Workshop on Future Physics @ COMPASS

Measurement of electric and magnetic π and K polarizability

@ COMPASS

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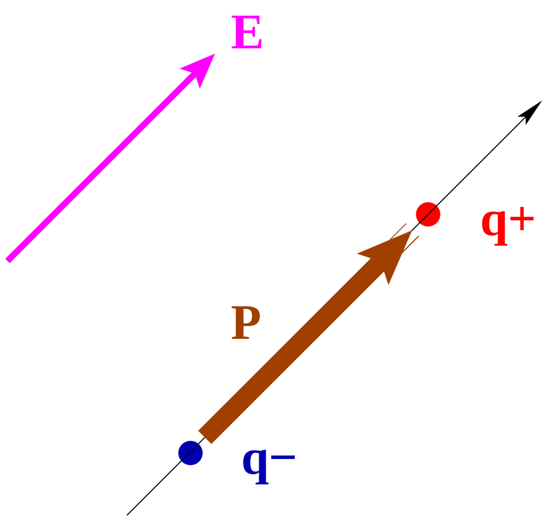
on behalf of the COMPASS coll.

Polarizability

The polarizability (electric α and magnetic β) relates the average dipole (electric $\vec{p}$ and magnetic $\vec{\mu}$) moment to external electromagnetic field.



dipole moment: $\vec{p} \;=\; \alpha\vec{E}$

magnetic moment: $\vec{\mu} \;=\; \beta\vec{H}$

The *polarizability* is a quantity which characterizes a particle like its charge, radius, magnetic moment etc.

Pion polarizabilities

The pion polarizabilities can be described in the framework of the Chiral perturbation Theory ($\underline{\chi PT}$) based on the chiral symmetry of QCD and Goldstone theorem.

Chiral dynamics describes:

- properties
- production
- decay amplitudes
- low-energy interactions

of the $\underline{Goldstone\ boson}$ (π, η, K) among themselves and with γ's.

Pion polarizabilities

The χPT provide a rigorous way to determine $\alpha_\pi, \ \beta_\pi$ via the effective Chiral lagrangian using the coupling constants $L_r^9, \ L_r^{10}$ obtained in the radiative pion beta decay ($\pi^- \ \rightarrow \ e \ + \overline{\nu} \ + \ \gamma$):

$$\overline{\alpha}_\pi \ = \ \frac{4\alpha_f}{m_\pi f_\pi^2}(L_r^9 \ + \ L_r^{10})$$

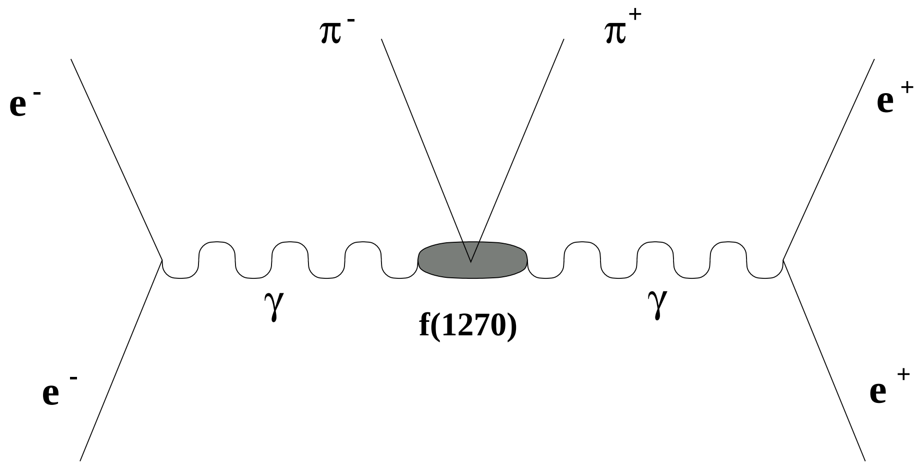
the numerical values are:

$$\overline{\alpha_\pi} = (2.4 \pm 0.5)10^{-4} \ fm^3$$
$$\overline{\beta_\pi} = (-2.1 \pm 0.5)10^{-4} \ fm^3$$

consistent with the chiral symmetry $(\overline{\alpha}_\pi + \overline{\beta}_\pi) = 0$.

$U.\ B\ddot{u}rgi,\ Phys.\ Lett.\ B\, 377\, (1996)\, 147$

Photon-Photon Collision :

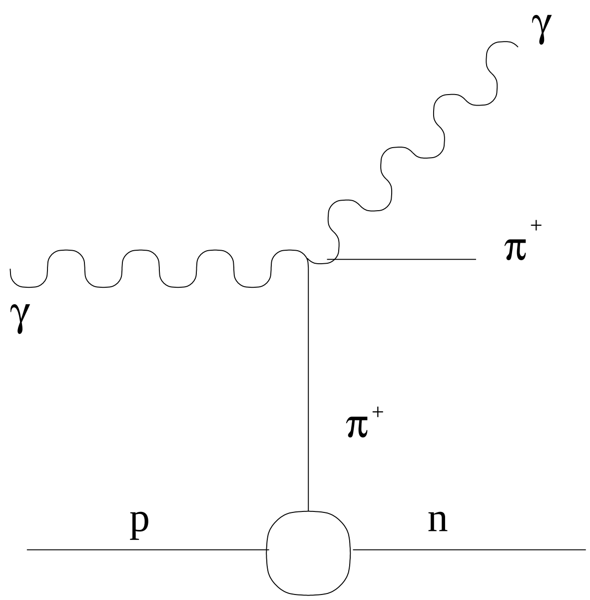


- From the results of the MARK II group (1990)[1] with the reaction $\gamma + \gamma \longrightarrow \pi^- + \pi^+$ the value of $\alpha_\pi = (2.2 \pm 1.6_{stat+sys})10^{-4}\ fm^3$ was deduced [2].

