Double charge π production in pp and np reactions at T_p = 1.25 GeV with HADES

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Outline of the talk

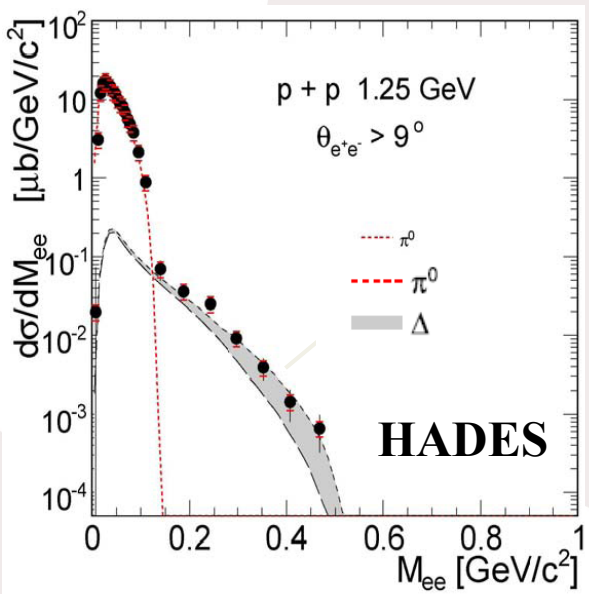
- ✓ Motivation
- ✓ Introduction: world data, theoretical models
- ✓ Data analysis
- ✓ Comparison with the models
- ✓ Conclusion

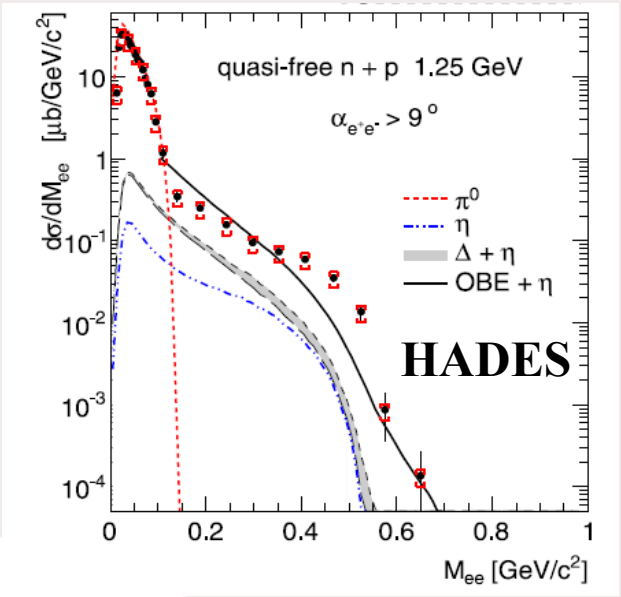
Motivation

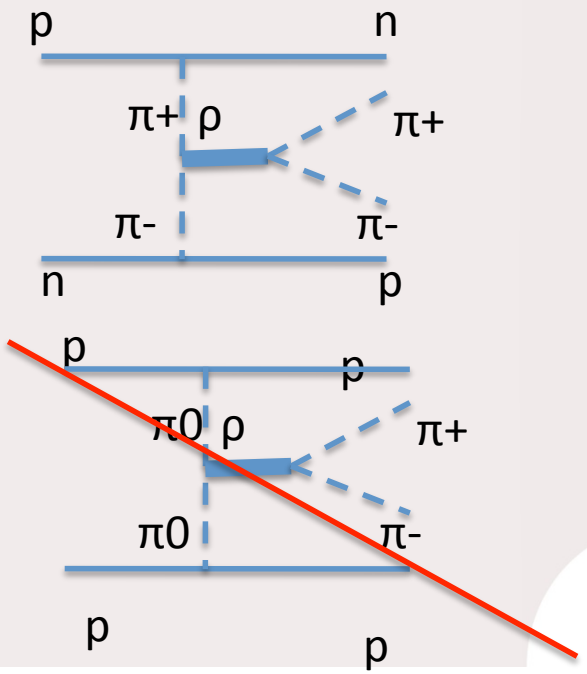
- Double-π production in NN collision is of a particular interest in view of studying of simultaneous excitation of the two baryons and their subsequent decays.

- Specific interest in pp and pn is :
  N*(1440)→ Δπ, N*(1440)→ Nσ, N*(1440)→ρN, ΔΔ excitation.

- Important to look in parallel to π+π- 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 resuts.

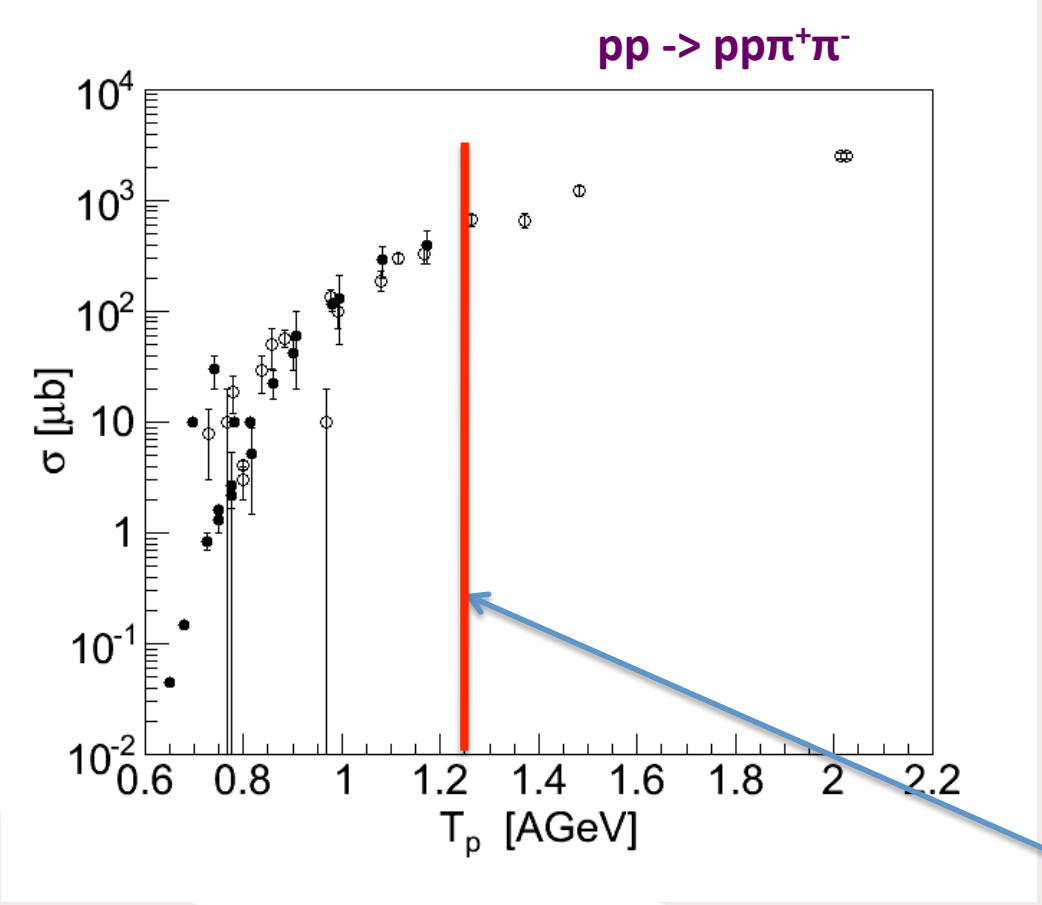






World data on the pp->pp$\pi^+\pi^-$ reactions

Two-pion production in proton-proton collisions is one way to obtain information about the nucleon-nucleon, pion-nucleon and pion-pion interactions. The production mechanism is likely to be dominated by resonance production.

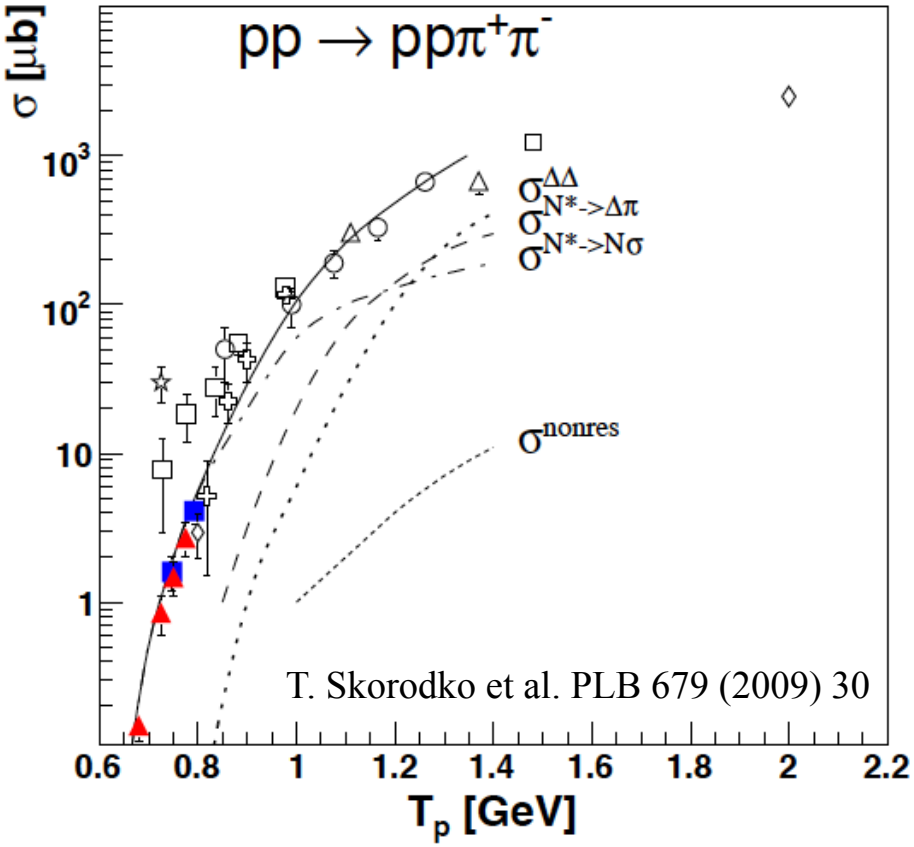


- ✓ closed points (●):
  data from before 1983
  (bubble chamber exp)
- ✓ open points (○):
  - ✓ low energy: PROMICE/WASA
  - ✓ high energy : WASA

