Advance Study Institute
SYMMETRY and SPIN
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on behalf of the COMPASS coll.

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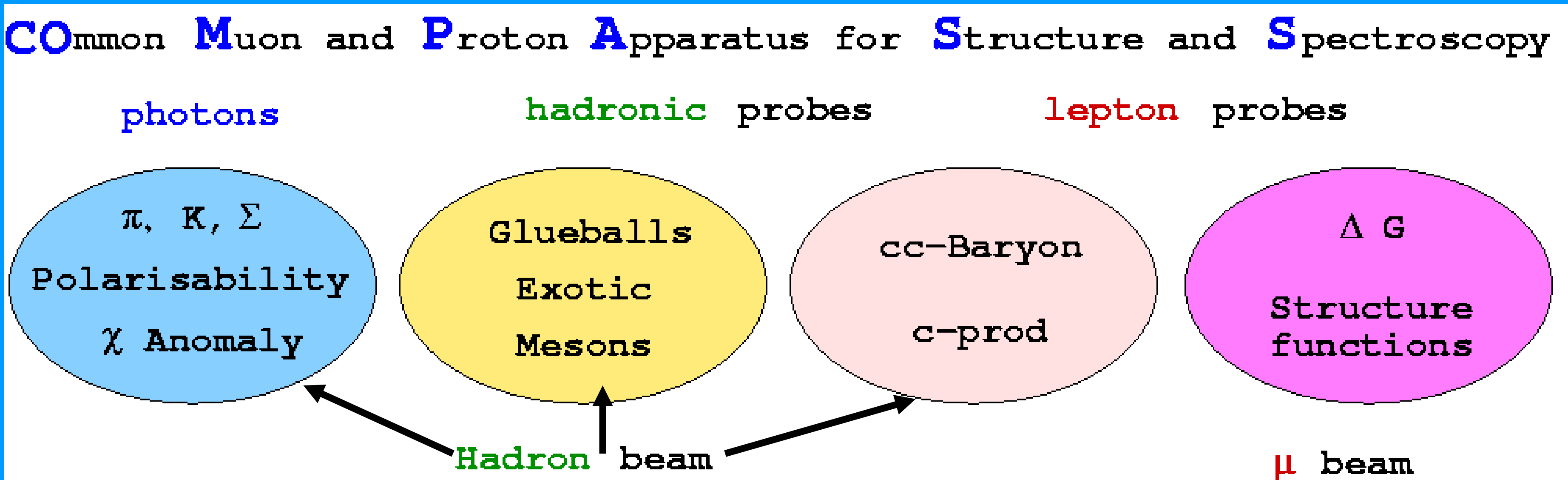
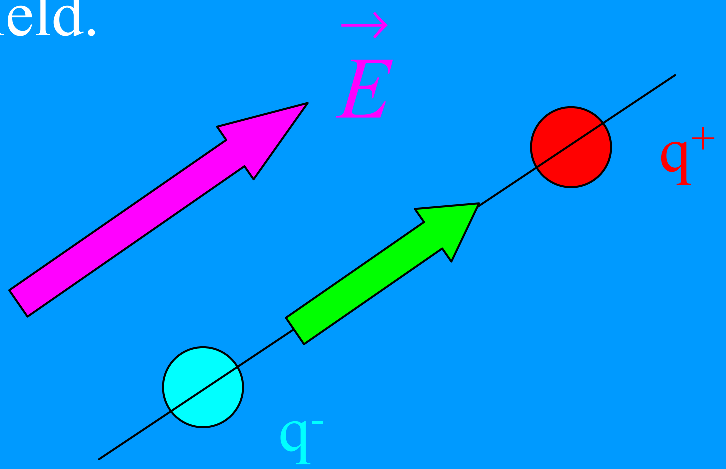
Measurement of electric and magnetic pion polarizabilities with Primakoff reaction at Compass spectrometer

Compass physics program



The polarizability

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



$$\vec{p} = \alpha \vec{E}$$

$$\vec{\mu} = \beta \vec{H}$$

The polarizability is a quantity which characterizes a particle like its charge, radius ….

Chirality

What is the chiral symmetry?

Nambu, Quarks frontiers in elementary particle

$$q = \begin{bmatrix} u \\ d \\ s \end{bmatrix}$$ in the limit of zero quark masses

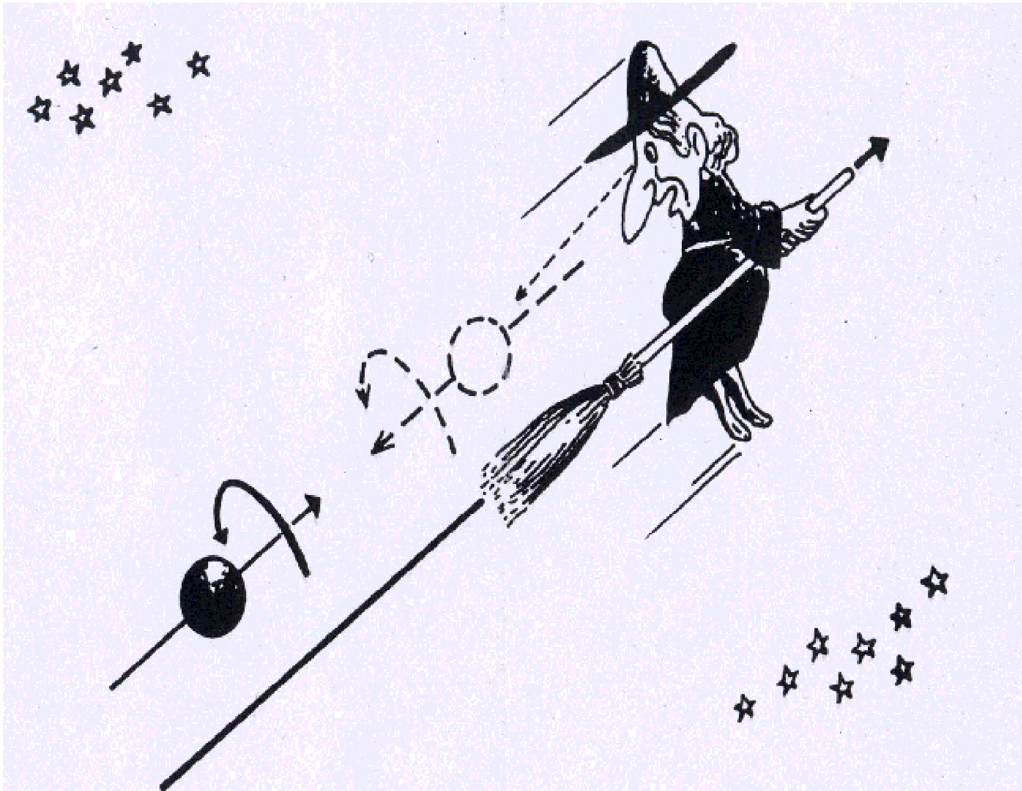
$SU(3)_L \times SR(3)_R$ exact chiral symmetry

$$q \rightarrow \exp\left[i\sum_{j=1}^{8} \lambda_j \alpha_j \right] q_L = L q_L$$

$$q \rightarrow \exp\left[i\sum_{j=1}^{8} \lambda_j \beta_j \right] q_R = R q_R$$

Chirality

The inclusion of quark mass introduces a small breaking of chiral symmetry $\rightarrow$ perturbative expansion in energy



Nambu, Quarks frontiers in elementary particle

Pion polarizabilities

The pion polarizabilities can be described in the framework of the Chiral Perturbation Theory (χPT) based on the chiral symmetry of QCD and Goldstone theorem

Chiral dynamics describes:

- properties
- production
- decay amplitude
- low energy interactions

of the *Goldstone bosons* (π, η, K) among themselves and with γ's

The χPT

L_{QCD} (quark,gluon) $\rightarrow$ at low energy $\rightarrow L_{eff}$ (π,K,η,p,n..)