[1] J. Boyer et al., Phys. Rev. D42, 1350 (1990)

[2] P. Babusci et al., Phys. Lett. B 277 158 (1992)

Pion Photoproduction:



- A test made by the Lebedev group (1986) with the reaction

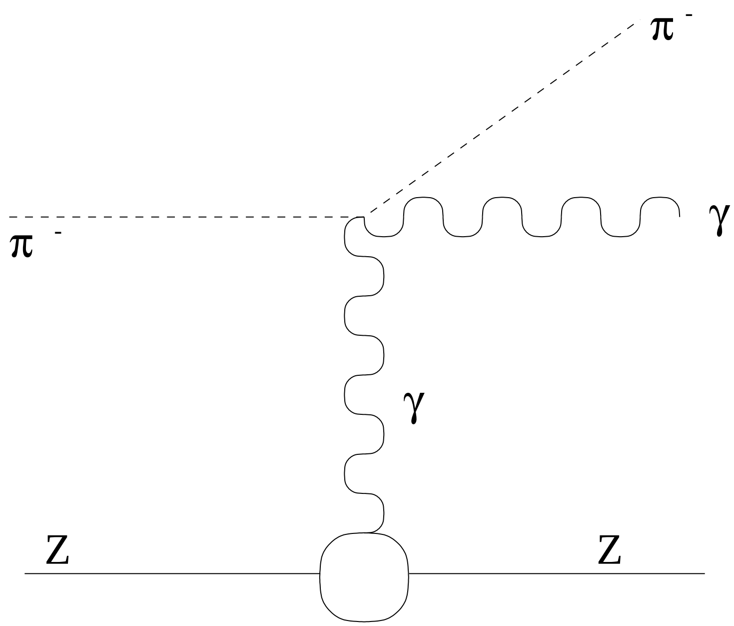
$\gamma + p \longrightarrow \gamma + \pi^+ + n$ showed feasibility.

High precision measurement made @ MAMI (A2 coll.). Data analysis is in progress.

We want to use

$$\pi + \gamma \longrightarrow \pi + \gamma$$

the Primakoff Reaction



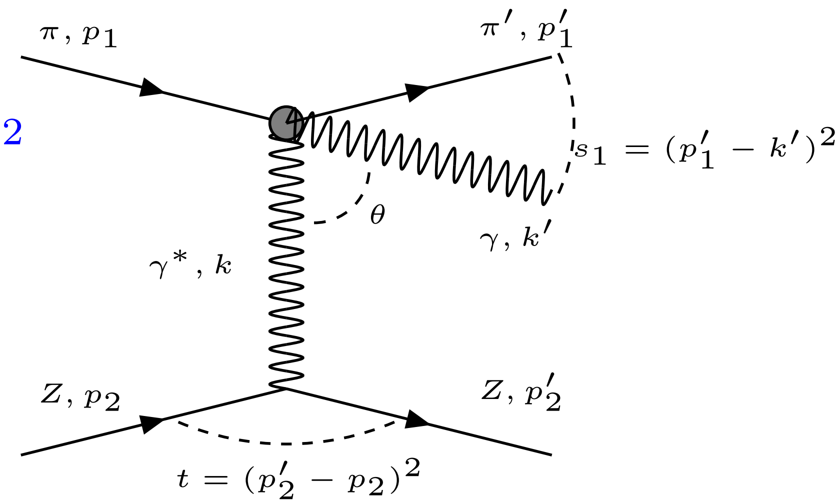
The Primakoff reaction

For the reaction:

$$\pi + Z \rightarrow \pi' + Z + \gamma$$

one measures the *Primakoff cross section*

$$\frac{d^3\sigma}{dt d\omega dcos\theta} = \frac{\alpha_f Z^2}{\pi\omega} \frac{t - t_0}{t^2} \frac{d\sigma_{\pi\gamma}(\omega,\theta)}{dcos\theta} |F_A(t)|^2$$



ω photon energy in the antilab system

$t = (p_2' - p_2)^2$

$t_0 = (\frac{m_\pi \omega}{p_{beam}})^2$

θ real photon scattering angle

$$\frac{d\sigma_{\pi\gamma}(\omega,\theta)}{dcos\theta} = \frac{2\pi\alpha_f^2}{m_\pi^2} \cdot \left(F_{\pi\gamma}^{Th} + \frac{m_\pi \omega^2}{\alpha_f} \cdot \frac{\alpha_\pi(1+cos^2\theta)+\beta_\pi cos\theta}{(1+\frac{\omega}{m_\pi}(1-cos\theta))^3} \right)$$

α_π, β_π pion electric and magnetic polarizability

Measurement via Primakoff reaction

- The Serpukhov group (1985) with the Primakoff reaction $\pi + Z \rightarrow \pi + \gamma + Z$ at 40 GeV obtains:

$$\alpha_\pi = (6.8 \pm 1.4_{stat} \pm 1.2_{sys})10^{-4}\ fm^3$$ [1]

with the hypothesis $(\alpha_\pi + \beta_\pi) = 0$ and

$$\beta_\pi = (-7.1 \pm 2.8_{stat} \pm 1.8_{sys})10^{-4}\ fm^3$$

$$(\alpha_\pi + \beta_\pi) = (1.4 \pm 3.1_{stat} \pm 2.5_{sys})10^{-4}\ fm^3$$ [2]

