

Diffraction pion production at COMPASS – First results on 3π final states – neutral mode



Frank Nerling

Universität Freiburg, Physikalisches Institut

on behalf of the
COMPASS Collaboration

*Hadron 2009, XIII Intern. Conf. on Hadron Spectroscopy,
Nov 29th – Dec 4th 2009, Florida State University*

Outline:

- The COMPASS experiment:
- Diffractive dissociation into 3π final states
- First look into 3π neutral mode
 - Event selection
 - First PWA fits, main waves



bmb+f - Förderschwerpunkt

COMPASS

Großgeräte der physikalischen
Grundlagenforschung



The COMPASS experiment



COmmun **M**uon **P**roton **A**pparatus for **S**tructure and **S**pectroscopy
(~270 physicists, 25 institutes, 12 countries)

a) Nucleon spin structure:

- **polarised muon beam** (160 GeV/c μ^+)
- data taken 2002-04, 2006/07

Target
(different kind)

muon or
hadron beam

b) Nucleon & meson spectroscopy:

- Diffractive production
- Central production
- Primakoff
- **Hadron beams** (190 GeV/c π^-, K^-)

Hadron run in 2008 & 2009 (after pilot run in 2004)



The COMPASS experiment



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a) Nucleon spin structure:

- **polarised muon beam** (160 GeV/c μ^+)
- **data taken 2002-04, 2006/07**

→ see 3D

Target
(different kind)

muon or
iron beam

b) Nucleon & meson spectroscopy:

- **Diffractive production**
- **Central production** → see 7D,8C
- **Primakoff** → see 6D
- **Hadron beams** (190 GeV/c π^-, K^-)

[hep-ex/0703049, NIM A 577, 455 (2007)]

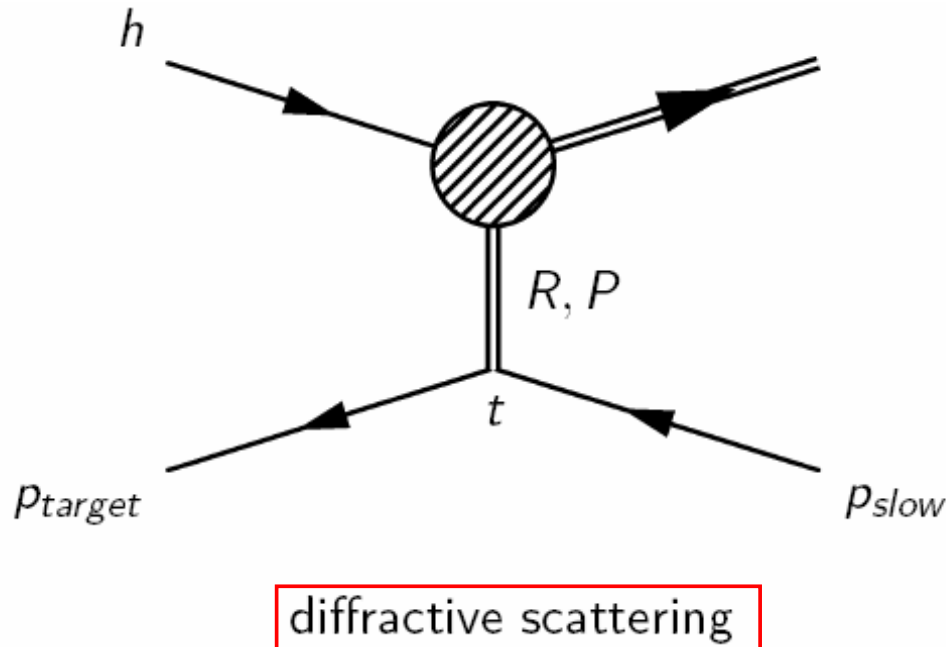
Hadron run in 2008 & 2009 (after pilot run in 2004)



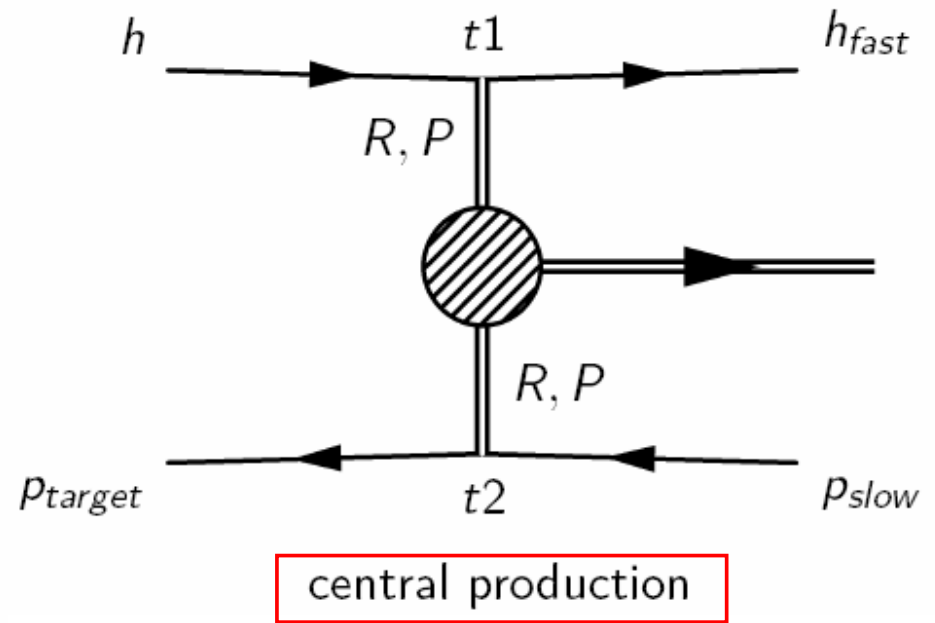
COMPASS Hadron spectroscopy



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



- large rapidity gap between p_{slow} , h_{fast} , X
- possible source of glueballs



Light meson sector ($< 2.2 \text{ GeV}/c^2$):

exotics $J^{PC} = 1^{--}$

- $\pi_1(1400)$: VES, E852, Crystal Barrel
- $\pi_1(1600)$: E852, VES

.... still controversial \rightarrow COMPASS

Also: **photo-production**, e.g.
 $\mu p \rightarrow \mu p_{\text{slow}} + X^0$



COMPASS Hadron spectroscopy

-- Diffractive pion dissociation

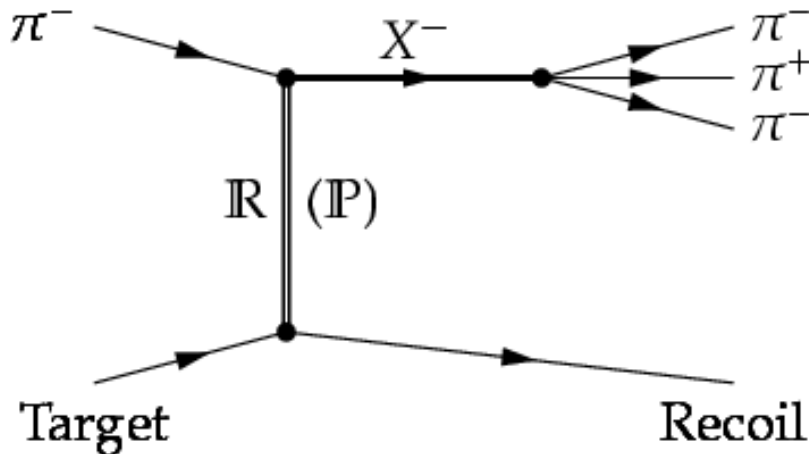


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Diffr. pion dissociation:

- incoming π^- excited to resonance X^-
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 $\pi^- p \rightarrow \pi^- \pi^+ \pi^- p$ (charged mode)



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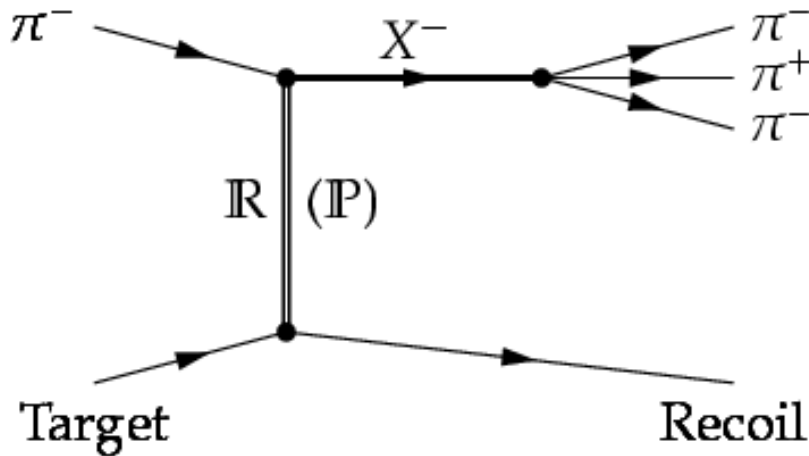


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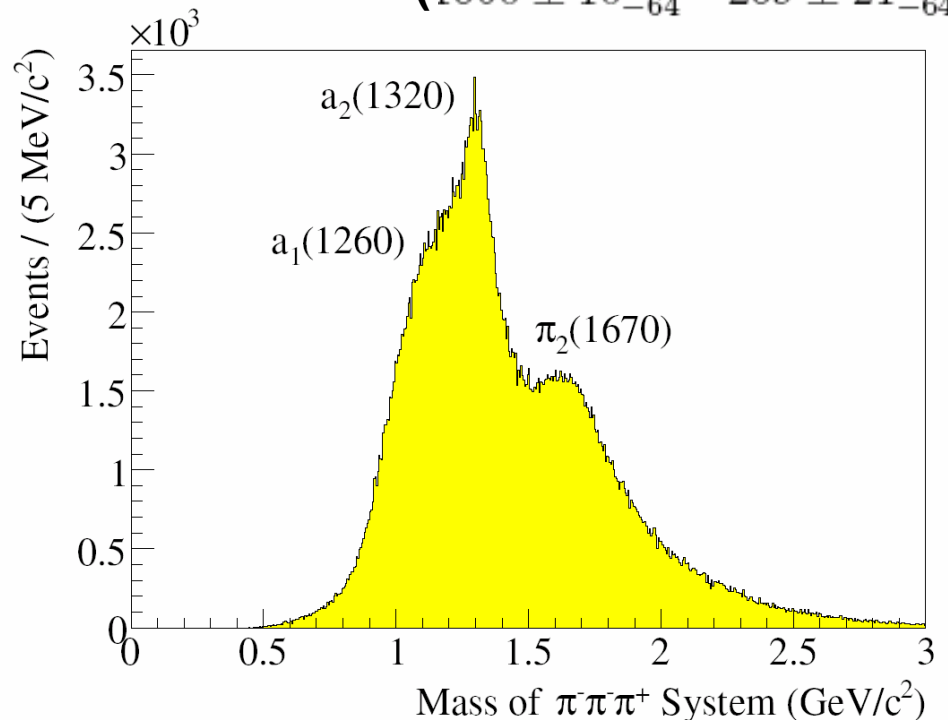
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Submitted to Phys.Rev.Let:

J^{PC} exotic $\pi_1(1600)$ evidence in **2004 data (Pb)**:
 $(1660 \pm 10_{-64}^{+0} \quad 269 \pm 21_{-64}^{+42})$



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COMPASS Hadron spectroscopy

-- Diffractive pion dissociation

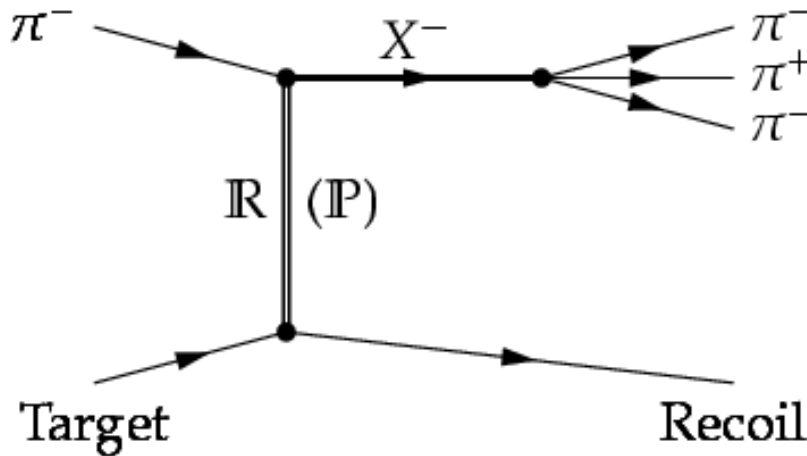


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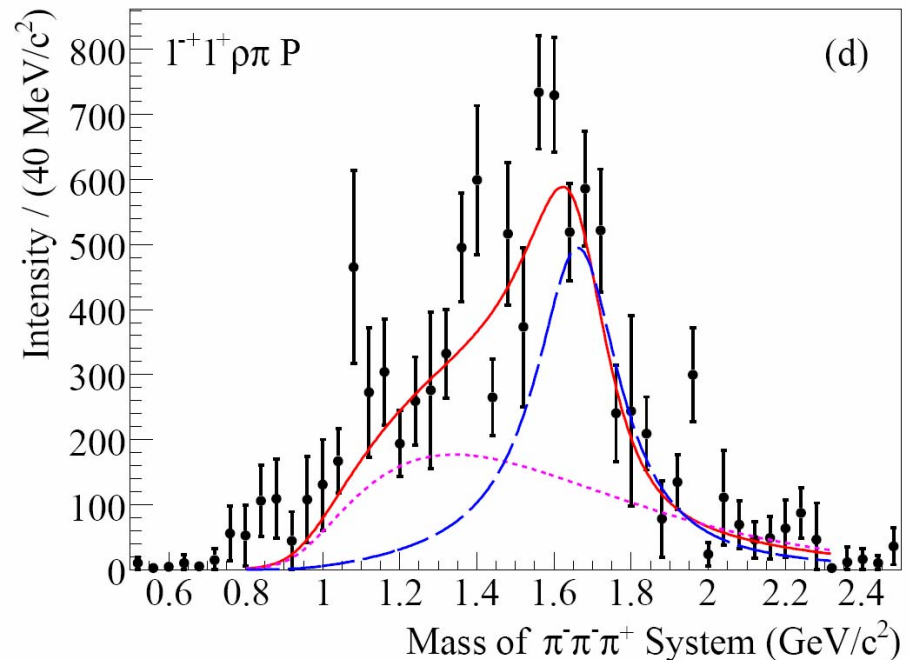
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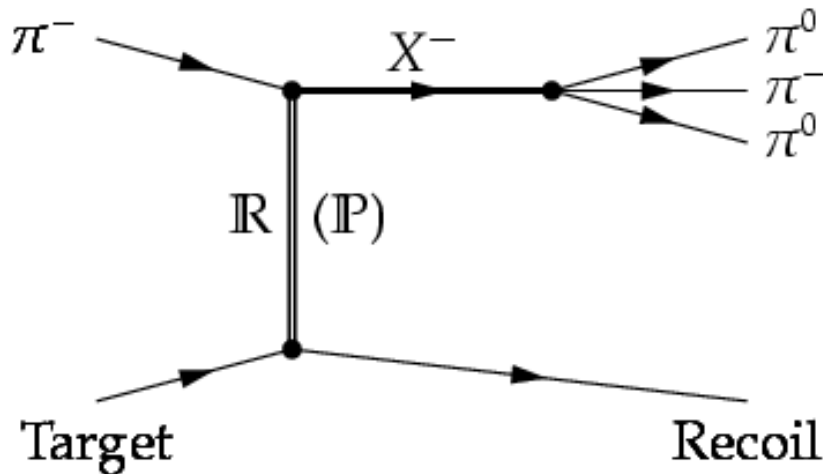
COMPASS Hadron spectroscopy

