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)

Frank Nerling
Universität Freiburg, Physikalisches Institut
for the COMPASS Collaboration

Hadron 2011, XIV Intern. Conf. on Hadron Spectroscopy, Munich, Germany, 13-17 June 2011

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 –> $f_1(1285)\,\pi$, $b_1(1235)\,\pi$

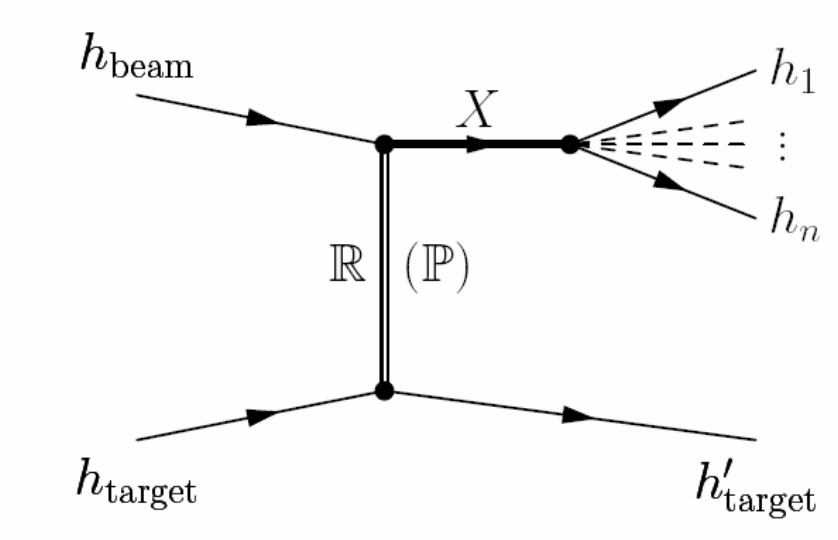
.... still controversal → COMPASS

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):

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 –> $f_1(1285)\,\pi$, $b_1(1235)\,\pi$

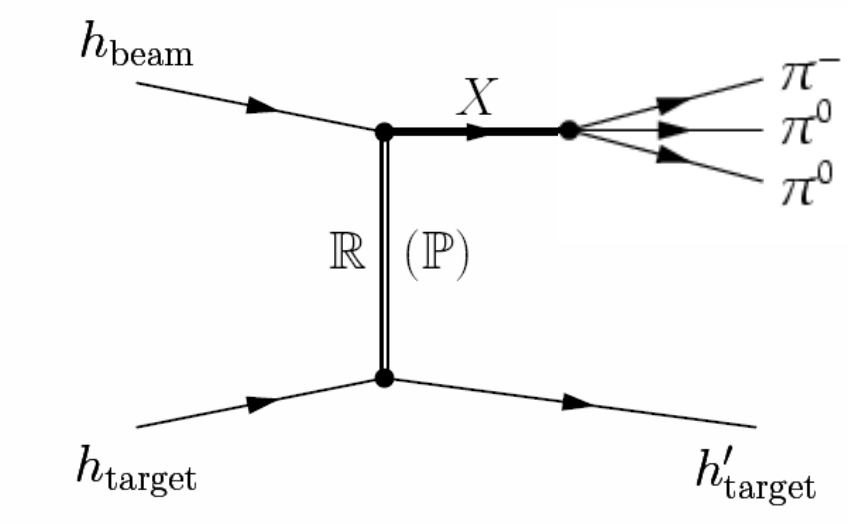
.... still controversal → COMPASS

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. $(3\pi)^-$:
  $\pi^-\,\mathbf{p} \longrightarrow \pi^-\pi^0\pi^0\,\mathbf{p}$ (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 –> $f_1(1285)\,\pi$, $b_1(1235)\,\pi$

.... still controversal → COMPASS

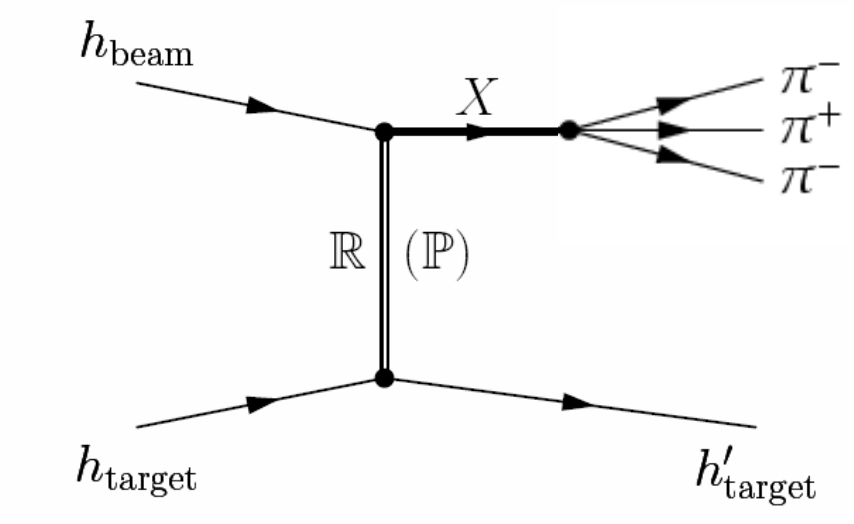
Diffractive scattering

- 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. $(3\pi)^-$:

  $\pi^-\,\mathbf{p} \longrightarrow \pi^-\pi^+\pi^-\,\mathbf{p}$ (charged mode)
- small momentum transfer

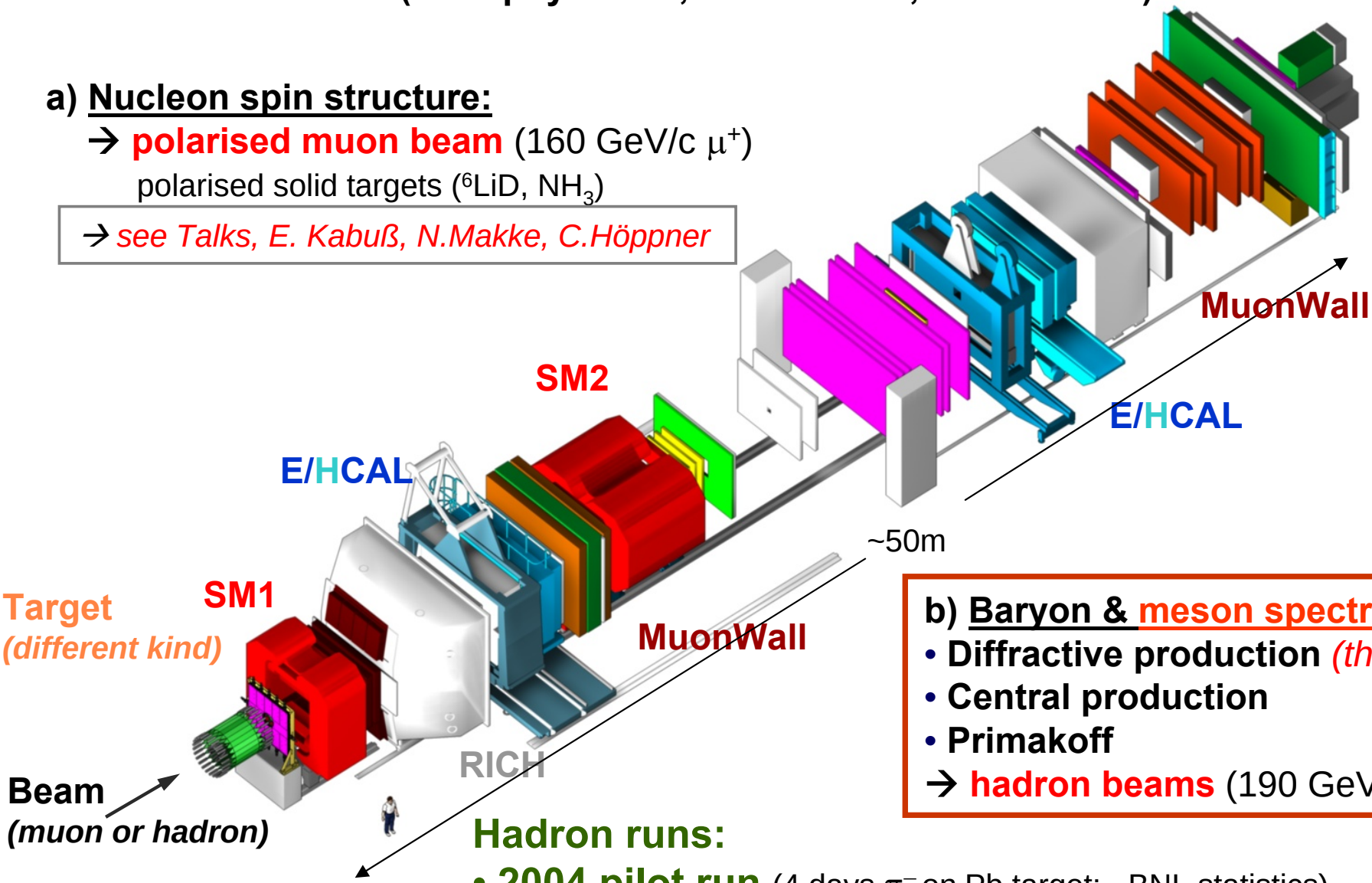


→ *cf. previous, talk by F. Haas*

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**

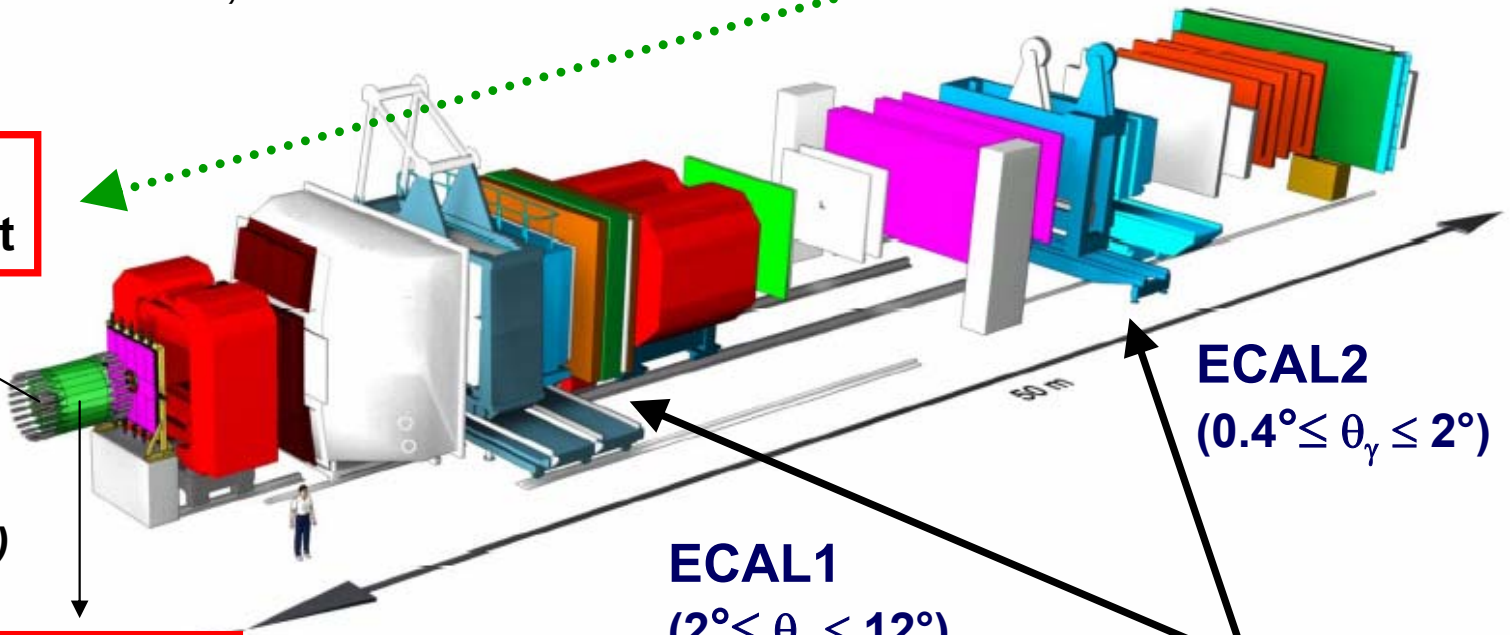
→ **hadron beams** (190 GeV/c π^-,K^-)

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*

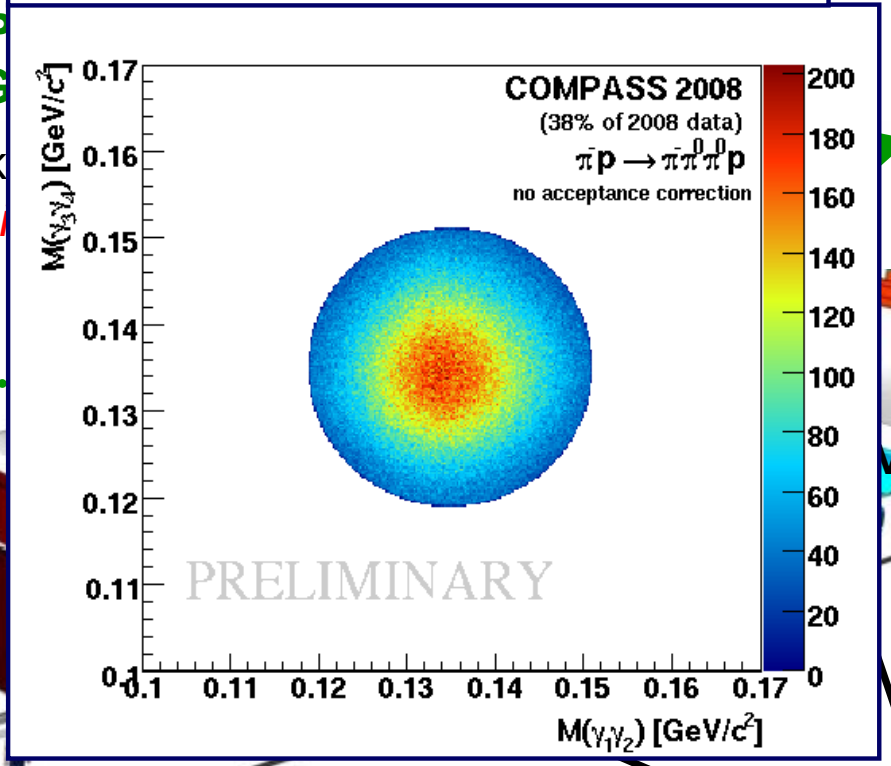
0.4m
liquid H_2 target

Beam

(muon or hadron)

Recoil detector (RPD)
to trigger on reactions
inside target

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



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

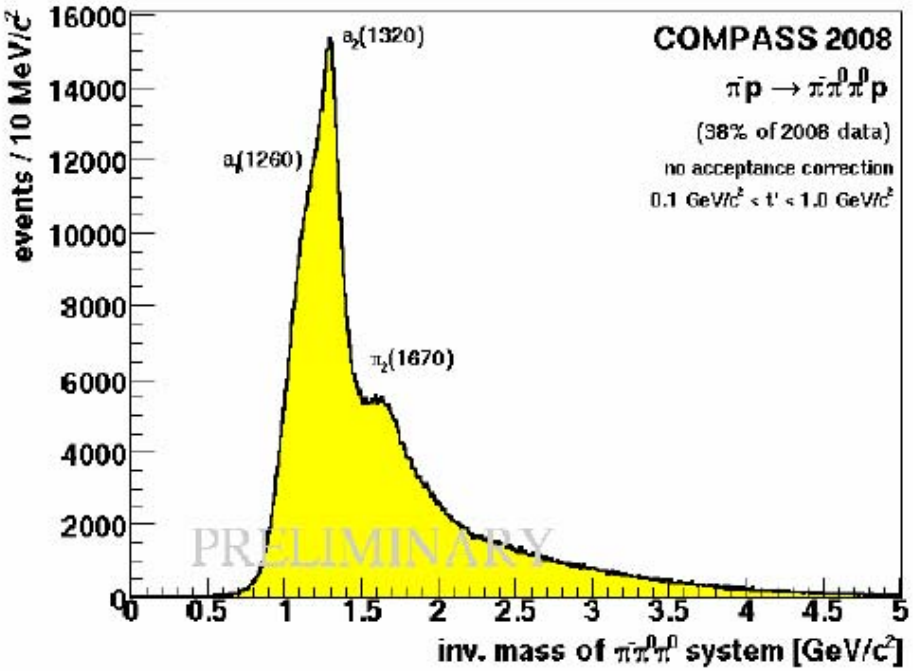
ECAL2
($0.4° \leq \theta_\gamma \leq 2°$)

Electromagnetic calorimeters

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

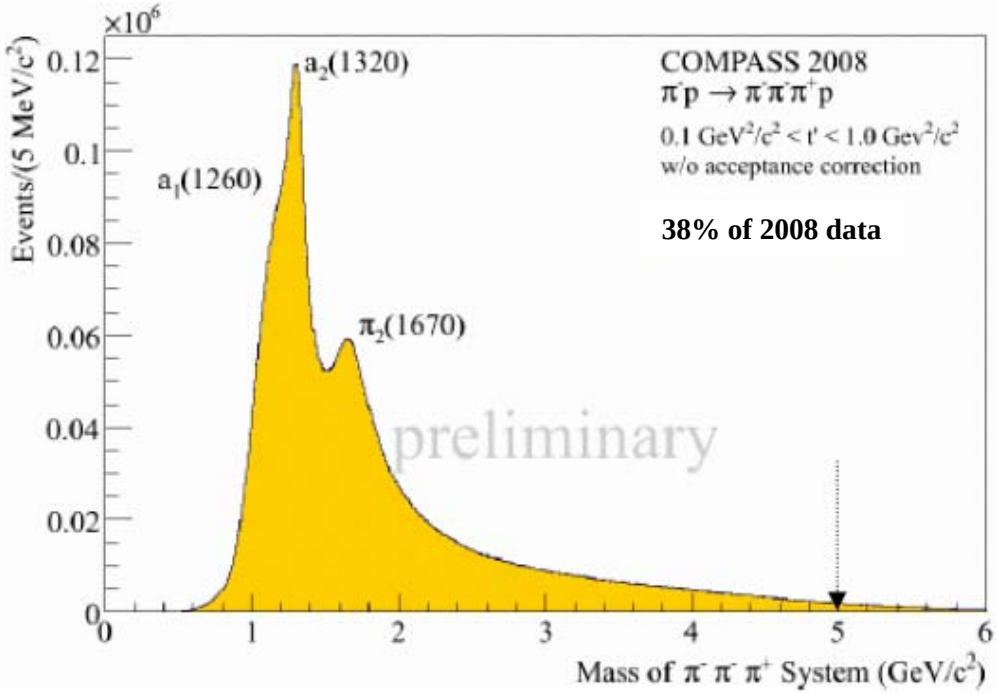
Diffractive dissociation into 3π final states
(2008 data, LH_2 target)

