STATUS AND PERSPECTIVES FOR FCCee DETECTOR BACKGROUNDS STUDIES

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Introduction

Estimation of beam induced backgrounds is a **driver element** for the design of detectors and MDI region.

A **streamlined procedure** for occupancy calculation in each subdetector is a key feature under development in the FCCSW framework:

- **repository** with primary particles for each **background source** at the four FCCee energies
- **detector description** for the three experiments and common **MDI elements** (DD4hep format)
- particle tracking performed using G4 based tool **ddsim**

In this presentation, we focused on the background produced by the **Incoherent Pairs Creation (IPC)** at the **FCCee Z working point**, in the IDEA vertex detector and drift chamber, and in ALLEGRO noble liquid based ECAL.

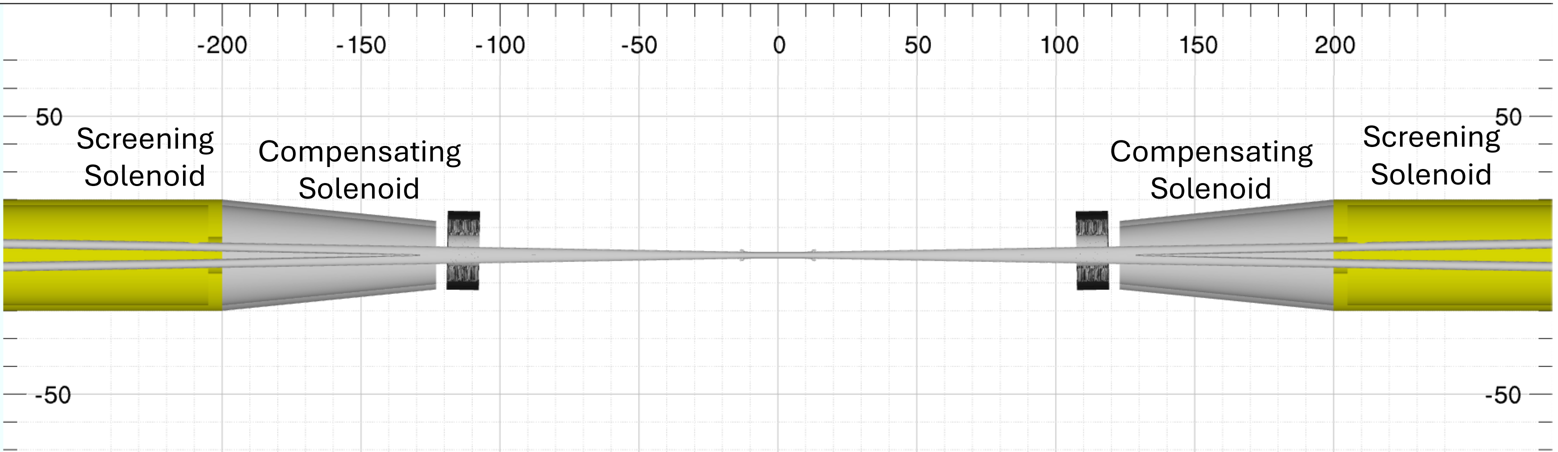
The following **preliminary results** are all at the **SIM Hit level**

ddsim and Geometry Description

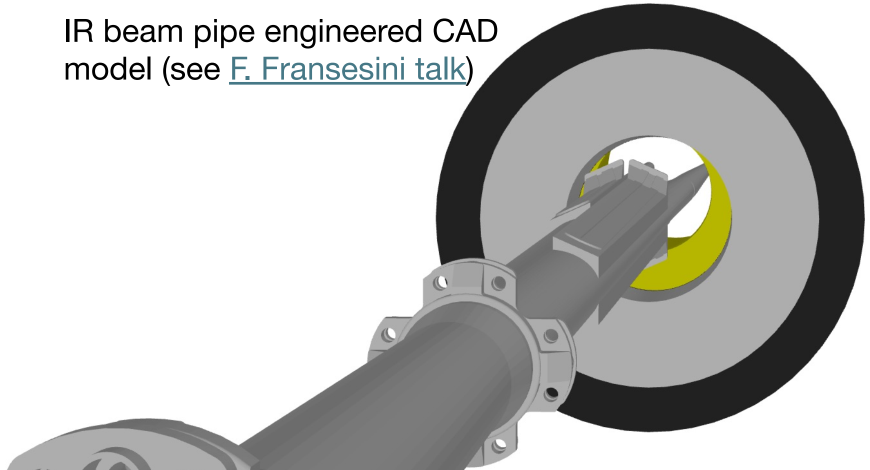
The tracking of background particles is performed using the Geant4 based tool **ddsim**.
ddsim can import primaries via **HEPMC3 format** and can directly handle **GuineaPig IPC outputs.**

Geometry includes the detectors and **common MDI elements**:

- CAD model beam pipe and cooling manifolds
- LumiCal, compensating and screening solenoids
- Tungsten SR masks
- Magnetic field of detector (2T), anti-solenoids and Final Focus Quadrupoles



IR beam pipe engineered CAD model (see F. Fransesini talk)

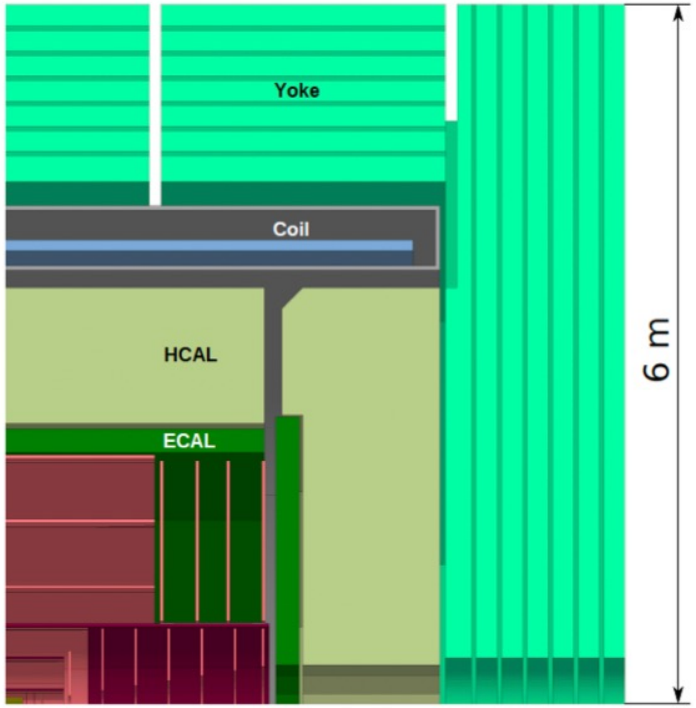


ddsim and Geometry Description

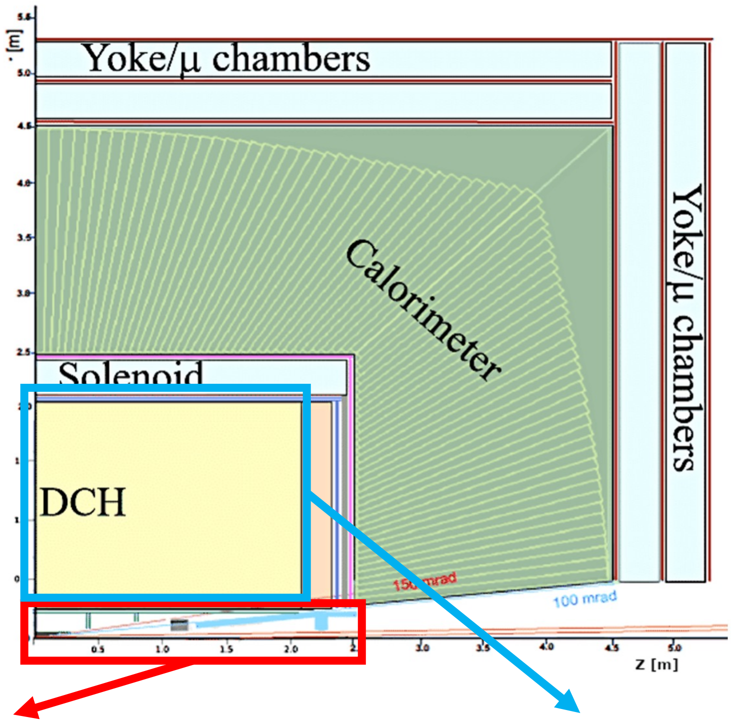
more on yesterday's session
"PED: Detector Concepts (iii)"

Detector modelization in DD4hep format → plug and play geometries
git repository for the three detector concepts: CLD, IDEA and ALLEGRO
https://github.com/key4hep/k4geo/tree/main/FCCee

