Diffractive Dissociation into $\pi^-\pi^-\pi^+$ Final States at COMPASS

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for the COMPASS collaboration

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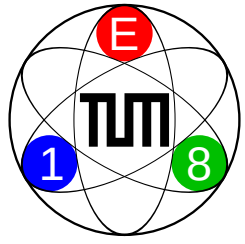
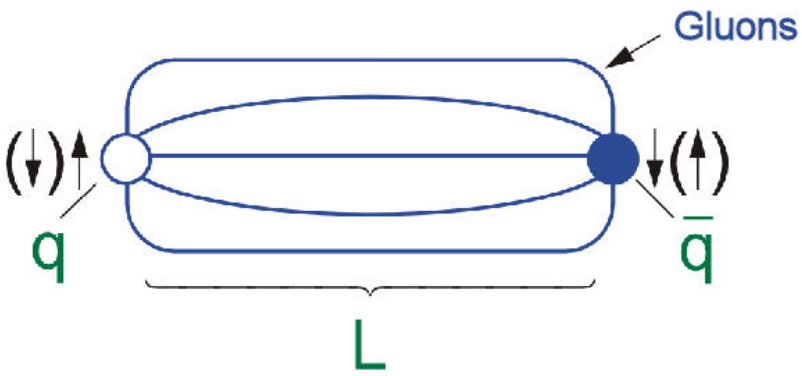
Hadron 2009, December 1st 2009



Overview

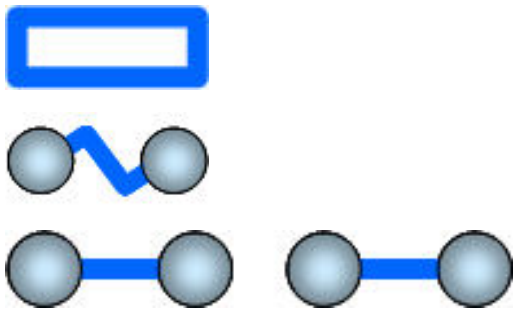
Quarkmodel and QCD



- $X(I^G J^{PC})$
- LS-Coupling:
  $J = \ell \oplus s = |\ell - s| ... \ell + s,$
  $(s = 0, 1)$
- Isospin and G-Parity conservation:
  $G = (-1)^{I+\ell+s}$
- Parity:
  $P = (-1)^{(\ell+1)}$
- Charge conjugation:
  $C = (-1)^{(\ell+s)}$

Quarkmodel and QCD

QCD allows states which are forbidden in the quarkmodel

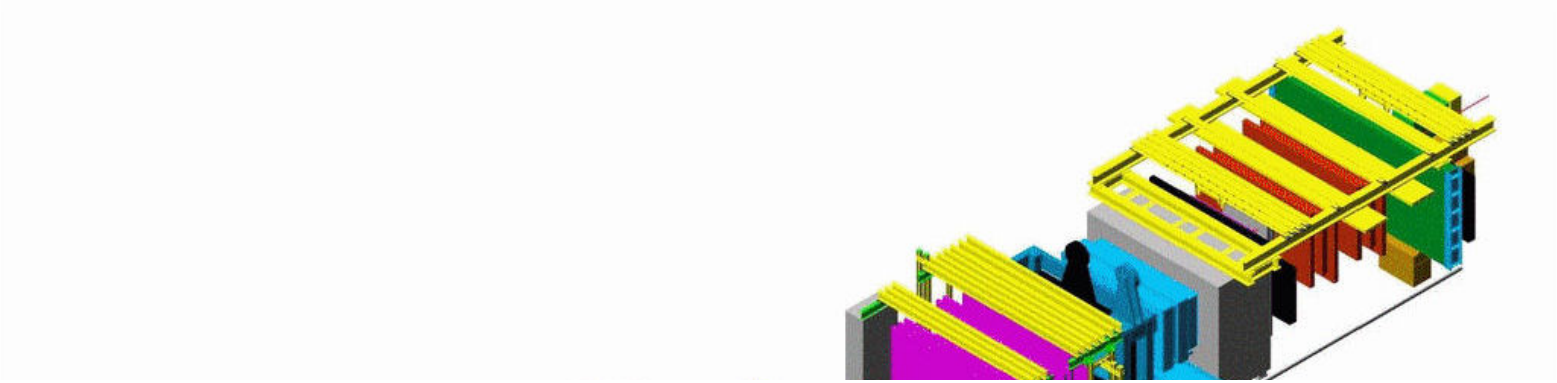


Glueballs: gg, ggg

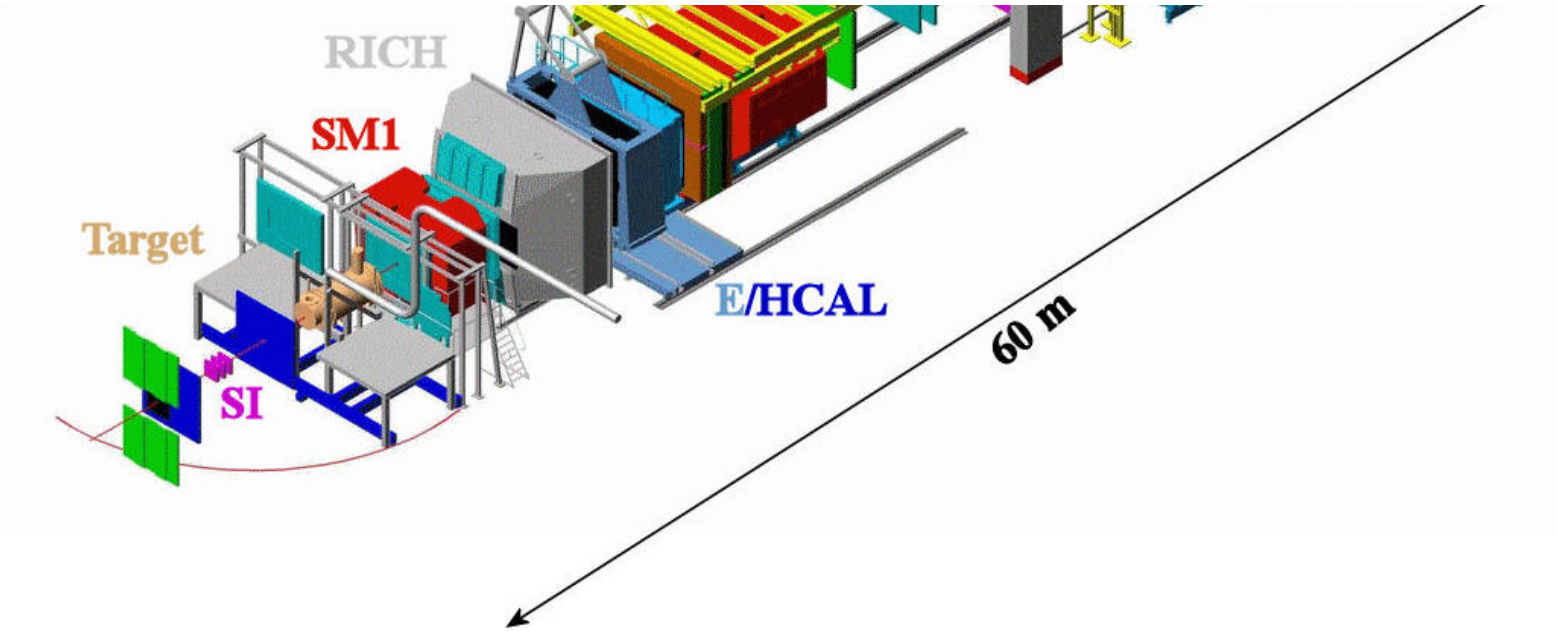
Hybrids: $qg\overline{q}$

Tetraquarks: $(q\overline{q})(q\overline{q})$

- Mixing of color neutral configurations with same quantum numbers
- leading $q\overline{q}$ term vanishes
  $\Rightarrow$ exotic $J^{PC}: 0^{--}, 0^{+-}, 1^{-+}, ...$

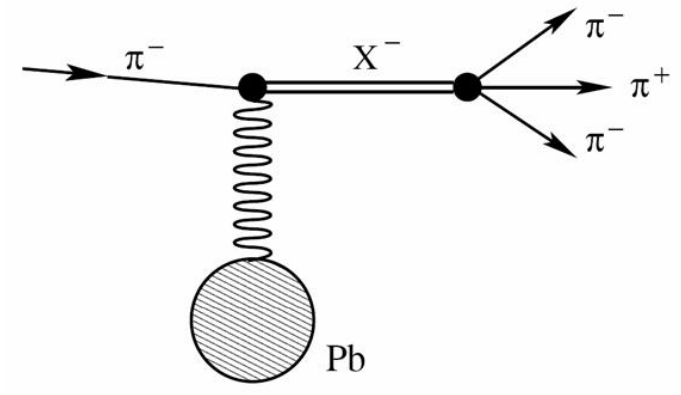


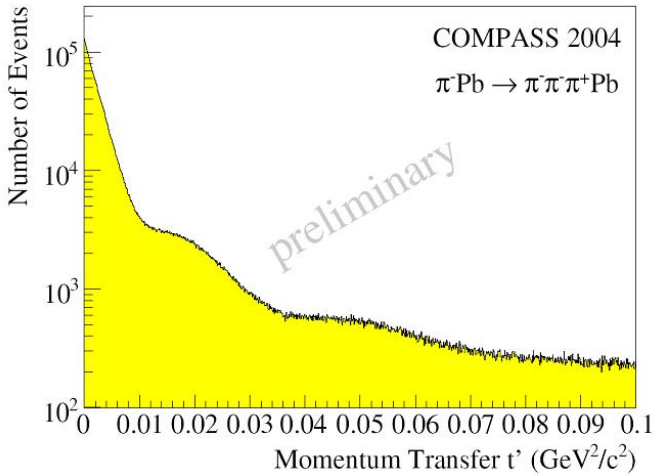
COMPASS can contribute significantly in the low mass region

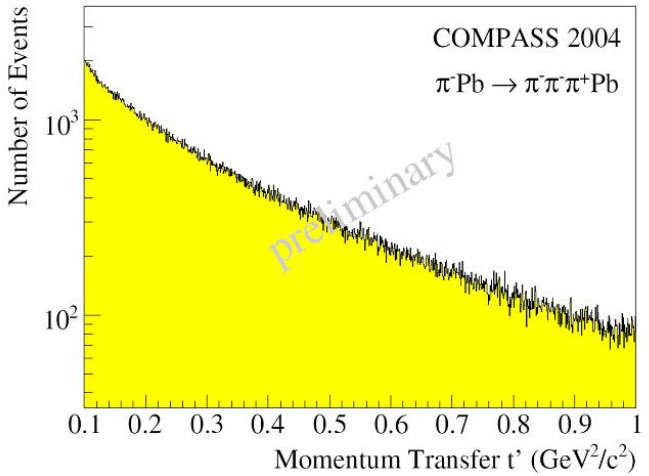


Diffractive Dissociation into $\pi^-\pi^-\pi^+$ Final States

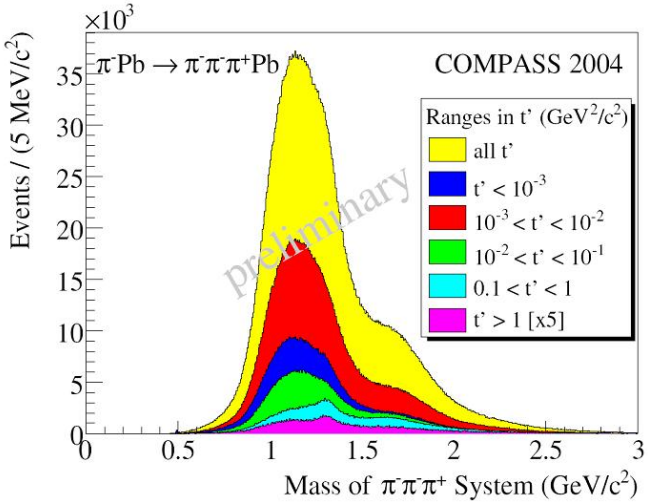
- Decoupling of resonance and target vertex, no final state interaction
- Space-like Regge process, Pomeron exchange $\longrightarrow$ only momentum and angular momentum transfer to beam particle







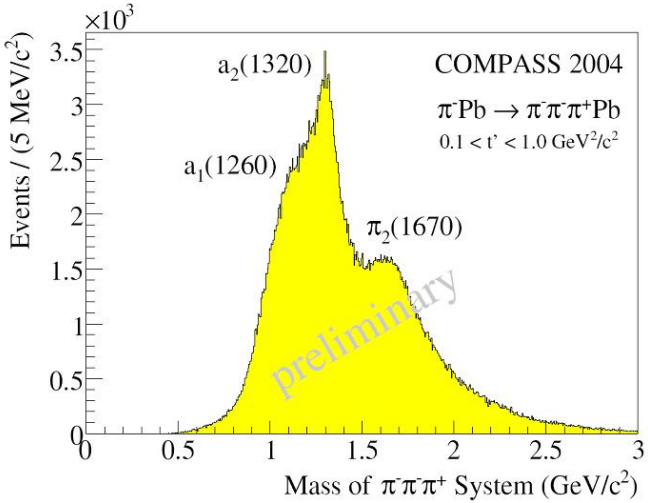
Invariant Mass of 3π System



COMPASS

- $p_\pi = 190 GeV/c$
- 4M events in 3 days (full t range)
- 450k events in $0.1 < \text{t'} < 1.0\ GeV^2/c^2$