HADES pp@1.25 GeV

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

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



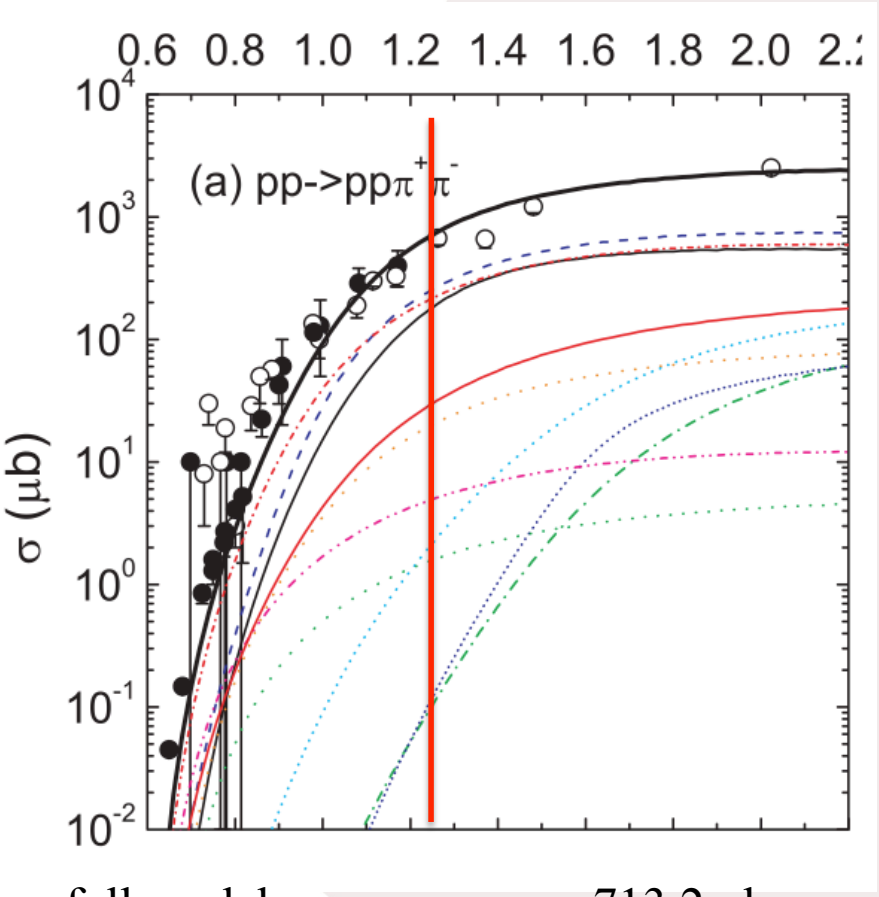
The Valencia model predict that

- At energies near threshold the ππ production is dominated by the excitation of one of the nucleons into the Roper resonance N*(1440) via σ-exchange (N*→Nσ→Nππ)
- As the beam energy increases, the decay N*→Δπ→Nππ gives an increasing contribution to the cross section.
- At higher energies the double-Δ excitation is expected to be the dominant reaction mechanism for ππ production.

In Valencia model only old data points (from before 1983) has been used to fit the model

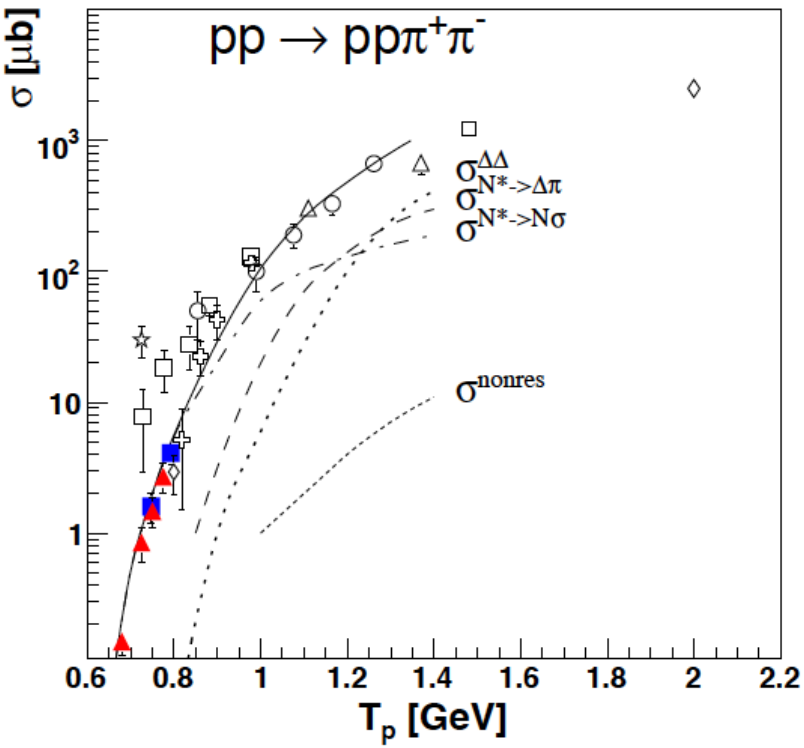
Existing models for the pp->ppπ+π- reactions

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

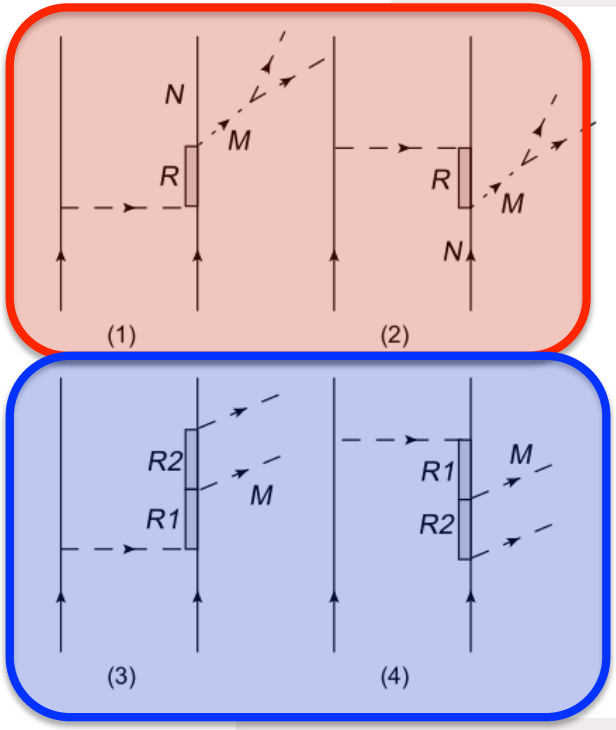
L. Alvarez-Ruso, E. Oset et al. Nucl. Phys. A 633 (1998) 519-543



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

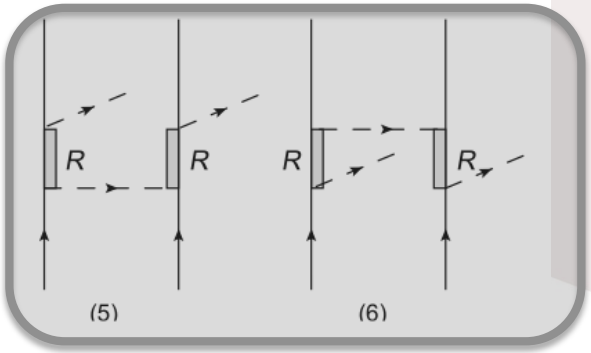
Existing models for the pp->ppπ+π- reactions

