COMPASS Results on Pion Polarizabilities

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on behalf of the COMPASS Collaboration

Physik Department E18
Technische Universität München

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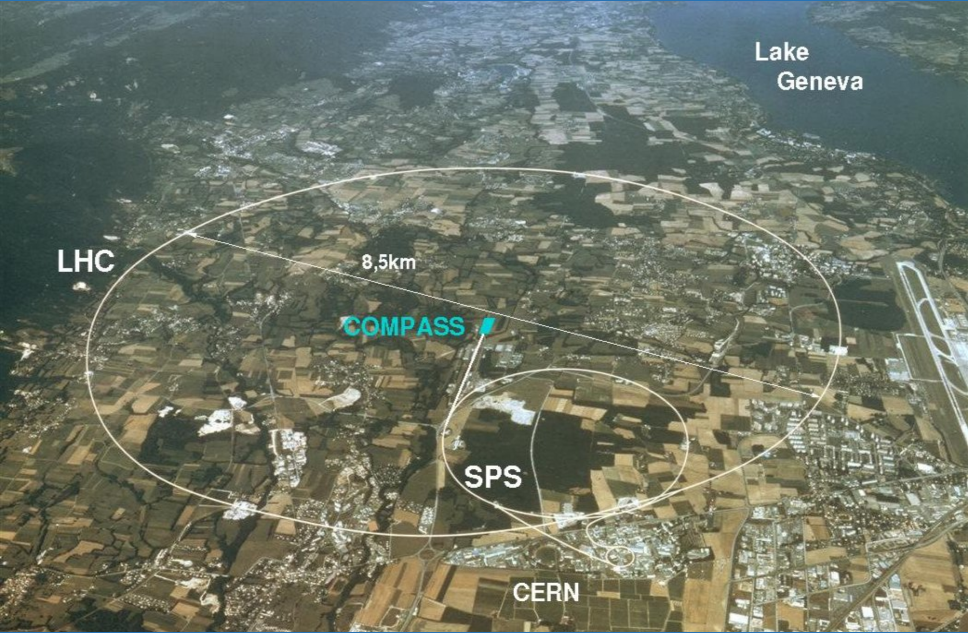
supported by: Maier-Leibnitz-Labor München,
Cluster of Excellence: Origin and Structure of the Universe,
Bundesministerium für Bildung und Forschung

