Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DI FRASCATI

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

Status update of the code development

Andrea Ciarma

Thanks to Manuela Boscolo

FCCee MDI Meeting #26 - 25 May 2020

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)

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)

CODE SPECIFICS

- **MAD-X** for the evaluation of transport matrices (simplectic)
- **Monte Carlo approach** (C++) to track the beam particles that experience:
  - Elastic beam-gas (Coulomb)
  - Inelastic beam-gas (Bremstrahlung)
  - Thermal photon scattering (H.Burkhardt FCCweek19)
  - Touschek
  - radiative Bhabha
  - beamstrahlung
- **Multiturn tracking** can be performed through the ring
- **Record 6D coordinates of the lost particles** in .root file

(to be tracked in the detectors with G4)

PARTICLE TRACKING METHOD

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) and length.

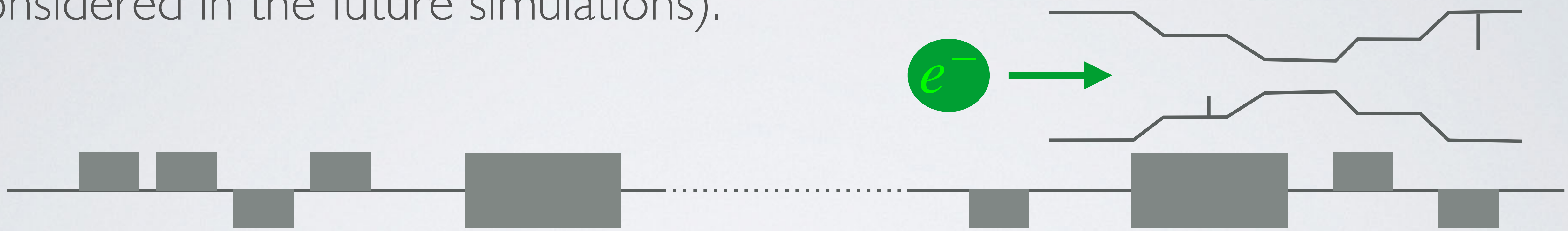
A particle with 6-D phase space coordinates $\overrightarrow{x_0}$ is transported through a given element according to:

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

The 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.

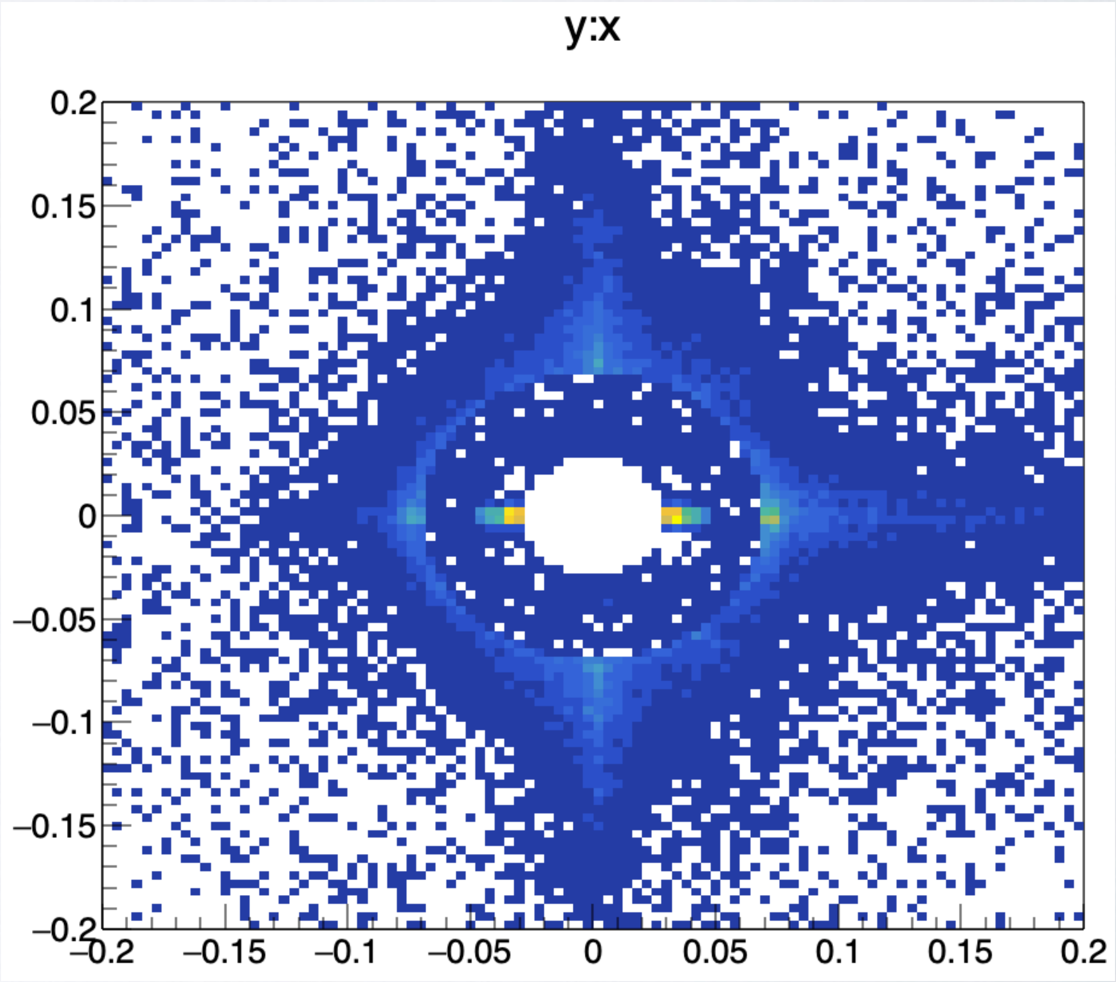
CHECK OF THE PHYSICAL APERTURE

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).



A particle is declared lost only if it is found outside the beam pipe transverse dimension

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



BEAM-GAS SCATTERING

Elastic beam-gas

Handbook of Accelerator Physics and Engineering
A. Chao, M. Tigner

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

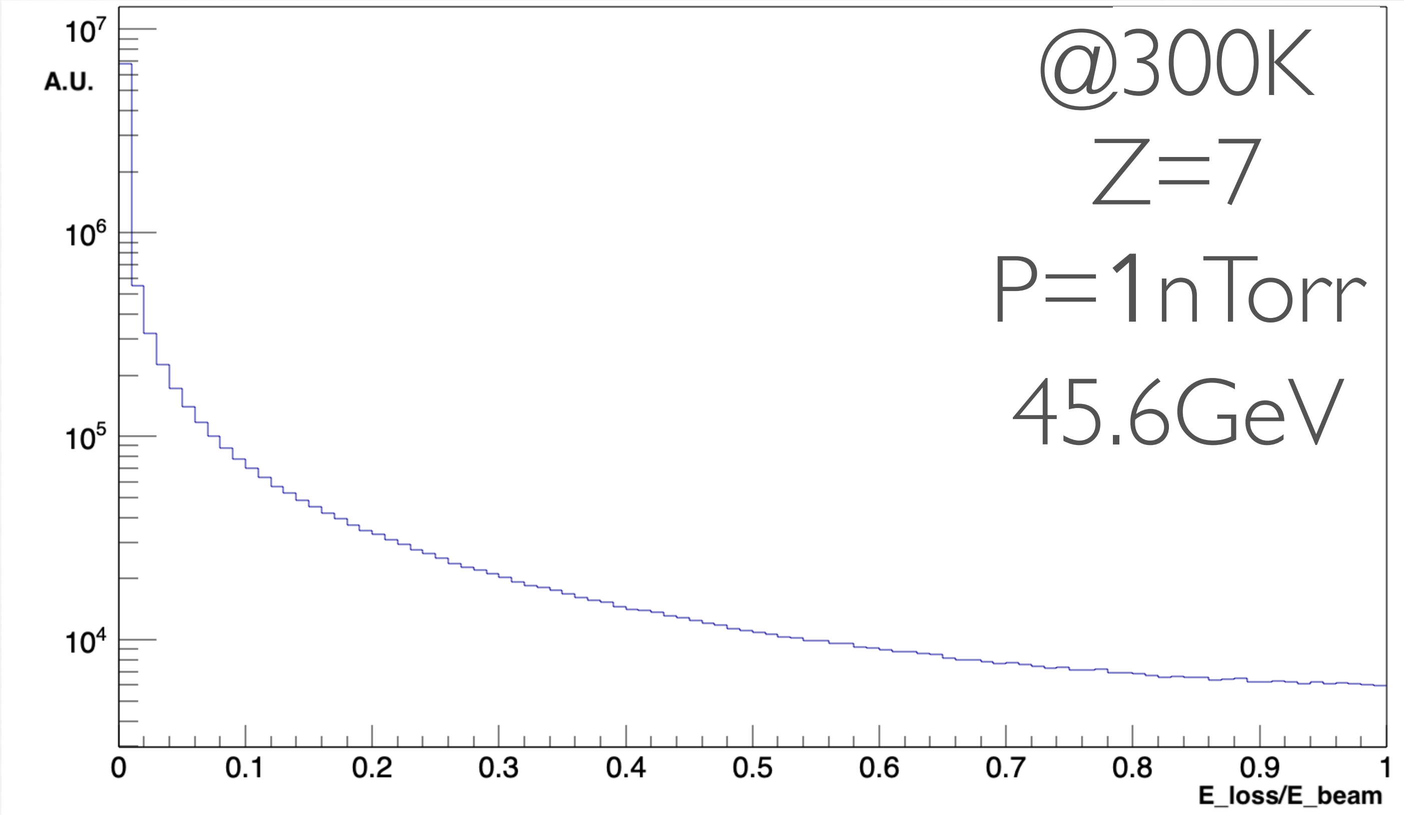
$$\theta_{min} = \alpha Z^{1/3} \frac{m_e}{E}$$

