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Beam background studies at C^3

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C^3 Workshop @ SLAC
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bold - did most of the work :-)

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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.

Recap

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
β_x^*	mm	12
β_y^*	mm	0.12
$\epsilon_{N,x}^*$	nm	900
$\epsilon_{N,y}^*$	nm	20
σ_x^*	nm	210.12
σ_y^*	nm	3.13
σ_z^*	μm	100
n_b		133
f_{rep}	Hz	120
N		$6.25 \cdot 10^9$
θ_c	rad	0.014

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

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

	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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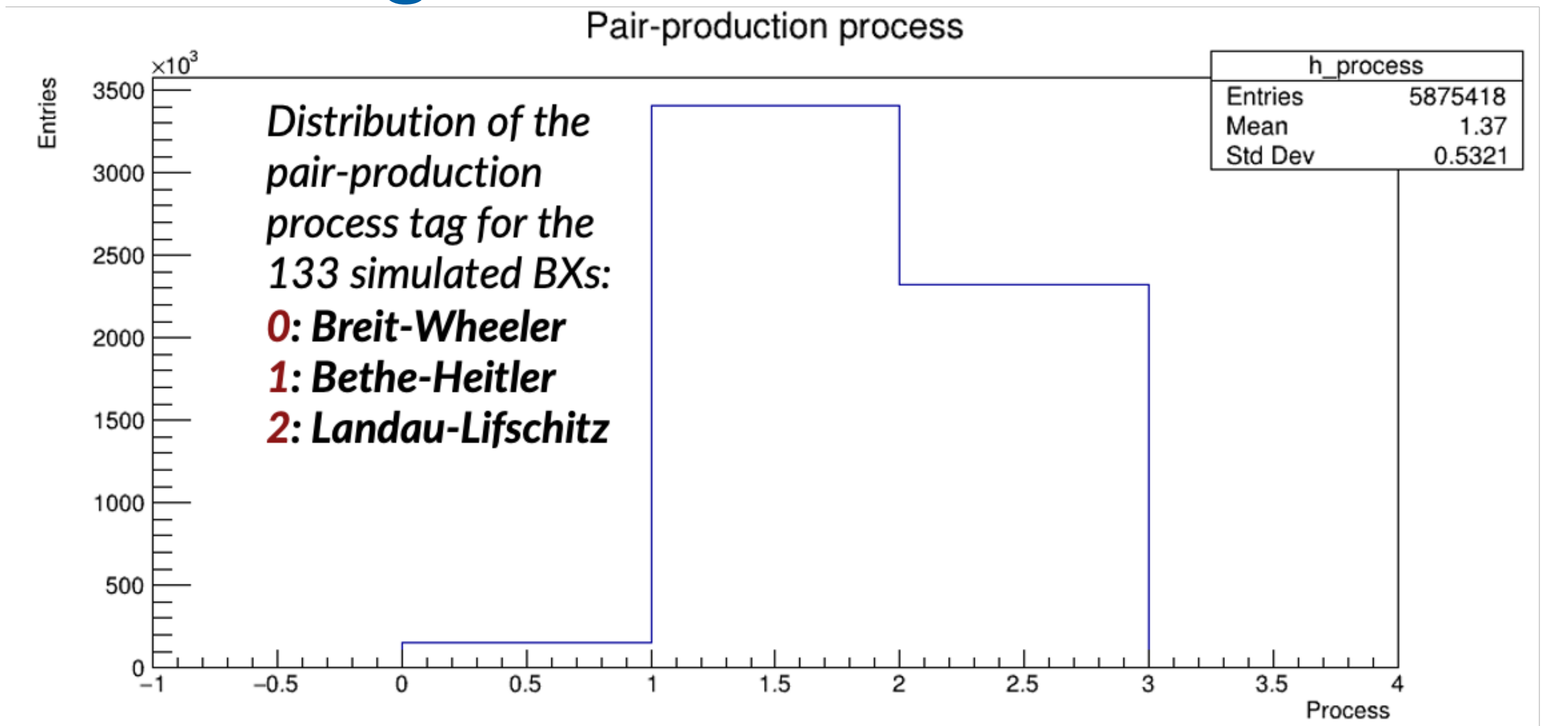
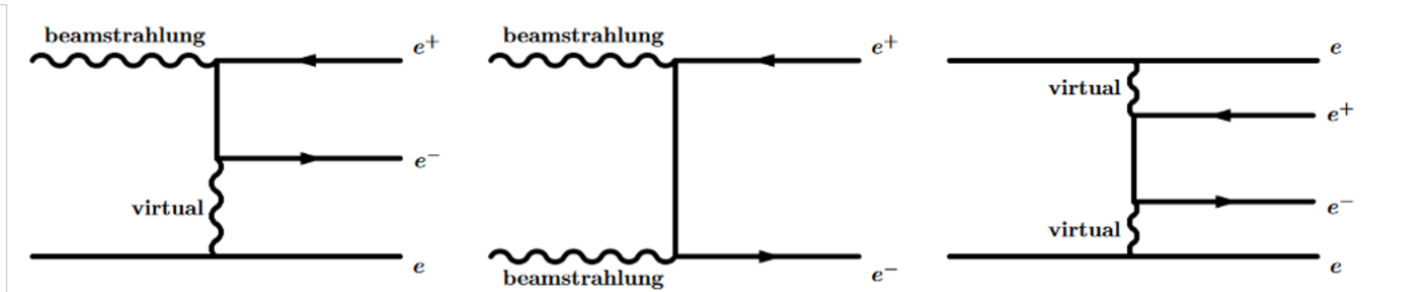
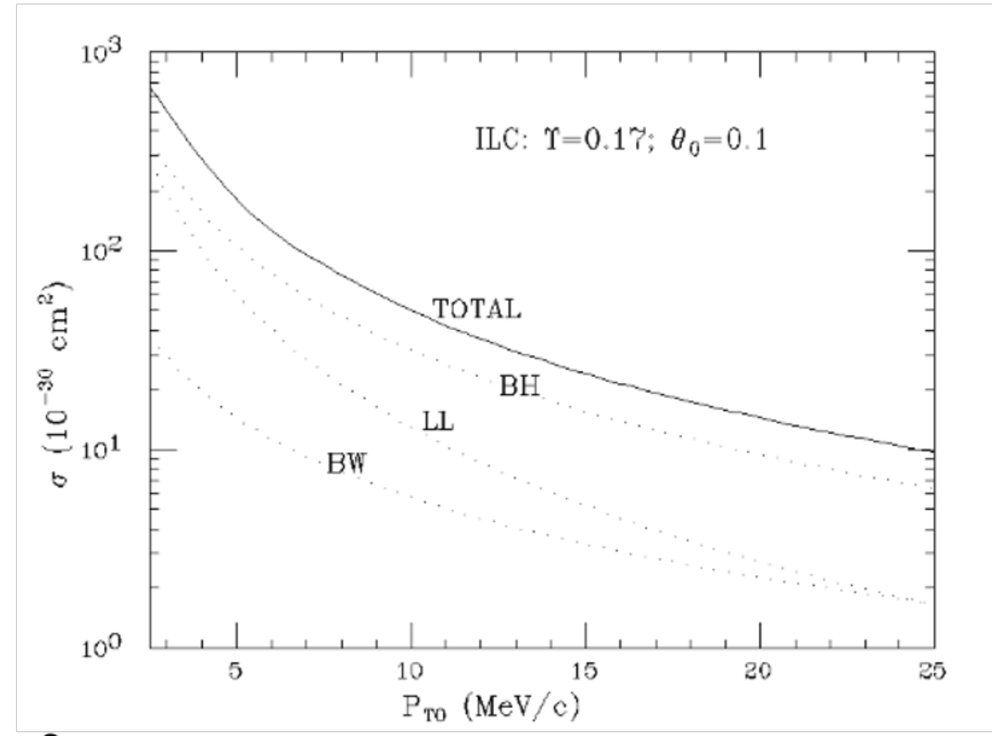
Guinea Pig and C³





