Hadron Spectroscopy at COMPASS

Séminaires du SPhN

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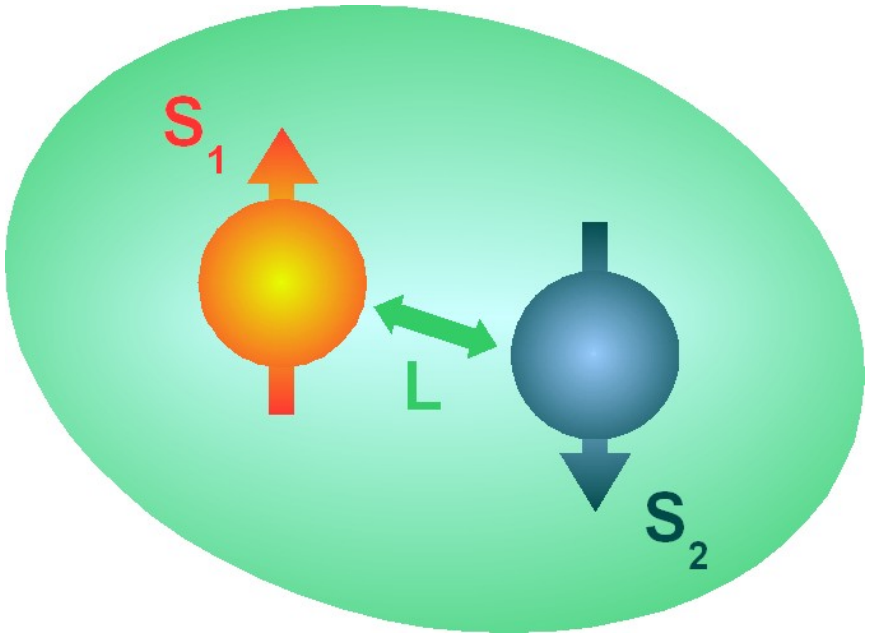
Outline

1. Introduction
2. Recoil Proton Detector
3. Trigger
4. Analysis and Results
5. Summary and Outlook

Spectroscopy with Mesons

- Simplified meson model: $q\bar{q}$ bound states
- characterized by
  1. Flavour (u,d,s,c,b,t)
  2. Quantum numbers $I^G J^{PC}$

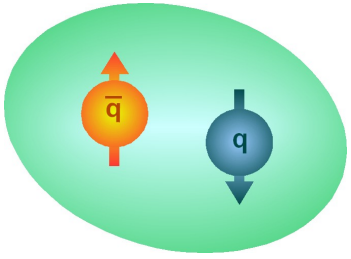


- allowed J^{PC} combinations: 0^{-+},0^{++},1^{--},...
- exotic J^{PC} combinations: 0^{--},0^{+-},1^{-+},...

Exotic Mesons

extend the simplified model by adding additional degrees of freedom:

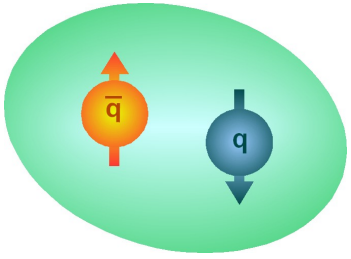
- $q\bar{q}$ mesons

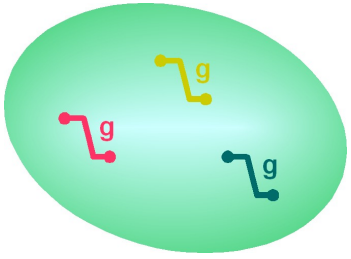


Exotic Mesons

extend the simplified model by adding additional degrees of freedom:

- $q\bar{q}$ mesons
- glueballs





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extend the simplified model by adding additional degrees of freedom:

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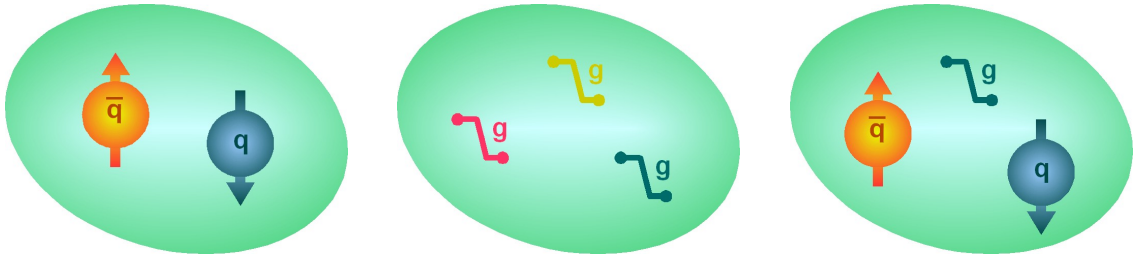
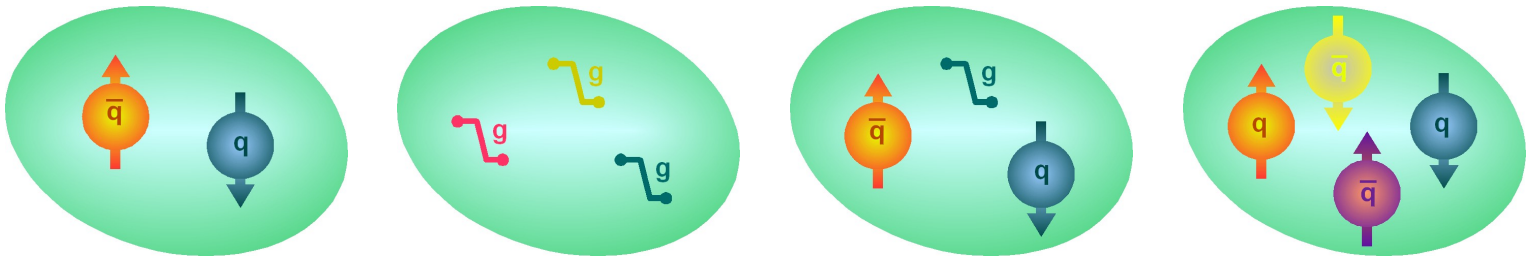
- glueballs
- hybrids



Exotic Mesons

extend the simplified model by adding additional degrees of freedom:

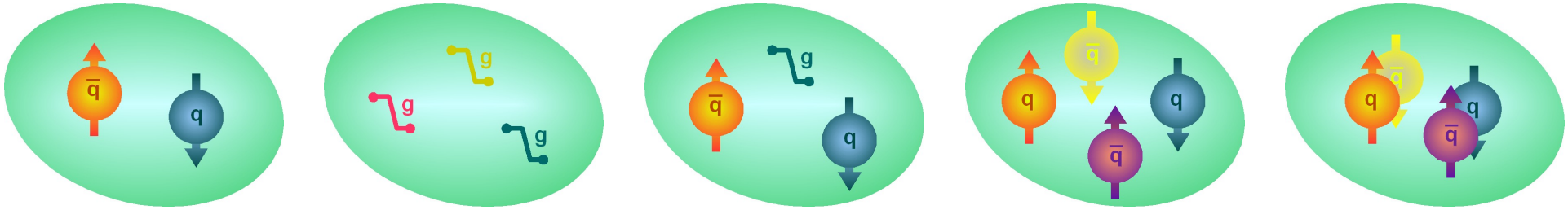
- $q\bar{q}$ mesons
- glueballs
- hybrids
- bound $q\bar{q}q\bar{q}$ states



Exotic Mesons

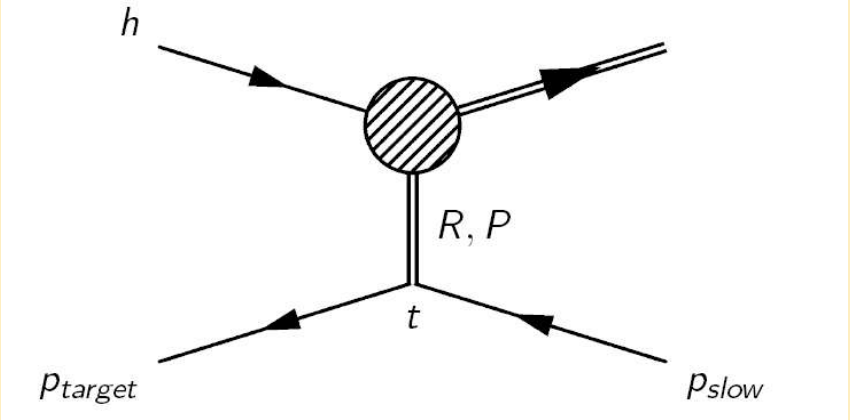
extend the simplified model by adding additional degrees of freedom:

- $q\bar{q}$ mesons
- glueballs
- hybrids
- bound $q\bar{q}q\bar{q}$ states
- mesonic molecules

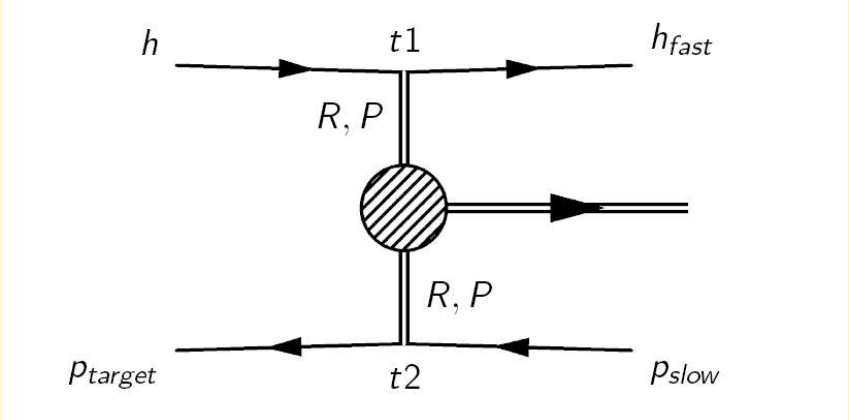


Formation processes

Diffractive Scattering:



Central Production:



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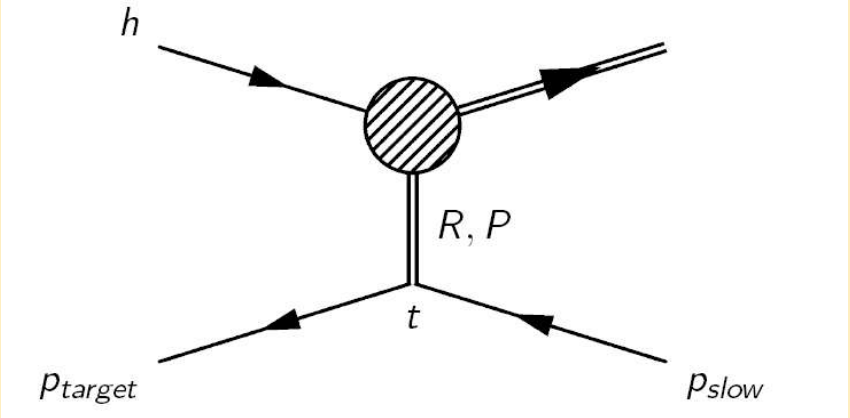
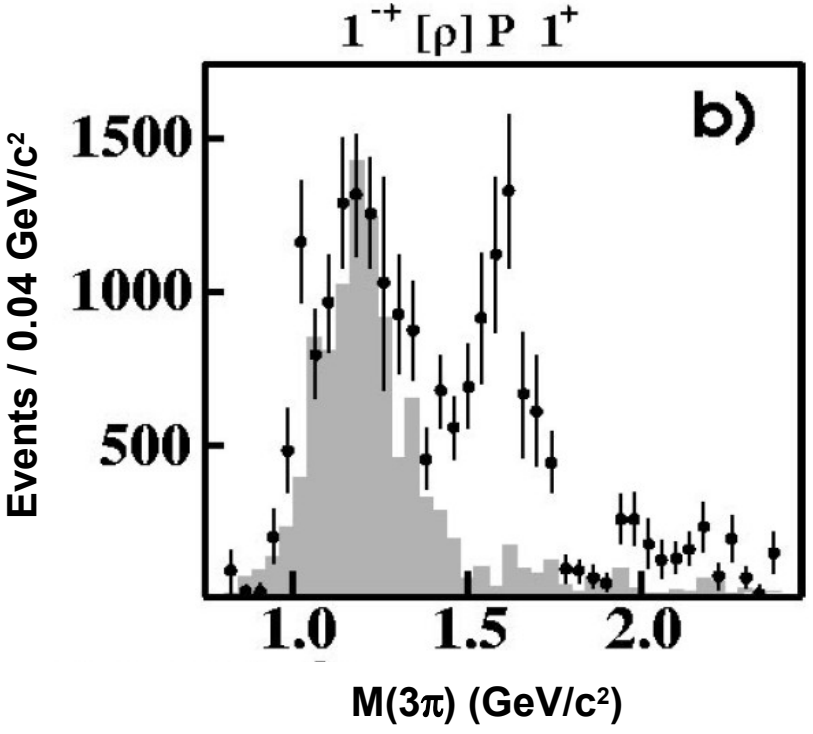
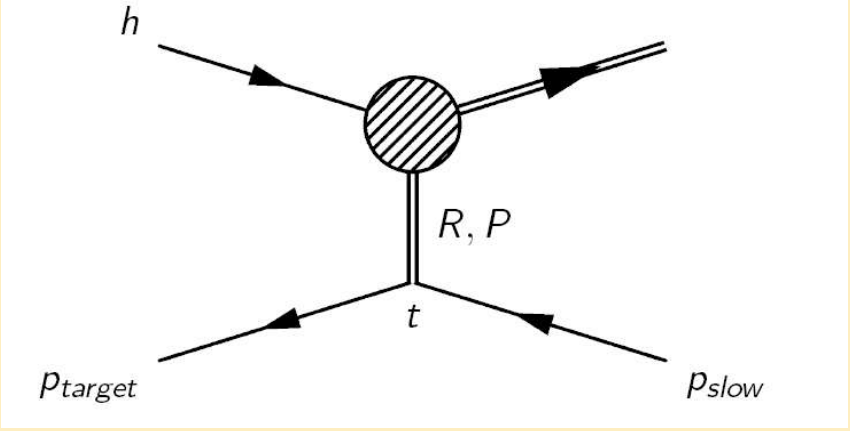




- SPE (single pomeron exchange)
- search for hybrid-candidates: $\pi(1600), \pi(1800)$

Formation processes

Diffractive Scattering:



