

Guinea-Pig & WarpX for Incoherent Pair Creation

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Today's updates

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

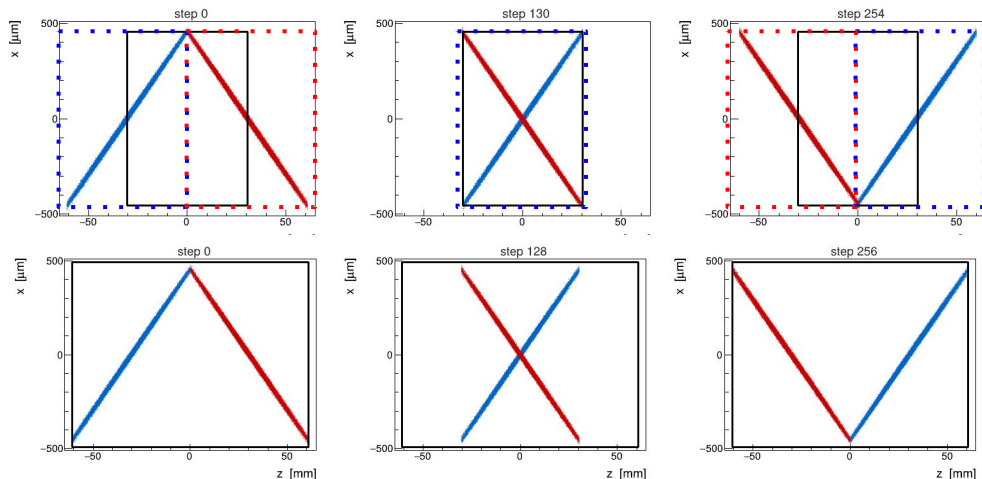
- In order to compare, we need to use configurations that are immune to numerical instabilities
 - Meaning stable luminosity outputs for each IPC process
- Matched the two simulations so they can be compared like for like
- Luminosity comparison
- Next steps

Which configuration we choose

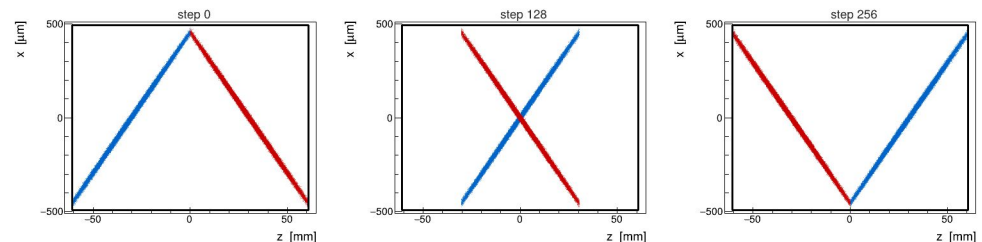
We use a relatively cheap Guinea-Pig configuration for our comparisons ($n_{x,y,z} = 128$ with $nt = 1$)

- Choose WarpX configuration based on our Guinea-Pig configuration
- Grids are defined differently in the two simulations
- We adjust $n_{x,y,z}$ in WarpX so that the cell sizes are the same (138 x 768 x 256)
 - Should result in the same physics

GP:



WX:



Guinea-Pig

$$L_x = 2 \sigma_z \sin \alpha$$

$$L_y = \sigma_y^* \sqrt{1 + \left(\frac{2 \sigma_z}{\beta_y^*} \right)^2}$$

$$L_z = 2 \sigma_z$$

Using $2\sigma_z$
(based on GP convergence studies, in backup)

WarpX

$$L_x = 2 \sigma_z \sin \alpha + 4 \sigma_x(z_0) \cos \alpha$$

$$L_y = 6 \sigma_y^* \sqrt{1 + \left(\frac{z_0}{\beta_y^*} \right)^2}$$

$$L_z = 4 \sigma_z \cos \alpha$$

$$\begin{aligned} z_0 &= 2 \sigma_z \cos \alpha \\ \sigma_x(z_0) &= \sigma_x^* \sqrt{1 + (z_0/\beta_x^*)^2} \\ \alpha &= 15 \text{ mrad} \\ \text{all } L &\text{ are half-widths} \end{aligned}$$

