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

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for the COMPASS collaboration

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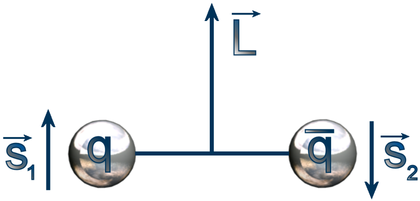
Overview

Overview

Preface

Mesons within the Quarkmodell



Quantum Numbers

- $X(I^G J^{PC})$
- LS-Coupling:
  $J = \ell \oplus s = |\ell - s| ... \ell + s$
- Parity:
  $P = (-1)^{(\ell+1)}$
- Charge Conjugation:
  $C = (-1)^{(\ell+s)}$
- Isospin I
- G-Parity:
  $G = C \cdot e^{i\pi I_2}$

Motivation

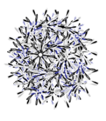
Quantumchromodynamics

QuantumChromoDynamics allows: meson states not foreseen within the quark model:

Tetraquarks

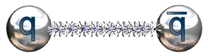
- Two $q\bar{q}$ pairs
- Possible lightest candidates: $f_0(600)$, $f_0(980)$, $a_0(980)$

Glueballs



- Consists only of glue
- Lattice gauge theory: ground state 0^{++}, first excited state 2^{++}
- Mixing with nearby $q\bar{q}$ states of same quantum numbers: $f_0(1370)$, $f_0(1500)$, $f_0(1710)$

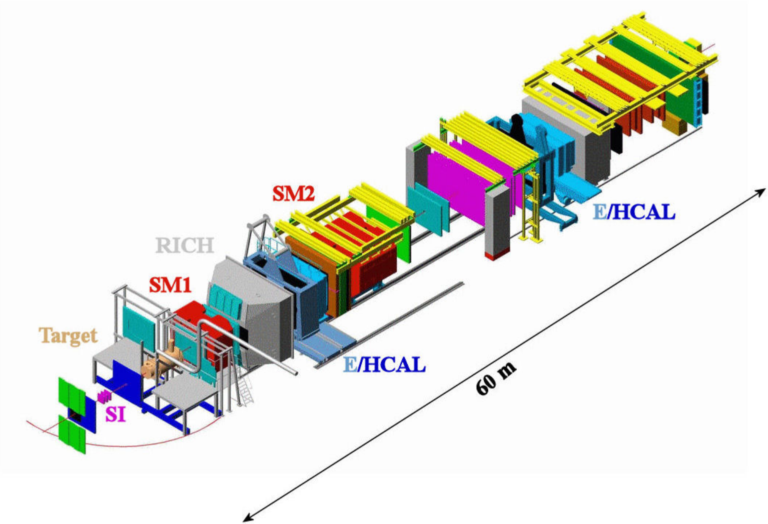
Hybrids



- $q\bar{q}$ pair bound by excited gluons, $q\bar{q}g$
- Lightest hybrid, $J^{PC} = 1^{-+}$, predicted in the mass region of 1.3-2.2 GeV/c^2

The COMPASS Experiment

Overview



The COMPASS Experiment

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Overview

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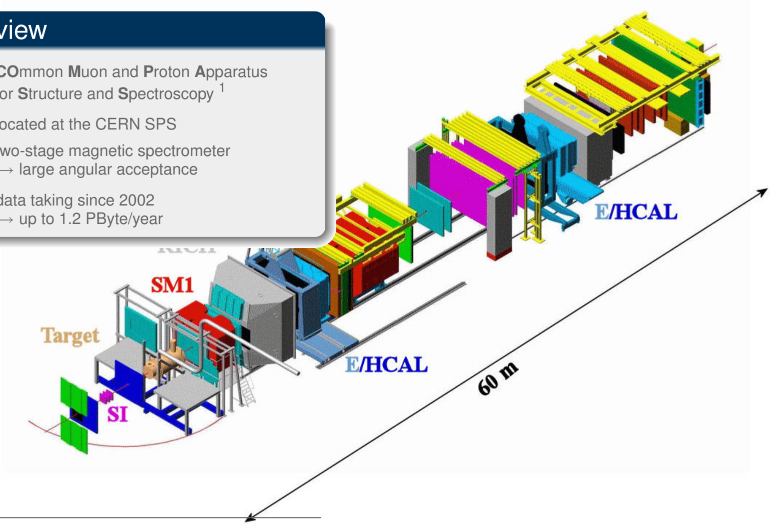
- **CO**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy [1]
- located at the CERN SPS
- two-stage magnetic spectrometer
  $\longrightarrow$ large angular acceptance
- data taking since 2002
  $\longrightarrow$ up to 1.2 PByte/year



