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

Amel Belounnas

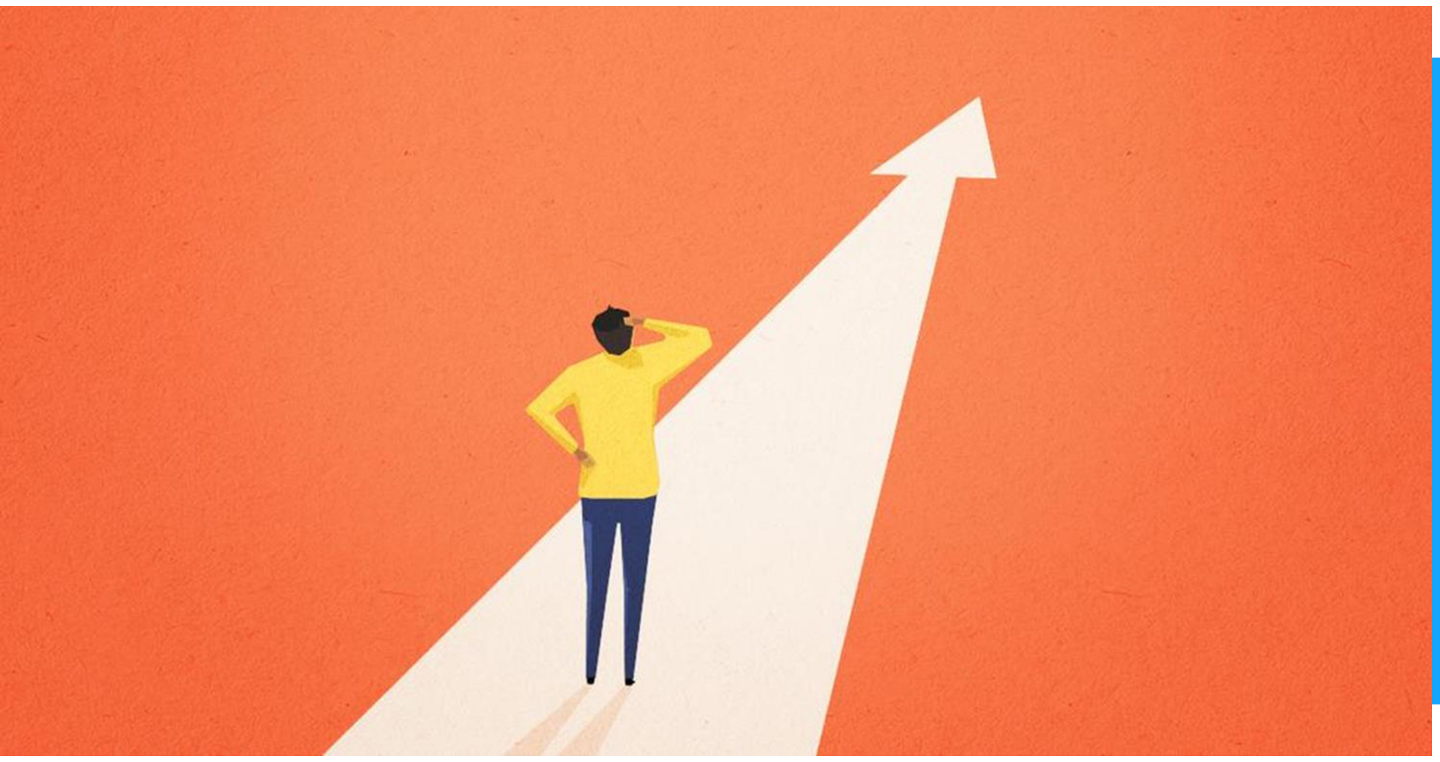
For the HADES Collaboration

MESON2018

11/06/2018

Outline

- Introduction.
- Data Analysis method.
- HADES resonance model (simulation).
- Analysis results.
- Conclusion & Perspectives.

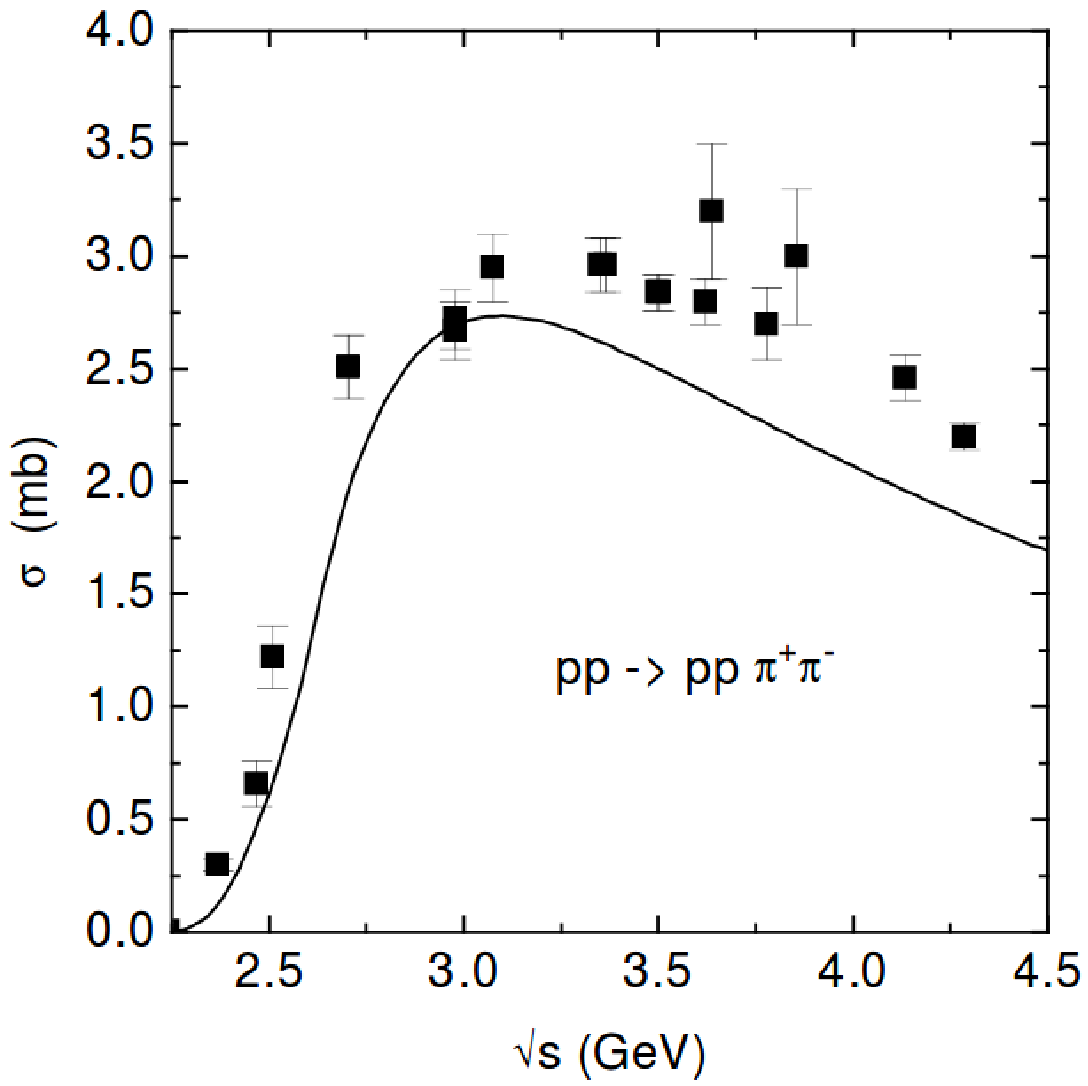


Introduction

Motivation for pion production

- One and double pion production in N-N collisions are important sources of information for meson and baryon production ($\rho\rightarrow\pi\pi$, Δ /N*$\rightarrow$ N π , Δ /N*$\rightarrow$ N $\pi\pi$)

- The $\pi^+ \pi^-$ production channel is particularly interesting for studying the ρ meson and double baryon production.



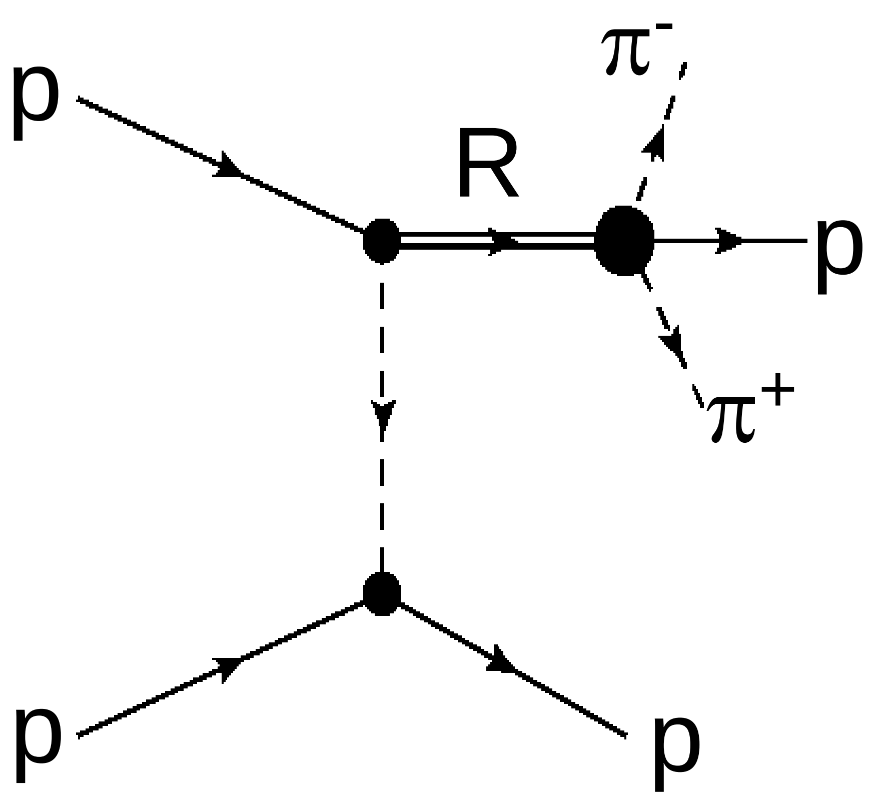
- Few data for NN$\rightarrow$ NN$\pi\pi$ and no precise differential cross sections available around 3.2 GeV.

- Available theoretical approaches :
  The effective Lagrangian models (Valencia, modified Valencia , Xu Cao)
  Transport models (GiBUU, UrQMD, SMASH)
  and OPER model (based on Nπ amplitudes).

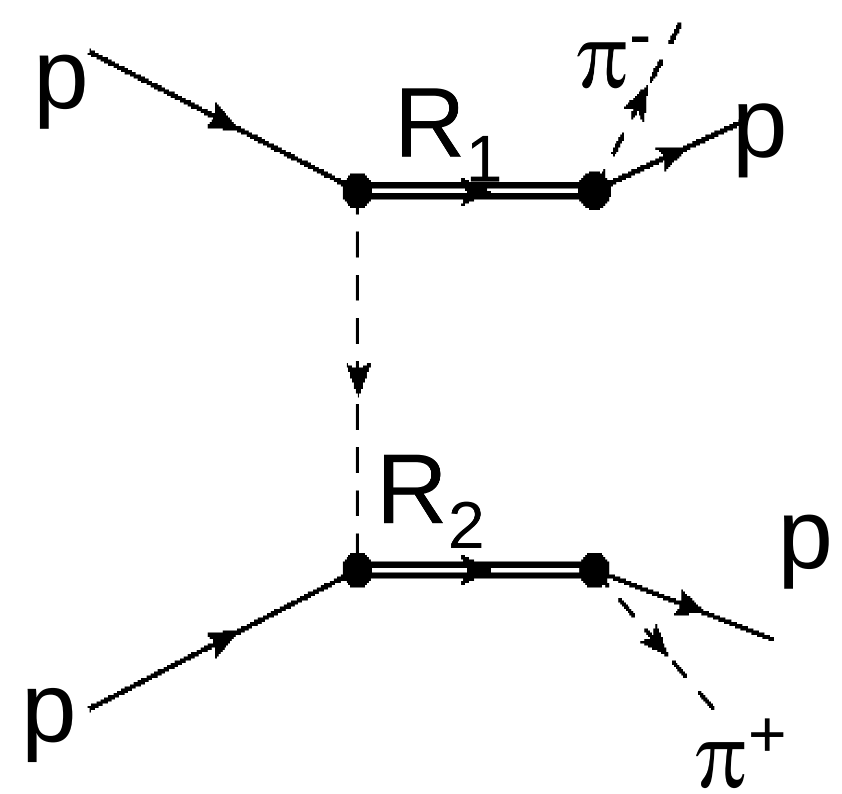
- In the context of HADES general program: pion production needed for the interpretation of the di-electron spectra (baryon resonances + ρ contribution). (see slide 30)

Study of the channel pp→ppπ+π- @ E=3.5 GeV

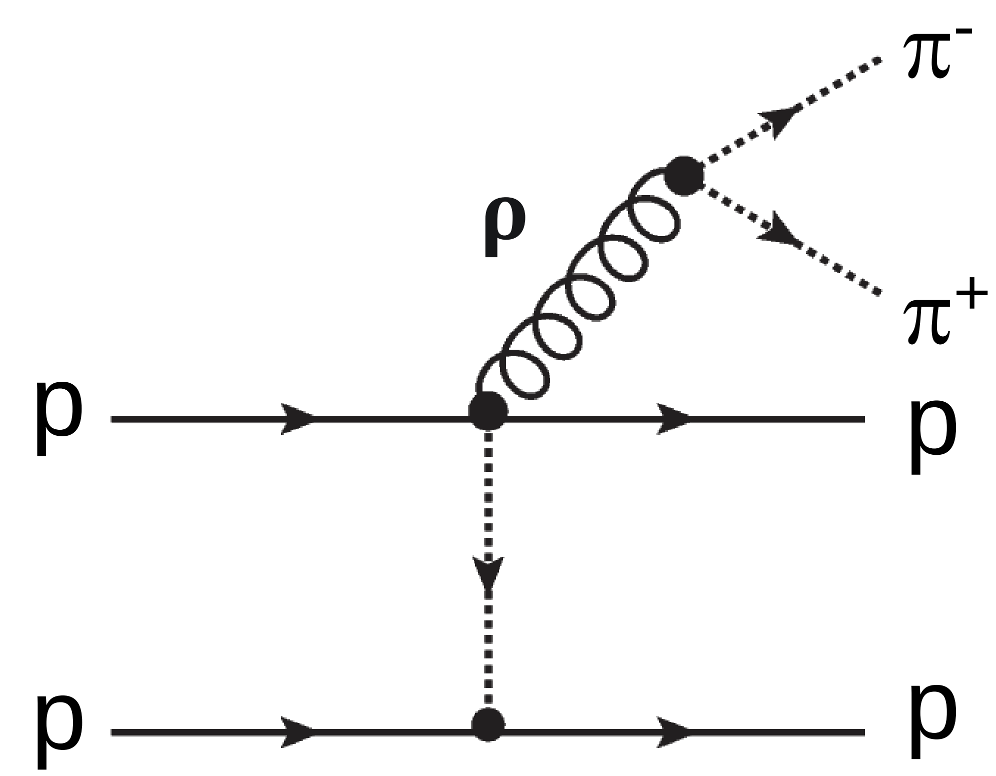
One resonance excitation (1R)



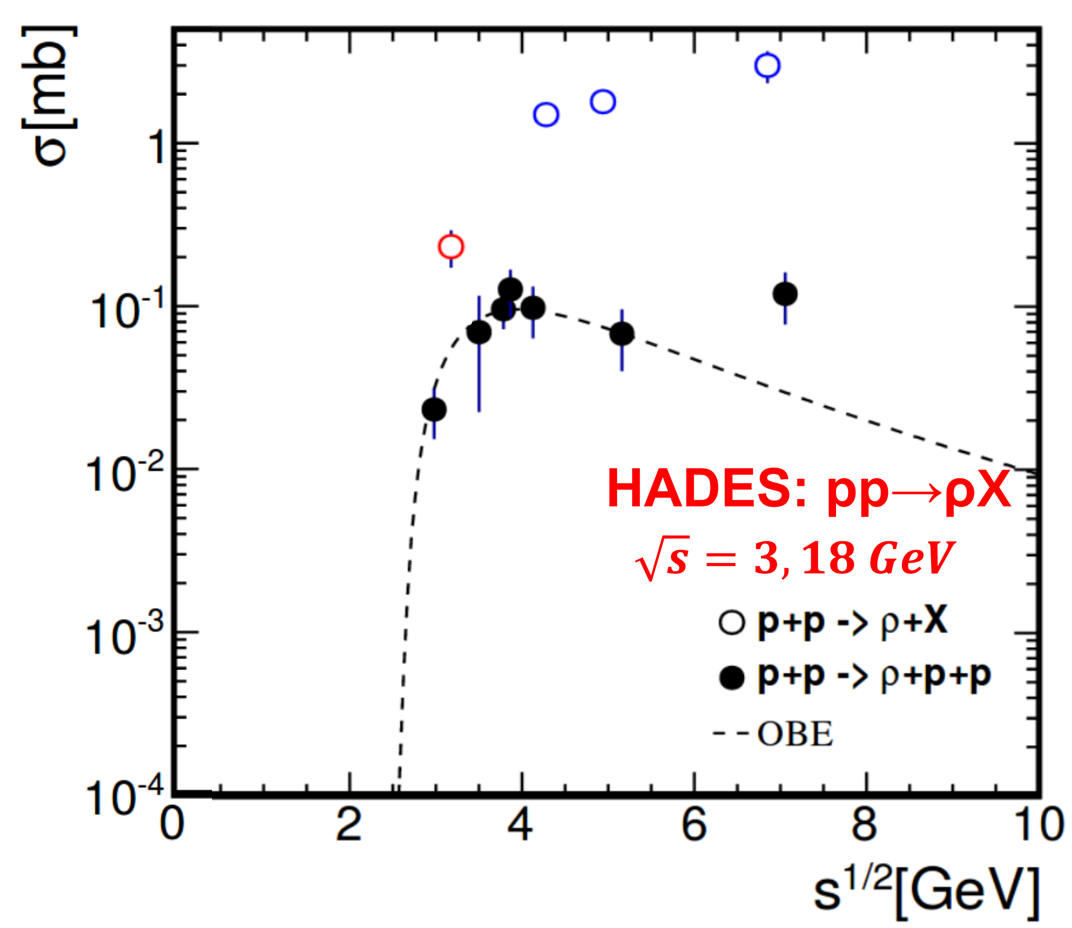
Double resonance excitation (2R)