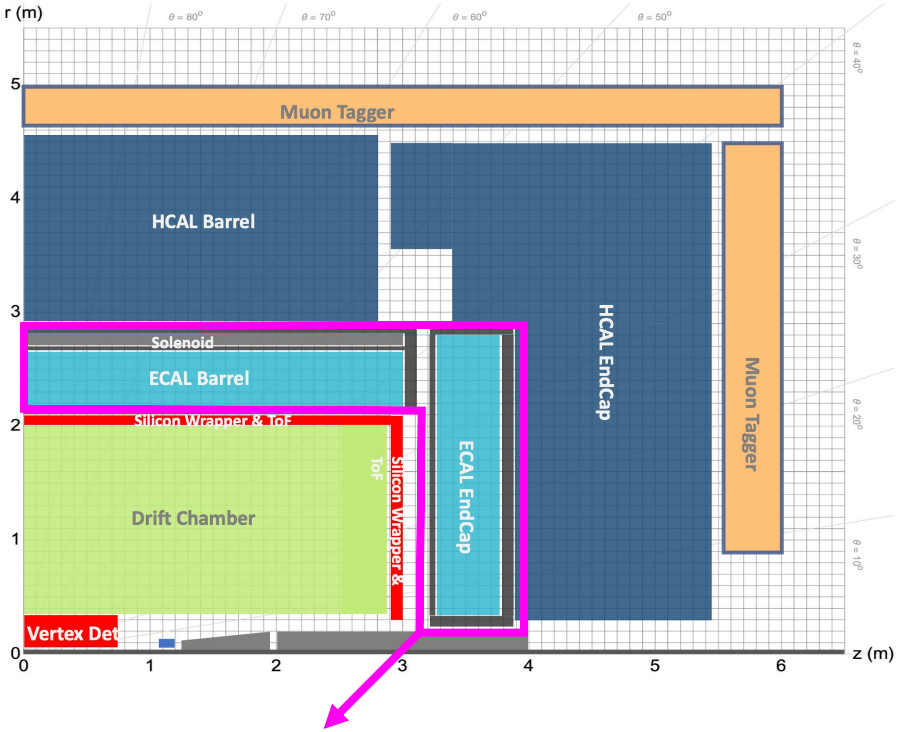
CLD



IDEA

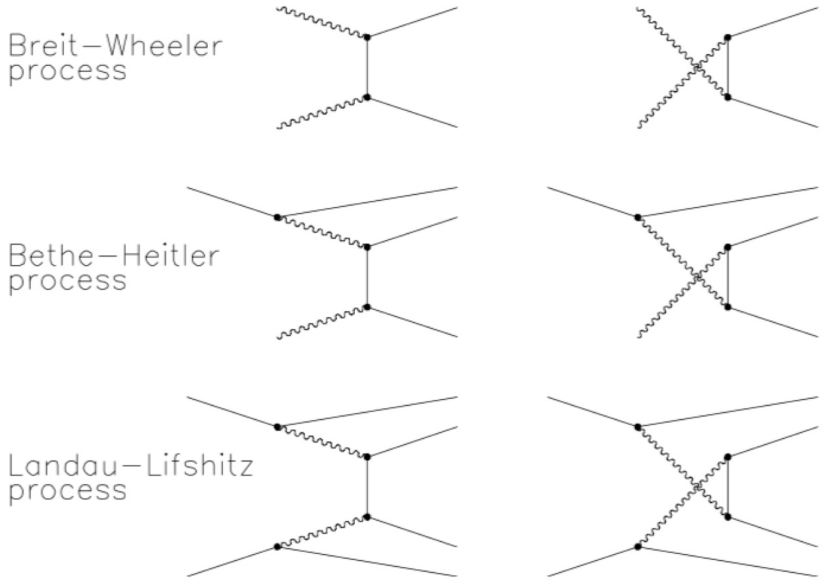


ALLEGRO



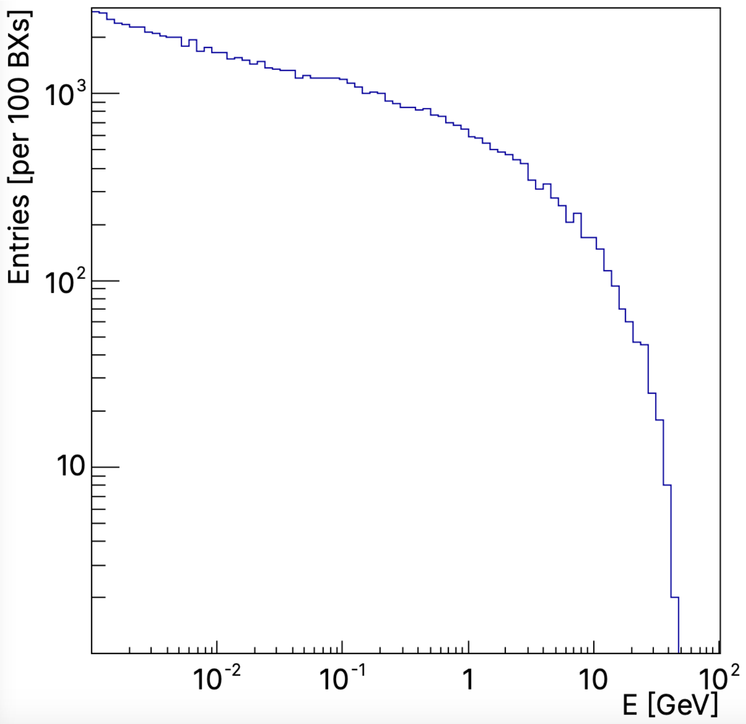
IDEA - VTX **IDEA - DCH** **ALLEGRO - ECAL**

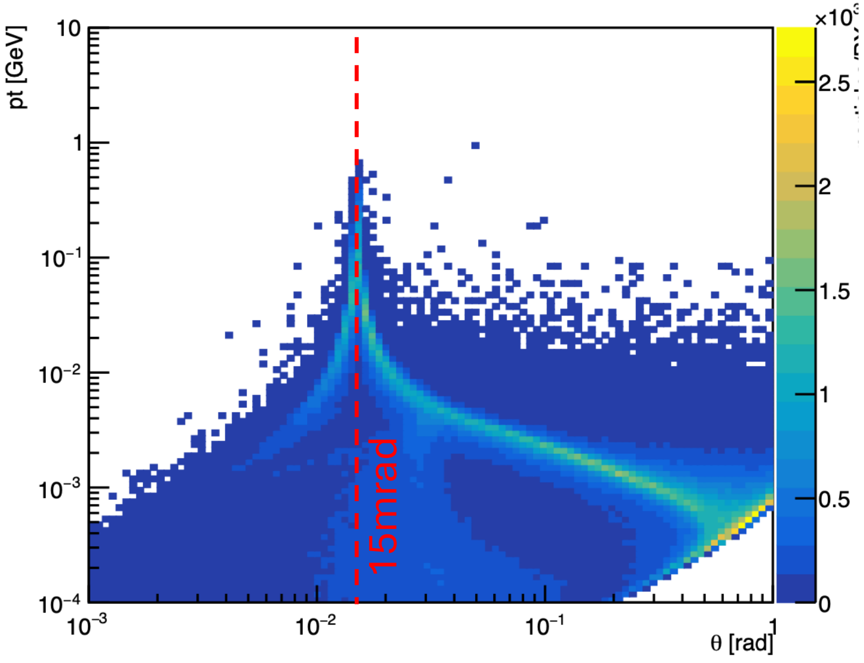
Incoherent Pairs Creation (IPC)



Secondary e^+e^- pairs produced during bunch crossing via the interaction of beamstrahlung photons with real or virtual photons.

The primary files have been produced using **GuineaPig++**, considering the beam parameters for **lattice V23** at the **Z pole**.





Beam parameters for V23 (06/05/2023)

β_x, β_y $[mm]$	110/0.7
σ_x, σ_y $[\mu m]$	8.837/0.031
σ_z $[\mu m]$	12700
N_e $[10^{11}]$	15.1
N_{IPC} $per\ BX$	~900

Number and kinematics of IPCs change with the evolution of the beam parameters!

IDEA - Vertex Detector

A. Ilg

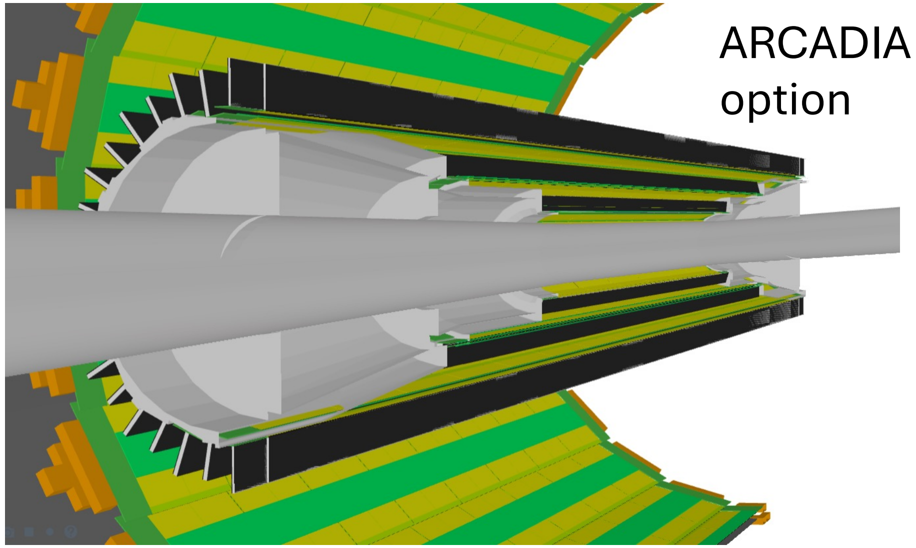
Occupancy levels are necessary to define:

- sensor requirements on **hit rate** (MHz/cm^2)
- feasibility a **trigger-less** detector

Focus on **first inner layer of VTX barrel** (r = 13.7mm)

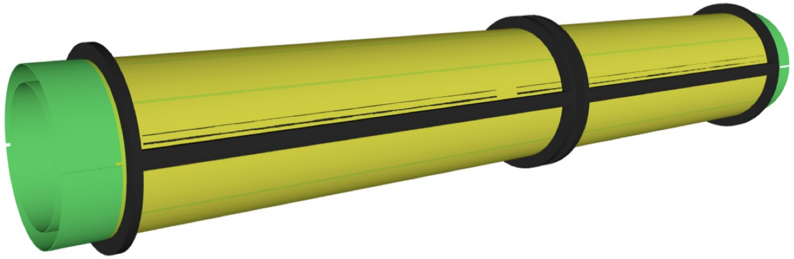
Two possible technologies explored:

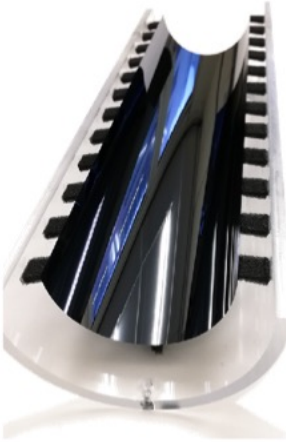
- ARCADIA sensor staves
- ultra-light ALICE ITS3 bent sensors



ARCADIA option

ALICE ITS3 option





IDEA - Vertex Detector

- Cluster size of 5, safety factor of 3, 25 μm pitch pixels
- Cut at 1.8 keV of deposited energy (500 e^-)

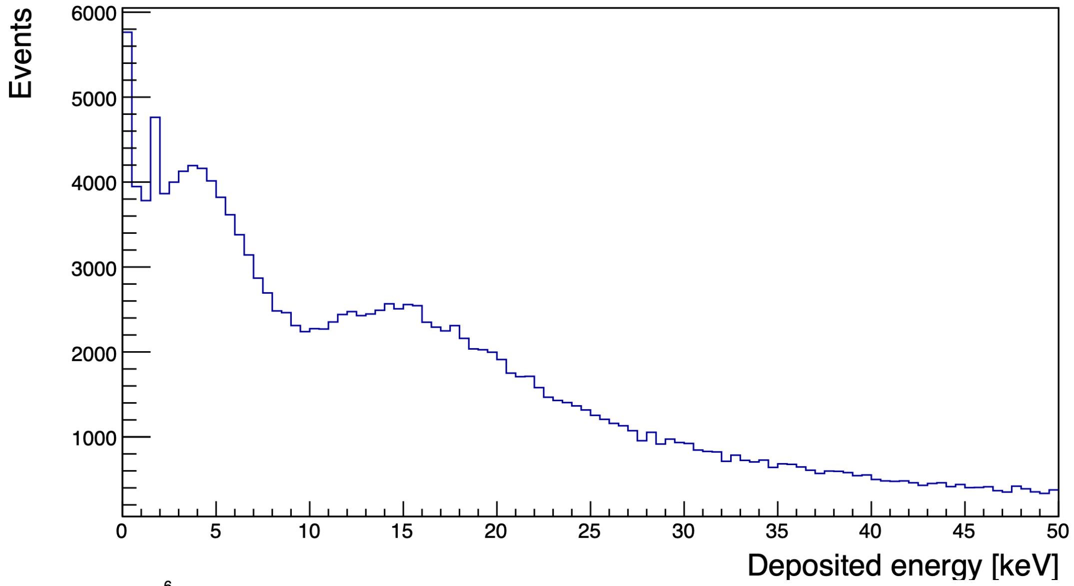
	ARCADIA	ALICE ITS3
Occupancy	$\sim 20\times10^{-6}$	$\sim 30\times10^{-6}$
Hit rate	$170\ MHz/cm^2$	$250\ MHz/cm^2$

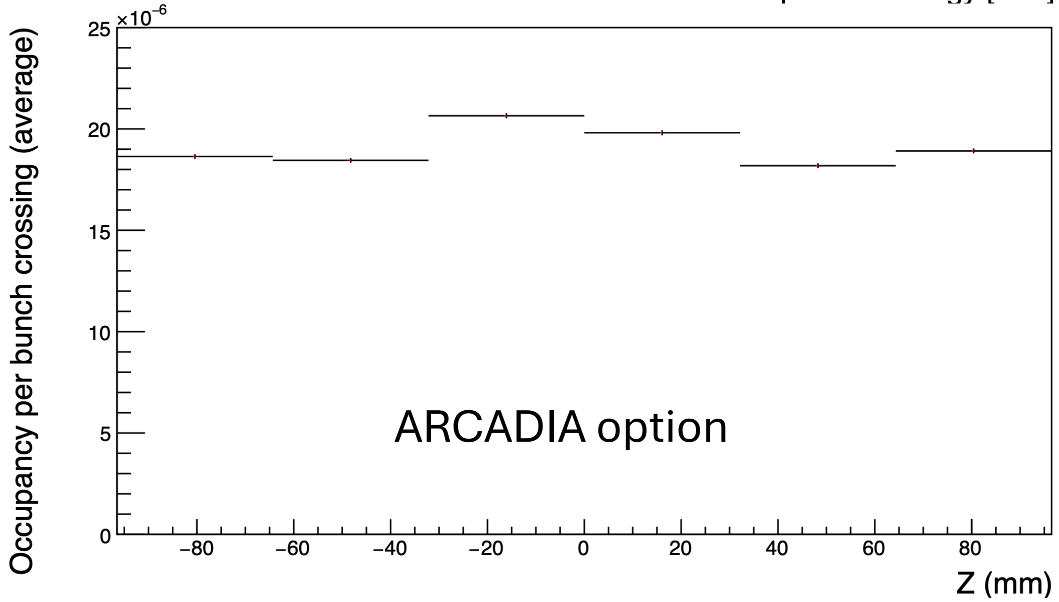
Similar occupancy levels in the first barrel VTX layer for the **two sensor options**, leading to data rates of O(10 Gb/s) per module.

