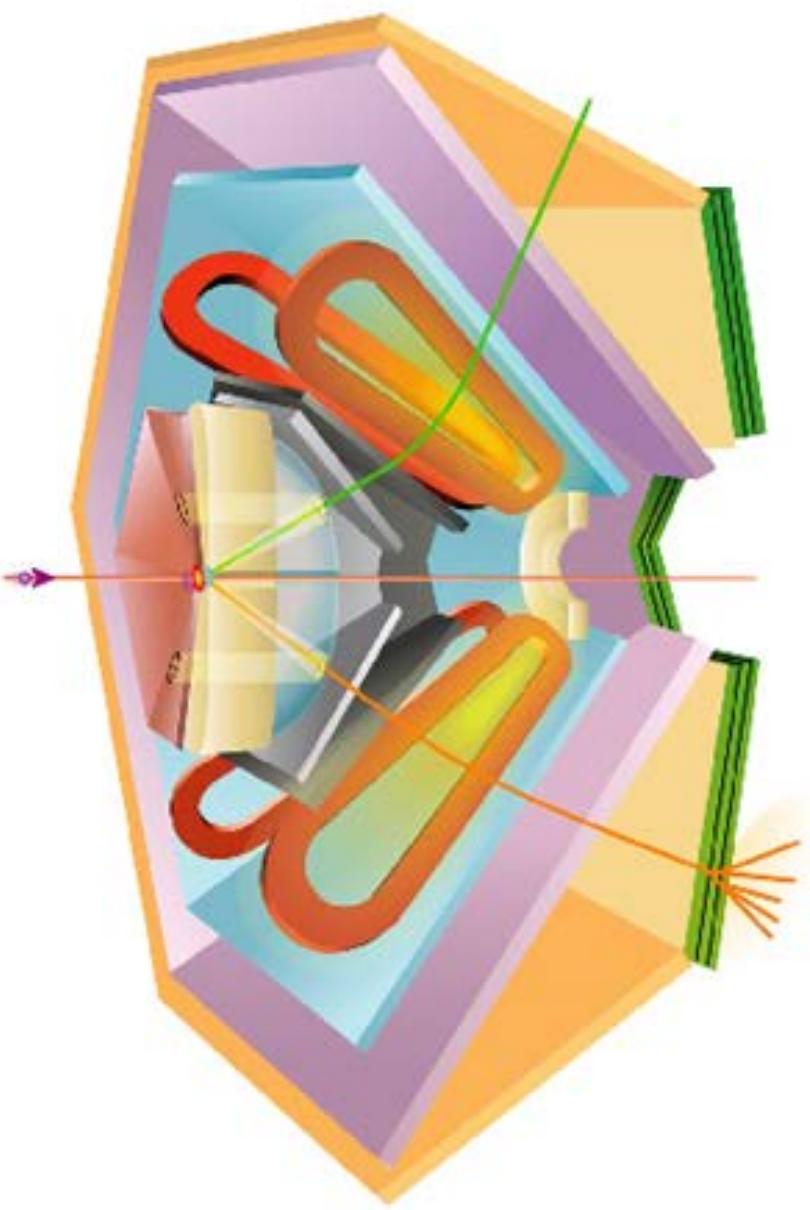
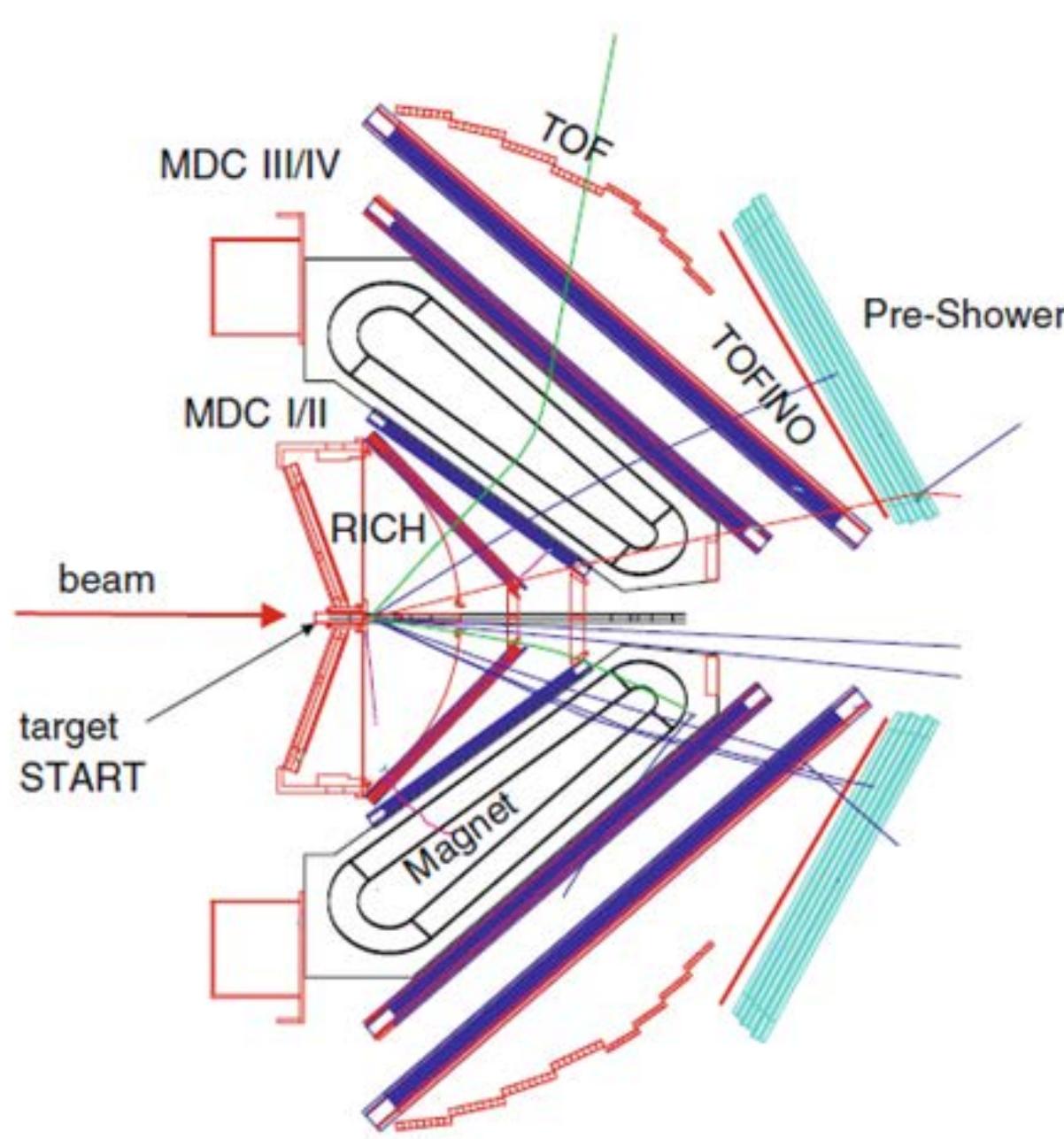


Study of baryonic resonances and ρ meson production in the channel $pp \rightarrow pp\pi^+\pi^-$ @ $E=3.5$ GeV with HADES

Amel Belounnas (IPN Orsay, France)
For the HADES Collaboration

NSTAR 2019
11/06/2019



Acceptance:

Azimuthal angles 85% (6 sectors)

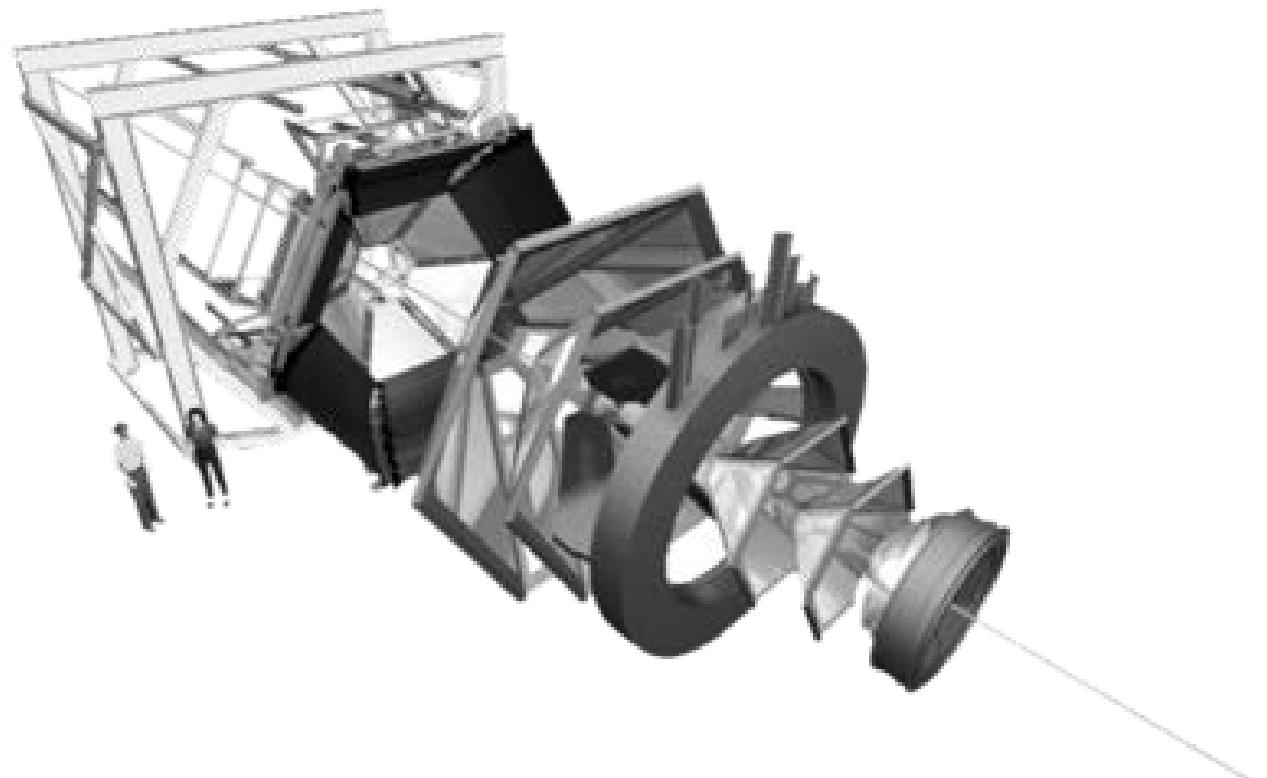
Polar angles: $18^\circ - 85^\circ$

Detected particles: e^\pm , p, π^\pm , K^\pm

Tracking: MDC

PID: e^\pm with RICH, TOF/PreShower

p, π^\pm , K^\pm identification TOF-Tracking



HADES

High
Acceptance
Di-
Electron
Spectrometer

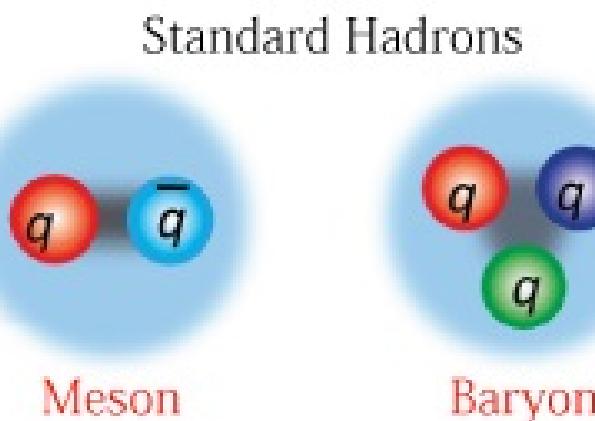
Pion production motivation at HADES

Hadron spectroscopy:

Mesons: $\rho \rightarrow \pi\pi$, $\omega \rightarrow \pi\pi\pi \dots$

Baryons: $\Delta/N^* \rightarrow N\pi$, $\Delta/N^* \rightarrow N\pi\pi$

Reaction mechanism.

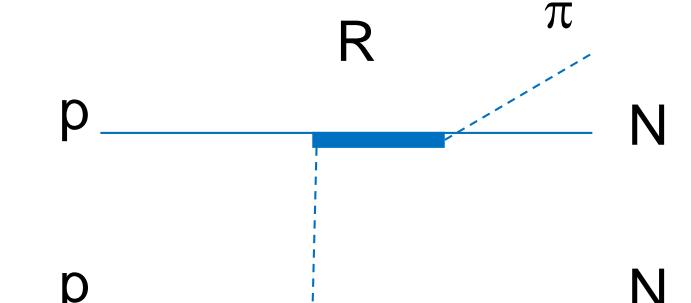
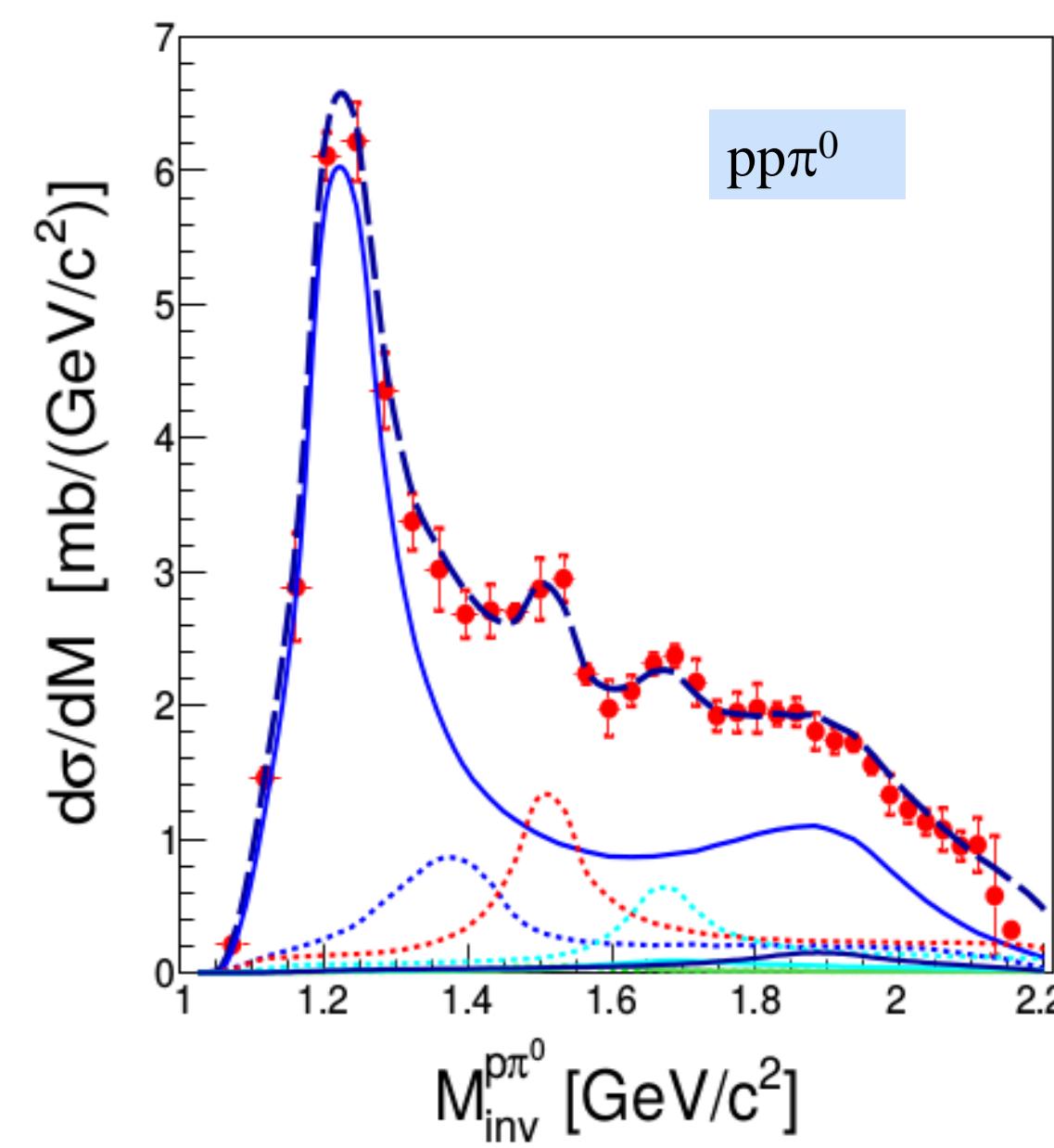
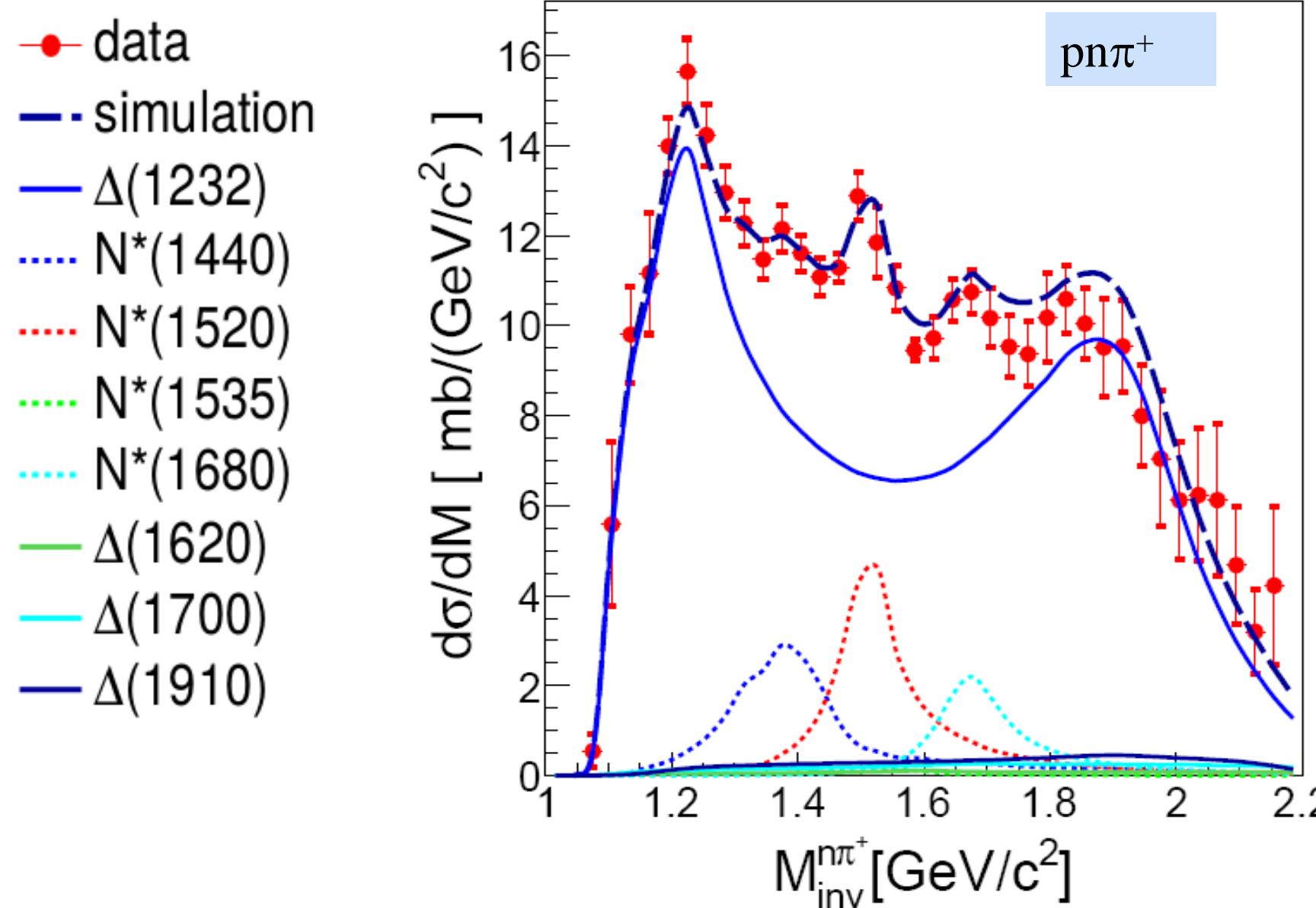


$pp \rightarrow np\pi^+$ and $pp \rightarrow pp\pi^0$ @ $E=3.5$ GeV

G. Agakishiev et al.
Eur.Phys.J. A50 (2014) 8

Cocktail of baryonic resonances obtained from the 1π production

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

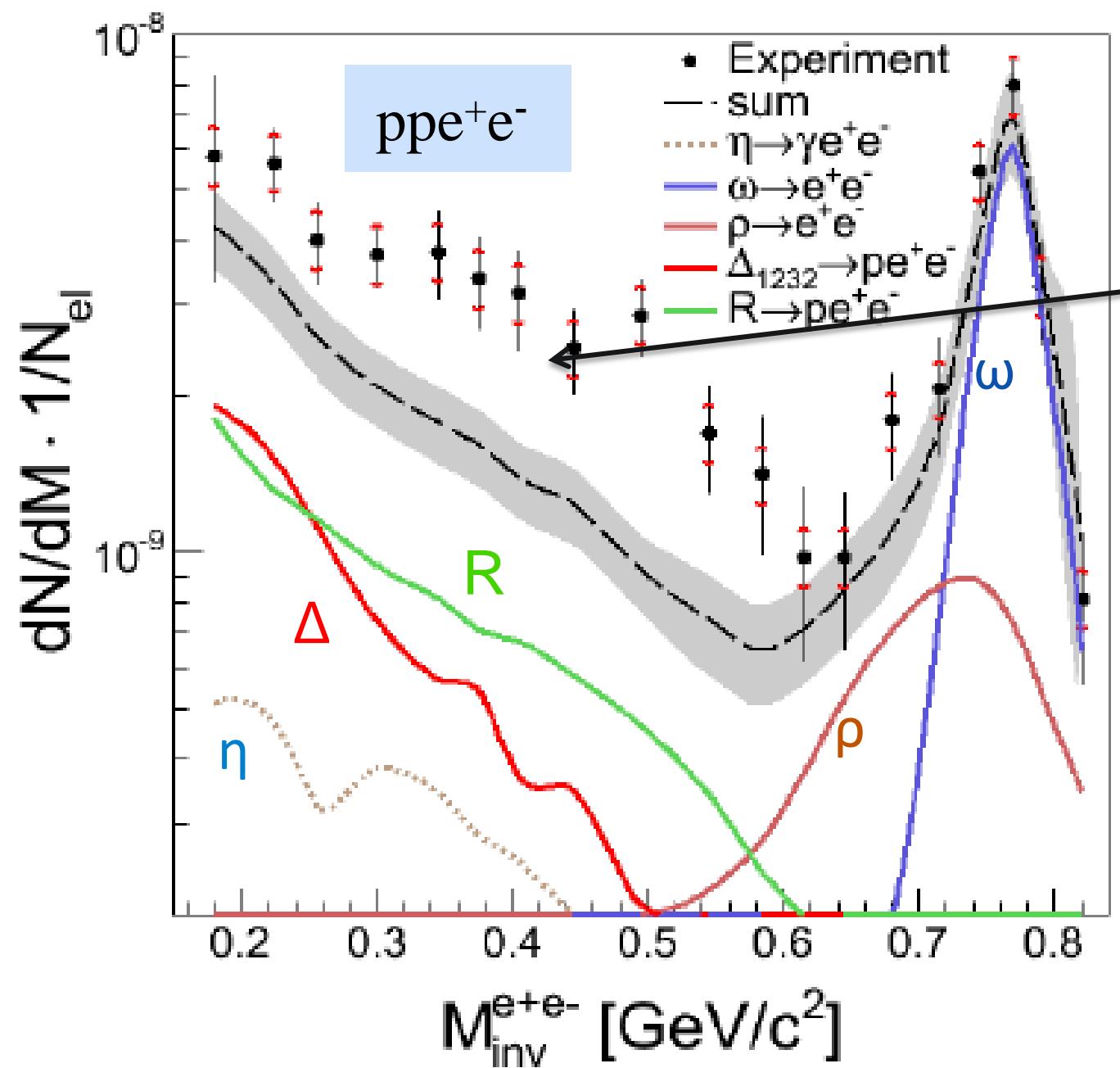


Pion production motivation at HADES

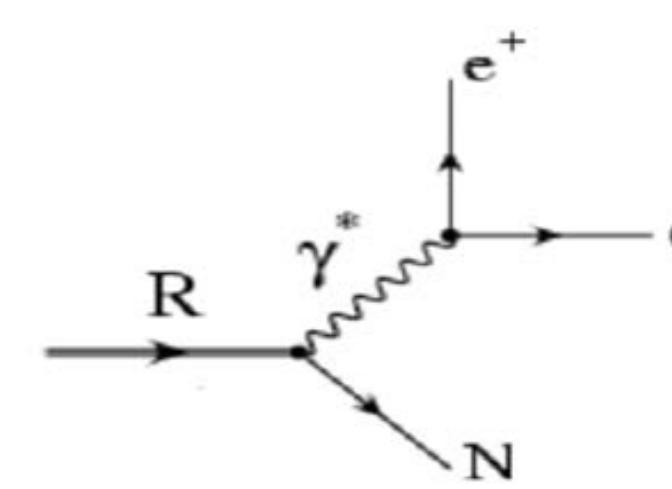
$pp \rightarrow ppe^+e^-$ @ $E = 3.5$ GeV

