Measurement of the Pion and Kaon Polarisabilities at COMPASS

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Outline

- Compton scattering and polarisabilities
  - Motivation
  - Related processes for unstable particles
  - Primakoff kinematics
- The COMPASS 2004 pilot hadron run
- Data analysis

Hadron structure

- How are hadrons built up in terms of their constituents?

  Static properties $\Leftrightarrow$ form factors

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- How do hadrons react to (small) external forces?

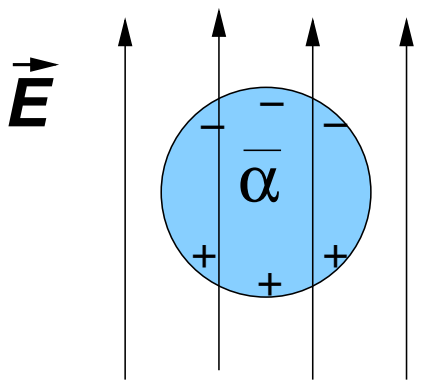
  Non-pointlike response $\Leftrightarrow$ polarisabilities

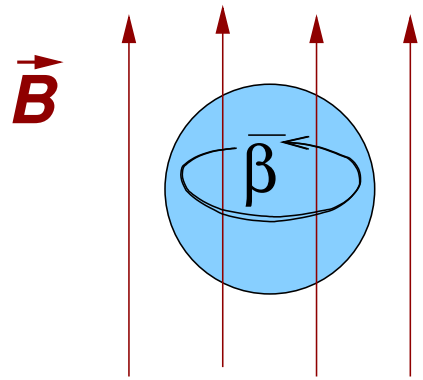
classical

$$\vec{d} = (eZ)2\ell = \bar{\alpha}\vec{E}$$

$$K\ell = (eZ)E$$

$$\bar{\alpha} = \frac{2(eZ)^2}{K}$$





Compton scattering

- for point-like target completely determined by QED
- polarisability contribution starting at $\mathcal{O}(E_\gamma)$ (for spin-$\frac{1}{2}$)

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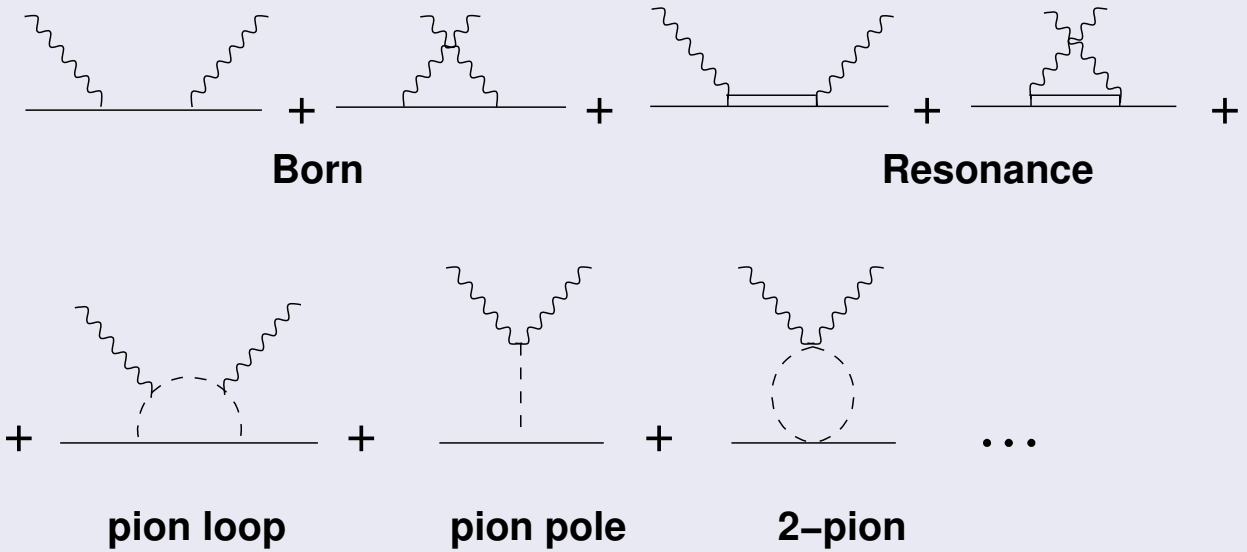
Nucleon case



