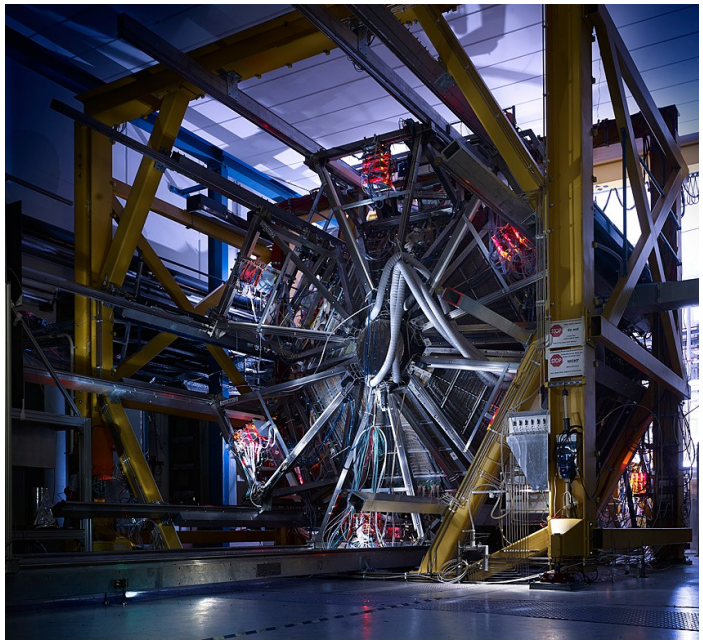
Analysis of HADES Data for Two-Pion Production in Pion-Nucleon Reactions



Izabela Ciepał
for the HADES Collaboration

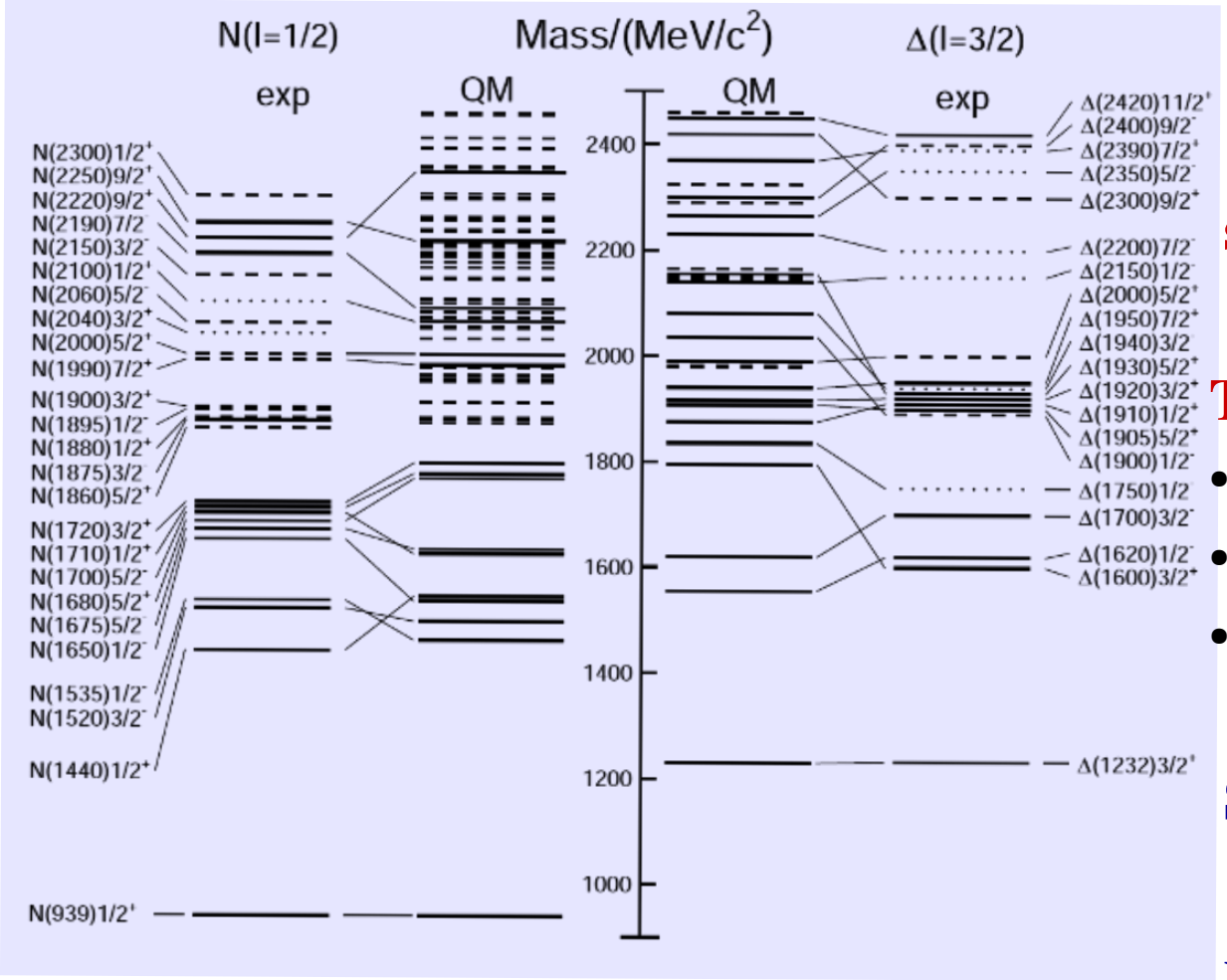
Outline

1) Motivations for experiments with pion beams,
2) Pion beam @ GSI,
3) Analysis of $\mathbf{p\pi^-}$, $\mathbf{n\pi^+\pi^-}$, $\mathbf{p\pi^-\pi^o}$ channels,
4) Partial Wave Analysis (PWA)
   by **Bonn-Gatchina group**,
5) Outlook.

Motivation

➔missing resonances problem

➔baryon specroscopy



1-2 GeV

(u, d, s)

s = ½, 3/2

Theory:

- quark model,
- Dyson-Schwinger approach,
- lattice QCD calculations

SU(6)xO(3) → 434

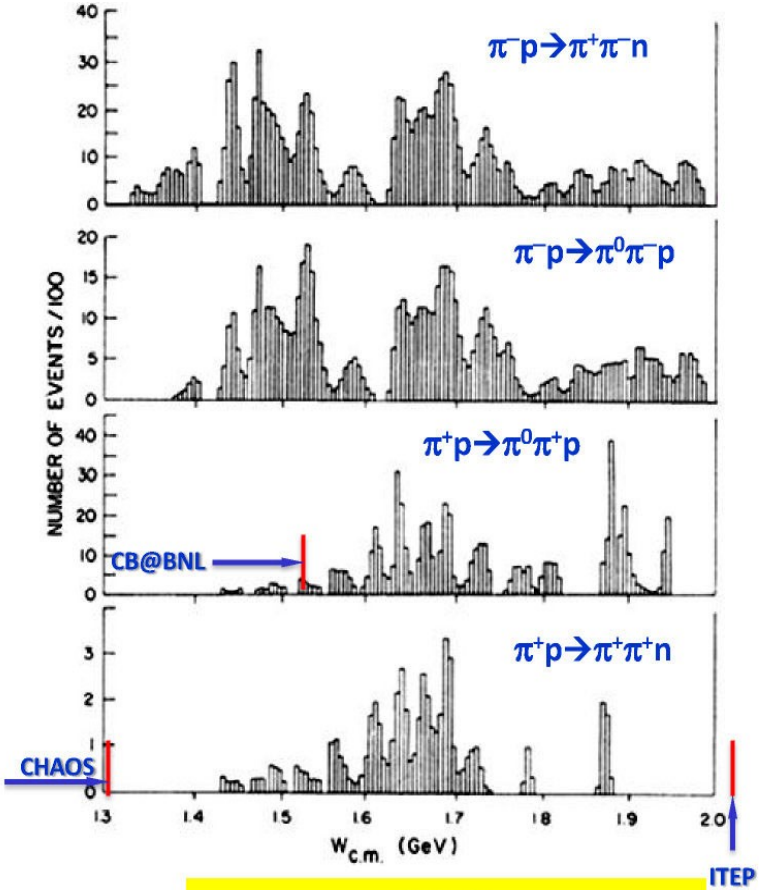
112 identified

in experiments (PDG)

πN→ππN status

most of data 1.3<s<2 GeV from

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



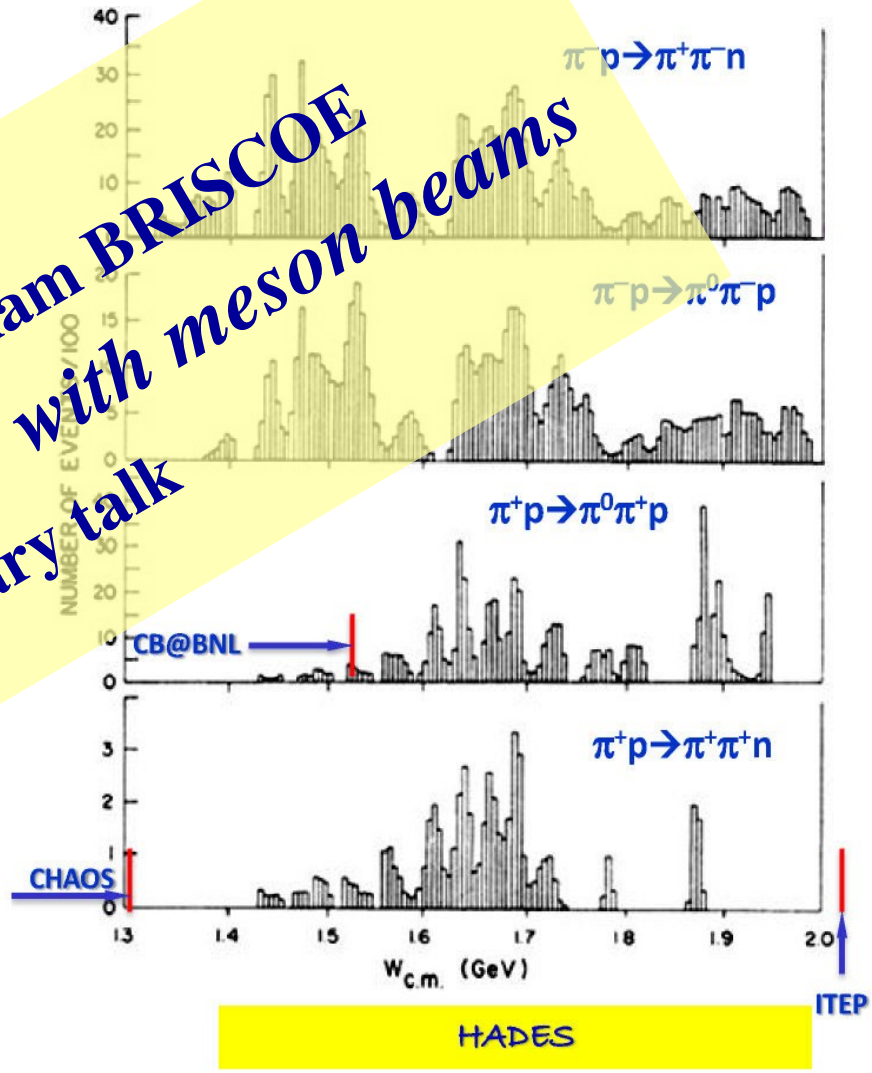
- Recent **post-Bubble Chamber** measurements:
  - **349,611** events for $\pi^-p\to\pi^0\pi^0n$ from CB@BNL at W = **1213** to **1527** MeV. [S. Prakhov *et al* Phys Rev C **69**, 045202 (2004)]
  - **20,000** events for $\pi^+p\to\pi^+\pi^+\pi^-n$ from TRIUMF CHAOS@TRIUMF at W = **1257** to **1302**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

can provide much higher statistics !

