Measurement of the Pion Polarizability with COMPASS

Stefan Huber
for the COMPASS collaboration

Physik Department E18 - Technische Universität München

CIPANP 2015

2015/05/22

Motivation

Technische Universität München

Pion structure as fundamental test of QCD (via χPT)

Quantities describing the charged pion:

- charge known
- scattering length known
- polarisability let's see

Motivation

Technische Universität München

Pion structure as fundamental test of QCD (via χPT)

Quantities describing the charged pion:

- charge known
- scattering length known
- polarisability let's see

Motivation

Technische Universität München

Pion structure as fundamental test of QCD (via χPT)

Quantities describing the charged pion:

- charge known
- scattering length known
- polarisability let’s see

Motivation

Pion structure as fundamental test of QCD (via χPT)

Quantities describing the charged pion:

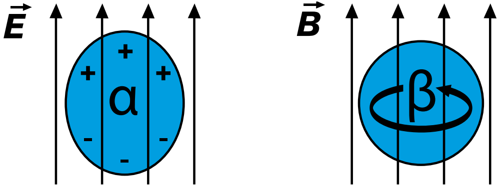
- charge known
- scattering length known
- polarisability let's see

Consider π^- in a strong EM-field ($\approx 300 kV/fm$)

Lowest order correction to point-like structure

Rigidity against deformation

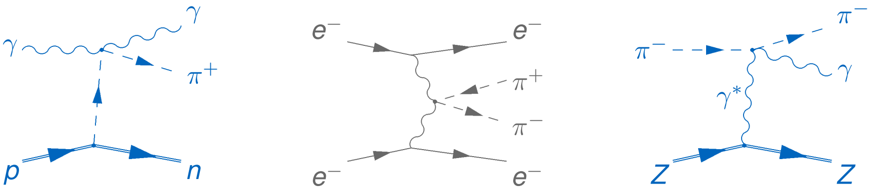
electric polarizability α magnetic polarizability β



χPT prediction: $\alpha_\pi - \beta_\pi = 5.7 \pm 1.0 \times 10^{-4}$ fm^3 $\alpha_\pi \approx -\beta_\pi$

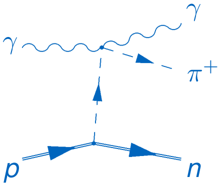
Gasser, Ivanov, Sainio, Nucl. Phys. B 745 (2006) obtaianed by relating to $\pi^+ \to e^+ \nu_e \gamma$

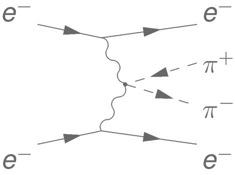
Previous Measurements of $\alpha_\pi - \beta_\pi$

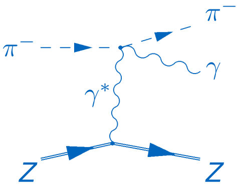


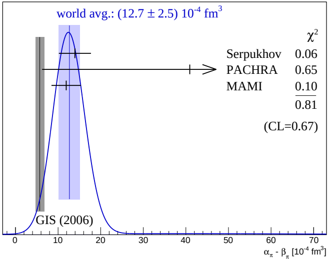
Previous Measurements of $\alpha_\pi - \beta_\pi$

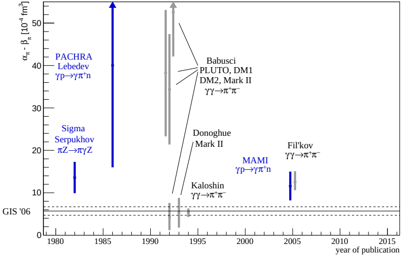
Technische Universität München











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

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

Pion Compton Scattering

Technische Universität München

$\pi^-\gamma \to \pi^-\gamma$ X-Section

$$\frac{d\sigma_{\pi\gamma}}{d\Omega_{cm}} = \frac{\alpha^2(s^2z_+^2+m_\pi^4z_-^2)}{s(sz_++m_\pi^2z_-)^2} - \frac{\alpha m_\pi^3(s-m_\pi^2)^2}{4s^2(sz_++m_\pi^2z_-)} \cdot P$$

$$P = z_-^2(\alpha_\pi - \beta_\pi) + \frac{s^2}{m_\pi^4} z_+(\alpha_\pi + \beta_\pi)$$

$$z_\pm = 1 \pm \cos\theta_{cm}$$

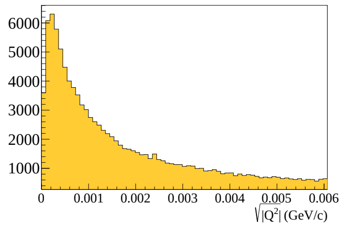
COMPASS: $\pi^-\mathrm{Ni} \to \pi^-\mathrm{Ni}\gamma$