G. Agakishiev et al. Eur.Phys.J. A50 (2014) 8

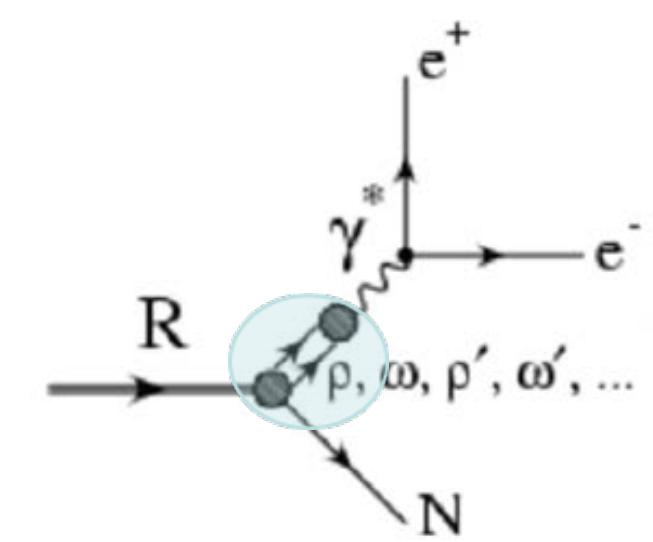
Dalitz decay of the resonance cocktail + ρ, ω and η



Effect of the coupling to ρ



QED: point-like $R-\gamma^*$ vertex



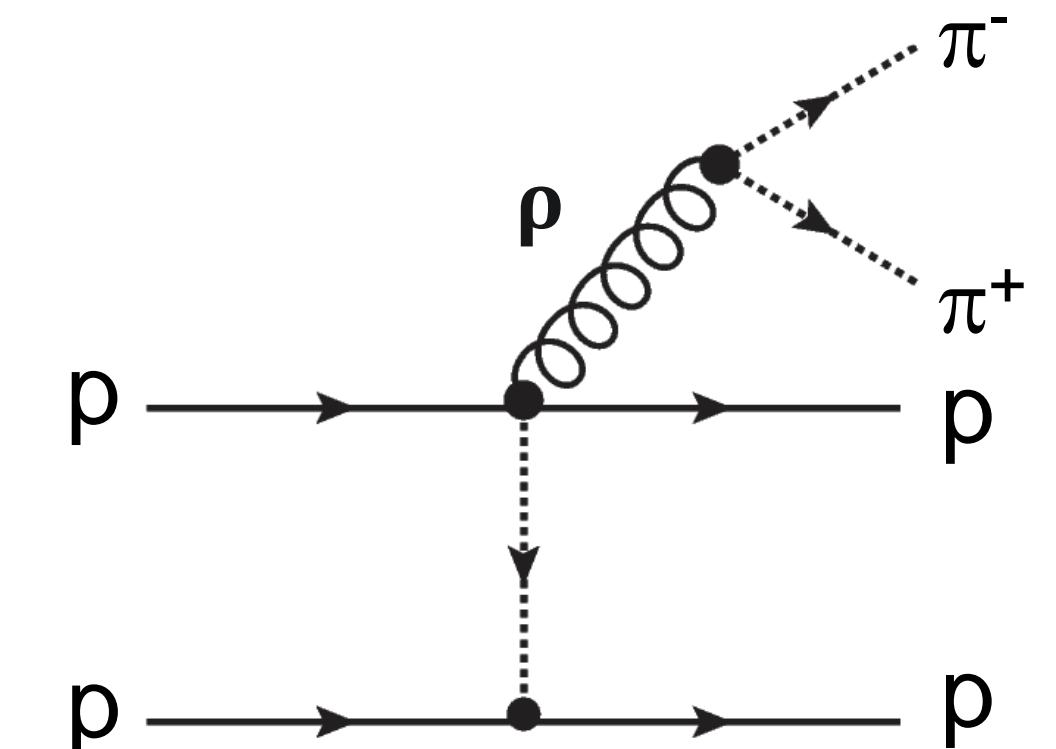
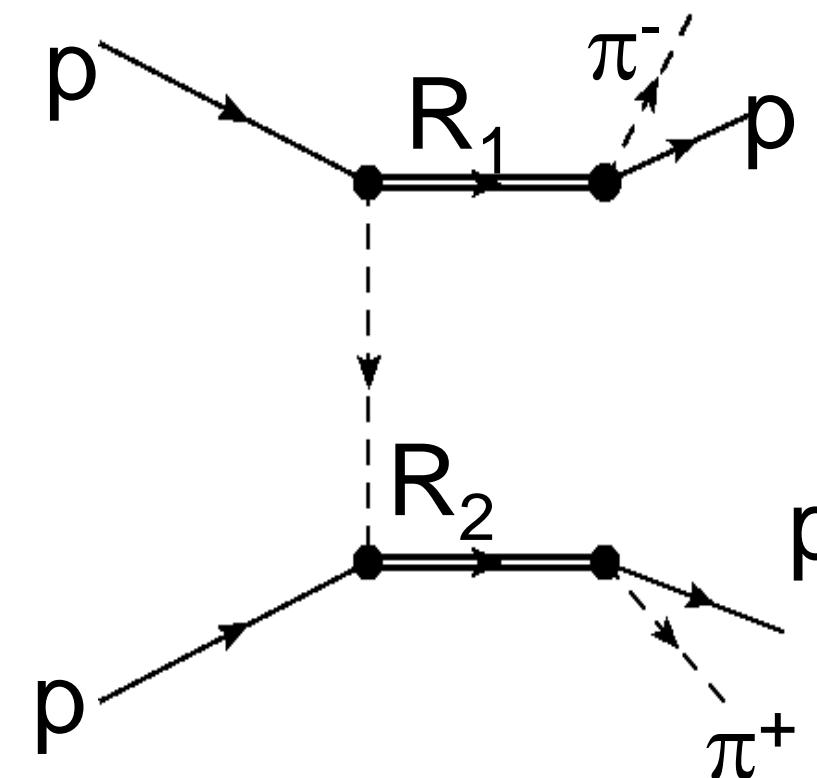
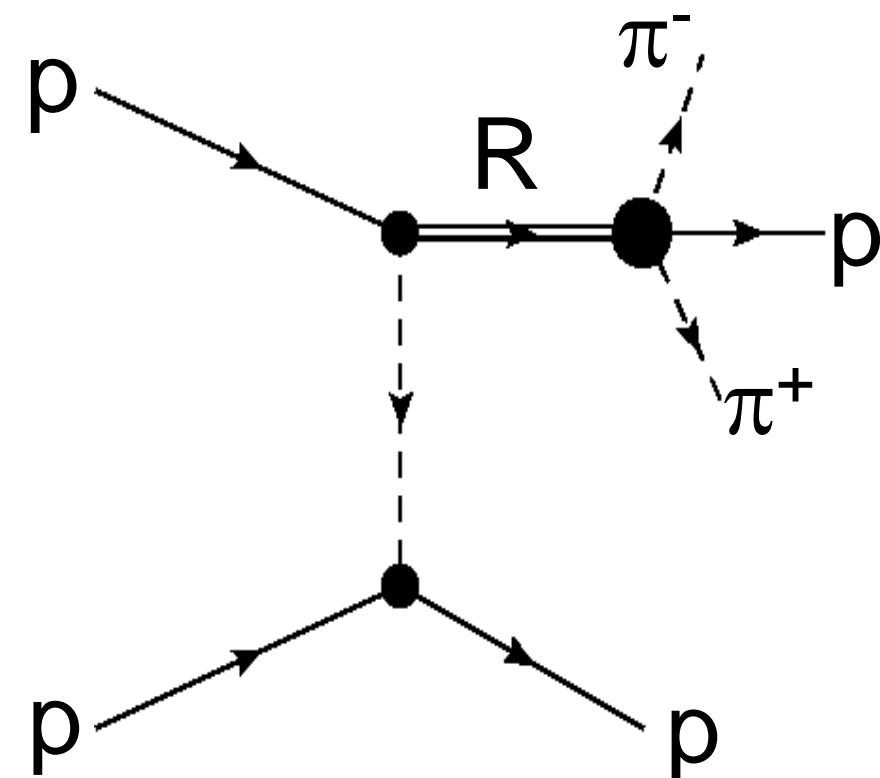
EM time-like form factor

Interest of the channel $pp \rightarrow pp\pi^+\pi^-$:

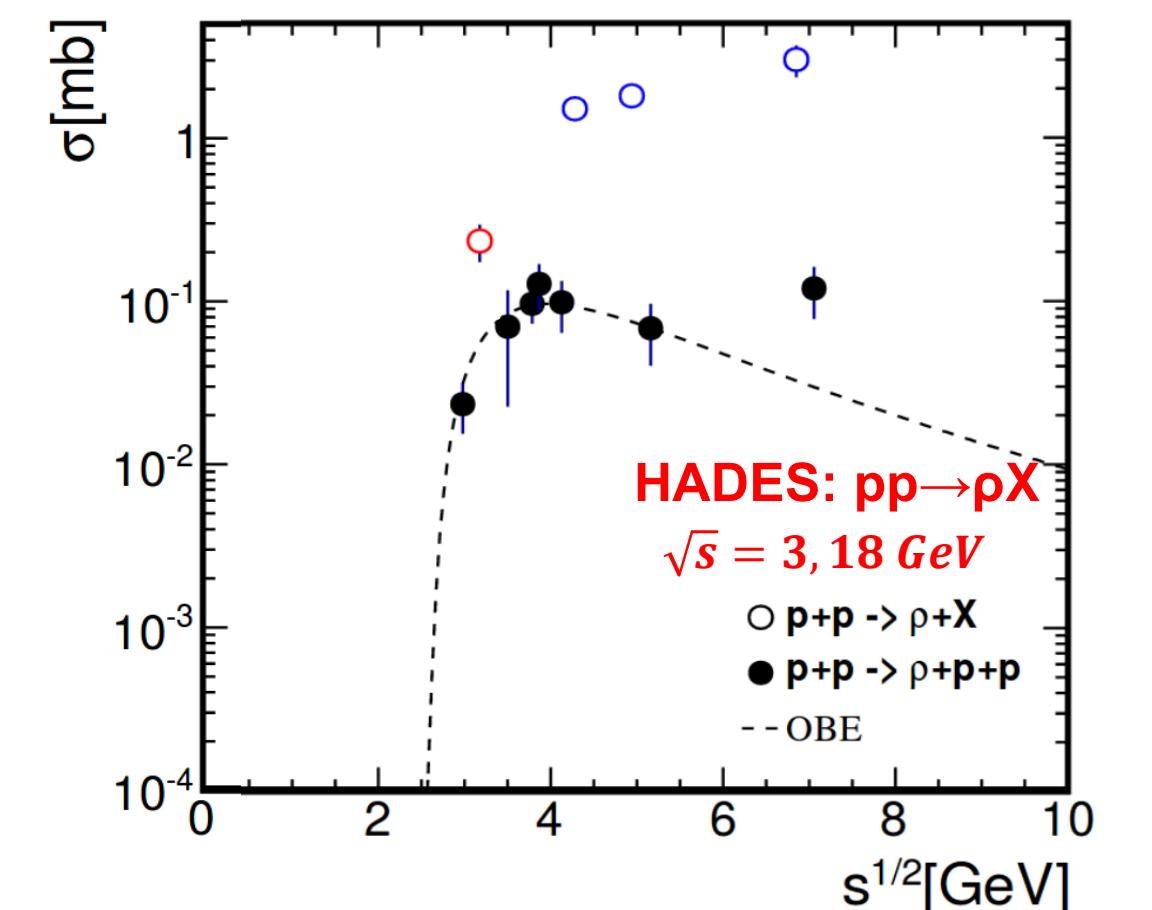
- ✓ Test the cocktail on the 2 pion production.
- ✓ Measure the ρ ($\rho \rightarrow \pi^+\pi^-$) production, direct and coupled to resonances .

Study of the channel $pp \rightarrow pp\pi^+\pi^-$ @ $E=3.5$ GeV

- One resonance excitation (1R)
- Double resonance excitation (2R)
- Direct ρ production

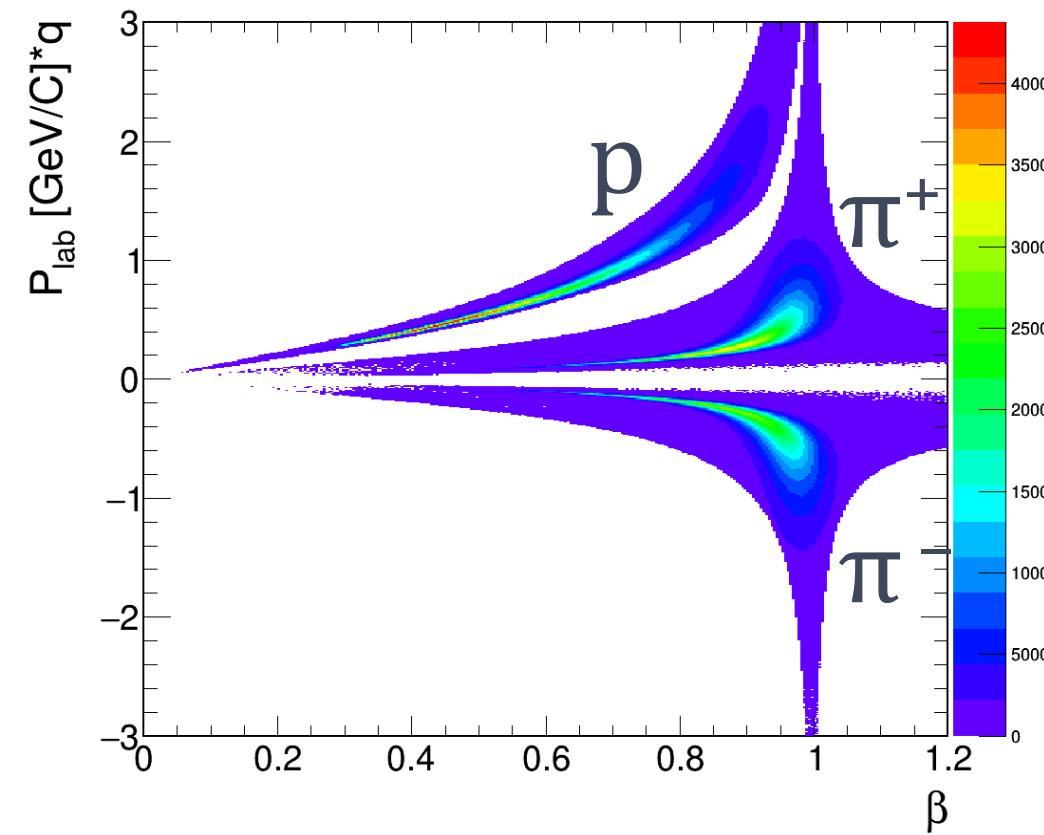


Few precise measurements

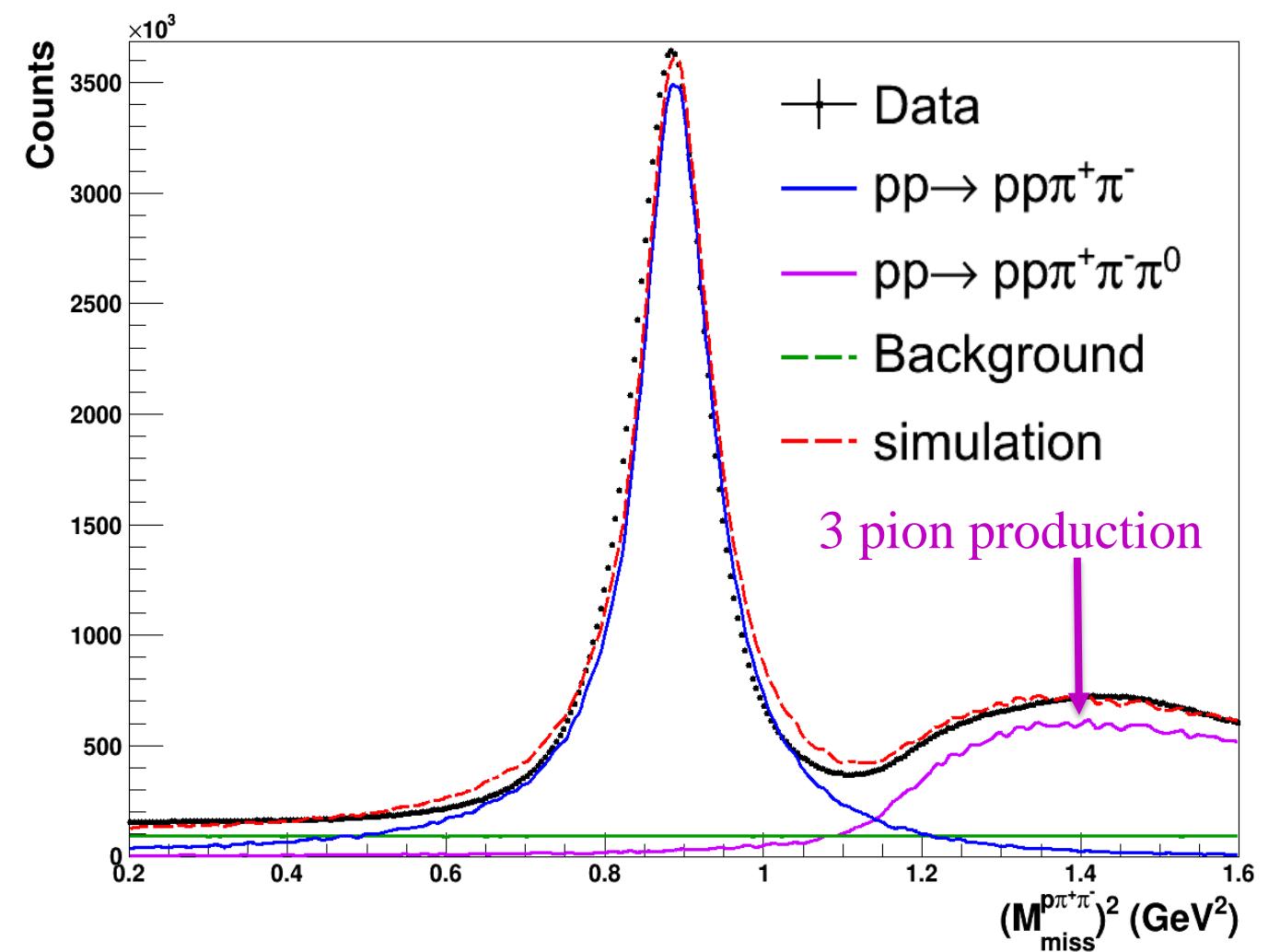


Data Analysis

- Channel selection: $1\pi^+ 1\pi^-$ and 1 proton at least



- Background subtraction.



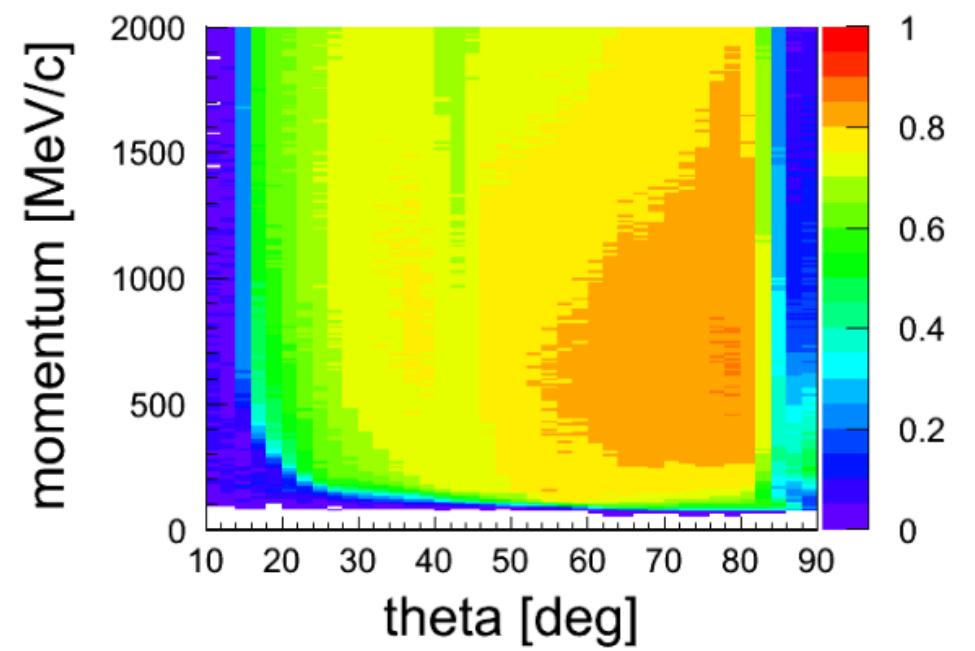
Squared missing mass $pp \rightarrow p\pi^+\pi^- X$

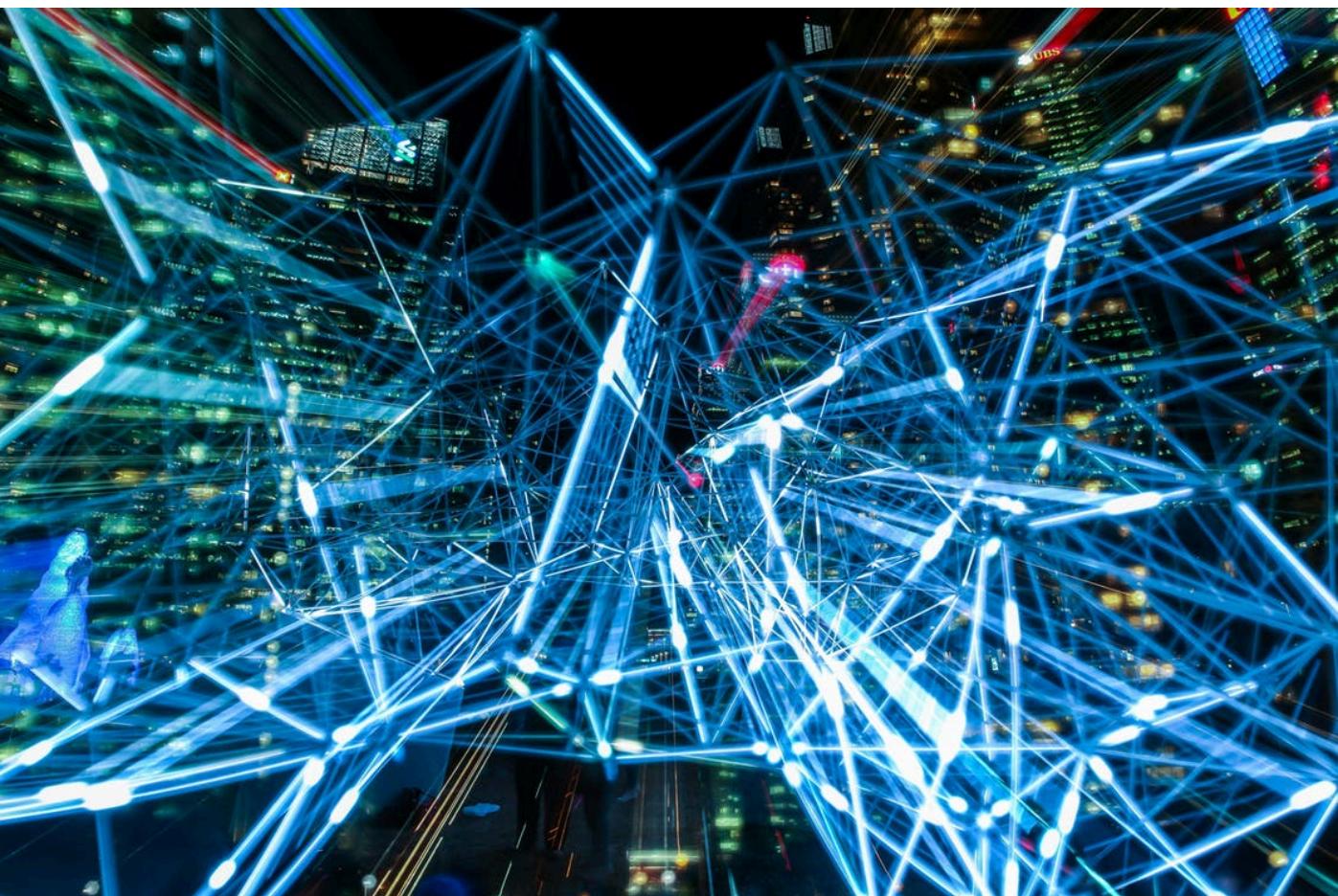
- Efficiency correction: using efficiency matrices from GEANT simulation

$$Eff_{total} = Eff_p * Eff_{\pi^+} * Eff_{\pi^-}$$

- Normalisation using pp elastic scattering:

$$\sigma_{Data} = N_{Data} \frac{\sigma_{el}^{pp}}{N_{el}^{pp}}$$





HADES Resonance Cocktail

PLUTO++ Simulations

*PLUTO is a Monte Carlo simulation framework developed by the HADES collaboration for heavy ion and hadronic-physics reactions.

