New results on the search for spin-exotic mesons with COMPASS
(diffractively produced on proton)

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Universität Freiburg, Physikalisches Institut
for the COMPASS Collaboration

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Outline:

- **Introduction**
  - Spin-exotic mesons & the COMPASS experiment
  - PWA method
- **First results on diffractive 3π production** (2008 proton data)
  - 3π final states neutral vs. charged mode
  - PWA results on main & small waves
- **Status on further relevant decay channels**
  - η`π, f_1π decay channels
- **Conclusions & outlook**

bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen Grundlagenforschung

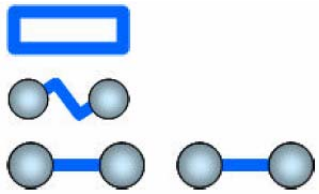
Mesons and Spin Exotic States

Constituent quark model

- color neutral $q\bar{q}$ systems
- Quantum numbers $I^G J^{PC}$
- $P = (-1)^{L+1}$ $C = (-1)^{L+S}$ $G = (-1)^{I+L+1}$
- J^{PC} multiplets: $0^{++}, 0^{-+}, 1^{--}, 1^{+-}, 1^{++}, 2^{++}, \ldots$
- Forbidden: $0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}, \ldots$

QCD: meson states beyond

- Glueballs: gg, ggg
- Hybrids: $q\bar{q}g$
- Tetraquarks: $(q\bar{q})(q\bar{q})$



Hybrid candidates (1.3 - 2.2 GeV/c²):

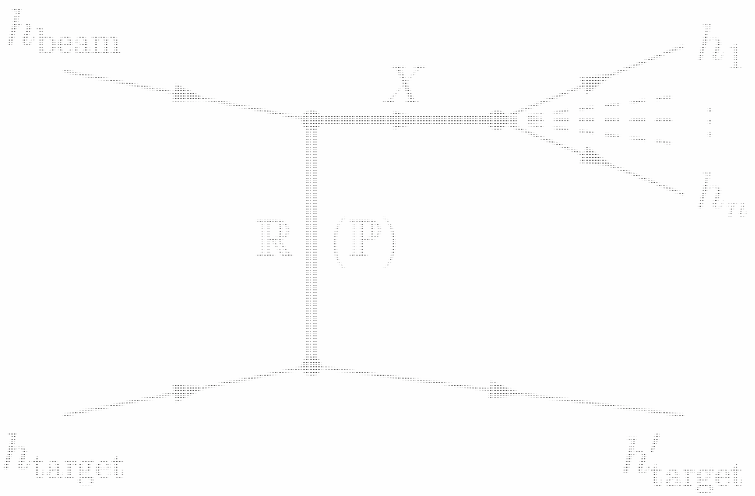
lightest hybrid predicted: exotic $J^{PC} = 1^{-+}$

- $\pi_1(1400)$: 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 controversial* → *COMPASS*

Diffractive scattering

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



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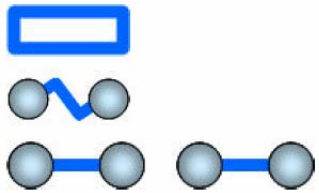

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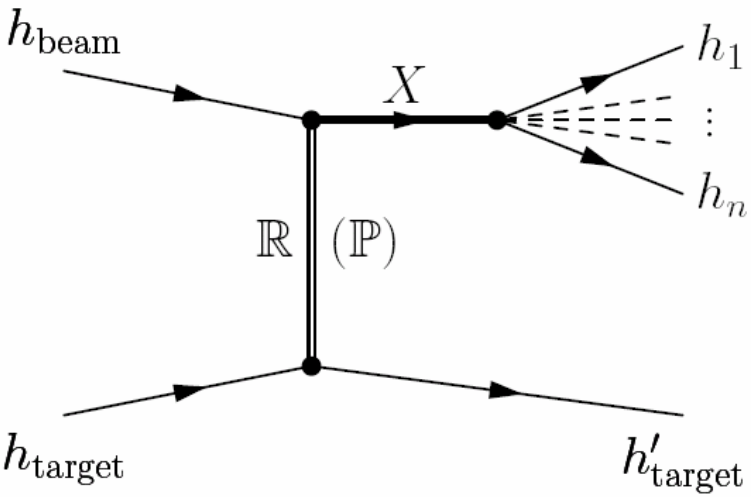

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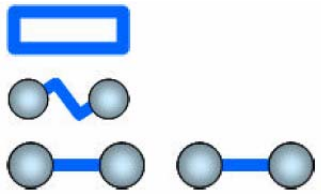

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COMPASS (2004 pilot run)

- 190 GeV π^- beam *(Pb target)*
- studied $\rho\pi$ decay channel via

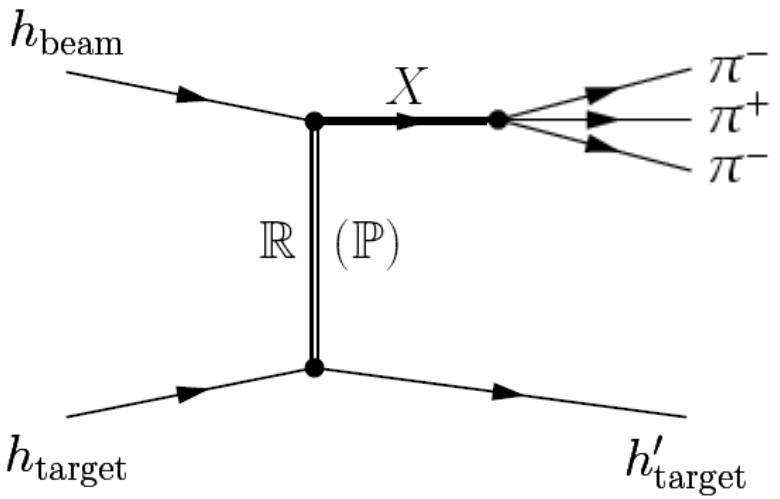
  π^- **Pb** —> $\pi^-\pi^+\pi^-$ **Pb**

=> **confirmation of a 1^{-+} resonance at 1.66 GeV**

[PRL 104 (2010) 241803]

Diffractive pion dissociation

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



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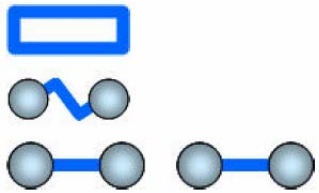

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  - a) π^- **p** —> $\pi^-\pi^+\pi^-$ **p** (charged mode)
  - b) π^- **p** —> $\pi^-\pi^0\pi^0$ **p** (neutral mode)

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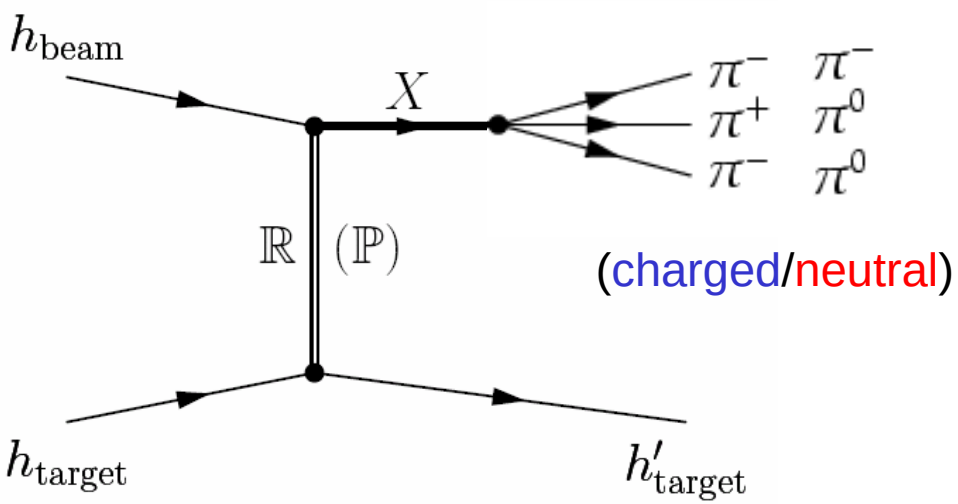
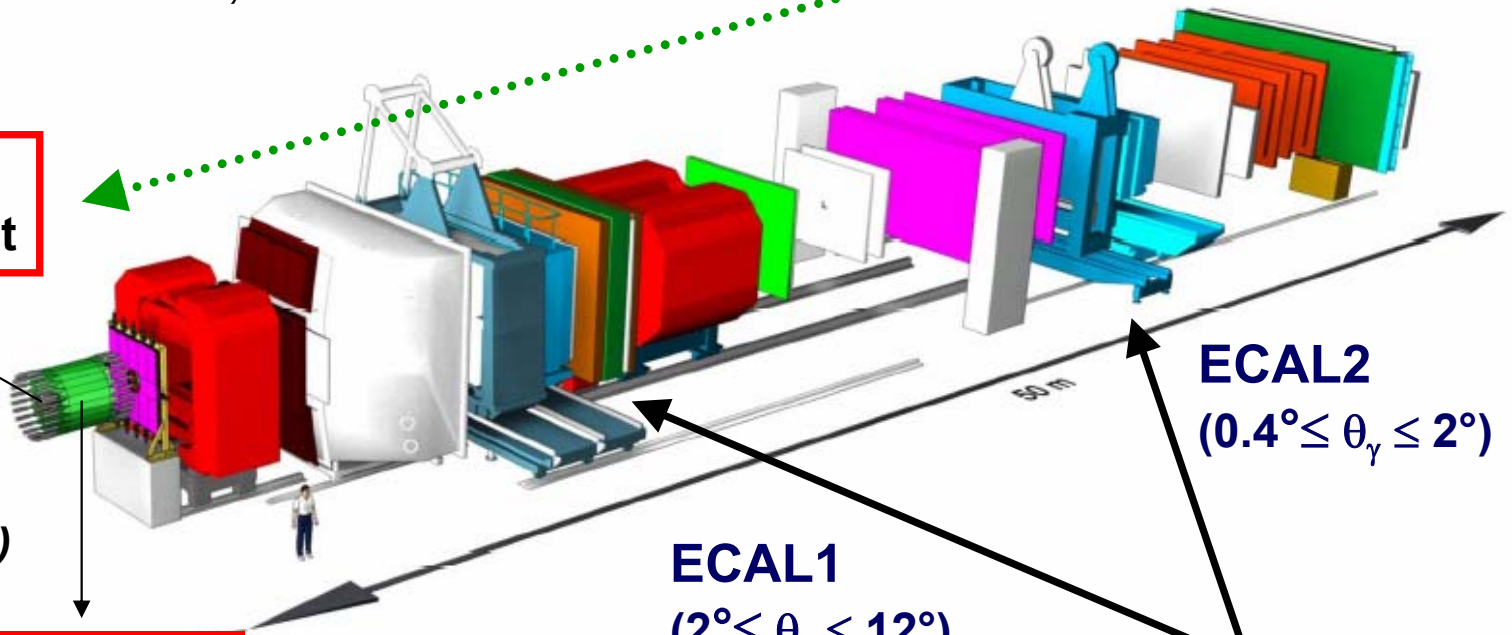


(charged/neutral)

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
($2° \leq \theta_\gamma \leq 12°$)

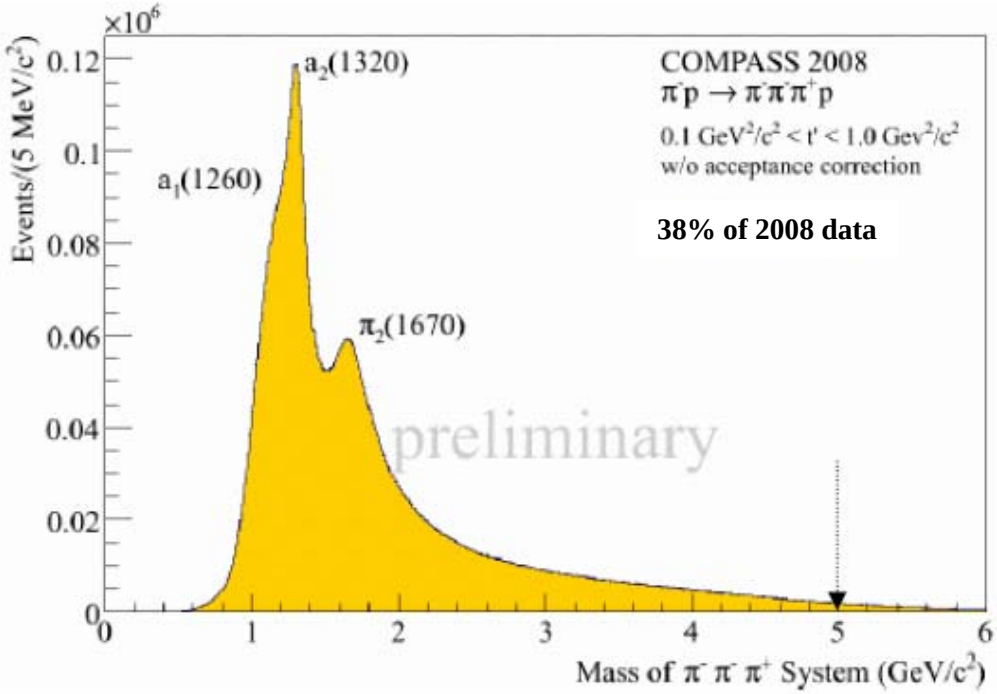
Electromagnetic calorimeters

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

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

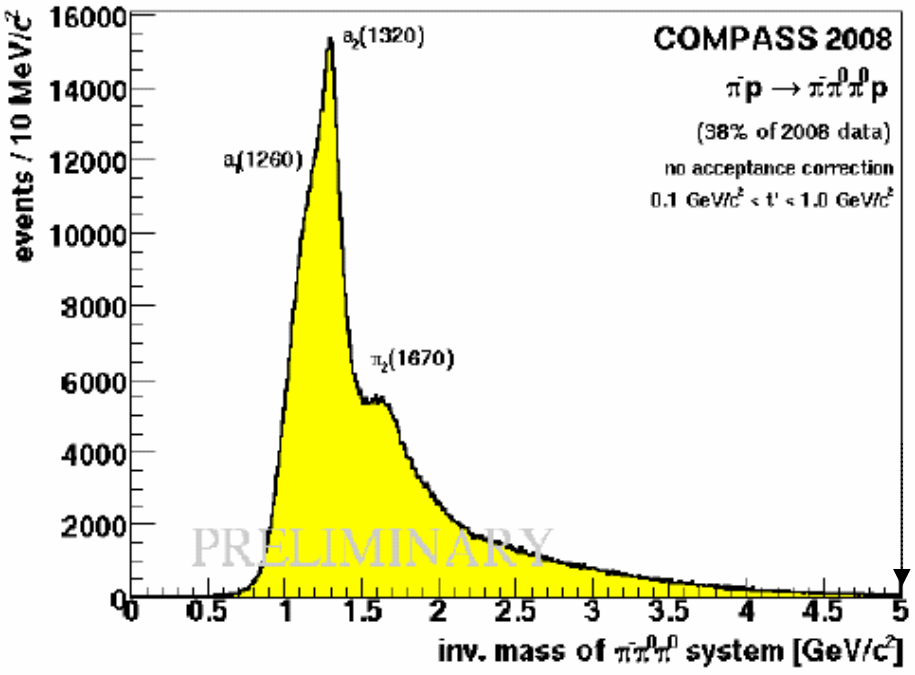
search for $\pi_1(1600)$

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



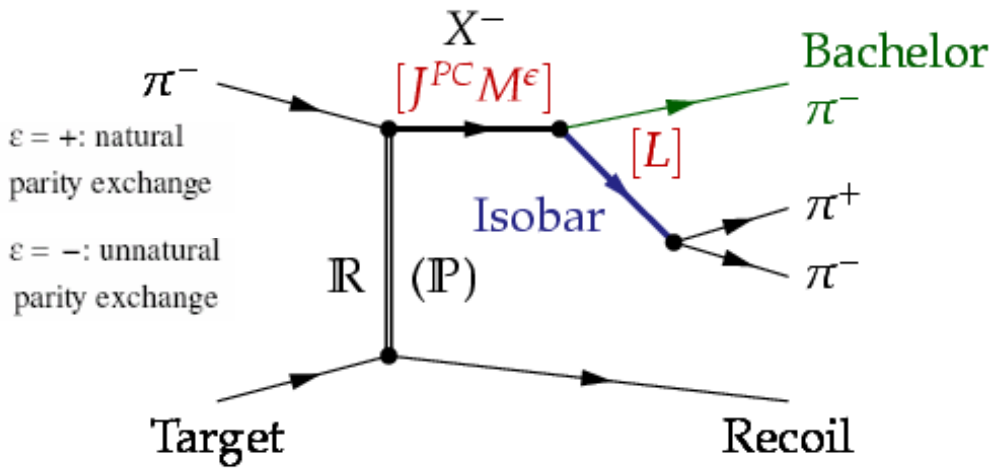
PWA: ~ 24M events (acceptance corrected)

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



PWA: ~ 1M events

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:

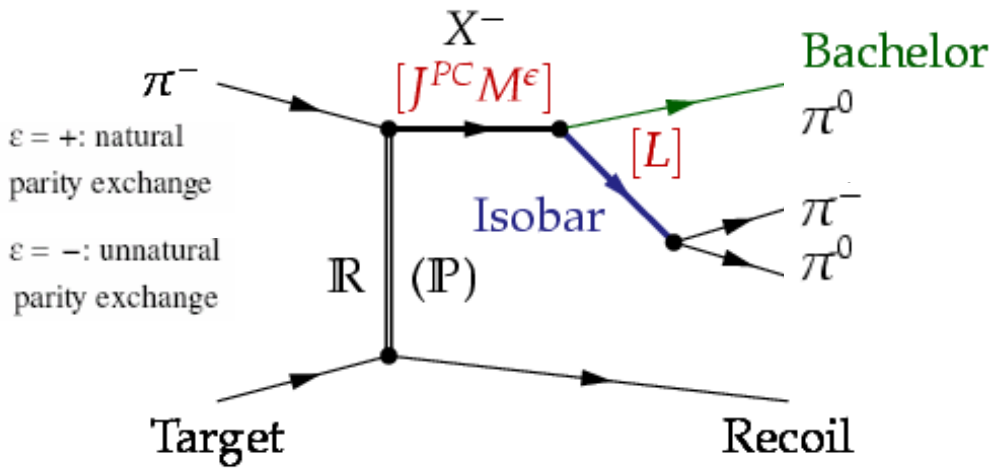
- **program:** Illinois/Protvino/Munich (D.Ryabchikov) software (IHEP/VES, TUM/COMPASS)
- **Isobars:** *$(\pi\pi)_S$ [broad $f_0(600)$+$f_0(1370)$], $f_0(980)$, $\rho(770)$, $f_2(1270)$, $\rho_3(1690)$*
- **Acceptance:** corrections (2008: rather flat for charged, neutral not yet included)

Step 1) Mass independent PWA: (40MeV/c² bins, 53 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



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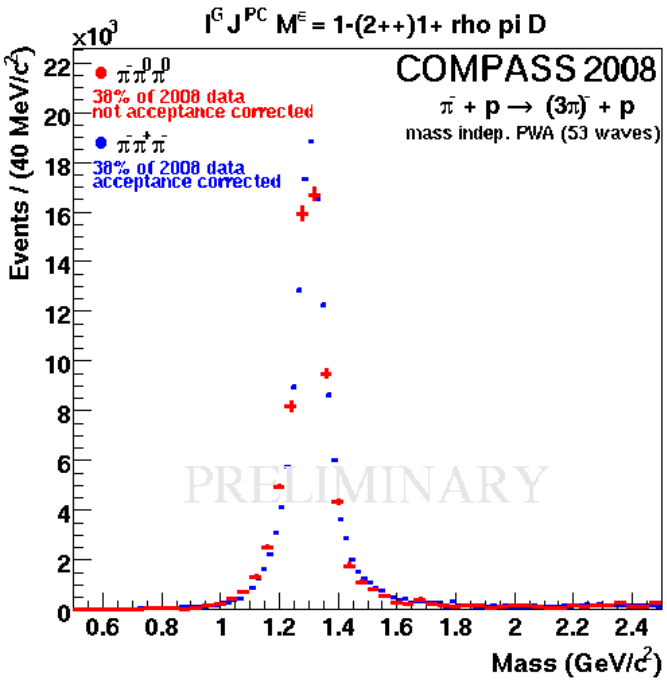
Comparison: Neutral vs. charged mode

