Collimators and radiation study in FCC-ee

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Emittance and beam spot calculations

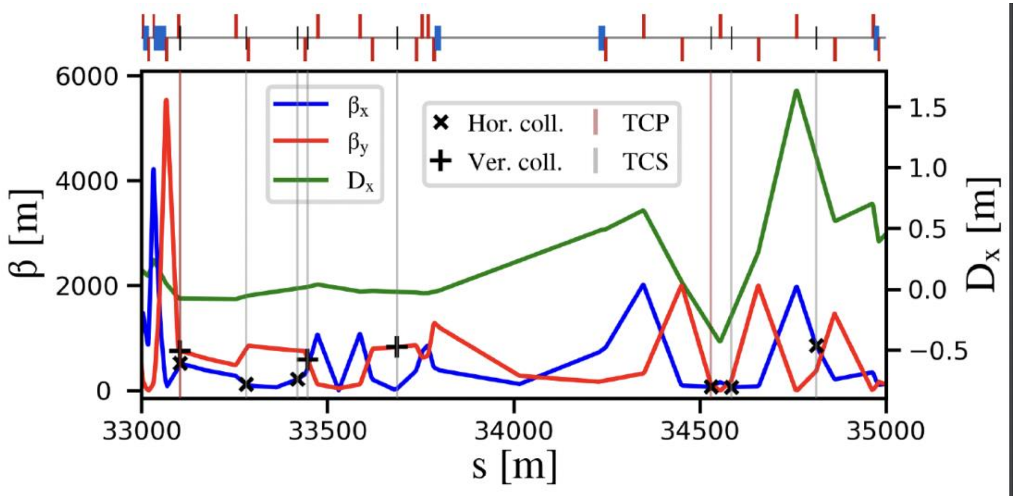
- Emittances from Katsuonobu Oide, FCC week 2024

$$\epsilon_x = 0.7\ \mathrm{nm}$$
$$\epsilon_y = 1.9\ \mathrm{pm}$$

Collimator gaps position based on Twiss parameters along the beam and the specified sigmas

For shower absorbers (SA), 15σ in x, 91σ in y.

β –function linearly interpolated between primary and secondary collimator for SA gaps



Relative Power Deposition

Vertical impact

	Primary V	Primary H	Secondary H	Secondary V	Secondary H	Secondary V
	0.014 %	0.11 %	1.53 %	0.33 %	0.0078 %	0.0042 %
	0.20 %	0.16%	18.4 %	2.00 %	0.080 %	0.040 %
	0.023 %	0.16 %	18.4 %	8.84 %	0.083 %	0.092 %

All quadrupoles : 2.14 %
Tunnel/earth/vacuum chamber: 47.26%

Horizontal impact

	V	H	H	V	H	V
	0 %	0.019%	1.50 %	0.35 %	0.023 %	0.009 %
	0.00 %	0.20%	10.55 %	5.94 %	0.097 %	0.13 %
	0.00 %	0.01 %	26.78 %	5.91 %	0.38 %	0.12 %

All quadrupoles : 1.84 %
Tunnel/earth/vacuum chamber: 45.9%

Absolute Power Deposition

Assumptions:

- Bunch intensity: 2.16×10^{11}
- Bunches per beam: 11200
- Loss decay time: 5 minutes

Collimator power loss: 37.19 kW

Vertical impact	Primary V	Primary H	Secondary H	Secondary H	Secondary V	Secondary V
(above)	0.0055 kW	0.041 kW	0.59 kW	0.13 kW	0.003 kW	0.0016 kW
(upper)	0.076 kW	0.062 kW	7.04 kW	0.76 kW	0.031 kW	0.015 kW
(lower)	0.0087 kW	0.061 kW	7.03 kW	3.39 kW	0.032 kW	0.0351 kW

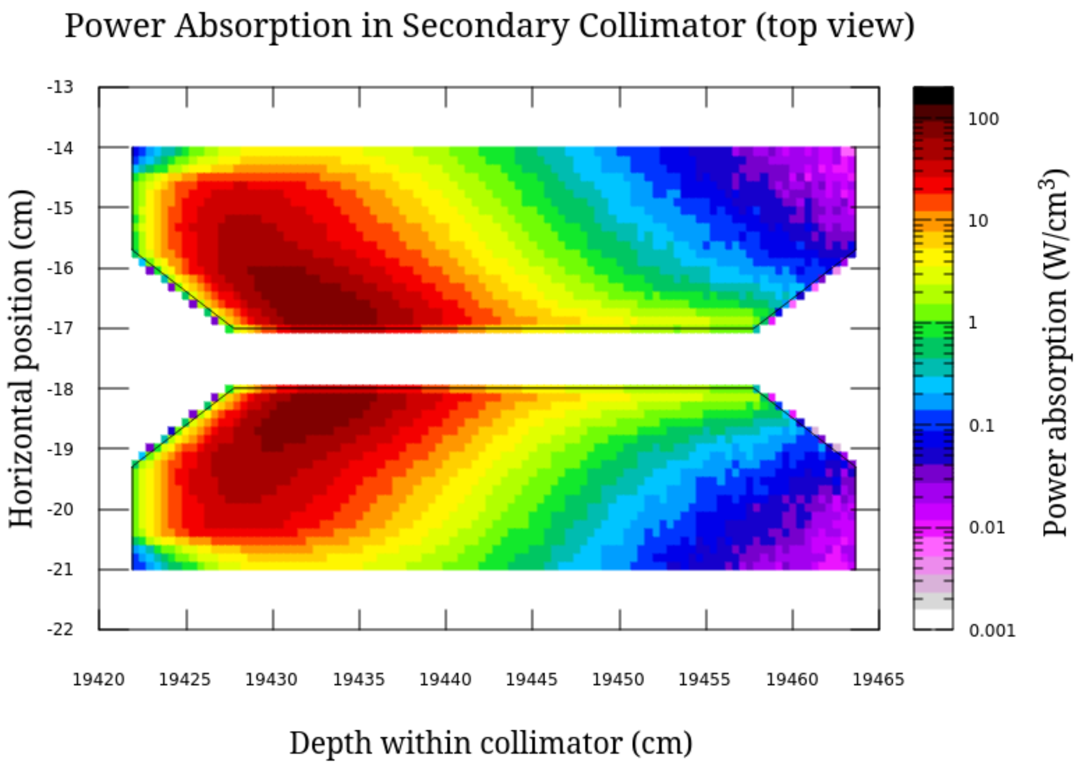
All quadrupoles : 0.82 kW
Tunnel/earth/vacuum chamber: 18.1 kW

Horizontal impact	V	H	H	H	V	V
(above)	0 kW	0.007 kW	0.57 kW	0.14 kW	0.0088 kW	0.0034 kW
(upper)	0 kW	0.0072 kW	4.04 kW	2.27 kW	0.037 kW	0.051 kW
(lower)	0 kW	0.075 kW	10.25 kW	2.26 kW	0.15 kW	0.047 kW

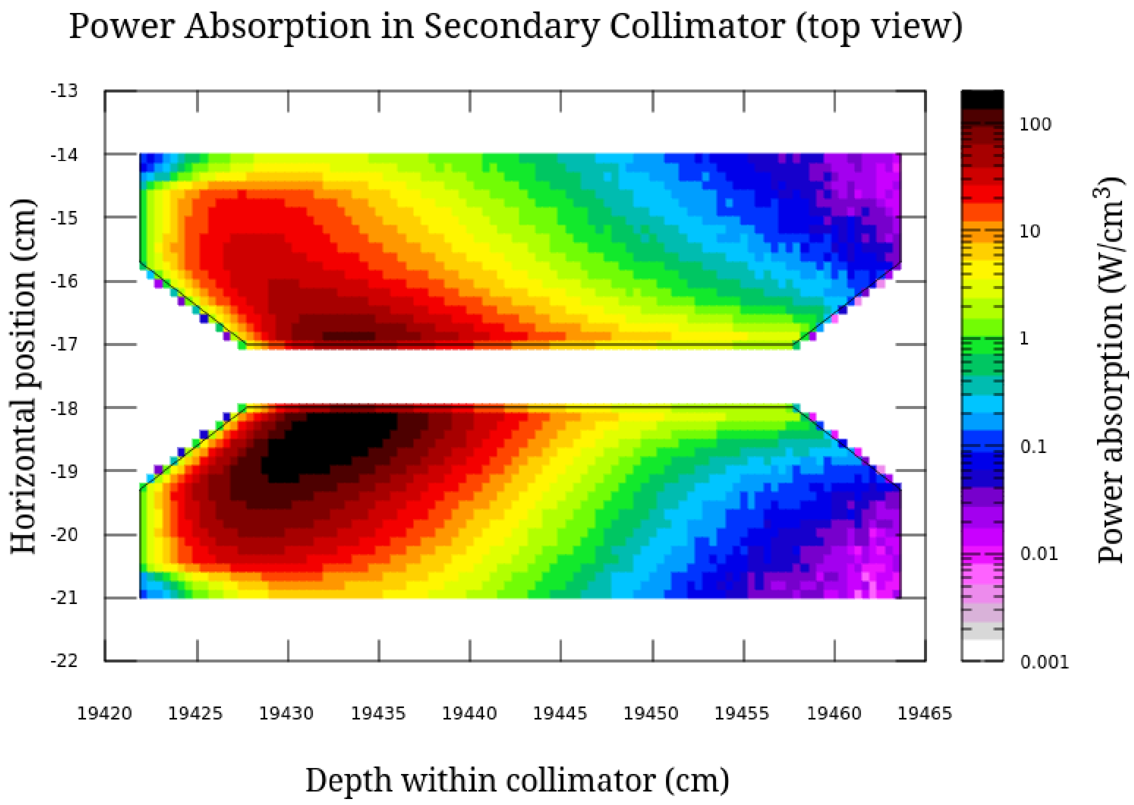
All quadrupoles : 0.70 kW
Tunnel/earth/vacuum chamber: 17.61 kW

