
CERN

# Week 3

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# What is WarpX?

- WarpX is a particle-in-cell (PIC) simulation code.
- In this study, WarpX is used for FCC-ee beam–beam simulations.
- The relevant outputs are particle phase-space distributions and boundary-scraped particles.

# What does WarpX produce?

WarpX produces simulation diagnostics in openPMD/HDF5 format.

- Beam particles:
  - `beam1`: electrons
  - `beam2`: positrons
- Photons:
  - `pho1`, `pho2`: real photons
  - `vpho1`, `vpho2`: virtual photons
- IPC particles:
  - `ele_ll`, `pos_ll`
  - `ele_bh`, `pos_bh`
  - `ele_bw`, `pos_bw`

# WarpX compared with Guinea Pig

- Guinea Pig is the standard reference code for beam–beam backgrounds.
- WarpX can run Multi-Core CPU and GPU's

# Simulation outputs analyzed

`particles_in`

- Full diagnostic at the final timestep.
- Particles still inside the simulation box.
- Used to study particles remaining near the interaction region.

`particles_out`

- Boundary-scraping diagnostic.
- Particles that leave through box boundaries.
- Used to study particles escaping toward the detector region.

# Beam specifics: Formenti original

| Quantity | Input variable | Value |
|---|---|---|
| Beam energy | `energy` | 45.6 GeV |
| Bunch population | `npart` | $20.20 \times 10^{10}$ |
| Macroparticles per beam | `nmacropart` | $2 \times 10^{6}$ |
| Crossing angle | `crossing_angle` | 30 mrad |
| Rotation angle | `rotation_angle` | 15 mrad |
| Horizontal beta | `betax` | 90 mm |
| Vertical beta | `betay` | 0.7 mm |
| Horizontal beam size | `sigmax` | 7993.75 nm |
| Vertical beam size | `sigmay` | 35.20 nm |
| Bunch length | `sigmaz` | 16.7 mm |
| Energy spread | `espread` | $1.34 \times 10^{-3}\gamma$ |

# Box specifics: Formenti original

| Quantity | Input expression | Meaning |
|---|---|---|
| Horizontal box size | `Lx` | $8(\sigma_{x,\mathrm{init}} \cos\theta + \sigma_z \sin\theta$ |
| Vertical box size | `Ly` | $8\sigma_{y,\mathrm{init}}$ |
| Longitudinal box size | `Lz` | $16\sigma_z \cos\theta$ |
| Grid cells | `nx, ny, nz` | $256 \times 256 \times 256$ |
| Cell size | `dx, dy, dz` | `Lx/nx, Ly/ny, Lz/nz` |
| Domain lower edge | `geometry.prob_lo` | $(-L_x/2, -L_y/2, -L_z/2)$ |
| Domain upper edge | `geometry.prob_hi` | $(L_x/2, L_y/2, L_z/2)$ |
| Field boundary | `boundary.field_lo/hi` | open/open/open |
| Particle boundary | `boundary.particle_lo/hi` | absorbing |

