Measurement of the Pion Polarisability at COMPASS

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for the COMPASS collaboration

HADRON07 Frascati
October 2007

bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen Grundlagenforschung

COMPASS

Outline

- Compton scattering and polarisabilities
  - Motivation
  - Related processes for unstable particles
  - Primakoff kinematics
- The COMPASS 2004 pilot hadron run
- Data analysis and preliminary results

Hadron structure

- How are hadrons built up in terms of their constituents?

  Static properties $\Leftrightarrow$ form factors

Hadron structure

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  Static properties $\Leftrightarrow$ form factors

- How do hadrons react to (small) external fields?

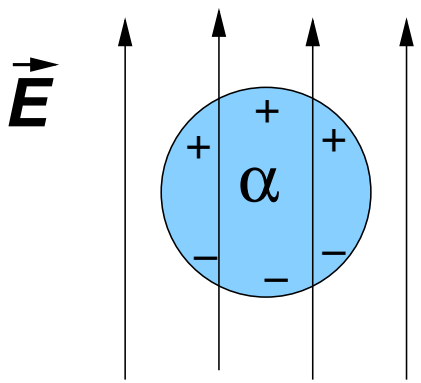
  Non-pointlike response $\Leftrightarrow$ polarisabilities

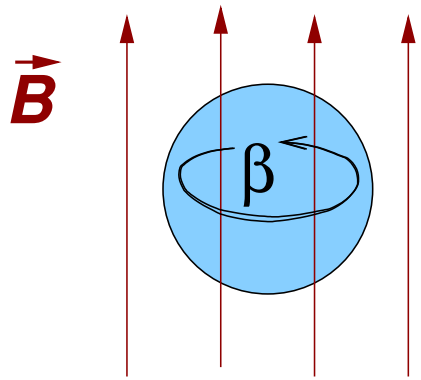
classical

$$\vec{d} = (eZ)2\vec{\ell} = \alpha\vec{E}$$

$$K\vec{\ell} = (eZ)\vec{E}$$

$$\alpha = \frac{2(eZ)^2}{K}$$

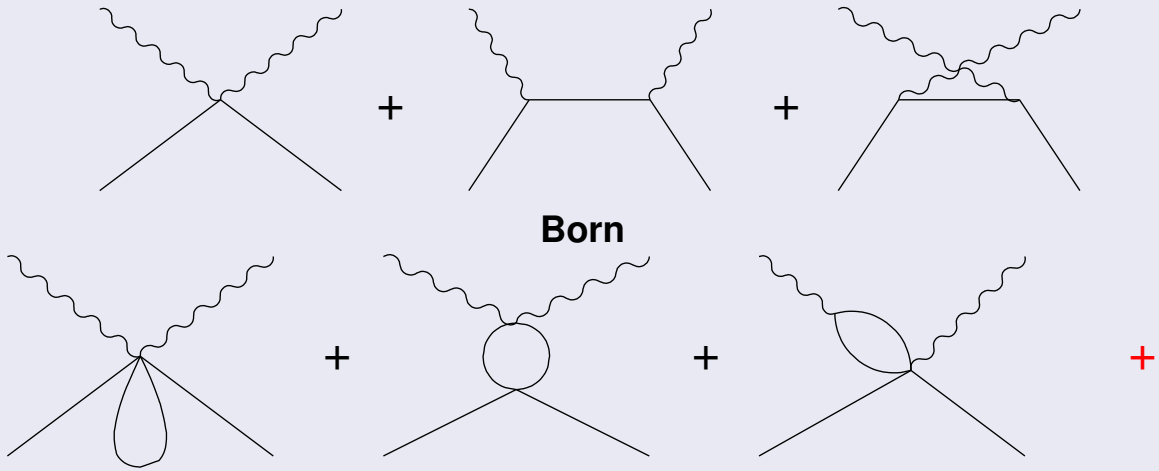




Compton scattering

- for point-like target completely determined by QED
- polarisability contribution starting at $\mathcal{O}(E_\gamma)$ (for spin-$\frac{1}{2}$)

Pion case



$$\mathcal{M} \propto \left(-\frac{\alpha}{m_\pi} + \alpha_\pi \cdot \omega_1\omega_2\right) \vec{\epsilon}_1 \cdot \vec{\epsilon}_2 + \beta_\pi \cdot (\vec{q}_1 \times \vec{\epsilon}_1) \cdot (\vec{q}_2 \times \vec{\epsilon}_2)$$

Meson Polarisabilities

Pion

- Low-energy expansion of QCD: Chiral perturbation theory

  Pion has a special role as the Goldstone boson
  (massless in the chiral limit)

- are the basic features correctly described?

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ChPT 1-loop for $\pi^{\pm}$

$$\begin{aligned} \alpha_\pi + \beta_\pi &= 0 \\ \alpha_\pi - \beta_\pi &= \frac{8\alpha_{em}}{m_\pi f_\pi^2}\left(L_9^r + L_{10}^r\right) \\ &= +5.4 \pm 0.8 \cdot 10^{-4}\mathrm{fm}^3 \end{aligned}$$

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ChPT 2-loop for $\pi^{\pm}$

$$\alpha_\pi + \beta_\pi = 0.2 \pm 0.1 \cdot 10^{-4} \text{fm}^3$$
$$\alpha_\pi - \beta_\pi = 5.7 \pm 1.0 \cdot 10^{-4} \text{fm}^3$$

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Dispersion sum rules $\pi^{\pm}$

$$\alpha_\pi + \beta_\pi = 0.39 \pm 0.4 \cdot 10^{-4}\text{fm}^3$$
$$\alpha_\pi - \beta_\pi \approx 10 \cdot 10^{-4}\text{fm}^3$$

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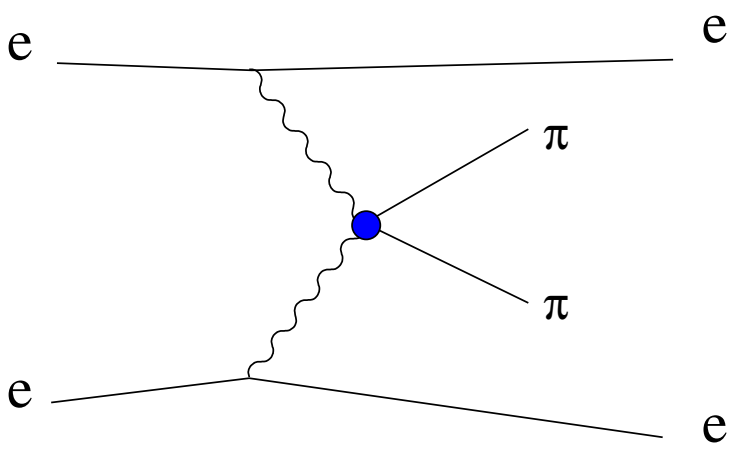
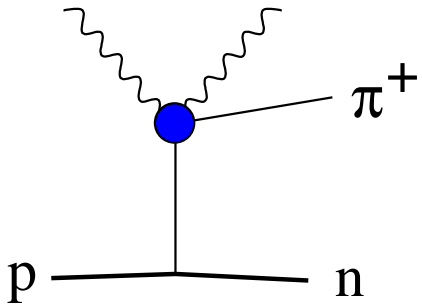
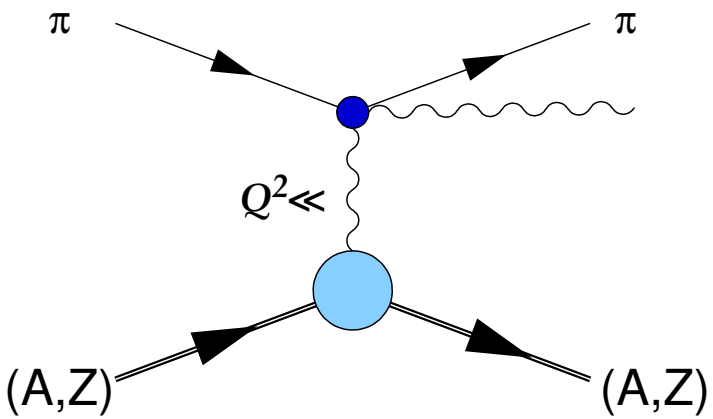
Kaon

- Higher mass $\Leftrightarrow$ smaller polarisability by a factor ~ 5
- theoretically very exciting – need for experimental data!