PDecayChannel (PLUTO Class)

BR x I

$N1520 \rightarrow p\pi^+\pi^-$ (0.04) (6% x 2/3)

$N1520 \rightarrow \Delta^{++}\pi^-$ (0.12) (23% x 1/2)

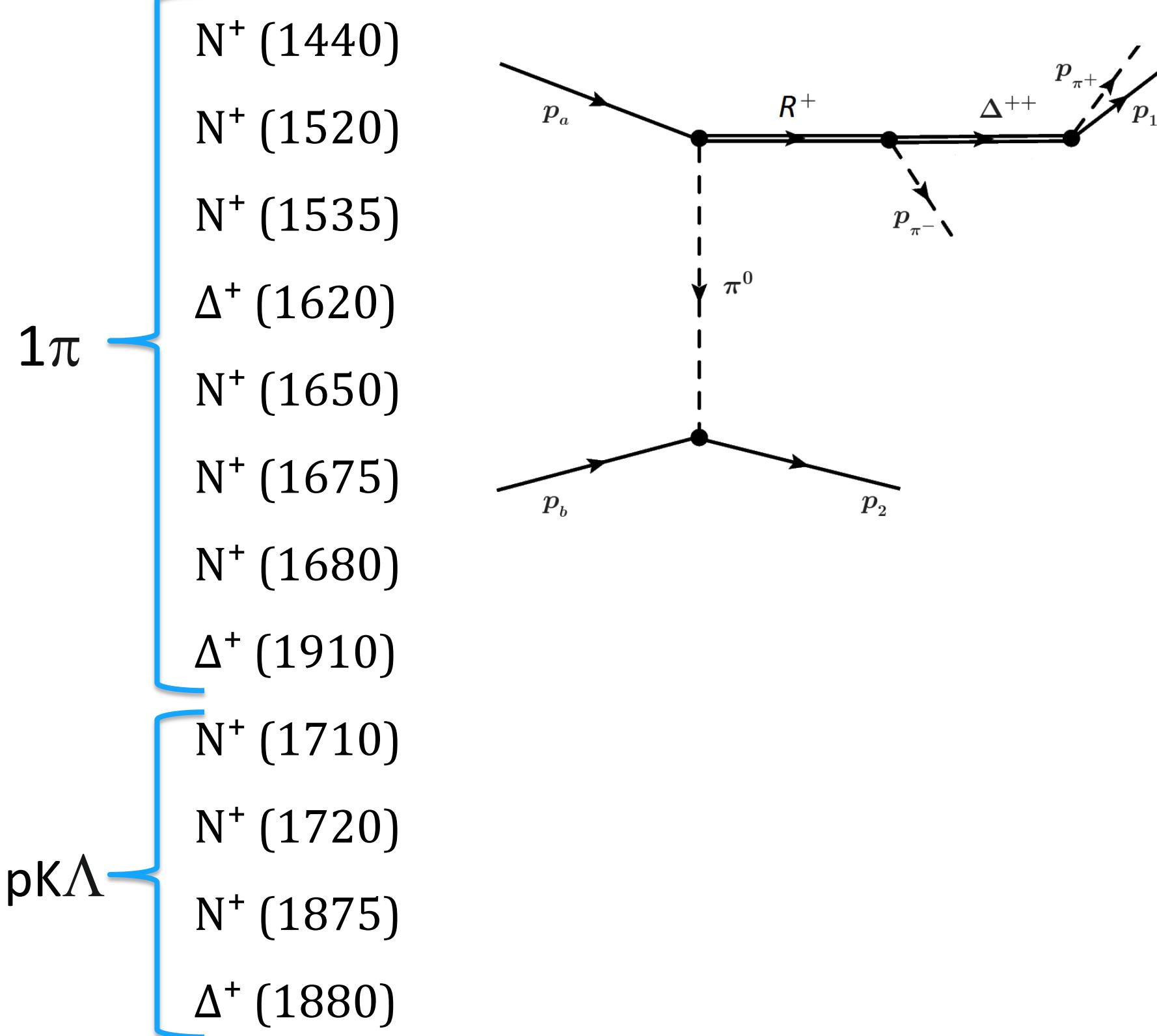
$N1520 \rightarrow \Delta^0\pi^+$ (0.04) (23% x 1/6)

$N1520 \rightarrow pp^0$ (0.003) (1% x 1/3)

Simulation (using PLUTO++)

$pp \rightarrow pR \rightarrow pp \pi^+ \pi^- (1R)$

(Using known cross sections from $1\pi^*$ and $pK\Lambda^{**}$ analysis)



Direct ρ production

$pp \rightarrow pp \rho$

$pp \rightarrow RR' \rightarrow pp \pi^+ \pi^- (2R)$

(cross sections adjusted to the data)

$\Delta^{++}(1232) \Delta^0(1232)$

$\Delta^{++}(1232) N^o(1440)$

$\Delta^{++}(1232) N^o(1520)$

$\Delta^{++}(1232) N^o(1535)$

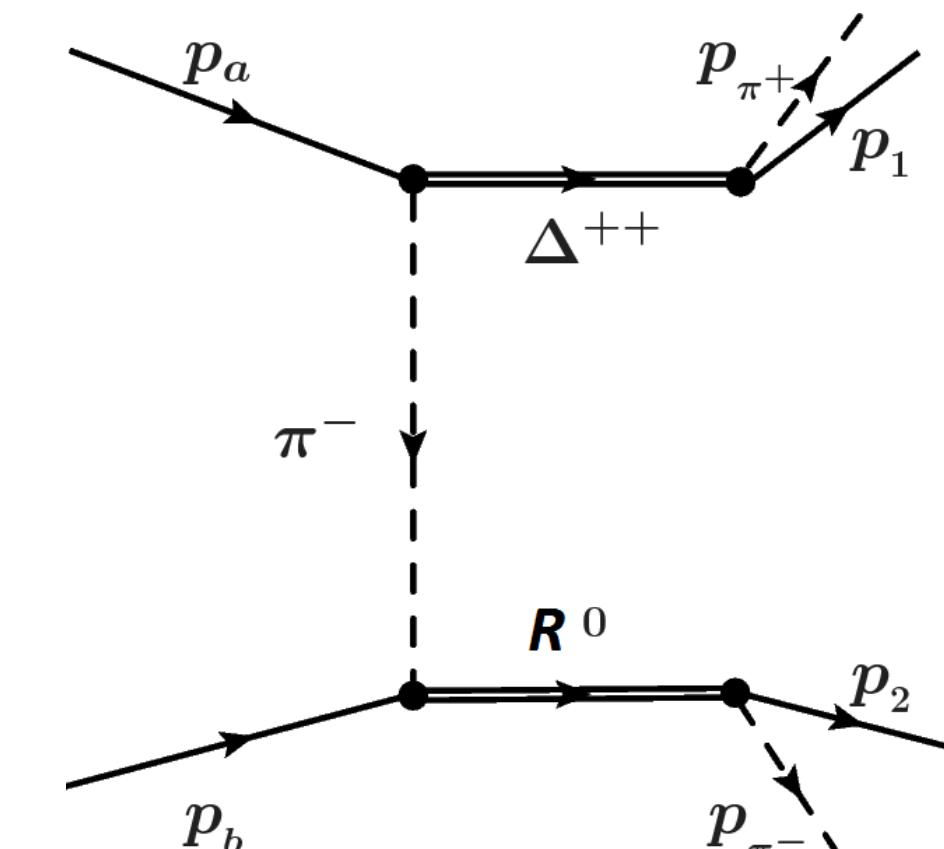
$\Delta^{++}(1232) \Delta^o(1620)$

$\Delta^{++}(1232) N^o(1650)$

$\Delta^{++}(1232) N^o(1680)$

$\Delta^{++}(1232) N^o(1720)$

$\Delta^{++}(1232) \Delta^o(1700)$



*G. Agakishiev et al. Eur.Phys.J. A50 (2014) 8

** R. Munzer et al. Phys. Lett. B 785 (2018) 574-580

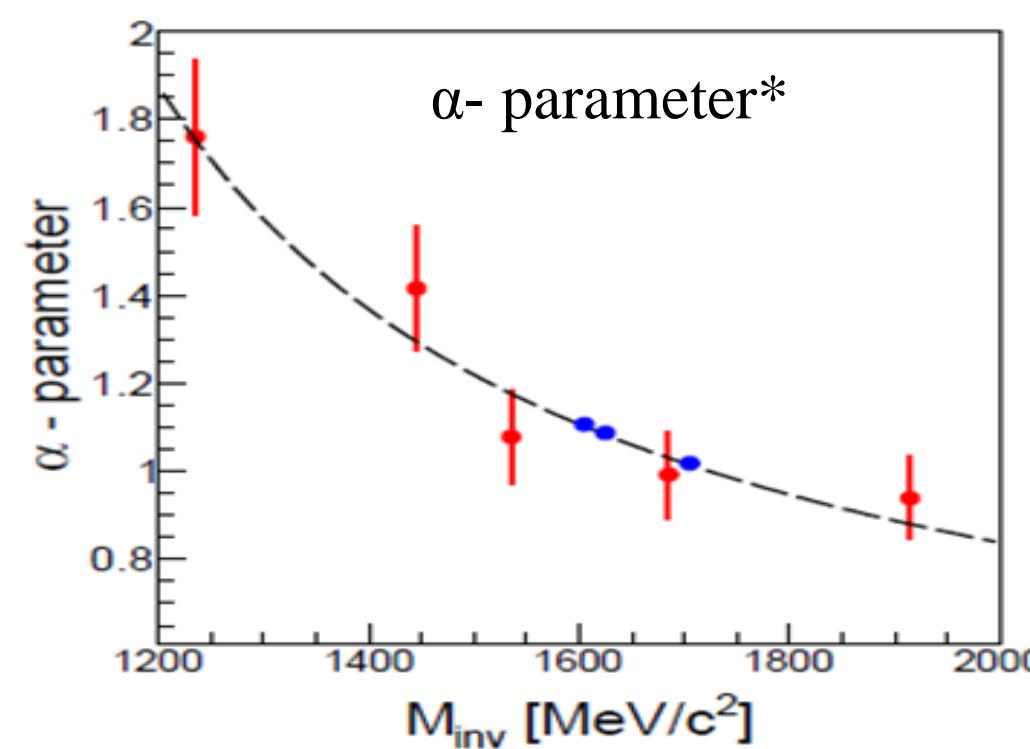
HADES data

Angular Distribution Model

Angular distributions need to be implemented (PLUTO = phase space)

Assuming anisotropic emission in the p-p CM depending on the four momentum transfer

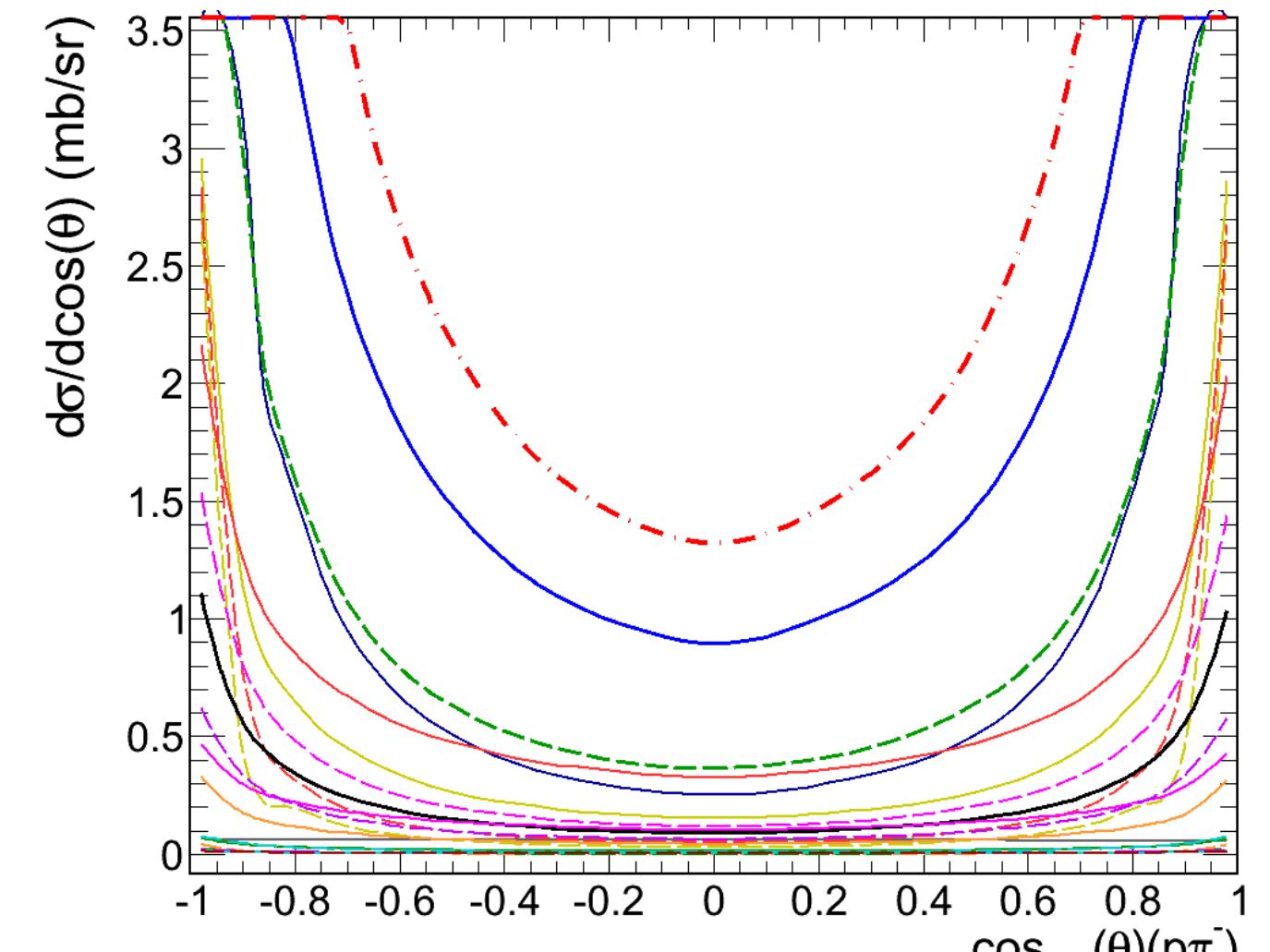
$$\frac{d\sigma_R}{dt} \sim \frac{1}{t^\alpha}$$



$$t_w = \frac{1}{t^\alpha} \quad (\text{4-momentum transfer})$$

- Model validated in 1π analysis.
- Extended to 2R production

The simulation is weighted by t_w



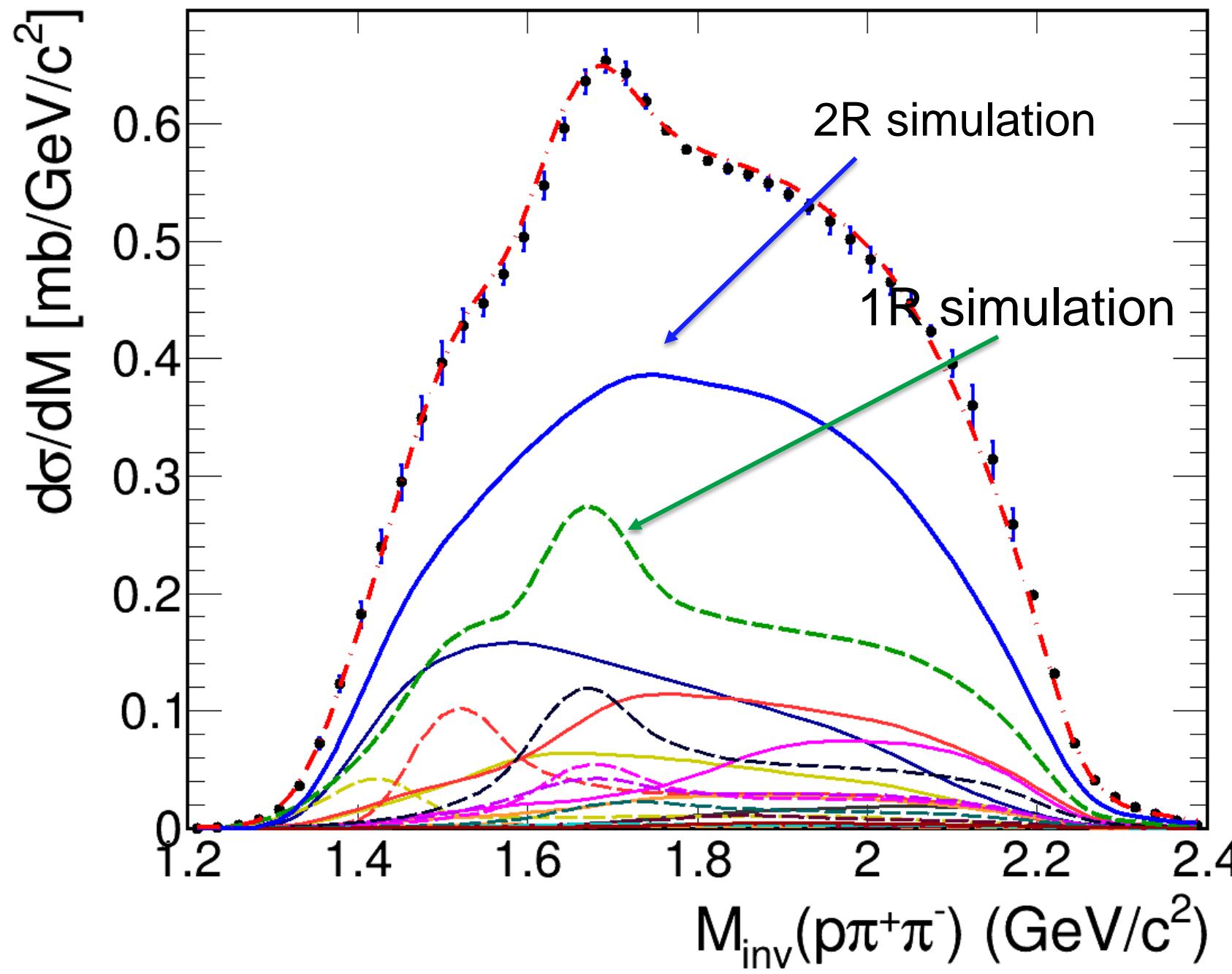
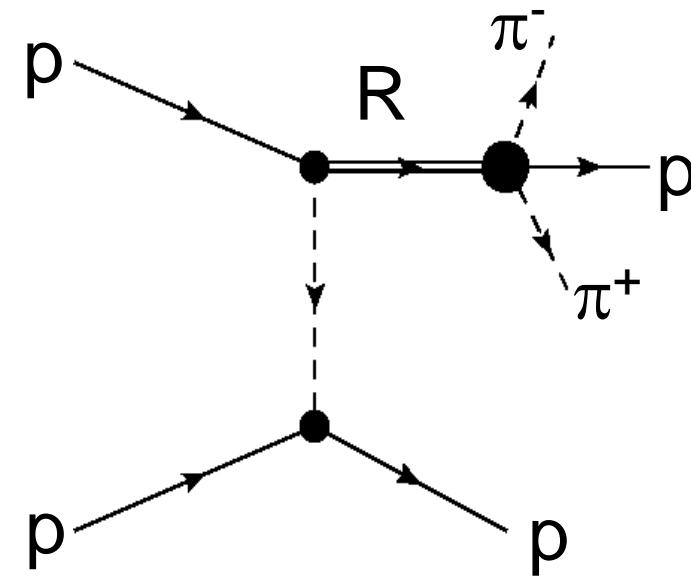
Before applying Acc. cuts



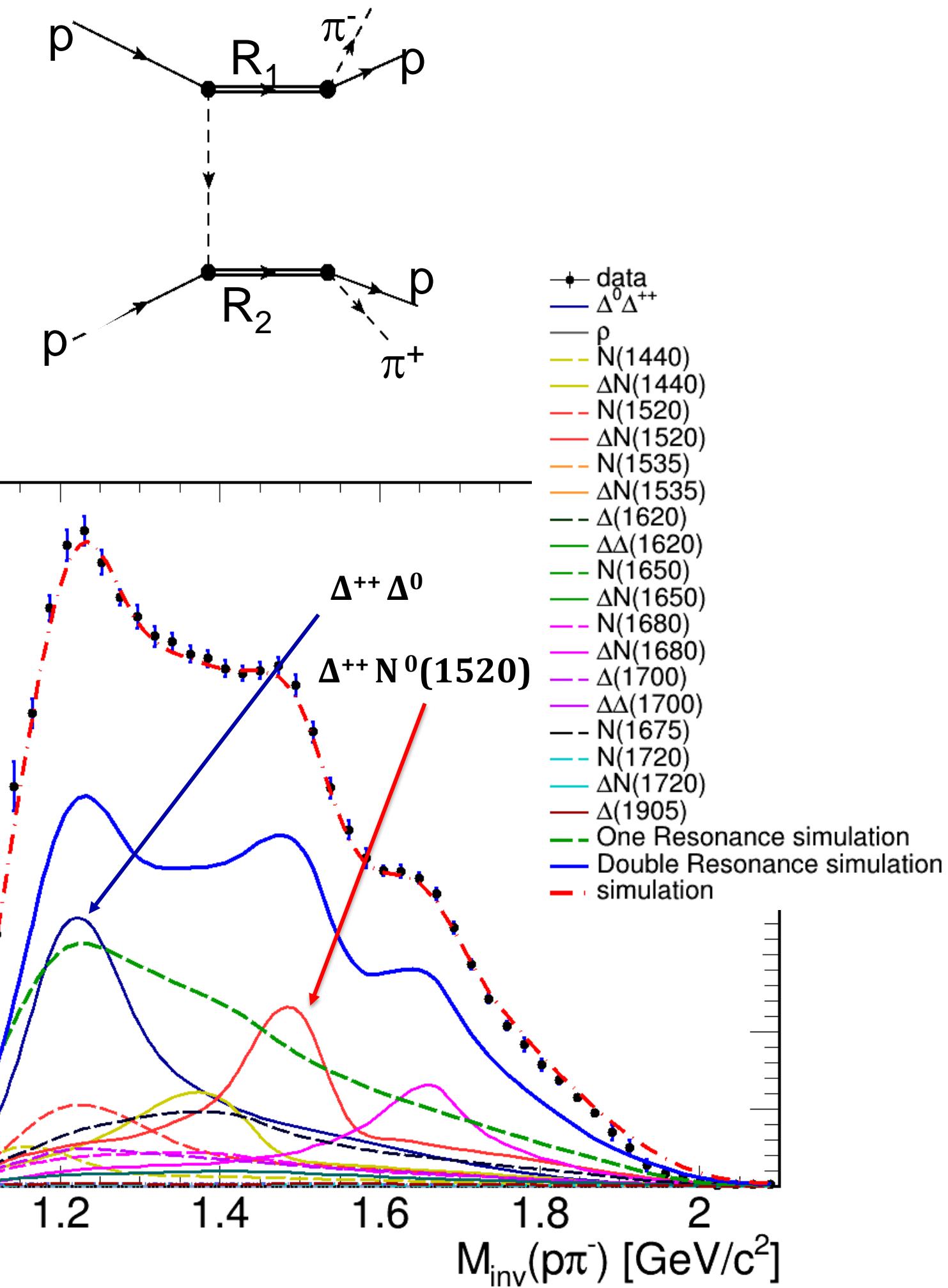
Analysis results

- All spectra include systematic errors
- Normalization err : 6.5% (not included).
- Stat.err are negligible

