Synchrotron Radiation Background Sampling for ePIC

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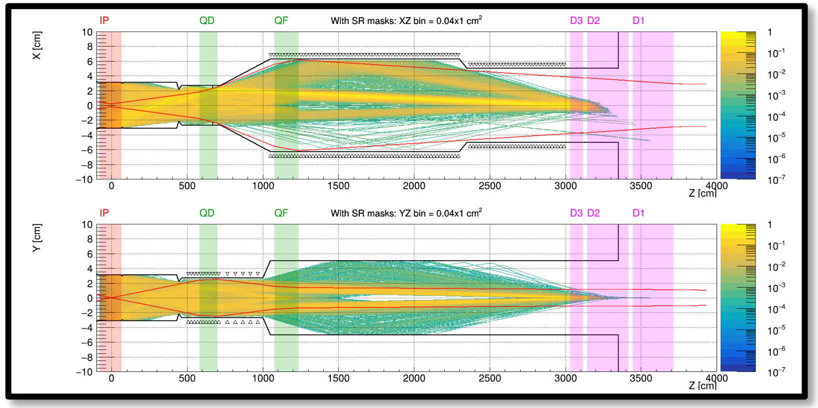
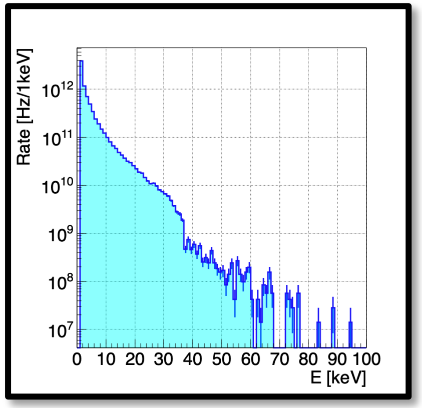
Overview (1)

- In the stand-alone Geant4-based framework SynradG4, we simulated $N_{SIM} = 10^{11}$ electrons.
  - Each with an energy of 18 GeV, passing through the IR.
  - Took approximately 10 days to complete on the JLab iFARM cluster.
- Each electron generates numerous SR photons as it travels through the IR magnets.
  - These photons are tracked along the beamline, including multiple reflections off the beam pipe surface, which features SR masks and surface roughness.
  - We retained only those photons that reached the IP6 beam pipe and had energies above 1 keV
    - The gold coating on the inner surface of the IP beam pipe absorbs most photons below 5 keV.
- The IR6 beam pipe model used in this study corresponds to the ePIC release 25.01.1.
- At 18 GeV, the beam current is $I = 0.227$ A, which corresponds to $N_{BEAM} = \frac{I}{q_e} \approx 1.4 \times 10^{18}\ \mathrm{e}^-/s$.
- Therefore, a single SynradG4 sample represents only a fraction of the real machine operation statistics.
- In the output file, we collected approximately $N_{FILE} \approx 1.2 \times 10^6$ events in which SR photons reached the inner surface of the IP6 beam pipe.
  - This implies that, under real operating conditions, the number of such events per second would be roughly

$$N_{REAL} = N_{BEAM} \times {}^{N_{FILE}}/_{N_{SIM}} \approx 1.7 \times 10^{13} \text{ events.}$$

SR tracks hitting the IP6 beam pipe. Horizontal (top) and vertical (bottom) planes. (Jan 2025)





Spectrum of SR photons (> 1 KeV) hitting the inner surface of the IP6 beam pipe. (Jan 2025)

Overview (2)

- For background mixing, we use a time integration window of $\Delta t = 2\ \mu s$.
    - This means we need $N_{HEPMC} = N_{REAL} \times dt \approx 3.4 \times 10^7$ events/window.
- Since our available MC sample is limited but large and stored in a single file, we must reuse the same file approximately $F_{REP} = {}^{N_{HEPMC}}/_{N_{FILE}} \approx 28$ times.
- Unfortunately, using this sample during the main MC campaign would overload the CPU resources and significantly degrade performance.
    - Moreover, we know that most SR photons are absorbed by the beam pipe material.
- Therefore, generating all these events during the production campaign is highly inefficient.
- Instead, we propose a more efficient approach:
    - Simulate all SR photons in a stand-alone run and collect only those that escape beyond the main beam pipe.
    - Thanks to Elke A., Sakib R., and Kolja K. for the idea.
- To do this, we need:
    1. Construct a virtual beam pipe just outside the main one.
    2. In the custom Geant4SteppingAction class, collect all particles that escape the main beam pipe into a single HEPMC3 file ($N_{ESC} \approx 6648$ particles).
    - This file represents a 2 μs time window and should be used for mixing with signal and other background samples.
- The corresponding mixing frequency is $F_{MIX} = {}^{N_{ESC}}/_{\Delta t} \approx 3.3$ GHz.
    - Since the mixing algorithm selects events from the file according to a Poisson distribution, this frequency ensures that, on average, all particles in the file (1 event = 1 particle) are used in each mixing window:

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gRandom->Poisson(3.3e9*2e-6) = 6647
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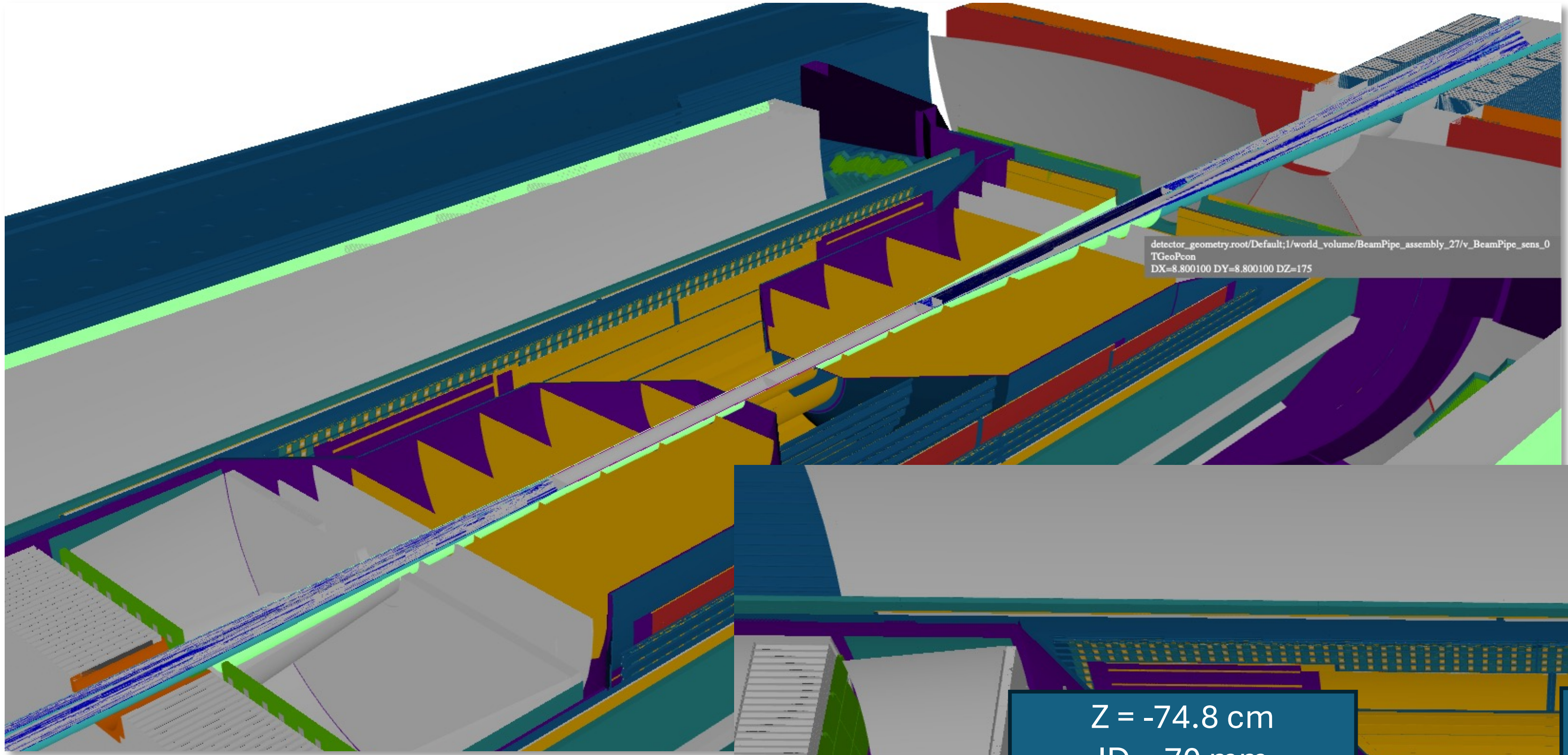
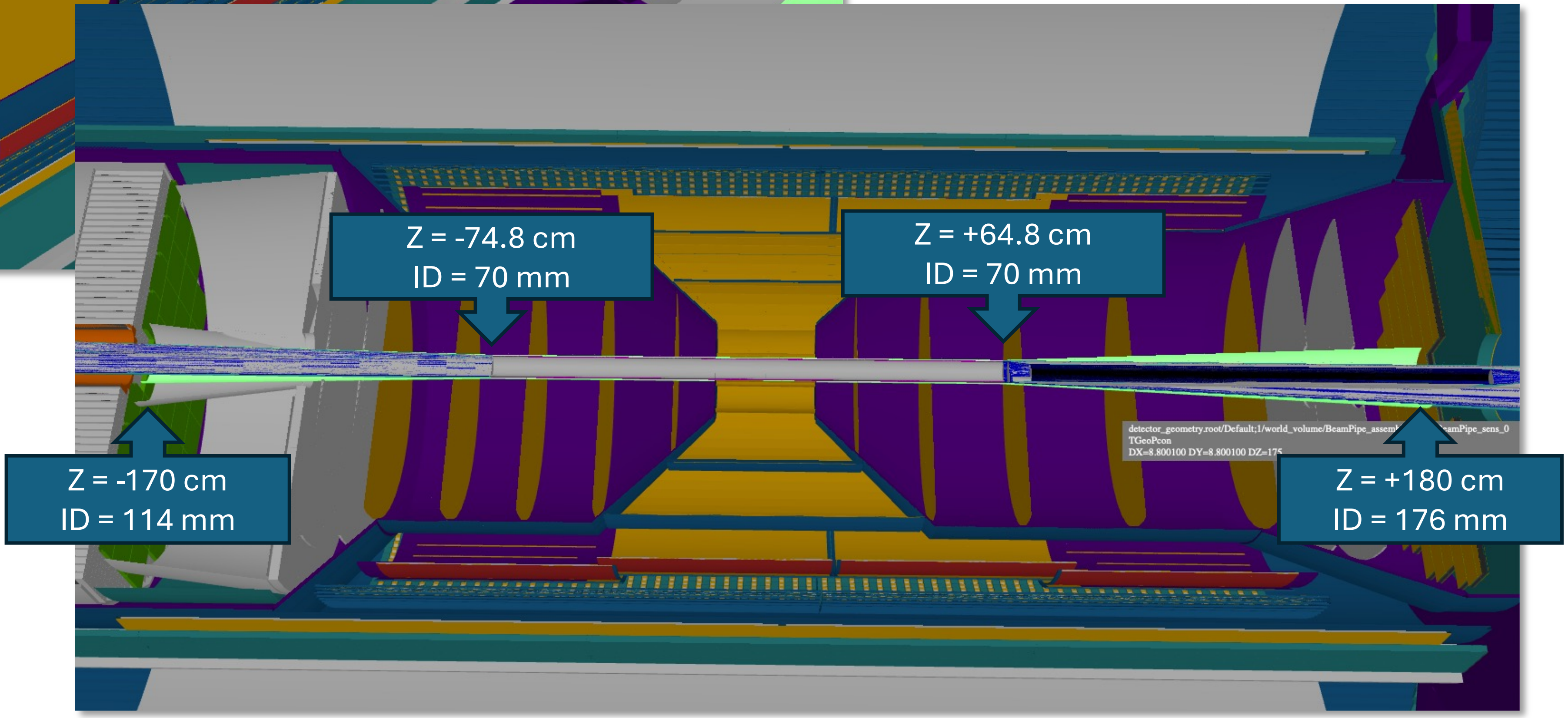
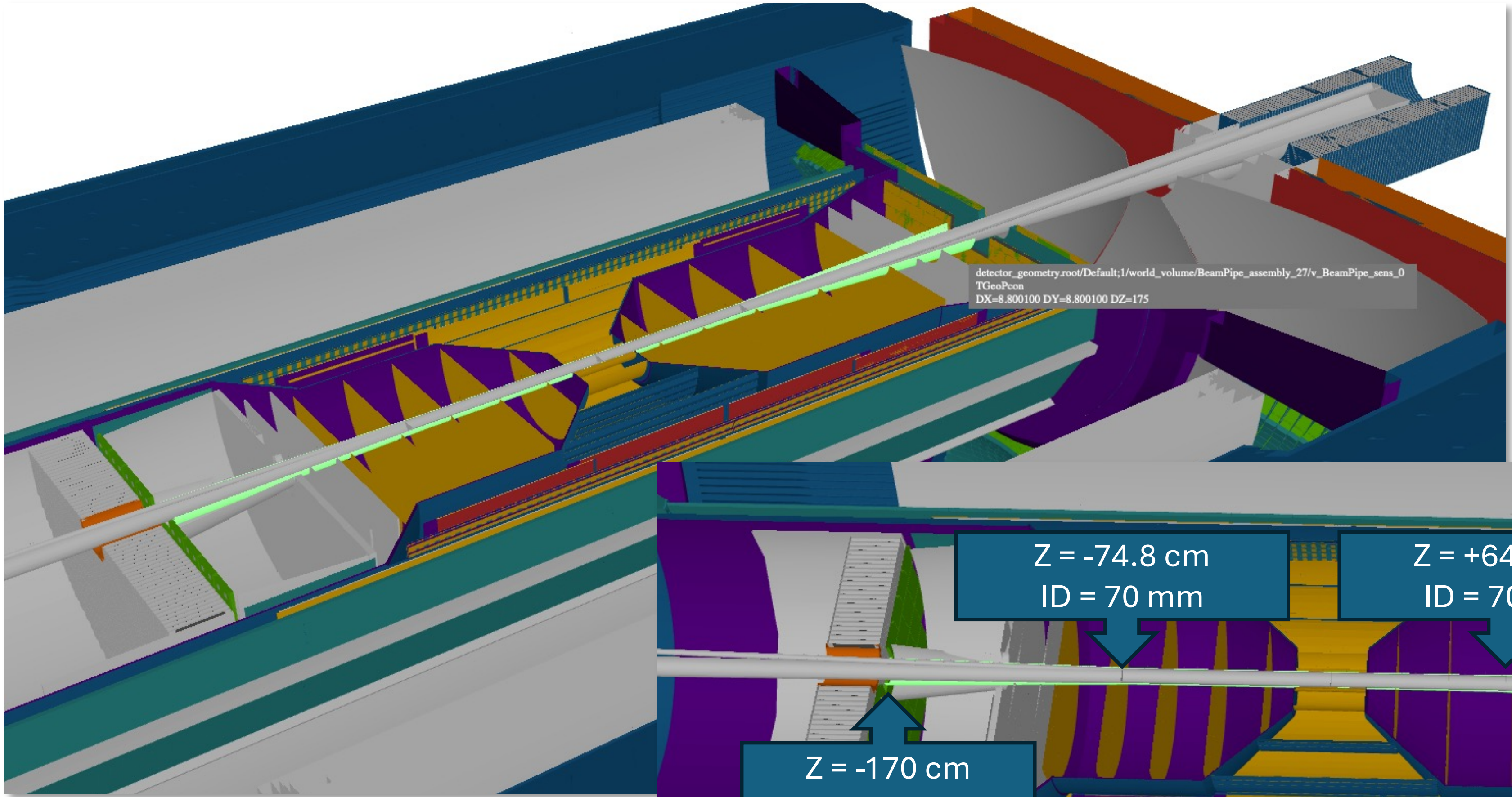
Virtual Pipe Around the Central Beam Pipe (1)

