First electric dipole moment measurement of the deuteron with the waveguide RF Wien Filter

(Proposal E 005.7, 2nd run)

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Contents

Introduction

- CBAC granted for 1st deuteron EDM run two weeks for machine development and four weeks of actual beam time:
  - Perfecting all involved techniques proved very time consuming.
  - Setting up machine took most of allocated time:
    - adjustment of all relevant beam parameters,
    - orbit corrections,
    - target setup,
    - detector operation,
    - RF Wien filter setup and tuning,
    - chromaticity adjustments and measurements
    - ensure long spin-coherence time,
  - ran for about 6 days with good machine conditions during 1st EDM run
- 1st run in fall 2018 provided necessary input and confirmed need for improvements

Preliminary results from 1st run I

Generalized Thomas-BMT equation [1]:

- in ideal ring EDM tilts invariant spin axis $\vec{n}_s$ in radial direction
- additional magnetic misalignments, so $\vec{n}_s$ tilted radially and longitudinally
- goal achieved during 1st run: determination of $\vec{n}_s \rightarrow$ access to EDM
- EDM obtained from spin dynamics calculation including magnetic imperfections in machine, difference to measured result is EDM

Induce vertical polarization build-up by RF Wien filter [2, 3]

- operated WF on harmonics of spin precession frequency ($\approx 871\,\text{kHz}$) and RF phase locked with spin-precession phase
- EDM mode: WF generates RF-driven spin rotations with $\vec{B}^{\text{RF}} \perp$ ring plane

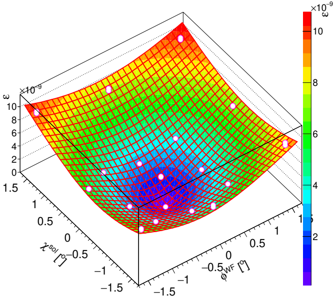
$\Rightarrow$ **Deuteron EDM accumulates as function of time**

Preliminary results from 1st run II

Obtain map of EDM resonance strength

- Different RF Wien filter rotations around beam axis and different solenoid settings affect resonance strength $\varepsilon^{\mathrm{EDM}}$ in predictable way (see [2])
- 31 points in total measured in 1st precursor run (November - December 2018)
- initial slopes of polarization build-up ($\dot{\alpha}$) observed for various phases of RF Wien filter, resulting in sinusoidal dependencies.

- Parametric resonance strength $\varepsilon \simeq \dot{\alpha}/\omega_{\mathsf{rev}}$, based on initial slope $\dot{\alpha}_{|t=0}$ for ϕ_0^{WF} and χ_0^{sol}
- Surface fit using analytic expression of Eq. (1)
- Minimum yields orientation of invariant spin axis, parameters given in Eq. (2)



Preliminary results from 1st run III

Analytic expression for surface derived in Eq. (A5) of [2]:

$$\varepsilon^{\mathrm{EDM}} = \frac{\chi_{\mathrm{WF}}}{4\pi}\left[A_{\mathrm{WF}}^2\left(\phi^{\mathrm{WF}} - \phi_0^{\mathrm{WF}}\right)^2 + A_{\mathrm{Sol}}^2\left(\xi_0^{\mathrm{Sol}} + \frac{1}{2\sin\pi\nu_s}\xi^{\mathrm{Sol}}\right)^2\right]^{\frac{1}{2}} + e_0\,, \tag{1}$$