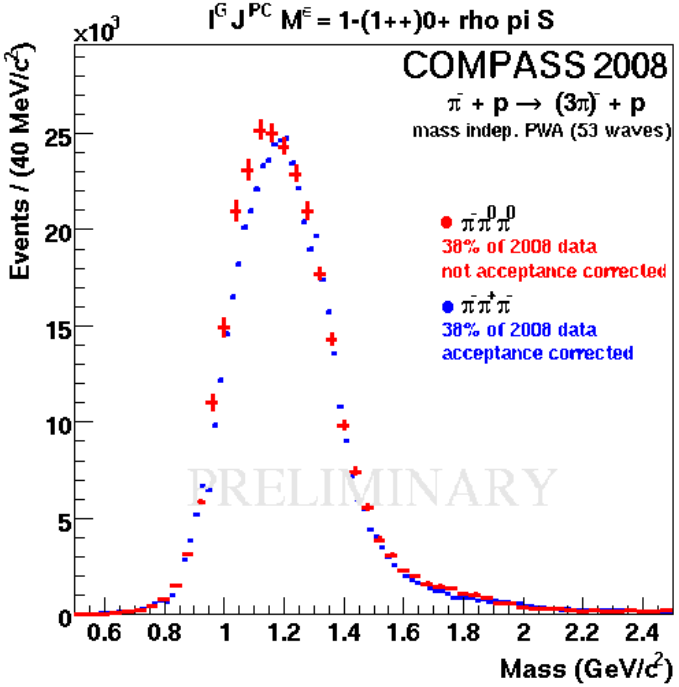
simple isospin symmetry check

$a_2(1320) \rightarrow \rho\pi$

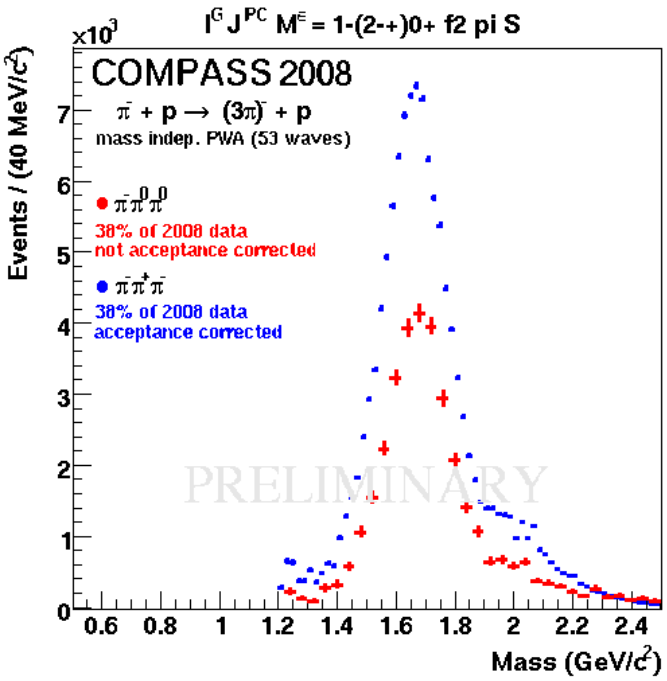


(used for normalisation)

$a_1(1260) \rightarrow \rho\pi$



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



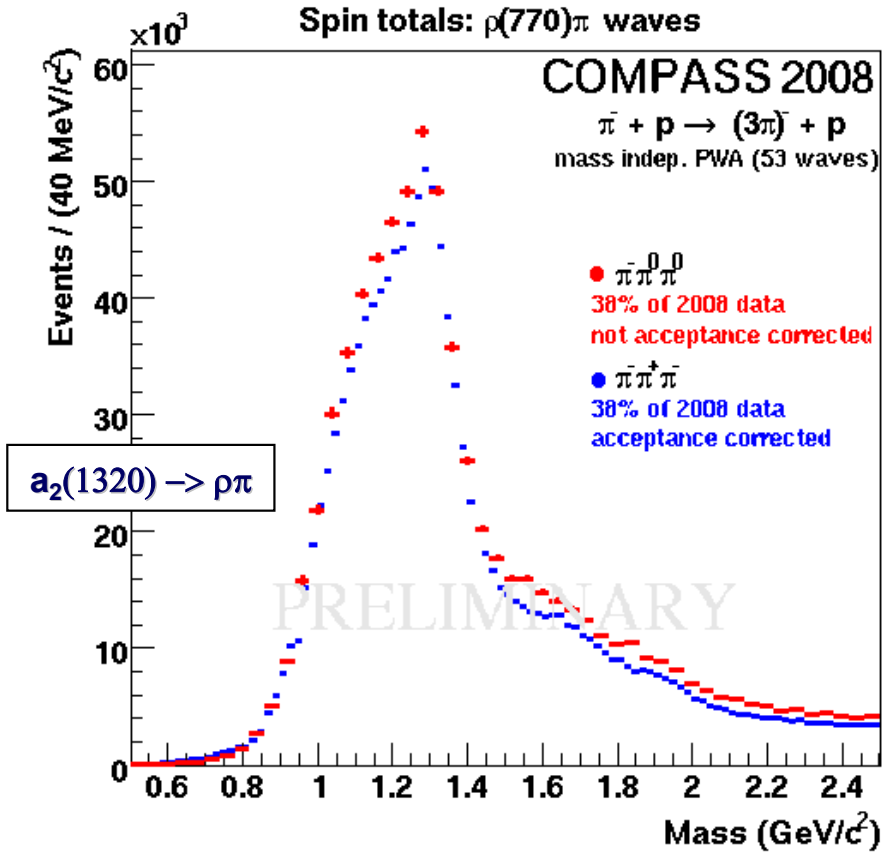
search for $\pi_1(1600)$

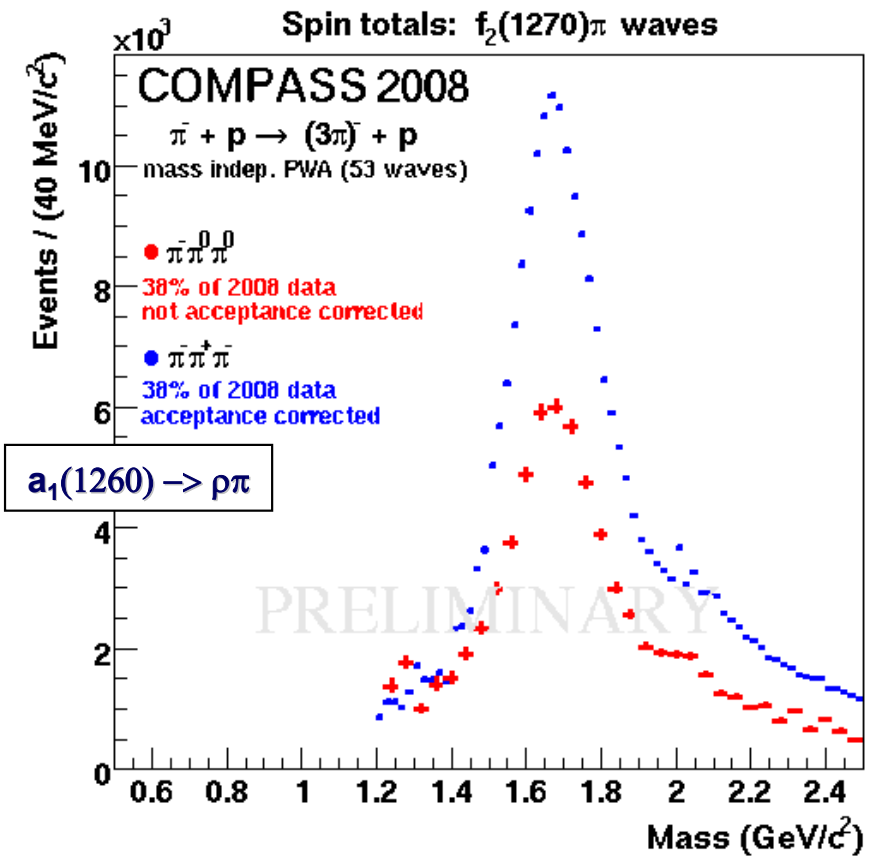
Isospin symmetry: neutral / charge mode

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

Two sets of partial wave totals

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





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- X^- decaying into $f_2\,\pi$: 1/2 intensity expected
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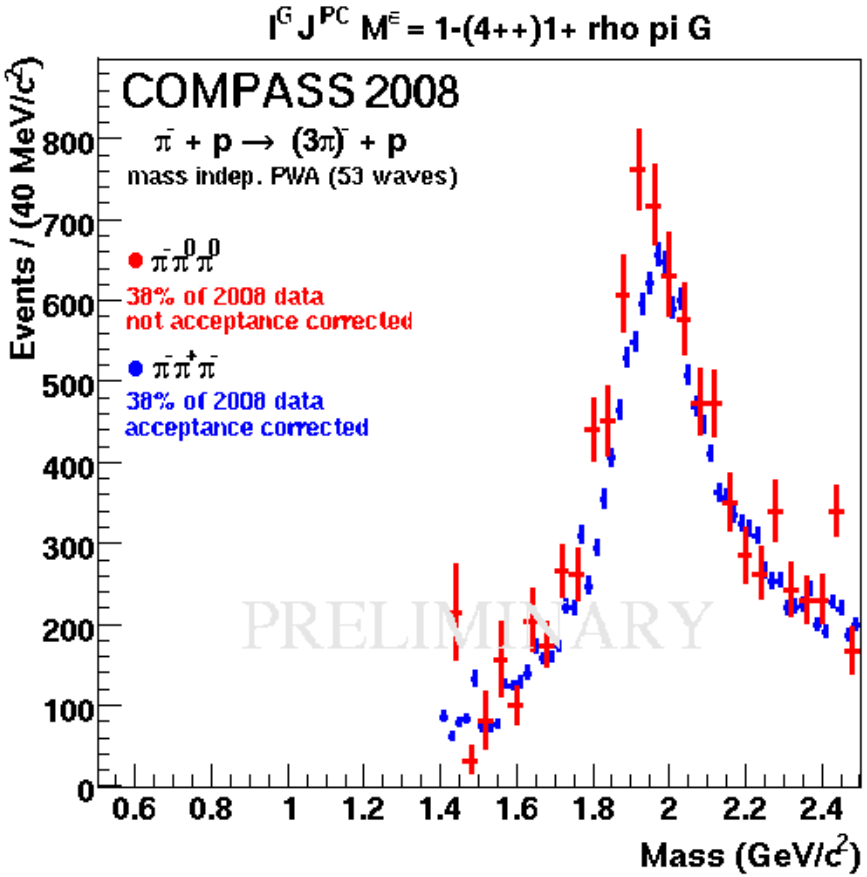
Data follows isospin symmetry:

- throughout full wave-set
- main and small waves, *next slides*

Selected partial waves
isospin symmetry check ctd.

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



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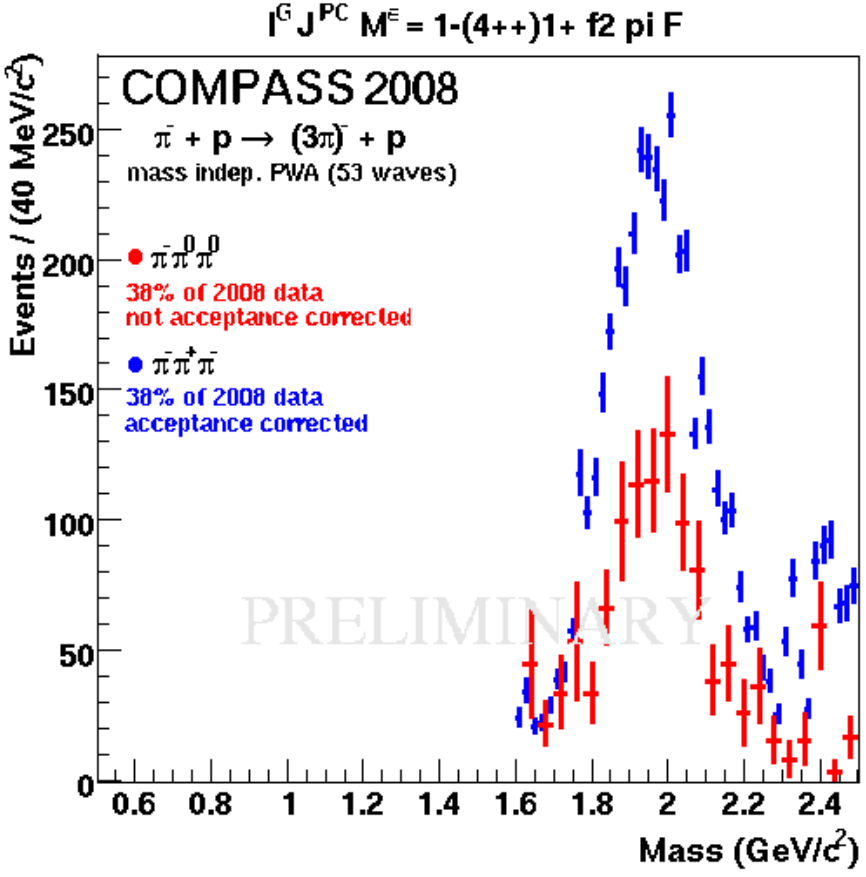
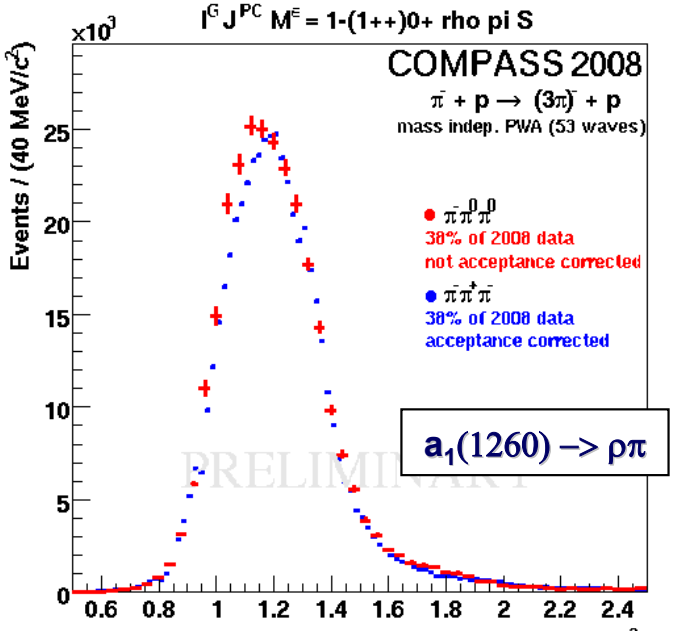
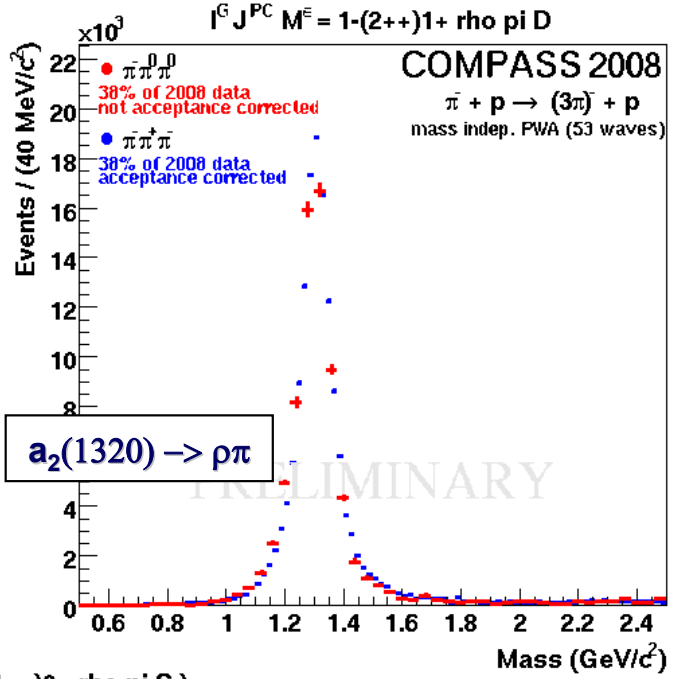
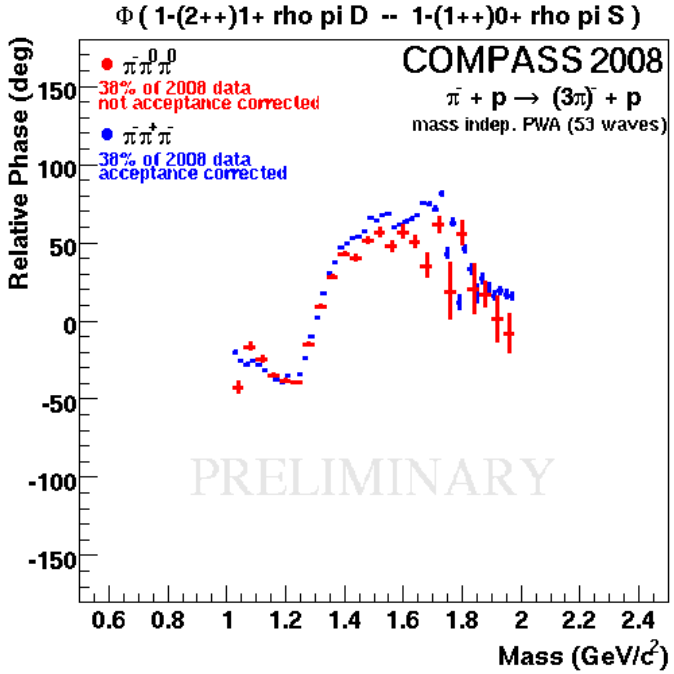


Selected partial waves & phases

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







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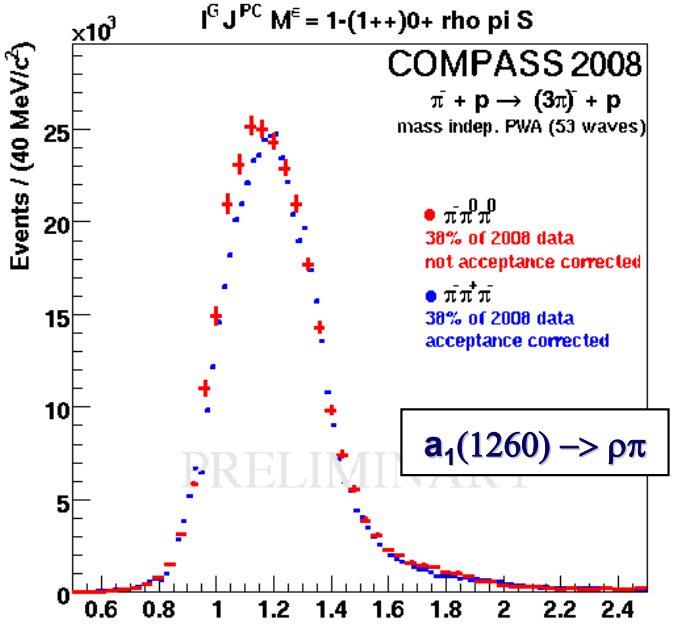

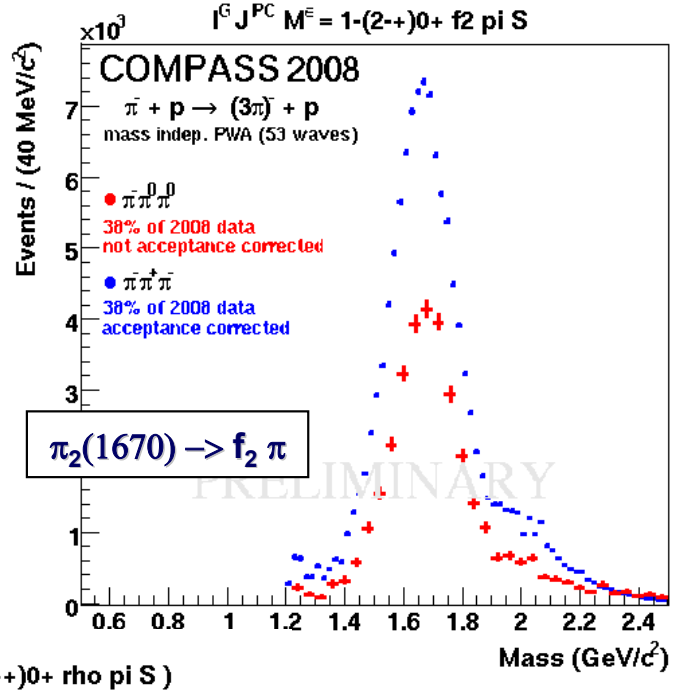

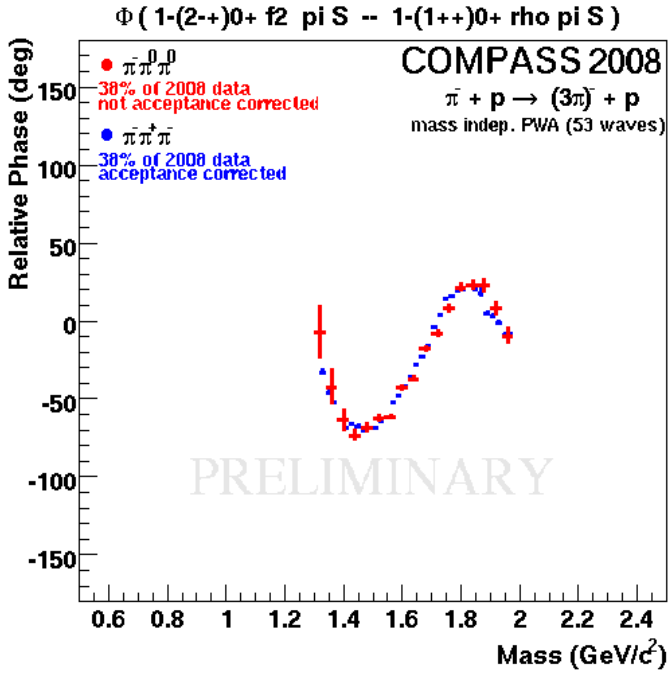

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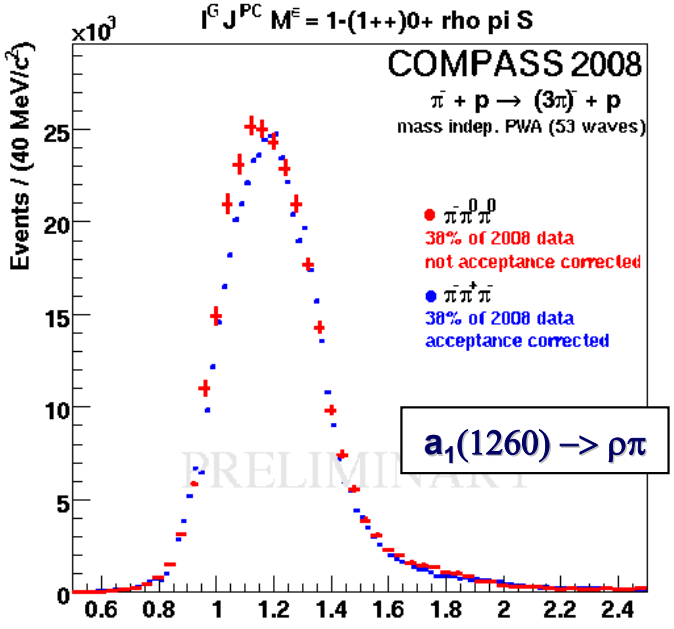