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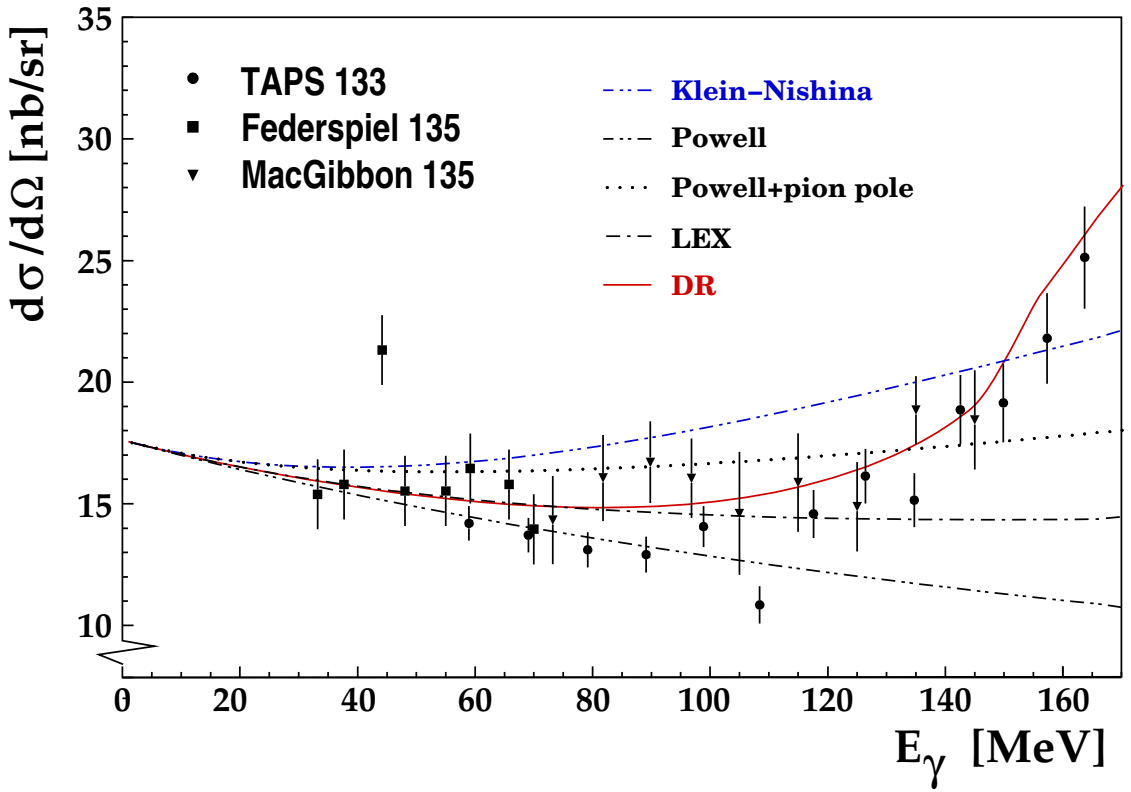
Proton data

$$\bar{\alpha}_p = 12.1 \pm 0.3_{\text{stat}} \mp 0.4_{\text{syst}} \pm 0.3_{\text{mod}} \cdot 10^{-4}\text{fm}^3$$

$$\bar{\beta}_p = 1.6 \pm 0.4_{\text{stat}} \pm 0.4_{\text{syst}} \pm 0.4_{\text{mod}} \cdot 10^{-4}\text{fm}^3$$

(cancellation of para- and diamagnetic contributions)



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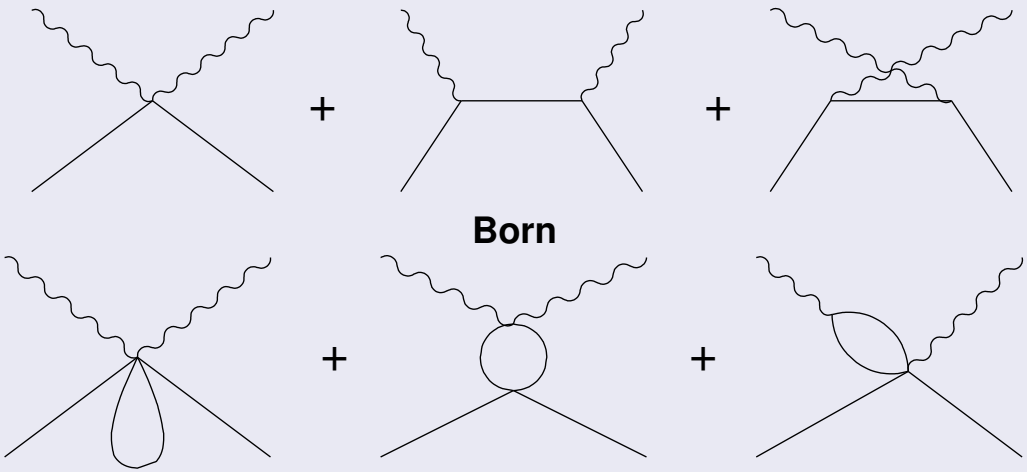
Pion case



$$\mathcal{M} = 8\pi i \cdot m_\pi \left[\left(-\frac{\alpha}{m_\pi} + \bar{\alpha} \cdot \omega_1 \omega_2 \right) \vec{\epsilon}_1 \cdot \vec{\epsilon}_2 + \bar{\beta} \cdot (\vec{q}_1 \times \vec{\epsilon}_1) \cdot (\vec{q}_2 \times \vec{\epsilon}_2) \right]$$

Meson Polarisabilities

Pion

- Low-energy expansion of QCD: Chiral perturbation theory

  Pion has a special role as the Goldstone boson
  (massless in the chiral limit)

- are the basic features correctly described?

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ChPT 1-loop for $\pi^{\pm}$

$$\begin{aligned} \bar{\alpha} + \bar{\beta} &= 0 \\ \bar{\alpha} - \bar{\beta} &= \frac{2e^2}{\pi m_\pi f_\pi^2} \left(L_9^r + L_{10}^r \right) \\ &= +5.4 \pm 0.8 \cdot 10^{-4} \mathrm{fm}^3 \end{aligned}$$

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Dispersion sum rules $\pi^{\pm}$

$$\begin{aligned} \bar{\alpha} + \bar{\beta} &= 0.39 \pm 0.4 \cdot 10^{-4} \mathrm{fm}^3 \\ \bar{\alpha} - \bar{\beta} &\approx 10 \cdot 10^{-4} \mathrm{fm}^3 \end{aligned}$$

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Kaon

- Higher mass $\Leftrightarrow$ smaller polarisability by a factor ~ 5
- theoretically very exciting – need for experimental data!

