Spin-exotic search in the ρπ decay channel:
First results on $\pi^-\pi^0\pi^0$ in comparison to $\pi^-\pi^+\pi^-$ final states
(diffractively produced on proton)

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Outline:

- **Introduction**
  - Spin-exotic mesons & the COMPASS experiment
  - PWA method
- **First results on diffractive 3π production** (2008 proton target data)
  - 3π final states neutral vs. charged mode
  - PWA results on main & small waves
- **Conclusions & outlook**

bmb+f - Förderschwerpunkt COMPASS Großgeräte der physikalischen Grundlagenforschung

Motivation: Search for Spin Exotic States

Hybrid candidates (1.3 - 2.2 GeV/c²):

lightest hybrid predicted: exotic $J^{PC} = 1^{-+}$

- $\pi_1(1400)$: VES, E852, Crystal Barrel –> $\eta\pi$
- $\pi_1(1600)$: E852, VES –> $\rho\pi$, $\eta'\pi$, $f_1\pi$, $b_1\pi$
- $\pi_1(2000)$: E852 –> $f_1(1285)\,\pi$, $b_1(1235)\,\pi$

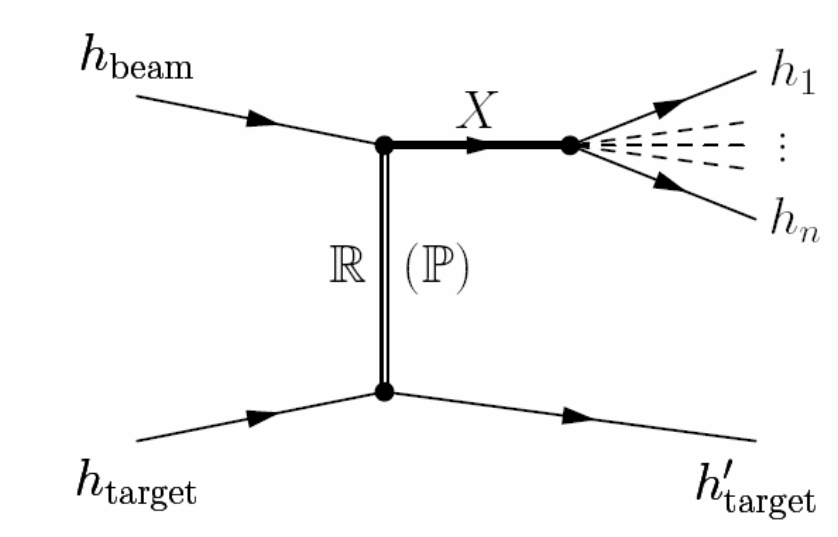
.... still controversal → COMPASS

Diffractive scattering

- study of J^{PC} exotic mesons
- t-channel Reggeon exchange
- forward kinematics, target stays intact

Diffractive pion dissociation

- incoming π^- excited to resonance X^-
- X^- decays into final state, e.g. $(3\pi)^-$
- small momentum transfer



Spin Exotic Search -- two decay modes of ρπ decay channel: Neutral Mode

Hybrid candidates (1.3 - 2.2 GeV/c²):

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- $\pi_1(1400)$: VES, E852, Crystal Barrel –> $\eta\pi$
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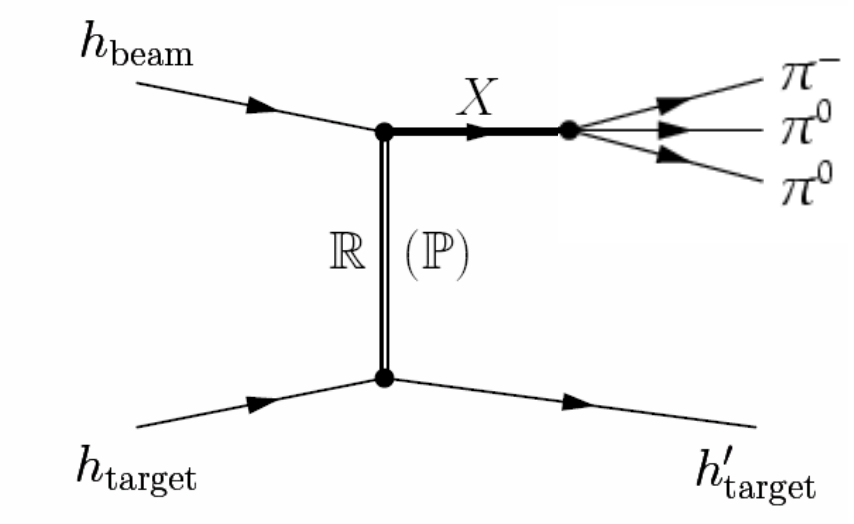
Diffractive pion dissociation

- incoming π^- excited to resonance X^-
- X^- decays into final state, e.g. $(3\pi)^-$:
  $\pi^-\,\mathbf{p} \longrightarrow \pi^-\pi^0\pi^0\,\mathbf{p}$ (neutral mode)
- small momentum transfer



Spin Exotic Search -- two decay modes of ρπ decay channel: Charged Mode

Hybrid candidates (1.3 - 2.2 GeV/c²):

lightest hybrid predicted: exotic $J^{PC} = 1^{-+}$

- $\pi_1(1400)$: VES, E852, Crystal Barrel –> $\eta\pi$
- $\pi_1(1600)$: E852, VES –> $\rho\pi$, $\eta'\pi$, $f_1\pi$, $b_1\pi$
- $\pi_1(2000)$: E852 –> $f_1(1285)\,\pi$, $b_1(1235)\,\pi$

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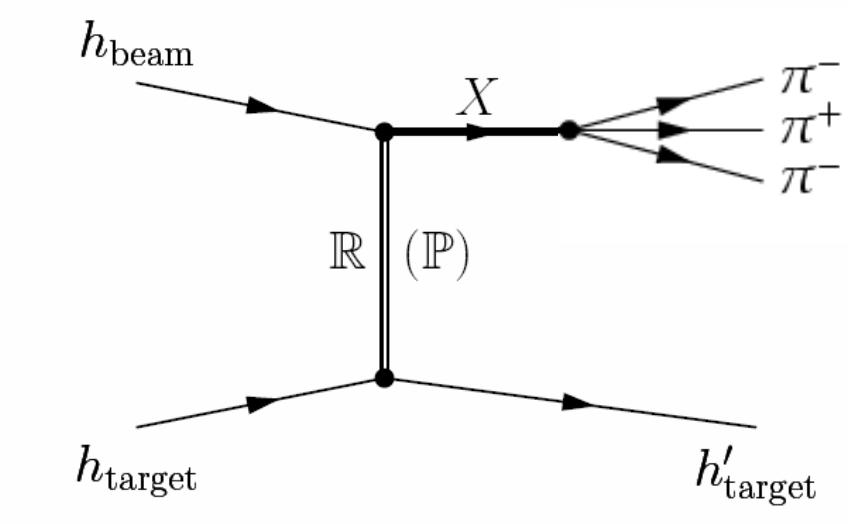
Diffractive scattering

- study of J^{PC} exotic mesons
- t-channel Reggeon exchange
- forward kinematics, target stays intact

Diffractive pion dissociation

- incoming π^- excited to resonance X^-
- X^- decays into final state, e.g. $(3\pi)^-$:
  $\pi^-\,\mathbf{p} \longrightarrow \pi^-\pi^+\pi^-\,\mathbf{p}$ (charged mode)
- small momentum transfer



→ *cf. previous, talk by F. Haas*

The COMPASS experiment

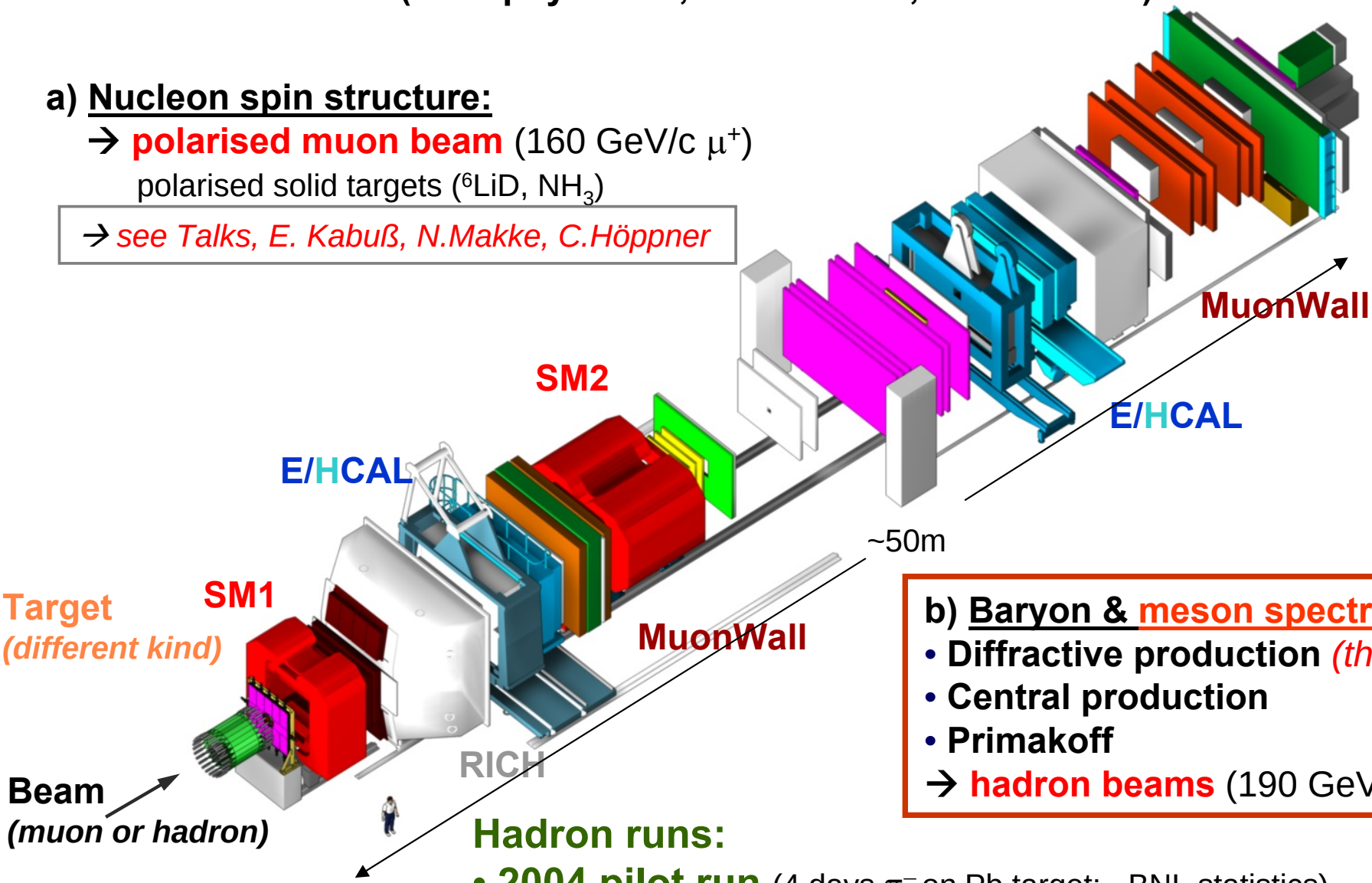
COmmon Muon Proton Apparatus for Structure and Spectroscopy
(~250 physicists, 25 institutes, 10 countries)

a) Nucleon spin structure:

→ **polarised muon beam** (160 GeV/c μ^+)

polarised solid targets (^{6}LiD, NH_3)

→ *see Talks, E. Kabuß, N.Makke, C.Höppner*



b) Baryon & meson spectroscopy:

- **Diffractive production** *(this talk)*
- **Central production**
- **Primakoff**

→ **hadron beams** (190 GeV/c π^-,K^-)