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

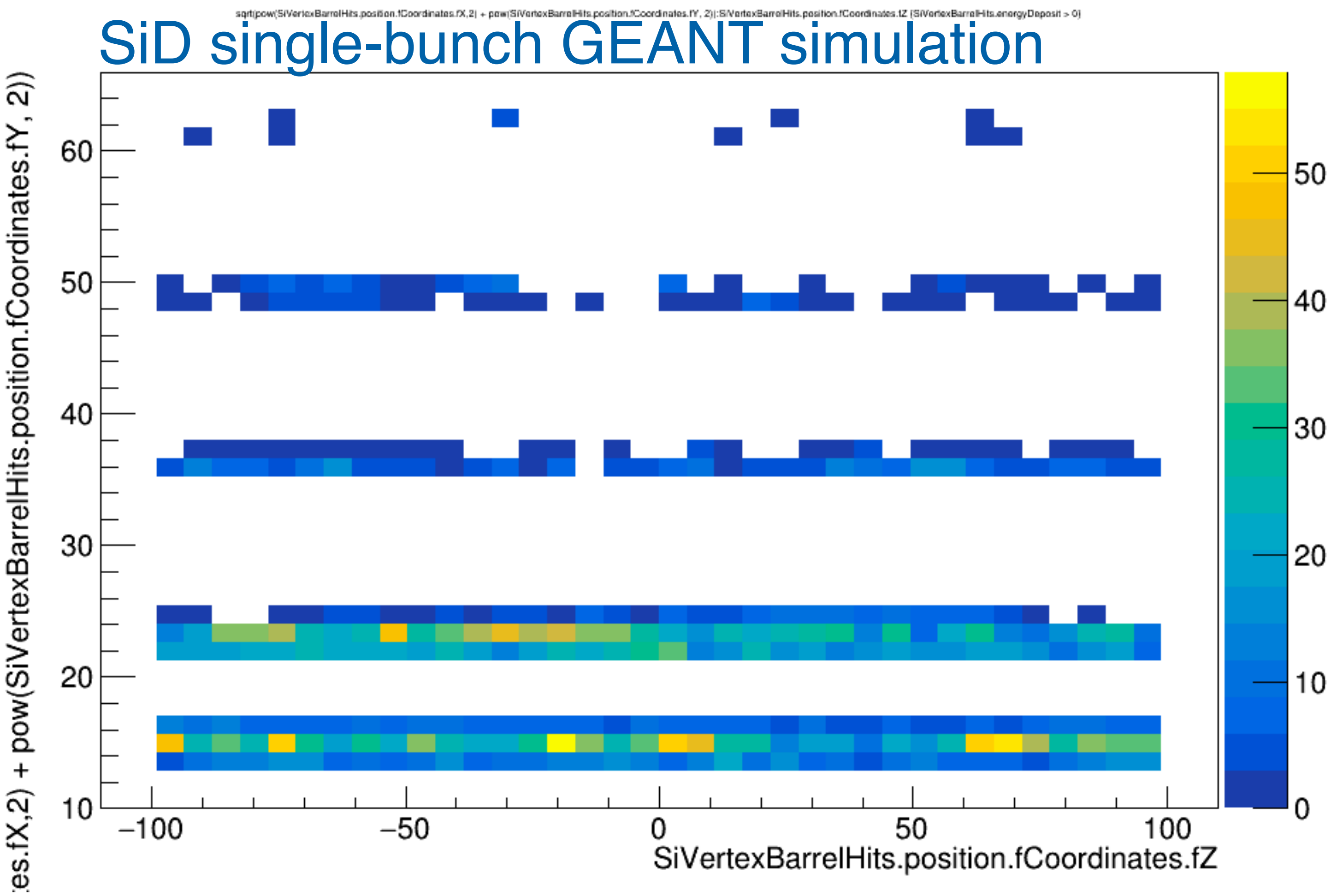
Source: https://bib-pubdb1.desy.de/record/405633/files/PhDThesis_ASchuetz_Publication.pdf



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)