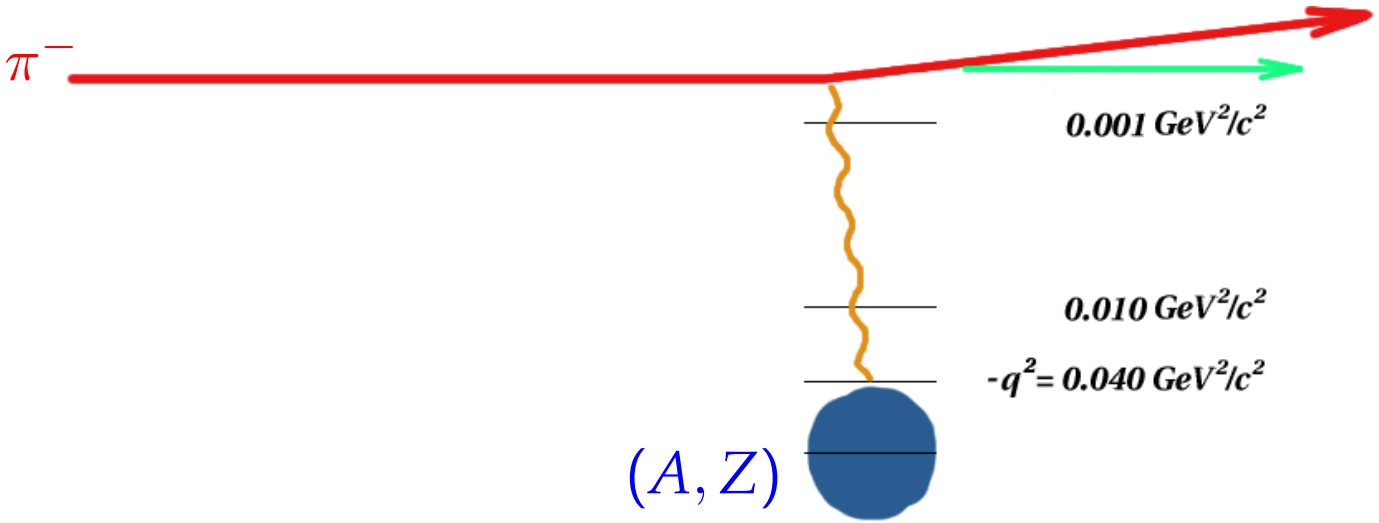
Compton scattering on unstable particles







Pion-nucleus scattering at small Q^2



$\pi + Pb \rightarrow X^- + Pb$

diffractive scattering:
$\rightarrow$ meson spectroscopy
$\rightarrow$ exotics

$Q^2 < 0.001\ \mathrm{GeV}^2/c^2$

- $\pi + \gamma^{(*)} \rightarrow \pi' + \pi^0$
- $\pi + \gamma^{(*)} \rightarrow \pi' + \gamma$
  Primakoff reaction
  $\rightarrow$ pion polarisability

Polarisability Extraction

E_γ dependence assuming $\beta_\pi + \alpha_\pi = 0$

$$\frac{d\sigma_{Prim}}{dE_\gamma} = \frac{d\sigma_{pl}}{dE_\gamma} + \frac{d\sigma(\alpha_\pi, \beta_\pi)}{dE_\gamma} = \frac{d\sigma_{pl}}{dE_\gamma} + \frac{d\sigma(\beta_\pi)}{dE_\gamma} =$$

$$= \frac{4Z^2\alpha^3}{m_\pi^2} \cdot \frac{E_{\pi'}}{E_{Beam}E_\gamma} \cdot \left(\frac{2}{3} \ln \frac{Q^2_{max}}{Q^2_{min}} - \frac{19}{9} + 4\sqrt{\frac{Q^2_{min}}{Q^2_{max}}} \right) +$$

$$+ \frac{4Z^2\alpha^3}{m_\pi^2} \cdot \frac{E_\gamma}{E^2_{Beam}} \cdot \frac{\beta_\pi m_\pi^3}{\alpha} \cdot \left(\ln \frac{Q^2_{max}}{Q^2_{min}} - 3 + 4\sqrt{\frac{Q^2_{min}}{Q^2_{max}}} \right)$$

$$Q_{min} = \frac{E_\gamma m_\pi^2}{2E_{Beam}E_{\pi'}}$$

$$\omega = \frac{E_\gamma}{E_{Beam}}$$

Ratio $R_\pi = d\sigma_{Prim}/d\sigma_{pl}$

$$R_\pi(\omega) \approx 1 + \frac{3}{2} \cdot \frac{m_\pi^3}{\alpha} \cdot \frac{\omega^2}{1-\omega} \beta_\pi$$

Data on the Pion Polarisability

	$\alpha_\pi + \beta_\pi$ $[10^{-4}\,\mathrm{fm}^3]$	$\alpha_\pi - \beta_\pi$ $[10^{-4}\,\mathrm{fm}^3]$
Bürgi/Gasser (ChPT)	0.2 ± 0.1	5.7 ± 1.0
$e^+e^- \to e^+e^-\pi^+\pi^-$		
Mark II	$0.22 \pm 0.07 \pm 0.04$	4.8 ± 1.0
CELLO	$0.33 \pm 0.06 \pm 0.01$	
$\gamma p \to n\pi^+\gamma$		
MAMI		$11.6 \pm 1.5 \pm 3.0 \pm 0.5$
$\pi^- Z \to Z\pi^-\gamma$		
Serpukhov	$1.8 \pm 3.1 \pm 2.5$	12.3 ± 2.6
COMPASS	?	?

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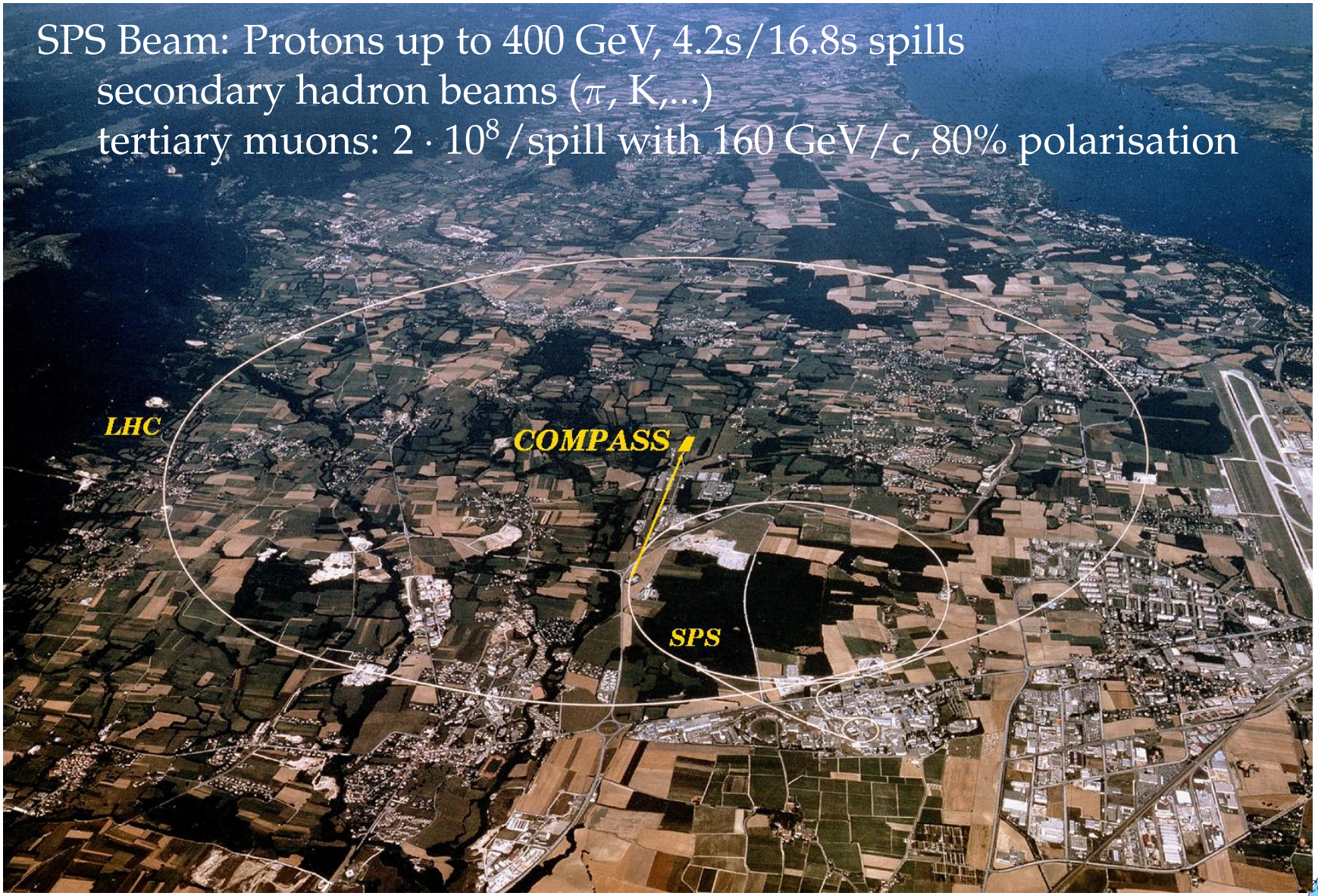
COMPASS	?	?

