# Incoherent Electron Pair Production Background @ $C^3$


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ECFA 2nd Topical Meeting on Generators

21 June 2023

**bold** - did most of the work :-)

# Background Simulations at $C^3$

- Linear collider machine and beam backgrounds play a significant role in:
  - Detector design (occupancies of innermost tracking layers)
  - Ultimate physics reach (fake rate / misreconstructions from spurious hits)

- Last workshop: demonstrated similarity of $C^3$ to ILC
  - We have been assuming ILC-like physics performance of an SiD-like detector @ $C^3$
  - Here we show refined estimates for the pair-production backgrounds without hadron photoproduction (effectively a 10% increase to what we will see)
  - Other machine backgrounds (tertiary muons, etc.) to come later, they are smaller effects

- We will see:
  - $C^3$ is quantitively equivalent to ILC from the perspective of backgrounds at the IR
  - While detector re-optimization is required (bunch structure) physics reach considerations are the same.

# C3 Parameters

- Input values to simulation derived from C3 optics and dynamics simulations @ 250 GeV CoM
  - Started this project with some guesses due to incomplete information
  - Now have complete configuration of the machine from background simulation perspective
- Note that bunch/repetition structure at C3 different from ILC

| Parameter | Units | Value |
|---|---|---|
| $\beta_x^*$ | mm | 12 |
| $\beta_y^*$ | mm | 0.12 |
| $\epsilon_{N,x}^*$ | nm | 900 |
| $\epsilon_{N,y}^*$ | nm | 20 |
| $\sigma_x^*$ | nm | 210.12 |
| $\sigma_y^*$ | nm | 3.13 |
| $\sigma_z^*$ | μm | 100 |
| $n_b$ | | 133 |
| $f_{rep}$ | Hz | 120 |
| $N$ | | $6.25 \cdot 10^9$ |
| $\theta_c$ | rad | 0.014 |

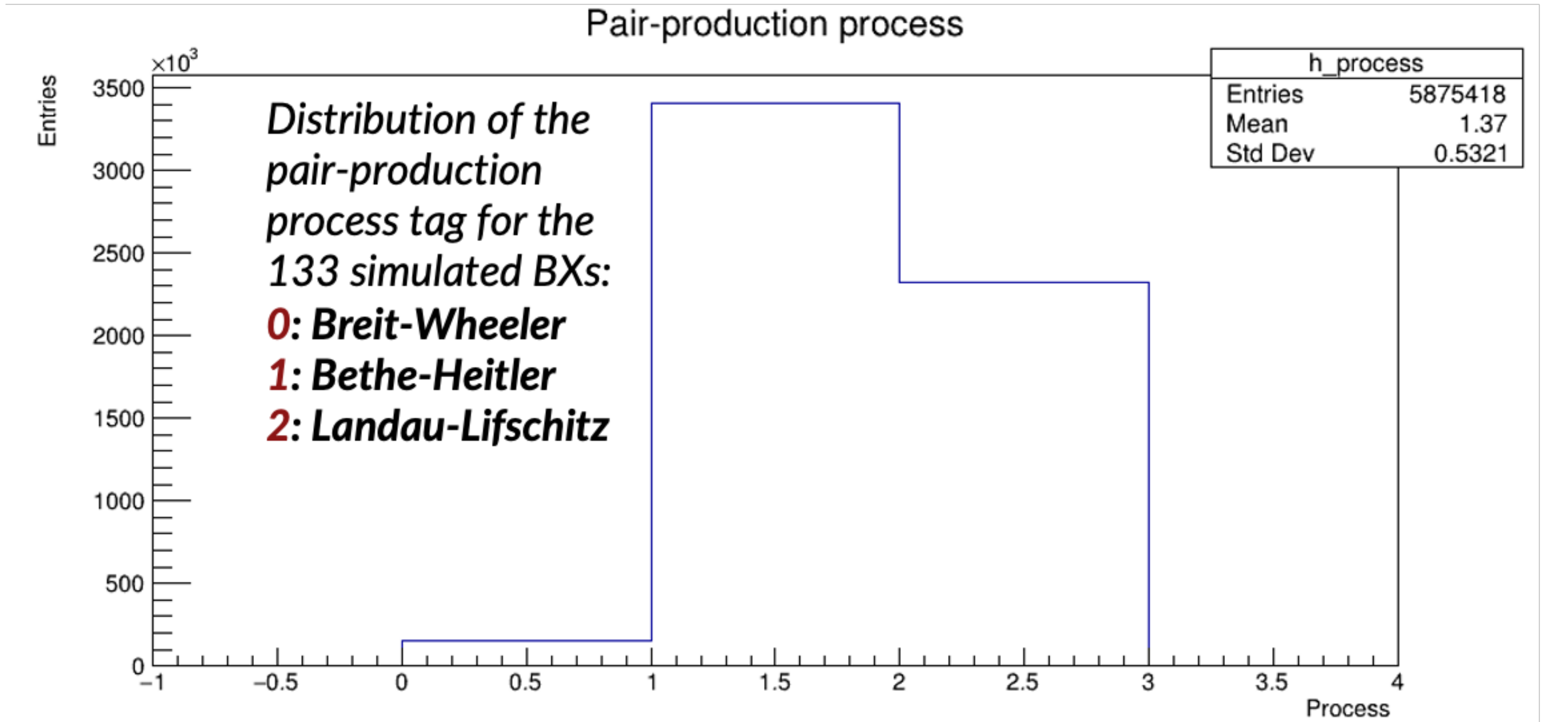
- The emittances on the table are normalized. The transverse beam size is calculated as:

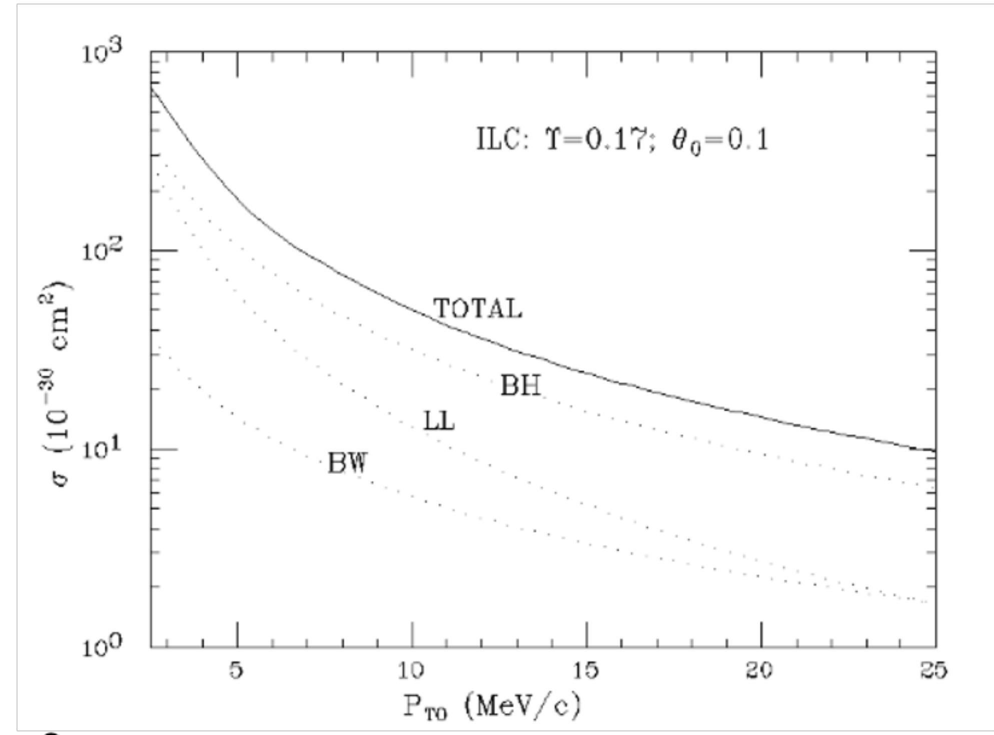
$$\sigma_{x,y}^* = \sqrt{\epsilon_{x,y}^* \beta_{x,y}^*} = \sqrt{\frac{\epsilon_{L,x,y}^* \beta_{x,y}^*}{\gamma}}, \quad \gamma = \frac{E}{m_e c^2} = \frac{\sqrt{s}}{2 m_e c^2}$$

| | Initial Tests | Emilio's Values |
|---|---|---|
| Energy spread | 0.1% | 0.3% |
| Energy spread distribution | Gaussian | Flat |
| Offset in x direction (nm) | 0 | 5 |
| Offset in y direction (nm) | 0 | 0.2 |
| Waist shift in x direction (μm) | 0 | 0 |
| Waist shift in y direction (μm) | 0 | 0 |
| Crossing angles (not compensated by crab scheme) | 0 | 0 |

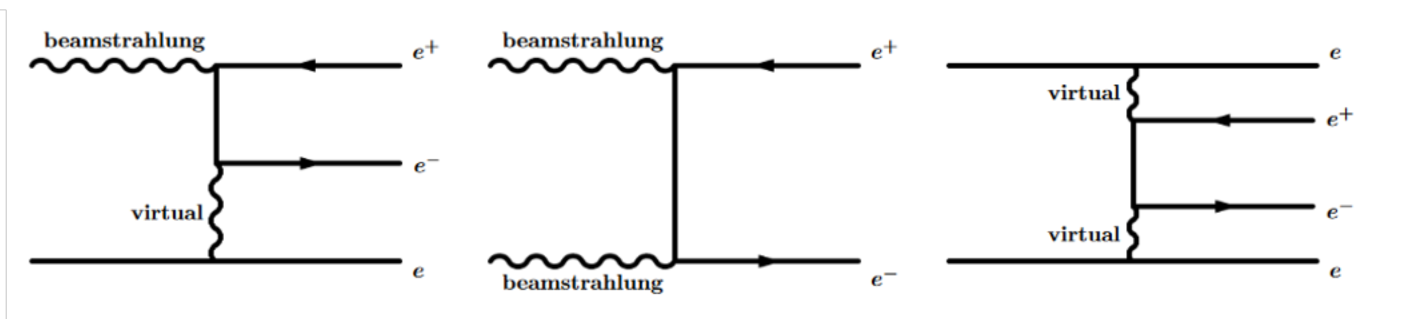
Thanks Emilio!

# Guinea Pig and C³




Source:
https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.44.2209&rep=rep1&type=pdf

