SR background simulation updates

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Reminder

from the previous meeting

1. Beam pipe material matters
2. Overall, SR background rates are very high ~ THz
3. SR masks can significantly reduce the rates
4. The beam pipe geometry is not fixed and needs revision

Summary (2)

- The latest simulation with the Jan-2024 (v6.2) lattice shows:
  - for the **aluminum beam pipe**, the majority of ePIC rates originate from the region **outside the IP** beam pipe;
  - for the **copper beam pipe**, the majority of ePIC rates originate **from the IP** beam pipe;
    - the copper beam pipe effectively stops SR photons in the energy region of interest (10-100 keV);
  - the overall rate of the SR background in all sub-detectors is **extremely high** (THz);
  - by placing a simple SR mask, we can **reduce the background rates by at least two orders** of magnitude;
    - we **need a more sophisticated SR mask** to reduce the rate further;
  - adding **additional shielding** around the IR beam pipe could be **another option** to mitigate the SR background;
  - **auxiliary detectors** will be exposed to the **ultrahigh rate of SR** (PHz);
    - however, the **geometry** of the far-backward beam pipe **needs revision**.

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Next steps

- We can continue using the manual approach of the beam pipe geometry description in Geant4 and eic-shell.
  - However, we should consider the advantages of transitioning to a unified 3D CAD drawing used in both frameworks.
- We have to implement a new SR mask and check its impact on the detector background and machine impedance.
- Also, it is essential to revisit the entire IR beam pipe used in Geant4 and eic-shell.
  - To ensure the accuracy of the beam pipe geometry description.
  - Close collaboration with the ePIC software group is desirable.
- For more details and materials regarding the custom-built Geant4 simulation code, please refer to backup slides and past EIC IR Synrad meetings [SupplementaryMaterials].

Thanks for your attention!

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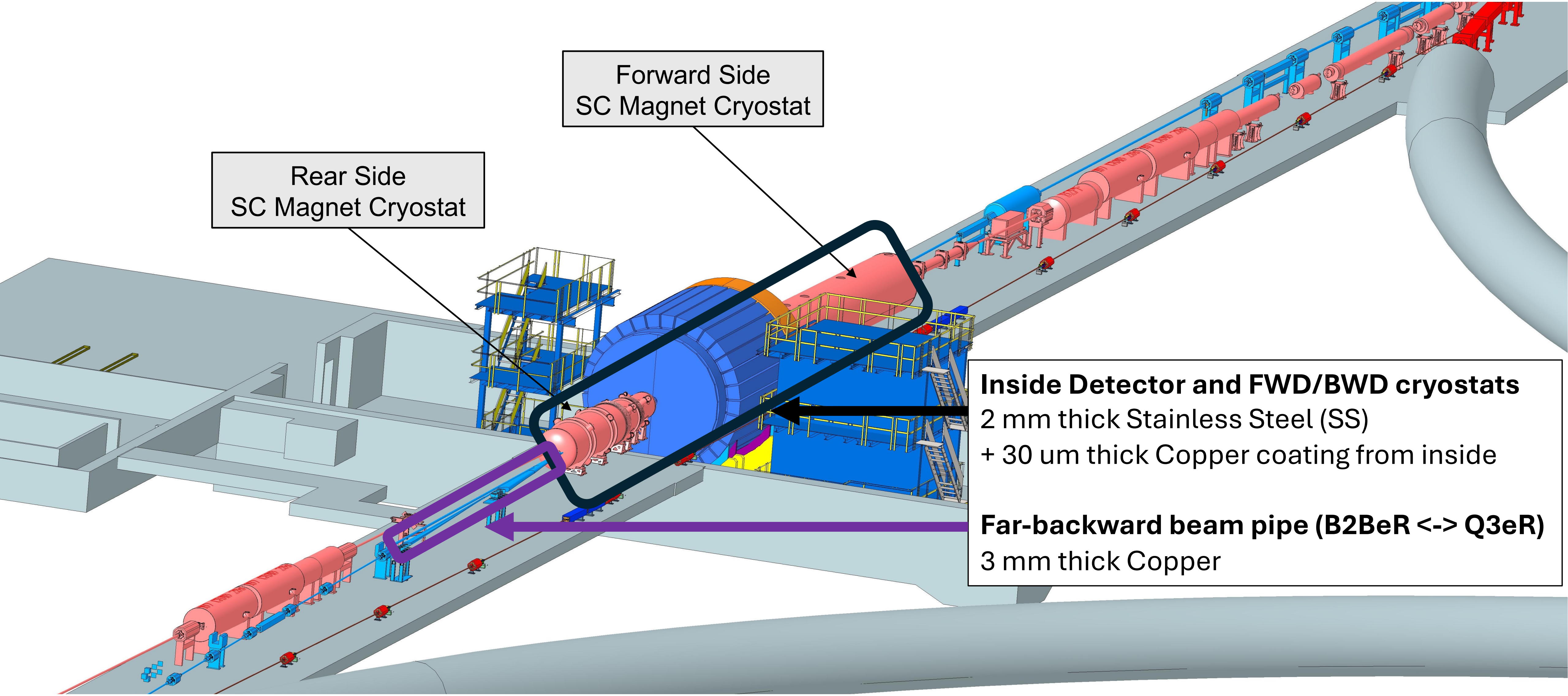
Beam pipe material modification



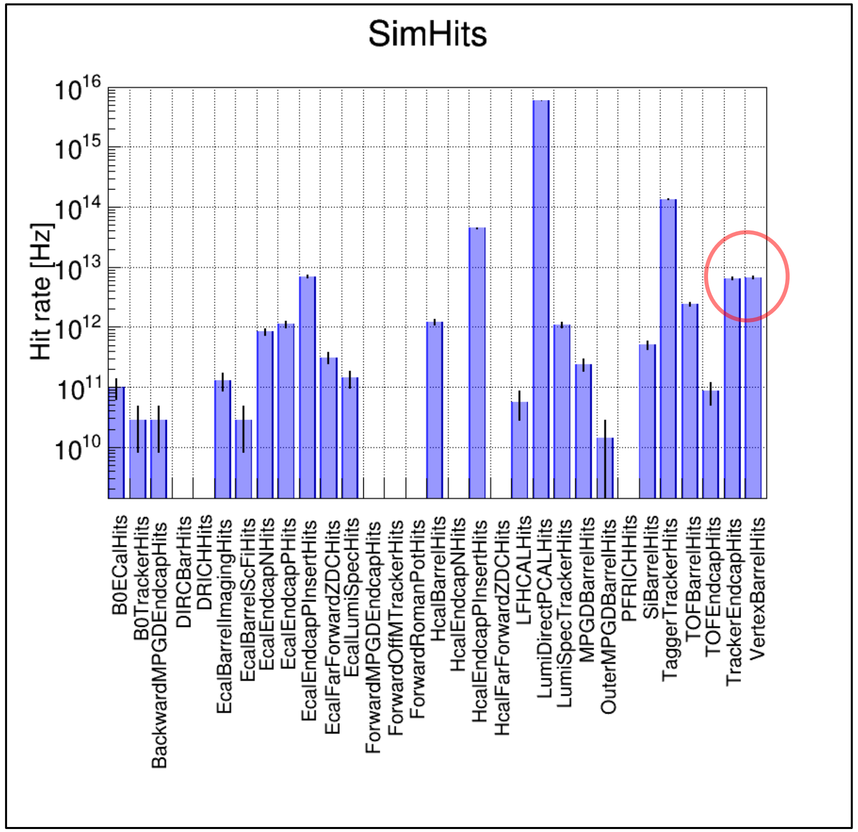
Inside Detector and FWD/BWD cryostats
2 mm thick Stainless Steel (SS)
+ 30 um thick Copper coating from inside

Far-backward beam pipe (B2BeR <-> Q3eR)
3 mm thick Copper

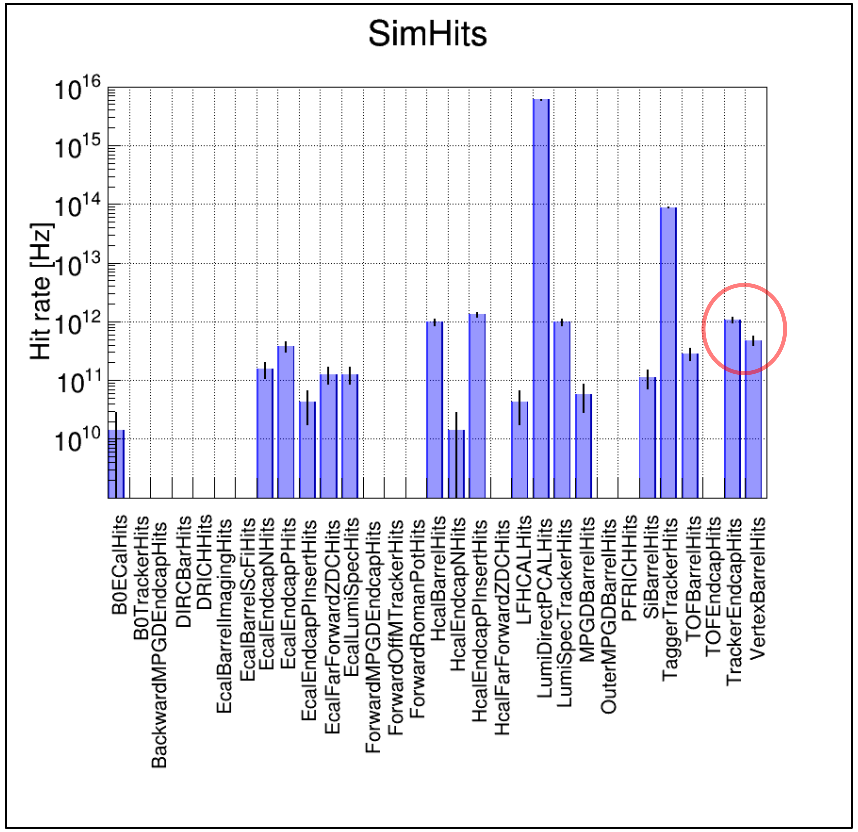
Beam pipe material impact

By changing the beam pipe material, we reduce SR background rates by an order of magnitude.

No SR masks
Al beam pipe



No SR masks
SS+Cu beam pipe



I = 0.227 A
-37m < z < 5m
E_γ > 1 keV

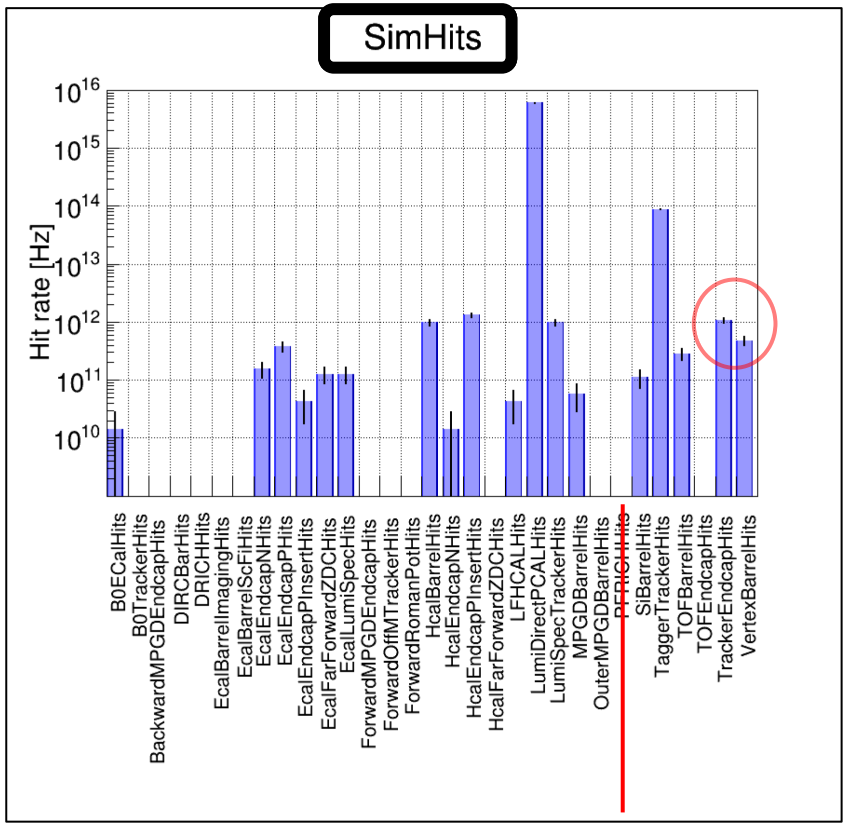
Lattice file v6.2 | 18 GeV | 2 IPs | I = 0.227 A

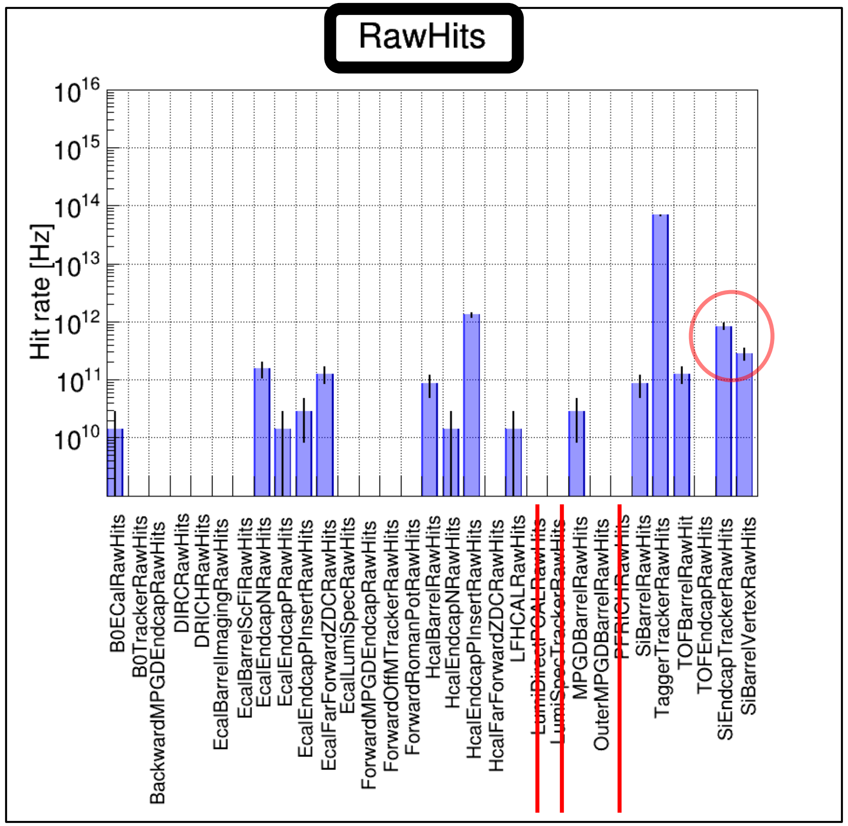
Background observables

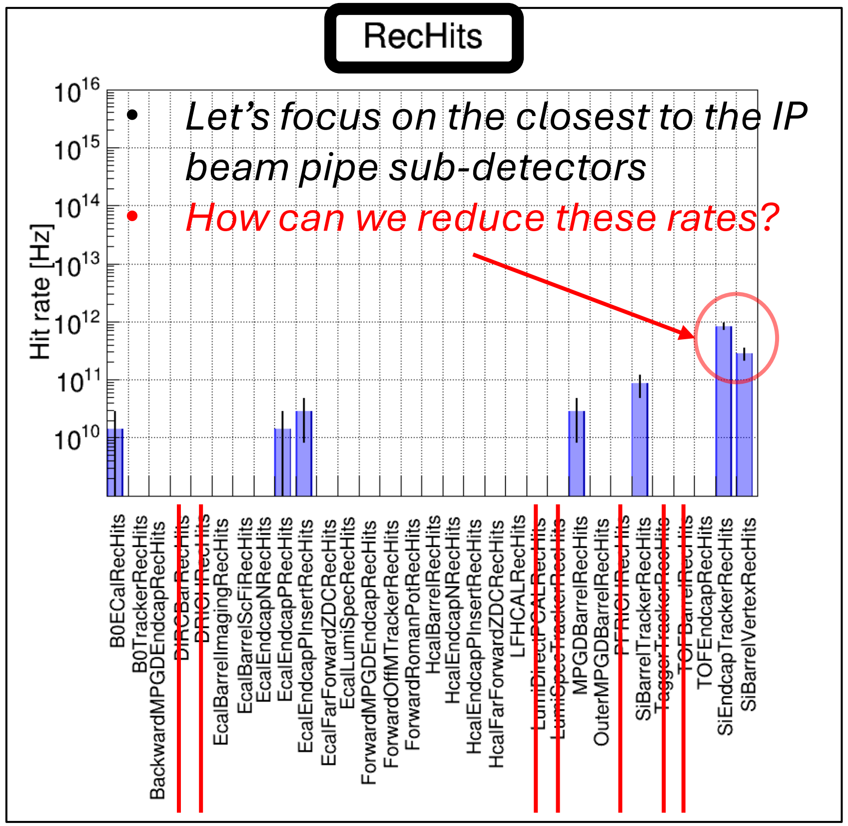
This is presumably what we will see in the experiment