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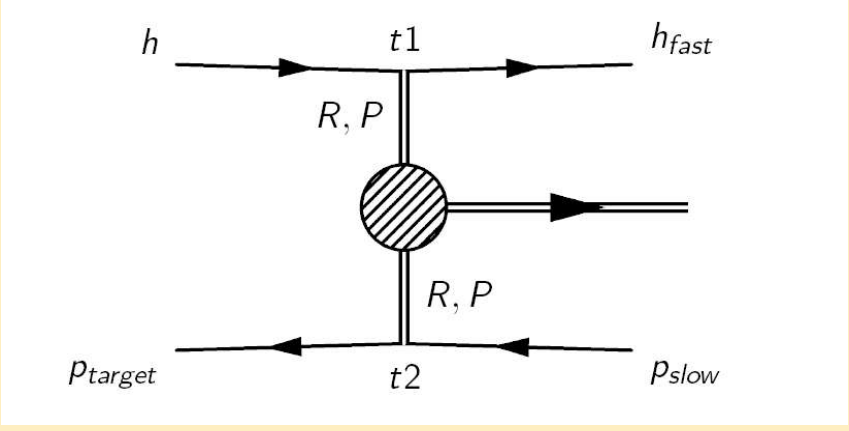


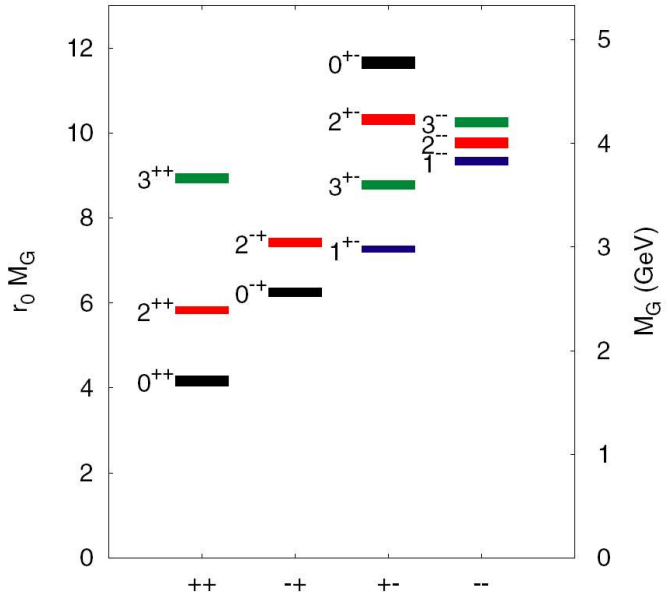
Context: Definition of Central Production

- Original definition, **not only** DPE (double pomeron exchange)
- formation of resonances at central rapidities

CP of charged pionic modes (e.g. $\pi^-\pi^+\pi^-\pi^+$)

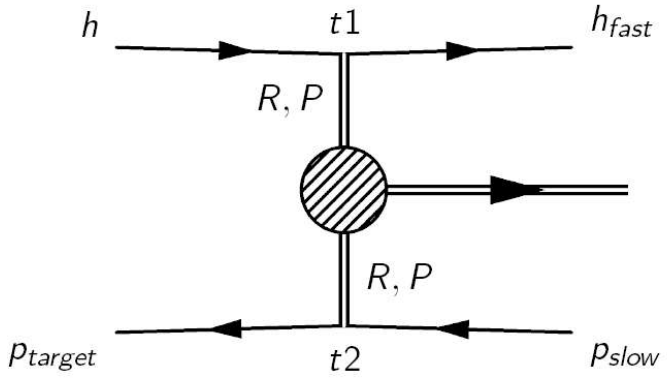
$\rightarrow$ well suited for the search for scalar and tensor glueballs
f_0 family of resonances most interesting to study

Formation processes



Y. Chen et al., Phys. Rev. D 73, 014516 (2006)

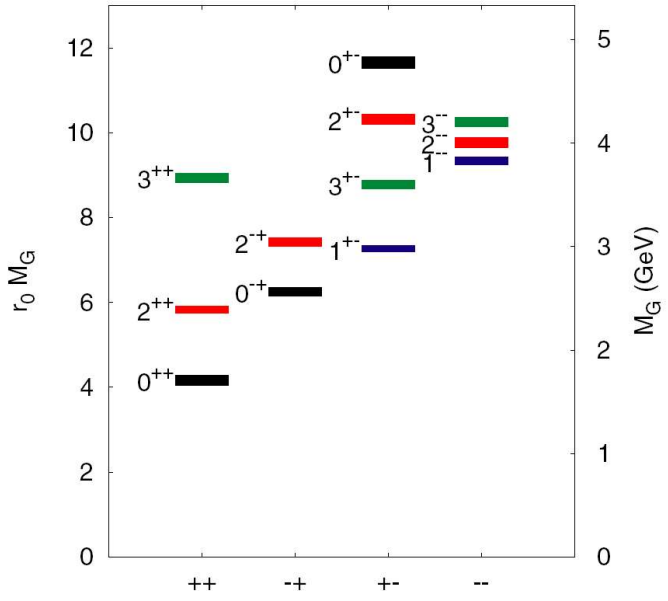
Central Production:



Some examples of central production studies with 4π final states

- F. Binon et al. GAMS Collaboration. *Nuovo Cimento*, 78, 1983
- S. Abatzis et al. WA91 Collaboration. Phys.Lett.**B** 324, 1994
- F. Antinori et al. WA102 Collaboration, Phys.Lett.**B** 353, 1995
- C. Amsler et al. Crystal Barrel Collaboration. Phys.Lett.**B** 380, 1996

Formation processes



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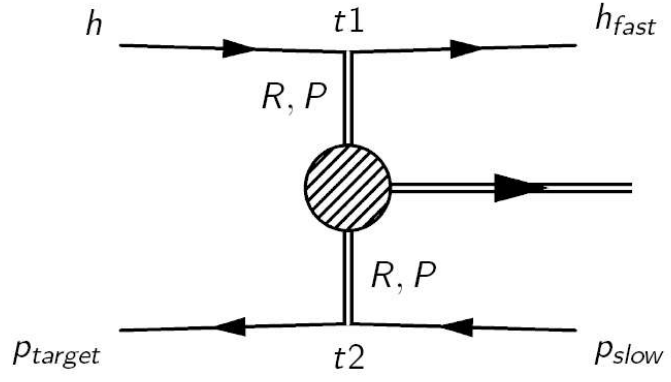
Central Production:



How to search for glueballs?

characterization by

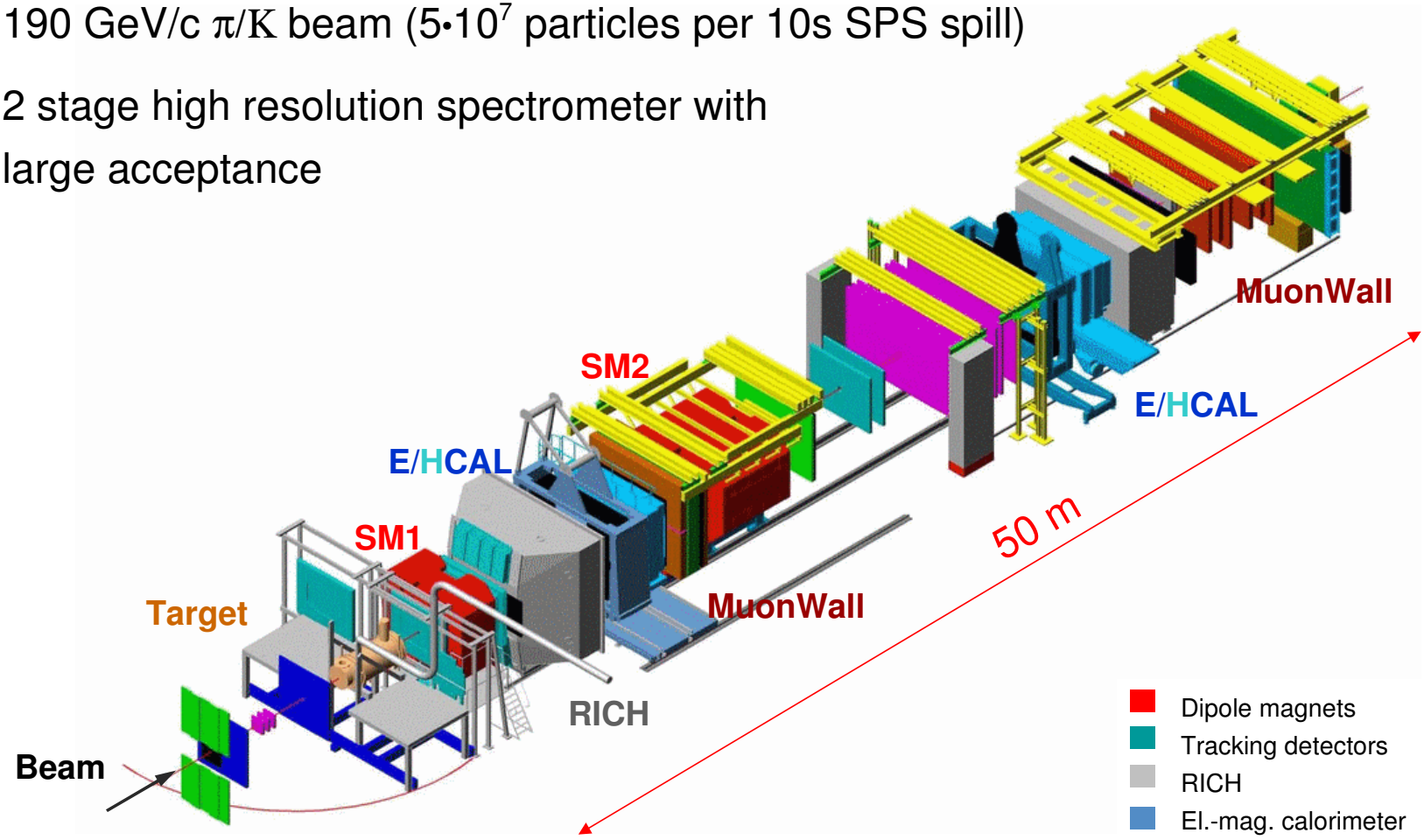
- flavour-neutral decay modes:
  X is supposed to be seen in $\pi^+\pi^-$, $\pi^0\pi^0$,$K\bar{K}$, 4π, $\eta\eta$, $\eta\eta'$
- formation kinematics: small $dP_t = p_t^{fast} - p_t^{slow}$

The COMPASS collaboration

The COMPASS spectrometer

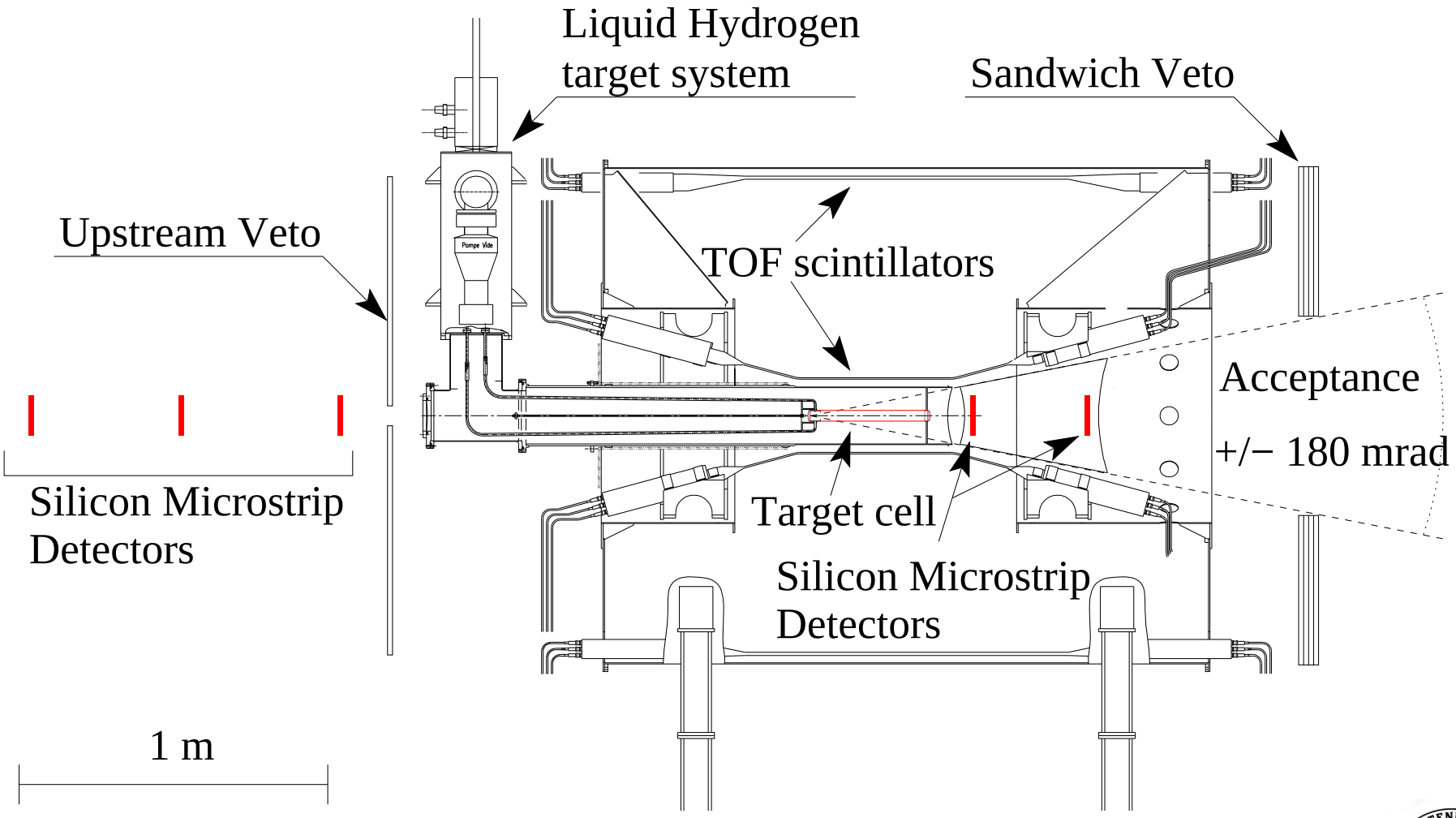
190 GeV/c π/K beam ($5 \cdot 10^7$ particles per 10s SPS spill)