The χPT provide a rigorous way to determine α_π, β_π via the effective chiral lagrangian

The numerical values are: $\overline{\alpha}_\pi = (2.4 \pm 0.5) \cdot 10^{-4}\, fm^3$

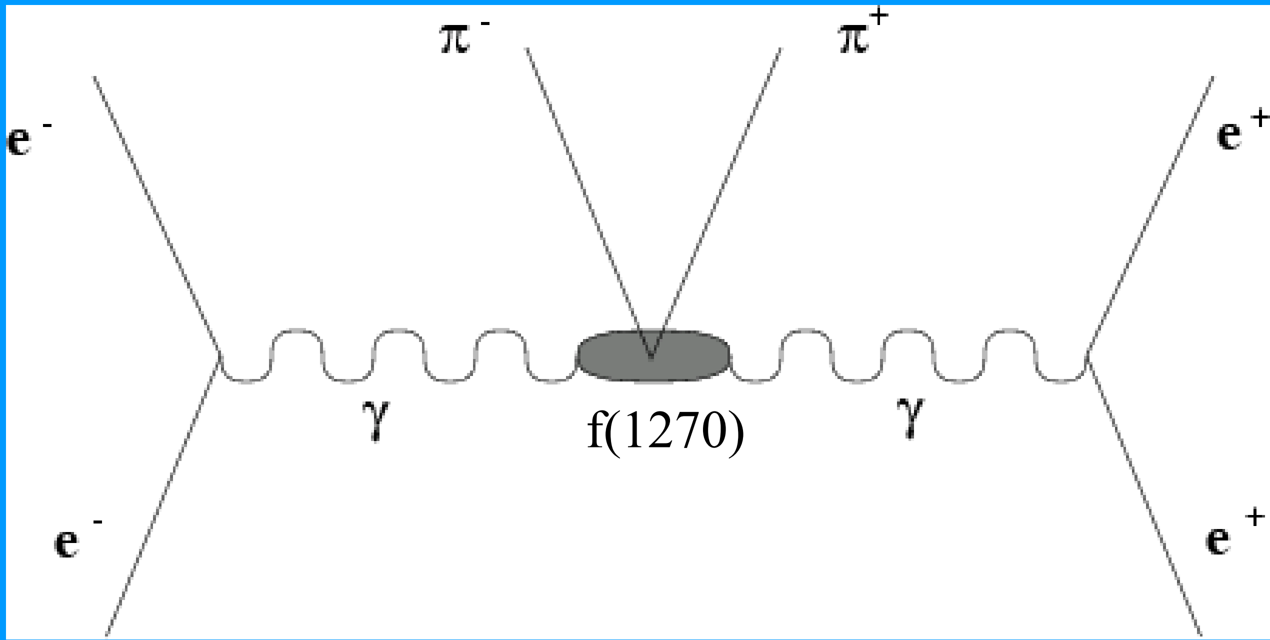
$$\overline{\beta}_\pi = (-2.1 \pm 0.5) \cdot 10^{-4}\, fm^3$$

U. Burgi, Phys.Lett. B 377 (1996) 147

Consistent with the chiral simmetry $\left(\overline{\alpha}_\pi + \overline{\beta}_\pi\right) = 0$

Measurements of pion polarizabilities

Photon-Photon Collision:



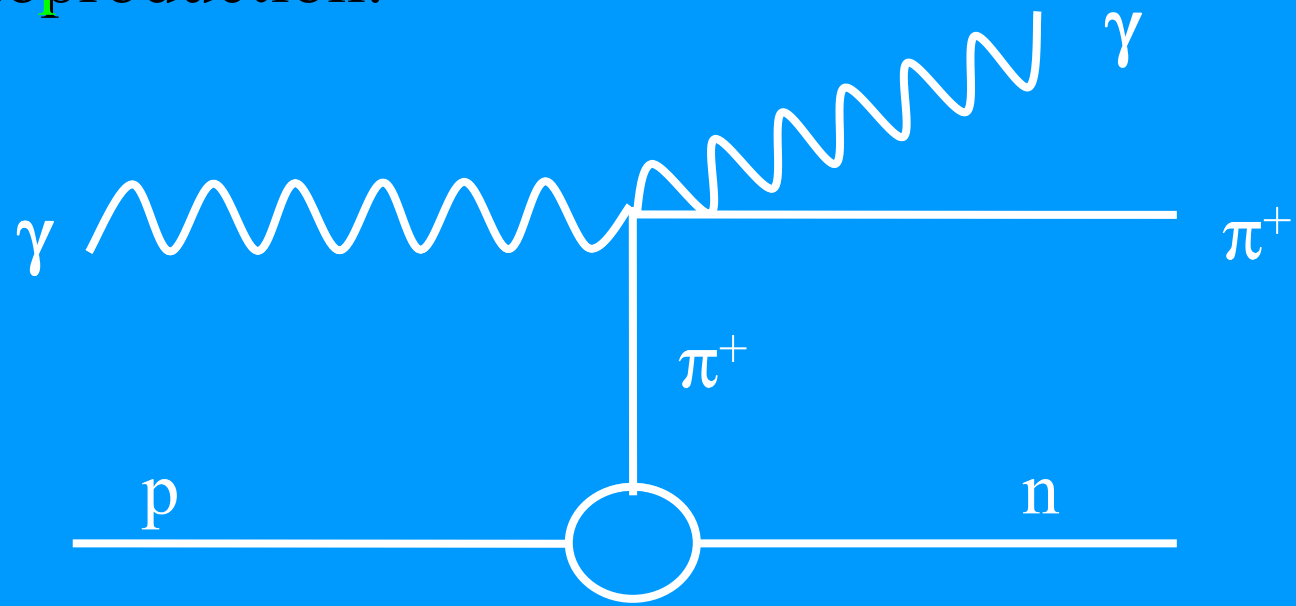
From the results of MARK II group (1990) [1] with the reaction:

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

Measurements of pion polarizabilities

Pion Photoproduction:



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

$\gamma + p \rightarrow \gamma + \pi^{+} + n$ showed the feasibility $\alpha_{\pi} = (20 \pm 12_{stat}) \cdot 10^{-4}\ fm^{3}$

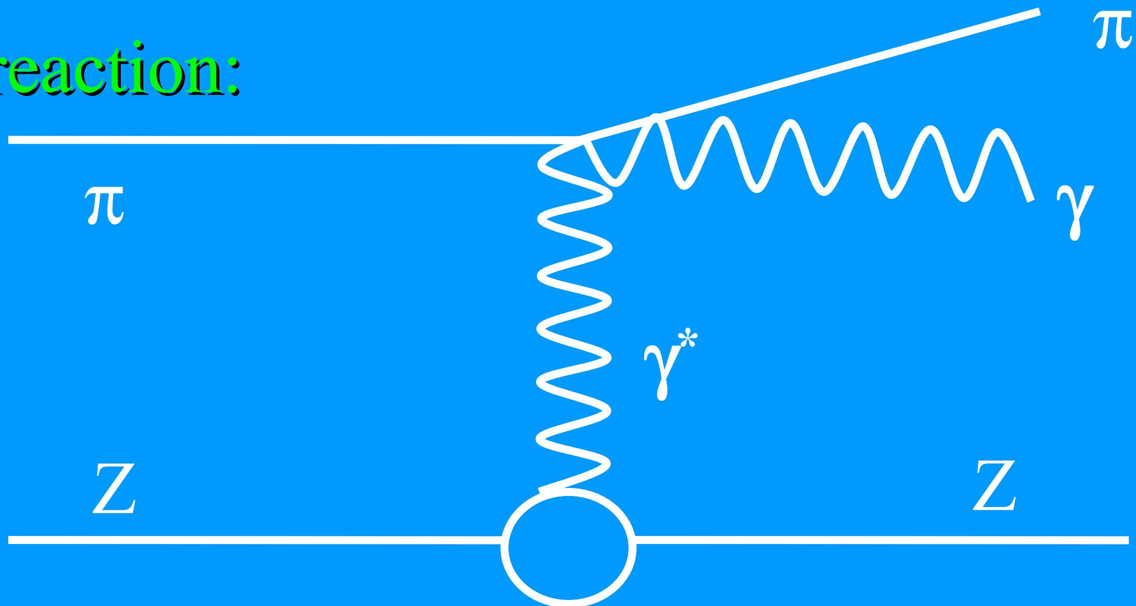
[3]. High precision measurement made @ MAMI (A2 coll.)