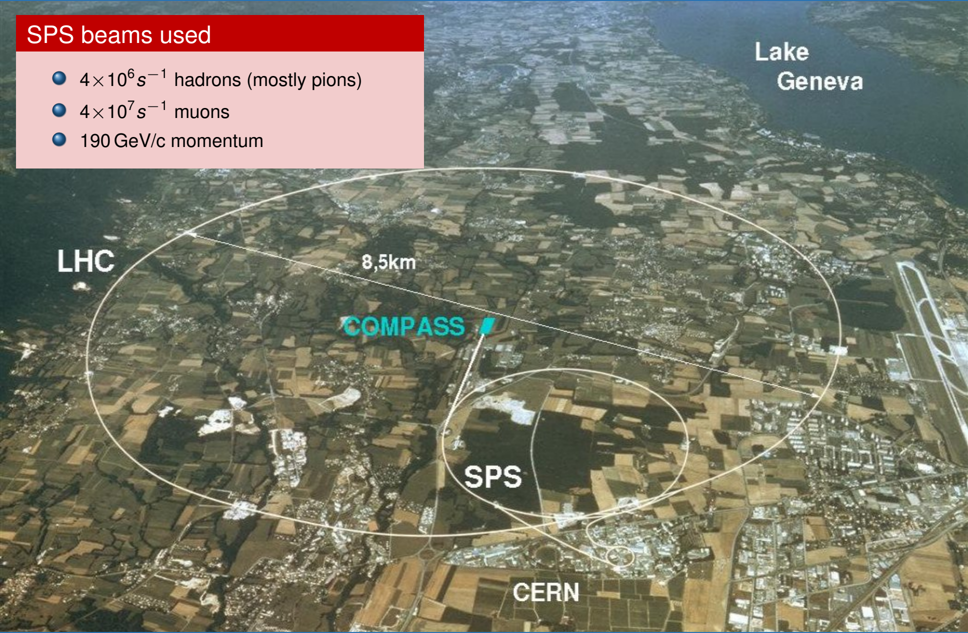
Outline

COMPASS at CERN



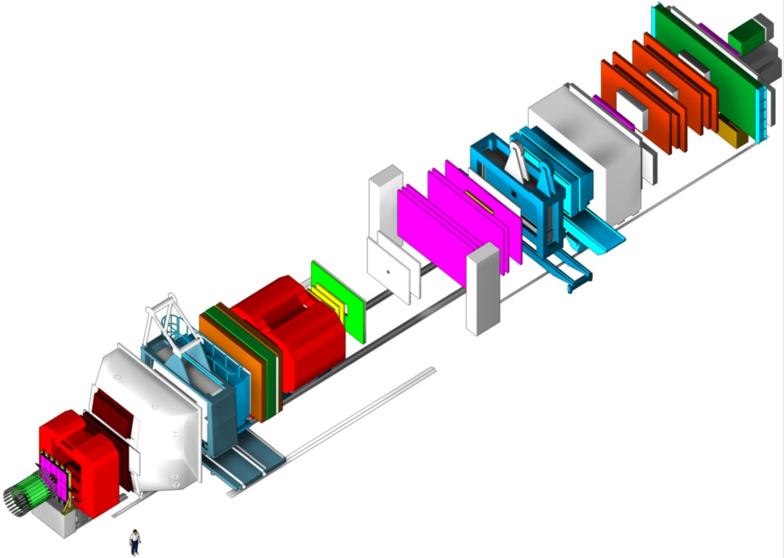
SPS beams used

- $4 \times 10^6 s^{-1}$ hadrons (mostly pions)
- $4 \times 10^7 s^{-1}$ muons
- 190 GeV/c momentum



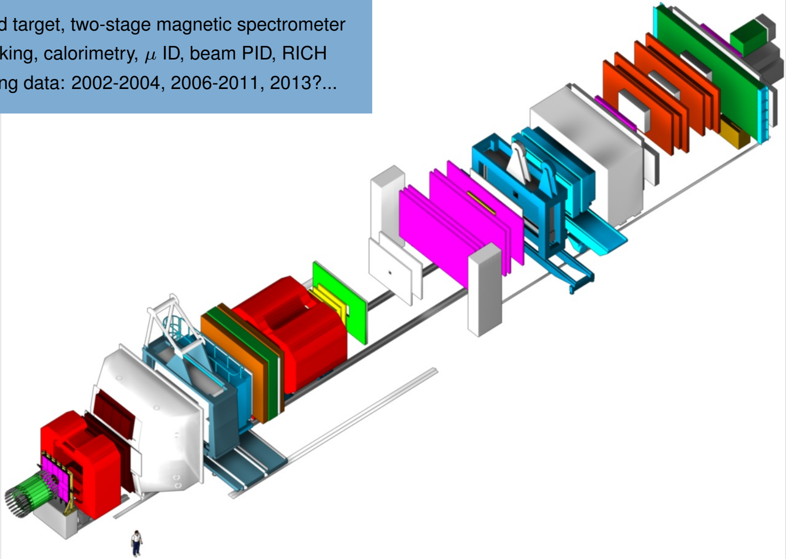
The COMPASS-Experiment

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



Overview

- fixed target, two-stage magnetic spectrometer
- tracking, calorimetry, μ ID, beam PID, RICH
- taking data: 2002-2004, 2006-2011, 2013?...



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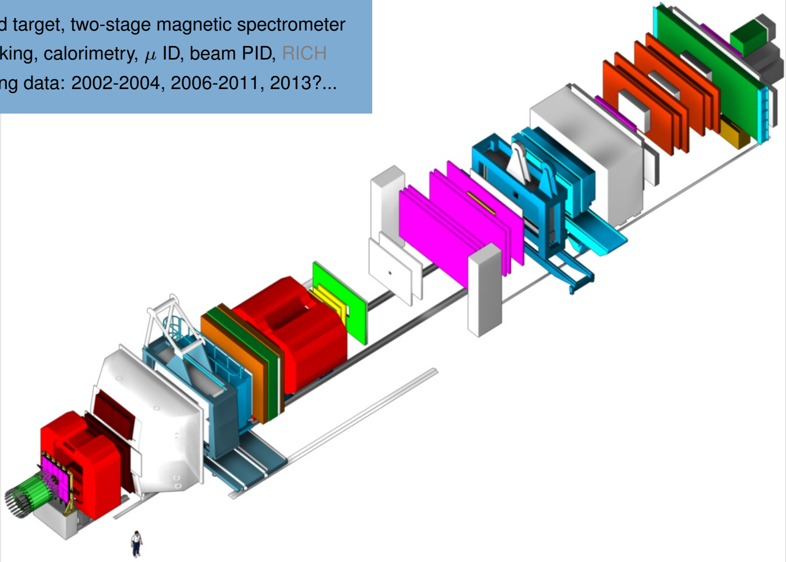

