# Baryon Spectroscopy in COMPASS

$$p\,p \rightarrow p_f\,\pi^+\pi^-\,p_s$$

$$p\,p \rightarrow p_f\,K^+K^-\,p_s$$

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for the
COMPASS Collaboration

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COMPASS
Großgeräte der physikalischen Grundlagenforschung

# Outline

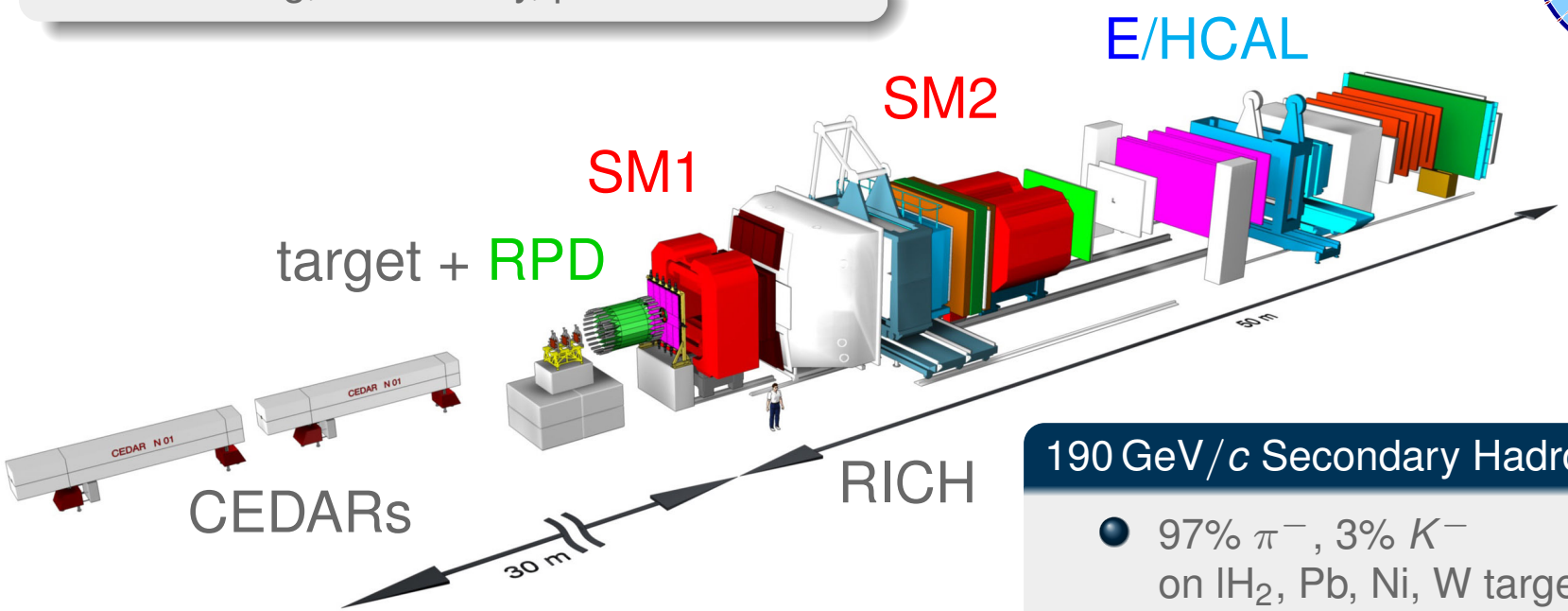
# The COMPASS Experiment

COmmom Muon and Proton Apparatus for Structure and Spectroscopy

Technische Universität München

## Setup

- Fixed target experiment at CERN SPS
- Two-stage magnetic spectrometer
- Tracking, calorimetry, particle ID



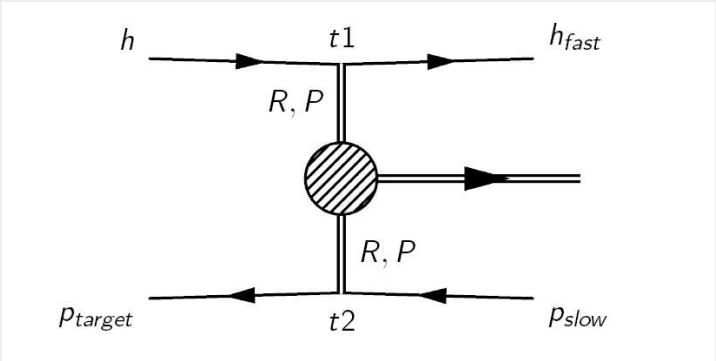

## 190 GeV/$c$ Secondary Hadron Beam

- 97% $\pi^-$, 3% $K^-$
  on $lH_2$, Pb, Ni, W targets
- **75% proton**, 24% $\pi^+$, 1% $K^+$
  on **$lH_2$ target**

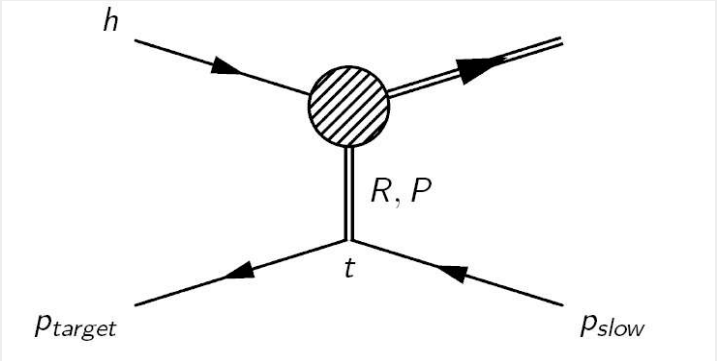
# Production Mechanism



## Central Production:




## Diffractive Dissociation:




- Data primarily recorded to study the formation of glue-rich meson resonances at central rapidities
- No bias introduced by the principal trigger (*diffractive trigger*)
  → high contribution of **diffractive dissociation of the beam proton**
  in analogy to pion beam data [c.f. COMPASS presentations in Light Mesons session]

# Baryon Spectroscopy



## Motivation

- Hadro-production complementary to existing photo- and electro-production experiments (CLAS, CBELSA, ..)
- High resolution spectrometer with flat acceptance
- Large data set
- High mass and high angular momentum states poorly known