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



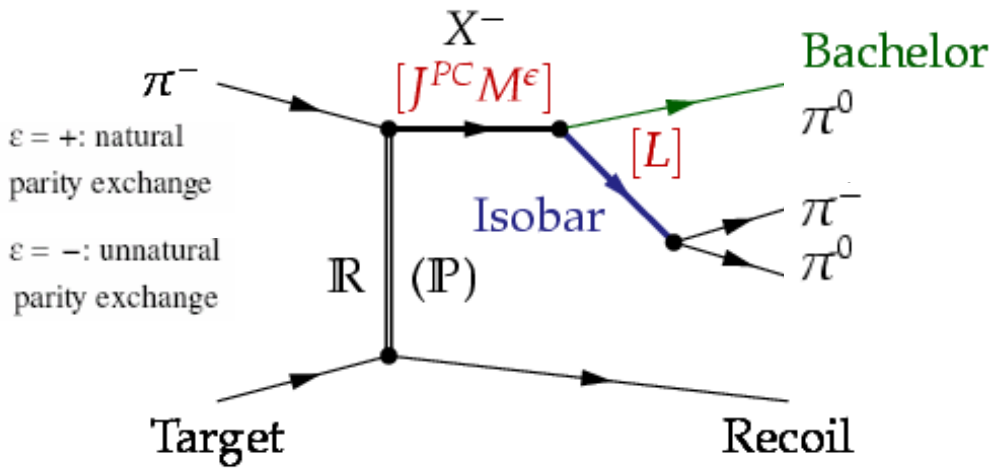
PWA: ~ 1M events

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:

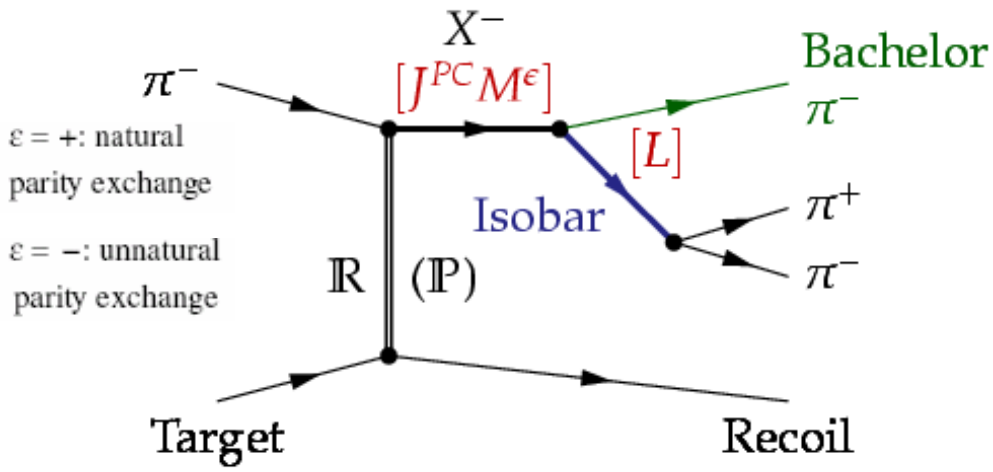
- **program:** Illinois/Protvino/Munich (D.Ryabchikov) software (IHEP/VES, TUM/COMPASS)
- **Isobars:** *$(\pi\pi)_S$ [broad $f_0(600)$+$f_0(1370)$], $f_0(980)$, $\rho(770)$, $f_2(1270)$, $\rho_3(1690)$*
- **Acceptance:** corrections included (2004: ~60%, rather flat, 2008: similar for charged, neutral 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



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:

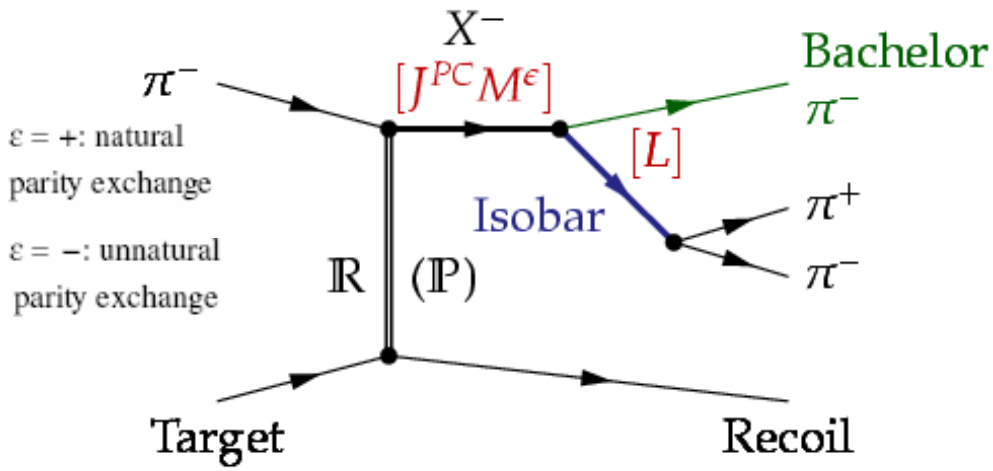
- **program:** Illinois/Protvino/Munich (D.Ryabchikov) software (IHEP/VES, TUM/COMPASS)
- **Isobars:** *$(\pi\pi)_S$ [broad $f_0(600)$+$f_0(1370)$], $f_0(980)$, $\rho(770)$, $f_2(1270)$, $\rho_3(1690)$*
- **Acceptance:** corrections included (2004: ~60%, rather flat, 2008: similar for charged)

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

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

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

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:

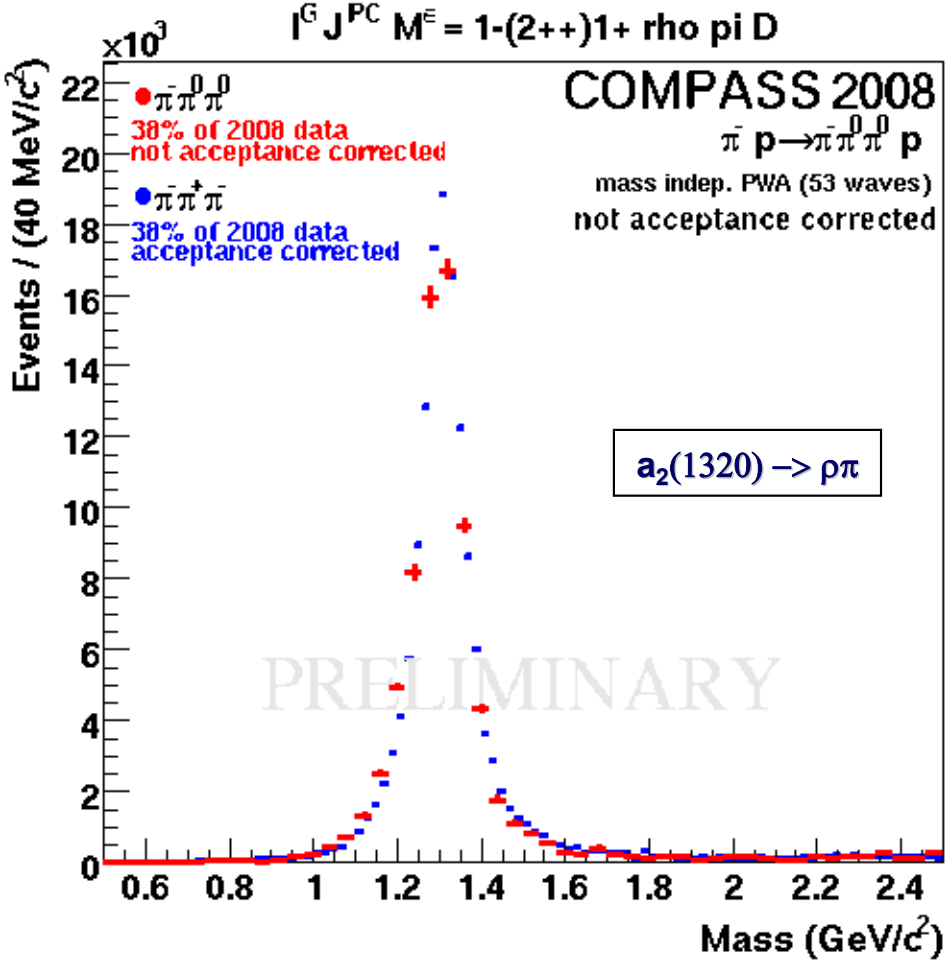
- **program:** Illinois/Protvino/Munich (D.Ryabchikov) software (IHEP/VES, TUM/COMPASS)
- **Isobars:** *$(\pi\pi)_S$ [broad $f_0(600)$+$f_0(1370)$], $f_0(980)$, $\rho(770)$, $f_2(1270)$, $\rho_3(1690)$*
- **Acceptance:** corrections included (2004: ~60%, rather flat, 2008: similar for charged)

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

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

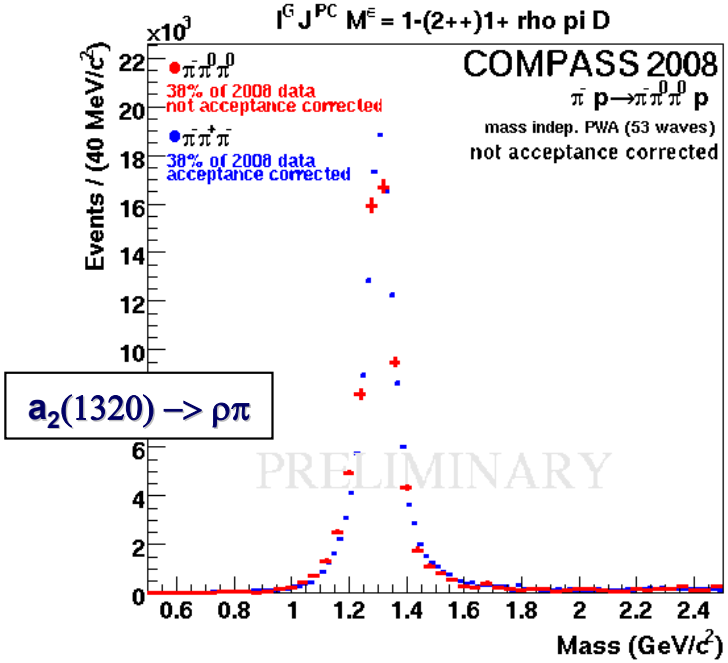
- Main partial waves chosen, parameterised by Breit-Wigner
- Coherent background for some waves

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



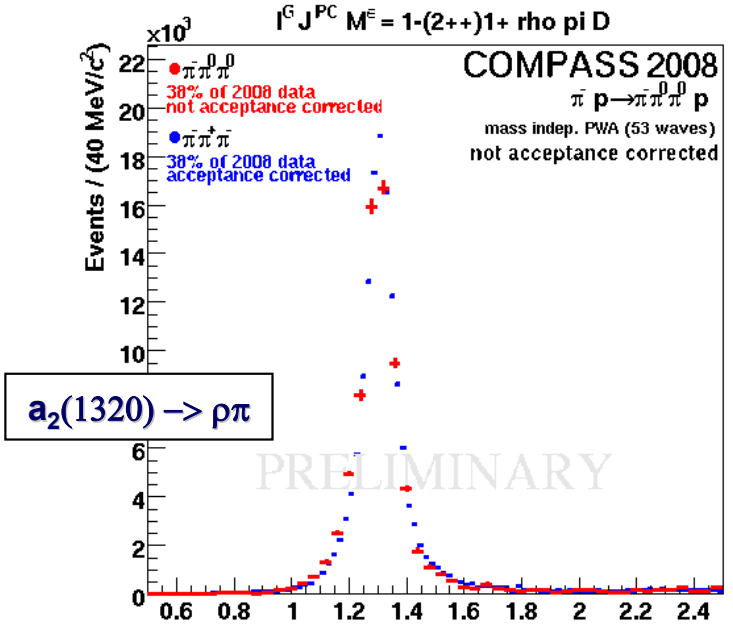
First comparison: Neutral vs. charged mode

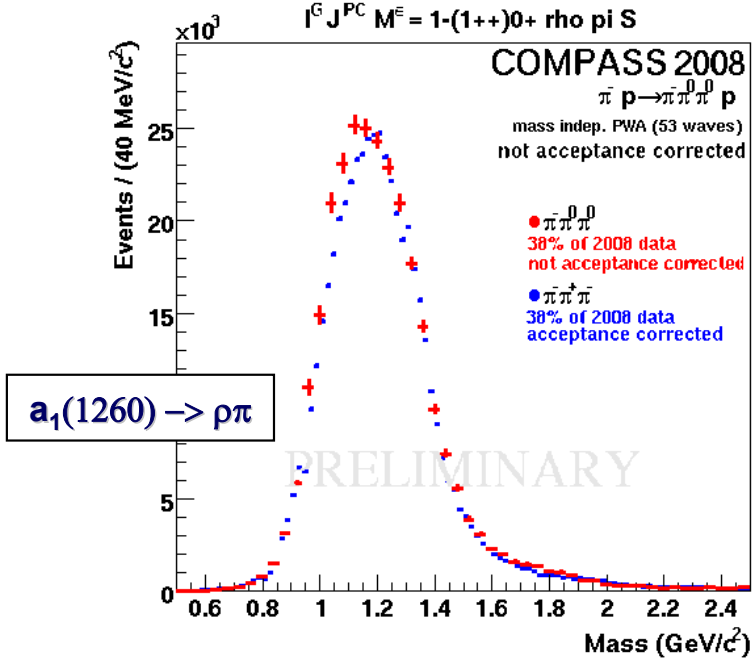
simple isospin symmetry check

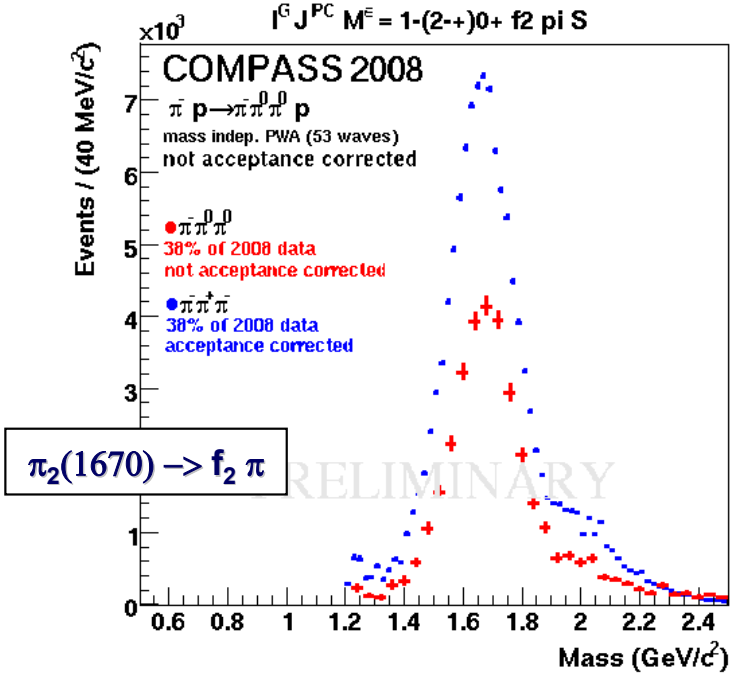


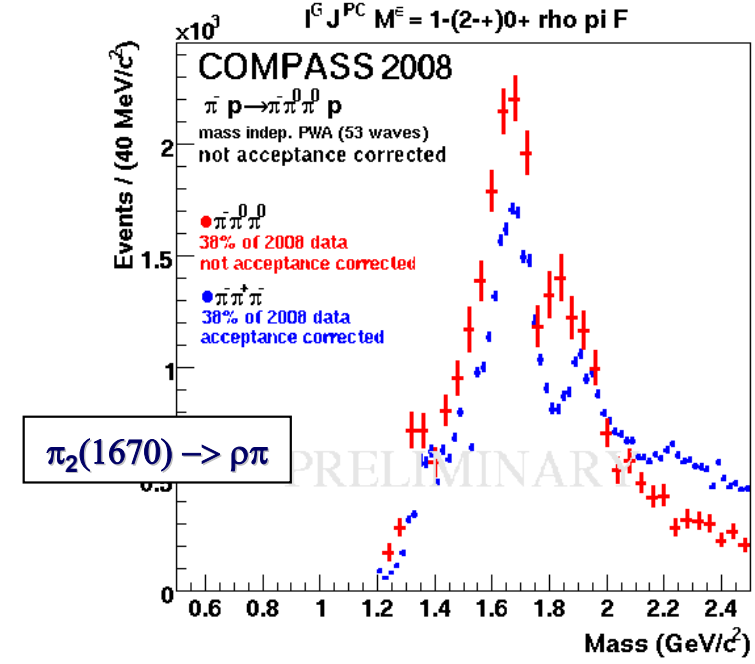
First comparison: Neutral vs. charged mode

