Hadron spectroscopy at COMPASS:
First results on diffractive dissociation

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Universität Freiburg, Physikalisches Institut

on behalf of the
COMPASS Collaboration

35th Internationl conference on High Energy Physics,
Paris, France, 22-28 July 2010

Outline:

- **Introduction**
  - The COMPASS experiment
  - PWA method
- **First results on diffractive production** (2008 data)
  - neutral channel: 3π final states neutral vs. charged mode
    → *First PWA fits - main wave*
  - kaonic channels: Kaon diffraction & first glimpse on $(K\bar{K}\pi)^-$
    → *Further ongoing analyses*
- **Conclusions & outlook**

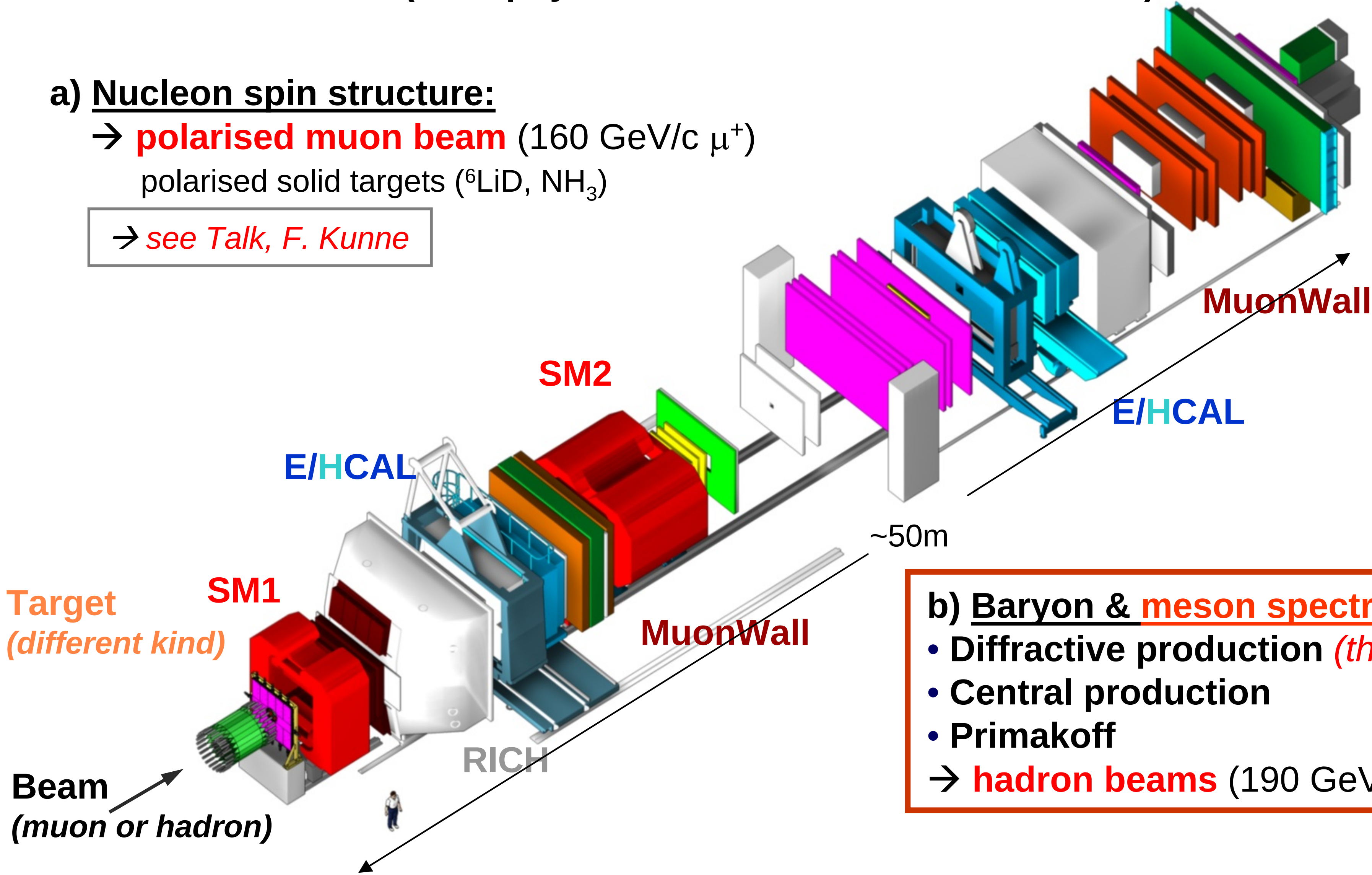
bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen Grundlagenforschung

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 Talk, F. Kunne*



b) Baryon & meson spectroscopy:
- **Diffractive production** *(this talk)*
- **Central production**
- **Primakoff**

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

[hep-ex/0703049, NIM A 577, 455 (2007)]
[NIM A Hadron Set-up 2008/09 under preparation]

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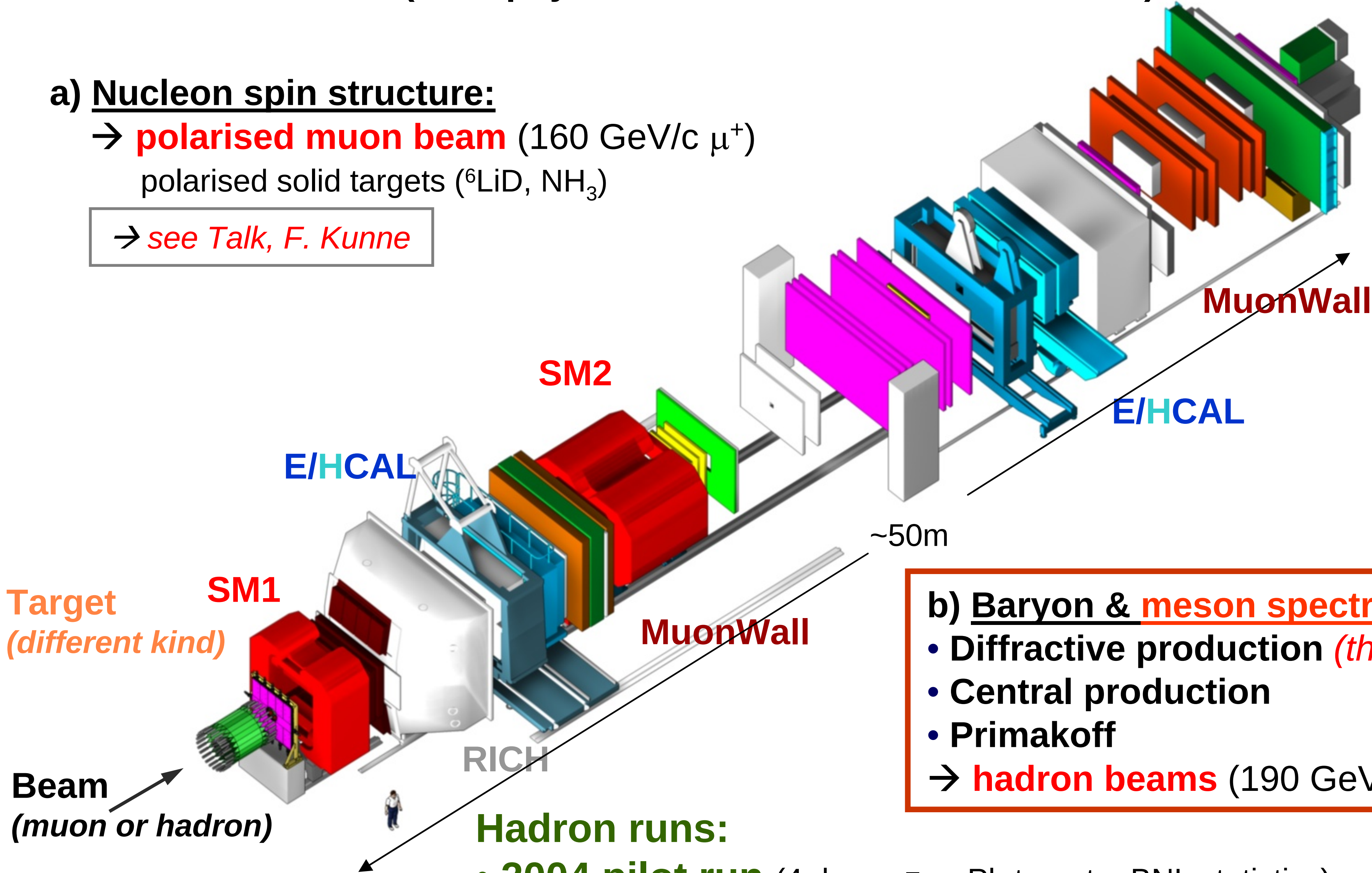

b) Baryon & meson spectroscopy:

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

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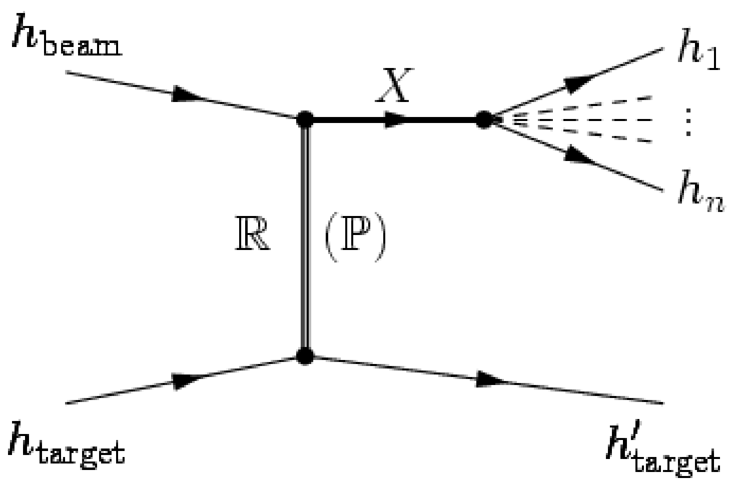
Hadron runs:

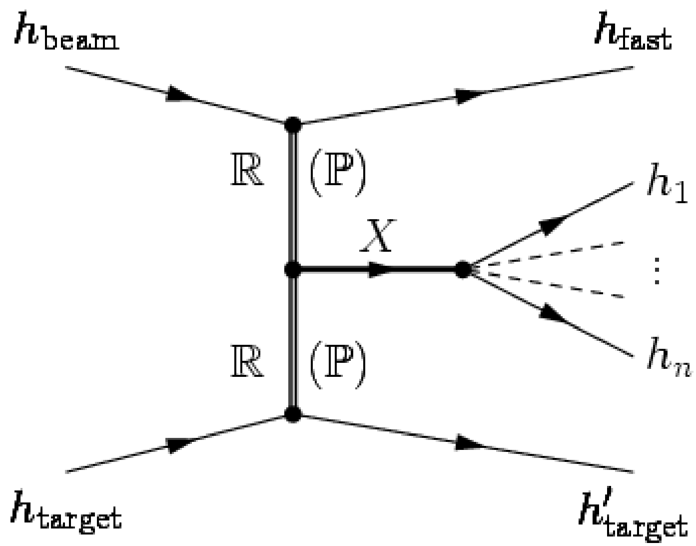
- **2004 pilot run** (4 days π^- on Pb target: ~BNL statistics)
- **2008/09** (10-100x world stats (LH_2), $\pi^\pm$, $K^\pm$, $p^\pm$ beam, *plus nuclear targets*)

Different production mechanisms

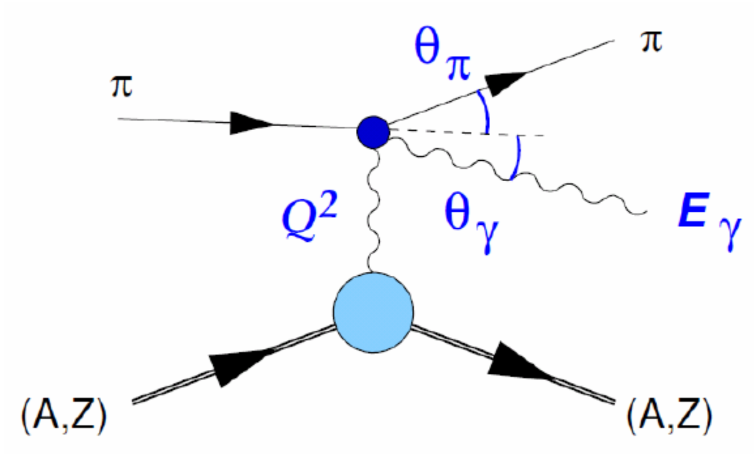
a) Diffractive production



b) Central production



c) Photo production (Primakoff reactions)



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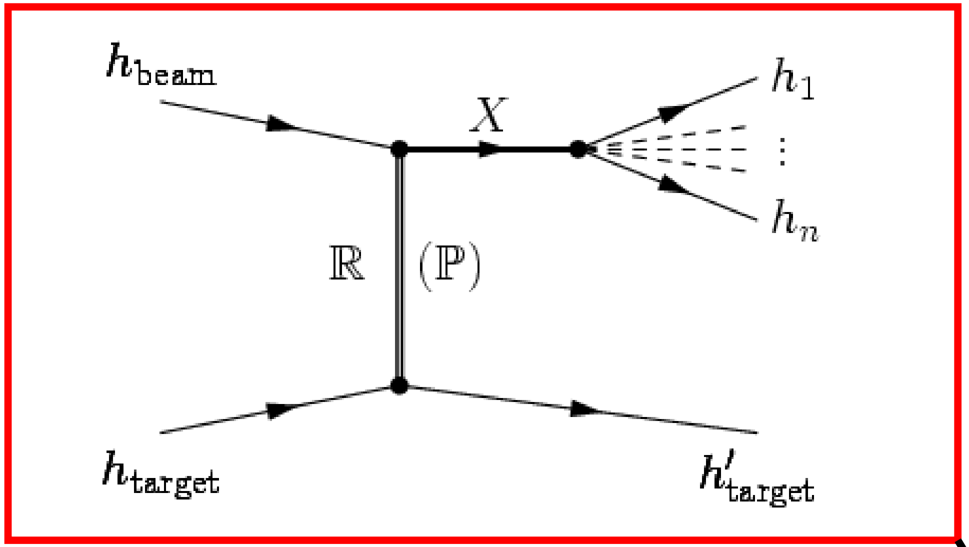

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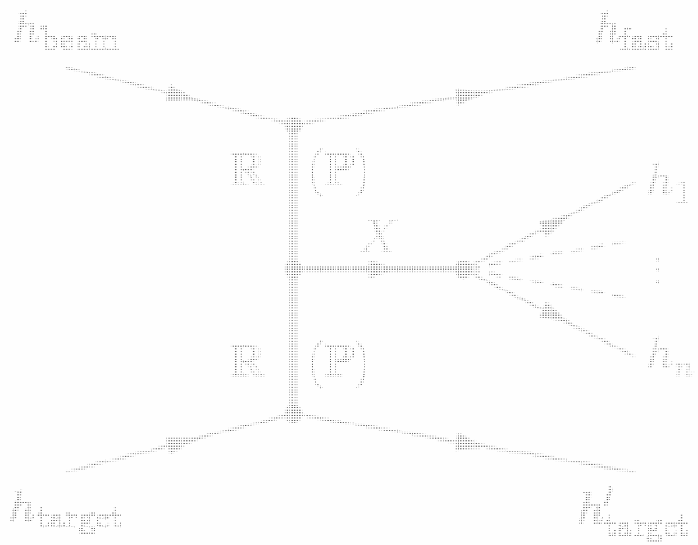

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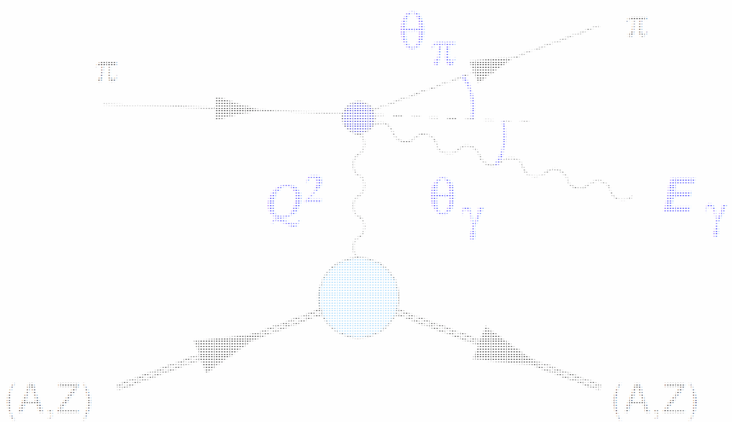


Focus on first results
from diffractive dissociation

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):

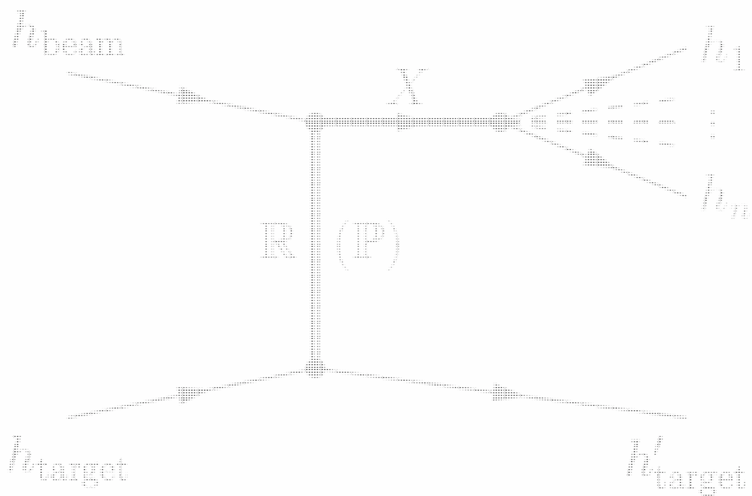
lightest hybrid predicted: exotic $J^{PC} = 1^{-+}$

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

Diffractive scattering

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



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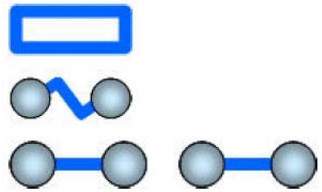