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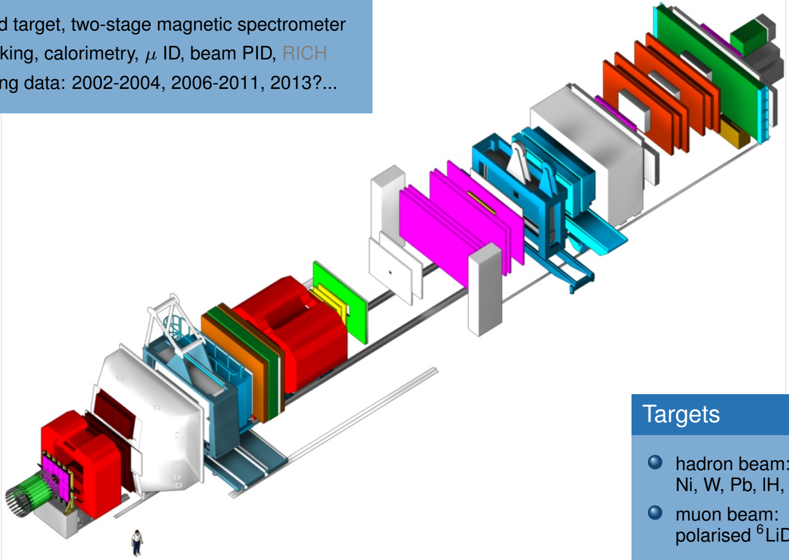

Targets

- hadron beam:
  Ni, W, Pb, lH, C, Cu
- muon beam:
  polarised ^{6}LiD / NH_3

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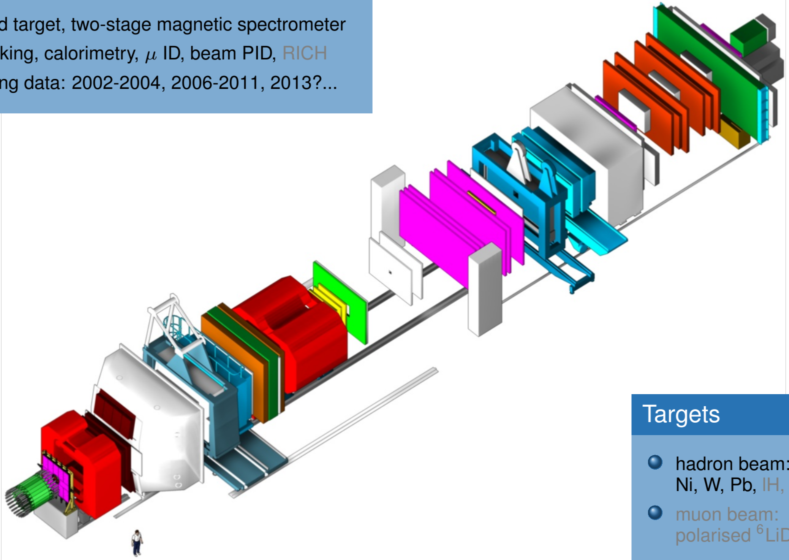

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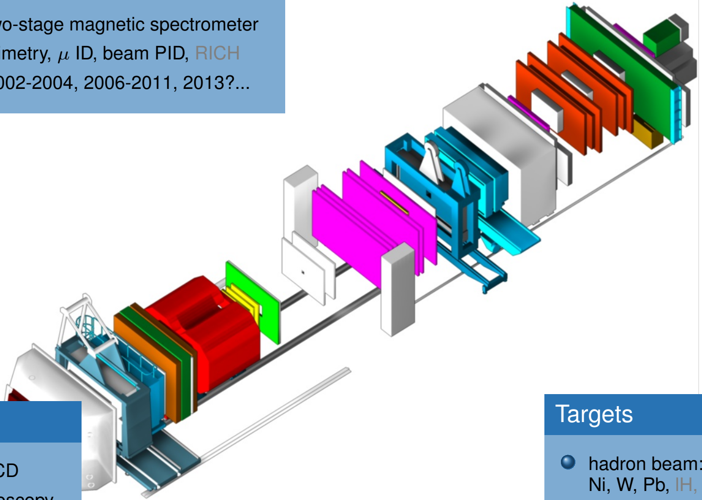

Physics Goals

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

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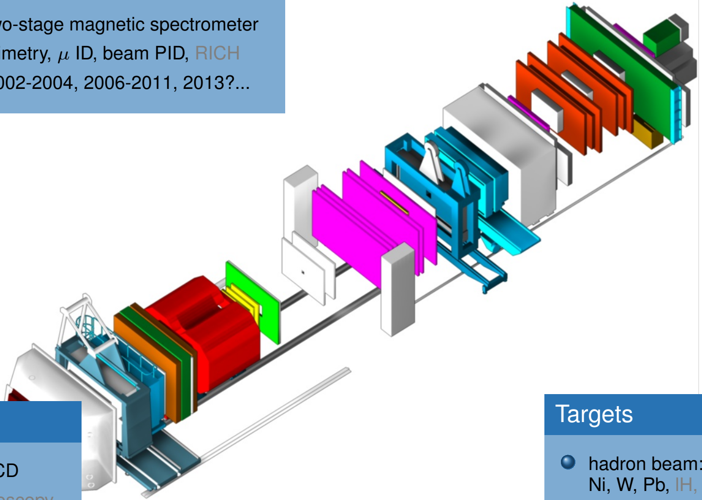

