Pion polarizabilities measurement at COMPASS

Guskov Alexey, JINR, Dubna
Alexey.Guskov@cern.ch

on behalf of the COMPASS collaboration

HEP '07, Manchester

COMPASS experiment

The fixed target experiment on SPS at CERN

1996 - COMPASS PROPOSAL

1999 - 2001 - CONSTRUCTION AND INSTALLATION

2001 - TECHNICAL RUN

2002 - 2004, 2006 - 2007 - DATA TAKING WITH MUON BEAM

OCTOBER-NOVEMBER 2004 - PILOT HADRON RUN

FUTURE (2008?) - DATA TAKING WITH HADRON BEAM

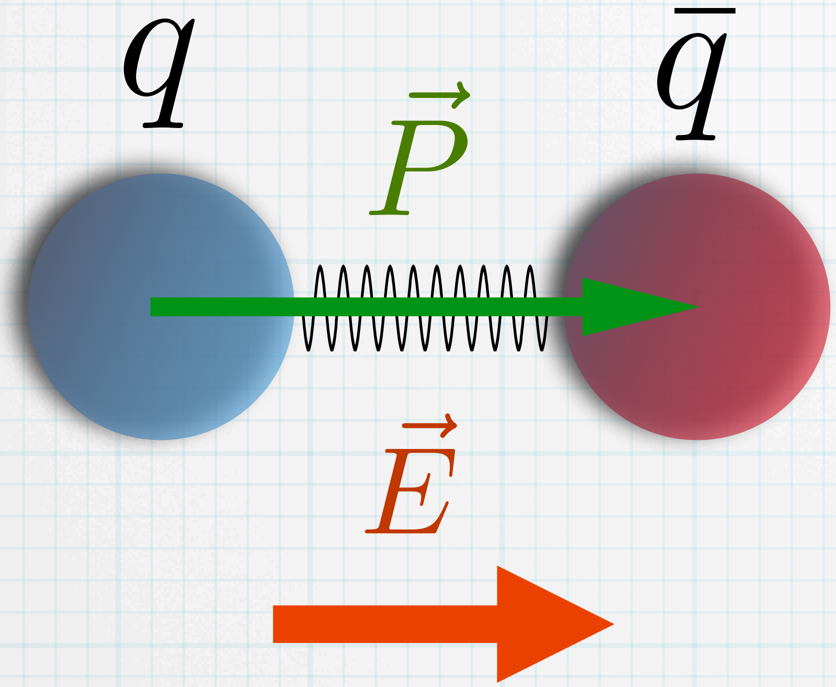
MUON PROGRAM

* $\Delta G/G$
* Structure functions
* Exclusive production of vector mesons
* Λ-physics
* Transversity

HADRON PROGRAM

* Pion polarizabilities
* Chyral anomaly
* Charm baryons
* Glueballs and exotic mesons

Pion polarizabilities

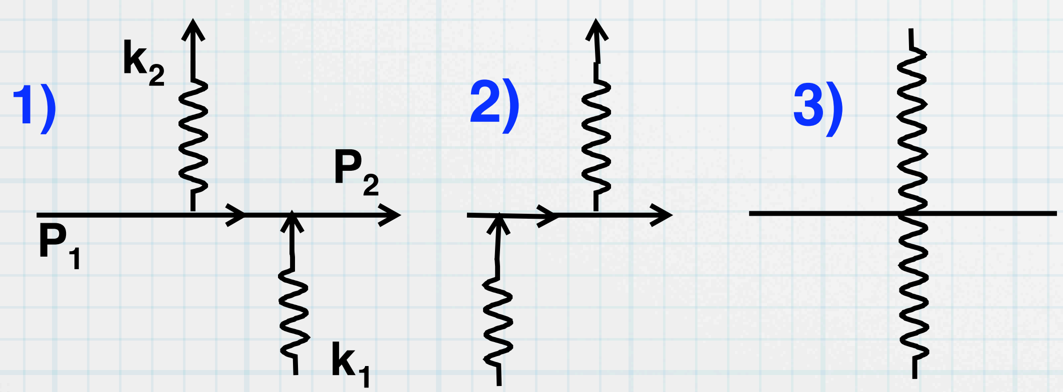


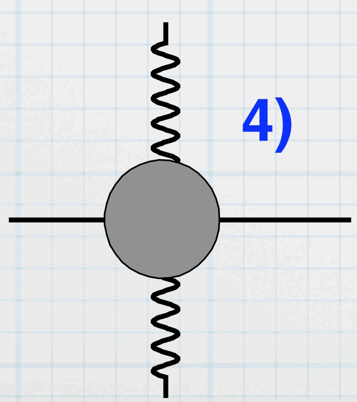
$$\vec{P} = \alpha_\pi \times \vec{E}$$

$$\vec{\mu} = \beta_\pi \times \vec{H}$$

The electric and magnetic polarizabilities of pion are the quantities characterizing the **regidity of quark-antiquark** system

πγ-scattering diagrams for point like pion





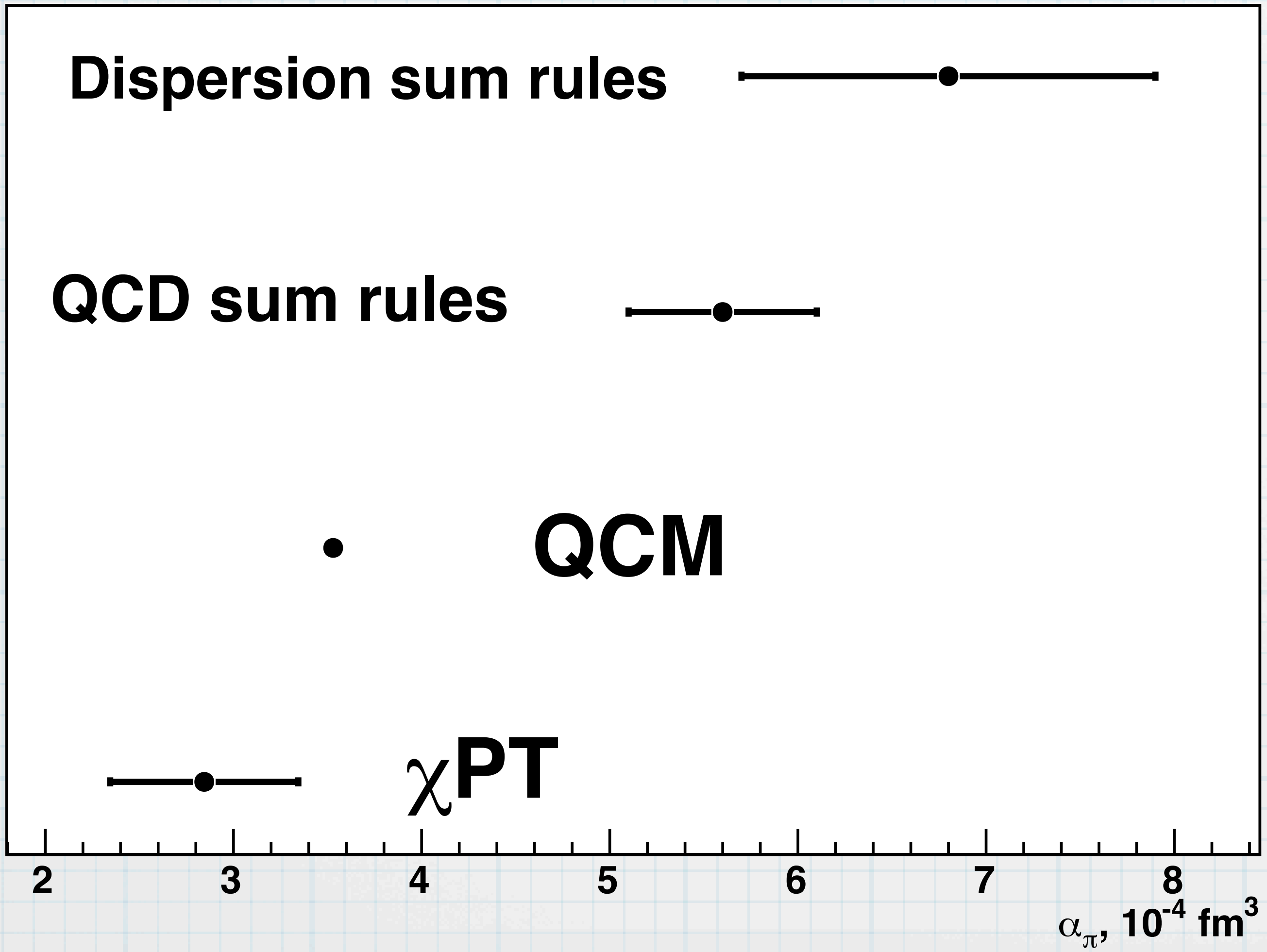
Corrections related to pion internal structure

