III Congressino di sezione
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on behalf of the COMPASS coll.

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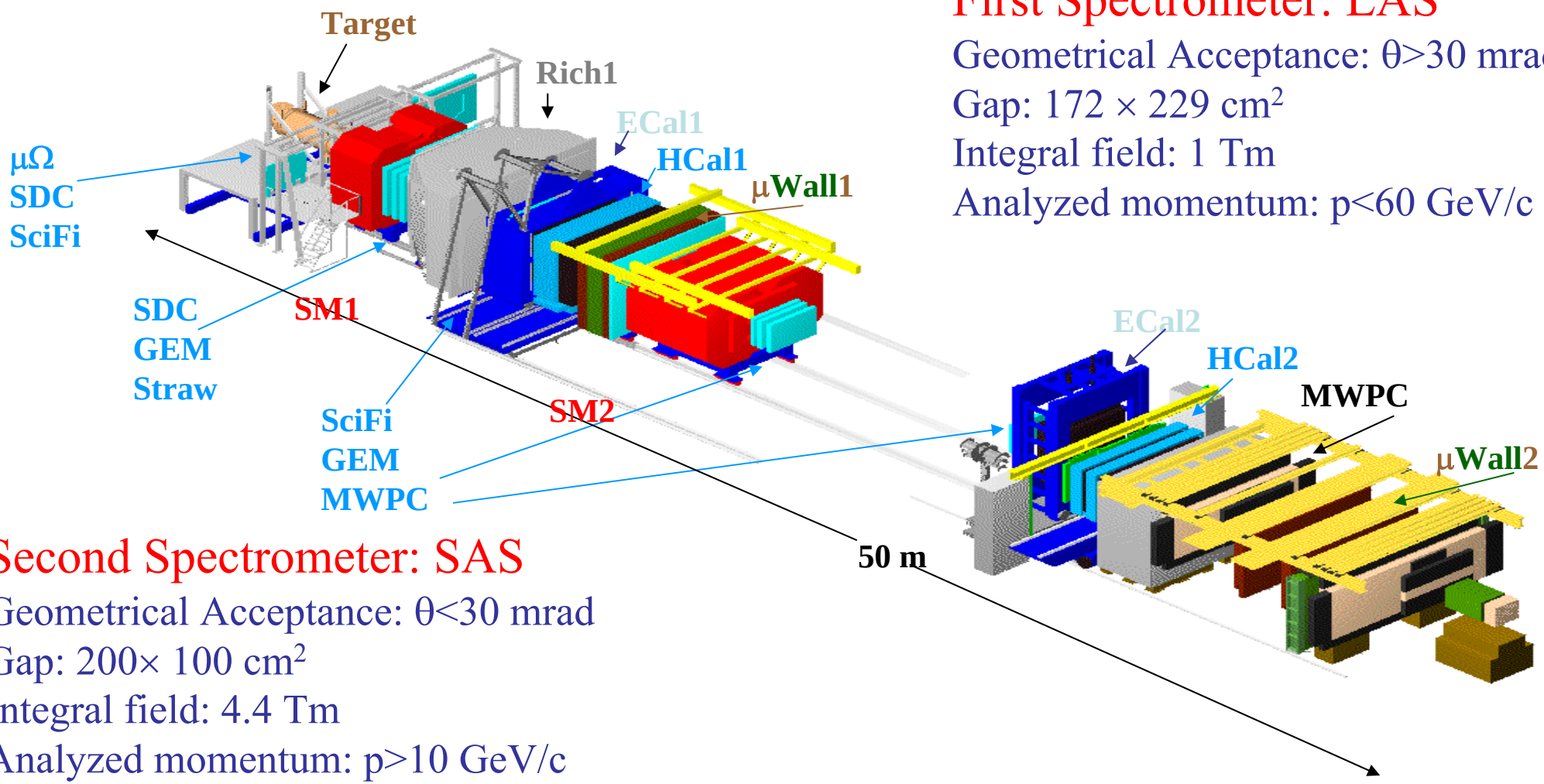
Primi risultati della misura dell'effetto Primakoff nell'esperimento COMPASS

