Hadron Spectroscopy at COMPASS

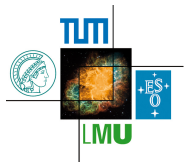
A Selective Overview

Sebastian Neubert
for the COMPASS collaboration

Technische Universität München

MENU 2010

Williamsburg, VA



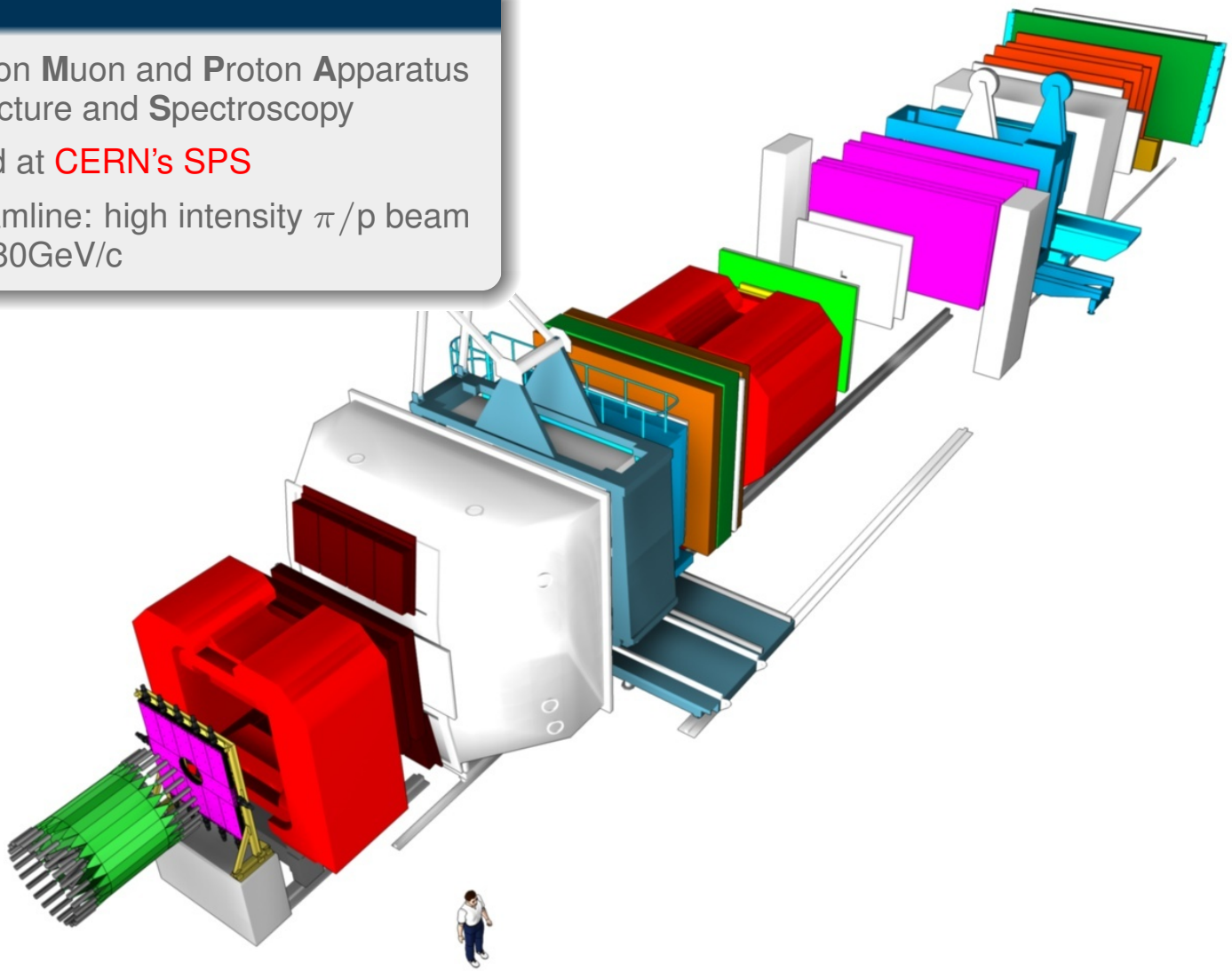
The COMPASS Experiment

Spectrometer and Hadron Beam

Technische Universität München

Overview

- **CO**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy
- Located at CERN's SPS
- M2-beamline: high intensity π/p beam up to 280GeV/c



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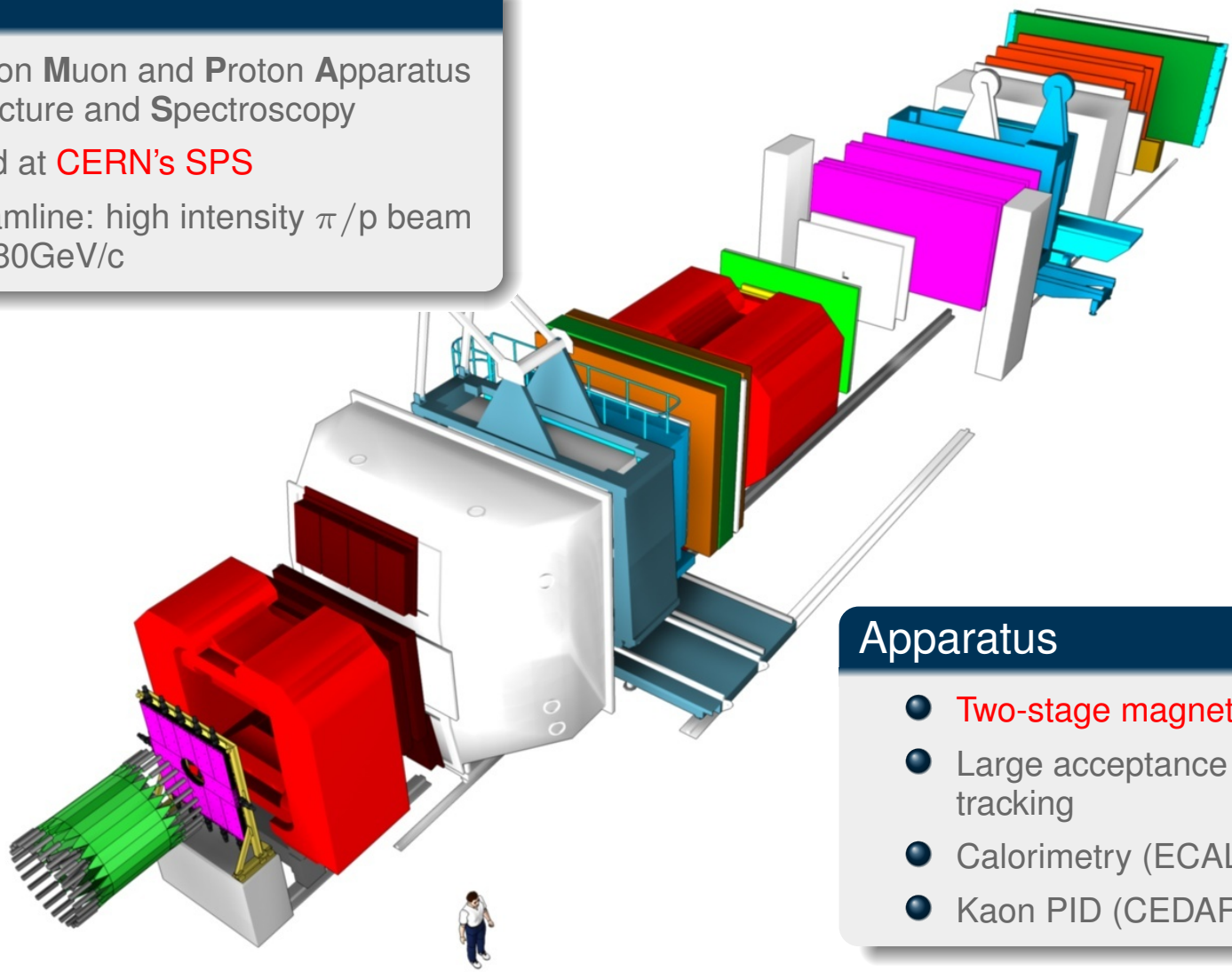

Apparatus

- Two-stage magnetic spectrometer
- Large acceptance charged tracking
- Calorimetry (ECAL/HCAL)
- Kaon PID (CEDARs/RICH)

COMPASS Hadron Runs

2004, 2008, 2009

- CERN SPS M2-beamline:
  - neg. beam: 190GeV/c $\pi^-(95\%), K^-(4.5\%)$
  - pos. beam: 190GeV/c $p(71.5\%), \pi^+(25.5\%), K^+(3\%)$
- Pilotrun **2004** 190 GeV π^- beam on nuclear targets (mainly Pb)
  - $3\pi^\pm$ high-t'analysis $\sim$ 400 000 events ($\pi_1(1600)$ PRL in print)
- **2008 Apparatus Upgrade**
  - Recoil Proton Detector (RPD), calorimetry, kaon PID
- **2008 Run** mainly 190 GeV π^- beam on lH_2 target
  - $3\pi^\pm$ diffractive on proton $\sim$ 100M events
- **2009 Run** pion / proton beams on lH_2 and nuclear targets

Production Mechanisms at COMPASS

and most prominent Phyics Motivations

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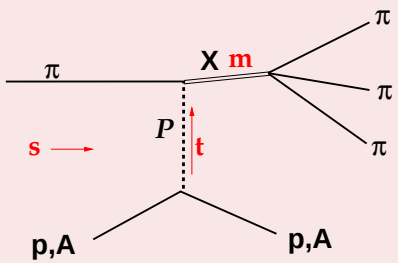
Diffractive Dissociation → Search for Spin-Exotics



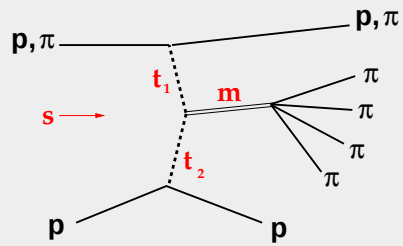
- Pomeron t-channel exchange

$$T \propto t^{\frac{1}{2}|\lambda_a - \lambda_x|} s^{\alpha(t)} t^{\frac{1}{2}|\lambda_b - \lambda_c|}$$

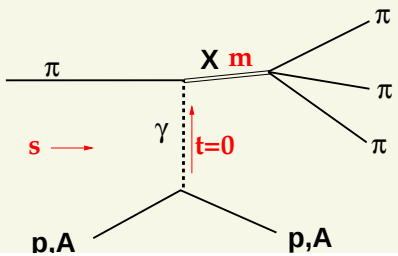
- Isospin Triplet States $I = 1$

Central Production → Glueball Search

- Pomeron-Pomeron fusion
- Isospin Singlet States $I = 0$



Primakoff Production → Radiative Widths



Photon exchange (Nucl.Field)

- $t \sim 0$
- Helicity $\lambda_X = 1$

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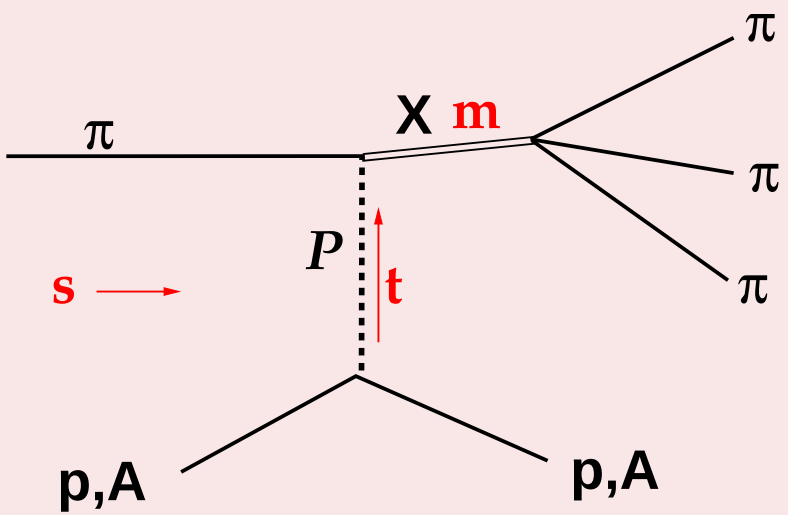

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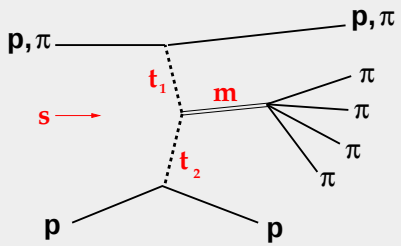