Invariant Mass of 3π System



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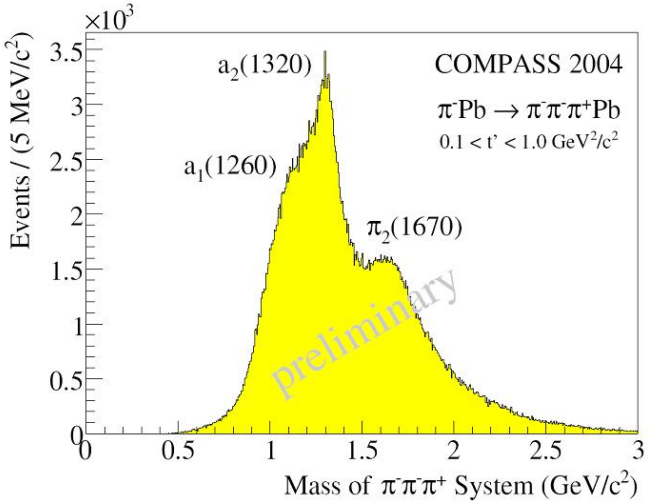
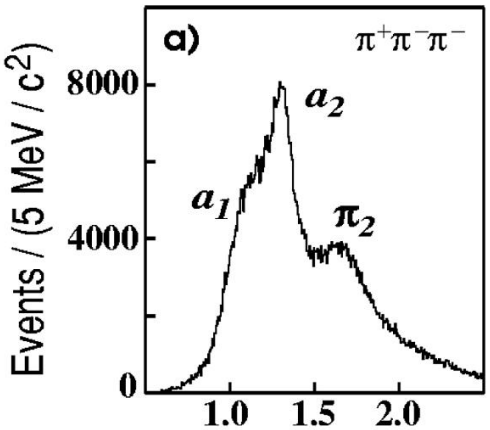




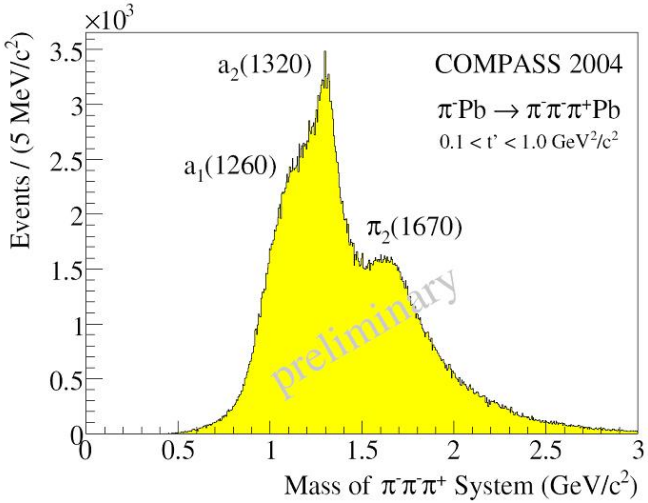
COMPASS

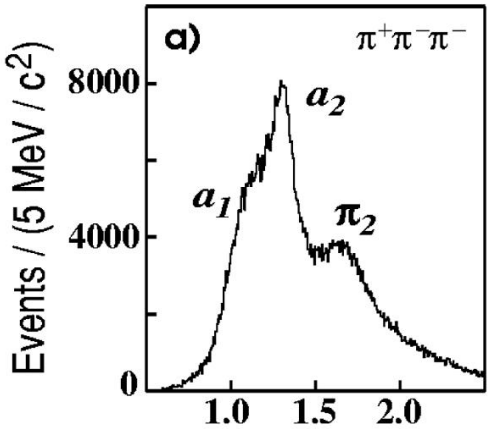
- $p_\pi = 190 GeV/c$
- 4M events in 3 days (full t range)
- 450k events in $0.1 < \text{t'} < 1.0\ GeV^2/c^2$

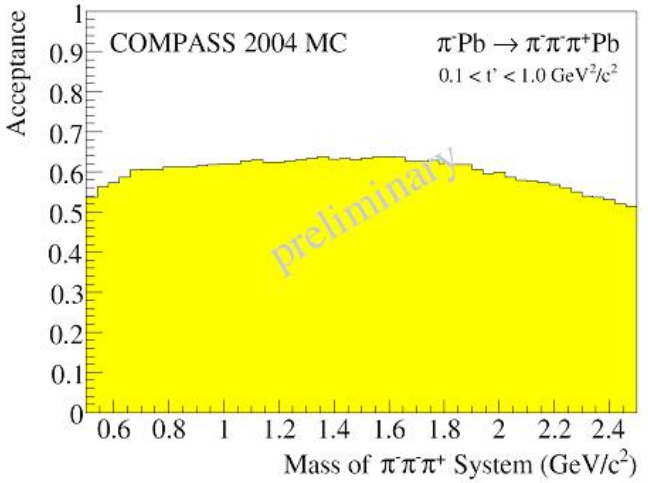
BNL E852

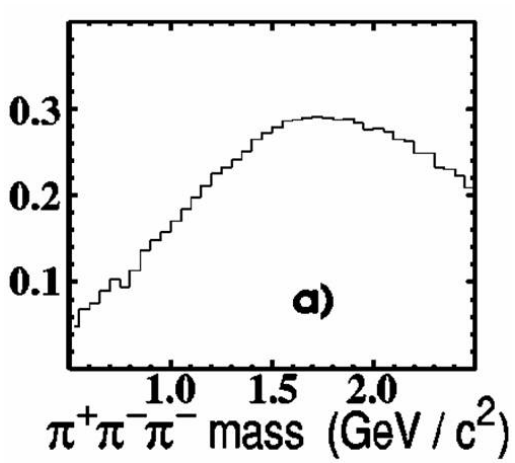
- $p_\pi = 18 GeV/c$
- 250k events in $0.08 < \text{t'} < 1.0\ GeV^2/c^2$

Invariant Mass of 3π System and Acceptance



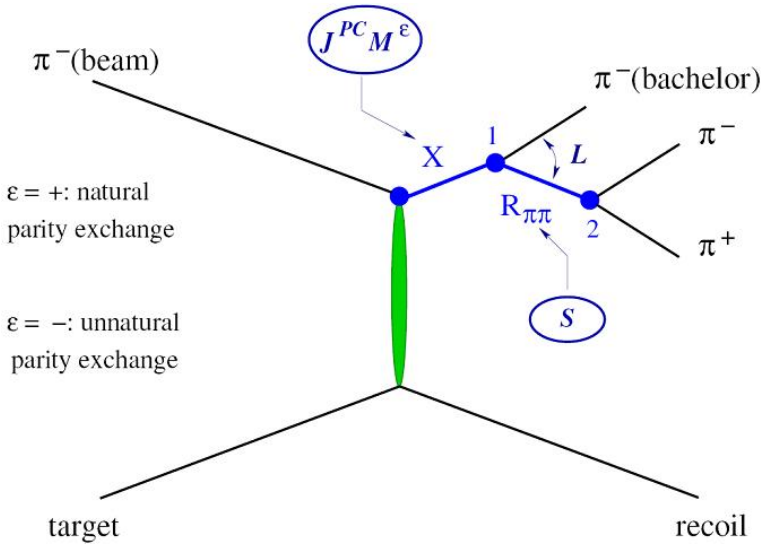


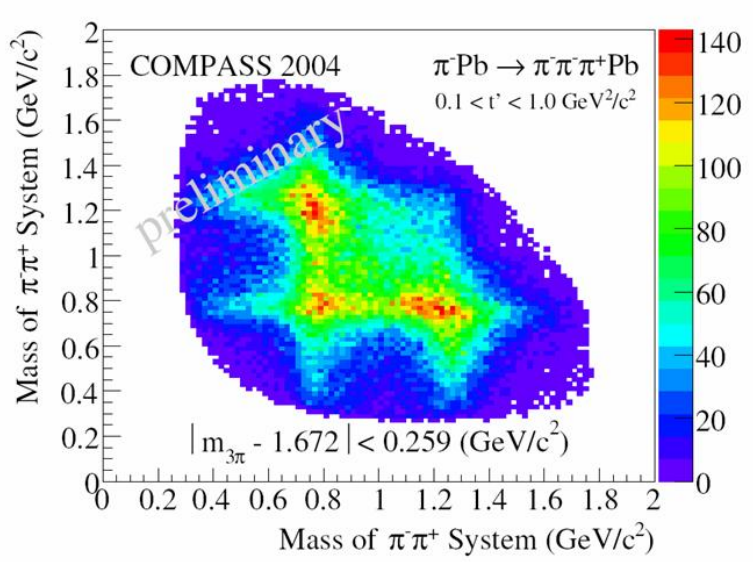




COMPASS: Flat acceptance 50 – 60%

Partial Wave Analysis - Isobar Model





PWA: more detailed informations on quantum numbers of resonances

PWA Technique

Illinois/Protvino/Munich Program - BNL/Munich Program

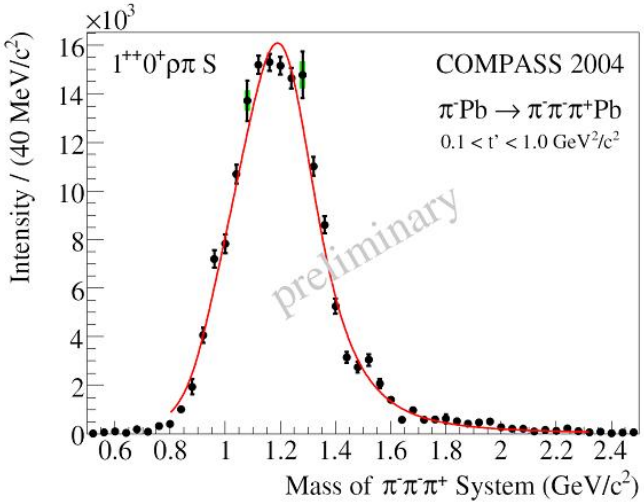
1. **Mass-Independent PWA**

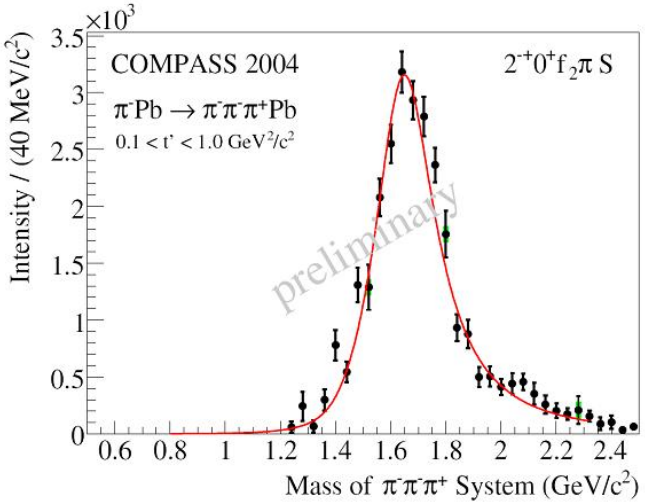
$$\sigma_{indep}(\tau, m, t') = \sum_{\epsilon=\pm1} \sum_{r=1}^{N_r} \left| \sum_i T^{\epsilon}_{ir} f^{\epsilon}_i(t') \psi^{\epsilon}_i(\tau, m) / \sqrt{\int \left|\psi^{\epsilon}_i(\tau', m)\right|^2 d\tau'} \right|^2$$

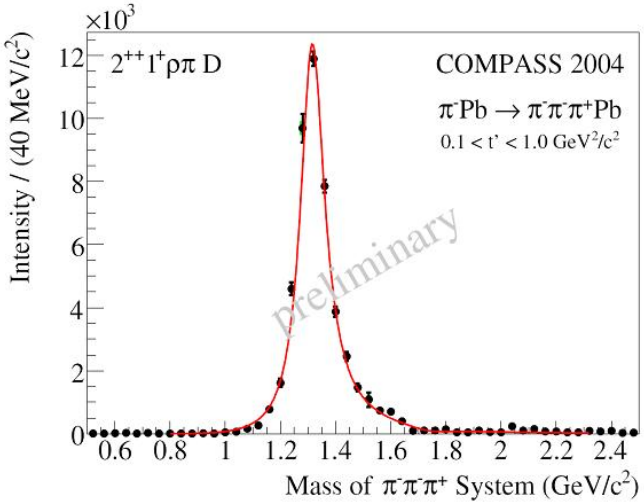
   - Production amplitudes T^{ϵ}_{ir} $\rightarrow$ extended maximum likelihood fit
   - Decay amplitudes $\psi^{\epsilon}_i(\tau, m)$ (Zemach tensors)
   - 41 partial waves $i = J^{PC} M^{\epsilon} [Y] L$
     - with $[Y] = (\pi\pi)_S, \rho(770), f_0(980), f_2(1270), \rho_3(1690)$
   - Background wave

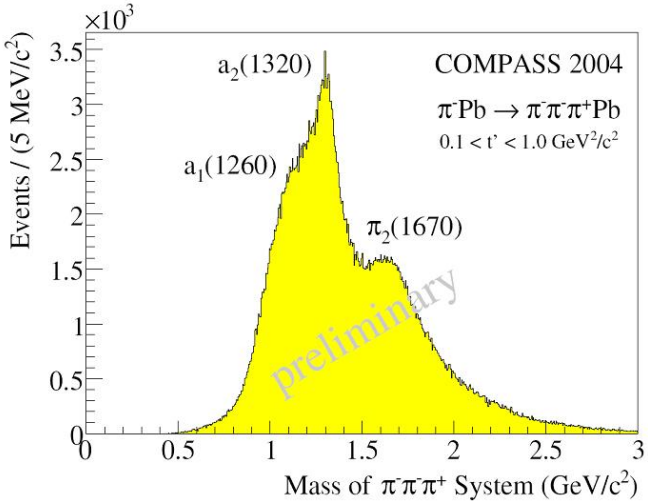
2. **Mass-Dependent χ^2 fit** to results of step 1
   - 6 waves
   - Parameterized by Breit-Wigner
   - Coherent background for some waves

