SIMULATIONS OF BEAM DYNAMICS FOR THE PROTOTYPE EDM STORAGE RING

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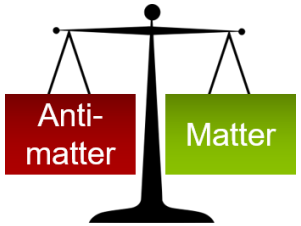
OUTLINE

1) Introduction
2) EDM Measurement using Storage Ring
3) Prototype EDM Storage Ring
4) Simulation Results
5) Summary

INTRODUCTION

Big Bang



Equal amount of matter & antimatter

Today

Matter

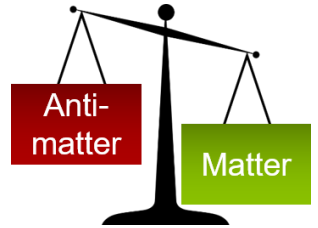
Baryon Asymmetry

$$= \frac{N_B - N_{\bar{B}}}{N_\gamma}$$

Observed value * $\approx 10^{-10}$

Expected value $\approx 10^{-18}$

Early Universe



Preference of matter

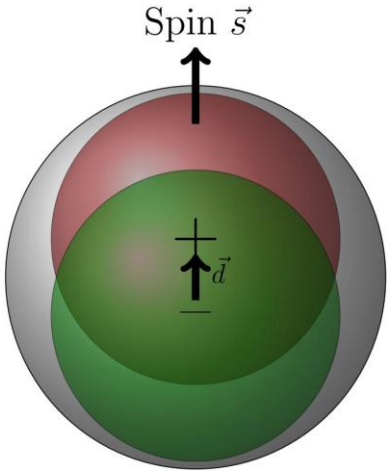
Sakharov criteria (1967):

- Baryon number violation
- No thermic equilibrium
- $\mathcal{C}$, $\mathcal{CP}$ **violation**

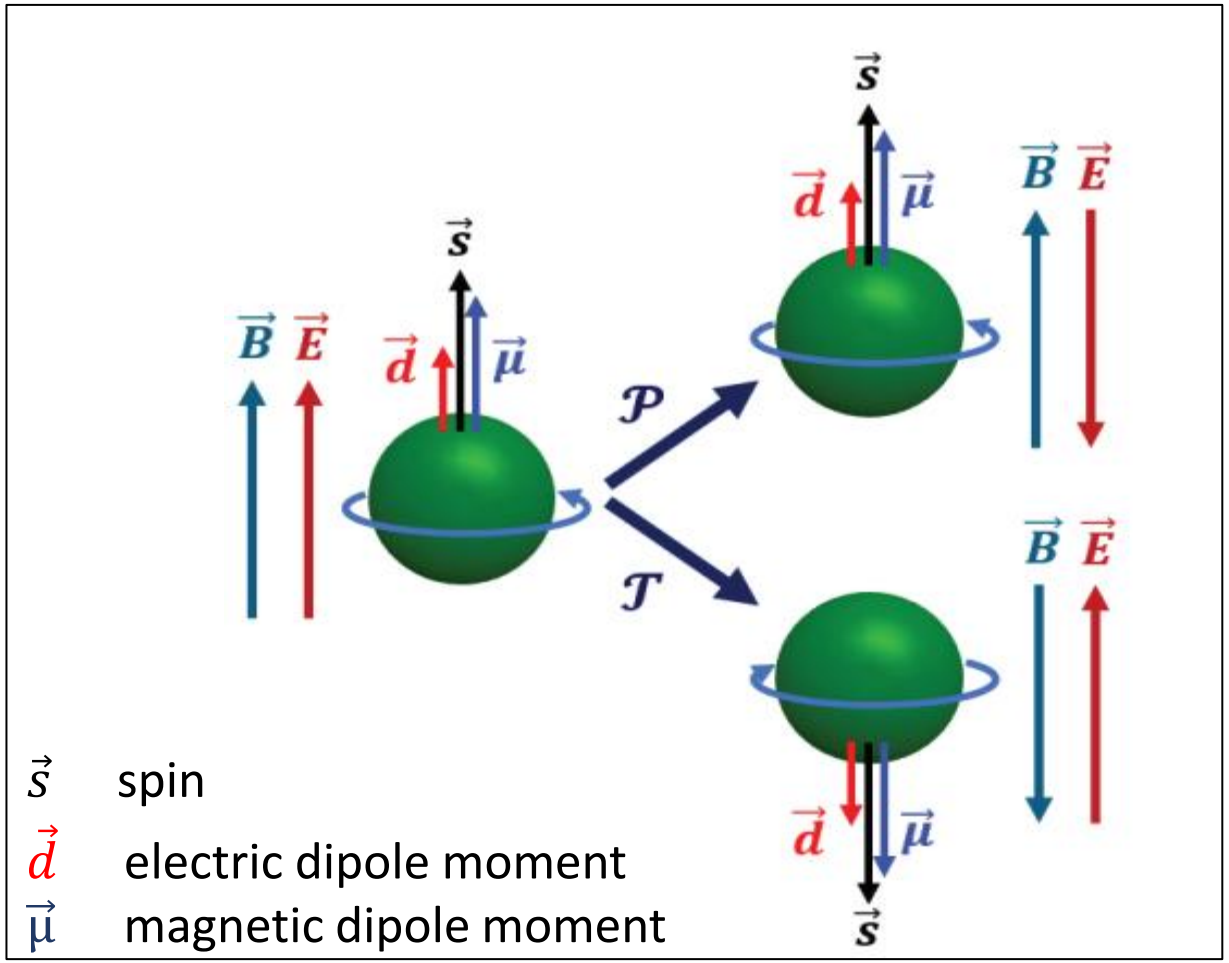
Search for $\mathcal{CP}$ violation beyond the Standard Model

