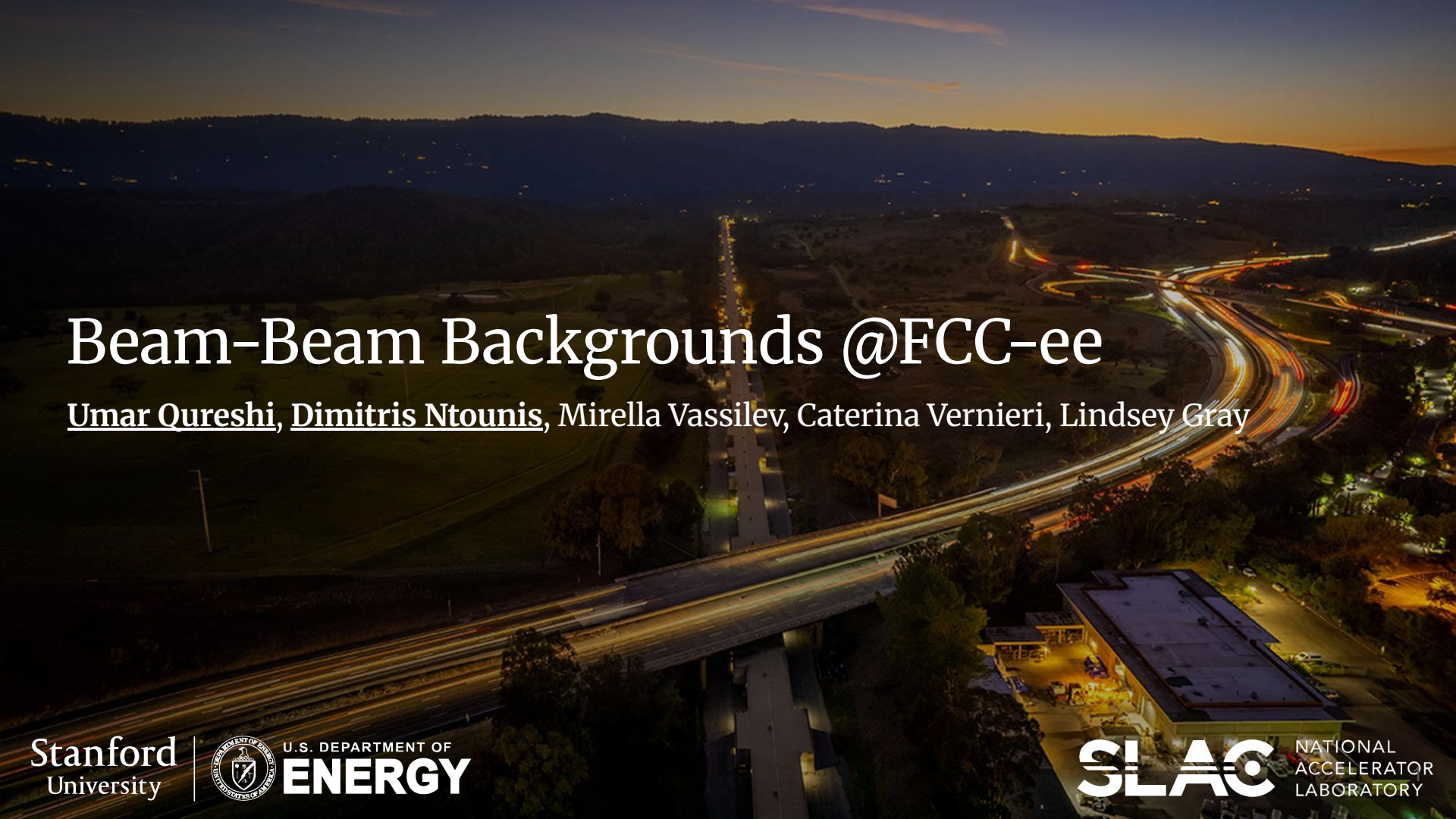


Beam-Beam Backgrounds @FCC-ee

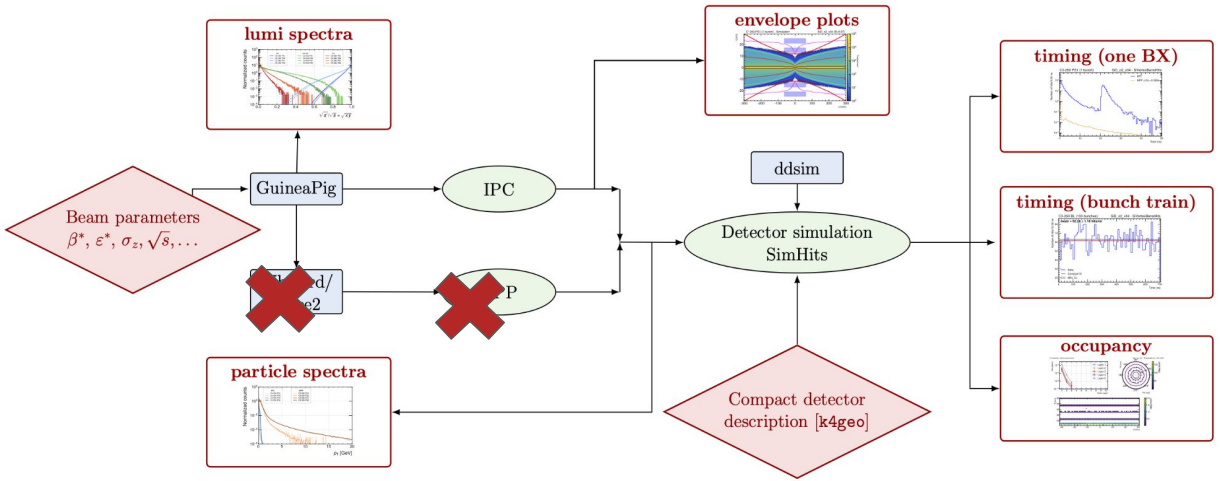
Umar Qureshi, **Dimitris Ntounis**, Mirella Vassilev, Caterina Vernieri, Lindsey Gray

Stanford University | U.S. DEPARTMENT OF ENERGY | SLAC NATIONAL ACCELERATOR LABORATORY

Simulation Workflow

Ongoing efforts with Anna Kinderman, Peter Kicsiny, Spencer Gessner to integrate full ddsim with WarpX

Framework from:
Dimitrios Ntounis et al 2026 JINST 21 P02024



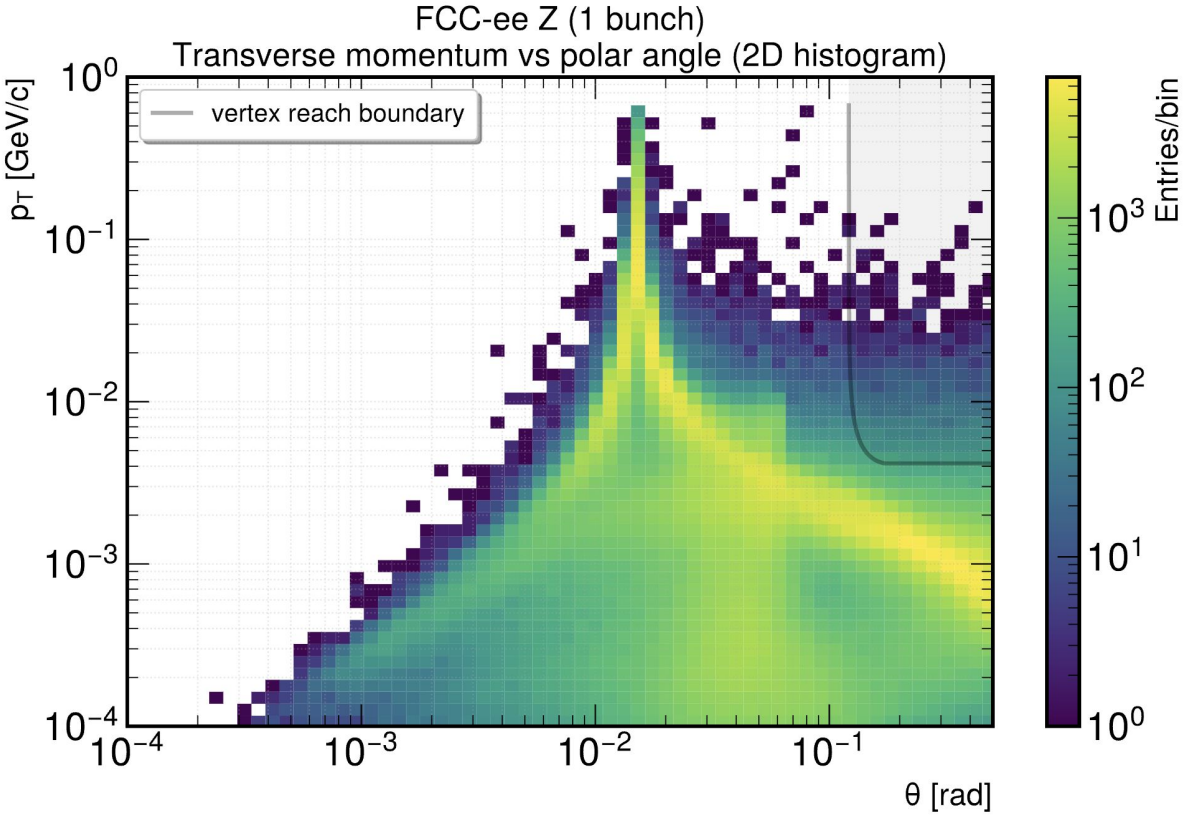
GuineaPig Simulation Setup

```
$ACCELERATOR:: FCCee_ZH_LCC
{
energy=120.0;
particles=20.20;
beta_x=300.0;
beta_y=1.0;
dist_z.1=0;dist_z.2=0;
sigma_x=13860.0;
sigma_y=35.9;
sigma_z=6000.0;
offset_x=0.0;
offset_y=0.0;
n_b=1;
f_rep=1;
angle_x=-0.015;
charge_sign=-1;
}
```

```
$ACCELERATOR::FCCee_Top
{
energy=182.5;
particles=23.7;
beta_x=1000;
beta_y=1.6;
offset_x=0.;
offset_y=0.;
sigma_x=38260.;
sigma_y=69.;
sigma_z=2740.;
charge_sign=-1;
angle_x=-0.015;
}
```

Move to the ZH and ttbar operation params.