N*(1440) -> Nσ



double-Δ

N*(1440) -> Δπ

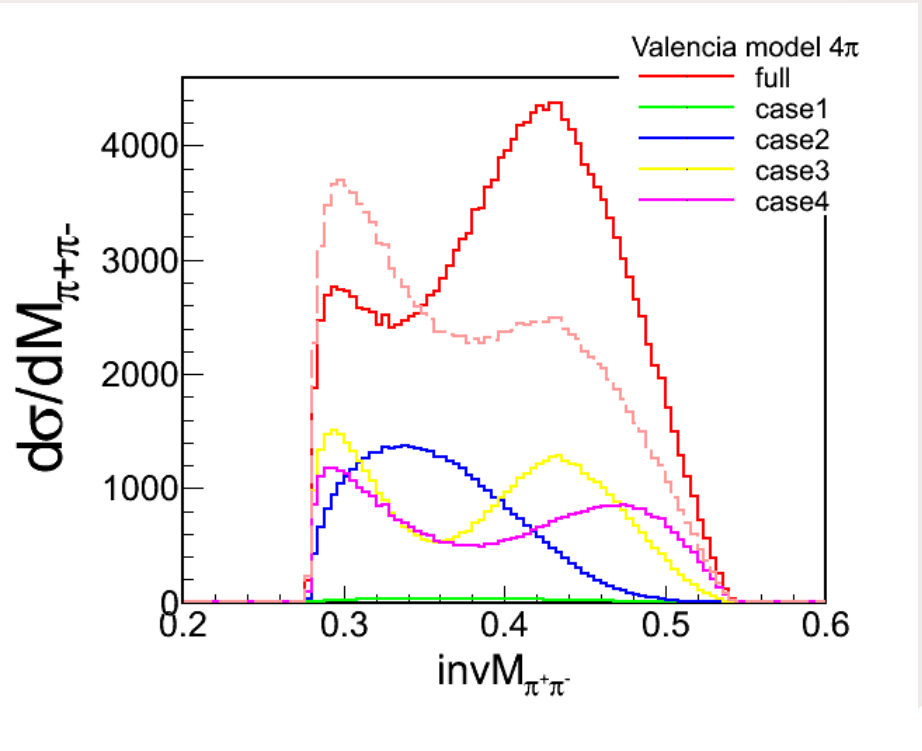


& exchange diagrams

In Valencial model in addition we have:

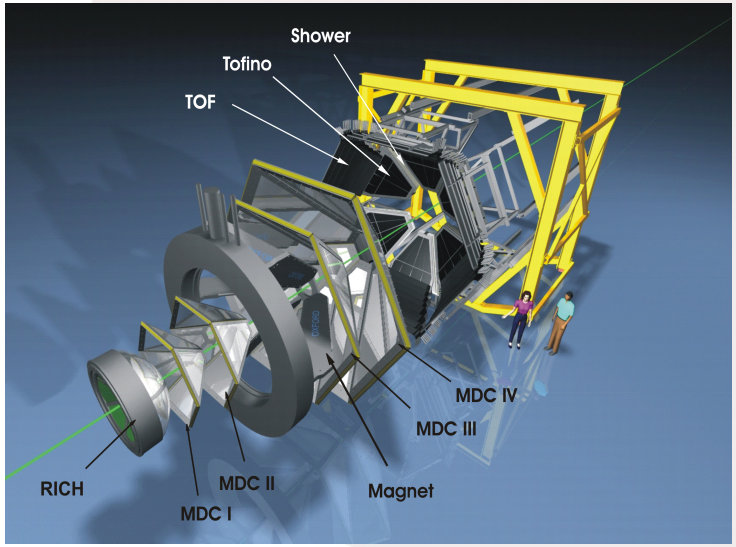
- ✓ non-resonant component
- ✓ interferences between different diagrams
- ✓ pre-emition diagrams

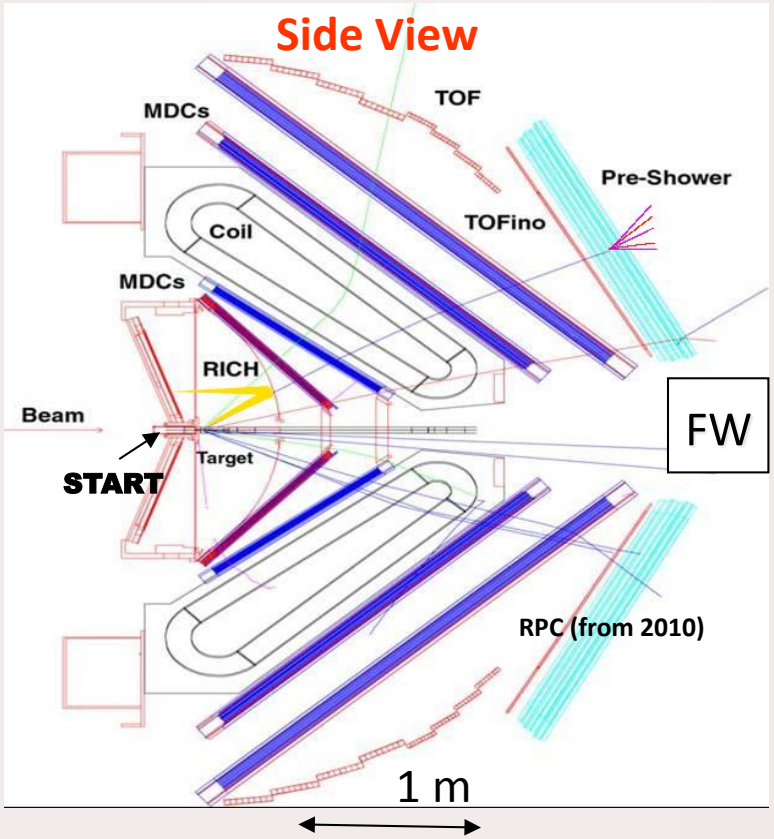
Interferences between different diagrams included in the Valencia model



The HADES detector

- Beams from SIS18: pions, protons, nuclei
- Spectrometer with high invariant mass resolution - 2% at ρ/ω
- Versatile detector for rear 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 LH_2 targets

see also HADES talks: L. Fabbietti, A. Dybczak, M. Lorenz
poster: P. Kurillkin

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*

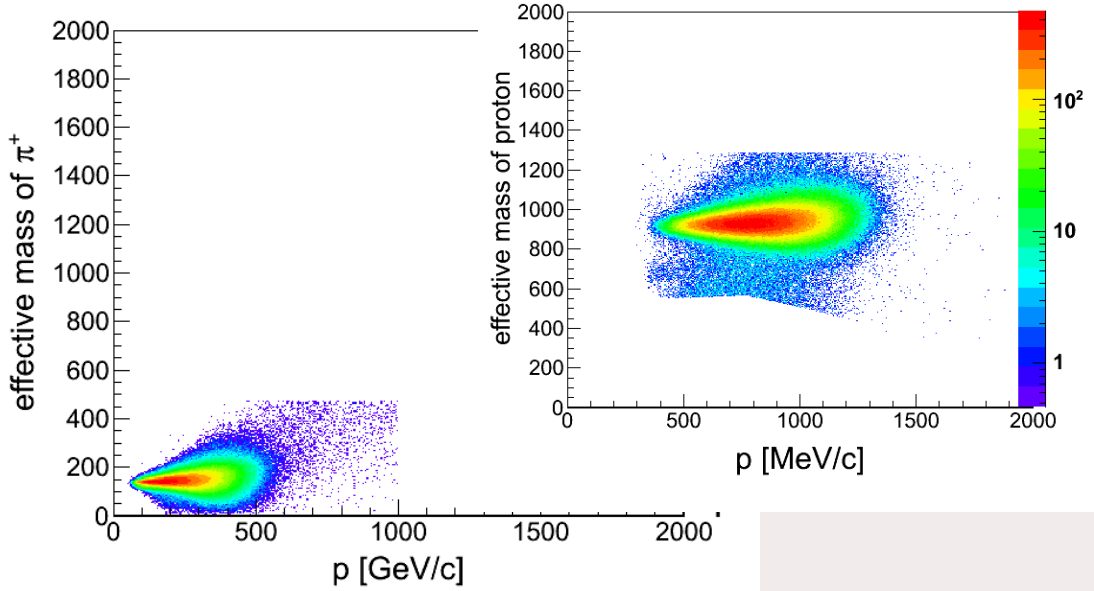
- *low mas e+e- „excess" : (DLS puzzle, emissivity,..)*
- *kaon production : K^0_s*
- *Hyperon production; Λ, Σ, Ξ (1321)*
- *ϕ production*
- *Λ-p, p-p, $\pi\pi$, correlations*

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

see also HADES talks: L. Fabbietti, A. Dybczak, M. Lorenz
poster: P. Kurillkin

Particle identification

No START detector – only relative time of flight. For all 4 particles time reconstruction possible based on tracking information + hypothesis.



Each combination must fit into PID cuts. PID based only on graphical 2-dim cuts.
The best combination (the lowest χ^2) wins.

Additionally we cut on:

- 4 particles ($pp\pi^+\pi^-$) missing mass a
- 4 degree opening angle between π^+ π^-

1 % acceptance for the detection of al 4 charged particles.

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 12 % (normalization, eff correction)

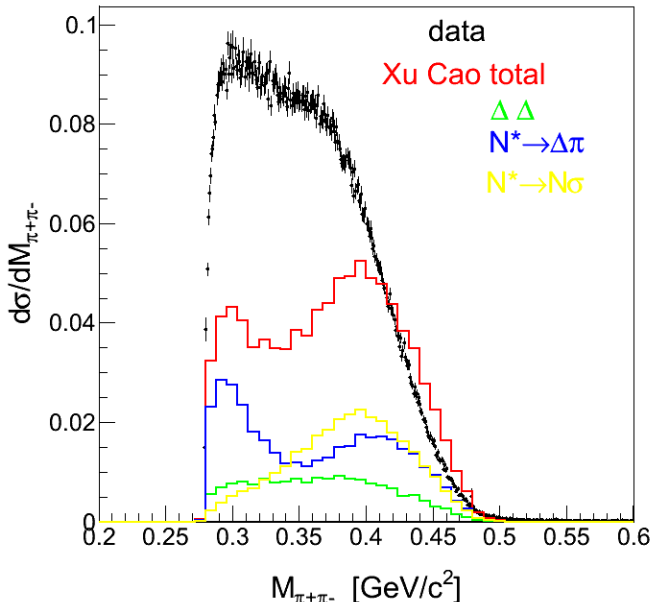
- Models filtered by the acceptance, normalized to the corresponding cross-sections.

