



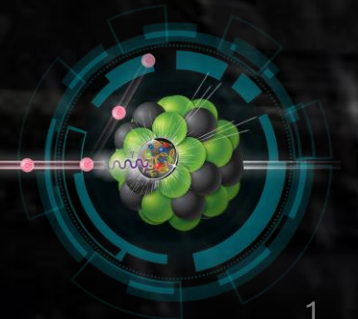
# ePIC Background Mixing

Merging events with backgrounds in simulation input/output

29<sup>th</sup> June 2026

TIC meeting

Simon Gardner for Physics and Detector Simulation WG



# Goal of our simulation

- Proactively reproduce and understand the data from the ePIC detector
- Our output comes from as a timeframe from the streaming DAQ to limit bias introduced by triggers.
- Making the timeframe as realistic as possible based on current understanding of the detector and accelerator allows us to most accurately assess the physics reach and where enhancements are most necessary.

## Simulation Timeframe

- 2 us window matching nominal MAPS integration window.

## DAQ Timeframe (Planned)

- 665 us basic data unit

## DAQ Super timeframe (Planned)

- 0.5 s contiguous collections of timeframes ~2GB

[ePIC\\_workflow\\_management\\_requirements\\_Draft.pdf](#)

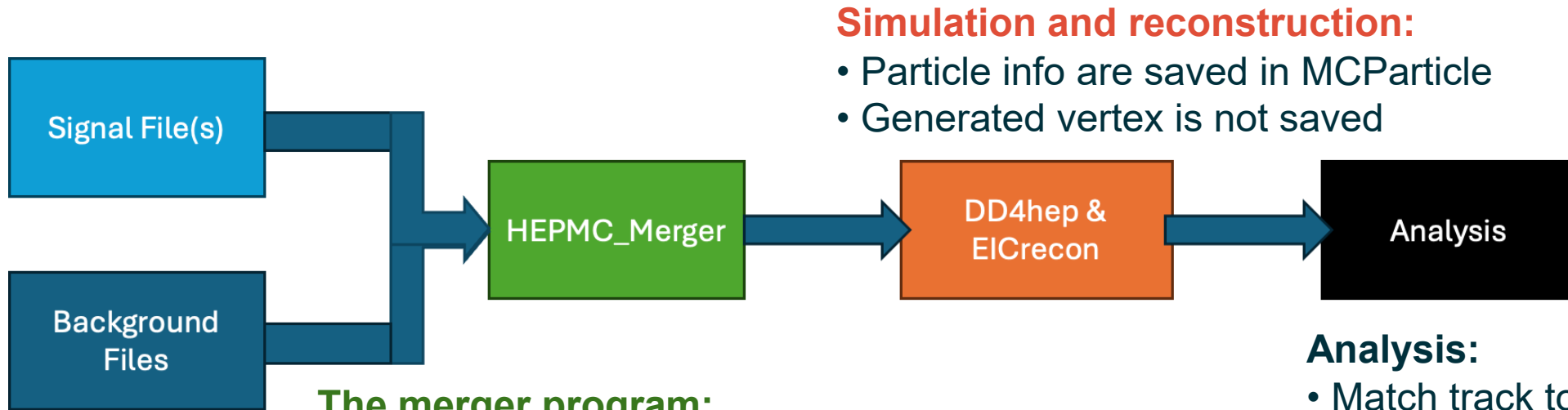
## An ideal timeframe sample needs to include:

- Events from beam collisions
- Beam backgrounds
- Environmental backgrounds
- Detector noise

# Signal/background merger in ePIC

## signal/background source files

- Individually generated in HEPMC3/root format
- Files have electron and proton as beam particles, and a list of outgoing primary particles per event



## Simulation and reconstruction:

- Particle info are saved in MCParticle
- Generated vertex is not saved

## The merger program:

[https://github.com/eic/Hepmc\\_merger](https://github.com/eic/Hepmc_merger)