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1st option

test the particle during its production process

A) $e^+e^- \rightarrow e^+e^- \pi^+\pi^-$ $\quad (\gamma\gamma \rightarrow \pi^+\pi^-)$

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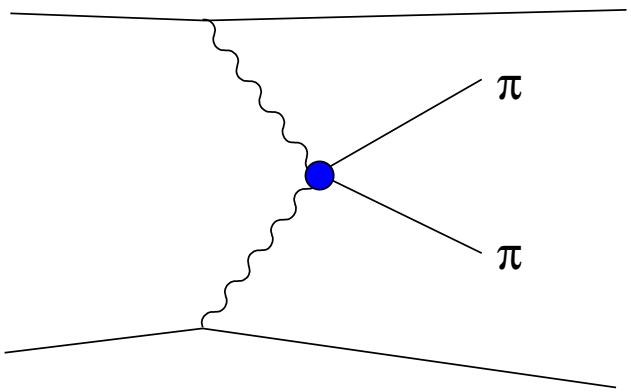

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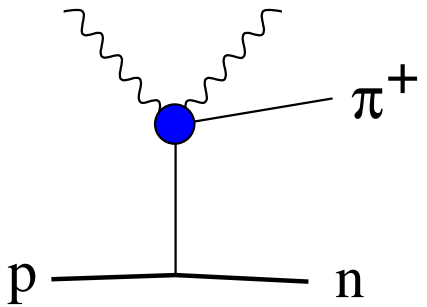
test the particle during its production process

A) $e^+e^- \rightarrow e^+e^-\,\pi^+\pi^- \qquad (\gamma\gamma \rightarrow \pi^+\pi^-)$

B) radiative pion photoproduction on the nucleon
$\gamma\,\mathrm{p} \longrightarrow \gamma\,\mathrm{n}\,\pi^+$

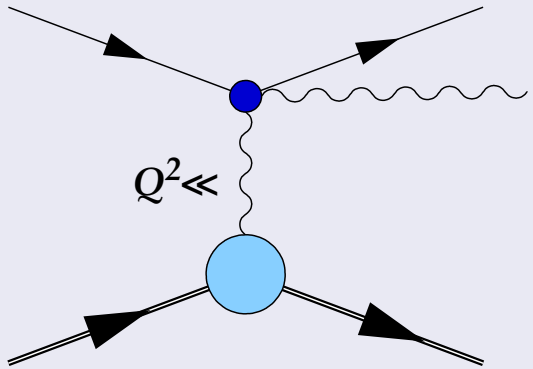


Compton scattering on unstable particles

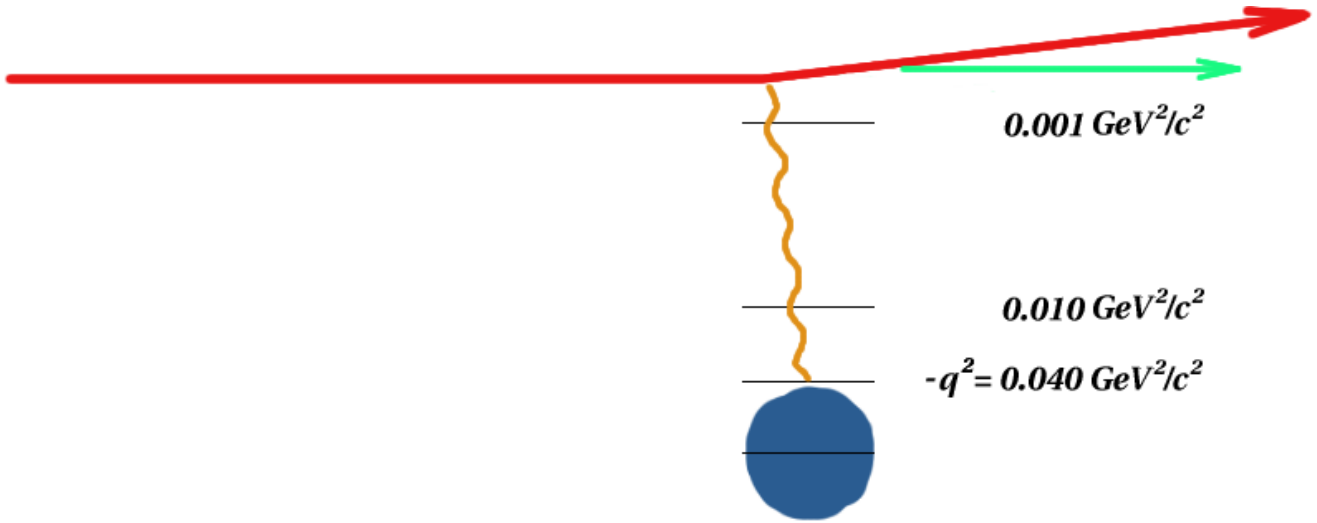
2nd option

use ultra-relativistic particle beam (quasi-stable)

on “photon target”:
Coulomb photon of a heavy nucleus participates in (semi-)hadronic interaction – Primakoff effect



Pion-nucleus scattering at small Q^2



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

diffractive scattering:
$\rightarrow$ meson spectroscopy
$\rightarrow$ exotics

$Q^2 < 0.001\ \mathrm{GeV}^2/c^2$

- $\pi + \gamma^{(*)} \rightarrow \pi' + \pi^0$
- $\pi + \gamma^{(*)} \rightarrow \pi' + \gamma$
  Primakoff reaction
  $\rightarrow$ pion polarisability