Related to $\pi\gamma \to \pi\gamma$ by Weizäcker-Williams Approximation

$$\frac{d\sigma}{ds\, dQ^2\, d\Omega_{CM}} \propto \frac{Q^2 - Q^2_{min}}{Q^4} \cdot \frac{d\sigma_{\pi\gamma}}{d\Omega_{CM}}$$

$\Rightarrow$Smallest momentum transfers

$Q^2 \approx 10^{-5}\ \mathrm{GeV^2/c^2}$



Primakoff reactions

Technische Universität München

COMPASS: $\pi^- \text{Ni} \to \pi^- \text{Ni}\gamma$

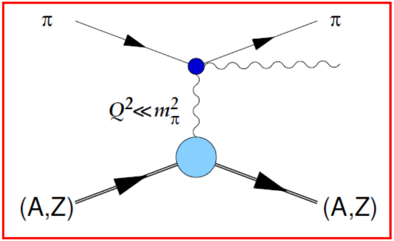
Related to $\pi\gamma \to \pi\gamma$ by Weizäcker-Williams Approximation

$$\frac{d\sigma}{ds\, dQ^2\, d\Omega_{CM}} \propto \frac{Q^2 - Q^2_{min}}{Q^4} \cdot \frac{d\sigma_{\pi\gamma}}{d\Omega_{CM}}$$

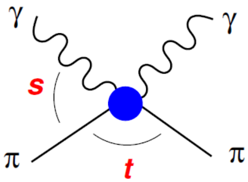
$\Rightarrow$Smallest momentum transfers

$Q^2 \approx 10^{-5}\,\text{GeV}^2/\text{c}^2$

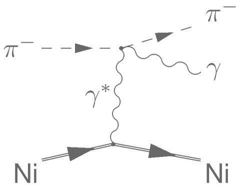
Scattering on quasi real photons



$\Rightarrow$



Technique



Primakoff scattering on the Coulomb field of Ni nuclei

$$\frac{d\sigma_{\pi\gamma}}{dE_\gamma} = \frac{d\sigma_{\text{Born}}}{dE_\gamma} + \frac{d\sigma_{\text{pol}}}{dE_\gamma}$$

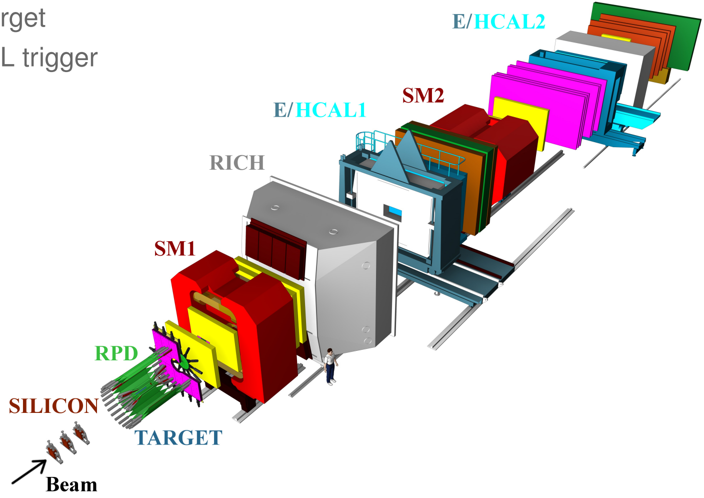
Cross-section ratio dependent on $x_\gamma = E_\gamma / E_{\text{beam}}$

$$R(x_\gamma) = \frac{N_{\text{data}}(x_\gamma)}{N_{\text{sim}}^{born}(x_\gamma)} \approx 1 + \frac{3}{2} \frac{m_\pi^3 x_\gamma}{\alpha_{em}(1 - x_\gamma)} \alpha_\pi$$