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

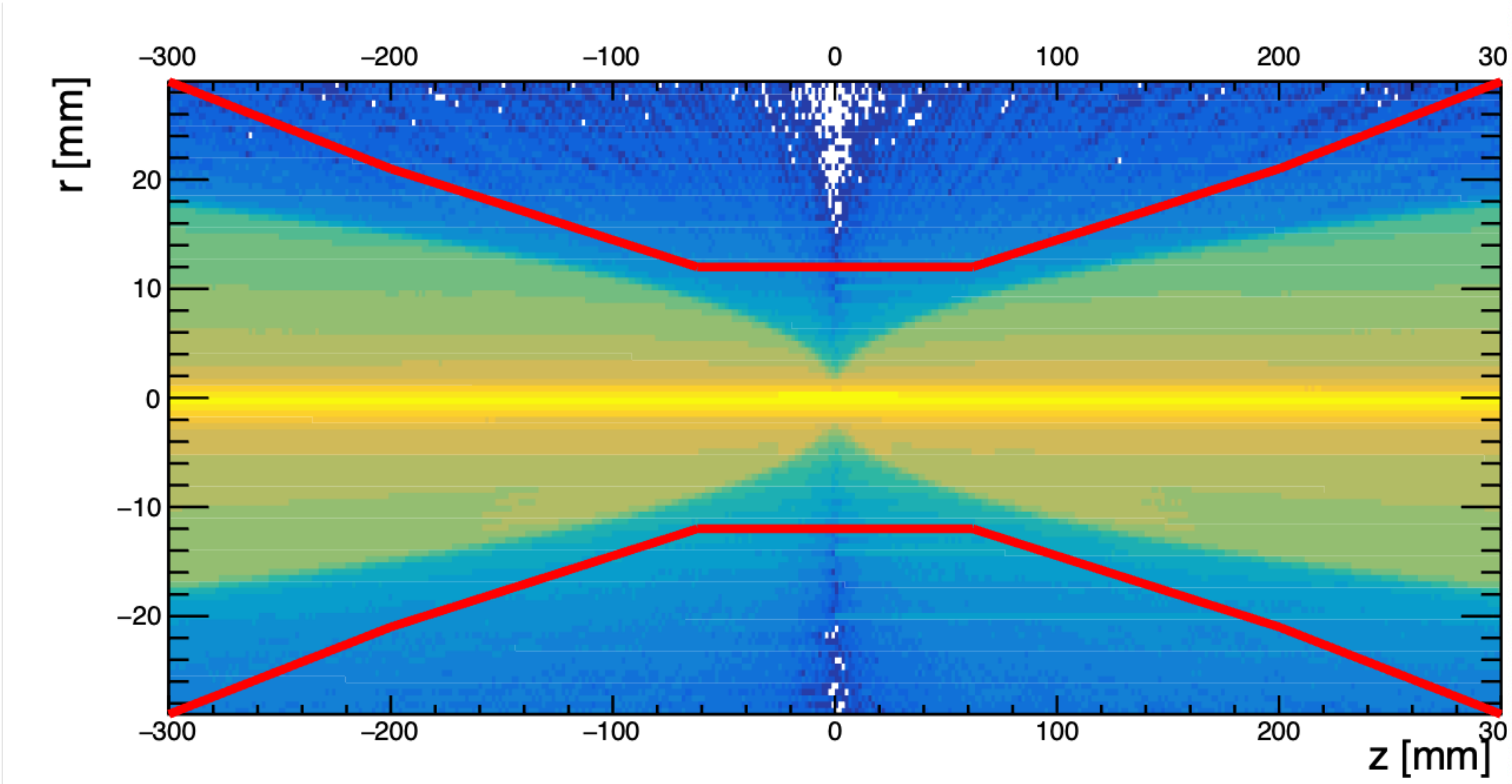
What’s new?