## Overview of light baryon spectrum

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $p$ | $P_{11}$ | **** | $\Delta(1232)$ | $P_{33}$ | **** | $\Sigma^+$ | $P_{11}$ | **** |
| $n$ | $P_{11}$ | **** | $\Delta(1600)$ | $P_{33}$ | *** | $\Sigma^0$ | $P_{11}$ | **** |
| $N(1440)$ | $P_{11}$ | **** | $\Delta(1620)$ | $S_{31}$ | **** | $\Sigma^-$ | $P_{11}$ | **** |
| $N(1520)$ | $D_{13}$ | **** | $\Delta(1700)$ | $D_{33}$ | **** | $\Sigma(1385)$ | $P_{13}$ | **** |
| $N(1535)$ | $S_{11}$ | **** | $\Delta(1750)$ | $P_{31}$ | * | $\Sigma(1480)$ | | * |
| $N(1650)$ | $S_{11}$ | **** | $\Delta(1900)$ | $S_{31}$ | ** | $\Sigma(1560)$ | | ** |
| $N(1675)$ | $D_{15}$ | **** | $\Delta(1905)$ | $F_{35}$ | **** | $\Sigma(1580)$ | $D_{13}$ | * |
| $N(1680)$ | $F_{15}$ | **** | $\Delta(1910)$ | $P_{31}$ | **** | $\Sigma(1620)$ | $S_{11}$ | ** |
| $N(1700)$ | $D_{13}$ | *** | $\Delta(1920)$ | $P_{33}$ | *** | $\Sigma(1660)$ | $P_{11}$ | *** |
| $N(1710)$ | $P_{11}$ | *** | $\Delta(1930)$ | $D_{35}$ | *** | $\Sigma(1670)$ | $D_{13}$ | **** |
| $N(1720)$ | $P_{13}$ | **** | $\Delta(1940)$ | $D_{33}$ | * | $\Sigma(1690)$ | | ** |
| $N(1900)$ | $P_{13}$ | ** | $\Delta(1950)$ | $F_{37}$ | **** | $\Sigma(1750)$ | $S_{11}$ | *** |
| $N(1990)$ | $F_{17}$ | ** | $\Delta(2000)$ | $F_{35}$ | ** | $\Sigma(1770)$ | $P_{11}$ | * |
| $N(2000)$ | $F_{15}$ | ** | $\Delta(2150)$ | $S_{31}$ | * | $\Sigma(1775)$ | $D_{15}$ | **** |
| $N(2080)$ | $D_{13}$ | ** | $\Delta(2200)$ | $G_{37}$ | * | $\Sigma(1840)$ | $P_{13}$ | * |
| $N(2090)$ | $S_{11}$ | * | $\Delta(2300)$ | $H_{39}$ | ** | $\Sigma(1880)$ | $P_{11}$ | ** |
| $N(2100)$ | $P_{11}$ | * | $\Delta(2350)$ | $D_{35}$ | * | $\Sigma(1915)$ | $F_{15}$ | **** |
| $N(2190)$ | $G_{17}$ | **** | $\Delta(2390)$ | $F_{37}$ | * | $\Sigma(1940)$ | $D_{13}$ | *** |
| $N(2200)$ | $D_{15}$ | ** | $\Delta(2400)$ | $G_{39}$ | ** | $\Sigma(2000)$ | $S_{11}$ | * |
| $N(2220)$ | $H_{19}$ | **** | $\Delta(2420)$ | $H_{3,11}$ | **** | $\Sigma(2030)$ | $F_{17}$ | **** |
| $N(2250)$ | $G_{19}$ | **** | $\Delta(2750)$ | $I_{3,13}$ | ** | $\Sigma(2070)$ | $F_{15}$ | * |
| $N(2600)$ | $I_{1,11}$ | *** | $\Delta(2950)$ | $K_{3,15}$ | ** | $\Sigma(2080)$ | $P_{13}$ | ** |
| $N(2700)$ | $K_{1,13}$ | ** | | | | $\Sigma(2100)$ | $G_{17}$ | * |
| | | | $\Lambda$ | $P_{01}$ | **** | $\Sigma(2250)$ | | *** |
| | | | $\Lambda(1405)$ | $S_{01}$ | **** | $\Sigma(2455)$ | | ** |
| | | | $\Lambda(1520)$ | $D_{03}$ | **** | $\Sigma(2620)$ | | ** |
| | | | $\Lambda(1600)$ | $P_{01}$ | *** | $\Sigma(3000)$ | | * |
| | | | $\Lambda(1670)$ | $S_{01}$ | **** | $\Sigma(3170)$ | | * |
| | | | $\Lambda(1690)$ | $D_{03}$ | **** | | | |
| | | | $\Lambda(1800)$ | $S_{01}$ | *** | | | |
| | | | $\Lambda(1810)$ | $P_{01}$ | *** | | | |
| | | | $\Lambda(1820)$ | $F_{05}$ | **** | | | |
| | | | $\Lambda(1830)$ | $D_{05}$ | **** | | | |
| | | | $\Lambda(1890)$ | $P_{03}$ | **** | | | |
| | | | $\Lambda(2000)$ | | * | | | |
| | | | $\Lambda(2020)$ | $F_{07}$ | * | | | |
| | | | $\Lambda(2100)$ | $G_{07}$ | **** | | | |
| | | | $\Lambda(2110)$ | $F_{05}$ | *** | | | |
| | | | $\Lambda(2325)$ | $D_{03}$ | * | | | |
| | | | $\Lambda(2350)$ | $H_{09}$ | *** | | | |
| | | | $\Lambda(2585)$ | | ** | | | |

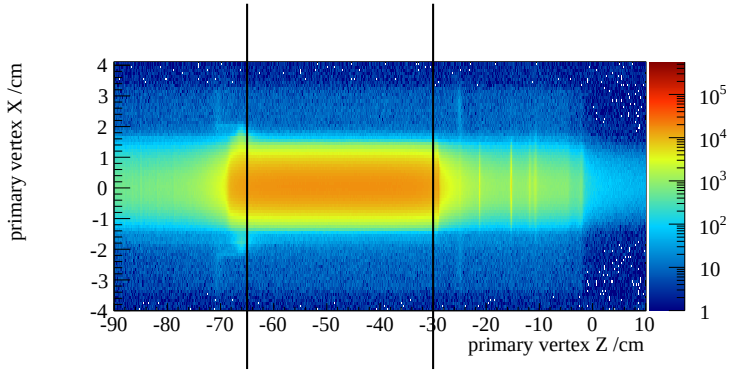
**** Existence is certain, and properties are at least fairly well explored
*** Existence ranges from very likely to certain, but further confirmation is desirable and/or are not well defined
** Evidence of existence is only fair