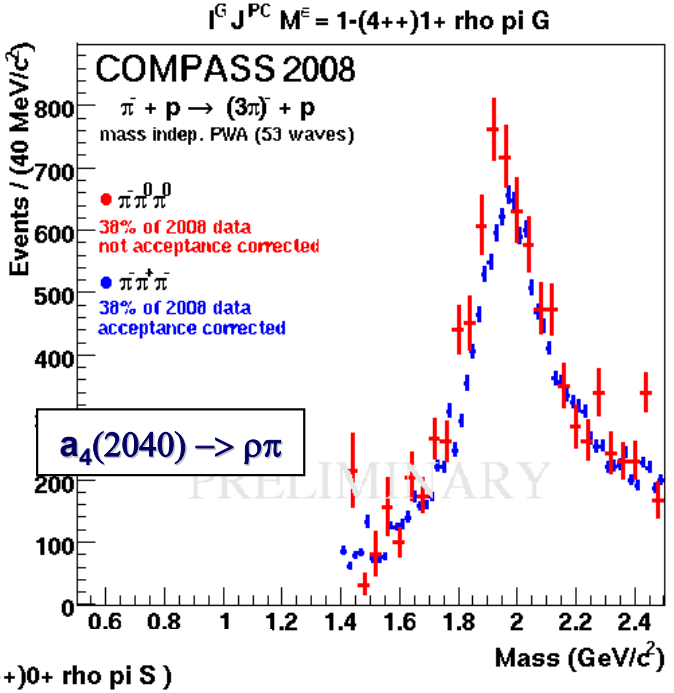

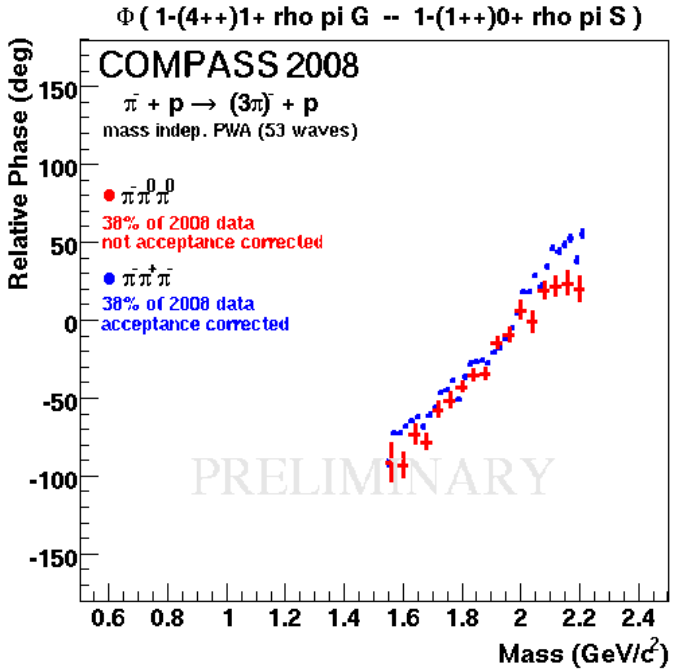

First glimpse on the exotic wave

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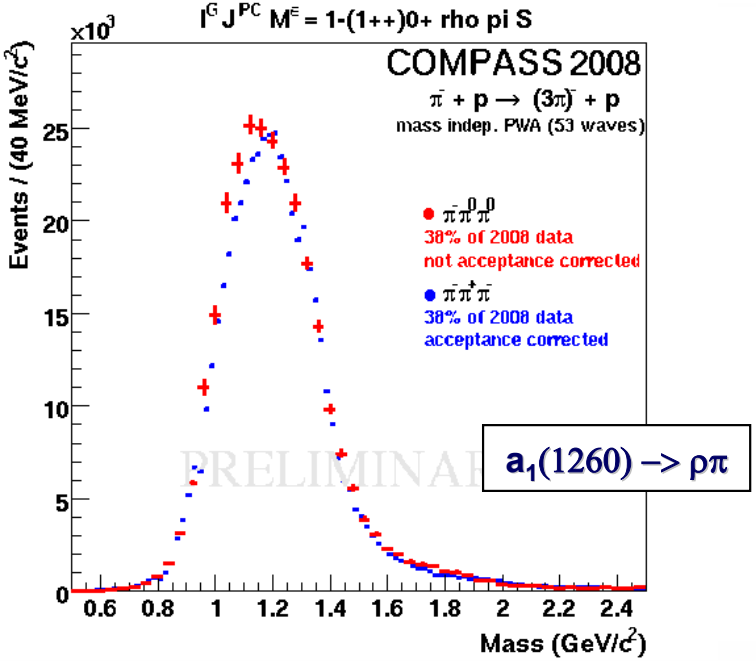

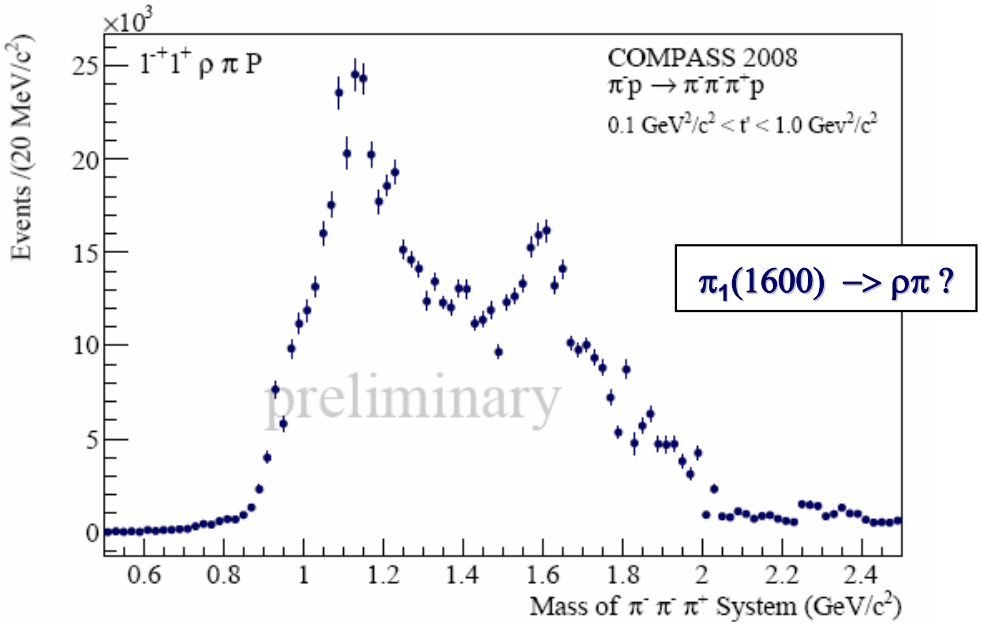

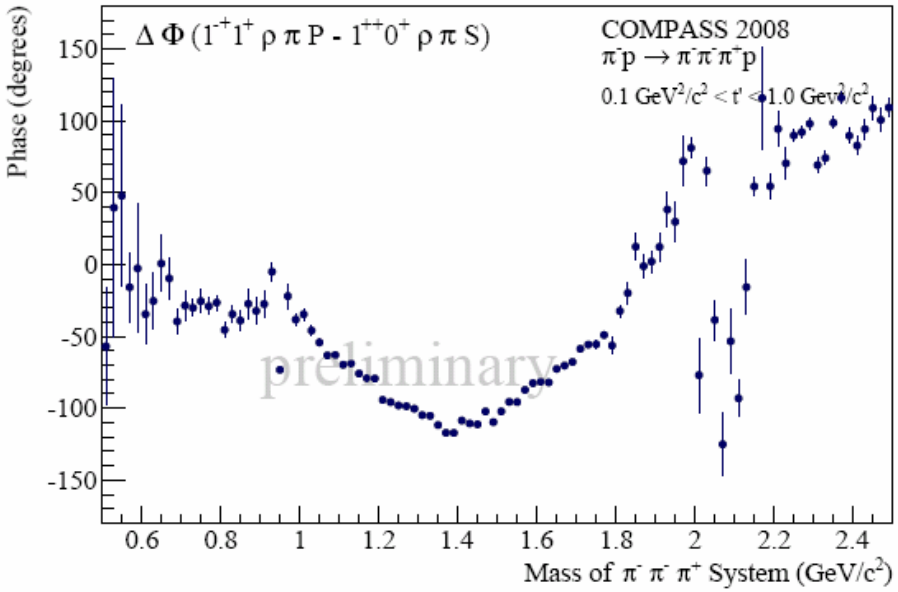

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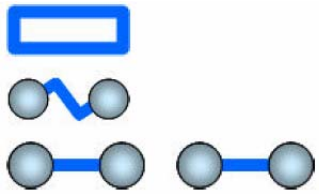

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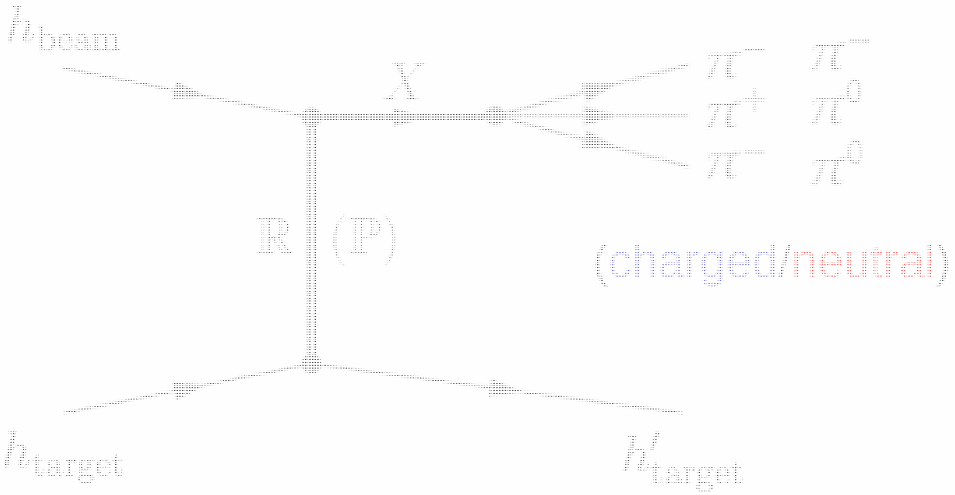

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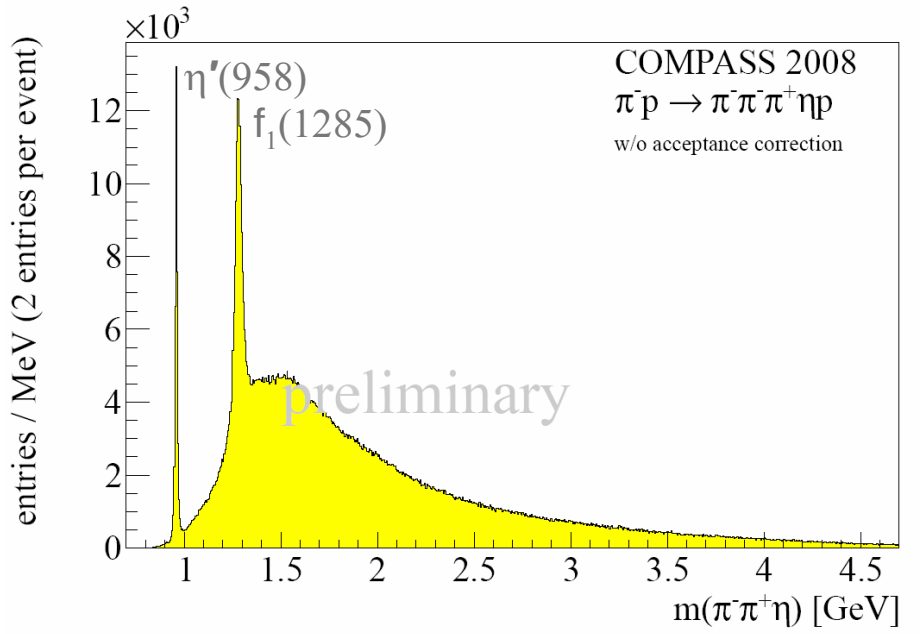
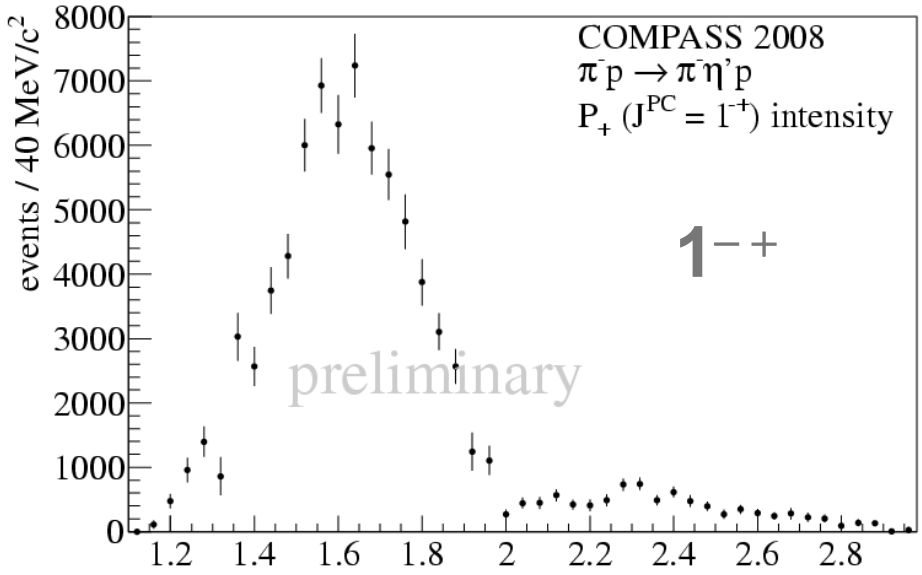
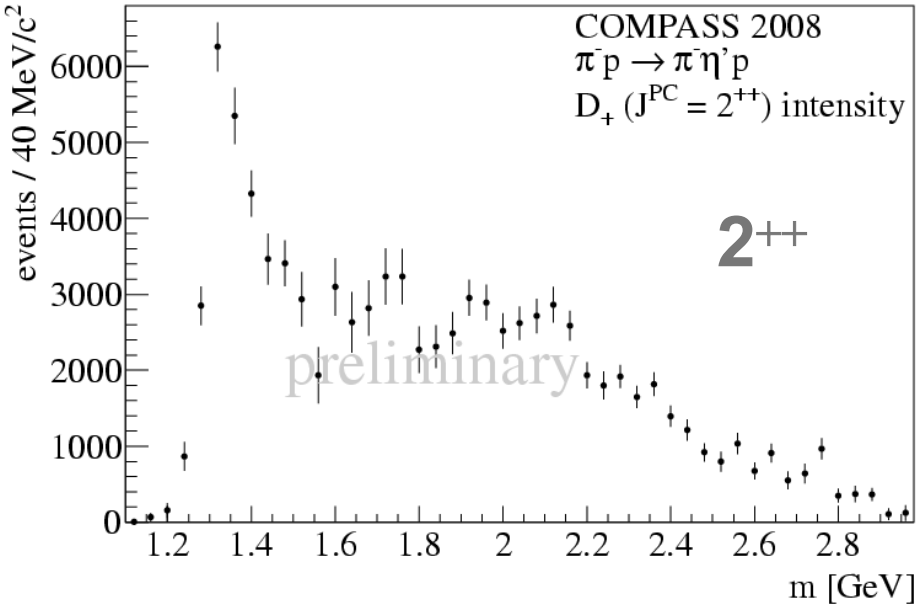
  - b) $\pi^- p \longrightarrow \pi^-\pi^0\pi^0 p$ (neutral mode)

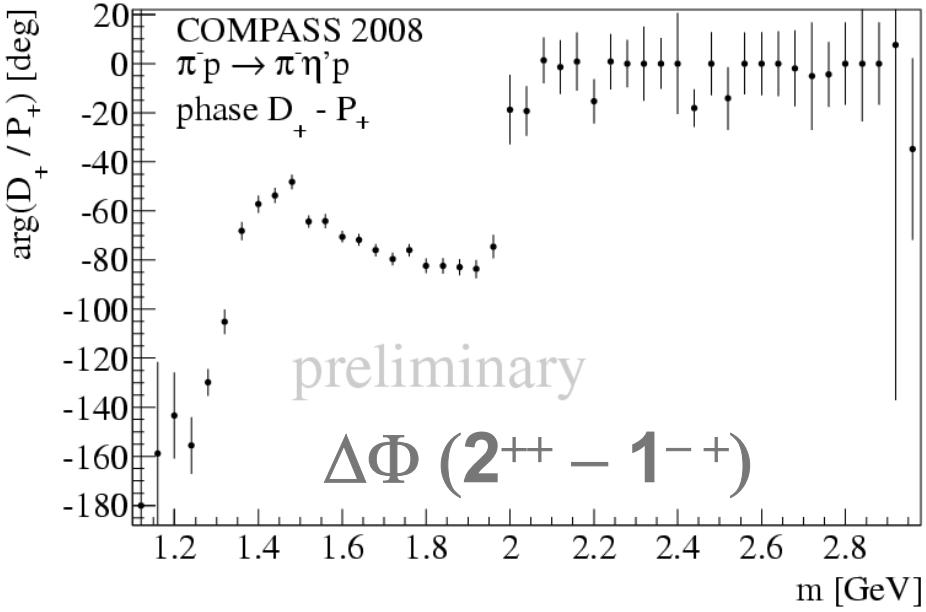
The Exotic $\eta'\pi^-$ Wave in 190 GeV $\pi^-+p \rightarrow \eta'+\pi^-+p$

search for $\pi_1(1600)$









First studies of diffractive dissociation into $K\bar{K}\pi\pi$ final states

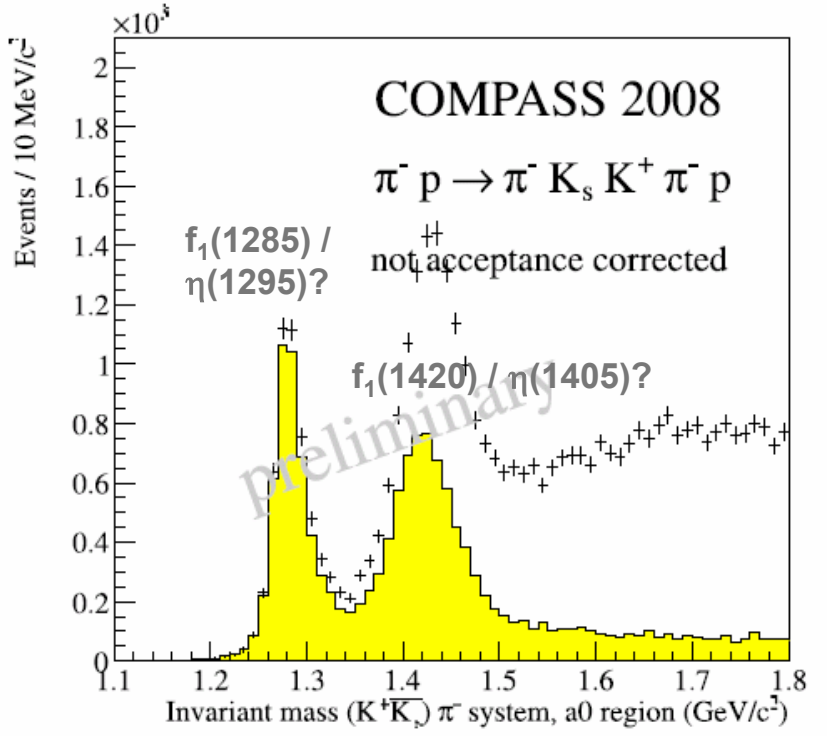
Physics channel: $\pi^- p \rightarrow K\bar{K}\,\pi\,\pi^-\,p$

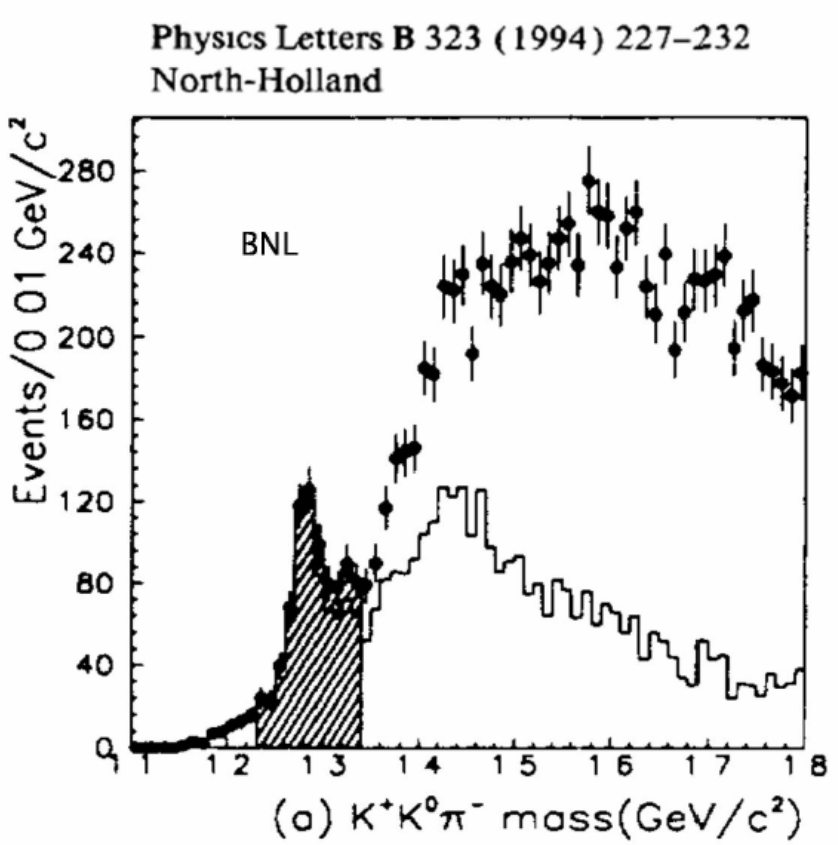
Motivation: Search for diffr. X^- coupling to $s\bar{s}$ final states

First preliminary PWA started: $\overline{K^0}\,K^+\,\pi^-\,\pi^-$

search for $\pi_1(1600)$, $\pi_1(2000)$

$(K\bar{K}\pi)^0$ subsystem:





Statistics: 2008 data => ~ factor 10 w.r.t. BNL (~20 for 2008/09)

Summary & conclusions

- **COMPASS: high potential for spin-exotic search**
  - ✓ **2008/09: Very high statistics taken** *(hadron beams, proton & nuclear targets)*
  - ✓ **COMPASS measures Neutral & Charged channels**

  => all relevant channels for spin-exotic search feasible

- **New physics results presented (incl. exotic signals):**
  - ➢ $(3\pi)^-$ **system studied in both decay modes: charged & neutral** *(consistent results)*

  => Independent confirmation of new states within same experiment!

