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TRACKING TOOL FOR BACKGROUND SIMULATIONS

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STATUS OF THE BEAM BACKGROUND SIMULATION TOOL

- Motivation for the study
- Description of the code
- Loss maps and lifetime estimates for:
    - inelastic beam-gas
    - thermal photon scattering
- Future improvements to the tool
- Conclusion and next steps

Our objective is to develop a **MAD-X based** software tool suitable for the **evaluation of beam losses** through the whole ring, with special attention to the MDI area and the regions upstream/downstream the experiments

- Study the **IR beam losses** to verify that beam-induced background in the detector is acceptable
- Study a **collimator scheme** to intercept particles that would be lost in the MDI area

Other existing codes for this purpose are:

- SAD + scattering process generator (i.e. BBBrem, GuineaPig)
- MDISim (MAD-X + Geant4)
- MAD-X + scattering process generator (H. Burkhardt)

- **MAD-X** for the evaluation of transport matrices
- **Monte Carlo approach** (C++) to generate the beam particles that experience:
    - Thermal photon scattering
    - Inelastic beam-gas
    - Elastic beam-gas (already under development)
    - Touschek (already under development - possibility of benchmark at DAFNE)
    - Radiative Bhabha
    - Beamstrahlung

- **Multi-turn tracking** can be performed through the ring
- Record **6D coordinates** of the lost particles in .root file for an easier interface with detector and physics simulation software

Scattering events are generated by a Monte Carlo at the **beginning of each element (or drift)** longer than 1mm. To obtain an **even distribution** along the ring, the number of events produced on a given element is **proportional to its length**:

$$N_i = N_{tot}\frac{L_i}{L_{tot}}$$

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

A particle with 6-D phase space coordinates $\overrightarrow{x_0}$ 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 particle is tracked through the ring, and **after every element** the position on the transverse x-y plane is checked against the beam pipe dimensions.

A particle is **declared lost** when it is found outside the beam pipe **physical aperture**

INELASTIC BEAM-GAS: SIMULATION RESULTS

$Z = 7 \quad P = 10^9[Torr] \quad \rho = 3.217 \times 10^{22}[m^{-3}]$

FCCee_t_213_nosol_13_noRF.seq
FCCee_z_213_nosol_18_noRF.seq

Multi-turn simulation performed at Z and at $t\bar{t}$ energies

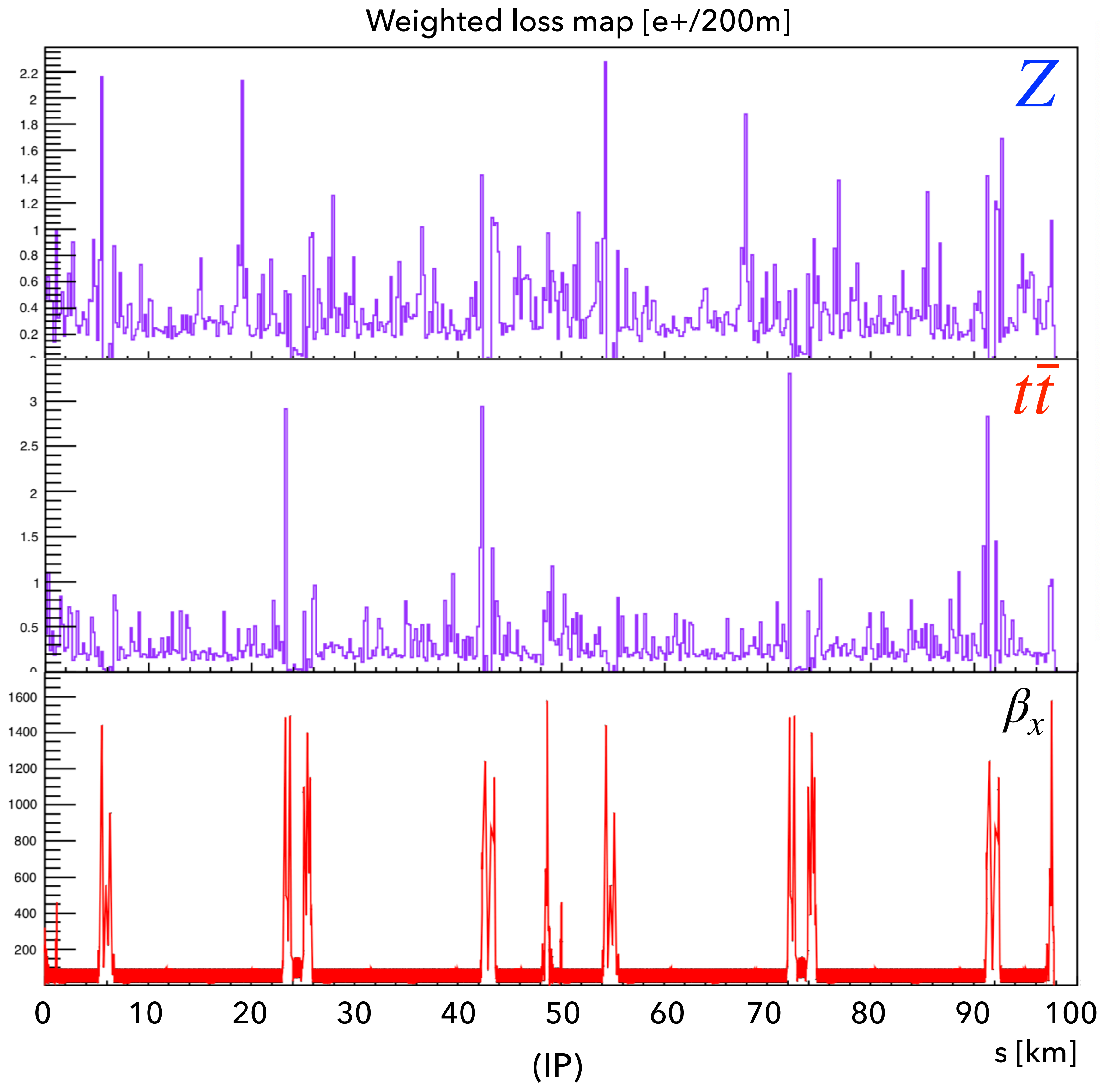
$N_{MC} = 10^7$ particles generated along the ring and tracked for **10 turns**