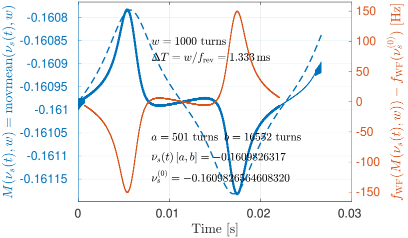
- Represents square root of elliptic paraboloid:
  - χ_{WF}: rot. angle in Wien filter, ϕ^{WF} and ξ^{Sol}: Wien filter and solenoid setting
  - surface minimum gives orientation of invariant spin axis at location of RF WF:
  $$\phi_0^{\mathrm{WF}} = -3.80 \pm 0.05\,\mathrm{mrad} \quad \text{and} \quad -\xi_0^{\mathrm{Sol}} = -5.68 \pm 0.05\,\mathrm{mrad} \tag{2}$$
  - Scaling coefficients and reduced χ^2/ndf of fit to data:
  $$\begin{aligned} A_{\mathrm{WF}} &= 0.755 \pm 0.004 \quad \text{and} \quad A_{\mathrm{Sol}} = 0.919 \pm 0.004 \\ e_0 &= (-1.1 \pm 0.1) \times 10^{-10} \quad \text{and} \quad \chi^2/\mathrm{ndf} = 459/26 = 17.65 \end{aligned} \tag{3}$$

Open questions:

1. Why $A_{\mathrm{WF}} \neq A_{\mathrm{Sol}}$?
2. Spin tracking calculations do not explain tilt parameters ϕ_0^{WF} and ξ_0^{Sol}

Spin tune feedback I

- During EDM measurement with RF WF, ensure it is operated on resonance with spin-precession of deuterons
- Spin tune defined strictly only for *static* machine, *i.e.*, for machine where no RF device affects polarization evolution
- With time-dependent *running* (*instantaneous*) spin tune, also direction of $\vec{n}_s$ changes as fct of time, i.e., $\vec{n}_s \equiv \vec{n}_s(t)$ (see [2])
- Operating RF WF modifies $\nu_s \Rightarrow$ **unavoidable**.
- Simulated data for precursor using framework of [2]:
  - effects magnified, $f_{\text{ampl}} = 10^3$
  - Moving mean of $\nu_s(t)$, $M(\nu_s(t), w)$
  - analytic prediction of $\nu_s(t)$ (NNN)
  - $\Delta f_{\text{WF}}(\nu_s(t))$



Spin tune feedback II

- What can be avoided is running spin tune as input to spin-tune feedback
- New scheme with multiple bunches:
  - 1 of 2 (or 3 of 4) bunches used to determine $\varepsilon^{\mathrm{EDM}}$
  - Bunch, not affected by RF WF, determines ν_s as if machine were static

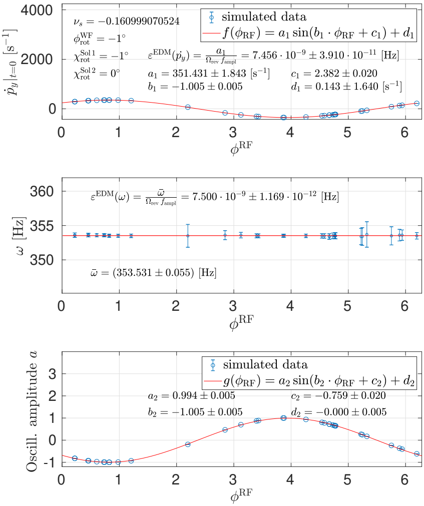
    $\rightarrow$ **pilot bunch**
  - accomplished by 6 fast RF switches into input (4) / output (2) ports of WF
    - see J. Slim et al., JEDI proposal `E005.6` [4]

Pilot-bunch technique provides a co-magnetometer:

- New application of pilot bunch:
  - selectively gate RF system so that *individual* bunches not exposed to RF
  - Spin manipulation of specific bunch stored in machine becomes possible

Determination of ε^{EDM} based on oscillation of $p_y(t)$ I

- With pilot bunch spin-tune feedback, oscillation of p_y proceeds as shown:



- Simulation [2, Fig. 19]:
  - one combination of RF WF and solenoid: $(\phi^{\text{WF}}_{\text{rot}}, \chi^{\text{Sol}\,1}_{\text{rot}}) = (-1^\circ, -1^\circ)$
  - random values of ϕ_{RF} to obtain ε^{EDM} from $p_y(t)$
  - extracted initial slopes $\dot{p}_y(t)|_{t=0}$ as fct of random ϕ_{RF}
  - amplitude a of p_y oscillation

