First results on pion polarizabilities at COMPASS

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for the COMPASS collaboration

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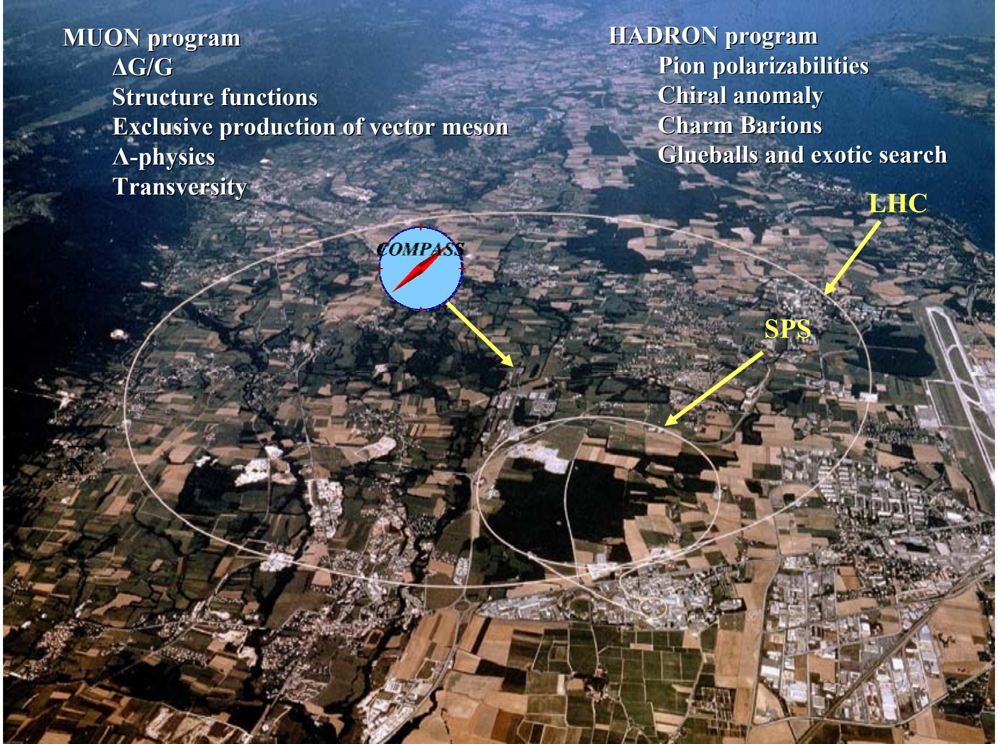
COMPASS

COmmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

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

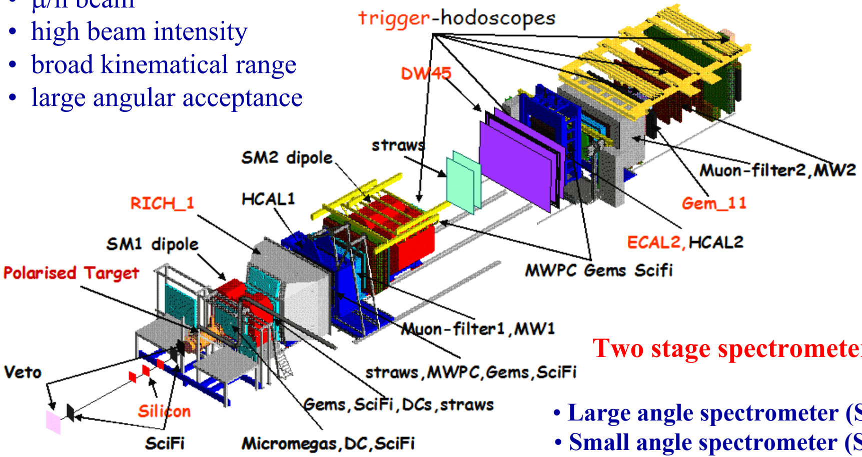
Bielefeld, Bochum, Bonn, Burdwan, Calcutta, CERN,
Dubna, Erlangen, Freiburg, Heidelberg, Helsinki, Lisbon,
Mainz, Miyazaky, Moscow, Munich, Nagoya, Prague, Protvino, Saclay, Tel Aviv, Torino, Trieste, Warsaw