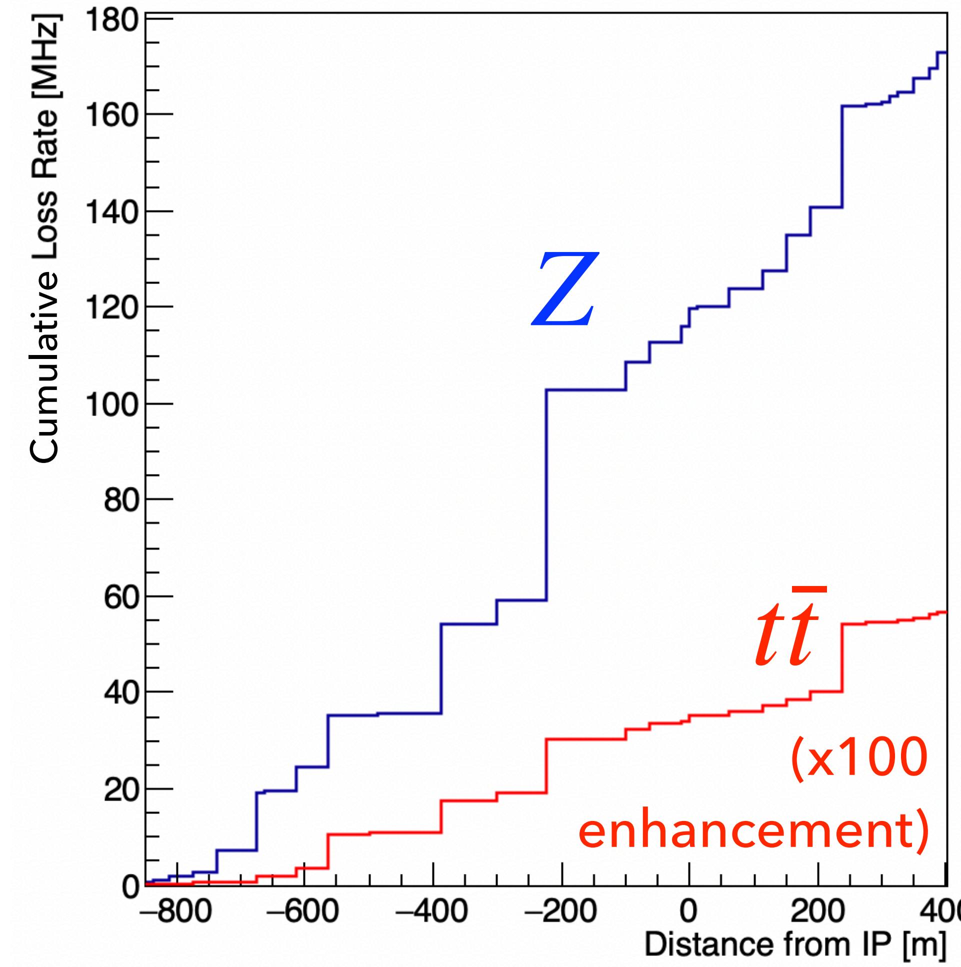
Synchrotron radiation and RF turned off

Results have been compared with theoretical values with **excellent agreement**

$$\sigma_{inel} = \frac{16}{3}\alpha r_e^2 Z^2 \; log\left(\frac{184.15}{Z^{1/3}}\right)\left(log\frac{1}{RF_{acc}} - \frac{5}{8}\right) \qquad \tau = \frac{1}{\rho c \sigma} \qquad \Gamma = \frac{N_{part}N_{bunch}}{\tau}$$

E[GeV]	RFacc	$\sigma_{inel}\ [m^2]$	$\tau_{inel}\ [h]$	$\tau_{MC}\ [h]$	bunches per beam	$\Gamma_{inel}\ [MHz]$	$\Gamma_{MC}\ [MHz]$
45.6	1.3%	3.43e-28	84	83	16640	9360	9500
182.5	2.4%	2.94e-28	98	100	48	31	30