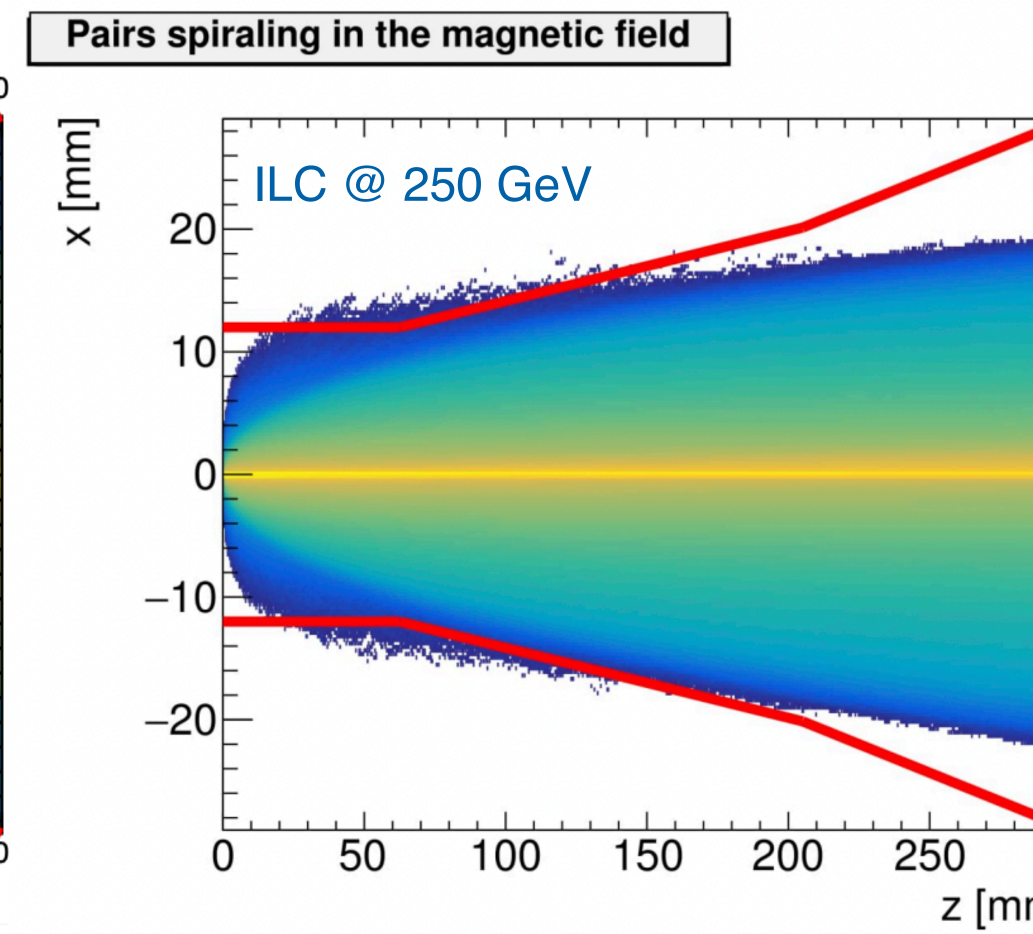
Doing better than 1 hour per bunch…

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

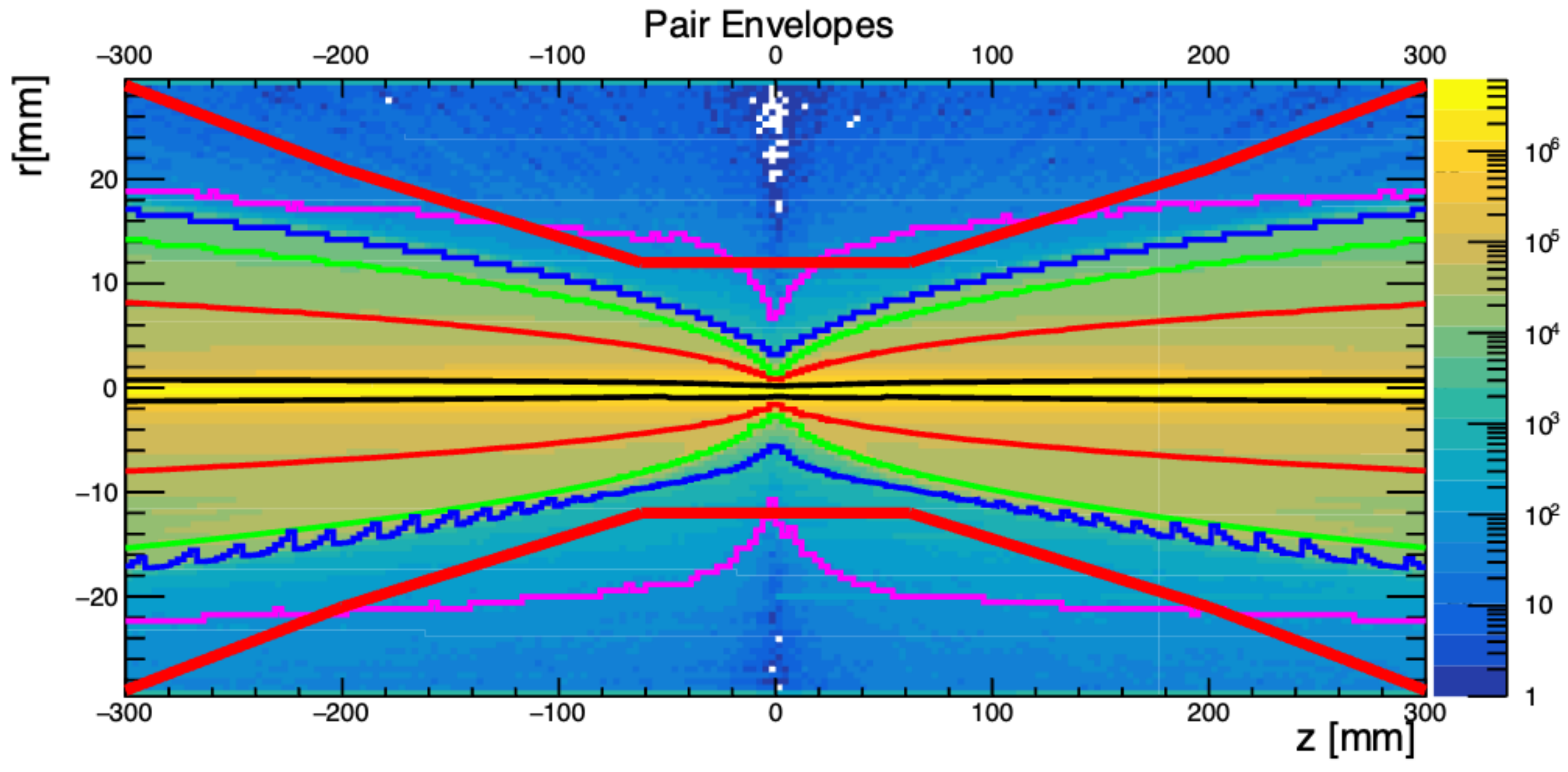
Envelope Plots a la ILC