  - ➢ $(\eta'\pi)^-$ **system shows large intensity in exotic wave** *(high mass range, to be understood)*
  - ➢ $(K\bar{K}\pi\pi)^-$ **system: feasibility shown for** $f_1\pi$ **decay channel(s)!**

    → *exemplarily, further kaonic channels, also:* Kaon diffraction *(using Kaon beam)*

Outlook:

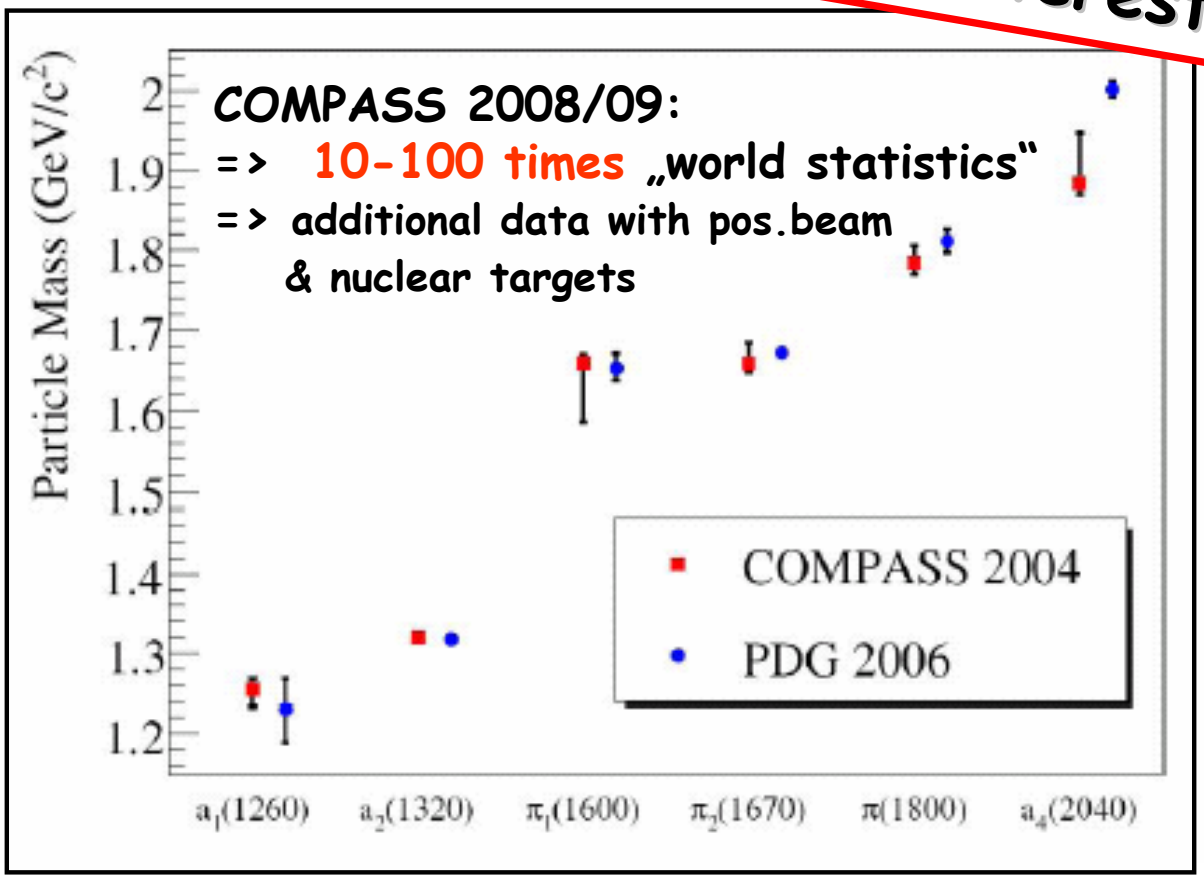
- **More systematic studies, PWA model, Mass-dependent PWA** → *more work ahead*

Not discussed: Low t', Primakoff, Central production, Baryon spectroscopy, OZI violation

→ *Quite rich physics programme: various further ongoing analsyes & results!*

Summary & conclusions

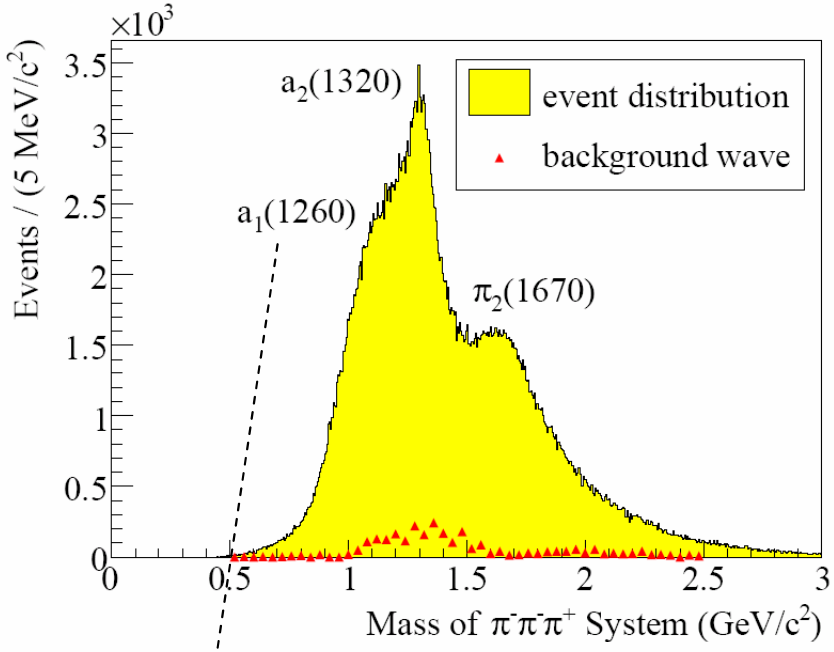
Stay tuned for more interesting COMPASS results …

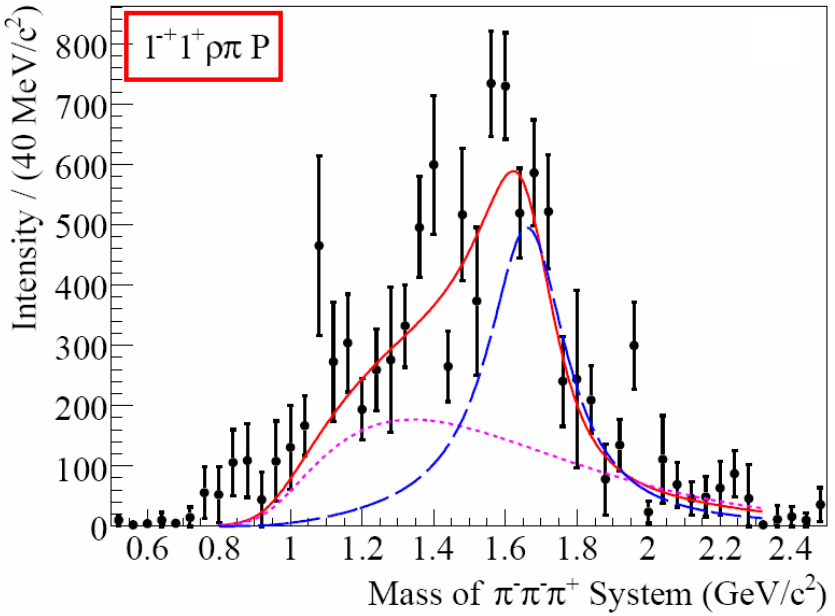


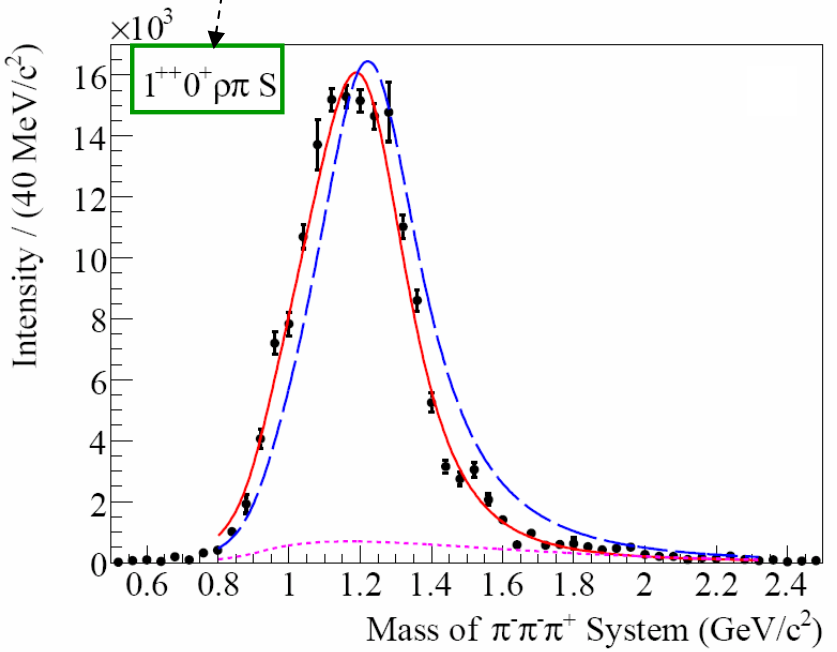
THANK YOU !!!

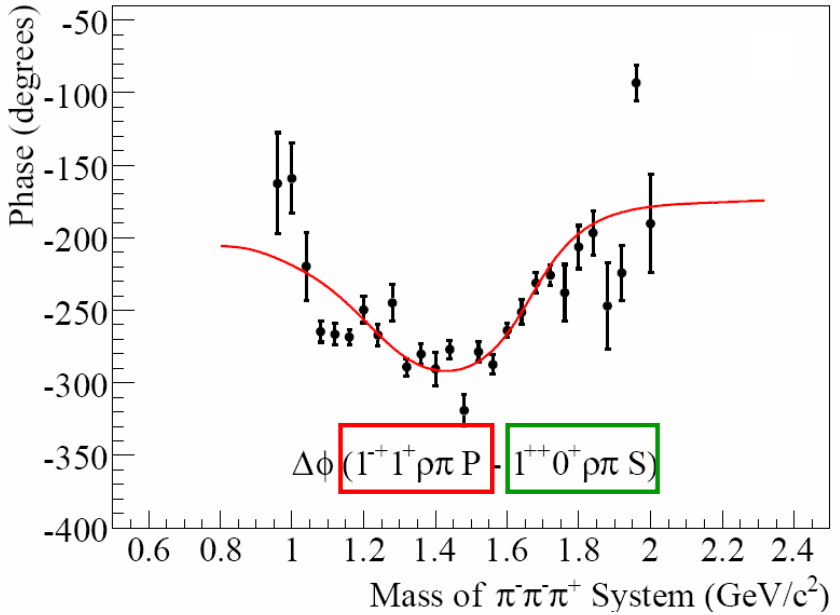
Additional material

Diffractive dissociation into 3π final states
(2004 data, Pb target) [PRL 104 (2010) 241803]

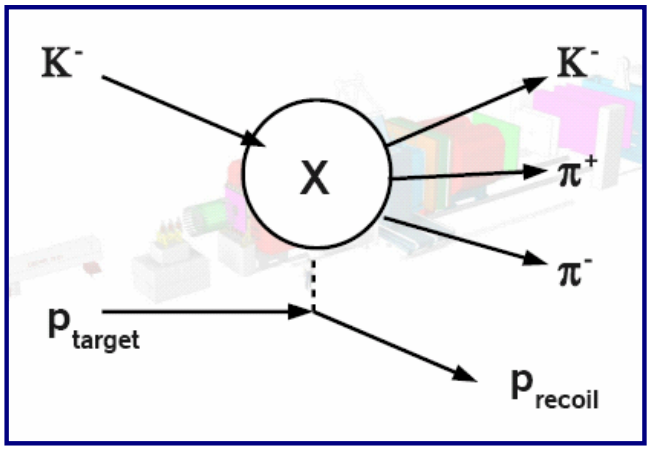


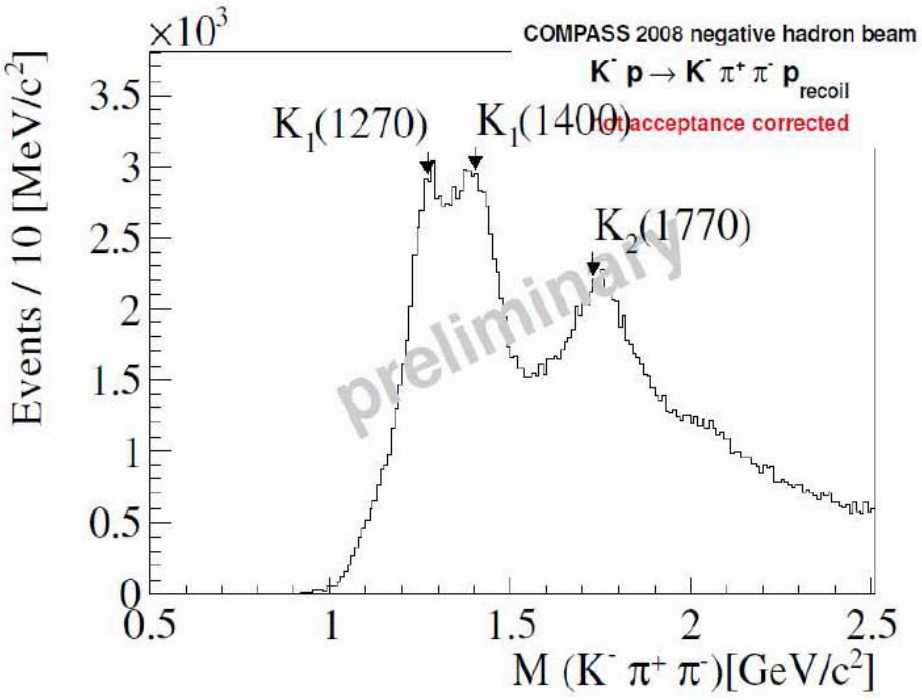




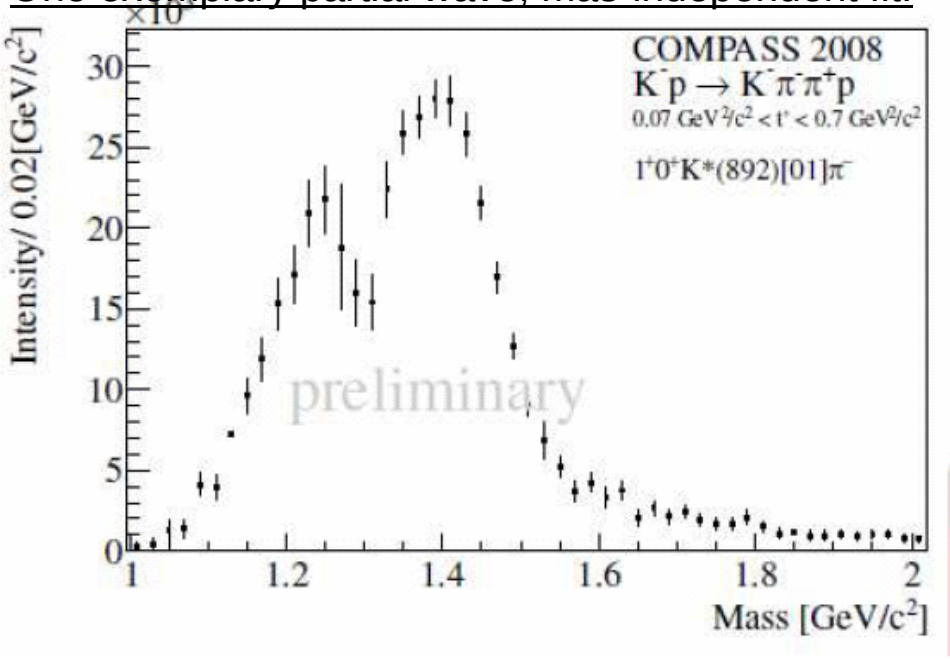


Physics with the kaon beam: Kaon diffraction





One exemplary partial wave, mas-independent fit:



- Statistics ~5 more than WA03
- Several states need confirmation,
  → *e.g. the K(1460)*

- Kaon physics will be an interesting option for future measurements!

Further exemplary channels of interest – involving neutrals

Relevant channels for exotic search:

→ *COMPASS has access to all intermediate isobars:* ***f_1, b_1, η, η',*** *and* ω

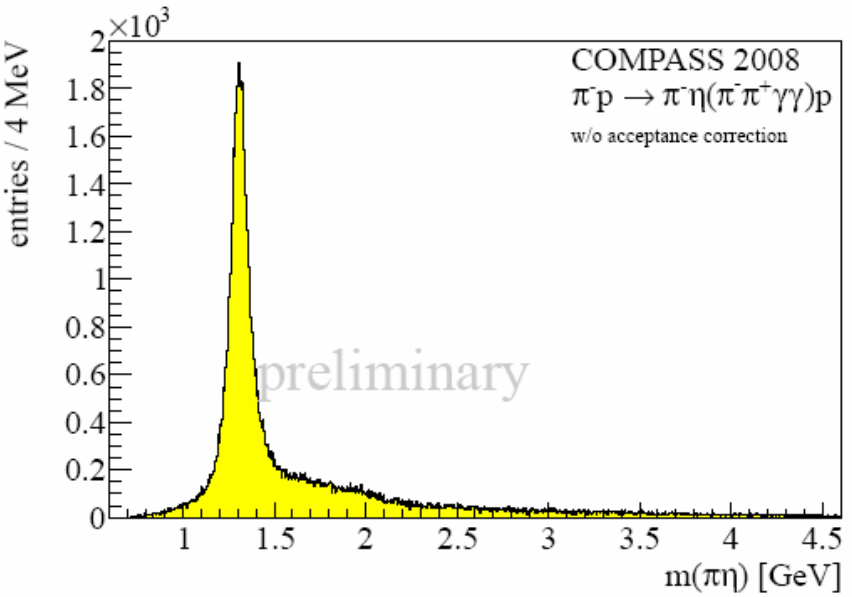
a) π^- **p** —> $\pi^-\eta$ **p** (η —> 3π)

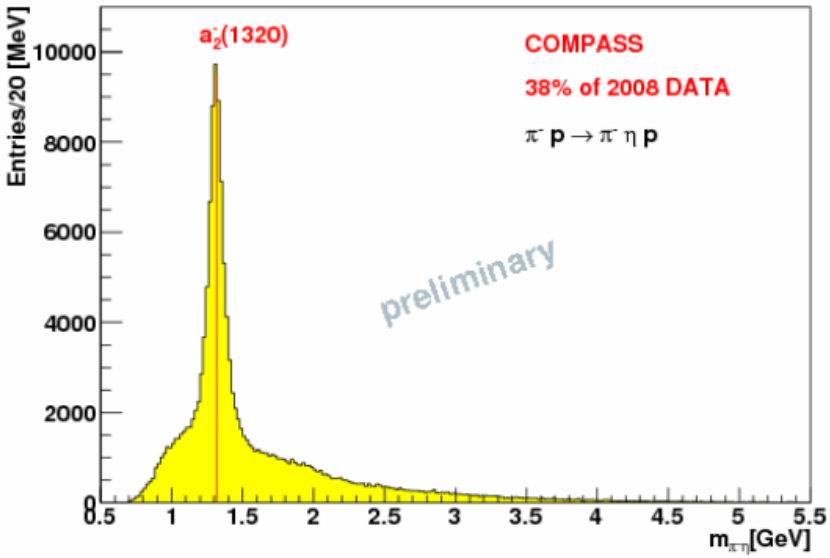
study $\pi_1(1400)$

b) π^- **p** —> $\pi^-\eta$ **p** (η —> $\gamma\gamma$)