The *COMPASS* setup

First Spectrometer: LAS

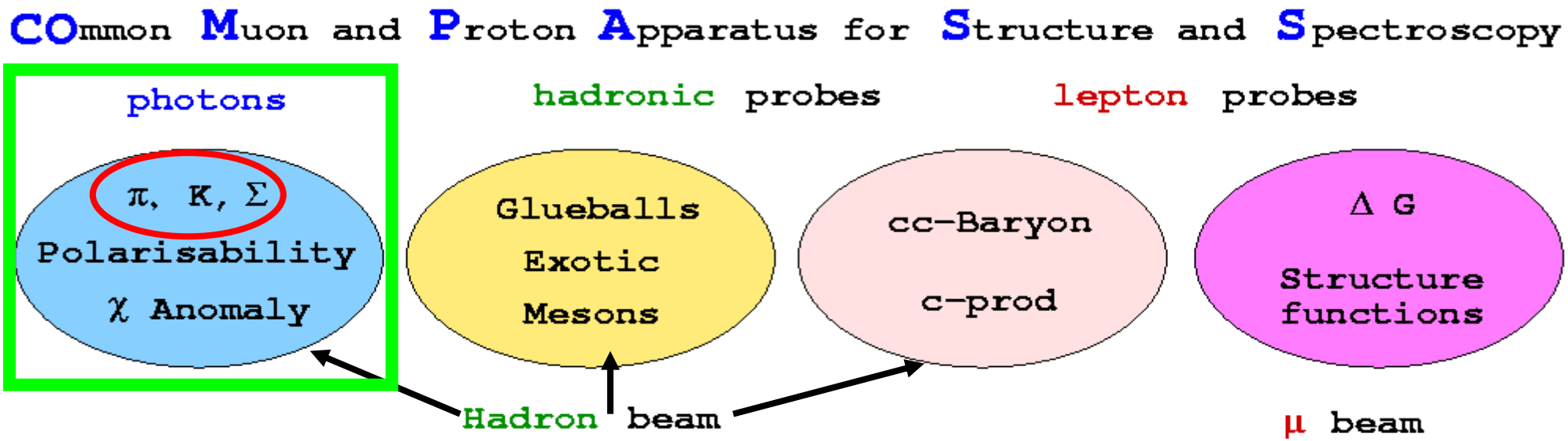
Geometrical Acceptance: θ>30 mrad
Gap: 172 × 229 cm^2
Integral field: 1 Tm
Analyzed momentum: p<60 GeV/c



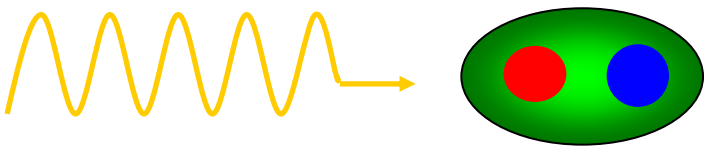
Second Spectrometer: SAS

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

COMPASS Physics program



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



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

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

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 using the effective chiral lagrangian.

Chiral dynamics describes:

- properties
- production
- decay amplitude
- low energy interactions

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

$$\mathcal{L}_{QCD}\,(\text{quark,gluon}) \rightarrow \text{at low energy} \rightarrow \mathcal{L}_{eff}\,(\pi,K,\eta,..)$$

Pion polarizabilities

The χPT through the effective lagrangian $\mathcal{L}_{eff}$, where the coupling constant are measured experimentally, provide prediction for the $\bar{\alpha}_\pi$ and $\bar{\beta}_\pi$:

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

The numerical value are [1]: $\bar{\alpha}_\pi = (2.4 \pm 0.5)\cdot 10^{-4}\ fm^3$

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

Other models (dispersion sum rules[2], QCD sum rule[3], lattice calculations[4],…)

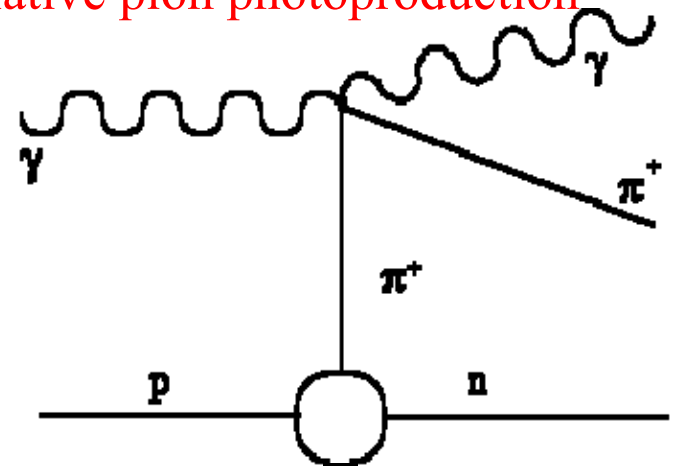
$$2.4\cdot 10^{-4}\ \mathrm{fm}^3 < \bar{\alpha}_\pi < 8\cdot 10^{-4}\mathrm{fm}^3$$

$$-8.0\cdot 10^{-4}\ \mathrm{fm}^3 < \bar{\beta}_\pi < -2.1\cdot 10^{-4}\mathrm{fm}^3$$

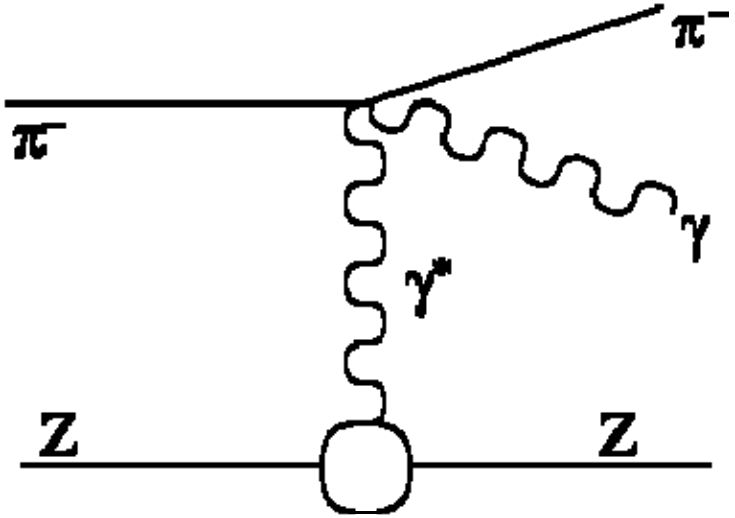
[1] U. Burgi, Phys.Lett. B 377 (1996) 147
[2] L.V Fil'kov et al., Eur. Phys. J. A5 (1999) 285
[3] M.J. Lavelle et al., Phys. Lett. B 335 (1994) 211
[4] W. Wlicox., Phys. Rev D 57 (1998) 6731

