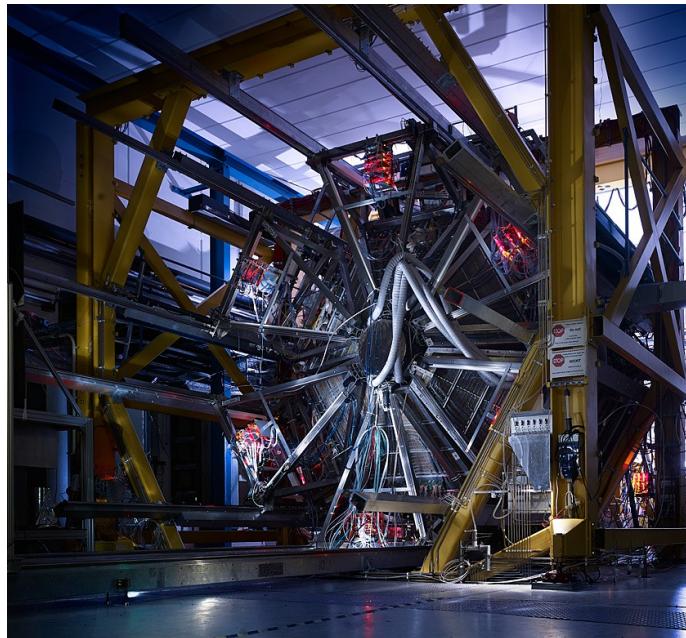
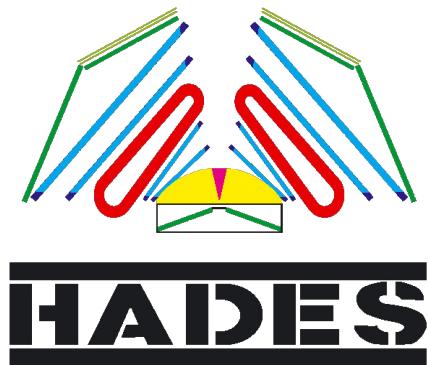
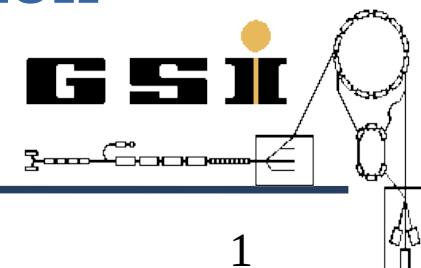




Partial Wave Analysis of HADES Data for Two-Pion Production in Pion-Nucleon Reactions



Izabela Ciepał
for the HADES Collaboration





Outline

- 1) Motivations for experiments with pion beams,
 - 2) HADES detector,
 - 3) Pion beam @ GSI,
 - 4) Identification of $p\pi^-$, $n\pi^+\pi^-$, $p\pi^-\pi^0$ channels,
 - 5) Results of PWA (BGa) - focus on ρ meson production,
 - 6) Summary and outlook.
-

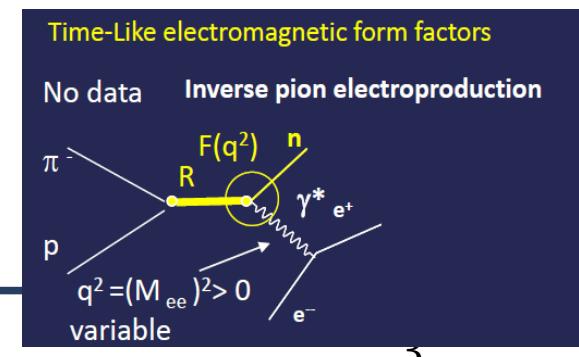
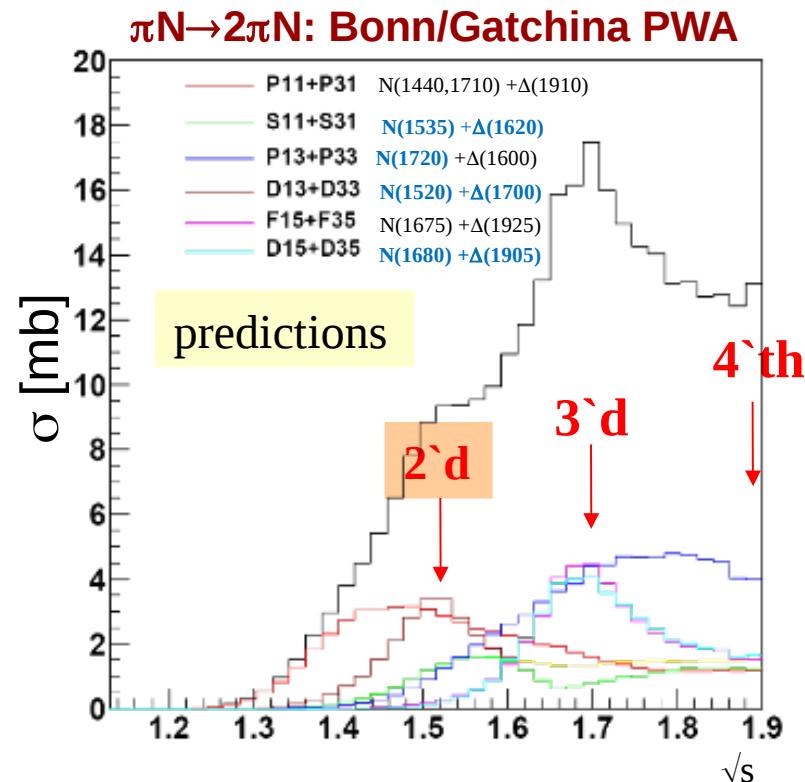


HADES Physics Programme'2014 with Pion Beams

Main advantages of pion beams:

- **selectivity:** resonances can be excited at given mass by choosing the beam (pion) momentum, HADES starts with $\sqrt{s} = (1.46-1.55)$ GeV - second resonance region,
- **$\pi^+ \pi^-$, $\pi^- \pi^0$ production:** off-shell coupling of ρ to resonance, $\rho \rightarrow \pi \pi$ (~100%) „golden channel”,
- **BR** of resonances in the ρ -N decay and two-pion production channels,
- **dilepton channel** $R \rightarrow N e^+e^-$, never measured in pion induced reactions.

Unique possibility to investigate em. resonance decays via **combined** Partial Wave Analysis of hadronic channels and Dalitz decays → **see also B. Ramstein talk**



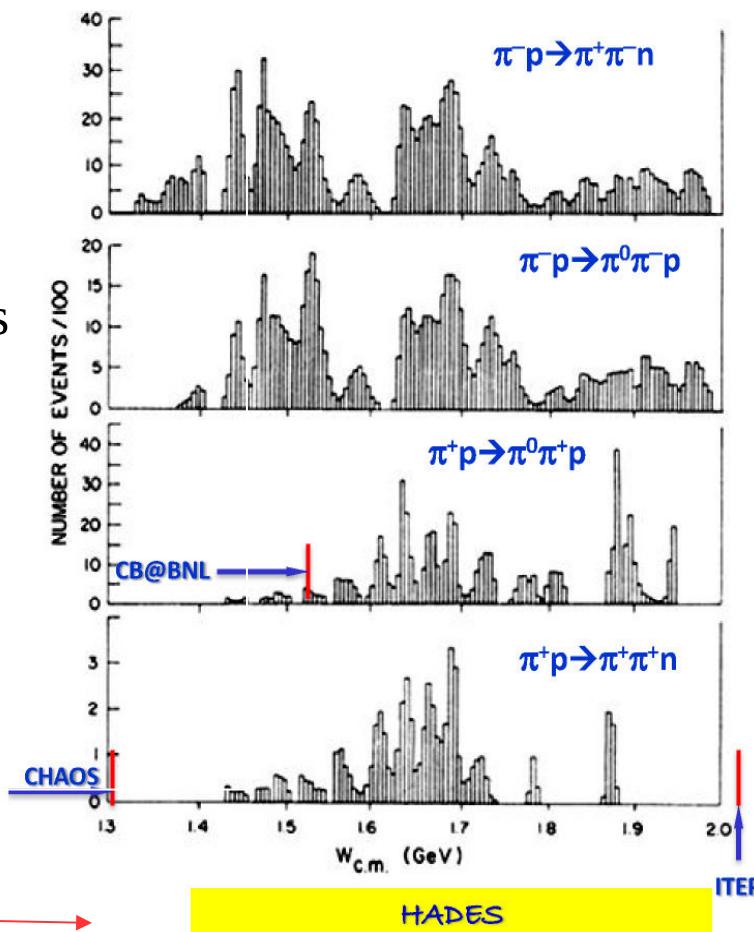


$\pi N \rightarrow \pi\pi N$ status

slide from
I. Strakovsky

most of data $1.3 < s < 2$ GeV from

- Manley *et. al* PRD30 (1984) 904,
241214 bubble chamber events analysed
in isobar PWA model
- very scarce data base for pion-nucleon reactions
- differential distributions are even more scarce
(or missing)
- more recent data (**CHAOS@ TRIUMF**)
do not help for $\pi^+\pi^-$ in $1.3 < s < 2$ GeV region



• Recent post-Bubble Chamber measurements:
• 349,611 events for $\pi^- p \rightarrow \pi^0 \pi^0 n$ from
CB@BNL at $W = 1213$ to 1527 MeV.
[S. Prakhov *et al* Phys Rev C 69, 045202 (2004)]
• 20,000 events for $\pi^+ p \rightarrow \pi^+ \pi^+ n$ from
TRIUMF CHAOS@TRIUMF at $W = 1257$ to
1302 MeV. [M. Kermani *et al* PRC 58, 3431 (98)]
• 40,000 events for $\pi^- p \rightarrow \pi^- \pi^+ n$ from ITEP at
 $W = 2060$ MeV.
[I. Alekseev *et al* Phys At Nucl 61, 174 (1998)]

