Beam Gas background characterization in the IR of FCC-ee

(mostly study of Inelastic Beam Gas
for FCCee Z 45.6GeV/beam
in this presentation)

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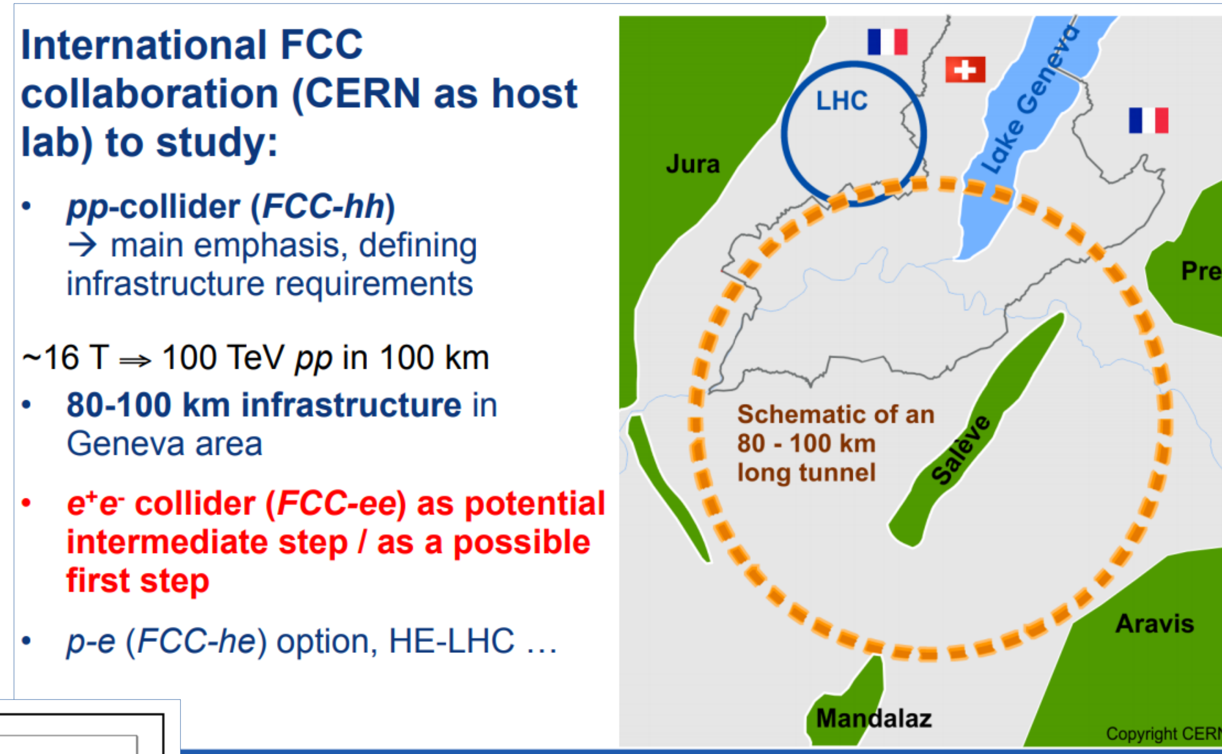
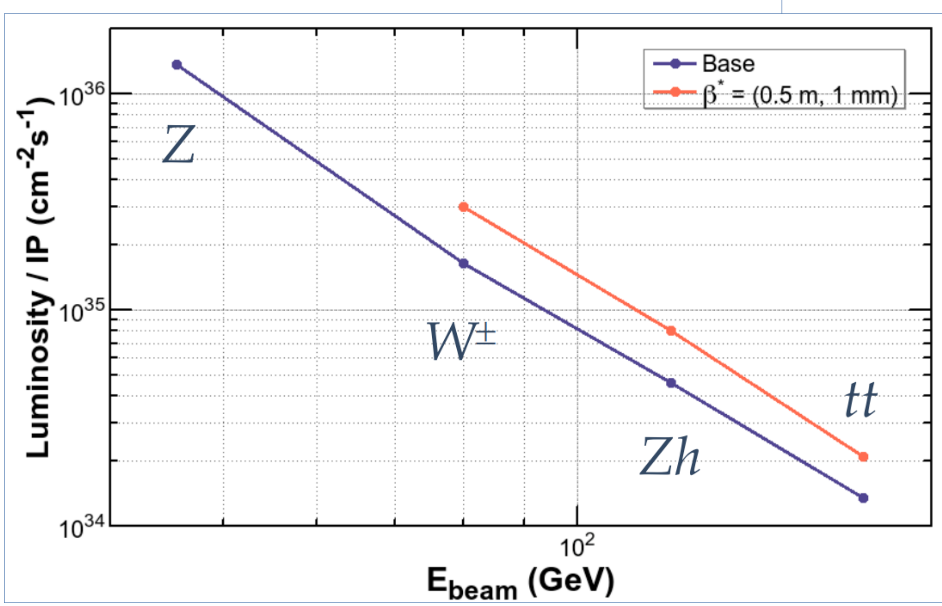
Workshop on the Circular Electron-Positron Collider - EU edition
Rome 2018/May/25

FCC-ee, the machine

- A 100km tunnel in the CERN area,
- thought to be used for pp collision,

  and as a first stage e+e- collisions,
- At 4 different center of mass energies

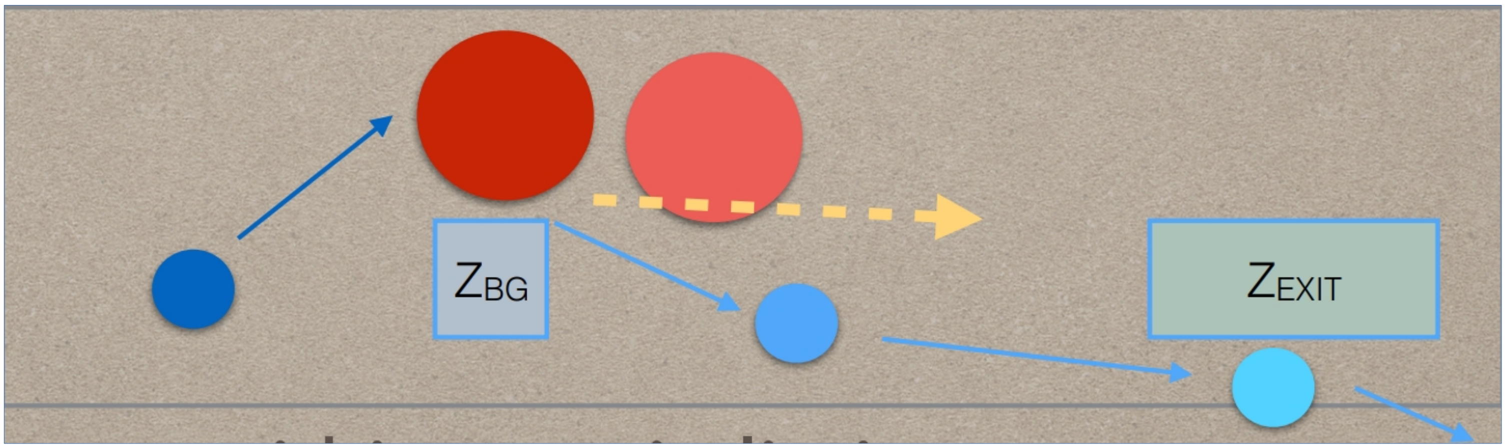




Oide, FCC week 2017
https://indico.cern.ch/event/556692/contributions/2483406/attachments/1466449/2271404/FCCee_Oide_170529.pdf

the BEAM GAS study

Gas in the beam pipe from the initial atmosphera (N_2, O_2, CO_2, ...),
or from desorption of the material in the beam pipe surface (H_2, CO, CH_4, ...)
Interact with the beam



It seems that there are two main criteria to evaluate this process :
a) Beam life time
b) Background in the experiment
DAFNE Tech Note V-3. Vaccarezza, 1991/JUL/08
"Preliminary Study for the Choice of the DAFNE Vacuum Chamber Material".

I will mostly address beam life time ...
There is another issue about the gas pressure from desorption due to radiation but this presentation DOES NOT address that.

the BEAM GAS scattering
Cross sections

Inelastic
e- losses energy in the interaction and is lost because of energy acceptance

$$\sigma\left(Z,\epsilon\right)$$

Cross section depends on :
Z, the atomic number
ε, the energy acceptance of the machine

Elastic
e- is kicked out of its trajectory and is lost because of large oscillation

$$\sigma\left(Z,\gamma,\langle\beta\rangle,a\right)$$

Cross section depends on :
Z, the atomic number
γ, the relativistic factor
‹β›, the average beta
a, the beam pipe aperture

The entire equation and references are in the back-up slides

Beam Gas Cross Section

for part of the ring

Equations give an estimate of the importance (order of magnitud) of the phenomena, mostly valid in the arcs.

However a detailed analisis requires a simulation, usually Monte Carlo.

Lattice Section	Gas	Elastic [barn]	Inelastic [barn]	
		(Z, γ, <β>, aperture)	(Z, ε)	
Arc	H2	0.0002 From Le Duff	0.3 Burkhardt	
Arc	N2	0.04 From Le Duff	**9.4** Burkhardt	
MDI	H2	0.2 New formula	-	
MDI	N2	**20** New formula	-	

WHAT WE DO WITH MDISim

We interfase optics (MAD-X), with geometry (.gdml) to perform Monte Carlo simulations (in Geant4)

First results of **Inelastic Beam-gas scattering** latest optics

→ Loss map and loss rates are obtained.

Results for:

IR at Z, H, W, H.
I am showing plots for the Z

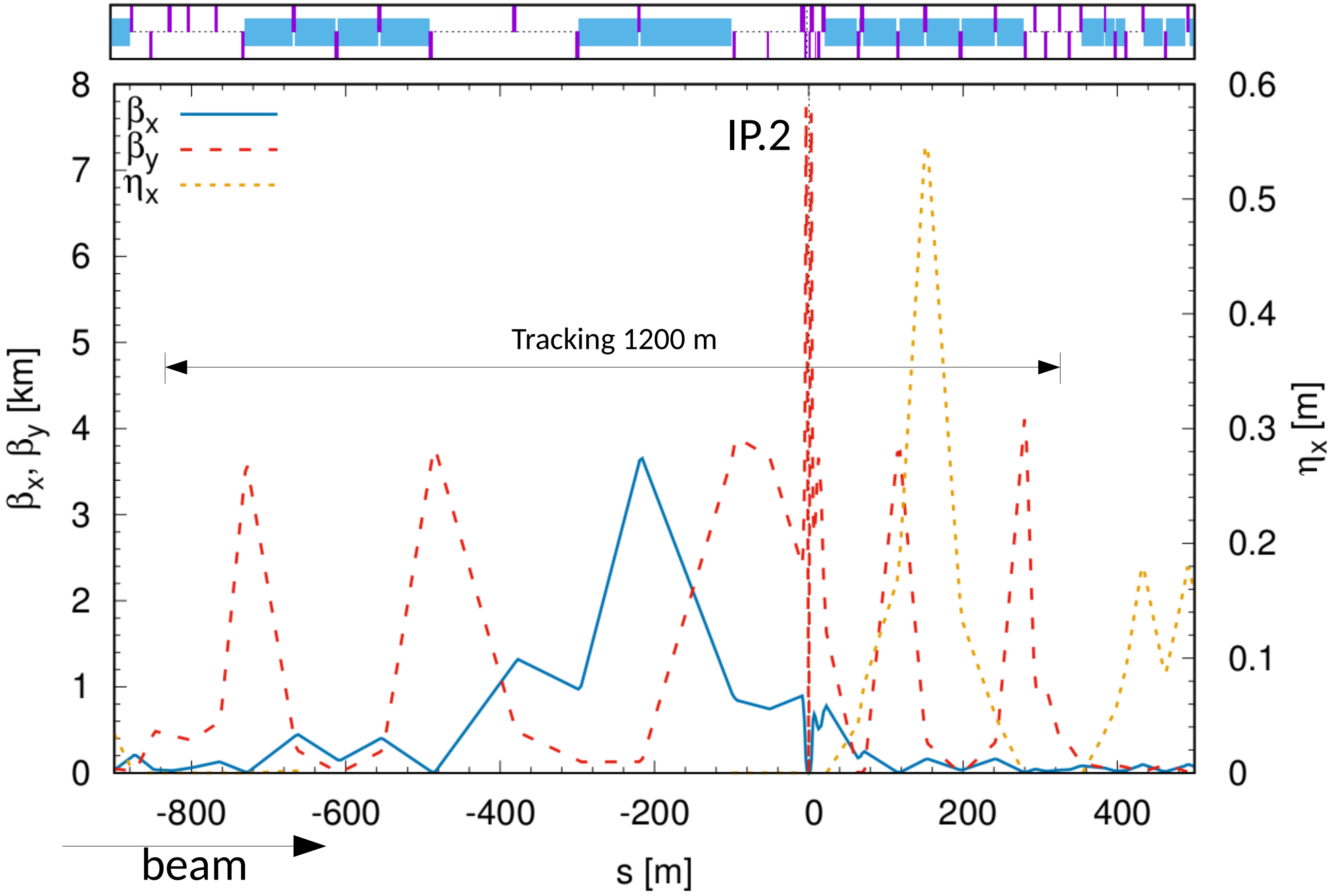
- Note that SR is not considered in the simulation.