Experimental methods:

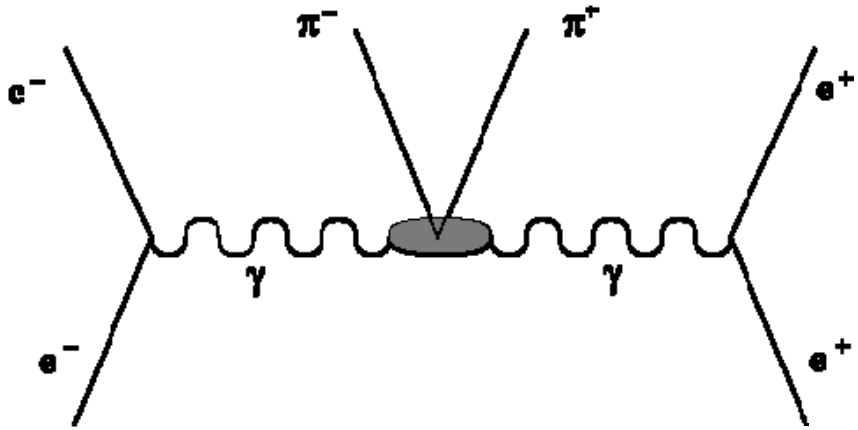
Radiative pion photoproduction



Radiative pion scattering



Photon-photon collision



Experimental values

Data	Reaction	α [10^{-4} fm^3]
Lebedev	$\gamma p \rightarrow \gamma \pi^+ n$	20±12
PLUTO	$\gamma\gamma \rightarrow \pi^+\pi^-$	19.1±4.8±5.7
DM1	$\gamma\gamma \rightarrow \pi^+\pi$	17.2±4.6
DM2	$\gamma\gamma \rightarrow \pi^+\pi$	26.3±7.4
MARK II	$\gamma\gamma \rightarrow \pi^+\pi$	2.2±1.6
Serphukov	$\pi Z \rightarrow \pi Z \gamma$	6.8± 1.4± 1.2

Data	Reaction	$(\alpha+\beta)$ [10^{-4} fm^3]
Serphukov	$\pi Z \rightarrow \pi Z \gamma$	1.4± 3.1±2.8

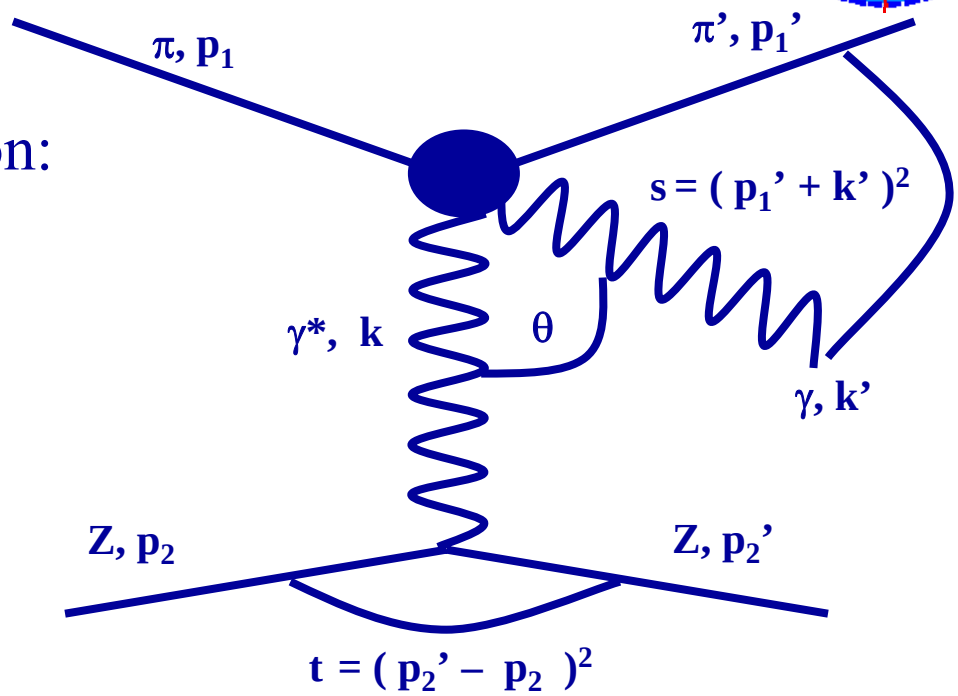
Data	Reaction	$(\alpha-\beta)$ [10^{-4} fm^3]
Serphukov	$\pi Z \rightarrow \pi Z \gamma$	13.6±2.8
MAMI-A2	$\gamma p \rightarrow \gamma \pi^+ n$	11.6±1.5±3.0±0.5

The experimental values are effected by too large statistical and/or systematic errors

