Prospects for a Primakoff measurement of the pion polarisability at COMPASS

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Goal of the COMPASS Primakoff (*pion*) program: Measure exclusive *pion-photon* reactions

$$\pi + \gamma \rightarrow \begin{cases} \pi + \gamma & \text{Compton reaction} \\ \pi + \pi^0 & \text{neutral pion production} \\ \pi + \pi^0 + \pi^0 & \text{double pion production} \\ \pi + n \cdot \pi^\pm & \text{resonances, exotics?} \end{cases}$$

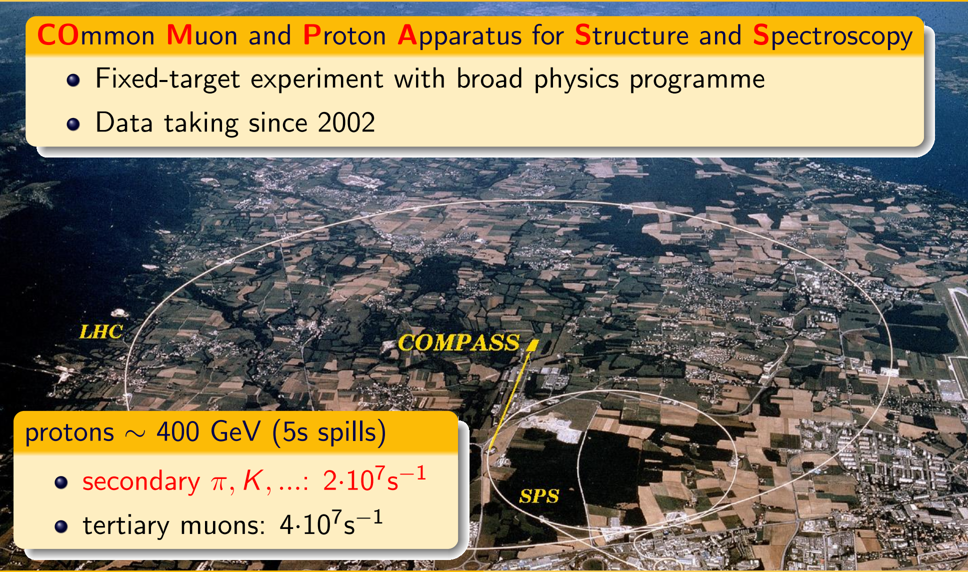
also accessible: Kaon-induced reactions $K + \gamma \rightarrow \cdots$

COMPASS at the CERN SPS

COMPASS at the CERN SPS

COmmon Muon and Proton Apparatus for Structure and Spectroscopy

- Fixed-target experiment with broad physics programme
- Data taking since 2002



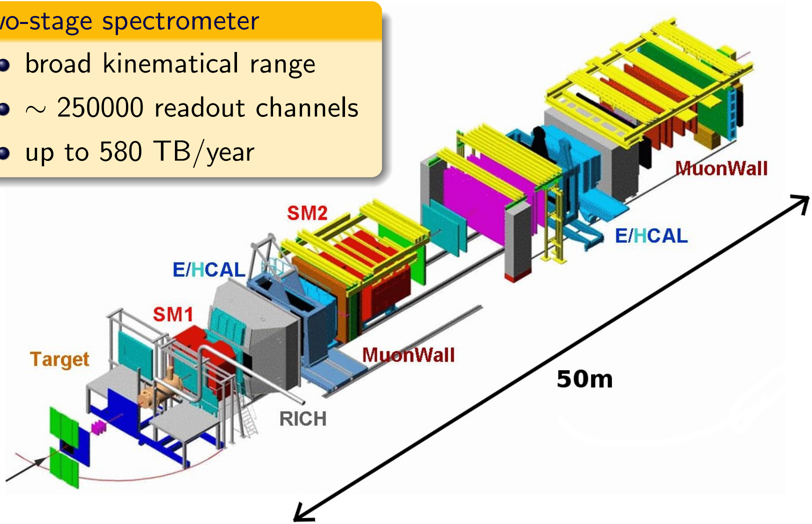
protons ~ 400 GeV (5s spills)

