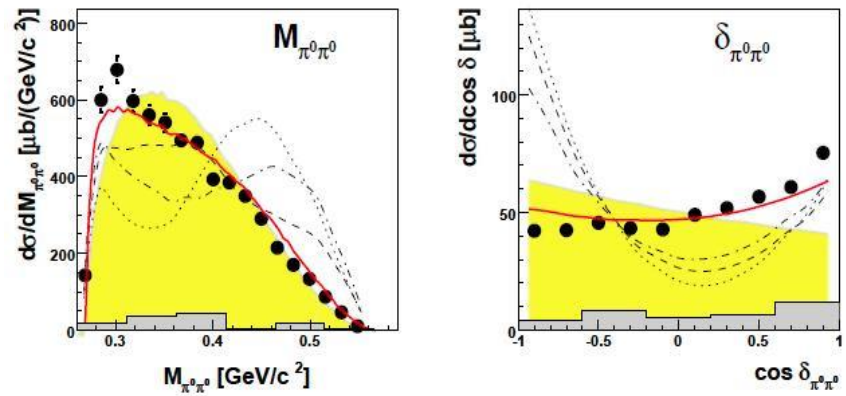
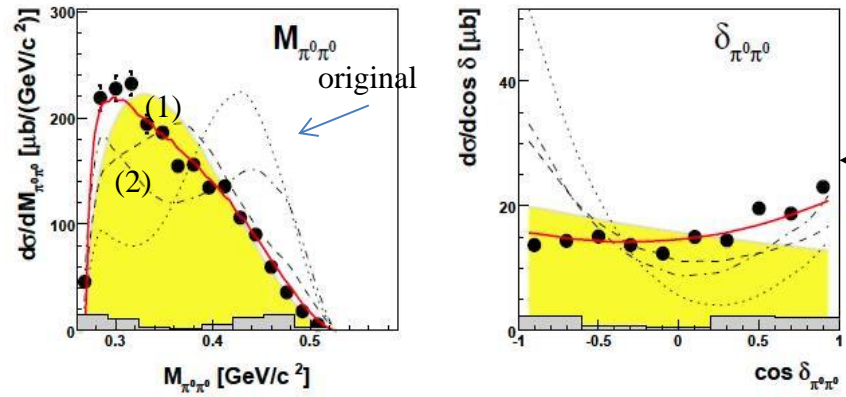
$pp \rightarrow pp\pi^0\pi^0 : 0.795, 1.3 \text{ GeV}$

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

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 $\pi\pi$ spectra at energies above 1.1 GeV which are left as an open problem.

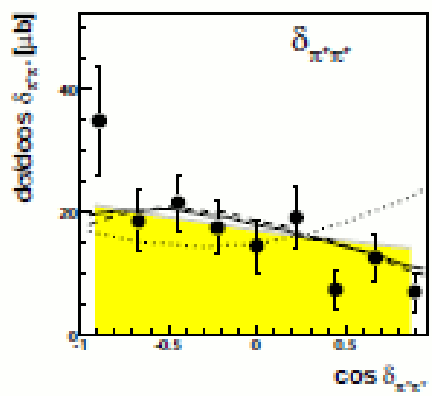
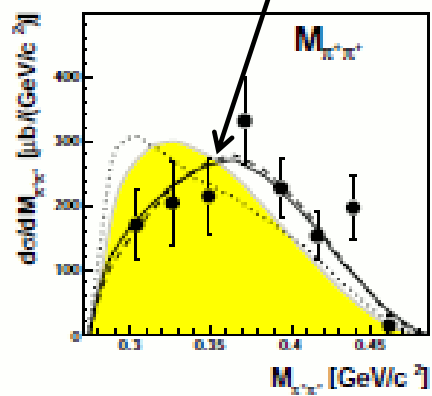
Existing experimental data and modified Valencia model



Influence of modifications of the model :

- dotted : original Valencia model
- dashed : (1) $N^* \rightarrow \Delta\pi$ and $N^* \rightarrow N\sigma$ branching ratio
- dashed-dotted : (2) readjustment of strength of the $N^*(1440)$
- red : ρ exchange in $\Delta\Delta$ excitation

↓ ... + $\Delta(1600) \rightarrow \Delta\pi$



$pp \rightarrow pp\pi^0\pi^0$: 1.2, 1.3 GeV

$pp \rightarrow nn\pi^+\pi^+$: 1.1 GeV

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

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 strategy:

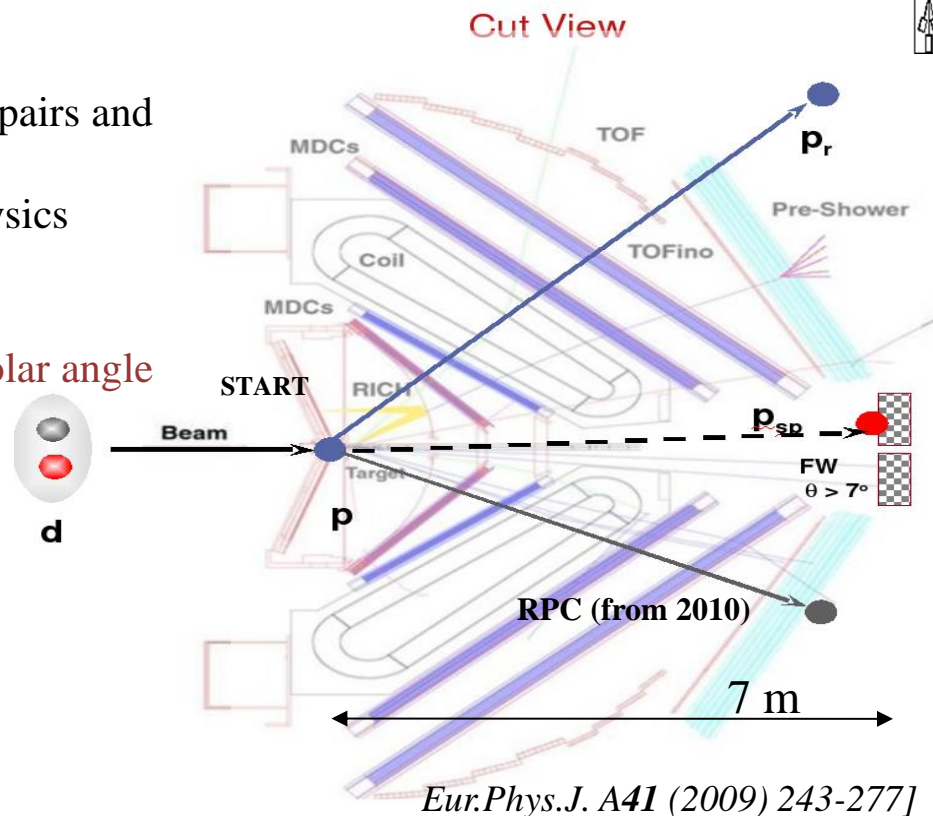
- ✓ Excitation function for low-mass lepton pairs and (multi-)strange baryons and mesons
- ✓ Various aspects of baryon-resonance physics