Comparing luminosities

After configuring WX and GP with the same grid cell size

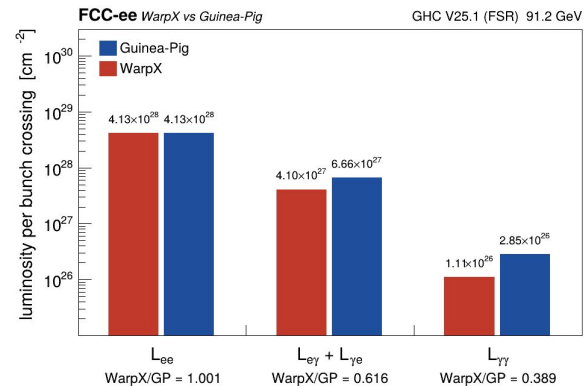
- Electron-positron (L_{ee}) luminosity agrees to 0.1%
- Photon luminosities (L_{eg} and L_{gg}) are lower in WarpX (0.62× and 0.39× that of Guinea-Pig)

Why do the photon numbers differ?

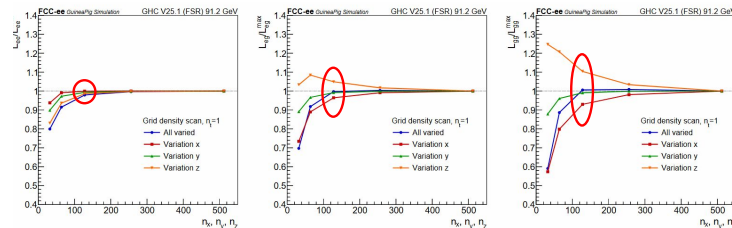
- At this resolution Guinea-Pig and WarpX numerical instabilities are still high for L_{eg} and L_{gg}
- A fair comparison should use numerically stable configurations

Why not just use the “converged” GP and WX as a comparison?

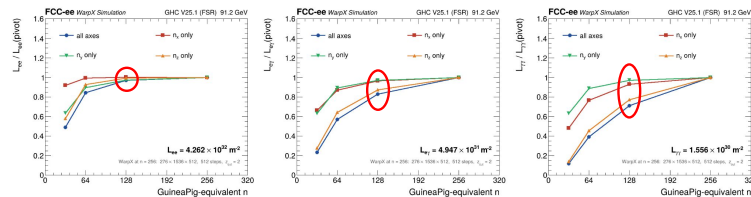
- WarpX’s simulation box has to hold both beams entirely
- So higher resolution quickly runs out of GPU memory
- Haven’t settled on a “correct” WarpX configuration to run with our resources



Guinea-Pig convergence plots:



WarpX convergence plots:



Both Guinea-Pig and WarpX photon luminosity still changing with resolution at the configuration we use (red circle)

Conclusions and next steps

Conclusions

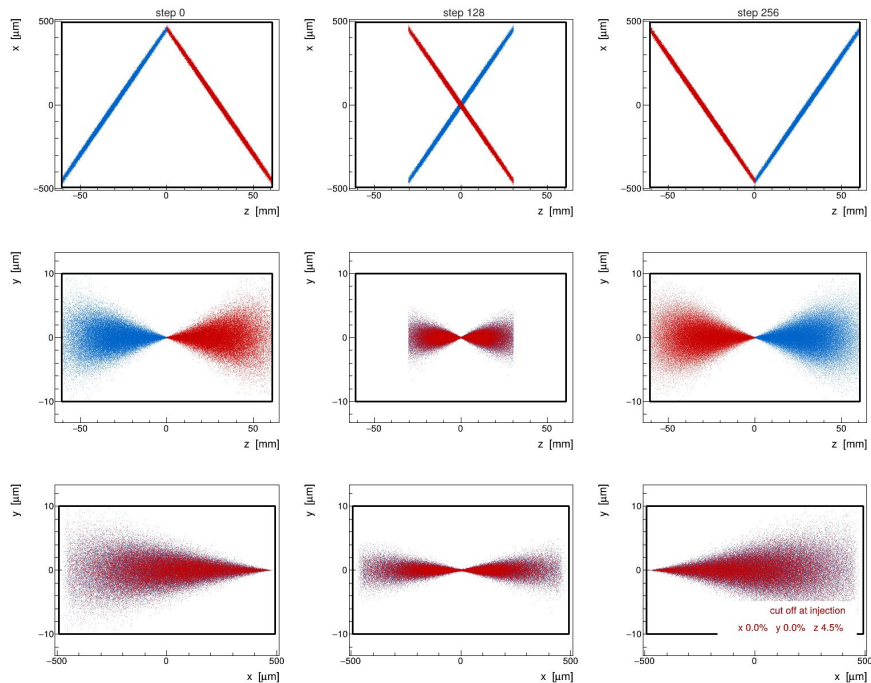
- WarpX and Guinea-Pig are now set up with matching grid cell sizes and time steps
- Electron-positron luminosity agrees to 0.1%
- Photon luminosities are lower in WarpX
- A fair comparison needs both codes converged