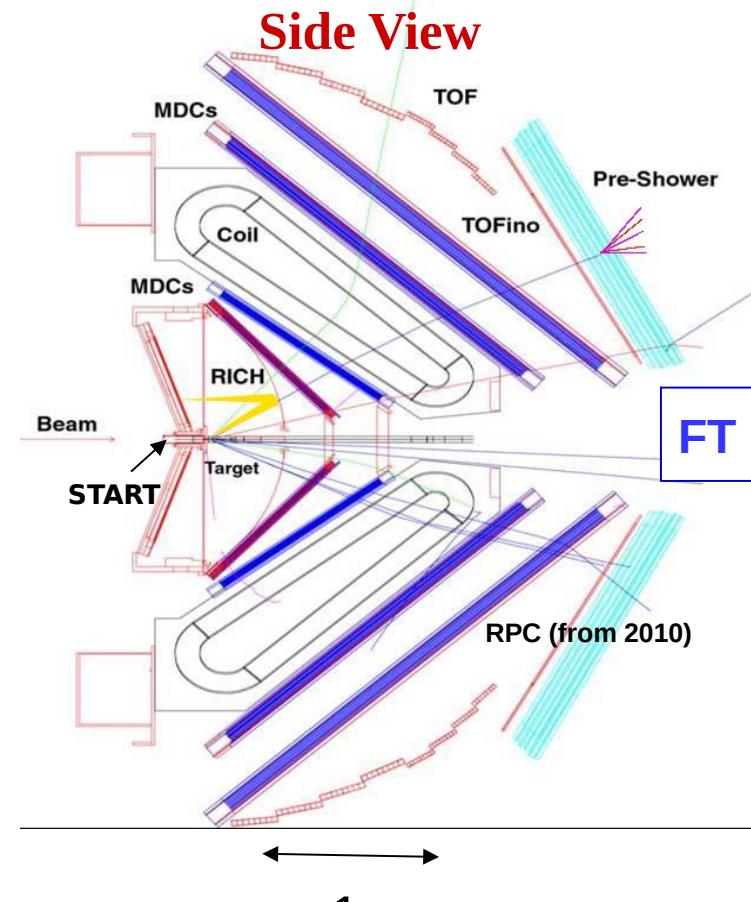
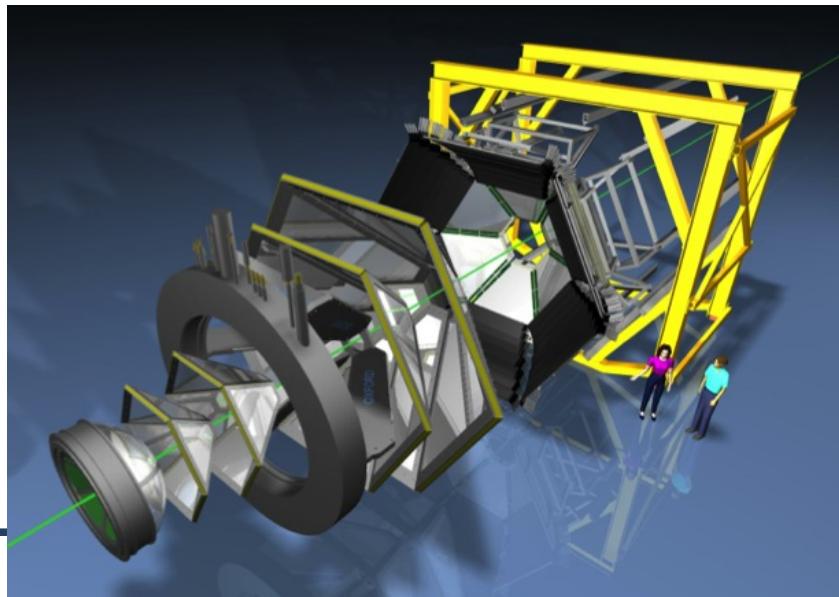
can provide much higher statistics !

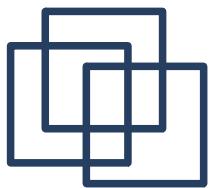


HADES Detector

High Acceptance Di-Electron Spectrometer

- ✓ Beams from SIS18: protons (1-4 GeV), nuclei (1-2 AGeV), pions (0.4-2 GeV/c) – secondary beam
- ✓ Spectrometer with $\Delta M/M - 2\%$ at ρ/ω
- ✓ **PID: TOF/tracking**
- ✓ electrons : RICH (hadron blind), TOF/Pre-Shower
- ✓ **momenta, angles: MDC+ magnetic field**
- ✓ **full azimuthal, polar angles $18^\circ - 85^\circ$**
- ✓ e^+e^- pair acceptance ~ 0.35





Pion Beam @ GSI

Eur. Phys. J. A (2017) 53: 188

The European Physical Journal
volume 53 · number 9 · september · 2017

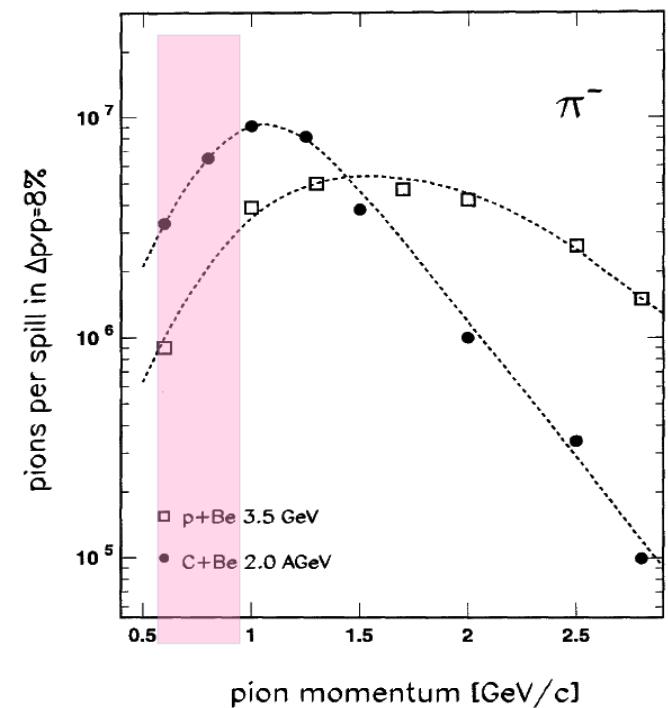
EPJ A
Recognized by European Physical Society

Hadrons and Nuclei

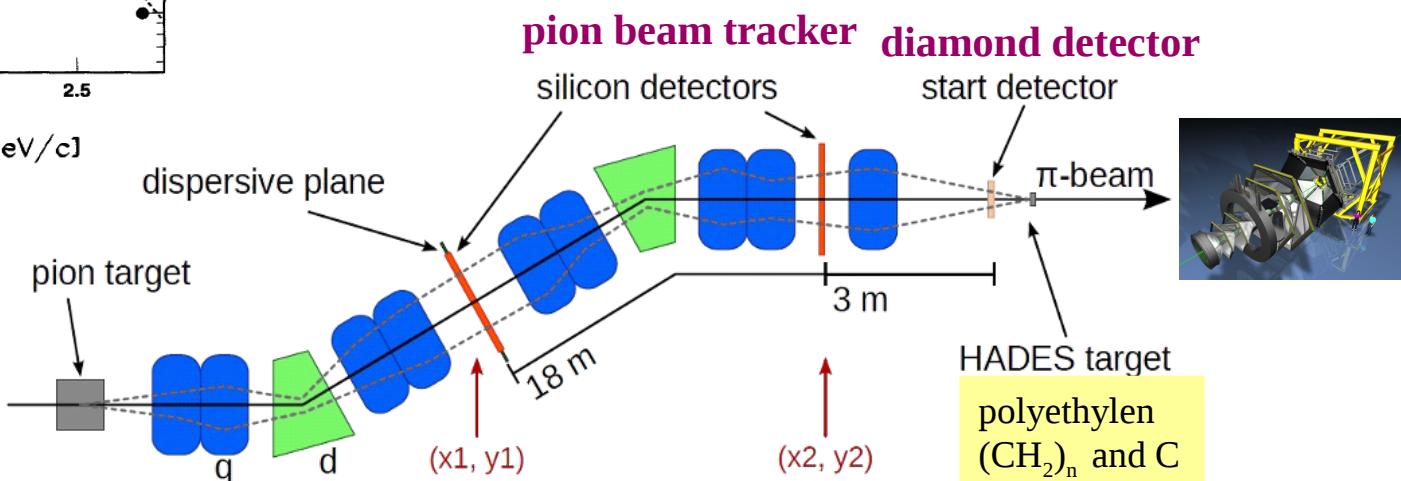
From multiparticle nuclear reaction studies with HADES

by HADES Collaboration

Springer



- reaction **N+Be**, $8-10 \cdot 10^{10} N_2$ ions/spill (4s)
- secondary π^- with $I \sim 2-3 \cdot 10^5/s$
- $p = 654, 686, 748, 787 (+/- 1) \text{ MeV}/c$
- **PE (CH_2)_n** and **C** targets