Determination of ε^{EDM} based on oscillation of $p_y(t)$ II

- Consequence of middle panel: number of build-up measurements at different RF phases can be reduced compared to approach using $\dot{p}_y(t)|_{t=0}$
- approach based on ω^{p_y} to get ε^{EDM} offers two new distinct advantages:
  1. possible to investigate systematic effects that appear *during* buildup process by inspecting $\omega^{p_y}(t)$
  2. amplitude a of polarization oscillation $p_y(t)$ available, so provide direct comparison of ε^{EDM} of two different methods

Technical improvements at COSY

A more detailed summary can be found in proposal E005.7

1. Better understanding of injection process into COSY
   - Master thesis B. Alberdi Esuain [5]
2. Alignment campaigns of COSY magnet system
   - Stollenwerk and IKP-4
3. Beam-based alignment
   - PhD thesis Tim Wagner [6, 7]
4. Improvements of COSY signals and distribution
   - Karim Laihem and Volker Hejny
5. New tools for fast tune and chromaticity measurements
   - Philipp Niedermayer and Bernd Breitkreutz
   - EPICS archiving and alarming
   - synchronous and fast
   - for automation of measurement tasks in every cycle
   - More to come: beam-based alignment, orbit-response matrix, etc.
6. New JEDI Polarimeter [8, 9]
   - see next talk by Irakli Keshelashvili

Technical improvements at RF Wien filter

A more detailed summary can be found in proposal E005.7

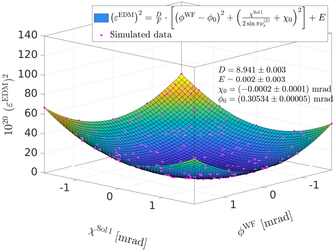
1. 8-channel Zurich Instruments signal generator
   - Feed RF signals more homogenouusly into RF Wien filter
2. Improved matching of RF Wien filter
   - reduction of Lorentz force from RF WF
   - beam oscillations $\approx 1\,\mu\mathrm{m}$ at BPM on opposite side of ring
   - publication in preparation
3. Optimization of Rogowski BPM system
   - PhD thesis Falastine Abusaif [10]
   - publication in preparation
4. Upgrade of slow-control system (G. Tagliente, INFN Bari)
   - inclusion of new Zurich Instruments 8-channel signal generator
   - fast RF switches

Theoretical understanding of precursor experiment [2]

FR, N.N Nikolaev, and J. Slim, *Spin dynamics investigations for the electric dipole moment exp't*

- Precision EDM experiments:
  - demand for understanding of spin dynamics with unprecedented accuracy
  - numerical predictions play crucial role for development and later application of spin-tracking algorithms.
  - polarization effects induced by RF Wien filter and static solenoids

- Fits to simulated data for $\left(\varepsilon^{\text{EDM}}\right)^2$ as fct of $\left(\phi^{\text{WF}}_{\text{rot}}, \chi^{\text{Sol}\,1}_{\text{rot}}\right)$ [2, Fig. 22]
- applied matrix formalism deals *solely* with spin rotations *on closed orbit*



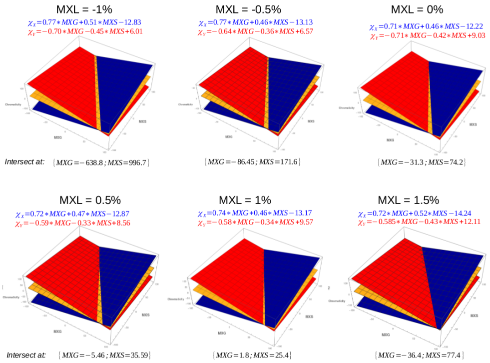
- Provides *numerical* guidance for beam and spin-tracking codes for real rings:
  - more realistic descriptions of electric and magnetic bending and focusing elements, solenoids etc., and realistically-modeled RF Wien filter.