- different reactions with different systematics
- challenging measurements
- no coherent picture of pion polarisability yet

CERN aerial view



COMPASS Collaboration

Czech Republic, France, Germany, India, Israel,
Italy, Japan, Poland, Portugal, Russia, CERN

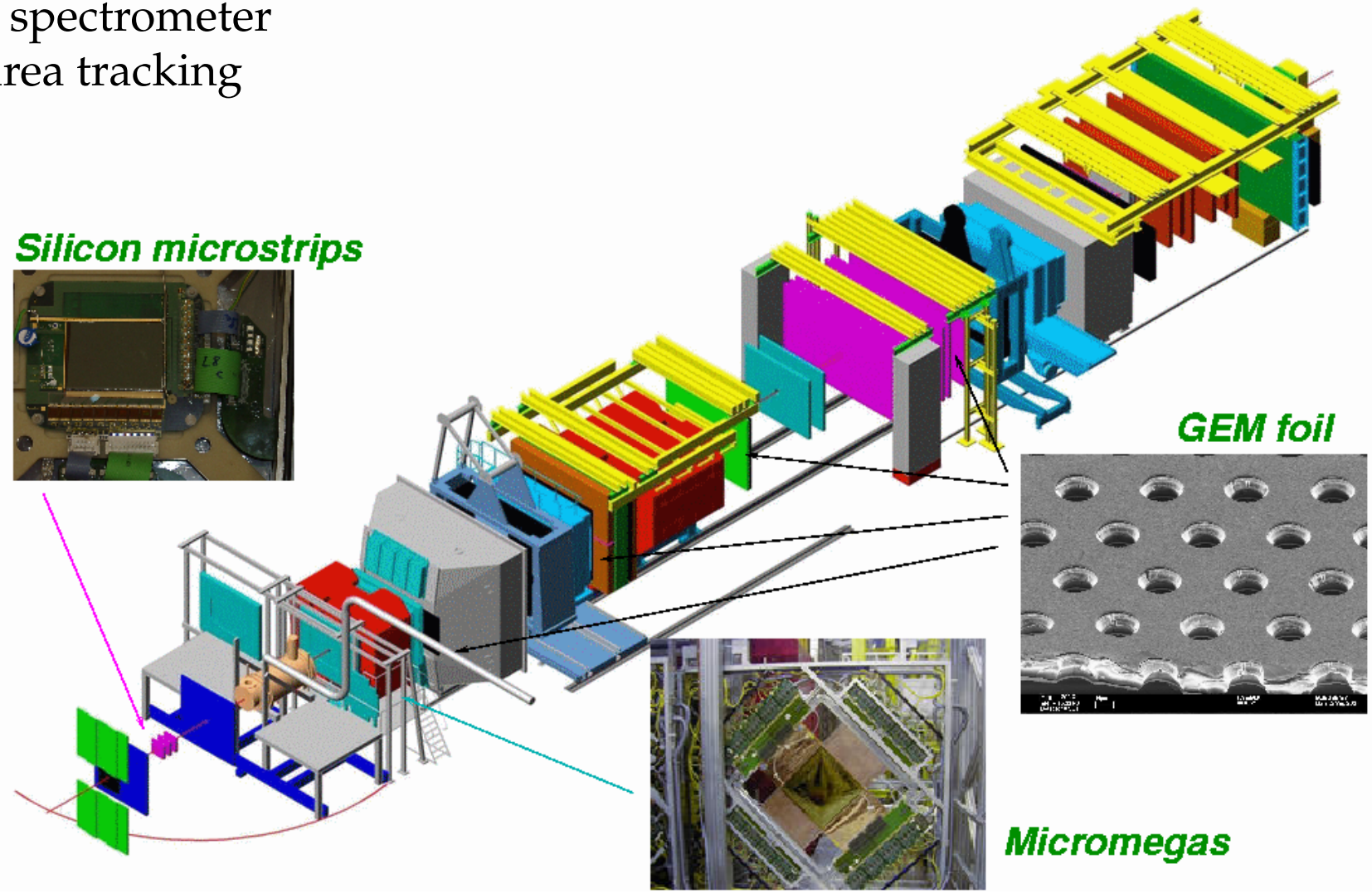
240 physicists from 28 institutes

Bielefeld, Bochum, Bonn, Burdwan/Calcutta, CERN, Dubna,
Erlangen, Freiburg, Lisboa, Mainz, Moscow, Munich, Nagoya,
Parg, Protvino, Saclay, Tel Aviv, Torino, Trieste, Warsaw

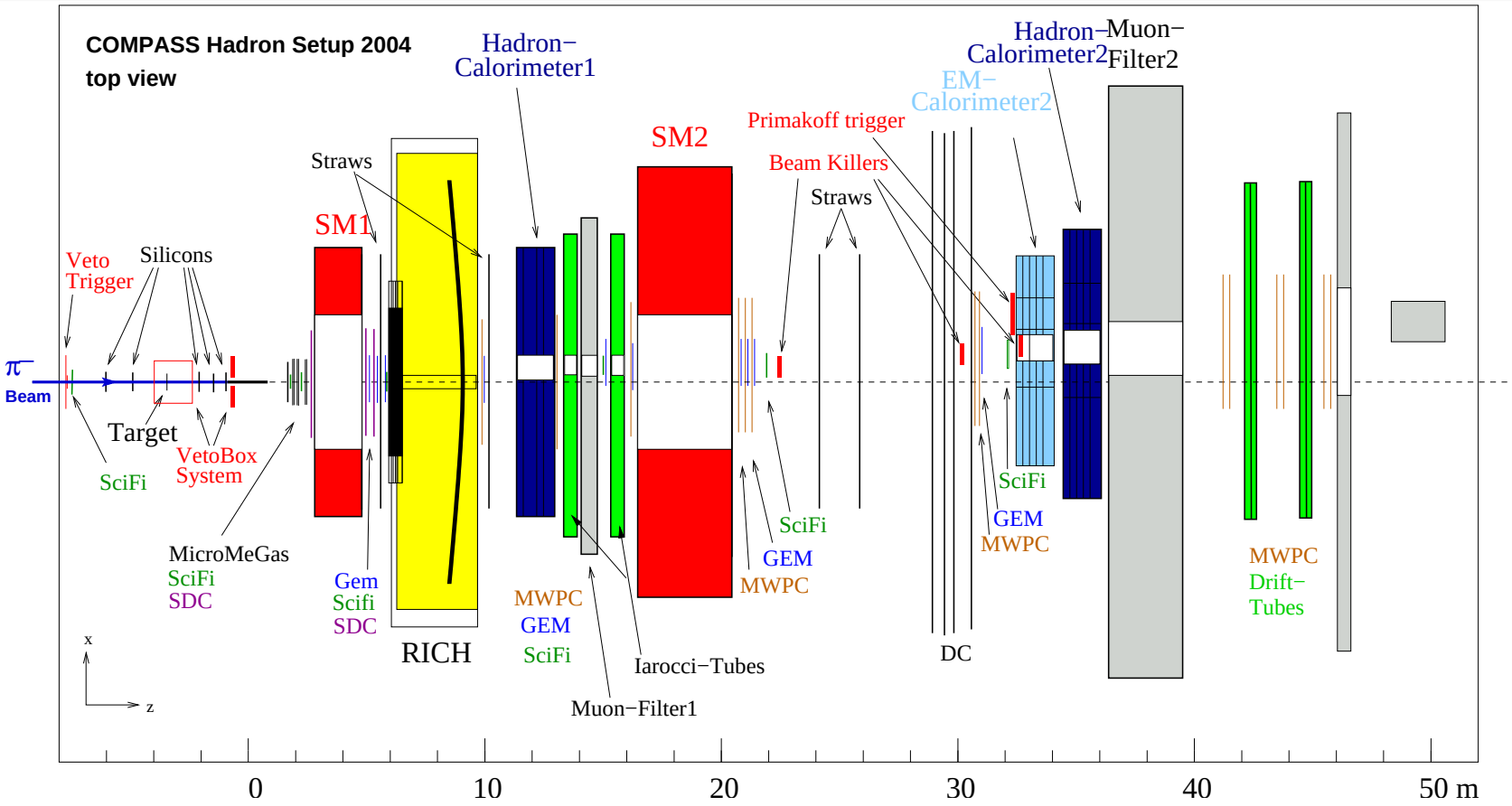
Data acquisition 2002, 03, 04, 06 with muon beam
on polarised LiD target
Oct. 2004: pilot hadron run (π^-)

The COmmon Muon and Proton Apparatus for Structure and Spectroscopy

2 stage spectrometer
small area tracking



Layout of the COMPASS 2004 pilot hadron run



- 4 weeks commissioning / data taking in 2004
- 190 GeV π^-/μ^--beam, $10^6/10^8$ particles/s
- Targets: Pb ($X_0 = 0.29, 0.5$), Cu (0.25), C (0.12)