Triggerless readout in the vertex for the moment seems neither impossible nor straightforward

A. Ilg

Preliminary

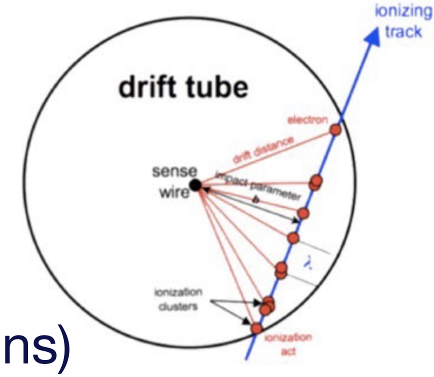




IDEA - Drift Chamber

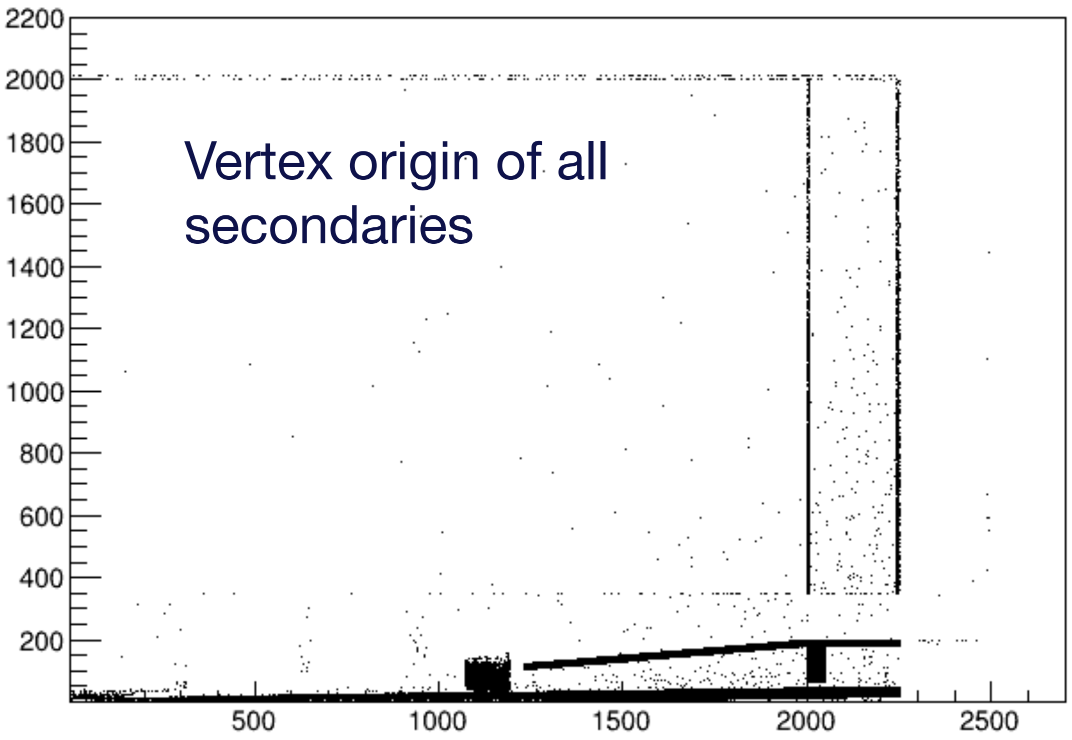
Preliminary

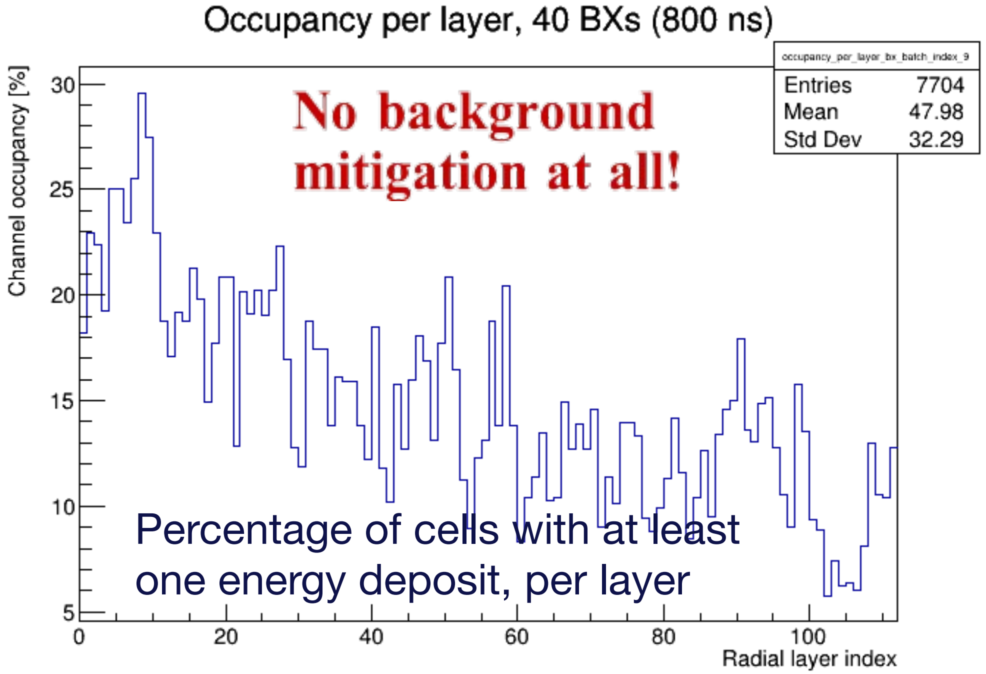
B. Francois



Investigated drift chamber (DCH) occupancy at the **SIM hit level** from IPC

- Assuming a conservative 400 ns maximum drift time
  - Need to consider twice this time window (e.g. hit far from wire occurring at –400 ns)
  - **Integrate** IPC bkg **contributions** for **800 ns** (Z-pole, 20 ns bunch spacing)
  - Keeping all Geant4 energy deposits (no filter): **overall SIM hit occupancy of ~15%**





See backup for details on technical set-up used for the study

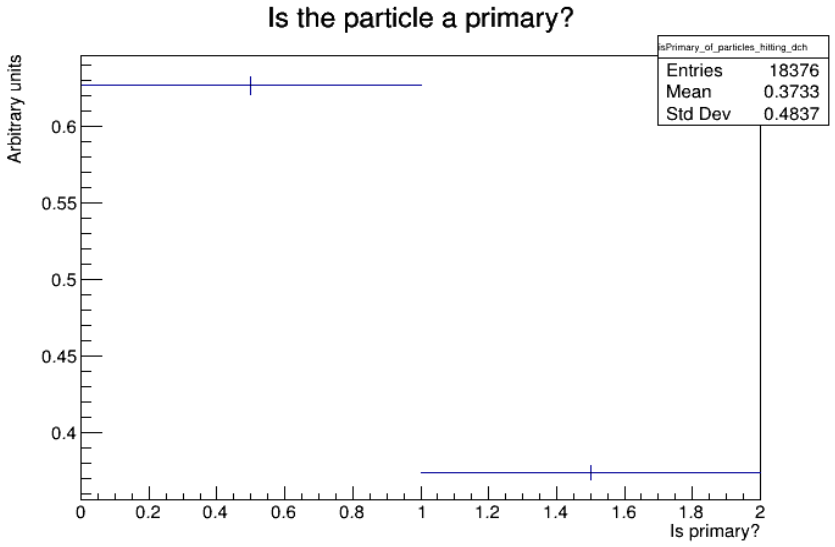
IDEA - Drift Chamber

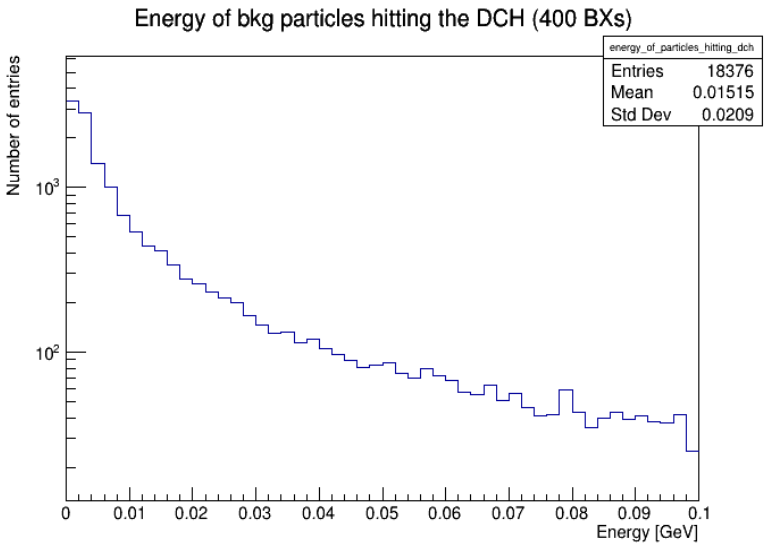
Preliminary

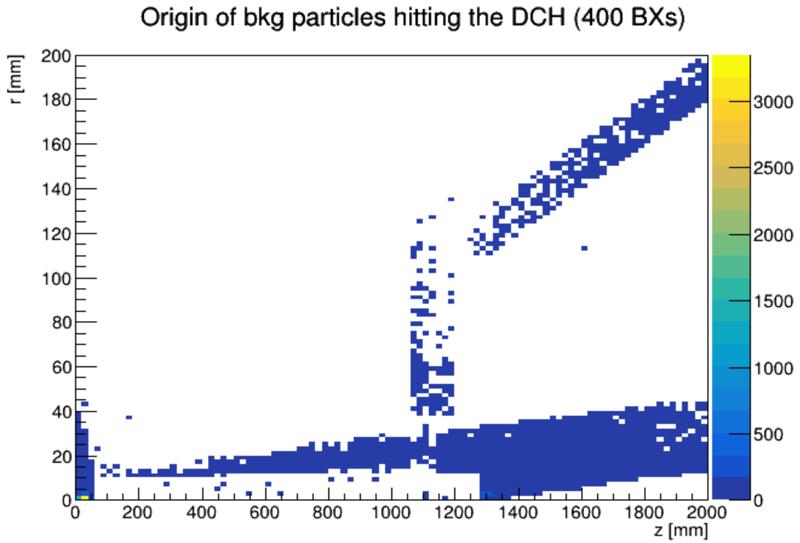
B. Francois

Properties of the background particles hitting the DCH

- ~40% of them are primaries
- They have low energies: <E> ~ 15 MeV
- No clear hot spot for the origin of secondaries, diffusion from the downstream beam line material





