The possibility of pion polarizabilities measurement at COMPASS

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on behalf of the COMPASS collaboration

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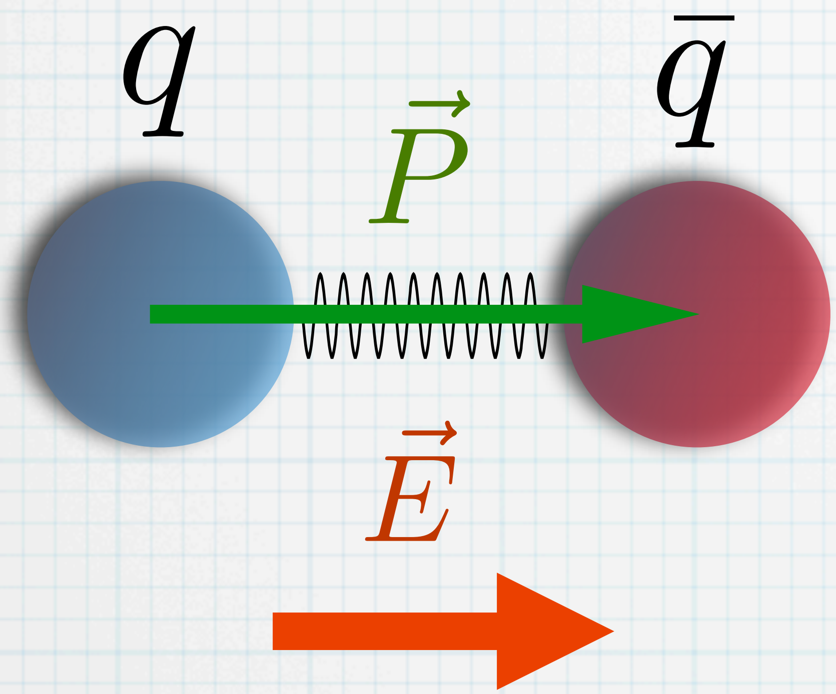
Pion polarizabilities

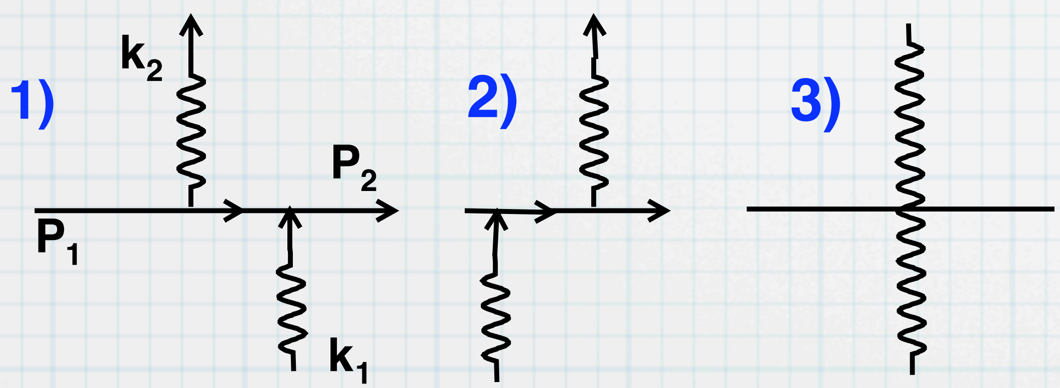


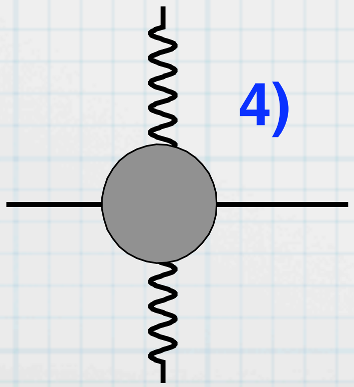
$$\vec{P} = \alpha_\pi \times \vec{E}$$

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

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

$\pi\,\gamma$ -scattering diagrams for point like pion





Corrections related to the pion internal structure

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

$$\mathrm{H} = -\frac{1}{2}(\alpha_\pi E^2 + \beta_\pi H^2)$$

Theoretical predictions for pion polarizabilities

Model	Parameter	$[10^{-4} fm^3]$
χPT	$\alpha_\pi - \beta_\pi$	5.7 ± 1.0
	$\alpha_\pi + \beta_\pi$	0.16
NJL	$\alpha_\pi - \beta_\pi$	9.8
QCM	$\alpha_\pi - \beta_\pi$	7.05
	$\alpha_\pi + \beta_\pi$	0.23
QCD sum rules	$\alpha_\pi - \beta_\pi$	11.2 ± 1.0
Dispersion sum rules	$\alpha_\pi - \beta_\pi$	13.60 ± 2.15
	$\alpha_\pi + \beta_\pi$	0.166 ± 0.024

Different theoretical models predict quite different values of pion polarizabilities. An experimental measurement provides a stringent test of theoretical approaches.

