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)

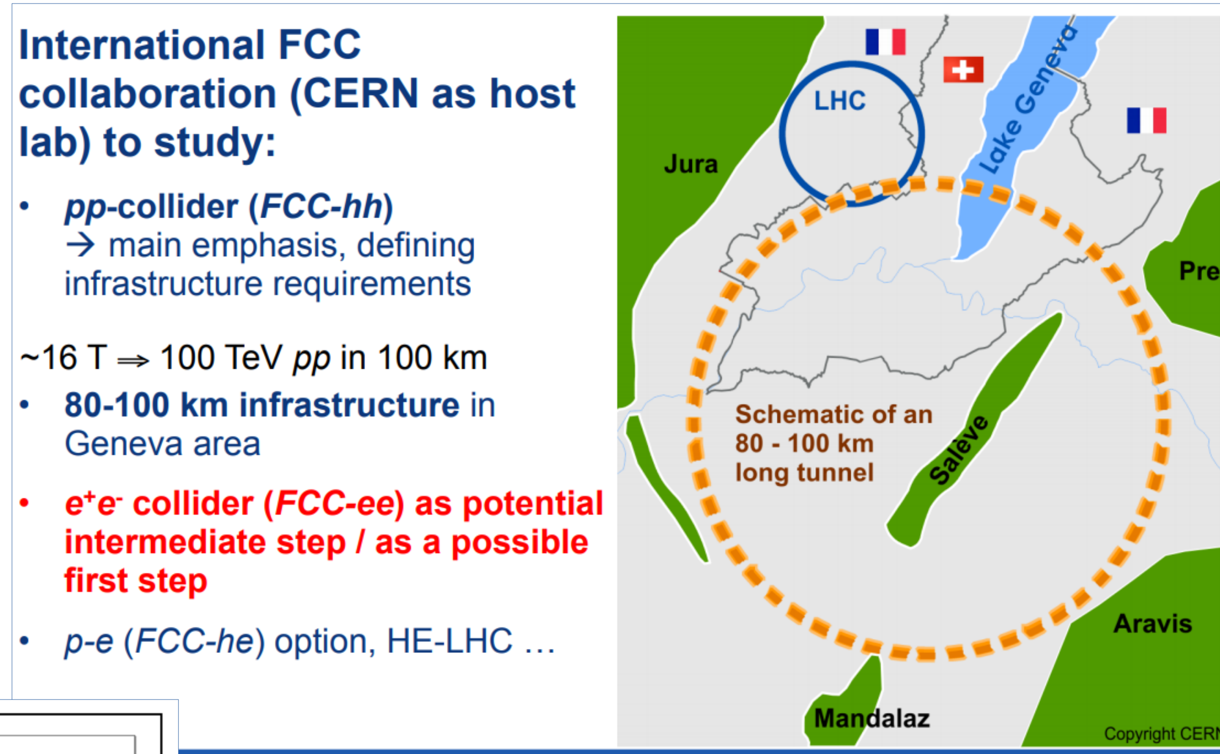
O. BLANCO, on behalf of : M. BOSCOLO, H. BURKHARDT
F. COLLAMATI, M. LUCKHOF

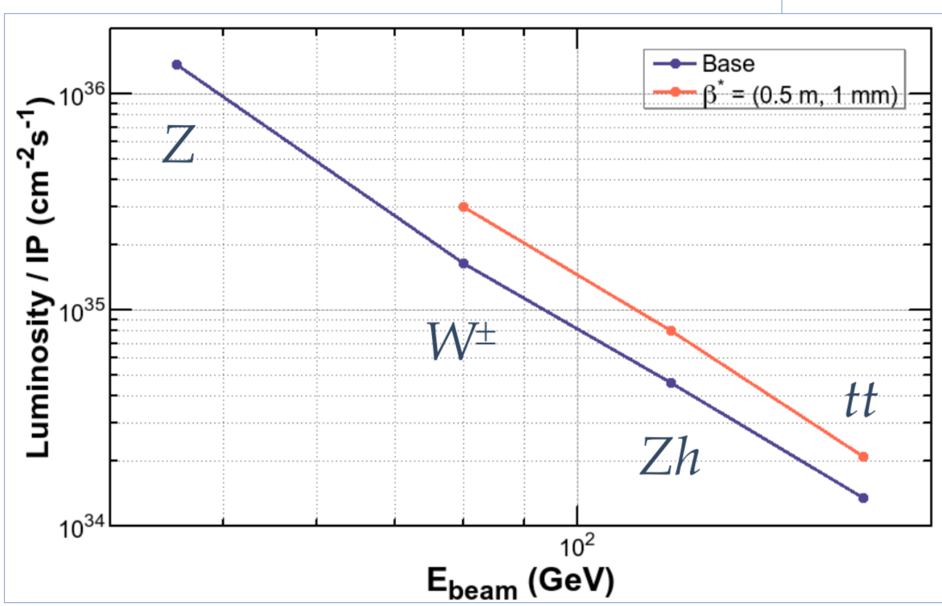
RD_FA Collaboration Meeting
2018/July/05

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

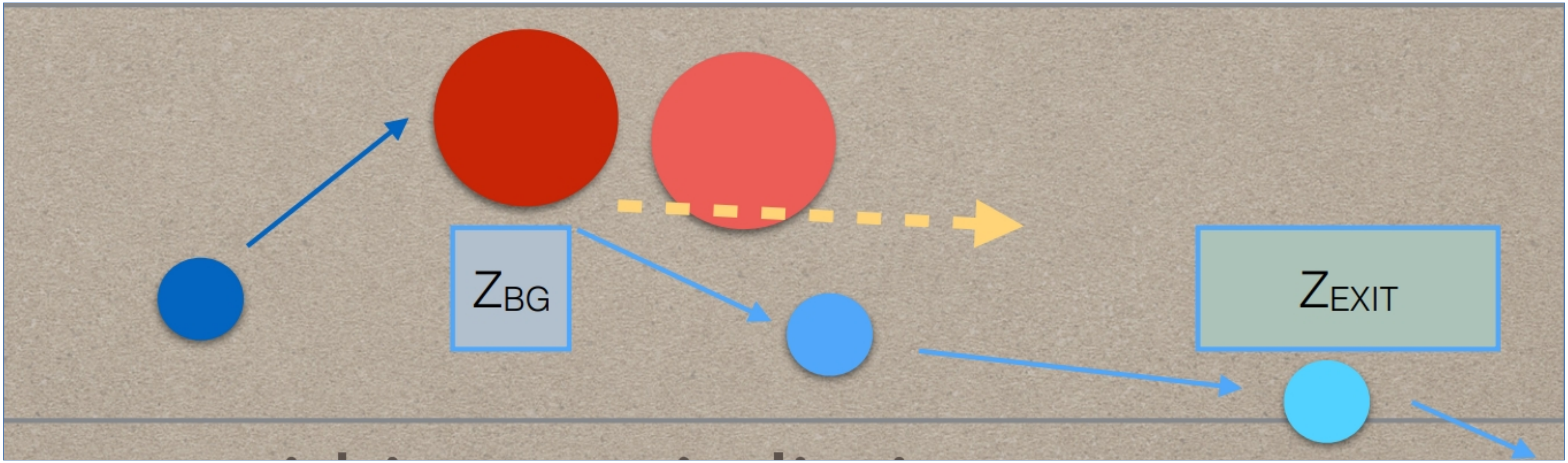




Oide, FCC week 2017
https://indico.cern.ch/event/556692/contributions/2483406/attachments/1466449/2271404/FCCee_Oide_170529.pdf

the BEAM GAS background 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



There are two main criteria to evaluate this process :

→ Beam life time

→ Background in the experiment

DAFNE Tech Note V-3. Vaccarezza, 1991/JUL/08
"Preliminary Study for the Choice of the DAFNE Vacuum Chamber Material".

the BEAM GAS scattering Cross sections

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

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

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

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

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	H_2	0.0002 From Le Duff	0.3 Burkhardt
Arc	N_2	0.04 From Le Duff	**9.4** Burkhardt
MDI	H_2	0.2 New formula	- Difficult to estimate (ε?)
MDI	N_2	**20** New formula	- Difficult to estimate (ε?)

WE SIMULATE INELASTIC SCATTERING IN

← THE ARC (benchmark)

← AND THE MDI <u>OUR GOAL</u>

WHAT WE DO WITH MDISim

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

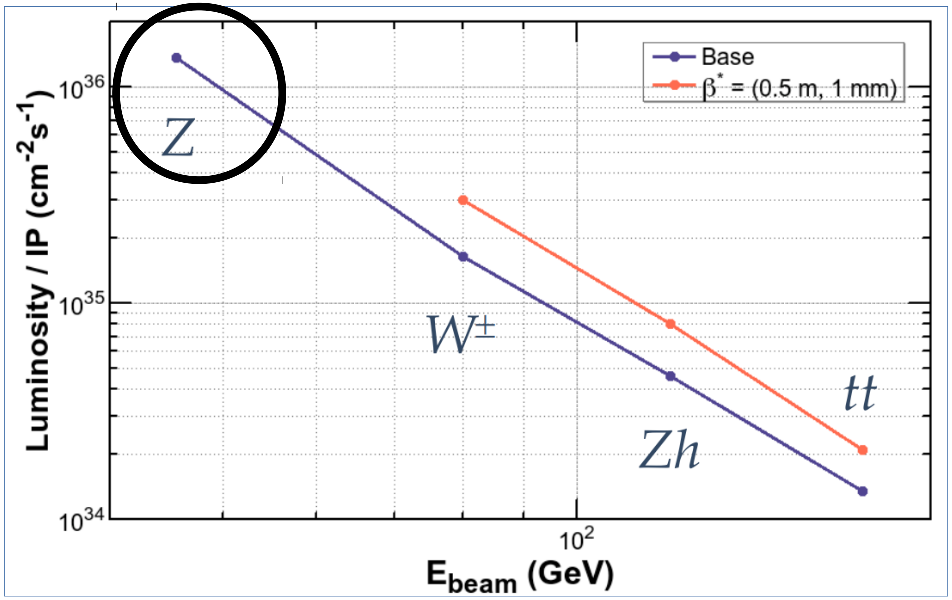
First results of **Inelastic Beam-gas scattering** latest optics

→ Loss map and loss rates are obtained.