Inelastic beam-gas

Handbook of Accelerator Physics and Engineering
A. Chao, M. Tigner

$$\frac{d\sigma}{dy} = \frac{16\alpha r_e^2}{3} Z(Z+1)\frac{1}{y} \cdot$$

$$\cdot (1 - y - 0.75y^2) log\left(\frac{184.15}{Z^{1/3}}\right)$$



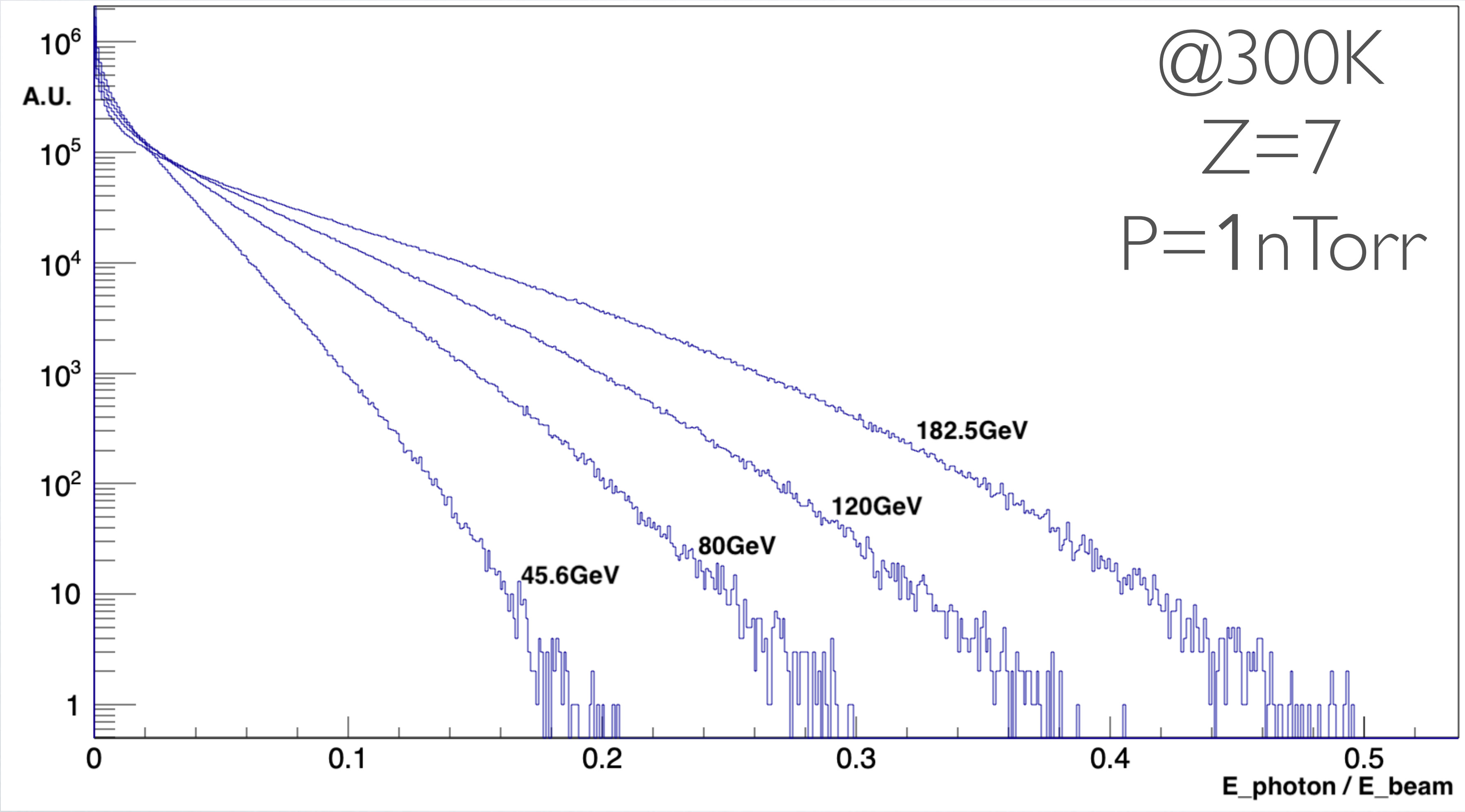
THERMAL PHOTON SCATTERING

Photon energy spectrum distribution

ThermalPhoton and Residual Gas Scattering in the NLC Beam Delivery
I.Reichel, F. Zimmermann, T.O. Raubenheimer, P.Tenenbaum - ICAP98

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

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



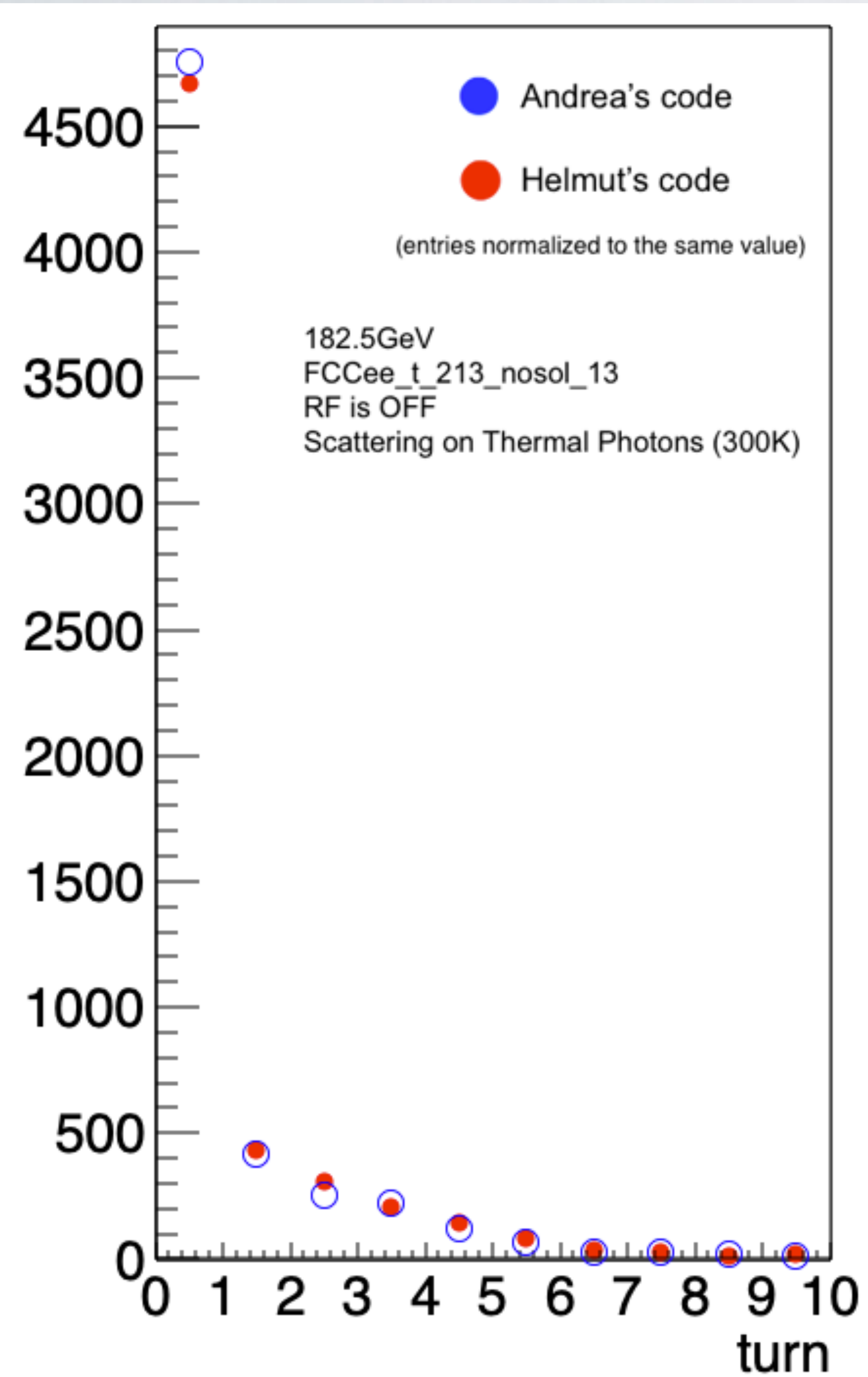
$$0 \leq y \leq y_{max} = \frac{x}{1+x}$$

$$y = \omega'/E$$

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

BENCHMARK: THERMAL PHOTONS

Validation of the code using H.Burkhardt (thank you!) simulations on thermal photon scattering