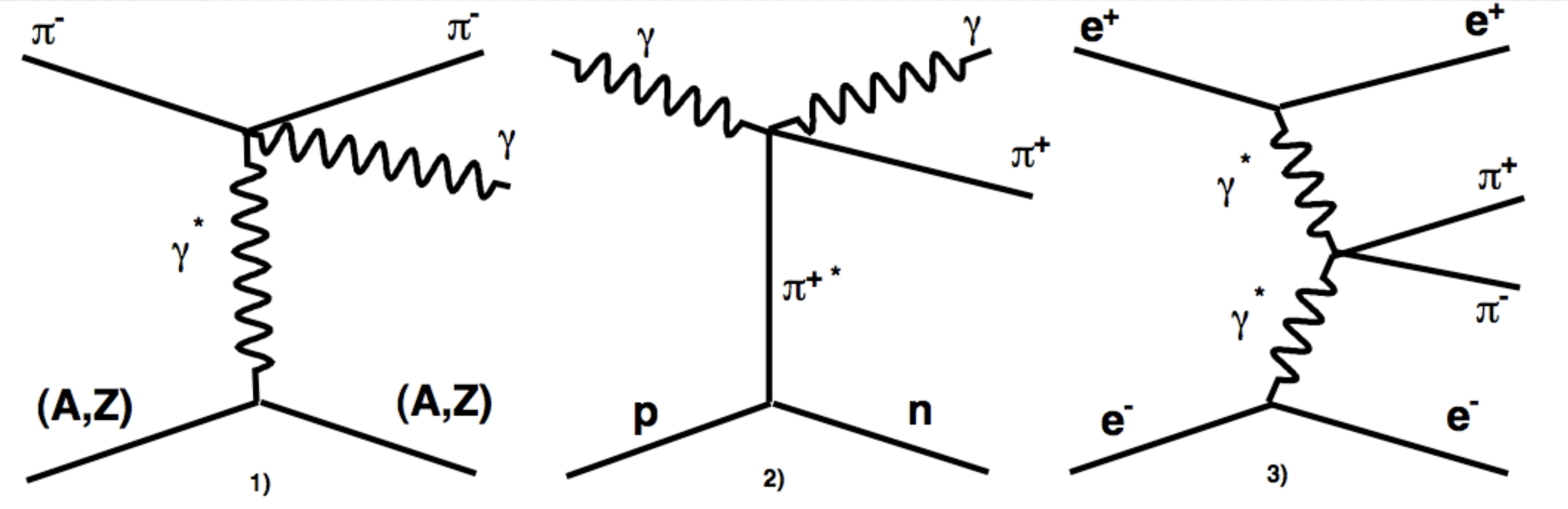
Experimental results for α_π and β_π

3 physical processes were used for experimental study of pion polarizabilities:

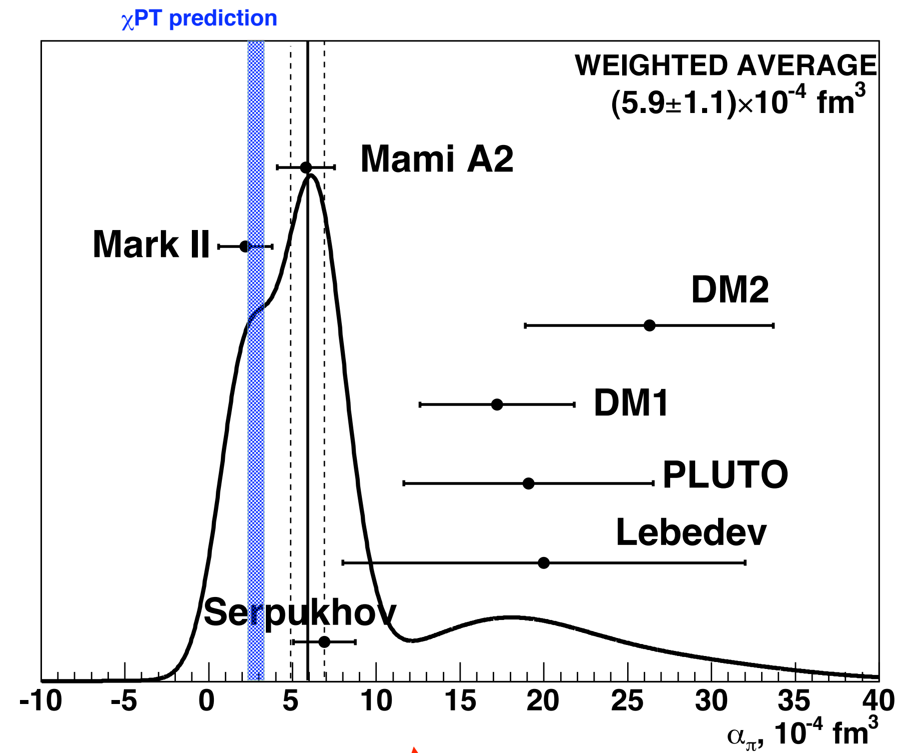
1) $\pi^- + A \rightarrow \pi^- + A + \gamma$

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

3) $e^+ + e^- \rightarrow \pi^+ + \pi^-$



Experimental results for α_π and β_π



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

Data	Reaction	Paramater	$[10^{-4} fm^3]$
Serpukhov ($\alpha_\pi + \beta_\pi = 0$)	$\pi Z \to \pi Z \gamma$	α_π	6.8±1.4±1.2
Serpukhov ($\alpha_\pi + \beta_\pi \neq 0$)		$\alpha_\pi + \beta_\pi$ β_π	1.4±3.1±2.8 $-7.1 \pm 2.8 \pm 1.8$
Lebedev	$\gamma N \to \gamma N \pi$	α_π	20±12
Mami A2	$\gamma p \to \gamma \pi^+ n$	$\alpha_\pi - \beta_\pi$	11.6±1.5±3.0±0.5
PLUTO	$\gamma\gamma \to \pi^+\pi^-$	α_π	19.1±4.8± 5.7
DM1	$\gamma\gamma \to \pi^+\pi^-$	α_π	17.2±4.6
DM2	$\gamma\gamma \to \pi^+\pi^-$	α_π	26.3±7.4
Mark II	$\gamma\gamma \to \pi^+\pi^-$	α_π	2.2±1.6
Global fit: MARK II, VENUS, ALEPH, TPC/2γ, CELLO, BELLE (L. Fil'kov, V. Kashevarov)	$\gamma\gamma \to \pi^+\pi^-$	$\alpha_\pi - \beta_\pi$ $\alpha_\pi + \beta_\pi$	$13.0^{+2.6}_{-1.9}$ $0.18^{+0.11}_{-0.02}$
Global fit: MARK II, Crystal ball (A. Kaloshin, V. Serebryakov)	$\gamma\gamma \to \pi^+\pi^-$	$\alpha_\pi - \beta_\pi$	5.25 ± 0.95

COMPASS - a fixed target experiment on SPS at CERN

MUON PROGRAM

- ΔG/G
- Structure functions
- Exclusive production of vector mesons
- Λ-physics
- Transversity