Intensities of Major Waves

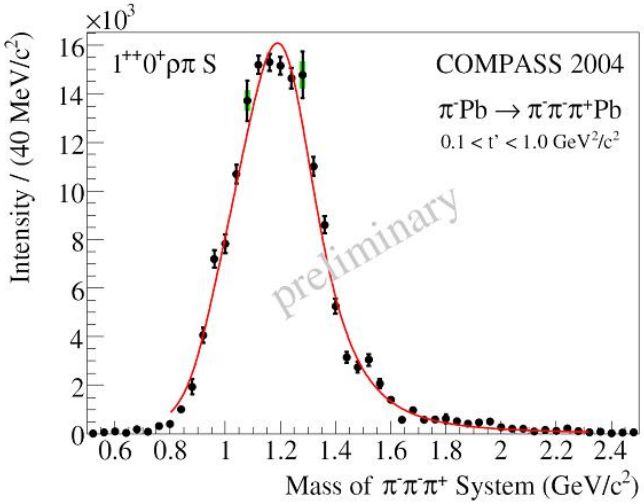


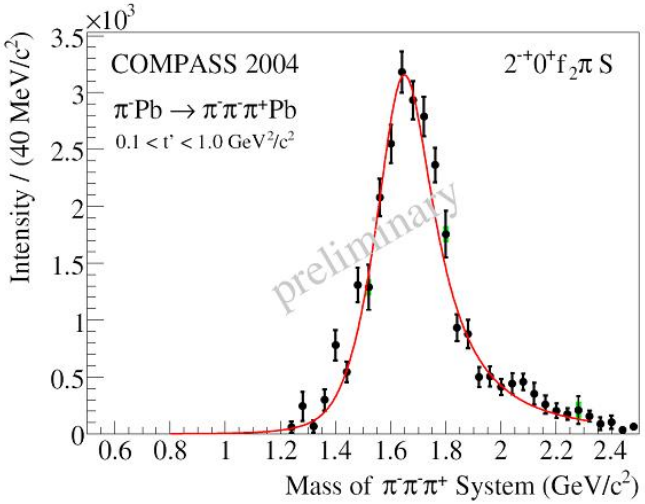


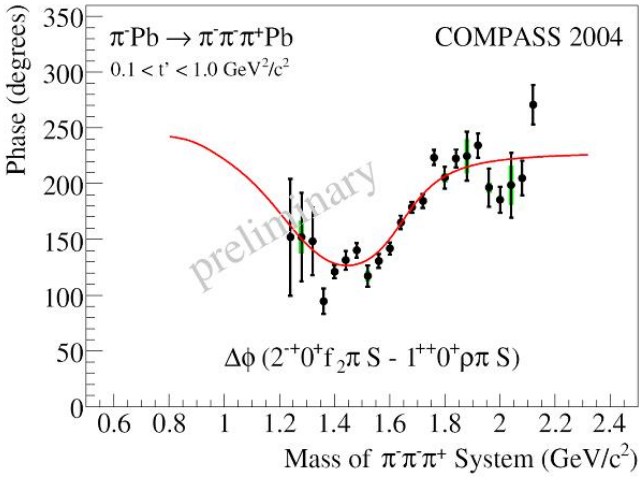




$a_1(1260)$ and $\pi_2(1670)$

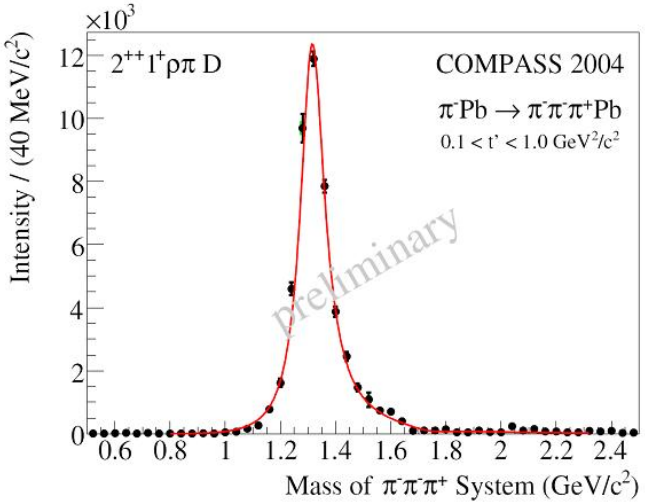


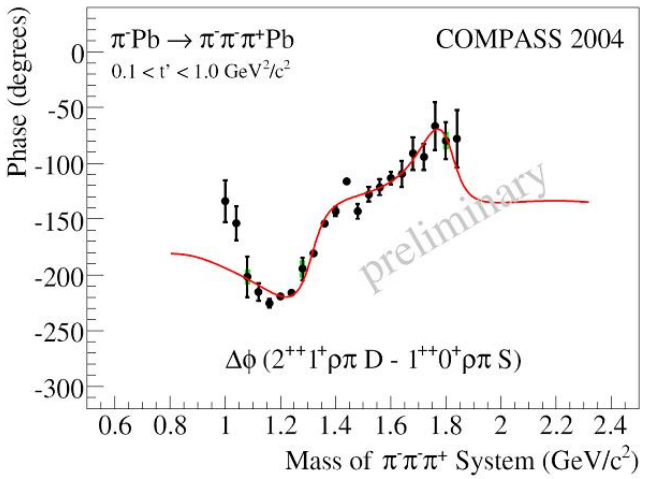




- BW for $a_1(1260)$ + bgr
  $M = \left(1255 \pm 6^{+7}_{-17}\right)\mathrm{MeV/c^2}$
  $\Gamma = \left(367 \pm 9^{+28}_{-25}\right)\mathrm{MeV/c^2}$
- BW for $\pi_2(1670)$
  $M = \left(1658 \pm 3^{+24}_{-8}\right)\mathrm{MeV/c^2}$
  $\Gamma = \left(271 \pm 9^{+22}_{-24}\right)\mathrm{MeV/c^2}$

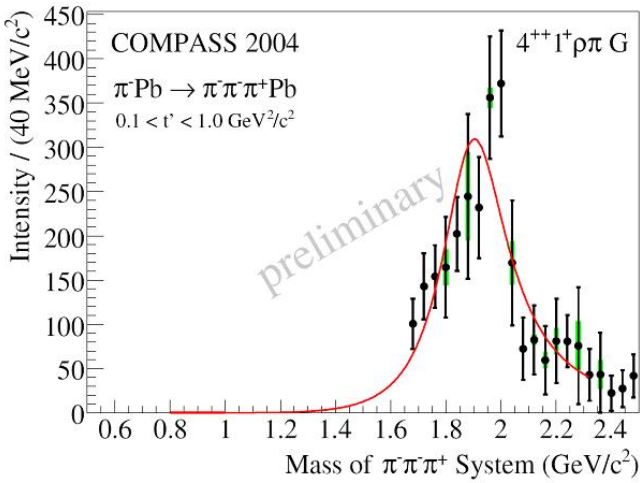
$a_2(1320)$

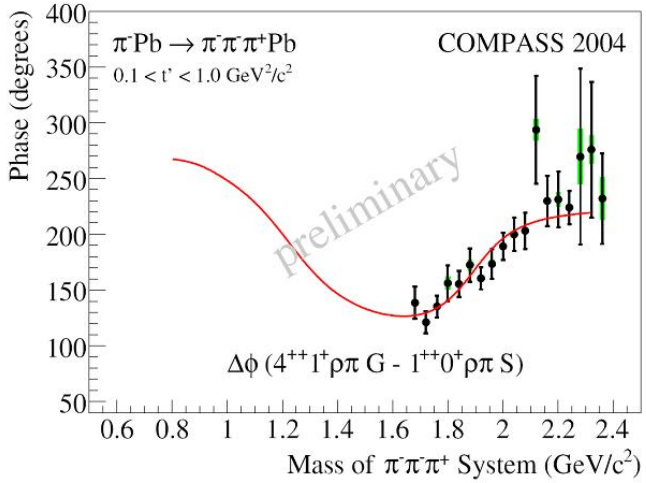




- Two Breit Wigner functions required to describe phase motion
- BW1 for $a_2(1320)$
  $M = \left(1321 \pm 1^{+0}_{-7}\right) \mathrm{MeV/c^2}$
  $\Gamma = \left(110 \pm 2^{+2}_{-25}\right) \mathrm{MeV/c^2}$
- BW2 for $a_2(1700)$: $M = 1732 MeV/c^2, \Gamma = 194 MeV/c^2$ (fixed PDG values)

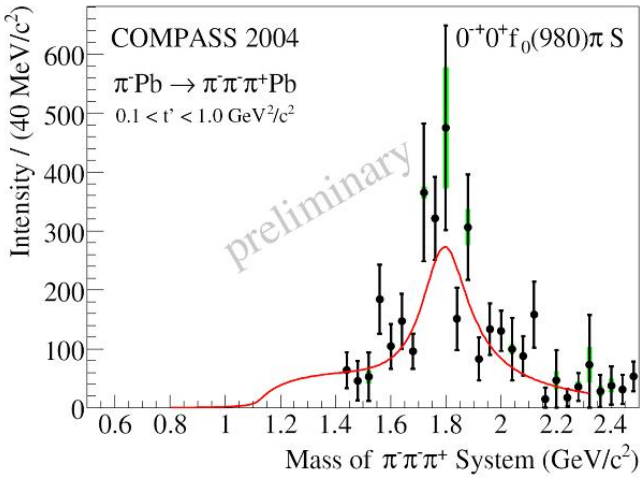
$a_4(2040)$

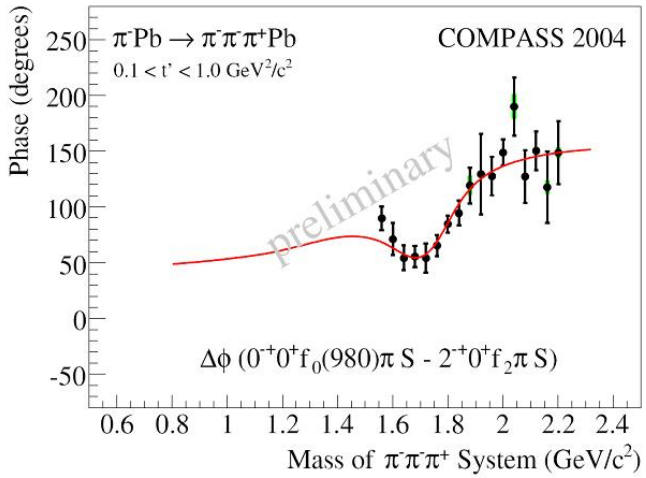




- Constant width BW used for $a_4(2040)$(branching ratios not known)
- BW parameters
  $M = \left(1885 \pm 13^{+50}_{-2}\right) \mathrm{MeV}/c^2$
  $\Gamma = \left(294 \pm 25^{+46}_{-19}\right) \mathrm{MeV}/c^2$

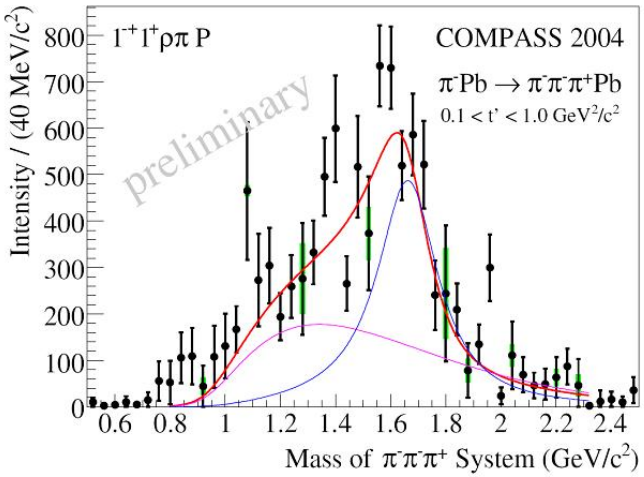
$\pi(1800)$

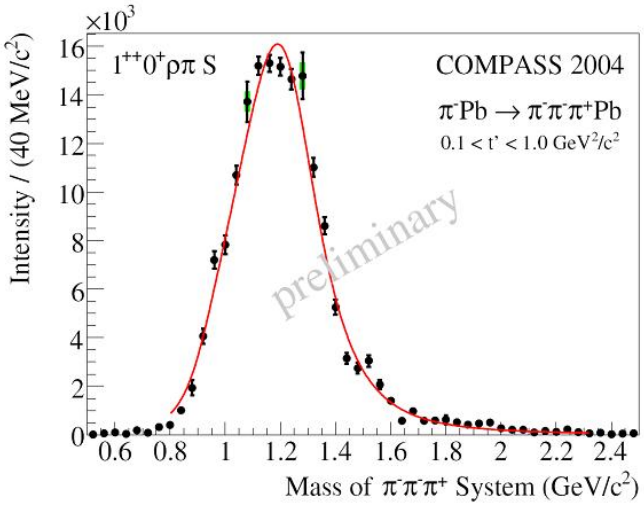


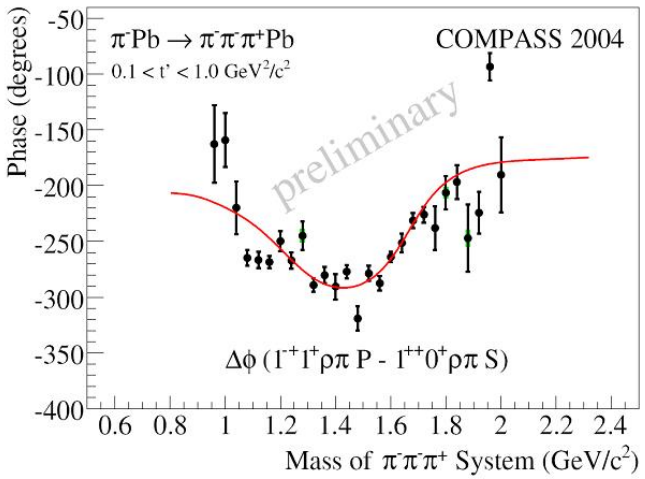


- Constant width BW used for $\pi(1800)$ and low-mass background
- BW parameters
  $M = \left(1785 \pm 9^{+12}_{-6}\right) \mathrm{MeV/c^2}$
  $\Gamma = \left(208 \pm 22^{+21}_{-37}\right) \mathrm{MeV/c^2}$