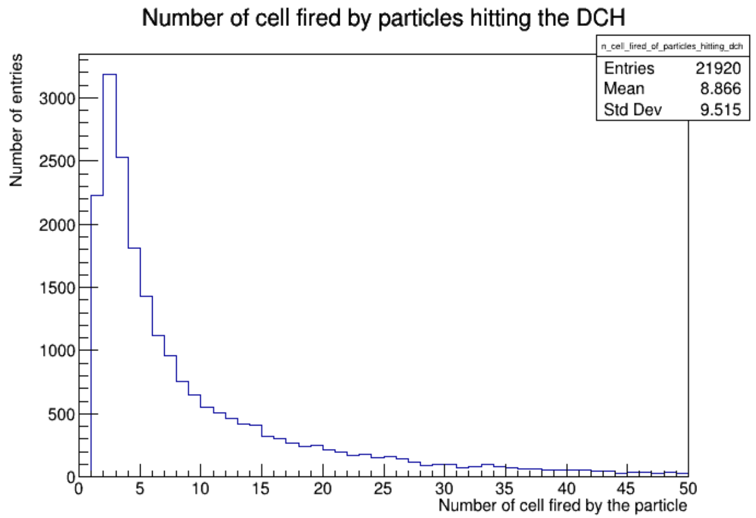


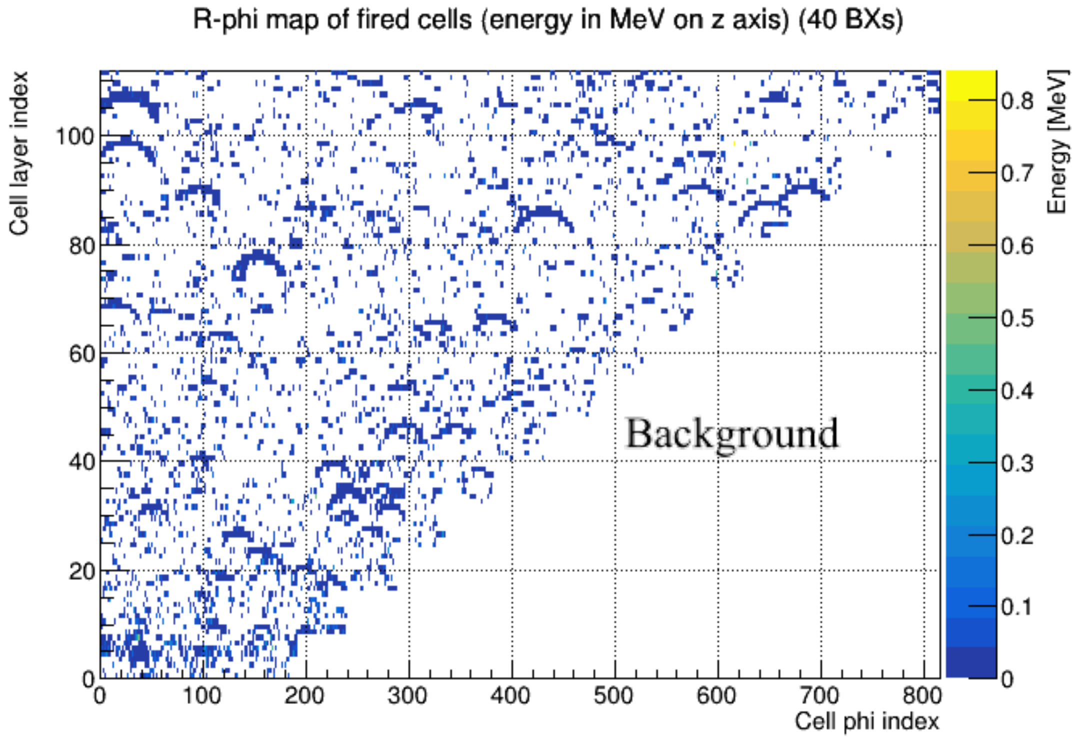
IDEA - Drift Chamber

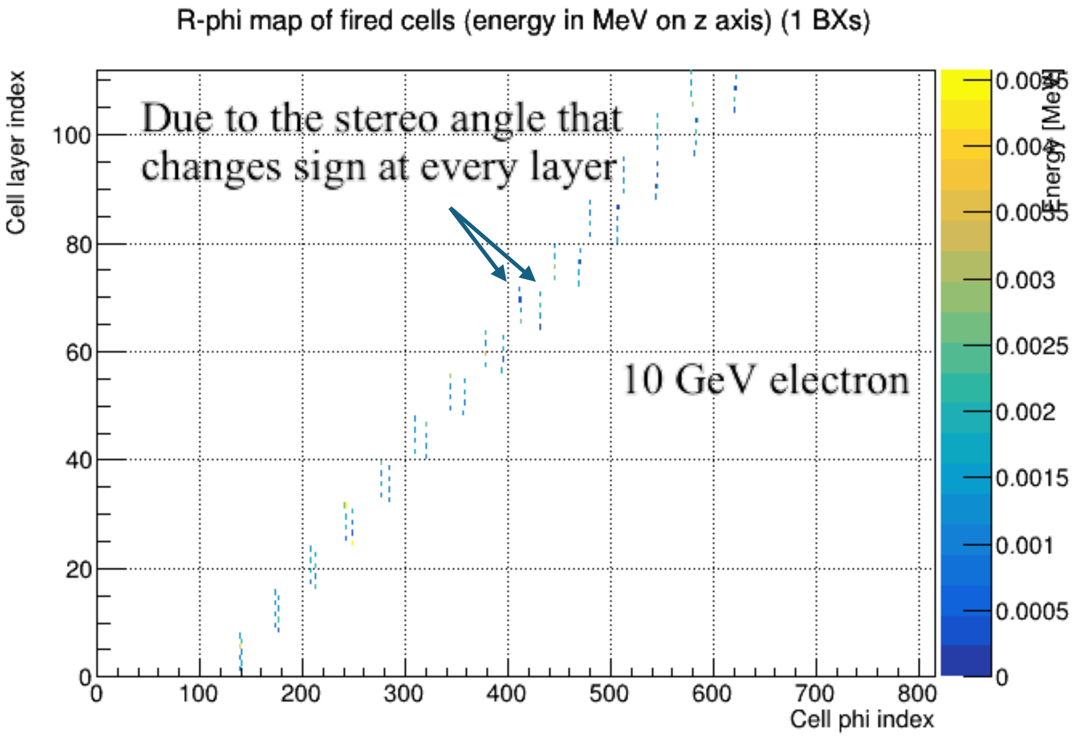
B. Francois

Preliminary

Potential handles to suppress background hits
- Cluster counting: will be studied when digitizer available
- Pattern recognition: background particles **fire few cells, no "straight lines" coming from the IP**
  - Can be done online: 1 FPGA reads multiple (>64) channels

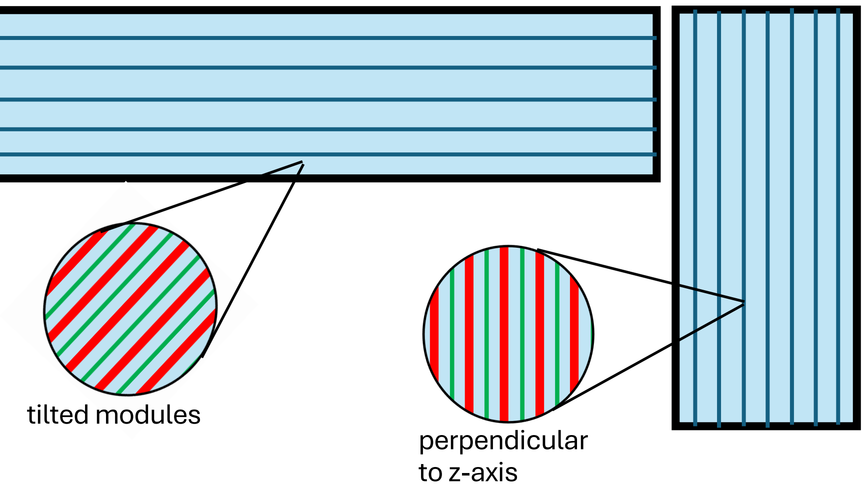






ALLEGRO - Noble Liquid ECAL

Preliminary

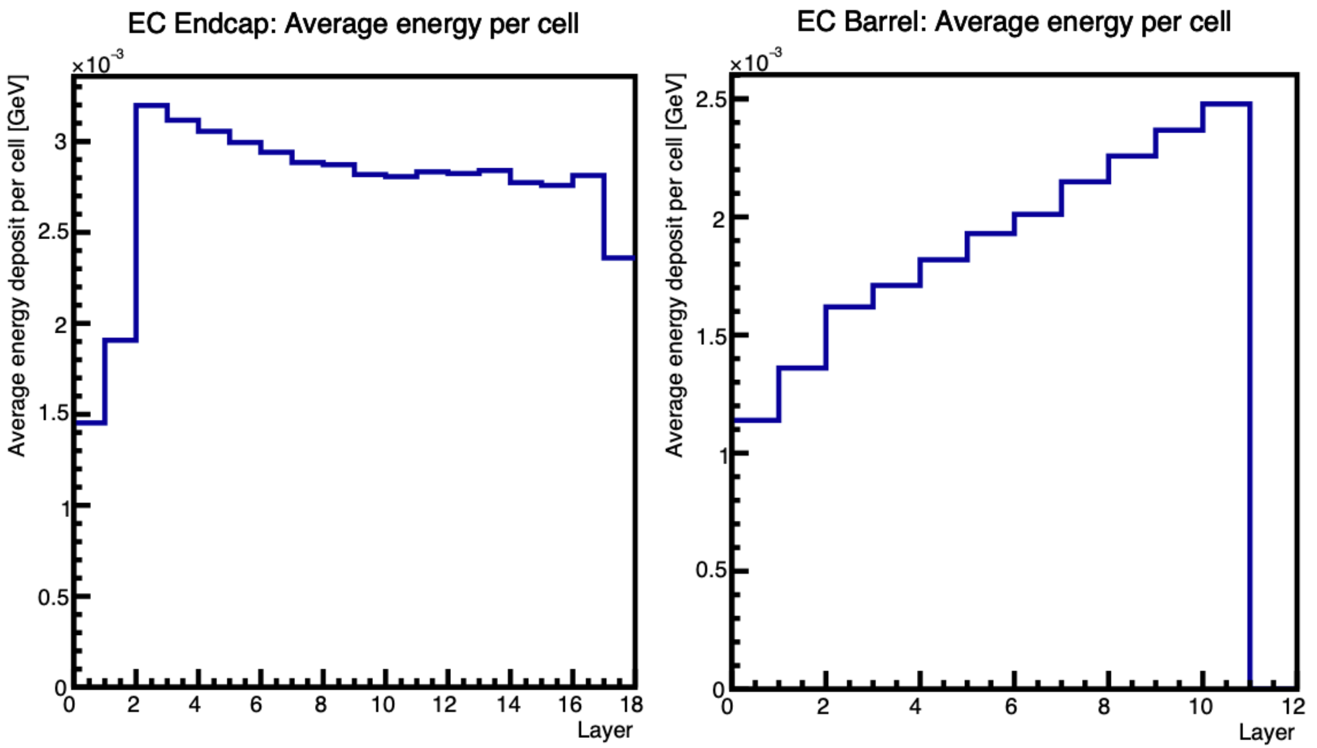


Sampling calorimeter: **lead absorbers**, **LAr gaps**, **high granularity readout**

- Barrel – 11 layers, double readout, segmentation projective in θ
- Endcap – 18 layers, single readout, simple geometry on x-y planes