Alignment optimization of magnetic elements using spin I

A. Saleev et al., JEDI proposal E010 [11]

Fast tune and chromaticity measurements:

Preliminary results from September 2020 exp't



- Tool crucial to understand interplay between beam emittance, chromaticities and spin-coherence time

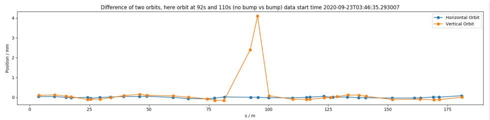
Alignment optimization of magnetic elements using spin II

A. Saleev et al., JEDI proposal E010 [11]

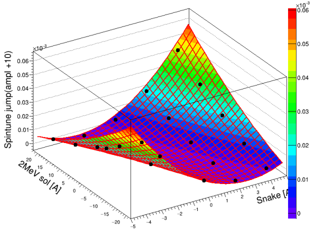
Map of spin-tune differences for local bumps

Preliminary results from September 2020 exp't

- Local bump using steerers SV18, SV20, and SV22
- bump applied without modifications to sextupoles



- $\nu_s(\text{bump} = +10) - \nu_s(\text{bump} = 0)$

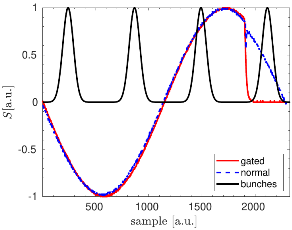


Goal:

- Determine unwanted magnetic fields using spin-tune response to local bumps

Pilot bunch approach ⇒ co-magnetometry for precursor

J. Slim et al., JEDI proposal `E005.6` [4]



Example for stored beam with 4 bunches:

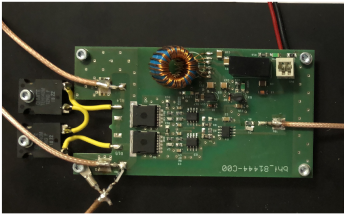
- revolution frequency $f_{\mathrm{rev}} = 750\,\mathrm{kHz}$
- RF WF at $K = -1$ with $f_{\mathrm{WF}} = 871\,\mathrm{kHz}$

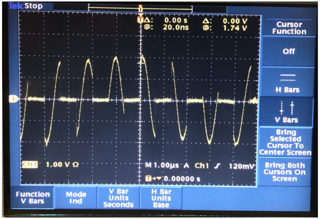
- RF WF fields visible to only to 3 of 4 bunches (or 1 of 2)
- RF field-free bunch ("pilot bunch") ⇒ ν_s ⇒ spin-precession freqency
- Feedback maintains phase-lock and $f_{\mathrm{WF}} = f_s$ for RF exposed bunches
- Selective gating → individual stored particle bunches not exposed to RF:
  - Spin manipulating particles of a specific bunch possible
  - Pilot-bunch technique provides co-magnetometer:
    - **monitors changes in machine during EDM measurement, like drifts of B field**

Fast switches for RF power input of Wien filter

GaN HEMT-based solution (Gallium Nitride Transistors):

- Short switch on/off times ($\approx$ few ns).
- High power capabilities ($\approx$ few kV).
- On board power damping.





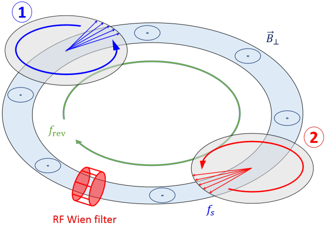
- symmetric switch on/off times ($\approx$ few ns).
- $-30\,\text{dB}$ power damping.