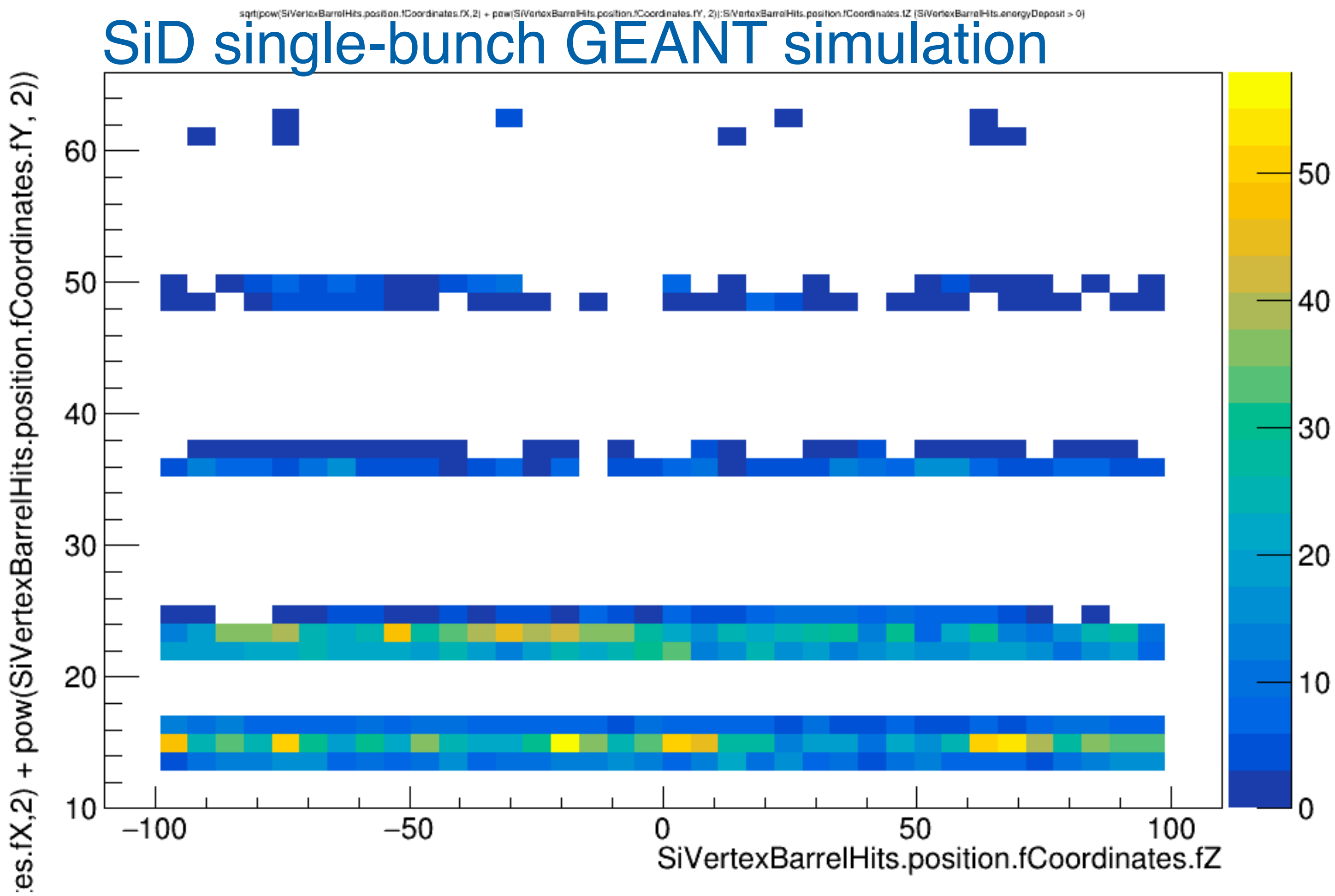



(a) *Bethe-Heitler* (b) *Breit-Wheeler* (c) *Landau-Lifschitz*

Source: https://bib-pubdb1.desy.de/record/405633/files/PhDThesis_ASchuetz_Publication.pdf

- To simulate the pair background we use the Guinea-Pig (GP) program
  - As configured for this study, simulates the primary production modes production of $e^+/e^-$ pairs from beam and beamstrahlung initiated backgrounds
  - There are additional handles for hadron photoproduction but GP’s implementation is known to be inaccurate (work beginning on more accurate simulation)

