Simulations of Beam-target Interaction for Prototype EDM Storage Ring

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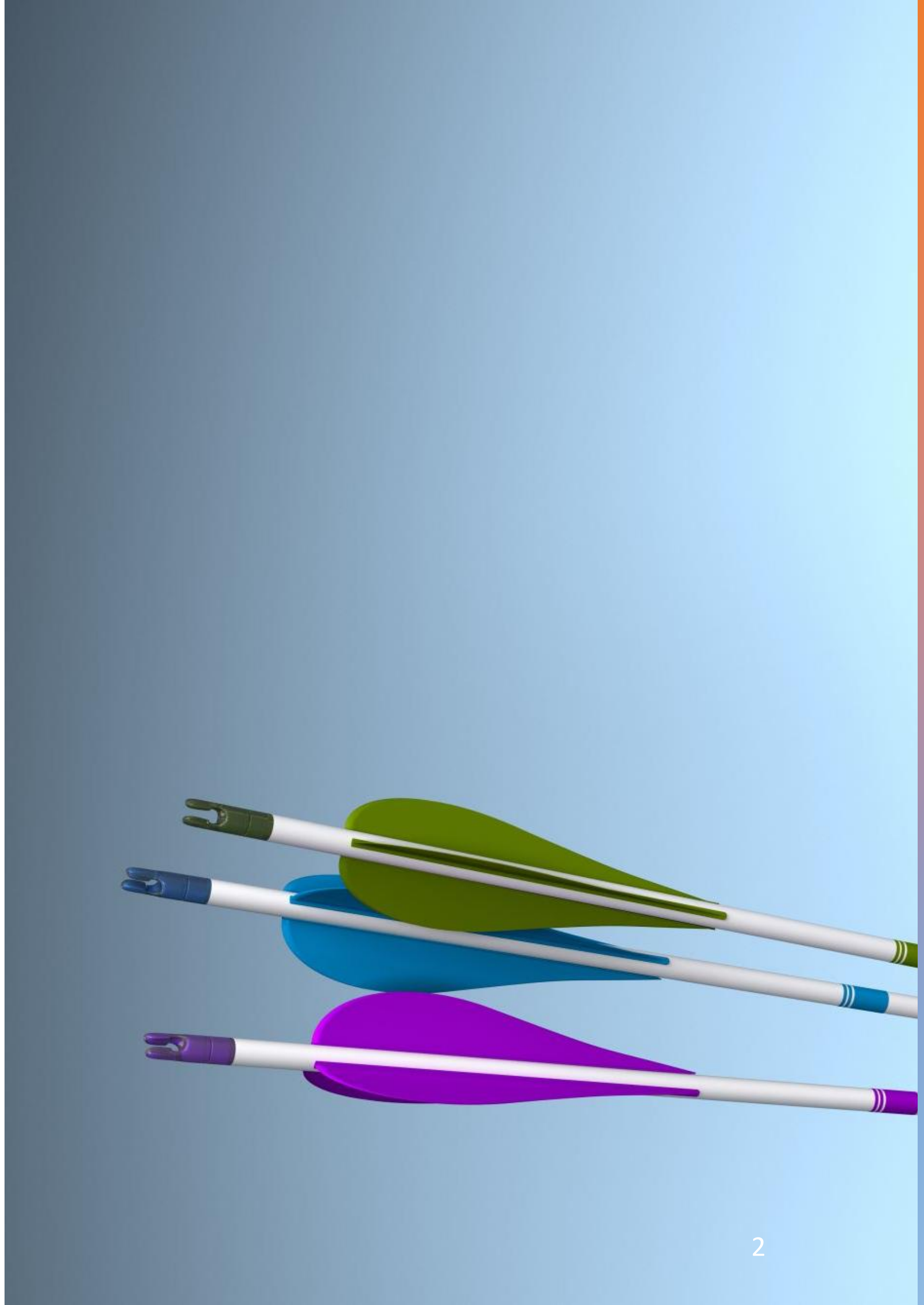
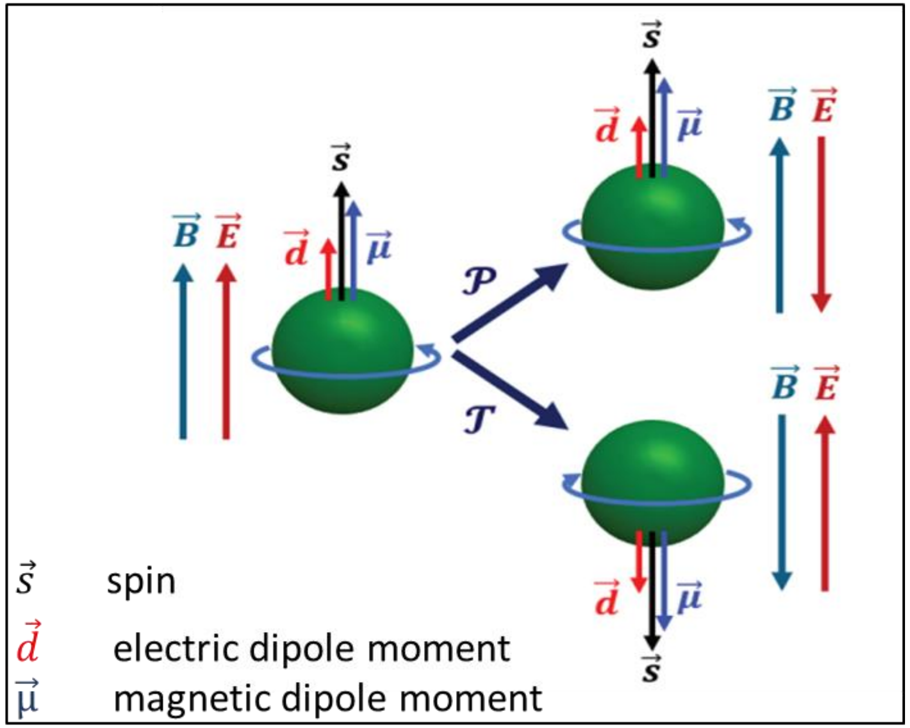
Content:

- Introduction
- Measurement of EDM
- Simulation Results
- Summary



Introduction:

- Matter-antimatter asymmetry in the Universe.
- Standard Model of Particle Physics fails to explain it.

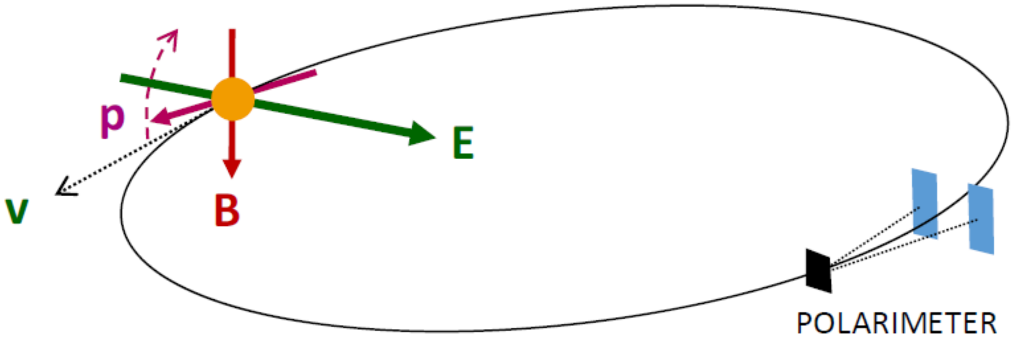


- According to **Sakharov criteria (1967):**
  - Baryon number violation
  - No thermic equilibrium
  - **Charge and Charge-Parity violation**
- One of the candidate is electric dipole moment (EDM) of charged particles.

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**

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

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

If G > 0 → pure electric ring
If G < 0 → combination of E-B

Frozen Spin $\vec{B} = 0$ ⇒ $\left(G - \frac{1}{\gamma^2 - 1}\right) \equiv 0!$ → Magic momentum

Stage 1

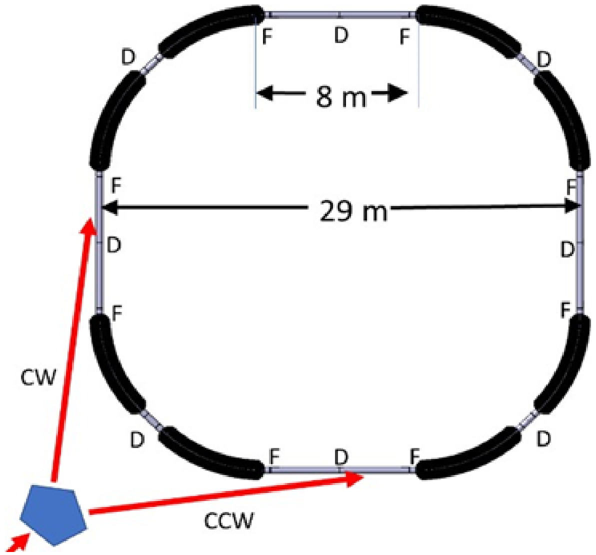
Precursor experiment at COSY FZ Jülich

- Magnetic storage ring
- Deuterons with p= 970 MeV/c

Advancement towards final storage ring will
- Decrease the systematic errors
- Increase EDM measurement`s precision

Stage 2

Prototype proton storage ring

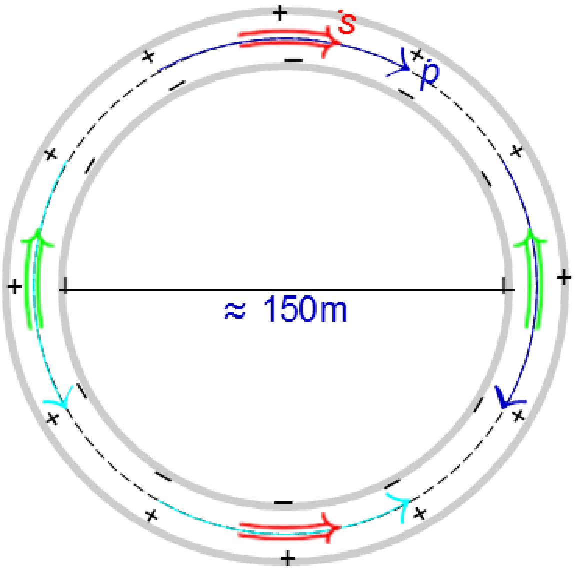


- Electric magnetic storage ring
- Simultaneous CW and CCW beams
- Operates at 30 MeV and 45 MeV

A proposal **PRESTO** has been submitted for grant approval.