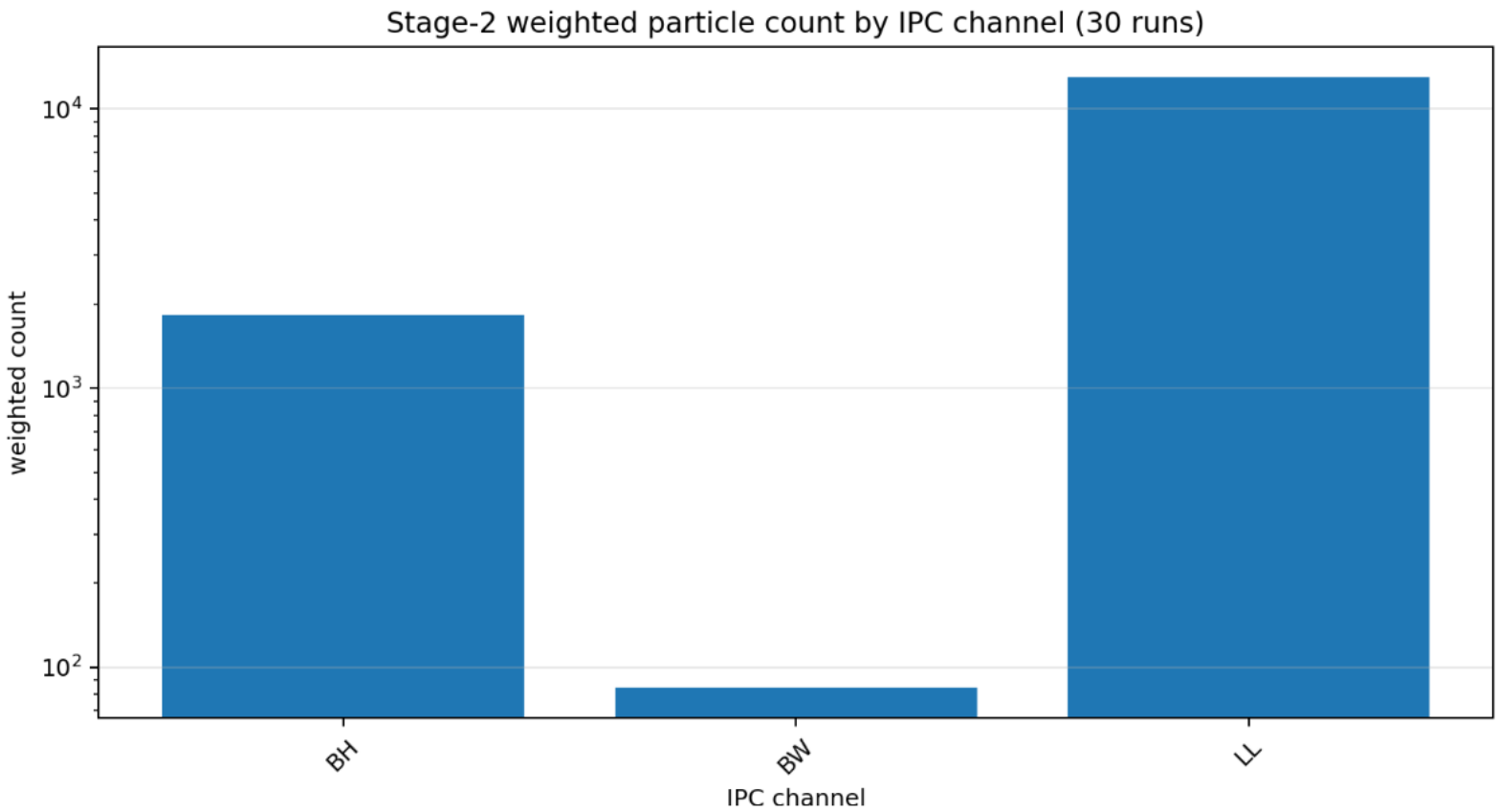
# Graphs

## Position distributions from WarpX diagnostics

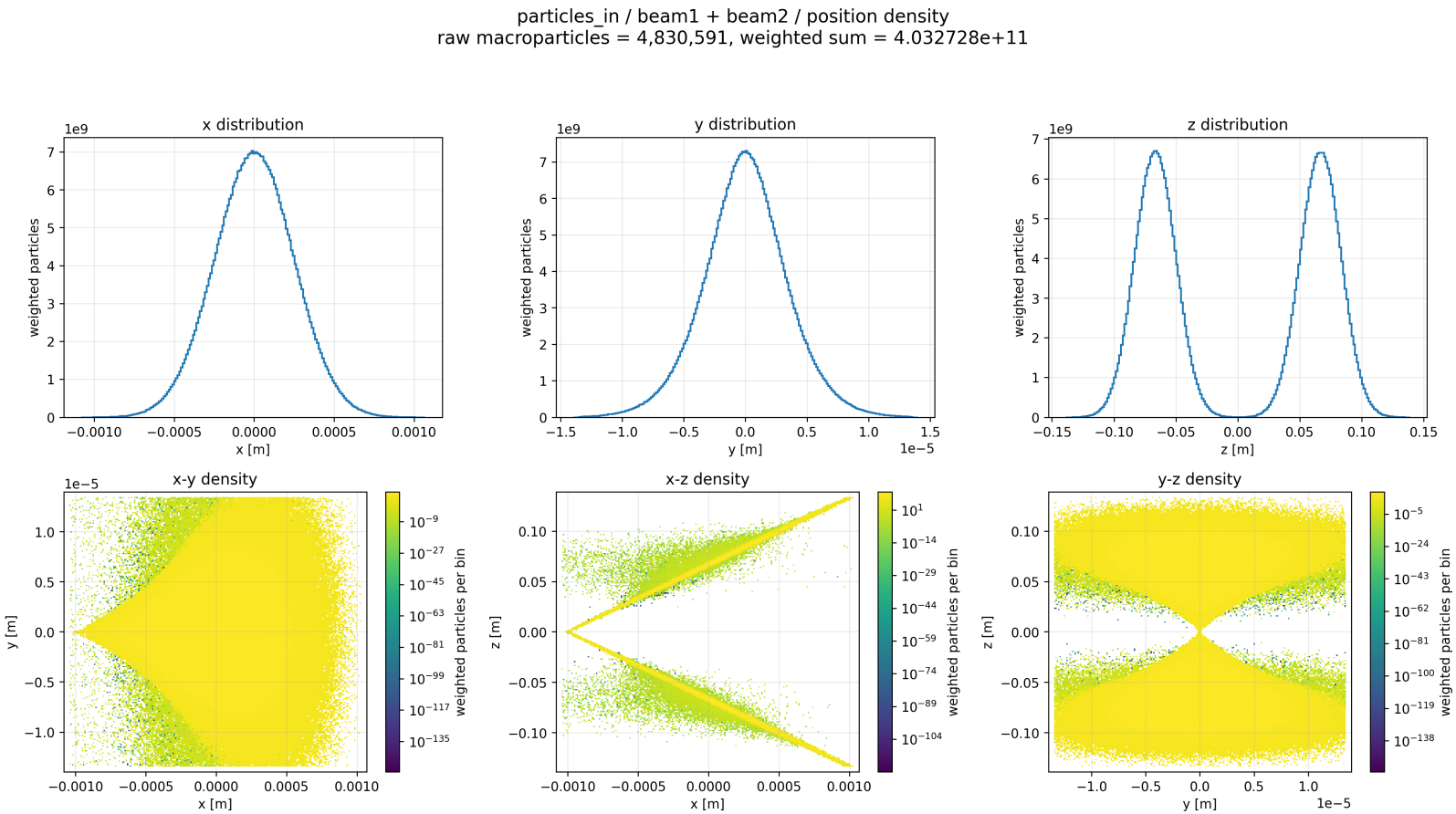
The following slides separate:

- `particles_in`: particles remaining inside the box
- `particles_out`: particles scraped at boundaries
- Beam particles and IPC particles