- Sample each file according to their frequency within a fixed-length (2us) time window
- Output in hepMC3 format. Each source are saved with a shifted generator status code

## Analysis:

- Match track to particles
- Study how well we can reconstruct signal particles

Slide from Sakib: [background\\_production\\_07082025 - Google Slides](#)

Additional details: [background\\_mixed\\_samples.md · GitHub](#)

[Background - Electron-Proton/Ion Collider Experiment](#)

# Expected Backgrounds

Event source	Scales with	Included	GenStatus offset	Notes
Physics sample (various)	Electron & ion beam current	✓	0	
Synchrotron radiation	Electron beam current	✓	2000	
Proton beamgas	Ion beam current and vacuum pressure	✓	6000	
Electron beamgas Bremsstrahlung	Electron beam current and vacuum pressure	✓	3000	
Electron beamgas Coulomb	Electron beam current and vacuum pressure	✓	4000	
Touschek	Beam bunch density?	✓	5000	
Interaction Bremsstrahlung	Electron & ion beam current	x		Signal for luminosity detectors
Minbias pythia6 sample	Electron & ion beam current	x		Care needed if overlap with physics sample.

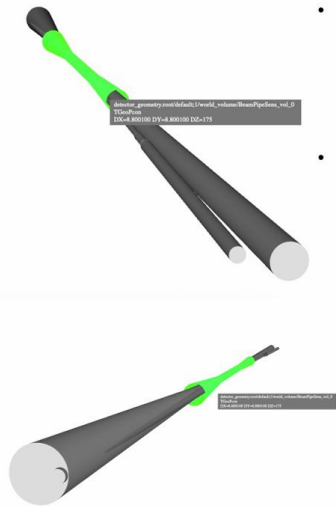
# Included backgrounds

- Synchrotron
  - [https://github.com/eic/EIC\\_SR\\_Geant4](https://github.com/eic/EIC_SR_Geant4)
  - Photons collected by virtual surface outside of beampipe model.
- Proton beamgas
  - [GitHub - eic/ProtonBeamGas · GitHub](#)
  - Pythia8 based proton beam – proton fixed target sample.
- Electron beamgas - Bremsstrahlung
  - [https://github.com/adamjaro/GETaLM/blob/master/models/gen\\_beam\\_gas.py](https://github.com/adamjaro/GETaLM/blob/master/models/gen_beam_gas.py)
  - Bremsstrahlung off fixed target protons.
- Electron beamgas - Coulomb scattering
  - [https://github.com/eic/EIC\\_ESR\\_Xsuite](https://github.com/eic/EIC_ESR_Xsuite)
  - elastic scattering off beamgas
- Touschek
  - [https://github.com/eic/EIC\\_ESR\\_Xsuite](https://github.com/eic/EIC_ESR_Xsuite)
  - Intra-beam scattering

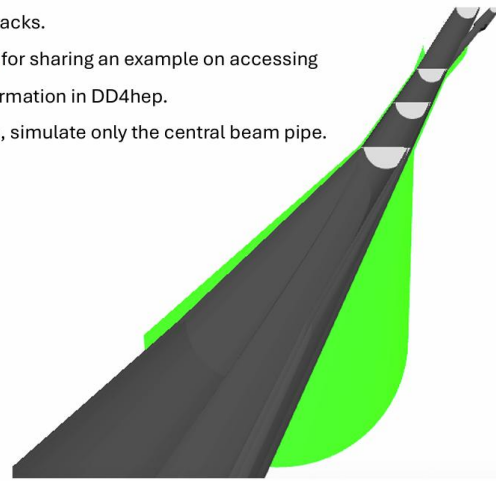
# Synchrotron sampling

- Full sample pre-simulated through Geant4 beampipe model.
- Sample entering virtual beampipe saved as sample for background merging.