Power absorption map for TCS_H1

Vertical impact

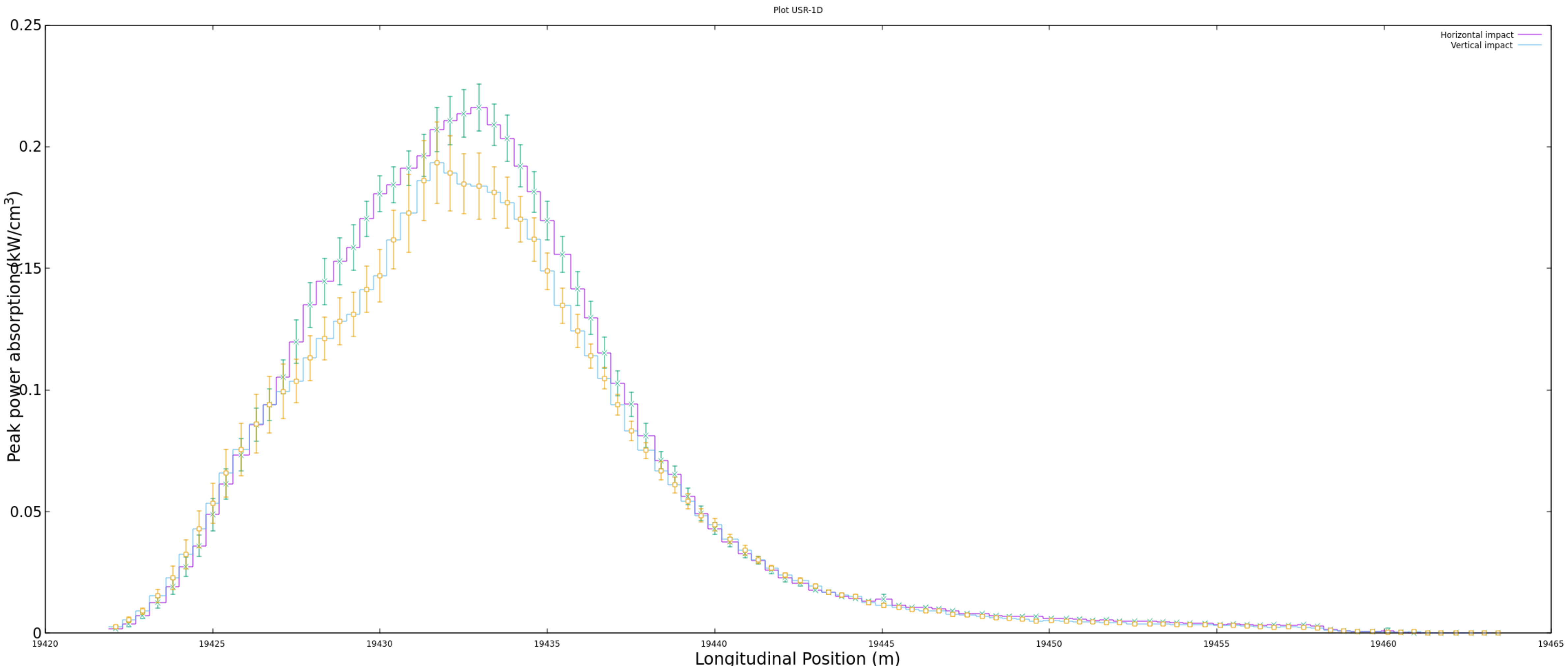


Horizontal impact

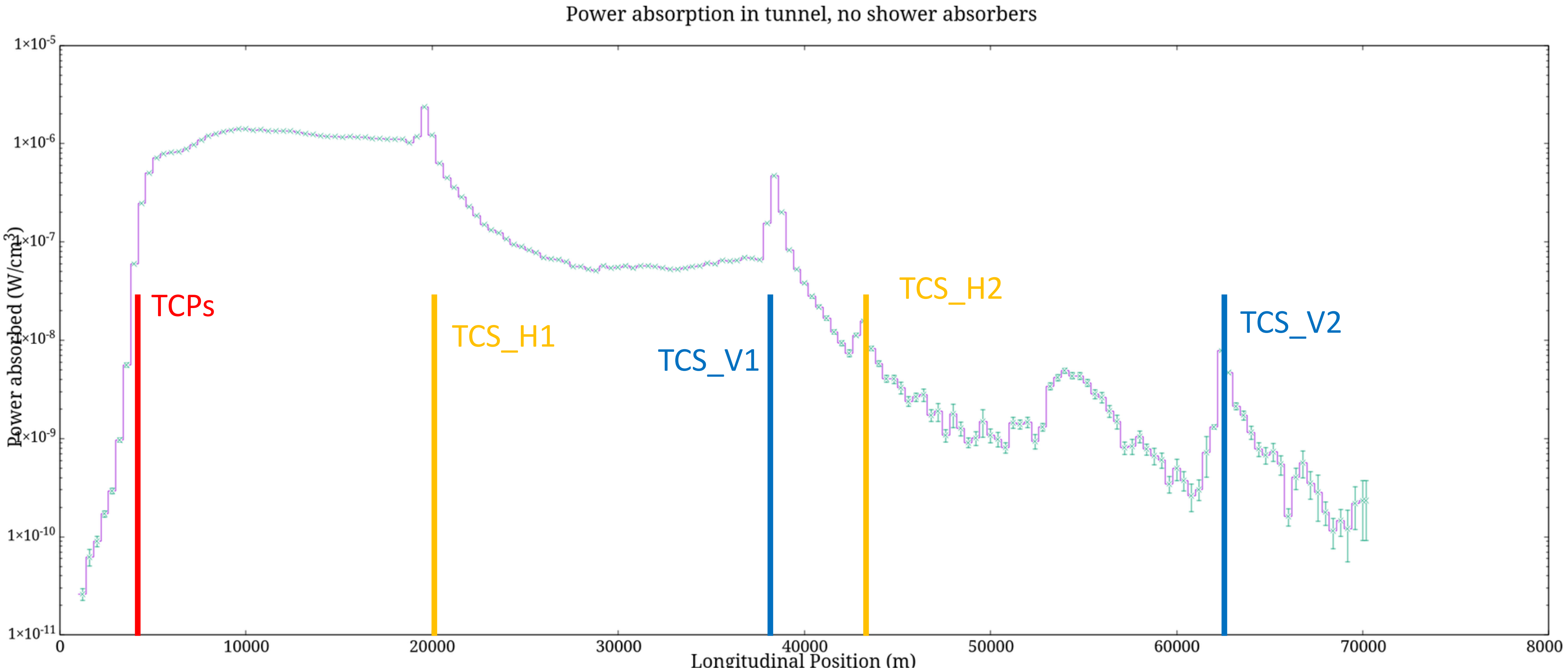


Sliced +/- 1.5 mm from beam spot in the vertical direction

Peak power absorption in TCS_H1



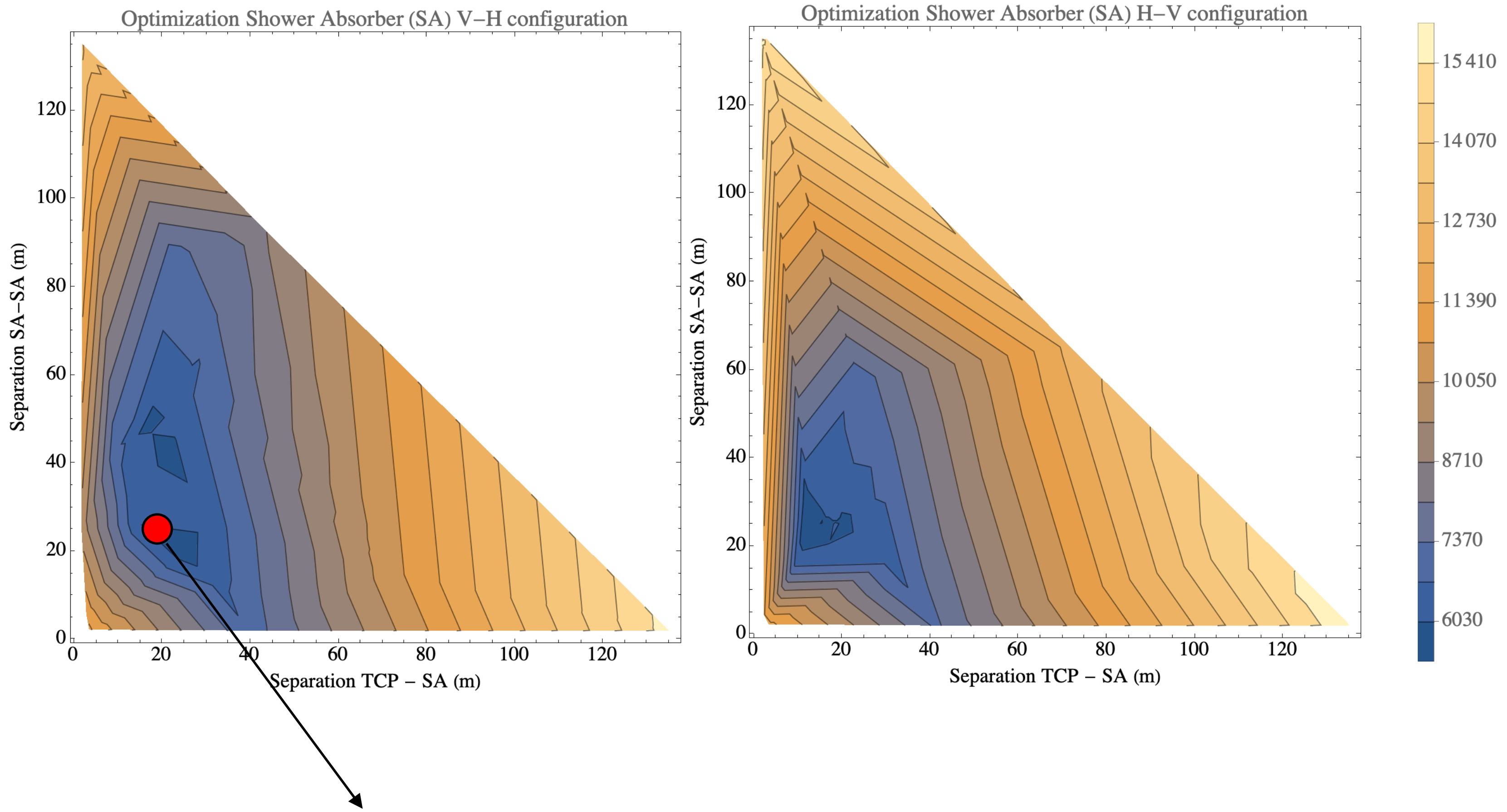
Power absorption in tunnel



Bayesian Optimization for Shower Absorbers

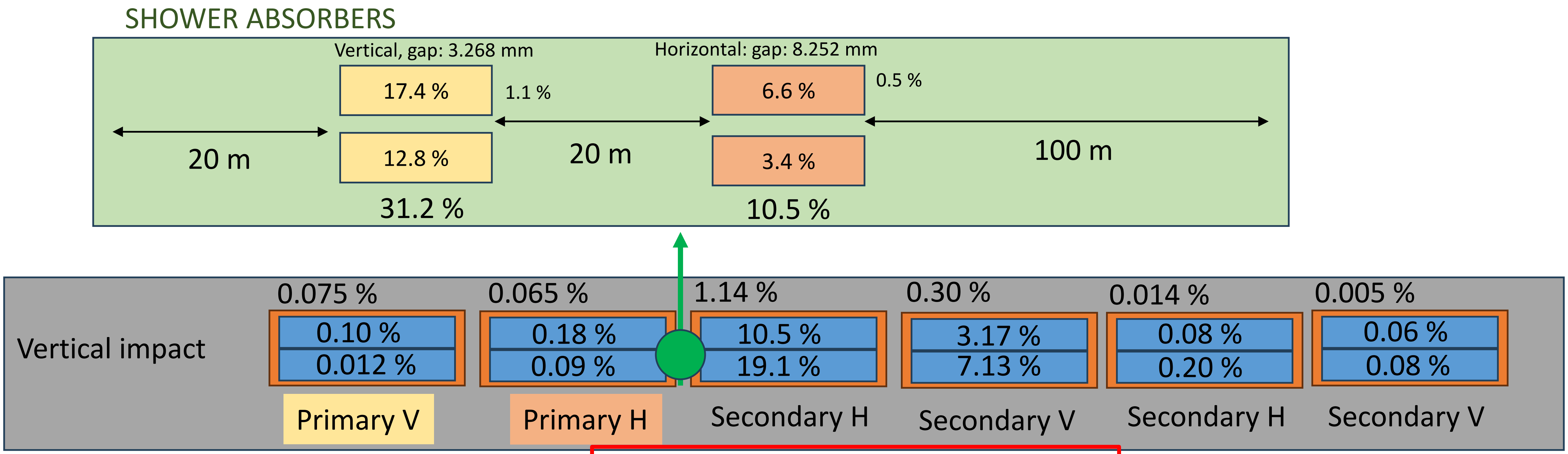
- To minimize the use of shower absorbers, as well as to reduce the power absorbed by the tunnel/environment
- Bayesian optimization of **position** of collimators, to be placed between TCP_H and TCS_H1, a 140m drift
- Optimizing first for only two shower absorbers

Power absorbed in environment (W)



20-20 separation minimizes the landscape, slightly better

Shower absorber effects (optimized two SA)



All quadrupoles : 0.78 %
Tunnel/earth/vacuum chamber: 15.1 %

Next steps

- Finish optimization for 4 shower absorbers
- Realistic impact parameter distribution