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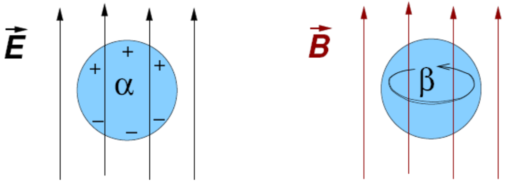


Theory and experiment agree on: $\alpha_\pi + \beta_\pi \approx 0$

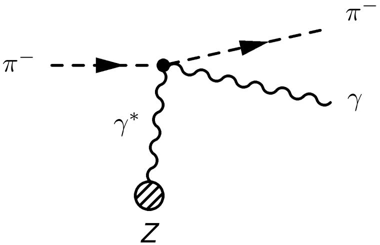
χPT prediction for the pion (Goldstone boson of chiral symmetry)

$$\alpha_\pi - \beta_\pi = 5.7 \pm 1.0 \times 10^{-4}\,\text{fm}^3 \qquad \text{(two loop calculation)}$$

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

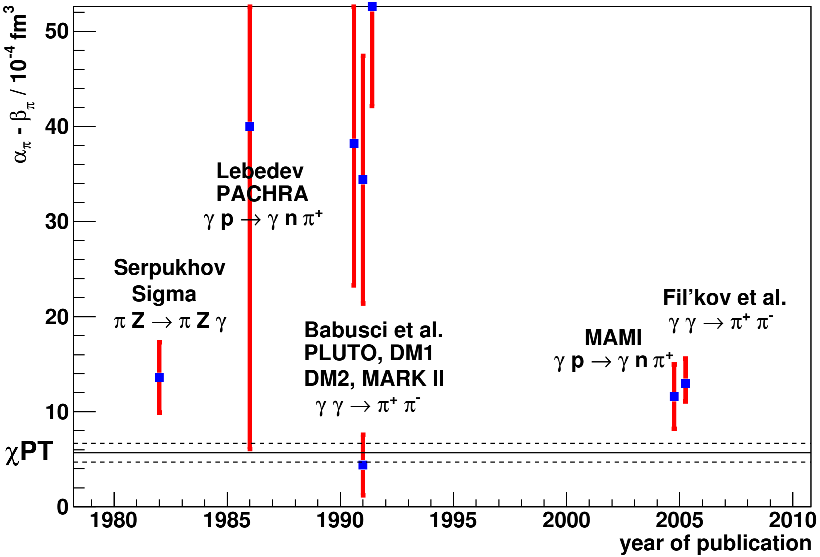
Ongoing discussion on the interpretation of dispersion sum rules (DSR)
$\longrightarrow$ cf. Chiral Dynamics 09 proceedings: Drechsel, Fil'kov

- $\gamma\, p \longrightarrow \gamma\, n\, \pi^+$: Lebedev, MAMI
- $\gamma\,\gamma \longrightarrow \pi^+\,\pi^-$: PLUTO, DM1, DM2, Mark II
  - Babusci et al., 1992
  - Fil'kov et al., 2005
  - related by crossing to $\pi\gamma \rightarrow \pi\gamma$
- $\pi^\pm\, Z \longrightarrow \pi^\pm\, Z\, \gamma$: Serpukhov, COMPASS