In nonrelativistic approximation the hamiltonian of pion interaction with external electromagnetic field corresponding to the 4th diagram can be represented as:

$$\boldsymbol{H} = 1/2\,(\alpha_\pi E^2 + \beta_\pi H^2)$$

Theoretical predictions for α_π and β_π

- ☑ χ PT (2 loops) $\alpha_\pi+\beta_\pi=0.16$, $\alpha_\pi-\beta_\pi=5.7\pm1.0$
- ☑ QCM $\alpha_\pi+\beta_\pi=0.23$, $\alpha_\pi-\beta_\pi=7.05$
- ☑ QCD sum rules $\alpha_\pi=5.6\pm0.5$
- ☑ Dispersion sum rules $\alpha_\pi+\beta_\pi=0.166\pm0.024$, $\alpha_\pi-\beta_\pi=13.60\pm2.15$



Different theoretical models predict quite different values of pion polarizabilities. Experimental measurement provides the stringent test of theoretical approaches.

Experimental results for α_π and β_π

10^{-4} fm^3

$\pi^- + A \to \pi^- + A + \gamma$ process

SIGMA-AYAKS (Protvino)

$\alpha_\pi = 6.9 \pm 1.4_{stat} \pm 1.2_{syst}$ (for $\alpha_\pi + \beta_\pi = 0$)

$\gamma + p \to \gamma + \pi^+ + n$ process

Lebedev

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

A2 (MAMI)

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

$\gamma + \gamma \to \pi^+ + \pi^-$ process

MARK II

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

PLUTO

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

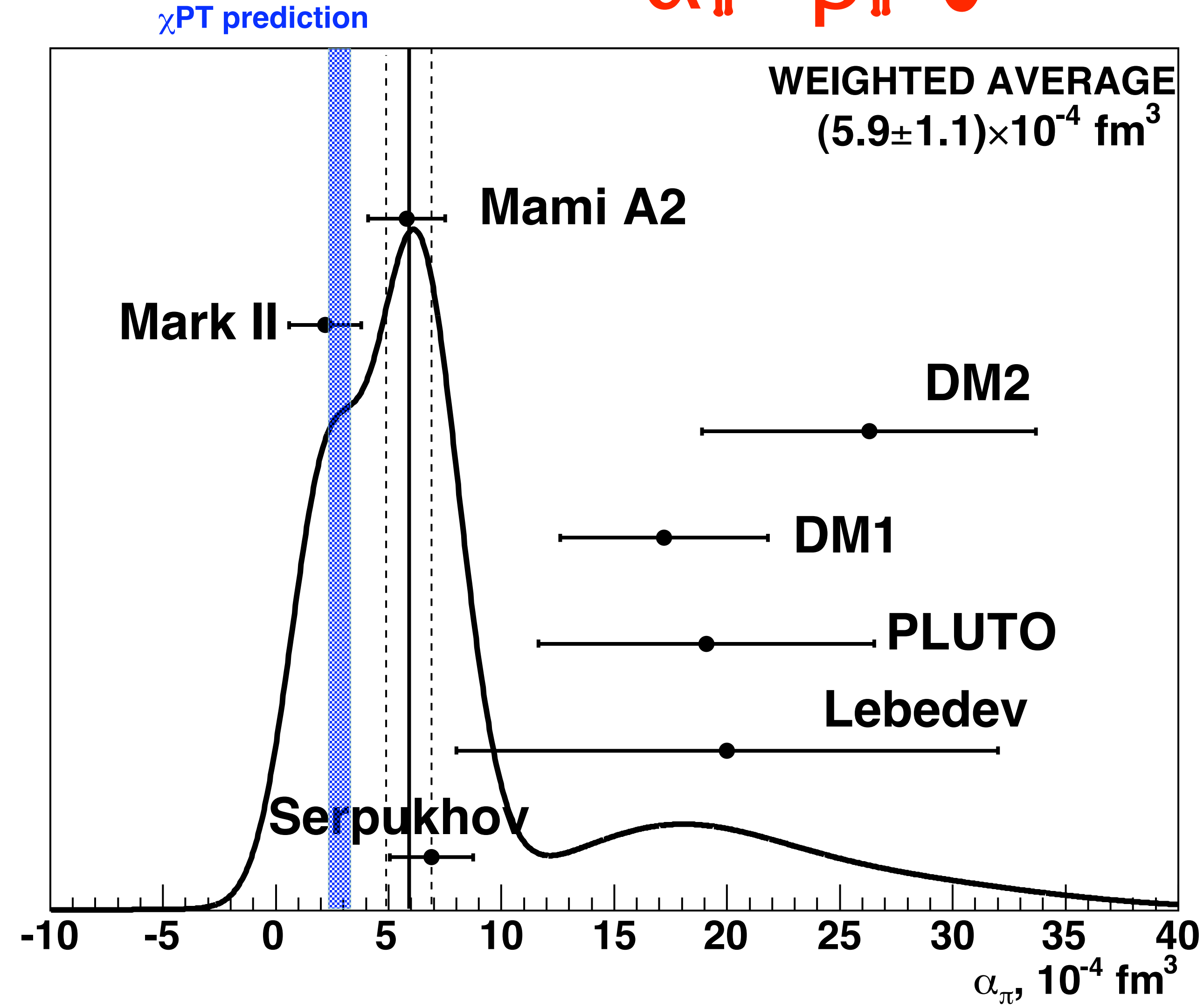
DM1

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

DM2

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

$\alpha_\pi + \beta_\pi = 0$



Global fit of $\gamma + \gamma \to \pi^+ + \pi^-$ data

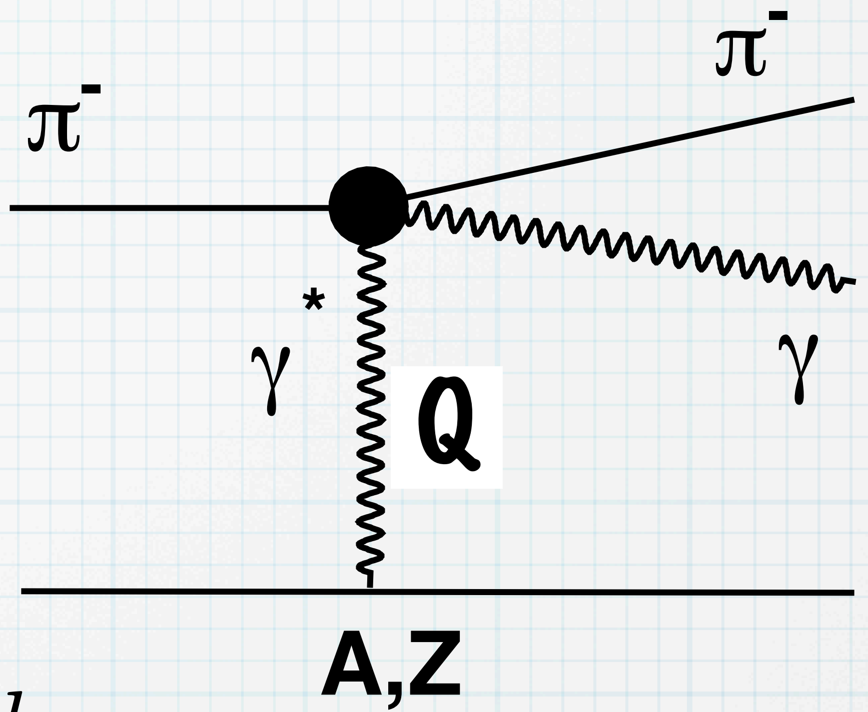
L.V. Fil'kov, V.L. Kashevarov **Phys.Rev.C73:035210,2006**

$$\alpha_\pi - \beta_\pi = 13.0^{+2.6}_{-1.9} \times 10^{-4} fm^3$$

$$\alpha_\pi + \beta_\pi = 0.18^{+0.11}_{-0.02} \times 10^{-4} fm^3$$

Primakoff reaction

$$\pi^- + Pb \to \pi^- + Pb + \gamma$$



In COMPASS we study quasi-real photon Compton scattering on π^-

$$d\sigma = \int d\sigma_{Compton} \times n(\omega_0, k_{0\perp}) d\omega_0 dk_{0\perp}$$

where $q = (\omega_0, k_0)$ is 4-vector of virtual photon

$$\boxed{\sigma_{Compton} = \sigma(\alpha_\pi, \beta_\pi)}$$

Main signatures:

$\sigma \sim Z^2$

$Q << m_\pi$

For measurement of pion polarizabilities we compare the measured differential cross section of Primakoff reaction and the theoretically predicted cross section for point like pion

COMPASS hadron run 2004

TARGETS:

main

Pb 3 mm

Pb 1.6 mm

Pb 2 + 1 mm

C 23,5 mm

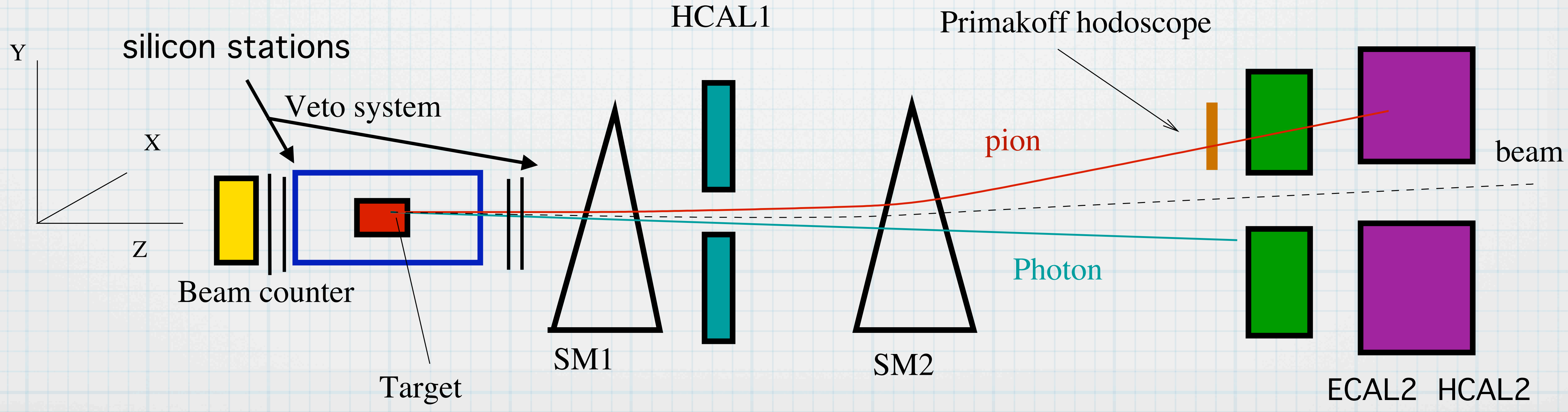
Cu 3.55 mm

Empty target

About 10 days of data taking (pilot run)
Integrated beam flux is 10^{11} pions

Beam:
secondary beam from SPS
π^- (190 GeV)
μ^- (190 GeV)

Trigger:
Primakoff1:
trigger hodoscope +
>50 GeV in electromagnetic calorimeter +
>18 GeV in hadron calorimeter
Primakoff2:
>100 GeV in electromagnetic calorimeter



Primakoff analysis

For measurement of α_π and β_π under approximation $\alpha_\pi + \beta_\pi = 0$ we compare differential cross section

$$\frac{d\sigma}{d\omega}, \text{ where } \omega = \frac{E_\gamma}{E_{beam}}$$

measured and theoretically predicted for point like pion

At COMPASS there is a possibility to measure α_π and β_π independently from comparison of 2-D cross sections

$$\frac{d^2\sigma}{d\omega d\theta}$$, where θ is the angle of photon emission

EVENT SELECTION

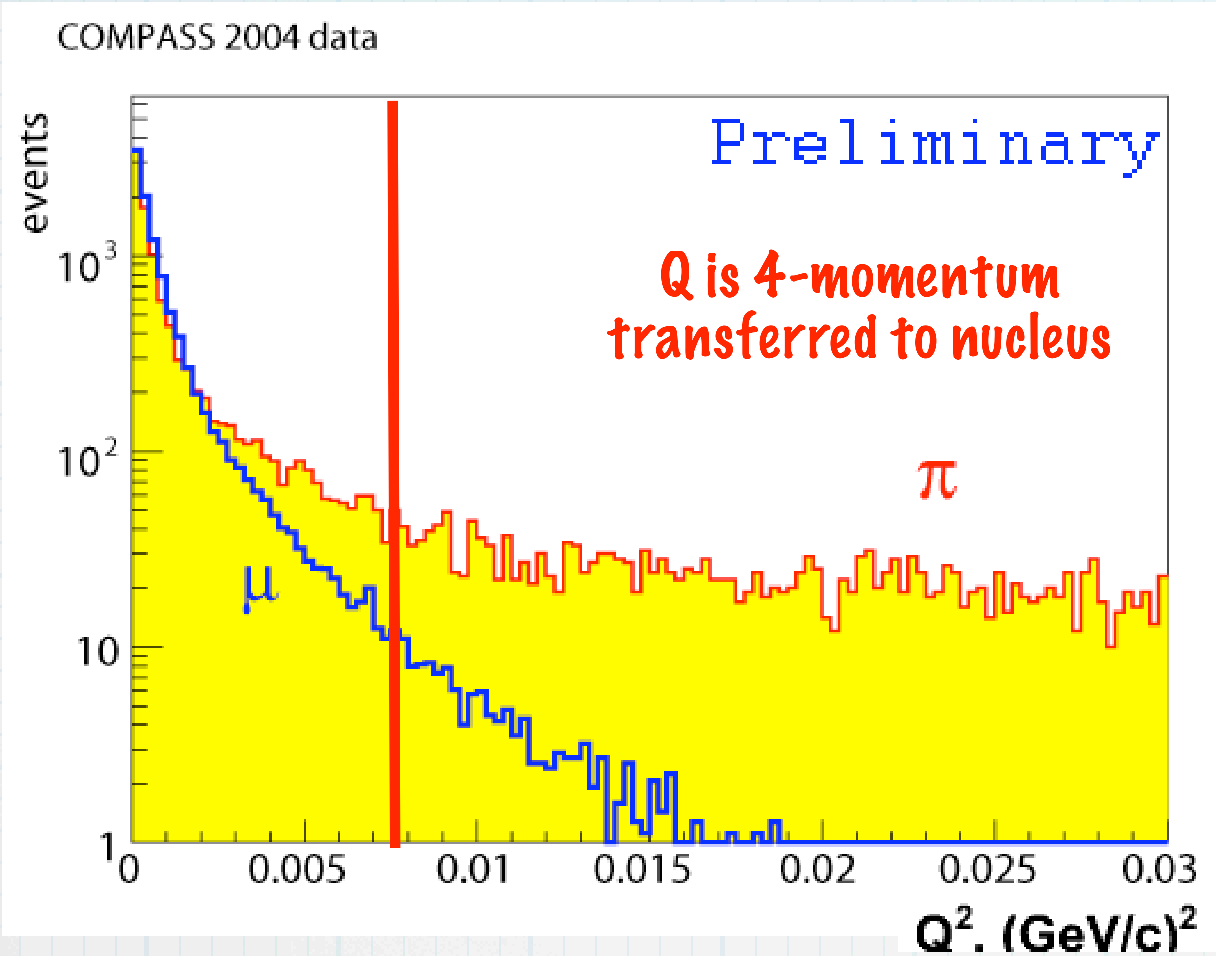
- ☑ $\pi + \gamma$ in the final state
- ☑ primary vertex near the nominal target position
- ☑ invariant mass $M_{\pi\gamma} < 3.75\ M_\pi$
- ☑ $|E_\gamma + P_\pi - P_{beam}| < 25$ GeV
- ☑ $P_t > 45$ MeV/c
- ☑ $0.5 < \omega < 0.9$
- ☑ $q < 7.5\times10^{-3}\ (\text{GeV}/c)^2$