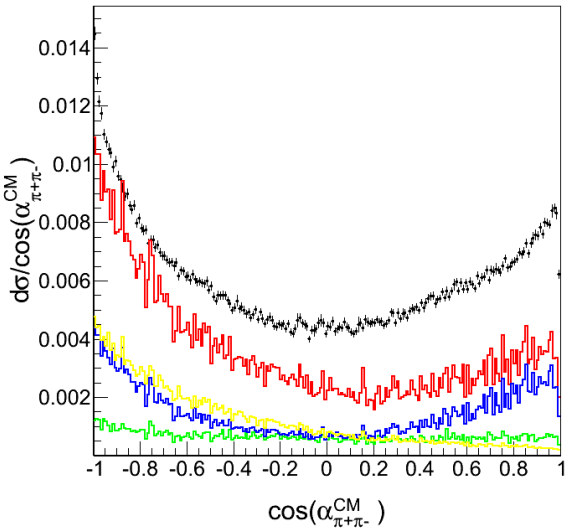
Several distributions can be presented, according to the models most sensitive one are:

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

Comparison of the models with HADES data

Xu Cao et al. model





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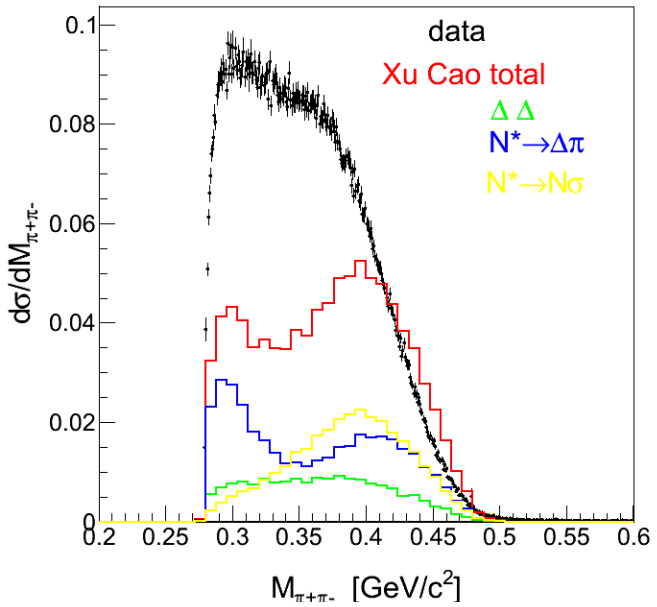
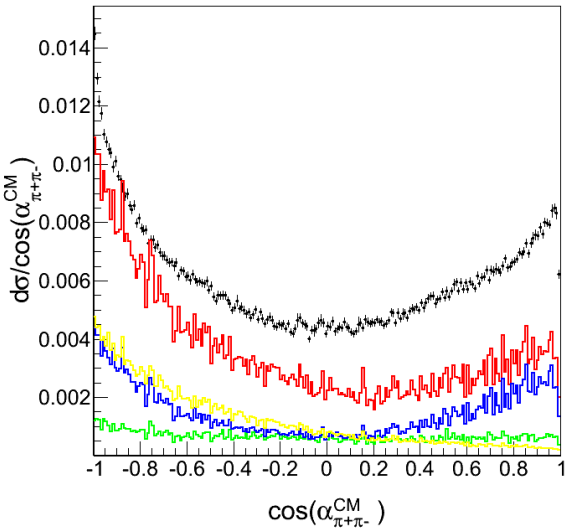
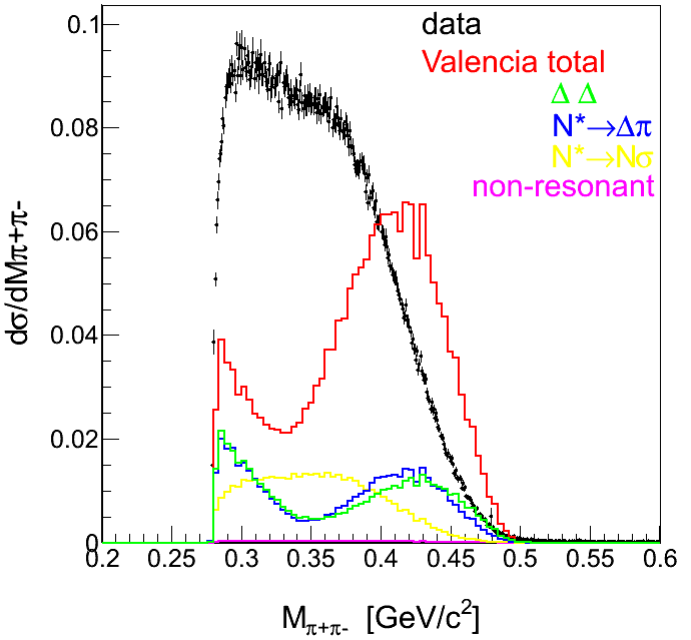
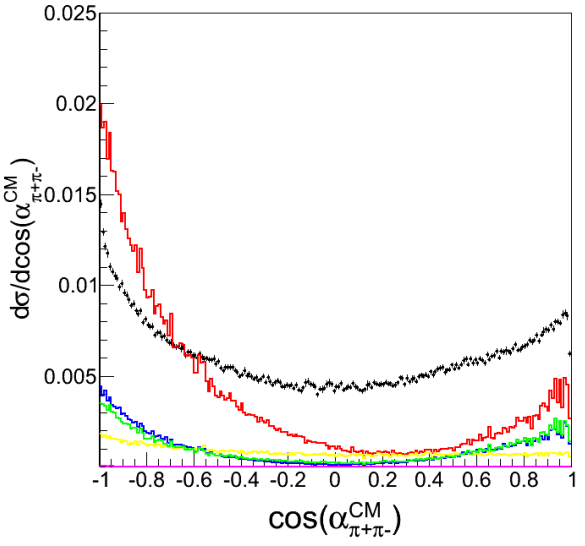