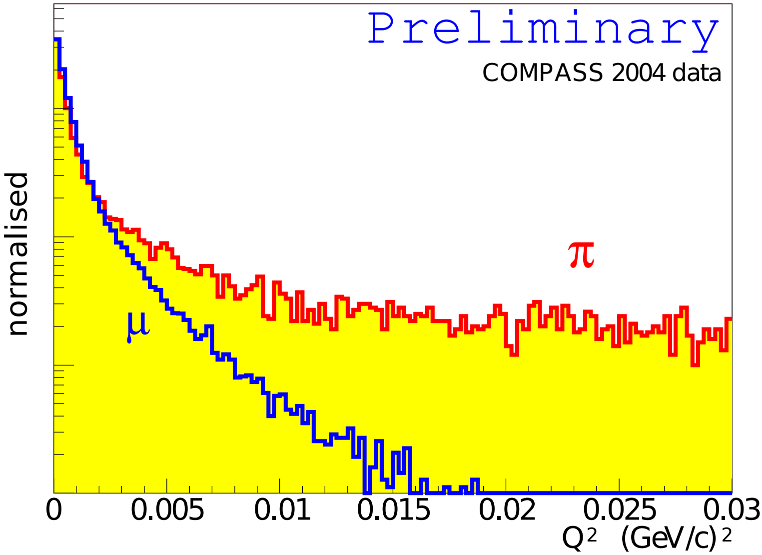
Previous Measurements

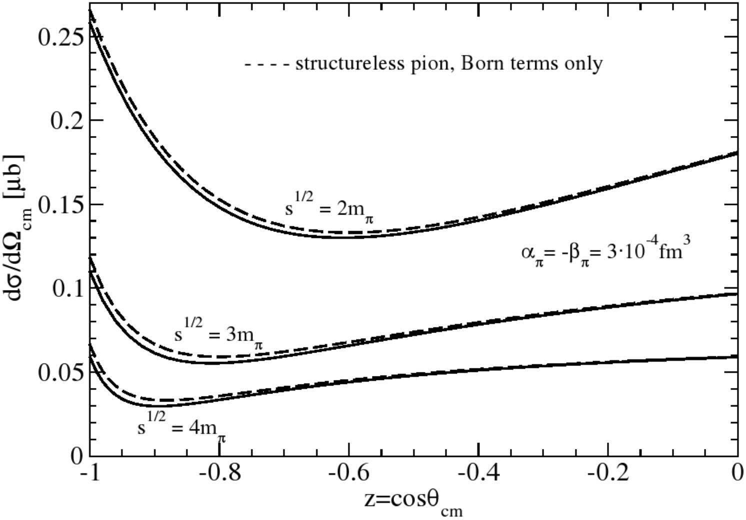
Charged Pion Polarizabilities



(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





Kaiser, Friedrich, Eur. Phys. J. A **36**, 181-188 (2008)

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- integrated π^- flux: $\sim 3 \times 10^{11}$
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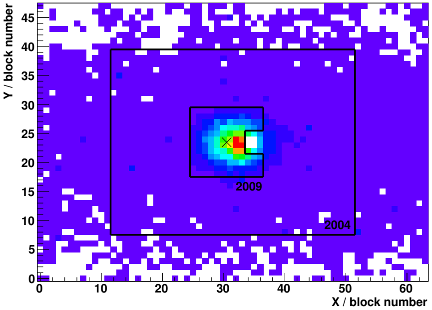

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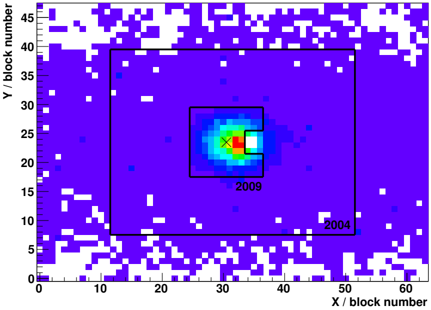

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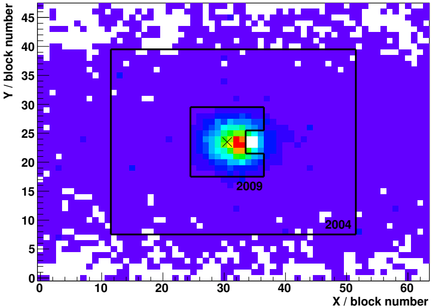

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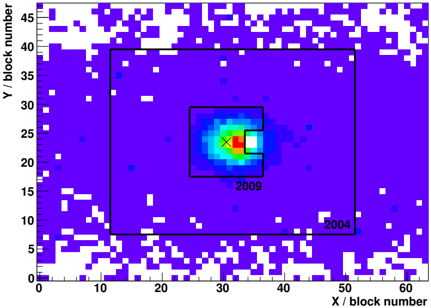

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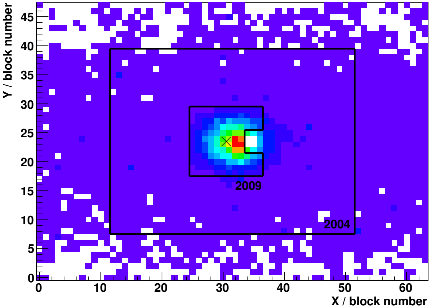

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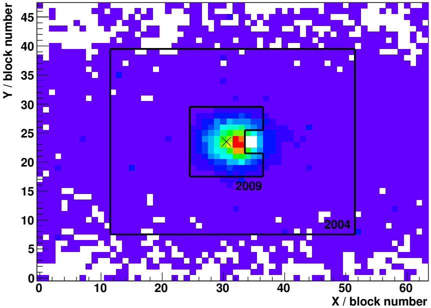

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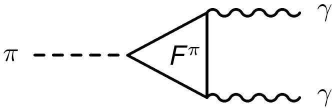
- beam e^- suppression by electron converter (5mm of Pb) in beamline