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- X^- decays into final state, e.g. $(3\pi)^-$:
 $\pi^- p \rightarrow \pi^- \pi^+ \pi^- p$ (charged mode)
 $\pi^- p \rightarrow \pi^- \pi^0 \pi^0 p$ (neutral mode)

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.... still controversial \rightarrow **COMPASS**

- Analysis of **2008 data** started (p-target)
- **Simultaneous observation in neutral mode**
 \rightarrow independent measurement (*same apparatus*)
 \Rightarrow important cross check (*understand acceptance*)

1st look into neutral mode (*main waves, isospin sym.*)

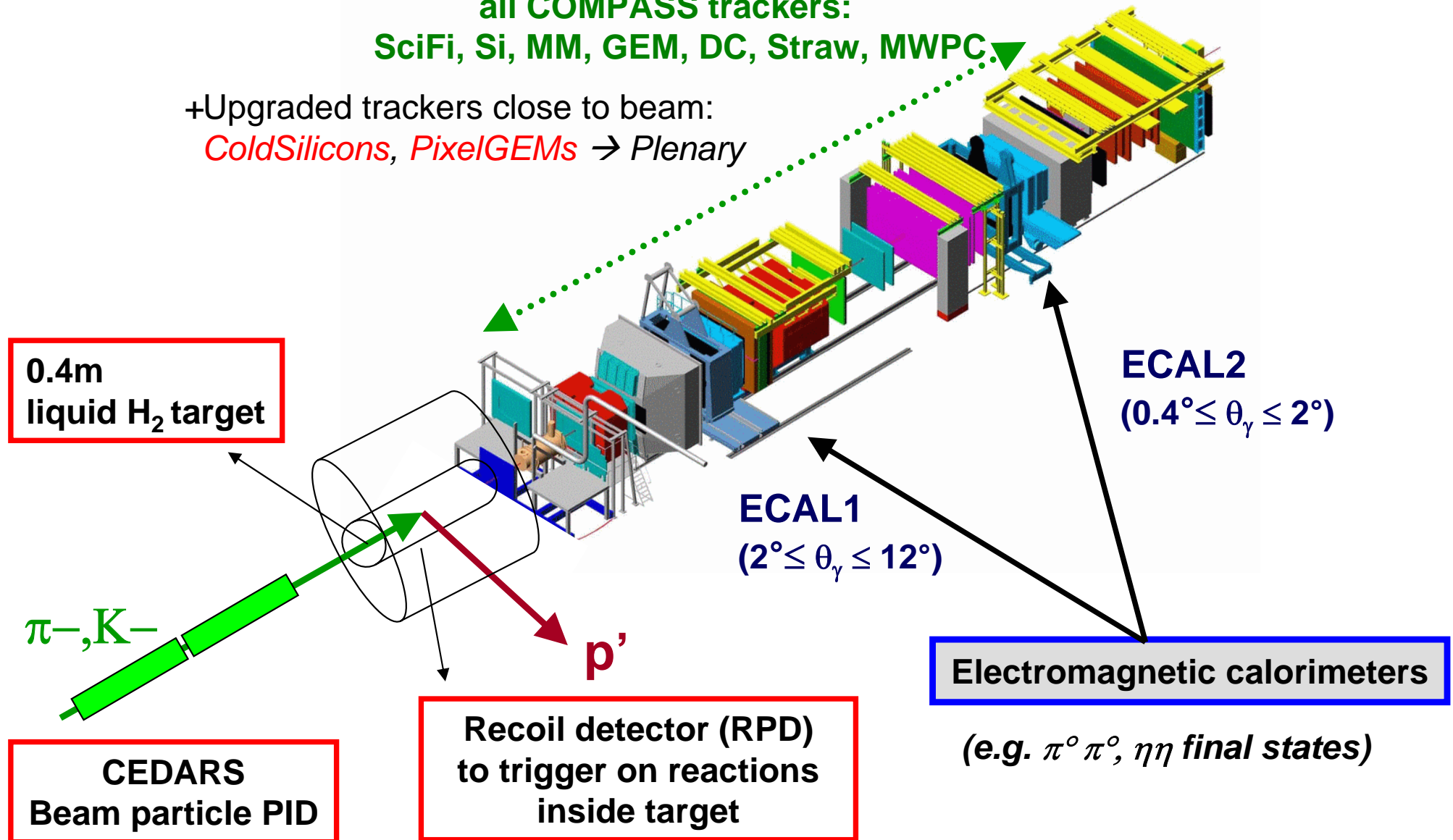


COMPASS spectrometer: Hadron setup 2008/09



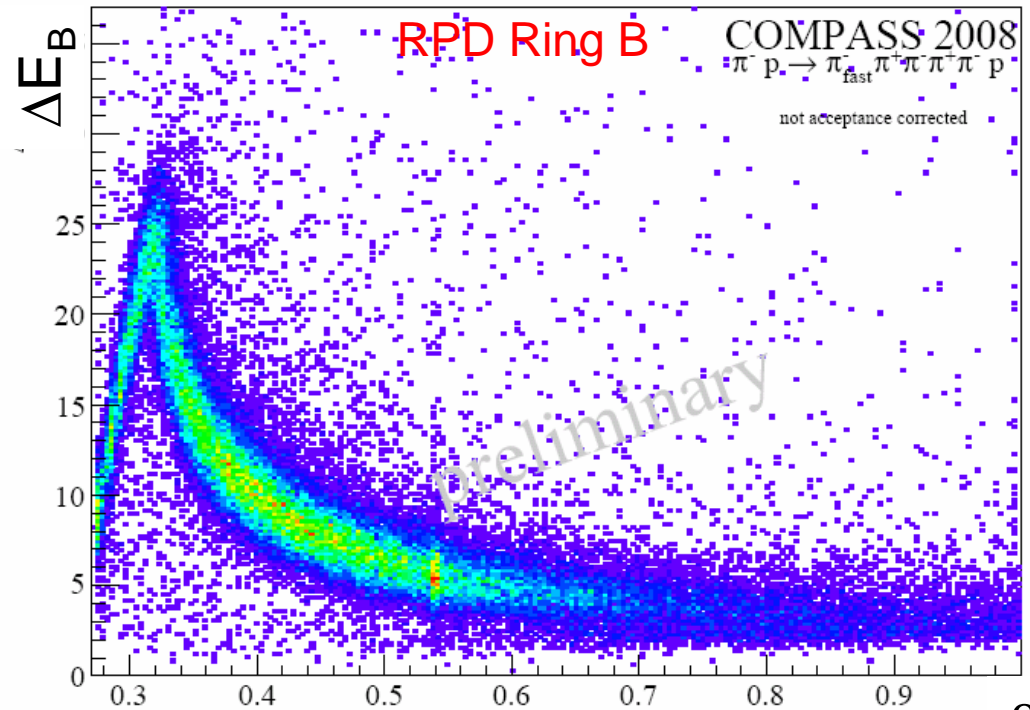
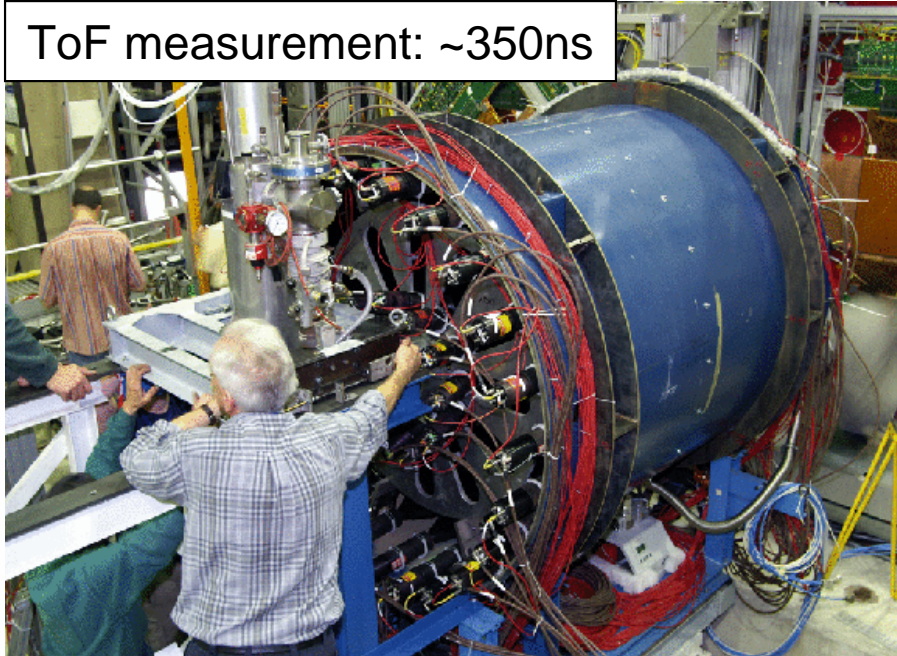
all COMPASS trackers:
SciFi, Si, MM, GEM, DC, Straw, MWPC.

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



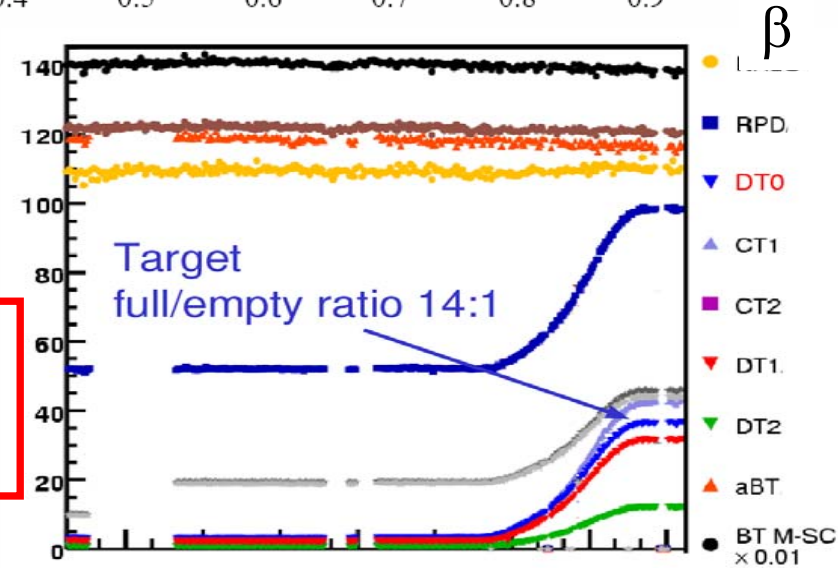


COMPASS spectrometer: Hadron setup 2008/09



Diffractive Trigger = BT \wedge RPD \wedge !Veto

Recoil detector (RPD) to trigger on reactions inside target

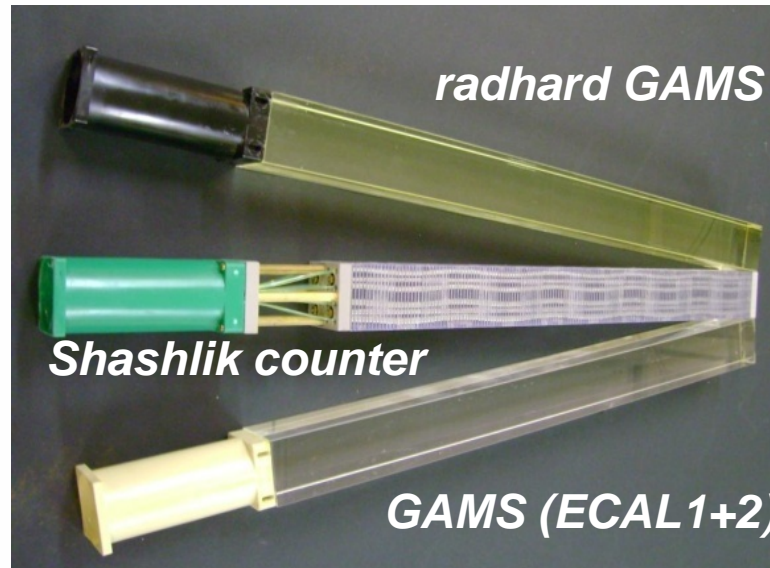
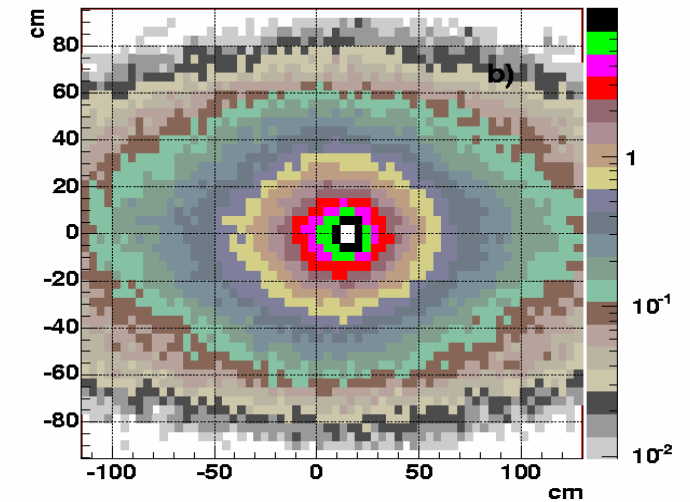




