Monte Carlo Samples for the ESR Beam Losses in IR6 @ 18 GeV

Xsuite Multi-Turn Beam Loss Simulation

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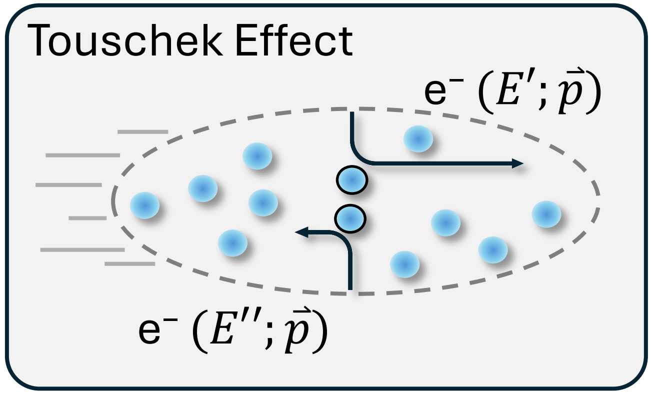
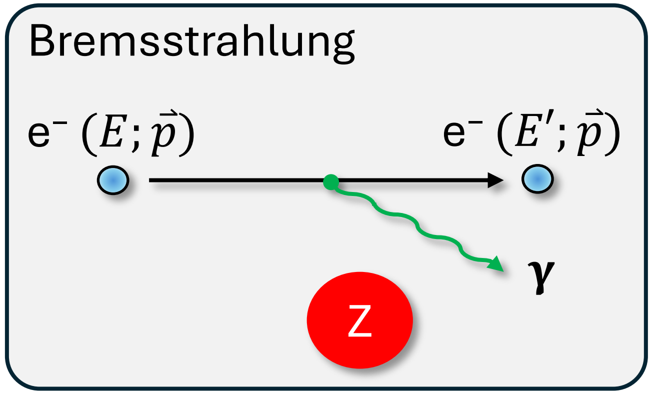
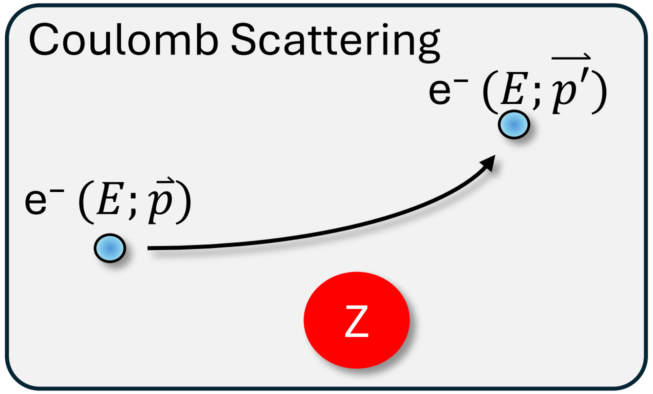
Electron Single-Beam Loss Source

Main beam loss processes in the electron machine for the single-beam operation [https://doi.org/10.1016/j.nima.2023.168550]:

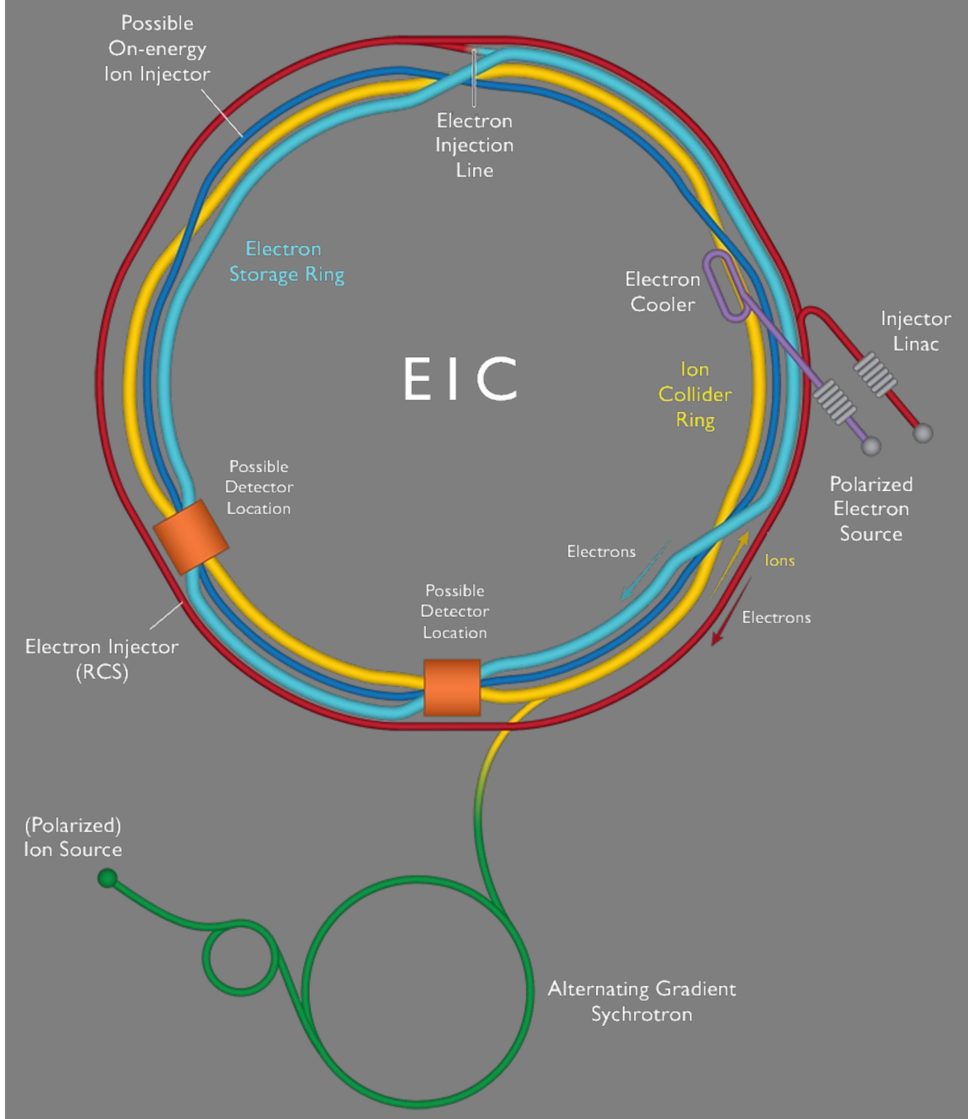
- **Touschek** – *an incoherent intra-beam scattering of the particles in the same bunch (energy change):*
  - Based on Bruck's formula
  - Flat beam ($\sigma_Y/\sigma_X << 1$)
  - Non-relativistic approximation (radial velocities are non-relativistic)
- **Coulomb** – *elastic scattering of the beam on the residual gas molecules (direction change)*
  - Rutherford's scattering formula, including cutoff Coulomb potential and screening effect for small angles.
- **Bremsstrahlung** – *inelastic beam scattering on the residual gas molecules (energy change)*
  - Bethe-Heitler following Koch-Motz formalism for complete screening in the Born approximation





