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MULTI-TURN PARTICLE TRACKING CODE FOR BACKGROUND STUDIES AT THE FCC-ee

First results for Coulomb scattering beam losses

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Thanks to Manuela Boscolo

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MOTIVATION

Develop a software tool suitable for the evaluation of beam losses through the ring with special attention to the MDI area and the region upstream /downstream the experiments



- ▶ Study the **IR beam losses** to verify that **beam-induced background** in the detector is acceptable
- ▶ Study a collimators scheme, in particular upstream the IR, to intercept particles that would be lost in the MDI area causing backgrounds in the experiments

Other existing codes for this purpose are:

- SAD + scattering process generator (i.e. BBBrem, GuineaPig) see talk by K. Oide on 12/9
- MDISim (MAD-X + Geant4)
- MAD-X + scattering process generator (H. Burkhardt today)

We started with a very similar approach to this last approach: our idea is to focus on different background sources and/or benchmark our results (or maybe also unify the codes, eventually)

APPROACH

- ▶ **MAD-X** for the evaluation of transport matrices
- ▶ **Monte Carlo approach** (C++) to track the beam particles that experience:
 - ▶ radiative Bhabha
 - ▶ beamstrahlung
 - ▶ beam-gas (Coulomb and Bremstrahlung)
 - ▶ Touschek
 - ▶ thermal photon scattering (presented by Helmut)
- ▶ Particles are **tracked** through the beamline (only few particles in small Regions Of Interest [ROIs])
- ▶ **Multiturn tracking** can be performed for through the ring
- ▶ **Record 6D coordinates of the lost particles** in .root file
(that can be tracked through the beampipe with G4 for example into detector, lumical,...)

PARTICLE TRACKING METHOD

The first and second order transfer matrices of every element of the beamline are evaluated using MAD-X and saved on a file, together with its element name, position (s) and length.

A particle with 6-D phase space coordinates \vec{x}_0 is transported through a given element according to:

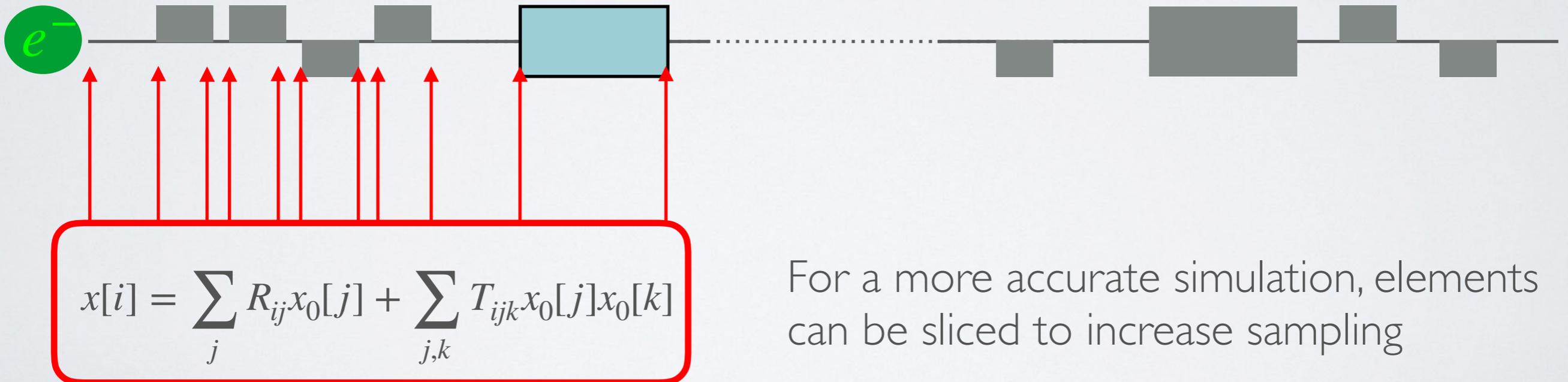
$$x[i] = \sum_j R_{ij} x_0[j] + \sum_{j,k} T_{ijk} x_0[j] x_0[k]$$

The transport process was at first performed by MAD-X, but the repeated calls to MAD-X implied extremely long computational times even for small jobs.

SCATTERING PROCESS EVALUATION

For each particle, the interaction happens during the first turn.
Multiple beam-gas scattering is neglected.