Installed switches:

- capable to handle up to $200\,\text{W}$ each
- permits system to run near a total power of $0.8\,\text{kW}$ in pulsed mode

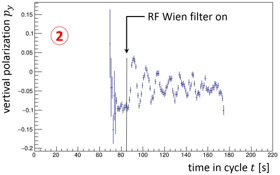
Bunch-selective spin manipulation, EDM co-magnetometry

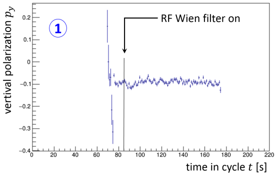
World-first (September 2020 JEDI, with d at 970 MeV/c)



- bunches 1 and 2 orbit at $f_{\mathrm{rev}} \approx 750\,\mathrm{kHz}$:
  - coherent ensembles in ring plane
  - precessing at $f_s \approx 120\,\mathrm{kHz}$
- waveguide RF WF [12] with radial field $\vec{B}_r$
  - on resonance[1] at $f_{\mathrm{WF}} = 871.430\,646\,\mathrm{kHz}$

- **Apply bunch-selective gating of RF Wien filter in 1:**
  - 2 **oscillating** $p_y(t)$, 1 **not affected** (pilot bunch → co-magnetometer)





[1] $f_{\mathrm{WF}} = K \cdot f_{\mathrm{rev}} + f_s = (K + \nu_s) f_{\mathrm{rev}}$, where $K \in \mathbb{Z}$ and ν_s is spin tune

Recent publications in refereed journals 2019 – 2020 I

1. S. Karanth et al. (JEDI), *Influence of electron cooling on the polarization lifetime of a horizontally polarized storage ring beam*, accepted for NIM A
2. F. Müller et al.(JEDI), *Measurement of deuteron carbon vector analyzing powers in the kinetic energy range 170 - 380 MeV*, EPJ **A56**, 211 (2020) [13]
3. F. Müller et al. (JEDI), *A new beam polarimeter at COSY to search for EDMs of charged particles*, submitted to JINST
4. T. Wagner et al. (JEDI), *Beam-Based alignment at the Cooler Synchrotron COSY for a precise EDM measurement*, submitted to JINST [6]
5. J. Slim et al. (JEDI), *Measurement of the excitation of the COSY deuteron beam due to a non-vanishing Lorentz force at an RF Wien filter*, (in preparation for submission, 2020):
6. F. Rathmann, N.N Nikolaev, and J. Slim, *Spin dynamics investigations for the electric dipole moment experiment*, Phys. Rev. Accel. Beams **23**, 024601 (2020) [2]
7. J. Pretz, S.P. Chang, V. Hejny, S. Karanth, S. Park, Y. Semertzidis, E. Stephenson, and H. Ströher, *Statistical sensitivity estimates for oscillating electric dipole moment measurements in storage rings*, Eur. Phys. J. **C80**, 107 (2020) [14]

Recent publications in refereed journals 2019 – 2020 II

8. N.N. Nikolaev, F. Rathmann, A.J. Silenko, Yu. Uzikov, *New approach to search for parity-even and parity-odd time-reversal violation beyond the Standard Model in a storage ring*, under review at PLB [15, https://arxiv.org/abs/2004.09943]
9. O. Javakhishvili, I. Keshelashvili, D. Mchedlishvili, M. Gagoshidze, T. Hahnraths, A. Kacharava, Z. Metreveli, F. Müller, T. Sefzick, D. Shergelashvili, H. Soltner, and H. Ströher, *Development of a multi-channel power supply for silicon photo-multipliers used with inorganic scintillators*, NIM **A977**, 164337 (2020) [16]
10. J. Slim, A. Nass, F. Rathmann, H. Soltner, G. Tagliente, and D. Heberling, *The driving circuit of the waveguide RF Wien filter for the deuteron EDM precursor experiment at COSY*, JINST **15**, P03021 (2020) [17]
11. K. Grigoryev, F. Rathmann, A. Stahl, and H. Ströher, *Electrostatic deflector studies using small-scale prototype electrodes*, Rev. Sci. Instrum. 90, 045124 (2019) [18]
12. J. Pretz, and F. Müller, *Extraction of azimuthal asymmetries using optimal observables*, Eur. Phys. J. **C79**, 47 (2019) [19]

Draft of CERN Yellow Report [20] by CPEDM[2] Coll.