There are three classes of MC variables

- **SimHits** – the Geant4-like hits in each sub-module (sensitive volume)
- **RawHits** – pre-analyzed SimHits with applied sensor calibration thresholds
- **RecHits** – pre-analyzed RawHits with applied channel calibration threshold



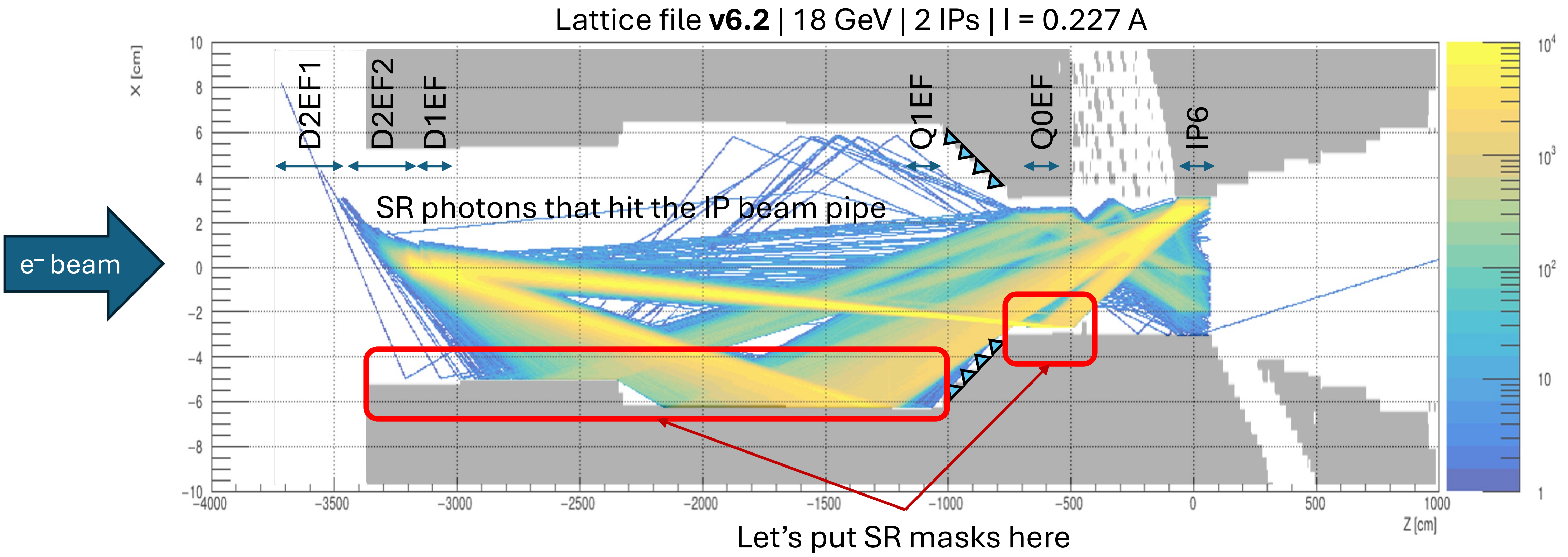




SR background mitigation

To reduce SR background rates in the ePIC detector, we implement the following:

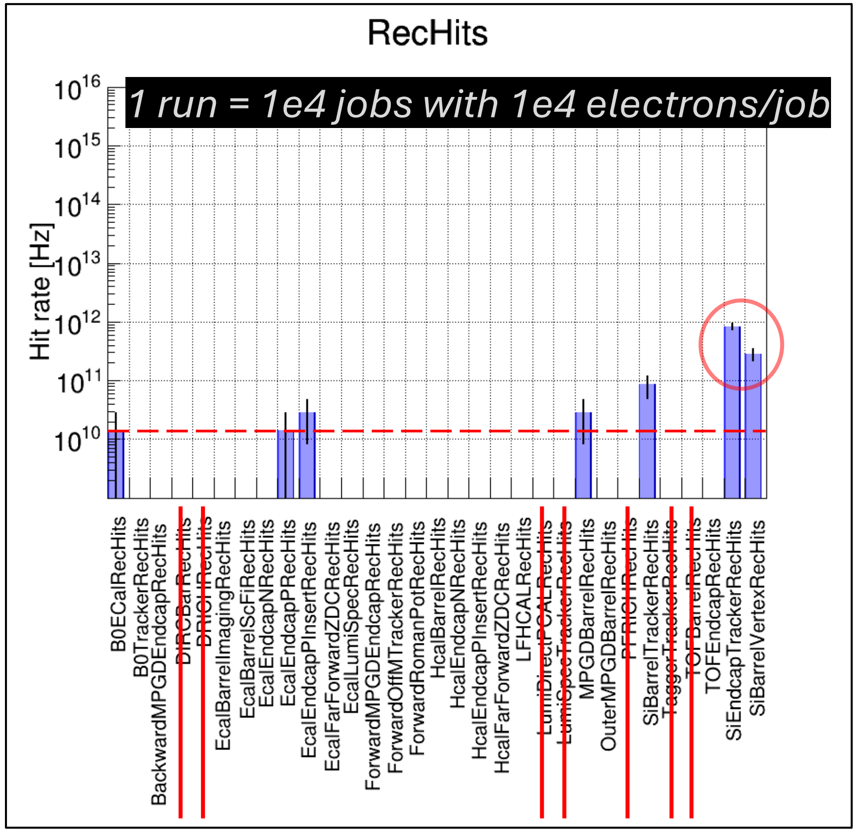
- add additional SR masks along the upstream e-beam pipe;
- add an additional SR mask inside the Q0 magnet, avoiding beam envelope restrictions (see backup slides);
- modify the central beam pipe in both Geant4 and eic-shell avoiding discrepancies and SR leakage, where beam pipes connect (see backup slides).



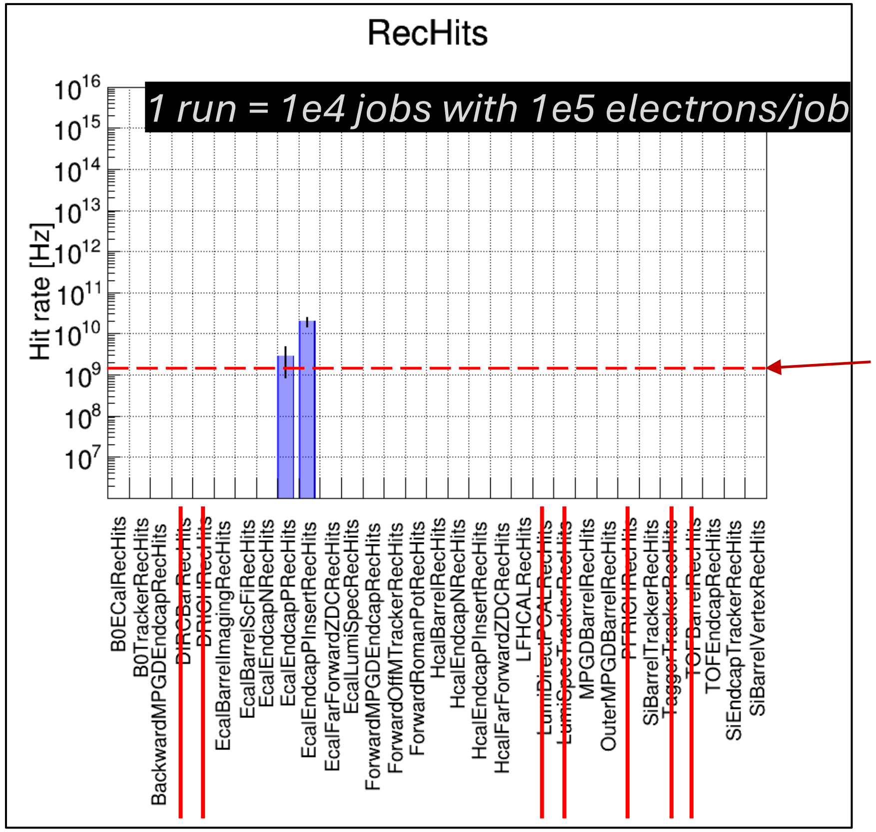
Reduced SR background and Simulation limits

- The implementation of the new countermeasures has led to a remarkable reduction in the SR background, which scaled down the rates by approximately two orders of magnitude.
- Unfortunately, the given simulation statistics do not allow us to look below **1.4 GHz** = 0.227A / (1e4 x 1e5 x 1.6e-19C).
- **For the comprehensive SR simulation, we need the final beam pipe design.**
- **To study the SR rate at the MHz level, we have to increase the number of simulated electrons by 3-4 orders.**

w/o SR masks



w/ SR masks



Simulation statistics limit, which corresponds to one hit/run in the detector

$I = 0.227$ A
$-37\text{m} < z < 5\text{m}$
$E_\gamma > 1$ keV

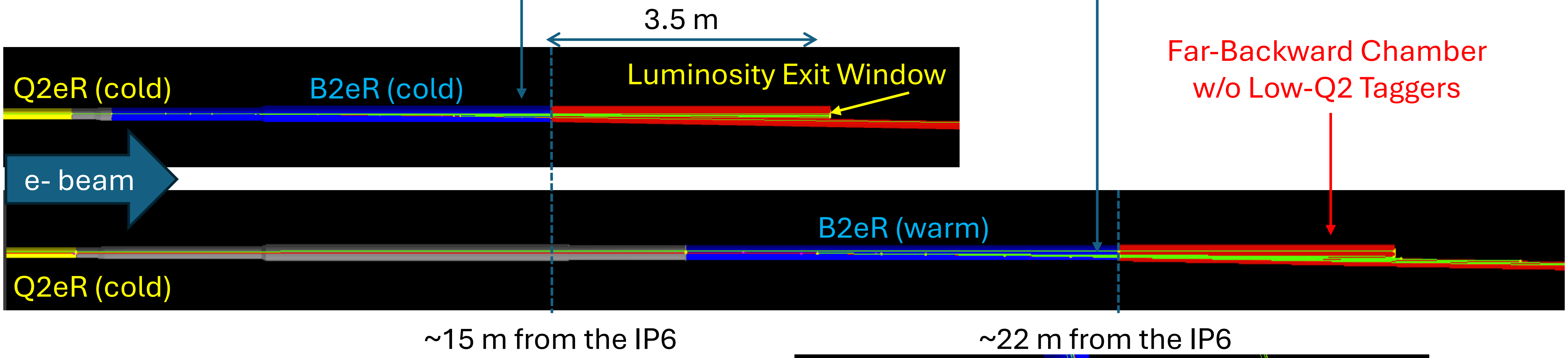
Possible solutions

1. **Geant4:** National Energy Research Scientific Computing Center (NERSC) is the largest computer cluster in the US.
   - Total cores: 311,296 (CPU/2.4 GHz)
   - 1e5 electrons/job = 3 hours

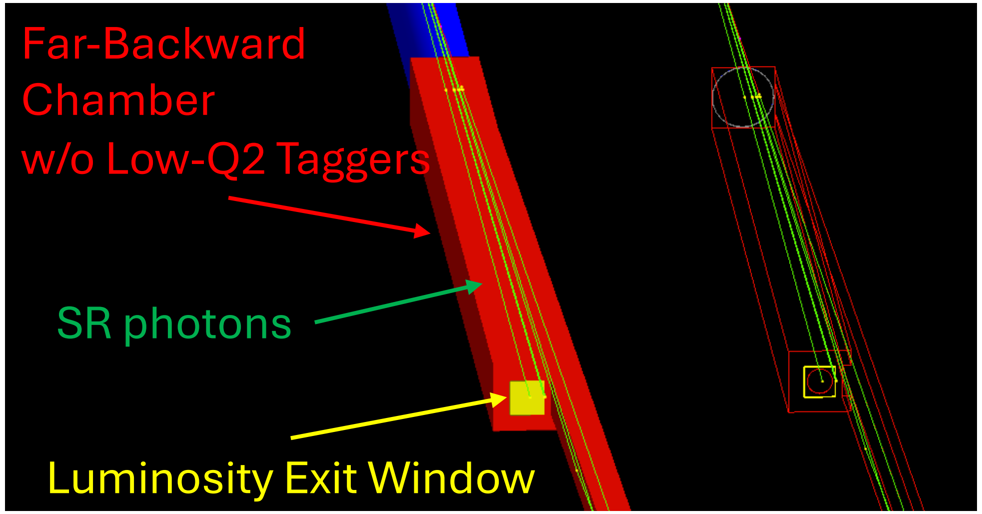
     → 0.227 A / (3e5 jobs x 1e5 electrons x 1.6/e-19) = **50 MHz**
2. **Analytically:** Creating SR photons and tracking them in 3D using analytical functions → could potentially speed up the simulation.
3. **Semi-analytically:** Creating SR photons using analytical functions and tracking them using Geant4 → could speed up the simulation by a factor of 2-3.