Data analysis is in progress

[3] T.A. Aibergenov et al., Cezch J. Phys B36, 948 (1986)

Measurements of pion polarizabilities

Primakoff reaction:



The Serpukhov group (1985) with the reaction

$\pi + {}^{12}C \rightarrow \gamma + \pi + {}^{12}C$ at 40 GeV gives:

$\alpha_\pi = (6.8 \pm 1.4_{stat} \pm 1.2_{sys}) \cdot 10^{-4}\ fm^3$ [4] with the hypothesis $(\alpha_\pi + \beta_\pi) = 0$

$\beta_\pi = (-7.1 \pm 2.8_{stat} \pm 1.8_{sys}) \cdot 10^{-4}\ fm^3$ [5]

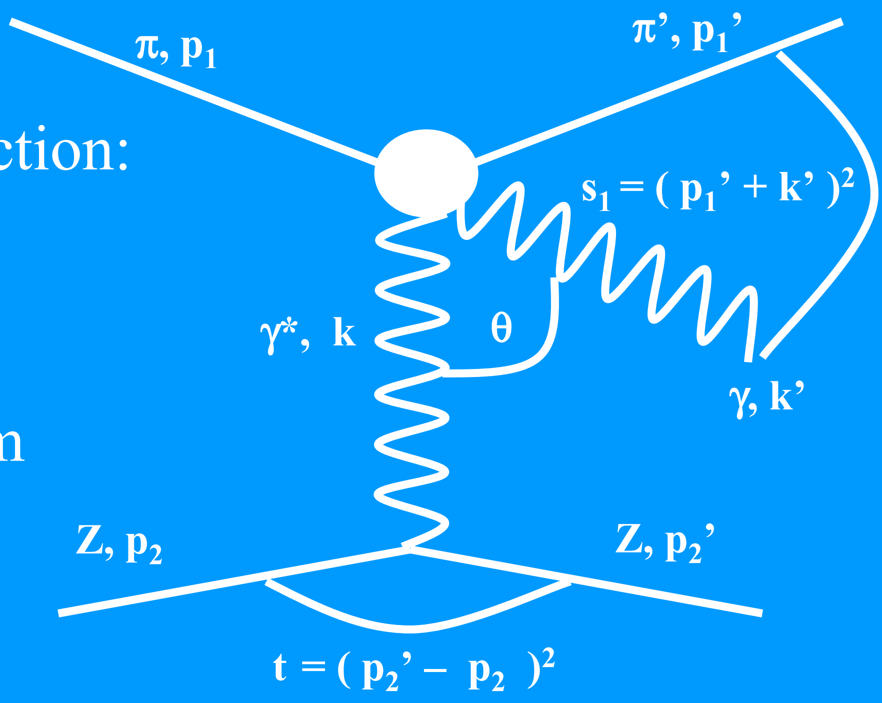
$(\alpha_\pi + \beta_\pi) = (1.4 \pm 1.4_{stat} \pm 1.2_{sys}) \cdot 10^{-4}\ fm^3$ [5]

[4] Yu M. Antipov et al., Phys. Lett. 121 B (1985) 445
[5] Yu M. Antipov et al., Z. Phys. C 26 (1985) 495

The Primakoff reaction

For the reaction $\pi + Z \to \pi' + Z + \gamma$
one measures the Primakoff cross section:

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



ω photon energy in the antilab system

$$t = (p'_2 - p_2)^2$$

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

θ real photon scattering angle

Electric & Magnetic polarizabilities

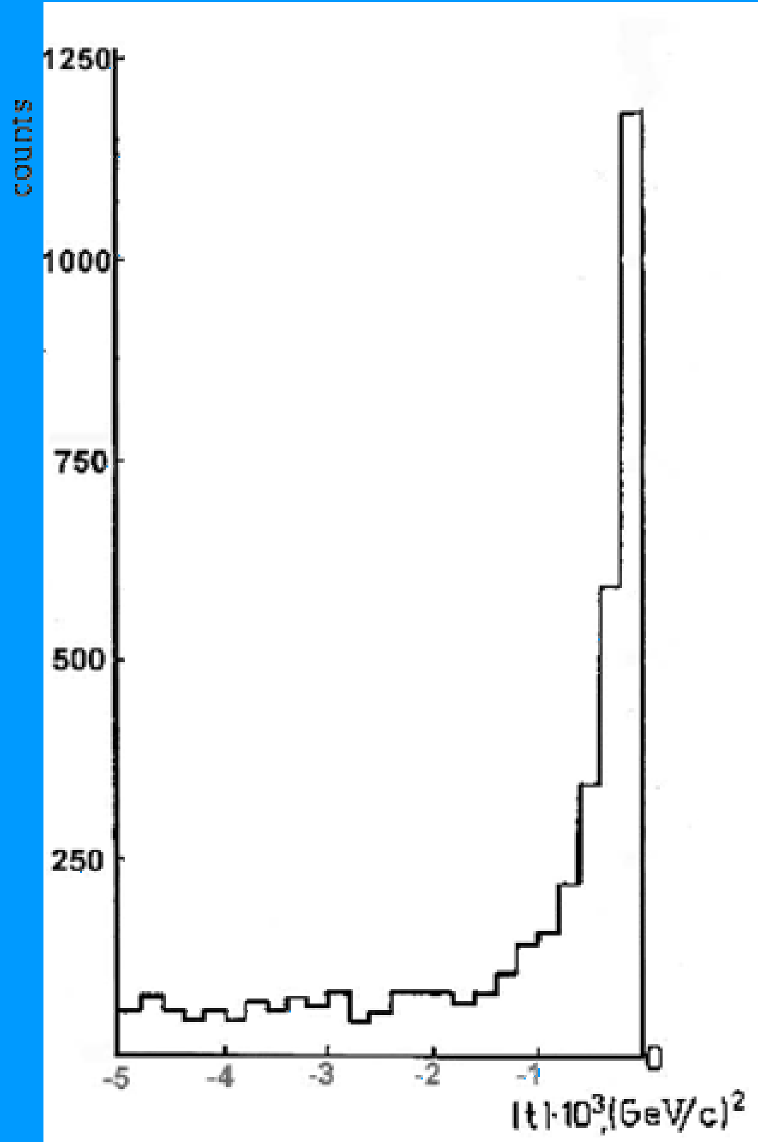
$$\frac{d\sigma_{\pi\gamma}(\omega,\vartheta)}{d\cos\vartheta} = \frac{2\pi\alpha_f^2}{m_\pi^2}\cdot\left(F_{\pi\gamma}^{Th} + \frac{m_\pi\omega^2}{\alpha_f}\cdot\frac{\alpha_\pi(1+\cos^2\vartheta)+\beta_\pi\cos\vartheta}{\left(1+\frac{\omega}{m_\pi}(1-\cos\vartheta)\right)^3}\right)$$