simple isospin symmetry check



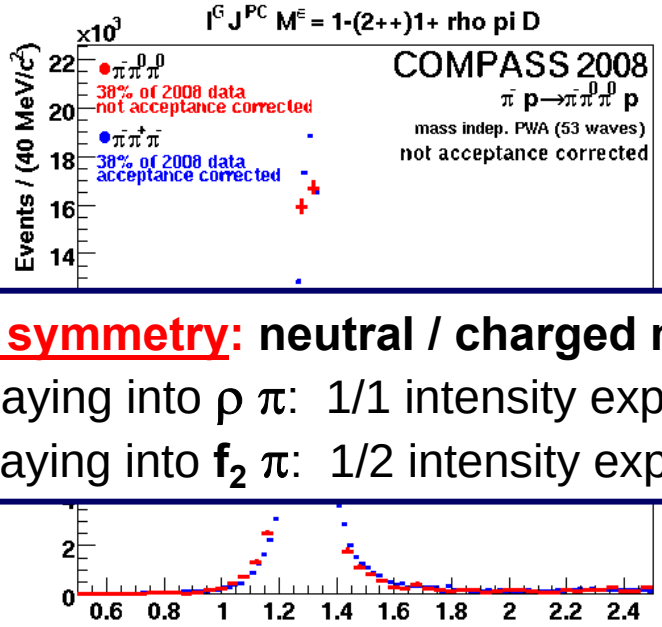


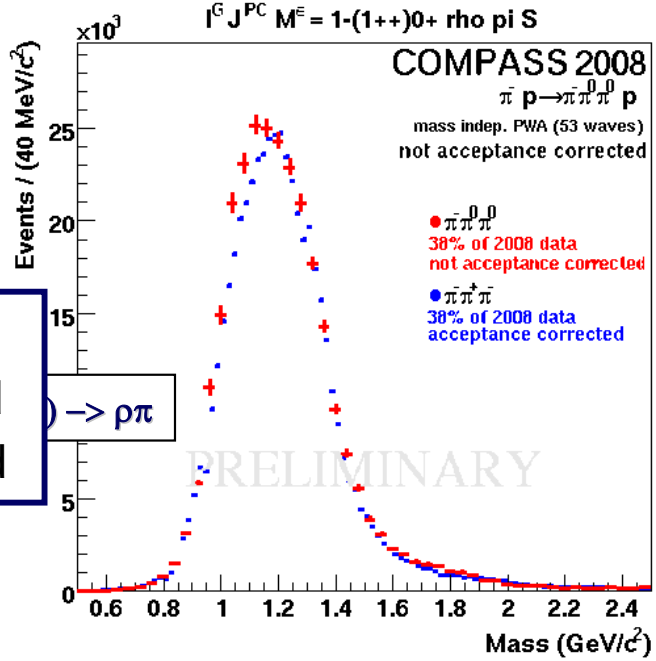




First comparison: Neutral vs. charged mode

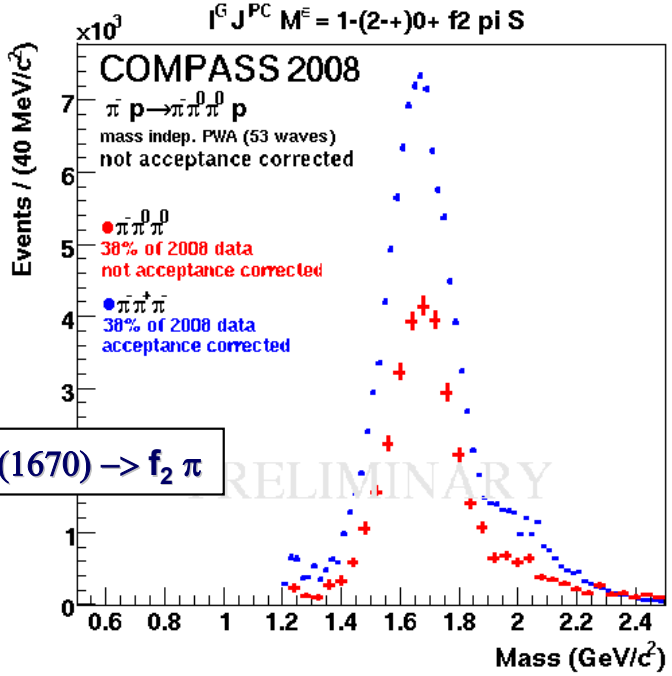
simple isospin symmetry check

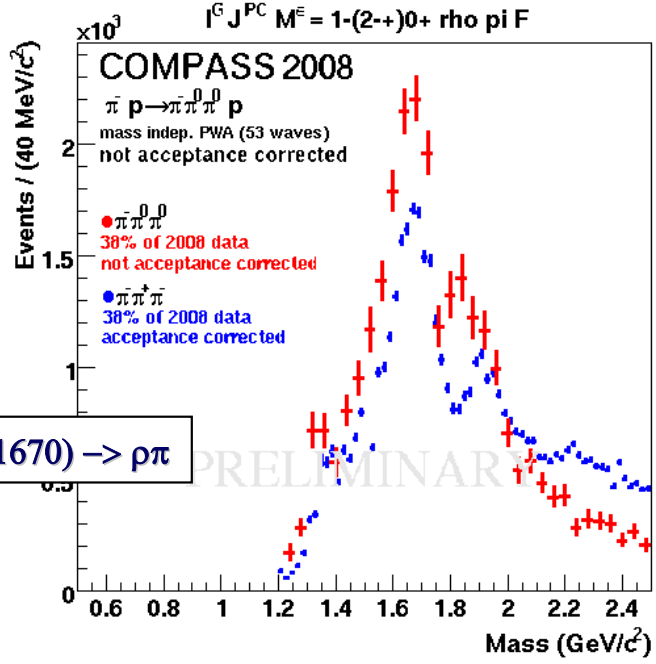




Isospin symmetry: neutral / charged mode

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





First comparison: Neutral vs. charged mode

simple isospin symmetry check

Isospin symmetry: neutral / charged mode

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

First comparison: Neutral vs. charged mode

simple isospin symmetry check

Isospin symmetry: neutral / charged mode

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

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* $f_{0,2}\pi$

First comparison: Neutral vs. charged mode

simple isospin symmetry check

Isospin symmetry: neutral / charged mode

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

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)

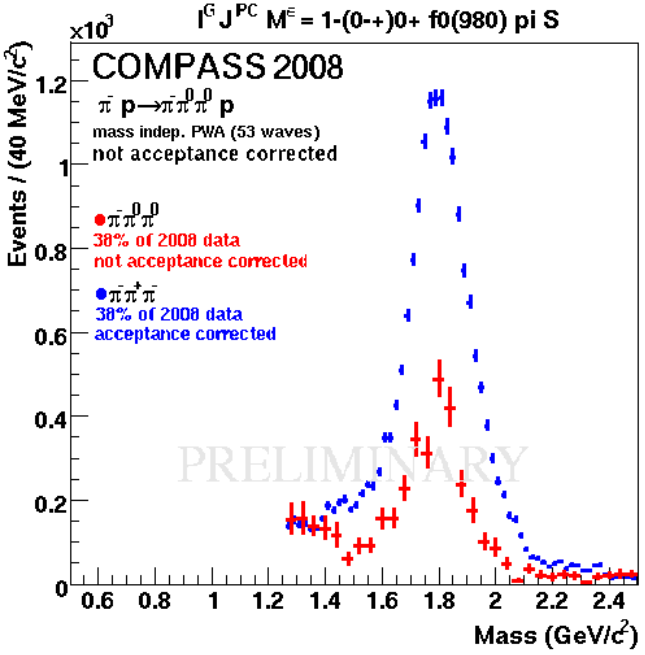
=> *BR might differ for resonances going to* $f_{0,2}\pi$

Checked by calculation:

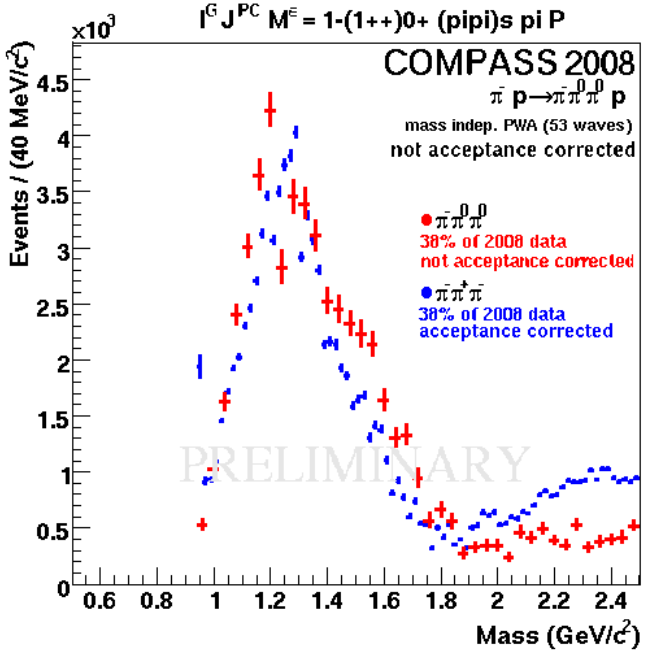
$\mathrm{BR} = \mathrm{N}(\pi^-\pi^0\pi^0)/\mathrm{N}(\pi^-\pi^-\pi^+)$ – calculated from isobar model amplitudes
$\mathrm{BR}(\ 0^{-+} f_0(980)\pi\ S) = 0.44$ (at 1.8 GeV)
$\mathrm{BR}(\ 1^{++}(\pi\pi)_s\pi\ P) = 0.80$ (at 1.3 GeV)
$\mathrm{BR}(\ 2^{-+} f_2(1270)\pi\ S) = 0.50$ (at 1.67 GeV)

Selected partial waves
isospin symmetry check ctd.

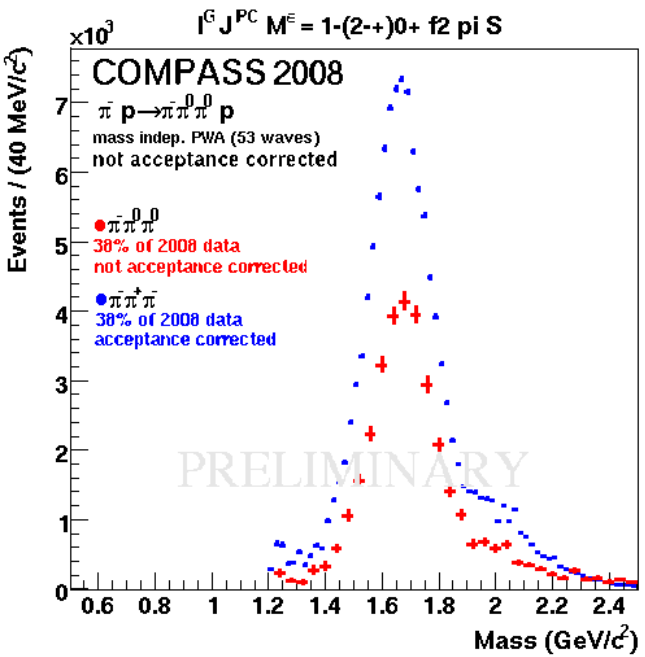
$\pi(1800) \rightarrow \rho\pi$



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



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

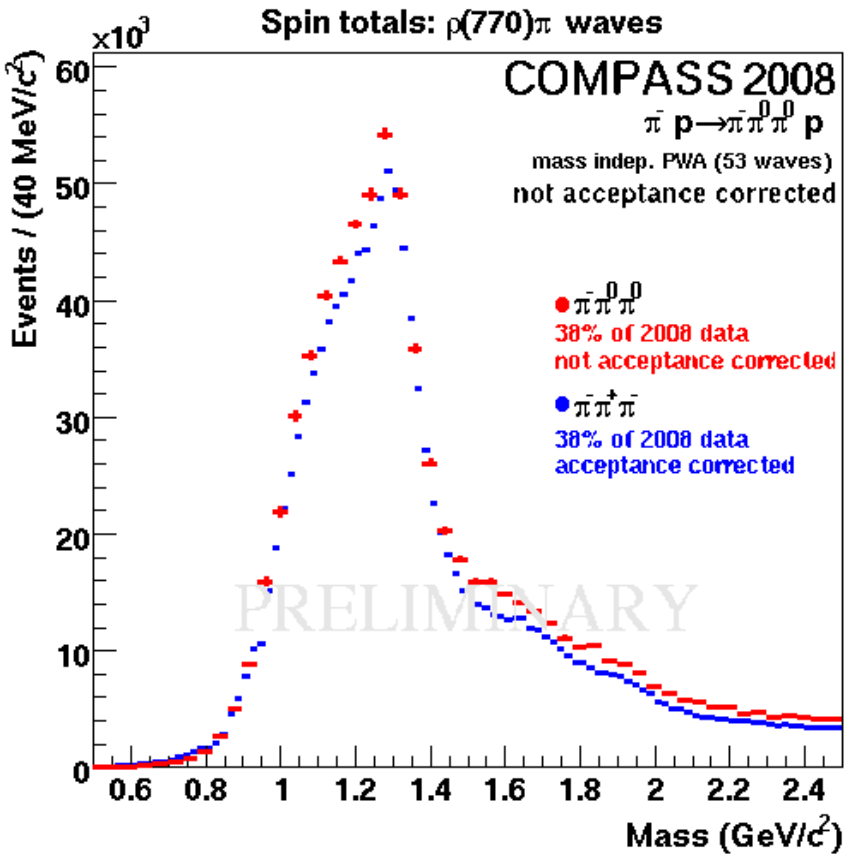


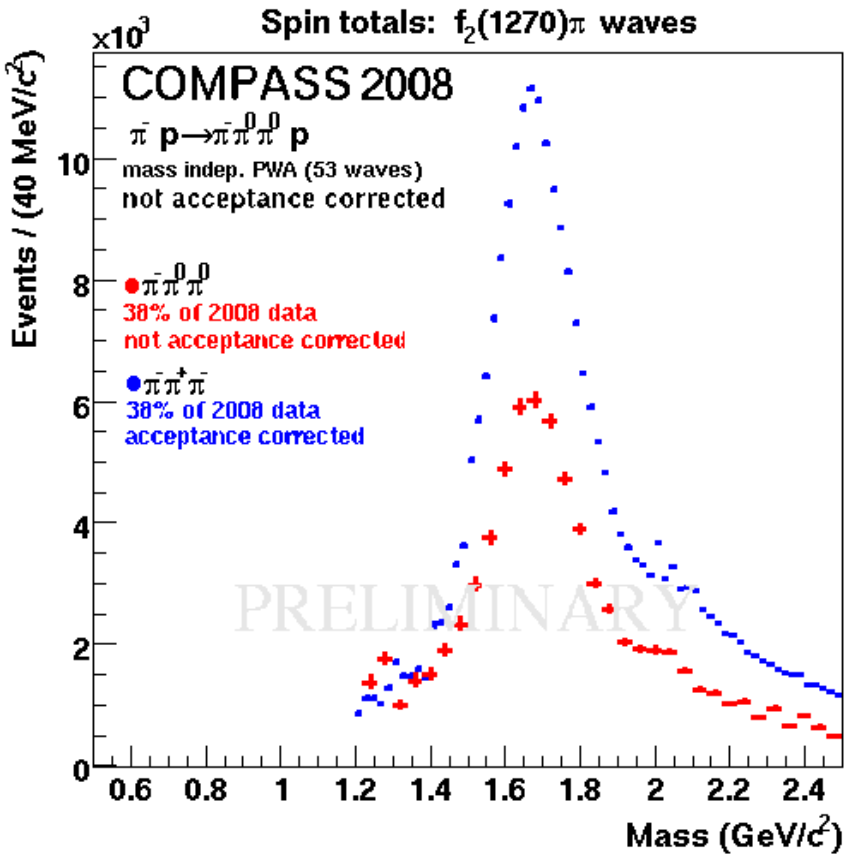
$BR = N(\pi^-\pi^0\pi^0)/N(\pi^-\pi^-\pi^+)$ – calculated from isobar model amplitudes	
$BR(\ 0^{-+} f_0(980)\pi\ S) = 0.44$ (at 1.8 GeV) $BR(\ 1^{++}(\pi\pi)_s\pi\ P) = 0.80$ (at 1.3 GeV) $BR(\ 2^{-+} f_2(1270)\pi\ S) = 0.50$ (at 1.67 GeV)	in fair agreement with our data

Two sets of partial wave totals

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

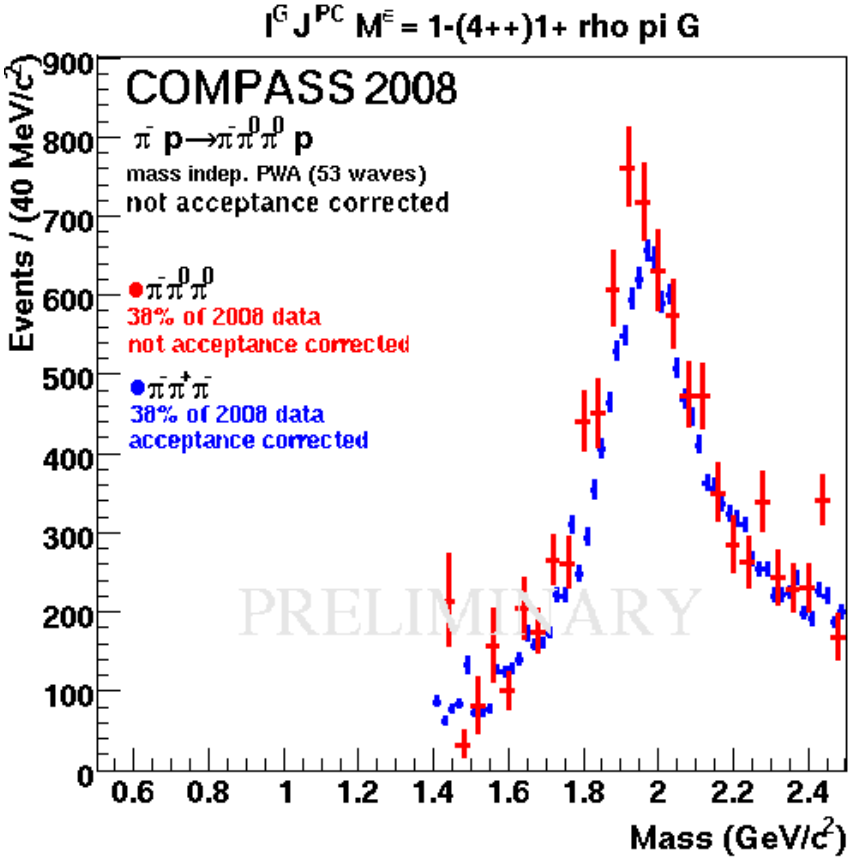
Spin totals show isospin symmetry:



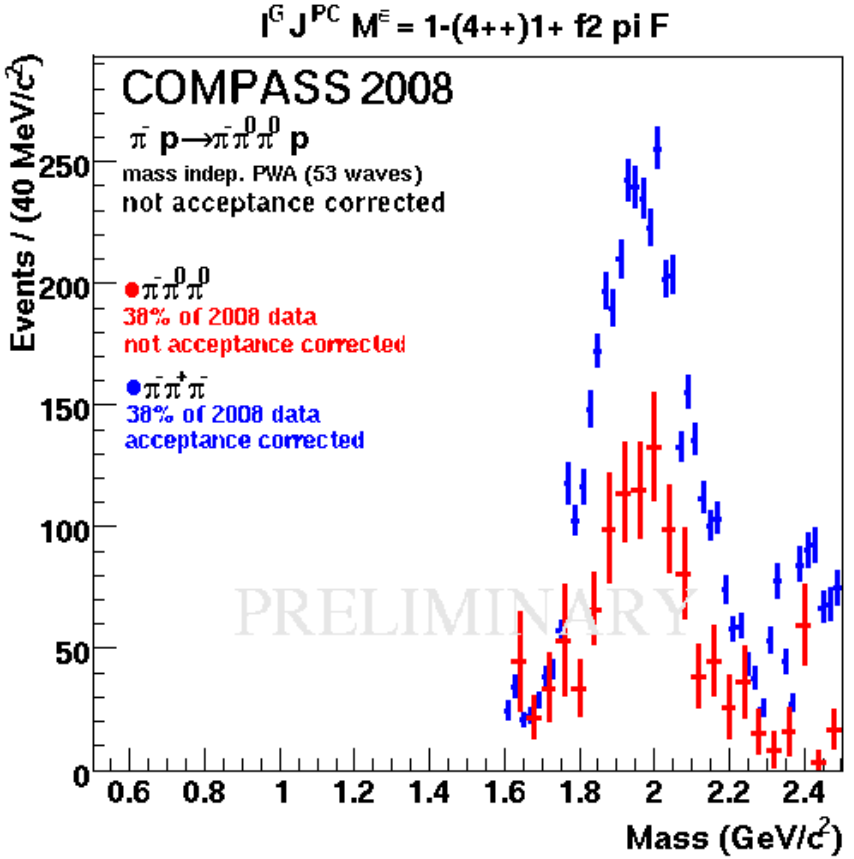


Selected partial waves
isospin symmetry check ctd.