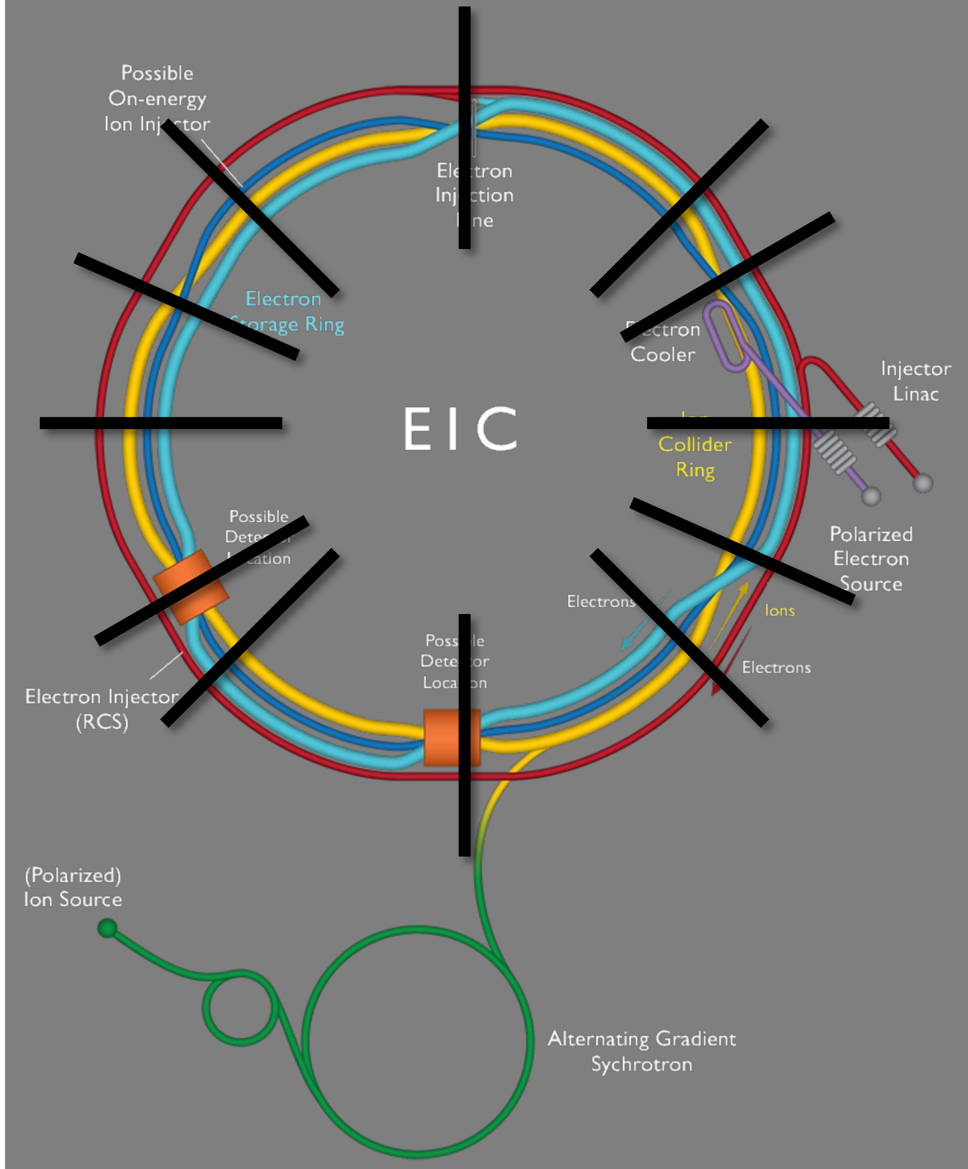


Simulation steps



Simulation steps

1. Define the scattering location around the ring by splitting the ring in a set of almost equidistant sections (~1500).



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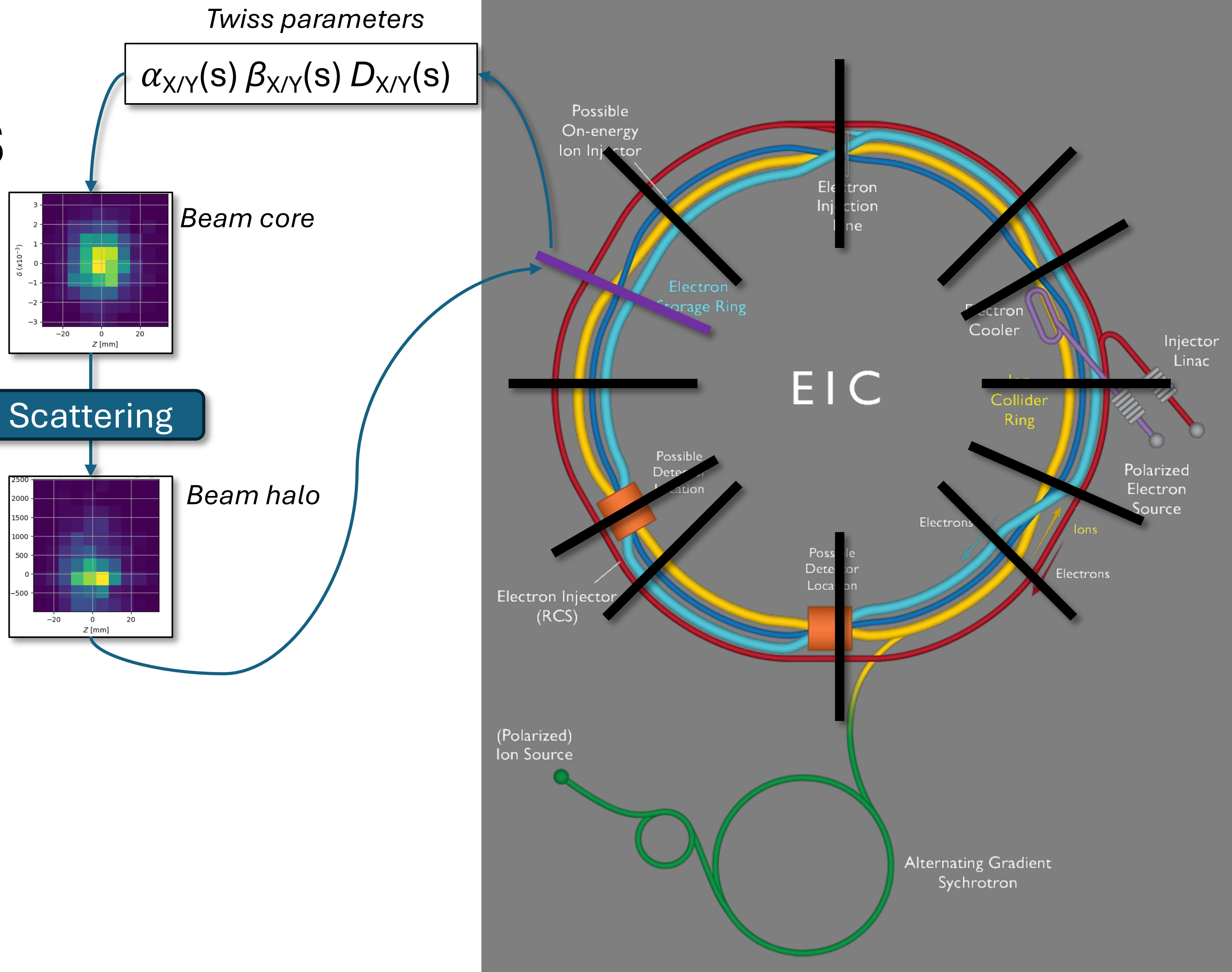
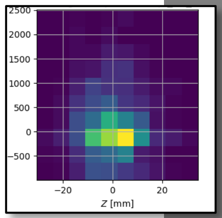
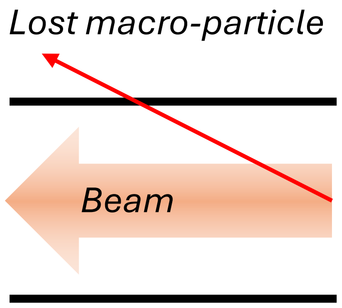
1. Define the scattering location around the ring by splitting the ring in a set of almost equidistant sections (~1500).
2. Generate 6D coordinates of macro-particles according to the scattering process.

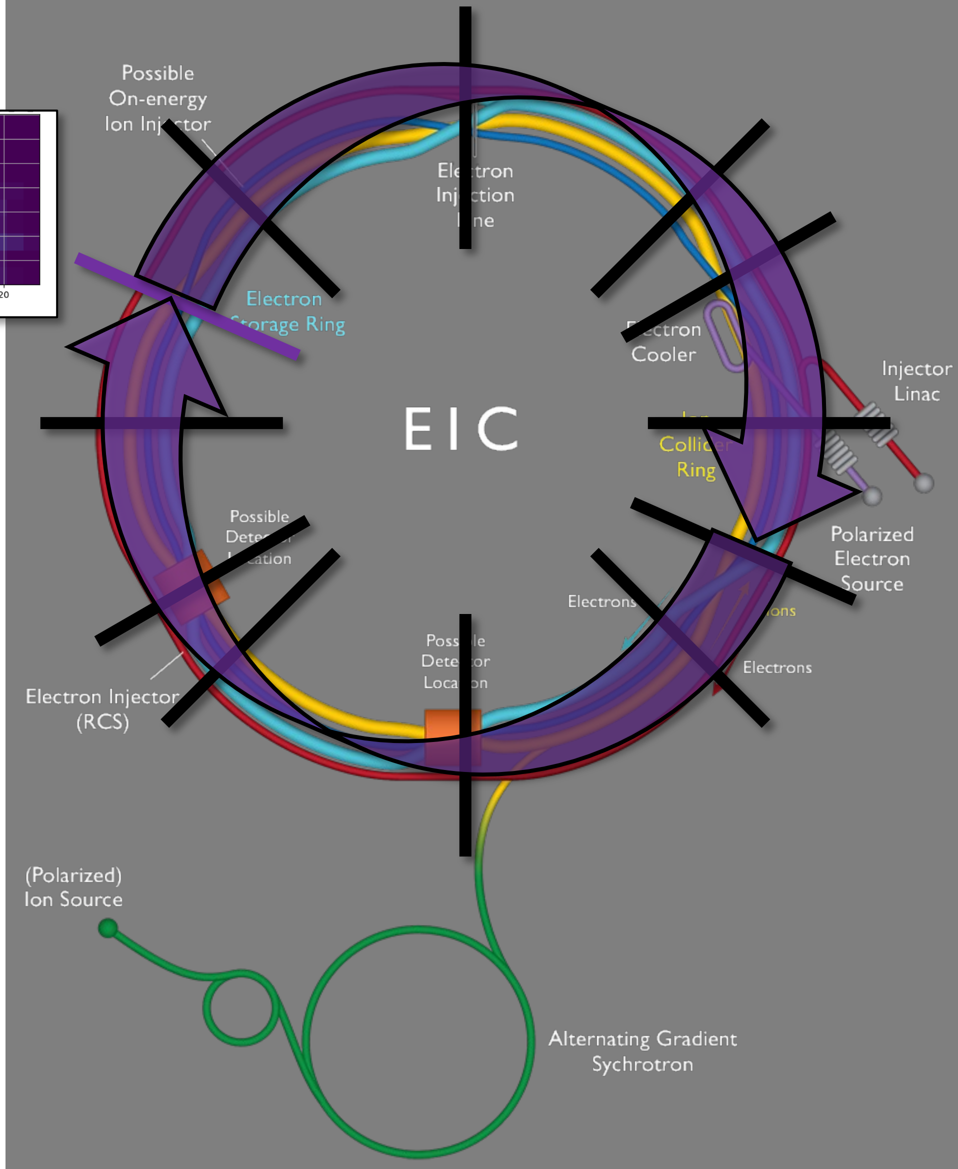


Simulation steps

1. Define the scattering location around the ring by splitting the ring in a set of almost equidistant sections (~1500).
2. Generate 6D coordinates of macro-particles according to the scattering process.
3. Track the scattered particles for N turns, collecting losses around the ring.