Z 45.6GeV/beam
MDI Region

at all energies the scattering distribution is similar, BUT, rates differ

FCCee Z 45.6GeV/beam

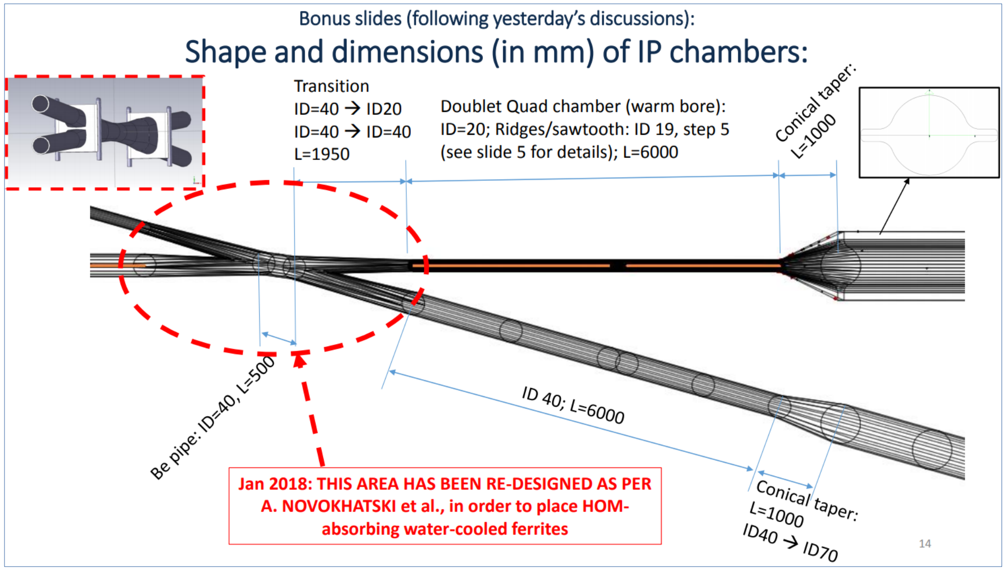
Lattice : FCCee_z_213_nosol_18.seq (ZOOM)

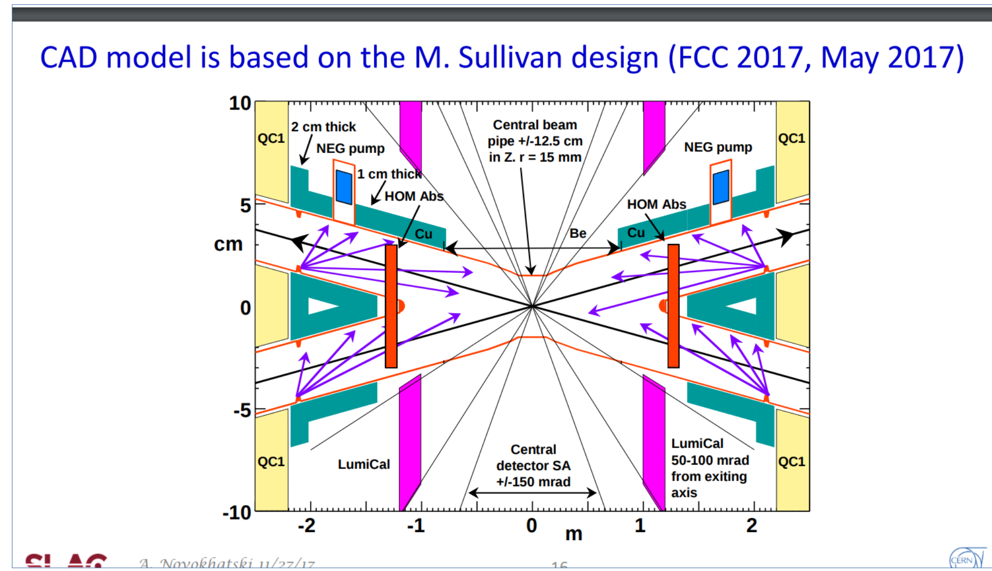


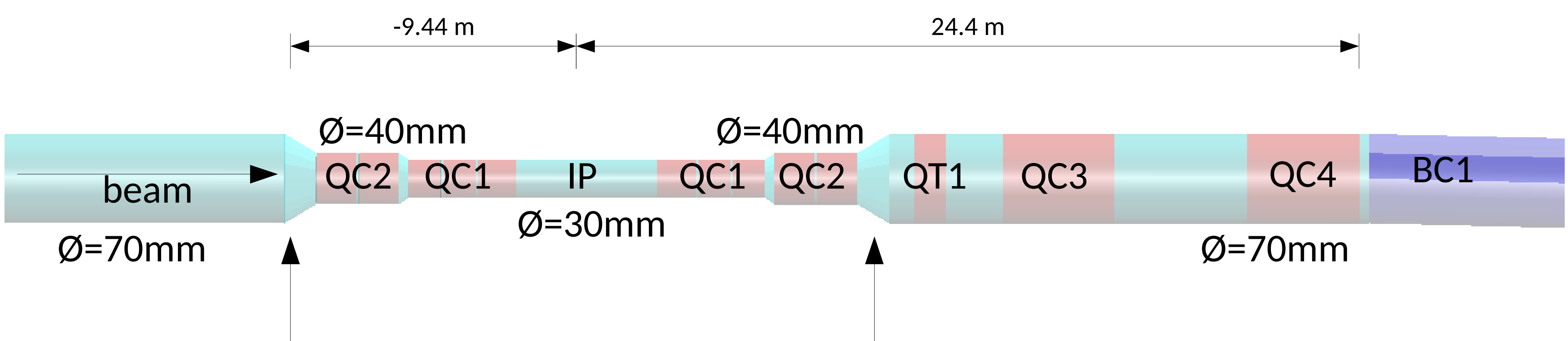
We consider to study from s=-830m to s=370m

Conical Tapers from Kersevan. IR Vacuum Concept.
Workshop on the Mechanical optimisation of the FCC-ee MDI
https://indico.cern.ch/event/694811/timetable/

