Pion polarizabilities measurement at COMPASS

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on behalf of the COMPASS collaboration

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# COMPASS Experiment

The fixed target experiment on SPS at CERN

## MUON PROGRAM

- \( \Delta G/G \)
- Structure functions
- Exclusive production of vector mesons
- \(^\wedge\)-physics
- Transversity

## HADRON PROGRAM

- Pion polarizabilities
- Chyral anomaly
- Charm baryons
- Glueballs and exotic mesons

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**1996 - COMPASS PROPOSAL**

**1999 - 2001 - CONSTRUCTION AND INSTALLATION**

**2001 - TECHNICAL RUN**

**2002 - 2004, 2006 - 2007 - DATA TAKING WITH MUON BEAM**

**OCTOBER-NOVEMBER 2004 - PILOT HADRON RUN**

**FUTURE (2008?) - DATA TAKING WITH HADRON BEAM**
The electric and magnetic polarizabilities of pion are the quantities characterizing the regidity of quark-antiquark system.

\[ \mathbf{P} = \alpha_{\pi} \times \mathbf{E} \]
\[ \mathbf{\mu} = \beta_{\pi} \times \mathbf{H} \]

The electric and magnetic polarizabilities of pion are the quantities characterizing the regidity of quark-antiquark system.

In nonrelativistic approximation the Hamiltonian of pion interaction with external electromagnetic field corresponding to the 4th diagram can be represented as:

\[ \mathbf{H} = \frac{1}{2} (\alpha_{\pi} \mathbf{E}^2 + \beta_{\pi} \mathbf{H}^2) \]
Theoretical predictions for $\alpha_\pi$ and $\beta_\pi$:

- $\chi$PT (2 loops): $\alpha_\pi + \beta_\pi = 0.16$, $\alpha_\pi - \beta_\pi = 5.7 \pm 1.0$
- QCM: $\alpha_\pi + \beta_\pi = 0.23$, $\alpha_\pi - \beta_\pi = 7.05$
- QCD sum rules: $\alpha_\pi = 5.6 \pm 0.5$
- Dispersion sum rules: $\alpha_\pi + \beta_\pi = 0.166 \pm 0.024$, $\alpha_\pi - \beta_\pi = 13.60 \pm 2.15$

Different theoretical models predict quite different values of pion polarizabilities. Experimental measurement provides the stringent test of theoretical approaches.
Experimental results for $\alpha_\pi$ and $\beta_\pi$

$10^{-4}$ fm$^3$

$\pi^- + A \rightarrow \pi^- + A + \gamma$ process

SIGMA-AYAKS (Protvino)

$\alpha_\pi = 6.9 \pm 1.4_{stat} \pm 1.2_{syst}$ (for $\alpha_\pi + \beta_\pi = 0$)

$\gamma + p \rightarrow \gamma + \pi^+ + n$ process

Lebedev

$\alpha_\pi = 20 \pm 12_{stat}$

A2 (MAMI)

$\alpha_\pi - \beta_\pi = 11.6 \pm 1.5_{stat} \pm 3.0_{syst} \pm 0.5_{mod}$

$\gamma + \gamma \rightarrow \pi^+ + \pi^-$ process

MARK II

$\alpha_\pi = 2.2 \pm 1.6_{stat+syst}$

PLUTO

$\alpha_\pi = 19.1 \pm 4.8_{stat} \pm 5.7_{syst}$

DM1

$\alpha_\pi = 17.2 \pm 4.6_{stat}$

DM2

$\alpha_\pi = 26.3 \pm 7.4_{stat}$

Global fit of $\gamma + \gamma \rightarrow \pi^+ + \pi^-$ data


$\alpha_\pi - \beta_\pi = 13.0^{+2.6}_{-1.9} \times 10^{-4}$ fm$^3$

$\alpha_\pi + \beta_\pi = 0.18^{+0.11}_{-0.02} \times 10^{-4}$ fm$^3$
In COMPASS we study quasi-real photon Compton scattering on $\pi^-$

\[ d\sigma = \int d\sigma_{Compton} \times n(\omega_0, k_{0\perp}) d\omega_0 dk_{0\perp} \]

where \( q = (\omega_0, k_0) \) is 4-vector of virtual photon

\[ \sigma_{Compton} = \sigma(\alpha_\pi, \beta_\pi) \]