The Primakoff reaction

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

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



ω photon energy in the antilab system

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

$$t_0 = \left(\frac{m_\pi \omega}{p_{beam}}\right)^2 \qquad F_A(t) \sim 1$$

θ real photon scattering angle

Electric & Magnetic polarizabilities

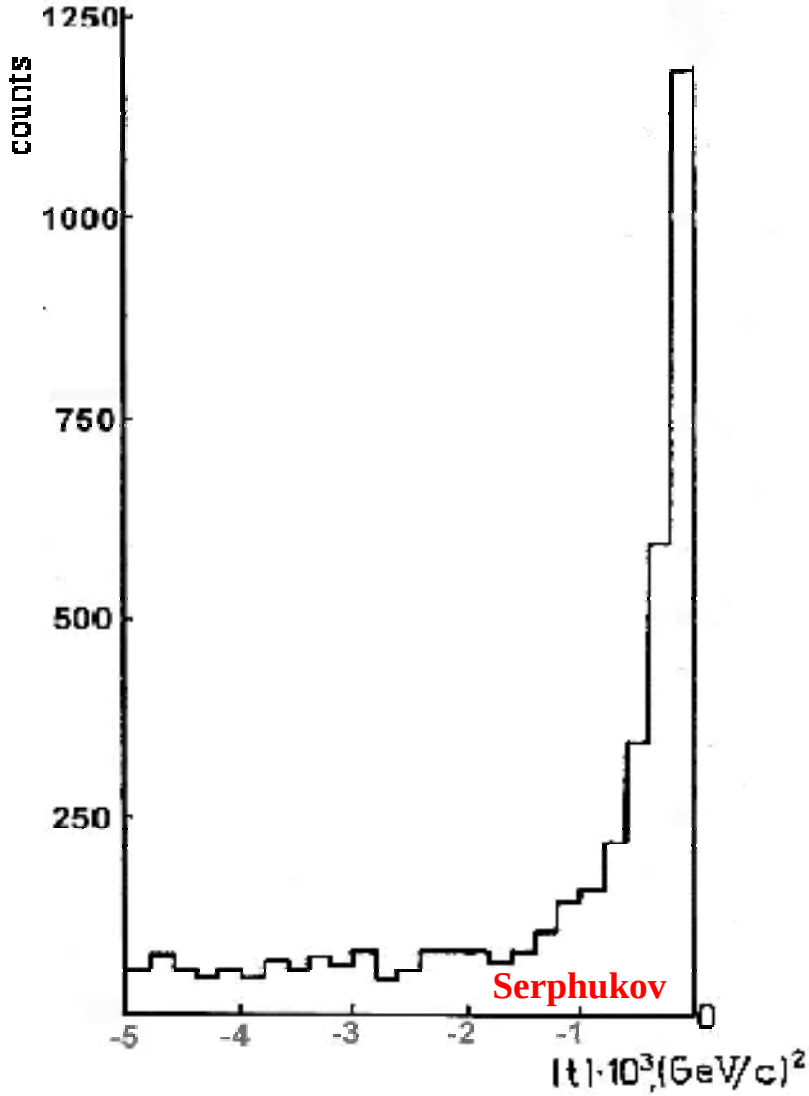
$$\frac{d\sigma_{\pi\gamma}(\omega,\vartheta)}{d\cos\vartheta} = \frac{2\pi\alpha_f^2}{m_\pi^2}\cdot\left(F_{\pi\gamma}^{Pt} + \frac{m_\pi\omega^2}{\alpha_f}\cdot\frac{\boxed{\alpha_\pi}(1+\cos^2\vartheta) + \boxed{\beta_\pi}\cos\vartheta}{\left(1+\frac{\omega}{m_\pi}(1-\cos\vartheta)\right)^3}\right)$$