28 Institutions, ~ 230 physicists


MUON program
ΔG/G
Structure functions
Exclusive production of vector meson
Λ-physics
Transversity
HADRON program
Pion polarizabilities
Chiral anomaly
Charm Barions
Glueballs and exotic search
LHC
COMPASS
SPS
N

The Spectrometer

- μ/h beam
- high beam intensity
- broad kinematical range
- large angular acceptance



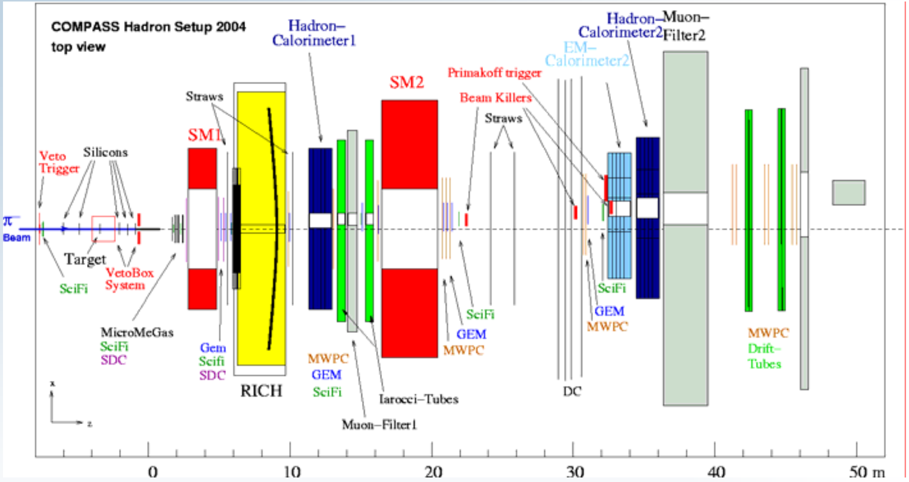
Two stage spectrometer

- **Large angle spectrometer (SM1)**
- **Small angle spectrometer (SM2)**

tracking, calorimetry, PID

SciFi	***Straws***
Silicon	***SDC***
Micromegas	***MWPC***
GEMs	***W45***

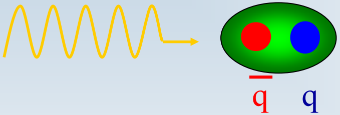
Hadron-beam Run 2004



• **Low beam intensity: 2 ·10^{6} π^{-}/spill**
• **Beam time: 10 days**
• **Different targets: 1.6 - (2+1) - 3 mm Pb, 7 mm Cu, 23 mm C**
• **Saturated trigger rate (40-50k/spill)**

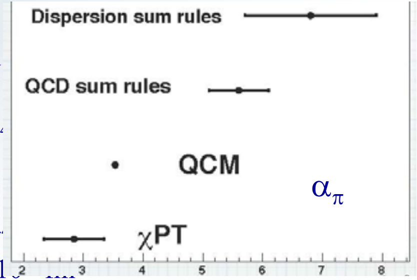
Pion polarizabilities

The polarizability (electric α and magnetic β) relates the average dipole (electric $\vec{p}$ and magnetic $\vec{\mu}$) moment to an external electromagnetic field, characterizing the rigidity of the quark-antiquark system



$$p = \alpha E$$
$$\mu = \beta H$$

Theoretical predictions



The pion polarizabilities has been described

Chiral Perturbation Theory (χPT)

χPT (2 loops) $\alpha_\pi+\beta_\pi = 0.16\cdot10^{-}$

Other theoretical models:

QCM $\alpha_\pi+\beta_\pi = 0.23\cdot10^{-}$

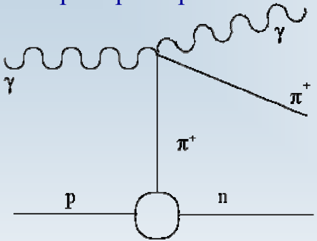
QCD sum rules $\alpha_\pi = (5.6 \pm 0.5)\cdot1$