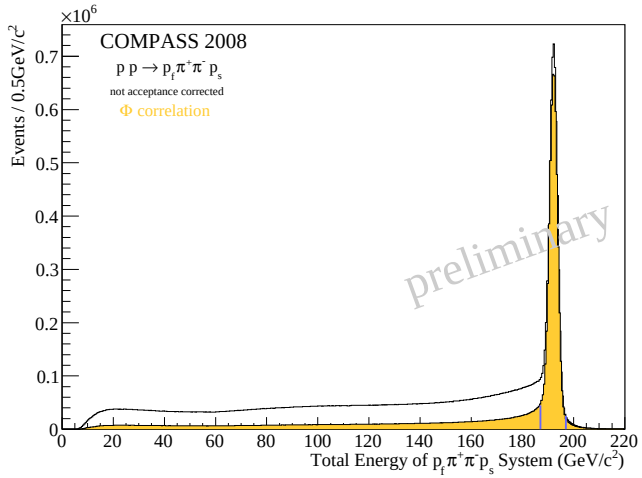
# Event Selection



- Diffractive trigger
- Exactly one primary vertex
  - in target
  - 3 outgoing charged tracks
  - charge conservation
- Beam proton (CEDAR)
- RICH identification
  - $\pi^+$ or $K^+$
- Exclusivity
  - Energy sum
  - $\Phi$ angle between forward system and recoil particle

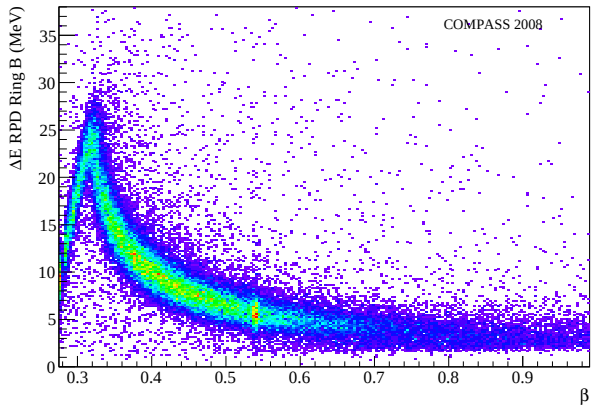
$\longrightarrow$ very low background



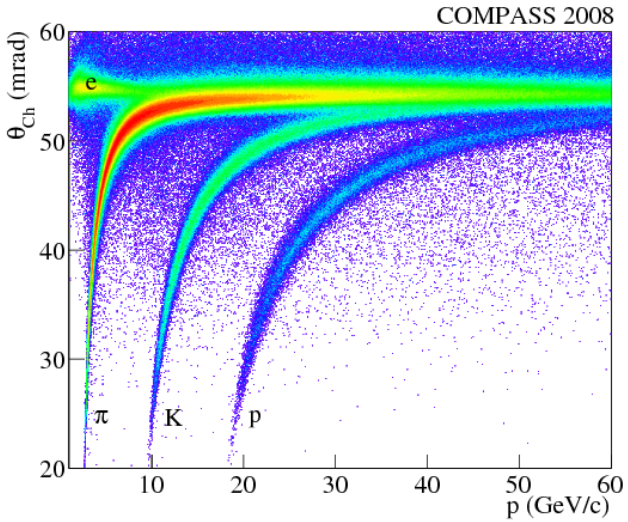
# Particle Identification






## Recoil Proton Identification

- Energy loss of recoil particle vs. velocity
- Very clean proton signal




## Final State Particle ID

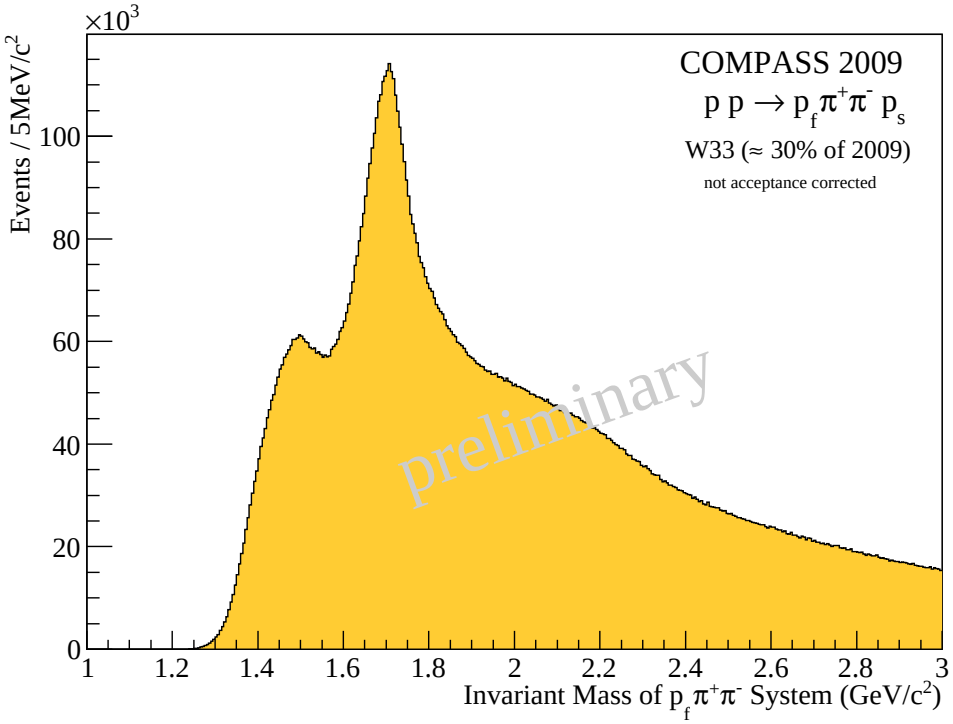
- Distinction between 2 positively charged particles in forward direction
  $\longrightarrow$ RICH (Ring Imaging CHerenkov) detector
- Proton ID not effective in this kinematic range
  $\longrightarrow \pi^+/K^+$ identification



$$p\,p \longrightarrow p_f\,\pi^+\pi^-\,p_s$$

# Invariant Mass of $p_f\pi^+\pi^-$ System






Unambiguous assignment of resonances difficult

for example: $N(1440)P_{11}$, $N(1520)D_{13}$, $N(1535)S_{11}$ and $N(1650)S_{11}$, $\Delta(1700)D_{33}$, $N(1710)P_{11}$, $N(1720)P_{13}$