COMPASS spectrometer: Hadron setup 2008/09



Radiation doses deposited in the ECAL2



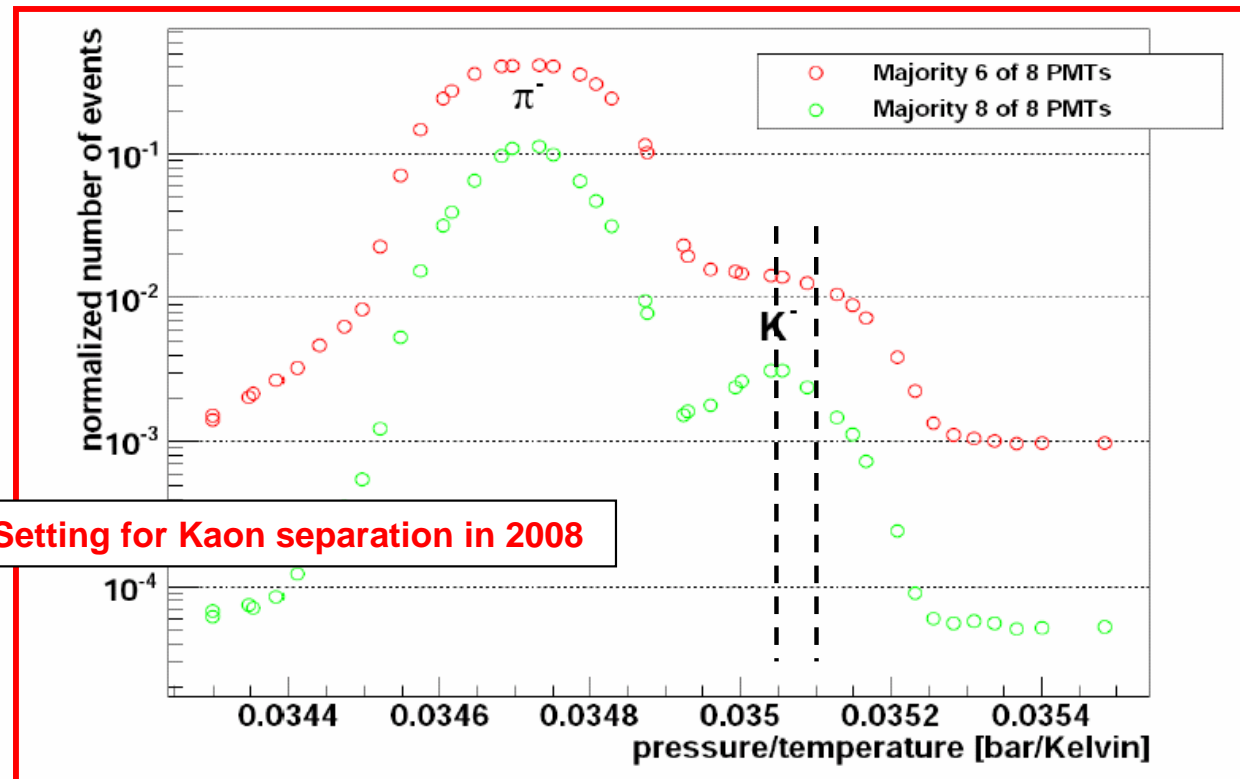
Electromagnetic calorimeters

ECAL2:

- rad. hard shashlik counter
- 10bit SADC \rightarrow 12bit MSADC
- DSP \rightarrow timing info



COMPASS spectrometer: Hadron setup 2008/09



**CEDARS
Beam particle PID**



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 $m_{\pi^0}(\text{PDG}) \pm 20 \text{ MeV}$	9.15084×10^5	0.13
exactly one $2\pi^0$ combination within $m_{\pi^0}(\text{PDG}) \pm 20 \text{ MeV}$	8.99705×10^5	0.13

Table 1: Remaining statistics after cuts - Preselection.

Type of cut applied	Nb of events	Remaining [%]
All events - preselected	8.99705×10^5	100.00
$E_{\pi^-} < 185 \text{ GeV}/c^2$	8.20096×10^5	91.15
RPDtracks==1 && $p_{\text{recoil}} > 250 \text{ MeV}$	5.85308×10^5	65.06
$\Delta\Phi < 0.2$	3.95250×10^5	43.93
Tightened cut on π^0 mass ($m_{\pi^0}(\text{PDG}) \pm 16 \text{ MeV}$)	3.25001×10^5	36.12
Exclusivity $\pm 6 \text{ GeV}$	2.41406×10^5	26.83
CEDAR Veto on Kaons	2.39511×10^5	26.62

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



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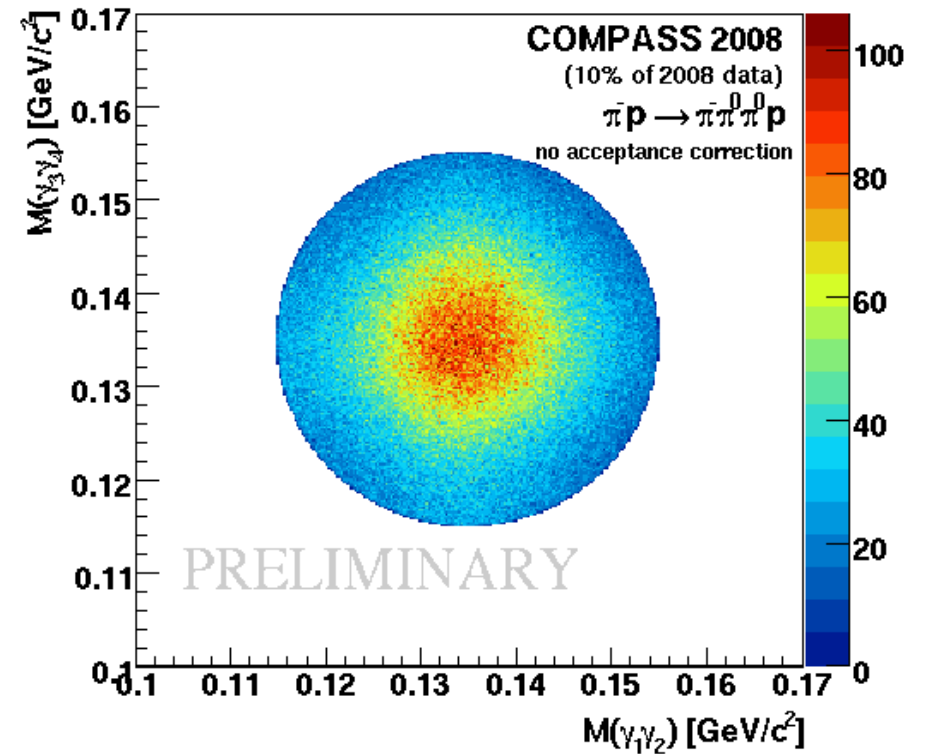
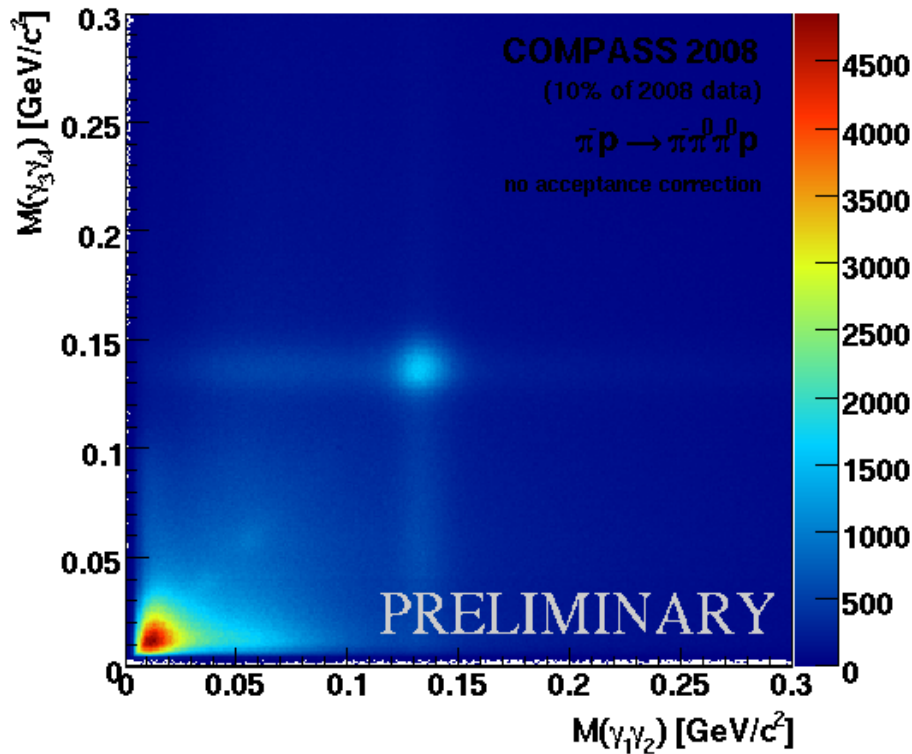
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Main cuts for exclusive events:
 \Rightarrow in terms of sigma ($\pm 2\sigma$)

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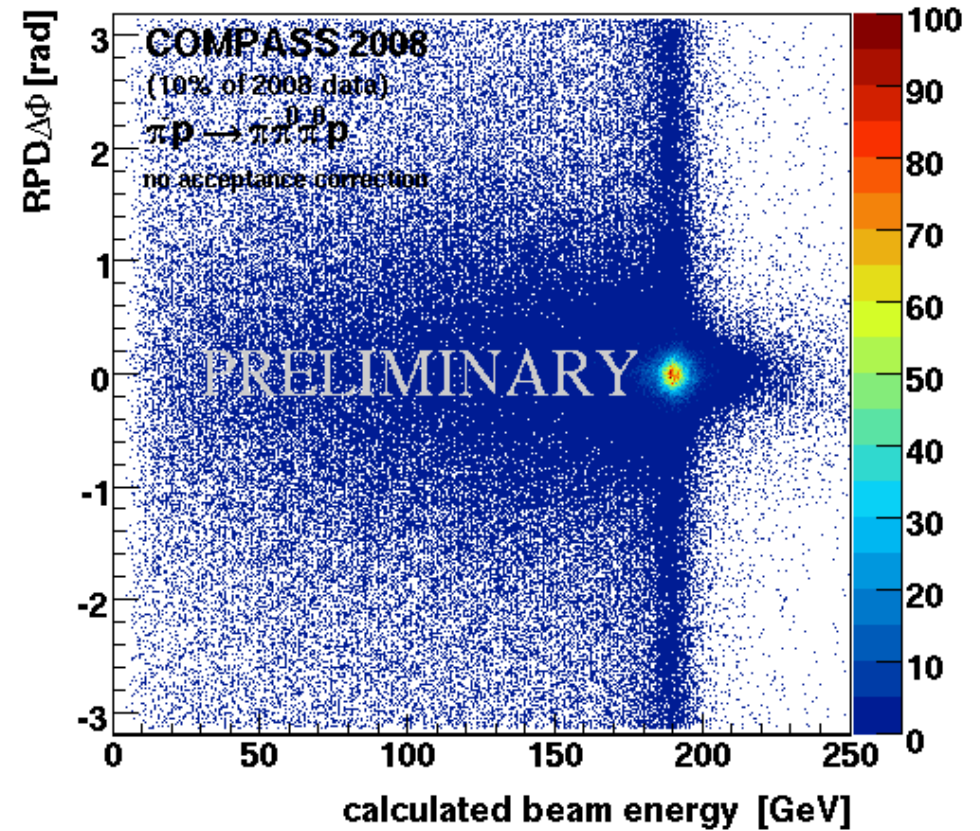
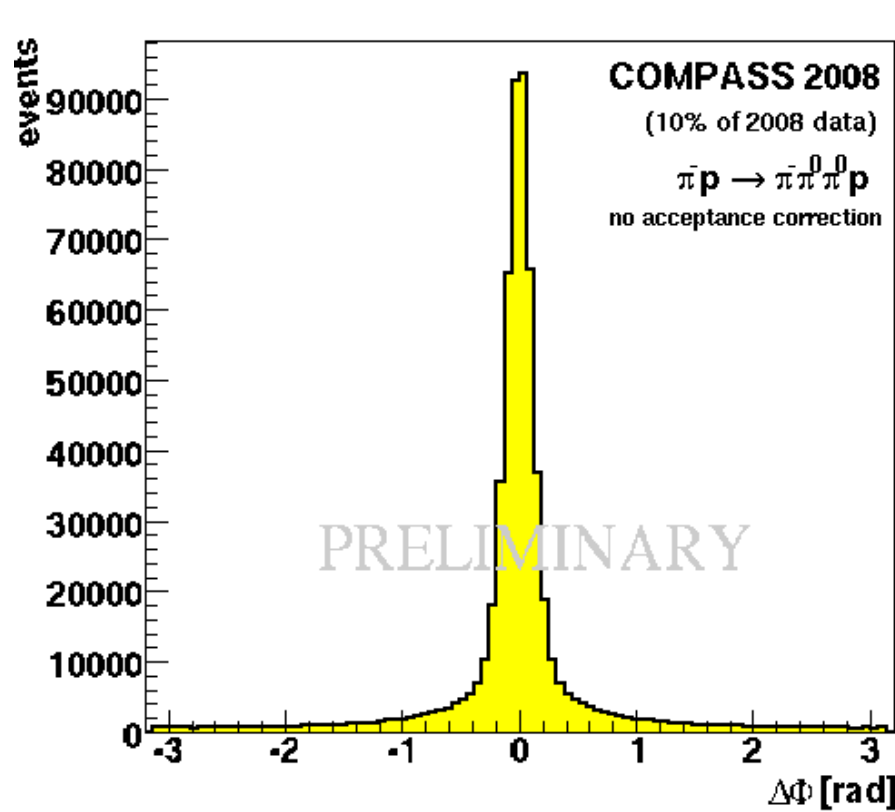
All & Preselected gg pairs, circular cut on PDG π^0 mass