Stage 3

Final storage ring



- Pure Electrostatic storage ring
- Proton Magic momentum (701MeV/c)

Pathfinder facility for a new class of **PRE**cision-physics **STO**rage rings

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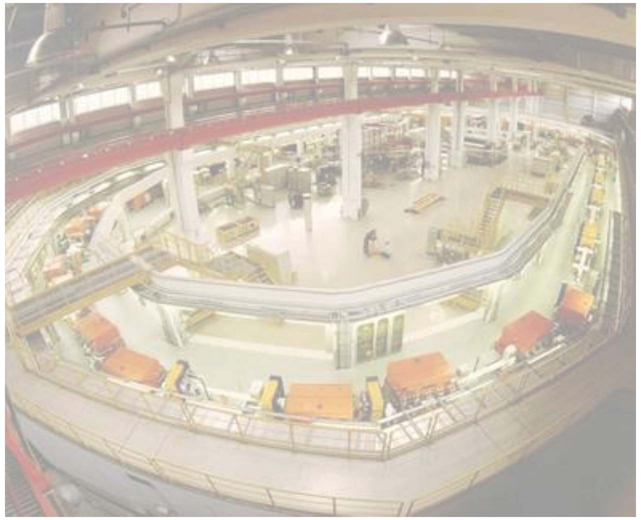
Precursor experiment at COSY at FZ Jülich



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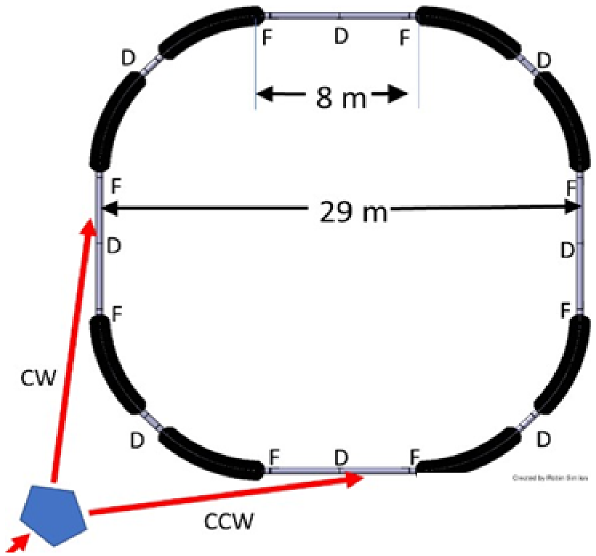

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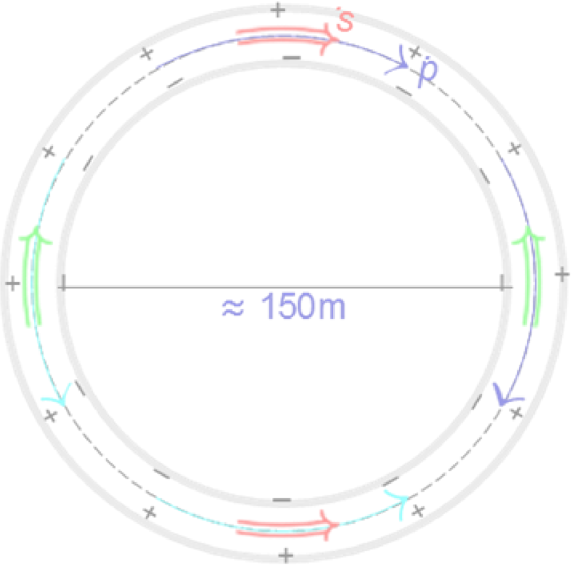

- Pure Electrostatic storage ring
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Prototype EDM Storage Ring

Goals:

- Frozen spin capability
- Storage of high intensity CW and CCW beams simultaneously $(i.e\ \ \tau > 1000\, sec)$
- 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

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Beam Losses:

- Beam losses were estimated by taking major effects only.
- Two scenarios were considered
  1. with residual gas only
  2. with carbon target
- Target causes higher beam losses.

- **with Target** - with only Residual Gas

Lattice Type β_{y-max} [m]	HI(s^{-1}) 10^{-6}	SCS(s^{-1}) 10^{-4}	IBS(s^{-1}) 10^{-4}	Total loss rate(s^{-1}) 10^{-4}	Total Beam Lifetime (s)
33	2.17(0.006)	7.12 (0.53)	2.34	9.47(2.87)	1055 (3480)
100		25.4(1.91)	2.10	27.5(4.01)	363(2493)
200		87.9(6.60)	1.99	90.0(8.59)	111(1163)
300		193.3(14.5)	1.90	195.2(16.4)	51(609)

HI : Hadronic Interactions , **SCS** : Single Coulomb Scatterings , **IBS** : Touschek effect

IPAC24- Proceedings

Doi : 10.18429/JACoW-IPAC2023-TUPM078

Beam Losses:

- Beam losses were estimated by taking major effects only.
- Two scenarios were considered
  - i. with residual gas only
  - ii. with carbon target
- Target causes higher beam losses. → Therefore, further investigations of beam-target interactions are needed to study.

- **with Target** - with only Residual Gas

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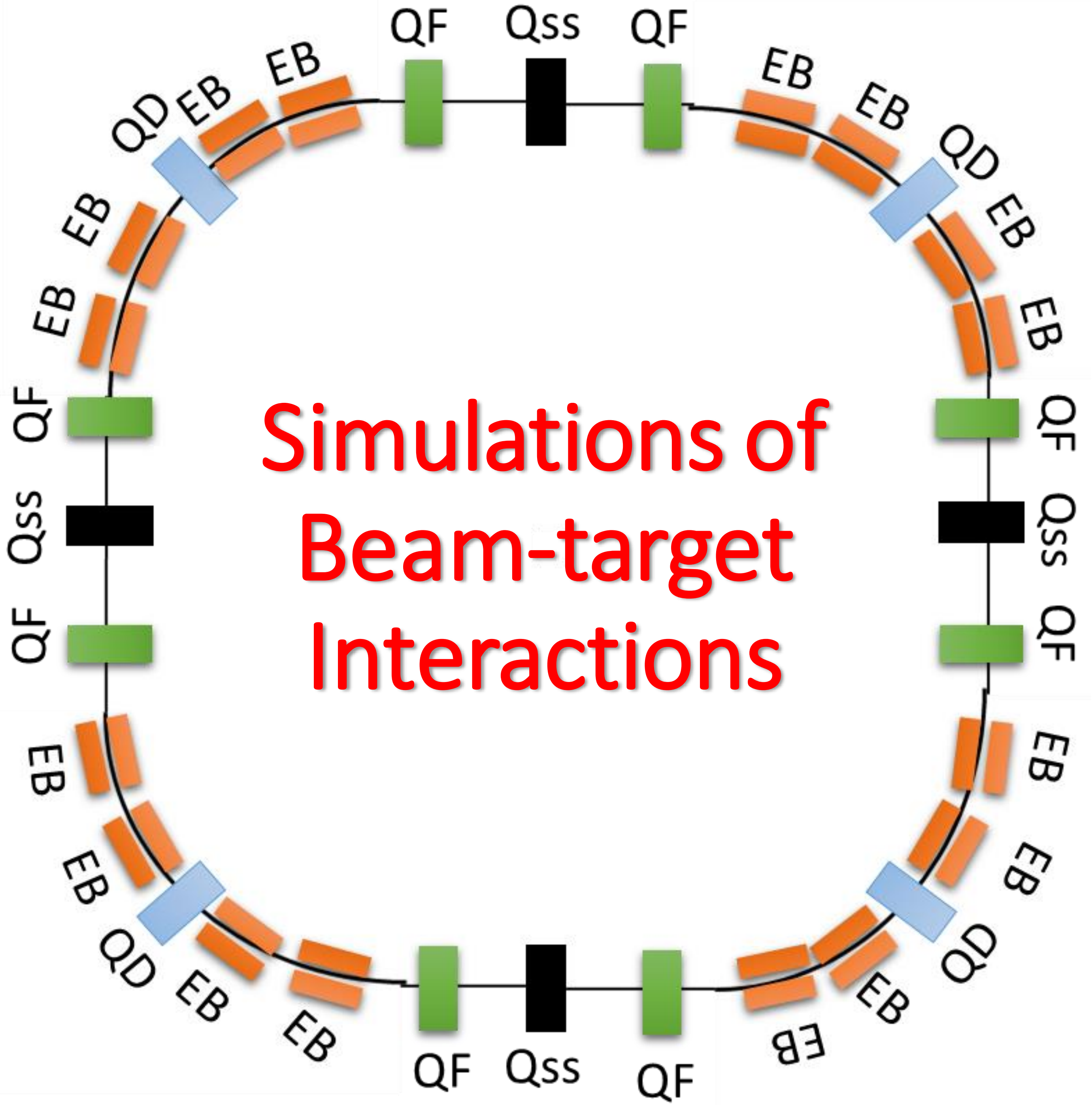
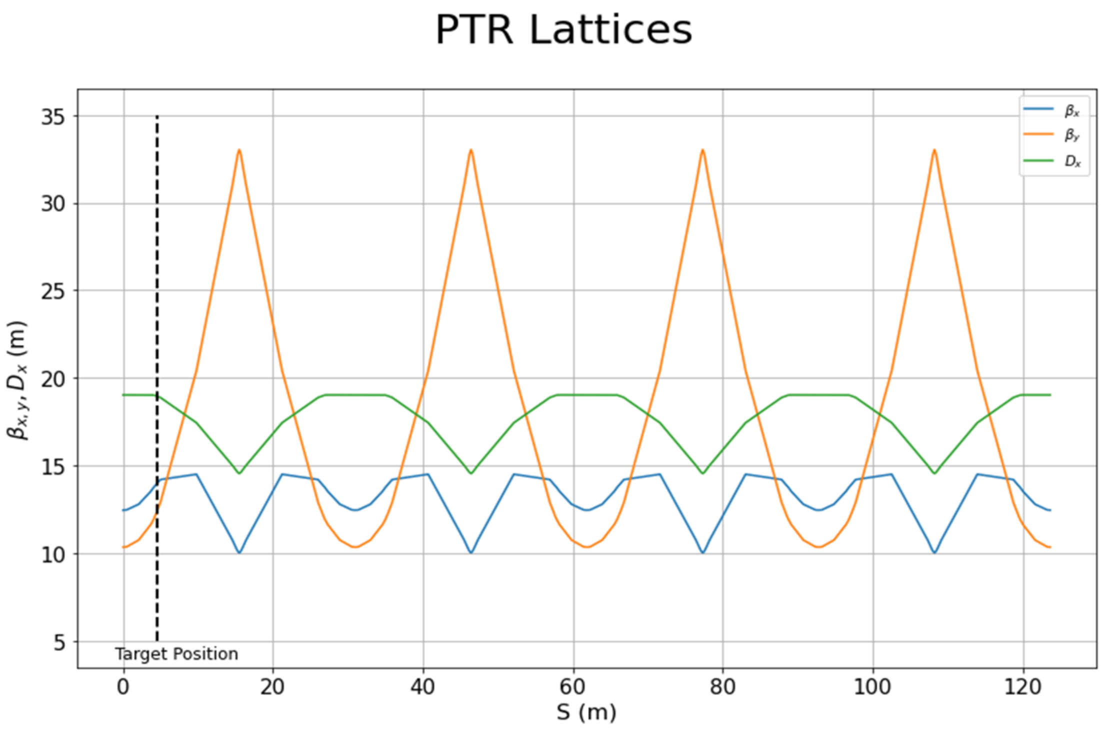
Simulations of Beam-target Interactions