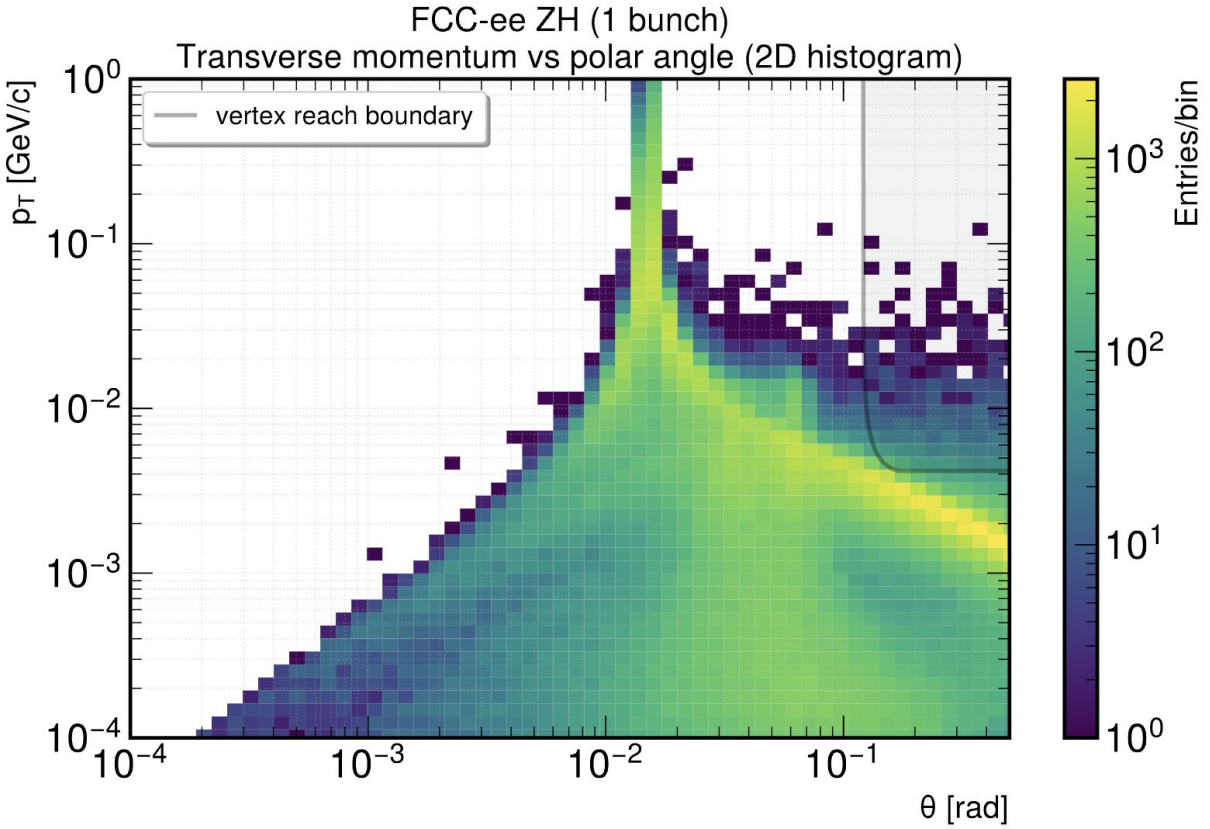
IPP Production - Z Pole



Deflection ridge parameterized as:

$$p_{\mathrm{T}} = 0.00071 \cdot \theta^{-0.59}$$

IPP Production - ZH

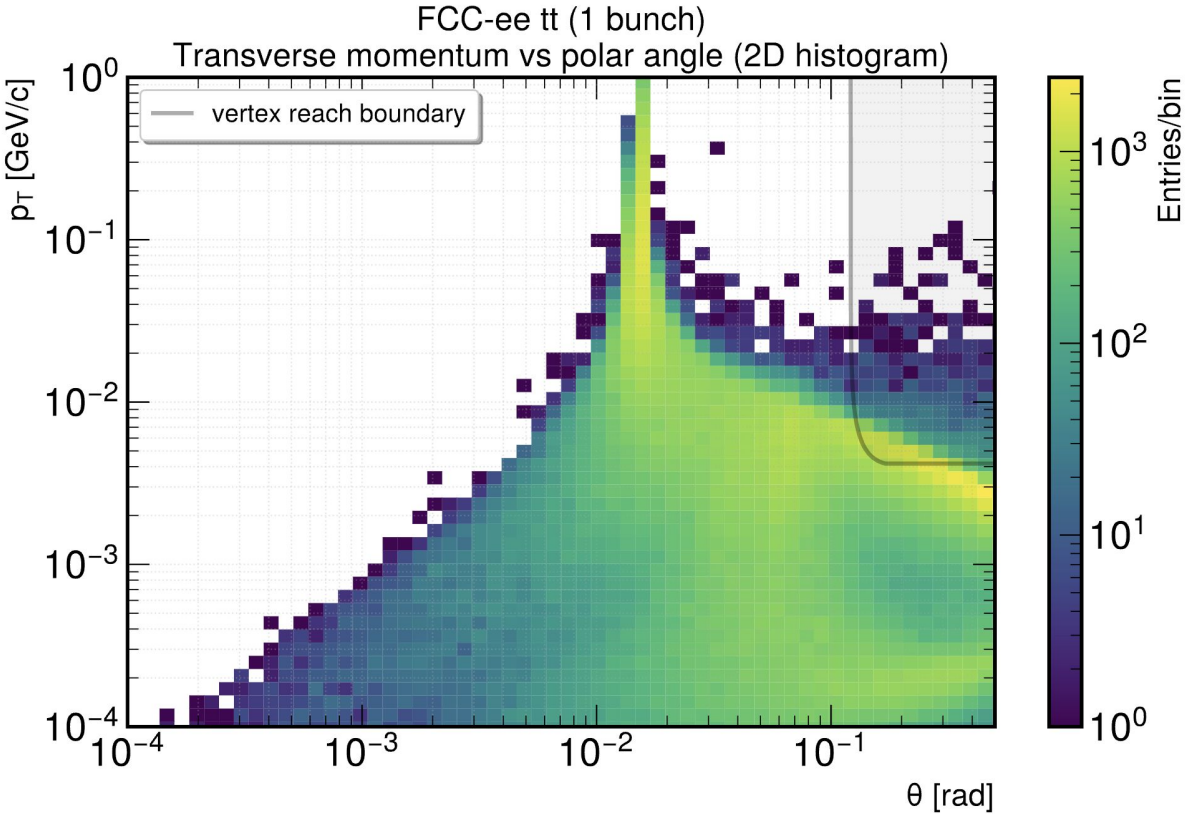


Deflection ridge parameterized as:

$$p_{\mathrm{T}} = 0.00092 \cdot \theta^{-0.74}$$

Significantly harder spectrum than Z-pole, as expected.

IPP Production - ttbar



Deflection ridge parameterized as:

$$p_{\mathrm{T}} = 0.0021 \cdot \theta^{-0.36}$$

Significantly harder spectrum than ZH-pole, even.

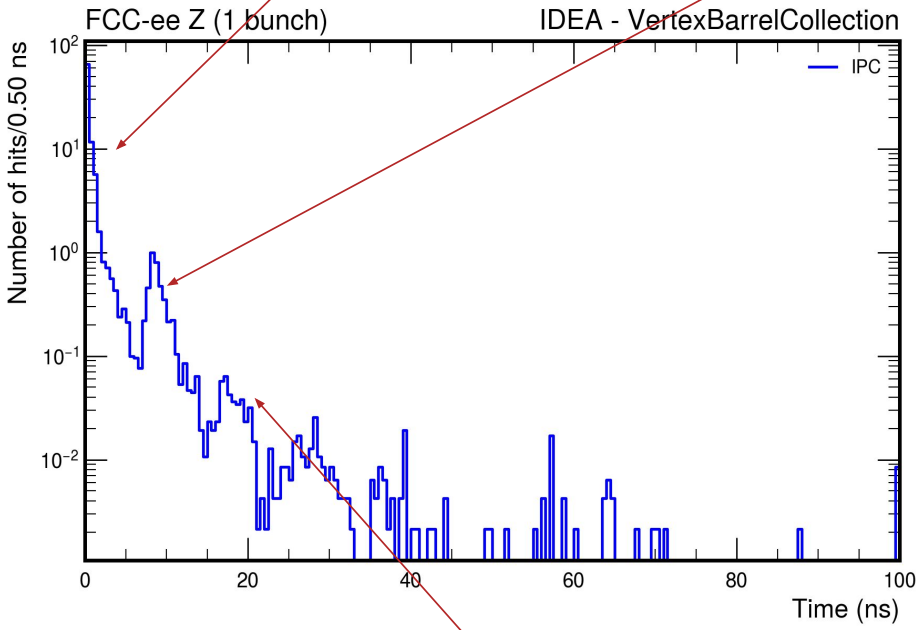
Detector Simulation

- Run Geant4-based full ddsim using the Key4Hep software stack.
- We select the IDEA/**CLD** detector geometry.
  - IDEA_o1_v03 from Key4Geo
  - **CLD_o4_v05 from Key4Geo**
- Crossing angle boost = 15mrad
- Using ~1000 (Z) ~100 (ZH+ttbar) seeds for this talk.

