Kaonic final states in $\pi^- p$ at COMPASS

Tobias Schlüter for the COMPASS collaboration

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Overview

- Overview of the COMPASS experiment
- Kaonic final states?
- Status of Analyses

Physics Goals – Overview

COMPASS, the "COmmon Muon and Proton Apparatus for Spectroscopy", pursues two programmes, one with μ beam, one with hadron beam. Overarching goals:

- μ programme: learn about the spin structure of the nucleus
- hadron programme: meson spectroscopy, properties of mesons

In 2008, 2009 we used $190\,\mathrm{GeV/c}$ hadron beams

- negative hadron beam (96% π^-, 3.5% K^-, 0.5% $\bar{p}$)
- positive hadron beam (70% p, 25% $\pi+$, 5% K^+)

impinging on a $\mathrm{LH_2}$ target. (Also short period with Pb target.)

Physics Goals – Meson Spectroscopy

Study by means of partial wave analysis (PWA) mesons produced in diffractive and central production processes mediated by Reggeon exchange.
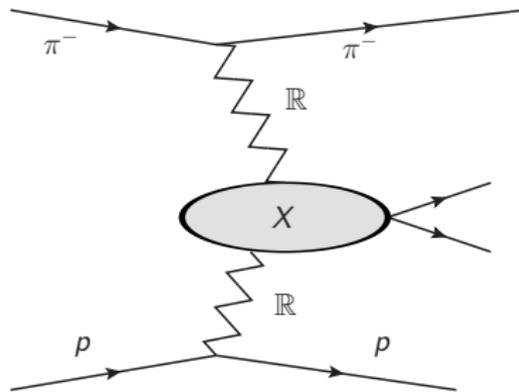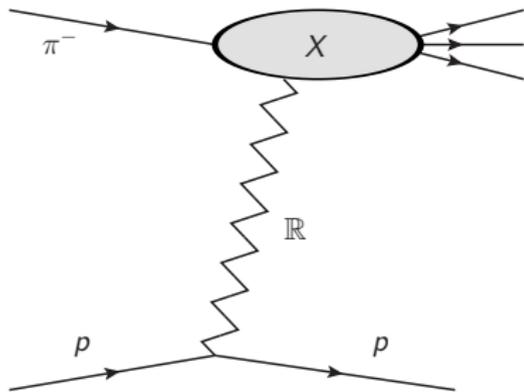

Needs:

- ▶ inert target
- ▶ exclusive measurement of final state
- ▶ full angular coverage

The COMPASS experiment (Hadron setup)
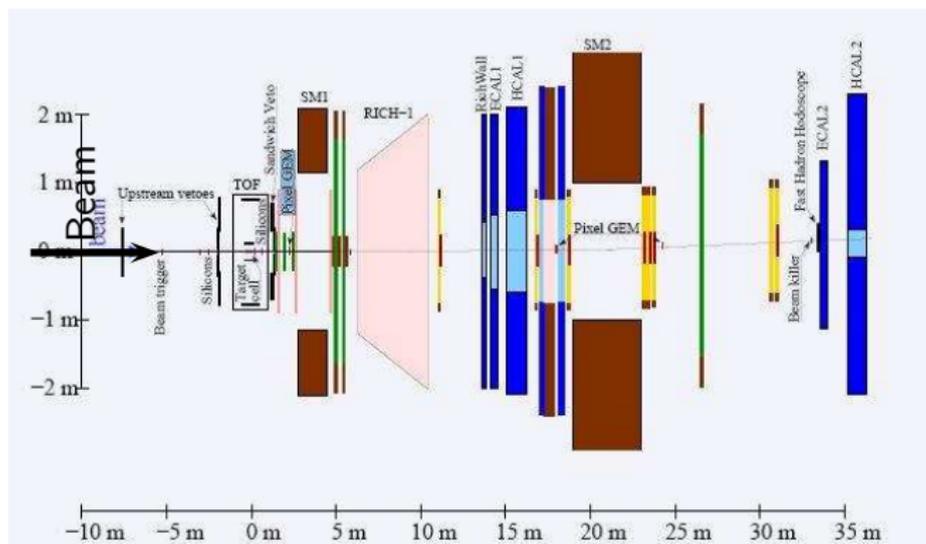
- ▶ two-stage spectrometer with tracking and calorimetry in both stages, O(100 000) readout channels
- ▶ with large acceptance,
- ▶ designed for combined μ and hadron programmes