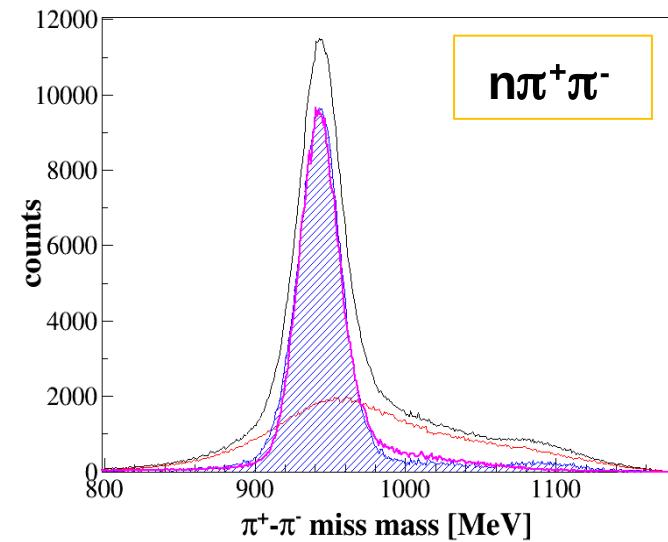
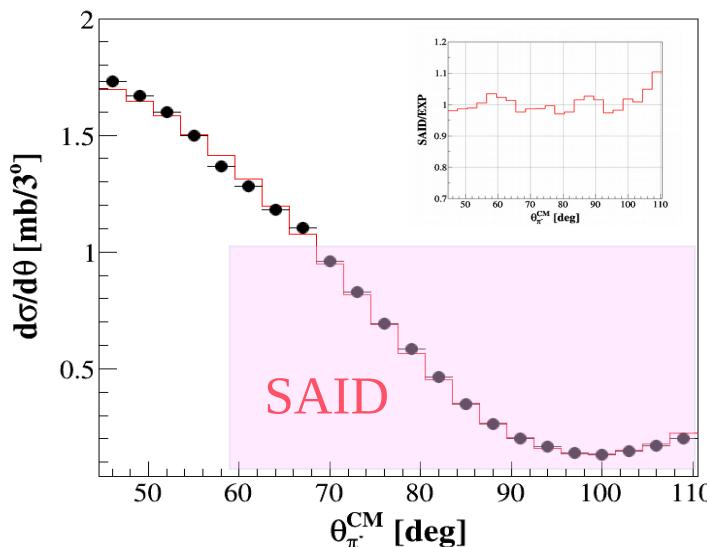
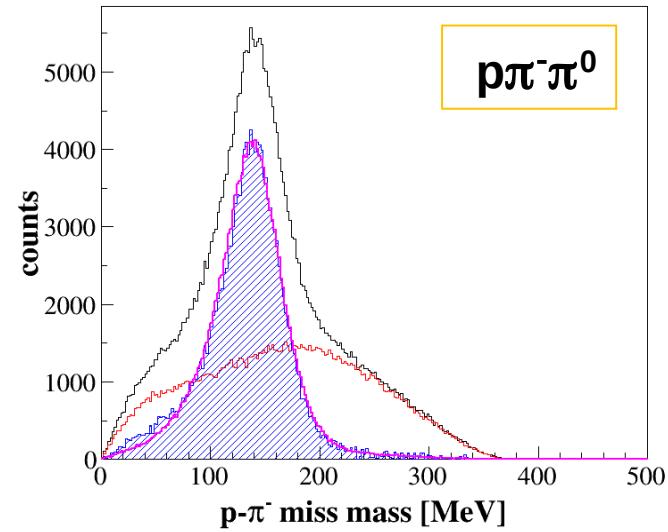
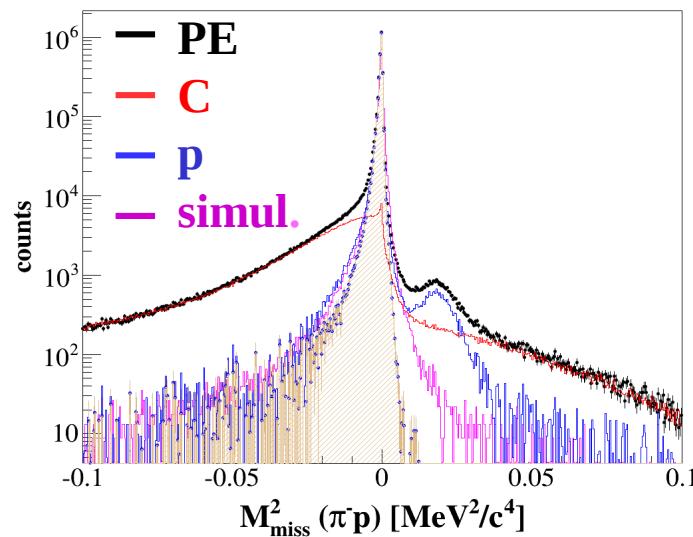
- pion momentum $\Delta p/p = 2.2\% (\sigma)$
- ~50% acceptance of pion beam line



Identification of Channels

two-pion identification: $n\pi^+\pi^-$, $p\pi^-\pi^0$

- elastic π^-p used for normaliz.
- event-by-event carbon subtraction:
 χ^2 test

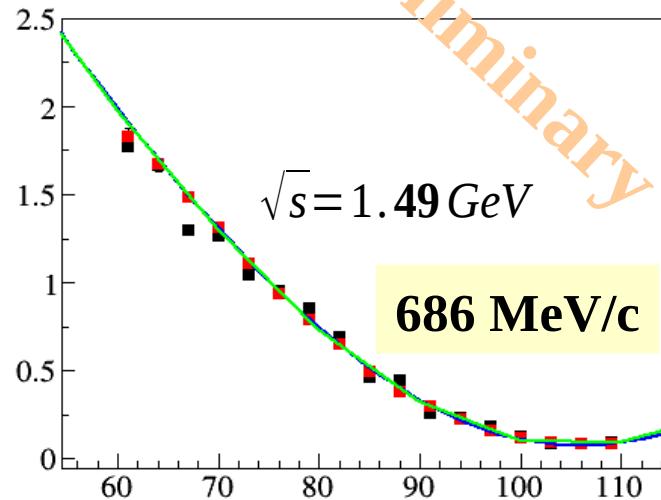
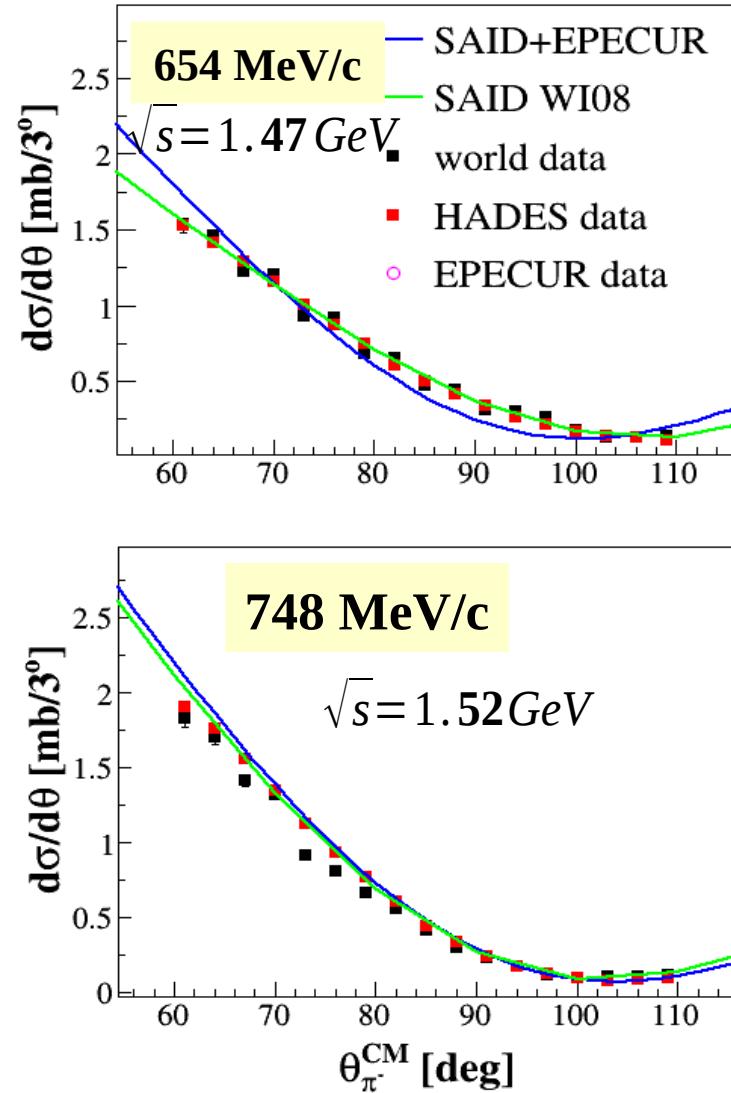




Elastic Scattering

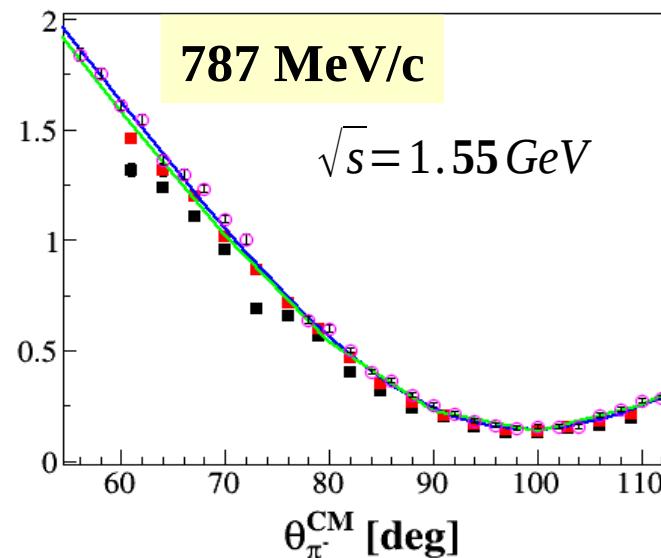
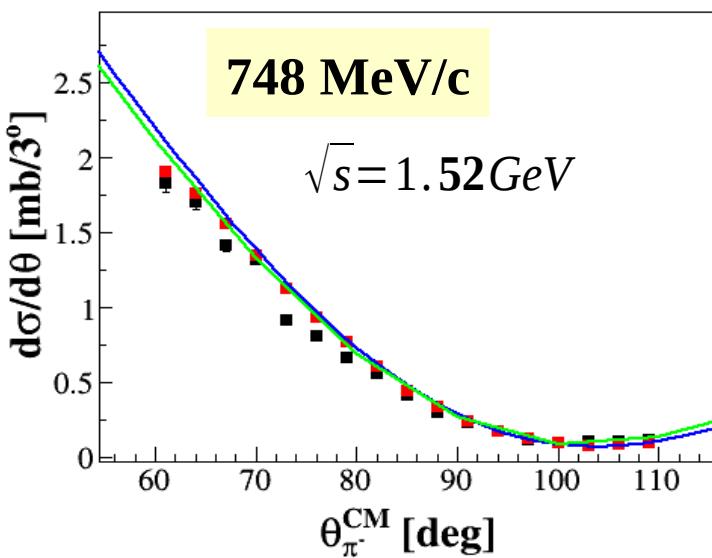
SAID+EPECUR solution
I. Strakovsky
private communication

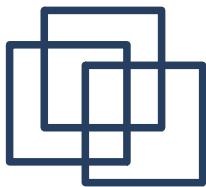
Preliminary



- syst. error of normaliz. ~2%,
- HADES data normalized to SAID in θ^{CM} : 60-110 deg

HADES more consistent with new EPECUR data:
Phys. Rev. C 91, 025205 (2015)





Petersburg
Nuclear Physics
Institute

Bonn-Gatchina Partial Wave Analysis



Address: Nussallee 14-16, D-53115 Bonn Fax: 228 / 73-2505

[Data Base](#)

[Meson Spectroscopy](#)

[Baryon Spectroscopy](#)

[NN-interaction](#)

[Formalism](#)