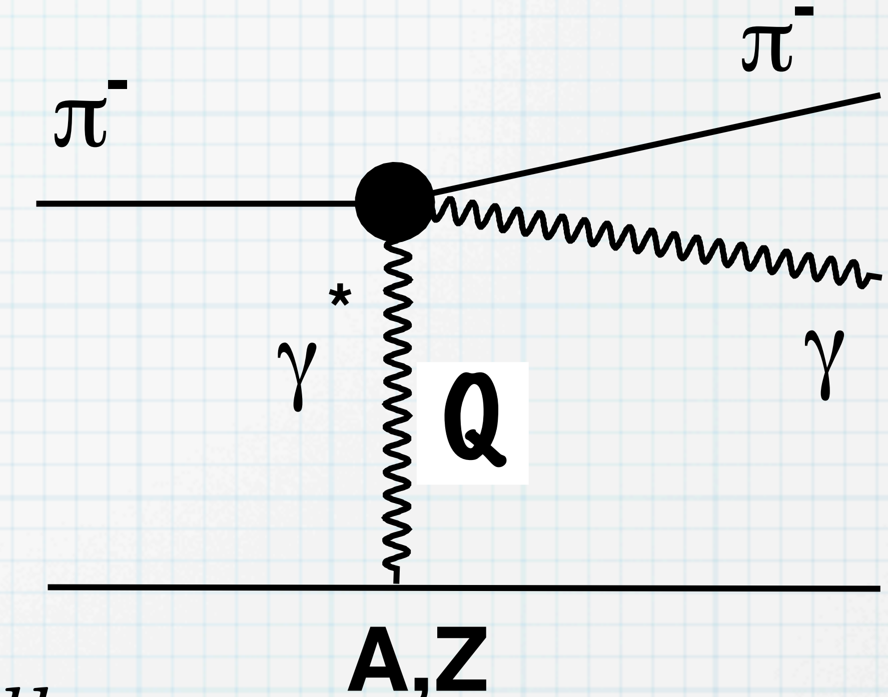
HADRON PROGRAM

- Pion polarizabilities
- Chiral anomaly
- Charm baryons
- Glueballs and exotic mesons

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
2008–2009 – data taking with hadron beam

Primakoff reaction

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



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

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

Main signatures:

$\sigma \sim Z^2$

$Q \ll m_\pi$

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

Primakoff analysis

$$R = \frac{\sigma_{real}}{\sigma_{p.l.}} \approx 1 - \alpha_{\pi,K} \times \frac{3m^3_{\pi,K}}{2\alpha} \times \frac{\omega^2}{1-\omega}$$

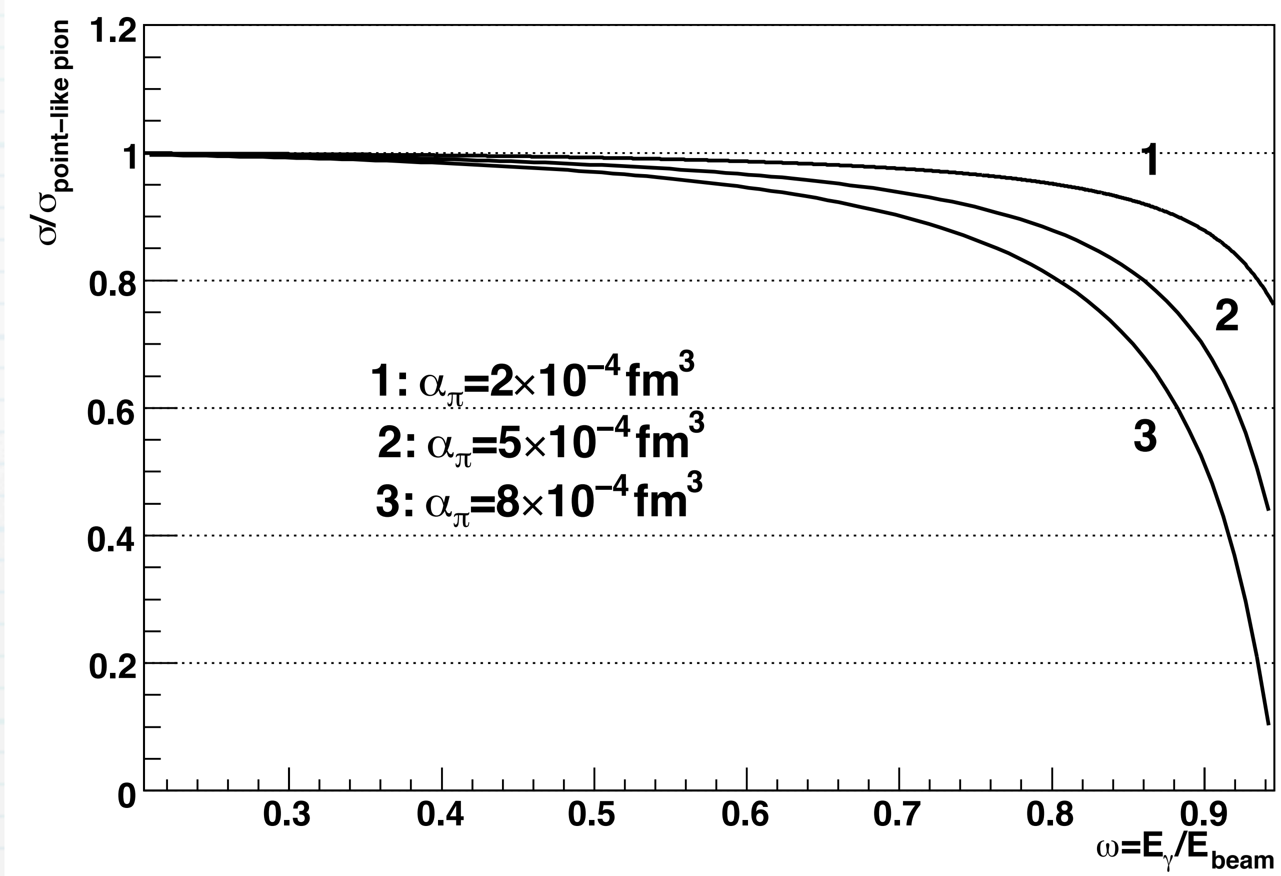
For measurement of α_π and β_π

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 also 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

COMPASS pilot hadron run 2004

TARGETS:

main

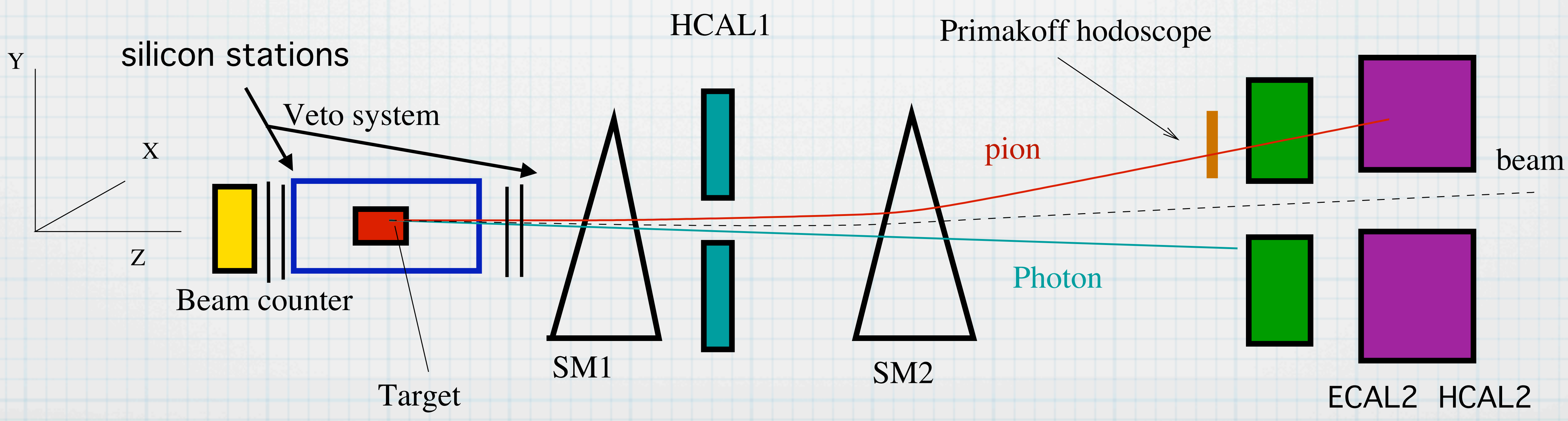
- Pb 3 mm
- Pb 1.6 mm
- Pb 2 + 1 mm
- C 23,5 mm
- Cu 3.55 mm
- Empty target