Results for:

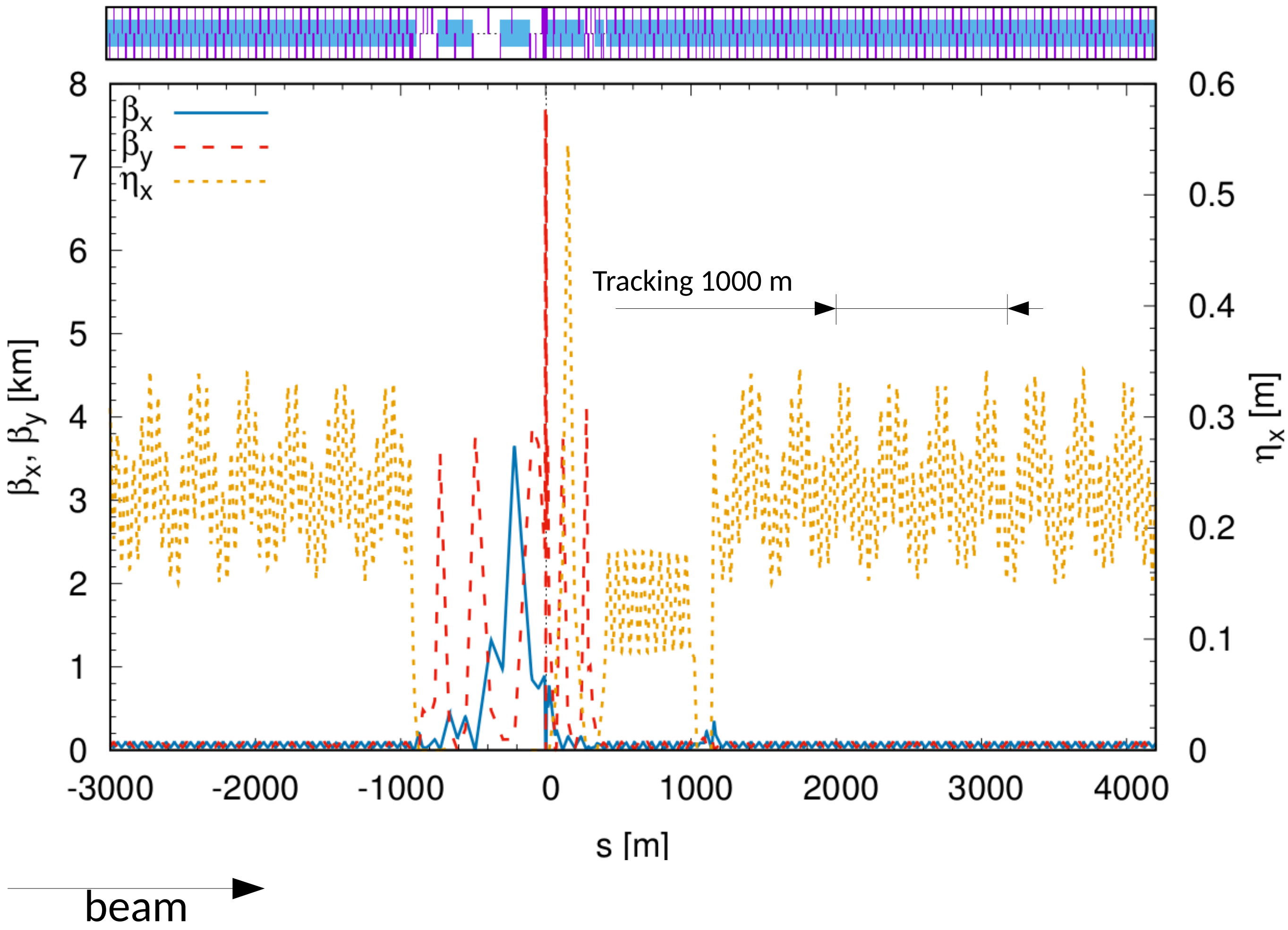
IR and arc at the 4 energies (Z, H, W, t)
I am showing plots for the Z

Z 45.6GeV/beam arc



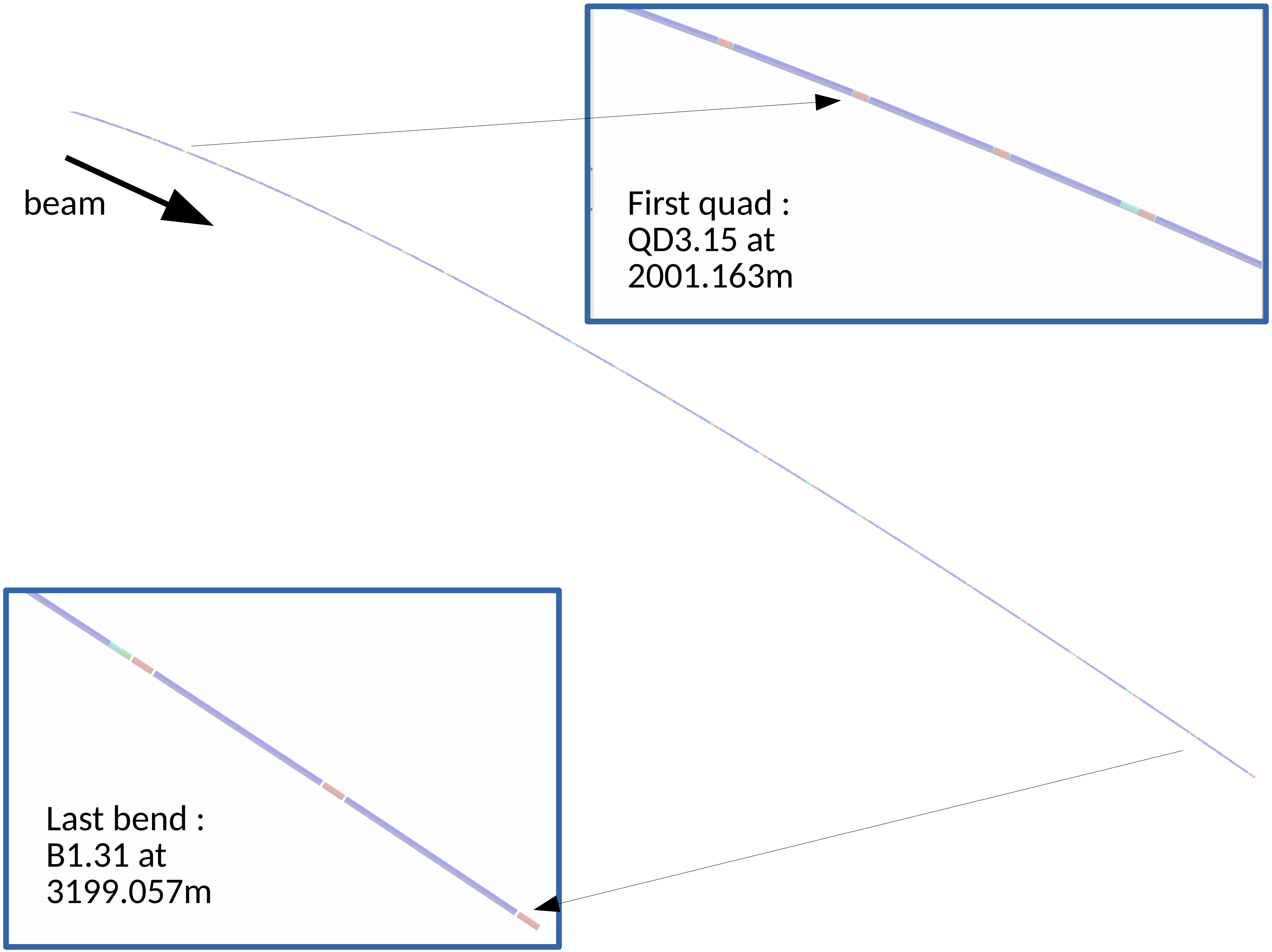
FCCee arc Z 45.6GeV/beam

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

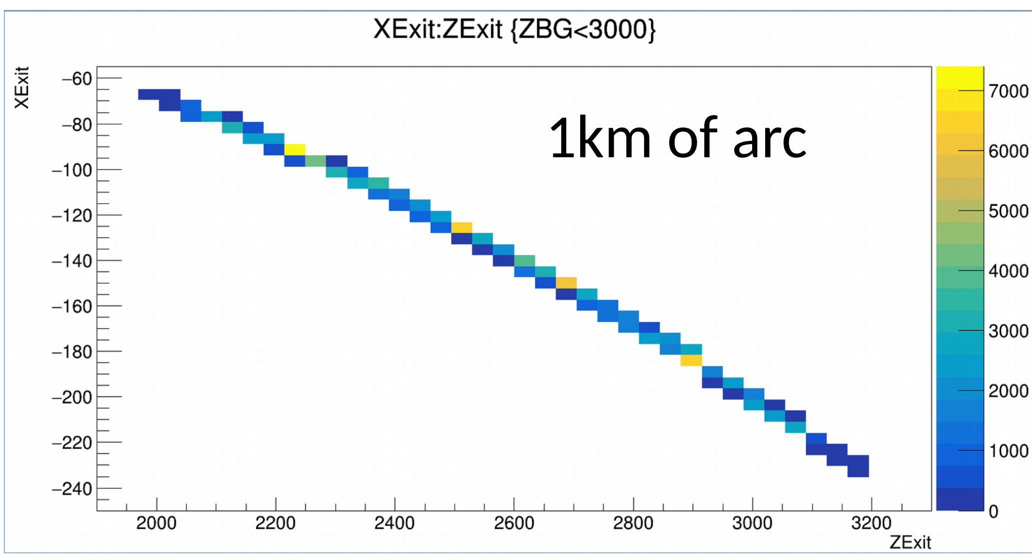
With an energy acc. of 2% and pressure of 10^{-9} mbar

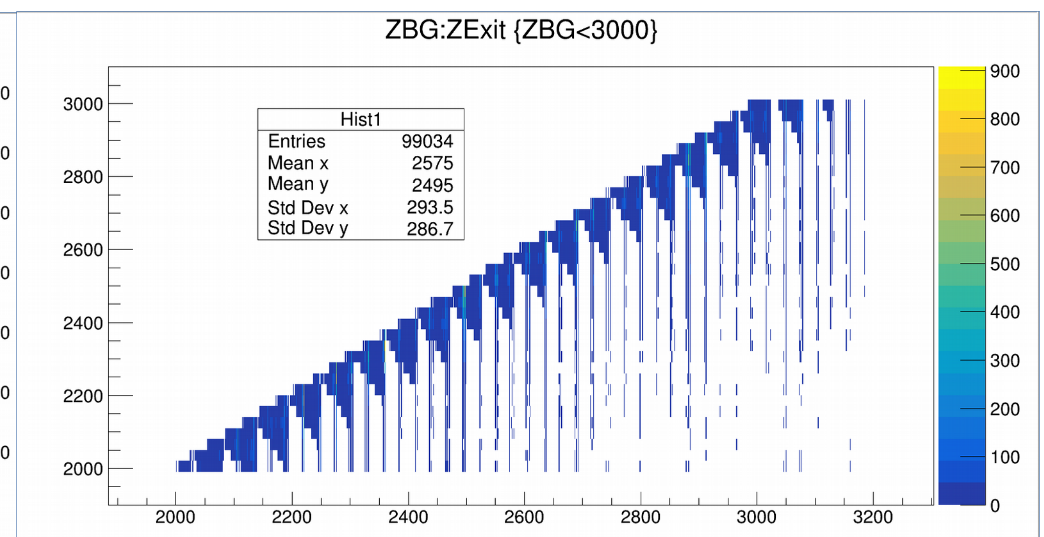
	Scattering Rate/m/beam Expected	Simulation
H2 : 0.328 barn	6.7 KHz	6.2 KHz
N2 : 9.386 barn	192.3 KHz	189.1 KHz