*Theoretical Cosmological Models

Electric Dipole Moment (EDM)



- **EDM**: a permanent separation of positive and negative charge (vector along spin direction)
- Fundamental property of particles (like mass, charge, magnetic moment)
- Existence of EDM only possible if violation of time reversal and parity symmetry.
- If **T** is violated then by the **CPT-theorem**, **CP** must be violated.



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

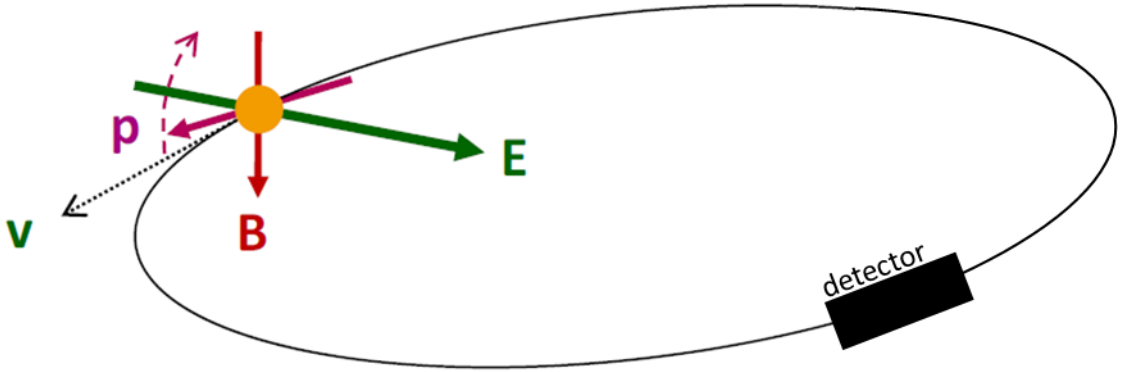
$$P : H = -\vec{\mu} \cdot \vec{B} + \vec{d} \cdot \vec{E}$$

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

EDM MEASUREMENT USING STORAGE RING

Basic Principle

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



Spin motion: **Thomas-BMT-Equation**

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

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

The dimensionless parameter η relates with EDM $\vec{d}$

$$\vec{d} = \eta \frac{q\hbar}{2mc}\vec{S}$$

To measure η, either pure electrostatic ring or electromagnetic ring will be used. It depends on G