Invariant Mass Spectra

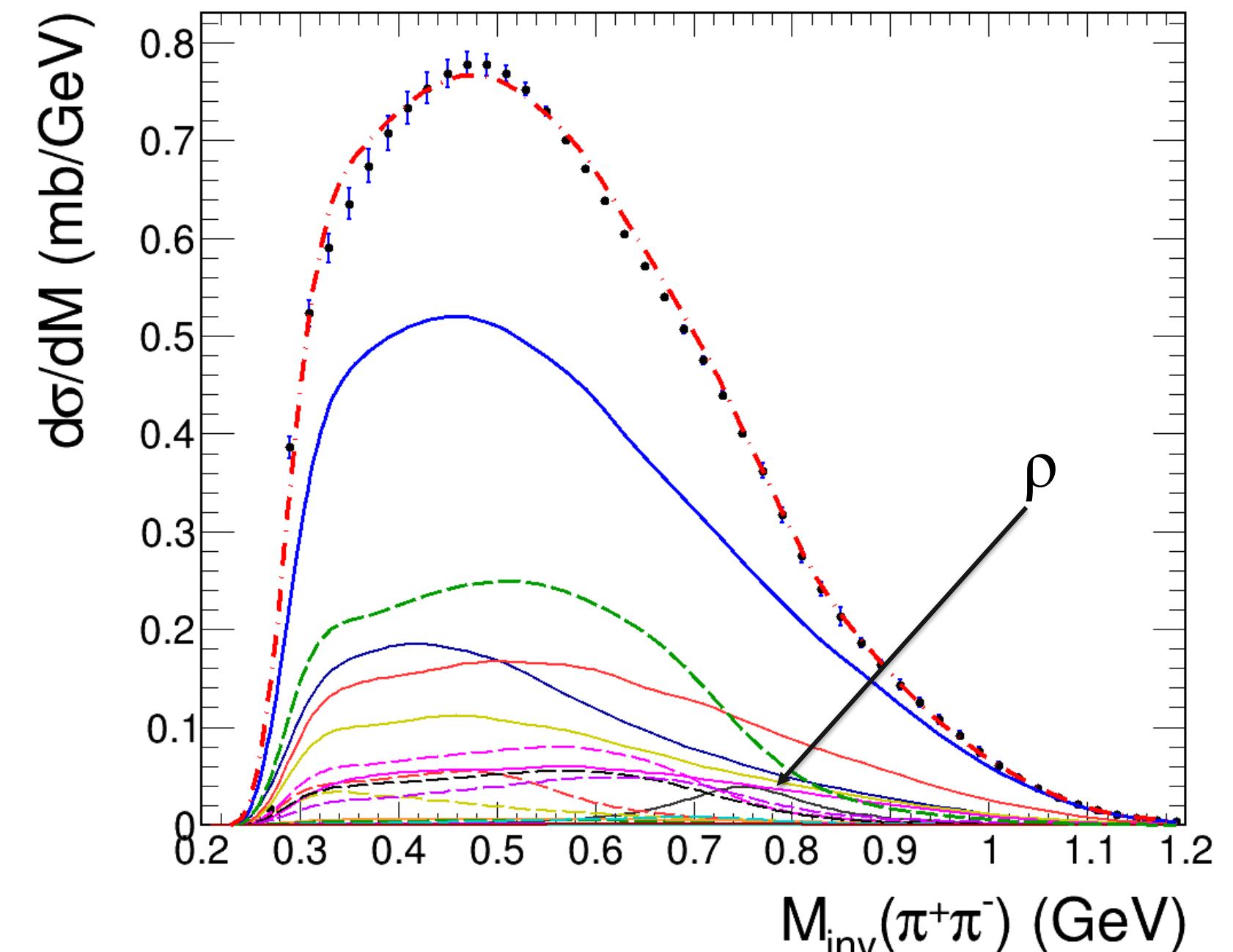
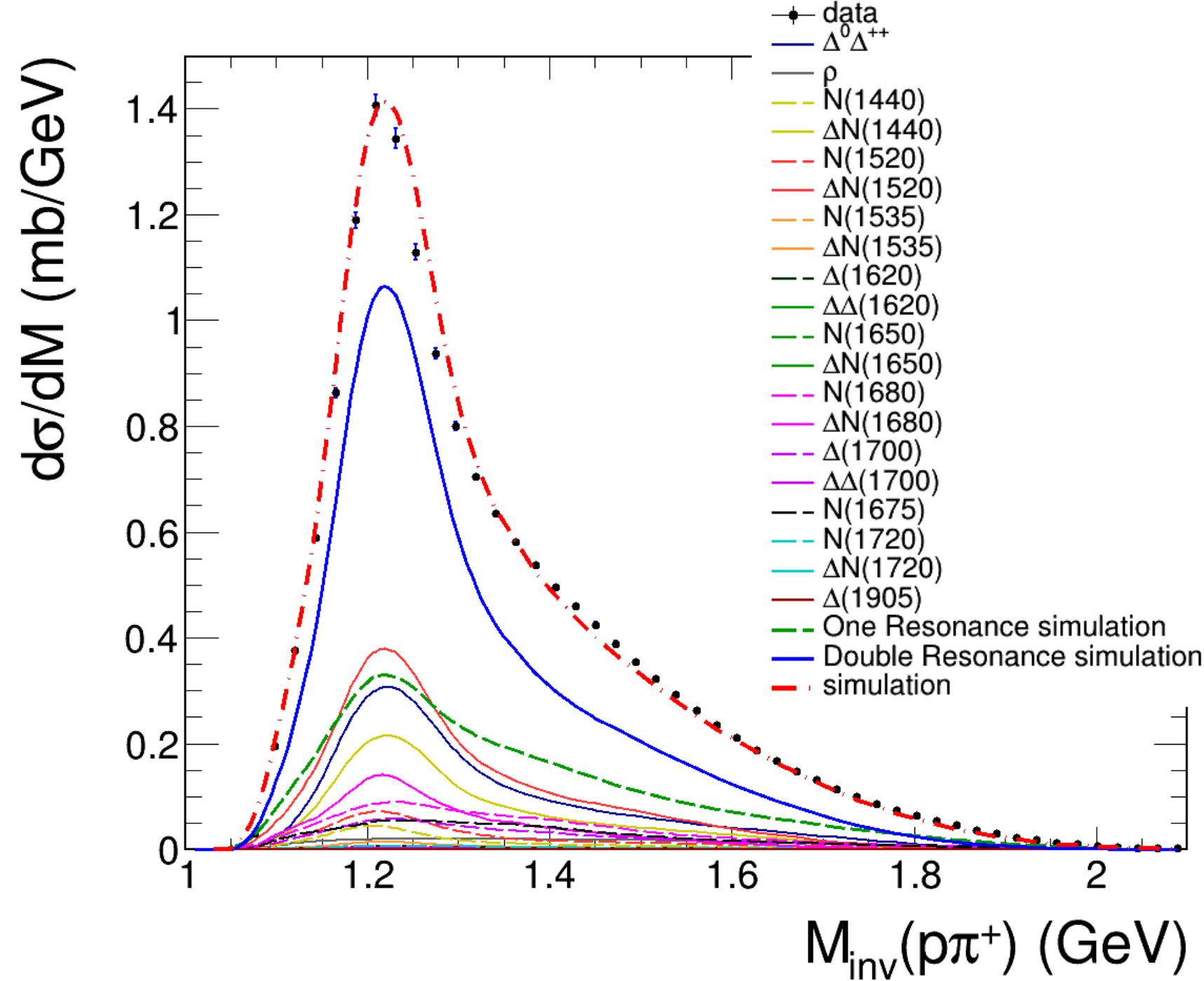


One peak in 1R (dashed green) due to $N^+(1520)$ and a large peak due to $N^+(1675)$, $N^+(1680)$...



3 peaks in 2R (blue) one due to $\Delta^{++}(1232)$, another to $N^0(1520)$, and another to $N^0(1680)$

Invariant Mass Spectra

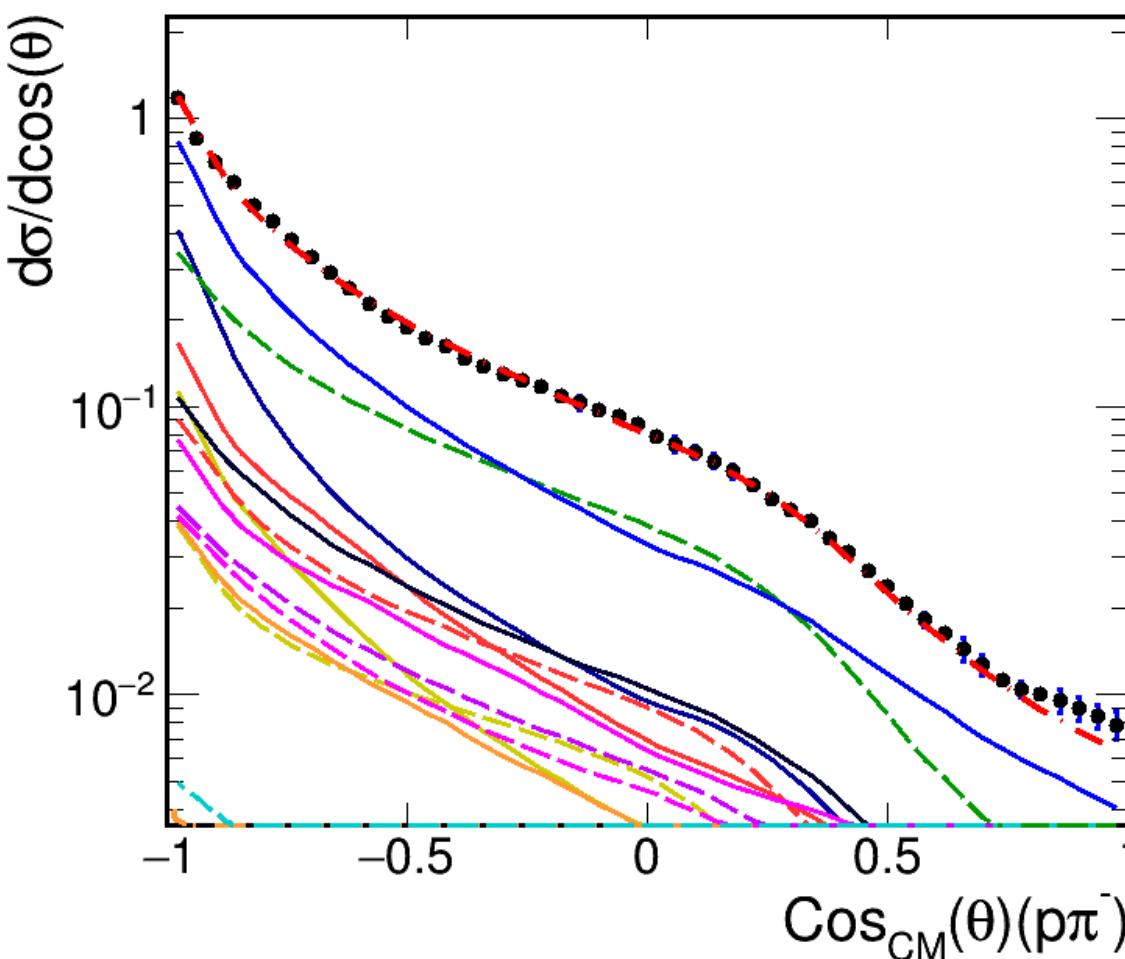


Strong dominance of $\Delta^{++}(1232)$, no significant contribution of heavier Δ^{++} resonances.

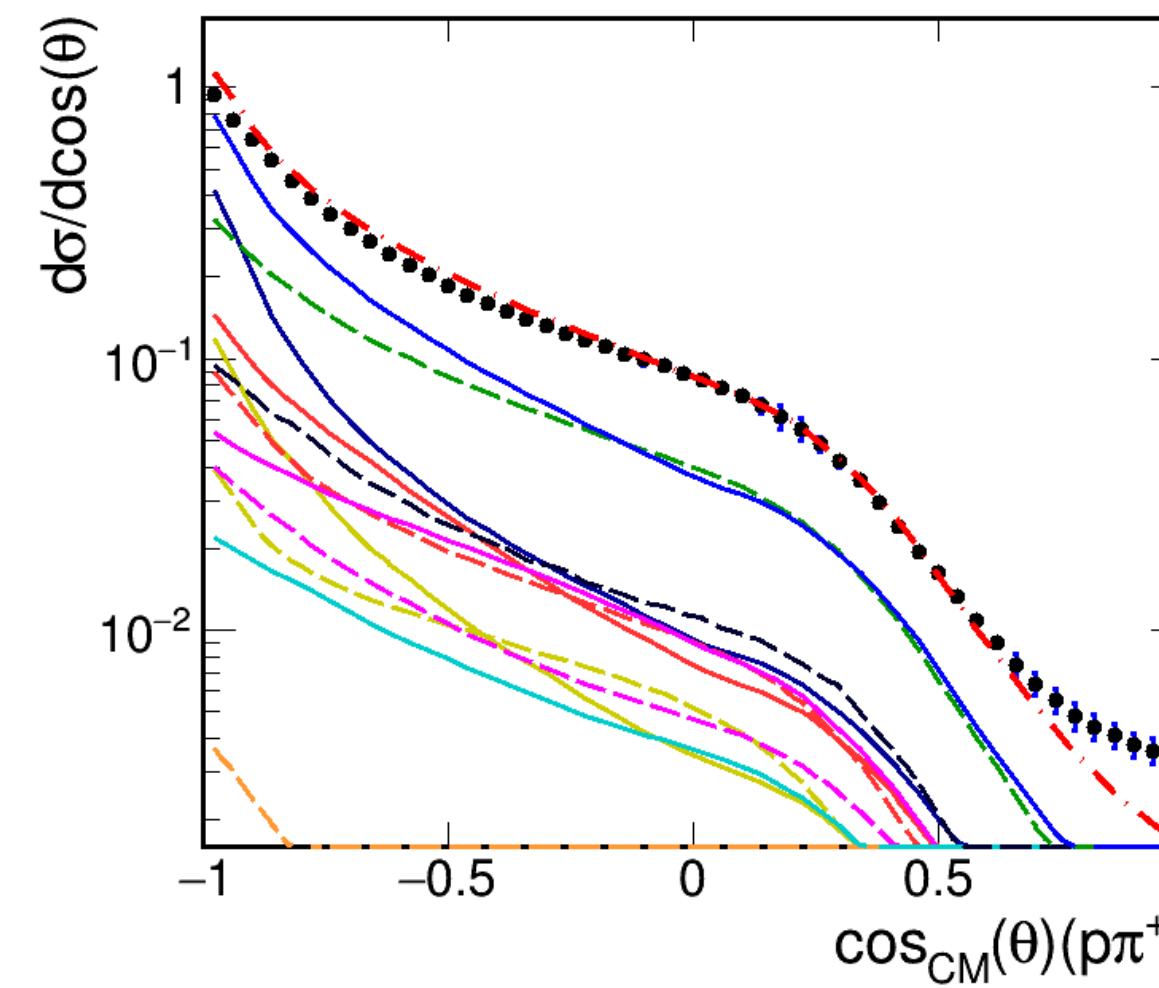
No clear evidence of direct ρ production

Angular Distributions

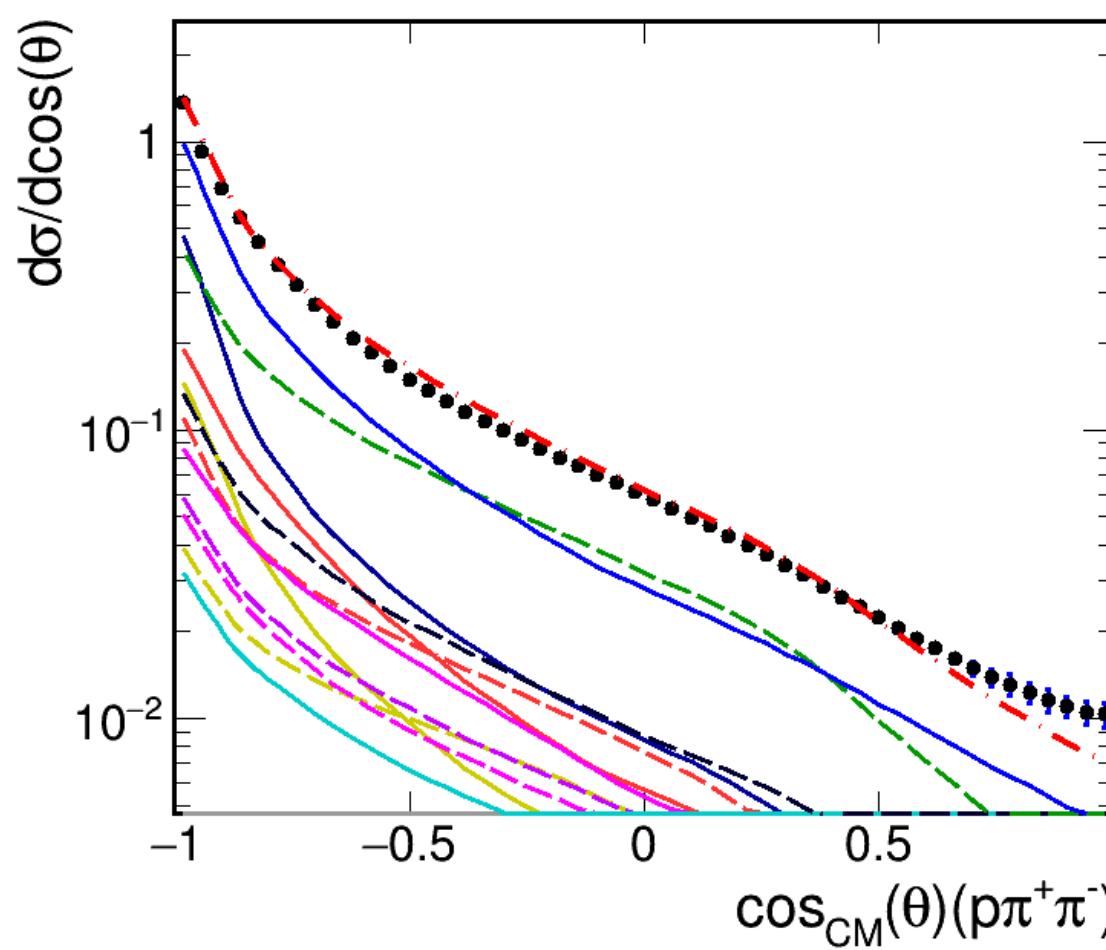
$\cos\theta_{CM}(p\pi^-)$



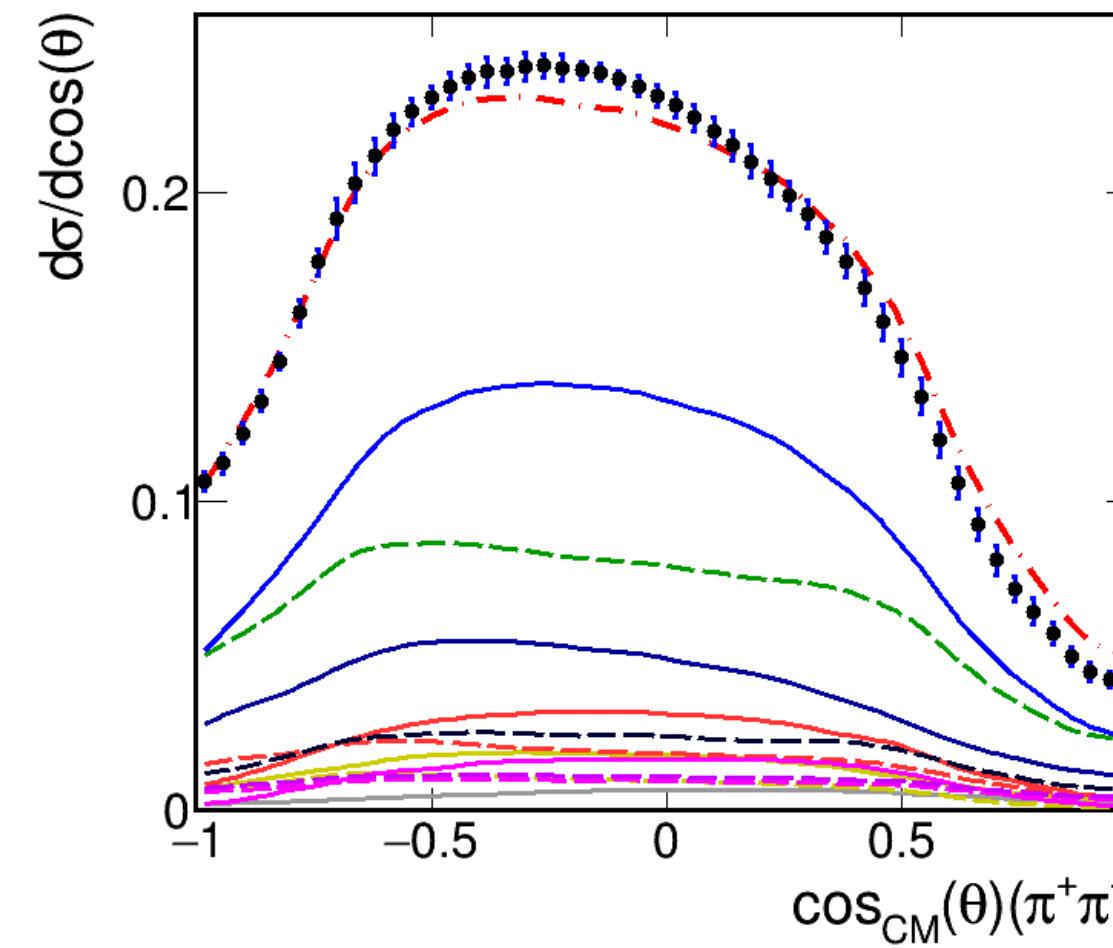
$\cos\theta_{CM}(p\pi^+)$



$\cos\theta_{CM}(p\pi^+\pi^-)$



$\cos\theta_{CM}(\pi^+\pi^-)$



- data
- $\Delta^0\Delta^{++}$
- ρ
- $N(1440)$
- $\Delta N(1440)$
- $N(1520)$
- $\Delta N(1520)$
- $N(1535)$
- $\Delta N(1535)$
- $\Delta(1620)$
- $\Delta\Delta(1620)$
- $N(1650)$
- $\Delta N(1650)$
- $N(1680)$
- $\Delta N(1680)$
- $\Delta(1700)$
- $\Delta\Delta(1700)$
- $N(1675)$
- $N(1720)$
- $\Delta N(1720)$
- $\Delta(1905)$
- One Resonance simulation
- Double Resonance simulation
- simulation

The angular distribution model for 1R and 2R production is quite valid.

Updated Cross Sections

1 Resonance	BR($N\pi\pi$)	σ (2π anal.) (mb)	σ (1π anal.*) (mb)
$N^+(1440)$	30%	1.4 ± 0.2	1.5 ± 0.4
$N^+(1520)$	30%	1.8 ± 0.2	1.8 ± 0.3
$N^+(1535)$	10%	0.15 ± 0.05	0.15 ± 0.015
$\Delta^+(1620)$	70%	$< 0.05 \pm 0.02$	$< 0.10 \pm 0.03$
$N^+(1650)$	11%	$< 0.05 \pm 0.03$	$< 0.81 \pm 0.13$
$N^+(1675)$	45%	1.05 ± 0.1	$< 1.65 \pm 0.27$
$N^+(1680)$	35%	0.78 ± 0.1	$< 0.9 \pm 0.15$
$N^+(1720)$	80%	0.05 ± 0.01	$< 4.4 \pm 0.7$
$\Delta^+(1700)$	55%	0.45 ± 0.1	0.45 ± 0.16
$\Delta^+(1910)$	90%	$< 0.15 \pm 0.05$	$< 0.85 \pm 0.53$

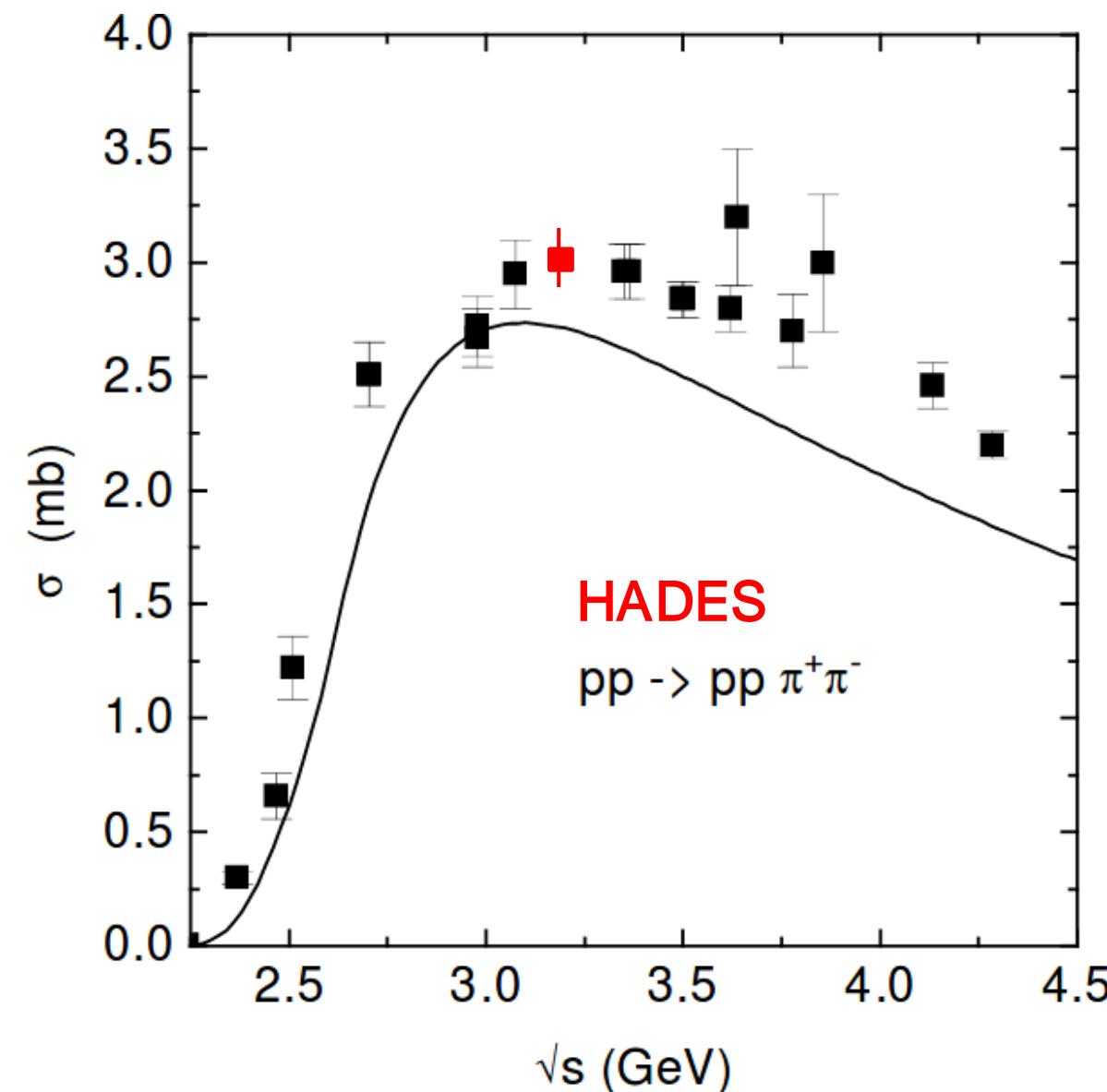
2 Resonances	BR($N\pi$)	σ (mb)
$\Delta^{++}(1232)\Delta^{\circ}(1232)$	100%	4.0 ± 0.1
$\Delta^{++}(1232)N^{\circ}(1440)$	70%	0.8 ± 0.1
$\Delta^{++}(1232)N^{\circ}(1520)$	55%	1.4 ± 0.1
$\Delta^{++}(1232)N^{\circ}(1535)$	46%	0.49 ± 0.1
$\Delta^{++}(1232)\Delta^{\circ}(1620)$	25%	$< 0.02 \pm 0.02$
$\Delta^{++}(1232)N^{\circ}(1650)$	70%	$< 0.05 \pm 0.04$
$\Delta^{++}(1232)N^{\circ}(1680)$	65%	0.8 ± 0.1
$\Delta^{++}(1232)N^{\circ}(1720)$	15%	$< 0.02 \pm 0.02$
$\Delta^{++}(1232)\Delta^{\circ}(1700)$	15%	$< 0.04 \pm 0.02$