[1] [Nucl. Instr. and Meth. A 577 (2007) 455]

The COMPASS Experiment

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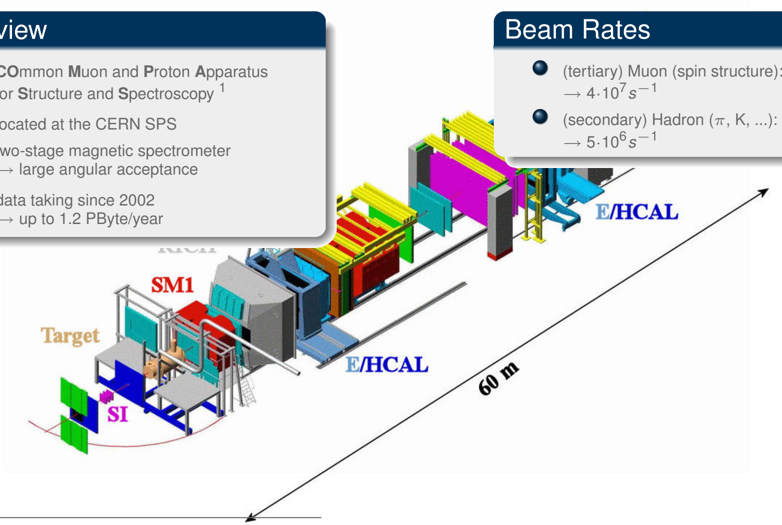
Beam Rates

- (tertiary) Muon (spin structure):
  $\longrightarrow 4{\cdot}10^7 s^{-1}$
- (secondary) Hadron (π, K, ...):
  $\longrightarrow 5{\cdot}10^6 s^{-1}$



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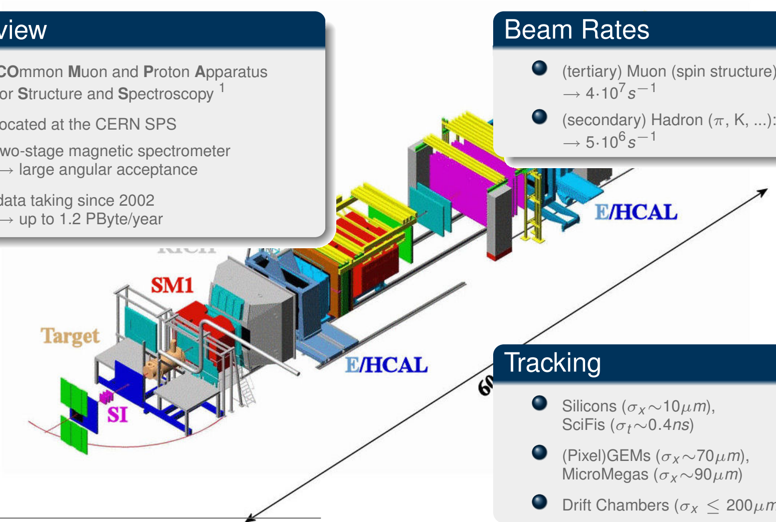


Tracking

- Silicons ($\sigma_x \sim 10\mu m$),
  SciFis ($\sigma_t \sim 0.4ns$)
- (Pixel)GEMs ($\sigma_x \sim 70\mu m$),
  MicroMegas ($\sigma_x \sim 90\mu m$)
- Drift Chambers ($\sigma_x \leq 200\mu m$)

[1] [Nucl. Instr. and Meth. A 577 (2007) 455]

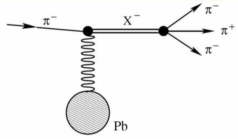
Overview

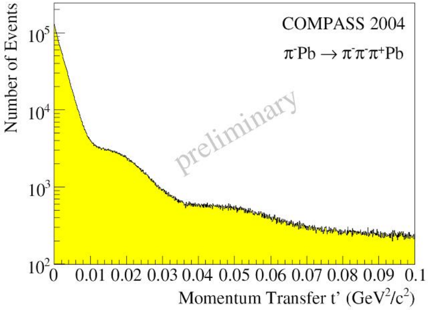
Diffractive Dissociation into $\pi^-\pi^-\pi^+$ Final States