Dispersion Sum Rules $\alpha_\pi+\beta_\pi = (0.166 \pm 0.024)\cdot10^{-4}\ \mathrm{fm}^3$;

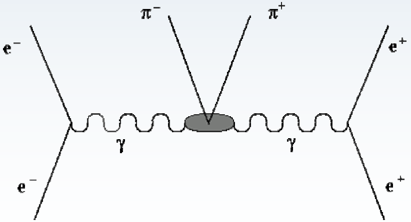
$\alpha_\pi-\beta_\pi = (13.60 \pm 2.15)\cdot10^{-4}\ \mathrm{fm}^3$

Experimental methods

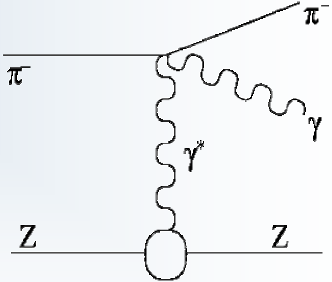
Radiative pion photoproduction



Photon-photon collision



Radiative pion scattering



Experimental values

$\pi^- + Z \rightarrow \pi^- + Z + \gamma$

SIGMA-AYAKS (Serpukhov)

$\alpha_\pi = 6.8 \pm 1.4_{stat} \pm 1.4_{syst}$ (for $\alpha_\pi + \beta_\pi = 0$)

$\gamma + p \rightarrow \gamma + \pi^+ + n$

Lebedev

$\alpha_\pi = 20 \pm 12_{stat}$

A2 (MAMI)

$\alpha_\pi - \beta_\pi = 11.6 \pm 1.5_{stat} \pm 3.0_{syst} \pm 0.5_{mod}$

$\gamma + \gamma \rightarrow \pi^+ + \pi^-$

MARK II

$\alpha_\pi = 2.2 \pm 1.6_{stat+syst}$

PLUTO

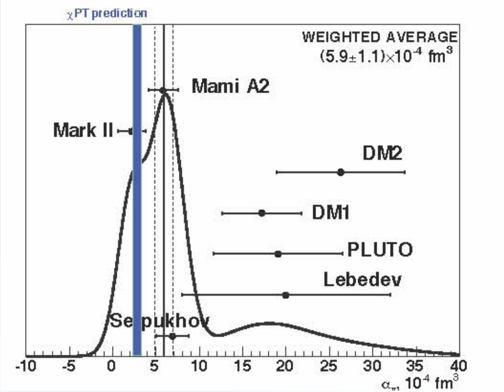
$\alpha_\pi = 19.1 \pm 4.8_{stat} \pm 5.7_{syst}$

DM1

$\alpha_\pi = 17.2 \pm 4.6_{stat}$

DM1

$\alpha_\pi = 26.3 \pm 7.4_{stat}$

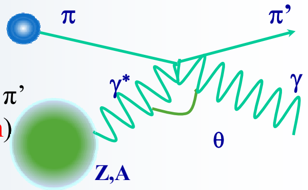


The experiments are affected by a large statistical and/or systematic errors

All values in: **10^{-4} fm^3**

The Primakoff Reaction

$$\pi^- + Z \rightarrow \pi^- + Z + \gamma$$



Inverse kinematics for the Compton scattering: $\gamma^*\pi \rightarrow \gamma\,\pi'$
In the incoming pion rest frame (Anti-laboratory system)

$$\frac{d^2\sigma_{\gamma\pi}}{d\omega d\cos\theta} \propto Z^2 \left\{ F_{\gamma\pi}^{pt}(\theta) + \frac{m_\pi \omega}{\alpha} \cdot \frac{\alpha_\pi (1+\cos^2\theta) + 2\beta_\pi \cos\theta}{\left[1 + \frac{\omega}{m_\pi}(1-\cos\theta)\right]^3} \right\}$$

α_π, β_π independently

ω is the energy of the virtual photon in the alab.

