Status of Day-1 Experiment at HESR

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for the PANDA collaboration

28.07.2014
ICNFP 2014, Crete, Greece
Outline

1. Proposal of Day-1 experiment
2. Design, construction and test of recoil detector
3. Beam commissioning of recoil detector at COSY
4. Preliminary results of pp elastic scattering
5. Summary and outlook
1.1 Introduction to PANDA luminosity monitor

- **Goal of PANDA luminosity monitor**
  - Integrated luminosity with ~3% absolute precision

- **Concept**
  - Low $t$ elastic scattering
  - Coulomb interference region
  - Forward going antiprotons, $3<\theta<8$ mrad
  - 4-layer HV-MAPS telescope at $Z\sim10$ m

PANDA luminosity group: Juelich and Mainz
http://portal.kph.uni-mainz.de/panda-paluma/index.php/luminostiy-monitor.html
1.2 Performance of PANDA luminosity monitor

Small range of $t$ to be measured.

\[
\frac{dN}{dt} = L \left( \frac{d\sigma_c}{dt} + \frac{d\sigma_{int}}{dt} + \frac{d\sigma_n}{dt} \right)
\]

\[
\frac{d\sigma_c}{dt} = \frac{4\pi\alpha^2 G^4(t)(\hbar c)^2}{\beta^2 t^2}
\]

\[
\frac{d\sigma_n}{dt} = \frac{\sigma_T^2 \left( 1 + \rho^2 \right) e^{2\theta}}{16\pi(\hbar c)^2}
\]

\[
\frac{d\sigma_{int}}{dt} = \frac{\alpha \sigma_T G^2(t)(\hbar c)^2}{\beta |t|} e^{-\frac{1}{2} \left| \frac{b}{t} \right|} (\rho \cos \delta + \sin \delta)
\]

Data of $\sigma_T$ and $\rho$ are from PDG, The Review of Particle Physics, PRD 86, 010001 (2012)

Lack of data for parameters $\sigma_T$, $\rho$ and $b$. 

PLB 385 (1996) p479
1.3 Proposal of Day-1 Experiment at HESR

- Antiproton-proton elastic scattering
- Coincidence (Forward & Recoil)
- Large range of $t$
  - Recoil arm only: 0.0008-0.1 GeV$^2$
  - + Forward: 0.0004-0.1 GeV$^2$

A large range of $t$ can be achieved by coincidence measurement at HESR!
2.1 Sketch of Recoil Arm

Recoil arm will cover the entire range of the expected t-spectrum.
2.2 Goals of Commissioning at COSY

- To validate the detector concept by measuring pp elastic scattering
- To answer the key questions
  - What is the minimum energy of recoil protons to be measured? *e.g. 400 keV protons possible to be measured by recoil detector alone?*
  - What precision of luminosity of PANDA could be expected? *e.g. 3% of absolute precision feasible?*
2.3 Chamber Design for Commissioning

- Proton beam maximum 3.7 GeV/c at COSY
- Expected t range at max recoil angle 13.6°

<table>
<thead>
<tr>
<th>P (GeV/c)</th>
<th>t expected (GeV²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>0.0008-0.0921</td>
</tr>
<tr>
<td>3.7</td>
<td>0.0008-0.1161</td>
</tr>
</tbody>
</table>

- Assessment of existing Hydrogen cluster target at ANKE target station
  - Density: 10E14 atoms/cm²
  - Thickness: ~1 mm by modifying collimate
  - Space: available for Day-1 chamber

Existing Hydrogen cluster target is suitable for commissioning.
2.4 Setup for Laboratory Test

- Si (~12 MeV): 76.8x50x1 (mm$^3$) (64/1.2 mm pitch)
- Ge (~60 MeV): 80.4x50x5/11 (mm$^3$) (67/1.2 mm pitch)

Expected energy resolution: ~22.5 keV of Si and ~30 keV of Ge
2.4.1 Temperature Dependence

- Response of detectors at different temperature
  - Si:
    ✓ Small leakage current below 250 K
    ✓ Higher temperature higher amplitude but no significant improvement on resolution
  - Ge (typically working at 77-100K):
    ✓ Leakage current increasing fast above 130 K
    ✓ Amplitude and resolution benefit from higher temperature
- Energy resolution of $^{244}\text{Cm}$ at 125 K
  - Si strips: <20 keV (FWHM)
  - Ge strips: <30 keV (FWHM)

Detector performance fulfills the design requirements.
Detector chamber installed at ANKE target station for commissioning.
3.1 Online Plots from Commissioning

Energy of recoil protons clearly observed.

\[ P = 3.2 \text{ GeV/c} \]
3.2 Data Acquired

- Data have been taken at 1.7 GeV/c, 2.5 GeV/c, 2.8 GeV/c and 3.2 GeV/c.

