# Status / Hadron Spectroscopy at COMPASS

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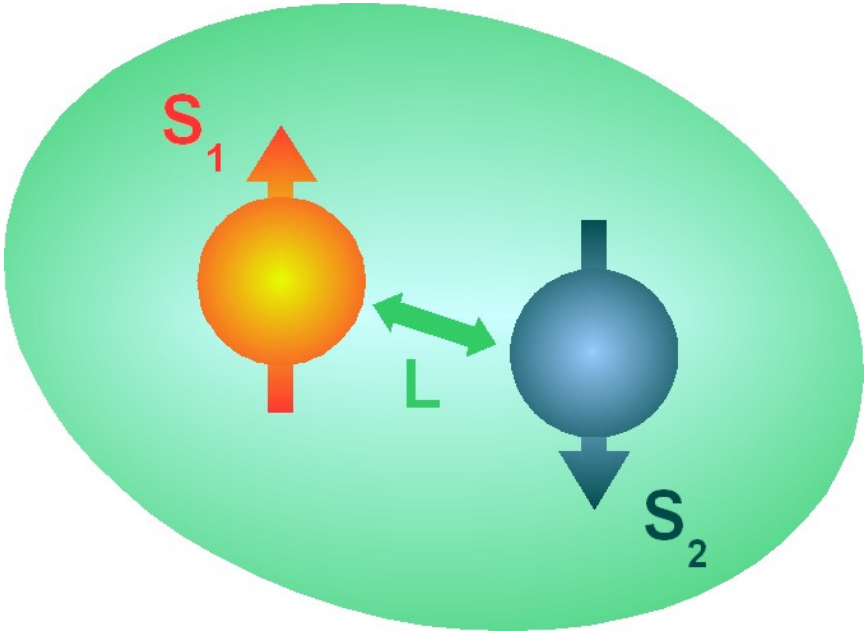
# Outline

## Spectroscopy with Mesons

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

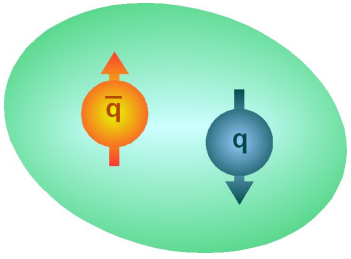



- allowed $J^{PC}$ combinations: $0^{-+}$,$0^{++}$,$1^{--}$,...
- exotic $J^{PC}$ combinations: $0^{--}$,$0^{+-}$,$1^{-+}$,...

## 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:

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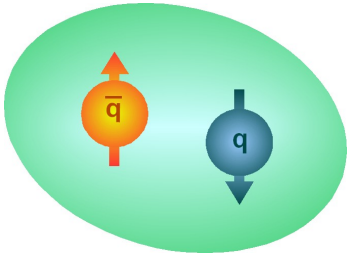
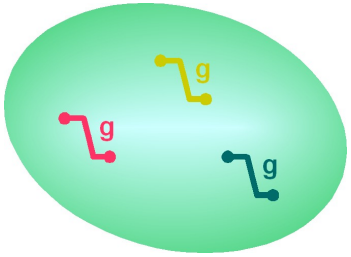
- glueballs



## Exotic Mesons

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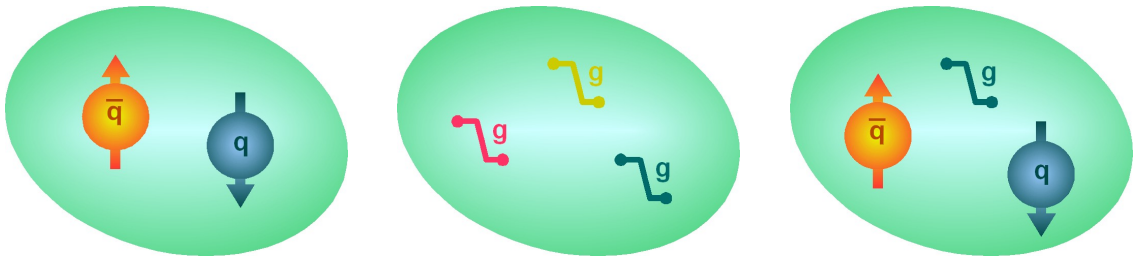
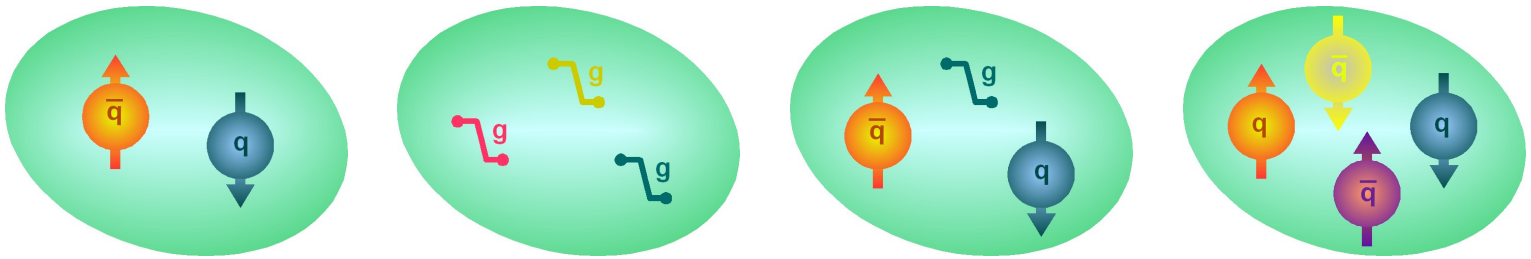
- hybrids



## Exotic Mesons

extend the simplified model by adding additional degrees of freedom:

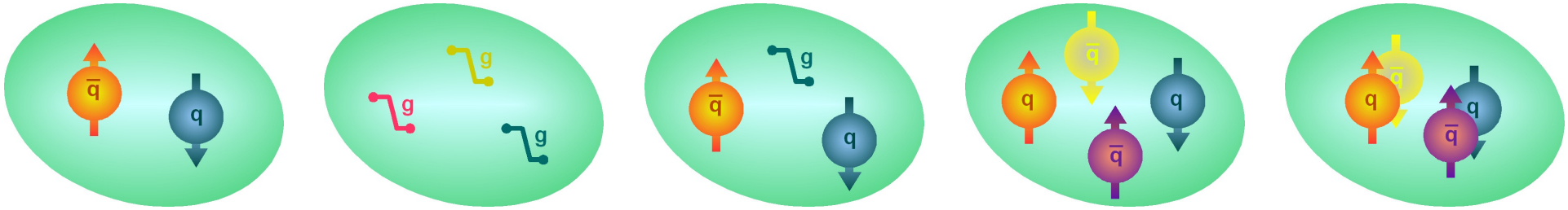
- $q\bar{q}$ mesons
- glueballs
- hybrids
- bound $q\bar{q}q\bar{q}$ states



## Exotic Mesons

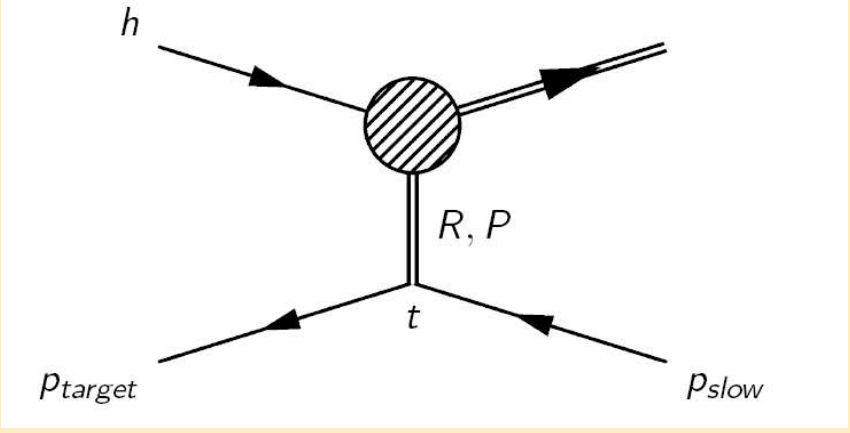
extend the simplified model by adding additional degrees of freedom:

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

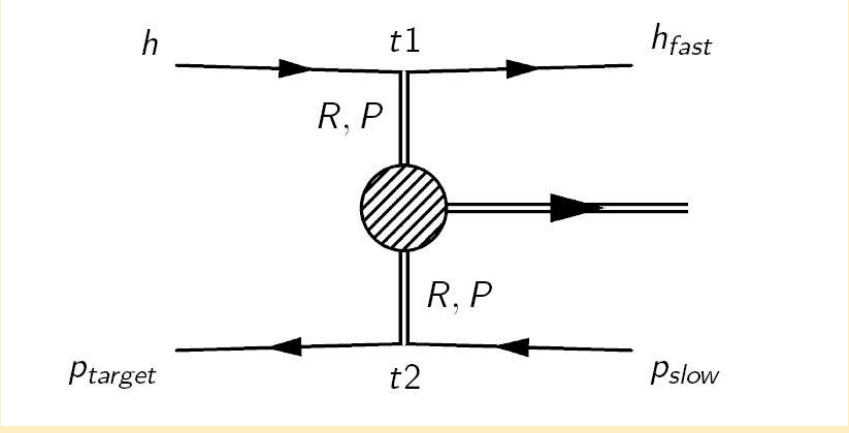


# Formation processes

## Diffractive Scattering:




## Central Production:



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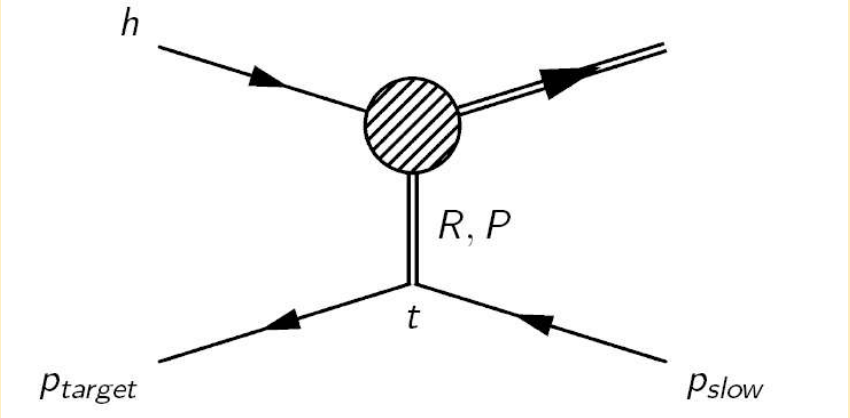


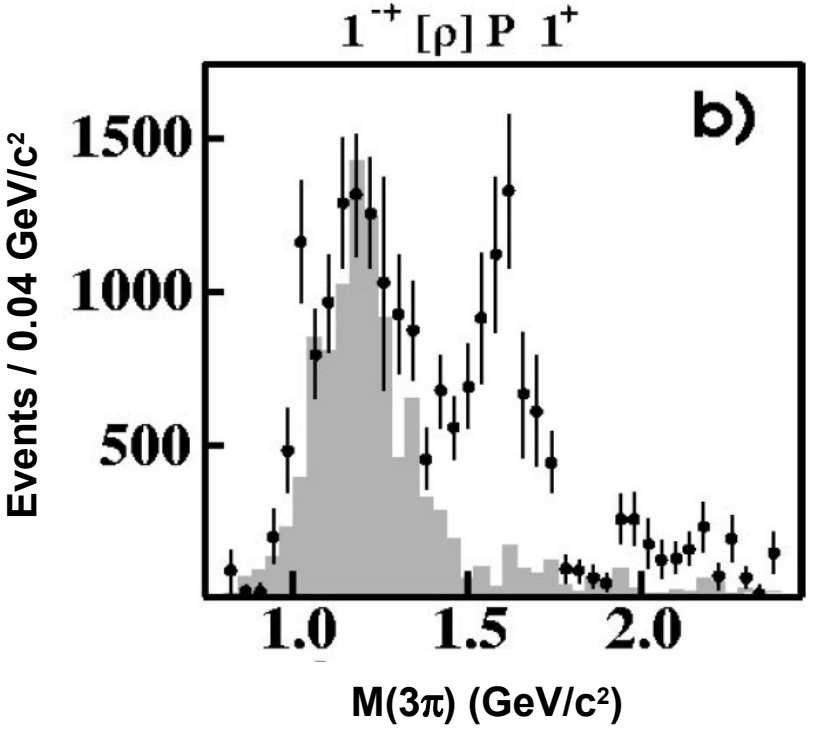


- SPE (single pomeron exchange)
- search for hybrid-candidates: $\pi(1600), \pi(1800)$

# Formation processes

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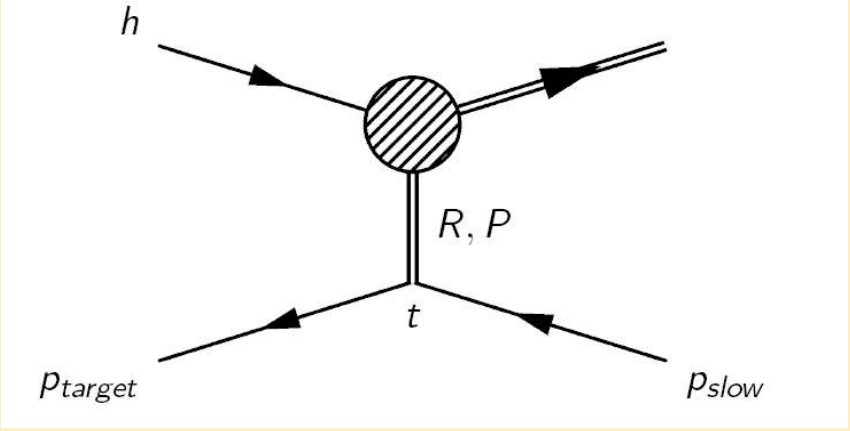


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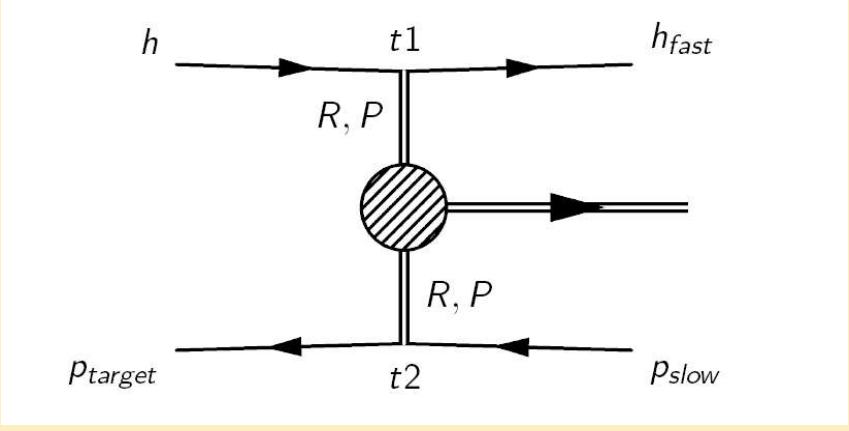