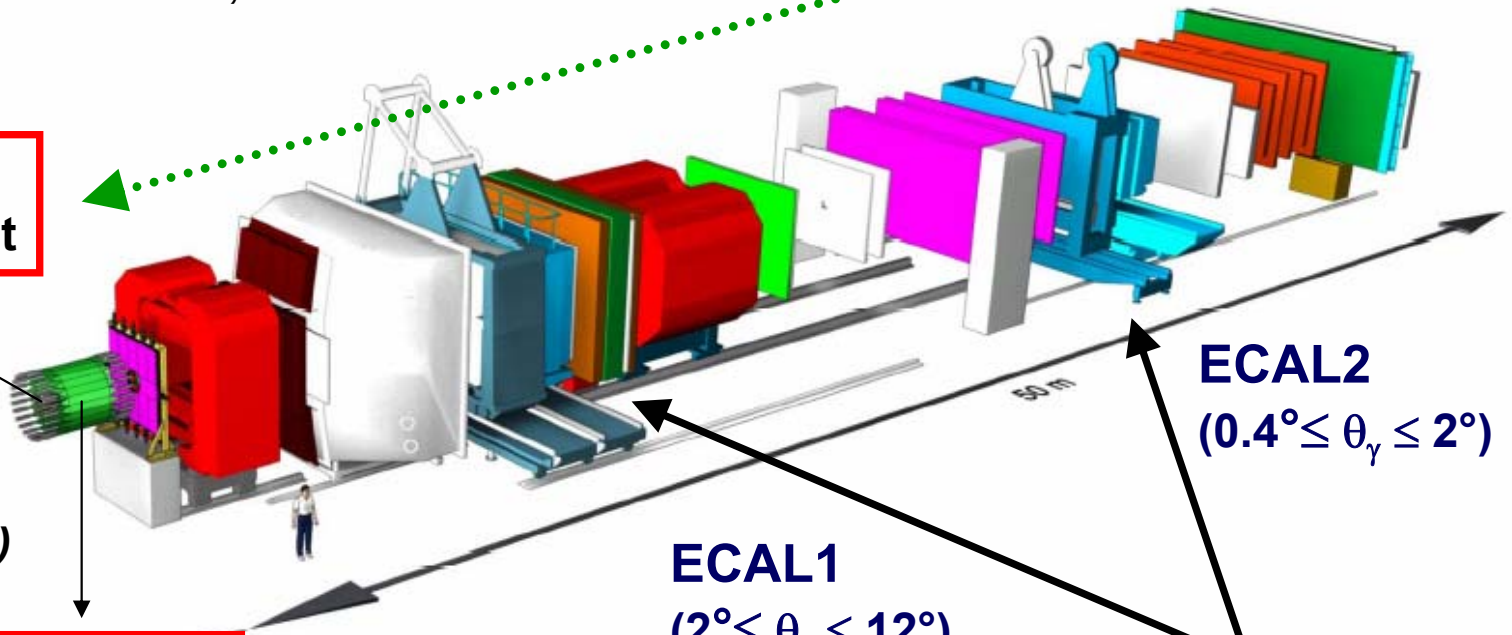
Hadron runs:

- **2004 pilot run** (4 days π^- on Pb target: ~BNL statistics)
- **2008/09** (large statistics (LH_2), $\pi^\pm$, $K^\pm$, $p^\pm$ beam, *plus nuclear targets*)

COMPASS spectrometer: Hadron setup 2008/09

all COMPASS trackers:
SciFi, Si, MM, GEM, DC, Straw, MWPC

+Upgraded trackers close to beam:
ColdSilicons, *PixelGEMs*



0.4m liquid H_2 target

Beam

(muon or hadron)

Recoil detector (RPD) to trigger on reactions inside target

ECAL2
($0.4° \leq \theta_\gamma \leq 2°$)

ECAL1
($2° \leq \theta_\gamma \leq 12°$)

Electromagnetic calorimeters

(final states involving neutrals, e.g. π^0, η, or η')

COMPASS spectrometer: Hadron setup 2008/09

all COMP
SciFi, Si, MM, G
+Upgraded track
ColdSilicons, *Pi*

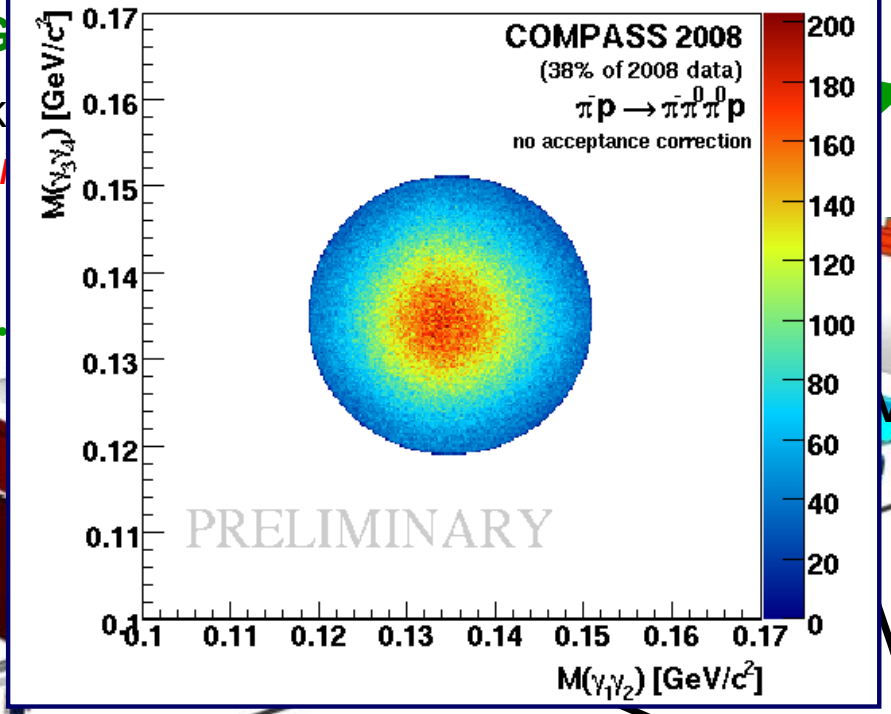
0.4m
liquid H_2 target

Beam

(muon or hadron)

Recoil detector (RPD)
to trigger on reactions
inside target

After final cuts on $\Delta\Phi$ and exclusivity:



ECAL1
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($0.4° \leq \theta_\gamma \leq 2°$)

Electromagnetic calorimeters

(final states involving neutrals,
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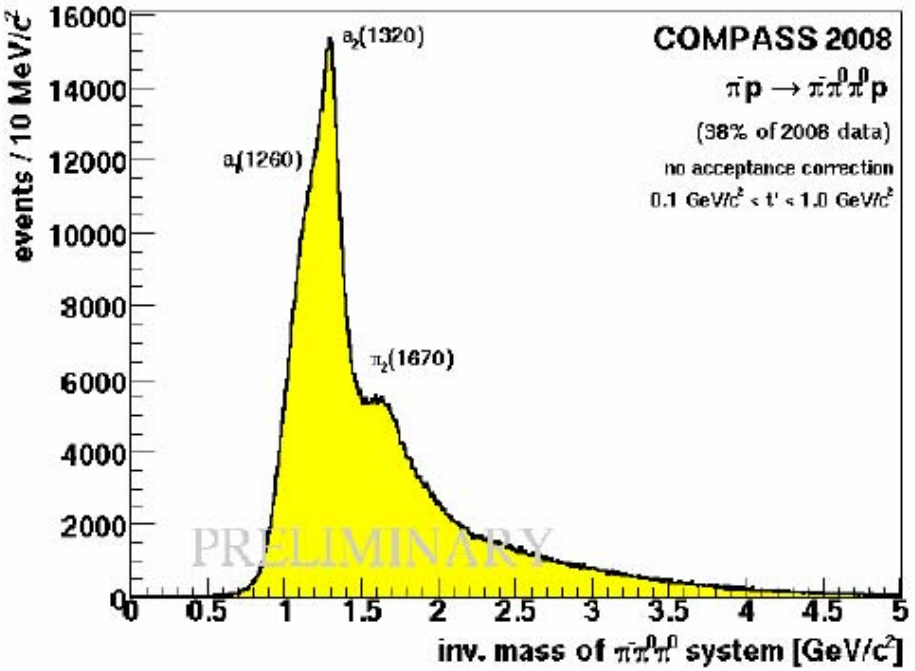
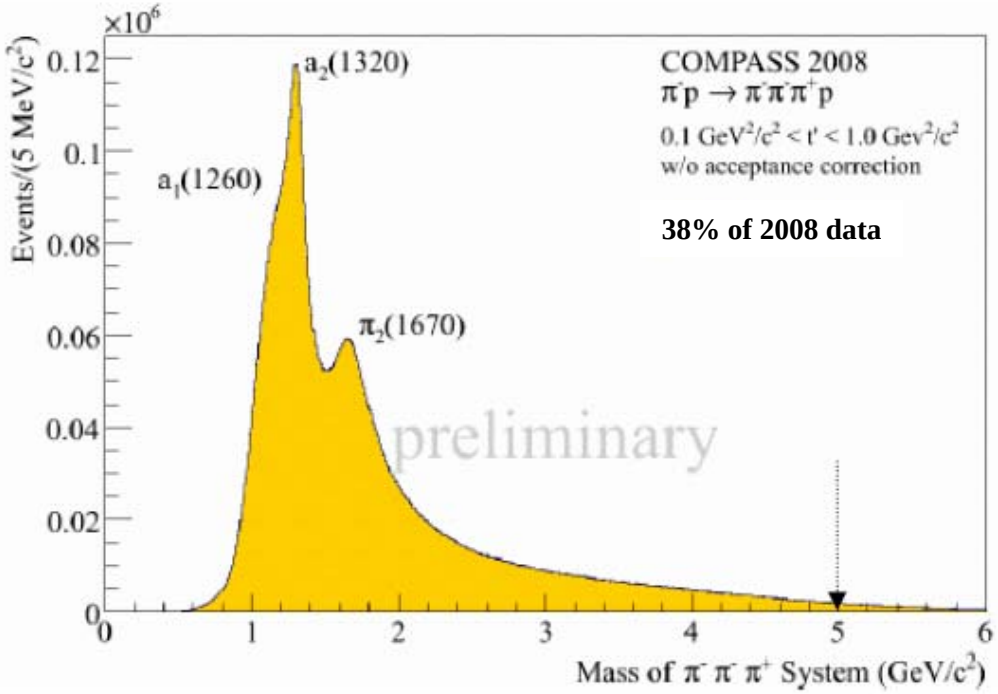
Diffractive dissociation into 3π final states
(2008 data, LH_2 target)

Mass of outgoing 3π system – neutral mode: $\pi^- p \longrightarrow \pi^-\pi^0\pi^0 p$



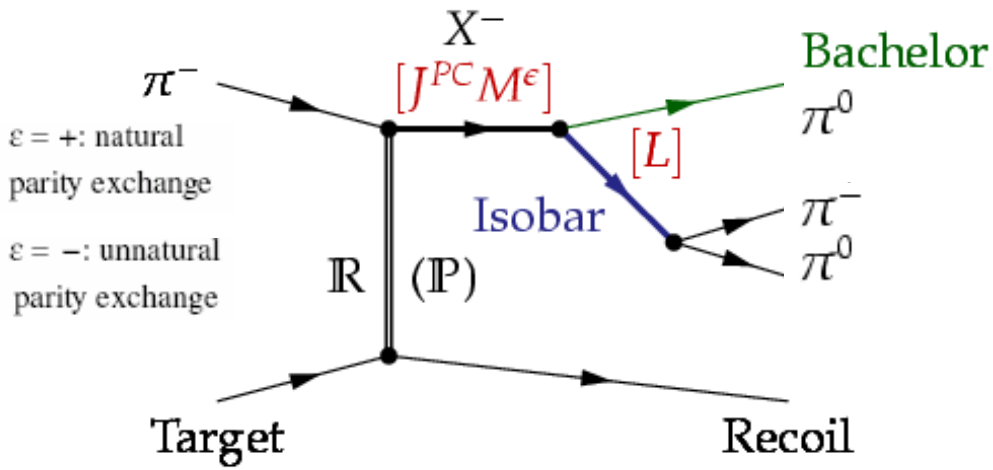
PWA: ~ 1M events

Mass of outgoing 3π system – charged mode: $\pi^- p \longrightarrow \pi^-\pi^+\pi^- p$



PWA: ~ 24M events (acceptance corr.)

