Measurement of QCD Low Energy Parameters in Primakoff Reactions at COMPASS

Thiemo Nagel
on behalf of the COMPASS Collaboration

Physik Department E18
Technische Universität München

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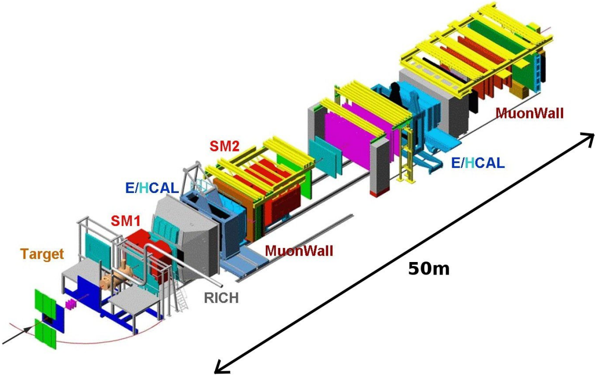
BMBF

Outline

1. COMPASS Experiment
2. Charged Pion Polarizabilities α_π and β_π
3. Chiral Anomaly: $F^{3\pi}$
4. π^0 Lifetime
5. Conclusion and Outlook

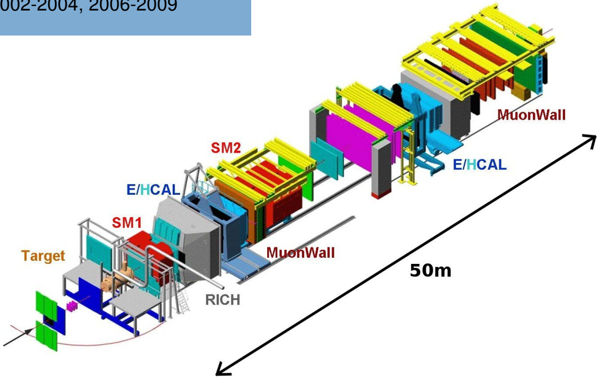
The COMPASS-Experiment

COmmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy



Overview

- fixed target
- beams provided by SPS (CERN)
- two-stage magnetic spectrometer
- taking data: 2002-2004, 2006-2009



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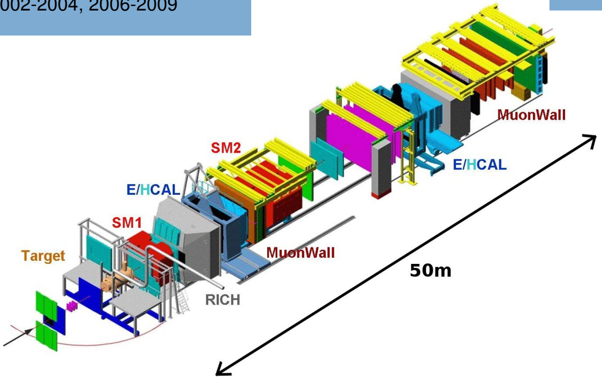
2 types of beam

- pions: $2 \times 10^7 s^{-1}$
- muons: $4 \times 10^7 s^{-1}$
- energy: 160-190 GeV



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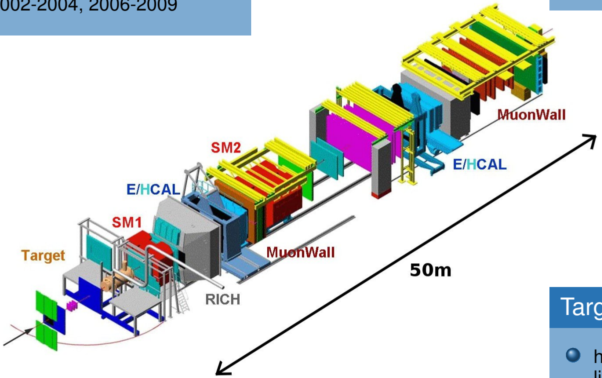

Targets

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- muon beam: polarised ^{6}LiD / NH_3