Storage Ring to Search for Electric Dipole Moments of Charged Particles – Feasibility Study

Storage Ring to Search
for Electric Dipole Moments of Charged Particles

Feasibility Study

F. Abusaif,[1] A. Aggarwal,[2] A. Aksentev,[19] B. Alberdi-Esuain,[3] A. Atanasov,[6] L. Barion,[4] S. Basile,[4] M. Berz,[5] M. Beyß,[3] C. Böhme,[1] J. Böker,[1] J. Borburgh,[6] C. Carli,[6] I. Ciepał,[7] G. Ciullo,[4] M. Contalbrigo,[4] J.-M. De Conto,[8] S. Dymov,[9] O. Felden,[1] M. Gagoshidze,[10] M. Gaisser,[3] R. Gebel,[1] N. Giese,[1] K. Grigoryev,[1] D. Grzonka,[1] M. Haj Tahar,[6] T. Hahnraths,[1] D. Heberling,[11] V. Hejny,[1] J. Hetzel,[1] D. Hölscher,[3] O. Javakhishvili,[10] L. Jorat,[6] A. Kacharava,[1] V. Kamerdzhiev,[1] S. Karanth,[2] C. Käseberg,[3] I. Keshelashvili,[1] I. Koop,[12] A. Kulikov,[9] K. Laihem,[3] M. Lamont,[6] A. Lehrach,[1] P. Lenisa,[4] N. Lomidze,[13] B. Lorentz,[1] G. Macharashvili,[13] A. Magiera,[2] K. Makino,[5] S. Martin,[1] D. Mchedlishvili,[13] U.-G Meißner,[1,b,14,25] Z. Metreveli,[10] J. Michaud,[8] F. Müller,[3] A. Nass,[1] G. Natour,[15] N. Nikolaev,[16] A. Nogga,[1,b] A. Pesce,[4] V. Poncza,[1] D. Prasuhn,[1] J. Pretz,[1] F. Rathmann,[1] J. Ritman,[1] M. Rosenthal,[6] A. Saleev,[1] M. Schott,[18] T. Sefzick,[1] Y. Senichev,[19] D. Shergelashvili,[13] V. Shmakova,[1] S. Siddique,[3] A. Silenko,[20] M. Simon,[1] J. Slim,[3] H. Soltner,[15] A. Stahl,[3] R. Stassen,[1] E. Stephenson,[21] H. Straatmann,[15] H. Ströher,[1] M. Tabidze,[13] G. Tagliente,[22] R. Talman,[23] Yu. Uzikov,[9] Yu. Valdau,[1] E. Valetov,[5] T. Wagner,[1] C. Weidemann,[1] A. Wirzba,[1,b] A. Wrońska,[2] P. Wüstner,[15] P. Zupranski,[24] M. Żurek.[26]

Abstract: The proposed method exploits charged particles confined as a storage ring beam (proton, deuteron, possibly helium-3) to search for an intrinsic electric dipole moment (EDM) aligned along the particle spin axis. Statistical sensitivities could approach 10^{-29} e.cm. The challenge will be to reduce systematic errors to similar levels. The ring will be adjusted to preserve the spin polarisation, initially parallel to the particle velocity, for times in excess of 15 minutes. Large radial electric fields, acting through the EDM, will rotate the polarisation. The slow rise in the vertical polarisation component, detected through scattering from a target, signals the EDM.