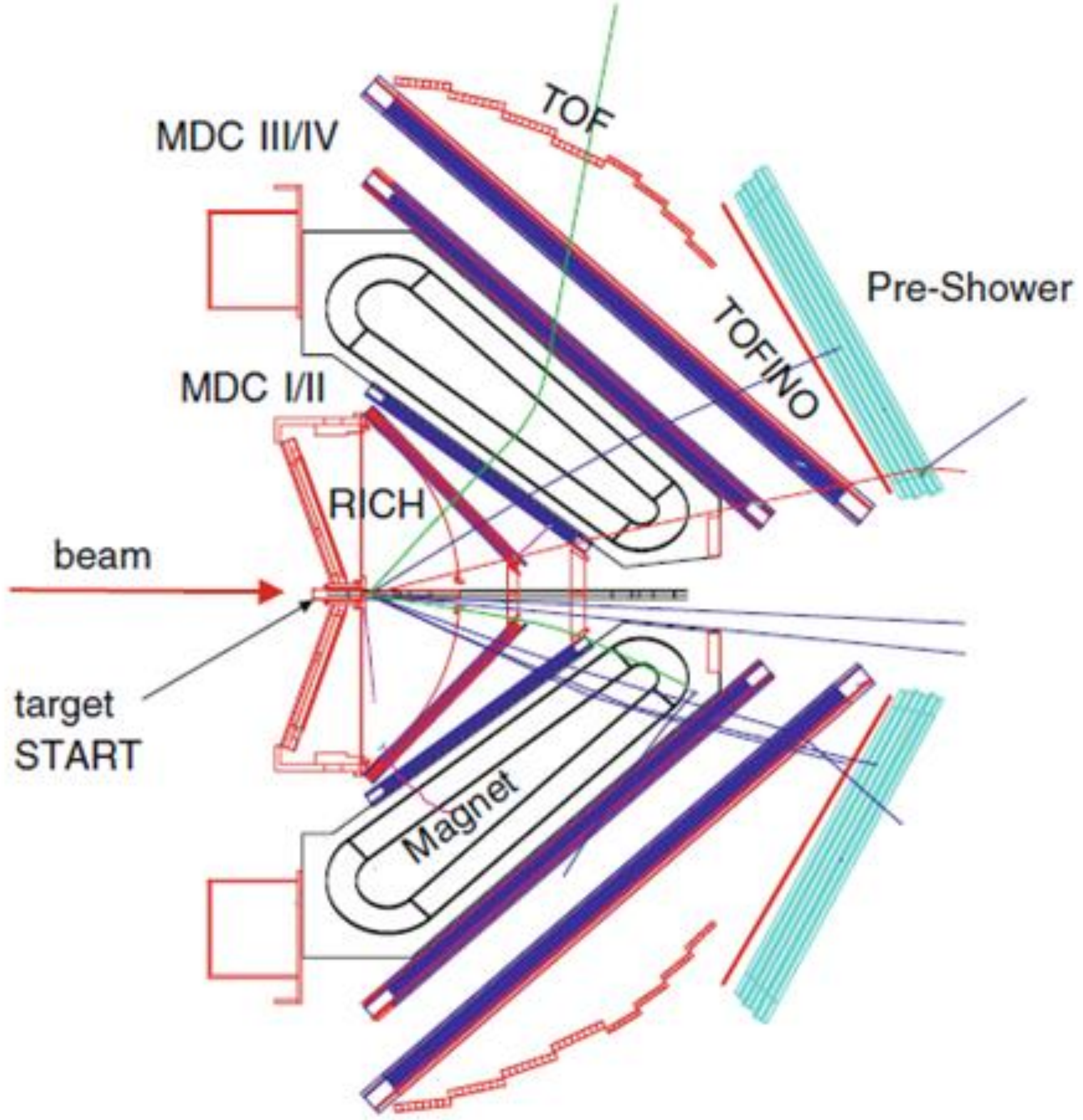


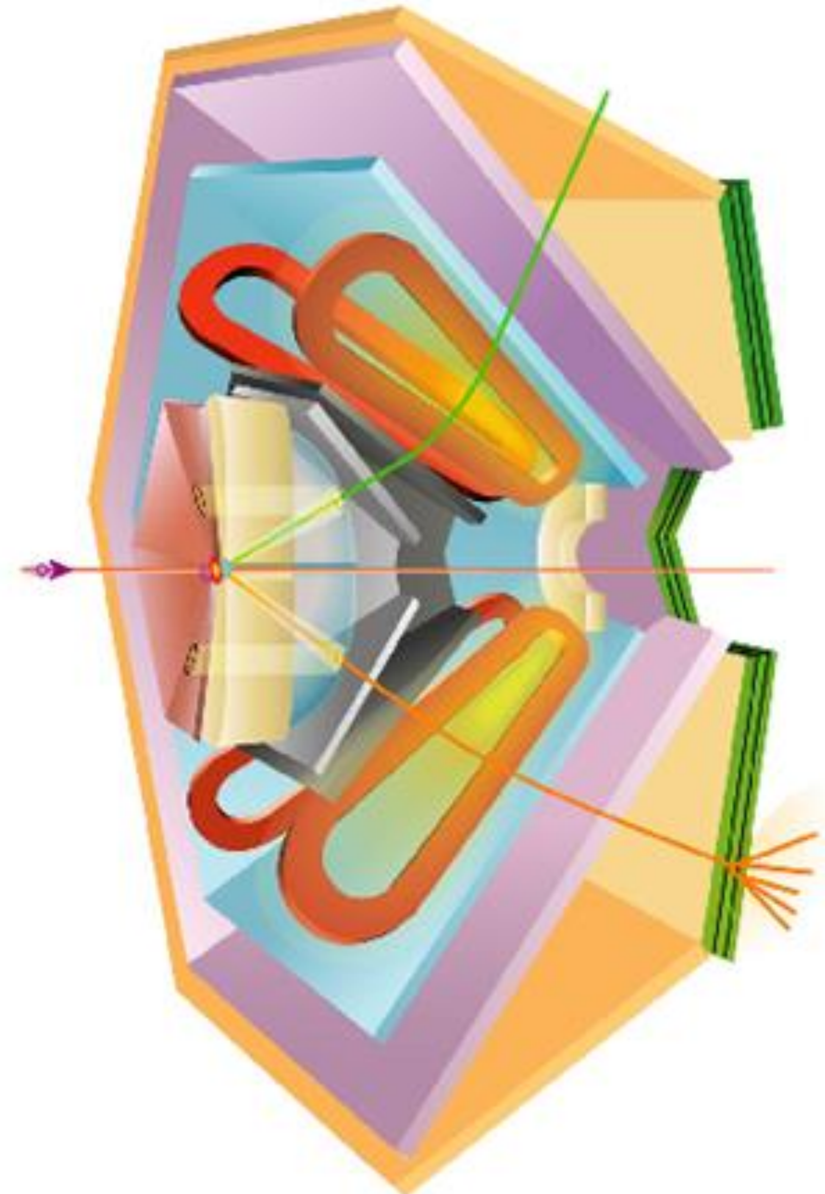
Direct ρ production



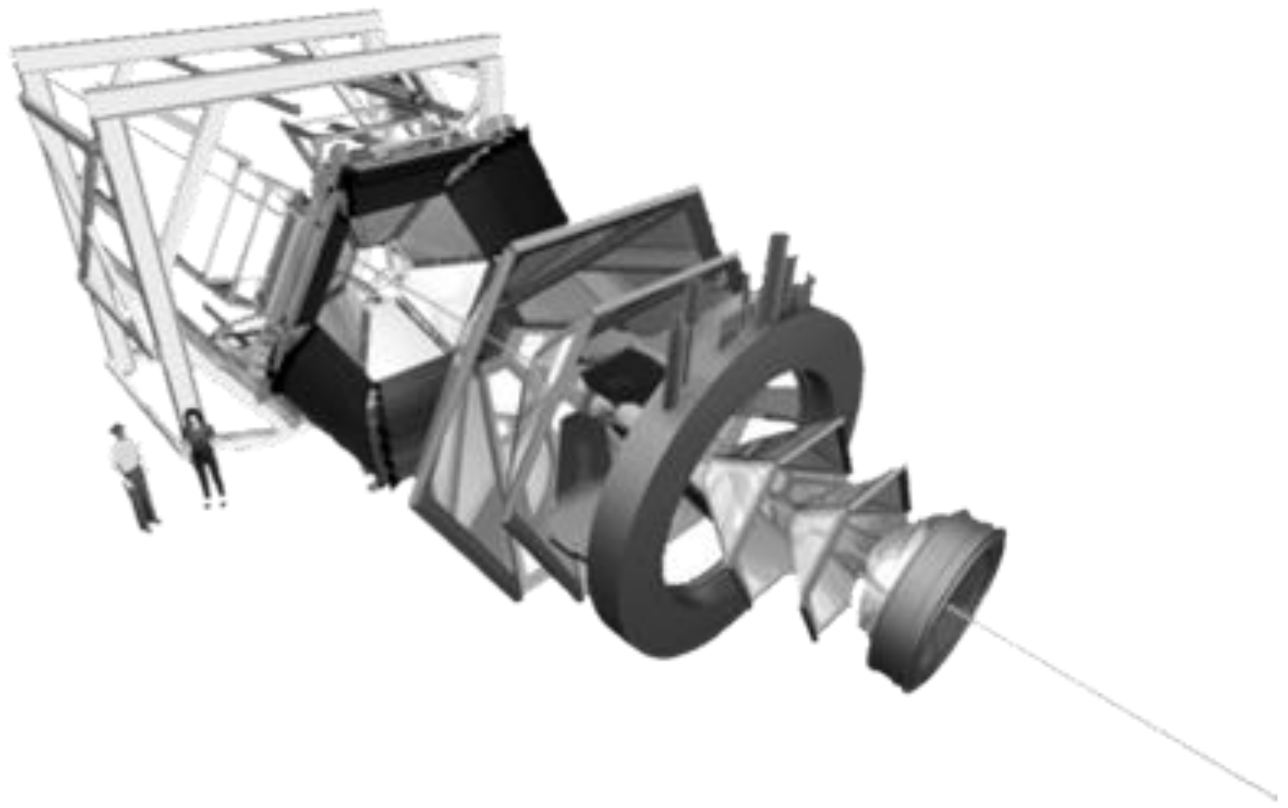
Few precise measurements







Acceptance:
Azimuthal angles 85% (6 sectors)
Polar angles: 18º - 85º
Detected particles: $e^{\pm}$, p, $\pi^{\pm}$, $K^{\pm}$
Tracking: MDC
PID: $e^{\pm}$ with RICH, TOF/PreShower
p, $\pi^{\pm}$, $K^{\pm}$ identification TOF-Tracking



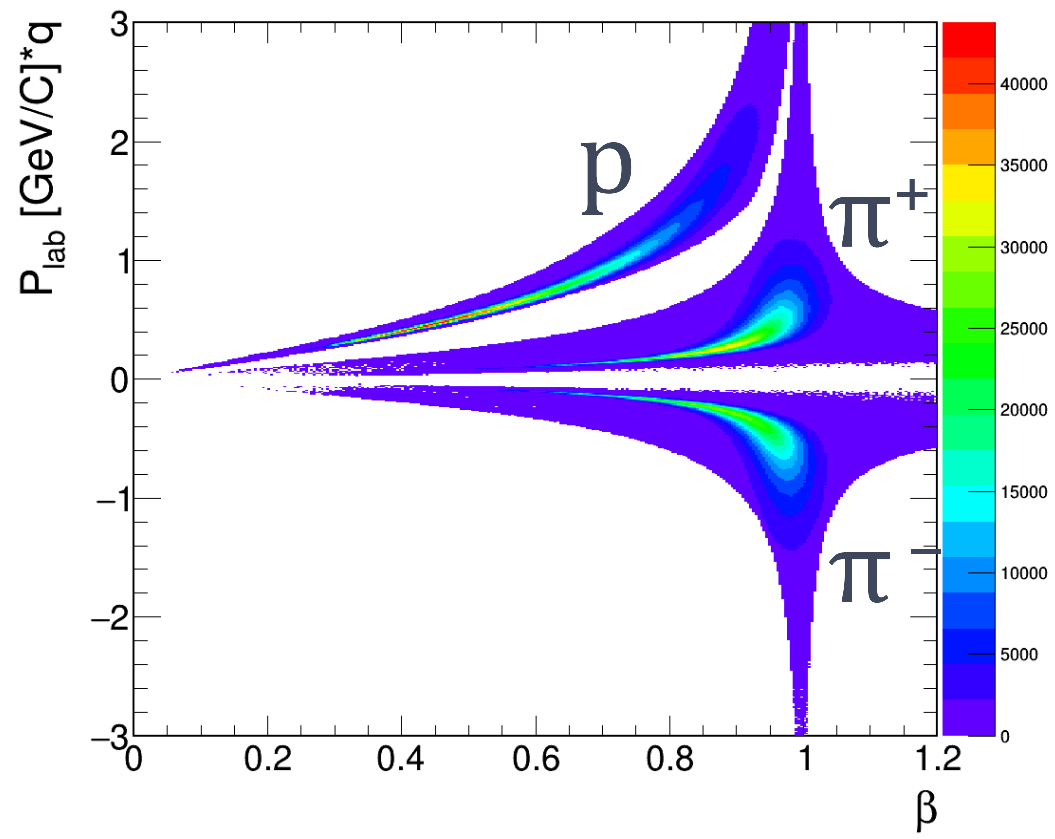
HADES

High Acceptance Di-Electron Spectrometer

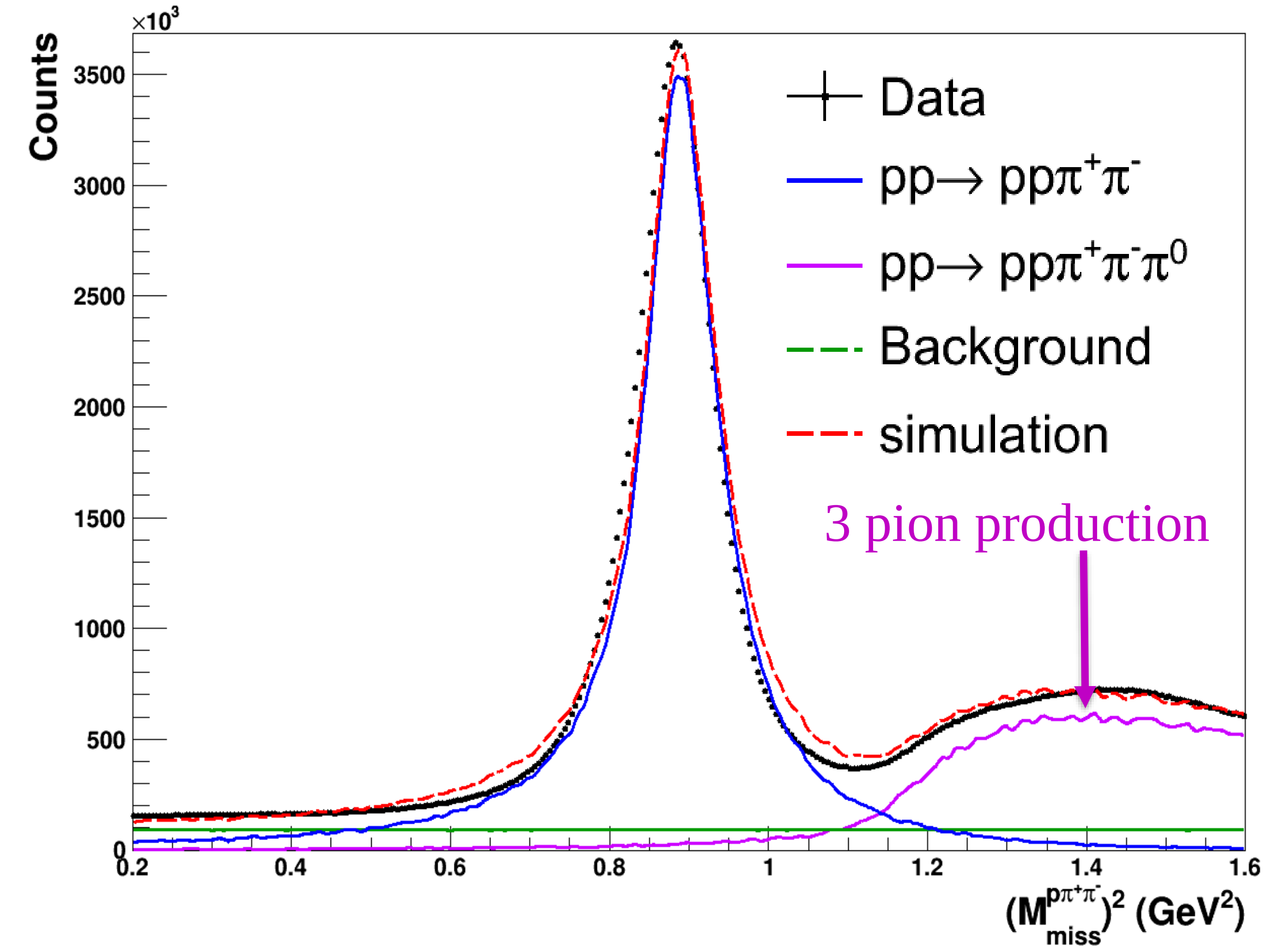
Data Analysis Method

Data Analysis

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



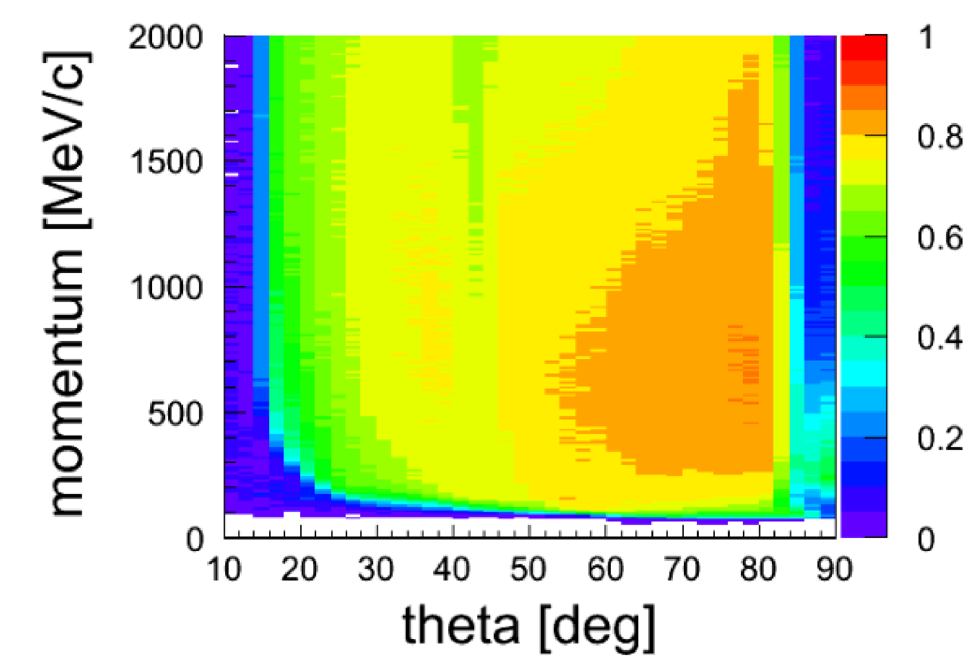
- Background subtraction.