- ❑ 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)

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

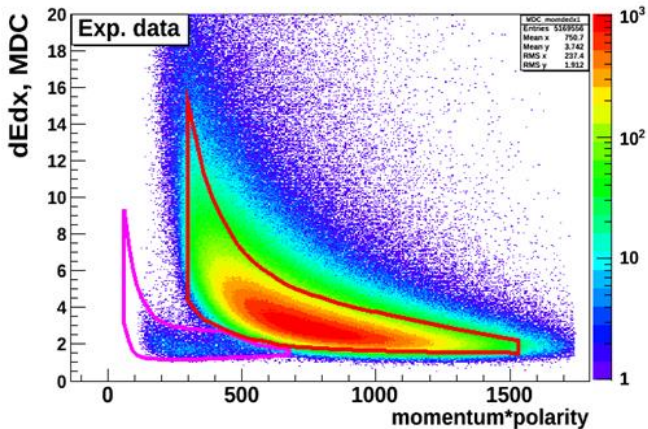
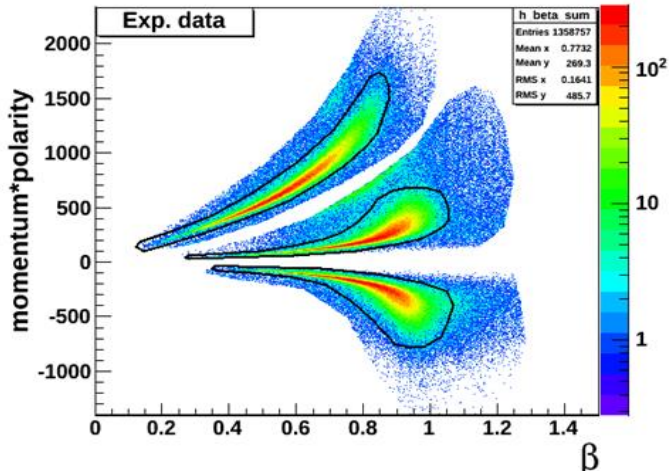


Kinematics for np :

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

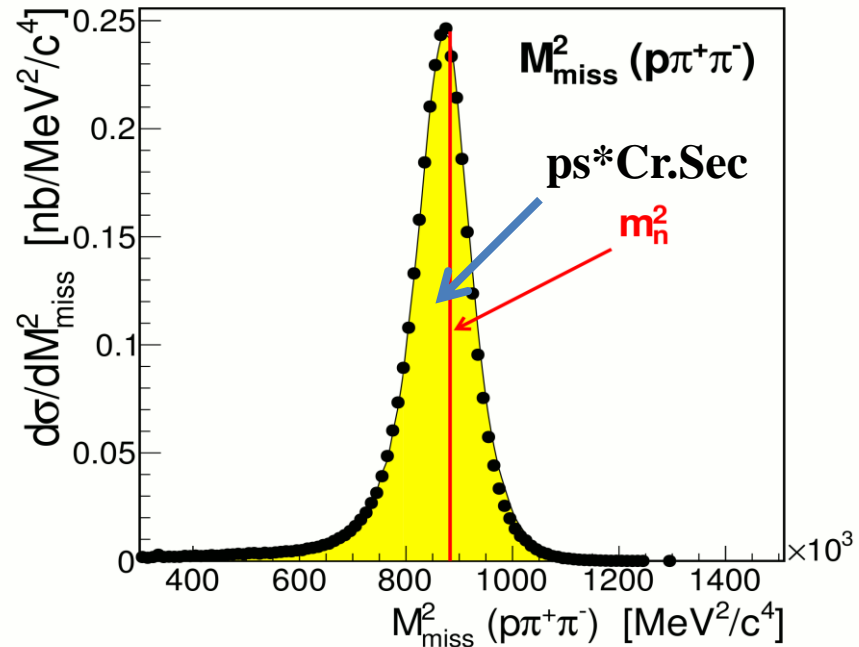
PID and selection of the reaction channel : $n p \rightarrow n p \pi^+ \pi^-$

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 χ^2) wins.

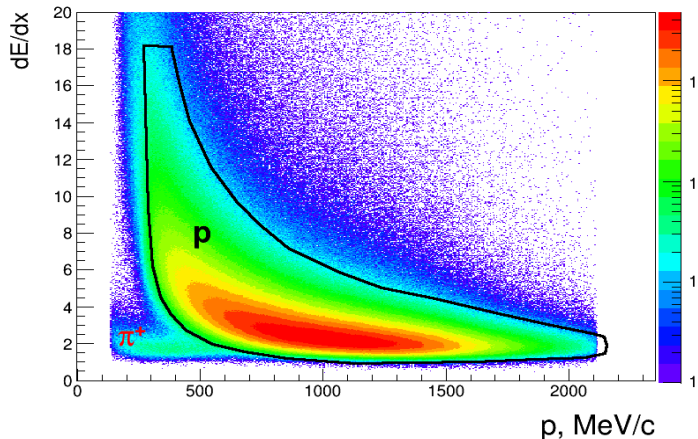
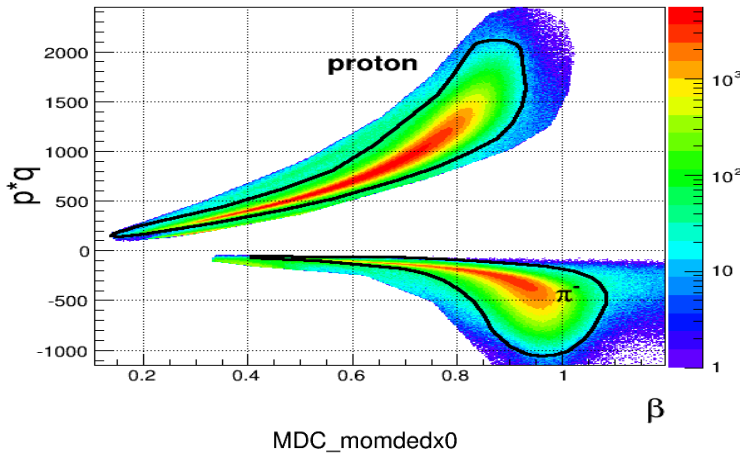


Simulation : phase space with taking into account the energy dependence of the total cross section according to :

J.Bystricky J.Physique 48 (1987)