=> cleanly seen: $a_2(1320)$

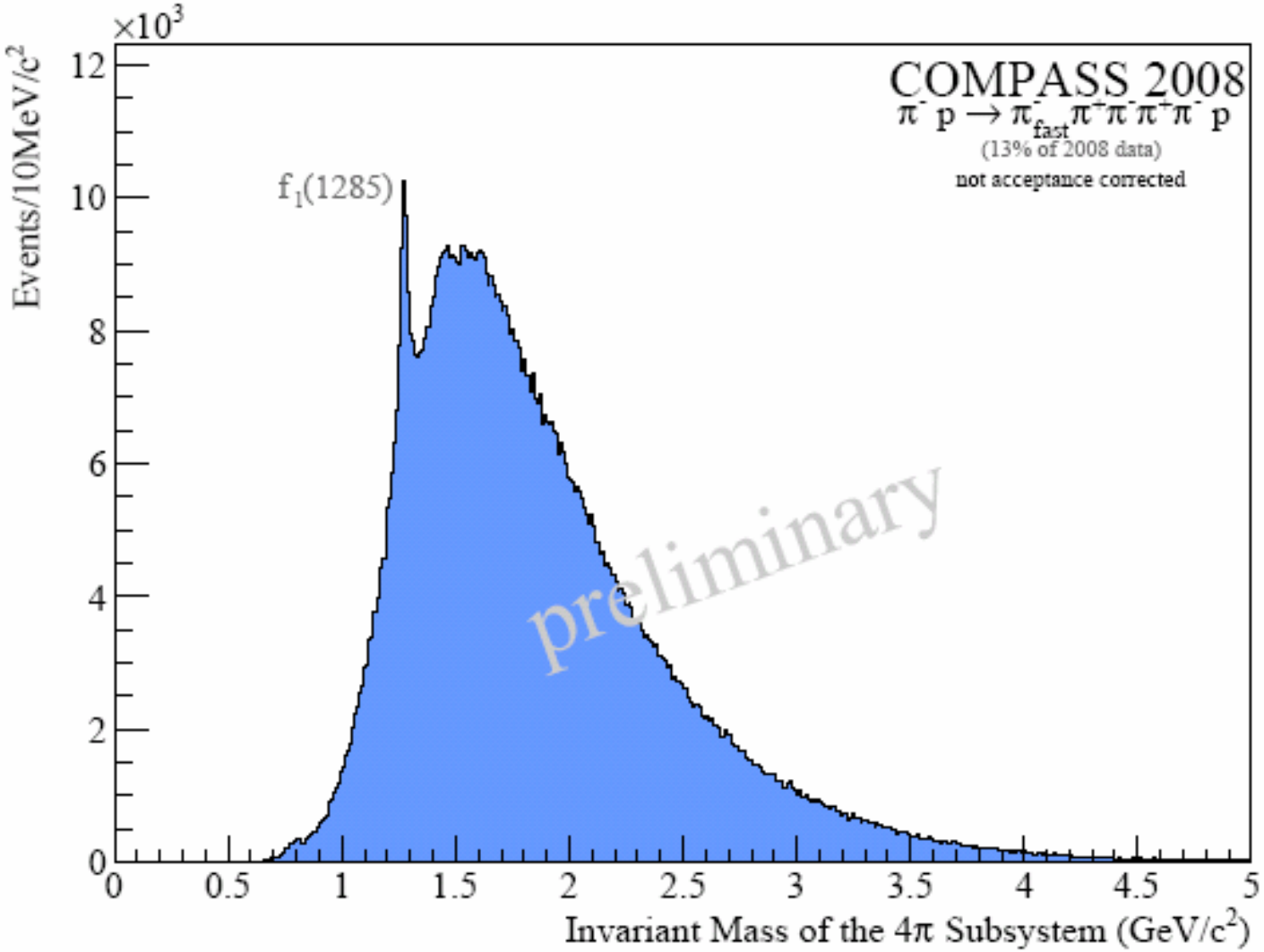
(more backgrd in η–> $\gamma\gamma$ mode)





Another channel for $\pi_1(1600)$ search: f1(1285)π

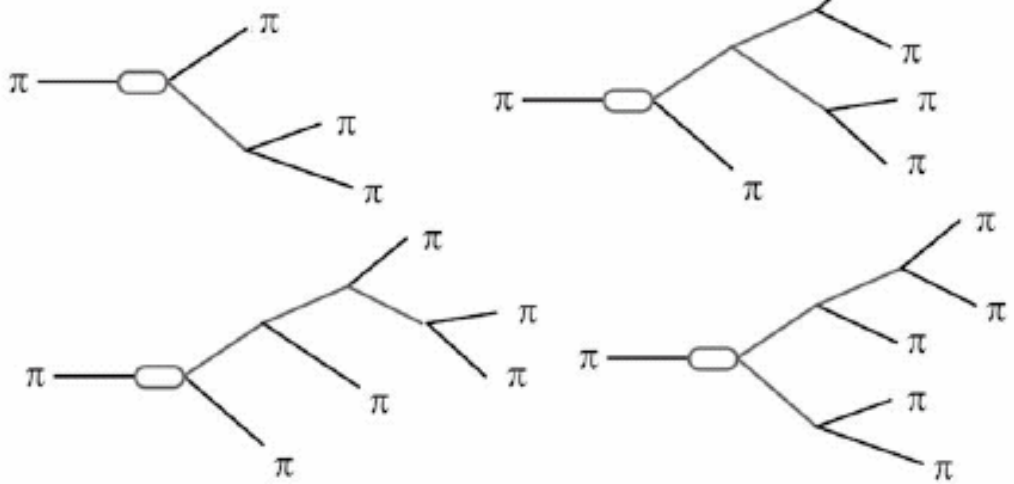
(also b1π in $\pi^-\pi^+\pi^-\pi^0\pi^0$ final states)



Hybrid nature:

Flux tube model: BR(π_1 –> $f_1\pi$) / BR(π_1 –> $b_1\pi$) [Isgur, Kokoski, Paton, PRL54, 869-872, 1985]

Decay modes of disputed $\pi_1(1600)$

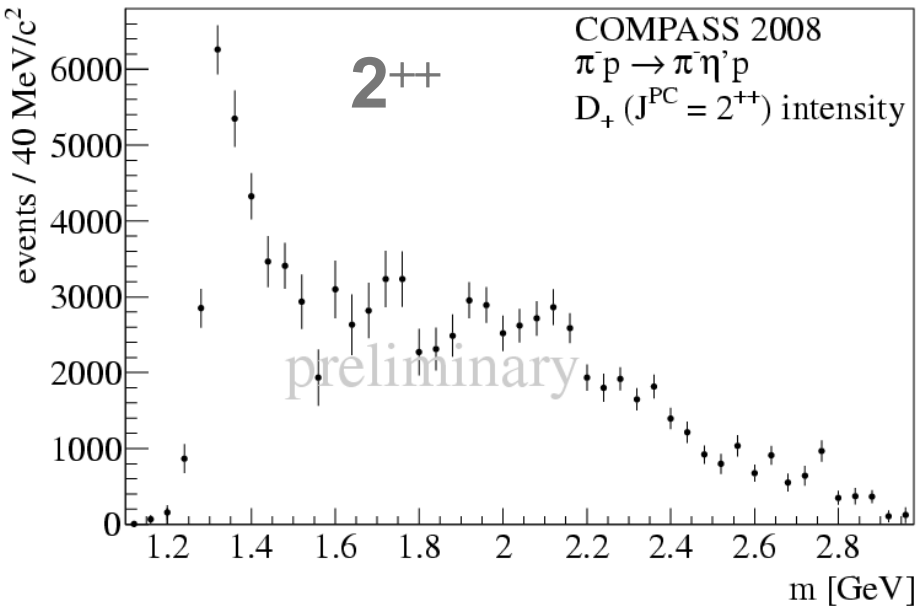


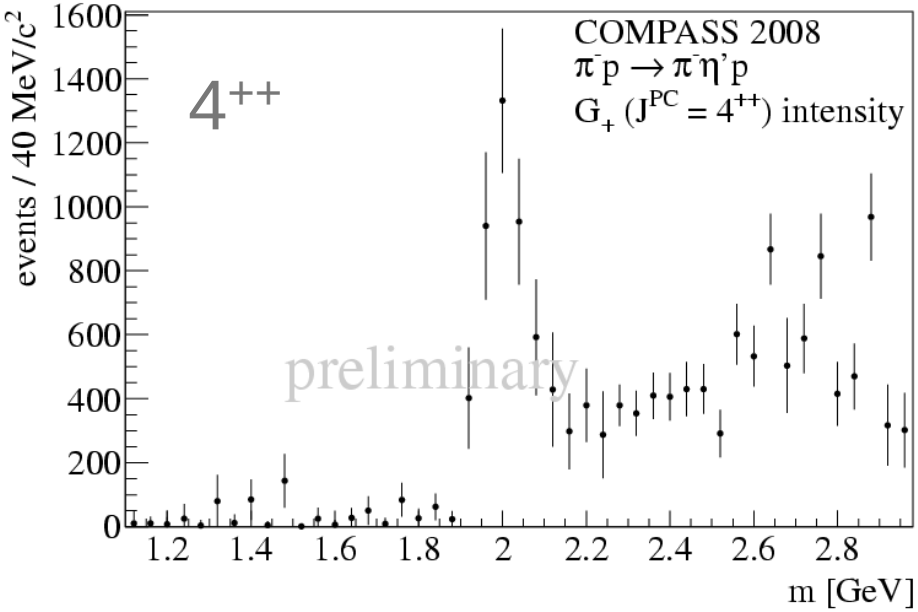
$\pi_1(1600)\ 1^-1^{-+}$

- $(2\pi)^0\pi^-$: $\rho\pi^-$, $f_2(1270)\pi^-$
- $(4\pi)^0\pi^-$: $b_1(1235)\pi^-$, $f_1(1285)\pi^-$
- $\eta'(958)\pi^-$

COMPASS has access to all of these decay modes

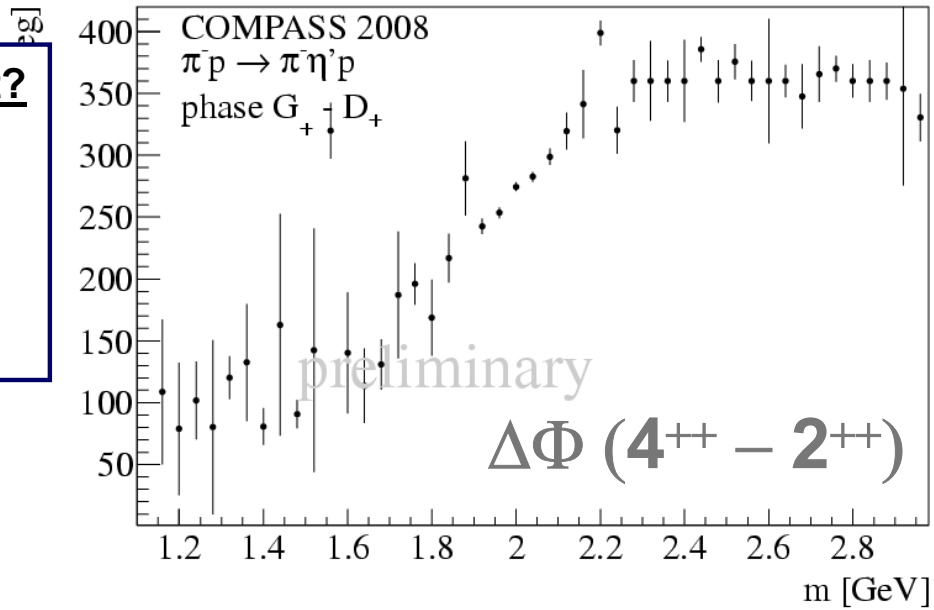
The Exotic $\eta'\pi^-$ Wave in 190 GeV π^-+p –> η'+π^-+p





Strong 1^{-+} signal in $\eta'\pi$ seen by E852/VES -- resonant?

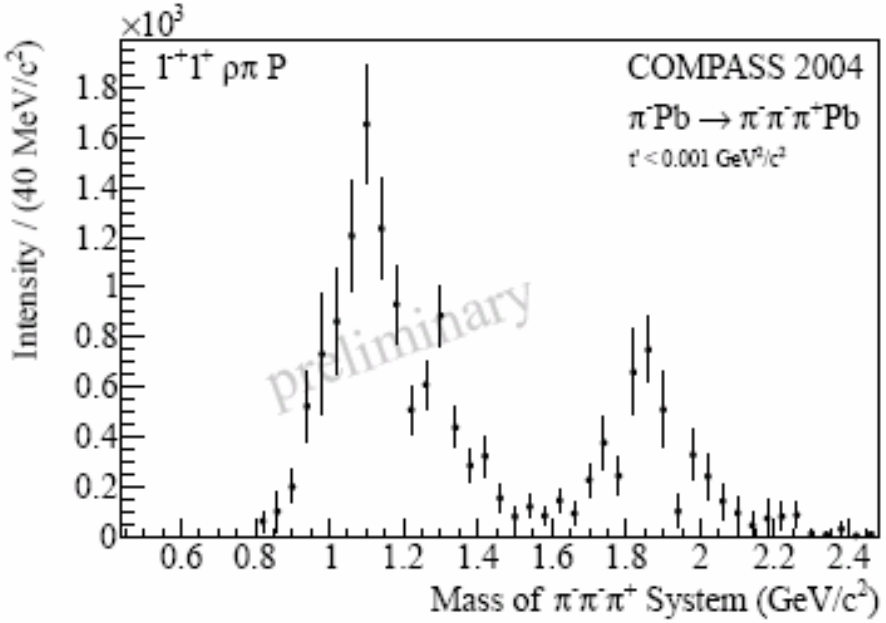
- Similar to BNL/VES, here:
  - → *4++ nicely seen*
  - → *clear phase motion in 4^{++} relative to 2^{++}*
- extended mass range
- no mass-dependent fit yet

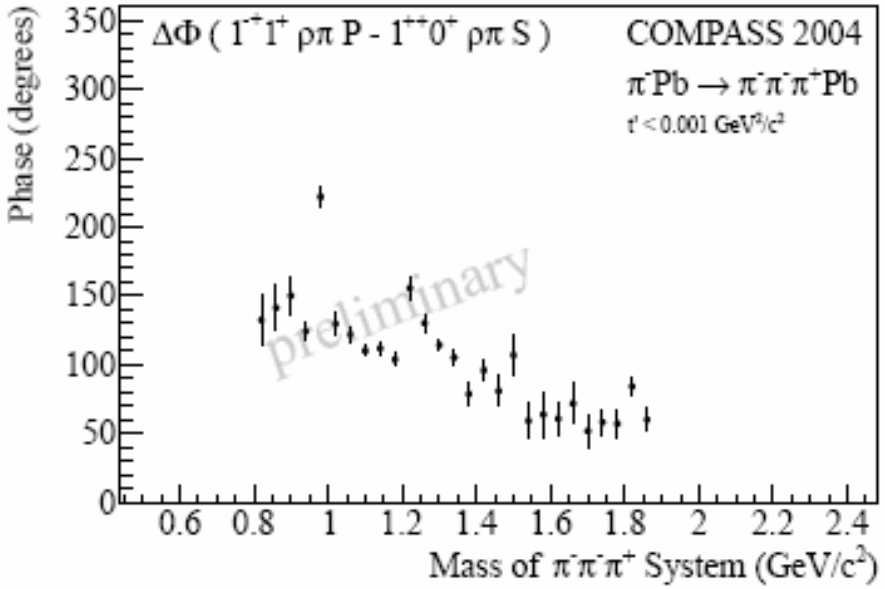


Primakoff production of charged 3π final states -- spin-exotic resonance?

Not main goal, but also:

search for $\pi_1(1600)$





No evidence for $\pi_1(1600)$ Primakoff production, **nor for** $\pi_1(1400)$

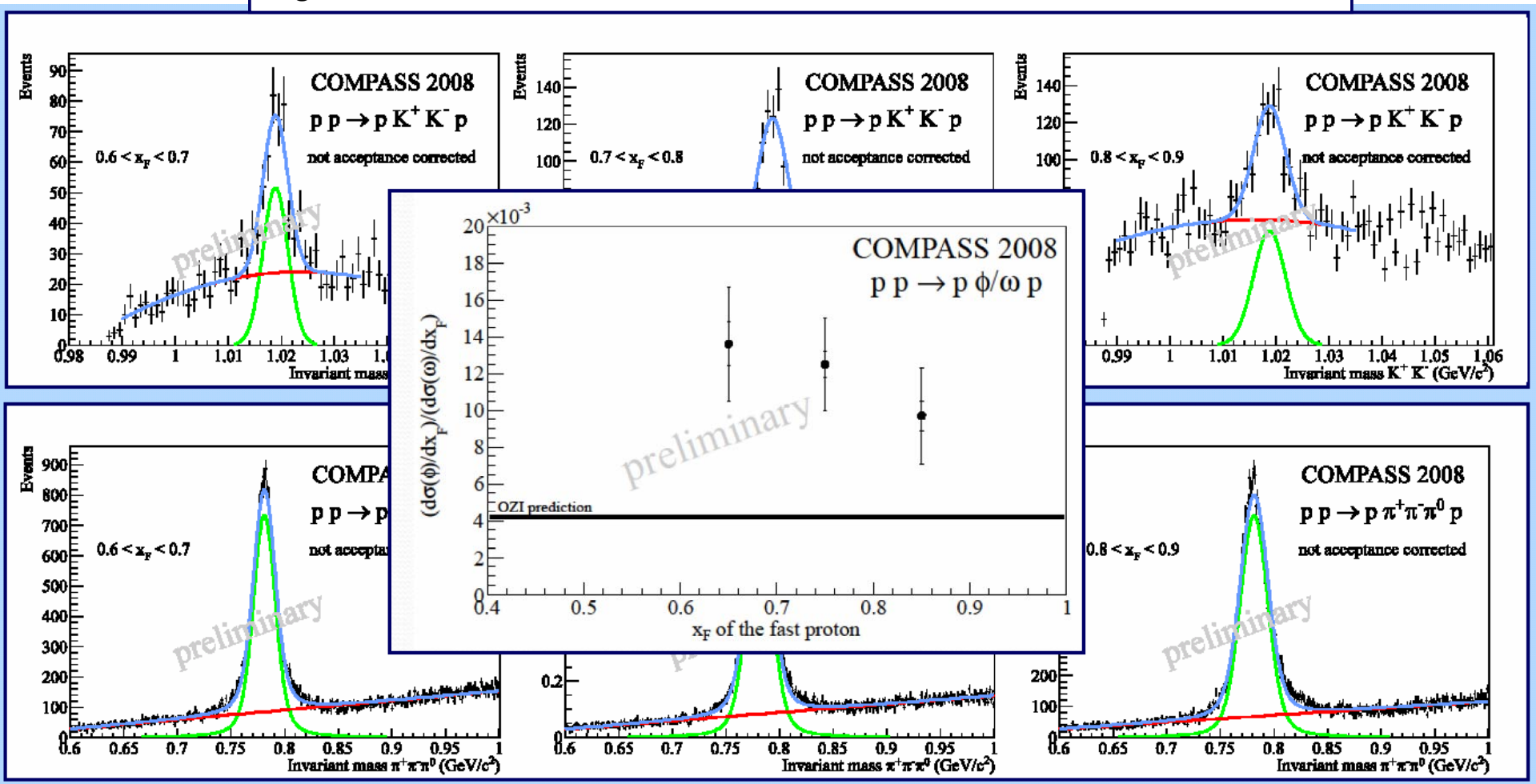
Preliminary confirmation of CLAS experiment:

→ no spin-exotic 1^{-+} signal in photoproduction

(structures at 1.1 GeV: non-resonating contribution (ChPT), at 1.9 GeV: some leakage)

Test of OZI violation

- Comparison of differential cross sections in ω and ϕ production *(with respect to x_F, in pp reactions)*
- value not yet released, in agreement with expectations
- good feedback received at conference



Top: Fit of φ yield in different x_F bins. The data is not yet acceptance corrected.
Bottom: Fit of ω yield in the same x_F binning.