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

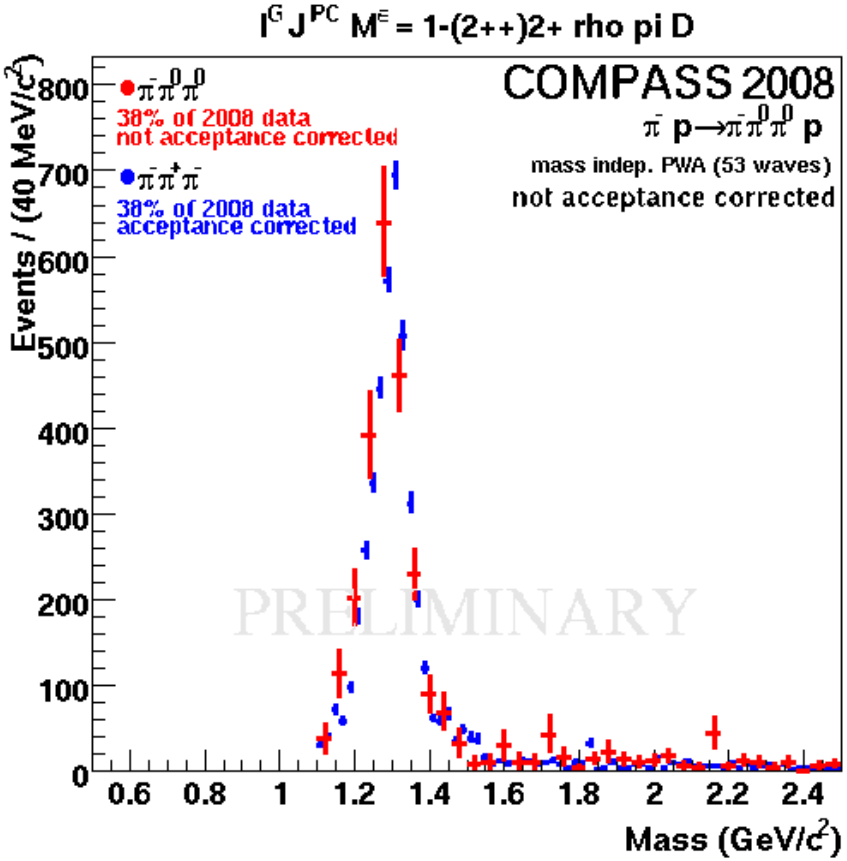


$a_4(2040) \rightarrow f_2\,\pi$

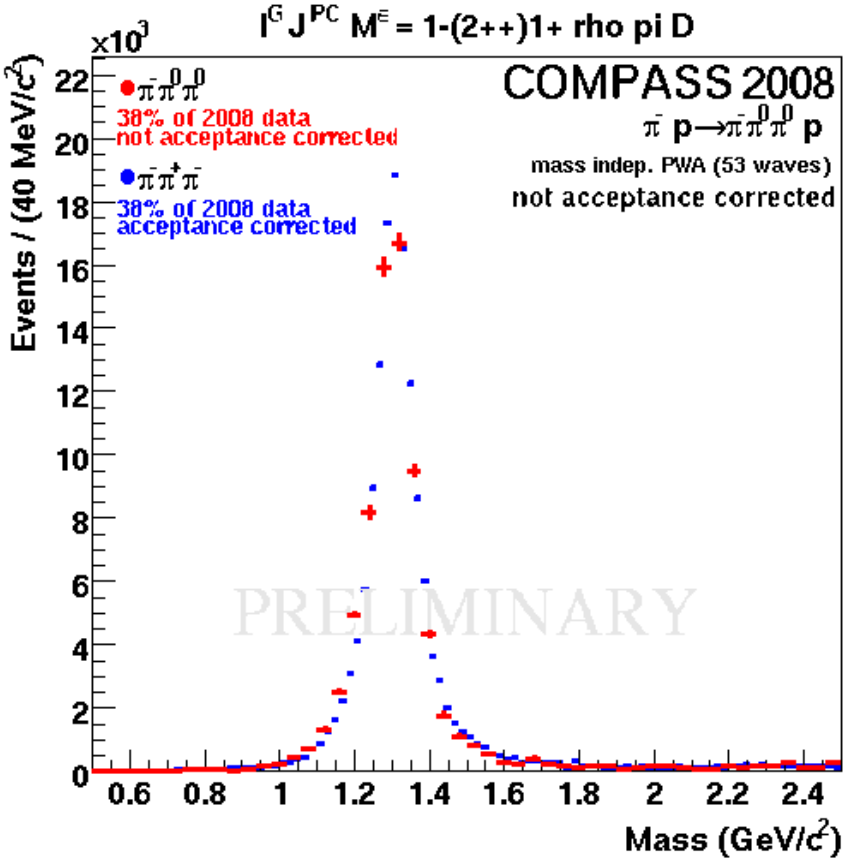


Selected partial waves
isospin symmetry check ctd.

$a_2(1320)$ (M=2) –> ρπ

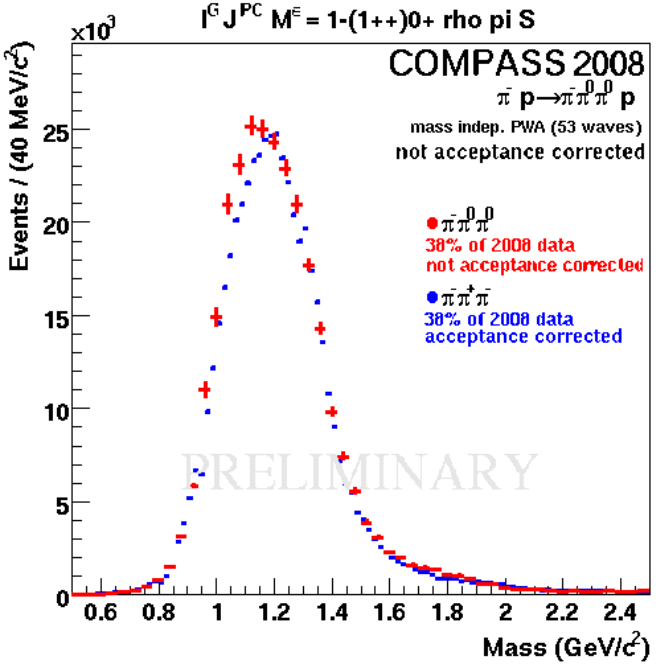


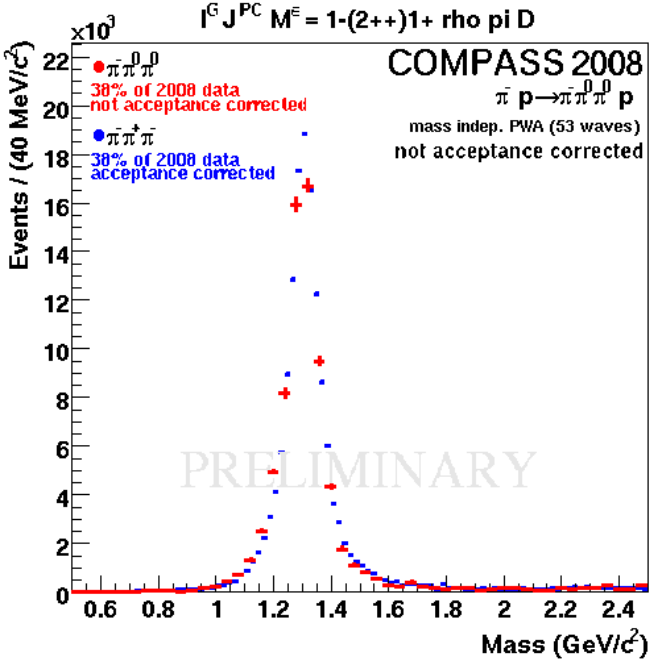
$a_2(1320)$ (M=1) –> ρπ



Selected partial waves & phases

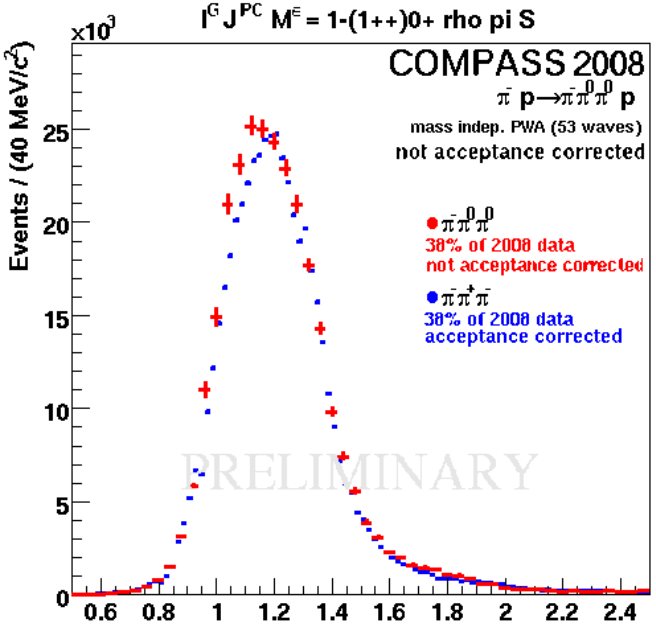
3π diffractive -- Neutral vs. Charged mode: 53 waves