Timing Distribution Z Within a BX (VXD Barrel)

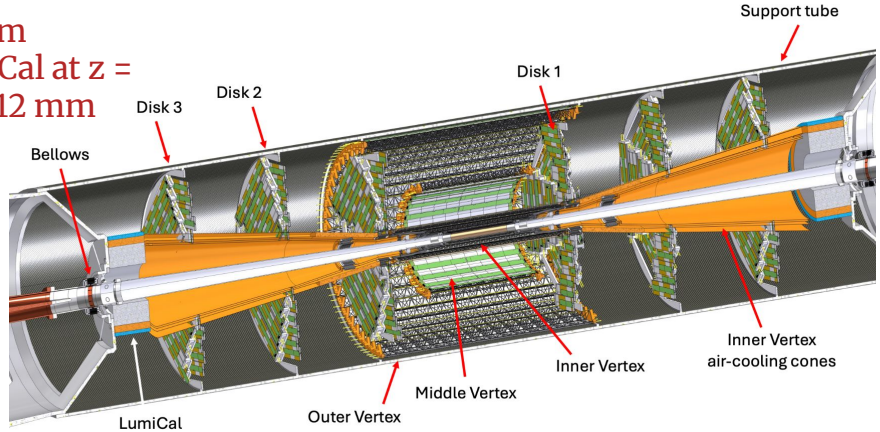
Virtually all hits contained in time within the bunch spacing.

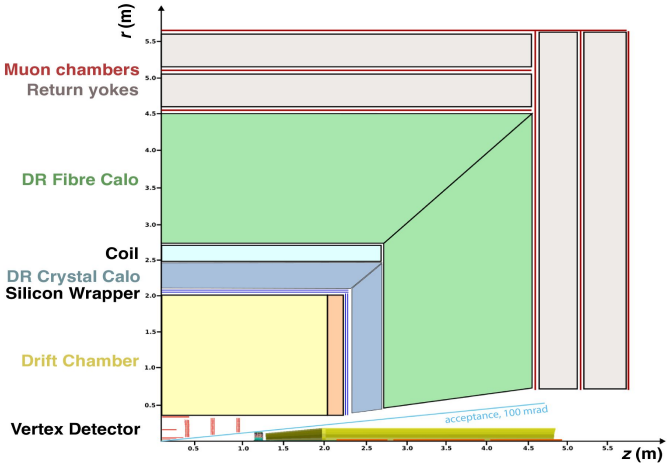
Secondary peak (~10 ns) from back-scattering off of LumiCal at z = 1074–1187 mm and r = 55–112 mm



Bunch spacing ~ 19.6ns

Peak (17 ns) from back-scattering off of Preshower/Solenoid

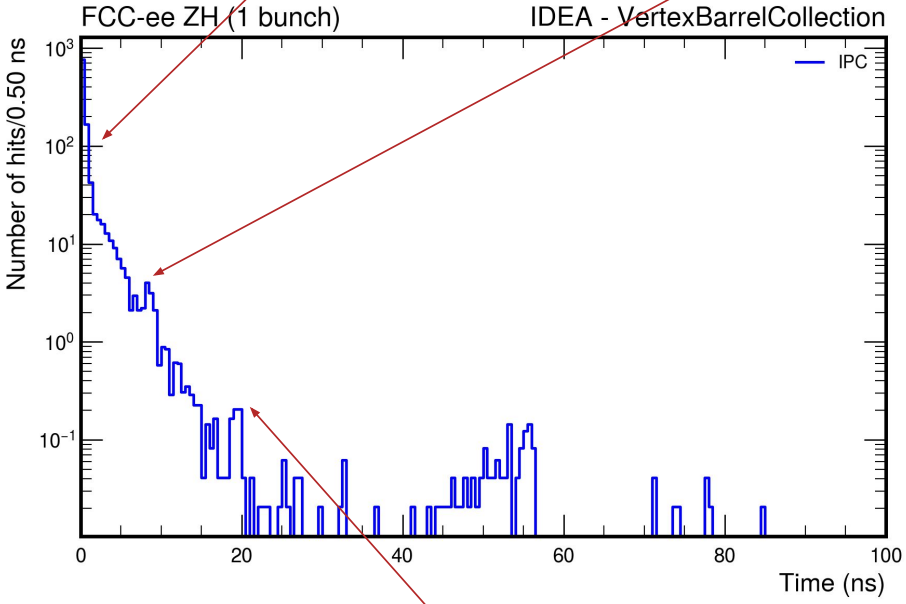




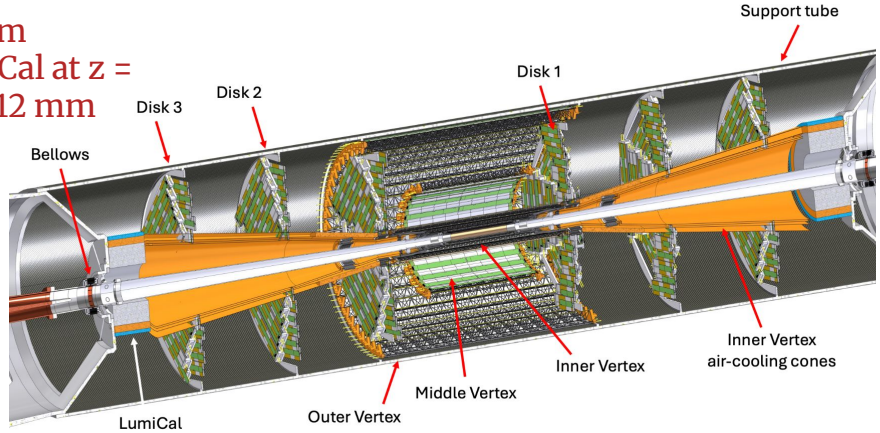
Timing Distribution ZH Within a BX (VXD Barrel)

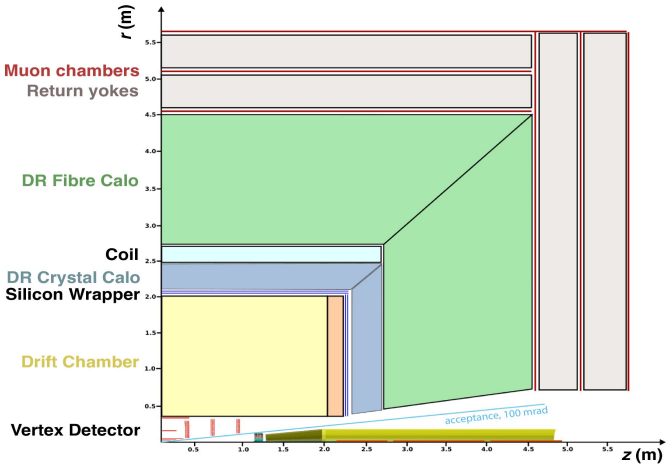
All hits contained in time within the bunch spacing.