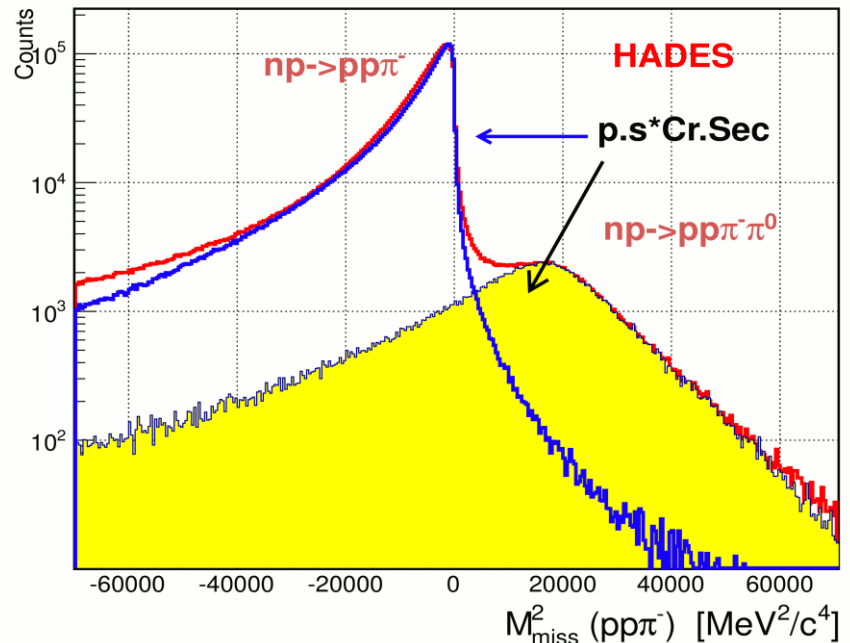
PID and selection of the reaction channel : $np \rightarrow pp\pi^-\pi^0$

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 χ^2) wins.



Additional criteria : $M_{miss}^2 \geq 20000$

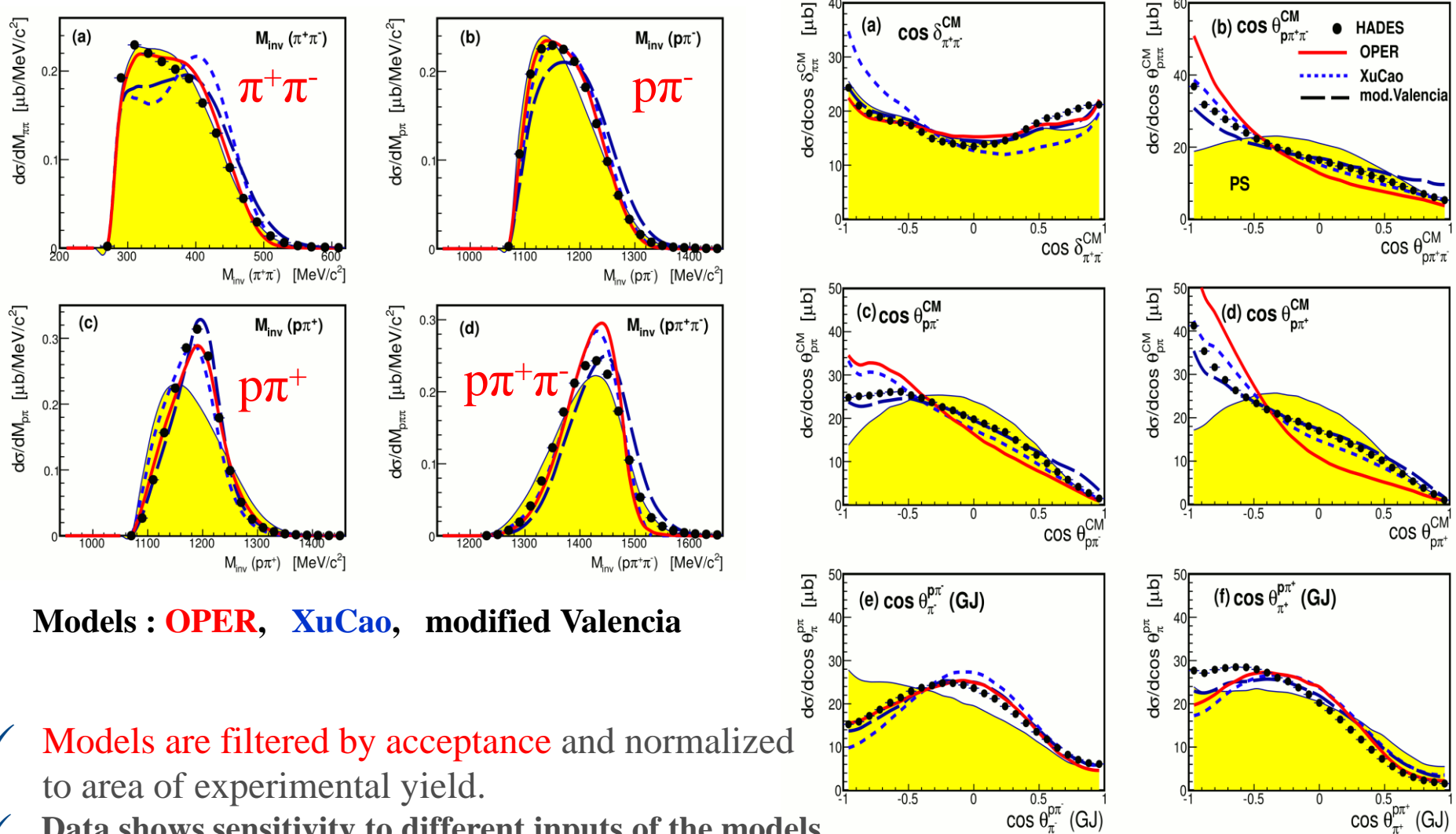
Simulation : phase space with taking into account the energy dependence of the total cross section according to :