πN→ππN status

most of data 1.3<s<2 GeV from

- **Manley *et. al* PRD30 (1984) 904**
  241214 bubble chamber events
  analyzed in isobar PWA model
- knowledge on N* coupl. to ρN, Δπ, σN
- **very scarce data** base for pion nucleon reactions
- differential distributions are much more scarce (or missing)
- more recent data do not help for $\pi^+\pi^-$ in **1.3<s<2 GeV region**



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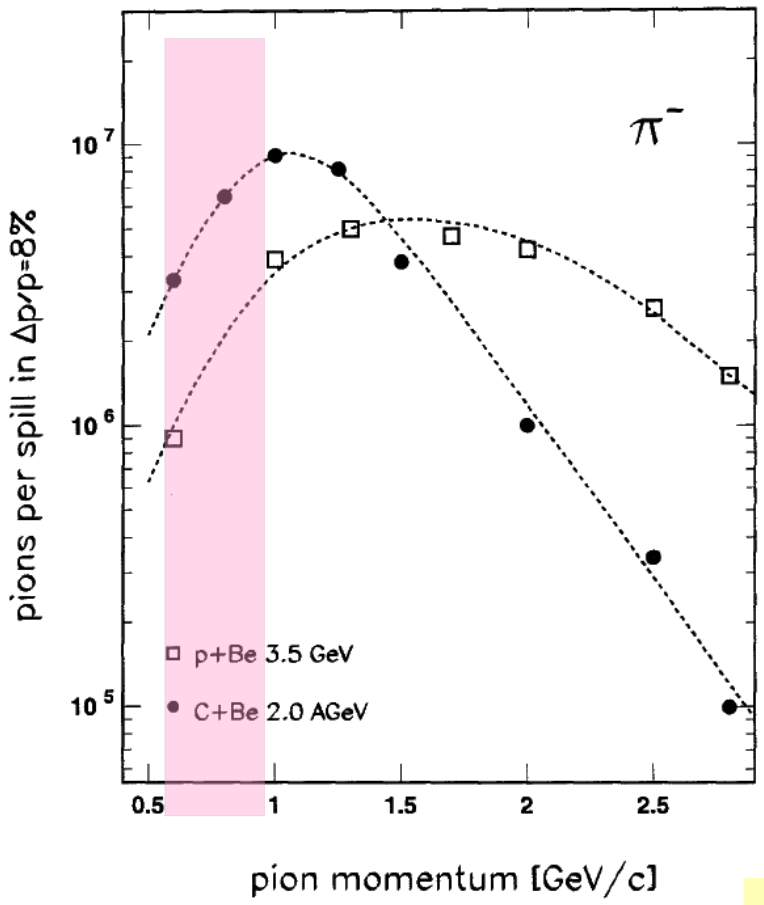
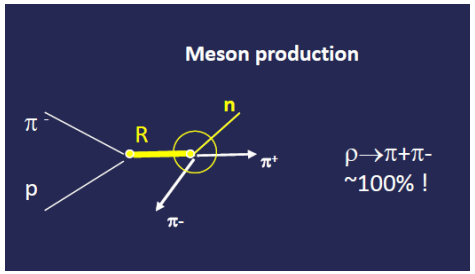
See also: Contribution of William BRISCOE Physics opportunities with meson beams plenary talk

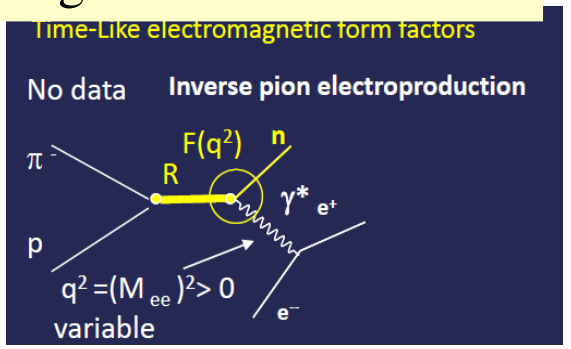
Pion Beam @ GSI



- reaction **N+Be**, 8-10*10^{10} N_2 ions/spill (4s)
- secondary **π^-** with **I ~ 2-3 10^5/s**
- **p = 654.1, 683.5, 738.9 , 791 MeV/c**
- **PE $(CH_2)_n$** and **C** targets

Unique possibility to investigate em. resonance decays via **combined** Partial Wave Analysis of hadronic and electromagnetic final states





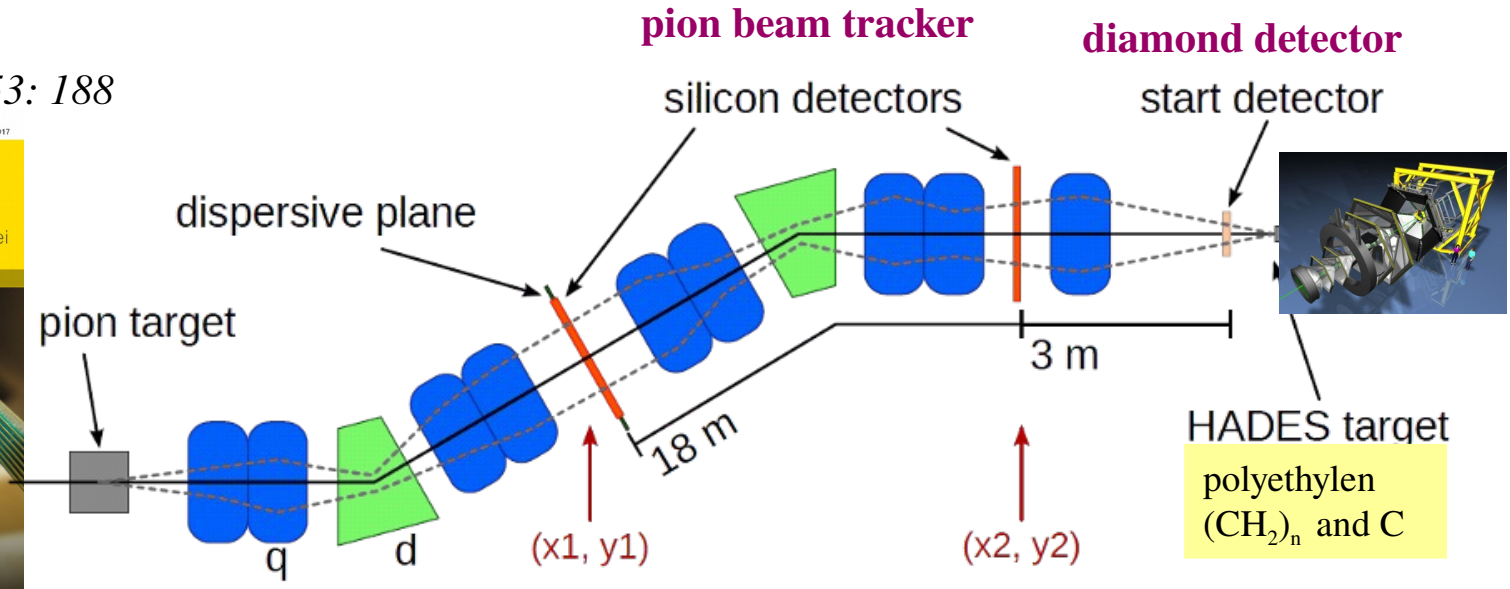
See also:

contribution of Beatrice RAMSTEIN

plenary talk

Pion Beam @ GSI

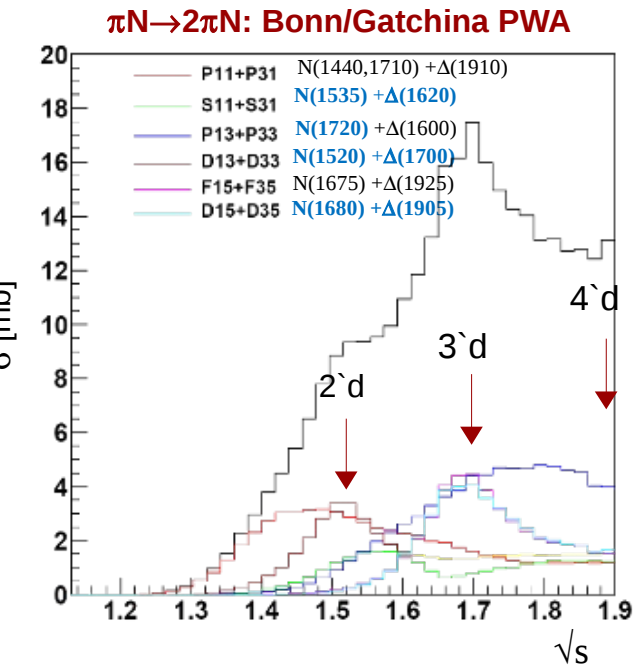
Eur. Phys. J. A (2017) 53: 188



- pion momentum $\Delta p/p = 2.2\%$ (σ), ~50% acceptance of pion beam line
- in beam **tracking system**: (X1,X2/Y1/Y2) for pion momentum determination: $\Delta p/p = 0.1\%$