# The COMPASS experiment (Hadron setup)
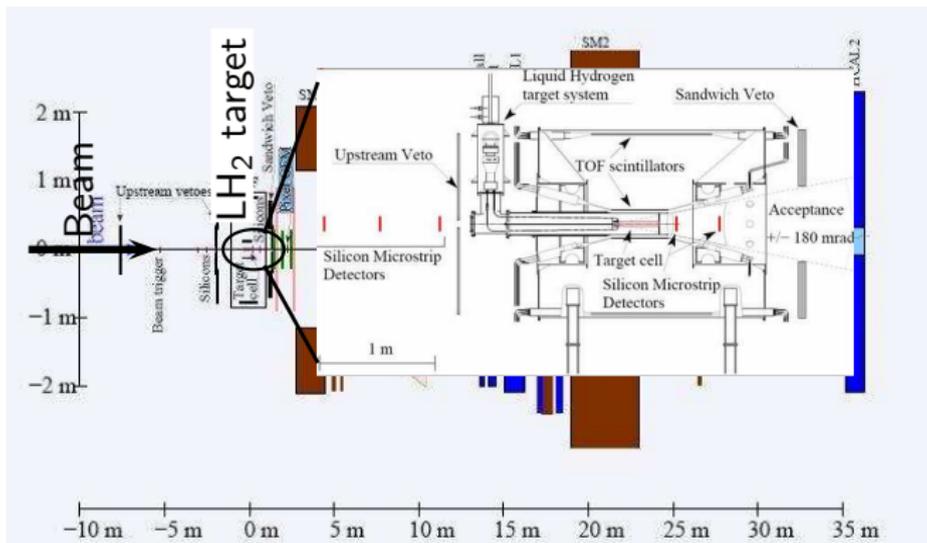
- ▶ 40 cm LH_2 target
- ▶ surrounded by recoil proton detector, and
- ▶ vertex detectors along the beam direction

The COMPASS experiment (Hadron setup)
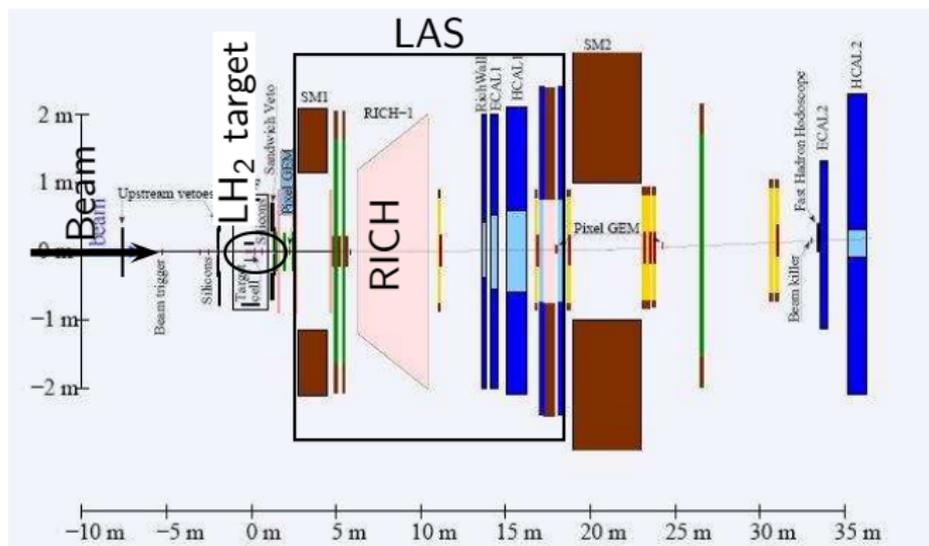
Large Angle Spectrometer