PWA using isobar model



X^- decay described using isobar model:

- Intermediate di-pion resonance (isobar)
  - *Spin S and rel. orbital angular momentum L w.r.t bachelor π^-*
  - *L+S couple to J*
- Partial waves (reflectivity basis): $J^{PC}\ M^{\varepsilon}$ [isobar] L

Partial wave analysis:

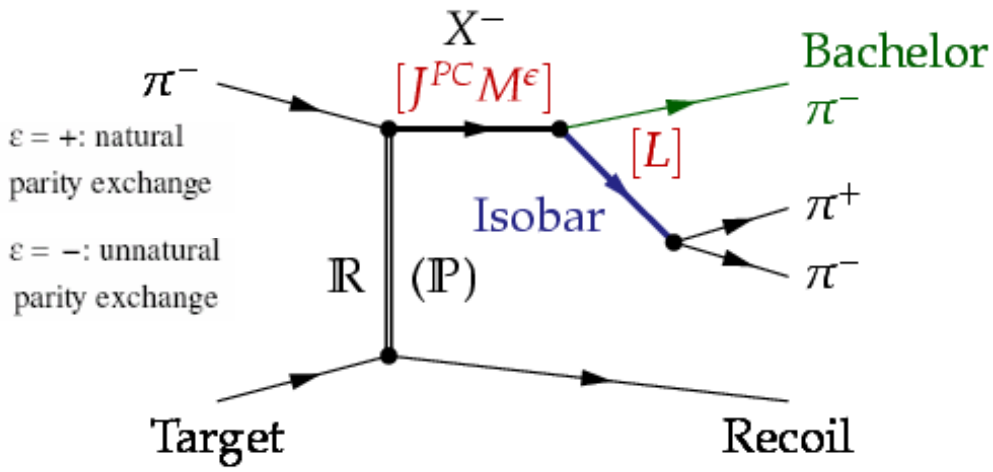
- **program:** Illinois/Protvino/Munich (D.Ryabchikov) software (IHEP/VES, TUM/COMPASS)
- **Isobars:** *$(\pi\pi)_S$ [broad $f_0(600)$+$f_0(1370)$], $f_0(980)$, $\rho(770)$, $f_2(1270)$, $\rho_3(1690)$*
- **Acceptance:** corrections included (2004: ~60%, rather flat, 2008: similar for charged, neutral not yet)

Step 1) Mass independent PWA: (40MeV/c² bins, 52+1 partial waves)

$$\sigma_{indep}(\tau, m, t') = \sum_{\epsilon=\pm1} \sum_{r=1}^{N_r} \left| \sum_i T^{\epsilon}_{ir} f^{\epsilon}_i(t') \psi^{\epsilon}_i(\tau, m) / \sqrt{\int \left|\psi^{\epsilon}_i(\tau', m)\right|^2 d\tau'} \right|^2$$

- Production amplitudes $T^{\epsilon}_{ir} \rightarrow$ extended maximum likelihood fit
- Decay amplitudes $\psi^{\epsilon}_i(\tau, m)$ (Zemach tensors, D functions)

PWA using isobar model



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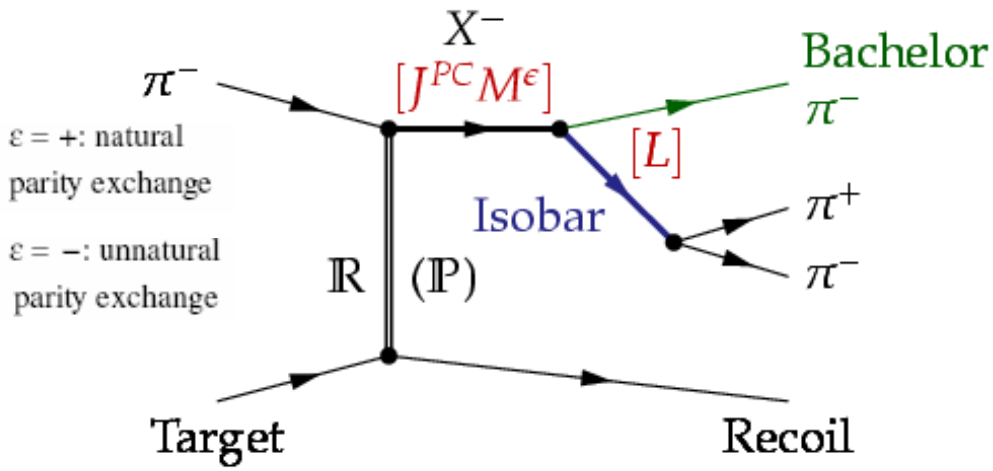
- Main partial waves chosen, parameterised by Breit-Wigner
- Coherent background for some waves

PWA using isobar model



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Step 2) Mass dependent χ^2 fit: (to mass independent result)

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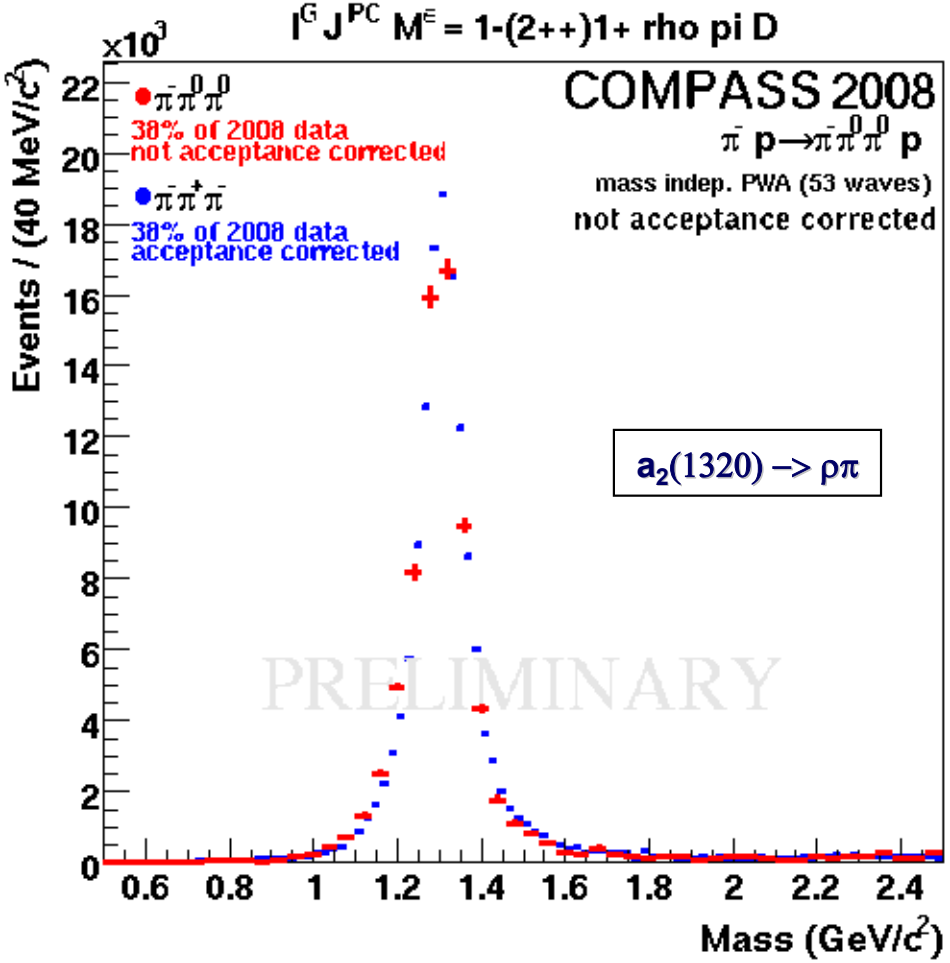
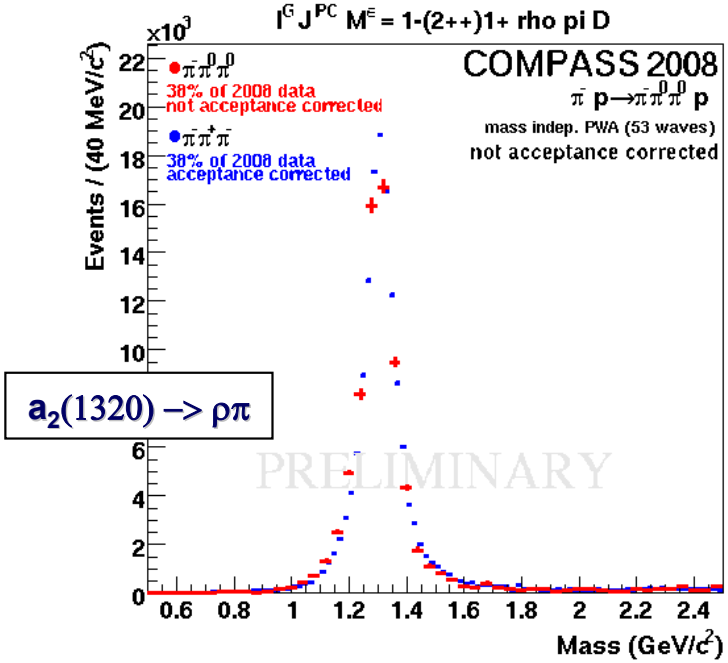
First comparison: Neutral vs. charged mode
Mass independent PWA results
-- normalisation --



First comparison: Neutral vs. charged mode

simple isospin symmetry check



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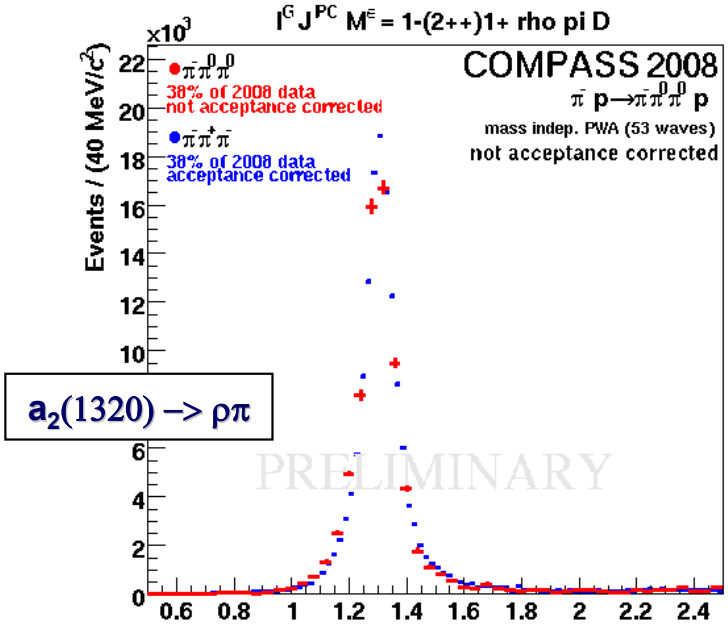