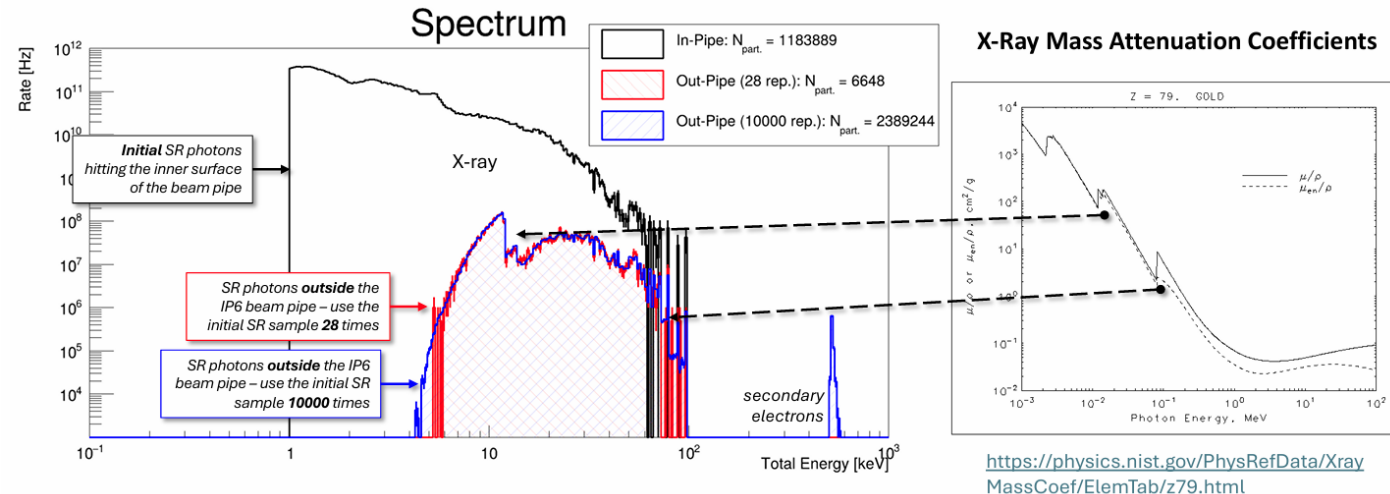
Virtual Pipe Around the Central Beam Pipe (3)



- 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.



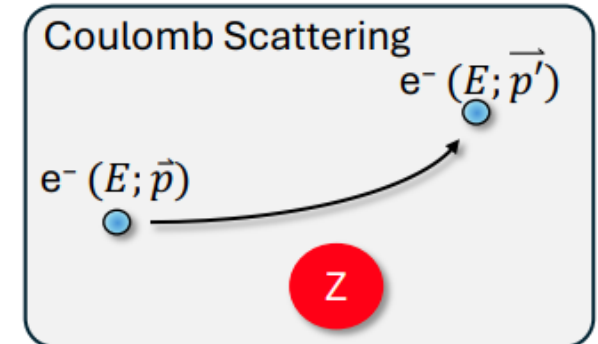
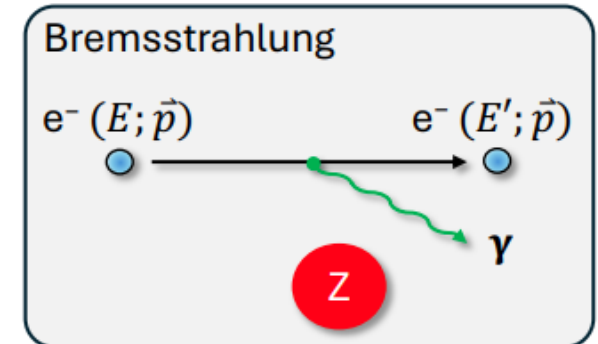
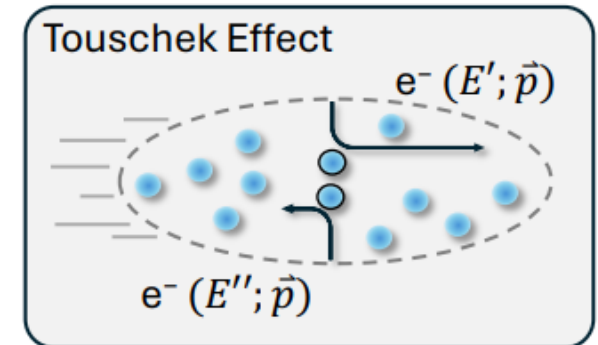
- Increasing the number of repetitions from 28 to 10000 extends the variation of particles (~6.6k → 2.4M) outside the IP6 beam pipe, preserving the spectrum.
- Gold absorption lines are clearly seen in the spectrum.