Next Steps

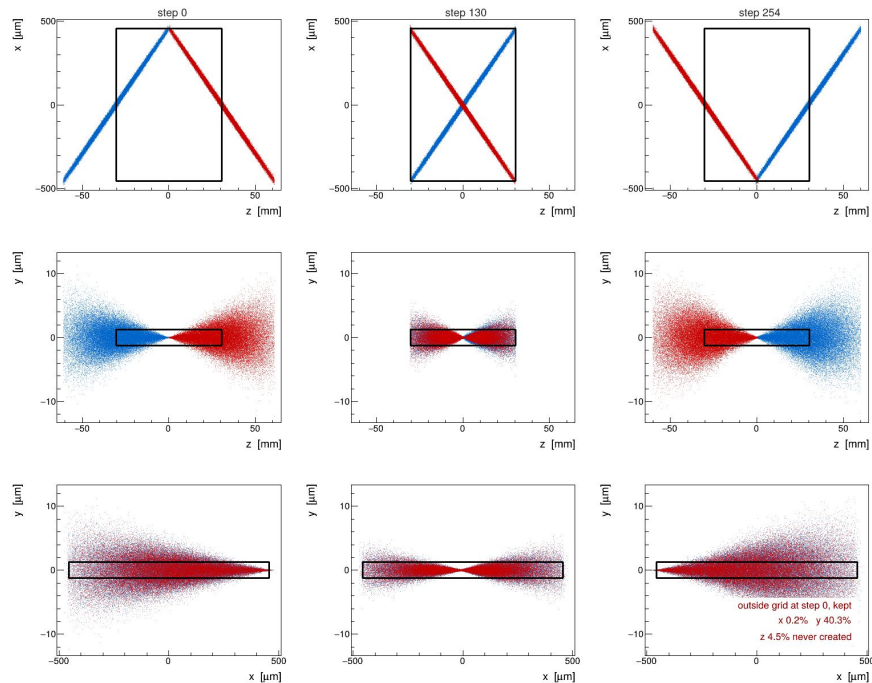
- Discuss allowing beam particles outside the grid in WarpX to shrink the grid and reach higher resolution
- Redo the comparison once both codes are converged
- Contribute WarpX bug fixes (luminosity calculation, boundary handling) back to the main code

Grid configuration differences

WarpX:



Guinea-Pig:



Primary grid size

X-dimension: should contain effect of crossing angle

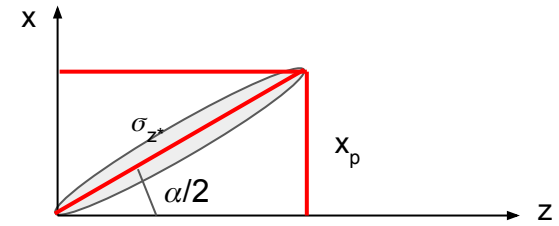
- Projection on σ_z^* x-axis: $\text{cut}_x = \sigma_z^* \sin(\alpha/2) \sim \sigma_z^* \alpha/2$