1 Resonance	BR($N\pi\pi$)	σ (2π anal.) (mb)	σ ($pK^+\Lambda$ anal.**) (mb)
$N^+(1650)$	38%	0.09 ± 0.03	0.12 ± 0.06
$N^+(1710)$	23%	0.05 ± 0.02	0.078 ± 0.05
$N^+(1720)$	80%	0.05 ± 0.01	0.06 ± 0.015
$N^+(1875)$	70%	0.038 ± 0.02	0.038 ± 0.018
$N^+(1880)$	63%	0.36 ± 0.1	0.74 ± 0.37

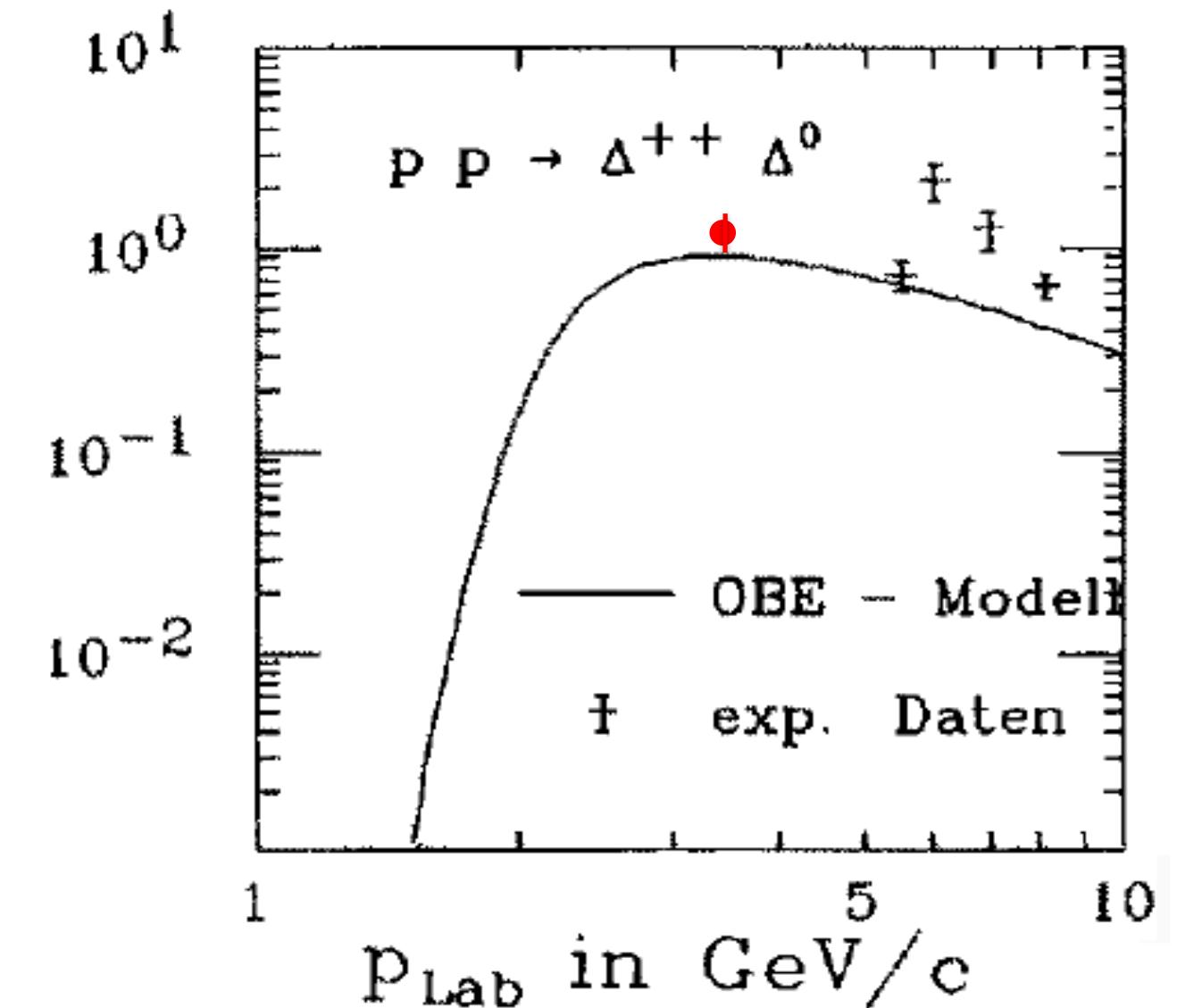
*G. Agakishiev et al. Eur.Phys.J. A50 (2014) 8
** R. Munzer et al. Phys. Lett. B785 (2018) 574

- ✓ The resonance cocktail reproduces 1π , 2π and $K\Lambda$ production.
- ✓ Based on the cocktail we estimate the total cross section $pp \rightarrow pp \pi^+ \pi^-$: $\sigma = 3.2 \pm 0.10$ mb

Comparing to Existing Data



S. Teis et al. Z. Phys. A 356, 421 (1997)



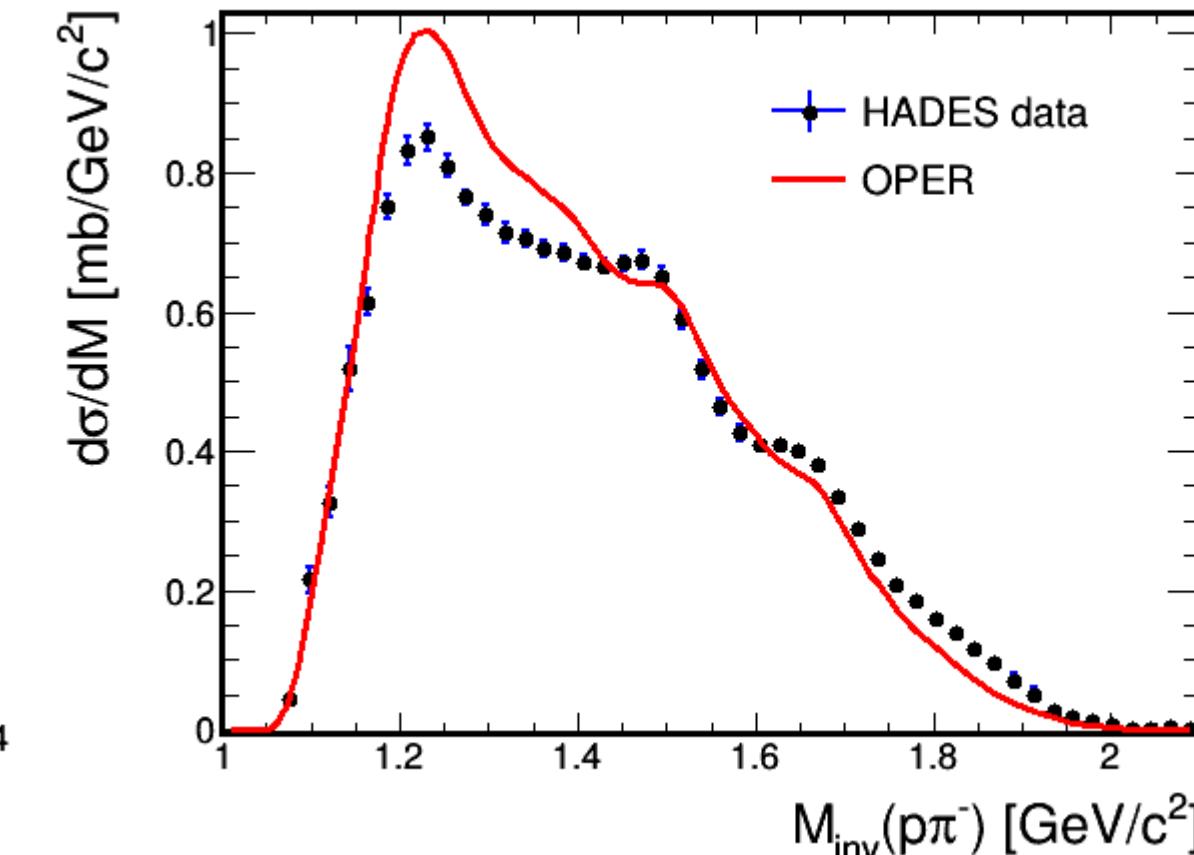
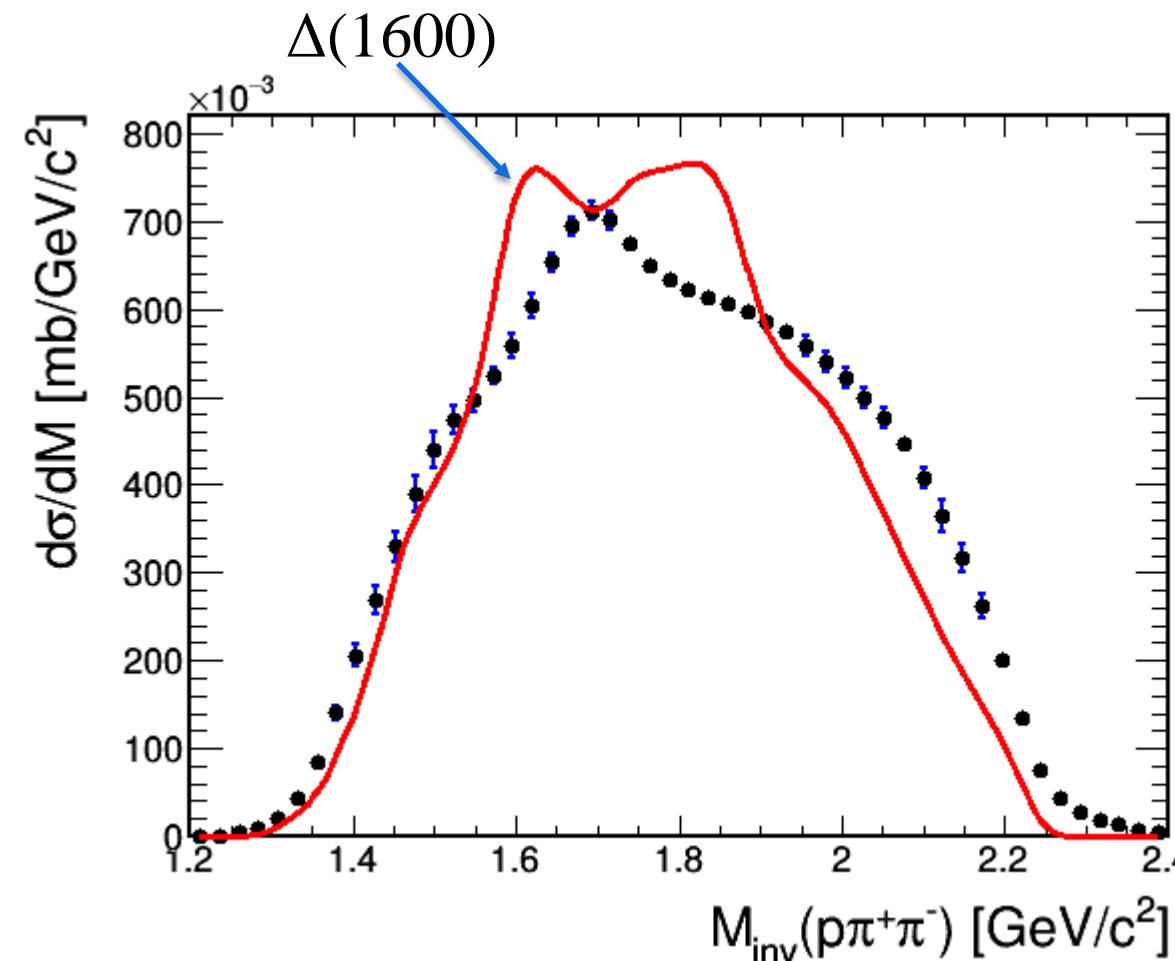
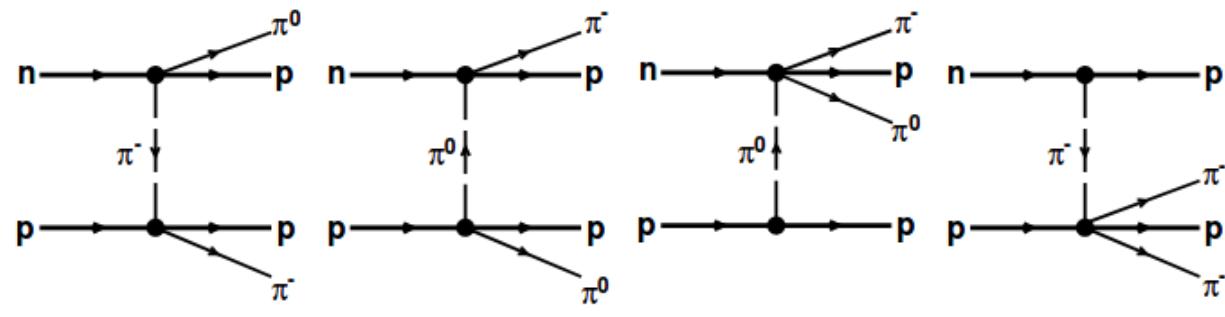
J. Aichelin, Nucl. Phys. A573, (1994) 587.

- Total cross section compatible with existing data. (HADES $\sigma=3.2$ mb)
- $\sigma (\Delta\Delta)=1.05$ mb, compatible with OBE (One boson exchange) model.

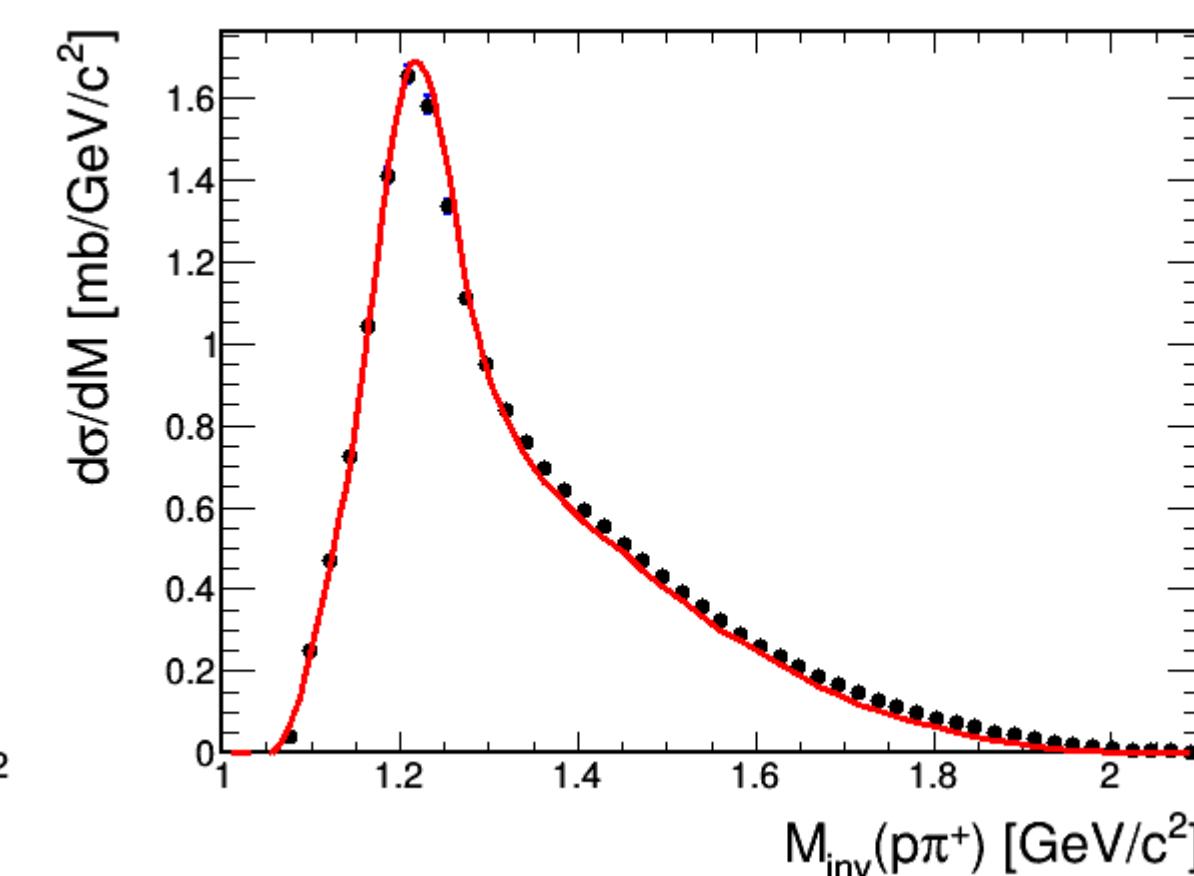
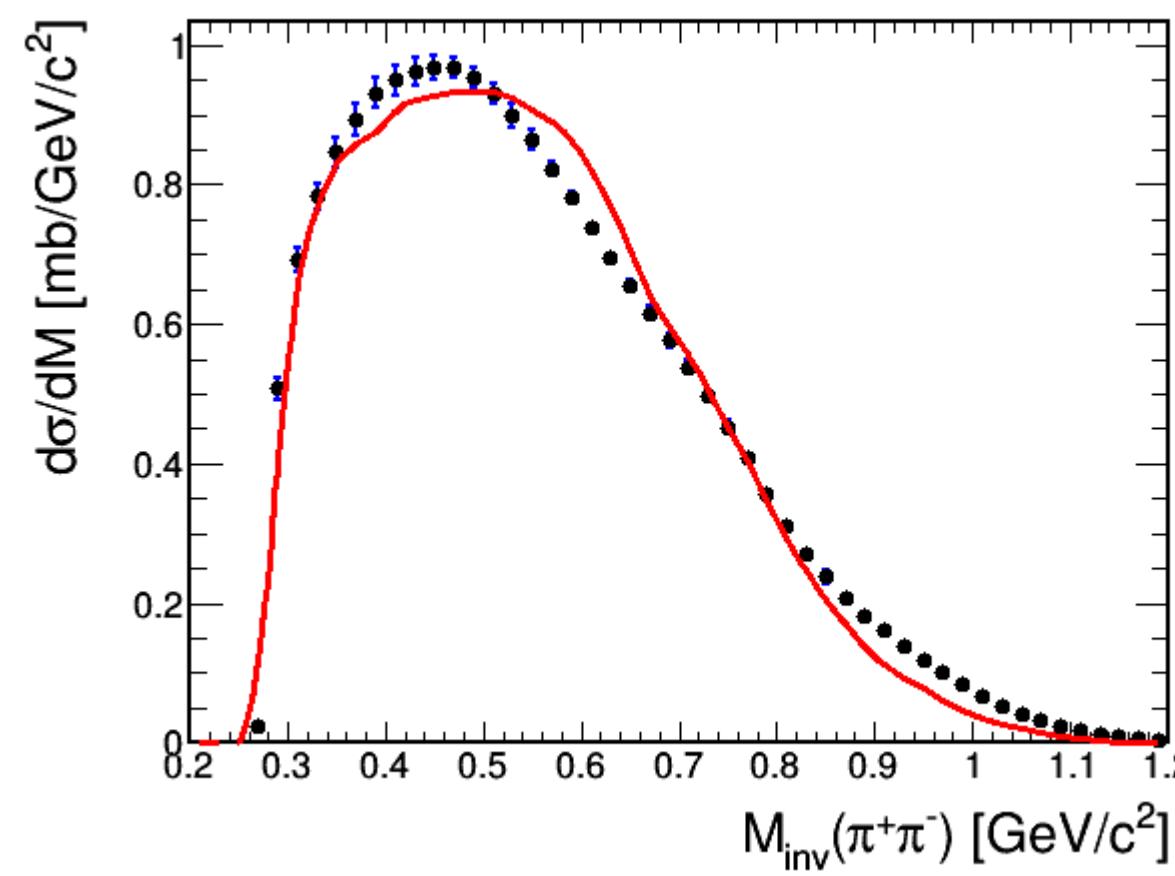
Comparing to Theoretical Models

OPER: One Pion Exchange Reggeized

A.P Jerusalimov et al. ArXiv:1203.3330v1 [nucl-th]



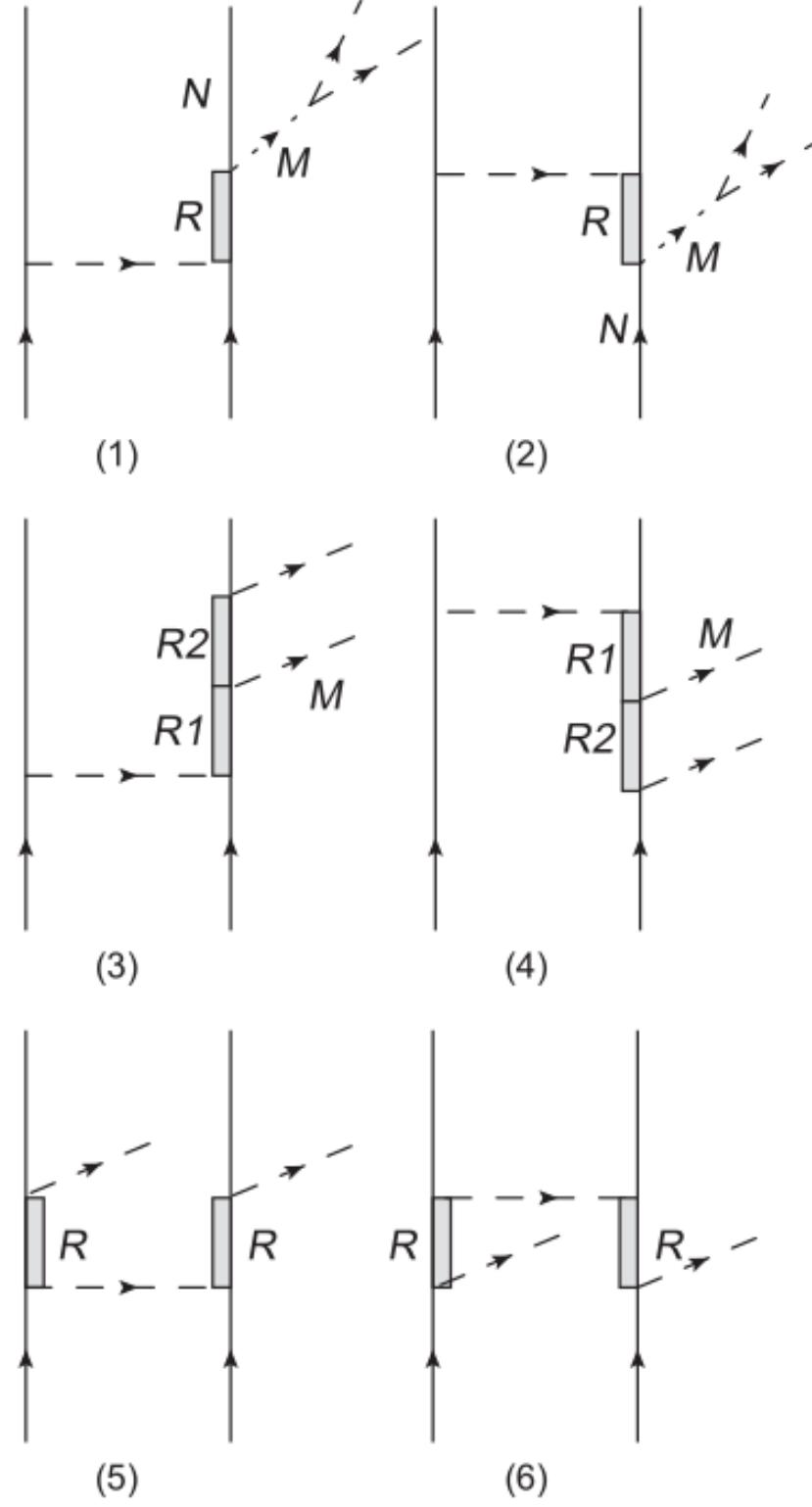
- Cross section adjusted to measured yield.
- $M_{inv}(p\pi^+\pi^-)$ distribution shows a too large production of $\Delta(1600)$ and resonances with mass > 1.7 GeV