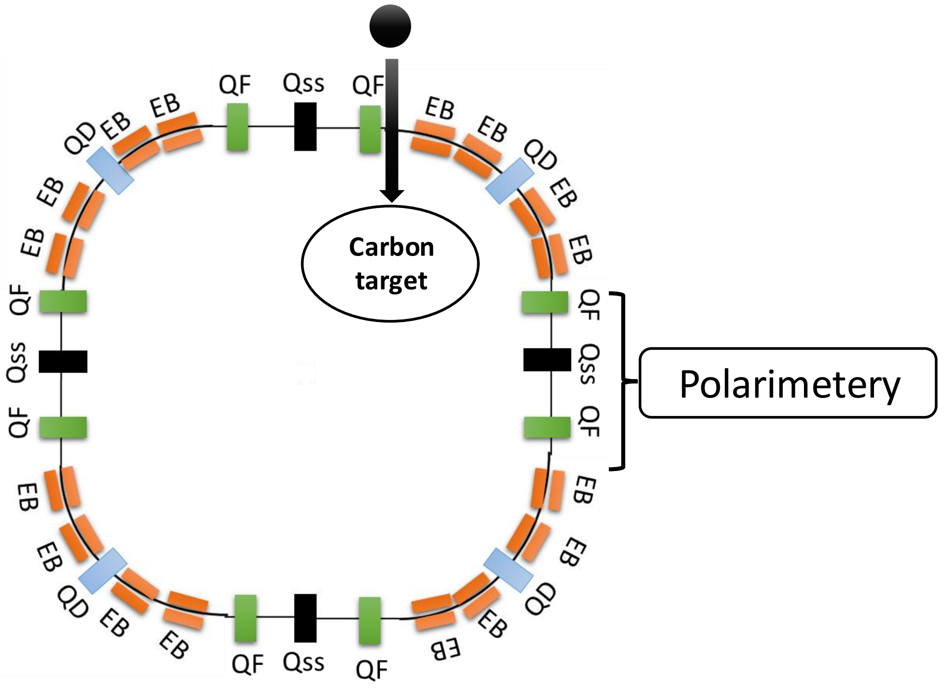
Beam-target interactions:

- A portion of beam is scattered with pellet target.
- The scattered beam is directed towards Polarimeter to measure its polarization.
- Position of target is crucial for meaningful scatterings of beam.
- Bending arcs is preferred position to separate primary beam from scattered beam.
- Therefore, target should interact with at bending arc of storage ring.



Pellet Target: Carbon diamond

- Density = 3.52 $^{g}/_{cm^3}$
- Diameter = 50µm
- Velocity of pellet = 60 m/s
- Gap b/w pellets : h = 60 mm
- $d_{loc} = 8.83 \times 10^{20}\ ^{atoms}/_{cm^2}\ with\ diameter =$



$$d_{eff} = Probability * d_{loc} \longrightarrow Probability = \frac{Vol_{pellet}}{\pi r_b^2 h}$$

Target Position

$\beta_y = 12.342$
$\alpha_y = -0.534$
$\gamma_y = 0.104$
$\beta_x = 13.951$
$\alpha_x = -0.236$
$\gamma_x = 0.076$
$D_x = 18.965$

Qx = 1.24, Qy = 1.49

- $d_{eff} = 2.73 \times 10^{13}\ ^{atoms}/_{cm^2}$
- $\theta_{rms} = 5.78 \times 10^{-7}\ rad$

- $d_{loc} = 8.83 \times 10^{20}\ ^{atoms}/_{cm^2}$
- $\theta_{rms} = 3.5 \times 10^{-3} rad$

Energy losses: with T=30 MeV with d=50µm

Maximum energy transferred to electrons of target	• Emax = 0.066 MeV
Average energy loss of beam per target transverse	• $\langle E \rangle$ = 0.232 MeV • $\left(\frac{\Delta P}{P}\right)_{\langle E \rangle}$ = 5.5×10^{-3} (momentum deviation)
Energy Loss straggling	• E_{str} = 38 KeV • $\left(\frac{\Delta P}{P}\right)_{E_{str}}$ = 8.9×10^{-4} (momentum deviation)

Simulation :

Generate particles according to Gaussian distribution

$\beta_x = 12.46515;$
$\alpha_x = 0.00321;$
$\gamma_x = 0.08022$
$D_x = 19.03090$
$D_{xp} = 1.1049 * 10^{-7}$

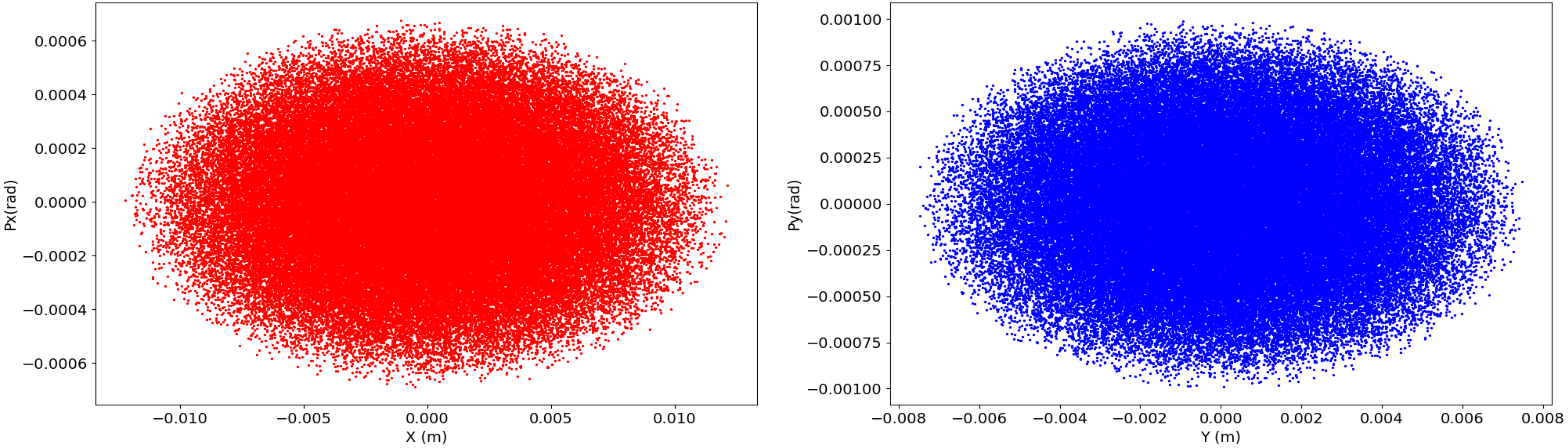
$$\frac{dp}{p} = 1 * 10^{-4}$$

$\epsilon_{x,y} = 1\ mm\ mrad$

$\boldsymbol{Beam} \rightarrow \mathbf{10^5}$ particles

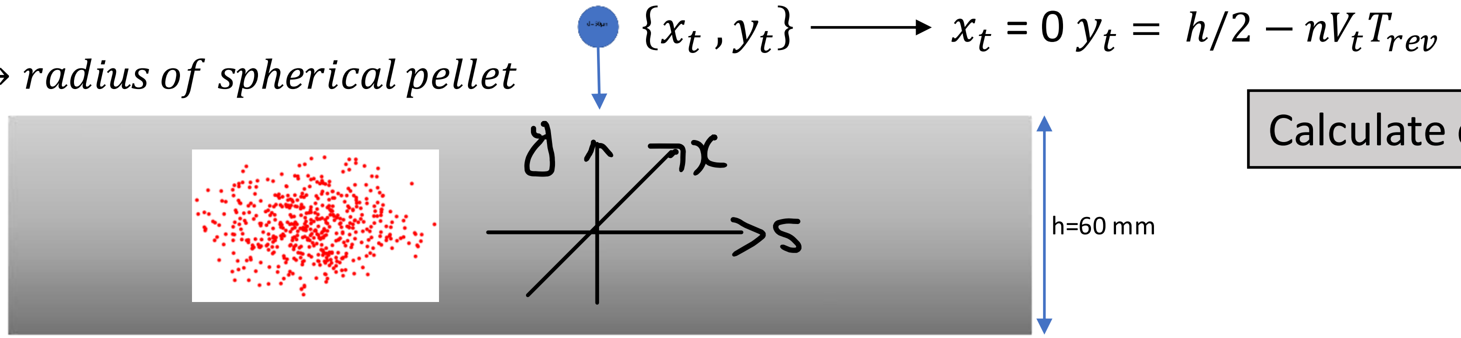
$\beta_y = 10.35478$
$\alpha_y = 0.00386$
$\gamma_y = 0.09658$