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

- Efficiency correction: using efficiency matrices $Eff(p,\theta,\varphi) = \frac{N_{reconstructed}}{N_{accepted}}$

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



- Normalisation using pp elastic scattering:

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

HADES Resonance Model

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 → $p\pi^{+}\pi^{-}$ (0.04) (6% x 2/3)

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

N1520 → $\Delta^{o}\pi^{+}$ (0.04) (23% x 1/6)

N1520 → $p\rho^{o}$ (0.003) (1% x 1/3)

*** I. Frolich et al. PoS ACAT2007 (2006)**

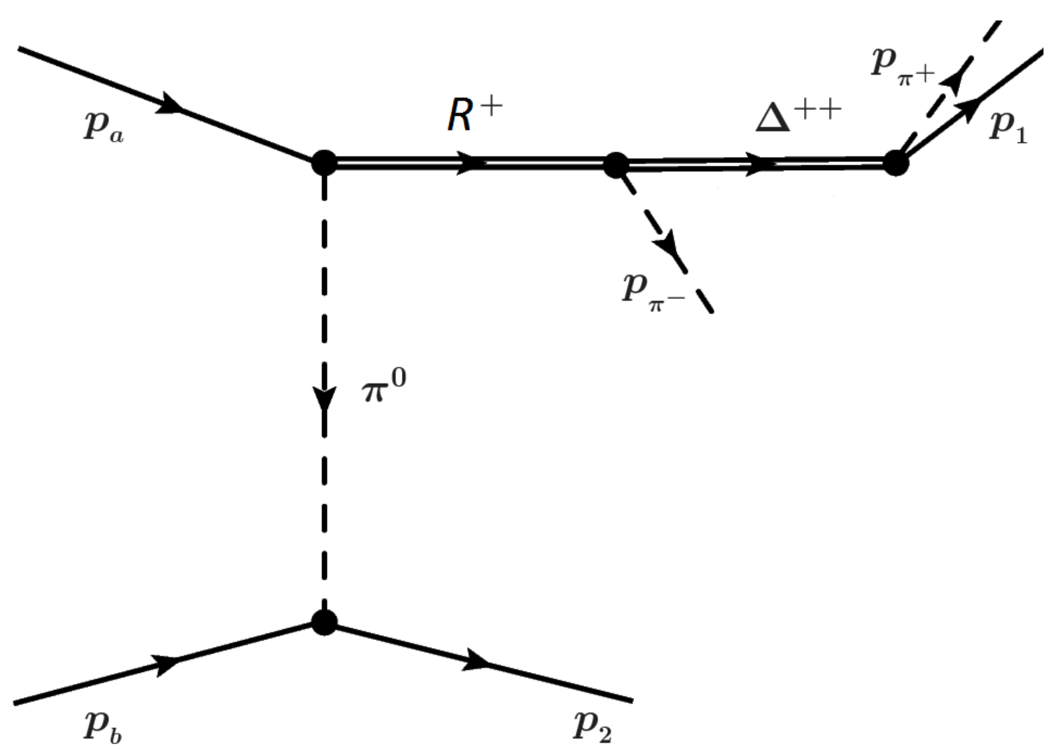
Simulation (using PLUTO++)

pp → pR → pp $\pi^+\pi^-$(1R)

(Using known cross sections from 1π* and pKΛ** analysis)

1π:
- N^+ (1440)
- N^+ (1520)
- N^+ (1535)
- Δ^+ (1620)
- N^+ (1650)
- N^+ (1675)
- N^+ (1680)
- Δ^+ (1910)

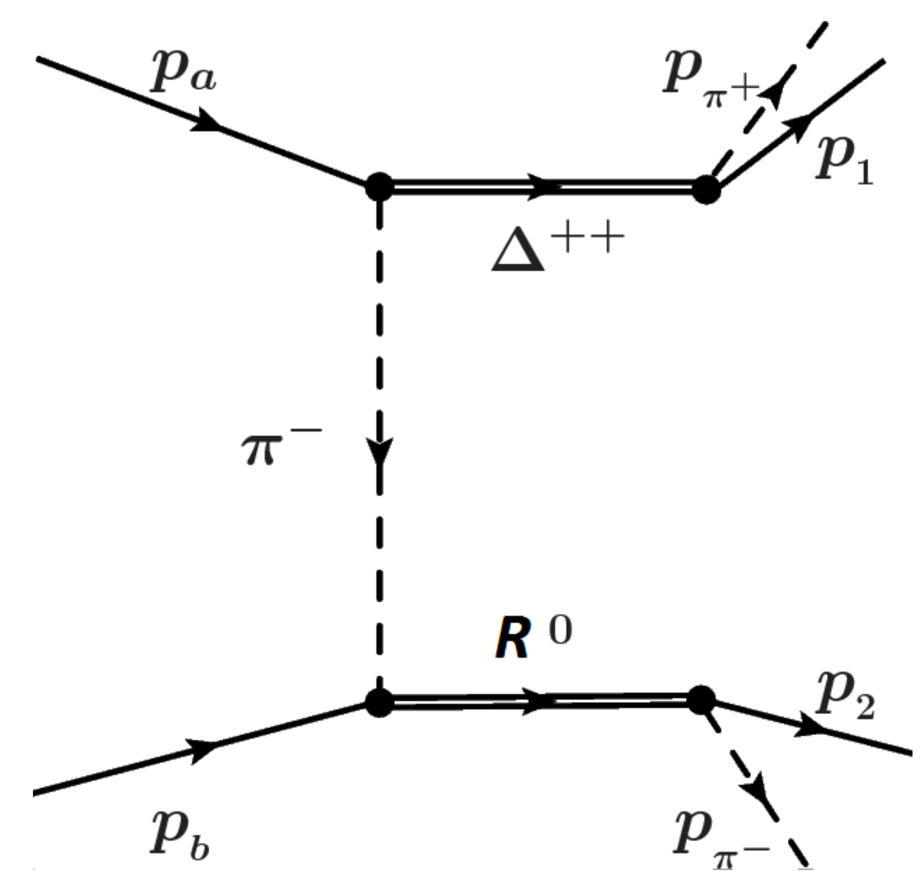
pKΛ:
- N^+ (1710)
- N^+ (1720)
- N^+ (1875)
- Δ^+ (1880)



pp → RR' → pp $\pi^+\pi^-$ (2R)

(cross sections adjusted to the data)

- Δ^{++}(1232) Δ^{o}(1232)
- Δ^{++}(1232) N^{o}(1440)
- Δ^{++}(1232) N^{o}(1520)
- Δ^{++}(1232) N^{o}(1535)
- Δ^{++}(1232) Δ^{o}(1620)
- Δ^{++}(1232) N^{o}(1650)
- Δ^{++}(1232) N^{o}(1680)
- Δ^{++}(1232) N^{o}(1720)
- Δ^{++}(1232) Δ^{o}(1700)



Direct ρ production simulation

σ = 60 μb (from existing data)

G. Agakishiev et al. Eur.Phys.J. A50 (2014) 8
** R. Munzer et al. arXiv:1703.01978

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

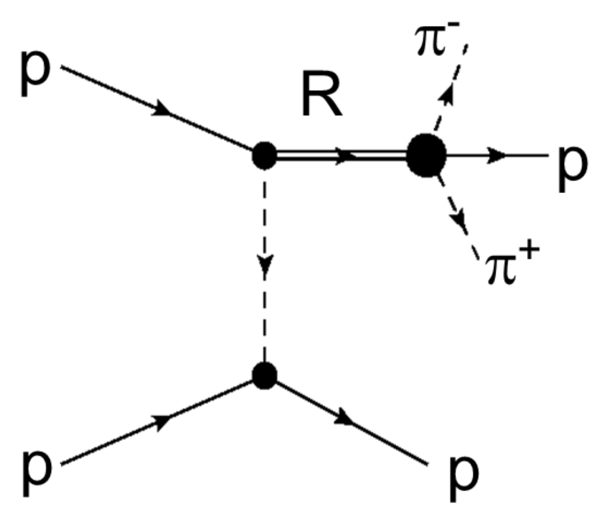
$$\frac{d\sigma_R}{dt} \sim \frac{1}{t^{\alpha}}$$

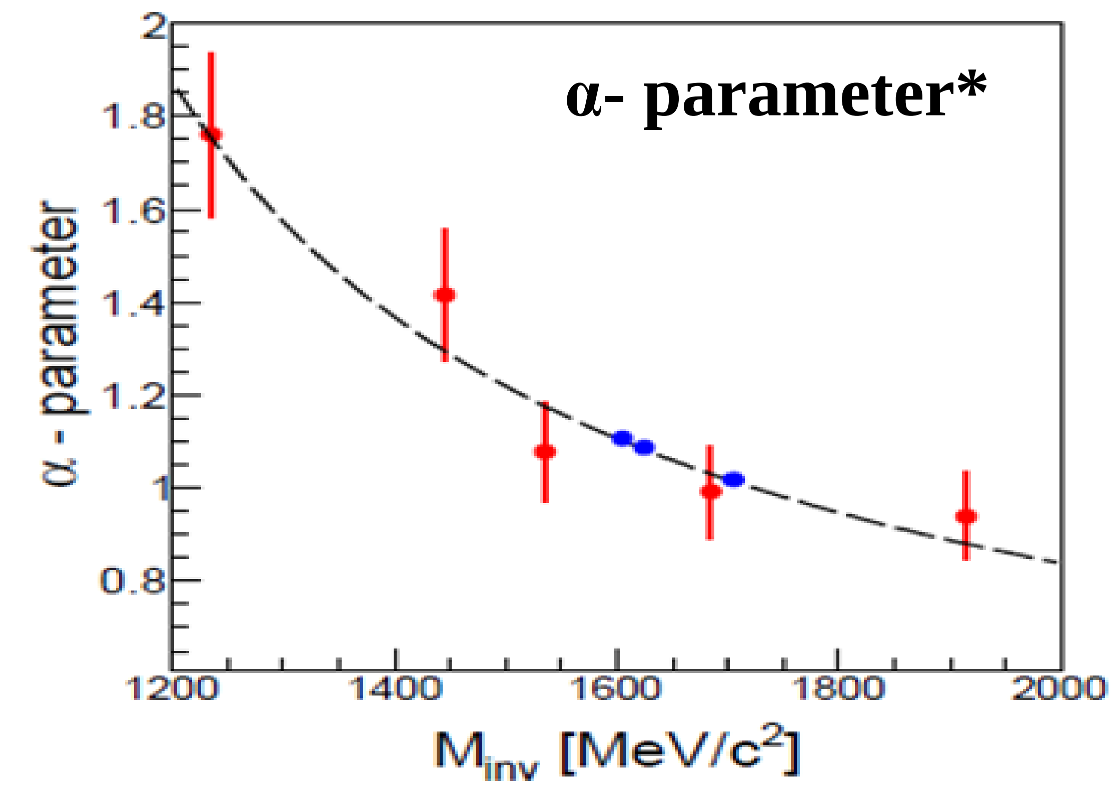
1R production:

$$t = (P_R - P_{beam})^2 \, if \; cos\, \theta_R < 0$$

$$t = \left(P_R - P_{target}\right)^2 if \; cos\, \theta_R > 0$$

$$t_w = \frac{1}{t^{\alpha}}$$





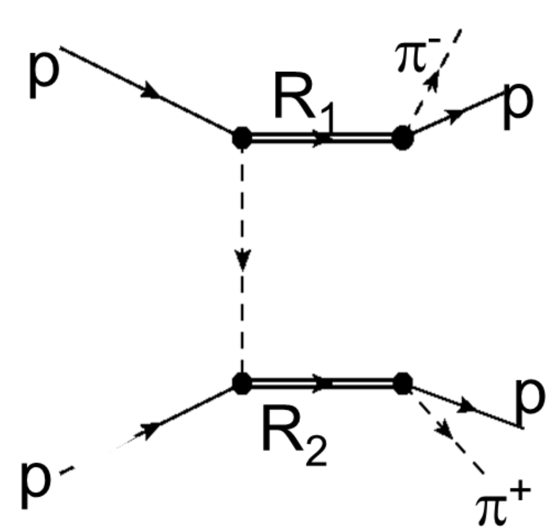
The simulation is weighted by t_w

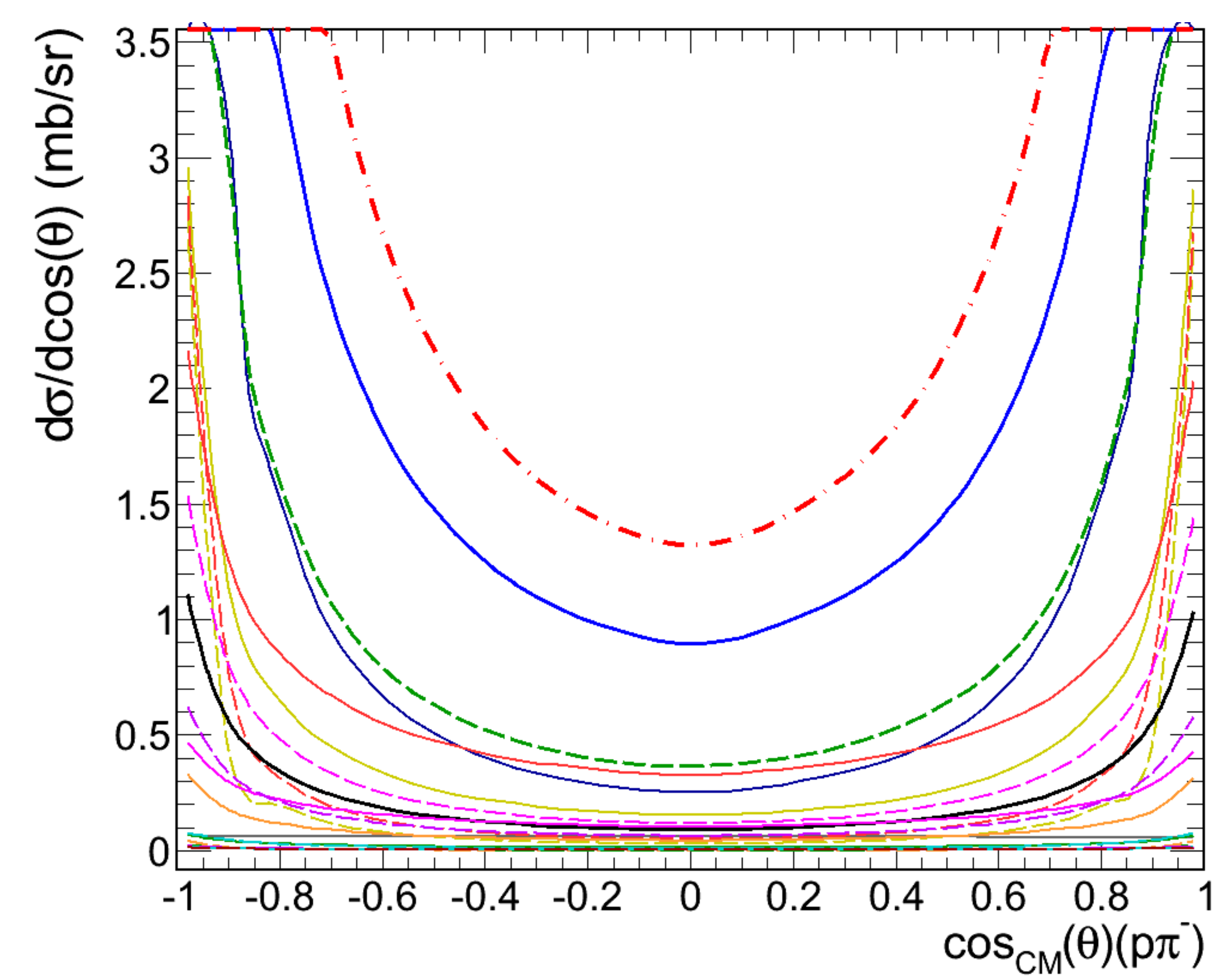
2R production:

$$t = \left(P_{R_1} - P_{beam}\right)^2 if \; cos\, \theta_{R_1} < 0$$

$$t = \left(P_{R_1} - P_{target}\right)^2 if \; cos\, \theta_{R_1} > 0$$

$$t_w = \frac{1}{t^{\alpha_1} . t^{\alpha_2}}$$





Before applying Acc. cuts

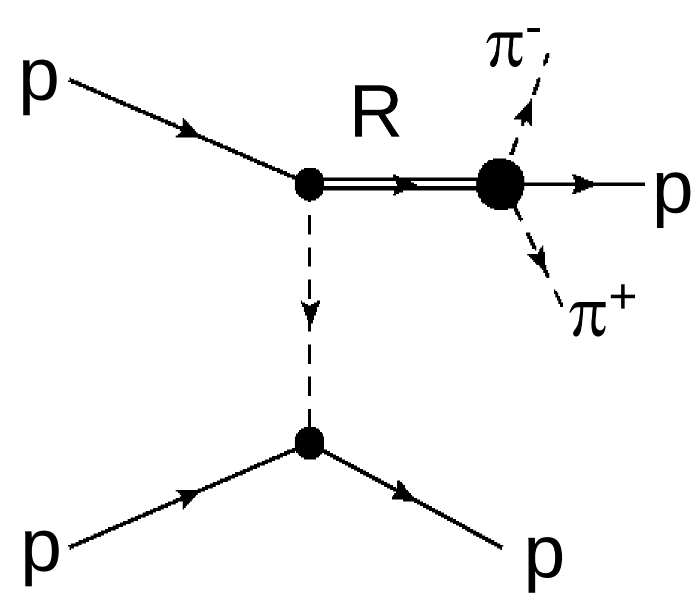
*1 π analysis

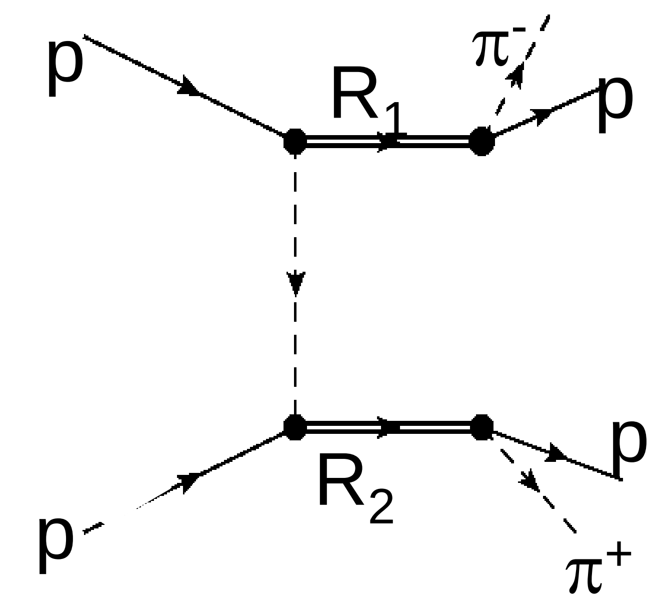
Analysis results

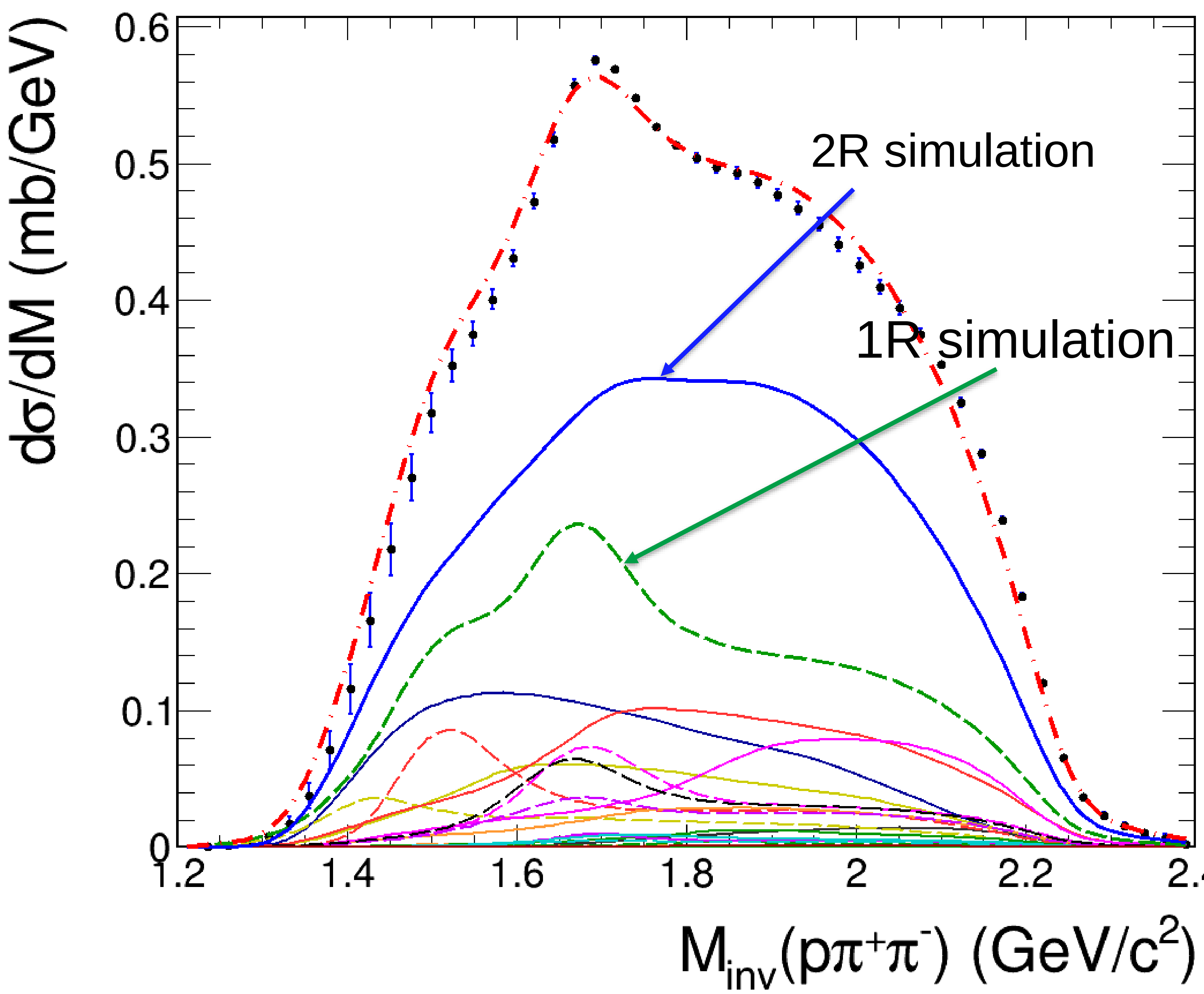
- All spectra include systematic errors
- Normalization err : 6.5% (not included).
- Stat.err are negligible

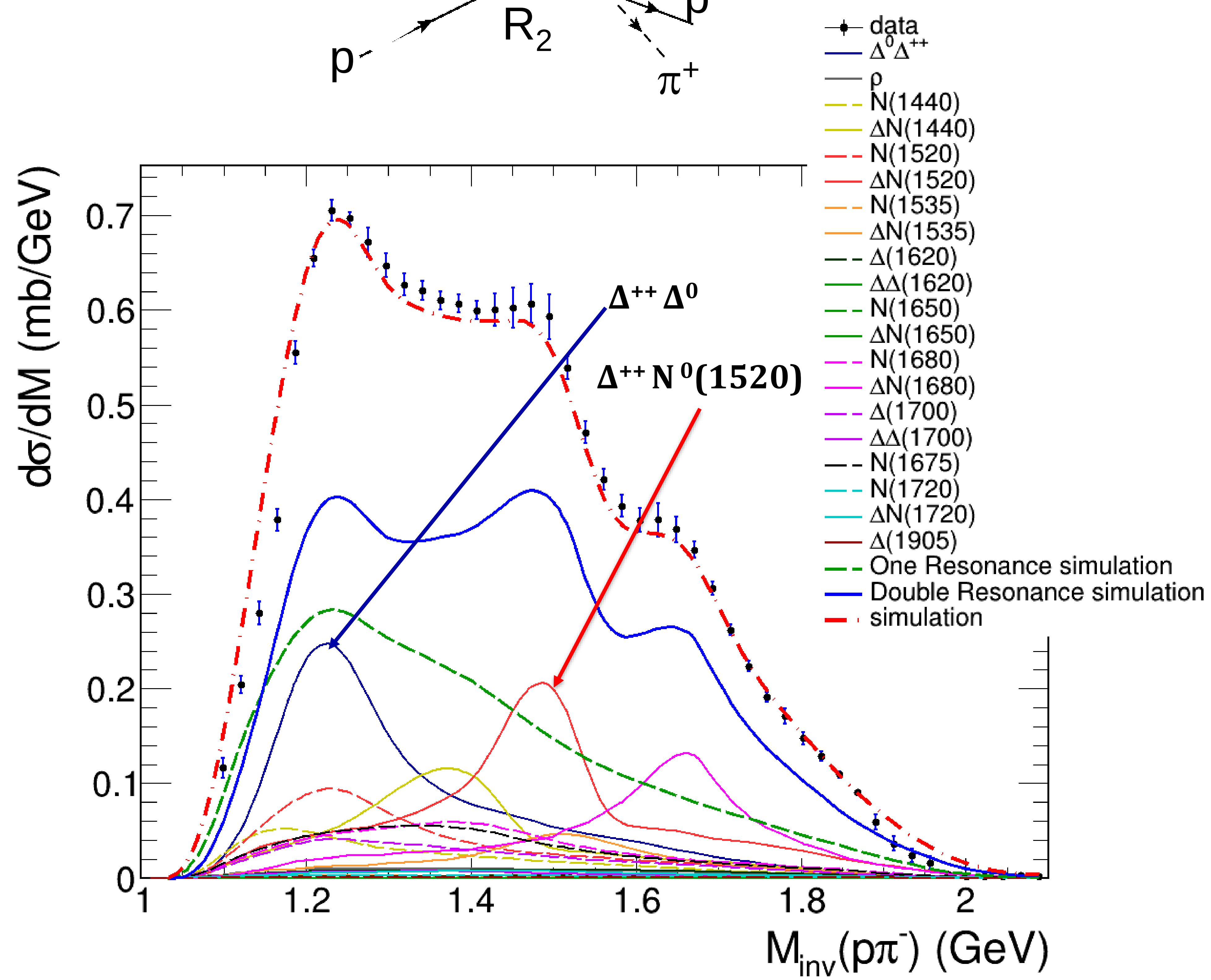
Invariant Mass Spectra

Preliminary







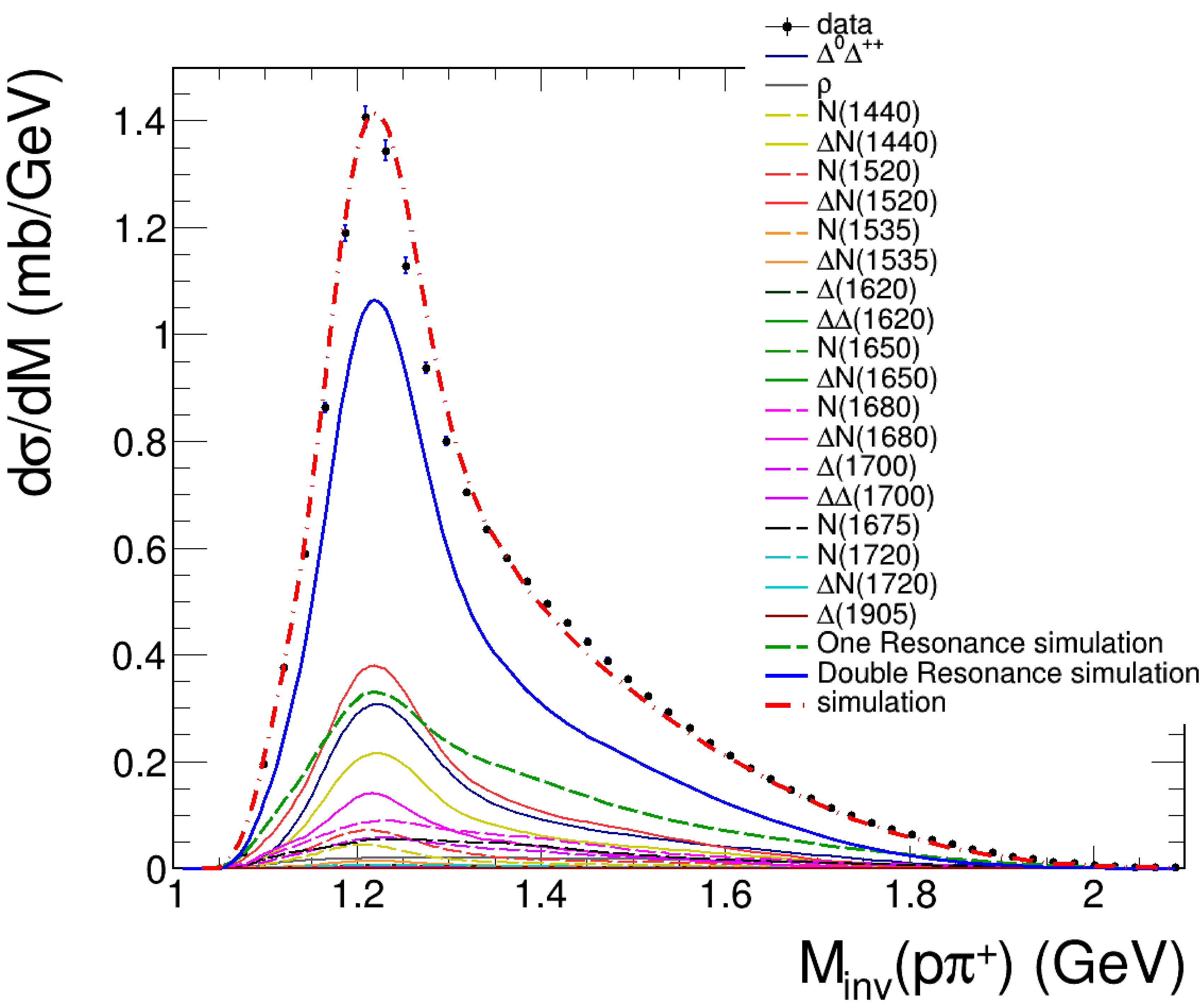


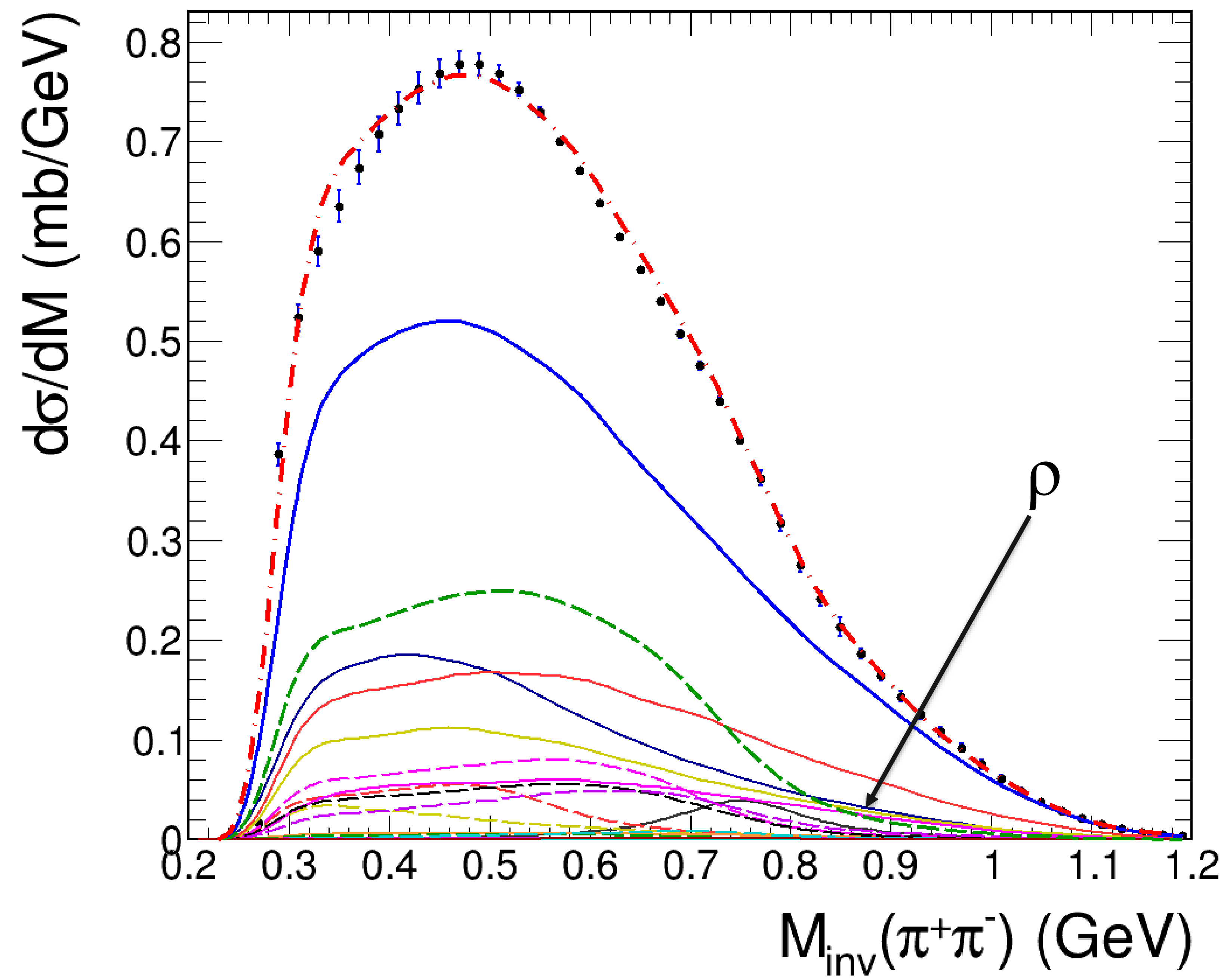
One peak in 1R (Dashed green) due to $N^+(1520)$ and a large peak due to $N^+(1675)$, $N^+(1680)$...

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

Invariant Mass Spectra

Preliminary



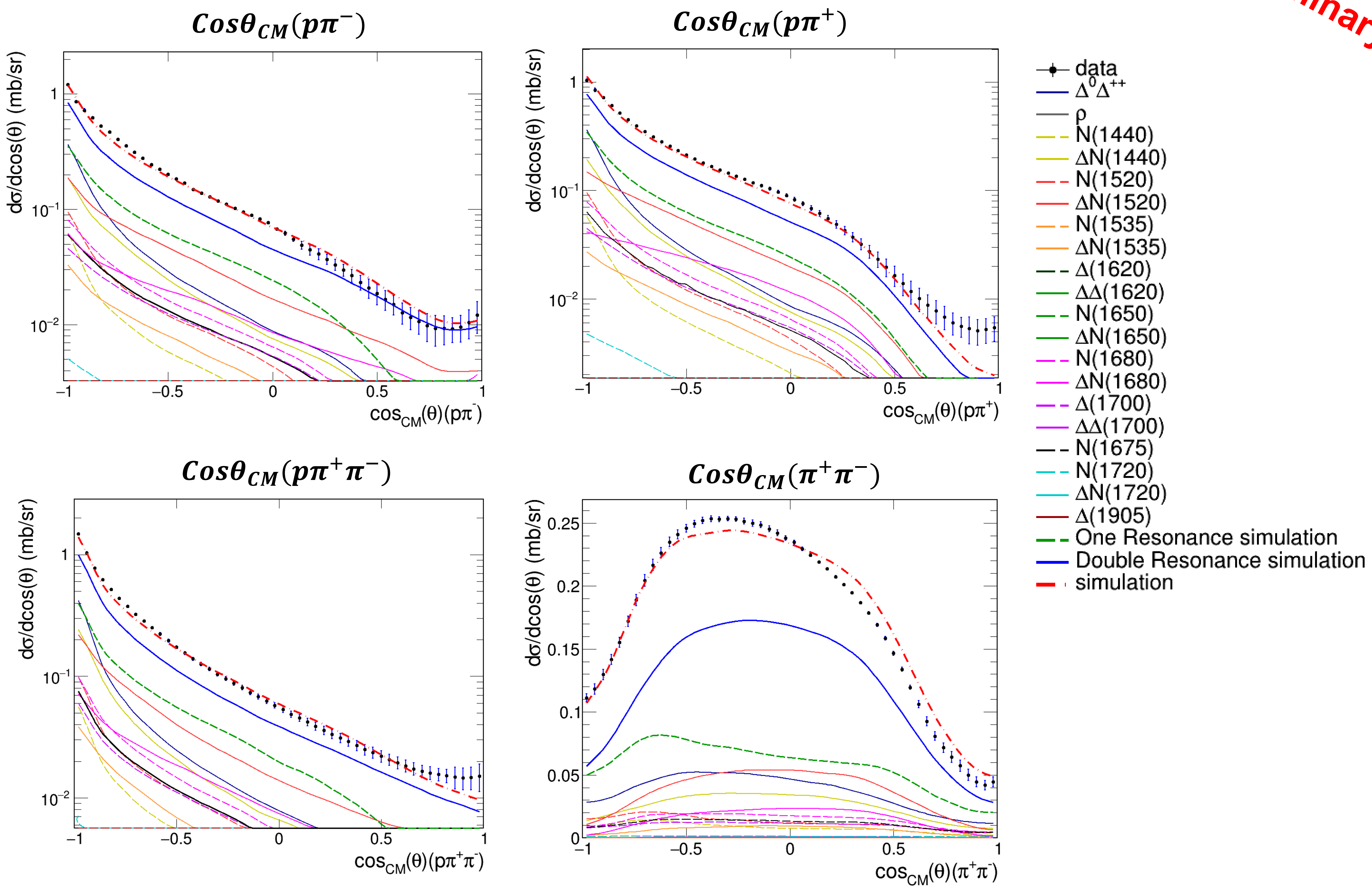


Strong dominance of $\Delta^{++}(1232)$, no significant contribution of heavier Δ^{++} resonances.