About 10 days of data taking
Integrated beam flux is 10^{11} pions

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

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

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



Outcome of the pilot hadron run 2004

* Possibility to detect and analyze Primakoff scattering at COMPASS was demonstrated
* Analysis procedure (selection criteria, MC simulation) was tested and optimized
* Study of the numerous background processes was performed
* Possible statistical error and contributions to the systematic uncertainties from different sources were estimated
* The obtained experience is used for the preparation of the new data taking

Q^2-distribution for pion and muon events

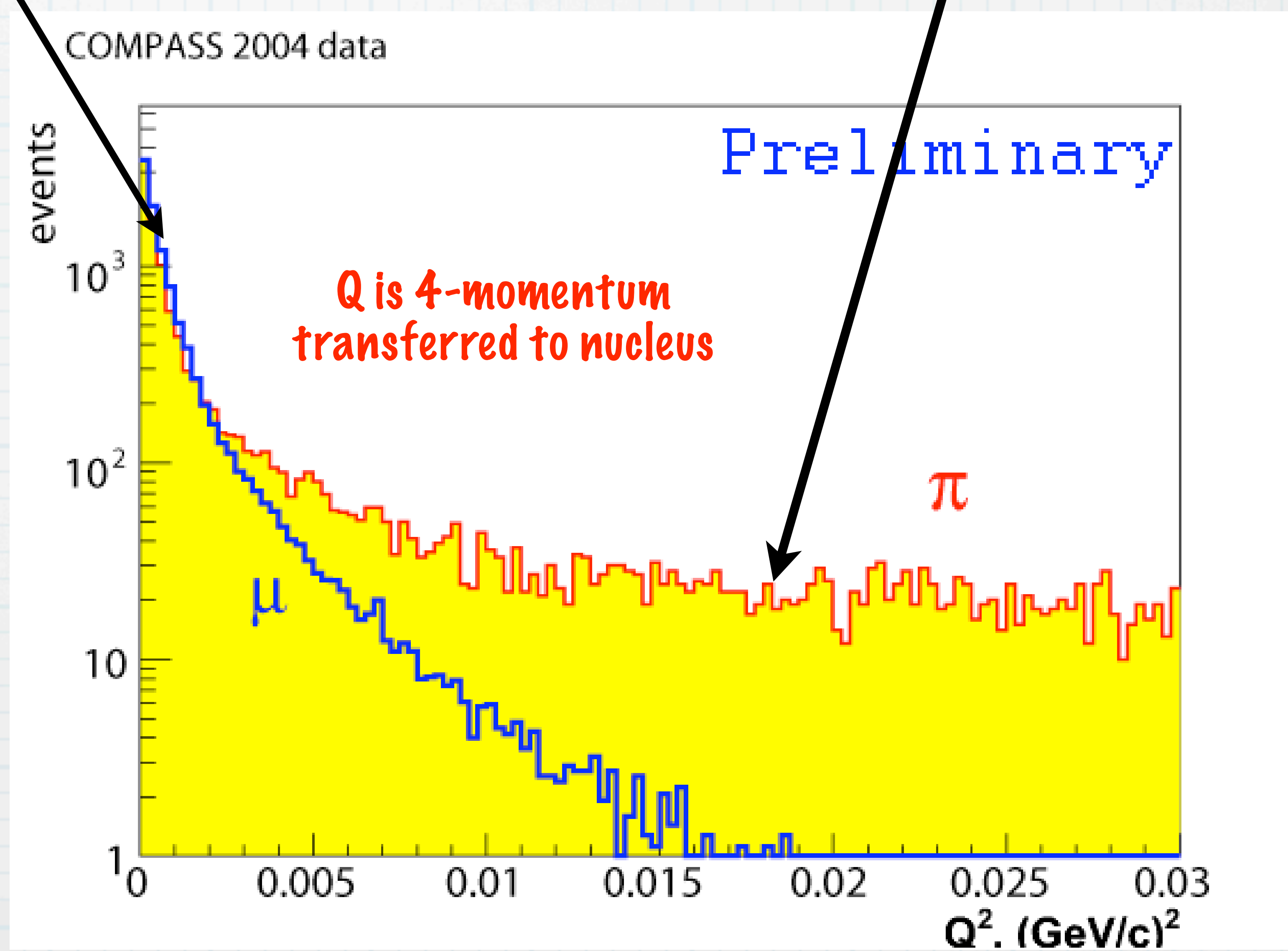
Primakoff peak $\approx e^{-\frac{Q^2}{dQ^2}}$