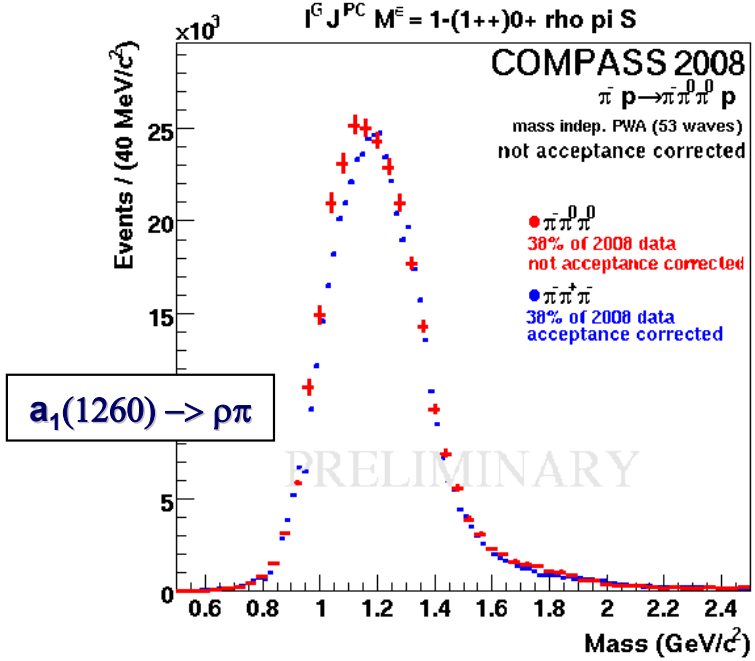

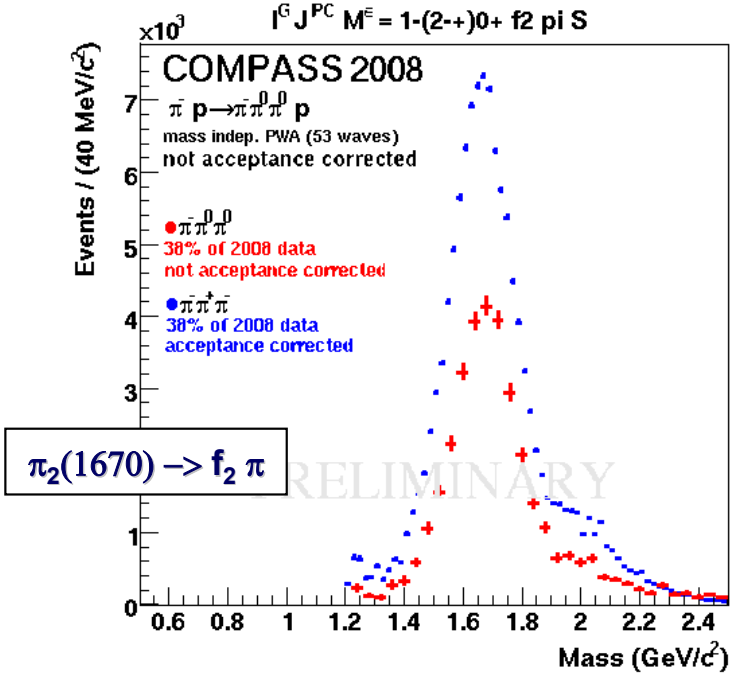

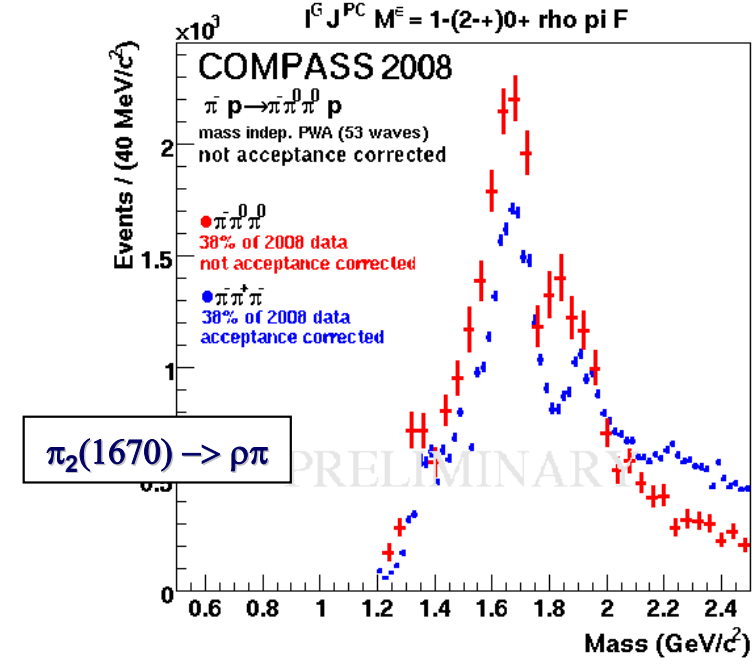

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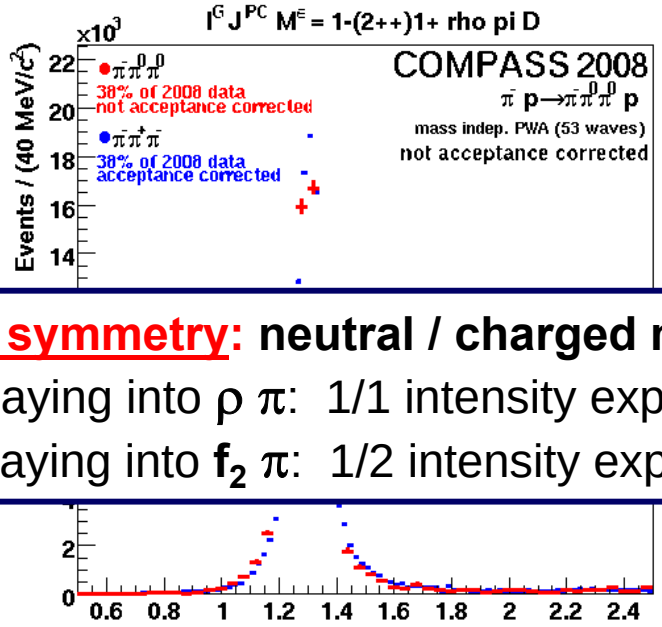
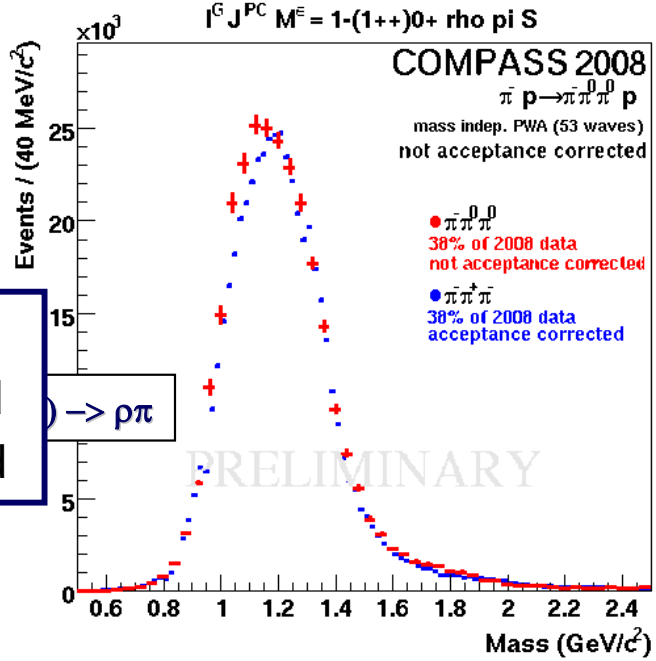
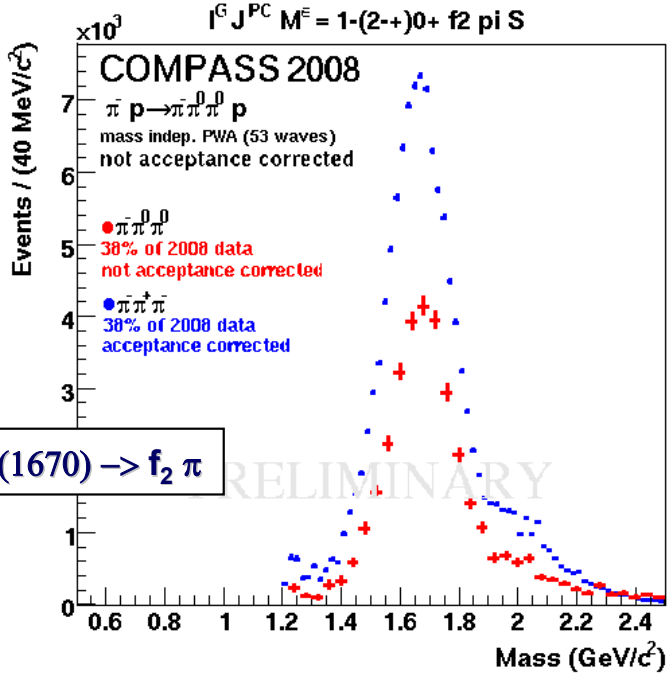
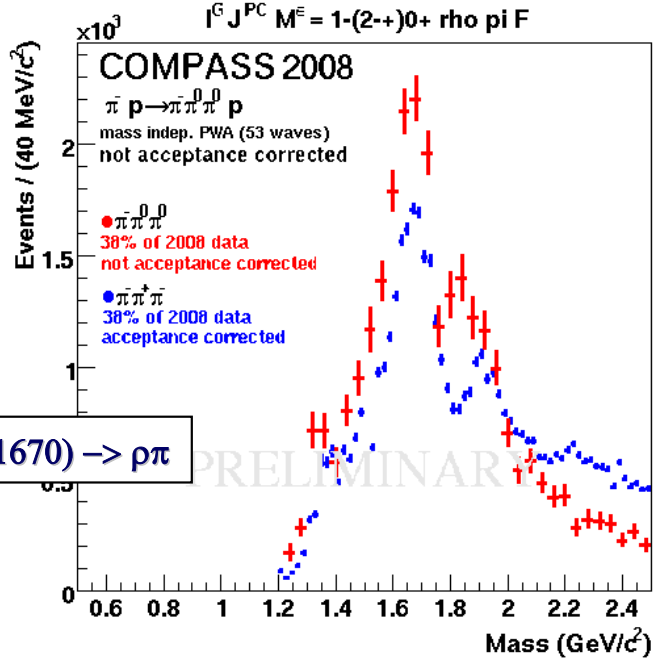




Isospin symmetry: neutral / charged mode

- X^- decaying into $\rho\,\pi$: 1/1 intensity expected
- X^- decaying into $f_2\,\pi$: 1/2 intensity expected





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General: Branching not entirely determined by Clebsch-Gordon coeff.,
but also Bose-Symmetrisation with the bachelor π:

=> *no effect for resonances decaying into* $\rho\pi$ (same effect)

=> *BR might differ for resonances going to* $f_{0,2}\pi$

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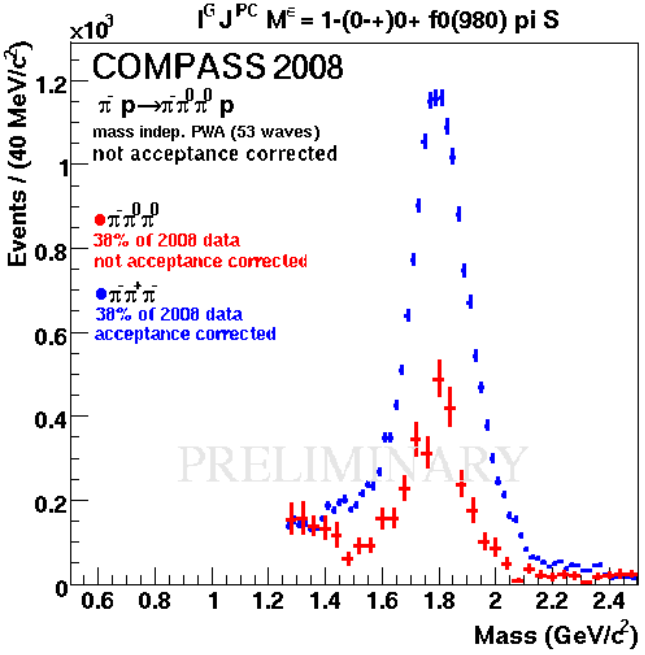
Checked by calculation:

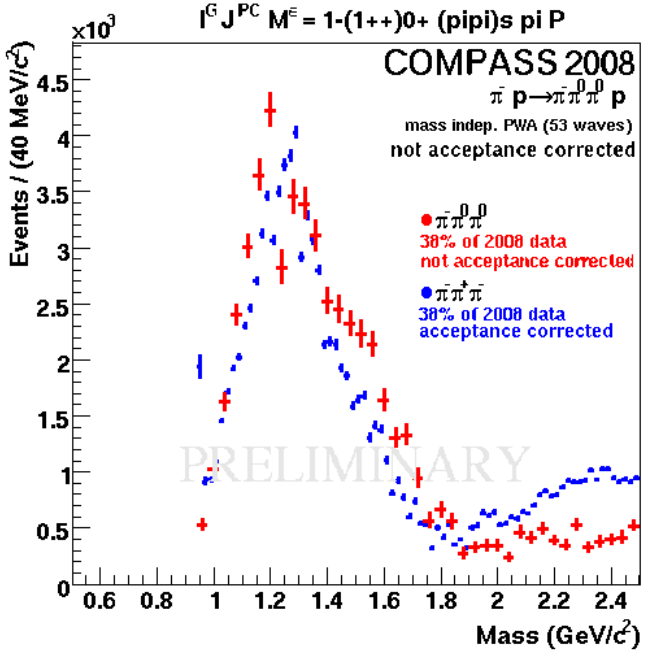
$\mathrm{BR} = \mathrm{N}(\pi^-\pi^0\pi^0)/\mathrm{N}(\pi^-\pi^-\pi^+)$ – calculated from isobar model amplitudes
$\mathrm{BR}(\ 0^{-+} f_0(980)\pi\ S) = 0.44$ (at 1.8 GeV)
$\mathrm{BR}(\ 1^{++}(\pi\pi)_s\pi\ P) = 0.80$ (at 1.3 GeV)
$\mathrm{BR}(\ 2^{-+} f_2(1270)\pi\ S) = 0.50$ (at 1.67 GeV)

Selected partial waves
isospin symmetry check ctd.

