First look at 10 TeV incoherent pair production

Federico Meloni (DESY),

with many thanks to Daniele Calzolari, Daniel Schulte and the MDI group for the inputs

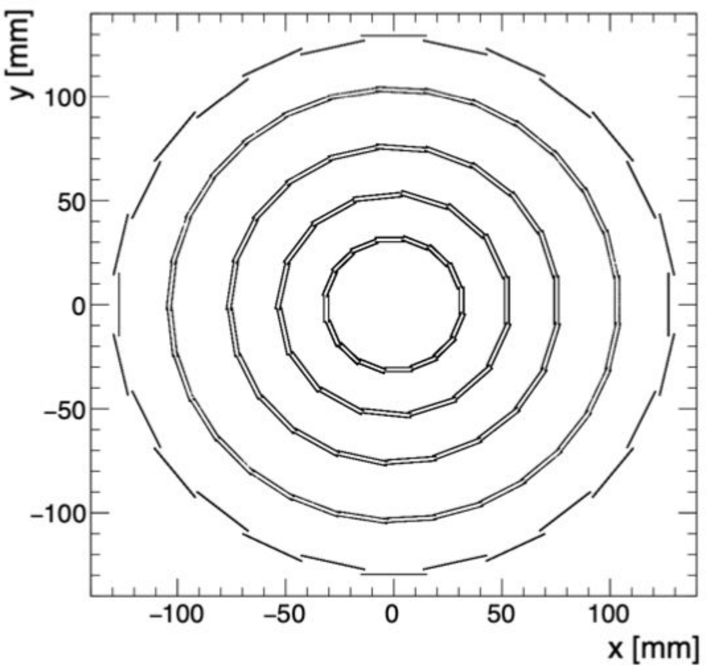
Physics and Detector simulation and MuCol WP2 meeting, 28/05/2024

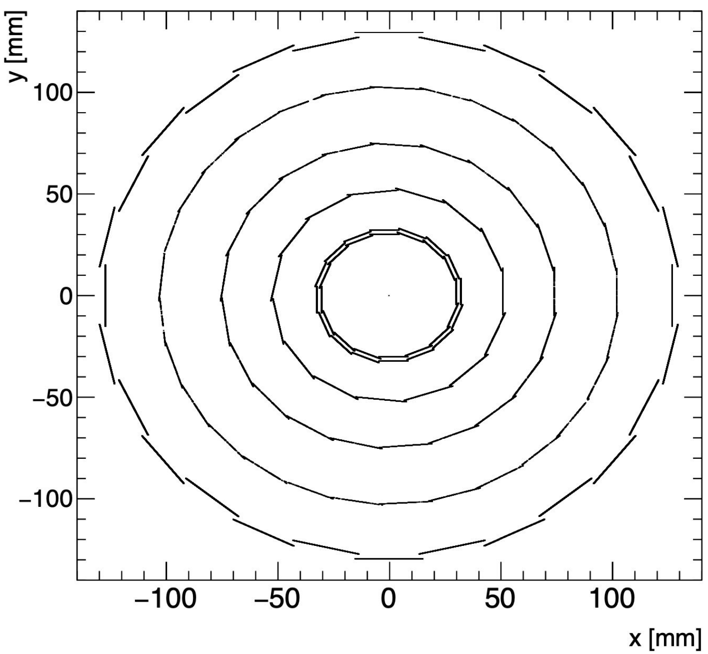
Tracker layout in “MuColl_10TeV_v0A”

Reminder of the most important change

Greatly improved tracking software (based on the ACTS library) made the double layers redundant

- Barrel region of vertex detector revised keeping only one double layer pair
- Endcaps also need re-optimisation (future work)





Incoherent pair production inputs

Inputs and validation

Study based on:

- preliminary set of predictions from GUINEA-PIG+FLUKA (1 full BX)

Important FLUKA features:

- hard edge 5T field

Many thanks to the MDI group and in particular Daniele and Daniel for the inputs and instantly (!) replying to all questions