The details between QC1's have been ignored for the moment

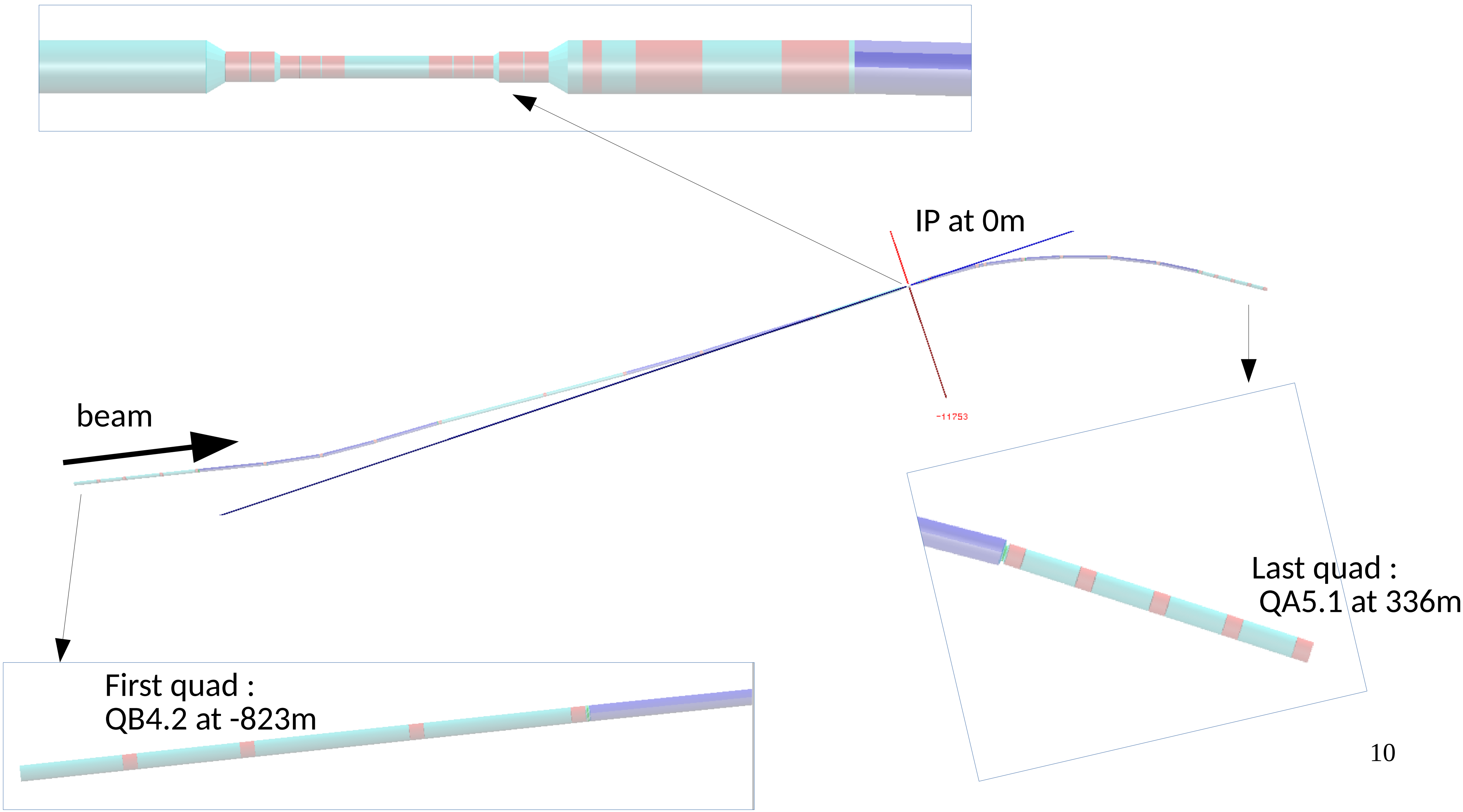




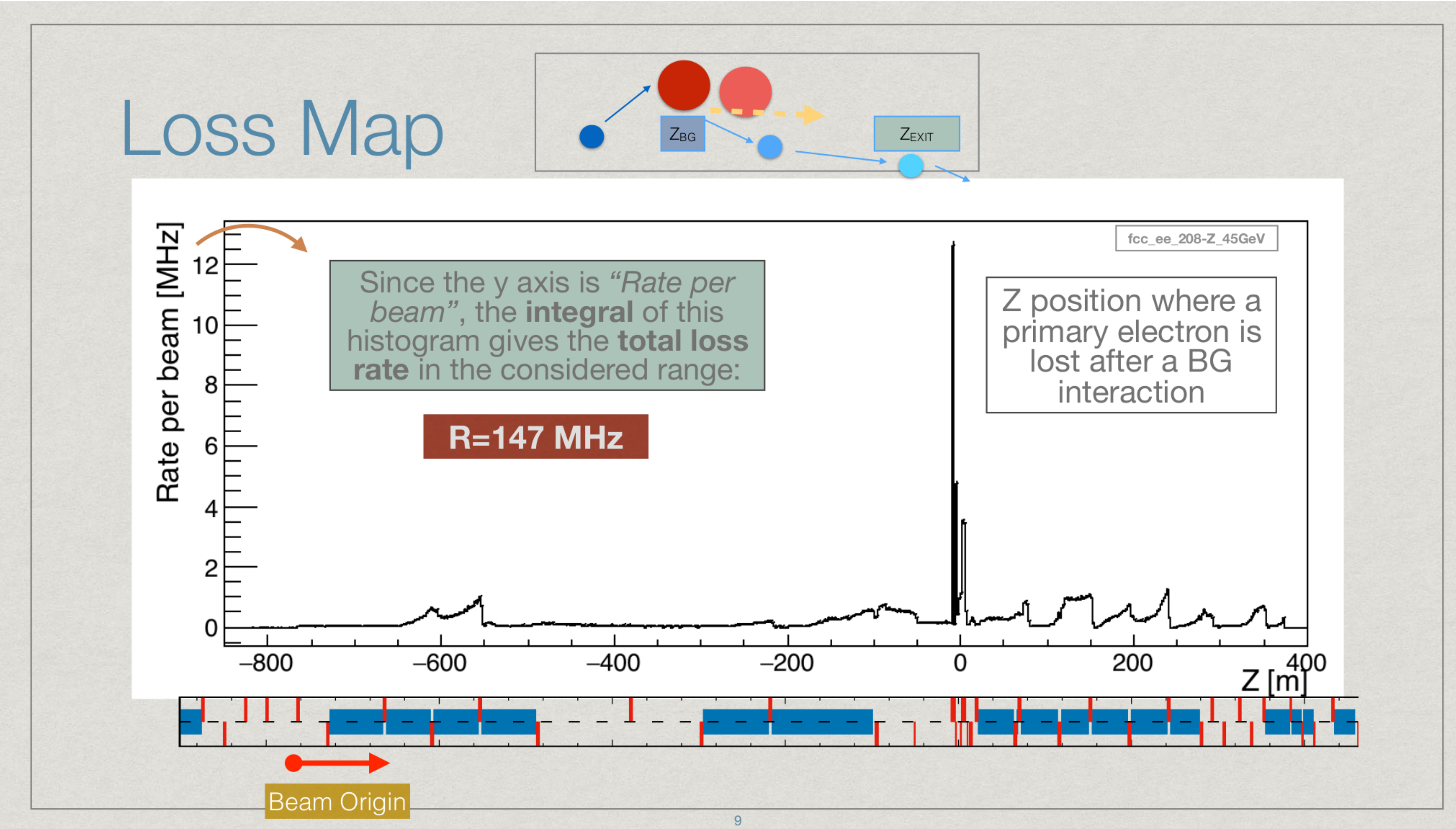


1m of conical taper between pipe diameters of 70mm and 40mm

FCCee Z geometry scalexy 50 :
(scalexy 1 is not displayed correctly, but IS used for the tracking studies)
Tracking starts at -830m and ends at 370m = 1200 m in total

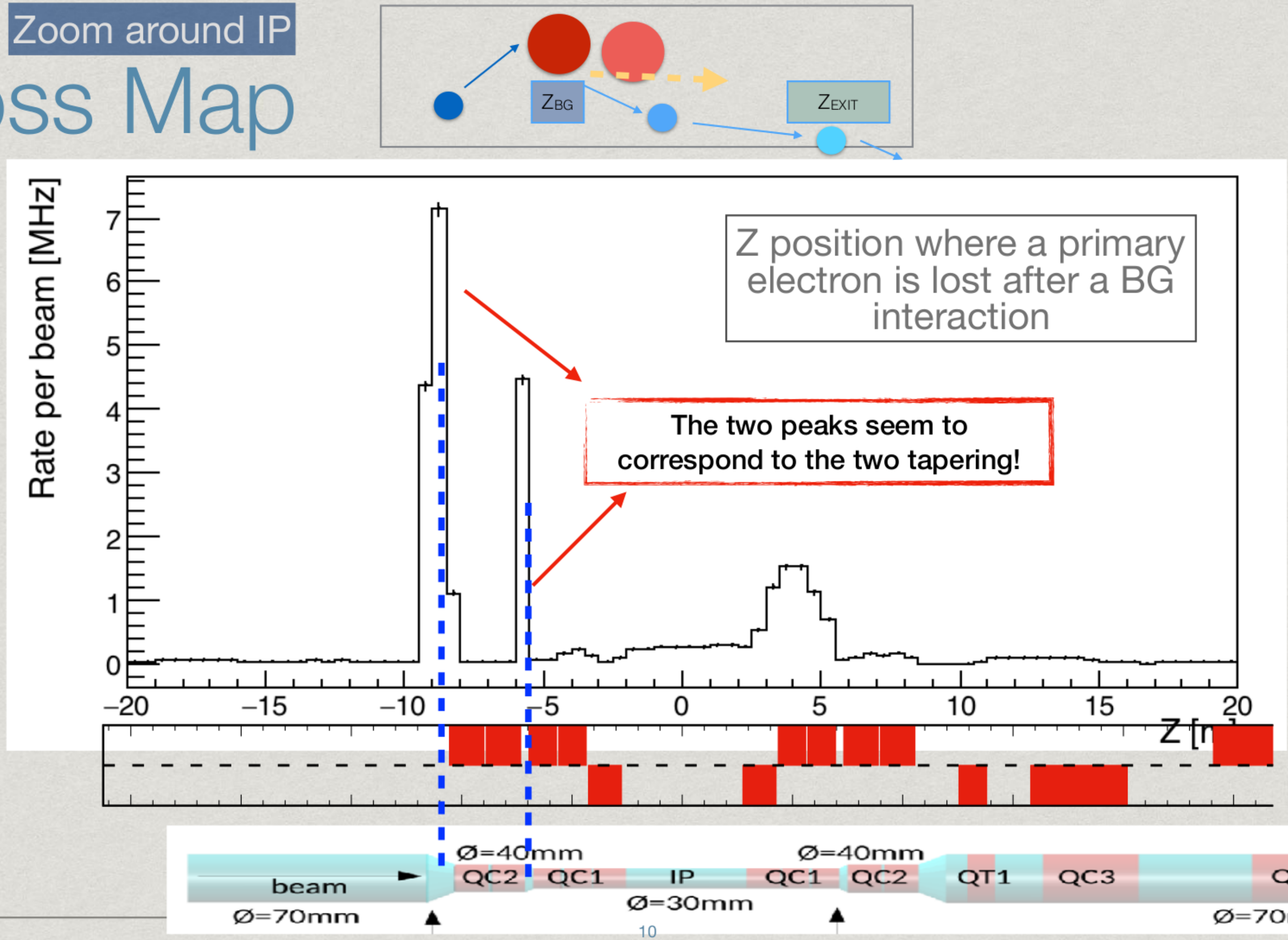


As reference τ=100h → Scattering Rate = 78.6 Mhz/km/beam
Meaning that a beam life time on the order of tens of hours is expected



Zoom around IP

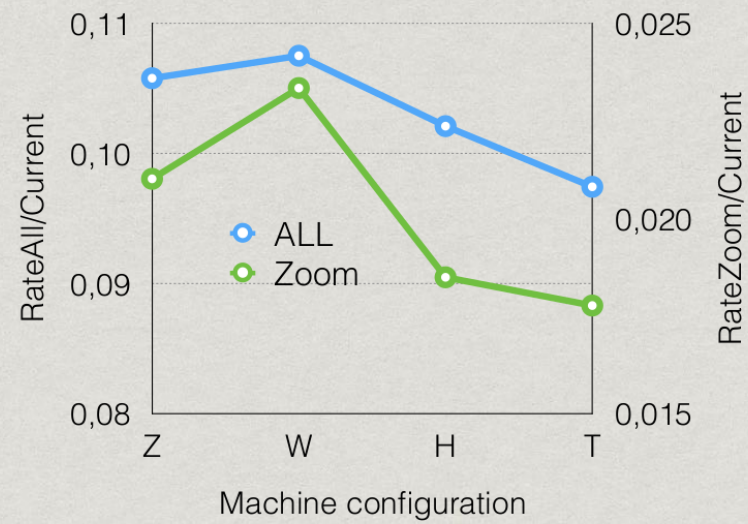
Loss Map

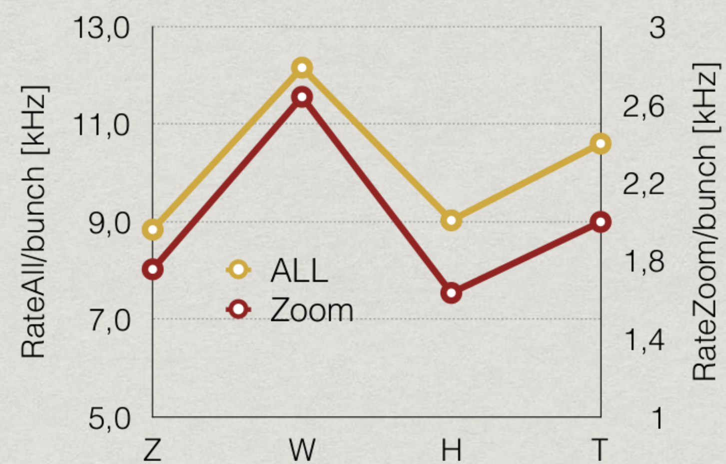


GOING QUANTITATIVE

	Current	N_{Bunch}/ beam	Rate ALL	R_{ALL}/ Current	R_{ALL}/bunch	Rate Zoom	R_{Zoom}/ Current	R_{Zoom}/ bunch
	[mA]	#	[MHz]	[MHz/mA]	[MHz]	[MHz]	[MHz/mA]	[MHz]
Z	1390	16640	**147,00**	1,1E-01	8,8E-03	**29,20**	2,1E-02	1,8E-03
W	147	1300	**15,80**	1,1E-01	1,2E-02	**3,43**	2,3E-02	2,6E-03
H	29	328	**2,96**	1,0E-01	9,0E-03	**0,54**	1,8E-02	1,6E-03
t	5,4	48	**0,53**	9,7E-02	1,1E-02	**0,10**	1,8E-02	2,0E-03