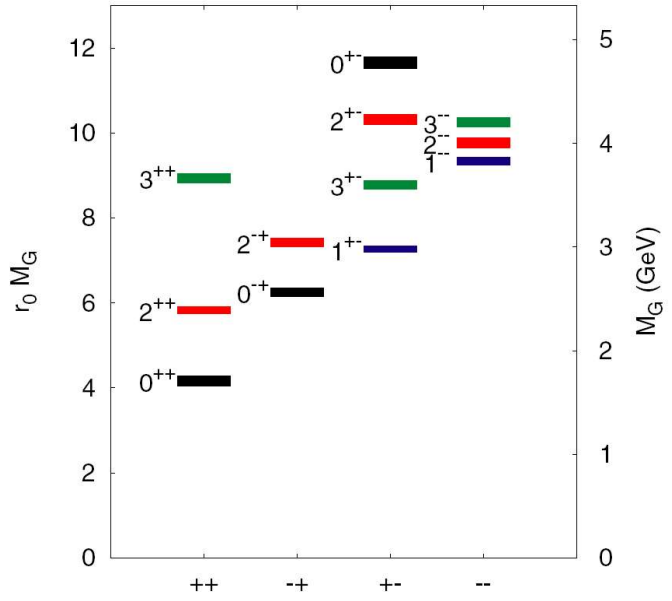

### Context: Definition of Central Production

- 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)

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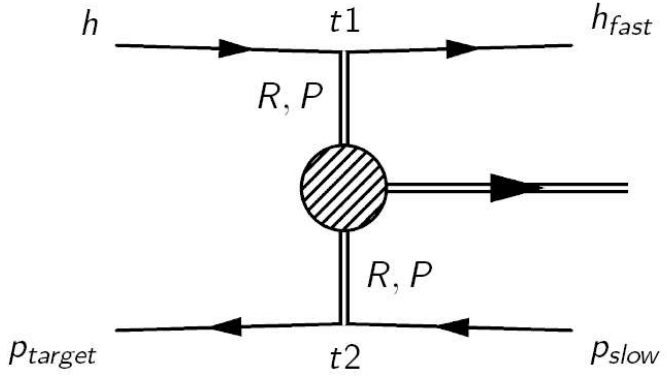
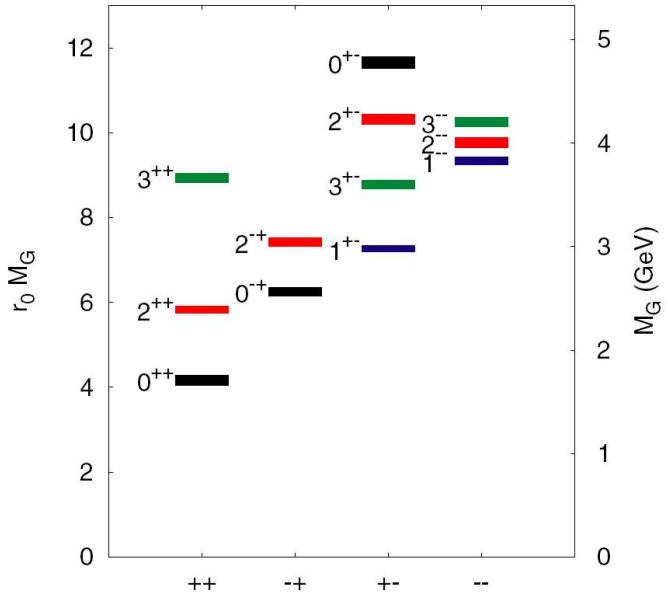



### Some examples of central production studies with $4\pi$ final states

- 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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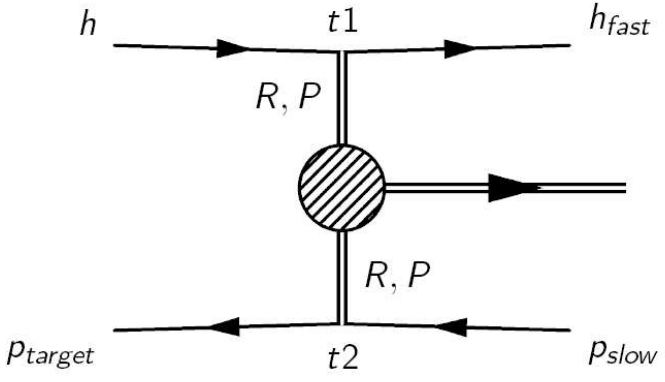



## How to search for glueballs?

characterization by

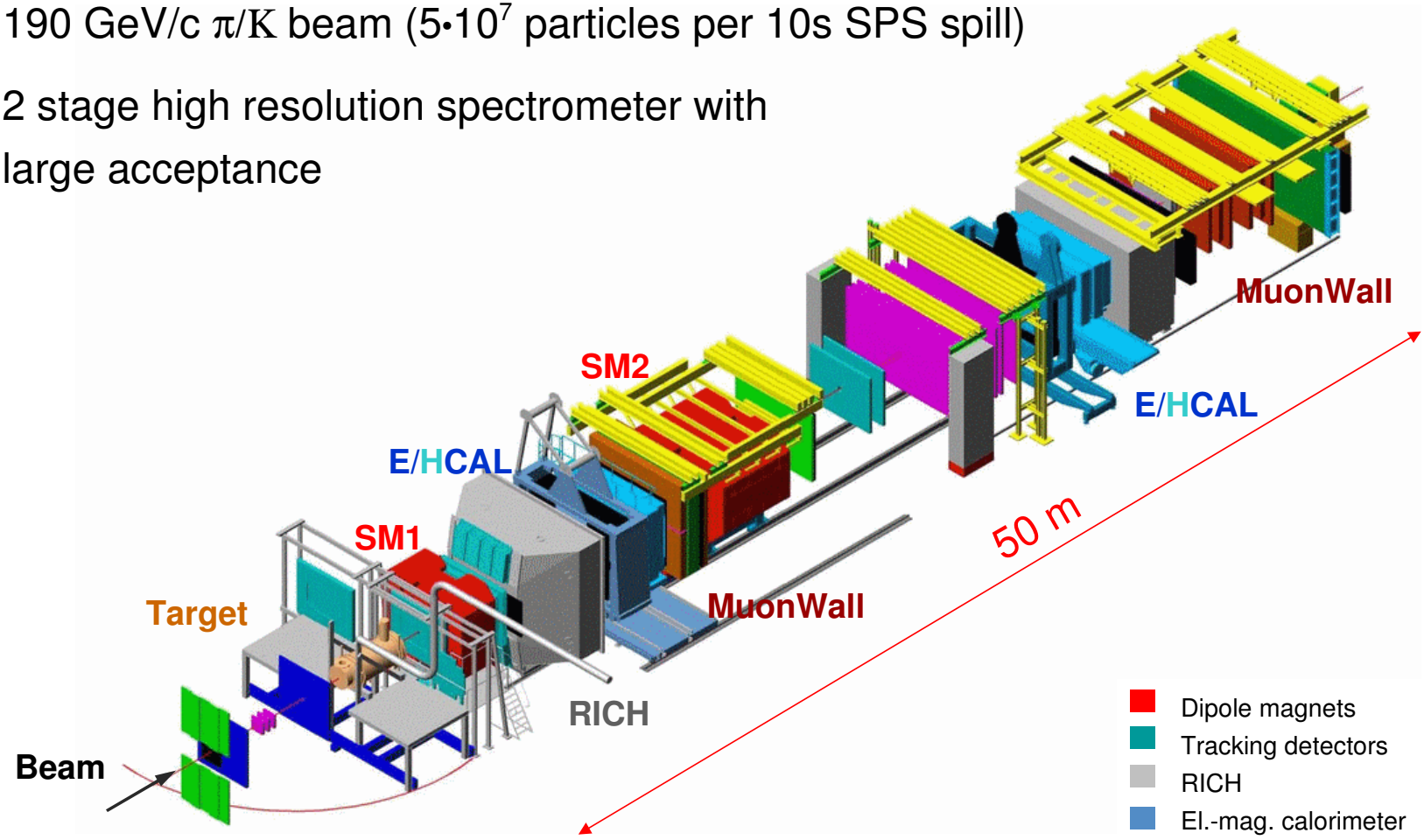
- flavour-neutral decay modes:
  $X$ is supposed to be seen in $\pi^+\pi^-$, $\pi^0\pi^0$,$K\bar{K}$, $4\pi$, $\eta\eta$, $\eta\eta'$
- formation kinematics: small $dP_t = p_t^{fast} - p_t^{slow}$

# The COMPASS collaboration

# The COMPASS spectrometer

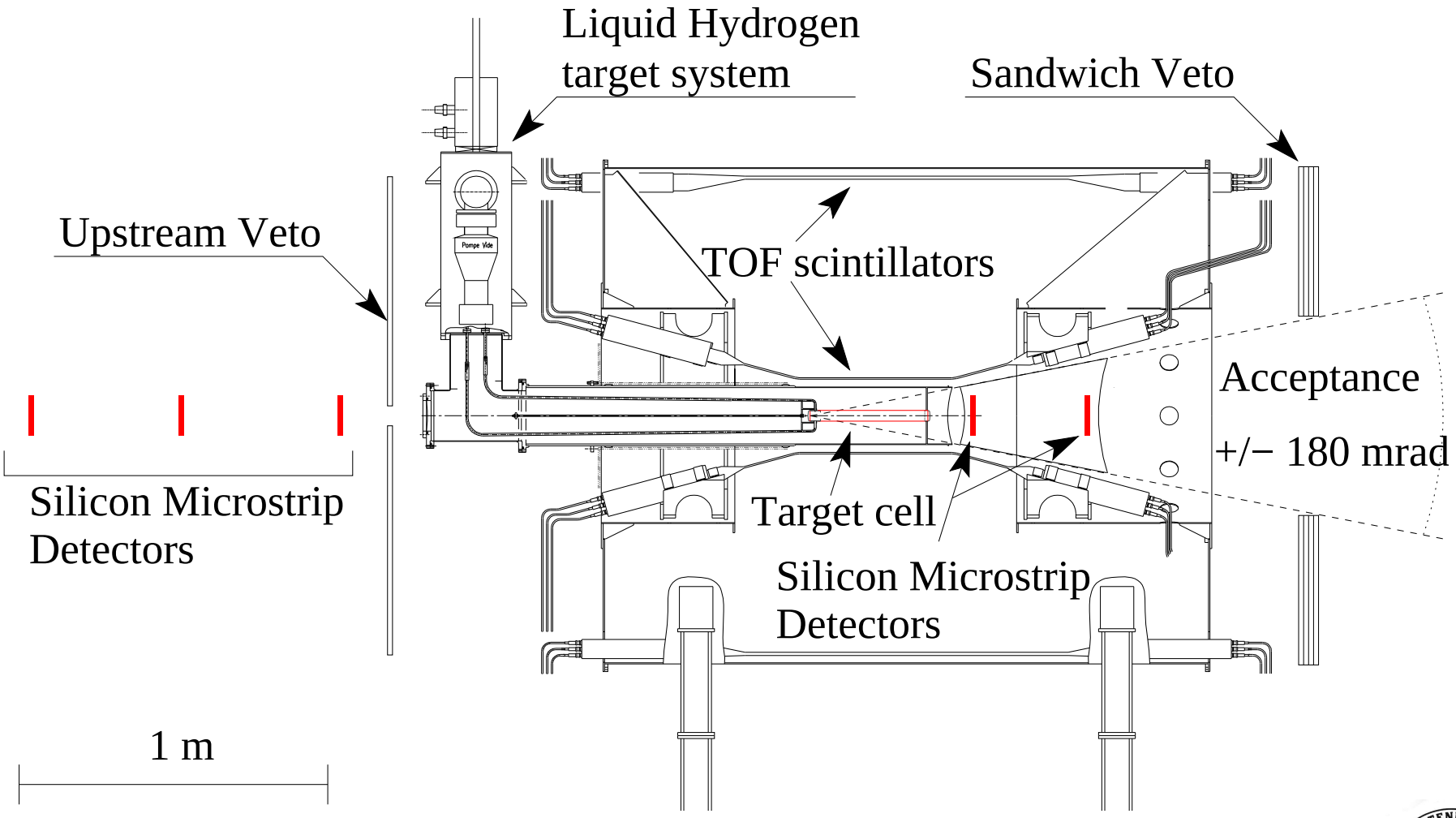
190 GeV/c $\pi$/K beam ($5 \cdot 10^7$ particles per 10s SPS spill)

2 stage high resolution spectrometer with large acceptance




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

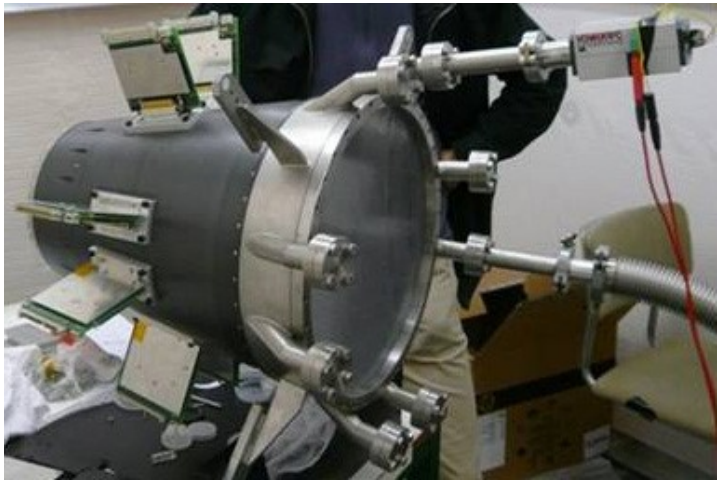
# Changes for the Hadron Run 2008/2009: Target Region




- 40cm $lH_2$ target

# Changes for the Hadron Run 2008/2009: New components

Installation of new components:



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

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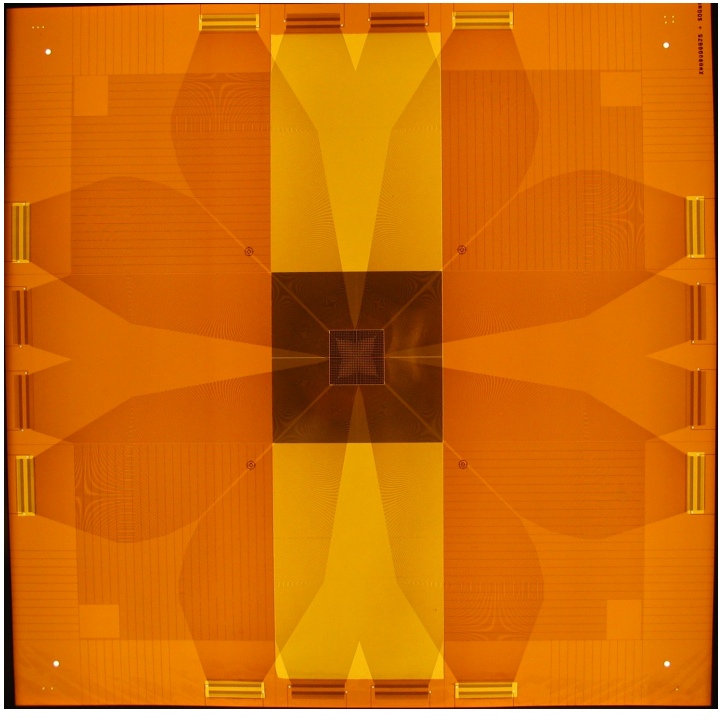

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- upgrade on tracking (PixelGEMs, MicroMegas)