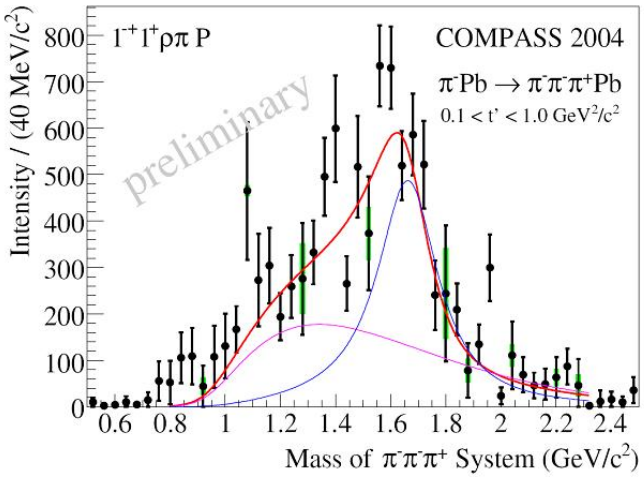
$J^{PC} = 1^{-+}$ Exotic Wave



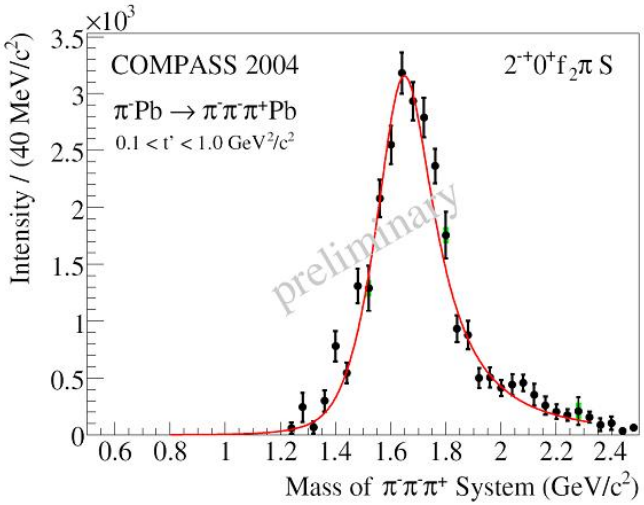


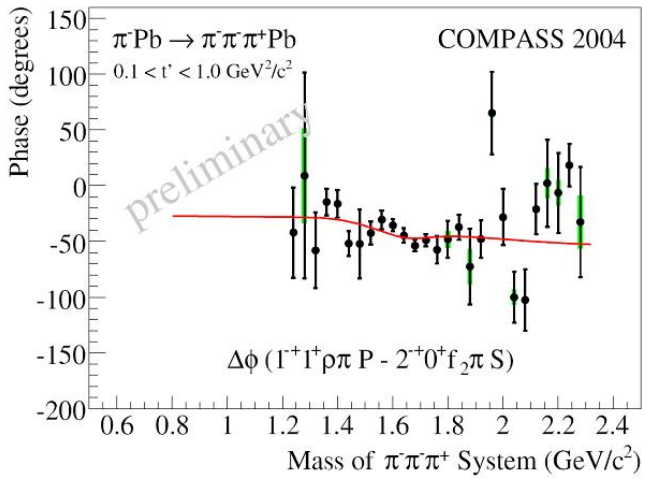


$J^{PC} = 1^{-+}$ Exotic Wave

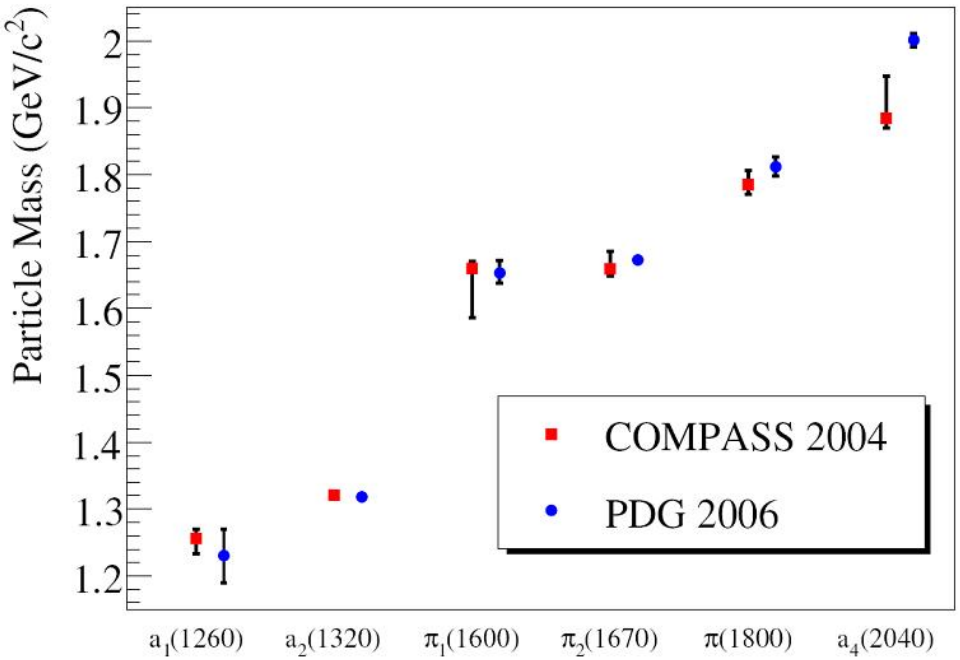


- BW parameters for $\pi_1(1600)$
  $M = \left(1660 \pm 10^{+0}_{-64}\right)\text{MeV}/c^2$
  $\Gamma = \left(269 \pm 21^{+42}_{-64}\right)\text{MeV}/c^2$
- Leakage negligible: $< 5\%$





Summary of Waves

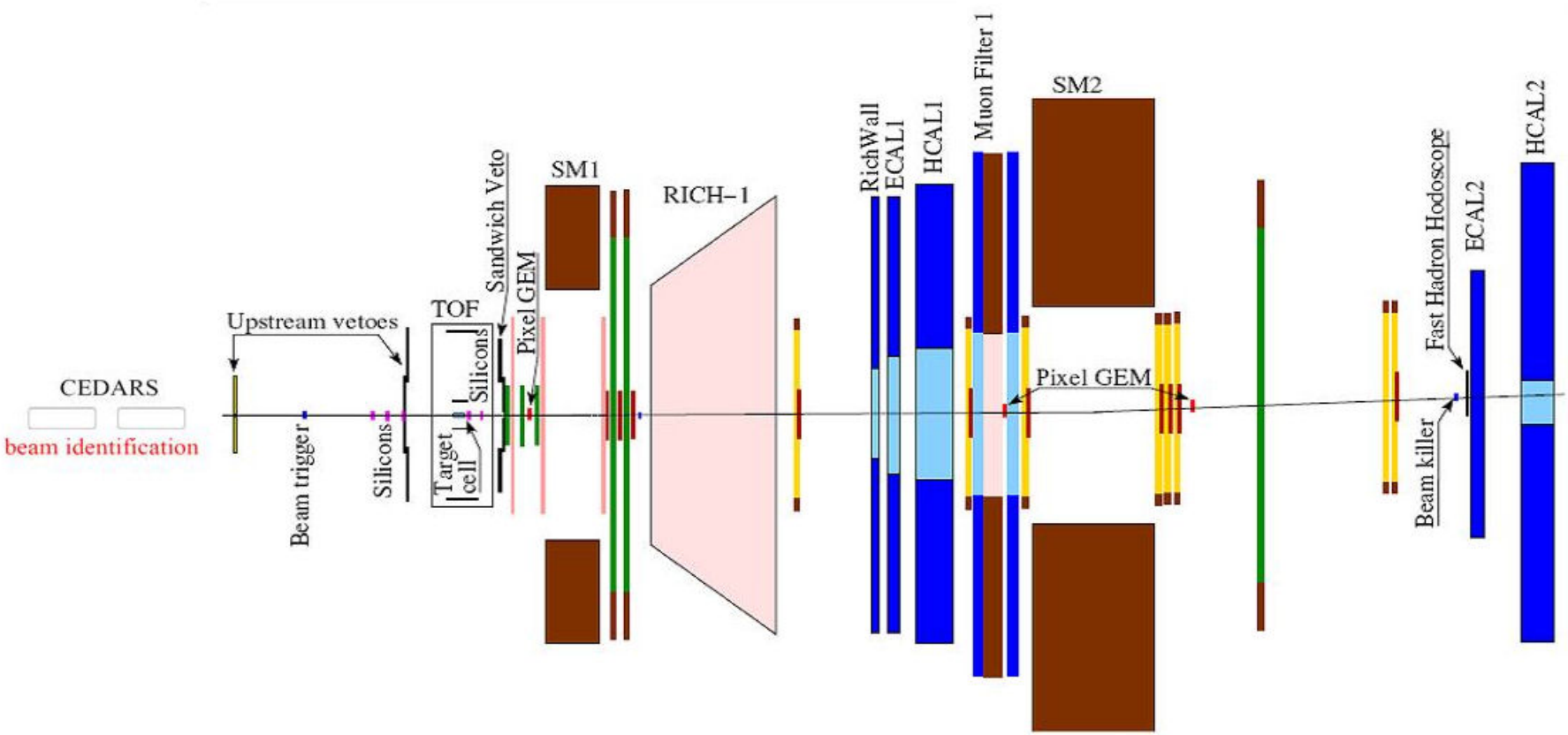


Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	Intensity (%)	Channel $J^{PC}M^{\epsilon}[\mathrm{isobar}]L$
$a_1(1260)$	$1255 \pm 6^{+7}_{-17}$	$367 \pm 9^{+28}_{-25}$	$67 \pm 3^{+4}_{-20}$	$1^{++}0^+ \rho\pi\, S$
$a_2(1320)$	$1321 \pm 1^{+0}_{-7}$	$110 \pm 2^{+2}_{-15}$	$19.2 \pm 0.6^{+0.3}_{-2.2}$	$2^{++}1^+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

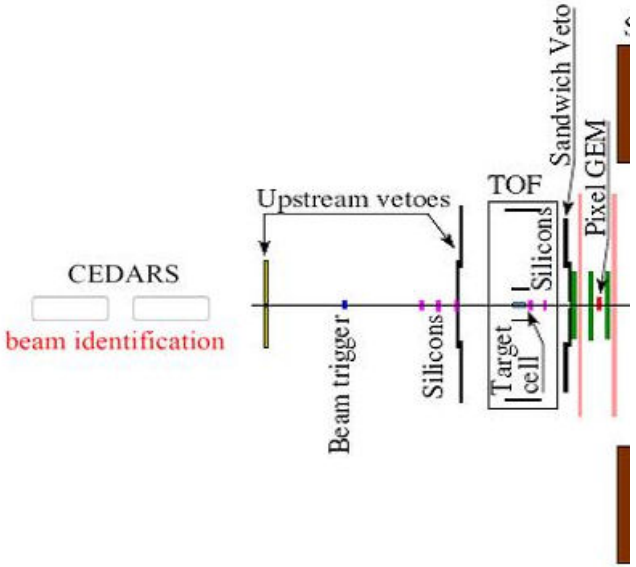
Systematic Studies

- Comparison of rank 1, 2, 3 mass independent fits
- Different Exclusivity Cut (189 ± 3 or 5 GeV)
- $\pi_1(1400)$ added as second Breit-Wigner resonance to describe 1^{-+} wave, parameters of $\pi_1(1400)$ fixed to PDG values
- 46 waves in mass-independent fit with four M = 2 waves included, thresholds adjusted
- D-functions with relativistic factors instead of Zemach tensors used for mass-independent fit
- Dynamical width for $a_4(2040)$ used instead of constant one