Phase Space of Particles at Start of Simulations

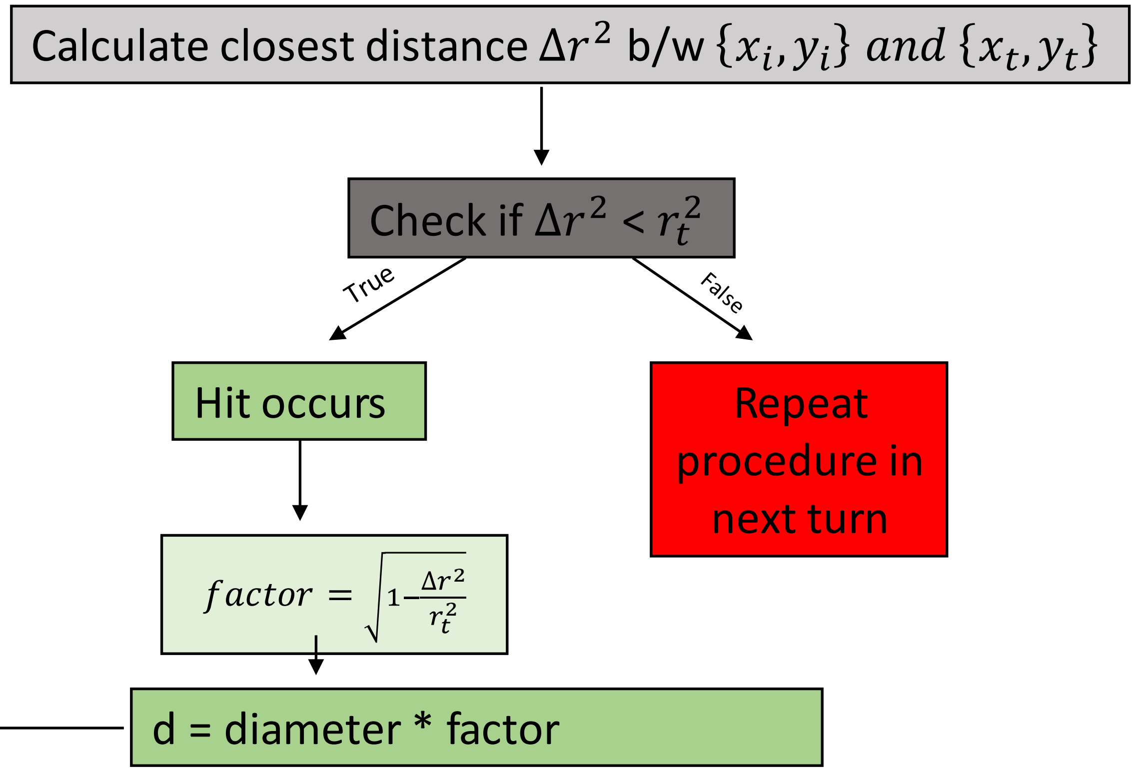


Simulation : Track particles over many turns

$r_t \rightarrow radius\ of\ spherical\ pellet$



$\{x_i, y_i\}$ where i= particle



n_x, n_y, n_z are random Gaussian numbers

$$x_p^{new} = \sqrt{\frac{\theta_{rms}^2}{2}}\, n_x + x_p^{old}$$

$$y_p^{new} = \sqrt{\frac{\theta_{rms}^2}{2}}\, n_y + y_p^{old}$$

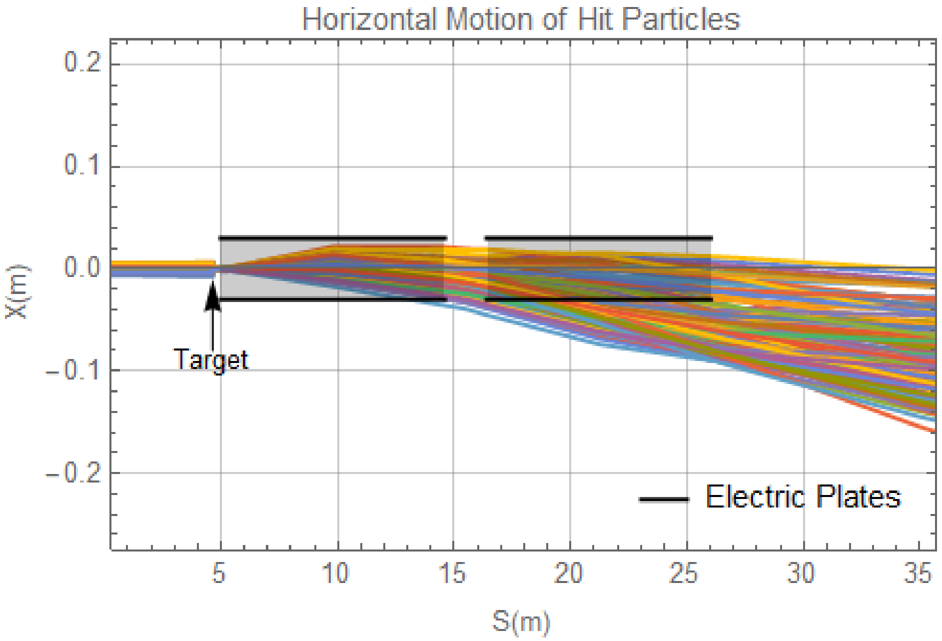
$$p_z^{new} = n_z\left(\frac{\Delta P}{P}\right)_{E_{str}} - \left(\frac{\Delta P}{P}\right)_{\langle E\rangle} + p_z^{old}$$

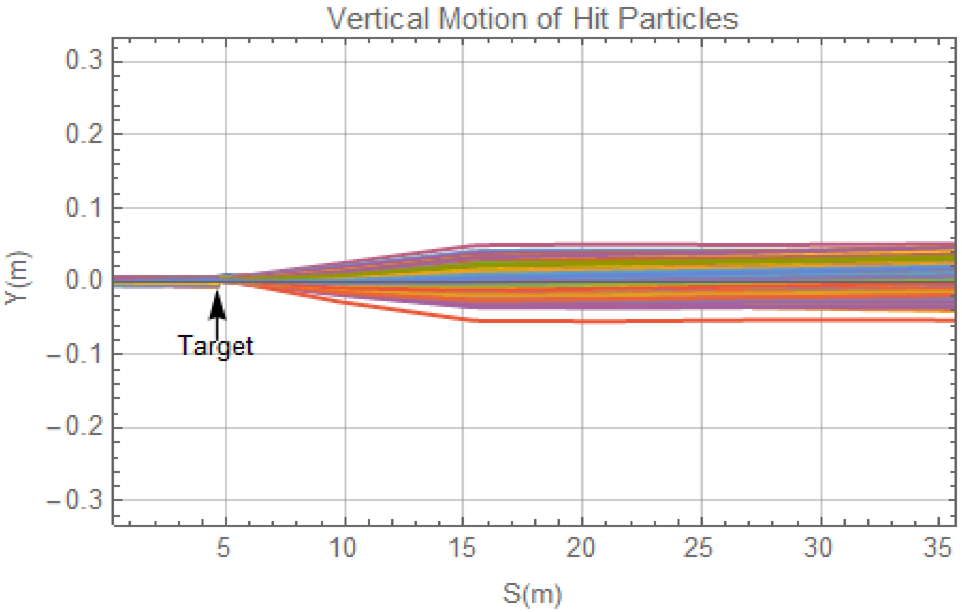
Effective density

$< E >, E_{str}$ and θ_{rms} all depend on effective density of target. Therefore, radially effective density is changing and E_{bb}, E_{str} and θ_{rms} also change. That's why every particle phase space changes accordingly

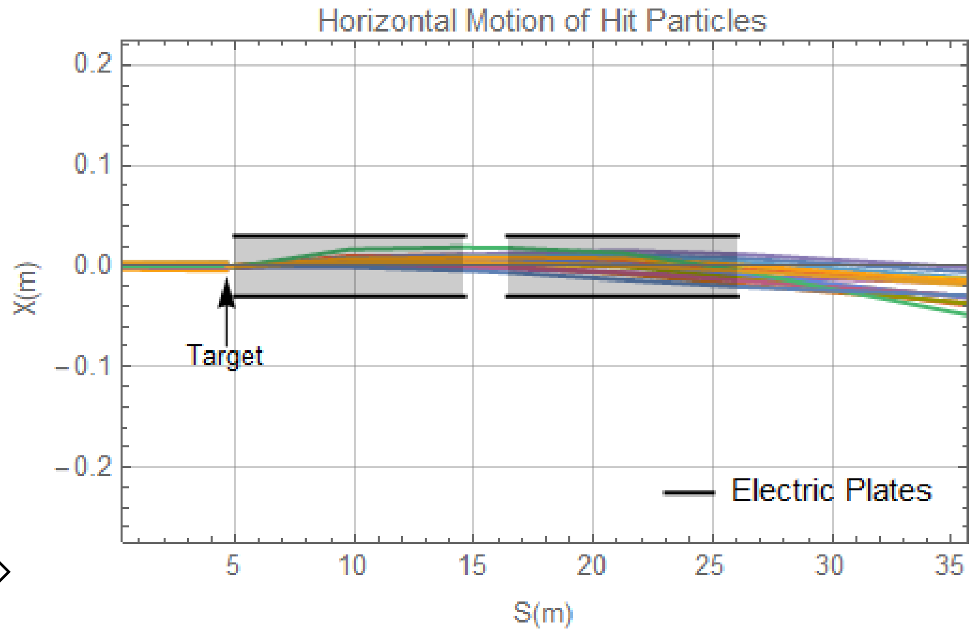
Simulations:

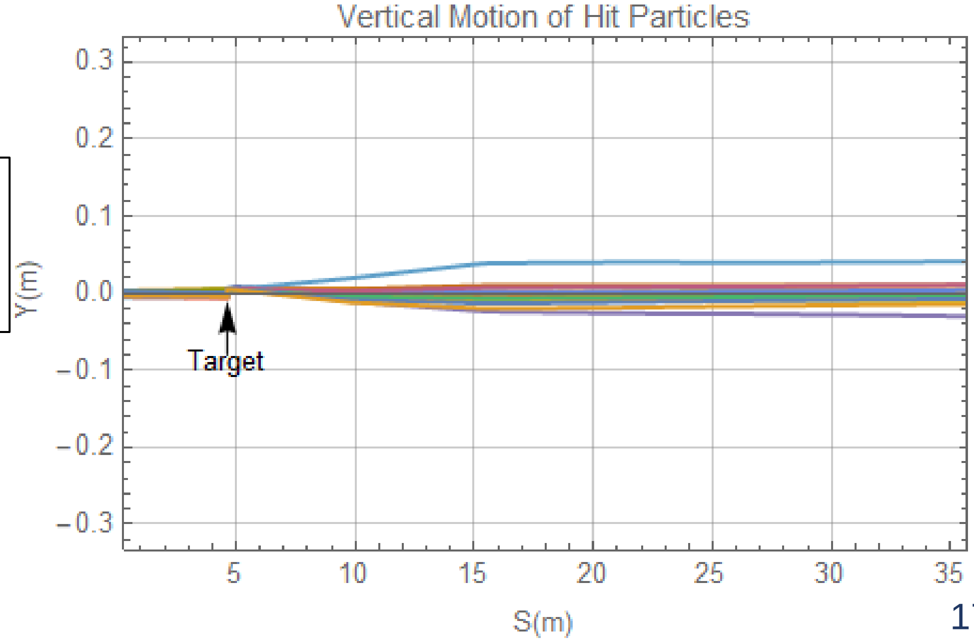
Diameter → 50μm, Particles → 10^5, Pellets → 2





Survived particles
from hitting with
bending plates

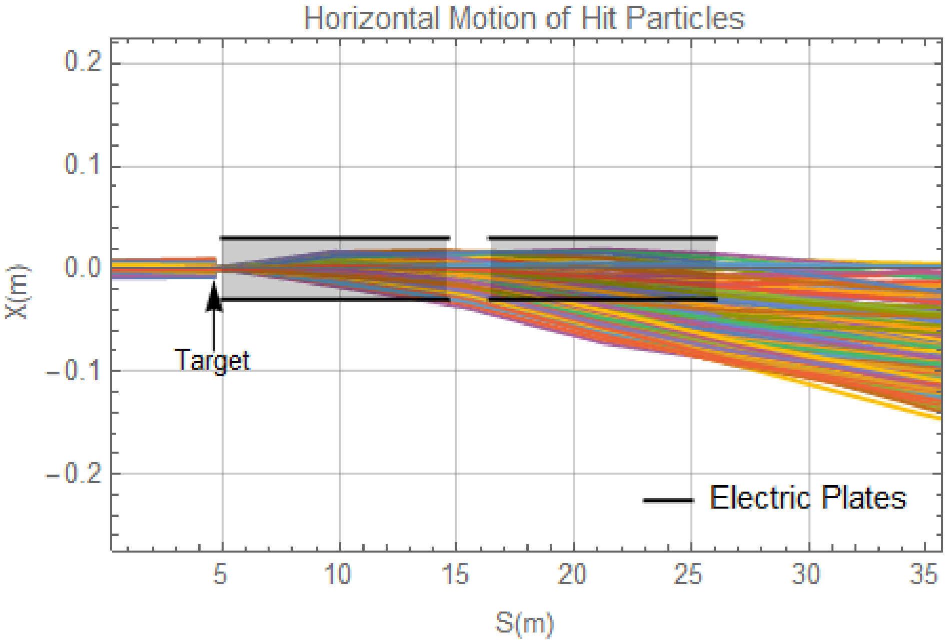


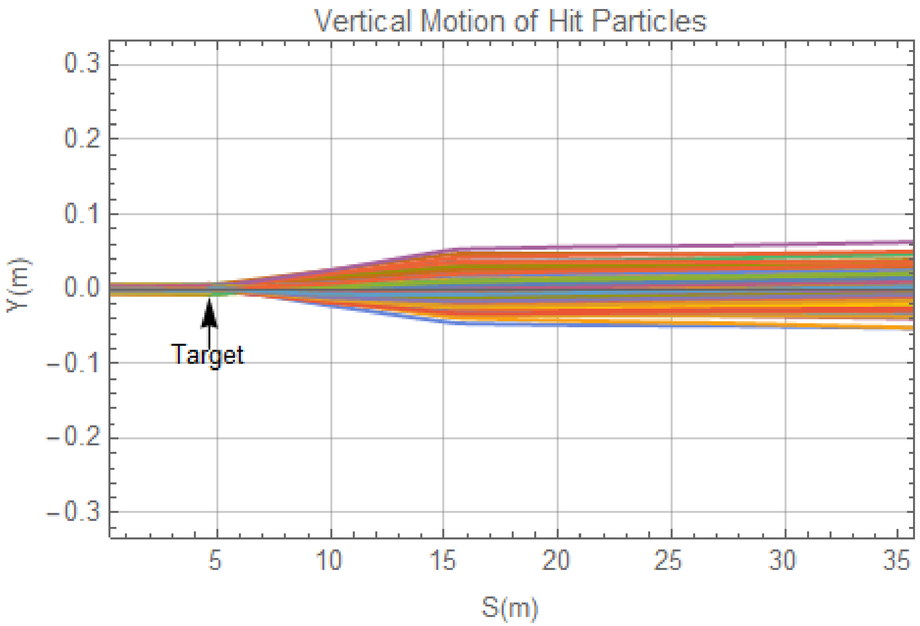


Hit with 1st Target = 411
Lost at EB = 394(96%)
Survived Particles = 17

Simulations:

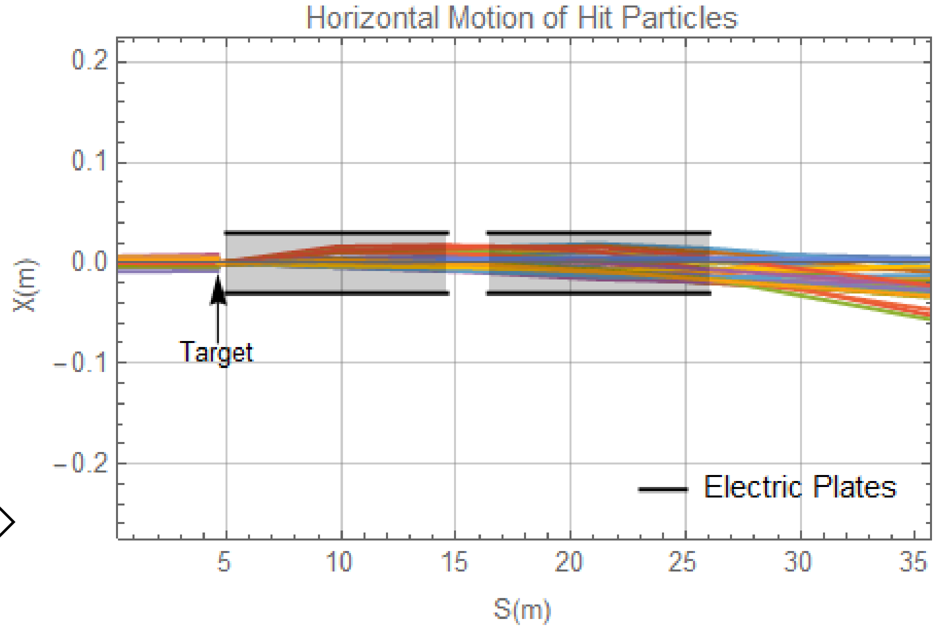
Diameter → 40μm, Particles → 10^5, Pellets → 2