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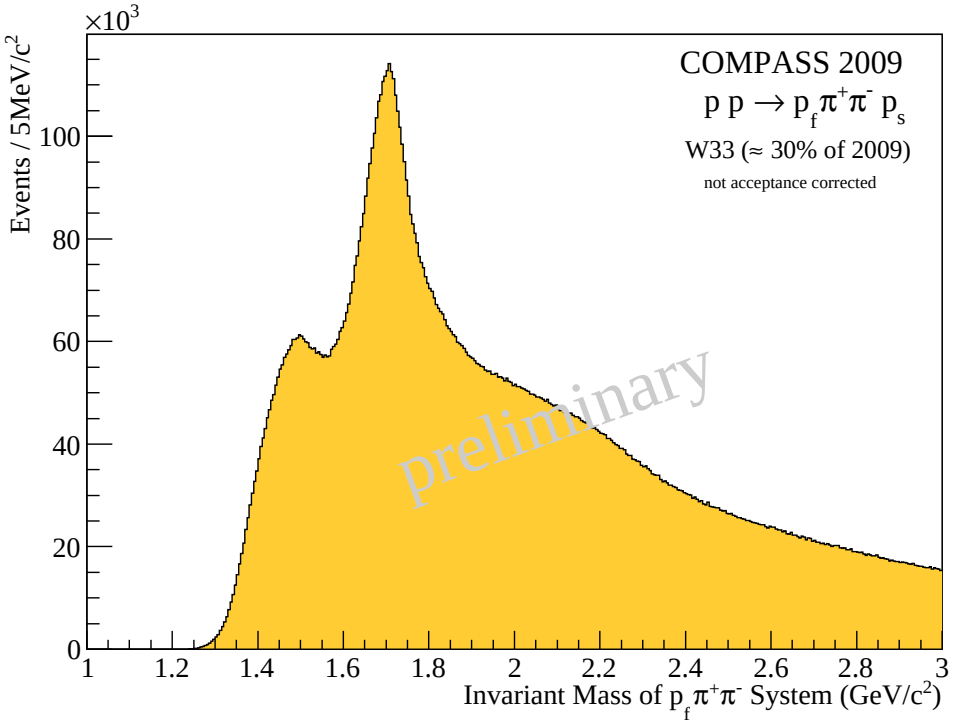


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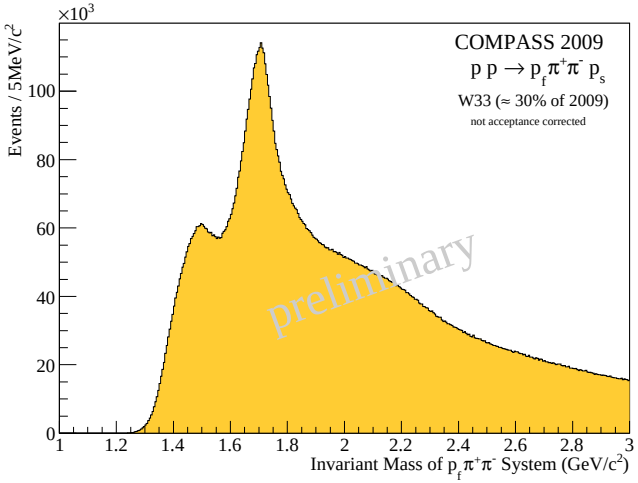
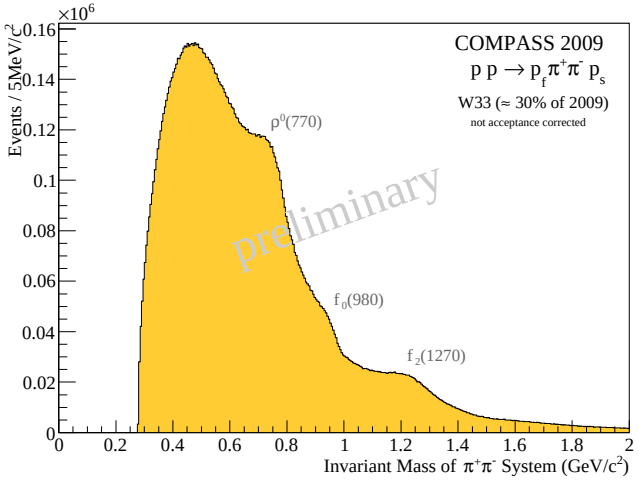
$\Rightarrow$ Spin Parity (= Partial Wave) Analysis