Secondary peak (~10 ns) from back-scattering off of LumiCal at z = 1074–1187 mm and r = 55–112 mm



Peak (17 ns) from back-scattering off of Preshower/Solenoid

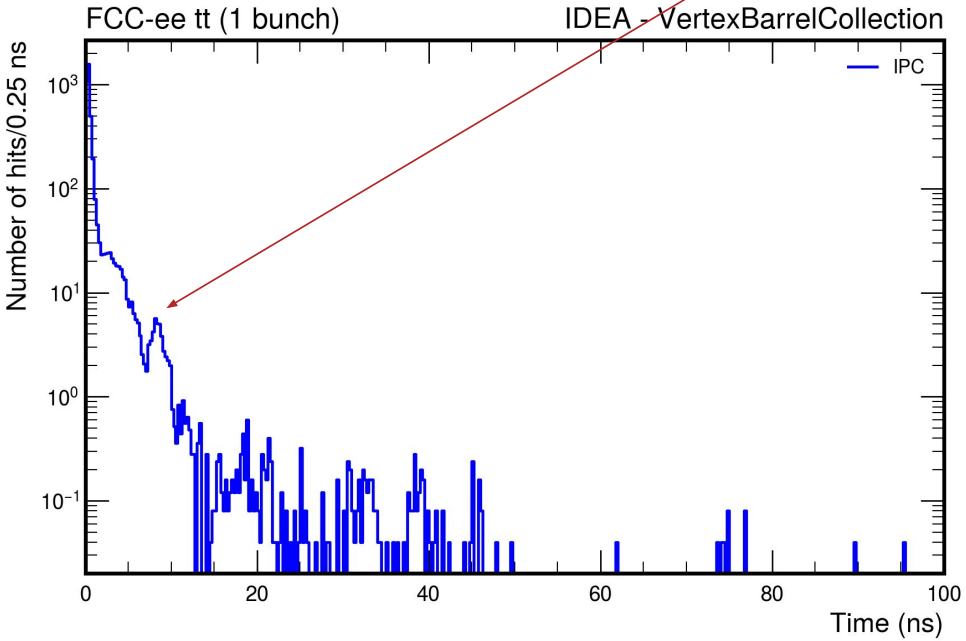


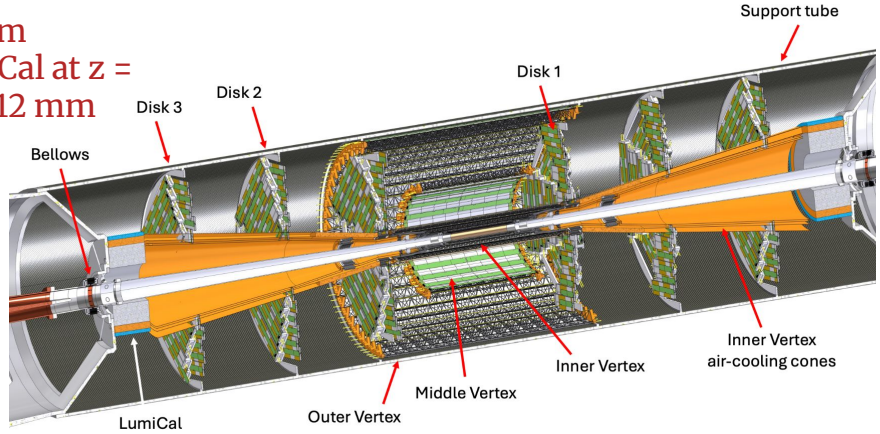


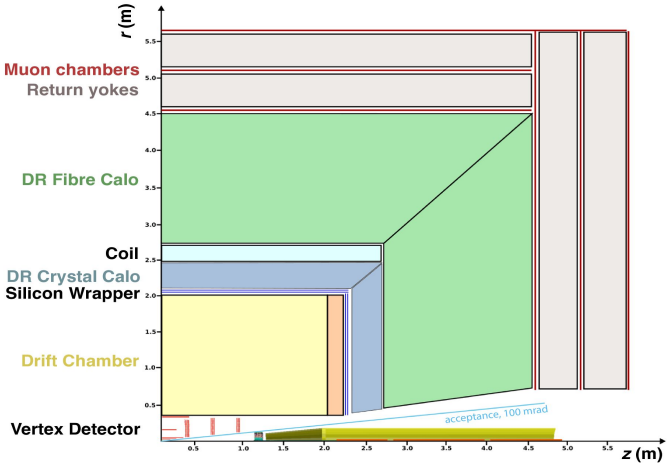
Timing Distribution ttbar Within a BX (VXD Barrel)

All hits contained in time within the bunch spacing.

Secondary peak (~10 ns) from back-scattering off of LumiCal at z = 1074–1187 mm and r = 55–112 mm



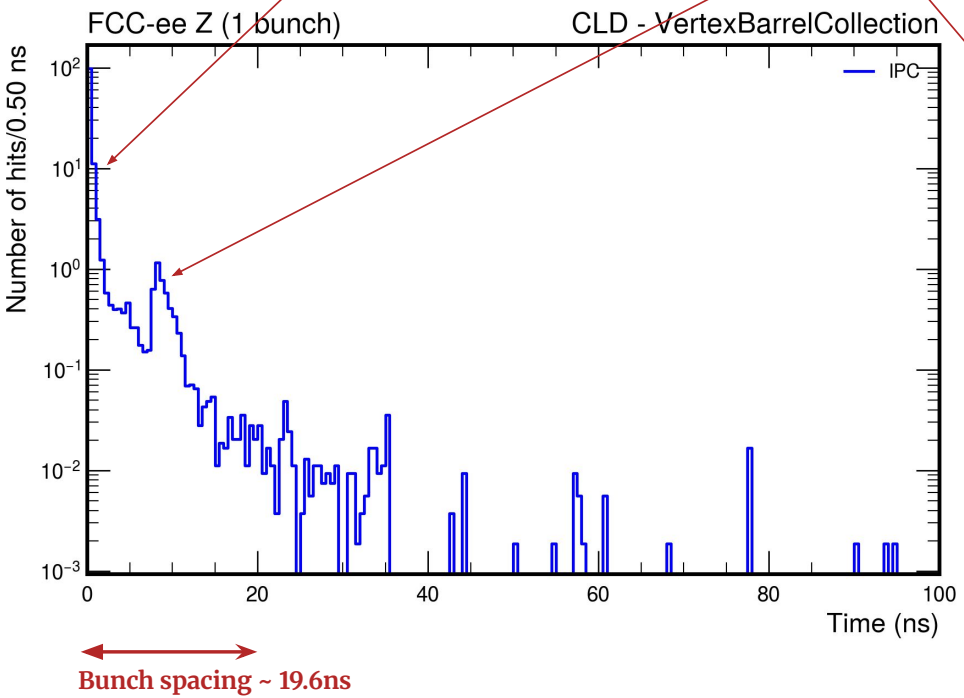




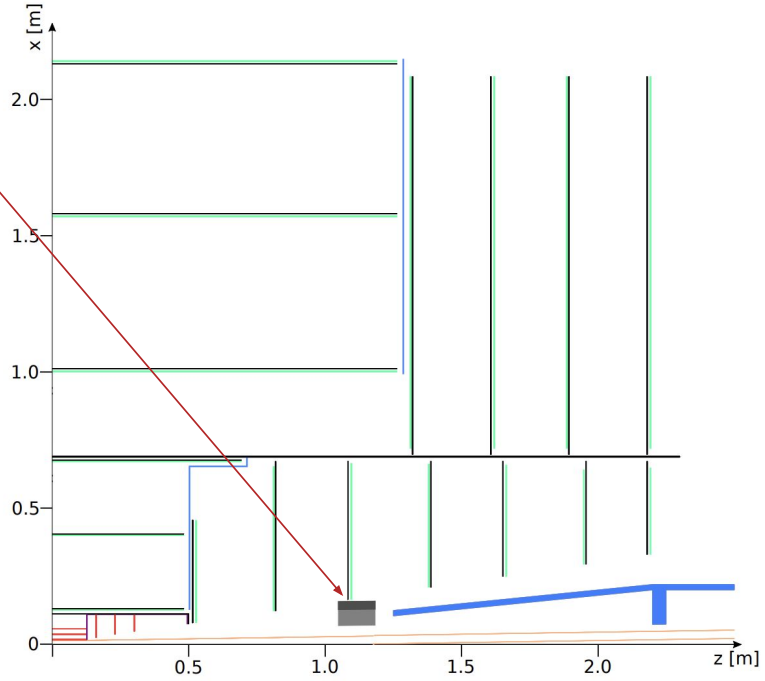
Timing CLD Z Within a BX (VXD Barrel)

Virtually all hits contained in time within the bunch spacing.

Secondary peak (~7-8 ns) from back-scattering off of LumiCal



Bunch spacing ~ 19.6ns



Layer Occupancy

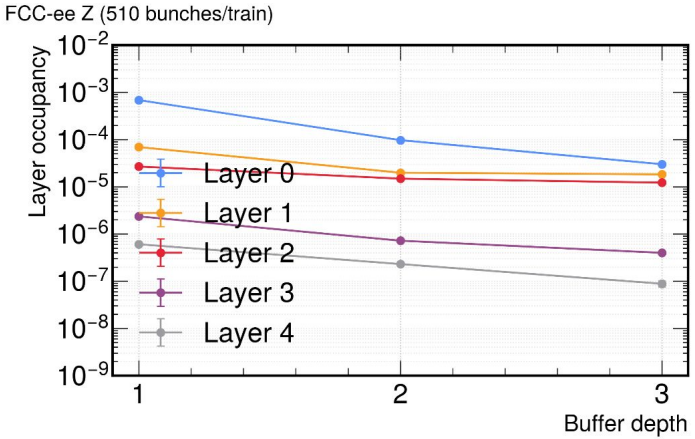
We define the layer occupancy as:

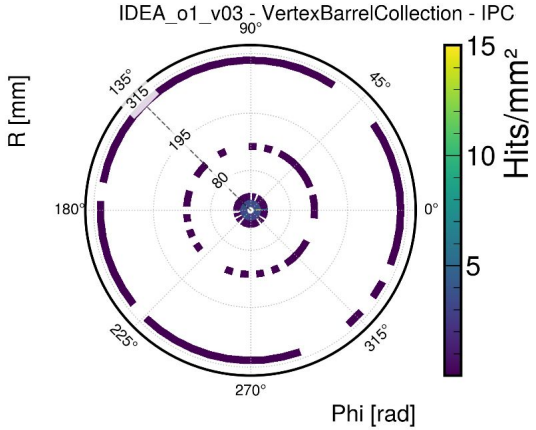
$$\text{layer occupancy}(\ell_D, \text{BD}) = S_D \cdot C_D \cdot \frac{\#\text{ of cells in } \ell_D \text{ with } \geq \text{BD hits}}{\#\text{ of cells in } \ell_D}$$