Energy deposition per cell calibration:
20GeV muons (MIP)

A fraction of the average energy deposit per cell per layer to be used as **threshold** for **background suppression**



ALLEGRO - Noble Liquid ECAL

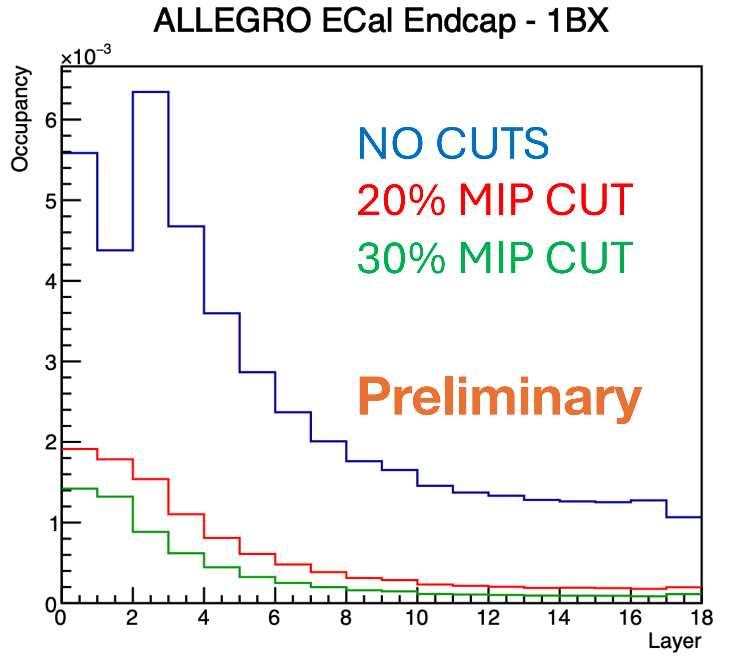
Preliminary occupancy estimates calculated for IPC.
Cut on the energy deposited in each layer is a fraction of the average energy deposit form a MIP.

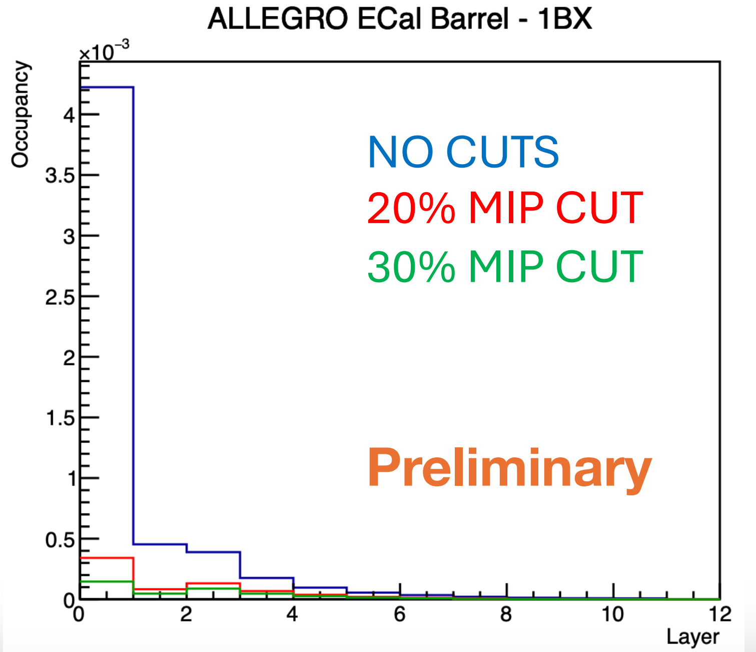
Average occupancy per BX (over 1000 BXs):

	NO CUTS	20% MIP CUT	30% MIP CUT
Endcaps	0.1% ~ 0.6%	0.02% ~ 0.2%	0.01% ~ 0.15%
Barrel	< 0.45%	< 0.03%	< 0.01%

Cut is very effective for the Barrel, a bit less for the Endcaps.

O(0.1%) occupancy/BX may grow up quickly if the **readout integration time** is larger than a few BXs ($\Delta t \sim 20ns$ at Z).





Other Sources of Backgrounds

Many **different generators** are used to produce the primaries from the other background sources.
A **custom conversion to HEPMC3** format is needed to read these particles in ddsim.

Sources currently under study are:

- **Radiative Bhabha:** beam particles which lose energy at bunch crossing and exit the machine dynamic aperture
- **Beam losses from failure scenarios:** high rate of beam losses in the IR coming from halo (transverse or longitudinal) being diffused by the collimators after lifetime drop
- **Synchrotron Radiation:** non-zero closed orbit, beam halo and tails (see K. Andrè talk)
- **Beam-gas** (elastic, inelastic) and Compton scattering on **thermal photons** (see G. Broggi talk)

Summary

Streamlined procedure for beam induced backgrounds estimates at FCCee

Preliminary **occupancy calculations** for Incoherent Pairs Creation at the **Z pole** have been presented:

IDEA VTX	**Two sensor options** investigated, both with **similar occupancy levels** $(20 \sim 30 \times 10^{-6})$, leading to O(10 Gb/s) data rates.
IDEA DCH	background integrated over **800ns**, **10%~15% occupancy** with no bckg suppression. Potential handles are **cluster counting** and **pattern recognition**
ALLEGRO ECAL	occupancy per layer **up to ~0.5% from 1BX**, reduced to 0.2% (endcap) applying a threshold on the energy deposit.

There is still a lot to do!

… other background sources
… other subdetectors
… (and upgrades of those we studied)
… mitigation strategies

Any help is welcome!

Backups

Parameters (for mid-term review)

V23

Table 1: FCC-ee collider parameters as of May 6, 2023.

Beam energy	[GeV]	45.6	80	120	182.5
Layout		PA31-3.0			
# of IPs		4			
Circumference	[km]	90.658816			
Bending radius of arc dipole	[km]	9.936			
Energy loss / turn	[GeV]	0.0394			
SR power / beam	[MW]	50			
Beam current	[mA]	1270	137	26.7	4.9
Colliding bunches / beam		15880	1760	440	60
Colliding bunch population	[10^{11}]	1.51	1.47	1.15	1.55
Horizontal emittance at collision ε_x	[nm]	0.71	2.17	0.71	1.59
Vertical emittance at collision ε_y	[pm]	1.4	2.2	1.4	1.6
Lattice vertical emittance $\varepsilon_{y,\mathrm{lattice}}$	[pm]	0.75	1.3	0.8	1.0
Arc cell		Long 90/90		90/90	
Momentum compaction α_p	[10^{-6}]	28.6		7.4	
Arc sextupole families		75		146	
$\beta^*_{x/y}$	[mm]	110 / 0.7	200 / 1	240 / 1	1000 / 1.6
Transverse tunes $Q_{x/y}$		214.158 / 214.200	214.130 / 214.200	398.150 / 398.188	398.148 / 398.182
Chromaticities $Q'_{x/y}$		0 / +5	0 / +2	0/ 0	0/ 0
Energy spread (SR/BS) σ_δ	[%]	0.039 / 0.089	0.069 / 0.110	0.104 / 0.143	0.160 / 0.192
Bunch length (SR/BS) σ_z	[mm]	5.60 / 12.7	3.47 / 5.52	3.40 / 4.70	1.81 / 2.17
RF voltage 400/800 MHz	[GV]	0.079 / 0	1.00 / 0	2.08 / 0	2.1 / 9.38
Harmonic number for 400 MHz		121200			
RF freuqeuncy (400 MHz)	MHz	400.786684			
Synchrotron tune Q_s		0.0288	0.081	0.032	0.091
Long. damping time	[turns]	1158	219	64	18.3
RF acceptance	[%]	1.05	1.15	1.8	2.9
Energy acceptance (DA)	[%]	±1.0	±1.1	±1.6	-2.8/+2.5
Beam crossing angle at IP	[mrad]	±15			
Crab waist ratio	[%]	70	60	50	40
Beam-beam ξ_x/ξ_y [a]		0.0023 / 0.096	0.0115 / 0.126	0.010 / 0.088	0.073 / 0.134
Lifetime (q + BS + lattice)	[sec]	15000	2500	2200	2200
Lifetime (lum) [b]	[sec]	1340	990	840	730
Luminosity / IP	[10^{34}/cm^{2}s]	140	20	5.0	1.25

Drift Chamber background study

Technical set-up

Key4hep release: source /cvmfs/sw-nightlies.hsf.org/key4hep/setup.sh -r 2024-06-06
Detector version:
/afs/cern.ch/user/b/brfranco/work/public/background_studies/k4geo/FCCee/IDEA/compact/IDEA_o1_v03/IDEA_o1_v03.xml
(beampipe from CAD, beamInstrumentation, lumiCal, vertex, DCH, solenoid)
2 Tesla solenoidal magnetic field + compensating solenoids + FFQuad fields
GuineaPig output fed to ddsim (Geant4) → SimHits
Crossing angle boost in ddsim (15 mrad)
PhysicsList: FTFP_BERT
Sensitive detector action: Geant4TrackerAction

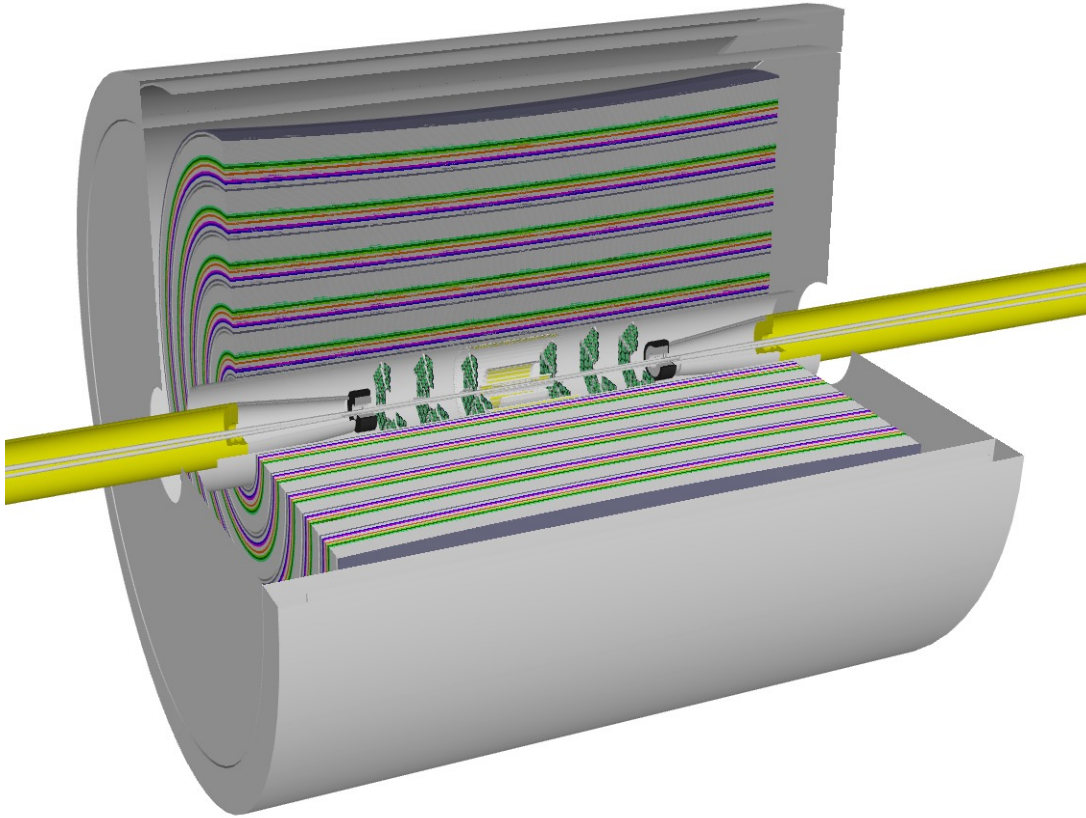
- One hit per step
- Default tracker action not appropriate
    - Combines hits from sensitive volume