The goals

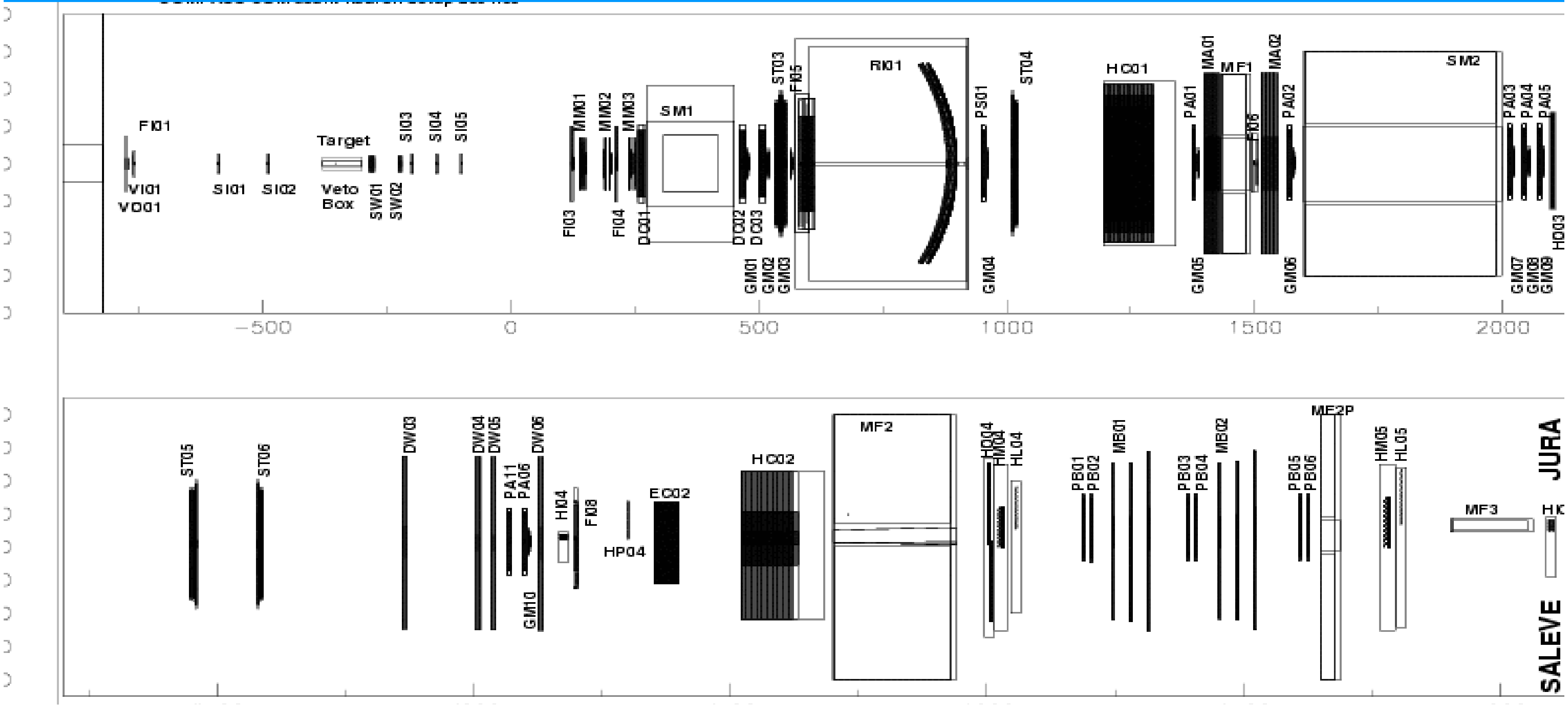
• P_{beam} =190 GeV/c to increase the ratio of the coulombian/nuclear cross section and less multiple scattering effect

GOALS:

- measure independently $(\alpha_\pi + \beta_\pi)$, α_π, β_π
- enough statistics:
  - to get the statistical errors negligible versus the systematic one
  - evaluate systematic errors due to different cuts
  - more complete angular distribution
- $\Delta t \sim 5 \cdot 10\text{-}4\ (GeV/c)^2$



The *COMPASS* hadron setup 2004



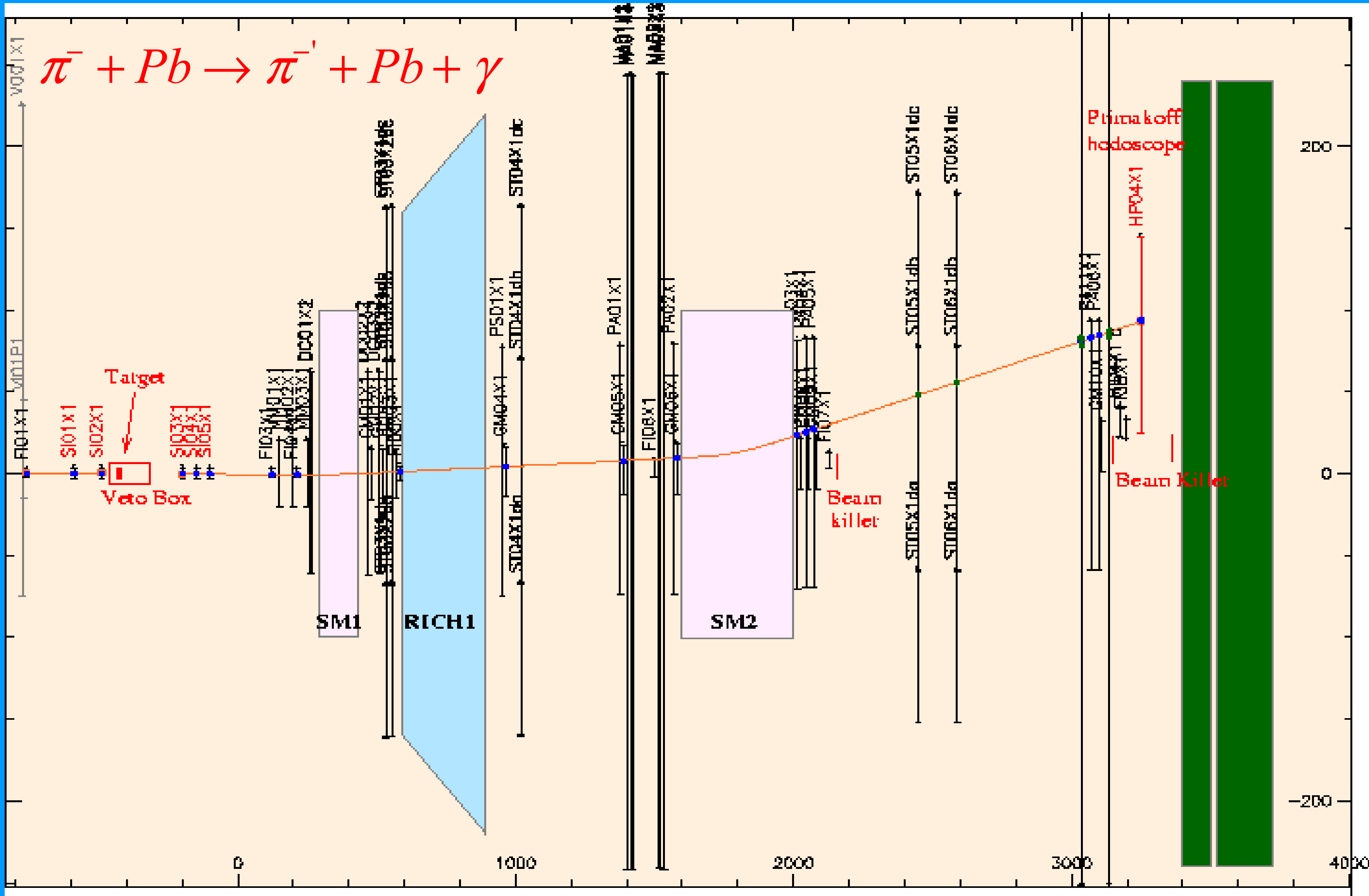
First Spectrometer: LAS

Geometrical Acceptance: θ>30 mrad
Gap: 172 × 229 cm^2
Integral field: 1 Tm
Analyzed momentum: p<60 GeV/c