Main advantages of pion beams:

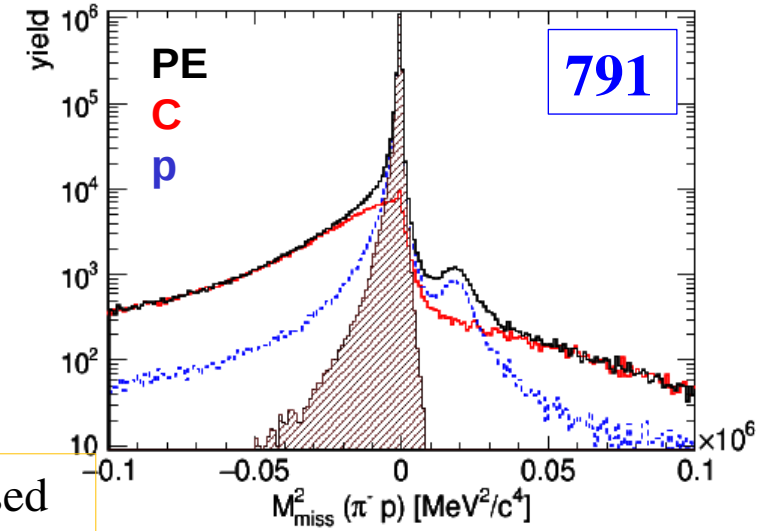
1) **selectivity:** resonances can be excited at given mass by choosing the beam (pion) momentum, HADES starts with $\sqrt{s}$=(1.46-1.55) GeV – N*(1520) resonance region, data obtained at 4 momenta: **0.656, 0.69, 0.748, 0.8 GeV/c**
2) **π+ π- production:** off-shell coupling of ρ to resonance, ρ→ π+ π- (~100%) „golden channel",
3) **dilepton channel** R → e+e-, never measured in pion induced reactions.

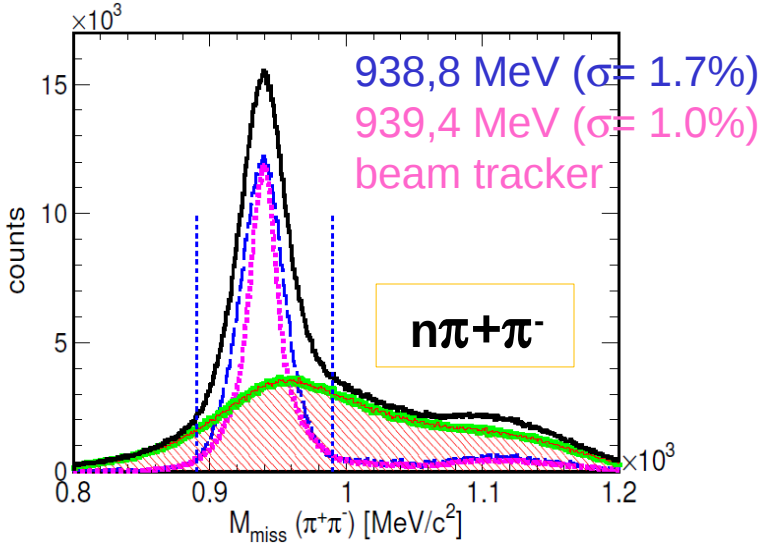


π^- p @ 0.656, 0.69, 0.748, 0.8 GeV/c

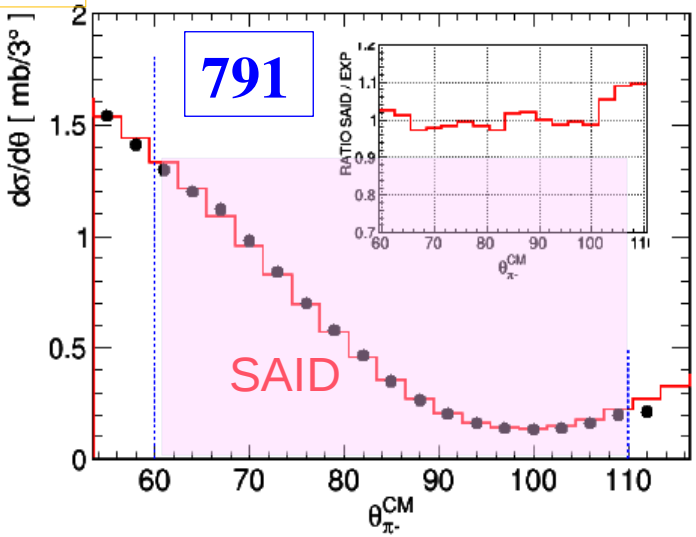
- (CH2)n polyethylene target (PE) and carbon (C) target,
- **elastic scattering identification**: $\pi^- p \rightarrow \pi^- p$,
- **two-pion identification** in channel: $n\pi^+\pi^-$, $p\pi^-\pi^o$ (exclusive channels via missing mass), partial wave analysis focused on N(1520) and ρ production,
- **dilepton identification** in channel: ne^+e^- (quasi-exclusive channel) baryon resonance Dalitz decays and two-body ρ decay.

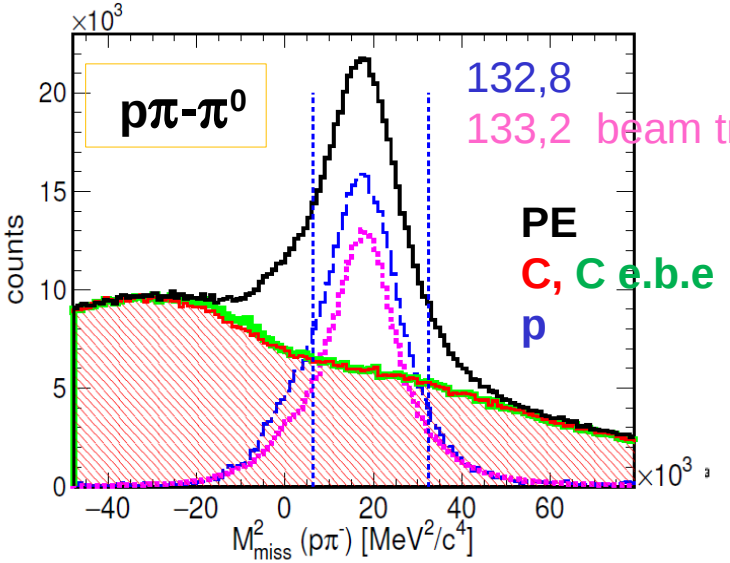
Identification of Channels



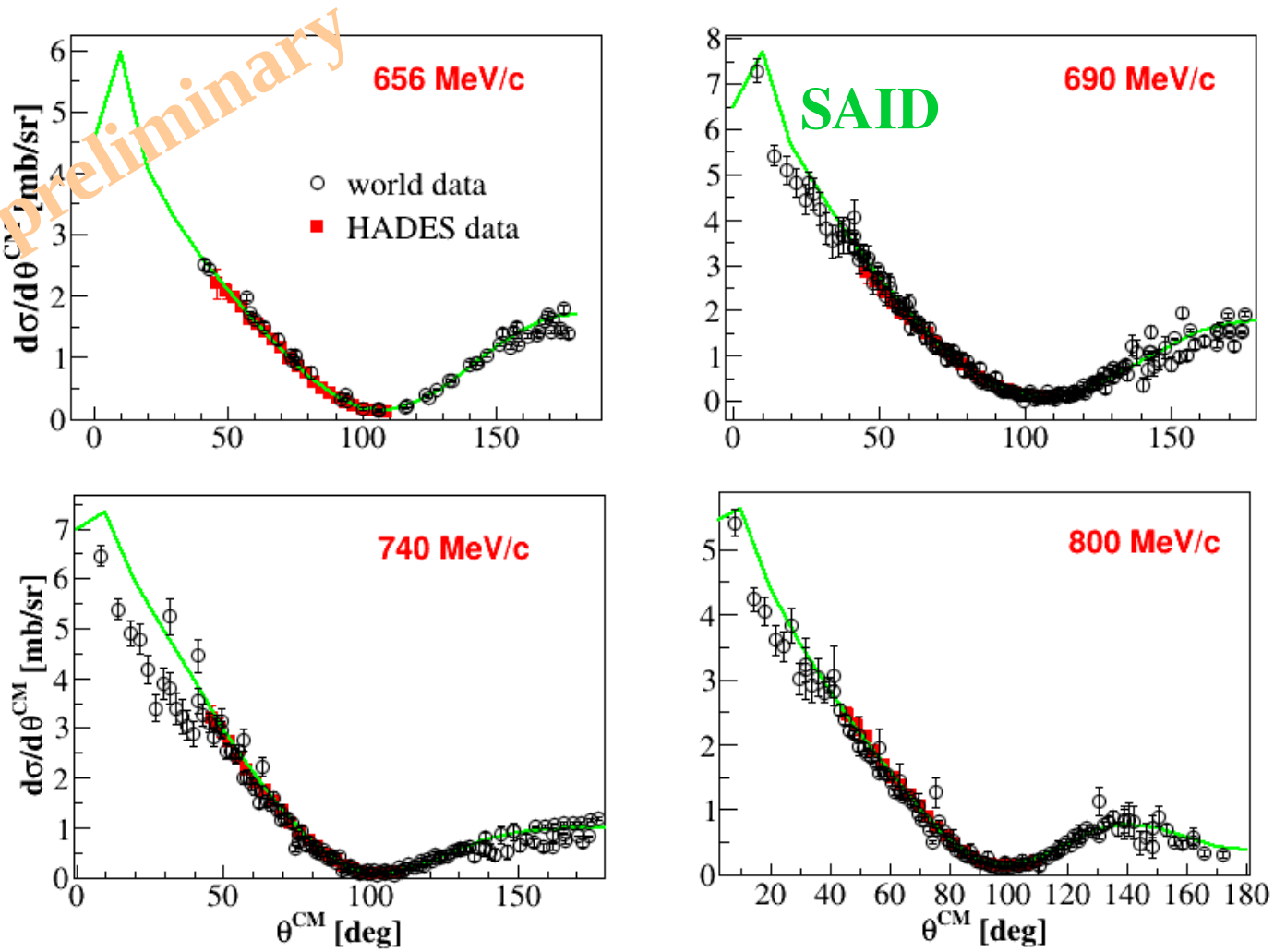


elastic **pπ-** used for normalization



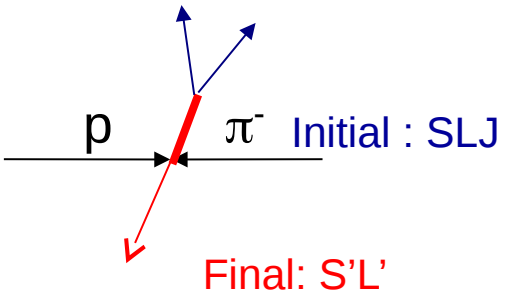


Elastic Scattering



statistics of existing database increased by more than 2 orders of magnitude (> $4*10^7$ events for each √s)