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

At 10^{-9} mbar of gas pressure we have low scattering rate and good agreement between simulation and analytical estimation

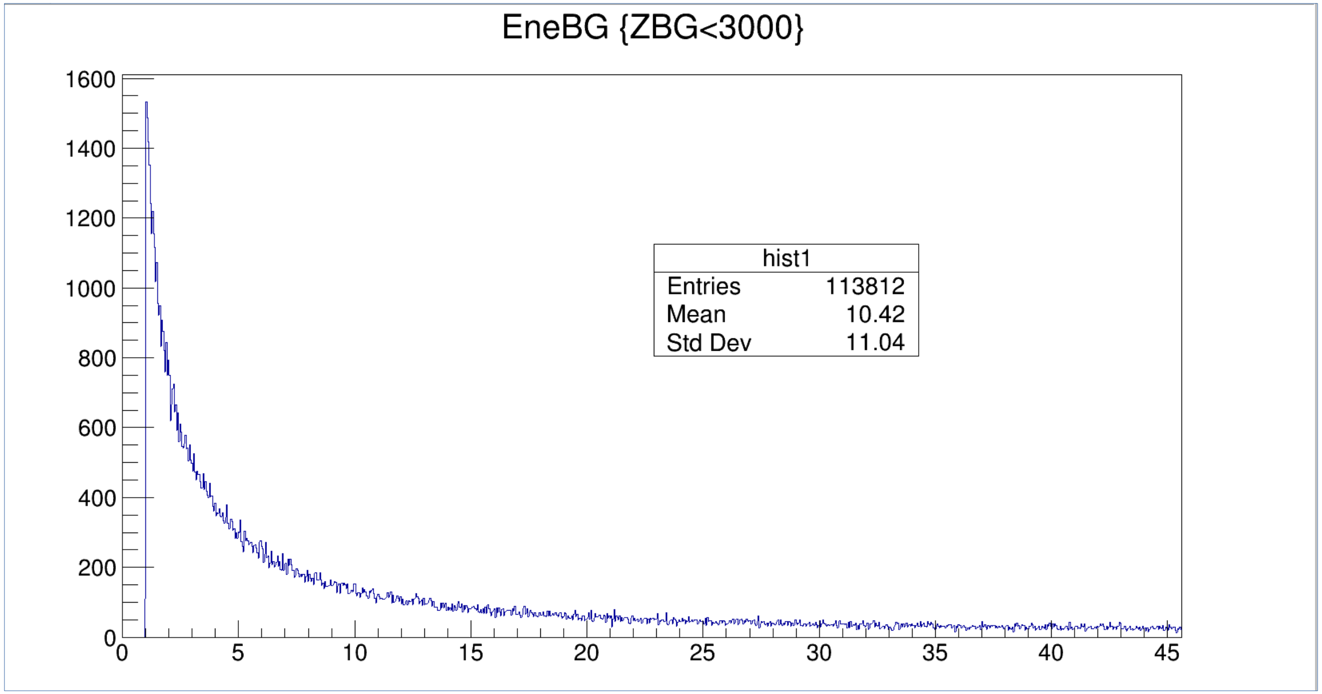
Beam gas particles generated in the arc are lost very soon, in the arc dipoles 100m~200m after interaction





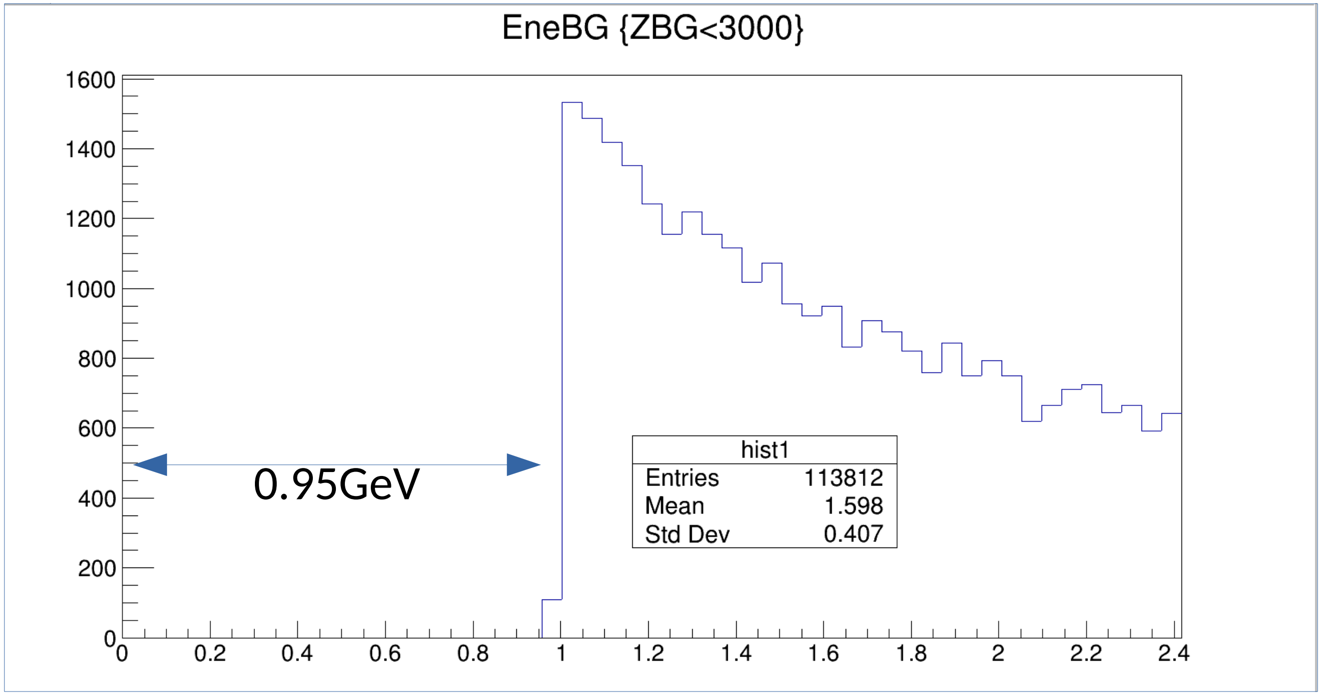
ENERGY EXCHANGE BETWEEN e- and gas ?

Energy loss
In the Beam Gas
event :



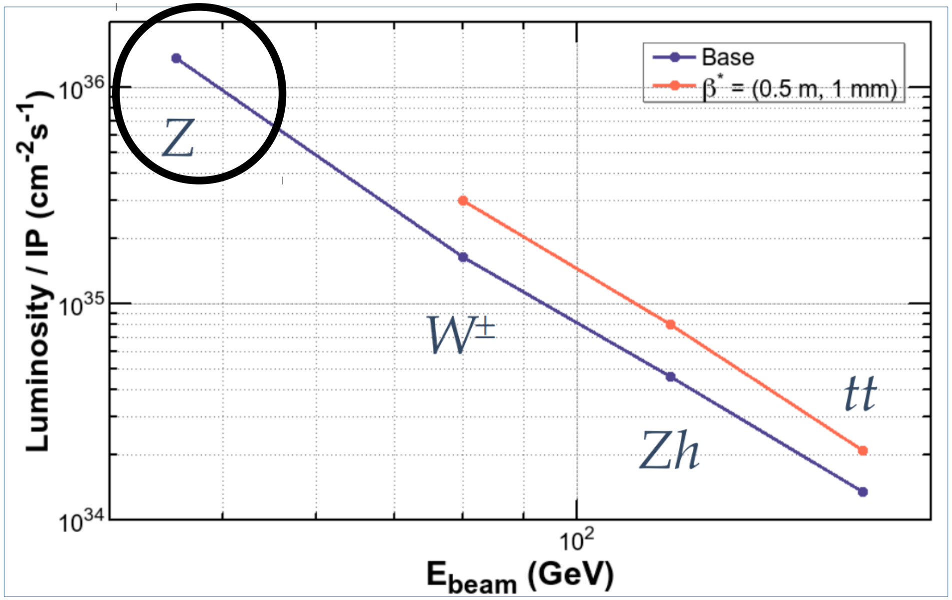
Particles loosing less
Than 0.95GeV continue
In the beam