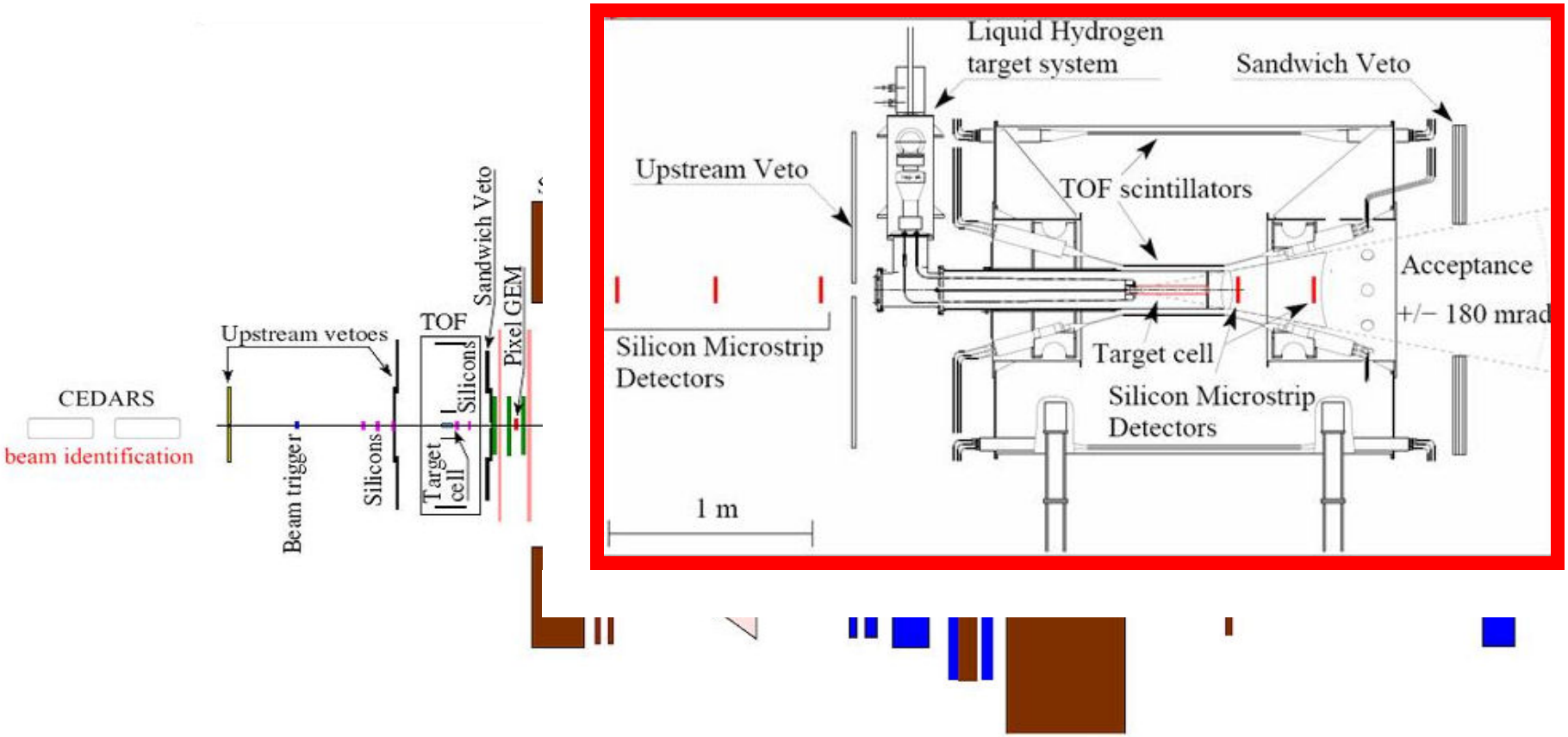
Spectrometer Upgrade 2008



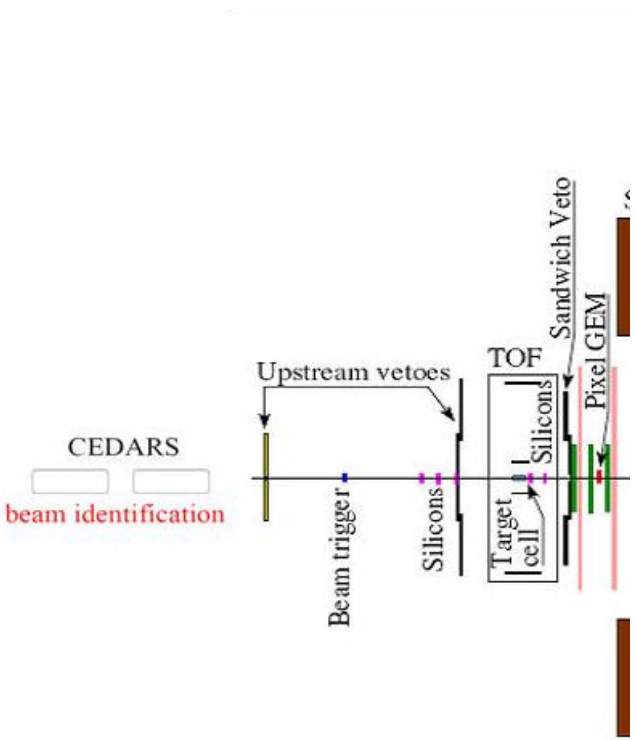
Spectrometer Upgrade 2008 - Beam Particle Identification

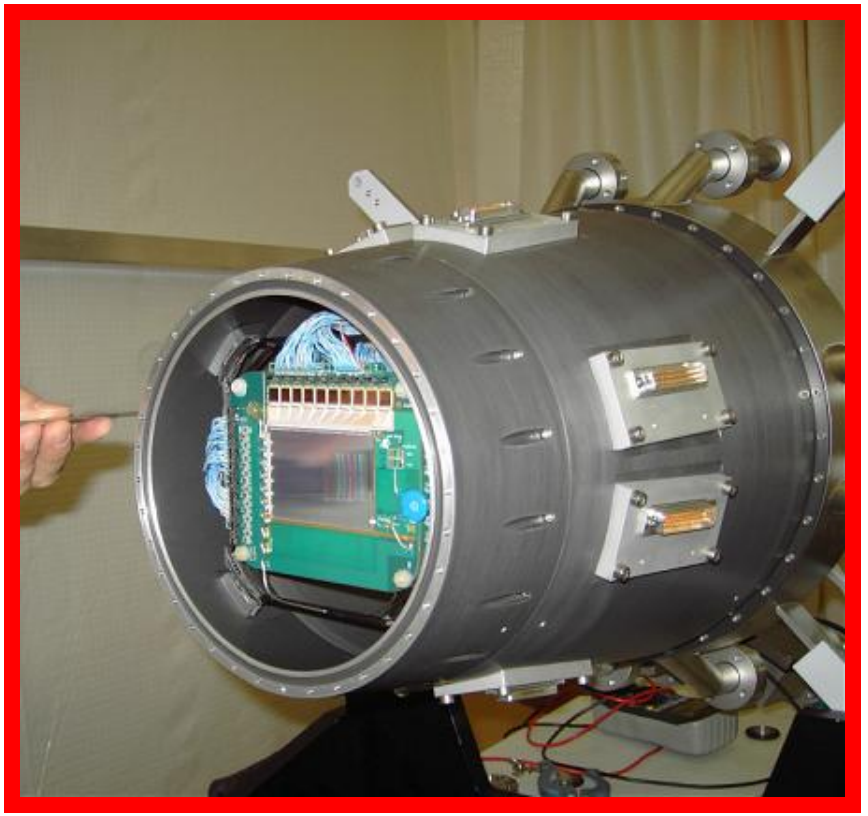


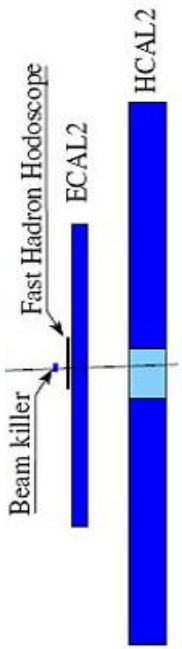
Spectrometer Upgrade 2008 - Liquid Hydrogen Target - Proton Recoil Detector



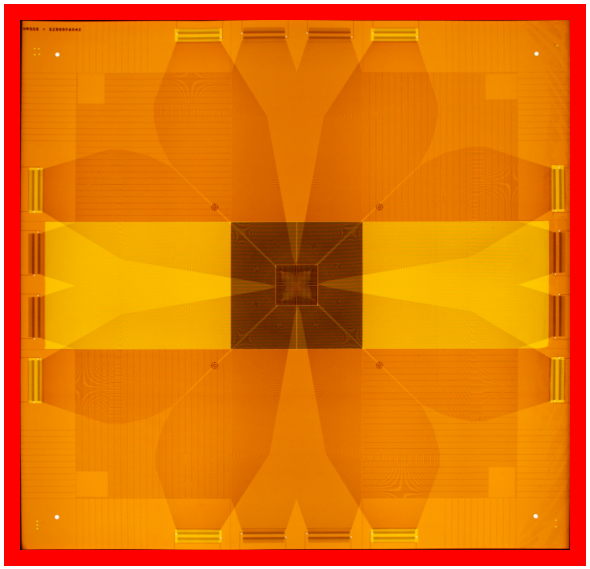
Spectrometer Upgrade 2008 - Target Region - Silicon Microstrip Detectors



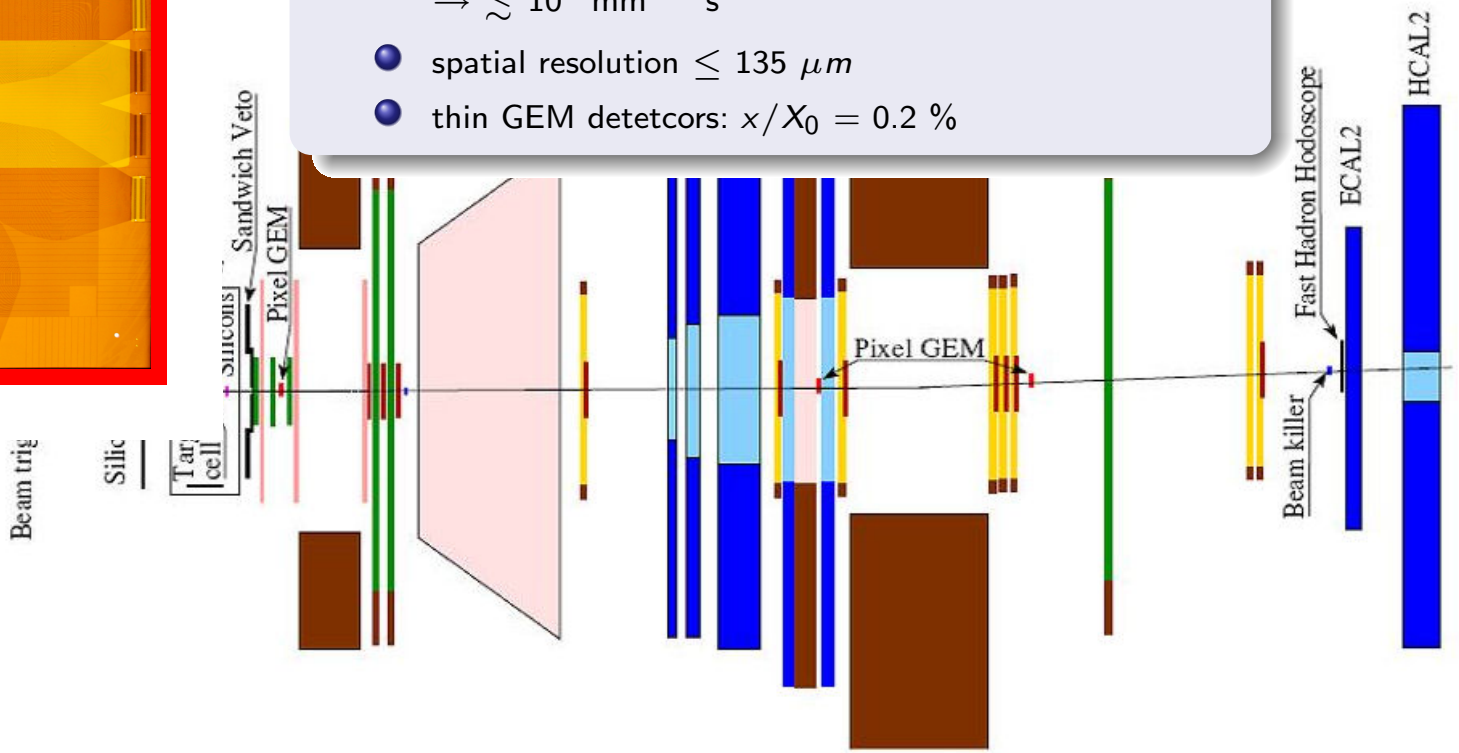




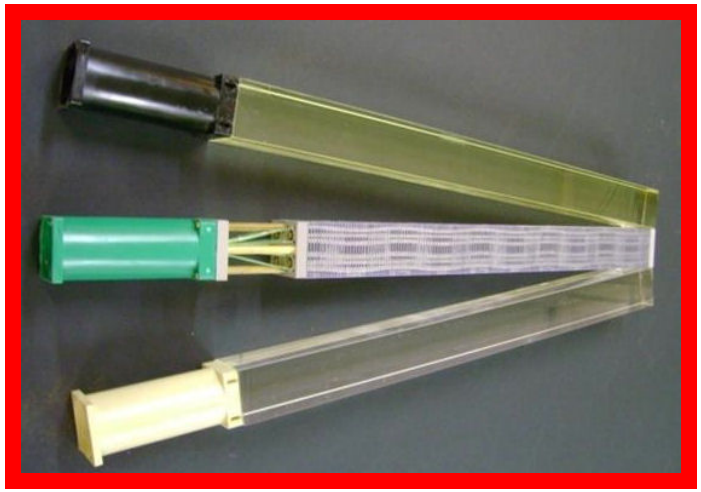
Spectrometer Upgrade 2008 - PixelGEM Detectors



- stable operation in high intensity muon/hadron beam $\rightarrow 4{\cdot}10^7 s^{-1}$
- Pixel readout allows tracking in a high rate beam $\rightarrow \lesssim 10^5$ mm^{-2} s^{-1}
- spatial resolution $\leq 135\ \mu m$
- thin GEM detetcors: $x/X_0 = 0.2$ %