π^-p Resonance Production



Partial Wave Analysis (PWA)

- goal of partial wave analysis is to look for nucleon resonance contributions on event based likelihood fits
- χ^2 fits to differential cross sections
- energy and angular dependencies of different observables are analysed simultaneously
- normalization to the total cross section

- **Coherent sum** of partial waves
- Energy dependent solutions: many experimental sets treated together by max. log-likehood method event by event
- Detector acceptances taken into account

transition amplitude

fit parameters

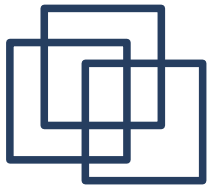
independent kinematic variables

$$|M(\vec{x}, X)| = \sum_{m_i, m_j, m_f} \left| \sum_a \alpha_a(\vec{x}, X) A^a_{m_i, m_j, m_f}(X) \right|^2$$

complex function build from the fit parameters

partial wave amplitudes (resonant, non resonant)

12



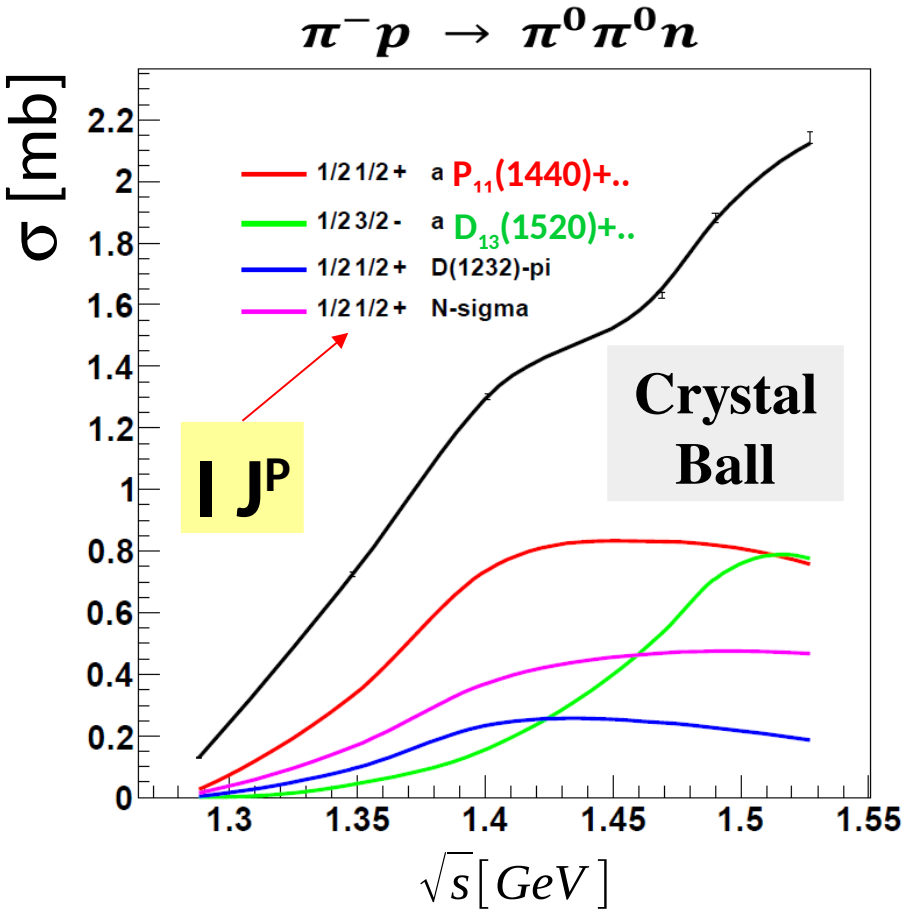
Bonn-Gatchina Partial Wave Analysis

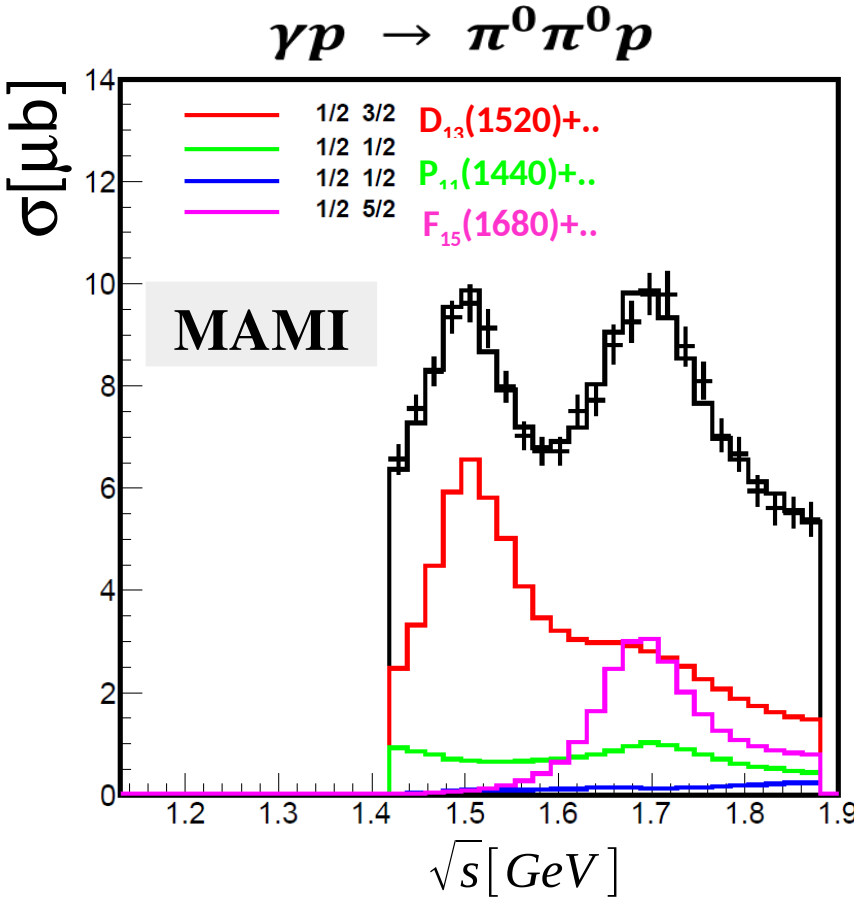
Address: Nussallee 14-16, D-53115 Bonn Fax: 228 / 73-2505

Data: 2016-2018
200 datasets
2 mln likelihoods

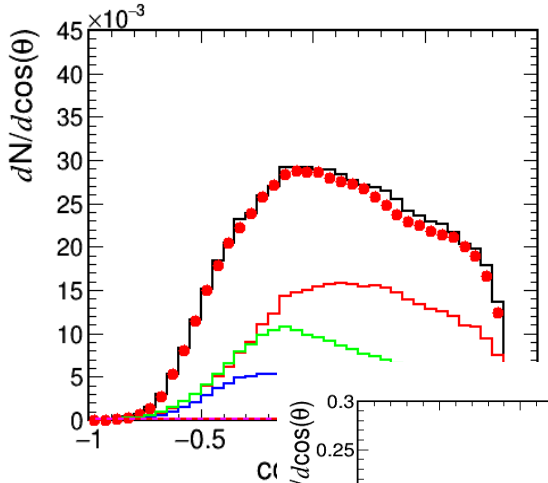
See also:
contribution of Andrey SARANSEV
plenary talk

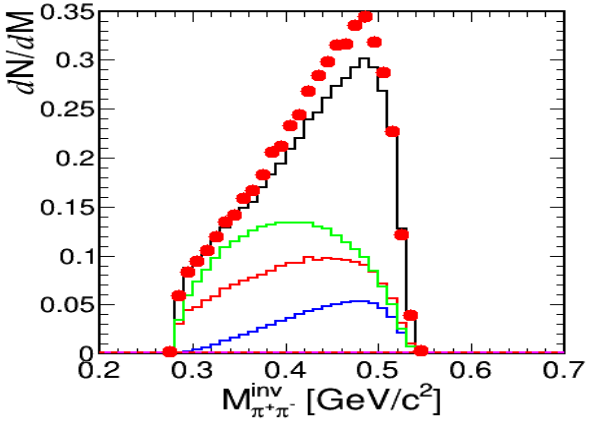
PWA: Initial Waves Constraints

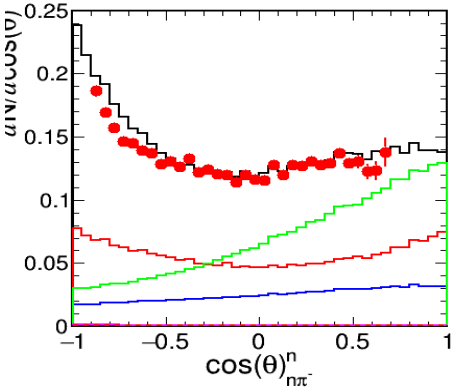


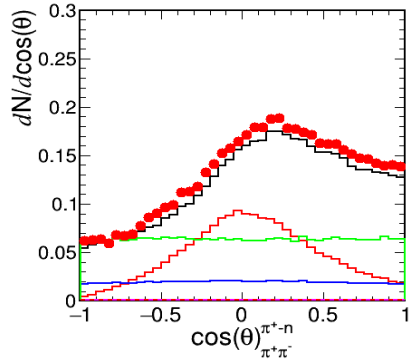


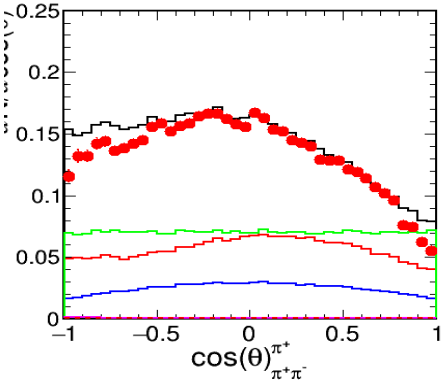
in energy range of **1.45 - 1.55 GeV** and in 2-pion production only few resonances matter: **$D_{13}(1520)$, $P_{11}(1440)$**