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



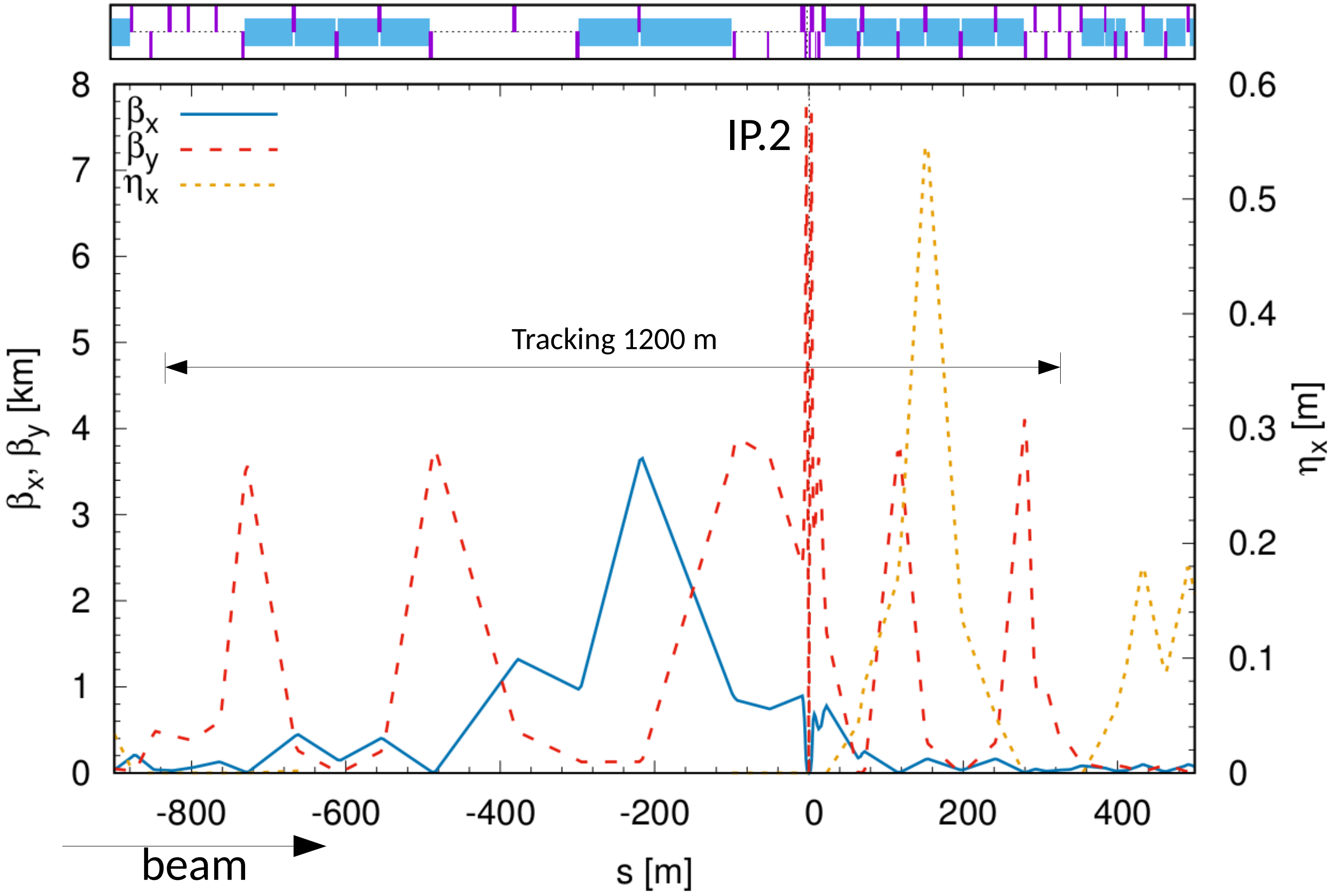
Z 45.6GeV/beam
MDI Region

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



FCCee Z 45.6GeV/beam

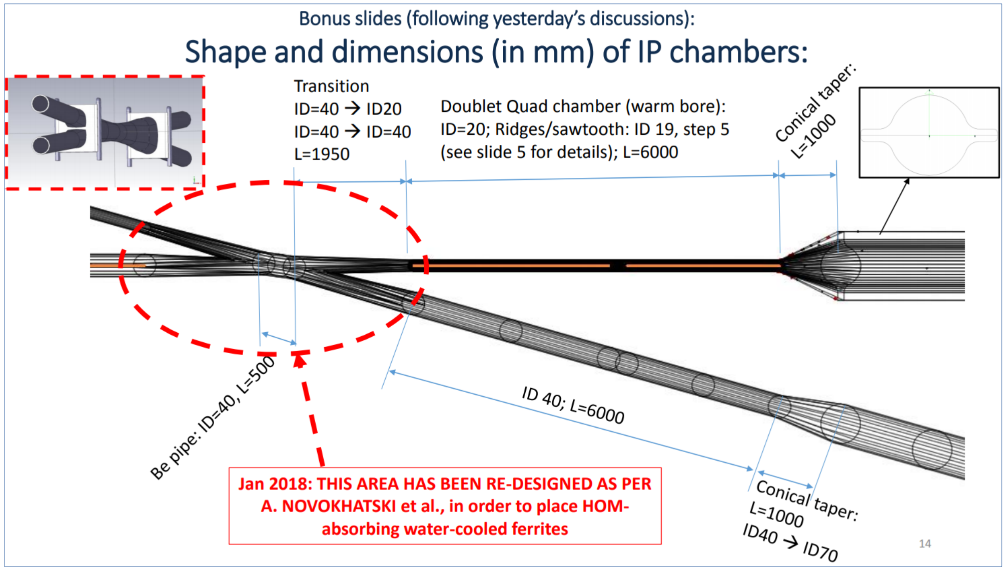
Lattice : FCCee_z_213_nosol_18.seq (ZOOM)

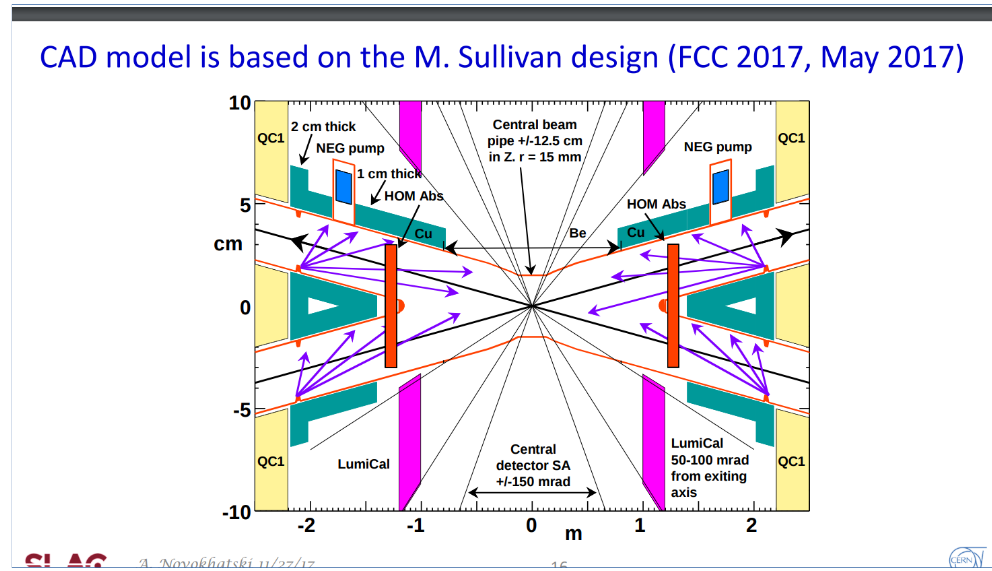


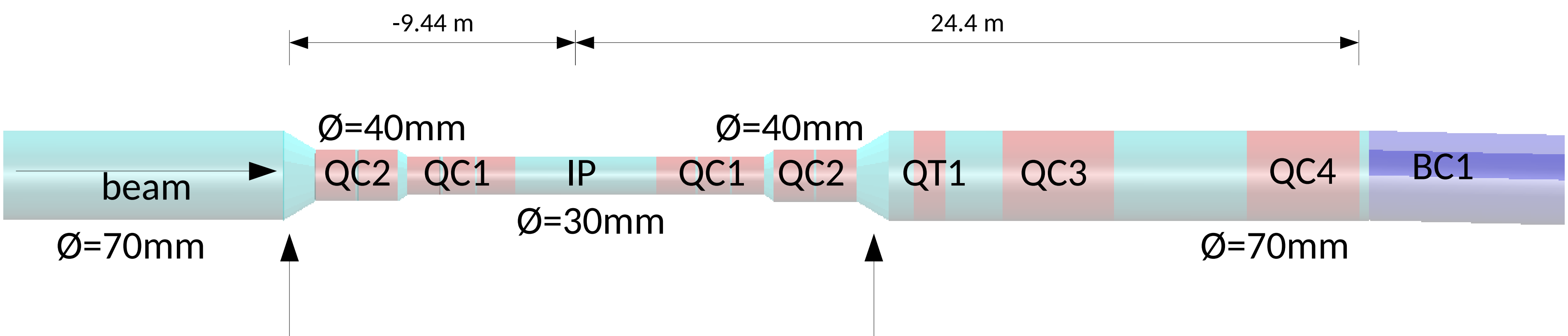
We consider to study from s=-830m to s=370m