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

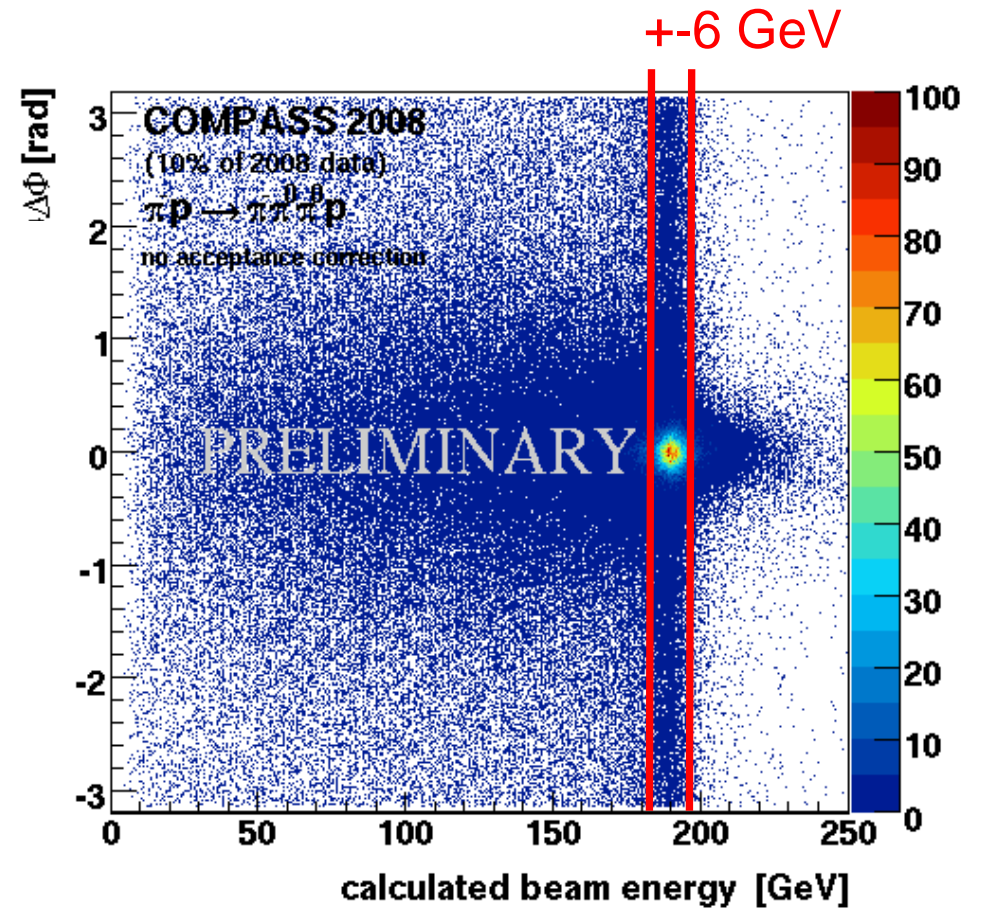
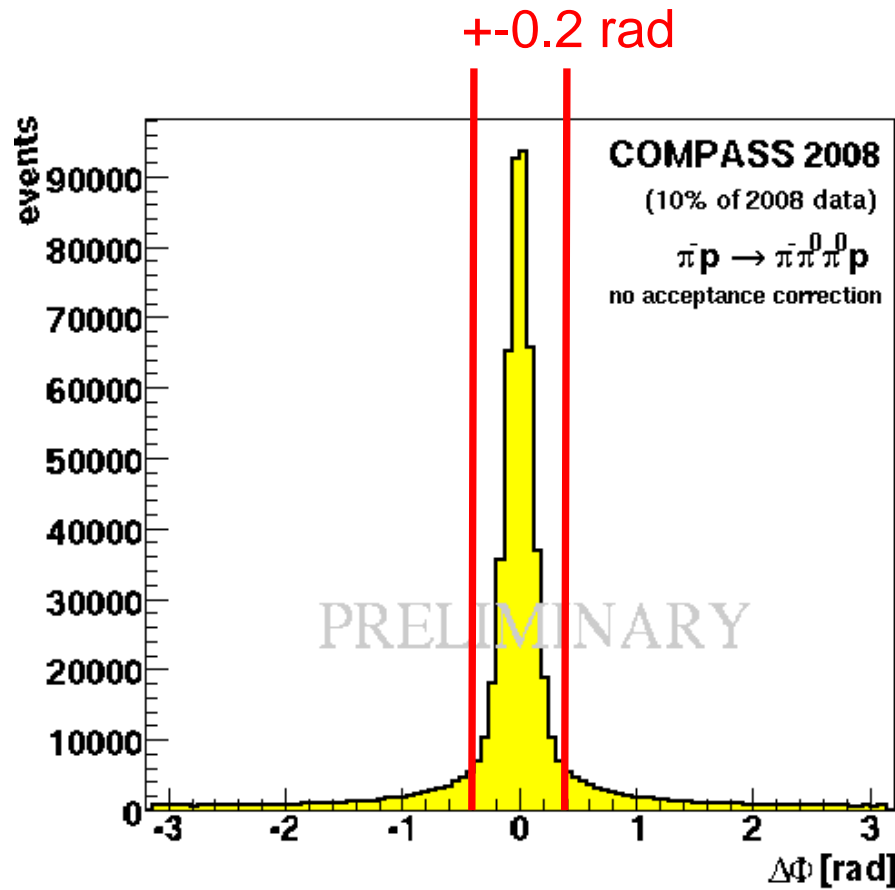


$\Delta\Phi$ (RPD-Spectro) vs. E_{beam}





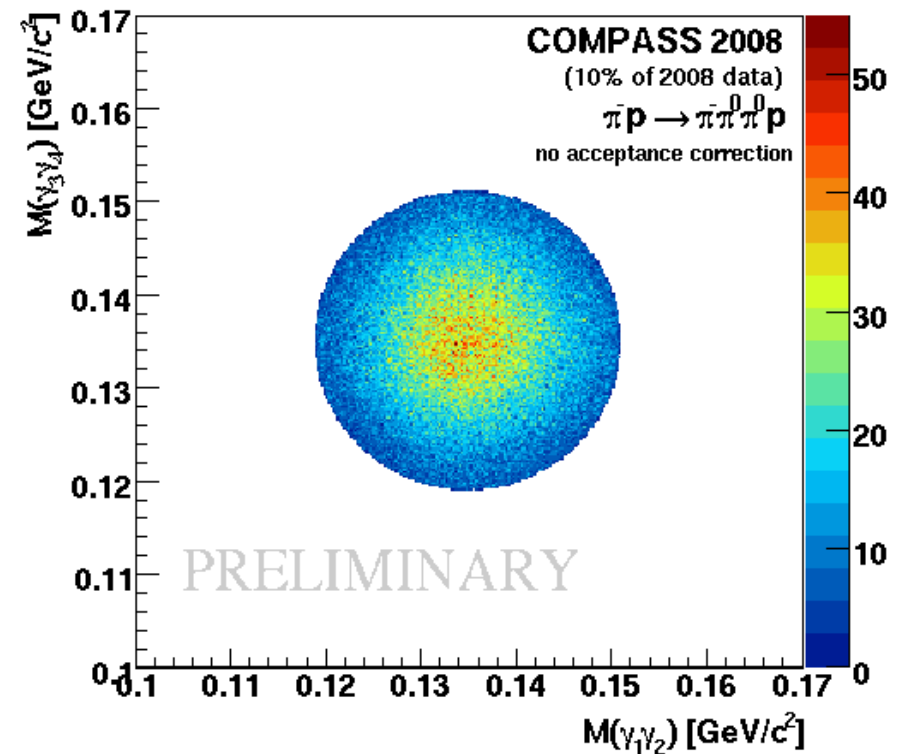
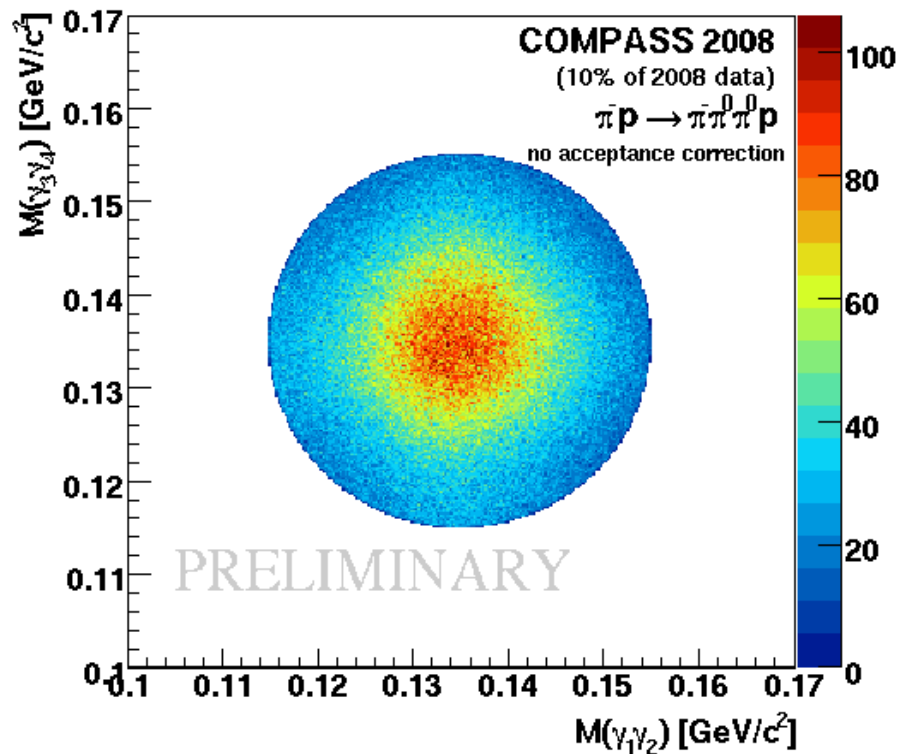
$\Delta\Phi$ (RPD-Spectro) vs. E_{beam}





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

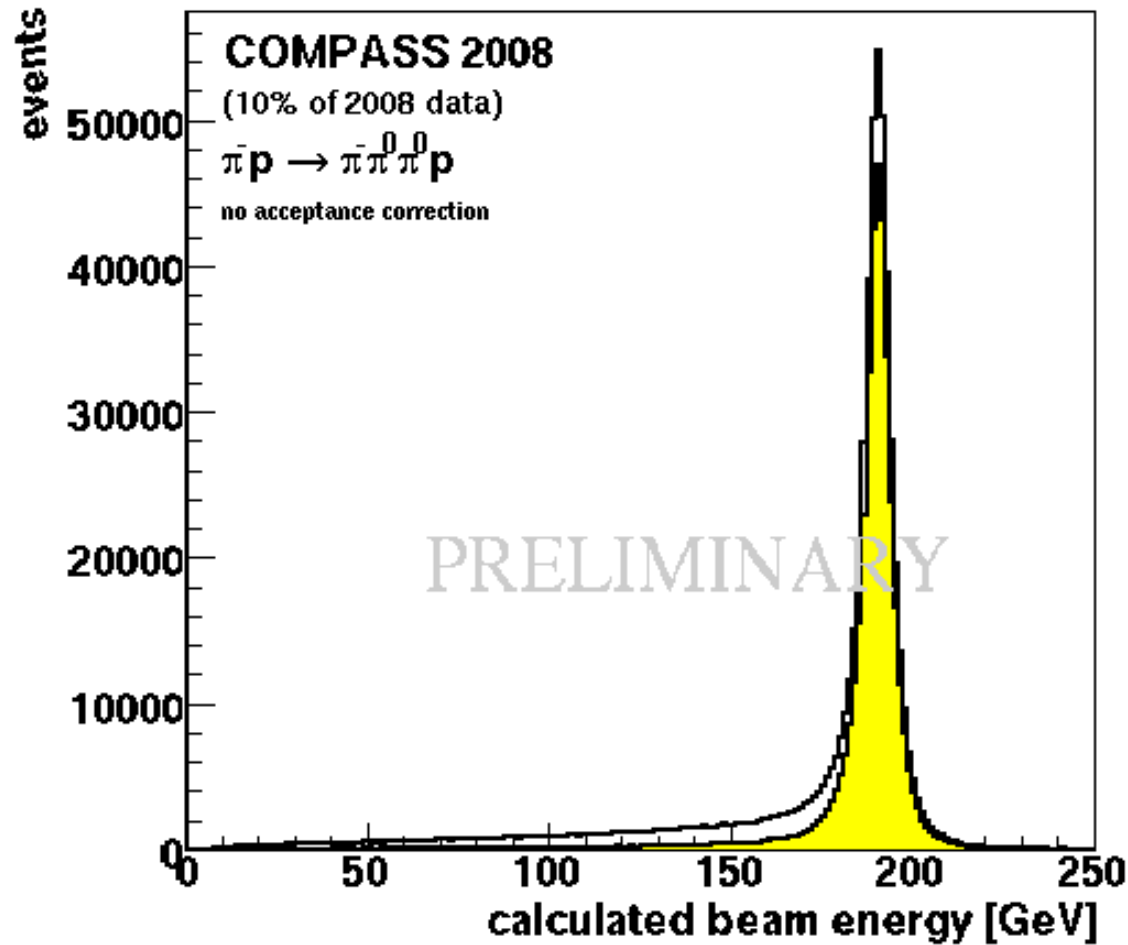
After final cuts on $\Delta\Phi$ and exclusivity



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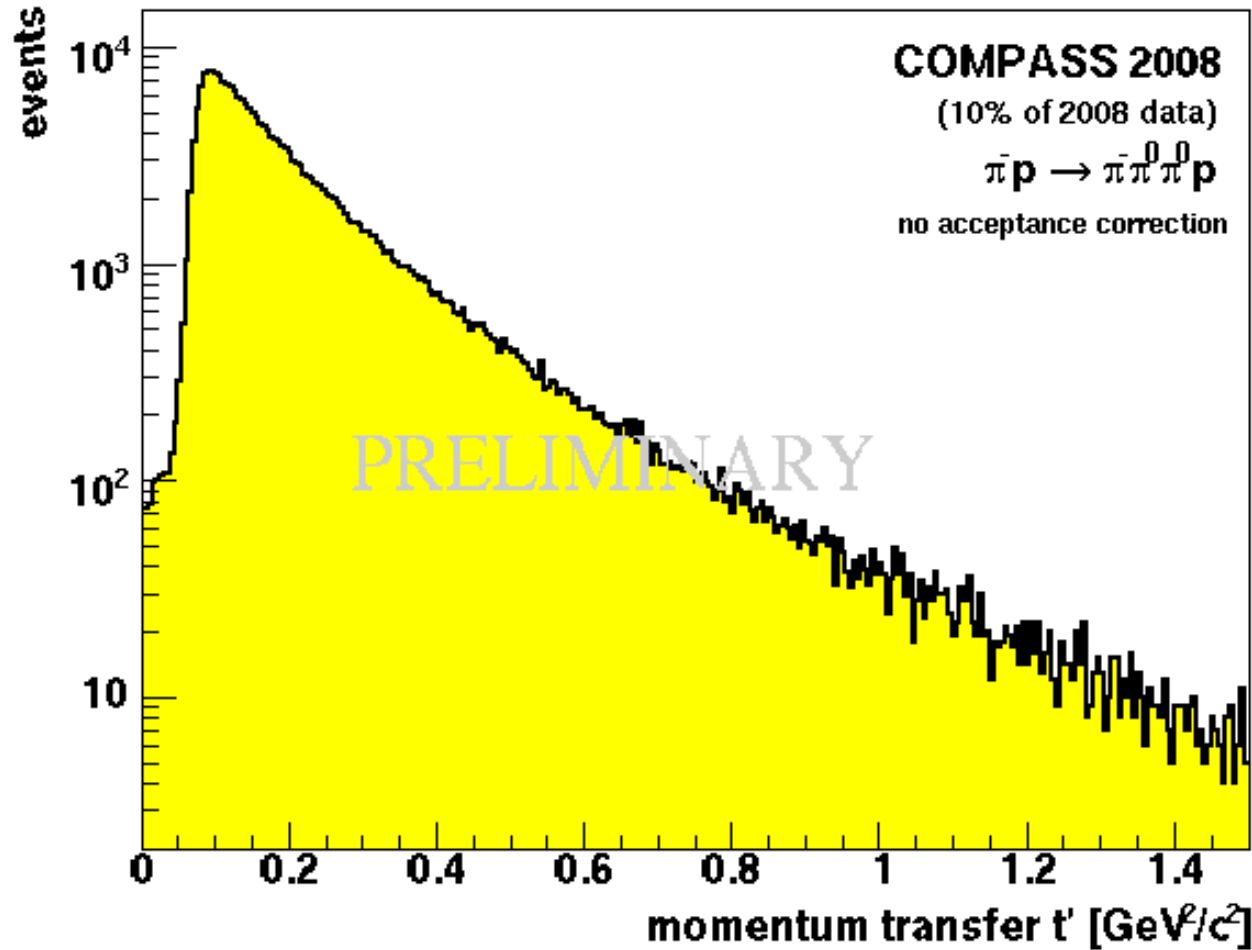