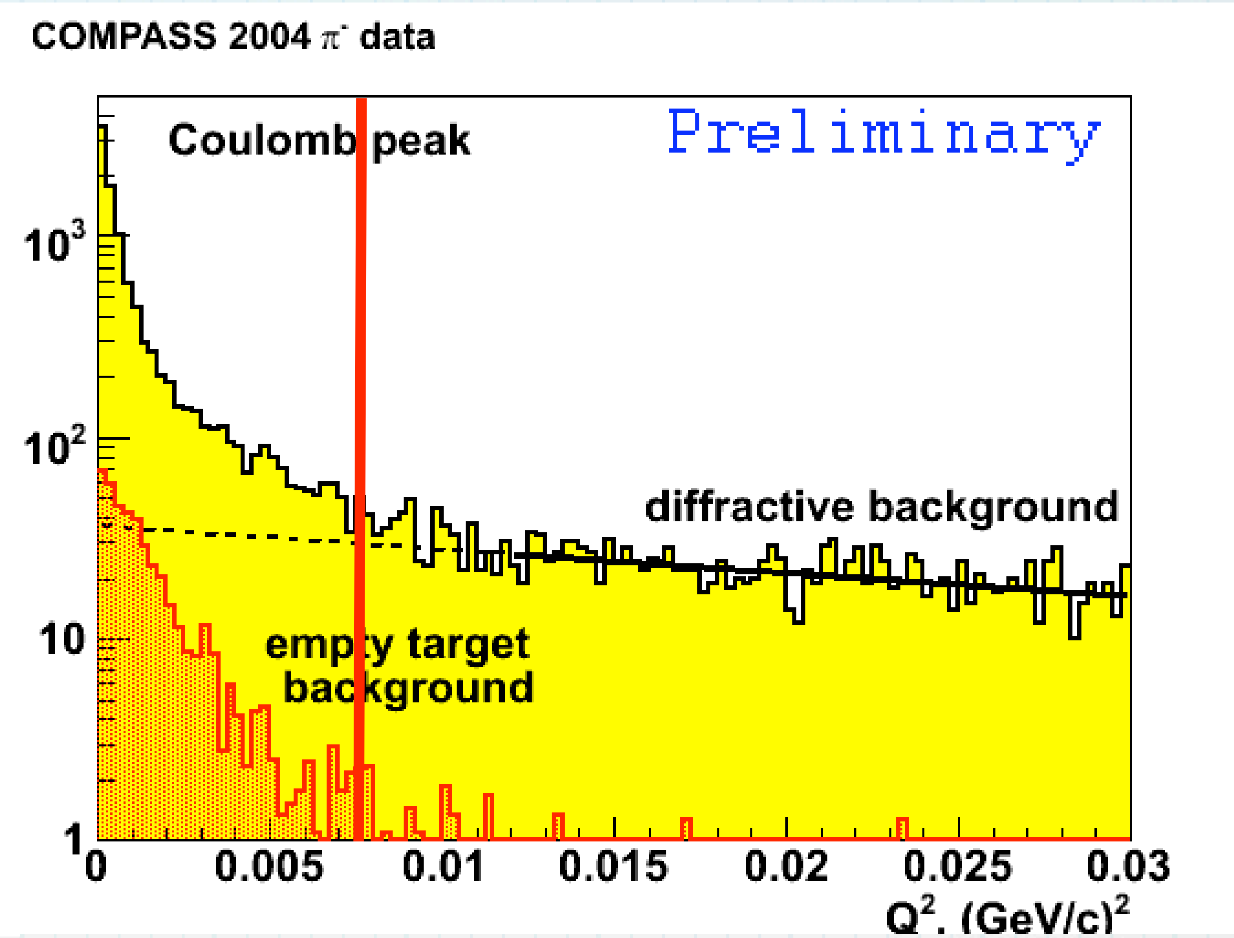
Since muon is the point like particle we use Primakoff statistics collected with muon beam as a reference.

In current analysis only the data with Pb 2+1 mm target and trigger Primakoff2 were used for pion polarizabilities estimation.

≈ 3 full days of data taking

Primakoff and background processes





can be subtracted

1) $\pi^- \rightarrow \pi^- + \gamma$ *diffractive*

2) $K^- \rightarrow \pi^- + \pi^0 \rightarrow \pi^- + \gamma + \gamma$ *(~4% of kaons in the beam)*

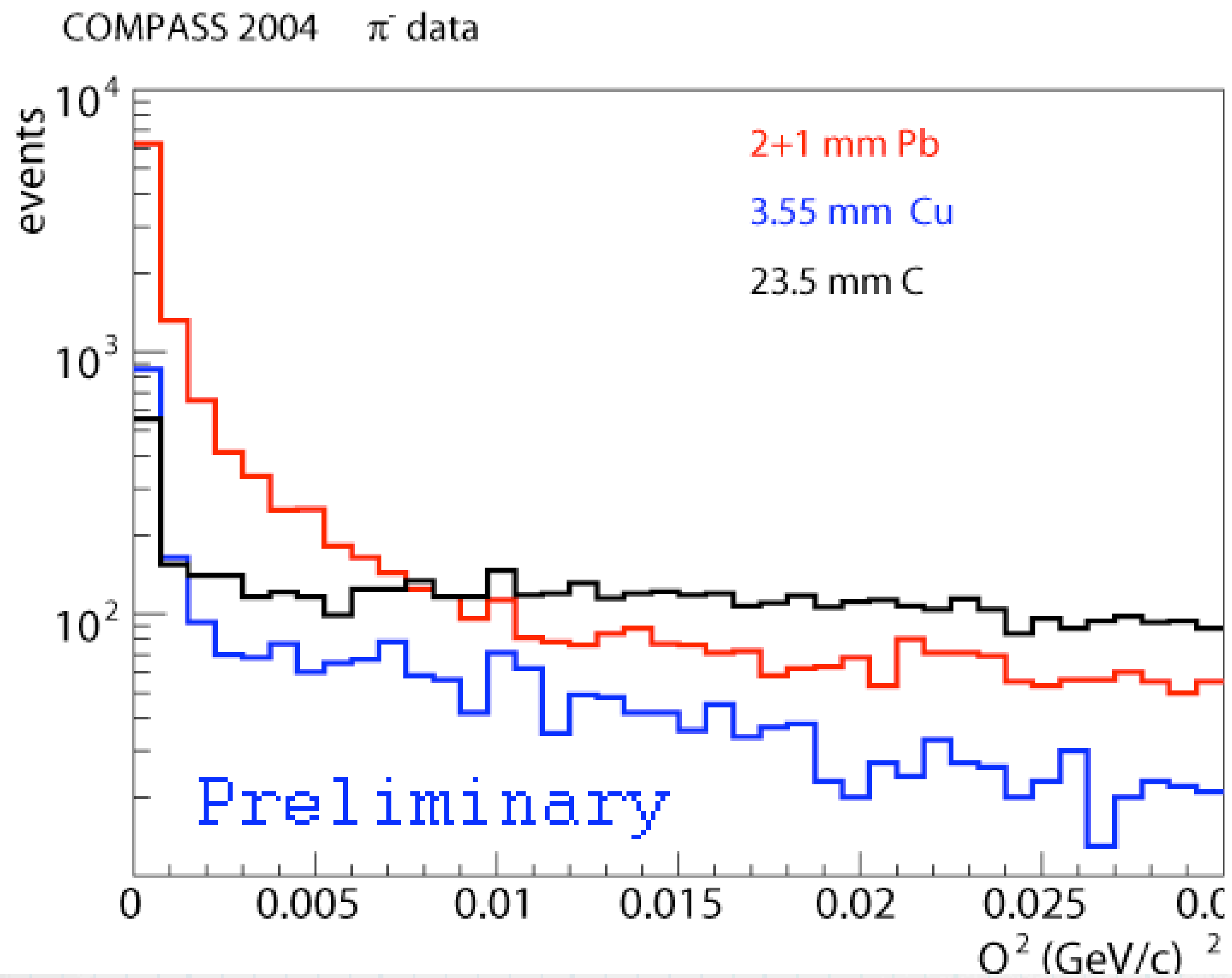
3) $\mu^- \rightarrow \mu^- + \gamma$ *(~3% of muons in hadron beam)* $\rightarrow \sigma_{syst}$