# Electron Single-Beam Loss Source

Main beam loss processes in the electron machine for the single-beam operation [<https://doi.org/10.1016/j.nima.2023.168550>]:

- **Touschek** – *an incoherent intra-beam scattering of the particles in the same bunch (energy change):*
  - Based on Bruck's formula
  - Flat beam ( $\sigma_y/\sigma_x \ll 1$ )
  - Non-relativistic approximation (radial velocities are non-relativistic)
- **Coulomb** – *elastic scattering of the beam on the residual gas molecules (direction change)*
  - Rutherford's scattering formula, including cutoff Coulomb potential and screening effect for small angles.
- **Bremsstrahlung** – *inelastic beam scattering on the residual gas molecules (energy change)*
  - Bethe-Heitler following Koch-Motz formalism for complete screening in the Born approximation



# Campaign datasets

Link to requested campaign datasets with/without backgrounds:

[Campaign Datasets · The EIC ePIC Simulation Production Campaign Website](#)

Please see Sakib/Torre's talk from last week for plans for automating production system:

[ePIC automated production 20260624 - Google Slides](#)

# Campaign workflow

simulation\_campaign\_datasets – config\_data contains background mixing configurations.

Dataset.ipynb – Colab – colab matching datasets to background configurations

HEPMC\_Merger – Program carrying out the merging

simulation\_campaign\_hepmc3 – run.sh passing the configuration

## Example background configuration file:

synrad\_egasbrems\_egascoulomb\_egastouschek\_hgas\_10GeVx130GeV\_GoldCoating\_10um\_10000Ahr\_machineruntime\_50s.json

```
1  [
2  {
3    "file": "root://dtn-eic.jlab.org//volatile/eic/EPIC/EVGEN/BACKGROUNDS/SYNRAD/dataprod_rel_1.0.0/10x275/GoldCoating/10um/dataprod_rel_1.0.0_synrad_10x275_run001.preproc_10000repeats.hepmc3.tree.root",
4    "freq": 13277000,
5    "skip": 0.0,
6    "status": 2000
7  },
8  {
9    "file": "root://dtn-eic.jlab.org//volatile/eic/EPIC/EVGEN/BACKGROUNDS/BEAMGAS/electron/GETaLM1.0.0-1.0/10GeV/GETaLM1.0.0-1.0_ElectronBeamGas_10GeV_foam_emin10keV_run001.hepmc3.tree.root",
10   "freq": 3177.25,
11   "skip": 0.0,
12   "status": 3000
13  },
14  {
15   "file": "root://dtn-eic.jlab.org//volatile/eic/EPIC/EVGEN/BACKGROUNDS/BEAMGAS/electron/coulomb/EIC_ESR_Xsuite/dataprod_rel_1.0.1/10x275/10000Ahr/MachineRuntime50s/dataprod_rel_1.0.1_electron_coulomb_10x275_10000Ahr.hepmc3.tree.root",
16   "freq": 29.56,
17   "skip": 0.0,
18   "status": 4000
19  },
20  {
21   "file": "root://dtn-eic.jlab.org//volatile/eic/EPIC/EVGEN/BACKGROUNDS/BEAMGAS/electron/touschek/EIC_ESR_Xsuite/dataprod_rel_1.0.1/10x275/10000Ahr/MachineRuntime50s/dataprod_rel_1.0.1_electron_touschek_10x275_10000Ahr.hepmc3.tree.root",
22   "freq": 233.5,
23   "skip": 0.0,
24   "status": 5000
25  },
26  {
27   "file": "root://dtn-eic.jlab.org//volatile/eic/EPIC/EVGEN/BACKGROUNDS/BEAMGAS/proton/pythia8.306-2.0/130GeV/minus5.5m_plus5m/pythia8.306-2.0_ProtonBeamGas_130GeV_run001.hepmc3.tree.root",
28   "freq": 31.97,
29   "skip": 0.0,
30   "status": 6000
31  }
32 ]
```