Exclusivity w/wo $\Delta\Phi$ (RPD-Spectro) cut



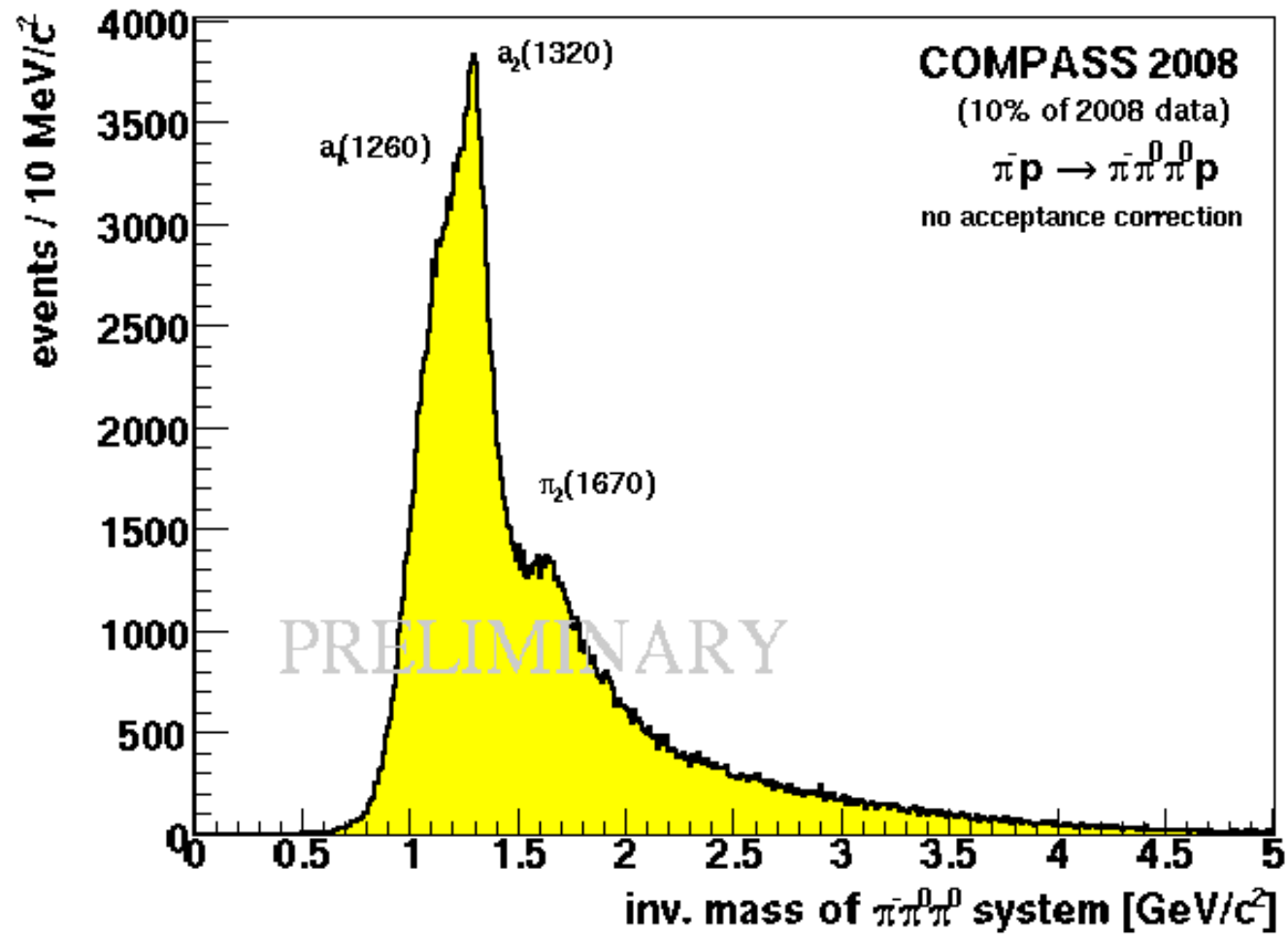


t' distribution



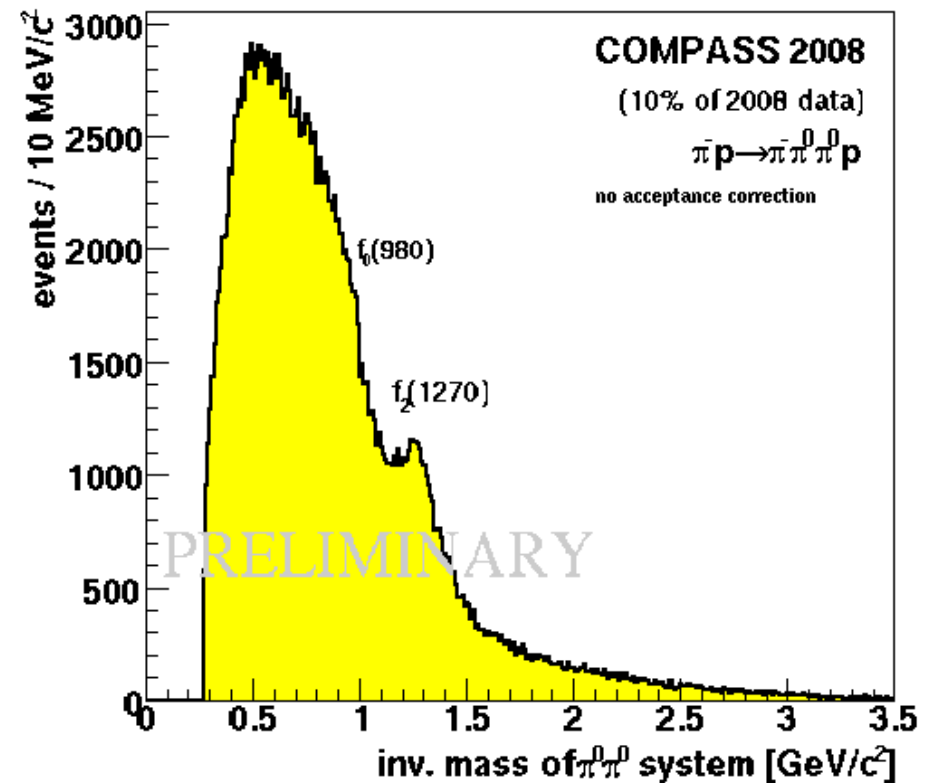
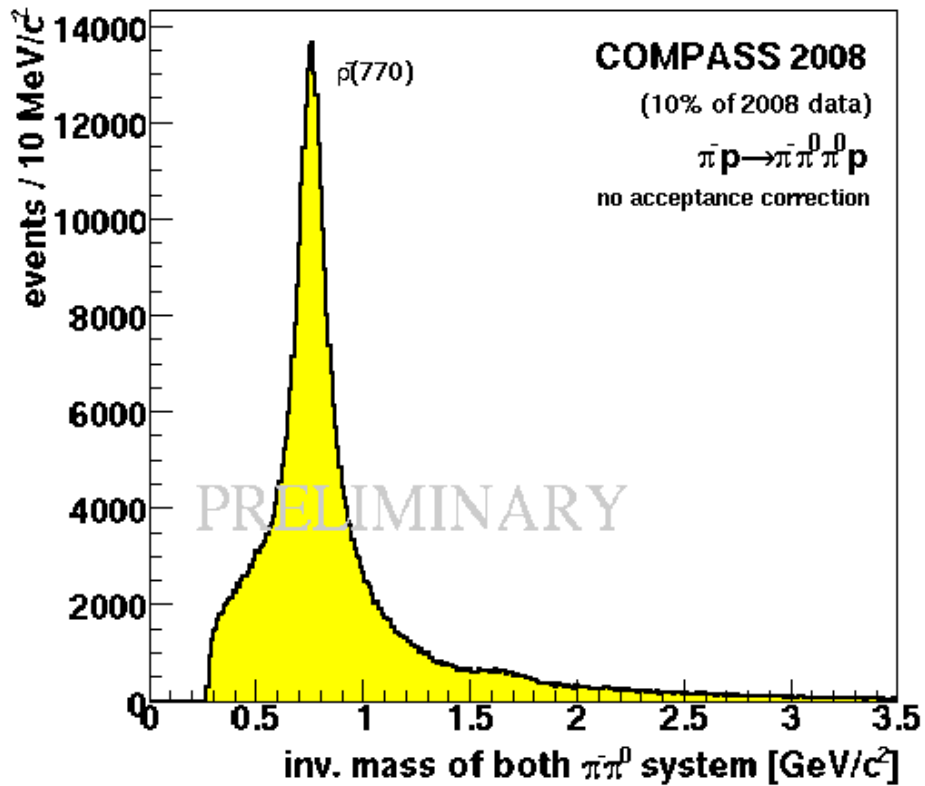


Mass spectrum of $\pi^-\pi^0\pi^0$ final state



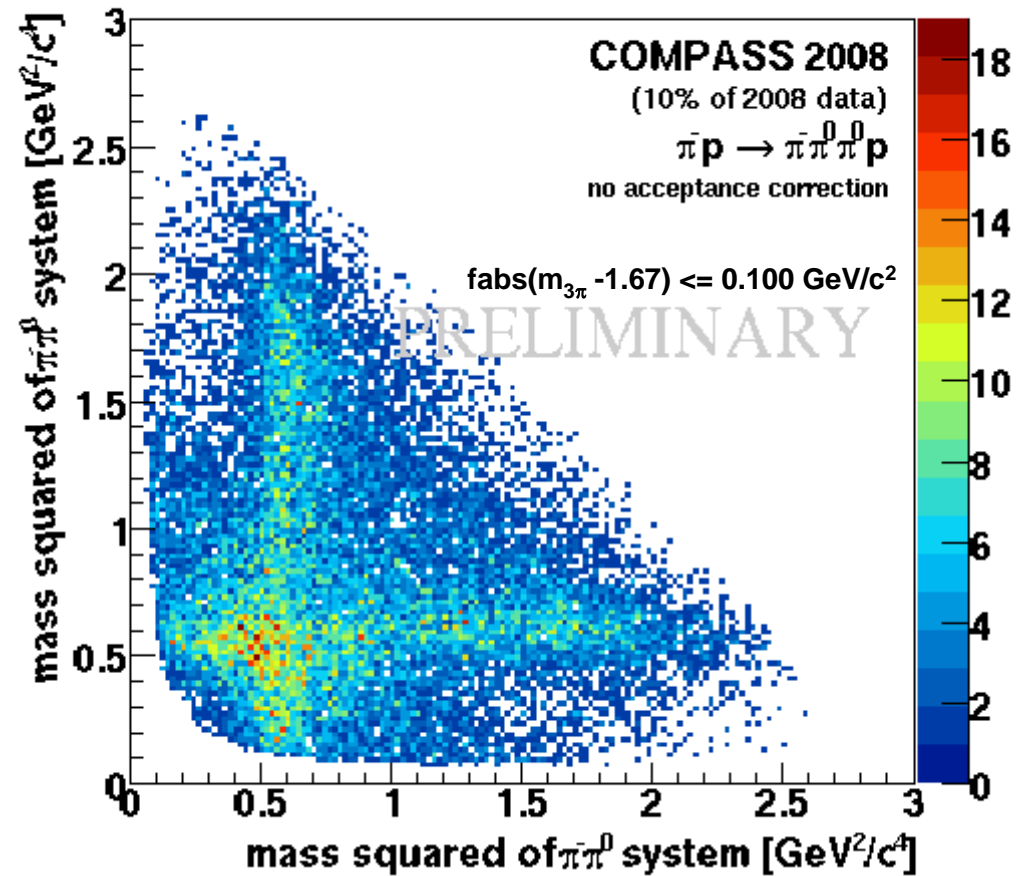
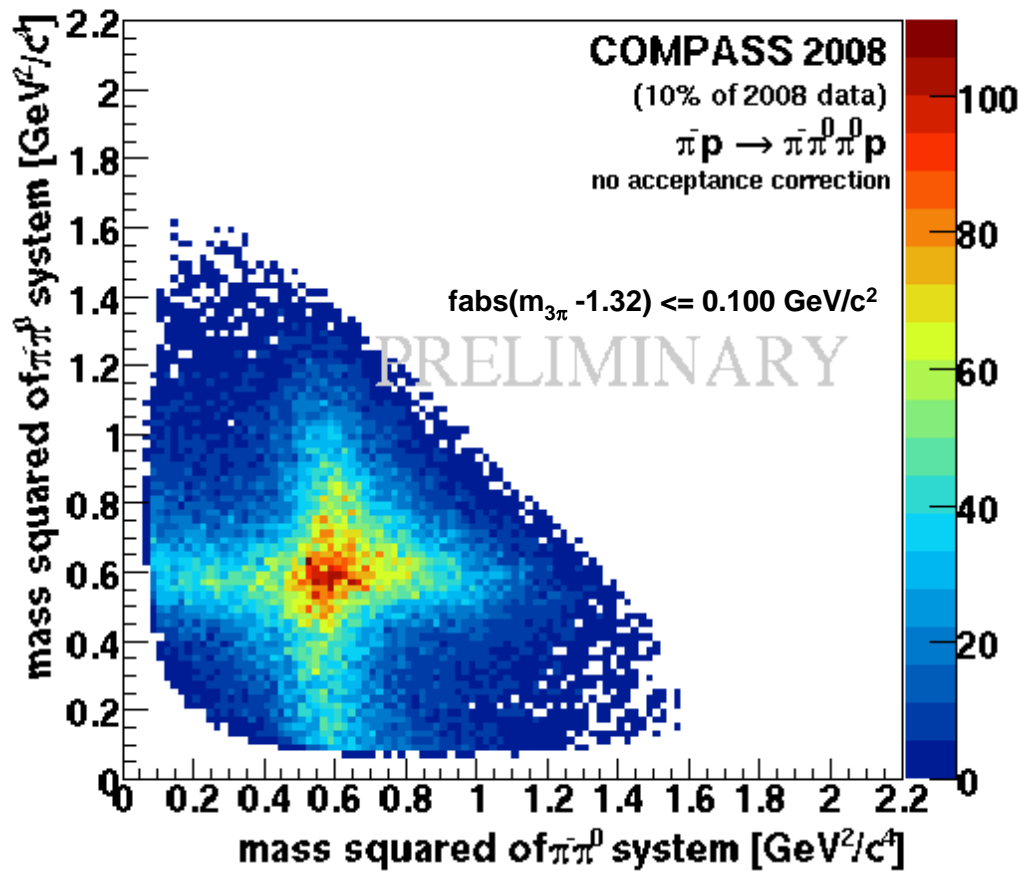