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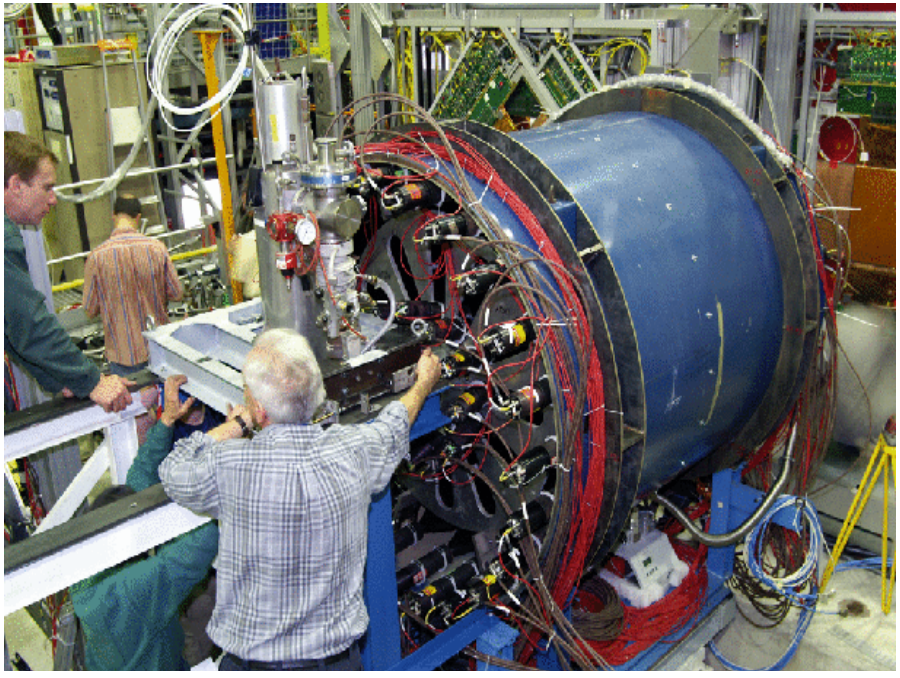
Installation of new components:


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

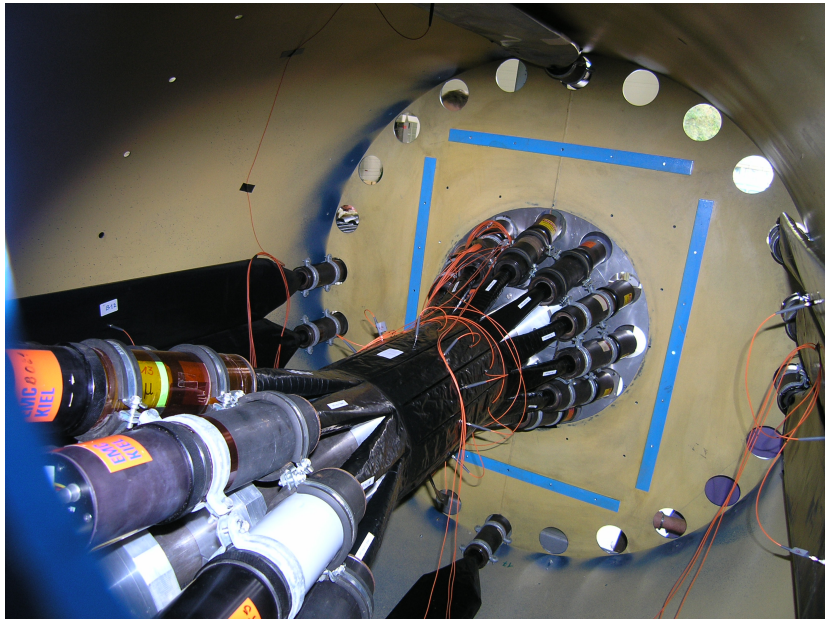
# Recoil Proton Detector

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 $\pi^-$ background
- time resolution $\sigma < 350\,\text{ps}$

# Calibration I

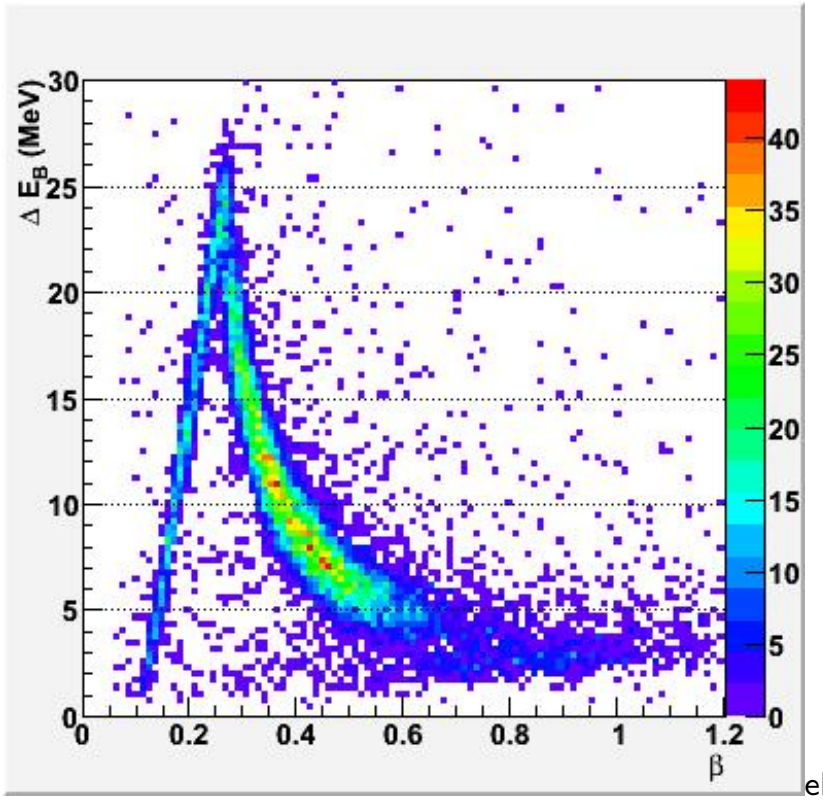
How to come to proton tracks?

- RPD measures **times** and **hits**
- with effective speed of light $\rightarrow$ hit postions
- combine measurements of TOF and positions to calculate angles and $\beta = \frac{v}{c}$
- no magnetic field around the target $\rightarrow$ no direct $p$ measurement
- combine with $E_{loss}$ meas. to obtain $p$
- calibration of energy and TOF necessary

# Calibration II

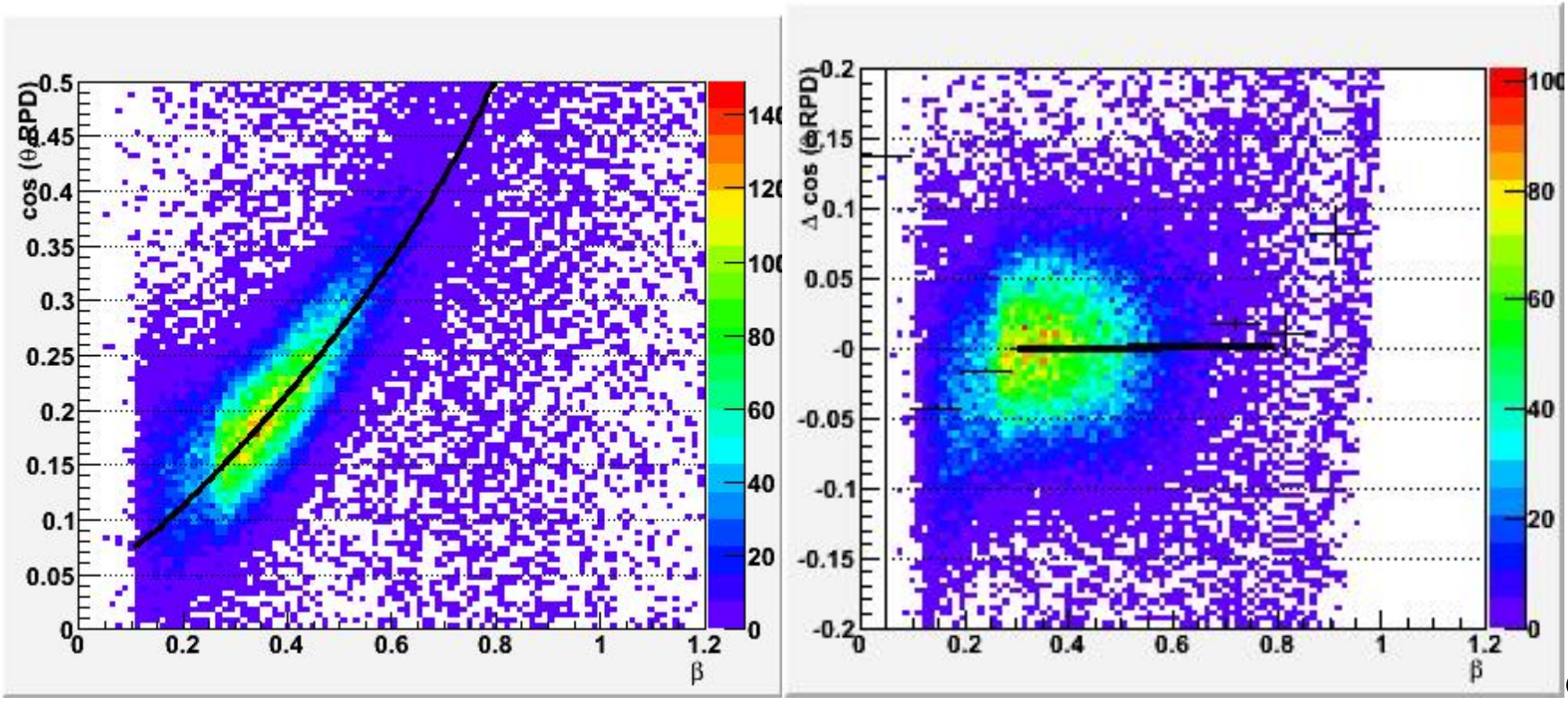
Strategy of calibration:

- test measurements w/ cosmics, $\mu$- and $e^-$ beam to determine eff. speed of light and MIP pulse spectra (HV settings), also energy cal.
- online calibration w/ hadron/$\mu$ on recoil proton signal to set $\beta$ in the correct range
- offline calibration w/ elastic and diffractive events for final tuning




elastic recoil proton signal (rec. data)

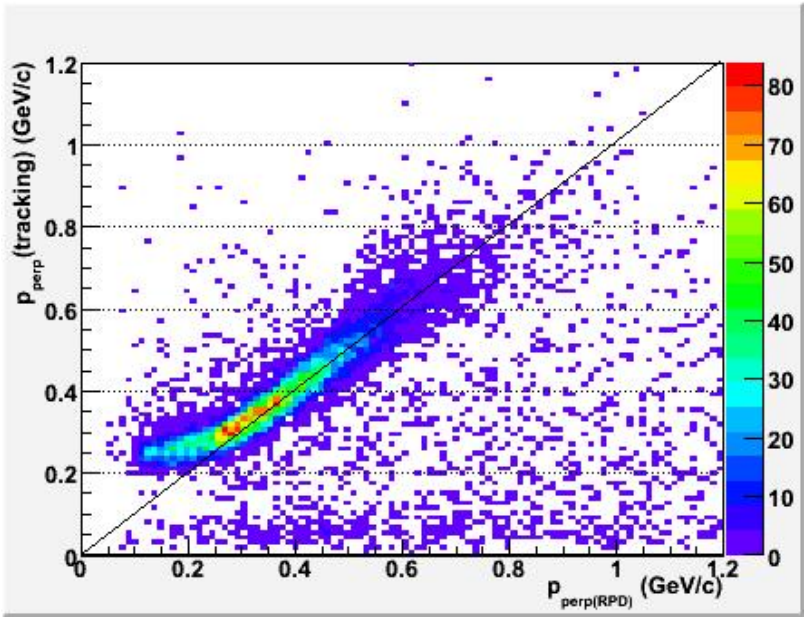
# Calibration III




calibra

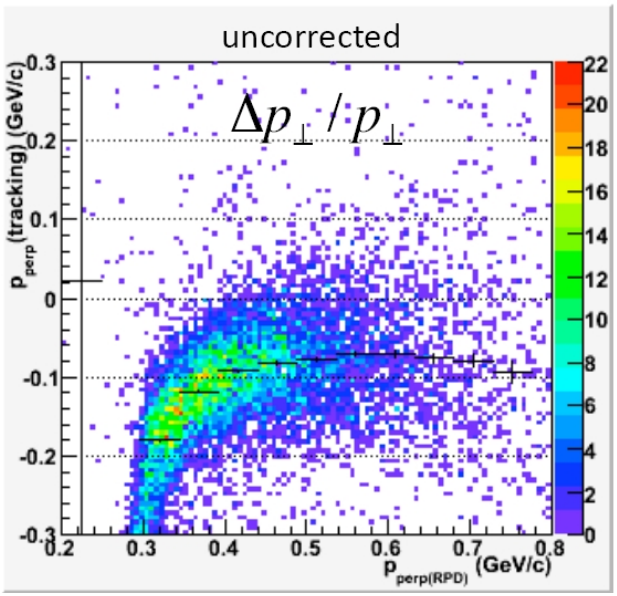
of $\beta$ with elastic events, determine offsets in time and space from position and slope

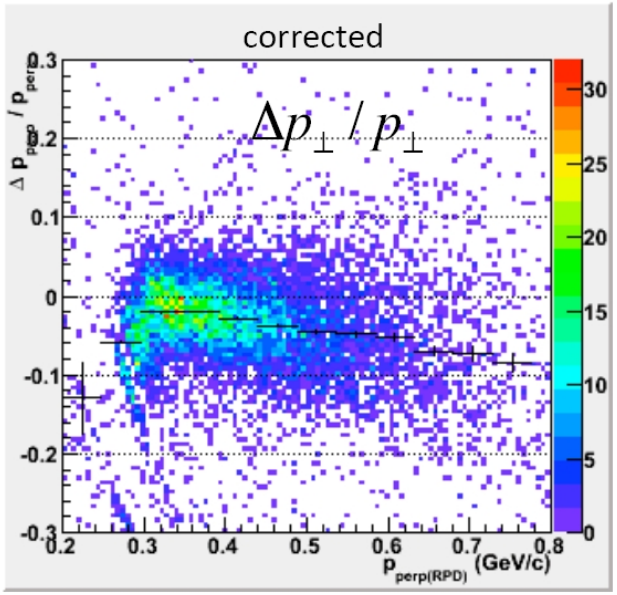
# Calibration IV




correct for second order effects like

- vertex offsets due to no point-like beam (RMS $\approx$ 1cm)
- energy loss in the target material