- ▶ bending magnet,
- ▶ tracking,
- ▶ PID via RICH and calorimeters

The COMPASS experiment (Hadron setup)
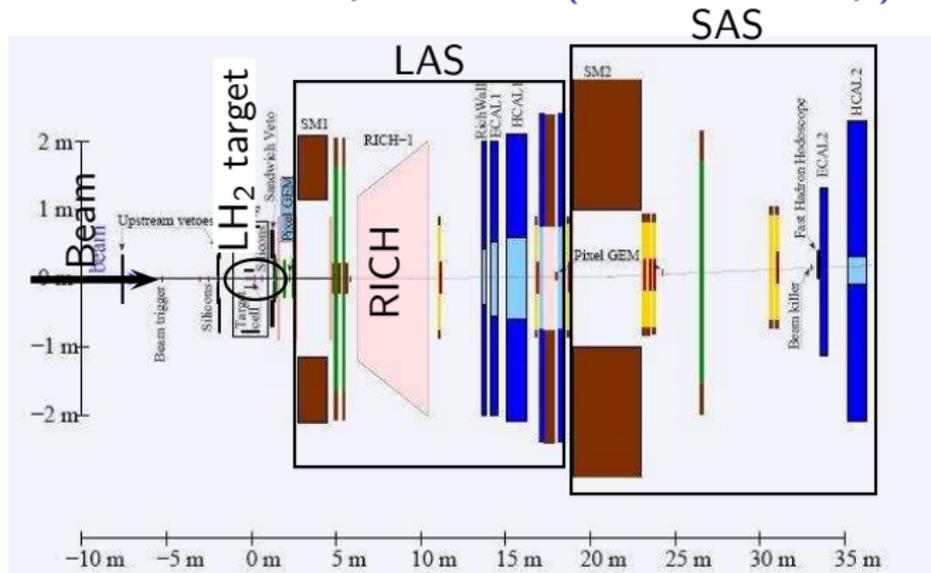
Small Angle Spectrometer

- ▶ strong bending magnet for high-momentum tracks,
- ▶ tracking,
- ▶ calorimetry

The COMPASS experiment (Hadron setup)
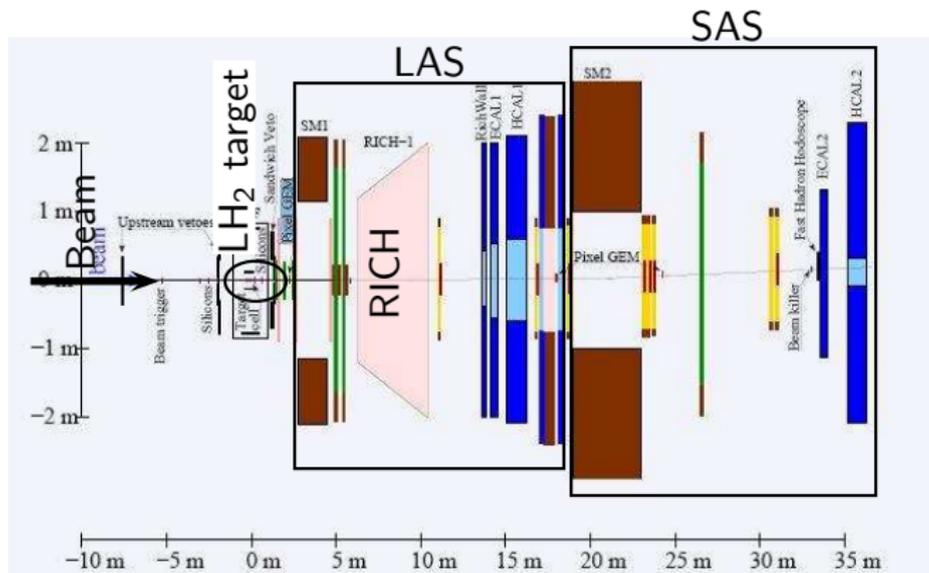
Not pictured:

- ▶ Muon detection system (downstream)
- ▶ beam particle identification (upstream)

