Overview and Highlights FZJ

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Subtopic coordinator ARD ST2
Introduction

Progress
First deuteron EDM measurement at COSY
Technical developments for proton EDM ring
Developments at COSY for HESR and EDM
Novel polarized proton source

Conclusion & Plans
Stepwise Approach for EDM

Measurements of charged particle EDMs from COSY to a prototype and final EDM storage ring

Cooler Synchrotron COSY

• Ideal starting point for R&D work
• Deliver first direct EDM measurement for deuterons

→ Design of a final EDM storage ring

Prototype EDM Ring

• Prototype EDM ring
• Energy 35 - 45 MeV, CW-CCW beams
• Pure electric and combined E/B
• Length roughly 100m
HIGHLIGHT: FIRST DEUTERON EDM MEASUREMENT PRECURSOR EXPERIMENT AT COSY

Waveguide RF Wien filter

Commissioning: Spin rotation

First ever deuteron EDM measurement

Installation in COSY

Glance into its inside

EDM Limits for COSY:

Statistical sensitivity: $10^{-23-24}$ e·cm
Systematics due to Imperfections & alignment: ~ $10^{-19}$ e·cm
**Design Study for Prototype EDM Ring**

### Beam Parameter for PT EDM Ring

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>kinetic energy</td>
<td>45</td>
<td>30</td>
<td>MeV</td>
</tr>
<tr>
<td>$\beta = \frac{v}{c}$</td>
<td>0.299</td>
<td>0.247</td>
<td>1</td>
</tr>
<tr>
<td>momentum</td>
<td>294</td>
<td>239</td>
<td>MeV/c</td>
</tr>
<tr>
<td>magnetic rigidity $B\rho$</td>
<td>0.981</td>
<td>0.798</td>
<td>T·m</td>
</tr>
<tr>
<td>electric rigidity $E\rho$</td>
<td>87.941</td>
<td>59.071</td>
<td>MV</td>
</tr>
<tr>
<td>$\gamma$-kinetic</td>
<td>1.048</td>
<td>1.032</td>
<td></td>
</tr>
<tr>
<td>emittance $\epsilon_x = \epsilon_y$</td>
<td>1.0</td>
<td>1.0</td>
<td>mm·mrad</td>
</tr>
<tr>
<td>acceptance $a_x = a_y$</td>
<td>10.0</td>
<td>1.0</td>
<td>mm·mrad</td>
</tr>
</tbody>
</table>

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Deflector Development

Static \textit{ExB} deflector

Challenge: Investigate/demonstrate the feasibility of \textit{ExB} deflector for deuteron EDM storage ring with 10 MV/m and 0.3 T. Study breakdown behavior in presence of magnetic fields.

Simulation of electron trajectories

- B-field: 0 T
- B-field: 0.15 T

Setup of electrodes using existing ANKE Magnet

Commissioning in April this year

Different shapes of electrodes will be tested
Stochastic Cooling

HESR slot-ring couplers

Successfully tested with PANDA cluster target at COSY

PANDA Cluster-Target with Stochastic Cooling

Plans:

• Further development of the slot ring couplers in terms of aperture limitation, frequency range and resonant design

Development of algorithms to adjust stochastic cooling while cooling is in operation

• Study of cooling structures for colliding beams

• Stochastic cooling with weak focusing EDM lattice

Poster by Nikolay SHURKHNO (FZJ)

Courtesy: Rolf STASSEN (FZJ)
Electron Cooling

PANDA cluster target (reduced thickness, $3 \cdot 10^{14}$) e-cooling with 0.6 A

Best e-cooling performance observed with fast stochastic transverse pre-cooling

Successful electron cooling down to $dP/P = 3.85 \cdot 10^{-5}$ $I_e = 0.6$ A, with barrier bucket

$P = 2425$ MeV/c

Courtesy: Seva KAMERDZIEV (FZJ)

Plans:

Modeling
- Cooler hardware
- Cooling process
- Compensation schemes

Improve transverse cooling

Move 2 MeV cooler to HESR
- Benefits heavy ion operation

Poster by Arthur HALAMA (FZJ)
Precision Beam Control

Enhanced orbit control
- Novel BPMs for EDM Development @ JEDI
- New BPM electronics
- Orbit correction software

Automatic correction & feedback
Developed together with industry partners

Tune measurement during ramping

Detailed and time-correlated archiving of beam parameters

**Plans:**
- Beam instrumentation for HESR
- Beam instrumentation developments for EDM
  Tune feedback in flat top and during acceleration