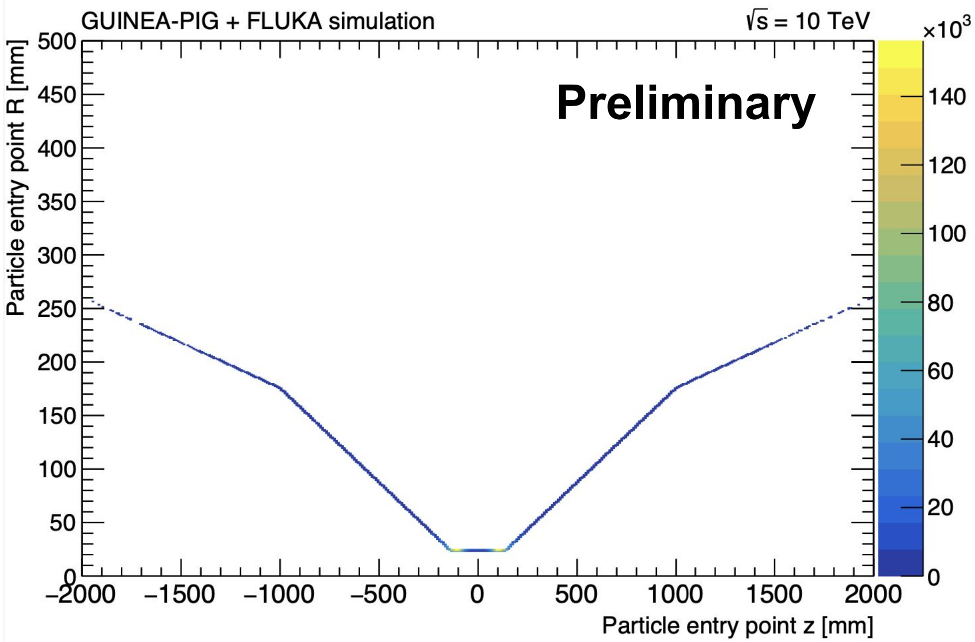
Simulation inputs

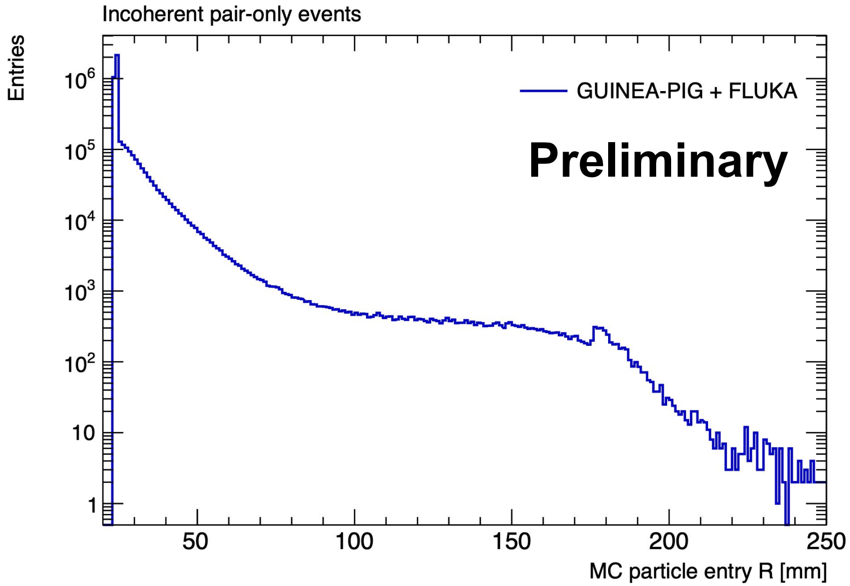
E > 0.1 MeV	FLUKA
Photons	$4.04\ 10^{6}$
Electrons	$2.09\ 10^{5}$
Charged Hadrons	51
Muons	1

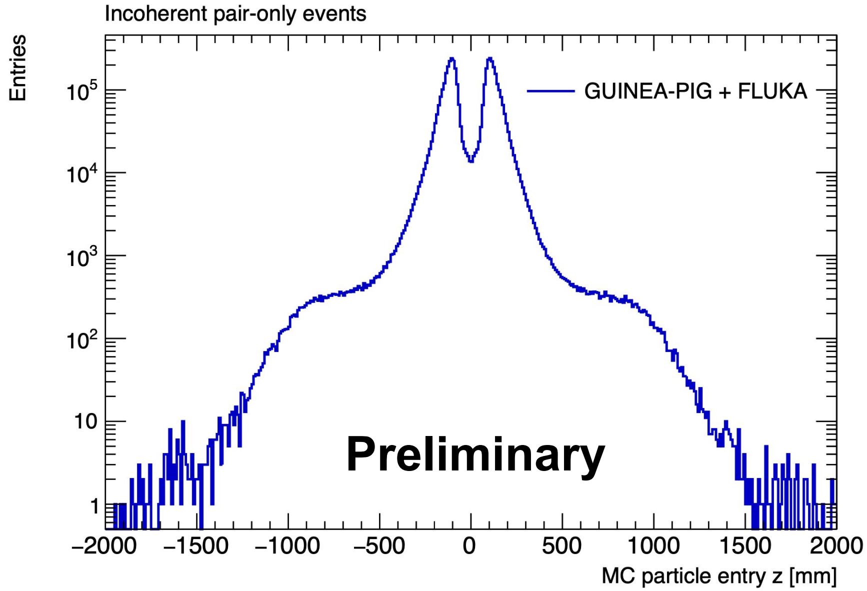
Incoherent pair production sanity checks