# Towards Full Simulation




- Using slightly modified geometry shipped with dd4hep with most recent SiD pixel barrel description
  - ~2000 hits in the first barrel layer in a single bunch (0.24% average occupancy per pixel per train 25x25um)
  - Simulation time is roughly **1 hour** per bunch (several routes for improvement)
- First results ~consistent with back-of-the-envelope expectation
  - Need to check endcaps, occupancy very angle-dependent

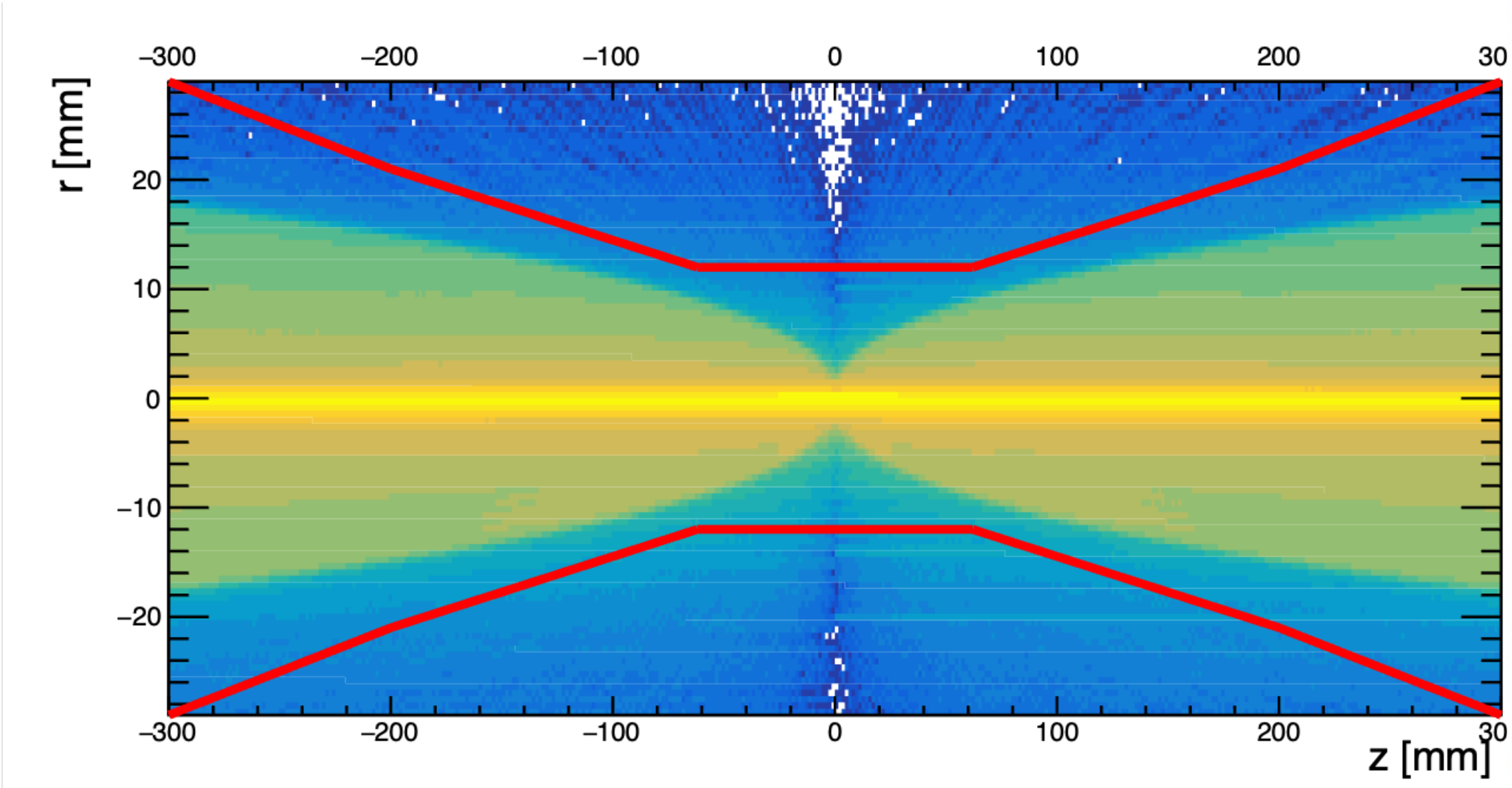
## What's new?