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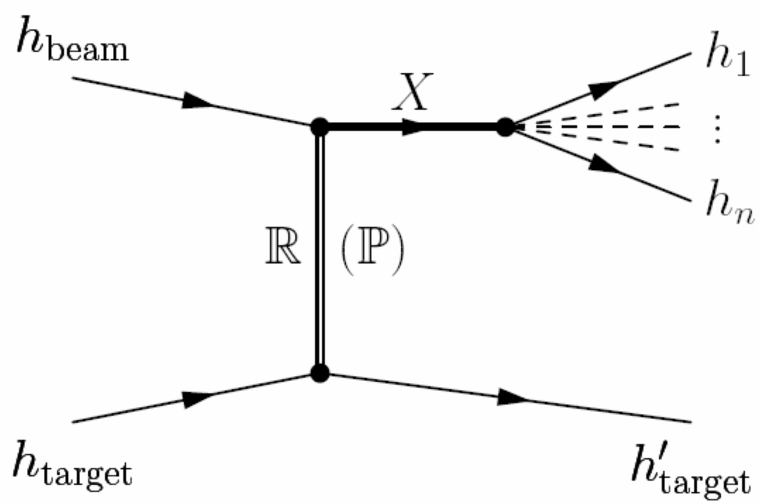

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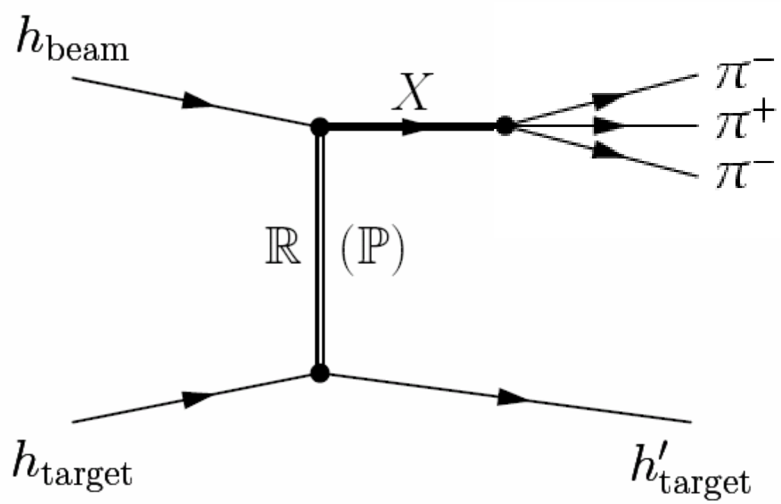
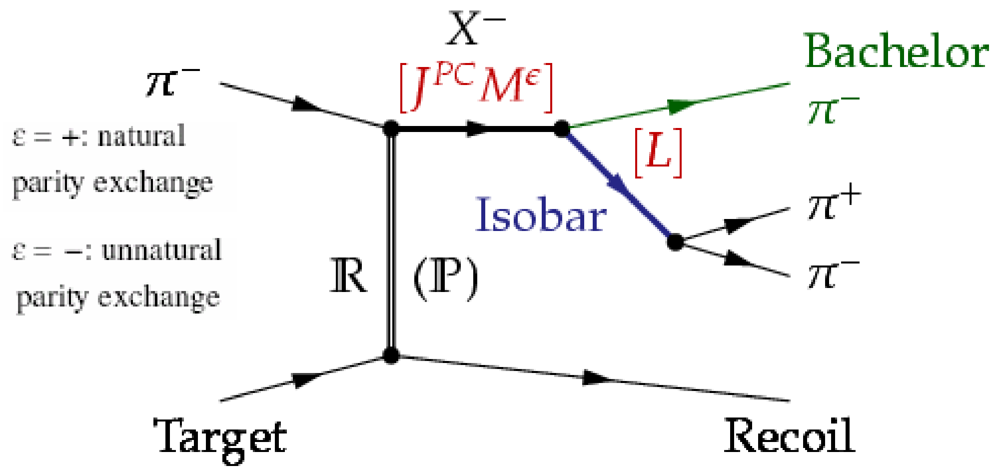


Diffractive pion dissociation

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

PWA using isobar model



<u>X^- decay described using isobar model</u>:

- 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:

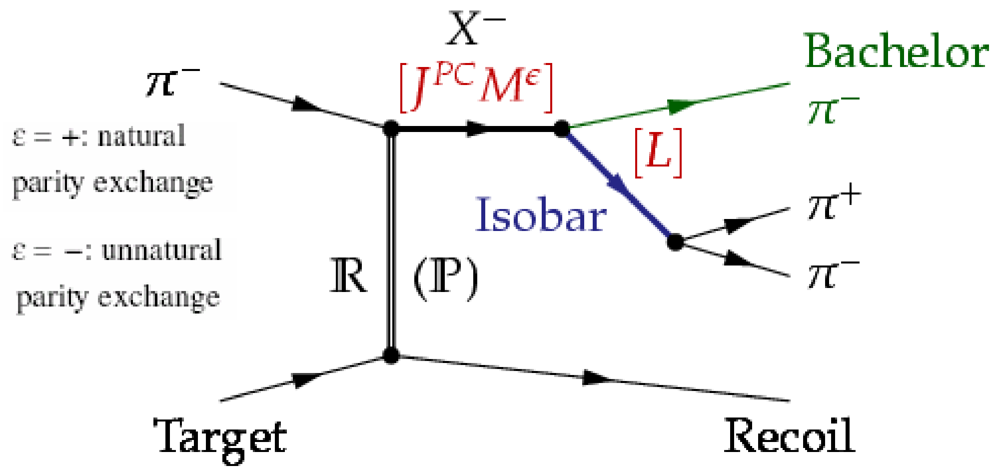
- **program:** Illinois/Protvino/Munich (D.Ryabchikov) software (IHEP/VES, TUM/COMPASS)
- **Isobars:** $(\pi\pi)_S$ [broad $f_0(600)$+$f_0(1370)$], $f_0(980)$, $\rho(770)$, $f_2(1270)$, $\rho_3(1690)$
- **Acceptance:** corrections included (2004: ~60%, rather flat)

Step 1) Mass independent PWA: (40MeV/c² bins, 41+1 partial waves)

$$\sigma_{indep}(\tau, m, t') = \sum_{\epsilon=\pm 1} \sum_{r=1}^{N_r} \left| \sum_i T_{ir}^{\epsilon} f_i^{\epsilon}(t') \psi_i^{\epsilon}(\tau, m) / \sqrt{\int \left|\psi_i^{\epsilon}(\tau', m)\right|^2 d\tau'} \right|^2$$

- Production amplitudes T_{ir}^{ϵ} → extended maximum likelihood fit
- Decay amplitudes $\psi_i^{\epsilon}(\tau, m)$ (Zemach tensors, D functions)

PWA using isobar model



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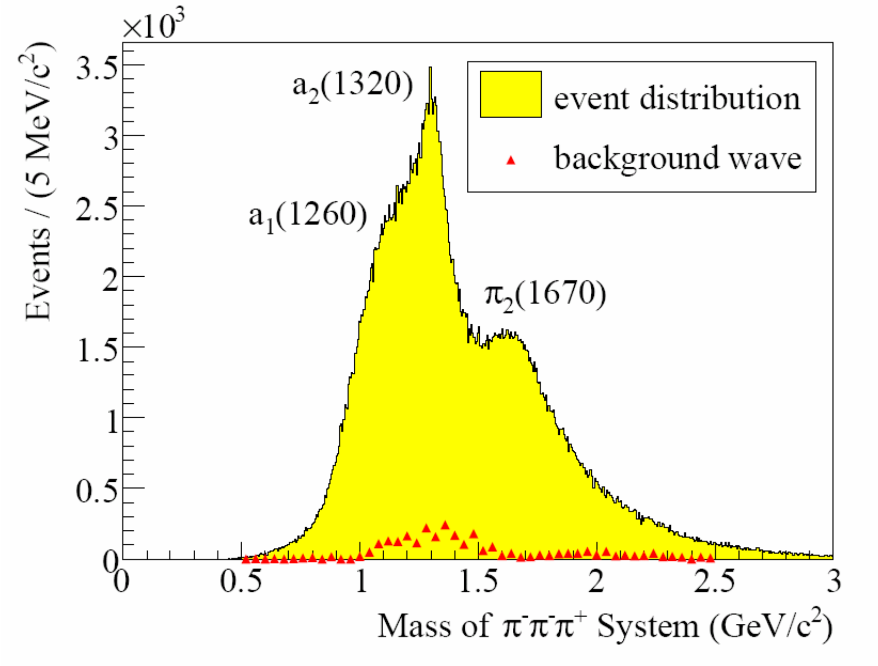
Step 1) Mass independent PWA: (40MeV/c² bins, 41+1 partial waves)

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

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

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



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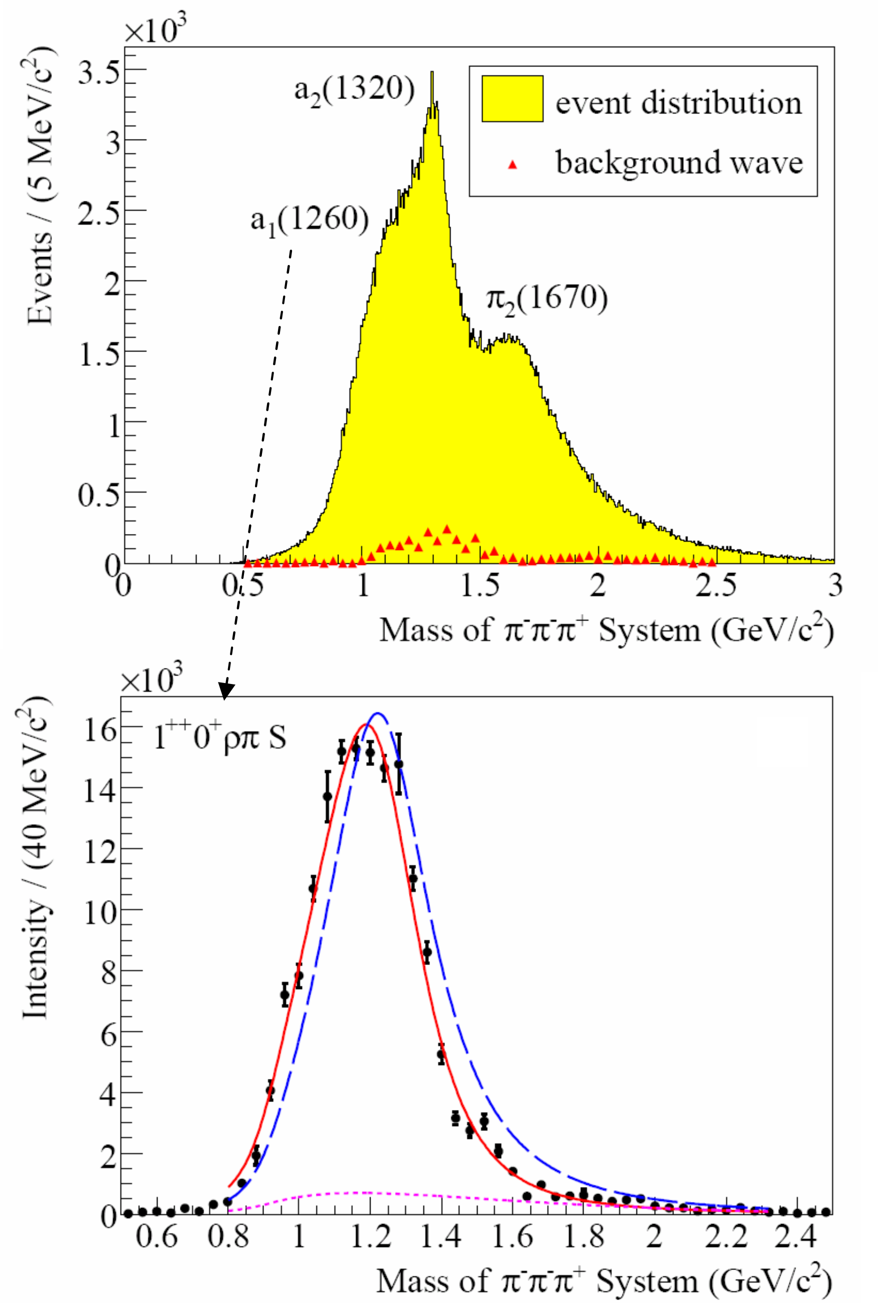

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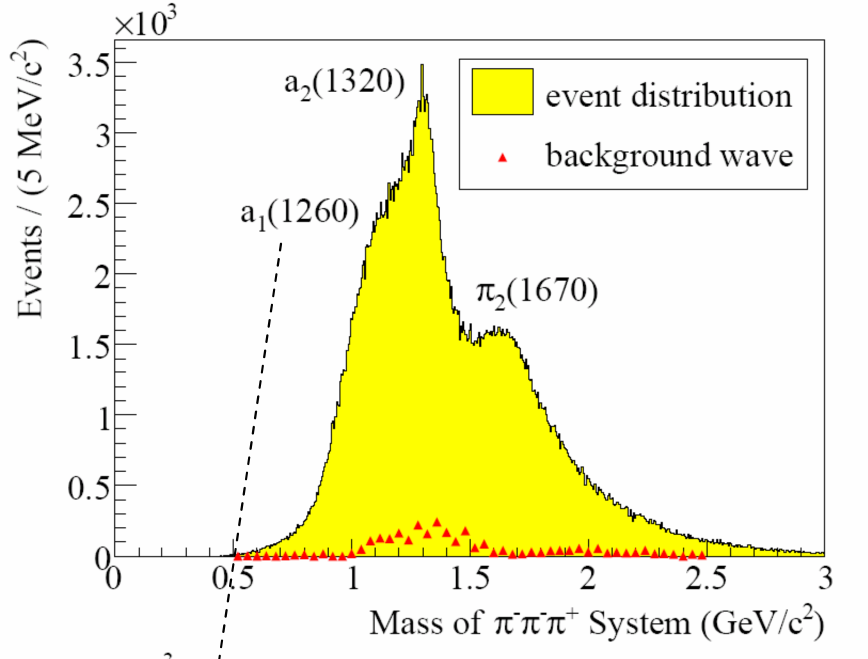

