Guinea-Pig Dev Updates for IPC at FCC-ee

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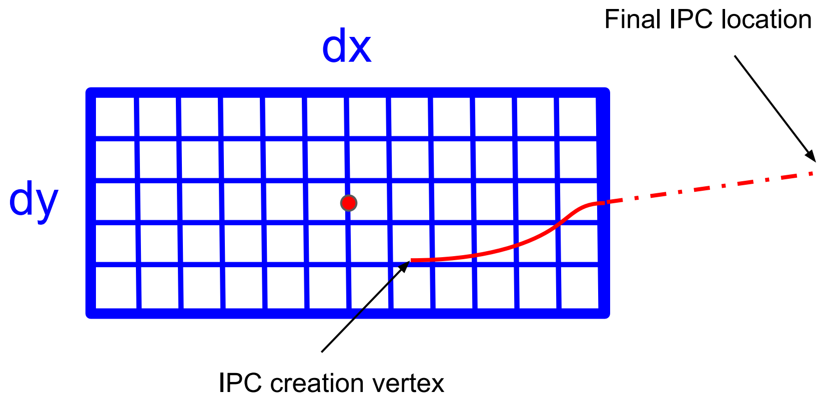
Simulation in Guinea-Pig

Guinea-Pig is based on finite-element calculation method (or particle-in-cell)

- Primary (Cartesian) grid defined to propagate the beams and calculate the electromagnetic (EM) fields in each cell
    - Routine to calculate IPC creation in each cell based on local EM fields
- Grid size depends on beam size and should be large enough in x to store the crossing angle
- Created particles are propagated through the grid under influence of the EM fields of the beams



Beam sizes (from latest lattice – see FSR)

- σ_x = 8837 nm
- σ_y = 31 nm
- σ_z = 12700 um

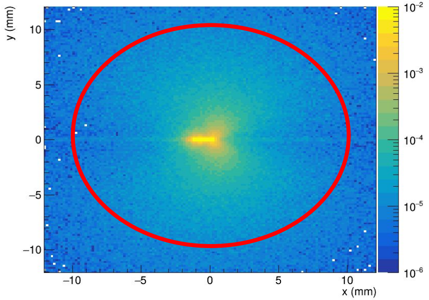
Window size → need to be rather large to contain the beams with large crossing angle

- dx = 12*150*σ_x = 1.32555 mm
- dy = 12*60.0*σ_y = 0.00186 mm
- dz = 2.0*σ_z = 25.4 mm

Issues with Guinea-Pig

Issue #1: early created particles can be propagated outside of the beampipe

- The outer grid size is already outside the beampipe (~16x16mm)
- IPCs propagate in vacuum after
- Potential solutions
    1. Move final IPCs to IP (“VTX000”)
        - Not ideal as particles can be created O(mm) away from IP, especially in z
        - Currently adopted as baseline sample and occupancy studies for FCC-ee → valid?
    2. Use GP kinematics at pair creation time and don’t track the particles in the beam (“GRIDS0”)
        - Effect of beam fields not taken into account
    3. Stop tracking of particles if a particle is outside of the grid (“GRIDSN”, with N the desired grid)
        - Geant4 takes over the propagation of the IPCs outside the grid
        - Neglects electric fields of the beam outside of the grid (effect being studied, but considered small)



Tails matter!

Issue #2: detector magnetic field is not taken into account

- Impact can be non-negligible for particles that have propagated large distances
- The VTX000 solution kind of mitigates it but correlations not taken into account
- Necessary to implement detector magnetic field and check the impact

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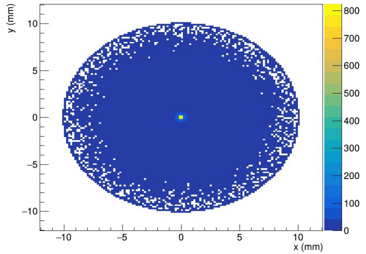
FIX 1: Now stopped before beam pipe, and is an input parameter to GP.

GRIDS8



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Implementation of detector solenoid

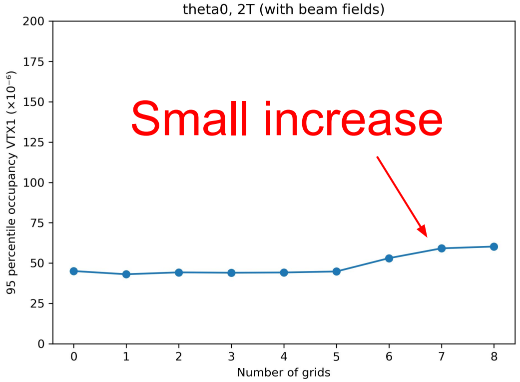
Extended magnetic field propagator to take into account external solenoid field