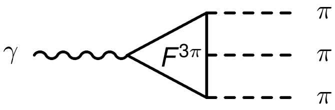
Outline

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:





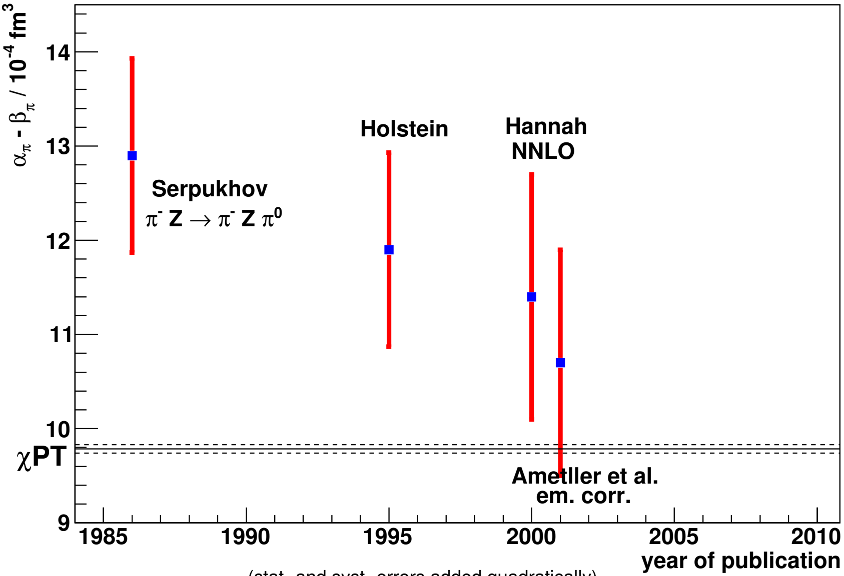
Coupling constants F^{π} and $F^{3\pi}$ are related by low-energy theorem

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

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

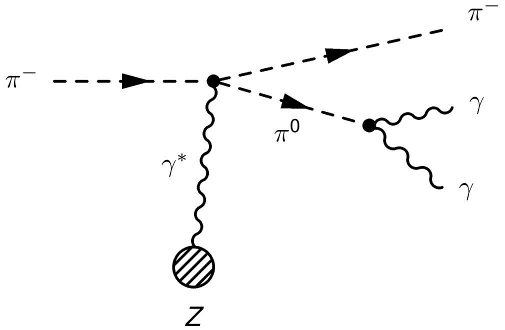
Eq. 1 and Wess-Zumino-Witten effective Lagrangian give:

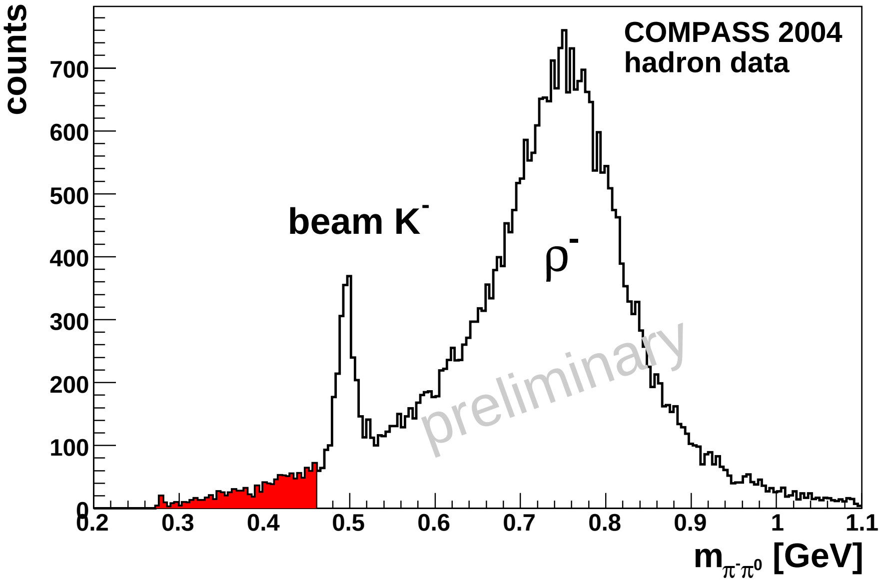
$$F^{3\pi}(0) = \frac{eN_c}{12\pi^2\, f_{\pi^\pm}^3} = 9.78 \pm 0.05_{\text{exp}}\ \text{GeV}^{-3} \tag{2}$$

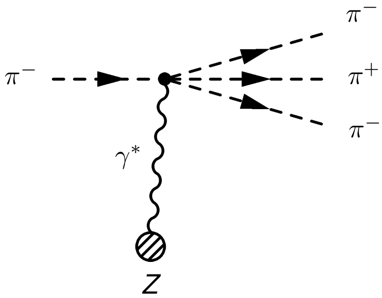


(stat. and syst. errors added quadratically)