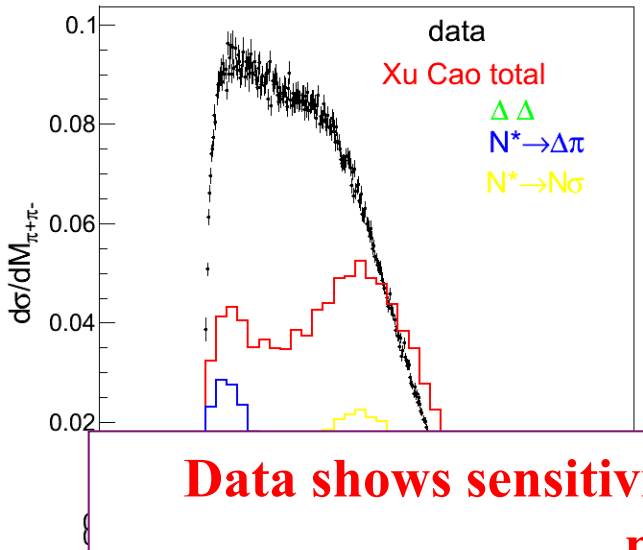
Valencia model



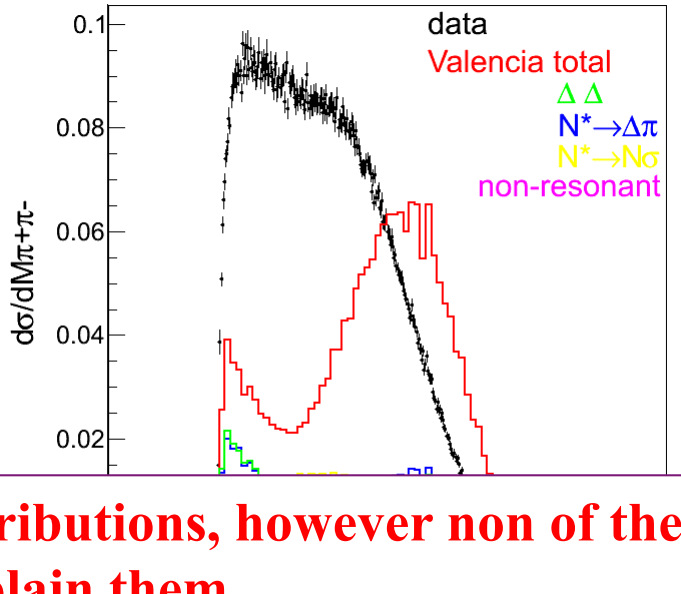


Comparison of the models with HADES data

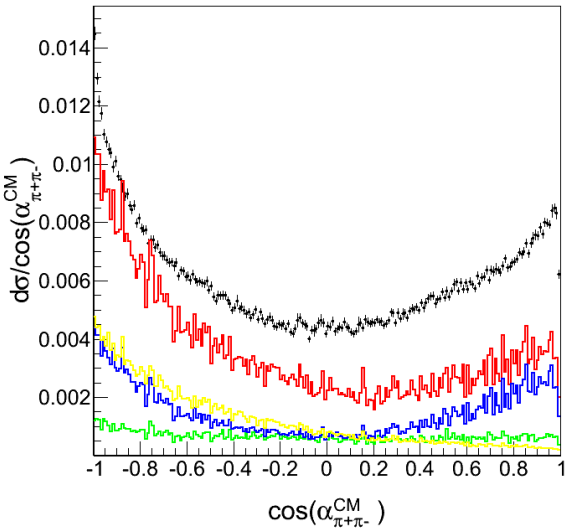
Xu Cao et al. model

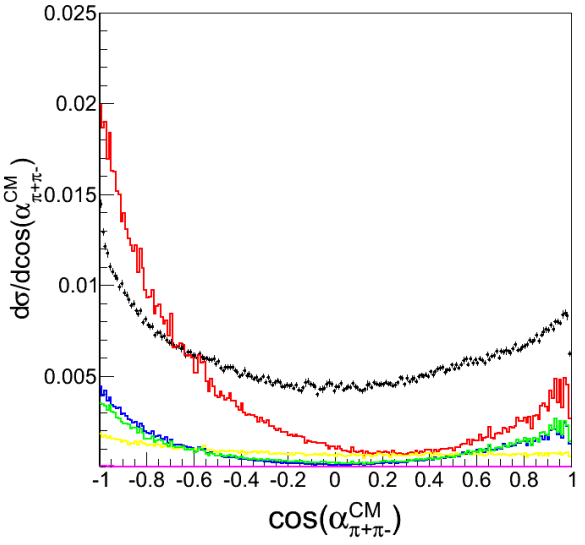


Valencia model



Data shows sensitivity to different contributions, however non of the models is able to explain them.





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)

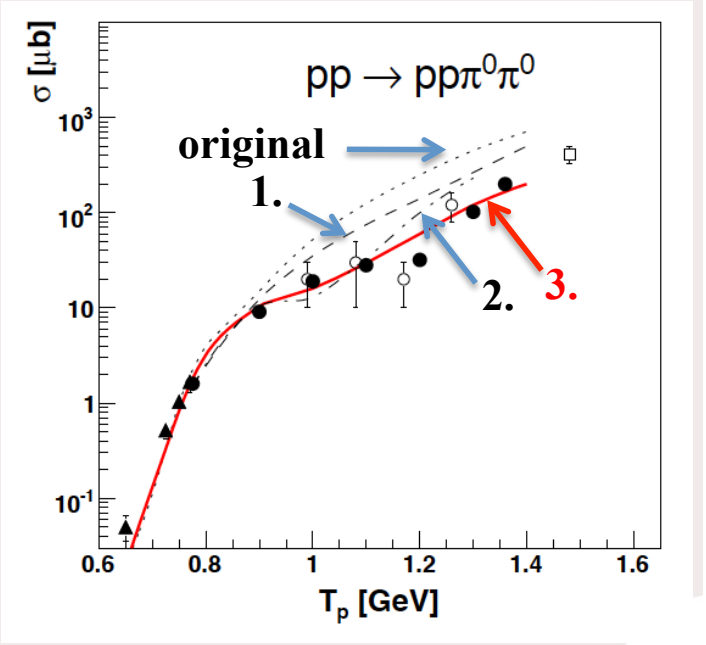
2. Strength of N*(1440)

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 has been suppress by fact of 12.

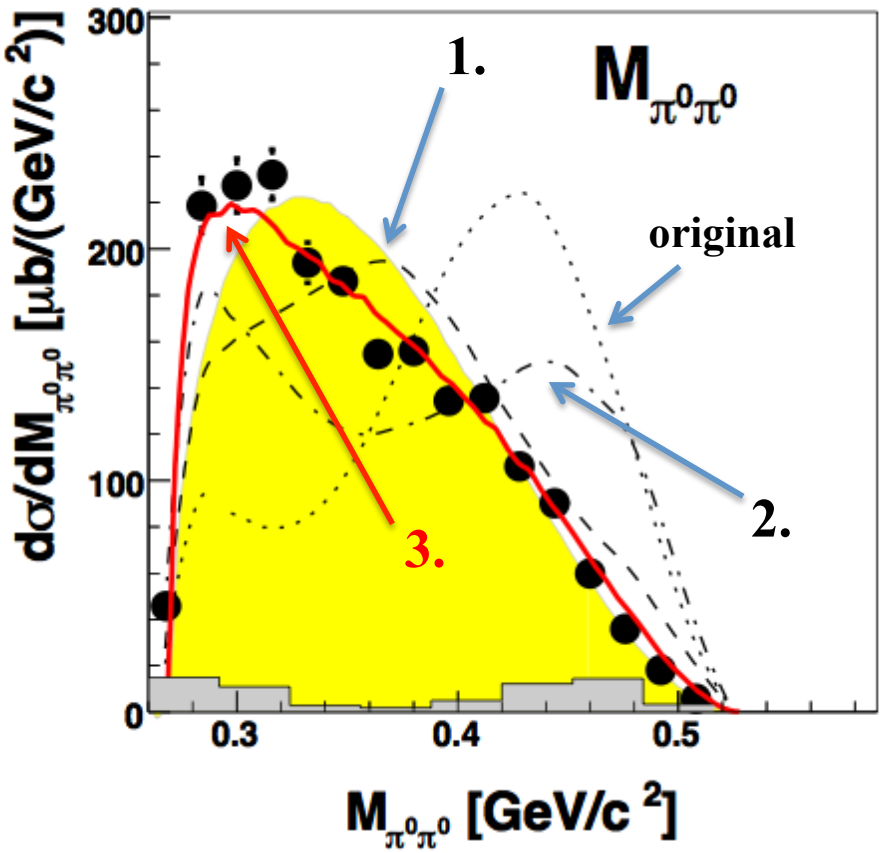
(ρ-exchange is not as wel fixed by exp. observables as π-exchange.)

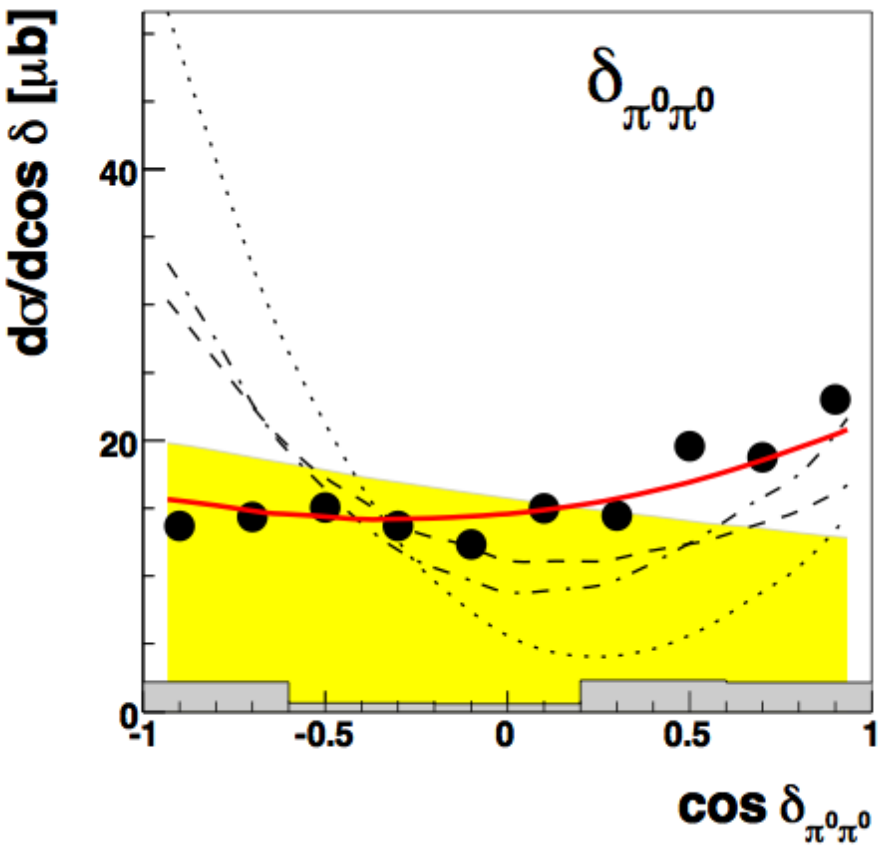


More details about the changes to the model can be found here:
Physics Letters B 679 (2009)30, Phys.Lett.B695:115-123,2011