Where

$G \rightarrow anomalous\ magnetic\ moment$

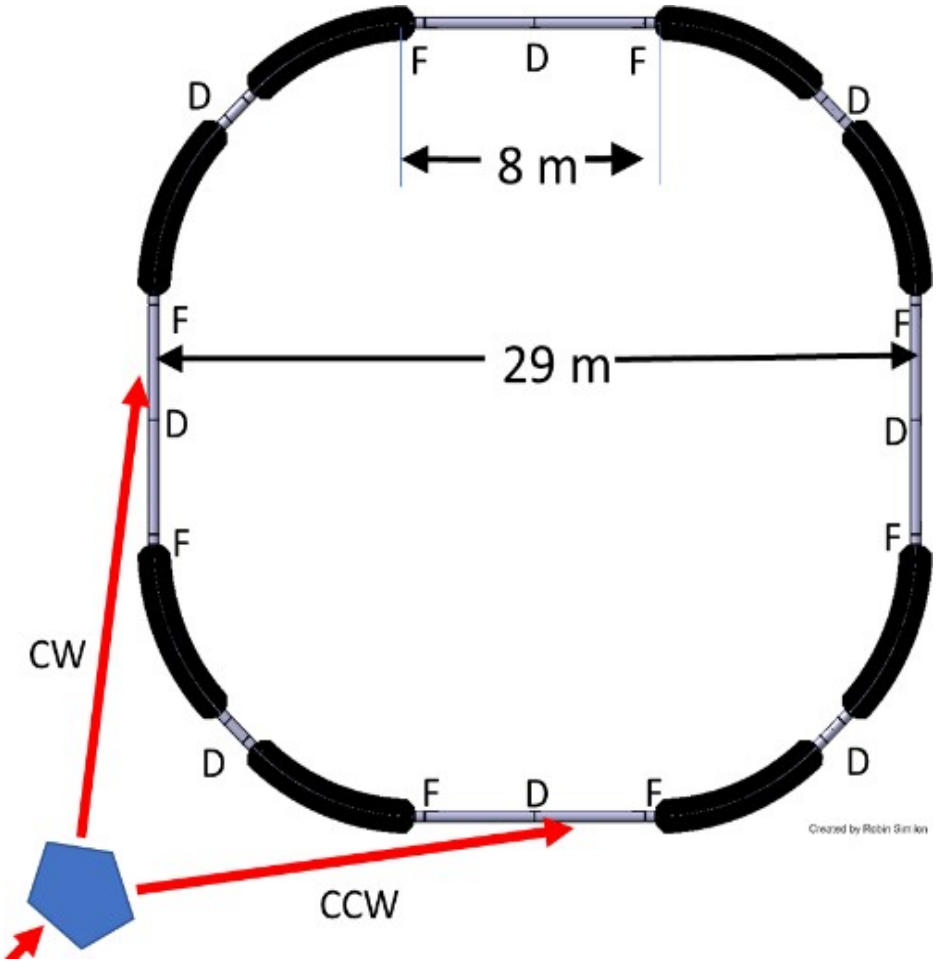
$G < 0\ i.e.\ Deutron$

$G > 0\ i.e.\ proton$

PROTOTYPE EDM STORAGE RING

Goals :

- **How long beam can be stored inside PTR ring.**
- Beam injection with multiple polarization states
- Develop and benchmark simulation tools
- Develop key technologies beam cooling, deflector, beam position monitors, magnetic shielding….
- Perform EDM measurement



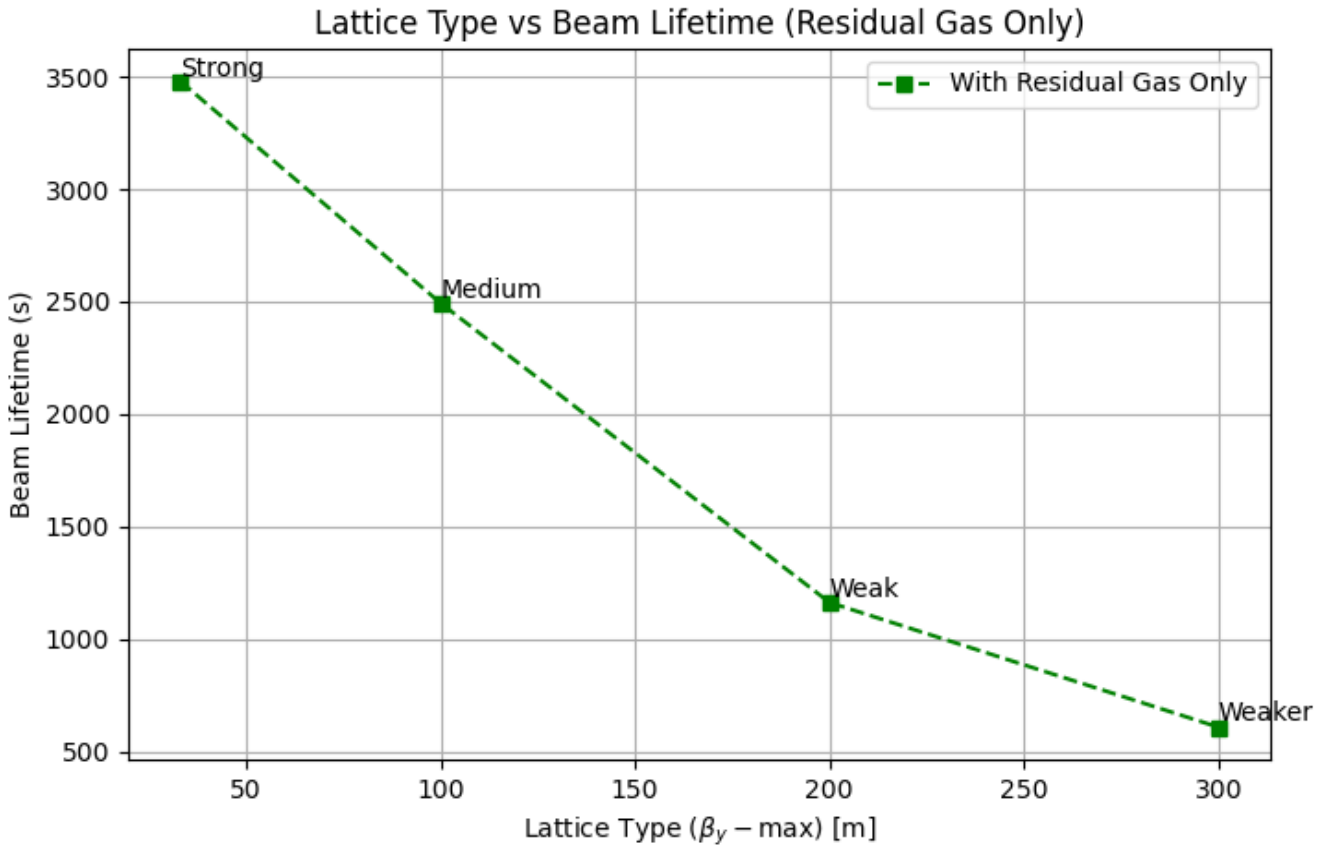
SIMULATION RESULTS

- Beam Lifetime
- Beam target interactions

PTR SIMULATION: Beam Lifetime

- PTR lattice flexibility.
- Beam losses were estimated by taking major effects only.
- Two scenarios were considered
  a) with residual gas only
  b) with carbon target

Lattice type	(m)	Qx	Qy
Strong	33	1.754	1.227
Medium	100	1.835	1.748
Weak	200	1.796	1.881
Weaker	300	1.770	1.923