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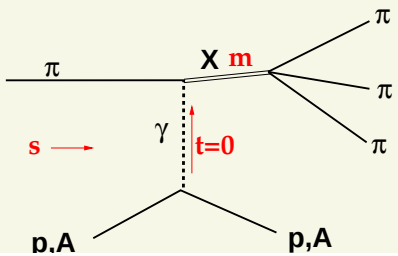

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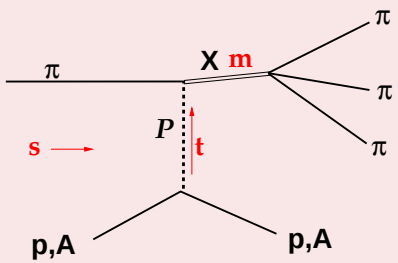

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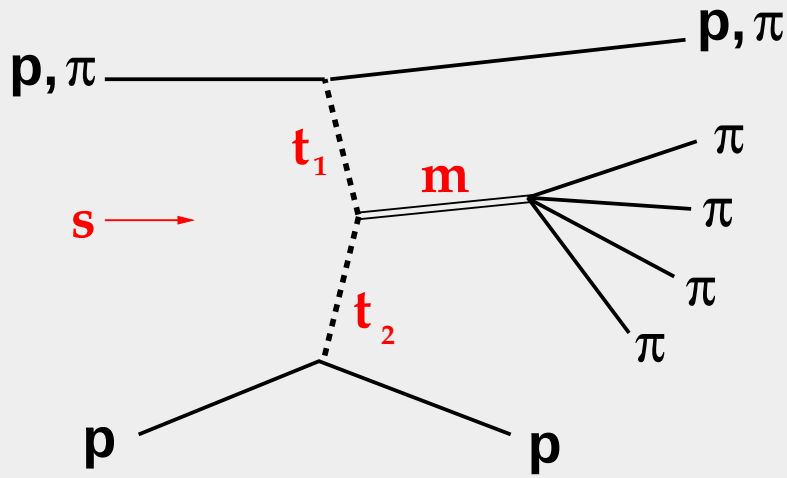

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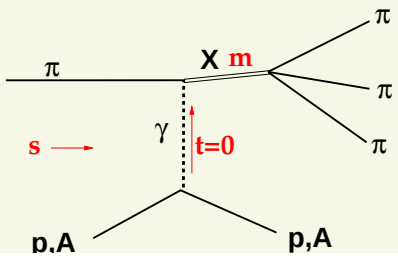

Pho

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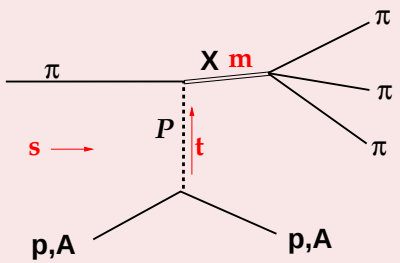

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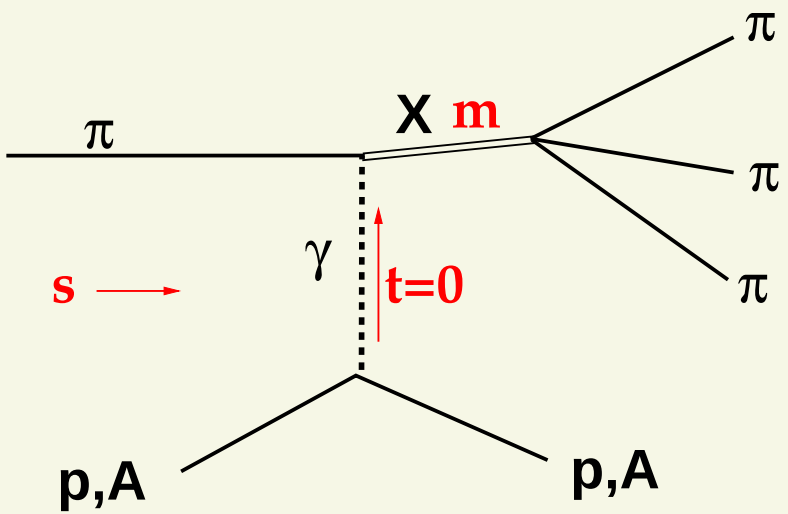

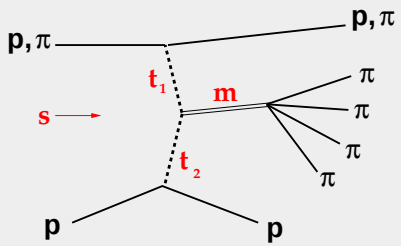

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Photon exchange (Nucl.Field)

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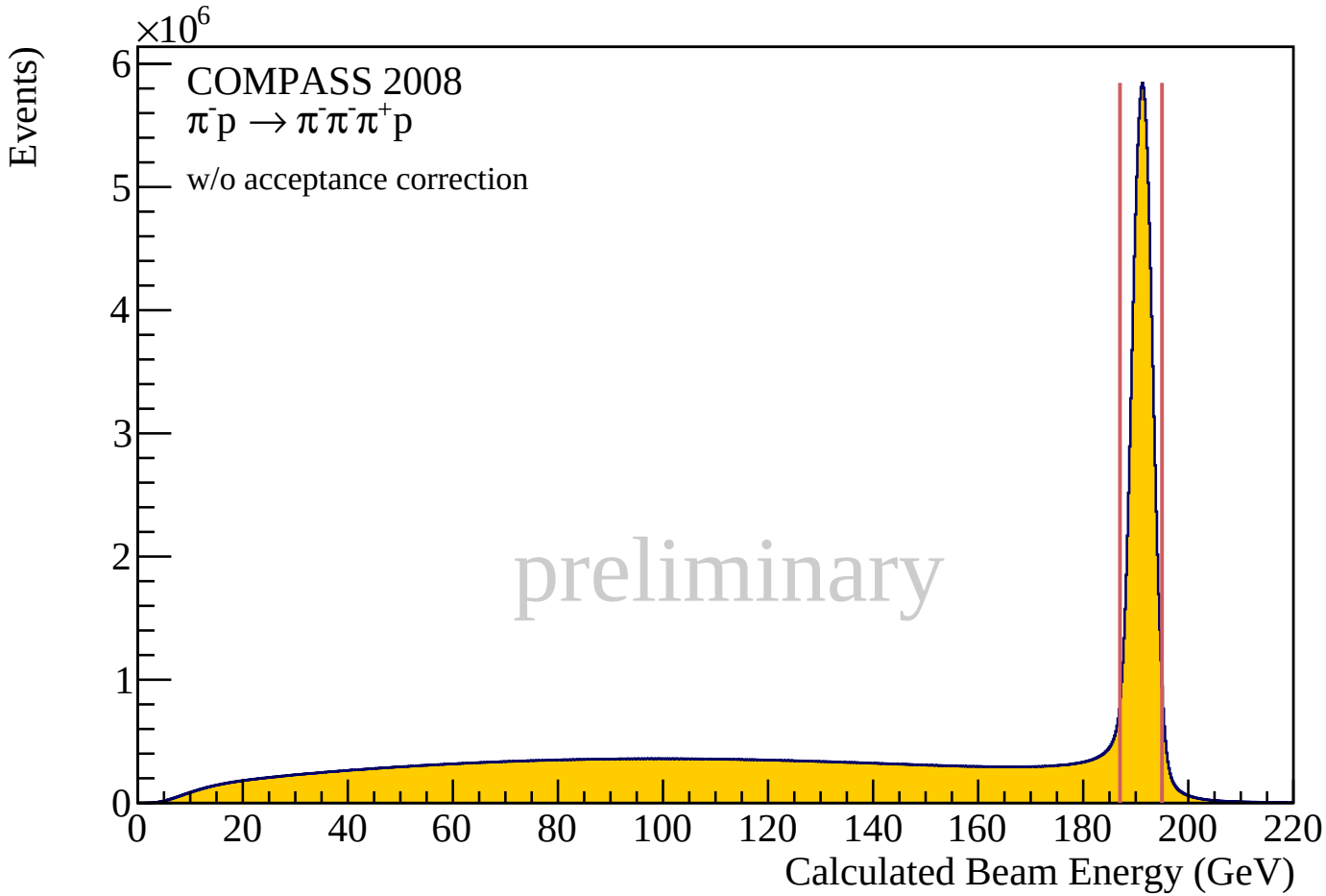
Basic Event Selection - Exclusivity

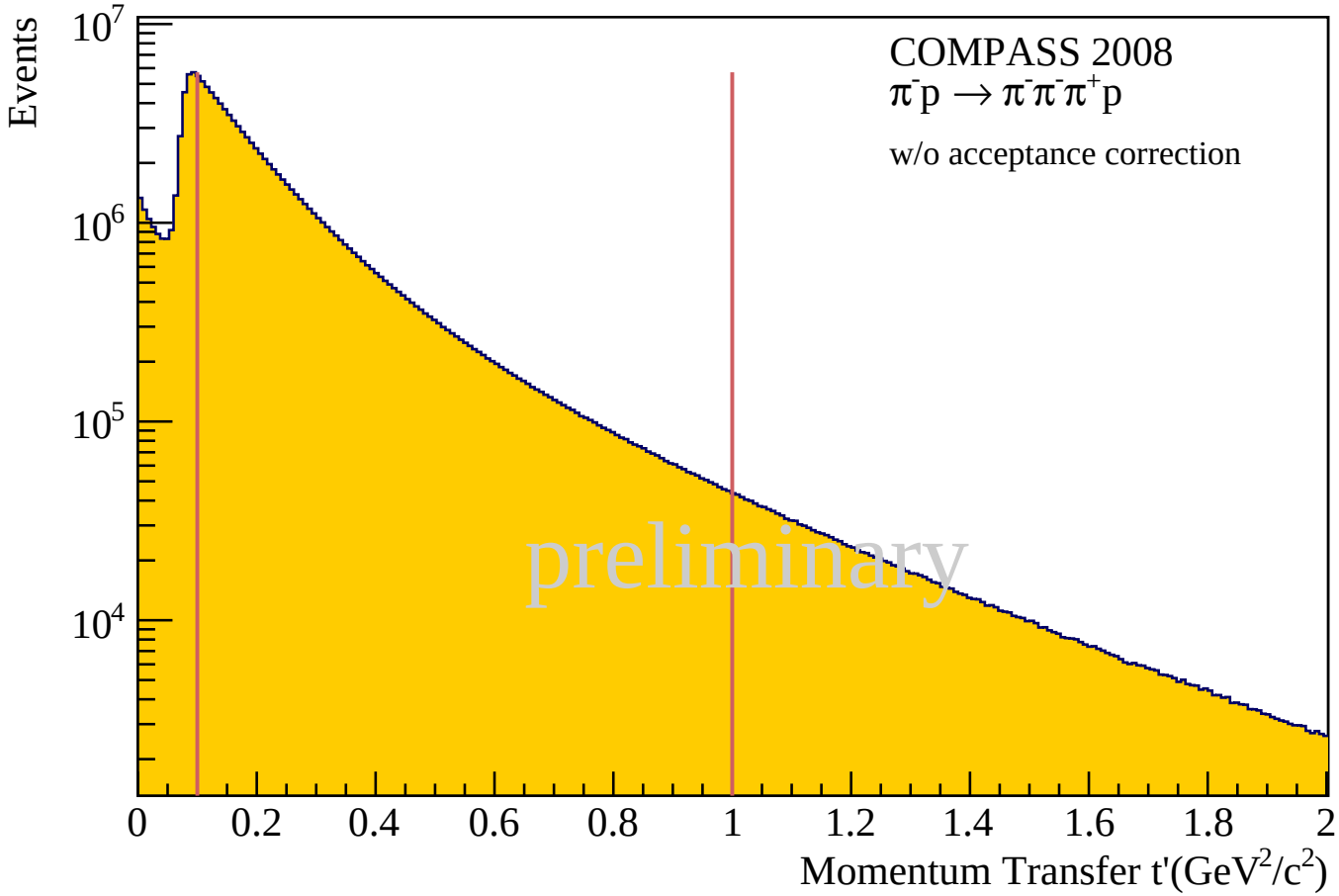
E. g. $\pi^-\pi^-\pi^+$ similar for all analyses



- Supplemented by recoil detector (see $\pi^-\pi^0\pi^0$ later in this talk)