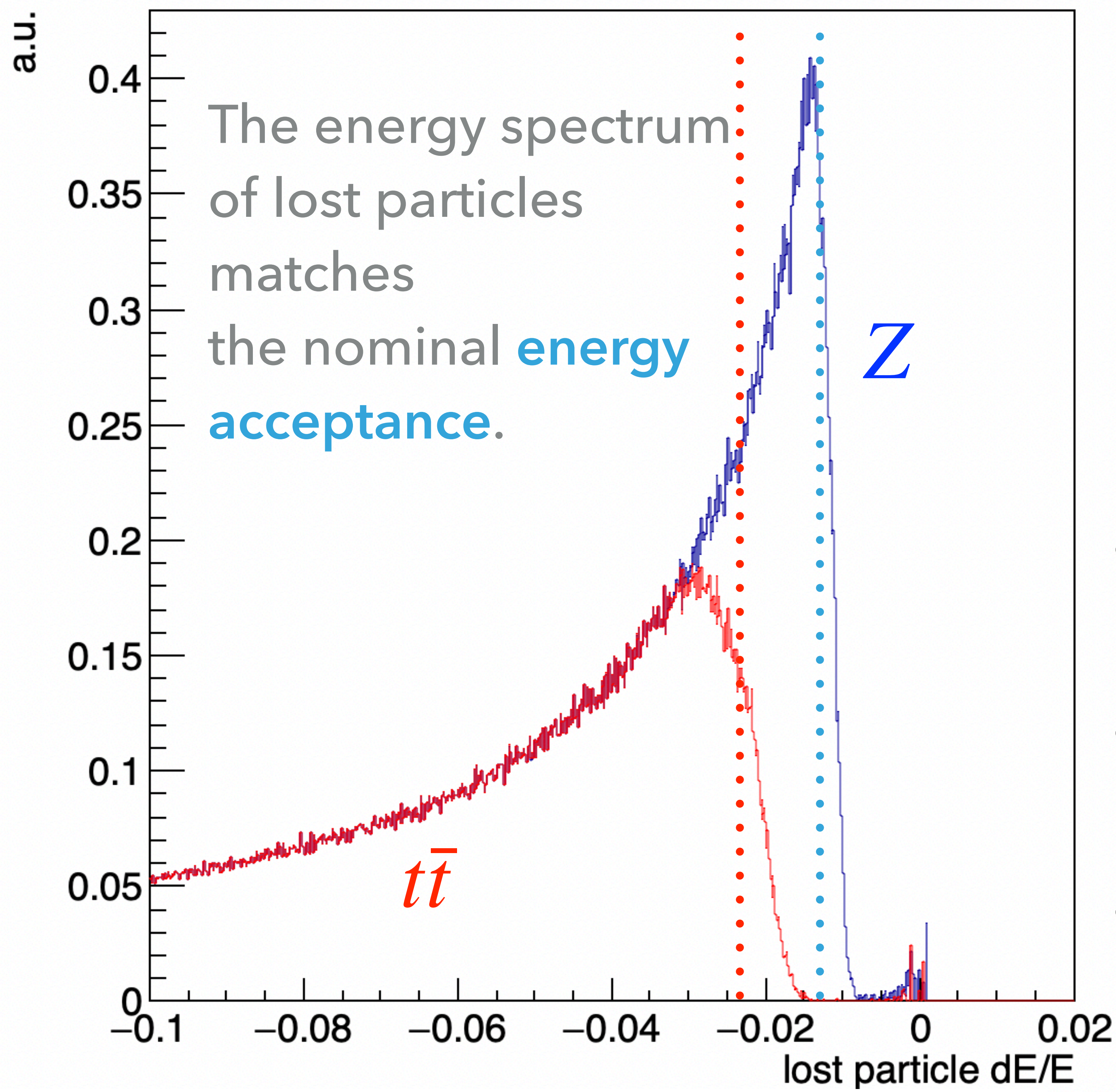




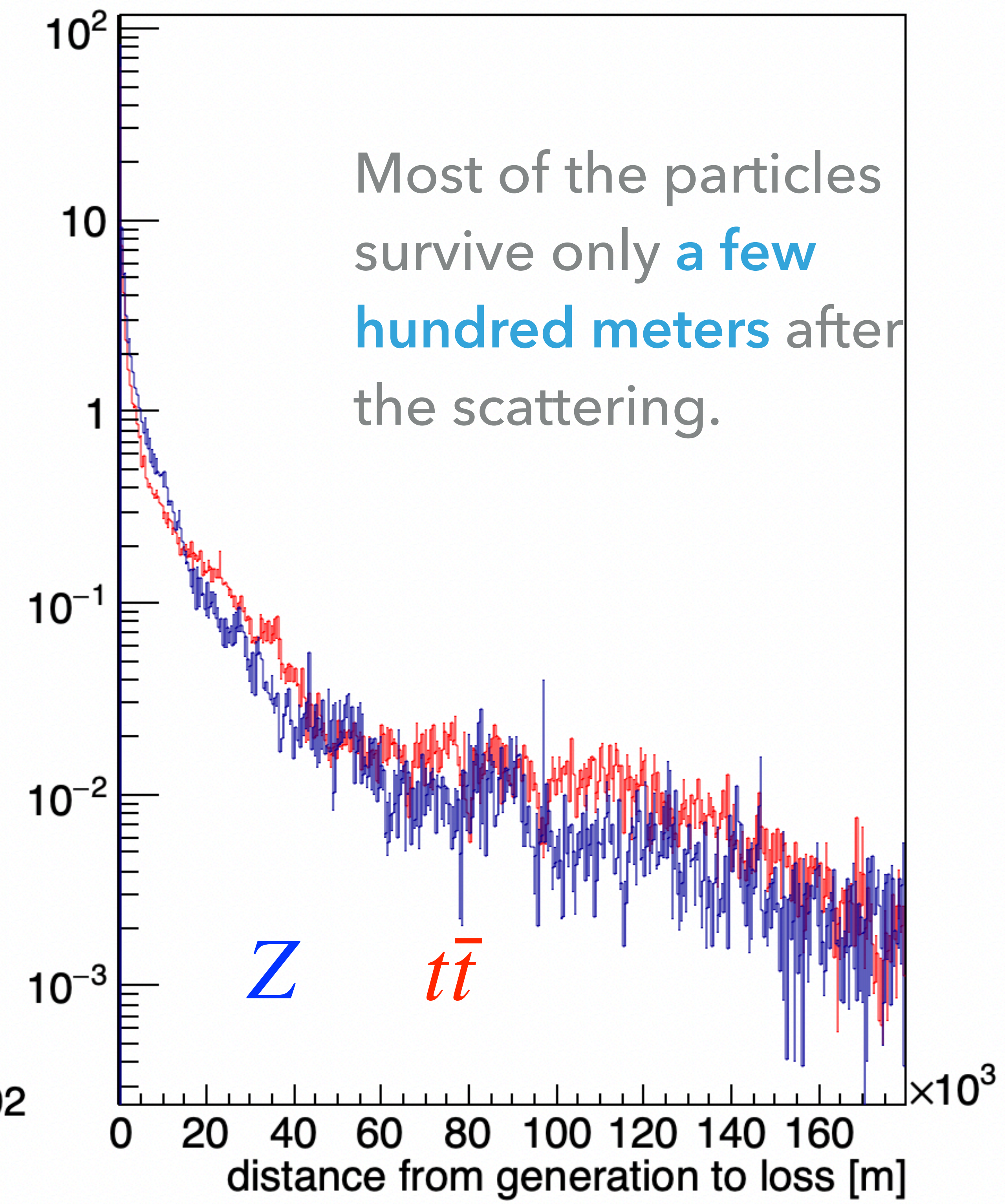
The cumulative loss rate in proximity of the IP is:

170MHz @45.6GeV in excellent agreement with MDIsim simulations (IPAC18 - M.Boscolo et al)

0.55MHz @182.5GeV due to the lower beam current



The energy spectrum of lost particles matches the nominal **energy acceptance**.



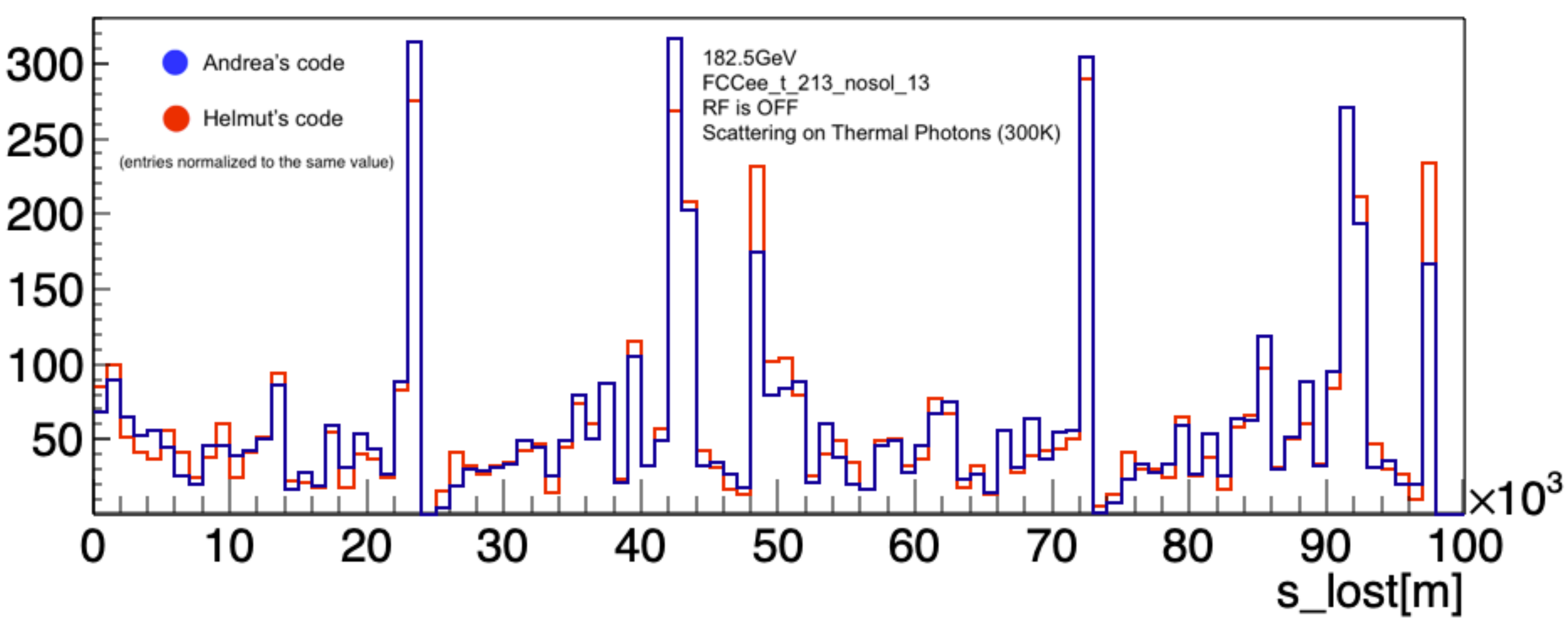
Most of the particles survive only **a few hundred meters** after the scattering.