Checking that the origin is distributed as expected

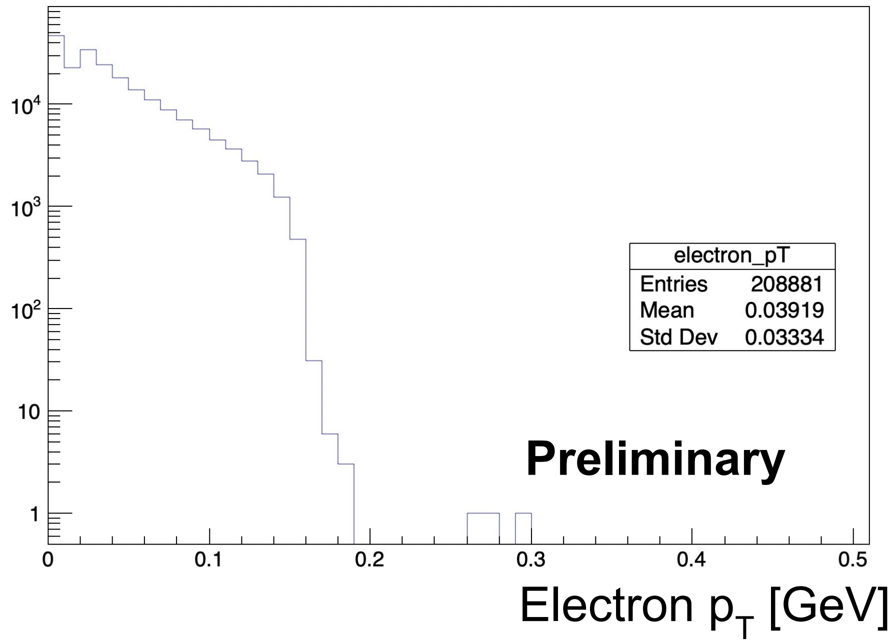
- Transport looks ok

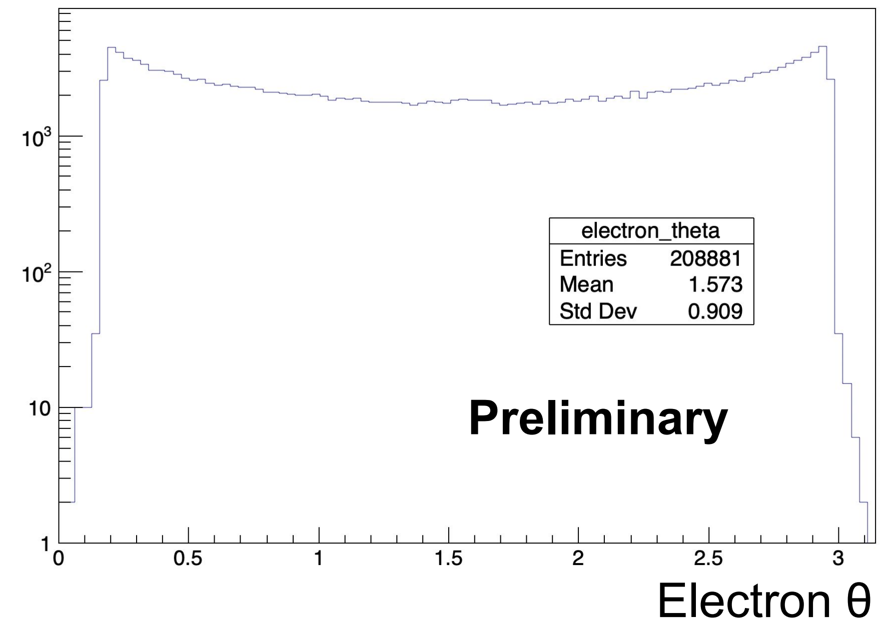


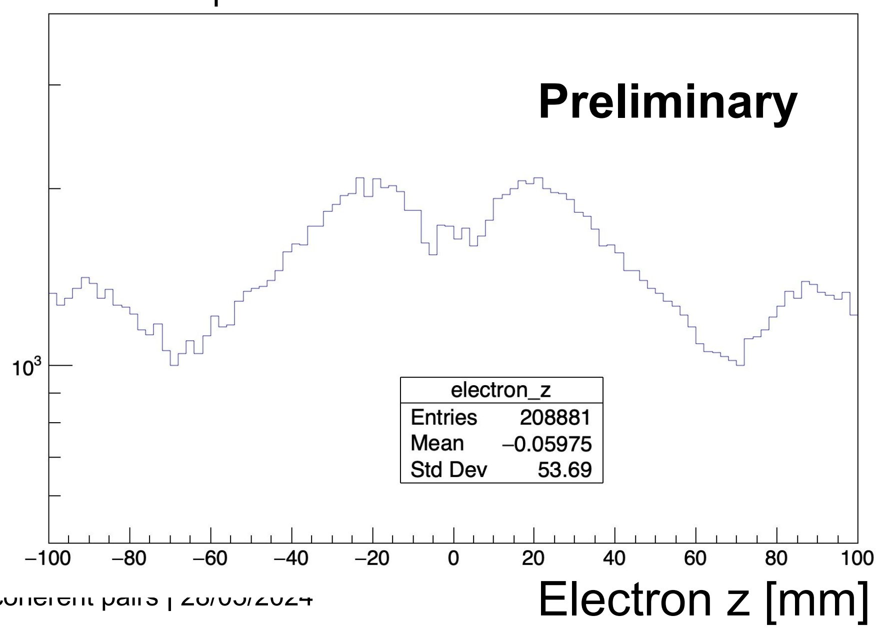




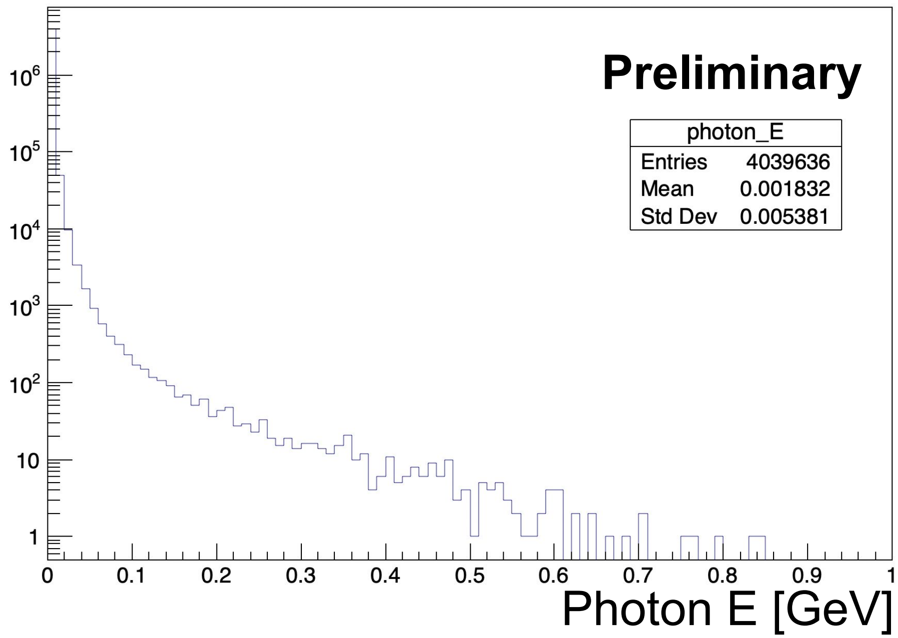
Additional distributions (electrons)