'edep0' filter: keep all hits

- Default is to keep only hits with EDep > 1 keV

Max Step Length: 1 m

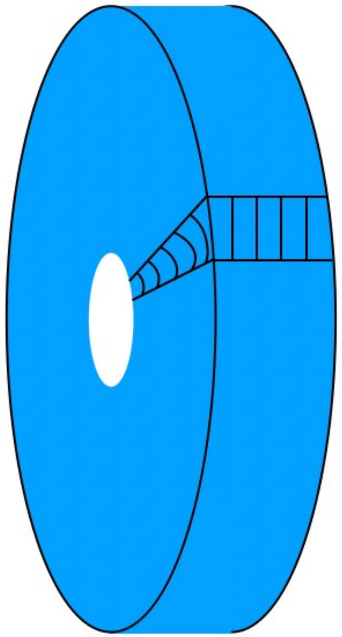
- Will effectively be limited by the sensitive cell size



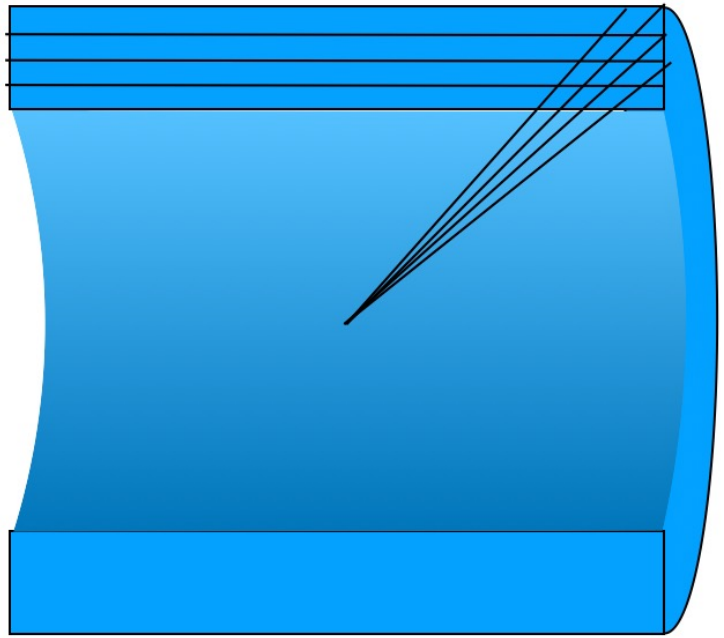
Had to use nightlies to have the last version of the drift chamber, for posterity, files can be analyzed with the 2024-04-12 release (or the one just after)

ALLEGRO ECal: MIP calibration

20GeV muons scan. For each event, calculate the energy deposition per cell per layer
Threshold per layer: 20% of the average energy deposition per cell

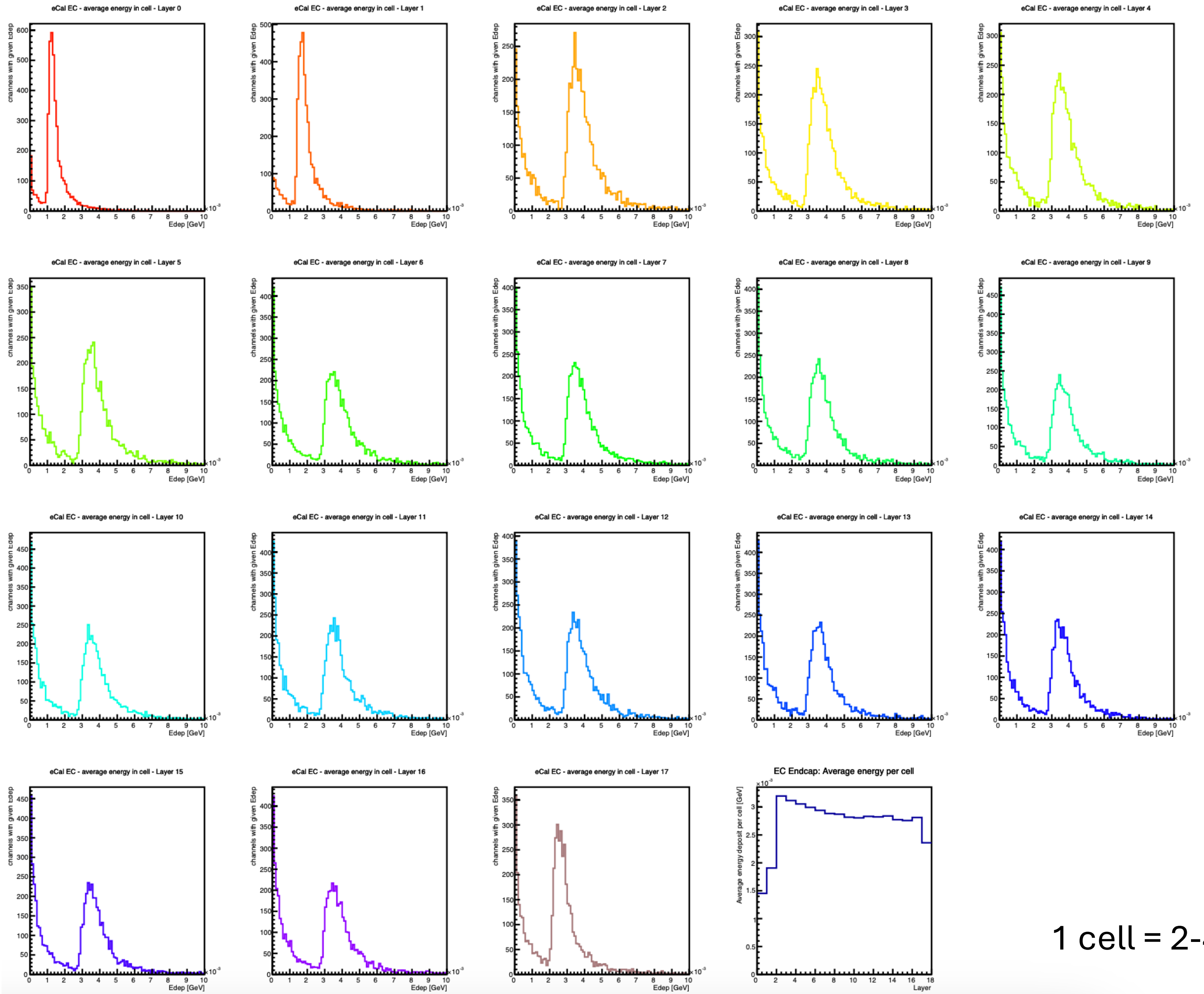


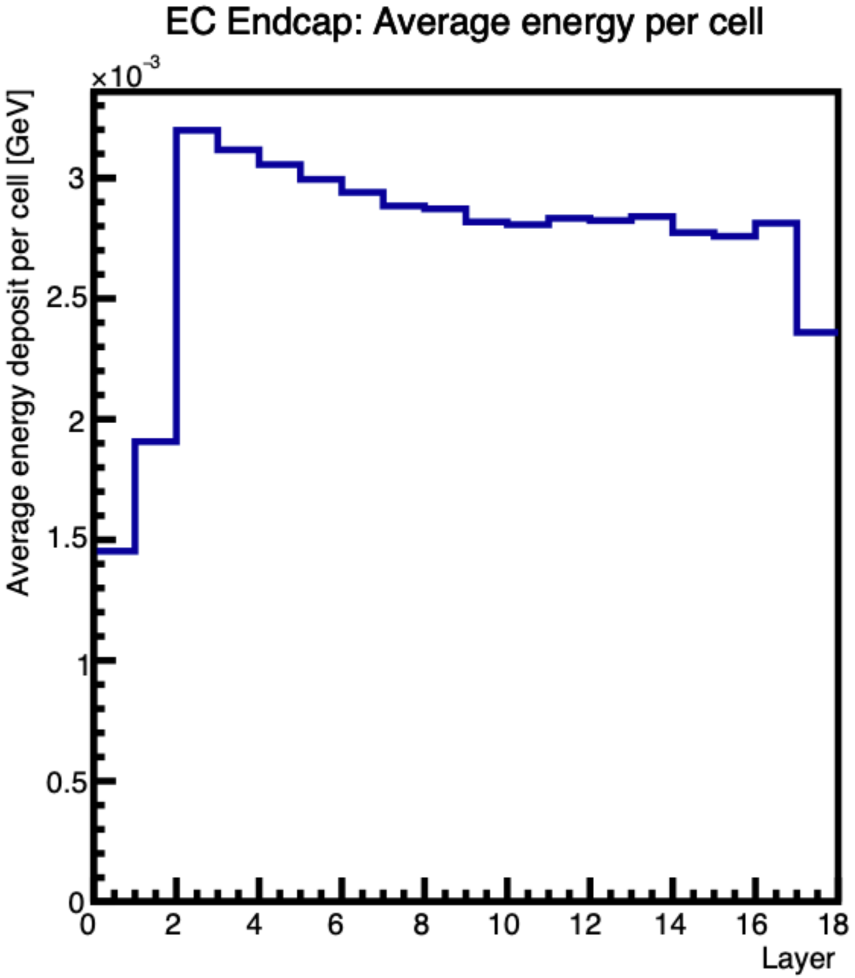
Endcaps:
- 18 layers in Z
  - 2 absorbers/gaps in L0, L1
  - 4 absorbers/gaps in L2-L17
- virtual $\theta - \phi$ segmentation