Y-dimension: Hourglass effect evaluated at z-bound

- $\sigma_y(z) = \sigma_y^* \sqrt{1 + (z/\beta_y^*)^2}$

Z-dimension: full overlap of bunches

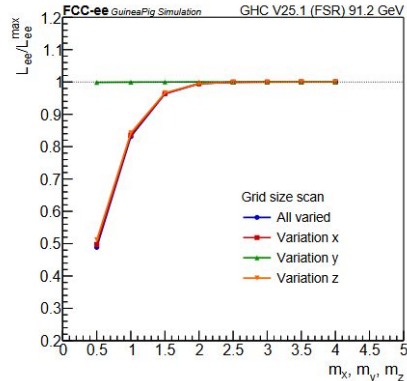
- Take $m^* \sigma_z^*$ envelope, m_z multiplier



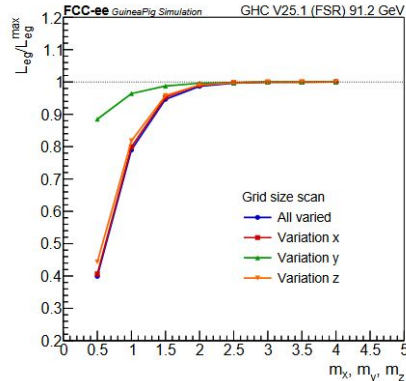
$$\Delta x(n_x) = m_x \sigma_z \sin \alpha,$$

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

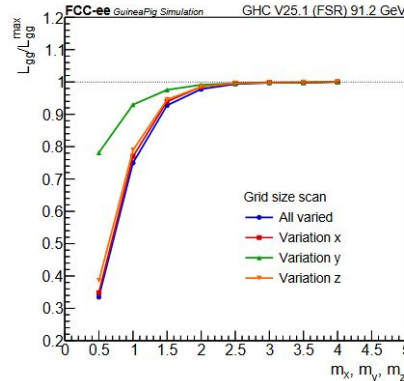
$$\Delta z(n_z) = m_z \sigma_z \cos \alpha.$$



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

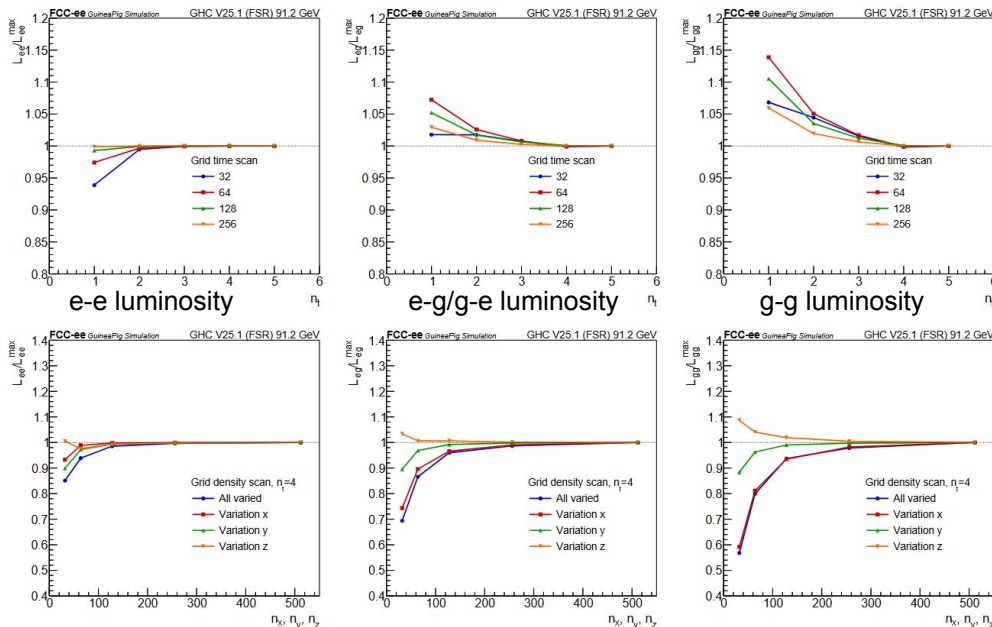
$$\begin{aligned} m_x &= 2 \\ m_y &= 2 \\ m_z &= 2 \end{aligned}$$

Primary grid density

Grid density in n_x , n_y and n_z

- n_z defines the crossing evolution
- Number of timesteps per z-slice

Total number of slices proportional to $n_z^2 n_t$



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

First scan on n_t : 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

- $n_x = n_y = n_z = 256$ good
- Use 128 for studies (faster)