- secondary $\pi, K, \ldots$: $2{\cdot}10^7\mathrm{s}^{-1}$
- tertiary muons: $4{\cdot}10^7\mathrm{s}^{-1}$

COMPASS Experiment – Setup

Two-stage spectrometer

- broad kinematical range
- $\sim$ 250000 readout channels
- up to 580 TB/year



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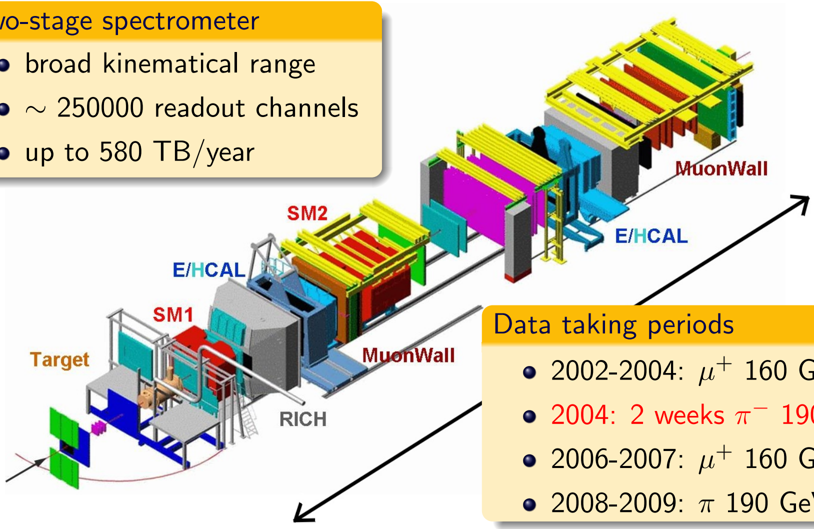


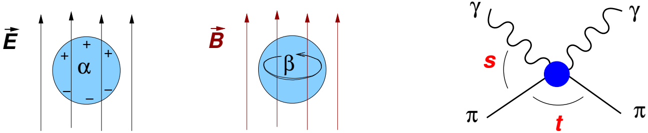
Data taking periods

- 2002-2004: μ^+ 160 GeV
- 2004: 2 weeks π^- 190 GeV
- 2006-2007: μ^+ 160 GeV
- 2008-2009: π 190 GeV

Physics of the Compton reaction

$$\pi + \gamma \rightarrow \pi + \gamma$$

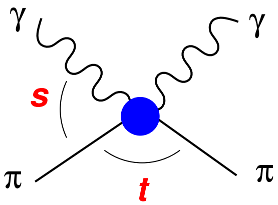
Leading deviation from pointlike particle $\leftrightarrow$ e.m. polarisability



for $\alpha_\pi - \beta_\pi$ [10^{-4} fm^3]: $(\alpha_\pi \approx -\beta_\pi)$

theory: 5.7±1.0 experiments: 4 — 14

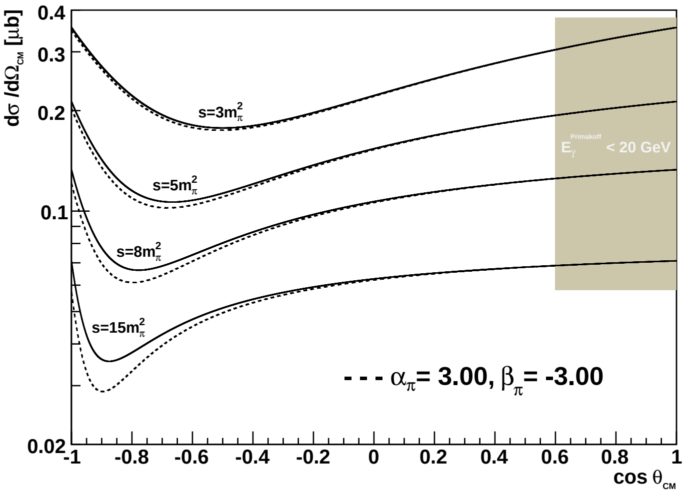
Compton cross section



- The polarisabilities α_π and β_π enter
  - with increasing s
  - as $\alpha_\pi + \beta_\pi$ in forward angles (small, but rel. weight $\sim s^2$)
  - as $\alpha_\pi - \beta_\pi$ in backward angles