The RICH – Particle Identification

COMPASS 2008 hadron data
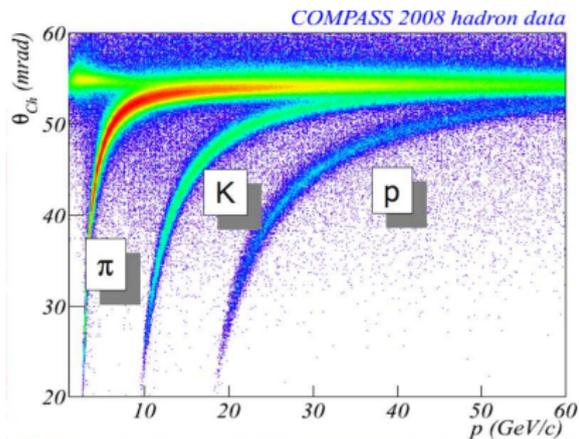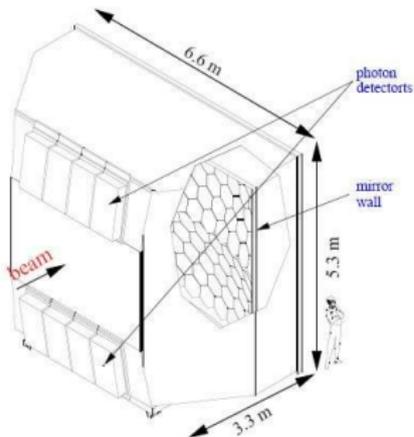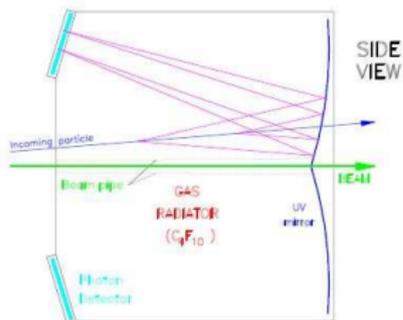
COMPASS's RICH detector allows separating Kaons from Pions up to some 30–40 GeV via measurement of particle velocity. Used here to identify final-state charged Kaons.

The CEDARs – Beam Particle Identification
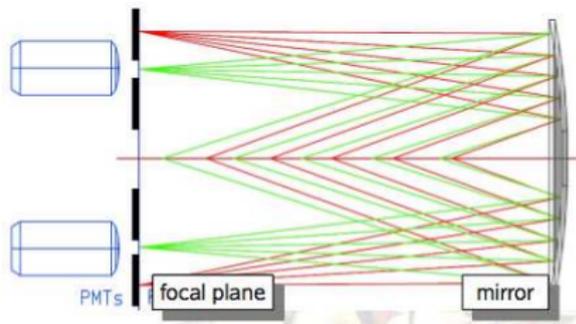
Two CEDARs (ChErenkov Differential counter with Achromatic
Focus) allow beam particle identification. We use them as a Kaon
veto ($\approx 3\%$ kaons in the negative beam).

Intro to Kaonic final states

Goals:

- ▶ find states with exotic quantum numbers J^{PC}
  $\rightarrow$ Accessible with $\pi K \bar{K}$.
- ▶ closely analyse glueball candidate states
  $\rightarrow$ Glueball favours decay into $K\bar{K}$ according to some theories
- ▶ expand knowledge of kaonic spectrum
  $\rightarrow$ only possible with kaons

Inside the collaboration the following processes are currently being investigated:

- ▶ $\pi^- p \rightarrow \pi^- K^+ K^- p$
- ▶ $\pi^- p \rightarrow \pi^- K_S^0 K_S^0 p$
- ▶ $K^- p \rightarrow K^- \pi^- \pi^+ p$ (not discussed in this presentation)
- ▶ $\pi^- p \rightarrow \pi^- K_S^0 K_L^0 p$ (not discussed)
- ▶ same with positive beam (not discussed)

Intro to Kaonic final states II

Good:

- allowed quantum numbers are different for different combinations of kaons, namely the neutrals pick out subsets:

| state	allowed J^{PC}				
$K_S^0 K_S^0$	0^{++}		2^{++}		4^{++}
$K_S^0 K_L^0$		1^{--}		3^{--}	
$K^+ K^-$	0^{++}	1^{--}	2^{++}	3^{--}	4^{++}