The project strategy is outlined. It foresees a step-wise plan, starting with ongoing COSY activities that demonstrate technical feasibility. Achievements to date include reduced polarisation measurement errors, long horizontal-plane polarisation lifetimes, and control of the polarisation direction through feedback from the scattering measurements. The project continues with a proof-of-capability measurement (precursor experiment; first direct deuteron EDM measurement), an intermediate prototype ring (proof-of-principle; demonstrator for key technologies), and finally the high precision electric-field storage ring.

CERN-PBC-REPORT-2019-002
CPEDM Collaboration
December 2019

In the framework of the process on Physics Beyond Colliders (PBC)

- $\approx$ 250 page document presently copy-edited and prepared for submission

[2] http://pbc.web.cern.ch/edm/edm-default.htm

Strategy toward a dedicated EDM ring

Charged Particle Electric Dipole Moment Collaboration[3]

Project stages and time frame toward a dedicated EDM ring: [20, CPEDM→ CYR]

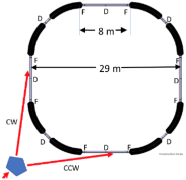
Stage 1

- precursor experiment

- magnetic storage ring
- Now

Stage 2

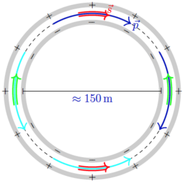
- prototype ring



- electric/magnetic bends
- simultaneous ↺ and ↻
- 5 years

Stage 3

- dedicated storage ring



- at magic p momentum
- 10 years

$\sigma_{EDM}/(e \cdot \mathrm{cm})$

10^{-17} 10^{-18} 10^{-19} 10^{-20} 10^{-21} 10^{-22} 10^{-23} 10^{-24} 10^{-25} 10^{-26} 10^{-27} 10^{-28} 10^{-29}

[3] http://pbc.web.cern.ch/edm/edm-default.htm

JEDI Grants, evaluations, applications

- ERC Advanced Grant srEDM (Hans Ströher, Proposal No. 694340)
- HGF Evaluation Report, Topic 2, Cosmic Matter in Laboratory, 01/2020:
  - **Goals** in the PoF IV period
    - Initiation of the proton Electric Dipole Moment (EDM) project at COSY-ring to open an opportunity to explore physics beyond the standard model.
  - **Work program:**
    - Use COSY, the world's only storage ring for polarized proton and deuterium beams at the IKP facility at FZJ. This will explore the scientific potential for proton/deuteron EDM experiments in the COSY-ring.
    - Perform within PoF IV an Axion search via oscillating EDMs at COSY, which may open the way to new concepts that may extend the reach in precision down to 1×10^{-29} e cm.
- Deliberation Document on 2020 Update of European Strategy for Particle Physics:
  - [...] the COSY facility could be used as a demonstrator for measuring the electric dipole moment of the proton at Jülich. These initiatives should be strongly encouraged and supported. [...]
- Contribution to Snowmass 2021:
  - *Storage Rings for the Search of Charged Particles Electric Dipole Moments*[4]
  - *Test of Standard Model and Search for Physics Beyond – Opportunities for Fundamental Physics using Small-scale Storage Ring Experiments*[5]
- New ERC Advanced Grant application *Pathfinder for a Charged-Particle EDM Storage Ring* (PI: Paolo Lenisa)

[4] https://www.snowmass21.org/docs/files/summaries/RF/SNOWMASS21-RF3_RF0_Frank_Rathmann-008.pdf

[5] https://www.snowmass21.org/docs/files/summaries/AF/SNOWMASS21-AF5_AF0_Frank_Rathmann-030.pdf

Beam request I

Results from 1st run

- Beam conditions favorable for only six days.
- Foreseen multiple and fine-graned repetitions of points on map $\varepsilon^{\mathrm{EDM}}(\xi^{\mathsf{Sol}}, \phi^{\mathsf{WF}})$ could not be recorded.
- Data from 1st run (see slide 4) appear inconsistent $\rightarrow$ large $\chi^2/\mathrm{ndf} = 17.65$

Requested beam time for 2nd run shall be used for:

- **Apply pilot-bunch approach in 2nd run for spin-tune feedback:**
  - unperturbed pilot bunch acts as co-magnetometer for EDM measurement

1. **Data map of $\varepsilon^{\mathrm{EDM}}(\xi^{\mathsf{Sol}}, \phi^{\mathsf{WF}})$ based on initial slopes needs to be substantially enhanced:**
   - Shape of elliptic paraboloid not completely understood.
   - More and better data required, using moderately long cycles of about 400 s duration, and measurements of initial slopes at 9 different RF phases.