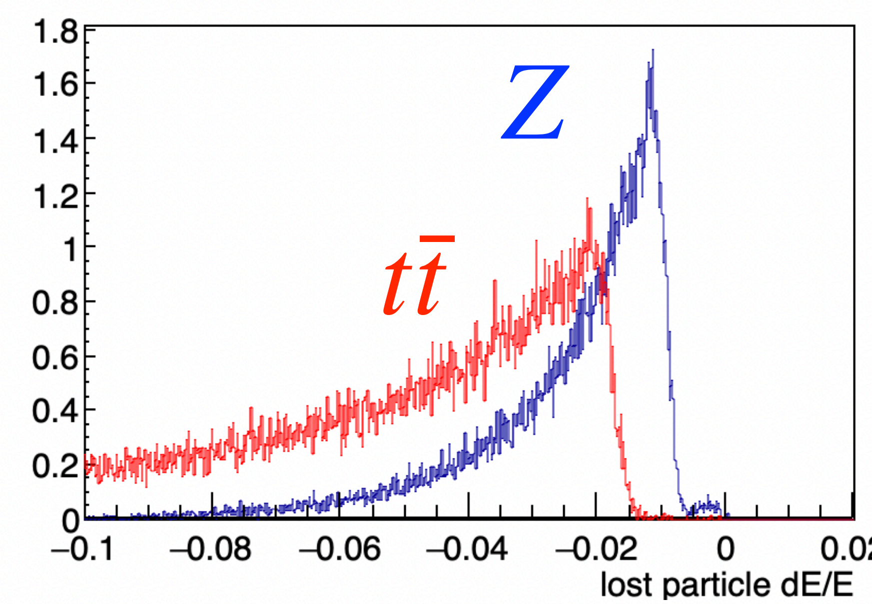
THERMAL PHOTON SCATTERING: SIMULATION RESULTS

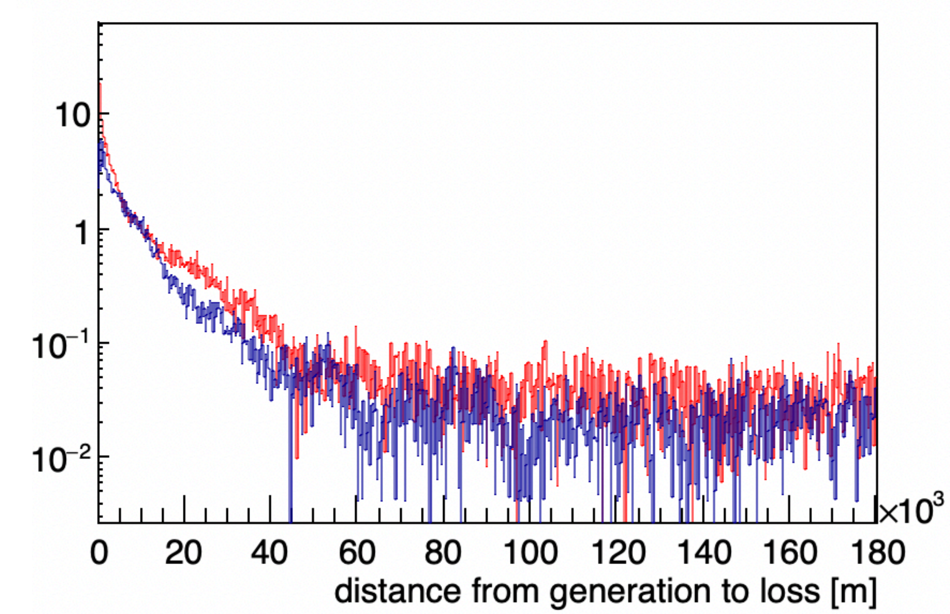
@300K RF off $N_{MC} = 10^5$ FCCee_t_213_nosol_13_noRF.seq FCCee_z_213_nosol_18_noRF.seq

E[GeV]	Beam Current [mA]	$\tau_{MC}\ [h]$	$\Gamma_{MC}\ [MHz]$
45.6	1390	69	11384
182.5	5.4	40	56