- high mass threshold suppresses low mass intermediate states

Bad:

- charged channel needs particle identification which cuts into acceptance (no problem for K_S^0s)

Selection

- $K_S^0 K_S^0$ final state:
  - reconstructed primary vertex
  - one negative track in spectrometer
  - exactly two displaced vertices which fit K_S^0 hypothesis
  - exclusivity (momentum conservation)
- $K^+ K^-$ final state:
  - reconstructed primary vertex
  - exactly three charged tracks $(+ - -)$ in spectrometer
  - one negative track $< 30\,\mathrm{GeV}$ identified by RICH as kaon
  - exclusivity (momentum conservation)
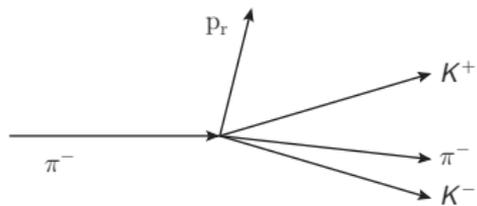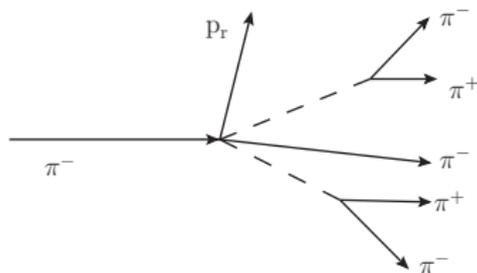
Mass spectra I

$K^+\pi^-$ mass
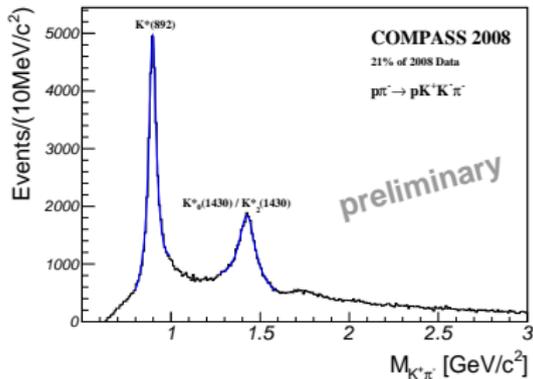
$K^0_S\pi^-$ mass
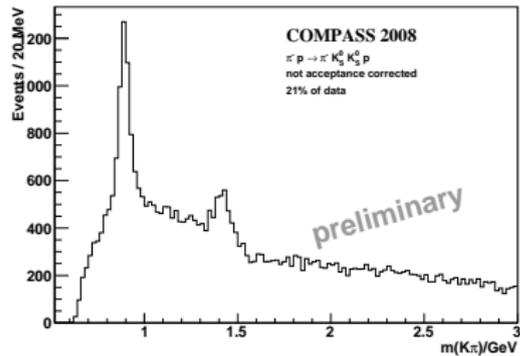
- ▶ Different shape in part due to two combinations in $K^0_S\pi^-$
- ▶ $K^*_1(892)$, $K^*_2(1430)$, $K^*_3(1780)$, and (with some good will) $K^*_4(2045)$ all appear to be there in the left plot

Mass spectra II

K^+K^- mass
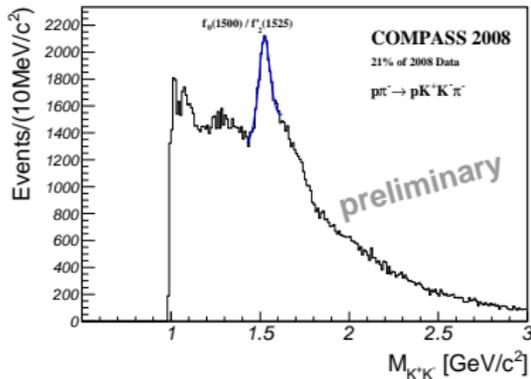
$K_S^0 K_S^0$ mass
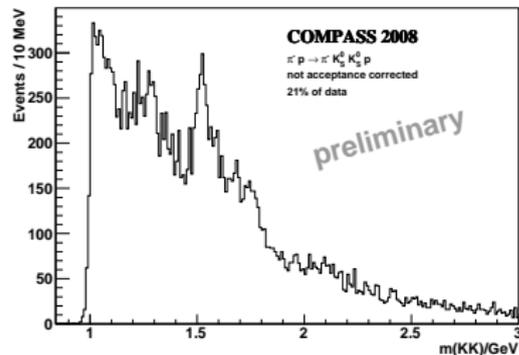
▶ Difference near threshold due to low momentum requirement for RICH identification (and a small ϕ contribution).