Beam request II

2. **Apply alternative technique in 2nd run:**
    - determine $\vec{n}_s$ at RF Wien filter in regime of elliptic paraboloid, where oscillation of $p_y(t)$ can be directly observed.
    - map out wider region of rotation angles ξ^{Sol} and ϕ^{WF}
    - For this, longer cycles needed, typical duration 1000 s
    - number of RF phases to be recorded can be smaller, *i.e.,* about 4.
3. **1. + 2. carried out using Siberian snake and 2 MV ecooler solenoid:**
    - measurements provide *independent* determinations of $\vec{n}_s$ at RF Wien filter

- Under perfect conditions, required beam time for 2nd run amounts to ≈ 22 d.

item	solenoid	# of pts.	cycle	repeat	no. of phases	time
1.	Snake	5×5	400 s	5	9	$25 \cdot 400\,\text{s} \cdot 5 \cdot 9 \approx 5.2\,\text{d}$
1.	2 MV cooler	5×5	400 s	5	9	$25 \cdot 400\,\text{s} \cdot 5 \cdot 9 \approx 5.2\,\text{d}$
2.	Snake	5×5	1000 s	5	4	$25 \cdot 1000\,\text{s} \cdot 5 \cdot 4 \approx 5.8\,\text{d}$
2.	2 MV cooler	5×5	1000 s	5	4	$25 \cdot 1000\,\text{s} \cdot 5 \cdot 4 \approx 5.8\,\text{d}$
						total time $= 22$ d

Beam request III

Beam request for 2nd deuteron EDM run

- Implicitly clear: 2nd run will be last for precursor EDM exp't on deuteron.
- **Goal: collect statistically and systematically meaningful data sample for deuteron EDM measurement:**
  - Allowing for contingency of $\approx 50\%$, 35 d of beam time are required
  - Given past experience, longer setup time is needed
- **Request: 2 weeks of MD time and 5 weeks of measurement time**
  - to be tentatively scheduled in 1st quarter of 2021.
  - combine beam time for 2ndrun (`E005.7`) with JEPO commissioning (`E002.8`)

Support

We would like to request support by the EU

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Spare slides

New idea to make use of in-plane oscillating deuterons

Parity-even and parity-odd time-reversal violation beyond Standard Model [15]

- Time-reversal breaking and parity-conserving millistrong interactions remain viable mechanisms of CP-violation beyond the Standard Model.
- **Possible manifestation:** T-odd asymmetry in transmission of tensor-polarized deuterons through a vector-polarized hydrogen gas target.
- With deuteron polarizations oscillating in ring plane, T-odd asymmetries, oscillate continuously with first or second harmonic of f_s.
- Fourier analysis of oscillating T-odd asymmetries allows separation from background,
    - prevailing in experiments employing static vector and tensor polarizations.

Frequencies of RF Wien filter [2, Fig. 3]

Spin resonance condition:

$$f_{\mathrm{WF}} = f_{\mathrm{rev}} \left(\gamma G \pm K\right) , k \in \mathbb{Z}. \qquad (4)$$

- RF Wien filter operates at frequencies between 0 to 2 MHz,
- Open symbols not reachable with present setup of driving circuit, *i.e.*,
  - deuterons at $K = 0$ (-120.8 kHz), and
  - protons at $K = -2$ (39.4 kHz).