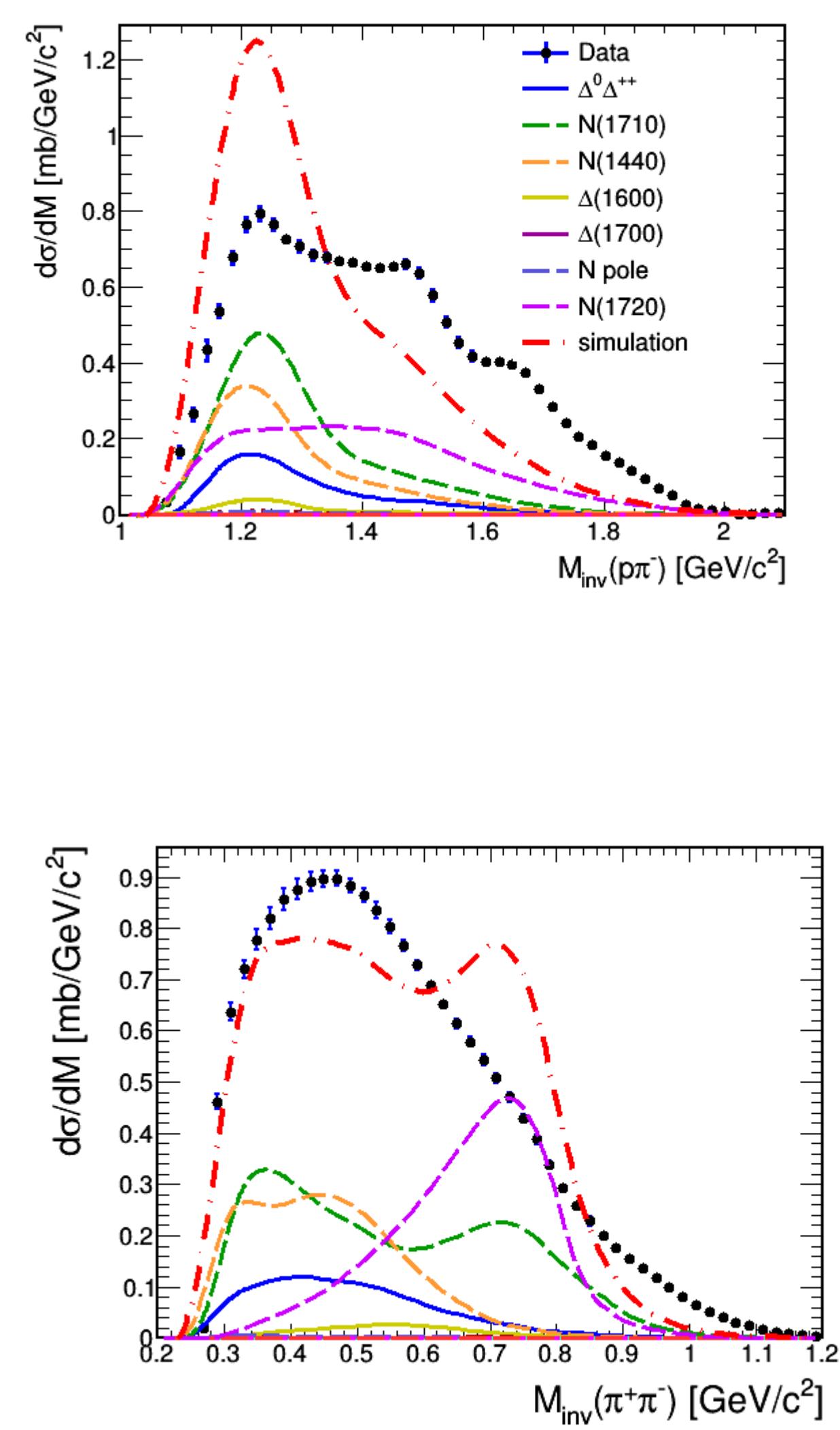
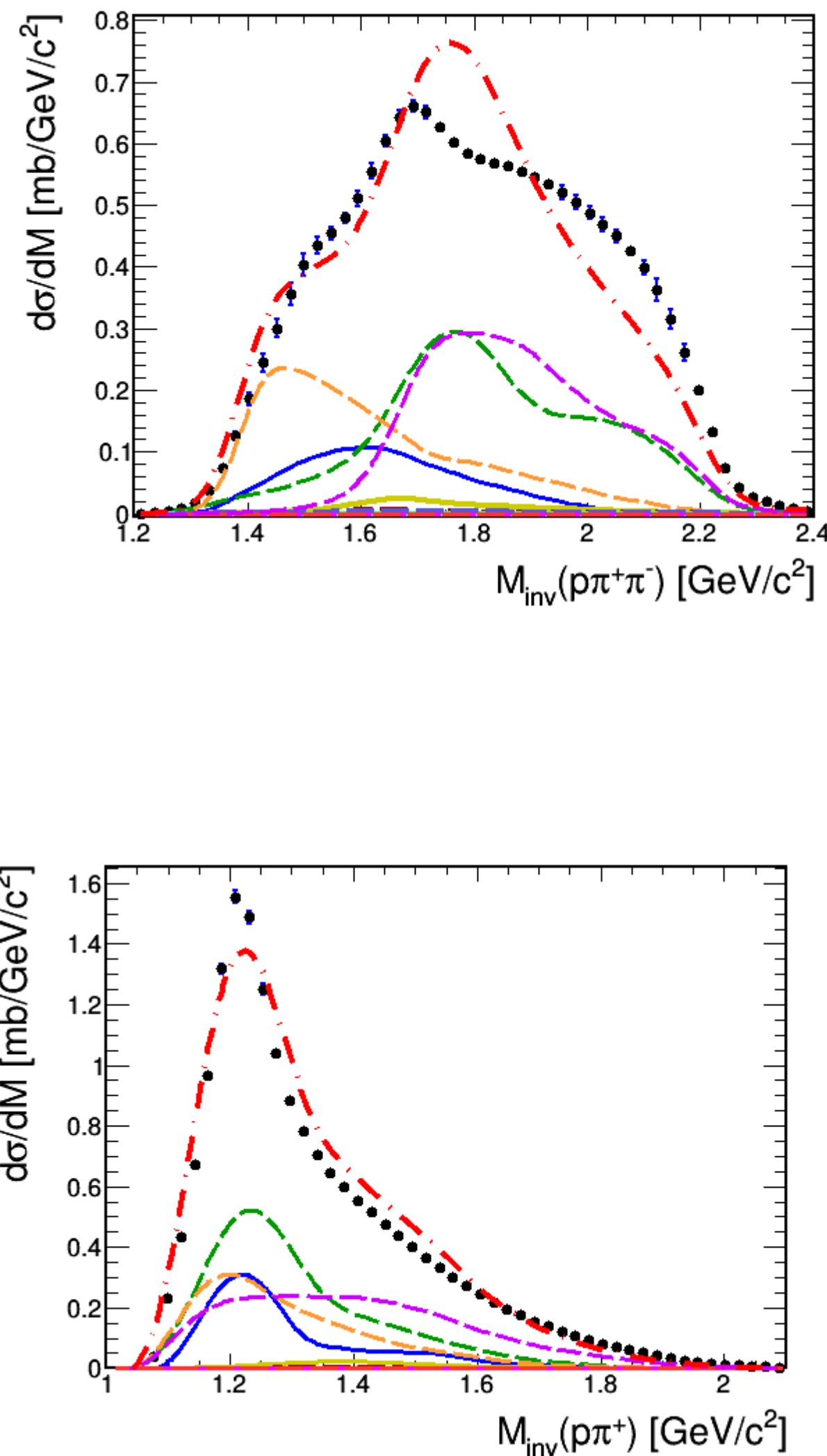
Comparing to Theoretical Models

Cao effective Lagrangian model:

X. Cao, B.-S. Zou and H.-S. Xu, Phys. Rev. C81 (2010) 12



- Only one 2R excitation contribution: $\Delta^{++}(1232)\Delta^{\circ}(1232)$
- Too large yield from $N^*(1710)$ and $N^*(1720)$ decaying to $N\pi$.



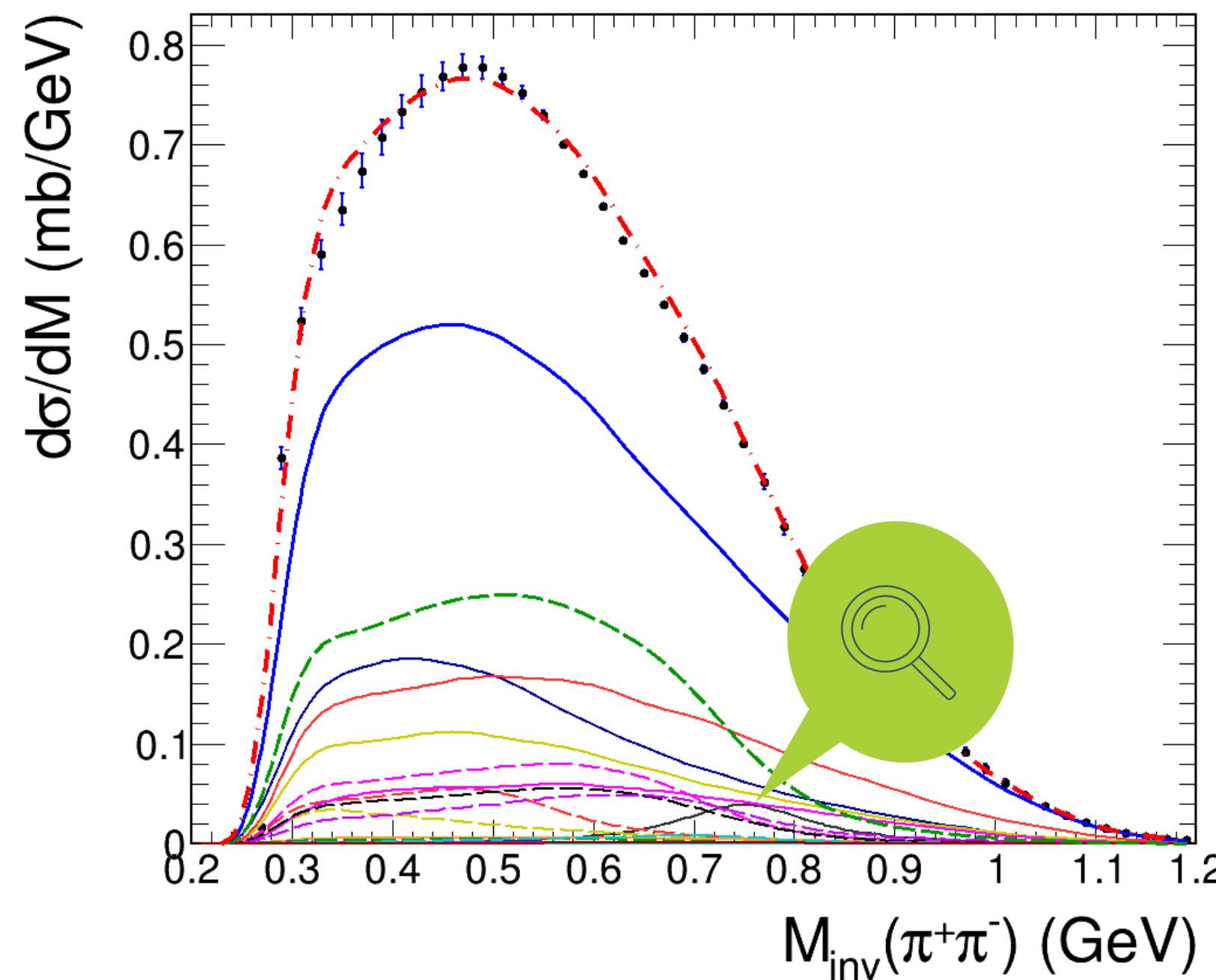
Tracking the ρ meson



Search for the direct “ρ”

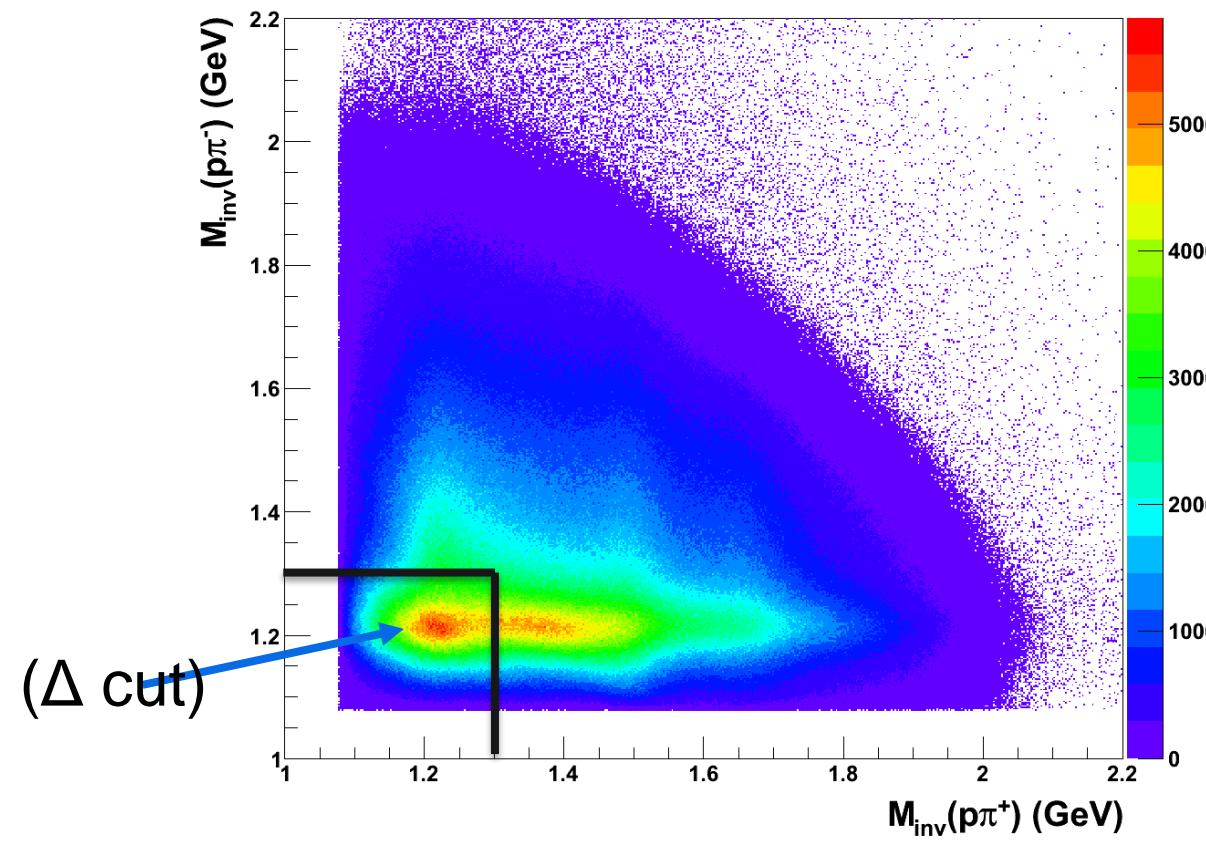
Apply kinematical cuts to reduce the baryonic resonance excitation background.

$$M(\rho) = 775 \text{ MeV}$$
$$\Gamma(\rho) = 149 \text{ MeV}$$

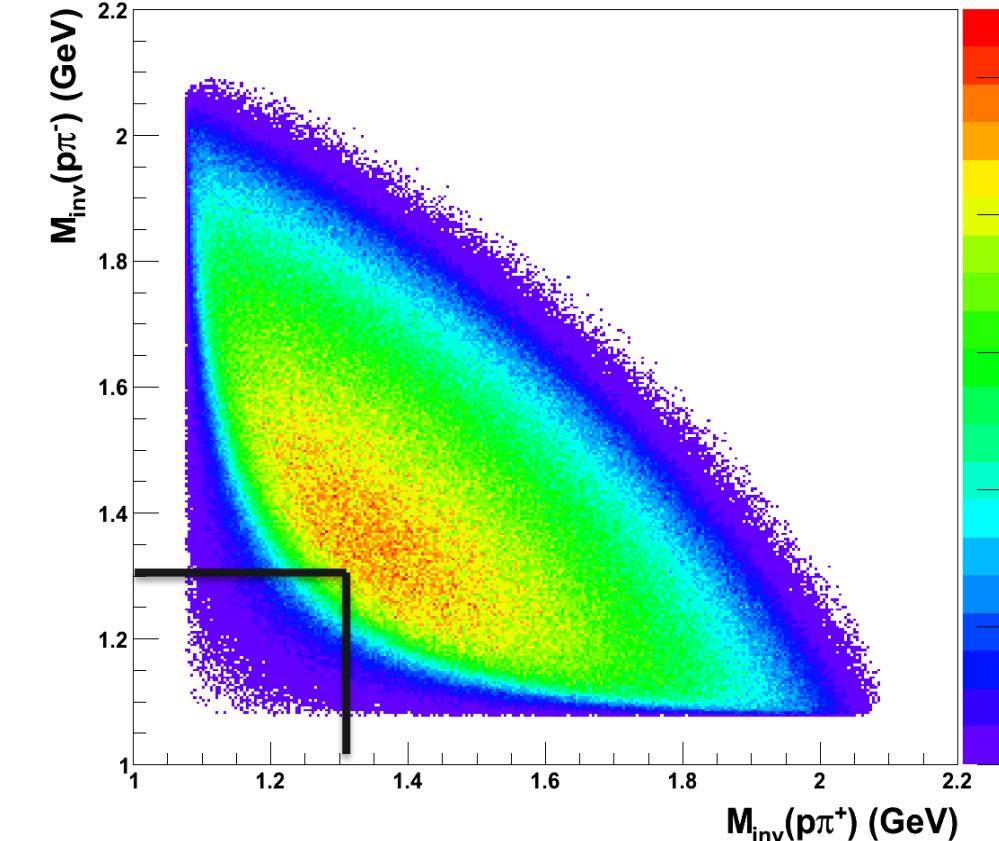


Search for the direct “ ρ ”

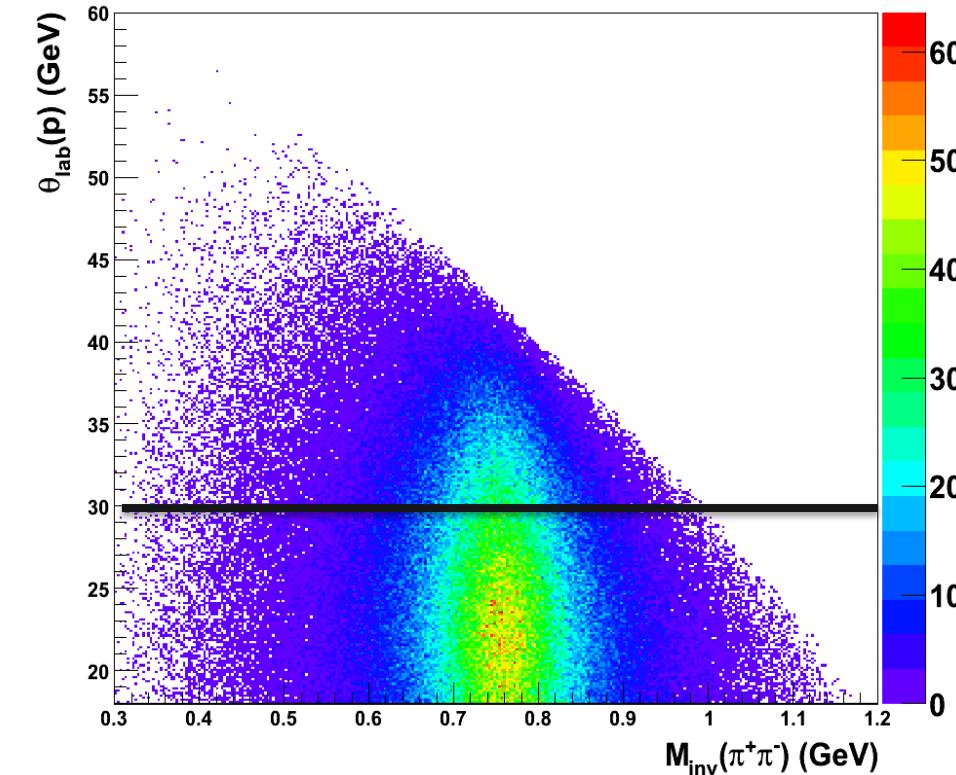
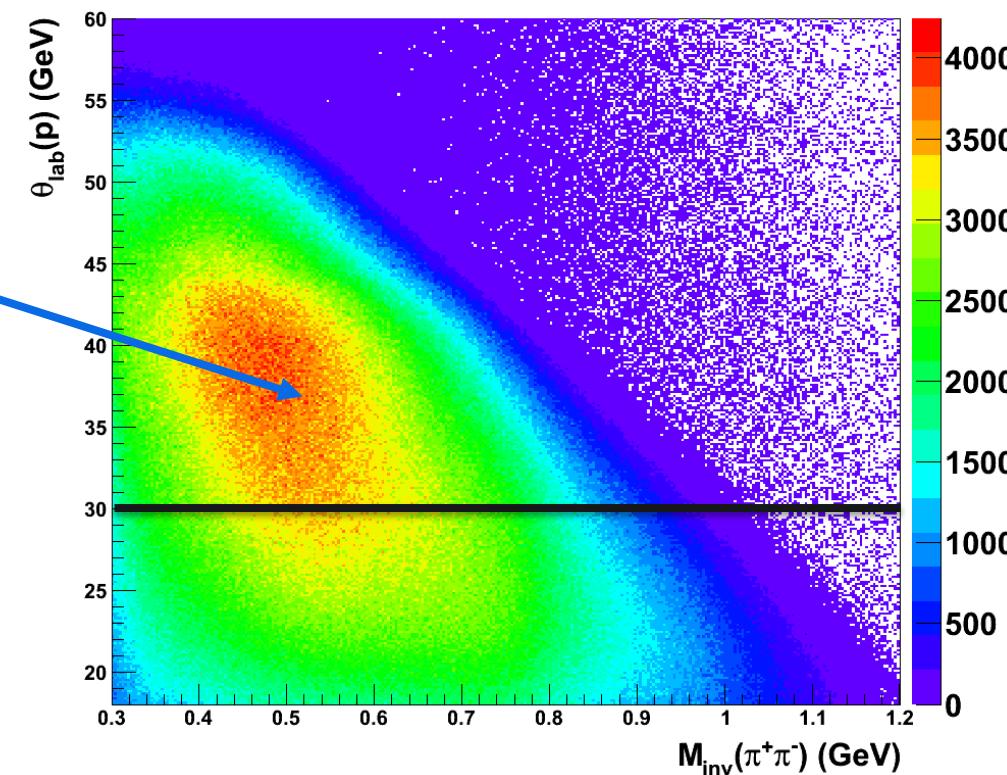
Data