No clear evidence of direct ρ production

Angular Distributions

Preliminary



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

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%	1.7 ± 0.2	1.8 ± 0.3
N^+(1535)	10%	0.15 ± 0.05	0.15 ± 0.015
Δ^+(1620)	70%	< 0.10 ± 0.05	< 0.10 ± 0.03
N^+(1650)	11%	0.09 ± 0.03	< 0.81 ± 0.13
N^+(1675)	45%	0.8± 0.1	<1.65± 0.27
N^+(1680)	35%	0.9 ± 0.2	< 0.9 ± 0.15
N^+(1720)	80%	0.06 ± 0.03	< 4.4 ± 0.7
Δ^+(1700)	55%	0.45 ± 0.1	0.45 ± 0.16
Δ^+(1910)	90%	< 0.01 ± 0.01	< 0.85 ± 0.53

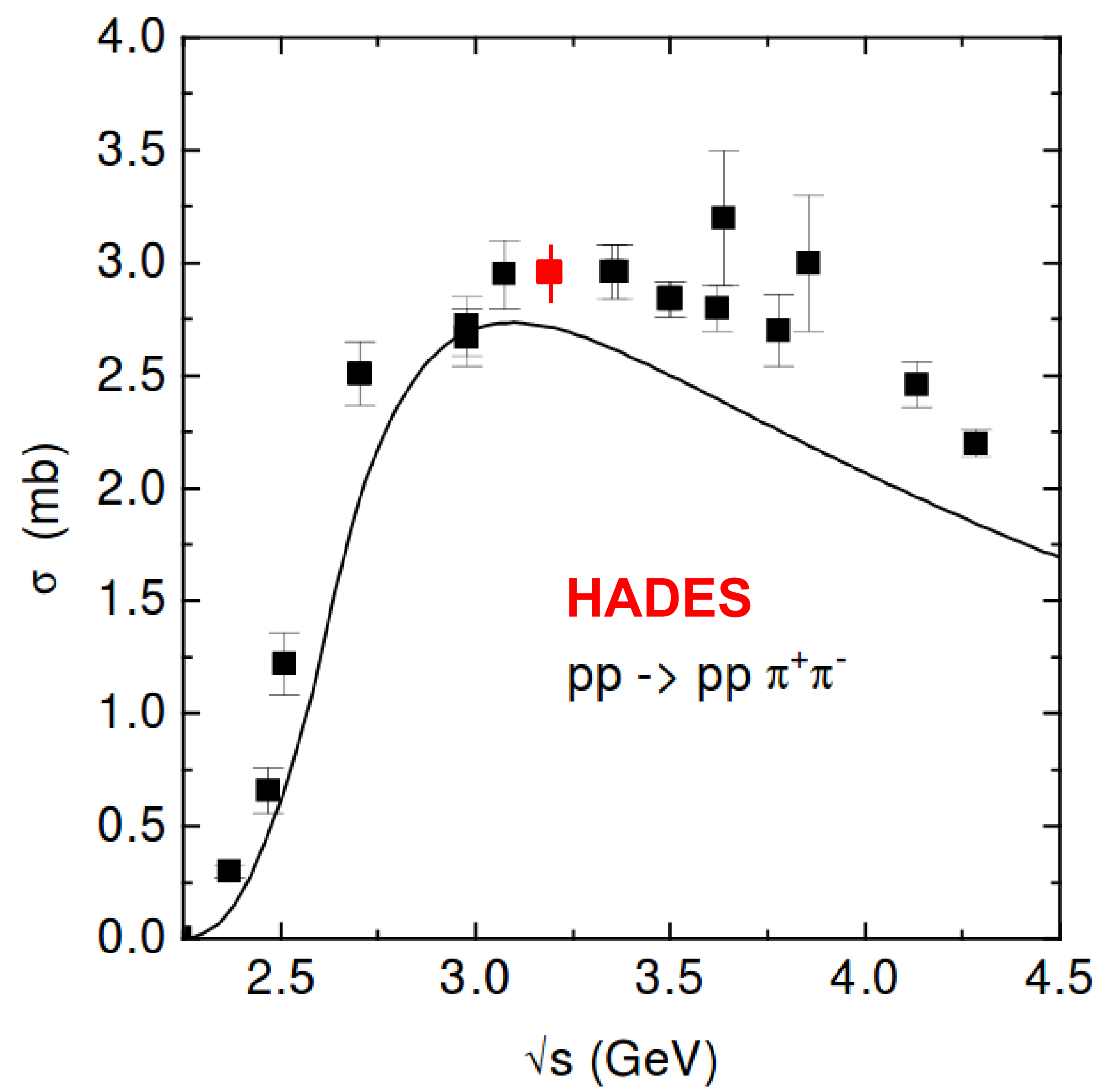
2 Resonances	BR($N\pi$)	σ (mb)
Δ^{++} (1232)Δ°(1232)	100%	3.2± 0.2
Δ^{++} (1232)N°(1440)	70%	1.5 ± 0.2
Δ^{++} (1232)N°(1520)	55%	1.5 ± 0.2
Δ^{++} (1232)N°(1535)	46%	0.5 ± 0.1
Δ^{++} (1232) Δ°(1620)	25%	< 0.05 ± 0.02
Δ^{++} (1232)N°(1650)	70%	< 0.05 ± 0.04
Δ^{++} (1232)N°(1680)	65%	0.9 ± 0.1
Δ^{++} (1232)N°(1720)	15%	< 0.02 ± 0.02
Δ^{++} (1232) Δ°(1700)	15%	< 0.04 ± 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%	0.06 ± 0.01	0.06± 0.015
N^+(1875)	70%	0.038 ± 0.02	0.038 ± 0.018
N^+(1880)	63%	0.4± 0.1	0.74 ± 0.37

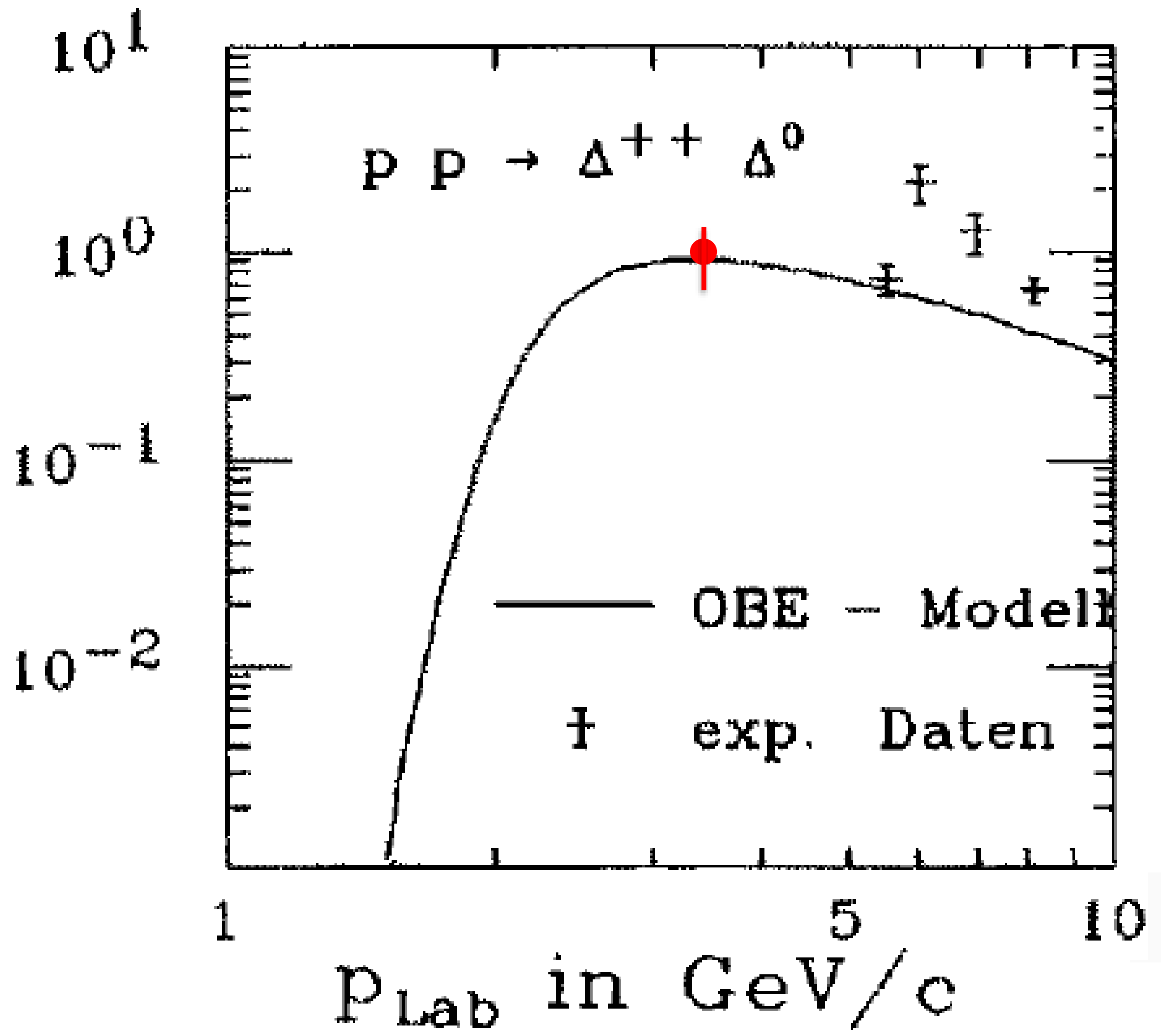
G. Agakishiev et al. Eur.Phys.J. A50 (2014) 8
** R. Munzer et al. arXiv:1703.01978

✓The resonance cocktail reproduces 1π , 2π and $K\Lambda$ production.
✓Based on the cocktail we estimate the total cross section pp $\rightarrow$ pp $\pi^+\pi^-$: σ = 2,95 ± 0.15 mb

Comparing to Existing Data



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



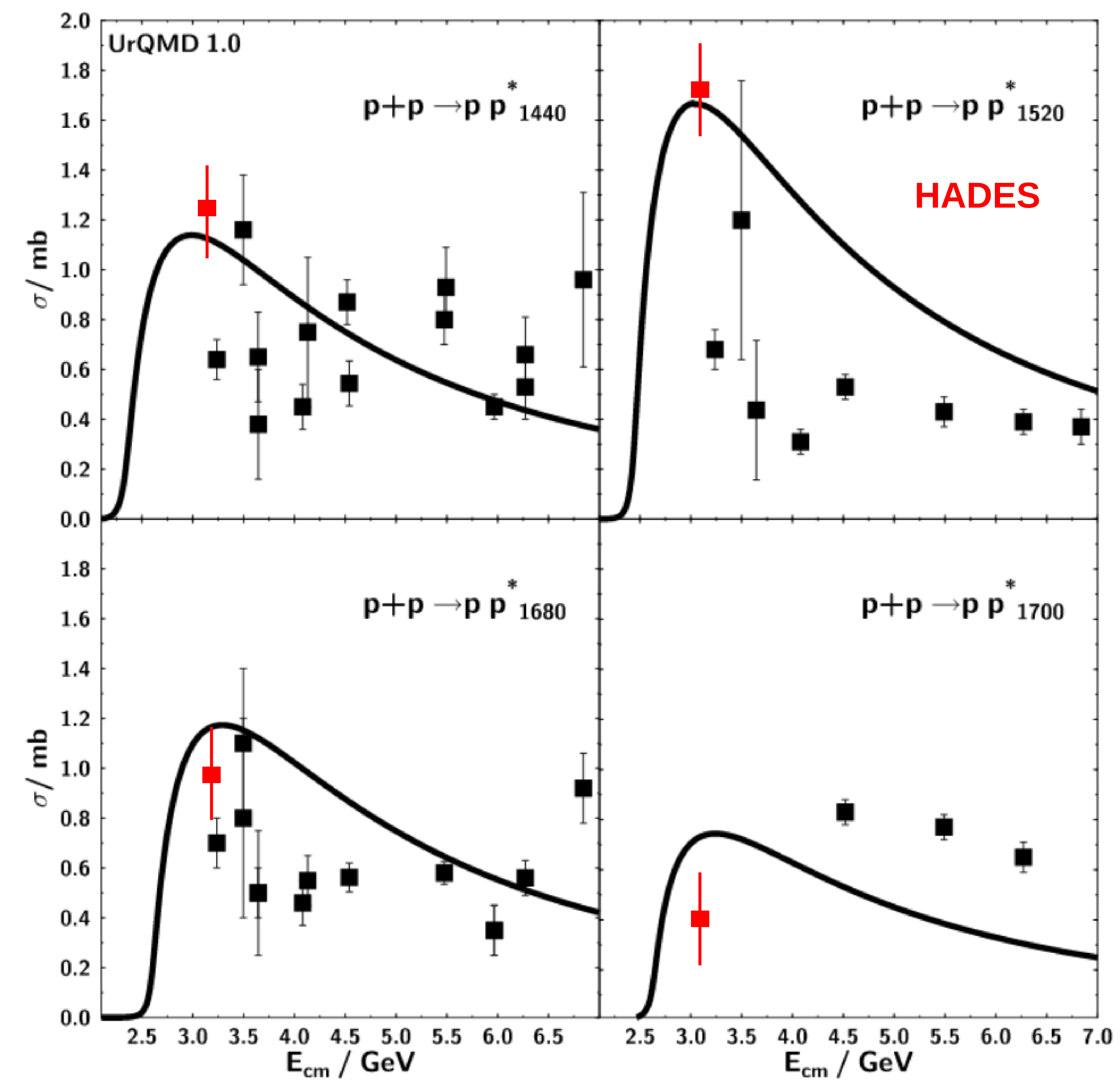
J. Aichelin, Nucl. Phys. A573, (1994) 587.

- Total cross section compatible with existing data. (HADES σ=2,95 mb)
- σ (ΔΔ)=1.05 mb, compatible with OBE (One boson exchange) model.

Comparing to other models

Resonance	σ_R (2π anal.)	σ_R GiBUU	σ_R UrQMD
$N^+(1440)$	1.4 ± 0.2	3.63	1.15
$N^+(1520)$	1.7 ± 0.2	0.27	1.7
$N^+(1535)$	0.15 ± 0.05	0.53	0.8
$\Delta^+(1620)$	< 0.10 ± 0.05	0.10	0.2
$N^+(1650)$	0.09 ± 0.03	0.24	0.4
$N^+(1675)$	0.8± 0.1	0.94	1.2
$N^+(1680)$	0.9 ± 0.2	0.22	1.2
$N^+(1720)$	0.06 ± 0.03	0.14	0.68
$\Delta^+(1700)$	0.45 ± 0.1	0.06	0.35
$\Delta^+(1910)$	< 0.01 ± 0.01	0.14	0.08

2 Resonances	σ (2π anal.)	σ_R UrQMD
$\Delta^{++}(1232)\Delta^{\circ}(1232)$	3.2 ± 0.2	1.5
$\Delta^{++}(1232)\,\Delta^*$	0.1 ± 0.05	0.6
$\Delta^{++}(1232)N^*$	4.5 ± 0.1	5.8
$p\Delta^*$	0.6 ± 0.1	1.3
pN^*	5.8 ± 0.2	8.3



- UrQMD model underestimates the double Δ(1232) production but overestimates the heavy resonances production

- GiBUU model underestimates the N(1520) production but overestimates N(1440)

UrQMD: S.A. Bass et al. Nuc. Phy. 642, 121-129 (1998)