# Invariant Mass of Subsystems





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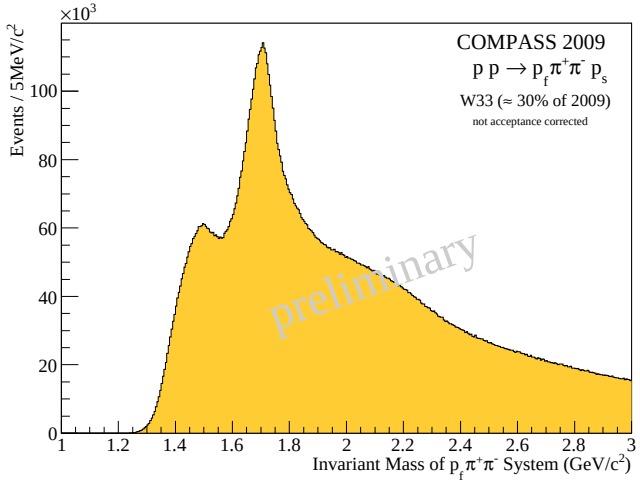
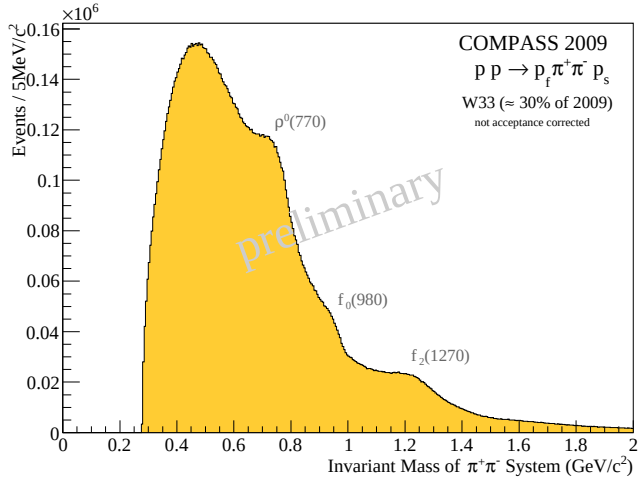
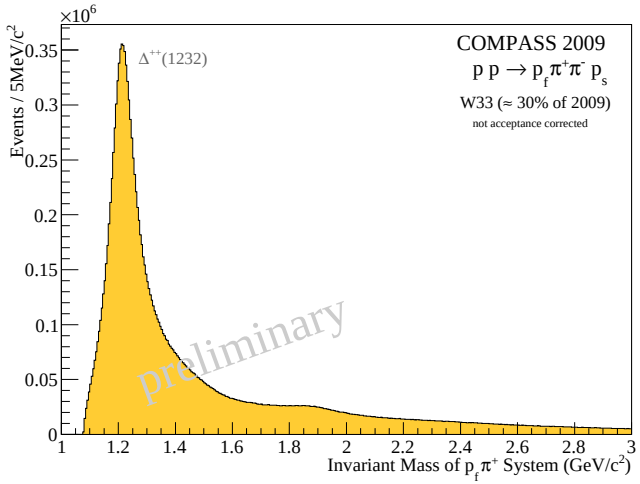
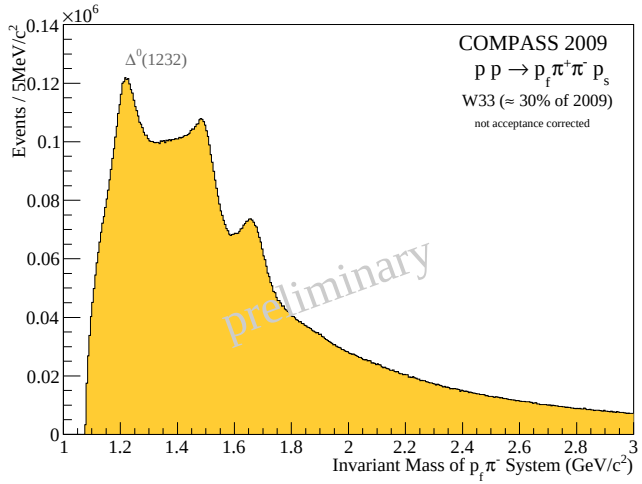