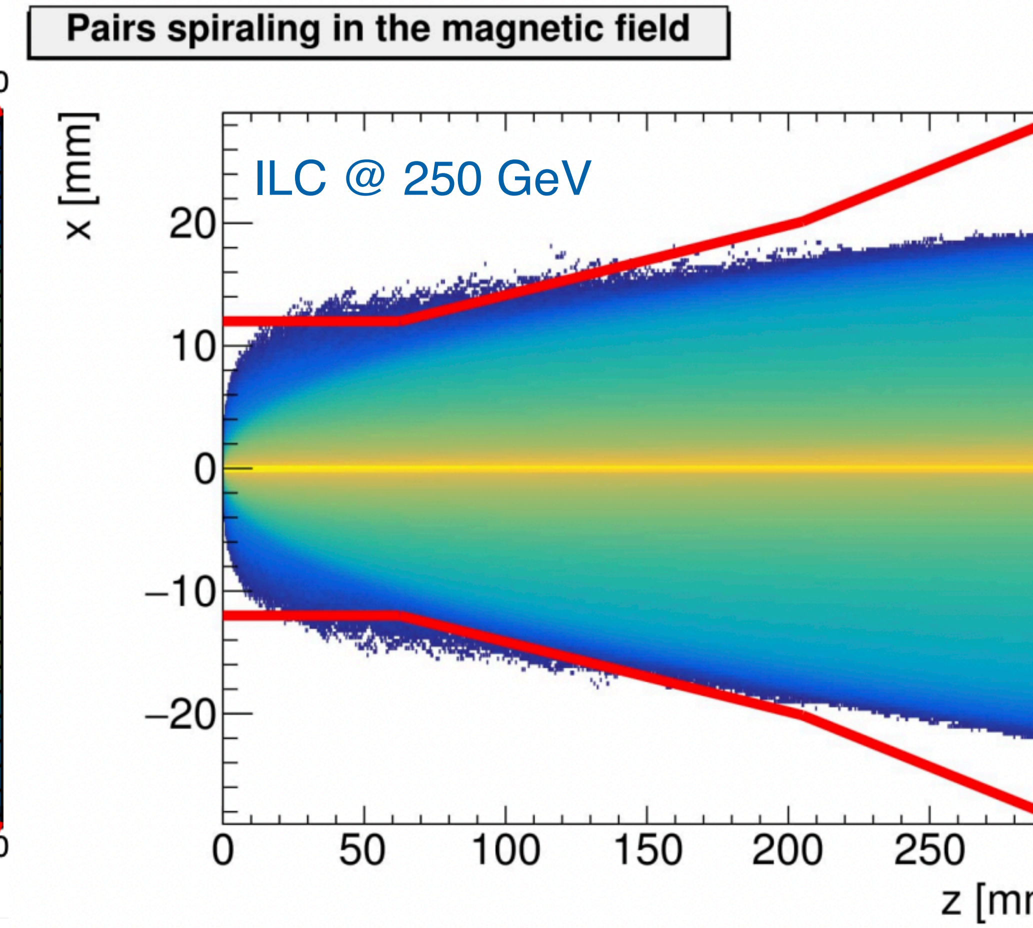
# Doing better than 1 hour per bunch…

| Vertex Barrel layer | Mean number of hits – 0 MeV cut | Mean number of hits –E> 10 MeV cut | Mean number of hits – pT> 5 MeV cut |
|---|---|---|---|
| 1st layer | 341.5 ± 2.6 | 218.5 ± 2.0 | 239.0 ± 2.2 |
| 2nd layer | 113.9 ± 1.8 | 101.5 ± 1.7 | 97.6 ± 1.6 |
| 3rd layer | 70.9 ± 1.8 | 63.2 ± 1.8 | 51.4 ± 1.7 |
| 4th layer | 51.1 ± 1.6 | 43.4 ± 1.7 | 38.6 ± 1.5 |
| 5th layer | 34.3 ± 1.4 | 25.1 ± 1.2 | 20.7 ± 1.2 |
| All 5 layers | 614.8 ± 4.2 | 451.6 ± 4.1 | 447.3 ± 3.9 |