Primakoff Reaction

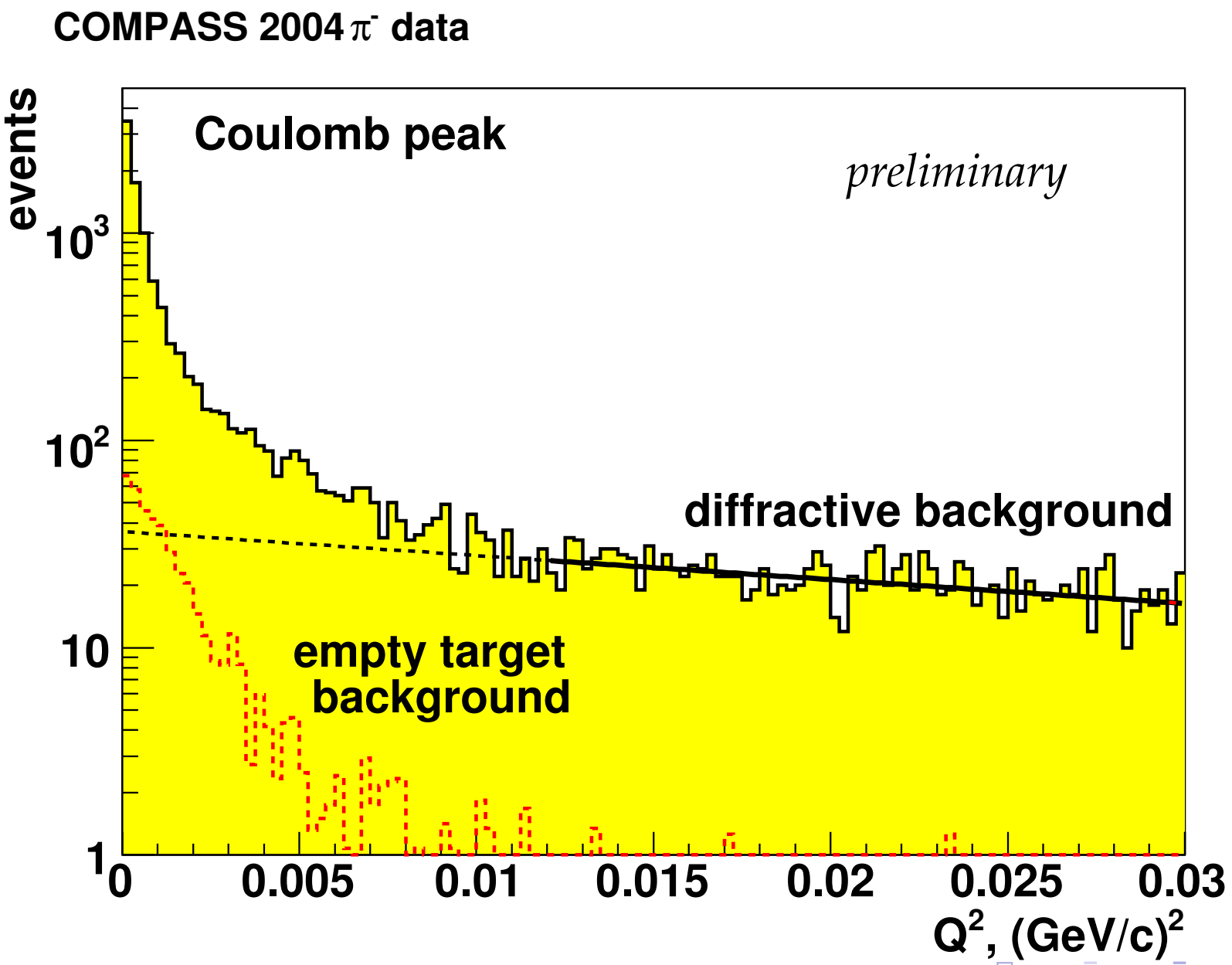
Selection of $\pi^- + \gamma^{(*)} \rightarrow \pi^- + \gamma$

- exactly one primary vertex in the target ($p_{T,\pi^-} > 15$ MeV)
- exactly one π^- track of high quality, $E_{\pi^-} < 170$ GeV
- exactly one Ecal2 cluster as photon candidate
- $| E_{\pi^-} + E_\gamma - E_{beam} | < 25$ GeV
- $M_{\pi\gamma} < 3.75 m_\pi$, $Q^2 < 0.0075\ \mathrm{GeV}^2/c^2$

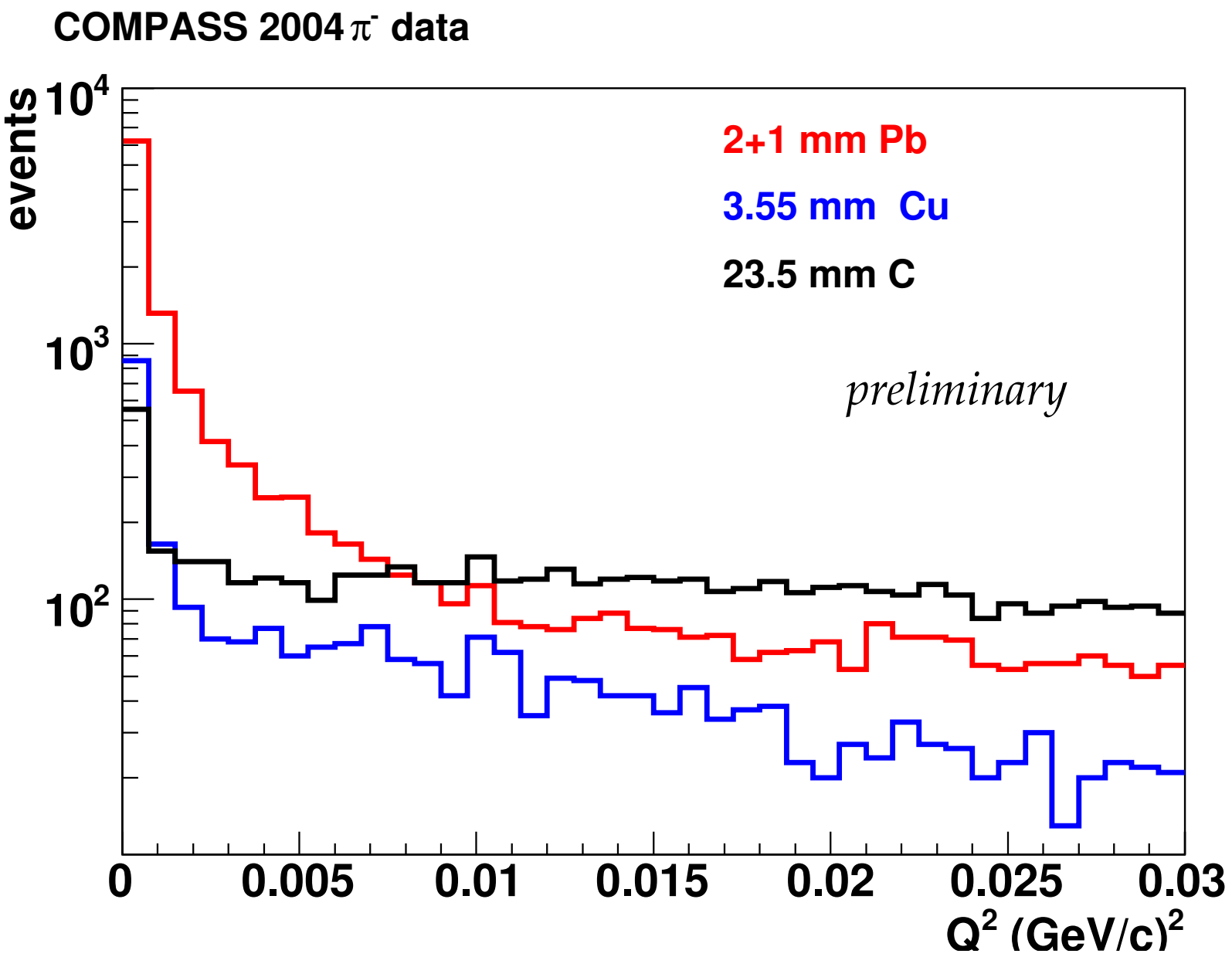
Background

- $K^- \longrightarrow \pi^- \pi^0$ (empty target subtraction)
- channels with one high-energetic photon (different Q^2 dependence)
- e^-, μ^- bremsstrahlung