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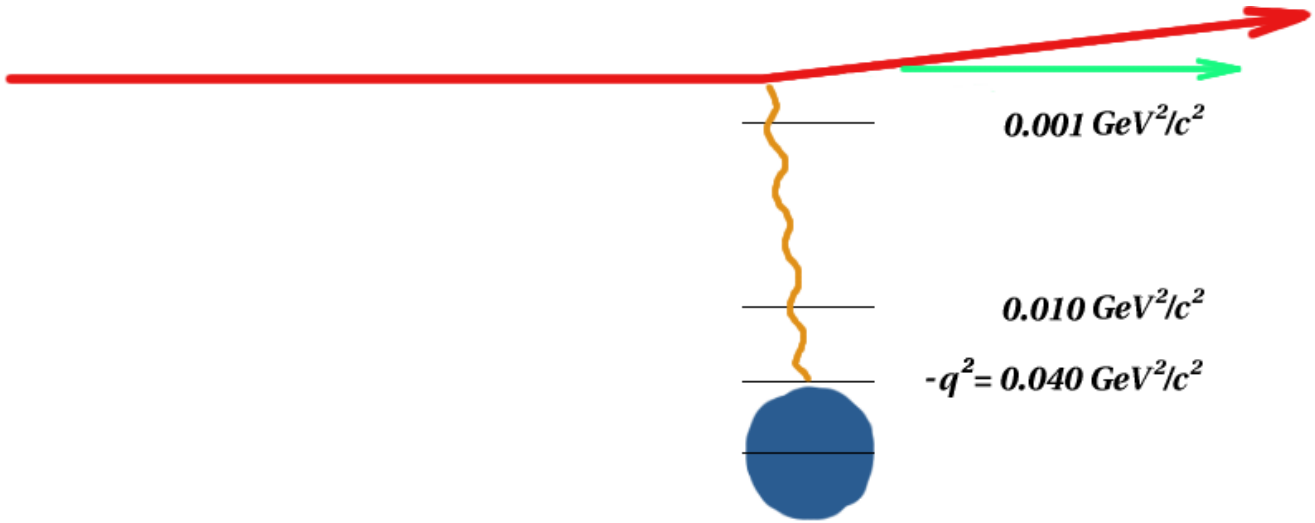

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e.m./strong Interference

Recently approached in eikonal approx. (G. Faeldt)

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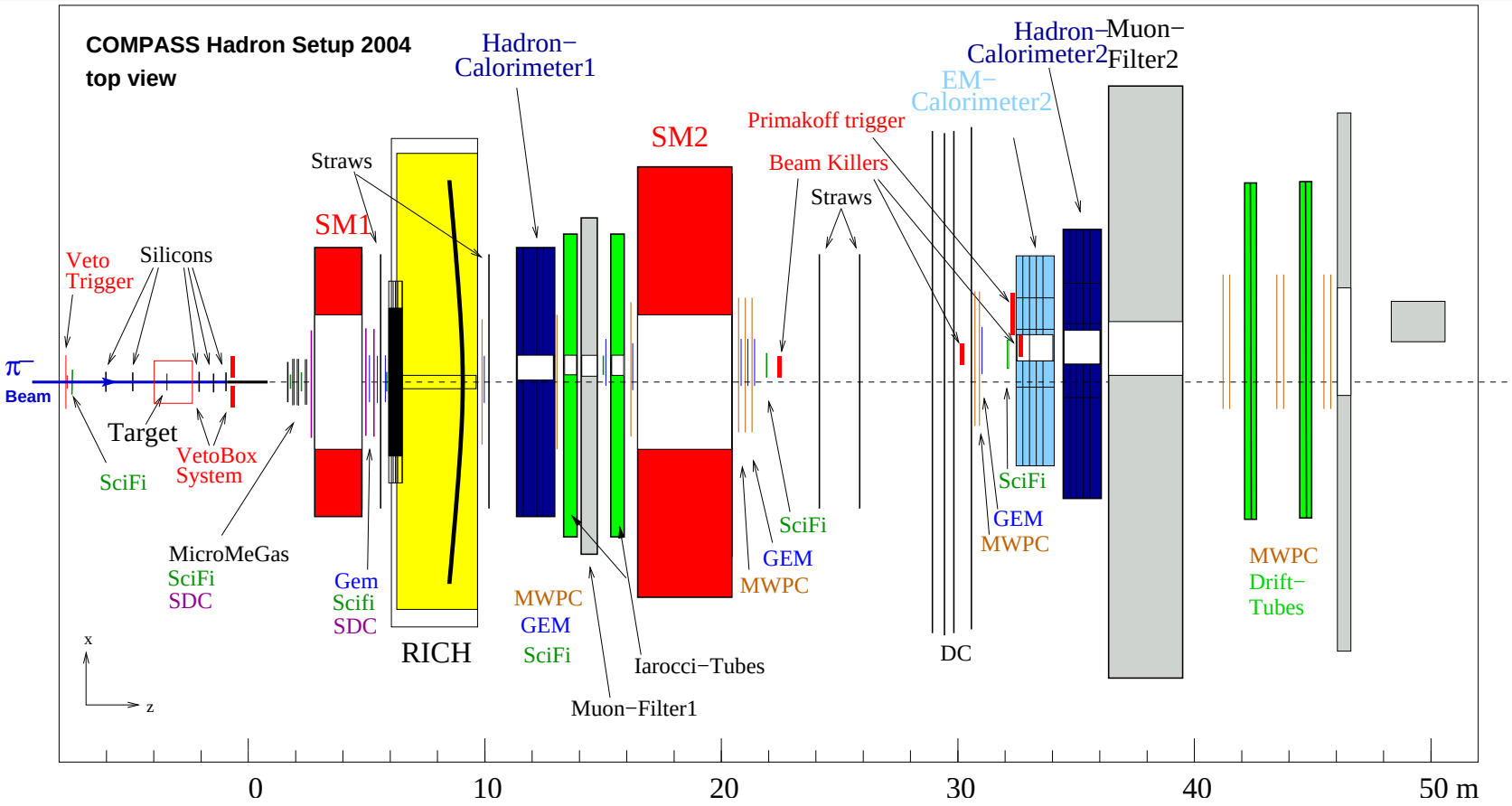
Data on the Pion Polarisability

	$\alpha + \beta$ $[10^{-4}\,\mathrm{fm}^3]$	$\alpha - \beta$ $[10^{-4}\,\mathrm{fm}^3]$
Bürgi (ChPT)	0.3 ± 0.1	4.4 ± 1.0
Mark II	$0.22 \pm 0.07 \pm 0.04$	4.8 ± 1.0
CELLO	$0.33 \pm 0.06 \pm 0.01$	
Serpukhov	$1.8 \pm 3.1 \pm 2.5$	12.3 ± 2.6
MAMI		$11.6 \pm 1.5 \pm 3.0 \pm 0.5$
COMPASS	?	?