4) $e^- \rightarrow e^- + \gamma$ *(~0.1% of electrons in hadron beam)* suppressed by P_t-cut

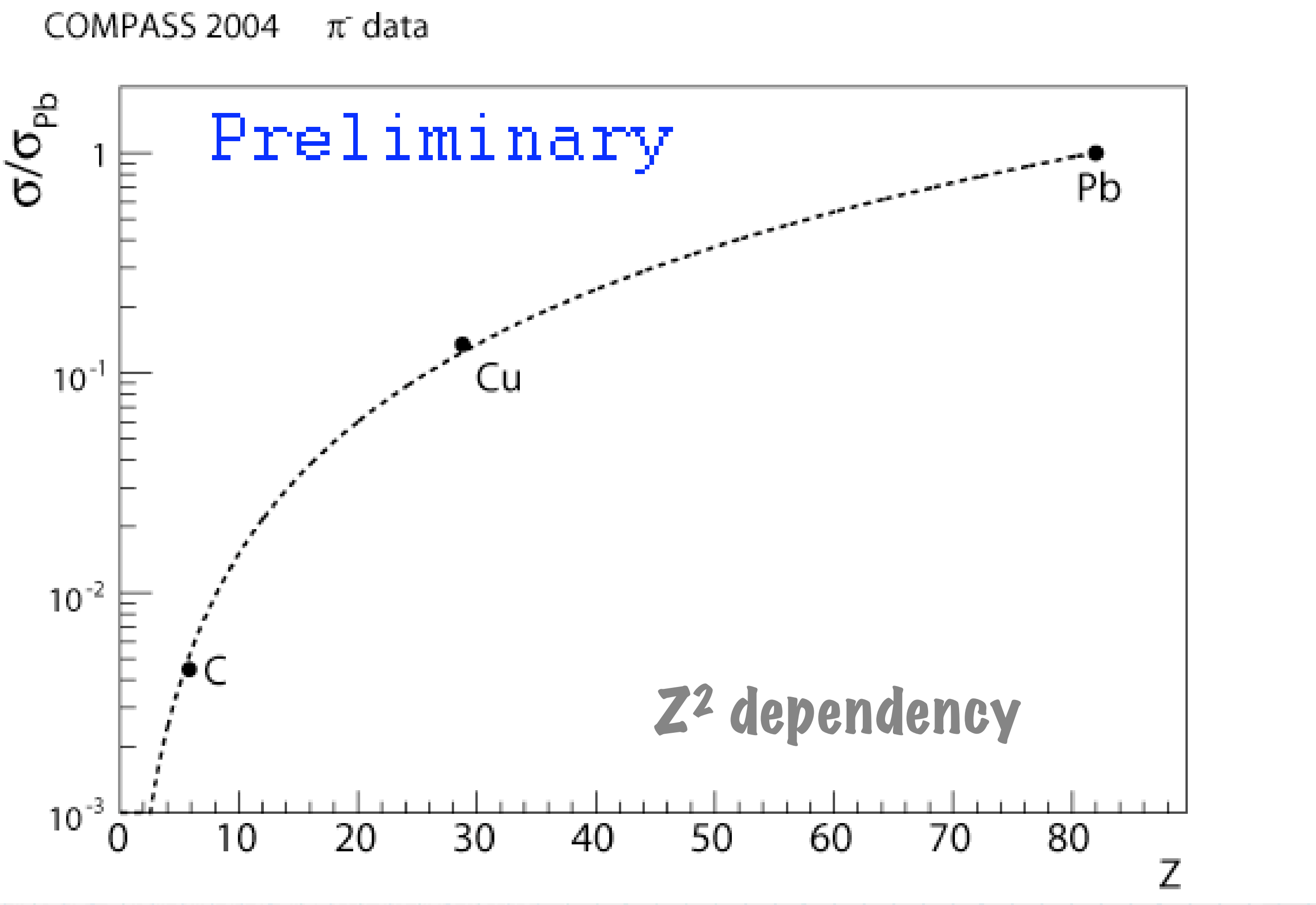
5) $\pi^- \rightarrow \rho^- \rightarrow \pi^- + \pi^0 \rightarrow \pi^- + \gamma + \gamma$ suppressed by $M_{\pi\gamma}$-cut

Primakoff scattering for different targets

Q²-distribution for different target materials



Z-dependency of the Primakoff cross section

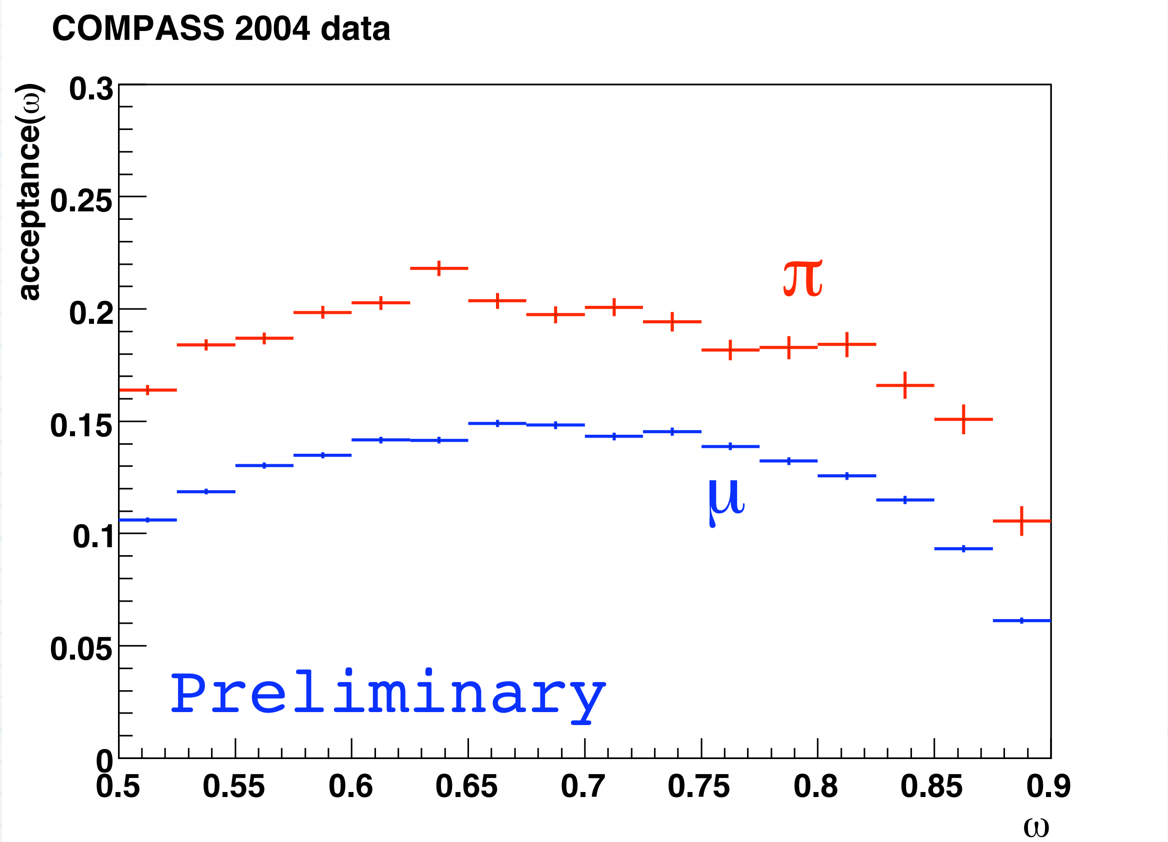


Strong dependency of Primakoff signal (Q=0) to diffractive background (Q>>0.01) ratio on the target material

Good agreement with Z^2-dependency for the Primakoff cross section in the wide Z range