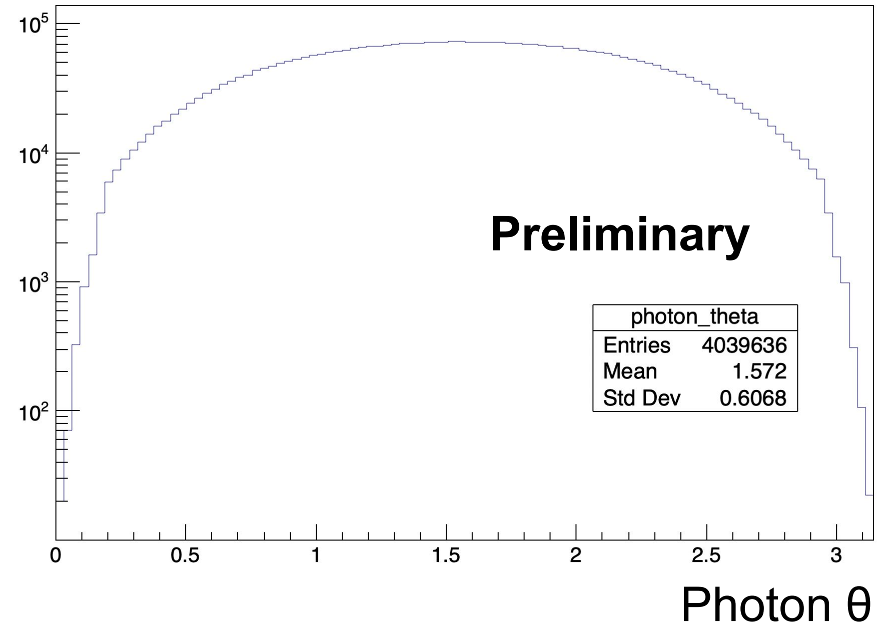


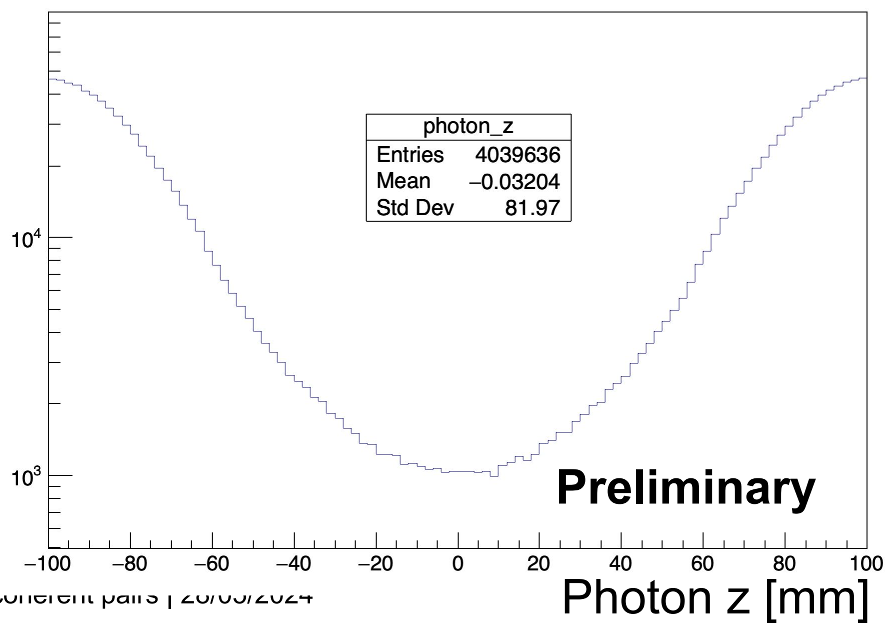




Additional distributions (photons)







Incoherent pair production

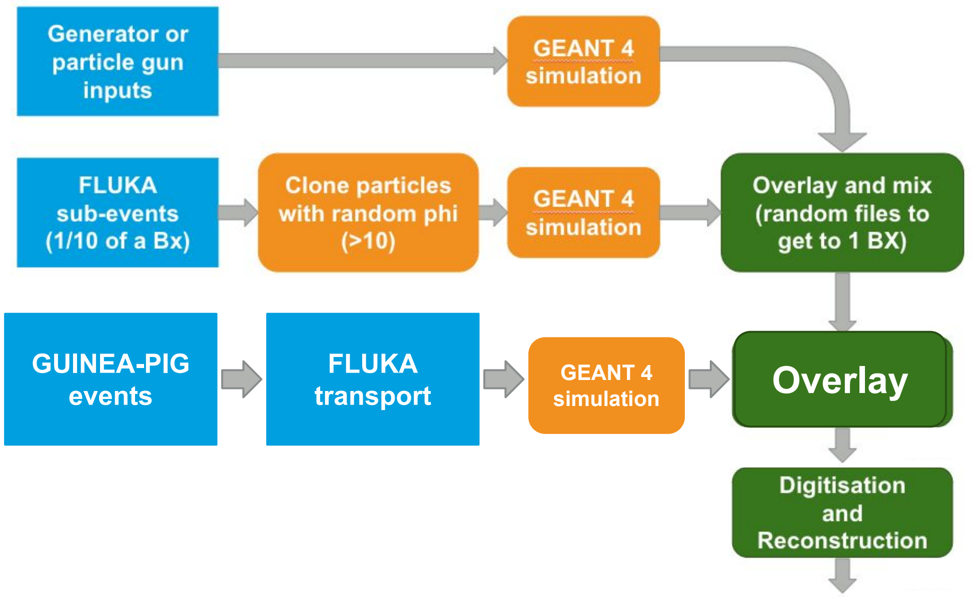
Workflow

GUINEA-PIG+FLUKA stored in a similar format as BIB files (i.e. minus the information on the muon decays)

Prepared:

- Conversion scripts
- Overlay machinery
- Processing pipeline

Everything seems ok so far



Digitisation

Used C. Sellgren / S. Pagan Griso's realistic digitiser (see talks here and here) to digitise tracker response.