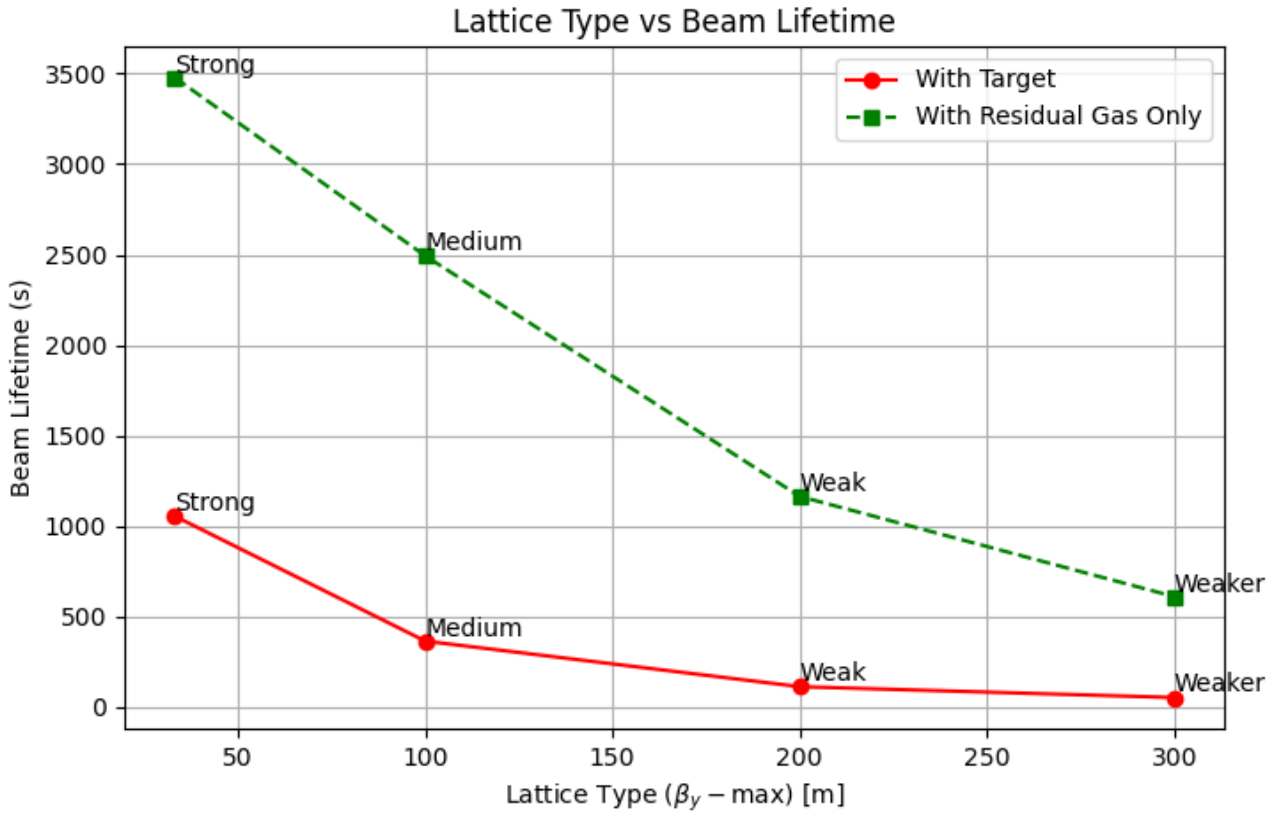


PTR SIMULATION: Beam Lifetime

- PTR lattice flexibility.
- Beam losses were estimated by taking major effects only.
- Two scenarios were considered
  a) with residual gas only
  b) with carbon target