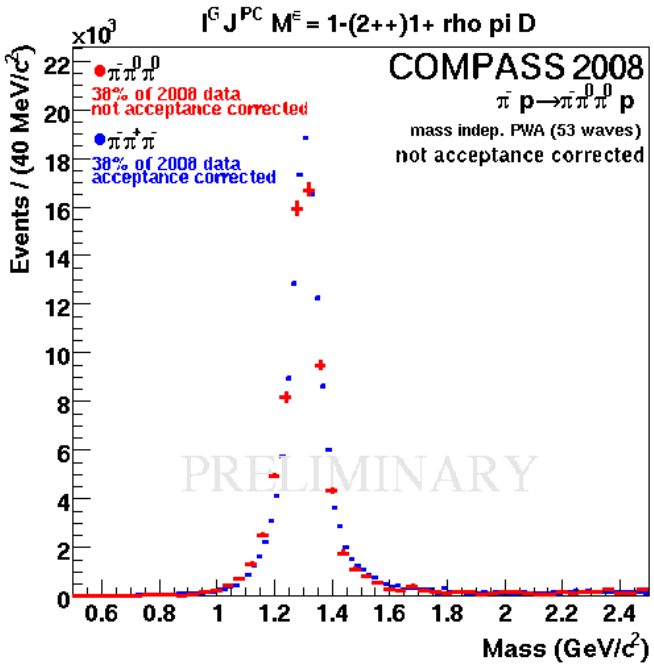


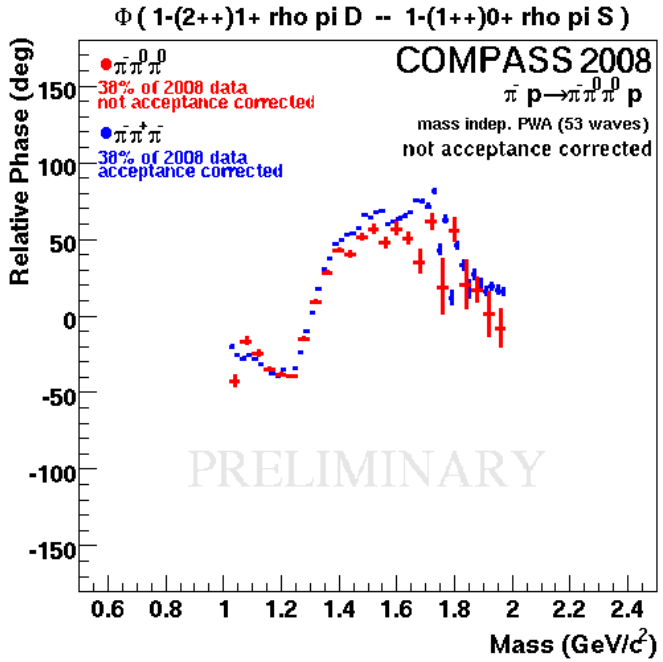


Selected partial waves & phases

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

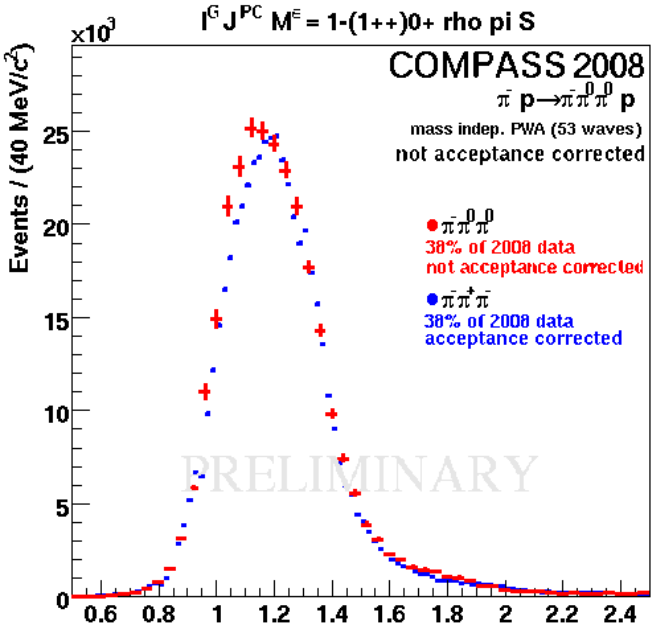


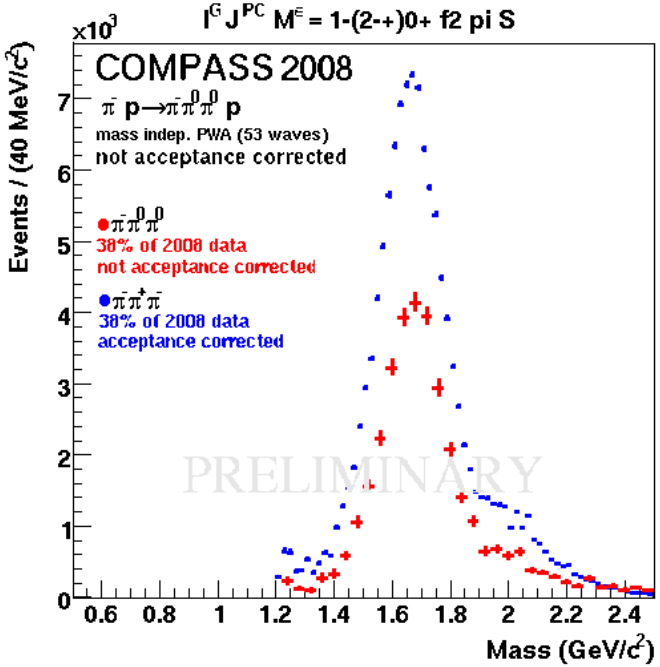


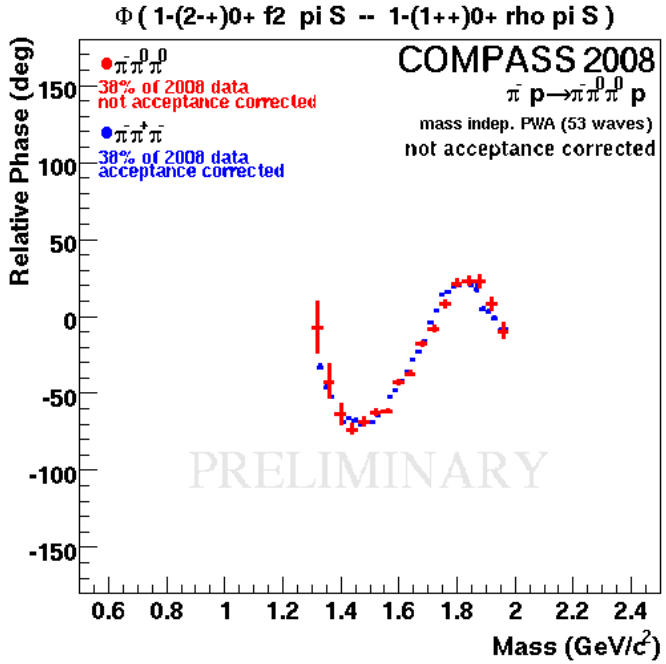


Selected partial waves & phases

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

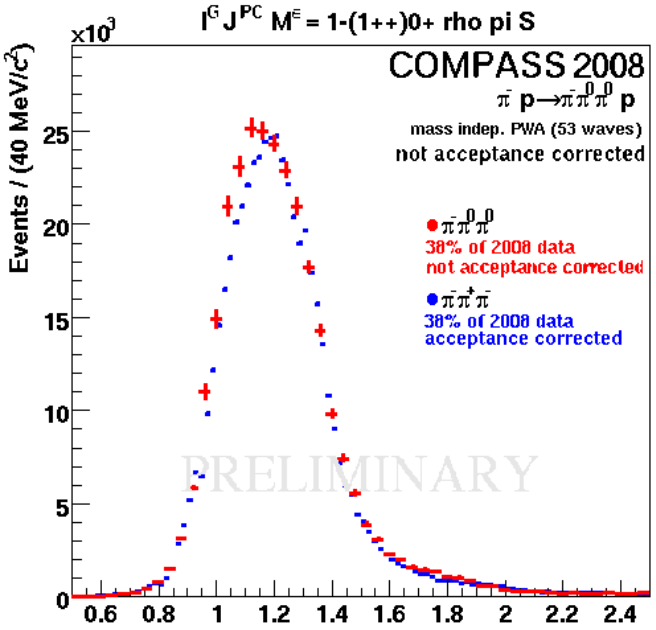


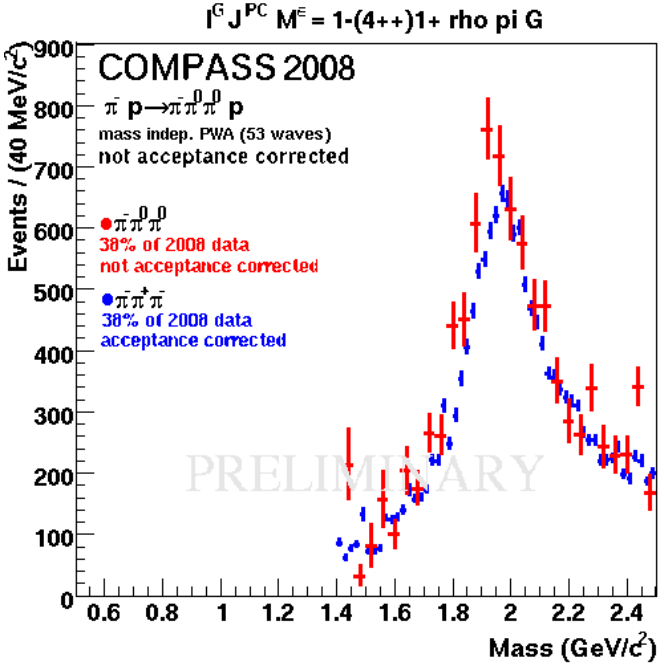


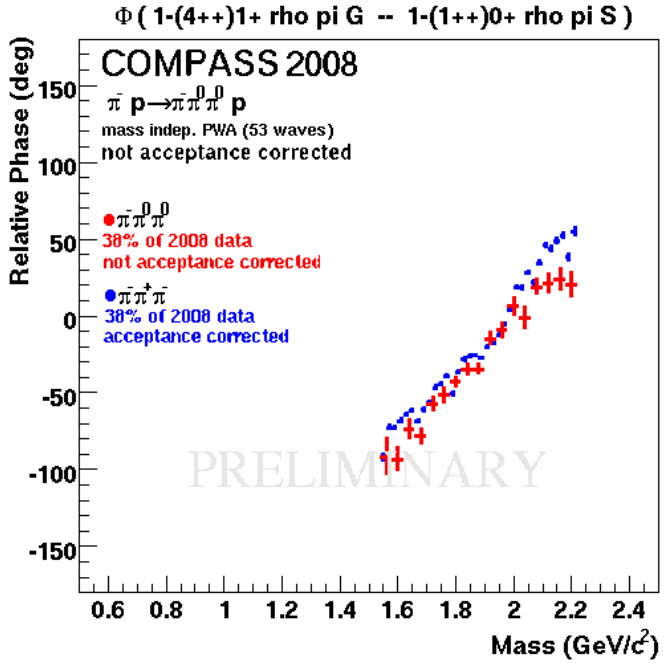


Selected partial waves & phases

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

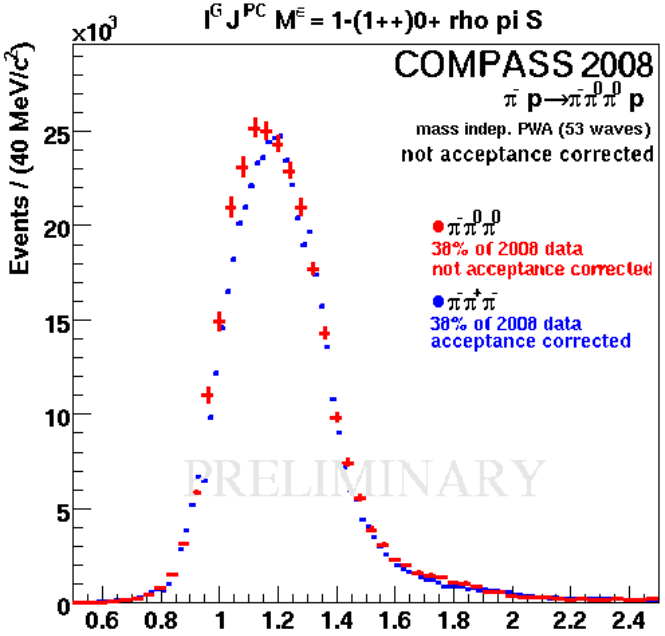


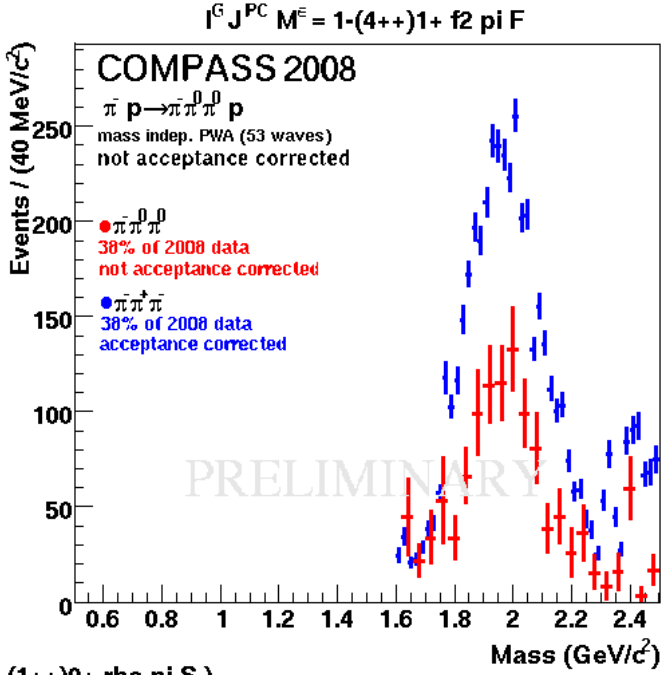


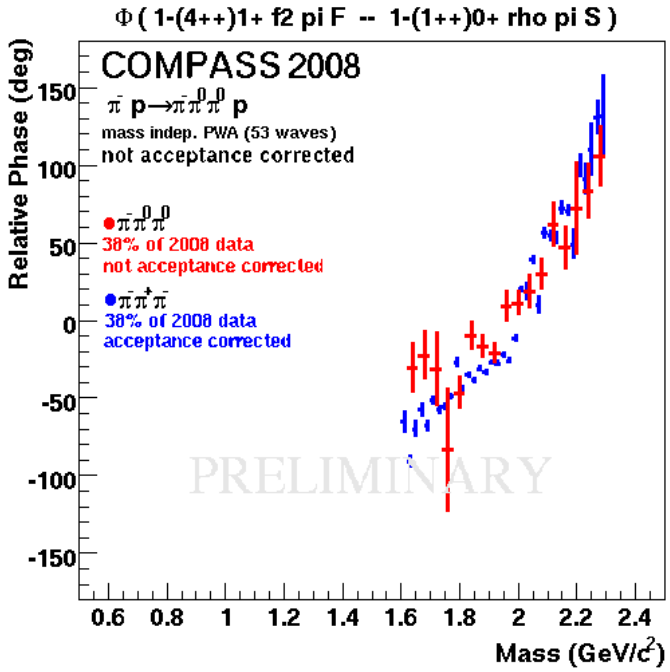


Selected partial waves & phases

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

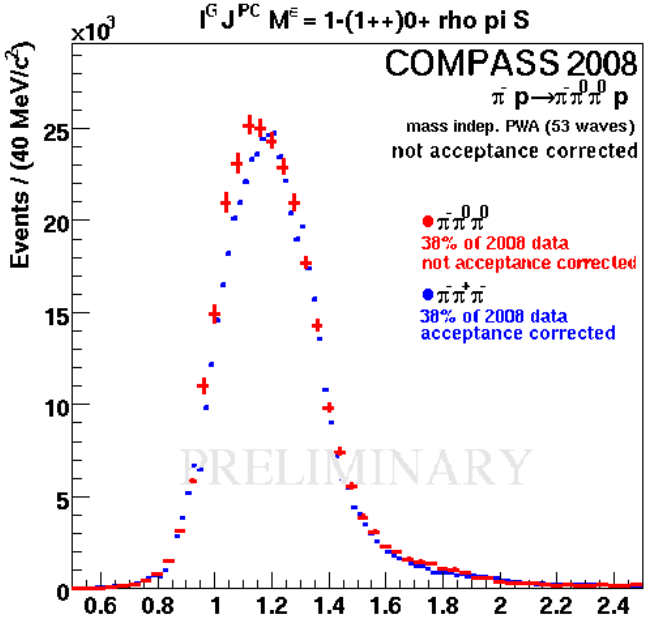


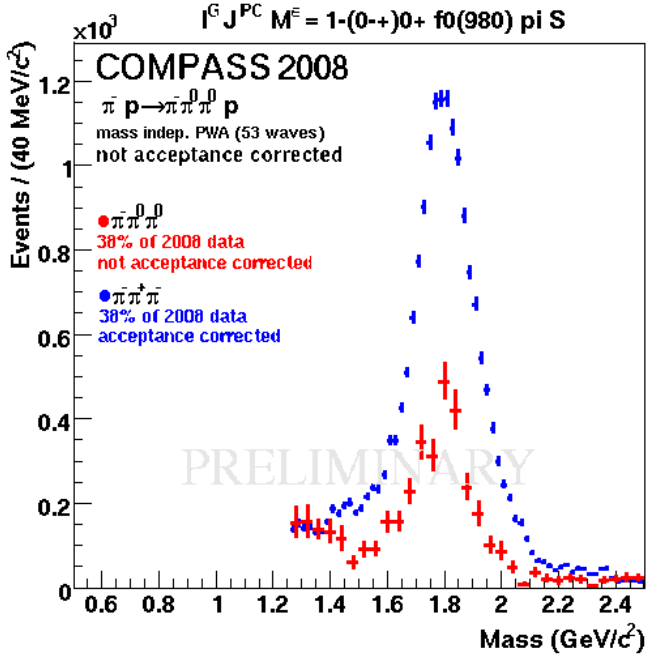


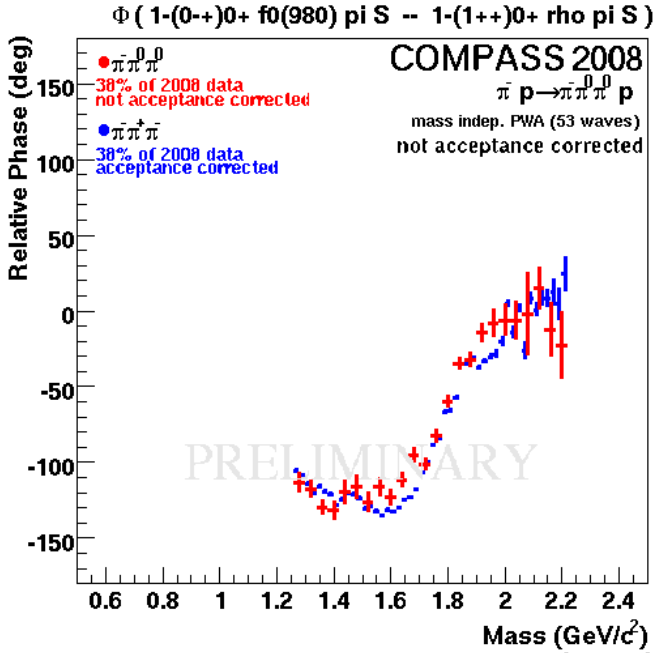


Selected partial waves & phases

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

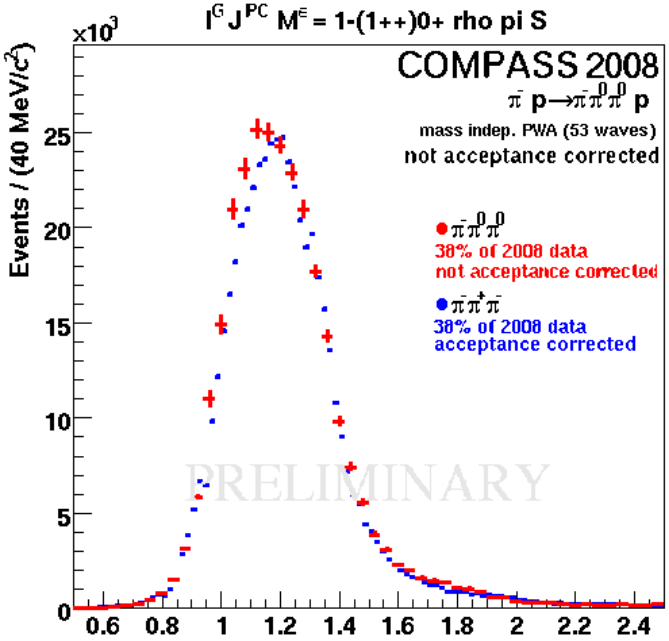


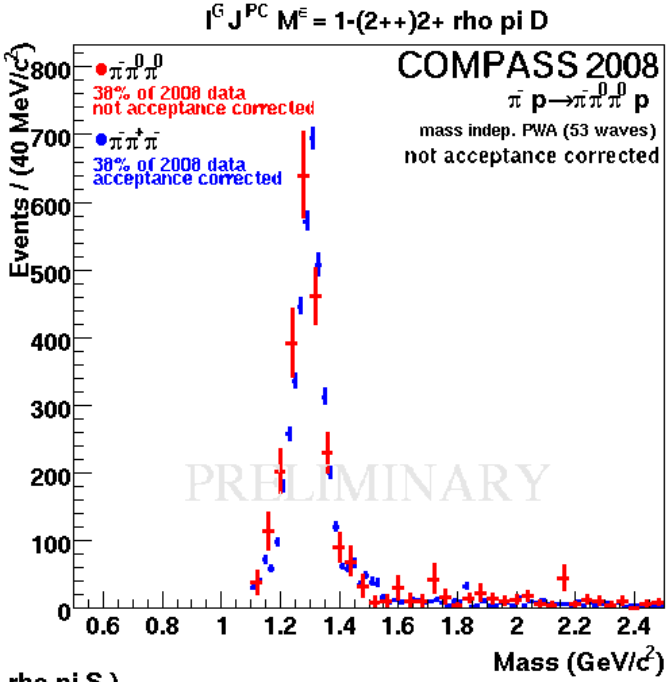


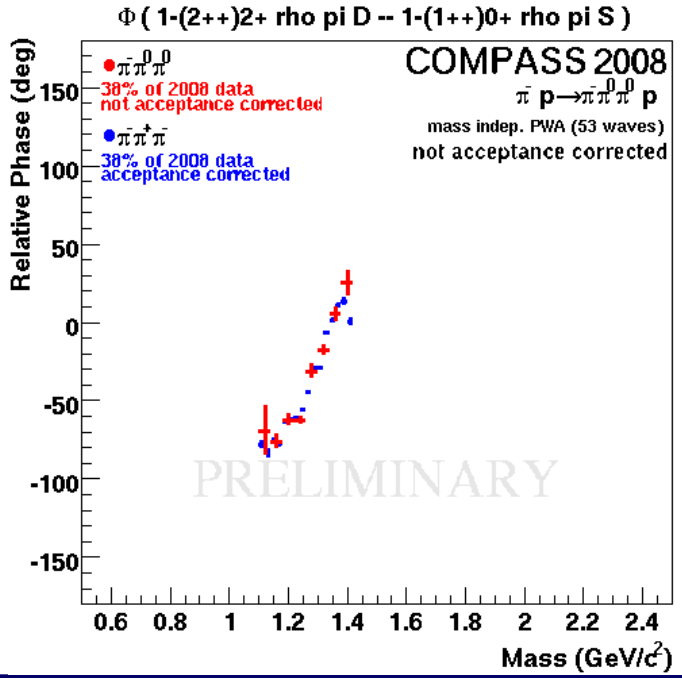


Selected partial waves & phases

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







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])

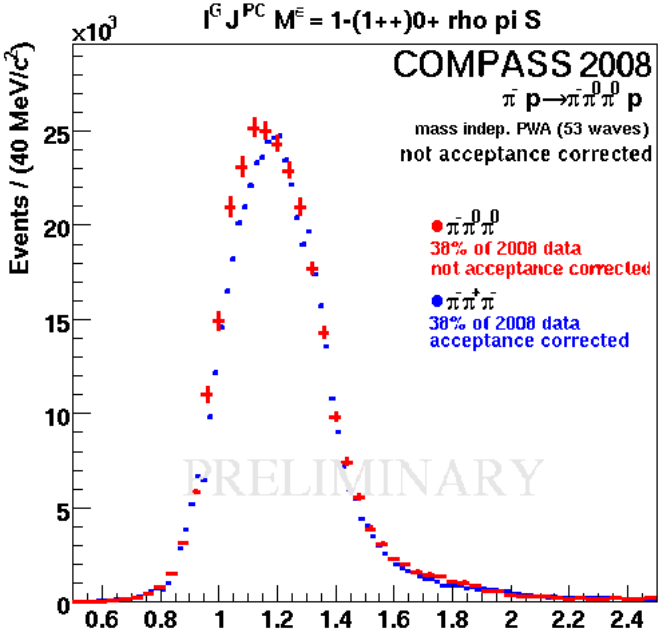
Outlook:

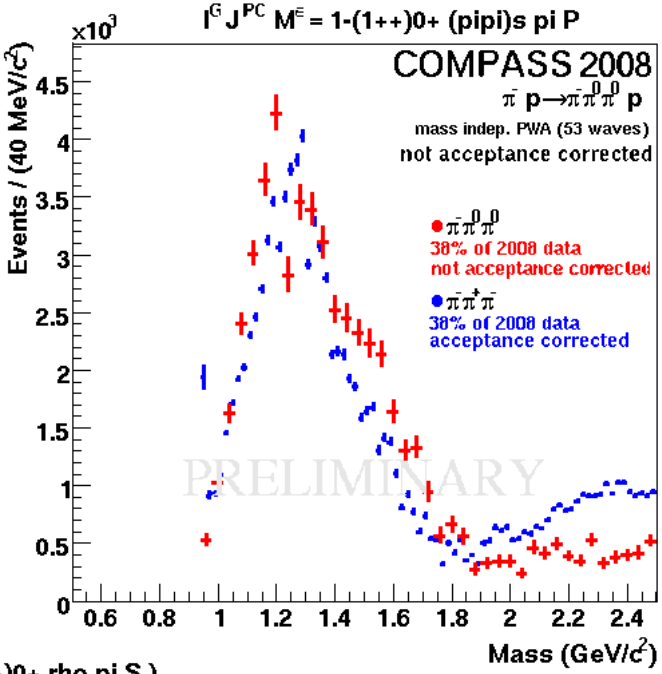
- Acceptance corrections for neutral mode *(before showing any signal in exotic 1^{-+} wave)*
- Dedicated leakage & background studies
- Further development of PWA model
- Mass-dependent PWA