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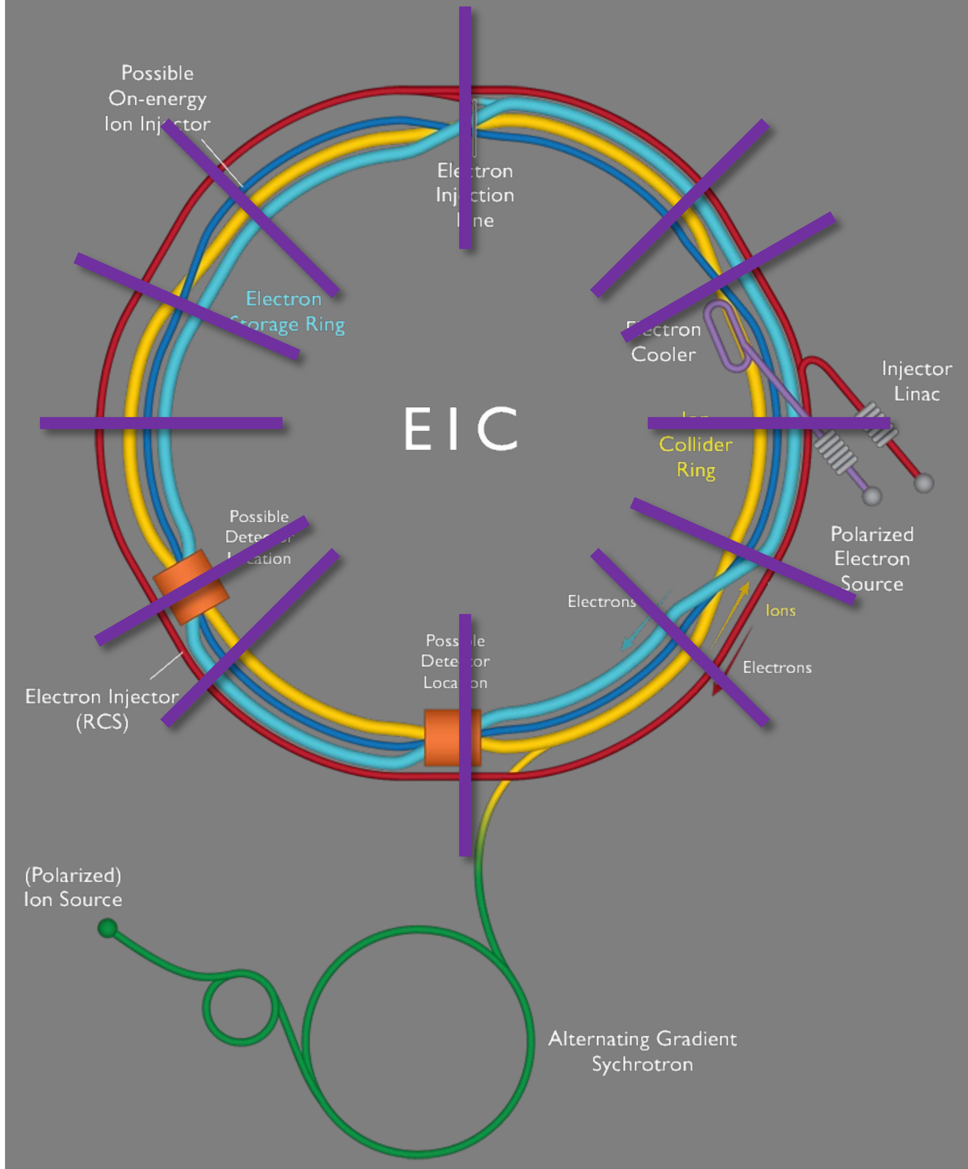
4. Repeat steps 1-3 for all scattering locations.



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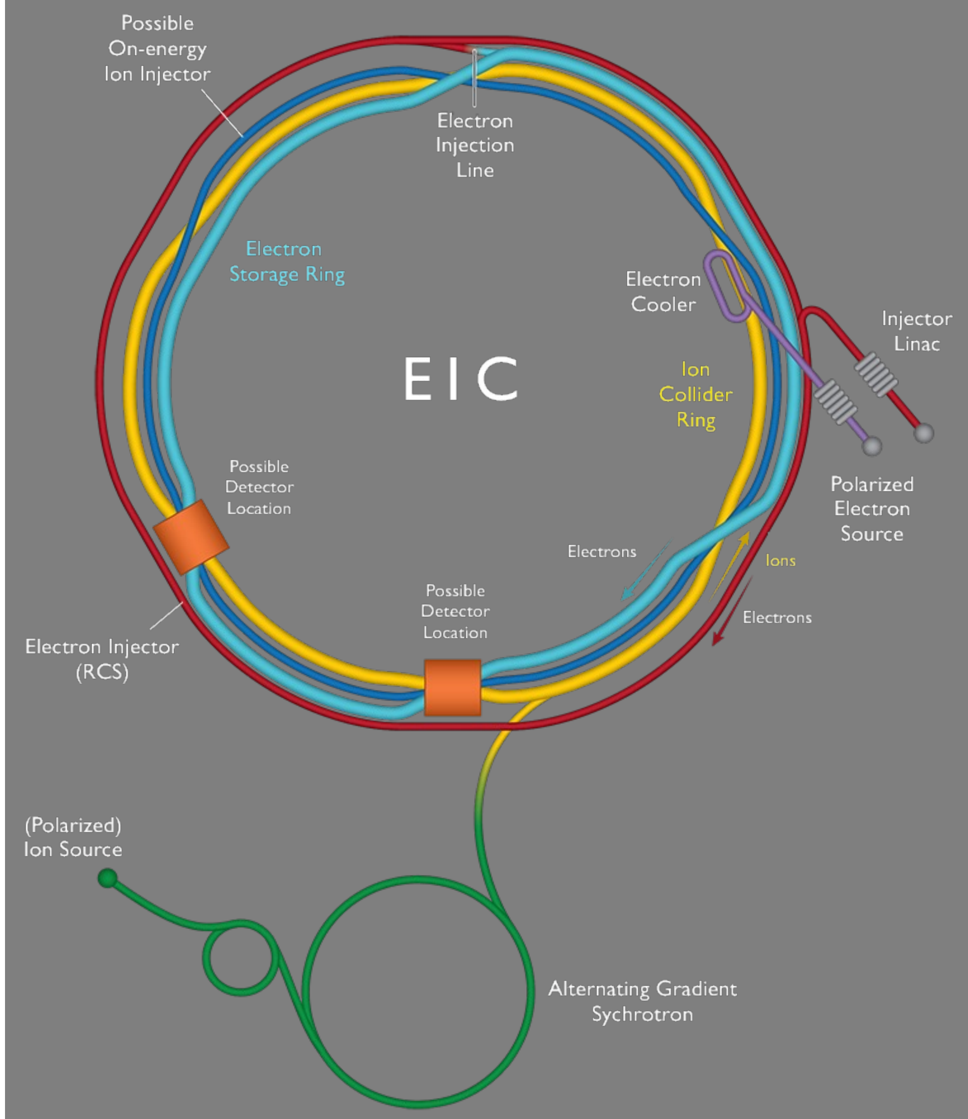
4. Repeat steps 1-3 for all scattering locations.
5. Calculate beam lifetime and IR beam losses for the given beam/machine settings (current, number of bunches, gas pressure, etc.).

$$\frac{1}{\tau} = \frac{1}{\tau_{\mathrm{Tous}}}(I, n_{\mathrm{b}}, \sigma_{\mathrm{x,y,z}}) + \frac{1}{\tau_{\mathrm{Coul/Brems}}}(I, P_{\mathrm{avg}}, Z_{\mathrm{eff}})$$



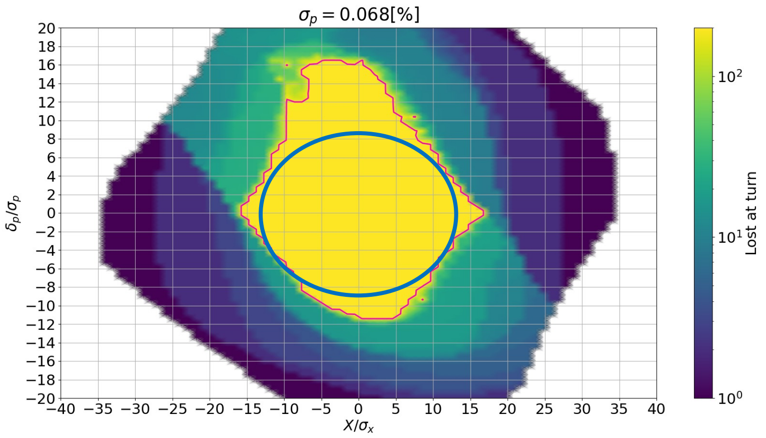
Optimized Lattice

- Larger dynamic aperture
- Long enough Touschek lifetime for swap-out injection
- Realistic beam losses

SR ON, RF ON (phase adjust.)
Without Physical Aperture
Without Machine Errors
200 revolutions
IP6 - starting tracking point