Squared Momentum Transfer $t = -q^2$

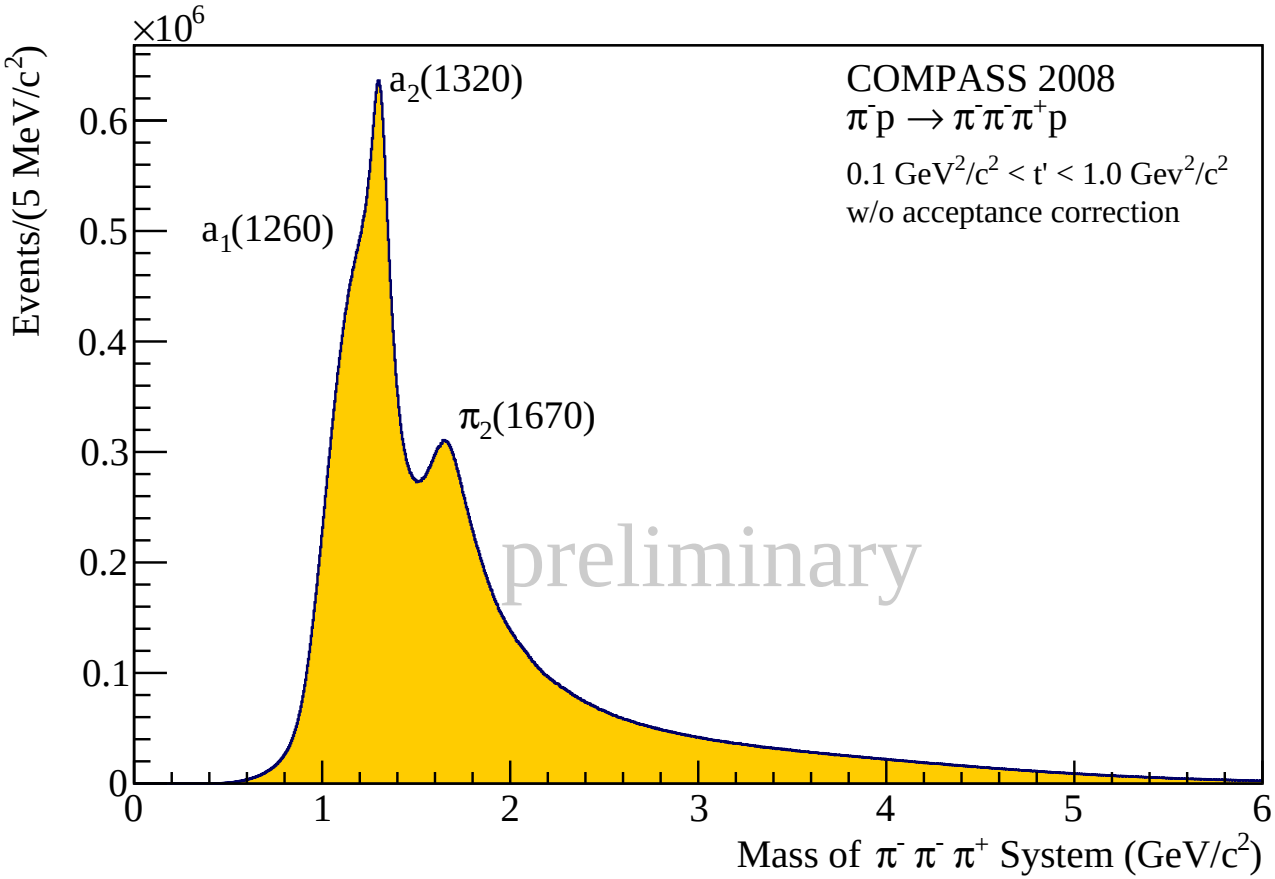
Diffractive Scattering



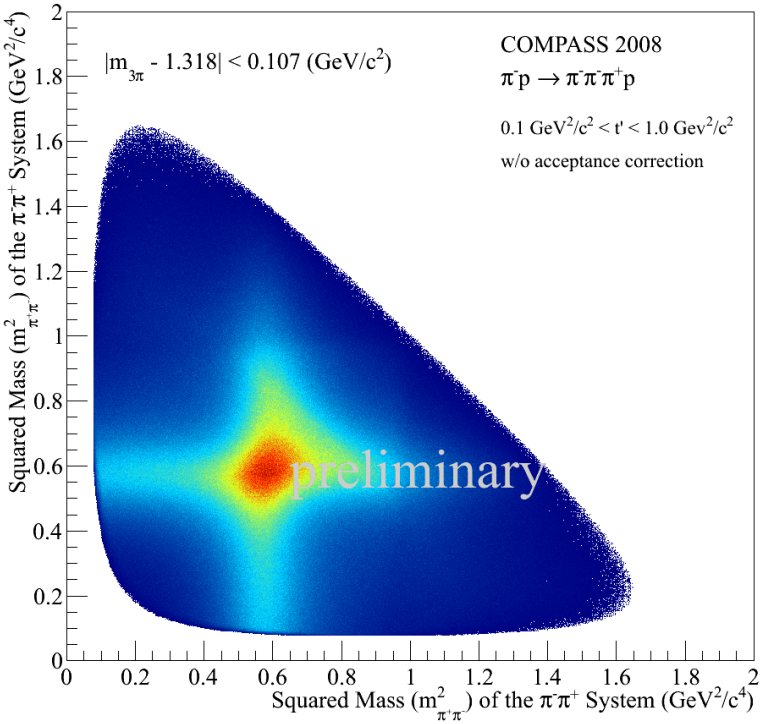
$$t' = t - t_{min}$$

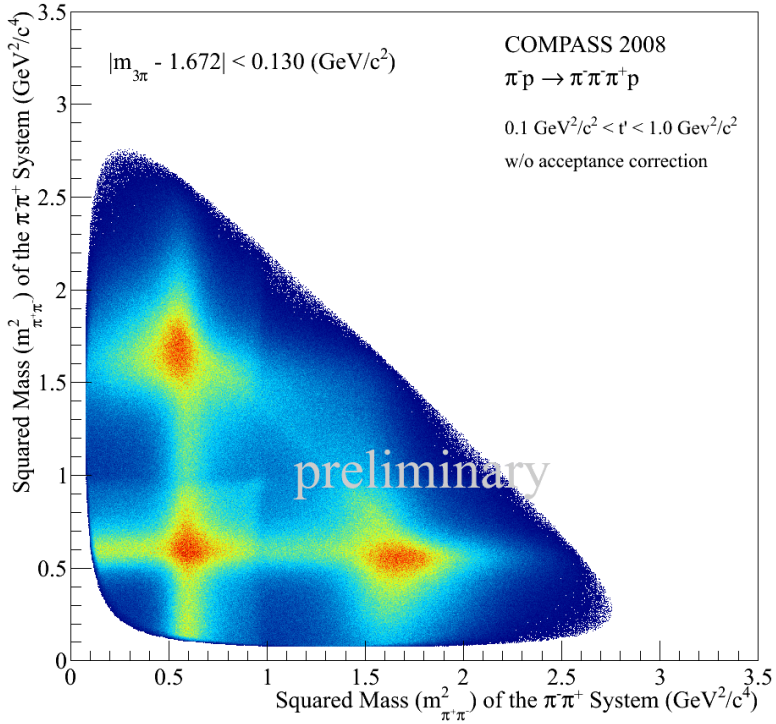
Invariant Mass Spectrum of $\pi^-\pi^-\pi^+$ (2008)

- 190 GeV/c hadron beam → $96\%\pi^-, 3.5\%K^-, 0.5\%\bar{p}$
- 40cm liquid hydrogen target
- $0.1\text{GeV}^2/c^2 < t' < 1.0\text{GeV}^2/c^2$
- ∼96M exclusive events (2008)



3π 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 $\pm 0.5\Gamma_0$.

- Input to PWA per mass bin: one Dalitz plot + 3 angles = 5 variables

PWA Formalism Redux

2Stage Isobar-Model Fit

Mass-Independent PWA

- Fit angular distributions + isobar systems in independent mass bins

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

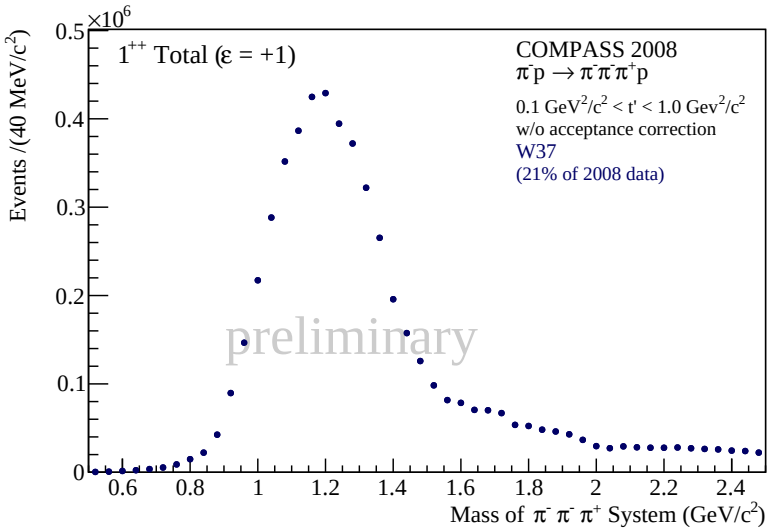
- Production amplitude
- t'-dependence (helicity "flip")
- Decay amplitude (Helicity formalism, reflectivity basis)

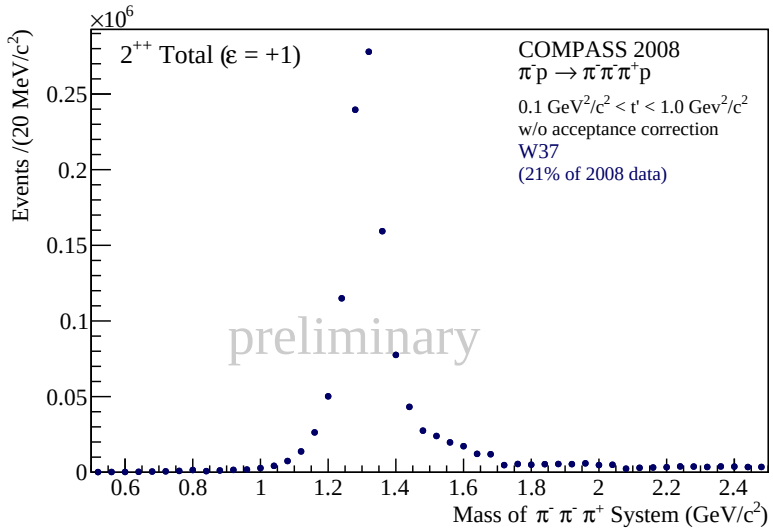
Mass-Dependent χ^2 fit $\rightarrow$ Extract Resonance Parameters

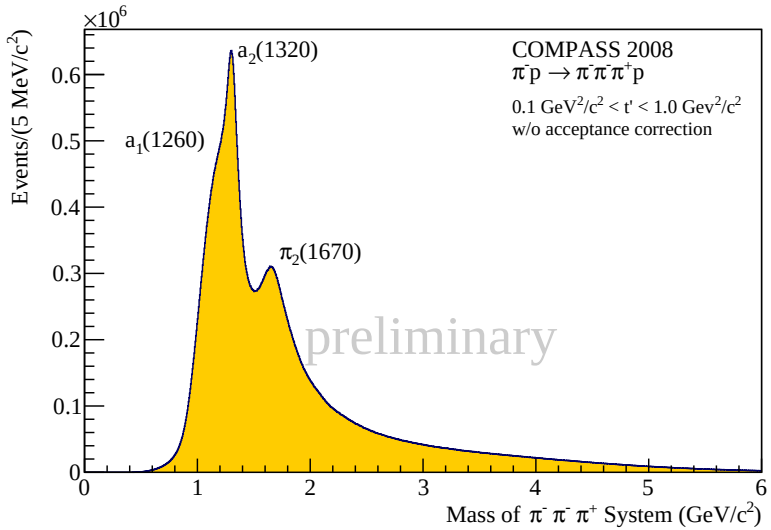
- Parameterization of spin-density matrix elements $\sum_r T_{ir}^{\epsilon} T_{jr}^{\epsilon *}(m_x)$
- Takes into account interference terms
- Coherent background for some waves

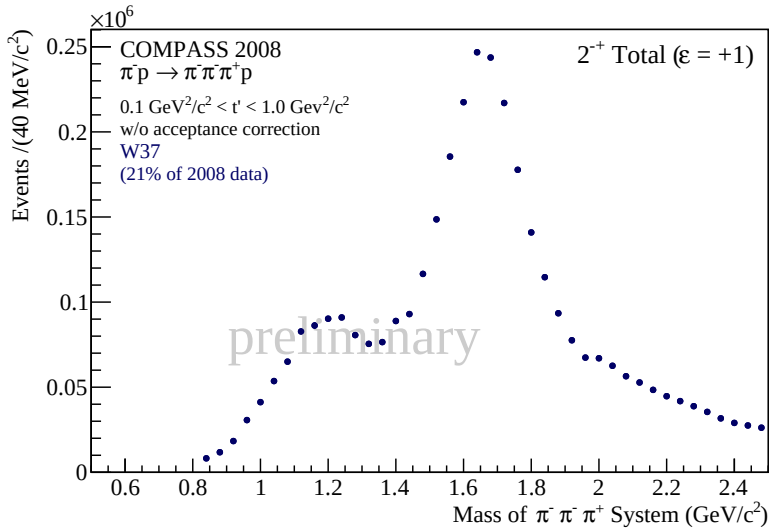
Intensities of dominant J^{PC} states

First results from mass independent PWA (2008)