optics: fcc_ee_208, $P_{VAC}=10^{-9}$ mbar

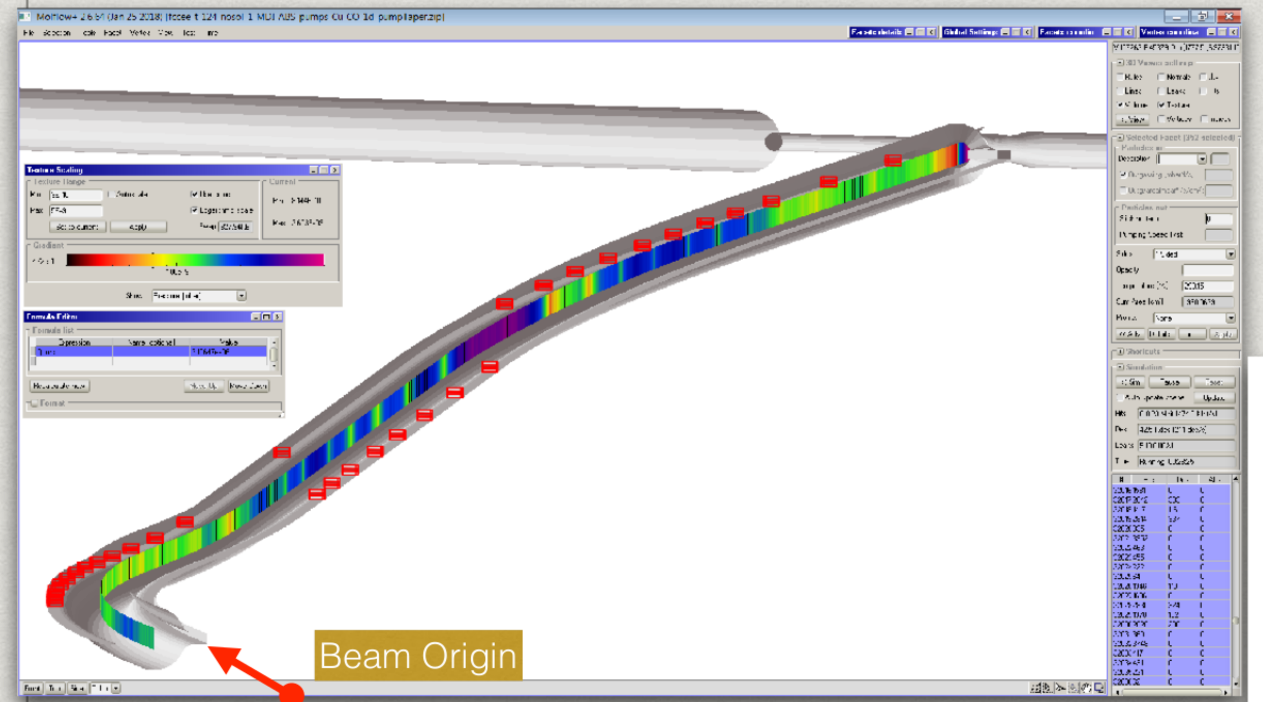




Local pressure variations

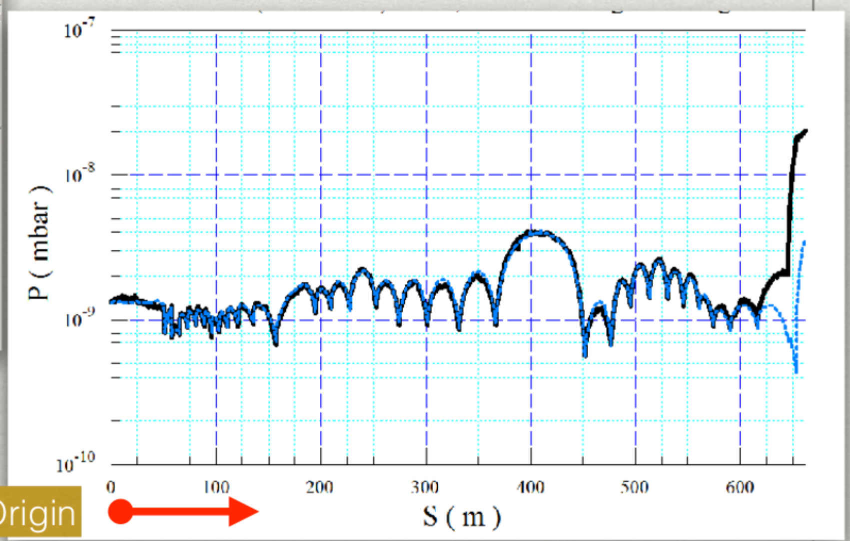
- Up to now, in the study it was **assumed** that the **pressure** is **constant** all over the beam pipe
- However, **this is not the case**:
  - In fact, we expect to have a **locally variating pressure** profile due to **gas desorption** caused by:
    - Interaction of SR photons with the beam pipe
    - Pump effect gradient due to pipe conductance
- It is possible to study this pressure profile using **SynRad** + **MolFlow**
- This study was performed **@t** (182.5GeV) configuration (expected worst case)

Local pressure variations



Is it thus possible to use the pressure profile to “**weight**” **the results** of the BG studies

The gas pressure (and hence the interaction probability) is not constant along the machine



Molflow+

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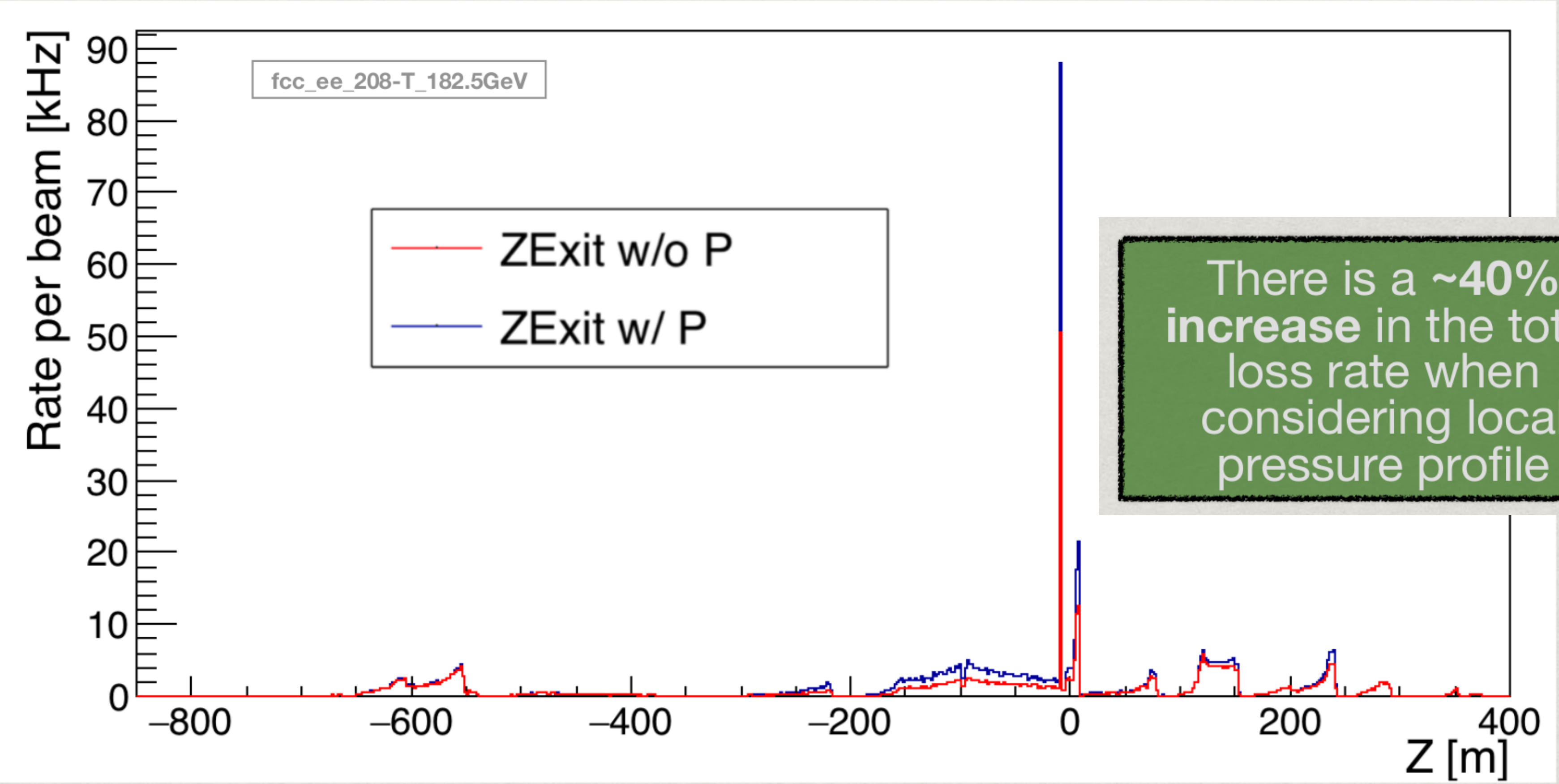
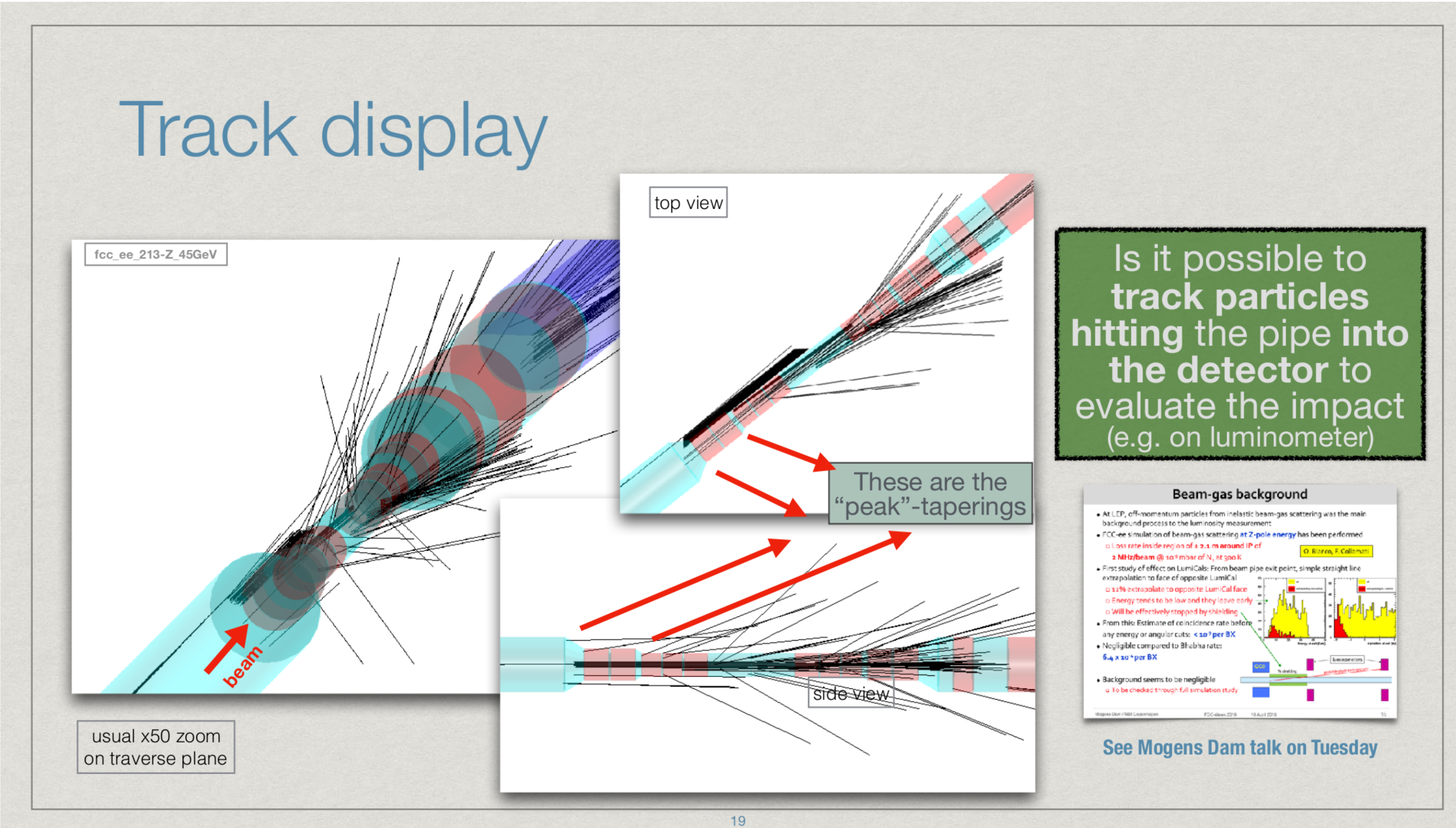
[Kersevan, Vaccum Systems for the FCC-ee
7th Low Emittance Workshop, Jan-2018, CERN
https://indico.cern.ch/event/671745/contributions/2788843/attachments/1582988/2502801/7thLowEmittanceWorkshop_RKersevan_Vacuum.pdf](https://indico.cern.ch/event/671745/contributions/2788843/attachments/1582988/2502801/7thLowEmittanceWorkshop_RKersevan_Vacuum.pdf)