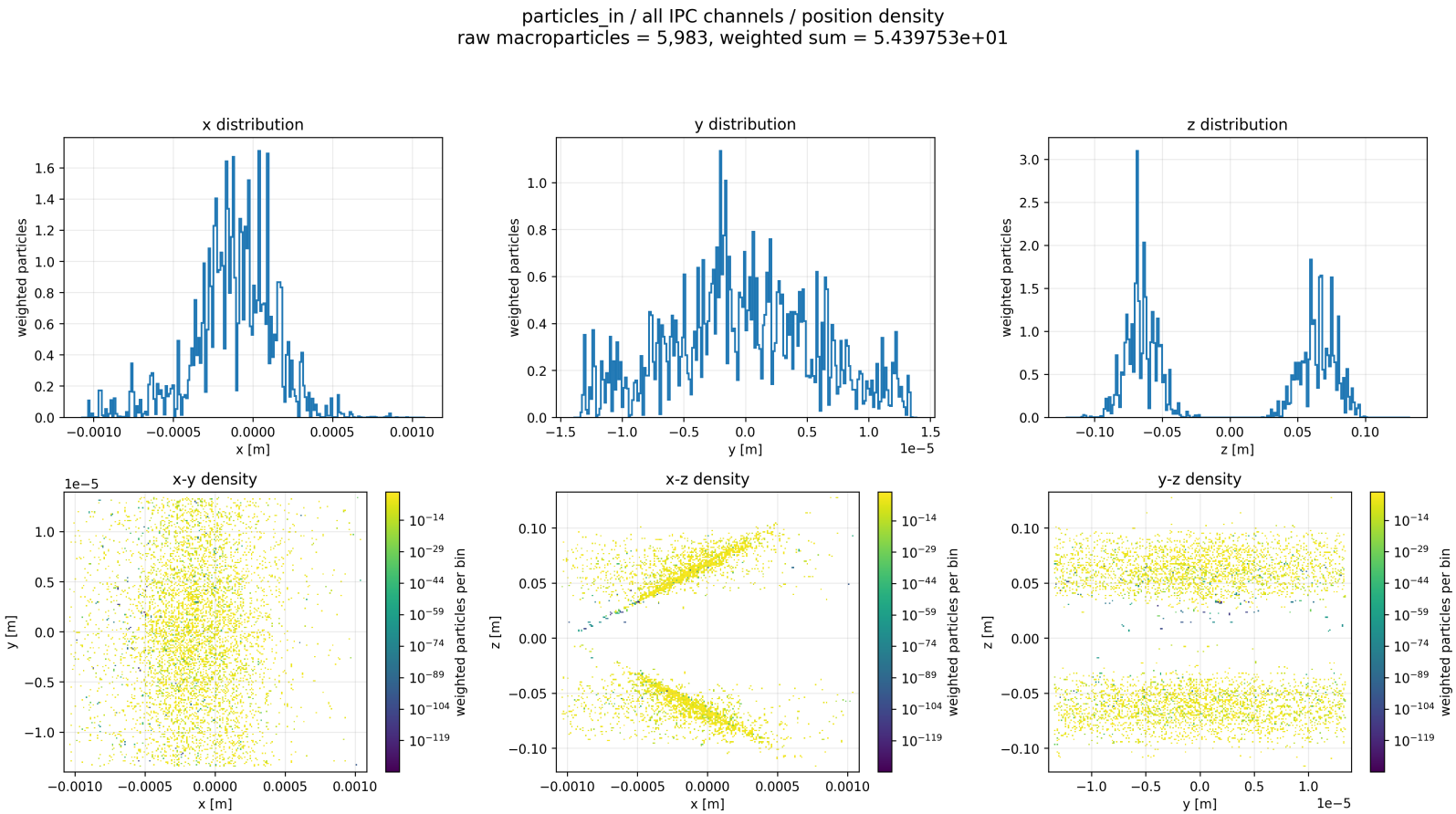
# Weighted Percentages



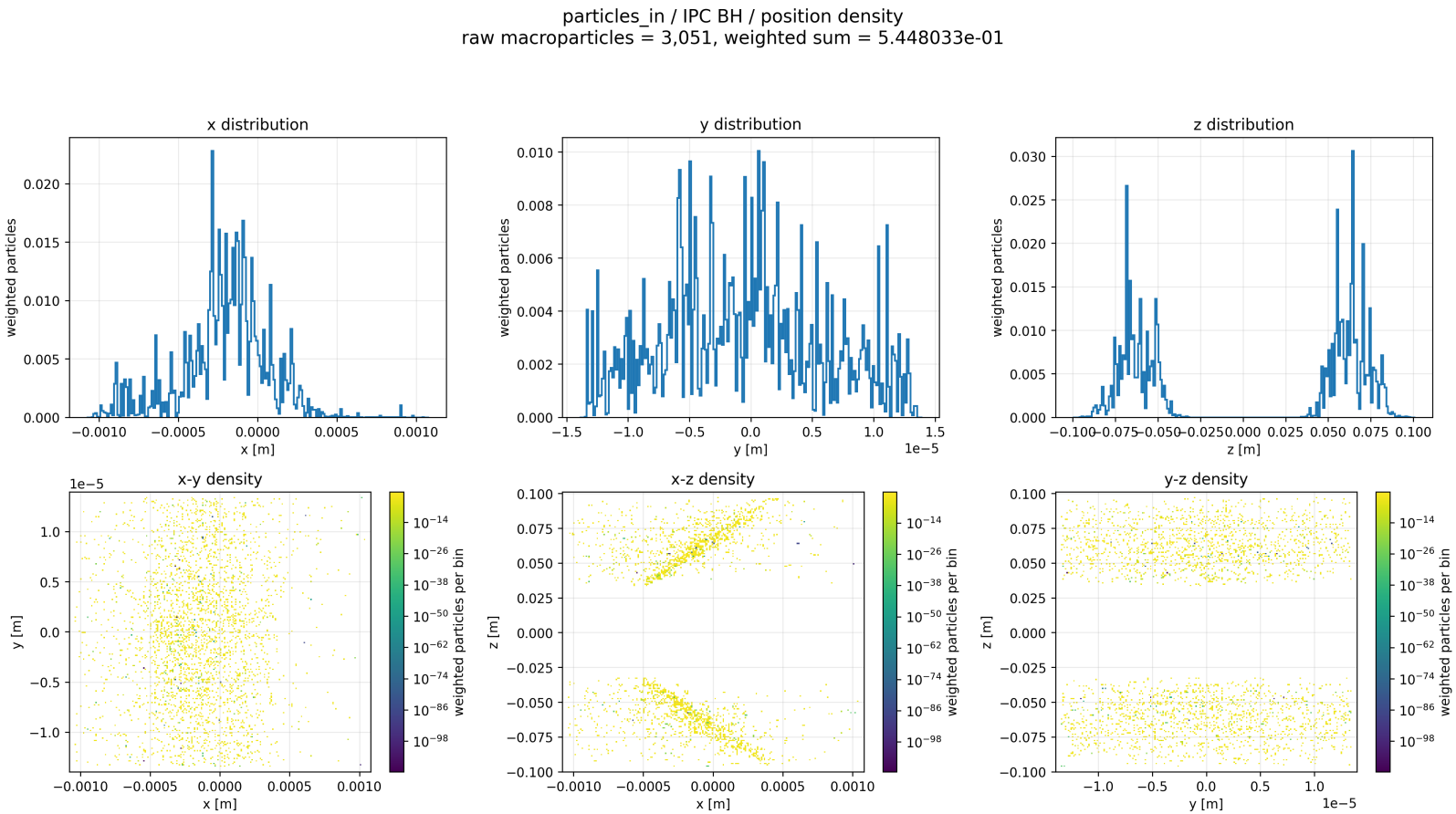
# Particles In: Beam All Position



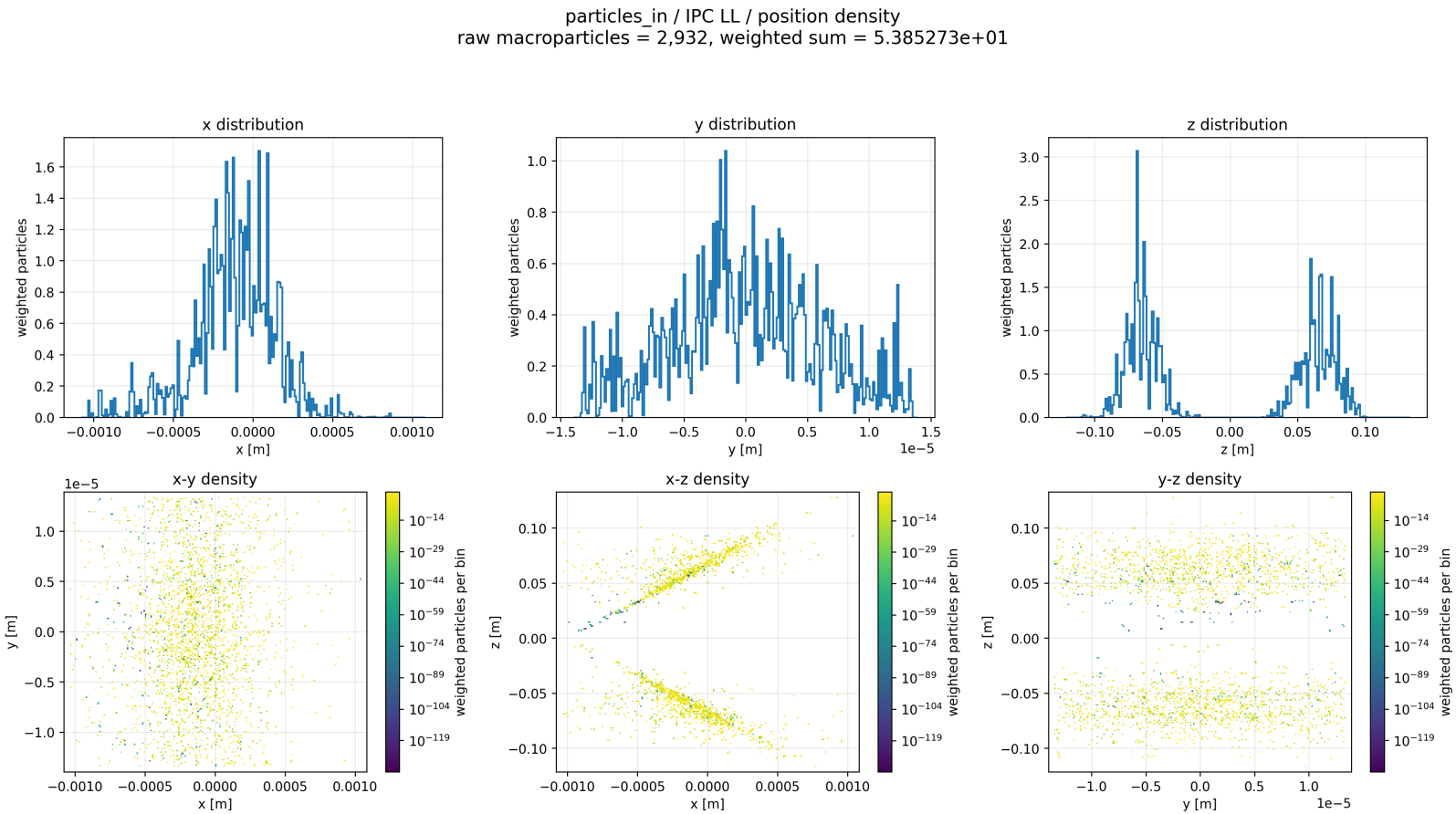
# Particles In: IPC All Position



# Particles In: IPC BH Position



# Particles In: IPC LL Position



# Proposed two-stage process

## Stage 1: Production

- Run the original beam–beam configuration.
- Produce IPC particles through the LL, BH, and BW channels.
- Save both `particles_in` and the boundary-scraped `particles_out`.

## Stage 2: Transport

- Inject the IPC particles produced in Stage 1.
- Transport the particles.
- Check whether the IPC particles reach the longitudinal boundaries.

# Stage 1 specifications

- Input deck: `Formenti_stage1.in`
- Physics purpose: IPC production from the Formenti beam–beam configuration.
- Box:
  - $x = \pm 150\sigma_x$
  - $y = \pm 60\sigma_y$
  - $z = \pm 6\sigma_z$
- Grid: $256 \times 256 \times 256$
- Time step: `dt = dz / (2 c)`
- Number of steps: `nt = 256`
- External solenoid: $B_z = -2$ T
- Diagnostics:

# Stage 2 specifications

- Inputs:
  - `Formenti_3.051_in.in`
  - `Formenti_3.051_out_x_low.in`
  - `Formenti_3.051_out_x_high.in`
  - `Formenti_3.051_out_y_low.in`
  - `Formenti_3.051_out_y_high.in`
- External field:
  - $B_z = -2$ T