# Calibration V / MonteCarlo

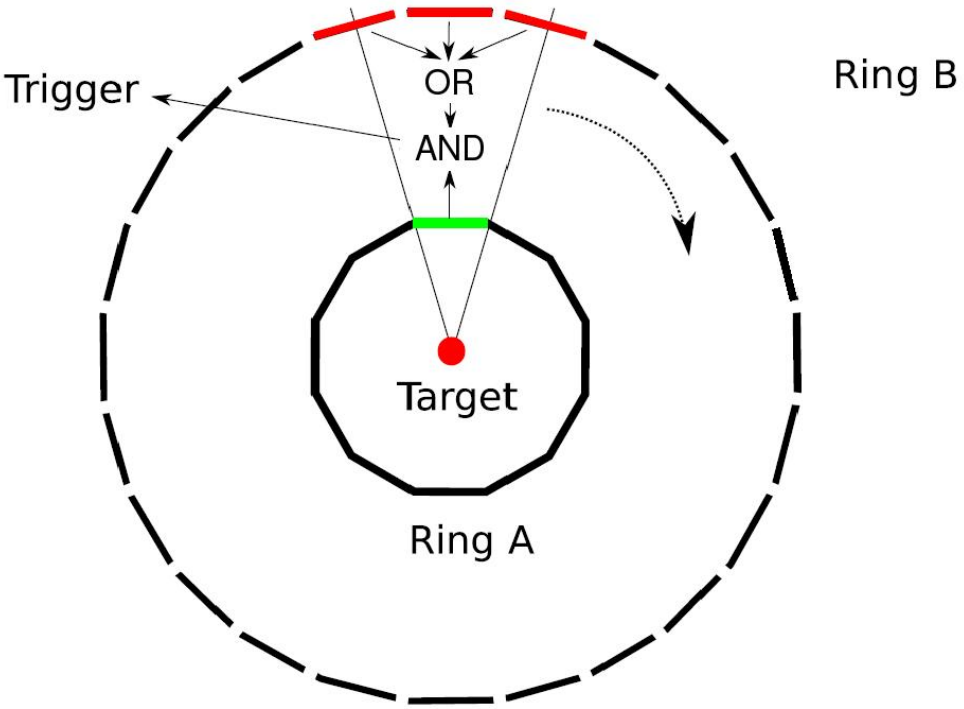
New developments:

- $t_0$ calibration for all channels
- time-dependent calculation of the calibration constants
- automized and transparent calibration
- to be done for all 2008 and 2009 data

MonteCarlo implementation on the way:

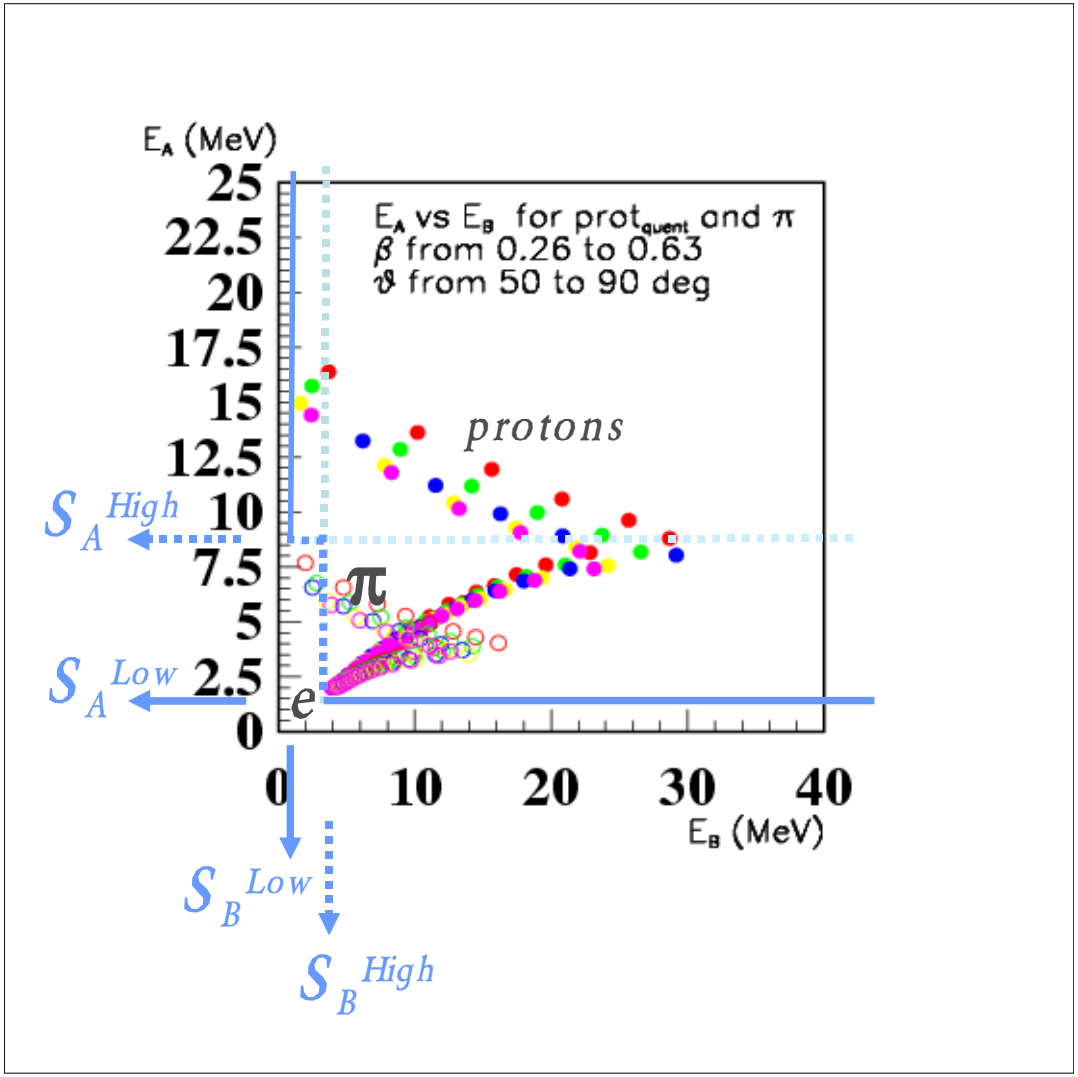
- RPD software group formed
- detector geometry basically finished
- digitization nearly done (Promme)
- detector response on the way
- will be included in the RPDHelper

# 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

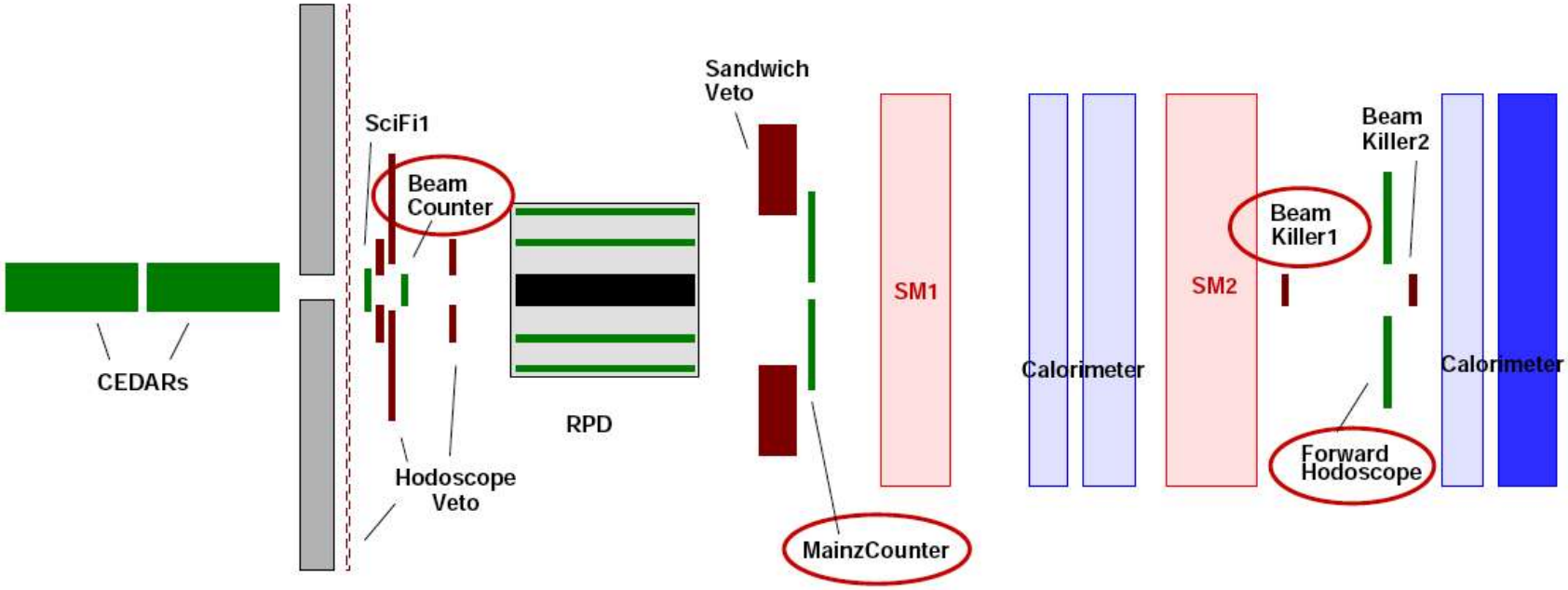
# Proton Trigger




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

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

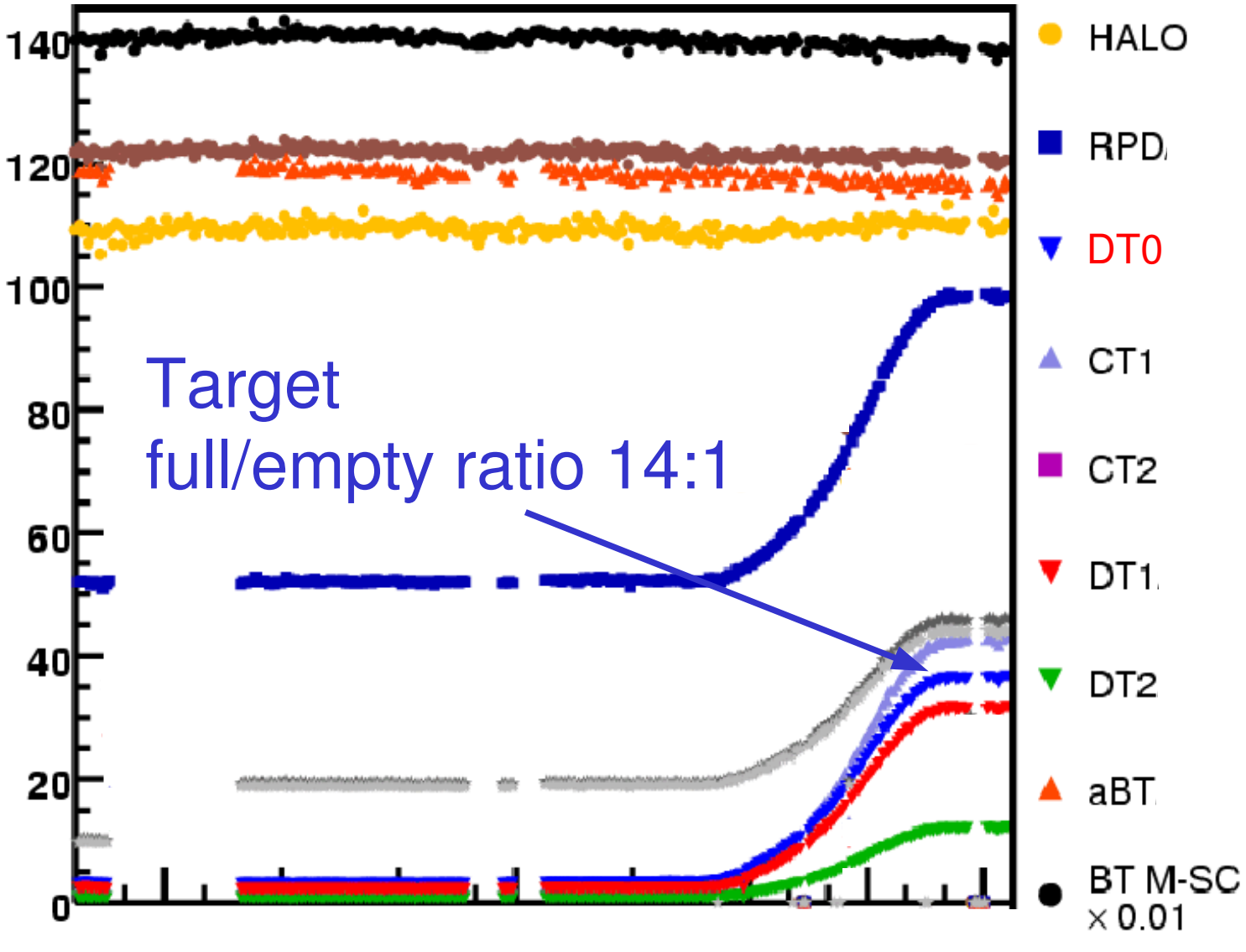
# Physics Trigger




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 $4\pi$ channel

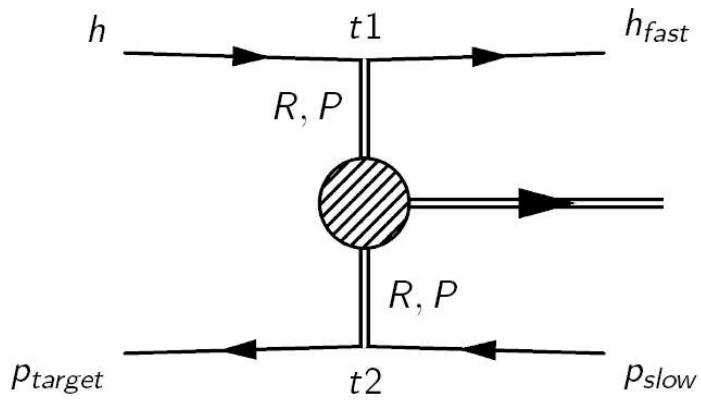
Compass 2008 Run (shown here: 13% of 2008 data)