Second Spectrometer: SAS

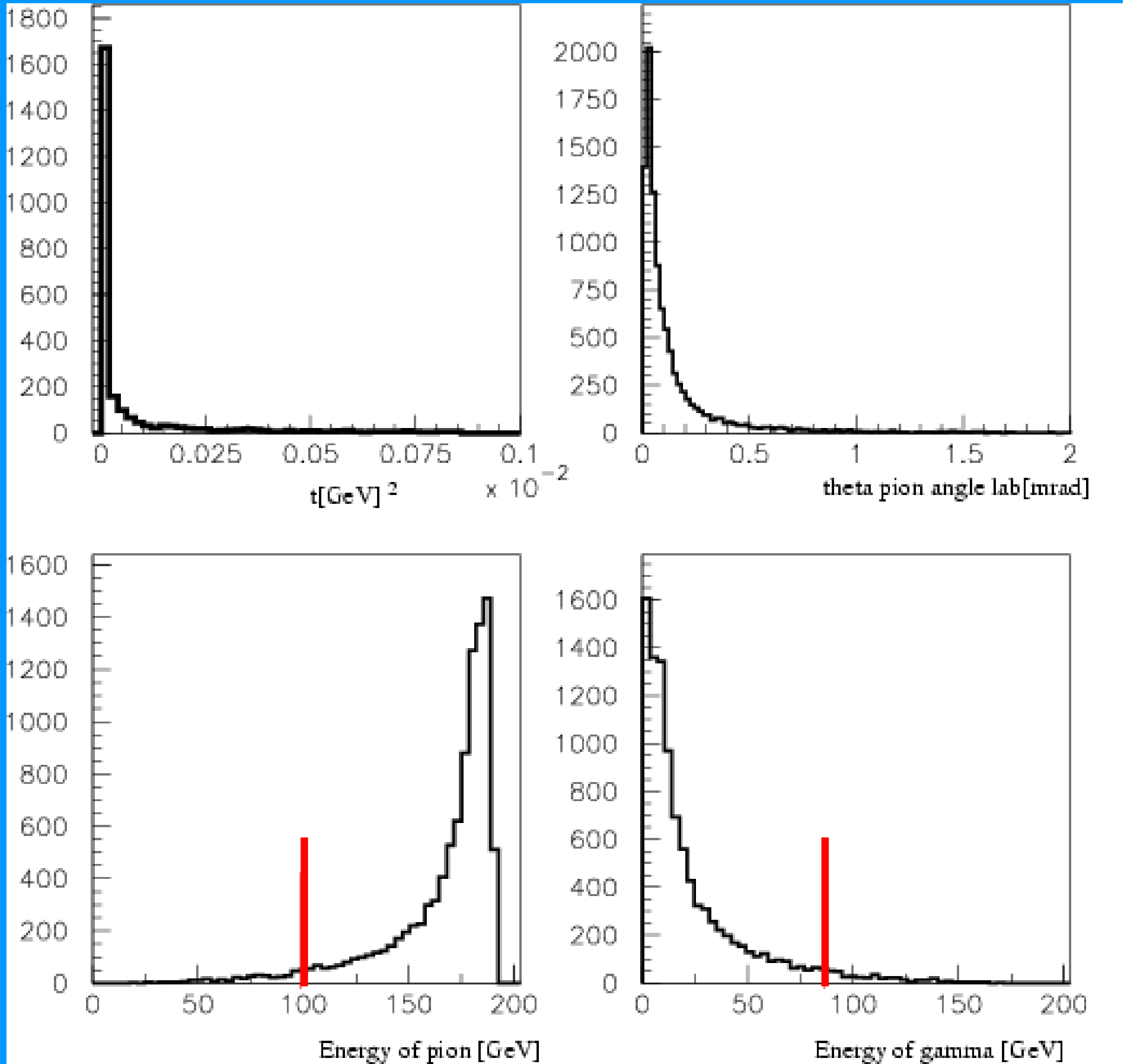
Geometrical Acceptance: θ<30 mrad
Gap: 200× 100 cm^2
Integral field: 4.4 Tm
Analyzed momentum: p>10 GeV/c

Typical reconstructed event:



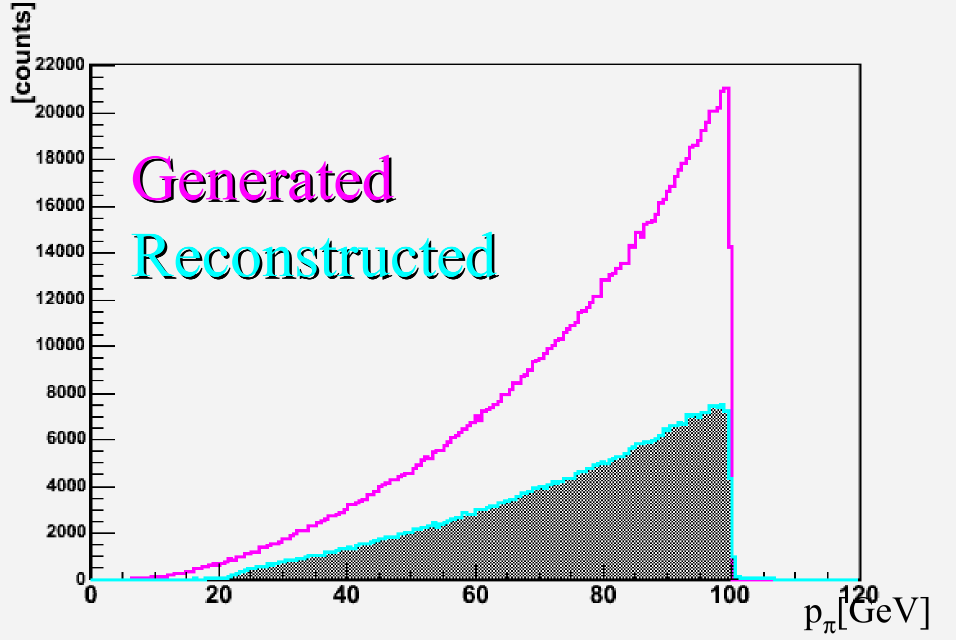
The generator

- Target ^{208}Pb
- $t < 850\ MeV^2$
- $1.05 \cdot m^2_{\pi} < s1 < 30 \cdot m^2_{\pi}$