- "Default" configuration from Chris' github repository
- Ran on top of infnpd/mucoll-ilc-framework:1.7-almalinux9

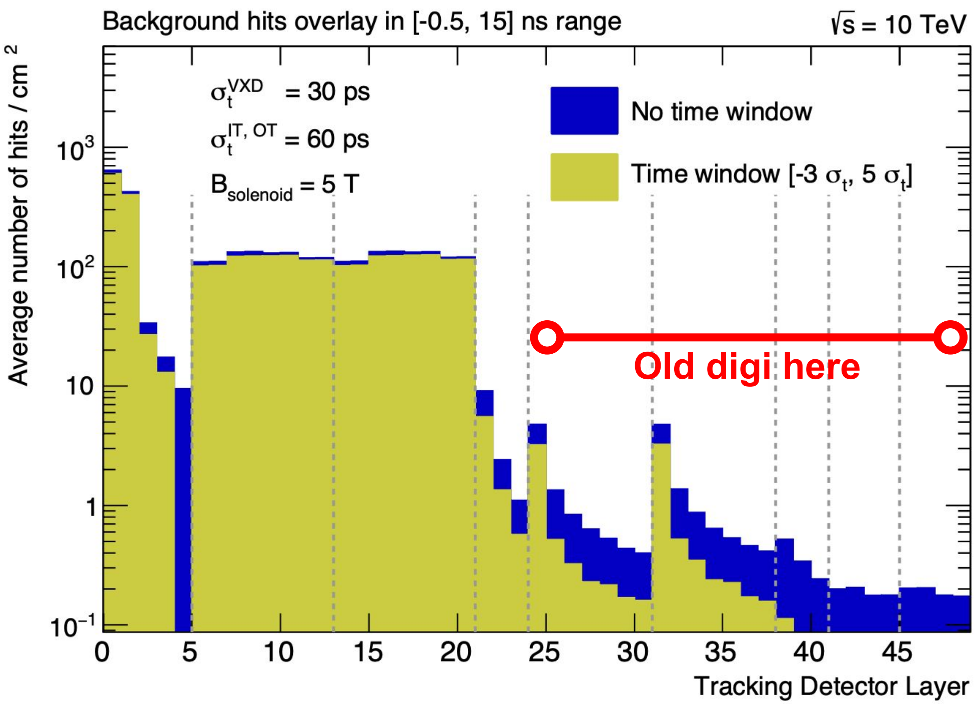
Actual mix of processors listed below:

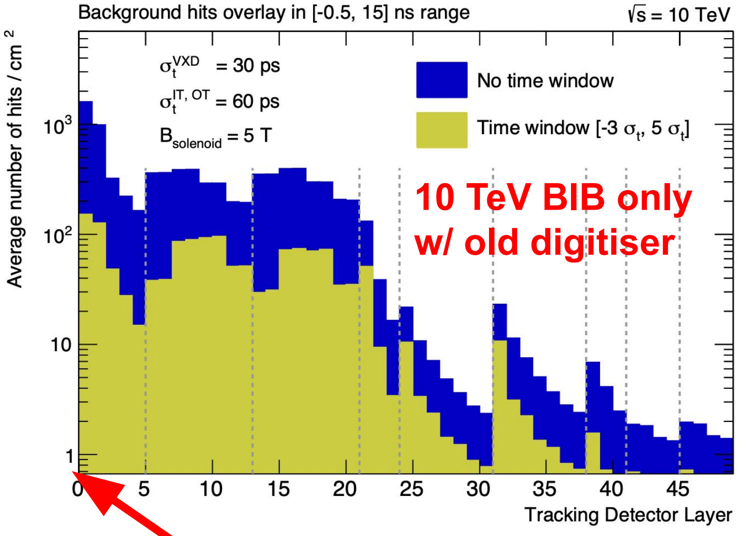
```
<!-- ==========  Tracker Digitization  ========== -->
<processor name="VXDBarrelRealisticDigi"/>
<processor name="VXDEndcapRealisticDigi"/>
<processor name="InnerPlanarRealisticDigi"/>
<processor name="InnerEndcapPlanarDigiProcessor"/>
<processor name="OuterPlanarDigiProcessor"/>
<processor name="OuterEndcapPlanarDigiProcessor"/>
```

```
<processor name="VXDBarrelRealisticDigi" type="MuonCVXDDigitiser">
    <parameter name="Verbosity" type="string"> MESSAGE </parameter>
    <parameter name="CollectionName" type="string"> VertexBarrelCollection </parameter>
    <parameter name="OutputCollectionName" type="string"> VBTrackerHits </parameter>
    <parameter name="RelationColName" type="string"> VBTrackerHitsRelations </parameter>
    <parameter name="SubDetectorName" type="string"> VertexBarrel </parameter>
    <!-- store all fired pixels -->
    <parameter name="StoreFiredPixels" type="int"> 1 </parameter>
    <!-- Pixel size (mm) -->
    <parameter name="PixelSizeX" type="float"> 0.025 </parameter>
    <parameter name="PixelSizeY" type="float"> 0.025 </parameter>
    <!-- FE threshold (in electrons) and electronic effects -->
    <parameter name="Threshold" type="float"> 500 </parameter>
    <parameter name="ChargeMaximum" type="float"> 15000. </parameter>
    <parameter name="ThresholdSmearSigma" type="int"> 25 </parameter>
    <parameter name="DigitizeCharge" type="int"> 1 </parameter>
    <parameter name="ChargeDigitizeNumBits" type="int"> 4 </parameter>
    <parameter name="ChargeDigitizeBinning" type="int"> 1 </parameter>
    <parameter name="DigitizeTime" type="int"> 0 </parameter>
    <parameter name="TimeDigitizeNumBits" type="int"> 10 </parameter>
    <parameter name="TimeDigitizeBinning" type="int"> 0 </parameter>
    <parameter name="TimeMaximum" type="float"> 15.0 </parameter>
    <parameter name="TimeSmearingSigma" type="float"> 0.05 </parameter>
    <parameter name="ElectronicEffects" type="int"> 1 </parameter>
    <parameter name="ElectronicEffects" type="int"> 1 </parameter>
    <parameter name="ElectronicNoise" type="float"> 80 </parameter>
    <!--Tangent of Lorentz angle (and optional Y component); SP note: a bit large.. did not
    <parameter name="TanLorentz" type="float"> 0.8 </parameter>
    <parameter name="TanLorentzY" type="float"> 0.0 </parameter>
    <!-- Apply Poisson smearing of electrons collected on pixels -->
    <parameter name="PoissonSmearing" type="int"> 1 </parameter>
    <!--Min threshold for delta-rays (MeV)-->
    <parameter name="CutOnDeltaRays" type="float"> 0.030 </parameter>
    <!-- Diffusion coefficient, defined as sqrt(D / mu / V) and
         correlated with diffusion sigma by sigma(z) = z*_diffusionCoefficient -->
    <parameter name="Diffusion" type="float"> 0.07 </parameter>
    <!-- Segment Length in mm -->
    <parameter name="SegmentLength" type="float"> 0.005 </parameter>
    <!-- Energy Loss keV/mm -->
    <parameter name="EnergyLoss" type="float"> 280.0 </parameter>
    <!-- Max delta in energy for hit in electrons -->
    <parameter name="MaxEnergyDelta" type="float"> 100.0 </parameter>
    <!-- Maximum values for track length (in mm) -->
    <parameter name="MaxTrackLength" type="float"> 10.0 </parameter>
    <!-- Number of electron-hole pairs per keV -->
    <parameter name="ElectronsPerKeV" type="float"> 270.3 </parameter>
</processor>
```

Tracker occupancy from incoherent pairs

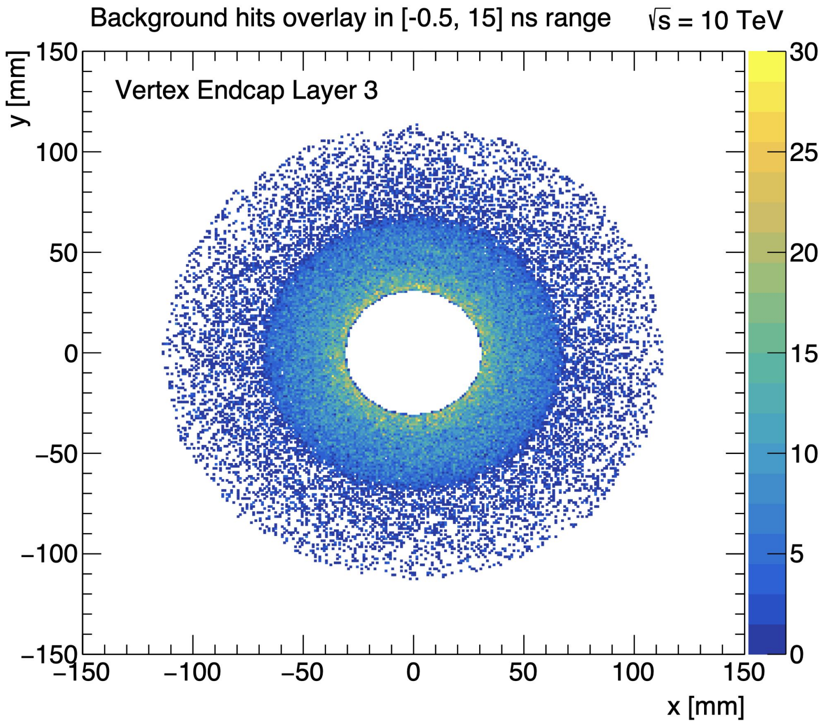
	Vertex Detector	Inner Tracker	Outer Tracker
Cell type	pixels	macropixels	microstrips
Cell Size	25 µm × 25 µm	50 µm × 1 mm	50 µm × 10 mm
Sensor Thickness	50 µm	100 µm	100 µm
Time Resolution	30 ps	60 ps	60 ps
Spatial Resolution	5 µm × 5 µm	7 µm × 90 µm	7 µm × 90 µm