- Threshold of power absorption from RP
- Add shower absorber after TCS

Preliminary results show that two shower absorbers between TCP and TCS can lower the power leakage by ~2/3

Supplemental slides

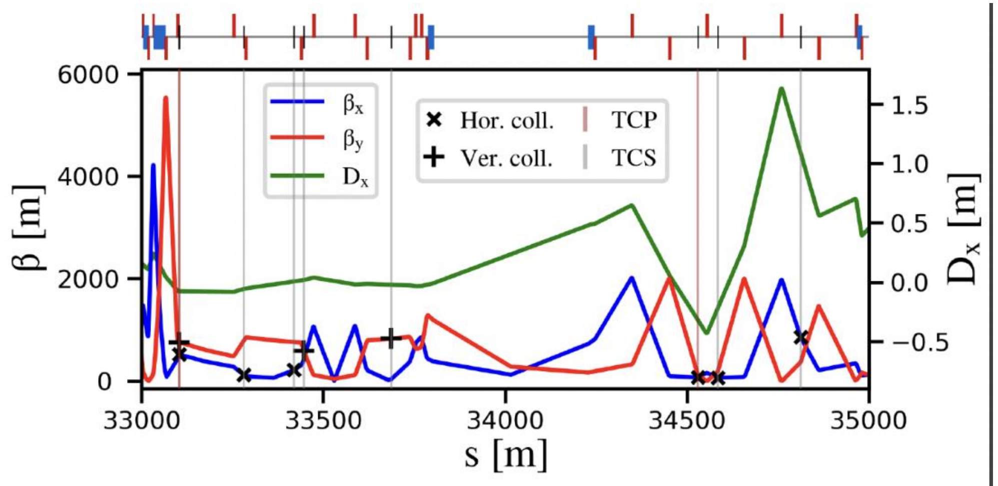
total pipe/tunnel: 10.4759
total_quadrupole: 0.0091
collimator tanks: [0.0082 0.0657 0.2408 0.1254 0.0102 0.0044]
collimator jaw 1: [0.1019 0.1812 2.1388 1.5943 0.0617 0.0814] collimator jaw 2: [0.0128 0.0959 4.6689 3.0921 0.1475 0.0454]
shower absorbers [17.4364 11.7059 39.0989 8.4531]

Extra slides

Results from last time

Setup

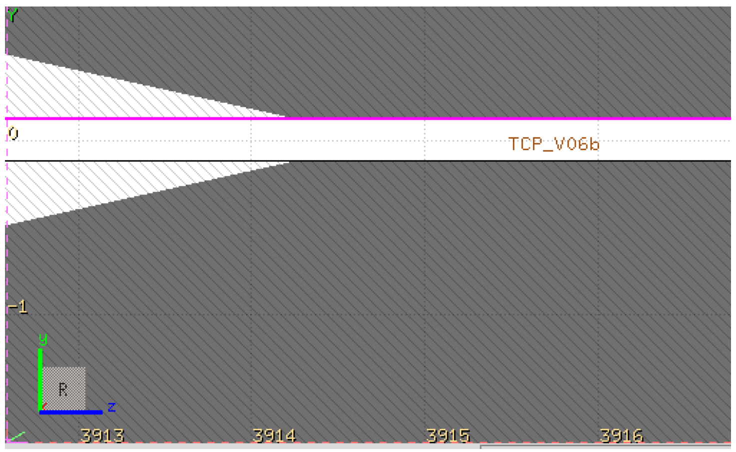
- Collimator straight section of FCC-ee
- Only positron beam, inner ring
- Energy of beam in *Z* mode (45.6 GeV/c)



We simulate beam losses close to the edge of the collimator:

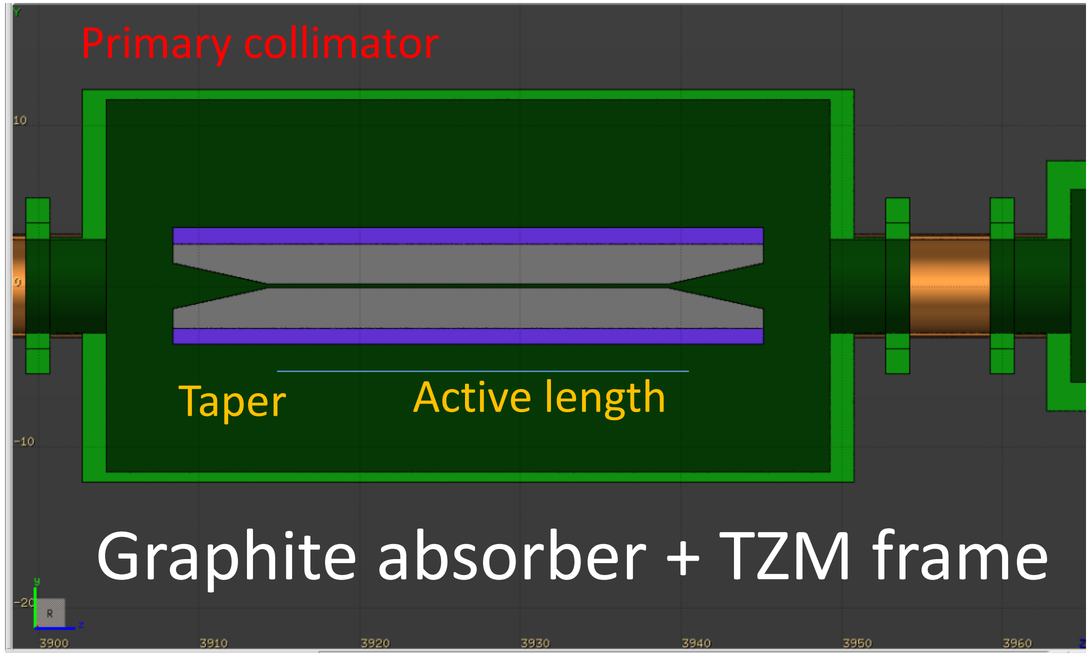
- Pencil beam
- An **impact parameter of 1 μm** on either the vertical or horizontal primary collimator
- Impact only on primary betatron collimators