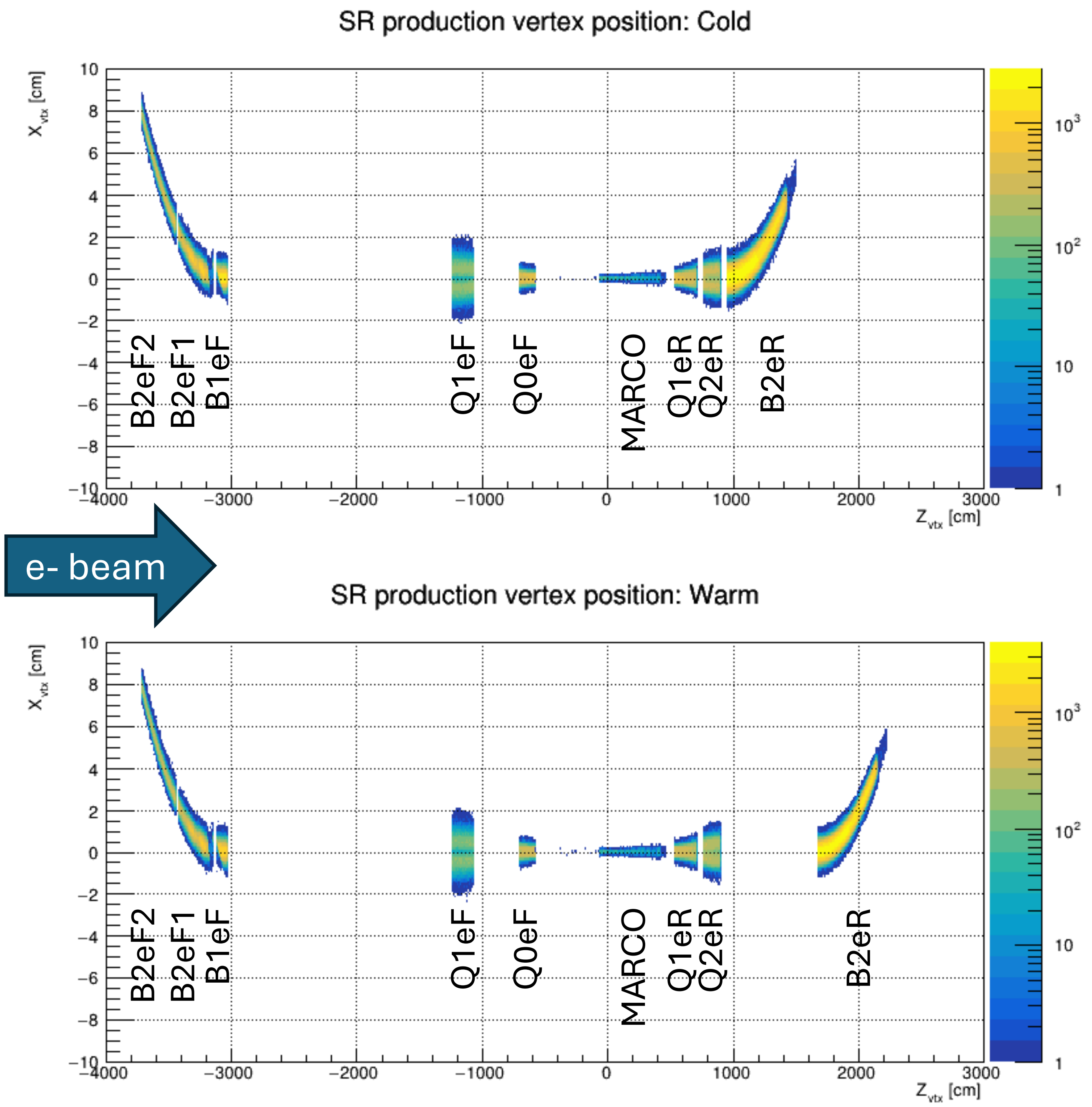
ESR lattice impact on the SR load in the far-backward region

Lattice file v6.2: Cold (Jan 2024) vs Warm (Mar 2024)

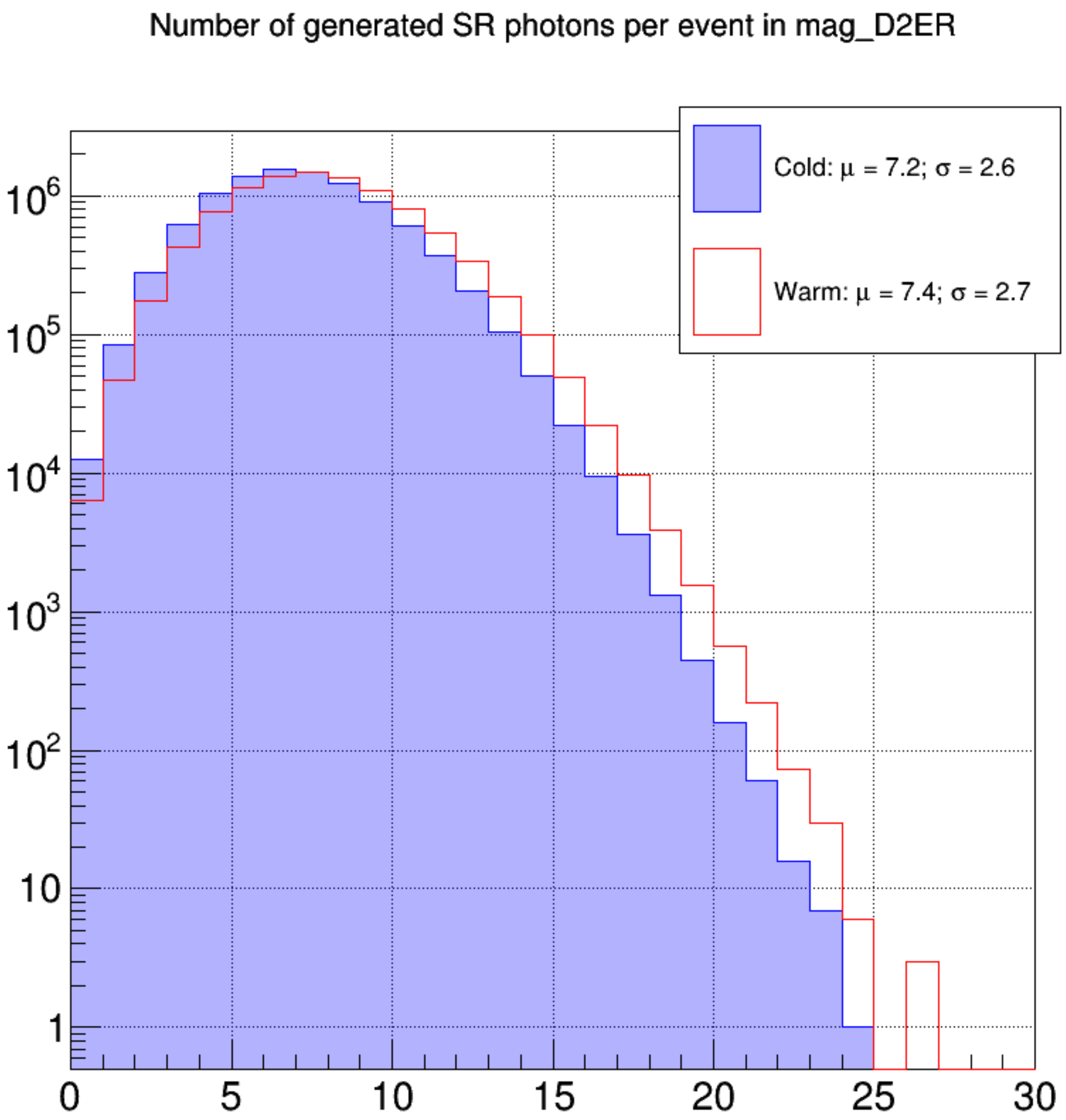


		Cold		Warm
• B2eR: θ	=	18 mrad	vs	20 mrad
• Q2eR: K1L	=	$-0.308\ m^{-1}$	vs	$-0.316\ m^{-1}$
• Q1eR: K1L	=	$+0.414\ m^{-1}$	vs	$+0.410\ m^{-1}$

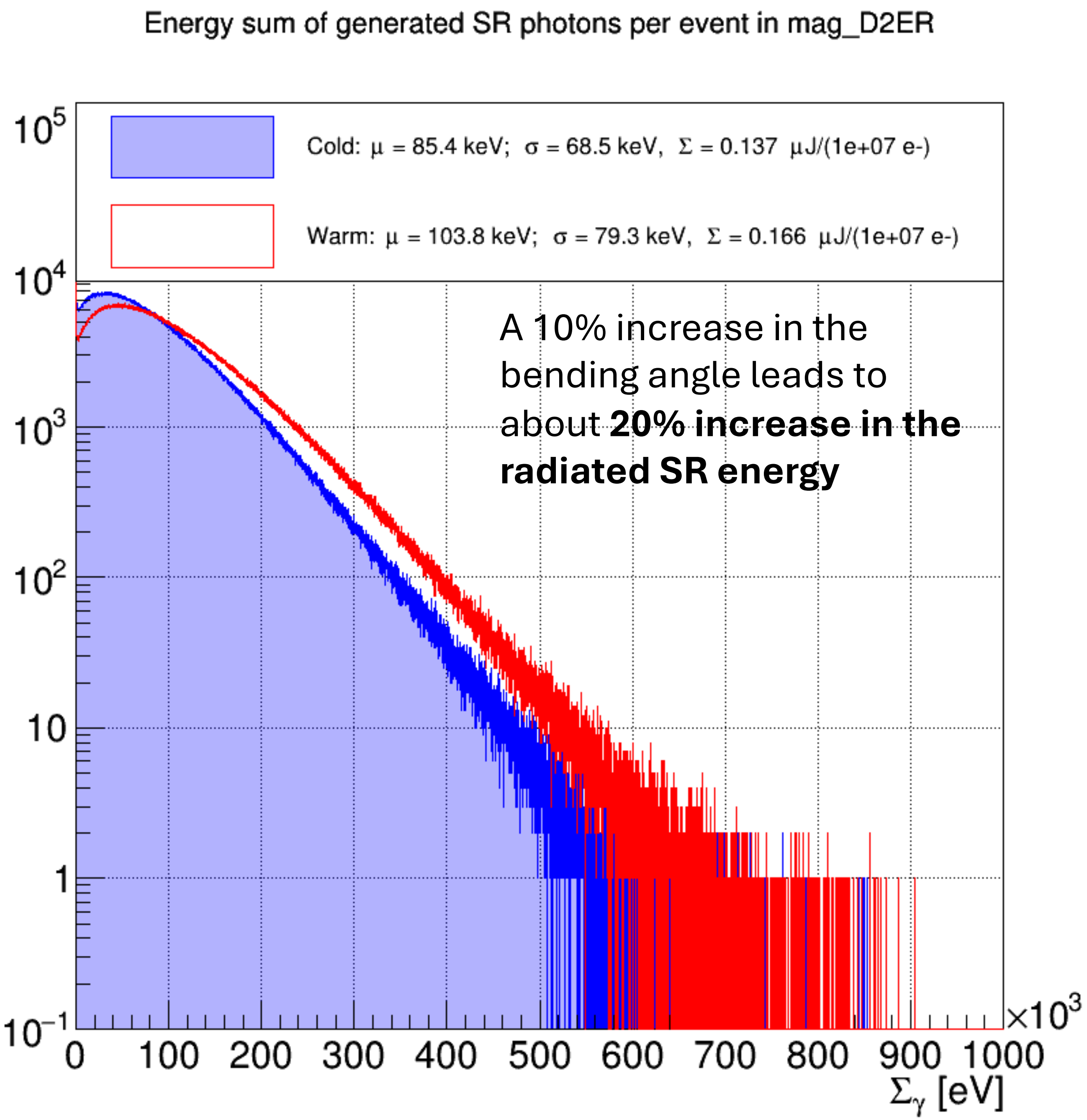




Production vertices of SR photons that were absorbed by the vacuum beam pipe

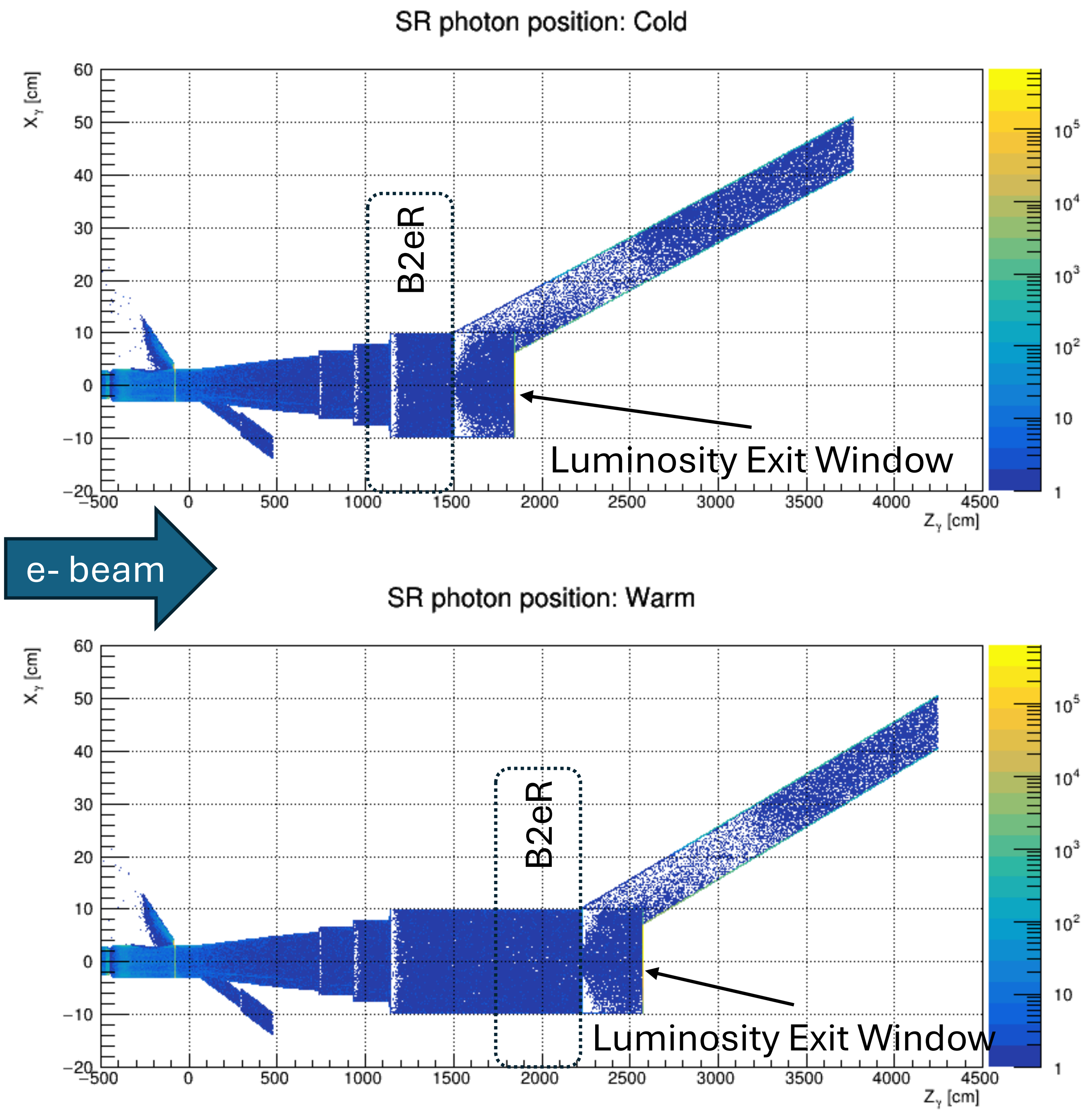


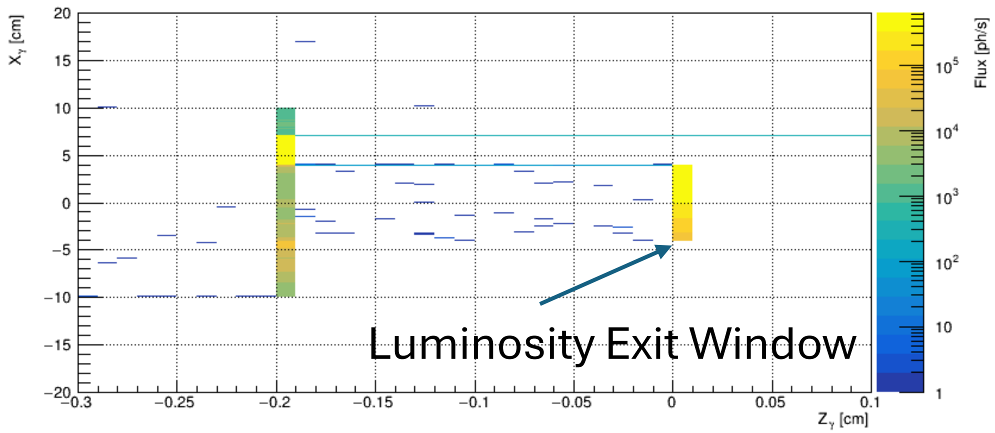
Number of SR photons generated by B2eR per electron