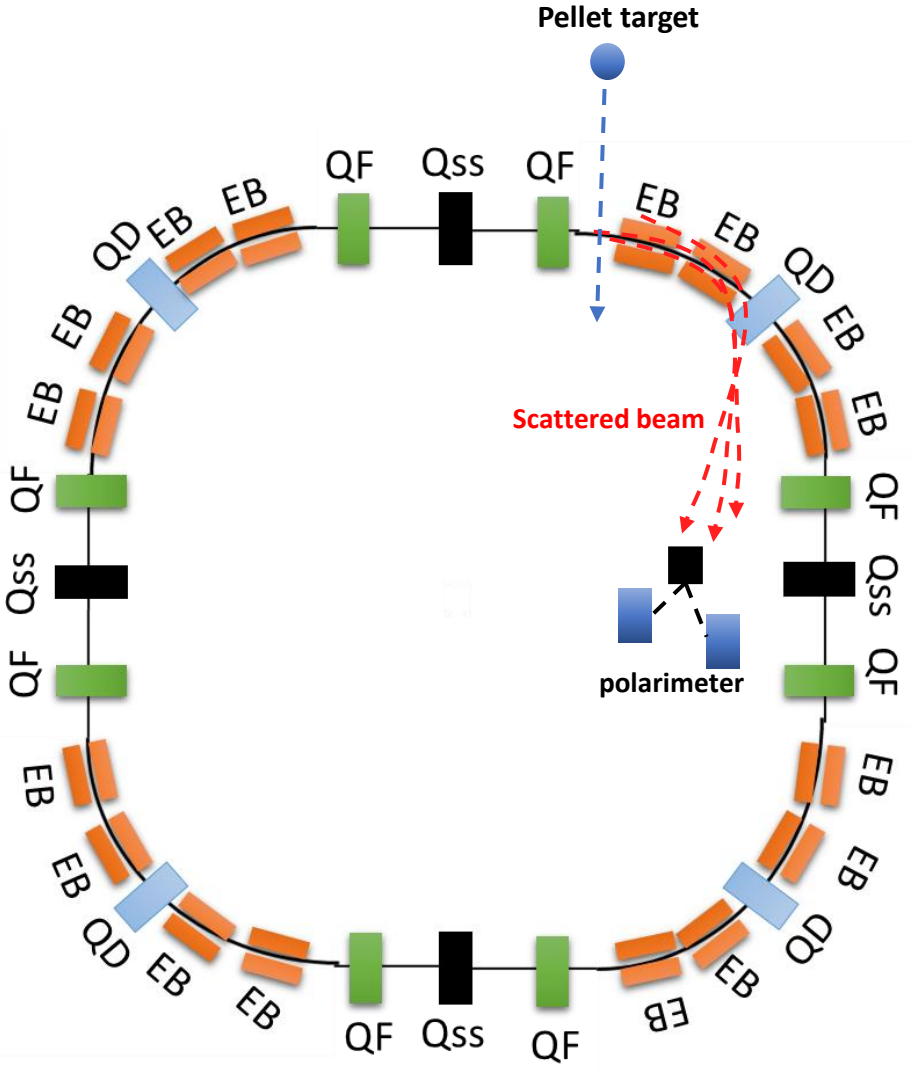
Target causes higher beam losses.

Lattice type	(m)	Qx	Qy
Strong	33	1.754	1.227
Medium	100	1.835	1.748
Weak	200	1.796	1.881
Weaker	300	1.770	1.923

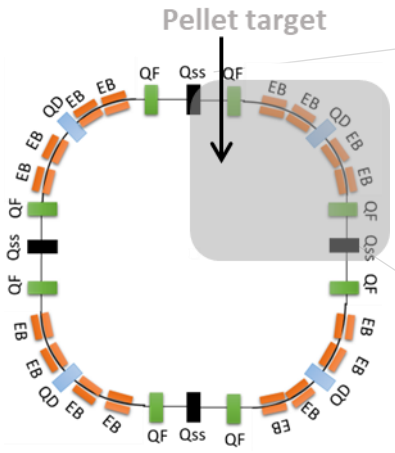


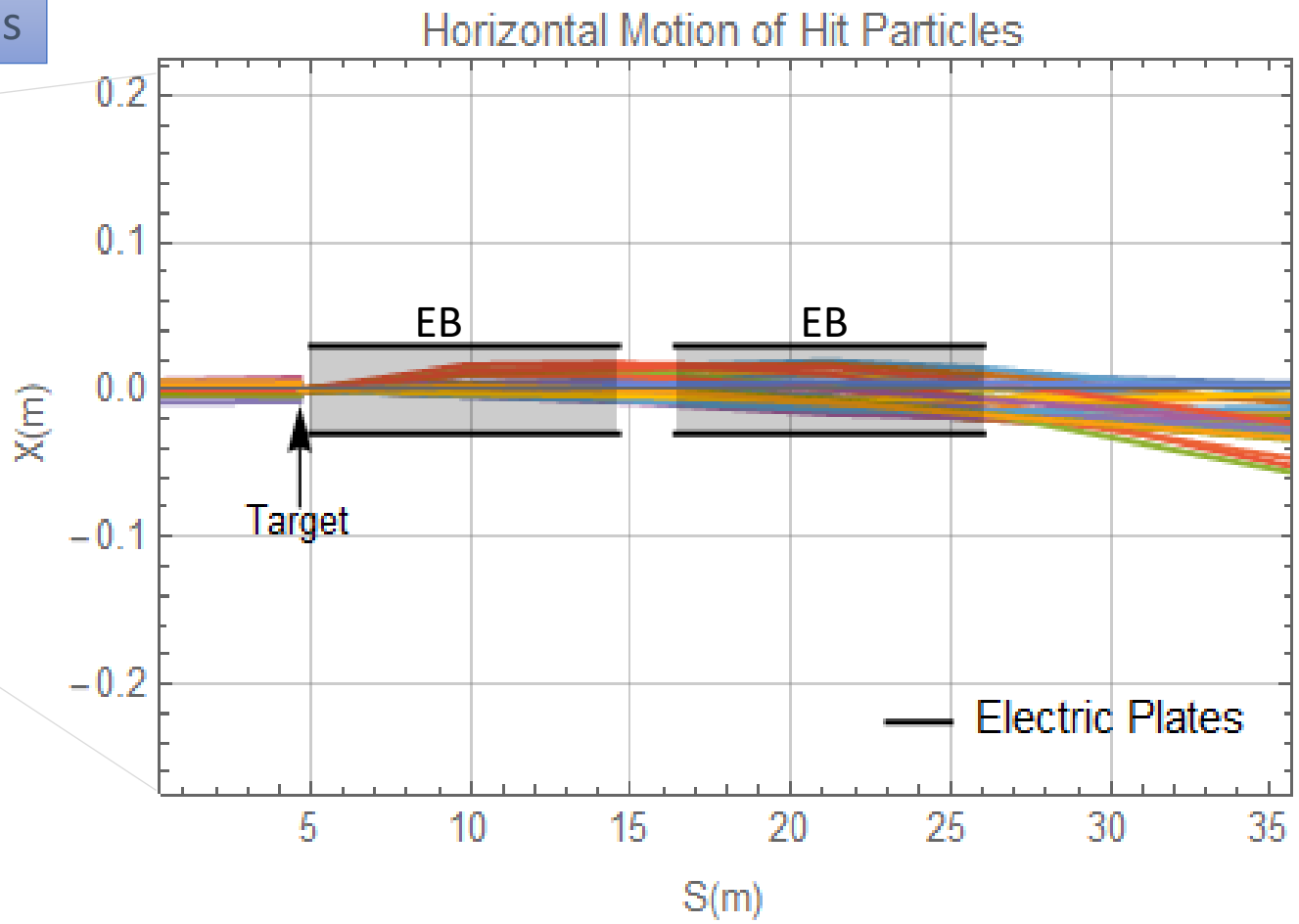
BEAM-TARGET INTERACTIONS:

- A portion of beam is scattered with pellet target.
- The scattered beam is directed towards Polarimeter.
- Position of target is crucial for meaningful beam scatterings.
- Bending arcs is preferred position to separate primary beam from scattered beam.



SIMULATIONS: Beam-target interactions

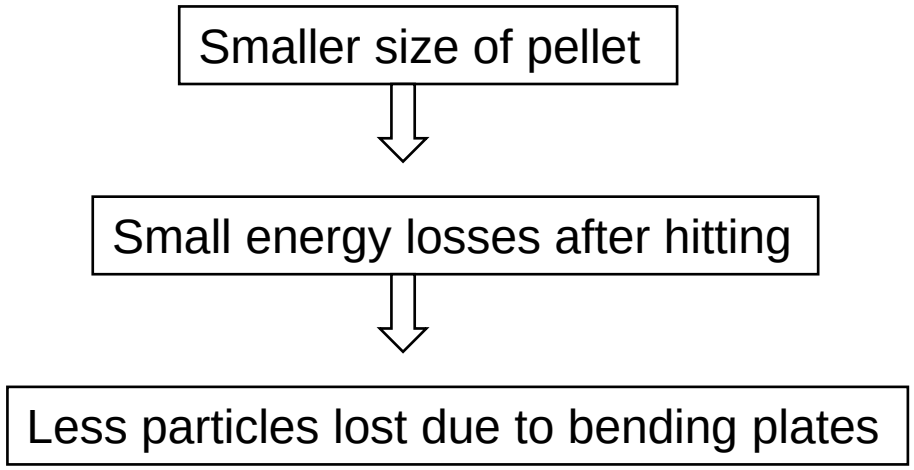




- Beam particles → 10^5
- Pellet target diameter → $40\mu m$
- Number of pellets → 2
- Number of scattered particles → 275
- Particles lost due to Electric plates → 252 (92%)
- Particles expected to reach polarimeter → 23 (8%)

COMPARISON B/W DIFFERENT SIZES OF PELLET TARGET:

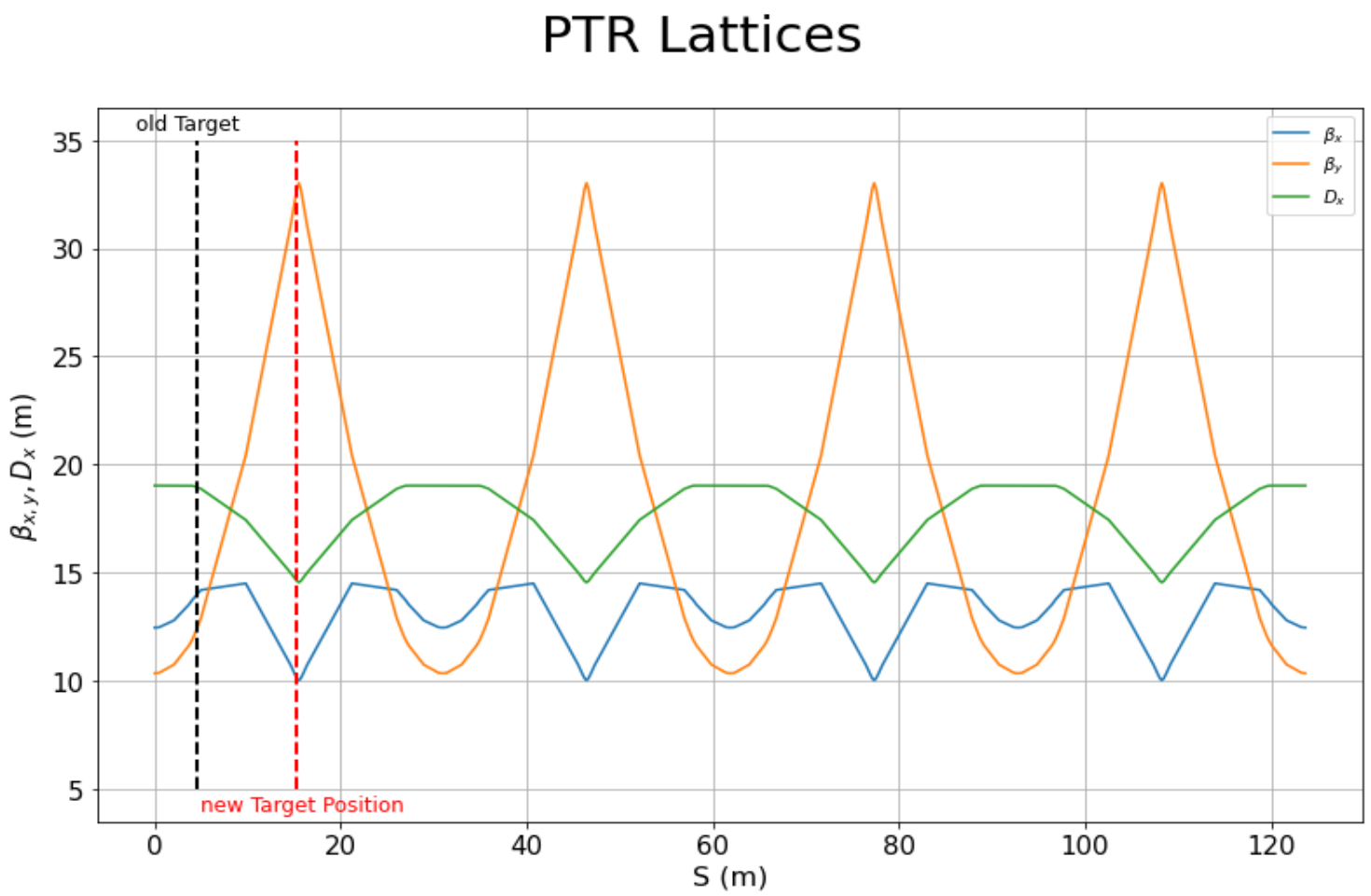
- Different sizes of pellet were used to scatter beam.

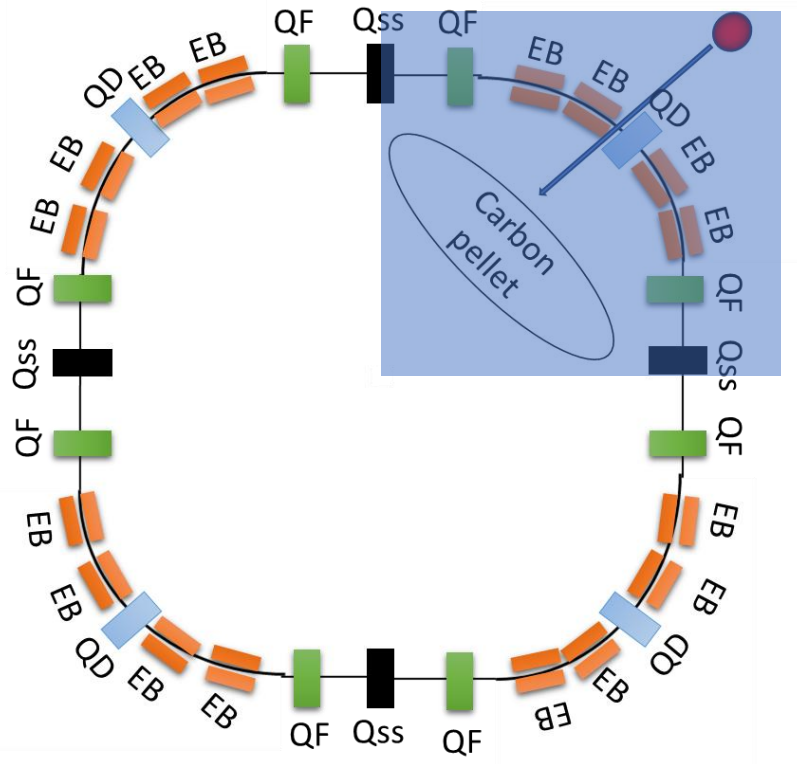


Diameter (µm)	Hits with 1T	Lost with EB	Particles reached end of arc
50	411	394	17 (4%)
40	275	252	23 (8%)
30	148	134	14 (9%)
20	50	35	15 (30%)

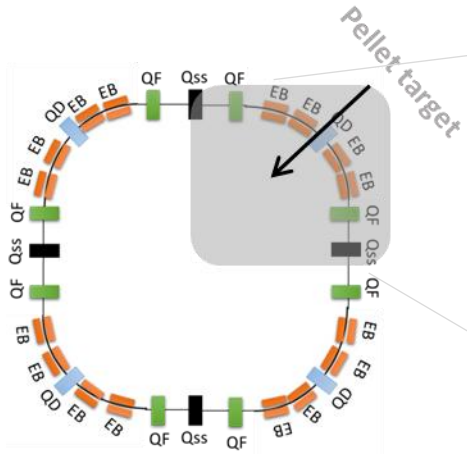
1T : Pellet Target to scatter beam, **EB** : Electric bending plates