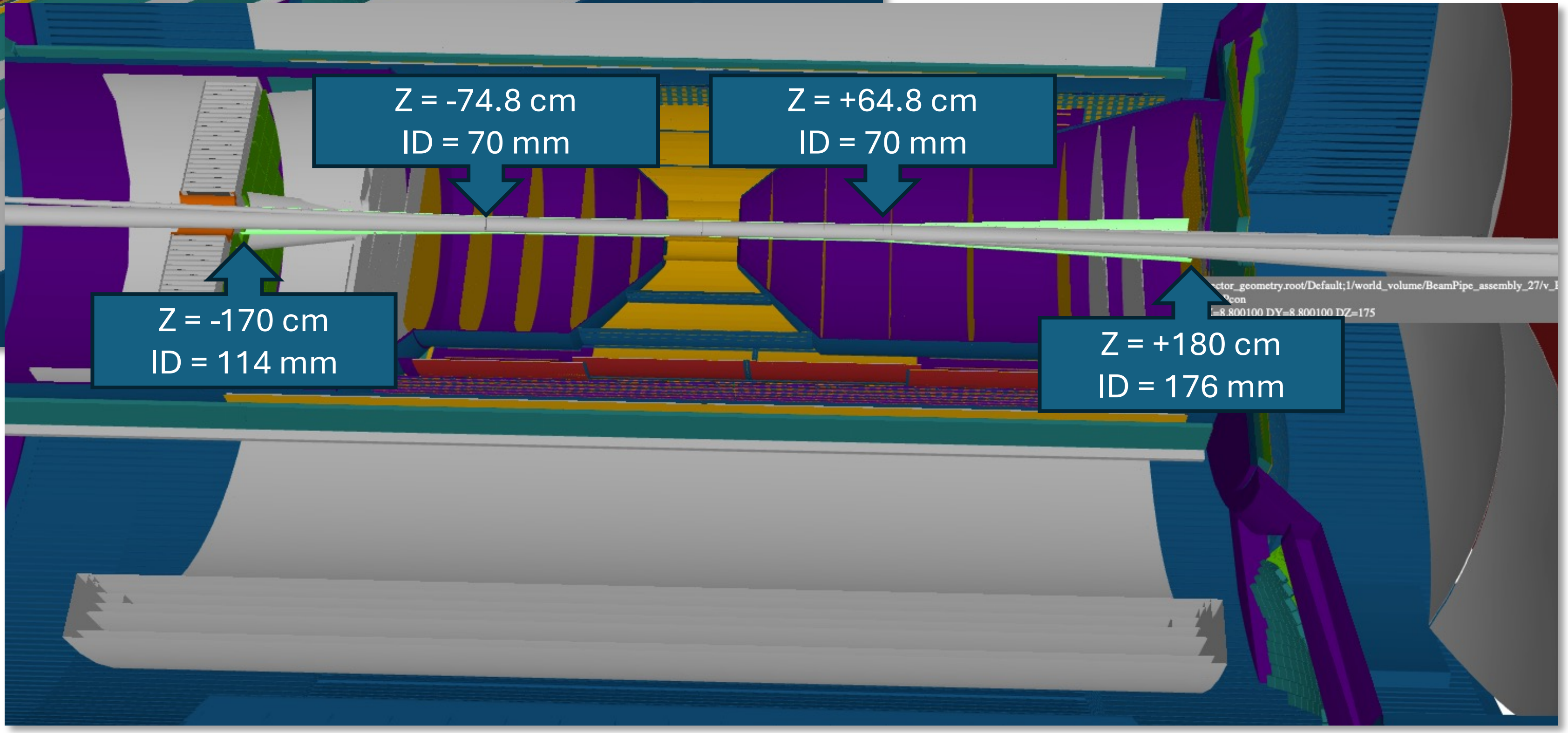
The 1 μm thick virtual pipe does not overlap with the current (main-2025.07.29) ePIC detector elements