Influence of the modifications of the model

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





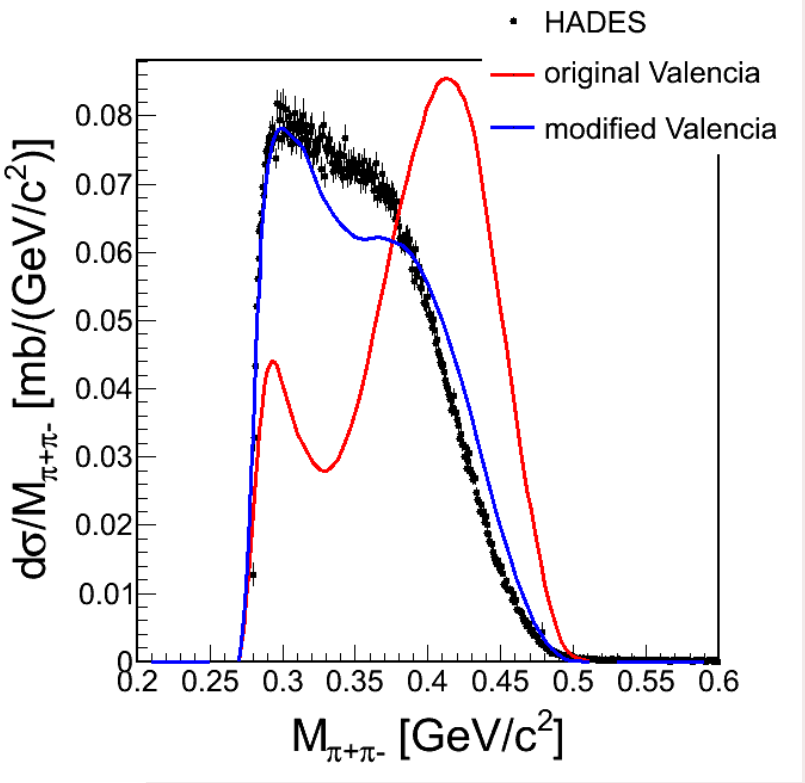
dotted : **original model**

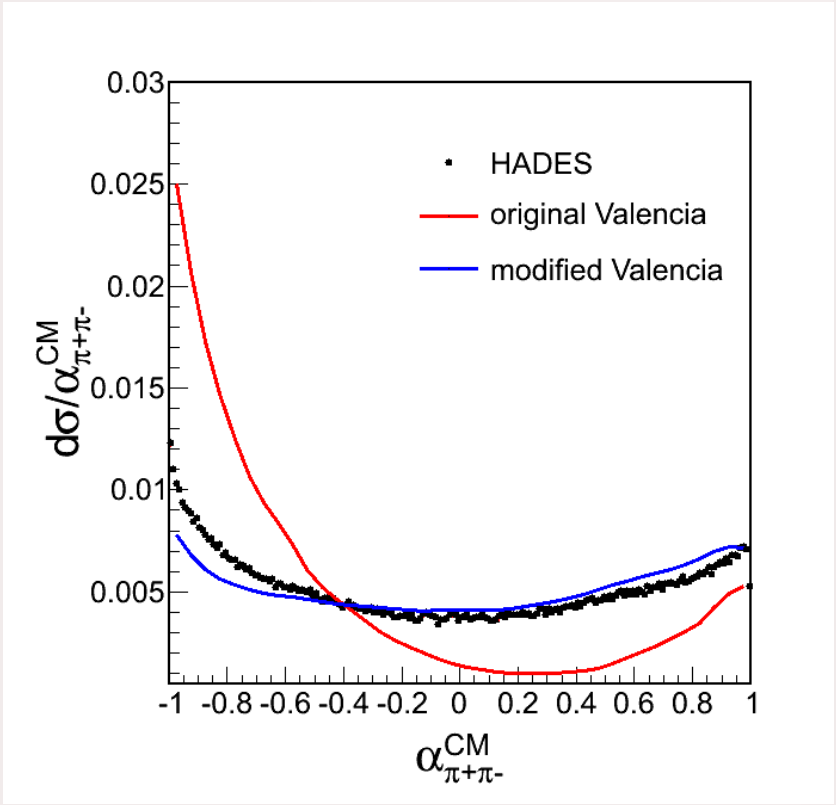
dashed : (1) **N* -> Δπ and N* -> Nσ branching ratio**

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

red: (3) **ρ exchange in double Δ excitation**

HADES vs modified and original Valencia model for pp->pp$\pi^+\pi^-$





Model normalized to area

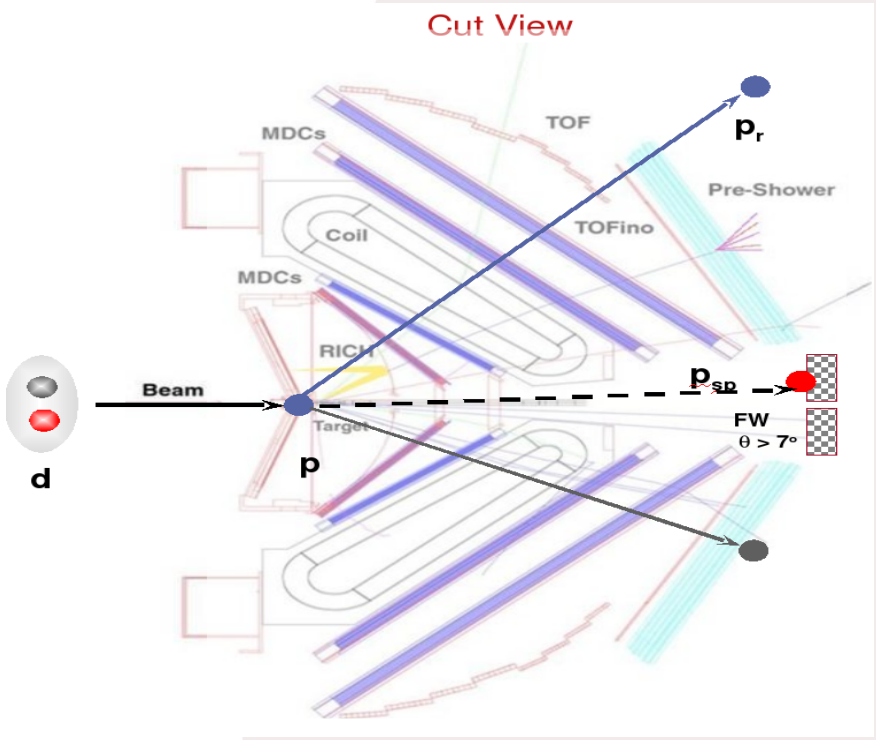
Improvement in the description of the data in both observables: $M_{\pi+\pi-}$, and $\cos^{CM}(\delta_{\pi+\pi-})$

Modified model provides a rather good agreement of both WASA ($\pi^0\pi^0$) and HADES ($\pi^+\pi^-$)

Still some space for the improvement of the model …

np reactions in HADES

np -> np π+π- + (p_{spec}) @ 1.25 GeV/u



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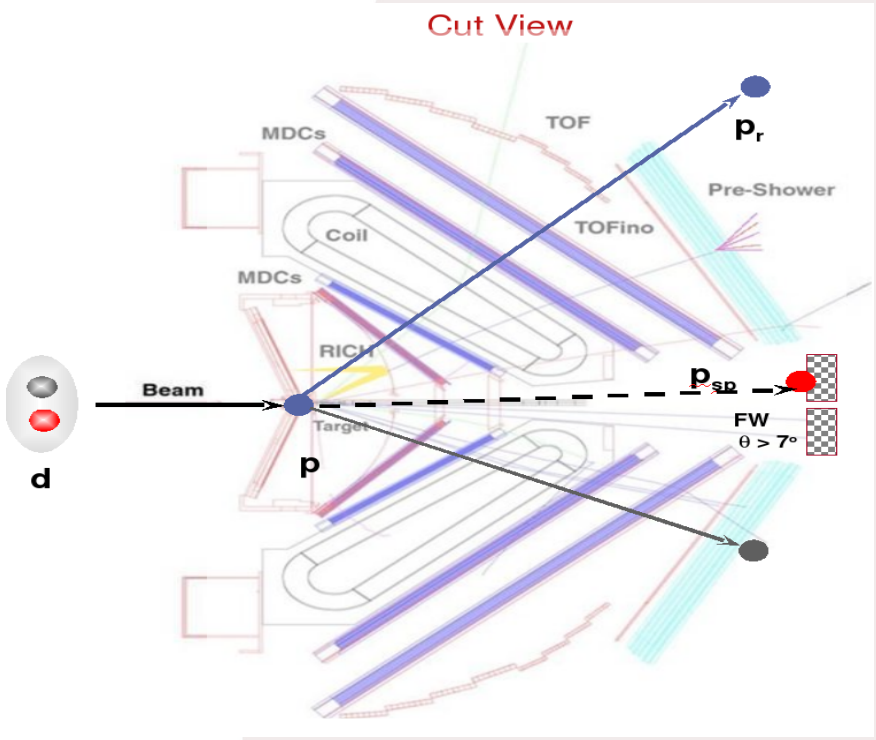
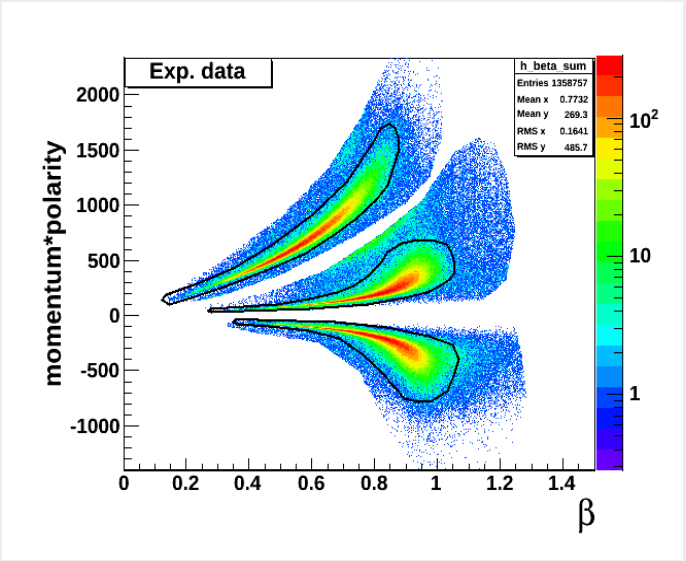
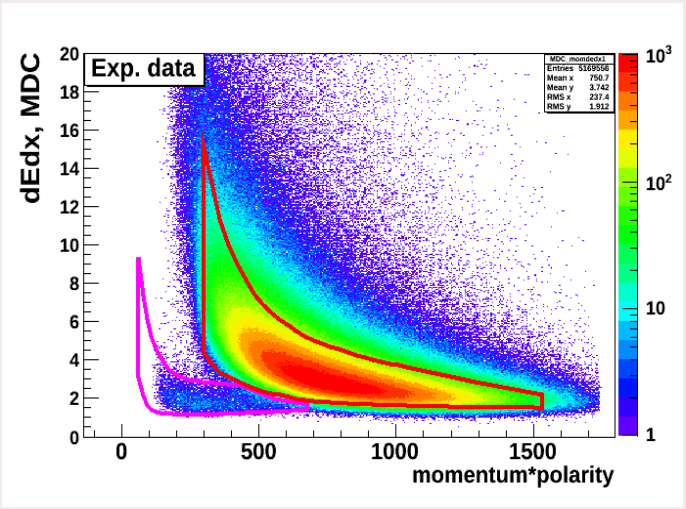