Courtesy: Bernd LORENTZ (FZJ)
Prototyping and Beam Physics

EDM accelerator component tests and experiments with spin at COSY
Development of a Novel Polarized Source

Nuclear polarized H atoms from HCl gas jet

** Principle **

- IR/UV Laser
  - For photo-dissociation & polarization of H atoms,
  - 100 mJ @ 1064 nm,
  - 20 mJ @ 213 nm,
  - 5 Hz, 170 ps

- Lamb-Shift polarimeter
  - For measurement of nuclear polarization

** Assembly at IKP **

- Nozzle
  - For HCl gas jet

Method described in:
- T. P. Rakitzis,

Build in cooperation: IKP 2 and 4, PGI-6, and University of Crete

Start of measurements: May 2018
Laser-Plasma Acceleration

Two new laser systems (JuSPARC I):

- Thales AMPHOS
- (40 mJ / 30 fs / 1 kHz) for SOFT X-RAY MAGNETO OPTICS
- (50 µJ / 100 fs / 10 MHz) for PHOTOELECTRON SPECTROSCOPY

• Participation in ATHENA_e:
  kHz Betatron radiation source

Injection of as electron bunches from nm-sized solid targets into a wake field

Simulation results:

• Participation in ATHENA_h:
  Polarized targets for proton and ion acceleration (and maybe, electrons)

Simulation results: Development of polarized targets:

- Two new laser systems (JuSPARC I):
  • (40 mJ / 30 fs / 1 kHz) for SOFT X-RAY MAGNETO OPTICS
  • (50 µJ / 100 fs / 10 MHz) for PHOTOELECTRON SPECTROSCOPY

- Injection of as electron bunches from nm-sized solid targets into a wake field

- Development of polarized targets:
  - Proton spin rotation during TNSA acceleration
  - Nuclear polarized H atoms from HCl jet

Cooperation partners: FZJ, HHUD, WWU, Univ. of Crete, SIOM

Talk by Anna HÜTZEN (FZJ)
Conclusion & Plans

Conclusion:
- First deuteron EDM measurement at COSY
- Conceptional design of Prototype EDM Ring
- Technical developments (Deflector, BPMs, …)
- Successful beam test at COSY for HESR and EDM

Plans:
- Push limit for Deuteron EDM measurement at COSY
- R&D work and technical design for prototype and final EDM storage ring
- Advanced phase-space cooling and beam control for FAIR (and EDM)
- Development of a novel polarized source

Deliverables for EDM Storage Rings:
- Scientific Input for The European Strategy for Particle Physics (ESPP)
- Executive Summary to CERN Physics Beyond Colliders (PBC)
- Design Report for Proton EDM Ring
Search for Electric Dipole Moments

Approach: EDM search in time development of spin in a storage ring:

\[ \vec{\Omega}_G = 0 \]
\[ \vec{\Omega}_d = \vec{d} \times \vec{E}^* \]

“Freeze“ horizontal spin precession; watch for development of a vertical component!

A *magic* storage ring for protons (electrostatic), deuterons, and helium-3

<table>
<thead>
<tr>
<th>particle</th>
<th>p (GeV/c)</th>
<th>E (MV/m)</th>
<th>B (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>proton</td>
<td>0.701</td>
<td>16.789</td>
<td>0.000</td>
</tr>
<tr>
<td>deuteron</td>
<td>1.000</td>
<td>-3.983</td>
<td>0.160</td>
</tr>
<tr>
<td>(^3\text{He})</td>
<td>1.285</td>
<td>17.158</td>
<td>-0.051</td>
</tr>
</tbody>
</table>

One machine with r ~ 30 m
Status of HESR at FAIR

High-Energy Storage Ring (HESR) in time and budget

• All **Dipoles** produced, tested in Jülich and 65% are delivered to FAIR

• **Quadrupoles** are all produced in Jülich

• Two assembly lines for the quadrupole groups in the arcs are in preparation

• **Sextupoles, steerers** and their power converters are in production (Romania), magnets arriving continuously in Jülich

• Nearly all other **power converters** are produced, in Jülich.

• **RF equipment** is in mechanical design

• **Stochastic cooling equipment, Beam diagnostics and Injection kickers** are in production
Production of Polarized Proton Beams

100 mJ @ 1064 nm
Alignment of HCl bonds

20 mJ @ 213 nm
Photo-dissociation and polarization of the H nucleus

300 J @ 800 nm
Acceleration of the protons in gas jet