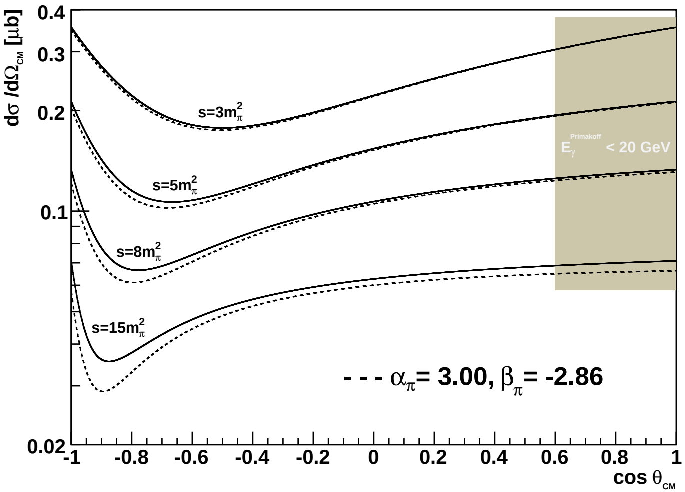
Polarisability effect (LO ChPT values)

loop effects not shown

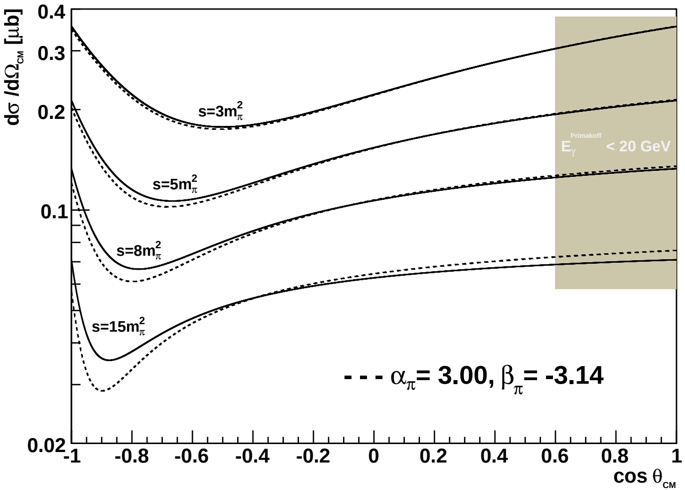


Polarisability effect (NLO ChPT values)

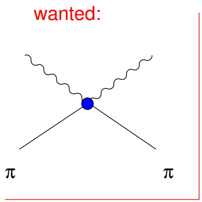
loop effects not shown

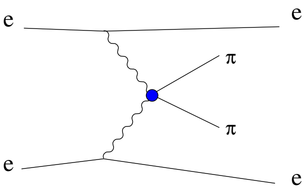


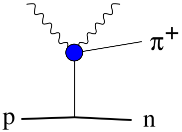
Polarisability effect (NLO ChPT, wrong sign $\alpha_\pi + \beta_\pi$)

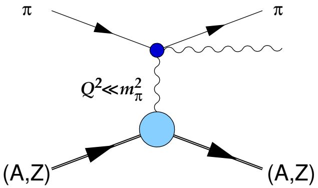


How to scatter photons on pions?