Setup resolution
$dQ \simeq 18$ MeV/c

Diffractive background

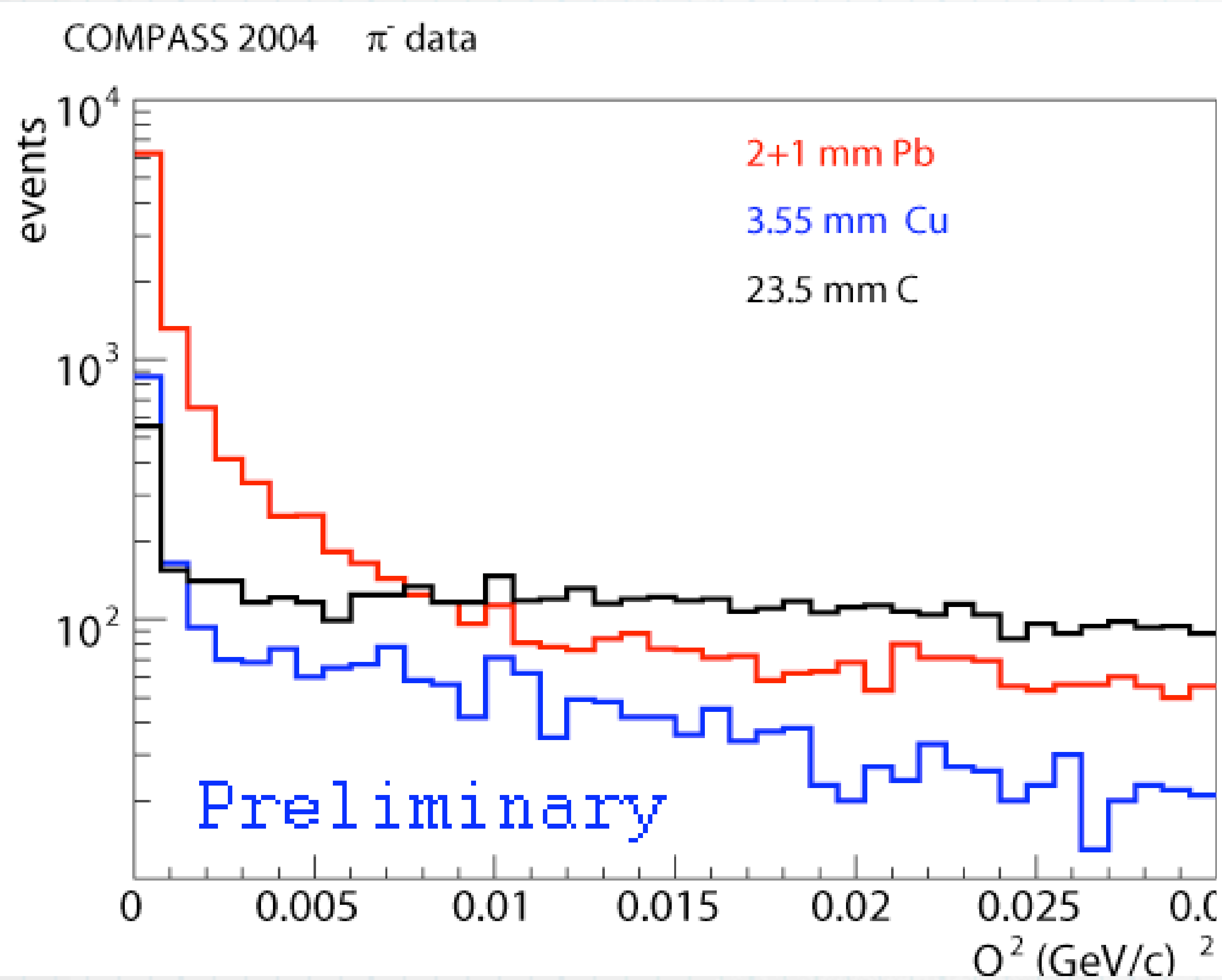
Selection criteria

- One negatively charged particle and one photon with E>7 GeV 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
- $0.5 < \omega < 0.9$

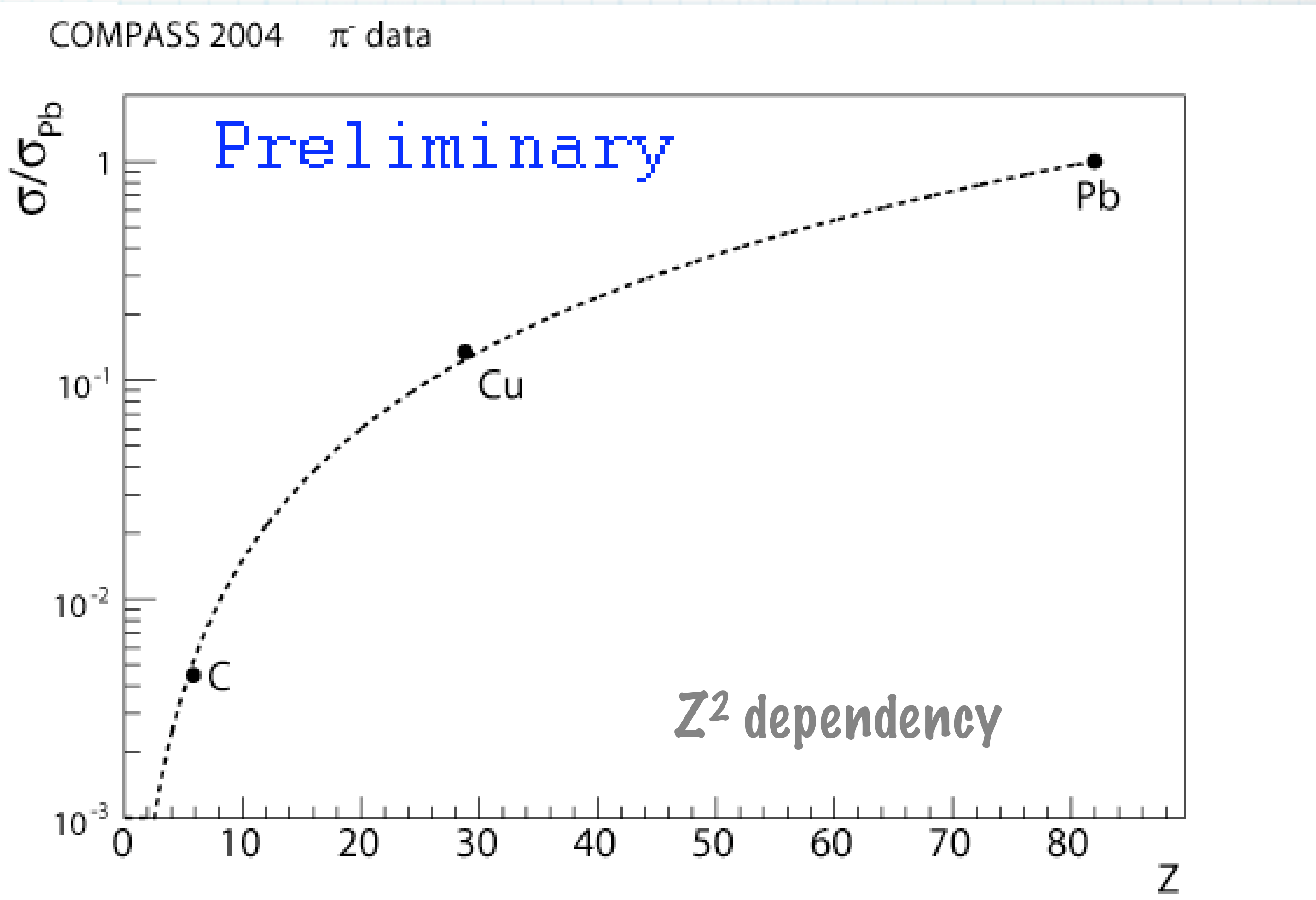


Primakoff scattering for different targets

Q^2-distribution for different target materials



Z-dependency of the Primakoff cross section



Strong dependence 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 a wide Z range

Background processes

$\pi \to \pi\gamma$ (Born)
Primakoff

$\pi \to \pi\gamma$
diffractive

Interference of Primakoff & diffractive

Too many processes correspond to $\pi^- \gamma$ (E_γ >7 GeV) final sate !