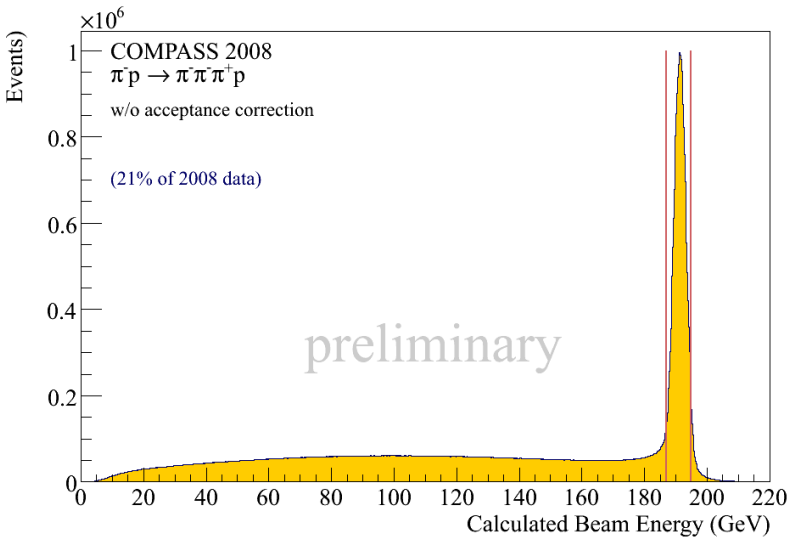


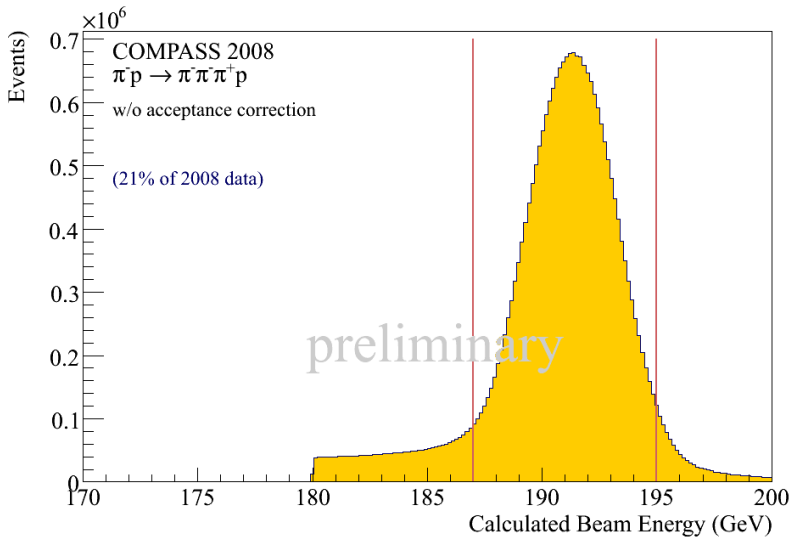
Spectrometer Upgrade 2008 - Electromagnetic Calorimeter



Diffractive Dissociation into $\pi^-\pi^-\pi^+$ Final States

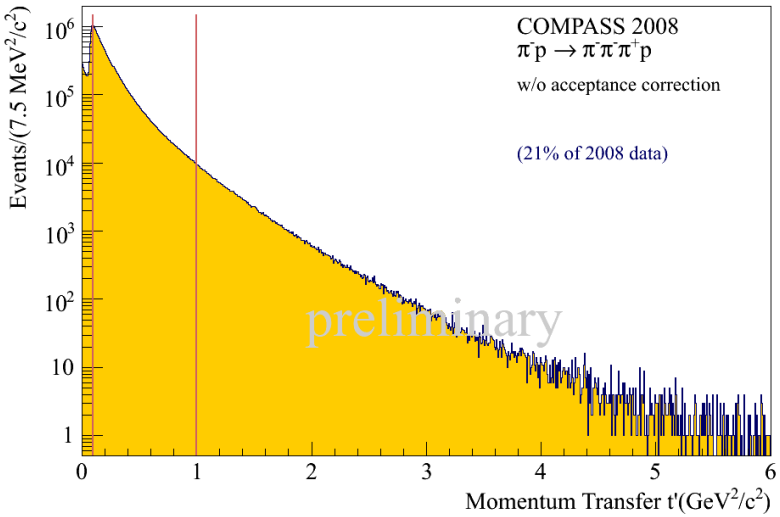
- 190 GeV/c hadron beam $\longrightarrow$ $96\%\pi^-, 3.5\%K^-, 0.5\%\overline{p}$
- 40cm liquid hydrogen target
- Exclusive measurement

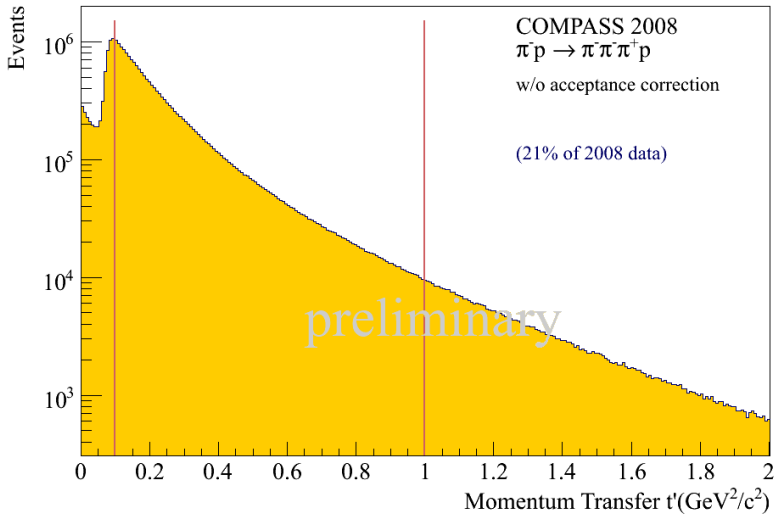




Diffractive Dissociation into $\pi^-\pi^-\pi^+$ Final States

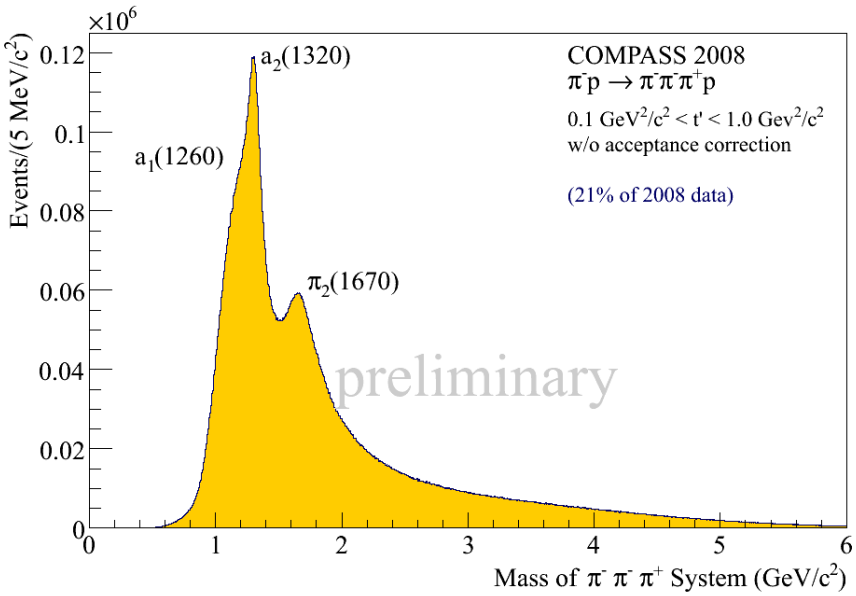
- 190 GeV/c hadron beam $\rightarrow 96\%\pi^-, 3.5\%K^-, 0.5\%\bar{p}$
- 40cm liquid hydrogen target
- Exclusive measurement
- Only high t' ($t' > 0.07\text{GeV}^2/c^2$) accessible in 2008

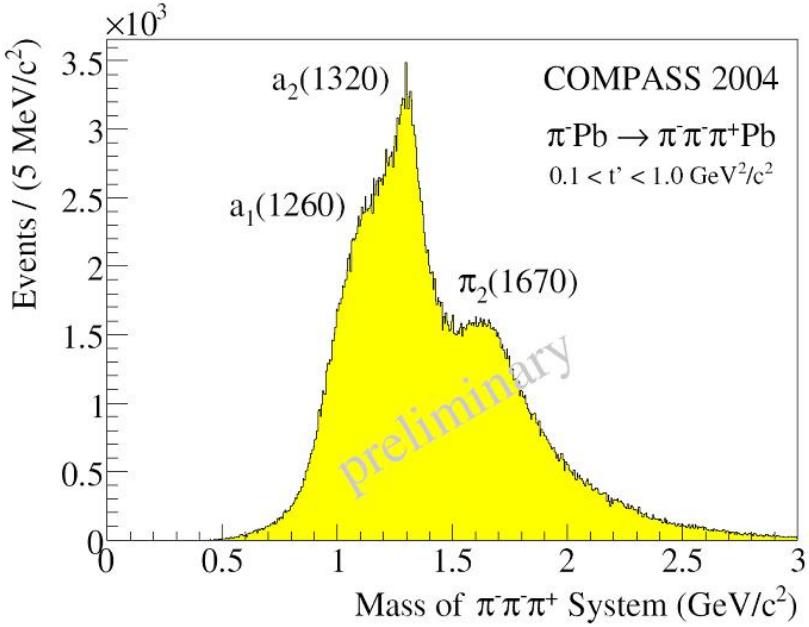




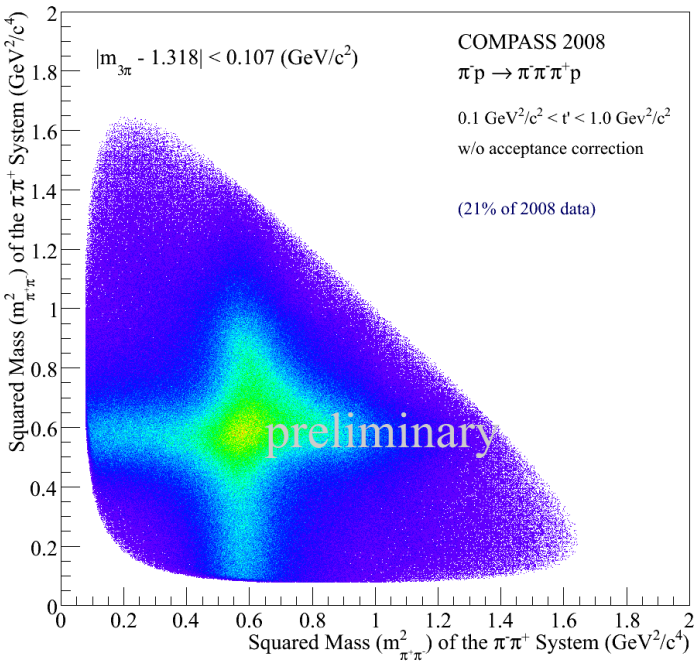
Ivariant Mass Spectrum of $\pi^-\pi^-\pi^+$ Final States

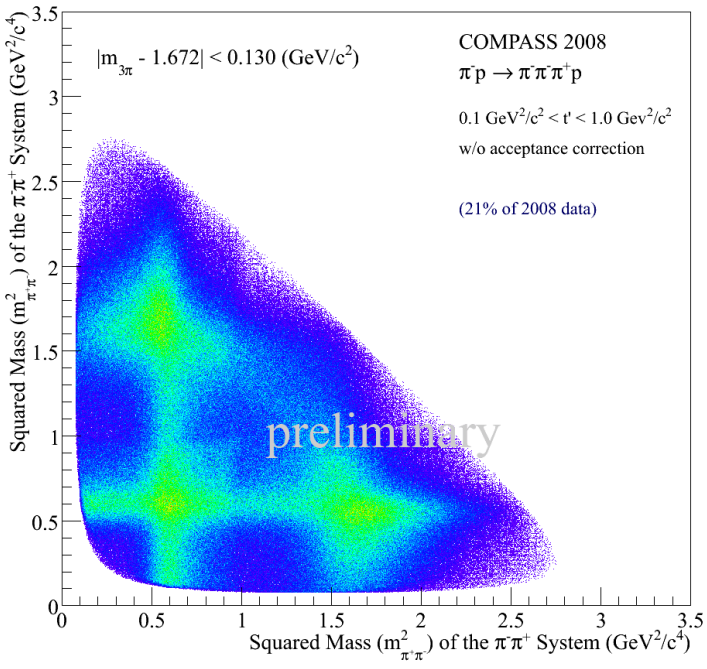
- 190 GeV/c hadron beam $\longrightarrow 96\%\pi^-, 3.5\%K^-, 0.5\%\overline{p}$
- 40cm liquid hydrogen target
- Exclusive measurement
- $0.1\text{GeV}^2/c^2 < t' < 1.0\text{GeV}^2/c^2$
- $\sim$16M events, 21% of 2008 data





Dalitz Plots





Left: Dalitz plot for $a_2(1320)$, events selected by $\pm\Gamma_0$ around a_2 mass.
Right: Dalitz plot for $\pi_2(1670)$ with $\pm 0.5\Gamma_0$.

Mass-Independent PWA

- Illinois/Protvino/Munich Program used.
- Same wave set (42 waves) and thresholds as for 2004 data.
- No acceptance correction applied yet.
- 40 MeV/c^2 mass bins.
- 10 fits per mass bin.
- D-Functions instead of Zemach-Tensors for parametrisation of decay amplitudes.
- Same mass range as for 2004 data: 0.5-2.5 GeV/c^2.