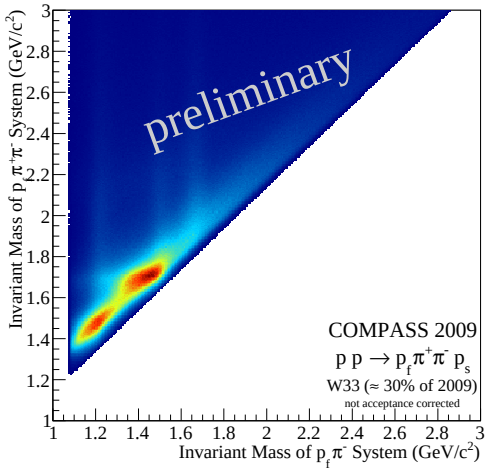



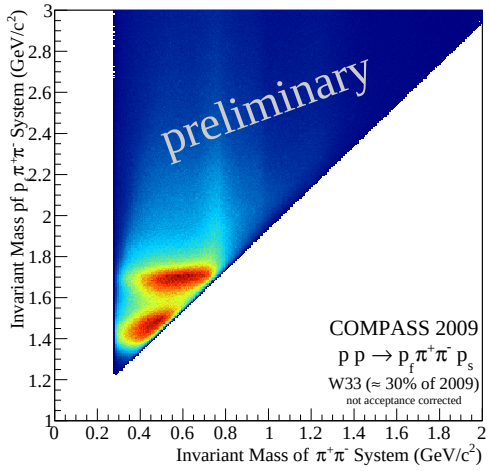



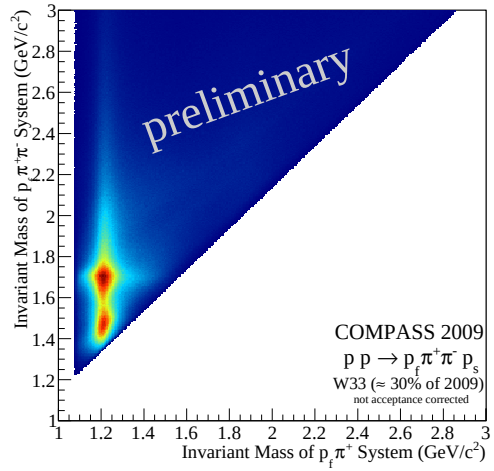



# $p_f\pi^+\pi^-$ System vs. Subsystems





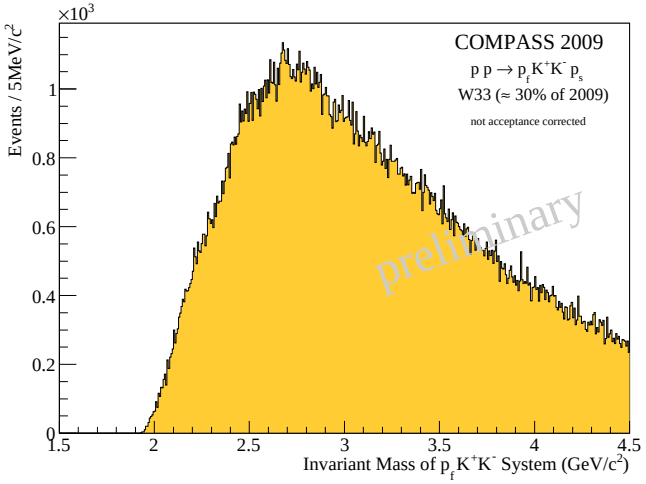



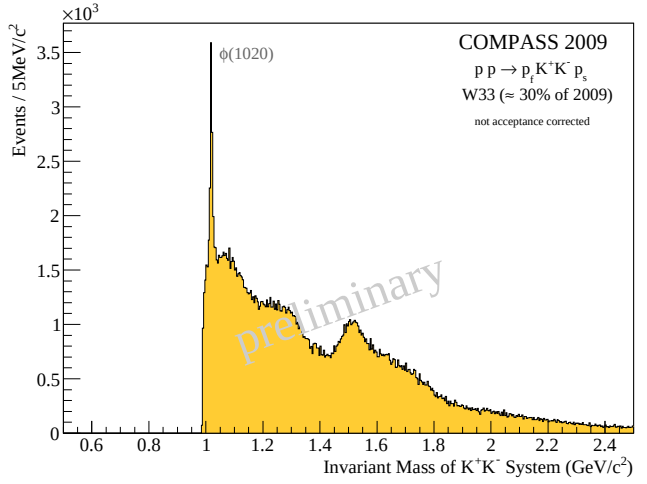


## Introducing Strangeness:
## $p\,p \longrightarrow p_f\,K^+K^-\,p_s$

# Invariant Mass of Subsystems





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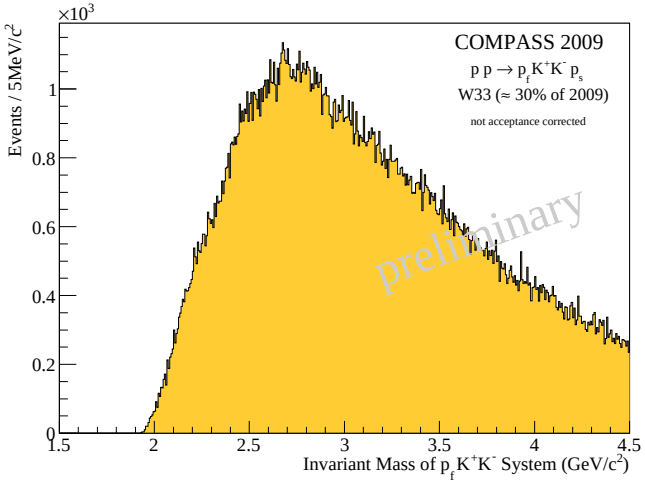
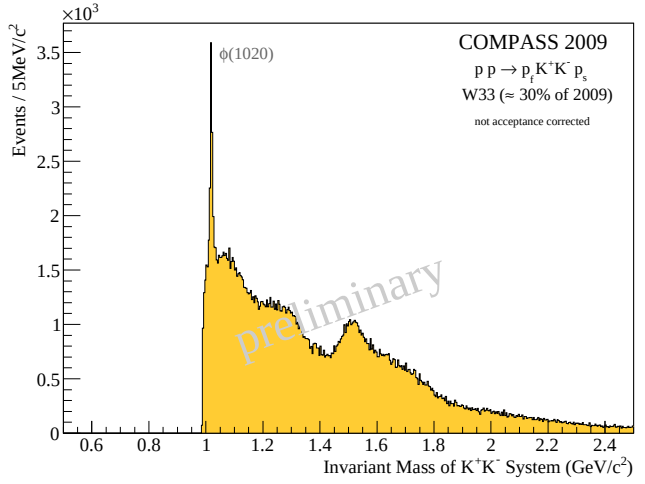
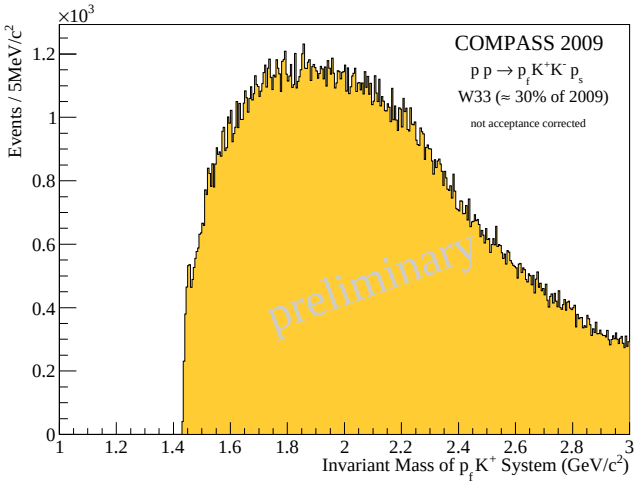
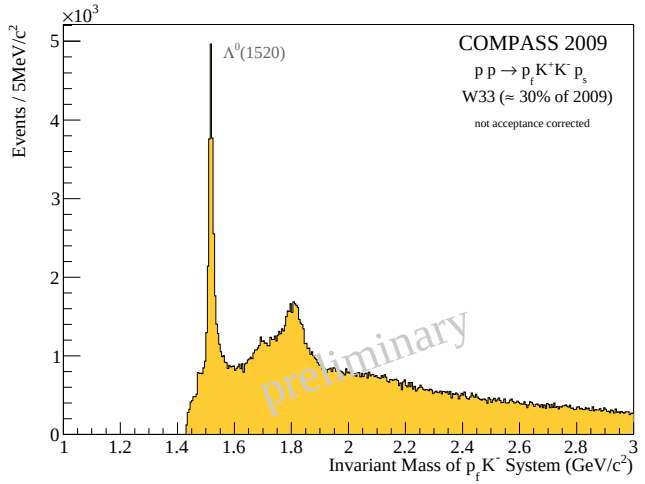