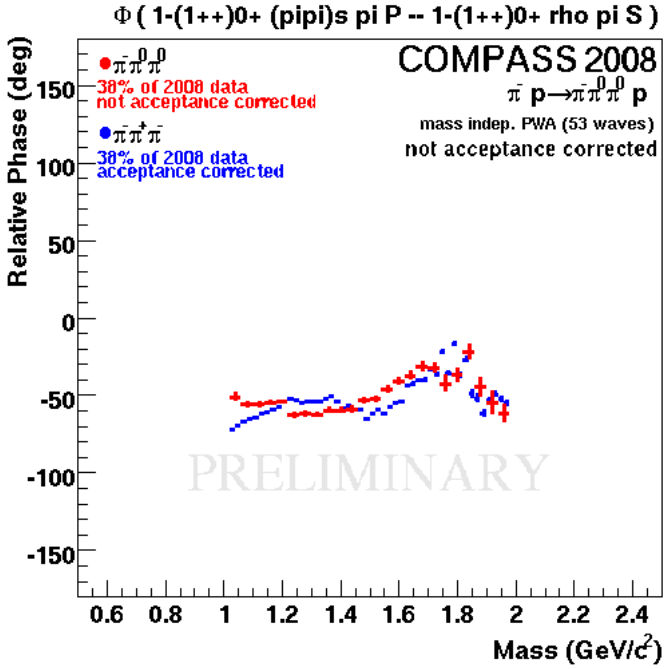
Additional material

Selected partial waves & phases

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

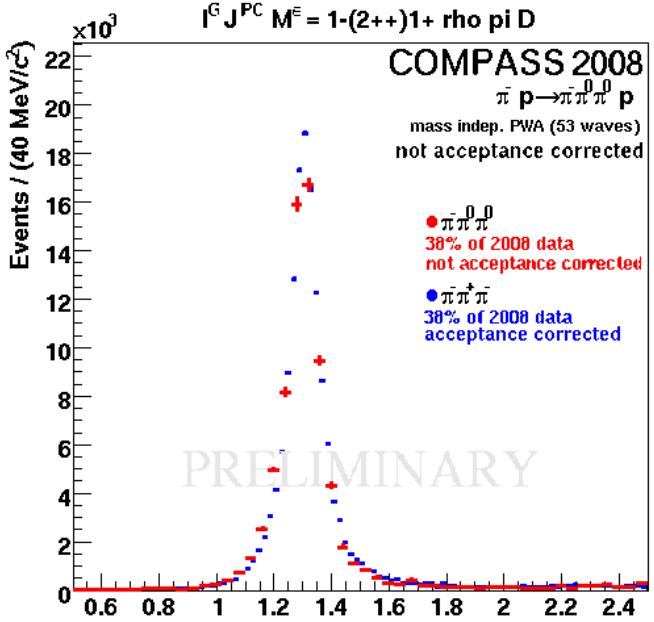


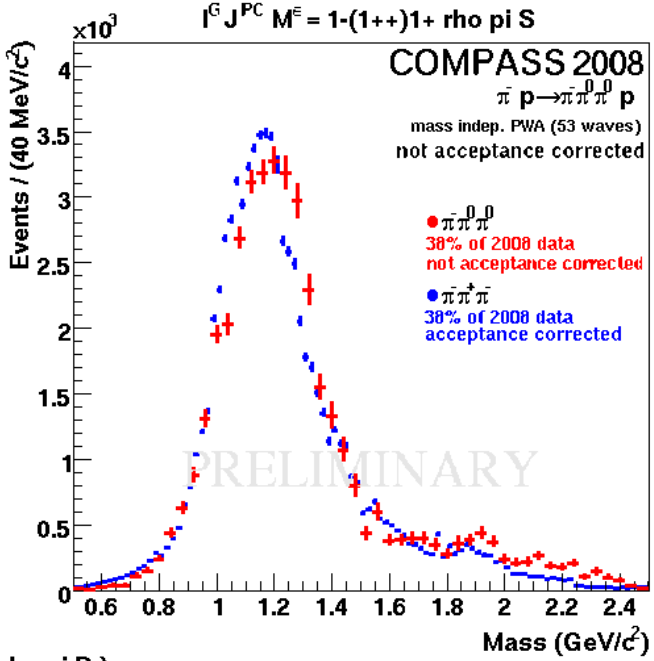


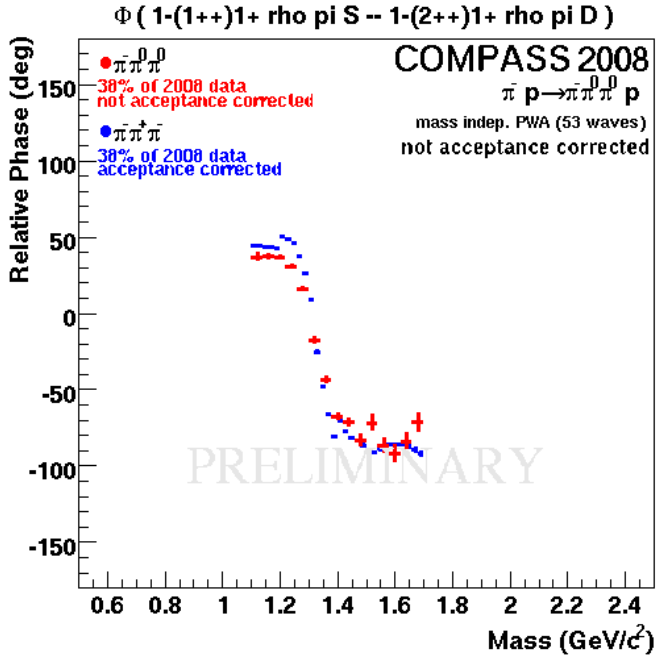


Selected partial waves & phases

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

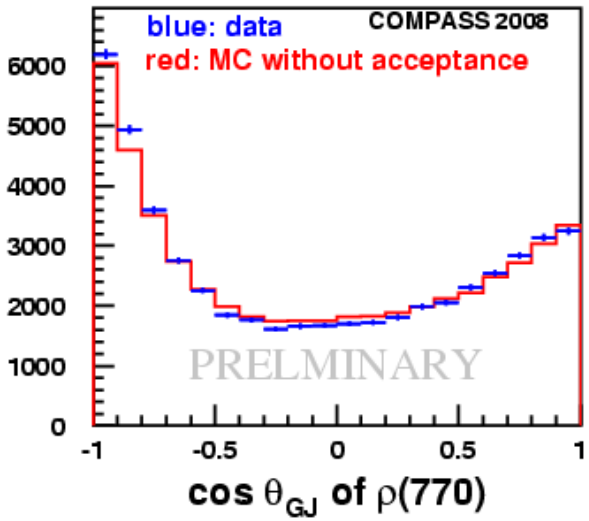


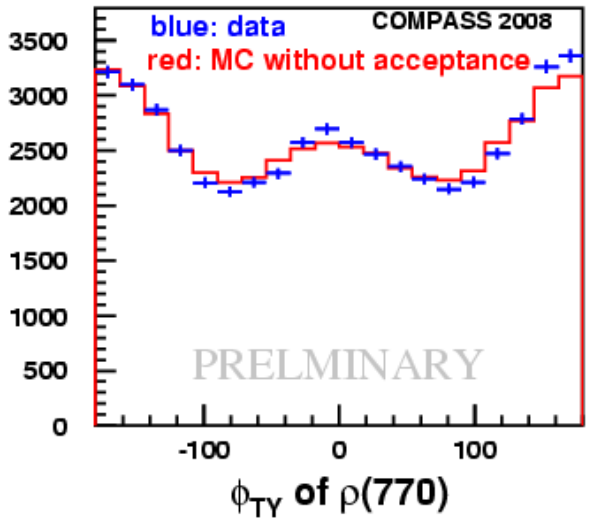




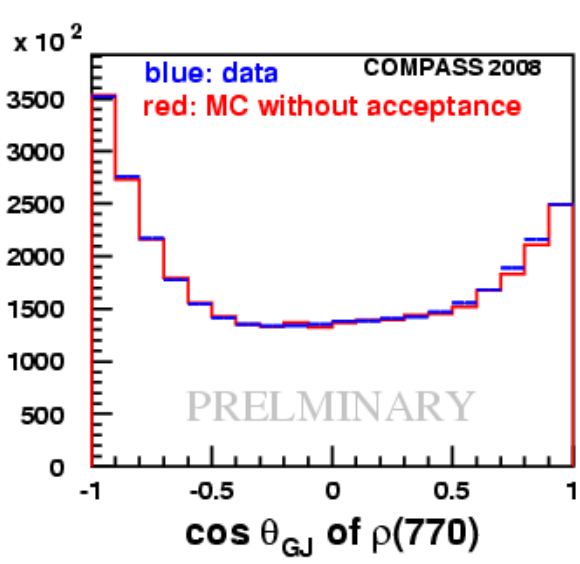
Decay angles in G.J. frame: Full PhaseSpace
Generated Prediction vs. fitted data

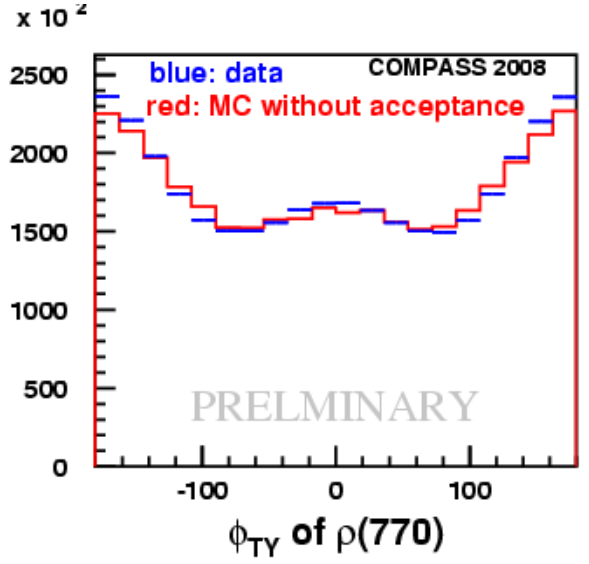
a1/a2 mass region - neutral
(1.22 - 1.38 GeV/c²)





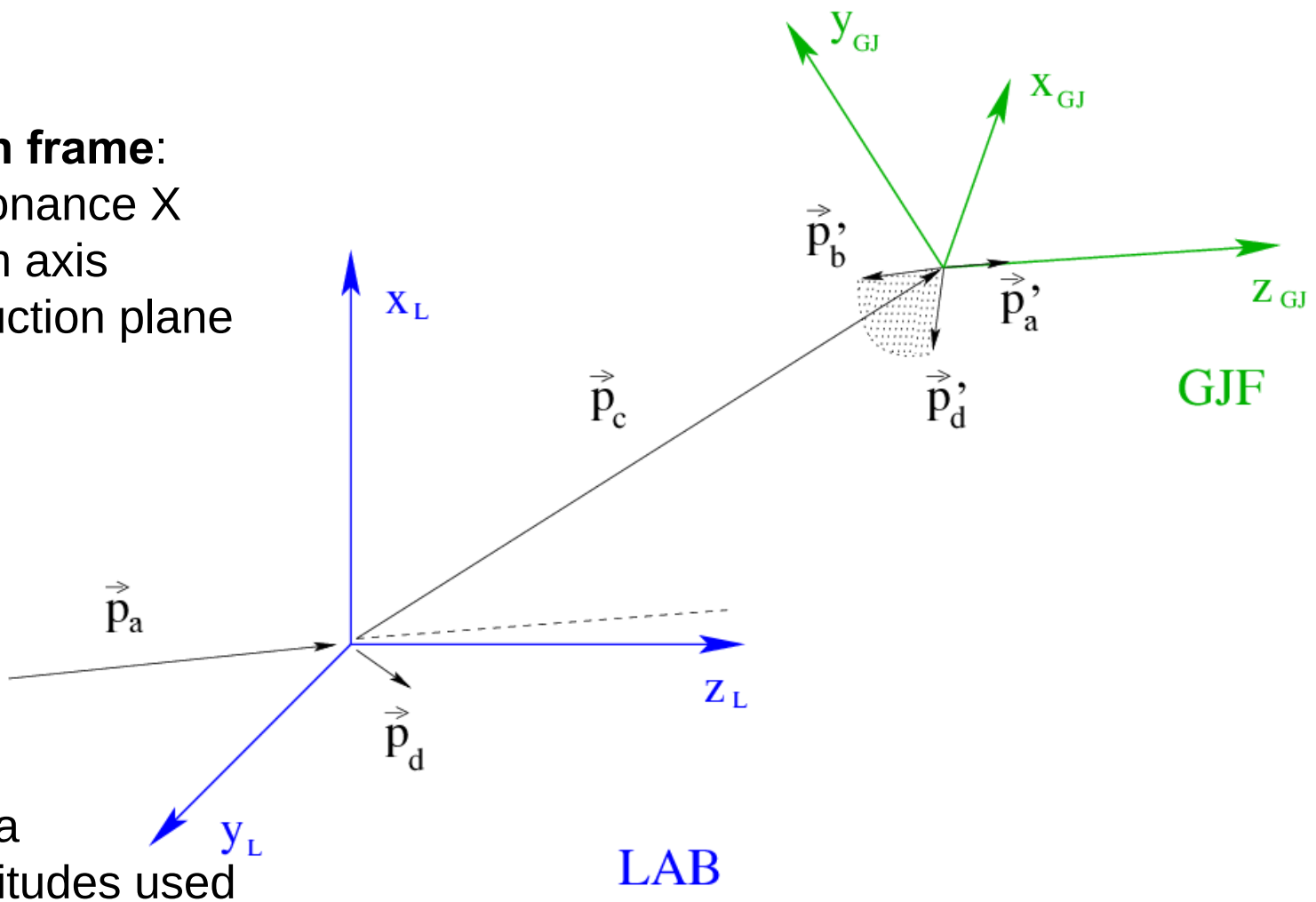
a1/a2 mass region - charged
(1.22 - 1.38 GeV/c²)





Decay angles in G.J. frame
Full PhaseSpace Generated Prediction

Gottfried-Jackson frame:
- rest frame of resonance X
- z parallel to beam axis
- y normal to production plane



„**PREDICT**“:
- fit waveset to data
- fitted decay amplitudes used to calculate decay angles
- under assumption of uniform acceptance
- normalised per mass bin to data

First PWA fits on $\pi^-\pi^0\pi^0$

Theoretical expectation: neutral / charge mode

- isobar decay into **f2** π: 1/2 intensity expected
- isobar decay into $\rho\,\pi$: 1/1 intensity expected

Examples, *$(J^{PC})\,M^{\varepsilon}$ [isobar] L notation*:

- **a2: (2++)1+ rho pi D**

  a) a2 $\longrightarrow \rho^0\,\pi^-$, $\rho^0 \rightarrow \pi^-\,\pi^+$ } $\pi^-\pi^+\pi^-$

  b) a2 $\longrightarrow \rho^-\,\pi^0$, $\rho^- \rightarrow \pi^0\,\pi^-$ } $\pi^-\pi^0\pi^0$

  } **a2 intensity expected** (neutral/charged): **1**

- **π2:**

  i) **(2-+)0+ f2 pi S:** $\pi 2 \longrightarrow f2\,\pi^-$

  $BR(\pi^0\pi^0) / BR(\pi^-\pi^+) = 1/3 / 2/3 = 1/2$

  } **π2 intensity expected** (neutral/charged): **½**
  (plus reduced acc. → eff x eff for neutrals)

  ii) **(2-+)0+ rho pi F**

  a) $\pi 2 \longrightarrow \rho^-\,\pi^0$, $\rho^- \rightarrow \pi^-\,\pi^0$ } $\pi^-\pi^0\pi^0$

  b) $\pi 2 \longrightarrow \rho^0\,\pi^-$, $\rho^0 \rightarrow \pi^+\,\pi^-$ } $\pi^-\pi^+\pi^-$

  } **π2 intensity expected** (neutral/charged): **1**

First PWA fits on $\pi^-\pi^0\pi^0$

Theoretical expectation: neutral / charge mode

- isobar decay into **f2** π: 1/2 intensity expected
- isobar decay into $\rho\,\pi$: 1/1 intensity expected

Examples, (

- **a2: (2++)1+**

  a) a2 –

  b) a2 –

- **π2:**

  i) **(2-+)0**

  BR($\pi^0\pi^0$) / BR($\pi^-\pi^+$) =1/3 / 2/3= 1/2

  ii) **(2-+)0+ rho pi F**

  a) π2 –> $\rho^-\,\pi^0$ → $\pi^-\,\pi^0$ } $\pi^-\pi^0\pi^0$

  b) π2 –> $\rho^0\,\pi^-$ → $\pi^+\,\pi^-$ } $\pi^-\pi^+\pi^-$

General: Branching not only from Clebsch-Gordon coeff., but also from Bose-Symmetrisation w bachelor π

=> IsospinSym. holds for isobars going to $\rho\pi$ (same effect)

=> - " - needs to be modified, BR may differ, for isobars going to $f_2\pi$

Calculated / checked: BR = N($\pi^-\pi^0\pi^0$)/N($\pi^-\pi^+\pi^-$)

BR(0-+ f0(1400) π S) = 0.26 (at 1.3 GeV)

BR(0-+ f0(980) π S) = 0.44 (at 1.8 GeV)

BR(2-+ f2(1270) π S) = 0.50 (at 1.67 GeV = π2 mass)

} *find very good agreement with experiment*

(plus reduced acc. → eff x eff for neutrals)

π2 intensity expected (neutral/charged): **1**

Waveset used for the PWA

$J^{PC}M^{\epsilon}$	L	Isobar π	Treshold (GeV/c^2)
$0^{-+}0^{+}$	S	$f_0(980)\pi$	1.25
$0^{-+}0^{+}$	S	$(\pi\pi)_s\pi$	-
$0^{-+}0^{+}$	P	$\rho\pi$	-
$1^{-+}1^{+}$	P	$\rho\pi$	-
$1^{++}0^{+}$	S	$\rho\pi$	-
$1^{++}0^{+}$	P	$f_2\pi$	1.20
$1^{++}0^{+}$	P	$(\pi\pi)_s\pi$	0.94
$1^{++}0^{+}$	D	$\rho\pi$	1.30
$1^{++}1^{+}$	S	$\rho\pi$	-
$1^{++}1^{+}$	P	$f_2\pi$	1.40
$1^{++}1^{+}$	P	$(\pi\pi)_s\pi$	1.20
$1^{++}1^{+}$	D	$\rho\pi$	1.40
$2^{-+}0^{+}$	S	$f_2\pi$	1.20
$2^{-+}0^{+}$	P	$\rho\pi$	0.80
$2^{-+}0^{+}$	D	$(\pi\pi)_s\pi$	0.80
$2^{-+}0^{+}$	D	$f_2\pi$	1.50
$2^{-+}0^{+}$	F	$\rho\pi$	1.20
$2^{-+}1^{+}$	S	$f_2\pi$	1.20
$2^{-+}1^{+}$	P	$\rho\pi$	0.80
$2^{-+}1^{+}$	D	$(\pi\pi)_s\pi$	1.20
$2^{-+}1^{+}$	D	$f_2\pi$	1.50
$2^{-+}1^{+}$	F	$\rho\pi$	1.20
$2^{++}1^{+}$	P	$f_2\pi$	1.20
$2^{++}1^{+}$	D	$\rho\pi$	-
$3^{++}0^{+}$	S	$\rho_3\pi$	1.76
$3^{++}0^{+}$	P	$f_2\pi$	1.20
$3^{++}0^{+}$	D	$\rho\pi$	1.20
$3^{++}1^{+}$	S	$\rho_3\pi$	1.76
$3^{++}1^{+}$	P	$f_2\pi$	1.20
$3^{++}1^{+}$	D	$\rho\pi$	1.50
$4^{-+}0^{+}$	F	$\rho\pi$	1.00
$4^{-+}1^{+}$	F	$\rho\pi$	1.20
$4^{++}1^{+}$	F	$f_2\pi$	1.60
$4^{++}1^{+}$	G	$\rho\pi$	1.40
$1^{-+}0^{-}$	P	$\rho\pi$	-
$1^{-+}1^{-}$	P	$\rho\pi$	-
$1^{++}1^{-}$	S	$\rho\pi$	-
$2^{-+}1^{-}$	S	$f_2\pi$	1.20
$2^{++}0^{-}$	P	$f_2\pi$	1.30
$2^{++}0^{-}$	D	$\rho\pi$	-
$2^{++}1^{-}$	P	$f_2\pi$	1.30
FLAT			