Data: 2016-2018
130 datasets
solutions: A. Sarantsev

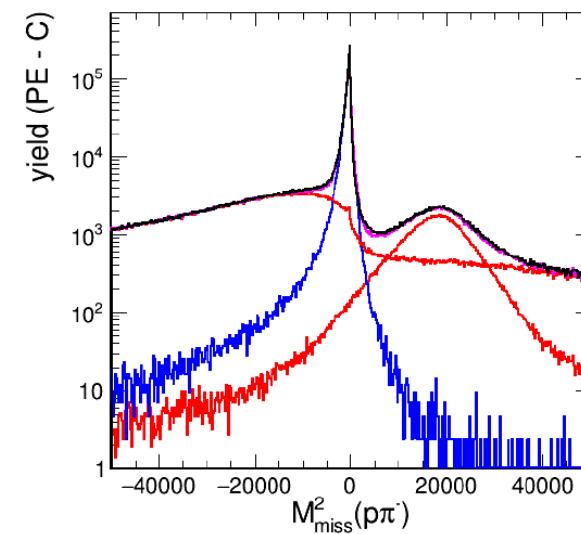
unique data set

2 π data included in fit

Reaction	Observable	W (GeV)	
$\gamma p \rightarrow \pi^0 \pi^0 p$	DCS, Tot	1.2-1.9	MAMI
$\gamma p \rightarrow \pi^0 \pi^0 p$	E	1.2-1.9	MAMI
$\gamma p \rightarrow \pi^0 \pi^0 p$	DCS,Tot	1.4-2.38	CB-ELSA
$\gamma p \rightarrow \pi^0 \pi^0 p$	P, H	1.45-1.65	CB-ELSA
$\gamma p \rightarrow \pi^0 \pi^0 p$	T, P_x, P_y	1.45-2.28	CB-ELSA
$\gamma p \rightarrow \pi^0 \pi^0 p$	P_x, P_x^c, P_x^s (4D)	1.45-1.8	CB-ELSA
$\gamma p \rightarrow \pi^0 \pi^0 p$	P_y, P_y^c, P_y^s (4D)	1.45-1.8	CB-ELSA
$\gamma p \rightarrow \pi^+ \pi^- p$	DCS	1.7-2.3	CLAS
$\gamma p \rightarrow \pi^+ \pi^- p$	I^c, I^s	1.74-2.08	CLAS
$\pi^- p \rightarrow \pi^0 \pi^0 n$	DCS	1.29-1.55	Crystal Ball
$\pi^- p \rightarrow \pi^+ \pi^- n$	DCS	1.45-1.55	HADES
$\pi^- p \rightarrow \pi^0 \pi^- p$	DCS	1.45-1.55	HADES

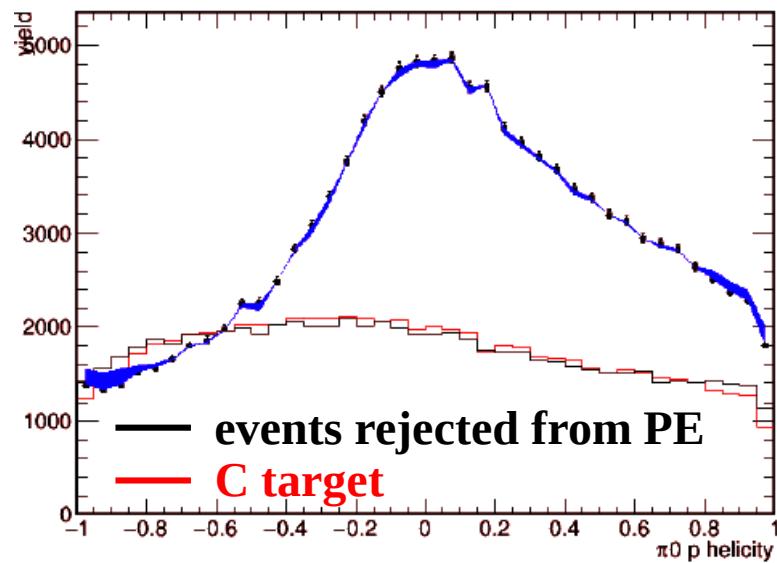
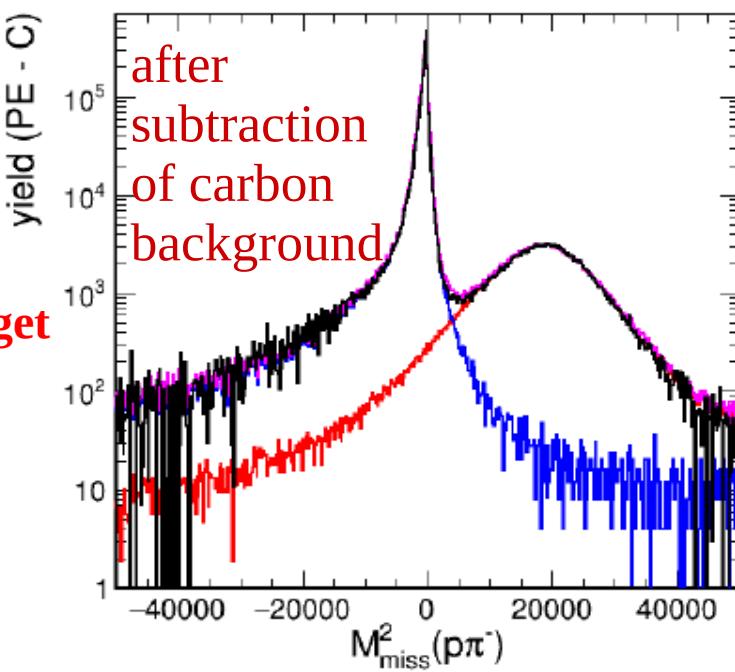


Preparation of Data for PWA



1) carbon level in PE:
multidimensional χ^2
analysis:

BLACK – PE
RED1 – events from C target
BLUE – $p\pi^-$ (simul.)
RED2 – $p\pi^-\pi^0$ (simul.)
MAGENTA (simul. sum)



2) event-by-event carbon subtraction:
matching C and PE by means of χ^2 :
→ momenta of 3 particles
→ angles of 3 particles: θ^{CM} , GJ, helicity



Systematic Errors

Errors related to:

- 1) normalization $\sim 2\%$,
- 2)* normalization factor with/without Pion Tracker $\sim 3\text{-}7\%$
- 3) precision of carbon level adjustment $\sim 1\%$
- 4) event-by-event carbon subtraction $\sim 2\%$
- 5) acceptance corrections derived from PWA $1.5\text{-}3\%$,
- 6) various PWA solutions (with fixed resonances masses,
width and free 2-pion couplings vs all parameters free)
 $\sim 2\%$

total systematics (added in quadrature) $\sim 8\%$

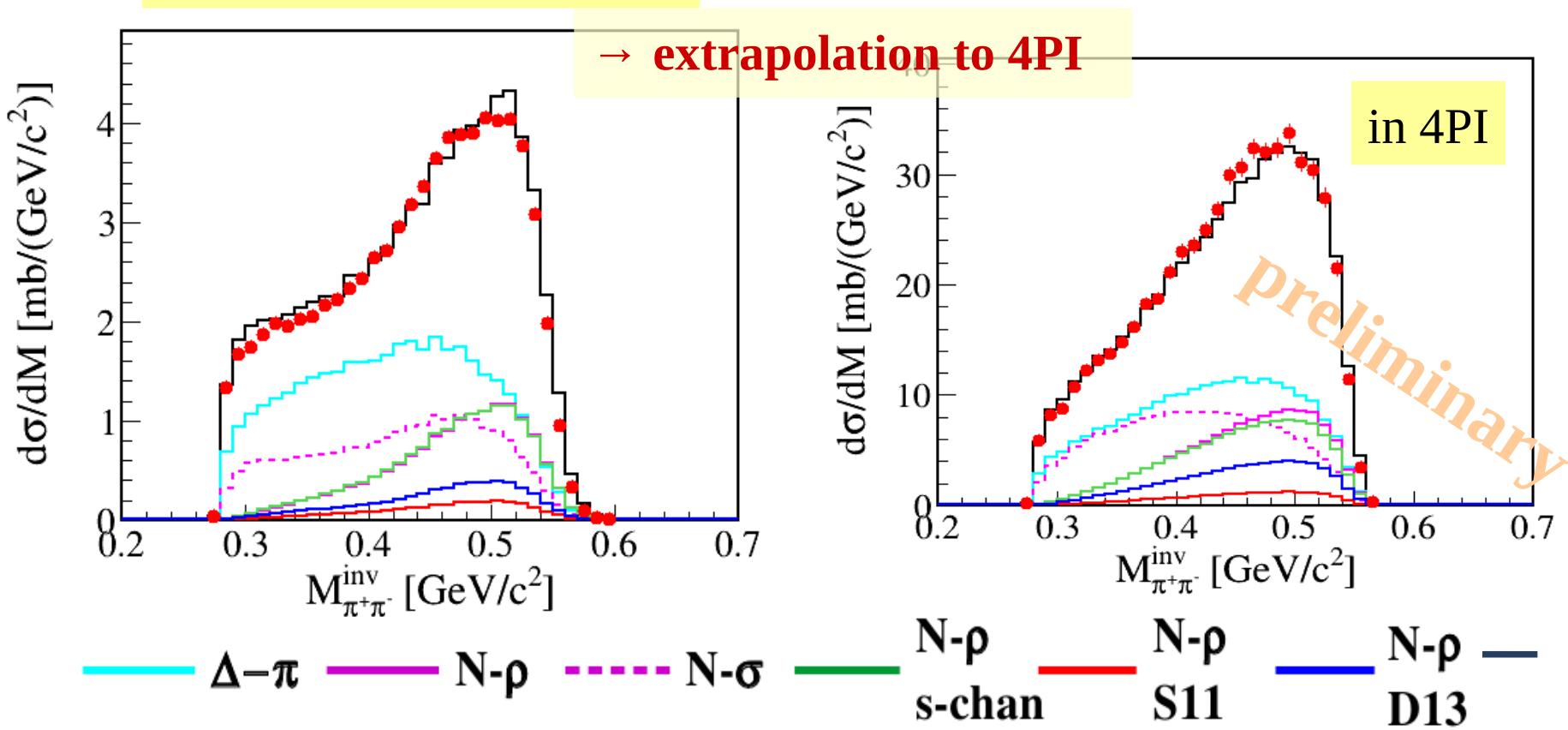
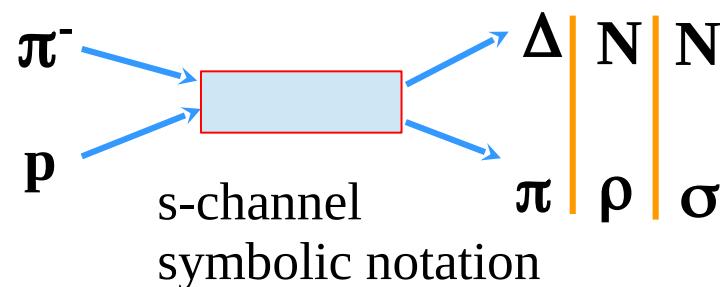