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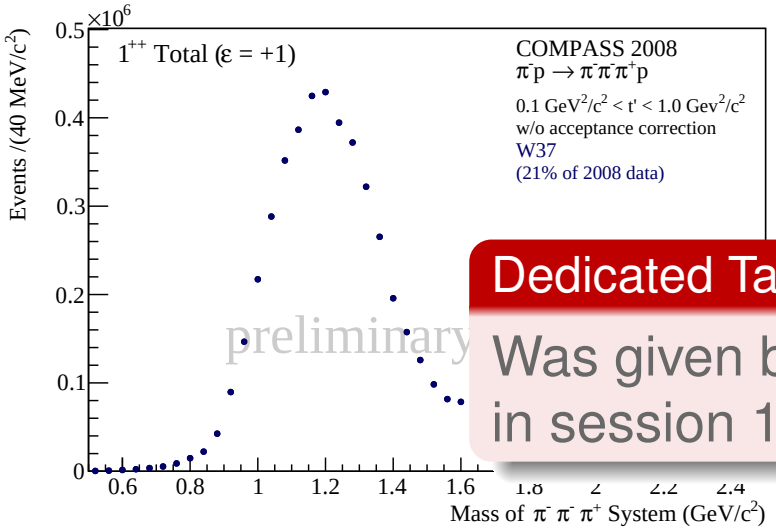
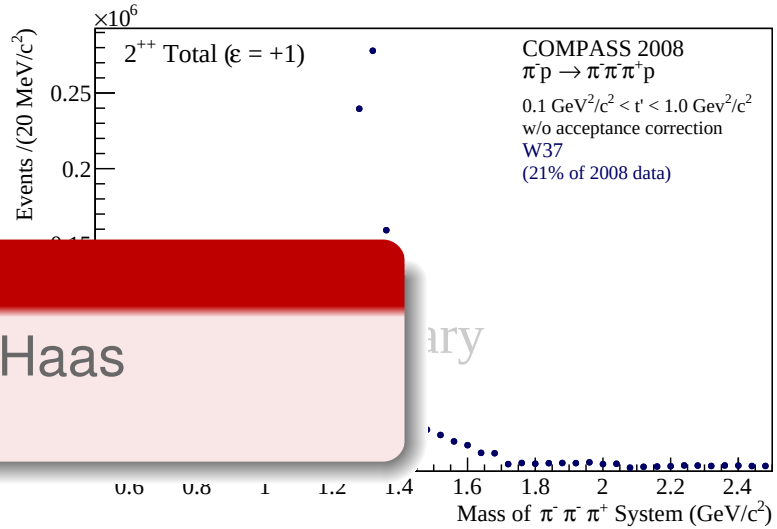
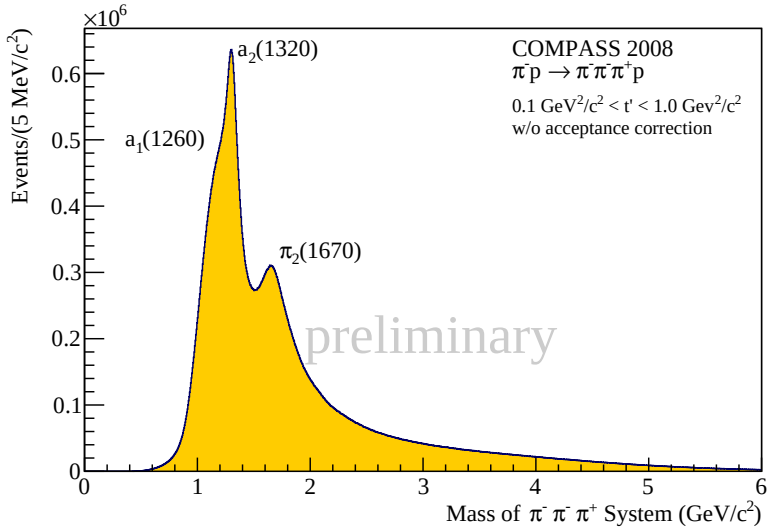
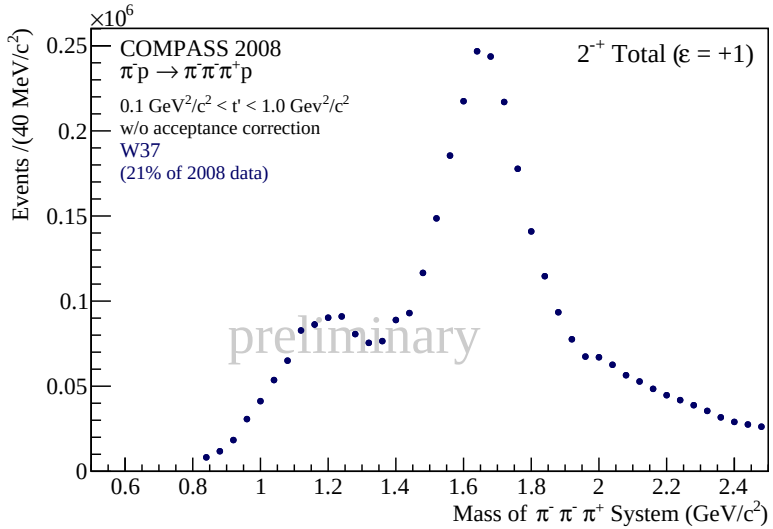




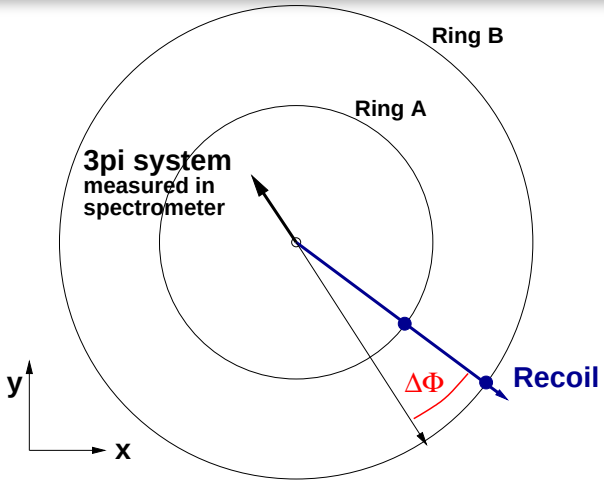
Dedicated Talk

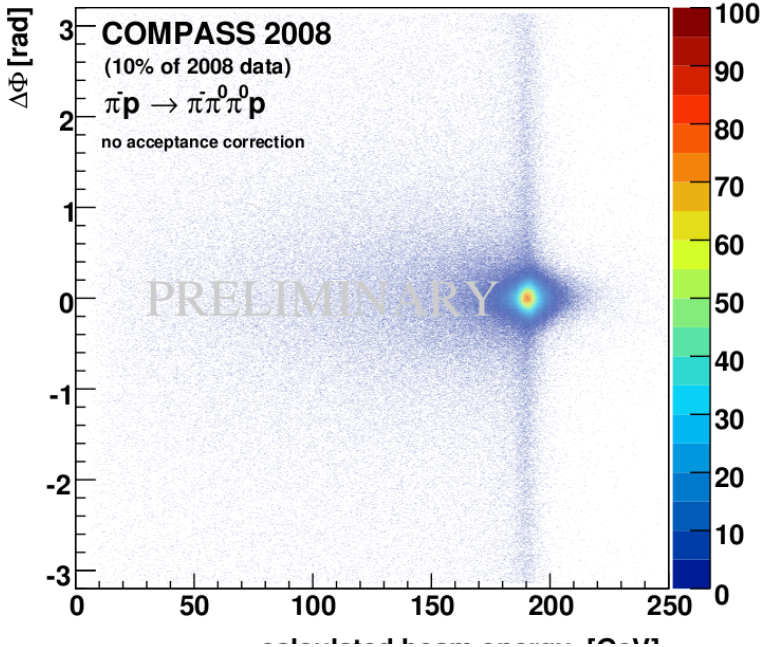
Was given by F. Haas
in session 1D



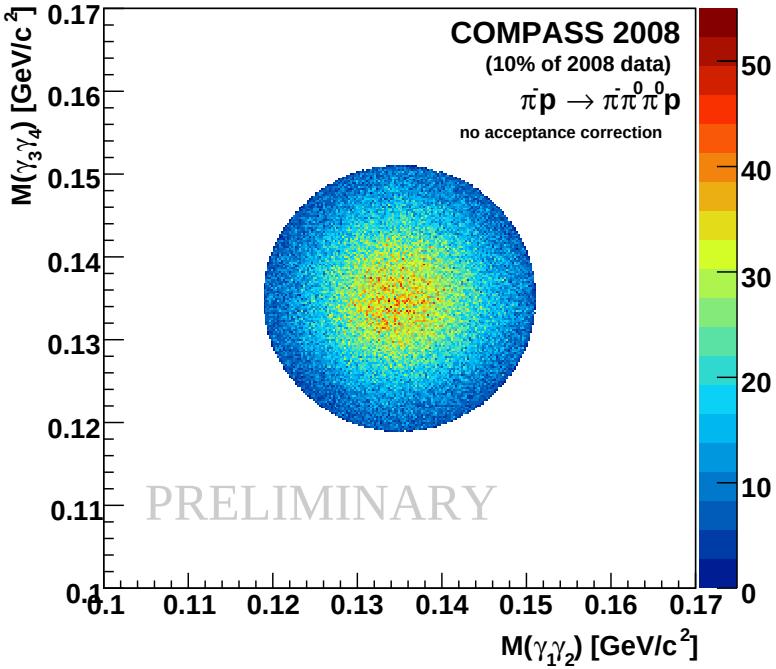


$\pi^-\pi^0\pi^0$ Final State - Selection



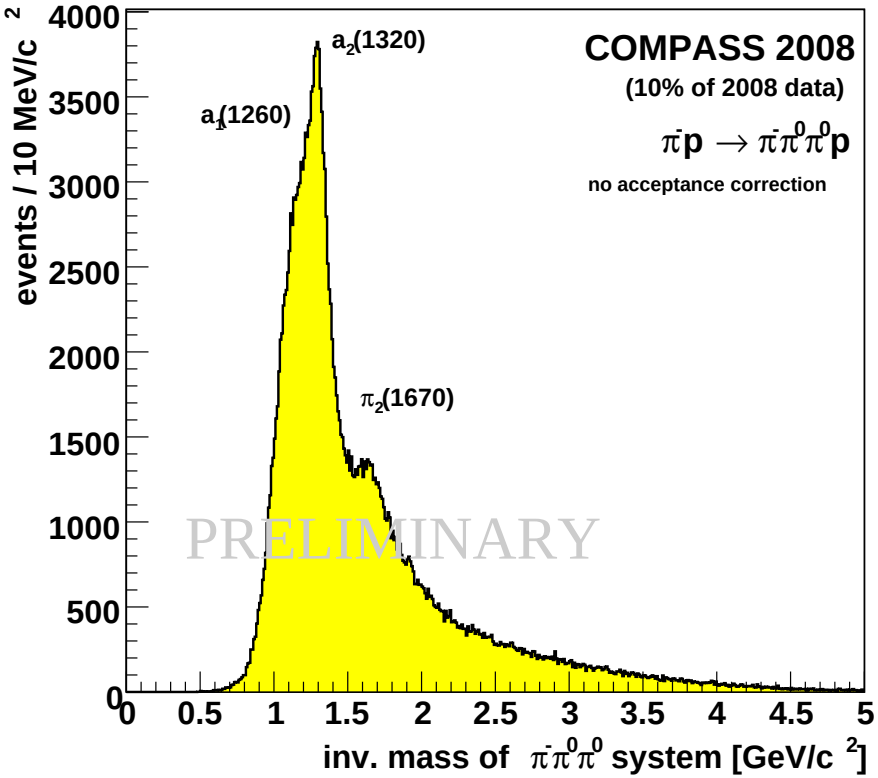


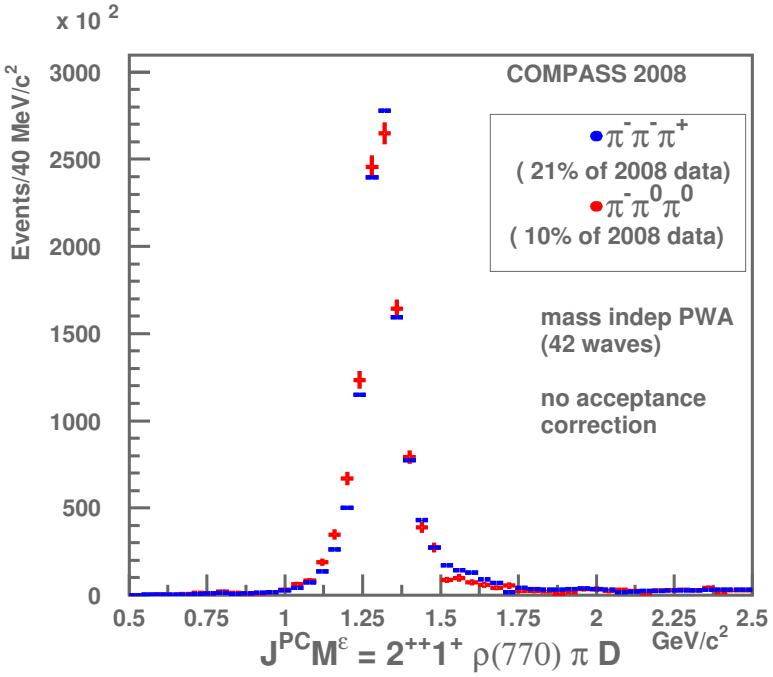
$m_{\gamma\gamma}$ vs $m_{\gamma\gamma}$:



$\pi^-\pi^0\pi^0$ Final State

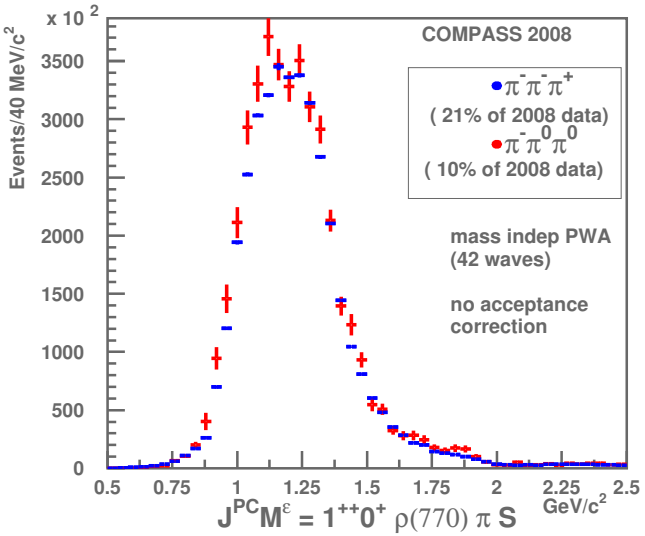
Mass spectrum and first fit $\longrightarrow$ a_2 peak

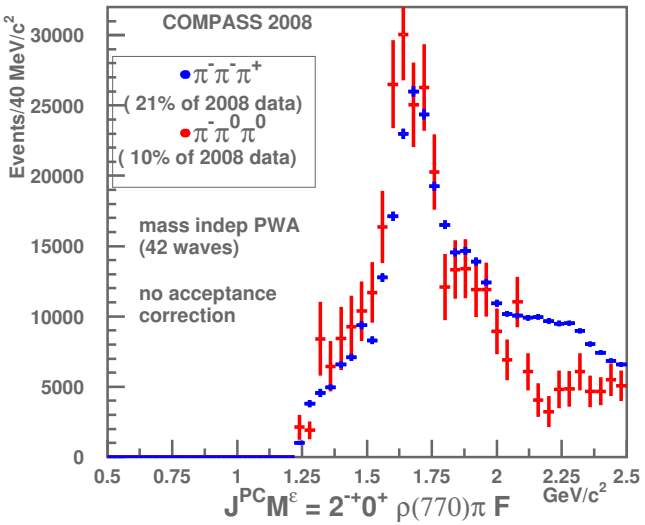




First results from 3π PWA (2008)

Comparison: $\pi^-\pi^+\pi^-$ vs. $\pi^-\pi^0\pi^0$ (normalized on $a2(1320)$ peak)





- Isospin symmetry
  $\pi^-\pi^+\pi^-$ vs. $\pi^-\pi^0\pi^0$
- $I = 0$ vs $I = 1$ $\pi\pi$ isobars
- $\Rightarrow$ factor 2 between
  $\pi^-\pi^+\pi^-$ and $\pi^-\pi^0\pi^0$ for $I_{\pi\pi} = 0$
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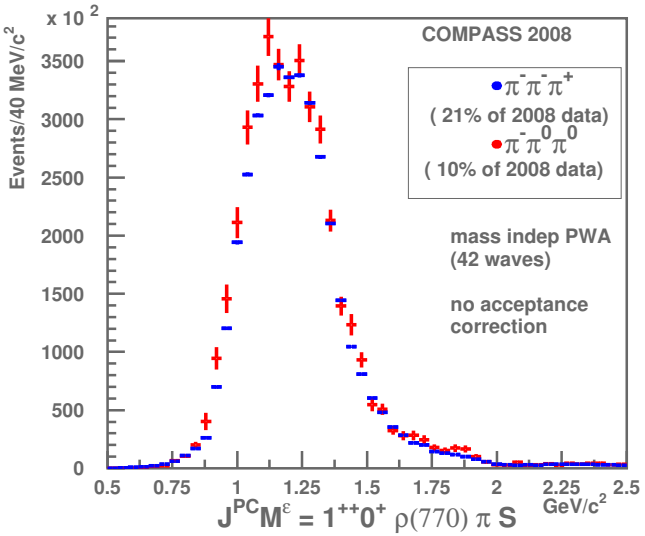

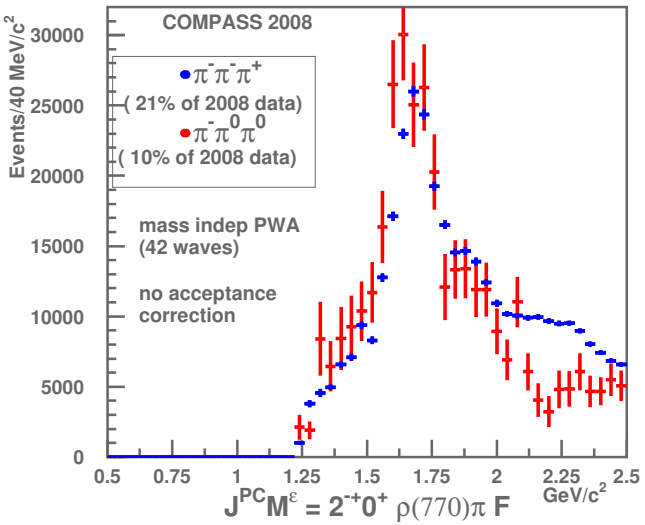

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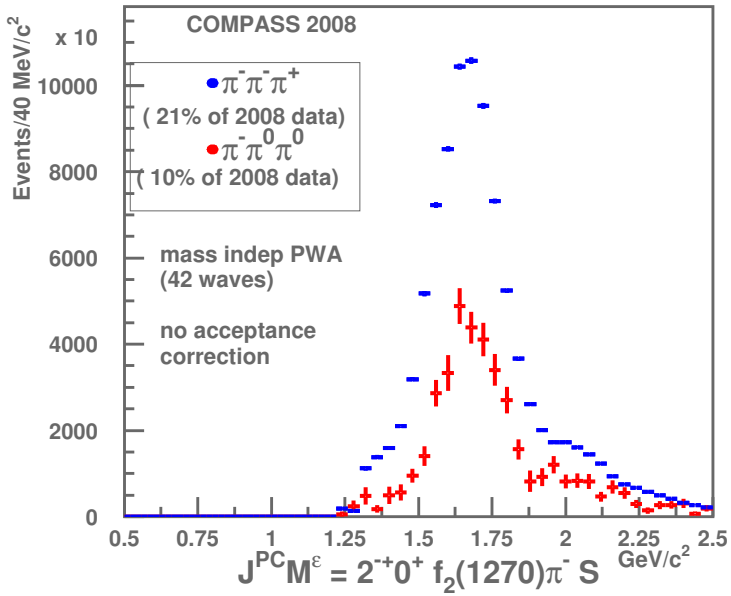
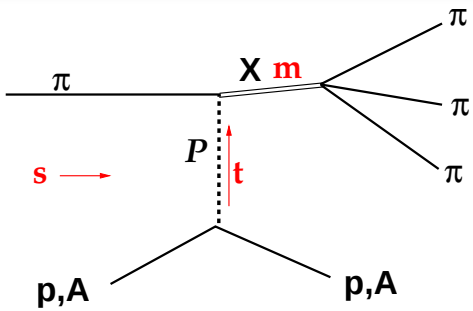
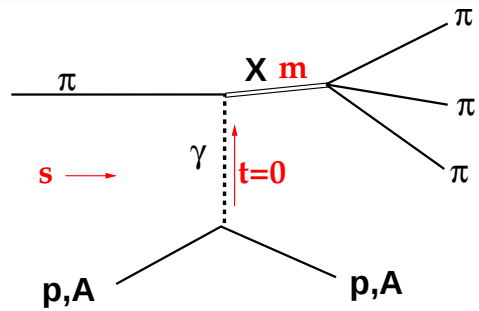


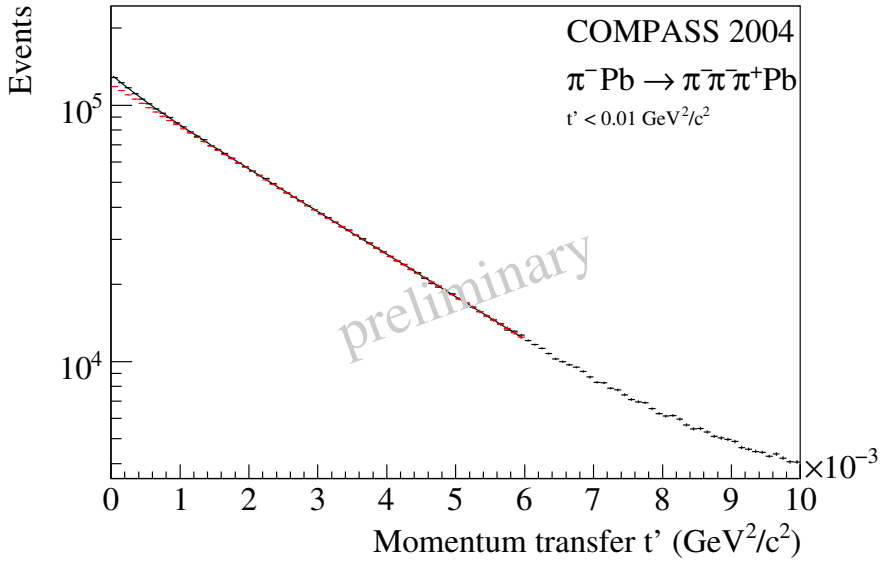
Primakoff Production of 3π States

Statistical Subtraction of Diffractive Component at low t'





- Diffraction: Spinprojection $M_J^X = 1$ suppressed for $t \to 0$
- Primakoff photon: helicity 1 $\Rightarrow M = \pm 1$ expected



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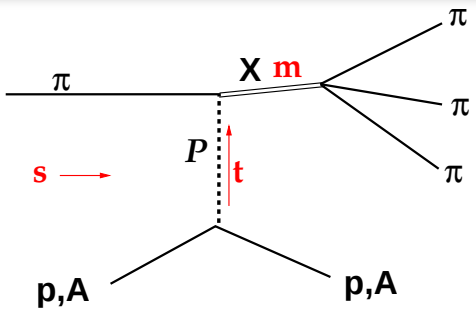