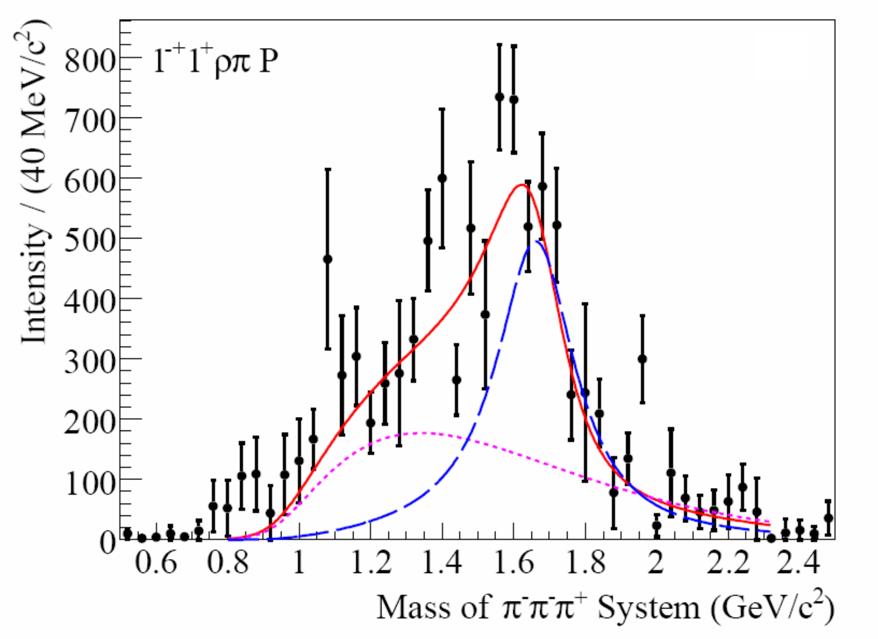

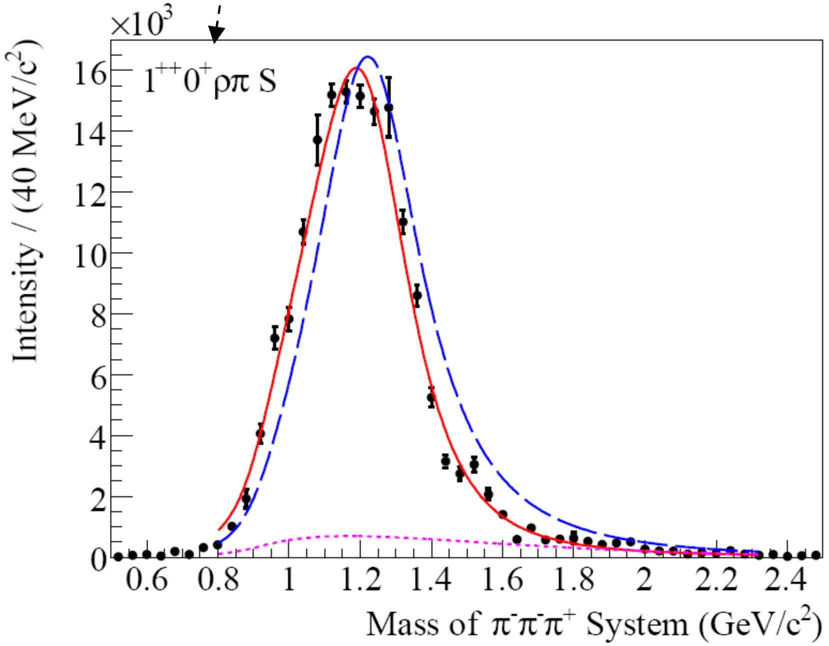

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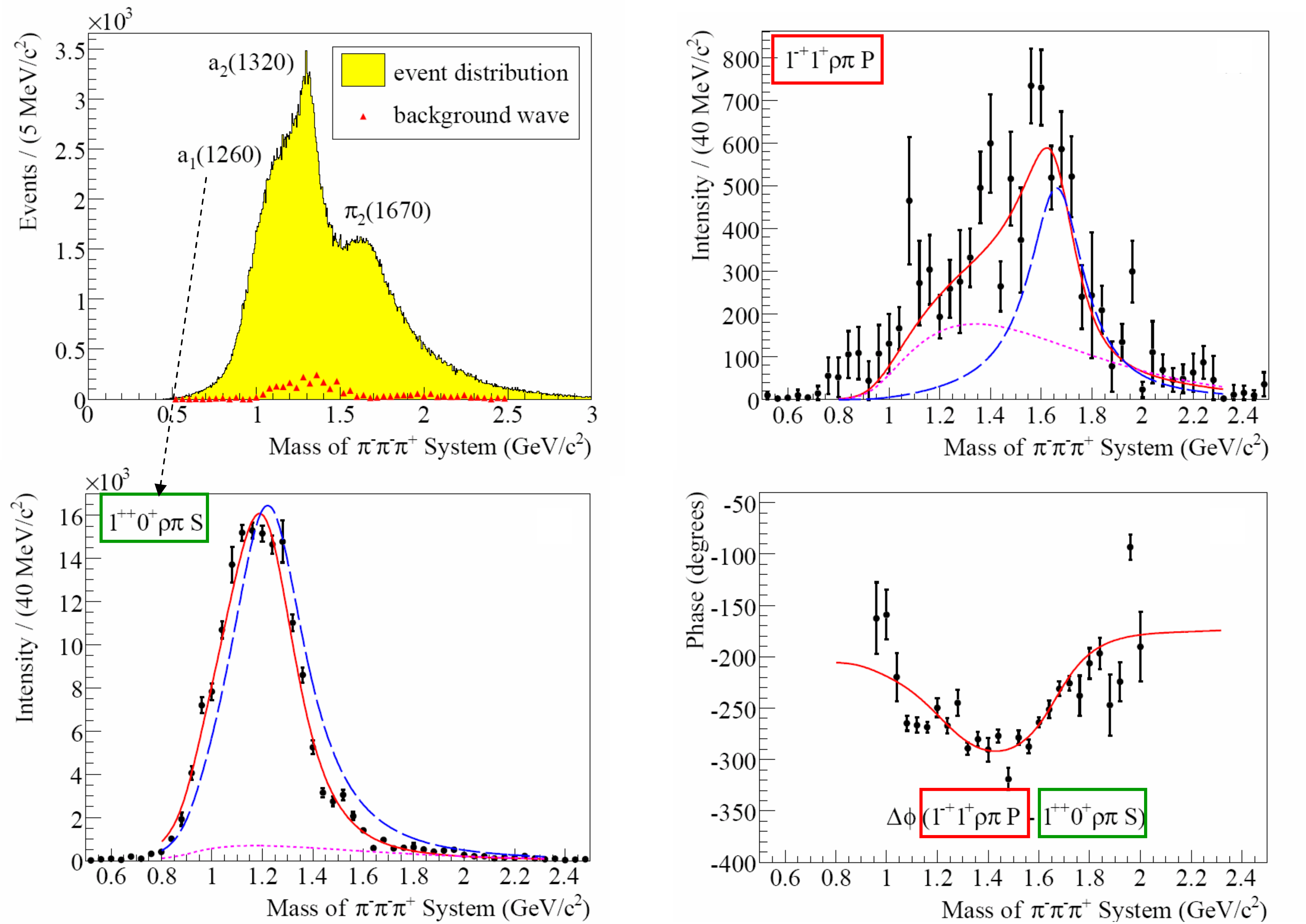
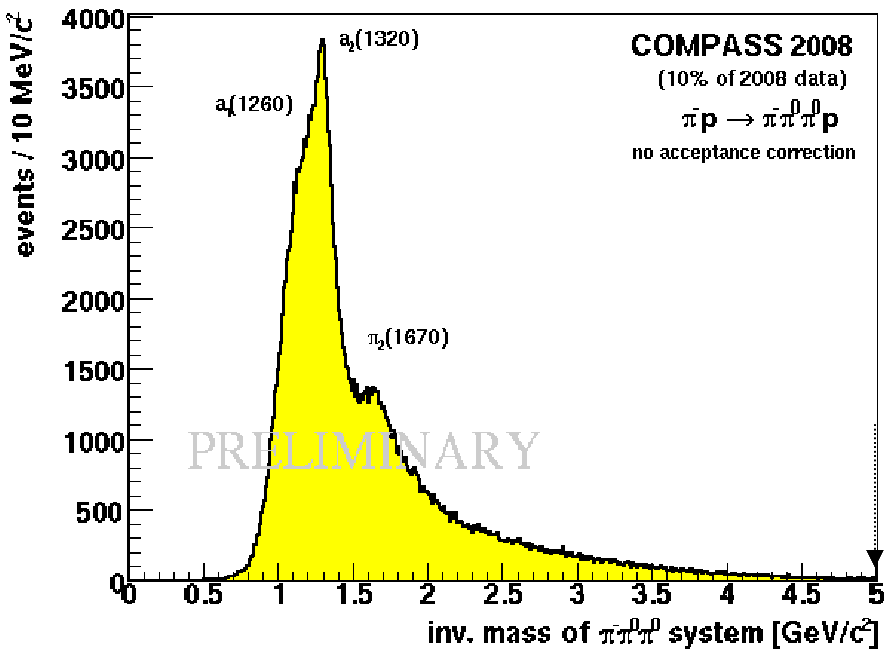
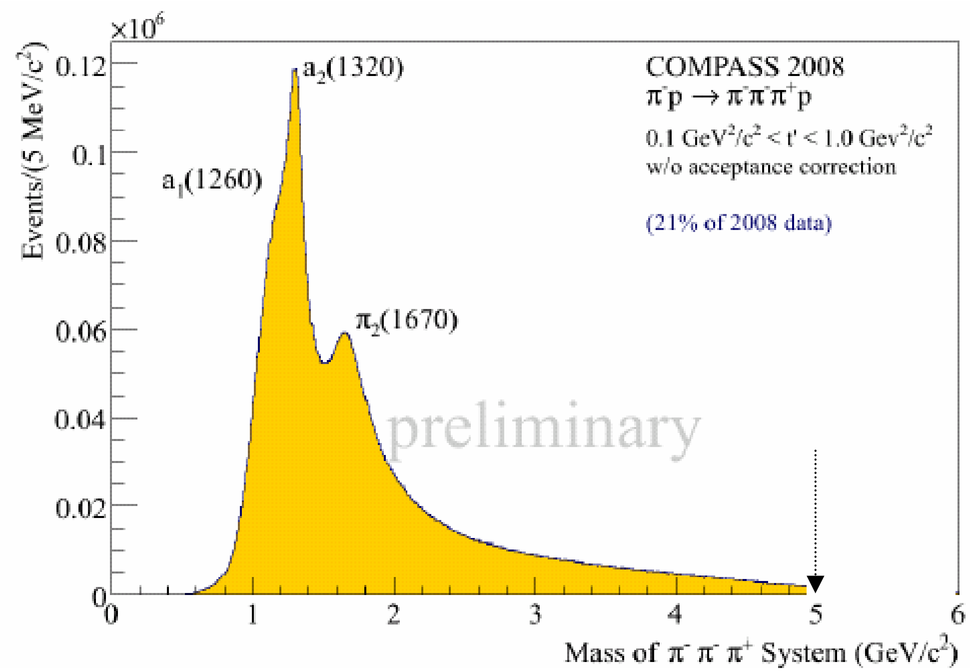


Diffractive dissociation into 3π final states
(2008 data, LH_2 target)

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

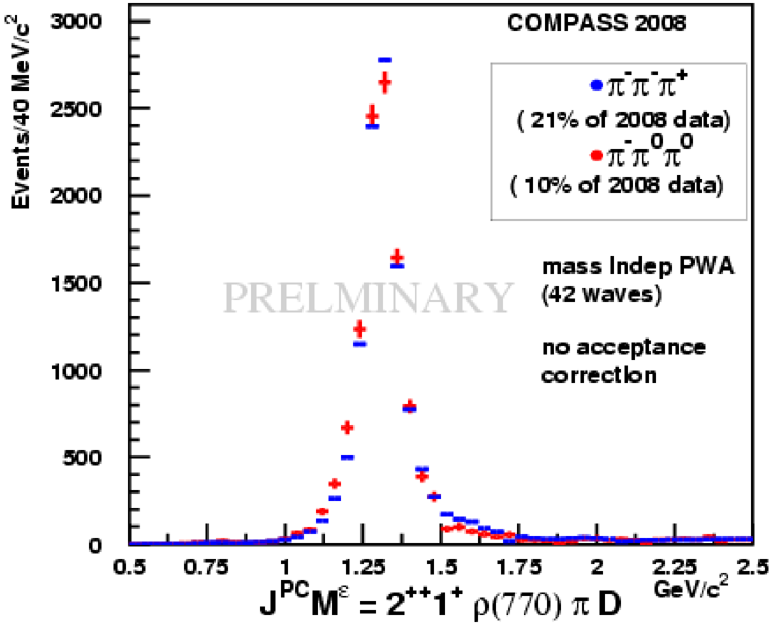


Mass of outgoing 3π system – charged mode: $\pi^- p \longrightarrow \pi^-\pi^+\pi^- p$



First comparison: Neutral vs. charged mode

simple isospin symmetry check



$a_2(1320)$ used as a standard candle for normalisation

Isospin symmetry: neutral / charged mode

- isobar decaying into f_2 π: 1/2 intensity expected
- isobar decaying into ρ π: 1/1 intensity expected

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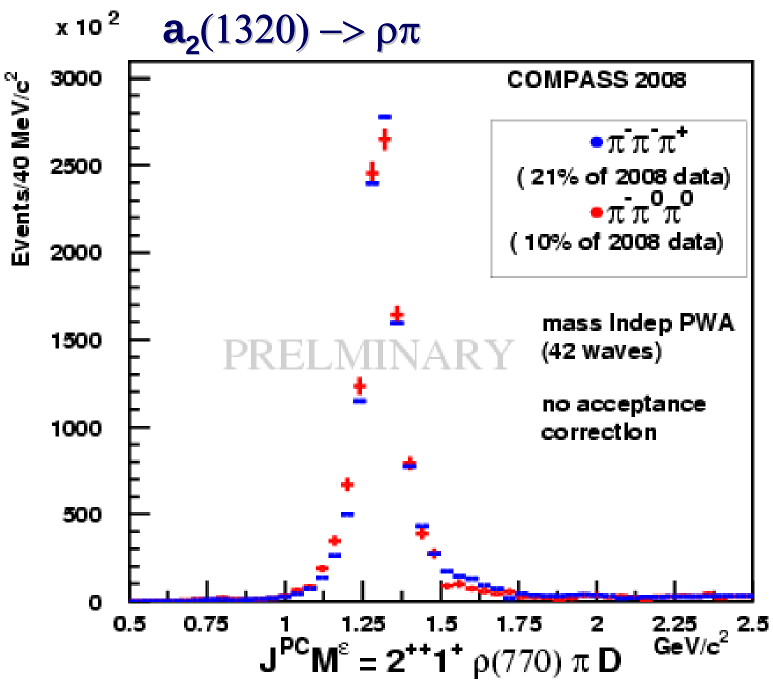

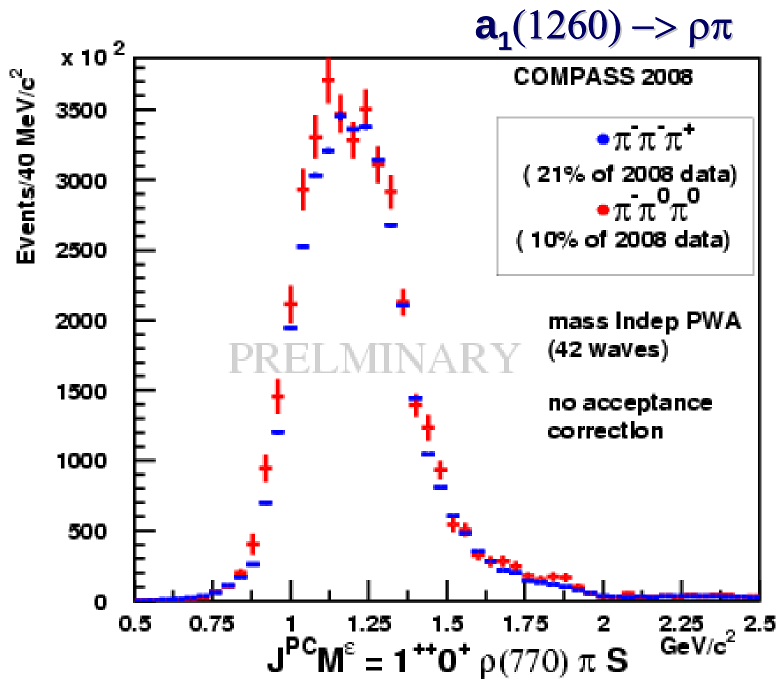

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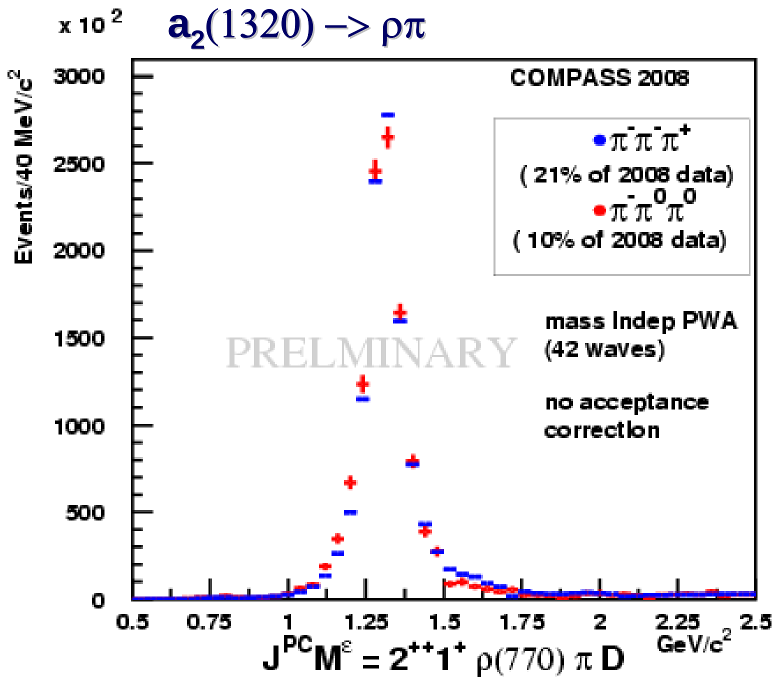
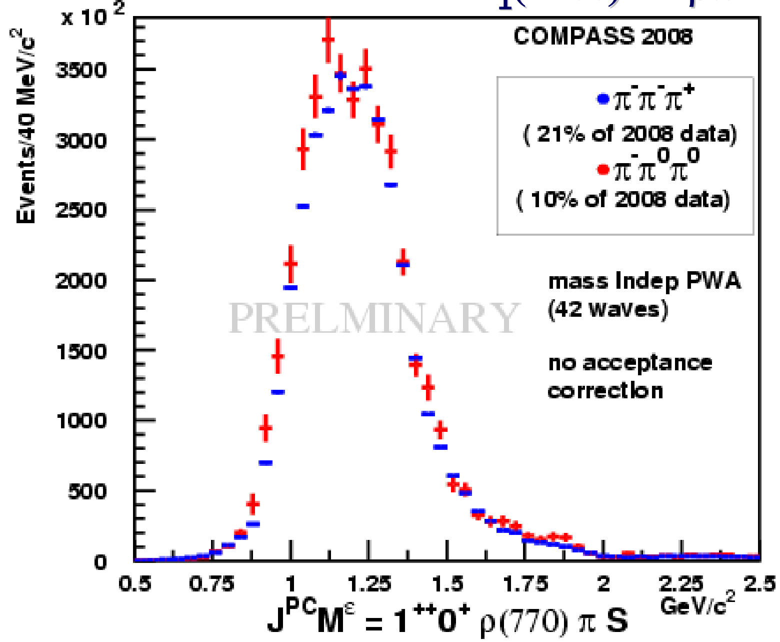
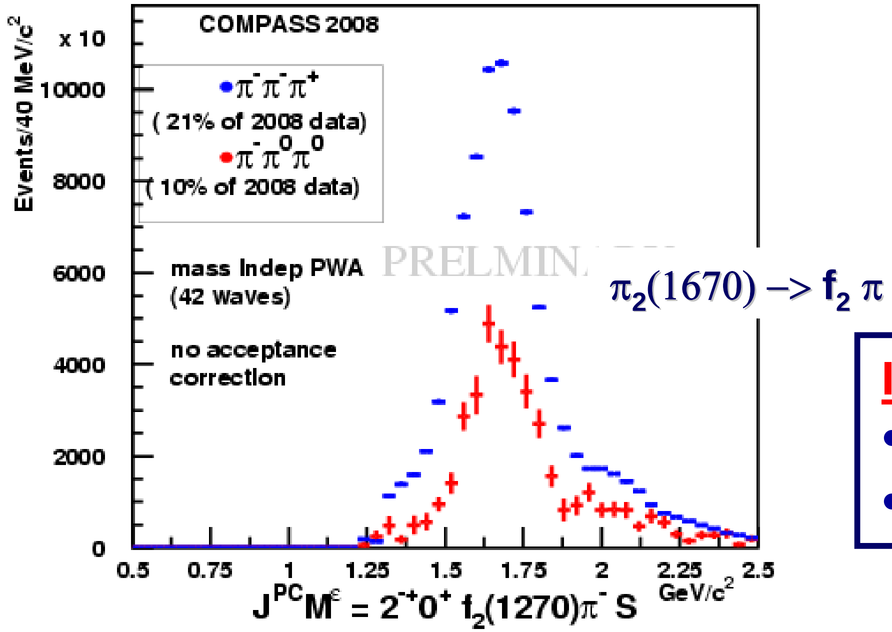