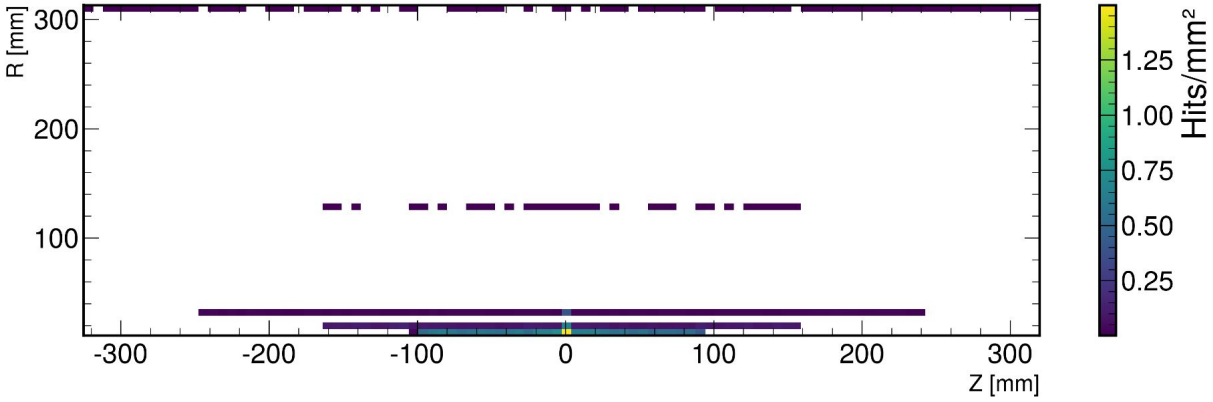
- l_D is the detector layer under consideration.
- BD is the buffer depth.
  - Max number of hits that can be stored.
- S_D, C_D, are the safety and and cluster size factors:
  - S_D set to 2.
  - C_D set to 3 for VXD, 2 otherwise.

Characterizes the fraction of "dead" cells that receive a number of hits exceeding their buffer depth after an entire bunch train.

Layer Occupancy (VXD Barrel) - Z Pole

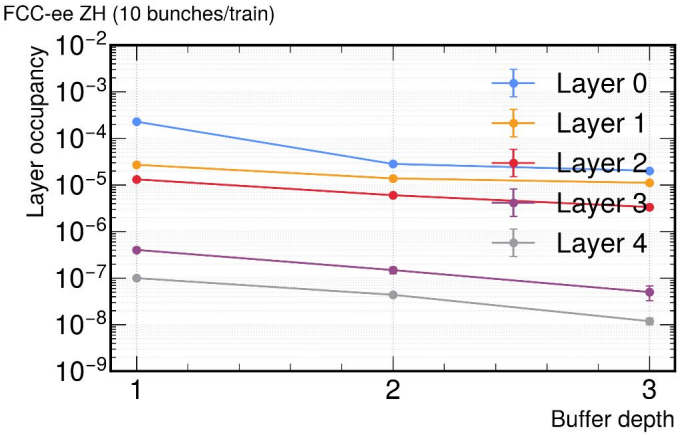


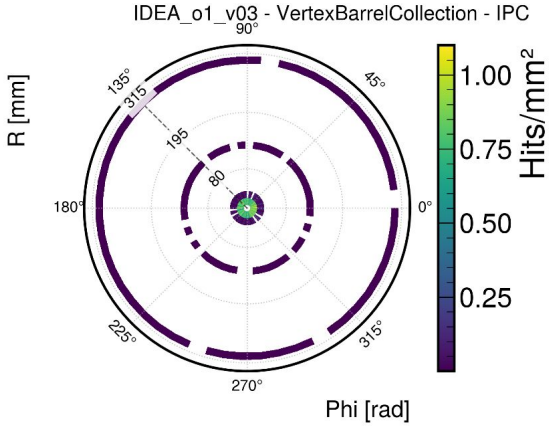


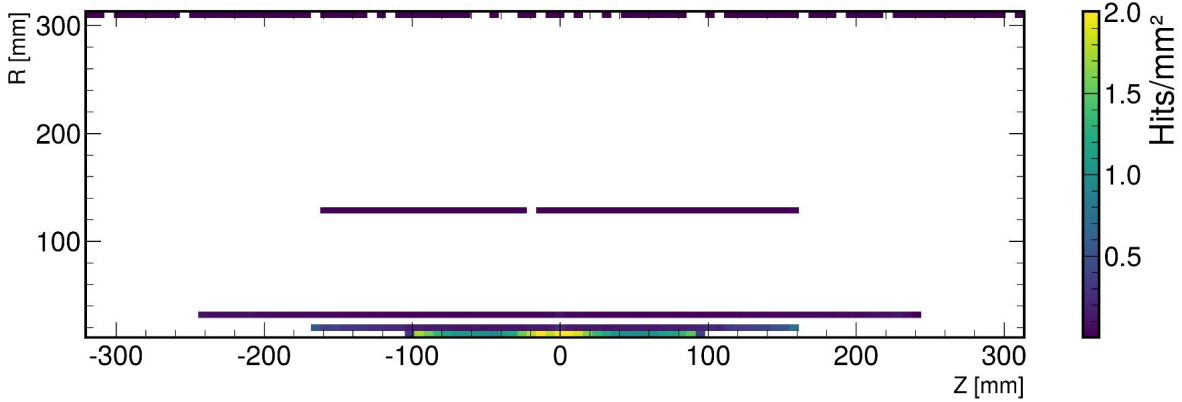


- Integrated over 510 bunches:
  - 10 µs readout window
- Fairly low occupancy environment.
- Below general recommendations at $O(10^{-4})$-$O(10^{-3})$.

Layer Occupancy (VXD Barrel) - ZH

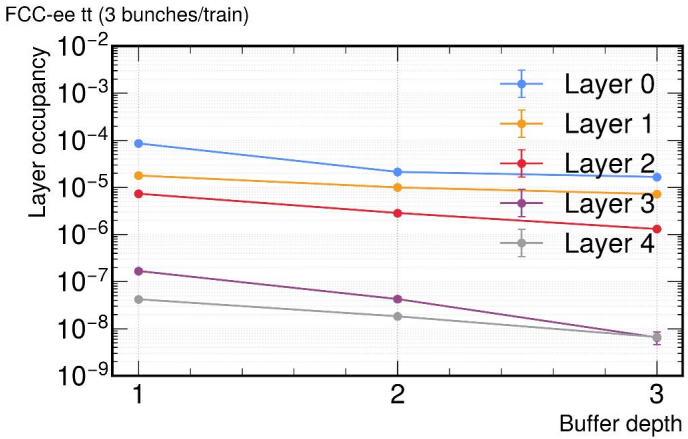


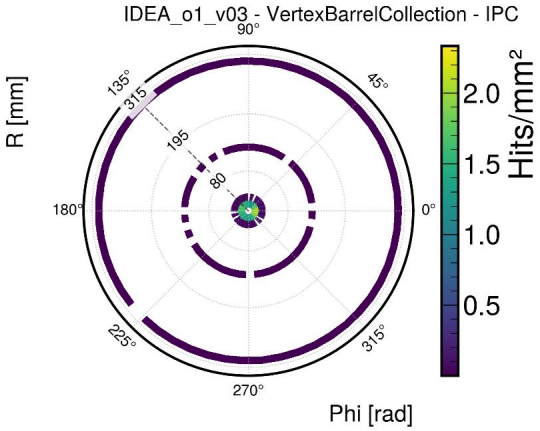


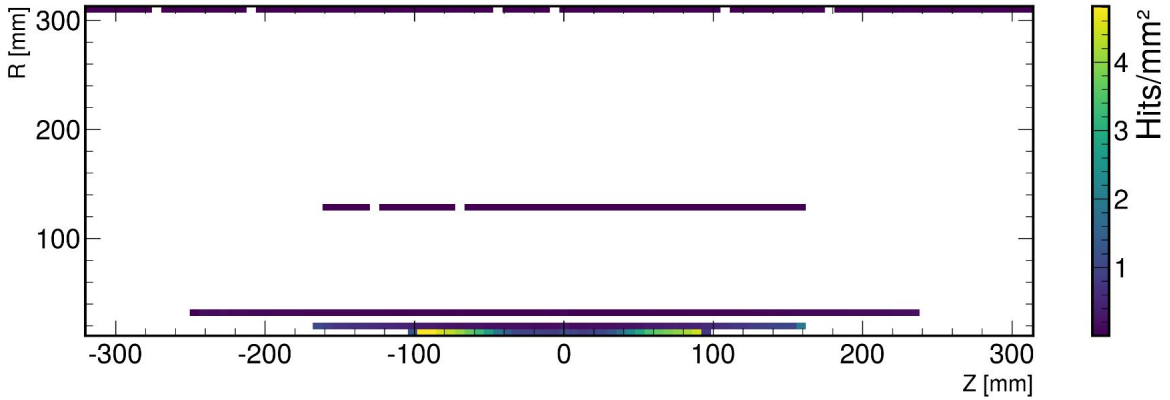


- Integrated over 10 bunches:
  - 10 µs readout window
- Fairly low occupancy environment.
- Below general recommendations at $O(10^{-4})$-$O(10^{-3})$.
- Even lower than Z operation due to 50x lower bx/readout window.