Once selected the element where to simulate the interaction (either randomly or performing a scan), the particle is tracked from the beginning of the beamline until the selected element



SCATTERING PROCESS EVALUATION



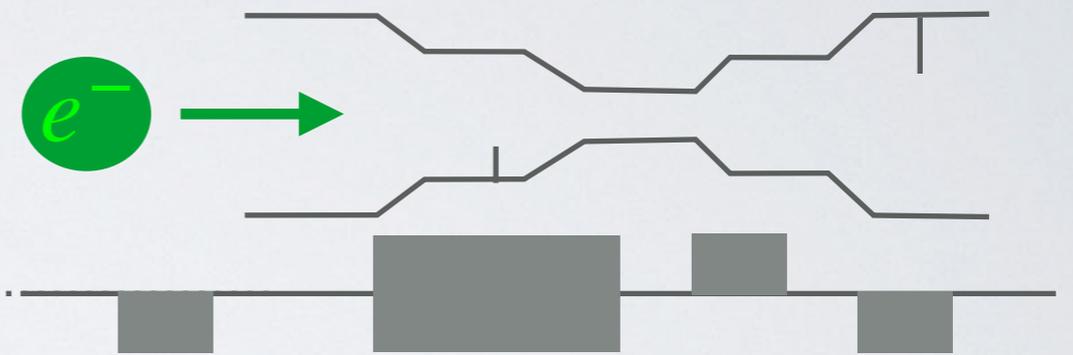
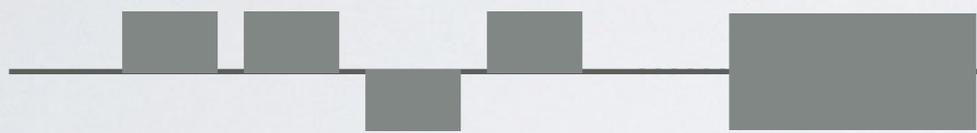
The effect of the interaction on the particle is then evaluated via Monte Carlo: for each event the associated weight is calculated according to:

$$w = P_{event} \frac{n_{bunch}}{n_{sim}}$$

- P_{event} is the probability of that event to happen, function of $\sigma(\theta, \phi, \delta E)$, density of the gas, length of the element, etc.
- n_{bunch} is the number of bunch particles
- n_{sim} is the number of particles simulated (for example 1000 in this case)