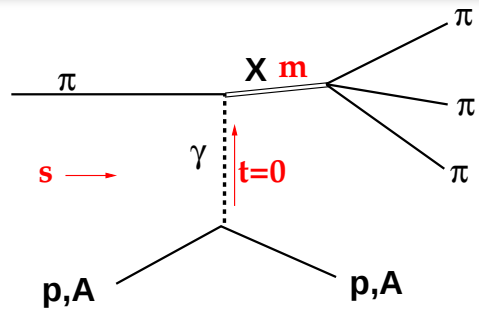

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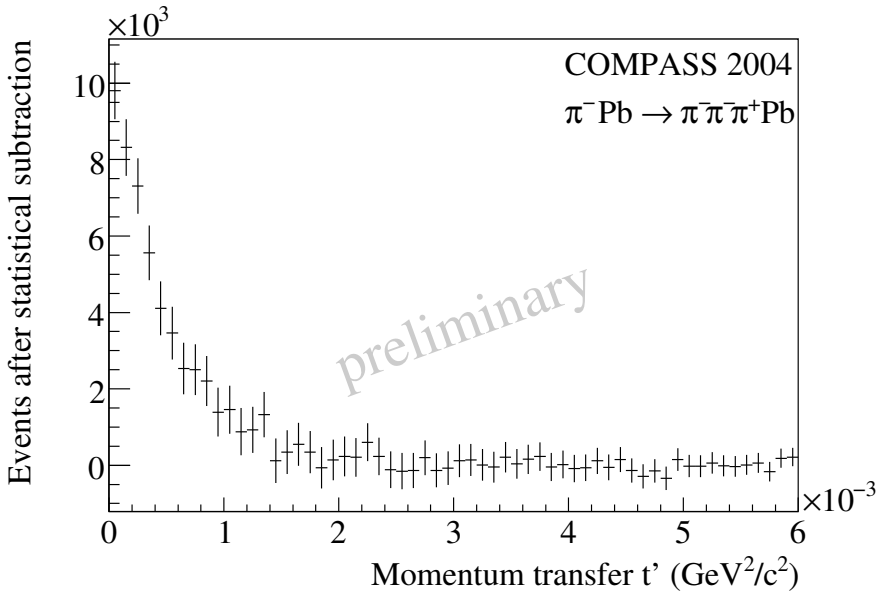
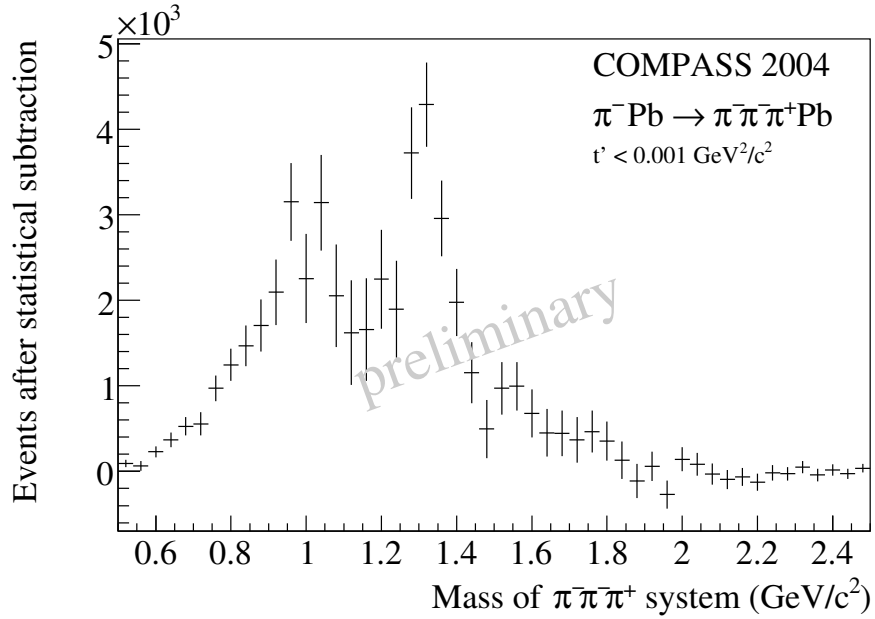
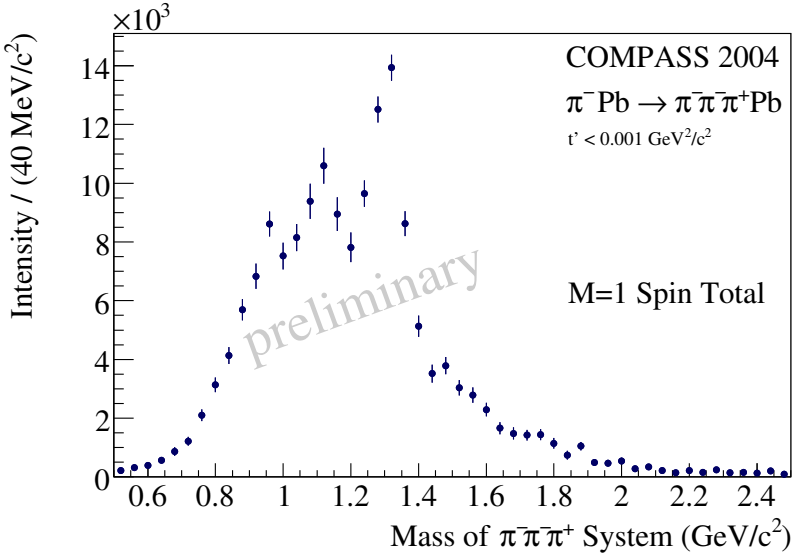


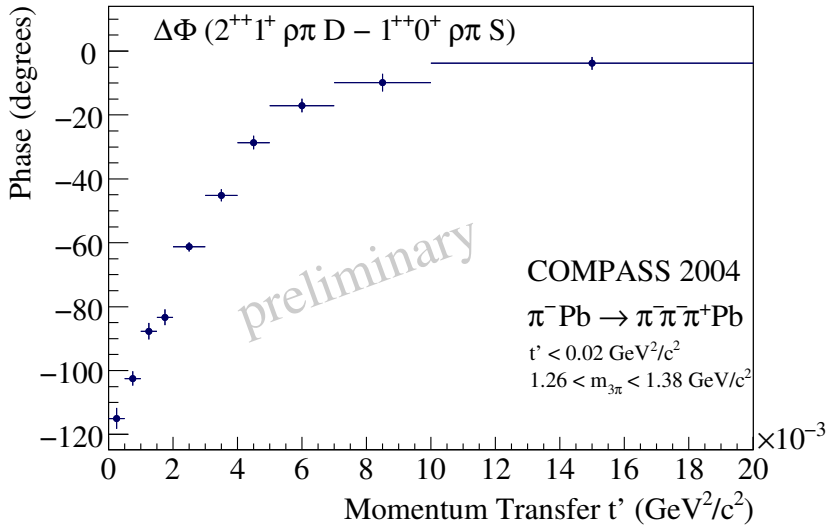


Extraction of a2(1320) Production Phase

- Partial wave fit $\Rightarrow 1^{++}$ and 2^{++} signals
- 2^{++} only produced with $M \geq 1$ (natural parity exchange)



Total intensity with $M = 1$



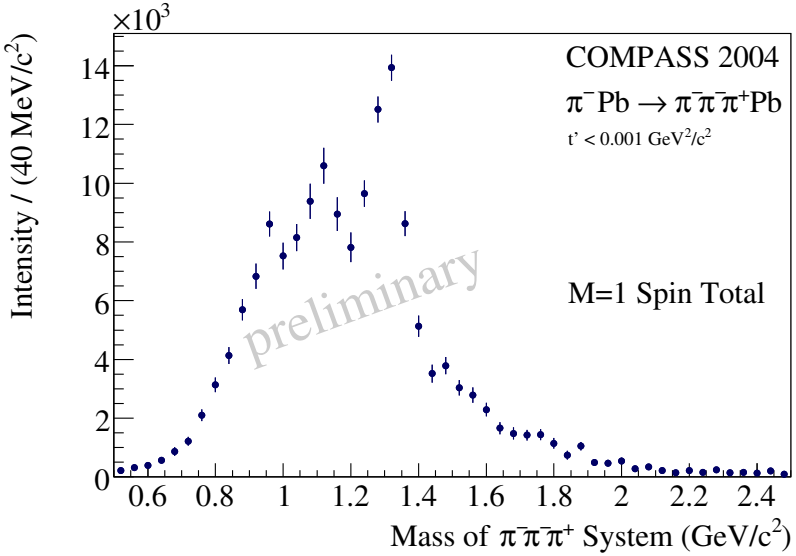
$a_2 - a_1$ phase difference

Extraction of a2(1320) Production Phase

- Partial wave fit $\Rightarrow 1^{++}$ and 2^{++} signals
- 2^{++} only produced with $M \geq 1$ (natural

Interpretation

Transition from dominantly Primakoff to dominantly diffractive production



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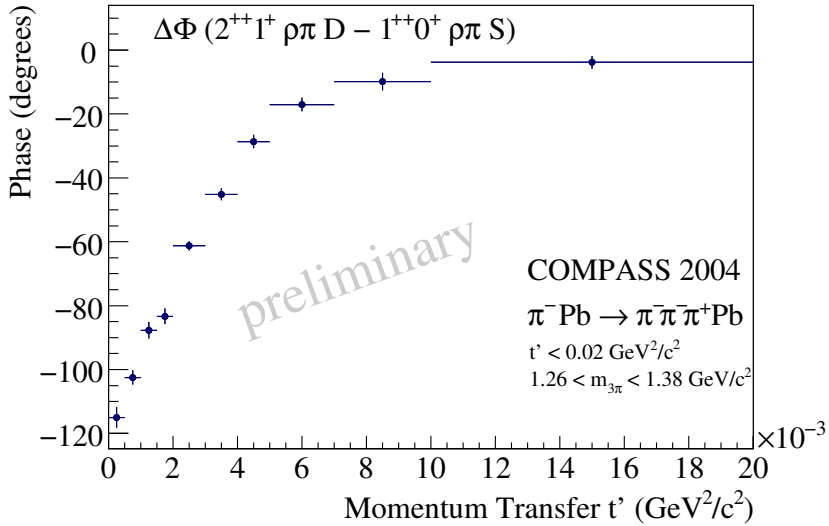


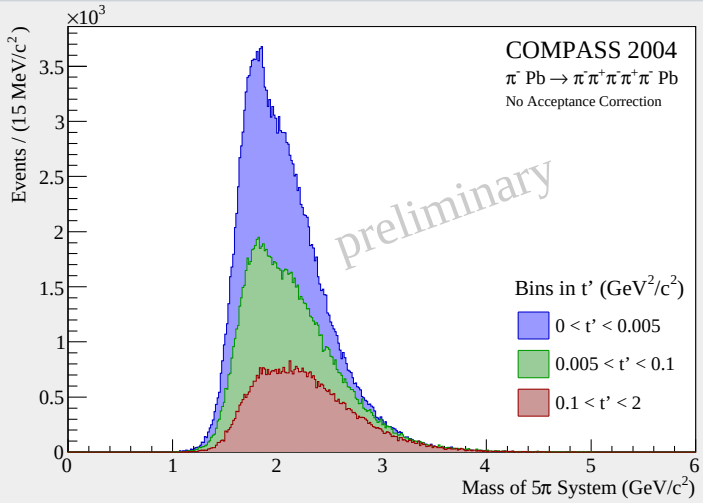
$a_2 - a_1$ phase difference

Multiparticle Final States: $\pi^-\pi^+\pi^-\pi^+\pi^-$

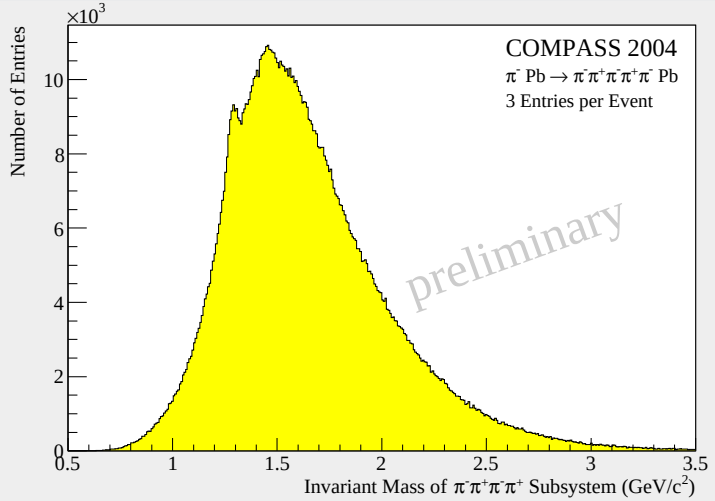
2004 Data Sample – Pb target

- Mass range $> 2\,\mathrm{GeV/c^2}$
- *Light meson frontier*:
  many disputed states in this region
  $(0^{-+})(1^{++})(1^{-+})(2^{-+})(4^{++})(4^{-+})$...
- Parity doublets?
  Effective restoration of classical QCD symmetries?
- Decay modes $b_1\pi$, $f_1\pi$, $\rho'\pi$