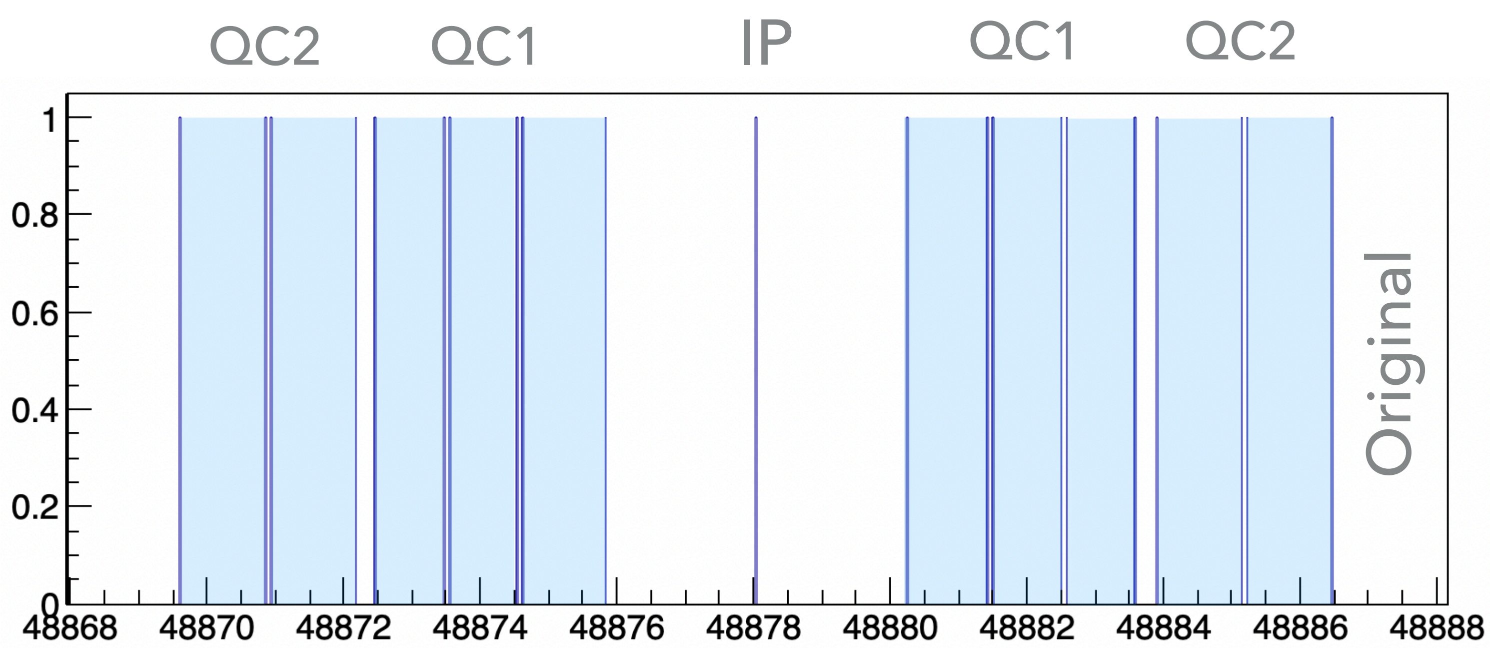
10 turns simulation performed at Z and at $t\bar{t}$ energies. **Generator benchmark** performed with the results from H. Burkhardt (FCCee week 2019)



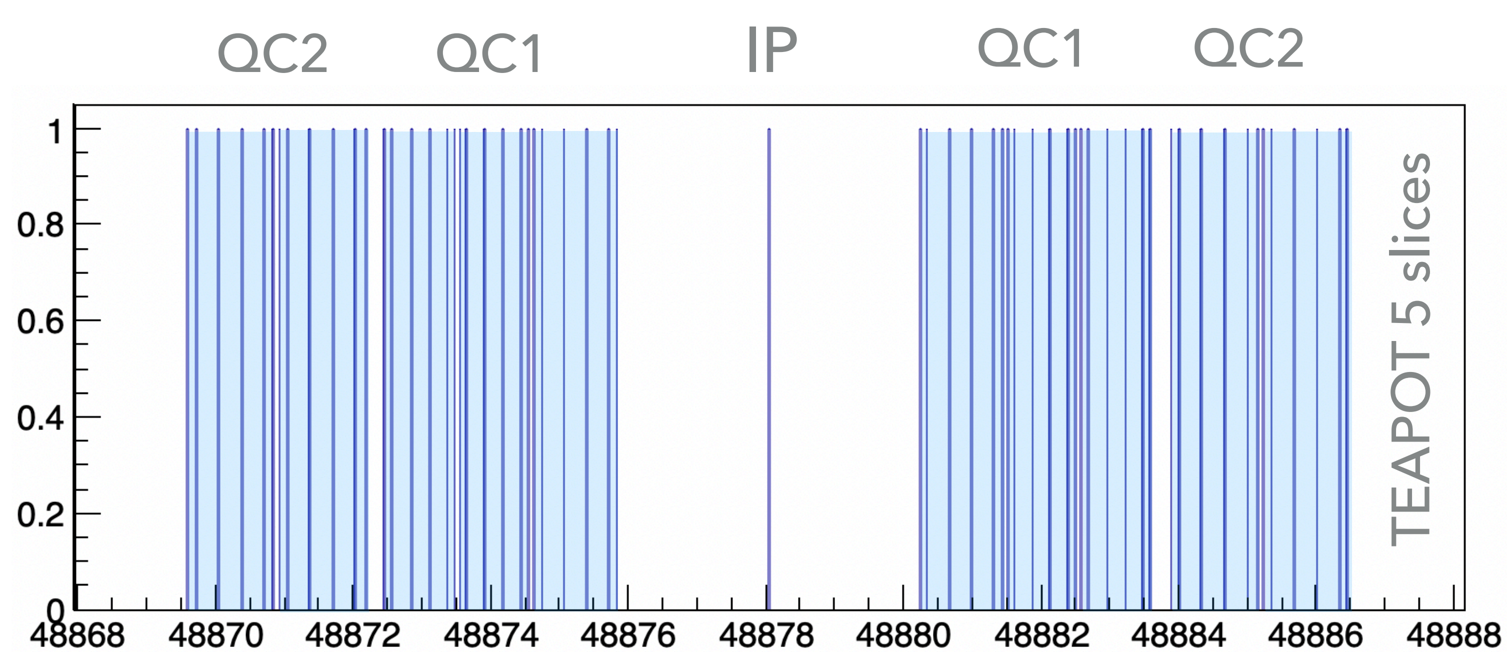




Also in this case scattered particles survive in the ring only for **a few hundred meters**.



As the aperture check is performed at the **beginning of each element** (or drift), we need to improve the longitudinal resolution, in particular for the IR