PWA Results @ 654, 686, 748, 787 MeV/c

Separation into Final States - Example for 686 MeV/c

invariant mass $\pi^+\pi^-$

in the acceptance HADES
distributions are distorted:



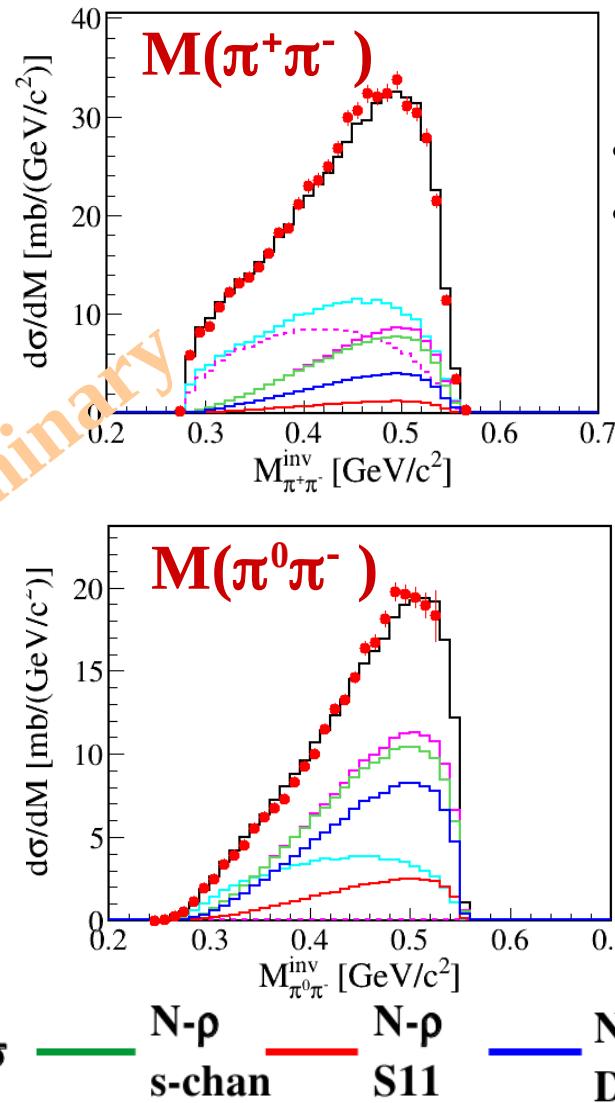
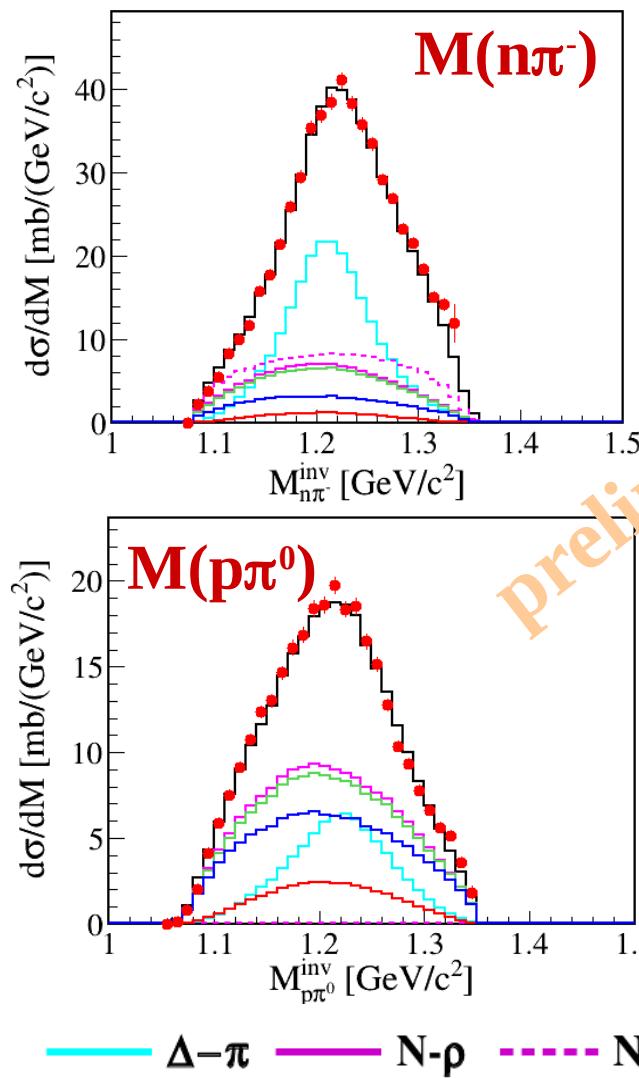


Decomposition into Final States - Example for 686 MeV/c

invariant masses

acceptance
corrected

„subthreshold” – no peak in $\rho \rightarrow \pi^+ \pi^- \pi^0$ mass distributions



n $\pi^+\pi^-$

- $\Delta\text{-}\pi$ dominant,
- significant $N\text{-}\rho$ contribution, dominated by s-channels and N^* (mainly D13)

- $\Delta\text{-}\pi$ rather small,
- $N\text{-}\rho$ dominant (s-channels, D13),
- no $N\text{-}\sigma$ ($I=0$)

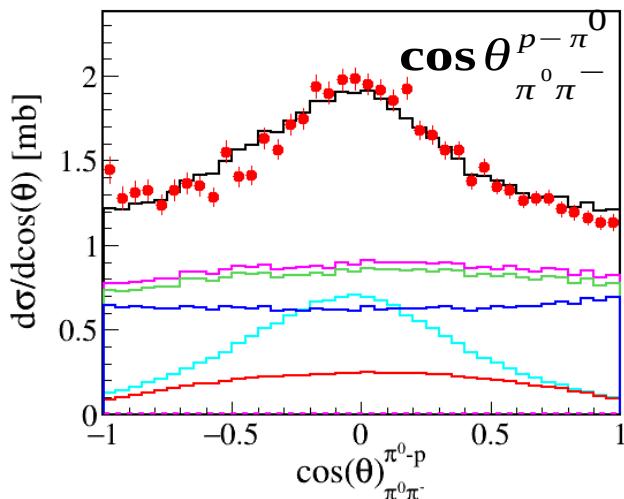
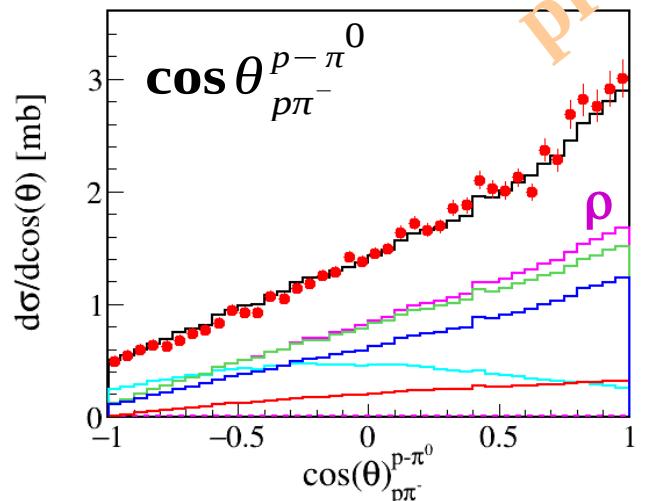
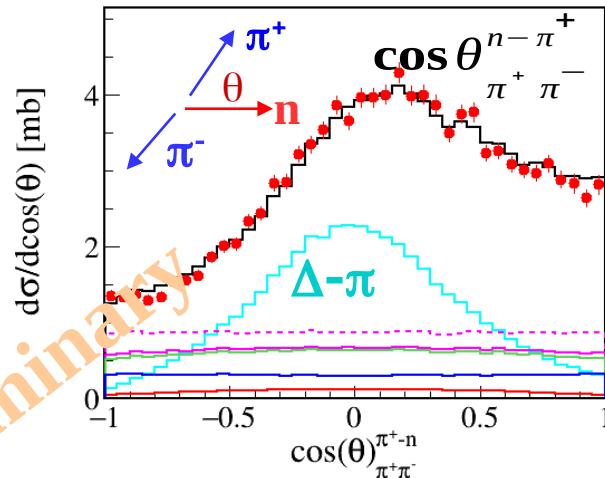
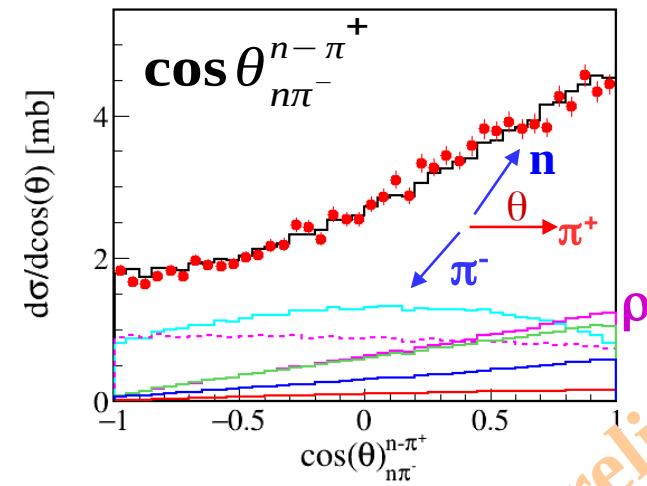
p $\pi^-\pi^0$