5π invariant mass



4π invariant mass $\rightarrow f1(1285)$



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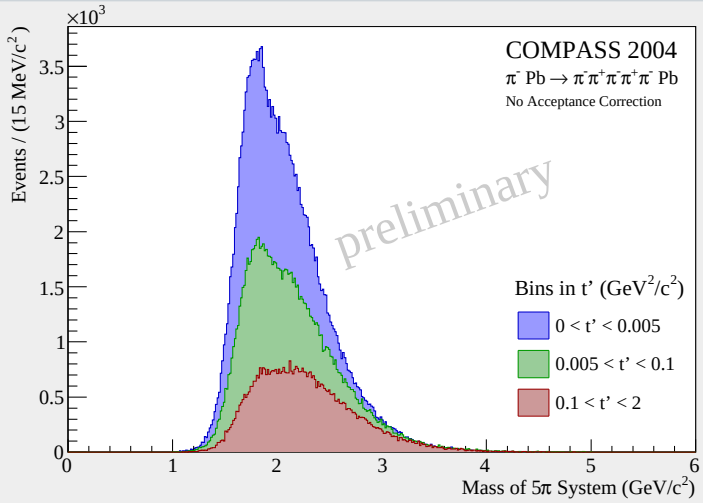
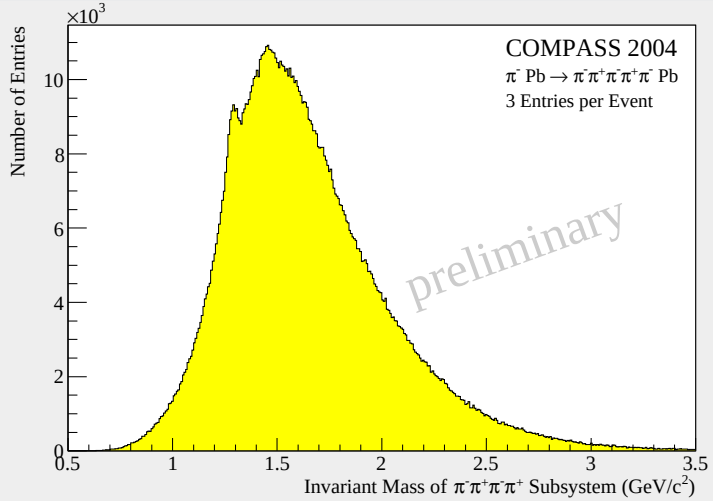
  $(0^{-+})(1^{++})(1^{-+})(2^{-+})(4^{++})(4^{-+})$...
- Parity doublets?
  Effective restoration of classical QCD symmetries?
- Decay modes $b_1\pi$, $f_1\pi$, $\rho'\pi$
- Prototype multiparticle analysis
- Complex isobar decays
- New algorithmic approaches
  $\rightarrow$ e. g. Genetic Optimization

5π invariant mass



4π invariant mass $\rightarrow$ $f1(1285)$



4π Central Production on Proton Target

Can we kinematically separate $I = 0$ 4π systems?

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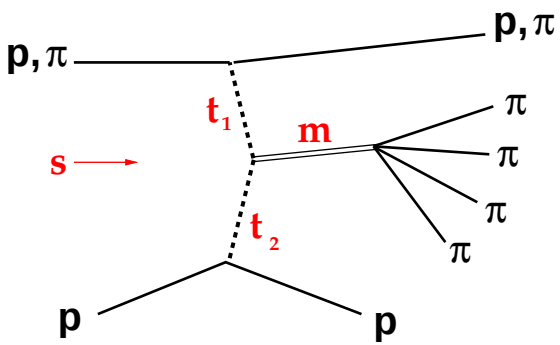
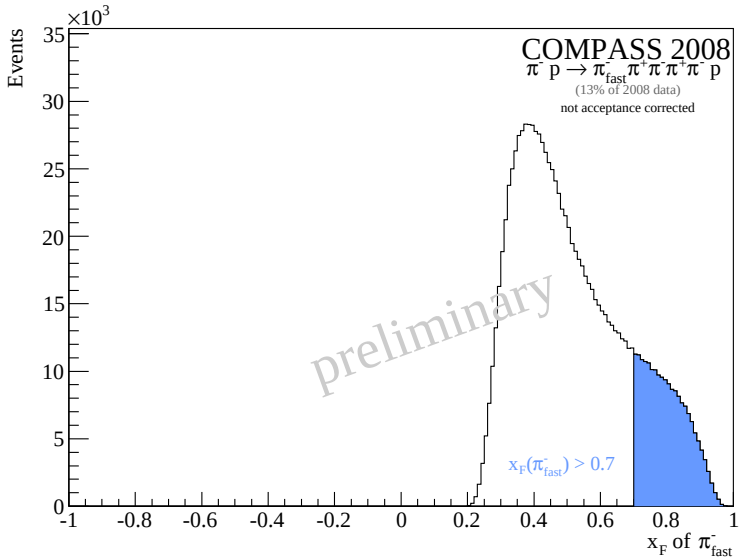
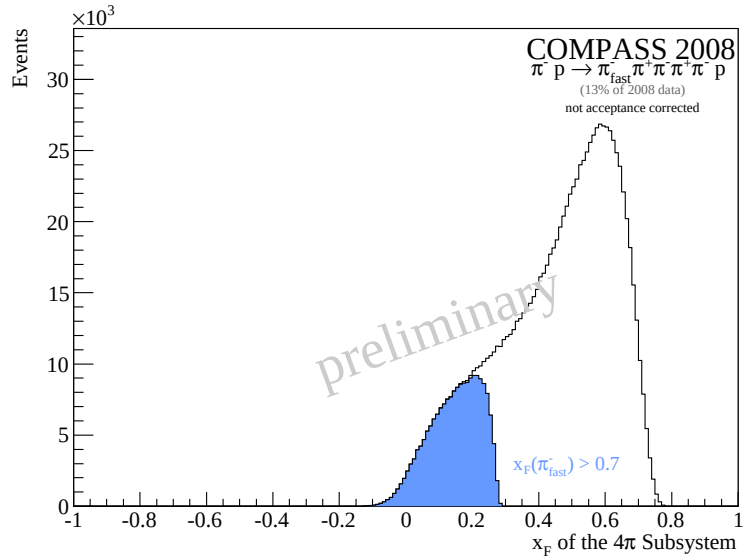


Event signature

- Fast outgoing π^-
- Slow recoil proton
- Rapidity gaps

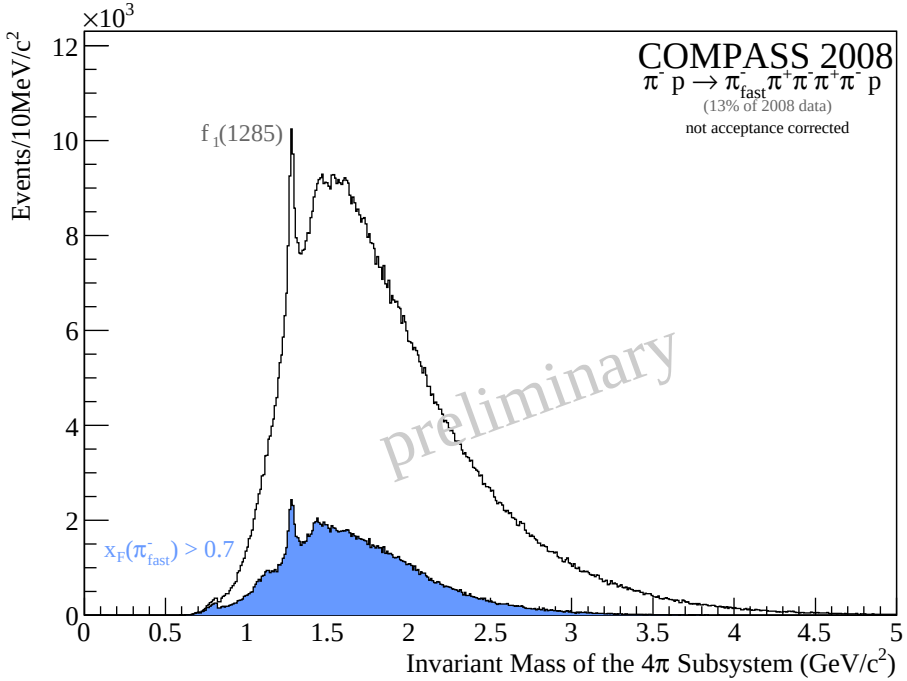
Selection of centrally produced 4π using cut $x_F^{\pi^-_{fast}} > 0.7$ $x_F = \frac{2p_l}{\sqrt{s}}$





Central Production of 4π

4π Subsystem Invariant Mass Distribution

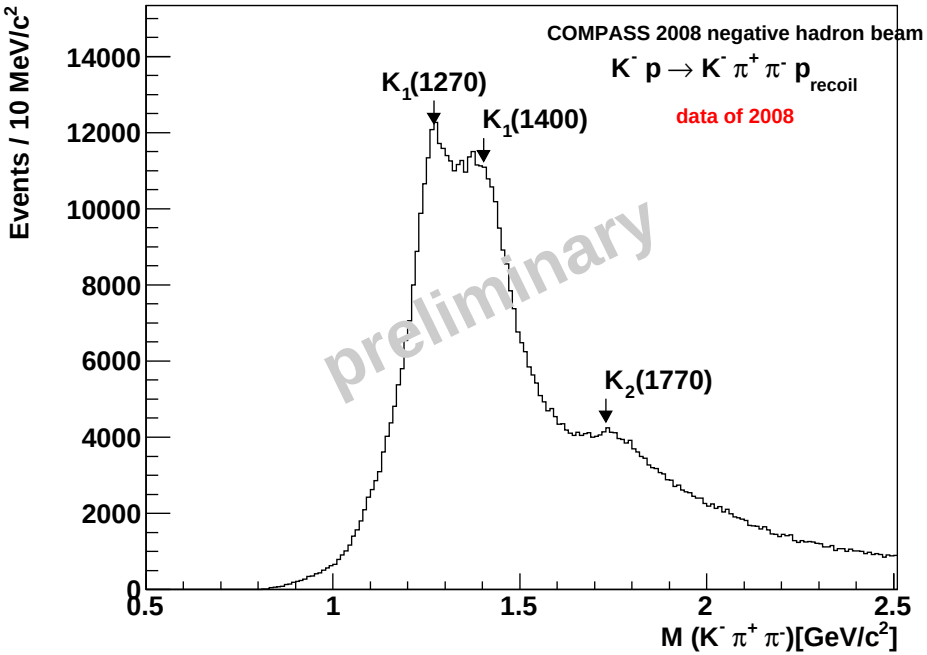


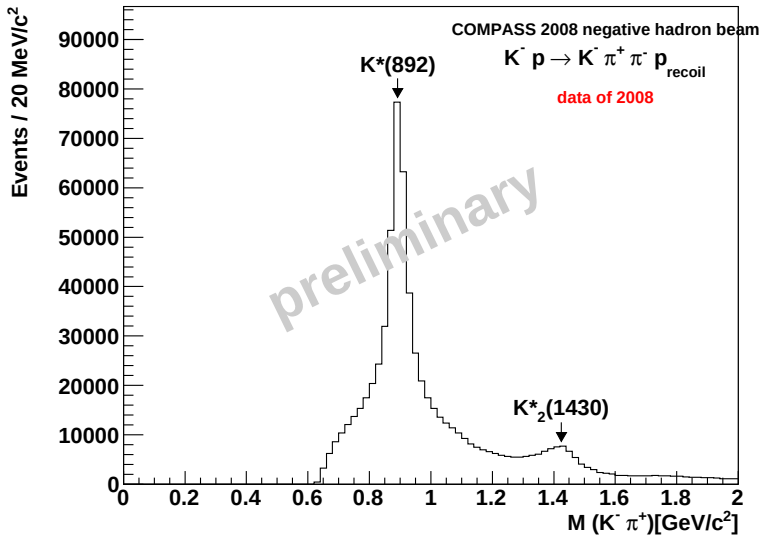
Separability from diffractive processes

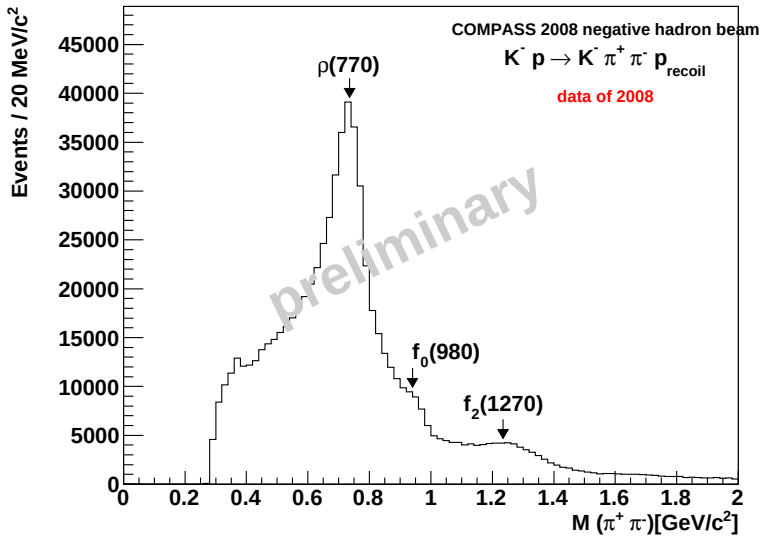
- x_F cut enriches $f_1(1285)$
- Both central prod. and diffraction present @ 190 GeV/c
- Unified analysis technique required