Mass spectrum of both $\pi^- \pi^0$ systems & the $\pi^0 \pi^0$ system



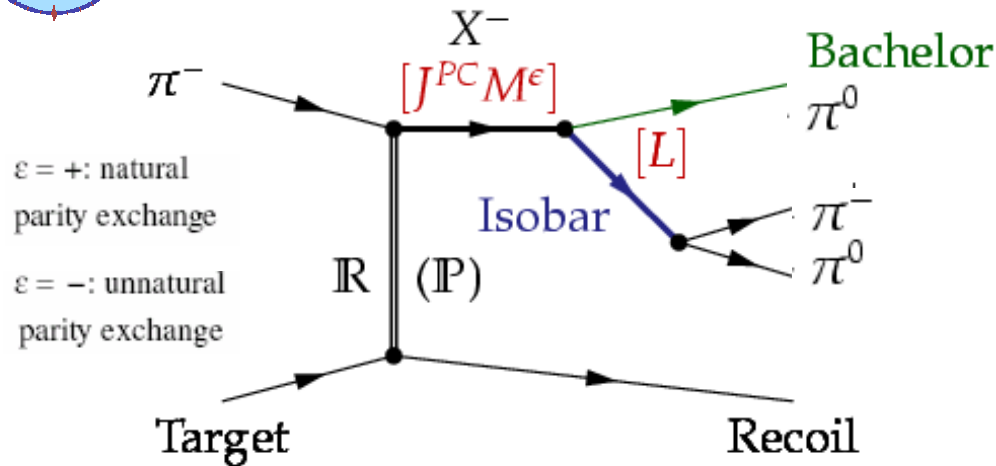


Dalitz plots: a_2 & π_2 region





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: $J^{PC} M^\epsilon$ [isobar] L

PWA:

- **program:** Illinois/Protvino/Munich (D.Ryabchikov) software (IHEP/VES, TUM/COMPASS)
- **Isobars:** $(\pi\pi)_S$ [broad $f_0(600)+f_0(1370)$], $f_0(980)$, $\rho(770)$, $f_2(1270)$, $\rho_3(1690)$
- **No acceptance correction yet** (assumed flat)

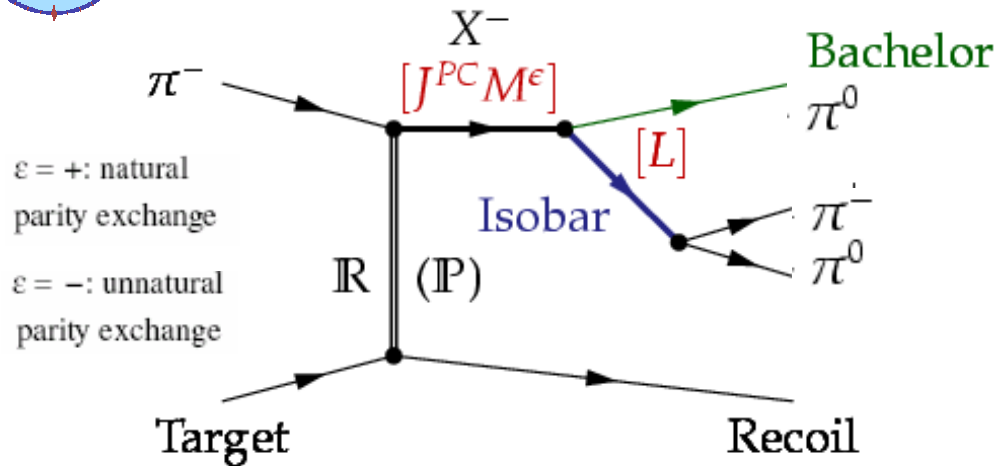
Mass independent PWA: (40MeV/c² bins, same waveset as used for 2004 data)

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

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



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Assumptions:

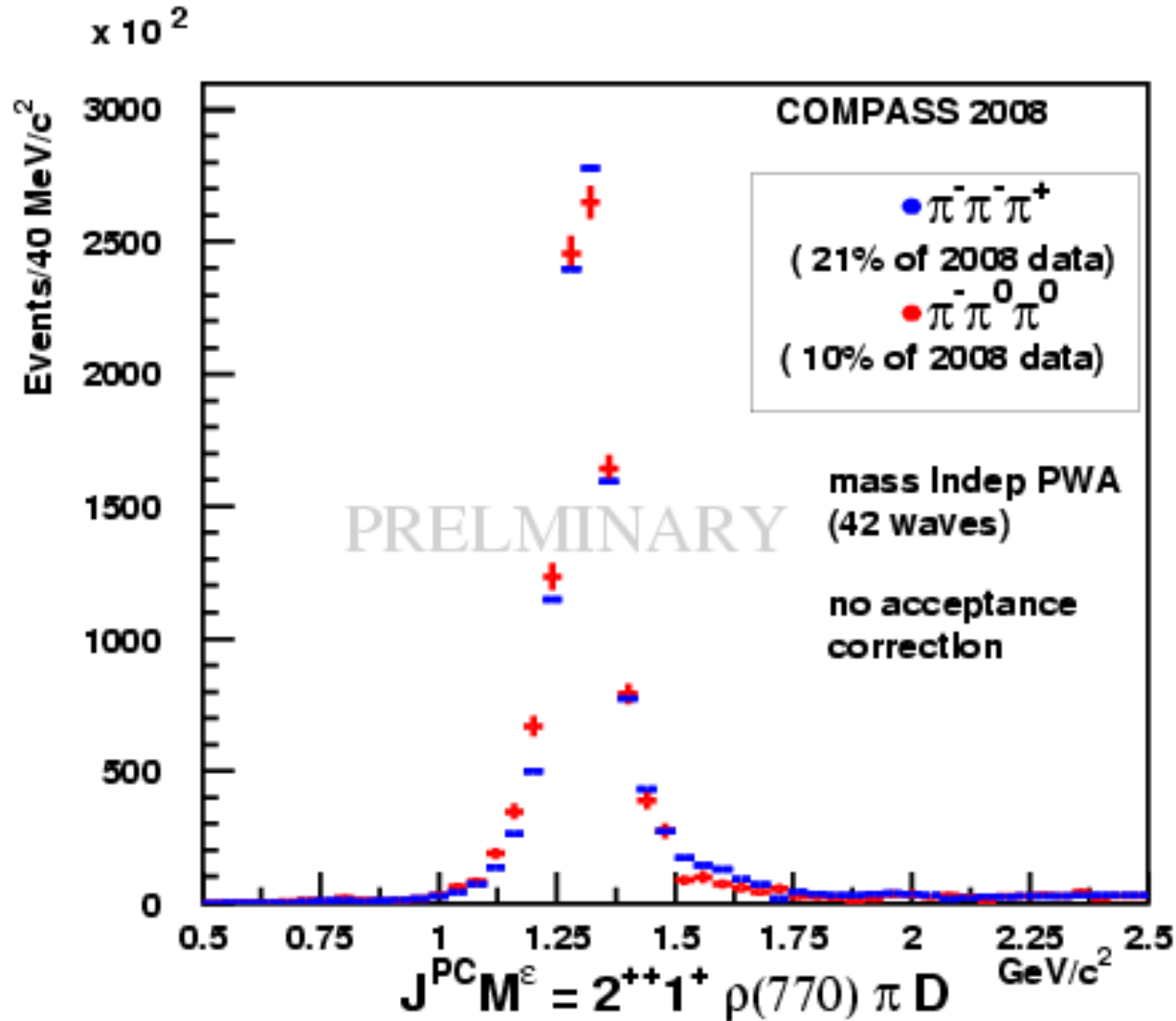
- *factorisation* of beam & target vertex, *no* final state interactions
- I^G conserved at *beam vertex* (π^- beam: $I^G = 1^-$)
- *Scattering on nucleons:* helicity flip & non-flip amps at target vertex (*rank2*)
- Using *reflectivity basis* in Gottfried Jackson frame (at high CM energies: reflectivity $\epsilon =$ naturality of R)

Isospin symmetry: neutral / charge mode

- isobar decaying into **f2** π : 1/2 intensity expected
- isobar decaying into ρ π : 1/1 intensity expected