ρ simulation



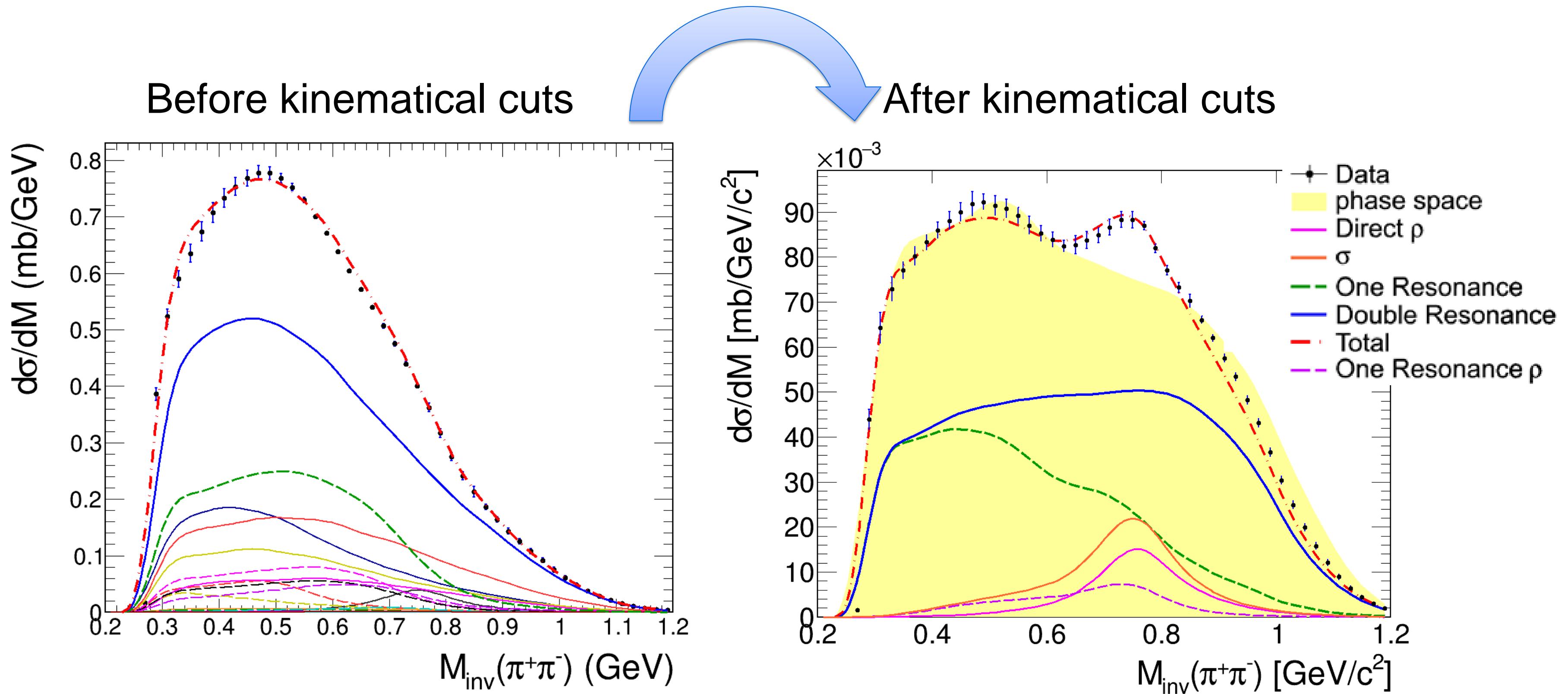
Resonances
cut



$M_{inv}(p\pi^+) > 1.3 \text{ GeV}$
 $M_{inv}(p\pi^-) > 1.3 \text{ GeV}$
Suppress $\Delta(1232)\Delta(1232)$

$\theta_{lab}(p) < 30^\circ$
Suppress remaining
resonances

Search for the direct “ ρ ”



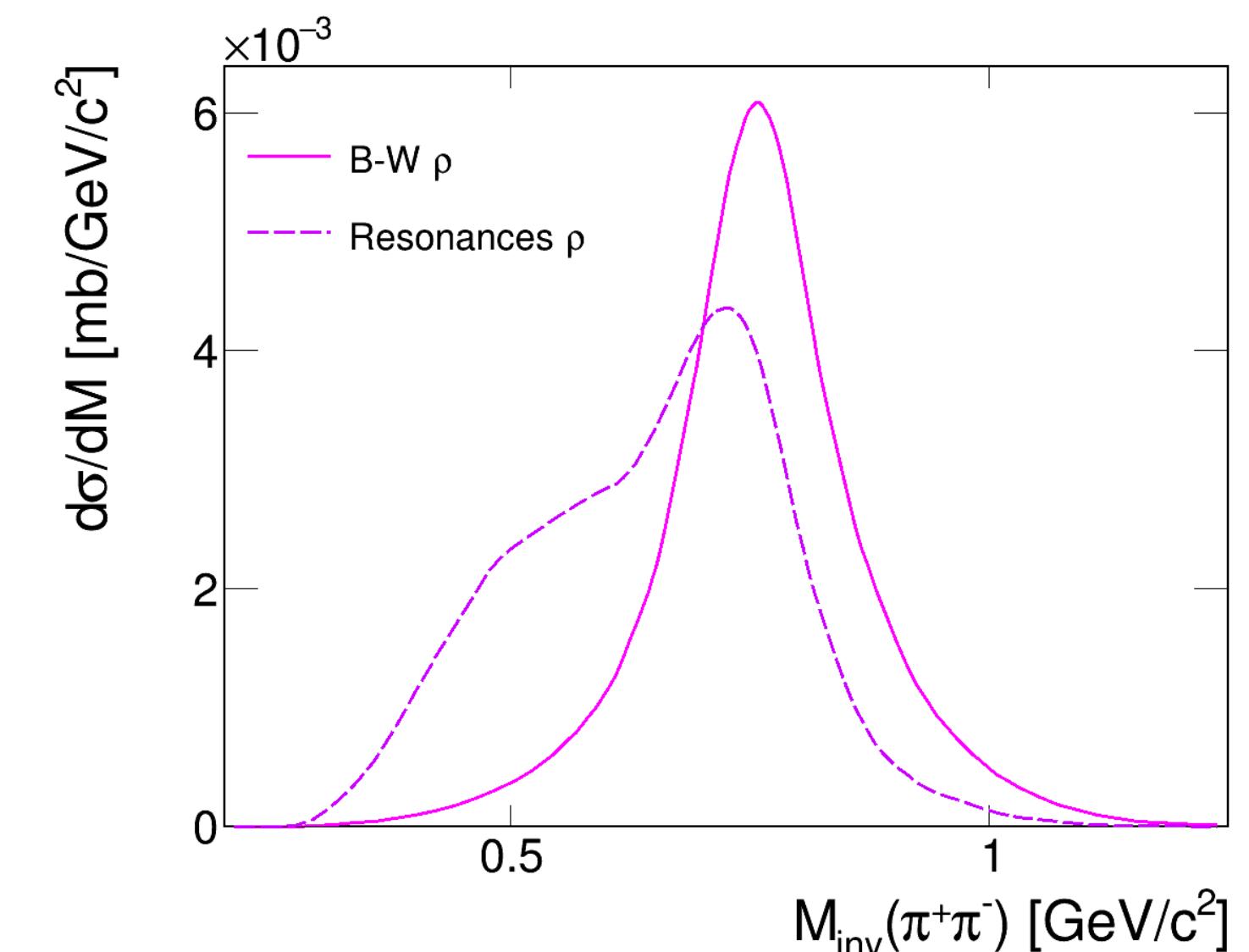
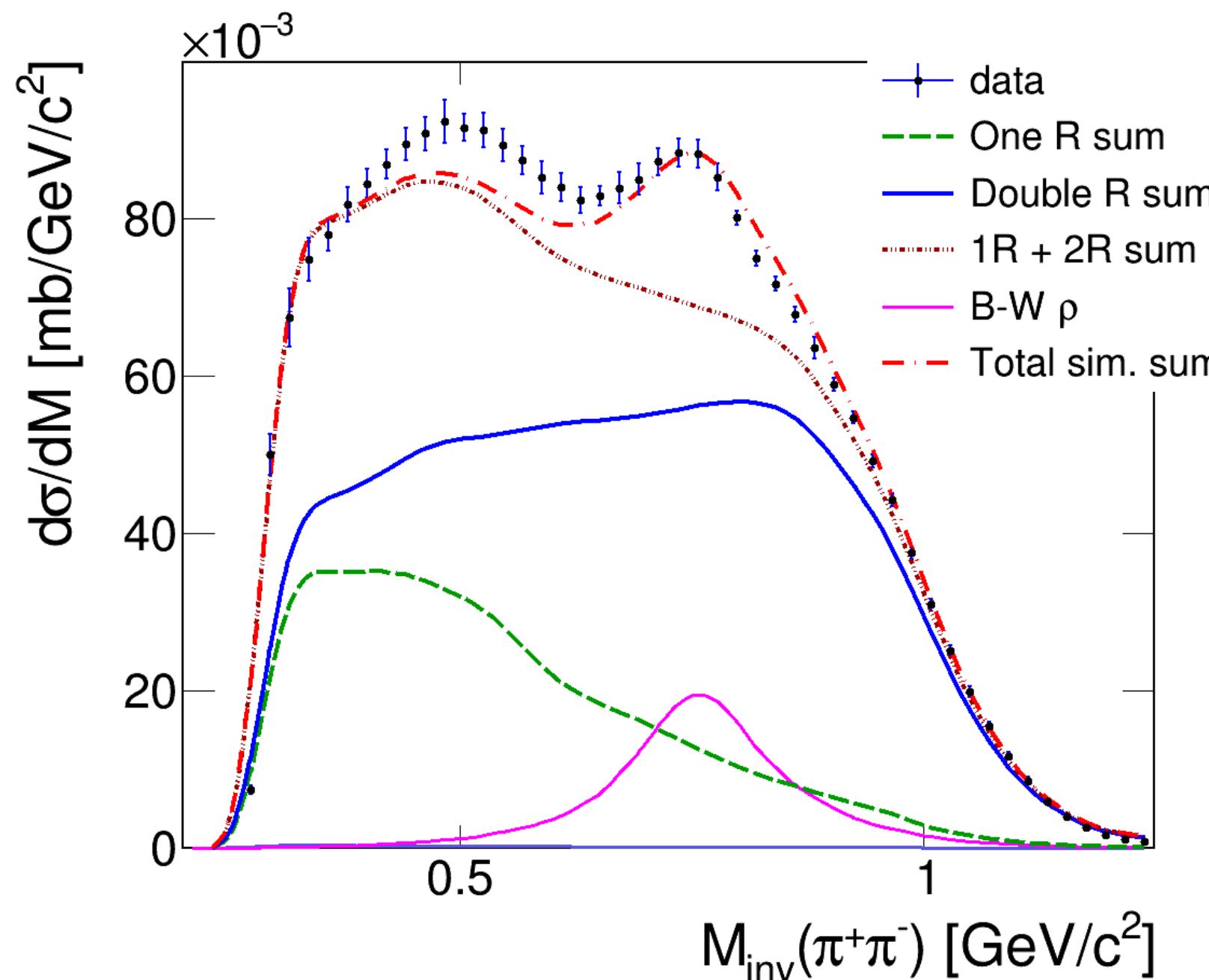
After kinematical cuts the ρ peak shows up

Resonance cocktail includes $R \rightarrow N \rho$

Direct ρ adjusted to the data

Experimental extraction of the “ ρ ” cross section

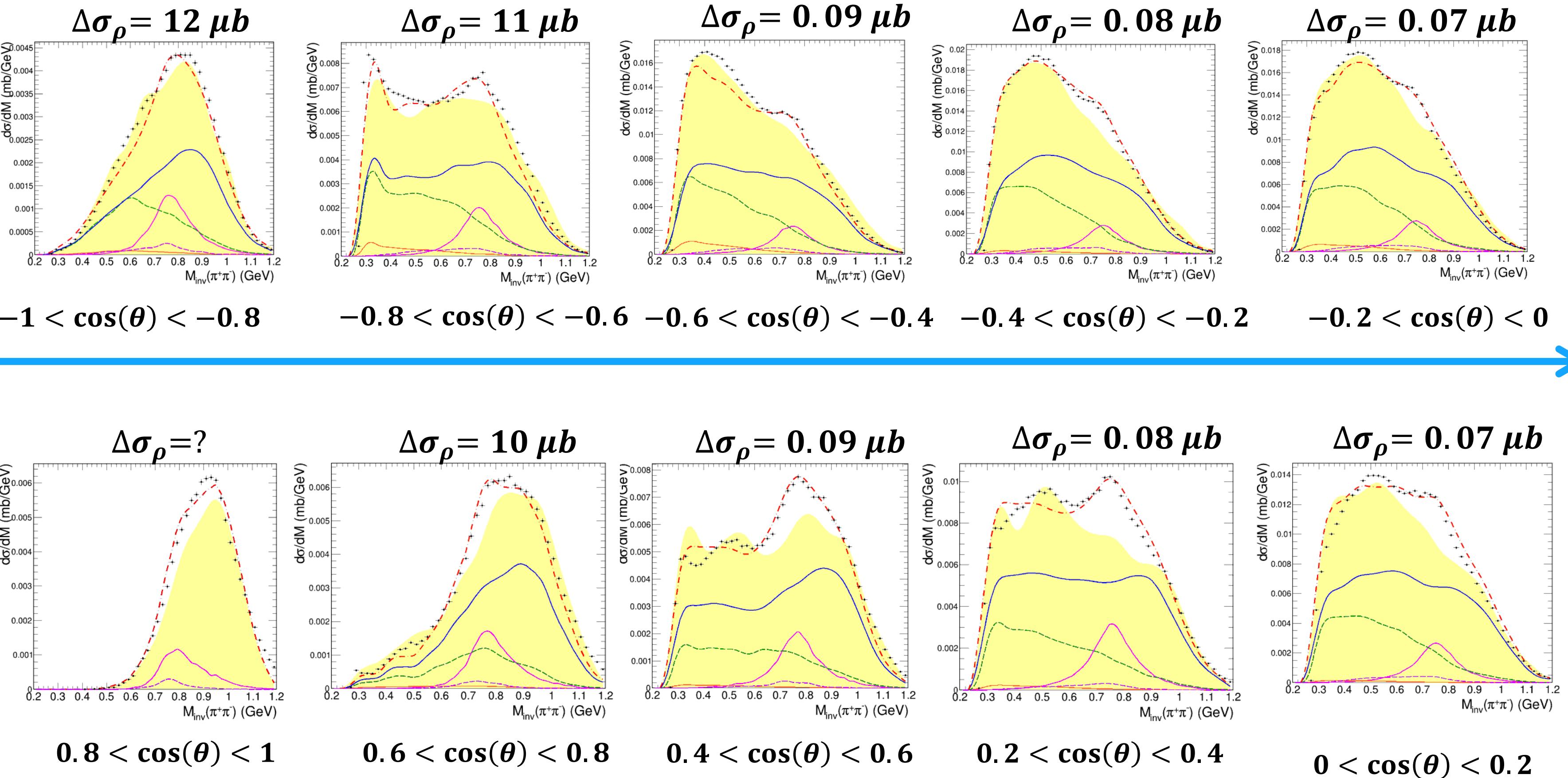
- Simulation without resonance decay to $N\rho$
- $pp \rightarrow p p \rho$ contribution adjusted to data.



Experimental extraction of the “p” cross section

Evaluate σ_ρ in bins of $\cos_{CM}(\theta)(\pi^+\pi^-)$
After reducing the resonance background

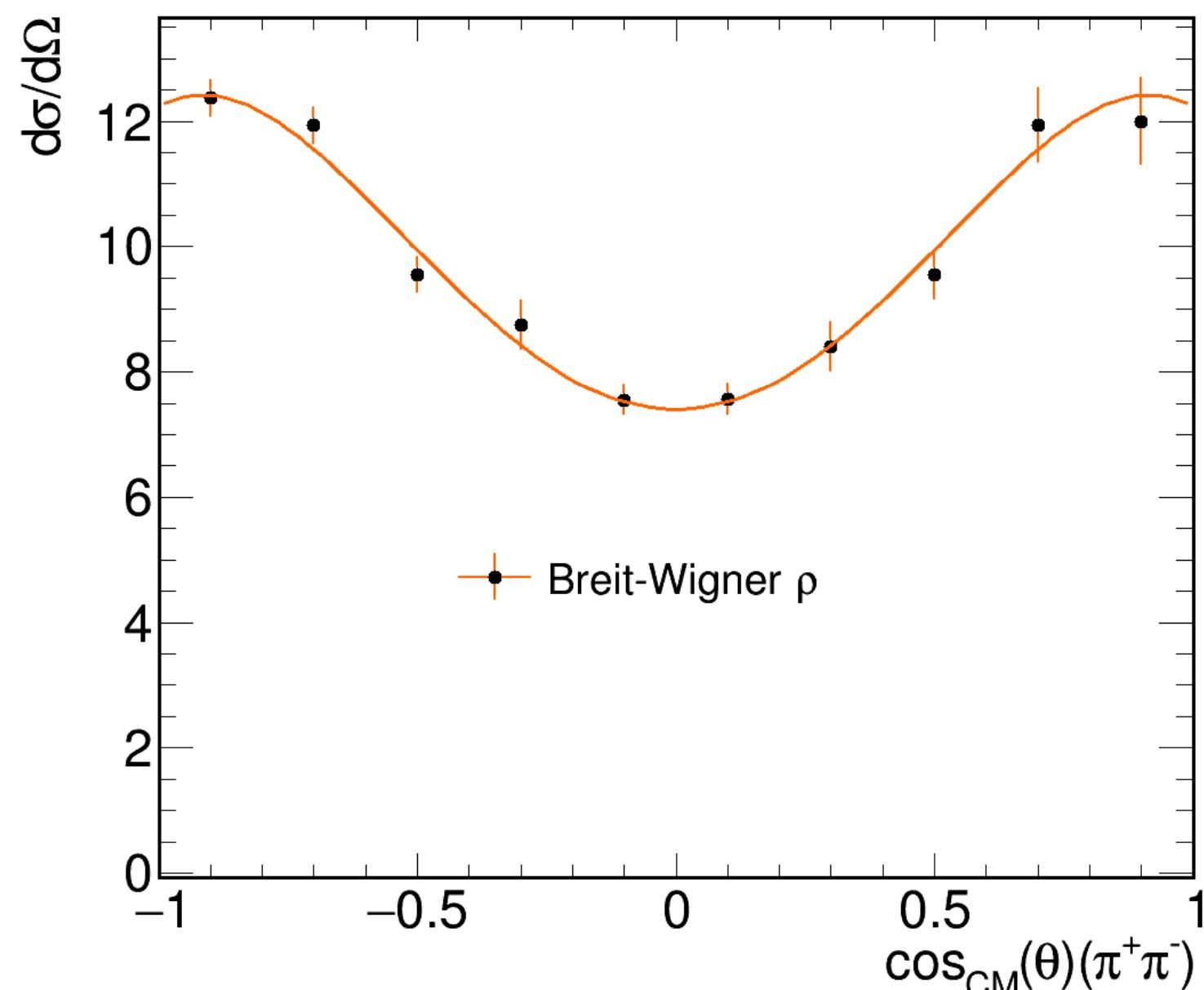
- Data
- phase space
- Direct ρ
- σ
- One Resonance
- Double Resonance
- Total
- One Resonance ρ



- Good backward/forward symmetry

“ρ” Angular Distribution

- ✓ Breit-Wigner ρ extraction is model independent.
- ✓ The angular distribution was fitted with Legendre polynomials.

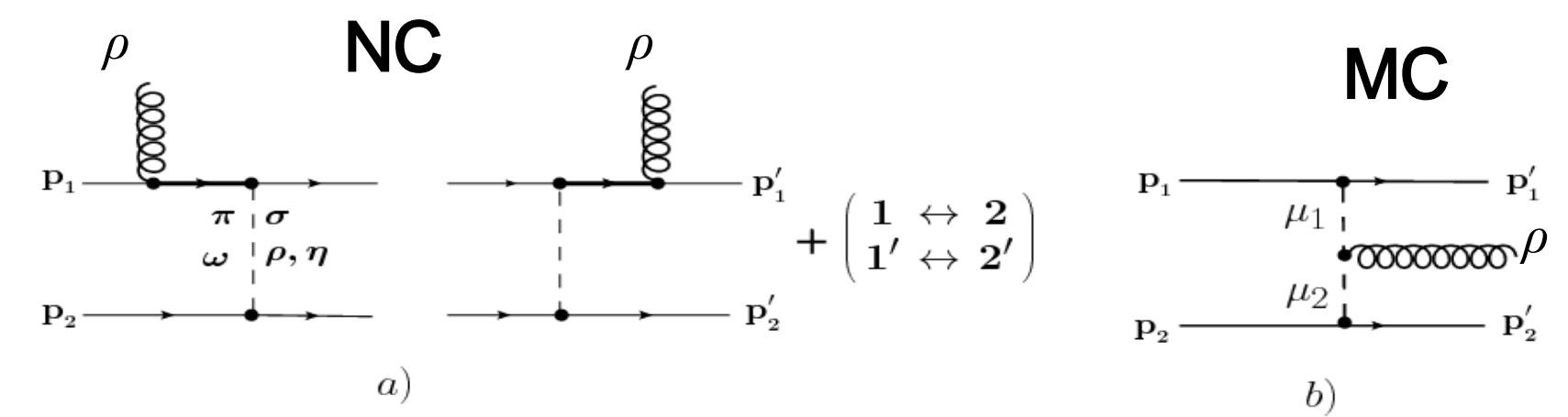
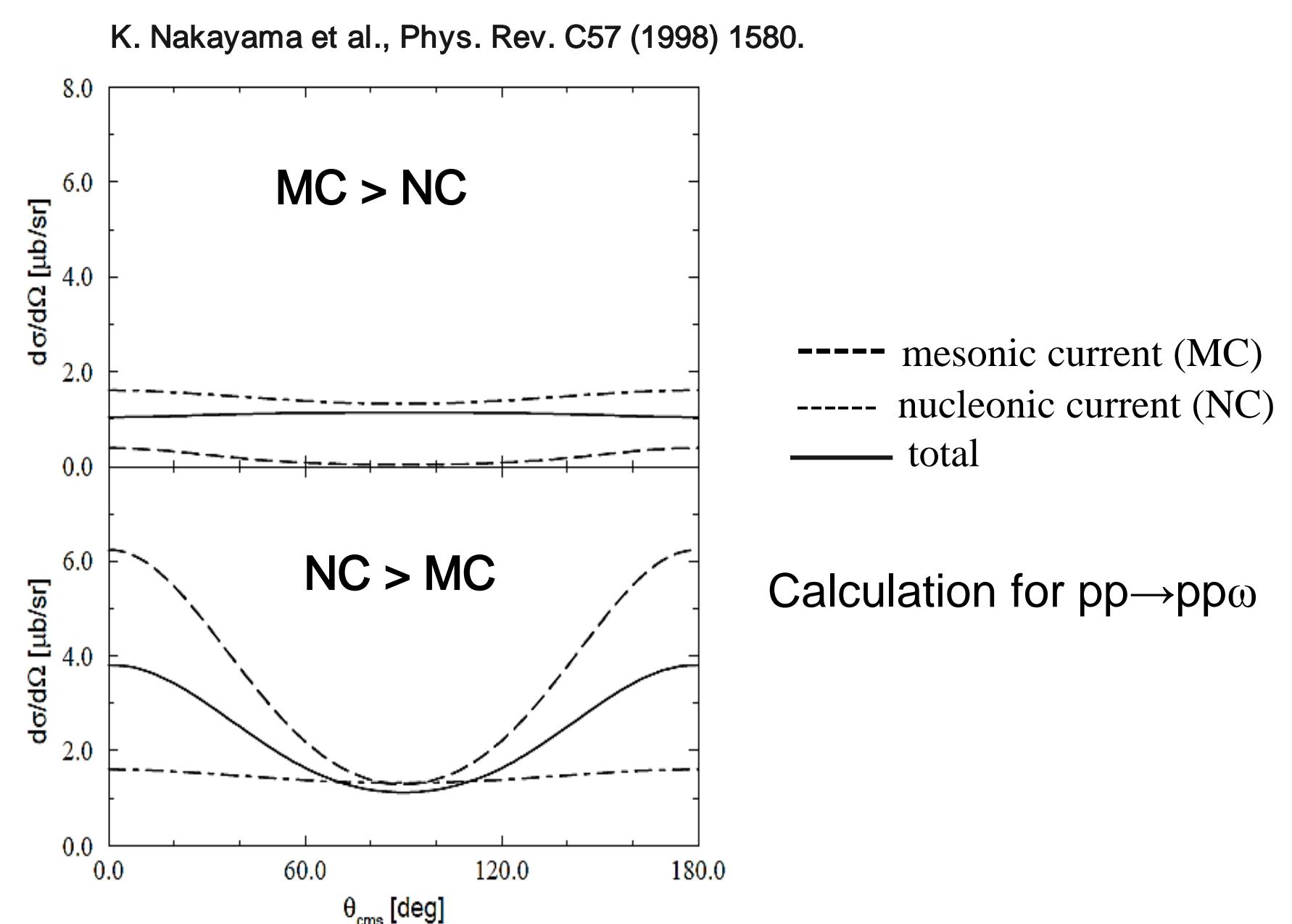


$$\frac{d\sigma}{d\Omega} = 9.98 P_0 + 3.96 P_2 - 1.57 P_4$$



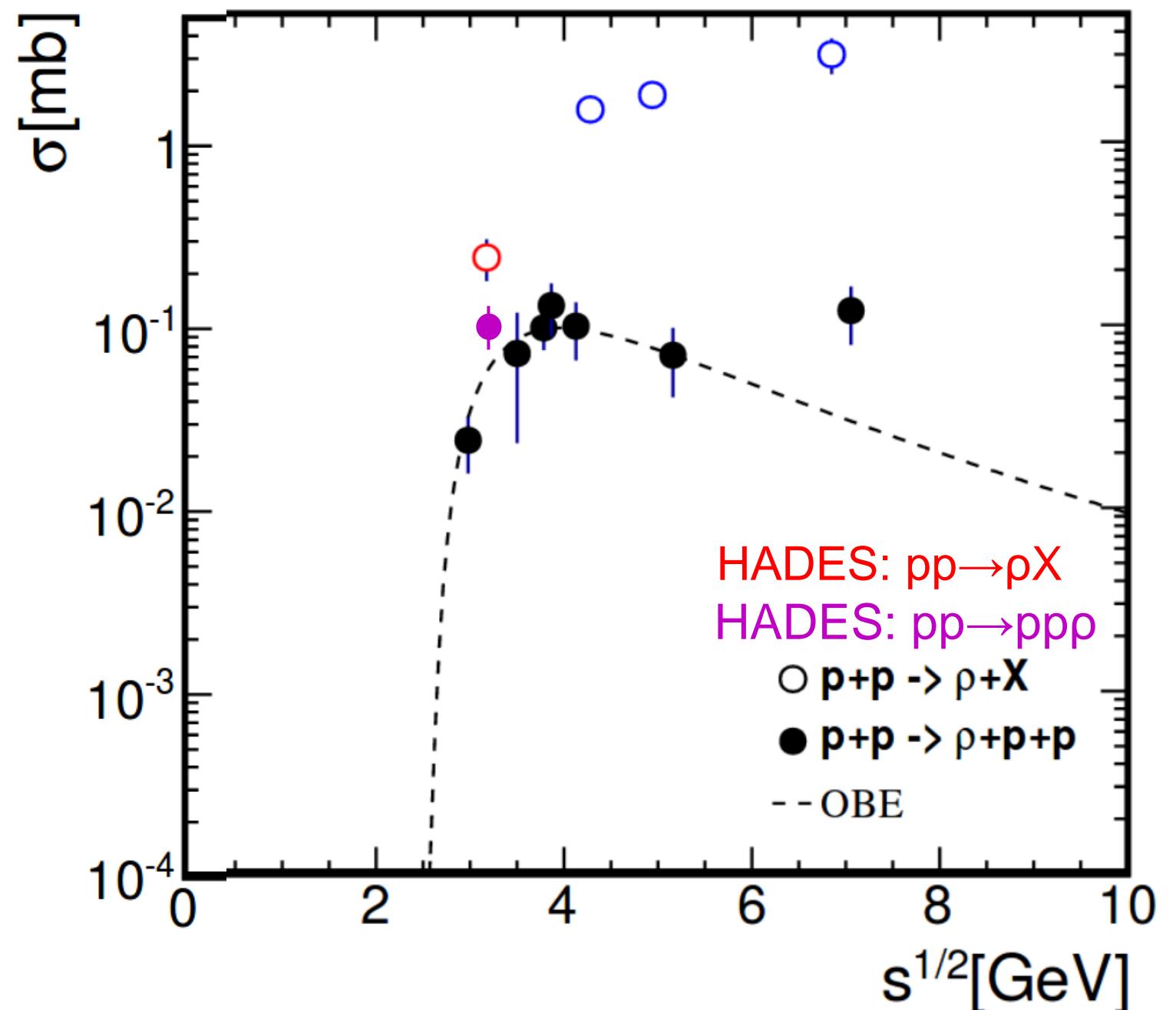
$$\sigma_\rho = 124 \pm 5 \mu b$$

$\frac{d\sigma}{d\Omega}$ consistent with dominant nucleonic current (NC)