File: Location of file to sample from

Freq: Poisson mean in kHz

Skip: Number of events to skip

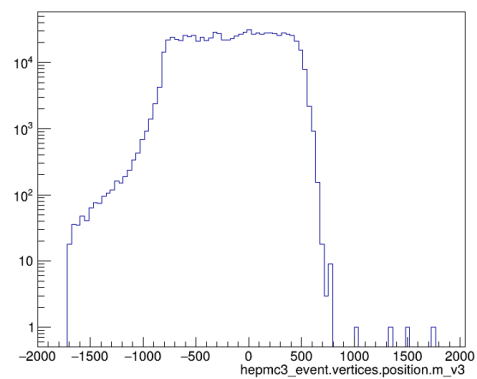
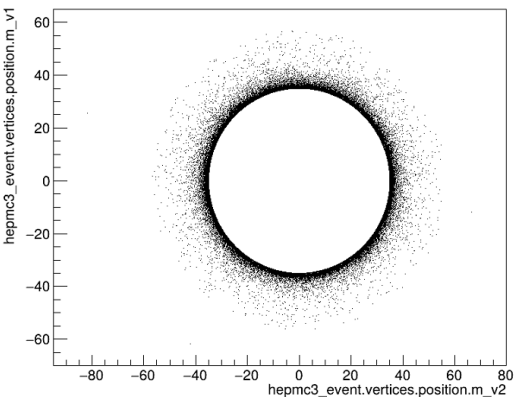
Status: Offset of generator status given to particles

# x/y and z distributions in hepmpc3 files

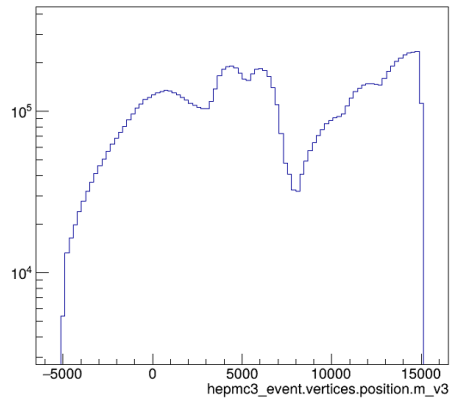
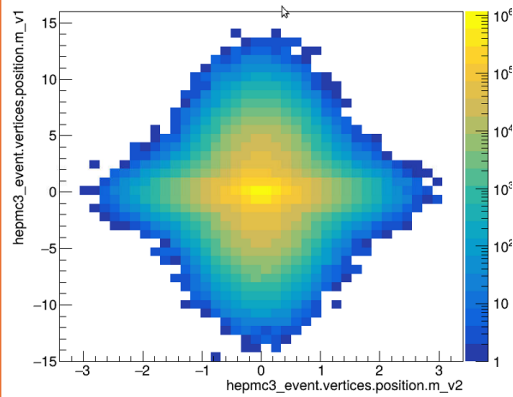
x/y plots are unintuitively x on the vertical axis