Local pressure variations



There is a **~40% increase** in the total loss rate when considering local pressure profile

Collamatti, FCC Week 2018 - Amsterdam
Beam-gas background characterization in the FCC-ee IR
[MOPMF085 Boscolo. BEAM-GAS BACKGROUND CHARACTERIZATION IN THE FCC-ee IR. IPAC18]



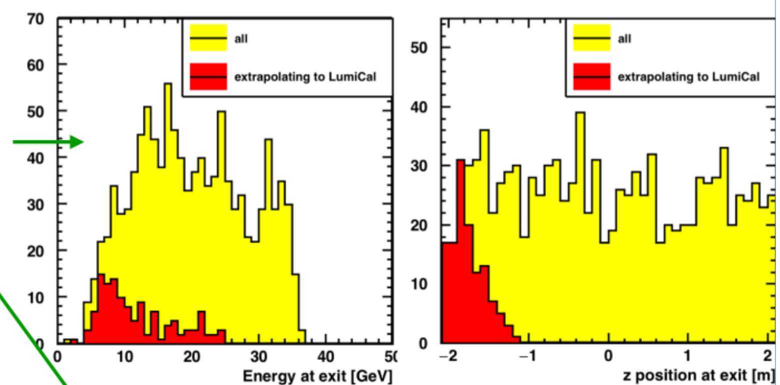
Mogens Dam, FCC Week 2018 - Amsterdam
LumiCal for FCC-ee and beam-background impact

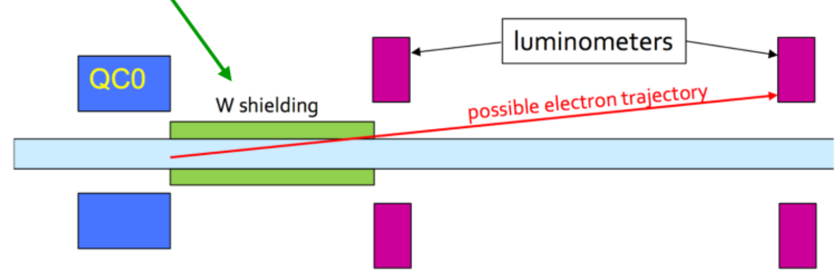
Beam-gas background

- At LEP, off-momentum particles from inelastic beam-gas scattering was the main background process to the luminosity measurement
- FCC-ee simulation of beam-gas scattering **at Z-pole energy** has been performed
  - Loss rate inside region of **± 2.1 m around IP** of **2 MHz/beam** @ 10^{-9} mbar of N_2 at 300 K

O. Blanco, F. Collamati

- First study of effect on LumiCals: From beam pipe exit point, simple straight line extrapolation to face of opposite LumiCal
  - 12% extrapolate to opposite LumiCal face
  - Energy tends to be low and they leave early
  - Will be effectively stopped by shielding
- From this: Estimate of coincidence rate before any energy or angular cuts: **< 10^{-7} per BX**
- Negligible compared to Bhabha rate: **6.4 x 10^{-4} per BX**





- Background seems to be negligible
  - To be checked through full simulation study

Mogens Dam / NBI Copenhagen FCC-Week 2018 10 April 2018 15

Sum-up and perspectives

- **MDISim** enables to **import** the whole **machine** configuration (beam + geometry) in **GEANT4** starting from MAD-X file
  - Initially thought for Synchrotron Radiation studies
  - Once in GEANT4, an accurate study of the **inelastic beam-gas** background induced in the IR can be done
    (loss maps, scattering points, total loss rate, particle tracks)
- If assuming a vacuum pressure of **10^{-9} mbar of N_2**, results suggest a loss rate of the order of **100 MHz per Ampere of beam** current in the region around IP
  - **Tapering** between different pipe apertures are **critical points** in which most BG scattered particles are lost
  - If **local pressure variations** due to gas desorption are taken into account, the total loss rate is **increased** of about **40%**
- Tracks of particles exiting the pipe can be fed into **detector simulations** to evaluate their impact

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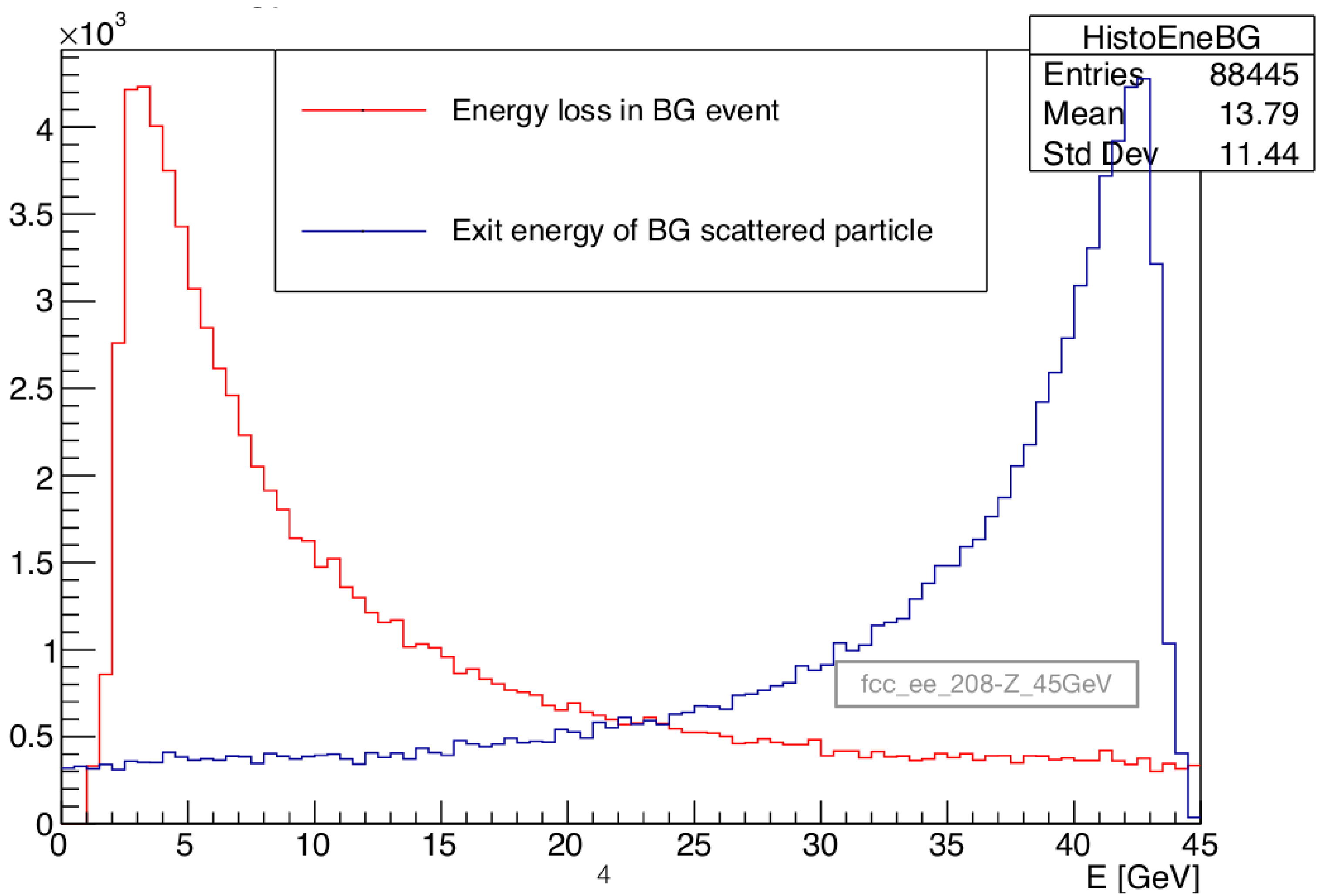
- Initial study of background from Beam Gas scattering indicates negligible effect in the LumiCal

BACK UP

ENERGY OF THE LOST PARTICLES

Energy lost by the primary particle in the interaction with the gas molecule that led to particle loss

Energy of the particles that get lost due to BG when hitting the pipe



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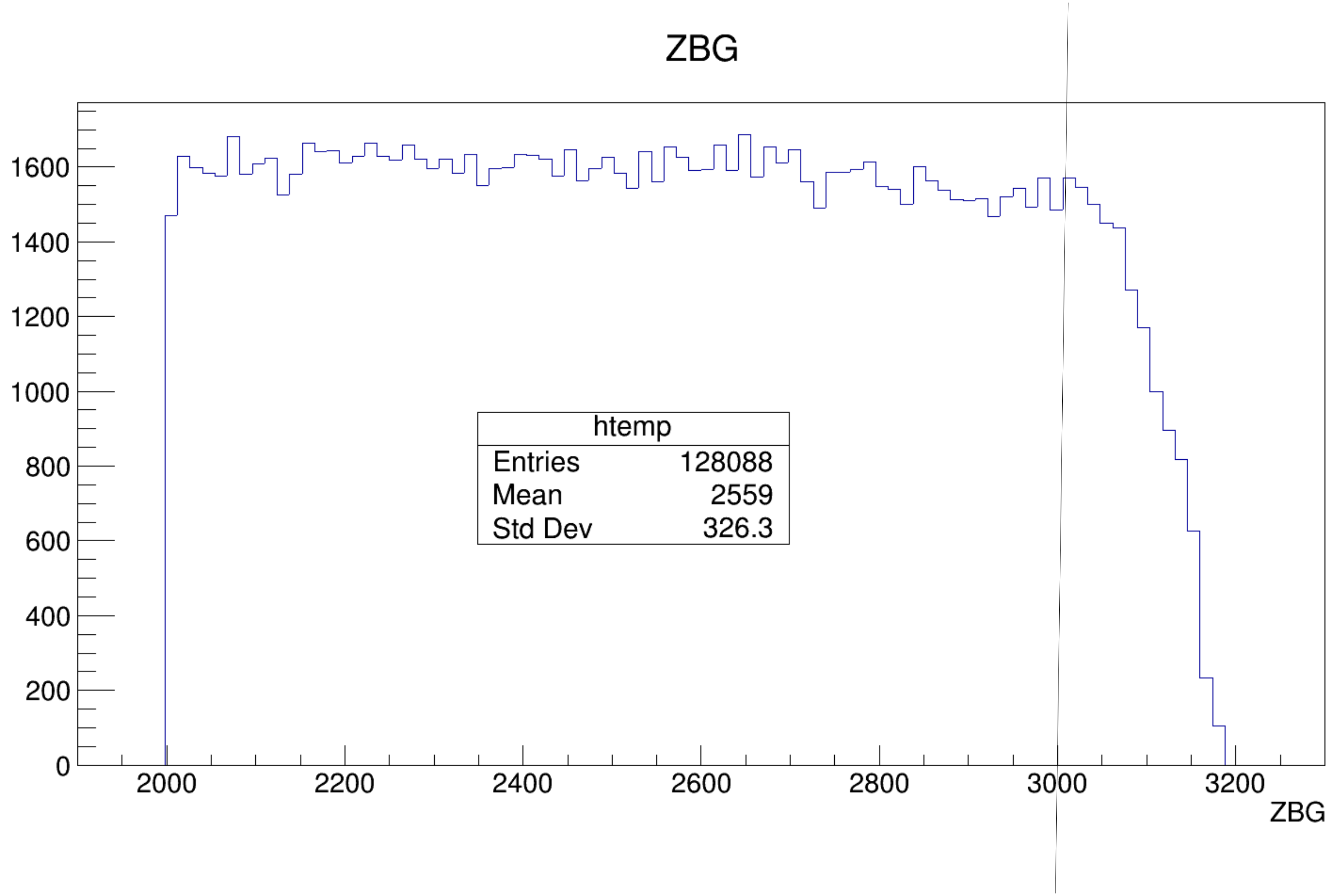
Lattices available in afs is X
Initial studies have been done with the ones marked with X
Latest lattice 213 for the t is now available

All these plots and numbers are available for all these optics/energies

	fcc_ee_208	fcc_ee_213
Z	X	X
W	X	X
H	X	X
T	X	–

Z (Euclidean) is NOT equal to S (C-S coordinates)
ZBG is the location along Z where a Beam Gas Interaction occurs.