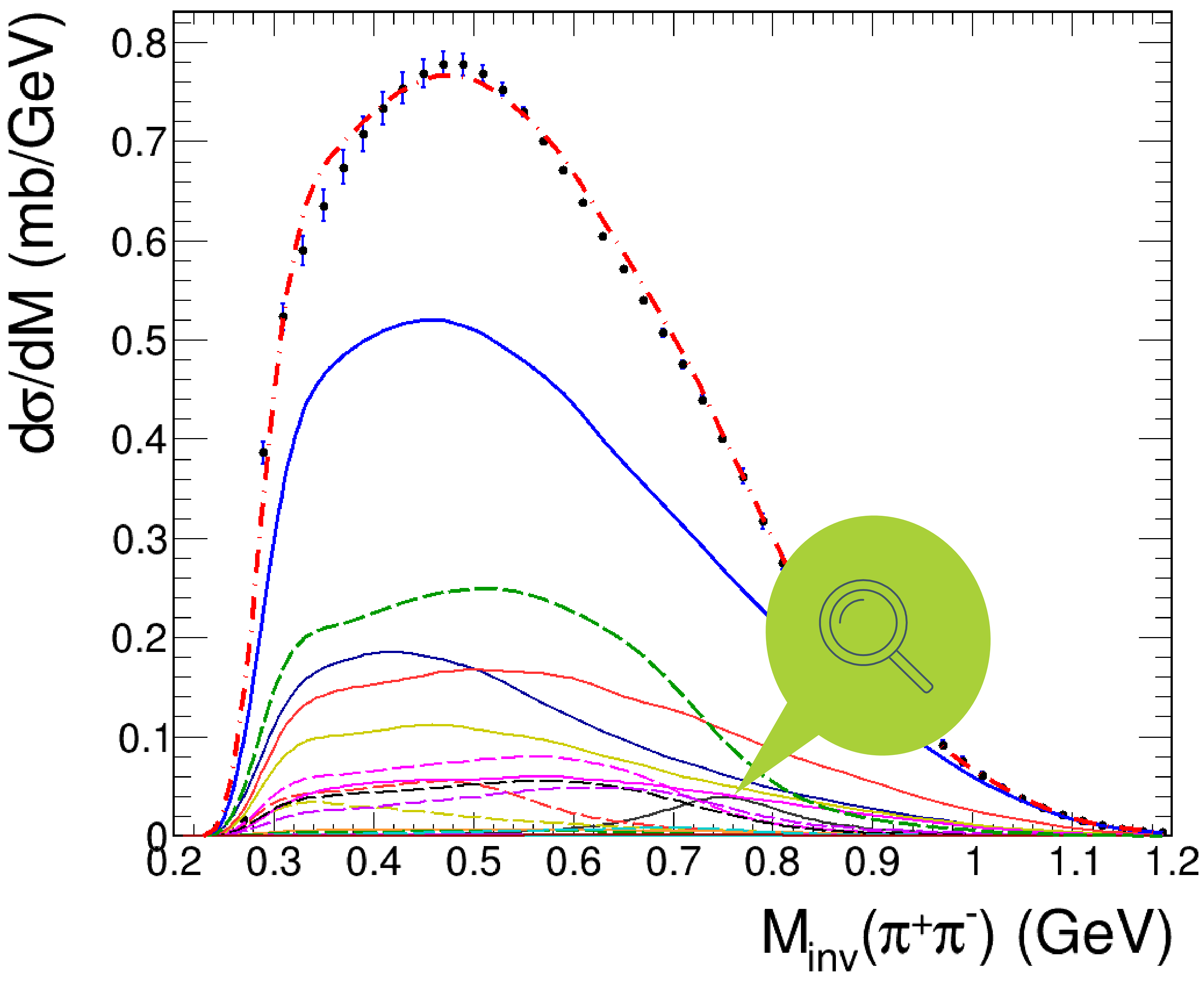
GiBUU: Weil, J., van Hees, H. & Mosel, U. Eur. Phys. J. A (2012)

Tracking the ρ meson

Search for the direct “ρ”

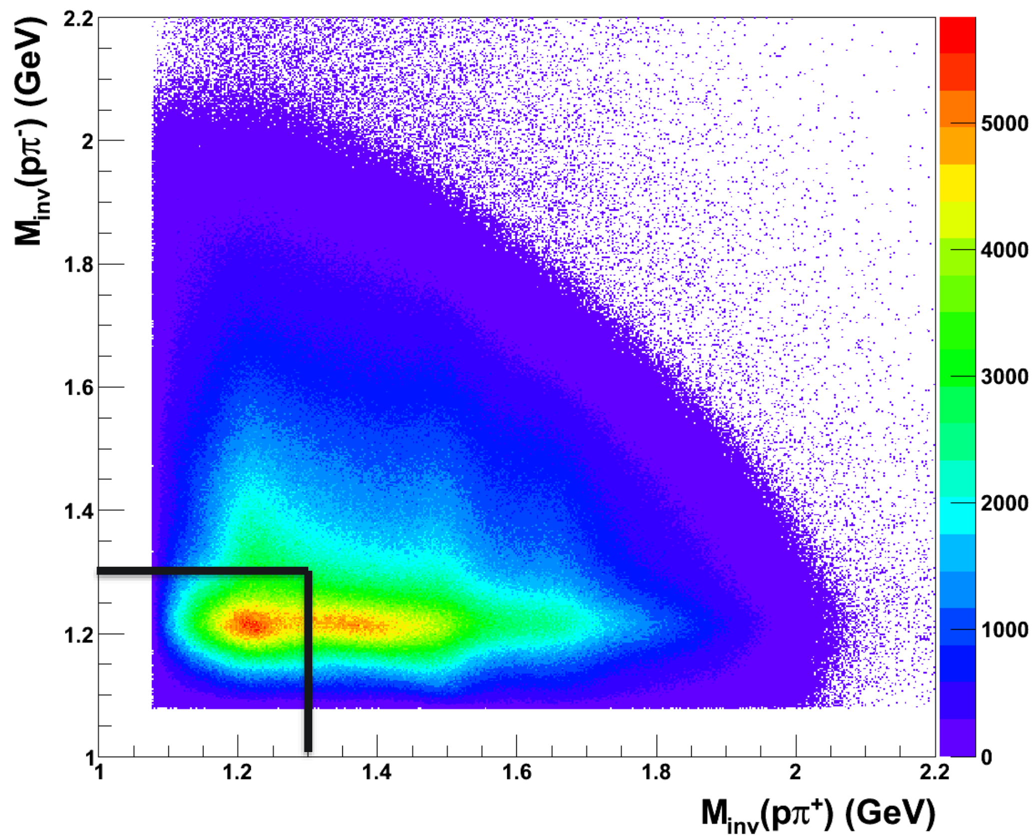
Apply kinematical cuts to reduce the baryonic resonance excitation background.

M(ρ) = 775 MeV
Γ(ρ) = 149 MeV

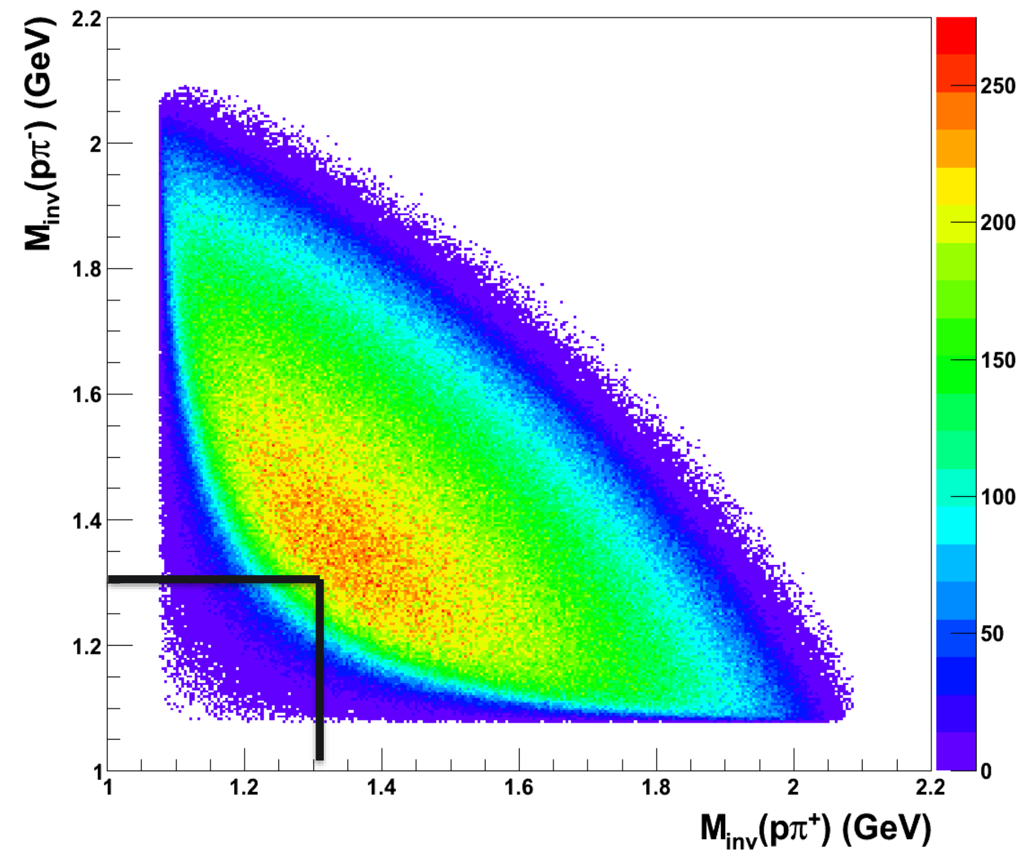


Search for the direct "ρ"

Data



ρ simulation

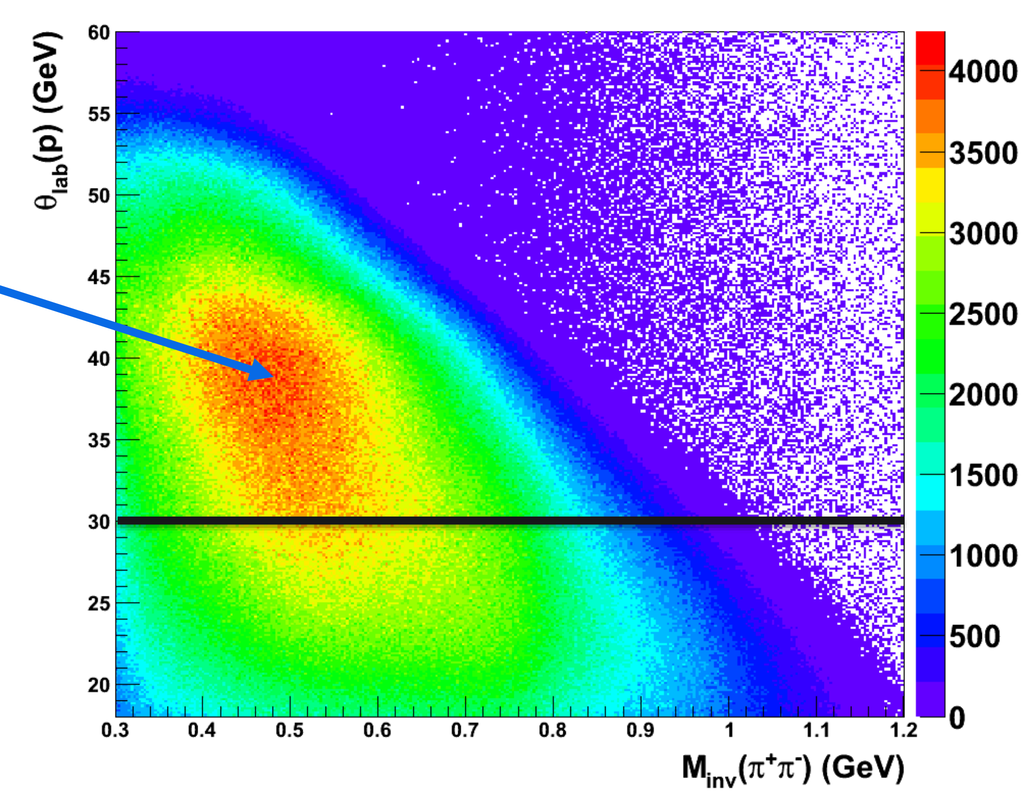


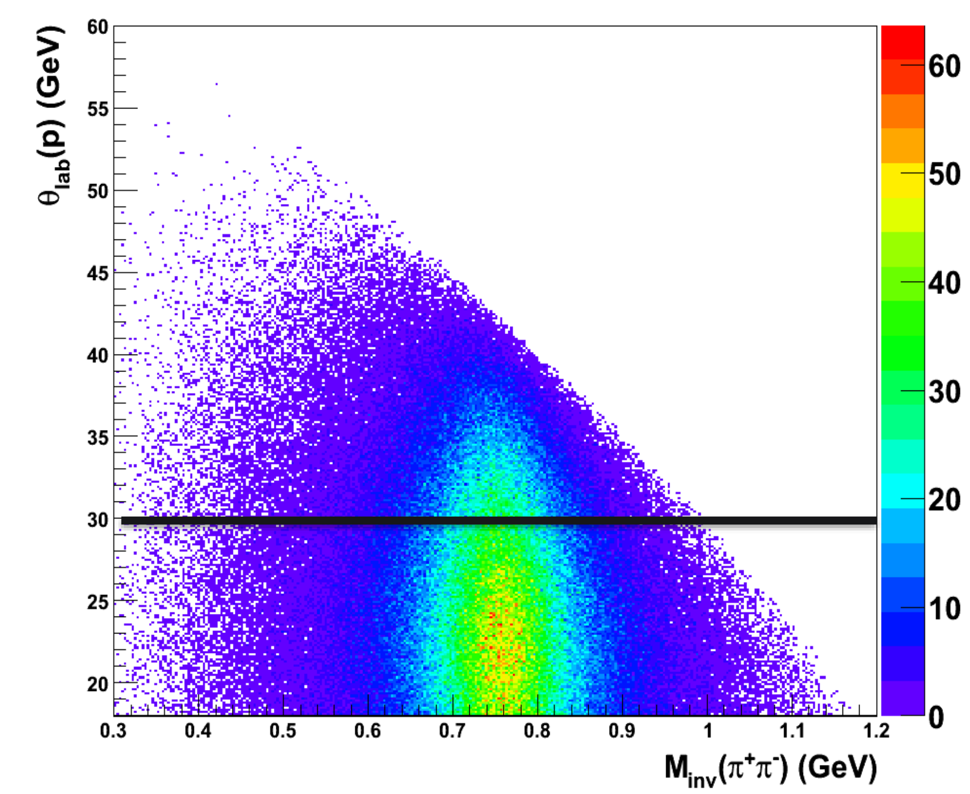
$M_{inv}(p\pi^{+}) > 1.3\ GeV$

$M_{inv}(p\pi^{-}) > 1.3\ GeV$

Suppress Δ(1232)Δ(1232)

resonances



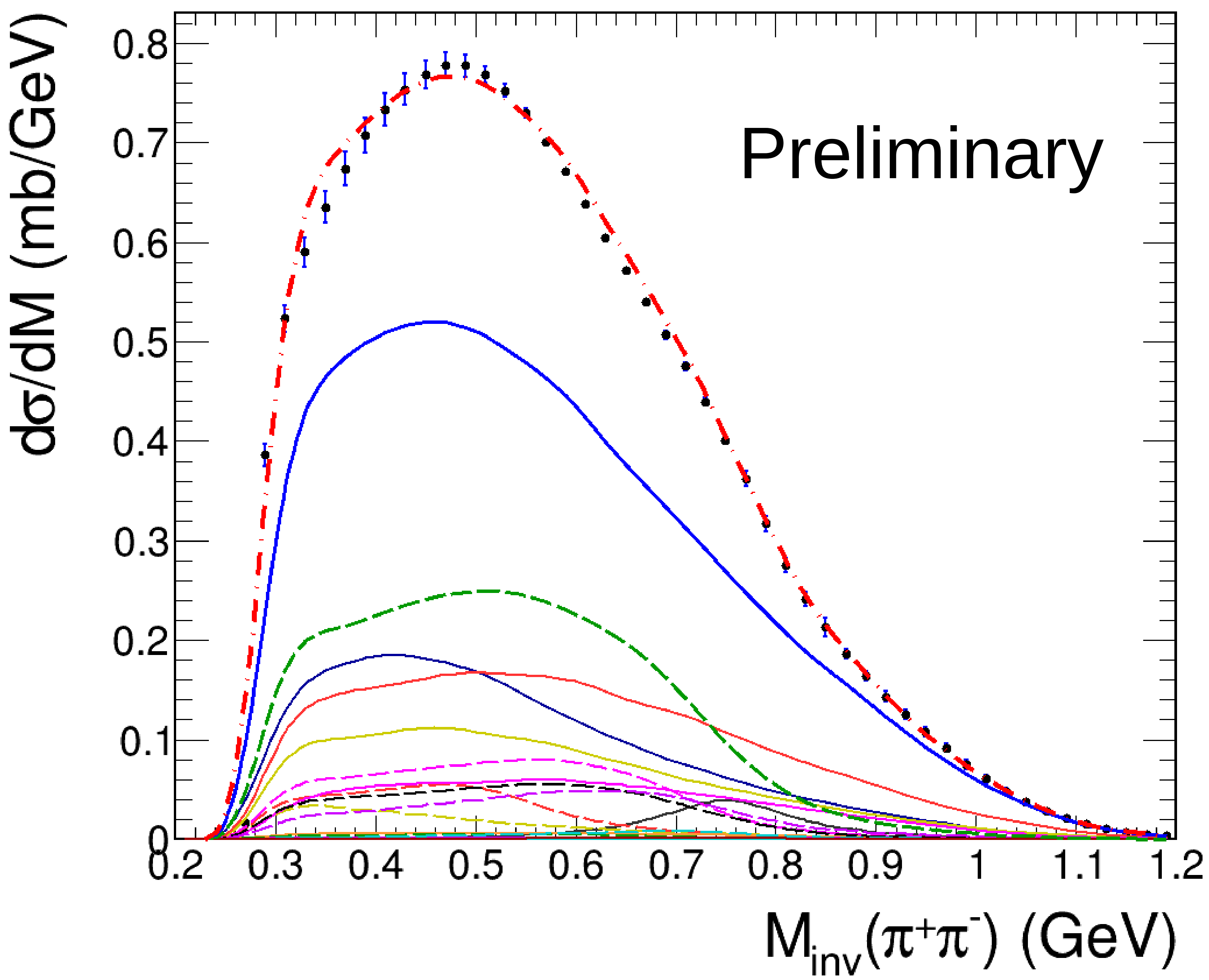


$\theta_{lab}(p) < 30°$

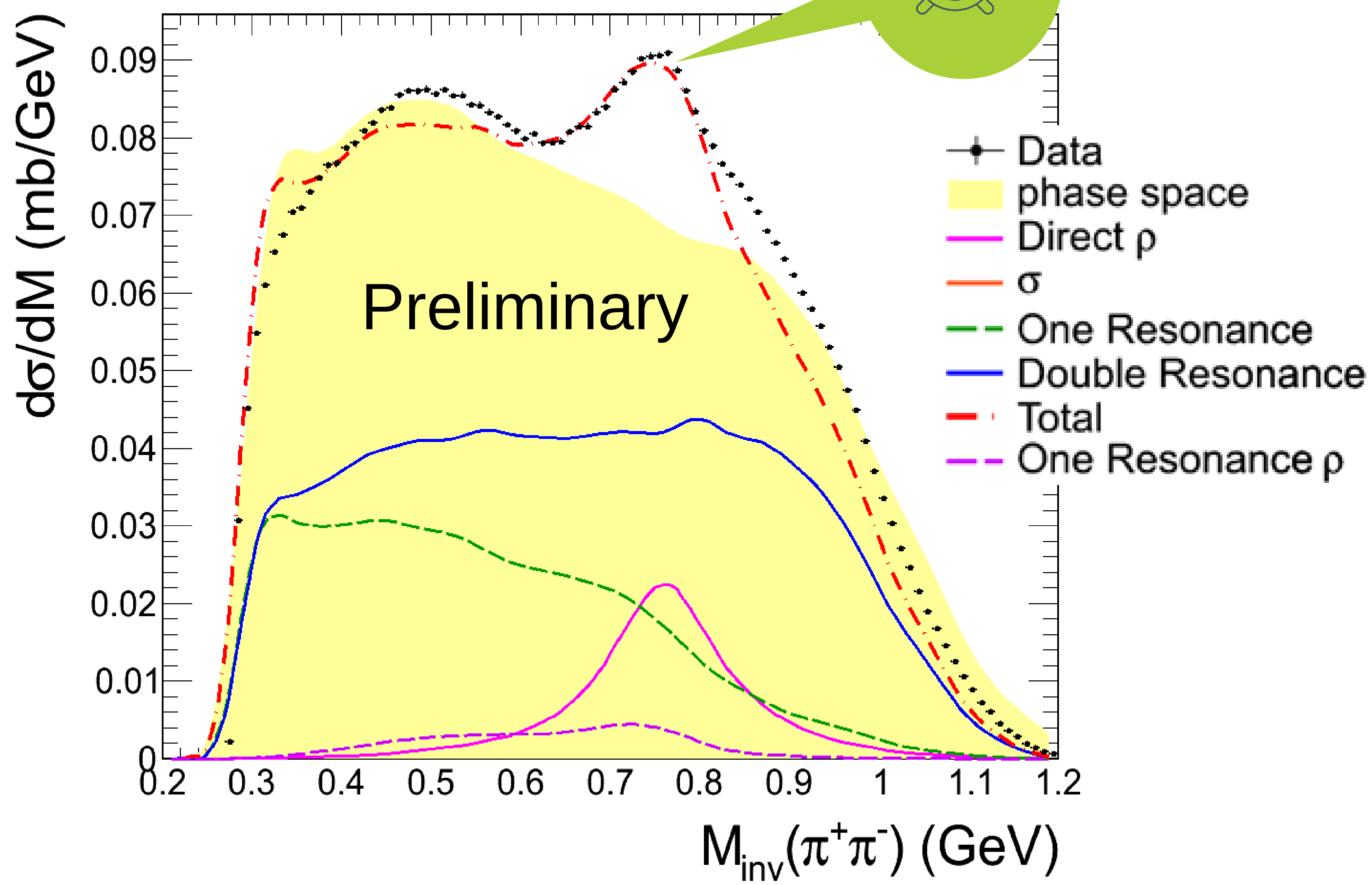
Suppress remaining resonances

Search for the direct “ρ”