2 stage high resolution spectrometer with large acceptance



[hep-ex/0703049, NIM A 577, 455 (2007)]

Changes for the Hadron Run 2008/2009: Target Region



- 40cm lH_2 target

Changes for the Hadron Run 2008/2009: New components

Installation of new components:

- Cold Silicon Microstrip Detectors (@200K)
- new LH_2 target
- Recoil Proton Detector

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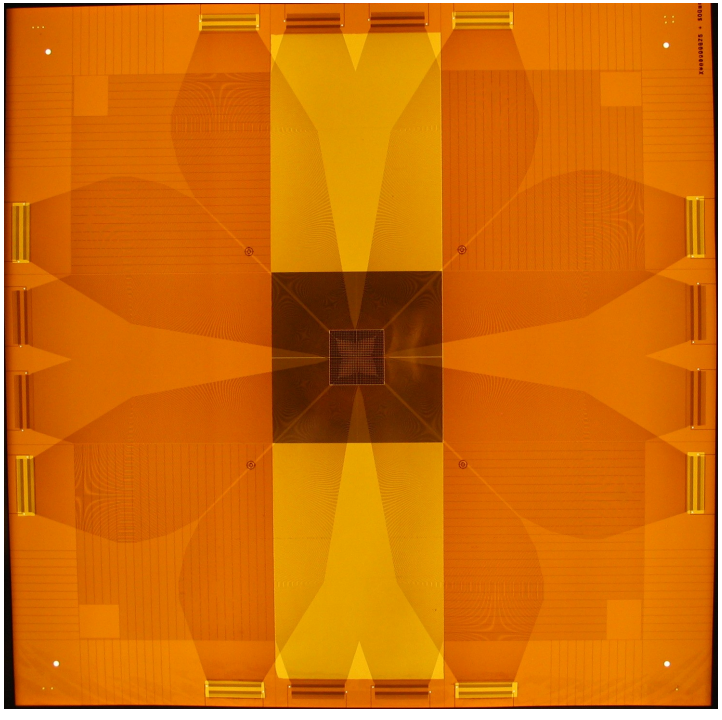

- Cold Silicon Microstrip Detectors (@200K)
- new LH_2 target
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- upgrade on tracking (PixelGEMs, MicroMegas)

Changes for the Hadron Run 2008/2009: New components

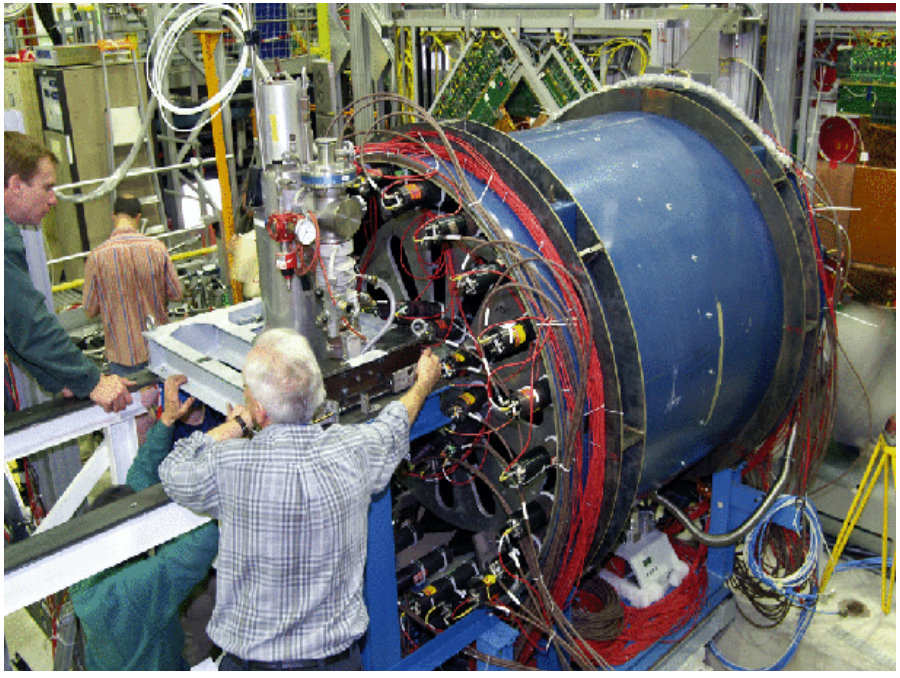
Installation of new components:

- Cold Silicon Microstrip Detectors (@200K)
- new LH_2 target
- Recoil Proton Detector
- upgrade on tracking (PixelGEMs, MicroMegas)
- beam PID with CEDARS
- el.mag. calorimetry upgrade with new laser monitoring

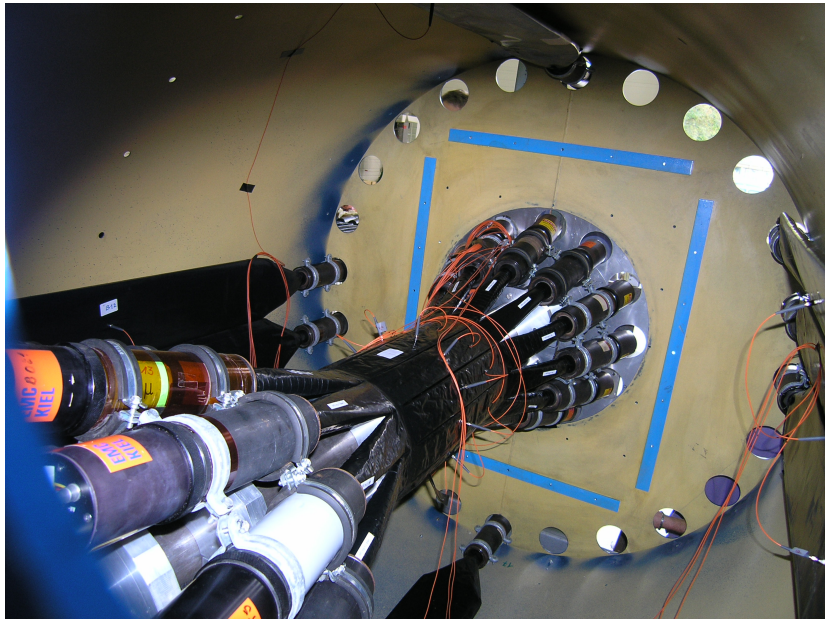
Recoil Proton Detector

Function:

1. fast **trigger** on recoil proton
2. Proton **PID** via TOF and dE/dx measurement



Recoil Proton Detector



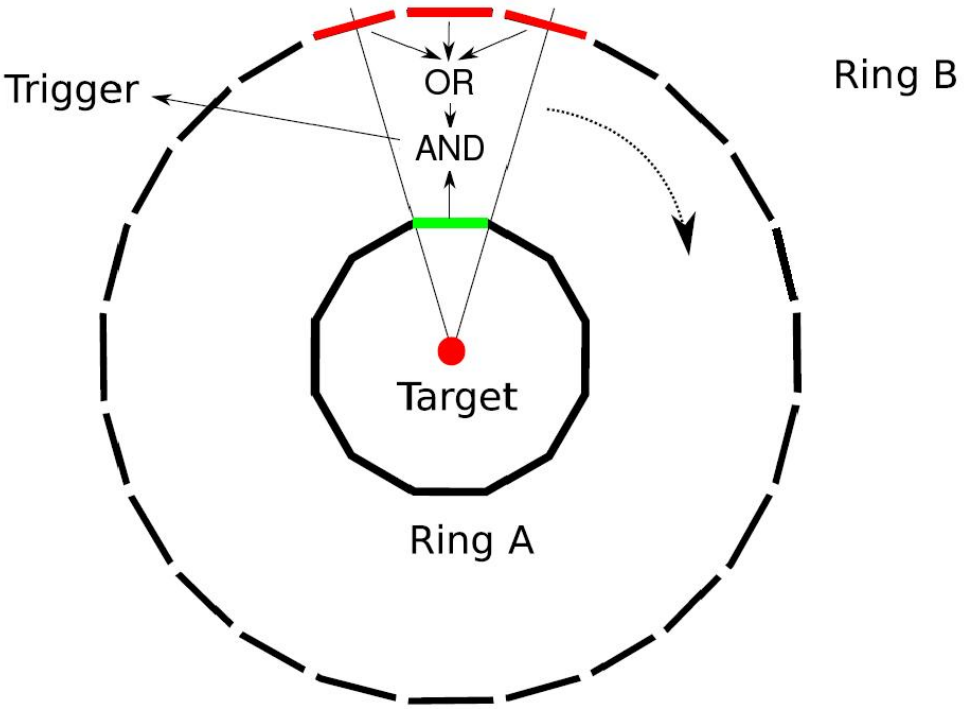
RPD during its assembly

- layout: 2 cylindrical layers of scintillators ($r_1 = 120\,\text{mm}$ and $r_2 = 755\,\text{mm}$ surrounding the target)
- inner ring w/ 12 scintillator slabs (5 mm x 500 mm BC404, U Mainz)
- outer ring w/ 24 scintillator slabs (10 mm x 1080 mm, IHEP Protvino)
- large dynamical range of the signals due to small attenuation length ($\lambda_{eff} \approx 70\,\text{cm}$)

head of project: IRFU-SPhN

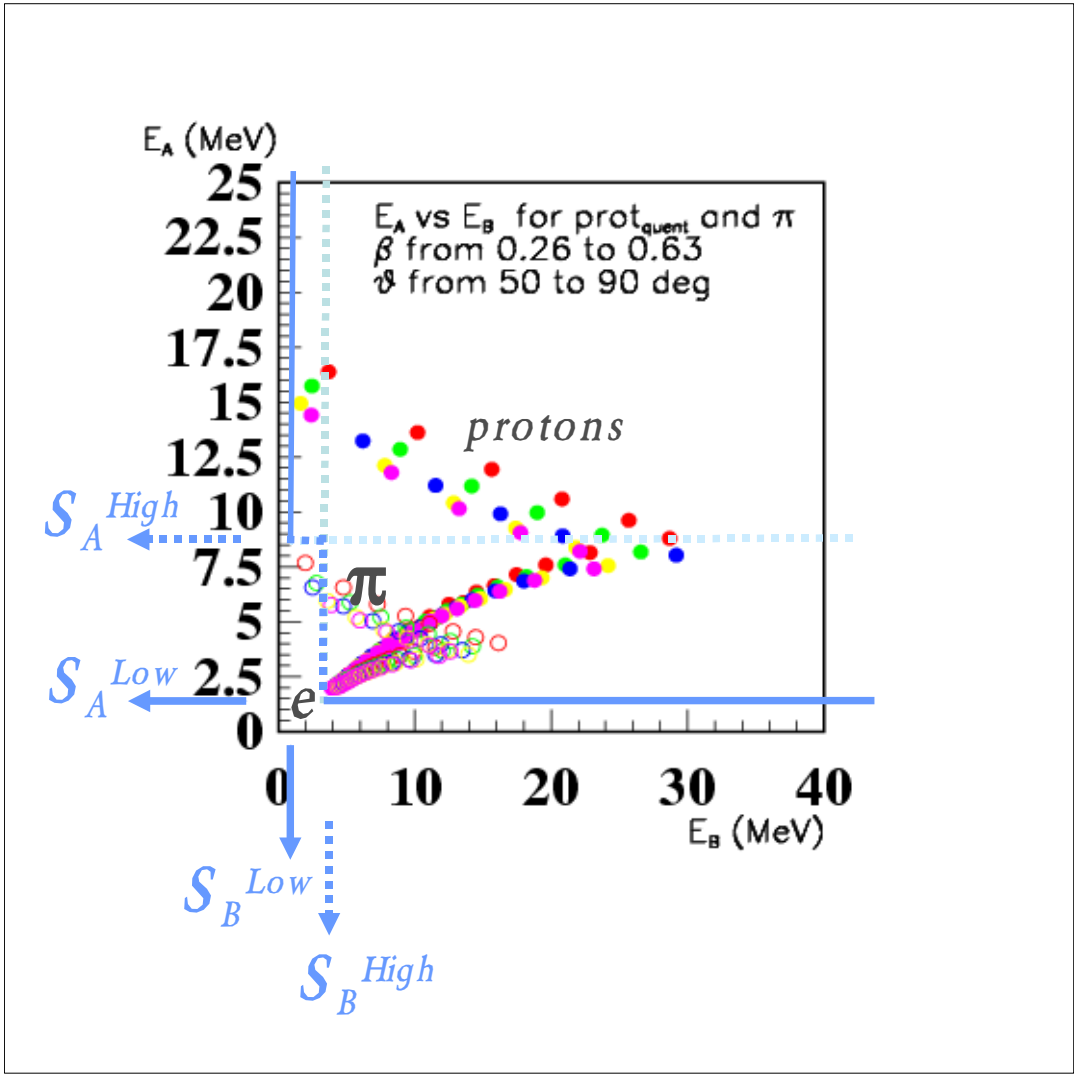
- small e^- and π^- background
- time resolution $\sigma < 350\,\text{ps}$

Proton Trigger



- no 2nd level trigger, so *fast*, *efficient* and *pure* trigger necessary
- trigger on slow recoil proton with RPD
- coincidence of one ring A element and one out of three possible ring B elements