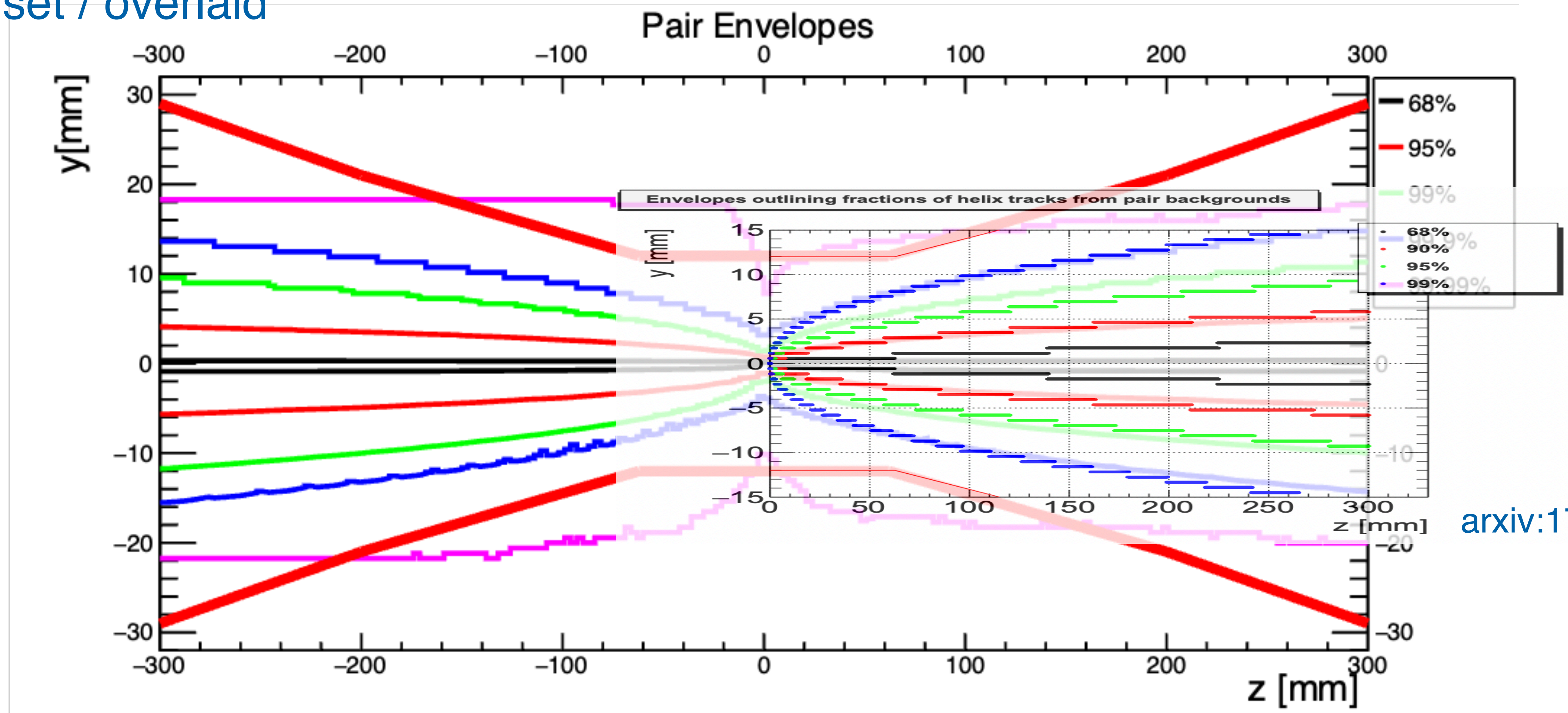


- Red line is latest placement of beam pipe at C³, most recent SiD geometry has first layer at 14mm away from IR
- Qualitatively similar results to ILC in this view…