It looks pretty flat up to 3000m, I cut at 3000m
For N :113812/1e7 = 1.13% are lost in 1km



WHAT IS THE LOSS RATE FROM BEAM GAS IN THE ARC ?

As calculated by Francesco :

Neloss = NelossMC/NeprimMC . Nebunch . Nbunches . Preal/Pmc

For H the rate is 2.35 MHz per km of arc at 10^{-9} mbar

Neloss = 68724/1e7 . 1.7e11 . 16640 . 1e-9/24.8
= 0.783e3
Rate_eloss = Neloss/Trev = 18.1e3/0.333ms = 2.35 Mhz

For H2 the rate is 6.22 MHz per km of arc at 10^{-9} mbar

Neloss = 90764/1e7 . 1.7e11 . 16640 . 1e-9/12.4
= 2.070e3
Rate_eloss = Neloss/Trev = 18.1e3/0.333ms = 6.22 Mhz

For N the rate is 54.3 MHz per km of arc at 10^{-9} mbar

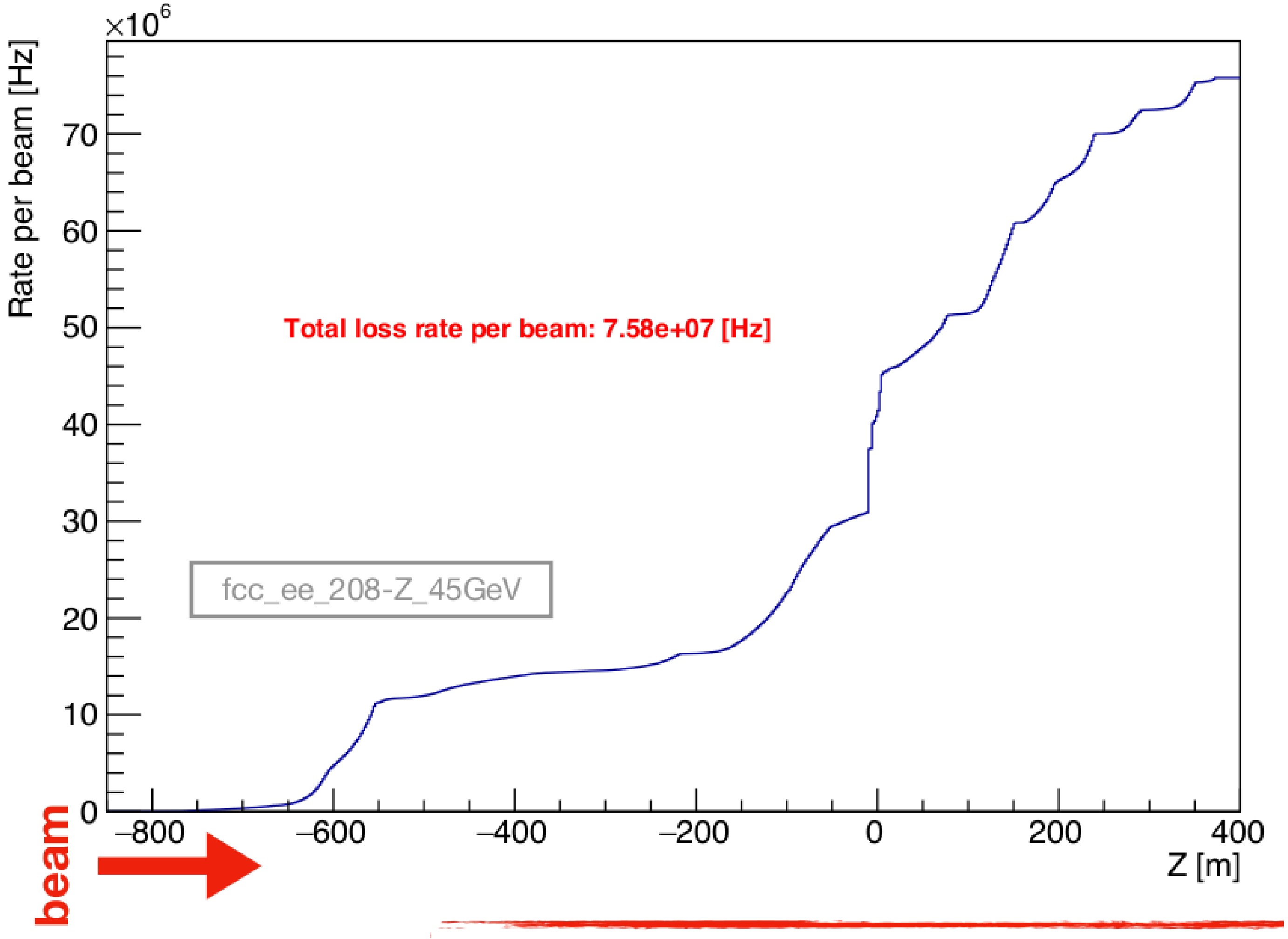
Neloss = 113812/1e7 . 1.7e11 . 16640 . 1e-9/1.78
= 18.1e3
Rate_eloss = Neloss/Trev = 18.1e3/0.333ms = 54.3 MHz

For N2 the rate is 189.1 MHz per km of arc at 10^{-9} mbar

Neloss = 99034/1e7 . 1.7e11 . 16640 . 1e-9/0.445
= 62.95e3
Rate_eloss = Neloss/Trev = 63.0e3/0.333ms = 189.1 MHz

THE PARTICLE LOSS IS NOT UNIFORMLY DISTRIBUTED

Cumulative distribution of losses



ELASTIC SCATTERING

Average cross section from average beta.
J Le Duff. Current and current density limitations in existing electron storage rings
Laboratoire de l'accélérateur Linéaire, LAL, NIM in Physics Research A239 (1985) 83-101.

Average beta is invalid in the MDI region.

2.1.1. The elastic scattering on nuclei

Elastic scattering on nuclei leads to an angular kick for the betatron motion. If the induced amplitude exceeds the vacuum chamber aperture the particle gets lost. The total cross section for this process is [1]:

$$\sigma_{t1} = \frac{4r_e^2 Z^2}{\gamma^2} \frac{\pi}{2} \left(\frac{\langle \beta \rangle}{a} \right)_z^2,$$

where

r_e = the classical electron radius,
γ = the normalized energy (E/m_0c^2),
Z = the atomic number for residual gas components,
$\langle \beta \rangle$ = the average betatron envelope function,
a = the half chamber aperture,

and it is assumed that the loss will occur in the vertical plane (z direction).

In the case of a non-smooth optic and assuming the aperture limit a_0 is located at some azimuth where the envelope function is β_0 one should replace $(\langle \beta \rangle / a)^2$ by $\langle \beta \rangle \, \beta_0 / a_0^2$ [2]. The elastic scattering effect goes up when the energy goes down.

References

[1] J. Haïssinski, Thèse, Laboratoire de l'Accélérateur Linéaire, Orsay (1965).
[2] H. Wiedemann, private communication.
[3] A. Berthelot, Rayonnement de particules atomiques, électrons et photons (Masson, Paris, 1956).
[4] F.F. Rieke and W. Prepejchal, Phys. Rev. A6 (4) (1972).
[5] H. Bruck, Accélérateurs circulaires de particules (Presses Universitaires de France, 1966).

ELASTIC SCATTERING

MODIFIED EQUATION

Based on Section 4.1 Elastic Scattering. CAS CERN Accelerator School. Fifth General Accelerator Physics Course, Vol 1. Jan/21/1994. Geneva, Switzerland.

$$\bar{\sigma} = \frac{1}{\sum L_k} \frac{1}{\sum L_i} \frac{\tau_2 Z^2 r_e^2}{\gamma^2} \sum_k \sum_i L_k L_i \frac{\beta_k \beta_i}{H_i^2} \; ; for\; k \neq i$$

Sigma = average cross section
k = index of element inside the considered region
i = index of element along the entire ring
Gamma = relativistic gamma factor
Tau_2 = 6.2832
L = total accelerator length
L_k = length of kth-element in the chosen region
L_i = length of the ith-element in the entire accelerator
Z = atomic number
r_e = the classical electron radius
Beta_i, Beta_k = the vertical beta at the kth/ith-sm element
H_i = the aperture of the ith-element

INELASTIC SCATTERING

Theoretical cross section from H. Burkhardt.

M Brugger, H Burkhardt, and B Goddard. Interactions of Beams With Surroundings. Landolt-Boernstein, 21C:5–1 – 5–17, 2013.

eN scattering relevant for electron rings

The elastic cross section for eN scattering scales strongly with energy (with $1/\gamma^2$) and scattering angle $1/\theta^4$. Elastic scattering is mostly relevant as halo production process for lower energy rings and becomes negligible for lifetime estimates for high energy electron rings.

At high energy, the dominating beam-gas process for electron rings is the inelastic scattering or bremsstrahlung in which the incident electron interacts with the field of the residual gas nucleus and radiates a photon.

The high energy cross section for eN scattering can be written in good approximation independently of the electron energy as [13]

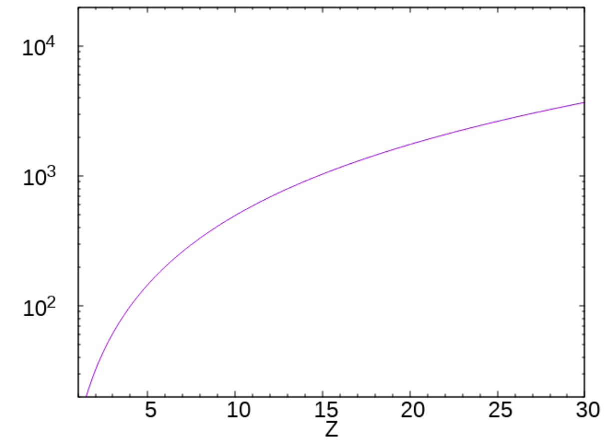
$$\sigma_{\mathrm{eN}} = 4\alpha\, r_e^2\, Z(Z+1)\, \log(287/\sqrt{Z}) \left(-\frac{4}{3} \log\, k_{\mathrm{min}} - \frac{5}{6} + \frac{4}{3} k_{\mathrm{min}} - \frac{k_{\mathrm{min}}^2}{2} \right) , \tag{5.4}$$

where k_{min} is the fractional energy loss or minimum photon energy in units of the electron energy, α the fine-structure constant (1/137) and Z the atomic number (or number of protons). We can see that the cross section scales with $Z(Z+1)$. Numerical values obtained from Eq. 5.4 for $k_{\mathrm{min}} = 0.01$ are shown in Tab. 5.4

Table 5.2. Numerical values for σ_{eN} for an energy loss of at least 1% and for σ_{pN}, the pN cross section at high energy ($p_{\mathrm{lab}} = 0.01$ to 10 TeV).