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

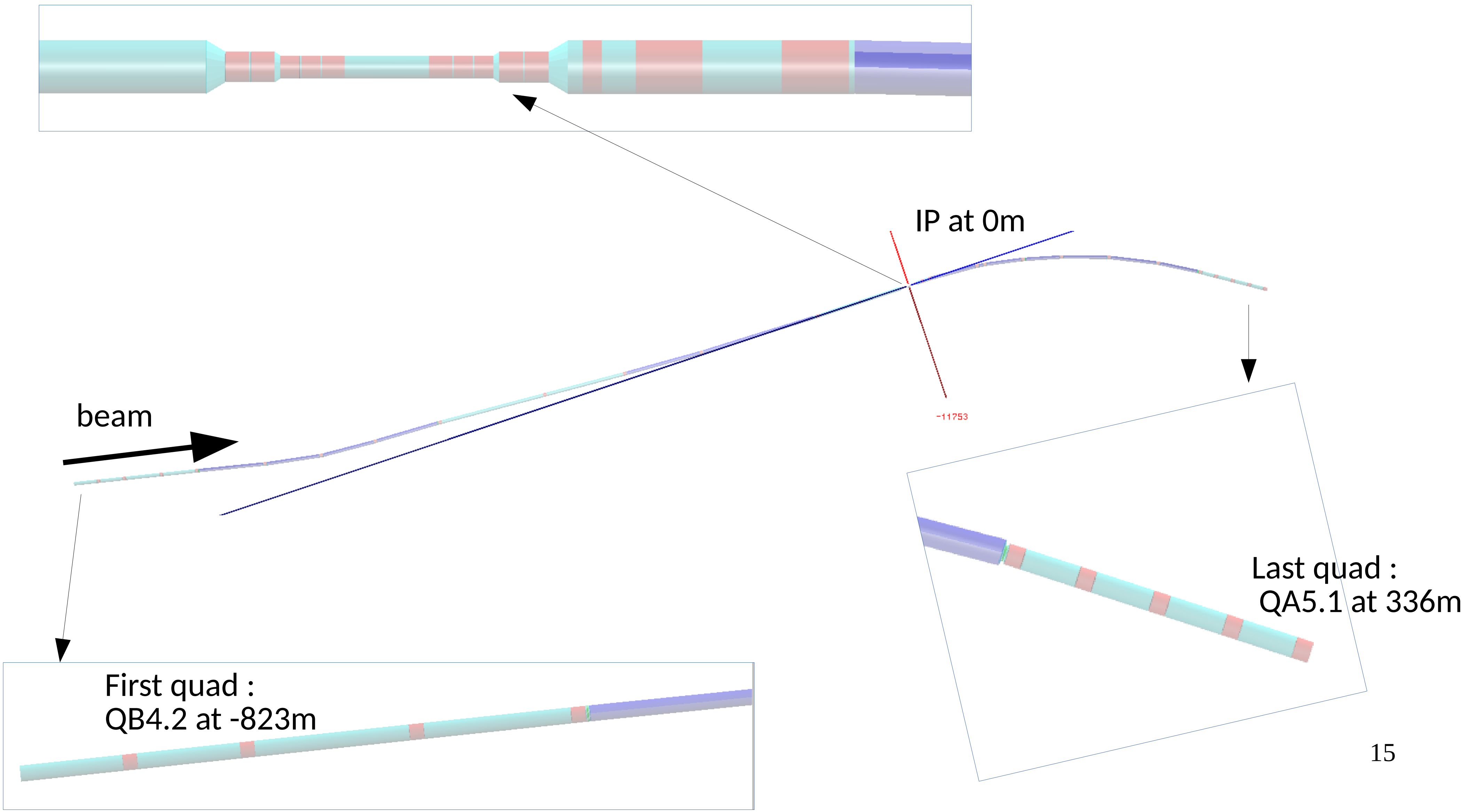




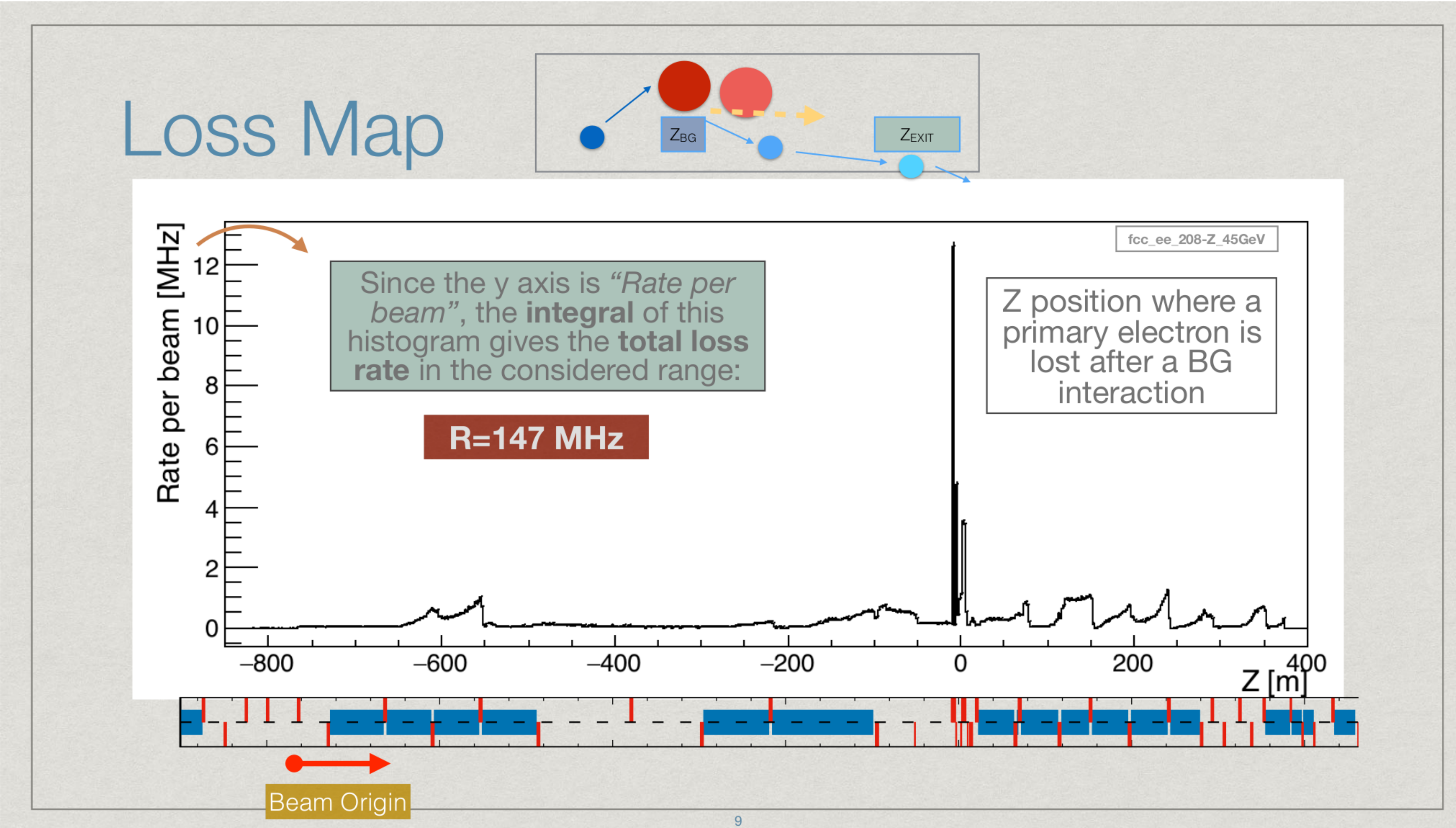


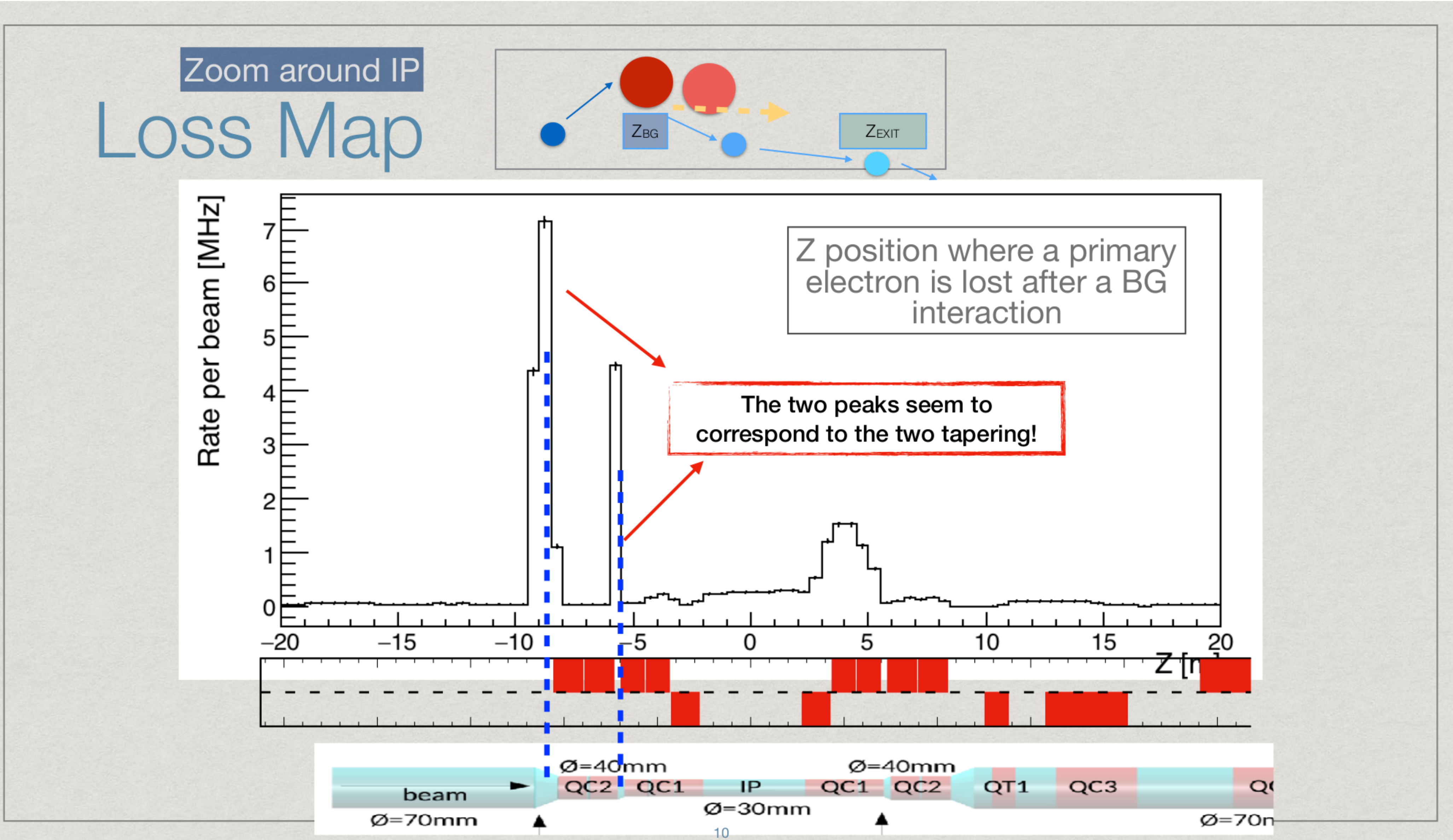
1m of conical taper between pipe diameters of 70mm and 40mm

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

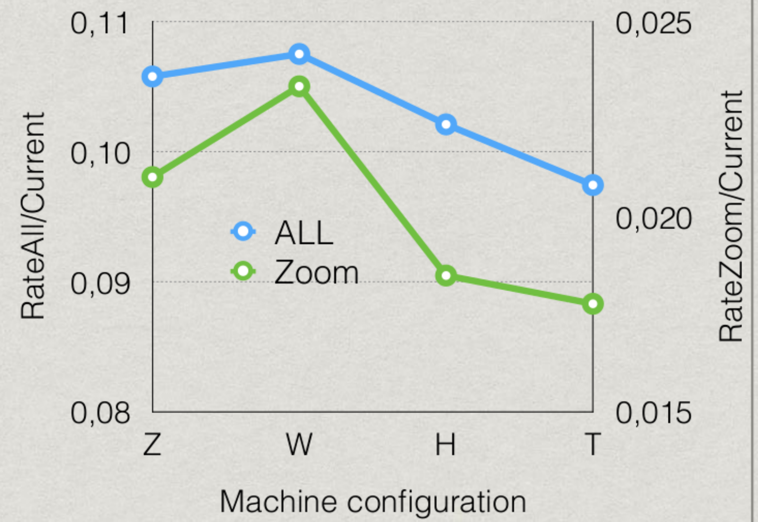


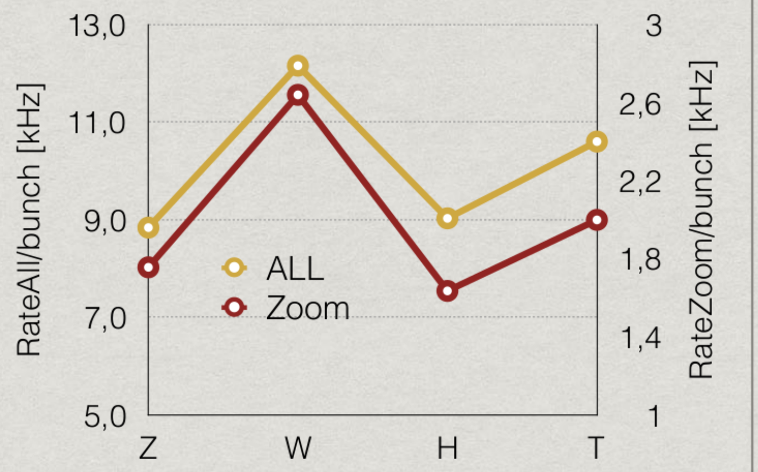

Zoom around IP
Loss Map
ZBG
ZEXIT
Rate per beam [MHz]
Z position where a primary electron is lost after a BG interaction
The two peaks seem to correspond to the two tapering!
Z [m]
Ø=40mm
Ø=40mm
beam
QC2
QC1
IP
QC1
QC2
QT1
QC3
Ø=30mm
Ø=70mm
10