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

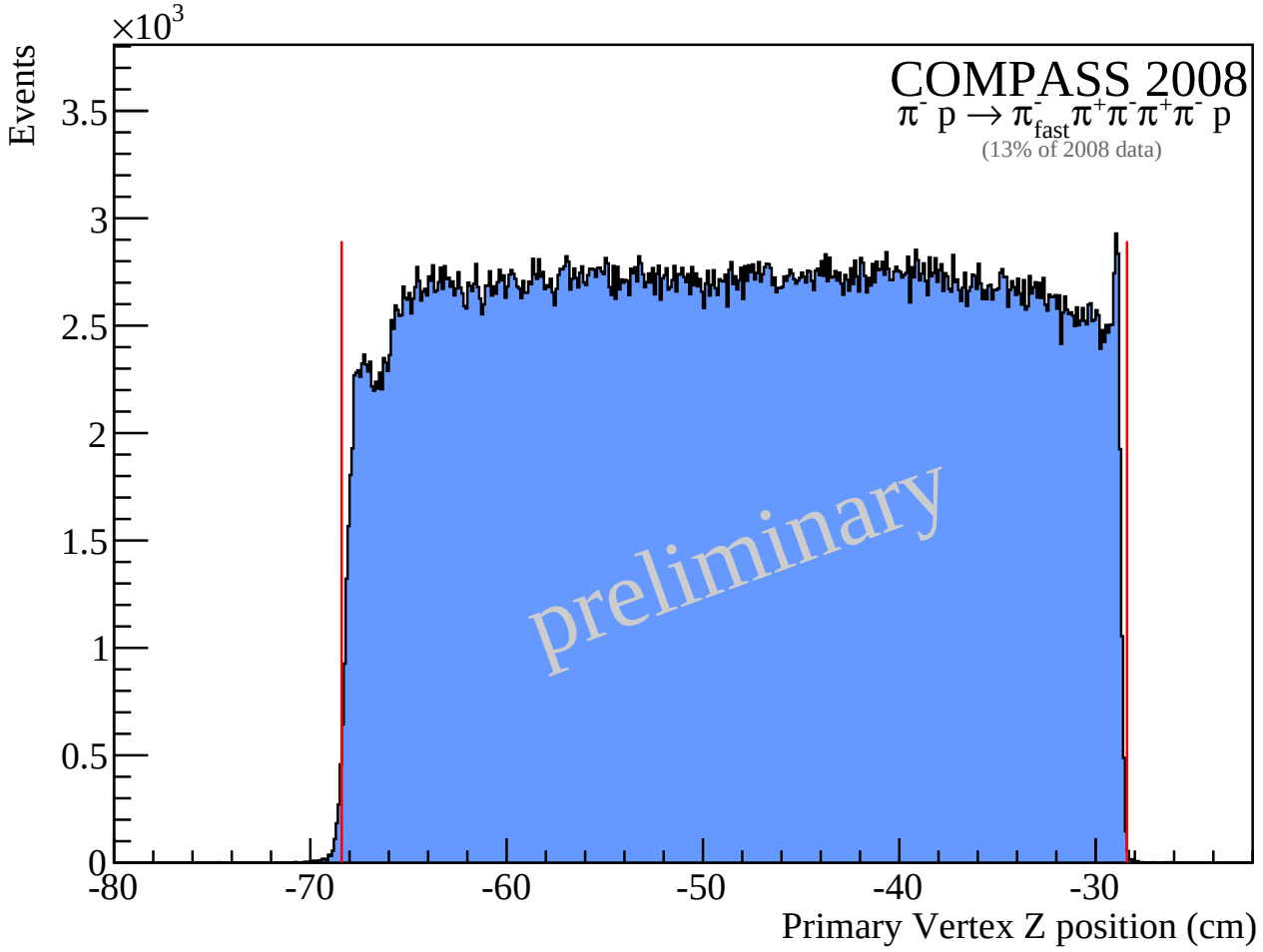
## Cuts:

| 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 $(190 \pm 5)$ GeV | 0.27 |
| $Q_{fast} = -1$ | 0.18 |

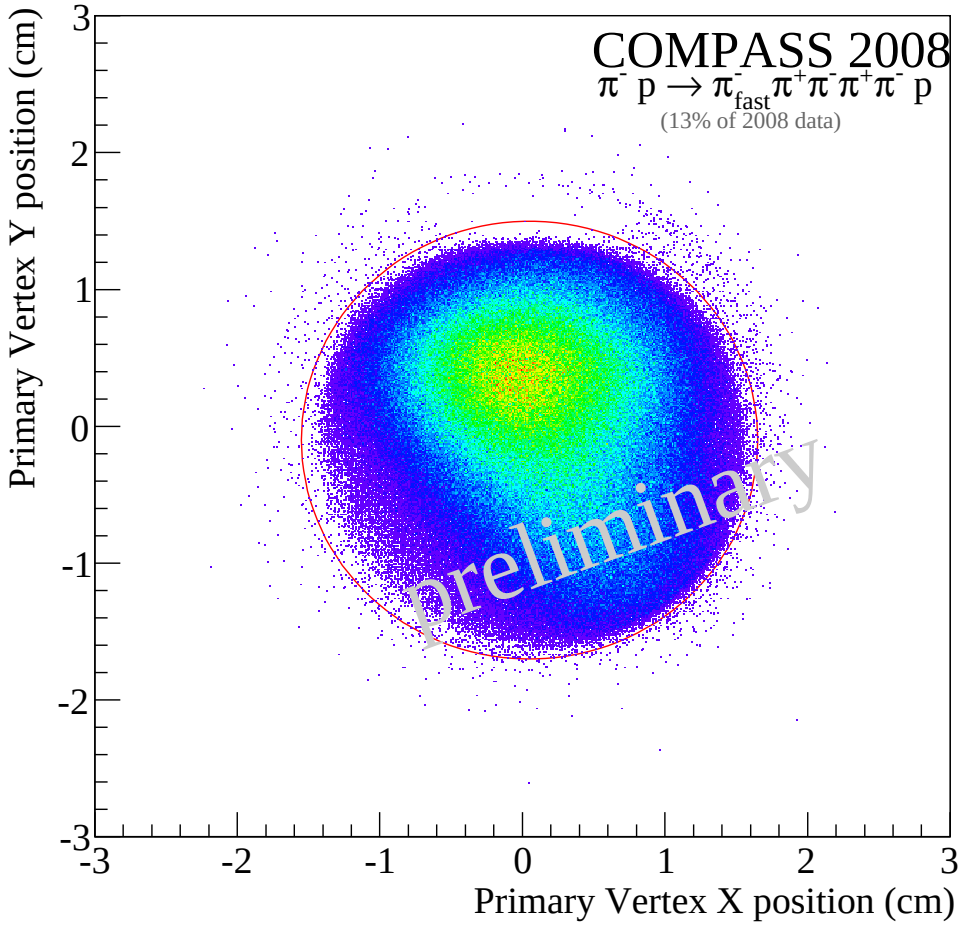
## Central Production:



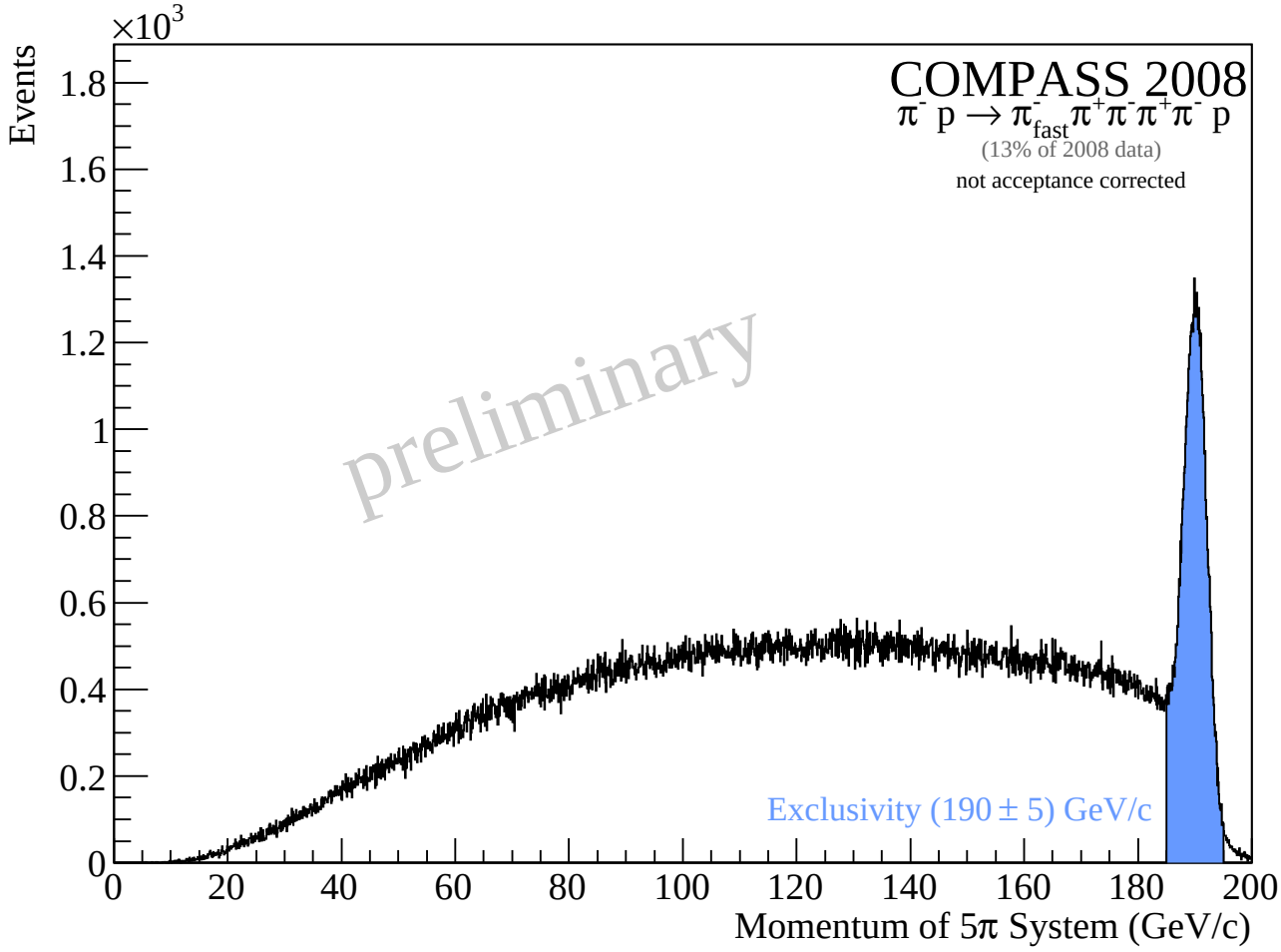
# Vertex Distribution in Z (beam) direction