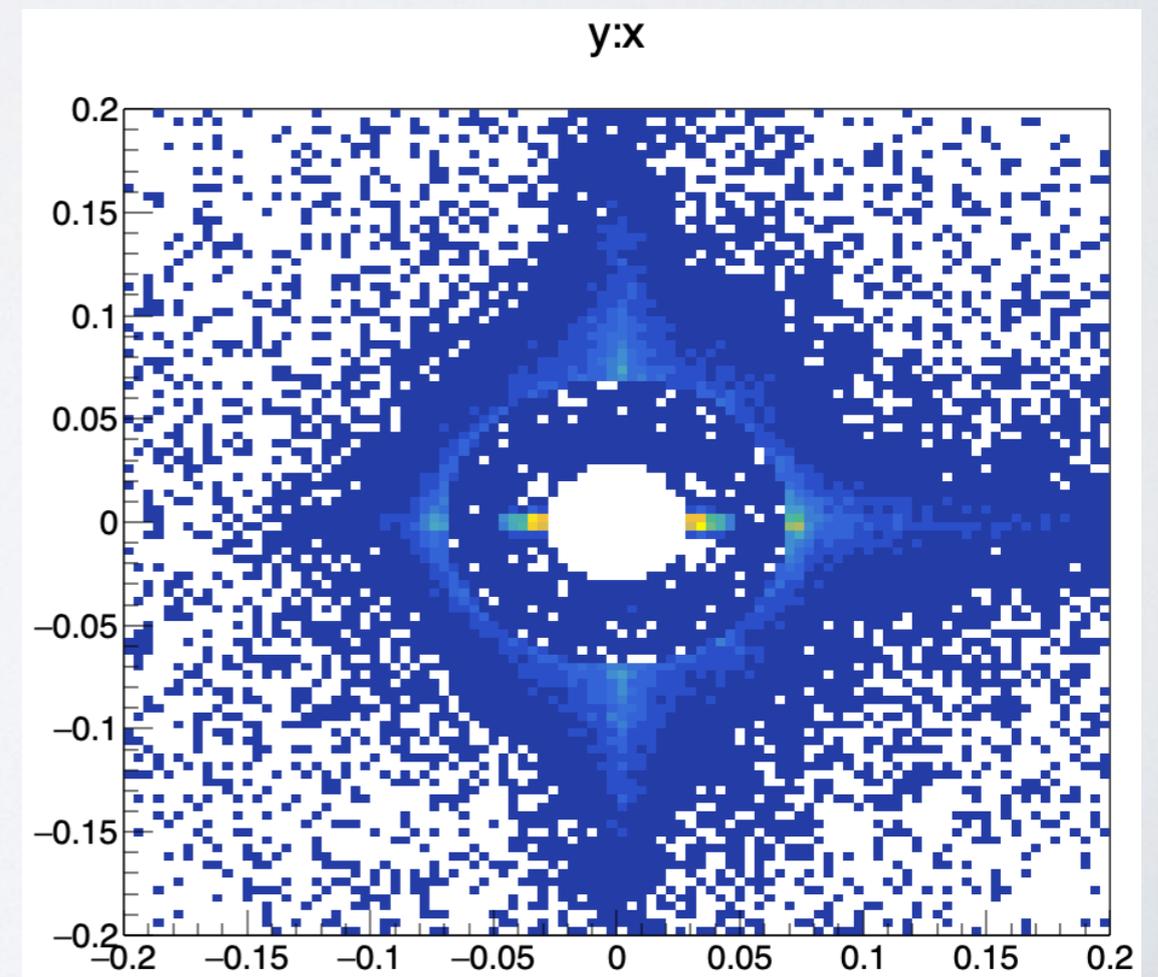
CHECK OF THE PHYSICAL APERTURE

After the interaction, the particle is again propagated through the ring, but after every step, the position on the transverse x-y plane is checked against the beam pipe dimensions at the current element (or at collimators when they will be considered in the future simulations).



If the particle is outside those boundaries is declared lost, its propagation stops and all relevant informations are stored in a TTree.

Otherwise the particle keeps going through the ring for a chosen amount of turns



FIRST RESULTS

Beam initial properties:

$$E = 45.6 \text{ GeV}$$

$$\beta_x^* = 0.15 \text{ m}$$

$$\beta_y^* = 0.0008 \text{ m}$$

$$\sigma_x^* = 6 \mu\text{m}$$

$$\sigma_y^* = 0.028 \mu\text{m}$$

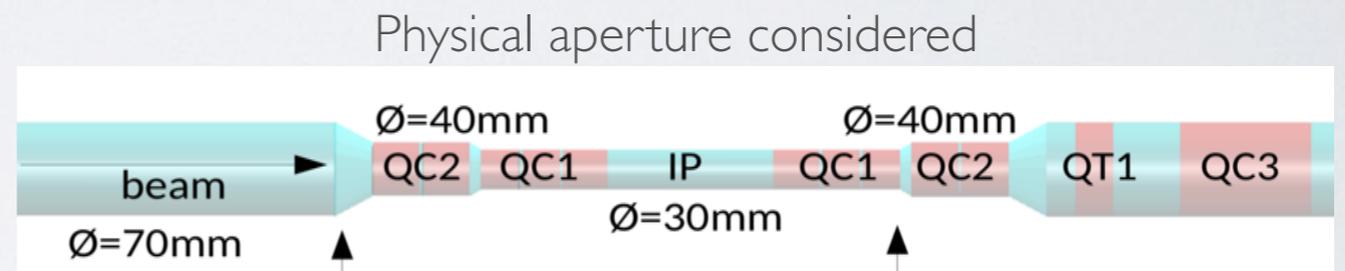
optics: FCCee_z_213_nosol_18.seq (Synchrotron Radiation OFF)

Length: 97756 m

N. of IPs: 2

N. of turns: 100

Pressure: $1 \text{ e-}9$ Torr ($1,3332 \text{ e-}12$ bar)