Beam lifetime: $\tau_{\mathrm{T}} \sim \frac{\gamma^2}{N}\delta_p^3$

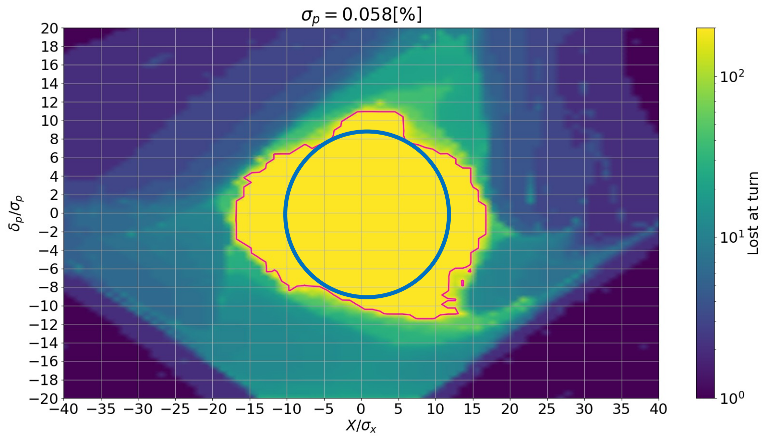
5x100 GeV – v6.3.1 Optimized



Mom. Acceptance:
$\pm 9\sigma_p \rightarrow \delta_p \approx \pm 0.61\%$

Lifetime ~5 h

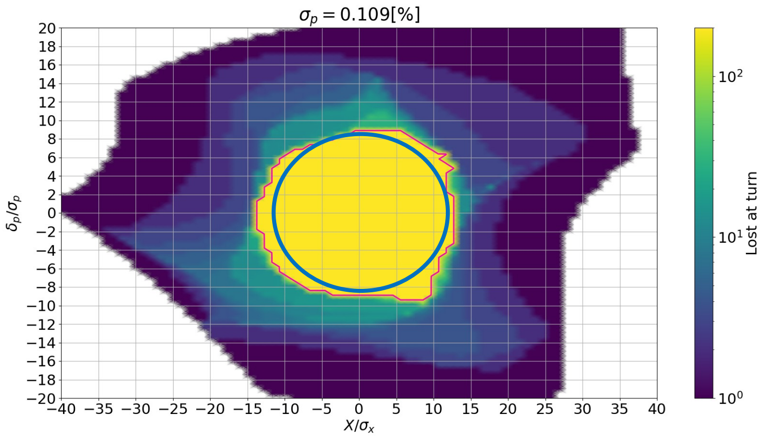
10x100 GeV – v6.3.1 Optimized



Mom. Acceptance:
$\pm 9\sigma_p \rightarrow \delta_p \approx \pm 0.52\%$

Lifetime ~12 h

18x275 GeV – v6.3.1 Optimized



Mom. Acceptance:
$\pm 8\sigma_p \rightarrow \delta_p \approx \pm 0.87\%$

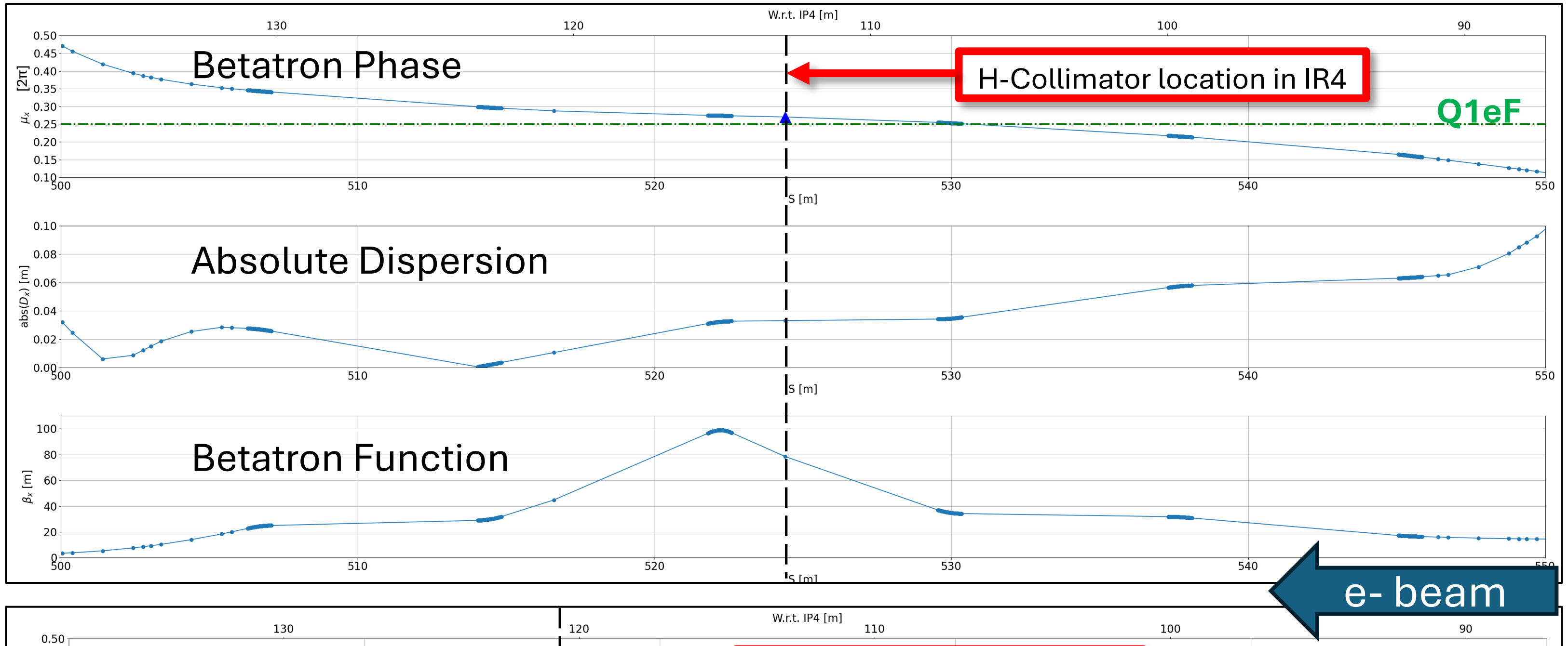
Lifetime ~800 h

Collimator Setup in IR4

Horizontal Plane

IR4 lattice optimized-2

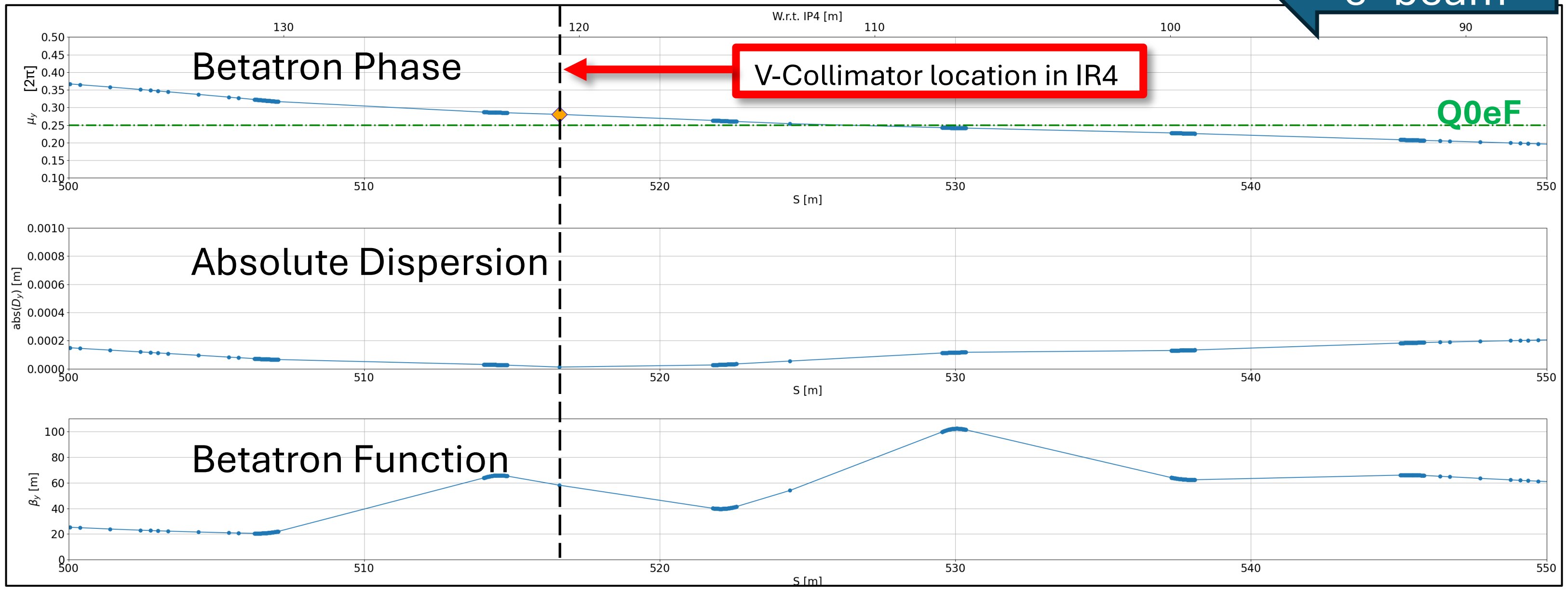
	D04H3	Q1eF
S_{IP6} [m]	524	11-12
β [m]	78	573-699
$\lvert D \rvert$ [cm]	3	15-17
$\Delta\mu_{IP6}$ [2π]	0.270	0.752
A [mm]	15.8	63.0
A [σ_β]	11.5	15.0