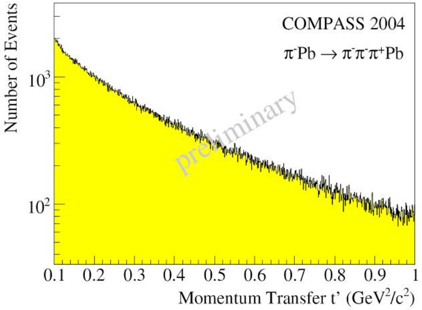
Diffractive Dissociation

- Decoupling of resonance and target vertex, no final state interaction with target
- Space-like Regge process, Pomeron exchange $\longrightarrow$ only momentum and angular momentum transfer to beam particle
- COMPASS 2004: $\pi^- + Pb \rightarrow \pi^-\pi^-\pi^+ + Pb$

Reaction







Invariant Mass of 3π System

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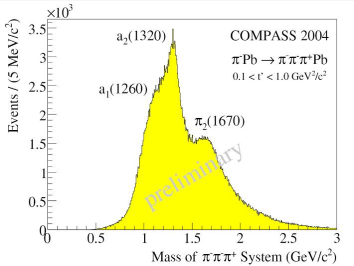
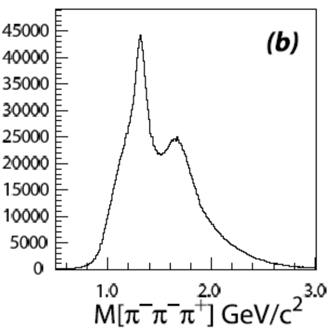


- $p_\pi = 190 GeV/c$
- 4M events (full t range)
- 450k events in $0.1 <$ t' < 1.0 GeV^2/c^2

BNL E852



Two analysis:

S. U. Chung *et al.*, Phys. Rev. **D65**, 072001 (2002)
A. R. Dzerbia *et al.*, Phys. Rev. **D73**, 072001 (2006)

Acceptance Simulations

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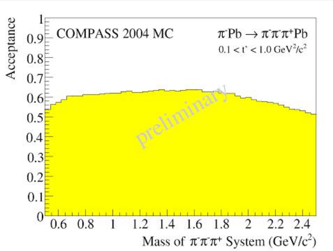
COMPASS



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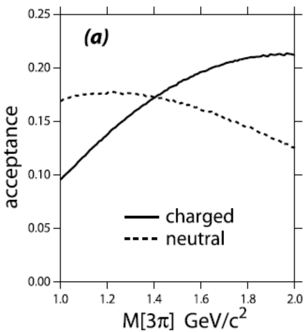

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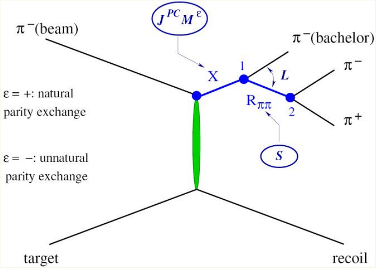
Partial Wave Analysis - Isobar Model

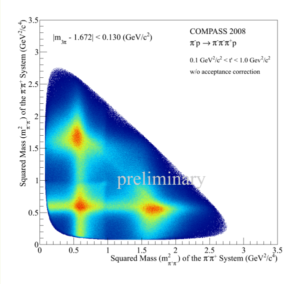
- Two independent PWA programs:
  - Illinois/Protvino/Munich
  - BNL/Munich
- Stepwise 2-body decays, intermediate isobar states
- Reflectivity basis

$$\psi^{\epsilon}_{JM} = c(M)[\psi_{JM}(\tau) - \epsilon P(-1)^{J-M}\psi_{J-M}(\tau)] \text{ with } \epsilon : -1, 1 \text{ and } M : 0, .., J$$

Isobar Model



Dalitz Plot $\pi_2(1670)$ region



PWA Technique

Step 1: Mass-Independent PWA

- Independent fits in 40 MeV mass bins

$$\sigma_{indep}(\tau, m, t') = \sum_{\epsilon=\pm1} \sum_{r=1}^{N_r} \left| \sum_i T_{ir}^{\epsilon} f_i^{\epsilon}(t') \psi_i^{\epsilon}(\tau, m) / \sqrt{\int \left| \psi_i^{\epsilon}(\tau', m) \right|^2 d\tau'} \right|^2$$