- Investigated possibility of cutting out particles that would not reach first layer
  - Simulated 400 random-seed variants of the same event with different kinematic cuts
  - Significant impact on mean number of hits in first layer, not viable for accurate simulations
- Main improvement came from choosing a more efficient random number generator
  - Mersenne Twister took us down to 15 minutes per background event which is at least not glacial

# Envelope Plots a la ILC

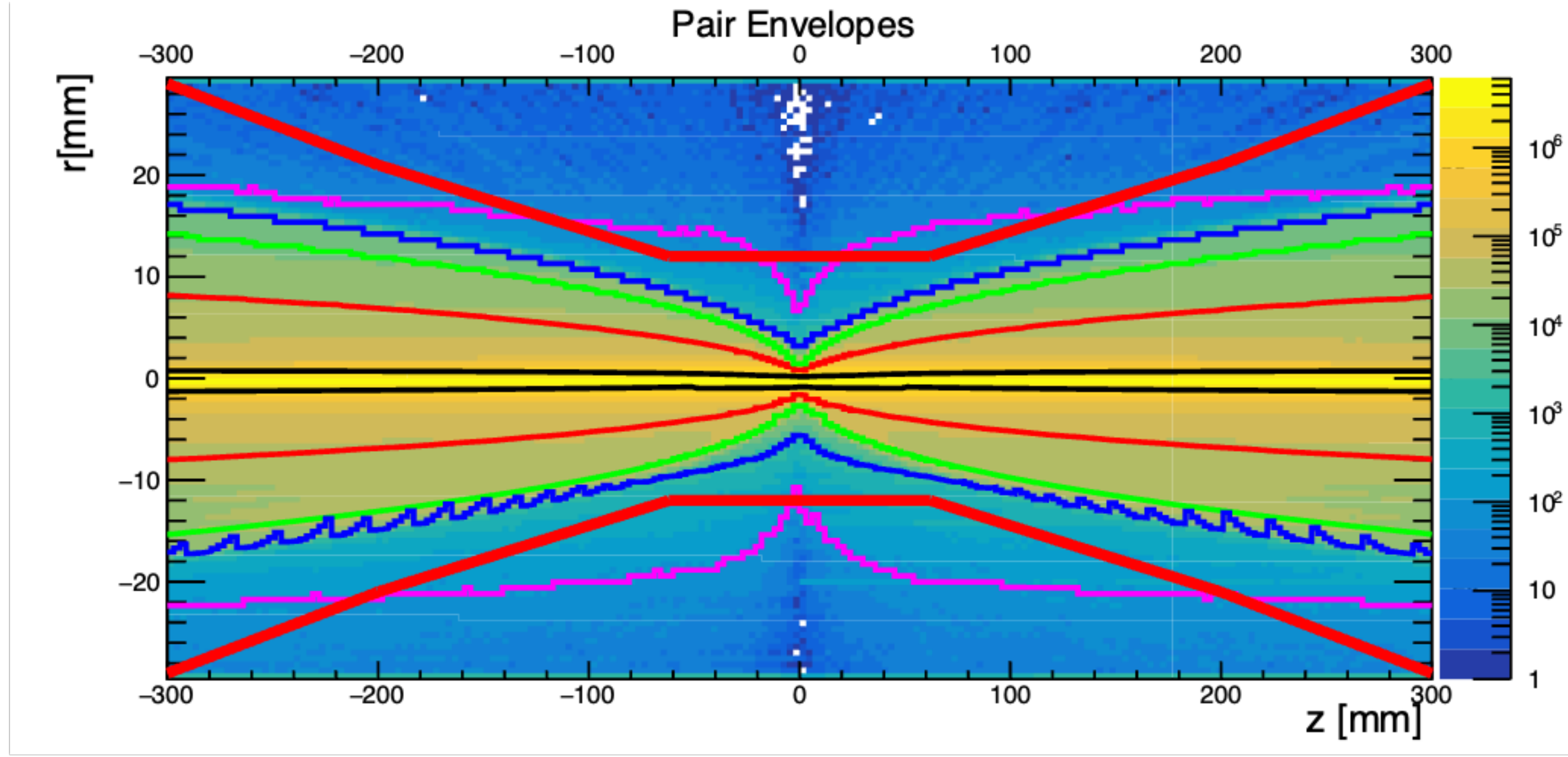


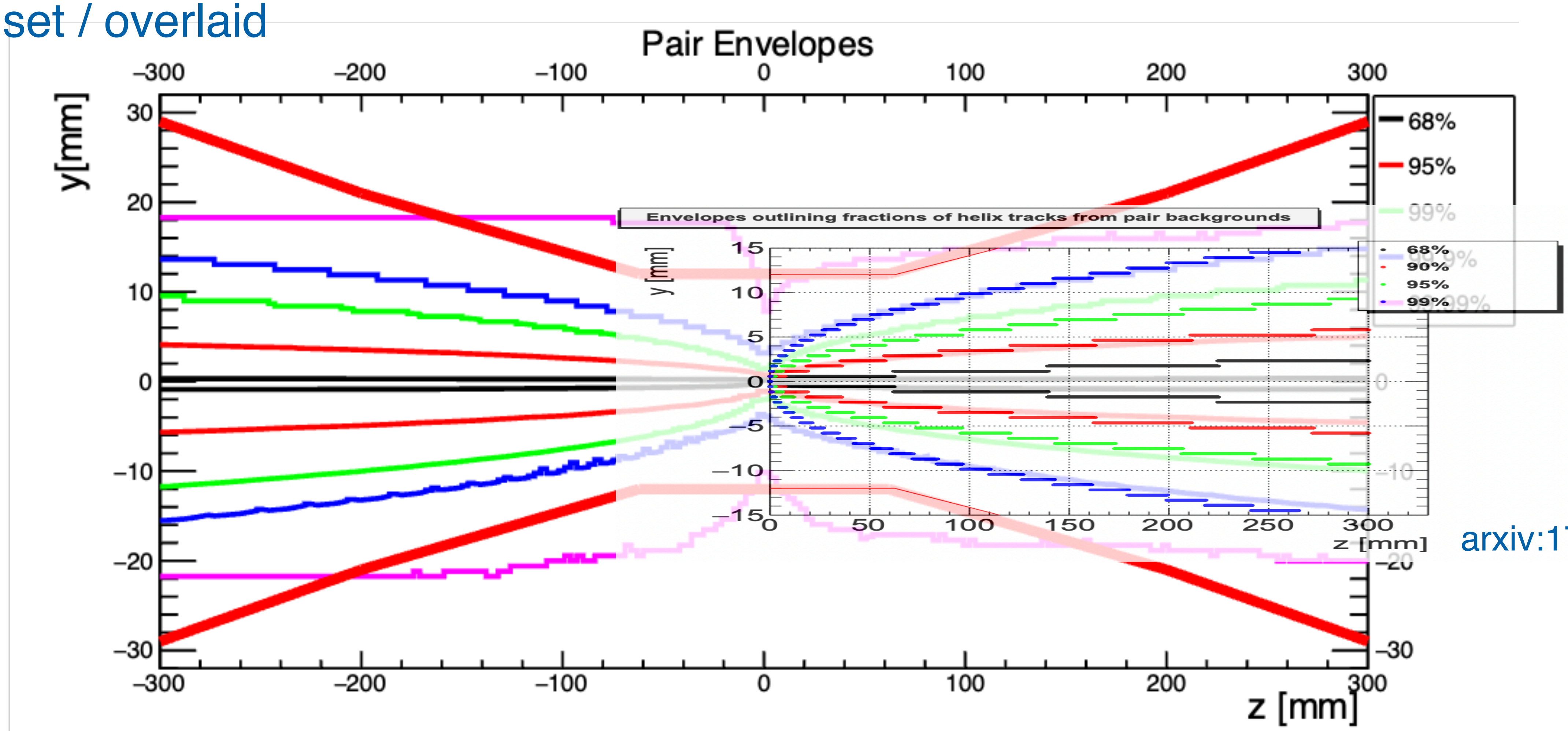

- Red line is latest placement of beam pipe at C³, most recent SiD geometry has first layer at 14mm away from IR
- Qualitatively similar results to ILC in this view…