For measurement of pion polarizabilities we compare the measured differential cross section of Primakoff reaction and the theoretically predicted cross section for point like pion

\[ \sigma \sim Z^2 \]

\[ Q << m_\pi \]
About 10 days of data taking (pilot run)
Integrated beam flux is $10^{11}$ pions

**TARGETS:**
- main
  - Pb 3 mm
  - Pb 1.6 mm
  - Pb 2 + 1 mm
  - C 23.5 mm
  - Cu 3.55 mm
  - Empty target

**Beam:**
Secondary beam from SPS
- $\pi^-$ (190 GeV)
- $\mu^-$ (190 GeV)

**Trigger:**
- **Primakoff1:**
  - trigger hodoscope +
  - $>50$ GeV in electromagnetic calorimeter +
  - $>18$ GeV in hadron calorimeter
- **Primakoff2:**
  - $>100$ GeV in electromagnetic calorimeter

**About 10 days of data taking (pilot run)**
**Integrated beam flux is $10^{11}$ pions**
Primakoff analysis

For measurement of $\alpha_\pi$ and $\beta_\pi$ under approximation $\alpha_\pi + \beta_\pi = 0$, we compare differential cross section

$$\frac{d\sigma}{d\omega}, \text{ where } \omega = \frac{E_\gamma}{E_{beam}}$$

measured and theoretically predicted for point like pion

At COMPASS there is a possibility to measure $\alpha_\pi$ and $\beta_\pi$ independently from comparison of 2-D cross sections

$$\frac{d^2\sigma}{d\omega d\theta}, \text{ where } \theta \text{ is the angle of photon emission}$$

EVENT SELECTION

- $\pi + \gamma$ in the final state
- primary vertex near the nominal target position
- invariant mass $M_{\pi\gamma} < 3.75 M_\pi$
- $|E_\gamma + P_\pi - P_{beam}| < 25 \text{ GeV}$
- $P_t > 45 \text{ MeV/c}$
- $0.5 < \omega < 0.9$
- $q < 7.5 \times 10^{-3} (\text{GeV/c})^2$

Since muon is the point like particle we use Primakoff statistics collected with muon beam as a reference.

In current analysis only the data with Pb 2+1 mm target and trigger Primakoff2 were used for pion polarizabilities estimation.

≈ 3 full days of data taking
Primakoff and background processes

Q is 4-momentum transferred to nucleus

1) $\pi^- \rightarrow \pi^- + \gamma$ diffractive
2) $K^- \rightarrow \pi^- + \pi^0 \rightarrow \pi^- + \gamma + \gamma$ (~4% of kaons in the beam)
3) $\mu^- \rightarrow \mu^- + \gamma$ (~3% of muons in hadron beam)
4) $e^- \rightarrow e^- + \gamma$ (~0.1% of electrons in hadron beam)
5) $\pi^- \rightarrow \rho^- \rightarrow \pi^- + \pi^0 \rightarrow \pi^- + \gamma + \gamma$

$\sigma_{\text{syst}}$ suppressed by $P_t$-cut

suppressed by $M_{\pi\gamma}$-cut

can be subtracted
Primakoff scattering for different targets

$Q^2$-distribution for different target materials

Z-dependency of the Primakoff cross section

Strong dependency of Primakoff signal ($Q=0$) to diffractive background ($Q>>0.01$) ratio on the target material

Good agreement with $Z^2$-dependency for the Primakoff cross section in the wide $Z$ range
The acceptance behavior is similar for pion and muon events. This fact proves our choice of muon events as reference.
Radiative corrections

- Vacuum polarization
- Compton vertex
- Multiple photon exchange
- Screening by atomic electrons

In spite of the significant corrections to the Born cross section (6-9%) the correction for pion polarizabilities is not too big: $0.6 \times 10^{-4}$ fm$^3$
COMPASS results

$R_\mu = \frac{\sigma_\mu\text{ measured}(\omega)}{\sigma_\mu\text{ theor}(\omega)} = \frac{N_\mu\text{ measured}}{A_\mu(\omega) \times \sigma_\mu\text{ theor}(\omega)}$