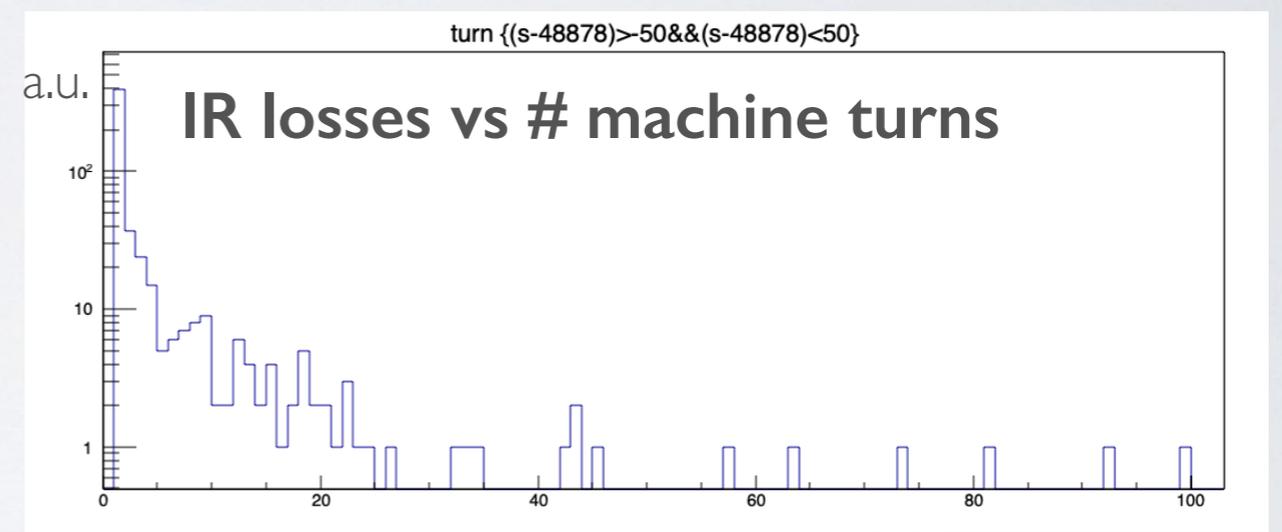
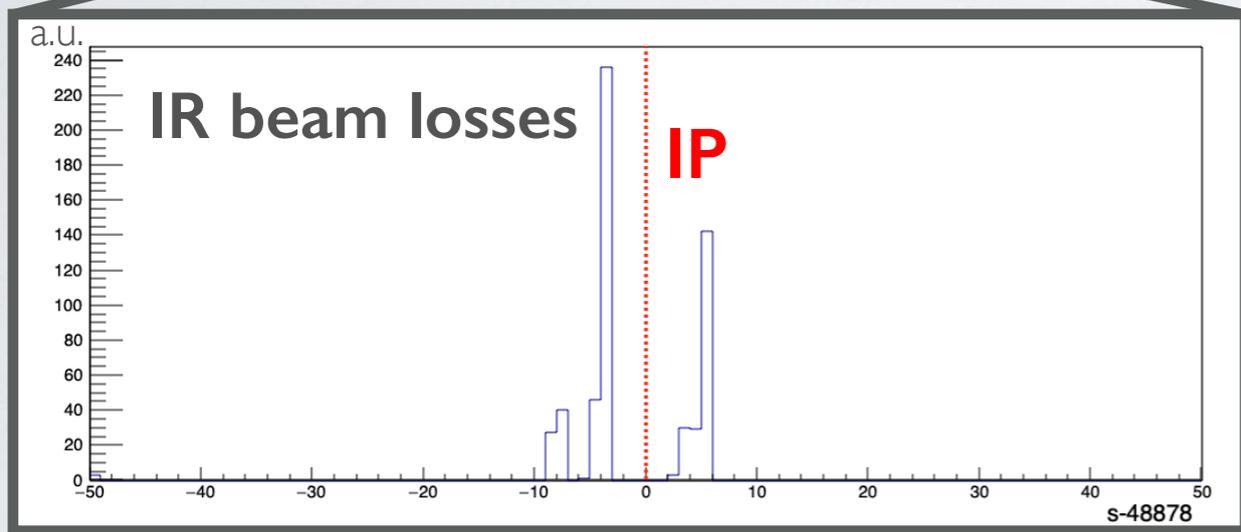