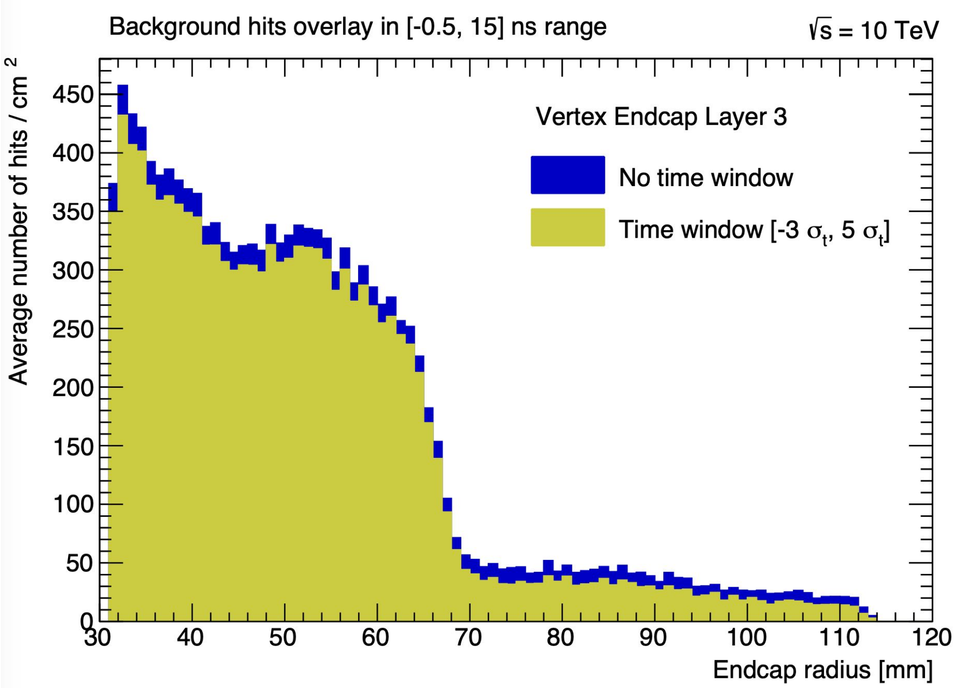




Note: average occupancy in endcaps does not capture the (important) radial dependence

Tracker endcap radial dependence

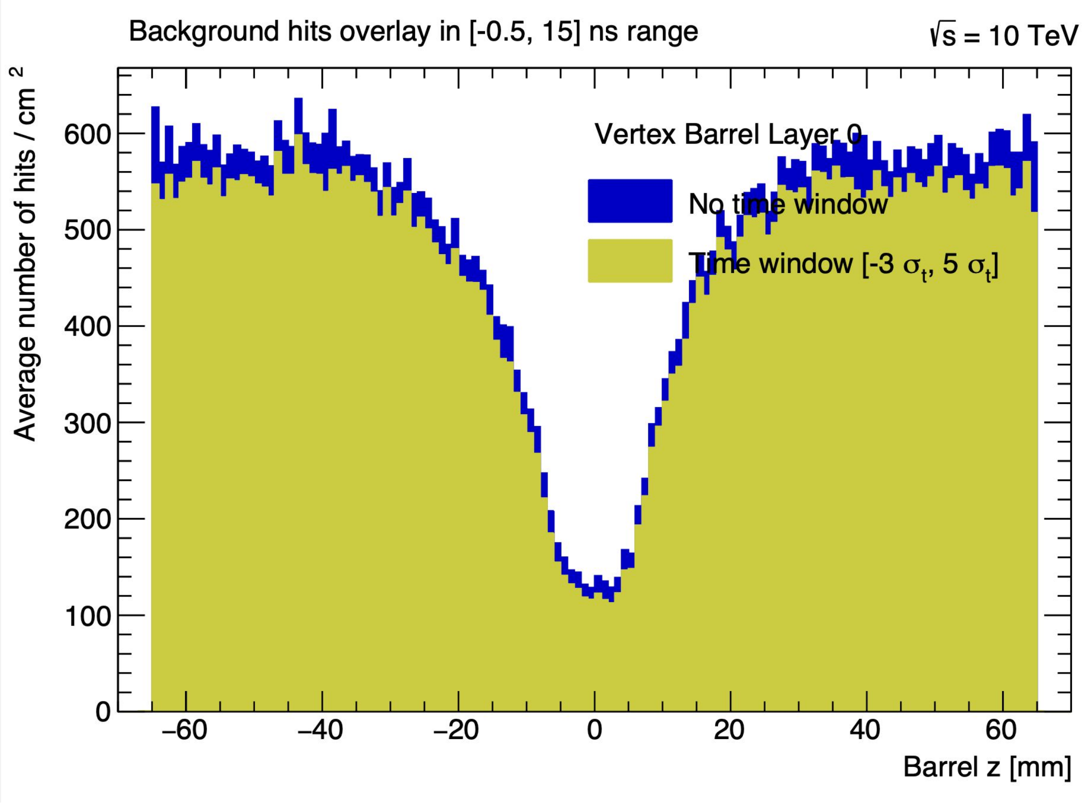


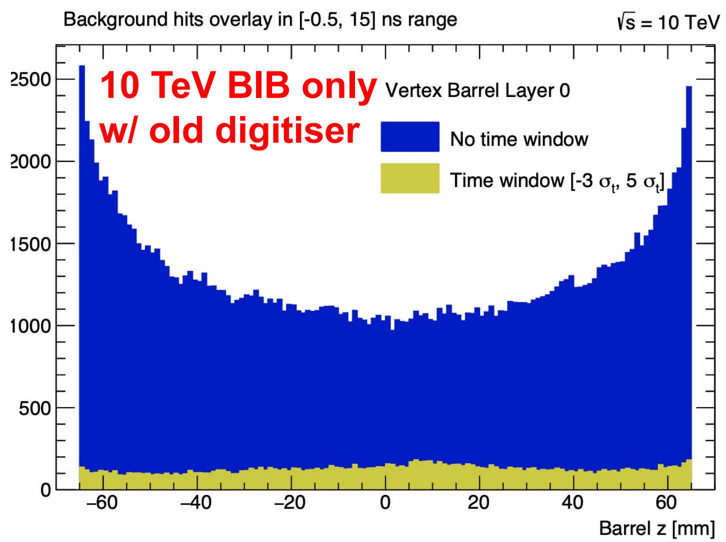


The region closest to the nozzles has a much higher occupancy than the rest of the endcap disk

- Most of the track reconstruction time is also spent here
- Showing here Vertex Endcap layer 3 (peak of BIB contribution)

What about the z dependence in the barrel?





