Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

# Beam background studies at $C^3$


Tim Barklow (SLAC), Lindsey Gray (FNAL),

**Elias Mettner**, Abdollah Mohammadi (UW-Madison),

**Dimitris Ntounis**, Caterina Vernieri (SLAC)


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

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

SLAC NATIONAL ACCELERATOR LABORATORY

# 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)
- Up to now no estimate of these backgrounds for $C^3$ beam configuration
  - We have been assuming ILC-like physics performance of an SiD-like detector @ $C^3$
  - Here we show first 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:
  - That we can start to answer the question if $C^3$ is no worse than ILC or CLIC from pair-background perspective
    - Spoiler - seems like yes, with some detector optimization
  - Interesting considerations in developing accurate simulations at scale

# 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 |
| $\sigma_x^*$ | µm | 210.12 |
| $\sigma_y^*$ | µm | 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!

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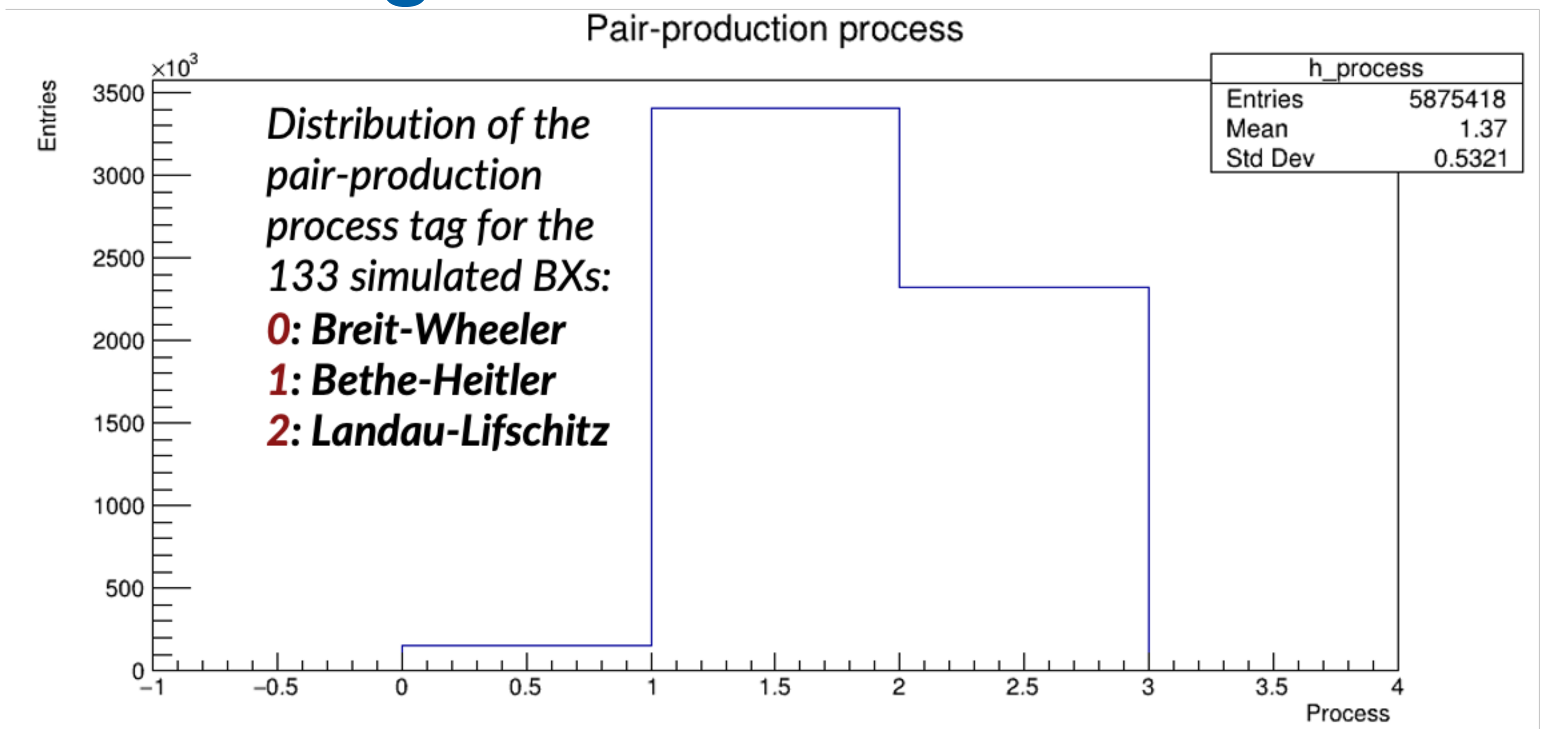
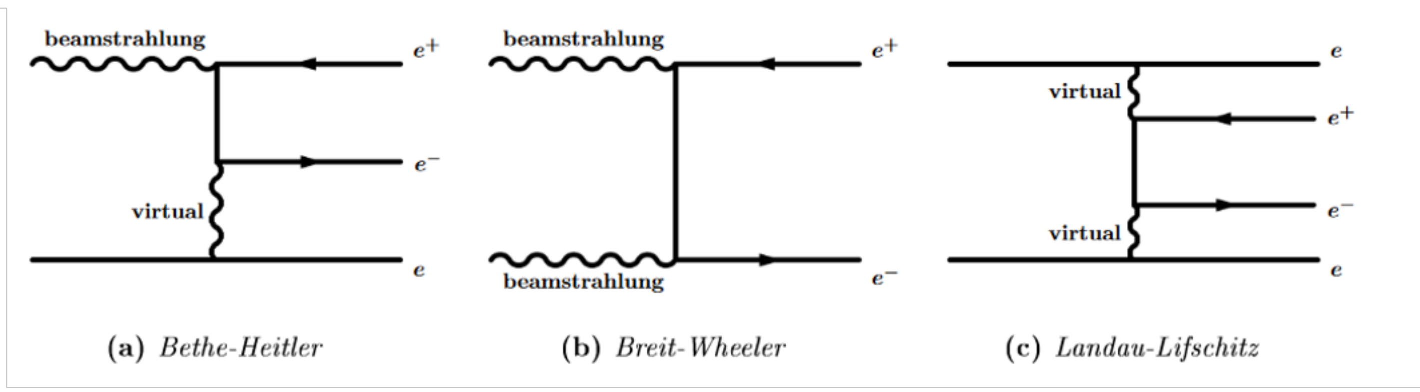
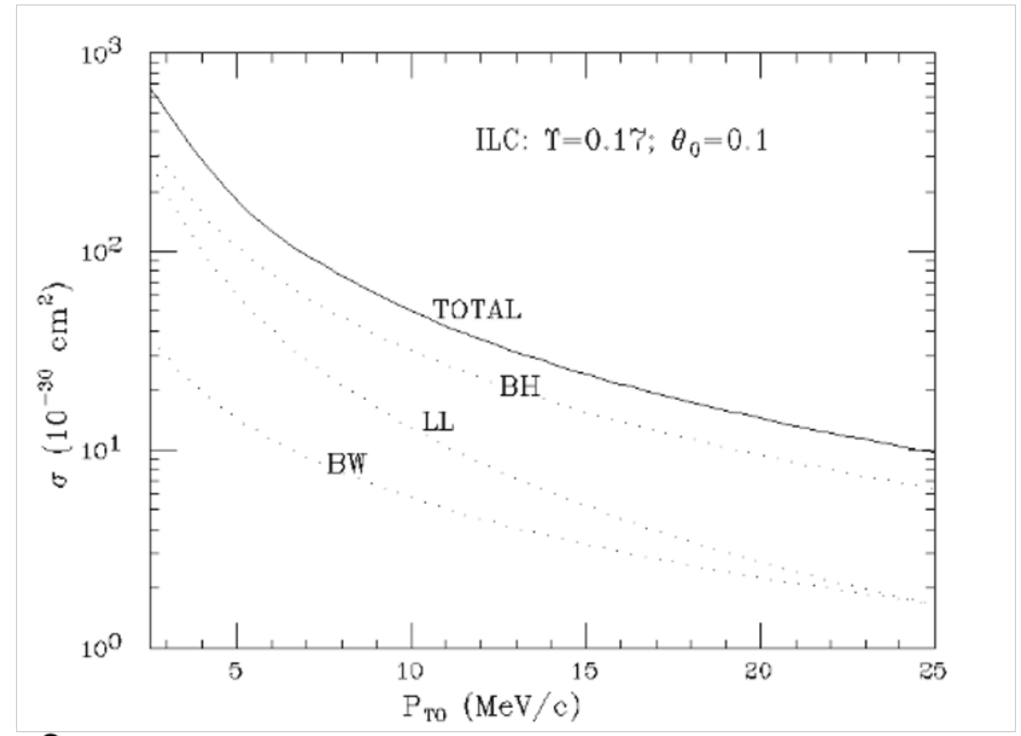
# Guinea Pig and C³