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





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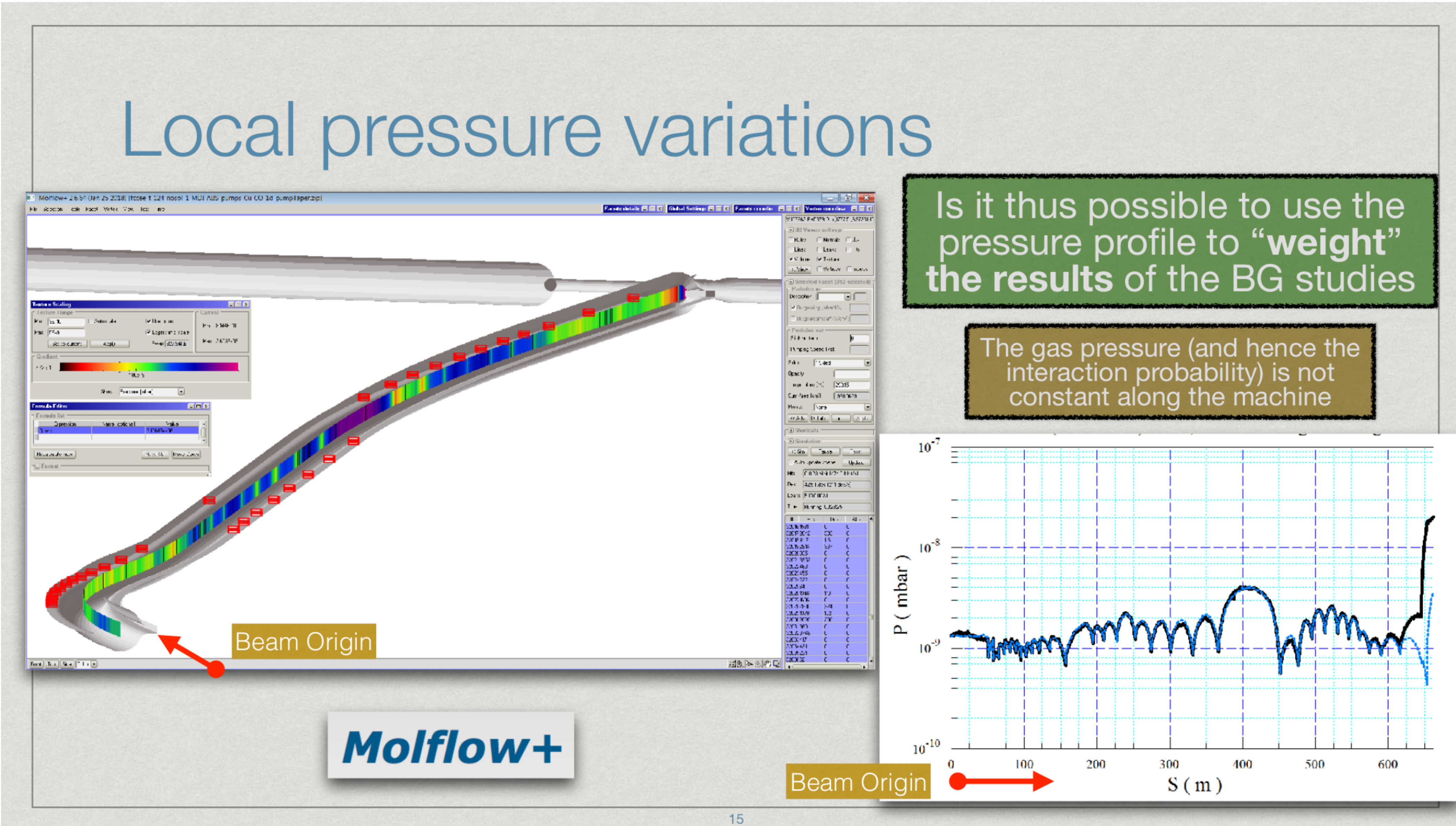
Collamatti, FCC Week 2018 - Amsterdam
Beam-gas background characterization in the FCC-ee IR

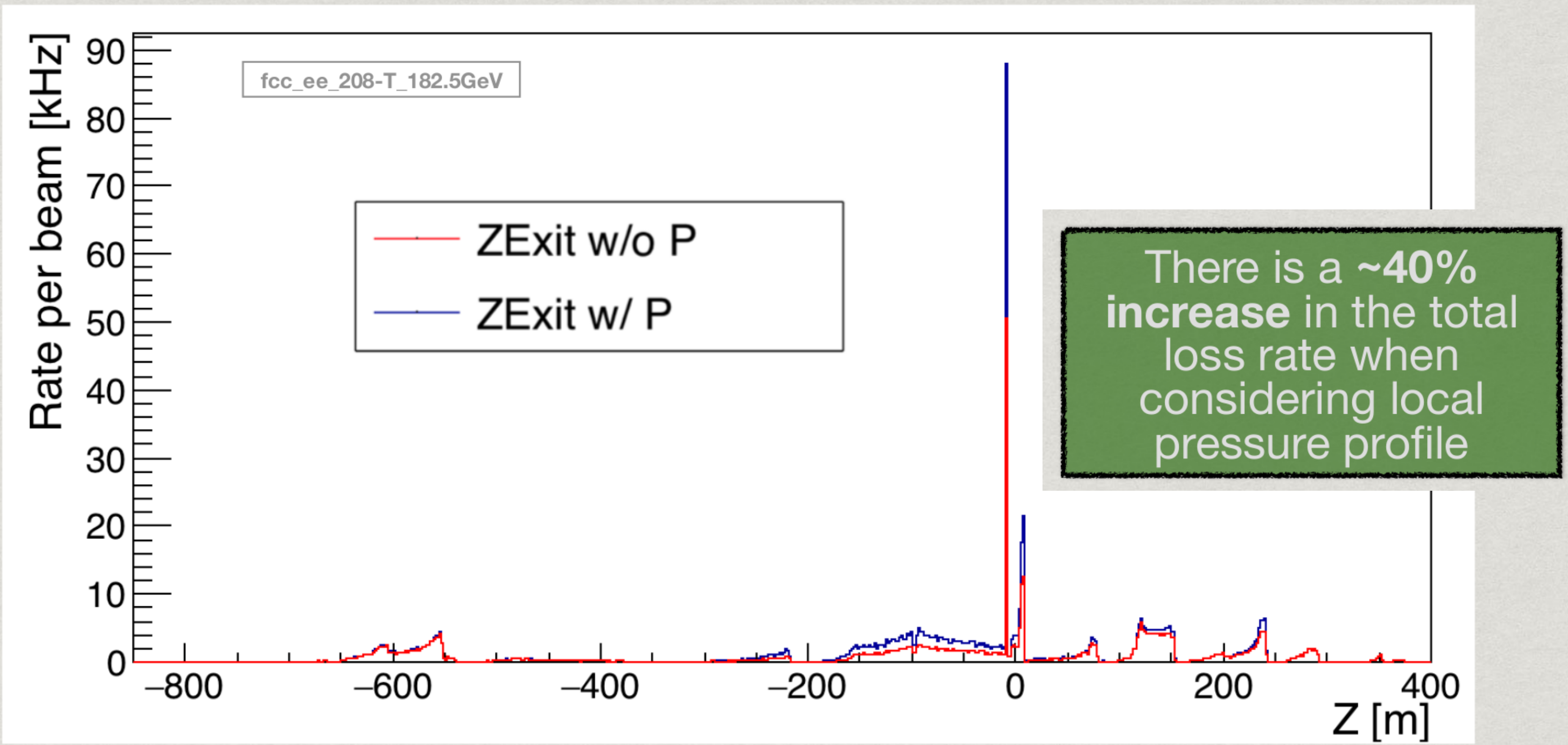
Local pressure variations

- 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)

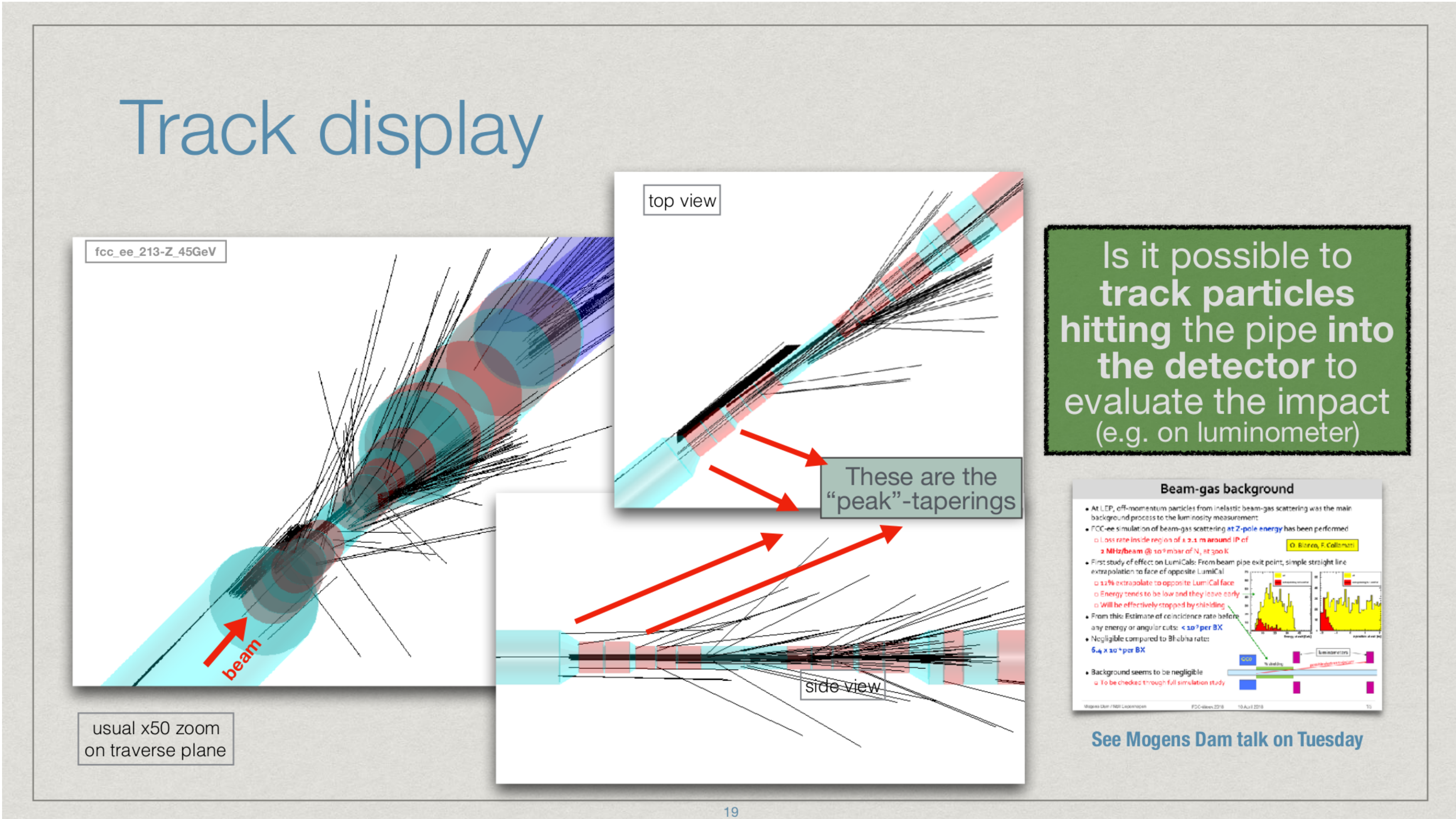


[Kersevan, Vacuum Systems for the FCC-ee
7th Low Emittance Workshop, Jan-2018, CERN
https://indico.cern.ch/event/671745/contributions/2788843/attachments/1582988/2502801/7thLowEmittanceWorkshop_RKersevan_Vacuum.pdf](https://indico.cern.ch/event/671745/contributions/2788843/attachments/1582988/2502801/7thLowEmittanceWorkshop_RKersevan_Vacuum.pdf)