Table 5: List of the 42 waves used for the mass independent PWA

Updated PWA model: 53waves

$J^{PC}M^{\epsilon}$	L	Isobar π	Treshold (GeV/c^2
$0^{-+}0^{+}$	S	$f_0(980)\pi$	1.25
$0^{-+}0^{+}$	S	$(\pi\pi)_s\pi$	-
$0^{-+}0^{+}$	P	$\rho\pi$	-
$1^{-+}1^{+}$	P	$\rho\pi$	-
$1^{++}0^{+}$	S	$\rho\pi$	-
$1^{++}0^{+}$	P	$f_2\pi$	1.20
$1^{++}0^{+}$	P	$(\pi\pi)_s\pi$	0.94
$1^{++}0^{+}$	D	$\rho\pi$	1.30
$1^{++}1^{+}$	S	$\rho\pi$	-
$1^{++}1^{+}$	P	$f_2\pi$	1.40
$1^{++}1^{+}$	P	$(\pi\pi)_s\pi$	1.20
$1^{++}1^{+}$	D	$\rho\pi$	1.40
$2^{-+}0^{+}$	S	$f_2\pi$	1.20
$2^{-+}0^{+}$	P	$\rho\pi$	0.80
$2^{-+}0^{+}$	D	$(\pi\pi)_s\pi$	0.80
$2^{-+}0^{+}$	D	$f_2\pi$	1.50
$2^{-+}0^{+}$	F	$\rho\pi$	1.20
$2^{-+}1^{+}$	S	$f_2\pi$	1.20
$2^{-+}1^{+}$	P	$\rho\pi$	0.80
$2^{-+}1^{+}$	D	$(\pi\pi)_s\pi$	1.20
$2^{-+}1^{+}$	D	$f_2\pi$	1.50
$2^{-+}1^{+}$	F	$\rho\pi$	1.20
$2^{++}1^{+}$	P	$f_2\pi$	1.20
$2^{++}1^{+}$	D	$\rho\pi$	-
$3^{++}0^{+}$	S	$\rho_3\pi$	1.76
$3^{++}0^{+}$	P	$f_2\pi$	1.20
$3^{++}0^{+}$	D	$\rho\pi$	1.20
$3^{++}1^{+}$	S	$\rho_3\pi$	1.76
$3^{++}1^{+}$	P	$f_2\pi$	1.20
$3^{++}1^{+}$	D	$\rho\pi$	1.50
$4^{-+}0^{+}$	F	$\rho\pi$	1.00
$4^{-+}1^{+}$	F	$\rho\pi$	1.20
$4^{++}1^{+}$	F	$f_2\pi$	1.60
$4^{++}1^{+}$	G	$\rho\pi$	1.40
$1^{-+}0^{-}$	P	$\rho\pi$	-
$1^{-+}1^{-}$	P	$\rho\pi$	-
$1^{++}1^{-}$	S	$\rho\pi$	-
$2^{-+}1^{-}$	S	$f_2\pi$	1.20
$2^{++}0^{-}$	P	$f_2\pi$	1.30
$2^{++}0^{-}$	D	$\rho\pi$	-
$2^{++}1^{-}$	P	$f_2\pi$	1.30
FLAT			

Table 5: List of the 42 waves used for the mass independent PWA.(**Table for Release**)

42 waveset extended by 11 waves:

```
1-(0-+)0+ f0(1500) pi S
1-(2++)2+ rho pi D
1-(2-+)2+ f2 pi S
1-(5++)0+ rho pi G
1-(6-+)0+ rho pi H
1-(0-+)0+ f2 pi D
1-(1-+)1+ f2 pi D
1-(2-+)0+ rho3 pi P
1-(3++)0+ f0(1400) pi F
1-(1++)0+ f0(980) pi P
1-(2-+)0+ f0(980) pi D
```

Diffractive pion dissociation into 3 pions - neutral
(2008 data, LH2 target)

Event selection: $\pi^- p \rightarrow \pi^- \pi^0 \pi^0 p$

~10% of 2008 data

Type of cut applied	Nb of events	Remaining [%]
All events	6.98800×10^8	100.00
DT0	5.07415×10^8	72.61
NbPV==1	4.02453×10^8	57.59
NbOutPar==1	2.25624×10^8	32.29
TargetCut	1.80785×10^8	25.87
ChargeSum	1.76766×10^8	25.30
$N_\gamma == 4$	9.75743×10^6	1.40
$2\pi^0$ within $m_{\pi^0}(\mathrm{PDG}) \pm 20\,\mathrm{MeV}$	9.15084×10^5	0.13
exactly one $2\pi^0$ combination within $m_{\pi^0}(\mathrm{PDG}) \pm 20\,\mathrm{MeV}$	8.99705×10^5	0.13

Table 1: Remaining statistics after cuts - Preselection.

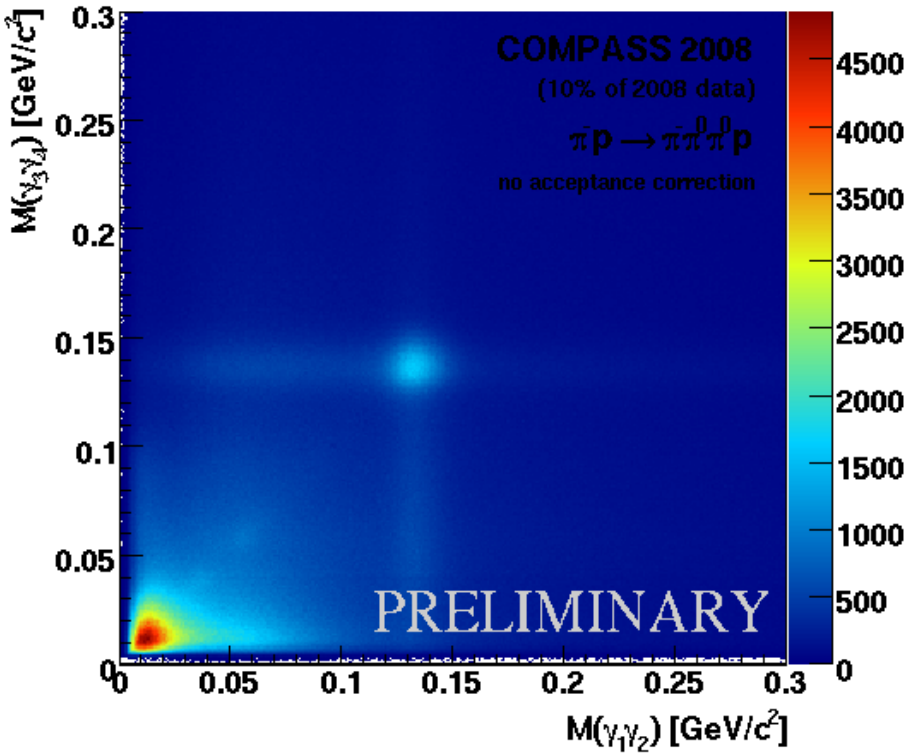
Type of cut applied	Nb of events	Remaining [%]
All events - preselected		
$E_{\pi^-} < 185\mathrm{GeV}/c^2$		
RPDtracks==1 && $p_{\mathrm{recoil}} > 250\,\mathrm{MeV}$		
$\Delta\Phi < 0.2$	3.95250×10^5	43.93
Tigthened cut on π^0 mass ($m_{\pi^0}(\mathrm{PDG}) \pm 16\,\mathrm{MeV}$)	3.25001×10^5	36.12
Exclusivity $\pm$ 6 GeV	2.41406×10^5	26.83
CEDAR Veto on Kaons	2.39511×10^5	26.62

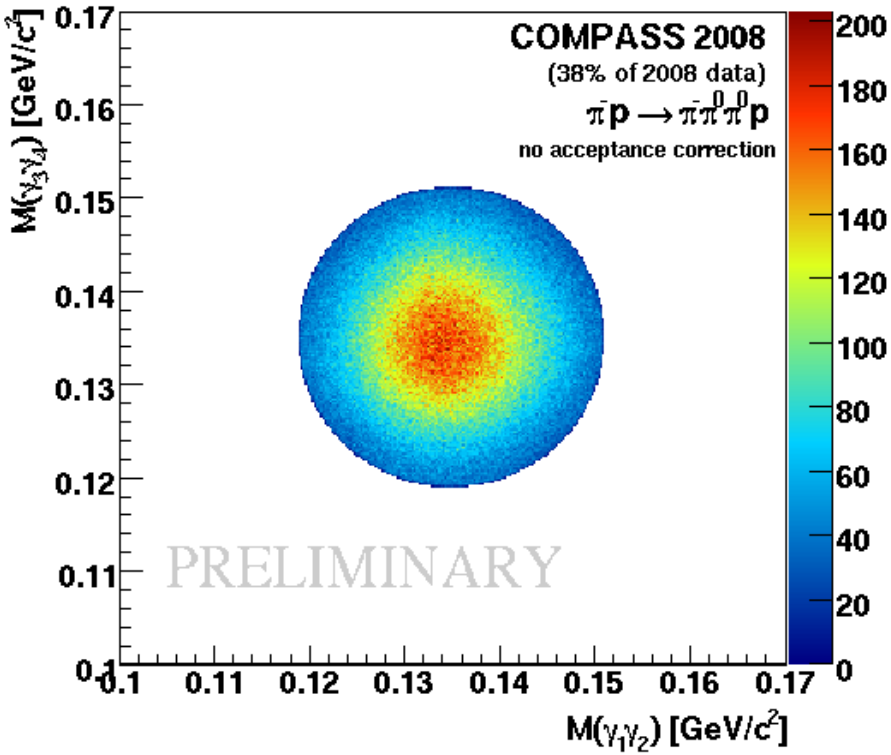
Main cuts for exclusive events:
=> *in terms of sigma ($\pm 2\sigma$)*

Table 2: Remaining statistics after further cuts applied on preselected events, cf. Tab. 1 - Final Selection.

All & Preselected gg pairs, circular cut on PDG π^0 mass

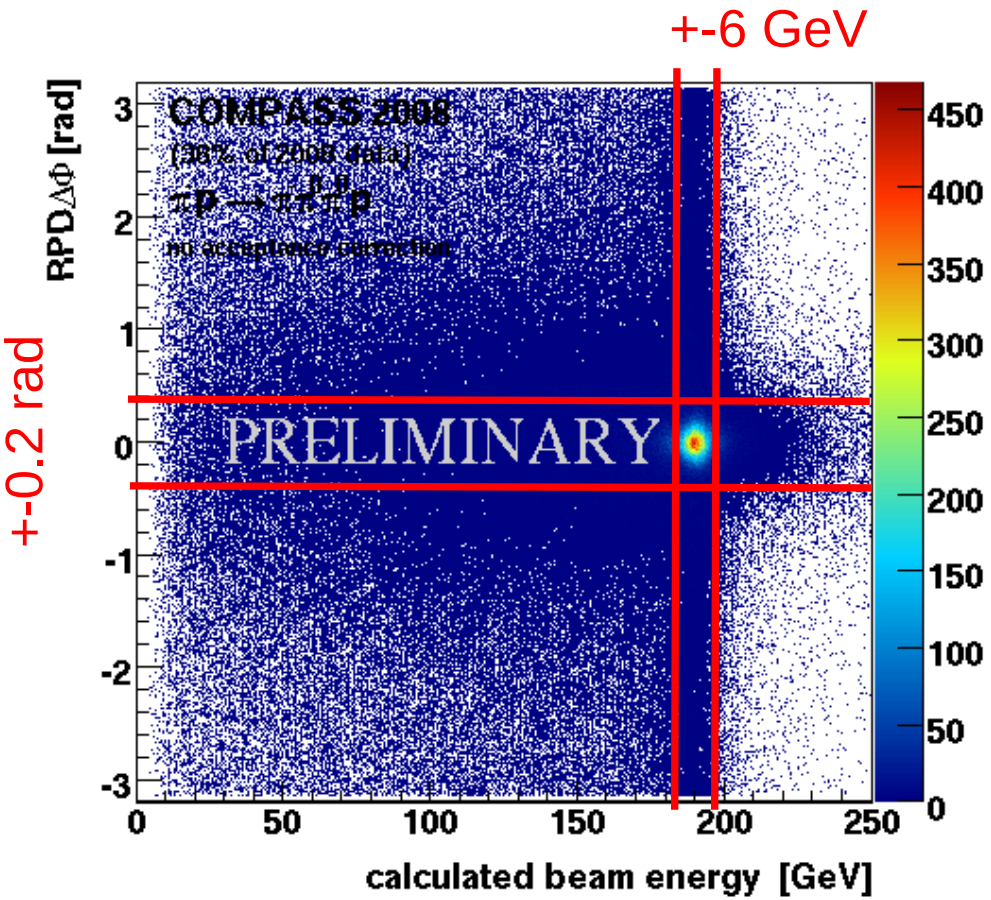
After final cuts on $\Delta\Phi$ and exclusivity, see next slides

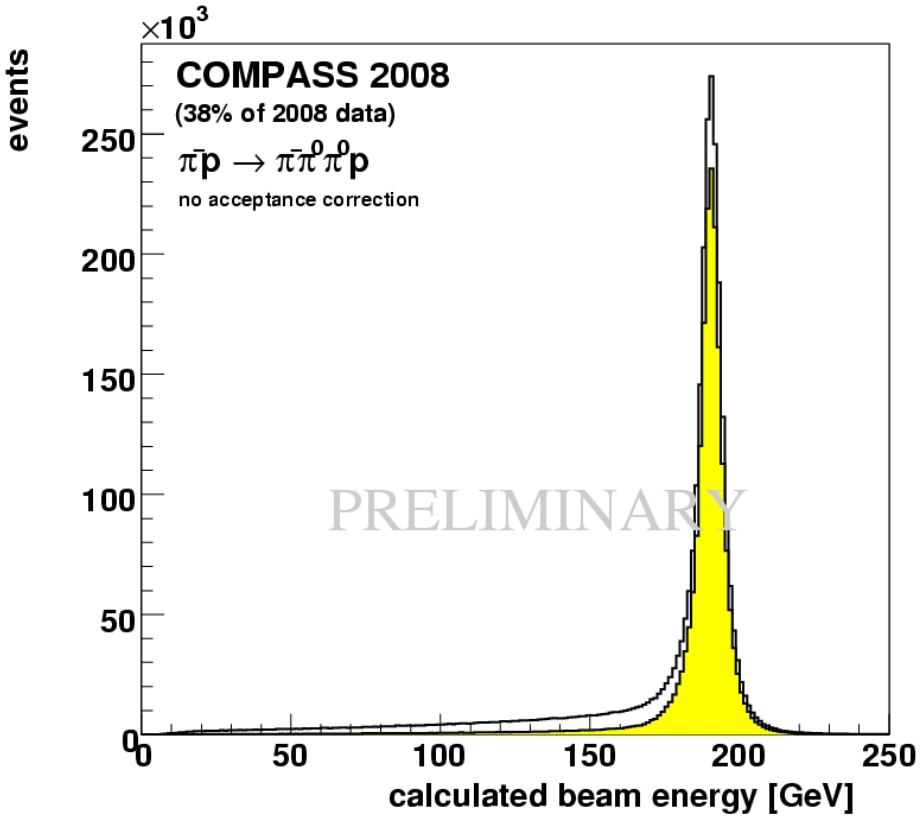




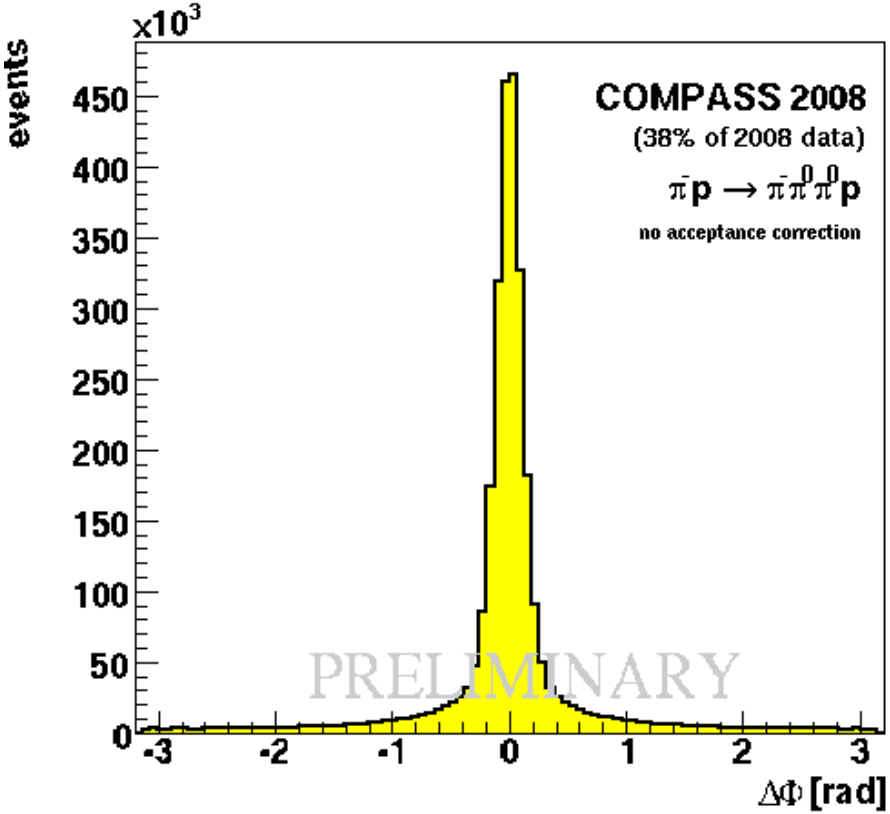
$2\pi^0$ evt := exactly 4 clusters, exactly one $2\pi^0$ combi within PDG +- 20 MeV