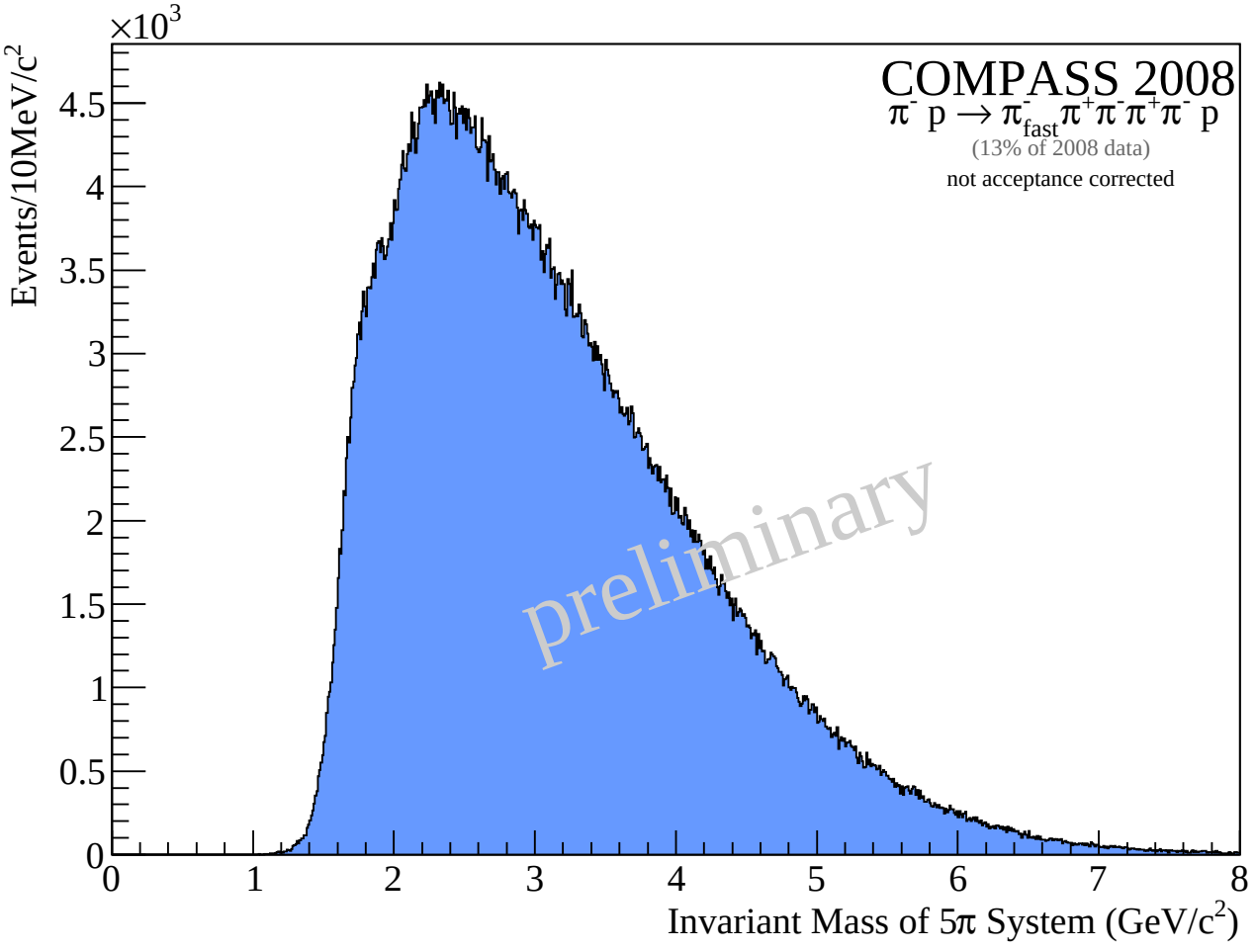
# Vertex Distribution in XY-Plane



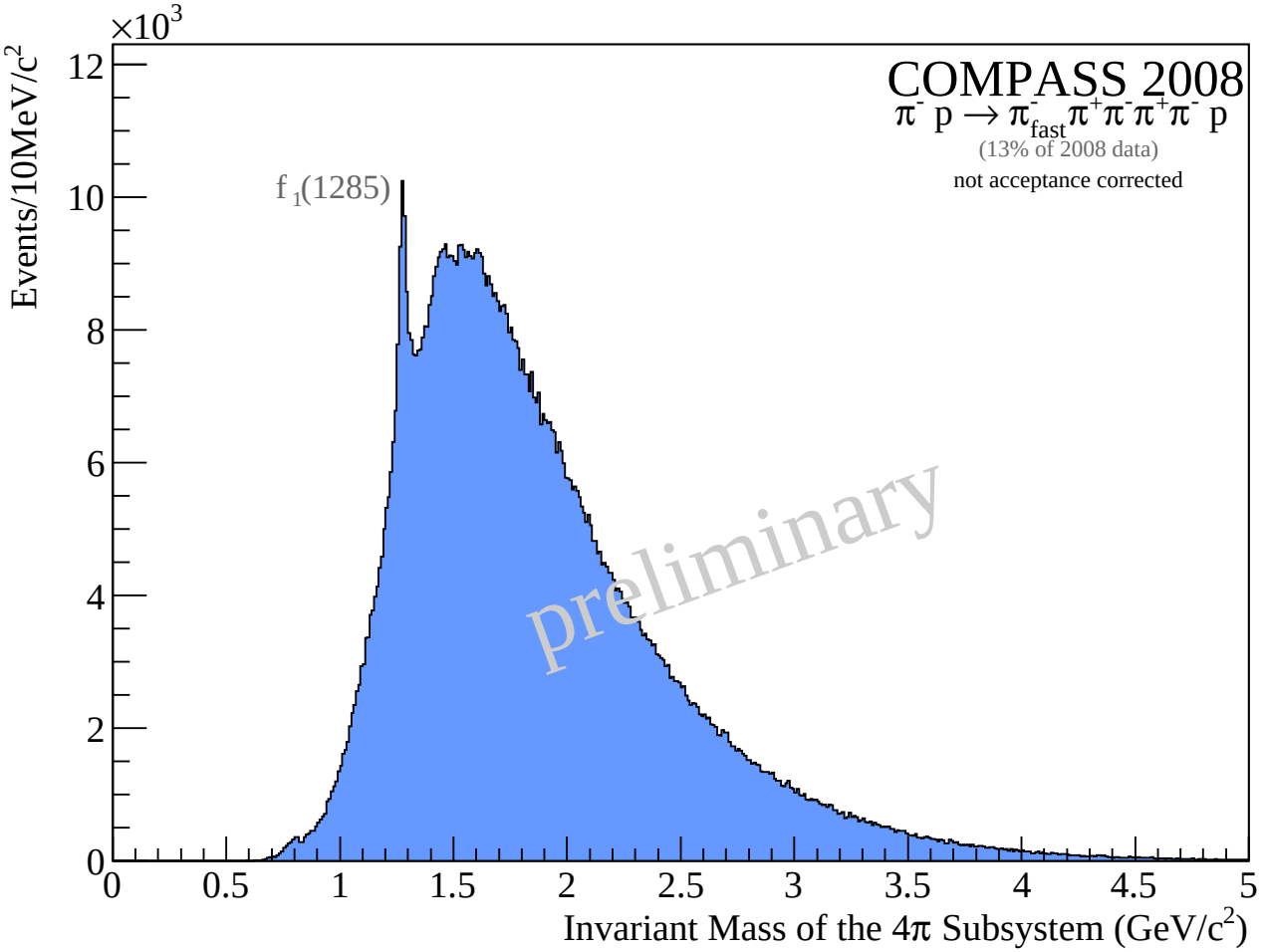
# Exclusivity



# Invariant Mass Distribution ($5\pi$)



# Invariant Mass of 4$\pi$ System

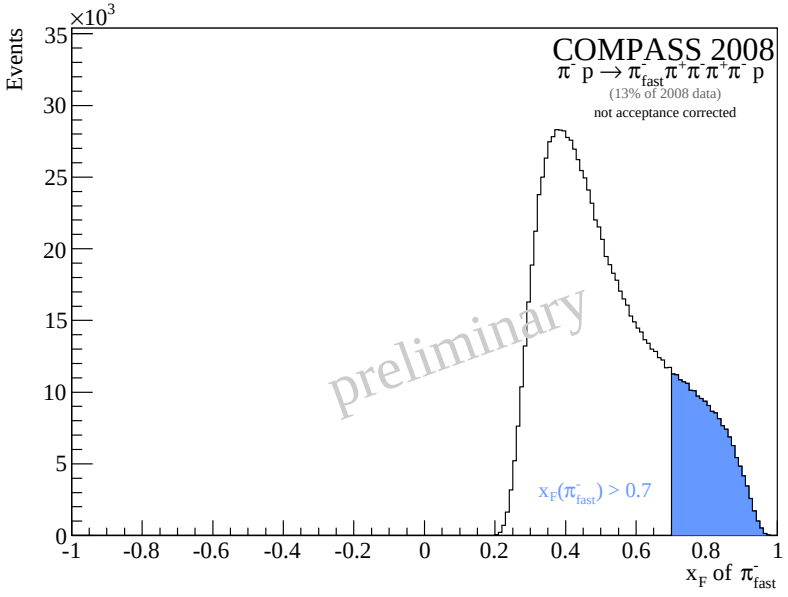


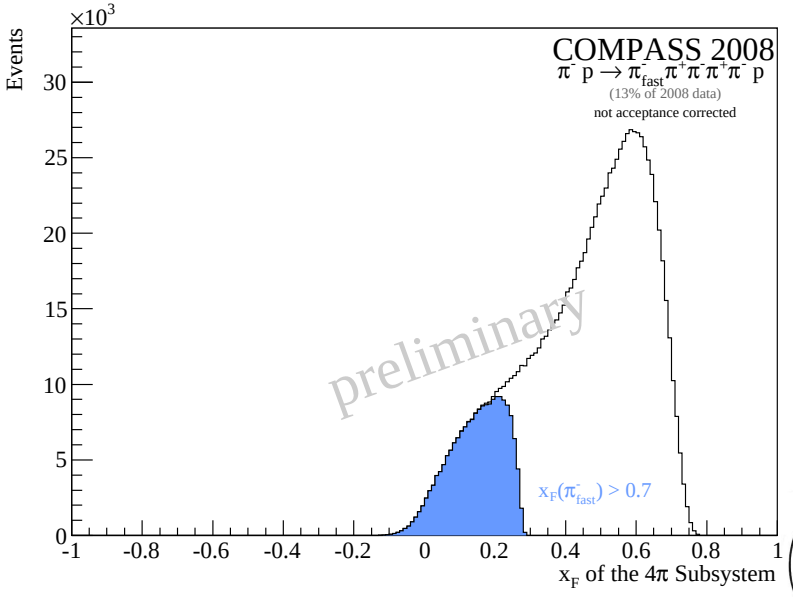
# Enhancement of CP events: xF

## One Approach to Select CP: Feynman $x_F$

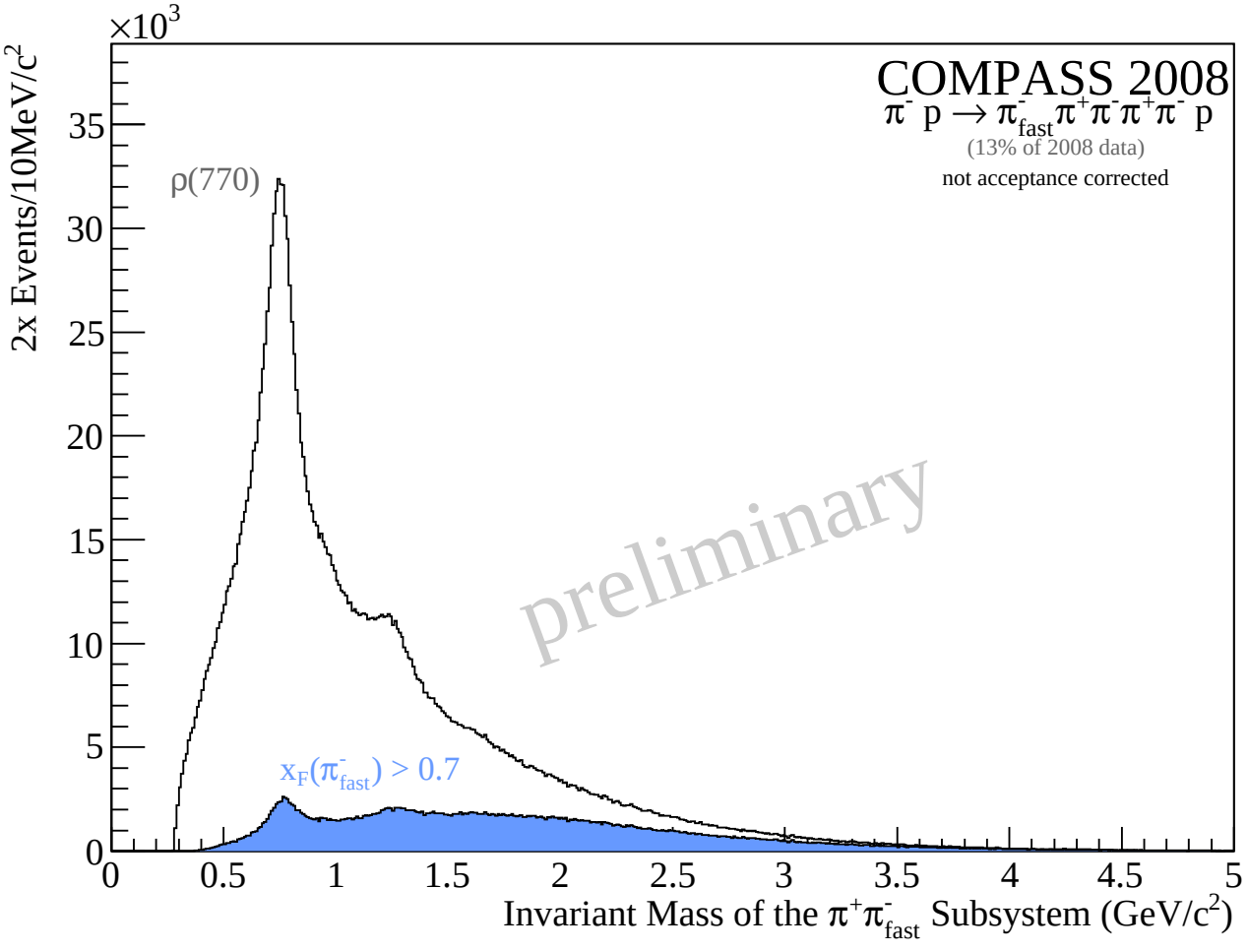
$$x_F = \frac{|\vec{p}_l|}{|\vec{p}_l^{\,max}|} = \frac{2\,|\vec{p}_l|}{\sqrt{s}},$$

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

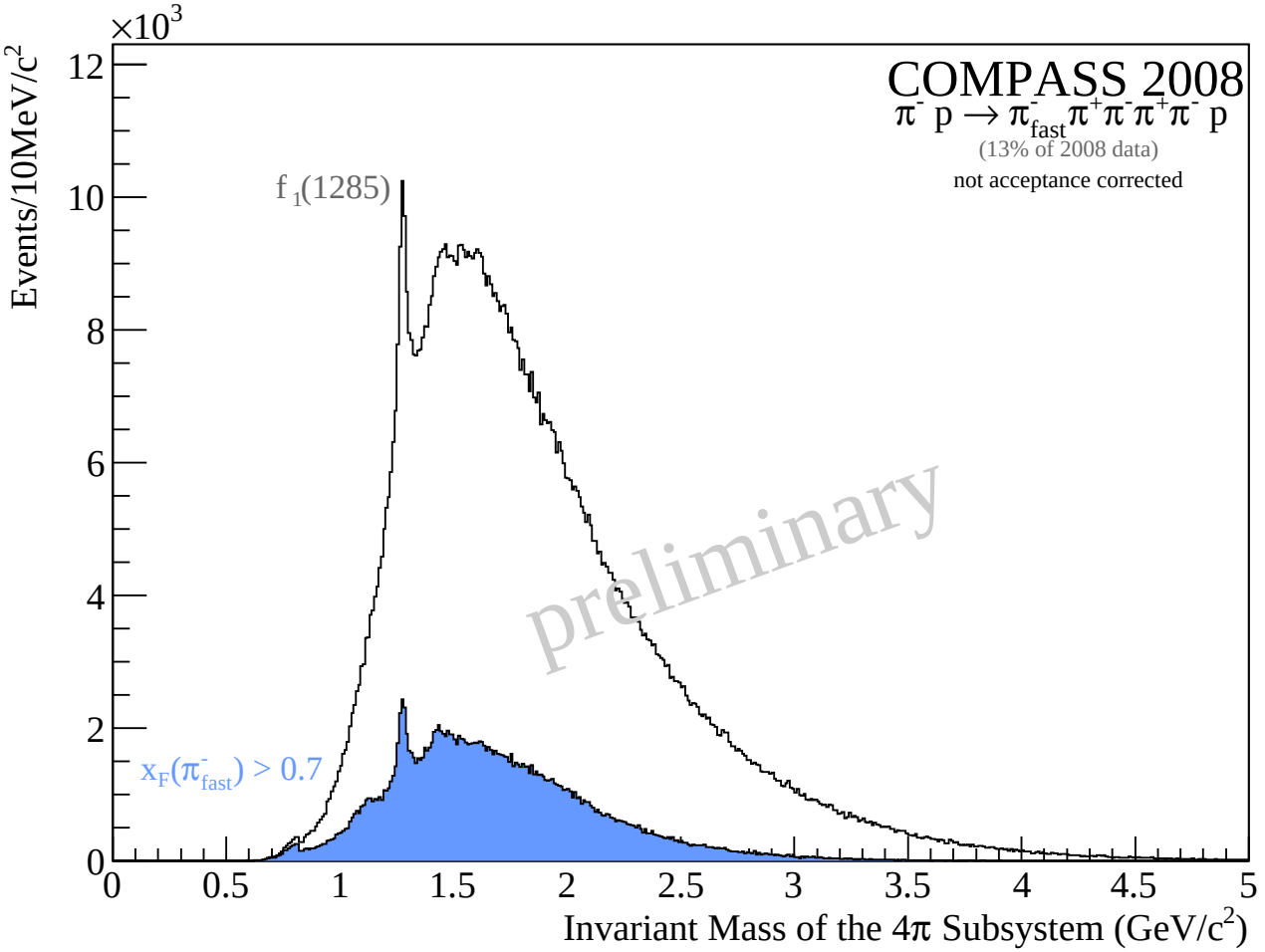


# Invariant Mass of $2\pi$ System with $\pi^-_{fast}$



# Invariant Mass of 4$\pi$ System



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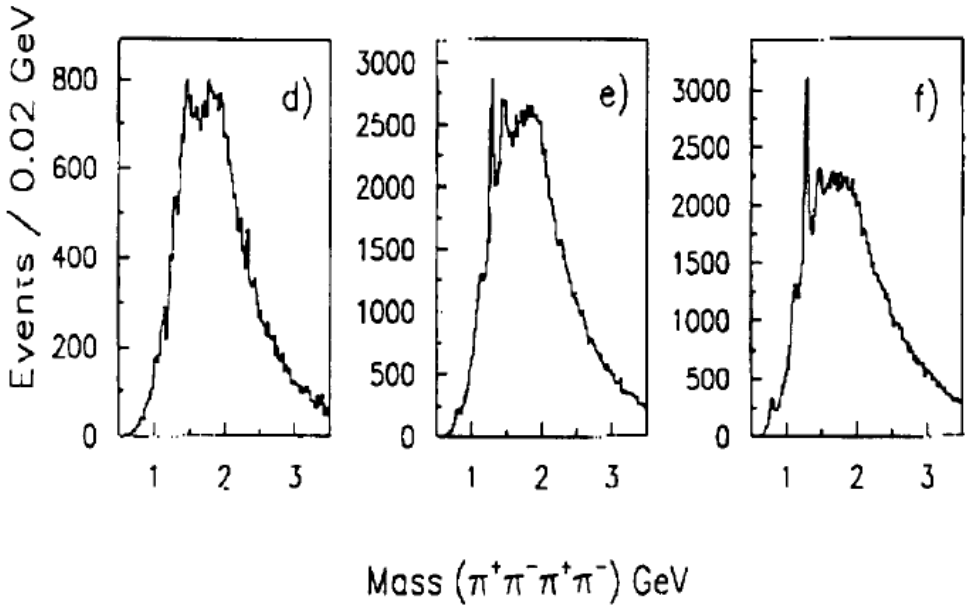
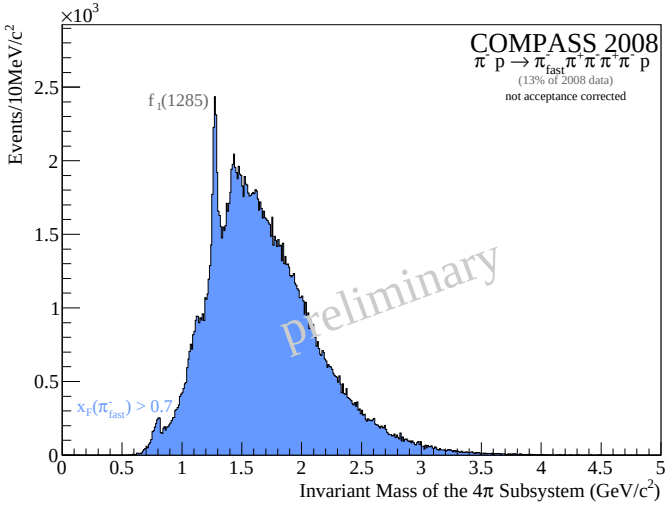