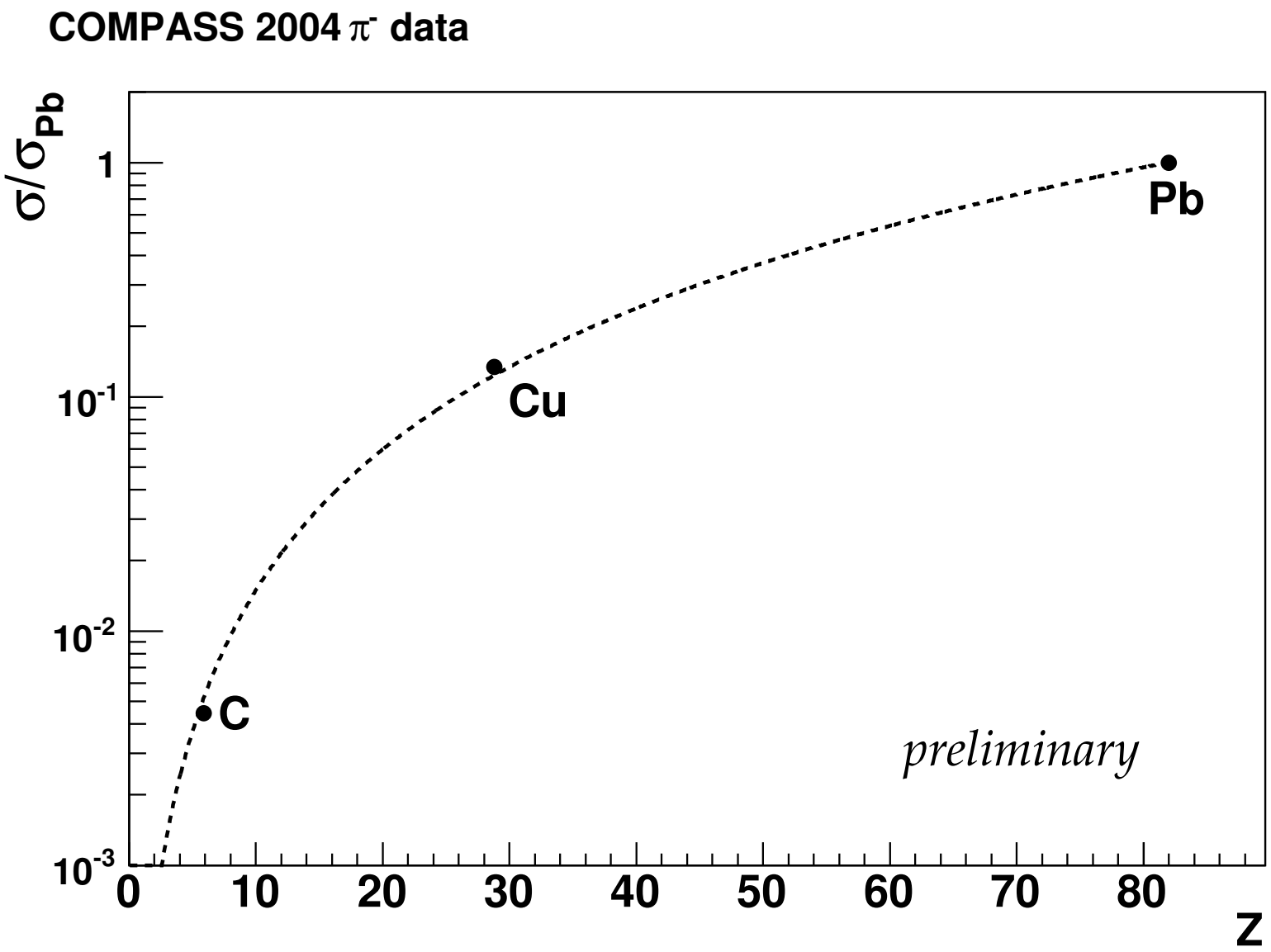
Q^2 distribution



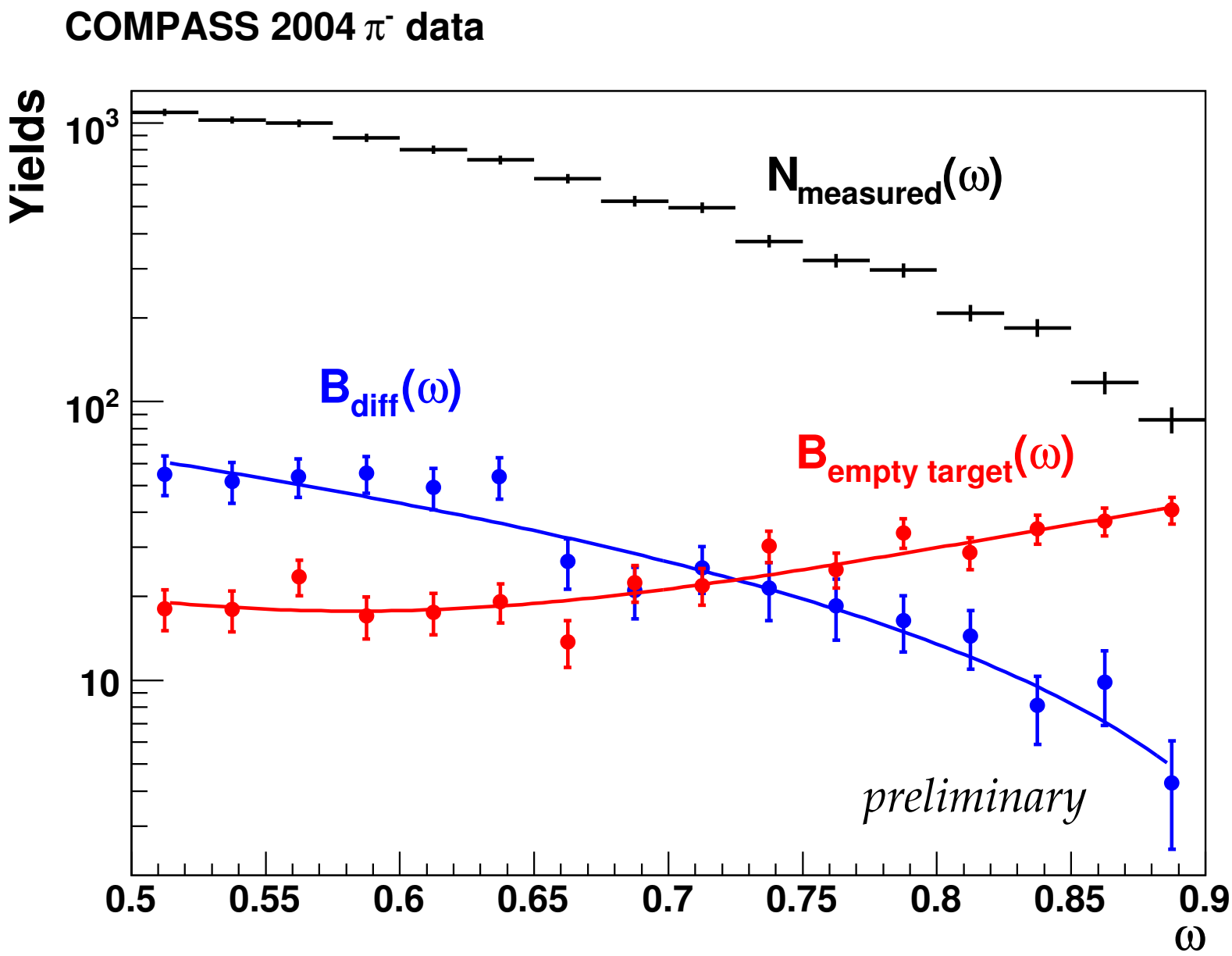
Q^2 distribution for different targets



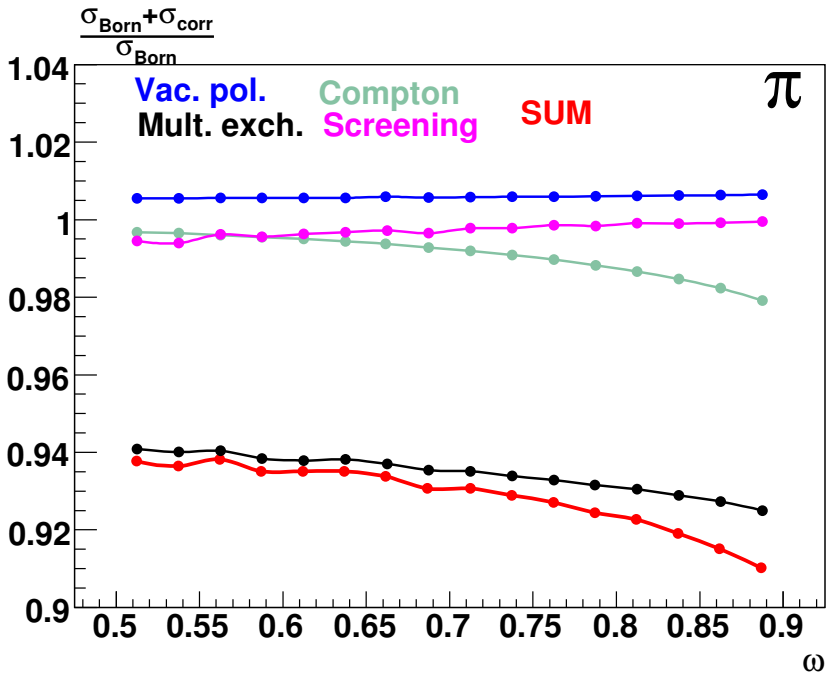
Z^2 dependence of Primakoff cross section