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**

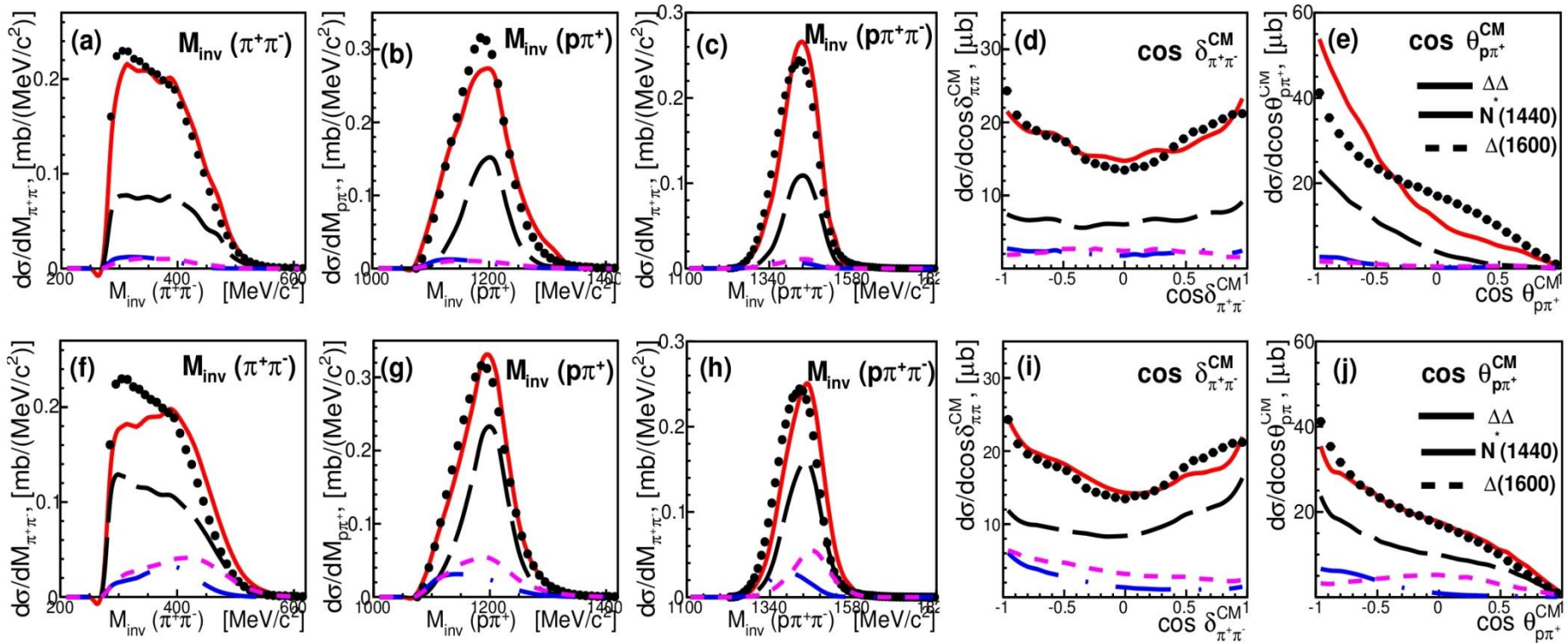
- ✓ Models are filtered by acceptance and normalized to area of experimental yield.
- ✓ Data shows sensitivity to different inputs of the models.
- ✓ None of the models is able to explain all experimental distributions simultaneously.
- ✓ OPER and Valencia models work generally better

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

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

$\Delta\Delta$, $N^*(1440)$, $\Delta(1600)$

OPER

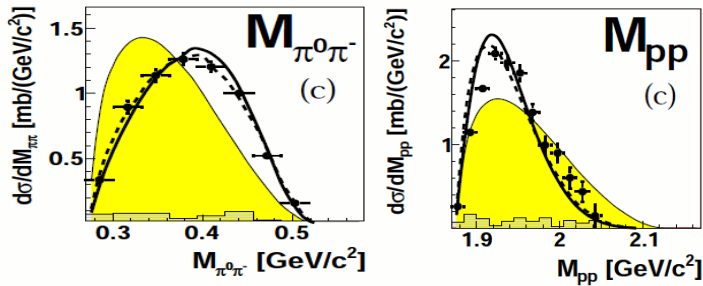
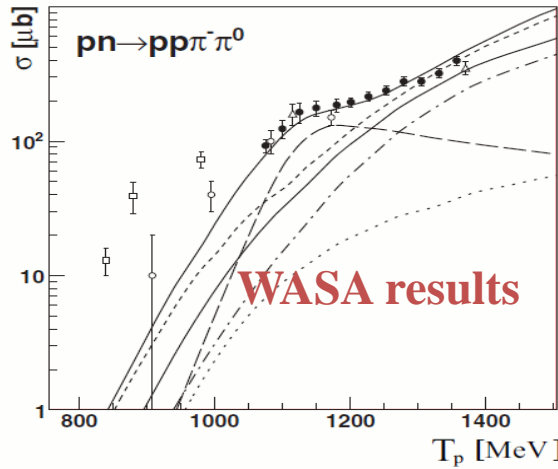


modified Valencia

OPER : main contributions from $\Delta\Delta$ and OBE, contributions of $N^*(1440)$ and $\Delta(1600)$ is small.

Modified Valencia : $\Delta\Delta$ excitation dominates, large $\Delta(1600)$ contribution is not favoured by data.

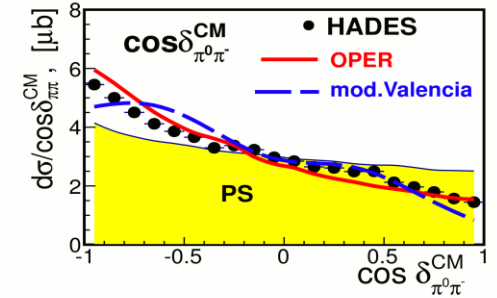
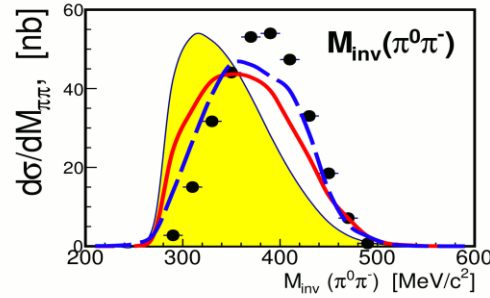
Comparison HADES data with models : $np \rightarrow pp\pi^-\pi^0$ at 1.25 GeV



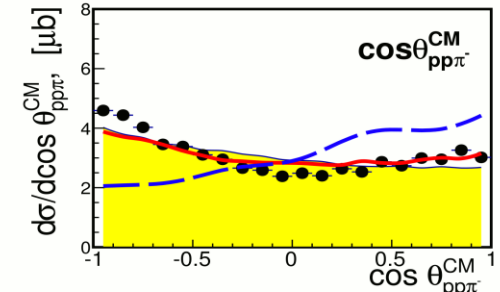
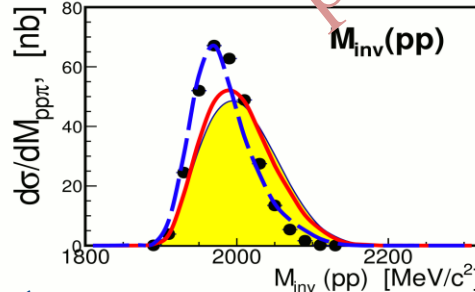
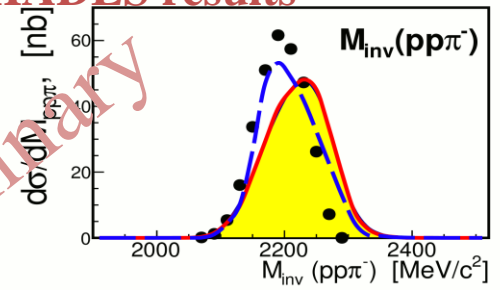
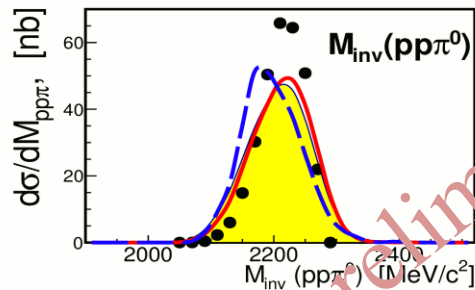
P. Adlarson et al, Phys.Rev. C88 (2013)