Layer Occupancy (VXD Barrel) - ttbar







- Integrated over 3 bunches:
  - 10 μs readout window
- Fairly low occupancy environment.
- Below general recommendations at $O(10^{-4})$-$O(10^{-3})$.
- Even lower than ZH operation due to ~3x lower bx/readout window.
- More forward than Z/ZH from higher boost.
  - Harder spectrum.

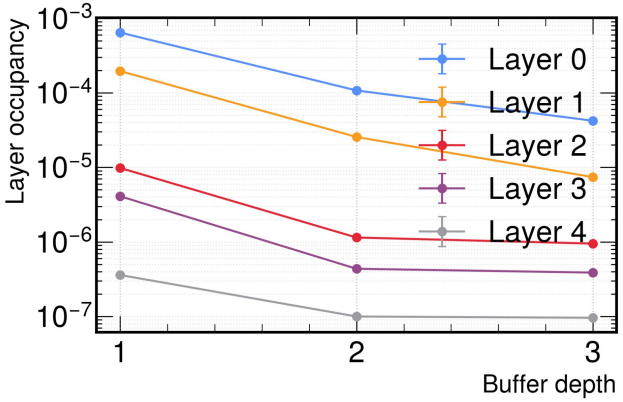
Layer Occupancy (VXD Barrel) - CLD

As with IDEA:

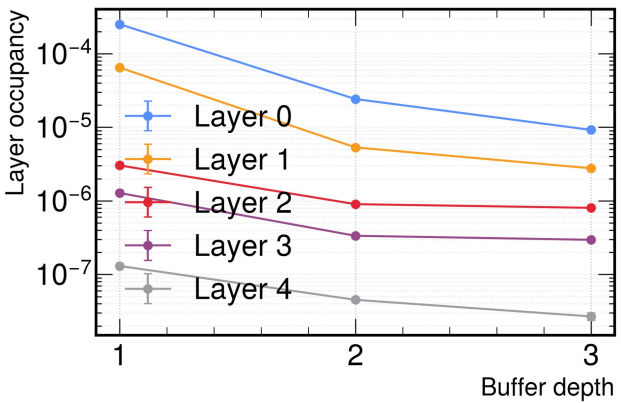
- Low occupancies across the board.
- Decreasing occupancy with higher energy!

- With buffer depth > 1, all occupancies <= O(10^{-4}).

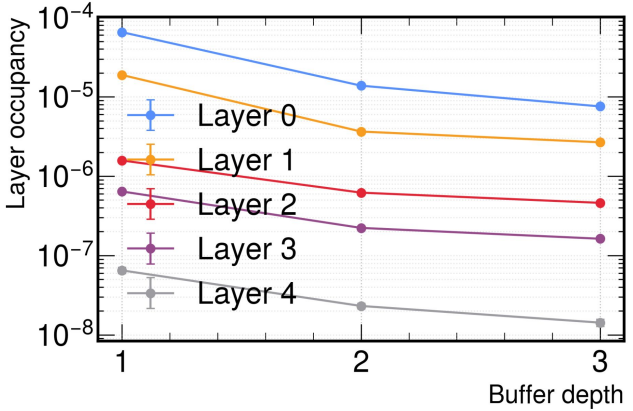
Z-Pole



ZH



ttbar



Next Steps

- FCC-ee occupancy targets $O(10^{-3})$ appear less stringent than LC $O(10^{-4})$
  - Investigate tracking performance as a function of occupancy.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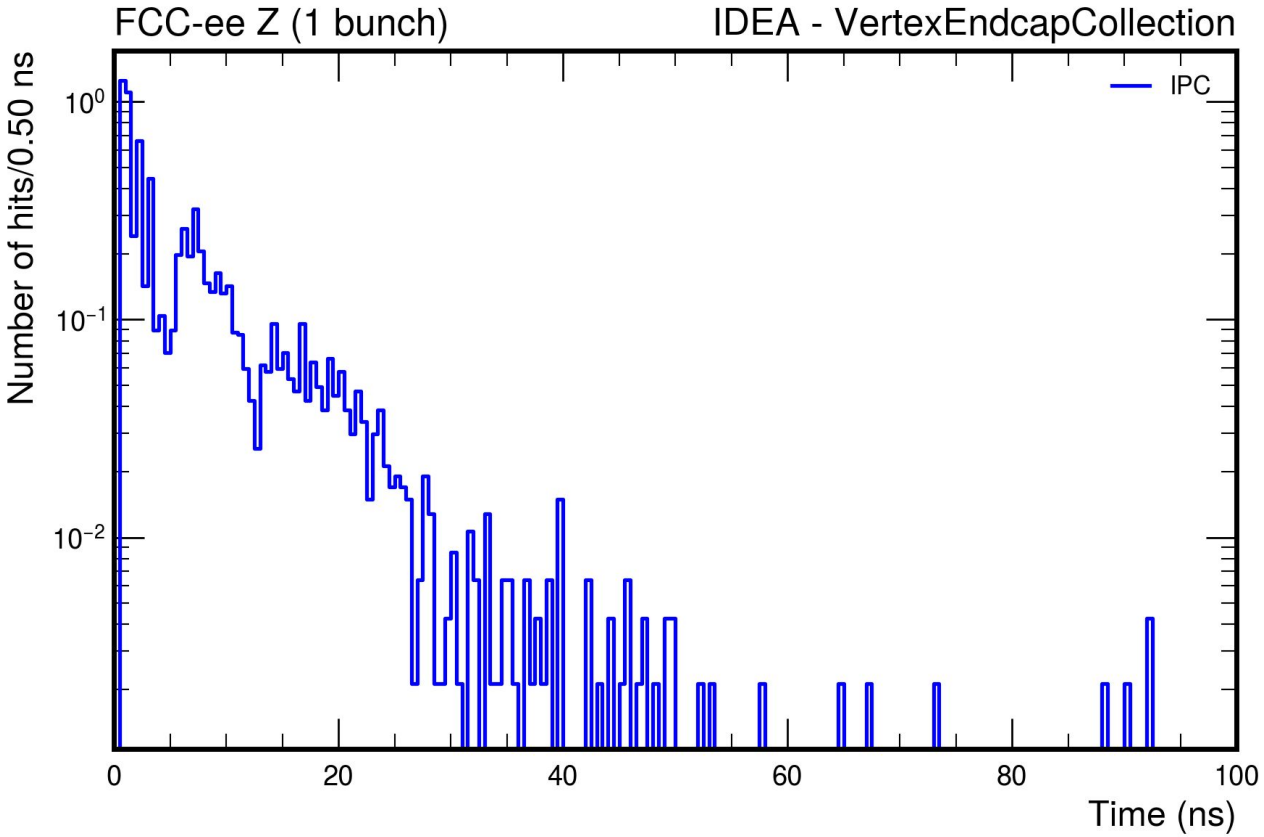
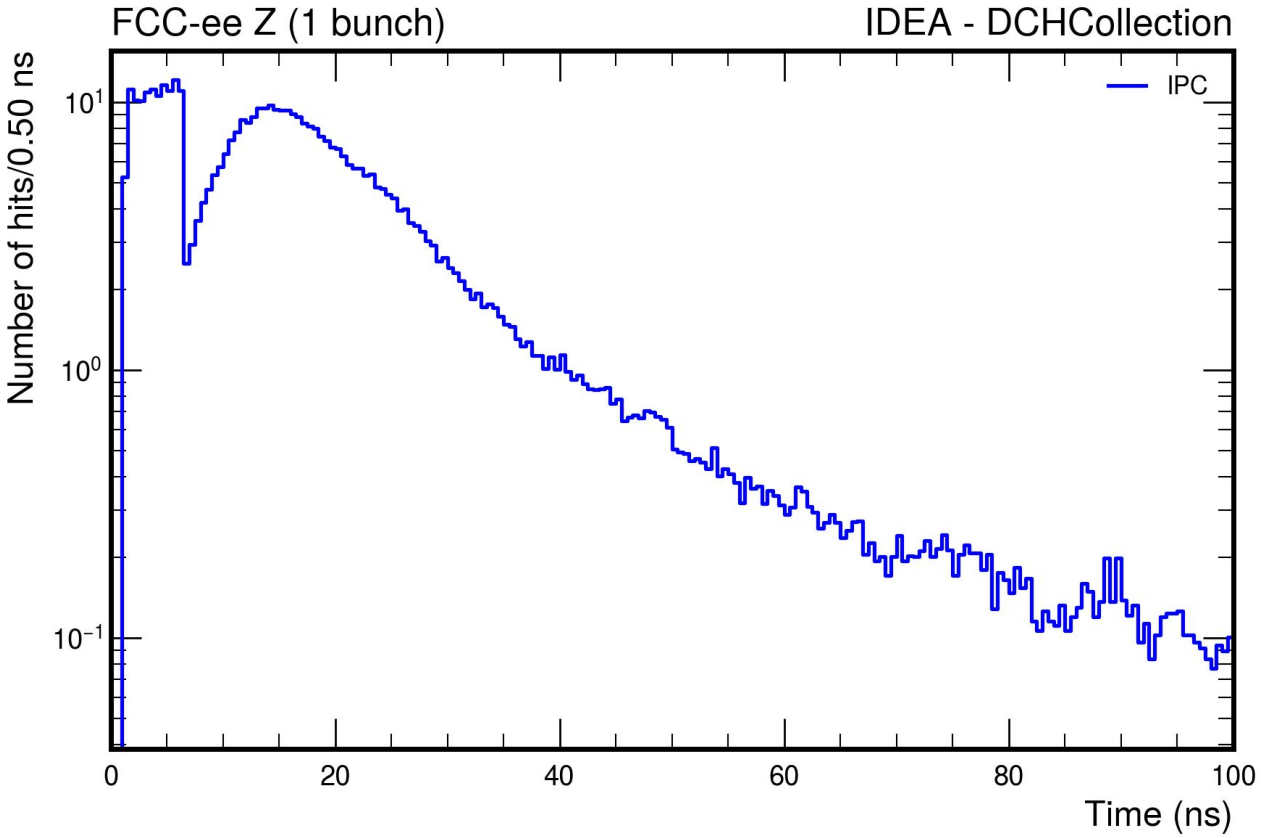
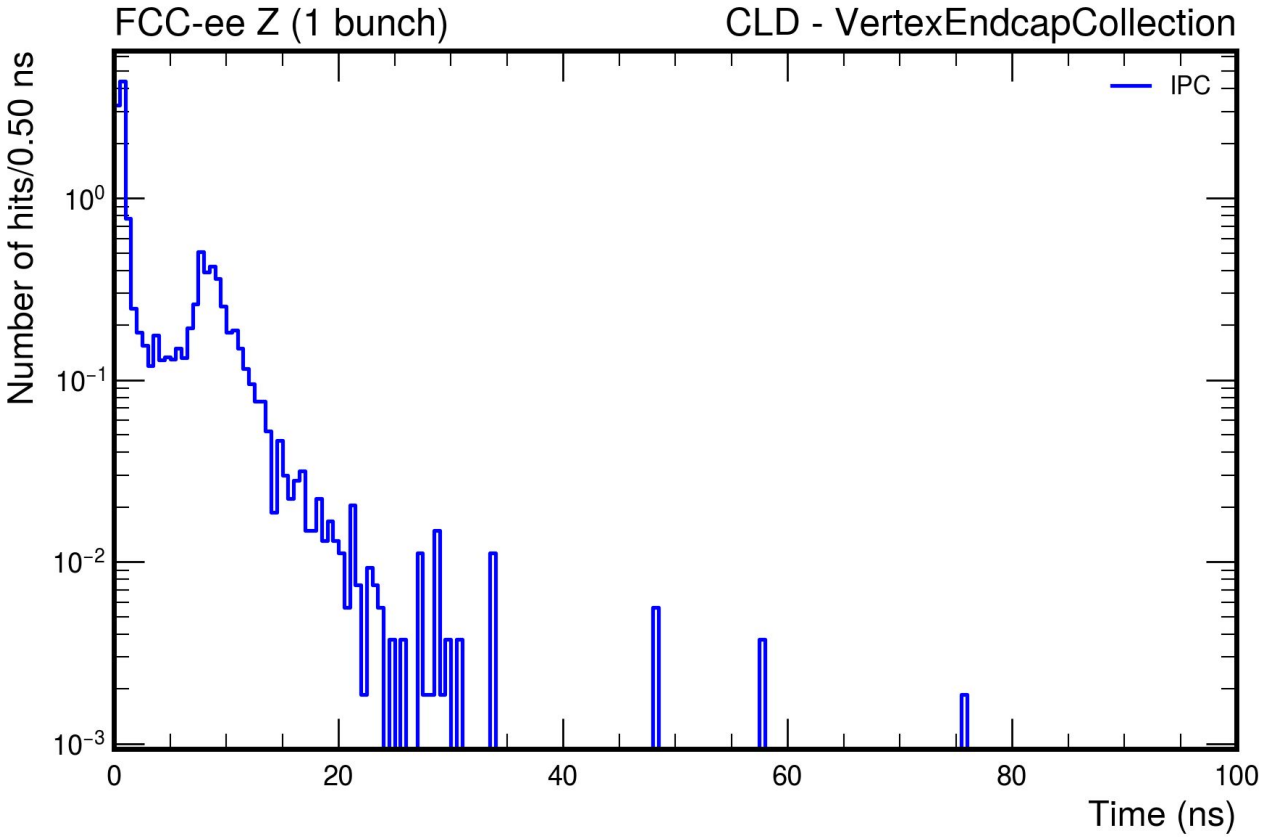
Timing IDEA Z (VXD Endcap)