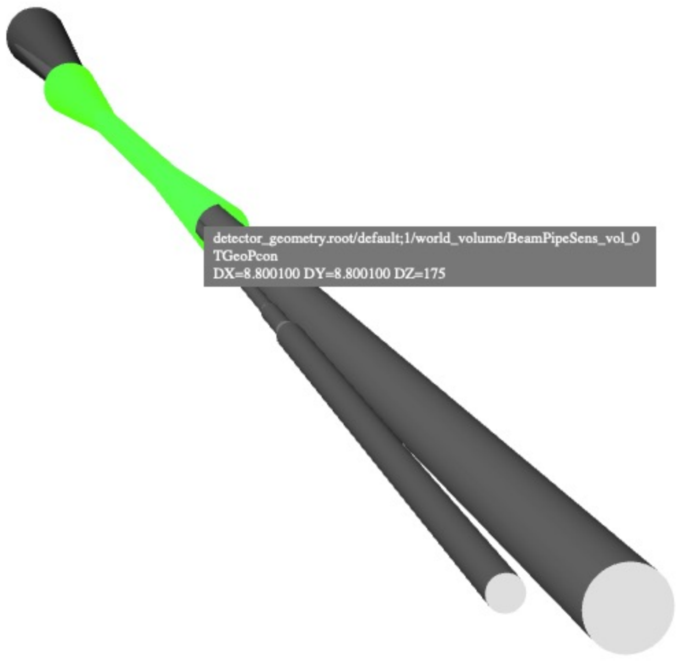
Virtual Pipe Around the Central Beam Pipe (2)