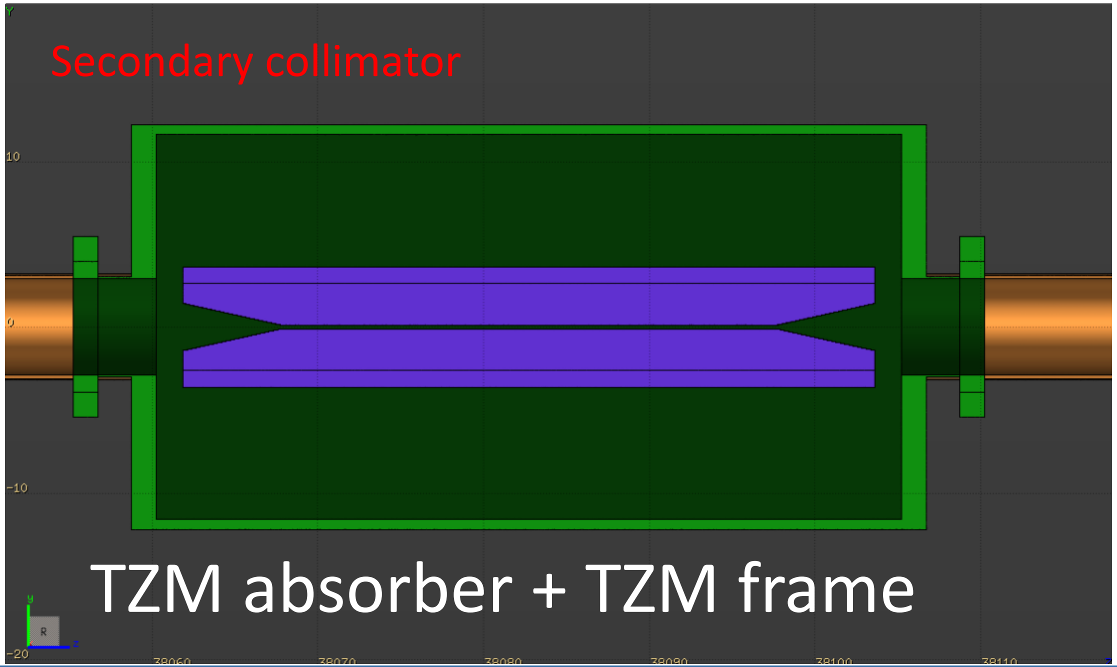
1 μm impact on collimator



FLUKA model of collimators

- All collimators composed of:
  - Two jaws
  - Frame
  - Vacuum tank (LHC design)
- Absorber length:
  - Active length given in twiss file: 25 cm for primary, 30 cm for secondary
  - Tapers on sides 12.5 degrees
  - Total length ~37 cm (primary), 42 cm (secondary)
- Transverse cross section (excluding frame)
  - 6 cm width
  - 2.5 cm height
- Materials used:
  - Absorber is Graphite at 1.8 g/cc for primary
  - TZM at 10.22 g/cc for secondary
  - Frame always TZM

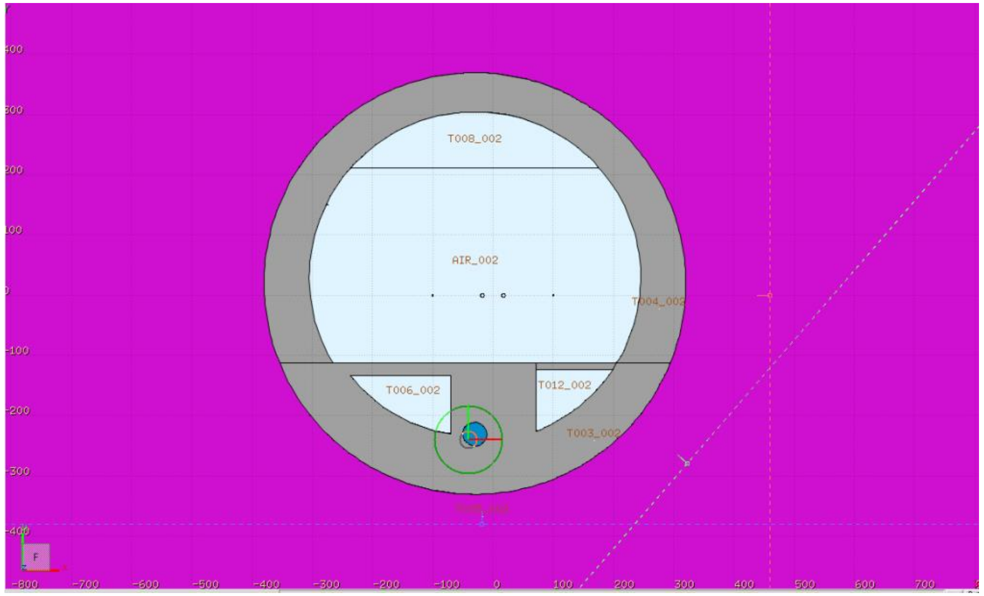


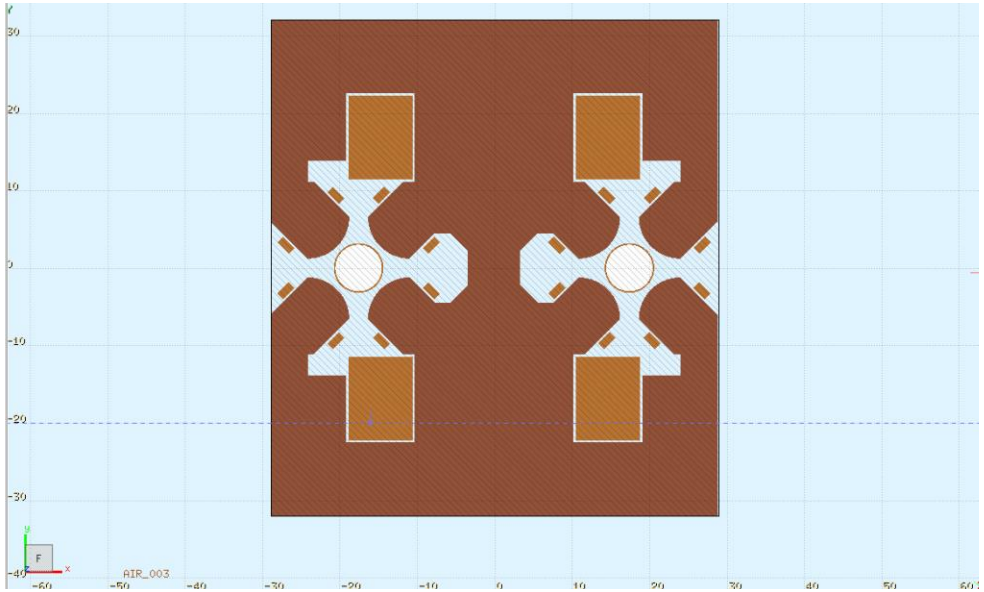


Tunnel and machine model

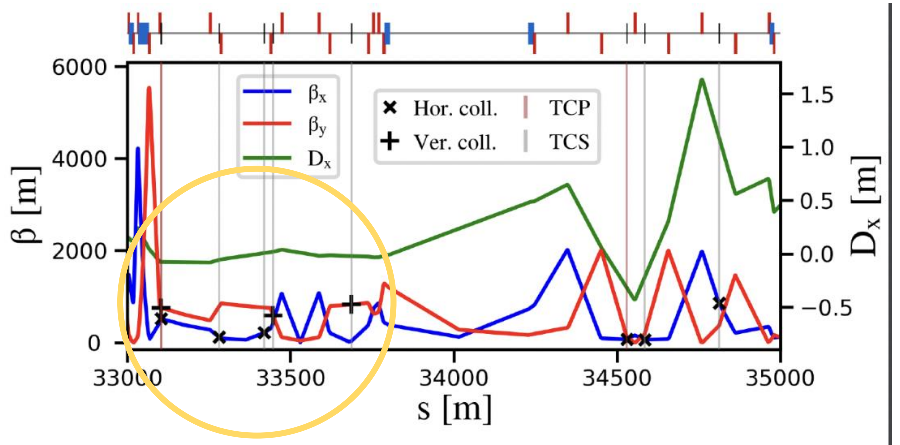
- Inner bore of 5.5 m diameter, outer wall at 7 m (1.5 m concrete wall)
- Circular vacuum chamber:
  - 6 cm diameter inner
  - 2 mm thick copper walls
- No supports