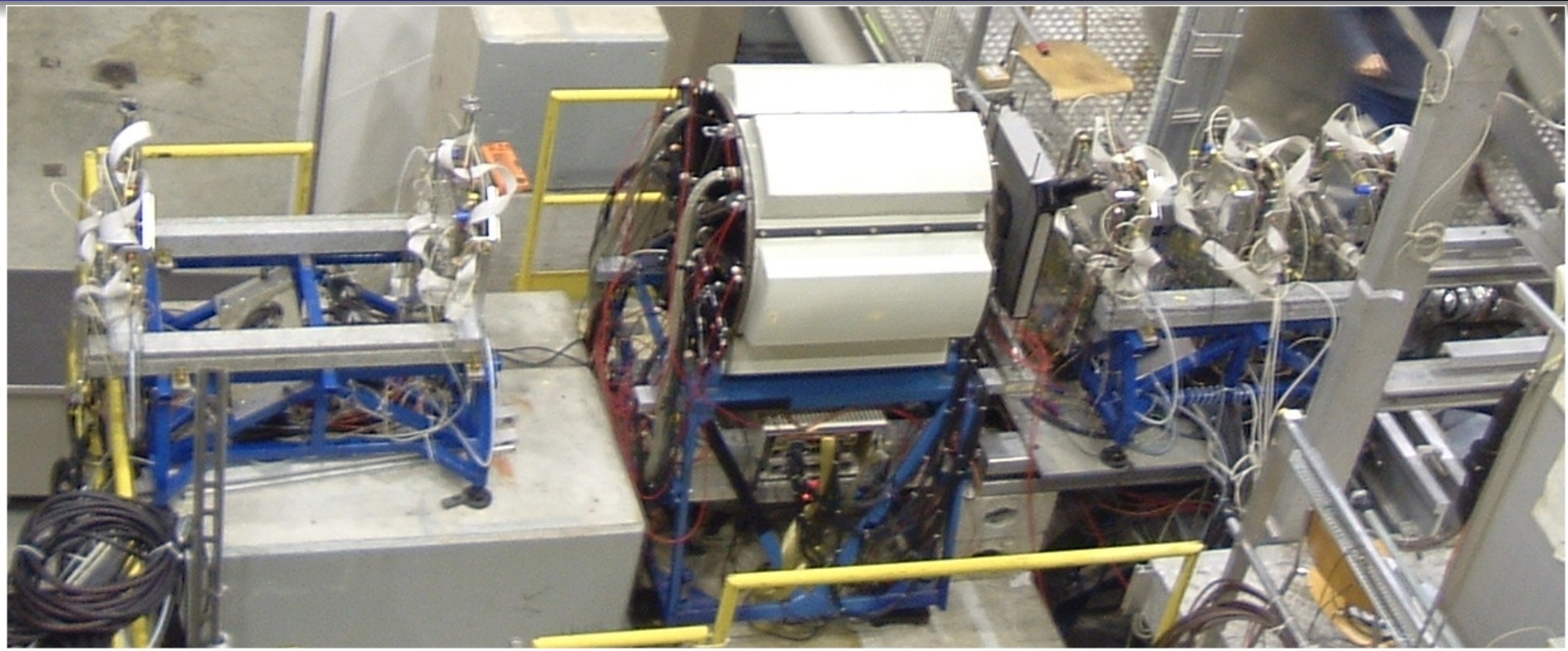
- different reactions with different systematics
- challenging measurements (Mainz $\sim$ 1000 h beam time!)
- no coherent picture of pion polarisability yet

Layout of the COMPASS 2004 pilot hadron run



- 4 weeks data taking in autumn 2004
- 190 GeV π^-/μ^--beam, 10^6 particles/s
- Targets: Pb ($X_0 = 0.29, 0.5$), Cu (0.25), C (0.12)