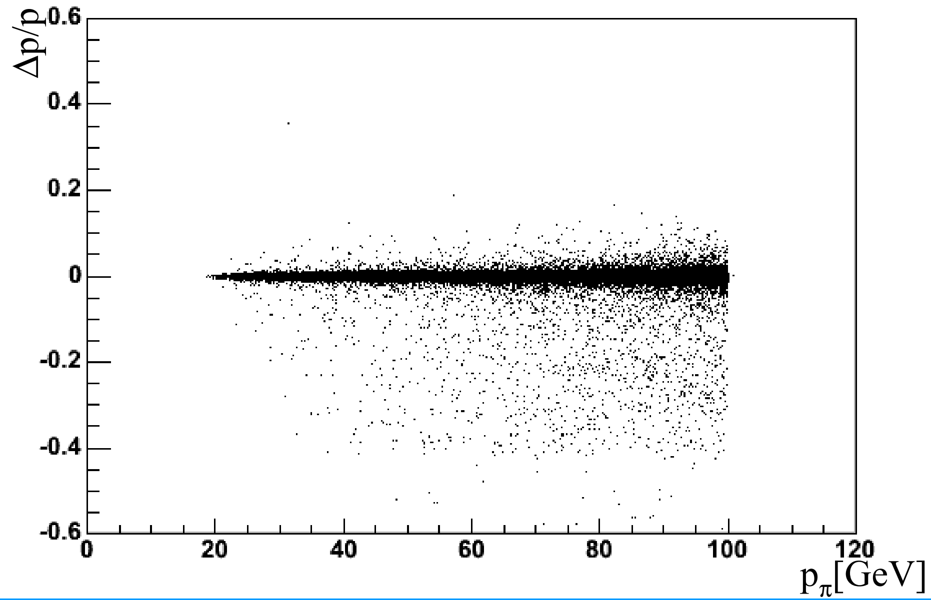


- $E_{\gamma} > 90$ GeV

Pion reconstruction

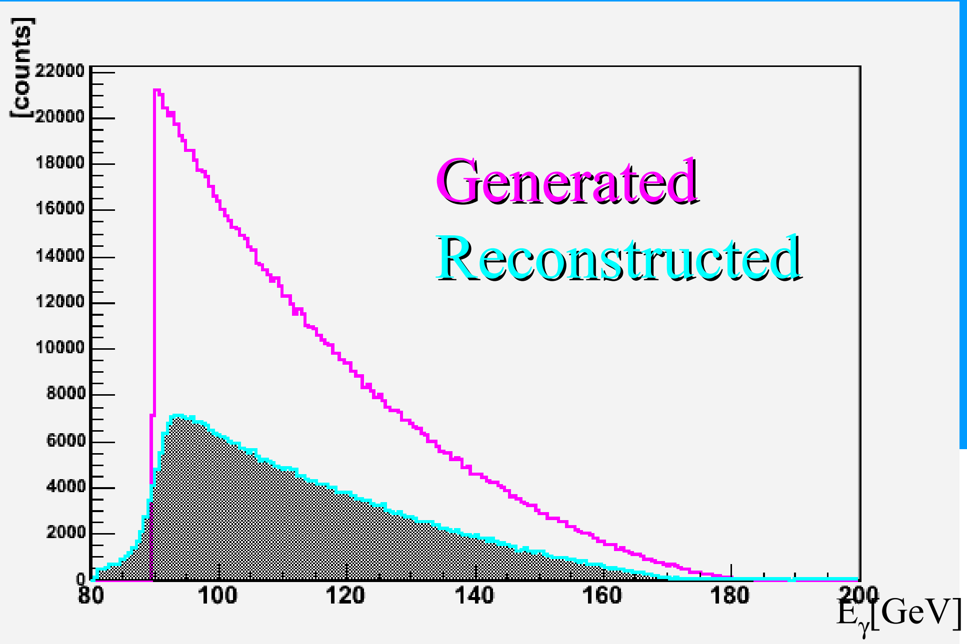


Pion momentum distribution



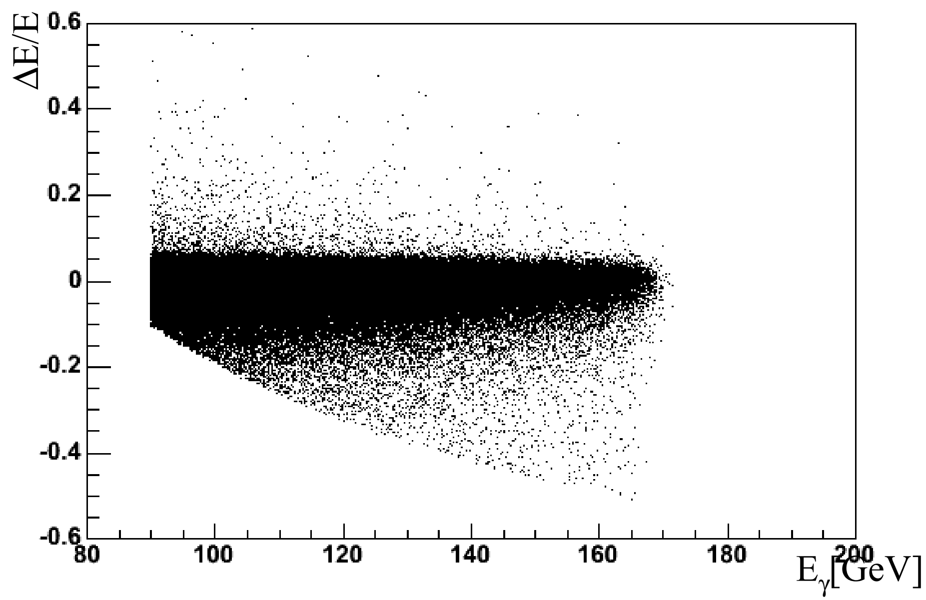
Pion momentum resolution
~0.35%

Photon reconstruction:

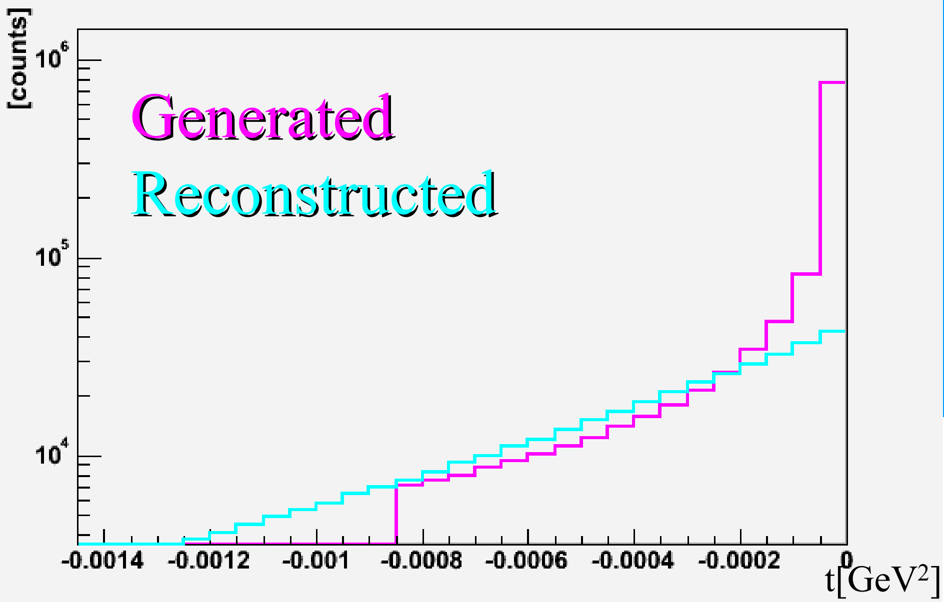


Photon distribution energy

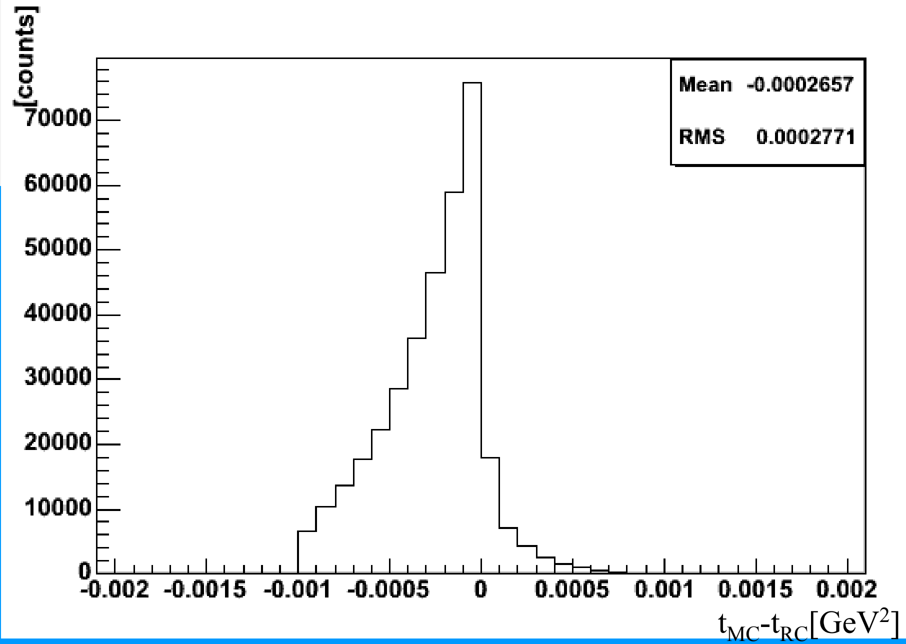
Photon energy resolution
~ 2.5%



πγ final state reconstruction:



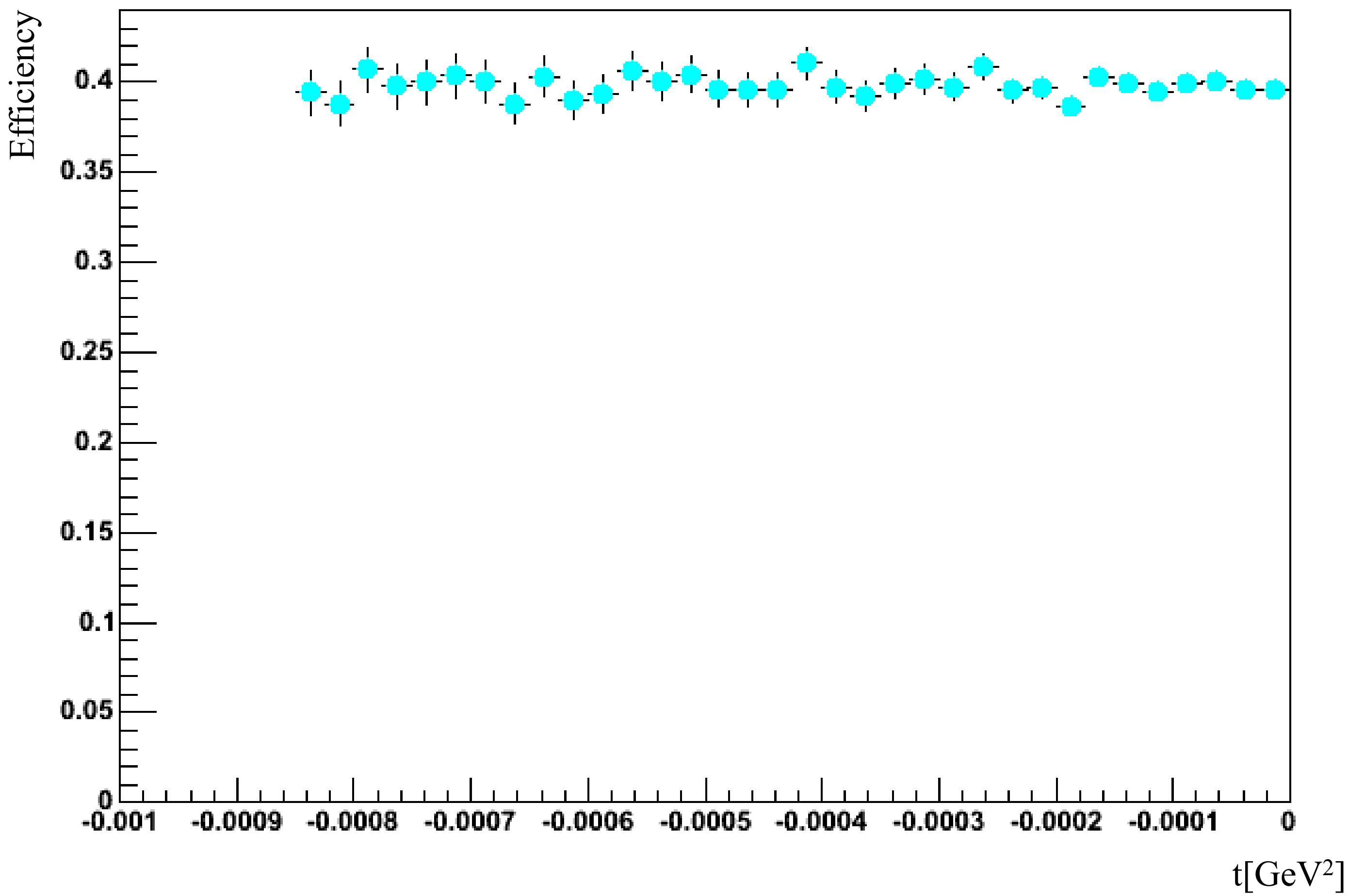
Four momentum transfer



Resolution of transversal components of the four-momentum transfer to (γπ):

$\sim 3 \cdot 10^{-4}\ (GeV/c)^2$

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



Polarizabilities statistics

With 10^7 π/s, the spill structure is 5 s beam every 16 s $\Rightarrow$ $2.2 \cdot 10^{11}$ π/day

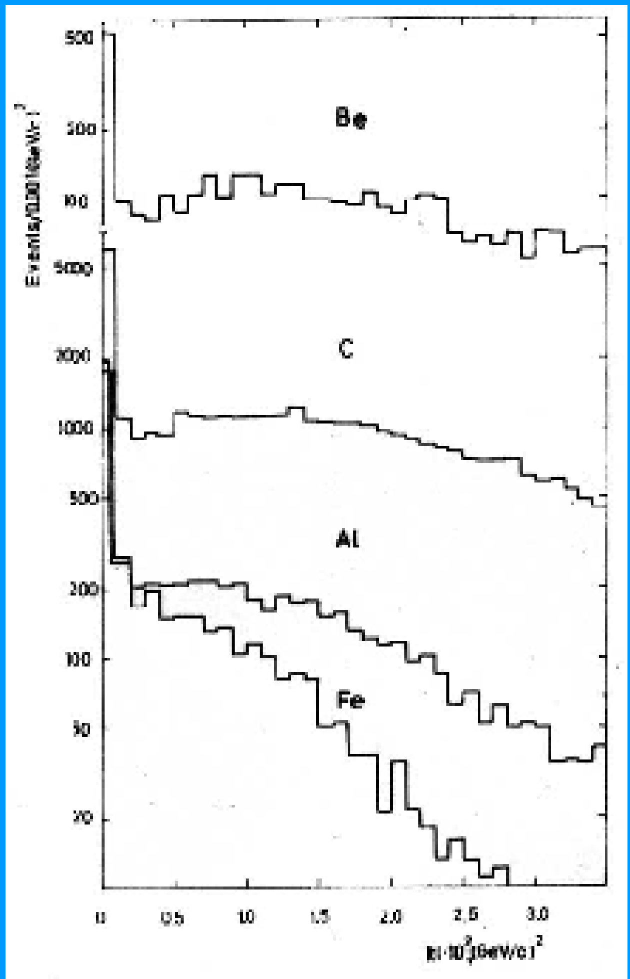
The interaction probability $R = \sigma N_T = 5 \cdot 10^{-6}$ assuming:
$\sigma = 0.5$ mbarn
$N_T = A\rho l / N_A = 10^{22}$ cm^{-2}

The global efficiency is estimated to be ε = 24 % due to:

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

$$2.2 \cdot 10^{11} \times 5 \cdot 10^{-6} \times 0.24 = 2.64 \cdot 10^{5} \text{ Events/day}$$