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

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



HADES results



- ✓ 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 $\pi\pi$ production in $np@1.25$ GeV
- Comparison of $\pi\pi$ 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 :

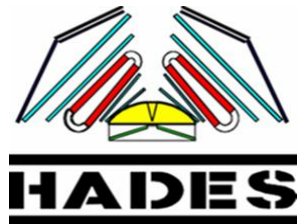
- ✓ dominance of $\Delta\Delta$ excitation
- ✓ contributions of $N^*(1440)$ and $\Delta(1600)$ are small

$np \rightarrow np\pi^+\pi^-$ and $np \rightarrow pp\pi^-\pi^0$ channels :

- ✓ strong constraints for existing models.

Impact:

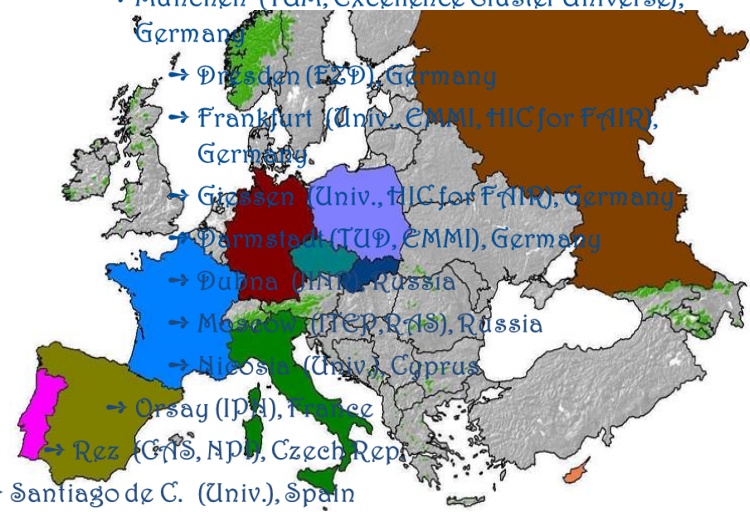
- better description of the contribution of baryonic resonances to meson and dilepton production in NN and heavy-ion production
- independent checks for existence of $I(J^P) = 0(3^+)$ dibaryon (WASA results)



Thank you for your attention!

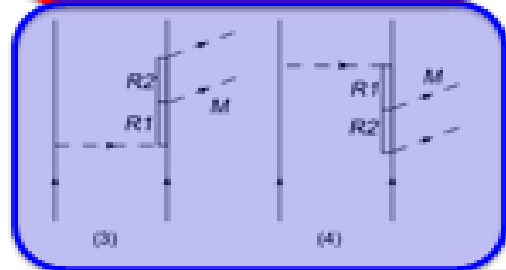
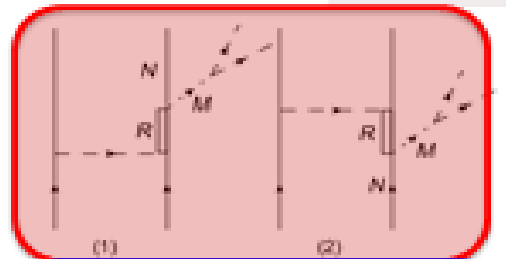


- Catania (INFN - LNS), Italy
- Cracow (Univ.), Poland
- Darmstadt (GSI, EMMI), Germany
- München (TUM, Excellence Cluster Universe), Germany
- Dresden (EZD), Germany
- Frankfurt (Univ., EMMI, HIC for FAIR), Germany
- Giessen (Univ., HIC for FAIR), Germany
- Darmstadt (TUM, EMMI), Germany
- Dubna (JINR),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