Target region



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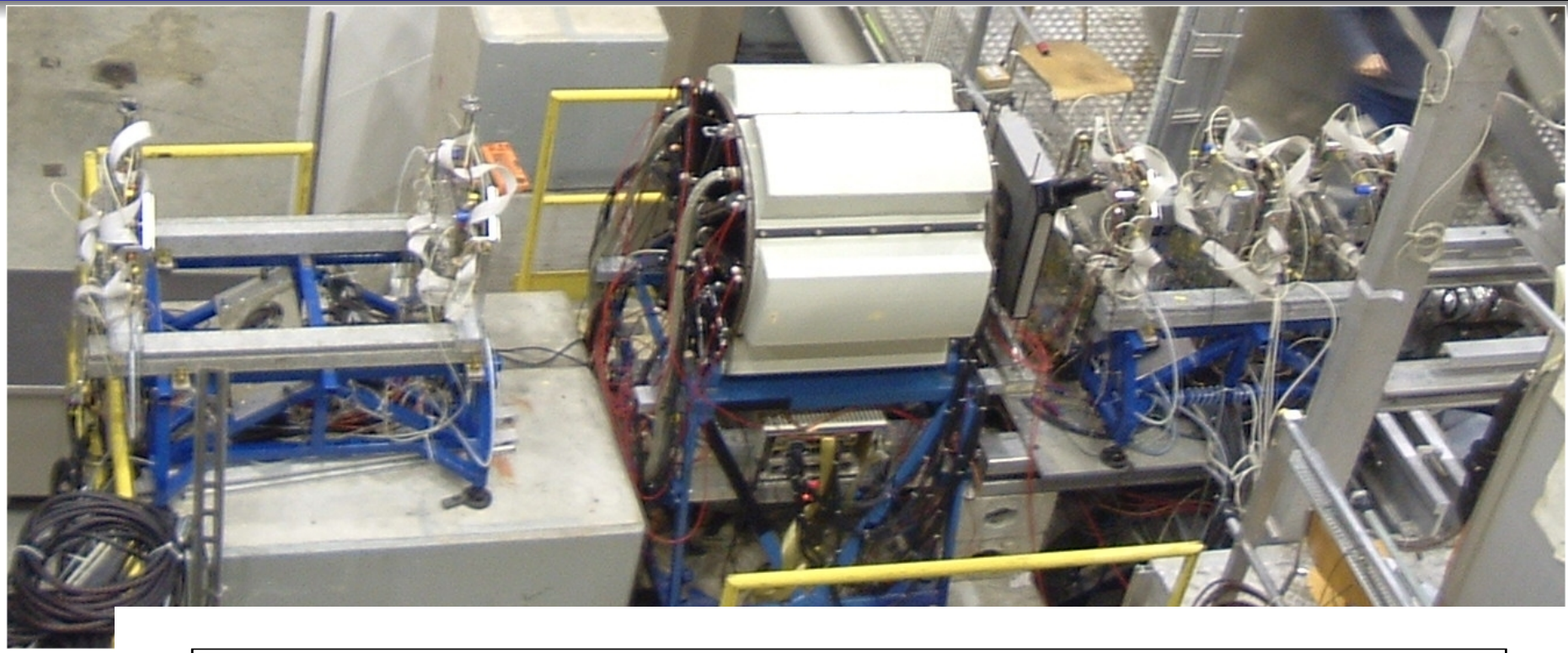

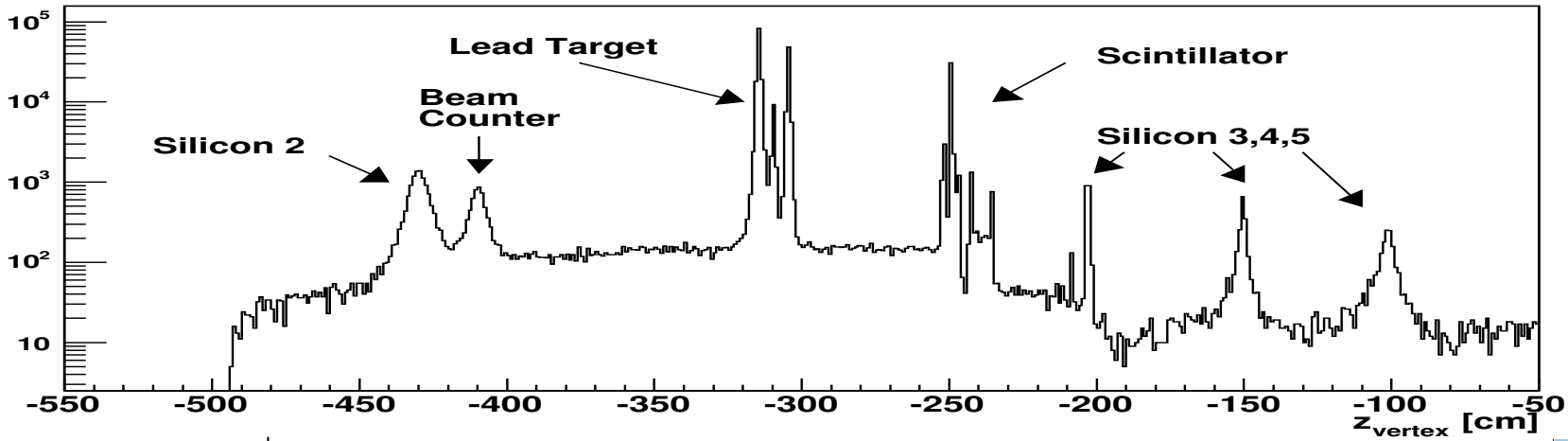

(diffractive $\pi^+\pi^-\pi^-$ vertices)