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



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

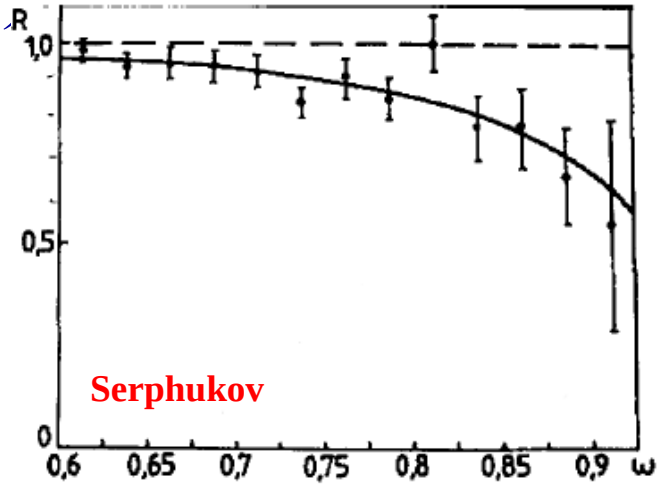
To extract α_π and β_π

Assuming $(\alpha_\pi + \beta_\pi)=0$

- Fit the ratio in the lab system

$(w = E_\gamma/E_0)$

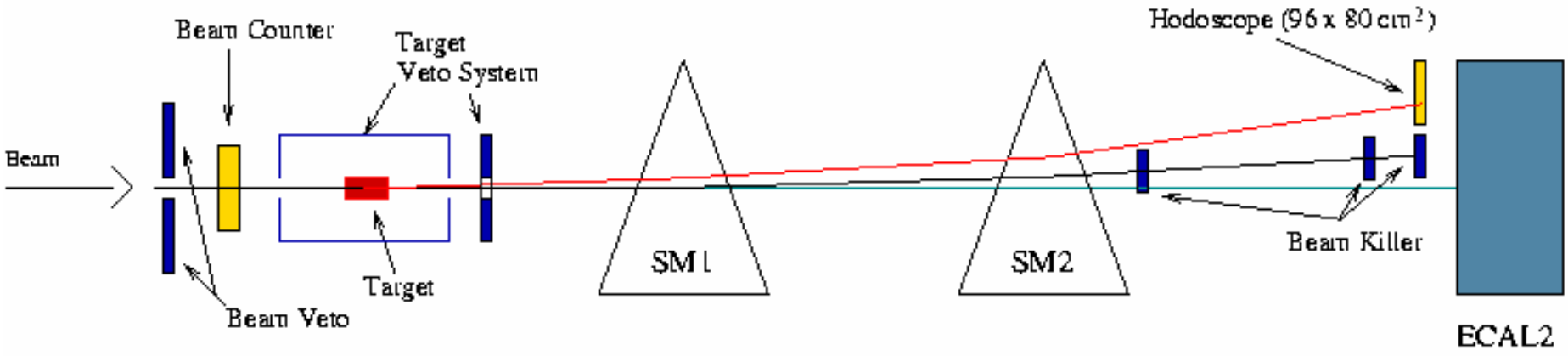
$$R = \frac{\left(\frac{d\sigma_{\beta_\pi \neq 0}}{dw}\right)^{nonPt}}{\left(\frac{d\sigma_{\beta_\pi = 0}}{dw}\right)^{Pt}} = 1 + \frac{3}{2} \times \frac{w^2}{1-w} \times \frac{m_\pi^3}{\alpha} \times \beta_\pi$$



INDEPENDENTLY

- Fit the 2-dim cross-section in the alab system
  - the MC-simulations are needed to correct for acceptance

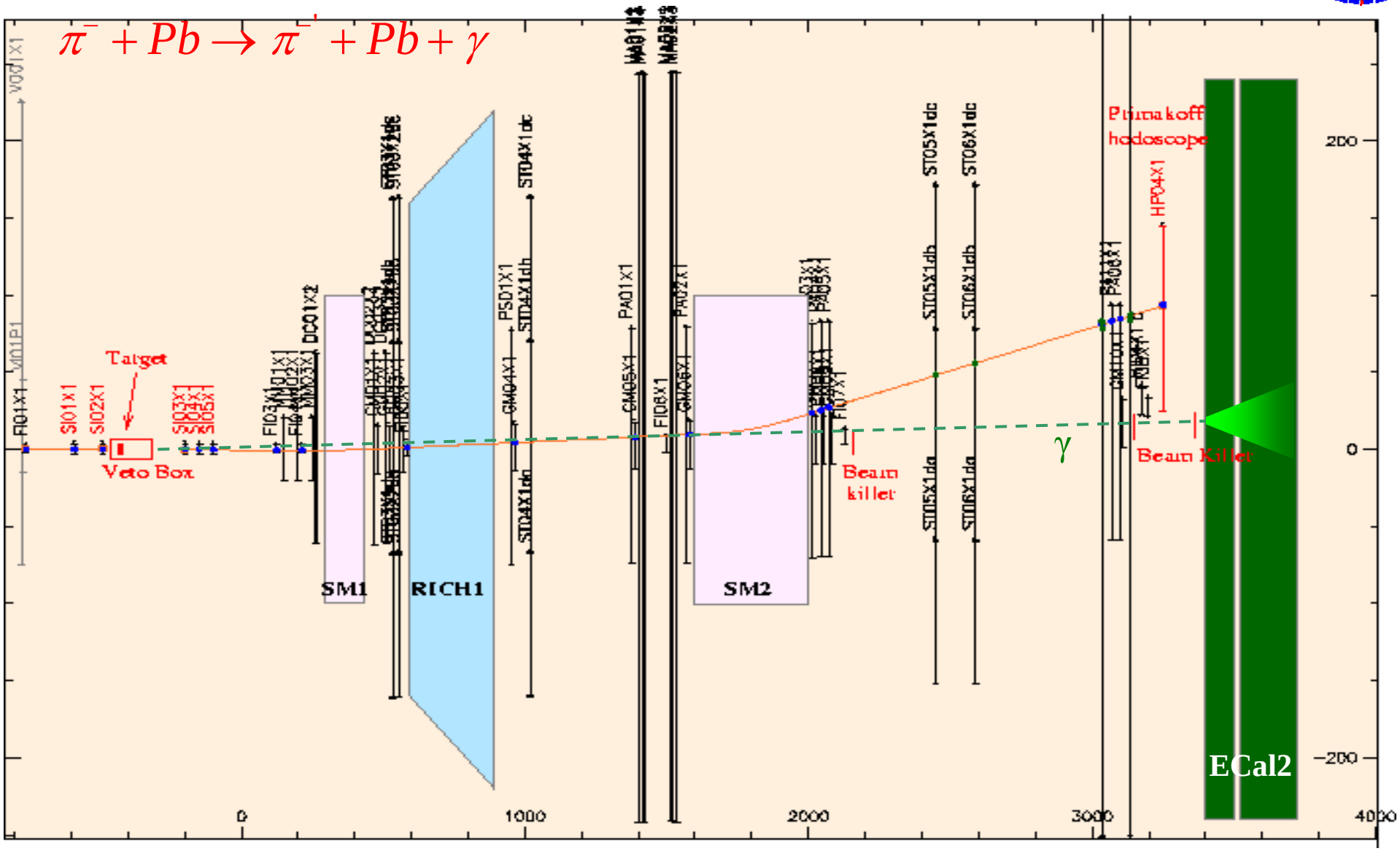
Trigger



Experimental conditions during the 2004 Pilot hadron run (7 days)