- Quadrupole magnet design from B. Humann (as in the arcs)
- Analytical quadrupole field in the beam pipe





Relative Power Deposition



Vertical impact

	Primary V	Primary H	Secondary H	Secondary H	Secondary V	Secondary V
	0.013 %	0.048 %	1.362 %	0.030 %	0.084 %	0.000 %
	0.20 %	0.11%	20.6 %	0.25 %	0.56 %	0.012 %
	0.030 %	0.11 %	20.5 %	0.25 %	2.34 %	0.021 %

All quadrupoles : 2.08 %
Tunnel/earth/vacuum chamber: 51.3%

Horizontal impact

	V	H	H	H	V	V
	0 %	0.016%	1.38 %	0.07 %	0.04 %	0.0008 %
	0.00 %	0.20%	9.64 %	0.42 %	0.75 %	0.016 %
	0.00 %	0.02 %	32.37 %	1.05 %	0.75 %	0.017 %

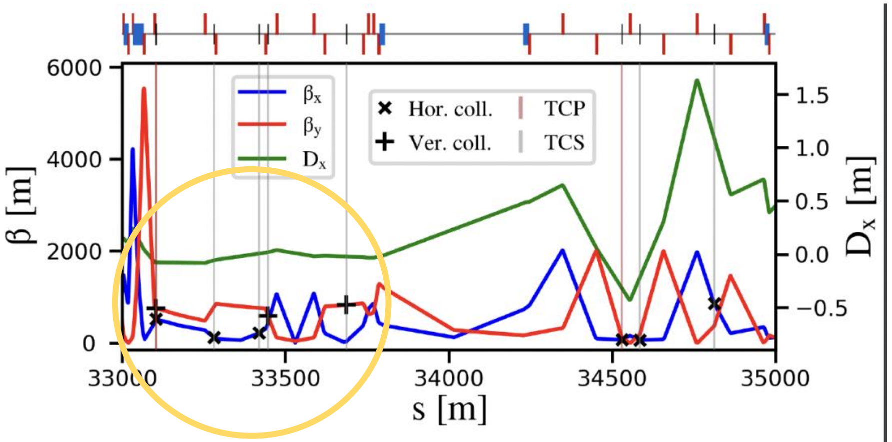
All quadrupoles : 1.9 %
Tunnel/earth/vacuum chamber: 51.1%

Absolute Power Deposition

Assumptions:

- Bunch intensity: 2.16×10^{11}
- Bunches per beam: 11200
- Loss decay time: 5 minutes

Collimator power loss: 37.19 kW



Vertical impact

	Primary V	Primary H	Secondary H	Secondary H	Secondary V	Secondary V
	0.005 kW	0.018 kW	0.51 kW	0.011 kW	0.031 kW	0.0 kW
	0.074 kW	0.041 kW	7.65 kW	0.095 kW	0.21 kW	0.0044 kW
	0.011 kW	0.041 kW	7.62 kW	0.094 kW	0.87 kW	0.008 kW

All quadrupoles : 0.78 kW
Tunnel/earth/vacuum chamber: 19.1 kW

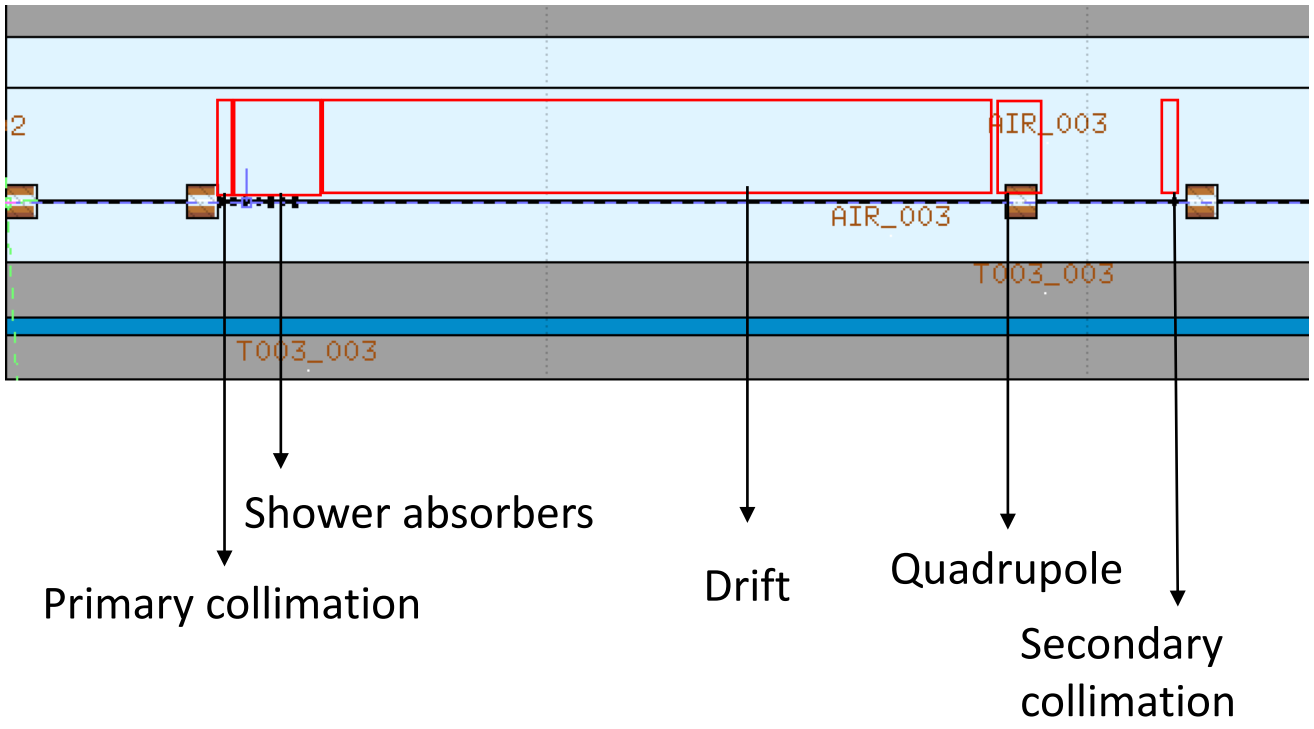
Horizontal impact

	V	H	H	H	V	V
	0 kW	0.006 kW	0.51 kW	0.025 kW	0.015 kW	0.0003 kW
	0 kW	0.073 kW	3.59 kW	0.15 kW	0.28 kW	0.0065 kW
	0 kW	0.0071 kW	12.07 kW	0.39 kW	0.28 kW	0.0063 kW

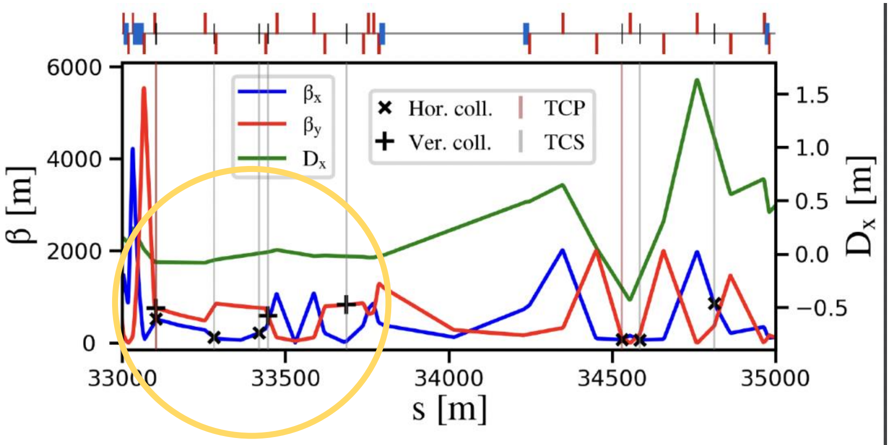
All quadrupoles : 0.70 kW
Tunnel/earth/vacuum chamber: 19.0 kW

Shower absorbers

- Shower absorbers are inserted right after the primary collimation system
- Gaps of shower absorbers larger than secondary collimators *(2.5 mm)*
    - To be matched to beam dynamics