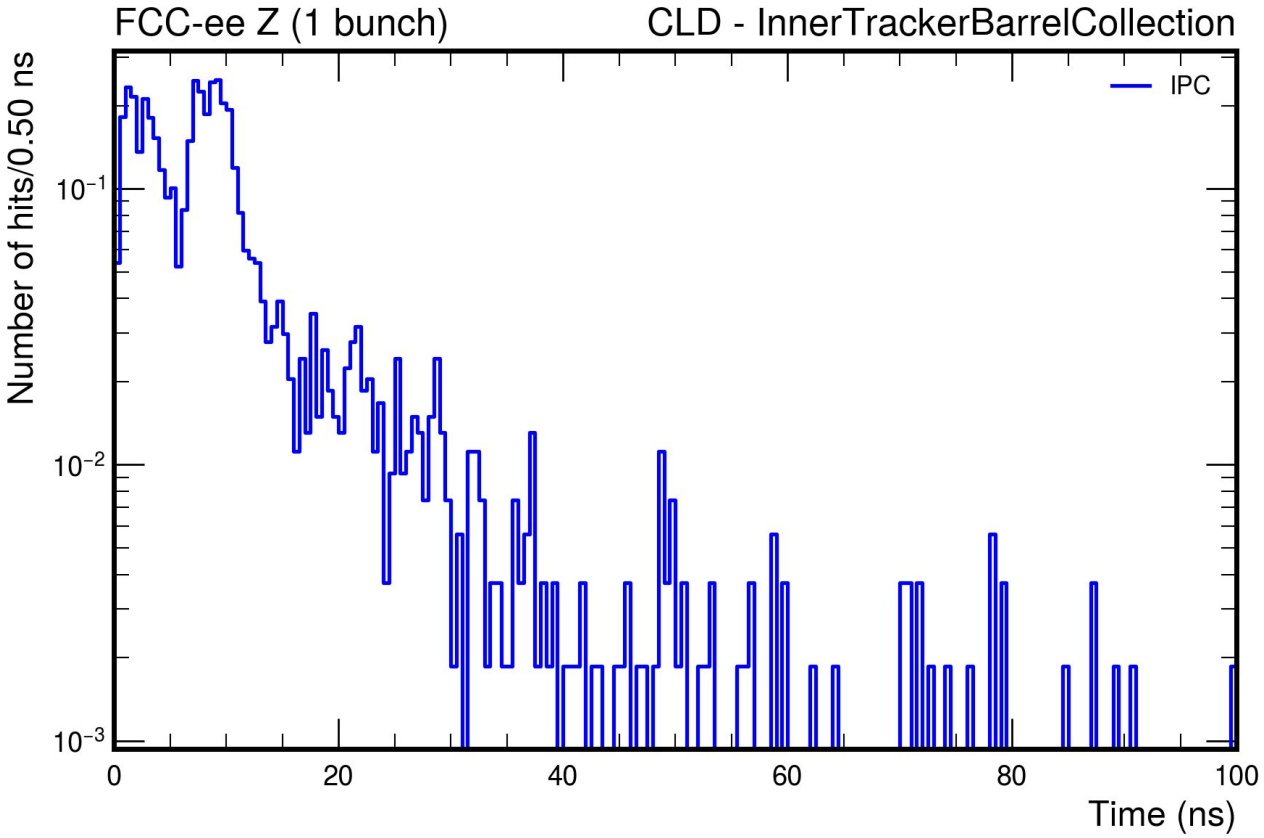
Timing IDEA Z (Drift Chamber)