- Beam: 190 GeV/c; ~10^6 π/s, 4.8 s / 16 s spill structure
  190 GeV/c; ~10^8 μ/s
- Targets: 1.6 - 3mm Pb (~25% - 50% X_0), 7 mm Cu, 23 mm C
- 3 possible triggers:
  - Veto x Hodoscope hit x ECal2 ($E\gamma$>50 GeV)
  - Veto x ECal2 ($E\gamma$>100 GeV)
  - Beam x Beam-Veto x Beam Killer

Typical reconstructed event:



Preliminary analysis of the 2004 COMPASS data

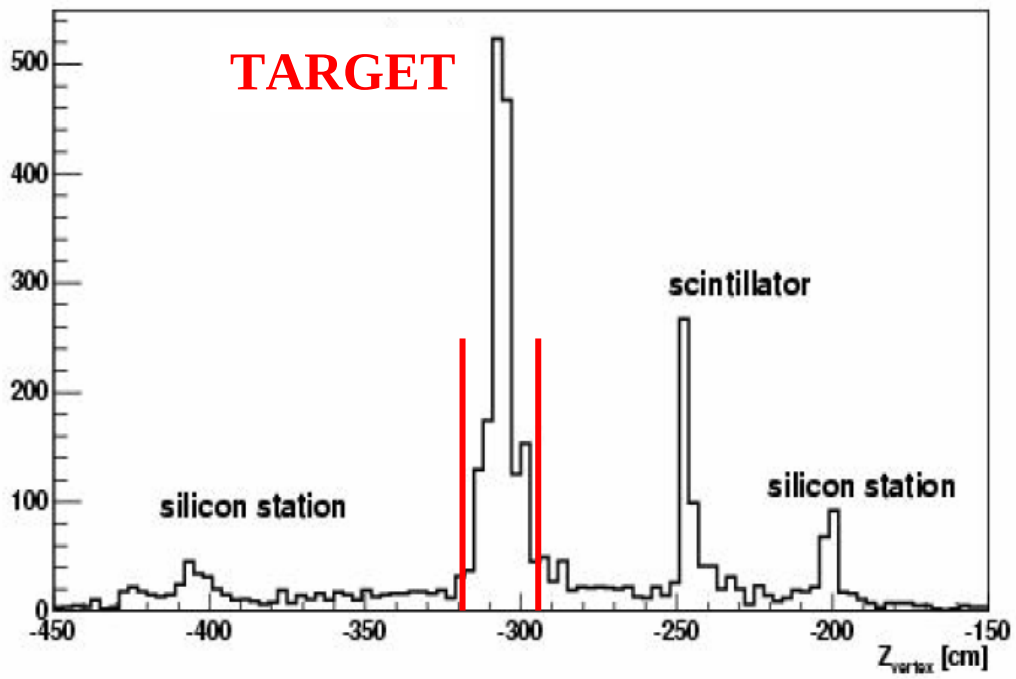
less than 1/10 of collected events

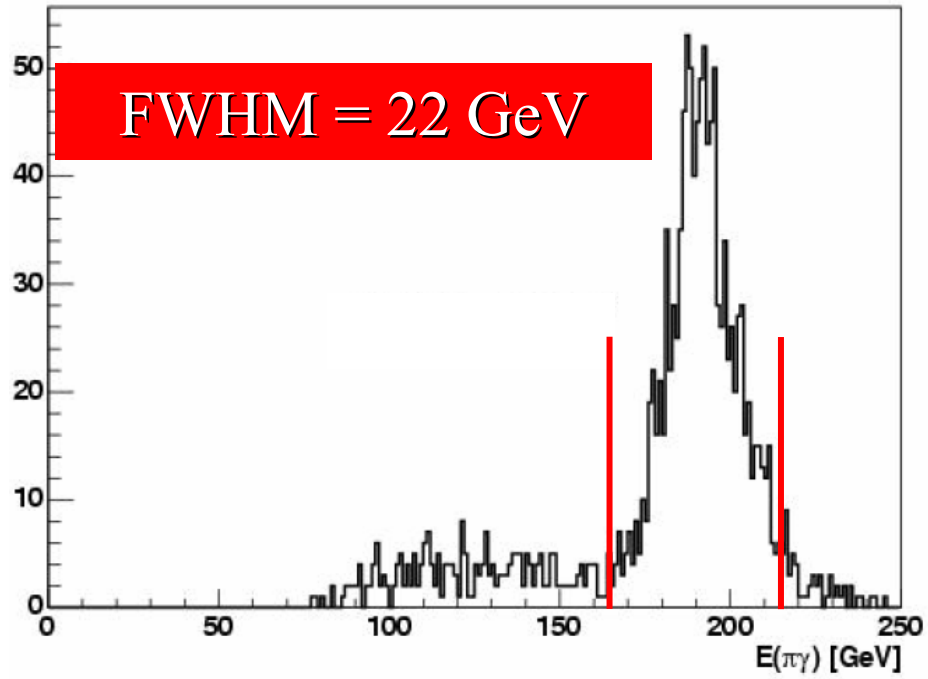
Select $\pi^- + Pb_{(3mm)} \rightarrow \pi^- + Pb_{(3mm)} + \gamma$