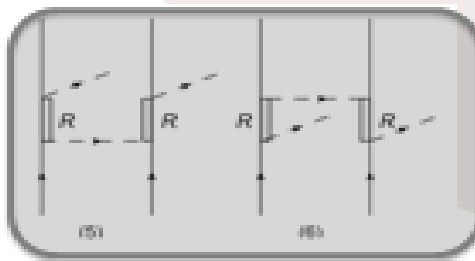


Existing models for the $pp \rightarrow pp\pi^+\pi^-$ reactions

$N^*(1440) \rightarrow N\sigma$



double- Δ $N^*(1440) \rightarrow \Delta\pi$

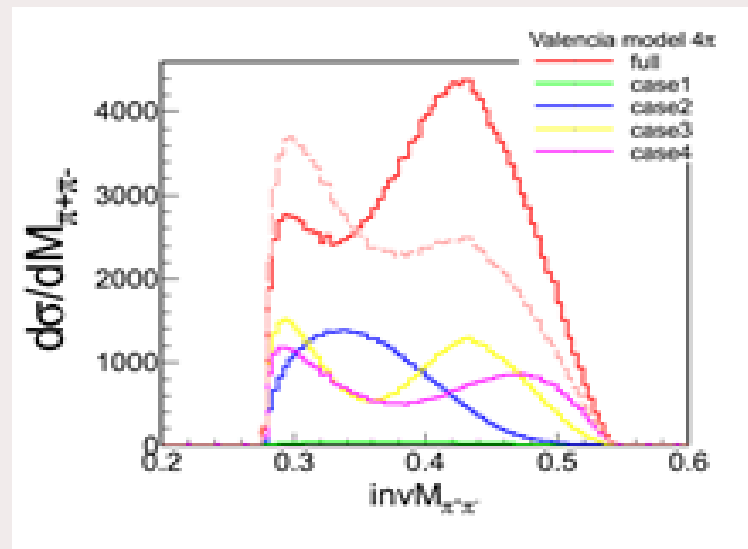


& exchange diagrams

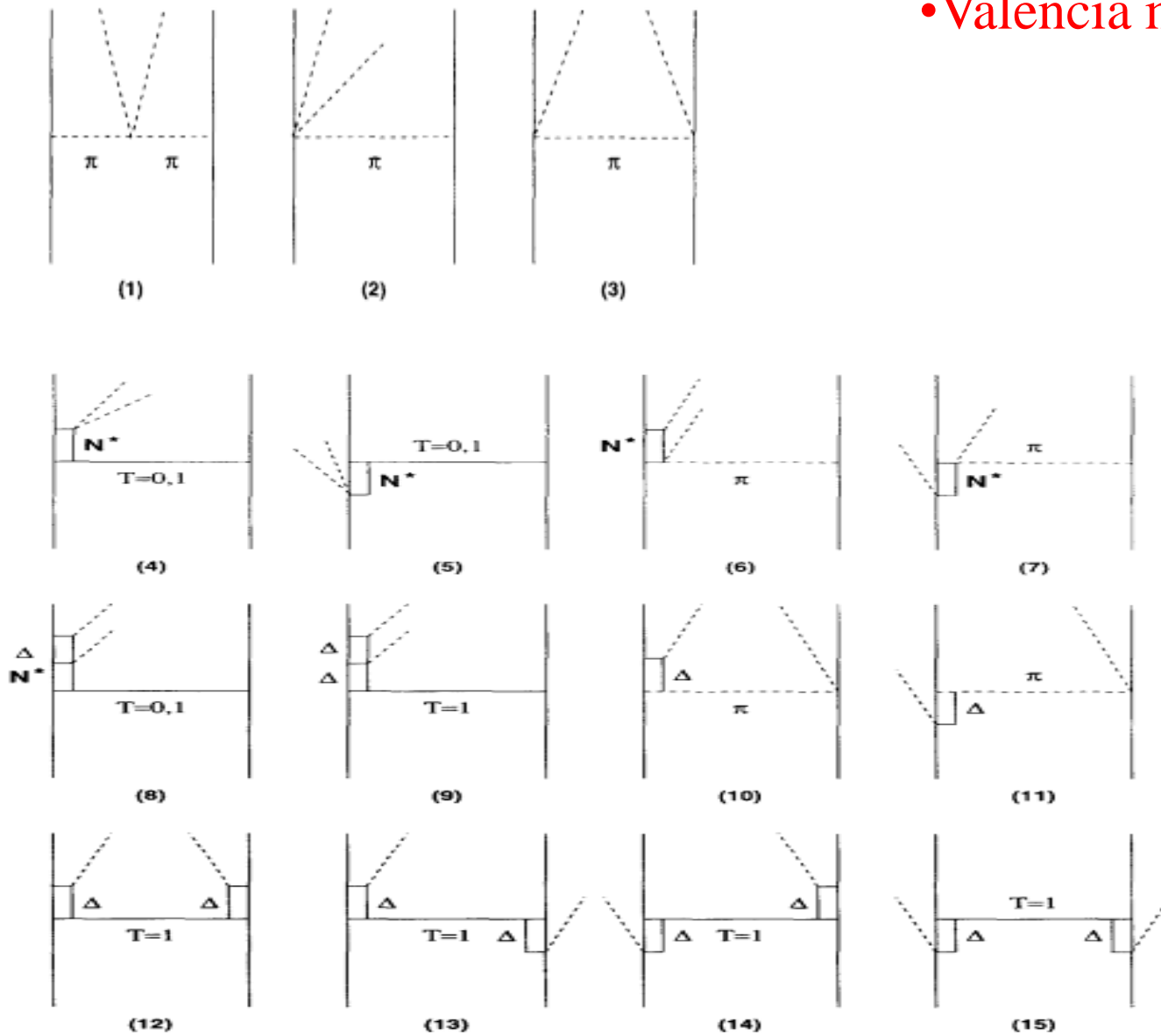
In Valencia model in addition we have:

- ✓ non-resonant component
- ✓ interferences between different diagrams
- ✓ pre-emission 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 $pp \rightarrow pp\pi^0\pi^0$. Events including modifications have been provided by T. Skorodko.