Correction to Compton vertex	Vacuum polarization	Nuclear charge screening	Multiple photon exchange	Electromagnetic form factor of nucleus
$e \to e\gamma$	$\mu \to \mu\gamma$	$K \to K\gamma$	$p \to p\gamma$	
$\pi \to \rho \to \pi^-\pi^0$	$K \to \pi^-\pi^0$	$\pi \to \pi^-\pi^0$ Primakoff	$\pi \to \pi^-\pi^0$ diffractive	
$K \to K^*(892) \to K^-\pi^0$	$K \to K_2^*(1430) \to K^-\pi^0$		$\pi \to \pi^-\pi^0\gamma$ (all channels)	

Preparation for new data taking

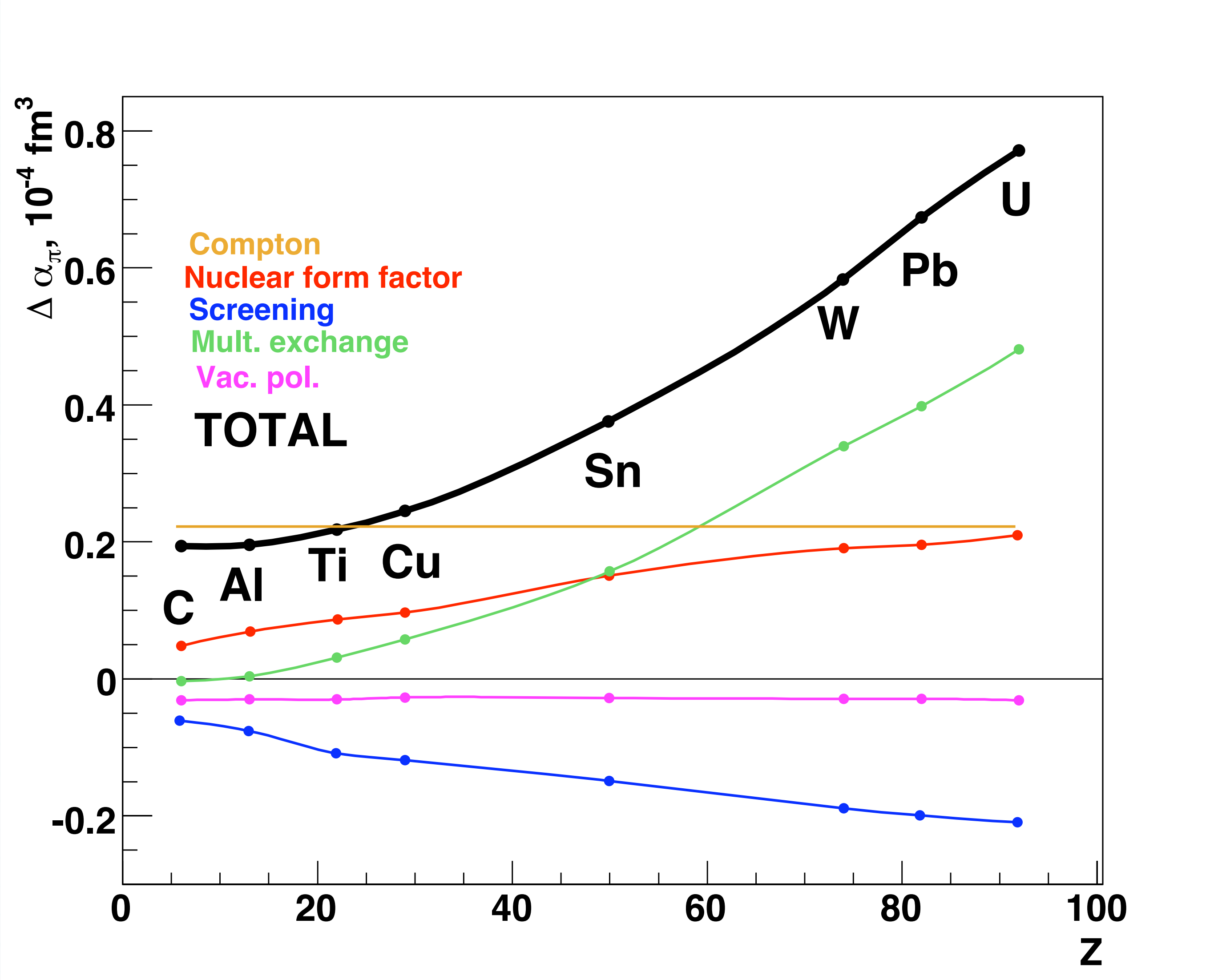
Nov. 2009, about 3 weeks of data taking

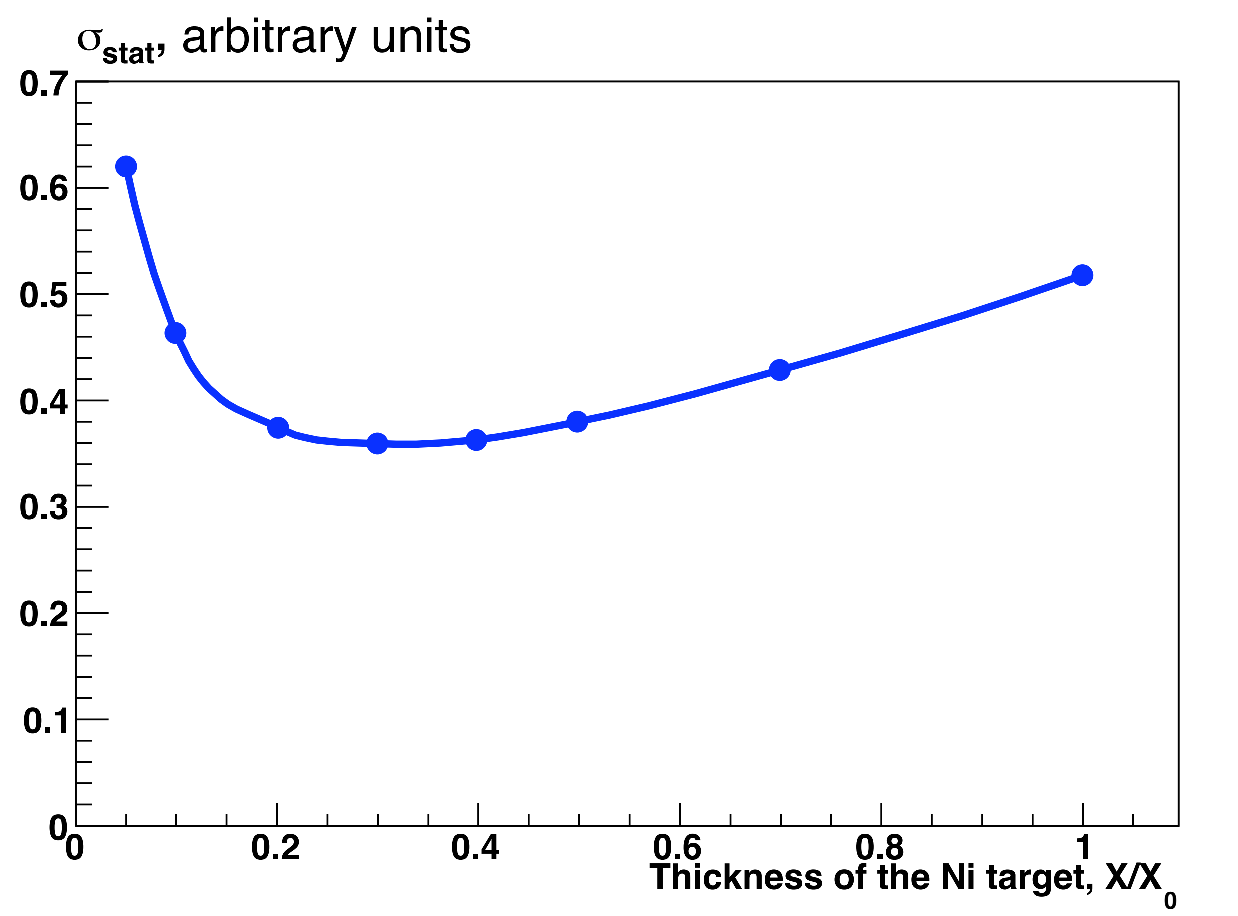
* Beam intensity and particle identification
* Target optimization
* Trigger optimization

Beam

* New COMPASS DAQ provides possibility to increase intensity of 190 GeV/c pion beam from $5 \cdot 10^6$ to $2 \cdot 10^7$ and intensity of 190 GeV/c muon beam from $2 \cdot 10^7$ to $2 \cdot 10^8$ per spill