$a_1(1260) \to \rho\pi$





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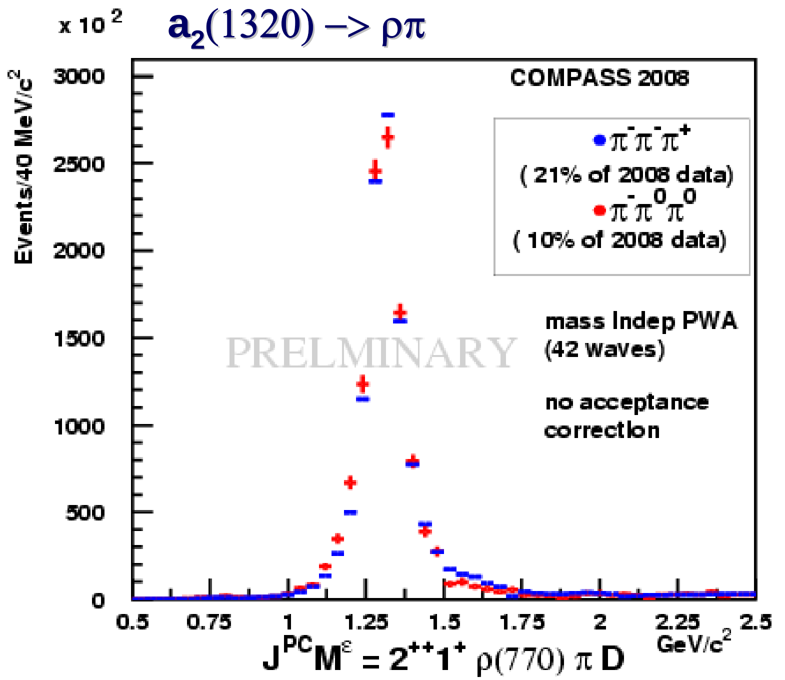
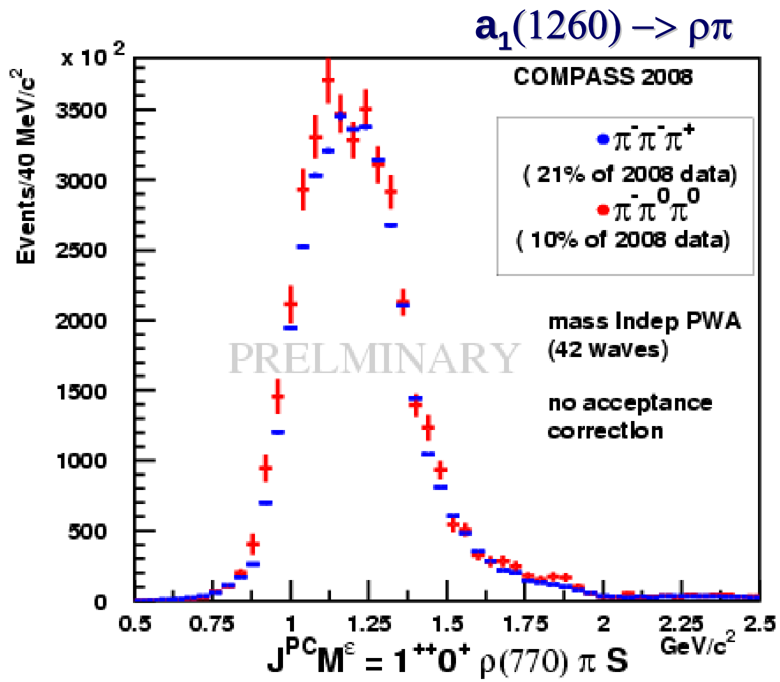
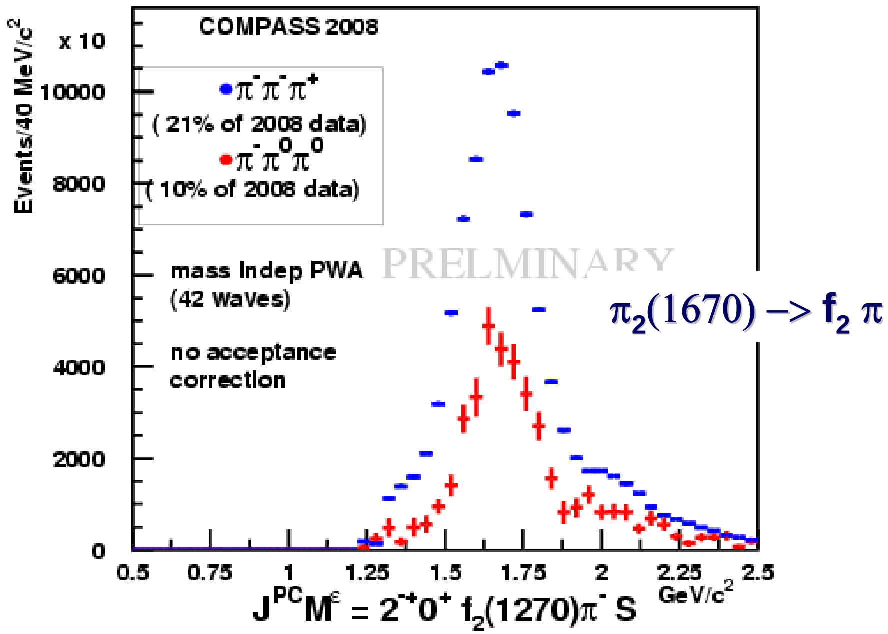
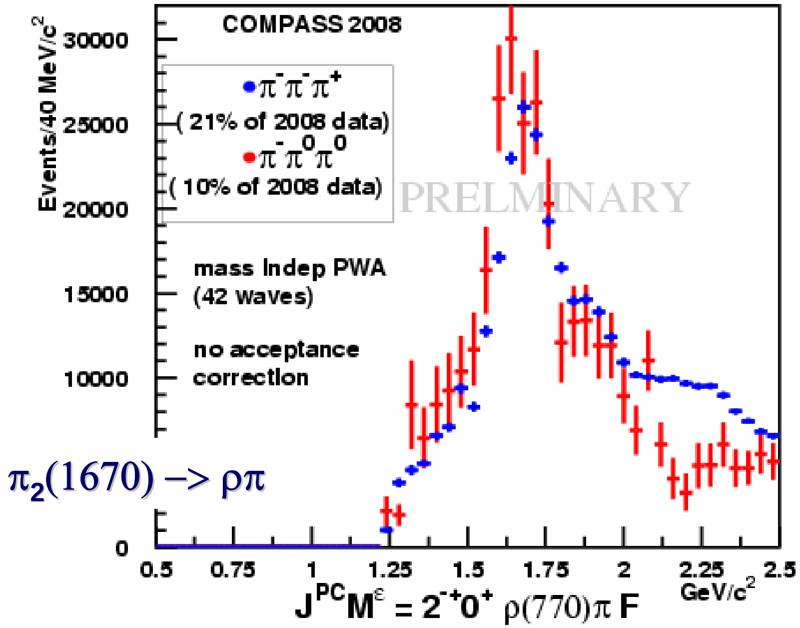


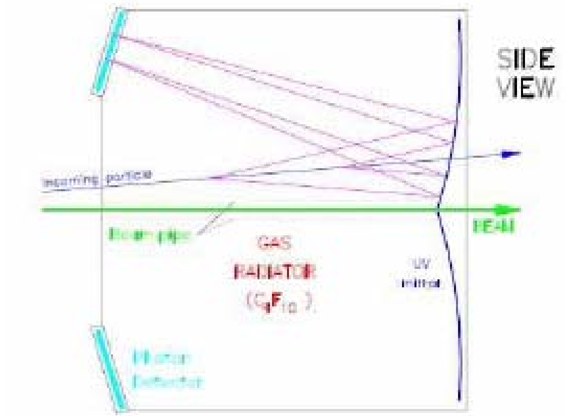


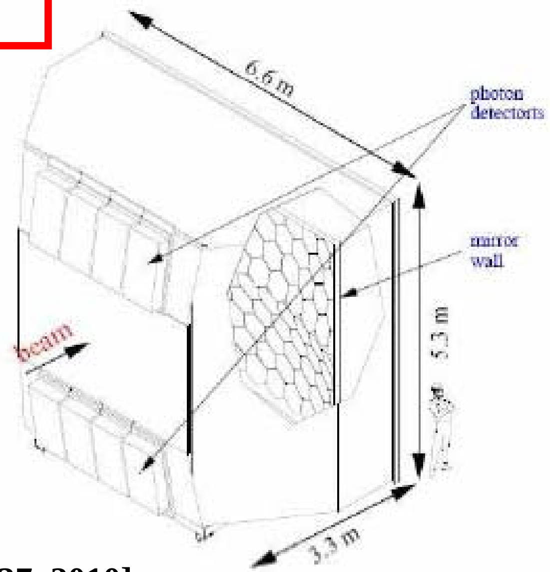


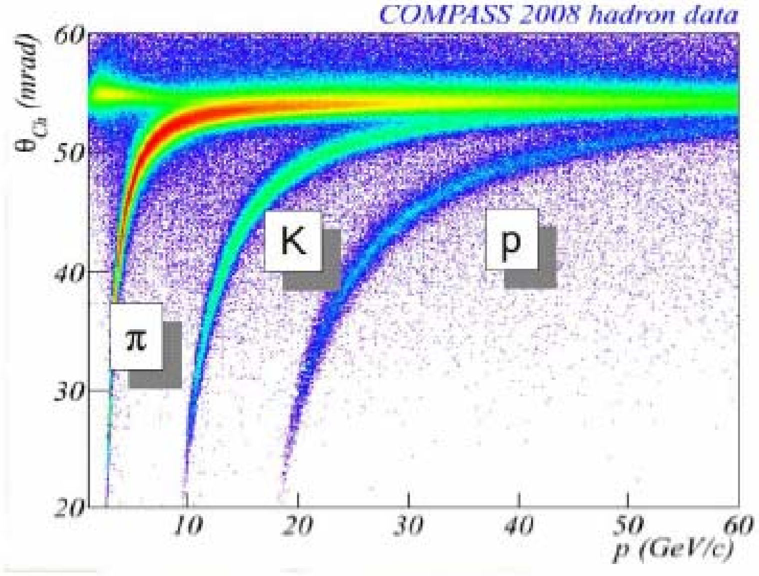


Studies of final states with (hidden) strangeness -- Kaonic channels

RICH: Final state particle ID

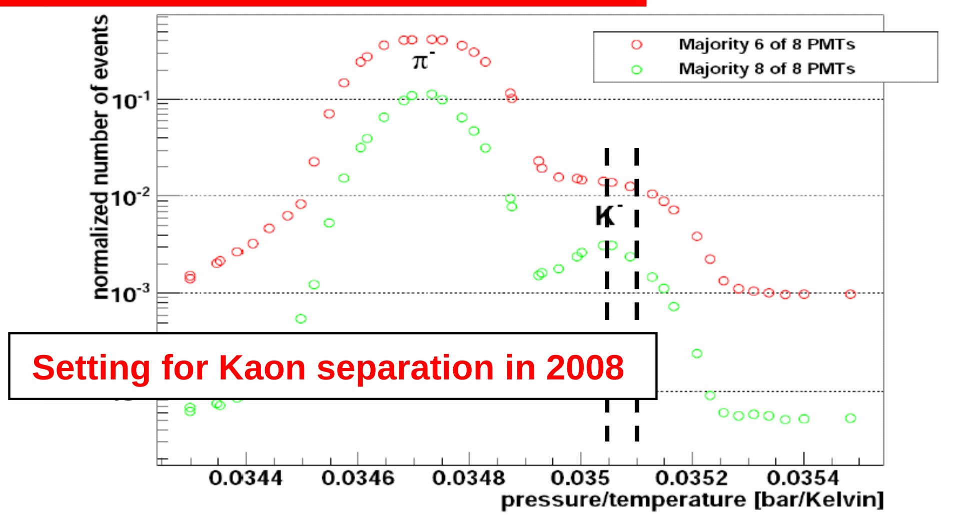






Major upgrade in 2006:
[NIM-A587:371-387, 2008], [NIM-A616:21-37, 2010]

CEDARs: Beam particle ID



Motivation:

- Search for J^{PC} spin exotic mesons decaying via $K\bar{K}\pi$
- Study glueball candidates predicted to decay into $K\bar{K}$
- New insights on kaonic spectrum in general

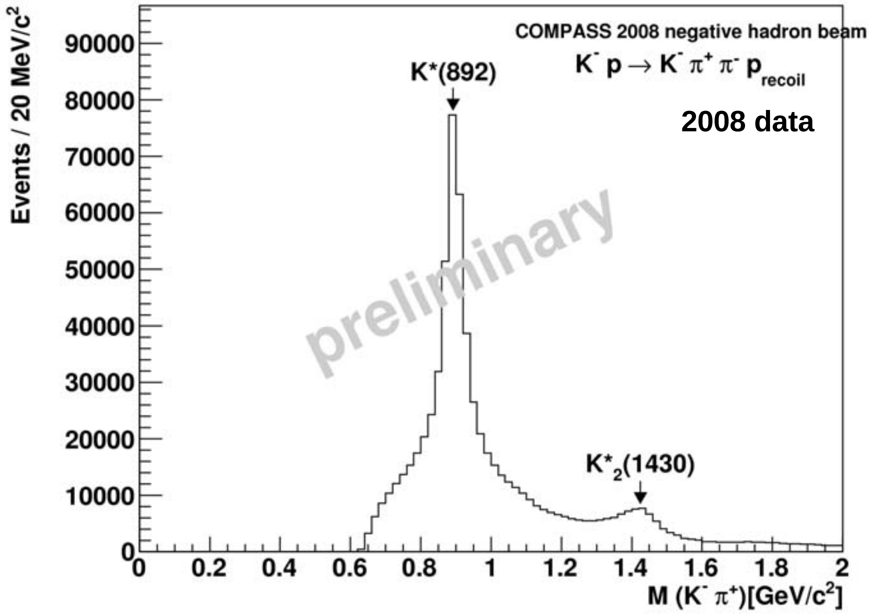
Kaonic channels I: Kaon diffraction

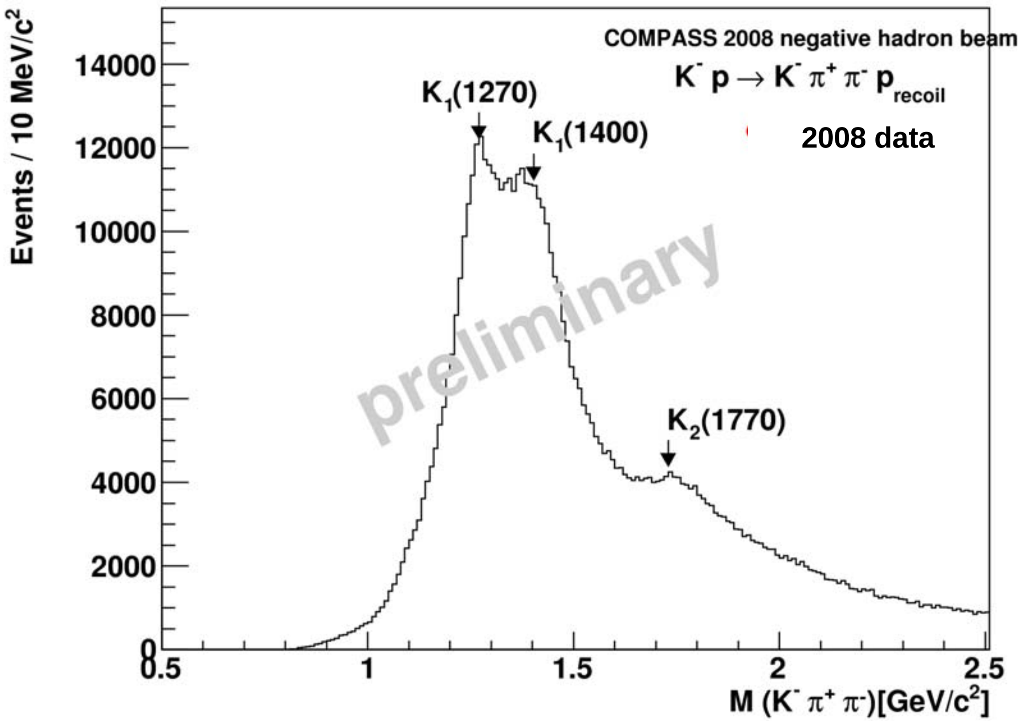
$K^- p \rightarrow K^- \pi^- \pi^+ p$

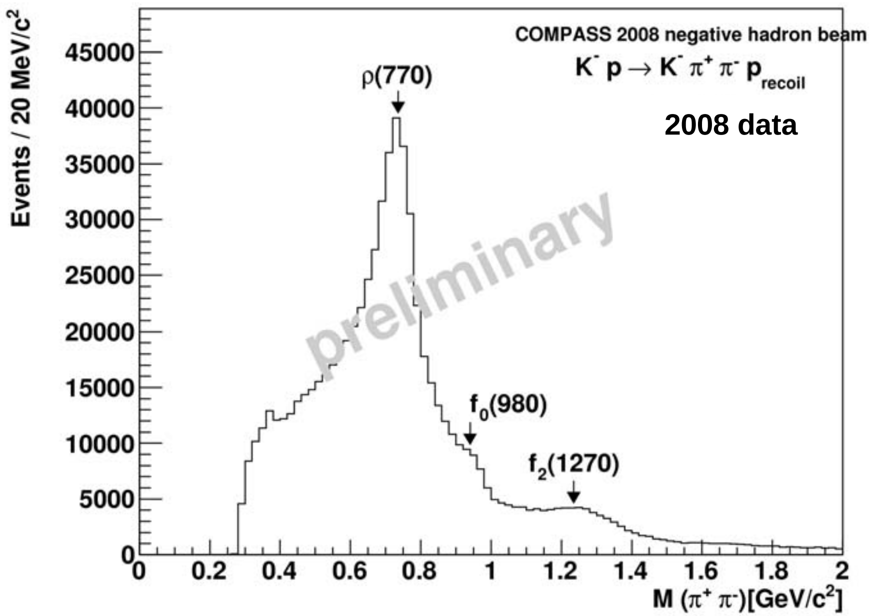
Main issues of selection:

- Beam kaon tagged by CEDARs
- Final state kaon identified by RICH
- ~600 k events on tape *(2008 data only)*

  → *to be compared with ~200 k events WA3*







Kaonic channels II: $(K\bar{K}\pi)^-$

$\pi^- p \to \pi^- K_s K_s p$ vs. $\pi^- p \to \pi^- K^+ K^- p$

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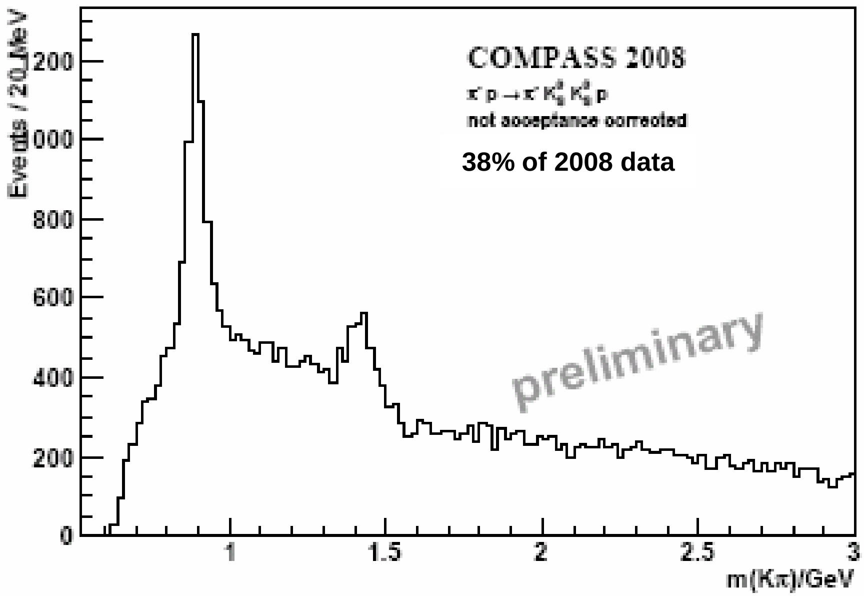

