Hadron Physics at COMPASS

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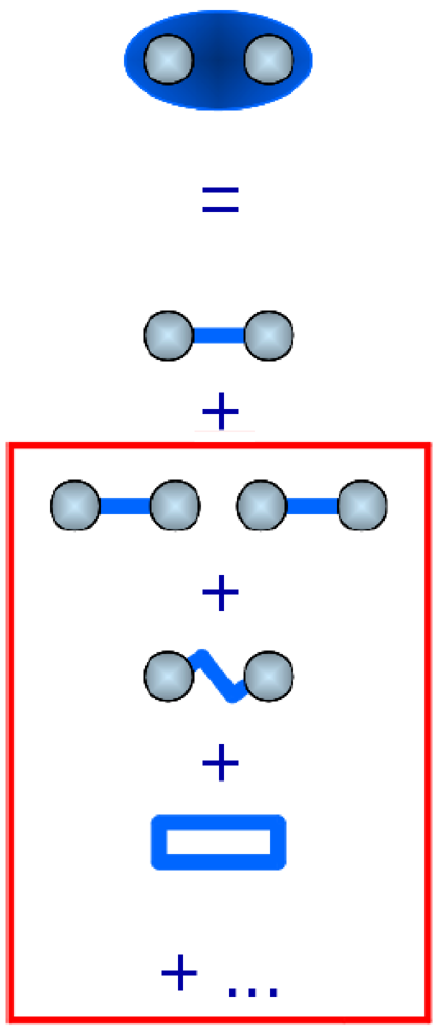
Outline

- Introduction
- The COMPASS experiment
- Diffractive Dissociation of pions
  - 3π final states
  - $\eta\pi$ and $\eta'\pi$ final states
  - 5π final states
- Physics with proton beam
  - Central production in *pp* collision
  - Vector meson production
- Coulomb production of pions
- Other hadron physics topics with COMPASS

Introduction

Meson Spectroscopy:

Study the meson spectrum and search for states other than conventional quark-antiquark pairs. For example *multiquarks*, *glueballs* and *hybrids*.



COMPASS

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Introduction

The light meson spectrum

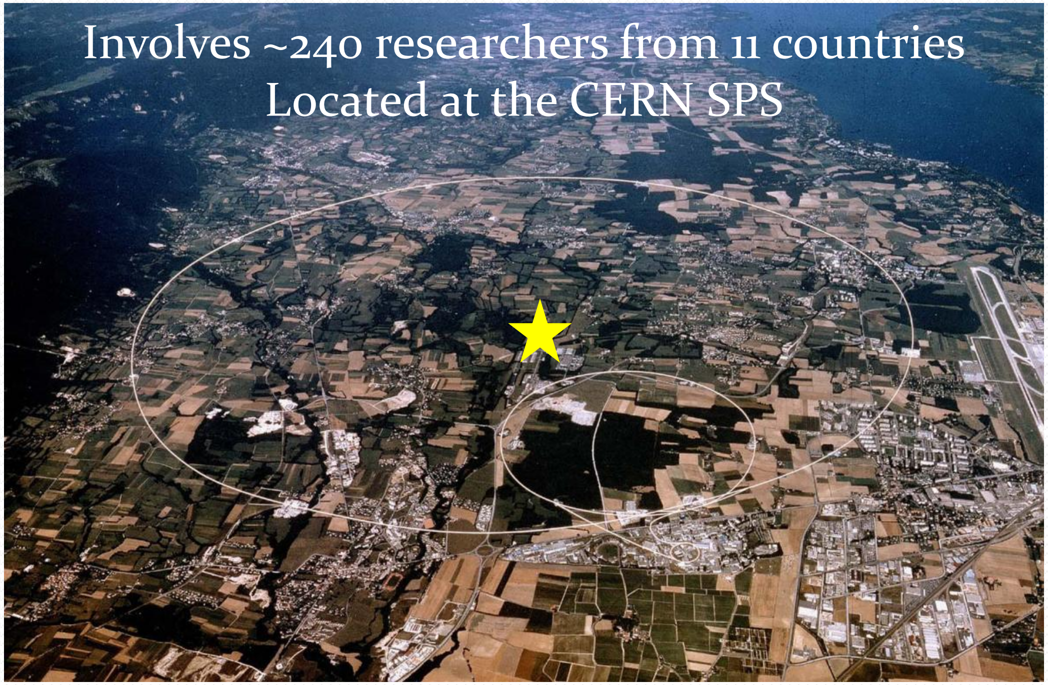
Hybrids:

- Low mass states with spin exotic quantum numbers $J^{PC} = 1^{-+}$ predicted
- Reported candidates:
  - $\pi_1(1400)$: VES, E852, Chrystal Barrel
  - $\pi_1(1600)$: E852, VES
  - $\pi_1(2000)$: E852
- Resonance interpretations still disputed

Glueballs:

- Lowest predicted states have the same quantum numbers as ordinary mesons → mixing.
- Candidates: $f_0(1370)$, $f_0(1500)$,$f_0(1700)$ with $J^{PC} = 0^{++}$ and $\eta(1405)$ with $J^{PC} = 0^{-+}$, but their interpretations are still disputed.

The COMPASS experiment



COmmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

Two-fold physics programme: Spin structure studies with muon beam and hadron spectroscopy with hadron beam (this talk)

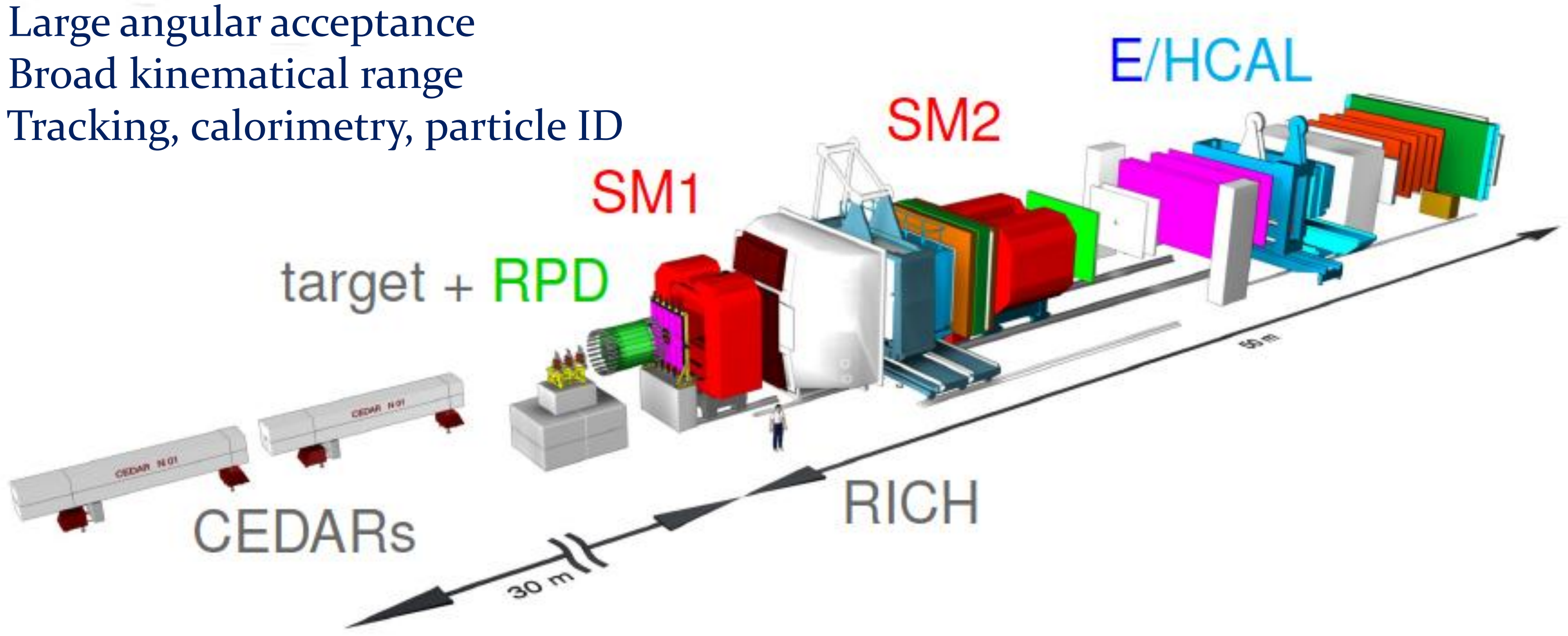
Hadron programme history:

- 2004: pilot run (4 days) with pion beam on Pb target
- 2008-2009: production run, positive and negative hadron beams, various targets
- 2012: Start of COMPASS II hadron programme

The COMPASS experiment

Two-stage magnetic spectrometer:

- Large angular acceptance
- Broad kinematical range
- Tracking, calorimetry, particle ID