Primakoff Reaction

Selection of $\pi^- + \gamma^{(*)} \rightarrow \pi^- + \gamma$

- exactly one primary vertex in the target ($p_{T,\pi^-} > 15$ MeV)
- exactly one π^- track of high quality, E_{π^-}<170 GeV
- exactly one Ecal2 cluster as photon candidate
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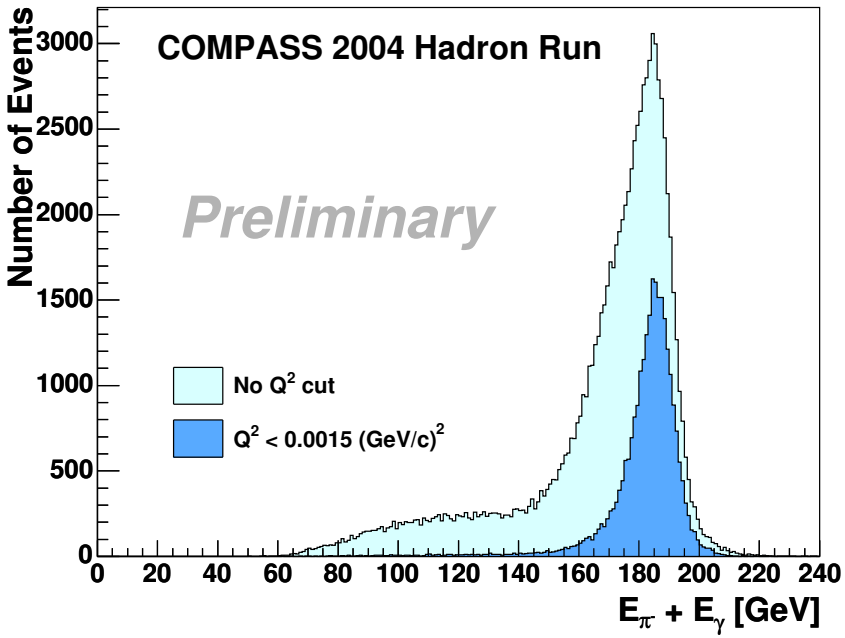
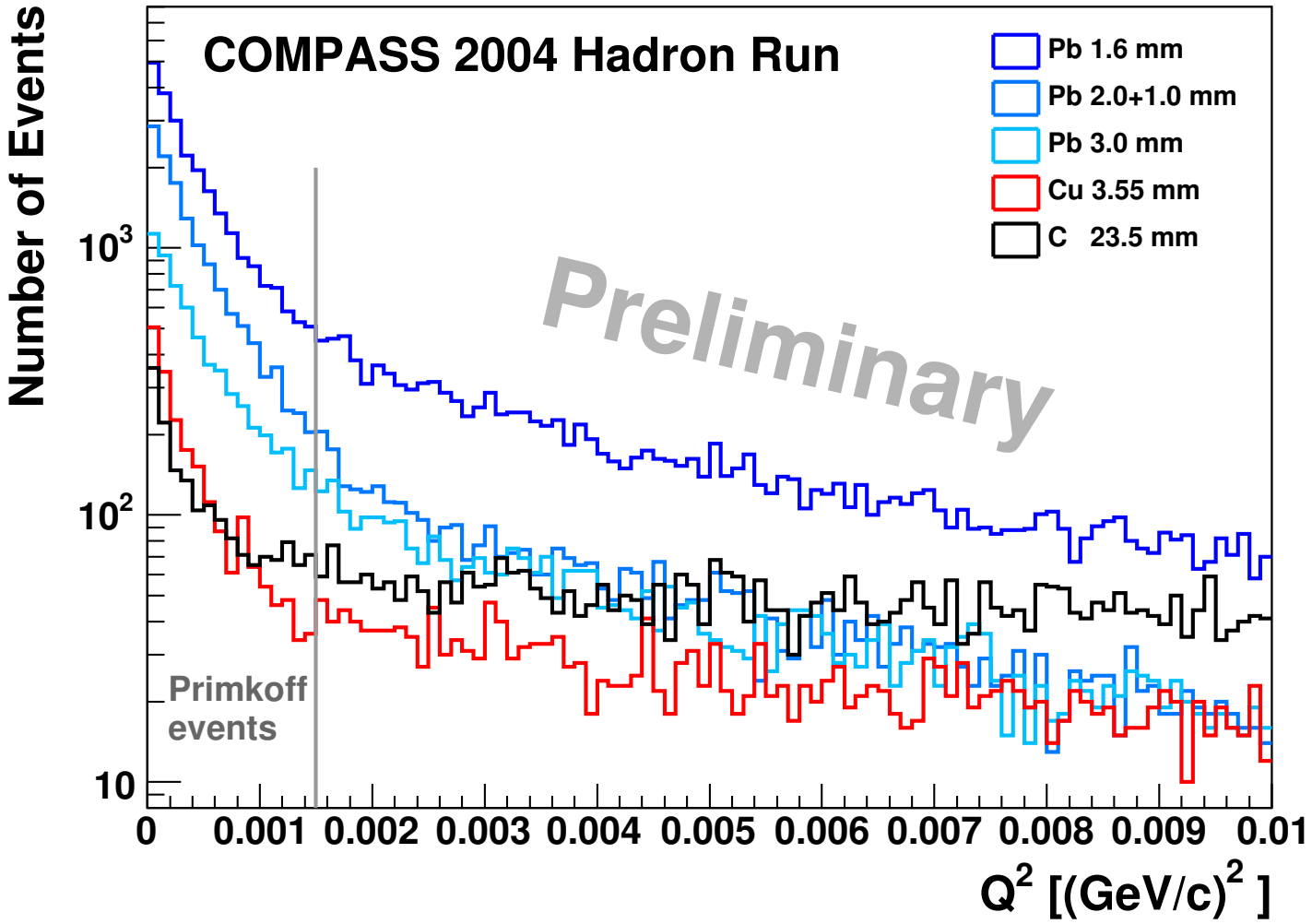
- exactly one π^- track of high quality, E_{π^-}<170 GeV
- exactly one Ecal2 cluster as photon candidate
- $Q^2 < 0.0015\ \mathrm{GeV}^2/c^2$