Blue: fit, red: background, green: peak

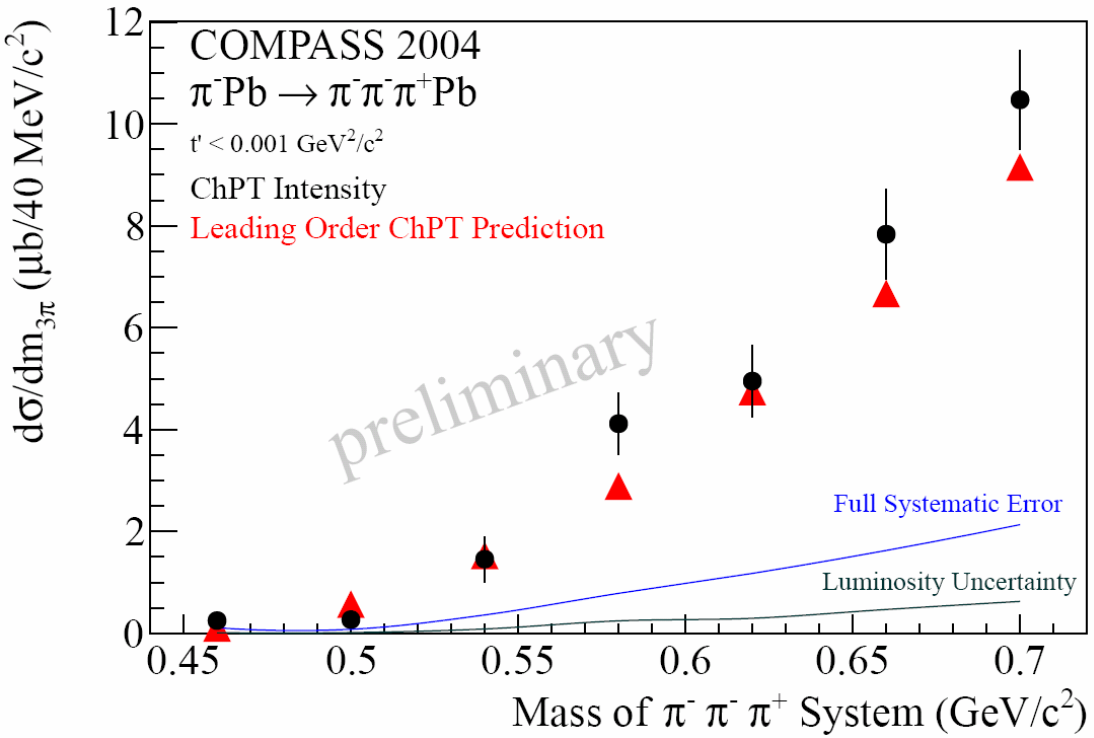
Primakoff production of charged 3pi at low masses

PWA analysis with amplitude from ChPT calculations substituting isobaric waves at low masses:

$$\pi^- Pb \rightarrow \pi^- \pi^- \pi^+ Pb$$

2004 lead data

- PWA analysis
- Absolute cross-section induced by photon exchange



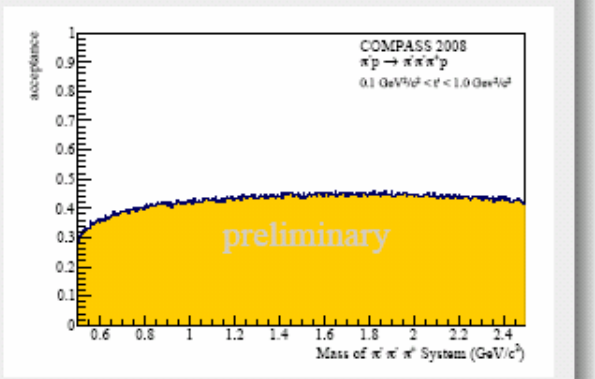
First measurement of $\gamma\pi^- \rightarrow \pi^-\pi^-\pi^+$ cross section in this range

Result in agreement with LO Ch.PT calculation

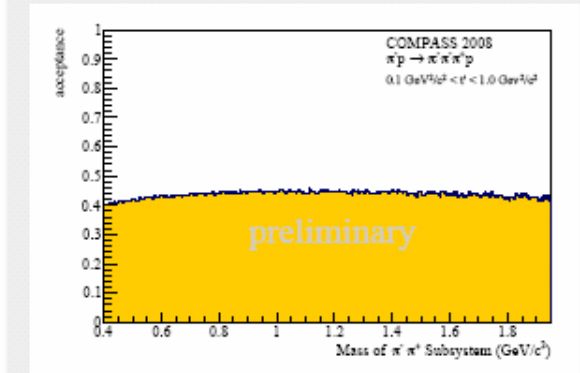
More data avalable from 2009 running on lead

Acceptance for $\pi^-\pi^+\pi^-$ final states

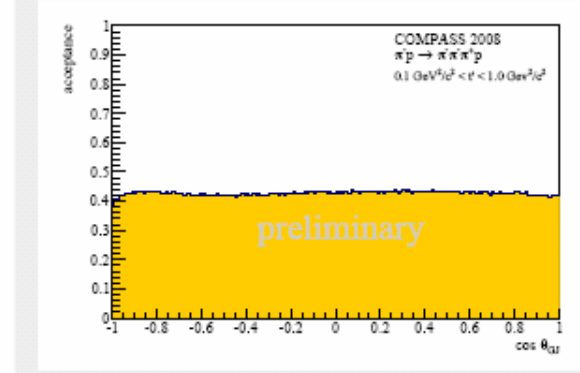
$\pi^-\pi^-\pi^+$ mass



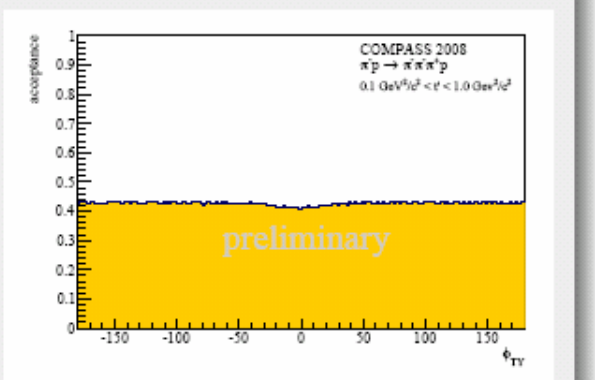
$\pi^-\pi^+$ mass



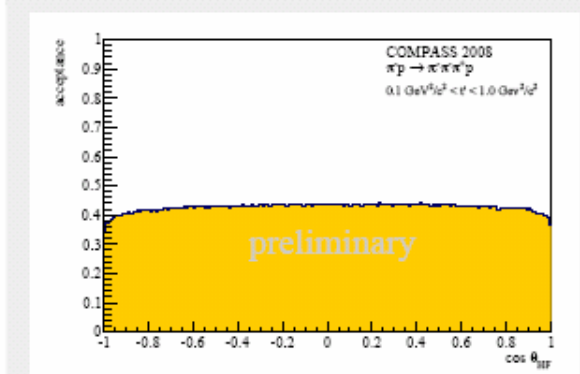
$\cos\theta_{GJ}$



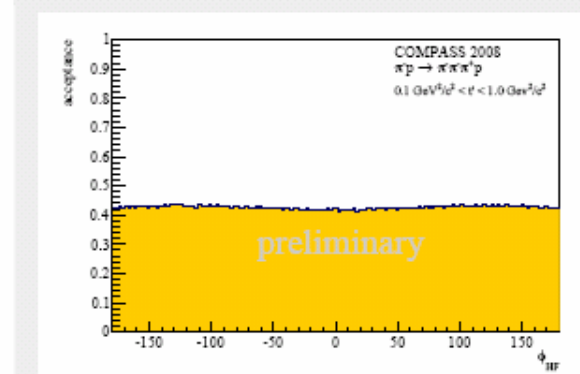
ϕ_{TY}



$\cos\theta_{helicity}$



$\phi_{helicity}$



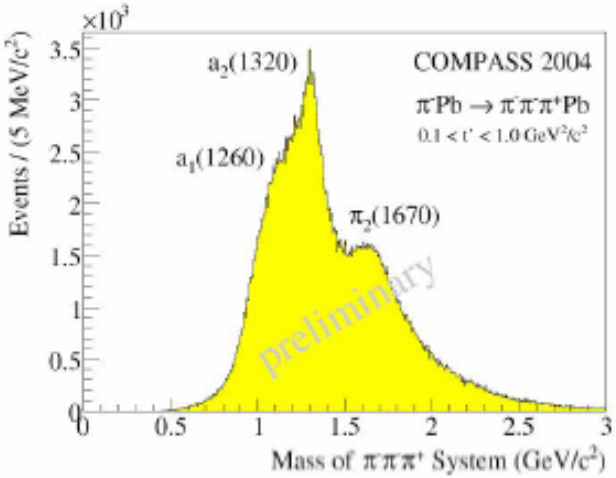
3pi analysis 2004 data vs BNL

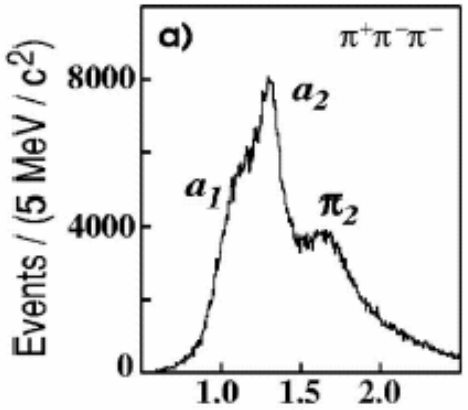
COMPASS: p_π=190 GeV/c

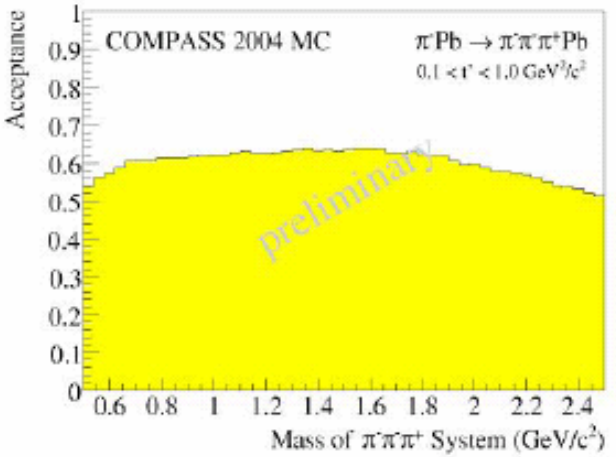
- 4M events in 3 days (full t range)
- 450k events in 0.1<t'<1.0 GeV^2/c^2

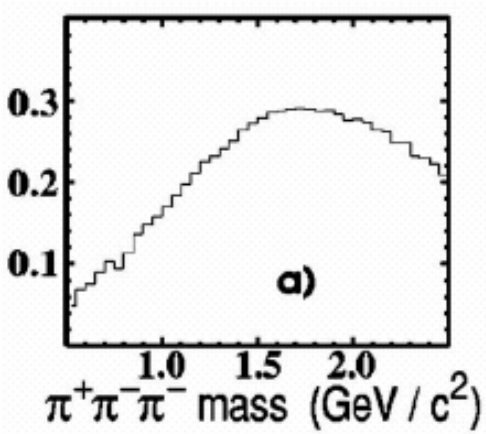
BNL852: p_π=18 GeV/c

- 250k events ⇨ $\pi_1(1600)$





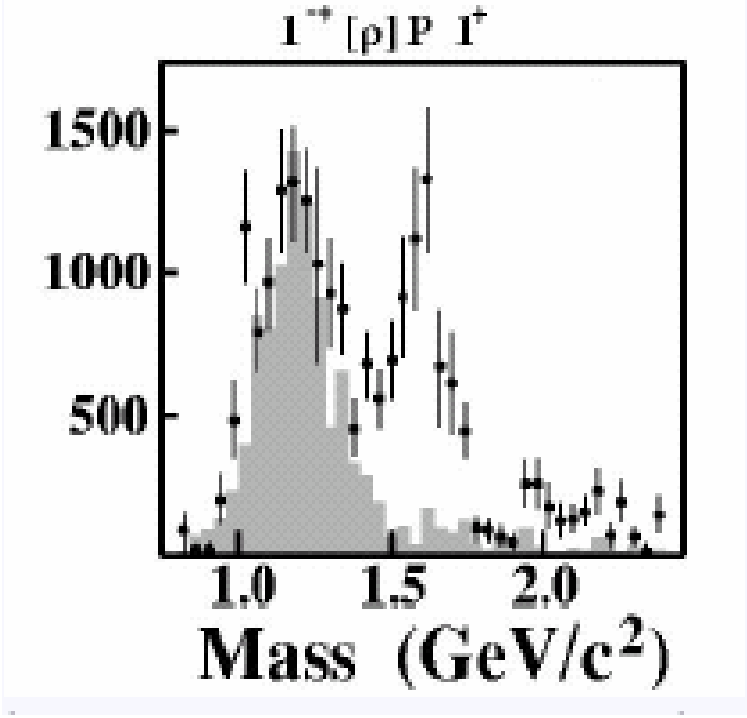




BNL controversial analyses

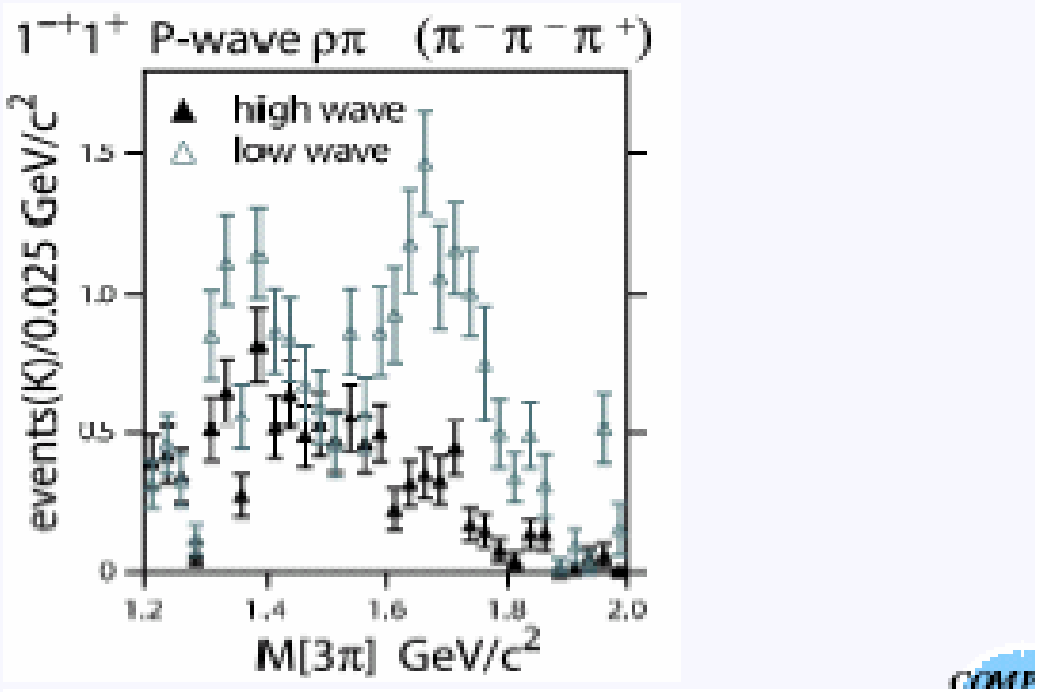
E,g.: E852: $\pi_1(1600)$ –> $[\rho^\circ\pi-]$ P
→ limited statistics

PRD **65**, 0721001 (2002)

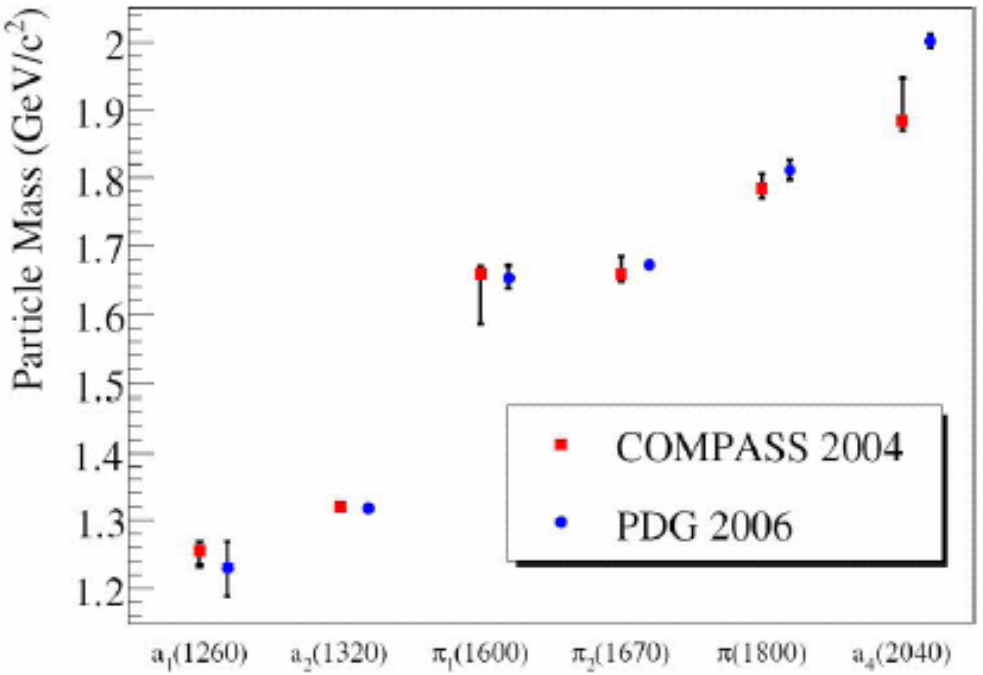


E,g.: E852: $\pi_1(1600)$ –> $[\rho^\circ\pi-]$ P
→ full statistics & extended waveset

PRD **73**, 0721001 (2006)

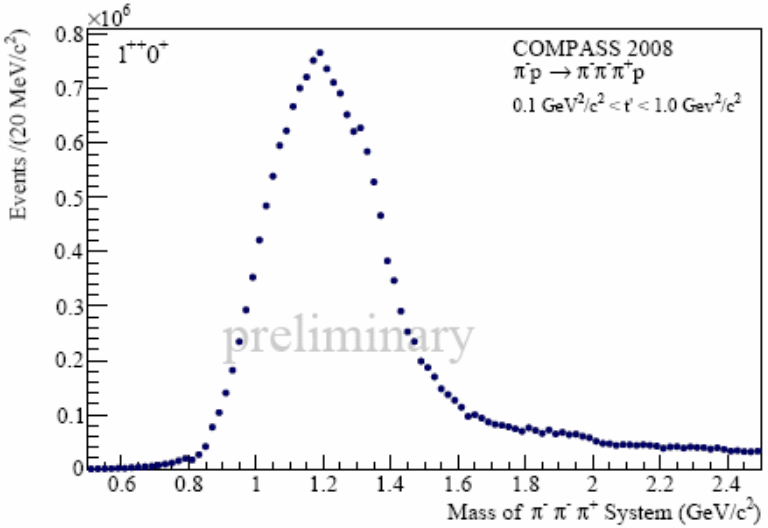


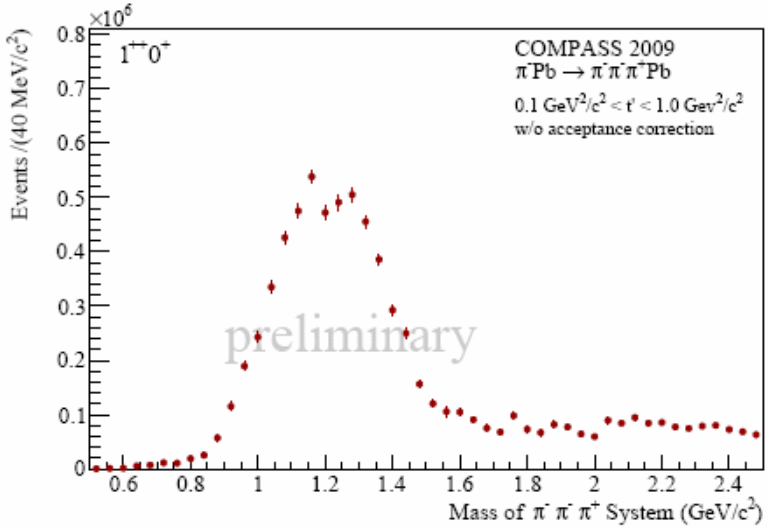
Fitted resonances (2004 data)

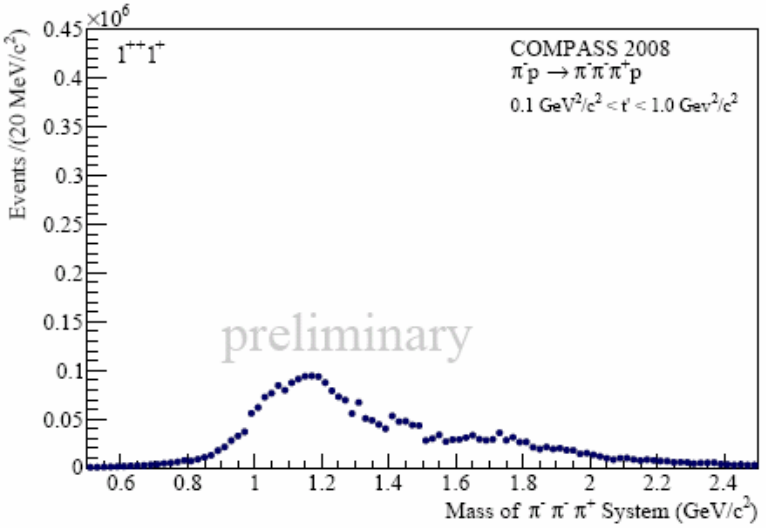


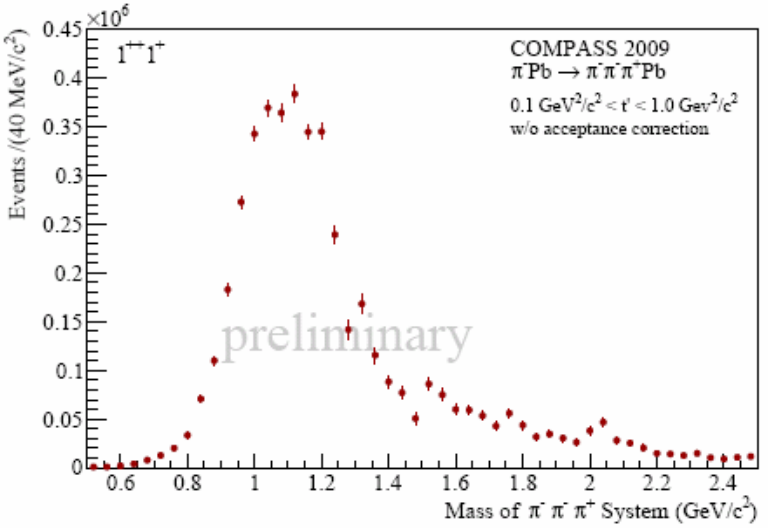
Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	Intensity (%)	Channel $J^{PC}M^{\epsilon}[\mathrm{isobar}]L$
$a_1(1260)$	$1255 \pm 6^{+7}_{-17}$	$367 \pm 9^{+28}_{-25}$	$67 \pm 3^{+4}_{-20}$	$1^{++}0^{+}\ \rho\pi\ S$
$a_2(1320)$	$1321 \pm 1^{+0}_{-7}$	$110 \pm 2^{+2}_{-15}$	$19.2 \pm 0.6^{+0.3}_{-2.2}$	$2^{++}1^{+}\ \rho\pi\ D$
$\pi_1(1600)$	$1660 \pm 10^{+0}_{-64}$	$269 \pm 21^{+42}_{-64}$	$1.7 \pm 0.2^{+0.9}_{-0.1}$	$1^{-+}1^{+}\ \rho\pi\ P$
$\pi_2(1670)$	$1658 \pm 3^{+24}_{-8}$	$271 \pm 9^{+22}_{-24}$	$10.0 \pm 0.4^{+0.7}_{-0.7}$	$2^{-+}0^{+}\ f_2\pi\ S$
$\pi(1800)$	$1785 \pm 9^{+12}_{-6}$	$208 \pm 22^{+21}_{-37}$	$0.8 \pm 0.1^{+0.3}_{-0.1}$	$0^{-+}0^{+}\ f_0\pi\ S$
$a_4(2040)$	$1885 \pm 13^{+50}_{-2}$	$294 \pm 25^{+46}_{-19}$	$1.0 \pm 0.3^{+0.1}_{-0.1}$	$4^{++}1^{+}\ \rho\pi\ G$