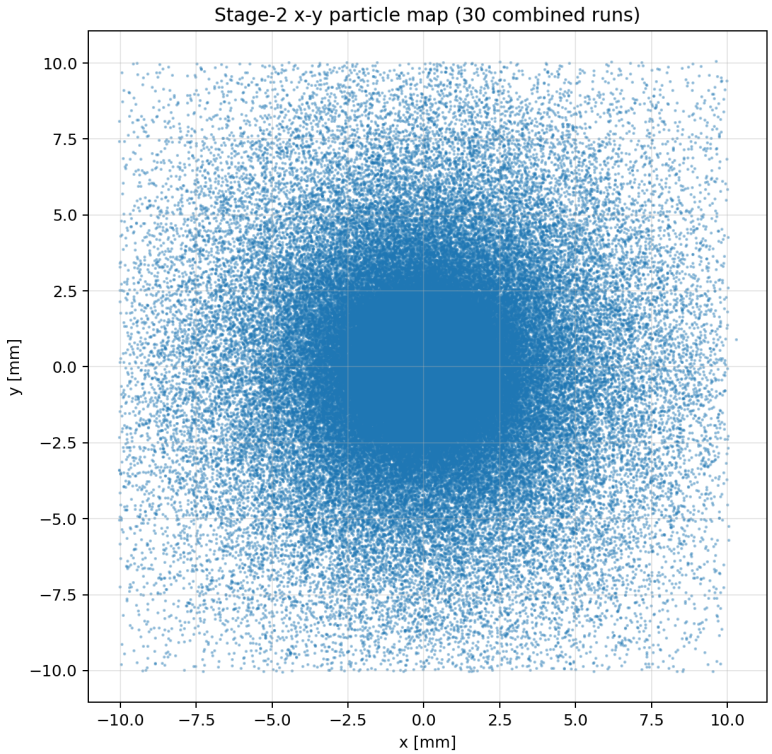
# Stage 2 geometry and injection

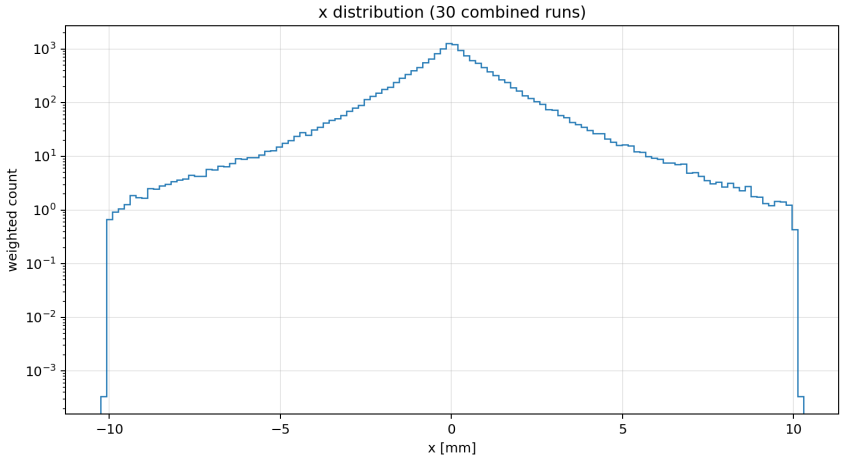
- Transport aperture:
  - $x = \pm 10$ mm
  - $y = \pm 10$ mm
  - $z = \pm 6\sigma_z$
- Injected IPC species:
  - `ele_ll`, `pos_ll`
  - `ele_bh`, `pos_bh`
  - `ele_bw`, `pos_bw`
- Injection method:
  - `injection_style = external_file`
  - Files come from the Stage 1 openPMD handoff.