Decomposition into Final States - Example for 686 MeV/c

helicity angles

acceptance corrected



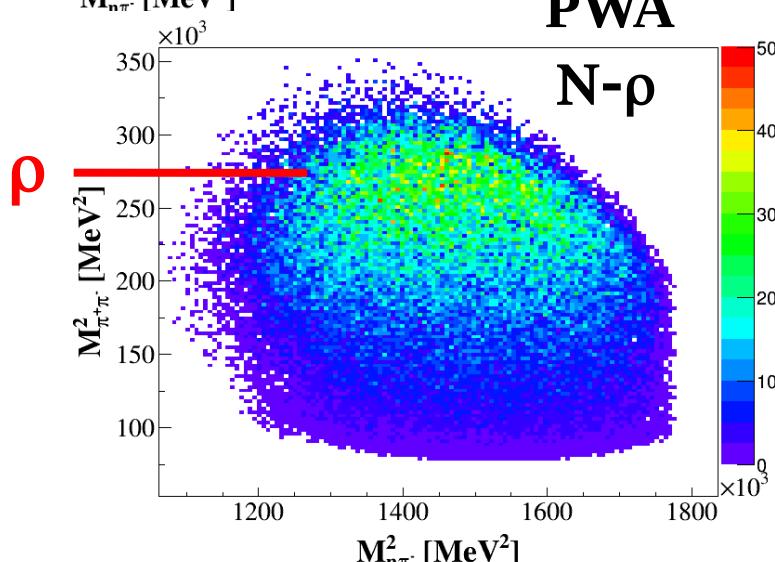
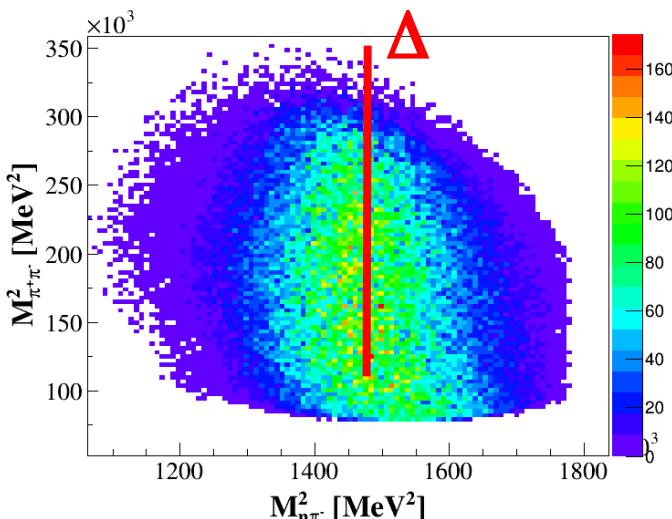
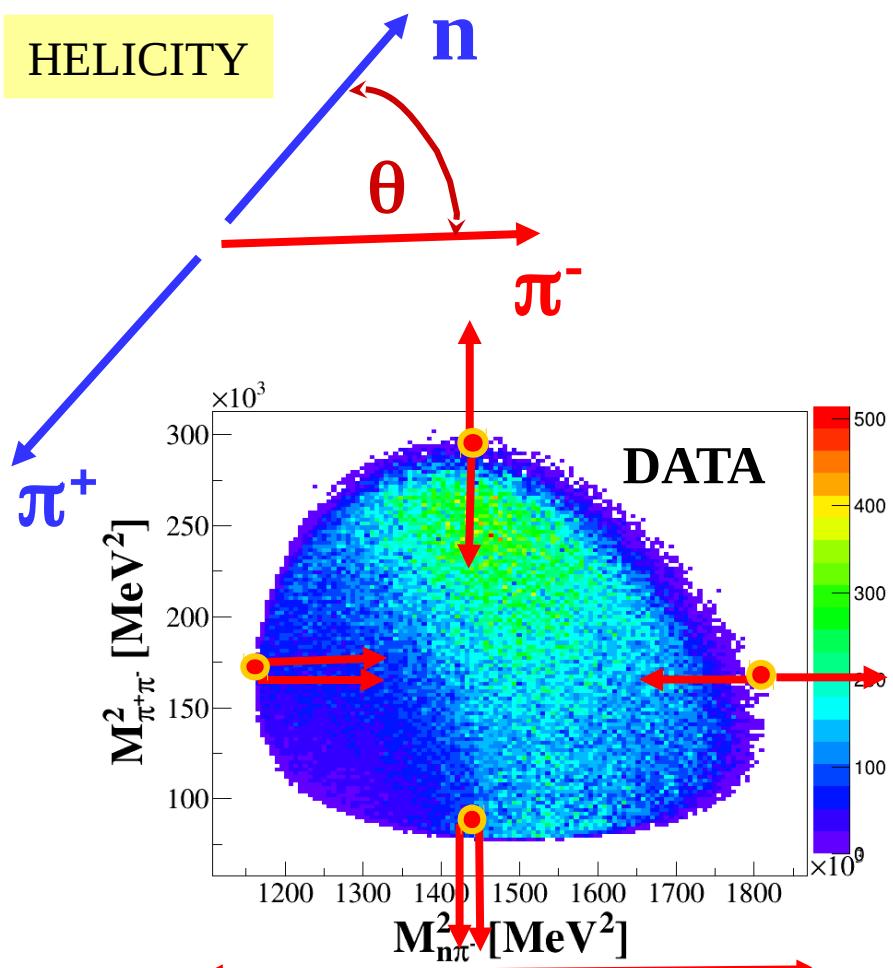
- $N-\rho$ component larger in $p\pi^+\pi^0$ channel,
- $\Delta-\pi$ and $N-\rho$ have different signatures - connected to Dalitz plot (next slide)



Dalitz Plots

in acceptance

HELICITY

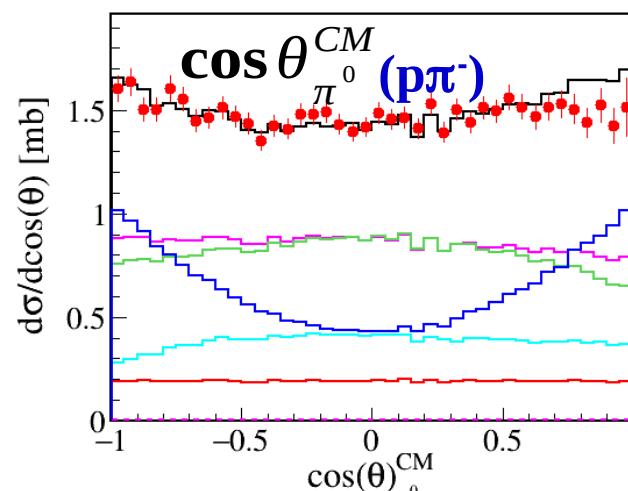
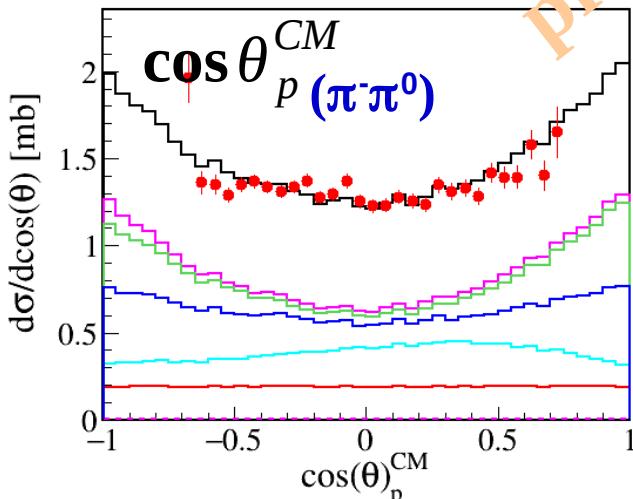
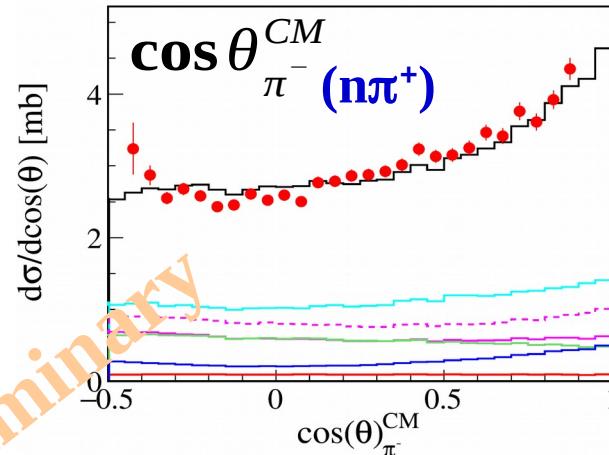
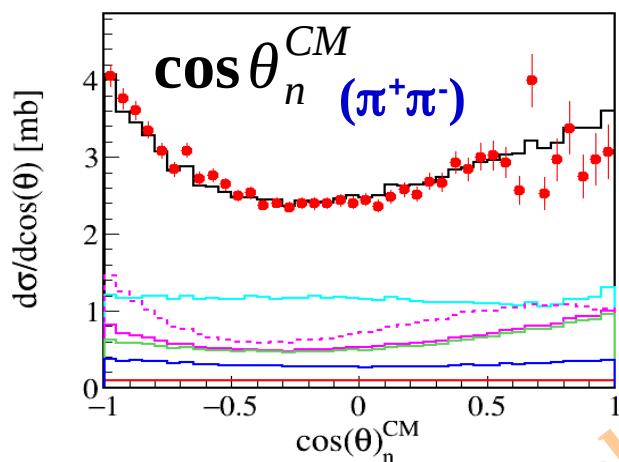




Decomposition into Final States - Example for 686 MeV/c

CM distributions

acceptance corrected



Legend for partial waves:

- $\Delta-\pi$ (cyan solid line)
- $N-\rho$ (magenta solid line)
- $N-\sigma$ (magenta dashed line)
- $N-\rho$ s-chan (green solid line)
- $N-\rho$ S11 (red solid line)
- $N-\rho$ D13 (blue solid line)

$n\pi^+\pi^-$

Anisotropic distributions

- higher partial waves involved in 2π production,
- in $p\pi$ dominance of ρ meson-main components:
S11-flat and **D13 anisotropic**