Monte Carlo simulation

- POLARIS generator for Primakoff $\pi\gamma$ and $\mu\gamma$ events (based on the Born approximation for the Primakoff cross sections)
- COMPASS setup simulation based on GEANT3



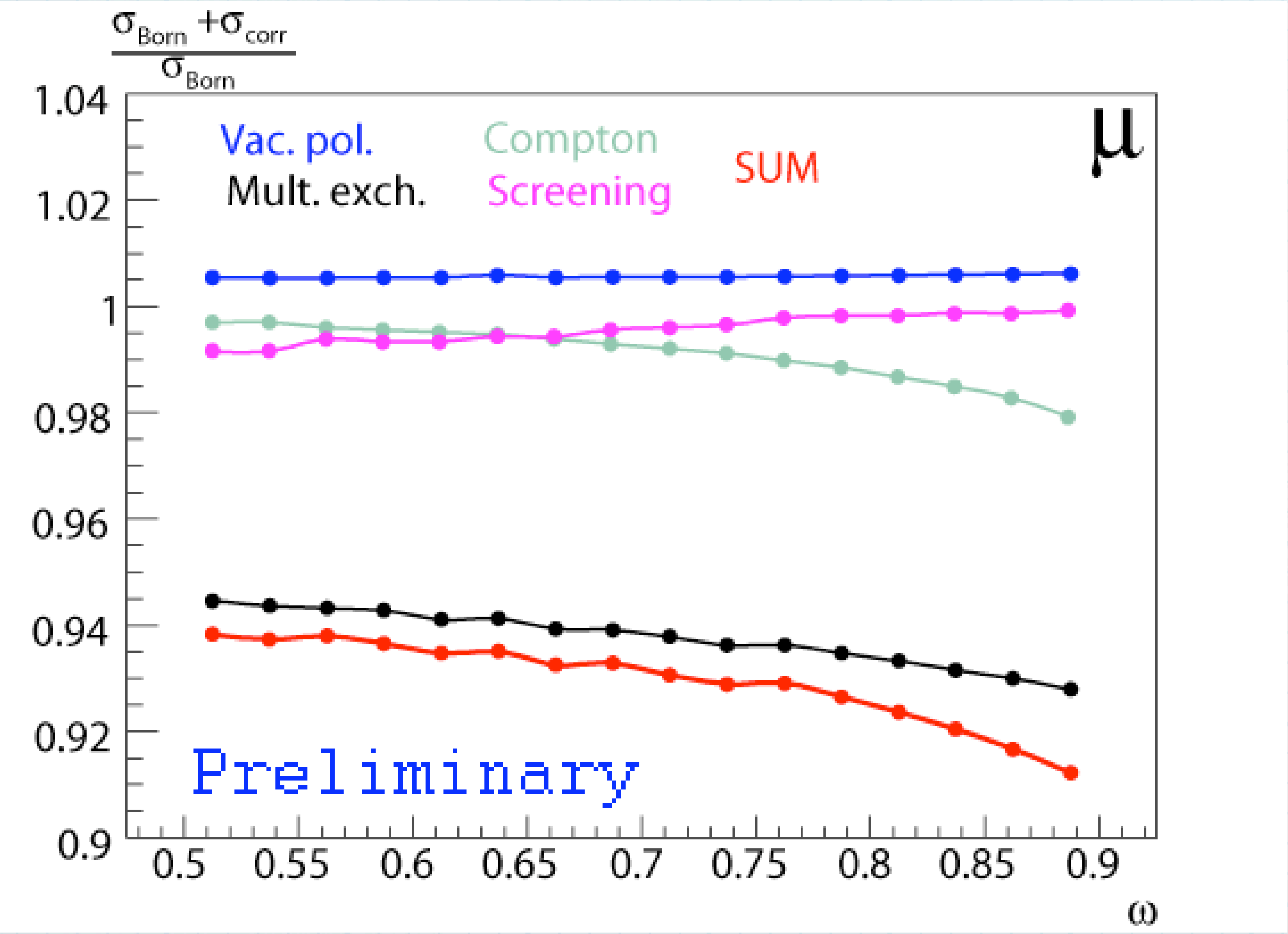
Acceptance of the COMPASS setup for Primakoff events

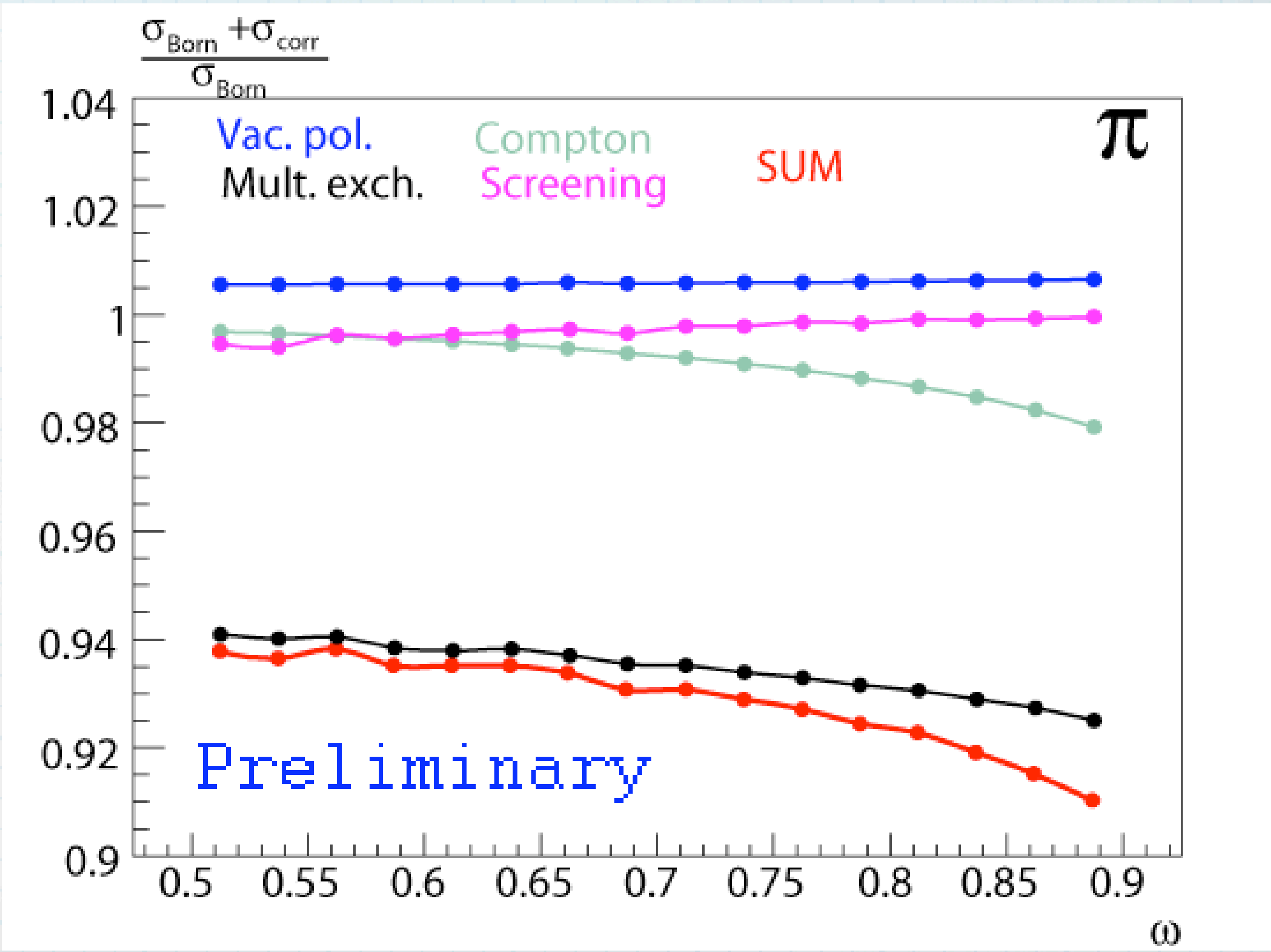
The acceptance behavior is similar for pion and muon events. This fact proves our choice of muon events as reference.