Important components

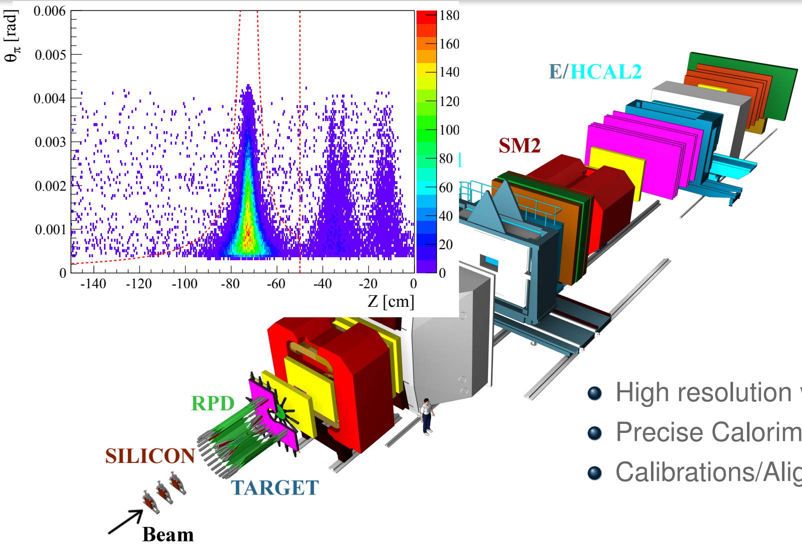
COmmon Muon Proton Apparatus for Structure and Spectroscopy

- π^- and μ^- Beams
- Ni target
- ECAL trigger



Important components

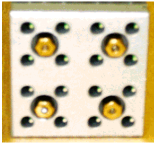
COmmon **M**uon **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

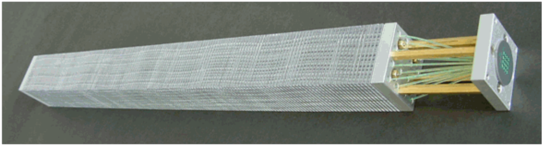


- High resolution vertexing
- Precise Calorimetry
- Calibrations/Alignment

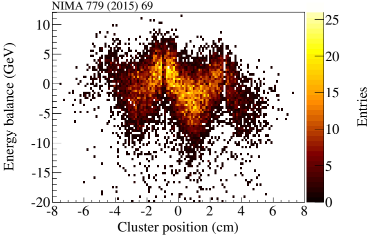
Important components

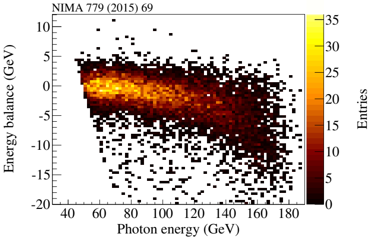
It's all about resolution





COMPASS calorimeter cell

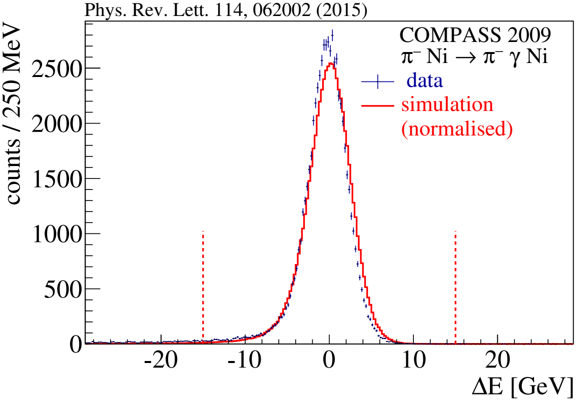




Position dependend energy calibrations necessary

Selection of $\pi\gamma \to \pi\gamma$ events

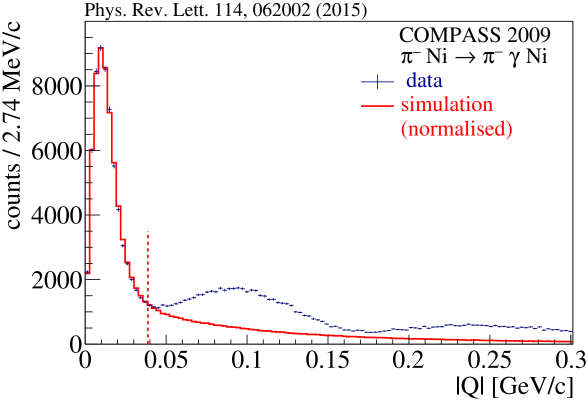
$$\Delta E = E_\gamma + E_{\pi^-} - E_{beam}$$