Relative Power Deposition



SHOWER ABSORBERS

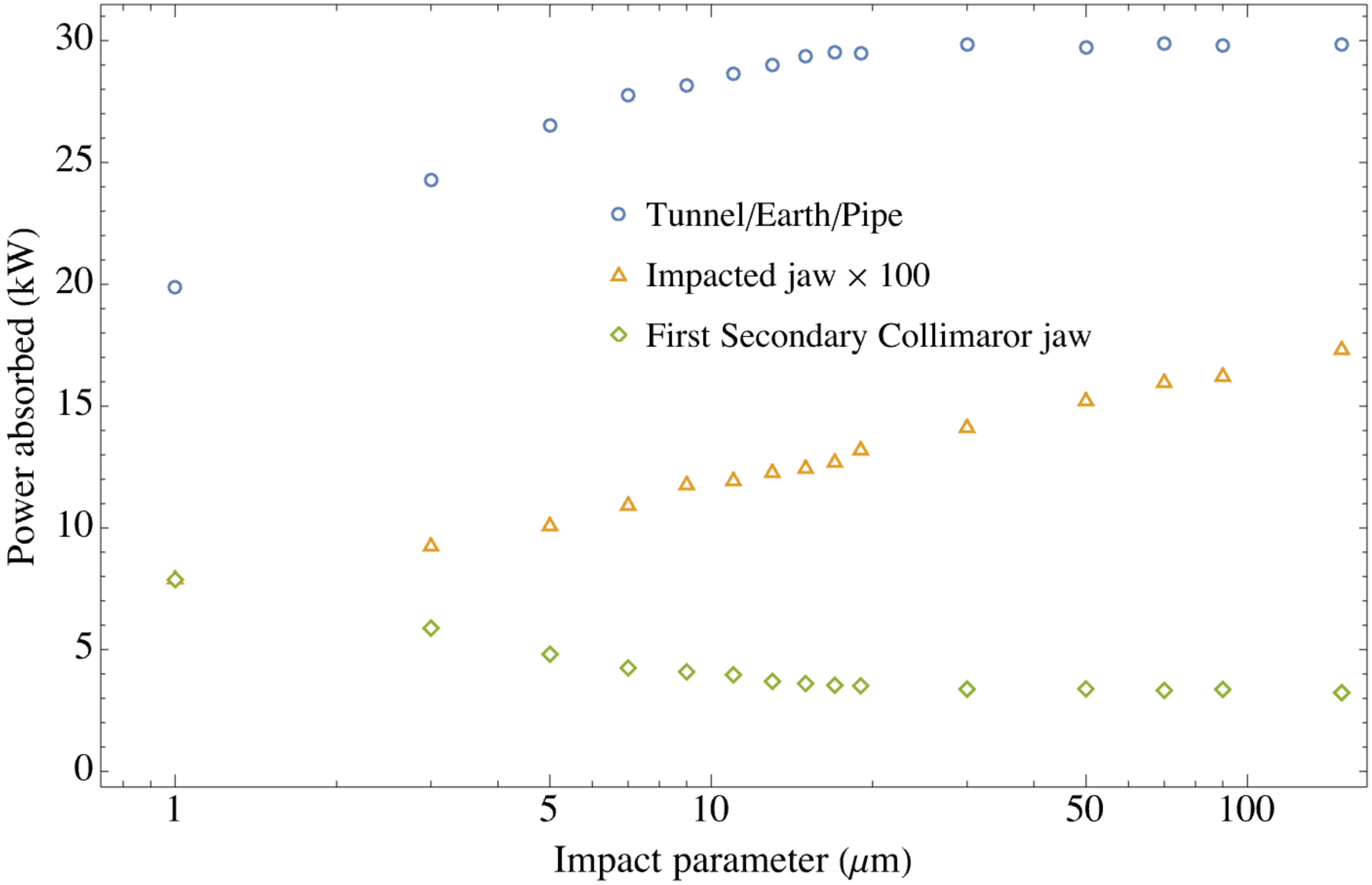
Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
4.3 %	11.8 %	7.4 %	5.3 %	6.7 %	3.3 %

Vertical impact

	Primary V	Primary H	Secondary H	Secondary H	Secondary V	Secondary V
	0.013 %	0.048 %	1.23 %	0.030 %	0.084 %	0.001 %
	0.20 %	0.11%	19.0 %	0.25 %	0.54 %	0.013 %
	0.030 %	0.11 %	19.2 %	0.25 %	2.30 %	0.021 %

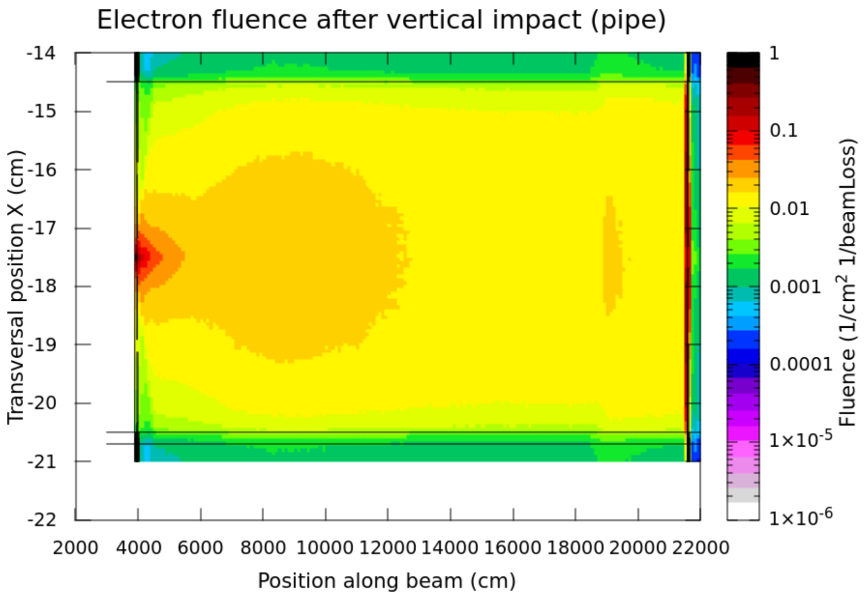
All quadrupoles : 1.45 %
Tunnel/earth/vacuum chamber: 16.3%