$E_{e+} = 182.5 GeV \;\; (t\bar{t})$

optics: FCCee_t_213_nosol_13

RF turned OFF

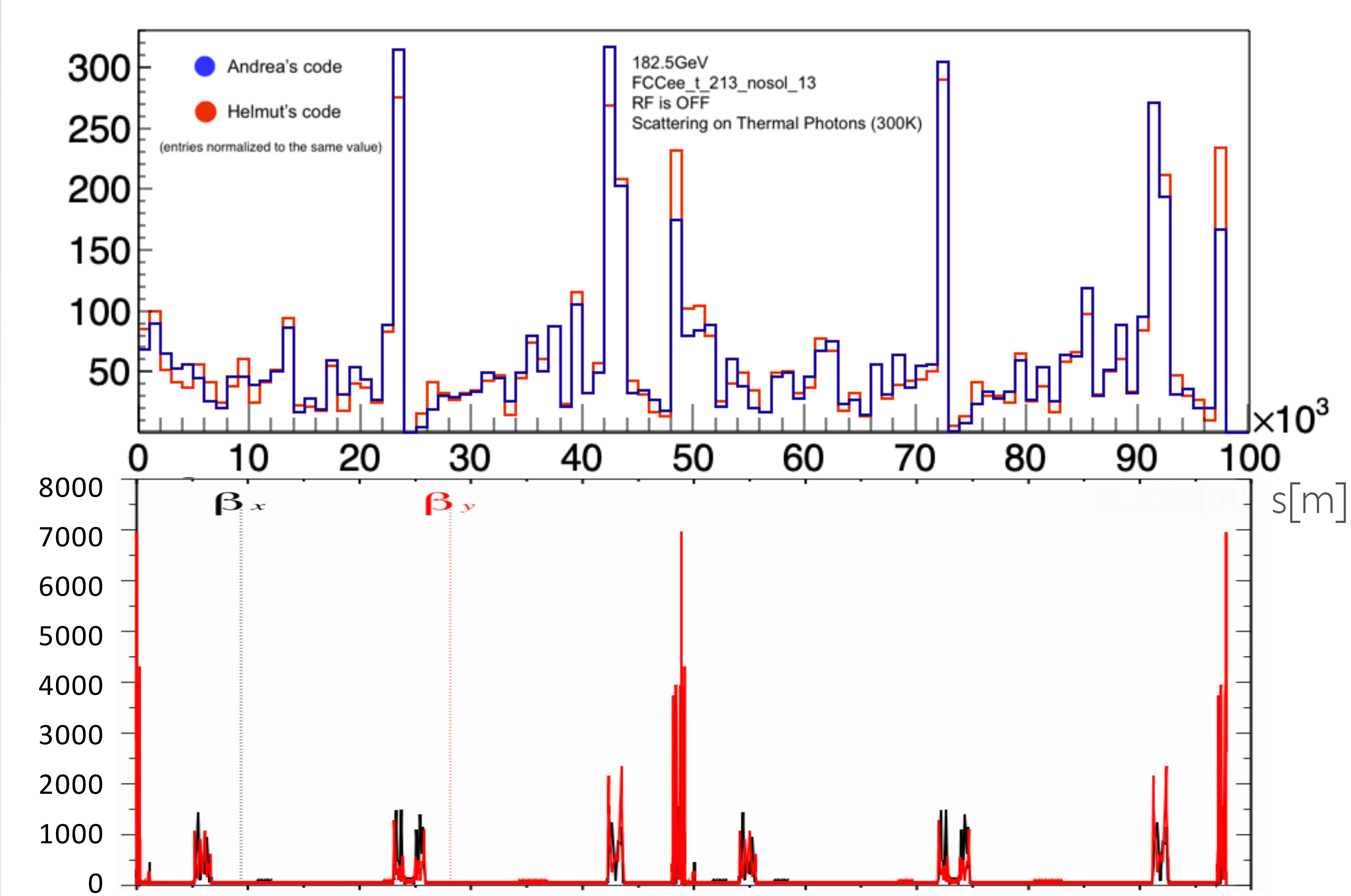
Scattering events evenly distributed along the ring during the first turn.

Most losses happens in the very first turn, so all the following data refer to losses in the **first 10 turns** after the scattering.

Helmut's code:	5923 LOST / 10000 TOTAL	= 59%
Andrea's code:	10680 LOST / 17192 TOTAL	= 62%

Good agreement for both the total loss number and loss/turn distribution

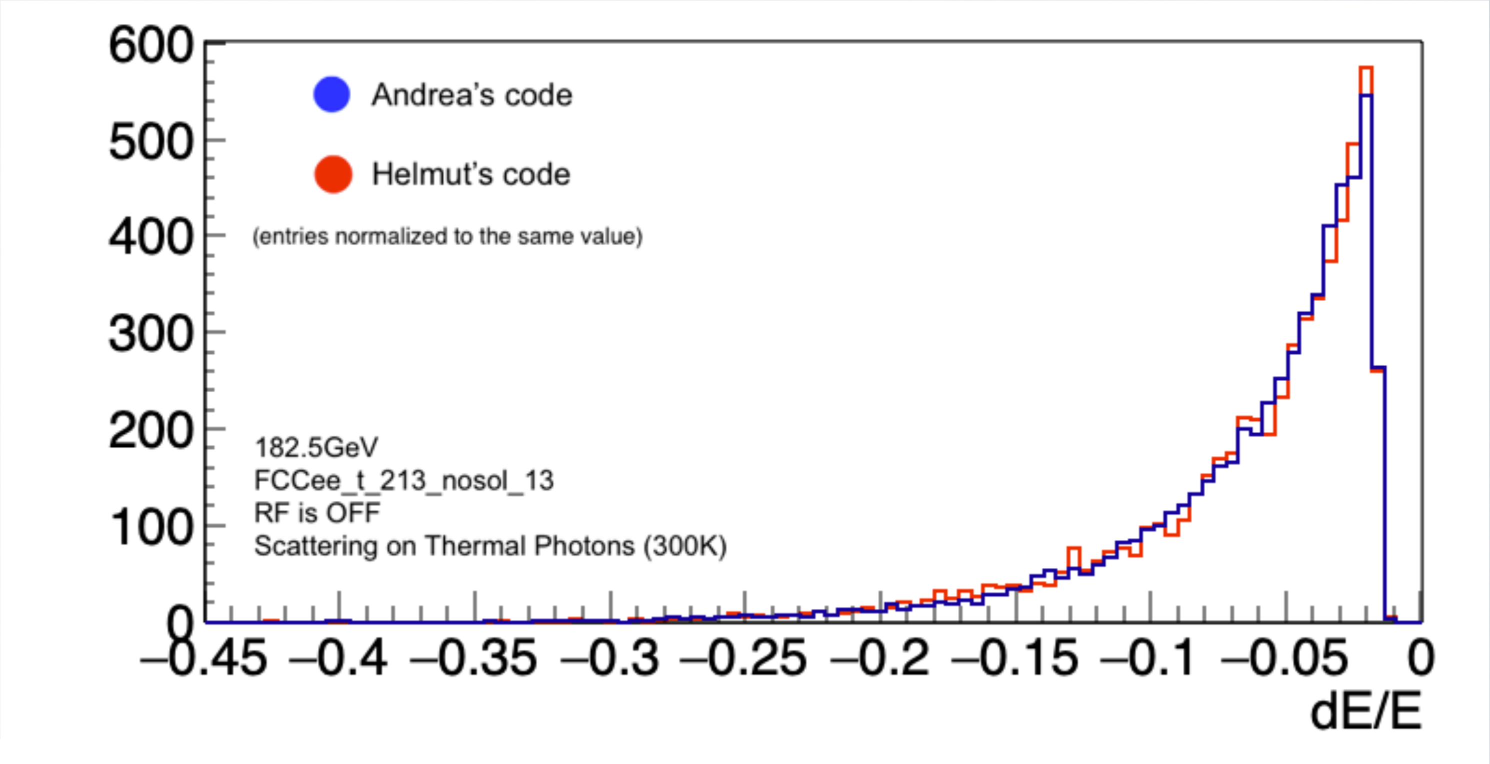
BENCHMARK: THERMAL PHOTONS

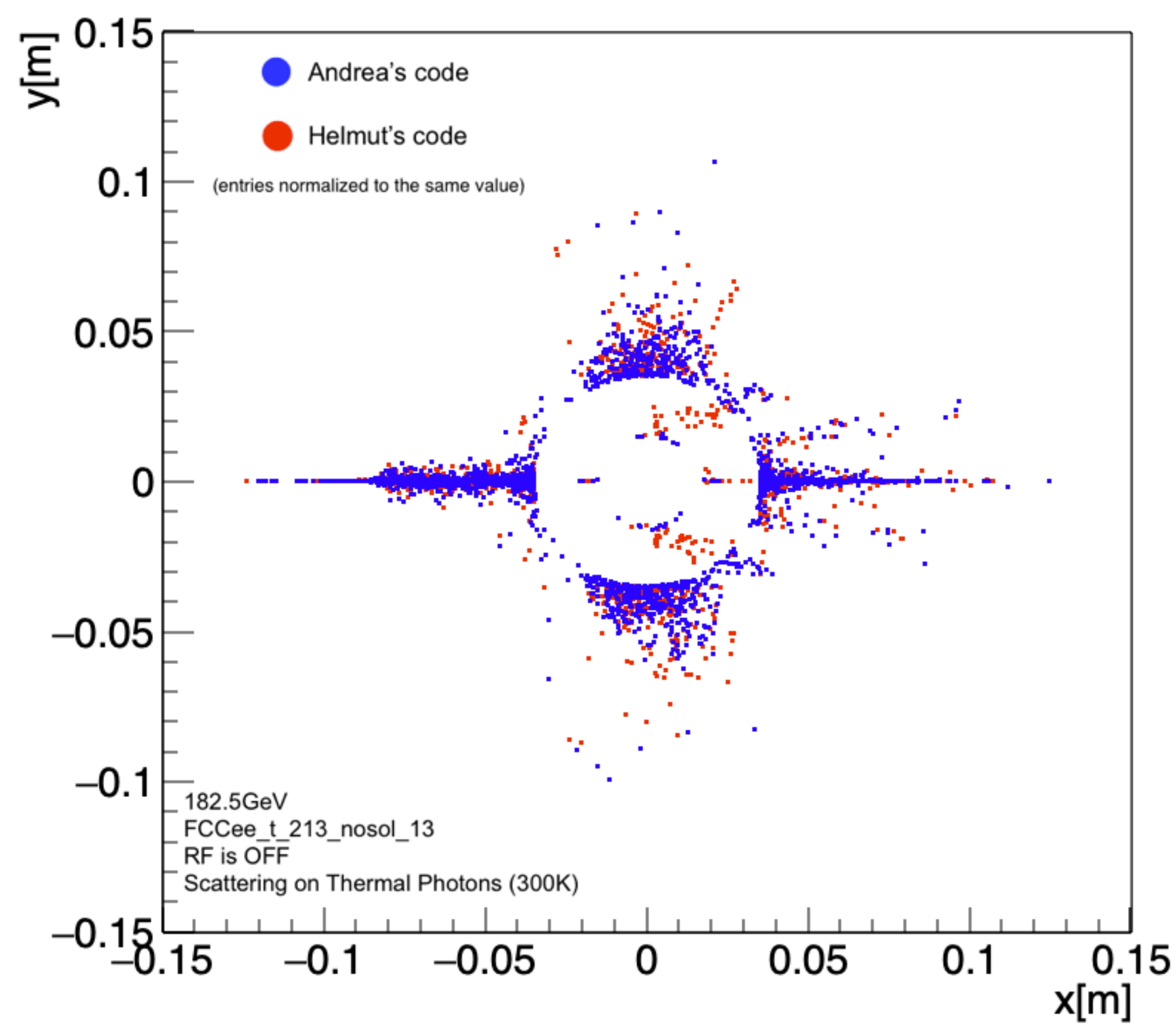


The **loss map** along the ring for the two codes follow the same distribution, with peaks localised in the high-β regions of the optics

BENCHMARK: THERMAL PHOTONS

Excellent agreement also for the energy distribution of the lost particles and their position on the transverse plane.