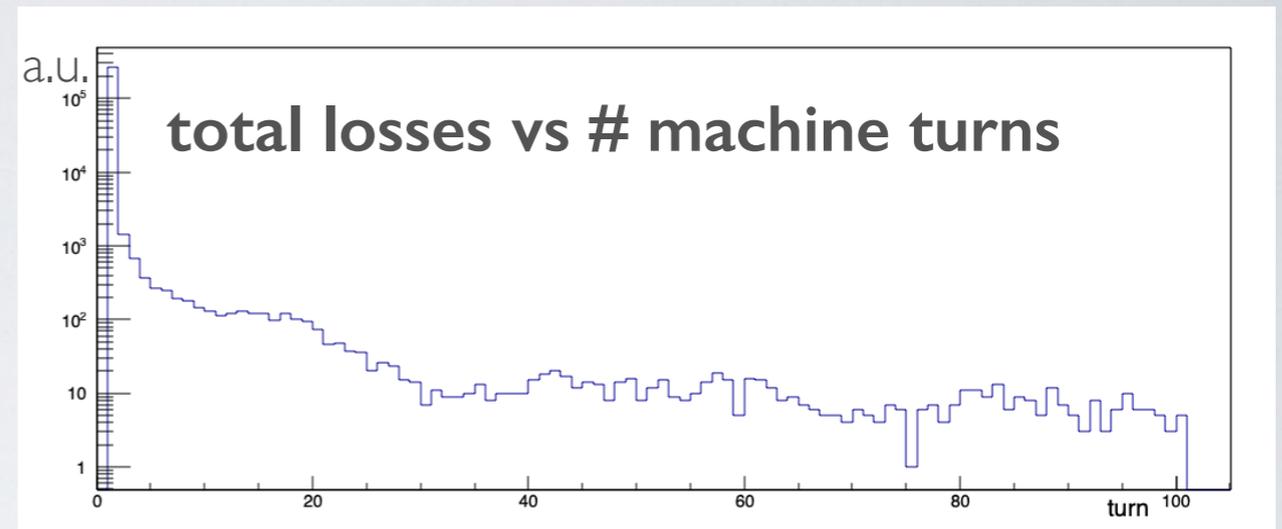
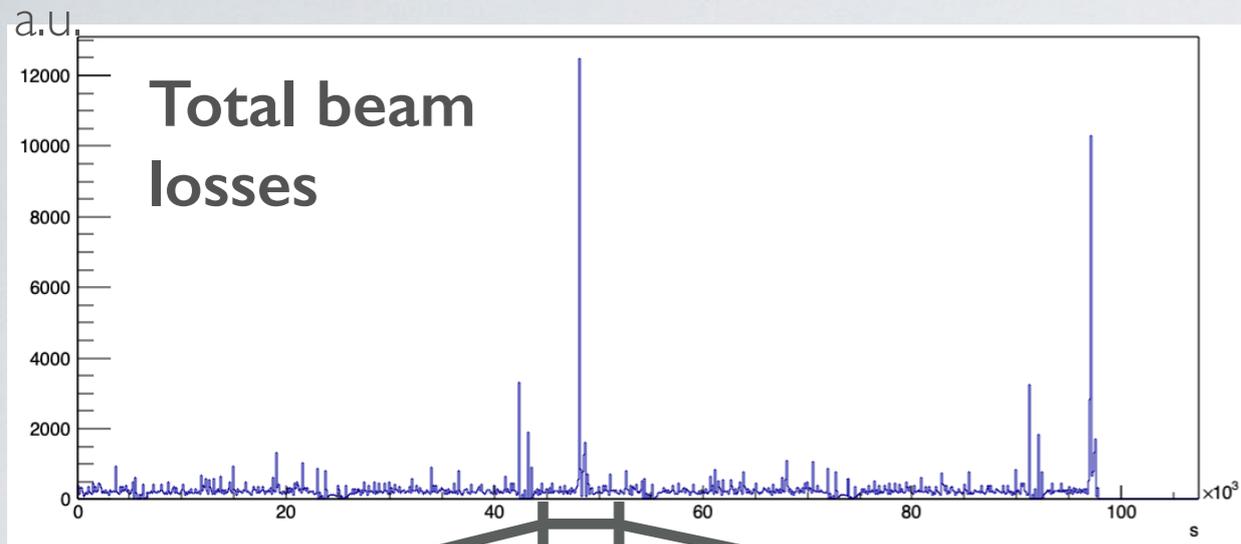
Elastic Beam-gas scattering