Mass-Independent PWA - Event Overview

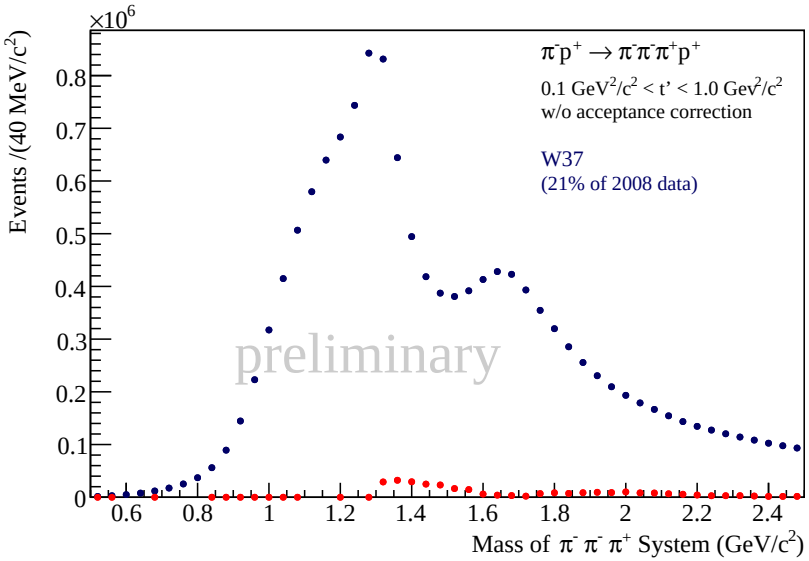


Figure: Comparison of all events with background wave ("FLAT")

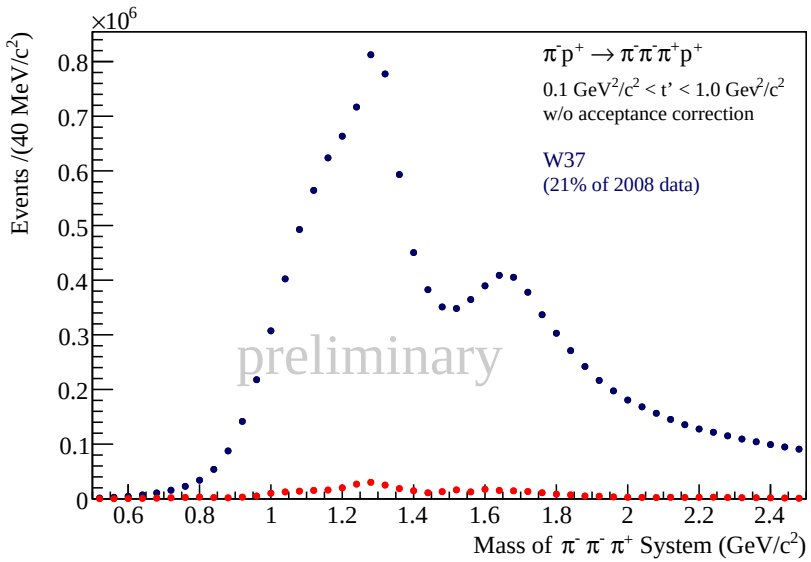
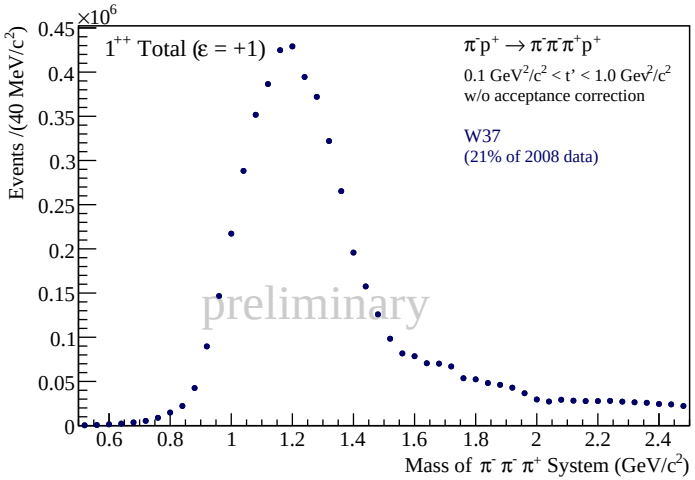
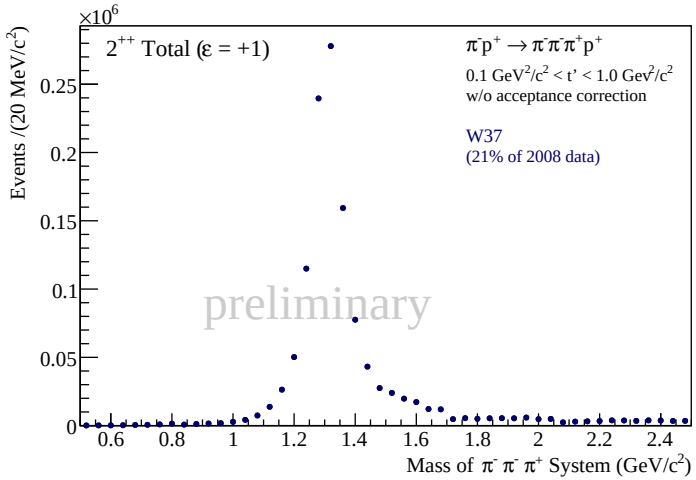
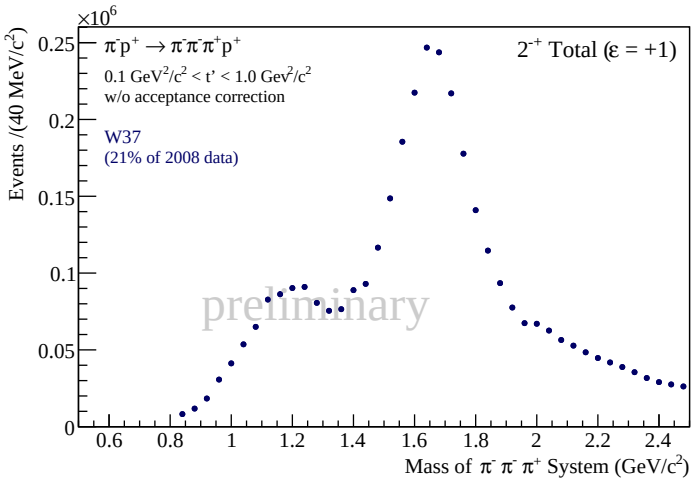


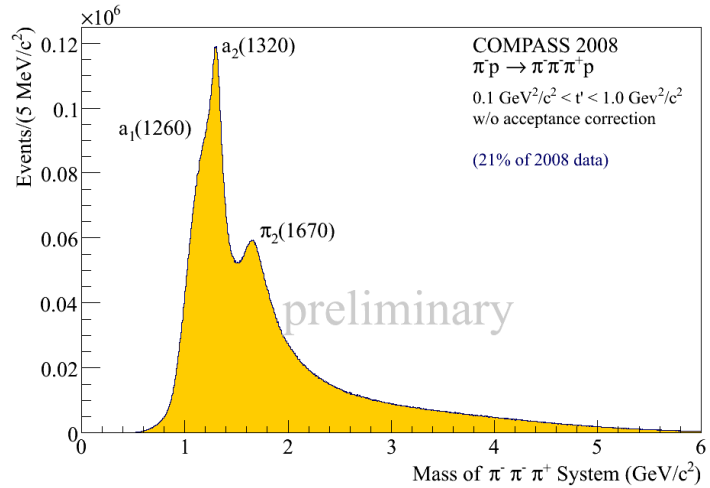
Figure: Comparison of positive and negative totals

Intensities of dominant J^{PC} states









M-Dependence on the Target Material

Comparison of fit results with 2004 data

- 2004 lead target, 2008 liquid hydrogen target
- Different statistcis
  - Normalisation to the integral of the $a_2(1320)$ in the mass region between 1.1 GeV/c^2 and 1.6 GeV/c^2
- Population of M = 1 states higher for lead target
- Population of M = 0 states higher for hydrogen target

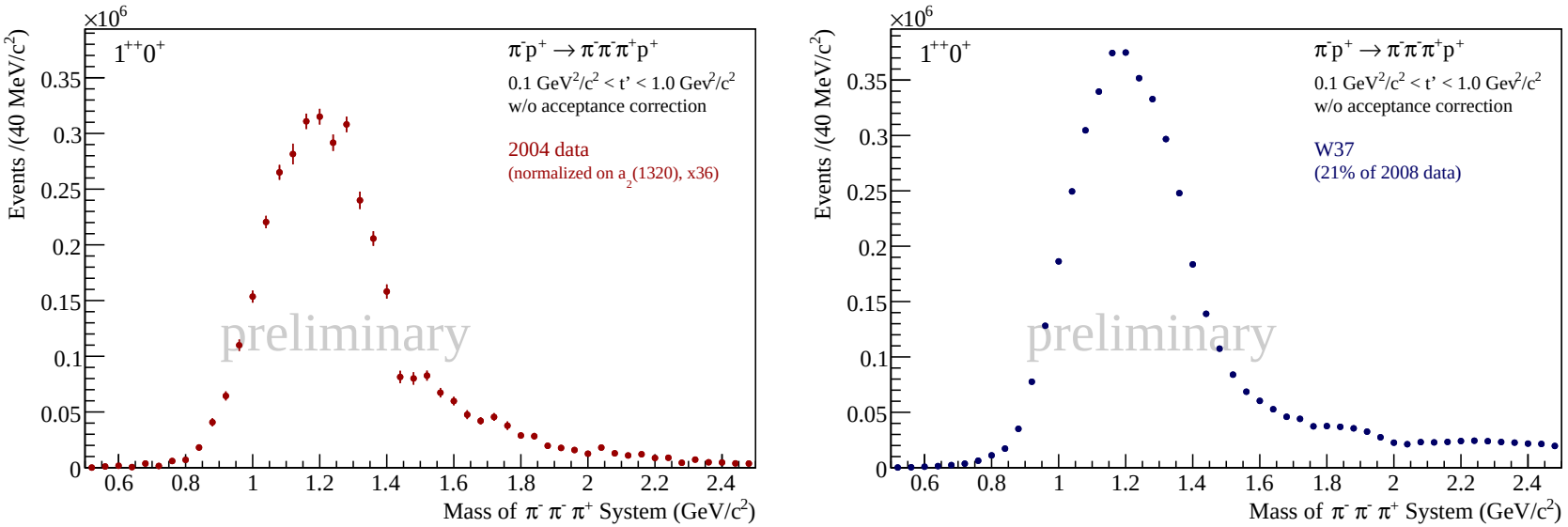


Figure: Total Intensities for $J^{PC} = 1^{++}$ with $M = 0$ (2004 red, 2008 blue)

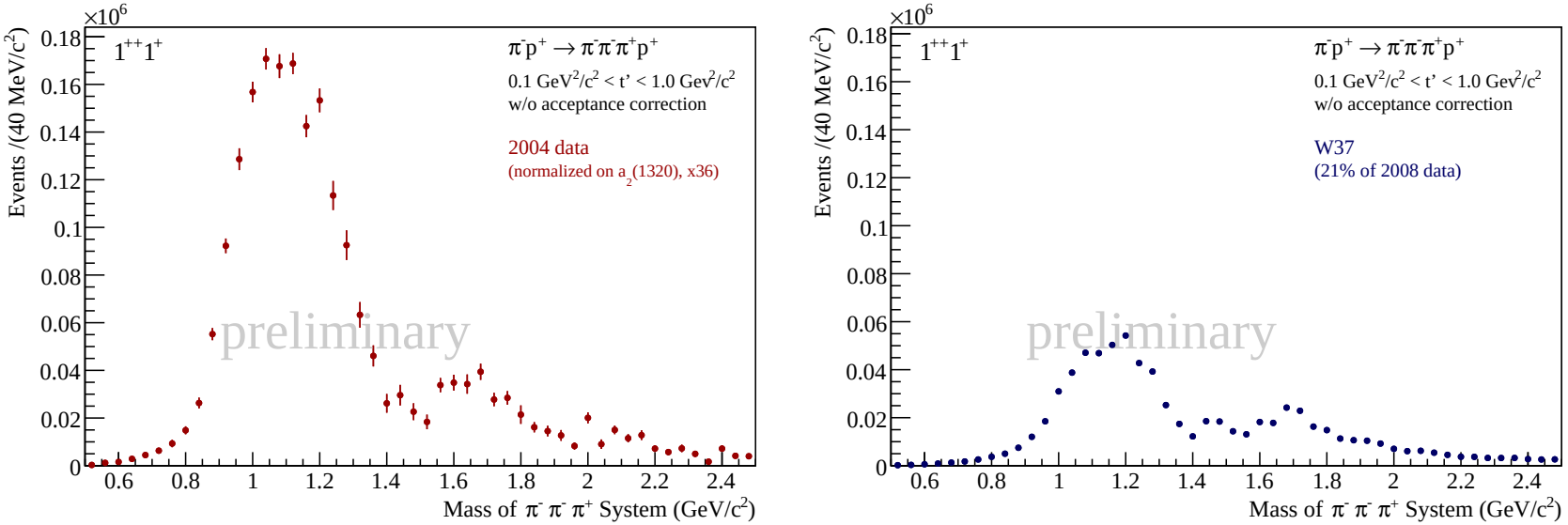


Figure: Total Intensities for $J^{PC} = 1^{++}$ with $M = 1$ (2004 red, 2008 blue)

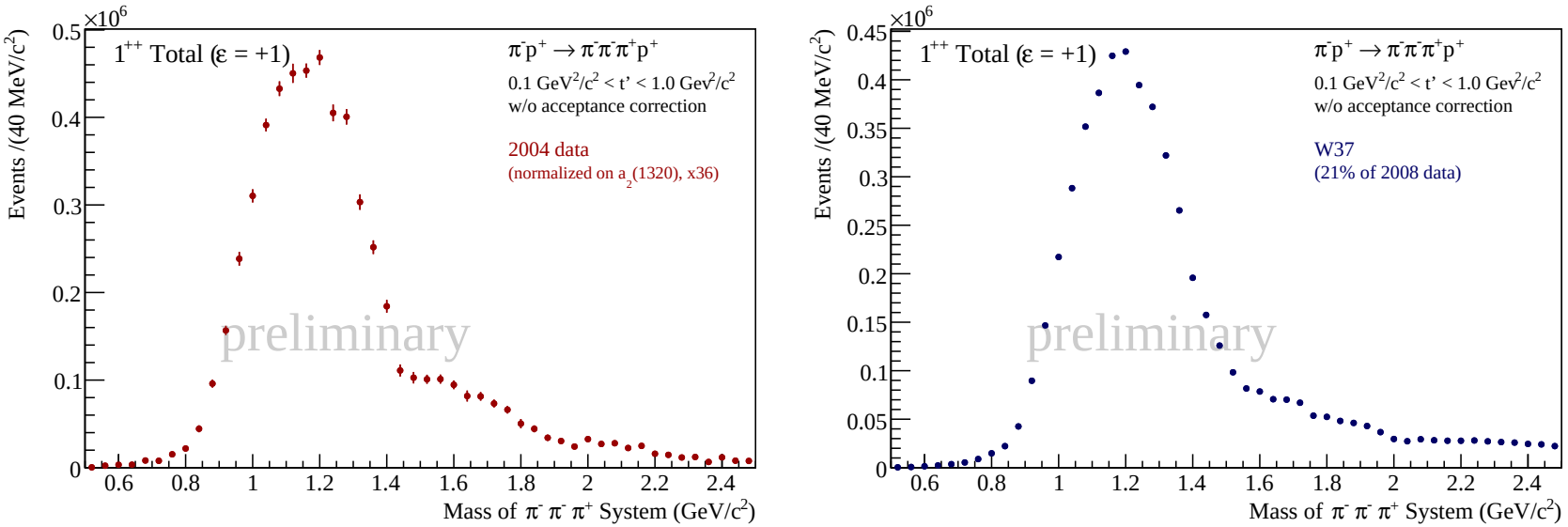


Figure: Total Intensities for $J^{PC} = 1^{++}$ (2004 red, 2008 blue)