Gas	σ_{eN} b	σ_{pN} b
H_2	0.28	0.08
He	0.39	0.19
CH_4	3.02	0.43
H_2O	4.38	0.40
N_2	6.47	0.56
CO	6.56	0.56
CO_2	10.7	0.87
Ar	17.8	0.60

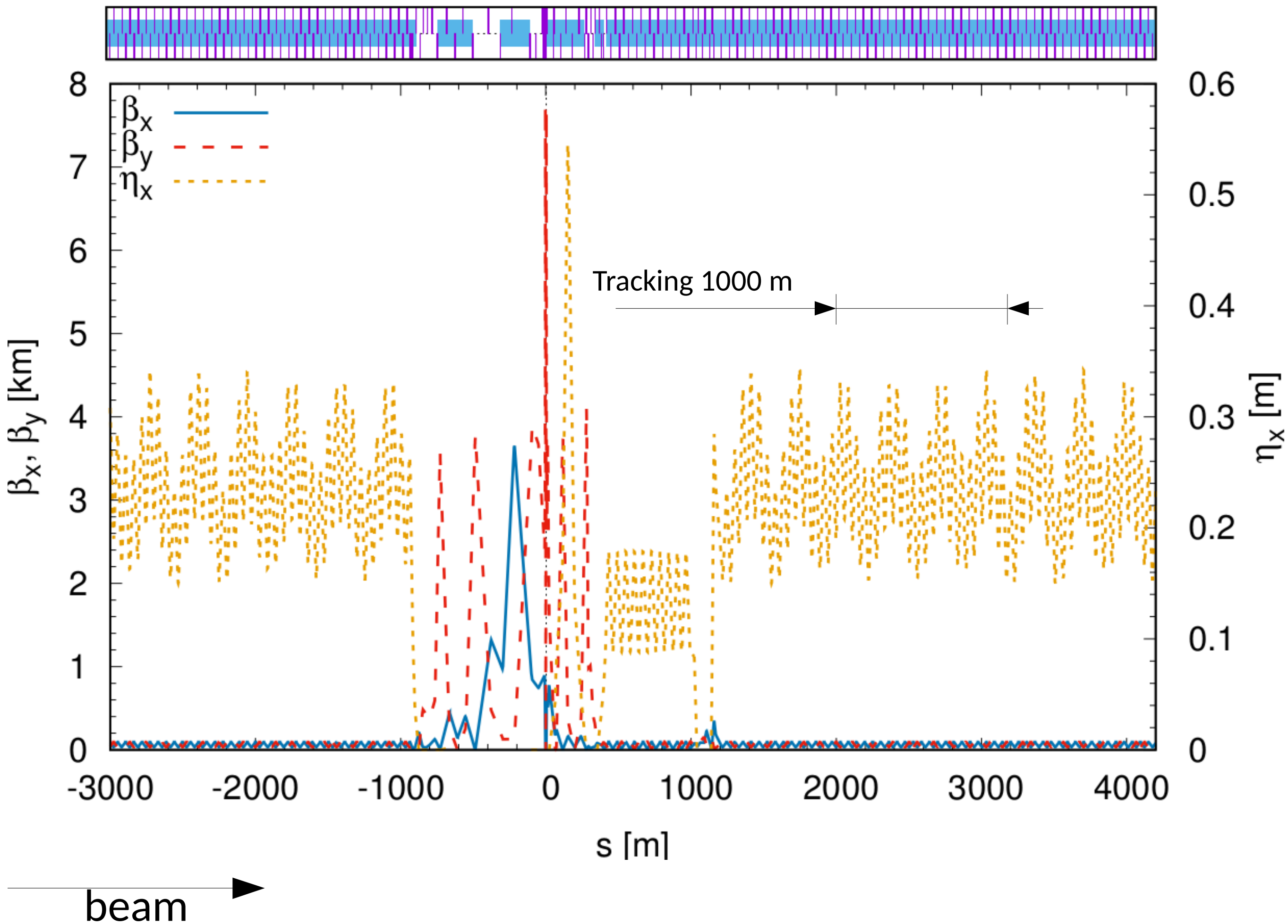
z*(z+1)*log(287/sqrt(z))



Z 45.6GeV/beam
arc

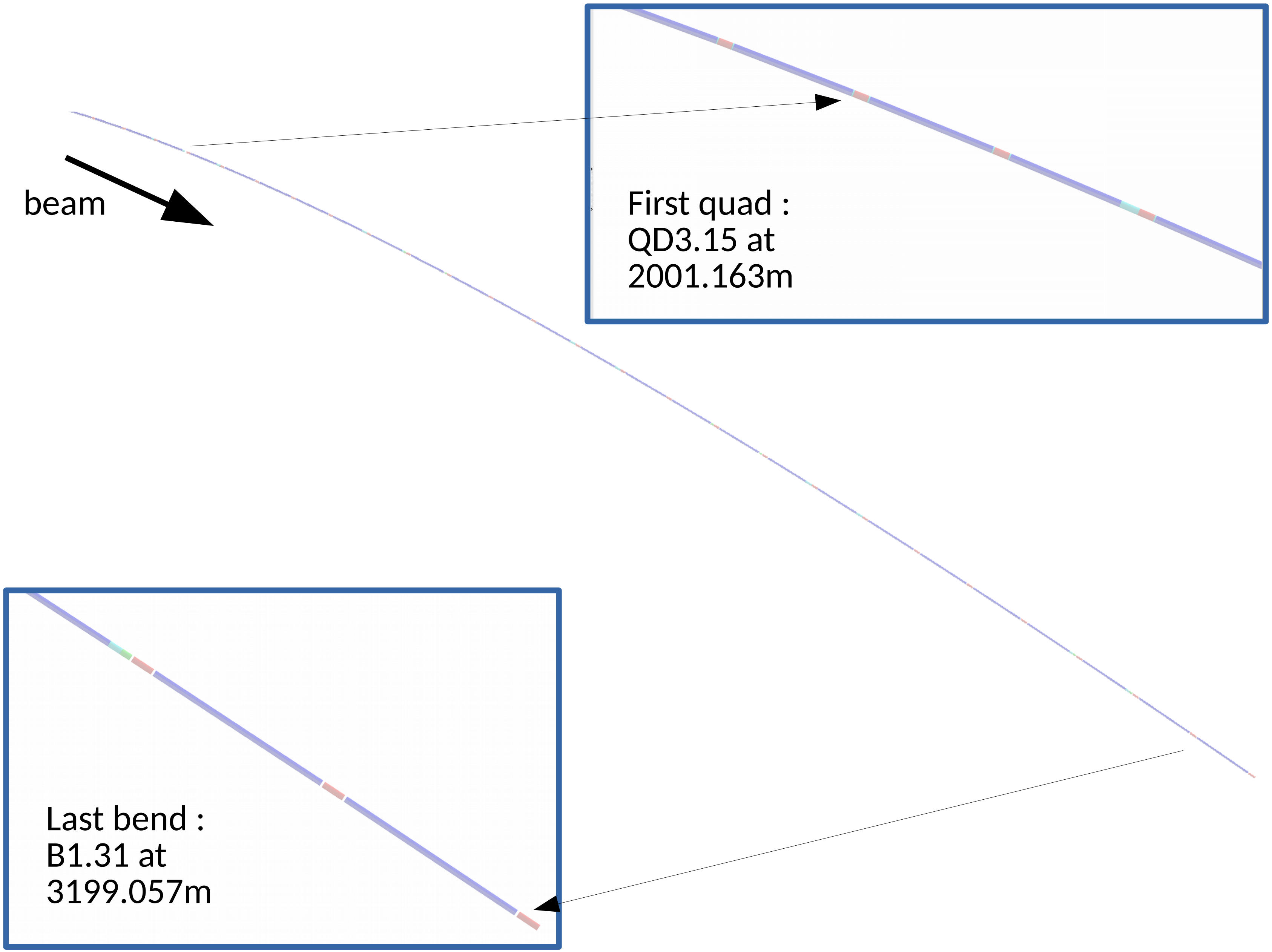
FCCee arc Z 45.6GeV/beam

Lattice : FCCee_z_213_nosol_4.seq (ZOOM)



Constant aperture : 35mm

FCCee Z geometry scalexy 50 :
(scalexy 1 is not displayed correctly, but IS used for the tracking studies)
Tracking starts at 2000m and ends at 3200m = 1200 m in total



WHAT IS THE PARTICLE LOSS RATE IN THE ARC ?

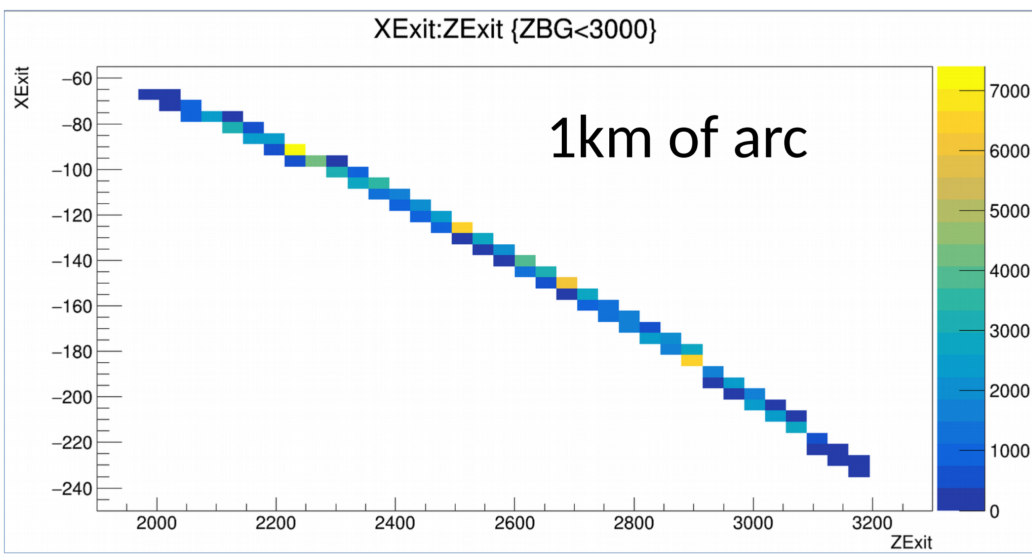
At 45.6GeV/beam : Npart = 1.7e11
Nbunches = 16640