Kaon Diffraction $K^- p \to K^- \pi^+ \pi^- p$

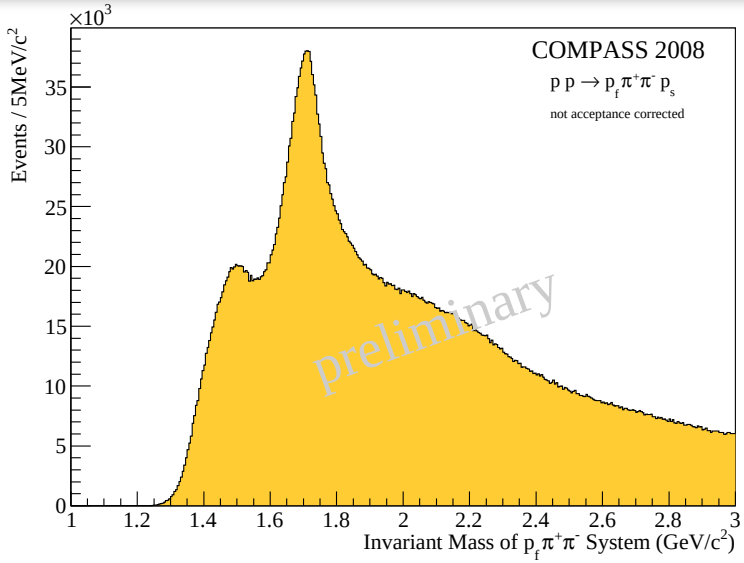
- Beam kaon tagging with Differential Cherenkov Counters (CEDAR)
- FS kaon ID with RICH
- $\sim$ 600 000 events on tape from 2008 (WA32: 200 000)

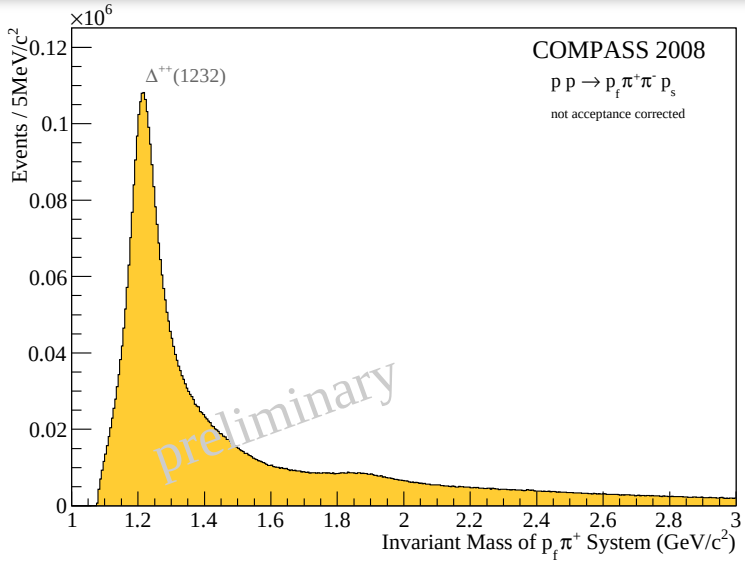


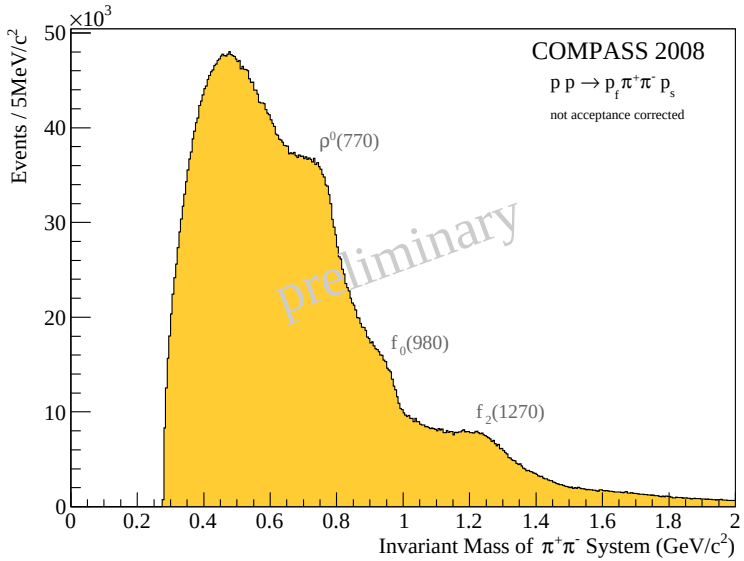


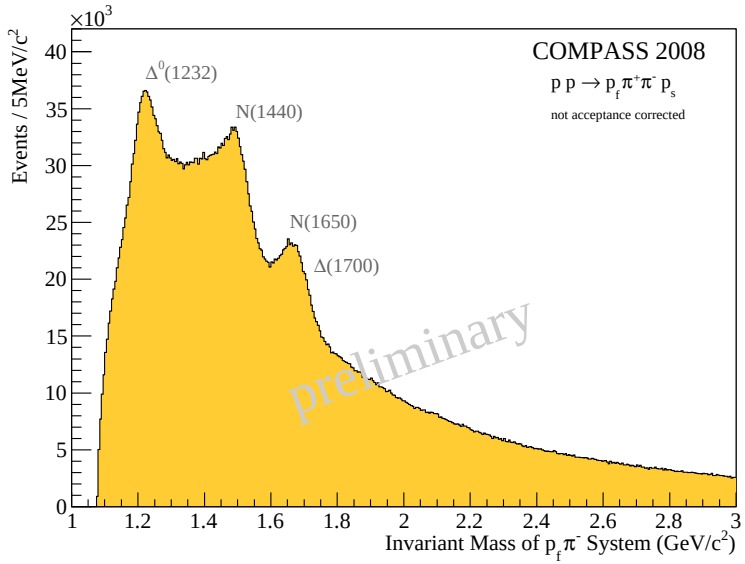


Proton Diffraction: $pp \longrightarrow p\pi^+\pi^- p_{recoil}$

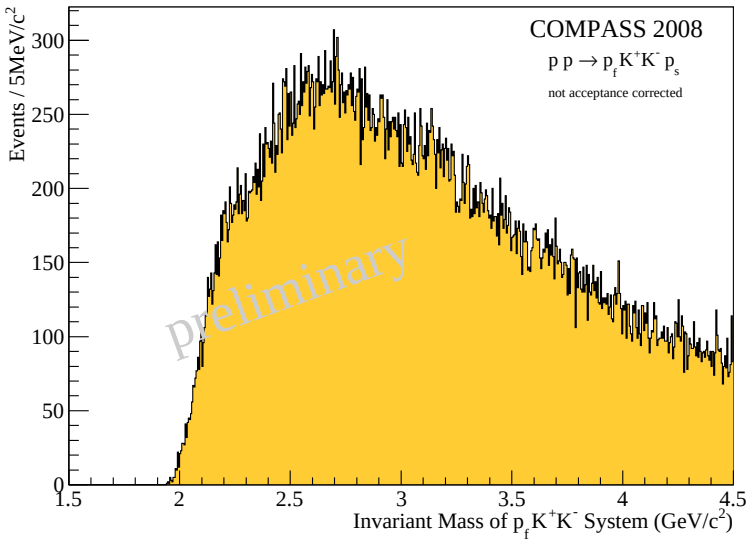


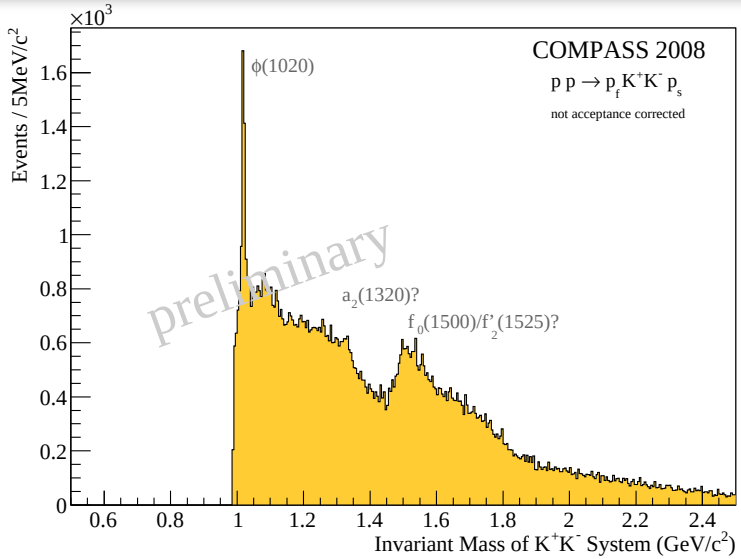


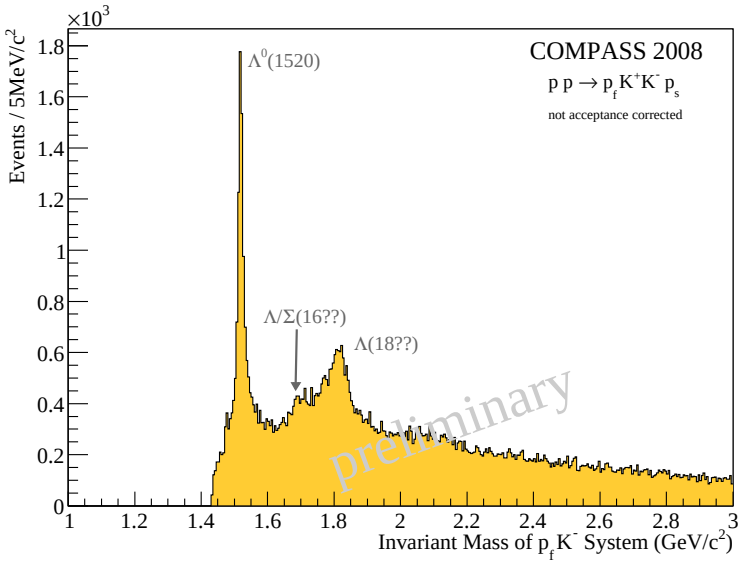


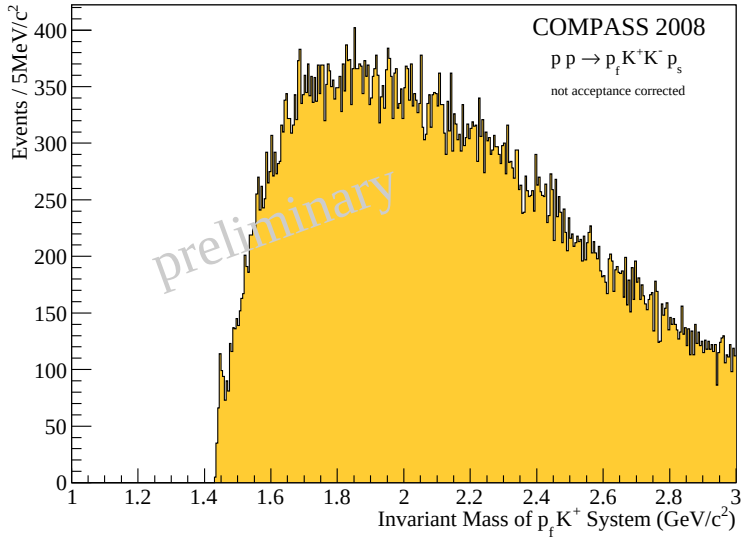


Proton Diffraction: $pp \longrightarrow p_{fast} K^+ K^- p_{slow}$









Summary and Outlook

Hadron Spectroscopy at COMPASS

Technische Universität München

Summary: Rich, high statistics data samples

- 96M $\pi^- p \to \pi^- \pi^+ \pi^- p$ events (2008)
- $\pi^- p \to \pi^- \pi^0 \pi^0 p$
  - $\to$ PWA started
- 5π, 3π Primakoff, Kaon diffraction, 4π central production, $\pi^- \eta$, $KK\pi\pi$, $K_s K_s$ central production
- Baryon Spectroscopy from 2008 pilot run

Outlook:

- Main focus: Acceptance simulation
- Ongoing work on ECal resonstruction (due to hardware upgrade)
- Advancement of PWA software
  `http://sourceforge.net/projects/rootpwa`
- 2009 data being prepared for analysis