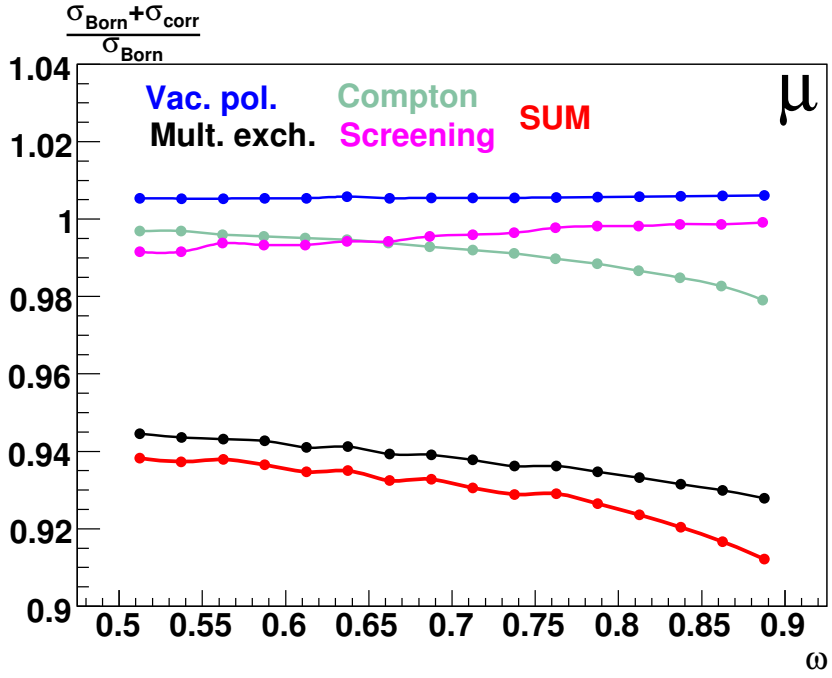


$\omega = E_\gamma / E_{Beam}$ dependence of signal and background

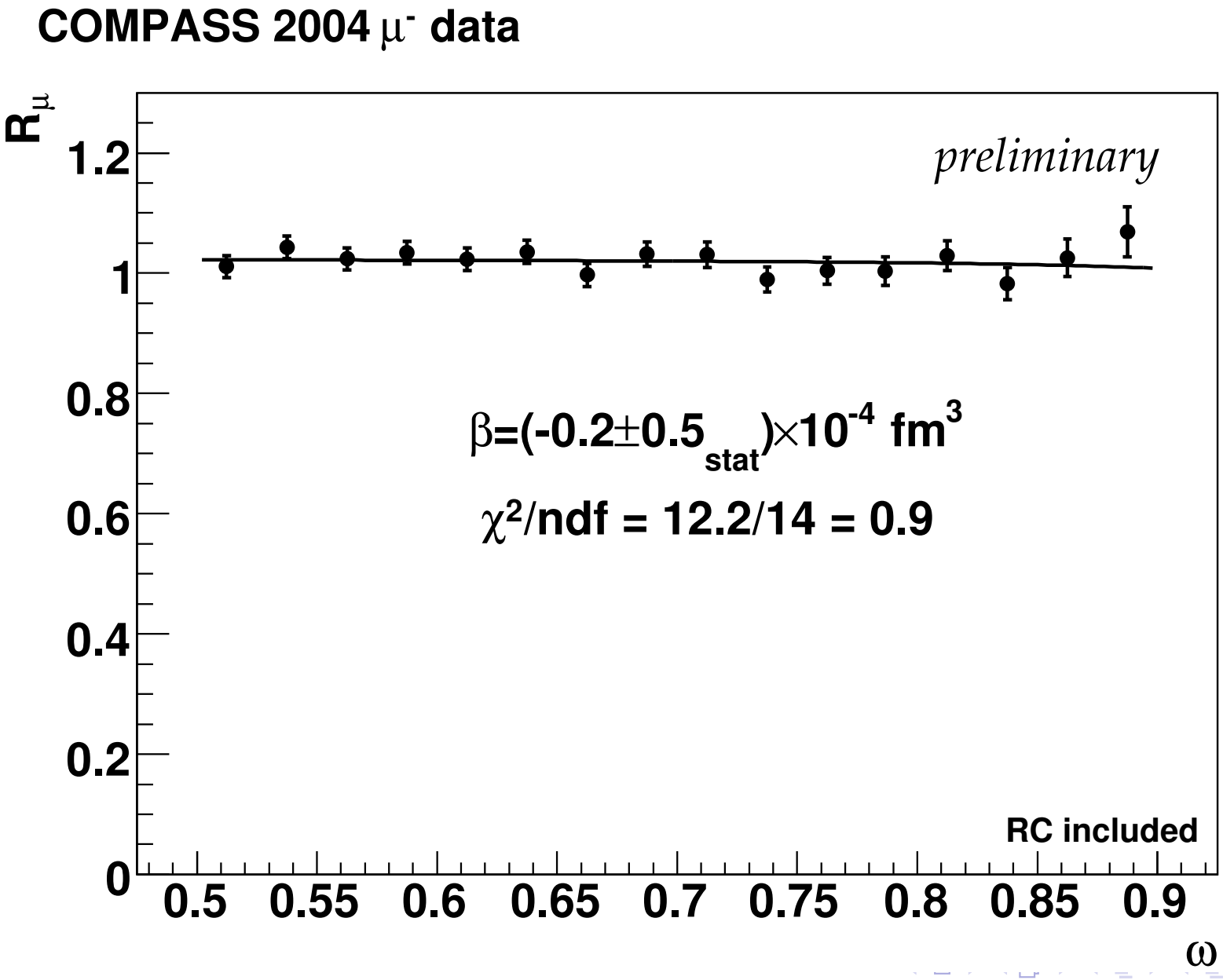


Radiative corrections for π and μ data

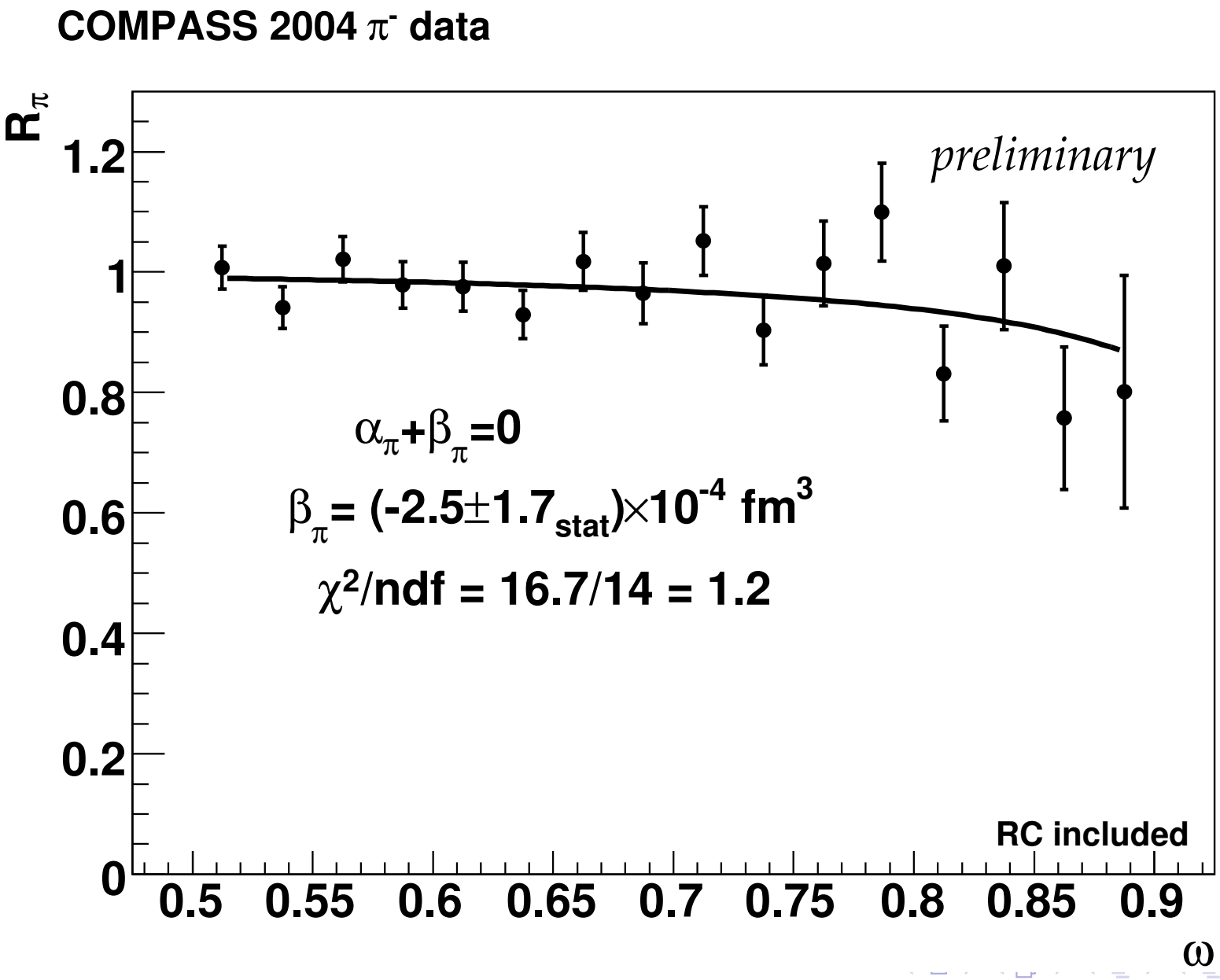




Muon control measurement



Pion measurement



Systematic error estimate

	Error, 10^{-4}fm^3
Setup description in MC (μ data)	± 0.5
Diffractive and empty target background subtraction	± 0.3
Muons background	$+0.2$
Electrons background	$<+0.1$
SYSTEMATIC TOTAL	± 0.6

Result and Outlook