$p\pi^+\pi^0$

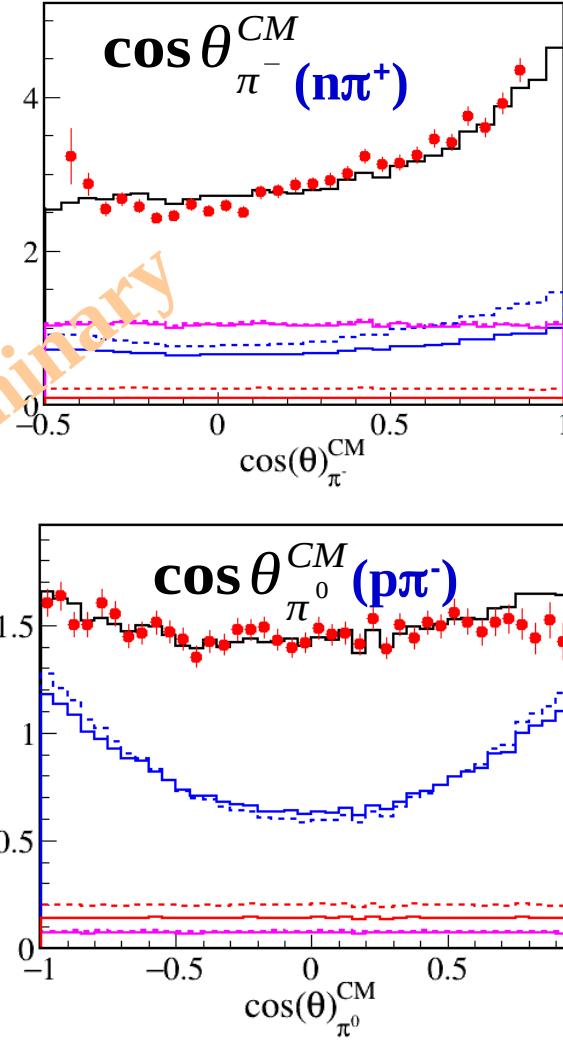
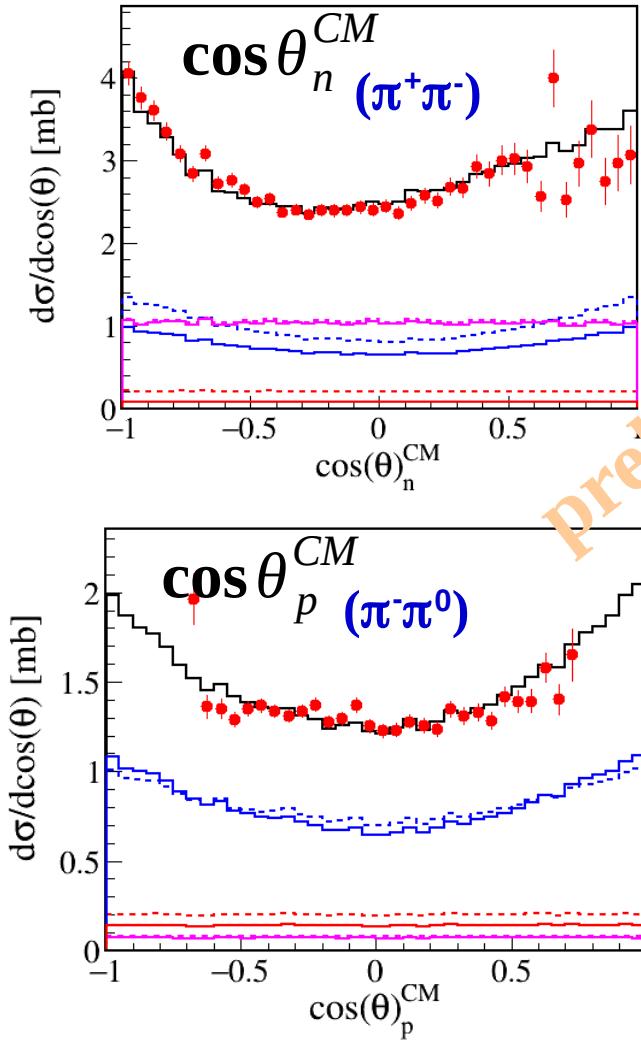
$N-\rho$ —
D13 —



Decomposition into Initial States - Example for 686 MeV/c

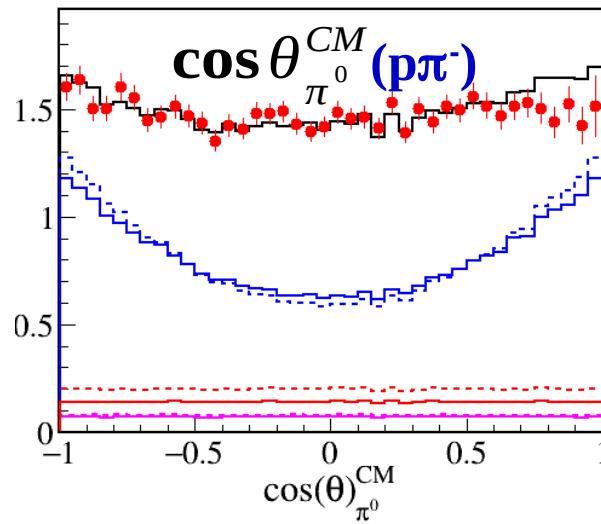
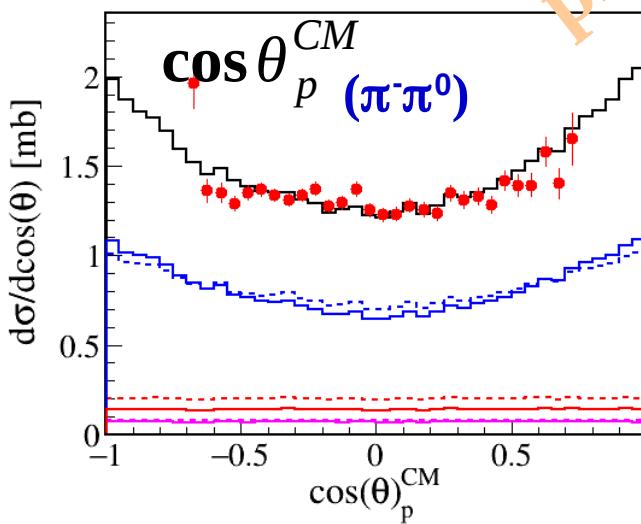
CM distributions