Fermilab

# Envelope Plots a la ILC

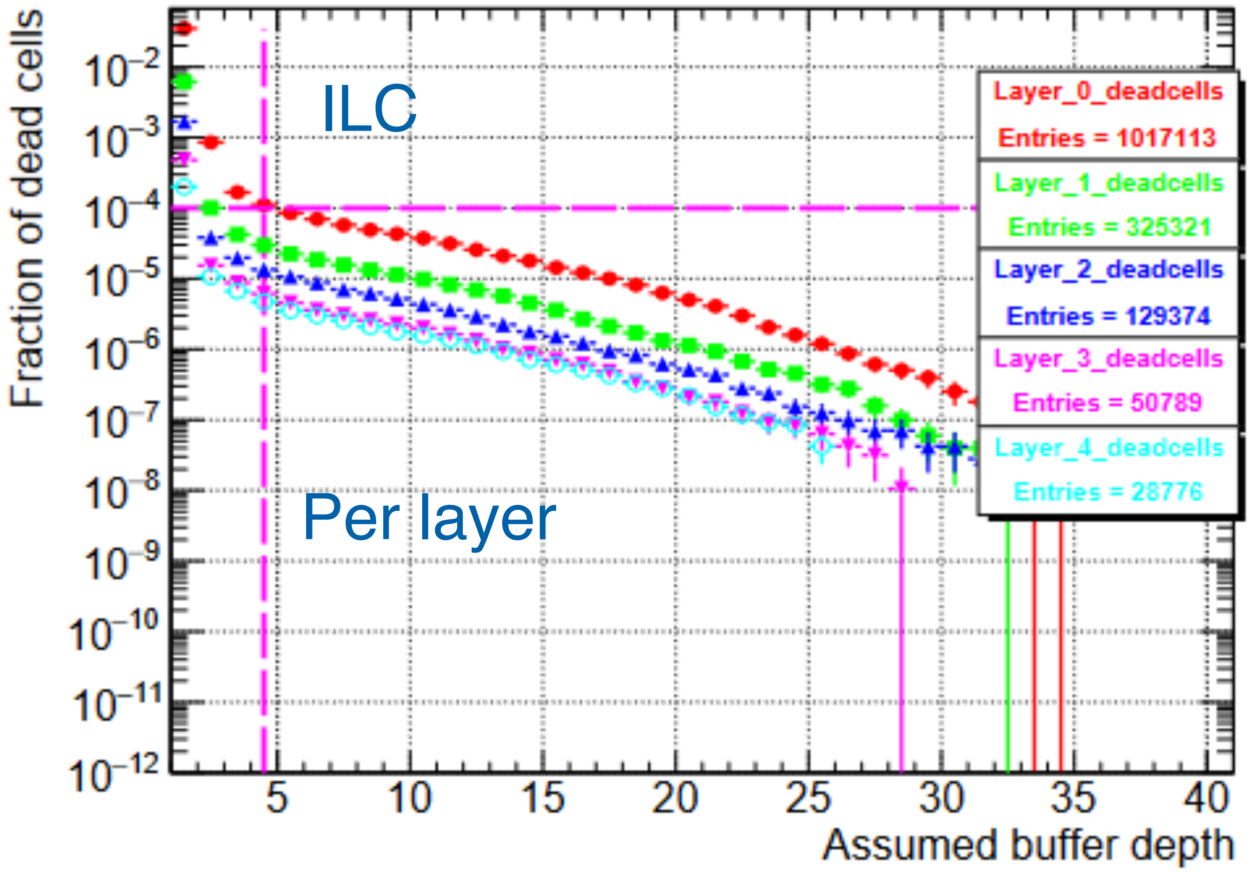


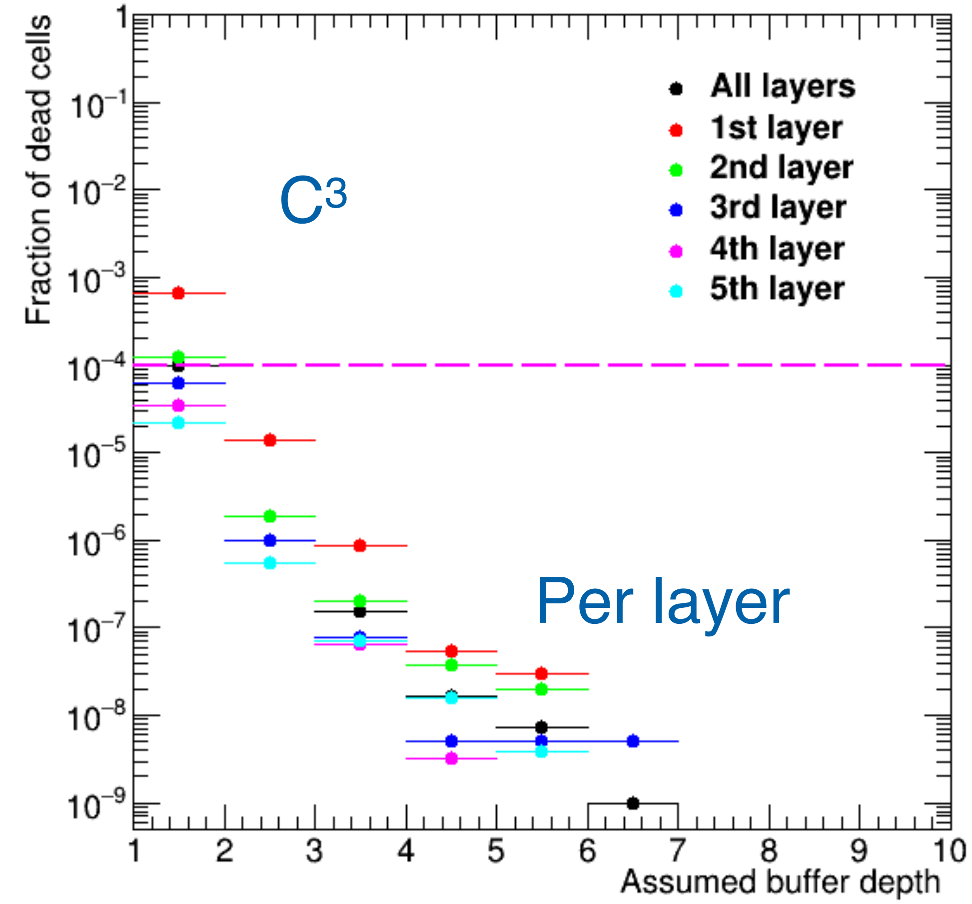

ILC inset / overlaid




arxiv:1703.05737

# Latest SiD Geometry in Full Simulation




- Checked many times to ensure fidelity of simulation and outcome of results
  - Concerns about magnetic field, exact versions of geometry, etc.
- Together with envelope confirmation indications that we could move the inner pixel layer closer
  - Closer hit: improved sagitta determination, HF tagging, triggering, electron reco.