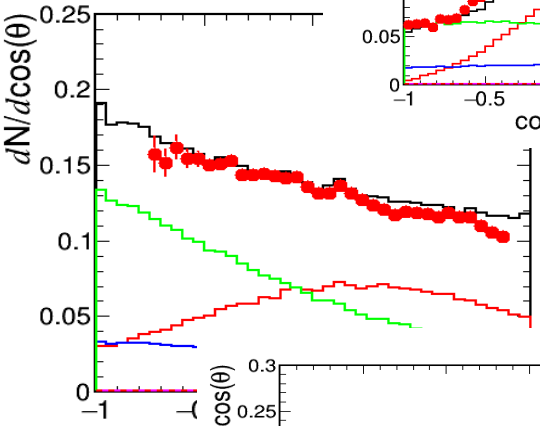

dN/dcos(θ)
×10⁻³

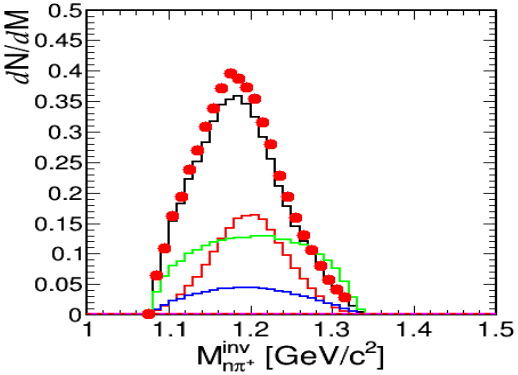

dN/dM
M^inv_π⁺π⁻ [GeV/c²]

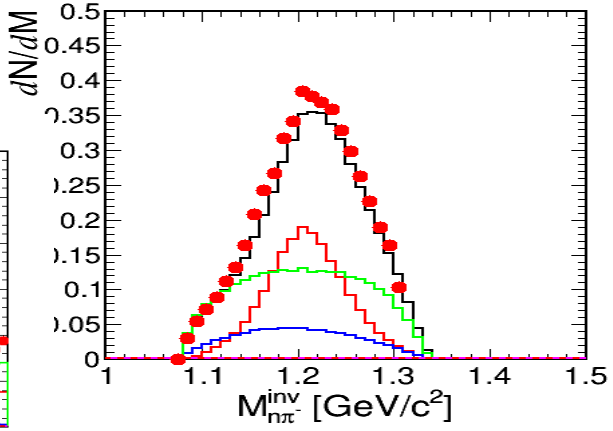

cos(θ)^n_nπ⁻

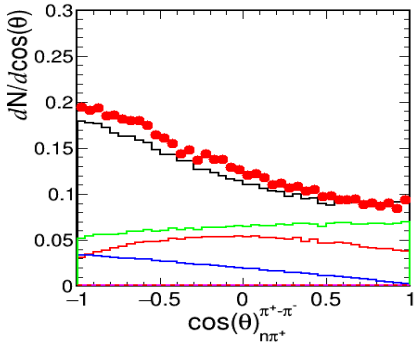

dN/dcos(θ)
cos(θ)^π⁺-n_π⁺π⁻

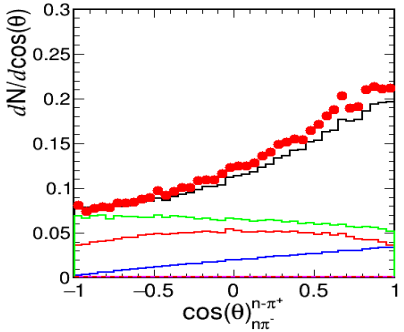

cos(θ)^π⁺_π⁺π⁻


dN/dcos(θ)


dN/dM
M^inv_nπ⁺ [GeV/c²]

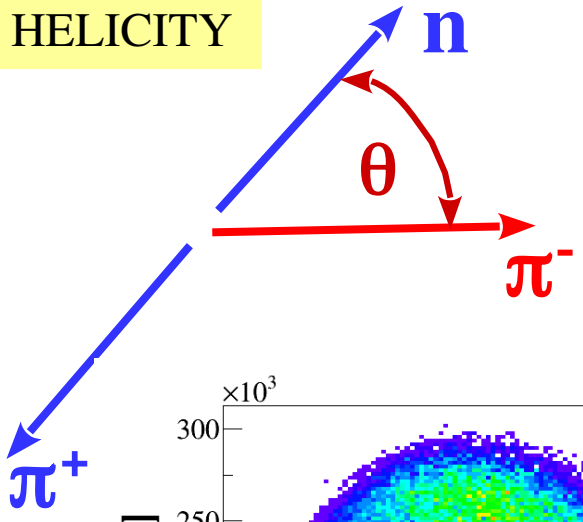

dN/dM
M^inv_nπ⁻ [GeV/c²]


dN/dcos(θ)
cos(θ)^π⁺-π⁻_nπ⁺

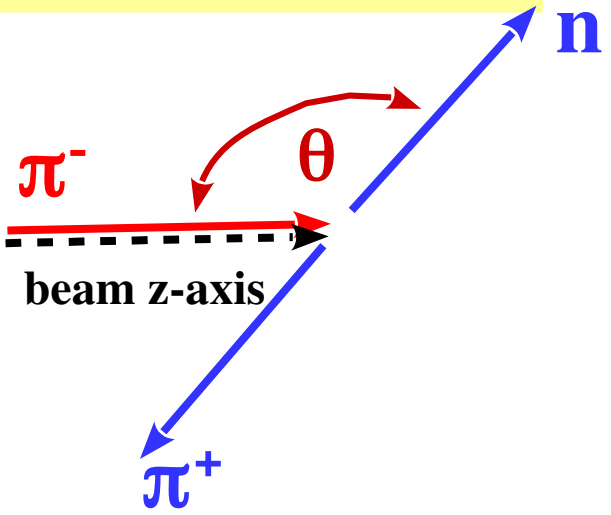

dN/dcos(θ)
cos(θ)^n-π⁺_nπ⁻

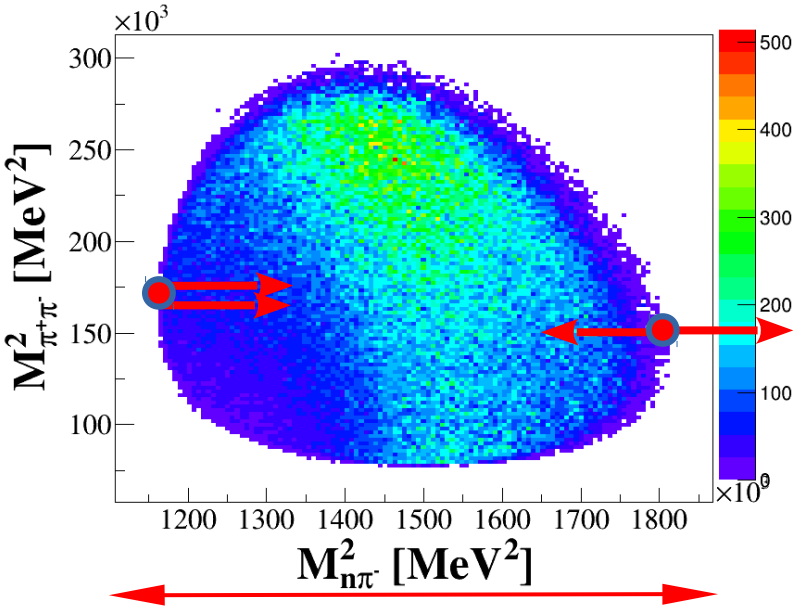
Angular Distributions & Reference Frames

HELICITY



GOTTFRIED - JACKSON





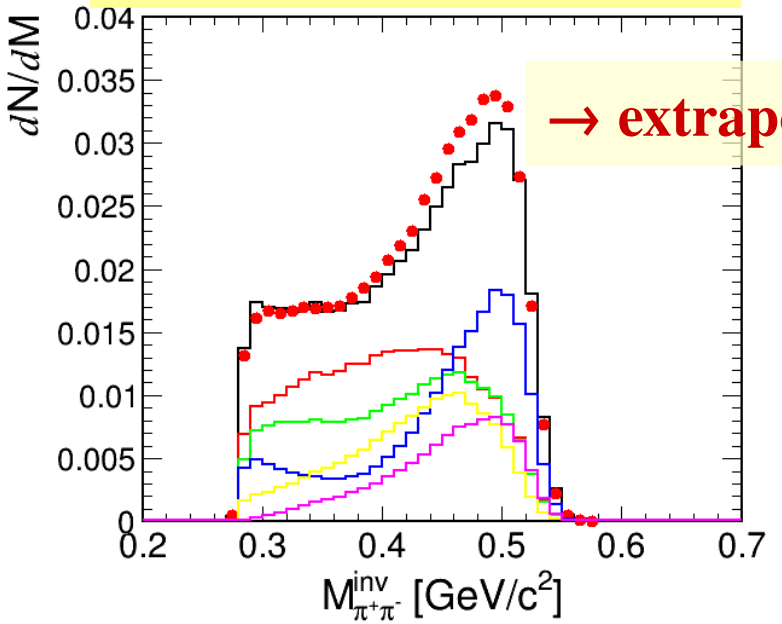
+Invariant masses

+CM angular distributions

PWA Results @ 656 MeV/c

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

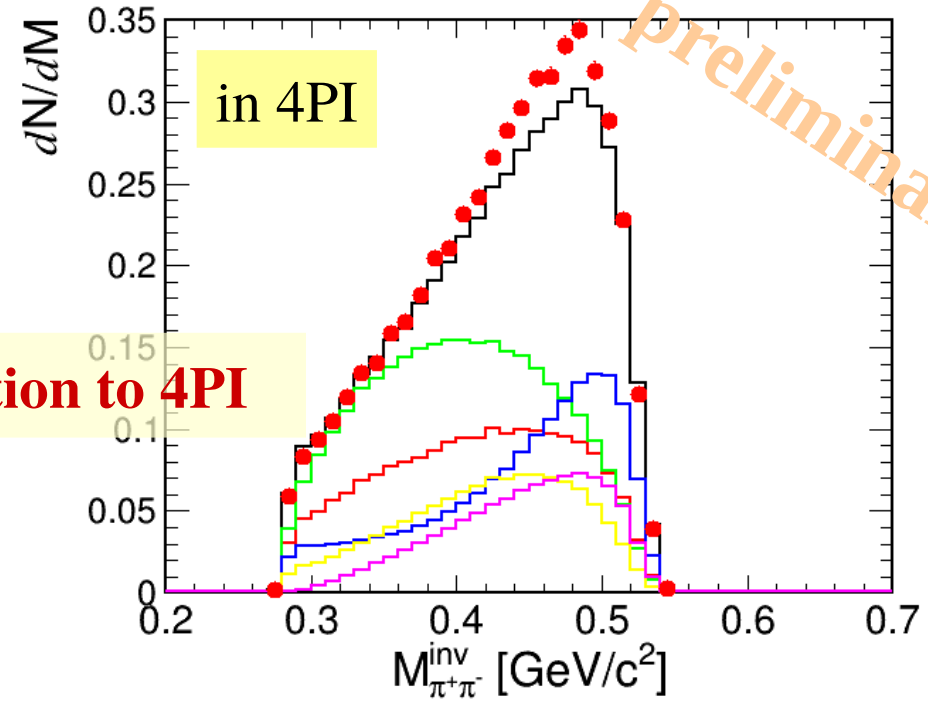
in the acceptance HADES
distributions are distorted:

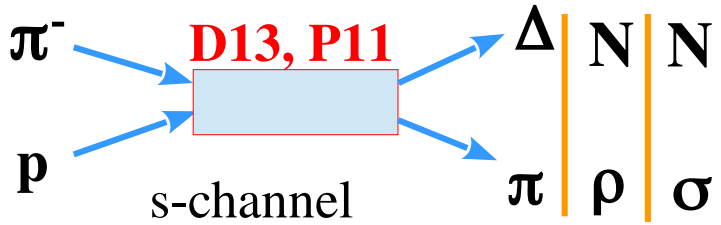


→ extrapolation to 4PI

in 4PI

preliminary



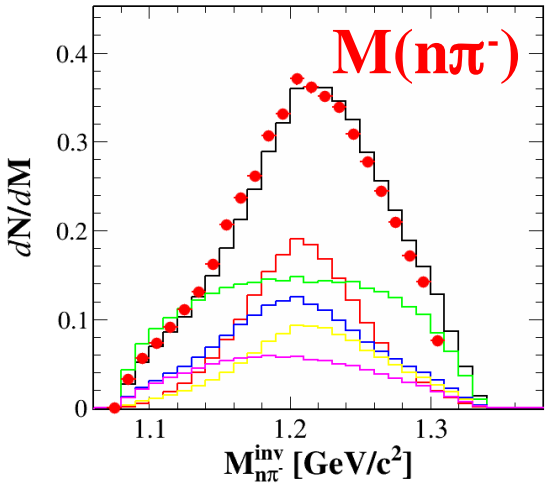


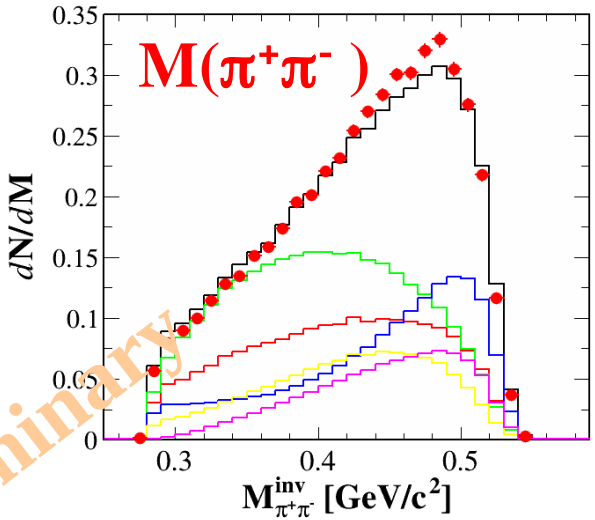
s-channel
symbolic notation

σN Δπ N(1440) N(1520) ρN

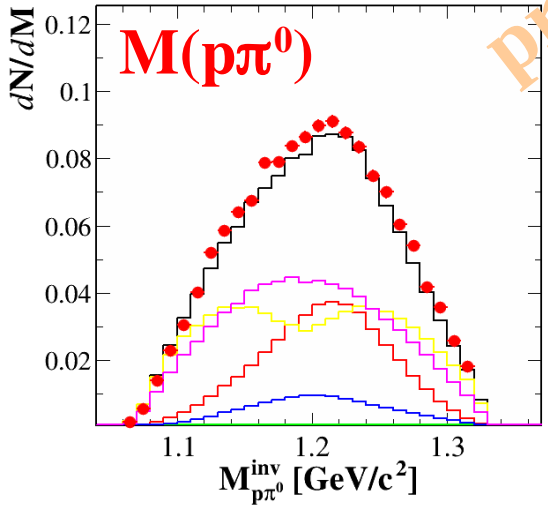
PWA Results @ 656 MeV/c

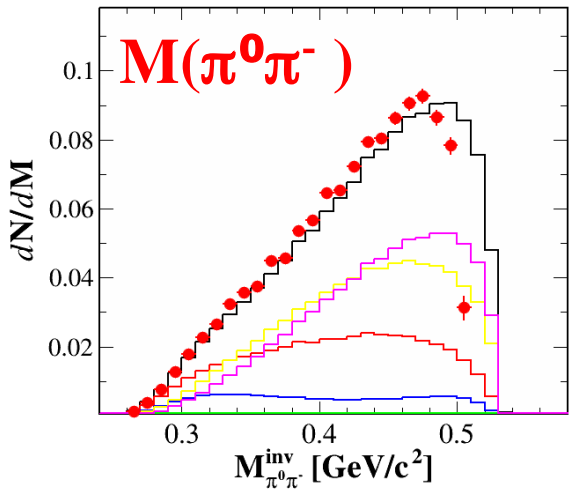
invariant masses





nπ+π-





pπ-π0

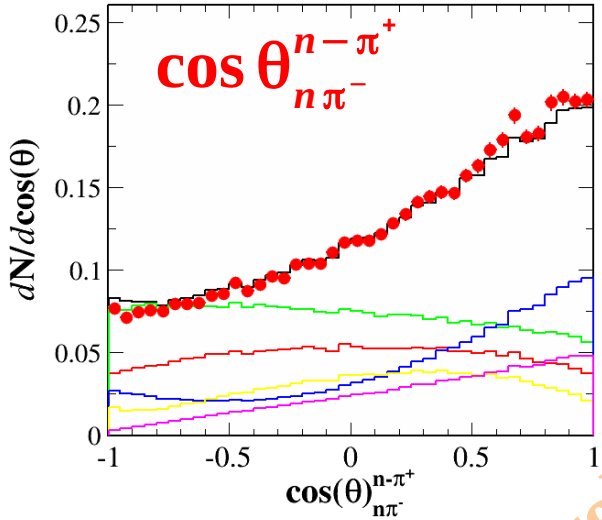
acceptance corrected

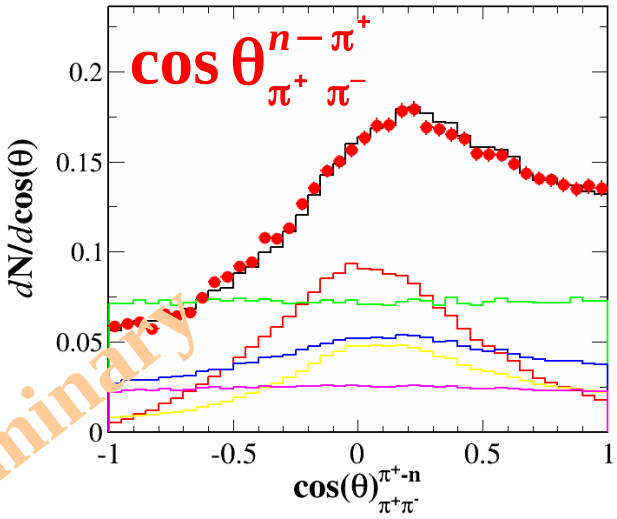
Preliminary

σN Δπ N(1440) N(1520) ρN18

PWA Results @ 656 MeV/c

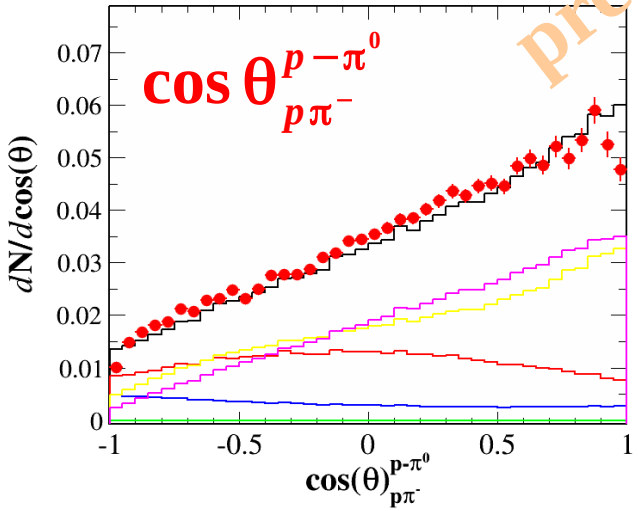
helicity angles

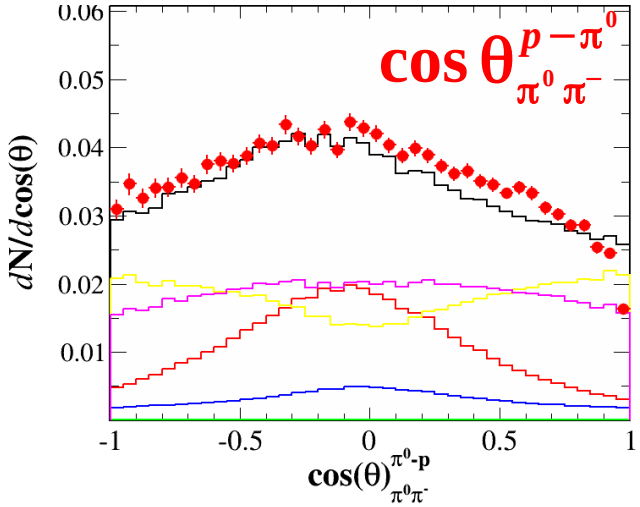




