WarpX & Guinea-Pig for Incoherent Pair Creation

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Today’s updates

Reminder: we are benchmarking beam-beam generators Guinea-Pig and WarpX for Incoherent Pair Creation (IPC) at the FCC-ee.

Today:

- Interfacing WarpX with DDSim
- How big does the grid need to be?

Unweighting in WarpX

What WarpX gives us

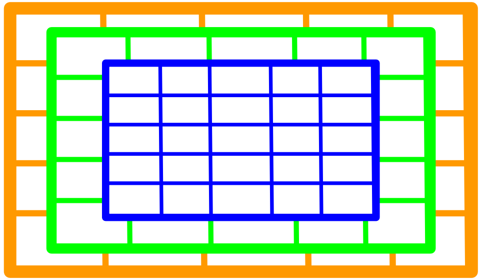
- About 6 million e^+e^- pairs per run but each is only a small fraction of a real pair, labelled with a weight
- The weights add up to 614 (the real number of pairs in one bunch crossing)

Turning fractions into real pairs

- Go through the list once; keep each pair with a probability equal to its weight
- On average 614 survive
- No weight is above 1, so nothing is ever counted twice; the e^+ and e^- are kept or dropped together
- Repeat with new random numbers for the next BX

Out: Ordinary events with ~614 whole pairs each, in standard EDM4hep format, identical to Guinea-Pig, ready for ddsim

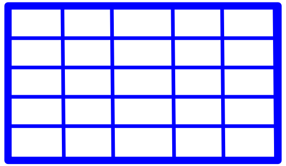
Grids in Guinea-Pig and WarpX



Guinea-Pig:

Several grids share the same cell count (ex. 128 × 128 × 128) but each covers a progressively larger area

- Fine cells where the beam core is, coarse cells out in the tails
- Grid1 = innermost grid only
- Grid5 = five nested layers



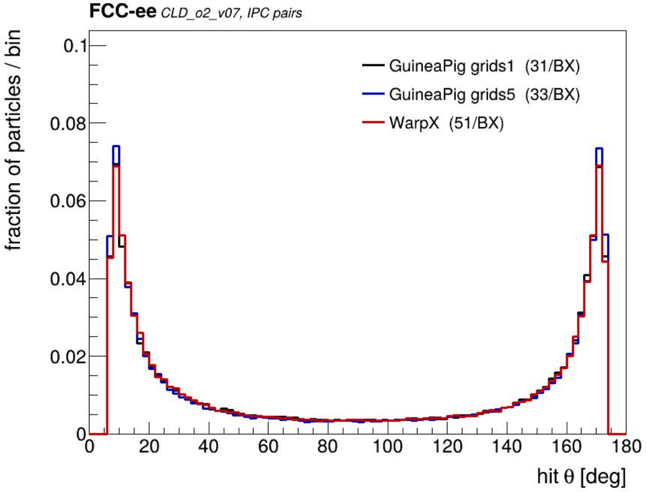
WarpX:

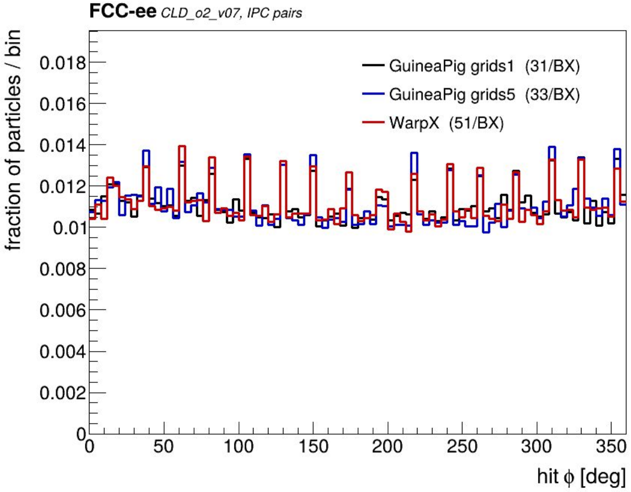
One uniform 3D Cartesian grid

- Here: 256 × 1024 × 512 cells chosen to match GP's cell sizes (7.44 μm × 26.0 nm × 475 μm)

Grid1 roughly corresponds to the WarpX grid extent.
Grid5 is the configuration that contains enough of the beam fields.