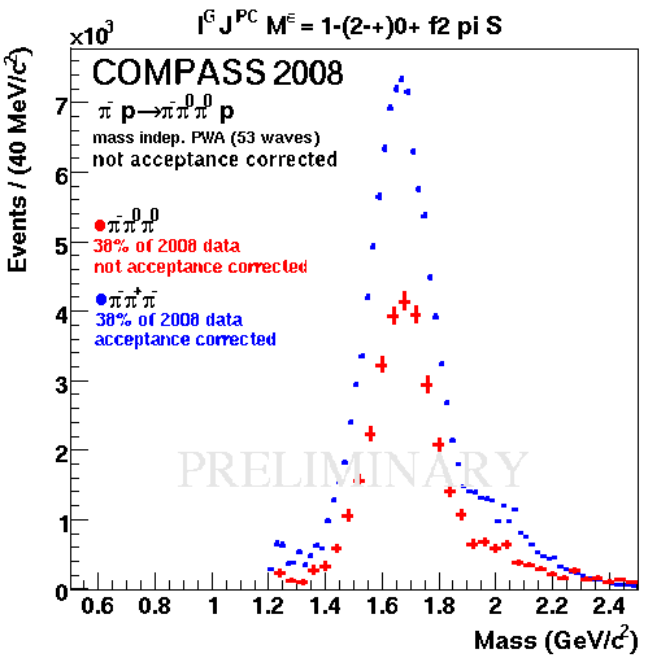
$\pi(1800) \rightarrow \rho\pi$



$a_1(1260) \rightarrow (\pi\pi)_s\,\pi$



$\pi_2(1670) \rightarrow f_2\,\pi$

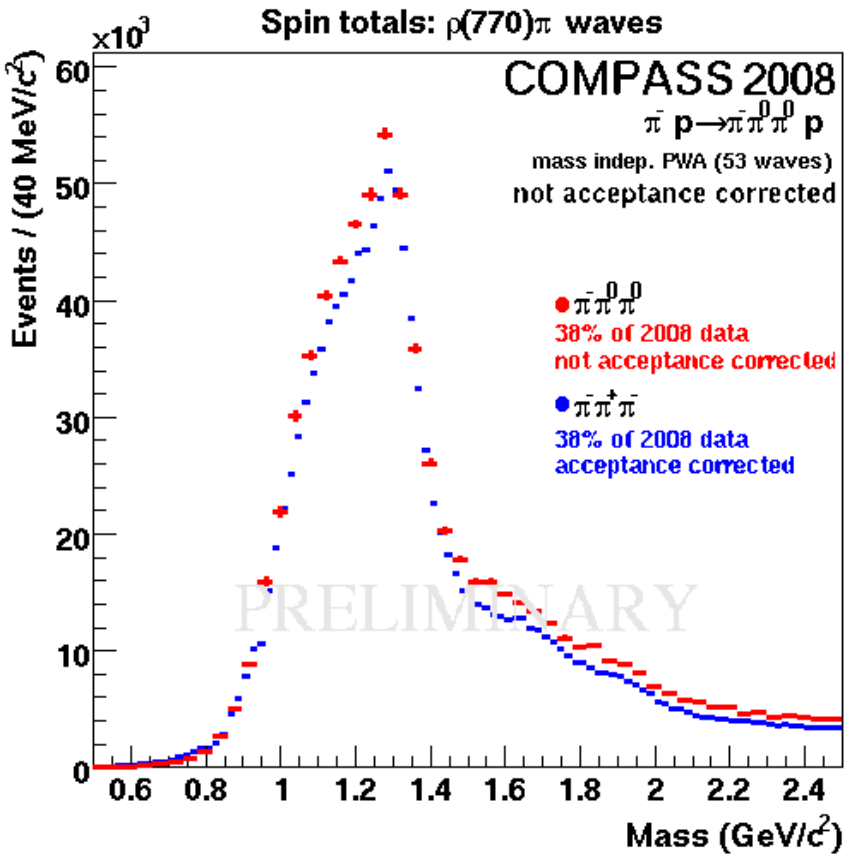


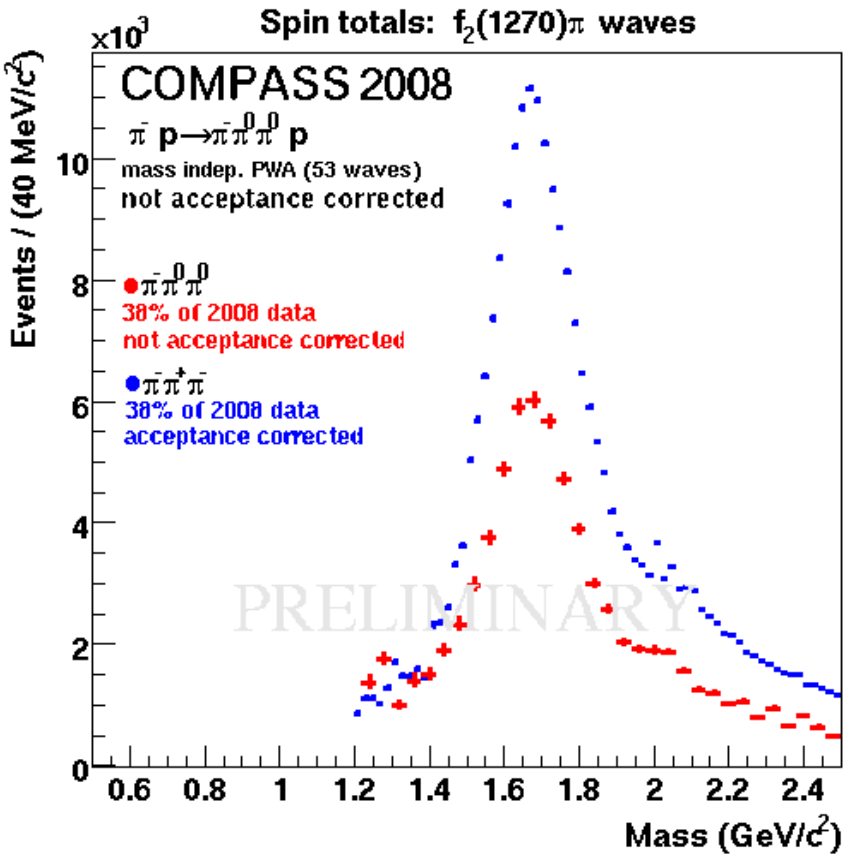
$BR = N(\pi^-\pi^0\pi^0)/N(\pi^-\pi^-\pi^+)$ – calculated from isobar model amplitudes	
$BR(\ 0^{-+} f_0(980)\pi\ S) = 0.44$ (at 1.8 GeV) $BR(\ 1^{++}(\pi\pi)_s\pi\ P) = 0.80$ (at 1.3 GeV) $BR(\ 2^{-+} f_2(1270)\pi\ S) = 0.50$ (at 1.67 GeV)	in fair agreement with our data

Two sets of partial wave totals

3π diffractive -- Neutral vs. Charged mode: 53 waves

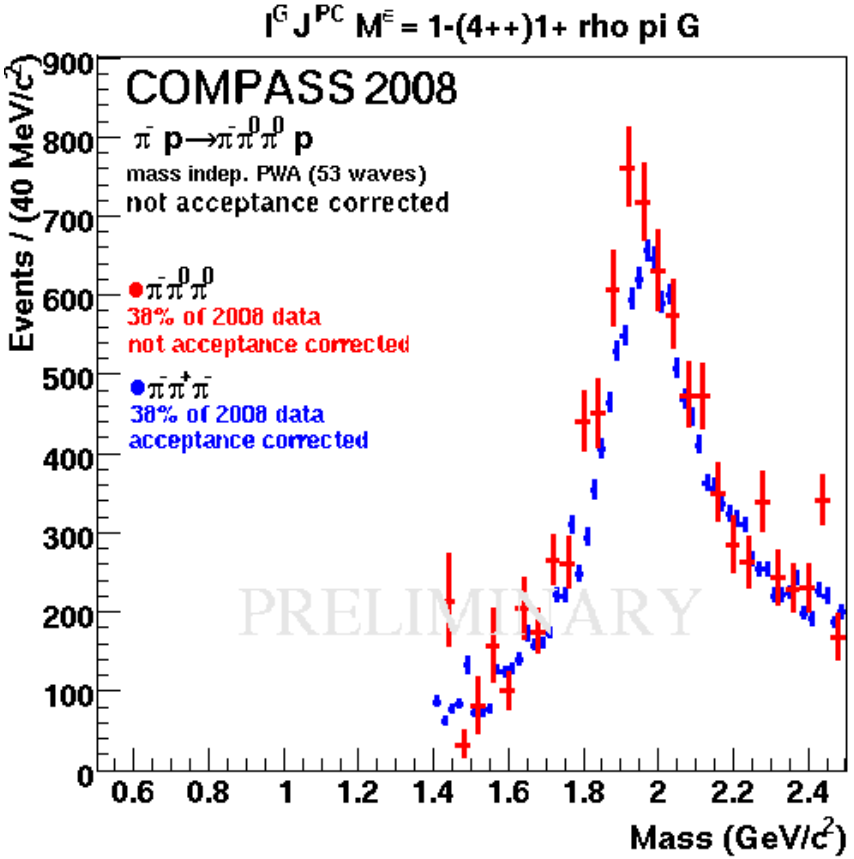
Spin totals show isospin symmetry:



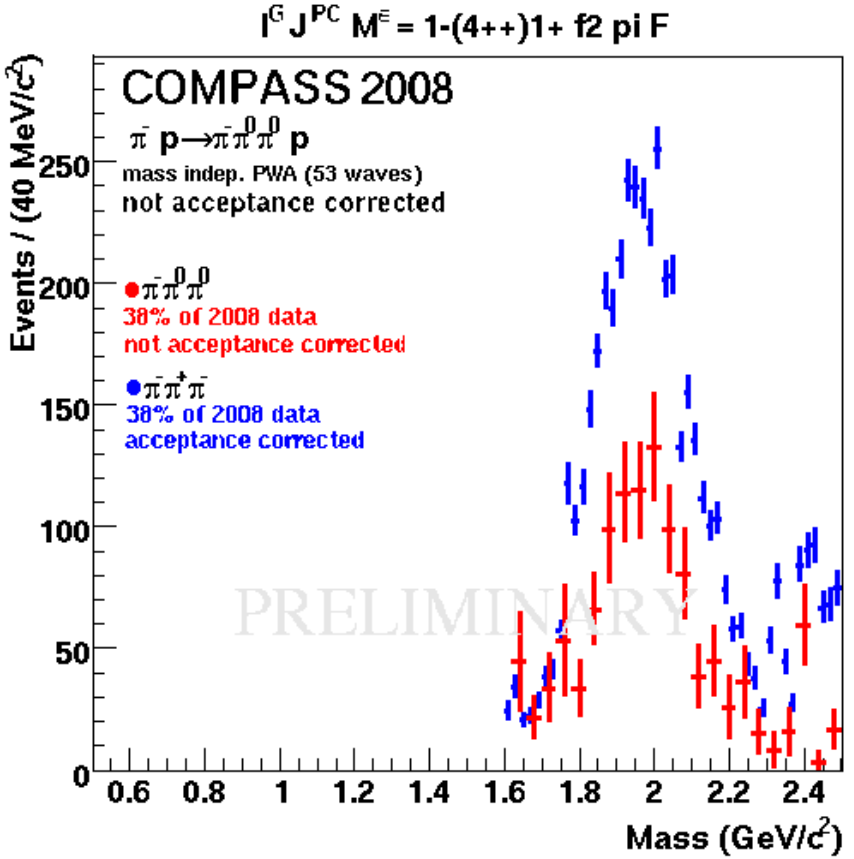


Selected partial waves
isospin symmetry check ctd.