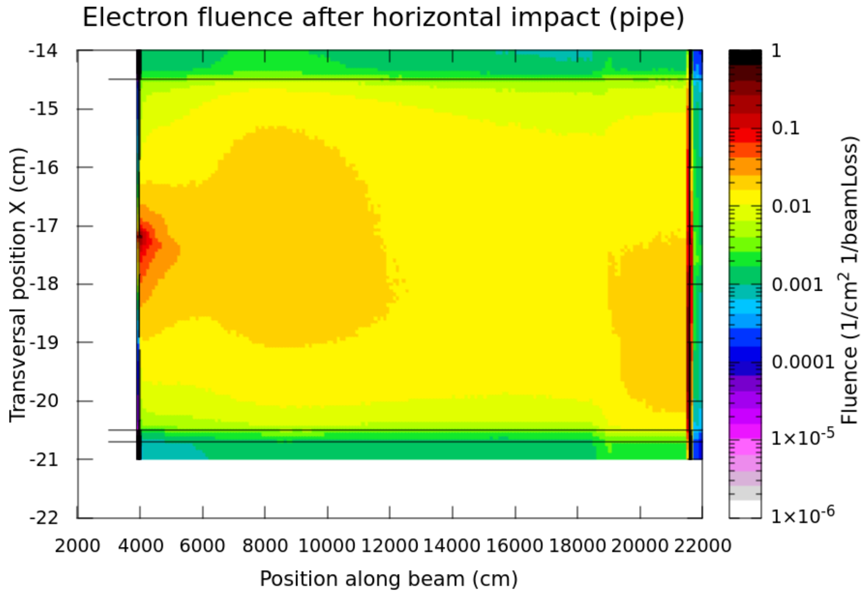
Effects of impact parameter

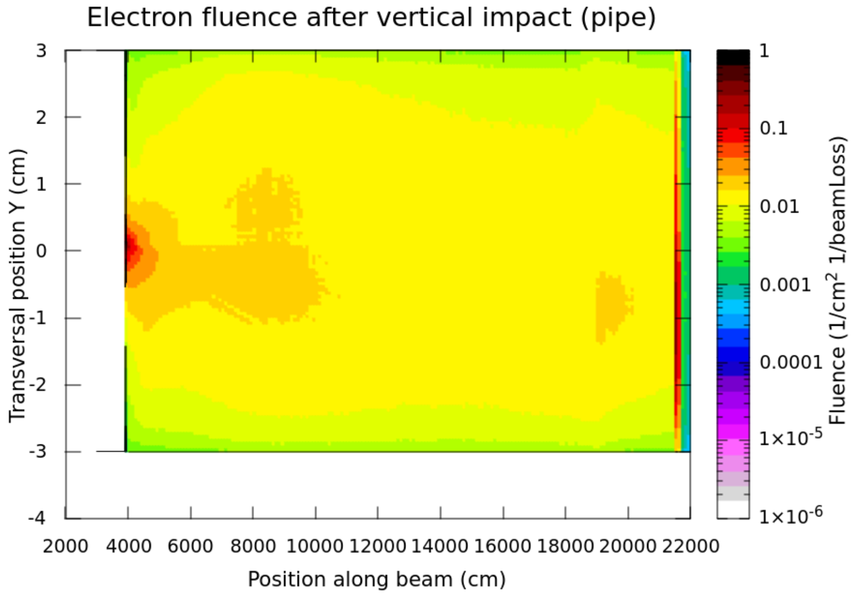


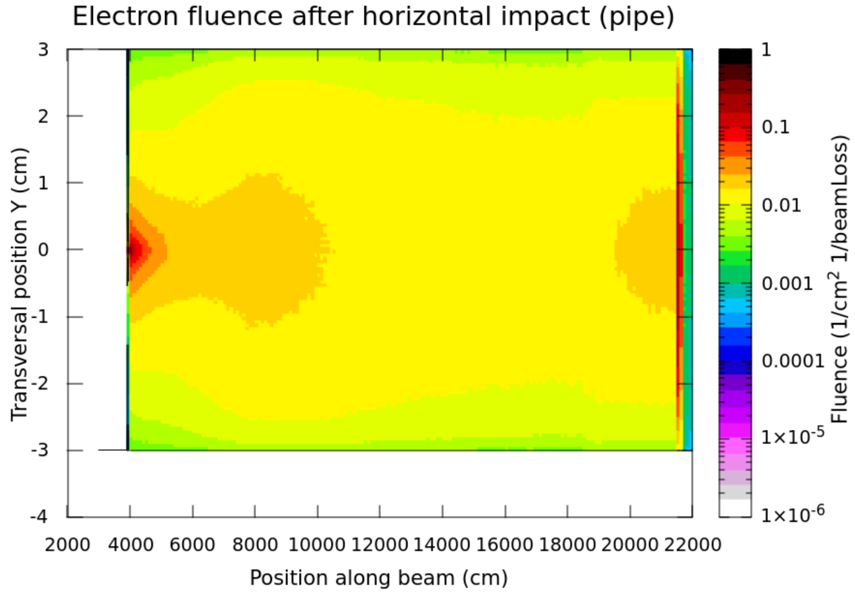
Extra-Extra slides

Electron fluence inside vacuum chamber

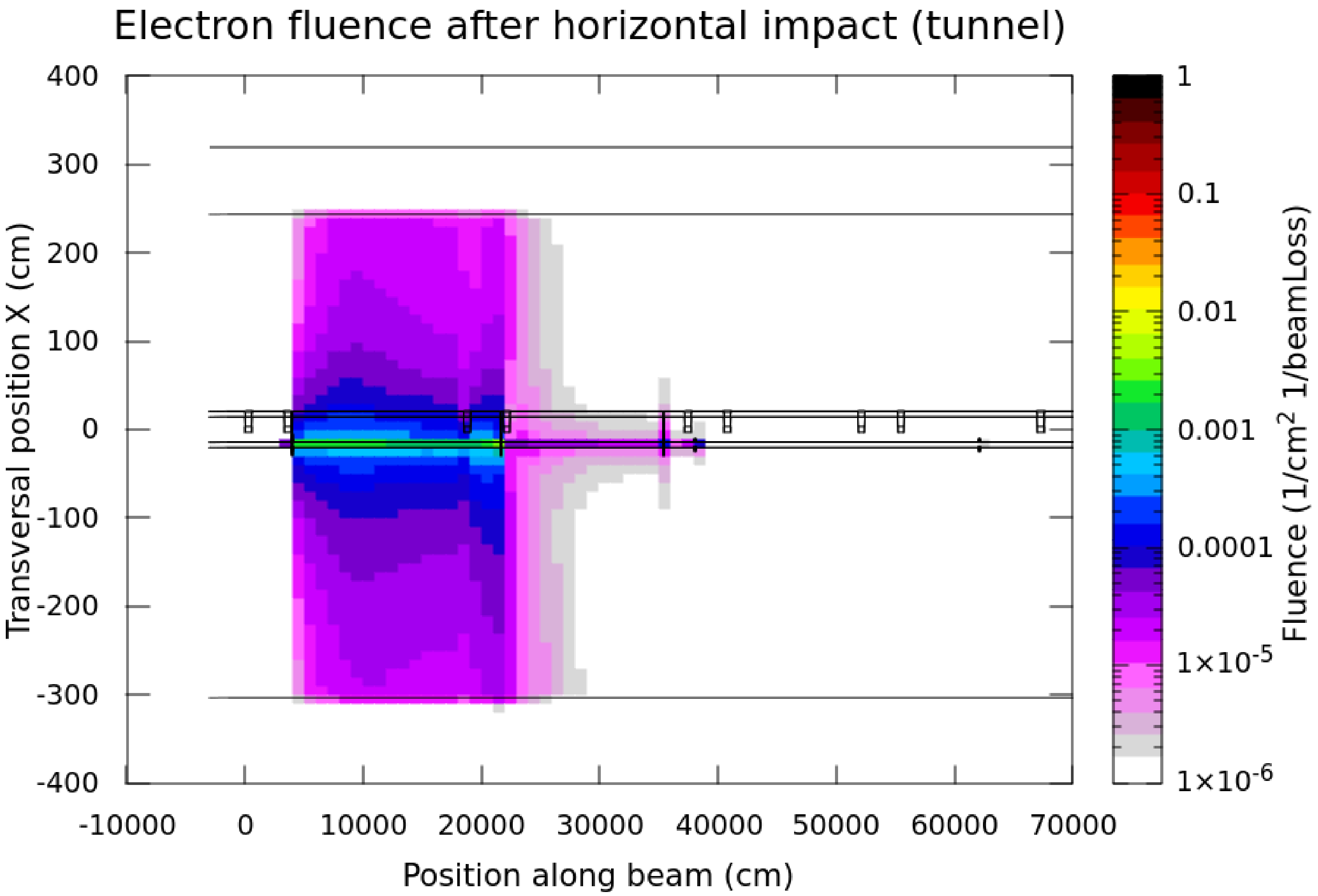




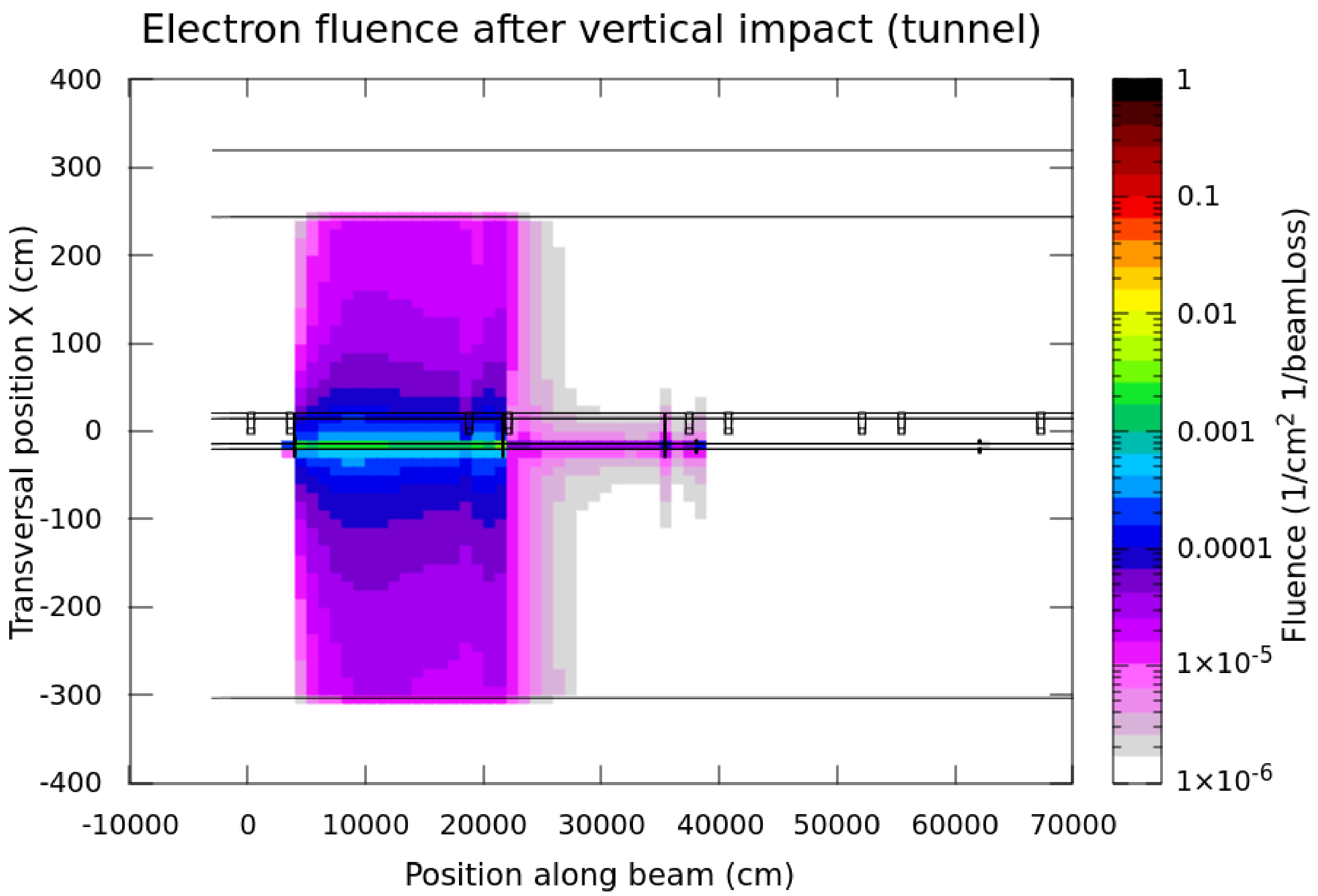


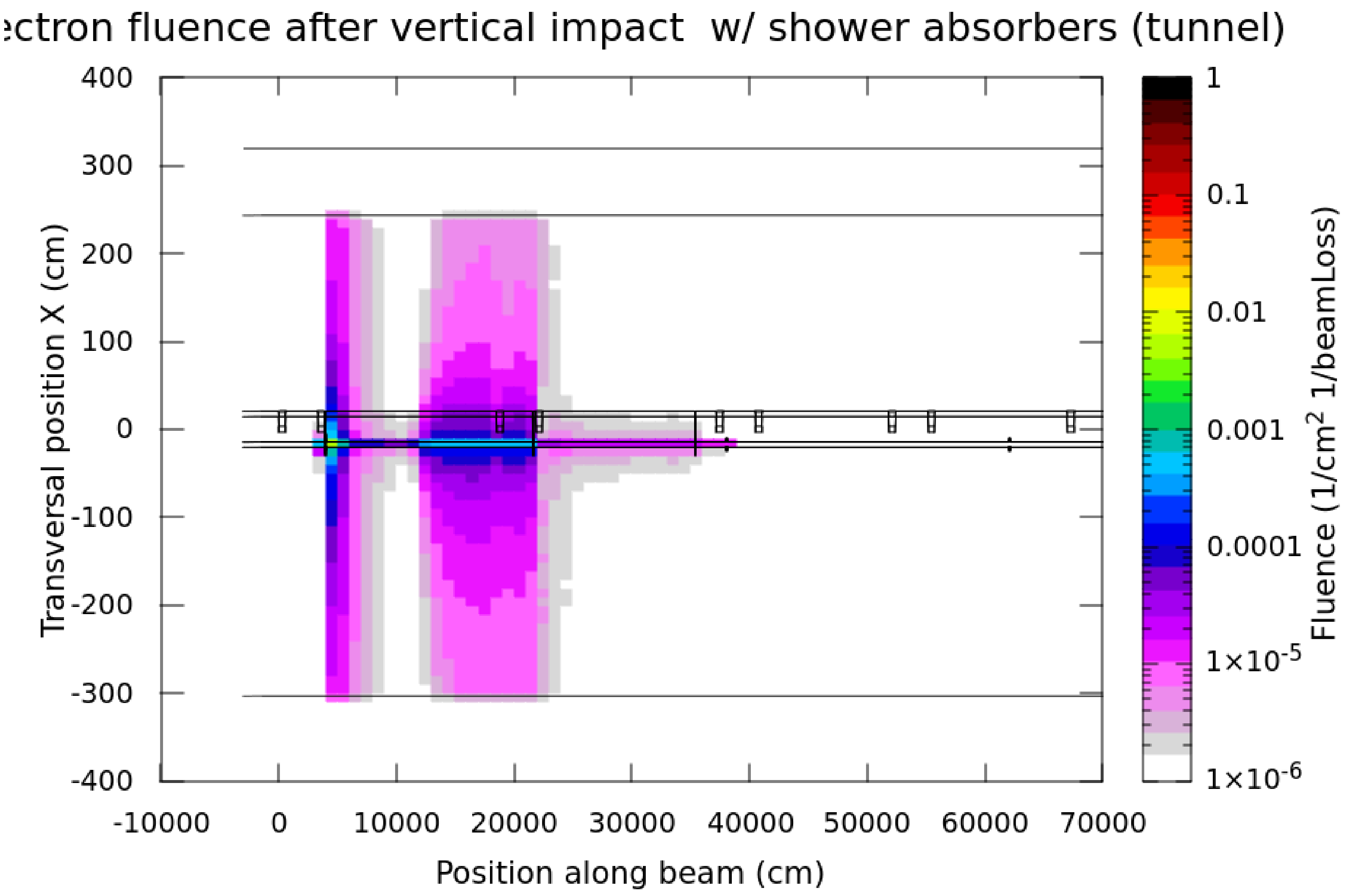


Electron fluence inside tunnel



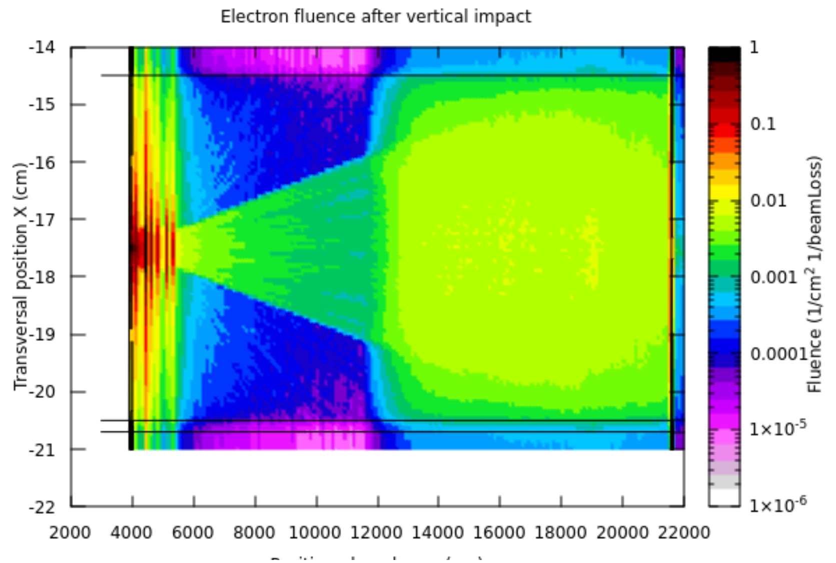
Electron fluence inside tunnel

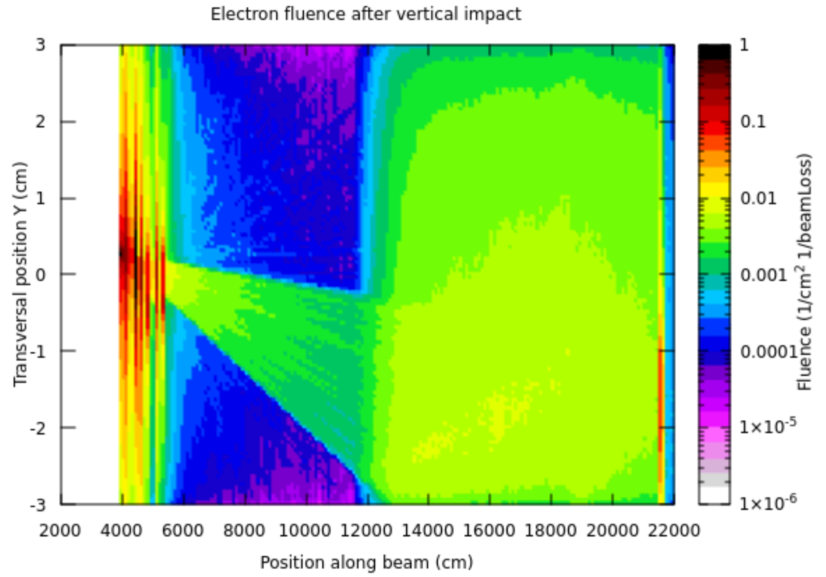



ectron fluence after vertical impact w/ shower absorbers (tunnel)
Transversal position X (cm)
400
300
200
100
0
-100
-200
-300
-400
-10000
0
