Development of High Precision Polarimeter for the charged particle EDM Experiment

on behalf of the JEDI collaboration

TIPP 2017 | Beijing

May 23rd, 2017 | Irakli Keshelashvili
Outline

- Mission of *JEDI* Collaboration
- COSY Accelerator Facility
- New Polarimeter Concept
- Experimental Results
- Summary
In the SM, the CP violation originates from the complex phase in the Cabibbo-Kobayashi-Maskawa (CKM) matrix, which couples the quarks’ weak and the mass eigenstates, and the \( \theta \) term in the QCD Lagrangian.

CP (\( K^0 \) decays) violation means T is also violated assuming CPT symmetry. The existence of a non-zero EDM is a violation of P and T simultaneously & the search for a EDM is a search for CP violation and a search for direct T symmetry violation.

SM CP violation is enough to explain what has been observed in the \( K \) & B meson systems but orders of magnitude smaller than observed in the universe

\[
\eta = \frac{N_B - N_{\bar{B}}}{N_\gamma} \approx 10^{-18} \text{ (SCM)} \approx 6 \cdot 10^{-10} \text{ (BAU)}
\]

1967: Sacharov conditions for the Baryon Asymmetry of the Universe
1) At least one \( N_B \) violating process.
2) C and CP violation
3) Interactions outside of thermal equilibrium.

Measurement of the non zero EDM \( \rightarrow \) physics beyond SM
Storage Ring – srEDM

For all EDM experiments Interaction of $d$ with $E$ is necessary!

$$\frac{d\vec{s}}{dt} \propto d \cdot \vec{E} \times \vec{s}$$

Store polarized deuterons (COSY)


Interact with an E-field (Wien-Filter)

Analyze Polarization Build-up (this talk)

$\vec{s}_\perp \propto |d|$
**COSY Accelerator Facility**  
**Cooler Synchrotron**

Internal and **external** beams  
High **polarization** \((p, d)\)  
**Spin manipulation !!!**

Energy range (min.-- max.):  
- \(0.045 \text{ – } 2.8 \text{ GeV (p)}\)  
- \(0.023 \text{ – } 2.3 \text{ GeV (d)}\)  
Max. momentum \(\sim 3.7 \text{ GeV/c}\)

*Electron & Stochastic* cooling  
Feed-forward machine

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JEDI Polarimeter
High Precision Polarimeter Concept

Ballistic Diamond Pellet Target
*(BDPT)*

Beam Position Monitor

LYSO-SiPM Modules

Beam

20 cm
Data Acquisition System
Flash ADC Based System

- Analog Signals
  - 4x3 LYSO +4 Pl.Sci
  - SIS3316-250-14
    - 16 channel
    - 250 MSPS
    - 14-bit
- Network
  - Network Switch
  - 2x Intel Xeon E5-2637 v4
  - 4-Core CPU
- Network
  - 1 Gbit/s
  - 1 Gbit/s
  - 1 Gbit/s
  - 10 Gbit/s

Amplitude vs. Samples

SIS3316-250-14
16 channel
250 MSPS
14-bit

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First Step: LYSO Crystal Test
E-Linearity, E/T-Resolution, d-Efficiency, DAQ, Bragg Peak, Vendors,...

- rejected events
Results of LYSO Tests
Study of the LYSO Properties

- Test of FADC (250 MS/s, 14-bit) ‘dead-time less’ DAQ system
  Full signal shape were recorded

- Linearity of particle energy vs. light output up to 270 MeV

- Energy Resolution ($\frac{\text{FWHM}}{\text{Amp}} \sim 1\%$), time resolution $\Delta t \sim 300\text{ps}$

- $d$ detection/reconstruction eff. @ 270 MeV drops $\sim 70\%$

- Measuring Bragg-Peak by rotating split LYSO,
  peak @ 6 cm @ 270 MeV $\rightarrow$ crystal length 8 cm (can be flipped)

- Tests of Saint-Gobain and EPIC Crystals with PMT & SiPM (C)
Second Step: New Modules
LYSO+SiPM Module Concept

SiPM sensor readout PCB

SensL SiPM array 8x8 (3mmx3mm), 20um pixels

Spring wave load

Silicon optical interface
24 x LYSO+SiPM Module
Tested December 2016/March 2017 Beam Time

- SG LYSO PreLude 420
  3x3x8cm
- Aluminum housing
- SensL SiPM 8x8
  3x3mm 20um pixel
- Wave-spring
  3D printed
  Nylon screw
- Passive Sum
  RC PCB
SiPM Voltage Supply
Very Good Long Term Stability $\sim 1\mu V_{pp}$

24 Channels
Experimental Setup
Asymmetry Measurements & Target Material Test

Normalization counter
LYSO Modules 2x (2x6)
Target Station
Collimator

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Event Selection
Online cuts

\[ A_y(\theta) = \frac{\sigma^{\uparrow}(\theta) - \sigma^{\downarrow}(\theta)}{\sigma^{\uparrow}(\theta) + \sigma^{\downarrow}(\theta)} \]

\[ \sigma^{pol}(\theta, \phi) = \sigma_0(\theta)[1 - \frac{3}{2} P A_y(\theta) \sin \phi] \]
Preliminary Results

\[ A_y(\Theta) \rightarrow dX \rightarrow dX \]

Vector Analyzing Power, Deuteron Scattering at 270 MeV

Vector Analyzing Power, Deuteron Scattering at 300 MeV
Preliminary Results

\[ \vec{d}X \rightarrow \vec{d}X \text{ at } T_d = 300 \text{ MeV} \]

\[ FOM(\theta) = \sigma(\theta) \times A_y^2(\theta) \]
Summary

- We had 3 very successful beam times. Preparing 4th, end of 2017 😊

- LYSO-SiPM - Excellent Performance

- $\Delta E(x)$ Plastic scintillator modules are under development...