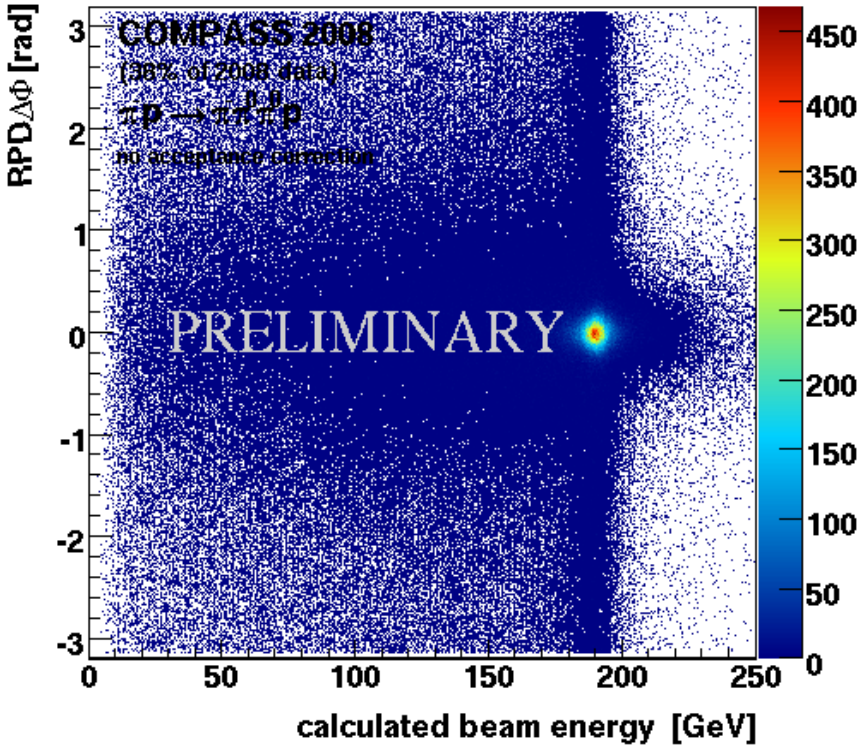
$\Delta\Phi$ (RPD-Spectro) vs. E_{beam}





$\Delta\Phi$ (RPD-Spectro) vs. E_{beam}

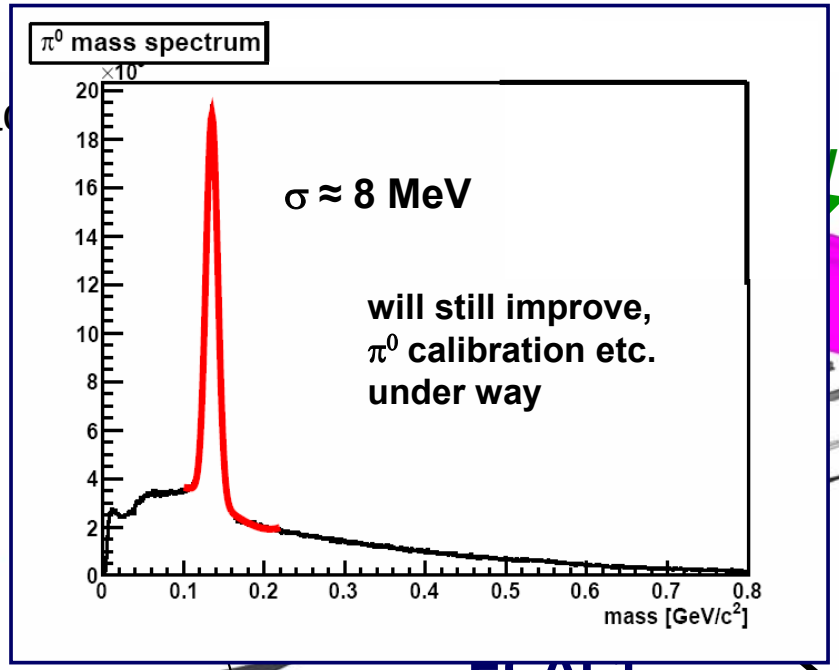




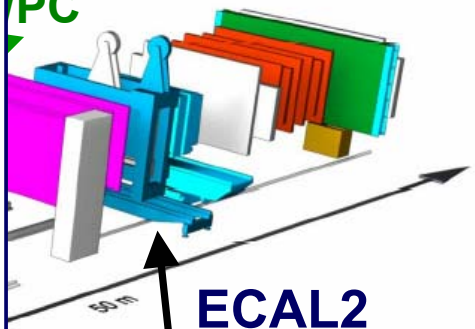
COMPASS spectrometer: Hadron setup 2008/09

+Upgraded trac
ColdSilicons,

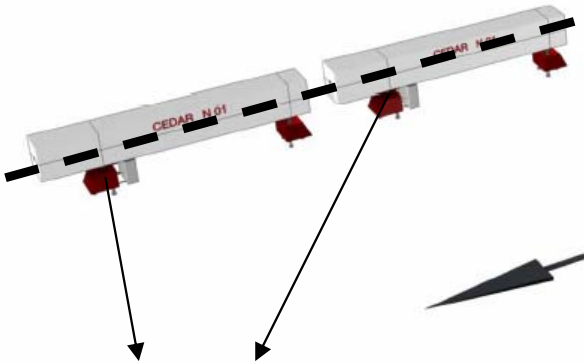
0.4m liquid H_2 target



/PC



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



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

30 m

CEDARS
Beam particle PID

Recoil detector (RPD)
to trigger on reactions inside target

Electromagnetic calorimeters

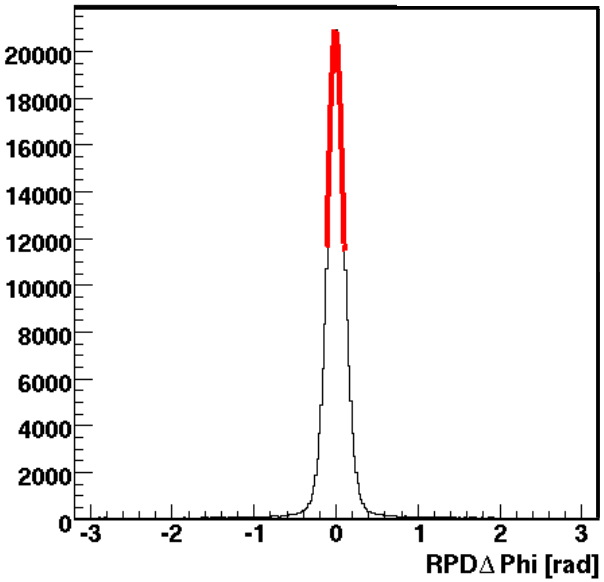
(e.g. $\pi^\circ\pi^\circ$, $\eta\eta$ final states)

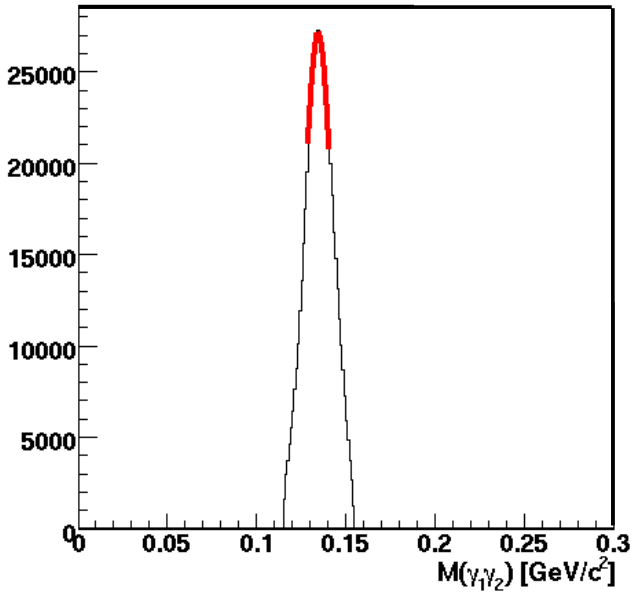
Main cuts for selection of exclusive events: +/- 2σ

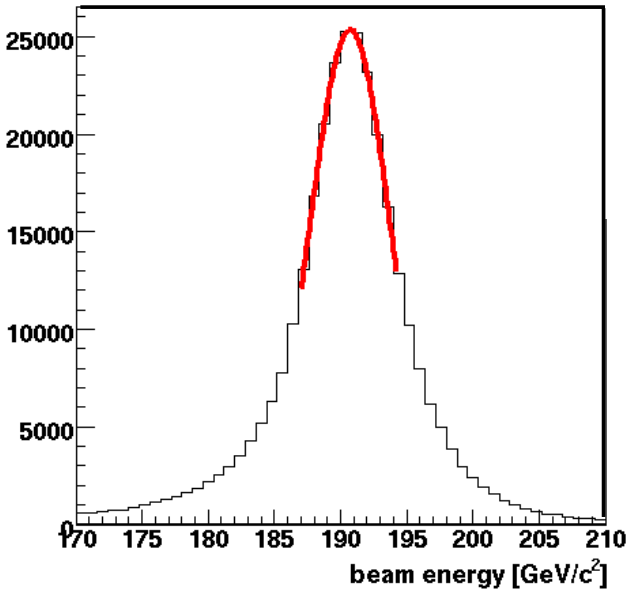
– of each distribution after the other two cuts applied

Main cuts for exclusive events in terms of resolutions, 2σ:

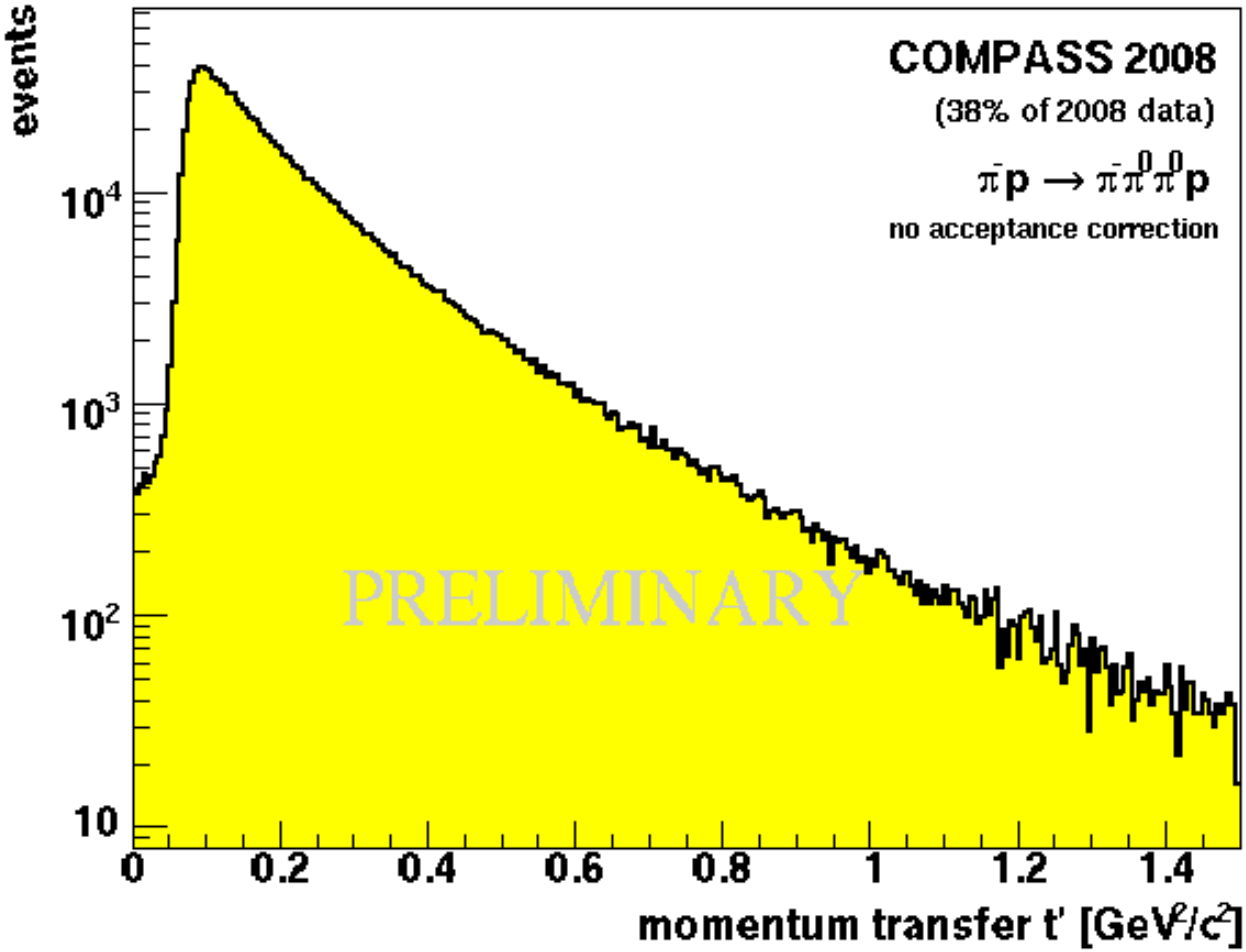
(a) π° mass cut = 16 MeV (b) RPD Δphi = 0.2 rad (c) Exclusivity = 6 GeV



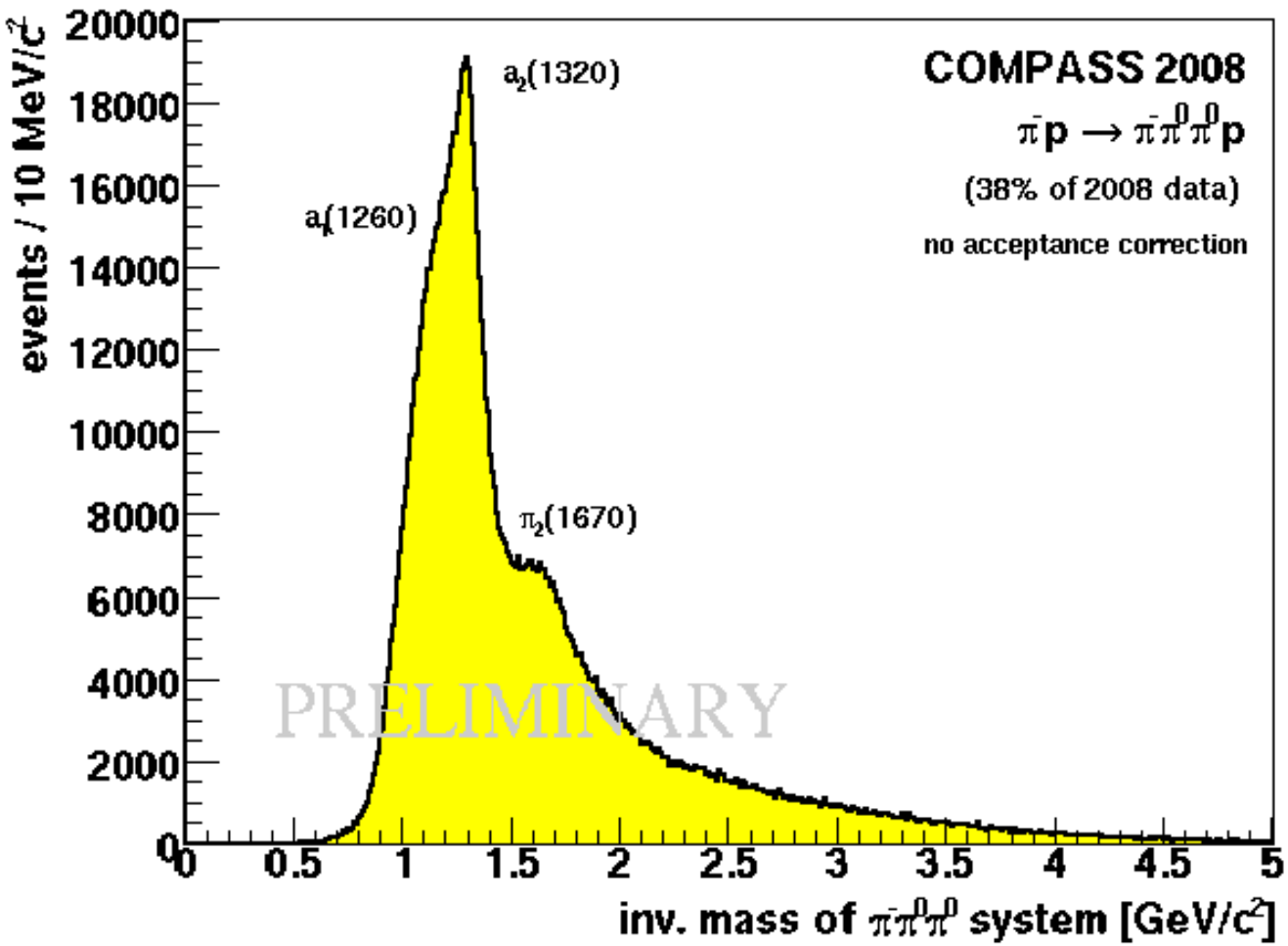




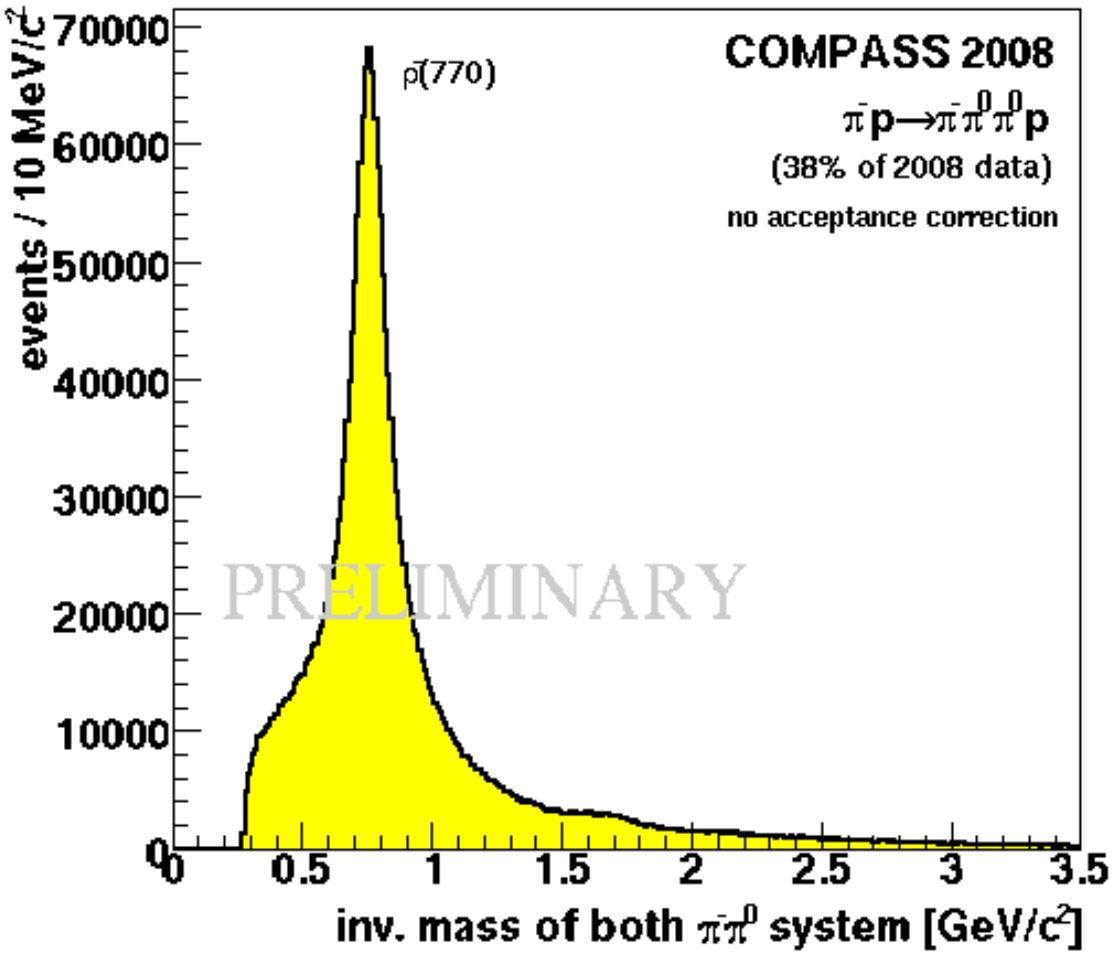
t‘ distribution



Mass spectrum of $\pi^-\pi^0\pi^0$ final state



Mass spectrum of both π–π^0 systems



Mass spectrum: $\pi^\circ\pi^\circ$ systems