“ρ” Cross Section

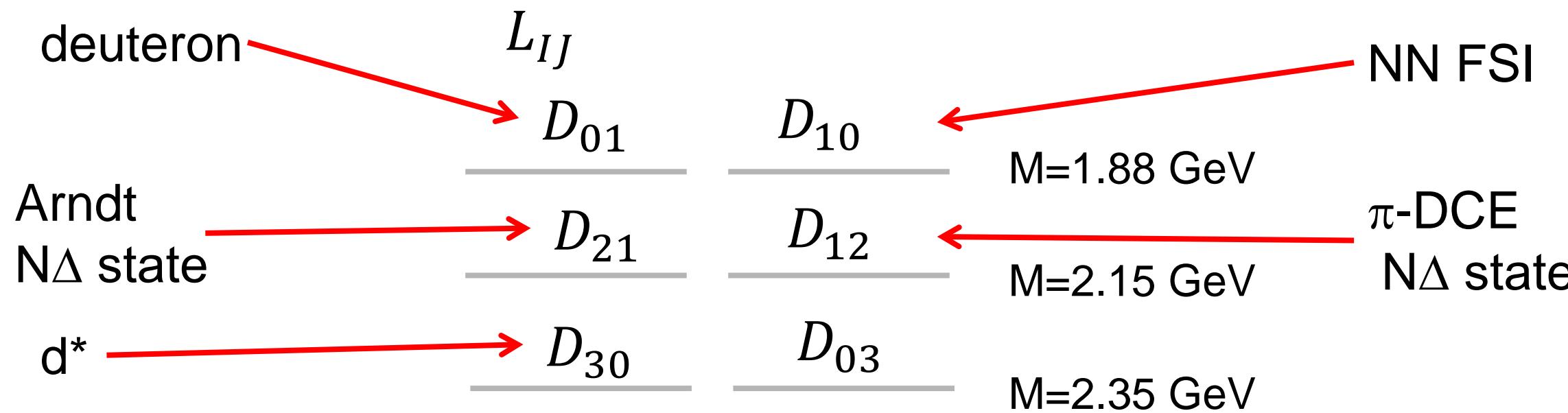
- Results from this analysis:
 - $R \rightarrow N\rho$ $160 \pm 40 \mu b$
 - $pp \rightarrow ppp$ $124 \pm 5 \mu b$
- Results from other analysis at 3.5 GeV:
 - $pp \rightarrow ppe^+e^-$, $\sigma_\rho = 1/2 \sigma_\omega$ $120 \pm 60 \mu b$
 - $pp \rightarrow ppe^+e^-X$ (PYTHIA) $233 \pm 60 \mu b$



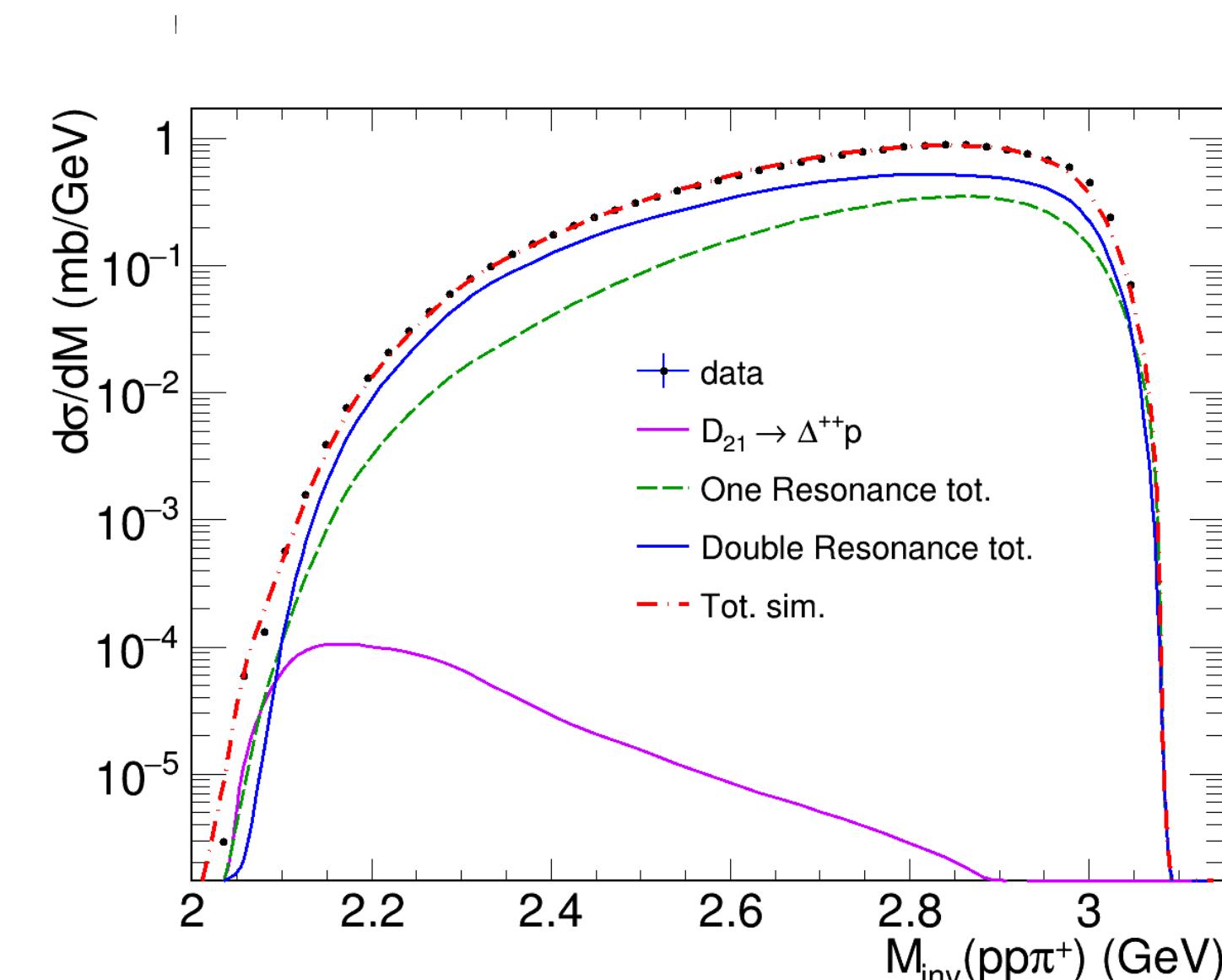
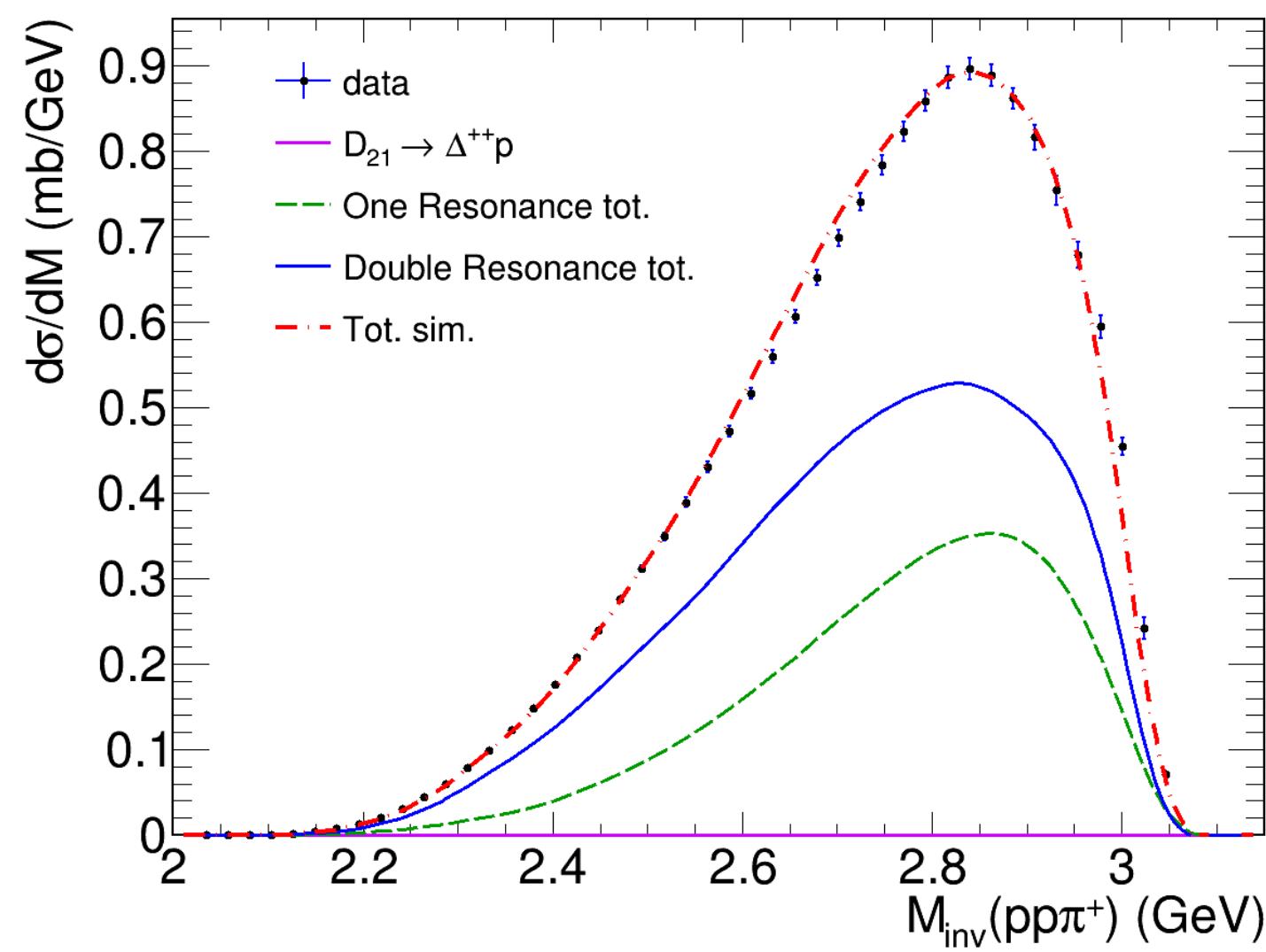
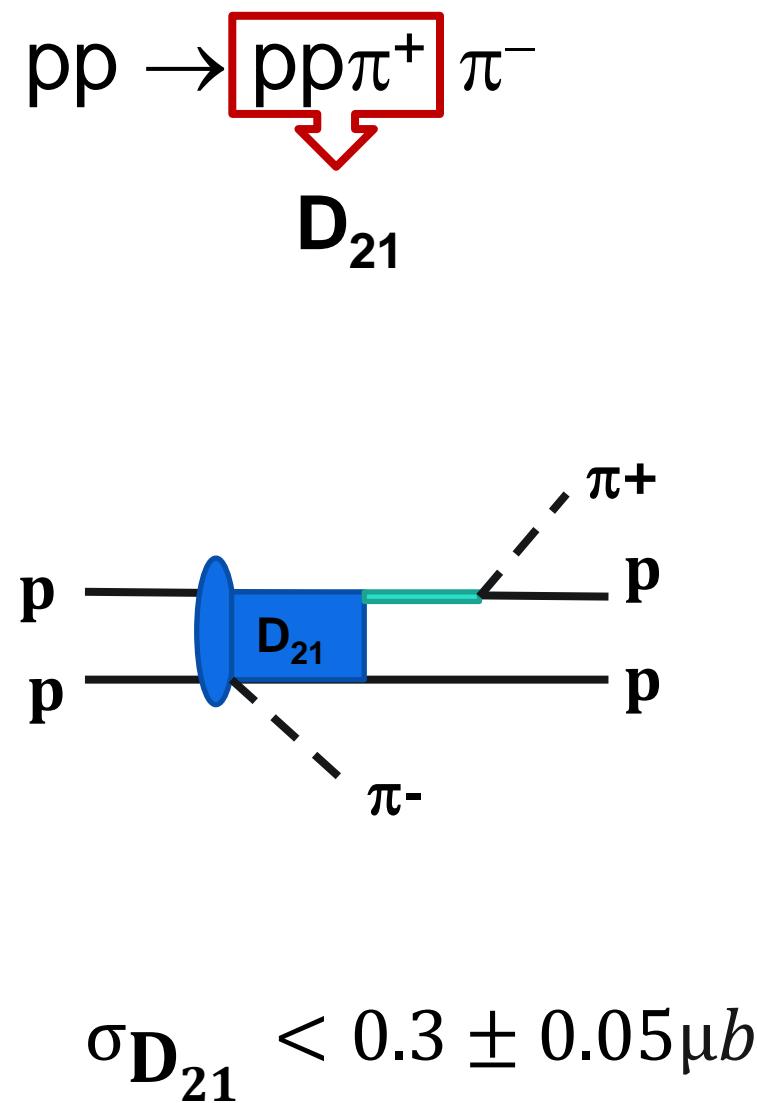
HADES: $pp \rightarrow ppp$ from 2 π analysis is compatible with the analysis $pp \rightarrow ppe^+e^-$ were $\sigma\rho$ was extracted following the hypothesis $\sigma\rho = 1/2 \sigma\omega$

Dibaryon investigation

6 Non-strange B=2 states



- Investigation for the dibaryon $D_{21}(2150)$



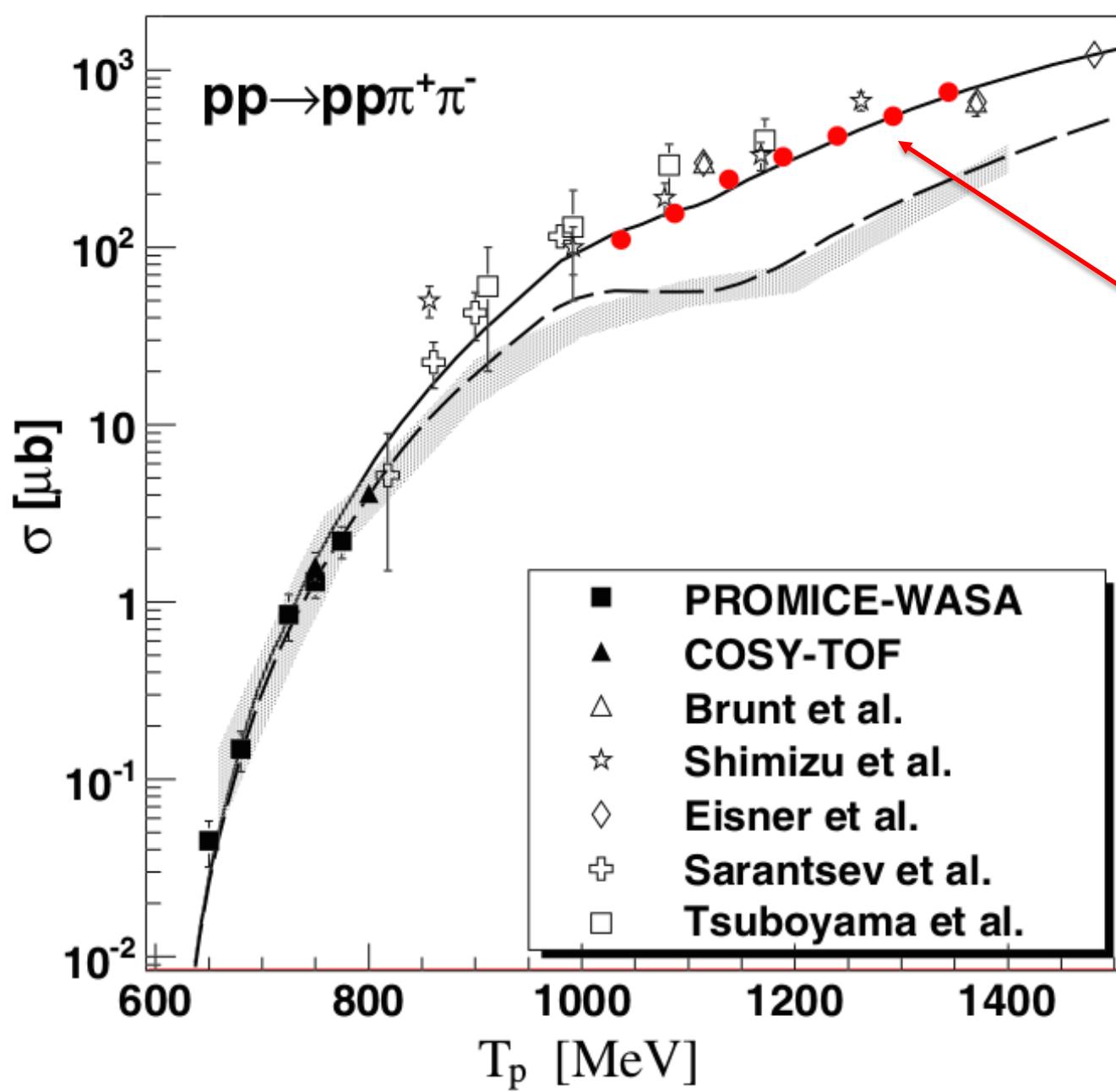
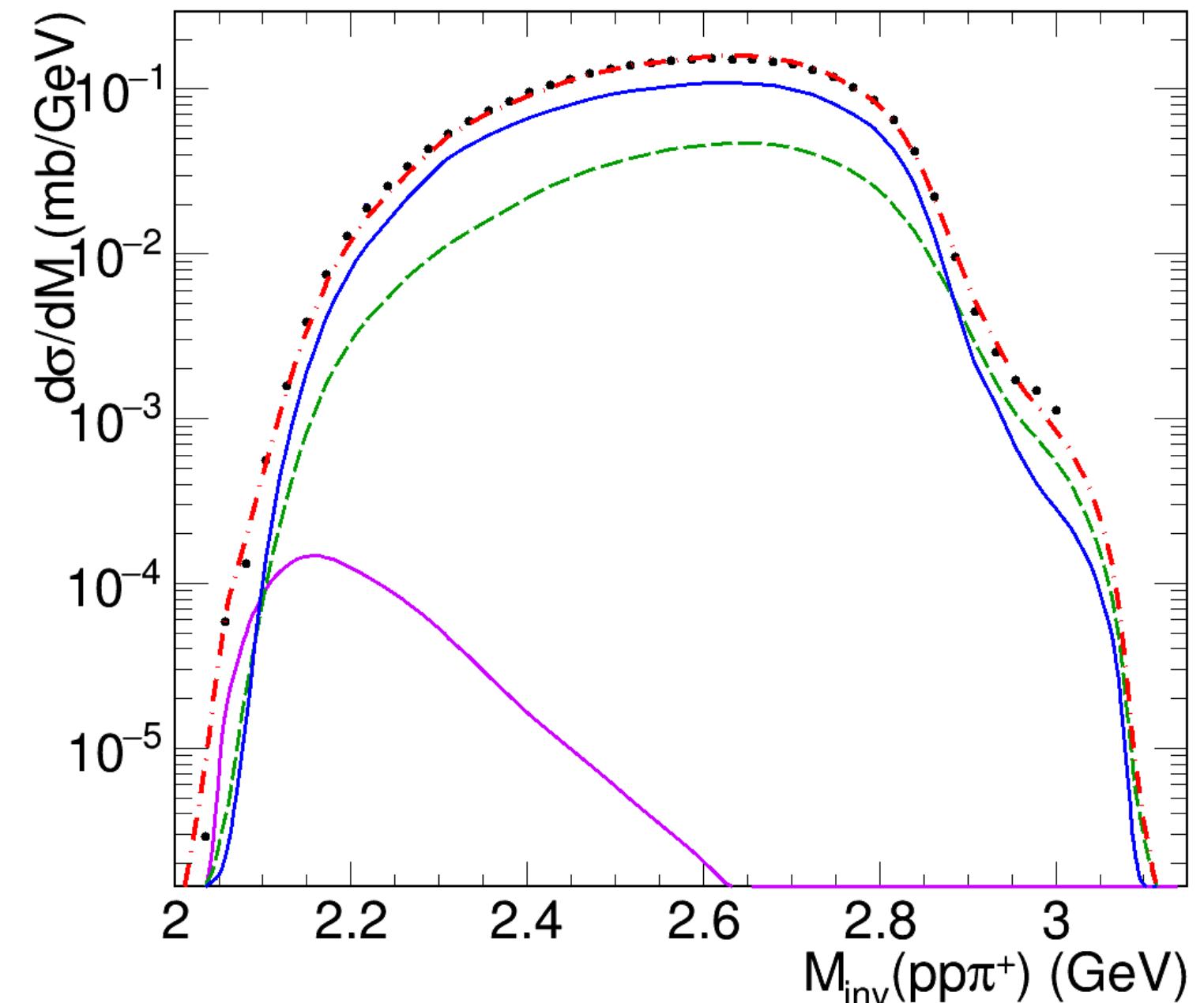
HADES resonances cocktail + D_{21} phase space production

Dibaryon investigation

We applied the χ^2 minimization to extract the possible Dibaryon cross section

$$\sigma_{D_{21}} < 0.3 \mu b$$

After applying kinematical cuts to reduce the resonances background, the minimization gave the same result



Result from WASA *Phy. Rev. Lett.* 121, 052001 (2018)

$$\sigma_{D_{21}} \sim 600 \mu b \text{ at } T_p = 1.5 \text{ GeV}$$

Where they fitted $\sigma(pp \rightarrow pp\pi^+\pi^-)$ with Modified Valencia model + D_{21}

Why is the D_{21} production suppressed at higher energy?

Conclusion

- ✓ This analysis confirms the presence of three channels:
One and double baryonic resonance production, direct ρ production. Contributions are extracted.
- ✓ The results show consistency between 1π , 2π and $K\Lambda$ within the “HADES resonance model” (input for e+e- production interpretation).
- ✓ ρ meson signal was extracted by applying the necessary kinematical cuts → anisotropic angular distribution.
- ✓ The results present valuable inputs for theoretical models (comparison with Cao Lagrangian Model and SMASH ongoing).



**Thanks For
Your
Attention!**

Any questions?