[1] Yu M. Antipov et al., Phys. Lett. 121B, 445 (1985)

[2] Yu M. Antipov et al., Z. Phys. C 26, 495 (1985)

The goals

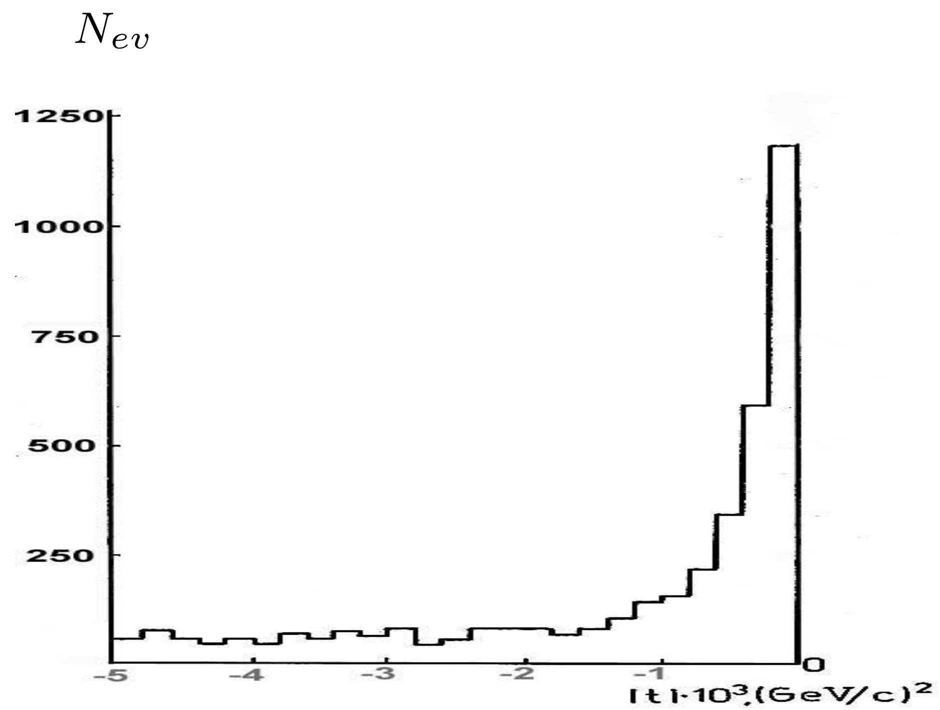
$p_{beam} = 190\ GeV/c$ to increase the ratio of the coulombian/nuclear cross section

Higher Z target $\longrightarrow$ $\sigma(Z^2)$

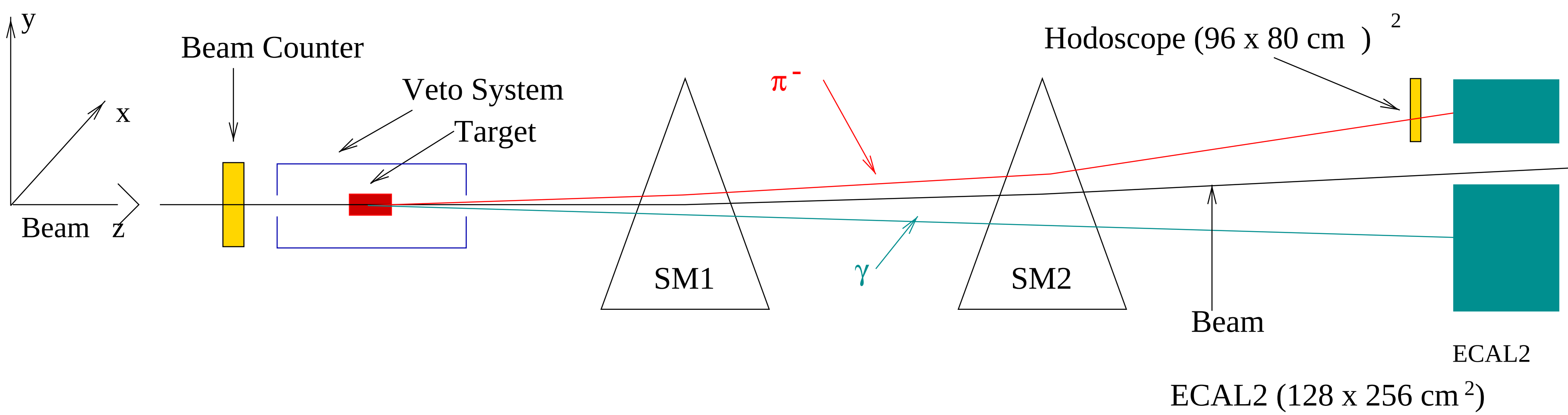
Our goals :

- measure independently $(\alpha + \beta)$, α, β
- enough statistics:
  - to get the statistical errors negligible versus the systematic ones
  - evaluate systematic error due to different cuts
  - more complete angular distribution
- higher energy $\longrightarrow$ smaller t $\longrightarrow$ to fit Compass acceptance
- $\sigma(p_T) \approx 15 MeV/c$ like in the Antipov

experiment:



Trigger



$$\textit{Trigger}: \quad Hodoscope \times ECAL2$$

$$\downarrow \qquad \downarrow$$

$$\pi^- \qquad \gamma$$

POLARIS

the generator

$\Downarrow$

COMGEANT:

the simulation program based on

Geant 3.21

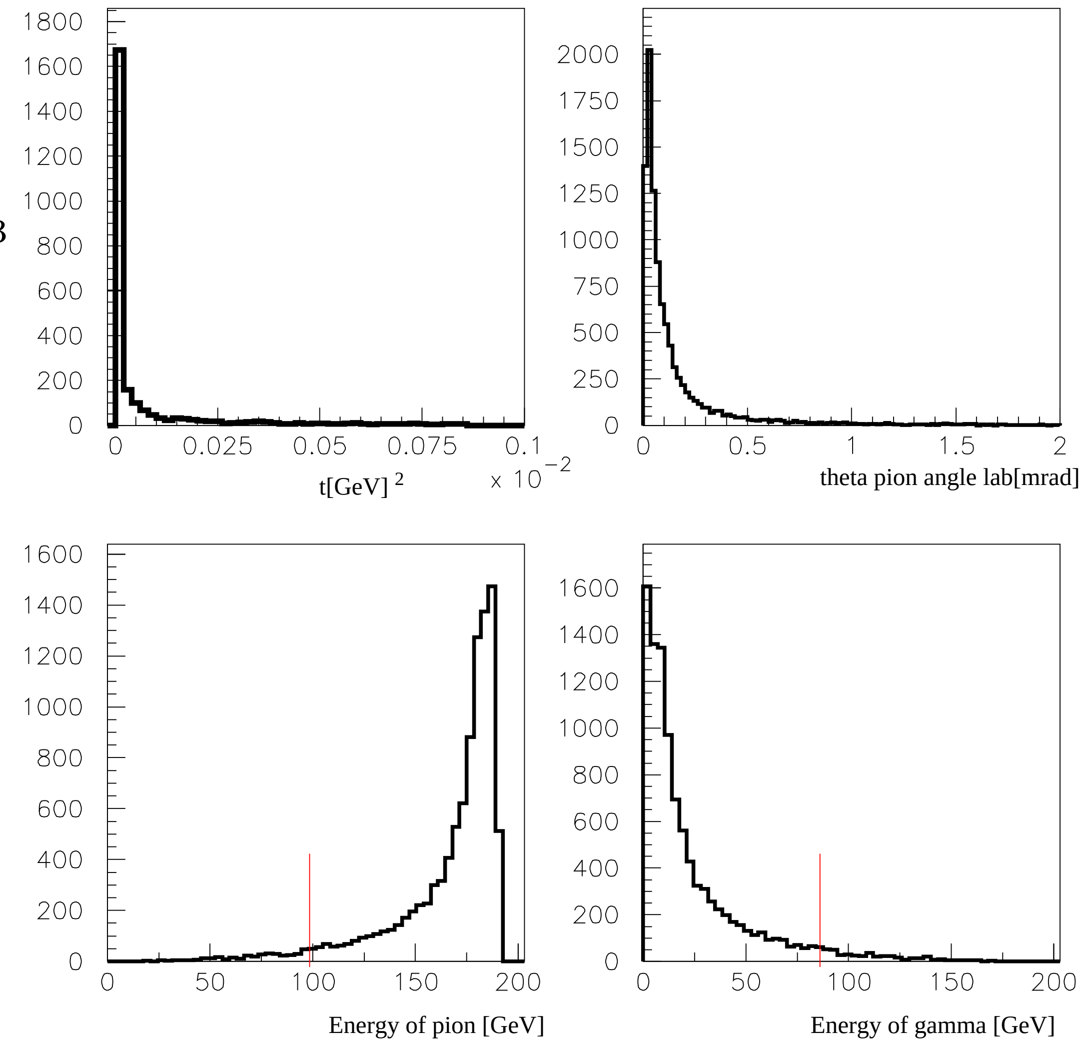
$\Downarrow$

CORAL:

COmpass Reconstruction and Analysis Library.

The generator

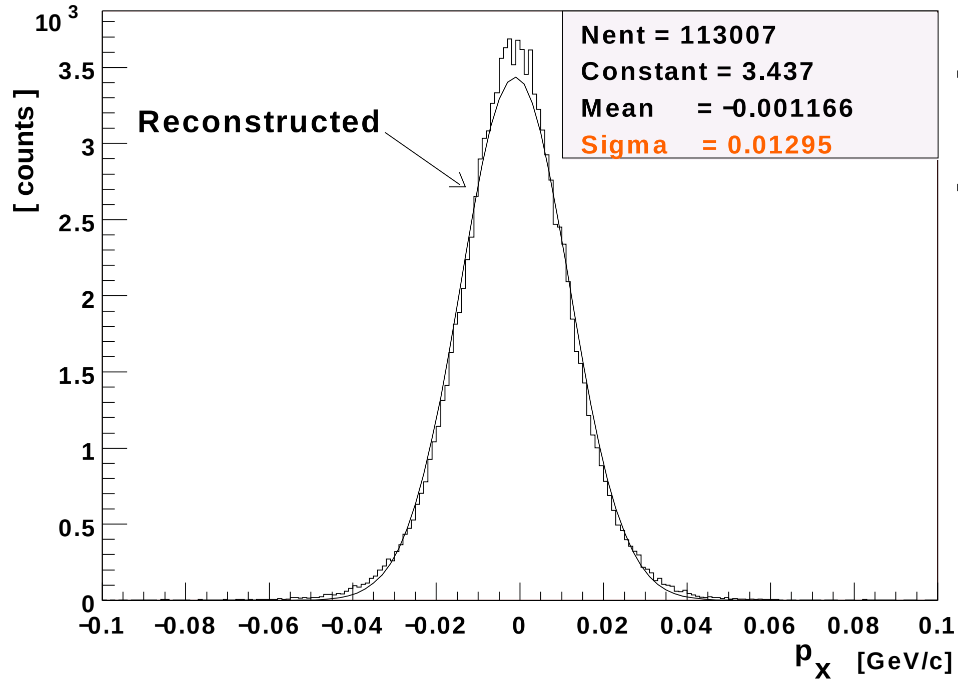
- Target ^{208}Pb
- Thickness $0.3\,X_0 = 1.7\,mm$
- $\overline{\alpha}_\pi = -\overline{\beta}_\pi = 6.8 \cdot 10^{-4}\, fm^3$