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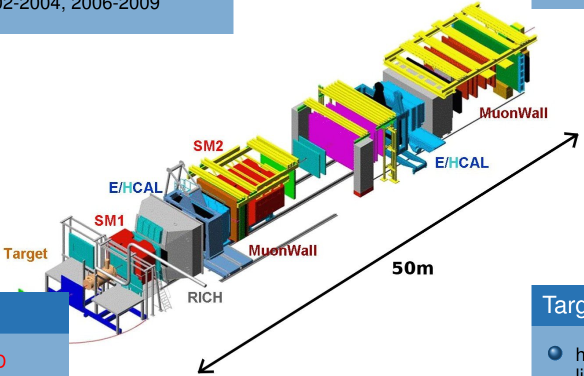

Physics Goals

- low-energy QCD
- hadron spectroscopy
- nucleon spin-structure

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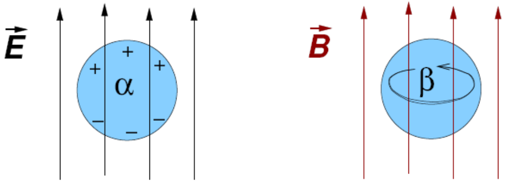


Theory and experiment agree on: $\alpha_\pi + \beta_\pi \approx 0$

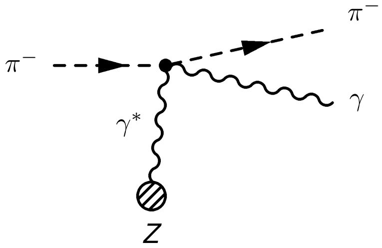
χPT prediction for the pion (Goldstone boson of chiral symmetry)

$$\alpha_\pi - \beta_\pi = 5.7 \pm 1.0 \times 10^{-4}\,\mathrm{fm}^3$$

Gasser, Ivanov, Sainio, Nucl. Phys. B 745 (2006)

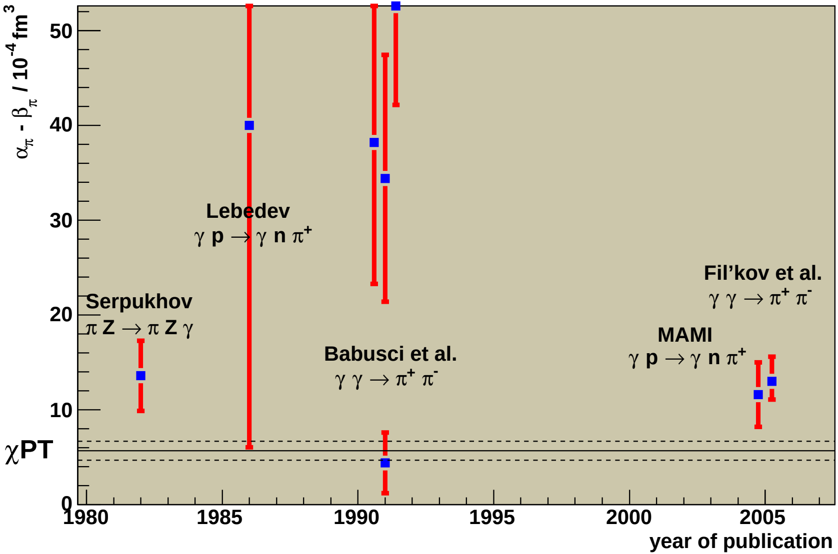
Ongoing discussion on the interpretation of dispersion sum rules (DSR)
$\longrightarrow$ cf. Chiral Dynamics 09 proceedings: Drechsel, Fil'kov

- $\gamma\, p \longrightarrow \gamma\, n\, \pi^+$: Lebedev, MAMI
- $\gamma\, \gamma \longrightarrow \pi^+\, \pi^-$: PLUTO, DM1, DM2, Mark II
  - Babusci et al., 1992
  - Fil'kov et al., 2005
  - theoretical difficulties
    $\longrightarrow$ M. R. Pennington, 2nd DAΦNE Physics Handbook, p. 531ff.
- $\pi^\pm\, Z \longrightarrow \pi^\pm\, Z\, \gamma$: Serpukhov, COMPASS