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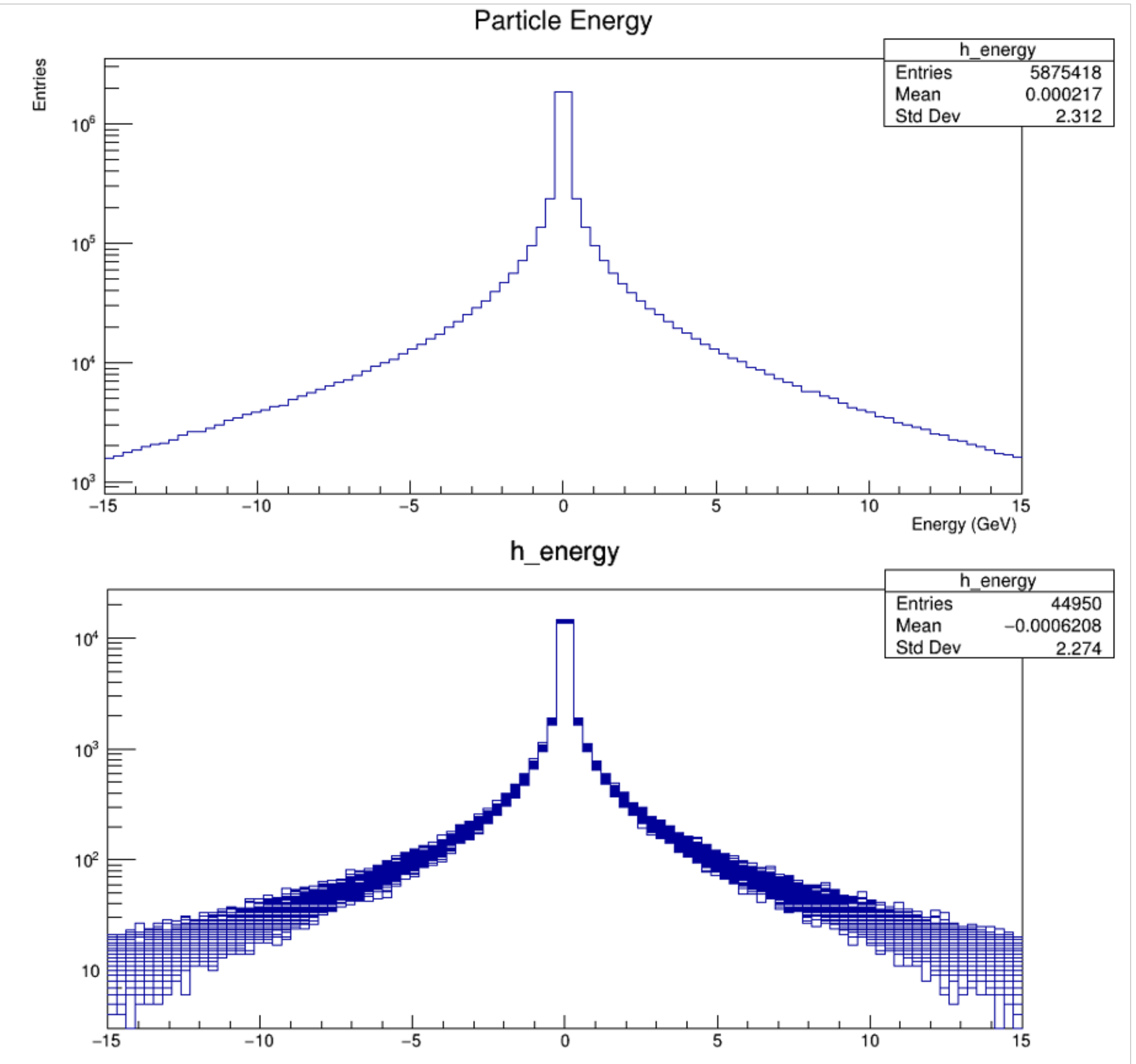
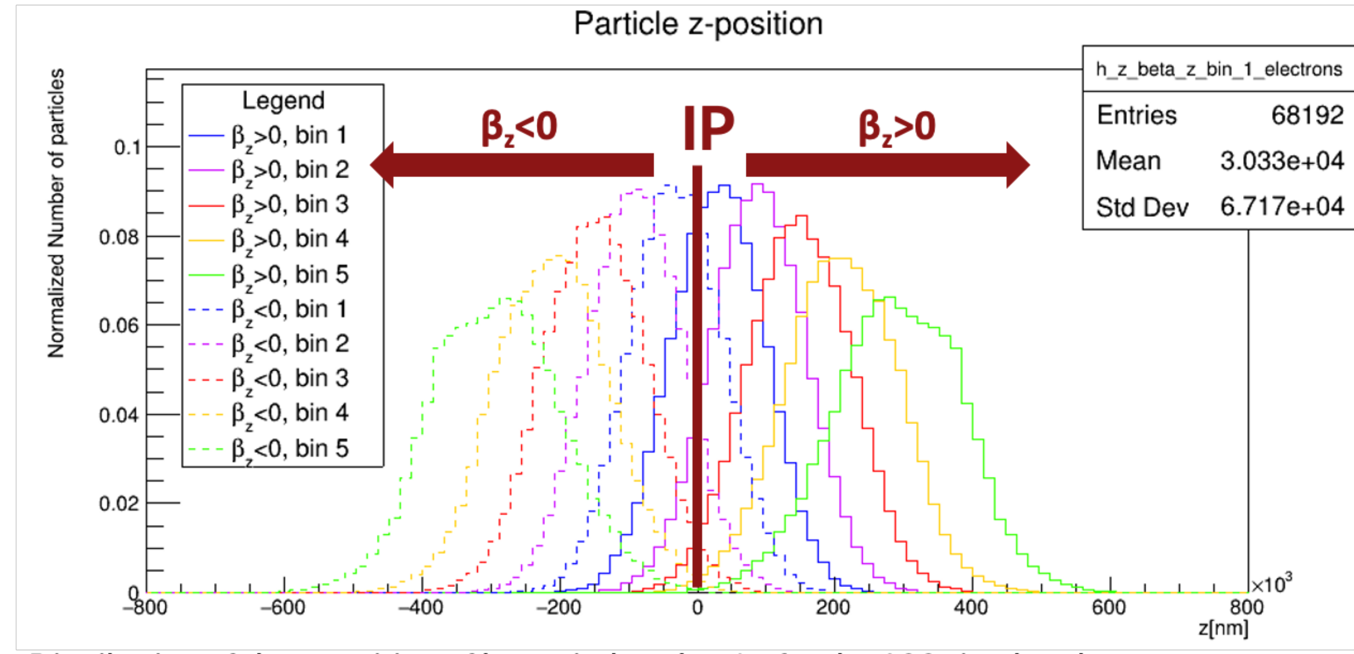
# Conclusions / Plans

- Very close beam-profile match between $C^3$ and ILC 250 (and 500)
  - For a full $C^3$ bunch train, 5T field
- General intuition from ILC background & physics studies applicable
  - We will continue to collect the revitalize all previous backgrounds
    - Will store copies and recreation instructions for all relevant code
- I think we are in a place to confidently back up the $C^3$ physics case with prior studies
- Your scrutiny, feedback, and participation is appreciated! Thanks in advance!

# Extras

# Raw GP Results




*Distribution of the z-position of beam-induced $e^+/e^-$ for the 133 simulated BXs for different bins of $\beta_z$:*

*bin 1: $0.0 < |\beta_z| < 0.2$*

*bin 2: $0.2 < |\beta_z| < 0.4$*

*bin 3: $0.4 < |\beta_z| < 0.6$*

*bin 4: $0.6 < |\beta_z| < 0.8$*

*bin 5: $0.8 < |\beta_z| < 1.0$*

- We generated 133 bunches configured with the C³ parameters ensuring unique random seeds to simulate a full bunch train
  - Simulation of $e^+/e^-$ propagation through bunch charge is apparent and consistent with expectations
  - Sub-distributions per bunch consistent with each other
  - Average of 44176 particles per bunch, observed expected steeply falling energy spectrum