Primakoff summary



- Different target → Z^2 dependence in the the cross section
- Possible comparison with point like particle via the reaction: $\mu + Z \rightarrow \mu + Z + \gamma$
- Constant efficiency on t
- t resolution → $3 \cdot 10^{-4}$ $(GeV/c)^2$
- Error on polarizabilities $\delta\alpha \approx 0.4 \cdot 10^{-4}$ fm^3 $(\approx\sigma_{theory})$
- Also kaon polarizabilities can be measured

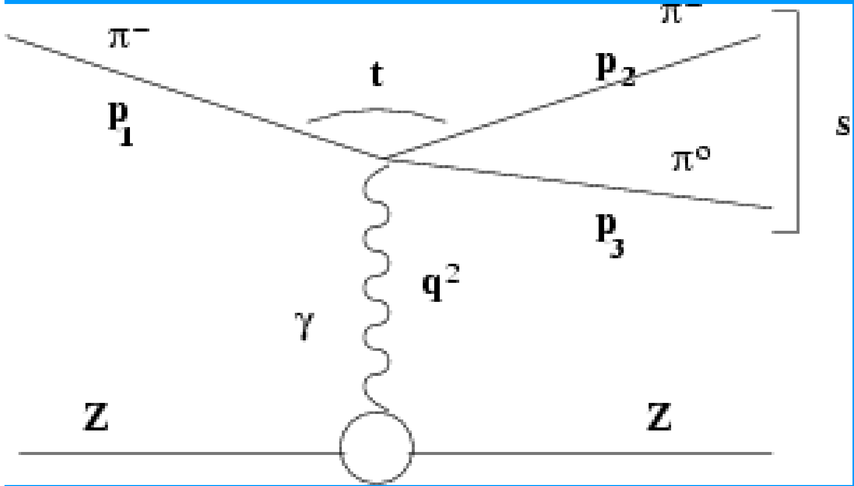
Kaon polarizability

The K cross section scales down as m^{-1} → 3 times smaller compared to the π one.
The polarizability goes as $\alpha_h = \frac{4\alpha_f}{m_h F_h^2}(L_r^9 + L_r^{10}) \rightarrow \alpha_K = \frac{\alpha_\pi}{5.4}$

Assuming :
$3 \cdot 10^5$ Kaon/s @ 190 GeV/c

we expect 10^3 Events/day

$F_{3\pi}$ measurement



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

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

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

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

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

$$\frac{d\sigma}{ds\,dt\,dq^2}=\frac{Z^2\alpha_f}{\pi}\left(\frac{q^2-q^2_{\min}}{q^4}\right)\frac{1}{s-m_\pi^2}\frac{d\sigma_{\gamma\pi\rightarrow\pi\pi}}{dt}$$

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

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

Expected ~ $5 \cdot 10^3$ events/day VS 200 Serpukov events in total

[1] Antipov et al., Phys Rev D36 21 (1987) [2] Moinester et al., Proc Conference on Physics with GeV Particle beam, Julic, Germany 1994, Miskimen et al., Theory and Experiment, MIT, 1994

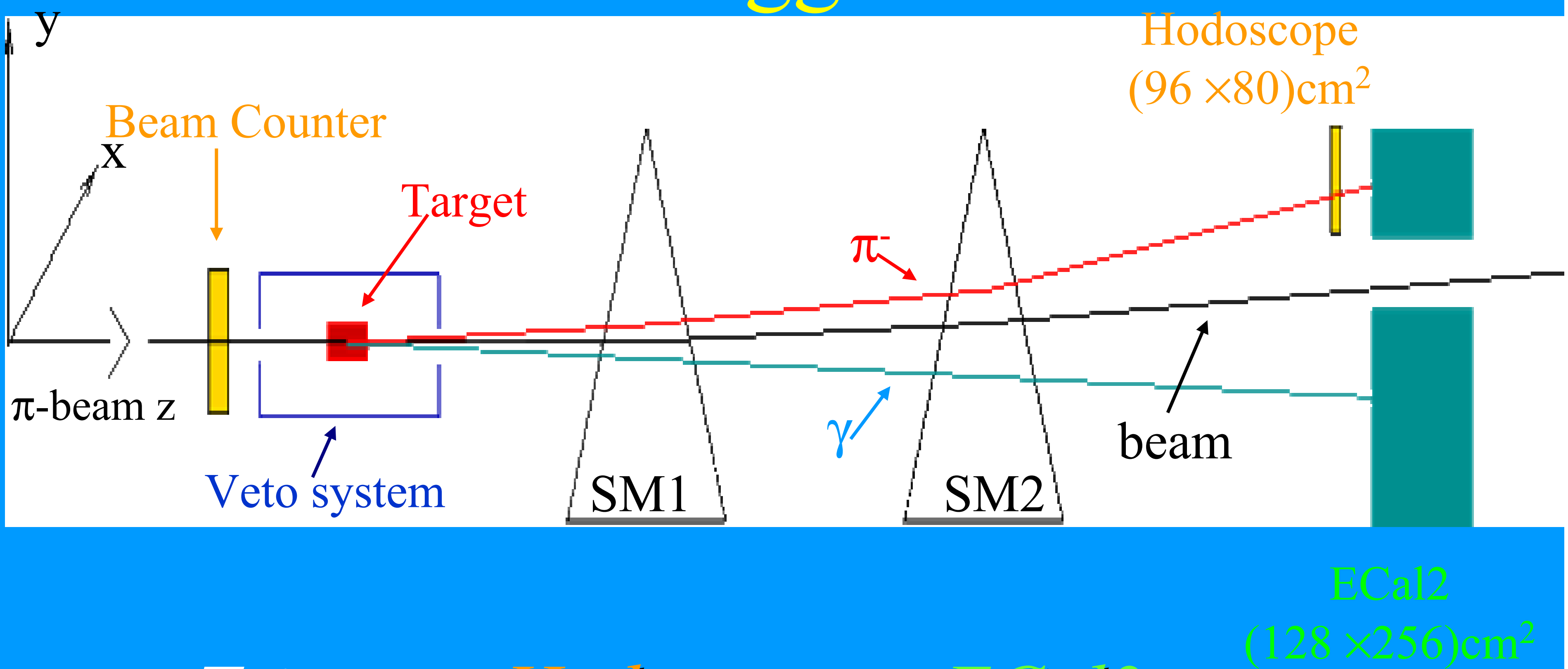
Conclusion

Using the ***COMPASS*** spectrometer one can:

- test the χPT measuring the pion polarizabilities via the Primakoff reaction.
- measure the kaon polarizabilities for the *first time*
- measure the chiral anomaly amplitude for $\gamma \rightarrow 3\pi$
- and more…

this is only a part of the wide research program

Trigger



Trigger: Hodoscope × ECal2

π^- γ

Comparison with the Serpukhov data

	@ Serpukhov	@COMPASS
beam momentum	40 GeV/c	190 GeV/c
beam intensity	10^6 π/spill	10^7 π/spill
target	Be, C, Cu, Fe	C, Cu, Pb
scattered pion	$\sigma_\theta \approx 1.2 \cdot 10^{-4}$ rad	$\sigma_\theta \approx 4 \cdot 10^{-5}$ rad
	$\sigma_p/p \approx 1\%$	$\sigma_p/p \approx (0.3 \div 1)\%$
outgoing photon	$\sigma_\theta \approx 1.5 \cdot 10^{-4}$ rad	$\sigma_\theta \approx 3.1 \cdot 10^{-5}$ rad
	$\sigma_E/E \approx 3.5\%$@27GeV	$\sigma_E/E \approx (5.5/\sqrt{E} + 1.5)\%$
total flux	10^{11}	10^{13} π/day
Primakoff events	$\sim 6 \cdot 10^3$ in total	$6.4 \cdot 10^4$/day