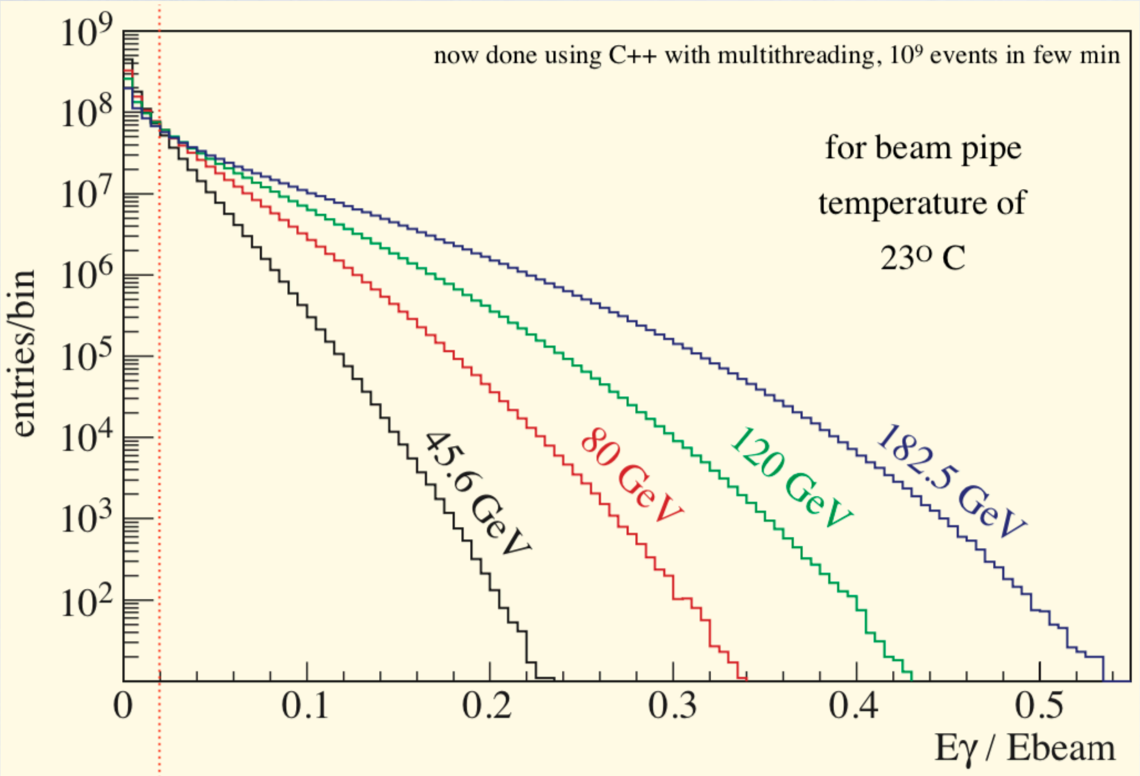
The only small difference (~0.6% of total events) is totally localised on **QC6L**, probably due to a misdefinition of the element aperture.

This element is located 378m from the IP and it is very few events so it is negligible.

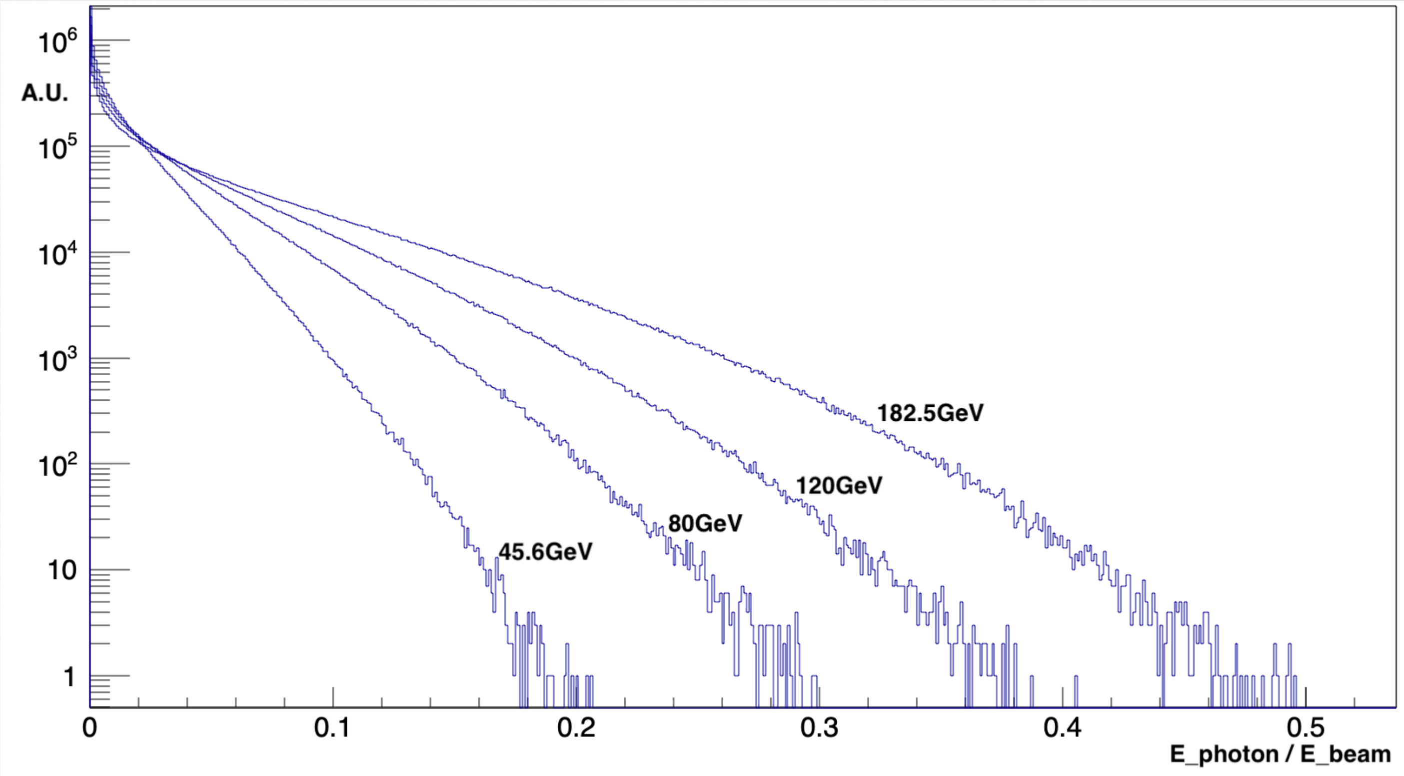
The outcome of this benchmark is an **overall excellent agreement** with Helmut's results

BENCHMARK: THERMAL PHOTONS

H.Burkhardt - FCCweek19



My code

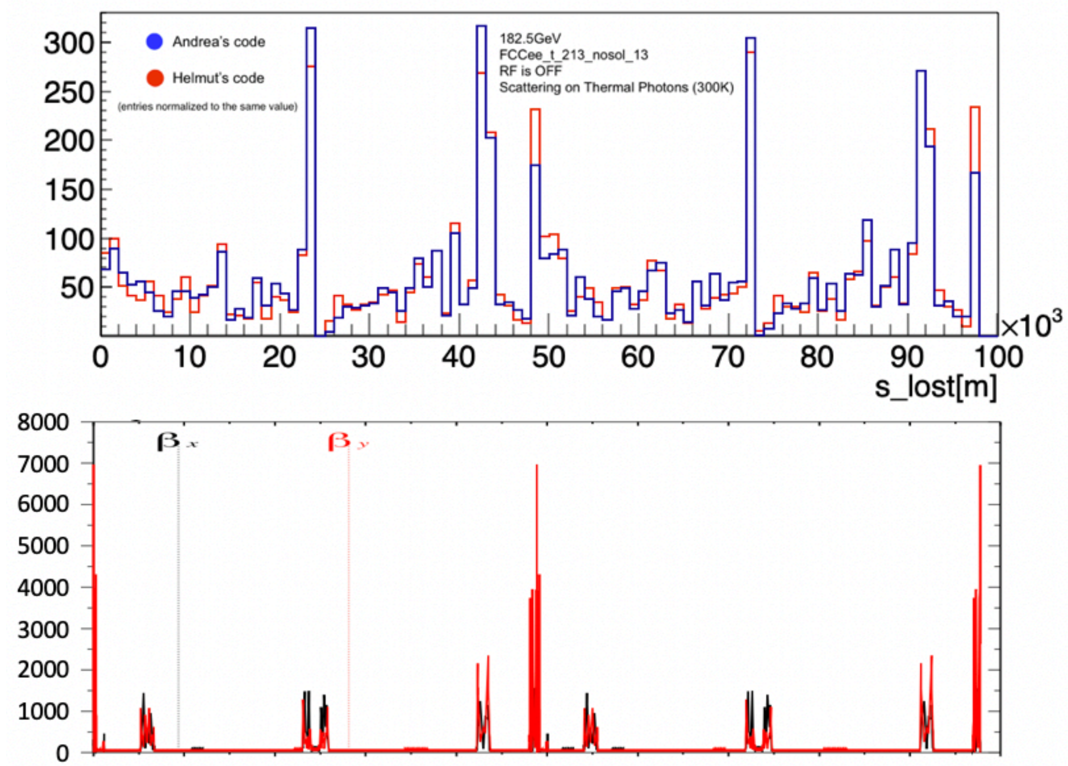


The event generator manages to reproduce correctly the photon energy spectra after the scattering also at **other beam energies**, as seen by the comparison with H. Burkhardt's plot.