* Since 2008 COMPASS has possibility to use the differential cherenkov counter (CEDAR) for identification of beam kaons

Target optimization





Radiative corrections for **Pb** target, used in 2004, are too high. For new data taking we plan to use **^{58}Ni** (0-spin) target

To optimize the statistical error we plan to reduce target thickness from **0.5** to **0.3 X_0**

Trigger optimization

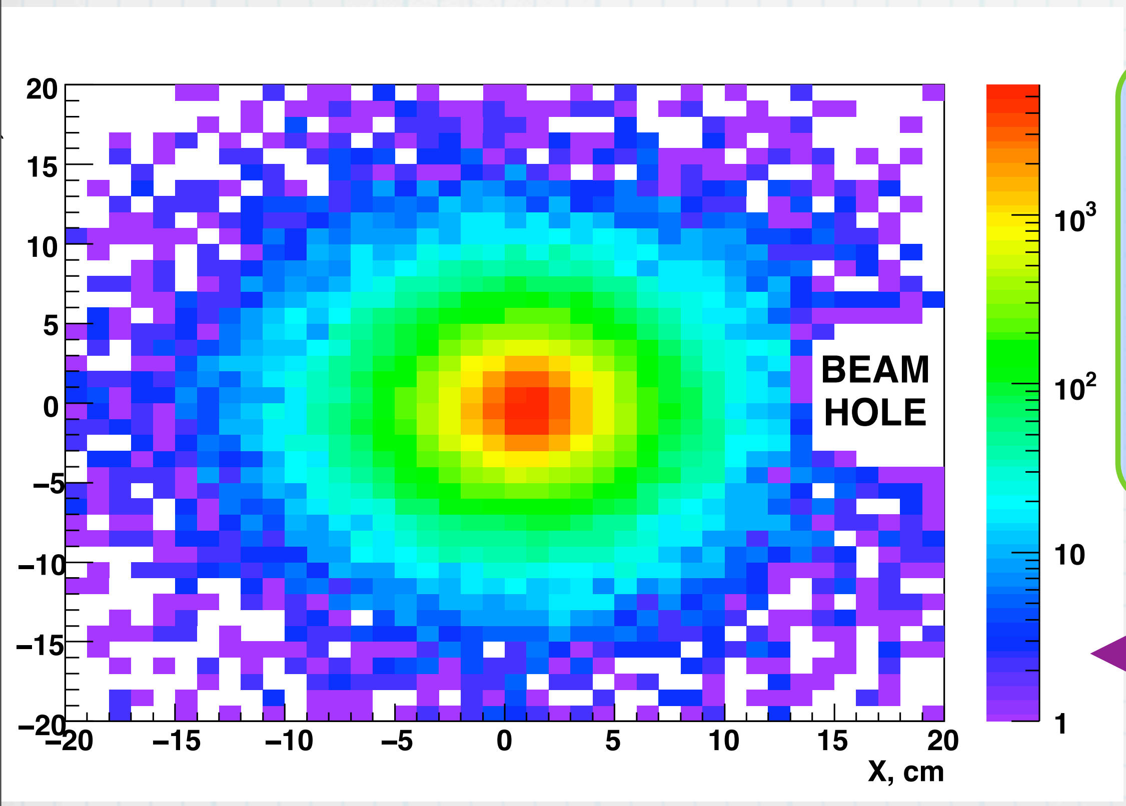
Primakoff1: veto+
trigger hodoscope +
>50 GeV in electromagnetic calorimeter +
>18 GeV in hadron calorimeter (π beam only)
Primakoff2: veto+
>100 GeV in electromagnetic calorimeter

2004

New trigger will be more simple and exactly the same for muon and pion beams.