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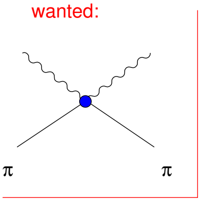
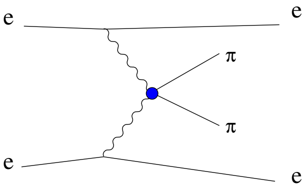
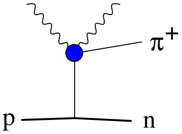
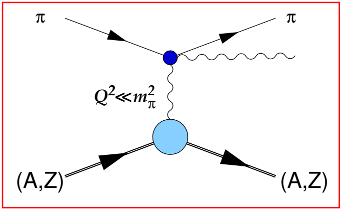
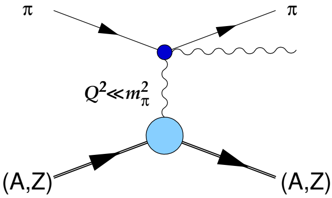








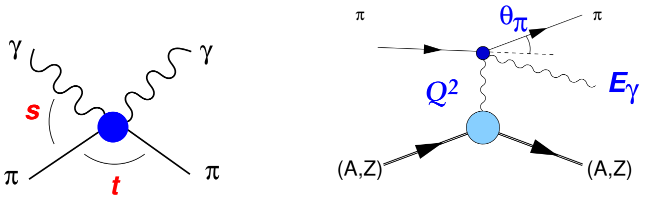
Primakoff technique



requires:

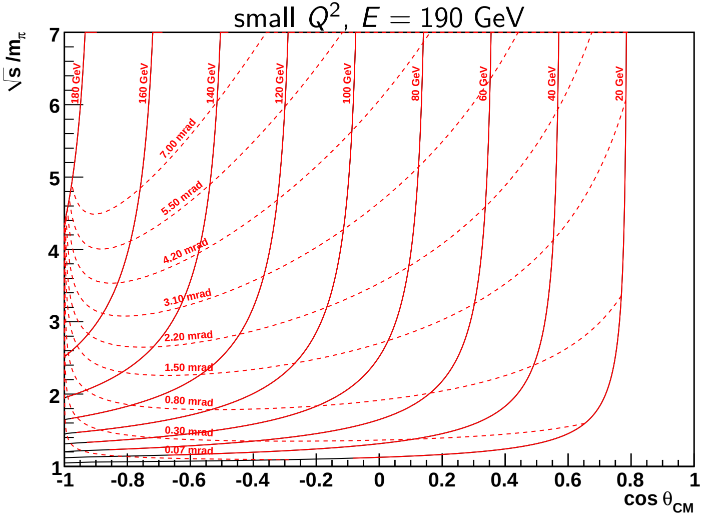
- high energy (unstable particle) beam
- sufficient luminosity, high rate DAQ
  (small cross section, large background contributions)
- high spatial precision $\longrightarrow$ *COMPASS!*

How are *relevant* and *kinematical* quantities related?

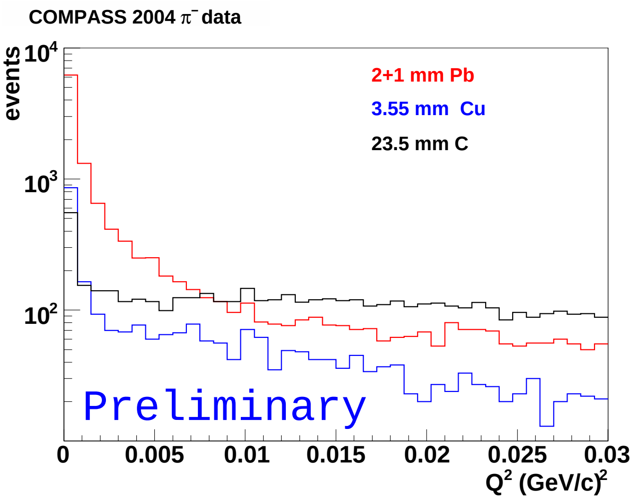


- recoil: negligible energy, small momentum Q^2
- θ_γ and θ_π related for vanishing Q^2
- Minimum momentum transfer $Q_{\text{min}} = \frac{s - m_\pi^2}{2p}$

Mandelstam $\{s, t\} \leftrightarrow$ Laboratory $\{E_\gamma, \theta_\pi\}$



Key experimental signature: $Q^2 \approx 0$



Caveat's on the Q^2 distribution

- High resolution is only achieved for transverse components, so only Q_T is determined (convoluted with the resolution)