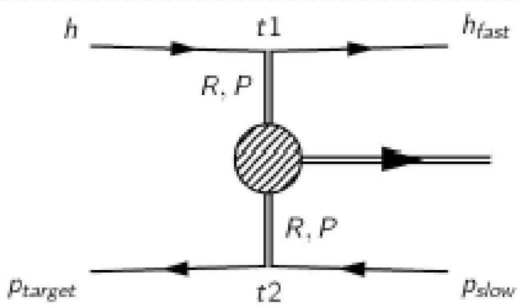


Beam: 190 GeV positive (p, π^+, K^+) or negative (π^-, K^-) hadron beam.
Targets: Liquid H_2, Nuclear targets (Pb, Ni, W).
Final states: charged ($\pi^\pm$, p, …), neutral (π^0, η, η', …),
kaonic ($K^\pm$, K_S, …)

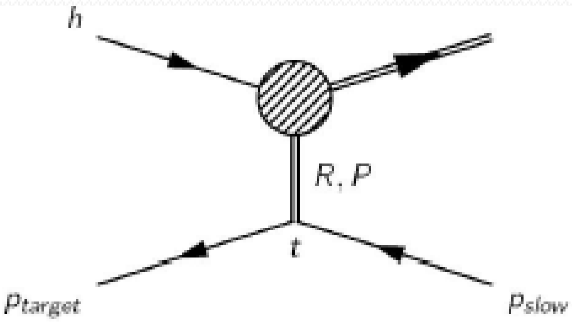
The COMPASS experiment

Production mechanisms:

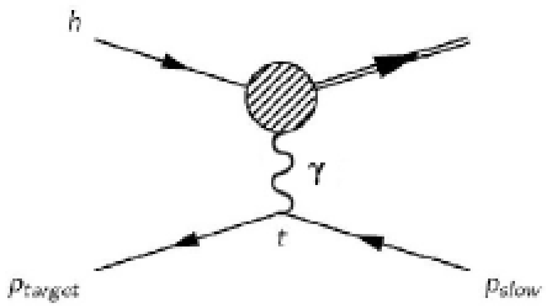
Central production:



Diffractive dissociation:



Coulomb production:

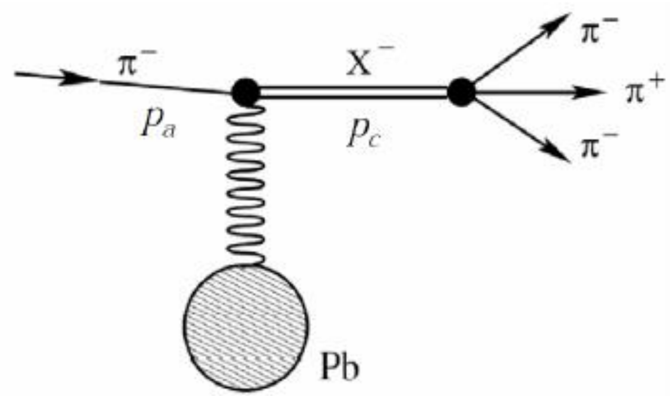


- Gluon-rich environment
- Rapidity gap

- Spin-exotic mesons
- Forward kinematics

- Test of ChPT
- Radiative widths

Diffractive Dissociation of pions: $\pi^- Pb \rightarrow \pi^-\pi^+\pi^- Pb$



- Data from 2004
- 190 GeV/c π^- on Pb
- Momentum transfer $0.1 < t' < 1$ $(GeV/c)^2$

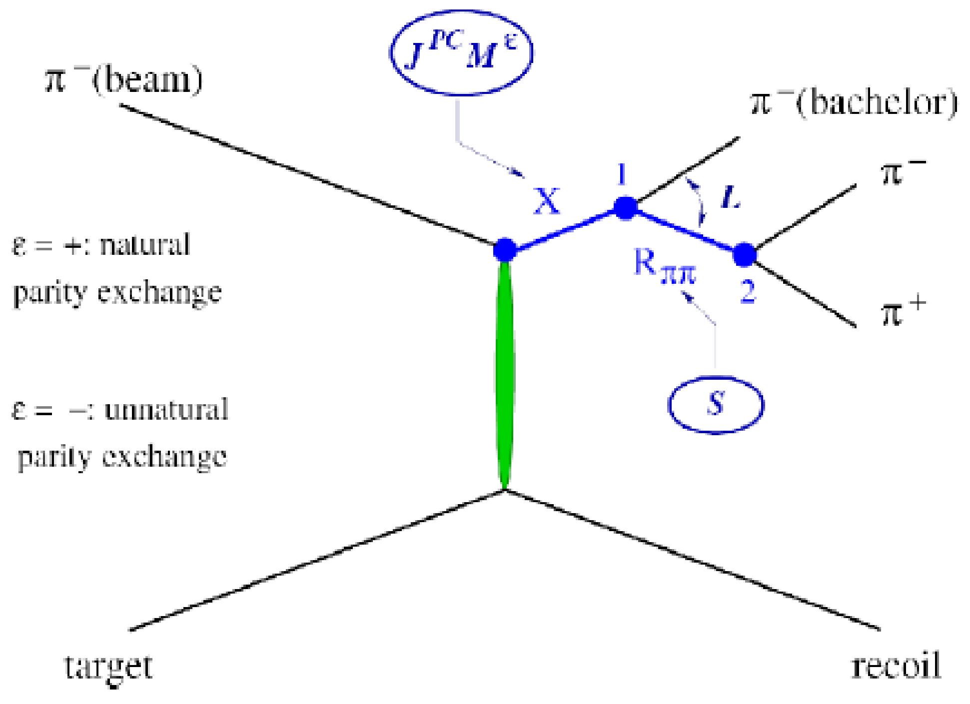
$\rightarrow$ quasi-free nucleons in Pb

Partial Wave Analysis (PWA) Model:

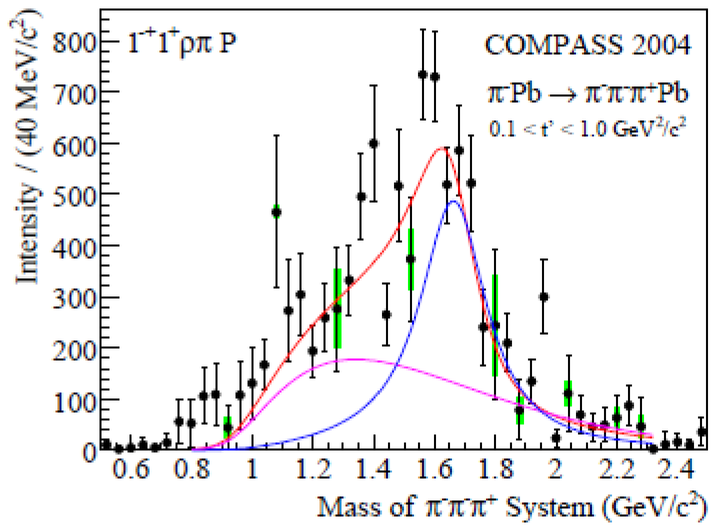
- *t*-channel Reggeon exchange
- Isobar model

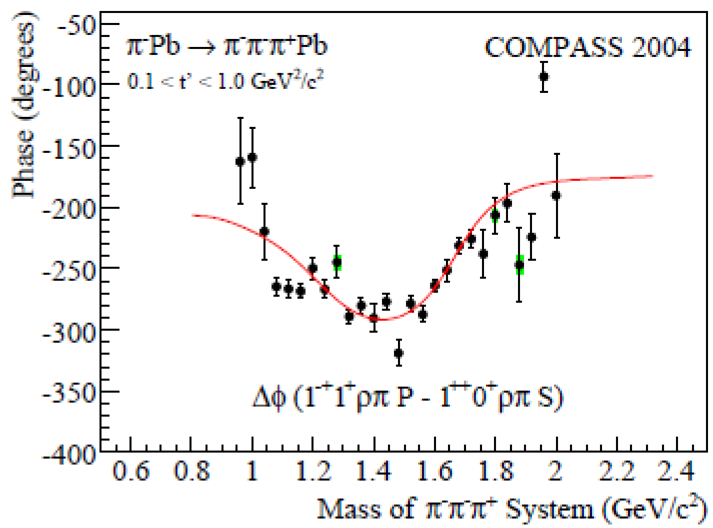
Quantum numbers of X:

Spin *J*, parity *P*,
charge conjugation *C*,
spin projection *M*
reflectivity ε



$\pi^- Pb \longrightarrow \pi^-\pi^+\pi^- Pb$



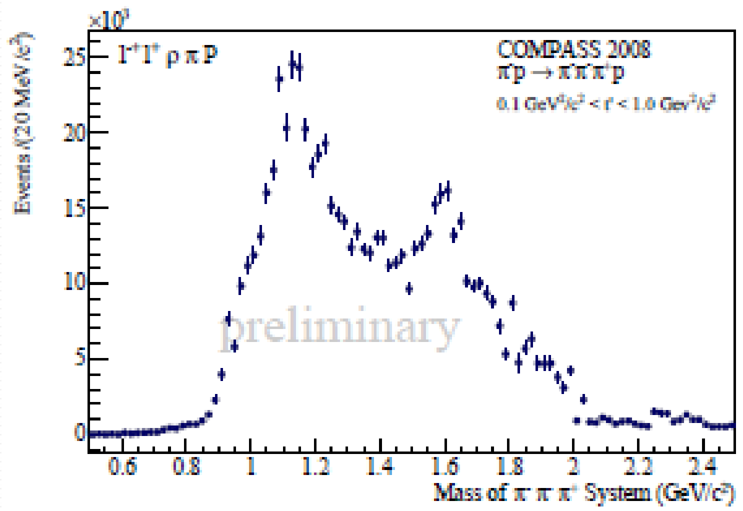


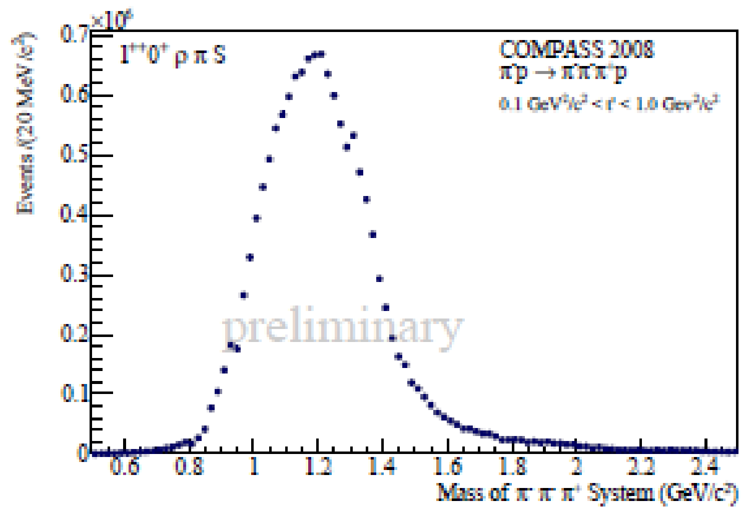
Significant spin exotic $J^{PC} = 1^{-+}$ wave [1]

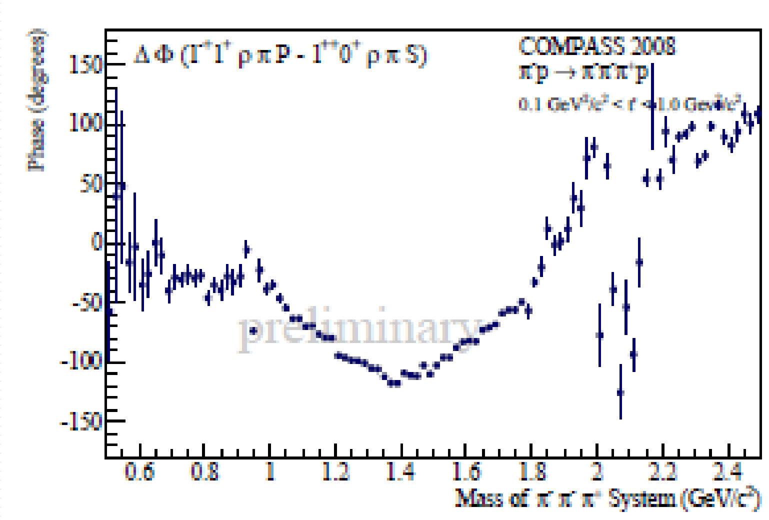
- $M = 1660 \pm 10^{+0}_{-64}$ MeV/c²
  $\Gamma = 269 \pm 21^{+42}_{-64}$ MeV/c²
- Consistent with $\pi_1(1600)$ seen by E852 and VES
- Negligible leakage from other waves

[1] COMPASS, Phys. Rev. Lett. 104 (2010) 241803

Diffractive dissociation of pions: $\pi^- p \longrightarrow \pi^-\pi^+\pi^- p$

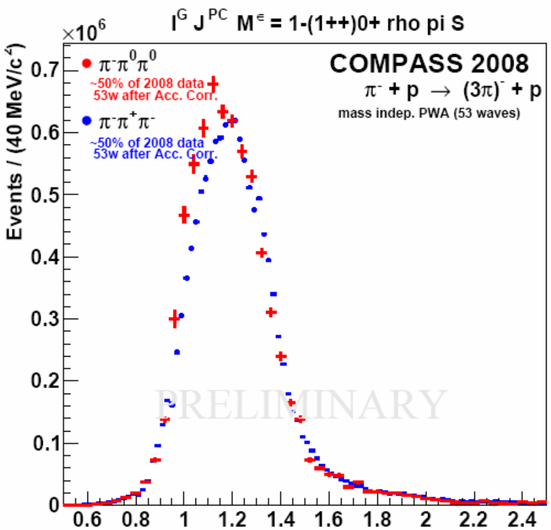




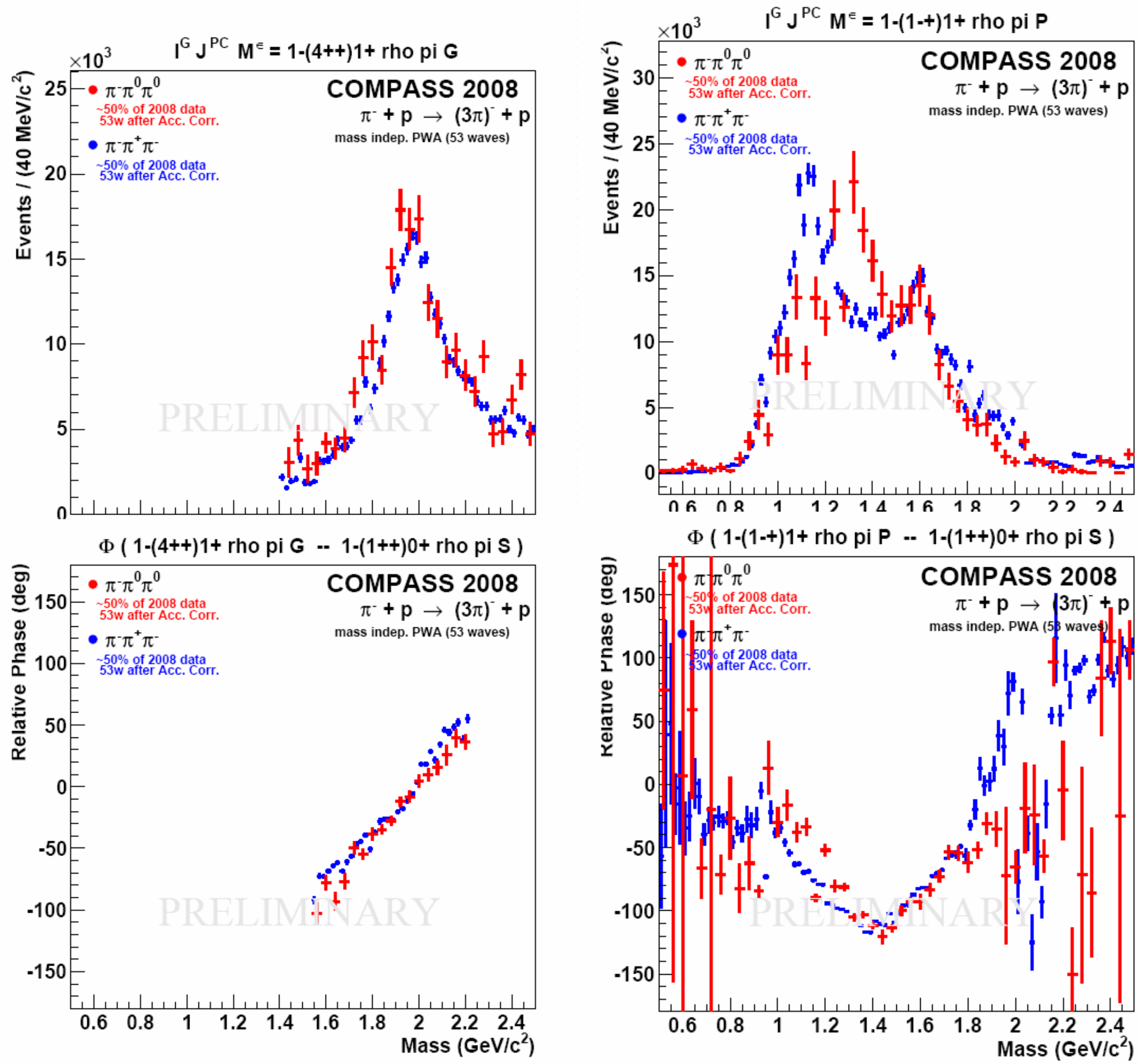


- Data from 2008
- 190 GeV/c π^- on liquid hydrogen
- 24M events
- Enhancement near the $\pi_1(1600)$ mass in the 1^{-+} wave, phase motion w.r.t 1^{++}
- Leakage studies, background (Deck) and mass dependent fit necessary for definite conclusions.