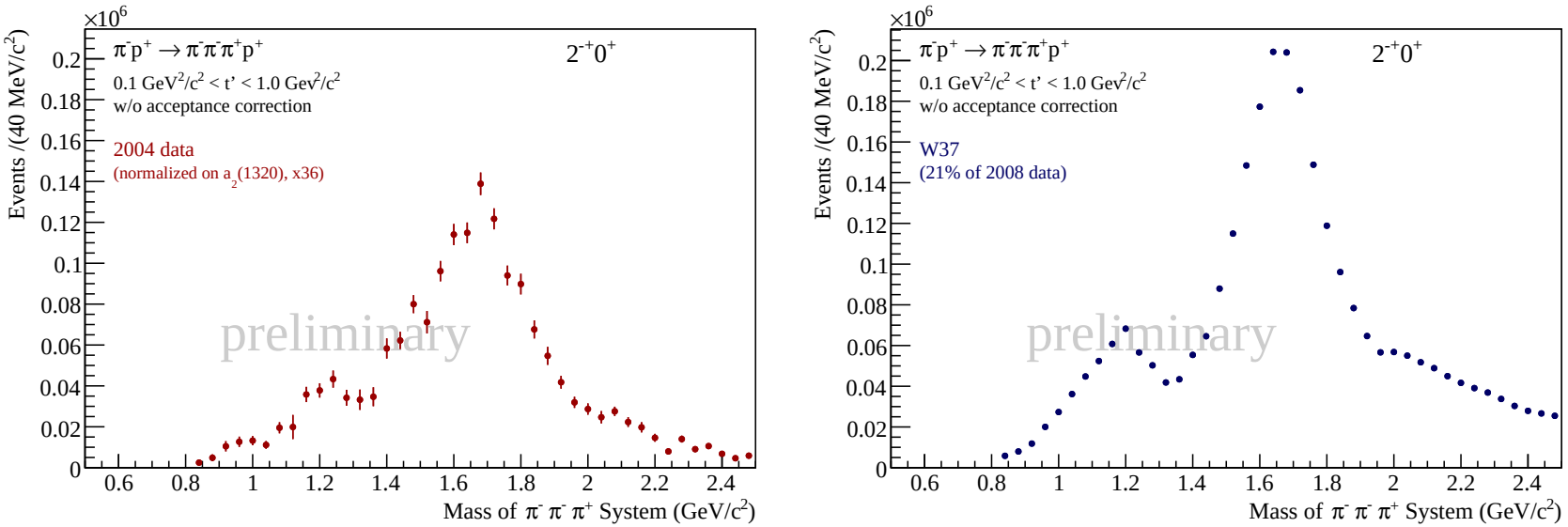


Figure: Total Intensities for $J^{PC} = 2^{-+}$ with $M = 0$ (2004 red, 2008 blue)

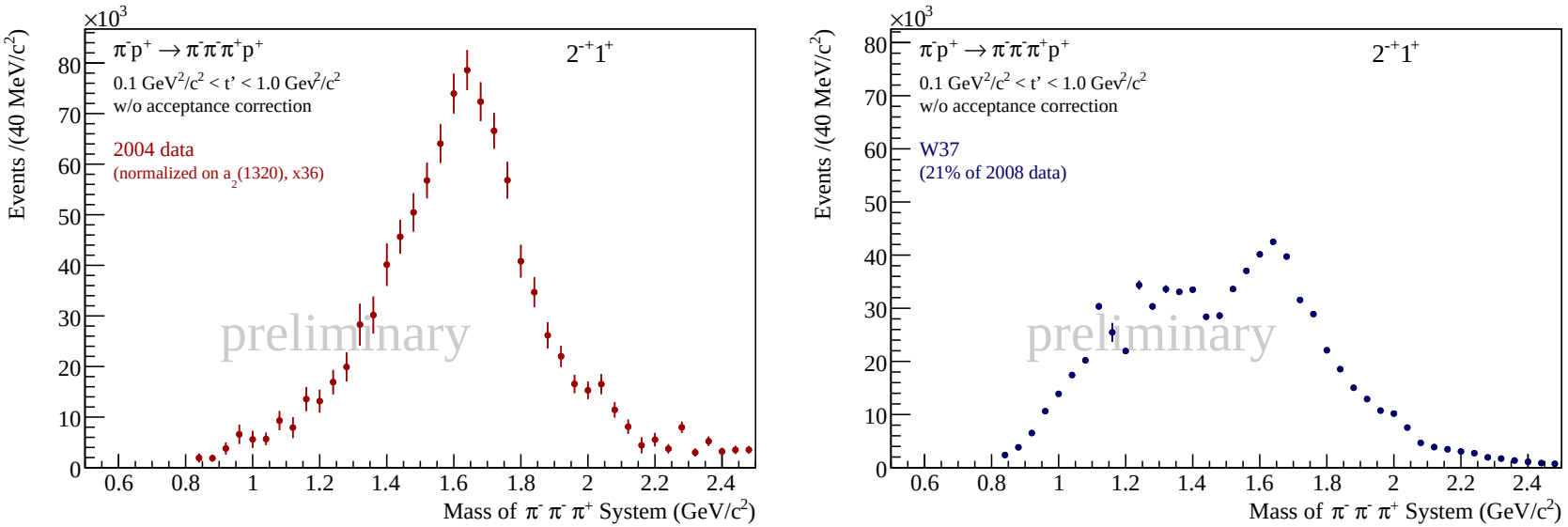


Figure: Total Intensities for $J^{PC} = 2^{-+}$ with $M = 1$ (2004 red, 2008 blue)

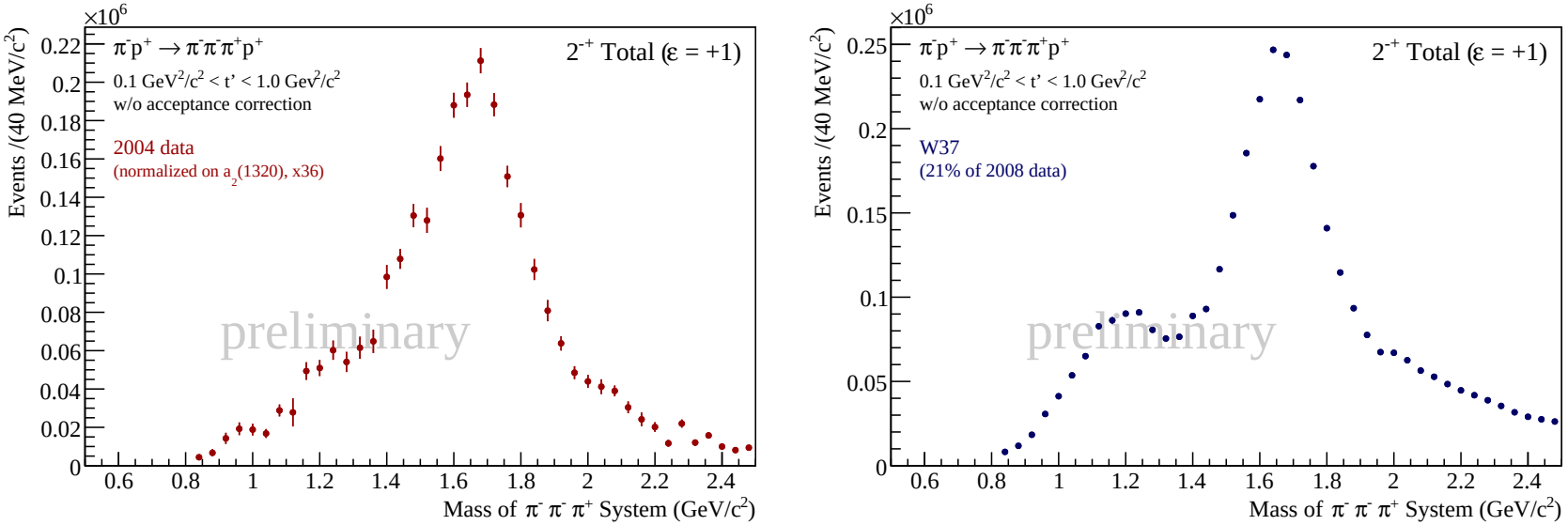
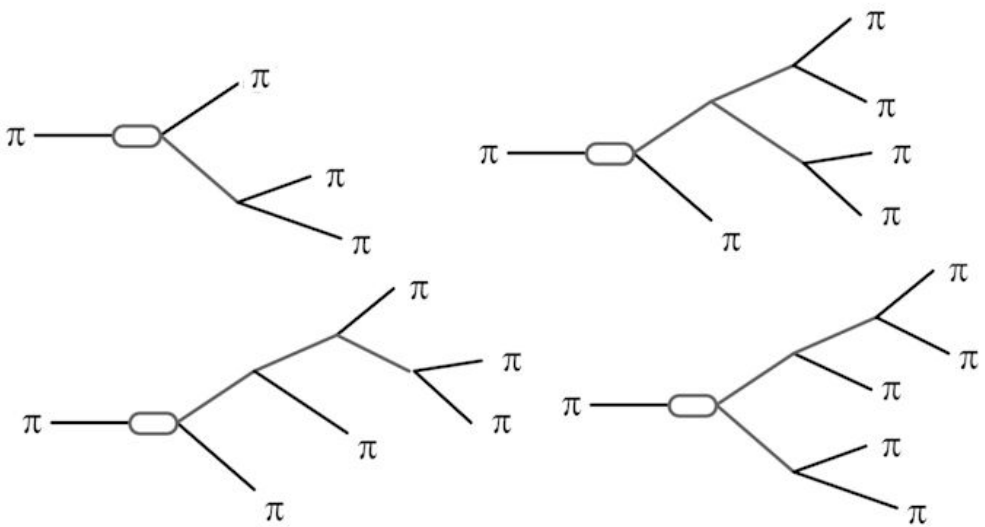


Figure: Total Intensities for $J^{PC} = 2^{-+}$ (2004 red, 2008 blue)

- Pilot Run 2004
  - Competitive amount of data in few days of data taking
  - Significant intensitiy of exotic wave 1^{-+} at 1.66 GeV/c^2
- COMPASS 2008/2009
  - Spectrometer upgrade:
    $\rightarrow$CEDARS, liquid hydrogen target, RPD, additional Silicons, PixelGEMs, ECALs
  - Diffractive reactions: 10x BNL E852 statistics
  - Analysis ongoing
    - Enhancement of wave set
    - Acceptance correction
    - Study of Deck Effect
    - Isobar parametrisations
    - Analysis of M-Dependence with different targets
- Two independent PWA programs ($\rightarrow$ see Seabstian Neubert's talk!)

Backup

Interesting Candidate



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

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

COMPASS has access to all of these decay modes

Wave Set of 2004 3π PWA

$J^{PC}M^{\epsilon}$	L	Isobar π	Thresh. [GeV]
$0^{-+}0^{+}$	S	$f_0\pi$	1.40
$0^{-+}0^{+}$	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	$(\pi\pi)_S\pi$	0.84
$1^{++}0^{+}$	D	$\rho\pi$	1.30
$1^{++}1^{+}$	S	$\rho\pi$	-
$1^{++}1^{+}$	P	$f_2\pi$	1.40
$1^{++}1^{+}$	P	$(\pi\pi)_S\pi$	1.40
$1^{++}1^{+}$	D	$\rho\pi$	1.40
$2^{-+}0^{+}$	S	$f_2\pi$	1.20
$2^{-+}0^{+}$	P	$\rho\pi$	0.80
$2^{-+}0^{+}$	D	$f_2\pi$	1.50
$2^{-+}0^{+}$	D	$(\pi\pi)_S\pi$	0.80
$2^{-+}0^{+}$	F	$\rho\pi$	1.20
$2^{-+}1^{+}$	S	$f_2\pi$	1.20
$2^{-+}1^{+}$	P	$\rho\pi$	0.80
$2^{-+}1^{+}$	D	$f_2\pi$	1.50
$2^{-+}1^{+}$	D	$(\pi\pi)_S\pi$	1.20
$2^{-+}1^{+}$	F	$\rho\pi$	1.20

$J^{PC}M^{\epsilon}$	L	Isobar π	Thresh. [GeV]
$2^{++}1^{+}$	P	$f_2\pi$	1.50
$2^{++}1^{+}$	D	$\rho\pi$	-
$3^{++}0^{+}$	S	$\rho_3\pi$	1.50
$3^{++}0^{+}$	P	$f_2\pi$	1.20
$3^{++}0^{+}$	D	$\rho\pi$	1.50
$3^{++}1^{+}$	S	$\rho_3\pi$	1.50
$3^{++}1^{+}$	P	$f_2\pi$	1.20
$3^{++}1^{+}$	D	$\rho\pi$	1.50
$4^{-+}0^{+}$	F	$\rho\pi$	1.20
$4^{-+}1^{+}$	F	$\rho\pi$	1.20
$4^{++}1^{+}$	F	$f_2\pi$	1.60
$4^{++}1^{+}$	G	$\rho\pi$	1.64
$1^{-+}0^{-}$	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			