Envelope Plots a la ILC

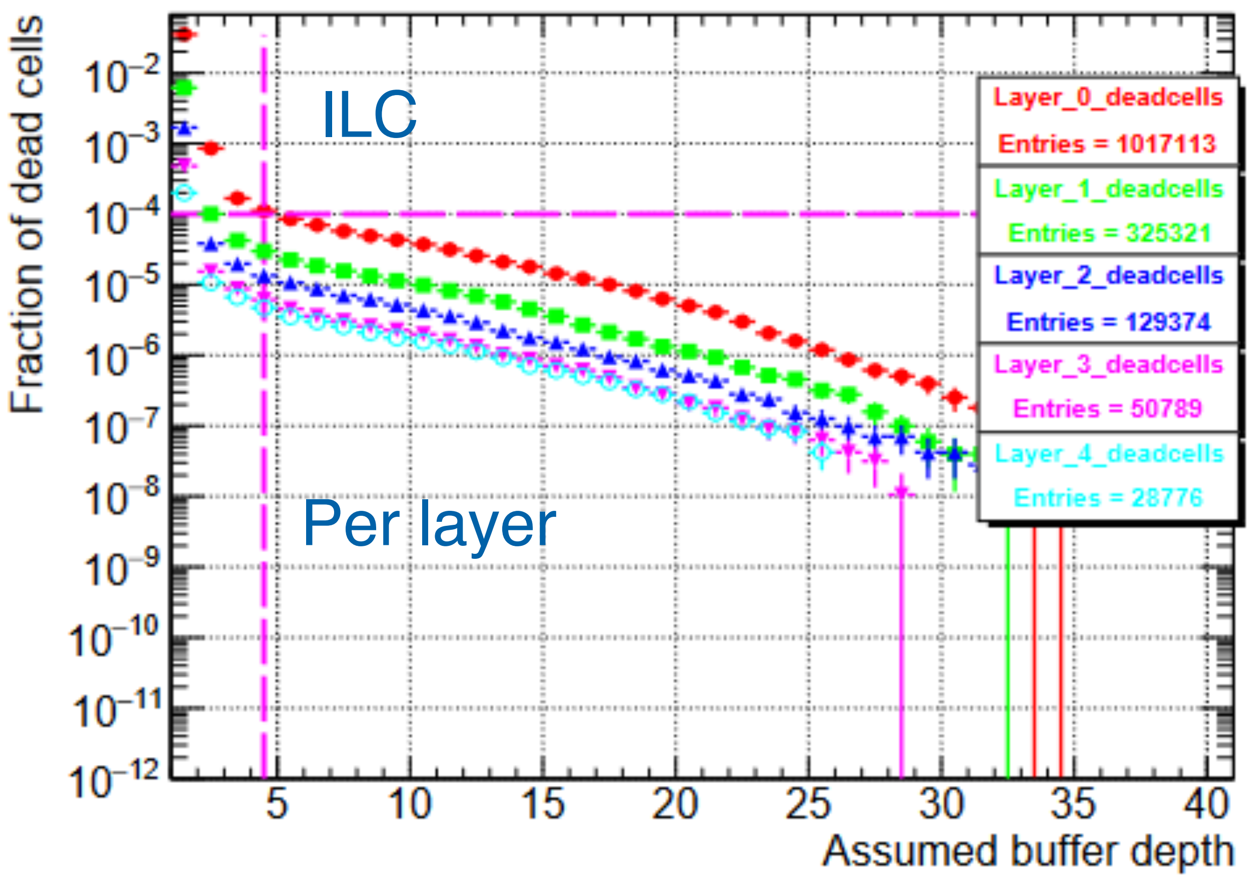


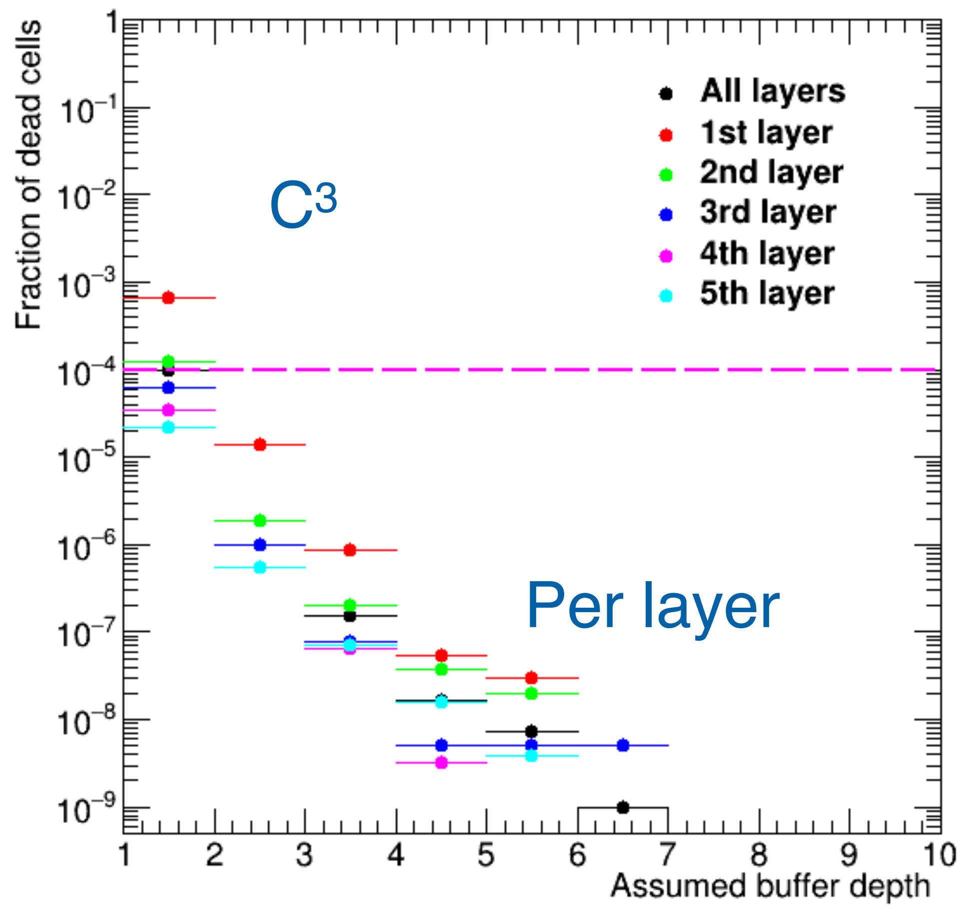
ILC inset / overlaid



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.