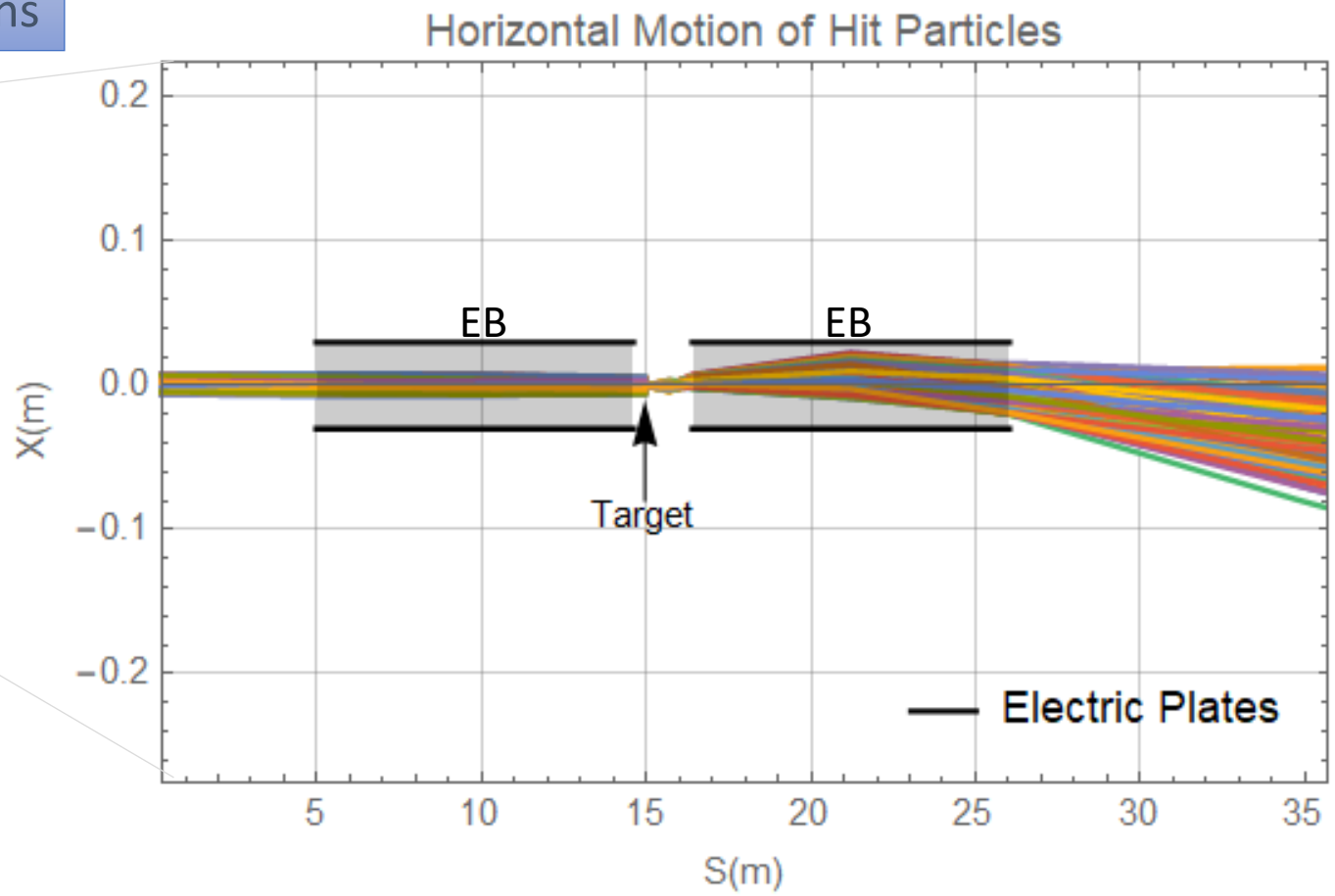
NEW POSITION OF PELLET TARGET: (In between bending arc)





SIMULATIONS: Beam-target interactions





- Beam particles → 10^5
- Pellet target diameter → $50\mu m$
- Number of pellets → 2
- Number of scattered particles → 504
- Particles lost due to Electric plates → 296 (59%)
- Particles expected to reach polarimeter → 208 (41%)

COMPARISON B/W DIFFERENT SIZES OF PELLET TARGET:

Less particles losses due to Electric bending plates as compared to previous pellet position.

Diameter (µm)	Hits with 1T	Lost with EB	Particles reached end of arc
50	504	296 (58%)	208(42%)
40	326	175 (54%)	151(46%)
30	172	65 (38%)	107(62%)
20	121	31 (25%)	90(75%)

1T : Pellet Target to scatter beam, **EB** : Electric bending plates

SUMMARY :

- Charged particles EDM measurement with a storage ring is possible and so far all simulations results show very promising outcomes on ground.
- PTR Lattice with moderate focusing strength *i.e.* $\boldsymbol{33m \leq \beta_{y-max} \leq 100m}$ is acceptable to store beam for longer time.
- Position of pellet target at centre of the arc is better than at the start of the arc.
- Dynamic Aperture Simulations were performed to counter check the boundary limits to loss particles and found that physical aperture i.e. gap b/w electric plates (60mm) is the limit.
- Long term beam tracking with given magnet settings of high SCT (spin coherence time) is in progress with all possible beam loss effects.

THANKS FOR YOUR ATTENTION

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