- Production amplitudes T_{ir}^{ϵ} $\longrightarrow$ extended maximum likelihood fit
- Decay amplitudes $\psi_i^{\epsilon}(\tau, m)$ (Zemach tensors, D-functions)
- 41 partial waves $i = J^{PC} M^{\epsilon} [isobar] L$ + flat background
  - no assumption on resonant behaviour of any wave
  - isobars: $(\pi\pi)_S$, $\rho(770)$, $f_0(980)$, $f_2(1270)$, $\rho_3(1690)$
  - positive reflectivity dominates
  - 7 negative reflectivity waves included
  - more M=1 waves than previous (e.g. BNL E852) analyses

Step 2: Mass-Dependent χ^2 fit

- 6 waves
- Parameterized by relativistic Breit-Wigner functions with dynamic widths
- Coherent background for some waves

Intensities of Major Waves

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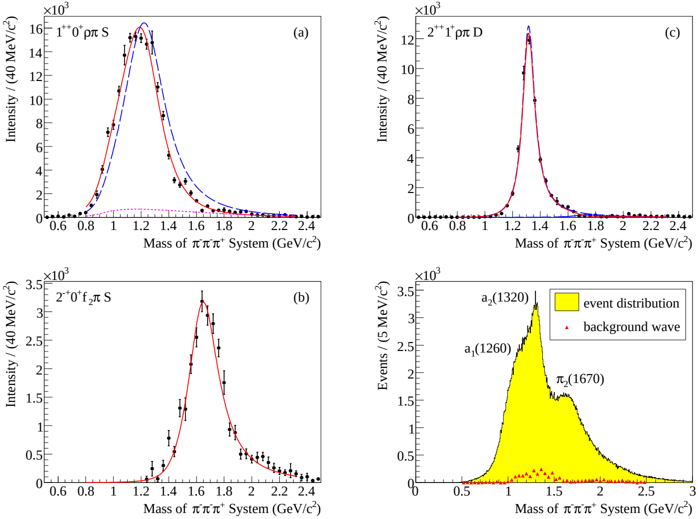
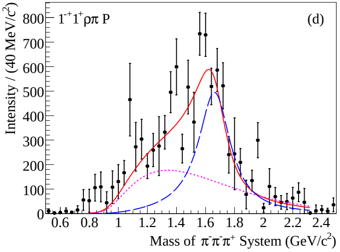
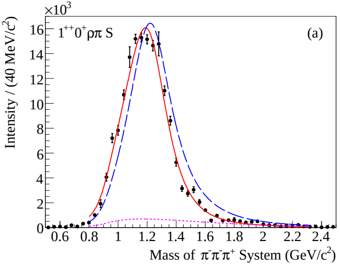
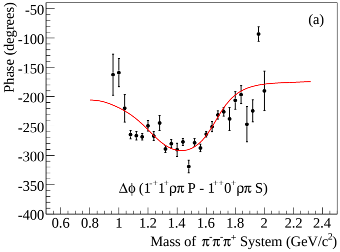


$J^{PC} = 1^{-+}$ Exotic Wave







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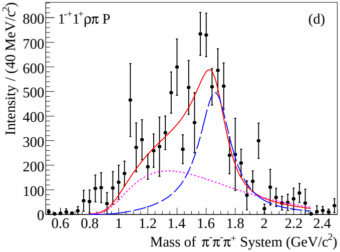

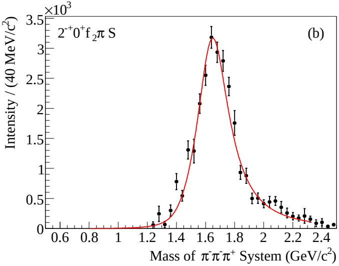

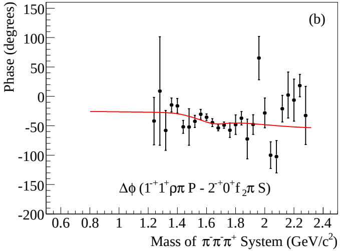

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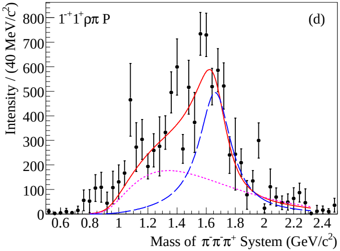