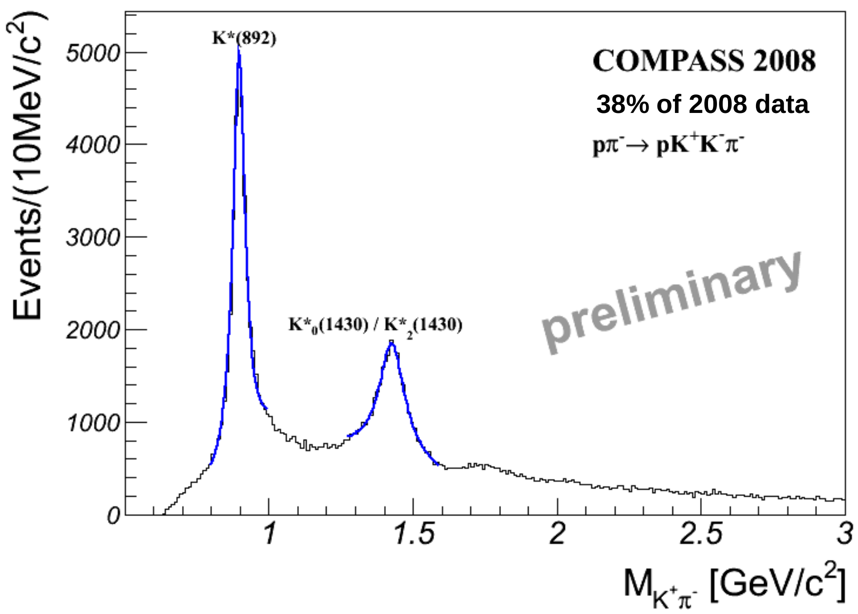

- Combinatorics in $K_s\pi^-$ case
- Resonances: K*(892), K_2*(1430), K_3*(1780), also probably K_4*(2045)

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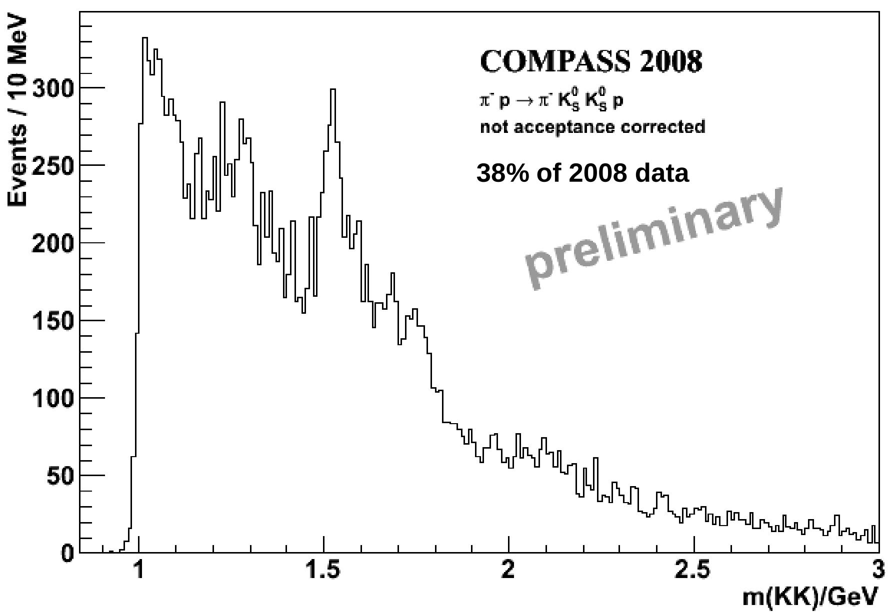
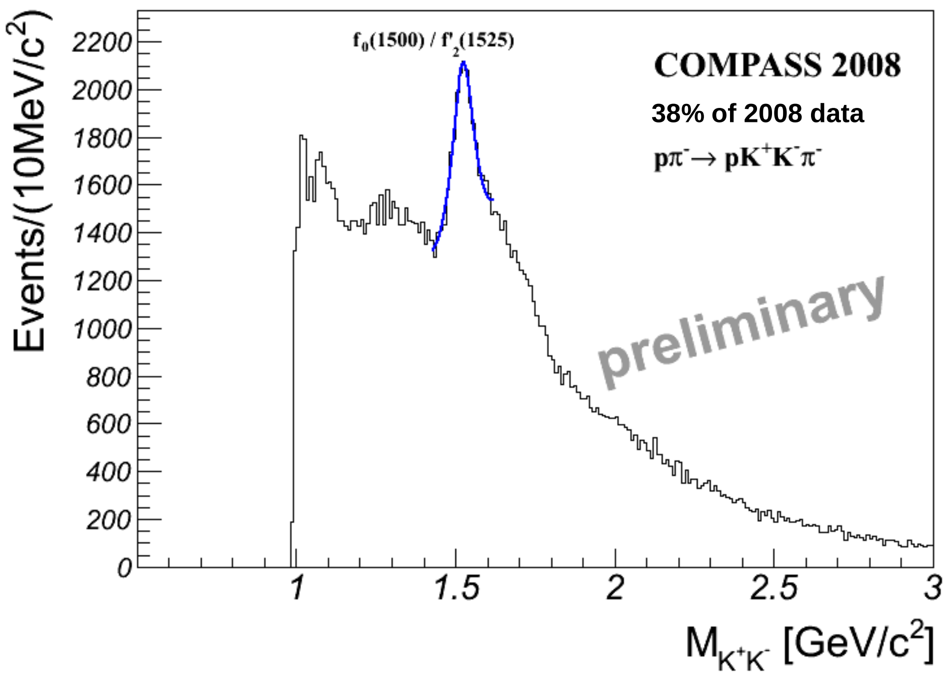




- Difference near threshold → momentum cut due to RICH
- known resonances seen as expected

Summary & conclusions

- **COMPASS: high potential for Hadron Spectroscopy**
  - ✓ 2004 data: **Observed exotic J^{PC} → π_1(1600)** **[PRL 104 (2010) 241803]**
  - ✓ 2008/09: ***Data taken with hadron beams on proton & nuclear targets***
  - ✓ ***Very high statistics*** *(10-100x world statistics)*

- **COMPASS measures Neutral & Charged channels**
  - ✓ **First results on 3π final state 2008 data** (diffr. dissociation)
    - → *First comparision neutral vs. charged mode* (PWA: isospin symmetry)
    - **=>** independent confirmation of new states within same experiment

=> **Ongoing:** Ecal calibration *(for full usage of hardware upgrades)*

- **COMPASS measures kaonic final states** (diffr. dissociation)
  - ✓ **Kaon diffraction:** First look into $K^-\pi^+\pi^-$ promising *(2008 only: 3x WA32))*
  - ✓ $(KK\pi)^-$: First comparison $K_sK_s\pi^-$ ***vs.*** $K^-K^+\pi^-$ (PWA underway)

Further:

- $(KK\pi)^0$*:* in $K_sK^{+/-}\pi^{-/+}\pi^-$ final states (PWA started, higher masses (> 2.2 GeV)
  - → *PWA of* *f_1(1285)π* & *f_1(1420)π* *(→ never done before)*

=> **more results soon**

Conclusions & outlook

Further

- **Central production** (*charged & neutral, pionic & kaonic*),
- **Baryon spectroscopy** (*charged & neutral, pionic & kaonic*),
- **Primakoff & low t'** => transition region of production mechanisms

…. different targets also

→ detailed study of different production mechanisms

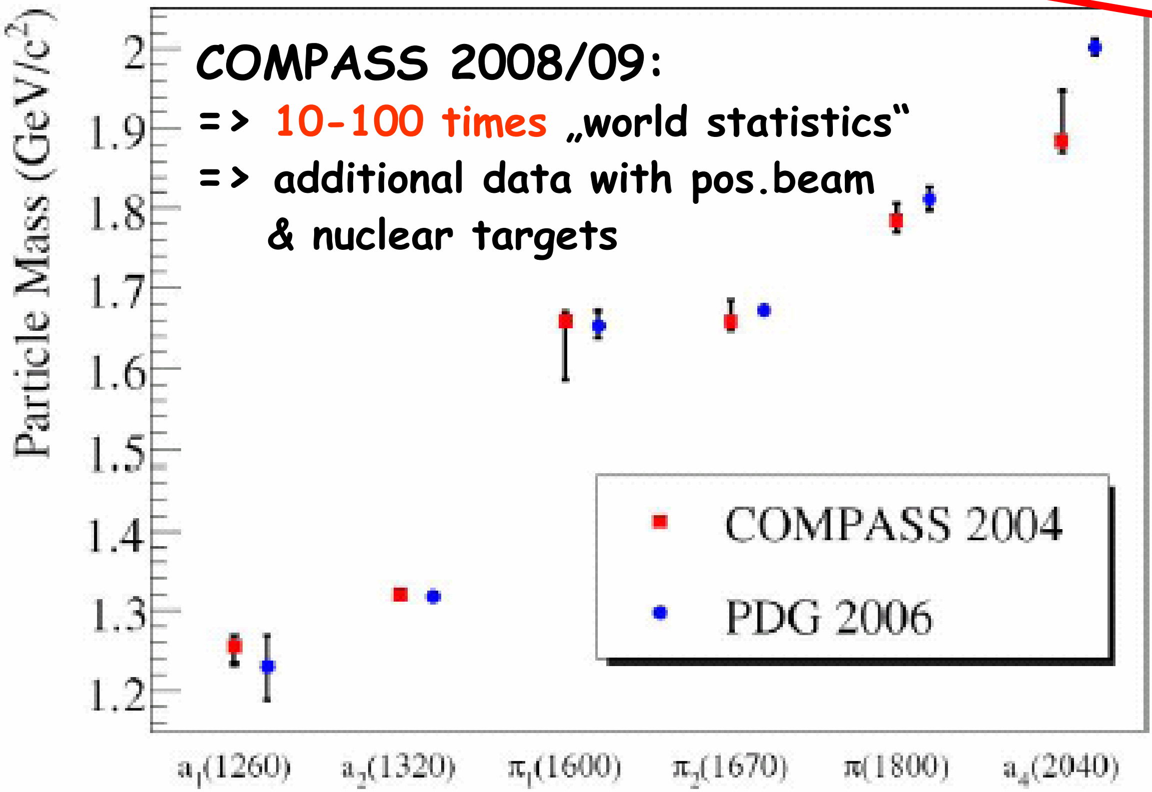
Conclusions & outlook

Stay tuned for interesting COMPASS results …

COMPASS 2008/09:

=> 10-100 times „world statistics"

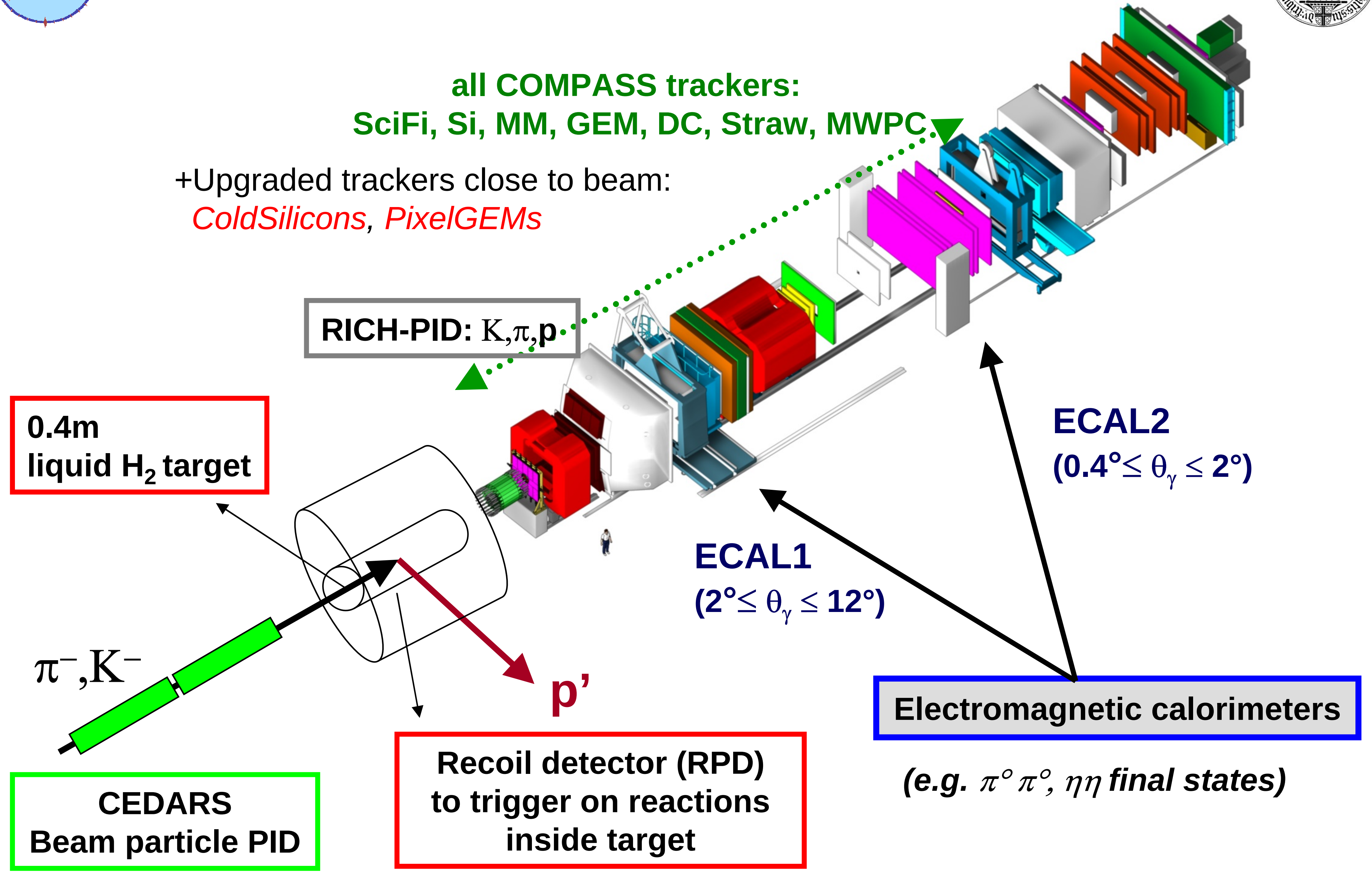
=> additional data with pos.beam & nuclear targets



THANK YOU !!!

Backup

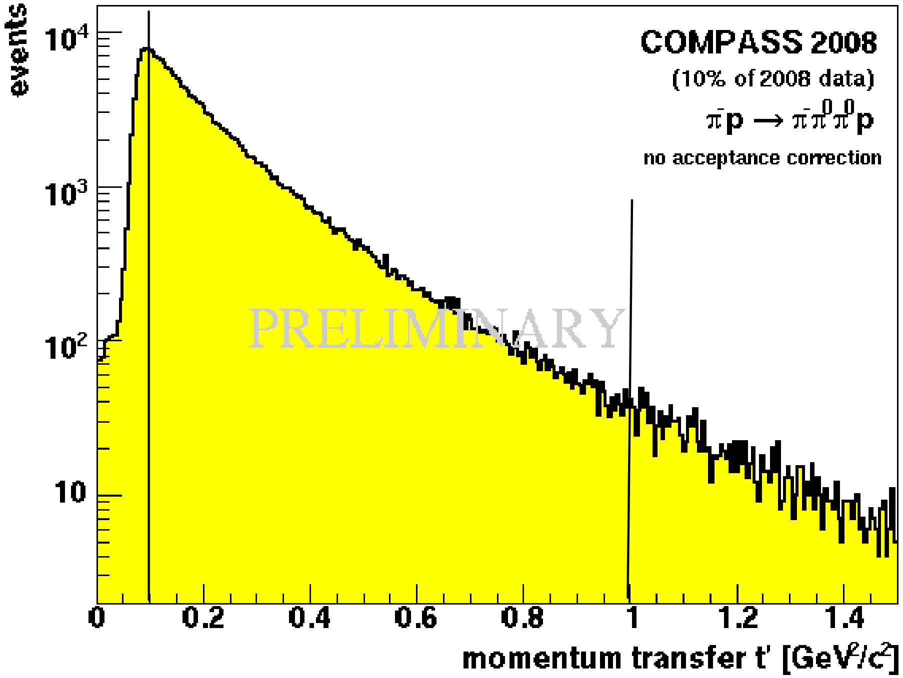
COMPASS spectrometer: Hadron setup 2008/09