1. Modification of the partial decay width between the decay $N^* \rightarrow N\sigma$ via Δ and direct

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

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

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

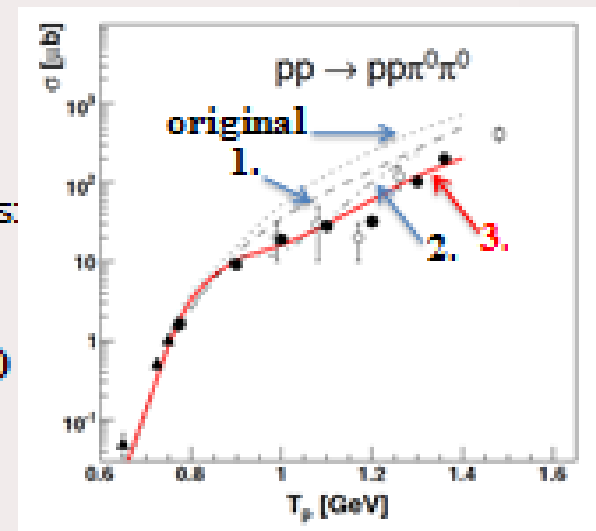
2. Strength of $N^*(1440)$

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

3. ρ exchange in double Δ excitation

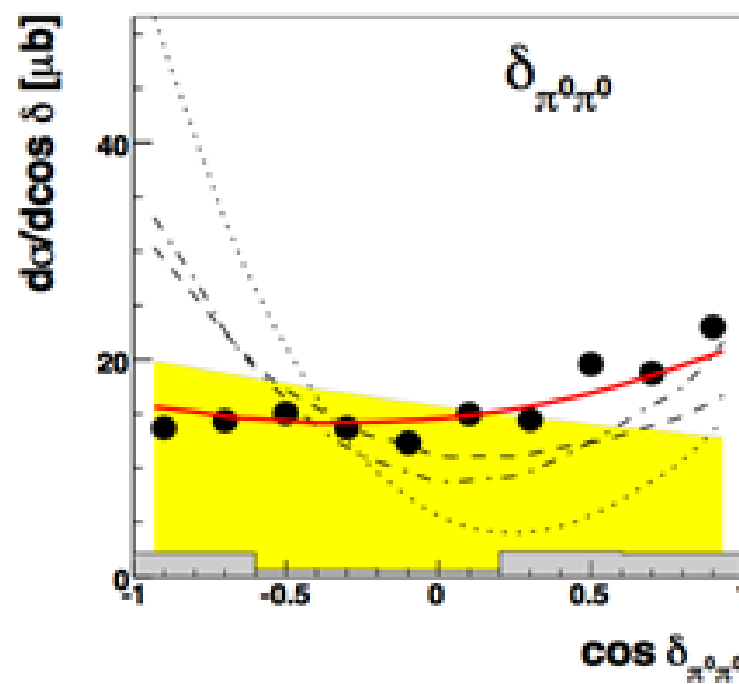
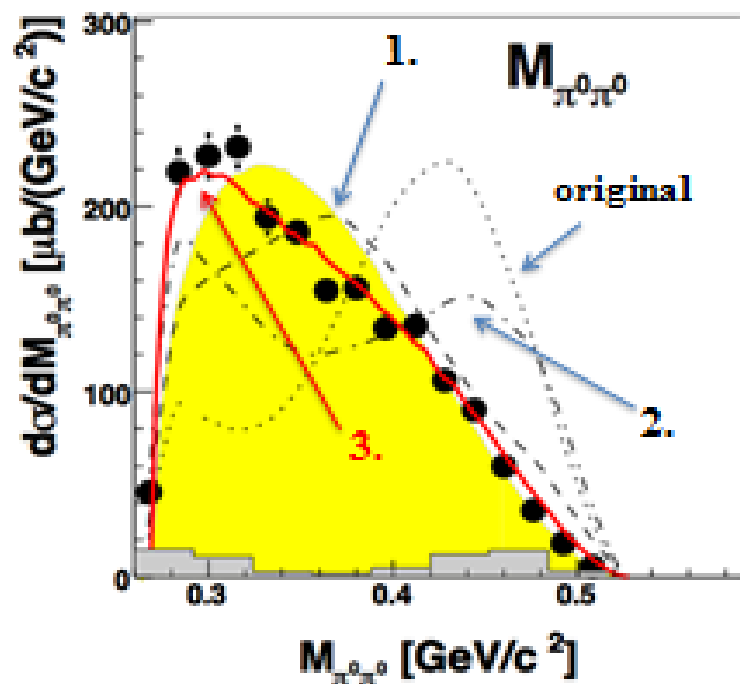
Amplitude for the Double- Δ excitation, consists of two parts: one for π -exchange and second for ρ . The ρ part has been suppress by fact of 12.

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



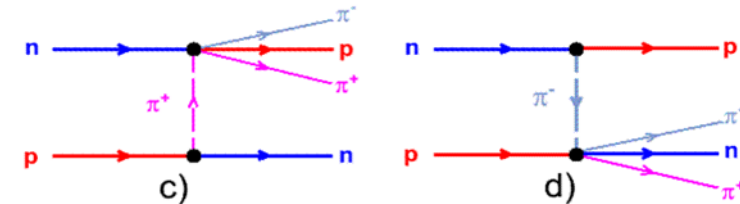
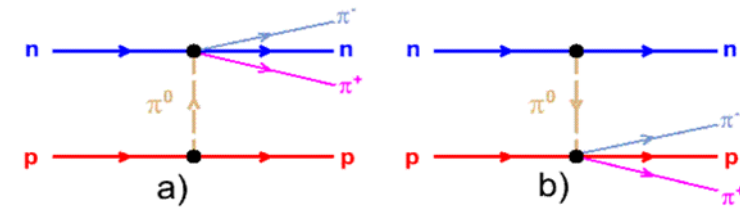
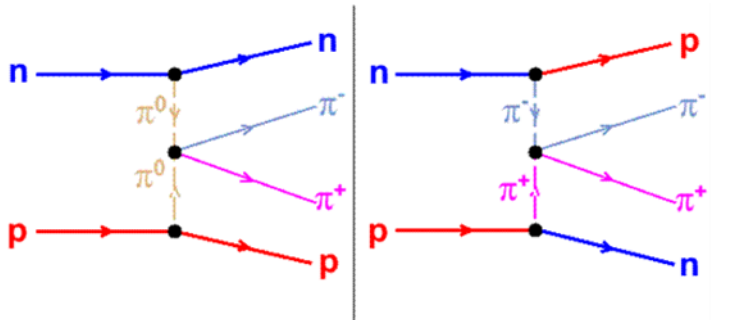
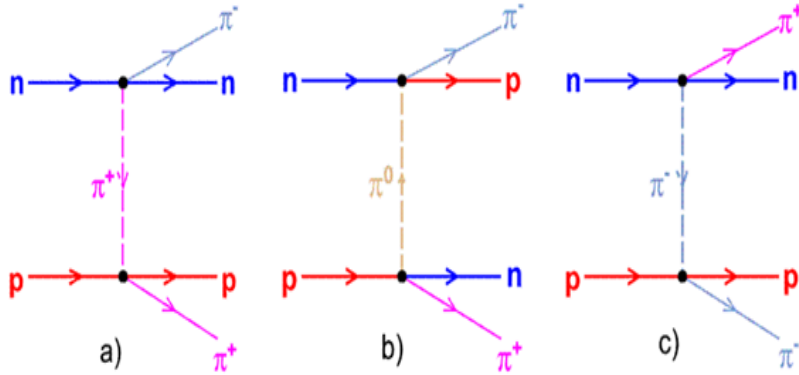
More details about the changes to the model can be found here:

Physics Letters B 679 (2009)30, PhysLettB695: 115-123,2011

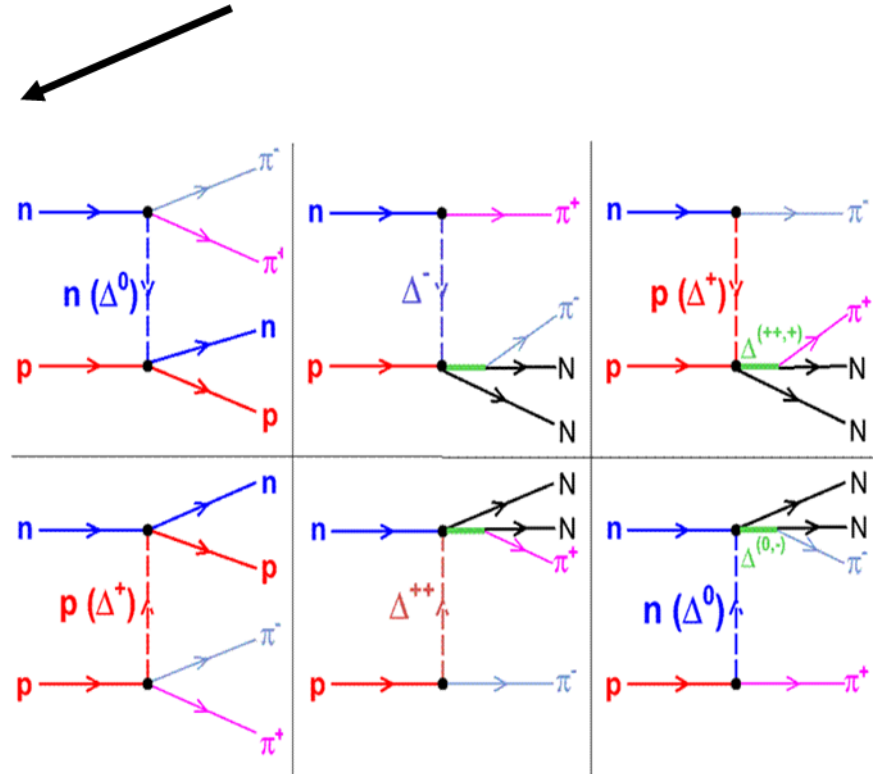


- dotted : original model
- dashed: (1) $N^* \rightarrow \Delta\pi$ and $N^* \rightarrow N\sigma$ branching ratio
- dashed-dotted : (2) readjustment of strength of the $N^*(1440)$
- red: (3) ρ exchange in double Δ excitation