▶ Threshold not sharp in $K_S^0 K_S^0$, because K_S^0s not yet kinematically fitted.

▶ known resonances appear to be at their places

Mass spectra III – an aside

Comparison of $K^+\pi^-$ mass distribution to data taken with the muon beam

Pion data
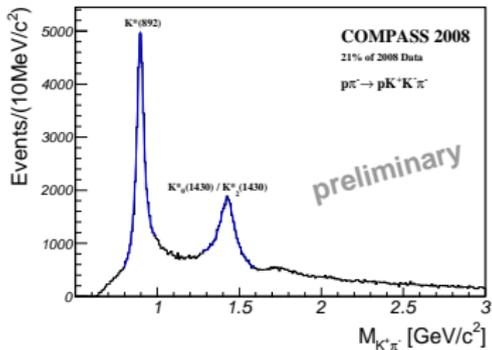
Muon data
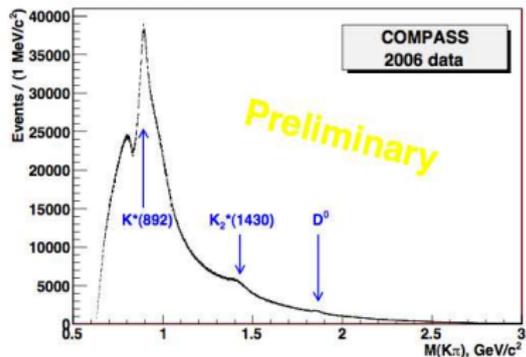
COMPASS produces similar states under very different circumstances.

Mass spectra IV – decay chains

Three-body invariant mass over two-body invariant mass

$K^+\pi^-$ vs $K^-K^+\pi^-$
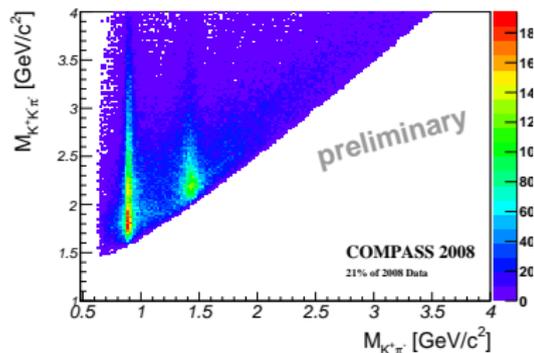
$K_S^0\pi^-$ vs $K_S^0K_S^0\pi^-$
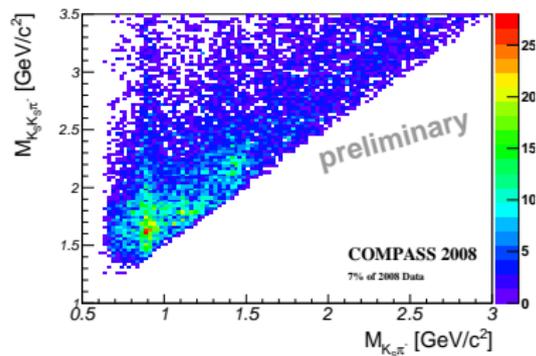
- ▶ notice bulks at $2.2\,\mathrm{GeV}$, resonance which decays via the K^*s?
- ▶ more structure near 3-body threshold in neutral channel due to crosstalk from KK states which are not affected by $30\,\mathrm{GeV}$ (RICH) cut near threshold