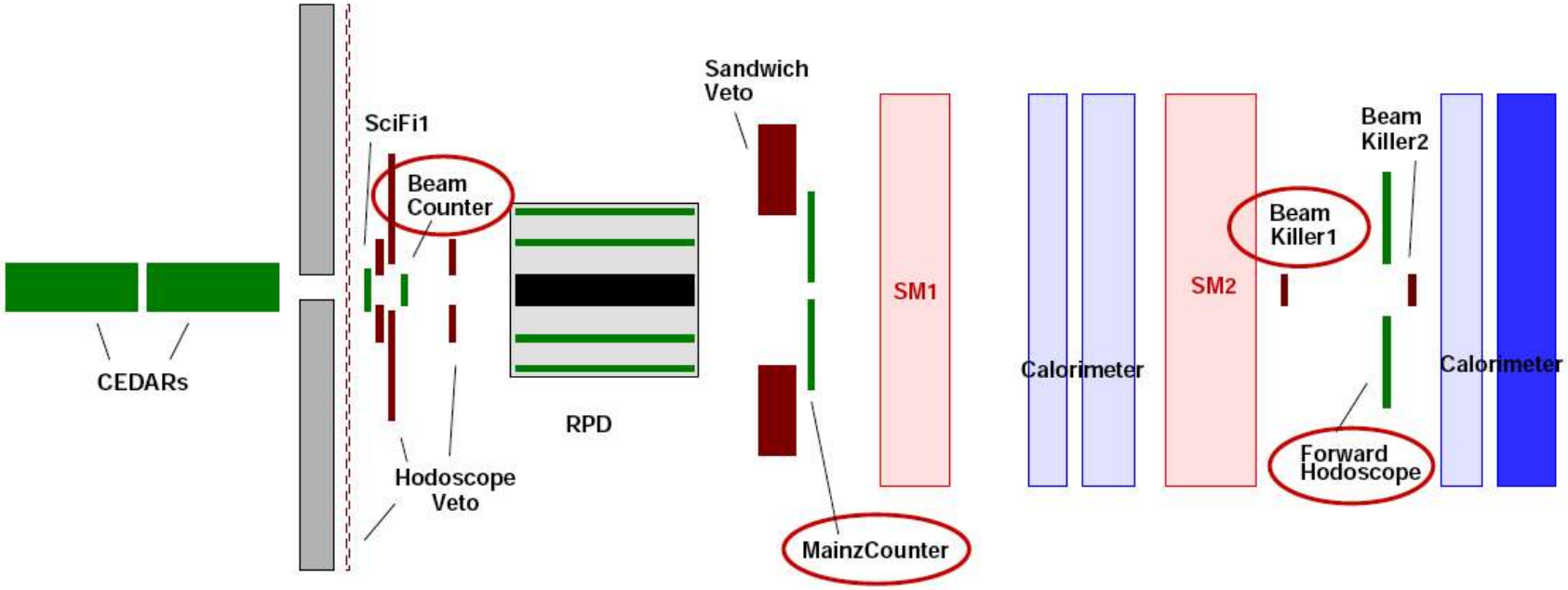
Proton Trigger



- identify proton by TOF and dE/dx meas. (with thresholds to cut out e^- and $\pi^\pm$)

calculated energy losses in both rings for different incident angles and particles

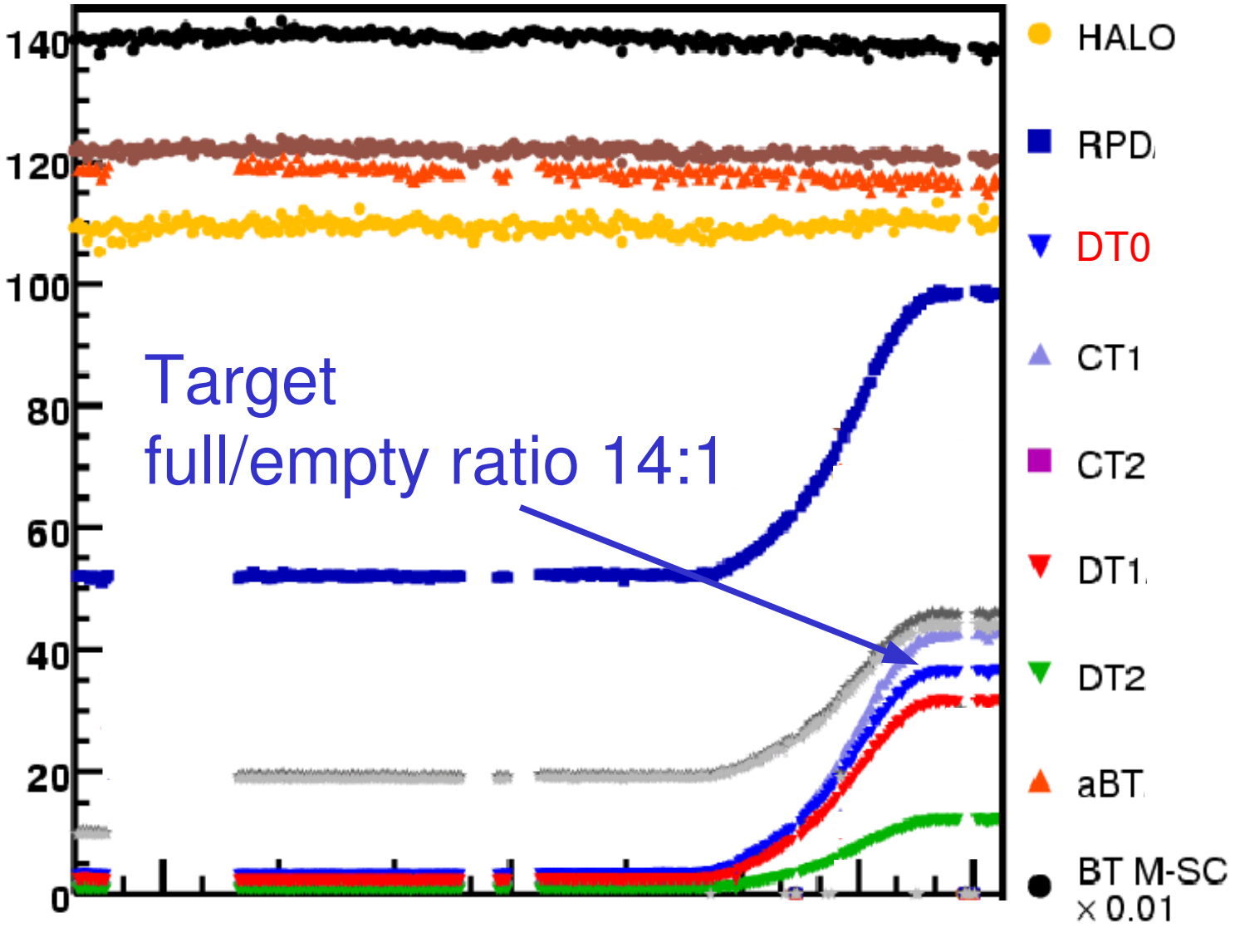
Physics Trigger



1. **Beam Definition:** Beamtrigger
2. **Target Pointing:** Proton Trigger
3. **Vetos**

Physics Trigger DT0 = Beamtrigger $\wedge$ RPD $\wedge$!(Vetos)

Physics Trigger - Empty/Full Target Effect



Example for a Hadron analysis: The 4π channel

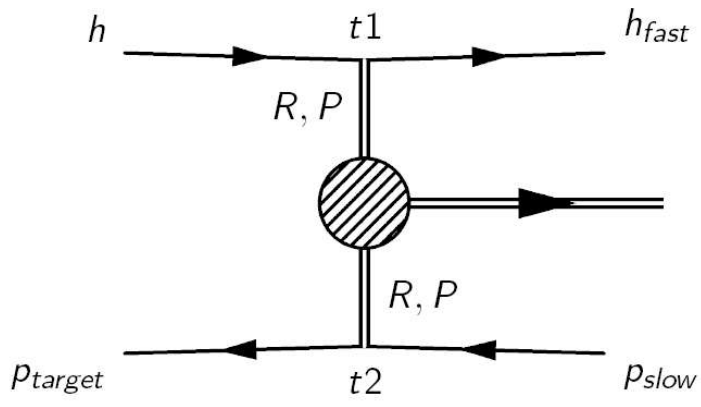
Compass 2008 Run (shown here: 13% of 2008 data)

$\pi^- p \rightarrow \pi^-_{fast}(\pi^+\pi^-\pi^+\pi^-)p_{recoil}$

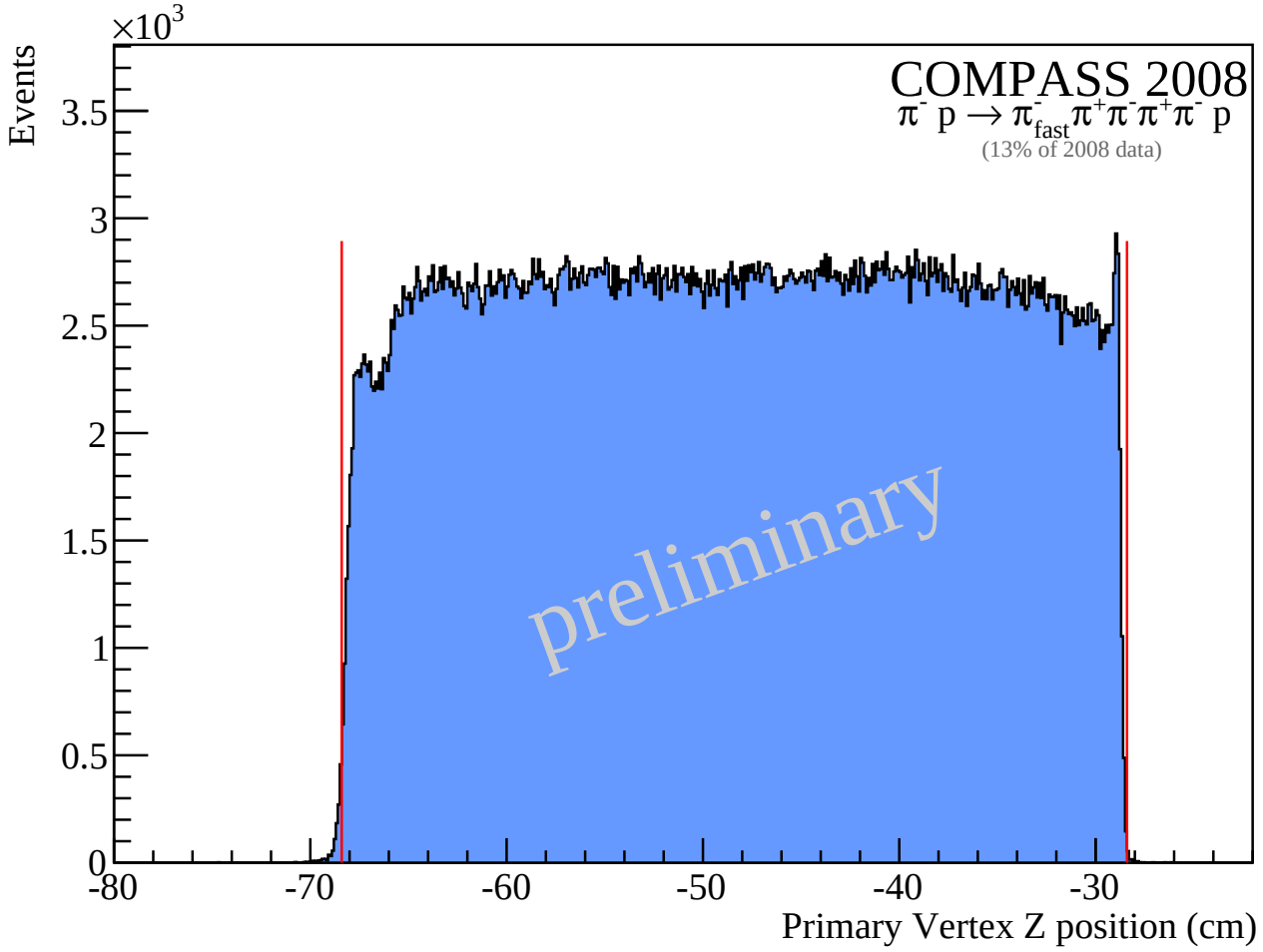
Cuts:

Cut	%
-no-	100
1 Primary Vertex	67.9
DT0 Trigger	58.4
5 Outgoing Charged Tracks	3.52
PV in Target	3.51
CEDAR Kaon Veto	3.46
Charge Conservation $\Sigma Q = -1$	2.52
Exclusivity (190 ± 5) GeV	0.27
$Q_{fast} = -1$	0.18

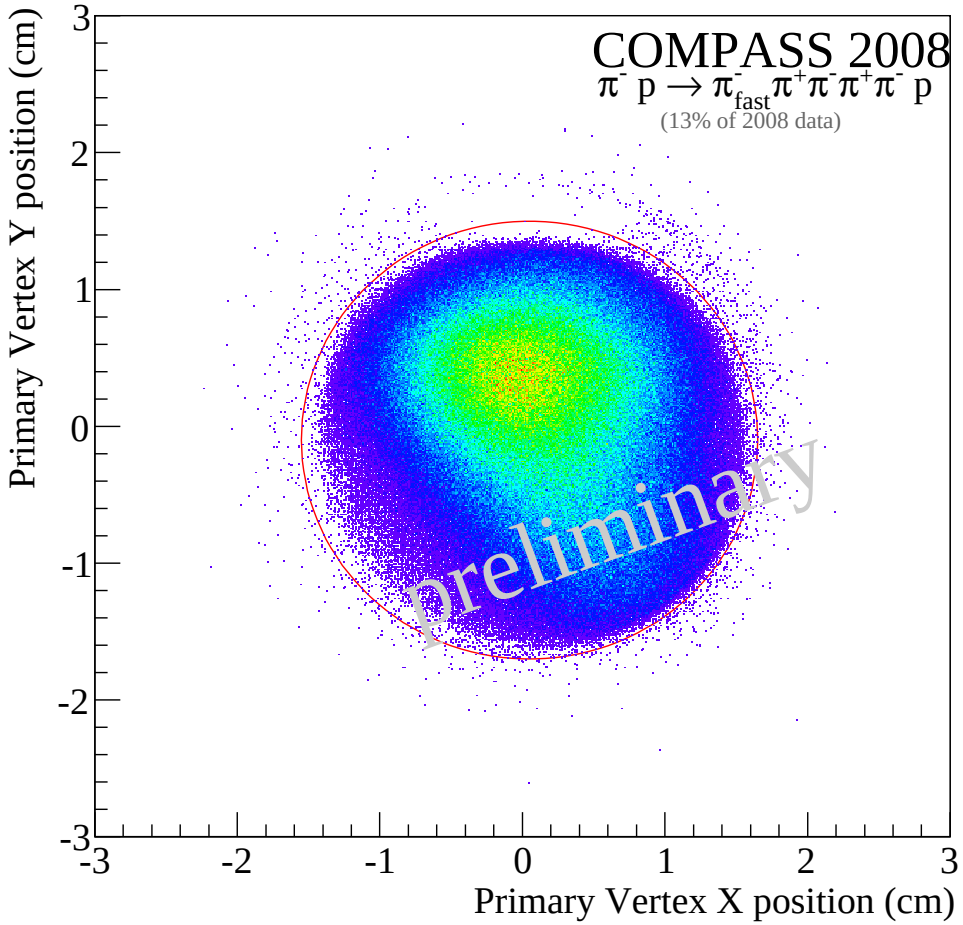
Central Production:



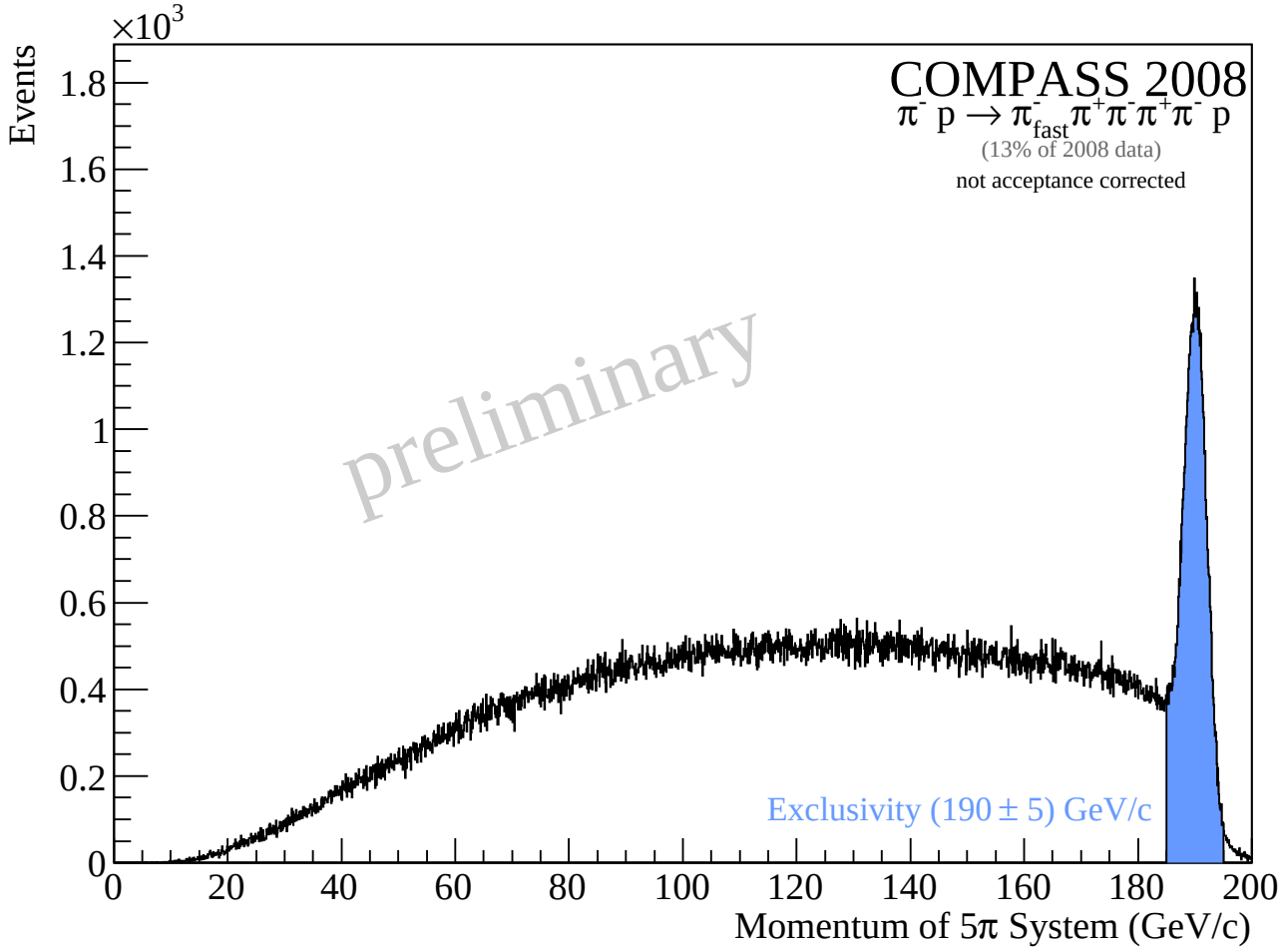
Vertex Distribution in Z (beam) direction



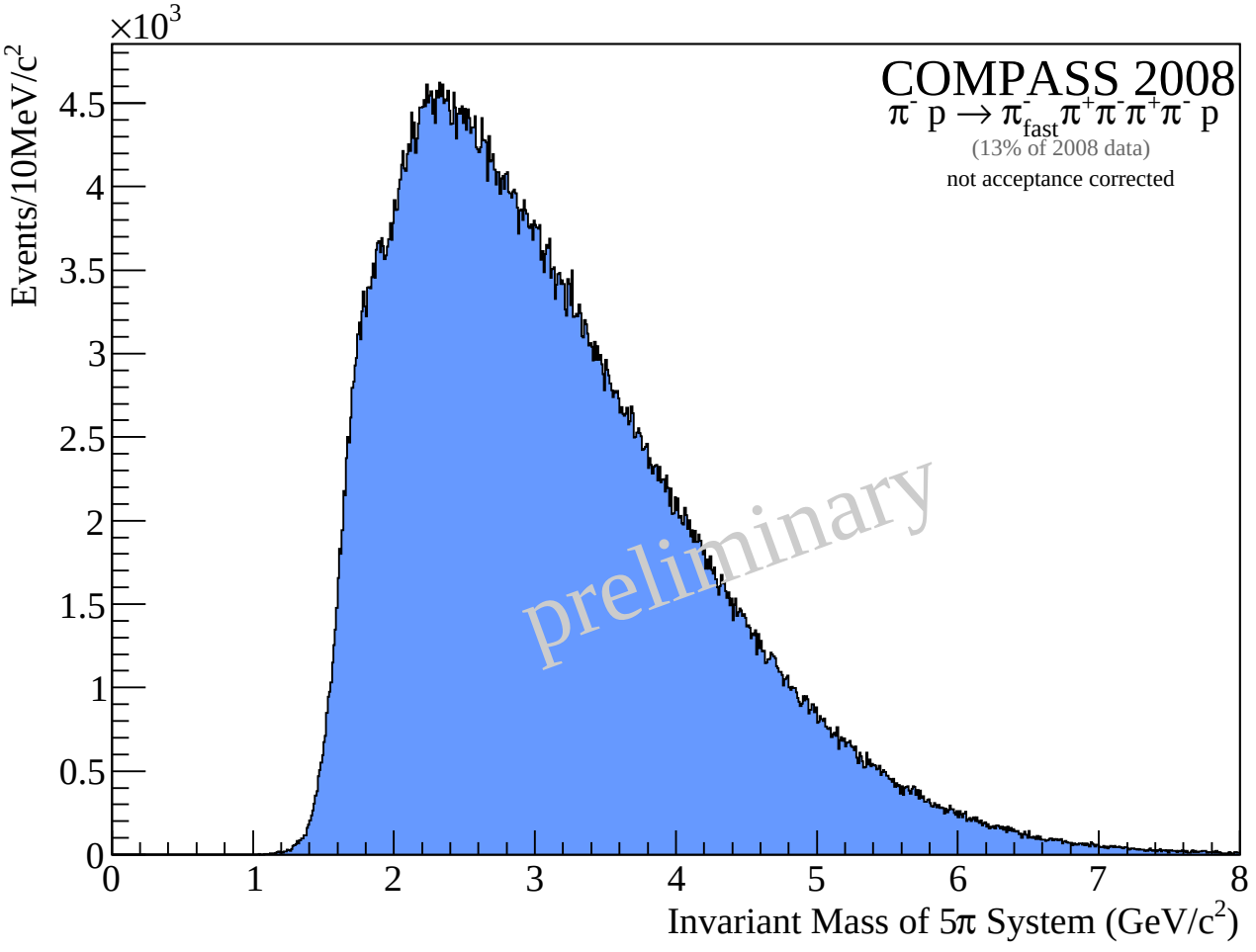
Vertex Distribution in XY-Plane



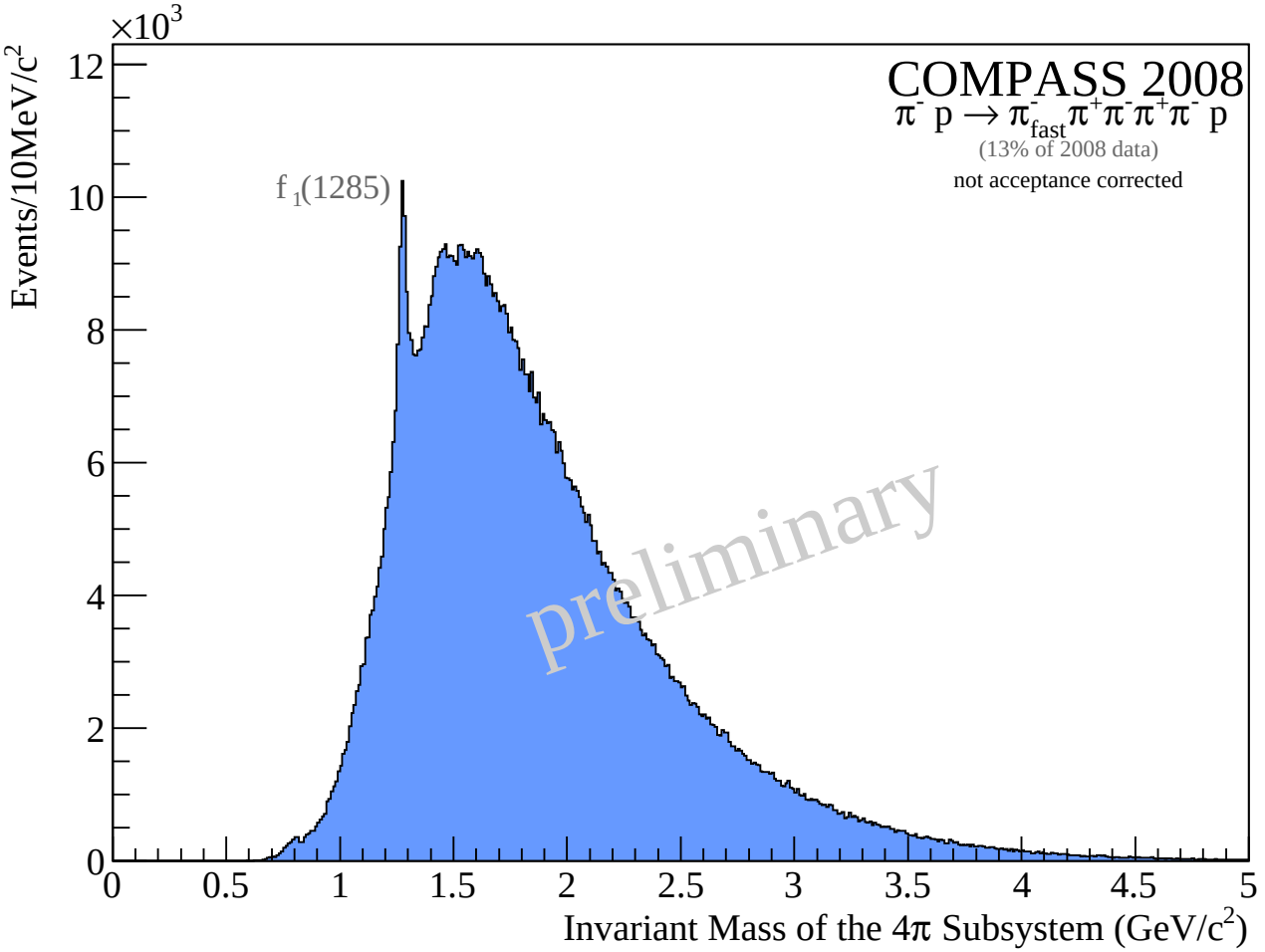
Exclusivity



Invariant Mass Distribution (5π)