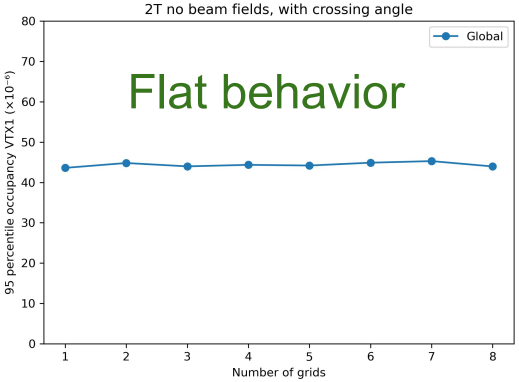
- Constant solenoid magnetic field along z, magnitude in Tesla
- New input parameter to GP configuration

```
$PARAMETERS:: FCCee_Z
{
bfield_z=-2.0;
beam_fields_on_pairs=0;
beampipe_r=10.0;
}
```

Extensive validation performed

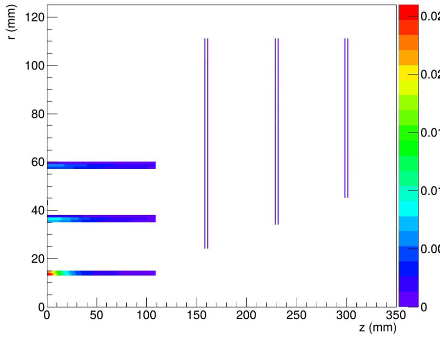
- Calculating Larmor radii and compare with analytic formulae
- Switching off beam EM fields to have pure solenoidal field (additional input parameter for debugging)
    - Compare with Geant4 by scanning each grid and calculate number of hits hitting the VTX → expect flat distribution
- Revealed small bug in current GP code that calculates the infinitesimal rotation angle
    - Impacts as well the beam magnetic field on the IPCs (but small effect, further being studied)
    - Equivalent of a lower absolute B field





grid	dx (mm)	dy (mm)	area xy (mm^2)
0	Production kinematics		
1	2.7	0.004	0.01
2	5.3	0.007	0.04
3	5.3	0.07	0.35
4	5.3	0.6	3.15
5	5.3	5.3	28.11
6	10.6	10.6	112.45
7	15.9	15.9	253.02
8	Inner beam pipe radius		

Final results

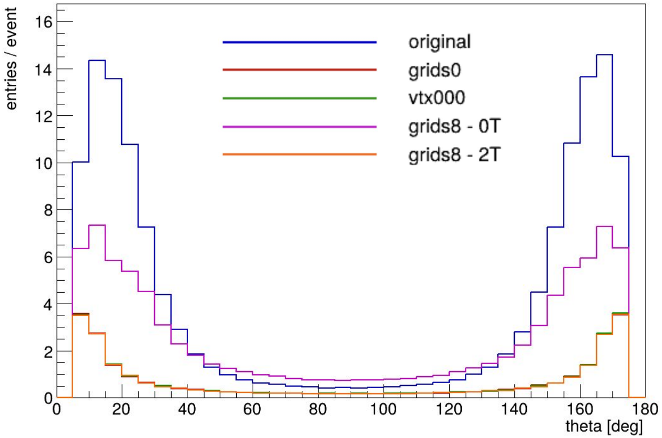


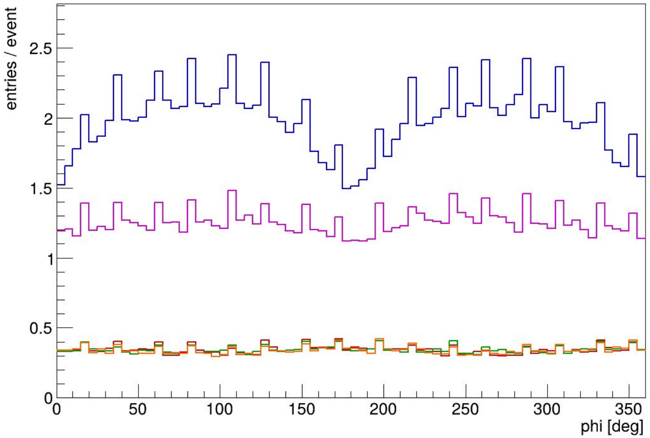
Shown the inner vertex layer 1 simhit distribution (CLD_o2_v07, 2T)

- θ distribution typically peaked in forward region
- ϕ structure due to beam field effects (little spikes due to overlapping VTX modules)

Comparison of different configurations

- ORIGINAL: largest number of IPCs as tails propagate without B-field beyond beam pipe
- VTX000: strong reduction as IPCs do propagate in B-field, curling and therefore lowering hits
- GRIDS0: take production kinematics, results in similar distribution as VTX000
- GRIDS8–0T: IPCs correctly stopped at beam pipe, but no B-field, less curl, therefore higher hit distribution
- GRIDS8–2T: IPCs correctly stopped at beam pipe with B-field, resulting in similar distribution as VTX000





Final results

Shown average number of hits on layer 1 (CLD_o2_v07, 2T)

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	Average number of hits
Original	141.9
Moved to IP (VTX000)	20.9
Production kinematics (GRIDS0)	20.2
Stopped at beampipe GRIDS8 + 0T in GP	88.6
Stopped at beampipe GRIDS8 + 2T in GP	20.7