  $Q \approx Q_{\text{min}}$: $Q \to Q_L$ and $Q_T \to 0$ (σ large!)
  $Q \gg Q_{\text{min}}$: $Q \to Q_T \gg Q_L \approx Q_{\text{min}}$

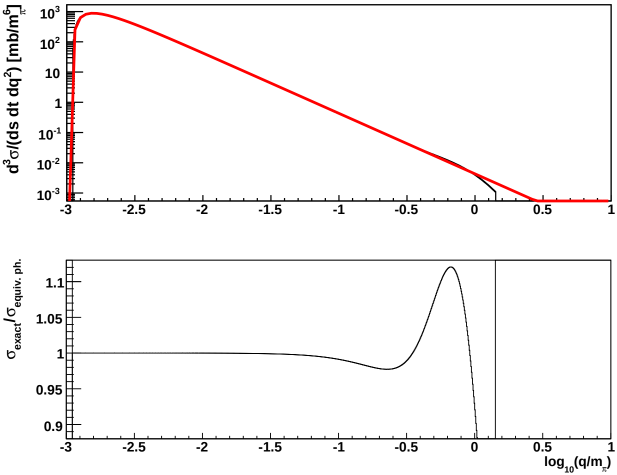
  (which justifies the method to neglect Q_L)
- The Weizsäcker-Williams (Pomeranshuk) factorization

$$\frac{d\sigma}{ds\,dt\,dQ^2} = \frac{\alpha Z^2}{\pi(s - m_\pi^2)} \cdot \frac{Q^2 - Q^2_{\text{min}}}{Q^4} \cdot \frac{d\sigma_{\pi\gamma}}{dt}$$

  is an approximation with limited validity

Beyond equivalent photons: exact cross section

Equivalent photons vs. exact calc. (N. Kaiser, TUM) → few % !

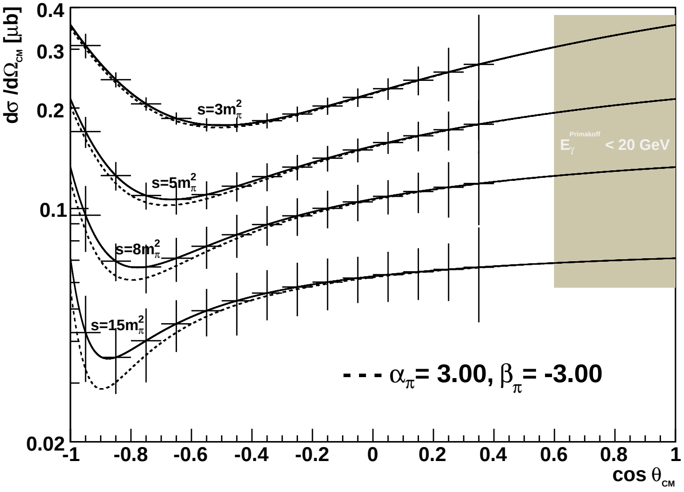


Summary & Outlook

- The COMPASS Primakoff measurement accesses the full kinematical range of pion Compton scattering to disentangle the relevant ChPT parameters
  - polarisabilities α_π, β_π
  - 1- and 2-loop effects
  - higher-order polarisabilities
- Effect of the exact Q^2 distribution
  - background determination
  - polarisability extraction
  - muon control data: include higher-order effects
- *Go for new data*
  - preparations for taking data in 2009 ongoing (still some work on hardware required)
  - longer term: full Primakoff run $\geq$ 30 days