- New 24 modules will be assembled and tested in 2017 in total 48 (4x12) Modules

- Now we have universal external beam experimental setup with various measurement possibilities.
Appendix
Acknowledgment
People contributing to the experiment

- PhD: F. Müller, S. Basile, & D. Shergelashvili
- Mechanics: N. Giese, M. Maubach, G. D’Orsaneo & D. Spölgen
- Electronics: Tanja Hahnratshs-von der Gracht & T. Sefzick
- DAQ & FEE: D. Mchedlishvili, L. Barion & P. Wüstner
- G4: G. Macharashvili, P. Maanen & N. Lomidze
- Ms & Bs: O. Javakhishvili, M. Gagoshidze
Motivation

General Requirements for the Polarimeter

EDM – *Precision Experiment* !!

- Reaction with Large $A_y$: Best $dC \rightarrow dC$ !!
- Maximum Detection & Data Taking Efficiency !!
- Full $\phi$ in Reasonable FOM($\theta$) region !!
- No Magnetic / Electric Field !!
- Stability – Long / Short Term !!!
JuDiT
Jülich ballistic Diamond pellet Target

- Target capable to measure polarization profile
- Huge dynamic range in effective target thickness
- Non-invasive, no rest gas

Beam position Monitors (Rogowski coils) Ballistic Diamond Pellet Target (BDPT) Tracking the Pellet and measuring precise scattering time allows scanning 2D polarization profile of the beam.
First Saturation Test
December 2016 Beam Time

Entries 193500
Mean 106.3
RMS 58.48

270 MeV
dE(10mm Plastic)
### Slow Control System

**December 2016 Beam Time**

#### LYSO Beamtime II - Slowcontrol

<table>
<thead>
<tr>
<th>Arm Positions:</th>
<th>Aperture &amp; Normalisation:</th>
<th>Left Modules:</th>
<th>Right Modules:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Arm - Horizontal</td>
<td>9.0 deg</td>
<td>11.0 mm</td>
<td></td>
</tr>
<tr>
<td>Right Arm - Horizontal</td>
<td>9.0 deg</td>
<td>4.0 mm</td>
<td></td>
</tr>
<tr>
<td>Left Arm - Vertical</td>
<td>0.0 mm</td>
<td>Target Slit: Carbon 19 mm</td>
<td></td>
</tr>
<tr>
<td>Right Arm - Vertical</td>
<td>0.0 mm</td>
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<td></td>
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</table>

**Target Position Control**

<table>
<thead>
<tr>
<th>Container</th>
<th>Position</th>
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<tbody>
<tr>
<td>Empty</td>
<td></td>
</tr>
<tr>
<td>Target Holder</td>
<td>5.5 mm</td>
</tr>
<tr>
<td>Carbon 10 mm</td>
<td></td>
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<tr>
<td>CH2, Polystyrene</td>
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</table>

#### Enable / Disable LYSO Modules - Left Side

<table>
<thead>
<tr>
<th>Module</th>
<th>Enable / Disable</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Disable</td>
</tr>
<tr>
<td>2</td>
<td>Enable</td>
</tr>
<tr>
<td>3</td>
<td>Disable</td>
</tr>
<tr>
<td>4</td>
<td>Enable</td>
</tr>
</tbody>
</table>

#### Enable / Disable LYSO Modules - Right Side

<table>
<thead>
<tr>
<th>Module</th>
<th>Enable / Disable</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Disable</td>
</tr>
<tr>
<td>6</td>
<td>Enable</td>
</tr>
<tr>
<td>7</td>
<td>Disable</td>
</tr>
<tr>
<td>8</td>
<td>Enable</td>
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</table>

**Aperture - Vertical**

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1.15 - 205 [mm]</td>
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</table>

**Aperture - Position**

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1.17 - 17 [mm]</td>
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</table>

**Aperture - Size**

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
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<tr>
<td>12.8 - 218.8 [mm]</td>
<td></td>
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</tbody>
</table>
Collimator System
December 2016 Beam Time

X ~ 8mm

y ~ 9mm

Empty target holder

2D movement

Spot diameter

4x2.5cm Iron collimator blades

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Preliminary results at 150 MeV
December 2016 Beam Time

Measurement on \( CH_2 \) Polyethylene target

\[
\begin{align*}
\text{E (x1000)} & \quad 0 \quad 500 \quad 1000 \quad 1500 \quad 2000 \\
\text{dE (x1000)} & \quad 0 \quad 200 \quad 400 \quad 600 \quad 800 \quad 1000 \quad 1200 \quad 1400 \\
\end{align*}
\]

<table>
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<tr>
<th>hdEvsER14</th>
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<tbody>
<tr>
<td>Mean x</td>
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<tr>
<td>Mean y</td>
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<tr>
<td>RMS x</td>
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<tr>
<td>RMS y</td>
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<tr>
<td>Integral</td>
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<tr>
<td>Skewness x</td>
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<tr>
<td>Skewness y</td>
<td>0.6087</td>
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<th>6</th>
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<td>51</td>
<td>59140</td>
<td>109</td>
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</tr>
<tr>
<td>100</td>
<td>1353</td>
<td>5</td>
<td></td>
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</tbody>
</table>

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Measurement on $CH_2$ Polyethylene target
Target System + Start Counter
December 2016 Beam Time
Online Analysis Software
December 2016 Beam Time

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DAQ

**Signal shapes** *Struck FADC: 14 bit, 250 MS/s, 200 samples*