GSI Helmholtzzentrum für Schwerionenforschung

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SIMULATIONS OF BEAM DYNAMICS AND BEAM LIFETIME FOR THE PROTOTYPE EDM RING

Saad Siddique, on behalf of the JEDI and CPEDM Collaborations

III. Physikalisches Institut B, RWTH Aachen University, Germany

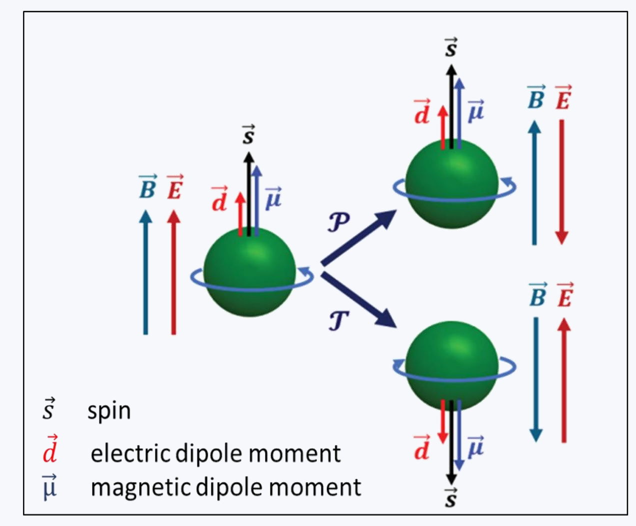
GSI Helmholtzzentrum für Schwerionenforschung GmbH Darmstadt, Germany

saad.siddique@rwth-aachen.de

Physics Case:

- Matter antimatter asymmetry can be explained by CP-violation.
- Permanent electric dipole moment (EDM) is fundamental property of particles (like mass, charge , magnetic moment)
- Existence of EDM only possible if violation of time reversal and parity symmetry.[1]

$$H = H_M + H_E = -\vec{\mu}\cdot\vec{B} - \vec{d}\cdot\vec{E}$$
$$P : H = -\vec{\mu}\cdot\vec{B} + \vec{d}\cdot\vec{E}$$
$$T : H = -\vec{\mu}\cdot\vec{B} + \vec{d}\cdot\vec{E}$$



Methodology :

- Inject longitudinally polarized beam in the storage ring
- Radial electric field interacting with EDM (**torque**)
- Observe vertical polarization with time

Thomas-BMT-Equation

$$\frac{d\vec{S}}{dt} = \vec{\Omega}\times\vec{S} = (\vec{\Omega}_{MDM} + \vec{\Omega}_{EDM})\times\vec{S}$$

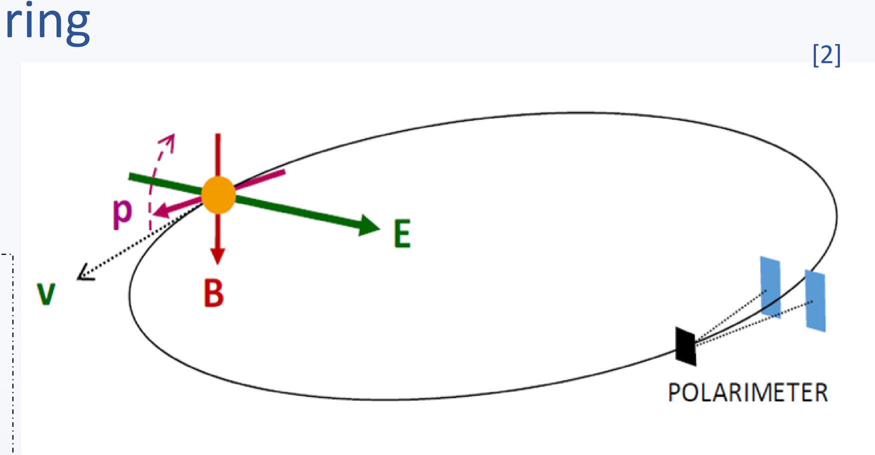
$$\vec{\Omega} = \frac{q}{m}\left\{G\vec{B} + \left(G - \frac{1}{\gamma^2-1}\right)\frac{\vec{\beta}\times\vec{E}}{c} + \frac{\eta}{2}\left\{\frac{\vec{E}}{c} + \vec{\beta}\times\vec{B}\right\}\right\}$$

Frozen Spin Idea

$$\vec{B} = 0 \text{ and } \left(G - \frac{1}{\gamma^2-1}\right) \equiv 0!$$

Magic momentum

[2]