Handbook of Accelerator Physics and Engineering
by A. Chao and M. Tigner pp. 216 formula (2)

$$\frac{d\sigma}{d\Omega} = 4Z^2 r_e^2 \left(\frac{m_e}{E} \right)^2 \frac{1}{(\theta^2 + \theta_{min}^2)^2}$$

$$\theta_{min} = \alpha Z^{1/3} \frac{m_e}{E}$$

FIRST RESULTS: ELASTIC BEAM-GAS

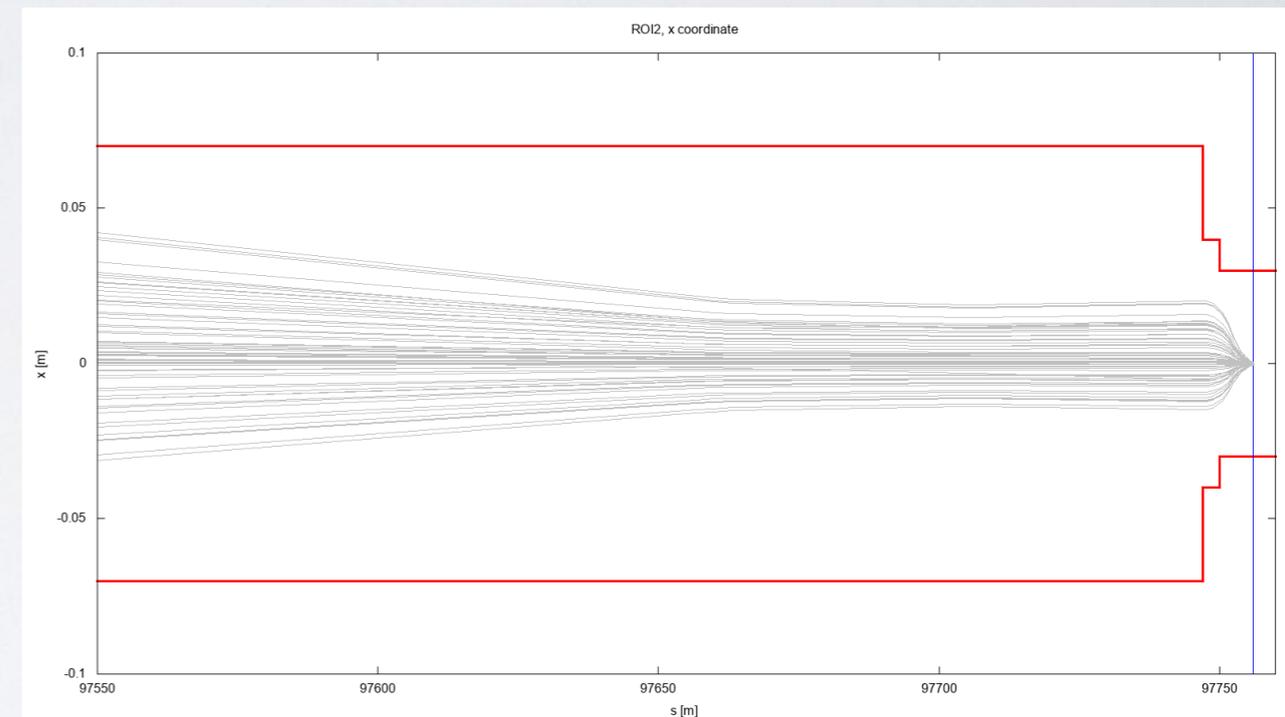
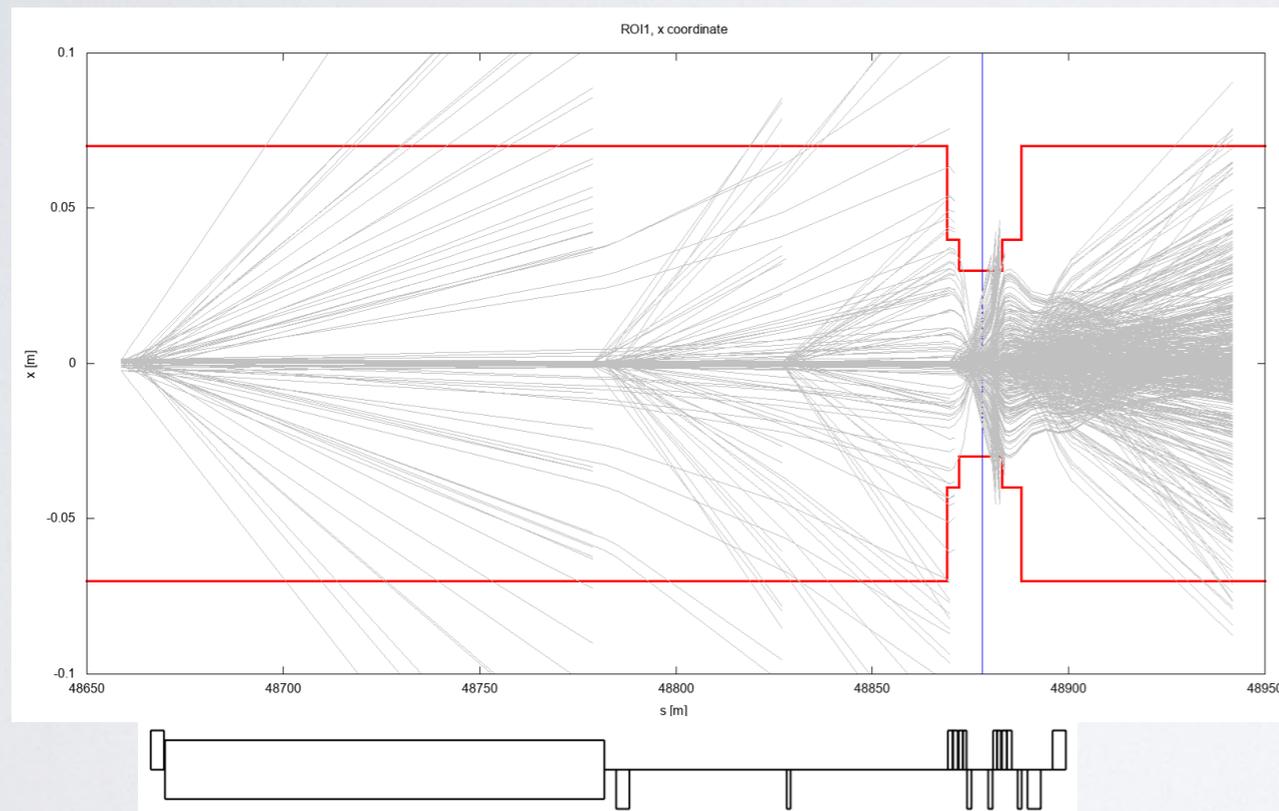