WA102:

d) $dP_t < 0.2$ GeV

e) 0.2 GeV $< dP_t < 0.5$ GeV

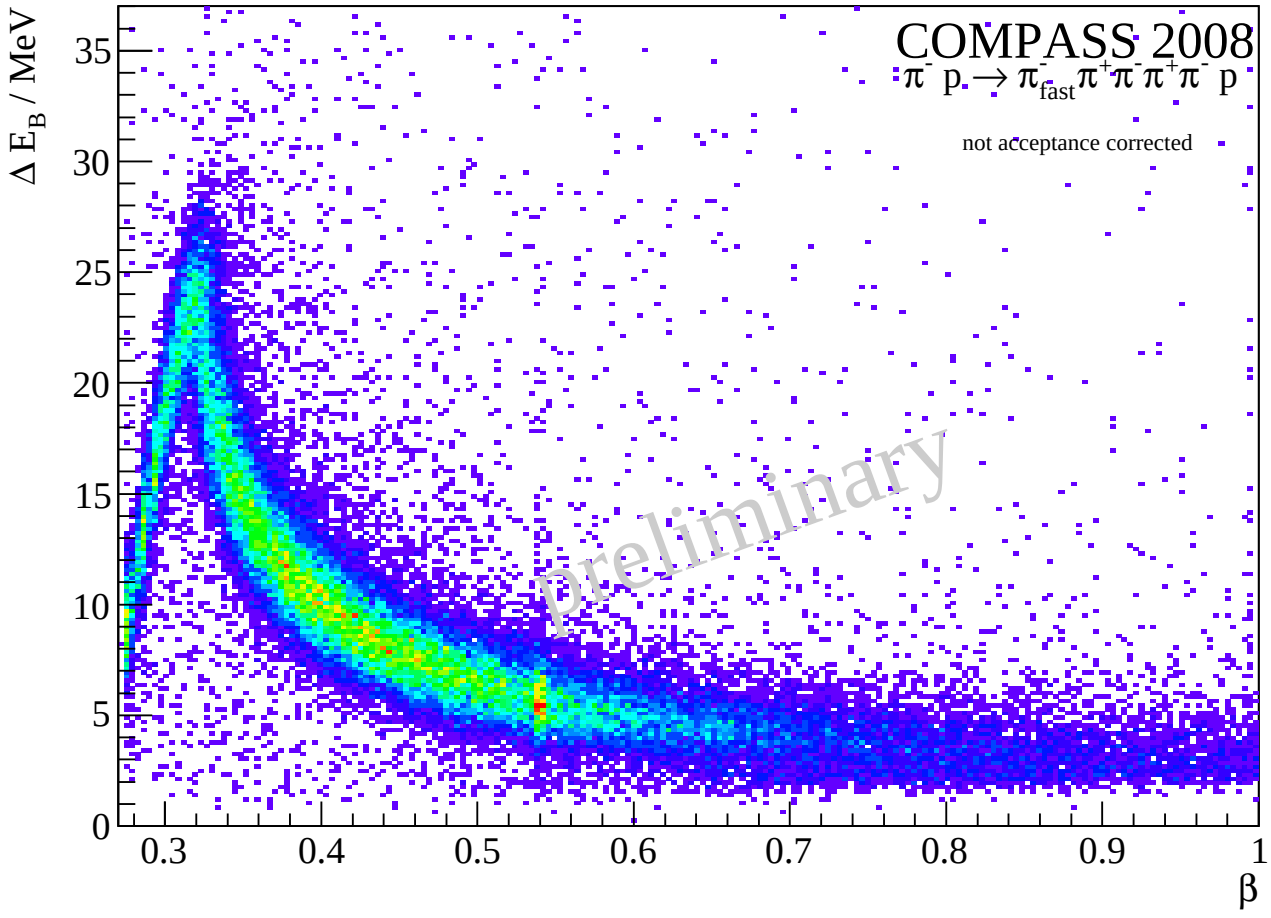
f) $dP_t > 0.5$ GeV

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:

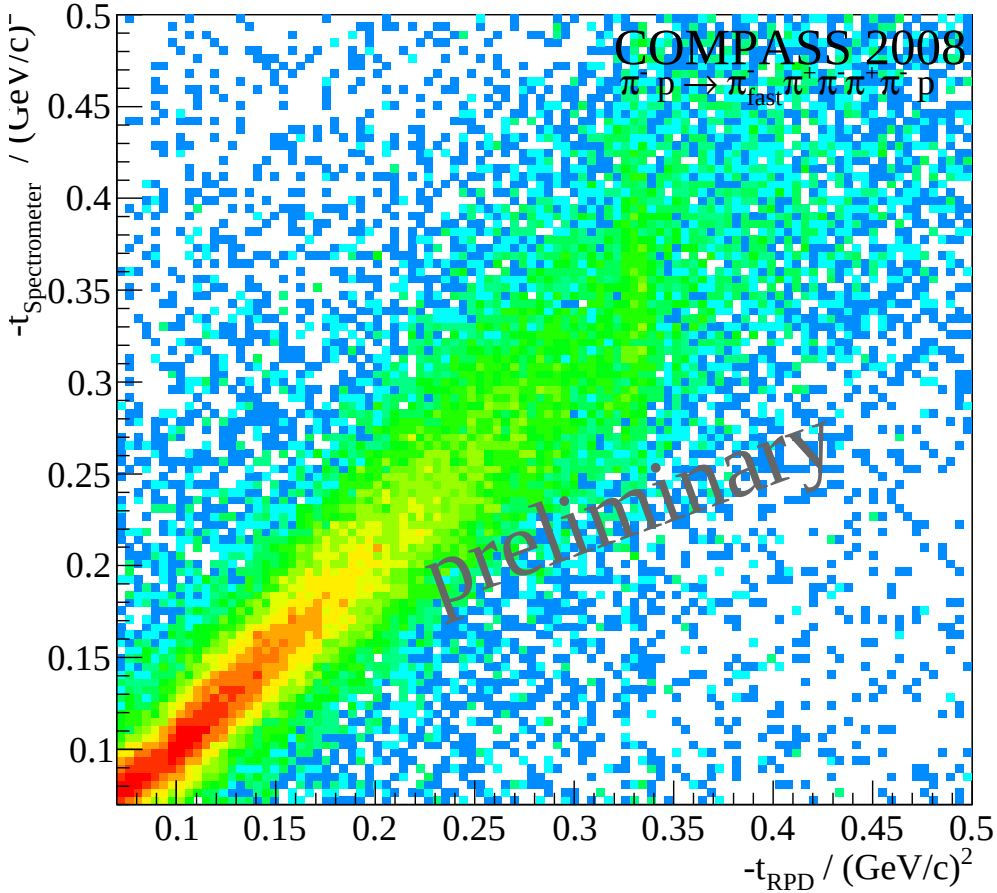
- measures TOF and $dE/dx \rightarrow$ recoil particle momentum and PID



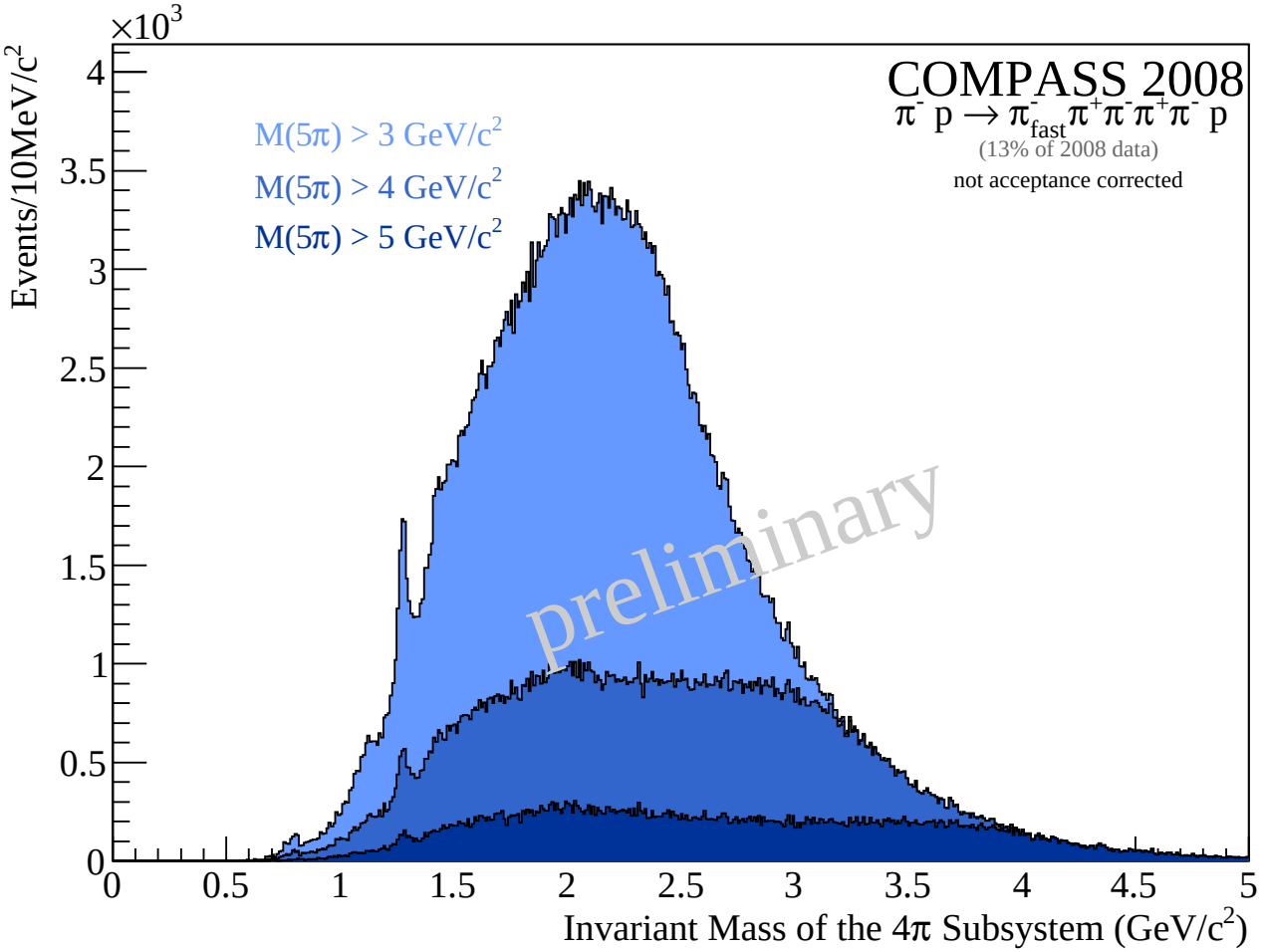
# RPD information

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 $t_2$

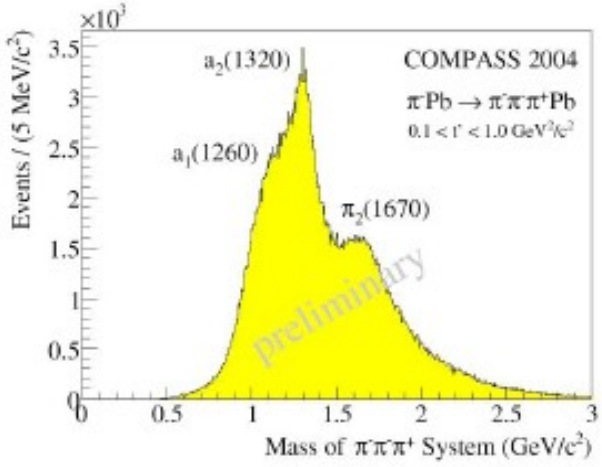


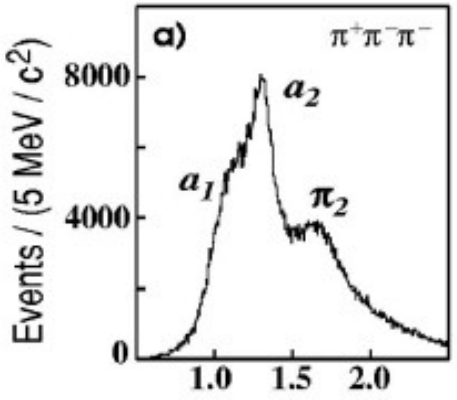
# Different Approach: Cut on M(5$\pi$)

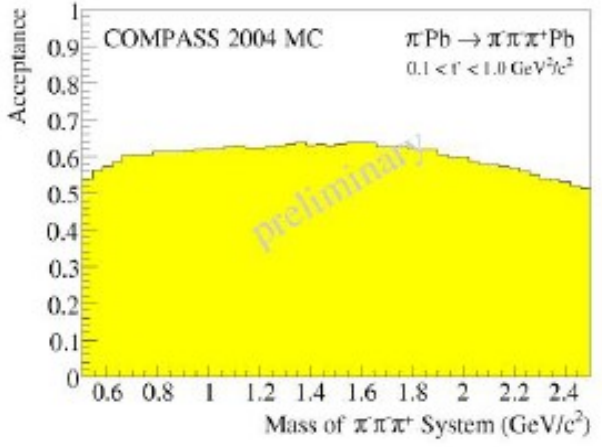


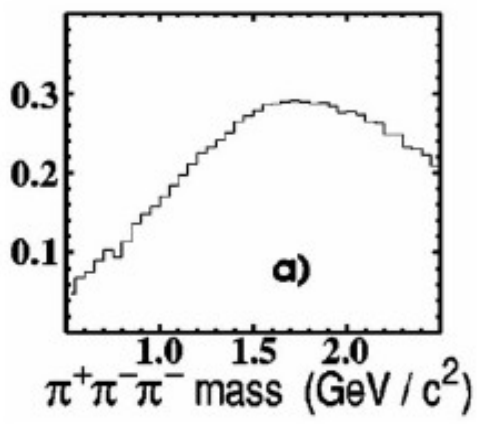
# $3\pi$ analysis (2004 data)

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



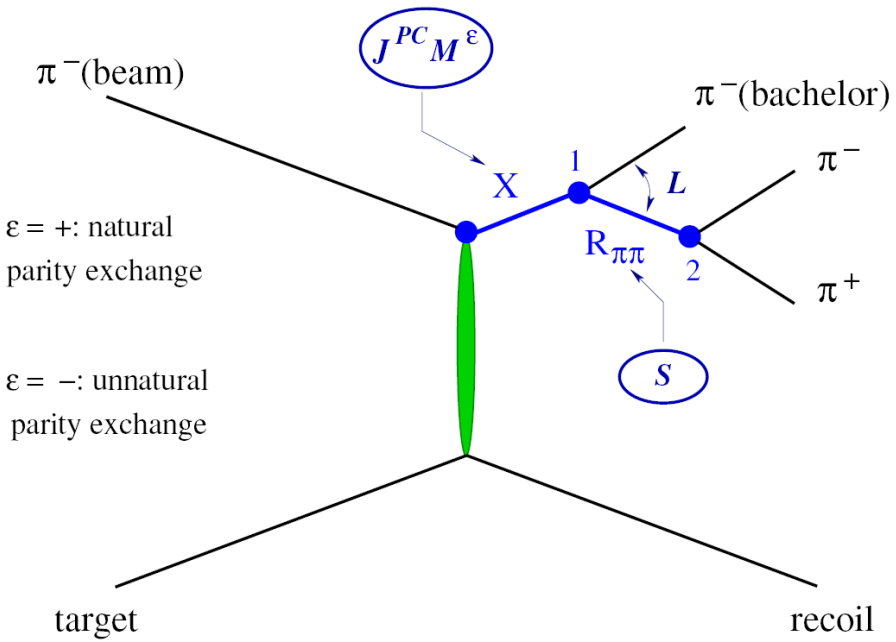




COMPASS 2004 vs. BNL 853

# Selected results: PWA on 2004 $3\pi$ data

Analyse decay in the *isobar model*:

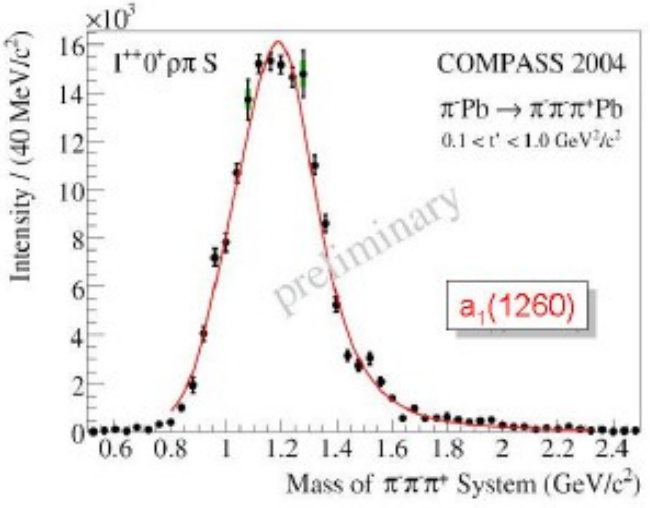


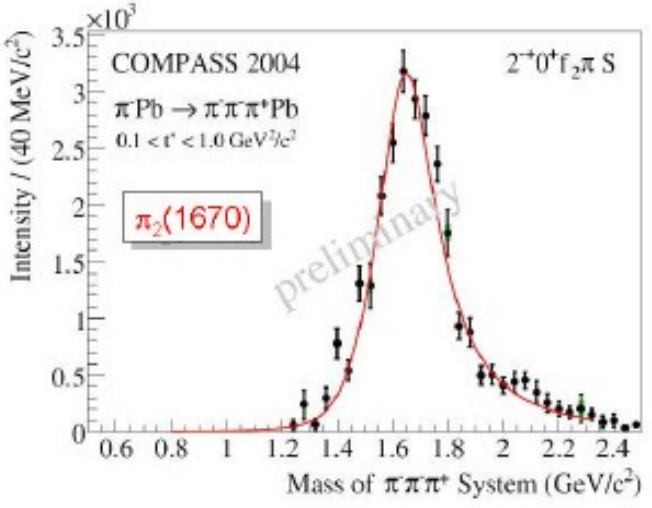

- intermediate two-particle decays
- introduce *reflectivity* basis:
  $M = -L, -L+1, ..., L-1, L$
  $\Rightarrow |M|\epsilon = |M|\text{sgn}(M)$
- amplitudes in the *helicity* formalism:
  expand to D-Functions

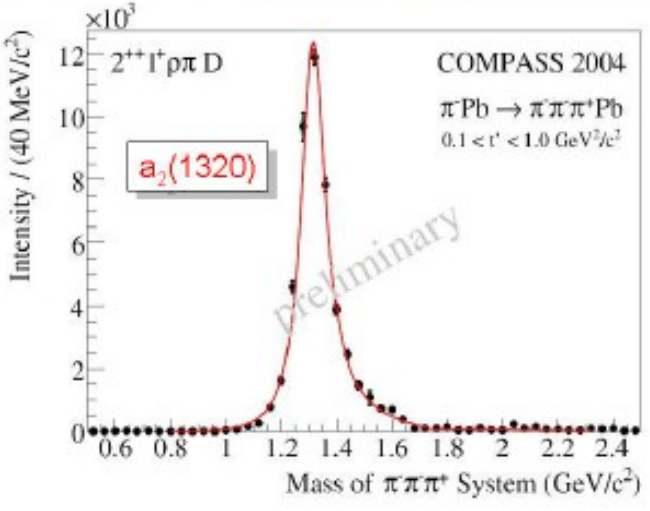
two-step-fit:

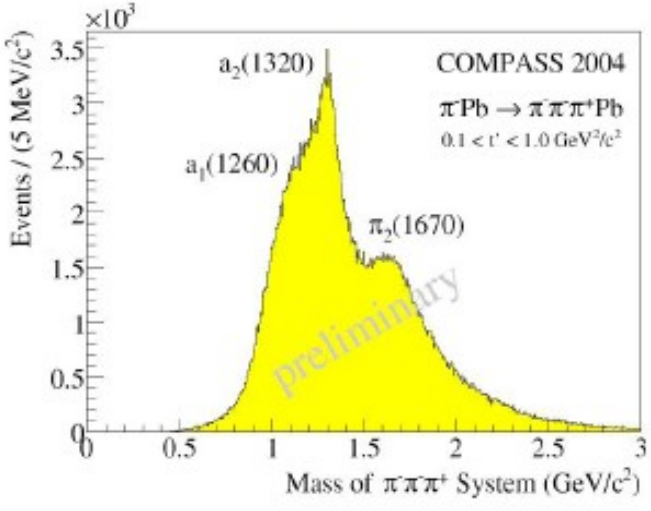
1. Mass-independent PWA in $40 MeV/c^2$ bins
   - extended log-Likelihood fit with an extended set of waves (42)
   - acceptance corrected
2. Mass-dependent $\chi^2$ fit
   - contains the 6 dominant waves
   - Breit-Wigner parametrization of the resonances

# PWA results



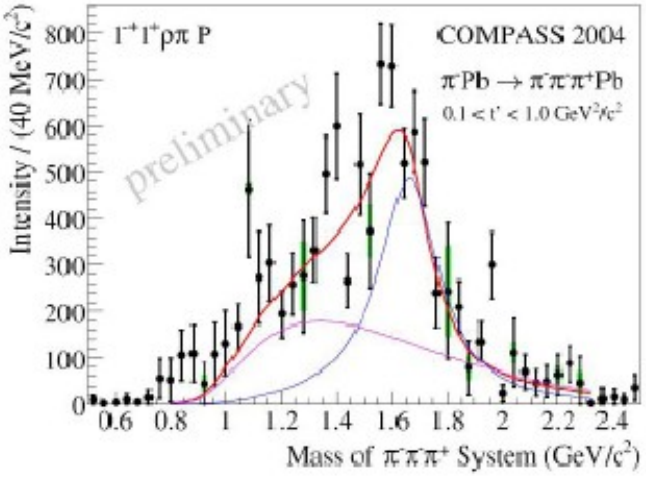



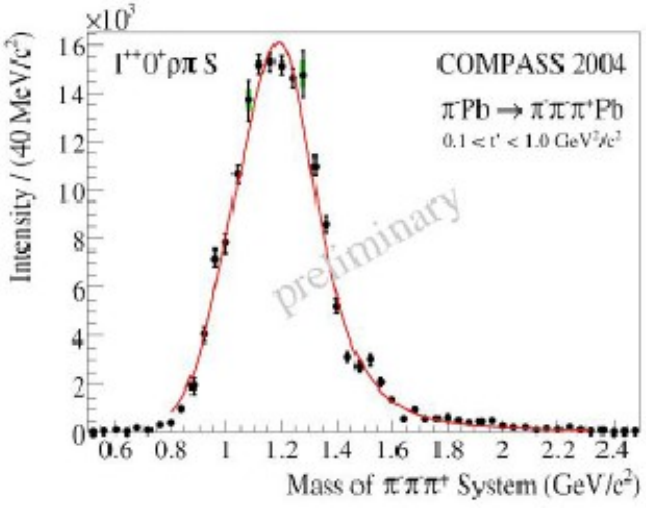



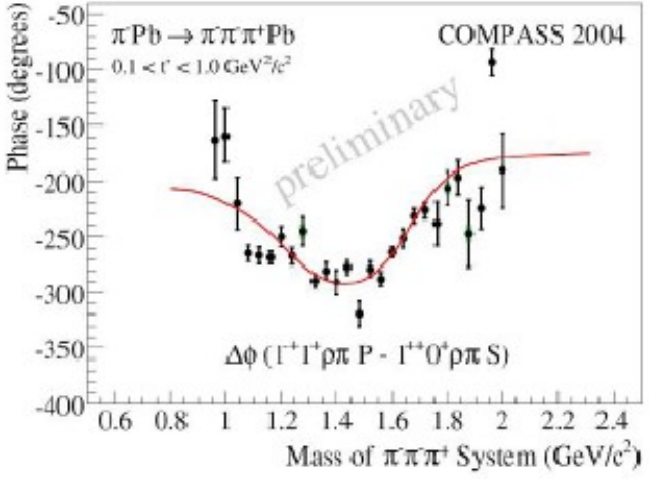




major waves

# PWA results

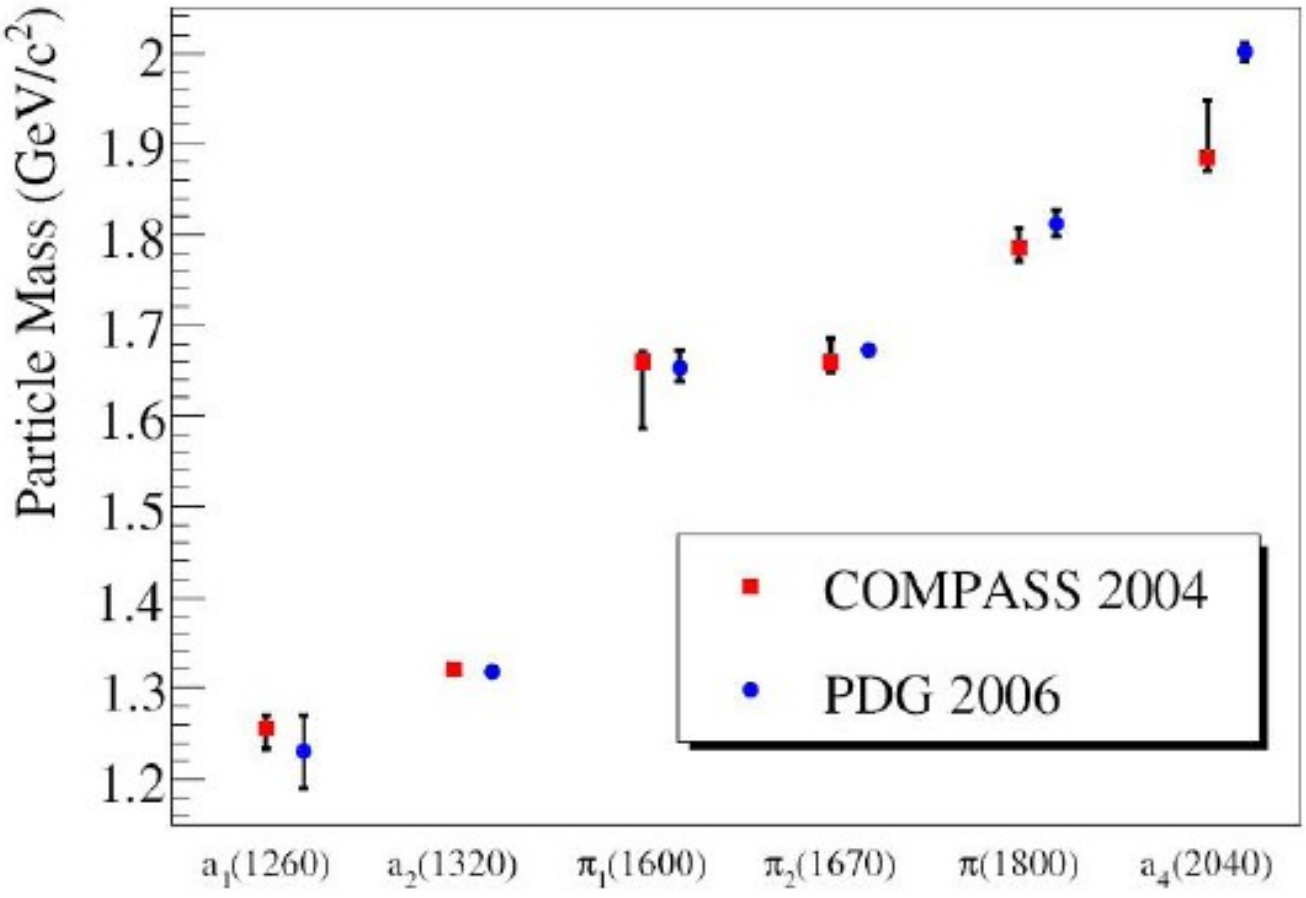



exotic $1^{-+}$

# PWA results

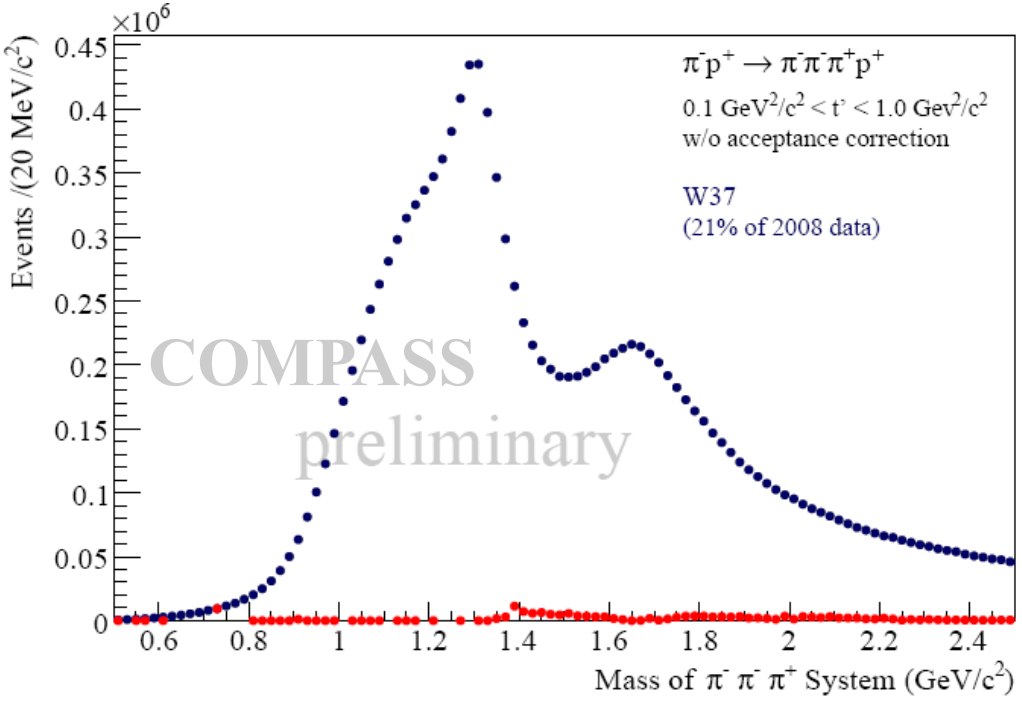



summary

# Selected results

Results for the $3\pi$ 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