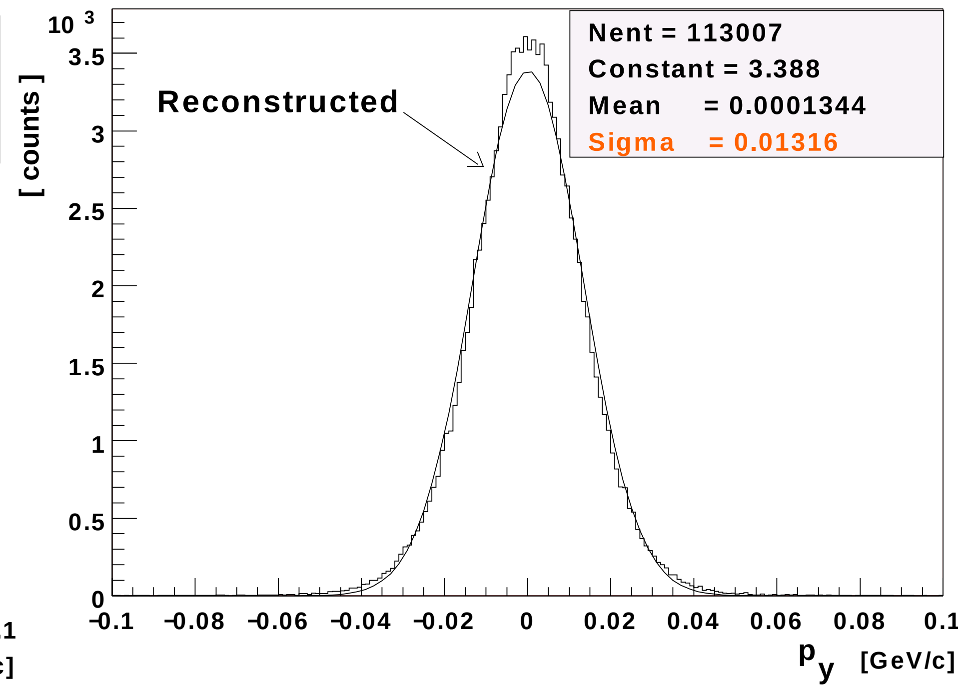


- $t < 850 MeV^2$
- $1.05 \cdot m_\pi^2 < s_1 < 30 \cdot m_\pi^2$
- $E_\gamma > 90\; GeV$