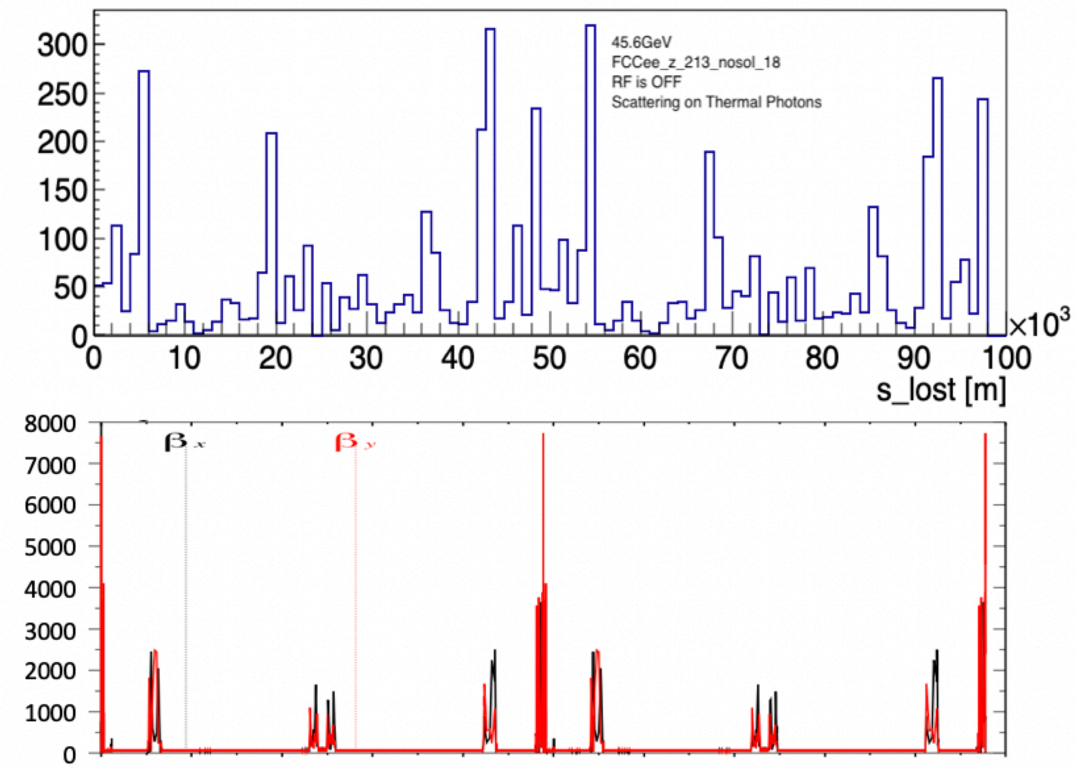
FIRST RESULTS: THERMAL PHOTONS

After the validation I have performed the same simulation for $E_{e+} = 45.6GeV$ (Z)

FCCee @$t\bar{t}$ (182.5GeV)



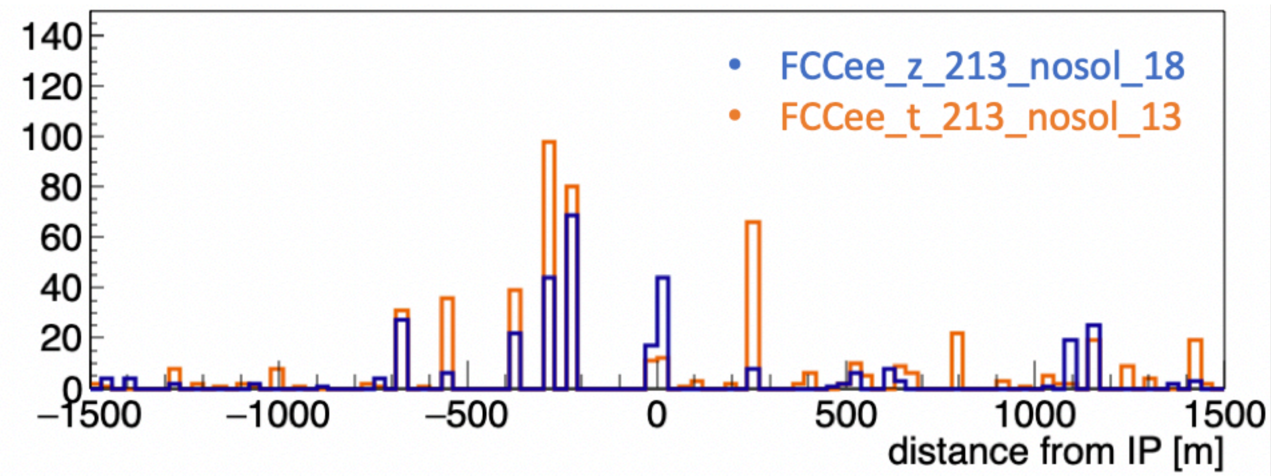
FCCee @Z (45.6GeV)



E [GeV]	σ_{tot} $[barn]$	N_e $[10^{11}]$	% Lost	N_{lost}	N_{bunch}	$Rate_{loss}$ $[GHz]$
45.6	0.666	1.7	40%	234	16640	11.98
182.5	0.616	2.3	62%	455	48	0.067

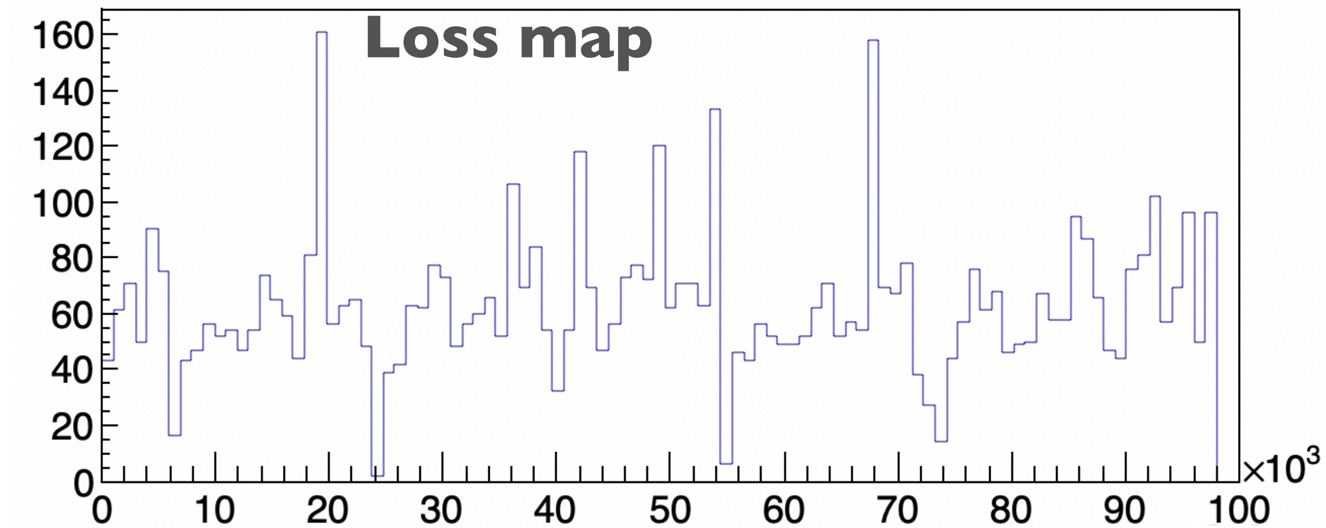
Losses near IP (Thermal Photons)

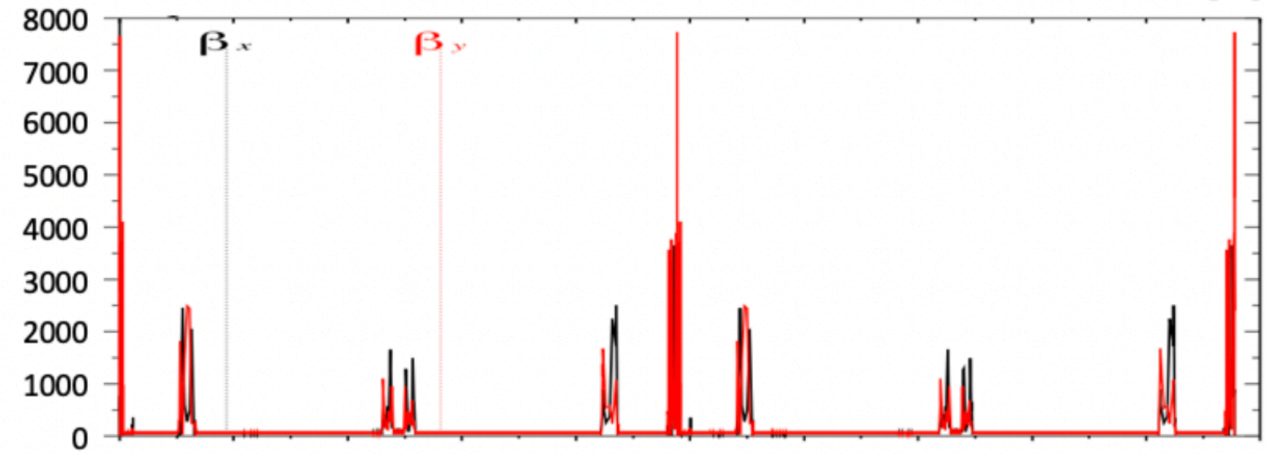
E [GeV]	N_{lost}	$Rate_{loss}[MHz]$
45.6	13.32	681
182.5	22.90	3.37