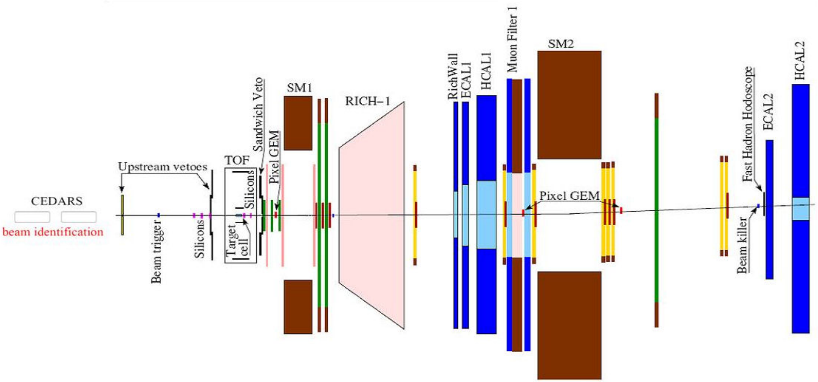
BW parameter[1] for $\pi_1(1600)$

- $M = \left(1660 \pm 10^{+0}_{-64}\right)$ MeV/c^2
- $\Gamma = \left(269 \pm 21^{+42}_{-64}\right)$ MeV/c^2

[1] A. Alekseev *et. al.*, COMPASS Collaboration, arXiv:0910.5842v1 (2009), Phys. Rev.Lett. in print

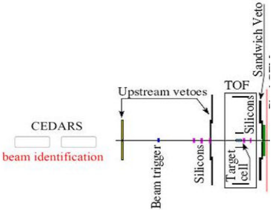
Overview

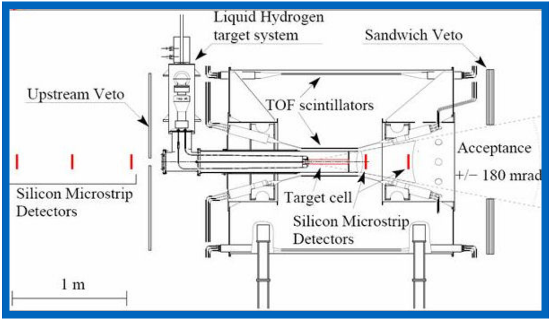
Spectrometer Upgrade 2008

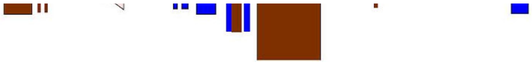


Spectrometer Upgrade 2008

Liquid Hydrogen Target - Proton Recoil Detector







Spectrometer Upgrade 2008

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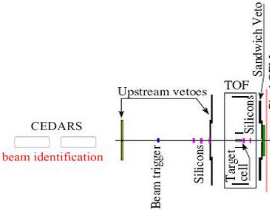

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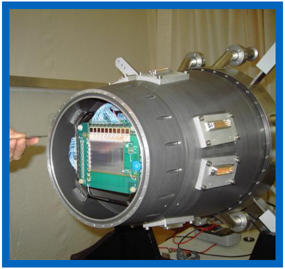

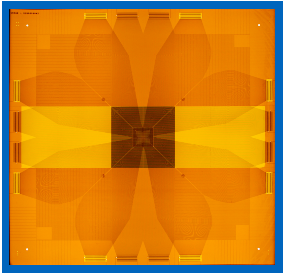

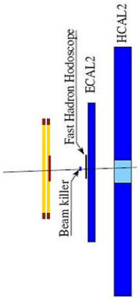

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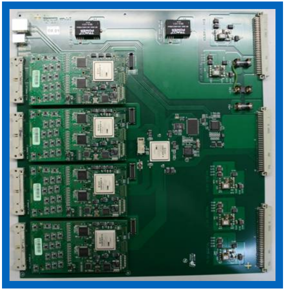
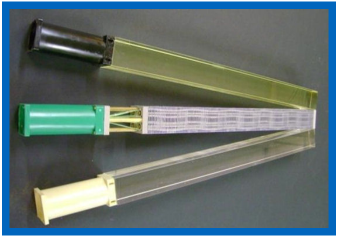
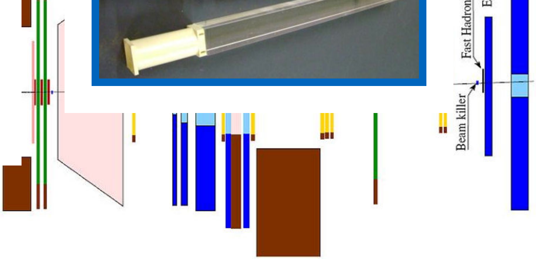
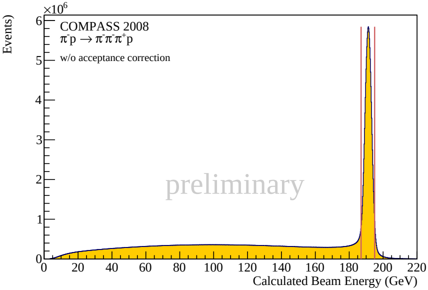