nπ+π-

acceptance corrected



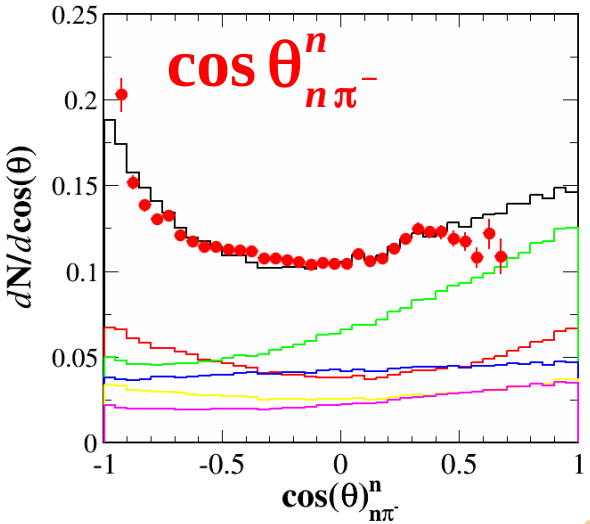


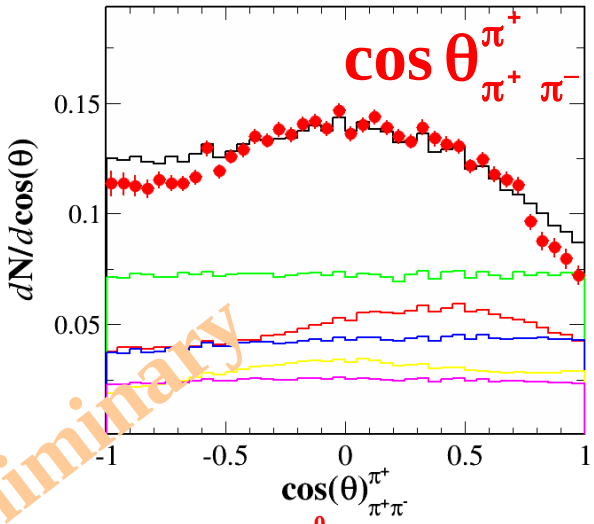
pπ-π0

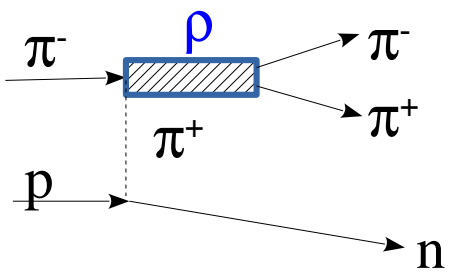
σN Δπ N(1440) N(1520) ρN19

PWA Results @ 656 MeV/c

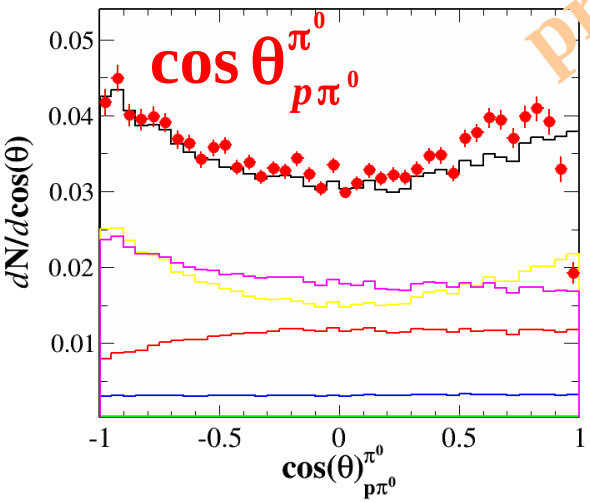
Gottfried-Jackson

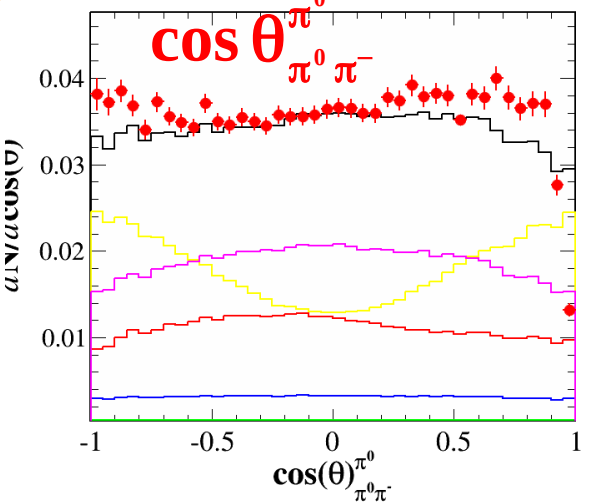






nπ+π⁻





pπ-π⁰

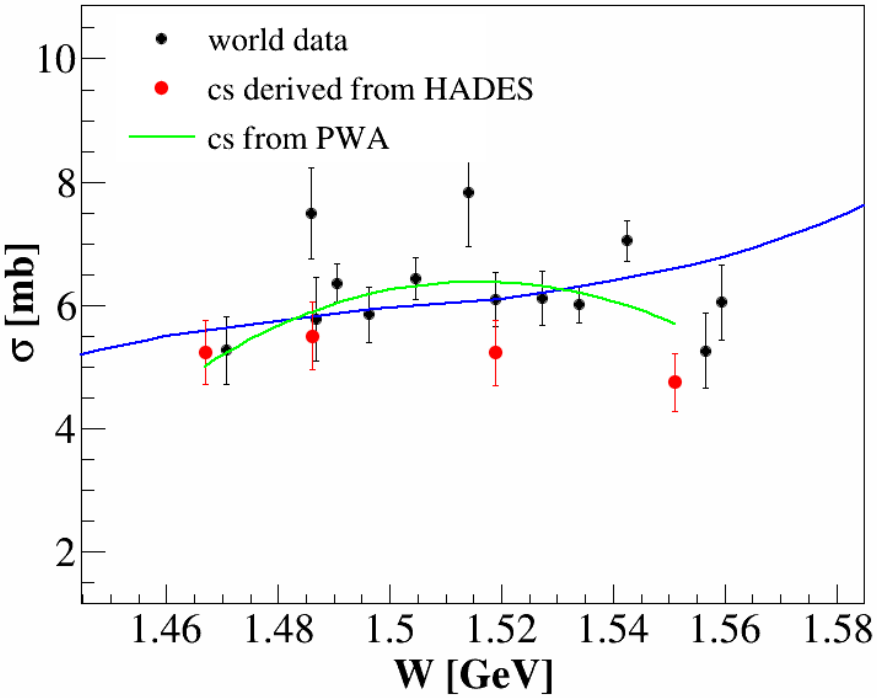
Preliminary

acceptance corrected

σN Δπ N(1440) N(1520) ρN20

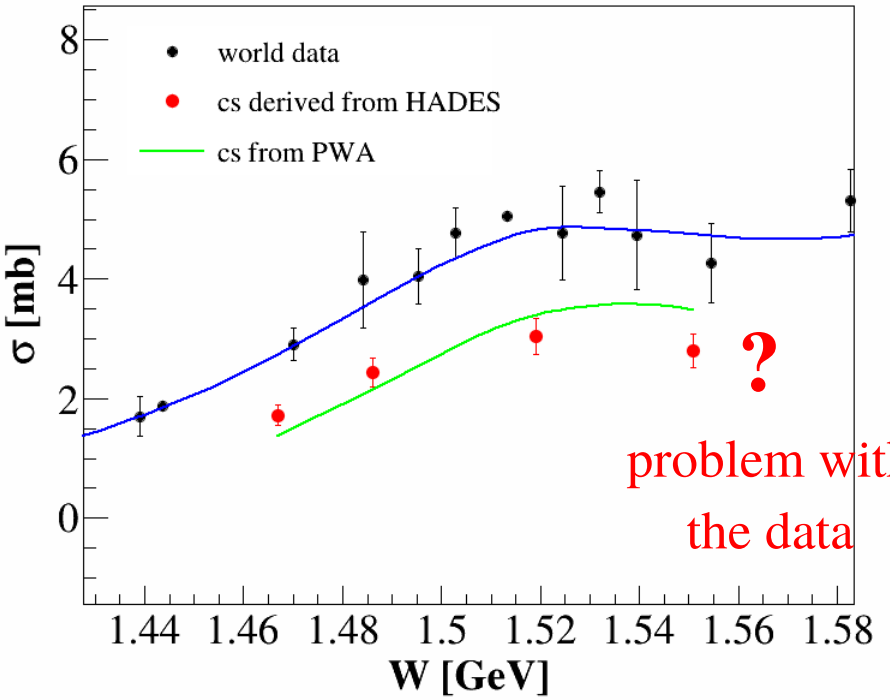
Total Cross Section

$n\pi^+\pi^-$



world data - D. M. Manley *et al*. Phys. Rev. D 30 (1984) 904

$p\pi^-\pi^o$



PWA – solution with small HADES weight (80)