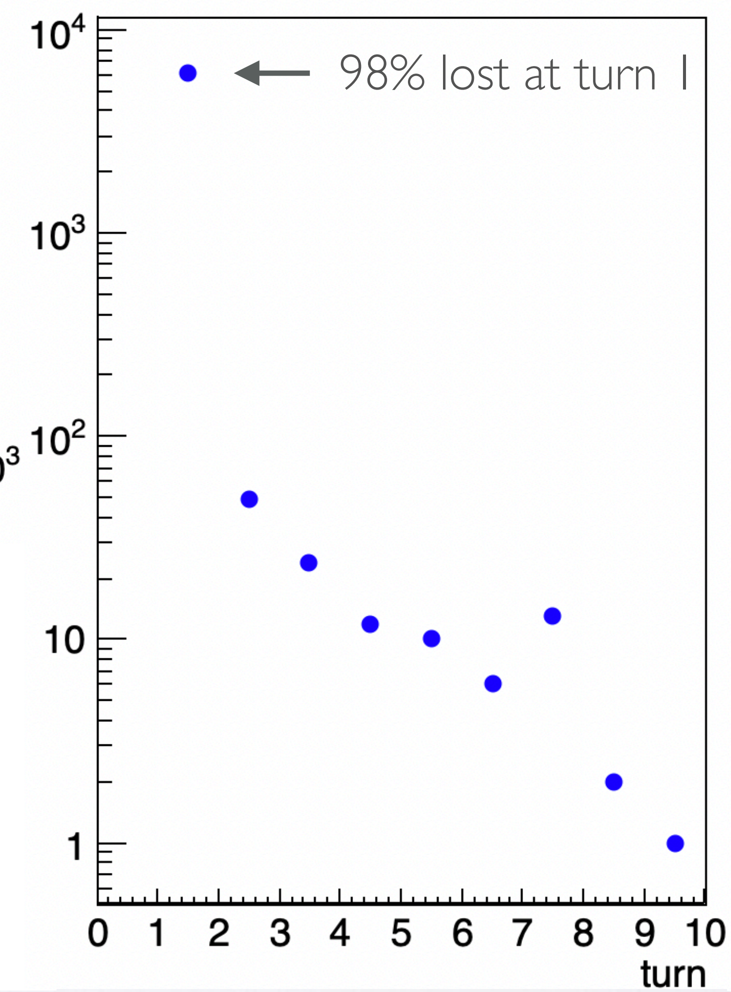


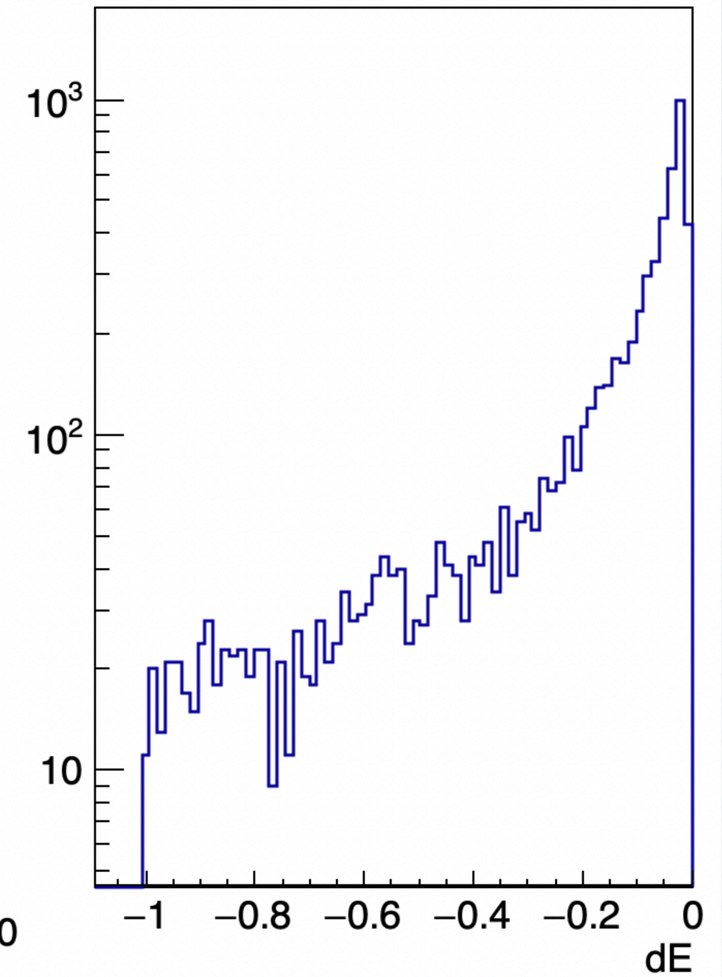
FIRST RESULTS: INELASTIC BEAMGAS

$E_{e+} = 45.6GeV$ FCCee_z_213_nosol_18 (RF OFF)









6246 LOST / 9912 TOTAL = 63%

$Z = 7$ P = 1nTorr

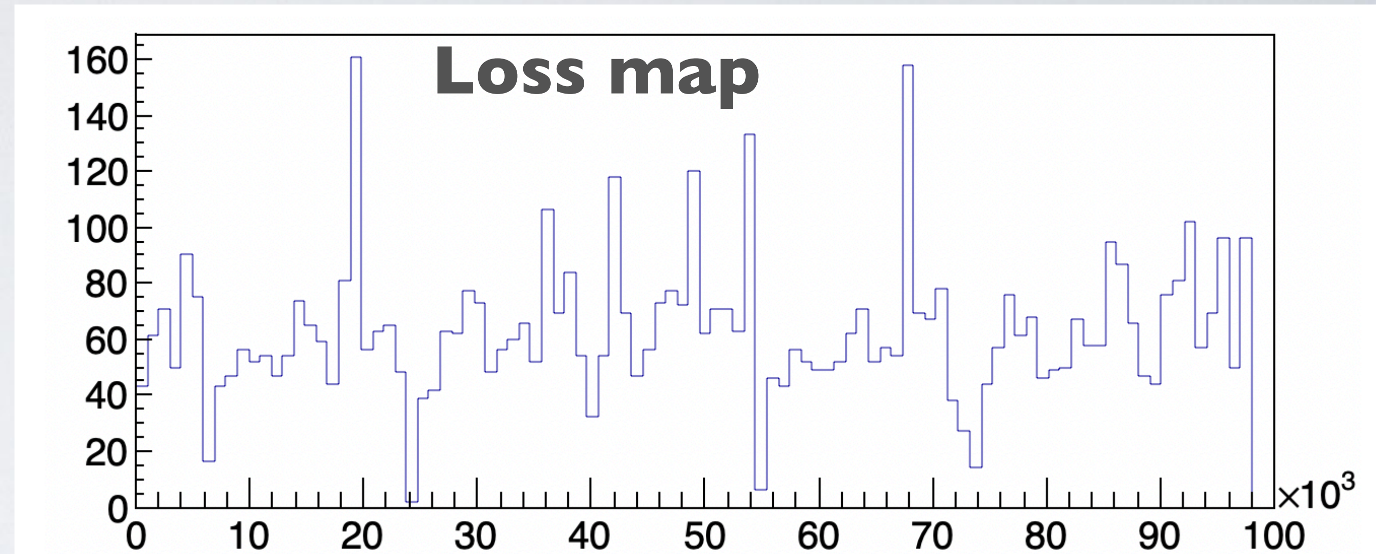
$N_e = 1.7 \times 10^{11}$ $\sigma_{tot} = 4.30 barn$