•Model : OPER (A.P.Jerusalimov)

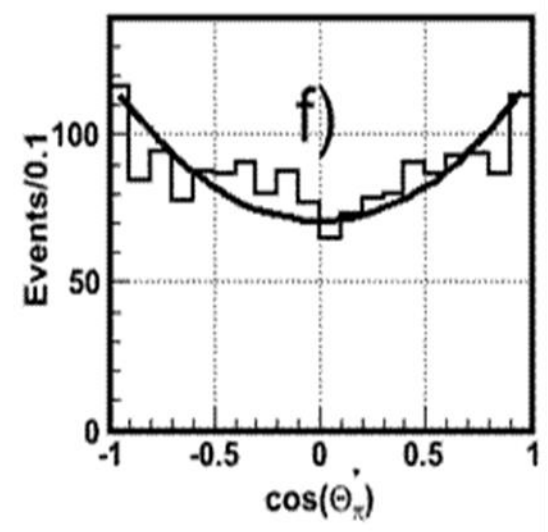
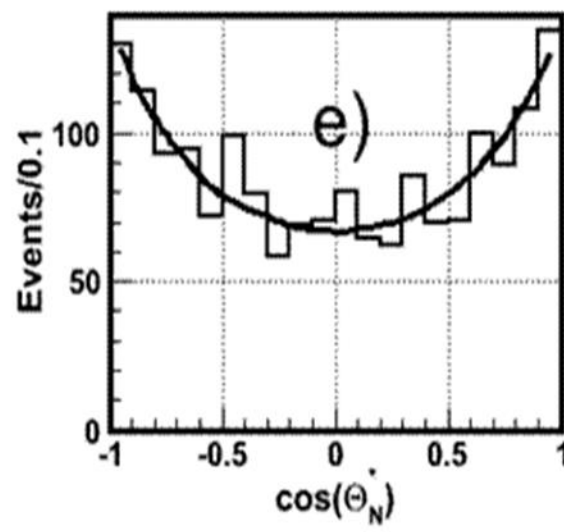
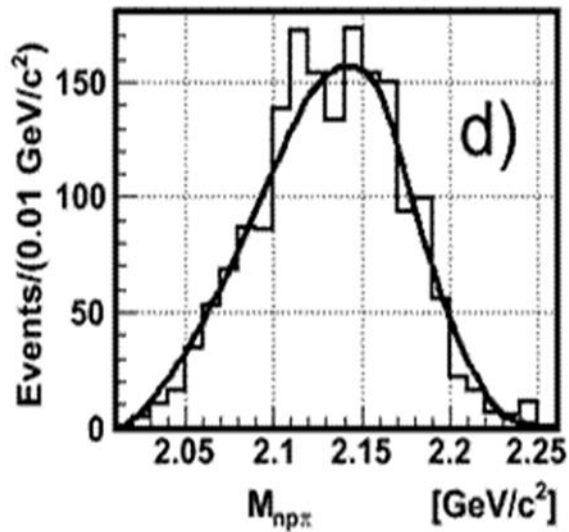
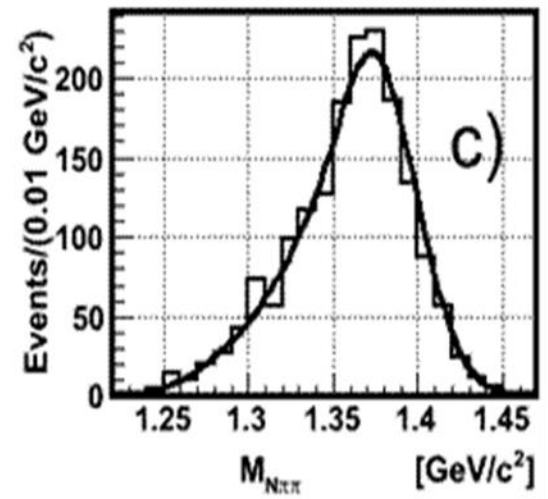
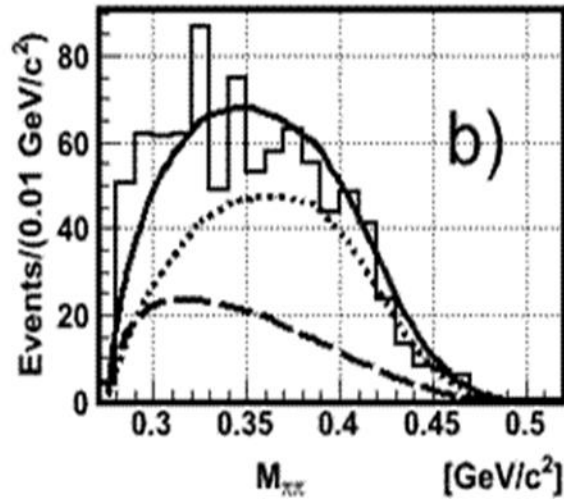
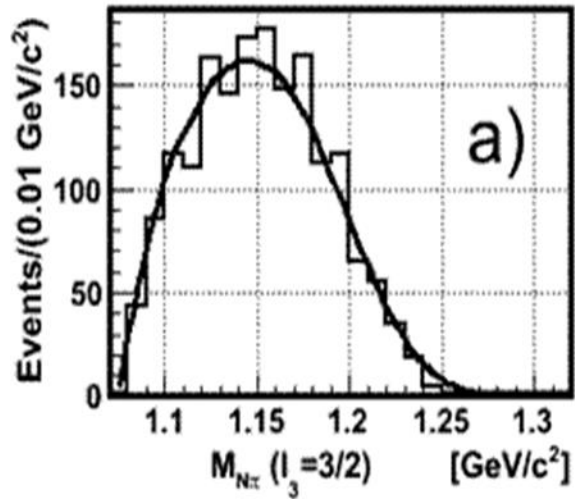


•diagrams OPE



•diagrams OBE

- Experimental distributions for $np \rightarrow n\rho\pi^+\pi^-$ at p 1.73 GeV/c



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