Mass spectra V – decay chains ctd

Three-body invariant mass over two-body invariant mass
K^+K^- vs $K^-K^+\pi^-$ $\qquad\qquad\qquad$ $K_S^0 K_S^0$ vs $K_S^0 K_S^0 \pi^-$
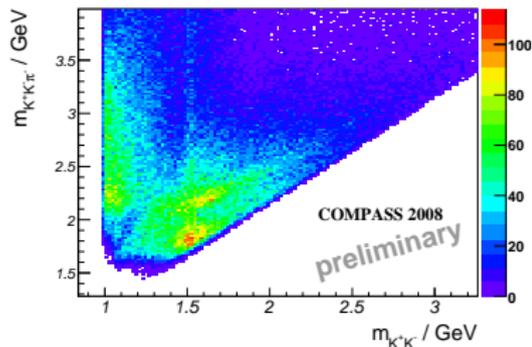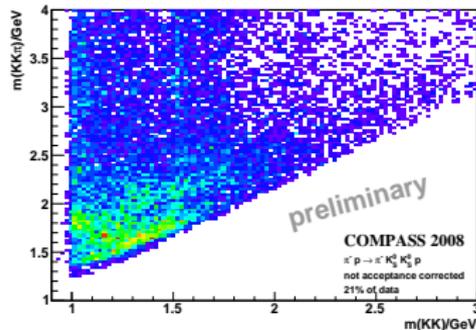
- ▶ structure looks fairly different until one realises that this is due to the $30\,\mathrm{GeV}$ (RICH) cut
- ▶ notice bulks near $1.8\,\mathrm{GeV}$, resonance which decays via the $K\bar{K}$? Also bulks at $2.2\,\mathrm{GeV}$.
- ▶ $f_0(980)$ ($a_0(980)$) stands out quite well

Rapidity, central vs. diffractive production
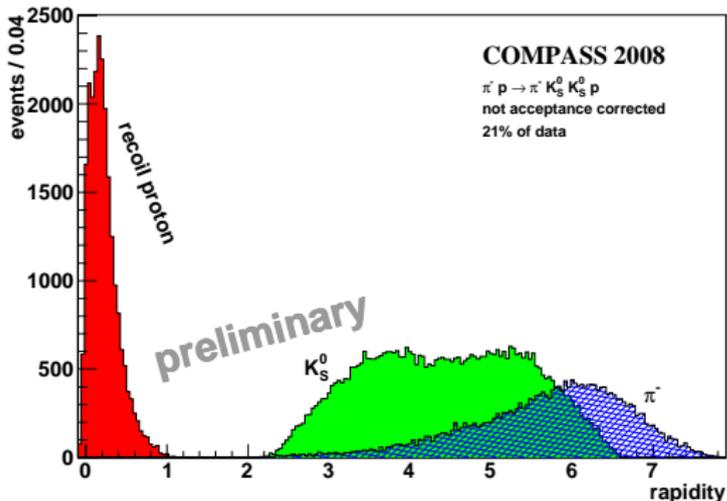
- ► large overlap in rapidity between π^- and K_S^0s
- ► therefore separation between central and diffractive productions doesn't come for free
- ► employed various separation strategies

The $\pi(1800)$

Decision to do PWA of diffractive states in neutral channel first.
Selected subsample with no rapidity gap between Kaons and Pions.

Barnes et al. (PRD 55, 4157) give the following partial widths for
the $\pi(1800)$ ($J^{PC} = 0^{-+}$) interpreted as a 3S $n\bar{n}$ state vs. an
interpretation as a hybrid state:

	$\rho\pi$	$\rho\omega$	$\rho(1465)\pi$	$f_0(1300)\pi$	$f_2\pi$	K^*K	Total
$n\bar{n}$	30	74	56	6	29	36	231
hybrid	30	0	30	170	6	5	≈ 240

Hence: PWA of $K\bar{K}\pi$ is important in determining whether the
$\pi(1800)$ is a hybrid.