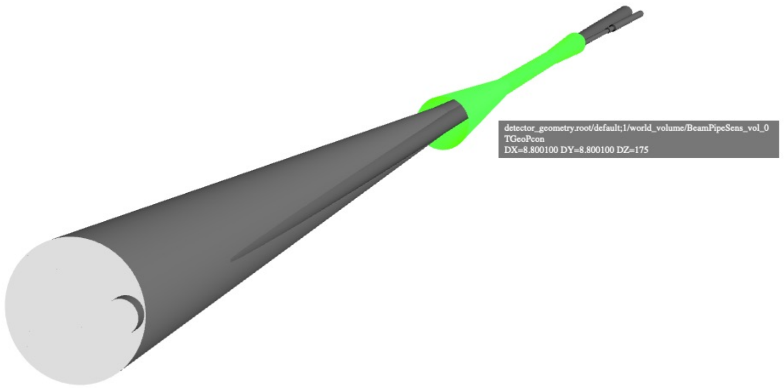


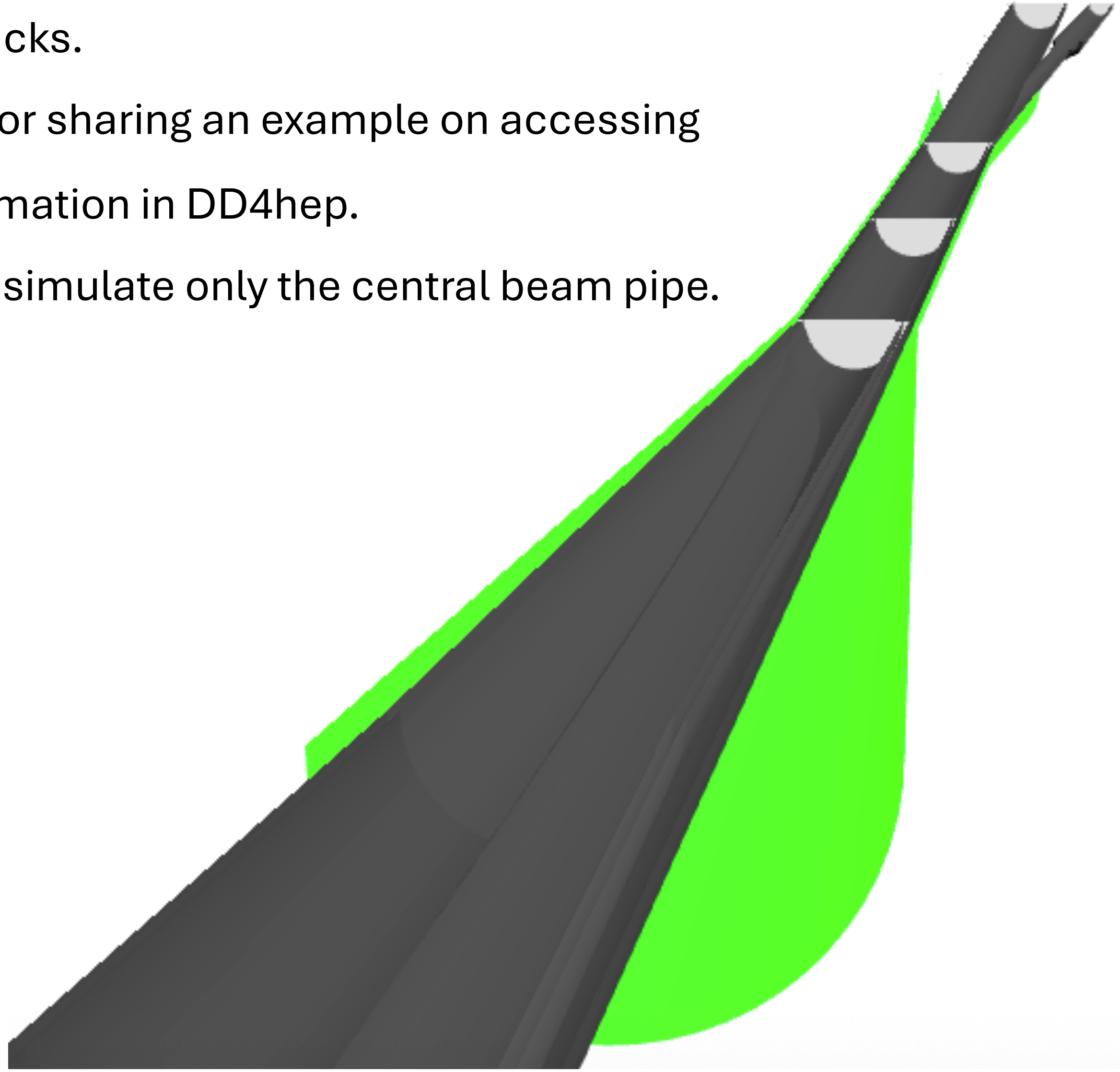
The 1 μm thick virtual pipe does not overlap with the old (tag-25.01.1) ePIC detector elements

Virtual Pipe Around the Central Beam Pipe (3)

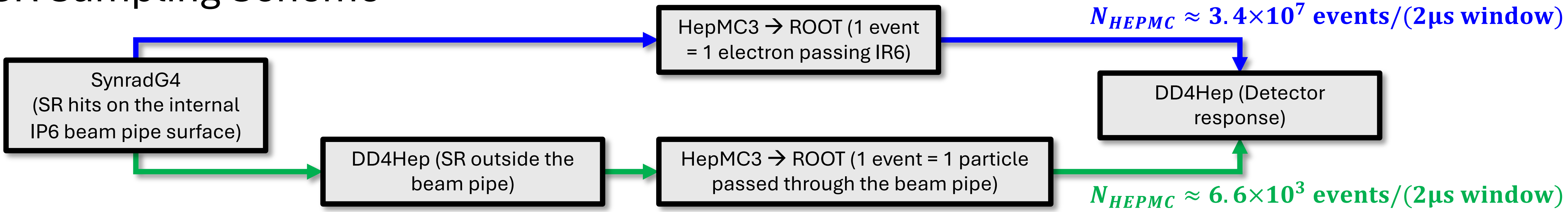


- Collect information on particles entering the virtual volume and terminate their tracks.
    - Thanks to Alex J. for sharing an example on accessing G4 stepping information in DD4hep.
- To reduce CPU usage, simulate only the central beam pipe.