About 60 000 exclusive events

Four-Momentum transfer

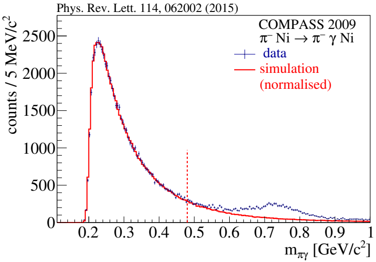
$|Q| = \sqrt{|Q^2|}$

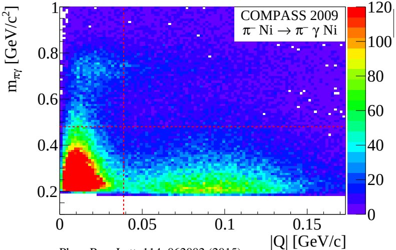


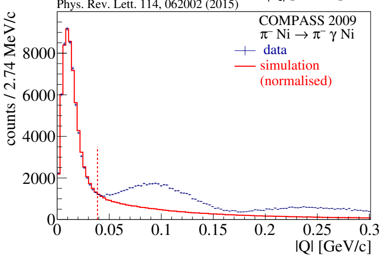
Primakoff production distinguishable from strong interaction by cut on $Q^2 < 1.5 \cdot 10^{-}3\,\mathrm{GeV}^2/c^2$

Backgrounds in the Pion measurement

Technische Universität München

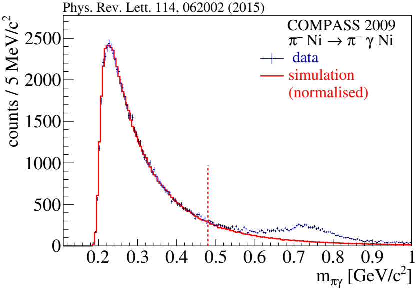






- Background coming from mis-identified π^0
- Background from strong interaction

Background coming from mis-identified π^0

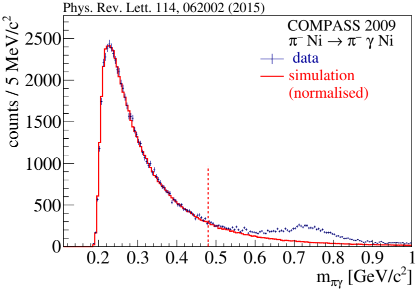


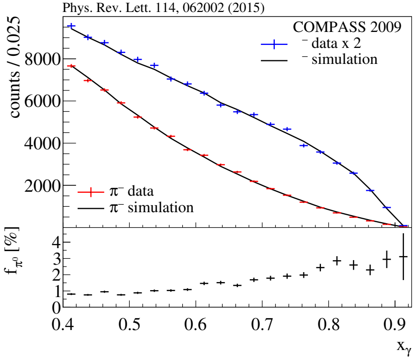
Background fraction

Beam kaon content

- Decay: $K^- \to \pi^- \pi^0$
- Determine mis-identification probability
- Scale by π^-Ni $\to \pi^-$Niπ^0

Background coming from mis-identified π^0



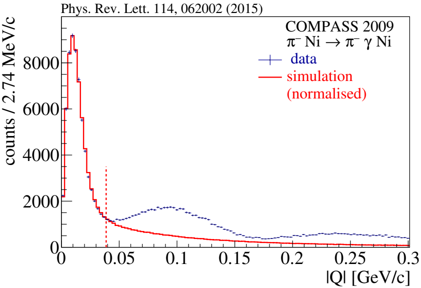


Background fraction

Beam kaon content

- Decay: $K^- \to \pi^-\pi^0$
- Determine mis-identification probability
- Scale by $\pi^-\text{Ni} \to \pi^-\text{Ni}\pi^0$

Background coming from strong interaction



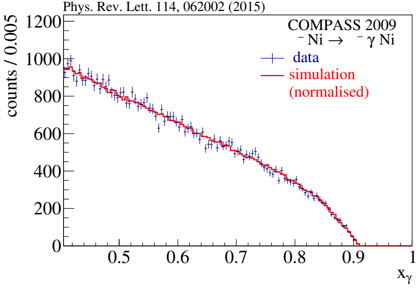
Background fraction

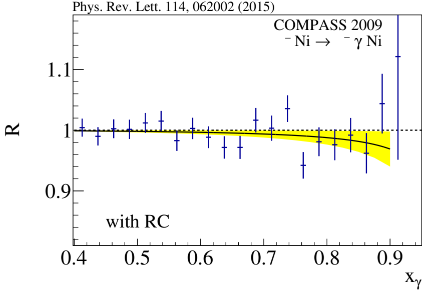
- Fit with Primakoff-peak shape, diffractive pattern and interference term
- Take into account resolution
- Indications for negative interference
- Result statistically limited $\Rightarrow$ systematic error

Muon control measurement

Unique Feature

- Switching between π^- and μ^- beams
- Background free reaction of point-like particle
- Allows control of systematic effects