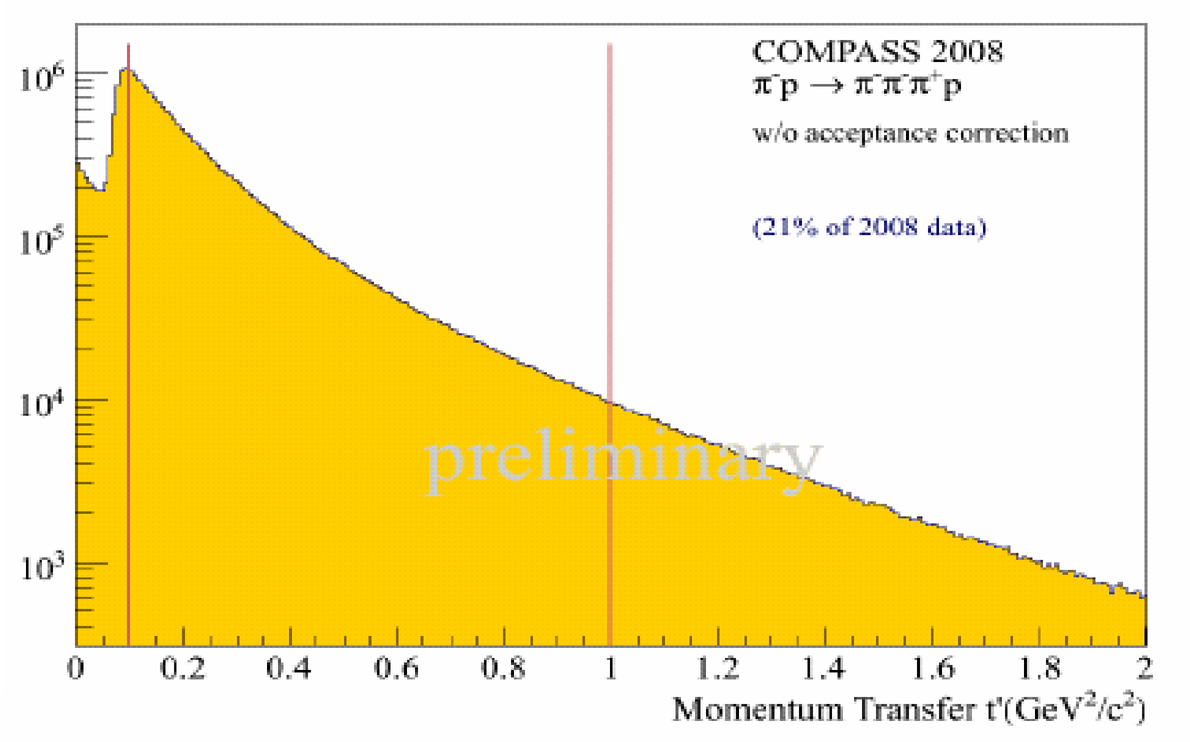


Diffractive dissociation into 3π final states
(2008 data, LH_2 target)

neutral mode

charged mode



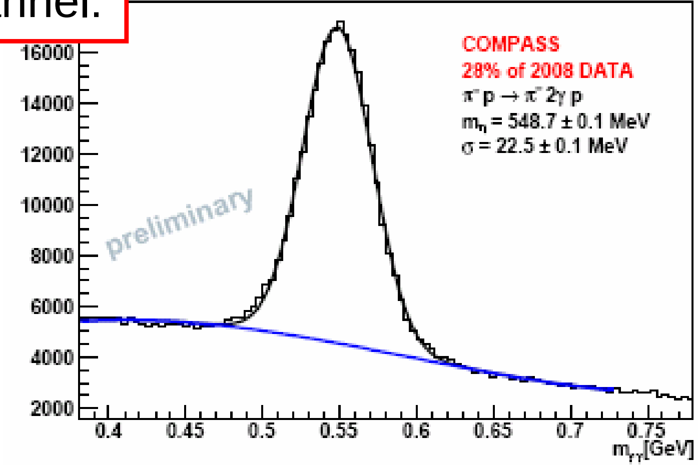


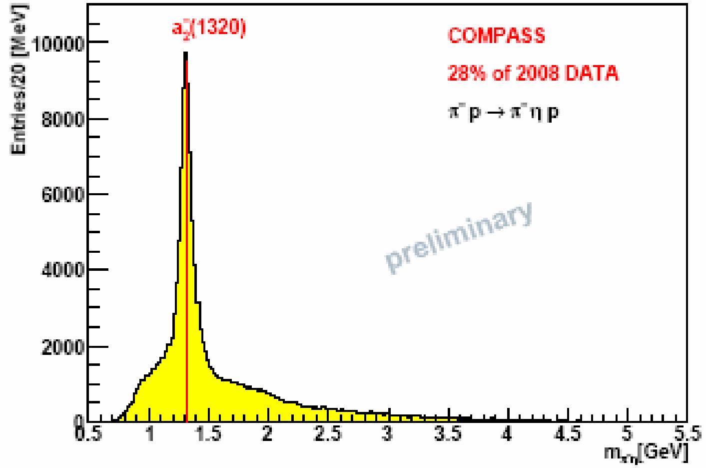
$$t = (p_{\text{beam}} - p_X)^2 < 0 \qquad t' \equiv |t| - |t|_{\min} > 0$$

Further neutral channels (PWA ongoing):

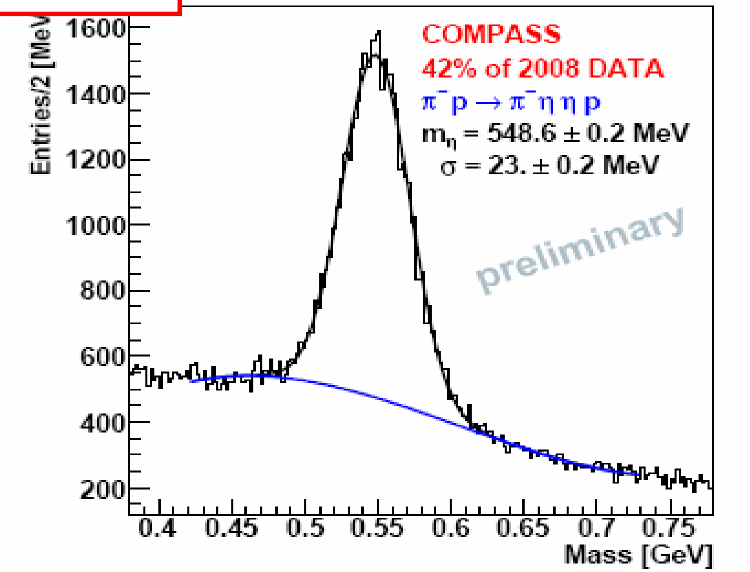
$\pi^- p \to \pi^- \eta p$ & $\pi^- p \to \pi^- \eta\eta p$

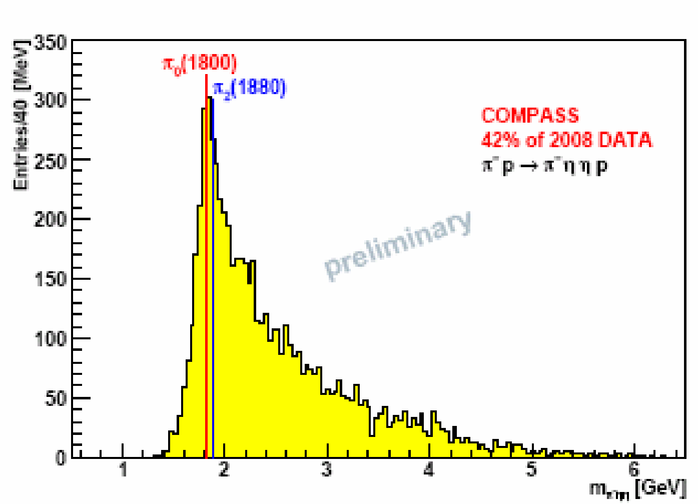
η masses in 2 γ channel:





η masses in 4 γ channel:

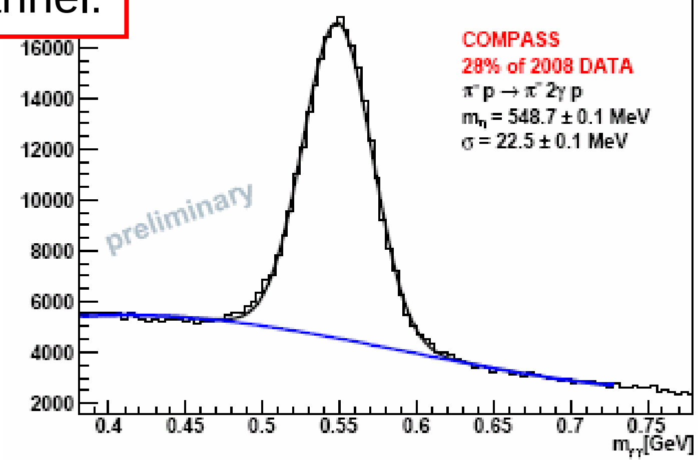


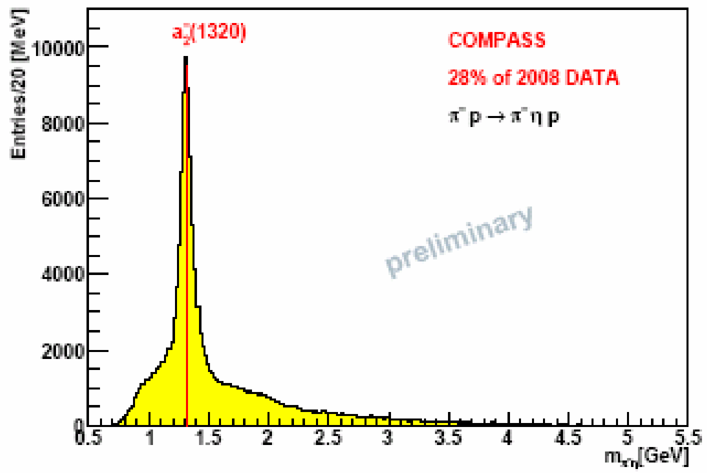


Further neutral channels (PWA ongoing):

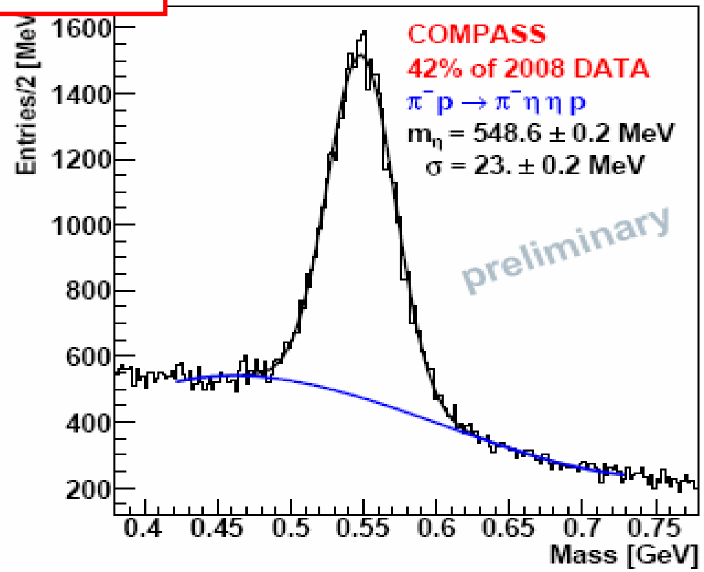
$\pi^- p \to \pi^- \eta\, p$ & $\pi^- p \to \pi^- \eta\eta\, p$

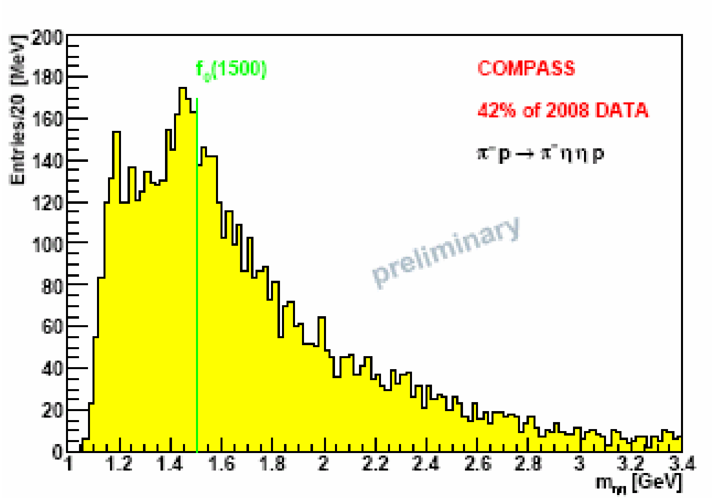
η masses in 2 γ channel:





η masses in 4 γ channel:

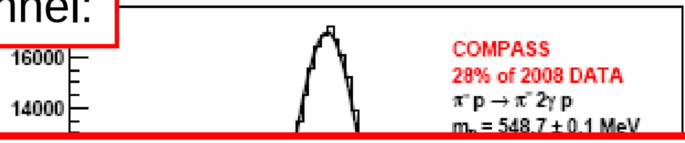


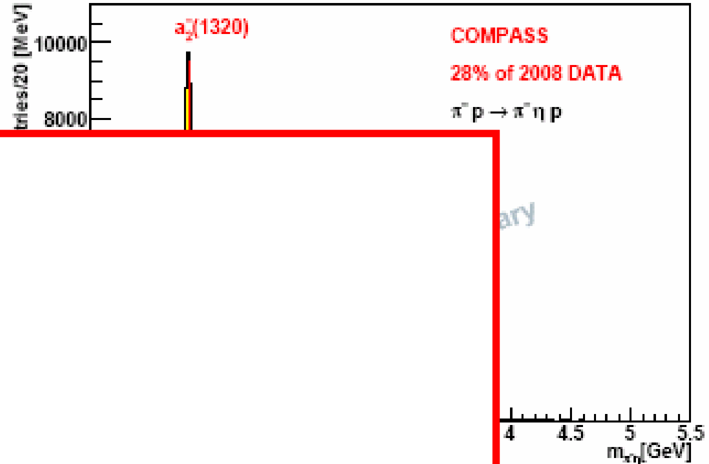


Further neutral channels (PWA ongoing):

$\pi^- p \to \pi^- \eta\, p$ & $\pi^- p \to \pi^- \eta\eta\, p$

η masses in 2 γ channel:





η ma

Further ongoing analyses (involving neutrals)

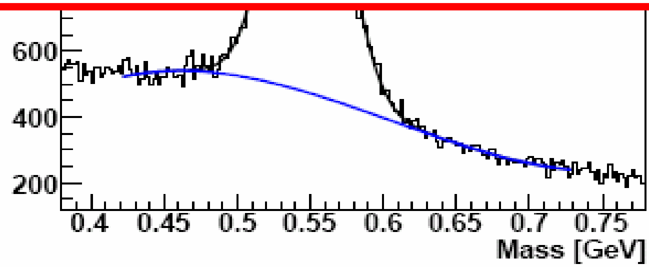
- $\pi^-\eta$, $\pi^-\eta\eta$ & $\pi^-\pi^-\pi^+\eta$ ($\eta \to \gamma\gamma$ & $\eta \to 3\pi$)
  - –> $\pi_1(1400) \to \pi^-\eta$,
  - –> lightest glueball candidate $0^{++} \to \eta\eta$
- $\pi^-\pi^-\pi^+\pi^0$, $\pi^-\pi^-\pi^+\eta$ & $\pi^-\pi^-\pi^+\pi^0\pi^0$
  - => accessible intermediate isobars: f_1, b_1 η, η', ω → search for spin exotic states

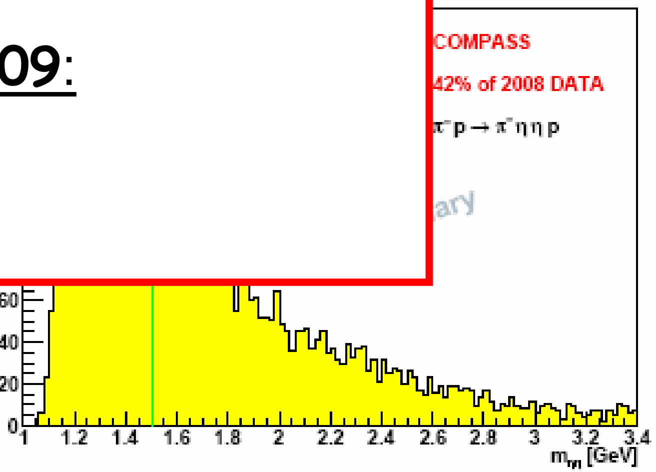
--> *COMPASS: significantly more statistics w.r.t. previous experiments*

After hardware upgrades introduced in 2008/09:

- Optimisation of ECals reconstruction *(under development)*
- important for all final states involving neutrals

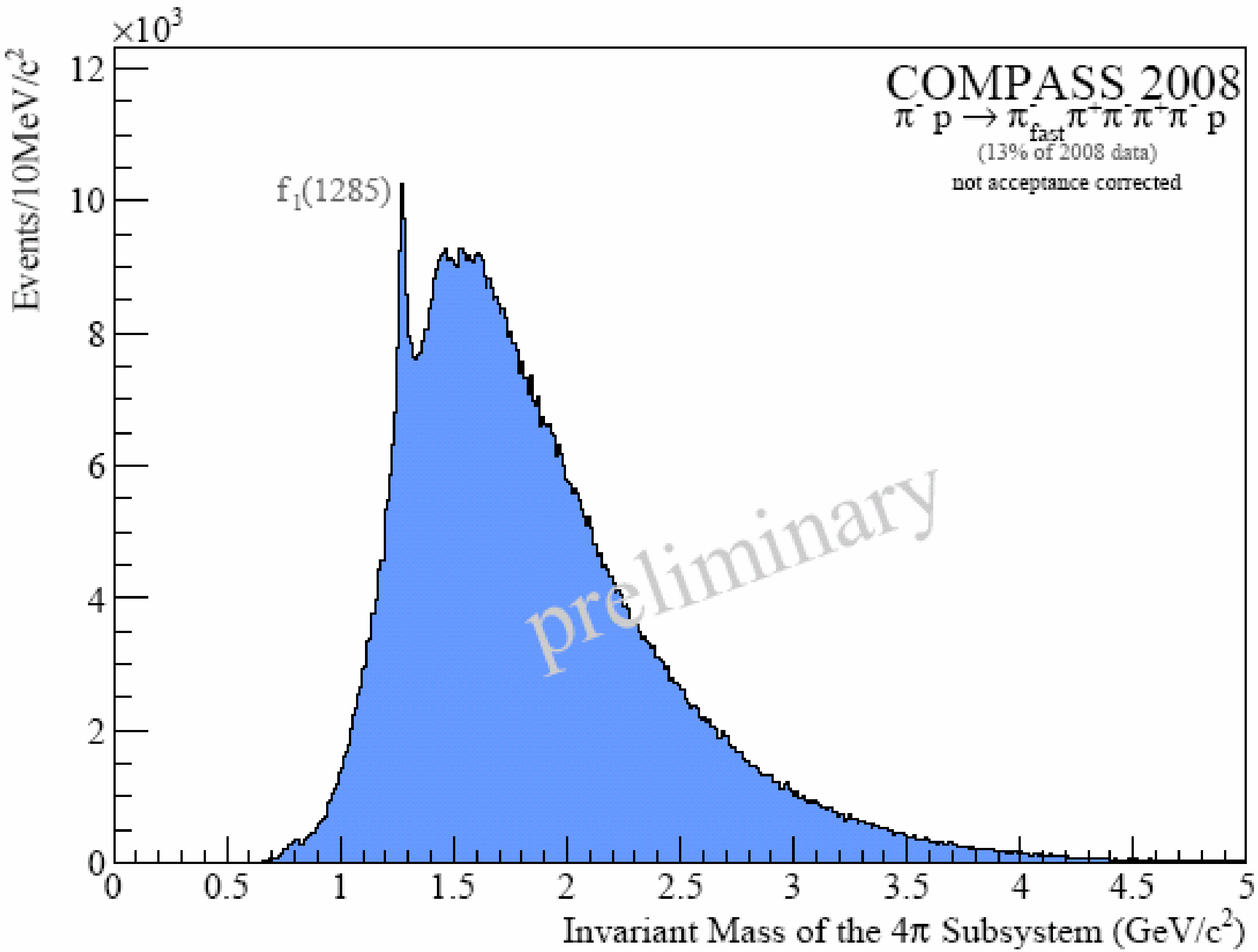
=> **Will improve statistics outcome & resolutions**