10000
20000
30000
40000
50000
60000
70000
Position along beam (cm)
1
0.1
0.01
0.001
0.0001
1×10-5
1×10-6
Fluence (1/cm2 1/beamLoss)

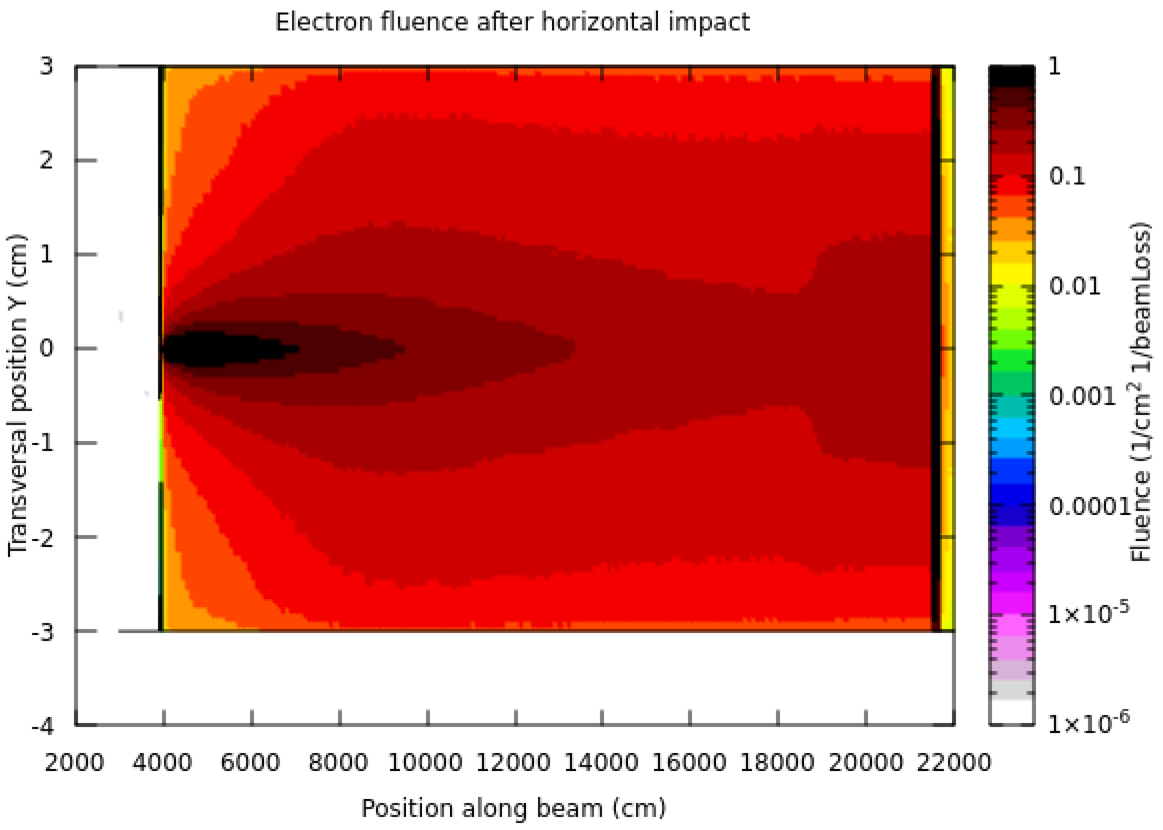
Shower absorbers fluence

- The presence of shower absorbers significantly reduces the fluence of secondary particles
- Optimization of the position/number of absorbers can be performed next





Photons



Electron fluence after horizontal impact
Transversal position Y (cm)
Position along beam (cm)
Fluence (1/cm² 1/beamLoss)
3
2
1
0
-1
-2
-3
-4
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
22000
1
0.1
0.01
0.001
0.0001
1×10-5
1×10-6

Scattered beam shape