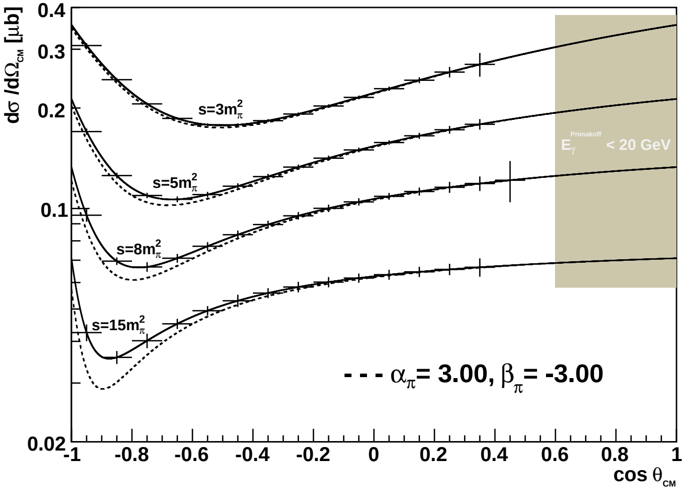
Approximate statistical errors of 3 days data (2004)

only statistical *errors* shown



Prospected statistical errors for future run

only statistical *errors* shown

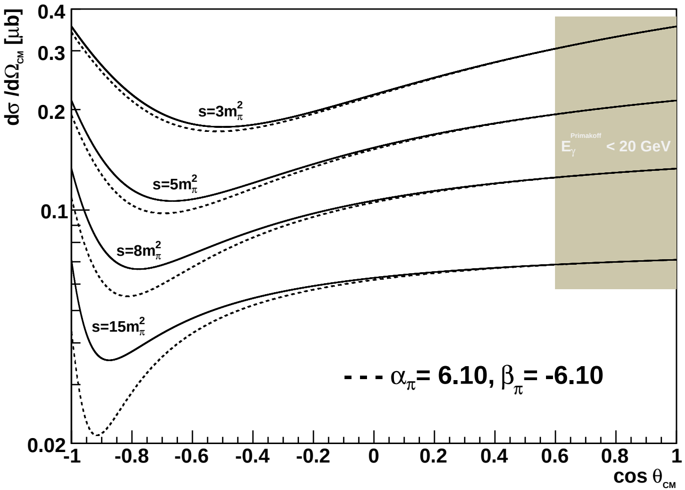


$\gamma\gamma \to \pi\pi$ and the pion polarisability

M.R. Pennington in the 2nd DAΦNE Physics Handbook,
"What we learn by measuring $\gamma\gamma \to \pi\pi$ at DAΦNE":

> All this means that the only way to measure the pion polarisabilities is in the Compton scattering process near threshold and not in $\gamma\gamma \to \pi\pi$. Though the low energy $\gamma\gamma \to \pi\pi$ scattering is seemingly close to the Compton threshold (...) and so the *extrapolation* not very far, the dominance of the pion pole (...) means that the energy scale for this continuation is m_π. Thus the polarisabilities cannot be determined accurately from $\gamma\gamma$ experiments in a model-independent way and must be measured in the Compton scattering region.

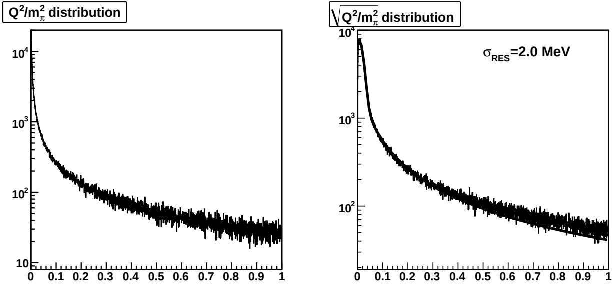
Polarisability effect – Serpukhov values



Q^2 and Q in detail

Trick: $Q^2 \longrightarrow Q$:

$$\frac{Q^2 - Q_{\min^2}}{Q^4} \times RESOLV(Q^2) \qquad (\sigma_{RESOLV} = 5 \text{ MeV})$$



Radiative corrections for Primakoff - Status

- e.m. corrections for $\pi\gamma \to \pi\gamma$ subprocess established
- Chiral loop corrections (à la Unkmeir, Scherer,...) adapted to Primakoff kinematics
- Influence of polarisability terms studied (small)
- Uncertainties on high-Z/atomic f.f. effects
- Theoretical base for understanding of radiative tail (and q^2 distribution) – numerical evaluation on the way