Local pressure variations



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]



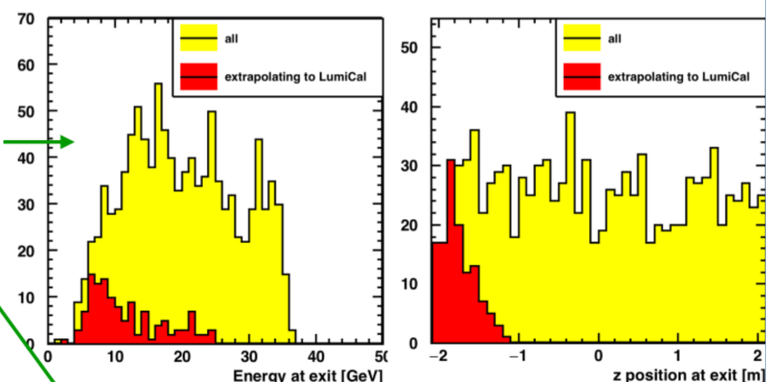
Mogens Dam, FCC Week 2018 - Amsterdam
LumiCal for FCC-ee and beam-background impact

Beam-gas background

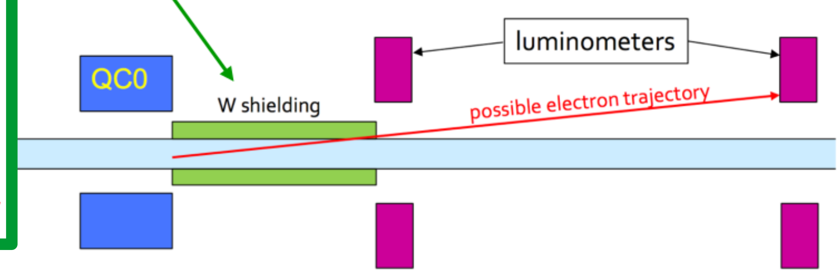
- At LEP, off-momentum particles from inelastic beam-gas scattering was the main background process to the luminosity measurement
- FCC-ee simulation of beam-gas scattering **at Z-pole energy** has been performed
  - Loss rate inside region of **± 2.1 m around IP** of **2 MHz/beam** @ 10^{-9} mbar of 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: **6.4×10^{-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

MEANING THAT 10^{-9} mbar shows to be OK for the experiment

Mogens, FCC Week 2018 - Amsterdam

LumiCal for FCC-ee and beam-background impact

CONCLUSIONS

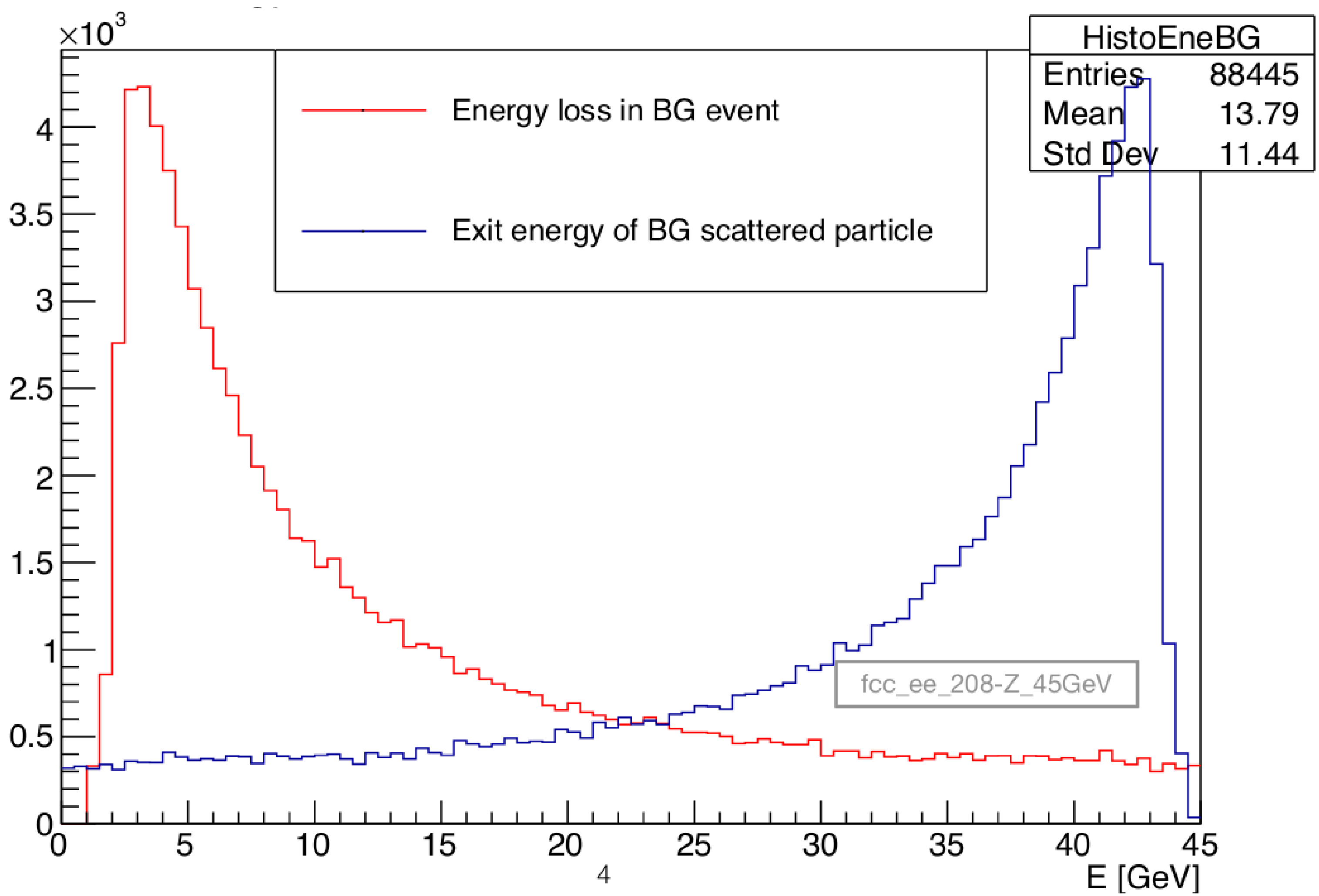
- We have initial studies of the beam gas background for the latest FCC-ee machine optics design
- It seems that the beam gas background is negligible at pressures in the beam pipe of the order of 10^{-9} mbar, which agrees with the current goals of the Vacuum Team.
- Detailed Loss maps and Loss rates for all 4 energy runs have been studied with MDISim, which results have been benchmarked against theory for the FCCee arc with very good agreement.
- The loss map indicates that collimation will be needed → THIS COULD BE ONE OF THE POSSIBLE CONTINUATIONS OF THIS WORK + UPDATES IN CASES WHEN OPTICS IS MODIFIED
- This work has been used as input for the Detertor Team and initial studies show that The background for the experiment from Beam Gas scattering seems negligible when compared to other backgrounds
- THIS RESULTS ARE USED AS INPUT FOR THE FCC-ee CDR, currently under edition.
- In addittion, in the future we could think to study other kinds of background (thermal photons has been mentioned as an option)

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



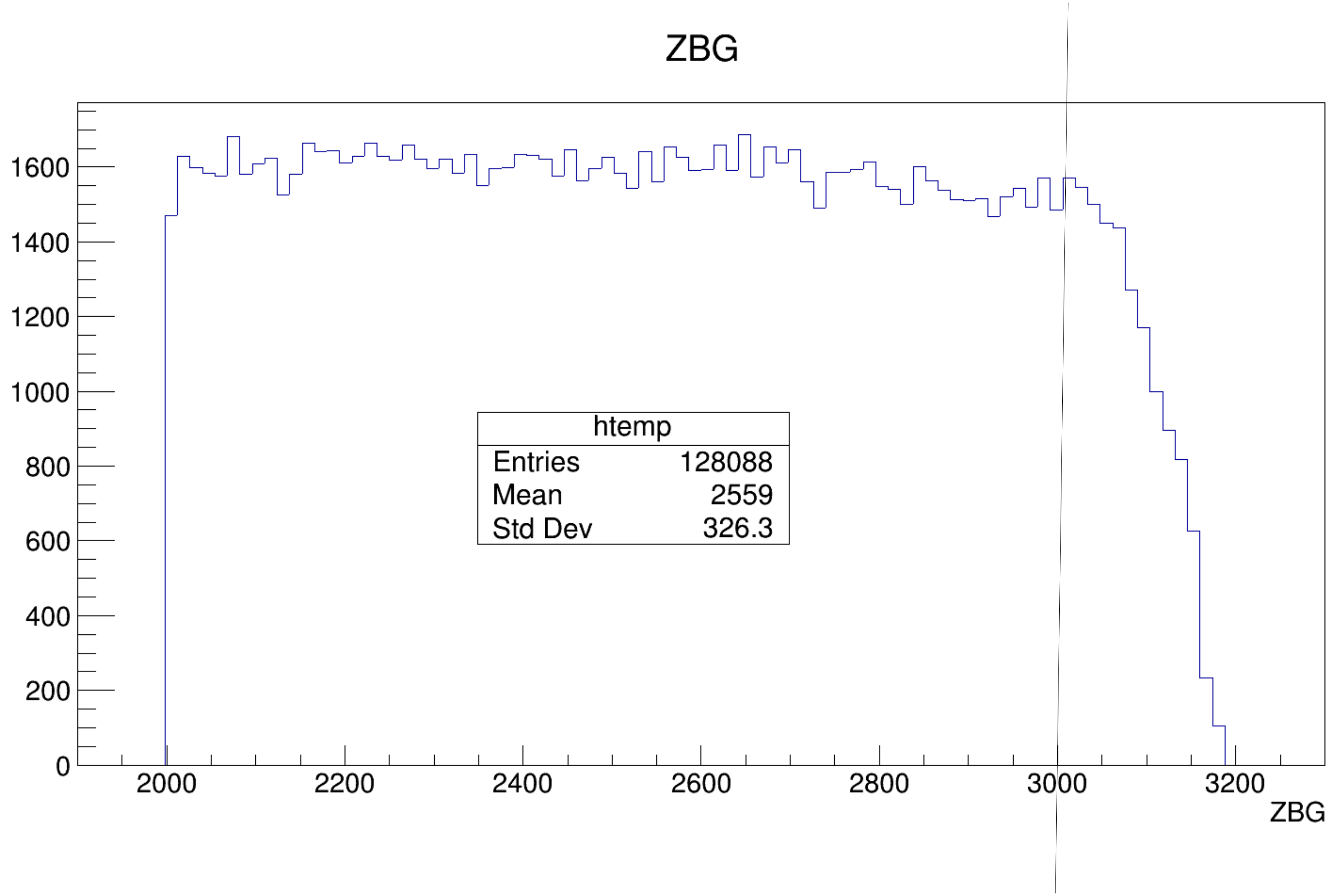
Lattices available in afs is X
Initial studies have been done with the ones marked with X
Latest lattice 213 for the t is now available