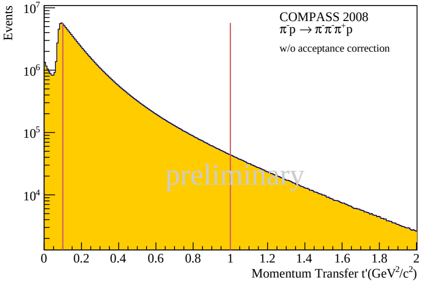




Diffractive Dissociation into $\pi^-\pi^-\pi^+$ Final State

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





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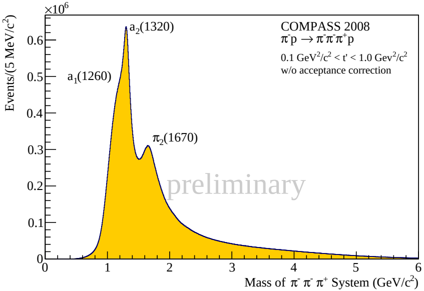
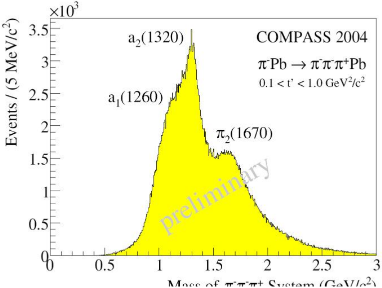
- 190 GeV/c hadron beam $\rightarrow 96\%\pi^-, 3.5\%K^-, 0.5\%\overline{p}$
- 40cm liquid hydrogen target
- Exclusive measurement
- $0.1\text{GeV}^2/\text{c}^2 < t' < 1.0\text{GeV}^2/\text{c}^2$
- $\sim$ **96M events**

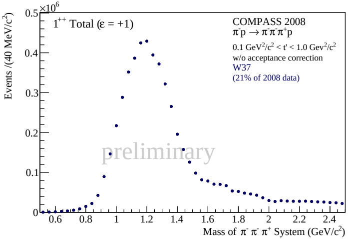


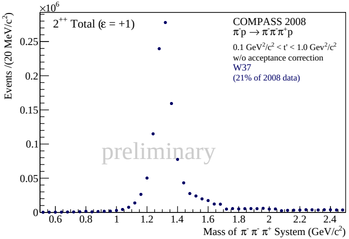


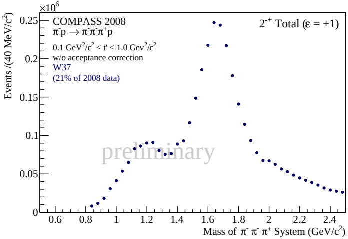
Mass-Independent PWA

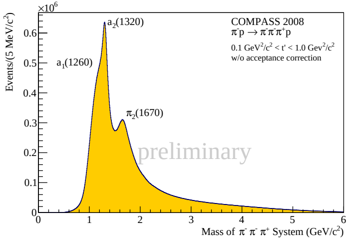
- Illinois/Protvino/Munich Program used.
- Same wave set (42 waves) and thresholds as for 2004 data.
- No acceptance correction applied yet.
- 40 MeV/c^2 mass bins.
- 10 fits per mass bin.
- D-Functions instead of Zemach-Tensors for parametrisation of decay amplitudes.
- Same mass range as for 2004 data: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

Intensities of dominant J^{PC} states



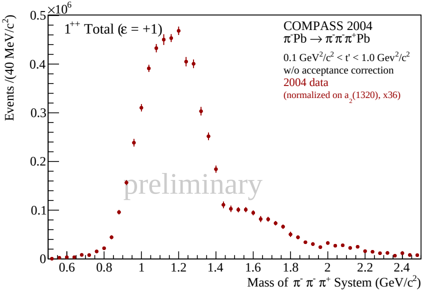


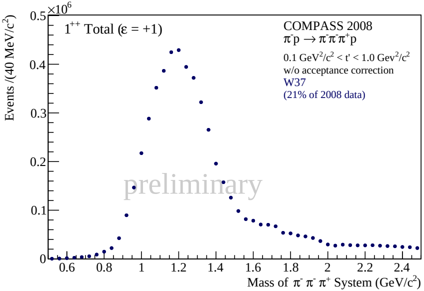




Total Intensities for $J^{PC} = 1^{++}$

2004 red, 2008 blue





- 2004 lead target, 2008 liquid hydrogen target
- Different statistics
  - 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