$a_4(2040) \rightarrow \rho\pi$

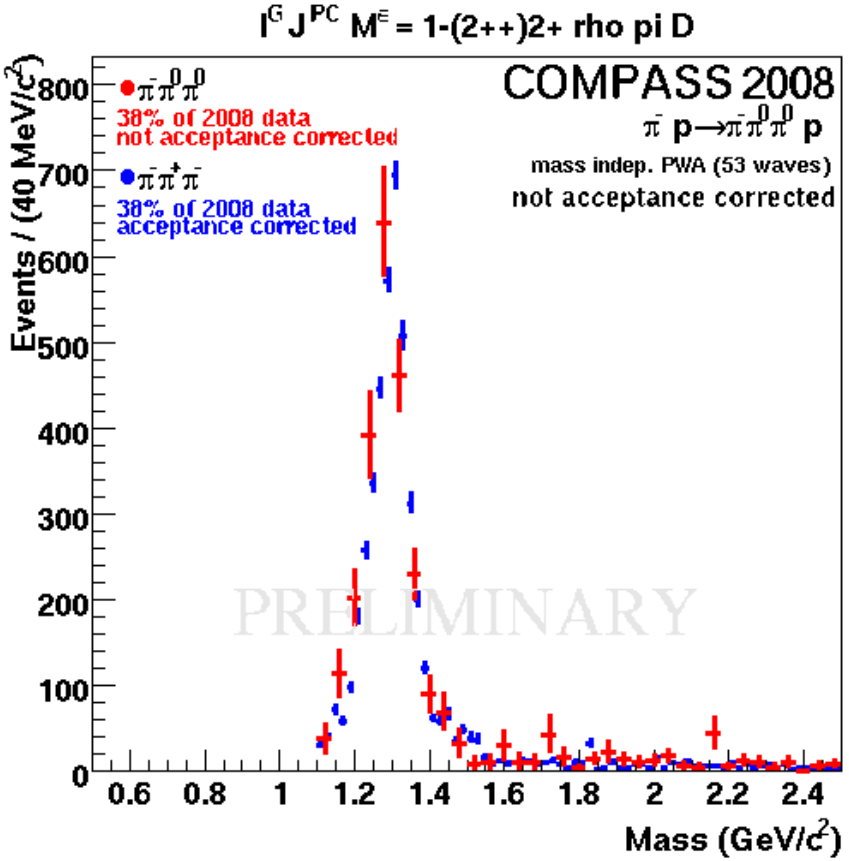


$a_4(2040) \rightarrow f_2\,\pi$

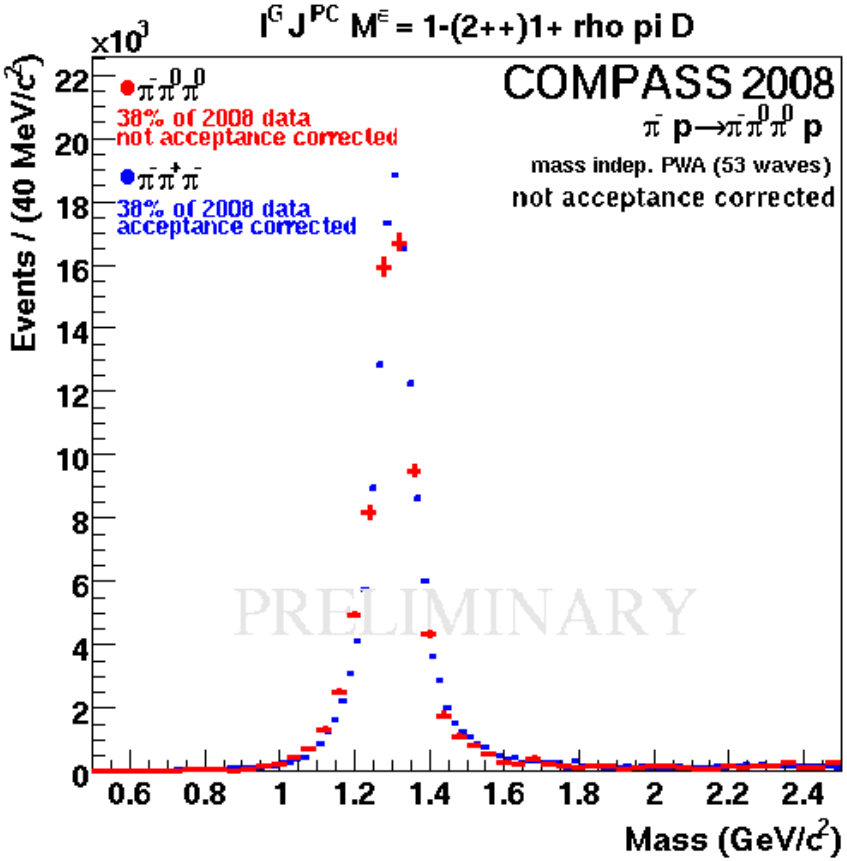


Selected partial waves
isospin symmetry check ctd.