Pressure

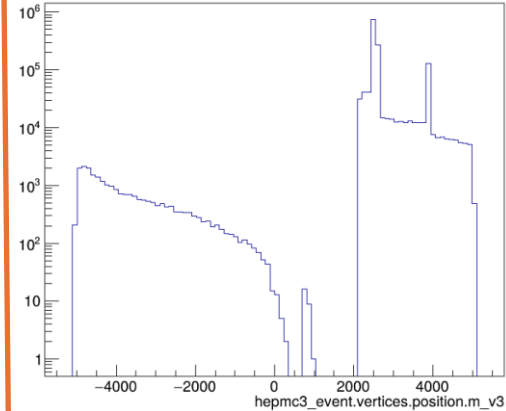
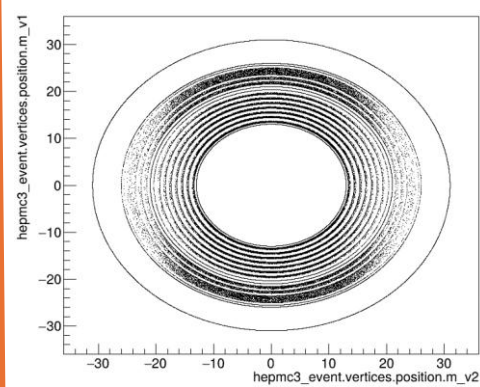
## Synchrotron



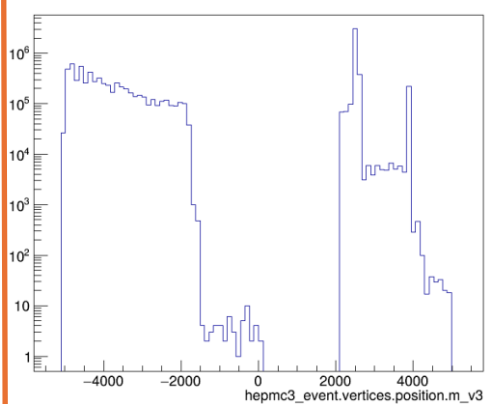
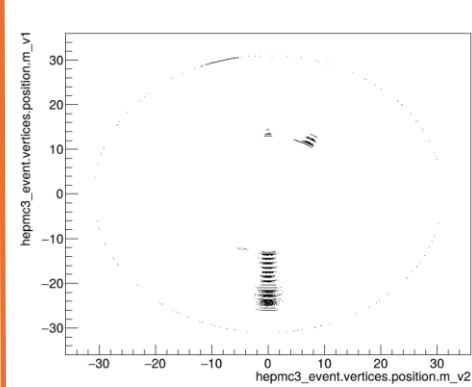
## electron-BG Brems



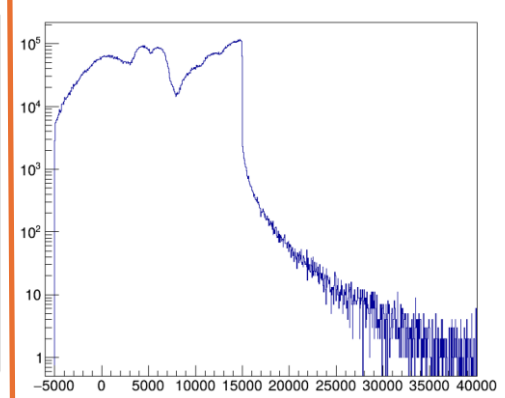
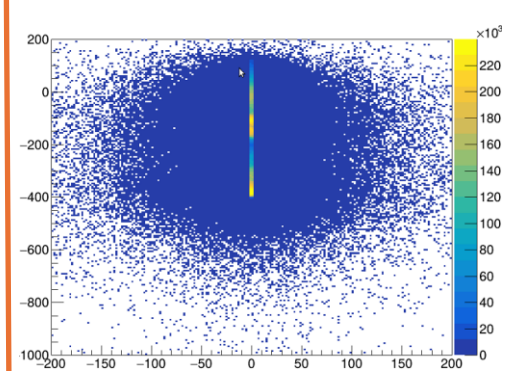
## electron-BG Coulomb



## Touschek



## Proton BG



# Currently partially/not included backgrounds

- Background range is focused on the central detector; most samples do not extend into FF/FB regions.
  - Samples are already available to include but need geometry changes to make sense.
- Bethe-Heitler/Bremsstrahlung from beam-beam interaction
  - Mostly relevant for Far-Backwards detectors as signal for Luminosity and background for Low-Q2 Tagger.
- Detector noise is not present for any subsystem but is not part of Geant4 simulations.