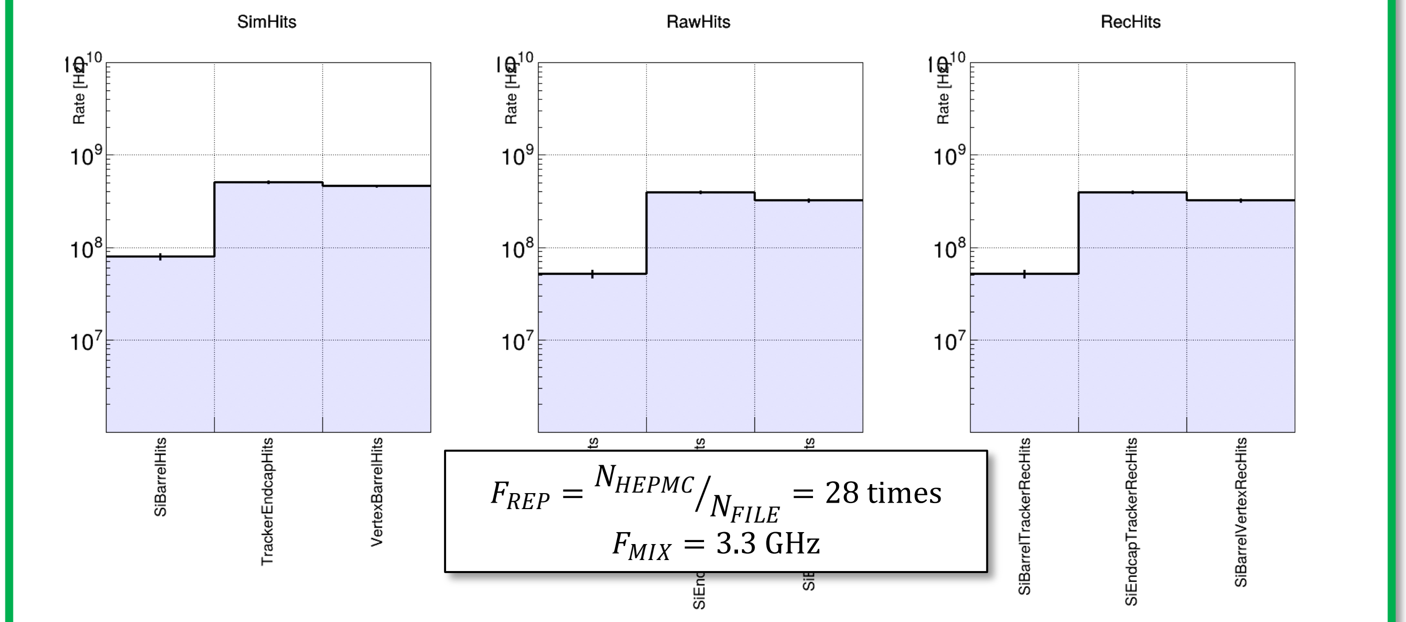




New SR Sampling Scheme



New approach (July 2025)



$$F_{REP} = {N_{HEPMC}}/{N_{FILE}} = 28 \text{ times}$$

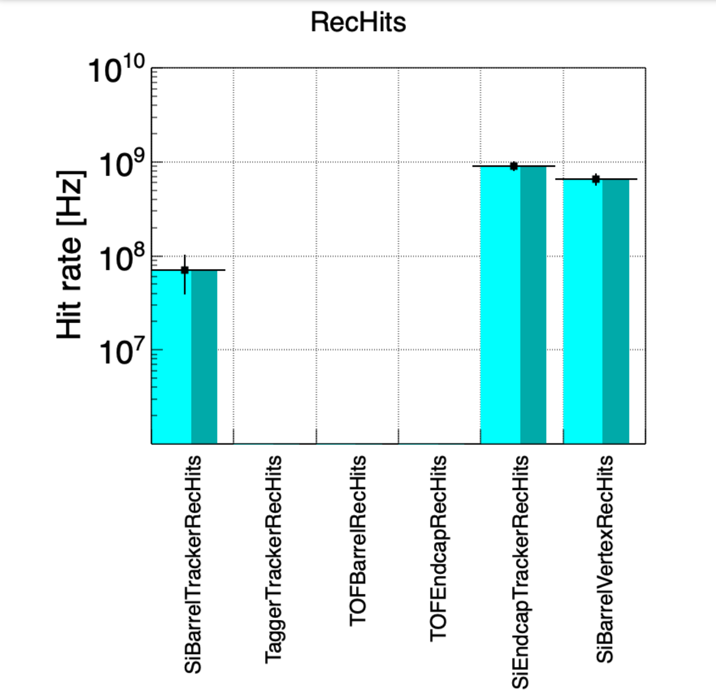
$$F_{MIX} = 3.3 \text{ GHz}$$

same as before

Rate [Hz] = {(# of detector hits) / 2 us}

/gpfs02/eic/anatochii/SynradG4_HepMC_Files_SR_on_IP6/data/synrad/dataprod_rel_1.0.0/18x275/dataprod_rel_1.0.0_synrad_18x275_run001.**preproc_28repeats**.hepmc3.tree.root

Previous results (January 2025)