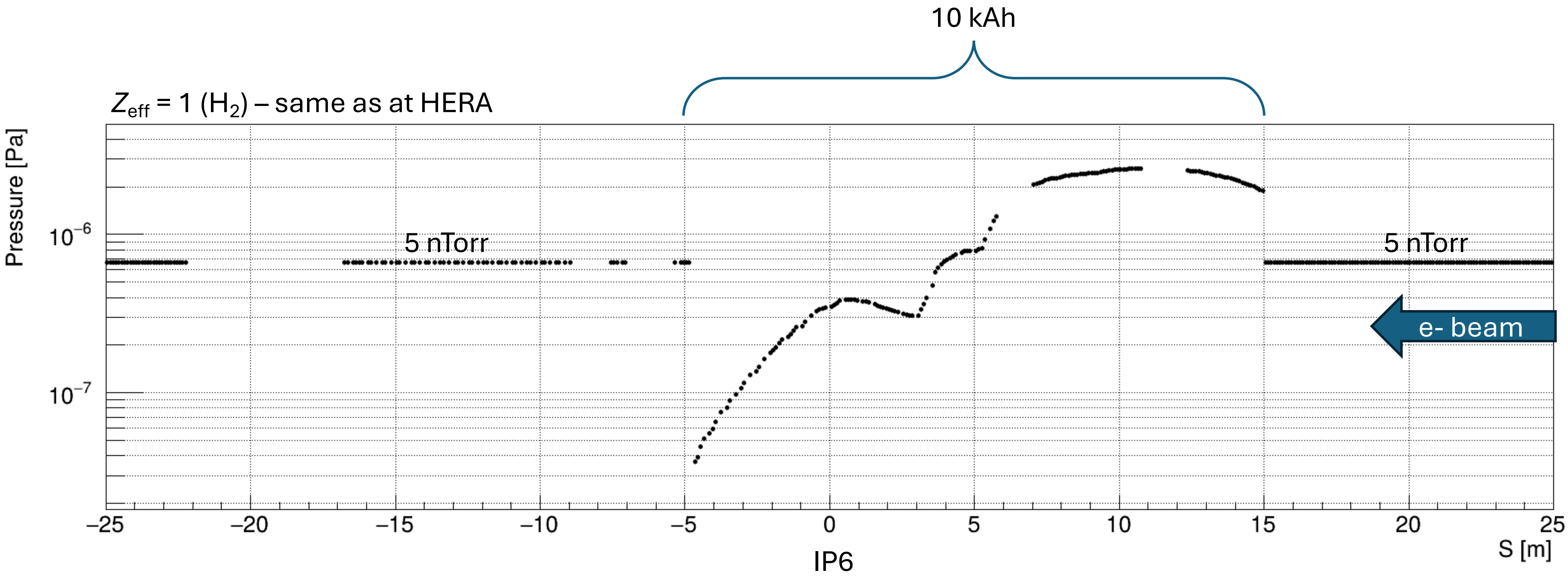
Vertical Plane

IR4 lattice optimized-2

	D04V2	Q0eF
S_{IP6} [m]	517	6-7
β [m]	58	605-659
$\lvert D \rvert$ [cm]	0	<1
$\Delta\mu_{IP6}$ [2π]	0.280	0.748
A [mm]	6.3	54.0
A [σ_β]	18.5	23.0



Vacuum Pressure



Collimator Aperture Optimization

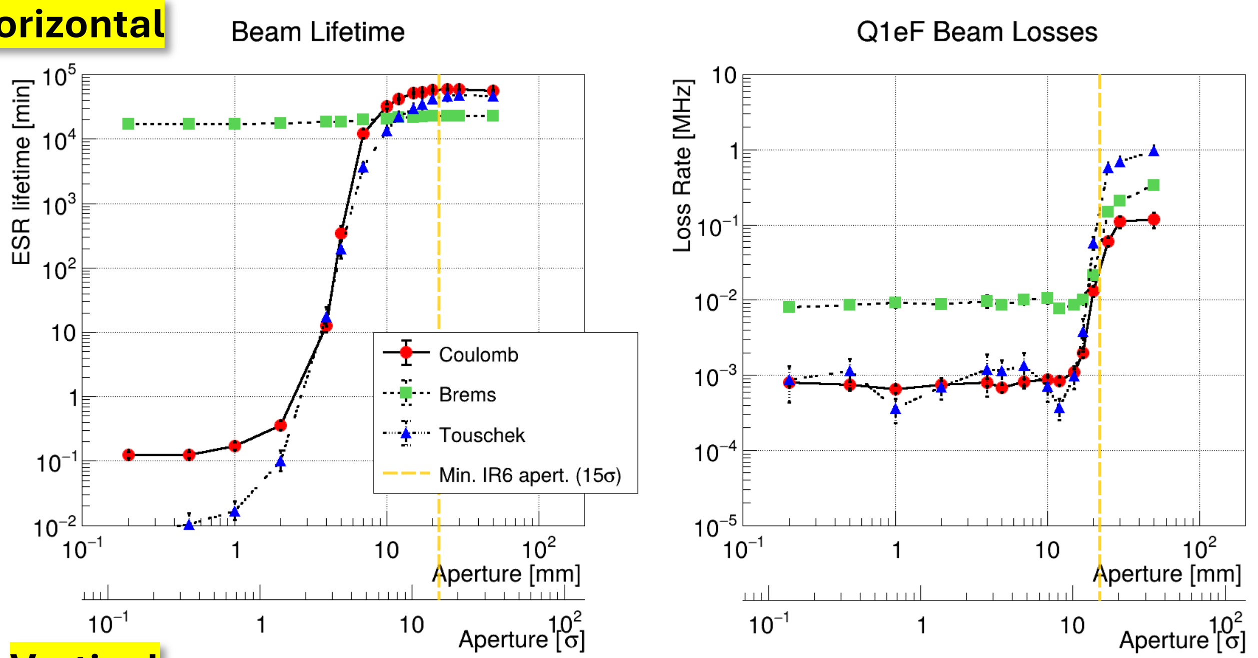
Optimal collimator aperture:

- Minimal impact on beam lifetime
- Maximum loss rate reduction
- Minimal impedance contribution

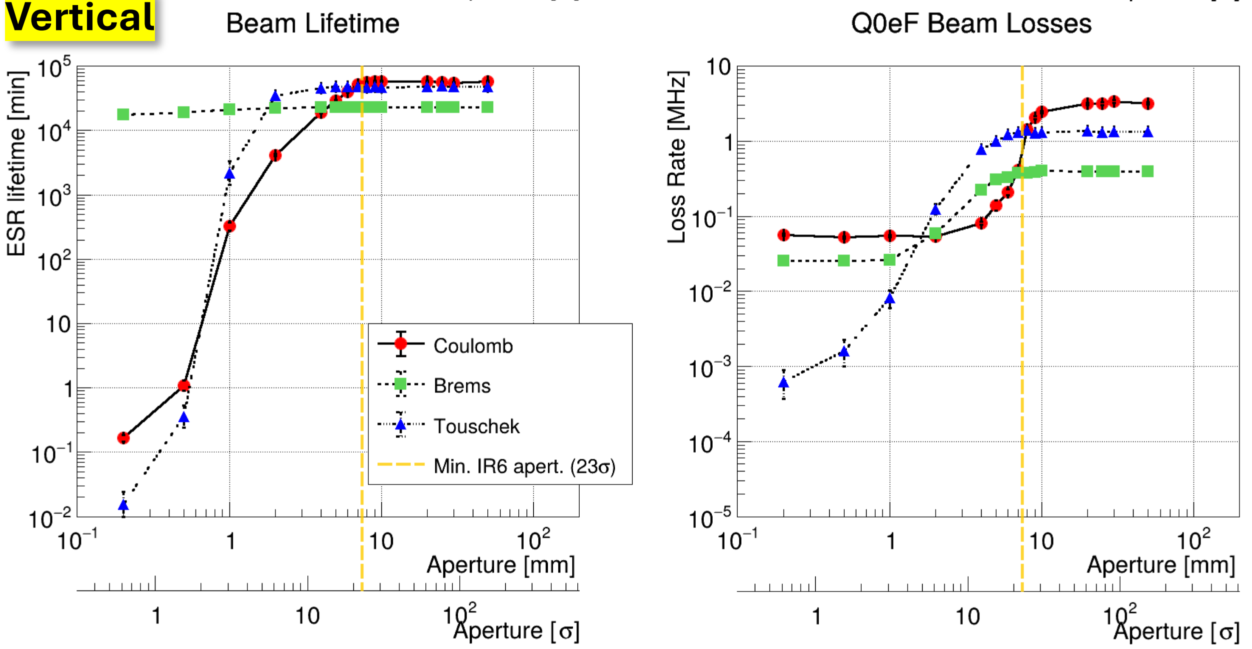
$\sim[\beta_{x/y} \cdot k_{\perp}(\sigma_s, A_{x/y})]^{-1}$

- At 18 GeV, the Touschek lifetime is approximately 800 hrs.
- Therefore, we can reduce IR losses by sacrificing some lifetime.