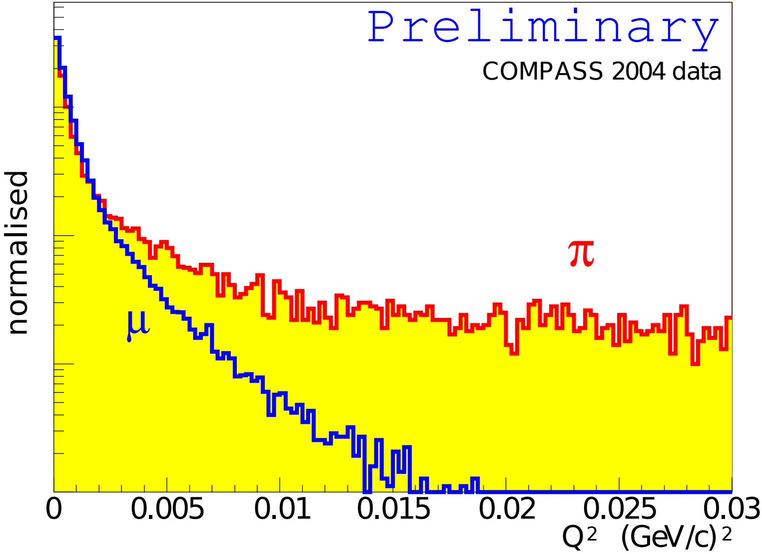
Previous Measurements

Charged Pion Polarizabilities

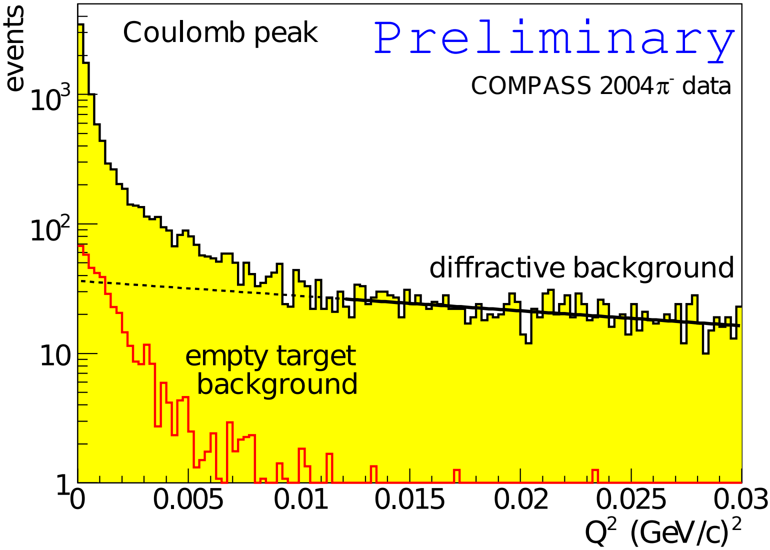


(stat. and syst. errors added quadratically; if syst. errors isn't quoted, syst. error = stat. error is assumed)

Q^2: pion and muon beam, 2004 pilot run



Q^2 background: pion beam, 2004 pilot run



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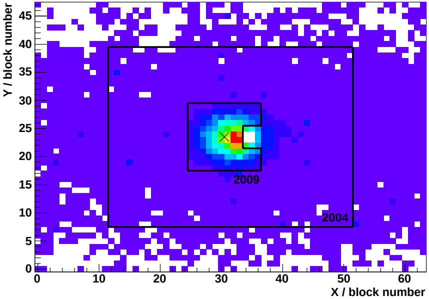