Assuming $(\alpha_\pi + \beta_\pi) = 0$ in the Laboratory system:

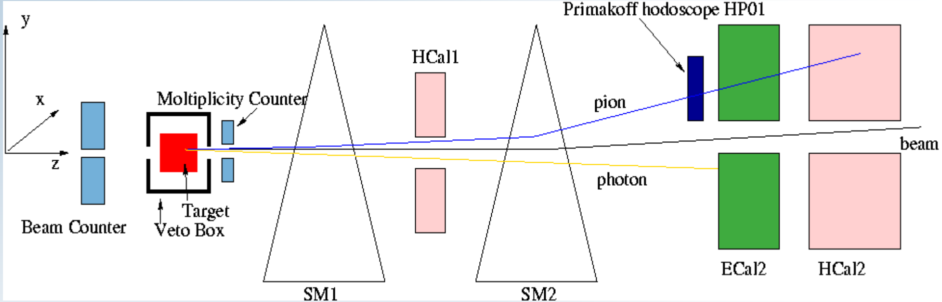
$$\frac{d\sigma_{\gamma\pi}}{dE_\gamma} = \frac{d\sigma_{\gamma\pi}^{pt}}{dE_\gamma} + 4Z^2\alpha^2 m_\pi \frac{E_\gamma}{E_{beam}^2} \beta_\pi \left(\ln\frac{Q^2{}_{max}}{Q^2{}_{min}} - 3 + 4\sqrt{\frac{Q^2{}_{min}}{Q^2{}_{max}}} \right)$$

β_π

$$Q^2_{min} = \left(\frac{E_\gamma m_\pi}{2E_{beam}(E_{beam} - E_\gamma)} \right)^2$$

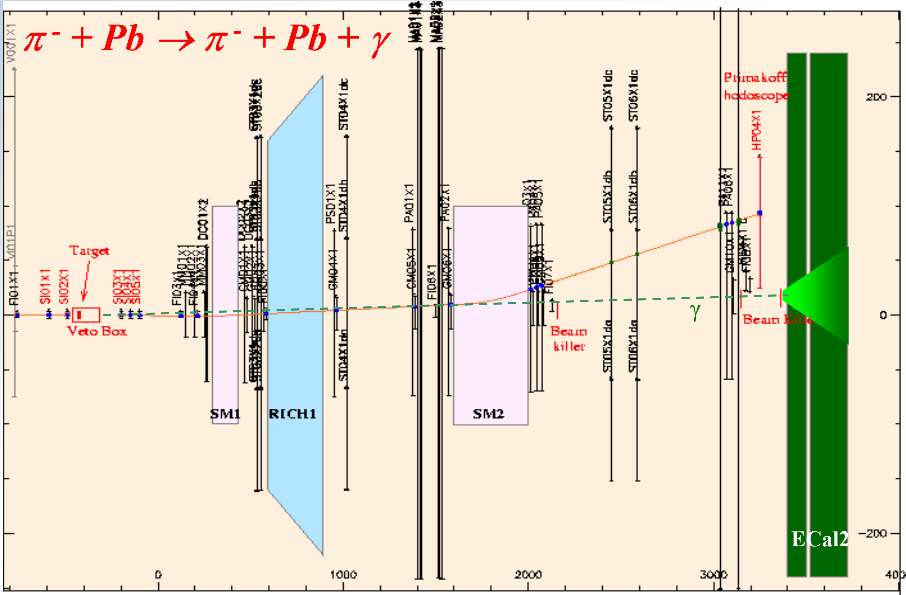
Q^2_{max} depends on analysis cut
E_γ is the energy of the real photon

Trigger



- About 10 days of data taking (pilot run); integrated beam flux is 10^{11} pions
- Beam: 190 GeV/c; ~10^6 π/s, 4.8 s / 16 s spill structure
  190 GeV/c; ~10^8 μ/s
- 2 triggers:
  - **Veto** x **Hodoscope hit** x **Ecal2** (E > 50 GeV) x **Hcal** (E > 18 GeV) (**primakoff1**)
  - **Veto** x **Ecal2** (E > 100 GeV) (**primakoff2**)