Horizontal

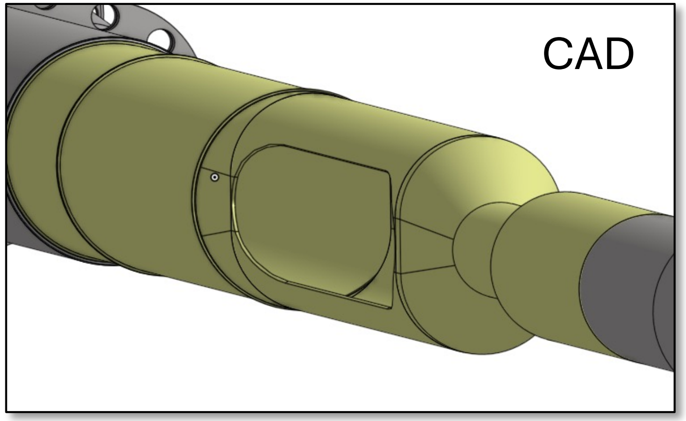


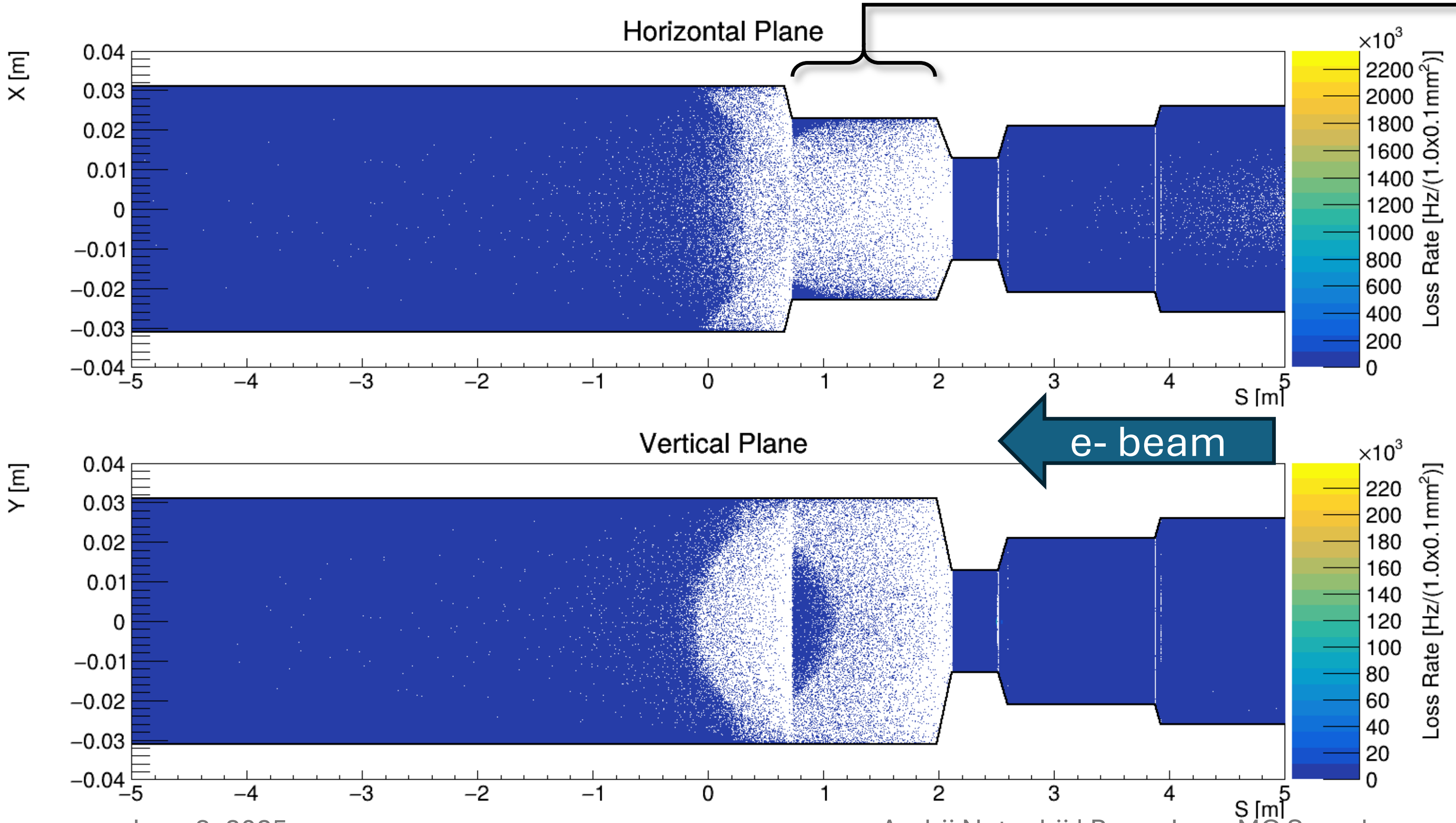
Vertical

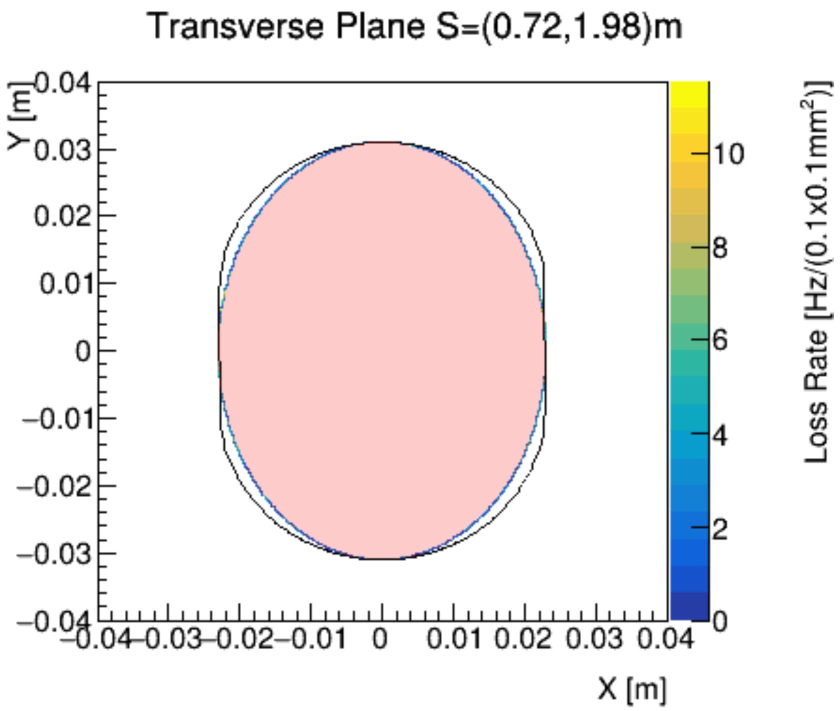


Hit Distribution

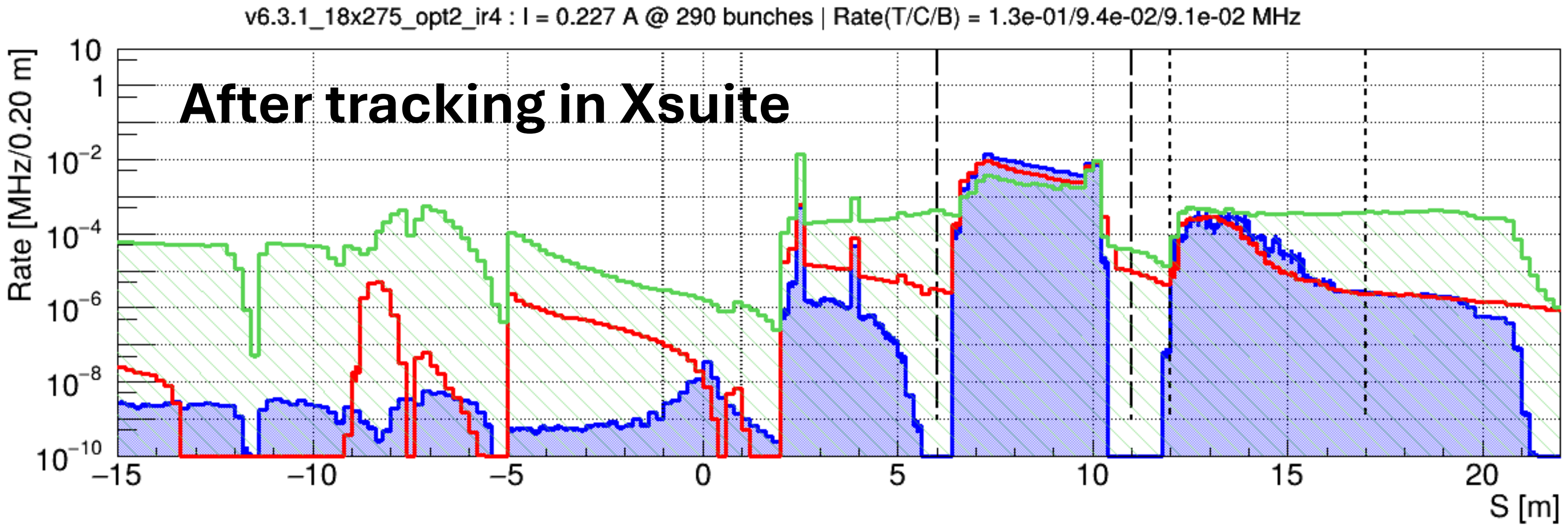
- DD4Hep contains only the ePIC beam pipe updated recently (v2025)
- Set all lost particles on the internal surface of the beampipe within ePIC
- Approximate the racetrack beam pipe as an elliptical aperture in the tracking until the next model revision (coming soon)