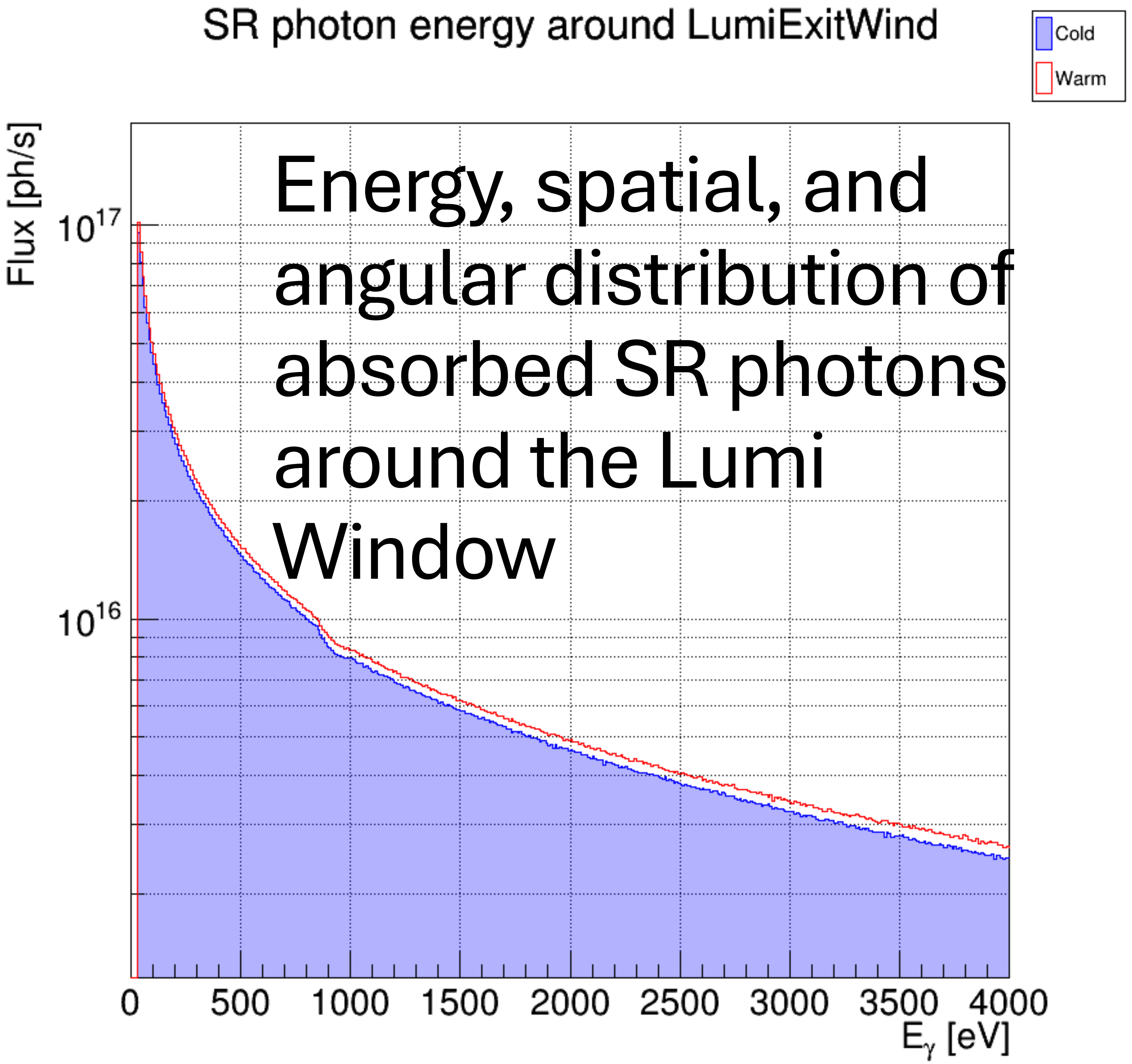
Total energy of all generated SR photons in B2eR per electron

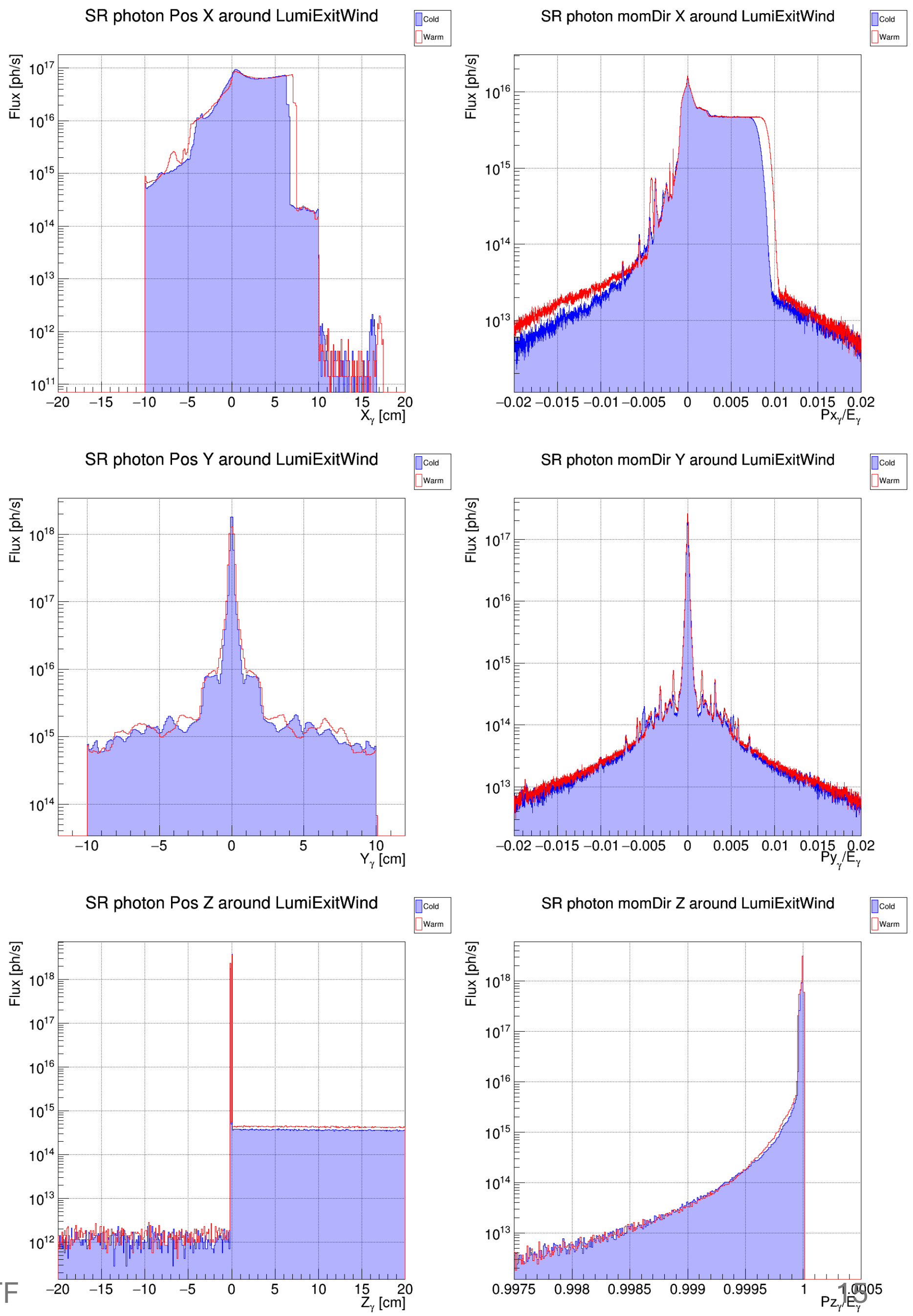
XZ distribution of absorbed SR photons on the inner surface of the vacuum beam pipe





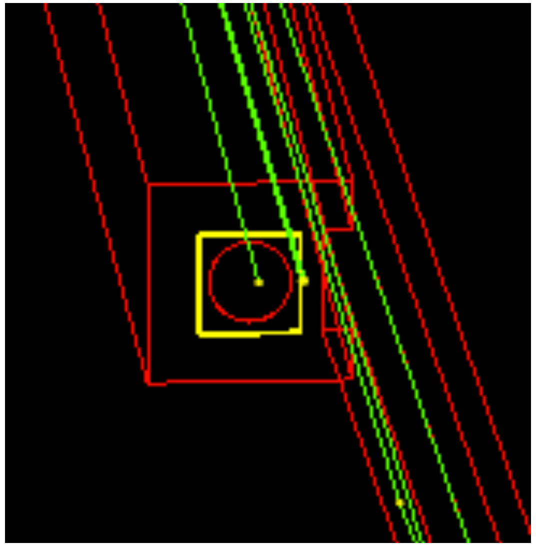
Energy, spatial, and angular distribution of absorbed SR photons around the Lumi Window

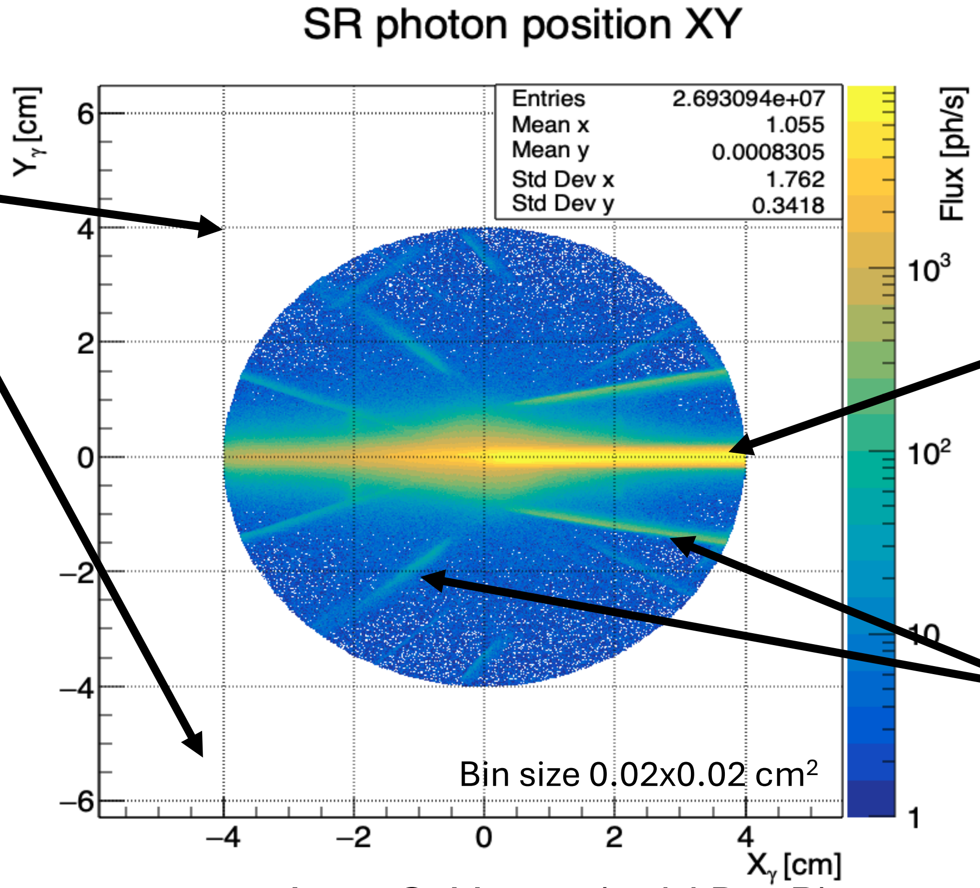




Absorbed SR photon distribution on the Lumi Window *(before propagation through the window material)*

This (white) area is shadowed by the beam pipe in front of the Lumi Window.
The beam pipe hole has a round shape.



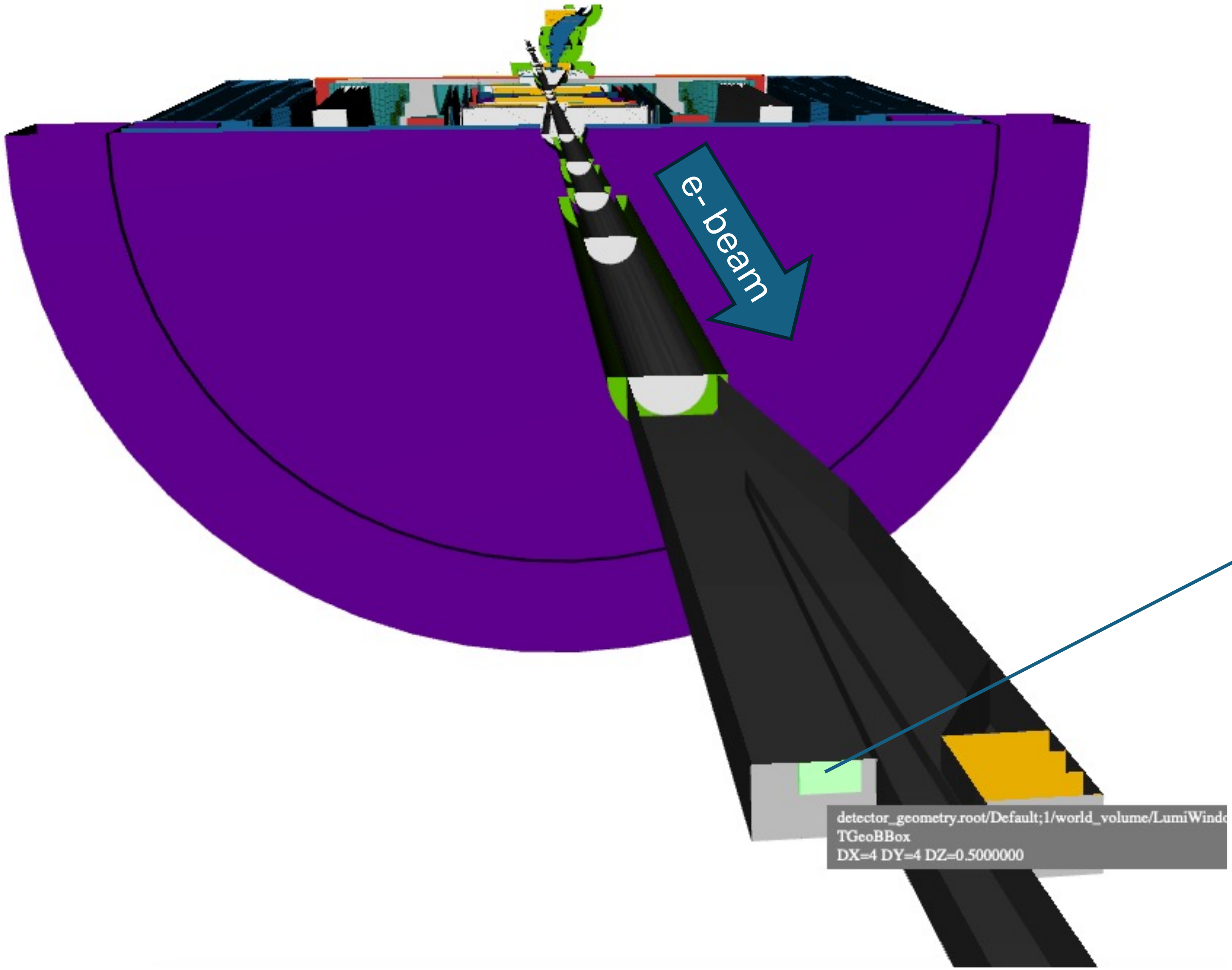


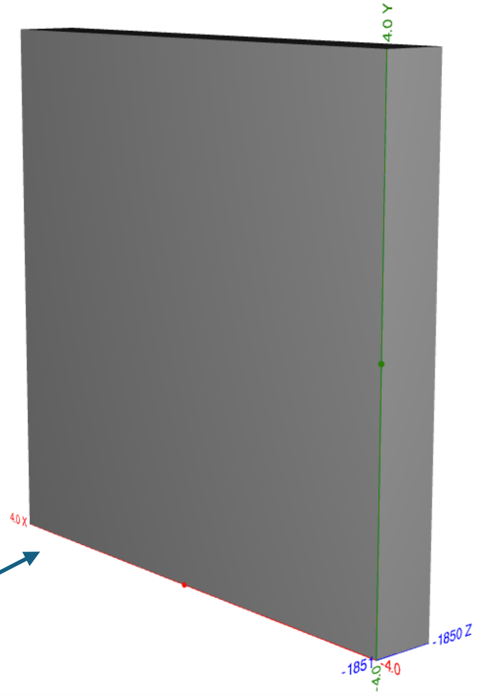
0.227 A, 18 GeV, v6.2 (cold B2eR)

This distribution hits the aluminum Lumi Window.