Total Intensities for $J^{PC} = 1^{++}$ with M = 0

2004 red, 2008 blue

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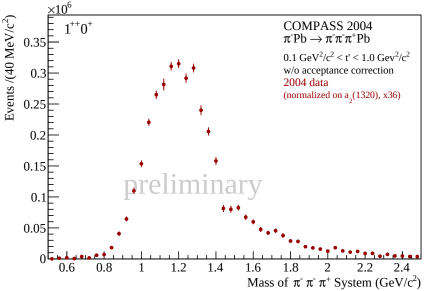

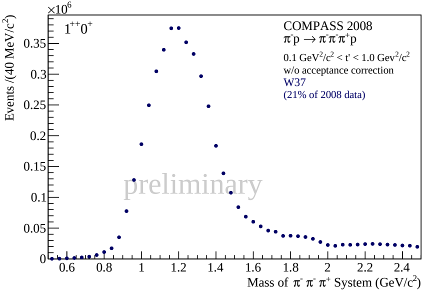

Population of M = 0 states higher for hydrogen target

Total Intensities for $J^{PC} = 1^{++}$ with M = 1

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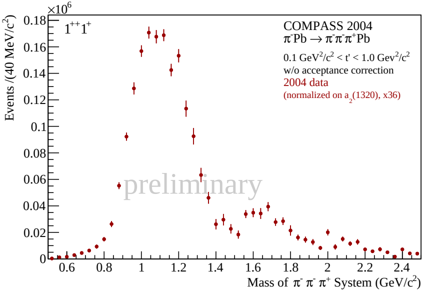
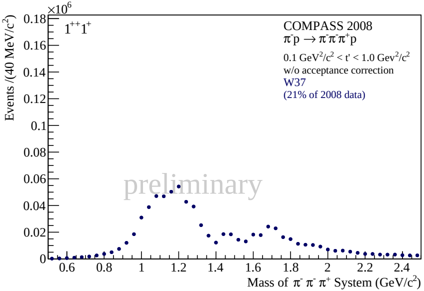
2004 red, 2008 blue





Population of M = 1 states higher for lead target

Overview

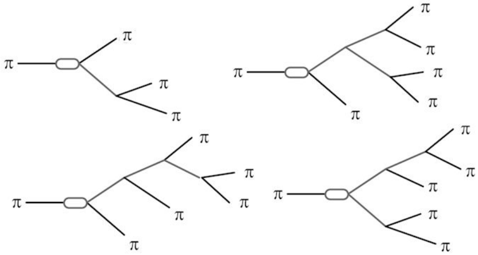
- Pilot Run 2004
    - Diffractive pion dissociation on Pb
    - Significant intensitiy of exotic wave 1^{-+} at 1.66 GeV/c^2
- COMPASS 2008/2009
    - Spectrometer upgrade
    - $100 \cdot 10^6$ **exclusive high t' events**
    - Analysis ongoing
        - Enhancement of wave set
        - Acceptance correction
        - Study of Deck Effect
        - Isobar parametrisations
        - Analysis of M-Dependence with different targets (p,Ni,W,Pb)
- Two independent PWA programs
- Analysis on charged, neutral and kaonic final states, see Sebastian Neubert's Talk (parallel session 2D)!

Backup

Systematic Studies

- Comparison of rank 1, 2, 3 mass independent fits
- Different Exclusivity Cut (189 $\pm$ 3 or 5 GeV)
- π_1(1400) added as second Breit-Wigner resonance to describe 1^{-+} wave, parameters of π_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

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

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$J^{PC}M^{\epsilon}$	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			

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

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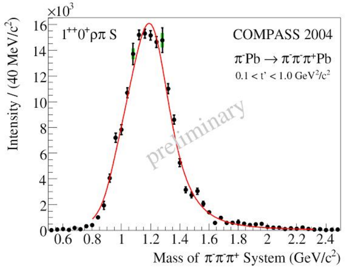
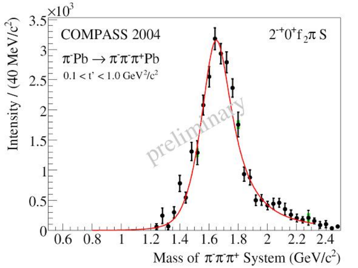
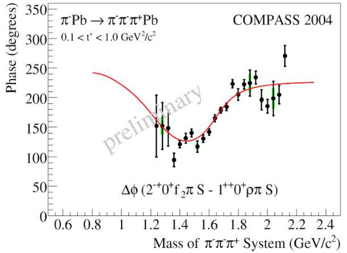
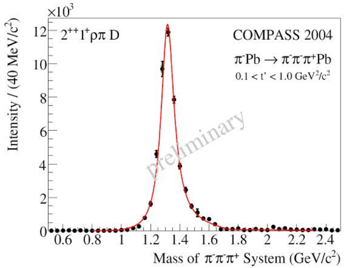