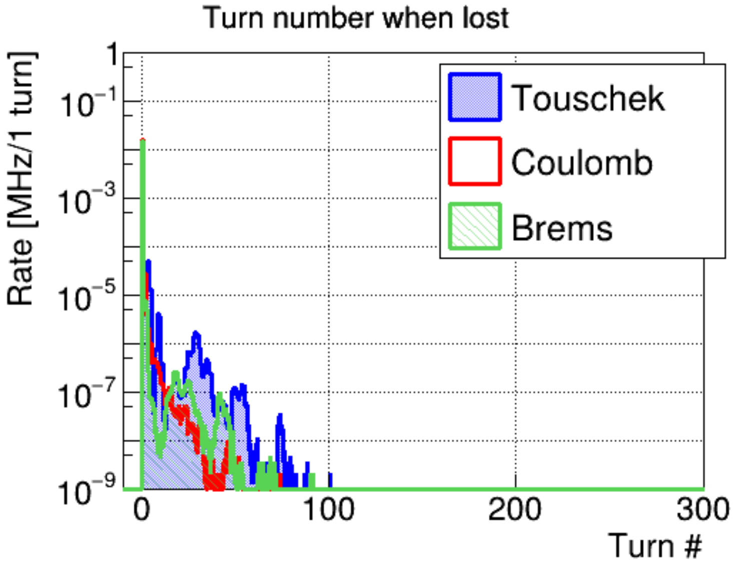


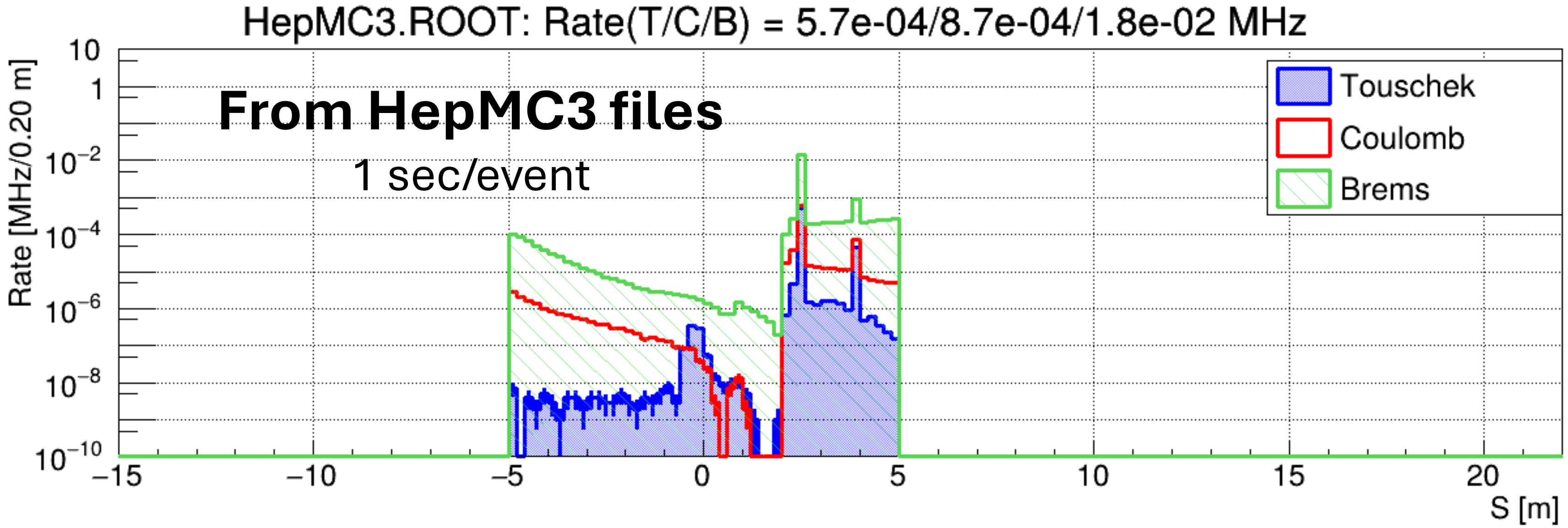




IR6 Beam Losses : Run#001 **[1000 msec/event]**

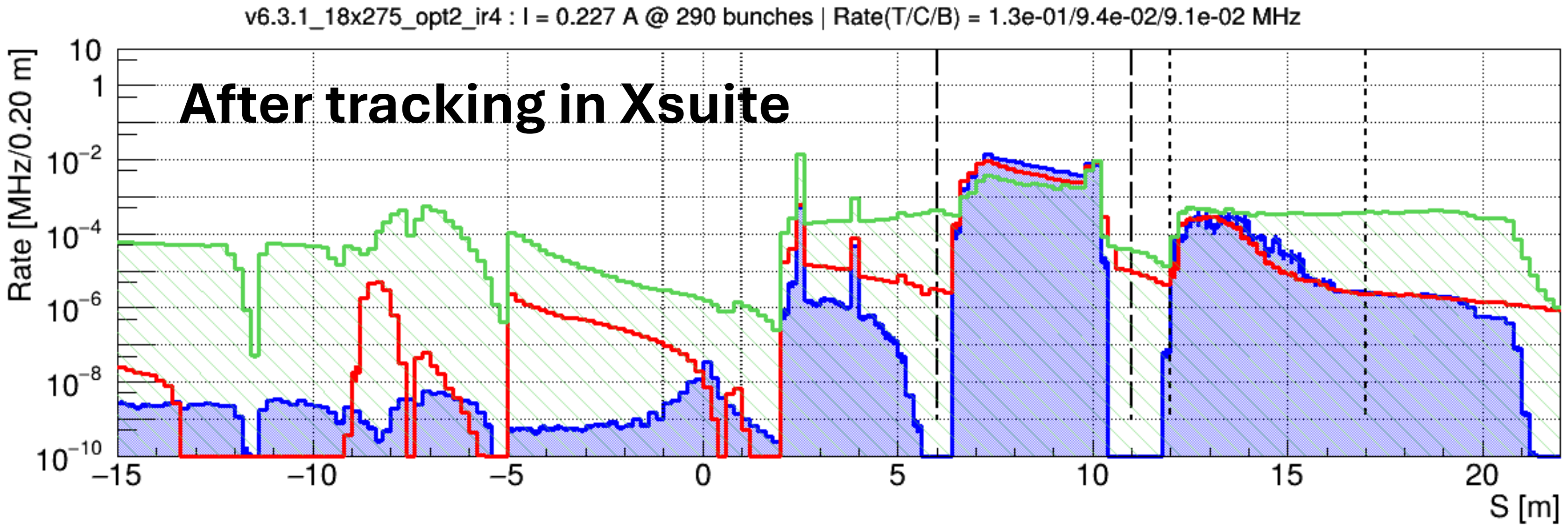


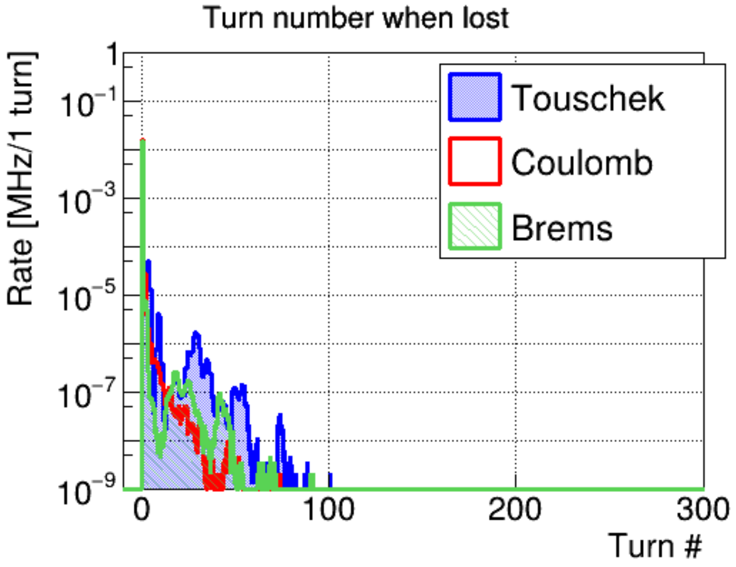


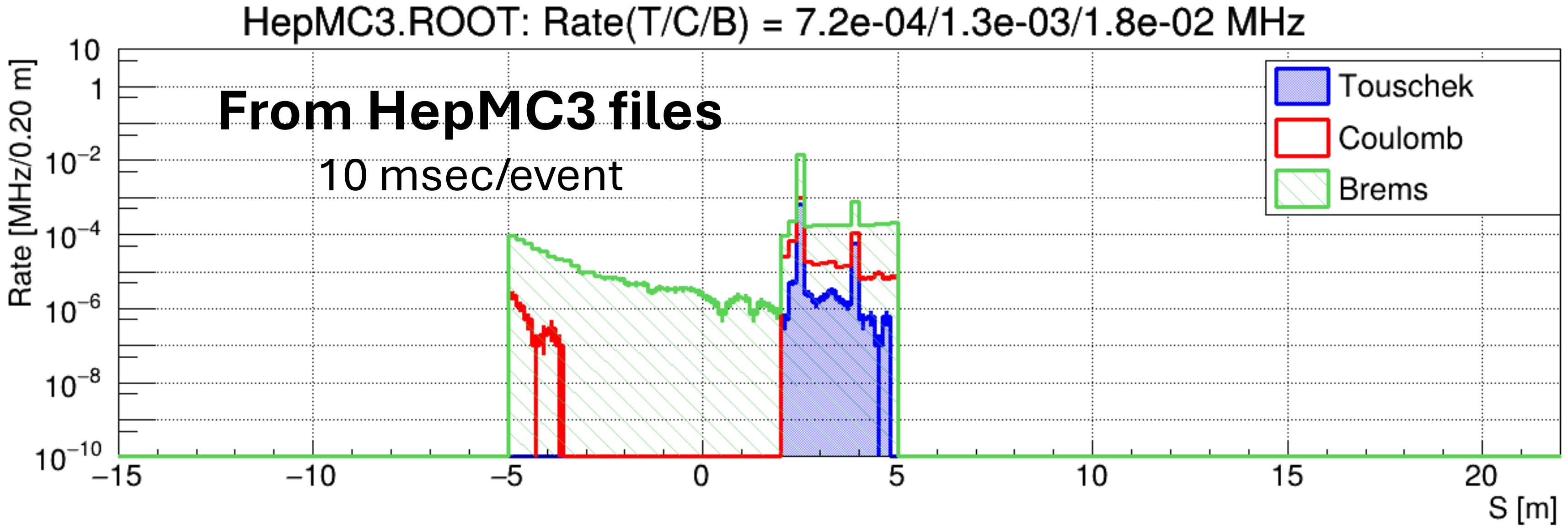


Generate beam losses only within the detector region since far-FWD/BWD beampipe models are still outdated – working on the new beam pipe model

IR6 Beam Losses : Run#002 **[10 msec/event]**







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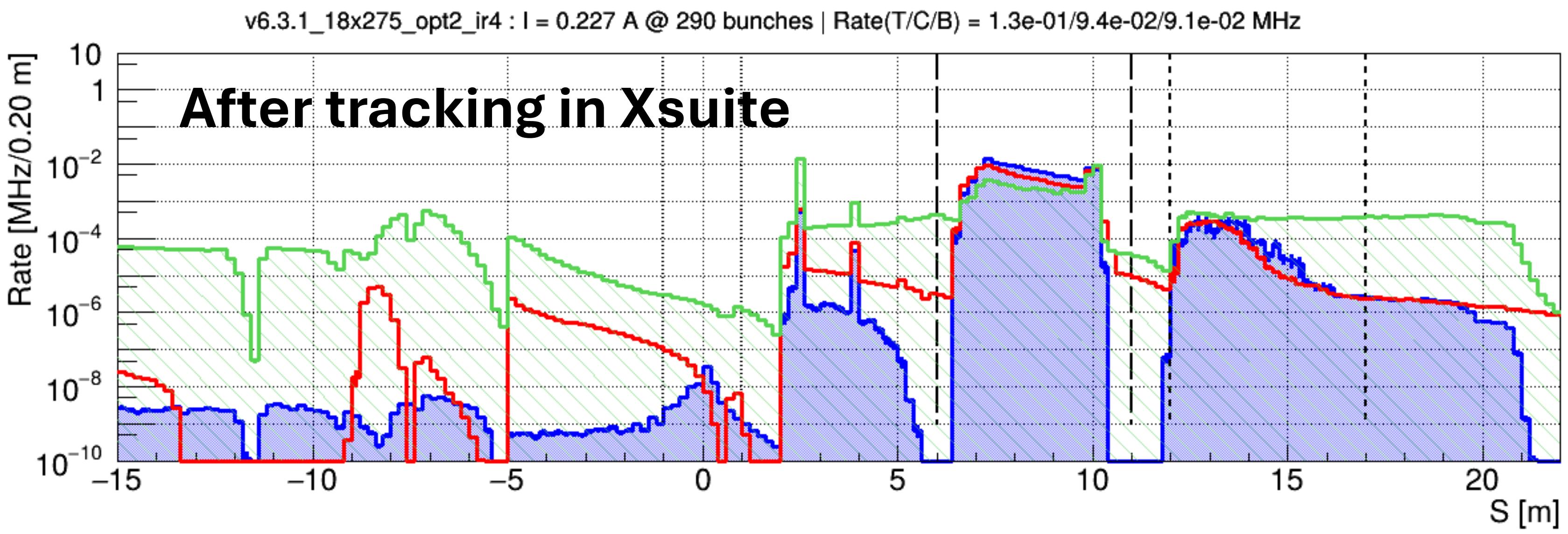
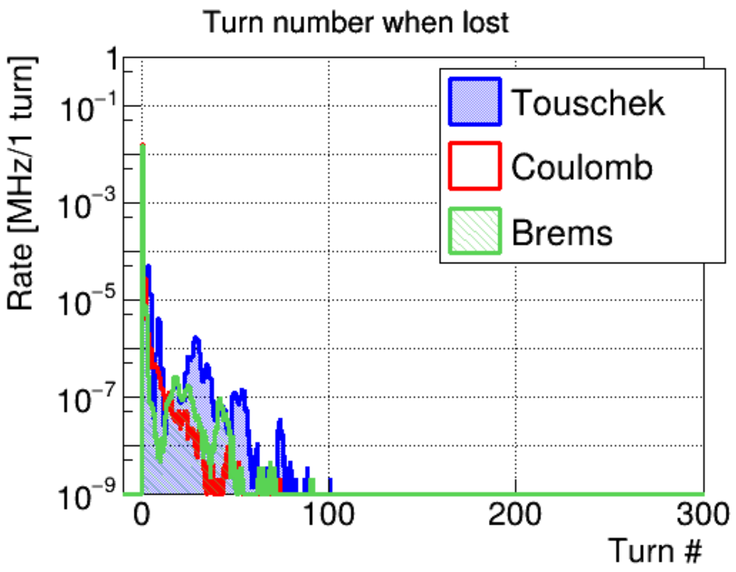
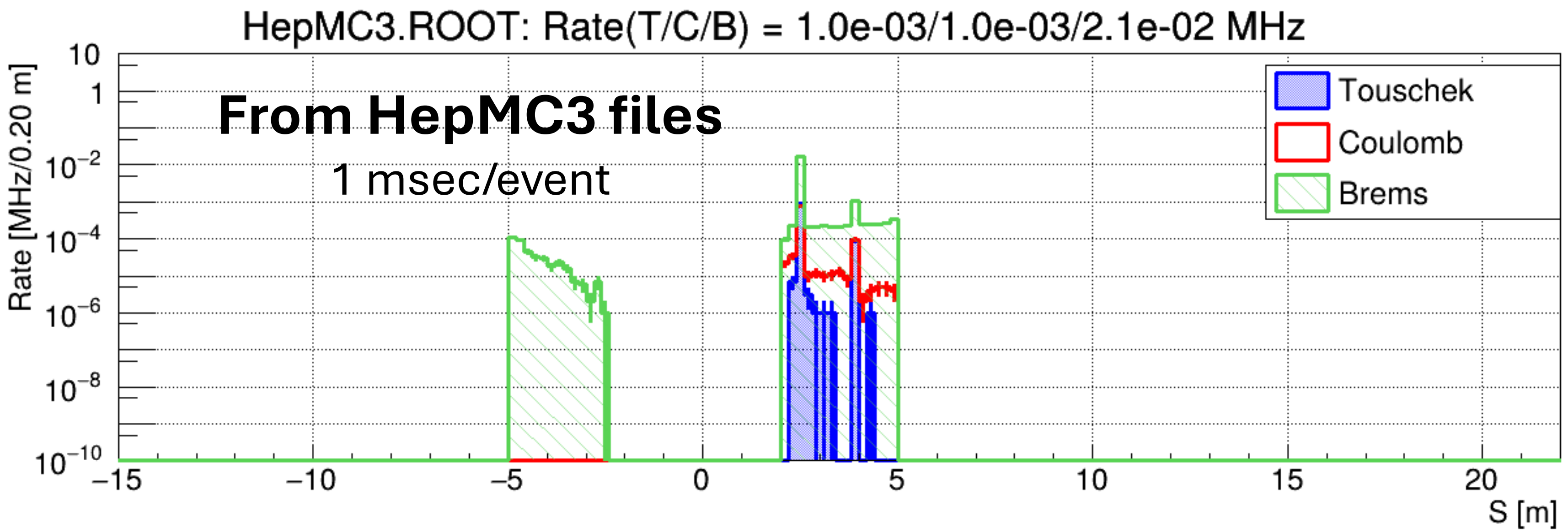
IR6 Beam Losses : Run#003 **[1 msec/event]**







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HepMC3.ROOT Files for Background Overlay – Mixing with Phys. Signal

- File location on SDCC:
  - /gpfs02/eic/anatochii/Xsuite_HepMC_Files_ESR_BeamLoss_on_ePIC
- There are three files for i) Coulomb, ii) Bremsstrahlung (files do not contain gammas), and iii) Touschek electron beam losses in the ePIC detector region (±5m around IP6)
- Each event in the files corresponds to 1 sec (run#001), 10 msec (run#002), or 1 msec (run#003) of machine operation at 0.227 A @ 18 GeV with collimators, and vacuum pressure at 10 kAh of the beam dose
- The particles (lost primary electrons) are distributed over the internal surface of the central beam pipe
- ESR Lattice v6.3.1 optimized with tuned IR4 optics (May 2025)
- MC sample production source code: https://github.com/eic/EIC_ESR_Xsuite