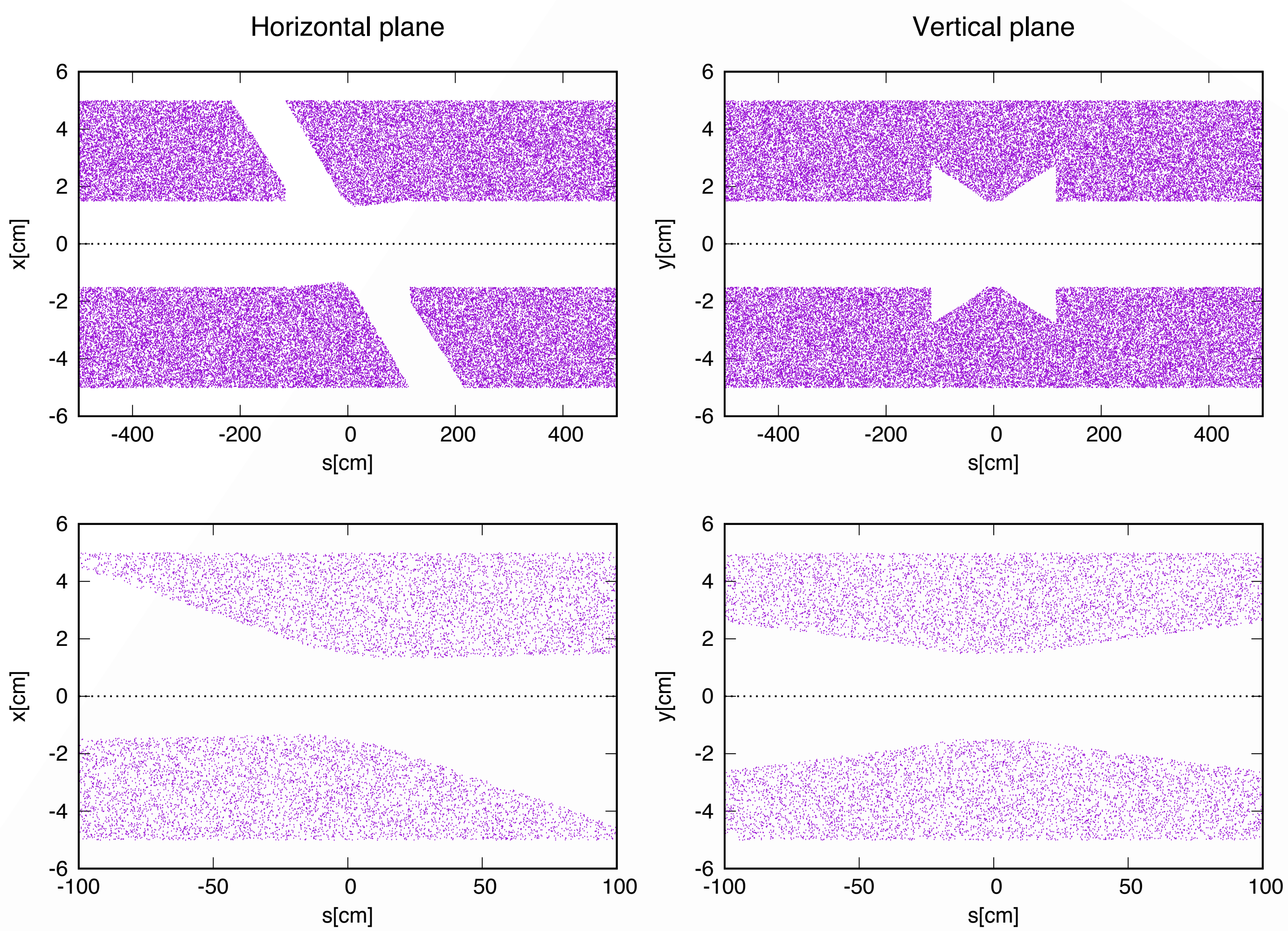


Possible solutions:

- Magnetic elements can be correctly sliced in MAD-X using the **MAKETHIN** routine.
- Drifts cannot be split in this way. A possibility is to use the **INTERPOLATE** routine in MAD-X or to develop a custom script

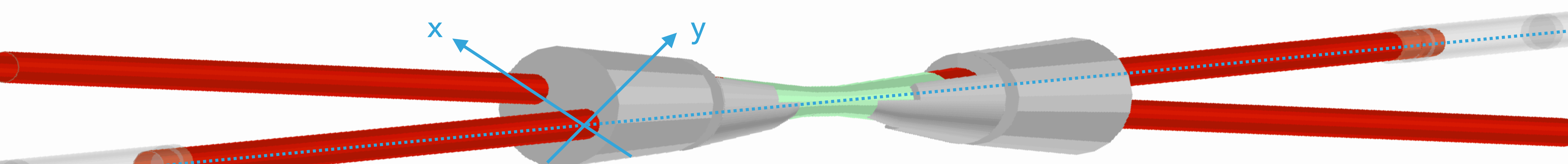
GDML – GEOMETRY DESCRIPTION MARKUP LANGUAGE

GDML is an XML-based language designed to describe the geometries of detectors. This format is very similar to the **Geant4 geometry description** and can easily be read using **ROOT**.



This geometry description allows a much more precise check on physical apertures, in particular for **irregularly shaped** sections, like the IR

Test: generate random particles in the IR, and consider **lost** those who are in a volume with material **different from vacuum**.



Geometry_beampipeAssembly_v01_scale1.gdml

IN CONCLUSION:

An update on the status of the **beam background simulation tool** has been presented

An introduction to the **structure of the code** and first results for **inelastic beam-gas** and **thermal photon** scattering at Z and $t\bar{t}$ have been shown

Still working to improve the **longitudinal axis resolution** for the loss map. Slicing of magnetic elements is ok, while for drifts it is still on-going.

Information on the geometry of the IR can now be read from GDML files, in order to **improve the check on physical aperture**

Proposal of further improvements and applications:

- CPU speed optimisation
- development of generators for other processes (beamstrahlung, touschek, elastic bg)
- study of **non-gaussian beam-induced background**
- use more **realistic lattices** using synchrotron radiation, solenoids, misalignments…