Typical reconstructed event

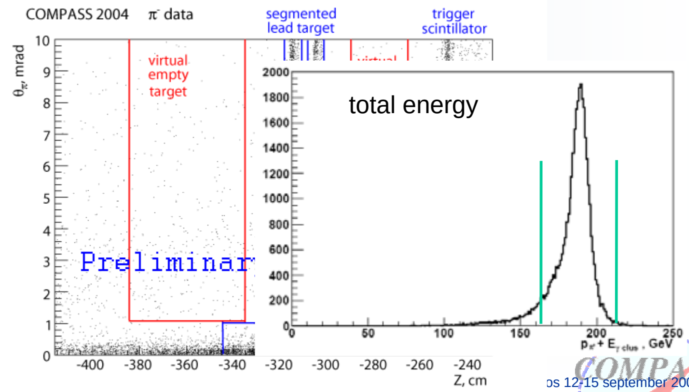


Event Selection

The current analysis is based on:

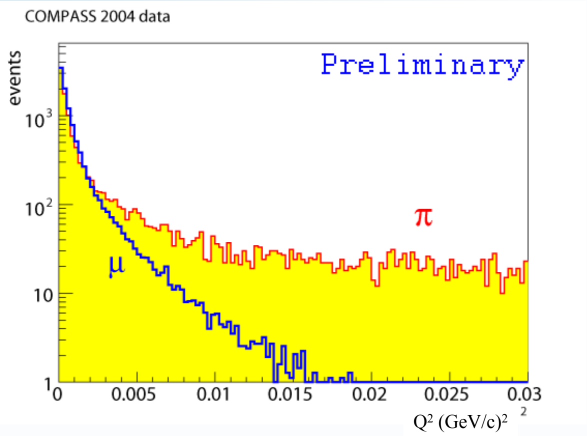
- 3 days of data taking
- Pb 2+1 mm target
- primakoff2 trigger

- $\pi + \gamma$ in the final state
- primary vertex near the target nominal position
- invariant mass
- $|E_{\gamma}+E_{\pi}$ - E_{beam}
- $P_T > 45$ MeV/
- $0.5 < E_{\gamma}/E_{beam}$
- $Q^2 < 7.5 \cdot 10^{-3}$ (



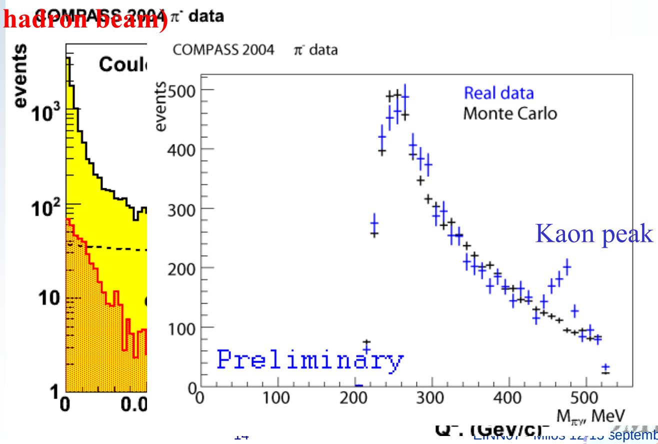
Analysis procedure

use pointlike reference particle within the same setup (μ)



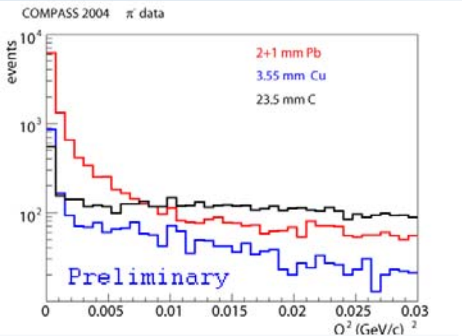
Background corrections

1) **ρ production: $\pi^- + Z \rightarrow \rho^- + Z \rightarrow \pi^- + Z + \gamma + \gamma$** *suppressed by $M_{\pi\gamma}$ cut*
2) **$e^- \rightarrow e^- + \gamma$ (0.1% of e^- in hadron beam)** *suppressed by P_T cut*
3) **$\mu^- \rightarrow \mu^- + \gamma$ (0.1% of μ^- in hadron beam)** *σ_{syst}*
4) **diffractive process** *subtracted*
5) **kaon decay: $k^- \rightarrow \pi^- \pi^0 \rightarrow \pi^- + \gamma + \gamma$** *subtracted with empty target*
   (~4% of K^- in hadron beam)