Comparison between $\pi^- p \rightarrow \pi^-\pi^+\pi^- p$ and $\pi^- p \rightarrow \pi^0\pi^0\pi^- p$

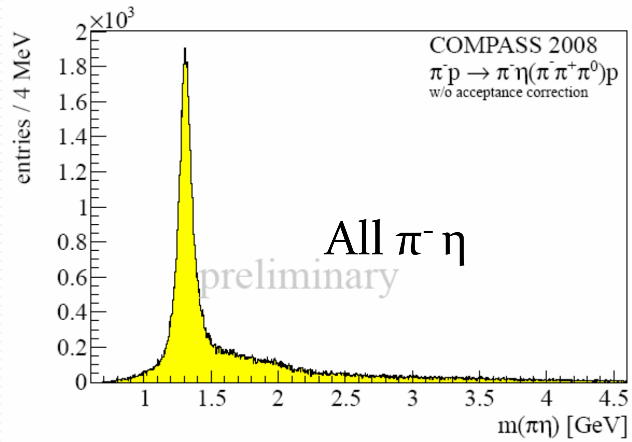


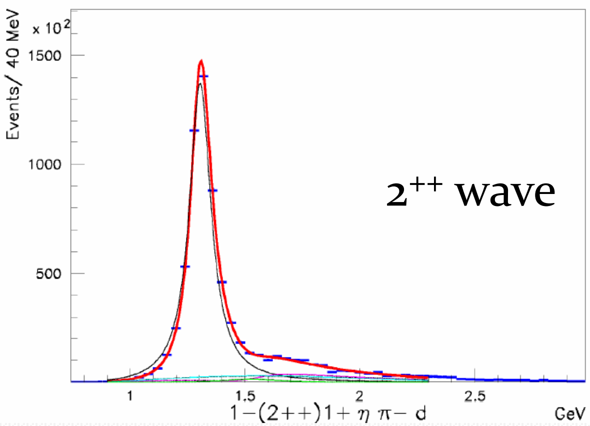
- Data from 2008
- Valuable consistency check
- Relative amplitudes known from symmetry
- Different parts of the detector are used in the two channels.

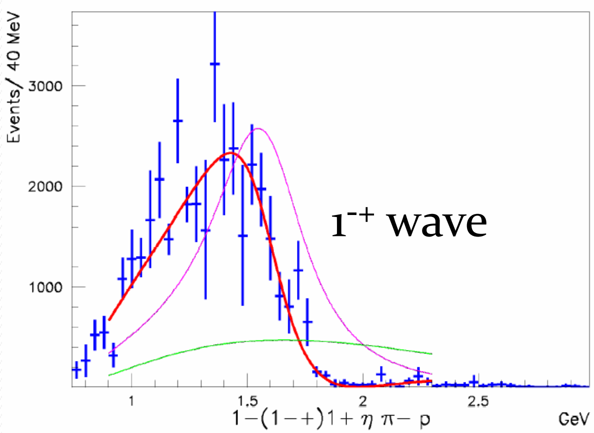


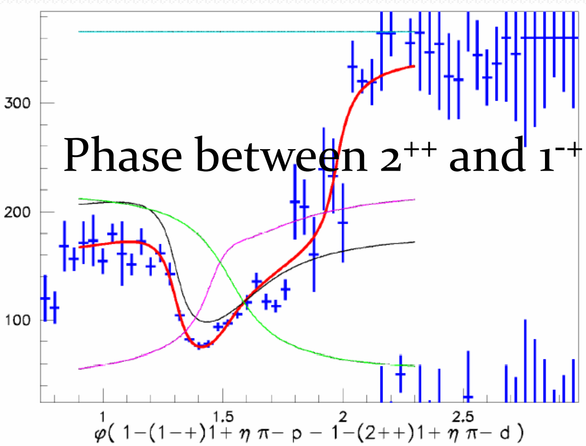
Diffractive dissociation of pions: $\pi^- p \longrightarrow \pi^- \eta$

Mass dependent fit





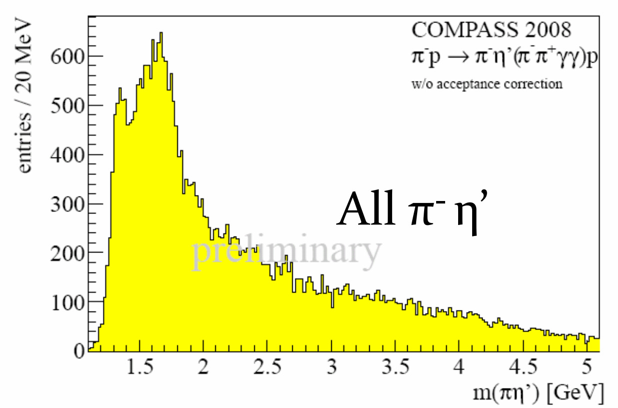


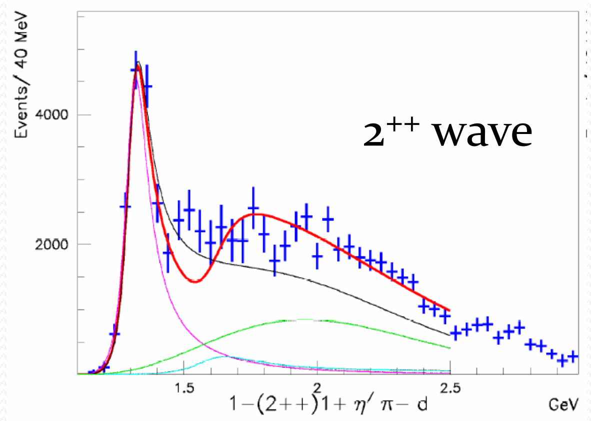


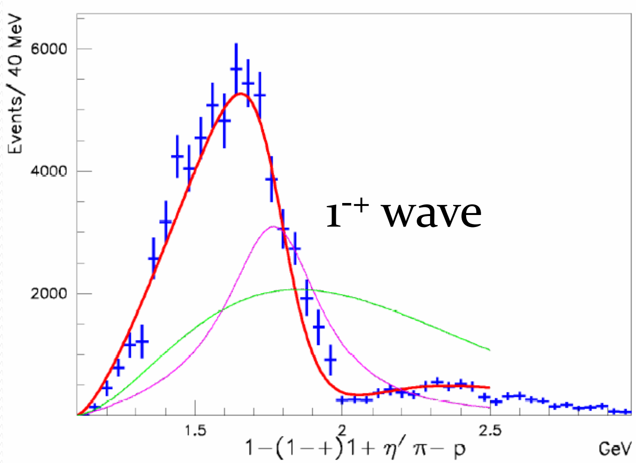
- $a_2(1320)$ dominating wave
- Difficult to draw conslusions yet about the P-wave (spin exotic 1^{-+})

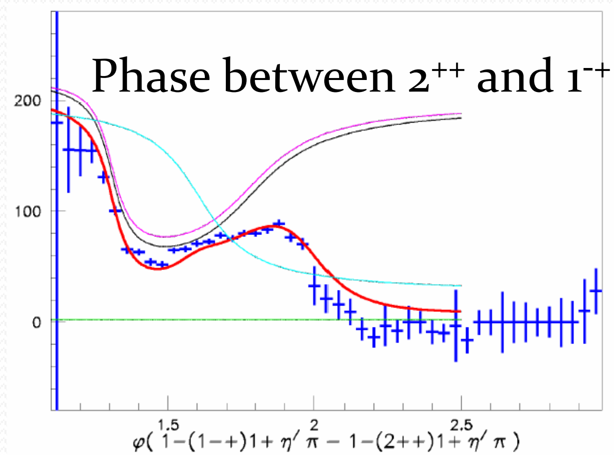
Diffractive dissociation of pions: $\pi^- p \longrightarrow \pi^- \eta'$