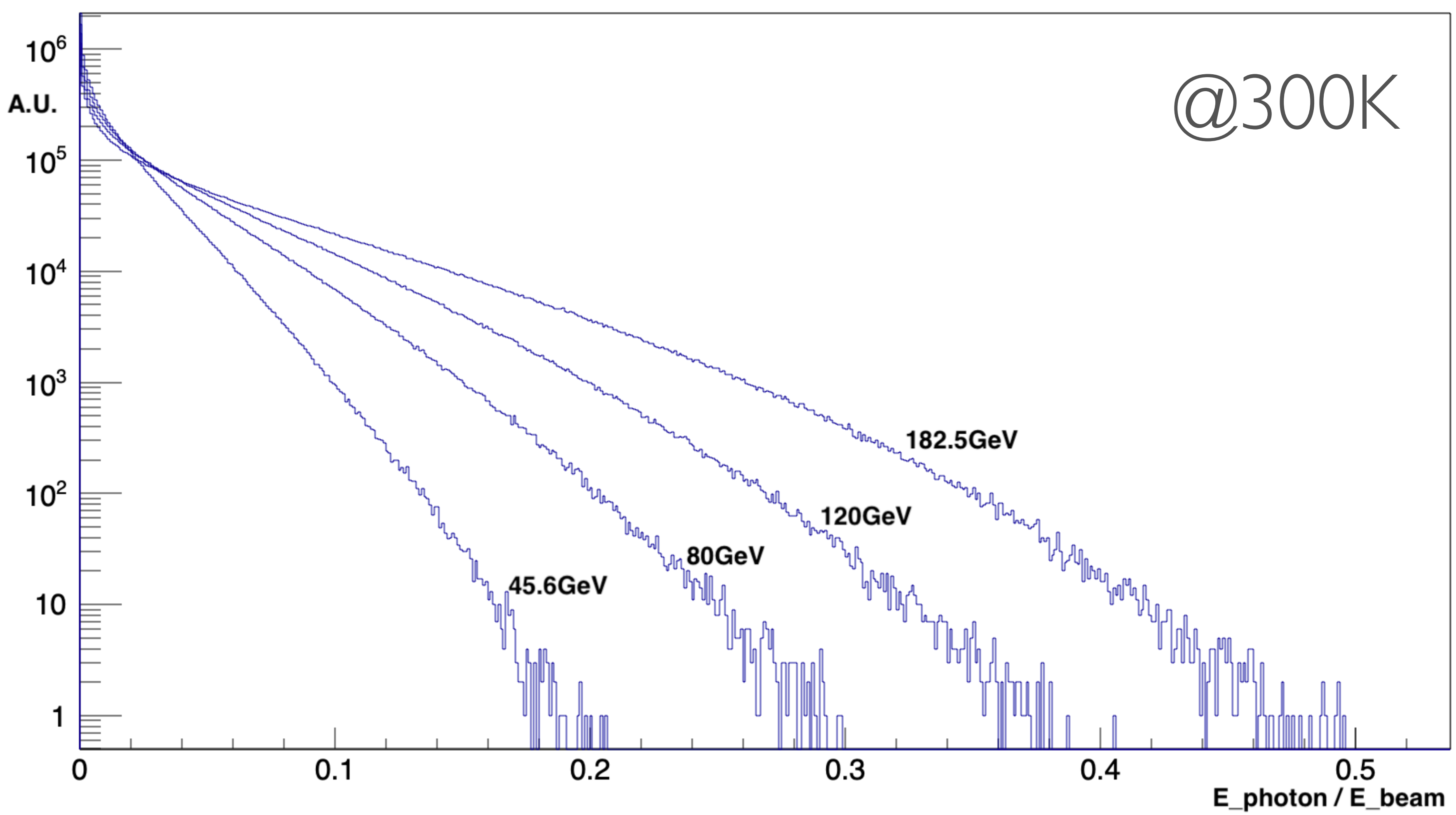
BACKUP

PHOTON ENERGY SPECTRUM DISTRIBUTION

V. I. Telnov - NIM A260 (1987) 304-308
H. Burkhardt - SL/Note 93-73 (OP)

$$\frac{d\sigma}{dy} = \frac{2\sigma_0}{x}\left[\frac{1}{1-y} + 1 - y - 4r(1-r)\right]$$

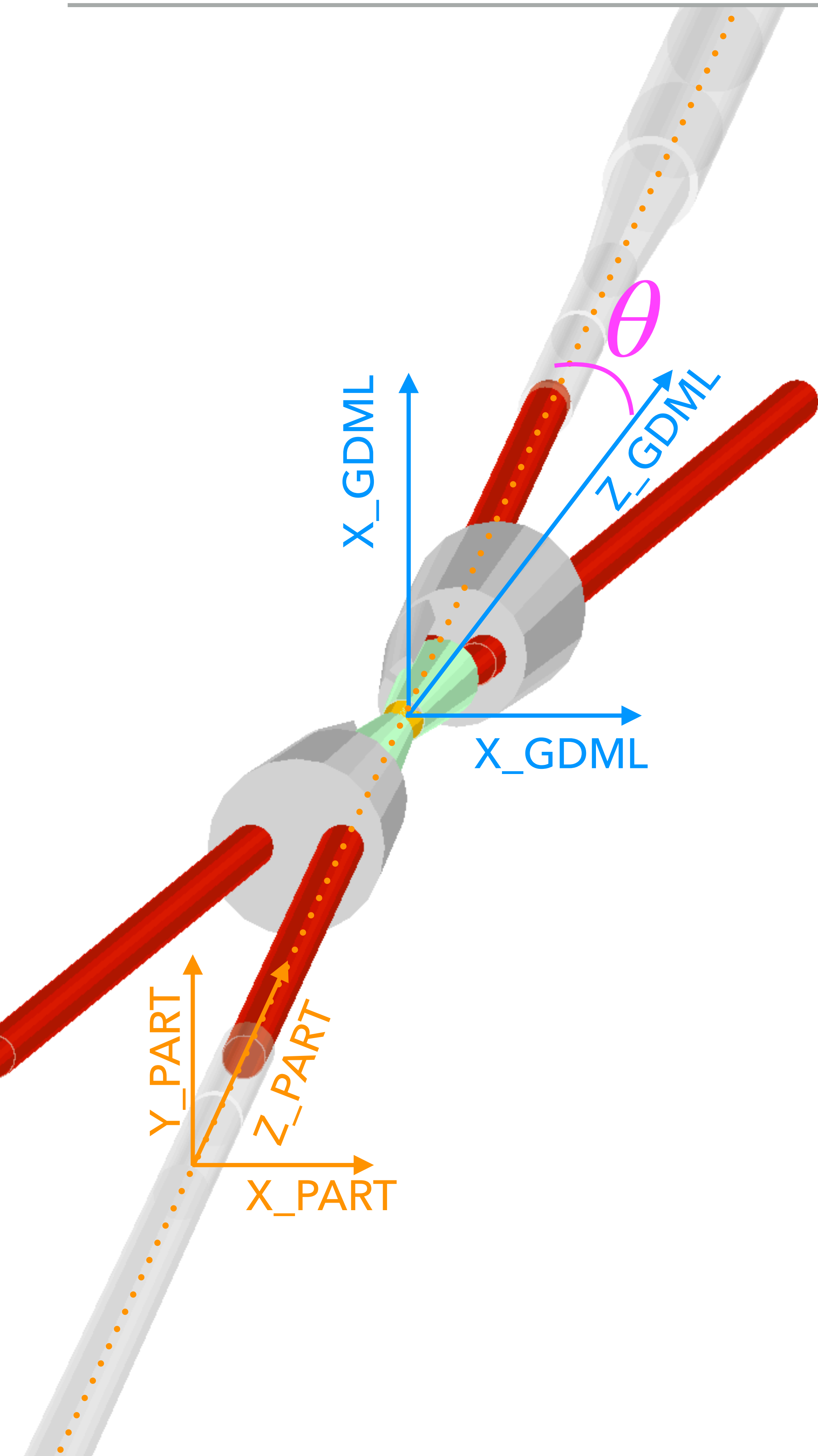
$$x = \frac{4E\omega_0 cos^2(\alpha/2)}{(mc^2)^2}$$