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

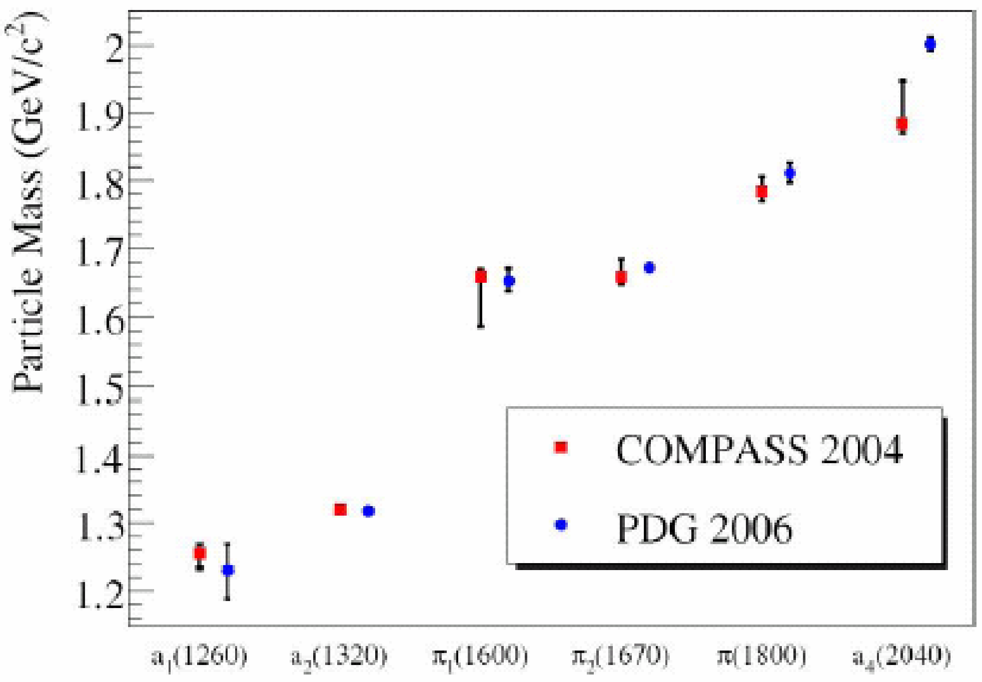
(also b1π in $\pi^-\pi^+\pi^-\pi^0\pi^0$ final states)



<u>Hybrid nature:</u>

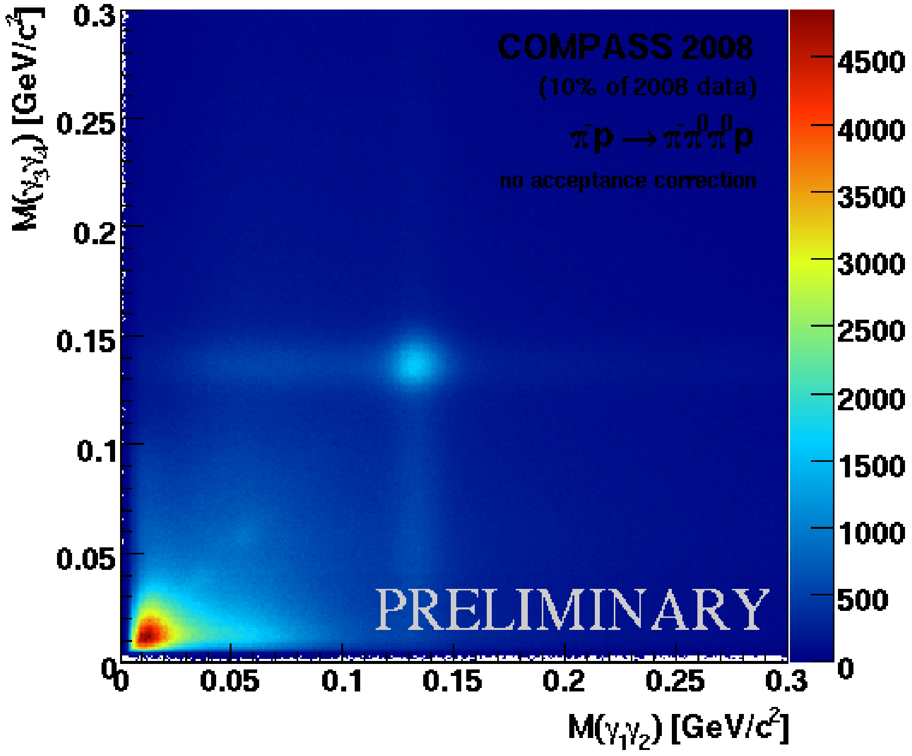
Flux tube model: BR(π_1 –> $f_1\pi$) / BR(π_1 –> $b_1\pi$) [Isgur, Kokoski, Paton, PRL54, 869-872, 1985]

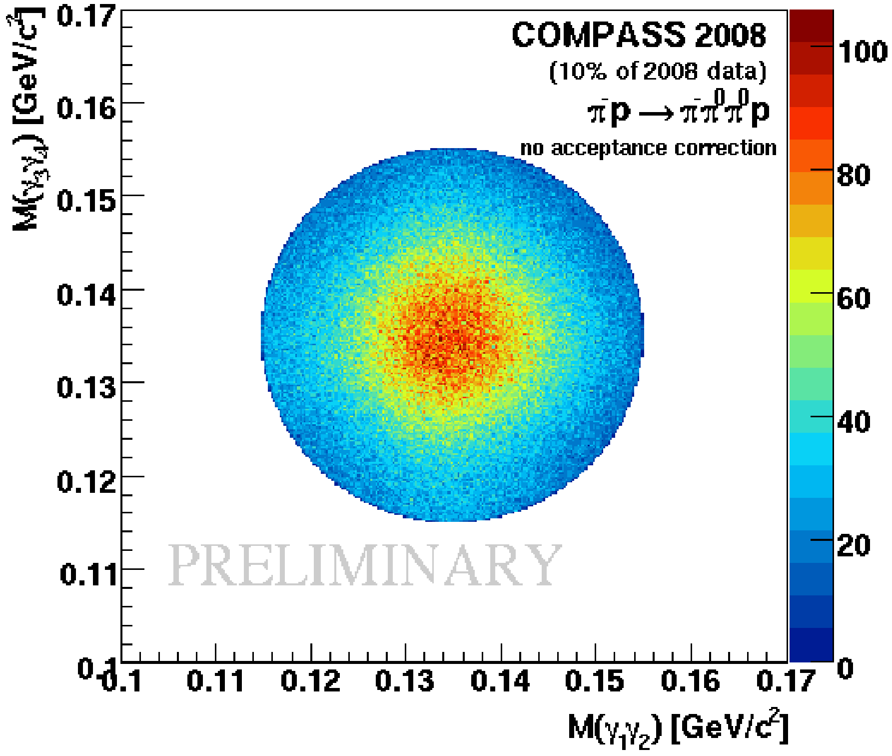
Fitted resonances (2004 data)



Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	Intensity (%)	Channel $J^{PC}M^{\epsilon}$[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

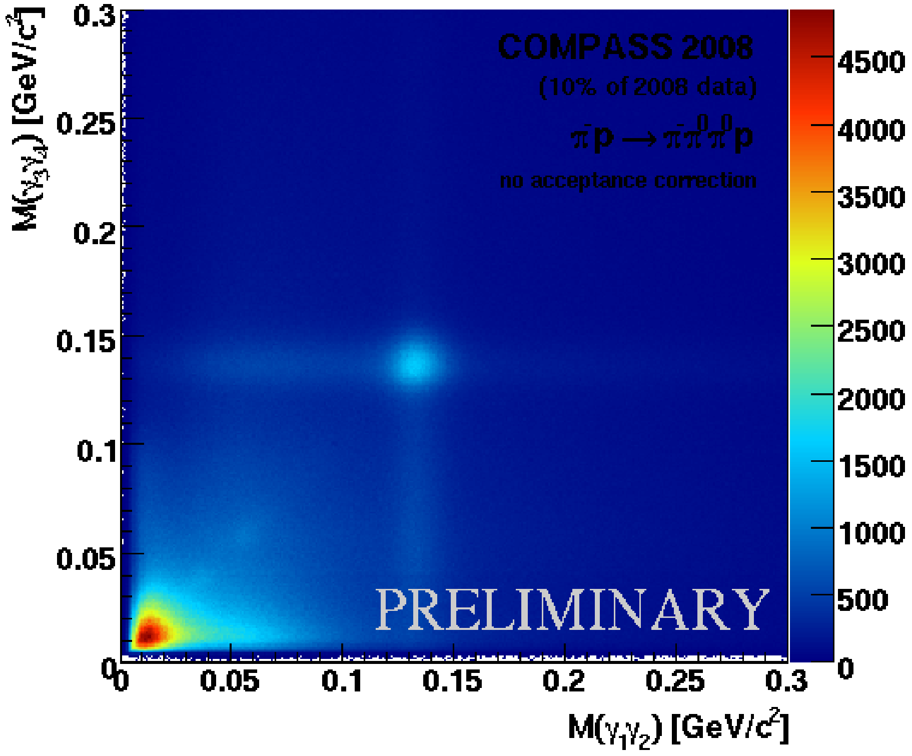
All & Preselected gg pairs, circular cut on PDG π^0 mass



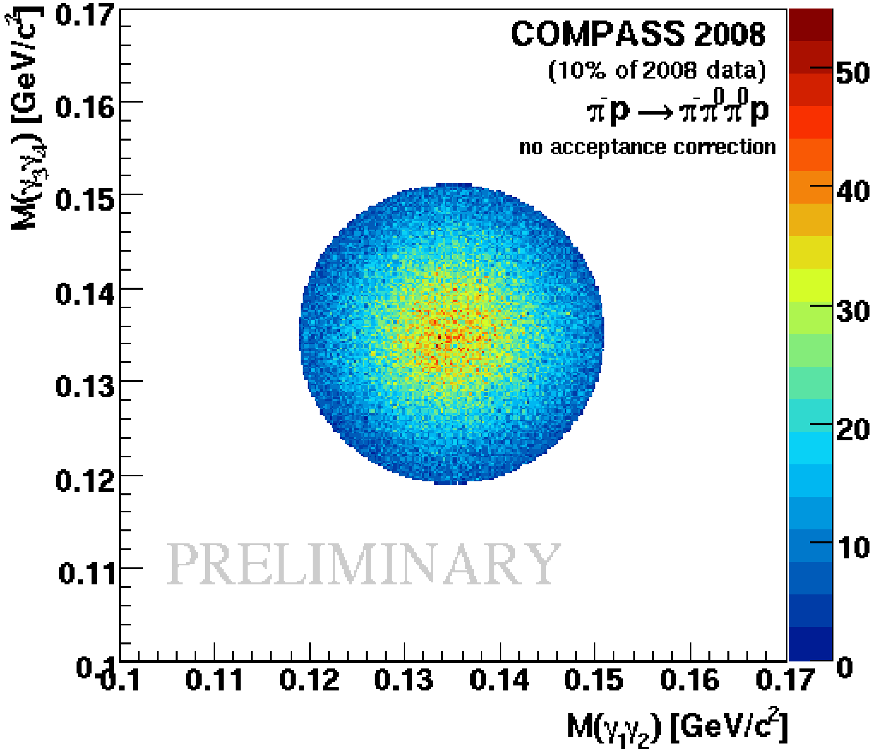


$2\pi^0$ evt := exactly 4 clusters, exactly one $2\pi^0$ combi within PDG +- 20 MeV

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

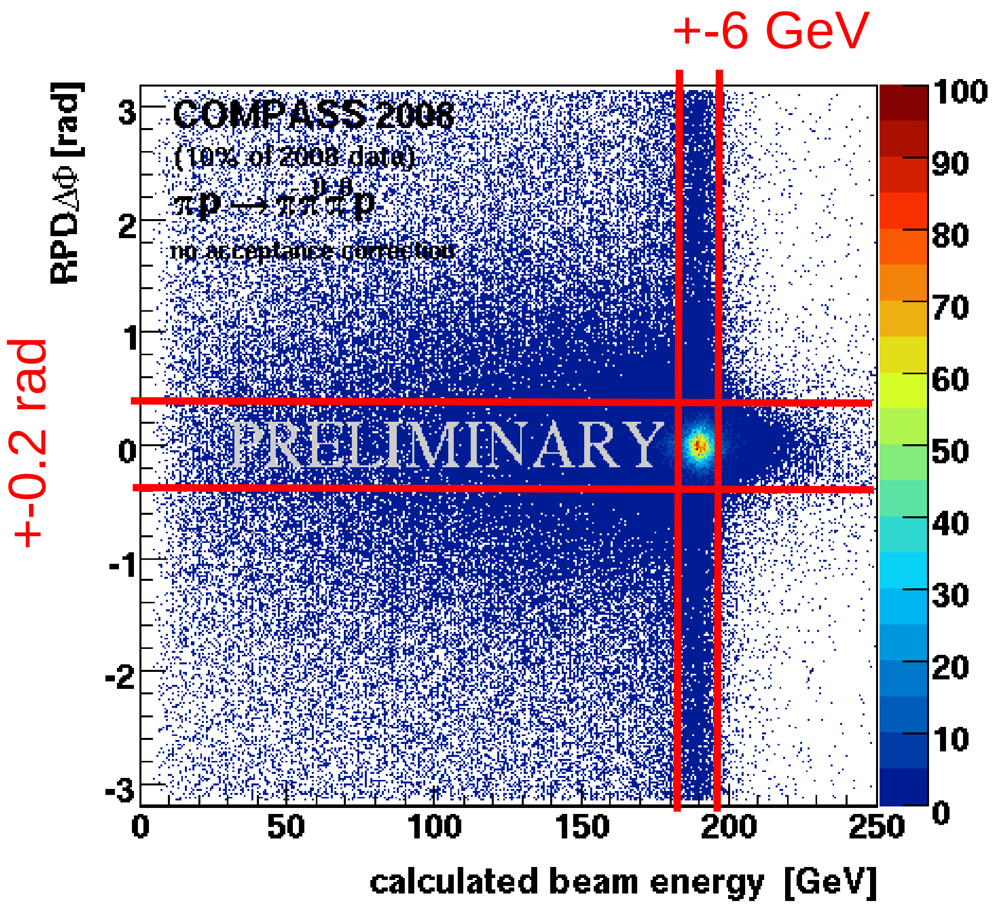


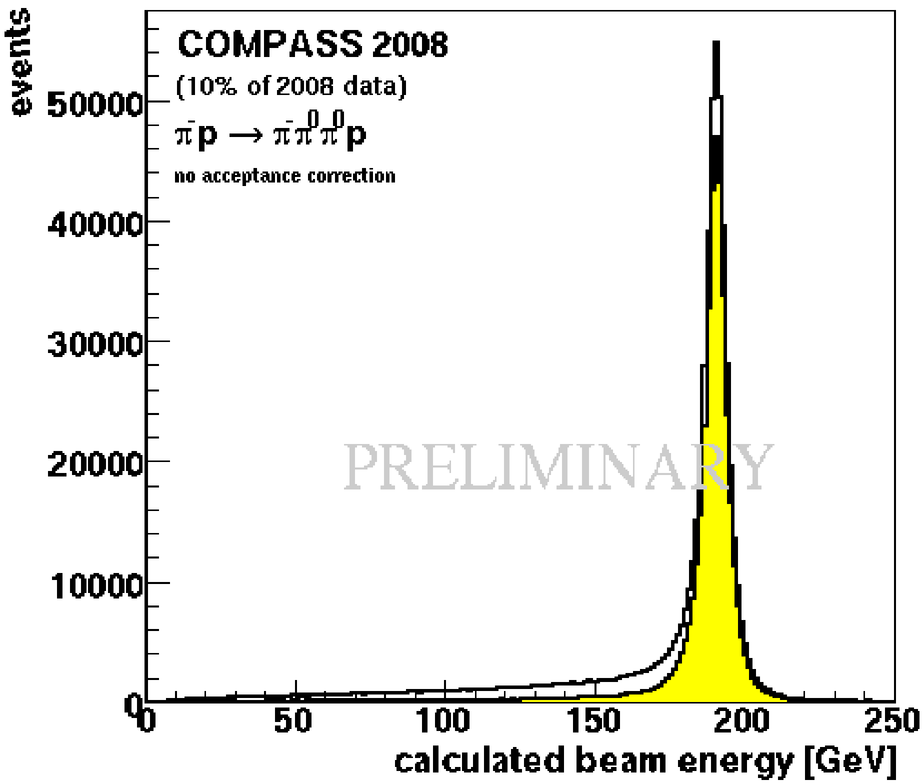
After final cuts on $\Delta\Phi$ and exclusivity, see next slides