# Outlook



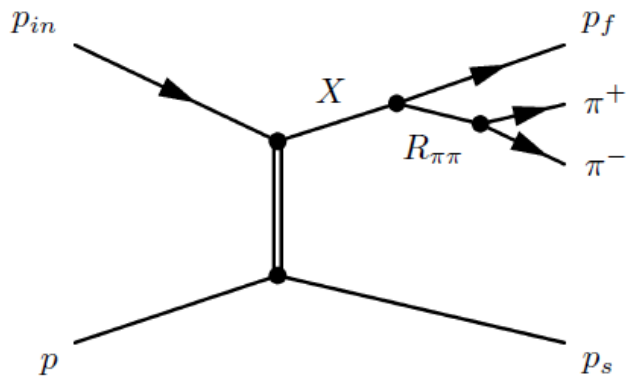
## Techniques for Partial Wave Analysis

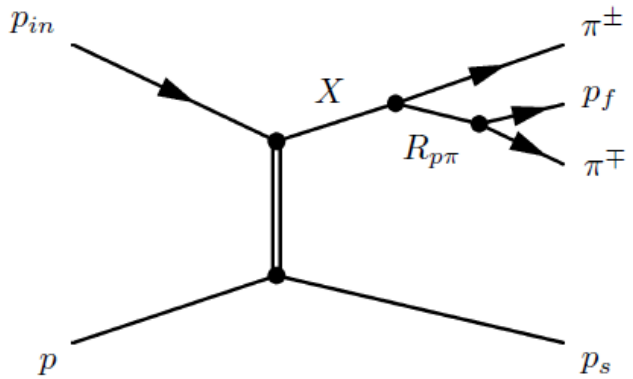
# Analysis Technique



## Partial Wave Analysis

- Target proton remains intact
- Pomeron exchange dominates at high energies
- Isobar model
  $\longrightarrow$ Subsequent two-body decays
  $\longrightarrow$ Two different decay topologies
  $\longrightarrow$ Isobars: $R_{\pi\pi}$, $R_{p\pi^+}$, $R_{p\pi^-}$
- Both mesons and baryons as intermediate states
  $R_{\pi\pi}$ : $(\pi\pi)_S$, $\rho^0(770)$, $f_0(980)$, $f_2(1270)$, ..
  $R_{p\pi}$ : $\Delta^0(1232)P_{33}$, $N(1440)P_{11}$, $N(1650)S_{11}$, $\Delta(1700)D_{33}$, ..



# Summary



## Conclusion

- Interesting data set including diffractive dissociation of the beam proton
- Light baryon spectrum accessible in great detail
- $N\pi$, $NK$, $\pi\pi$ and $KK$ decay modes
- PWA analysis formalism developed

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- Adaptation of PWA software
- Acceptance correction with Monte Carlo
- Perform PWA
  - Determine poorly known parameters (widths, branching ratios, ..)
  - Identify new decay modes ($N\rho$, $N\phi$,...)
  - Gain insight into production mechanism

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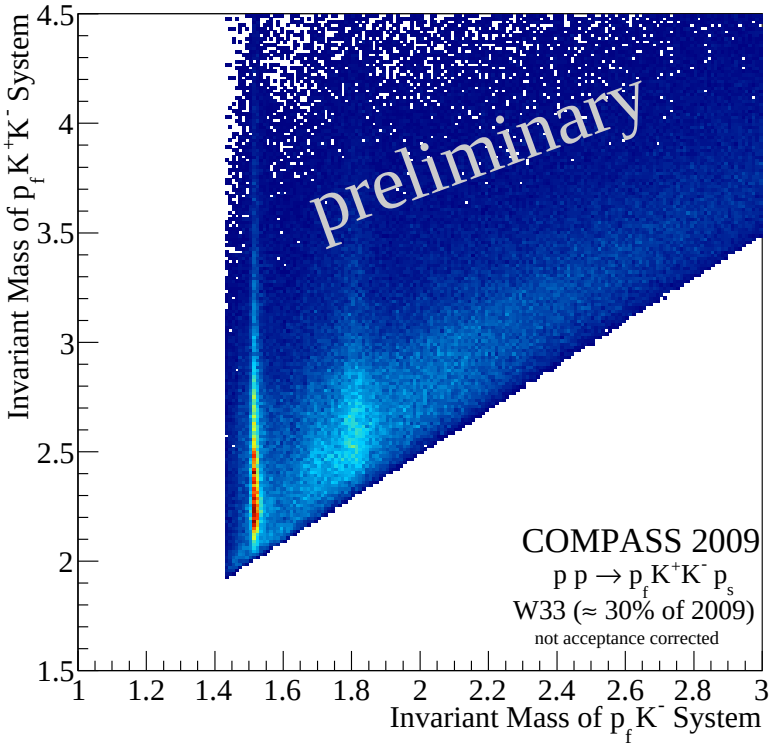
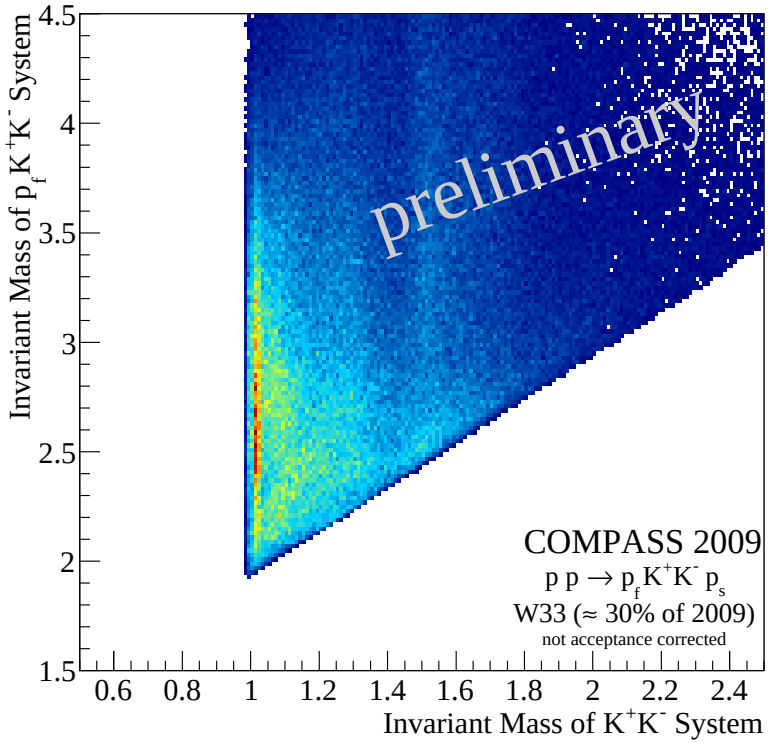
Thank you.