Primakoff π^0 production (Serpukhov, COMPASS)



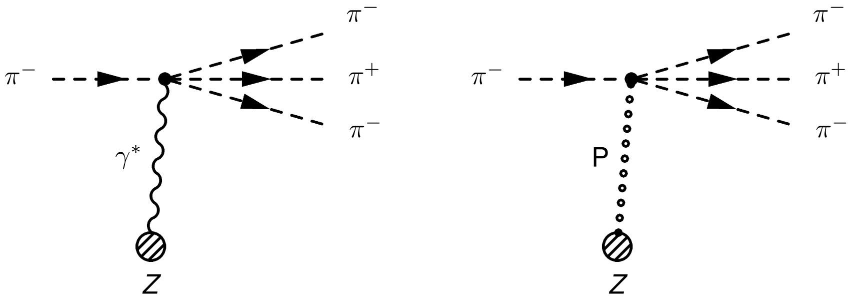

counts
700
600
500
400
300
200
100
0
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
COMPASS 2004
hadron data
beam K-
ρ-
preliminary
m π-π0 [GeV]



electromagnetic interaction
(Primakoff)

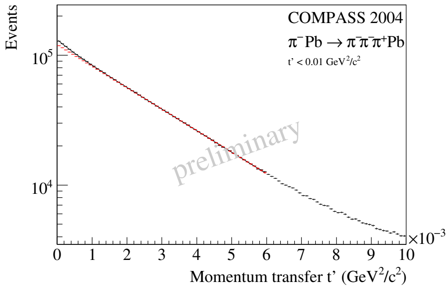
Competing reactions for the 3π final state

Two pion photoproduction



electromagnetic interaction
(Primakoff)

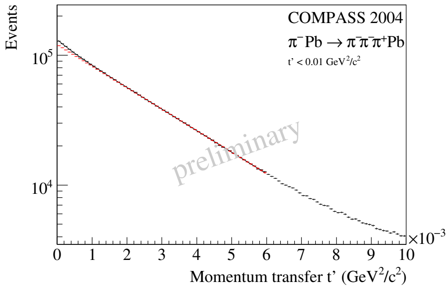
strong interaction
(diffractive)



Primakoff
+ diffractive background

Momentum transfer to target nucleus

Two pion photoproduction



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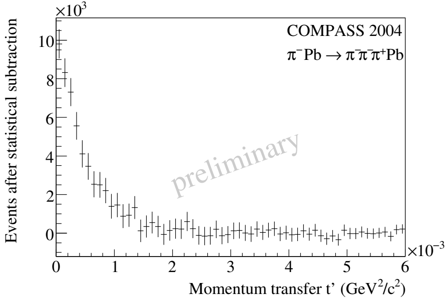
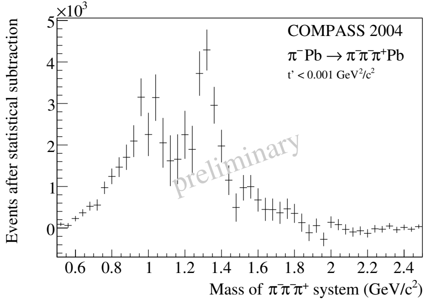


Primakoff,
background subtracted

counts per 40 MeV/c^2



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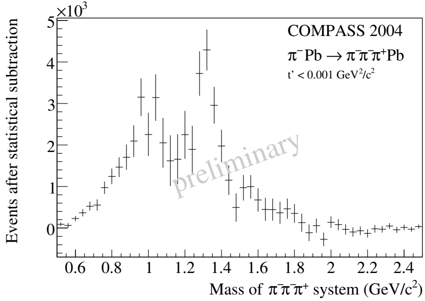
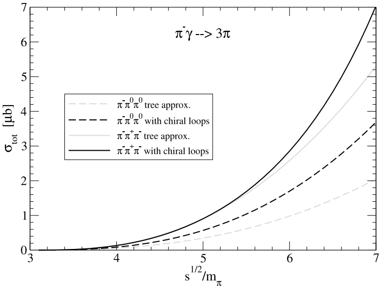


Primakoff, background subtracted

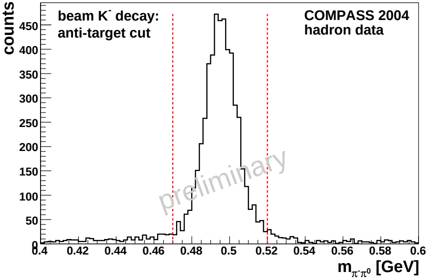
total cross section



1-loop calculation
Norbert Kaiser
(priv. comm.)