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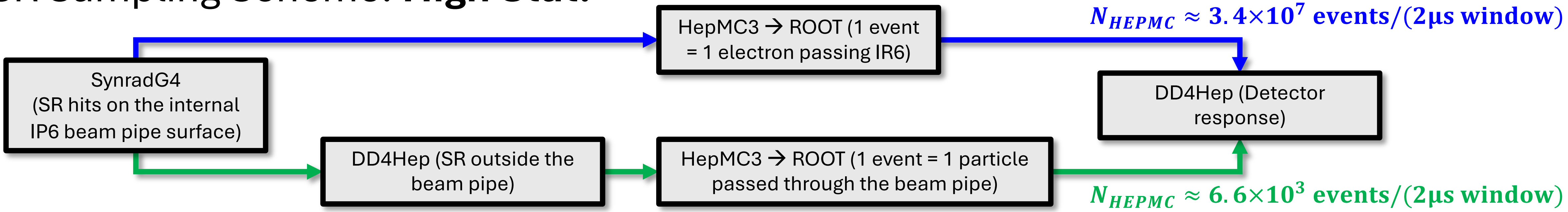
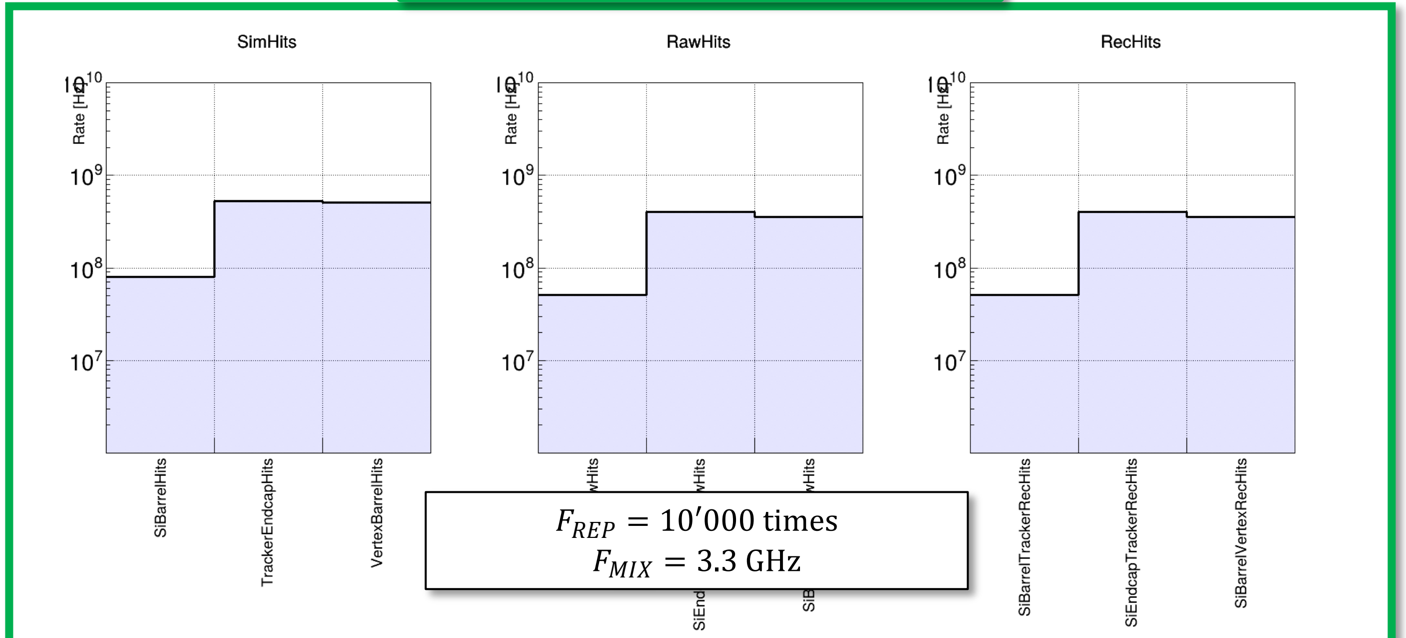
New SR Sampling Scheme: **High Stat.**



New approach (July 2025)

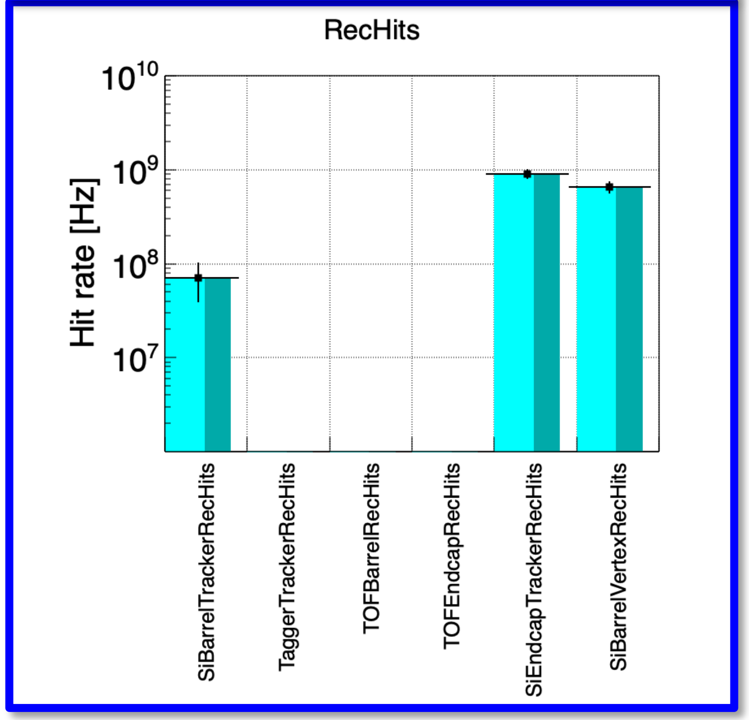


same as before

Rate [Hz] = {(# of detector hits) / 2 us} * **28/10000**

/gpfs02/eic/anatochii/SynradG4_HepMC_Files_SR_on_IP6/data/synrad/dataprod_rel_1.0.0/18x275/dataprod_rel_1.0.0_synrad_18x275_run001.**preproc_10000repeats**.hepmc3.tree.root