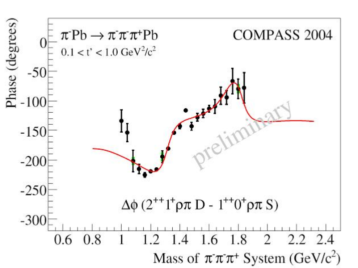




- BW für $a_1(1260)$ + Untergrund
  $M = \left(1255 \pm 6^{+7}_{-17}\right)\mathrm{MeV/c^2}$
  $\Gamma = \left(367 \pm 9^{+28}_{-25}\right)\mathrm{MeV/c^2}$
- BW für $\pi_2(1670)$
  $M = \left(1658 \pm 3^{+24}_{-8}\right)\mathrm{MeV/c^2}$
  $\Gamma = \left(271 \pm 9^{+22}_{-24}\right)\mathrm{MeV/c^2}$

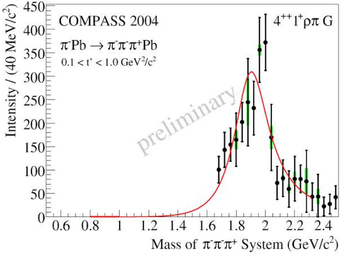
$a_2(1320)$

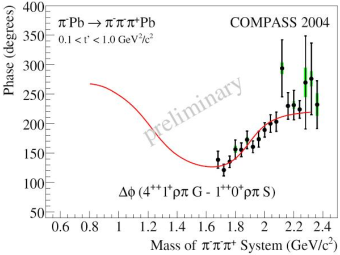




- Zwei Breit Wigner funktionen nötig um die Phasen Bewegung zu beschreiben
- BW1 für $a_2(1320)$
  $M = \left(1321 \pm 1^{+0}_{-7}\right)\mathrm{MeV/c^2}$
  $\Gamma = \left(110 \pm 2^{+2}_{-25}\right)\mathrm{MeV/c^2}$
- BW2 für $a_2(1700)$: $M = 1732$ MeV/c^2, $\Gamma = 194$ MeV/c^2(feste PDG Werte)

$a_4(2040)$





- BW mit konstanter Breite für $a_4(2040)$(Verweigungsverhältnis unbekannt)
- BW Parameter
  $M = \left(1885 \pm 13^{+50}_{-2}\right)\text{MeV/c}^2$
  $\Gamma = \left(294 \pm 25^{+46}_{-19}\right)\text{MeV/c}^2$

$\pi(1800)$

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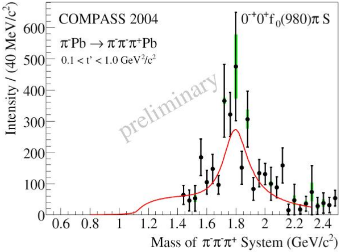
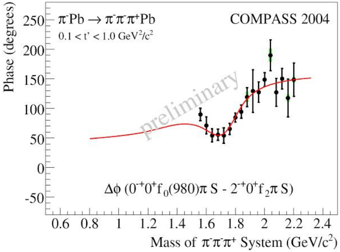
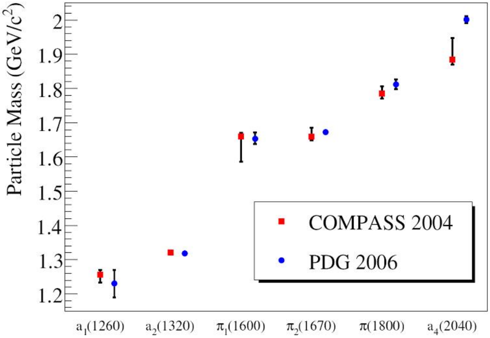




- BW mit konstanter Breite für $\pi(1800)$ und Untergrund bei niedrigen Massen
- BW Parameter
  $M = \left(1785 \pm 9^{+12}_{-6}\right)\mathrm{MeV/c}^2$
  $\Gamma = \left(208 \pm 22^{+21}_{-37}\right)\mathrm{MeV/c}^2$

Überblick



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