Sizeable occupancy throughout most of the barrel layer

- May require online filtering (previous projections already were assuming tighter window with max 1ns in this region)

Summary

First look at new incoherent pairs dataset. Focus on:

- Truth-level distributions
- Tracker occupancy

Important to **monitor hot spots and general fluence** in trackers to determine the technological R&D targets

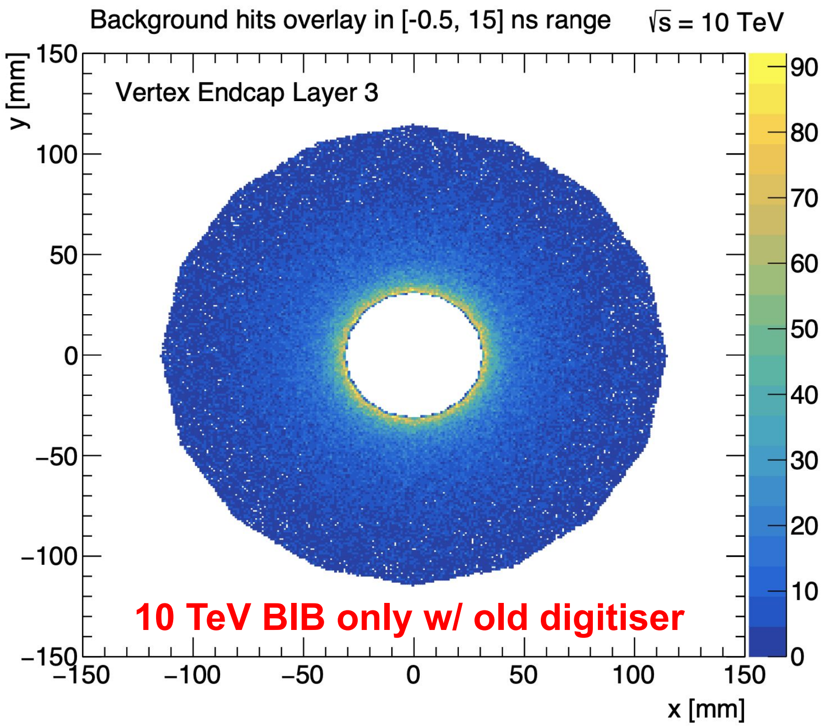
Tested pipeline to overlay and analyse incoherent pair production

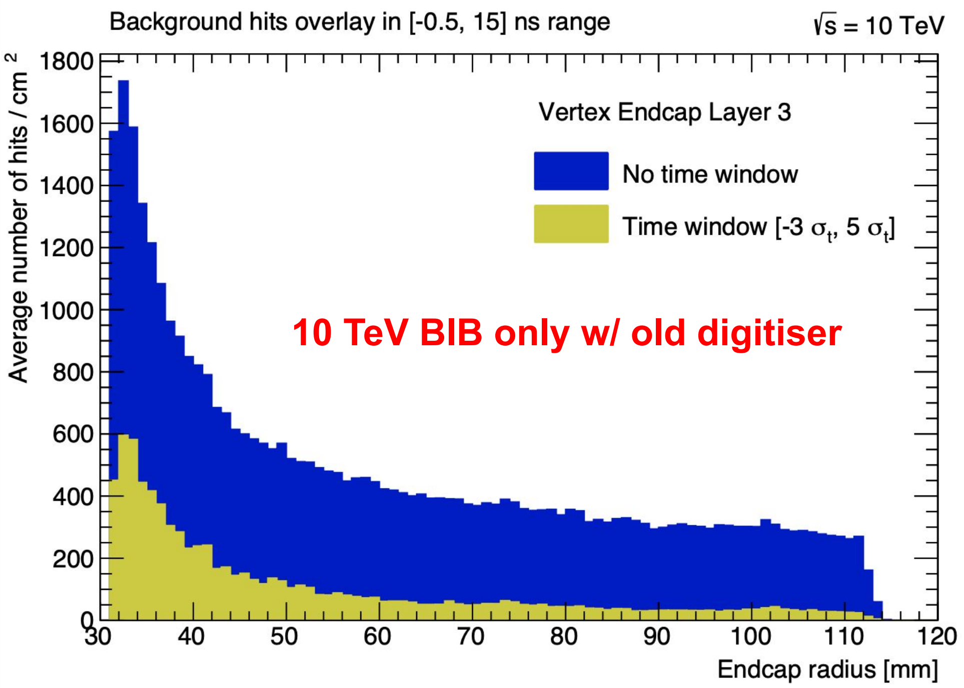
Next steps:

- Attempt at digitising BIB+incoherent pairs
- Actually run tracking
- Study occupancy from incoherent pairs vs magnetic field
  - Agreed with Daniele to get dedicated samples with B = 0-4T

Thank you!

Tracker endcap radial dependence





The region closest to the nozzles has a much higher occupancy than the rest of the endcap disk

- Causes an hotspot close to occupancy target
- Most of the track reconstruction time is also spent here