Barrel:
- 11 layers in R
- Projective θ segmentation
- Symmetric ϕ segmentation

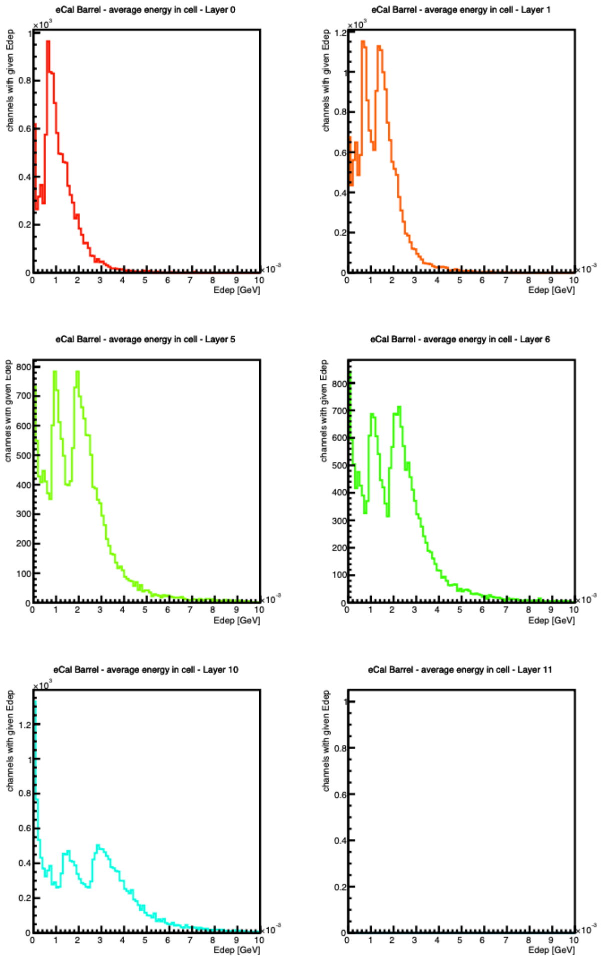
ALLEGRO ECAL – MIP calibration



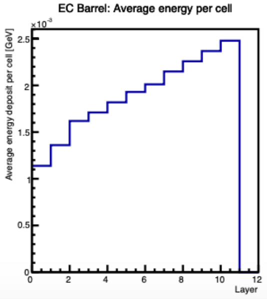


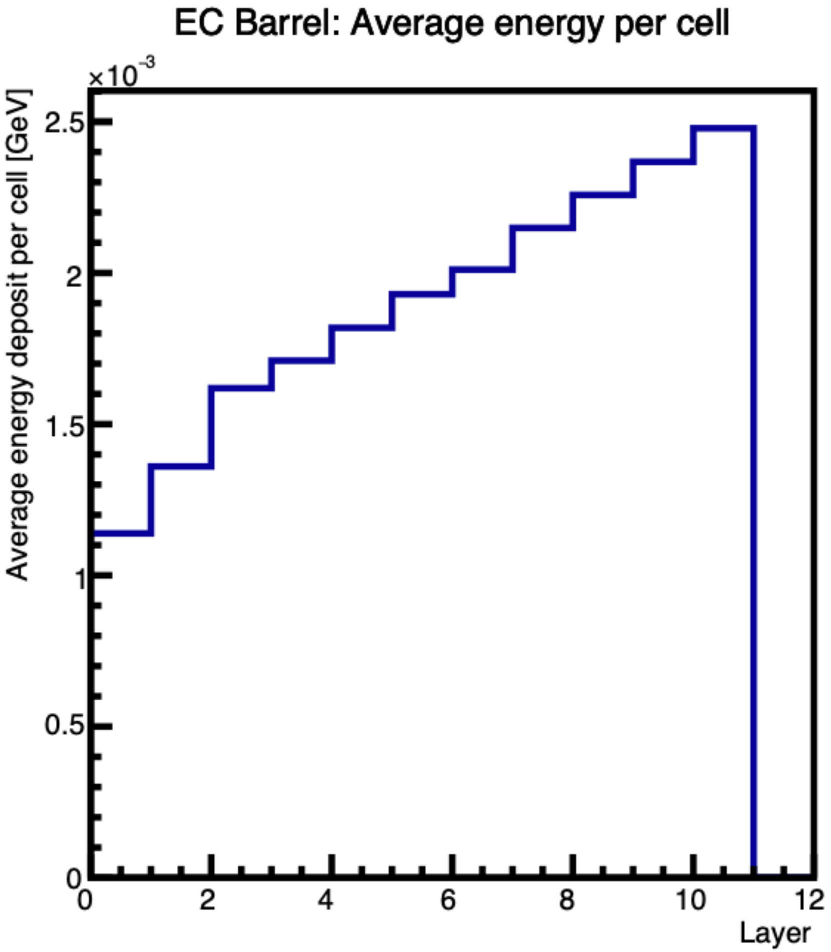
1 cell = 2-4 absorbers+gaps

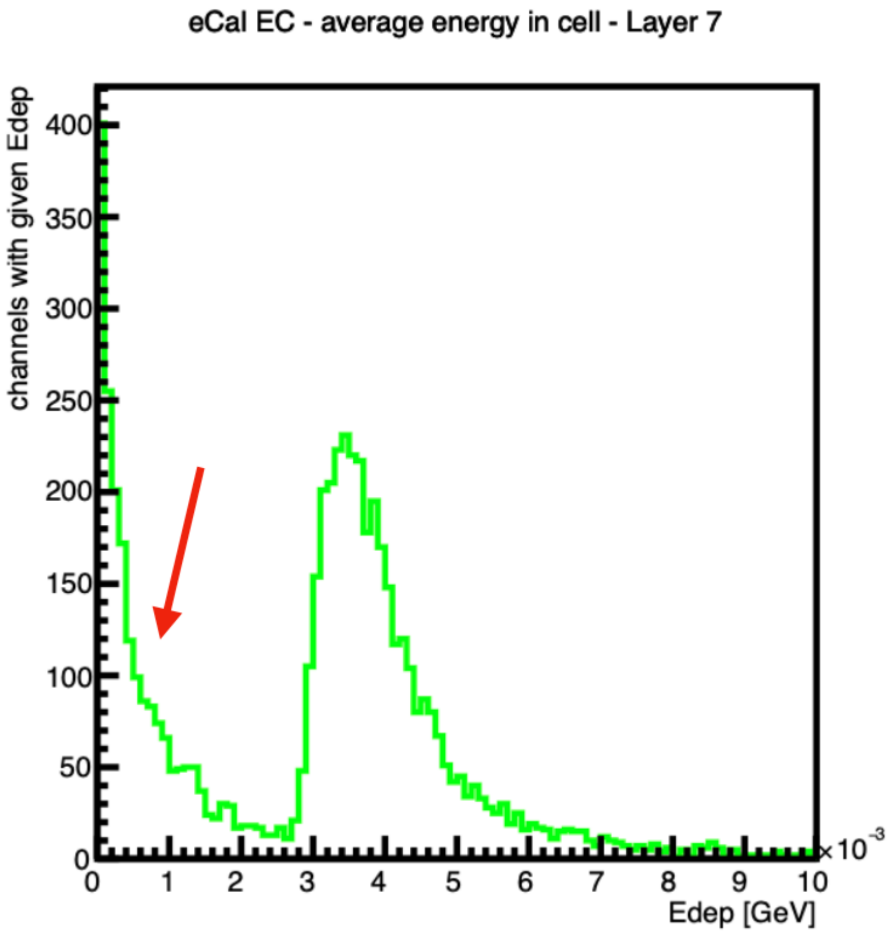
ALLEGRO ECAL – MIP calibration

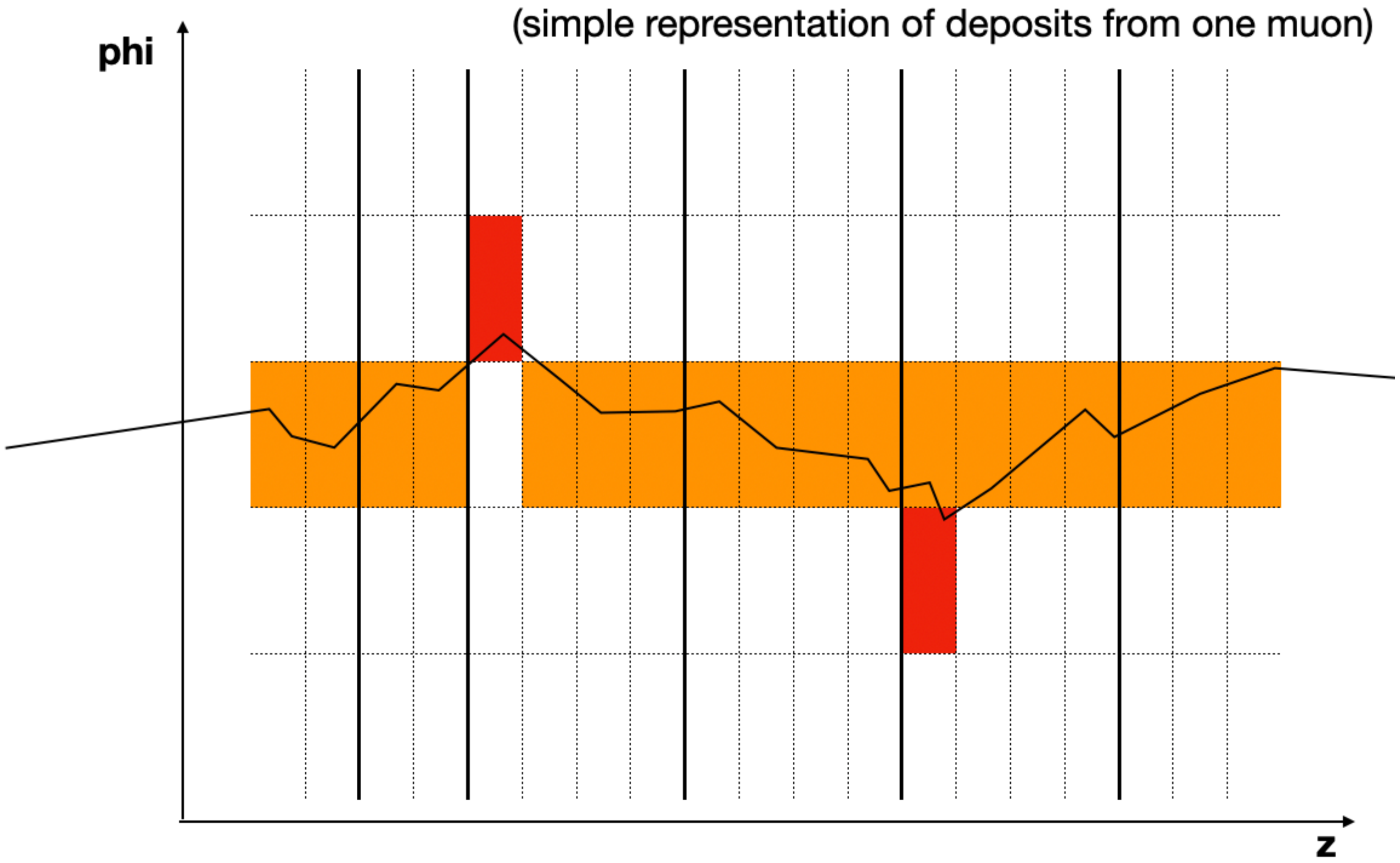


double readout cells



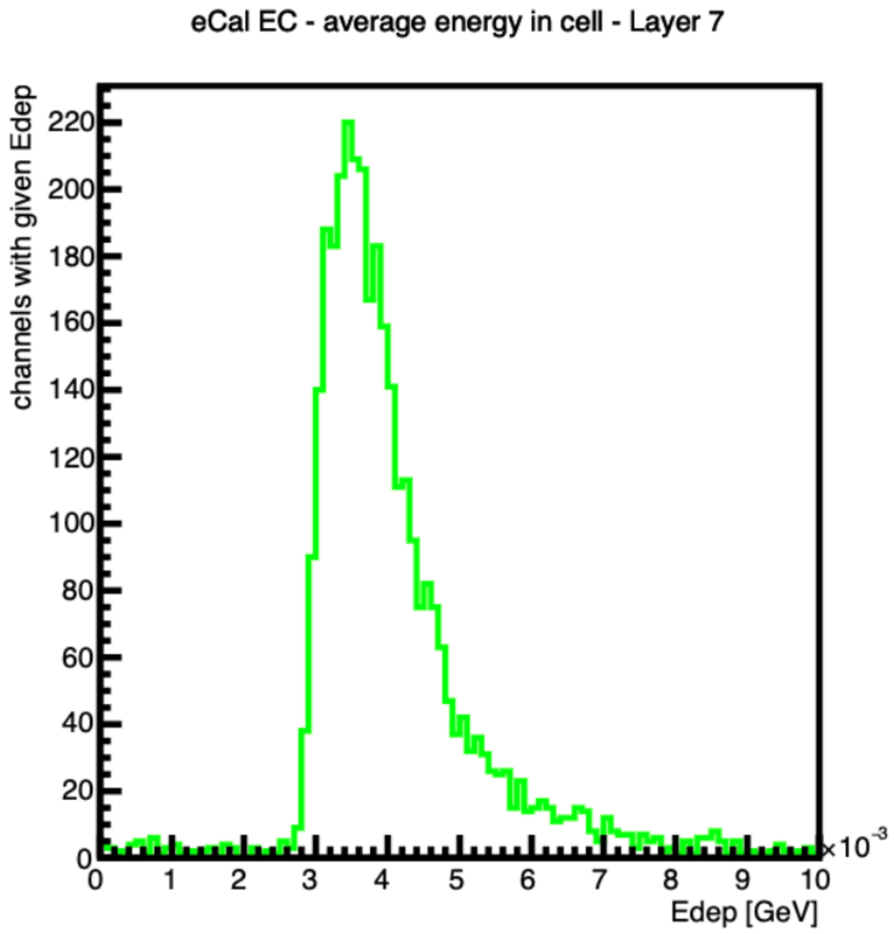


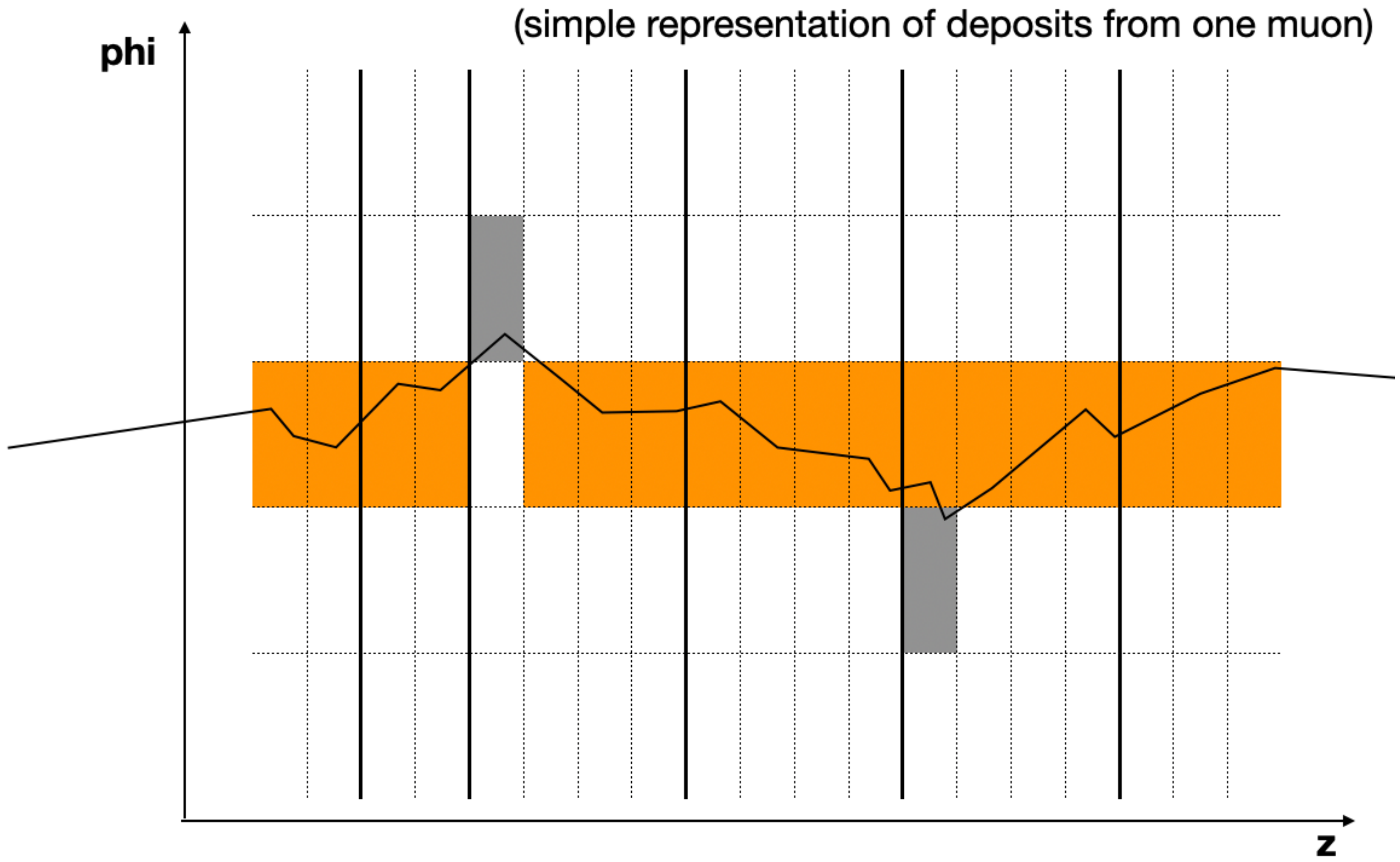




A muon will deposit energy mostly in the same **theta-phi bin** in each sublayer (i.e. abs+gap module). Sometimes a small deposit can happen in neighbouring cells, causing this tail at low energy.

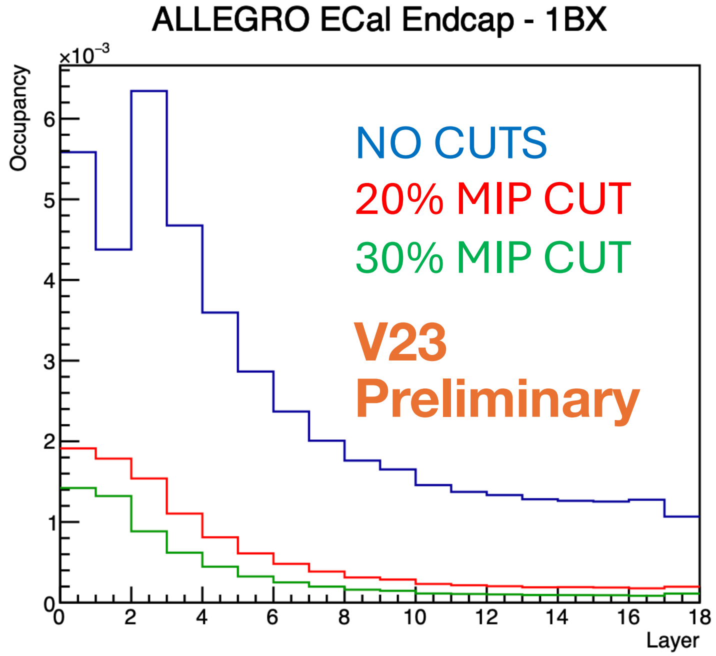
1 cell = 2-4 absorbers+gaps

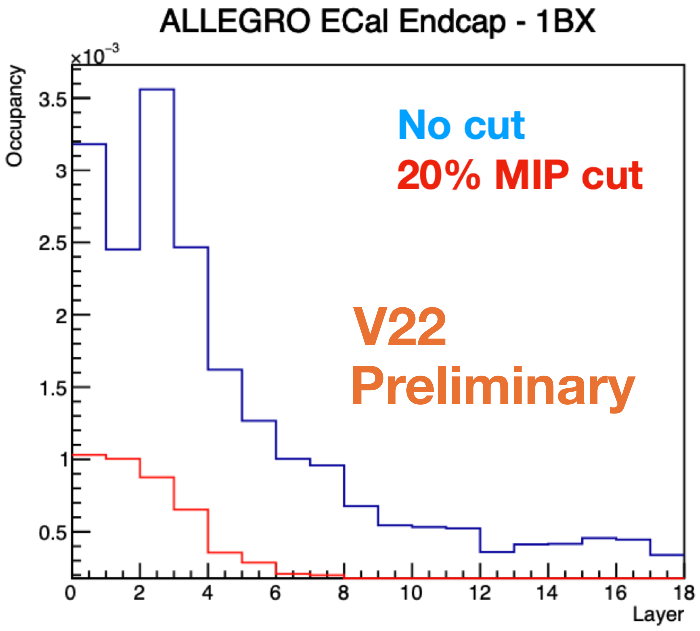


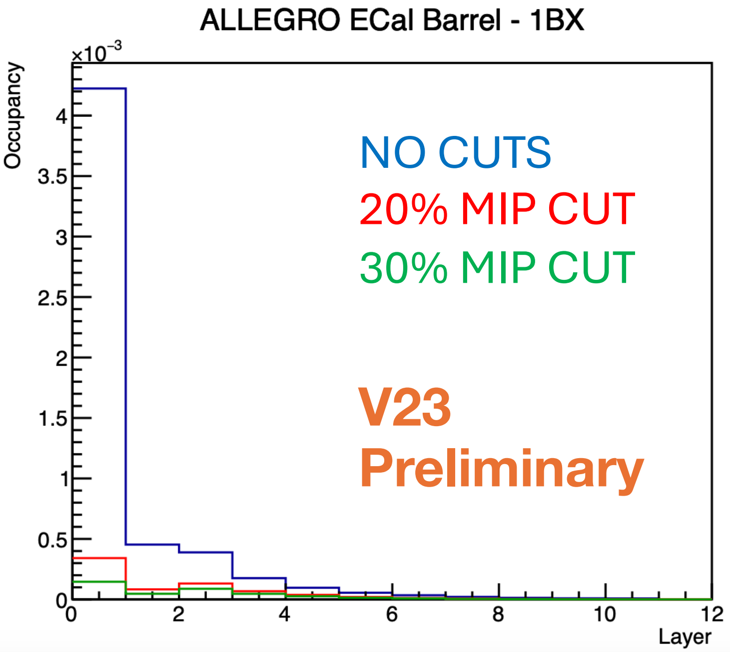