Cuts:

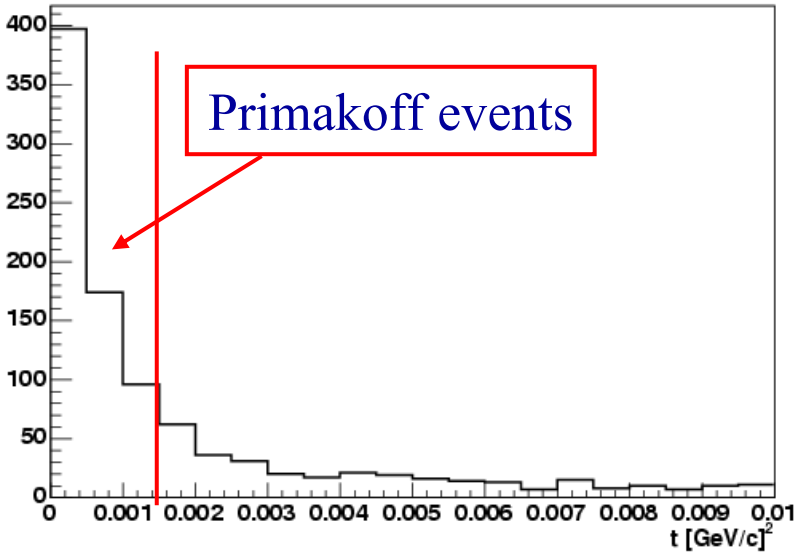
Position of the reconstructed interaction vertex

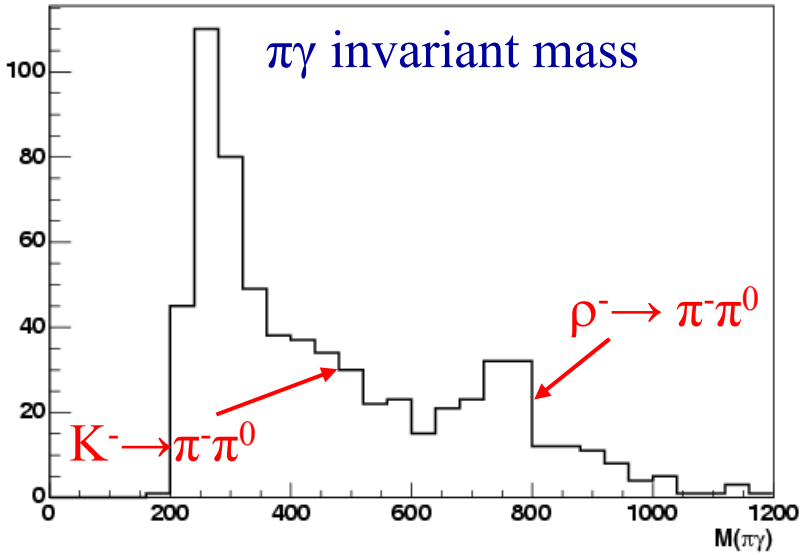
Energy of the final state($\pi^-\gamma$)





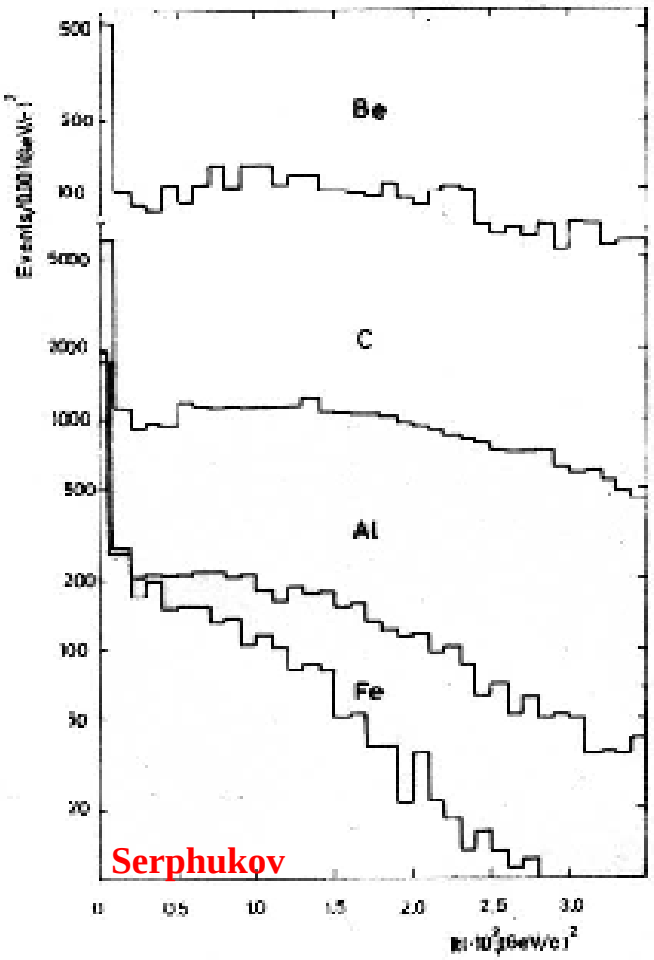
Primakoff signature





- Background contribution will be also estimated using empty target runs
- Systematic effect will be estimated using a sample of data collected with **muon beams** in the same experimental conditions. Very peculiar features of the COMPASS experiment