Mass dependent fit



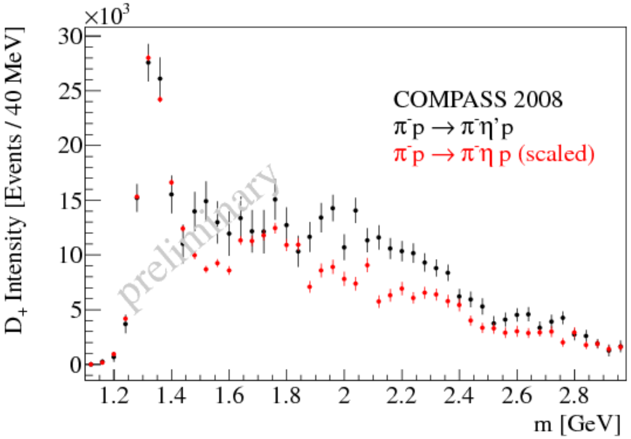


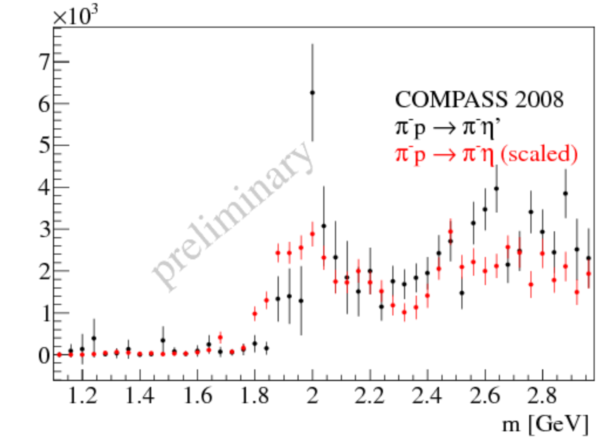


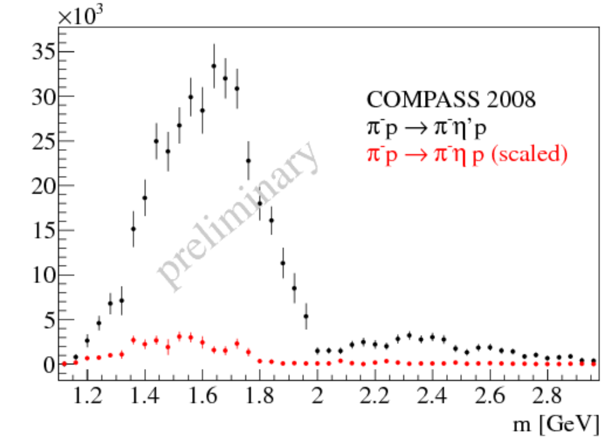


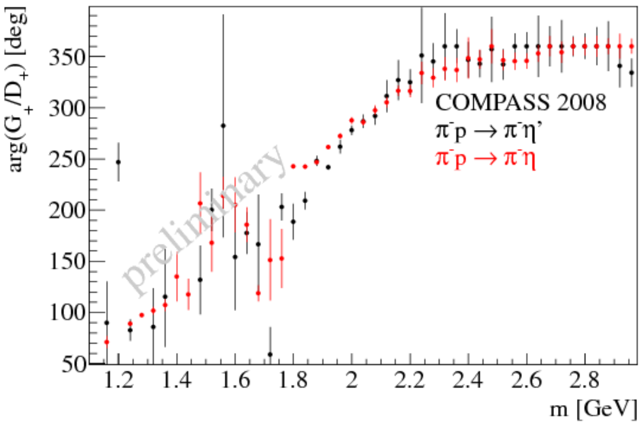
- The 1^{-+} (spin exotic) wave dominates
- Fitted BW of the P-wave and a large contribution from non-BW background

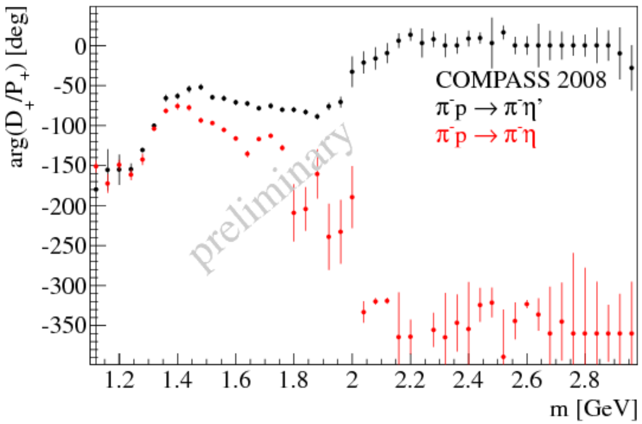
Comparison between $\eta'\pi^-$ and $\eta\pi^-$







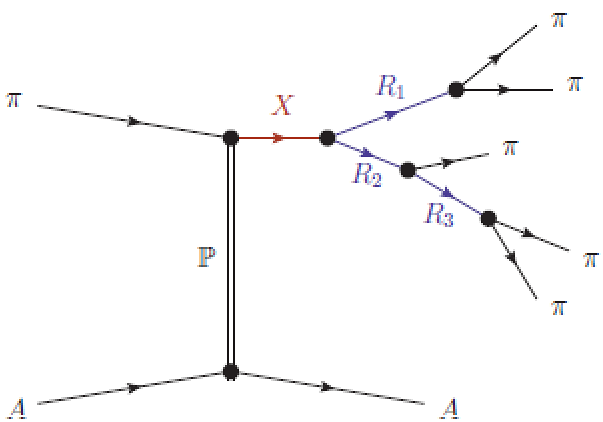


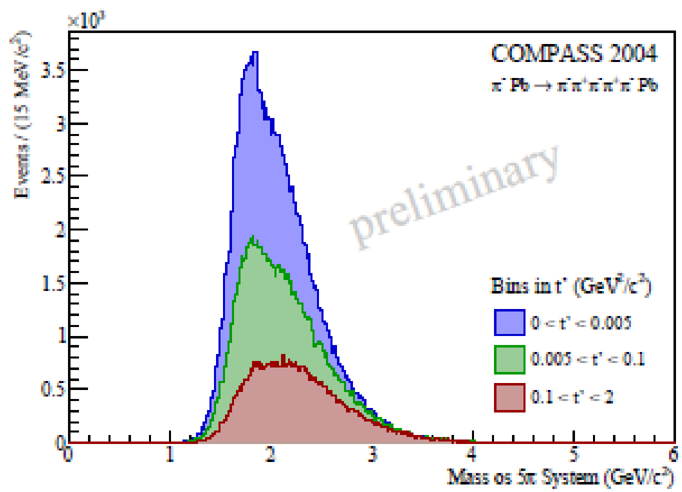


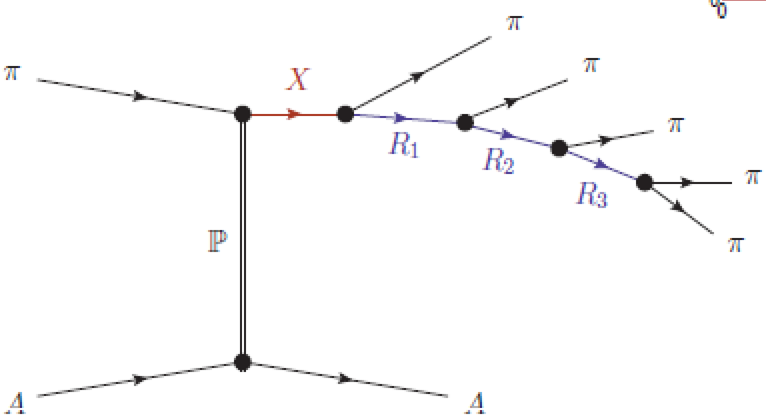
Even waves
(D and G)
very similar, as
expected
for $q\bar{q}$ states

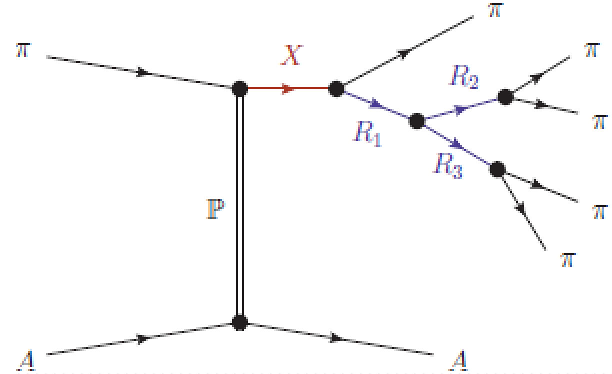
Remarkable difference in the P-wave case, as expected for $q\bar{q}g$ states.

Diffractive dissociation of pions: $\pi^- Pb \longrightarrow \pi^-\pi^+\pi^-\pi^+\pi^- Pb$





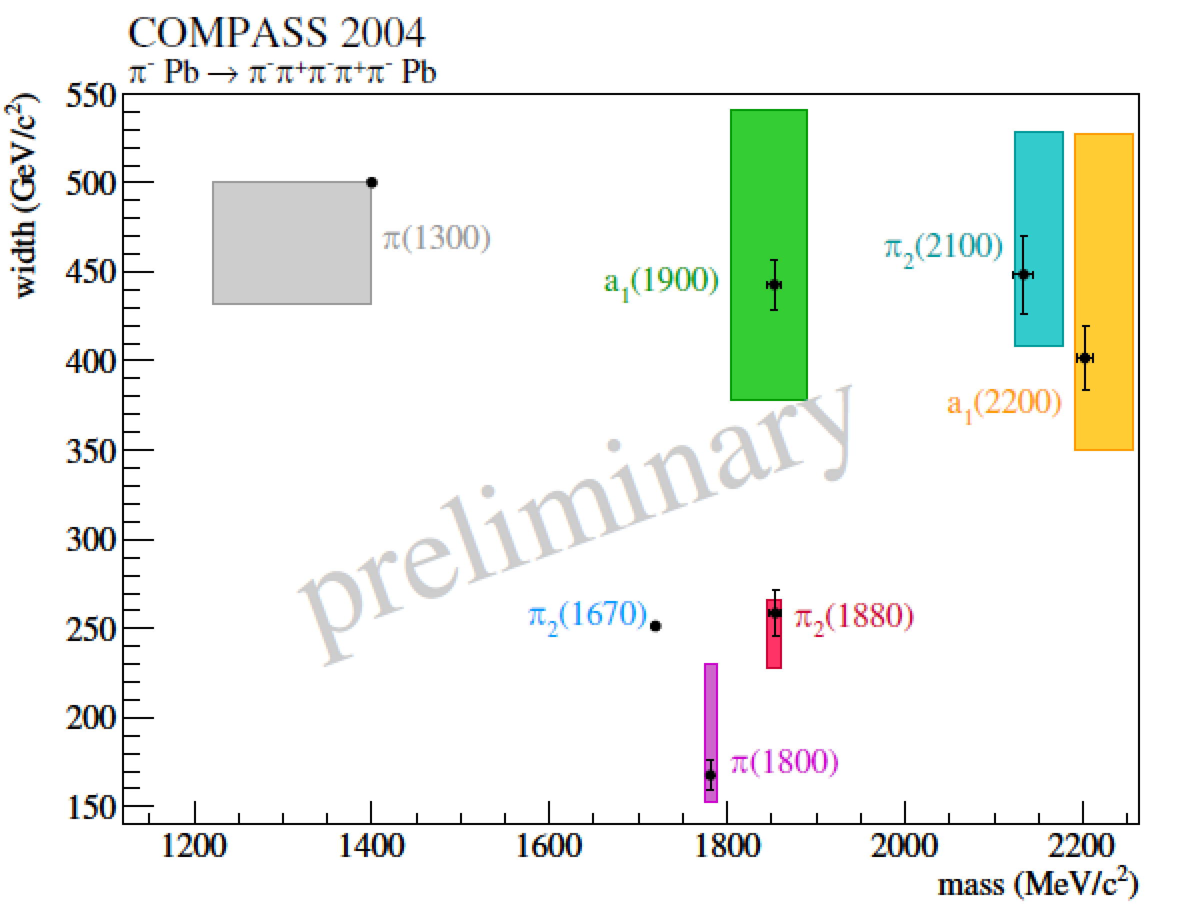




The large data sample from COMPASS and the advanced analysis tools developed within COMPASS enables studies of complicated final states, *e.g.* 5 –body PWA.