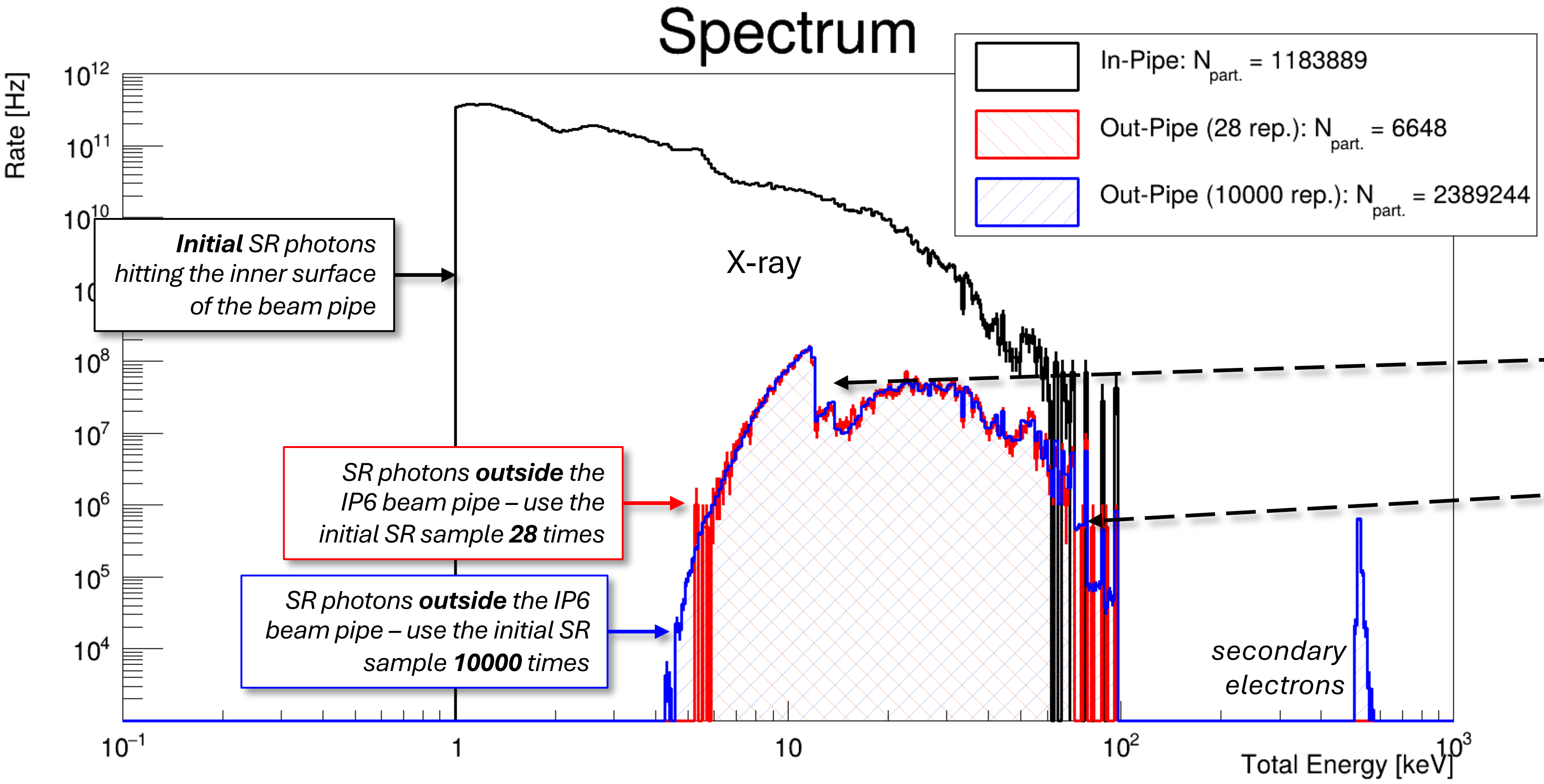
Previous results (January 2025)



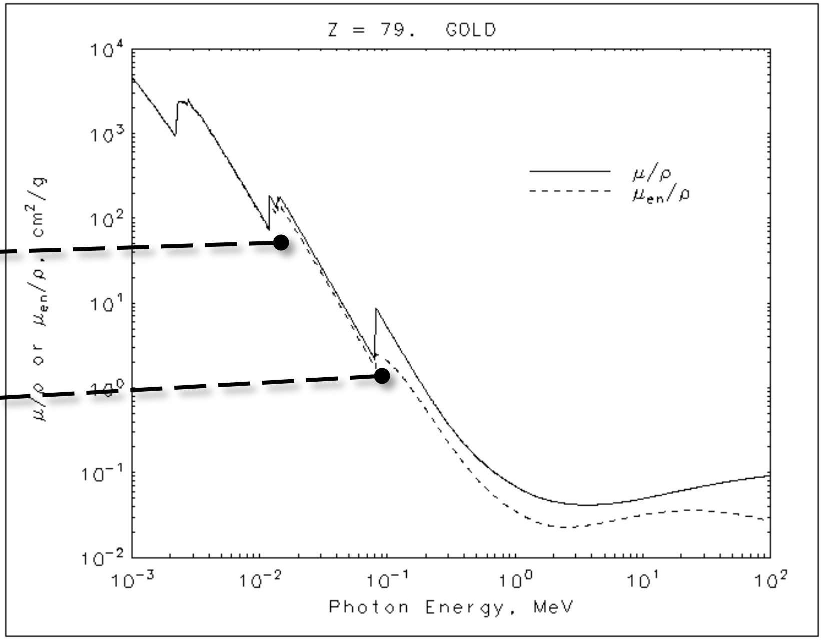
/gpfs02/eic/anatochii/SynradG4_HepMC_Files_SR_on_IP6/data/synrad/dataprod_rel_1.0.0/18x275/dataprod_rel_1.0.0_synrad_18x275_run001.hepmc3.tree.root

Statistics

- Increasing the number of repetitions from 28 to 10000 extends the variation of particles (~6.6k → 2.4M) outside the IP6 beam pipe, preserving the spectrum.
- Gold absorption lines are clearly seen in the spectrum.



X-Ray Mass Attenuation Coefficients



https://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z79.html