$R_\pi = \frac{\sigma_\pi\text{ measured}(\omega)}{\sigma_{\text{p.l.}\pi}\text{ theor}(\omega)} = \frac{N_\pi\text{ measured} - B_{\text{diff}}(\omega) - B_{\text{empty target}}(\omega)}{A_\pi(\omega) \times \sigma_{\text{p.l.}\pi}\text{ theor}(\omega)}$

$\beta = (-0.2 \pm 0.5_{\text{stat}}) \times 10^{-4} \text{ fm}^3$

$\chi^2/\text{ndf} = 12.2/14 = 0.9$

$\alpha_\pi + \beta_\pi = 0$

$\beta_\pi = (-2.5 \pm 1.7_{\text{stat}}) \times 10^{-4} \text{ fm}^3$

$\chi^2/\text{ndf} = 16.7/14 = 1.2$

$\alpha_\pi = -\beta_\pi = 2.5 \pm 1.7 \times 10^{-4} \text{ fm}^3$
Estimations for systematic error

<table>
<thead>
<tr>
<th>Description</th>
<th>Error, $10^{-4}$ fm$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setup description in MC</td>
<td>±0.5</td>
</tr>
<tr>
<td>Diffractive and empty target backgrounds subtraction</td>
<td>±0.3</td>
</tr>
<tr>
<td>Muon background</td>
<td>+0.2</td>
</tr>
<tr>
<td>Electron background</td>
<td>&lt; +0.1</td>
</tr>
<tr>
<td><strong>SYSTEMATIC TOTAL</strong></td>
<td>±0.6</td>
</tr>
</tbody>
</table>

\[ \alpha_\pi = -\beta_\pi = (2.5 \pm 1.7_{\text{stat}} \pm 0.6_{\text{syst}}) \times 10^{-4} \text{ fm}^3 \]
Experimental results for $\alpha_\pi$ and $\beta_\pi$

(with COMPASS result)

<table>
<thead>
<tr>
<th>Process</th>
<th>$\alpha_\pi$</th>
<th>Stat</th>
<th>Syst</th>
<th>Mod</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^- + A \rightarrow \pi^- + A + \gamma$</td>
<td>$2.5 \pm 1.7$</td>
<td>$0.6$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIGMA-AYAKS (Protvino)</td>
<td>$6.9 \pm 1.4$</td>
<td>$1.2$</td>
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<td>$\gamma + p \rightarrow \gamma + \pi^+ + n$</td>
<td>$20 \pm 12$</td>
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<td>A2 (MAMI)</td>
<td>$11.6 \pm 1.5$</td>
<td>$3.0$</td>
<td>$0.5$</td>
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</tr>
<tr>
<td>$\gamma + \gamma \rightarrow \pi^+ + \pi^-$</td>
<td>$2.2 \pm 1.6$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MARK II</td>
<td>$19.1 \pm 4.8$</td>
<td>$5.7$</td>
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</tbody>
</table>

$10^{-4}$ fm$^3$

$\alpha_\pi + \beta_\pi = 0$

$\chi^2$PT prediction

COMPASS

WEIGHTED AVERAGE

$\times 0.8 \pm (5.2 \pm 0.8) \times 10^{-4}$ fm$^3$

Serpukhov

Lebedev

PLUTO

DM1

DM2

Mark II

Mami A2

PLUTO
SUMMARY

- Preliminary result of the measurement of pion polarizabilities at COMPASS under approximation $\alpha_\pi^+ + \beta_\pi = 0$ is $\alpha_\pi = -\beta_\pi = (2.5 \pm 1.7_{\text{stat}} \pm 0.6_{\text{syst}}) \times 10^{-4} \text{ fm}^3$.

- Current result demonstrates the great possibilities of COMPASS setup: present statistical uncertainty (achieved during about 3 days of data taking is on the level of the most precise previous measurements. The systematic uncertainty also not too big and mainly appointed by limited statistics with muon beam for MC setup description test.

- Current precision of polarizabilities measurement is not enough for test of the theoretical models. At COMPASS we plan to perform new data taking for Primakoff reaction for more precise measurement of $\alpha_\pi$ and $\beta_\pi$. 