# Merging process

Default process:

- Sample single signal
- For each background type:
  - Random sample N events from Poisson distribution.
  - Randomly distribute each event in 2us timeframe.
  - Update particle status.
- **Currently every configuration starts with offset 0 so merged files contain same ordered background events. ([Issue #24 · eic/HEPMC\\_Merger](#))**

Features of the merger allow for other configurations:

- Realistic signal sampling
- Only background samples

# Beam configurations assumed in samples

- Interaction luminosities - nominal preTDR.
- Beam currents (need checking)
- Vacuum pressure generating samples follows distribution after 10000Ahr
  - Pressure in simulation static at  $10^{-9}$  mbar ([Vacuum material](#))
- [Beampipe configuration](#)
  - 0.757 mm Beryllium
  - 10 um Gold coating

# What happens next

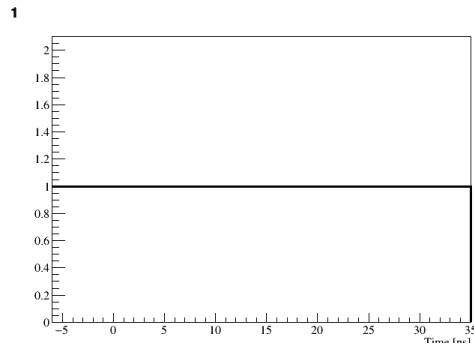
- EICrecon handles digitization
  - Detector codes are at different levels of development
  - Require detailed understanding of the sensor and ASIC response to know when hits might be combined/lost depending on clock cycles and relative hit arrival times.
  - Detector electronic noise needs to be added – in development.
- Main tracking uses hit times and detector resolution
  - Hit time uncertainty per-detector needs to be implemented
  - Timeframe Splitter under development.
  - May see improvements in background separation

# Proposed improvements

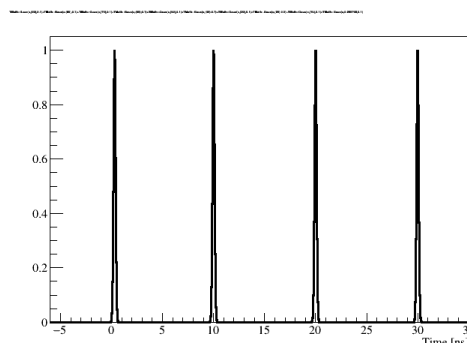
## TimeframeBuilder adds features

- Merge hepmc3 input or EDM4hep reusing simulated samples.
- Configurable time correlations to enable timing studies
  - Discrete beam bunch matching
  - Direction/location-based offsetting

Uniform

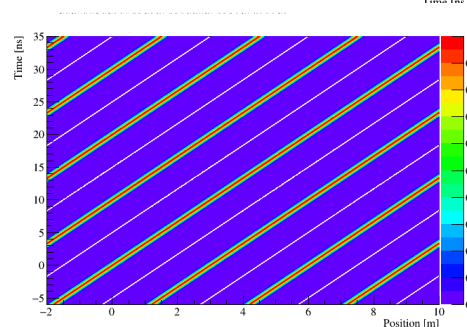
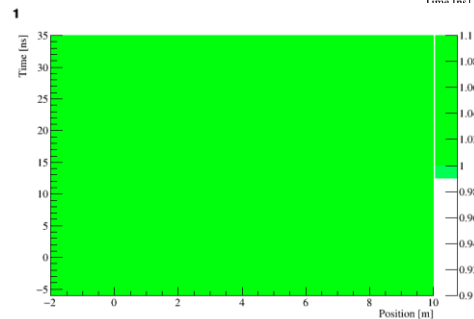


Bunch attached



## Longer term

- Detailed bunch structure/variation.
- Backgrounds from particle interaction before the timeslice
- Correct polarization state mixing.



# Questions