These "islands" are artifacts due to the reflection of SR photons from the beam pipe faces.

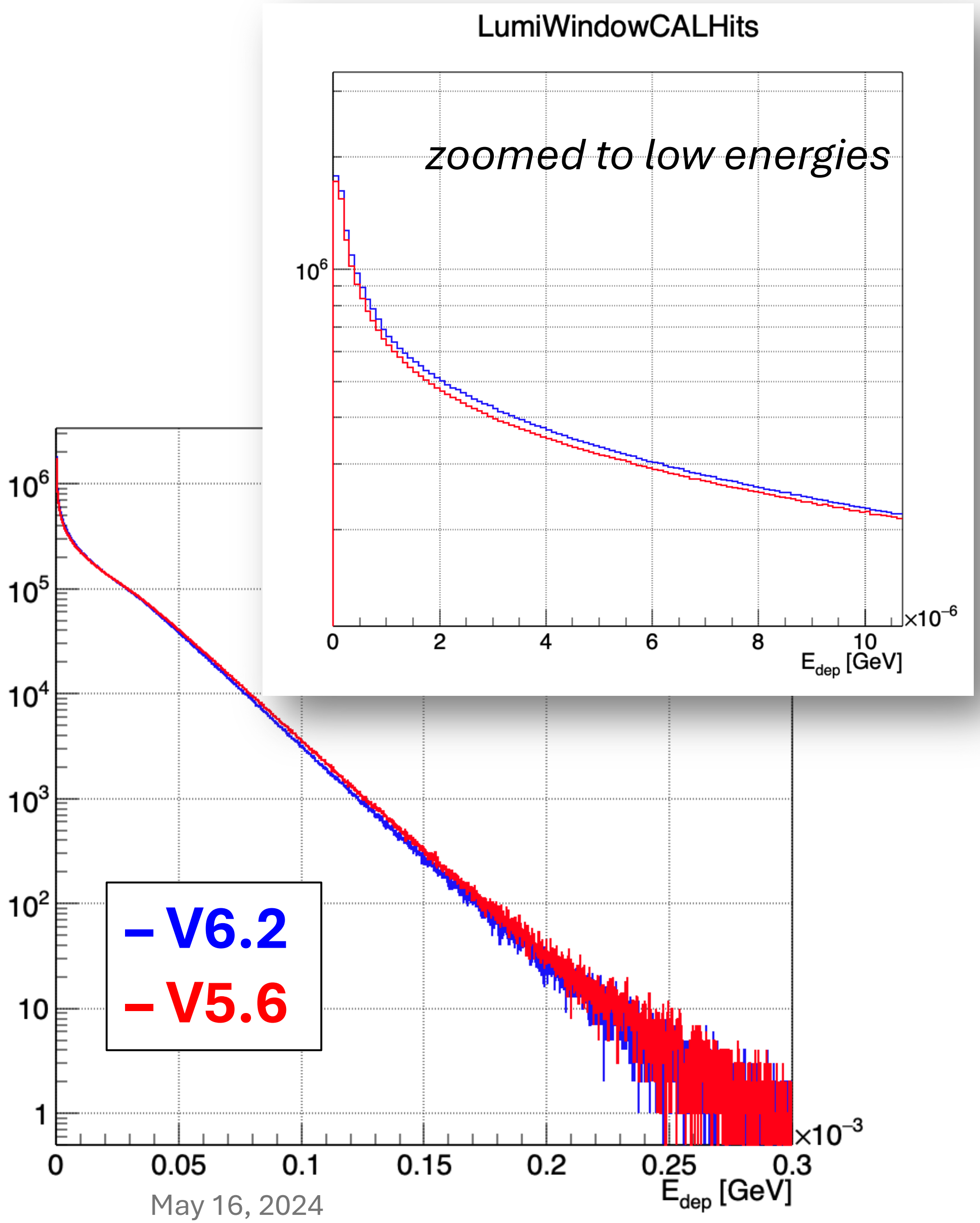
Luminosity monitor exit window

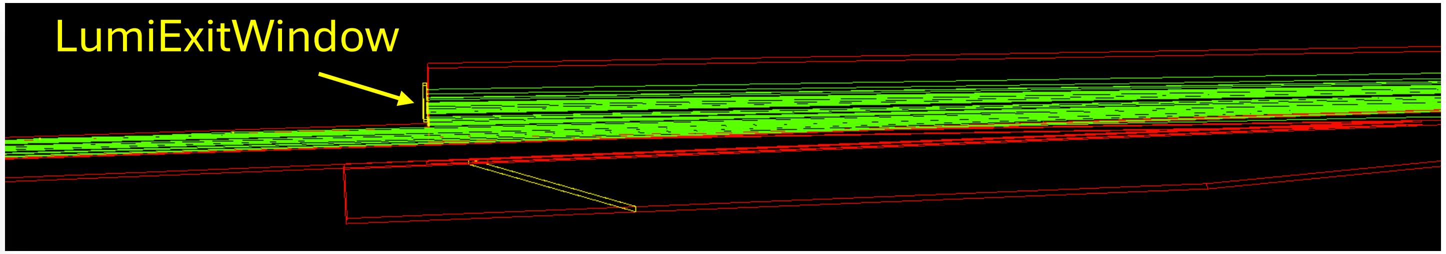




Material = aluminum
Size = 8 cm x 8 cm x 1 cm
Density = 2.7 g/cm^3
Mass = 172.8 g
Heat capacity = 0.9211 J/(g ^{o}C)
Melting point = 660.3 ^{o}C

SR energy deposition in the window: Cold B2eR

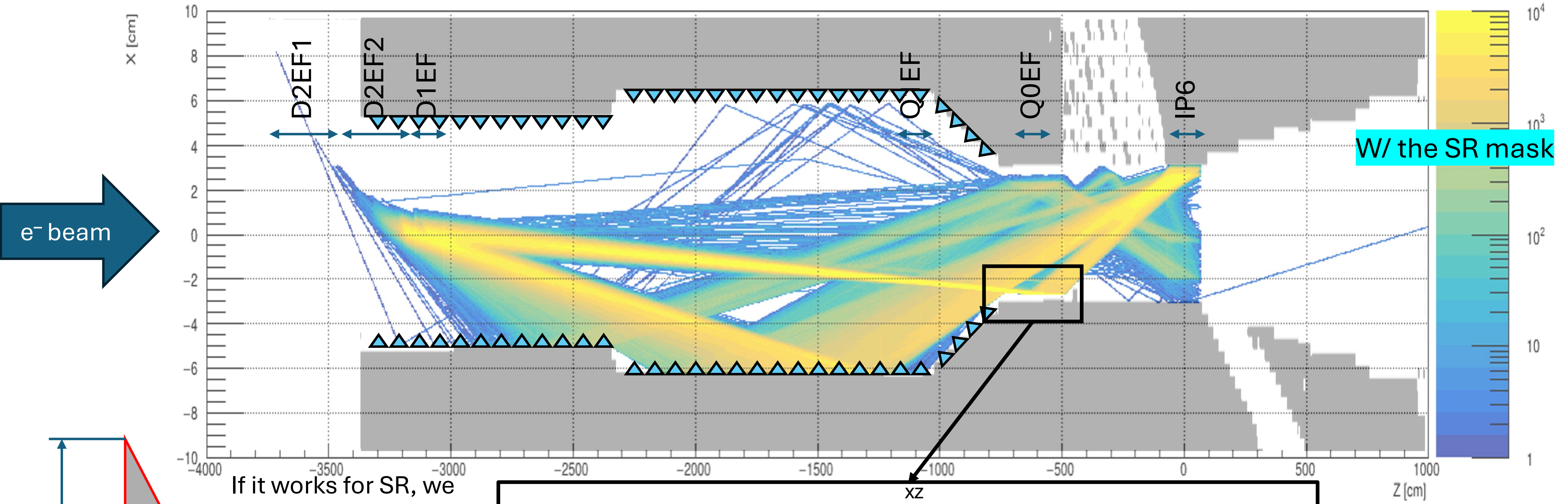


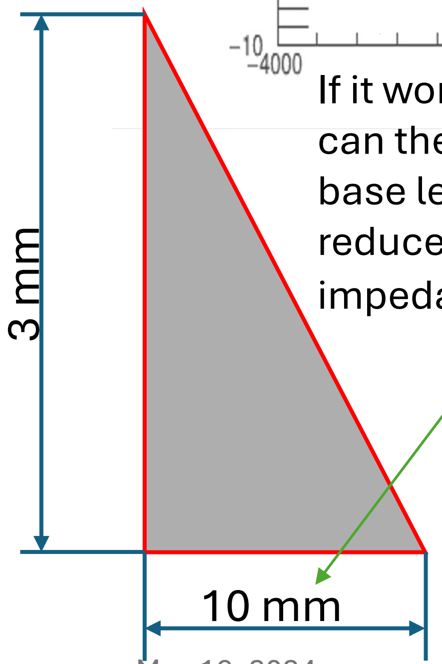


Lattice	V6.2	V5.6
# of simulated 18-GeV electrons	10^8	
Simulated beam current [A]	0.227	
E_{dep} [GeV] – deposited energy in the Al block	1729.5	1792.1
E_{dep} rate [GeV/s]	2.45e+13	2.54e+13
Dose rate [MRad/s]	2.3	2.4
Wattage [kW]	3.9	4.1
Temperature rise [°C/min]	1480.0	1533.5

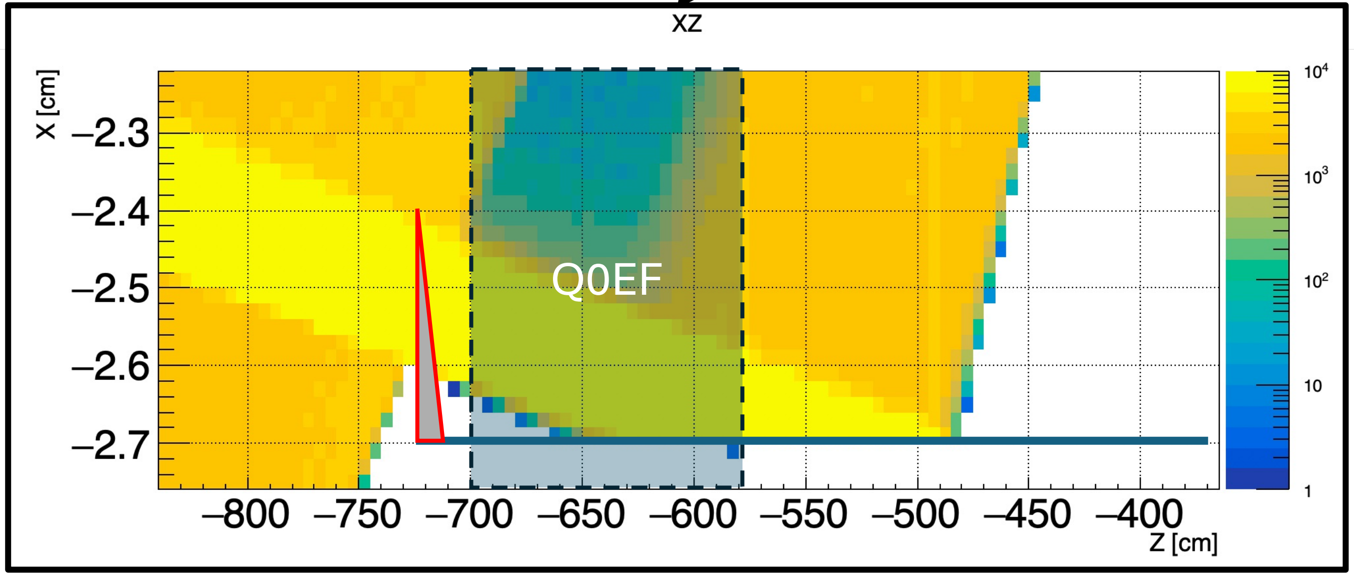
Without cooling, Lumi Window will melt in less than a minute!

Backup slides

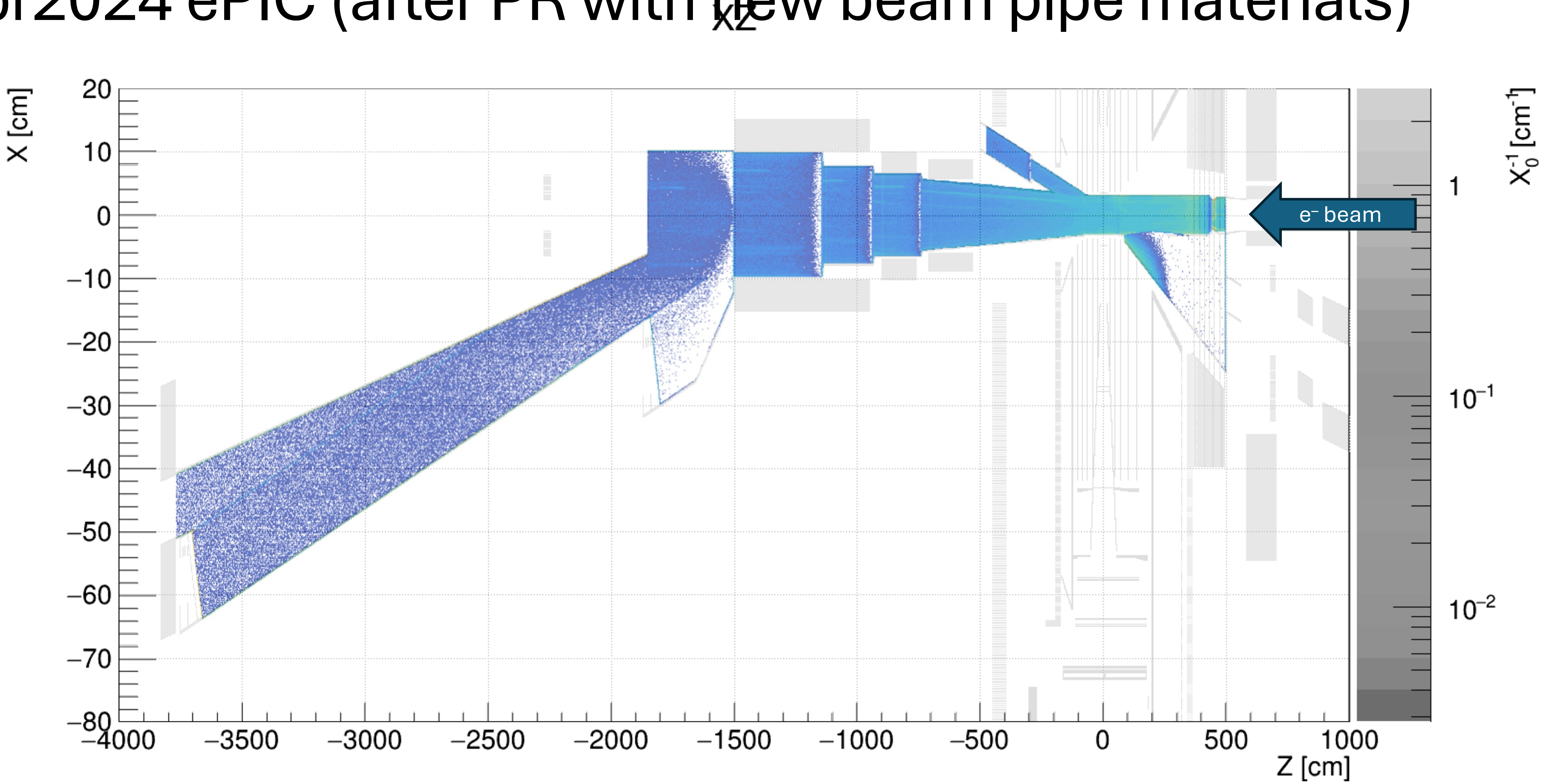




If it works for SR, we can then adjust the base length to reduce the impedance budget