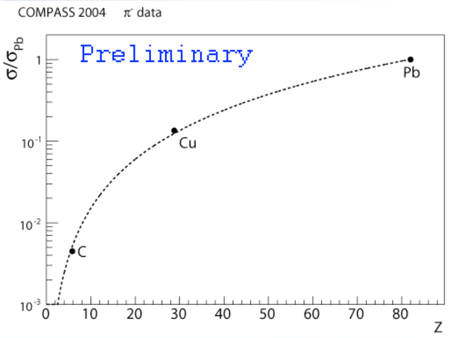


Primakoff analysis

Q^2 distribution for different target material



Z^2 dependency



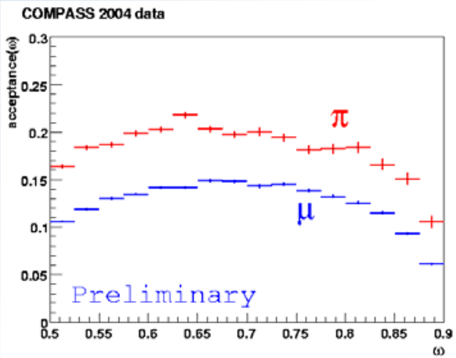
Good agreement of the Z^2 dependency for the Primakoff cross-section for a large Z range

COMPASS preliminary results

MC simulation

- POLARIS generator for Primakoff $\pi\gamma$ and $\mu\gamma$ events.
- COMPASS simulation based on GEANT3

$\omega = E_\gamma/E_{beam}$



The acceptance behaviour is similar for muon and pion

COMPASS preliminary results

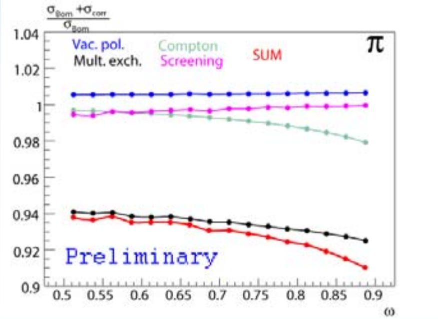
Preliminary estimation of the Radiative Corrections

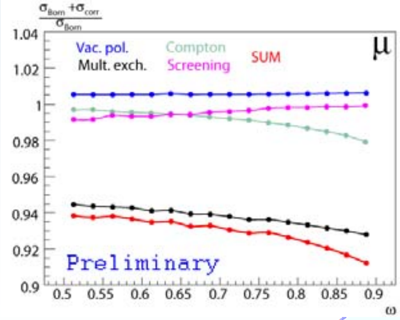
work still ongoing

- ✓ Vacuum polarization
- ✓ Compton vertex
- ✓ Multiple photon exchange
- ✓ Screening by atomic electrons

The correction for pion polarizability is about:

0.6×10^{-4} fm^3





COMPASS preliminary results

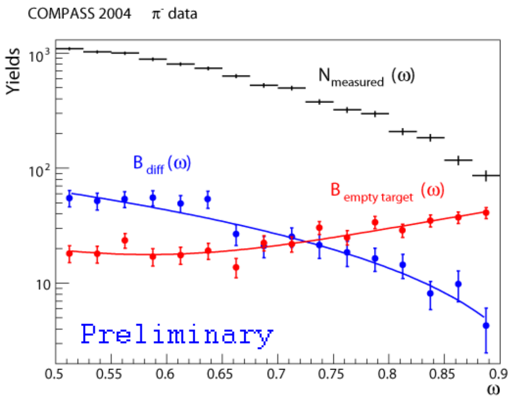
$$R_\pi = \frac{\sigma_{\pi\, measured}(\omega)}{\sigma_{\pi\, ptl.theor}(\omega)} = \frac{N_\pi(\omega) - B_{diff}(\omega) - B_{empty\ target}(\omega)}{A_\pi(\omega)\times\sigma_{\pi\, ptl.theor}(\omega)}$$