Diffr. dissociation into 3π final states – Charged M-dependence





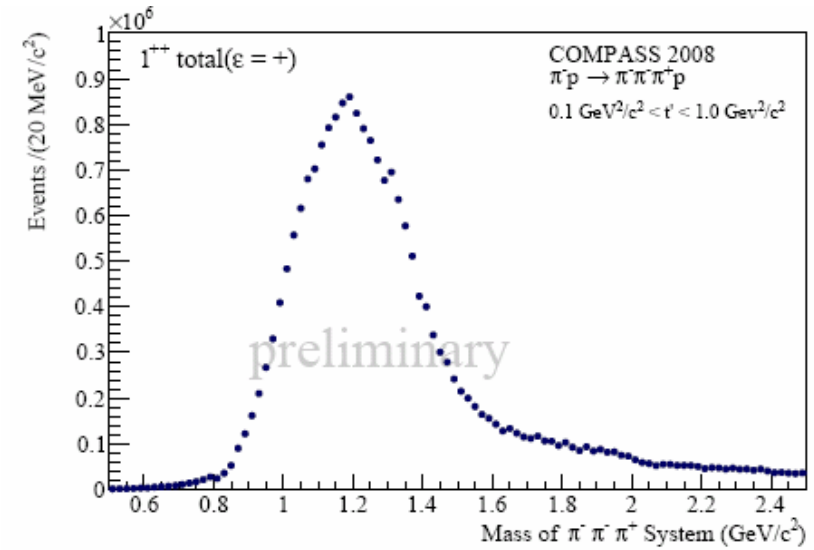




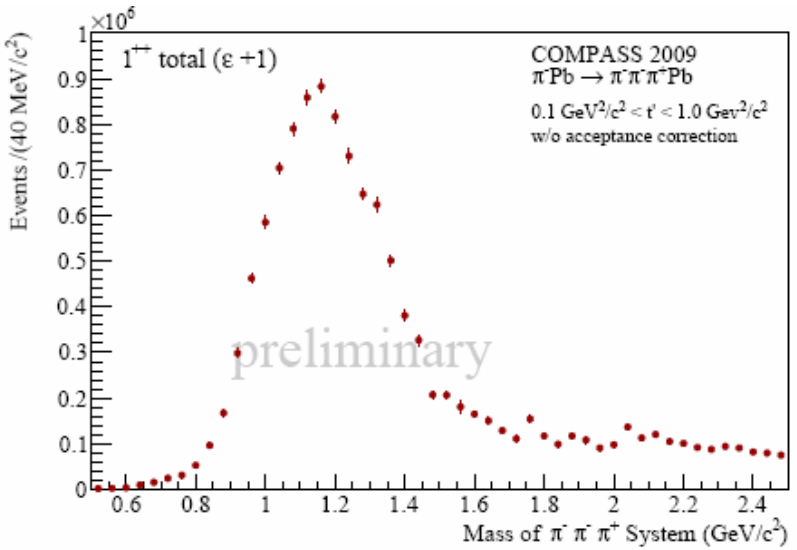
$\pi^- p \to \pi^-\pi^-\pi^+ p$ (2008)

$\pi^- Pb \to \pi^-\pi^-\pi^+ Pb$ (2009)

Diffractive dissociation into 3π final states – Charged M-dependence



$\pi^- p \to \pi^-\pi^-\pi^+ p$ (2008)



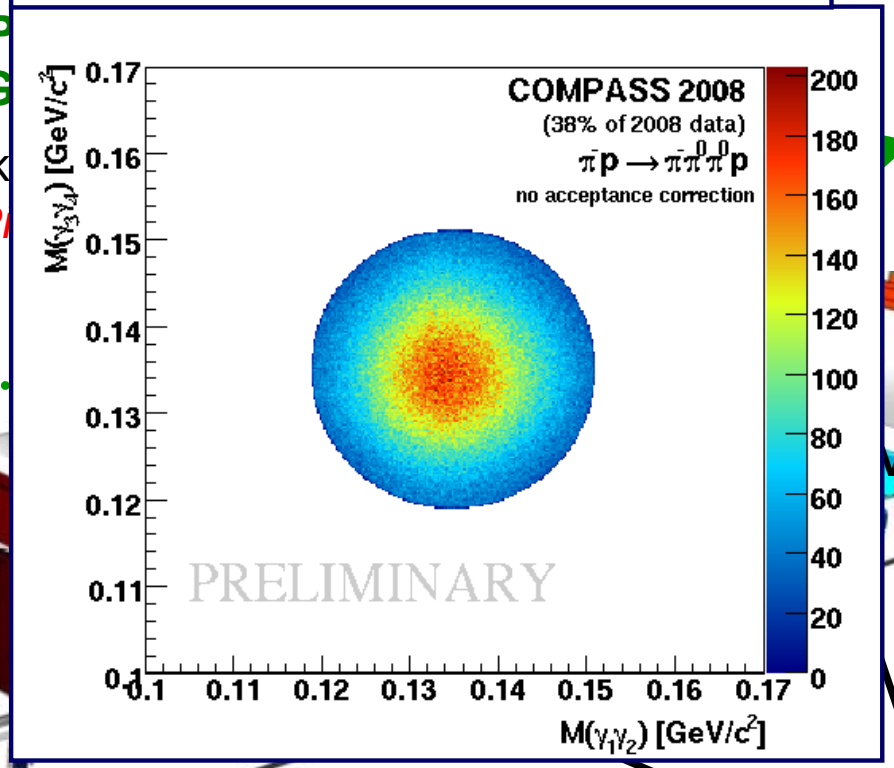
$\pi^- Pb \to \pi^-\pi^-\pi^+ Pb$ (2009)

Observed M-dependence:

- *production strength for M=1 vs. M=0 states depend on target material*
- *confirmed on 2009 data → real effect*
- *interesting to understand physics wise*

COMPASS spectrometer: Hadron setup 2008/09

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



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

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')

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)

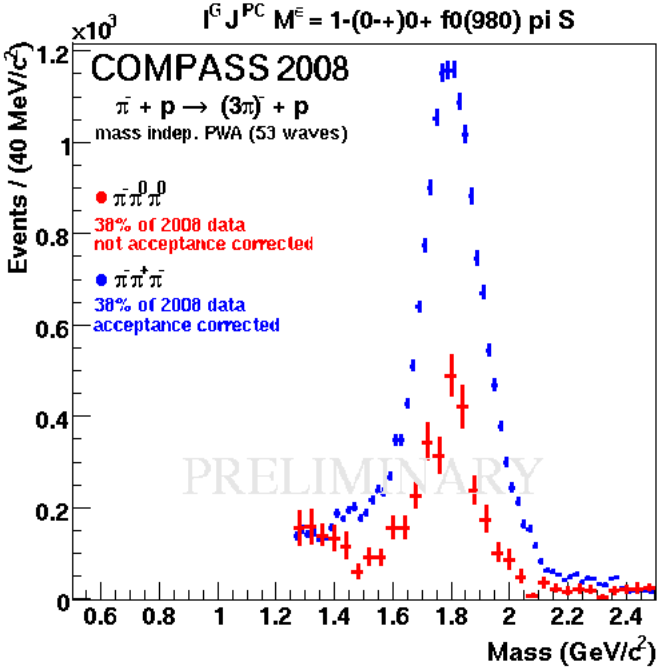
=> *BR might differ for resonances going to* $f_{0,2}\pi$

Checked by calculation:

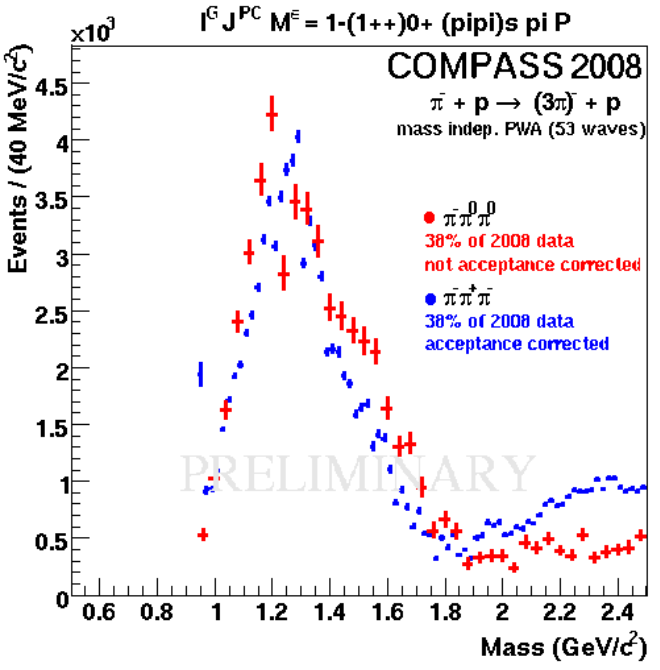
$\mathrm{BR} = \mathrm{N}(\pi^-\pi^0\pi^0)/\mathrm{N}(\pi^-\pi^-\pi^+)$ – calculated from isobar model amplitudes
$\mathrm{BR}(\ 0^{-+} f_0(980)\pi\ S) = 0.44$ (at 1.8 GeV)
$\mathrm{BR}(\ 1^{++}(\pi\pi)_s\pi\ P) = 0.80$ (at 1.3 GeV)
$\mathrm{BR}(\ 2^{-+} f_2(1270)\pi\ S) = 0.50$ (at 1.67 GeV)

Selected partial waves
isospin symmetry check ctd.

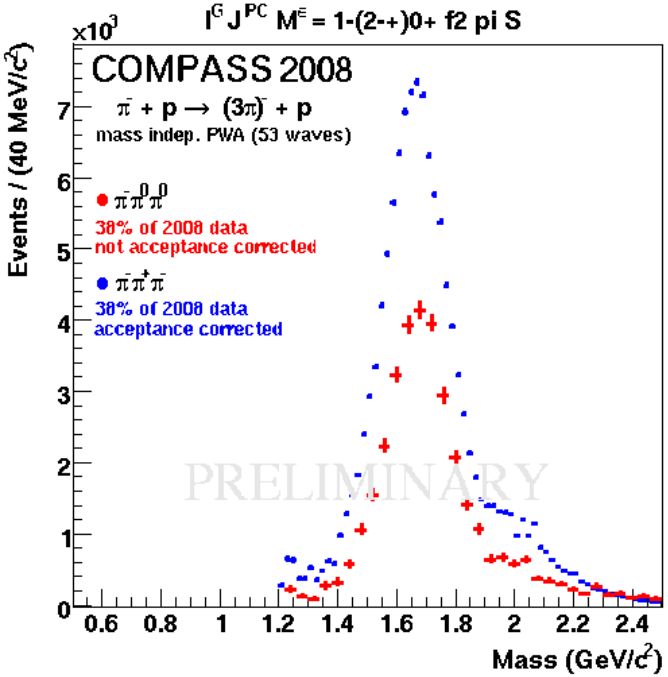
$\pi(1800) \rightarrow \rho\pi$



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



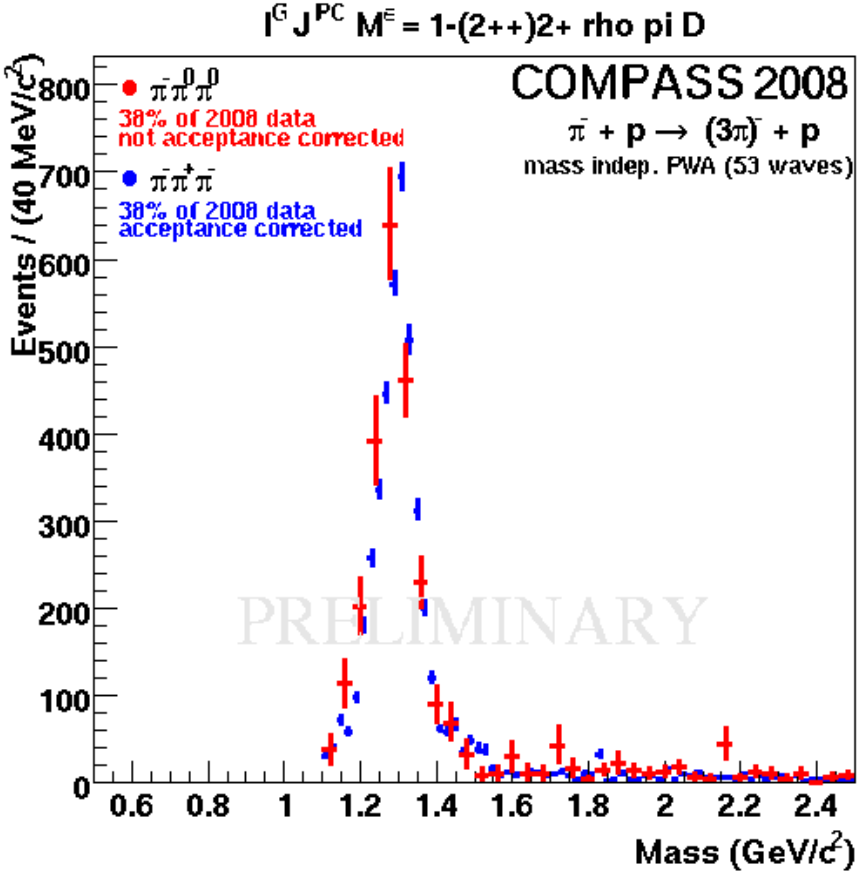
$\pi_2(1670) \rightarrow f_2\,\pi$

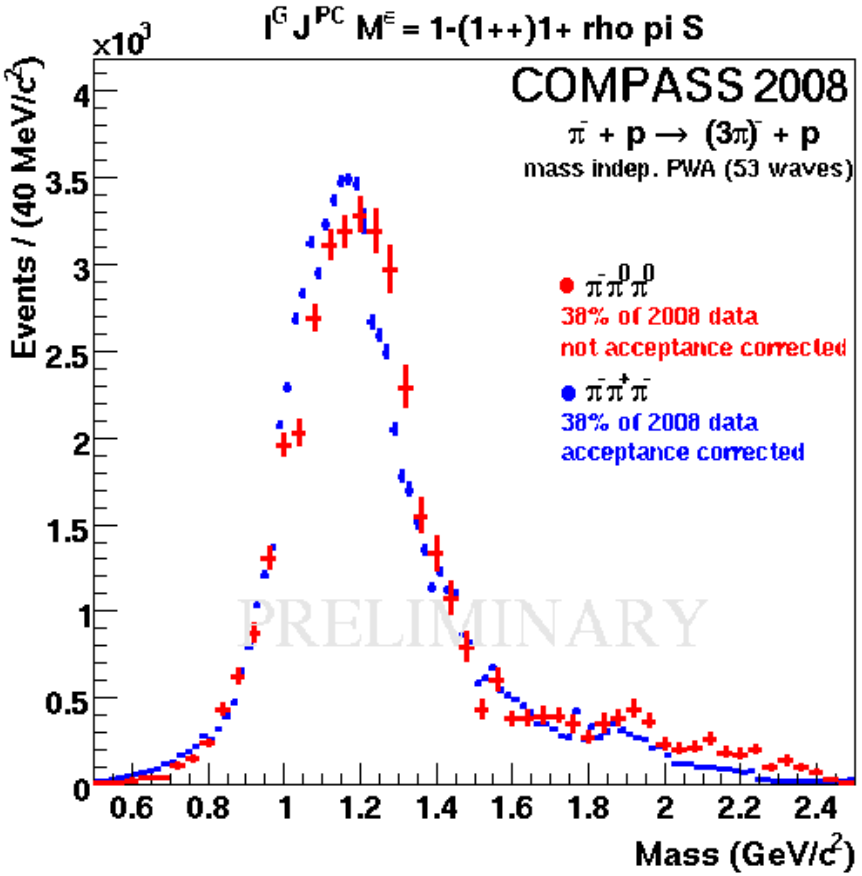


$BR = N(\pi^-\pi^0\pi^0)/N(\pi^-\pi^-\pi^+)$ – calculated from isobar model amplitudes	
$BR(\ 0^{-+} f_0(980)\pi\ S) = 0.44$ (at 1.8 GeV) $BR(\ 1^{++}(\pi\pi)_s\pi\ P) = 0.80$ (at 1.3 GeV) $BR(\ 2^{-+} f_2(1270)\pi\ S) = 0.50$ (at 1.67 GeV)	in fair agreement with our data

Selected partial waves
isospin symmetry check ctd.