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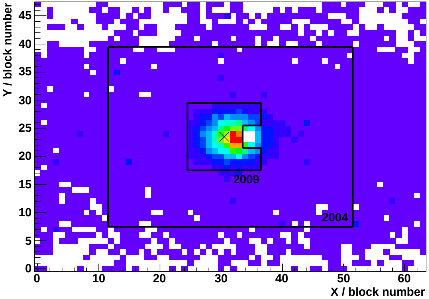

COMPASS Primakoff run 2009

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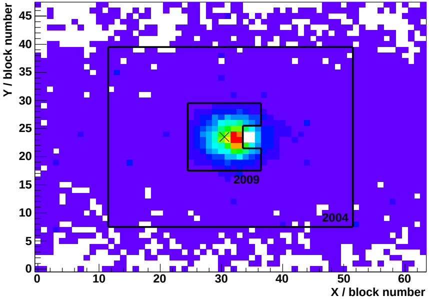

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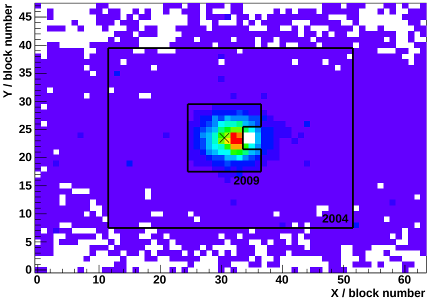

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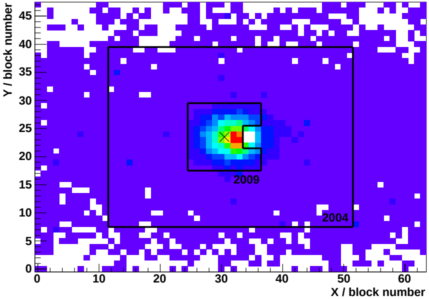

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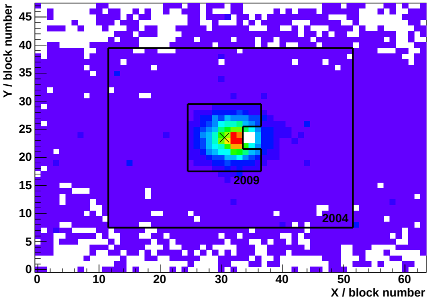

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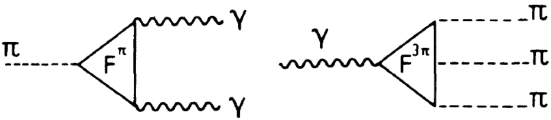
- beam e^- suppression by electron converter (5mm of Pb) in beamline

χPT prediction

Chiral Anomaly: $F^{3\pi}$

Processes $\pi^0 \to 2\gamma$ and $\gamma \to 3\pi$ in the low-energy limit are fully described by loop diagrams:



Coupling constants F^{π} and $F^{3\pi}$ are related by low-energy theorem

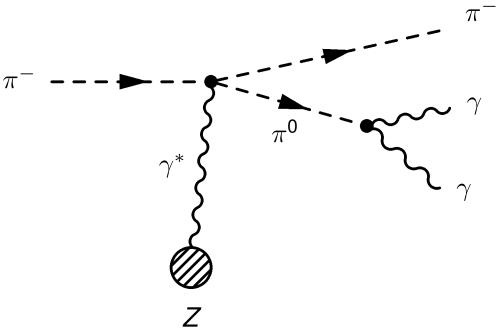
$$\frac{F^{3\pi}(0)}{F^{\pi}(0)} = \frac{1}{e\, f_{\pi^\pm}^2} \tag{1}$$