Particle identification of p, π^+, π^-

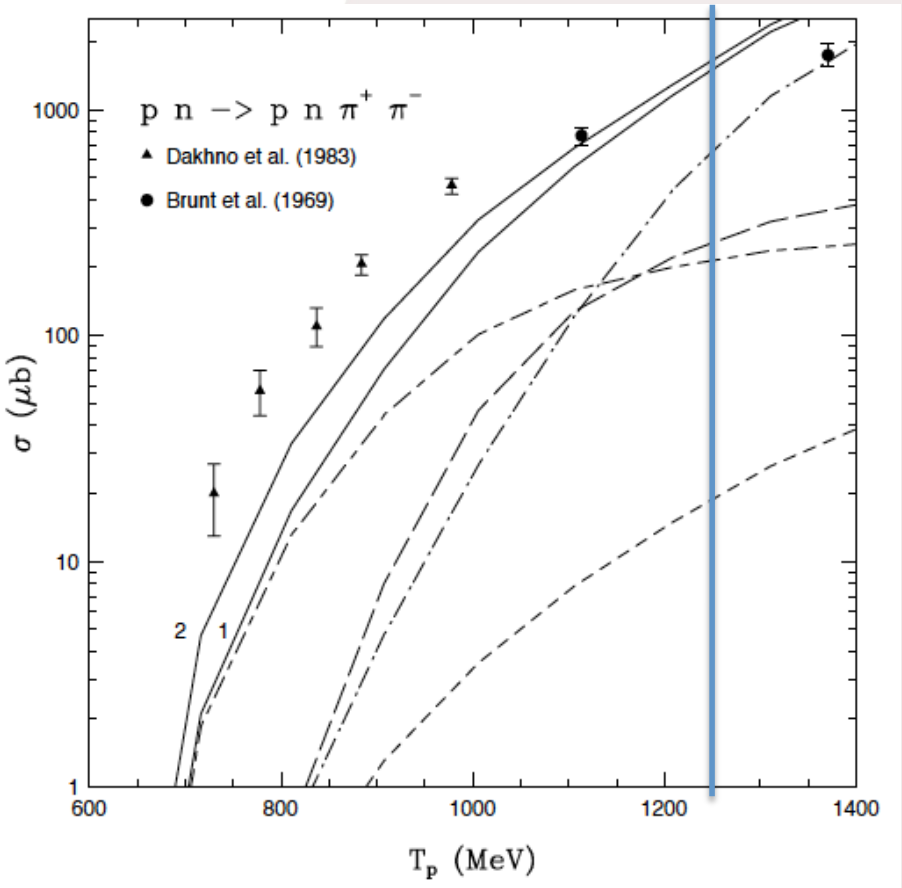




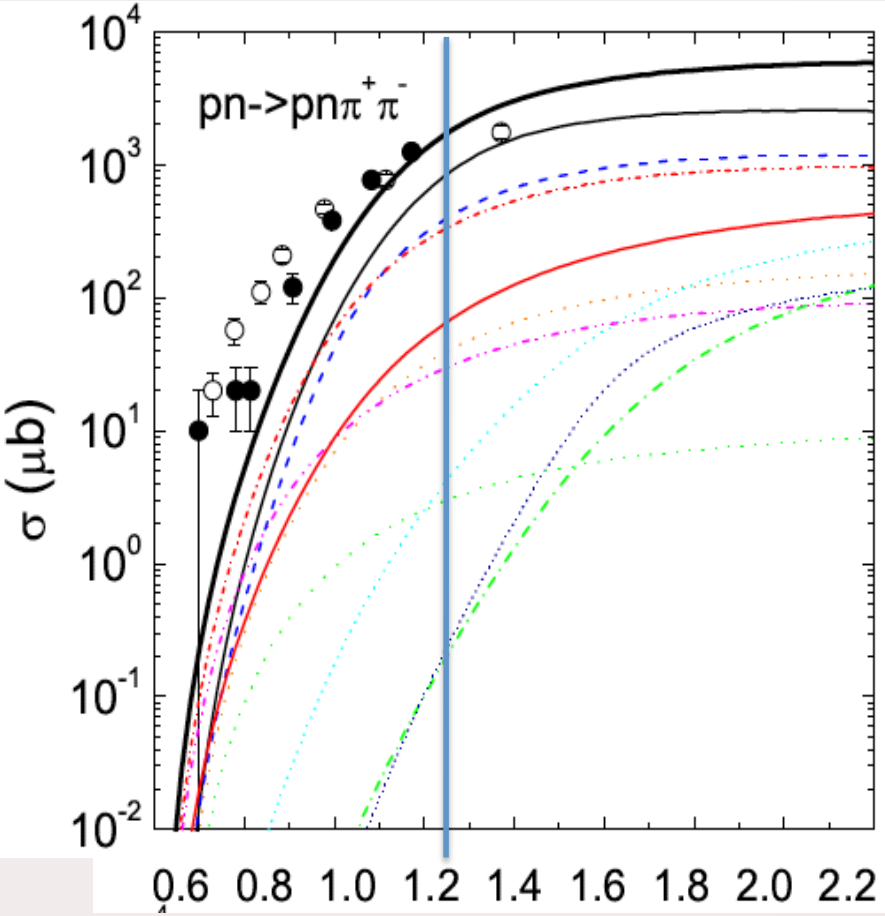
& proton spectator in Forward Wall

np reactions in HADES

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



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



On-going comparisons with models

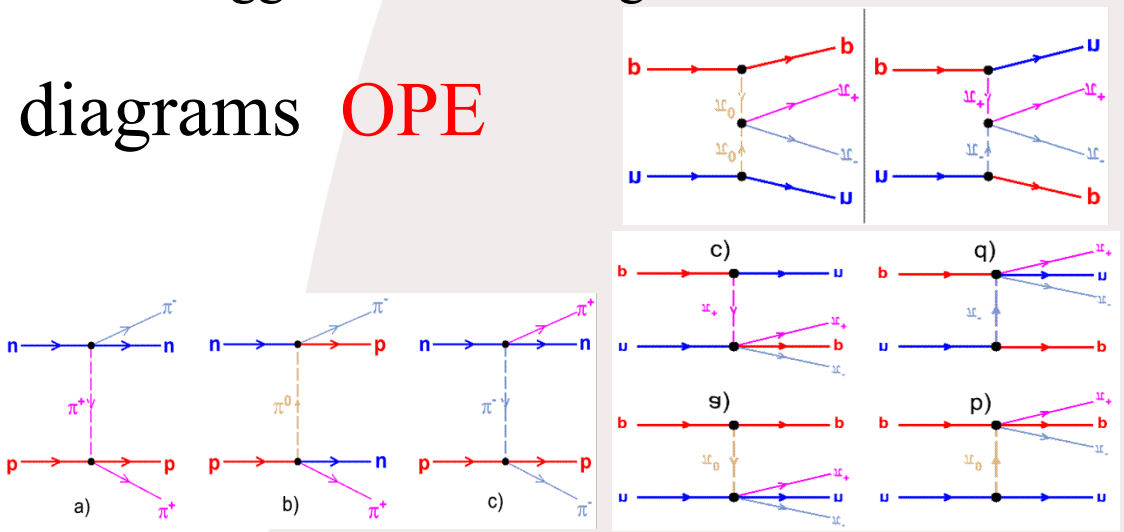
Comparison with OPER model

A. Jerusalimov: arXiv:1203.3330 [nucl-th]

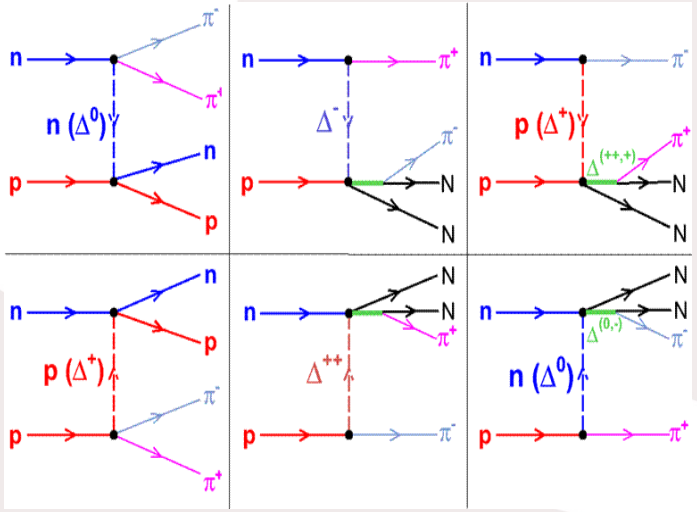
$np \rightarrow np\pi^+\pi^-$

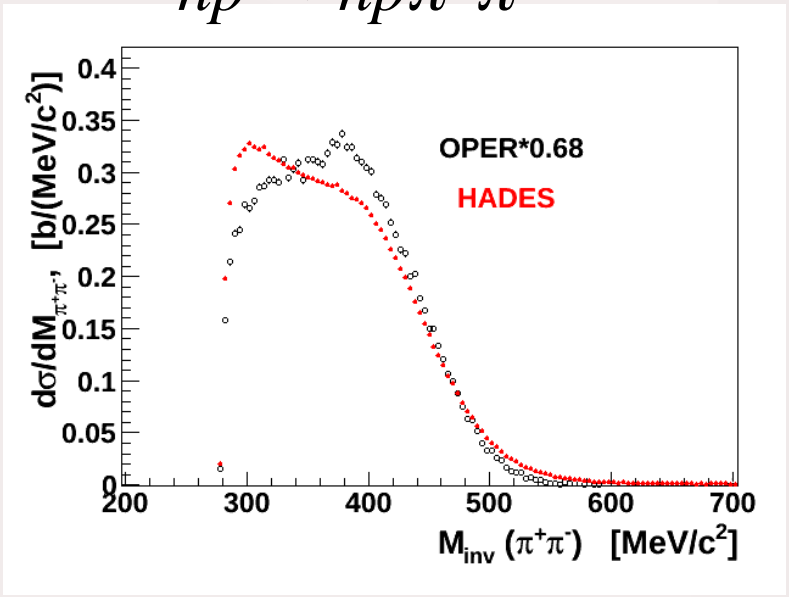
OPER : reggeized π-exchange model

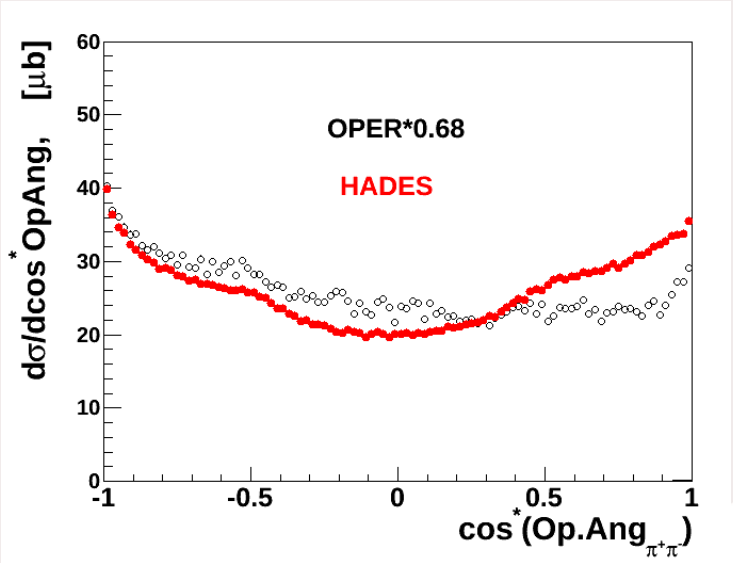
diagrams OPE



diagrams OBE







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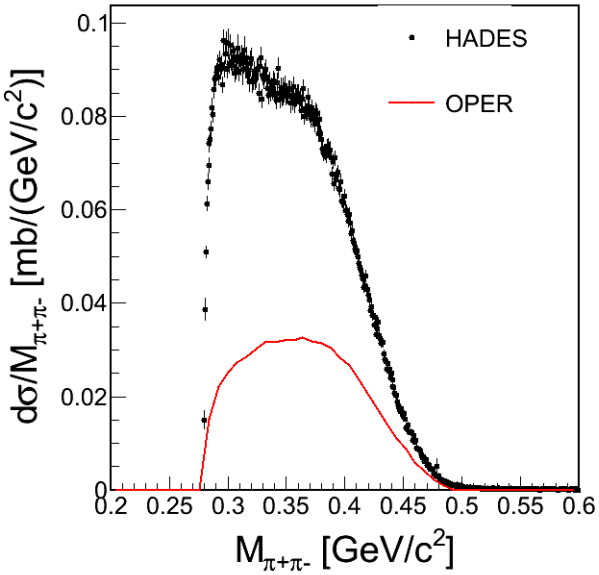