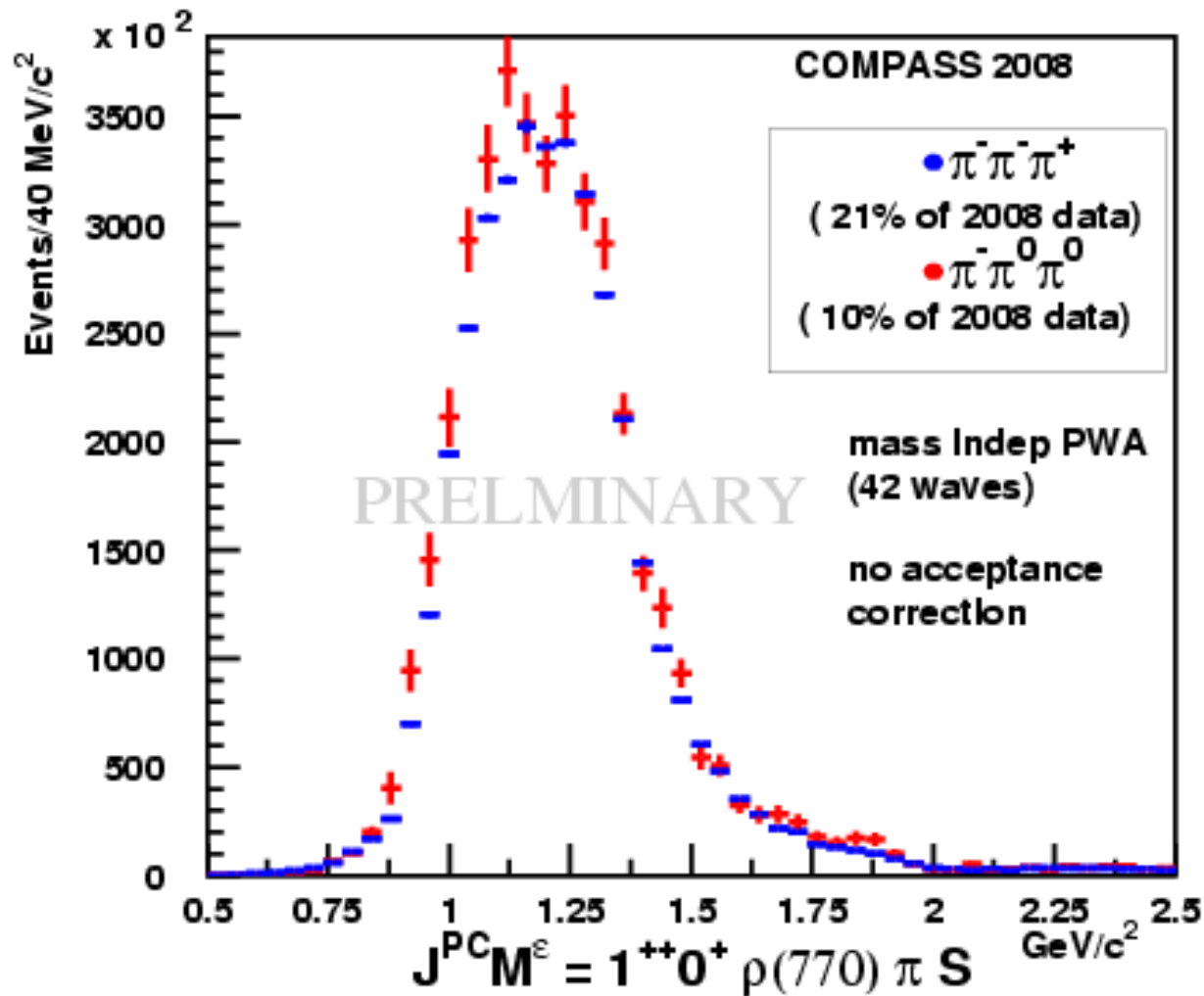


First PWA fits – normalisation to a2



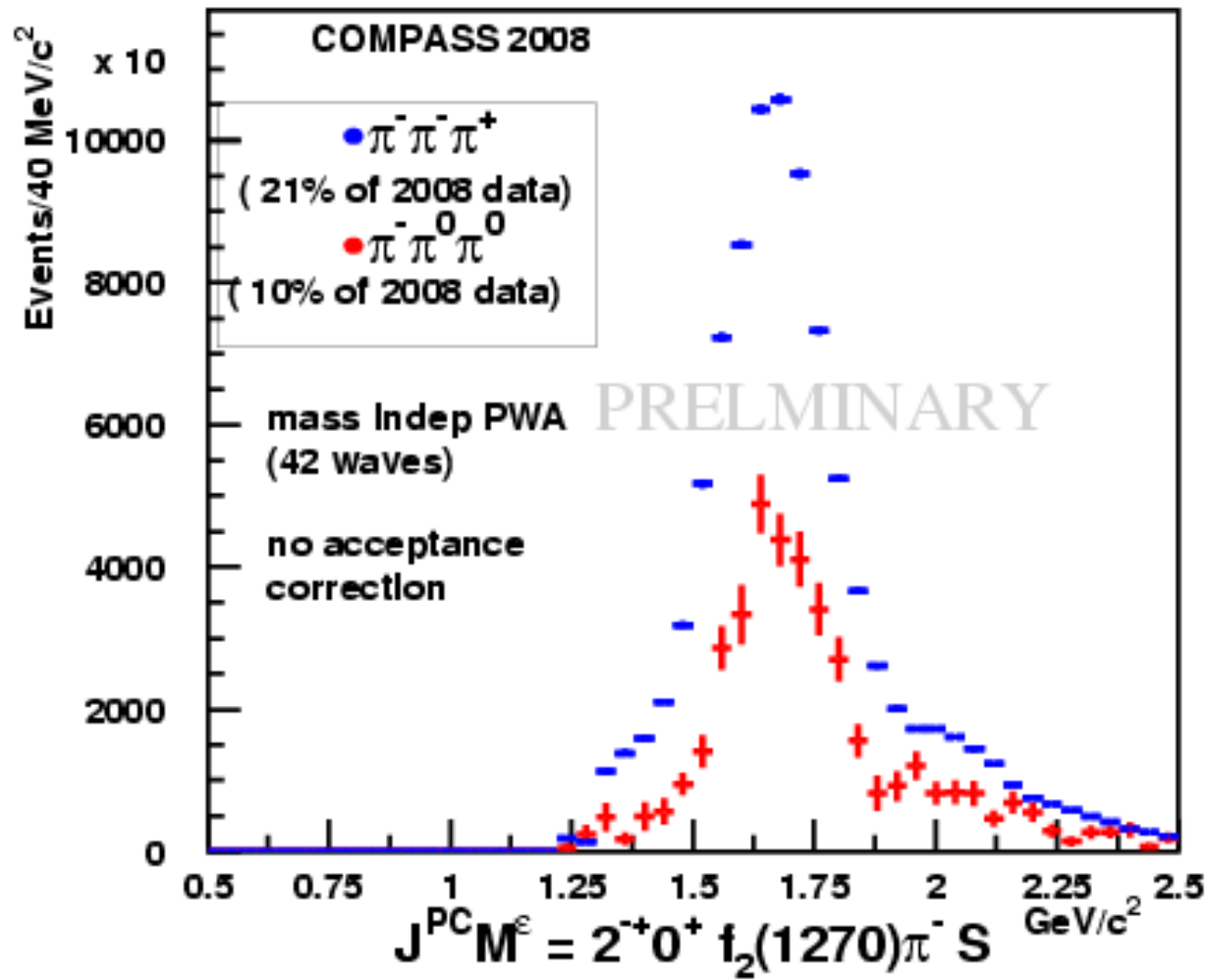


First PWA fits – check intensities a1 to rho pi



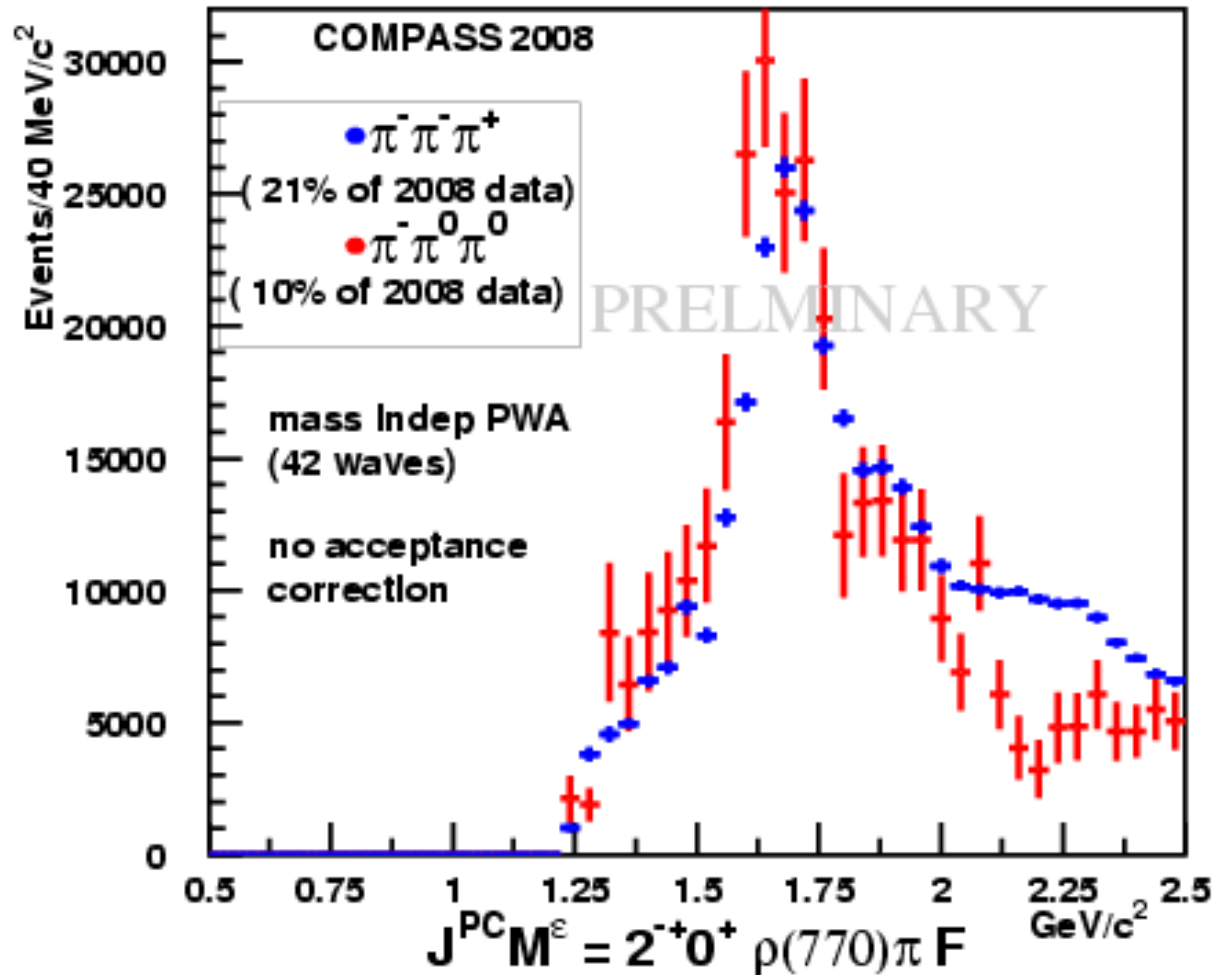


First PWA fits – check intensities π^2 to $f_2\pi$





First PWA fits – check intensities a1 to rho pi

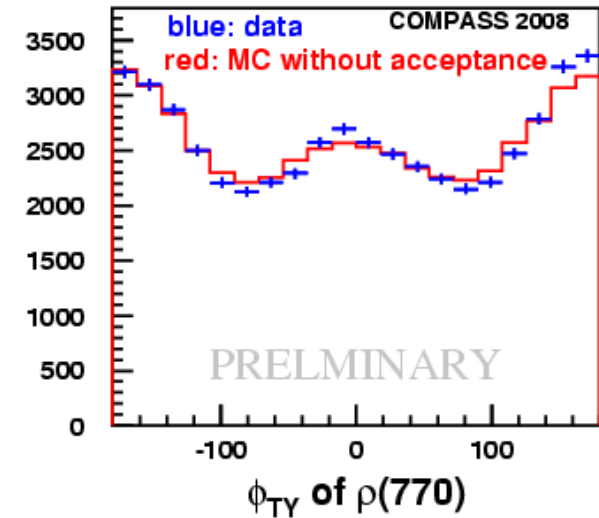
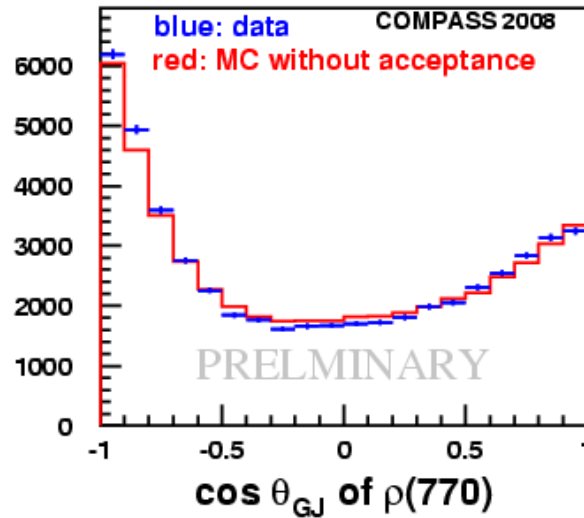




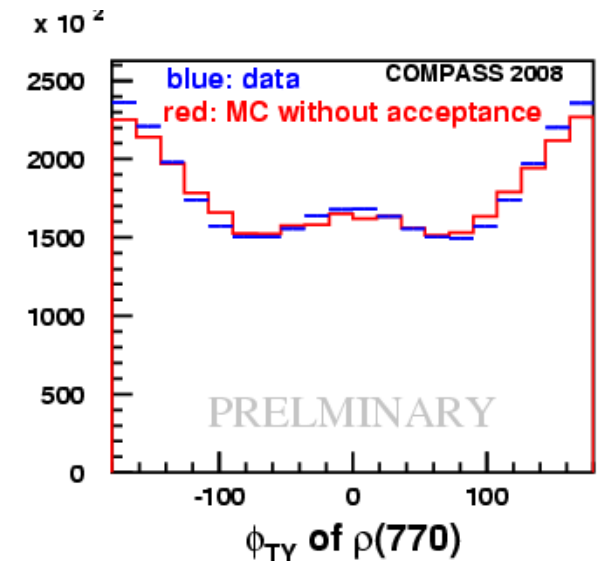
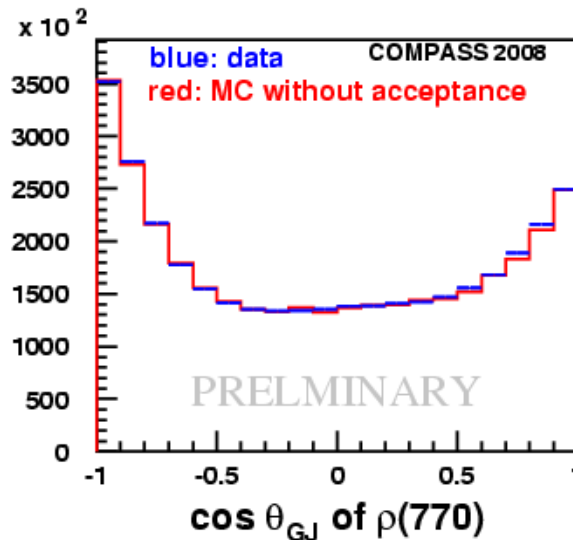
Decay angles in G.J. frame: Full PhaseSpace Generated Prediction vs. fitted data



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



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





Conclusions & outlook



- **COMPASS spectrometer well suited for Hadron Spectroscopy**
→ *Data taken with hadron beams on p target in 2008 & 09*
- **COMPASS measures Neutral & Charged channels**
- **First results on 3π final state -- neutral mode (diffr. dissociation)**
 - + *Evt selection & 1st PWA fits (mass independent)*
 - + *First look **promising**: mass spectra, main waves, isospin symmetry*

=> Important cross-checks & independent confirmation of any new state observed
- **Statistics less than charged mode**
 - *event selection presently limited to (exactly) 4γ events*
 - *will improve (allowing 5th => gain ~20%)*
 - *Ecals reconstruction under redevelopment*
- **Next steps:**
 - *Further development of Ecals reconstruction → MSADC info, DSP etc*
 - *Increase statistics, acceptance corrections, extend waveset, ...*



Backup





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

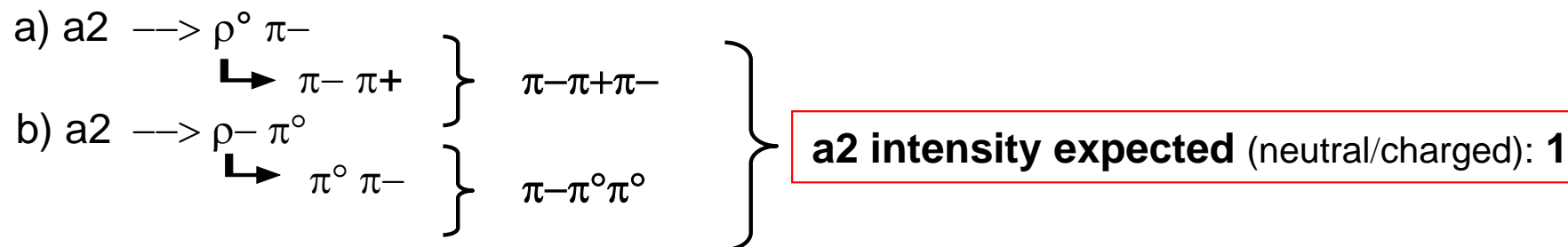


Theoretical expectation: neutral / charge mode

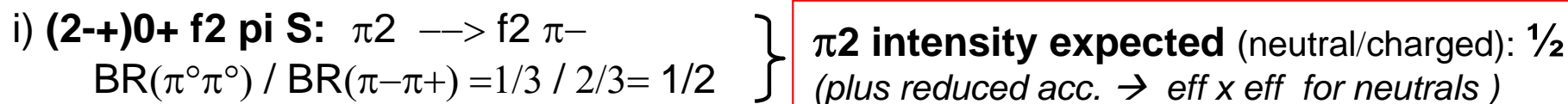
- isobar decay into $f_2 \pi$: 1/2 intensity expected
- isobar decay into $\rho \pi$: 1/1 intensity expected

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

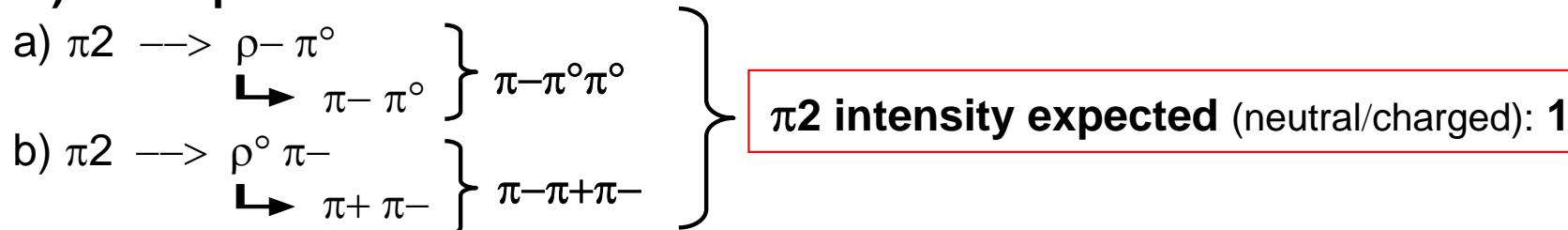
• $a_2: (2^{++})1^+$ rho pi D



• $\pi_2:$



ii) $(2^{-+})0^+$ rho pi F





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



Theoretical expectation: neutral / charge mode

- isobar decay into $f_2 \pi$: 1/2 intensity expected
- isobar decay into $\rho \pi$: 1/1 intensity expected

Examples,

General: Branching not only from Clebsch-Gordon

• $a_2: (2^{++})1^-$

coeff., but also from Bose-Symmetrisation w bachelor π

a) a_2

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

=> - " - needs to be modified, BR may differ

b) a_2

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

$BR(0^+ f_0(1400) \pi S) = 0.26$ (at 1.3 GeV)

$BR(0^+ f_0(980) \pi S) = 0.44$ (at 1.8 GeV)

• $\pi_2:$

i) $(2^{--})0^+$

$BR(2^{--} f_2(1270) \pi S) = 0.50$ (at 1.67 GeV = π_2 mass)

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

(plus reduced acc. \rightarrow eff x eff for neutrals)

} find very good agreement with experiment

ii) $(2^{--})0^+ \rho \pi F$

$$\begin{array}{l}
 \text{a) } \pi_2 \longrightarrow \left. \begin{array}{l} \rho^- \pi^0 \\ \searrow \pi^- \pi^0 \end{array} \right\} \pi^- \pi^0 \pi^0 \\
 \text{b) } \pi_2 \longrightarrow \left. \begin{array}{l} \rho^0 \pi^- \\ \searrow \pi^+ \pi^- \end{array} \right\} \pi^- \pi^+ \pi^-
 \end{array}$$