Primakoff event reconstruction: $E_\gamma > 90 GeV$

Trasversal component of four-momentum transfer





$$\sigma_{p_x} = \sigma_{p_y} = 13\ MeV/c$$

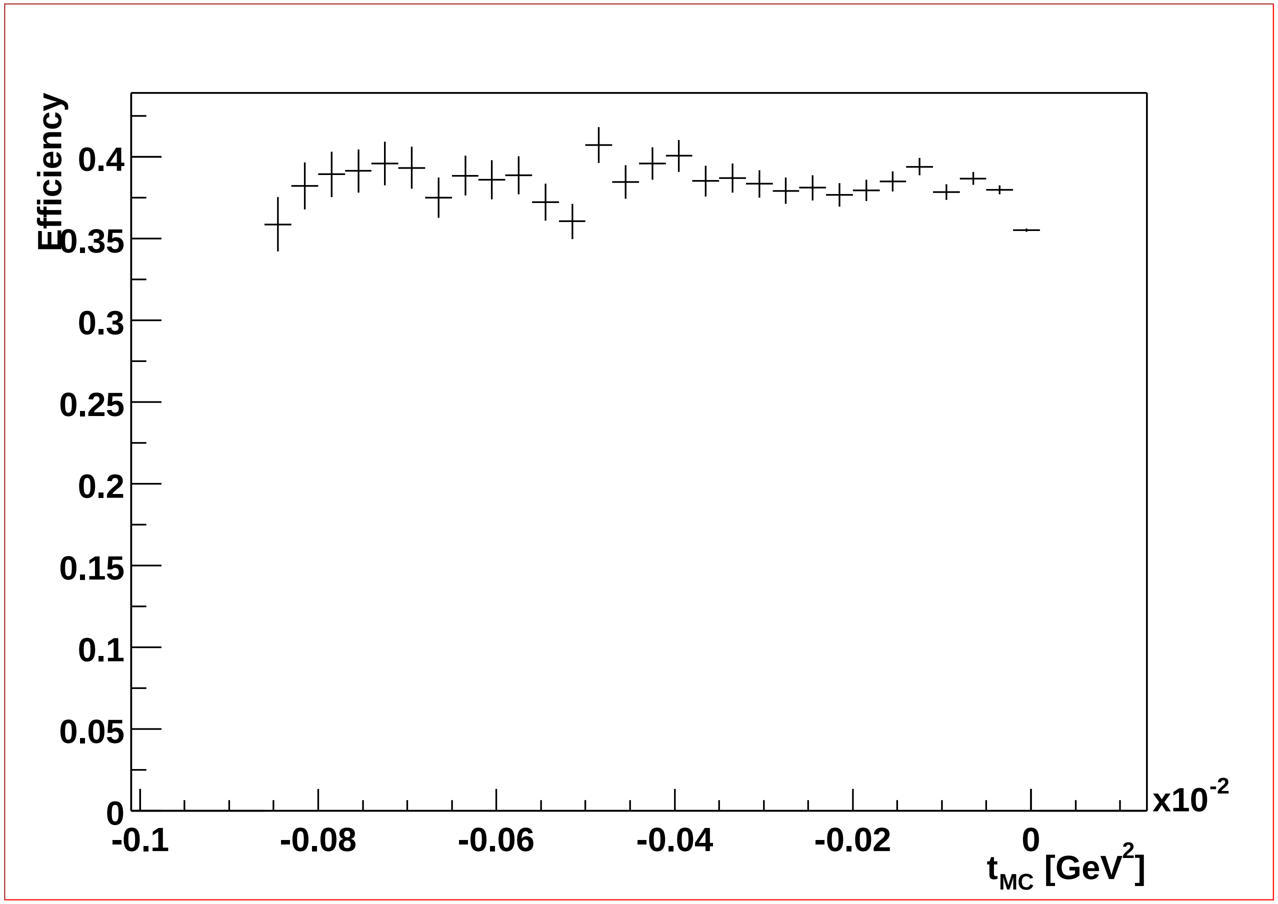
$$\sigma_{p_T} = 18 MeV/c$$

The efficiency = N_{rec} / N_{gen}

Constant

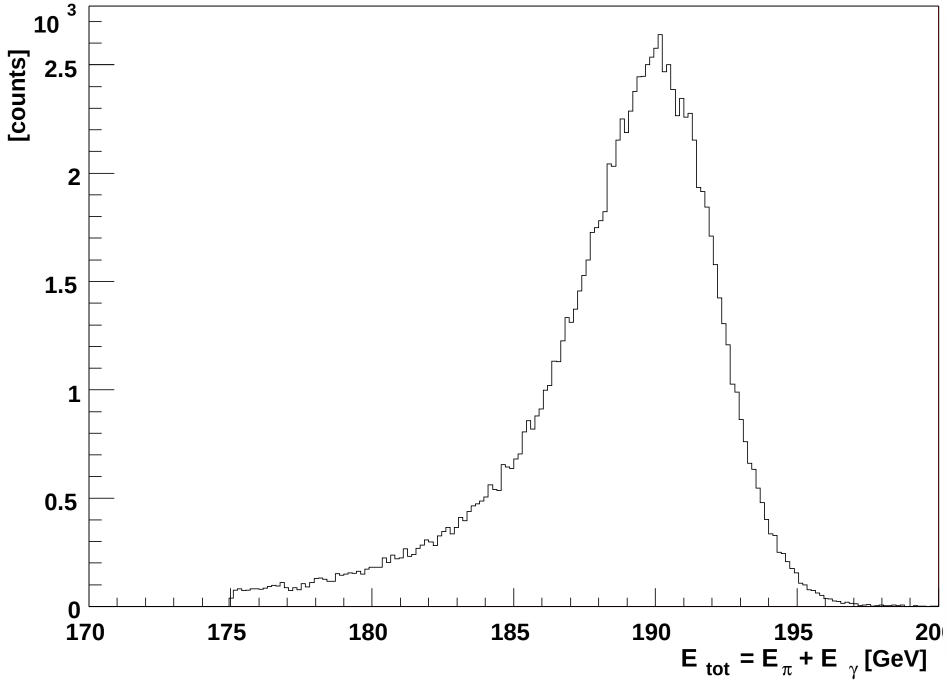
efficiency vs t

$\longrightarrow$

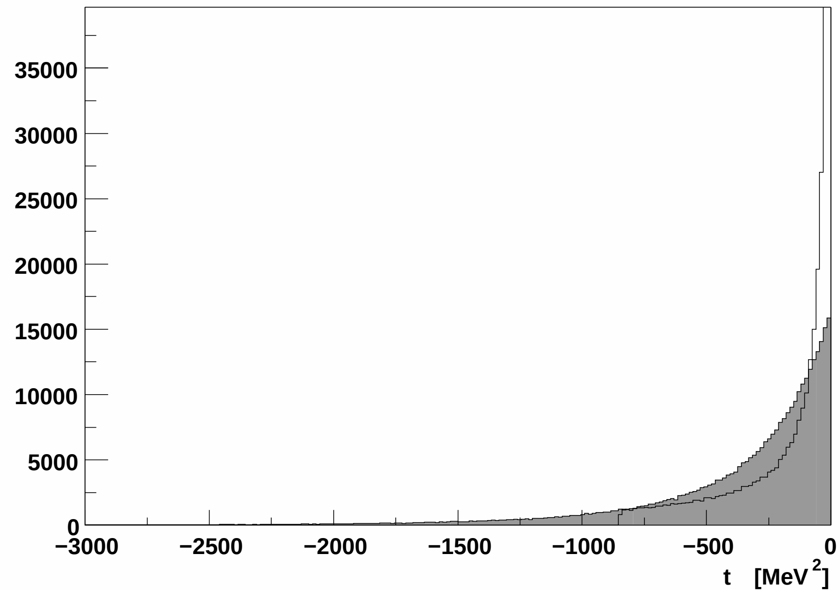


Primakoff event reconstruction

Pair ($\pi\gamma$) total energy



The t variable



Comparison with the Serpukhov data

	@ Serpukhov	@ COMPASS
beam momentum	$40\,GeV/c$	$190\,GeV/c$
beam intensity	$10^6/spill$	$4 \cdot 10^7/spill$
target	$Z < Fe$	Pb
scattered pion	$\sigma_\Theta \approx 0.12\,mrad$	$\sigma_\Theta \approx 0.04\,mrad$
	$\sigma_p/p \approx 1\%$	$\sigma_p/p \approx (0.3 \div 1)\%$
outgoing gamma	$\sigma_\Theta \approx 0.15\,mrad$	$\sigma_\Theta \approx 0.031 mrad$