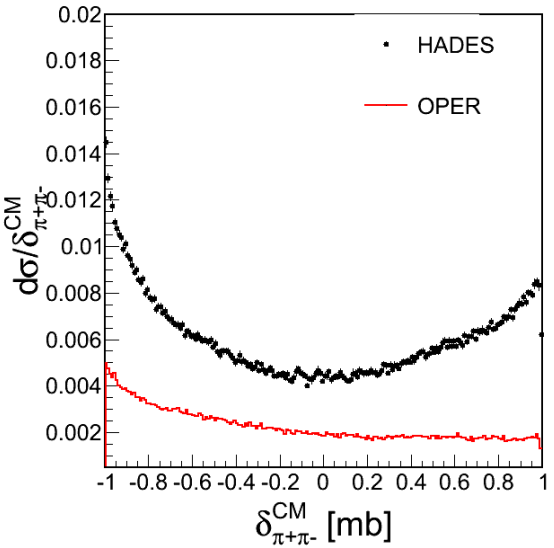
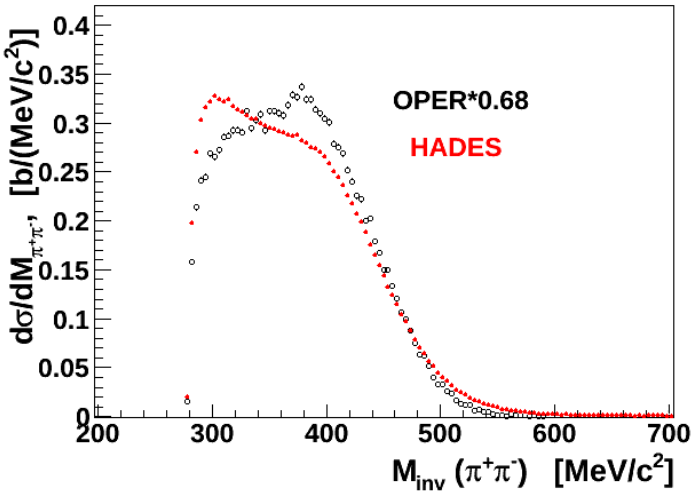
Comparison with OPER model

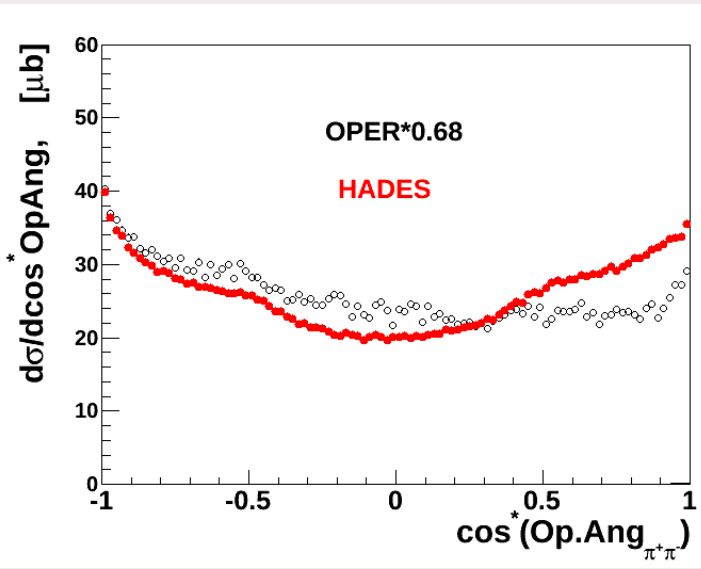
$pp \rightarrow pp\pi^+\pi^-$





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





Summary and outlook

- ✓ HADES provides high statistics data for double-pion production in pp and np @ 1.25 GeV
- ✓ Comparison with the theoretical models has been performed for pp, and on-going for np
  - ✓ Valencia model
  - ✓ Xu Cao et al.
  - ✓ OPER model
- ✓ Data excess over models calculation in case of pp
- ✓ Comparison to the modified Valencia model (a-la WASA style) has been also shown
  - ✓ better agreement with the HADES ($pp \to pp\pi^+\pi^-$) and WASA ($pp \to pp\pi^0\pi^0$) achieved

THANK YOU VERY MUCH FOR YOUR ATTENTION !!!