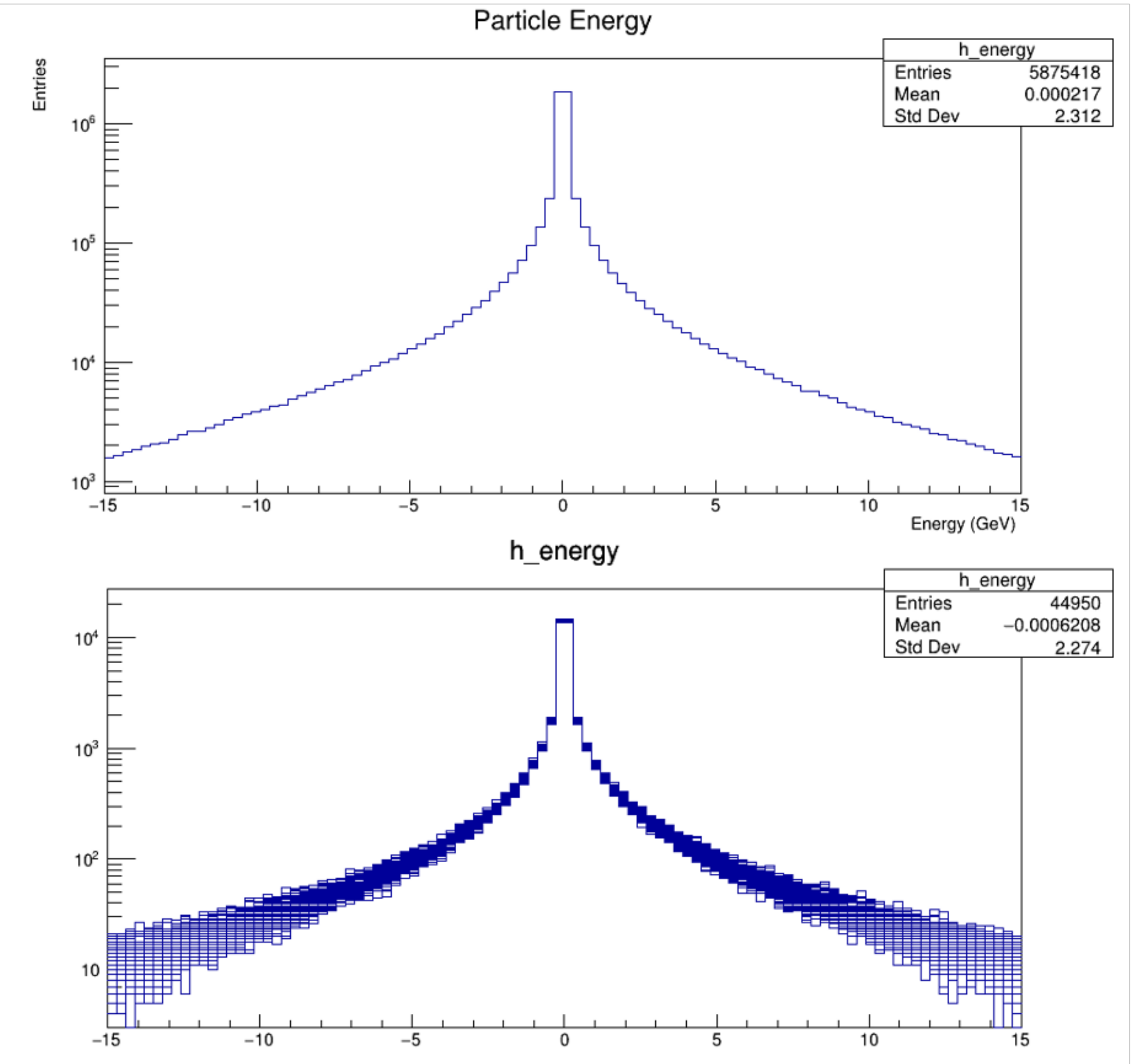

Source: https://bib-pubdb1.desy.de/record/405633/files/PhDThesis_ASchuetz_Publication.pdf

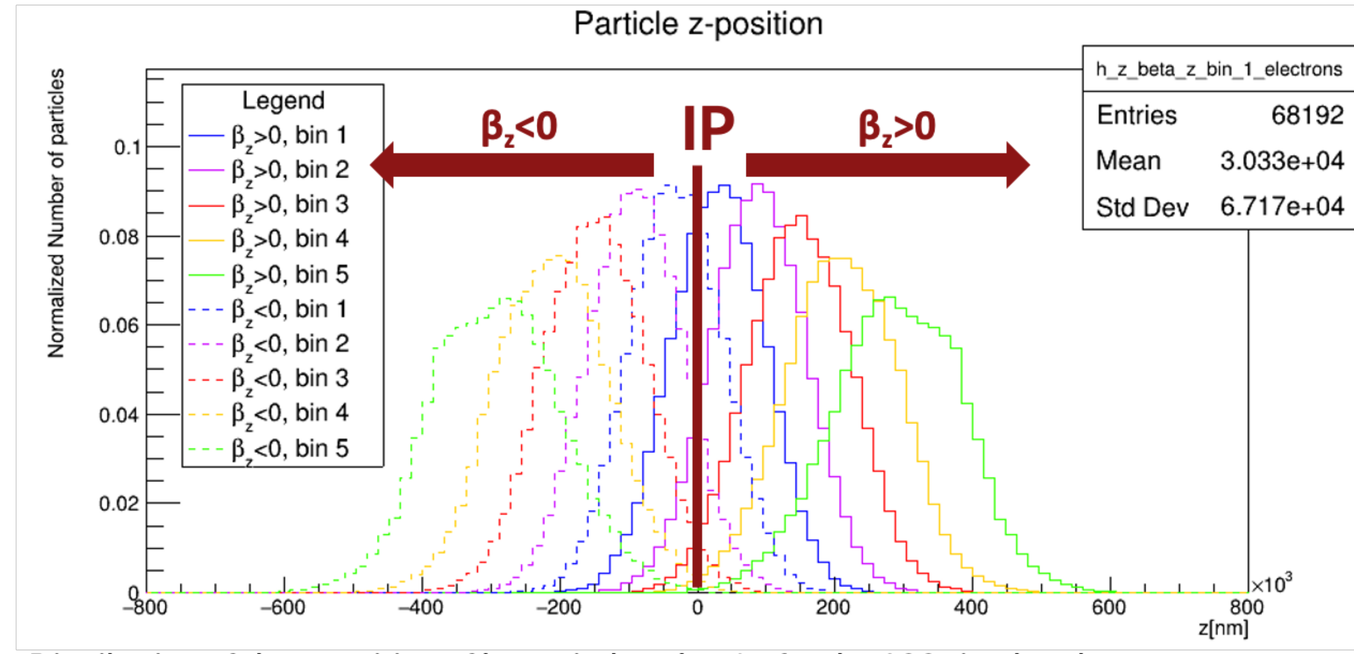



Source: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.44.2209&rep=rep1&type=pdf

- 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)