<table>
<thead>
<tr>
<th></th>
<th>Run1, 2013</th>
<th>Run2, 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam intensity</td>
<td>1E10 protons</td>
<td>2-3E10 protons</td>
</tr>
<tr>
<td>Data file size</td>
<td>27 GB @ P = 3.2 GeV/c</td>
<td>41 GB @ P = 3.2 GeV/c</td>
</tr>
<tr>
<td></td>
<td>19 GB @ P = 1.7 GeV/c</td>
<td>53 GB @ P = 2.8 GeV/c</td>
</tr>
<tr>
<td></td>
<td>(1GB ~1M entries)</td>
<td>24 GB @ P = 2.5 GeV/c</td>
</tr>
<tr>
<td>Elastic events</td>
<td>~ 60% of entries</td>
<td>~ 50% of entries</td>
</tr>
</tbody>
</table>

- Schottky measurements have been performed at 2.5 GeV/c and 3.2 GeV/c
4.1 Luminosity Determination

By Day-1 (online estimate)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>P = 3.2 GeV/c</th>
<th>P = 2.5 GeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic events on Ge5 (background incl.)</td>
<td>389900</td>
<td>314300</td>
</tr>
<tr>
<td>DAQ dead time factor</td>
<td>0.622</td>
<td>0.689</td>
</tr>
<tr>
<td>Integrated time, s</td>
<td>6279</td>
<td>6261.5</td>
</tr>
<tr>
<td>Cross section, mb</td>
<td>3.487±0.15</td>
<td>3.179±0.15</td>
</tr>
<tr>
<td>t range, GeV²</td>
<td>0.0165-0.0571</td>
<td>0.0141-0.0488</td>
</tr>
<tr>
<td>Acceptance</td>
<td>0.785%</td>
<td>0.785%</td>
</tr>
<tr>
<td>Luminosity, cm⁻²s⁻¹</td>
<td>(3.647±0.157)E+30</td>
<td>(2.917±0.138)E+30</td>
</tr>
</tbody>
</table>

By Schottky measurement

<table>
<thead>
<tr>
<th>Parameters</th>
<th>P = 3.2 GeV/c</th>
<th>P = 2.5 GeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target thickness n_T, atoms/cm²</td>
<td>8.867E+13</td>
<td>1.310E+14</td>
</tr>
<tr>
<td>Beam current n_B</td>
<td>2.711E+10</td>
<td>2.180E+10</td>
</tr>
<tr>
<td>Initial beam frequency f₀, Hz</td>
<td>1567975</td>
<td>1529797</td>
</tr>
<tr>
<td>Luminosity n_T<em>n_B</em>f₀, cm⁻²s⁻¹</td>
<td>(3.769±0.169)E+30</td>
<td>(4.350±0.247)E+30</td>
</tr>
</tbody>
</table>

~1.25

~1.24
4.2 Analysis: Clustering

Clustering algorithm implemented for energy reconstruction.
4.3 Analysis: Energy vs Recoil Angle

P = 3.2 GeV/c

To be corrected:
- Detector alignment
- Beam target overlapping

Energy of recoil protons precisely reconstructed.
4.4 Analysis: Detection Threshold

P = 3.2 GeV/c

Threshold: ~ 600 keV

Forward measurement is required for a coincidence.
5 Summary and Outlook

- A recoil detector has been designed and constructed in order to validate the method of the Day-1 experiment at HESR.
- Laboratory tests prove that the recoil detector fulfills the requirements.
- Preliminary results of commissioning at COSY.
- Forward measurement is expected for a complete coincidence in order to suppress background.
  - Data analysis for the construction of a full range of the t-spectrum.
  - Determination of luminosity as well as forward elastic scattering parameters.

The Day-1 Experiment with full set-up will be performed as soon as the first antiproton beams are available at HESR!
Backup
2.3.2 Detector Energy Resolution

- Silicon strips: ~20 keV (FWHM) achieved
- Germanium strips: ~30 keV (FWHM) achieved

by Q. Hu, PhD student in IKP, Juelich
2.3.3 Energy Calibration

- Silicon: dead layer < 0.1 µm
- Germanium: dead layer <1 µm
  - (Ge1: ~0.72 µm, Ge2: ~0.45 µm)

by Q. Hu, PhD student in IKP, Juelich
Required t-range

- **Optical point and b**
  - Nuclear dominated region

- **t:ρ and σ_{tot}**
  - Coulomb-strong region

- **Known b, ρ and σ_{tot}**
  - Absolute luminosity <1%

\[ b \text{ and } \frac{d\text{Nel}}{dt}|_{t=0} \]
\[ t: [0.05-0.1] \text{ GeV}^2 \]

- **ρ and σ_{tot}**
  - \[ t: [0.001-0.02] \text{ GeV}^2 \]

- **Luminosity error**
  - < 1% by parameters

### t_MC0_all_bin5000

<table>
<thead>
<tr>
<th>Entry</th>
<th>1.500203e+07</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.03812</td>
</tr>
<tr>
<td>RMS</td>
<td>0.03112</td>
</tr>
<tr>
<td>( \chi^2 / \text{ndf} )</td>
<td>955.7 / 877</td>
</tr>
<tr>
<td>Sig_{tot}</td>
<td>84.98 ± 0.30</td>
</tr>
<tr>
<td>Rho</td>
<td>-0.06246 ± 0.00239</td>
</tr>
</tbody>
</table>

### t_MC0_uncovered_bin5000

<table>
<thead>
<tr>
<th>Entry</th>
<th>296241</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.00083</td>
</tr>
<tr>
<td>RMS</td>
<td>0.0004438</td>
</tr>
<tr>
<td>( \chi^2 / \text{ndf} )</td>
<td>99.24 / 66</td>
</tr>
<tr>
<td>Lumi</td>
<td>3.222e+05 ± 6.238e+02</td>
</tr>
</tbody>
</table>
Raw spectrum

Si#1_Raw

Ge#1_Raw

Si#2_Raw

Ge#2_Raw
After clustering