Radiative corrections

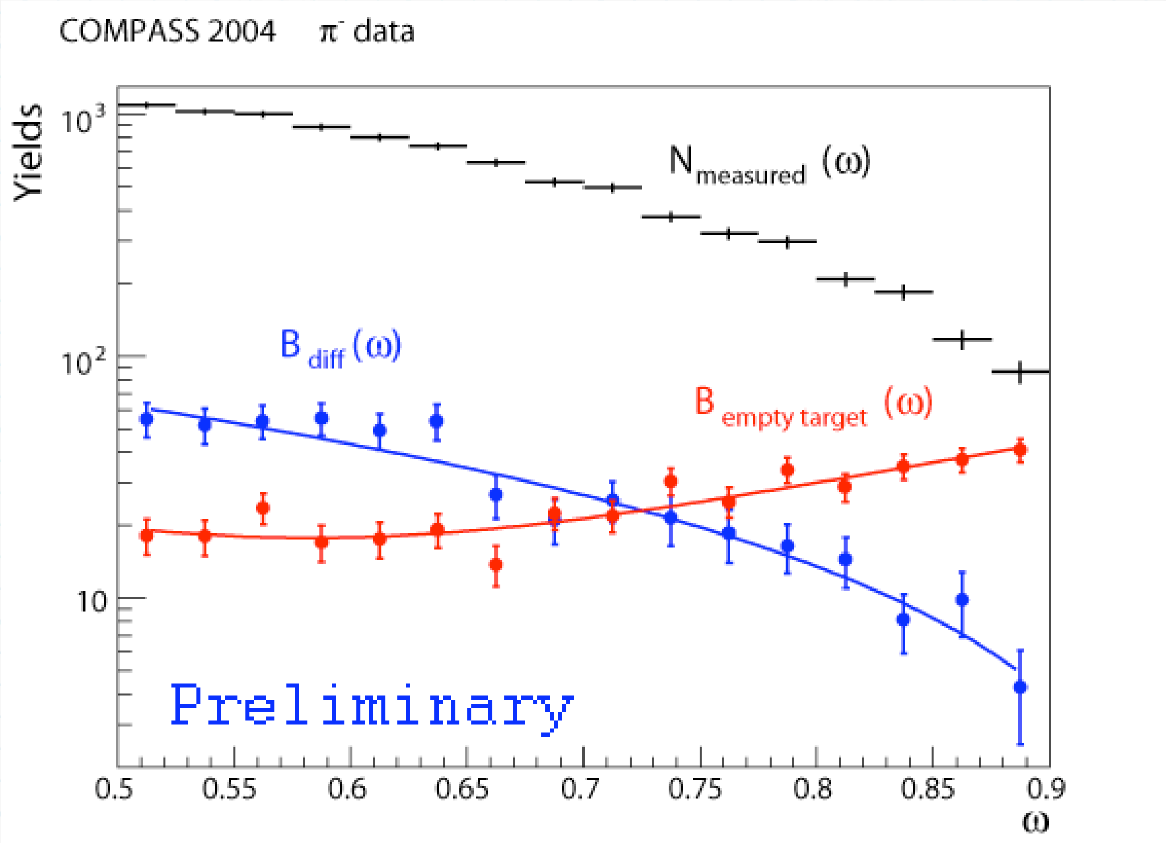
* Vacuum polarization
* Compton vertex
* Multiple photon exchange
* Screening by atomic electrons

In spite of the significant corrections to the Born cross section (6-9%) the correction for pion polarizabilities is not too big: 0.6×10^{-4} fm^3