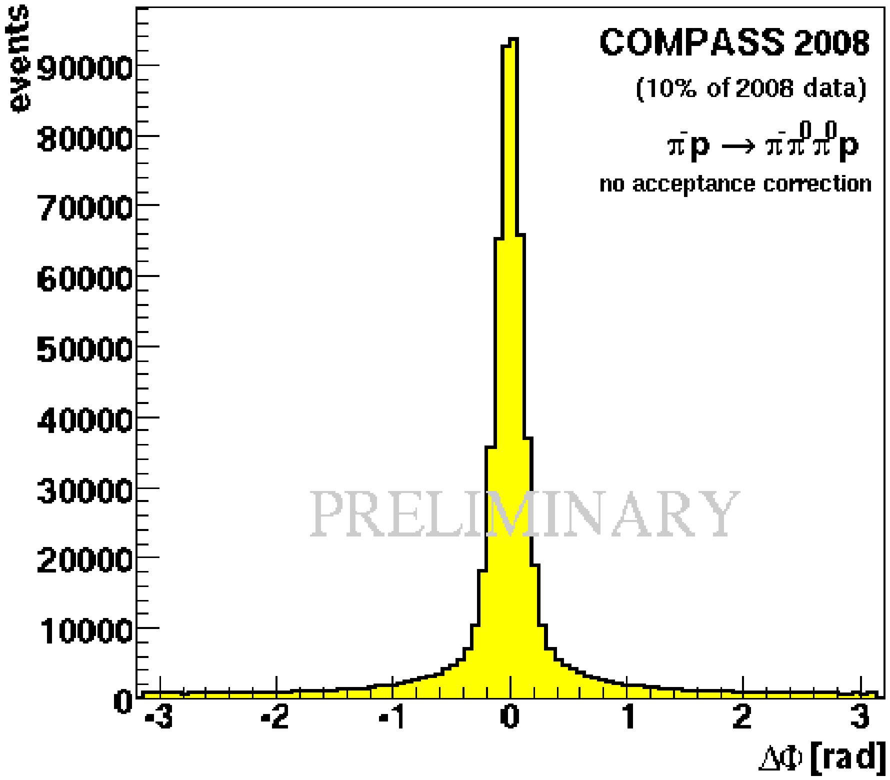
$2\pi^0$ evt := exactly 4 clusters, exactly one $2\pi^0$ combi within PDG +- 20 MeV

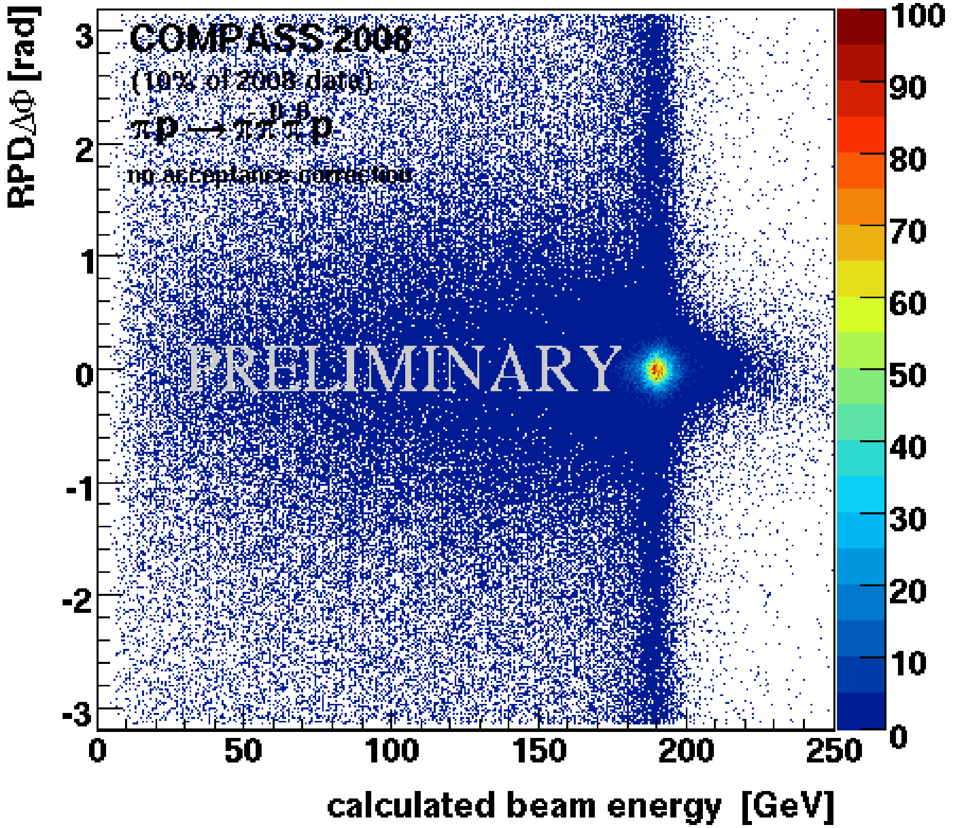
ΔΦ (RPD-Spectro) vs. E_{beam}



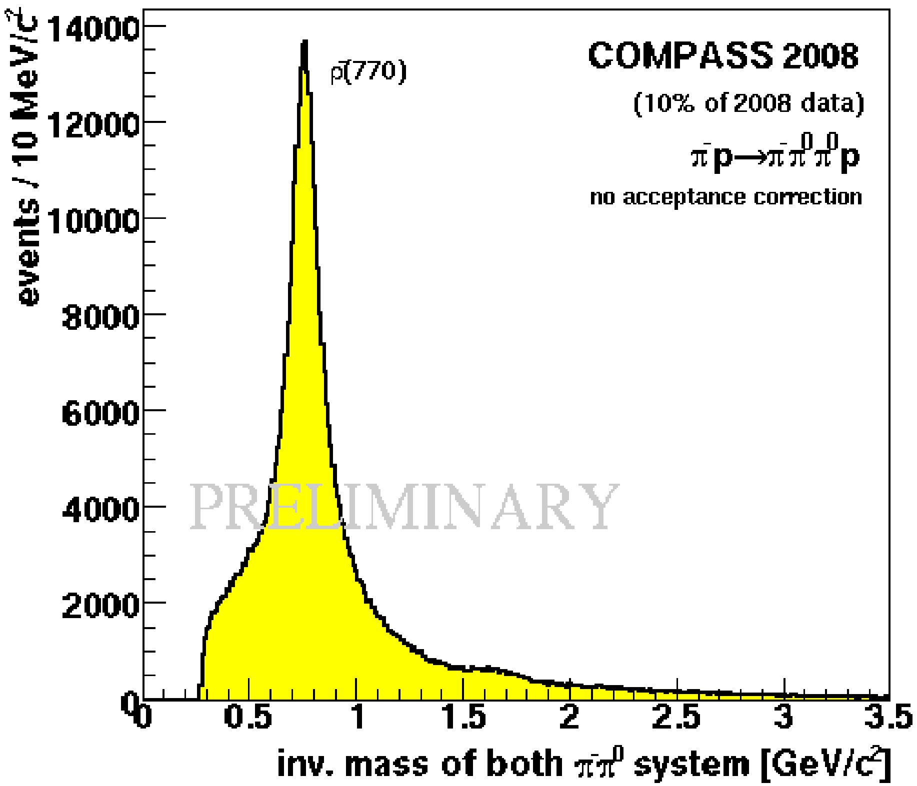


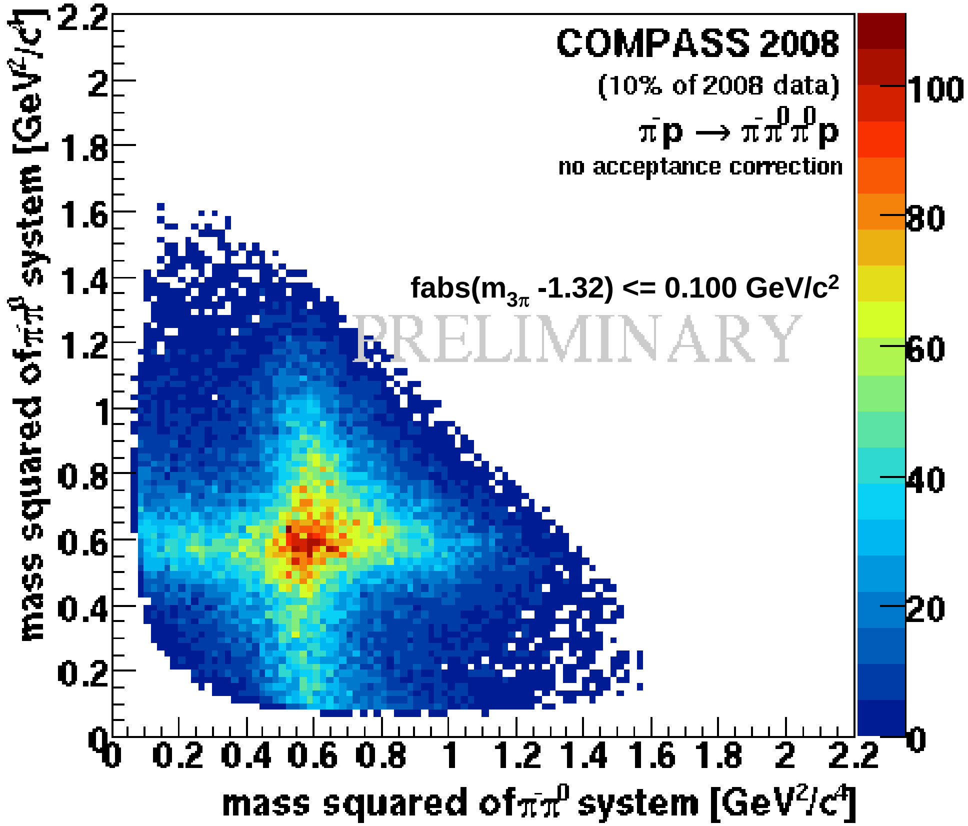
$\Delta\Phi$ (RPD-Spectro) vs. E_{beam}



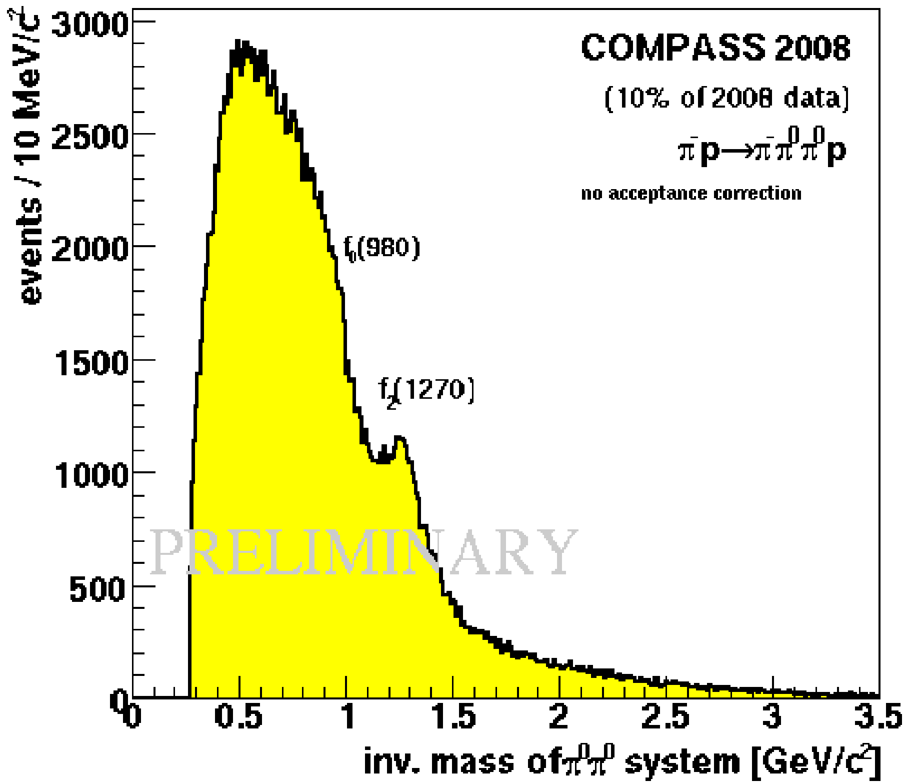


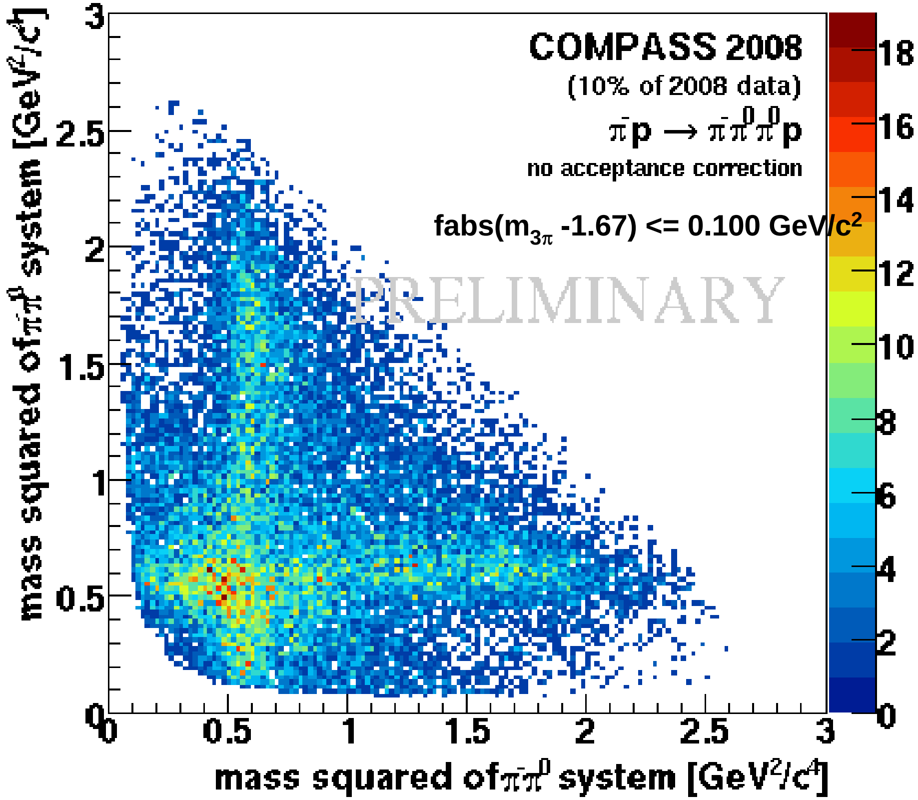
Mass spectrum of both $\pi^{-}\pi^{0}$ systems & Dalitz plot, a_2 region





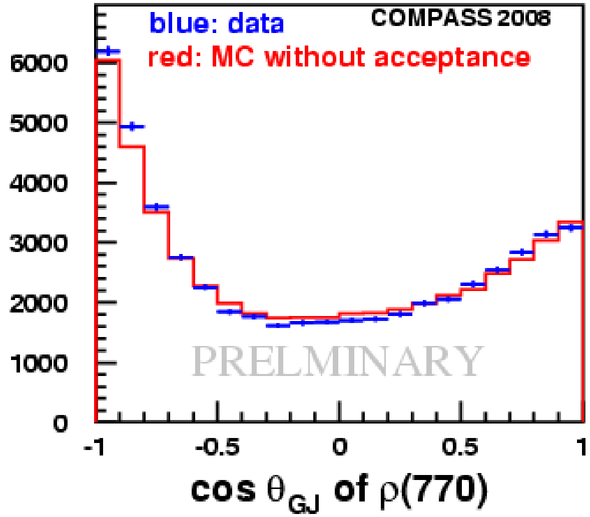
Dalitz plots: π_2 region

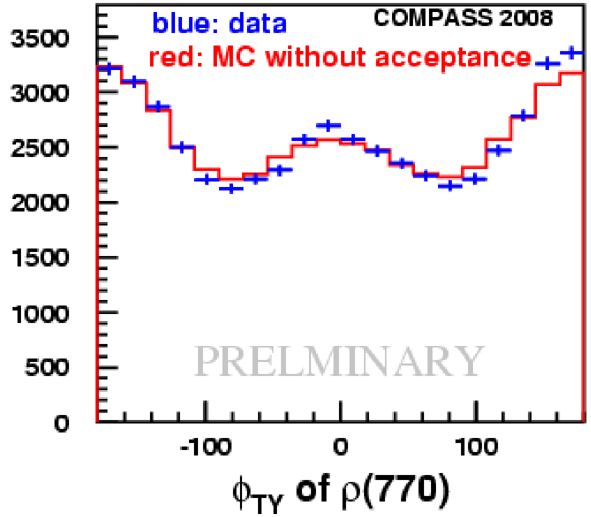




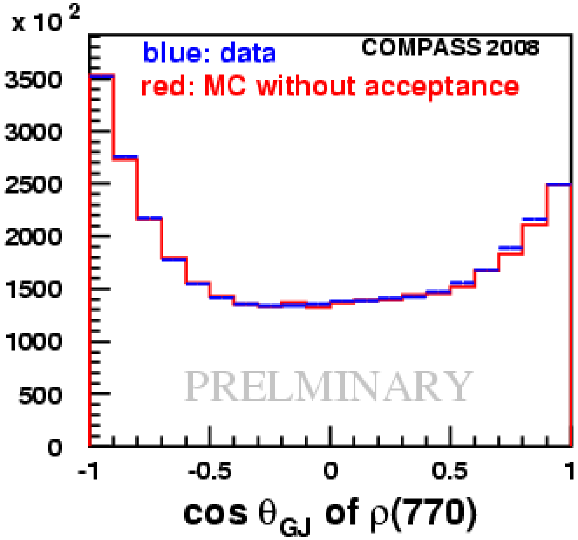
Decay angles in G.J. frame: Full PhaseSpace
Generated Prediction vs. fitted data

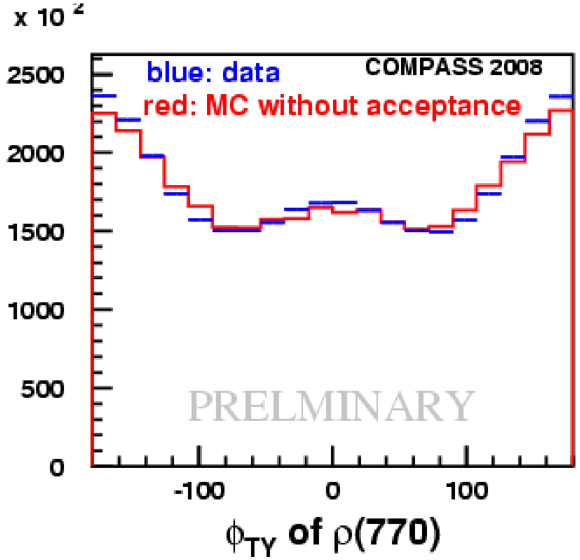
a1/a2 mass region - neutral
(1.22 - 1.38 GeV/c²)





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





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.