- Most of the particles are lost near the 2 IPs, close to the IR quadrupoles, where the physical aperture gets smaller.
- The losses occur mostly during the first turn, right after the elastic beam-gas scattering.

PRELIMINARY: Note that plots are not weighted!

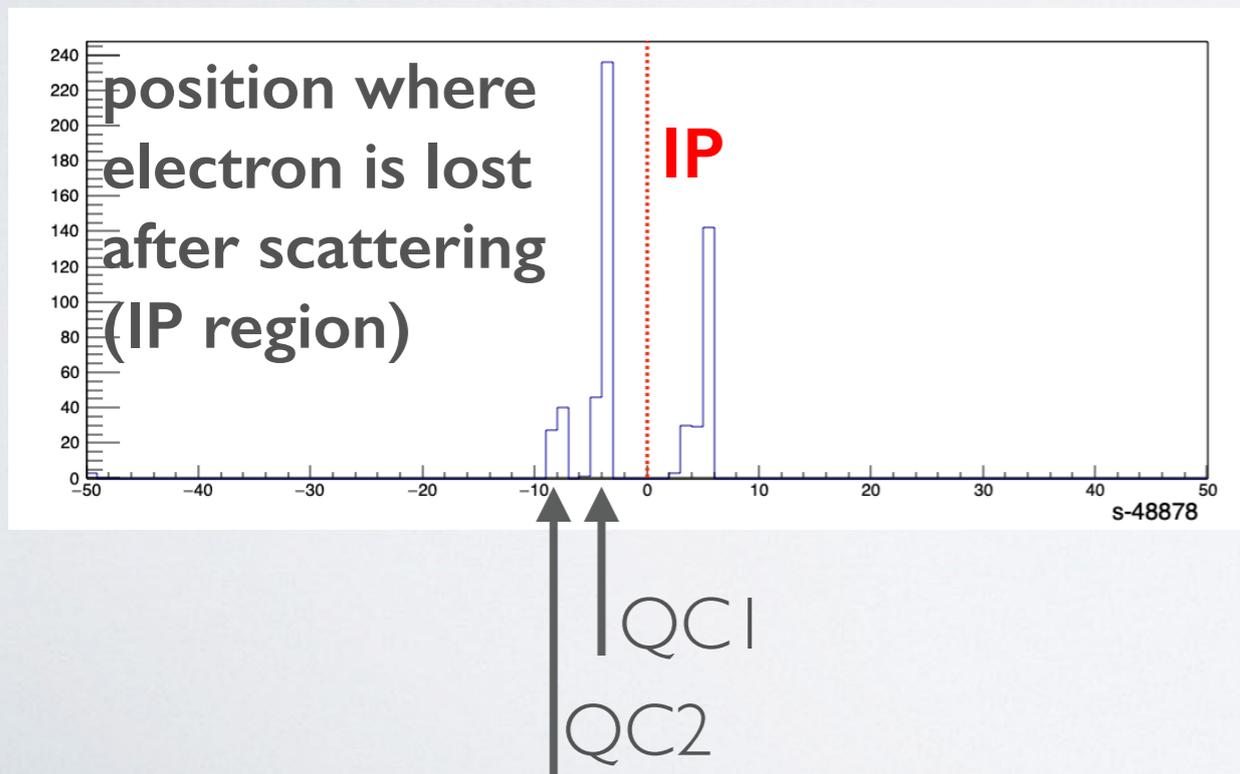
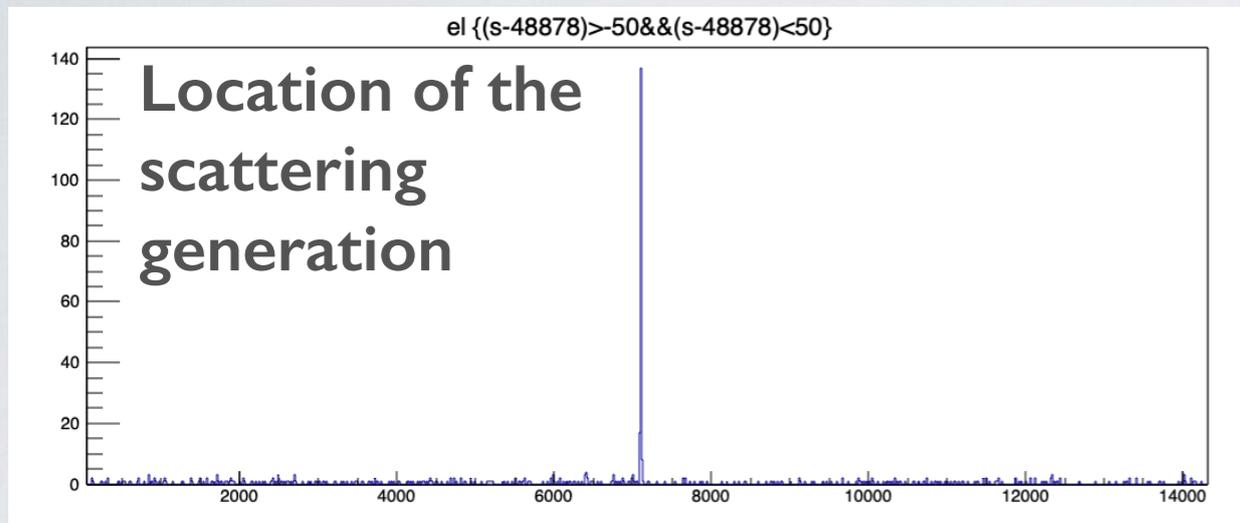
FIRST RESULTS: ELASTIC BEAM-GAS