COMPASS

Diffractive dissociation of pions: $\pi^- Pb \rightarrow \pi^-\pi^+\pi^-\pi^+\pi^- Pb$

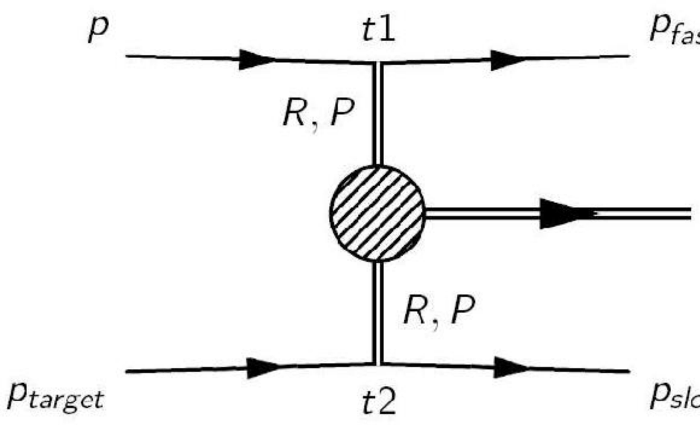


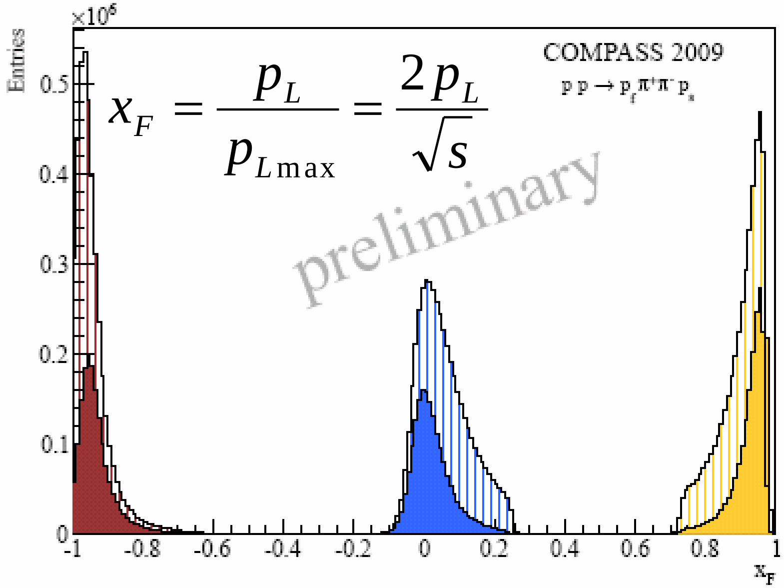
First mass-dependent fit:

- Known states: $\pi_2(1670)$; $\pi(1800)$ observed
- Elusive $\pi_2(1880)$ fitted in $a_1 \rho$ and $a_2\rho$
- Fit with two 1++ resonances
- Possible $\pi_2(2200)$ signal

COMPASS

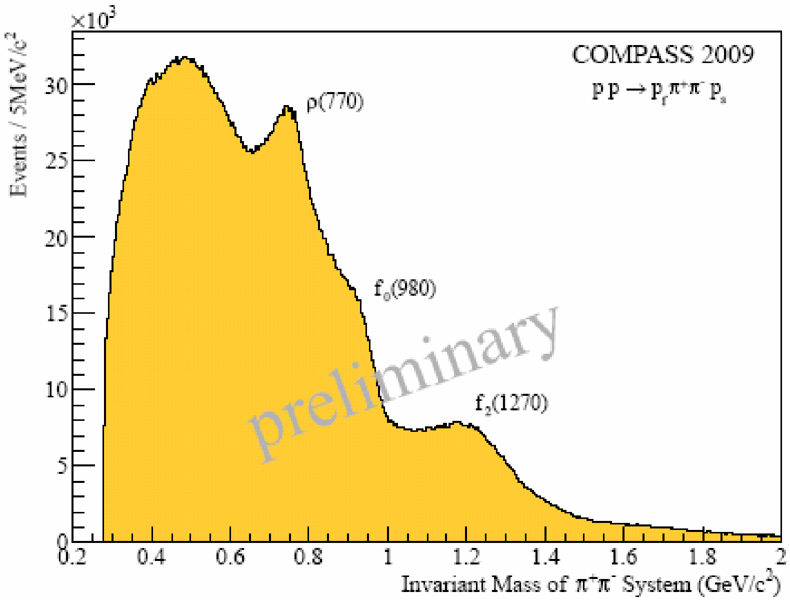
Physics with proton beam: central *pp* collisions

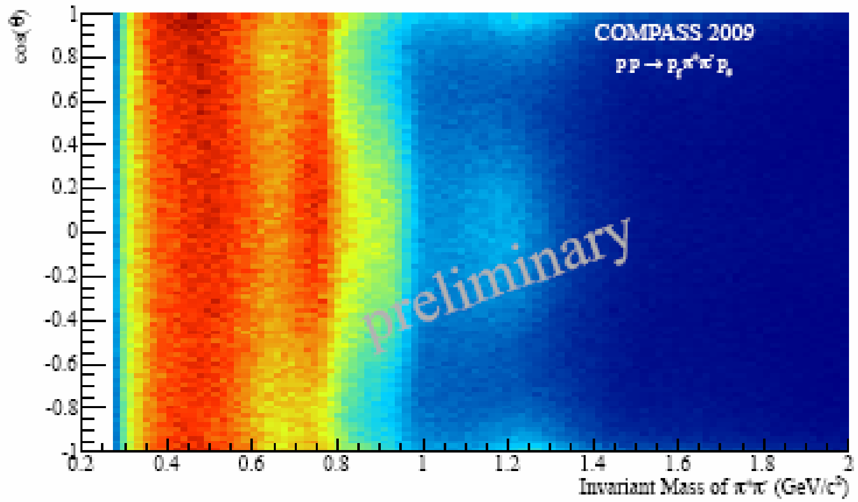


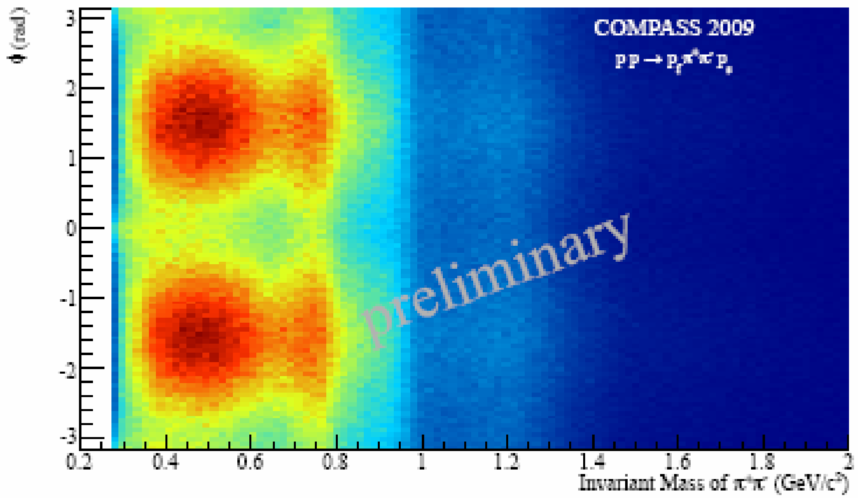


- Two-particle exchange where beam proton and target stays intact
- Characterised by two rapidity/Feynman x_F gaps
- At the COMPASS beam energy (191 GeV), central production is expected to be dominated by Pomeron-Pomeron exchange
- Pomeron-Pomeron collisions is a glue-rich process where glueballs should have a good chance to be produced

Physics with proton beam: central *pp* collisions







PWA recently started for the central $pp \rightarrow pp\, \pi^+ \pi^-$ channel.