From COMPASS data taken in ~ 3 days of beam time (7300 events), the pion polarisability value

$$\beta_\pi = -2.5 \pm 1.7_{stat} \pm 0.6_{syst} \cdot 10^{-4} \mathrm{fm}^3$$

is extracted (preliminary).

Outlook

- Refinement of analysis (necessary)
- Additional data on tape (adjusted MC needed)
- Independent extraction of α_π and β_π
- New improved measurement at COMPASS

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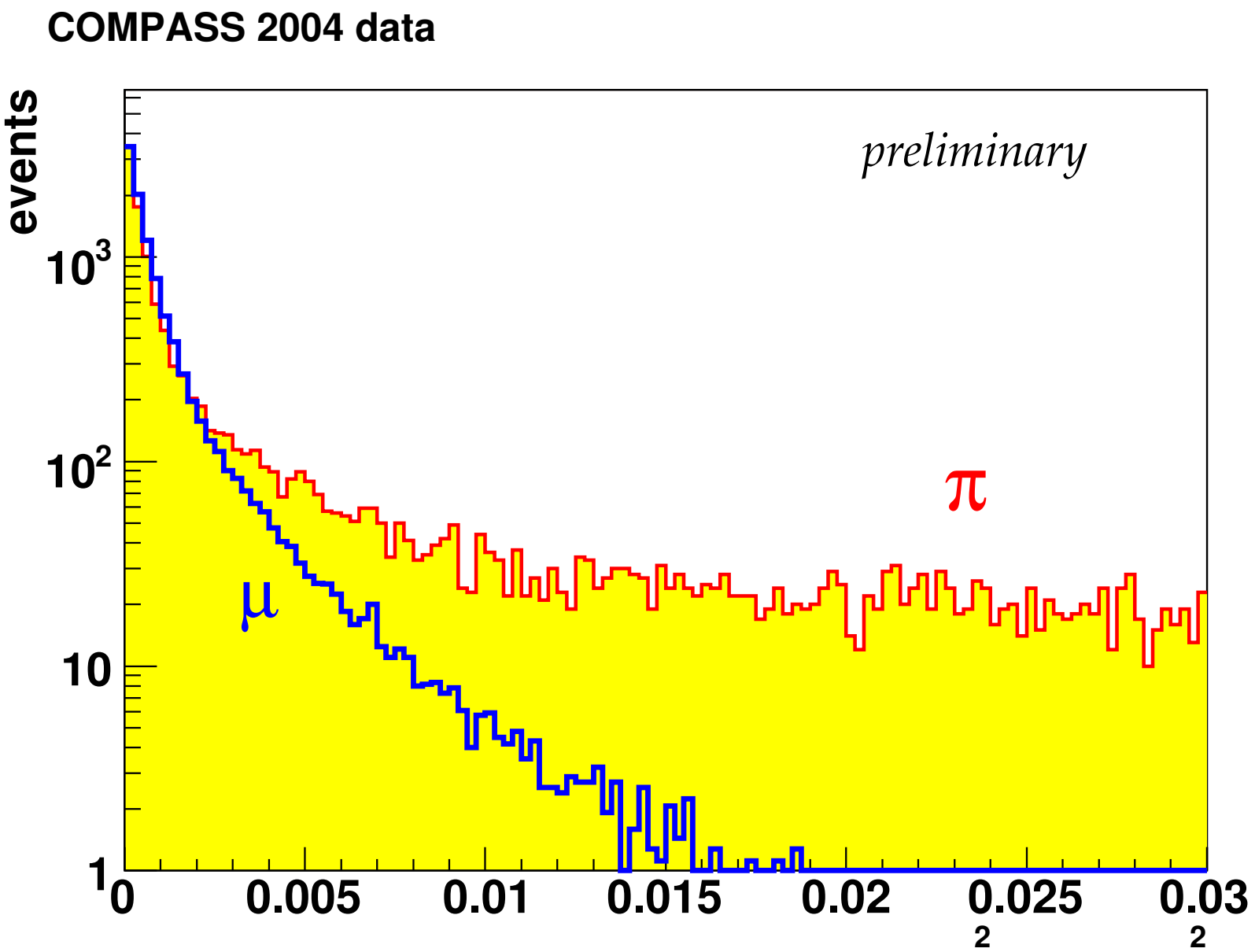
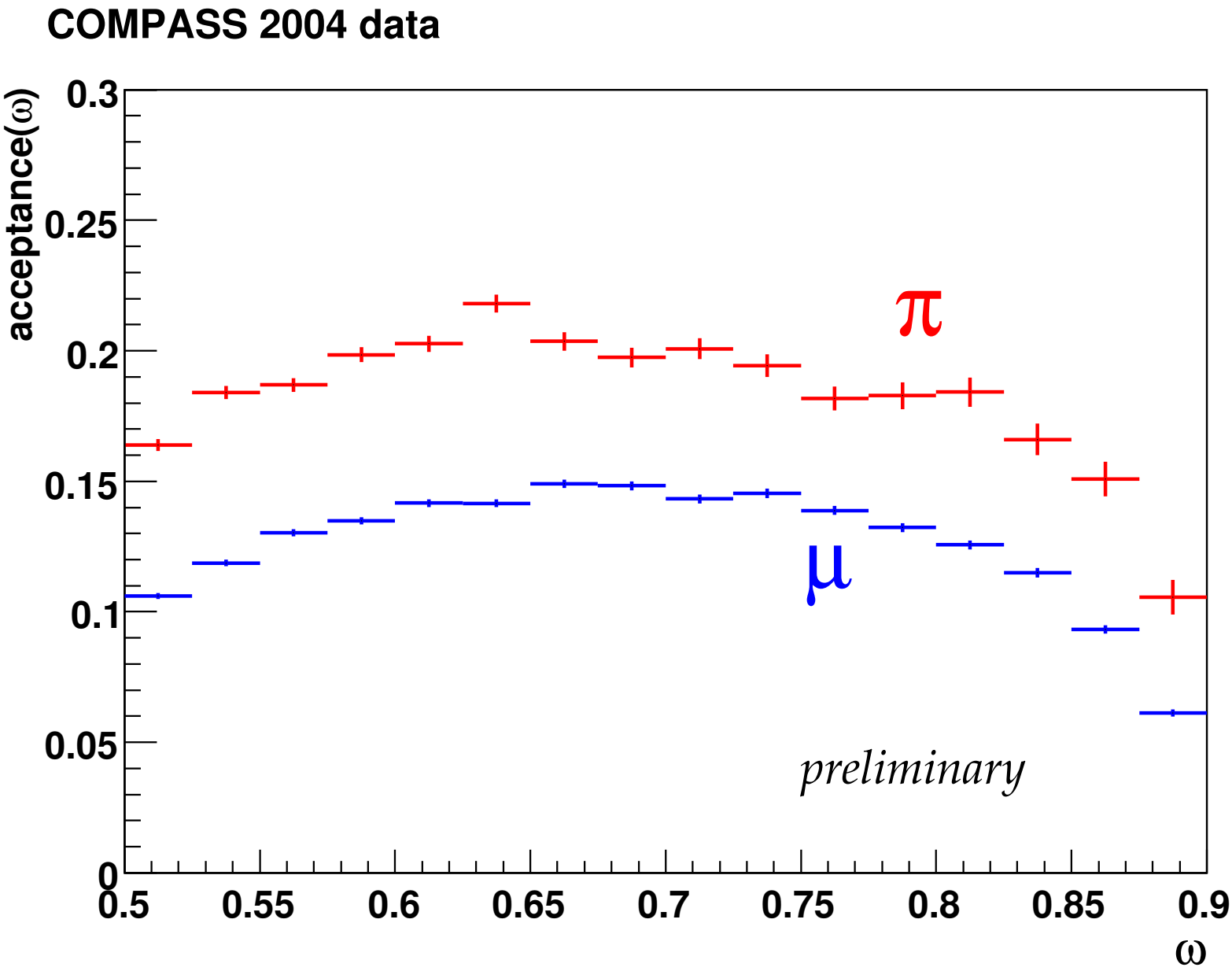
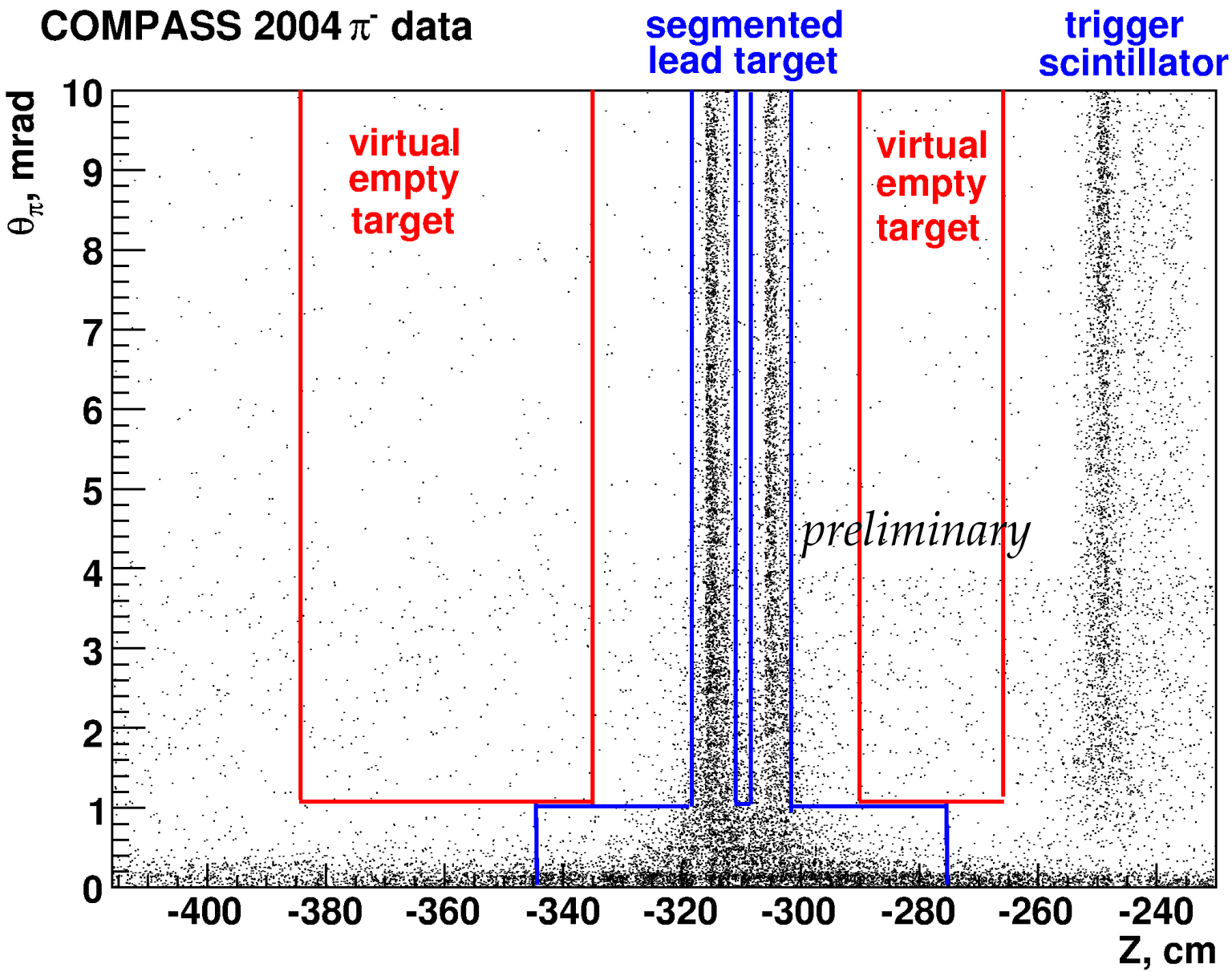
Q^2 for muon data