# Raw GP Results



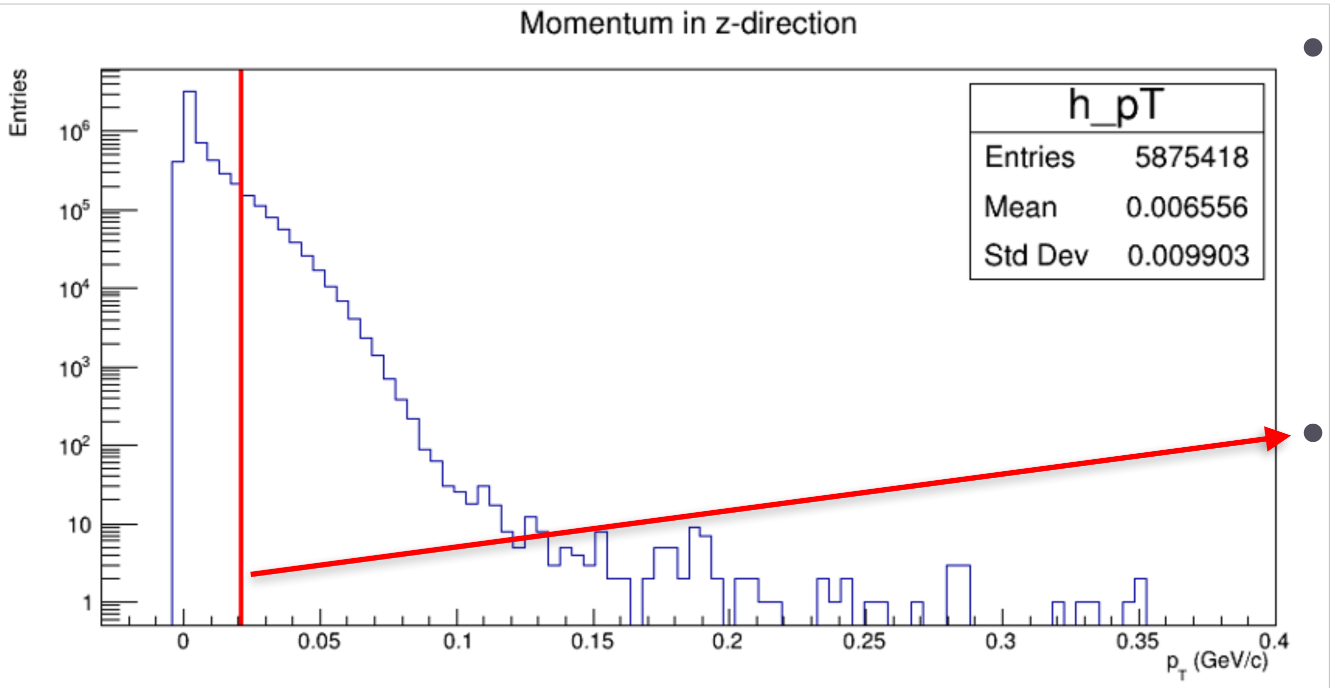




*Distribution of the z-position of beam-induced e+/e- for the 133 simulated BXs for different bins of $\beta_z$:*

*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

# Occupancy Back-of-the-envelope




- $p_T$ threshold for particles to reach the innermost pixel layer of SiD in the barrel region
- $p_T$ [GeV]=0.3 · (B [T]) · (r [m])
  =0.3 · 5 · 14 · 10^(-3)=0.021 GeV
  =21 MeV