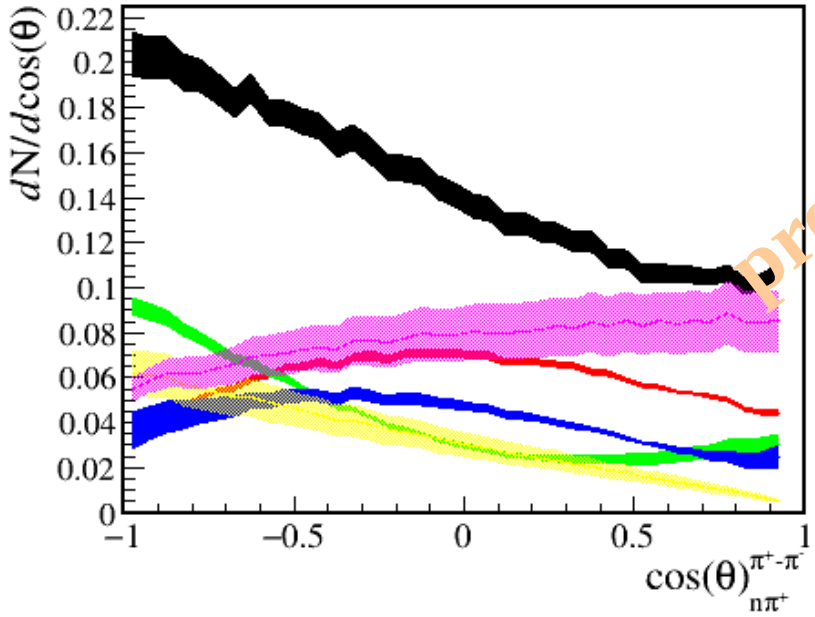
PWA Results - Systematics

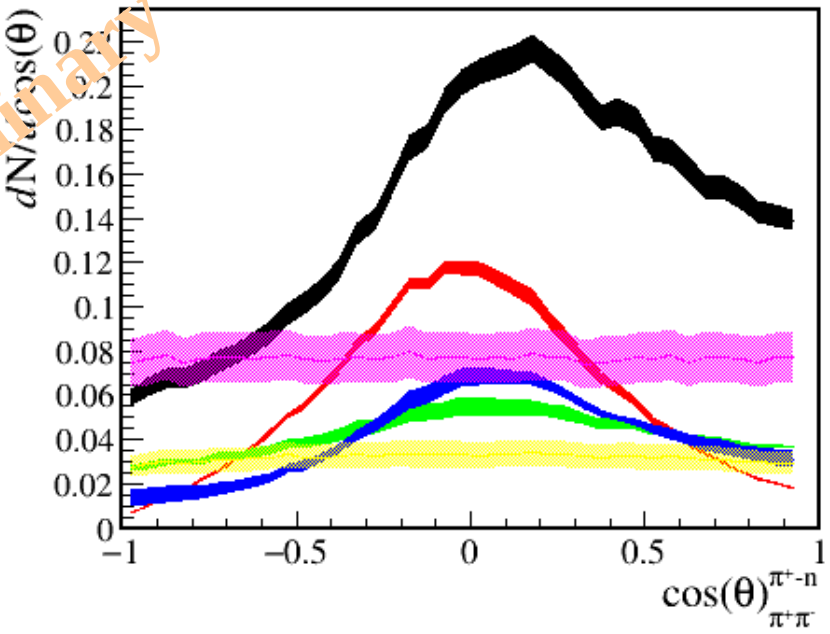
Bands represent spread of the PWA solutions in 3 cases:

- with 2 different weights for the HADES cross sections (300, 80)
- with heigh weight of Manley cross section (old data)

D. M. Manley *et al*.
Phys. Rev. D 30 (1984) 904

$n\pi^+\pi^-$

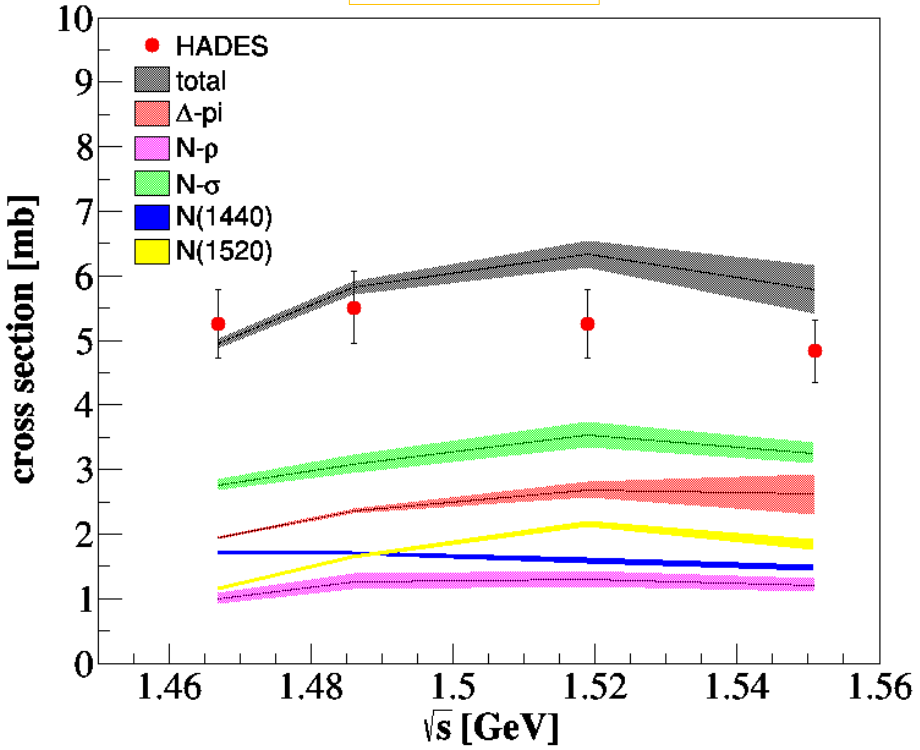




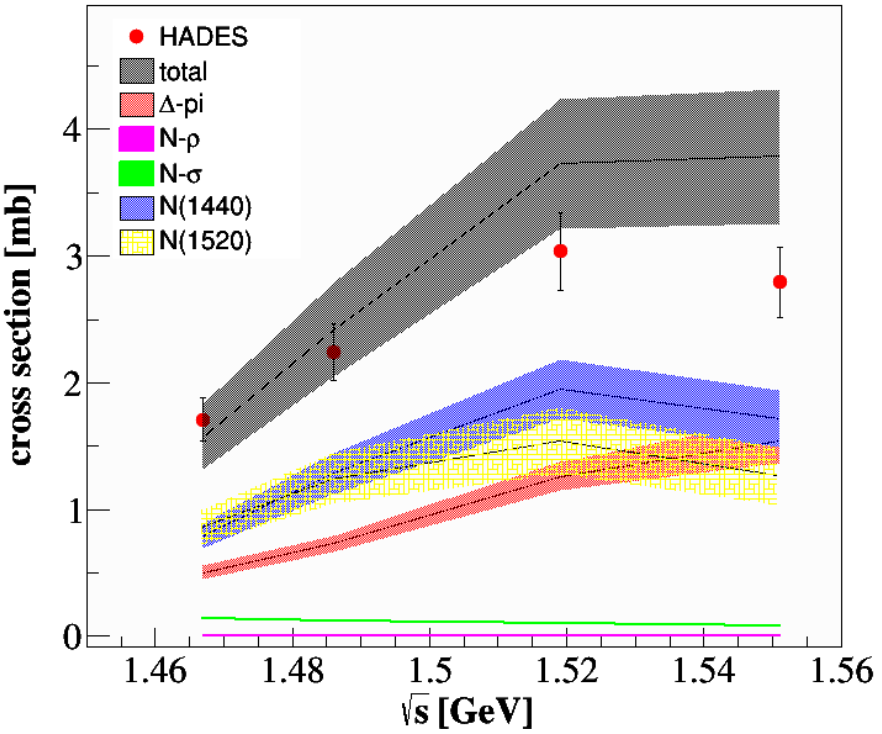
σN Δπ N(1440) N(1520) ρN

PWA Results – Total Cross Section

$n\pi^+\pi^-$

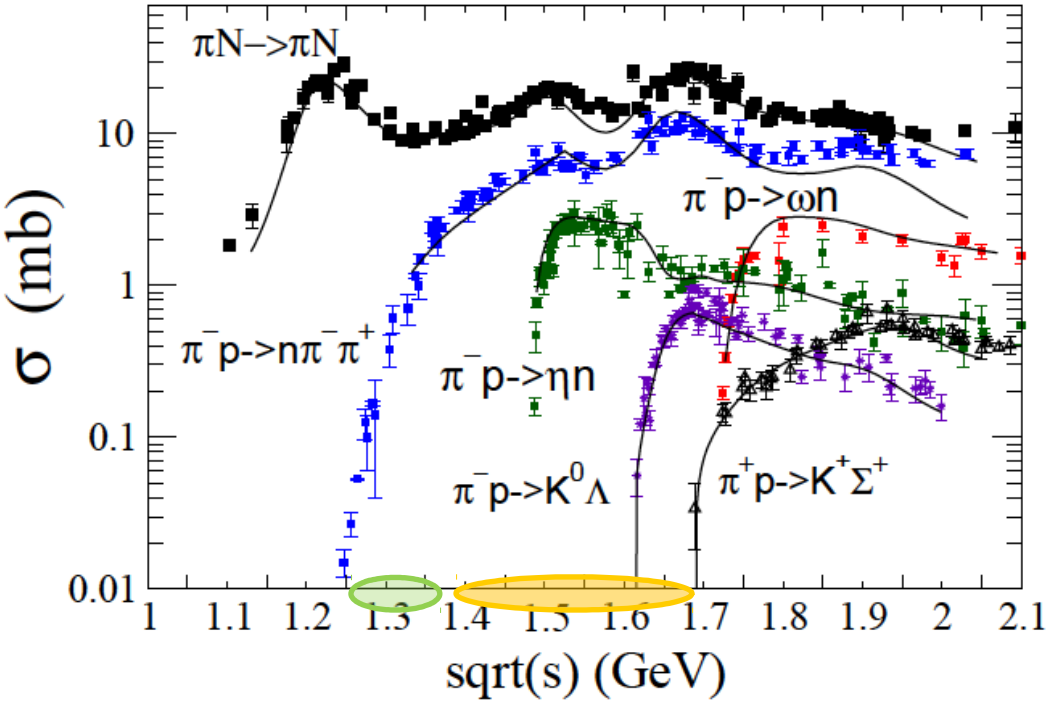


$p\pi^-\pi^o$



σN Δπ N(1440) N(1520) ρN

HADES Physics Program with Pion Beams – Near Future

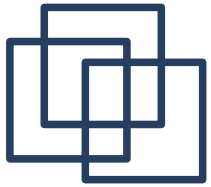


- High statistics beam energy scan : continuation and extension to third resonance region
- Hadronic final states, one pion, 2 pion, hyperon production to control resonance excitation (HADES upgrade with el. calorimeter ! neutral final states: η/π/ ω)
- Dielectron measurements : ρR couplings S31(1620), D33(1700), P13(1720),..

Summary

HADES & **pion beam** is an unique tool

- to understand in details baryon - ρ couplings
- significant off-shell contribution originating from $N(1520)D_{13}$ shown by combined PWA and e^+e^- data
- furhter investigation on specific observables (helicity, GJ $\rightarrow$ Dalitz plots) necessary in order to prove the conitrbuting channels



Thank You

for

Your Attention