Invariant Mass of 4π System

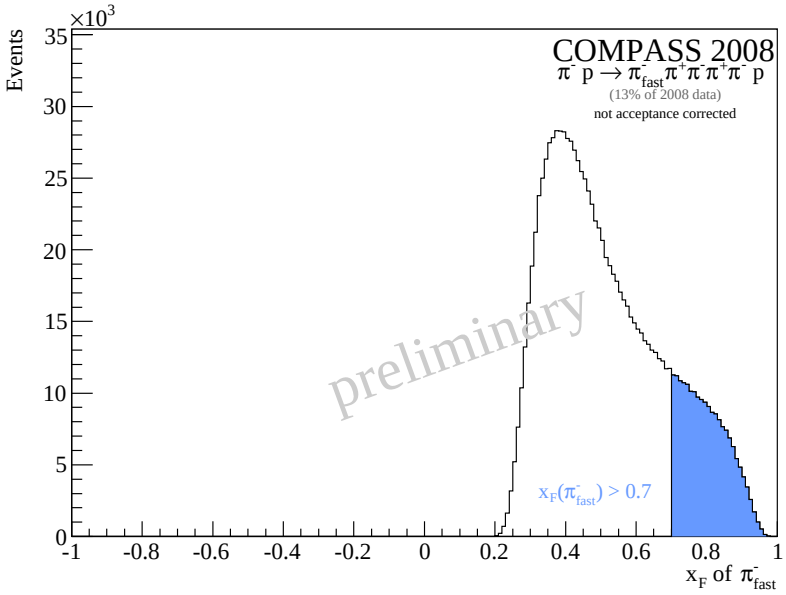


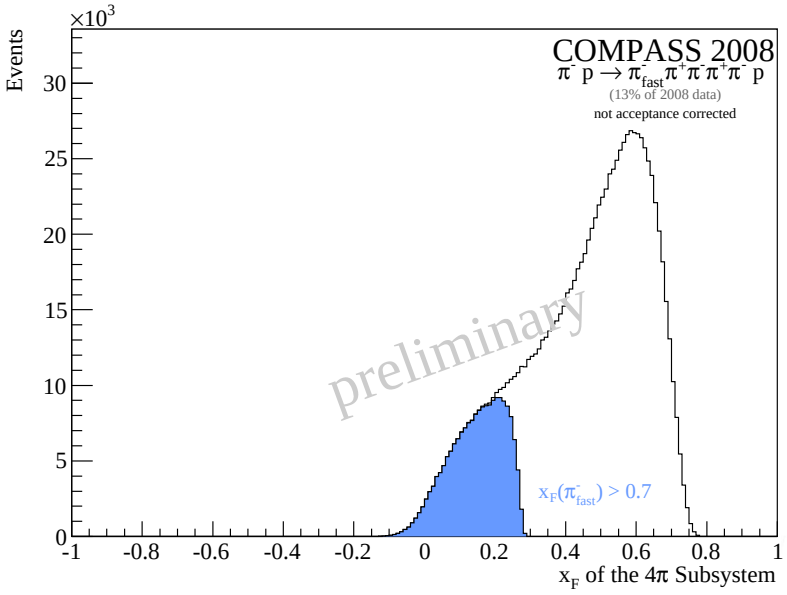
Enhancement of CP events: xF

One Approach to Select CP: Feynman x_F

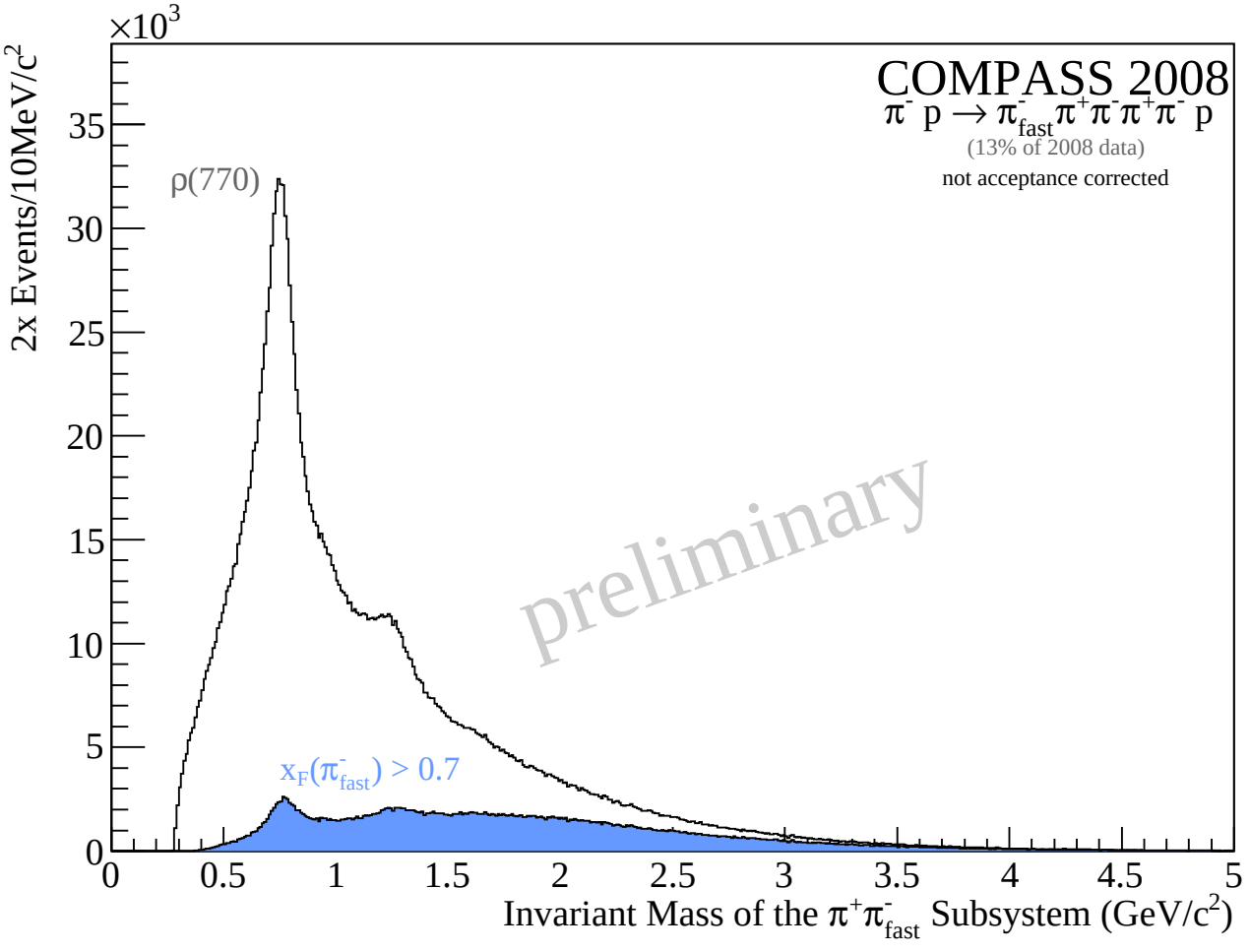
$$x_F = \frac{|\vec{p}_l|}{|\vec{p}_l^{\,max}|} = \frac{2\,|\vec{p}_l|}{\sqrt{s}},$$

- $|\vec{p}_l|$: longitudinal momentum
- $\sqrt{s}$: total center-of-mass energy of the interaction
- $|\vec{p}_l^{\,max}|$: the maximum allowed longitudinal momentum

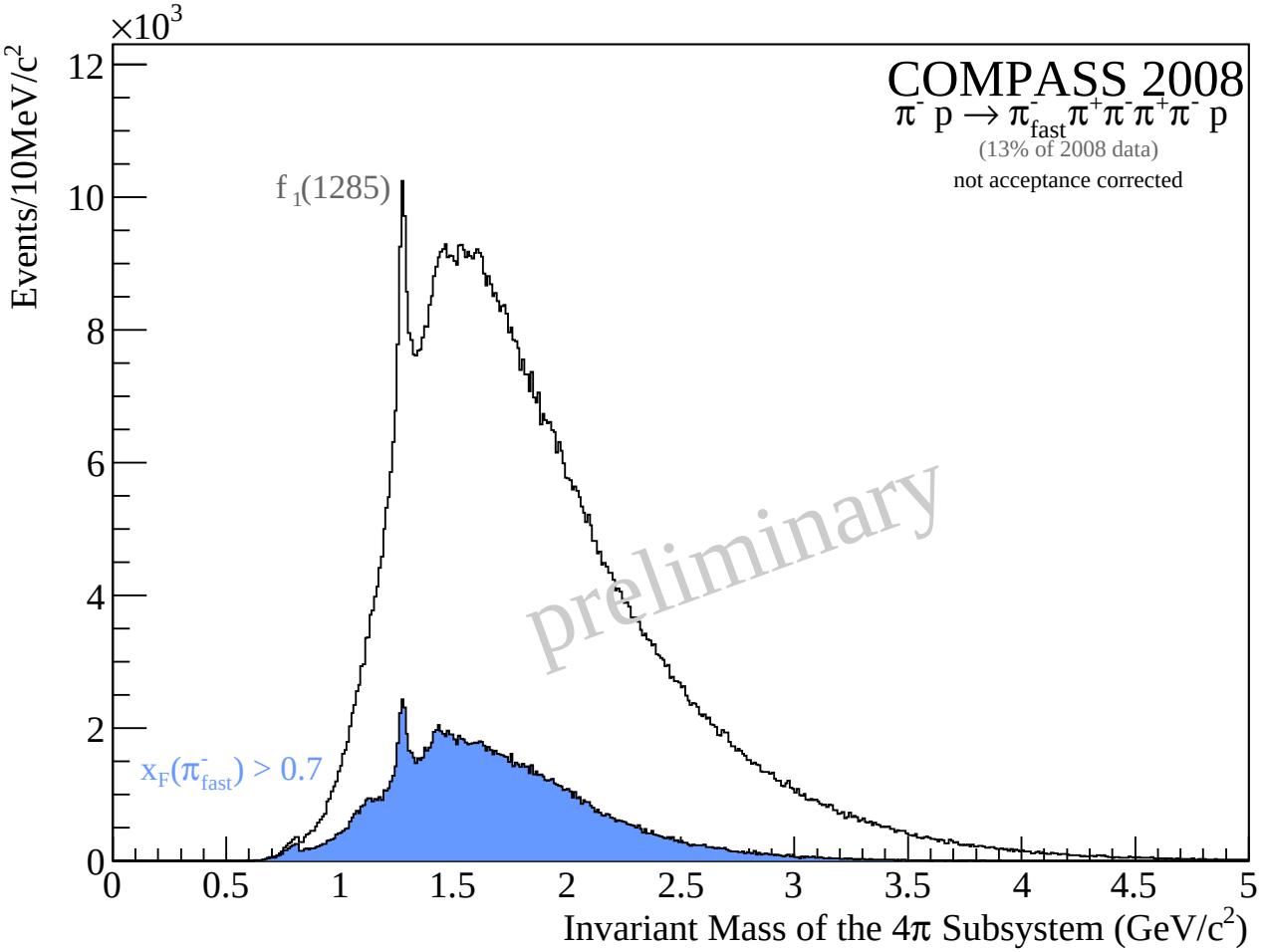




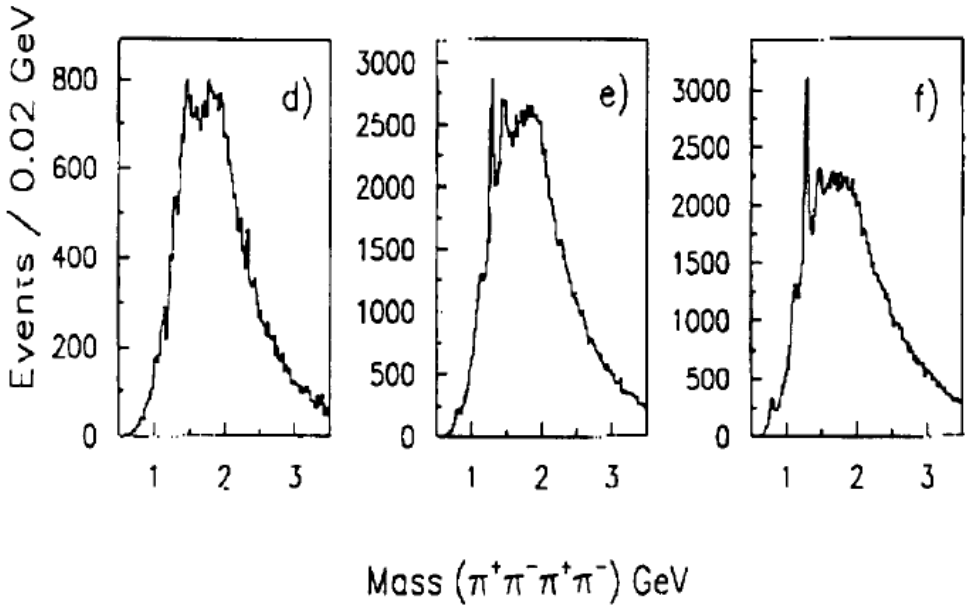
Invariant Mass of 2π System with π^-_{fast}

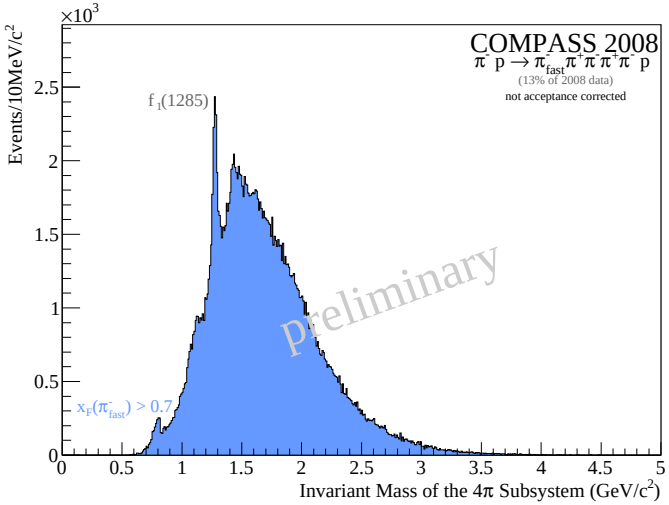


Invariant Mass of 4π System



Invariant Mass of 4π System





WA102:

d) $dP_t < 0.2$ GeV

e) 0.2 GeV $< dP_t < 0.5$ GeV

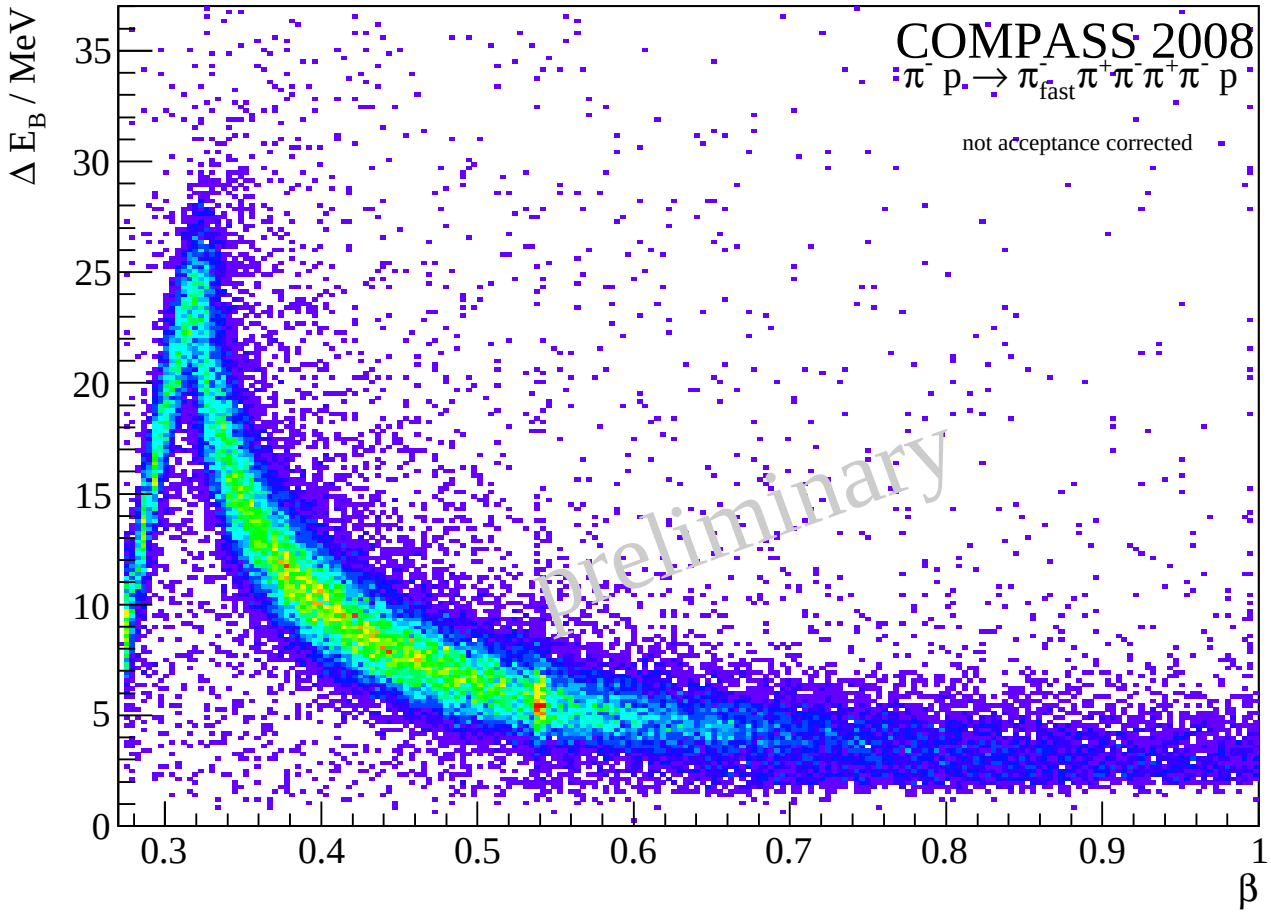
f) $dP_t > 0.5$ GeV

COMPASS: all dP_t up to now, binning in dP_t with the full data set to come

RPD information

RPD not only used in the trigger, but also in the offline analysis:

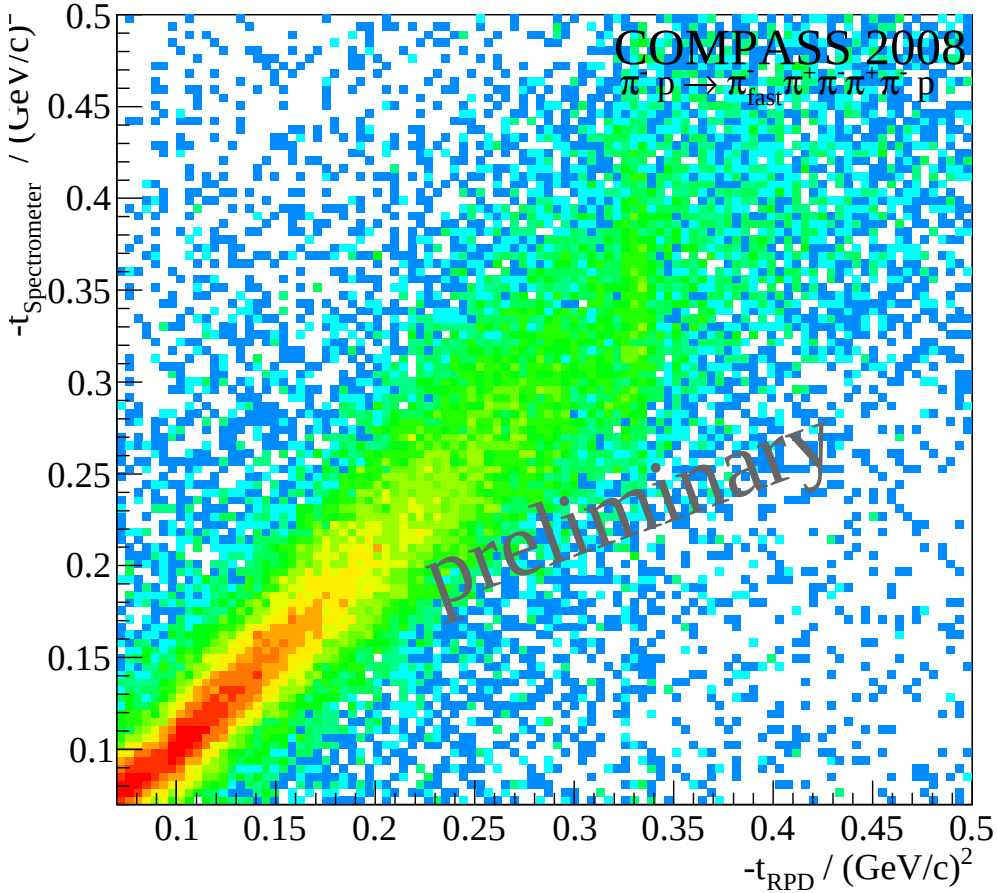
- measures TOF and $dE/dx \rightarrow$ recoil particle momentum and PID



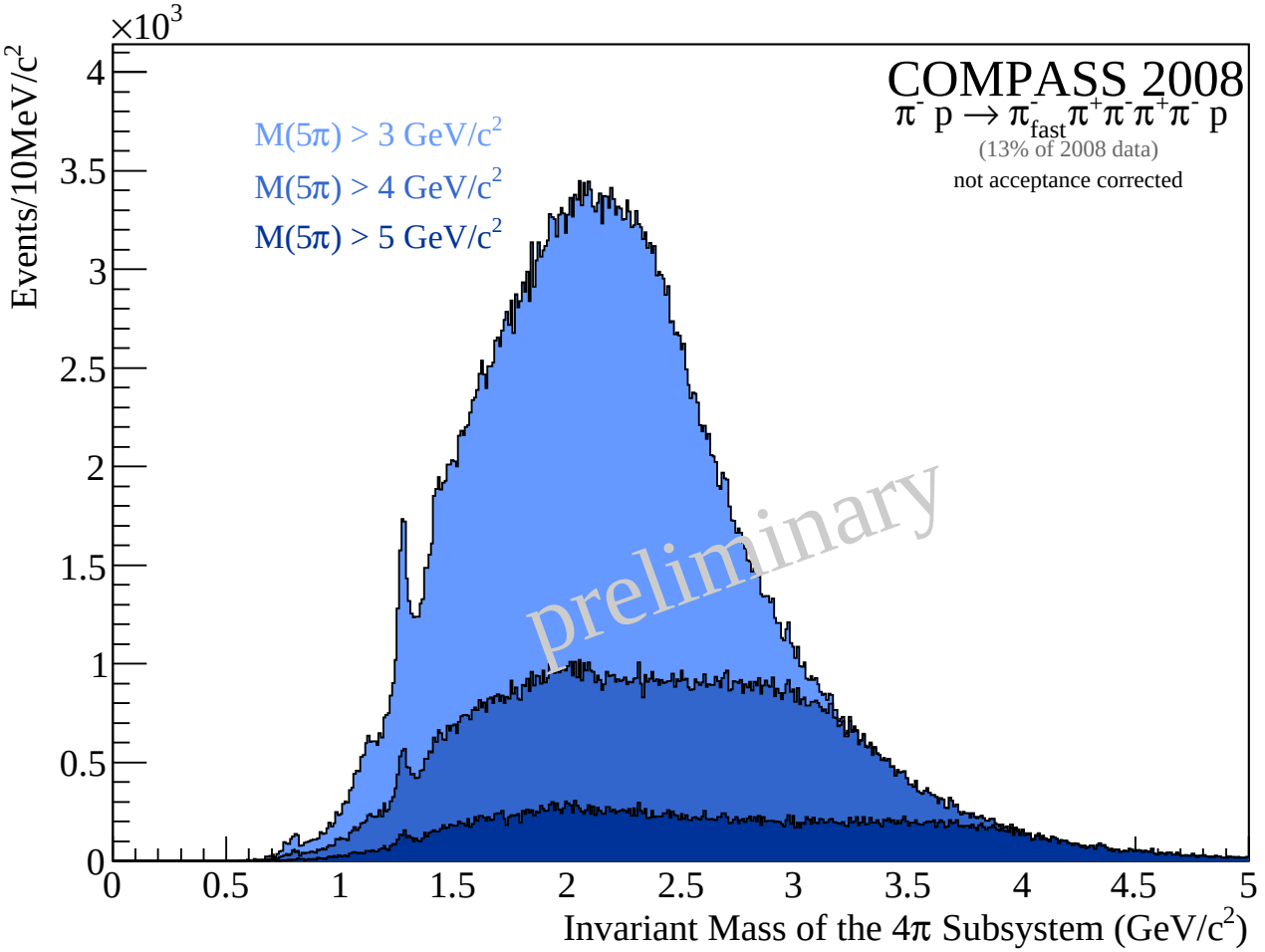
RPD information

RPD not only used in the trigger, but also in the offline analysis:

- measures TOF and $dE/dx \rightarrow$ recoil particle momentum and PID
- information on both t_1 and t_2

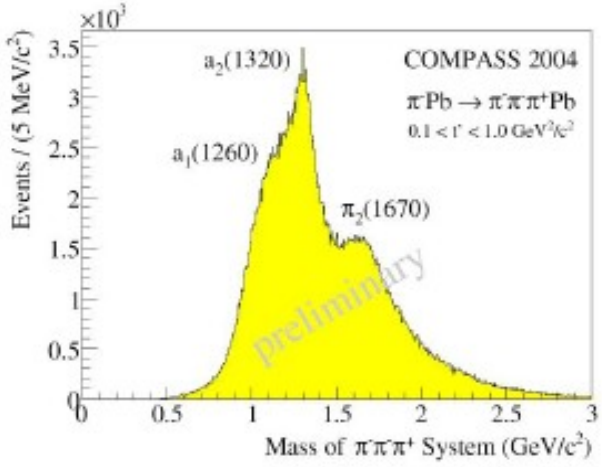


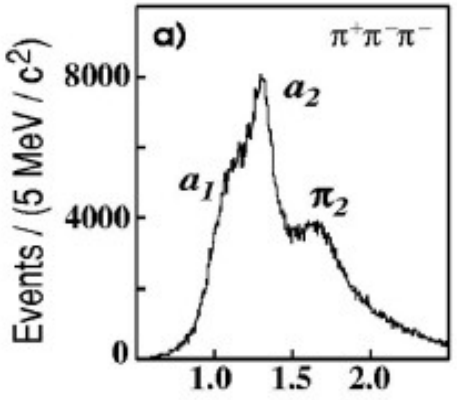
Different Approach: Cut on M(5π)

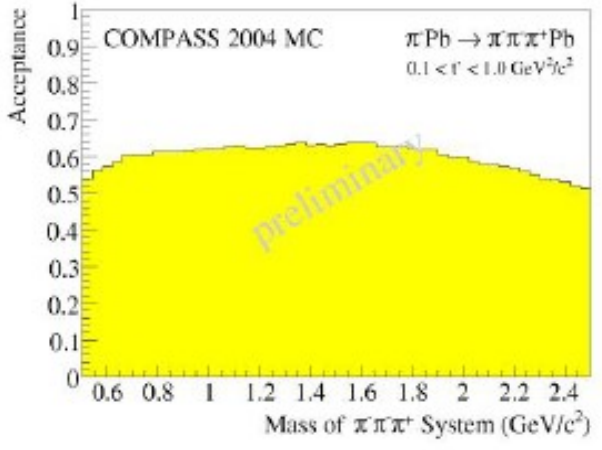


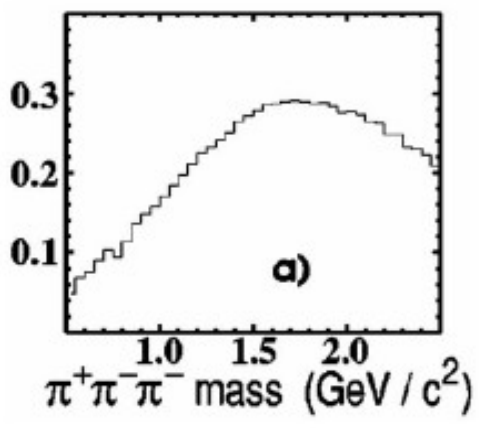
3π analysis (2004 data)

cf. CERN-PH-EP/2009-018 (submitted to PRL)





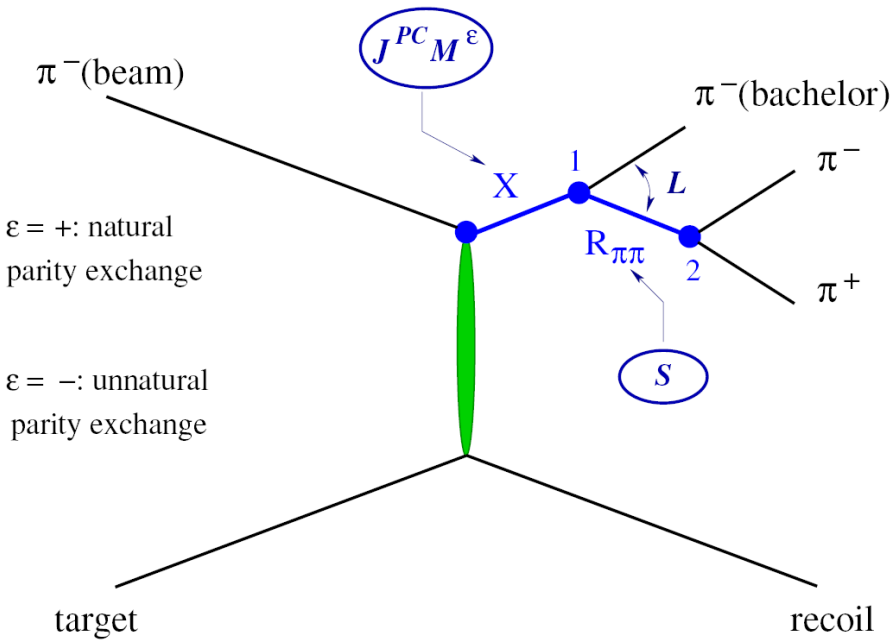




COMPASS 2004 vs. BNL 853

Selected results: PWA on 2004 3π data

Analyse decay in the *isobar model*:

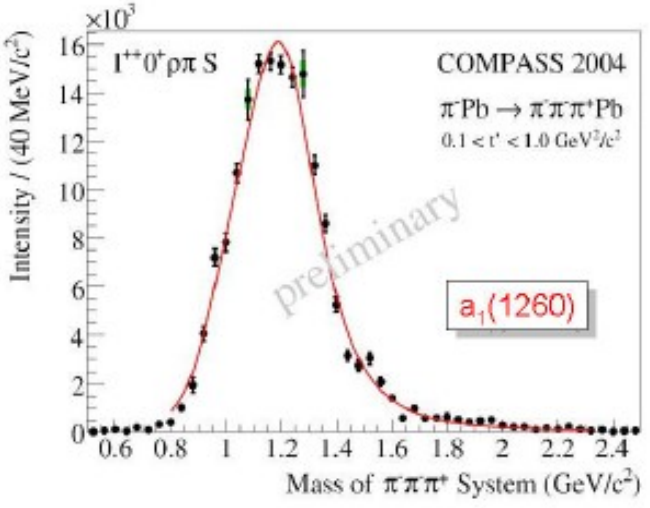


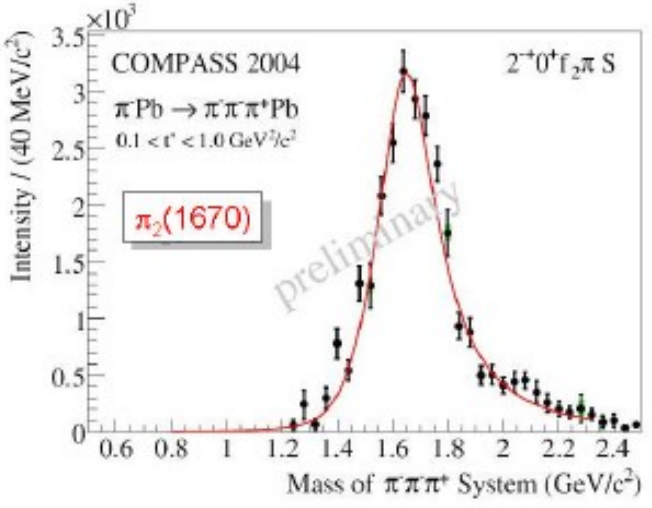
- intermediate two-particle decays
- introduce *reflectivity* basis:
  $M = -L, -L+1, ..., L-1, L$
  $\Rightarrow |M|\epsilon = |M|\text{sgn}(M)$
- amplitudes in the *helicity* formalism:
  expand to D-Functions

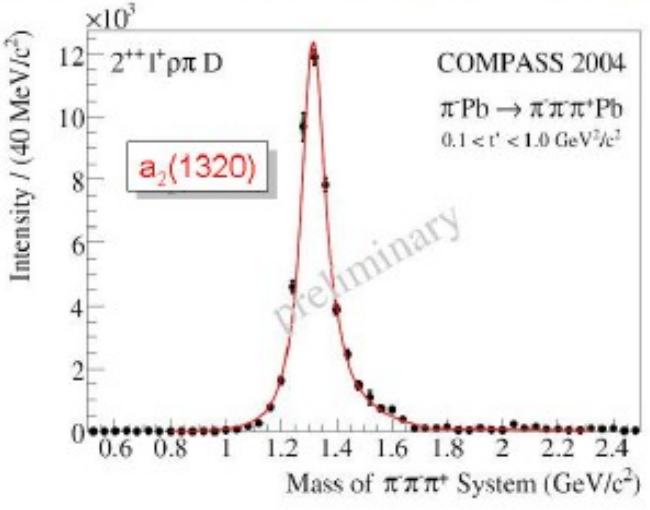
two-step-fit:

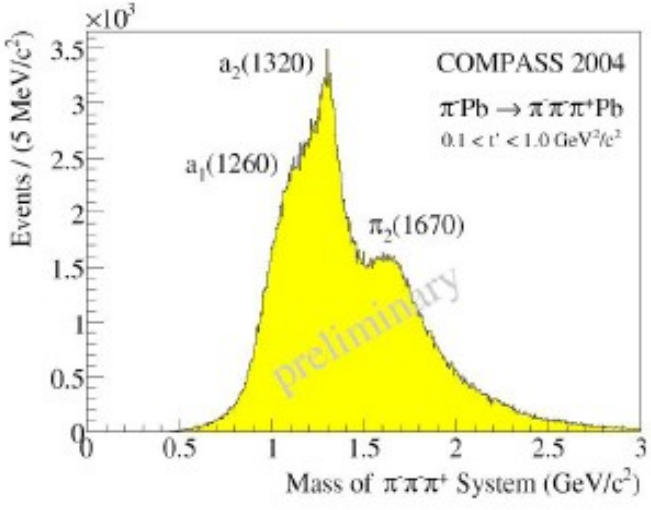
1. Mass-independent PWA in $40 MeV/c^2$ bins
   - extended log-Likelihood fit with an extended set of waves (42)
   - acceptance corrected
2. Mass-dependent χ^2 fit
   - contains the 6 dominant waves
   - Breit-Wigner parametrization of the resonances

PWA results



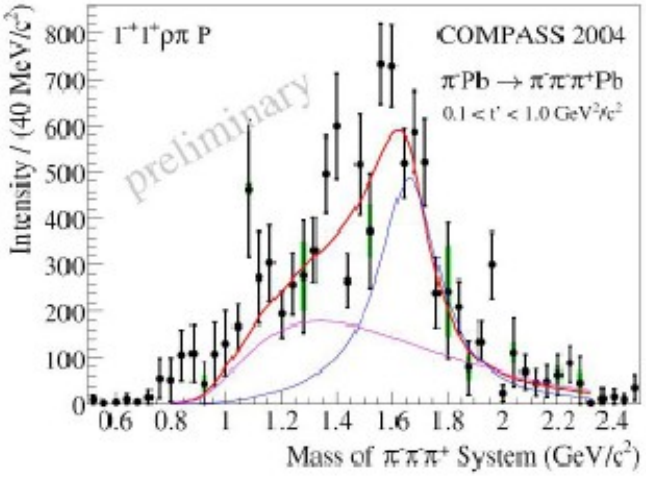


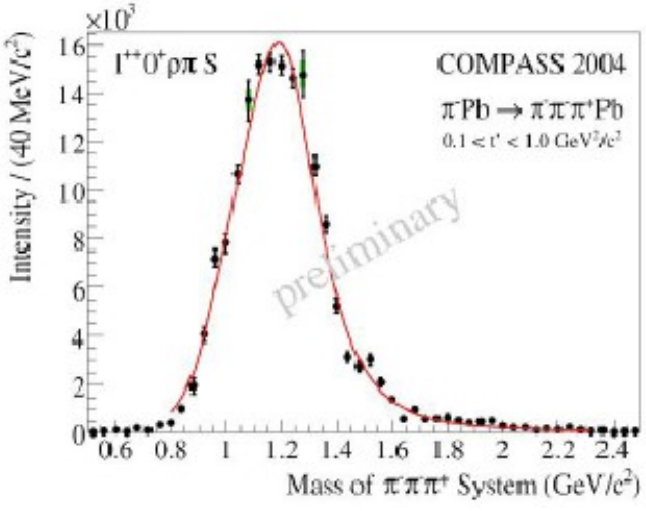


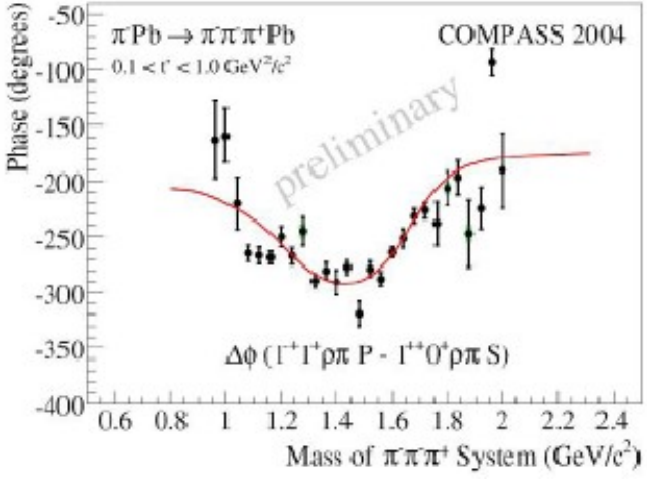


major waves

PWA results

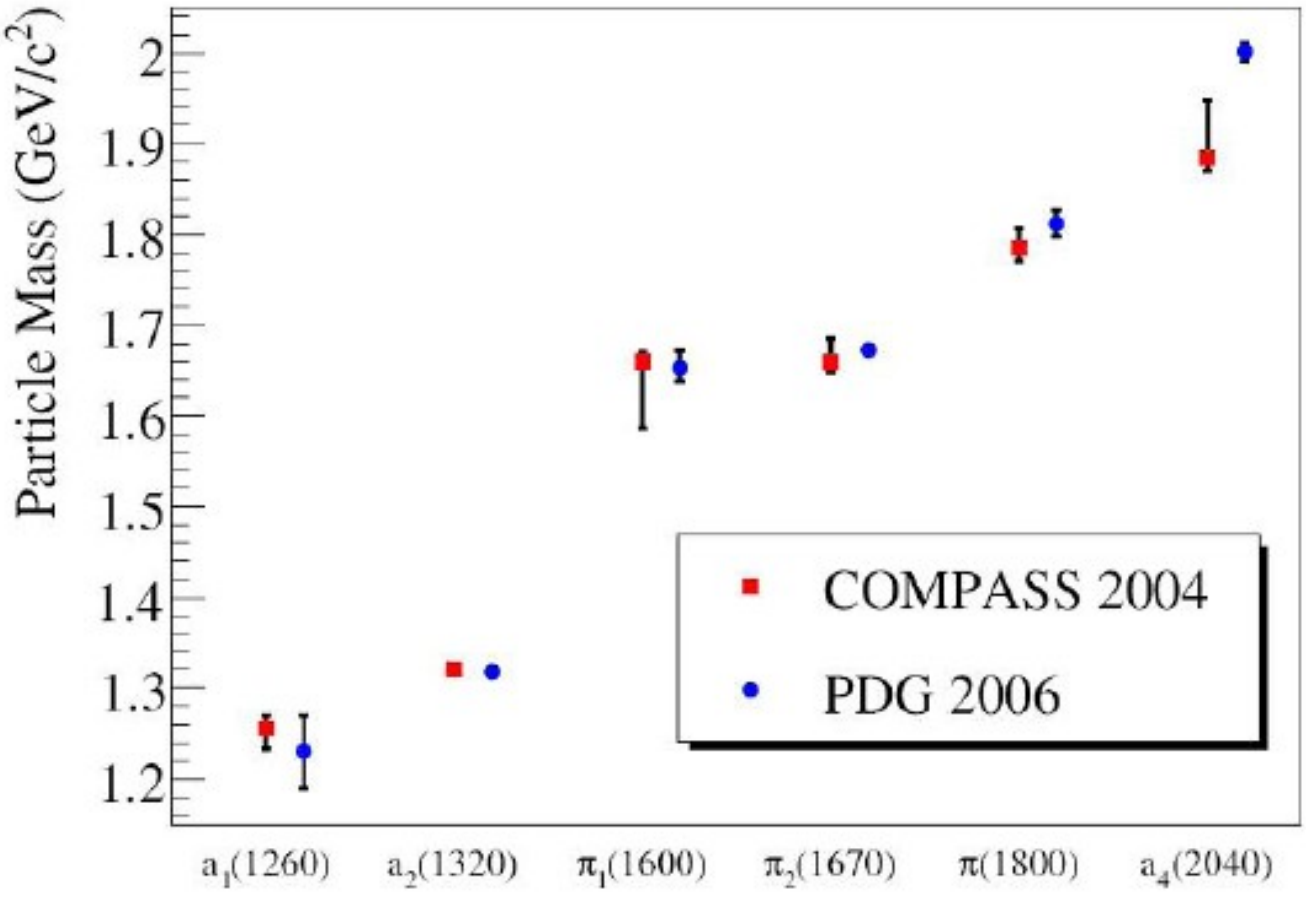






exotic 1^{-+}

PWA results

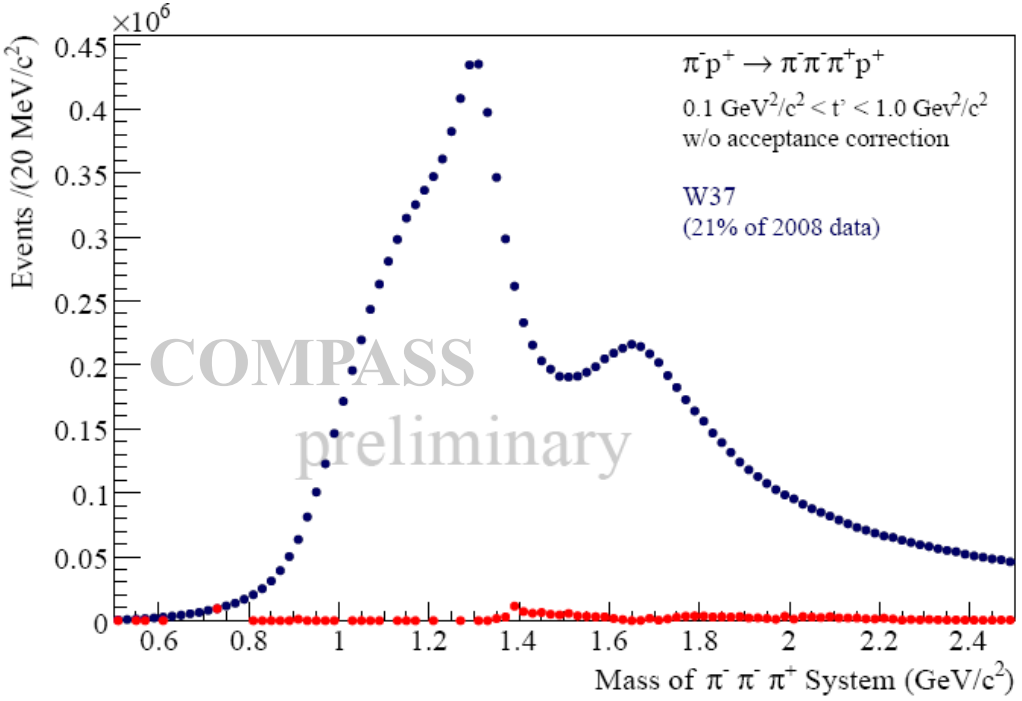


summary

Selected results

Results for the 3π channel already published for 2004 data

- complete Partial Wave Analysis performed
- search mainly for the $\pi(1600)$ - confirmed!
- as an appetizer, some 2008 data:



Summary and Outlook

- COMPASS Hadron program - a first glance at upcoming results
- huge amount of data, mostly 200x more than previous experiments
- only a few days of 2008 data taking (13%) used yet in most of the analyses, 2009 proton data to come!
- Partial Wave Analysis results available for a few channels, but not yet published

Next steps:

1. acceptance correction for 2008/2009 data
2. introduce the next level of event selection (eg. glueball filter)
3. include both central and diffractive mechanisms in the PWA
4. develop new formalisms for the PWA

Summary and Outlook

Stay tuned for 2009 data:

- Primakoff
- spectroscopy with different target materials (Pb, Ni, C, W)
- low t

and, of course:

- GPD@COMPASS (DVCS, DVMP)
- Drell-Yan