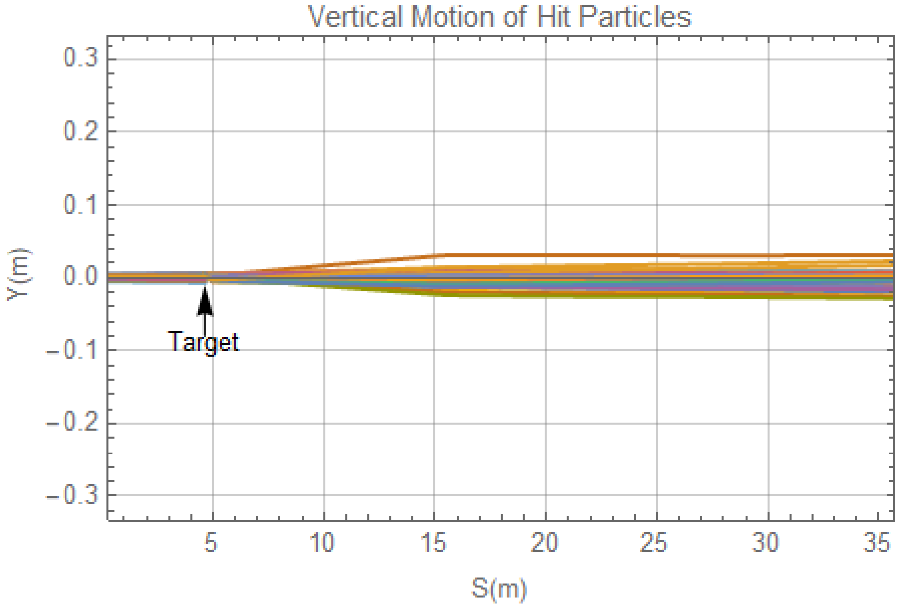




Survived particles
from hitting with
bending plates

Hit with 1st Target = 275
Lost at EB = 252 (92%)
Survived Particles = 23

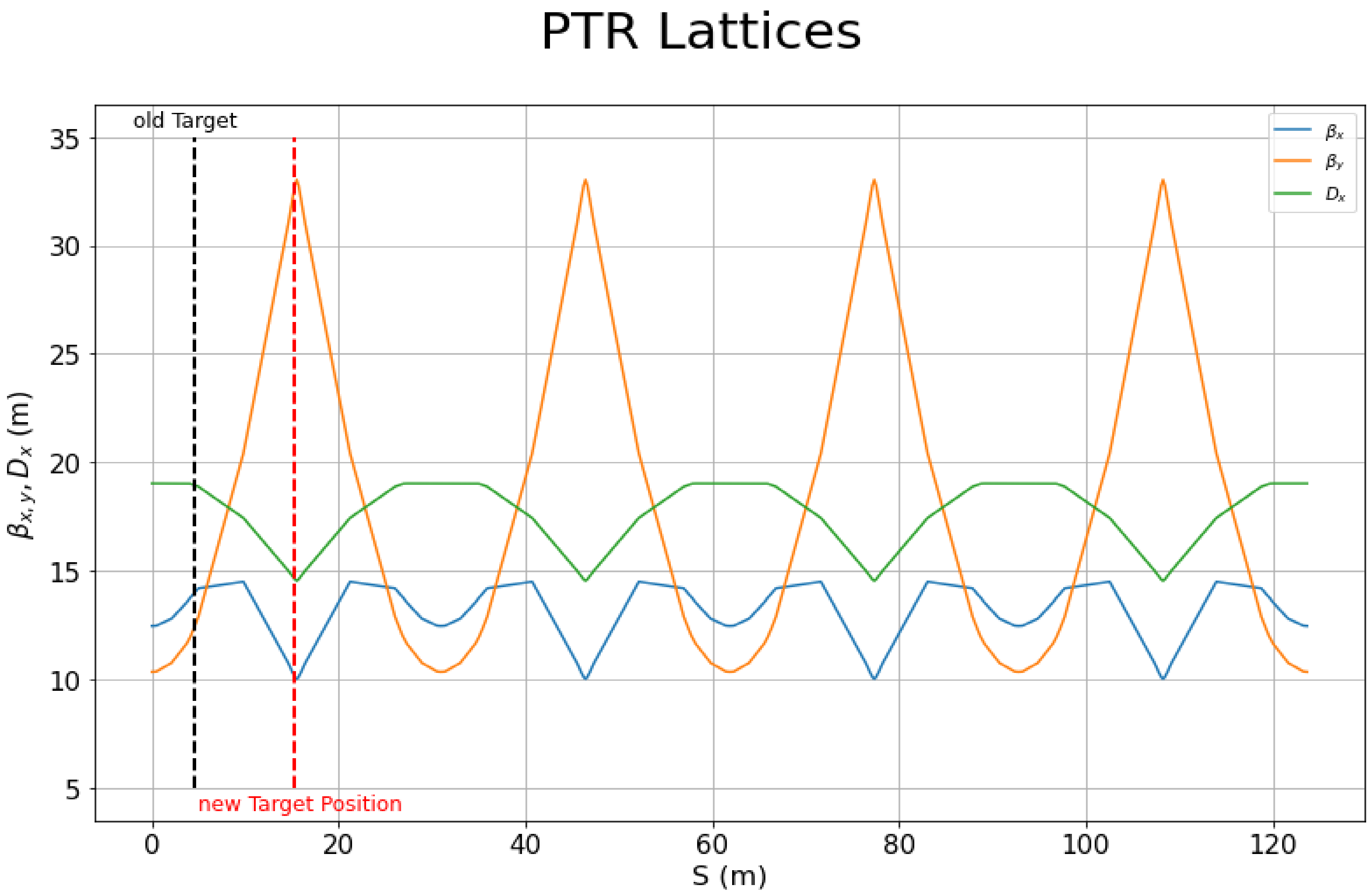


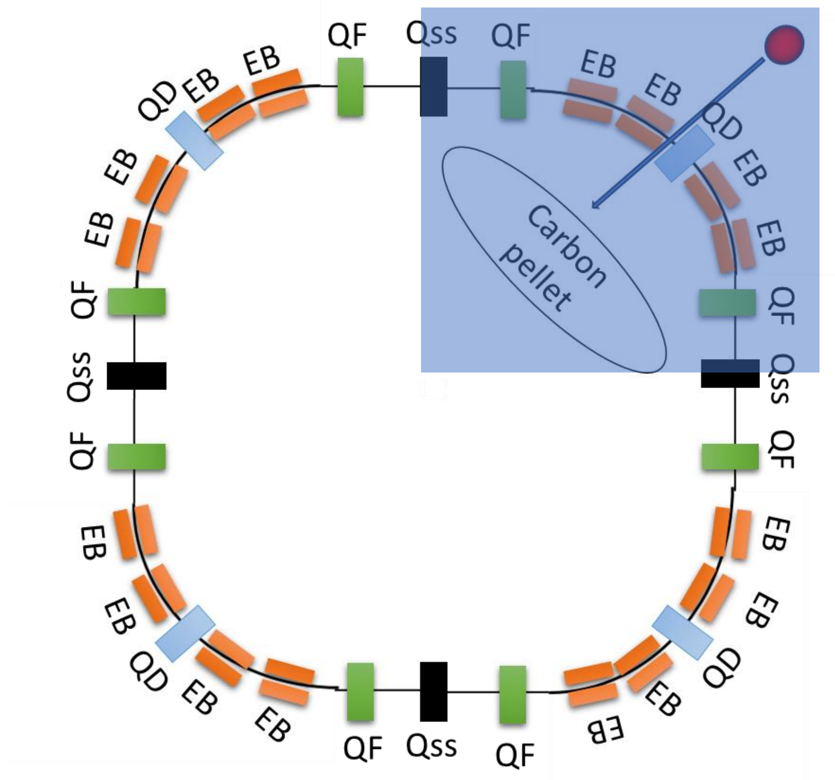


Comparison b/w different sizes of Pellet target:

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

New Position of Pellet Target:

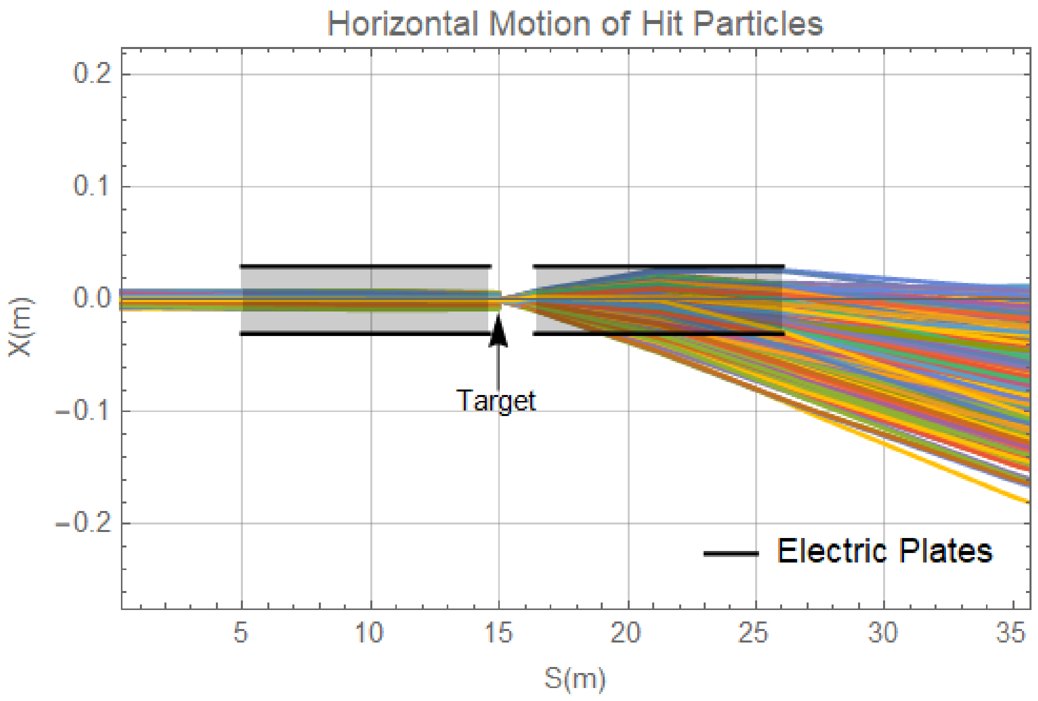


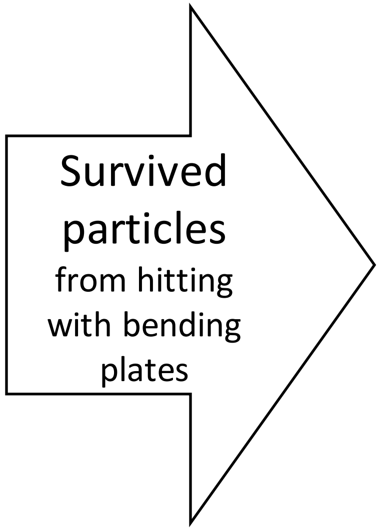


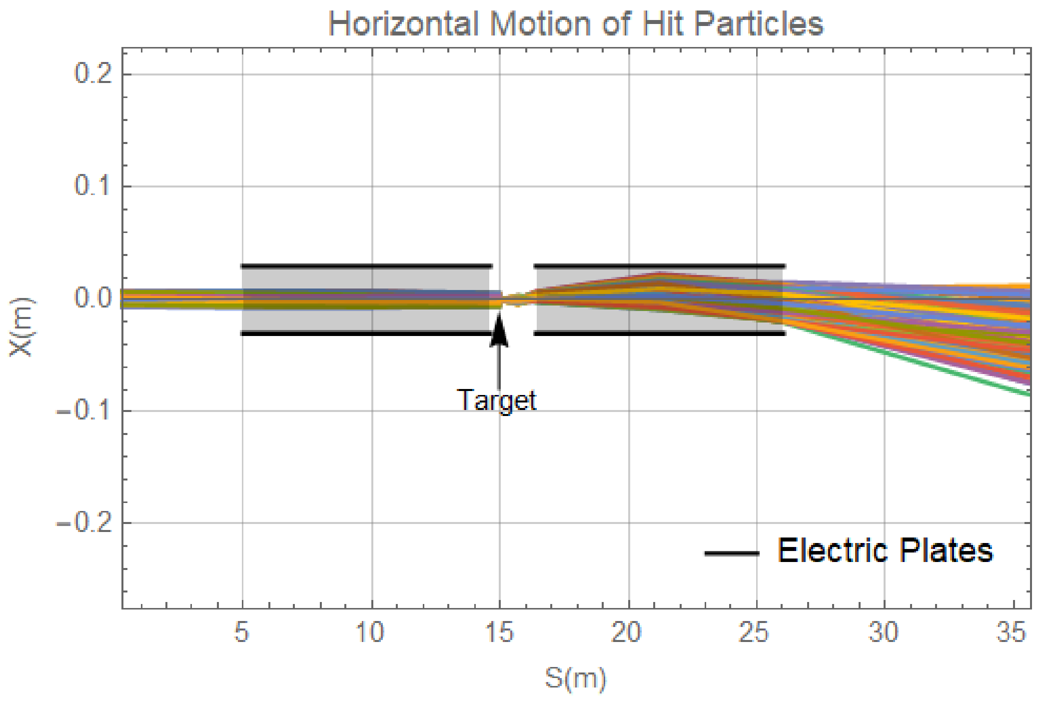
Simulations:

Diameter → 50μm, Particles → 10^5, Pellets → 2

Hit with 1st Target --> 504
Lost due with Electric bend --> 296(59%)
Survived Particles--> 208



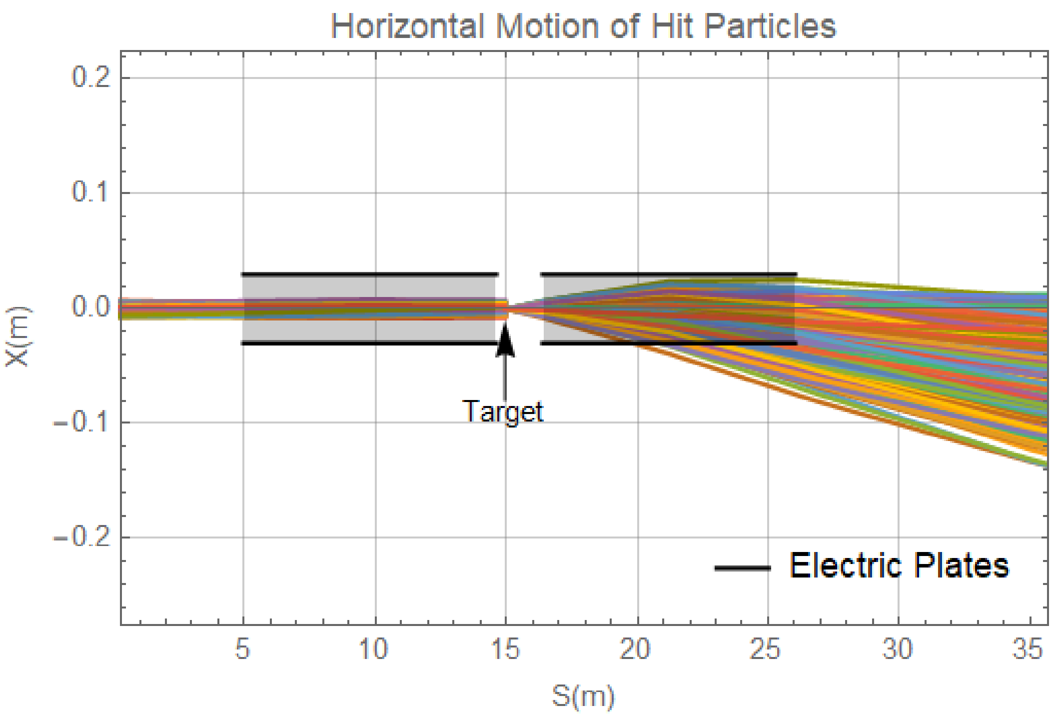




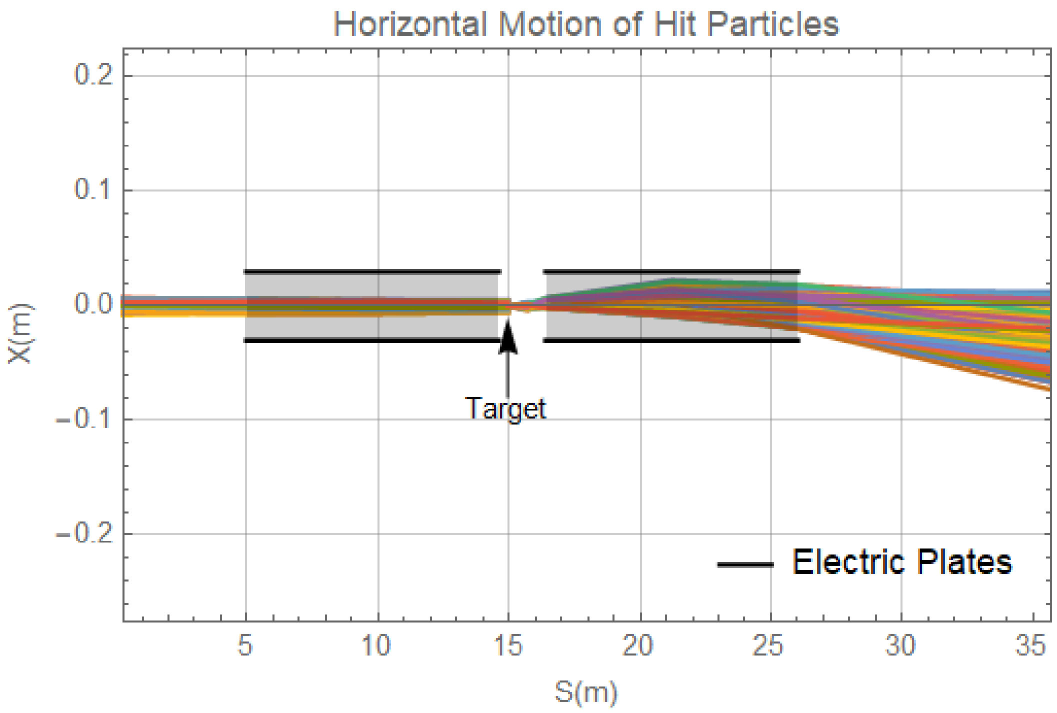
Simulations:

Diameter → 40μm, Particles → 10^5, Pellets → 2

Hit with 1st Target --> 326
Lost due with Electric bend --> 175(53%)
Survived Particles--> 151



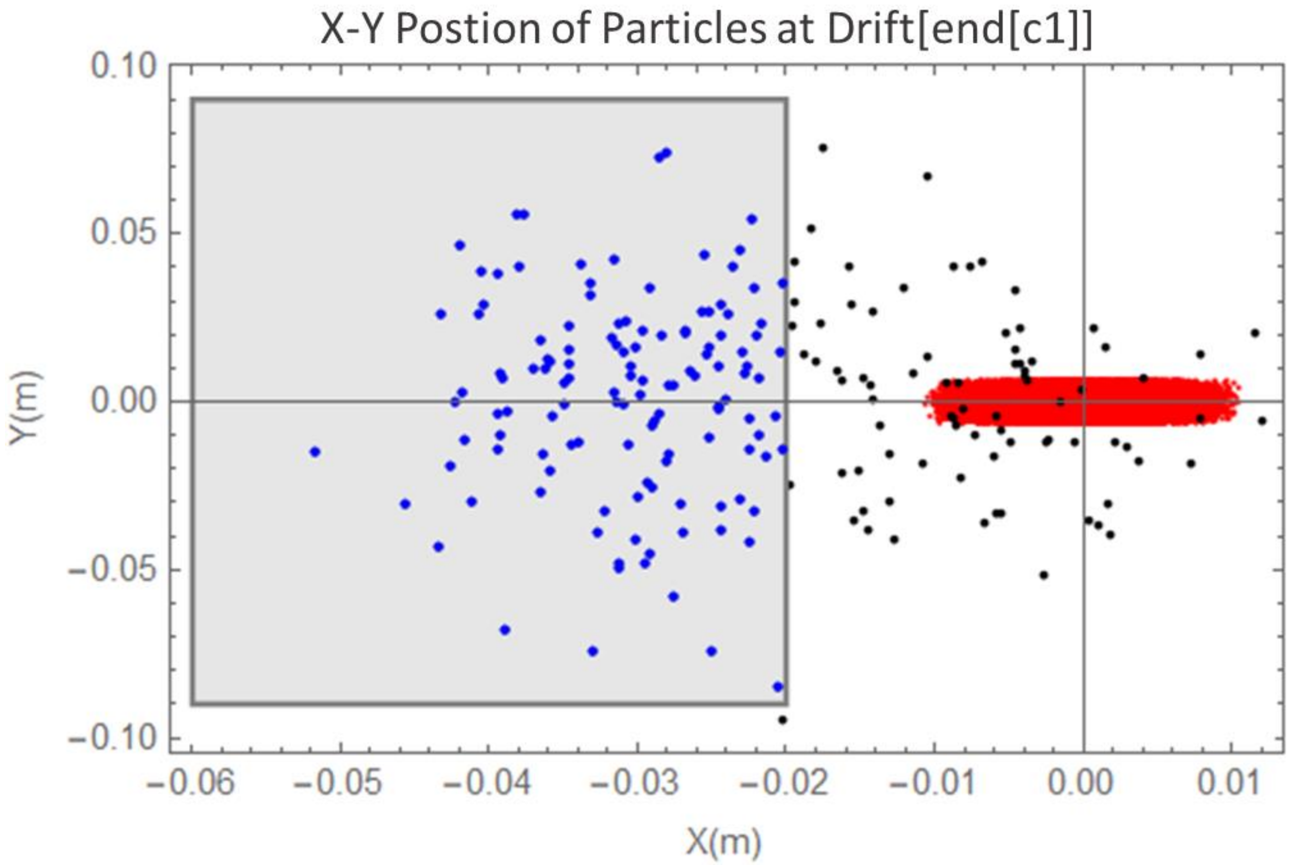
Survived particles from hitting with bending plates