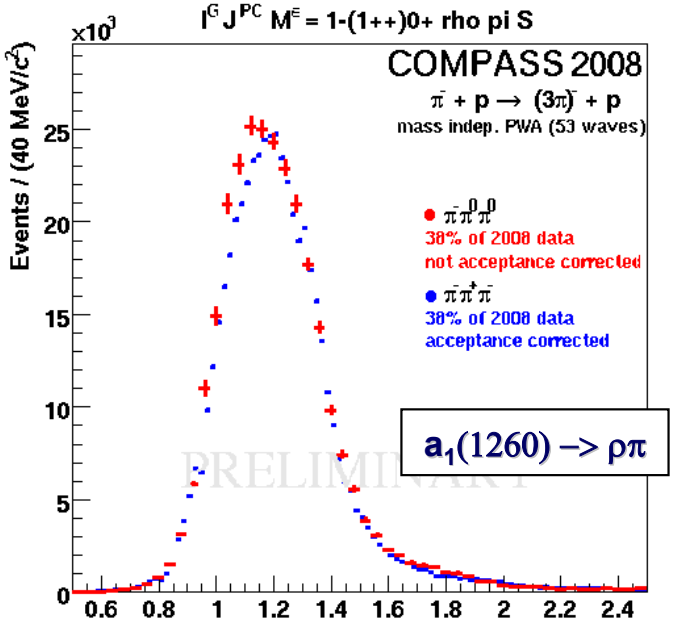
$a_2(1320)$ (M=2) –> ρπ

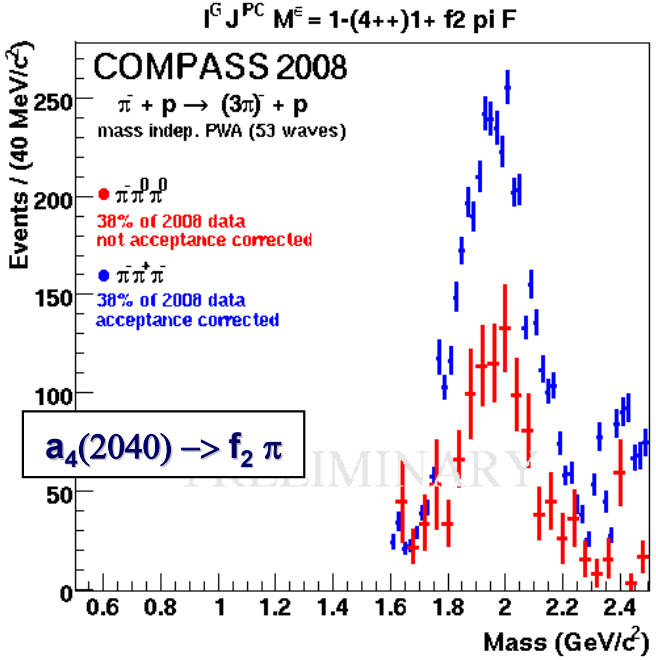


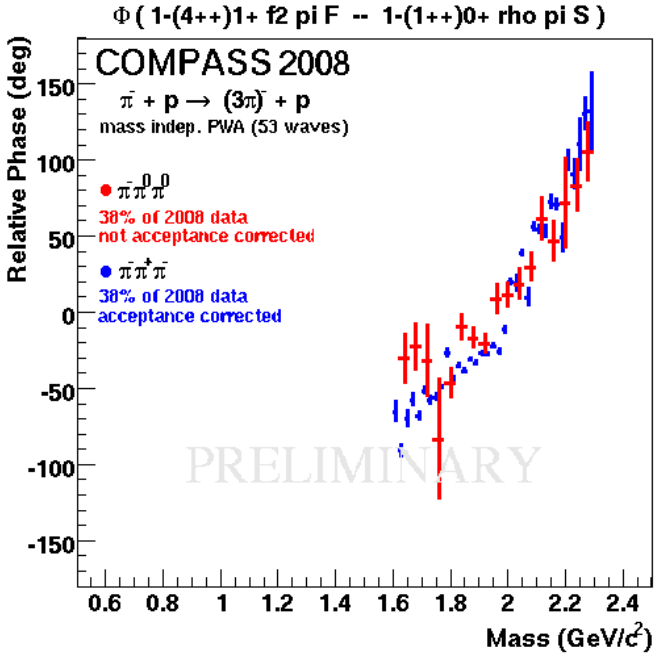


Selected partial waves & phases

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

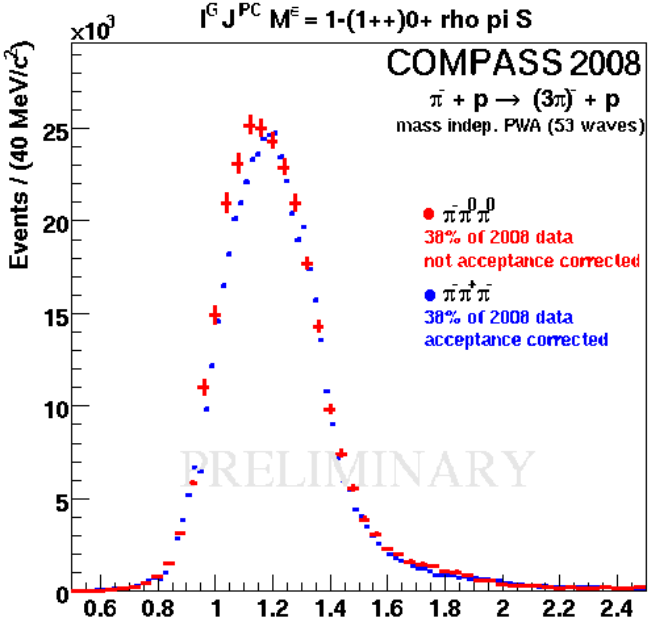


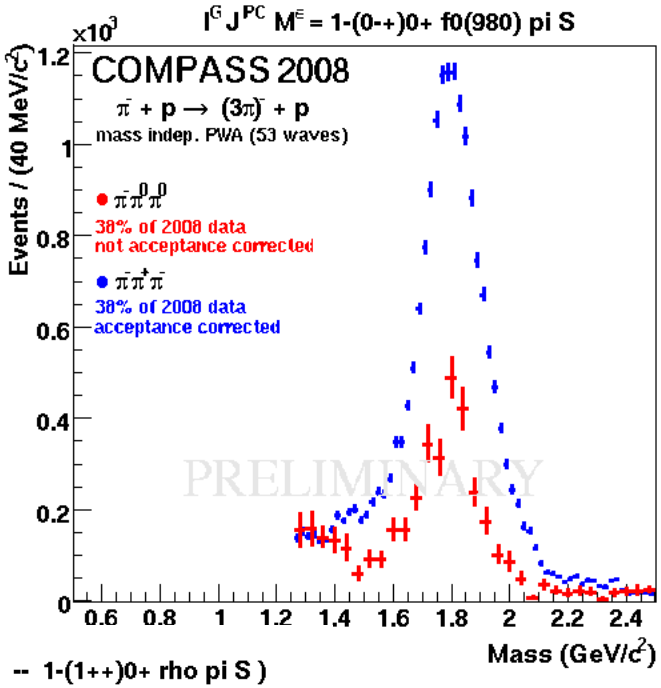


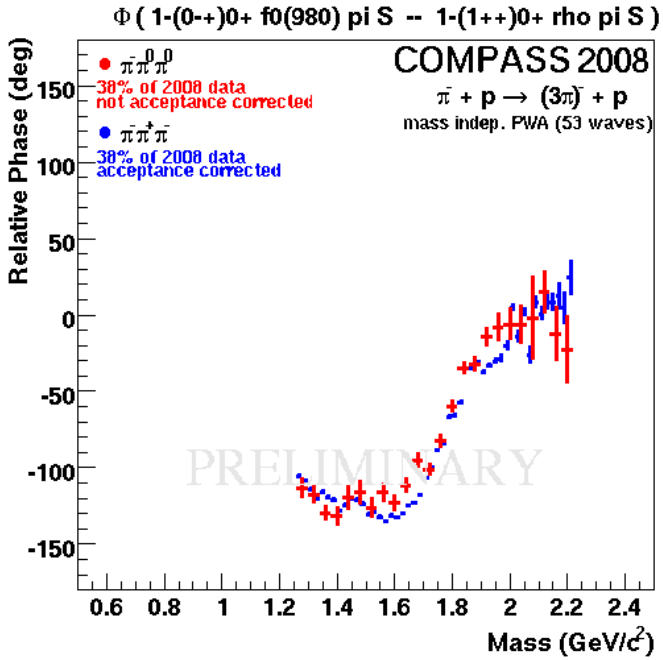


Selected partial waves & phases

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

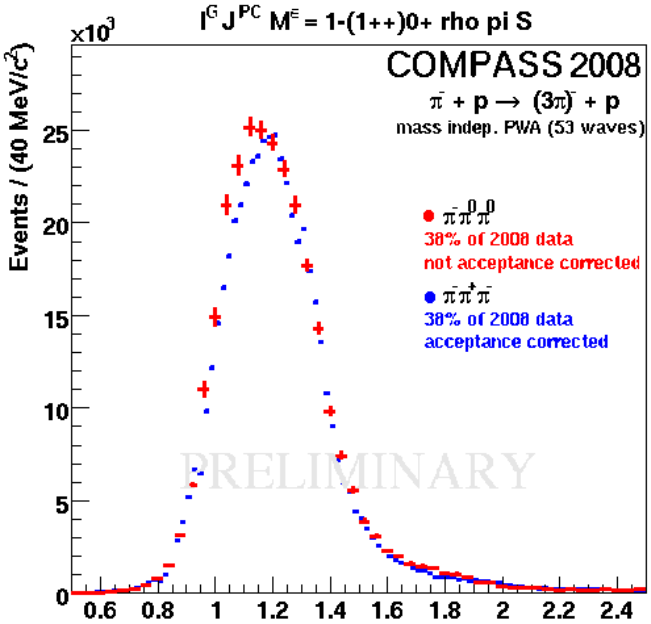


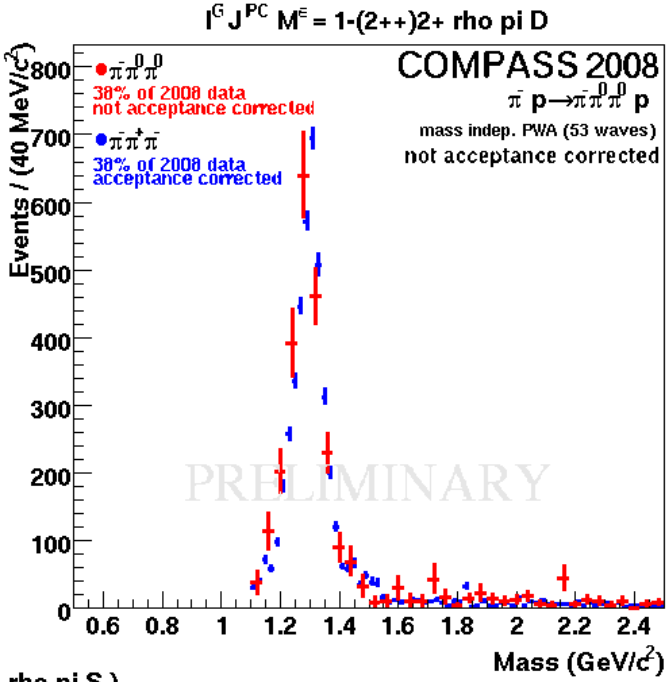


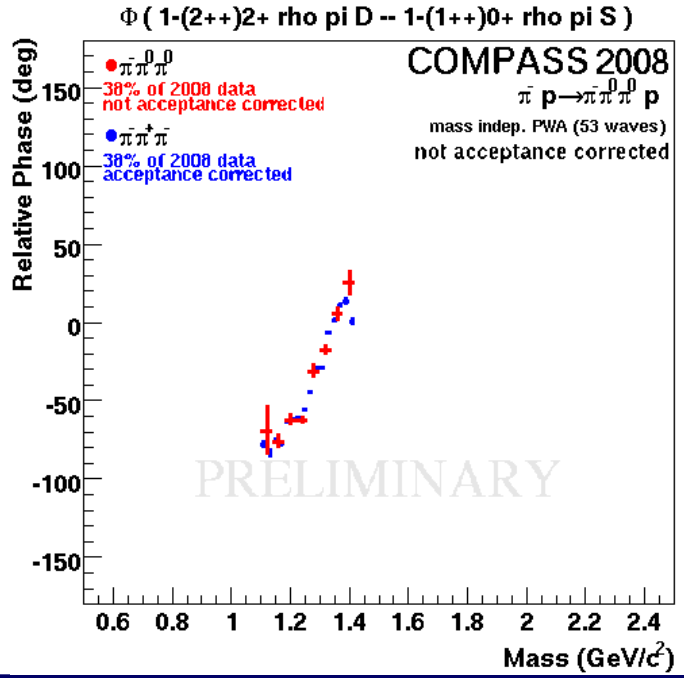


Selected partial waves & phases

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

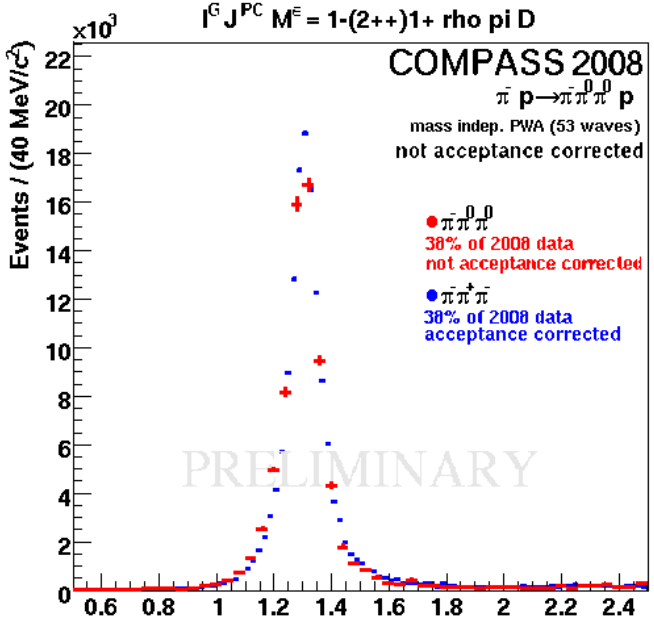


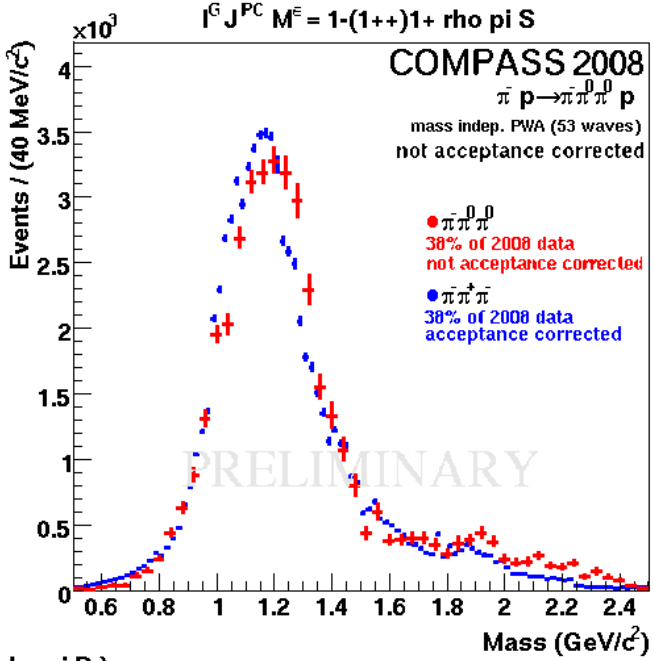


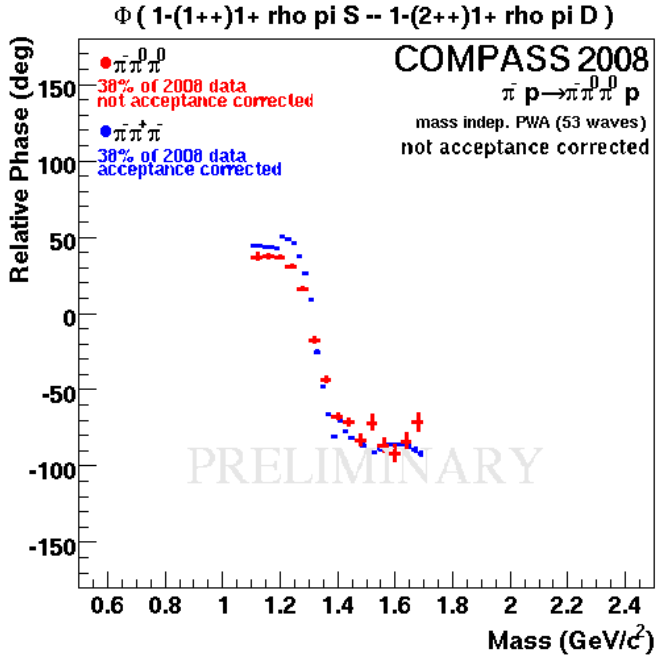


Selected partial waves & phases

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

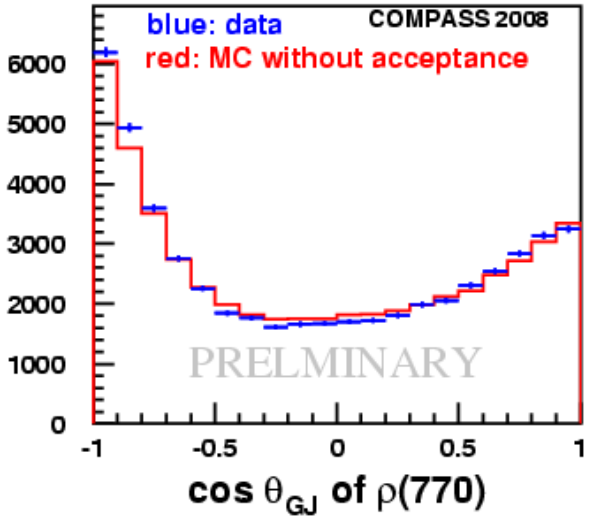


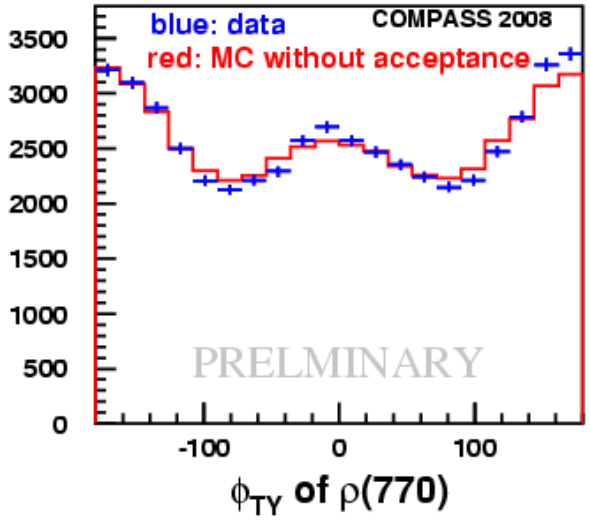




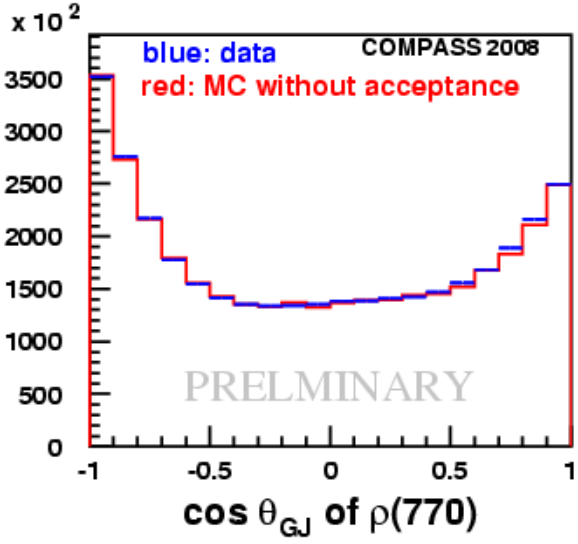
Decay angles in G.J. frame: Full PhaseSpace
Generated Prediction vs. fitted data

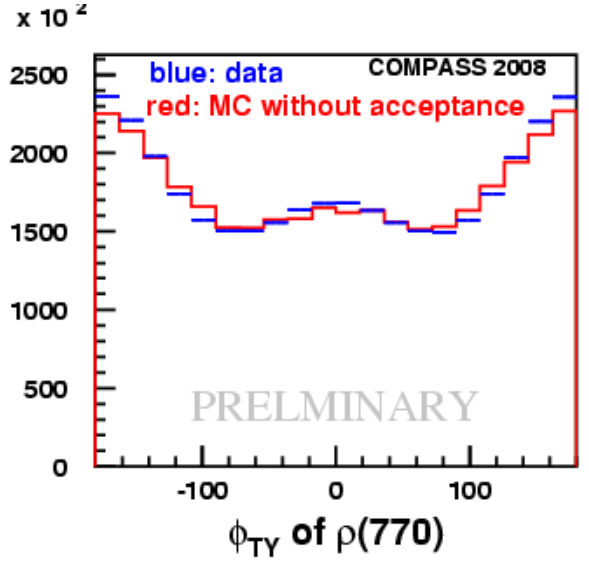
a1/a2 mass region - neutral
(1.22 - 1.38 GeV/c²)





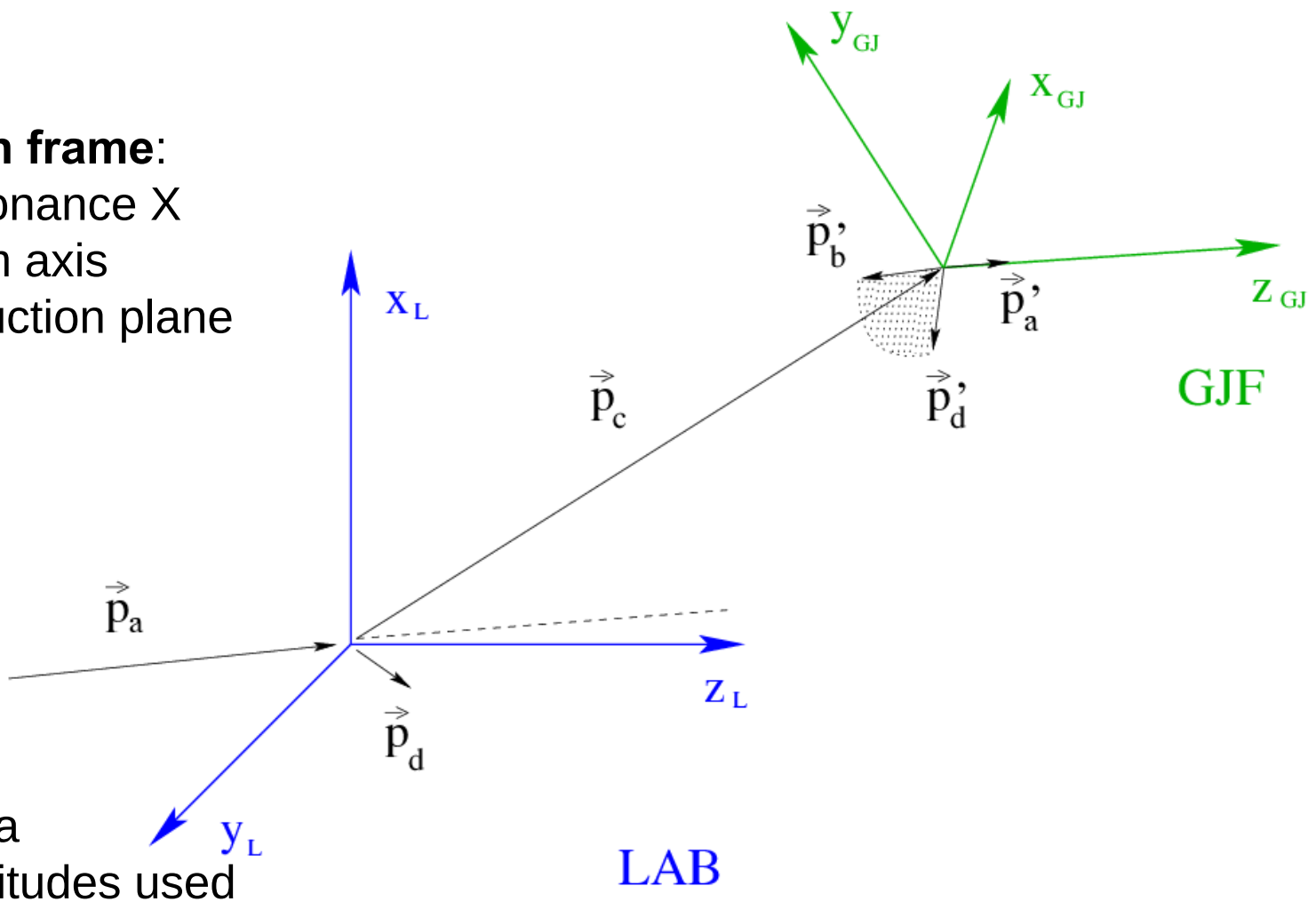
a1/a2 mass region - charged
(1.22 - 1.38 GeV/c²)





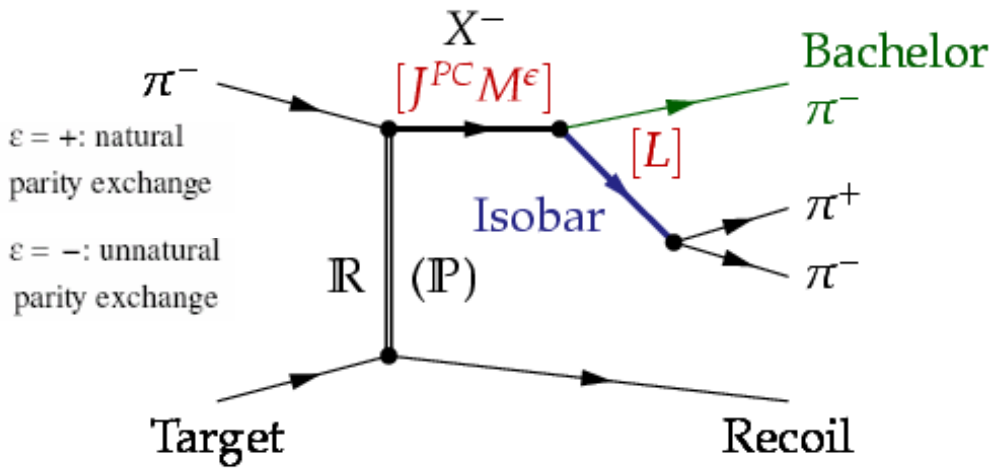
Decay angles in G.J. frame
Full PhaseSpace Generated Prediction

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

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 (2008: rather flat for charged, neutral not yet included)

Step 1) Mass independent PWA: (40MeV/c² bins, 53 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)

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
```