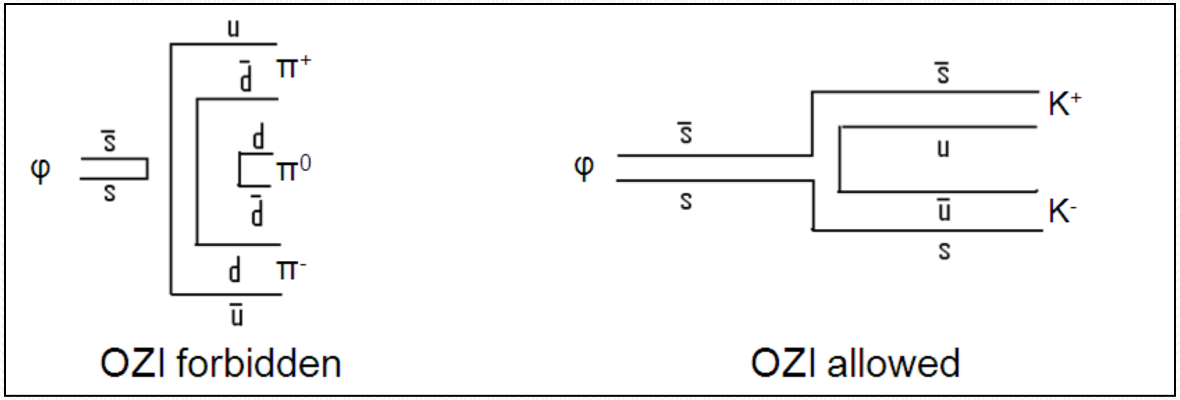
Many other channels available.

Physics with proton beam: vector meson production

The **OZI** (Okubo-Zweig-Iizuka) rule

• states that processes with disconnected quark lines are supressed.

• explains *e.g.* Why certain meson decay channels are preferred to others



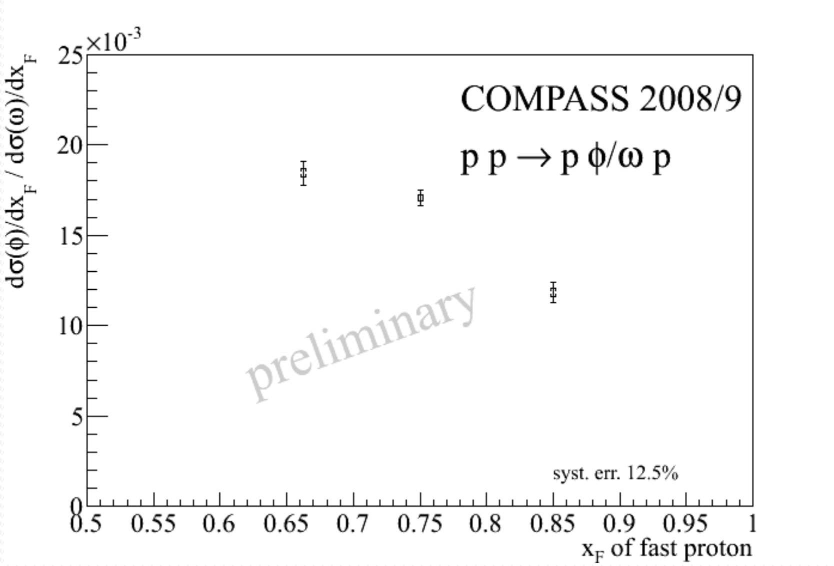
• gives a quantitative prediction of how the ω and ϕ cross sections are related, using their well-known deviation from ideal mixing

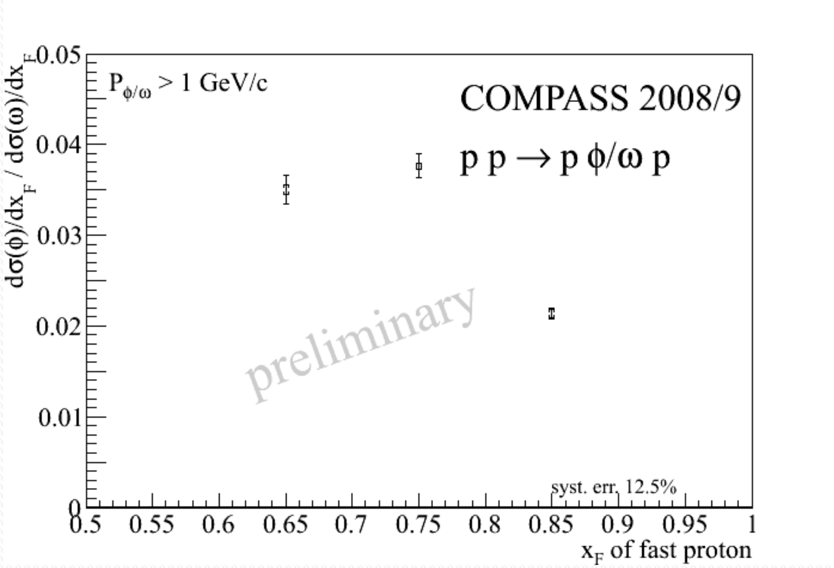
$$(AB \rightarrow \varphi X)/(AB \rightarrow \omega X) = 4.2 \cdot 10^{-3}$$

where A, B and X are non-strange hadrons.

• By measuring the cross sectio ratio we can learn more about the production mechanism.

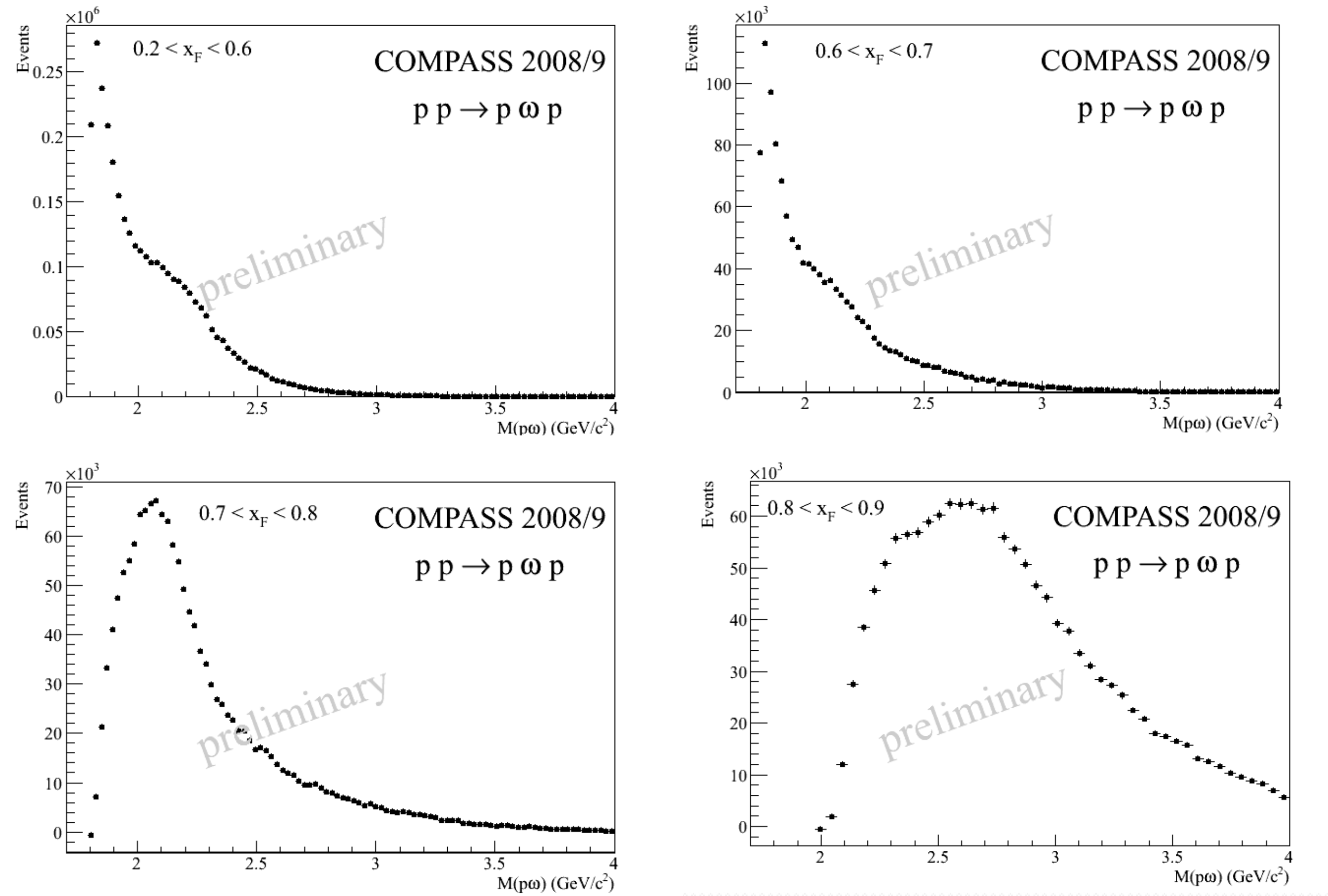
Physics with proton beam: vector meson production