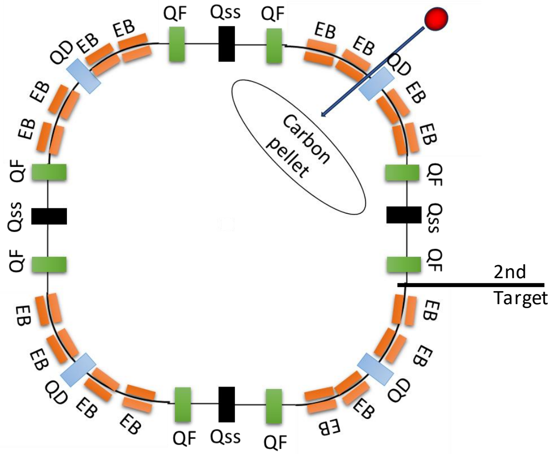


Introducing Second Target:

Diameter → 50μm, Particles → 10^5, Pellets → 2

Hit with 1st Target --> 504
Lost due with Electric bend --> 296(59 %)
Survived Particles--> 208
Hits with 2nd Target --> 127 (25 %)





0.2	QSS[c1]
3.88	Drift[QSS[c1]]
4.28	QF[c1]
4.98	Drift[bend[c1]]
9.78988	Ebend[c1]
14.5998	Ebend[c1]
15.2998	Drift[bend[c1]]
15.2998	Target
15.6998	QD[c1]
16.3998	Drift[bend[c1]]
21.2096	Ebend[c1]
26.0195	Ebend[c1]
26.7195	Drift[bend[c1]]
27.1195	QF[c1]
30.7195	Drift[end[c1]]
30.9195	QSS[c1]

Comparison b/w different sizes of Pellet target:

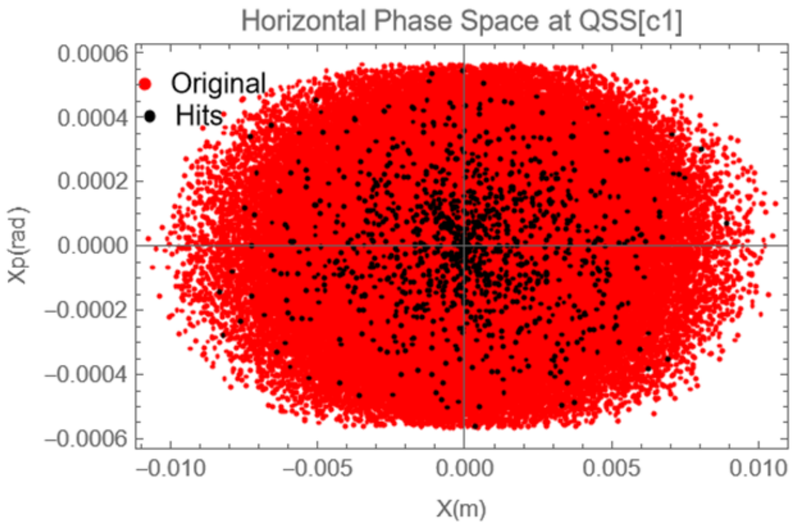
Diameter (µm)	Hits with 1T	Lost with EB	Survived	%age of Survived
50	504	296	208	41%
40	326	175	151	46%
30	172	61	111	65%
20	78	21	57	73%

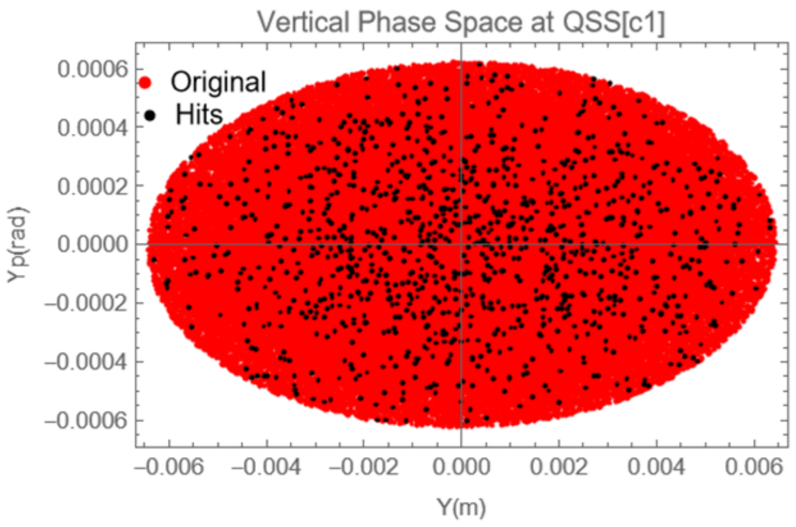
Summary and Outlook:

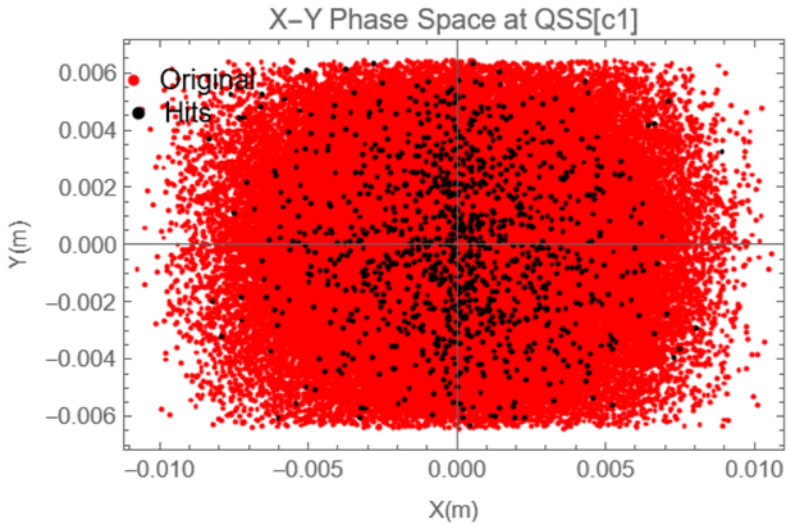
- Different positions of target were tried and position of target b/w bending arc is better than other positions.
- Beam tracking with only linear effects was performed.
- Target thickness reduces particle losses with Electric bends and more particles reaches to polarimeter.
- Beam Tracking with non-linear effects as well as other beam loss effects is under progress.
- Bmad software is being used to perform beam tracking along with
  - with Electrostatic bending model
  - customized beam-target interaction routine

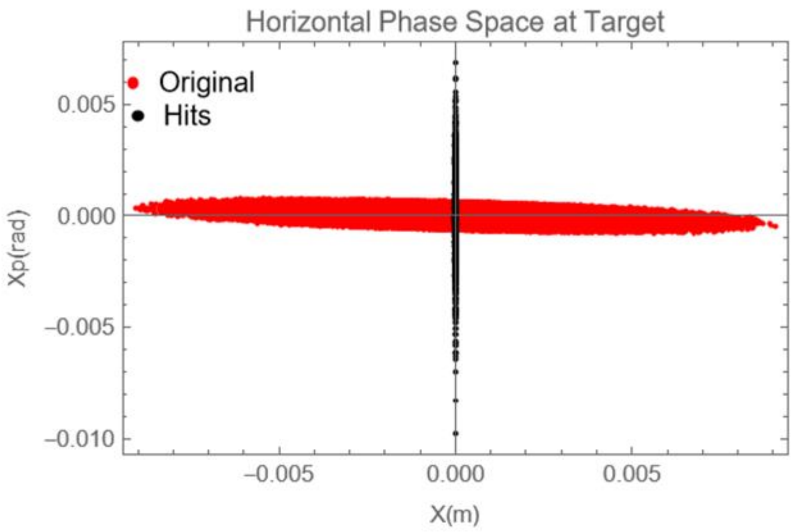
Thank you for your Attention ☺

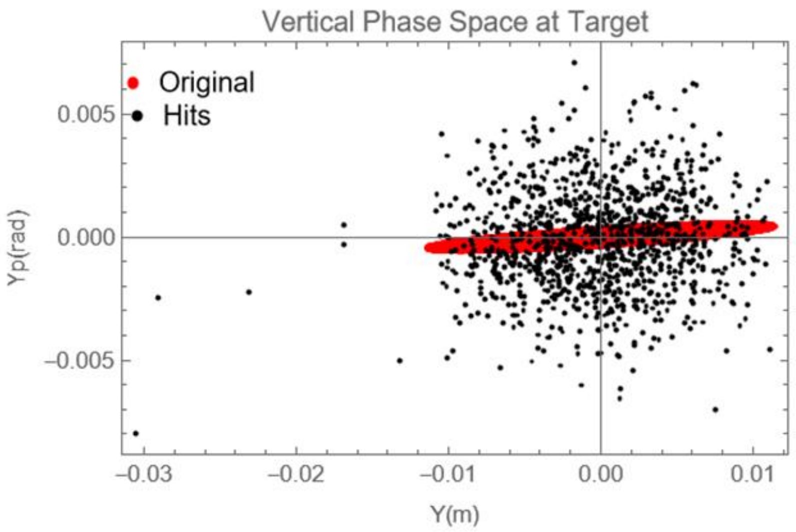
Back-up Slides

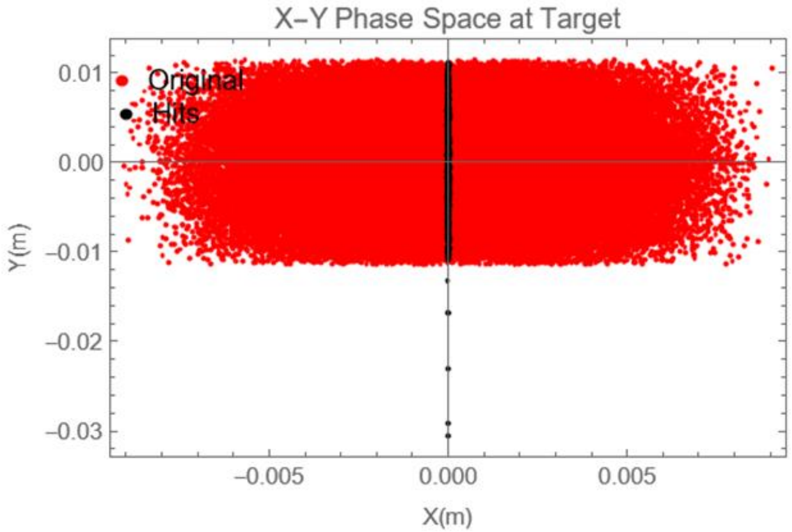












Back-up Slides