# $p_f K^+ K^-$ System vs. Subsystems

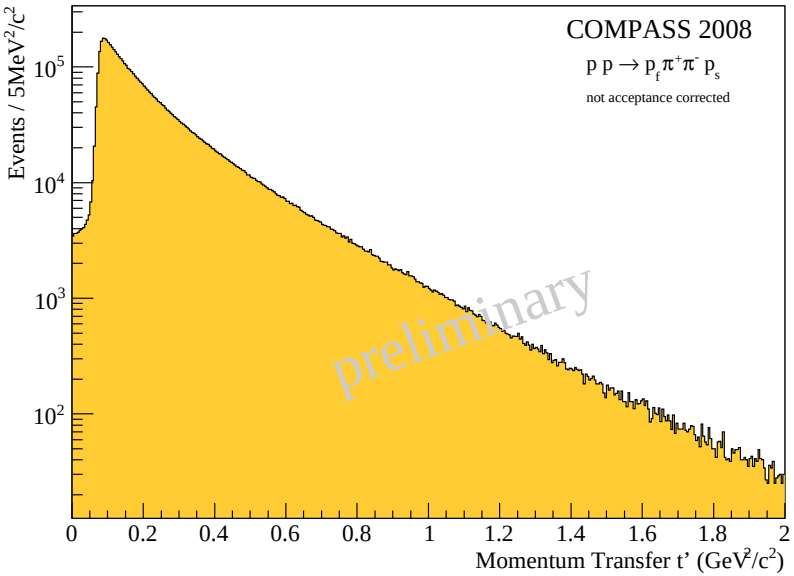


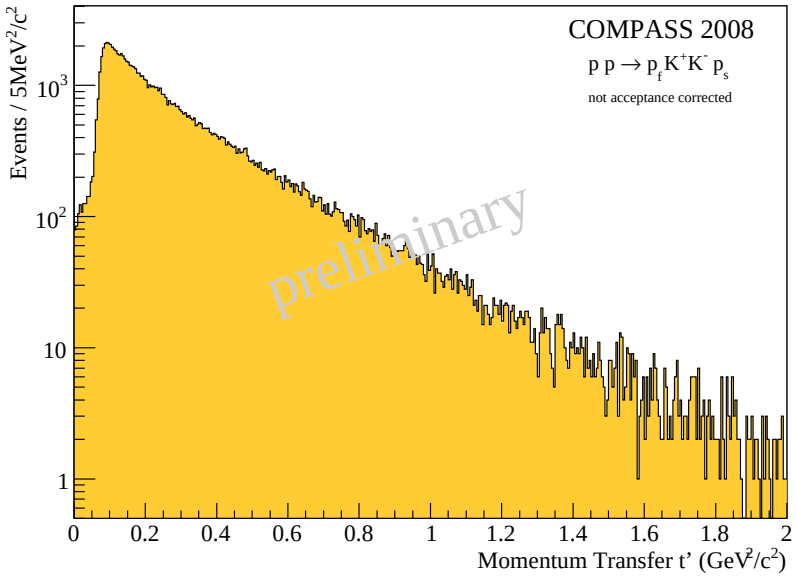


# Momentum Transfer





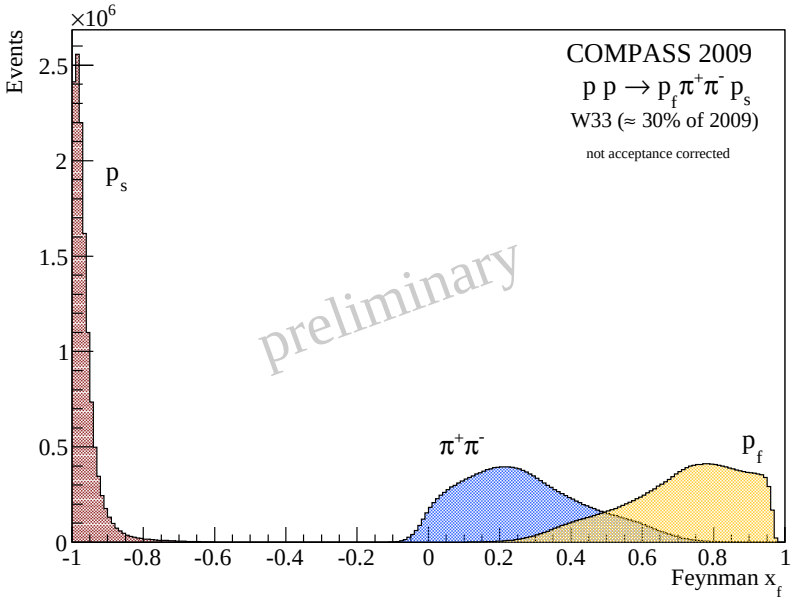



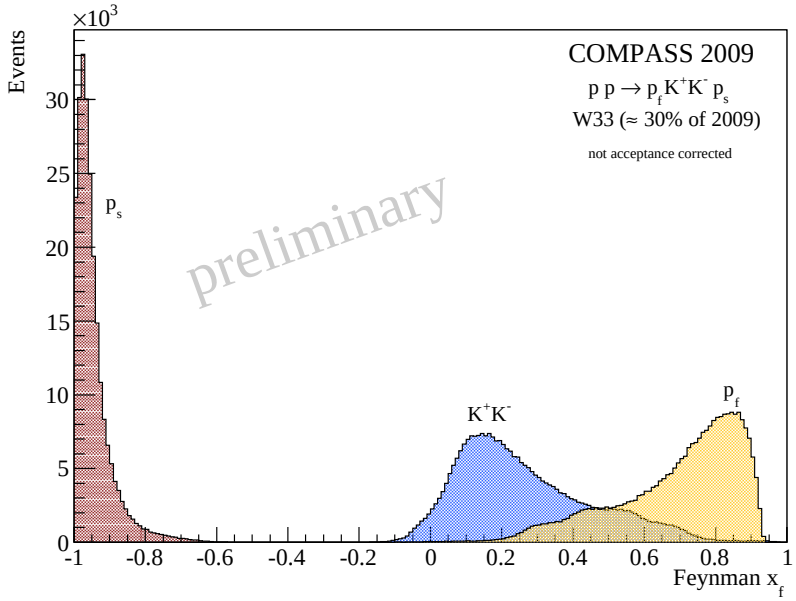

$p\,p \longrightarrow p_f\,\pi^+\pi^-\,p_s$

$p\,p \longrightarrow p_f\,K^+K^-\,p_s$

# Feynman $x_F$ Distribution



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