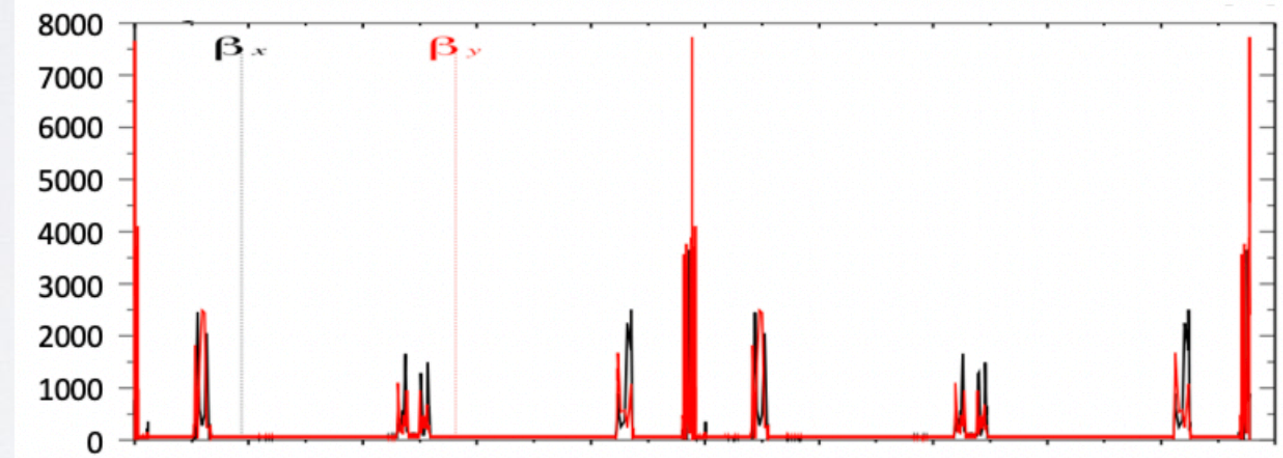
~230 lost particles per bunch

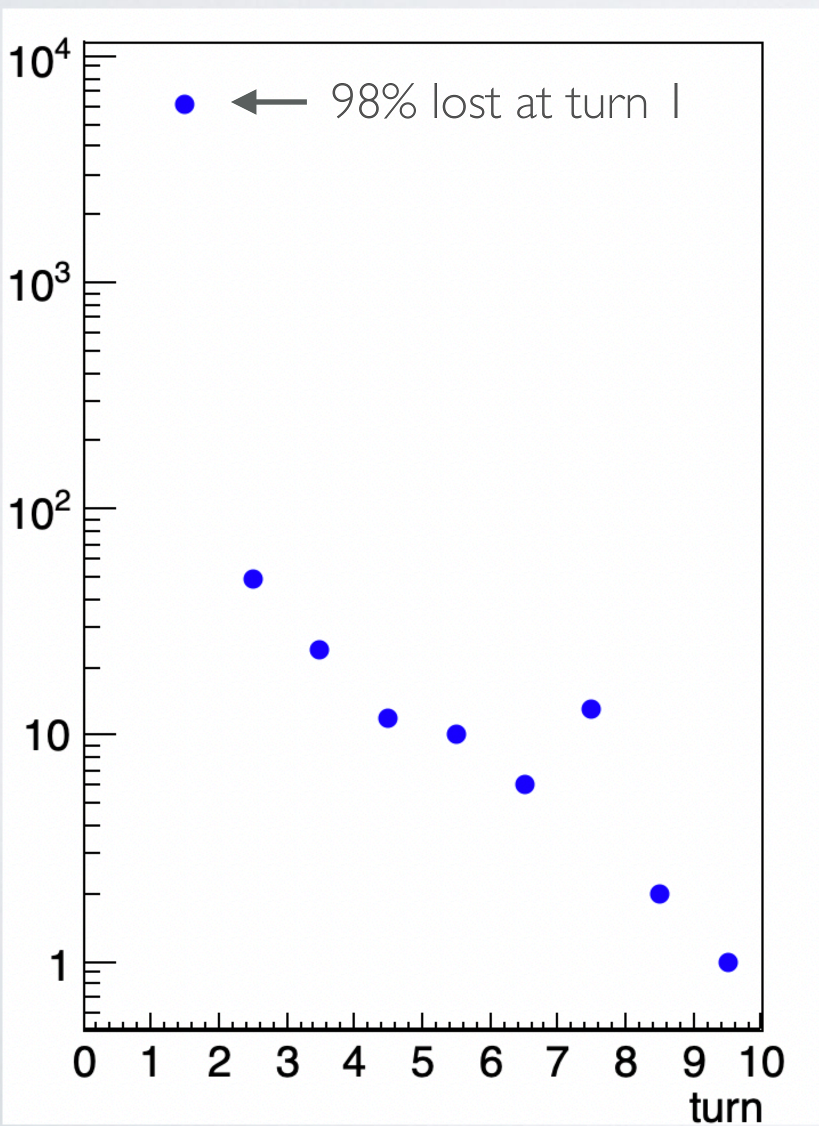
Total Loss Rate ~12GHz

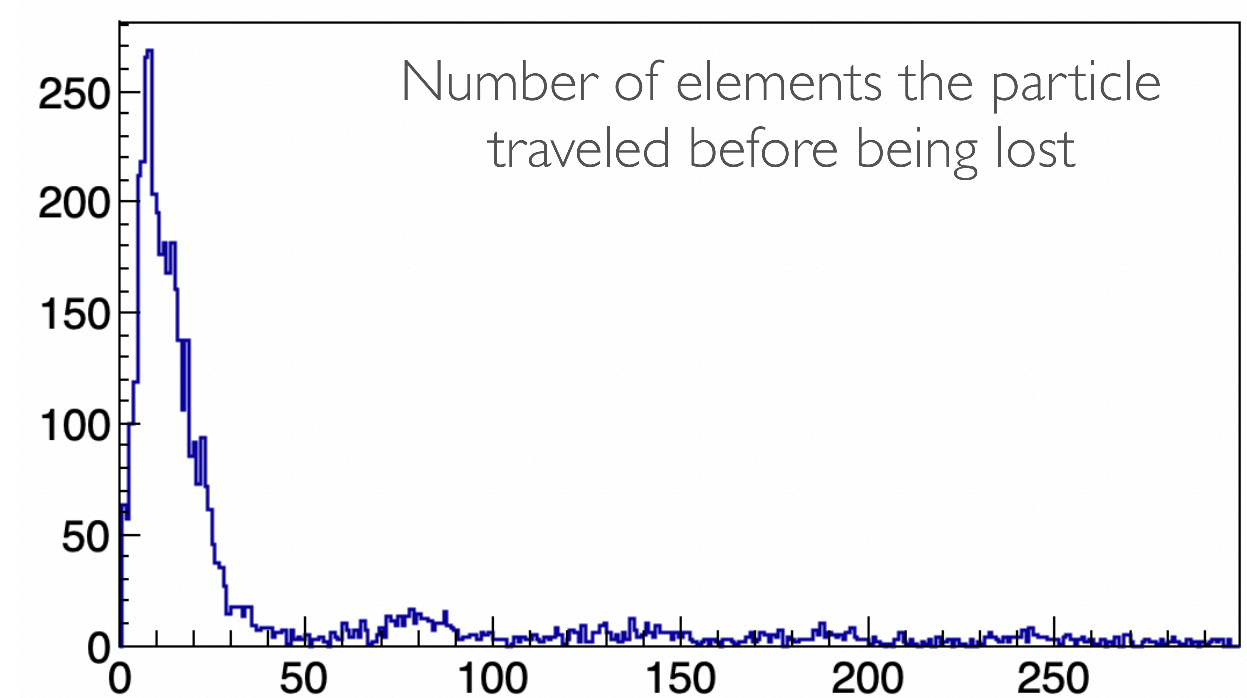
FIRST RESULTS: INELASTIC BEAMGAS

Almost every diffused particle is lost in the **very few next elements** during tracking. For this reason the loss map does not show any strong correlation with the optic functions of the lattice.





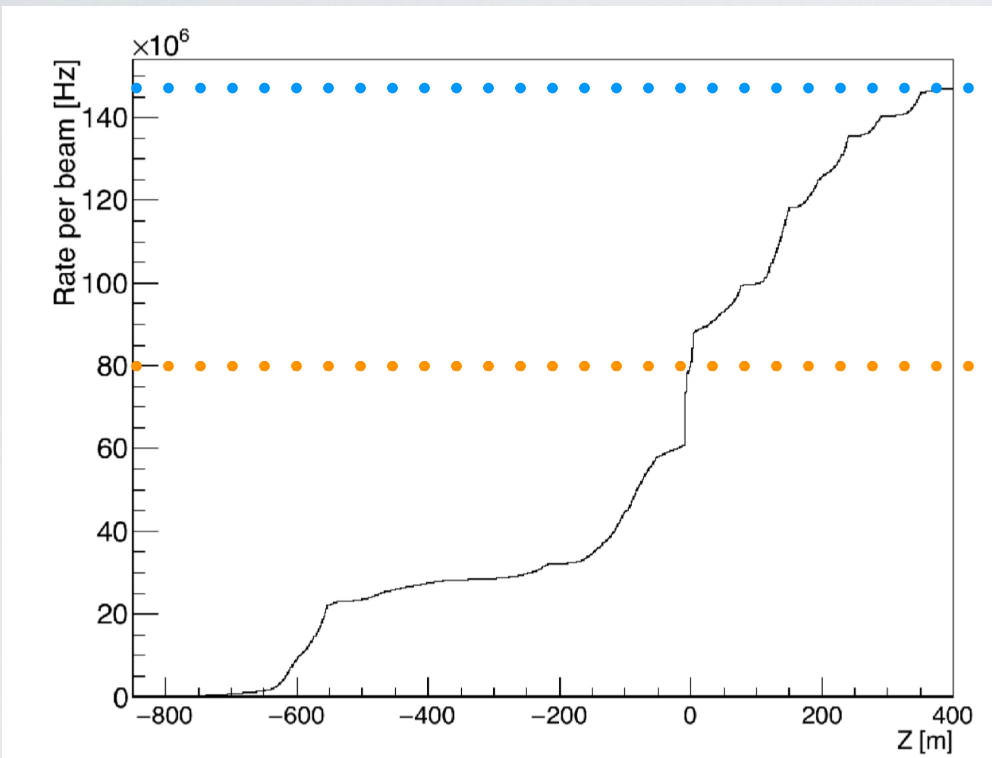




FIRST RESULTS: INELASTIC BEAMGAS

This results can be compared with a previous simulation for inelastic beam-gas in FCCee, presented at FCCweek2018 by F. Collamati

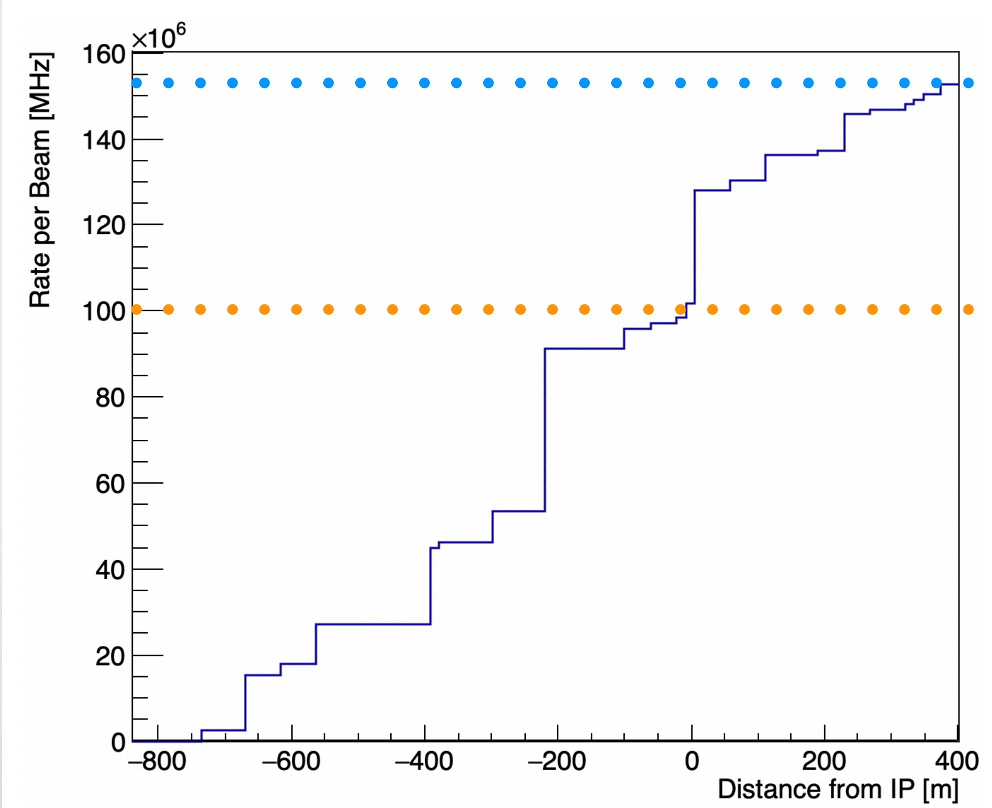
F.Collamati - FCCweek2018



Loss rate between -850m and 400m **~147MHz**

Loss rate between -850m and 0m **~80MHz**

My code



Loss rate between -850m and 400m **~153MHz**

Loss rate between -850m and 0m **~100MHz**

Overall good agreement, slight differences should be reduced after implementing a **fine slicing** of the elements

CONCLUSIONS

- An update for the development of the **beam losses tool** has been presented
- Benchmarking with H. Burkhardt's simulations was really helpful to **validate** and **grow confidence** with the code, both on the MC side and on the particle tracking side
- A first preliminary result for the **inelastic beam-gas** was presented, together with a comparison on previous results
- Next steps include **speeding up** the code, improving the MC generators and implementing a fine **slicing of the elements** to increase the resolution along the s coordinate.