acceptance corrected



$n\pi^+\pi^-$

→ coherent sum
of I=1/2 and I=3/2



$p\pi^-\pi^0$

----- 1/2+ ----- 3/2-

----- 1/2- -----

P11 -----

D13 -----

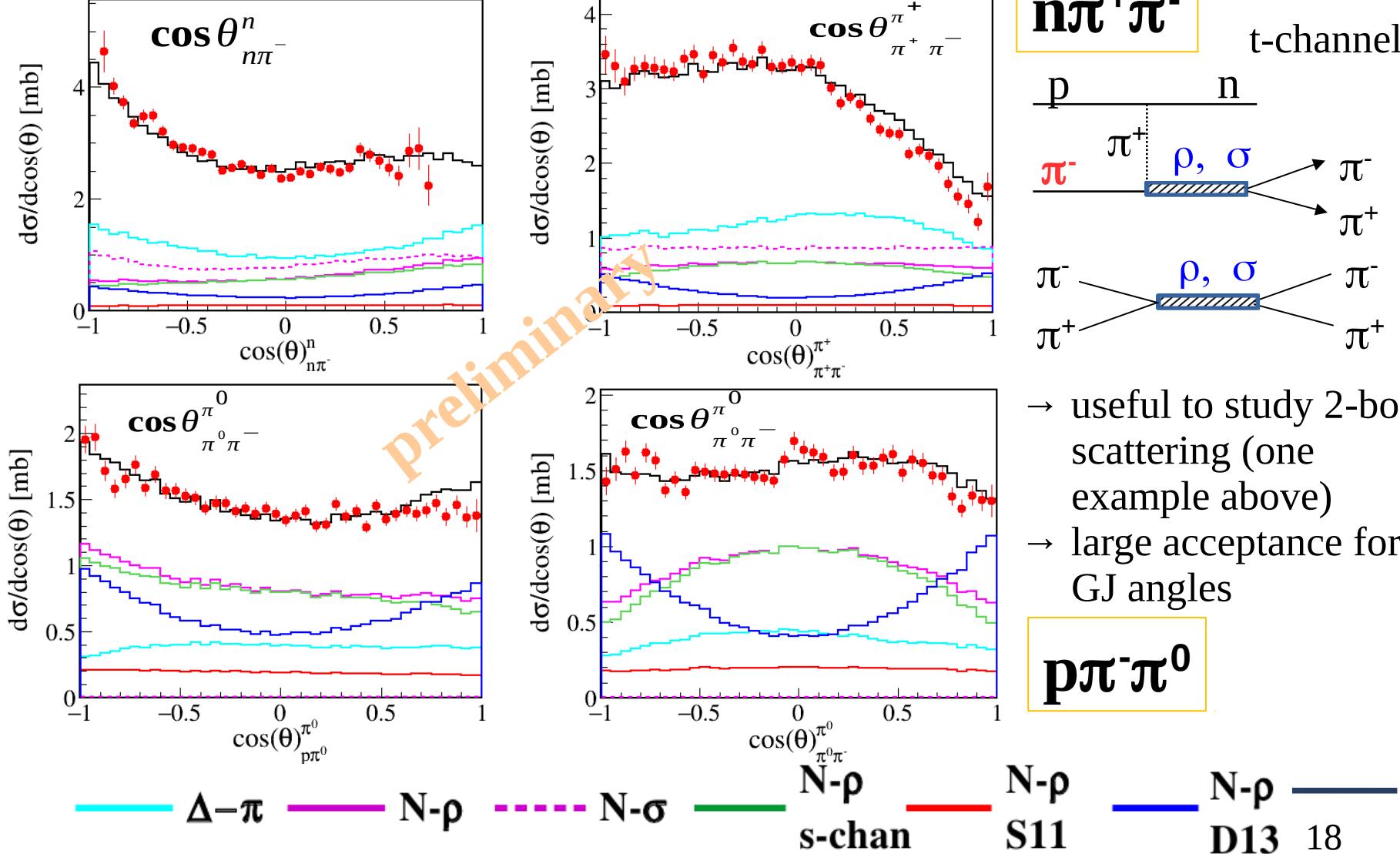
S11 -----



Decomposition into Final States - Example for 686 MeV/c

Gottfried-Jackson

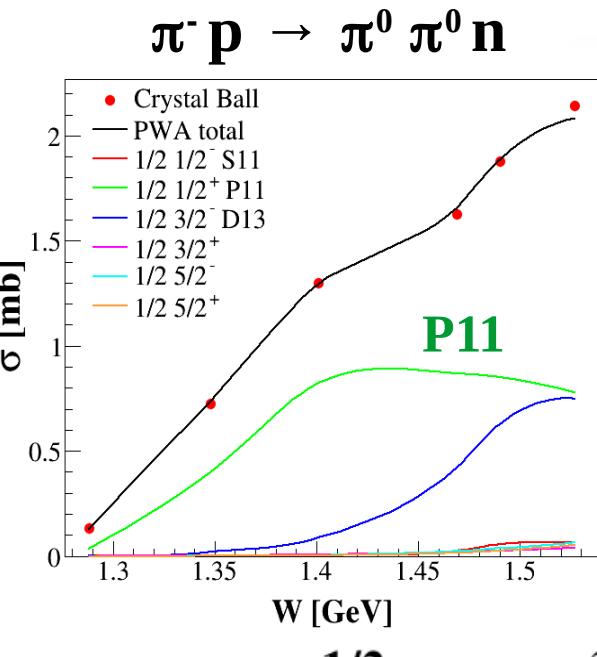
acceptance corrected





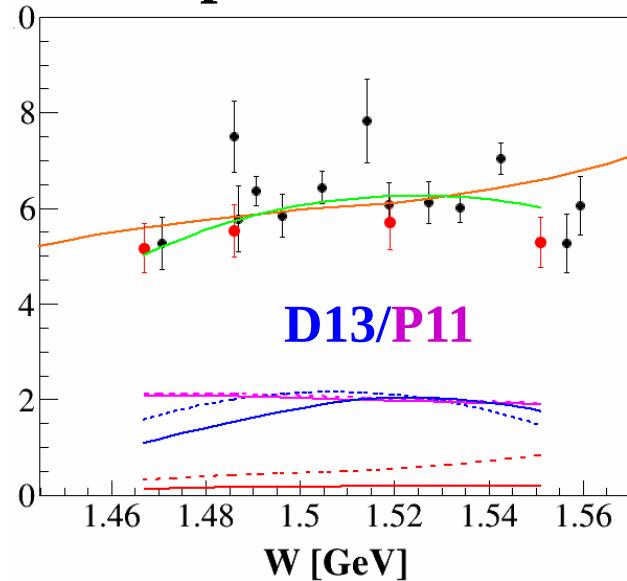
Decomposition into Initial States Total Cross Sections

Crystal Ball



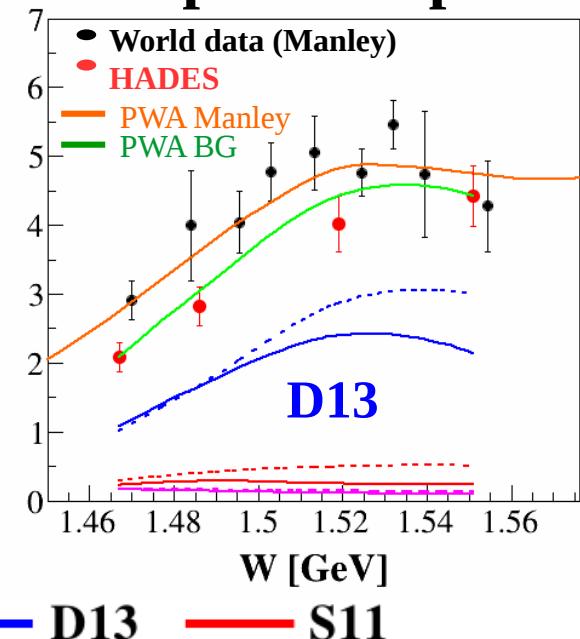
HADES

$\pi^- p \rightarrow \pi^+ \pi^- n$



HADES

$\pi^- p \rightarrow \pi^- \pi^0 p$



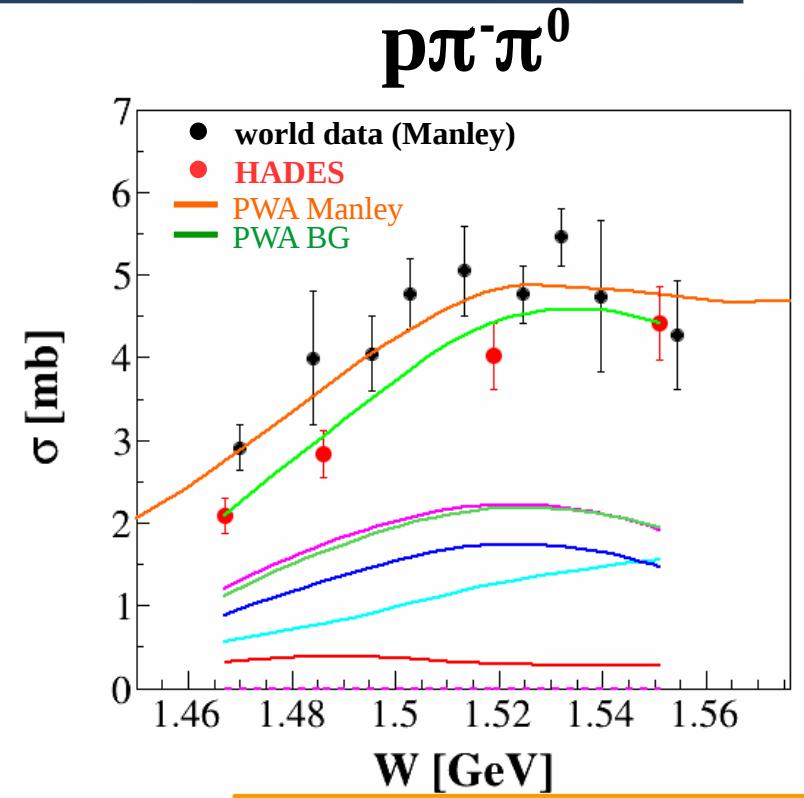
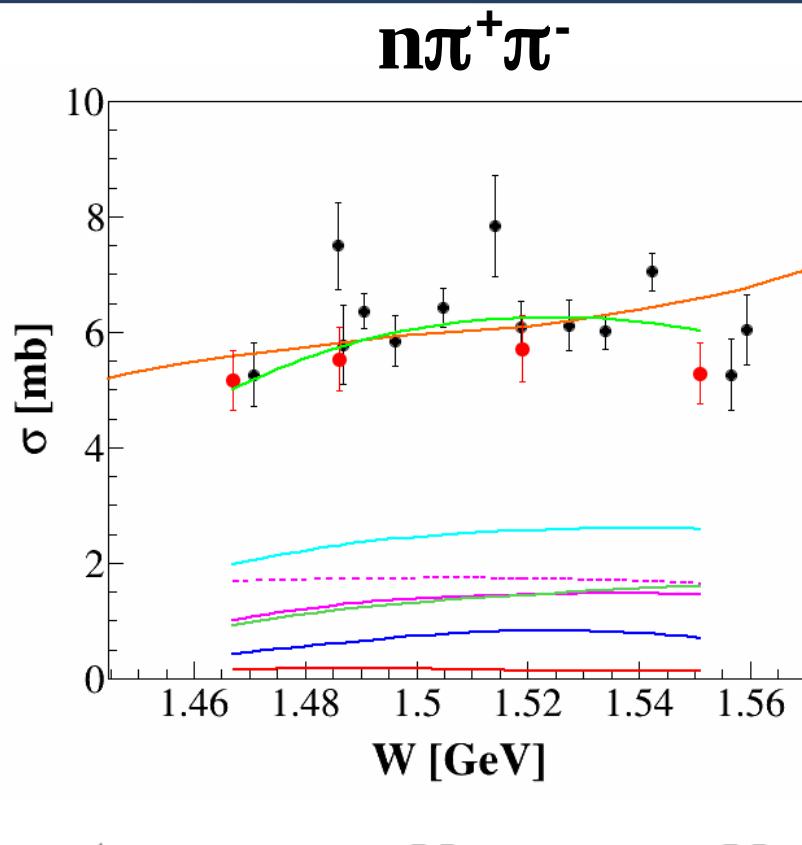
→ coherent sum of $I=1/2$ and $I=3/2$

N* contributions (P11, D13, S11)

- dominance of $I=1/2$ but interferences with $I=3/2$ important
- **D13** dominates in charged pion production
- **P11** more important in neutral channel



Decomposition into Final States Total Cross Sections



world data:

D. M. Manley *et al.*

Phys. Rev. D 30 (1984) 904

**D₁₃ (1520) dominant contribution
in ρ production**



BR(N-rho) @686 MeV/c

IMPORTANT FOR DILEPTON ANALYSIS:

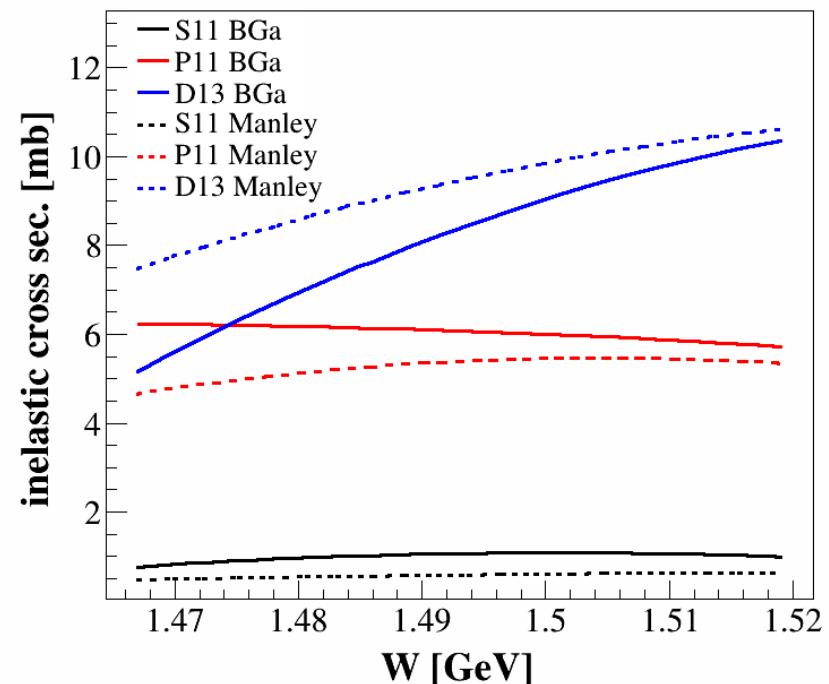
D13(1520) coupling to ρ -N: **12+/-2 %**

S11(1535): **3+-0.5 %**

P11(1440): **0.1+-0.1 %**

Total cross sec. ρ -N: **1.27 mb**
(2.5 mb from Manley *et al.*)

Comparison to solutions:
D. M. Manley *et al.*
Phys. Rev. D 30 (1984) 904





Summary and Outlook

- 1) **HADES & pion beam** is an unique tool to understand in details **baryon - ρ couplings**:
 - significant off-shell contribution originating from N(1520)D13 shown by combined PWA,
 - D13(1520) coupling to ρ -N: $12+/-2\%$,
 - dominance of $I=1/2$ in 2π production in second resonance region.
 - 2) Future measurement in 3'd resonance region with HADES are planned >2019
-



**Thank You
for
Your Attention**