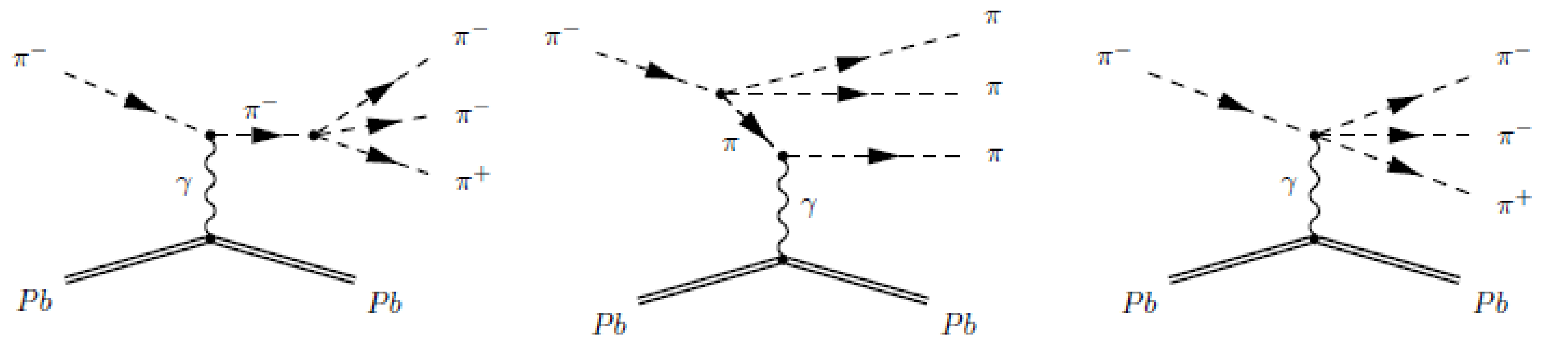
- COMPASS has measured the cross section ratio $\sigma(pp\phi)/\sigma(pp\omega)$ in 3 regions of x_F of the fast proton.
- The OZI violation is between a factor of 4.5 and 3.
- When the major part of the $p\omega$ resonant part is removed from the data, the OZI violation factor is between a 9 and 4.5.

Physics with proton beam: vector meson production



The M($p\omega$) spectrum show many interesting structures.
PWA needed to identify them.

Coulomb production of pions

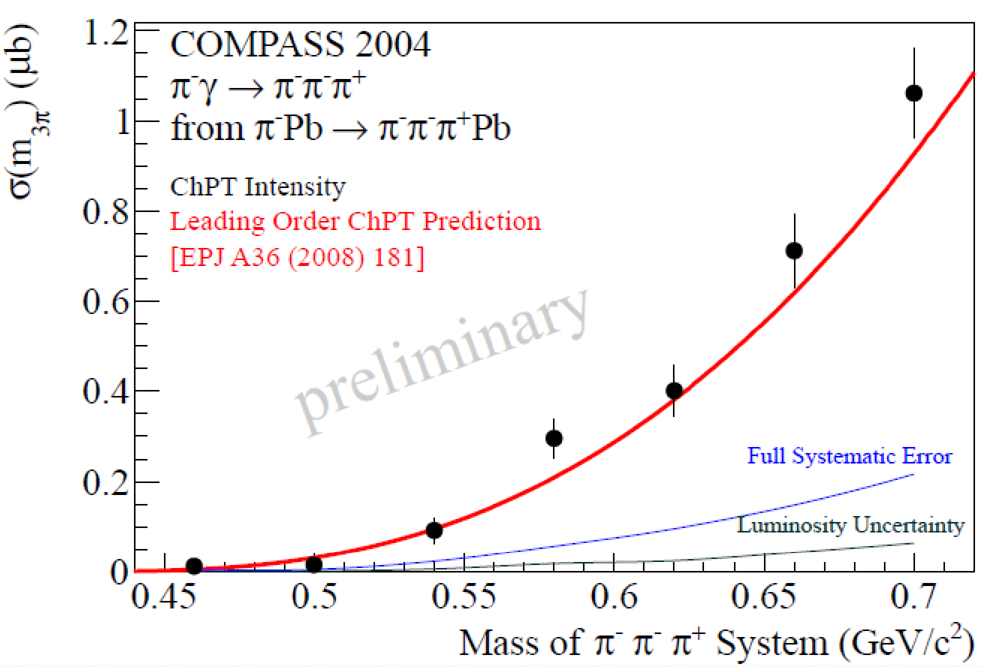


Low momentum transfer:

- Contribution from photon exchange

Low masses:

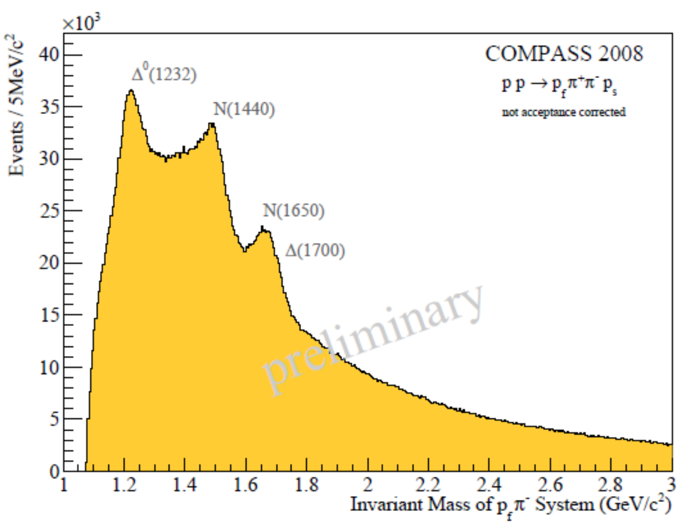
- Only pions produced → ChPT test.
- Results compared to LO ChPT predictions [EPJA 36 (2008) 181.]



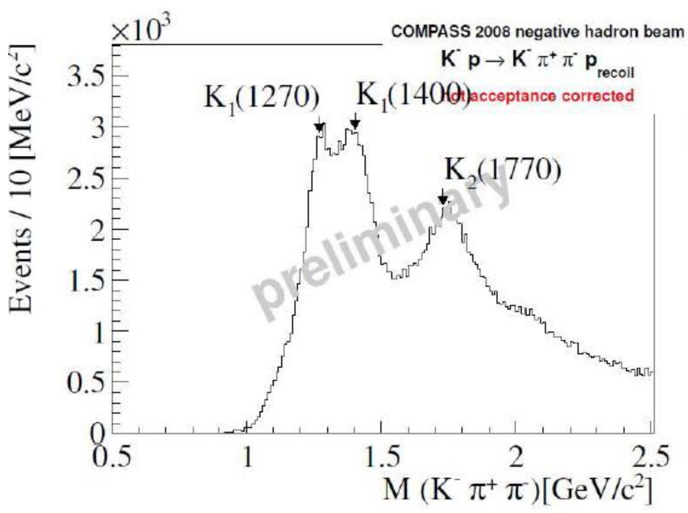
Other hadron physics topics in COMPASS

- Baryon spectroscopy
- Meson spectroscopy with kaon beam
- Kaonic final states
- Pion polarizabilities (test of Chiral Perturbation Theory)

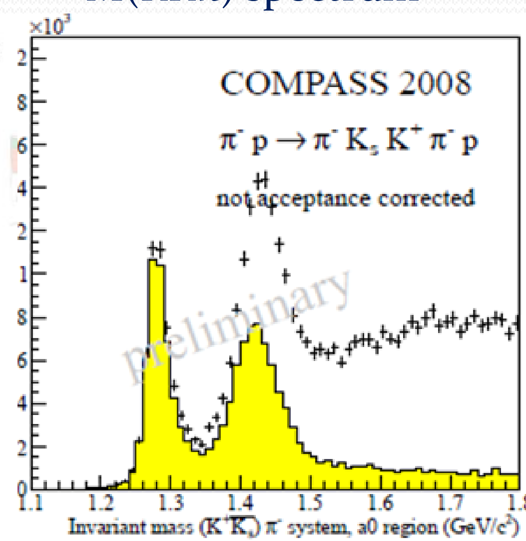
$M(p\pi^-)$ spectrum



$M(K^-\pi^+\pi^-)$ spectrum



$M(K\bar{K}\pi)$ spectrum



Summary

- Evidence for QCD allowed states like multiquarks, glueballs and hybrids still not beyond doubt.
- COMPASS has excellent potential to contribute:
  - Access to 3 different production mechanisms
  - Different beams and targets can be used
  - Measures charged and neutral final states
- Spin exotic wave $\pi_1(1600)$ in Pb target data from 2004 pilot run.
- Similar structure in proton target data from 2008.
- P-wave near the $\pi_1(1600)$ mass also observed in the $\pi\eta'$ final state.
- The difference in strength of the P-wave in $\pi\eta'$ compared to the $\pi\eta$ final state indicate a possible qqg interpretation.
- First results from the complicated 5π final state PWA.
- Great potential also in *pp* central production data.
- Vector meson production studies provides a test of the OZI rule which gives deeper insight into the production mechanism.
- Interesting structures in the $p\pi$, pK and $p\omega$ spectra.
- COMPASS low t' data provide test of ChPT – first results agree with LO prediction.