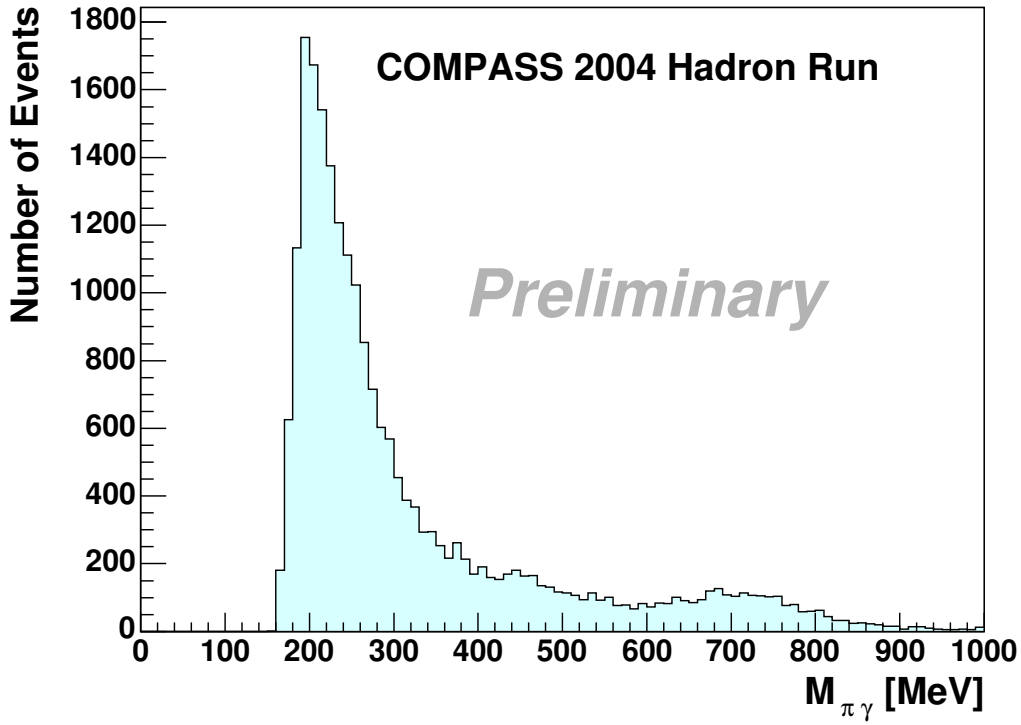


Q^2 distribution for different targets



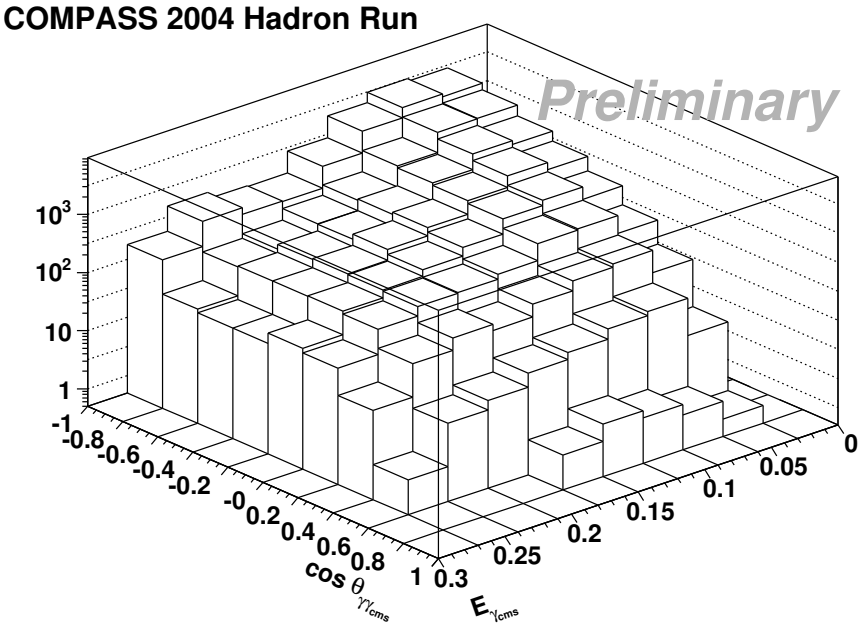
luminosity weighted: $\sigma_{\mathrm{Primakoff}} \sim Z^2$

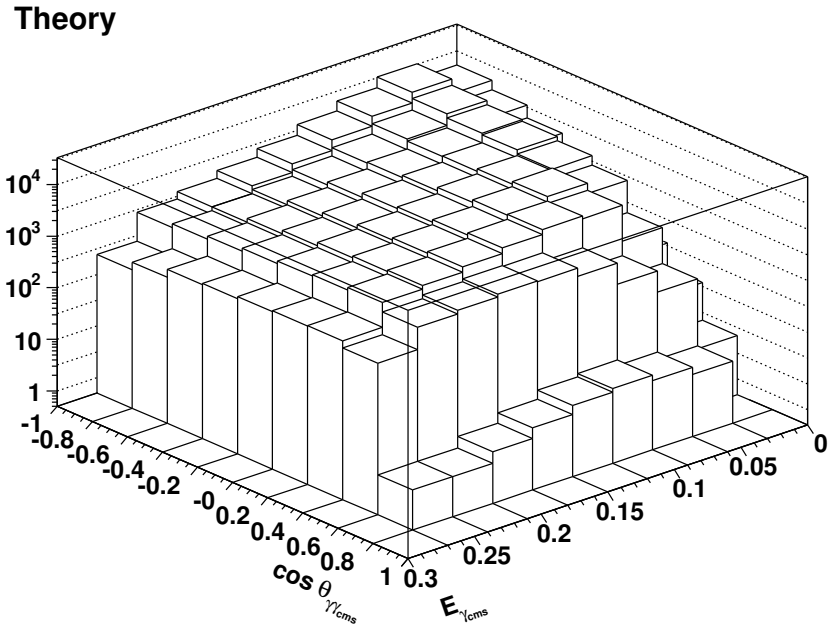
Invariant mass



- Used expansion valid up to $m_{\pi\gamma} < 550$ MeV
- Contribution from kaon and ρ background visible (statistically subtracted by vertex sideband method)

2-dimensional $E_\gamma - \theta_\gamma$ raw spectrum





with MC-correction

(mainly γ conversion, π^- decay, Ecal2 beam hole)
$\rightarrow$ determination of α and β without $\alpha + \beta = 0$ constraint

Possible improvements

Analysis

- new production of data
  - alignment
  - vertexing (for z<-100cm)
  - time-dependent Ecal2 calibration
  - retrieve scaler information
- refined Monte Carlo for different settings

New measurement

- CEDAR for incoming particle ID
- stable setup
- optimized material budget

Summary

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$\rightarrow$ **60000** Primakoff events

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Outlook: First release of values very soon!