Before kinematical cuts



After kinematical cuts



“ρ” Angular Distribution

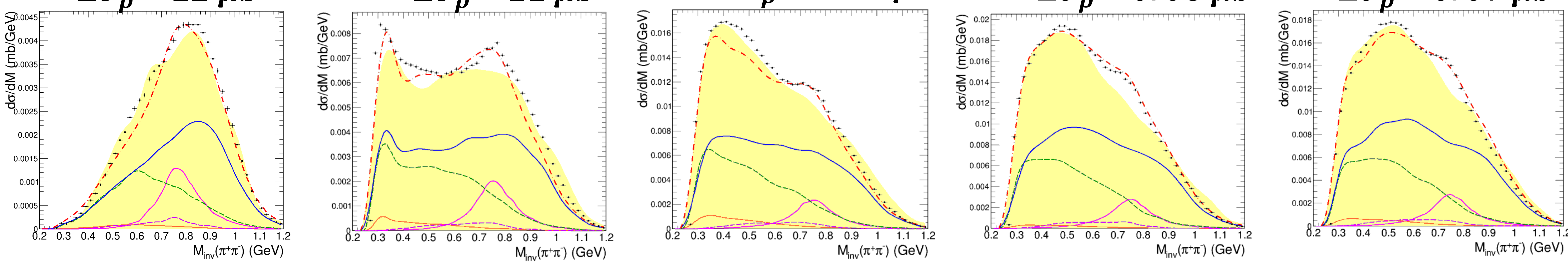
Preliminary

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

Backward

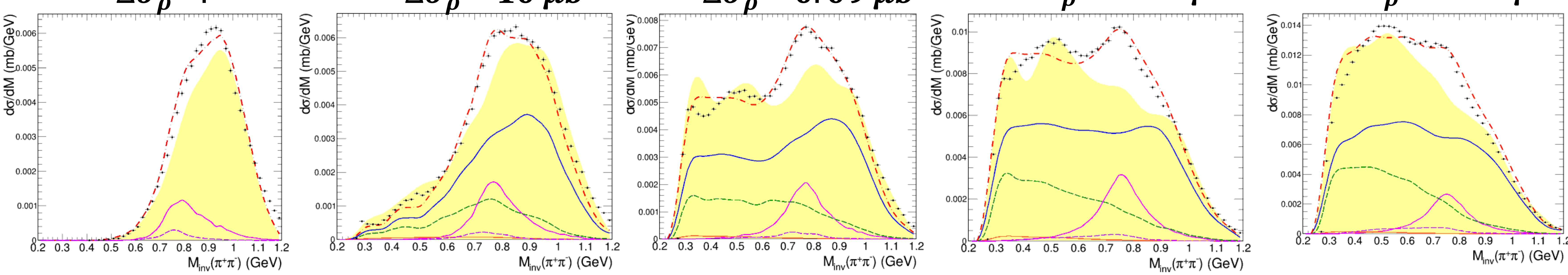
$\Delta\sigma_\rho = 12\ \mu b$ | $\Delta\sigma_\rho = 11\ \mu b$ | $\Delta\sigma_\rho = 0.09\ \mu b$ | $\Delta\sigma_\rho = 0.08\ \mu b$ | $\Delta\sigma_\rho = 0.07\ \mu b$



$-1 < \cos(\theta) < -0.8$ | $-0.8 < \cos(\theta) < -0.6$ | $-0.6 < \cos(\theta) < -0.4$ | $-0.4 < \cos(\theta) < -0.2$ | $-0.2 < \cos(\theta) < 0$

Forward

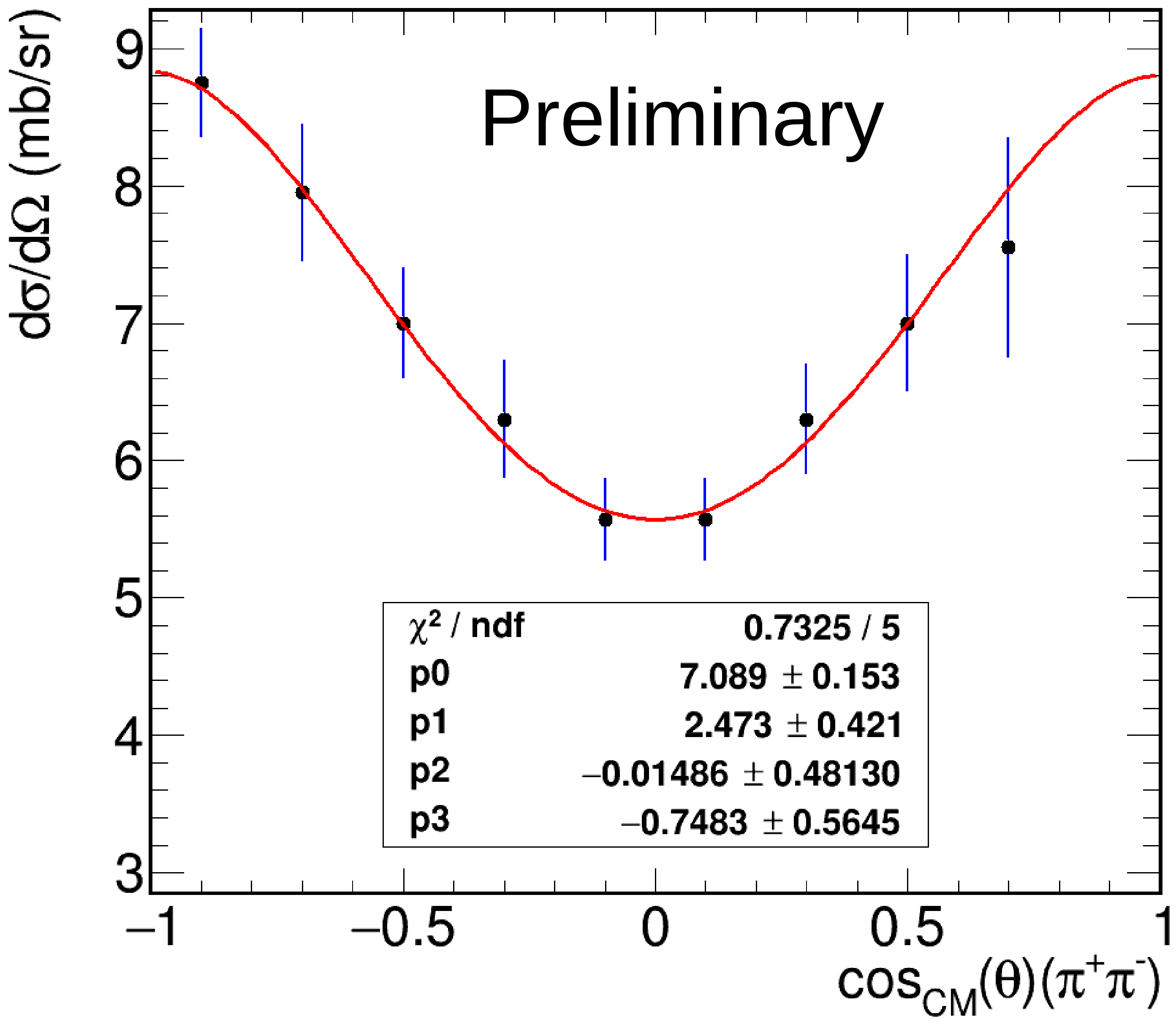
$\Delta\sigma_\rho = ?$ | $\Delta\sigma_\rho = 10\ \mu b$ | $\Delta\sigma_\rho = 0.09\ \mu b$ | $\Delta\sigma_\rho = 0.08\ \mu b$ | $\Delta\sigma_\rho = 0.07\ \mu b$



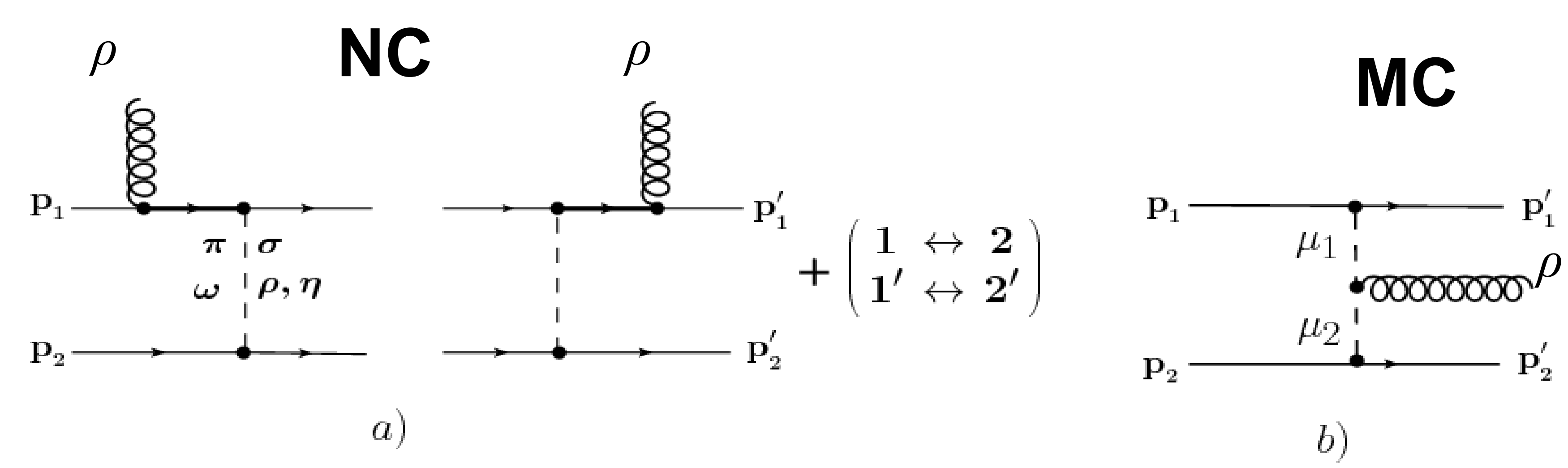
$0.8 < \cos(\theta) < 1$ | $0.6 < \cos(\theta) < 0.8$ | $0.4 < \cos(\theta) < 0.6$ | $0.2 < \cos(\theta) < 0.4$ | $0 < \cos(\theta) < 0.2$

- Good backward/forward symetry

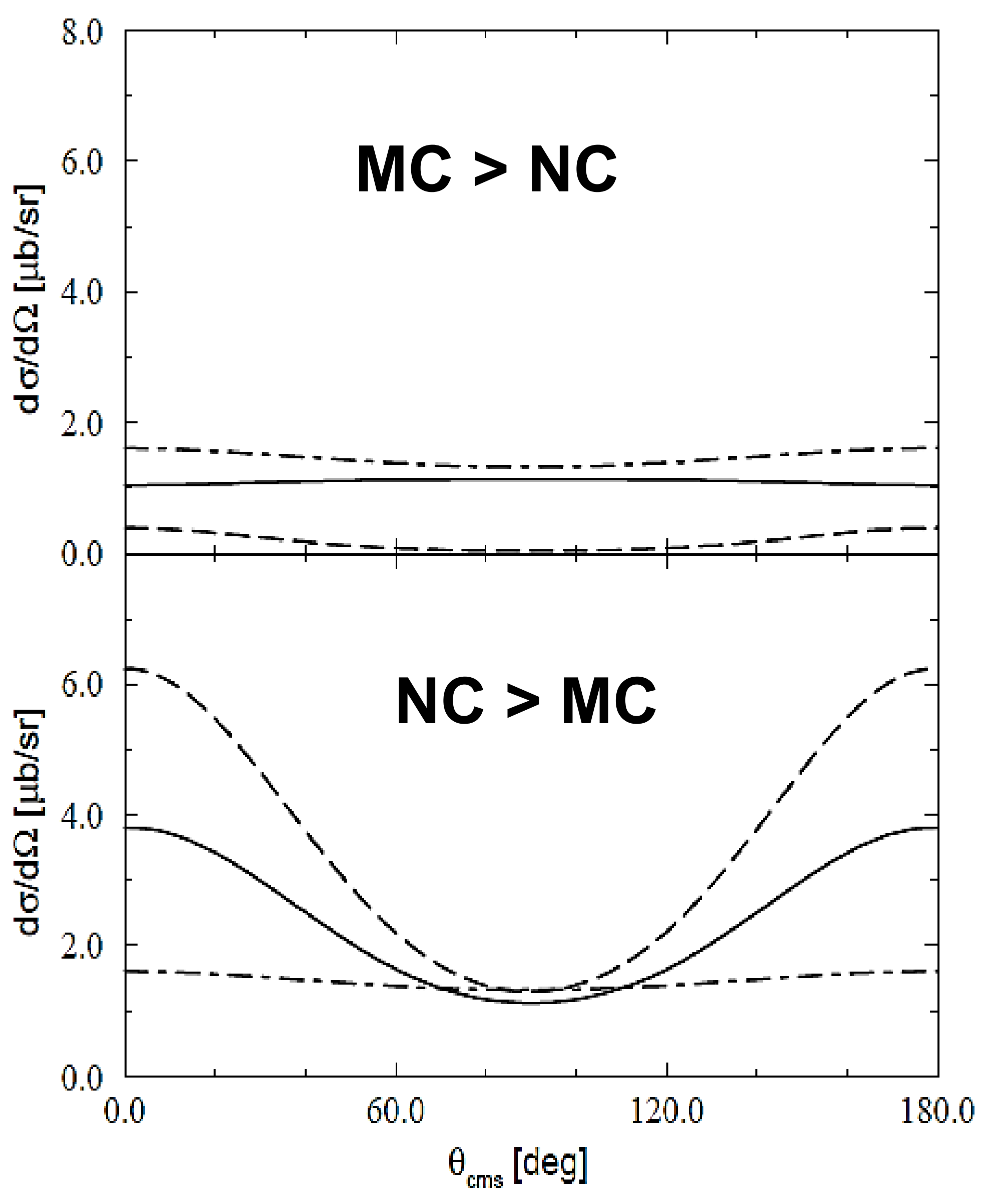
"ρ" Angular Distribution



$\frac{d\sigma}{d\Omega}$ expected to be isotropic for mesonic current (MC) and forward/backward peaked for nucleonic current (NC)



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



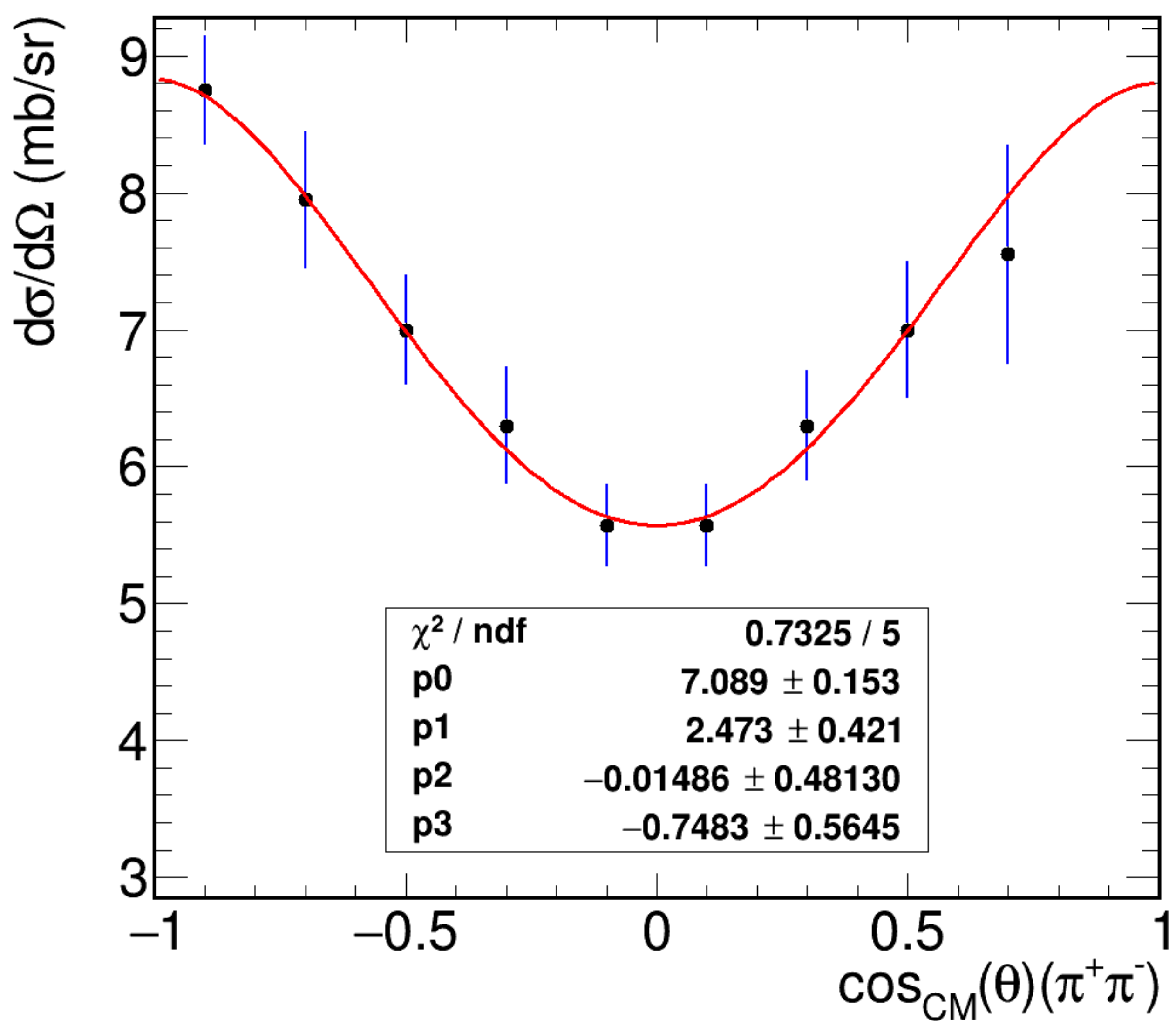
- - - - mesonic current (MC)
- - - - nucleonic current (NC)
—— total