$a_2(1320)$ (M=2) –> ρπ

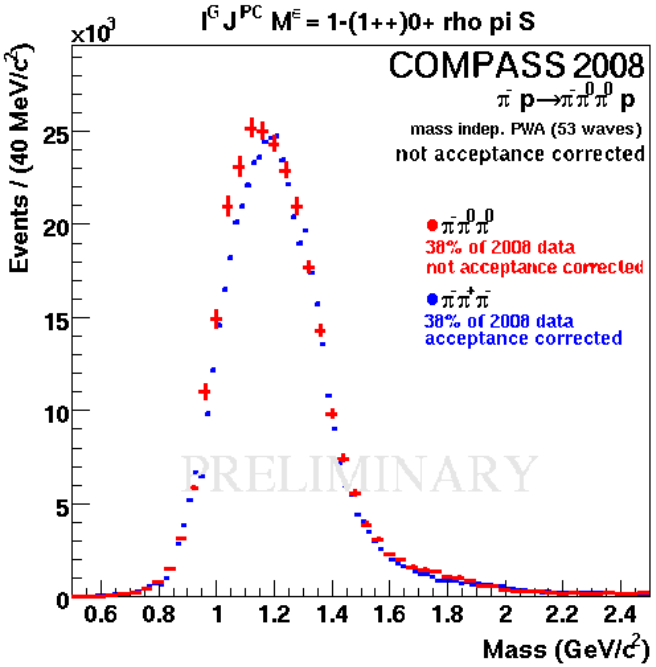


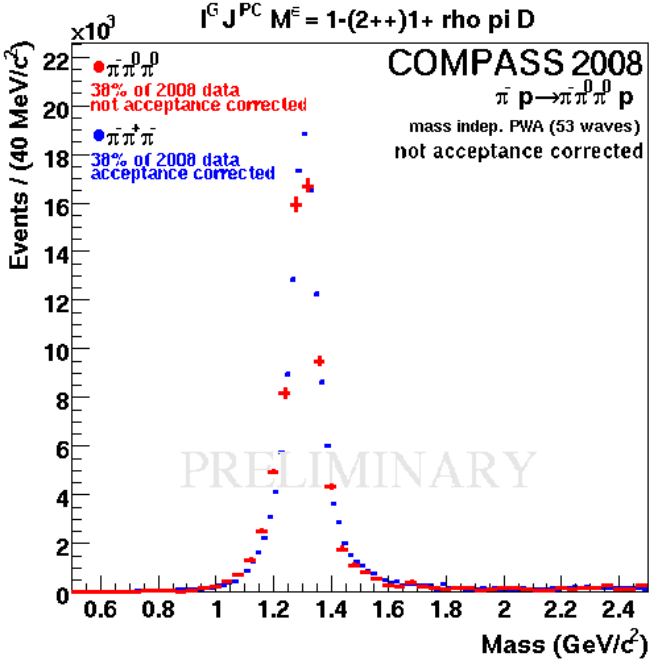
$a_2(1320)$ (M=1) –> ρπ



Selected partial waves & phases

3π diffractive -- Neutral vs. Charged mode: 53 waves





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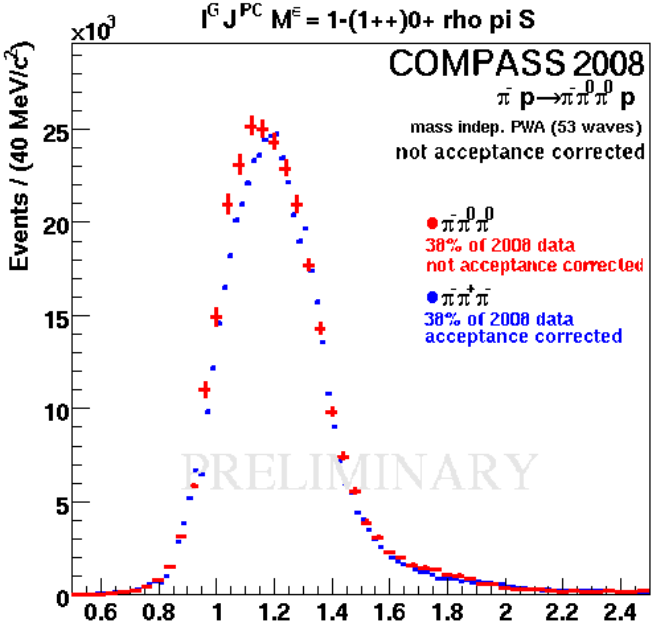
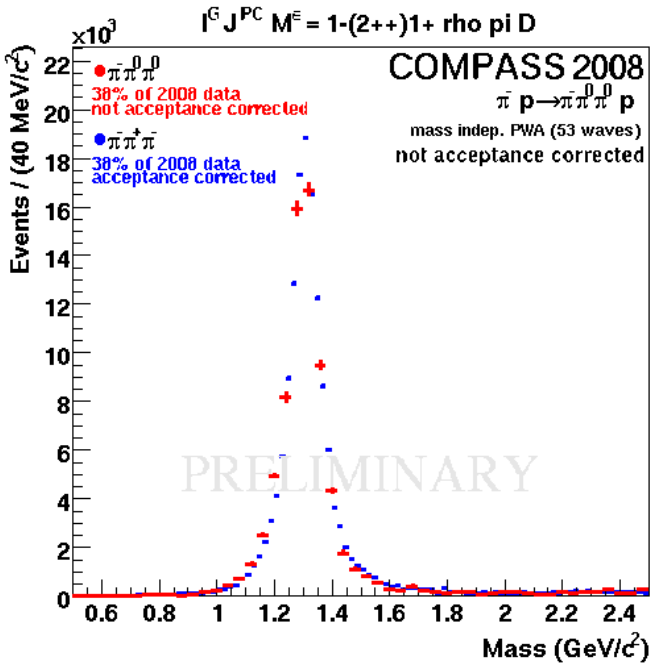
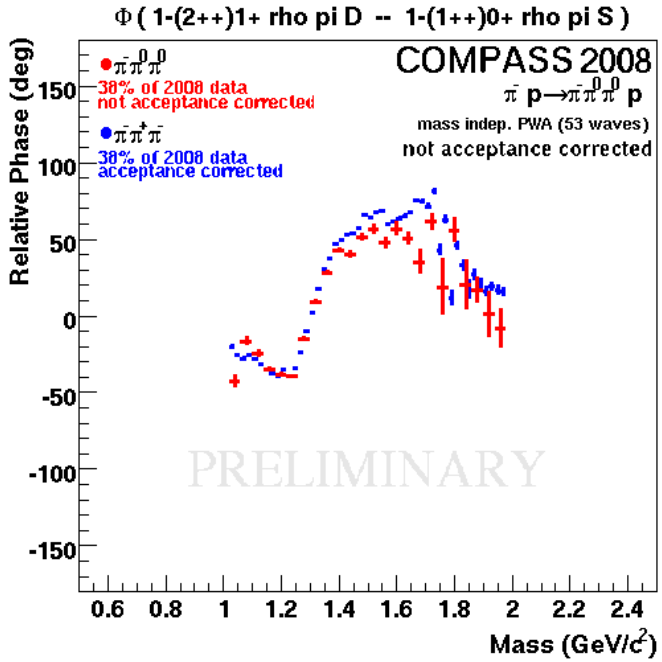
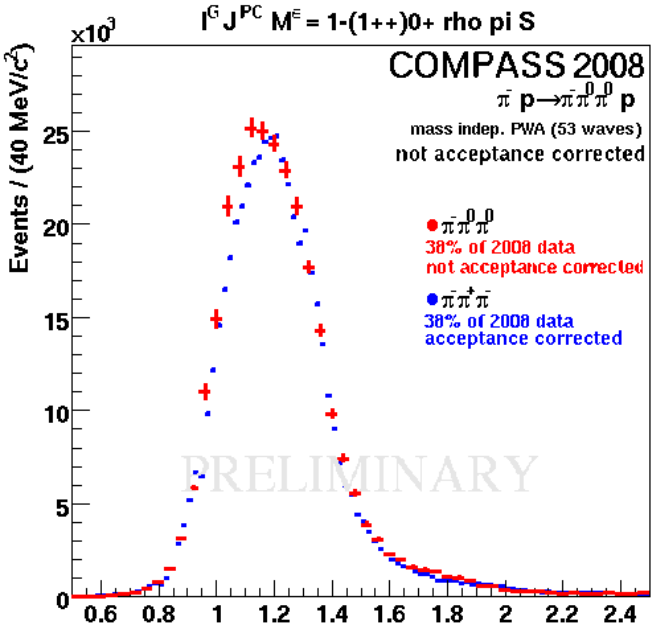


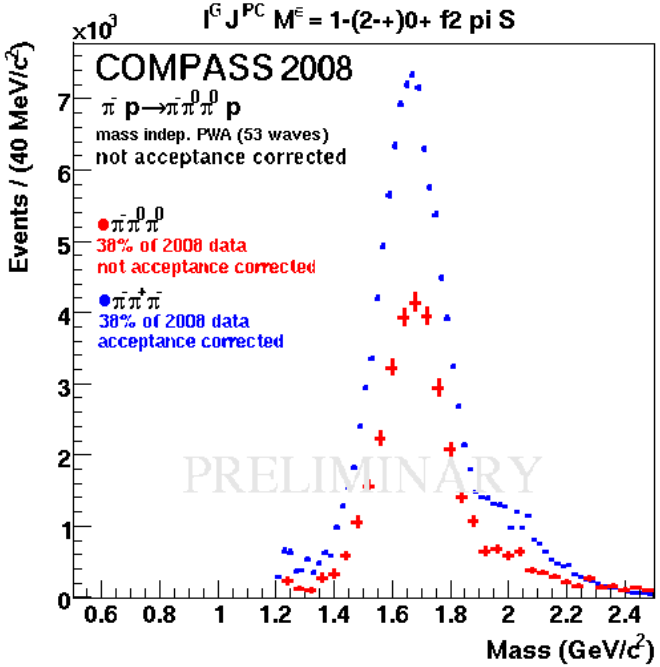


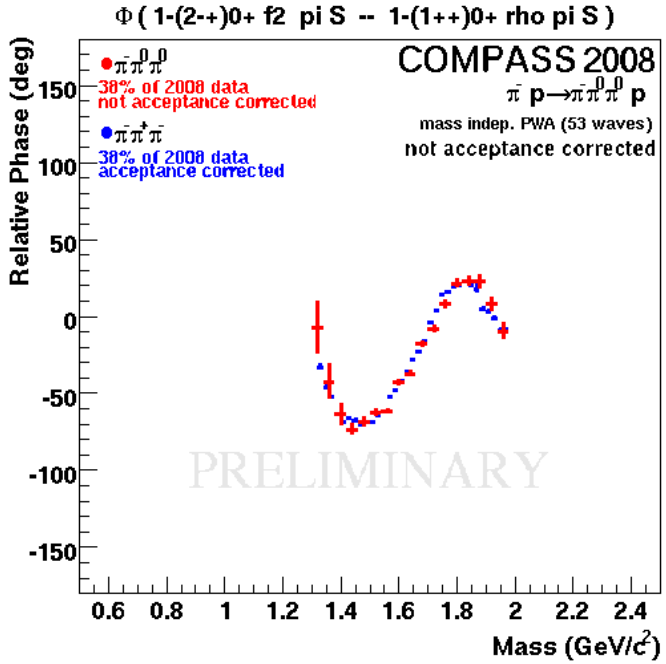


Selected partial waves & phases

3π diffractive -- Neutral vs. Charged mode: 53 waves







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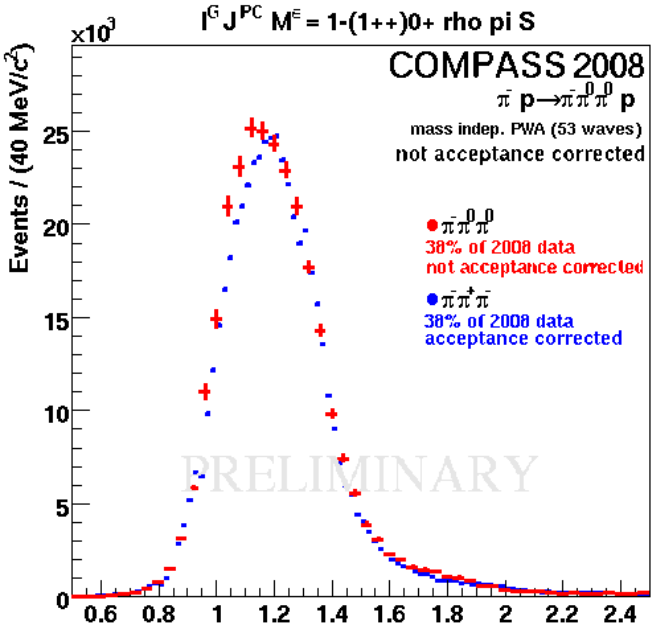

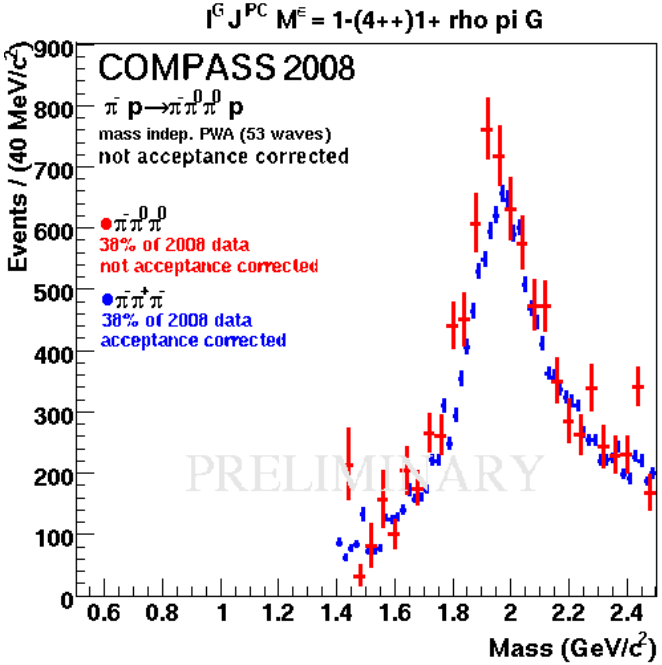

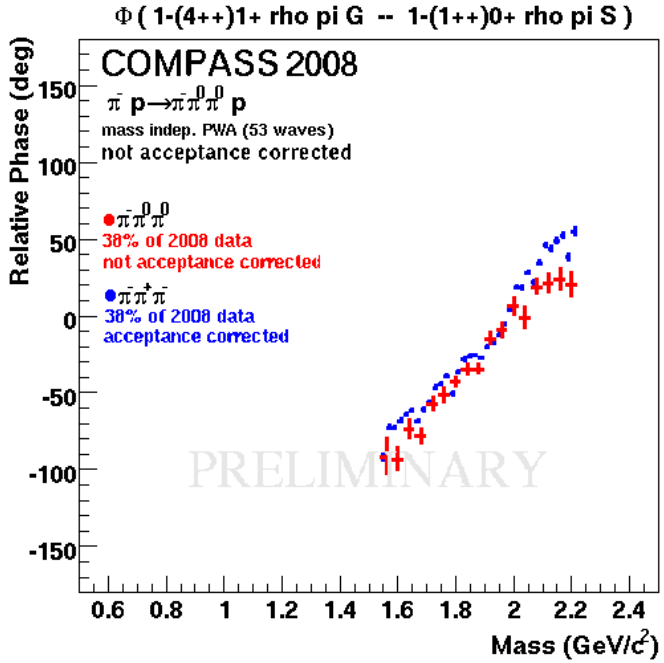

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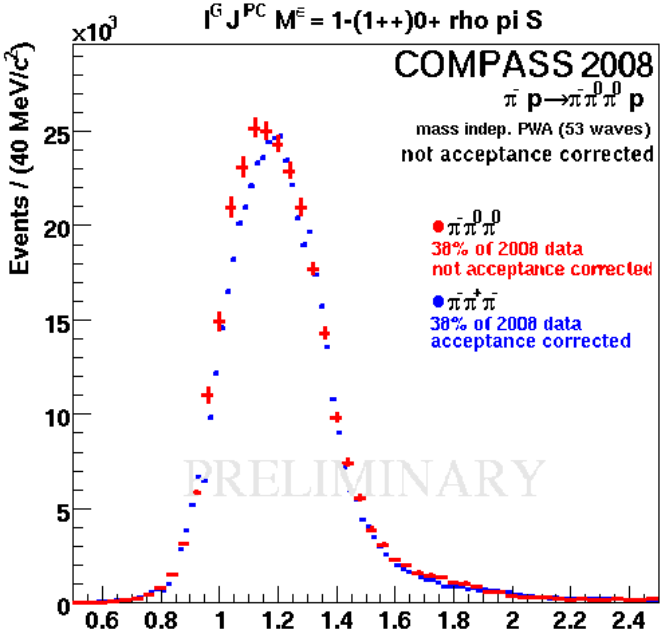