Pion

$$R_\mu = \frac{\sigma_{\mu\, measured}(\omega)}{\sigma_{\mu\, theor}(\omega)} = \frac{N_\mu(\omega)}{A_\mu(\omega)\times\sigma_{\mu\, theor}(\omega)}$$

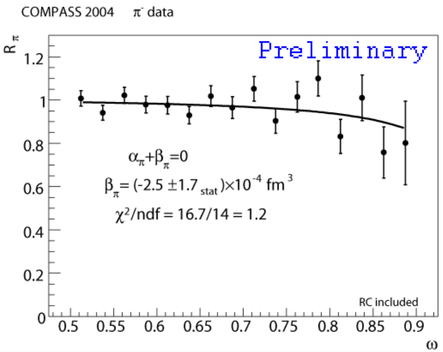
Muon

$$R = \frac{\frac{d\sigma^{exp}_{Data}}{d\omega}}{\frac{d\sigma^{ptl.}_{MC}}{d\omega}} \approx 1 + \frac{3}{2}\frac{m_\pi^2}{\alpha}\frac{\omega^2}{1-\omega}\beta_\pi$$

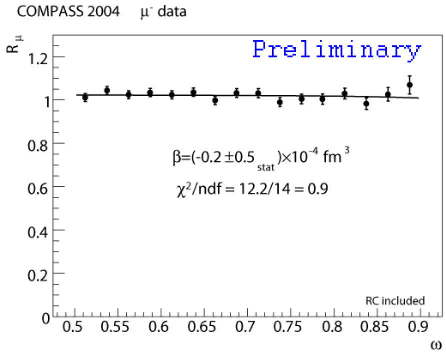


COMPASS preliminary results

Pion



Muon



$\beta_\pi = (-2.5 \pm 1.7_{stat}) \cdot 10^{-4}$ fm^3

$\beta_\mu = (-0.2 \pm 0.5_{stat}) \cdot 10^{-4}$ fm^3

COMPASS preliminary results

Systematic uncertainties

Origin	Syst. Error 10^{-4} fm^3
Setup description in MC	± 0.5
Background subtraction	± 0.3
Beam muons	< 0.2
Beam electrons	< 0.1
Total	± 0.6

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

COMPASS preliminary results

$\pi^- + Z \to \pi^- + Z + \gamma$
COMPASS
$\alpha_\pi = 2.5 \pm 1.7_{stat} \pm 0.6_{syst}$ (for $\alpha_\pi + \beta_\pi = 0$)

SIGMA-AYAKS (Serpukov)
$\alpha_\pi = 6.8 \pm 1.4_{stat} \pm 1.4_{syst}$ (for $\alpha_\pi + \beta_\pi = 0$)

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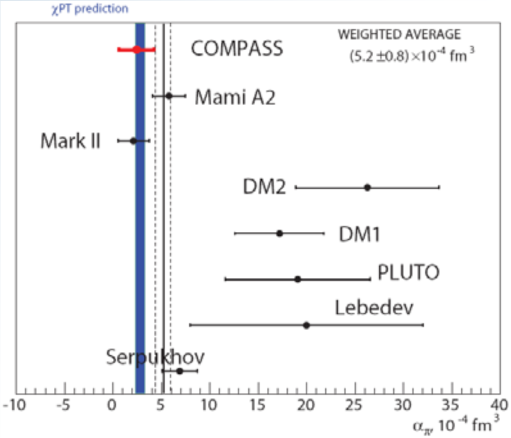

All values in: **10^{-4} fm^3**

Conclusions

Preliminary result of the measurement of pion polarizabilities at **COMPASS**, under the approximation $\alpha_\pi + \beta_\pi = 0$ is:

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

Present analysis is based on only 3 days of data taking and is at the level of the previous measurements

Systematic uncertainties are well understood and could be further improved with a better statistic with muon beam

Work is ongoing to extract separately α_π and β_π