CLD barrel results





- Theta and phi shapes align very nicely, especially between the **WarpX** run and **Grid1**
- Can see a slight difference between WarpX and **Grid5** in the forward regions
  - IPCs gain energy in the beam fields

Will see more differences in the lumi-cal or more forward regions

How to compensate for WarpX grid size?

The beam fields matter up to (half length) ~1 mm in x and y

- Guinea-Pig handles this with layered FFTs
- If we increase WarpX to this volume and discretize more to maintain resolution…

region	n_x	n_y	n_z	cells
WarpX today	256	256	256	1.7×10^{7}
±0.5 mm	281	153,850	256	1.1×10^{10}
±1 mm	561	307,700	256	4.4×10^{10}

So, we need to find a way to add area in WarpX's Poison solver while maintaining fine granularity
Layered FFT (like Guinea-Pig)? Dirichlet solver? Something else?

Conclusions and next steps

- Interfaced WarpX with DDSim in the FCC key4hep data format
- Have first results for CLD
- Must work towards a converged WarpX
- Must find a way to increase grid size in WarpX while maintaining resolution

Primary grid size

X-dimension: should contain effect of crossing angle

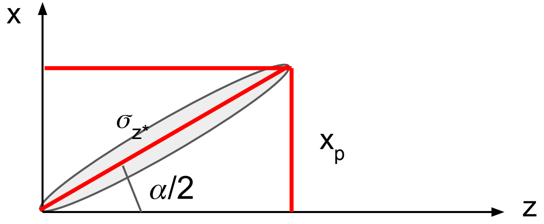
- Projection on σ_{z*} x-axis: cut_x = σ_{z*}*sin(α/2) ~ σ_{z*}*α/2

Y-dimension: Hourglass effect evaluated at z-bound

- σ_y (z) = σ_{y*}*sqrt(1+(z/β_{y*})^2)

Z-dimension: full overlap of bunches

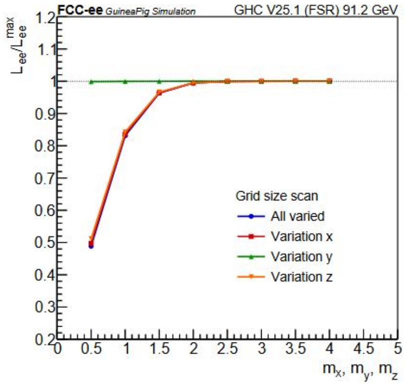
- Take m*σ_{z*} envelope, m_z multiplier



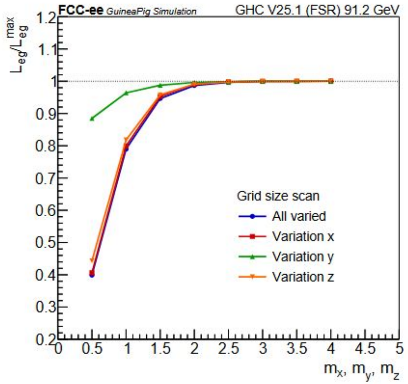
$$\Delta x(n_x) = m_x \sigma_z \sin\alpha,$$

$$\Delta y(n_y) = \sigma_y^* \sqrt{1 + \left(\frac{m_y \sigma_z}{\beta_y^*}\right)^2},$$

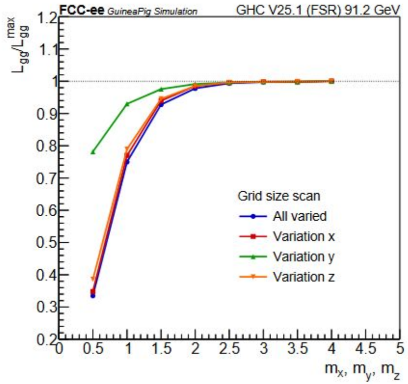
$$\Delta z(n_z) = m_z \sigma_z \cos\alpha.$$