BACKUP

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

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

For a more accurate simulation, elements can be sliced to increase sampling

INITIAL CONDITIONS

Beam initial properties:

$E = 45.6\ GeV$

$\beta_x^* = 0.15\ m$ $\sigma_x^* = 6\ \mu m$

$\beta_y^* = 0.0008\ m$ $\sigma_y^* = 0.028\ \mu m$

optics: FCCee_z_213_nosol_18.seq (Synchrotron Radiation OFF)

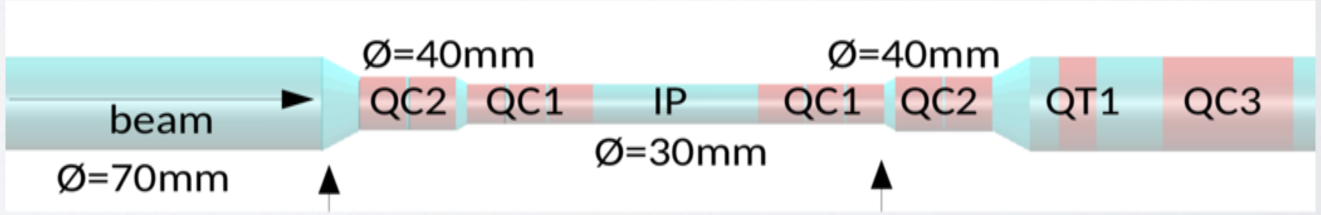
Length: 97756 m

N. of IPs: 2

N. of turns: 10

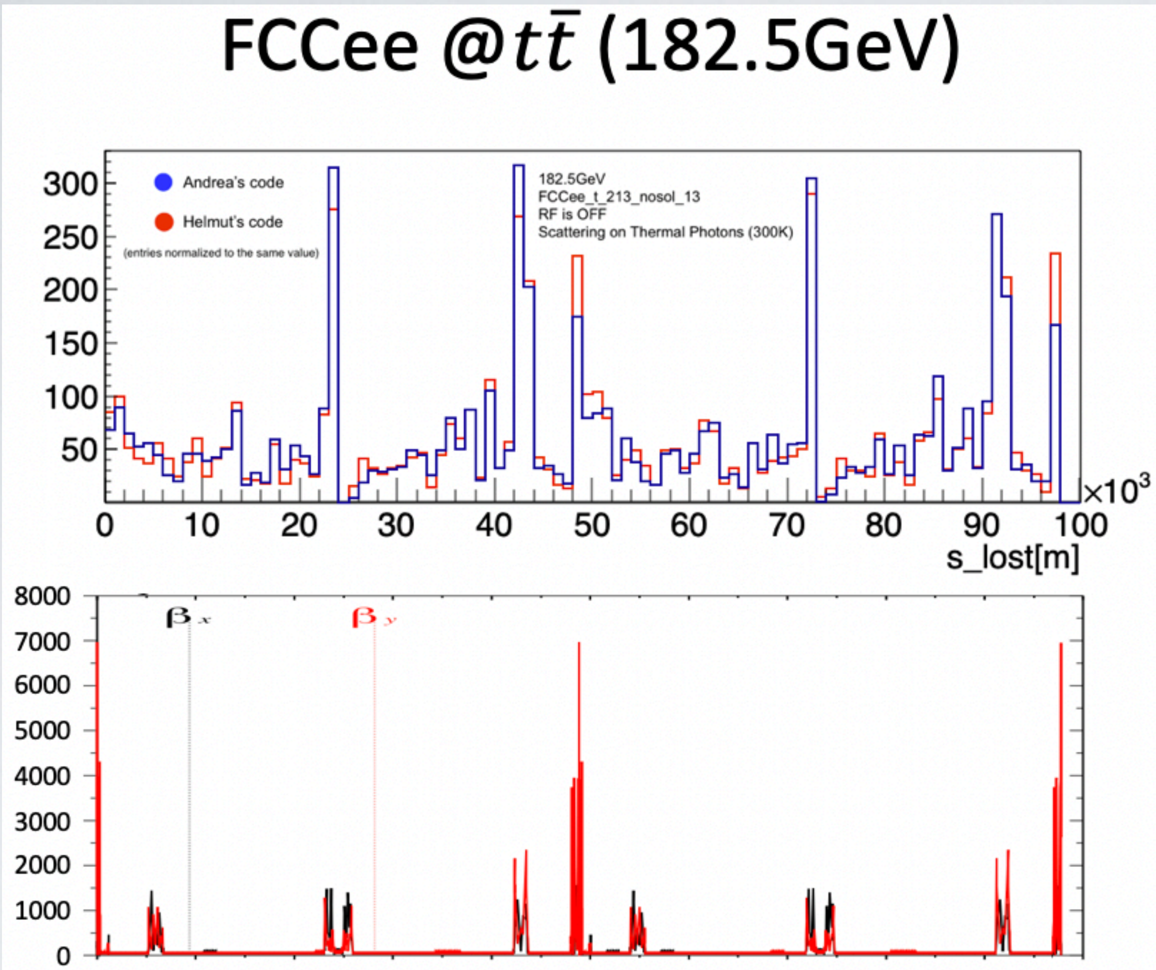
Pression: 1e-9 Torr (1,3332e-12 bar)

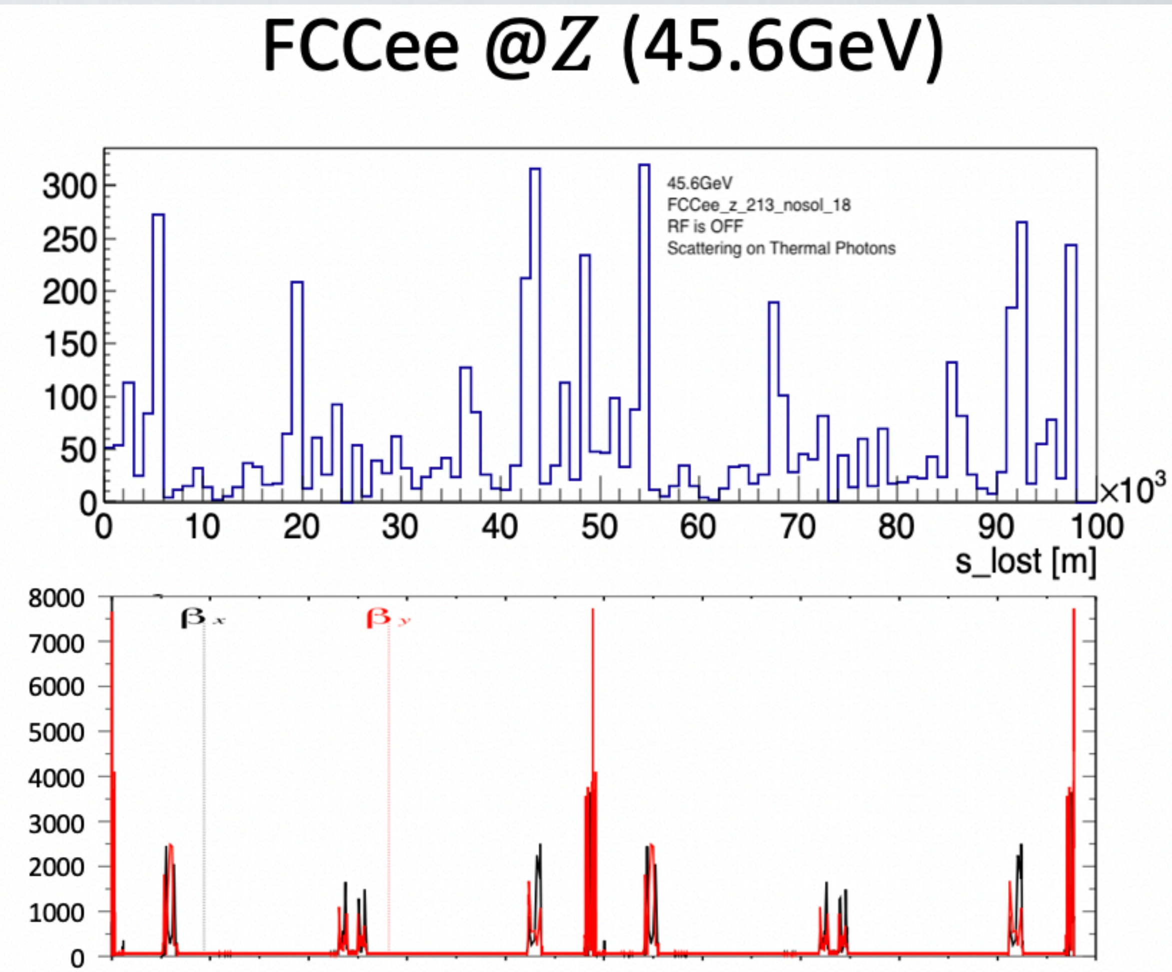
Physical aperture considered



Scattering 3000 macro particles per each considered element

FCCee @$t\bar{t}$ (182.5GeV) / FCCee @Z (45.6GeV)





E [GeV]	σ_{tot} [barn]	N_e [10^{11}]	% Lost	N_{lost}	N_{bunch}	$Rate_{loss}$ [GHz]
45.6	0.666	1.7	40%	234	16640	11.98
182.5	0.616	2.3	62%	455	48	0.067

$$Rate_{loss} = N_e \cdot \sigma_{tot}\rho L \cdot \%_{Lost} \cdot N_{bunch} \cdot \nu_{rev}$$
$$= N_{scattering\ events} \cdot \%_{Lost} \cdot N_{bunch} \cdot \nu_{rev}$$
$$= N_{lost} \cdot N_{bunch} \cdot \nu_{rev}$$