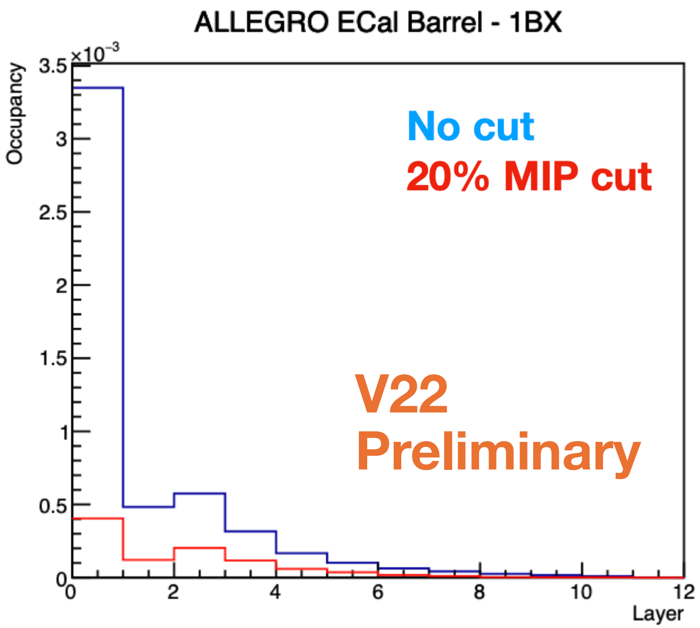
A muon will deposit energy mostly in the same theta-phi bin in each sublayer (i.e. abs+gap module). Sometimes a small deposit can happen in neighbooring cells, causing this tail at low energy.

Removing energy deposits from theta-phi cells different from the first one removes this tail.









	V23 (04may23)	V22 (04aug22)
$\beta_x, \beta_y \ [mm]$	110/0.7	100/0.8
$\sigma_x, \sigma_y \ [\mu m]$	8.837/0.031	8.426/0.034
$\sigma_z \ [\mu m]$	12700	10000
$N_e \ [10^{11}]$	15.1	24.3
N_{IPC} per BX	~900	~2100

$$\frac{N_{IPC}^{V23}}{N_{IPC}^{V22}} \propto \left(\frac{N_e^{V23}}{N_e^{V22}}\right)^2 \sim 0.5$$

BUT: Occupancy also depends on other factors, like kinematics and possible backscattered particles! e.g. $O_{EC}^{V23} > O_{EC}^{V22}$ but $O_{BAR}^{V23} \sim O_{BAR}^{V22}$