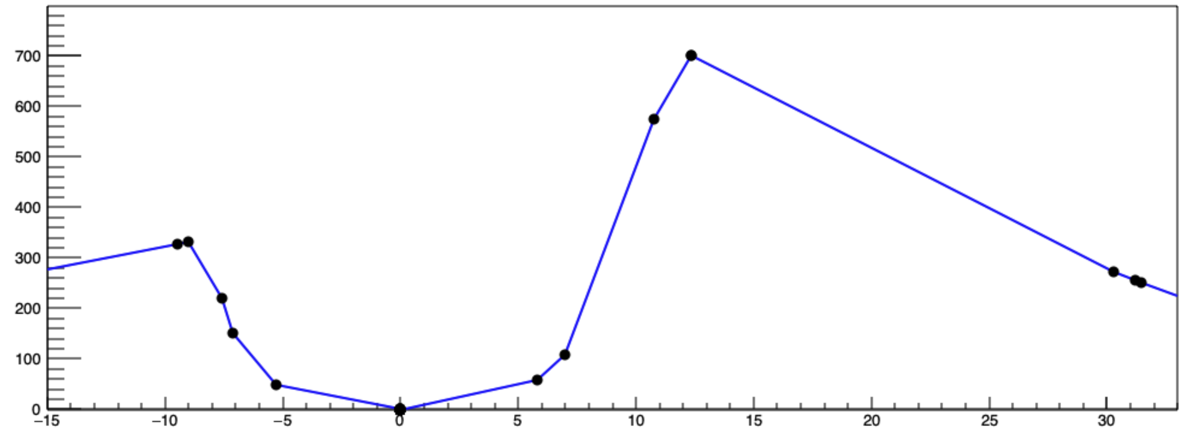


Apr2024 ePIC (after PR with new beam pipe materials)

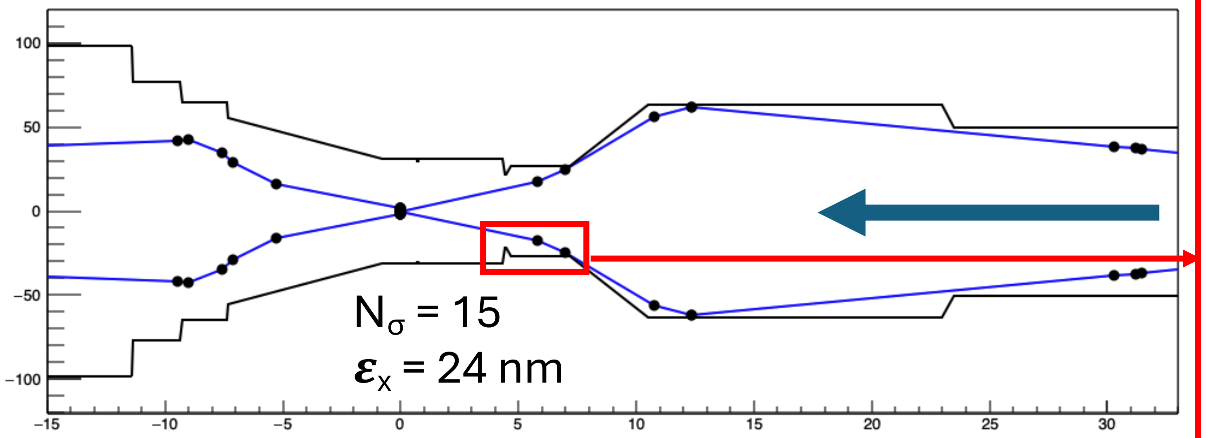


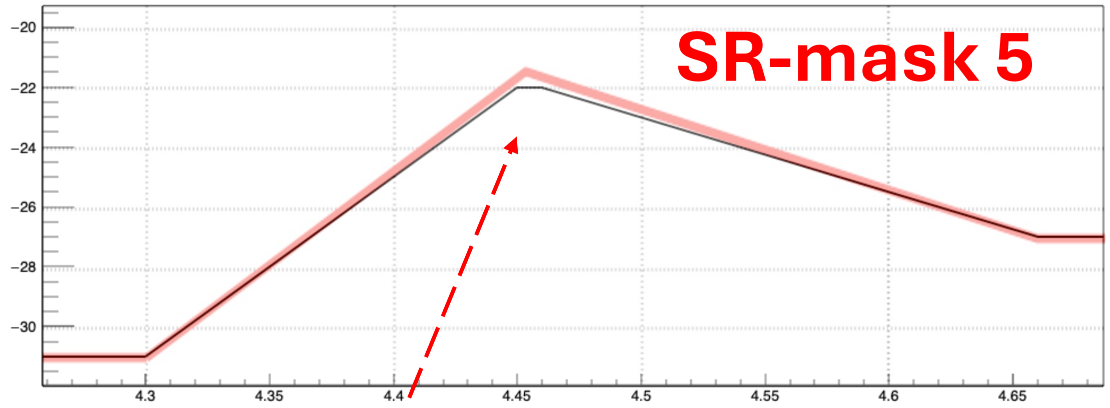
V6.2 | 2 IPs | 18 GeV

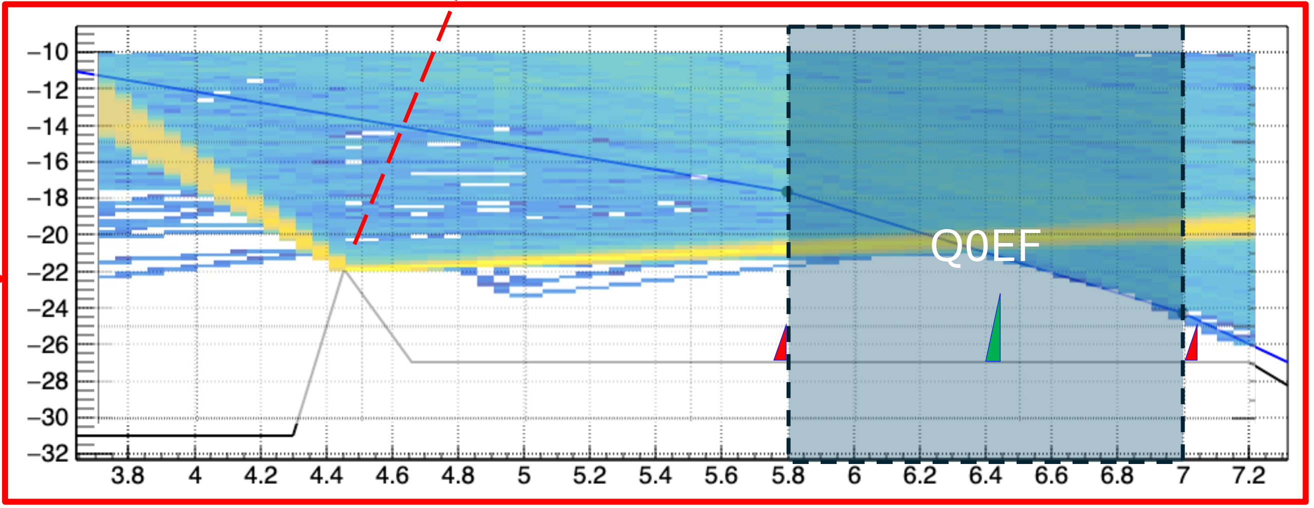
β_x [m] vs s[m]

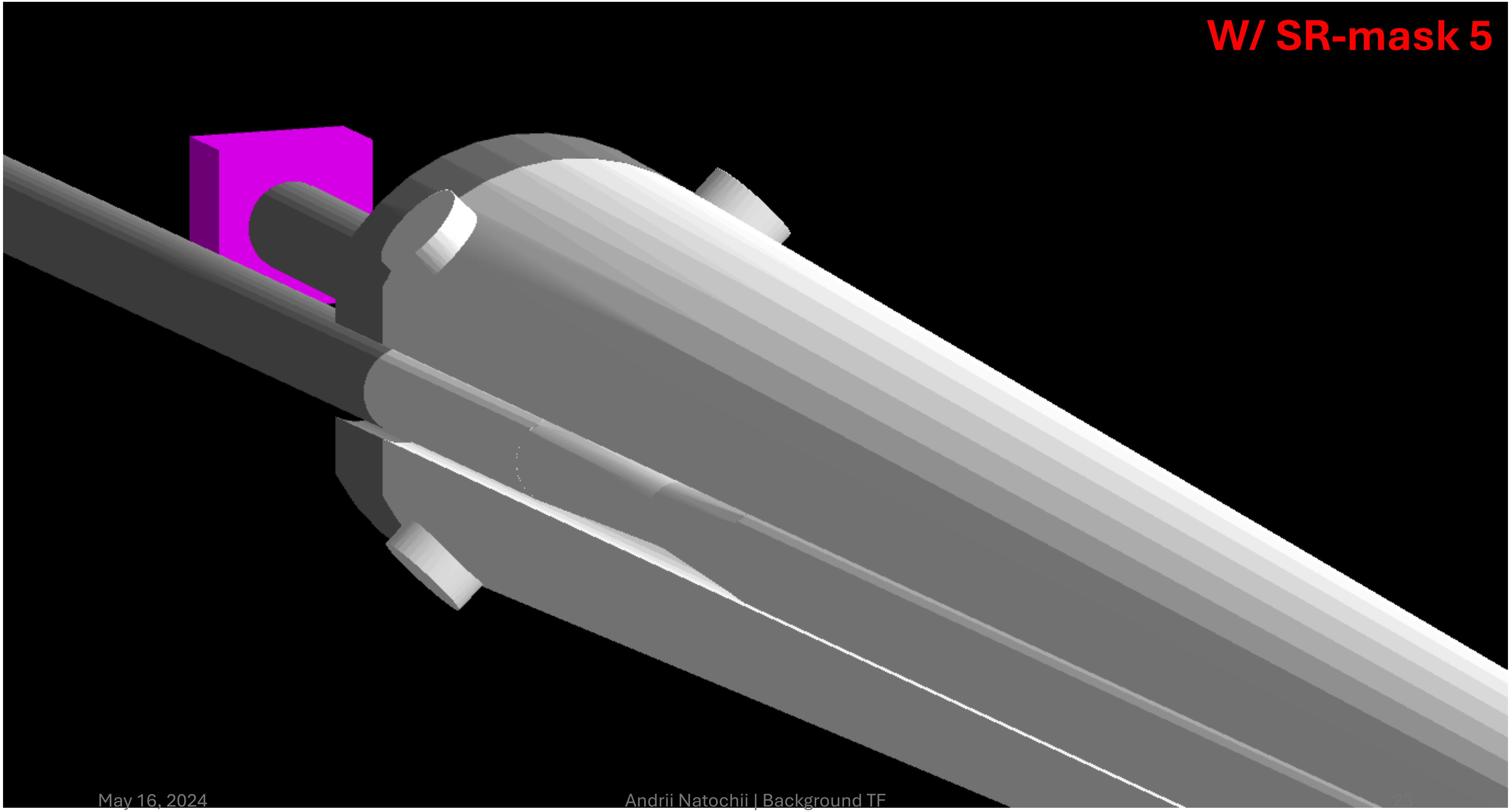


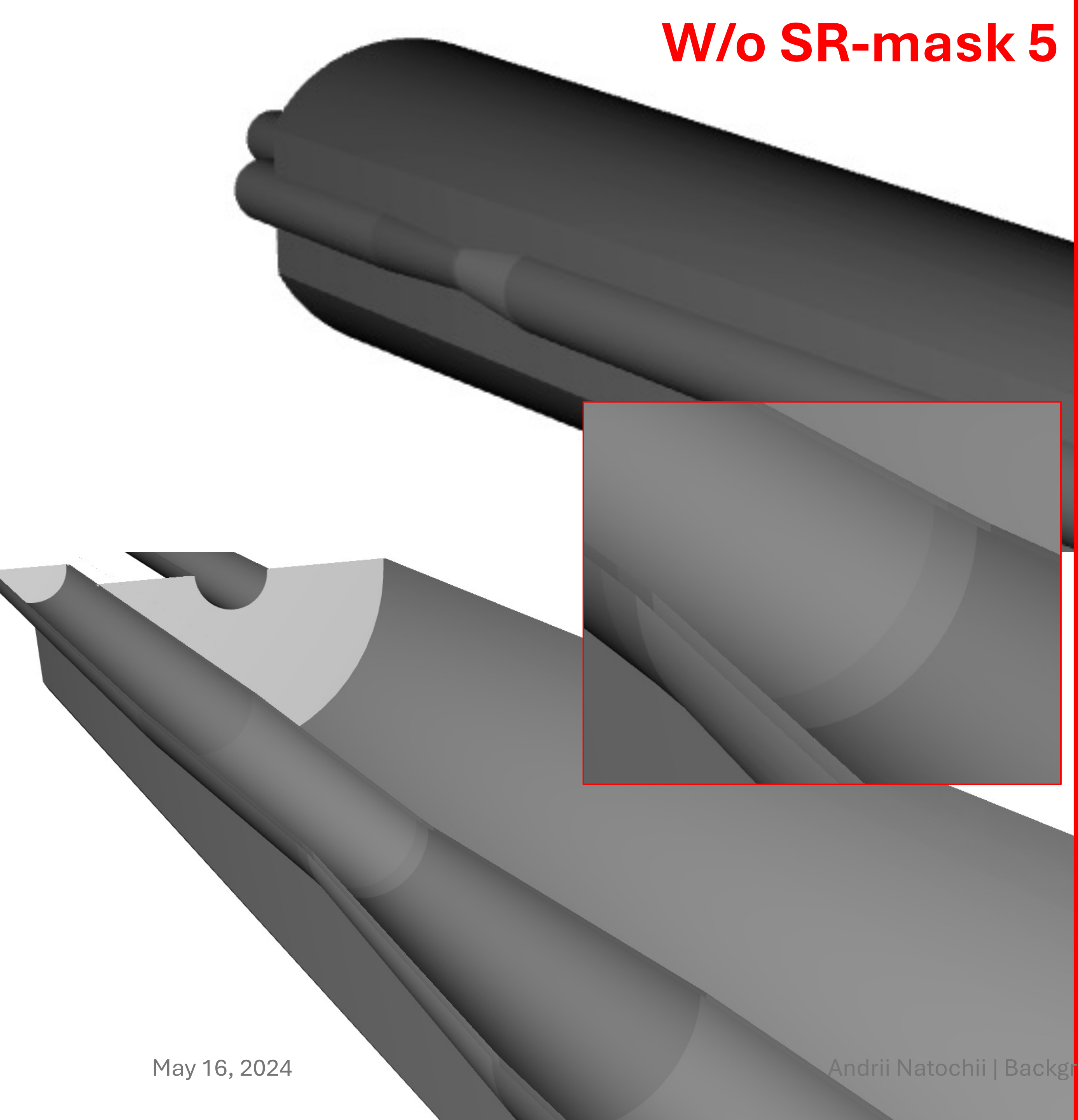
$N_\sigma * (\beta_x * \varepsilon_x)$ [mm] vs s[m]