Calculation for pp→ppω

K. Nakayama et al., Phys. Rev. C57 (1998) 1580.

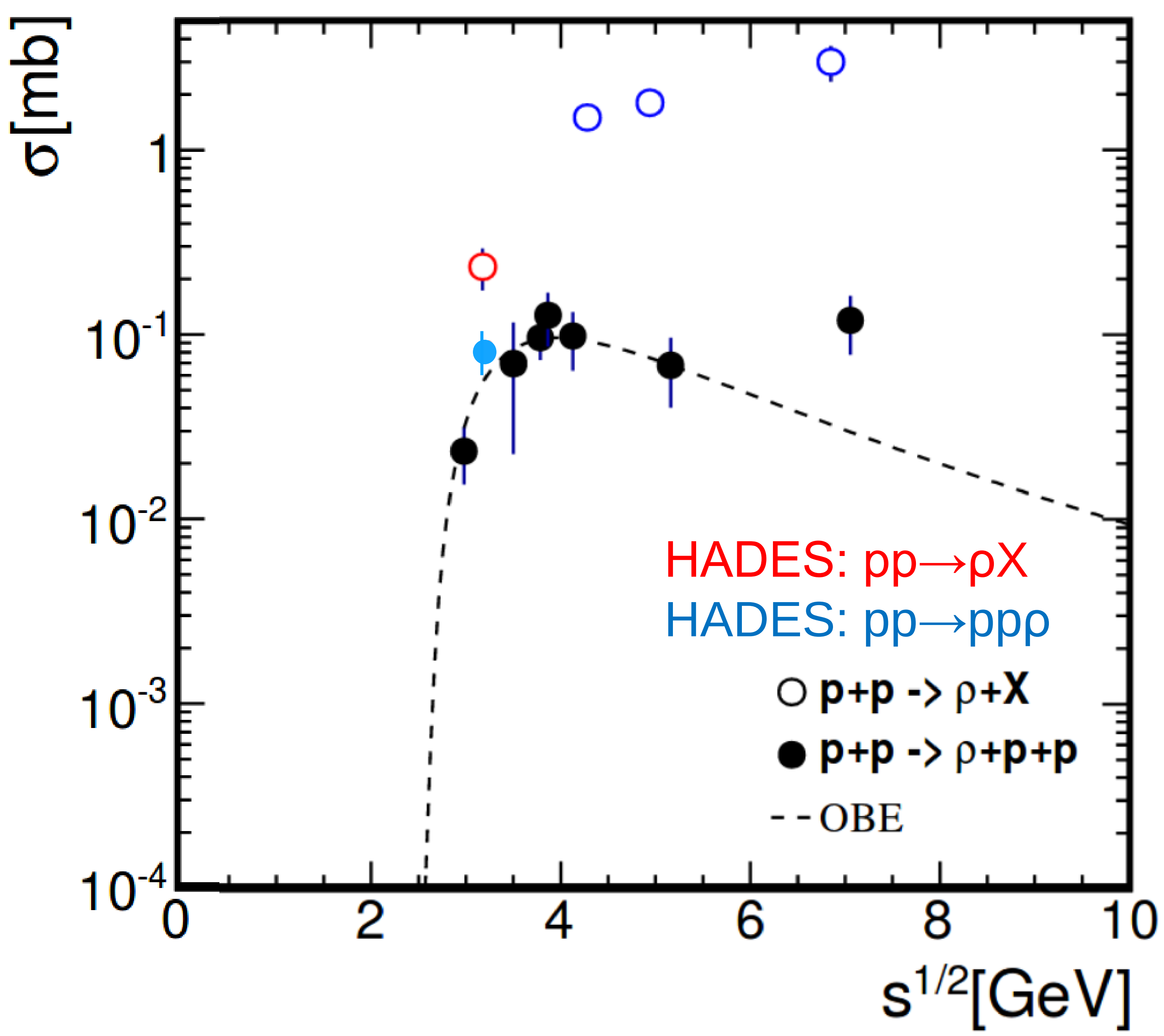
"ρ" Angular Distribution

Preliminary



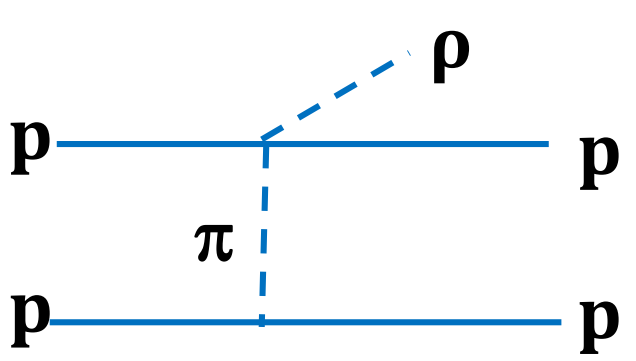
$$\frac{d\sigma_\rho}{d\Omega} = (7.08 \pm 0.15\,)P_0 + (2.47 \pm 0.48\,)P_2 - (0.74 \pm 0.56\,)P_4$$

$$\sigma_\rho = 89 \pm 5\ \mu b$$



- New measurement of pp→ppρ by HADES.
- Consistent with previous data and much more precise.
- Consistent with OBE model

Based on πp → ρp



G. Agakishiev et al. EPJ A48 (2012) 64

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 , 2 π and KΛ 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.

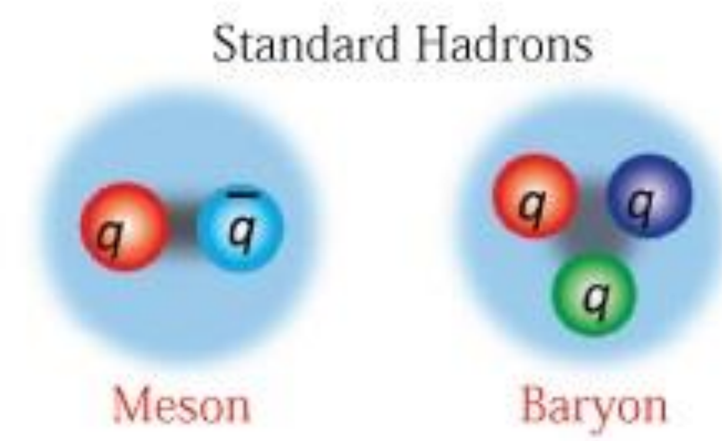
Thanks For Your Attention!

Any questions?

Backup

Pion production Motivation

- Hadron spectroscopy:
  - Mesons: ρ→ππ , ω→πππ …
  - Baryons: Δ /N*→ N π , Δ /N*→ N ππ
- Reaction mechanism.

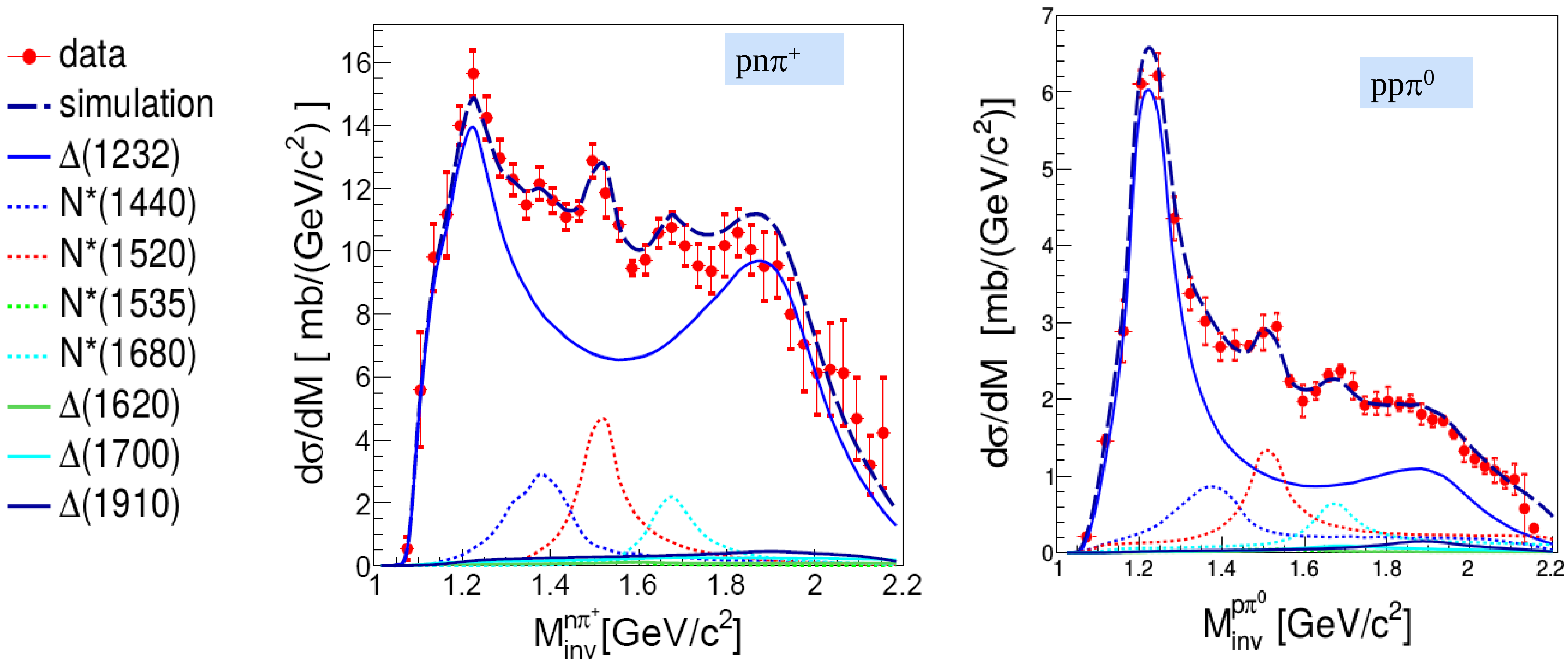


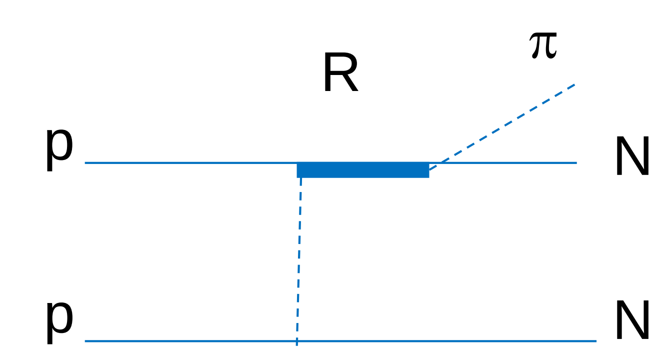
pp → npπ⁺ and pp → ppπ⁰ @ E=3.5 GeV

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

Cocktail of baryonic resonances obtained from the 1 π production

(Δ /N* → N π)



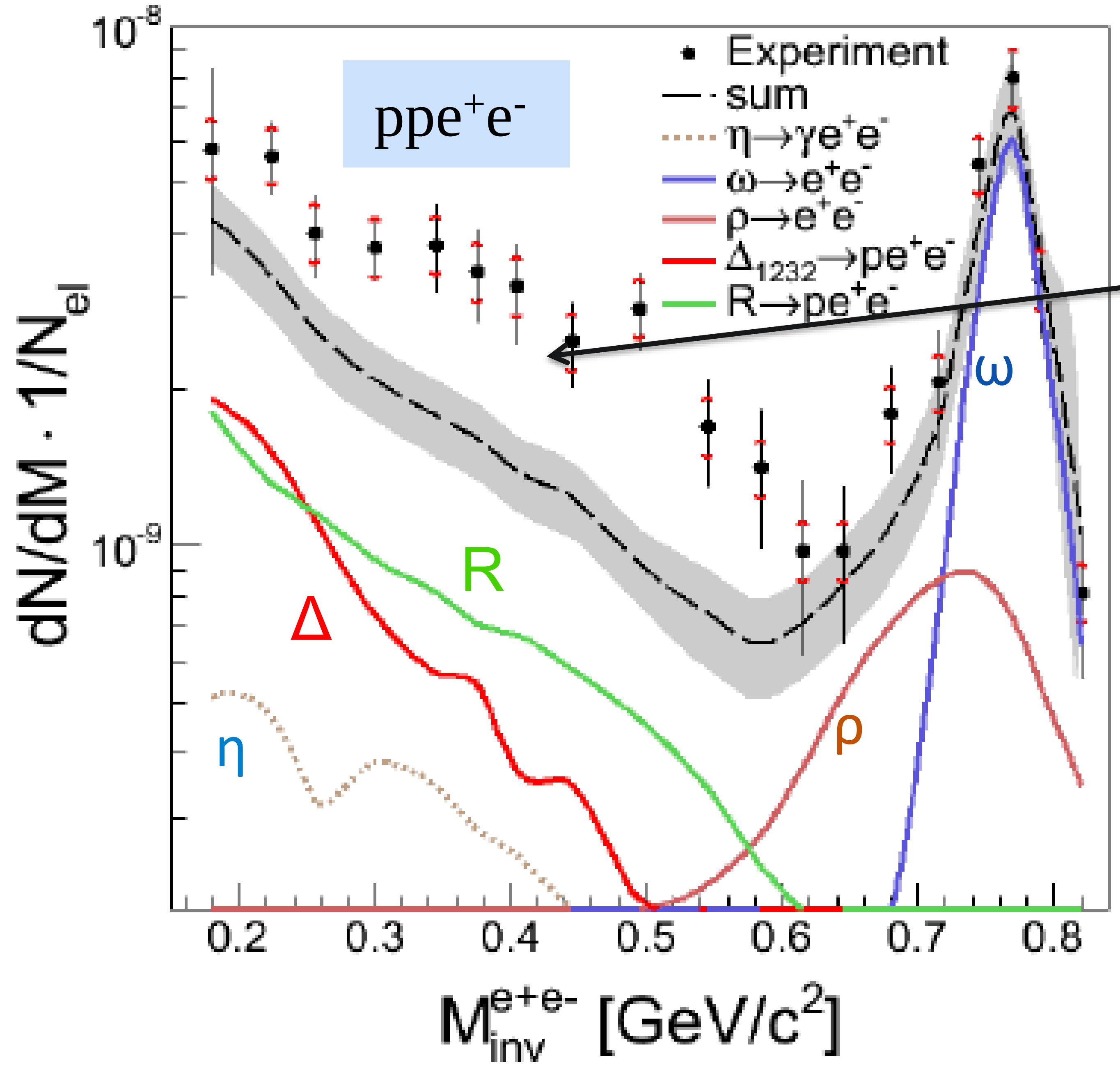


Pion production Motivation

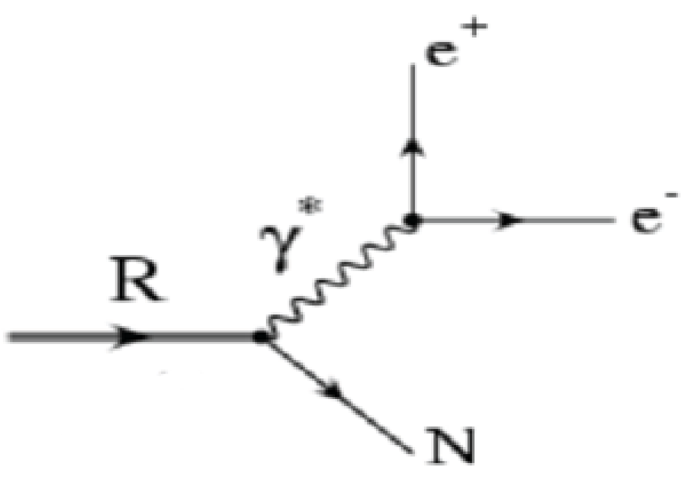
pp → ppe⁺e⁻ @ E=3.5 GeV

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

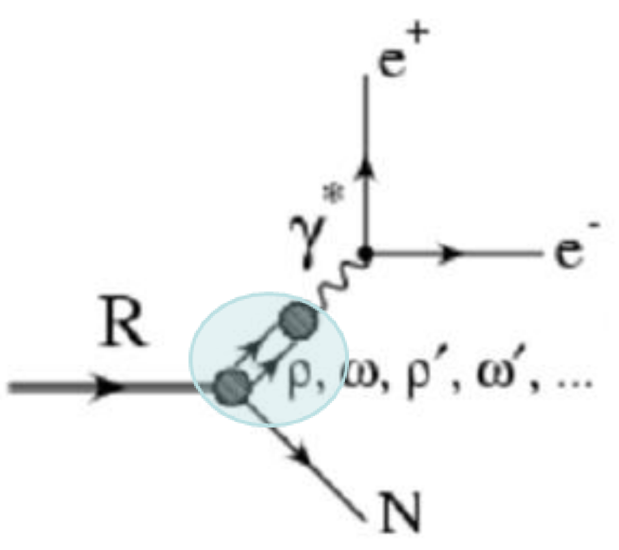
Dalitz decay of the resonance cocktail + ρ,ω and η



Effect of the coupling to ρ



QED: point-like R-γ* vertex



EM time-like form factor

Interest of the channel **pp→ppπ⁺π⁻** :
- ✓ Test the cocktail on the 2 pion production.
- ✓ Measure the ρ (ρ→ π⁺π⁻) production, direct and coupled to resonances .