} π_2 intensity expected (neutral/charged): 1

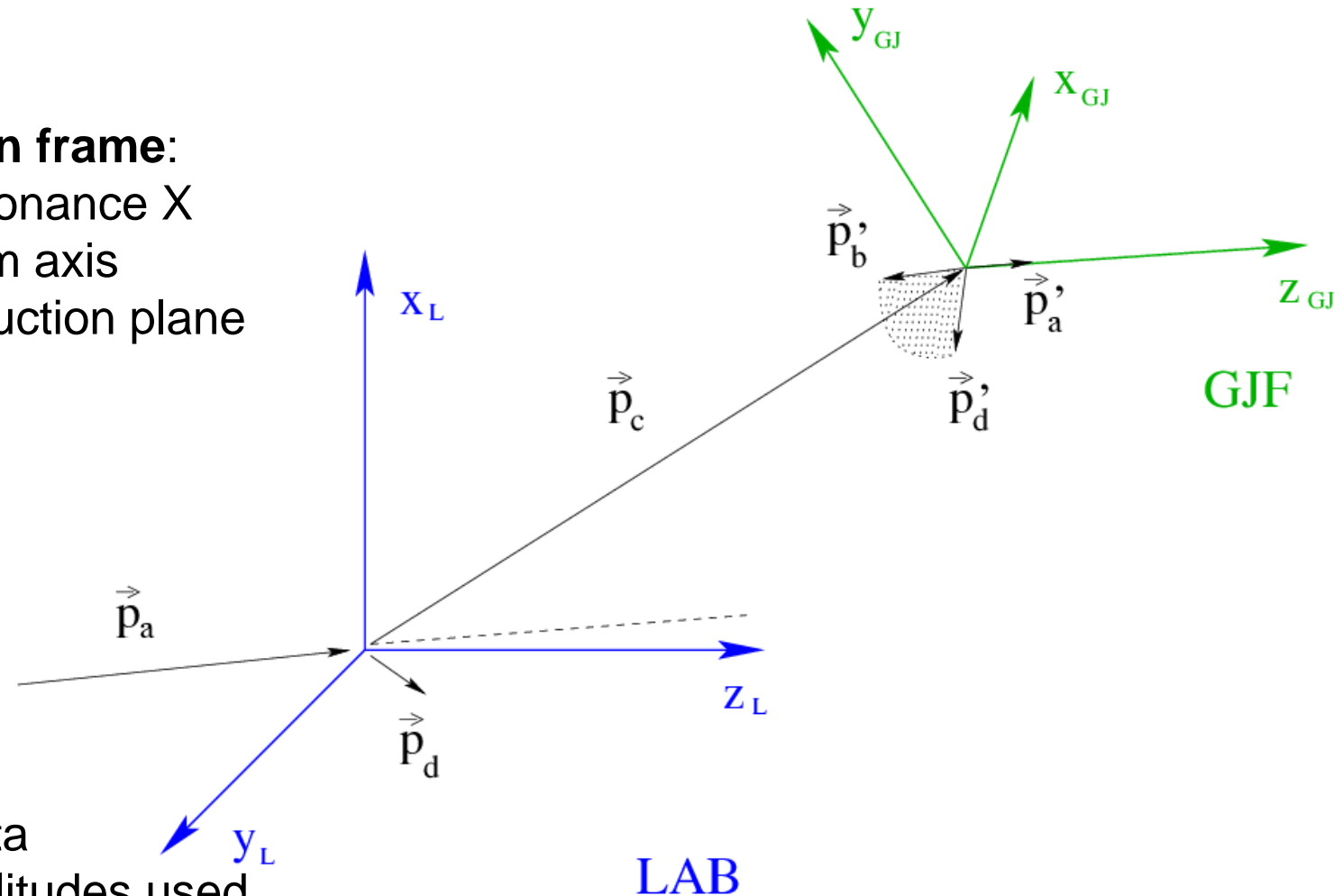


Decay angles in G.J. frame

Full PhaseSpace Generated Prediction

Gottfried-Jackson frame:

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

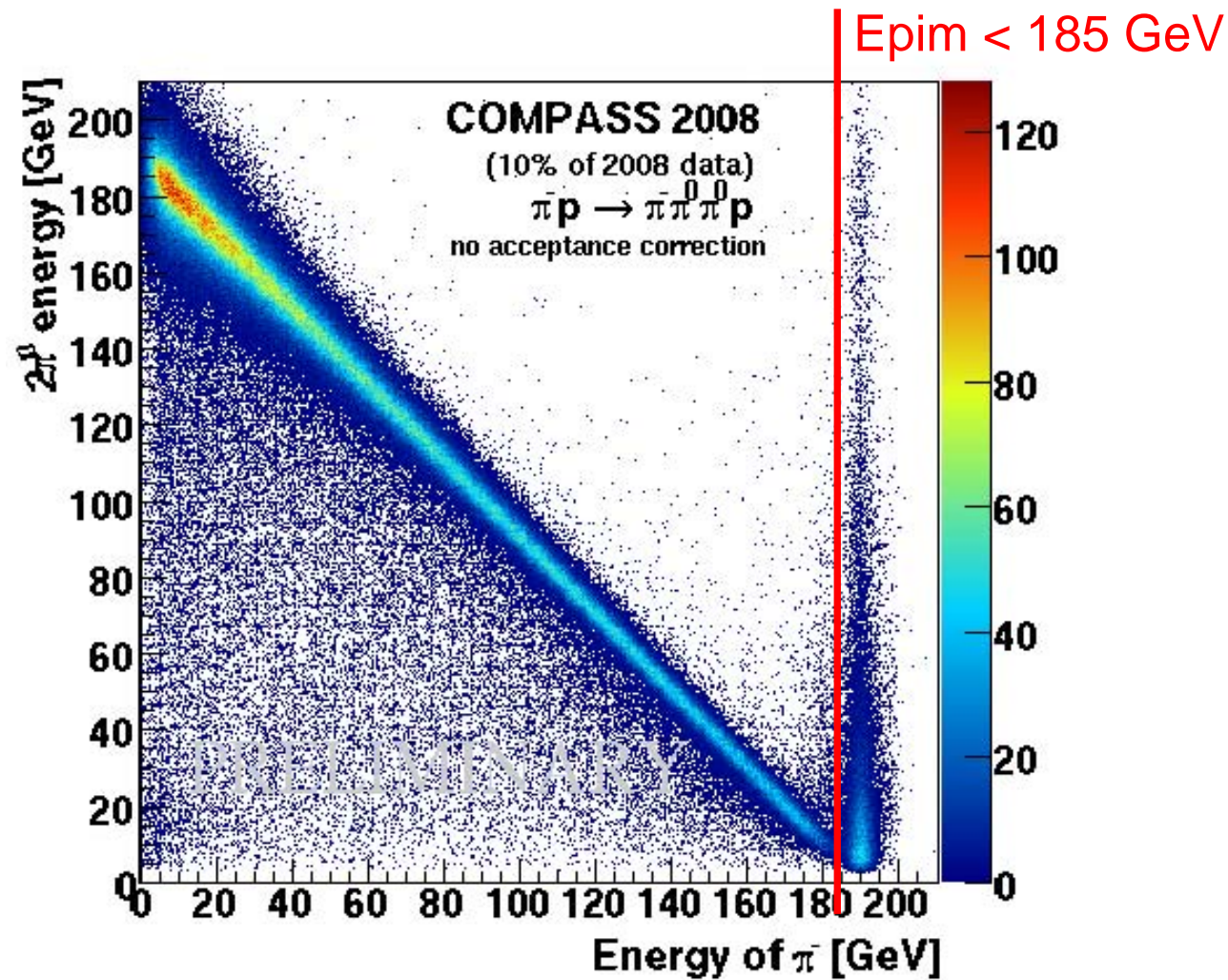


„PREDICT“:

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



Cut on energy of π^- (plot after RPDcut) (elastic events and background from e.g. pile-up)





Waveset used for the PWA



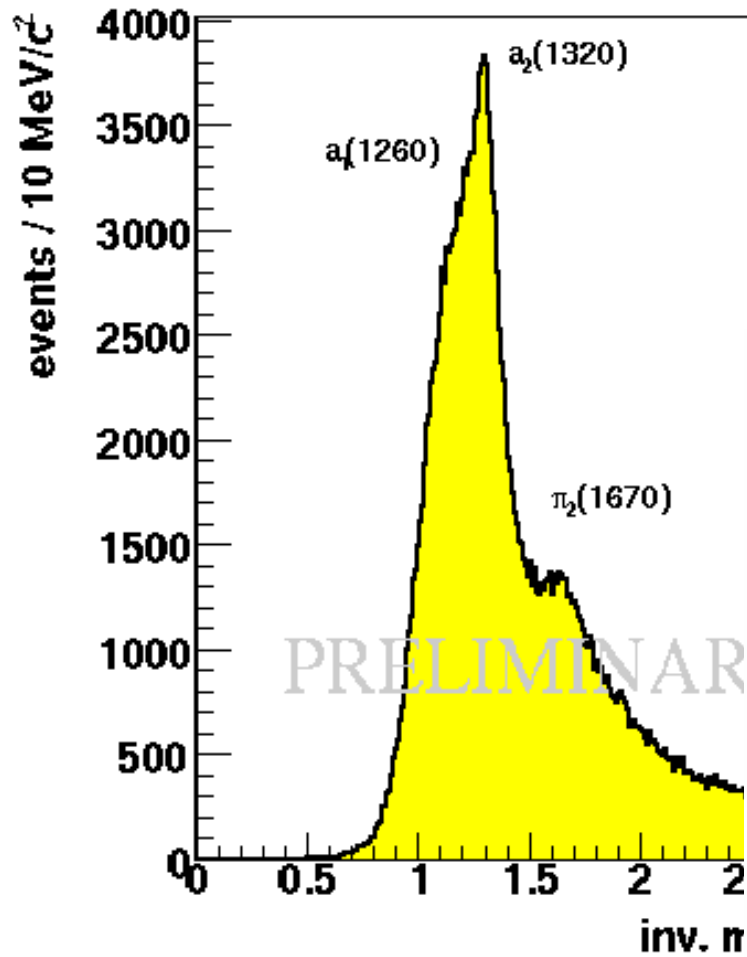
$J^{PC} M^\epsilon$	L	Isobar π	Threshold (GeV/ c^2)
$0^{-+}0^+$	S	$f_0(980)\pi$	1.25
$0^{-+}0^+$	S	$(\pi\pi)_s\pi$	-
$0^{-+}0^+$	P	$\rho\pi$	-
$1^{-+}1^+$	P	$\rho\pi$	-
$1^{++}0^+$	S	$\rho\pi$	-
$1^{++}0^+$	P	$f_2\pi$	1.20
$1^{++}0^+$	P	$(\pi\pi)_s\pi$	0.94
$1^{++}0^+$	D	$\rho\pi$	1.30
$1^{++}1^+$	S	$\rho\pi$	-
$1^{++}1^+$	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			

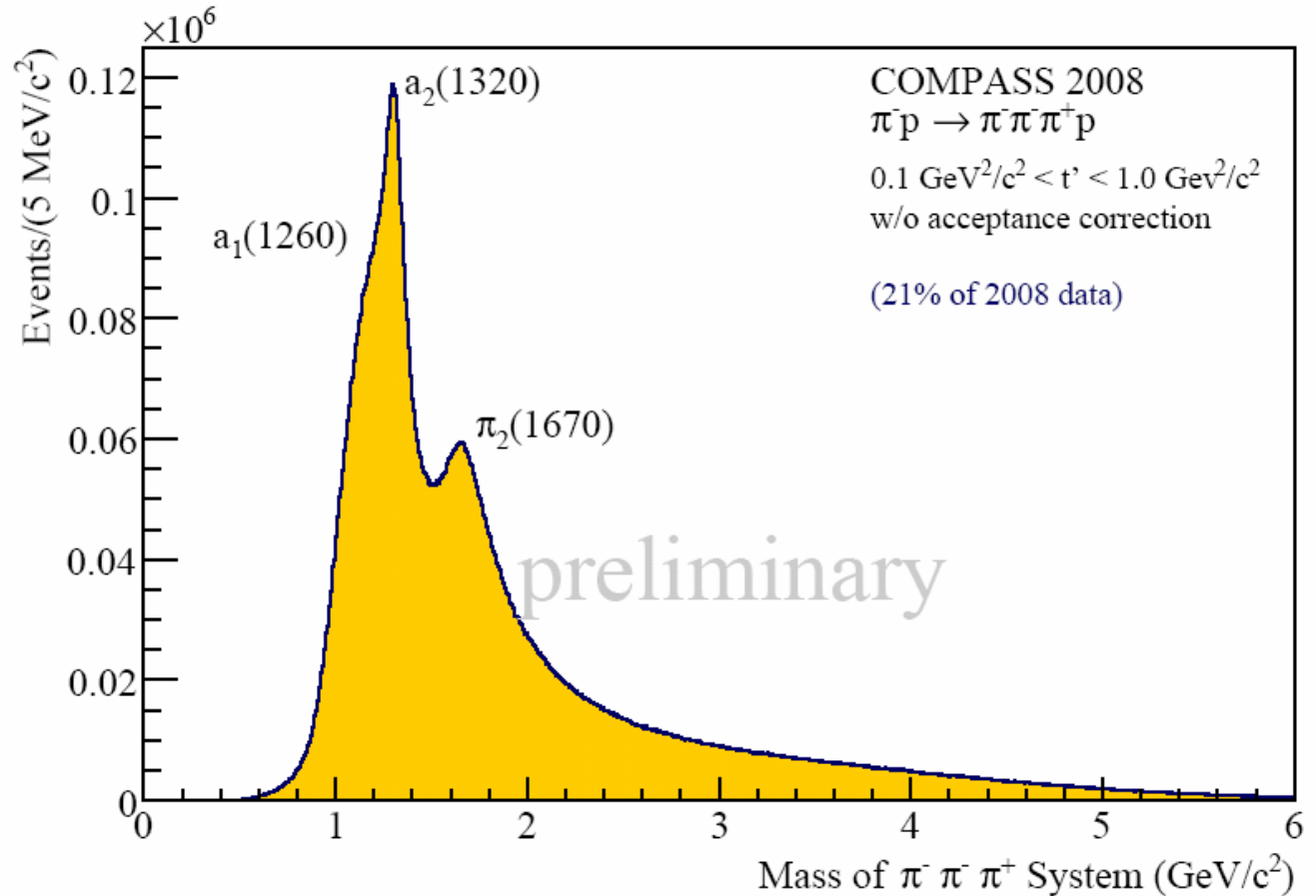
Table 5: List of the 42 waves used for the mass independent PWA.



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



COMPASS 2008
(10% of 2008 data)
 $\pi^- p \rightarrow \pi^- \pi^0 \pi^0 p$
no acceptance correction



COMPASS 2008
 $\pi^- p \rightarrow \pi^- \pi^0 \pi^0 p$
 $0.1 \text{ GeV}^2/c^2 < t' < 1.0 \text{ GeV}^2/c^2$
w/o acceptance correction
(21% of 2008 data)



Mesons and Spin Exotic States



Constituent quark model

- color neutral qqbar systems
- Quantum numbers $J^G J^{PC}$
- $P = (-1)^{L+1}$ $C = (-1)^{L+S}$ $G = (-1)^{l+L+1}$
- J^{PC} multiplets: 0^{++} , 0^{-+} , 1^{--} , 1^{+-} , 1^{++} , 2^{++} , ...
- **Forbidden:** $0^{- -}$, 0^{+-} , 1^{-+} , 2^{+-} , 3^{-+} , ...

QCD: Additional color-neutral objects

- Tetraquarks (qqbar)(qqbar)
- Hybrids (qqbar)g
- Glueballs gg

Spin Exotic States

- J^{PC} forbidden \rightarrow no simple qqbar state
- No mixing with quark model states