	$\sigma_E/E \approx 3.5\%@\,27\,GeV$	$\sigma_E/E \approx 2\%@\,120\,GeV$
total flux	10^{11}	$\approx\ 3 \cdot 10^{11}/day$
primakoff events	$6 \cdot 10^3$	$4 \cdot 10^5/day$

Polarizabilities Statistics

With a $2 \cdot 10^7\ \pi/s$, the spill structure is 5 sec beam every 16 sec, $3.2 \cdot 10^{11}\ \pi$ are expected per day.

The interaction probability $R = \sigma N_T = 5 \cdot 10^{-6}$ assuming:

$\sigma = 0.5\, mbarn$

$N_T = 10^{22}\ cm^{-2}$

The global efficiency is estimated to be $\epsilon = 24\%$ due to:

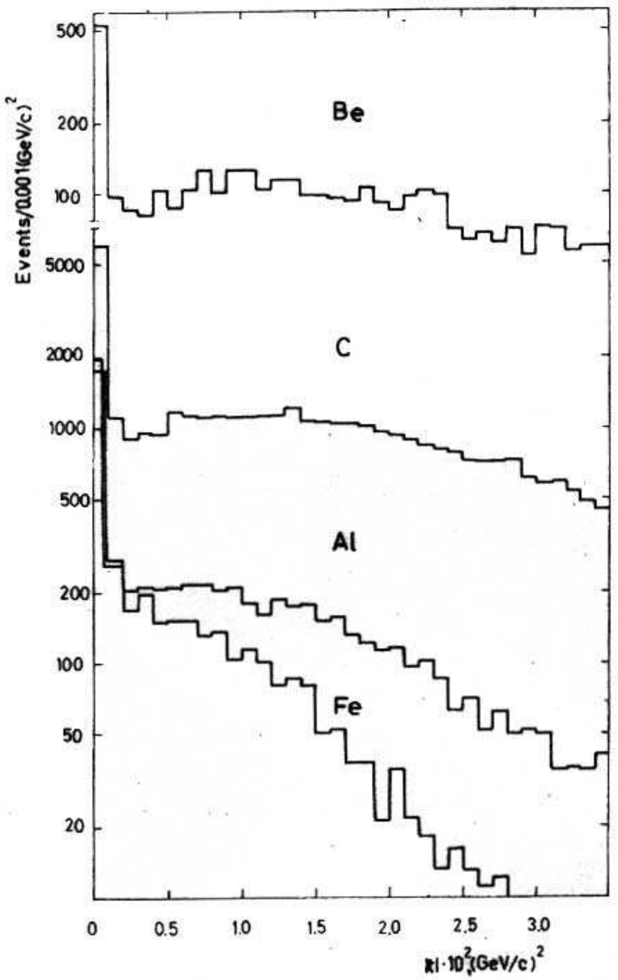
- tracking efficiency 92%
- gamma detection 58%
- combined acceptance of COMPASS and SPS 60%
- analysis cut to reduce backgrounds 75%

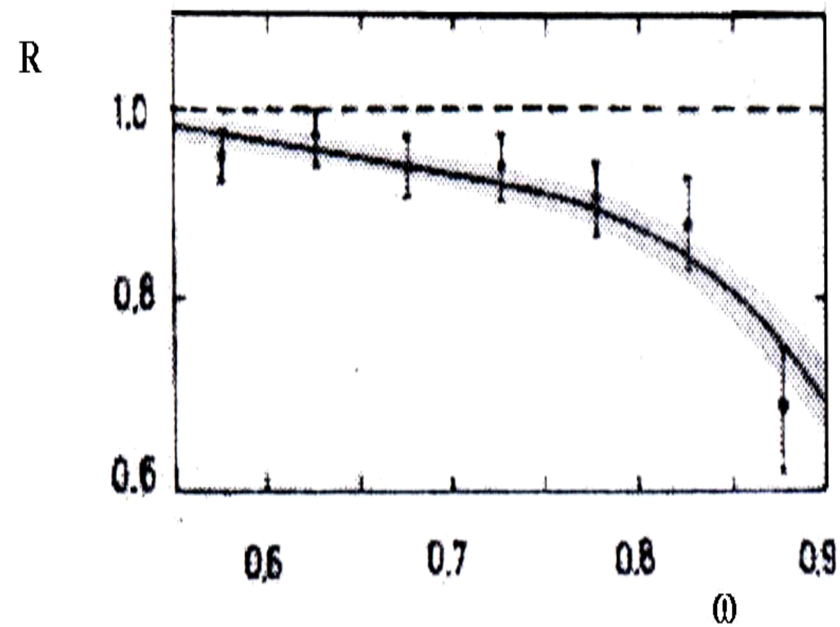
$$3.2 \cdot\ 10^{11}\ \times\ 5 \cdot 10^{-6}\ \times\ 0.24\ =\ 4 \cdot 10^5\ Events/day$$