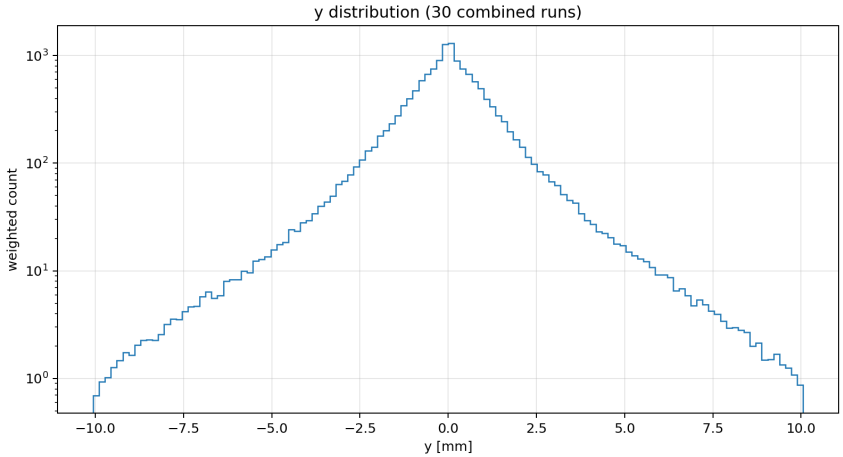
# Automated workflow

1. Run Stage 1.
2. Split Stage 1 openPMD files by IPC species.
3. Build Stage 2 handoff files.
4. Run available Stage 2 inputs.
5. Archive each Stage 2 result.
6. Repeat.

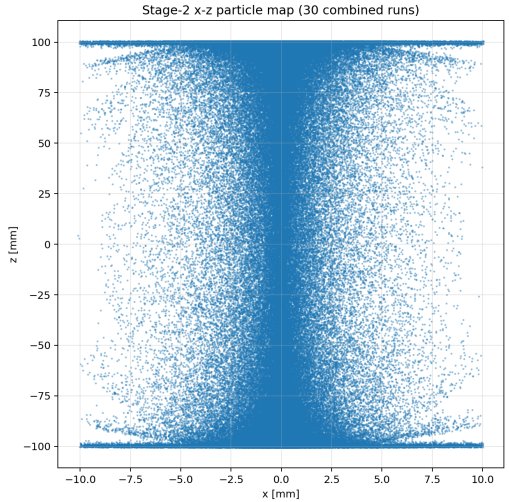
# Stage-2 transverse particle distributions

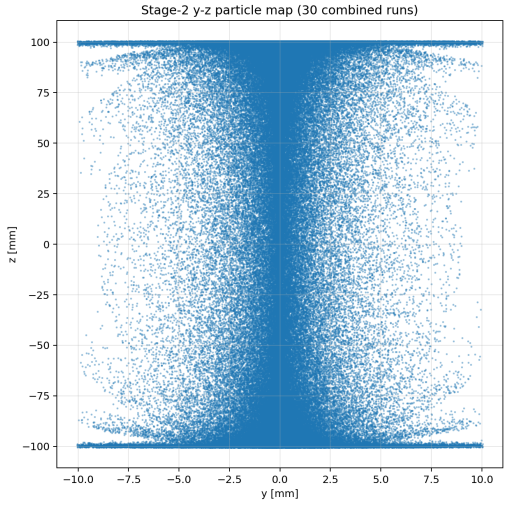


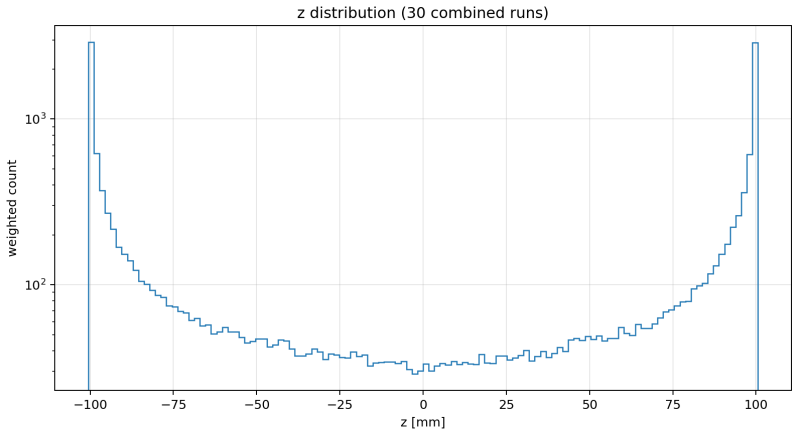



# Stage-2 longitudinal particle distributions



# Future work

- Understand Scraping of Particles for a better plotting.
- Validate all graphs with GP results.
- Consult WarpX team for recommendations or errors in the scripts