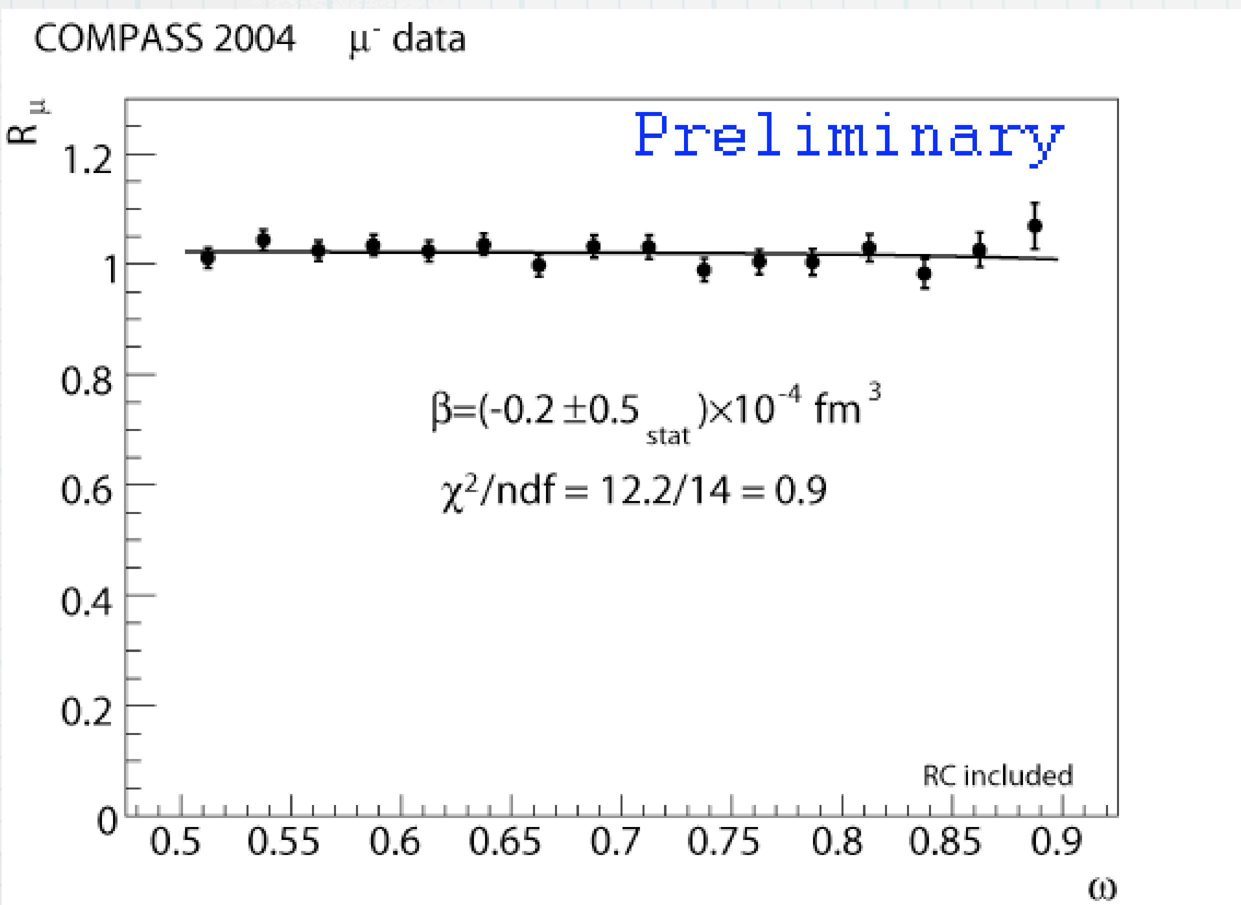


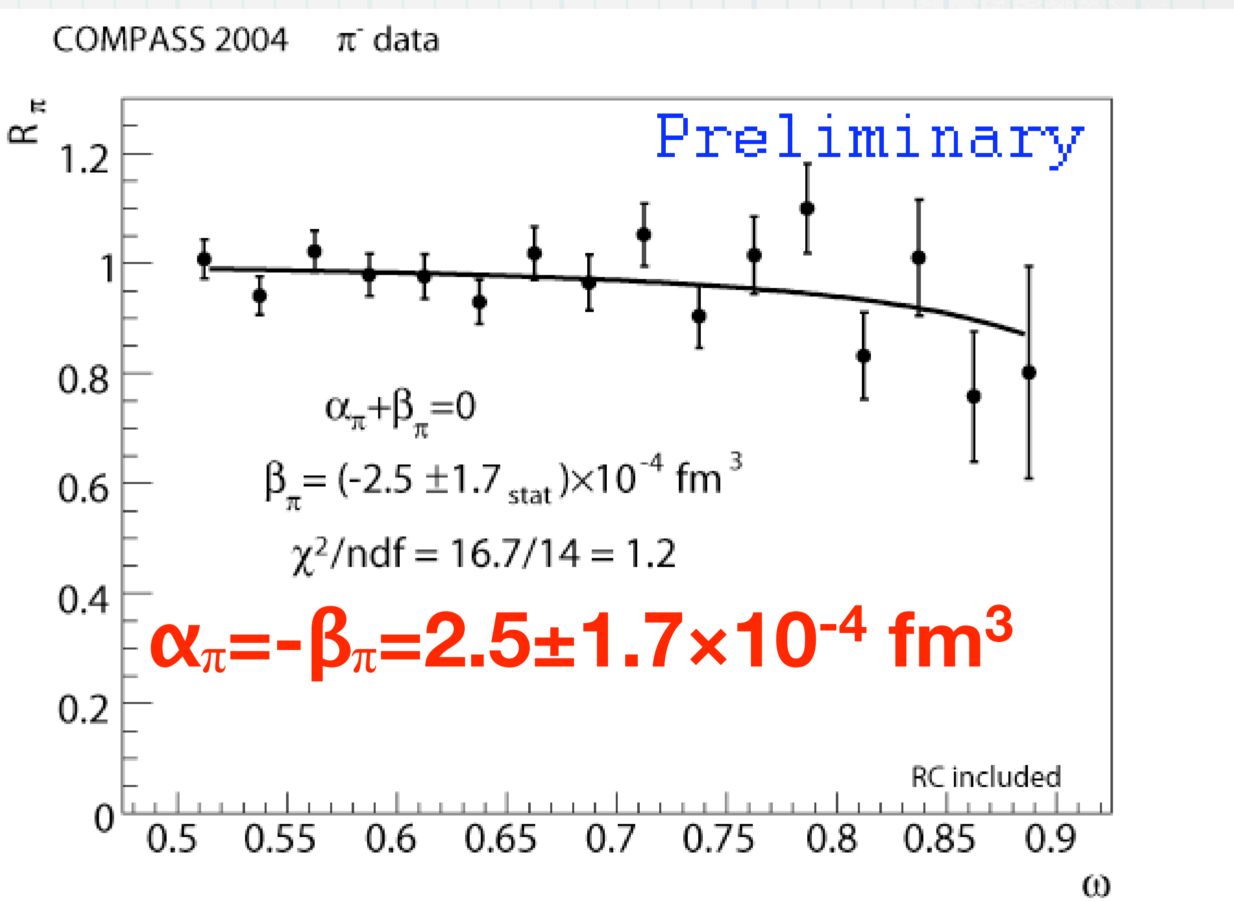
COMPASS results



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

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





$\alpha_\pi=-\beta_\pi=2.5\pm1.7\times10^{-4}$ fm^3

Estimations for systematic error

	Error, 10^{-4} fm^3
Setup description in MC	±0.5
Diffractive and empty target backgrounds subtraction	±0.3
Muon background	+0.2
Electron background	< +0.1
SYSTEMATIC TOTAL	±0.6

$$\alpha_{\pi}=-\beta_{\pi}=(2.5\pm1.7_{stat}\pm0.6_{syst})\times10^{-4}\ \mathrm{fm}^3$$

Experimental results for α_π and β_π

(with COMPASS result)

10^{-4} fm^3

$\pi^- + A \to \pi^- + A + \gamma$ process

COMPASS

$\alpha_\pi = 2.5 \pm 1.7_{stat} \pm 0.6_{syst}$ (for $\alpha_\pi + \beta_\pi = 0$)

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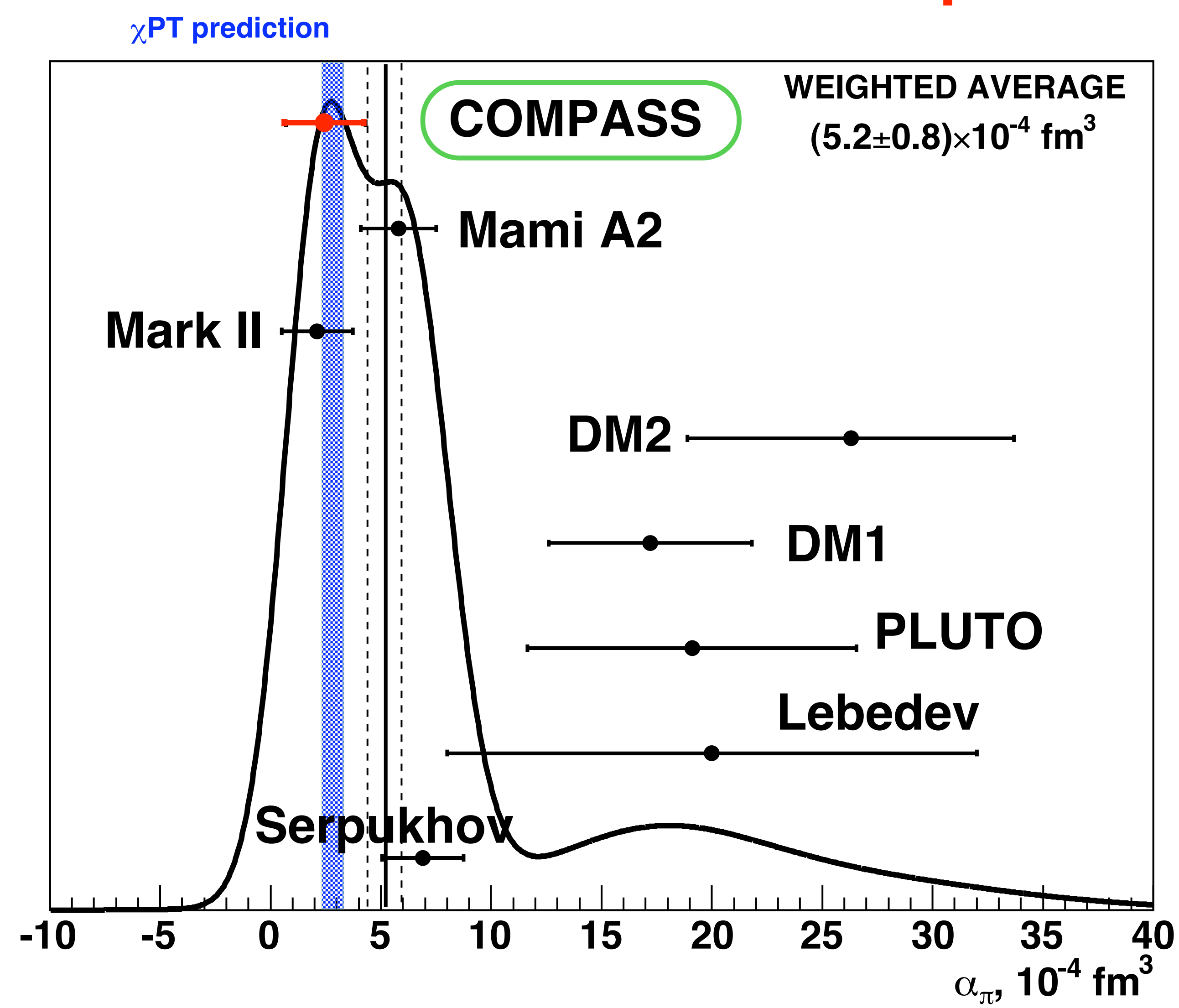

SUMMARY

- Preliminary result of the measurement of pion polarizabilities at COMPASS under approximation $\alpha_\pi + \beta_\pi = 0$ is $\alpha_\pi = -\beta_\pi = (2.5 \pm 1.7_{stat} \pm 0.6_{syst}) \times 10^{-4}\ \mathrm{fm}^3$.
- Current result demonstrates the great possibilities of COMPASS setup: present statistical uncertainty (achieved during about 3 days of data taking is on the level of the most precise previous measurements. The systematic uncertainty also not too big and mainly appointed by limited statistics with muon beam for MC setup description test.
- Current precision of polarizabilities measurement is not enough for test of the theoretical models. At COMPASS we plan to perform new data taking for Primakoff reaction for more precise measurement of α_π and β_π