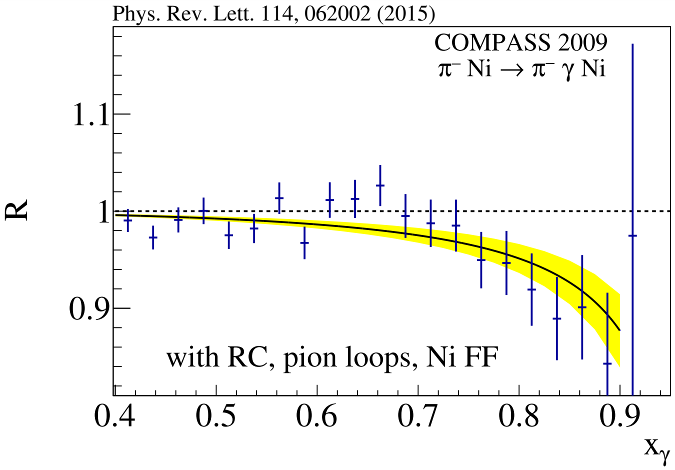


False polarizability for Muons compatible with point-like structure

$\alpha_{\mu}^{\text{false}} = (0.5 \pm 0.5_{\text{stat}}) \times 10^{-4}\ \text{fm}^3$

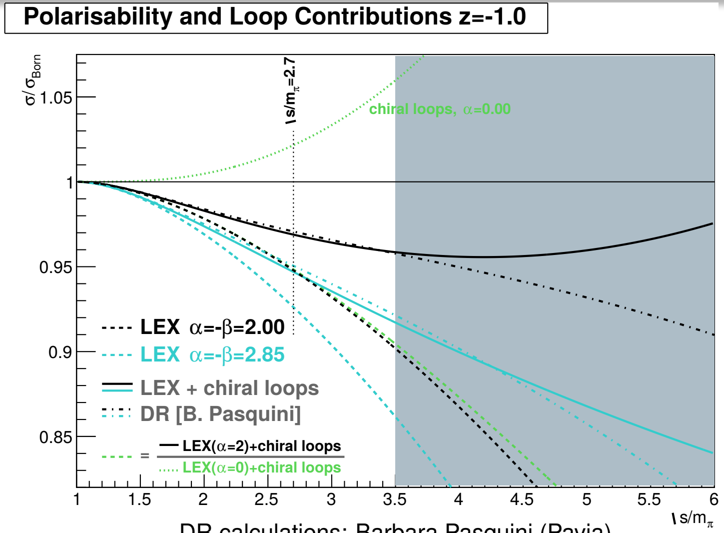
Fit to the data

Technische Universität München



$\alpha_\pi = (2.0 \pm 0.6_{\text{stat}}) \times 10^{-4}\ \text{fm}^3$

Validity of the chiral expansion



DR calculations: Barbara Pasquini (Pavia)

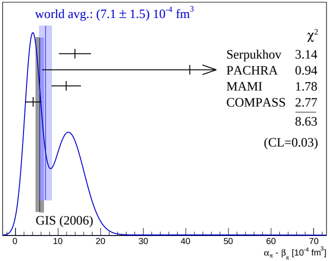
Systematic uncertainties

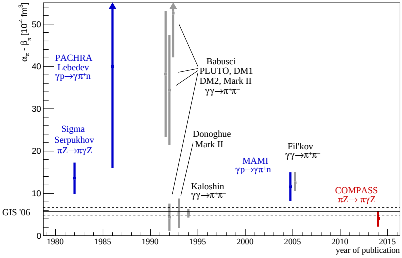
Source of uncertainty	Estimated magnitude $[10^{-4}\,\mathrm{fm}^3]$
Determination of tracking detector efficiency	0.5
Treatment of radiative corrections	0.3
Subtraction of π^0 background	0.2
Strong interaction background	0.2
Pion-electron elastic scattering	0.2
Contribution of muons in the beam	0.05
Quadratic sum	0.7

Result

Technische Universität München

- COMPASS result:
  $\alpha_\pi = (2.0 \pm 0.6_{\text{stat}} \pm 0.7_{\text{syst.}}) \times 10^{-4}\,\text{fm}^3$
- Assumption: $\alpha_\pi = -\beta_\pi$
- In tension with previous measurements
- Measurement in agreement with χPT prediction
- Most precise determination of π^--polarizability





Conclusion

Technische Universität München

- COMPASS result:
  $\alpha_\pi = (2.0 \pm 0.6_{\text{stat}} \pm 0.7_{\text{syst.}}) \times 10^{-4}\,\text{fm}^3$
- Strong constraints on previous experiments
- In tension with previous measurements
- Measurement in agreement with χPT prediction
- Published in Phys. Rev. Lett. 114, 062002 (2015)

- Bigger data set from 2012
- Separate measurement of α_π, β_π
- Kaon polarizabilities