If G > 0 → pure electric ring

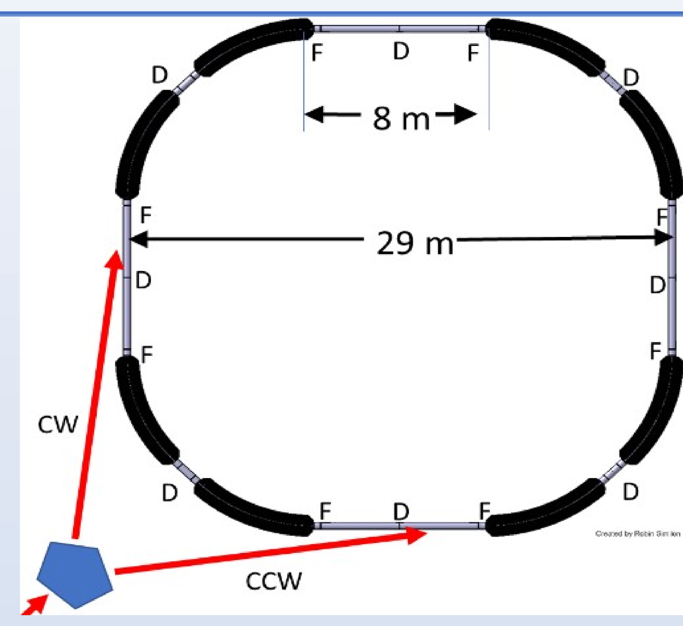
If G < 0 → combination of E-B

Strategy

1. Precursor Experiment @COSY Fz Jülich, Germany
2. Prototype Storage Ring
3. All Electric Storage Ring

Prototype Storage Ring :

- Beam injection with multiple polarization states and for longer time. (> 1000 sec)
- Develop key technologies beam cooling, deflector, beam position monitors, magnetic shielding….
- Perform EDM measurement



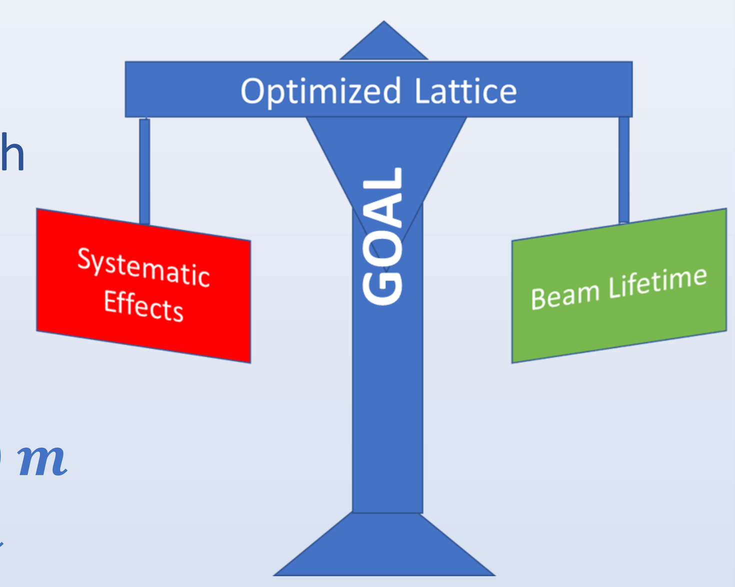
Ring will be operated in two modes:

a. Electrostatic bendings (at T=30 MeV)
b. Electromagnetic bendings (at T=45 MeV)

Beam Simulations :

Four Lattice with different focusing strength generated by MADX. [5]

- **Four different lattices studied**
  1. Strong Lattice with $\beta_{y-max} = 33\ m$
  2. Medium Lattice with $\beta_{y-max} = 100\ m$
  3. Weak Lattice with $\beta_{y-max} = 200\ m$
  4. Weaker Lattice with $\beta_{y-max} = 300\ m$



After generating these lattices, beam loss estimations were performed for all major effects and in two different scenarios, with residual gas only and with a carbon target.