Polarizabilities measurement summary



- Different targets (Pb, Cu, C) → Z^2 dependence in the cross section
- Point like contribution via the reaction: $\mu + Z \rightarrow \mu + Z + \gamma$
- Expected error on polarizabilities $\delta\alpha \approx 0.4 \cdot 10^{-4}\ fm^3$ ($\approx\sigma_{theory}$)
- Also kaon polarizabilities can be measured for the **first time**

Kaon polarizability

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

The polarizability goes as

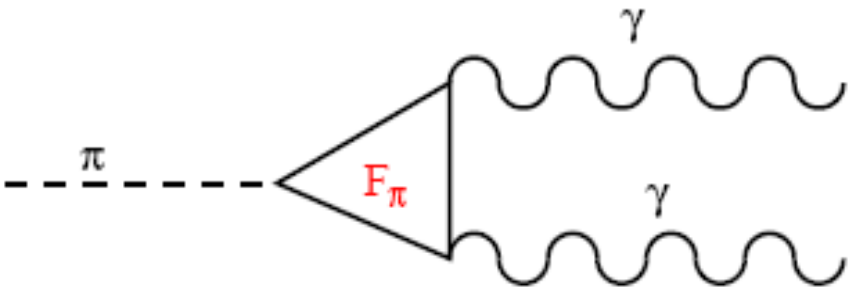
$$\alpha_h = \frac{4\alpha_f}{m_h F_h^2}(L_r^9 + L_r^{10}) \rightarrow \alpha_K = \frac{\alpha_\pi}{5.4}$$

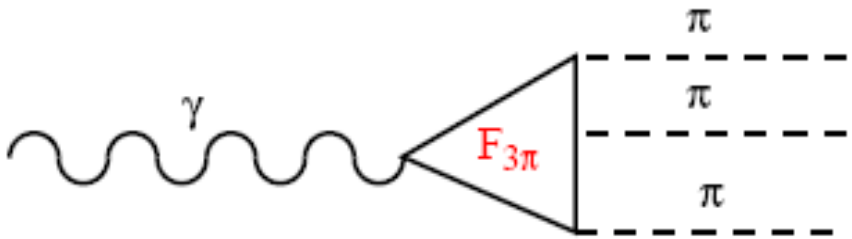
Assuming :

$3 \cdot 10^5$ Kaon/s @ 190 GeV/c we expect 10^3 Events/day

For this measurement the CEDARs counters are needed

Measurement of the chiral anomaly



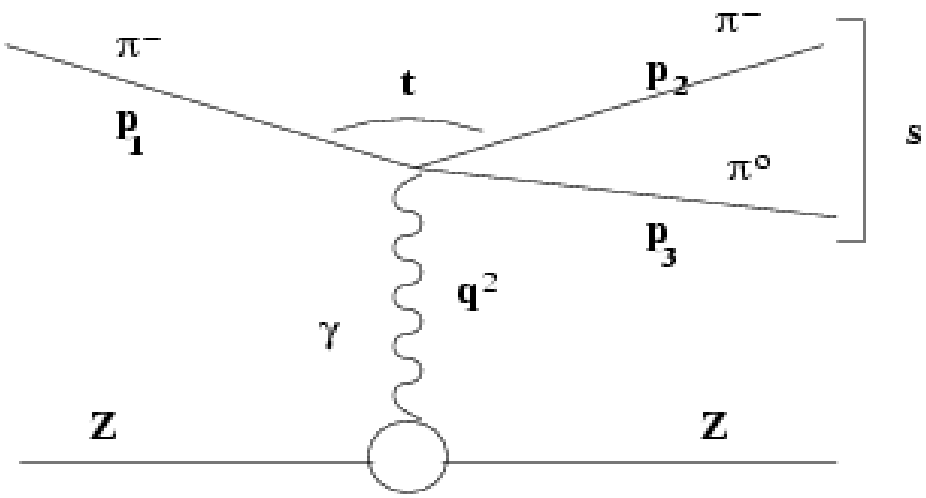


$F_{3\pi}$ allows to verify the low energy theorem:

$$F_{3\pi}(0) = \frac{F_\pi(0)}{\sqrt{4\pi\alpha_f}\, f^2}$$

$F_\pi(0)$ is the coupling constant for the 1st diagram
α_f is the fine structure constant
f is the charged pion decay constant

$F_{3\pi}$ 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 $\gamma \rightarrow 3\pi$

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

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

$F_{3\pi} = (12.9 \pm 0.9 \pm 0.5)$ GeV^{-3} [5] $F_{3\pi} = (9.72 \pm 0.09)$ GeV^{-3} [6]

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

[5] Antipov et al., Phys Rev D36 21 (1987) [6] Ll. Ametler, et al., Phys. Rev D 64, 094009, 2001

Conclusions

- The COMPASS pilot 2004 hadron run was successfully completed; collecting an integrating beam flux of more than 10^{11} π for the polarizabilities measurement

- The preliminary analysis shows clearly the signature of the Primakoff reaction and that a statistic of at least 4 times larger than in the previous experiment is expected (30-40k vs 7k events).

- The analysis of 3π events is in progress