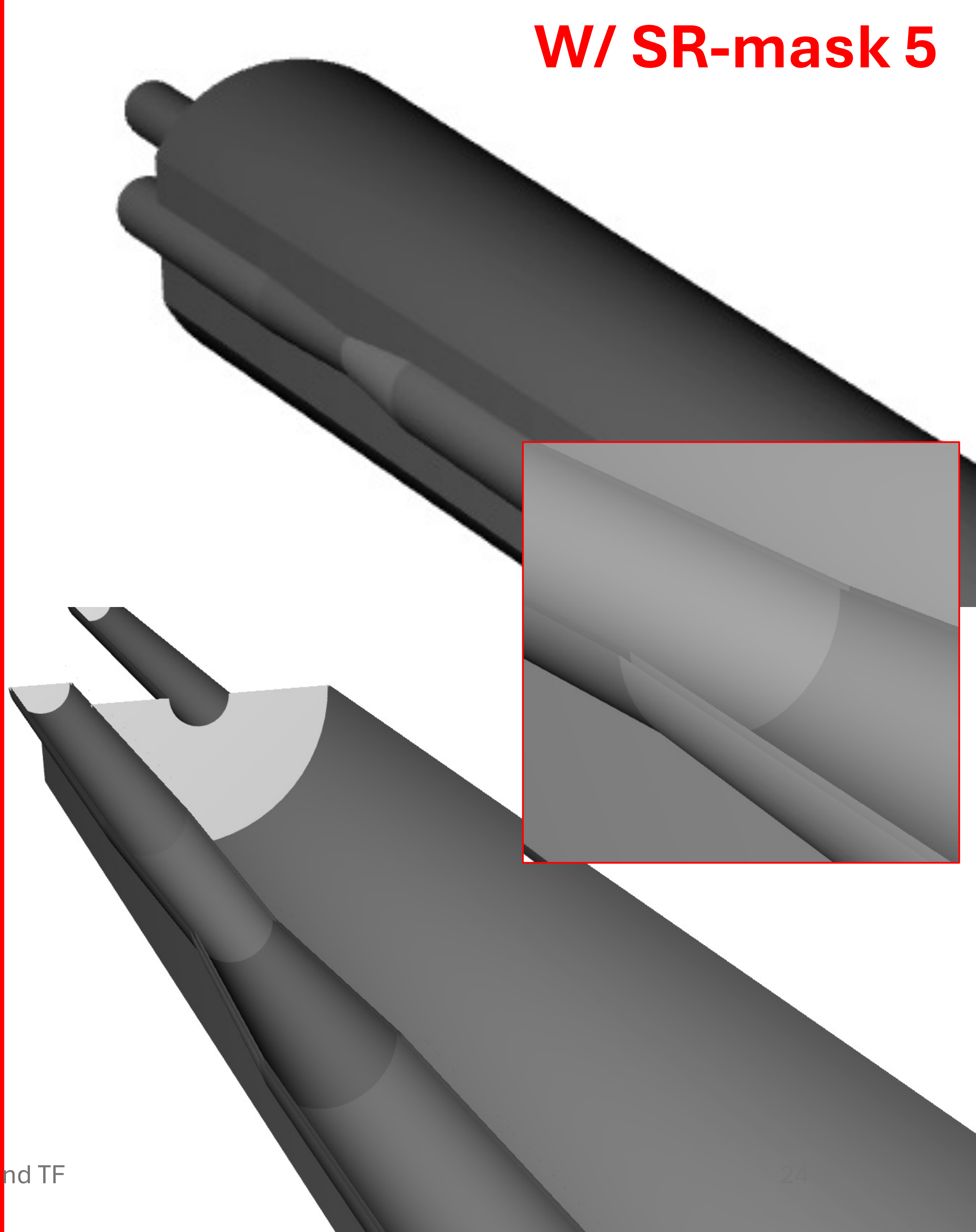


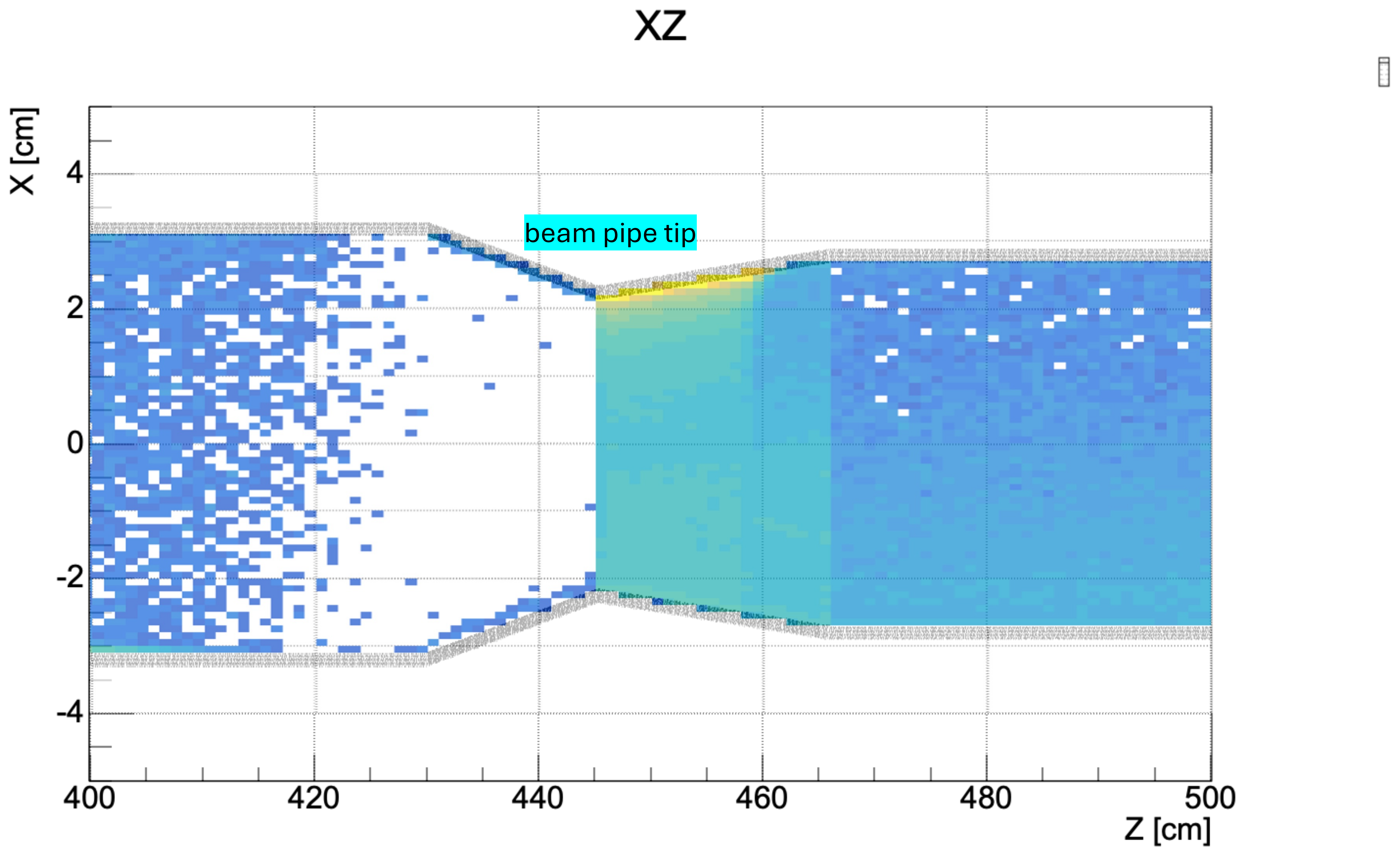


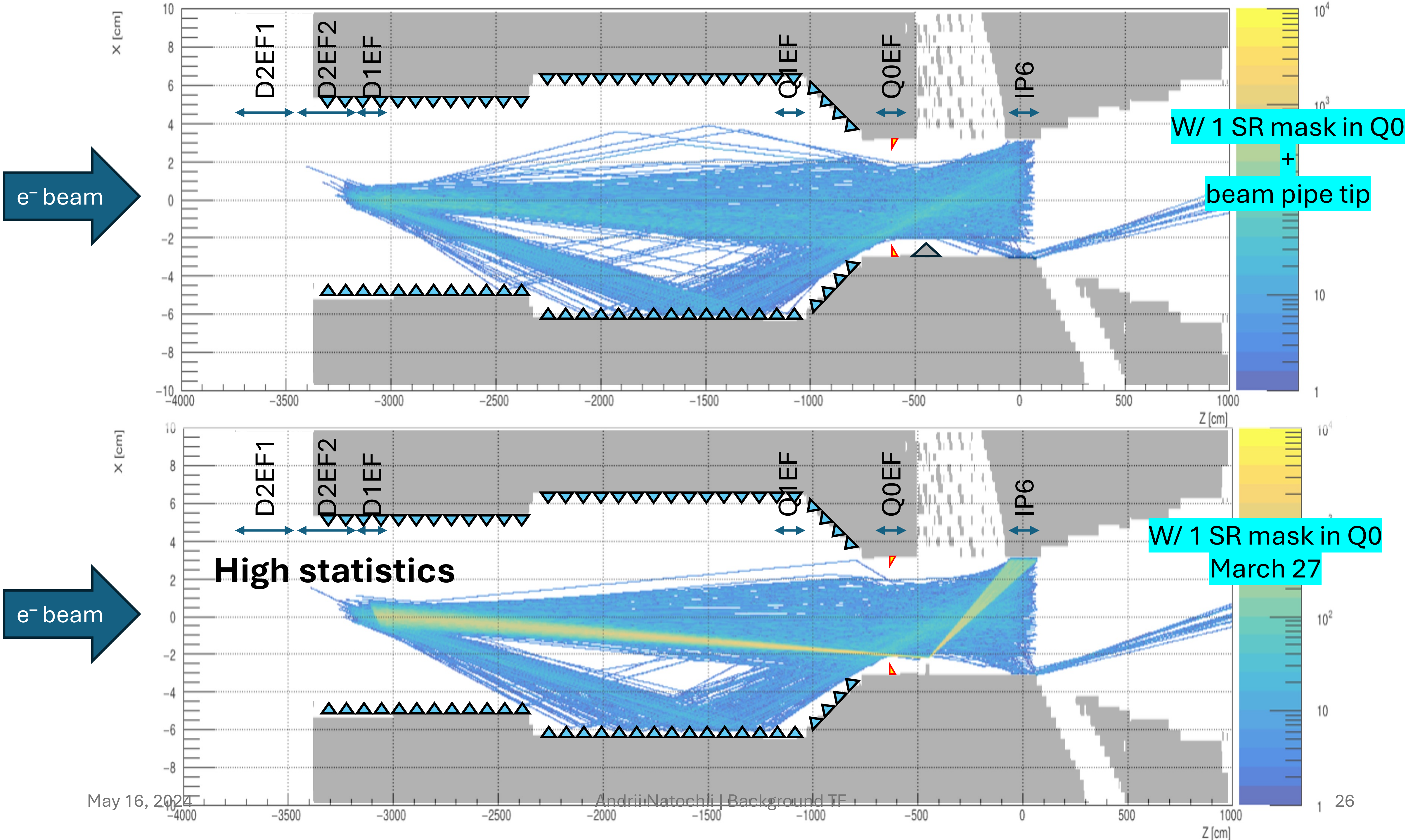



W/ SR-mask 5


W/o SR-mask 5


W/ SR-mask 5


XZ
beam pipe tip
X [cm]
Z [cm]
4
2
0
-2
-4
400
420
440
460
480
500


X [cm]
Z [cm]
D2EF1
D2EF2
D1EF
Q1EF
Q0EF
IP6
e⁻ beam
W/ 1 SR mask in Q0
+
beam pipe tip
High statistics
W/ 1 SR mask in Q0
March 27

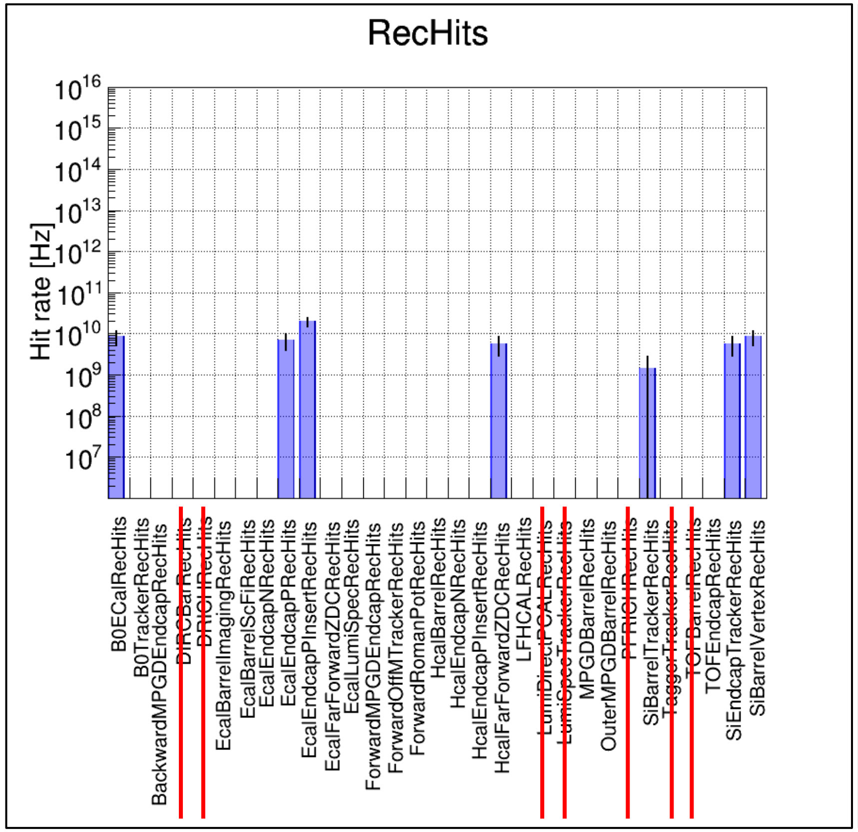
I = 0.227 A
-37m < z < 5m
E_γ > 30 eV

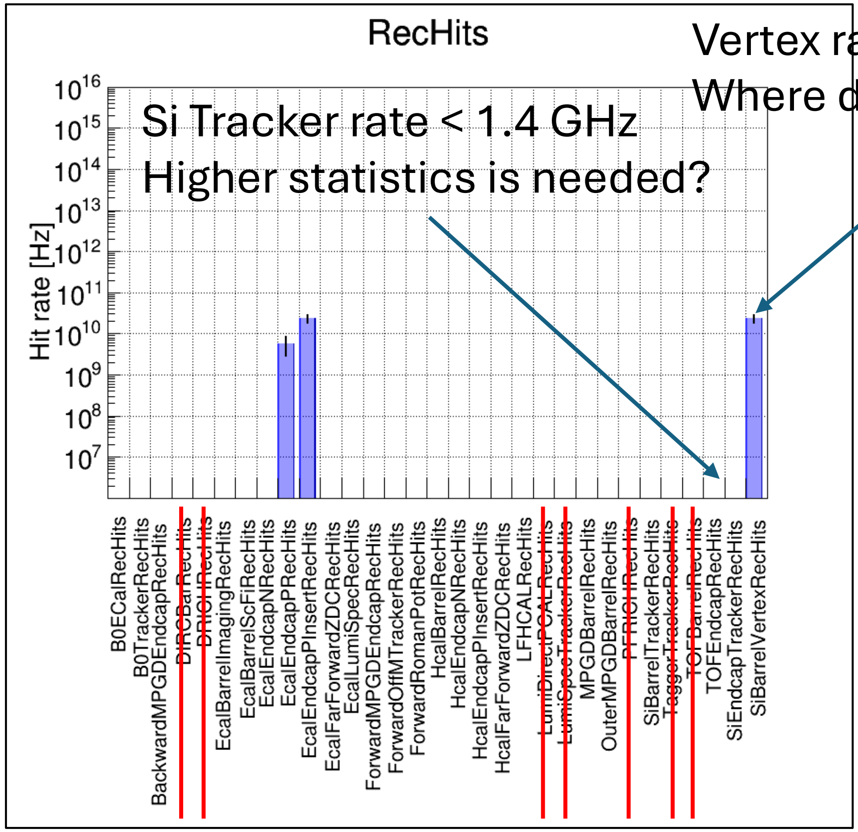
Lattice file v6.2 | 18 GeV | 2 IPs | I = 0.227 A