Acceptance from MC simulation

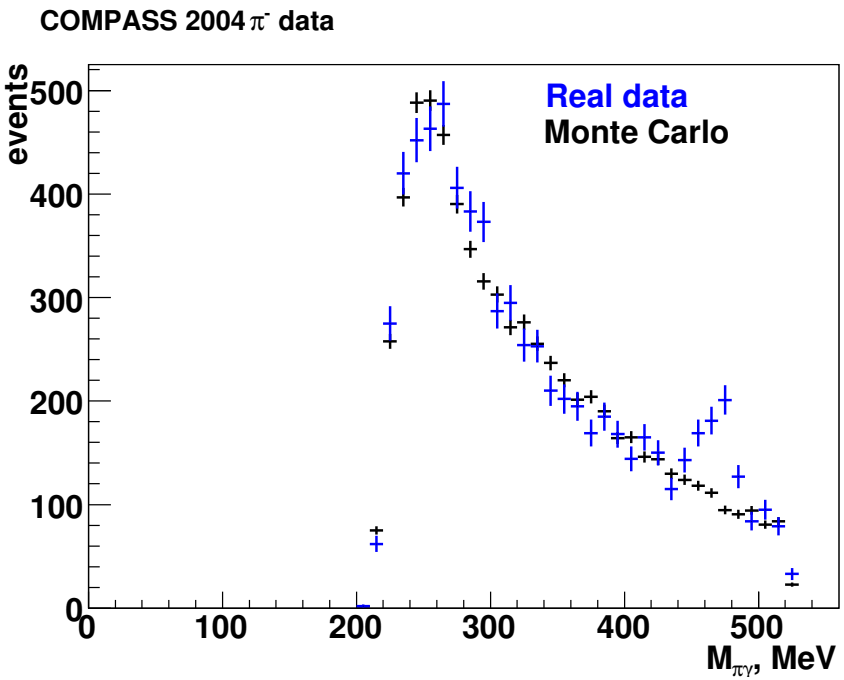


Virtual Empty Target Method

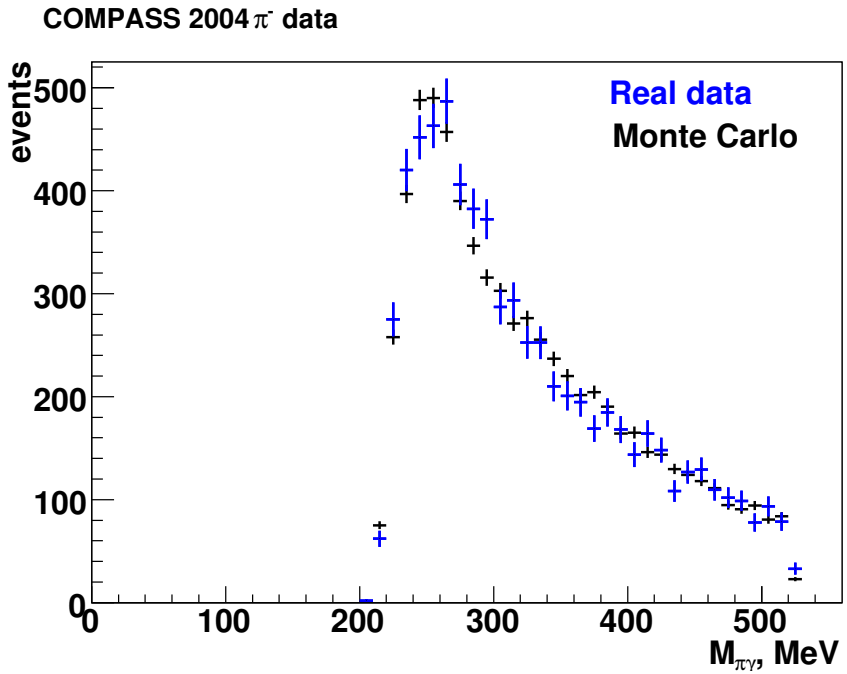


Empty target background subtraction

without,



with empty target subtraction



preliminary spectra

Possible improvements

Analysis

- new production of data
  - alignment
  - vertexing (for z<-100cm)
  - time-dependent Ecal2 calibration
  - retrieve scaler information
- refined Monte Carlo for different settings

New measurement

- CEDAR for incoming particle ID
- stable setup
- optimized material budget