$$0 \leq y \leq y_{max} = \frac{x}{1+x}$$

$$y = \omega'/E$$

$$r = \frac{y}{x(1-y)}$$



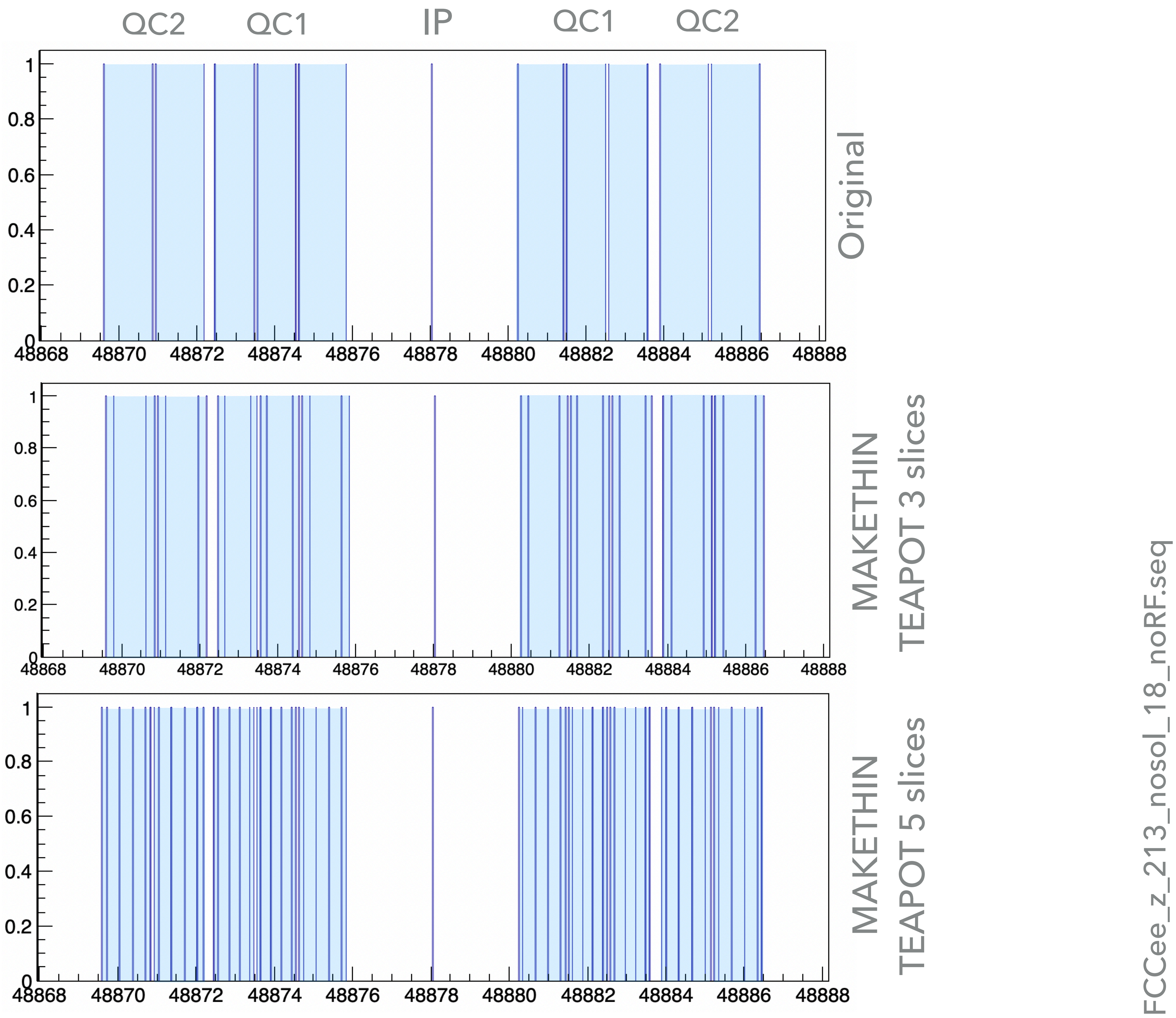
The only main issue at the moment is the **reference frame** of the GDML.

While for the tracking coordinates are given with respect to the trajectory of the reference particle, in GDML the origin is the center of the top volume, which is quite arbitrary.

Anyway, as long as the reference particle trajectory in the GDML frame is a **straight line**, the transformation between the two frames is just a rotation and a shift on the longitudinal direction

(0,0,0)_GDML = (0,0,S)_PART

$$\begin{pmatrix} x_{GDML} \\ z_{GDML} \end{pmatrix} = \begin{pmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{pmatrix} \begin{pmatrix} x_{PART} \\ z_{PART} - S \end{pmatrix}$$


QC2
QC1
IP
QC1
QC2
Original
MAKETHIN
TEAPOT 3 slices
MAKETHIN
TEAPOT 5 slices
FCCee_z_213_nosol_18_noRF.seq

```
select, flag=interpolate, class=drift, step=0.199999995;
```

WEIRD BEHAVIOR: an extra slice is created, at the place of the next element. All elements get shifted and the effect accumulates for each split element.

Original

Row	name	pos
0	"SEQ$STAR	0
1	"IP.1"	0
2	"DRIFT_0"	2.2002250
3	"QC1R1.1"	3.4002250
4	"DRIFT_1"	3.4802250
5	"QC1R2.1"	4.4802250
6	"DRIFT_2"	4.5602250
7	"QC1R3.1"	5.5602250
8	"DRIFT_3"	5.8602250
9	"QC2R1.1"	7.1102250
10	"DRIFT_4"	7.1902250
11	"QC2R2.1"	8.4402250
12	"PQC2RE.1	8.4402250
13	"DRIFT_5"	10.040249
14	"QT1.1"	11.040249
15	"DRIFT_6"	12.640274
16	"QC3.1"	16.140274
17	"DRIFT_7"	19.268681
18	"QC4.1"	22.768681
19	"DRIFT_8"	23.068681

Interpolate

Row	name	pos
0	"SEQ$STAR	0
1	"IP.1"	0
2	"DRIFT_0"	0.2000204
3	"DRIFT_0"	0.4000409
4	"DRIFT_0"	0.6000613
5	"DRIFT_0"	0.8000818
6	"DRIFT_0"	1.0001022
7	"DRIFT_0"	1.2001227
8	"DRIFT_0"	1.4001432
9	"DRIFT_0"	1.6001636
10	"DRIFT_0"	1.8001841
11	"DRIFT_0"	2.0002045
12	"DRIFT_0"	2.2002250
13	"DRIFT_0"	3.4002250
14	"QC1R1.1"	3.4802250
15	"DRIFT_1"	4.4802250
16	"QC1R2.1"	4.5602250
17	"DRIFT_2"	5.5602250
18	"QC1R3.1"	5.8602250
19	"DRIFT_3"	7.1102250