2009

Primakoff: veto+
> 30-40 GeV in the central cells of the electromagnetic calorimeter



Primakoff photons in the electromagnetic calorimeter (MC)

Run 2009: Expectations

Total flux (pions)	$5.7 \cdot 10^{11}$
Total flux (muons)	$5.7 \cdot 10^{11}$
Number of Primakoff $\pi\gamma$ events (ω>0.5)	150 000
Statistical error σ_α, 10^{-4} fm^3 ($\alpha_\pi+\beta_\pi=0$)	0.4
Best possible systematic error $\Delta\alpha_\pi$, 10^{-4} fm^3 ($\alpha_\pi+\beta_\pi=0$)	0.2
Statistical error σ_α, σ_β, 10^{-4} fm^3 ($\alpha_\pi+\beta_\pi\neq0$)	0.8

New opportunities:

- The first measurement of α_π dependence on the kinematic variables $\omega, \sqrt{s}, t$. Some theoretical models predict such dependencies (see arXiv: 0907.0983v1 for example)
- First observation of Primakoff scattering with kaons estimation of α_K

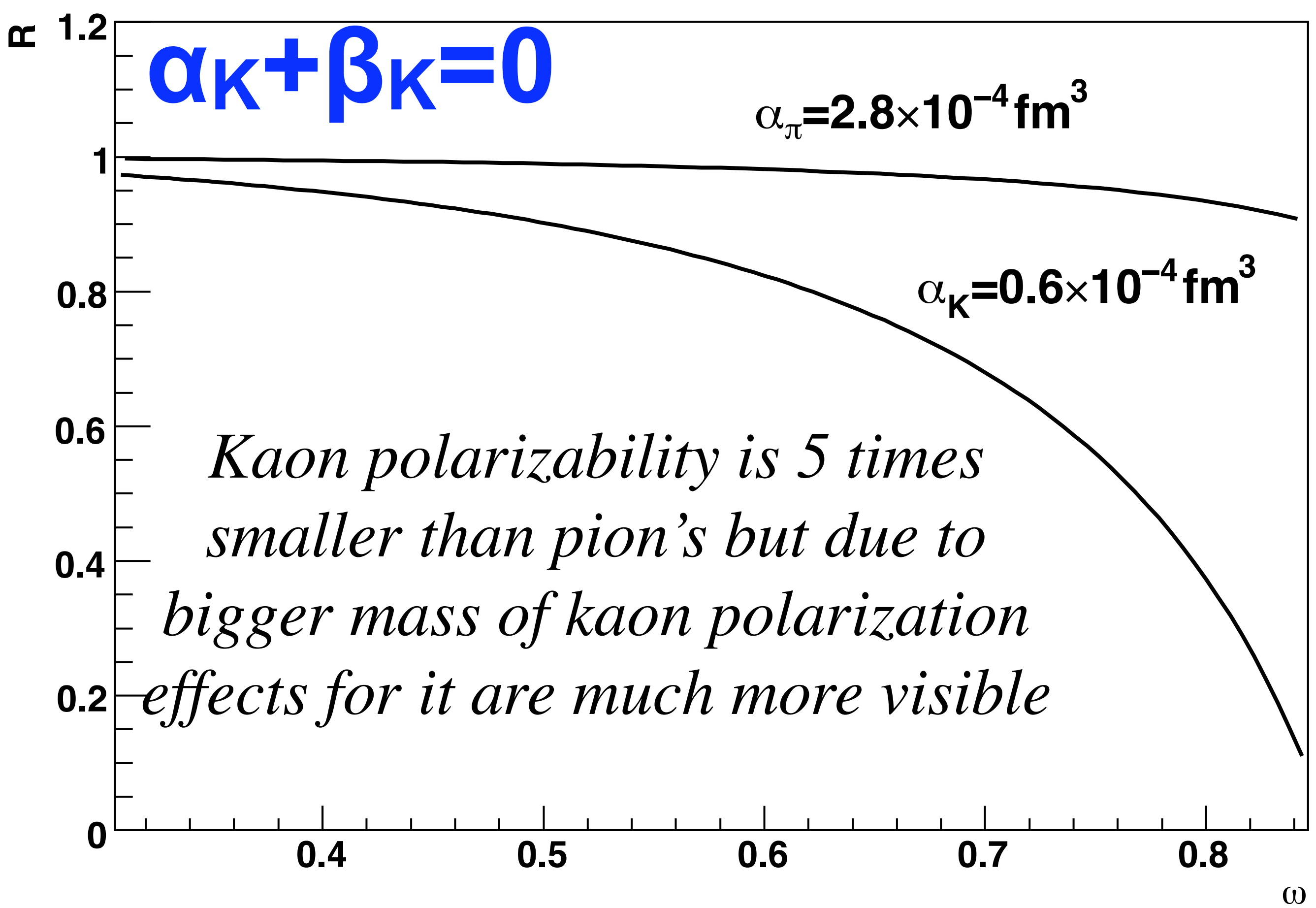
Kaon Primakoff scattering

Theoretical prediction:

$$\alpha_K = \alpha_\pi \times \frac{m_\pi F_\pi^2}{m_K F_K^2} \approx \frac{\alpha_\pi}{5}$$

$$\frac{\sigma_K}{\sigma_\pi} = \frac{m_\pi^2}{m_K^2} \approx 0.08$$

fraction of kaons in hadron beam is about 3% . So we can expect up to ≈300 kaon events



In the best possible case we will be able to perform first estimation of kaon polarizability α_K with statistical error $0.2 \cdot 10^{-4}$ fm³

$$R = \frac{\sigma_{real}}{\sigma_{p.l.}} \approx 1 - \alpha_{\pi,K} \times \frac{3m_{\pi,K}^3}{2\alpha} \times \frac{\omega^2}{1-\omega}$$

Summary

* During the pilot hadron run 2004 the possibility to measure pion polarizabilities at COMPASS was tested. The obtained experience is used for preparation for new data taking in 2009.
* In 2009 COMPASS has a chance to perform the most precise measurement of pion polarizabilities. Expected values of statistical and the best possible systematic errors for the assumption $\alpha_\pi+\beta_\pi=0$ are $0.4 \cdot 10^{-4}$ fm^3 and $0.2 \cdot 10^{-4}$ fm^3 correspondently.
* COMPASS also has a chance to perform the first measurement of the pion polarizability as a function of kinematic variables, observe Primakoff scattering with kaons and estimate kaon polarizability.