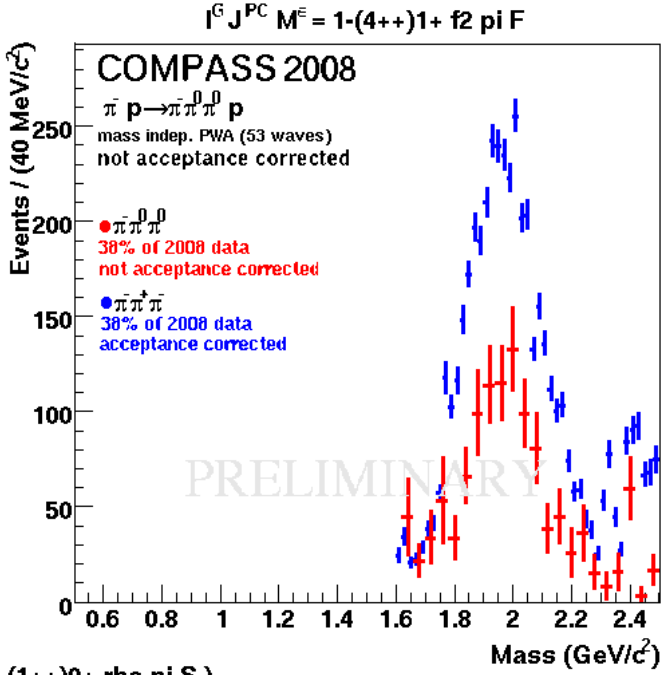

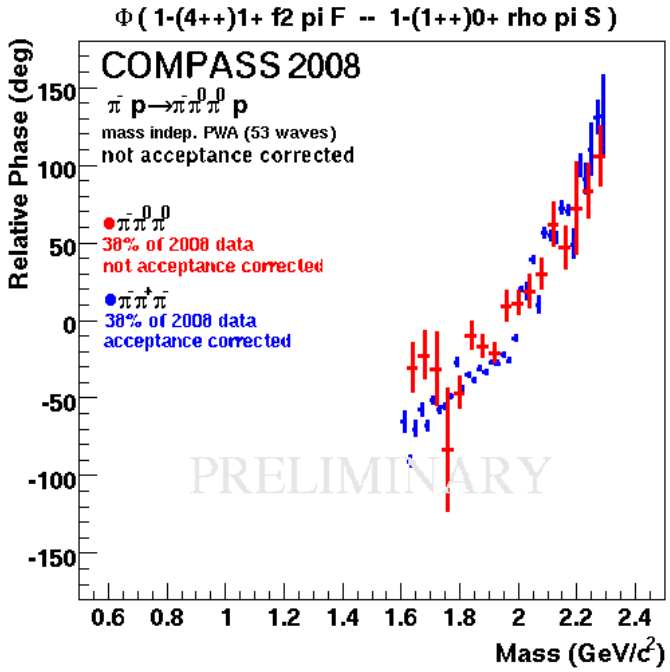

Selected partial waves & phases

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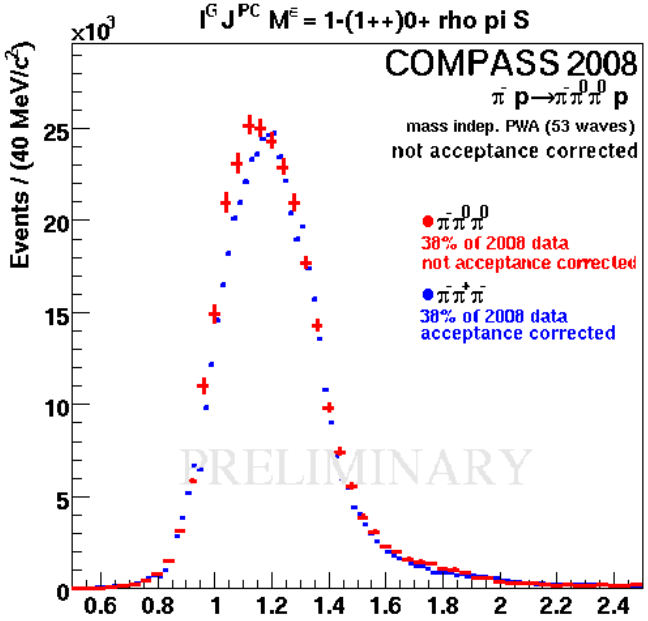

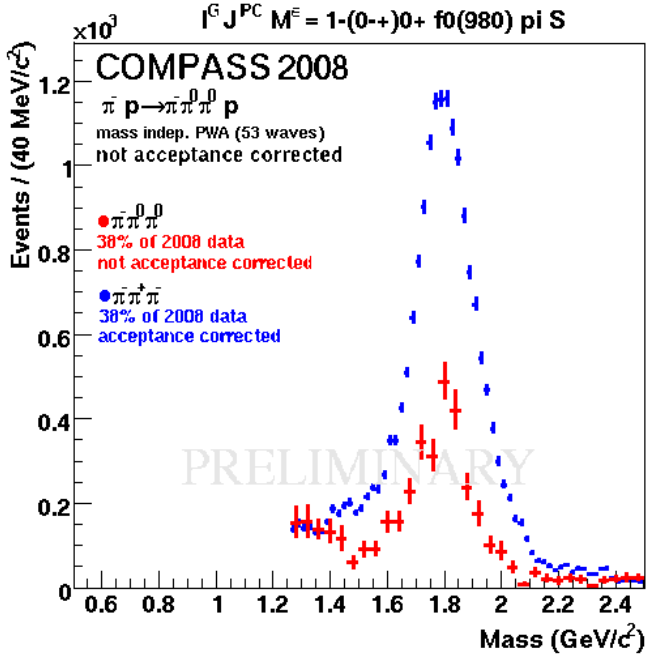

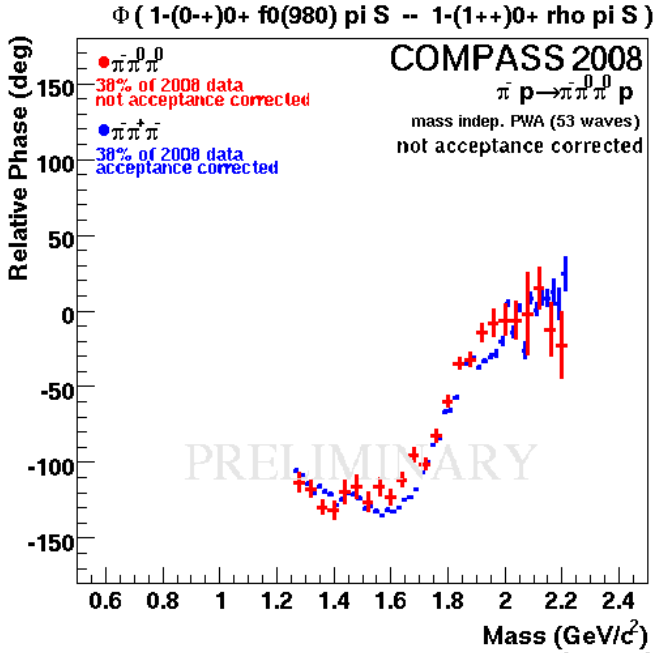

Selected partial waves & phases

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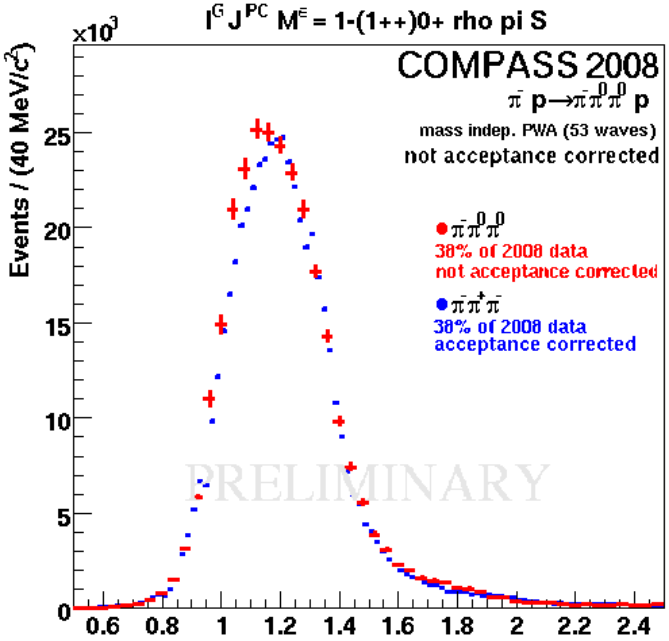

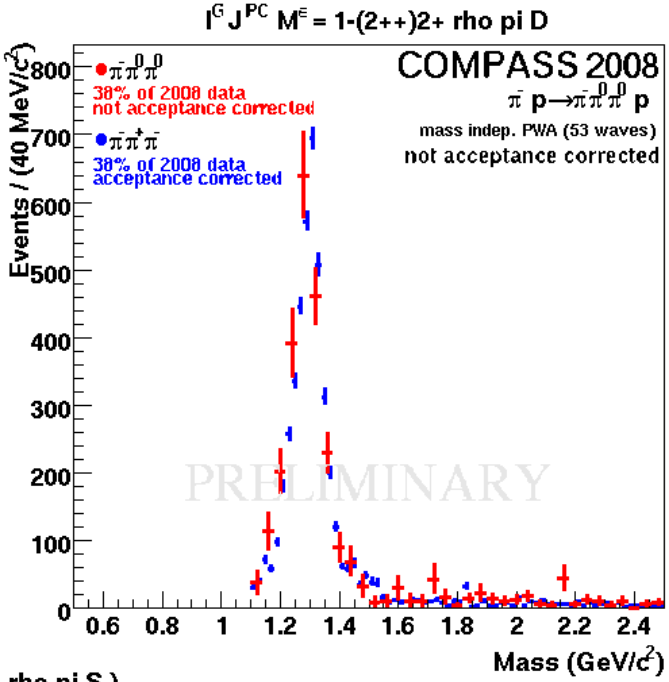

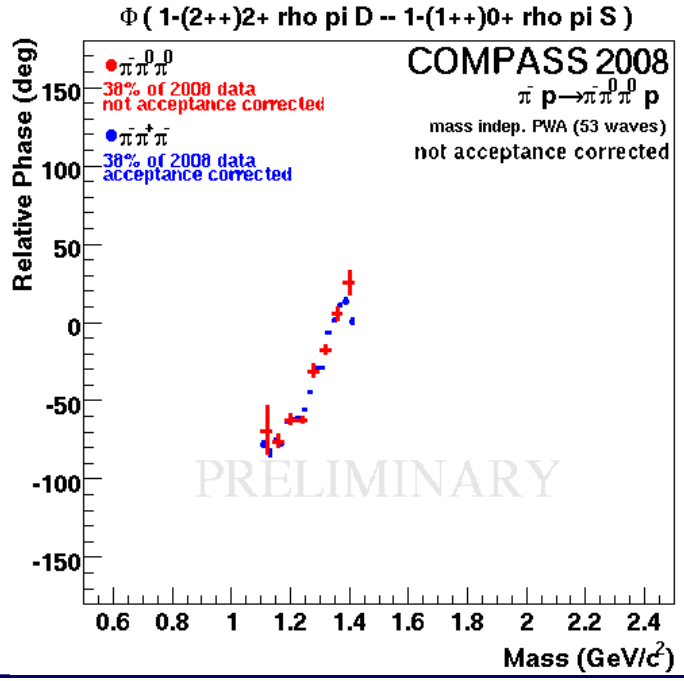

Summary & conclusions

- **COMPASS: high potential for spin-exotic search**
  - ✓ 2008/09: **Data taken with hadron beams on proton & nuclear targets**
  - ✓ **Very high statistics** *(1-2 orders of magnitude x world statistics)*

- **COMPASS measures Neutral & Charged channels**
  - ✓ **First results on 3π final states 2008 data** (diffr. dissociation)
  - ✓ **Comparison $\pi^-\pi^0\pi^0$ vs. $\pi^-\pi^+\pi^-$ final states quite promising:**
    - → *Mass-independent PWA: isospin symmetry*
    - → *main & small waves consistently seen → intensities & phases*
    - → *also angular distributions (GFJ: $\cos\theta$, Φ_{TY})*

=> Independent confirmation of new states within same experiment!

(competing statstics with BNL, E852 re-analysis [Dzierba et al., 2006])

Outlook:

- Acceptance corrections for neutral mode *(before showing any signal in exotic 1^{-+} wave)*
- Dedicated leakage & background studies
- Further development of PWA model
- Mass-dependent PWA