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

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

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

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

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

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

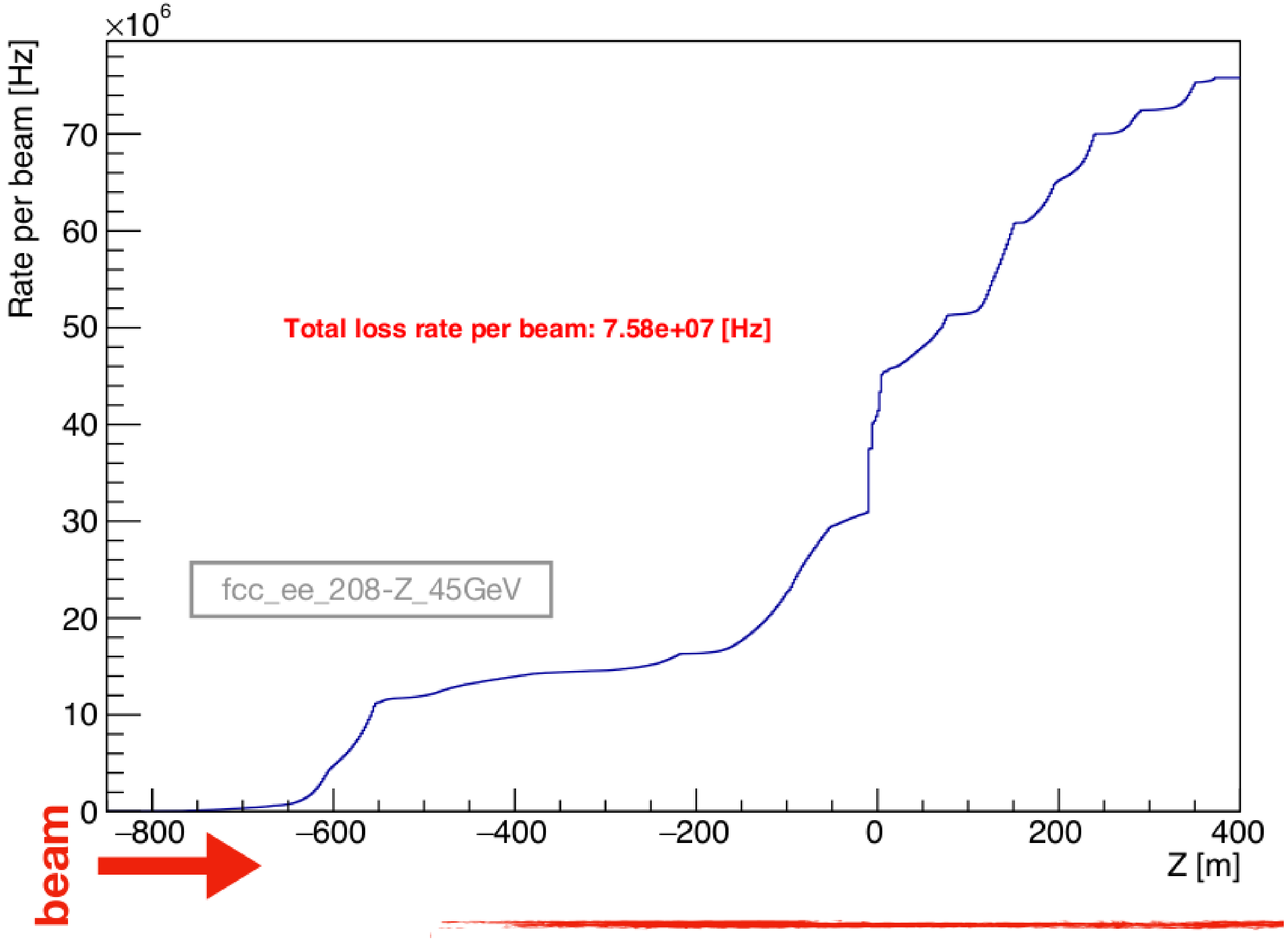
Neloss = 113812/1e7 . 1.7e11 . 16640 . 1e-9/1.78
= 18.1e3
Rate_eloss = Neloss/Trev = 18.1e3/0.333ms = 54.3 MHz

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

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.

84 *J. Le Duff / Current and current density limitations*

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]:

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

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 in dependently of the electron energy as [13]

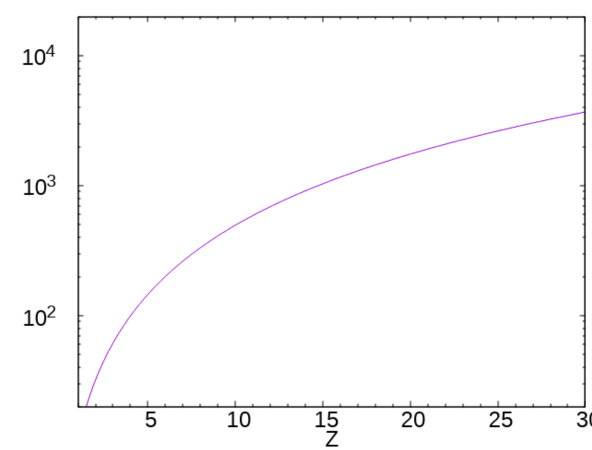
$$\sigma_{\mathrm{eN}} = 4\alpha\, r_e^2\, Z(Z+1)\, \log(287/\sqrt{Z}) \left(-\frac{4}{3}\log k_{\mathrm{min}} - \frac{5}{6} + \frac{4}{3}k_{\mathrm{min}} - \frac{k_{\mathrm{min}}^2}{2} \right), \qquad (5.4)$$

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).

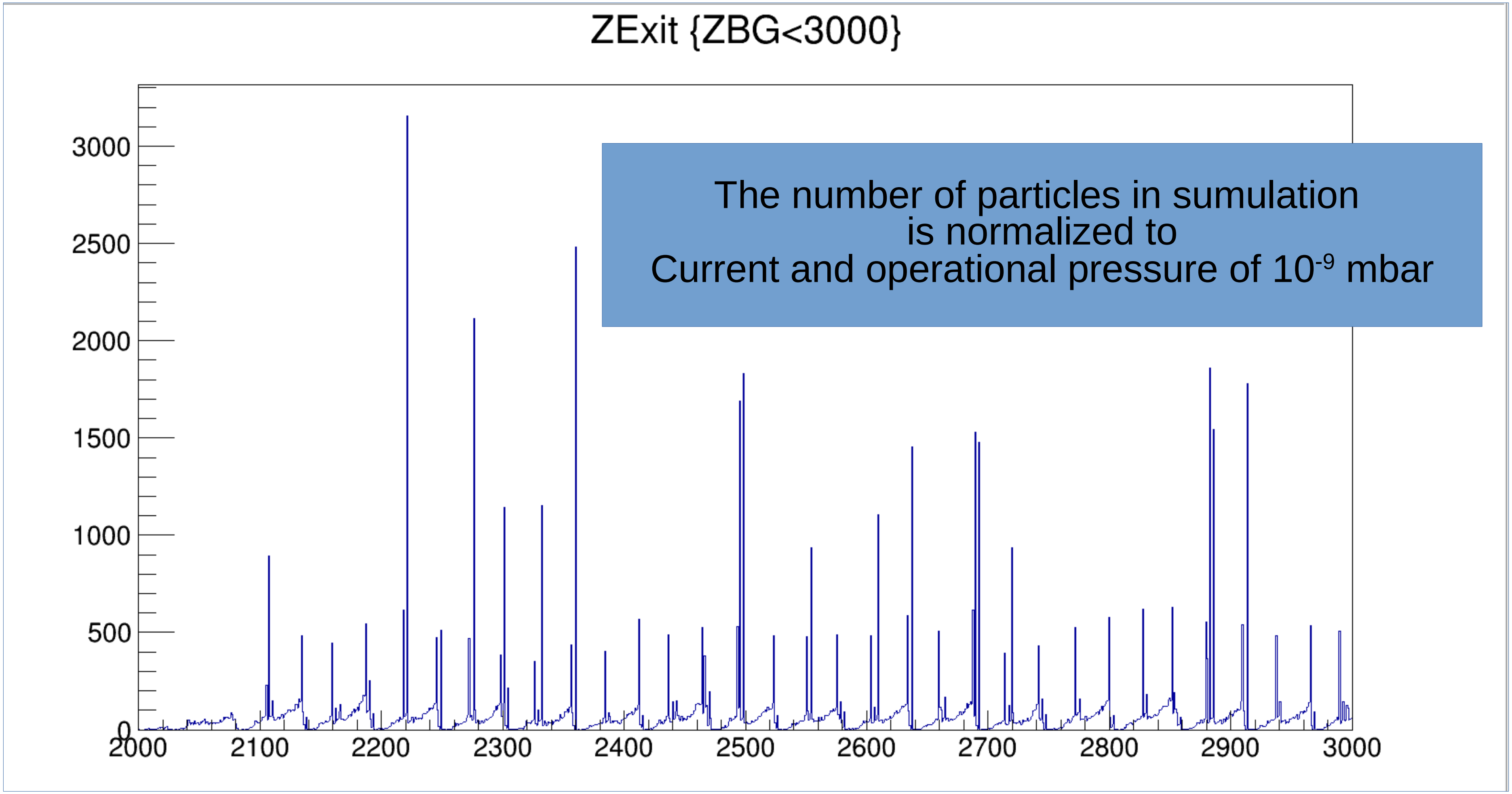
Gas	σ_{eN} b	σ_{pN} b
H_2	0.28	0.08
He	0.39	0.19
CH_4	3.02	0.43
H_2O	4.38	0.40
N_2	6.47	0.56
CO	6.56	0.56
CO_2	10.7	0.87
Ar	17.8	0.60

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



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