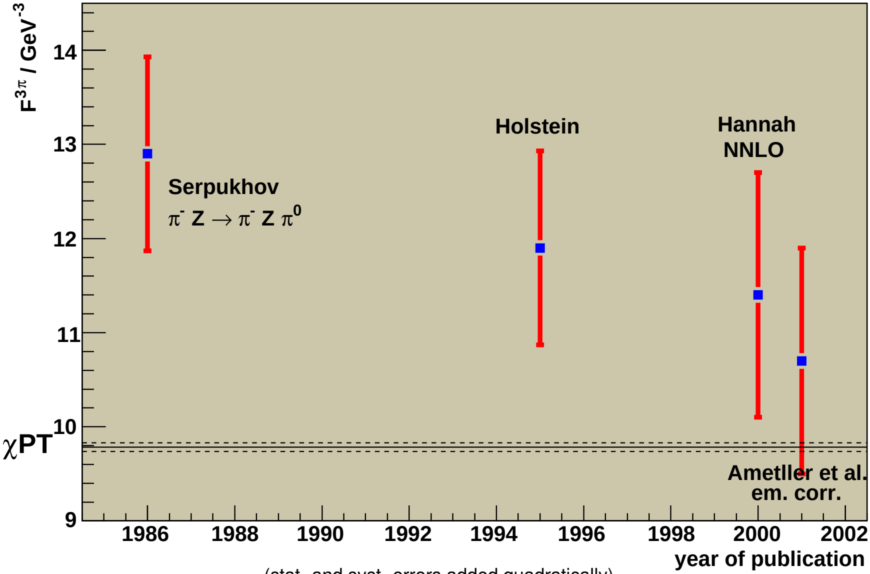
with pion decay constant $f_{\pi^\pm} = 92.21 \pm 0.14\,\mathrm{MeV}$ (PDG08) and $e = \sqrt{4\pi\alpha}$.

Eq. 1 and Wess-Zumino-Witten effective Lagrangian give:

$$F^{3\pi}(0) = \frac{eN_c}{12\pi^2 f_{\pi^\pm}^3} = 9.78 \pm 0.05_{\mathrm{exp}}\ \mathrm{GeV}^{-3} \tag{2}$$

Primakoff π^0 production (Serpukhov, COMPASS)





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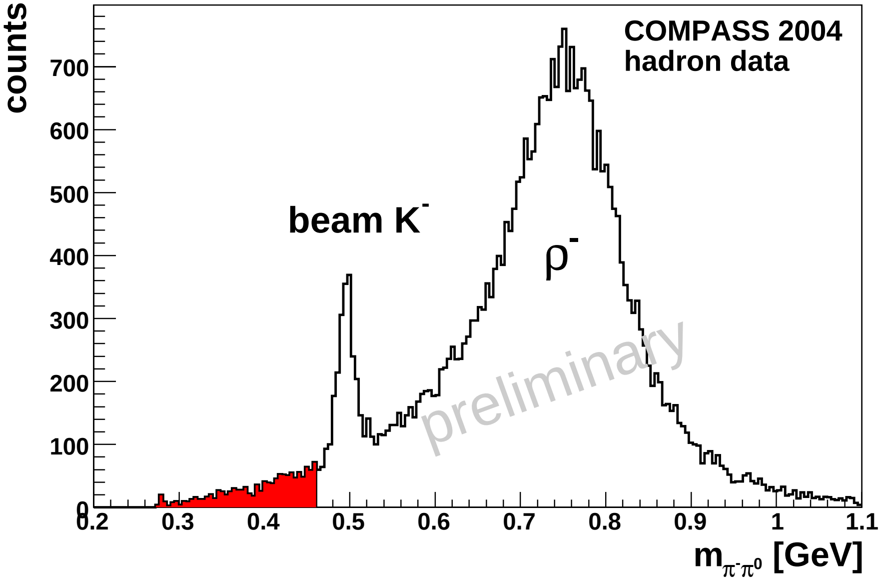
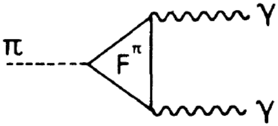

COMPASS 2004
hadron data
beam K-
ρ-
preliminary
counts
0
100
200
300
400
500
600
700
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
$m_{\pi^-\pi^0}$ [GeV]

π^0 Lifetime

The $\pi^0 \longrightarrow \gamma\gamma$ decay in lowest order is described by a loop diagram:



For massless quarks, the leading order χPT predictions for decay amplitude and decay width are

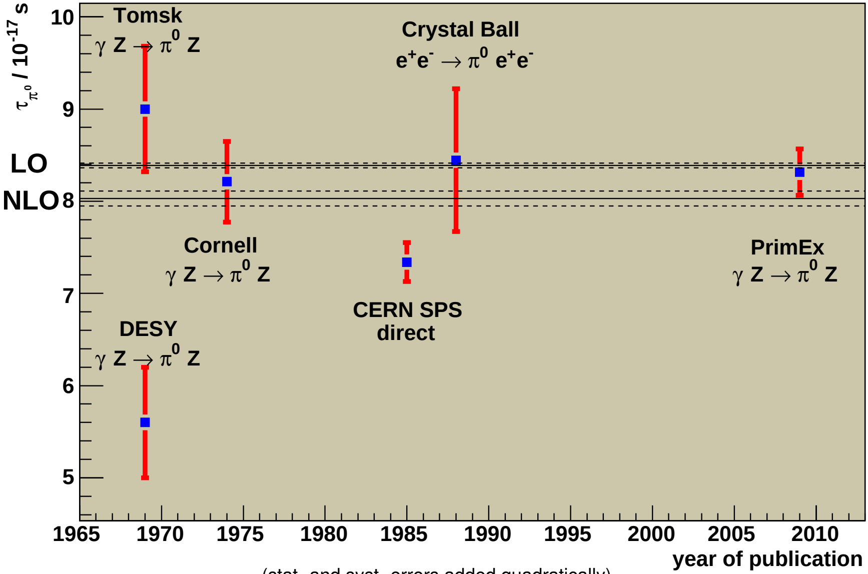
$$A_{\gamma\gamma} = \frac{\alpha_{\text{em}}}{\pi\, f_{\pi^\pm}} \tag{3}$$

$$\Gamma_{\gamma\gamma} = m_\pi^3 \frac{|A_{\gamma\gamma}|^2}{64\pi} = 7.754 \pm 0.024\,\mathrm{eV} \tag{4}$$

with pion decay constant $f_{\pi^\pm} = 92.21 \pm 0.14\,\mathrm{MeV}$ (PDG08).

NLO calculations with non-zero quark masses shift yield $\Gamma_{\gamma\gamma} = 8.10 \pm 0.08\,\mathrm{eV}$.

Previous Measurements
π^0 Lifetime



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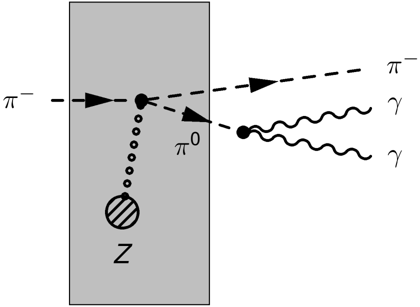

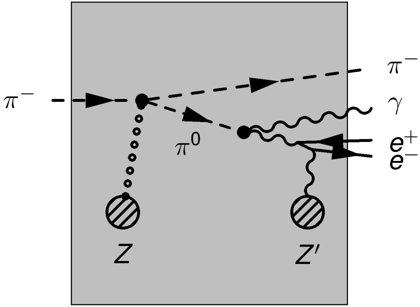

thin target: π^0 decays behind
$\longrightarrow$ no γ conversion

thick target: π^0 decays inside
$\longrightarrow$ γ conversion possible

π^0 decay length at 100 GeV is ~20 μm

Conclusion and Outlook

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- 2009 data taking was completed 2 weeks ago
- $\alpha_\pi - \beta_\pi$: world's largest $\pi Z \longrightarrow \pi Z \gamma$ data set
- $F^{3\pi}$: world's largest $\pi Z \longrightarrow \pi Z \pi^0$ data set

Outlook

- separate measurement of α_π and β_π
  - beam time application currently being prepared
  - earliest possible date: 2011
- feasibility study for π^0 life time measurement