SS + Cu
beam pipe

1 SR mask in Q0

1 SR mask in Q0 + beam pipe tip

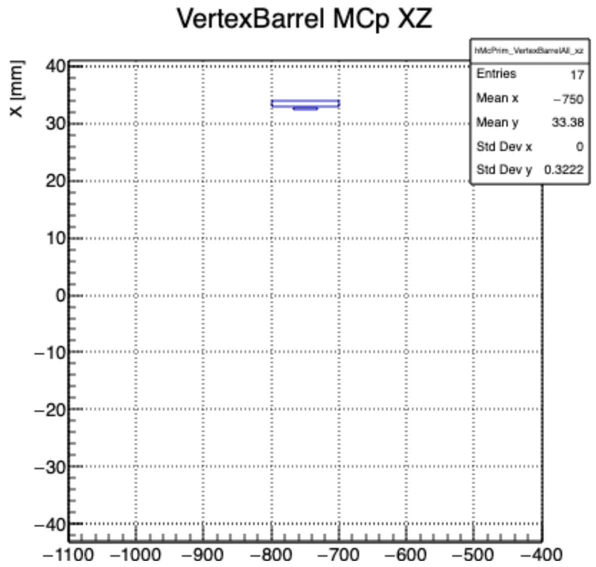


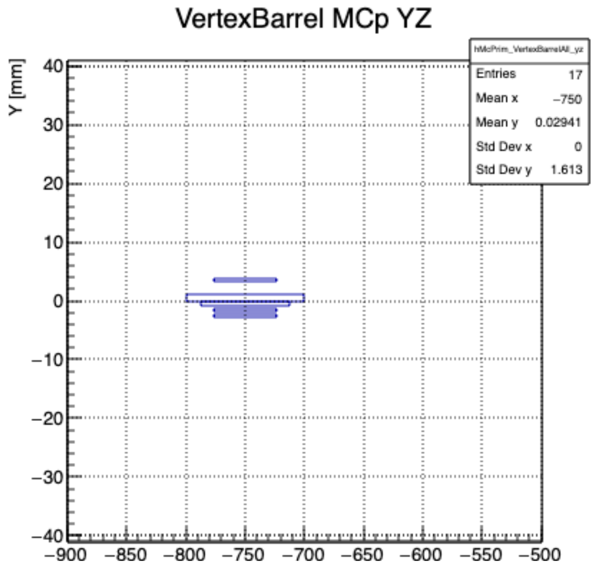


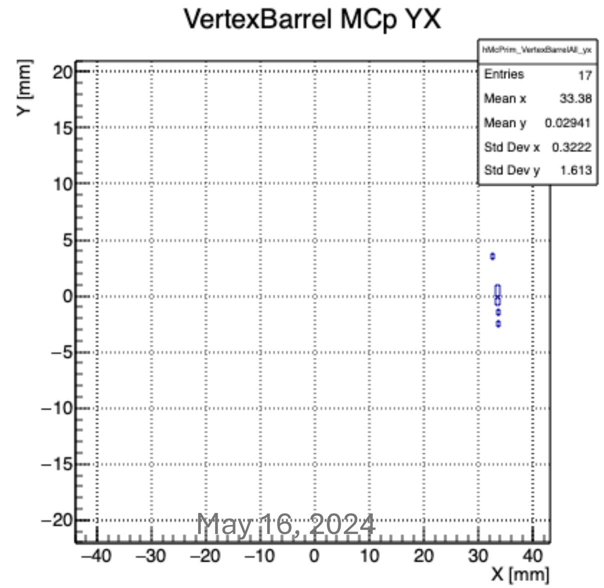
Vertex rate > 1.4 GHz
Where does it come from?

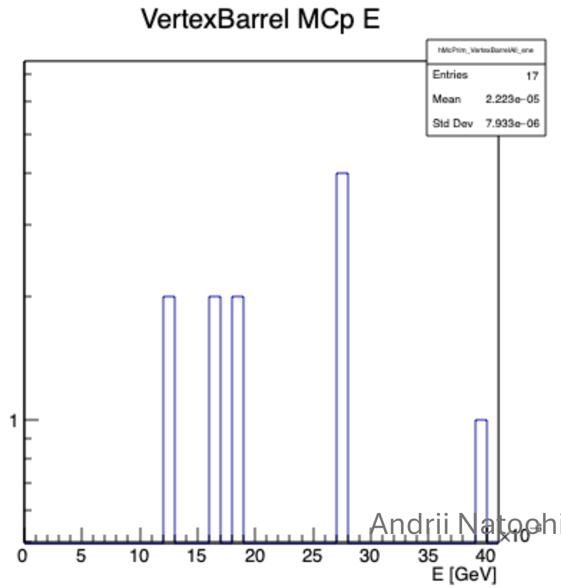
Si Tracker rate < 1.4 GHz
Higher statistics is needed?

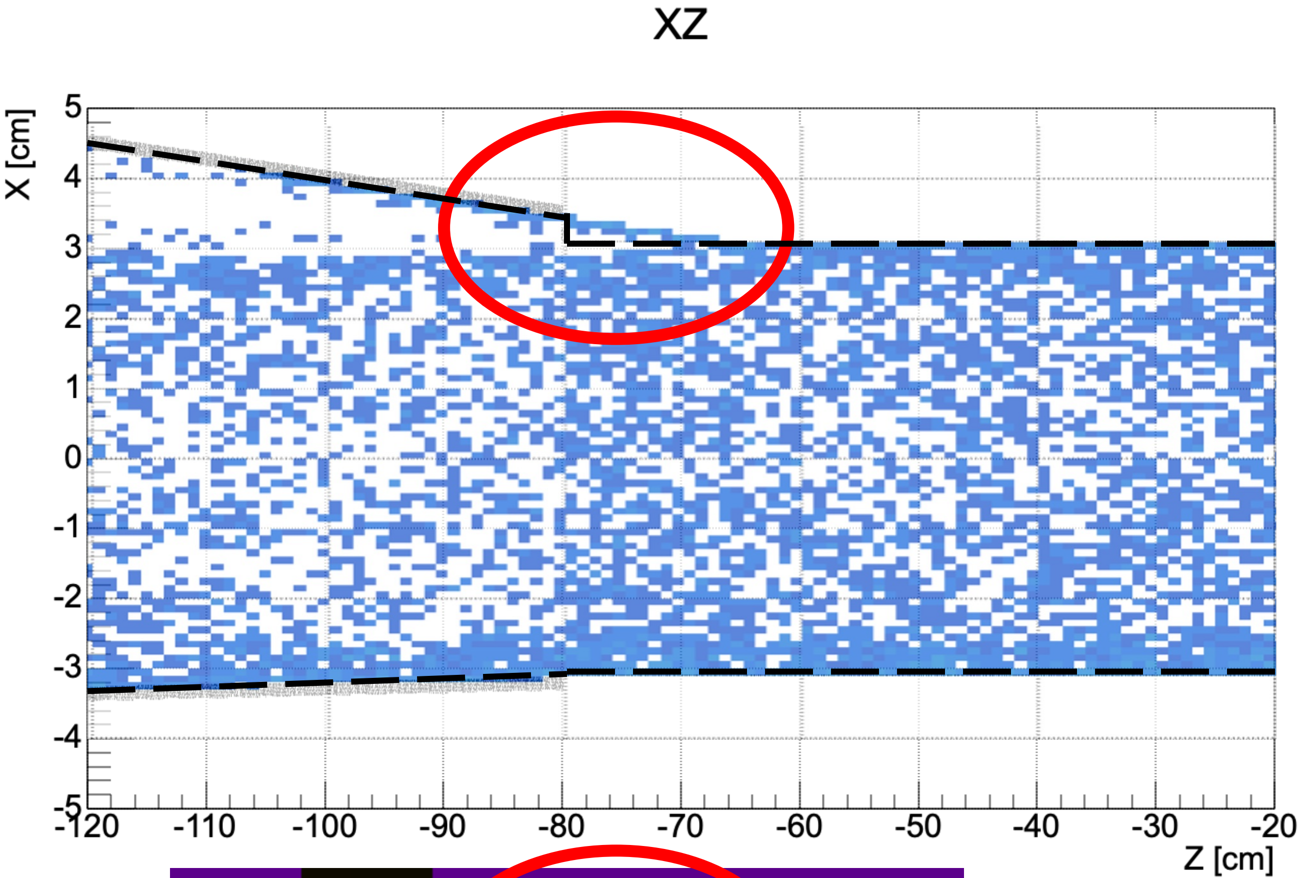
Absorbed SR photons that caused Vertex hits

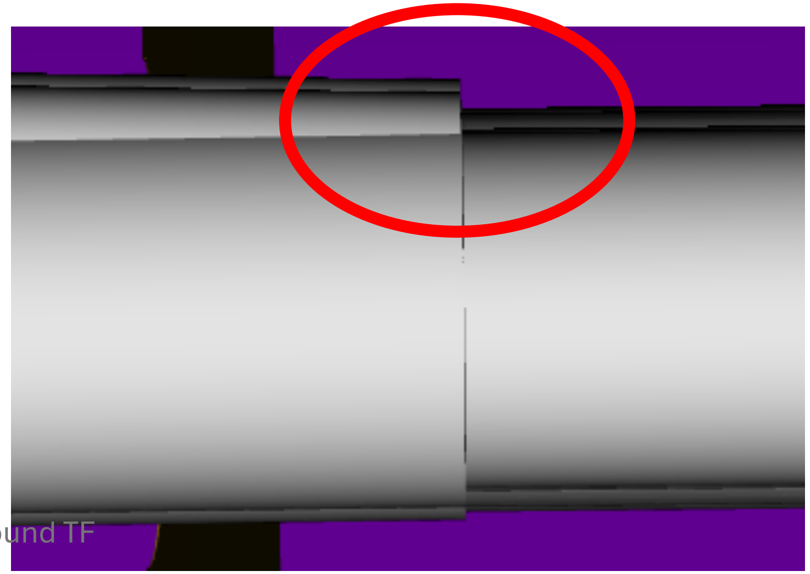


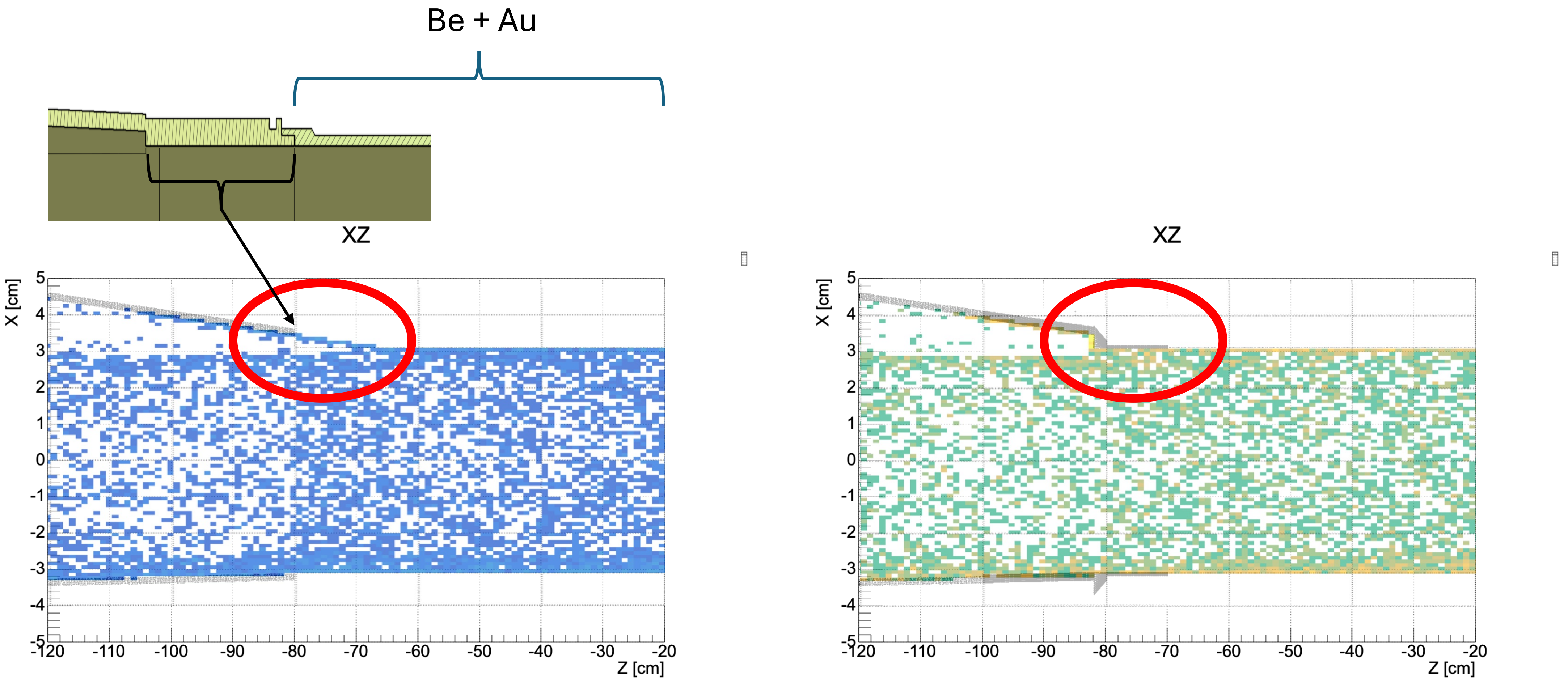










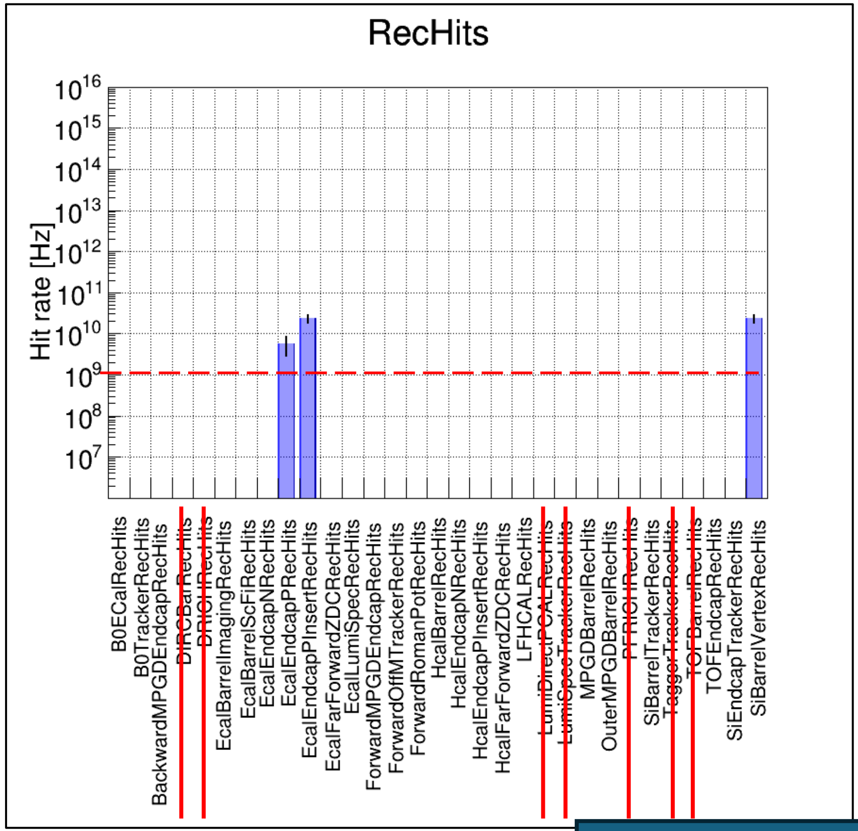

Be + Au
XZ
XZ
X [cm]
Z [cm]

I = 0.227 A
-37m < z < 5m
E_γ > 30 eV

Lattice file v6.2 | 18 GeV | 2 IPs | I = 0.227 A

SS + Cu
beam pipe

1 SR mask in Q0 + beam pipe tip



1 SR mask in Q0 + beam pipe tip