Conclusion on the VTX000 approximation

VTX000 takes the particles at the end of the original simulation and moves them to the IP

- Takes into account the 2T solenoid
- Takes into account beam fields
    - Direction of the particle momenta not correct → can have impact locally
    - Correlation of beam fields with B field neglected → can have an impact at low fields

Approximation on VTX000 seems valid for the vertex barrel detector

- Quasi identical shapes and occupancies when comparing with the fixed GP

However, possible local shape effects can become visible

- Need to study this in entire phase space: endcaps, higher momentum tails
- Need to check also impact on radiative bhabha for lumical (very local effect)

Final large-statistic samples will be produced and effects can be studied on all sub detector elements

Conclusions

Improvements Guinea-Pig simulation

- Proper interface between GP and Geant4: stop the particle propagation at the inner beam pipe radius
- Implemented and validated detector magnetic field in GP
- Preliminary effects on occupancy studied in various configurations
- Check effects of modifications in the forward region (IPCs, also radiative Bhabha)
- List of improvements

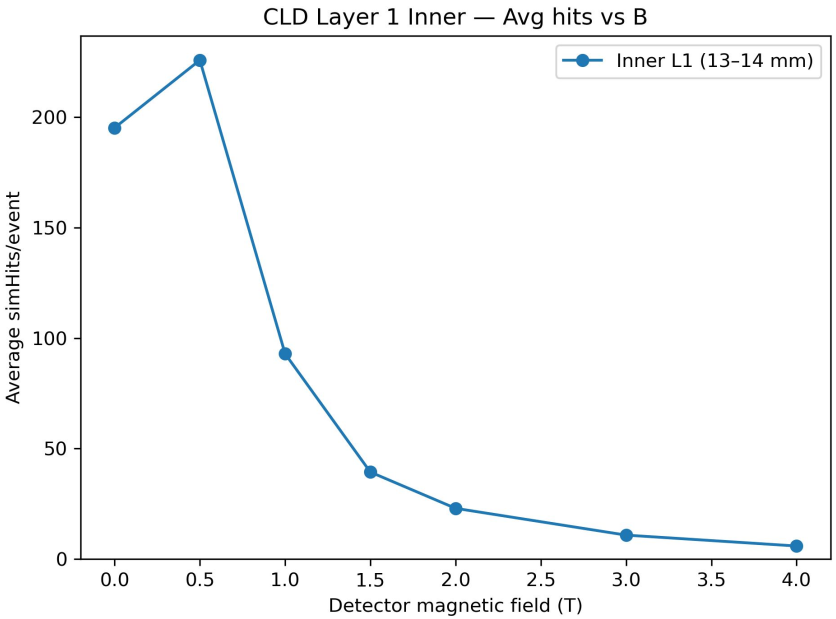
Working together with the WarpX developers for a common definition of this interface and data formats

- Will further be used to benchmark both codes and further validation

Effect of detector magnetic field

Studied the magnitude of the magnetic field on the occupancy/hits on the first vertex layer

- High occupancy at 0T as IPCs don't curl
- Maximum occupancy in between 0–0.5T due to positive correlation with beam fields and detector acceptance effects
- Steep decrease of occupancy when increasing the field



Field (T)	Average number of hits
0	195
1	93
2	23
3	11
4	6

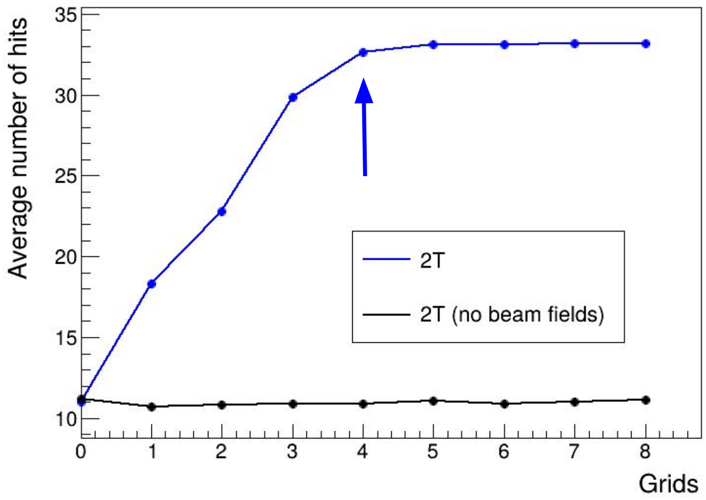
Effect of beam fields during tracking

IPCs are tracked in the primary and secondary grids under influence of the beam fields

- At large distance, the influence of the beam fields should vanish (net charge = 0)

To set a scale of this characteristic distance, plot the IPC occupancy/multiplicity on VTX at each grid step

- When grids starts to increase (0-4), IPCs gain energy due to the EM fields and the occupancy increases
- At larger grids (> 4), the effect vanishes and a constant/saturated occupancy is reached
- This typically correspond to a radius of around 5mm



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