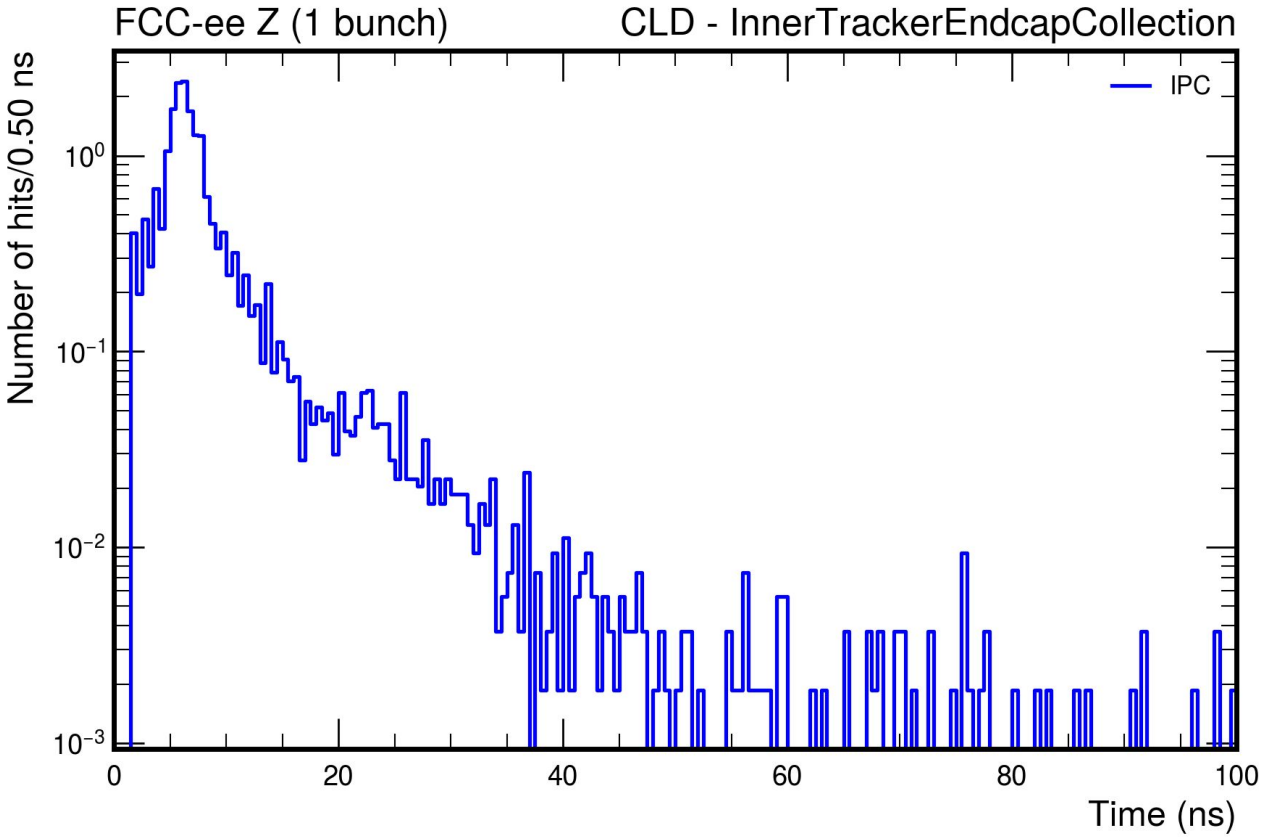
Timing CLD Z (VXD Endcap)



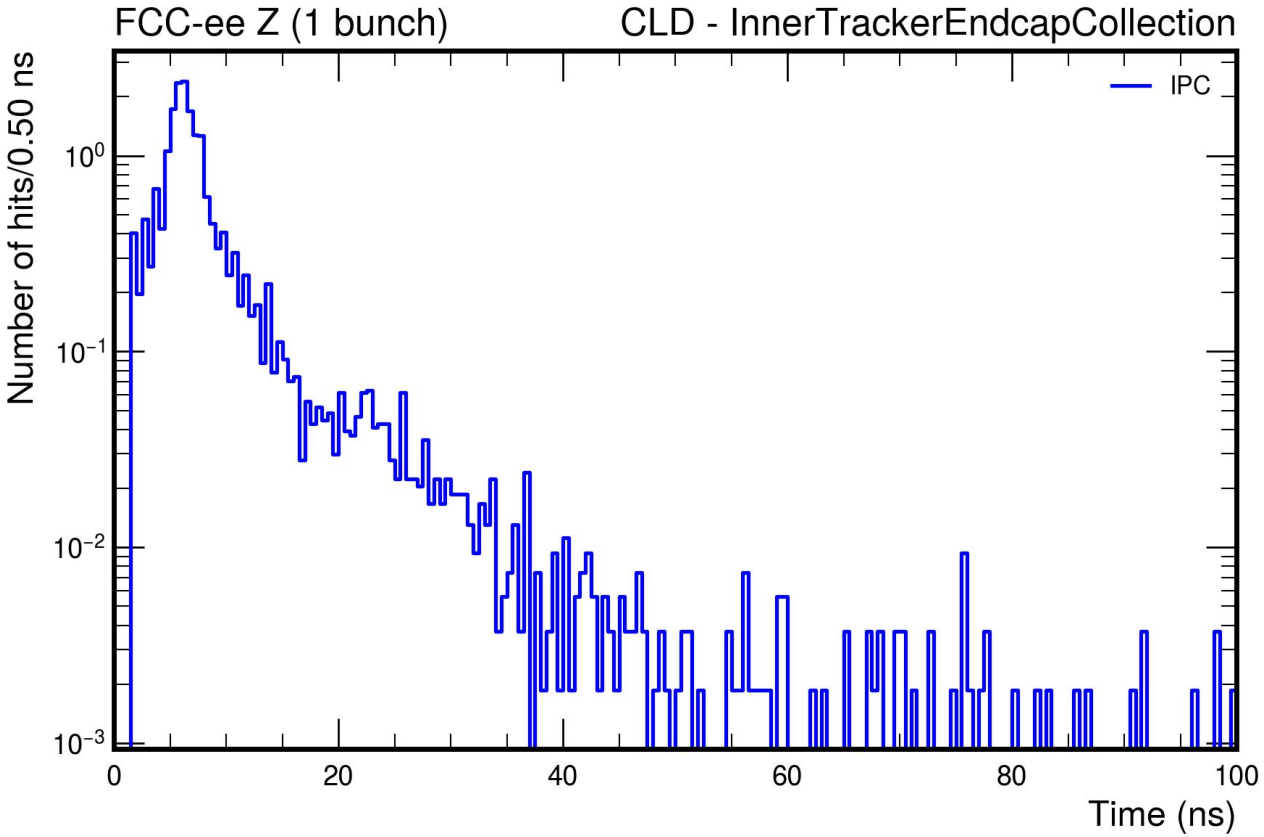
Timing CLD Z (ITB Barrel)



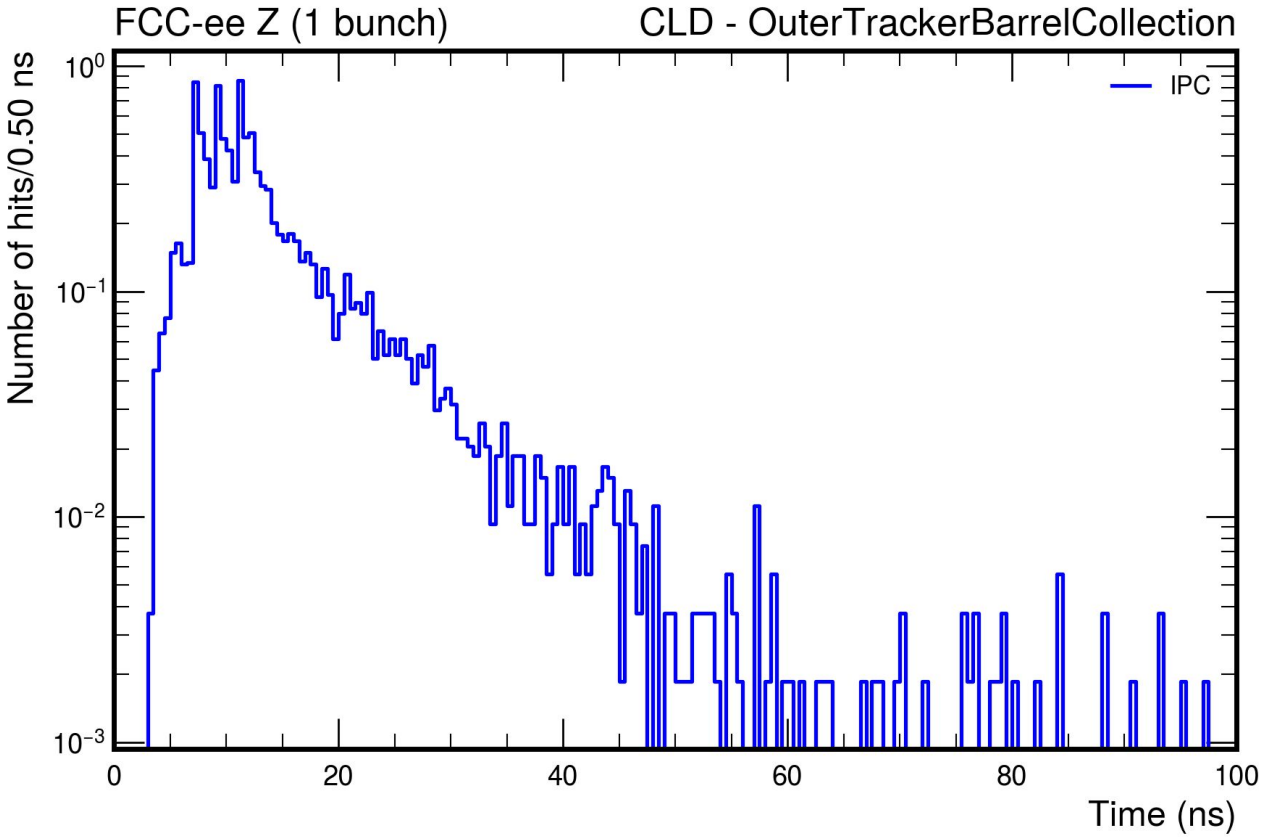
Timing CLD Z (ITB Endcap)



Timing CLD Z (ITB Endcap)



Timing CLD Z (OTB Barrel)



Timing CLD Z (OTB Endcap)