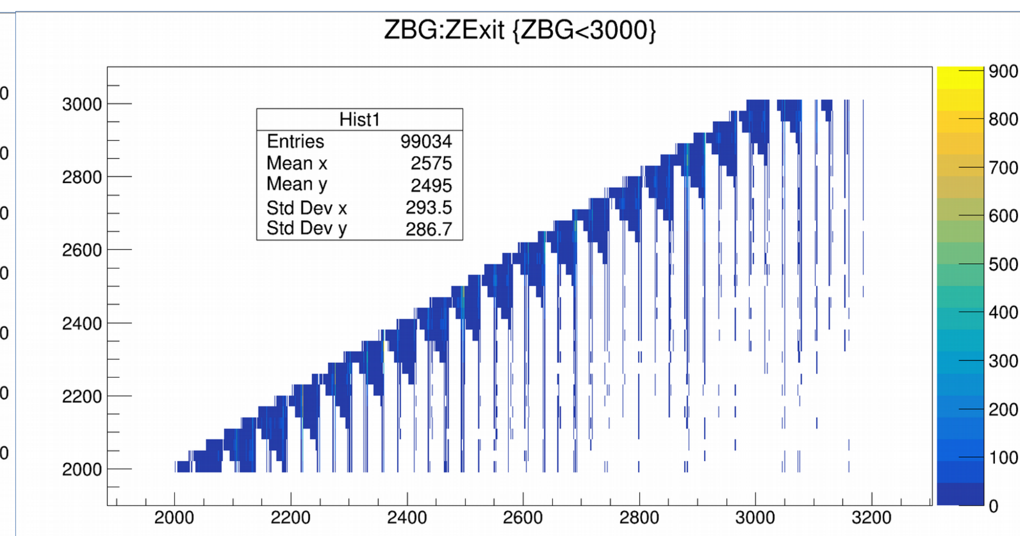
With an energy acc. of 2% and pressure of 10^{-9} mbar

	Scattering Rate/m/beam	
	Expected	Simulation
H2 : 0.328 barn	6.7 KHz	6.2 KHz
N2 : 9.386 barn	192.3 KHz	189.1 KHz

As reference τ=100h → Scattering Rate = 78.6 Khz/m/beam

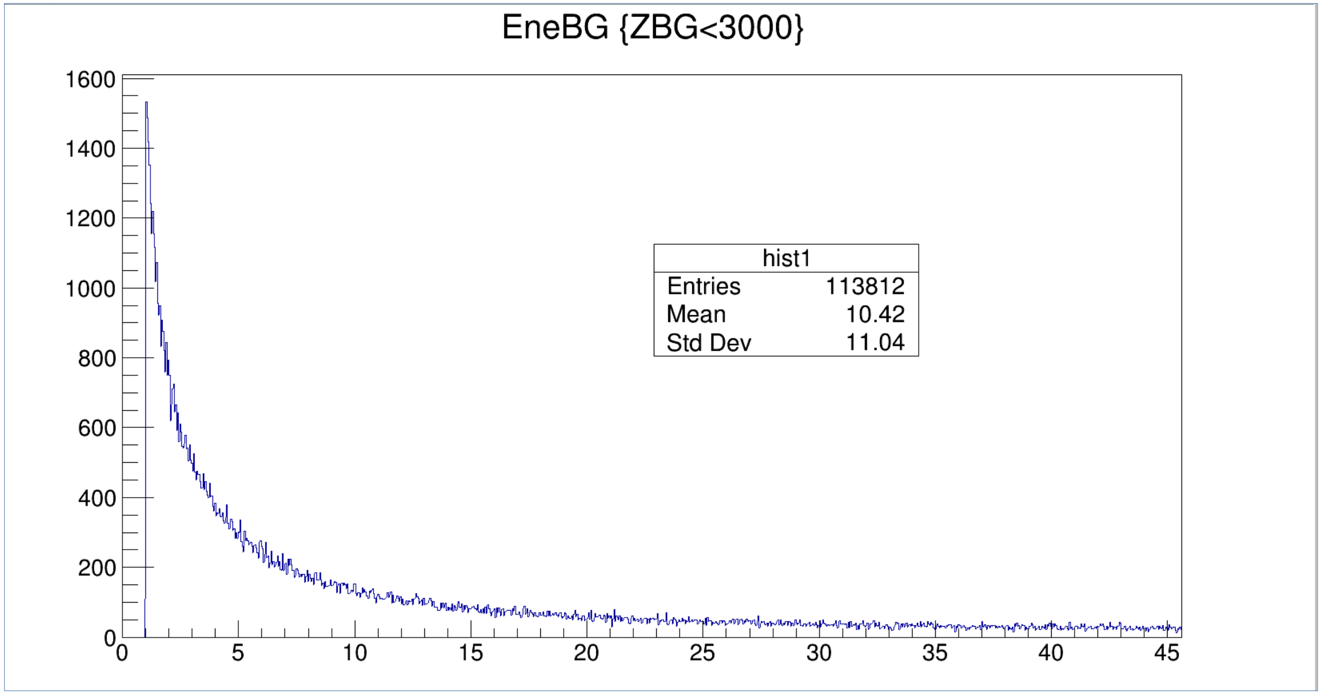
Beam gas particles generated in the arc are lost very soon, in the arc dipoles 100m~200m after interaction





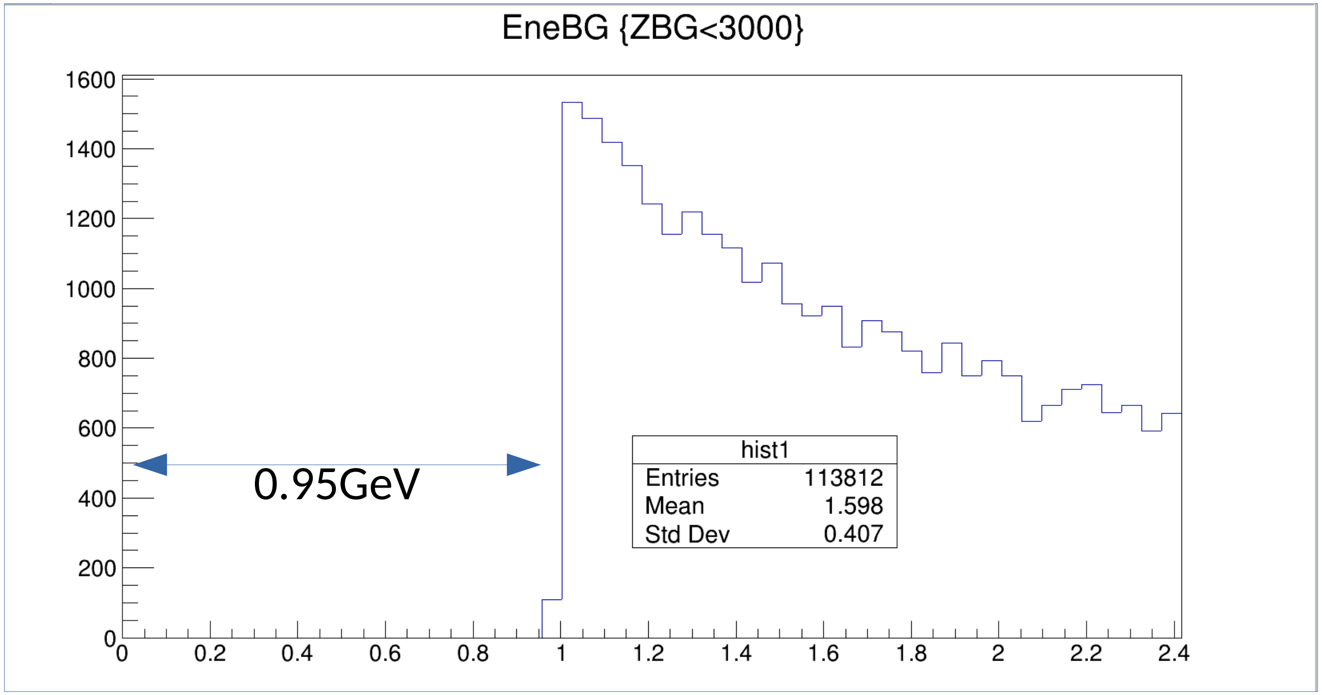
ENERGY EXCHANGE BETWEEN e- and gas ?

Energy loss
In the Beam Gas
event :



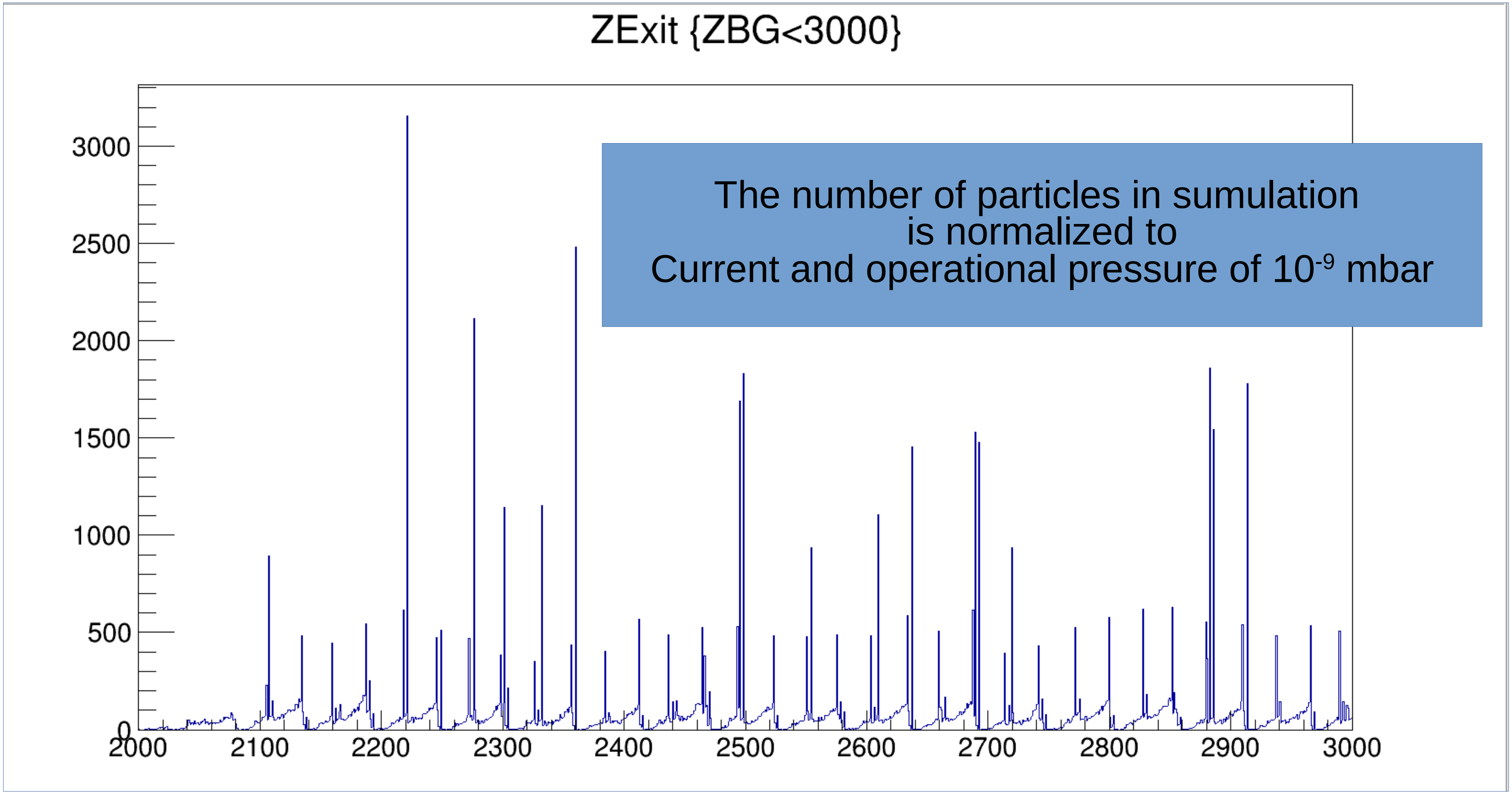
Particles loosing less
Than 0.95GeV continue
In the beam

Energy acceptance
0.95GeV , i.e.
0.95/45.6 = 2.1%



LOCATION OF PARTICLE LOSS ?

Particle distribution
Along Z :
Somehow uniform distribution of the particle loss



The number of particles in sumulation
is normalized to
Current and operational pressure of 10^{-9} mbar