e-e luminosity



e-g/g-e luminosity



g-g luminosity

Determine m_x, m_y and m_z by checking convergence on ee, eg/ge, gg luminosities

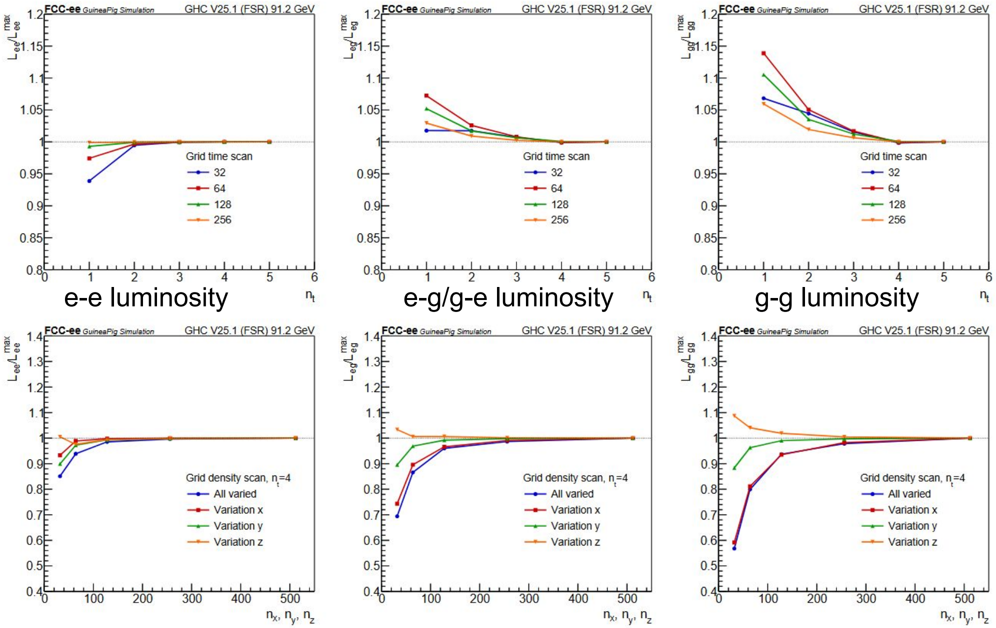
$m_x = 2$
$m_y = 2$
$m_z = 2$

Primary grid density

Grid density in nx, ny and nz

- nz defines the crossing evolution
- Number of timesteps per z-slize

Total number of slices proportional to nz^2nt



Determine nt, n_x, n_y and n_z by checking convergence on ee, eg/ge, gg luminosities

First scan on nt: necessary to get the overshoot of gg luminosity right

- Overshoot caused by dynamic effects in photon sampling

Then scan on n_x, n_y and n_z dd

- nx = ny = nz = 256 good
- Use 128 for studies (faster)

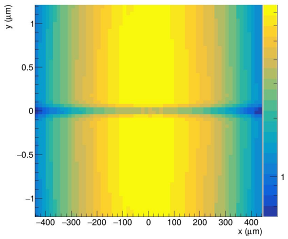
Secondary grid size

GP has a configurable amount of secondary grids, co-centric, with larger cell sizes (same nx)

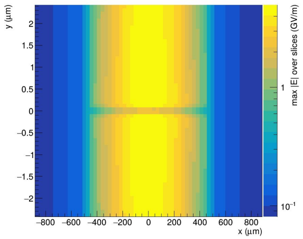
- Used for tracking of IPCc
- Extra grid dimensions defined till beam field matters
- Poisson equation solved in these grids
- Outside grid the fields are analytic using a line charge

Grids = 5 convergence reached on analytic field equations
→ beam effects important up to 1mm

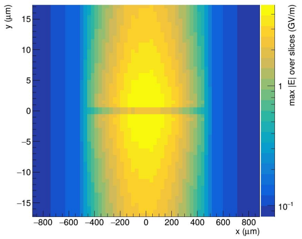
GRIDS1



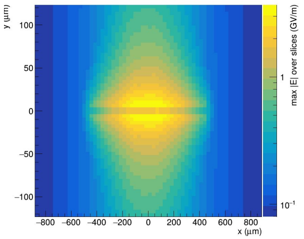
GRIDS2



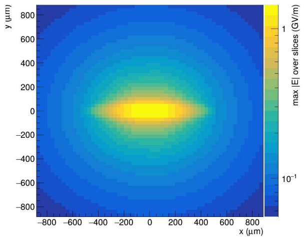
GRIDS3



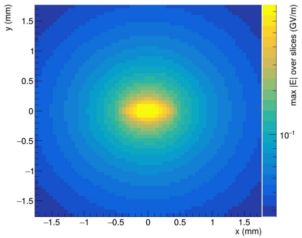
GRIDS4



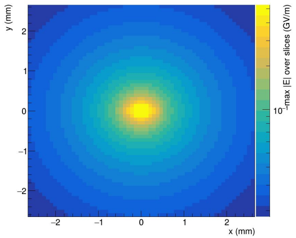
GRIDS5



GRIDS6



GRIDS7



GRIDS8