- Expect ~528k particles to reach innermost pixel layer per train
  - Majority of particles are very boosted / forward
    - For reference ~3900 particles with $p_T$ > 21 MeV per bunch
  - 3% occupancy per train for 25x25 micron pixels, assuming a cylinder of pixels with perfect packing as the innermost layer
    - For comparison ILC is 8% occupancy with a 2000 bunch-long train
- With alterations to the readout electronics schema compared to ILC baseline this occupancy is feasible with a commensurate increase in power budget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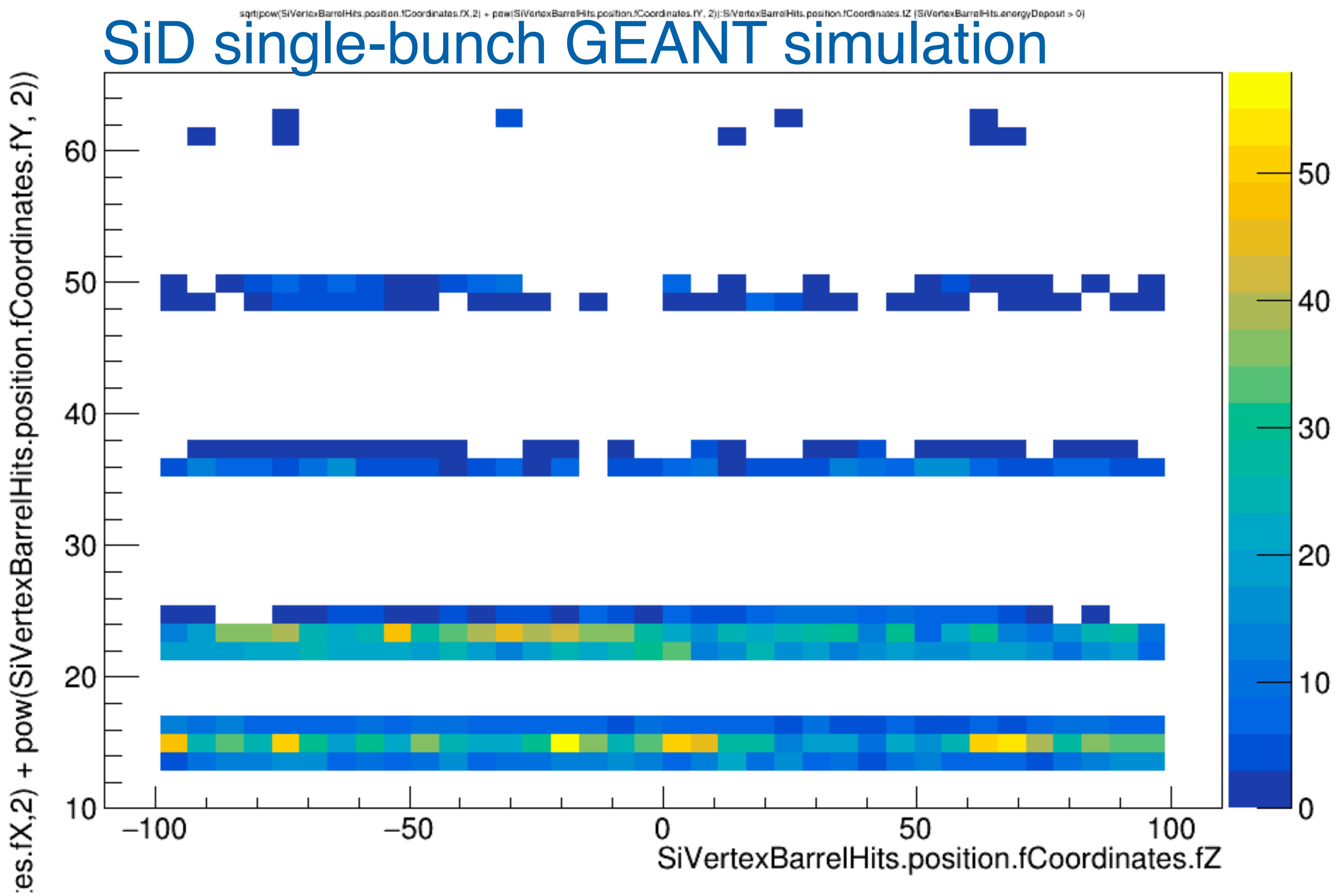
# Towards Full Simulation




- Hot off the press and even more recently reproducible
- 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 (~3% occupancy for 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

# Conclusions / Plans

- Simulated exact parameters for C3 using Guinea-Pig++ event generator
  - For a full $C^3$ bunch train

- $C^3$ beam parameters not inconsistent with high quality physics program from occupancy perspective, but more complete studies needed
  - Per-bunch-train occupancy is less than that of ILC and CLIC 3% vs 8%
    - Bunch structure significantly different - 120 Hz train repetition, 133 bunches per train
  - Electronics for this bunch configuration will have different power profile from ILC spec
    - However, still manageable from material/power budget perspective
    - Can take some hints from LHC-developed architectures

- Future plans:
  - Generate full suite of backgrounds and develop complete simulation of $C^3$ environment
  - Adopt full simulations in use by FCC/CLIC for detector optimization

- This is only the beginning of these studies, your scrutiny and feedback is appreciated!