Status of neutral mode diffractive PWA

- mass-independent PWA is getting off the ground
- acceptance approximately flat, decreases near 3-body threshold
- waveset mostly reproduces data, from the looks of it a high-spin wave is still missing, probably corresponds to the state at approx. $2.2\,\mathrm{GeV}$
- we see a 0^{-+} wave around $1.8\,\mathrm{GeV}$ decaying via the $K\bar{K}$ S-wave and the $K\pi$ S-wave, i.e. the $\pi(1800)$ (consistent with VES results), but I won't dare to give branching ratios at this point

Conclusions

- kaonic final states open up lots of physics that purely pionic final states don't
- two strong structures in $K\bar{K}\pi$ at $1.8\,\mathrm{GeV}$ and $2.2\,\mathrm{GeV}$ with prominent selective decays
- PWA of $K\bar{K}\pi$ ongoing, far from release, state at $1.8\,\mathrm{GeV}$ appears consistent with $J^{PC} = 0^{-+}$
- lots of work to be done

Backup: data quality in K_S^0 channel
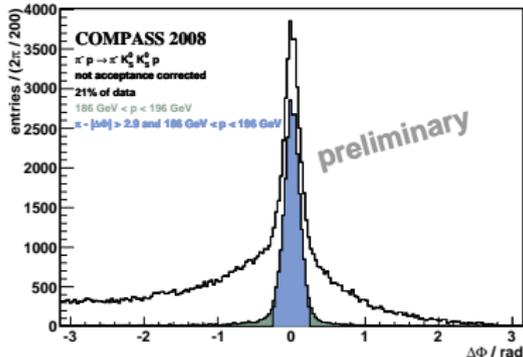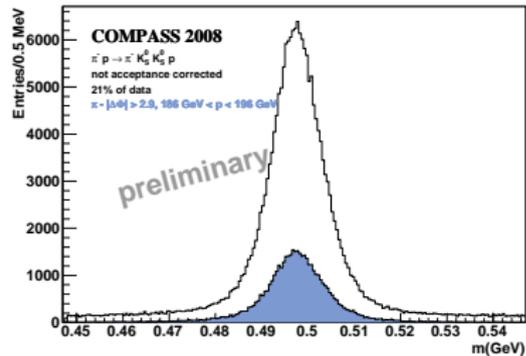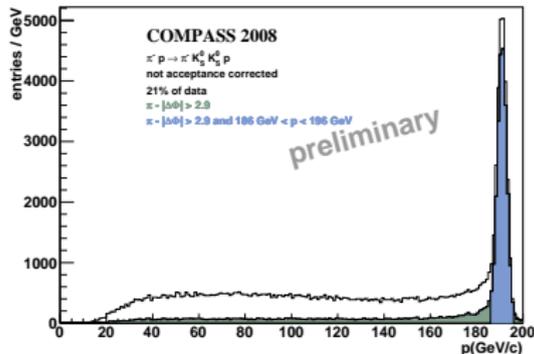
TL: momentum exclusivity
BL: co-planarity
TR: reconstructed K_S^0 masses

Backup: production regimes

COMPASS 2008
$\pi^- p \rightarrow \pi^- K_s^0 K_s^0 p$
not acceptance corrected
21% of data
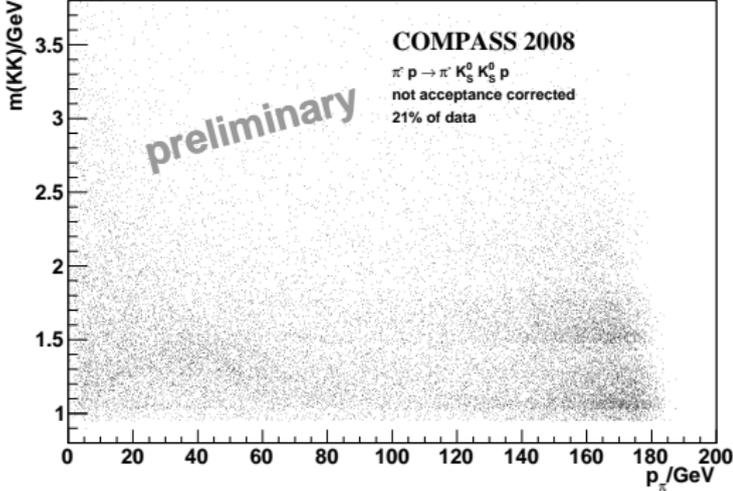
Apparent presence of different production regimes.

Backup: naïve central selection

Select events where π^- has the highest momentum