Beam flux estimation

Two pion photoproduction



- anti-target cut
- free decays of beam K^-
- efficient beam flux monitor
- acceptance control

Beam flux estimation
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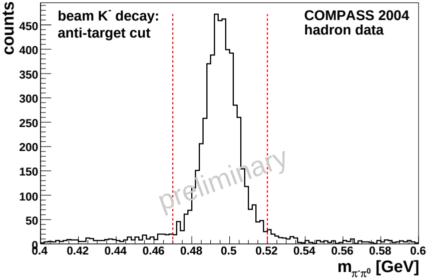

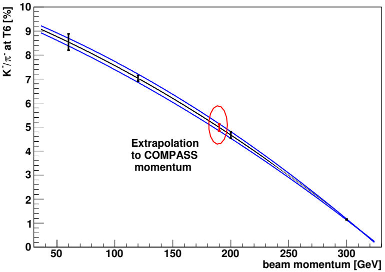

Atherton et al., 1980, CERN 80-07

- anti-target cut
- free decays of beam K^-
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- extrapolation to 190 GeV using 2nd-order polynomial
- K^- and π^- decays along 1025 m of beam line
- $\frac{K^-}{\pi^- + K^-} = 2.61\,\% \pm 0.08\,\%$

Conclusion

COMPASS is an unique machine for χPT precision tests:

Pion-Compton:
$\pi^- \gamma^* \longrightarrow \pi^- \gamma$

Single pion photoproduction:
$\pi^- \gamma^* \longrightarrow \pi^- \pi^0$

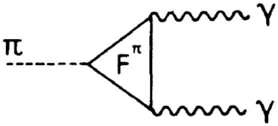
Two pion photoproduction:
$\pi^- \gamma^* \longrightarrow \pi^- \pi^+ \pi^-$
$\pi^- \gamma^* \longrightarrow \pi^- \pi^0 \pi^0$

Large data sample collected 2009, analysis in progress.

Backup Slides

π^0 Lifetime

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



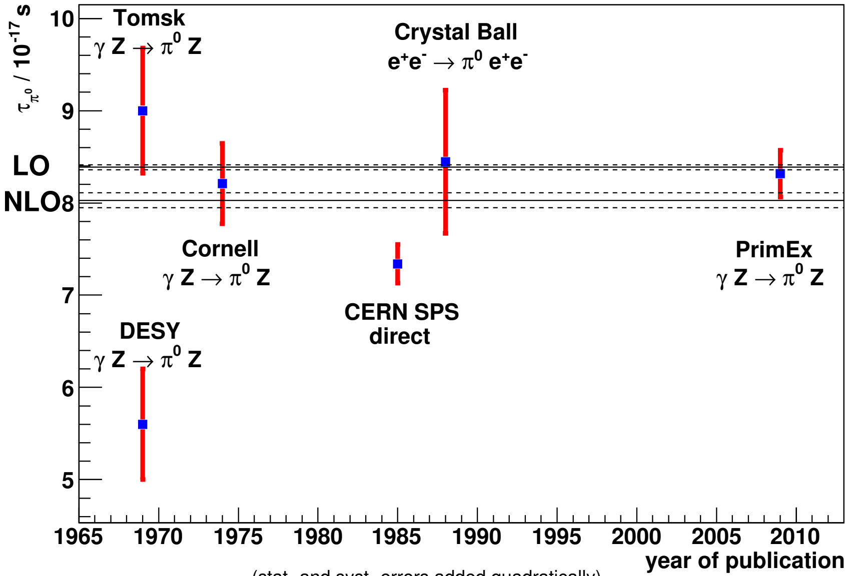
For massless quarks, the leading order χPT predictions for decay amplitude and decay width are

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

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

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

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



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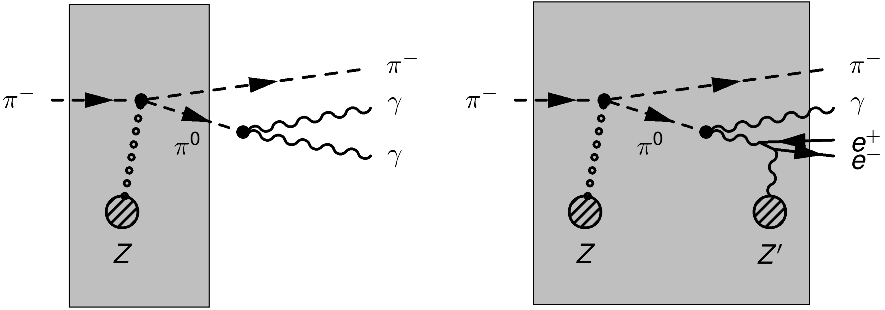

thin target: π^0 decays behind
$\longrightarrow$ no γ conversion

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

π^0 decay length at 100 GeV is $\sim$20 μm