Trajectories are presently too time consuming to be plotted. So for the moment **only a small number of particles** are tracked and only around the two IRs.



By **slicing** long elements simulation will be more accurate, at the cost of longer process time. We need to find the best compromise.

FIRST RESULTS: ELASTIC BEAM-GAS



PRELIMINARY!

Note that plots are not weighted!

Using the previously shown cross-section I obtained very very small values, which I am not sure of.

Therefore I decided to not weight the plots, only shown for the purpose of explaining how the simulation works.

FIRST RESULTS: ELASTIC BEAM-GAS

Very rough lifetime measurement

Considering probability of elastic BG event constant at $1e-10$
(overestimating what I get from the cross-section $1e-15 \sim 1e-10$)

I simulated $n_{tot} = 4.27 \cdot 10^{15}$ particles through the ring
 $n_{BG} = 4.27 \cdot 10^5$ particles undergo beam-gas scattering

Ratio of losses in 100 turns for particles interacting on the first turn:

$$n_{lost} = 3.9 \cdot 10^5 \quad \longrightarrow \quad \frac{n_{lost}}{n_{tot}} = 9.36 \cdot 10^{-11}$$

This means that almost every particle that interacts gets lost

10% of the beam is lost after ~ 100 h.

63% of the beam is lost after ~ 1000 h.

VERY PRELIMINARY!!!

FIRST CONCLUSIONS

Aim to develop a versatile tool for multi-turn beam background studies (i.e. tracking, energy deposition). Other processes can be studied too (next step: radiative Bhabha)

What to do next?

- ▶ **Long CPU time!!!** (suggestion to speed up?)
- ▶ Better **sampling** of the elements in the beamline by slicing
- ▶ Implementation of different beam scattering processes
- ▶ Pressure profile map can be added

- ▶ Suggestions are always welcome!