Summary & Outlook

Serpukhov:

Z^2 dependence





$$R = \frac{\frac{d\sigma}{d\omega}(extended)}{\frac{d\sigma}{d\omega}(pointlike)_{th}}$$

Compass:

- Different targets: $\longrightarrow$ Z^2 dependence in the cross section.
- Also interesting a comparison with a pointlike particle with the reaction: $\mu^- + Z \rightarrow \mu^- + Z + \gamma$
- Constant efficiency on t
- Statistics 10^3 times better $\longrightarrow$ overall resolution 3 times better

$$\delta\overline{\alpha}_\pi \approx 0.4 \cdot 10^{-4} fm^3 \text{ } (\approx \sigma_{theory})$$

- Polarizability measurements for K^- are possible.

Kaon polarizability

The cross section scales down as $m^{-1} \longrightarrow$ 3 times smaller compared to the π one,

the polarizability goes as $\overline{\alpha}_h = \frac{4\alpha_f}{m_h F_h^2}(L_r^9 + L_r^{10}) \longrightarrow \overline{\alpha}_K = \frac{\overline{\alpha}_\pi}{5.4}$

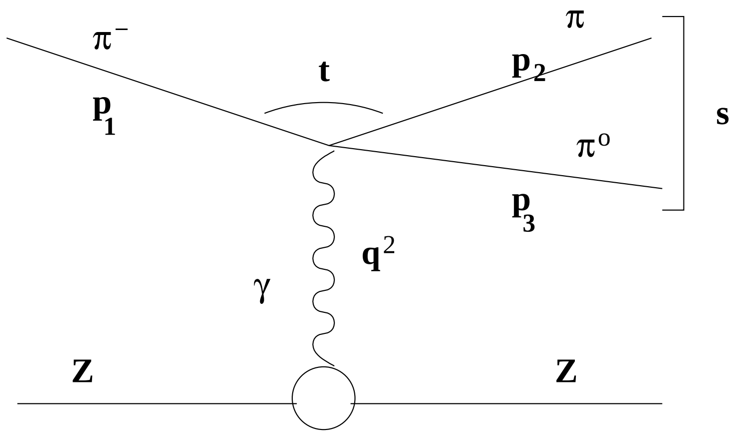
$\underline{Assume}$

- 3×10^5 Kaon/sec @ 190 GeV/c
- $60 < \omega < 300\ MeV$ to avoid $K^*\ 1^{st}$ excited state

overall resolution $\delta\overline{\alpha}_K = 0.6 \cdot 10^{-4}\ fm^3$

$2 \cdot 10^4 events/day$

$F_{3\pi}$ *measurement*



$t \;=\; (p_1 \;-\; p_2)^2$

$s \;=\; (p_2 \;+\; p_3)^2$

$q^2_{min} \;=\; (\frac{s-m_\pi}{2E})^2$

$\pi^- \;+\; Z \;\rightarrow\; \pi^- \;+\pi^0 +\; Z$ useful to access $\gamma \;\rightarrow\; 3\pi$

$F_{3\pi}$ allow to verifiy the low energy theorem: $F_{3\pi}(0) = \frac{F_\pi(0)}{ef^2}$

$$\frac{d\sigma}{dsdtdq^2} \;=\; \frac{Z^2\alpha_f}{\pi}(\frac{q^2-q_{min^2}}{q^4})\frac{1}{s-m_\pi^2}\frac{d\sigma_{\gamma\pi\rightarrow\pi\pi}}{dt}$$

$$\frac{d\sigma_{\gamma\pi\rightarrow\pi\pi}}{dt} \;=\; \frac{F^2_{3\pi}}{128\pi}\frac{1}{4}(s-4m_\pi^2)sin^2\theta$$

$F_{3\pi} \;=\; (12.9 \pm 0.9 \pm 0.5)GeV^{-3}$ [1] $\quad F_{3\pi} \;=\; (9.7 \pm 0.2)GeV^{-3}$ [2]

Expected $\approx 5 \cdot 10^3 \; events/day$ vs ≈ 200 Serpukov events in total.

[1] Antipov et al., Phys. Rev. D36 21 (1987) [2] M. Moinester et al, Proc. Confernce on Physics with GeV Particel beam, Julic, Germany 1994, Miskimen et al., Proc. Chiral Dinamic: Theory and experiment, MIT, 1994

Conclusions

Using $\underline{COMPASS}$ spectrometer one can measure:

- pion polarizabilities with an uncertanty of the same order of the theoretical one
- kaon polarizabilities for the $\underline{1^{st}}$ time with the Primakoff reaction

- the chiral anomaly amplitude for the $\gamma \rightarrow 3\pi$