Beam loss Estimations: [3]

1. Hadronic Interactions (HI)
2. Single Coulomb Scatterings (SCS)
3. Energy Loss straggling (ELS)
4. Intrabeam Scatterings (IBS)

$$\tau^{-1} = n\sigma_{tot}f_0$$

τ^{-1} = beam loss rate
n = target thickness or rest gas density
σ_{tot} = total cross section
f_0 = revolution frequency

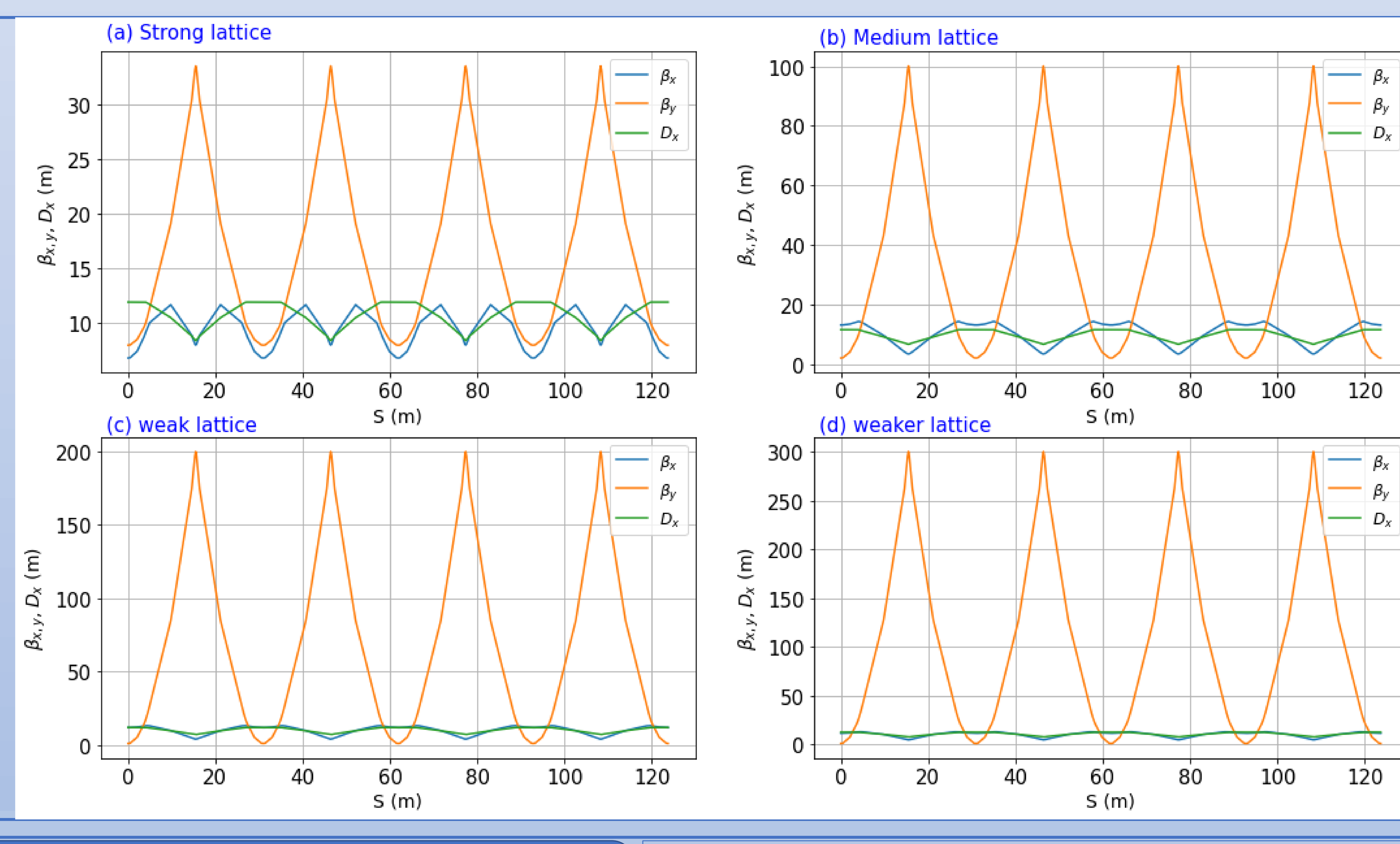
Parameters

Gas composition $H_2 : N_2$ with 80:20

Gas density : n_g=5.30 × 10^5 $atoms/cm^3$

$P_{eq} = 2.8 \times 10^{-11}\ Torr$

Carbon target density:$n_t \sim 2 \times 10^{12}$ $atoms/cm^2$



Results:

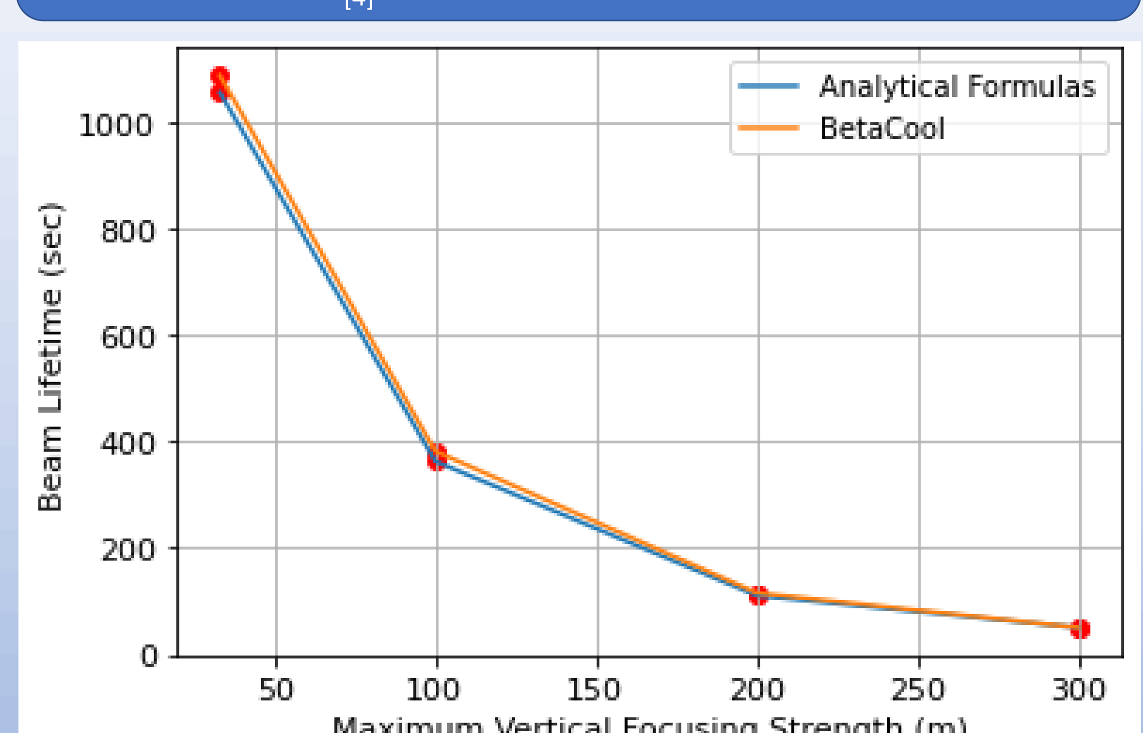
Total loss rate :

$$\left(\frac{1}{\tau}\right)_{Total} = \left(\frac{1}{\tau}\right)_{HI} + \left(\frac{1}{\tau}\right)_{SCS} + \left(\frac{1}{\tau}\right)_{ELS} + \left(\frac{1}{\tau}\right)_{IBS}$$

Lattice (β_{y-max})	H.I $10^{-6}\ s^{-1}$	SCS $10^{-4}\ s^{-1}$	IBS $10^{-4}\ s^{-1}$	τ^{-1} $10^{-4}\ s^{-1}$
33 m	2.7	7.6	2.34	9.47
100 m		27.3	2.10	27.5
200 m		94.6	1.99	90.0
300 m		208	1.90	195

Energy loss straggling isn't contributing theoretically in beam loss rates

Comparison b/w Analytical estimations and [4] Betacool Results



Summary

- Preliminary design of prototype EDM ring
- Most dominating effect is Single Coulomb Scatterings
- Lattice with $\beta_{y-max} \leq 100\ m$ is preferable for longer beam lifetime.
- Analytical formulas and BetaCool results showing an agreement.

References:

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2. Abusaif, Falastine *et al., CERN Yellow Reports: Monographs, Vol. 3 (2021): Storage ring to search for electric dipole moments of charged particles: Feasibility study* doi:10.23731/CYRM-2021-003
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4. A.O. Sidorin, I. N. Meshkov, I. A. Seleznev, A. V. Smirnov, E. M. Syresin, and G. V. Trubnikov, *BETACOOL program for simulation of beam dynamics in storage rings*, Elsevier, 2006.
5. H.Grote and F.Schmidt *CERN MADX introduction* http://mad.web.cern.ch/mad/madx.old/ Introduction/doc.html