Filling out the background simulation library

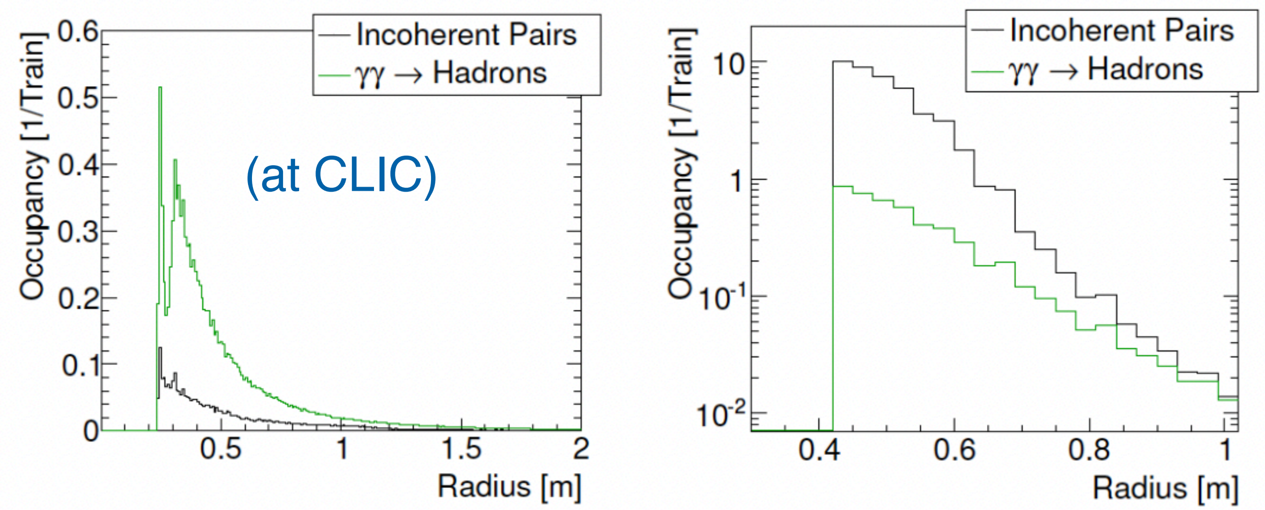


Figure 14. The radial distribution of the train occupancy per pad in ECal (left) and per cell in HCal (right) endcap [10].

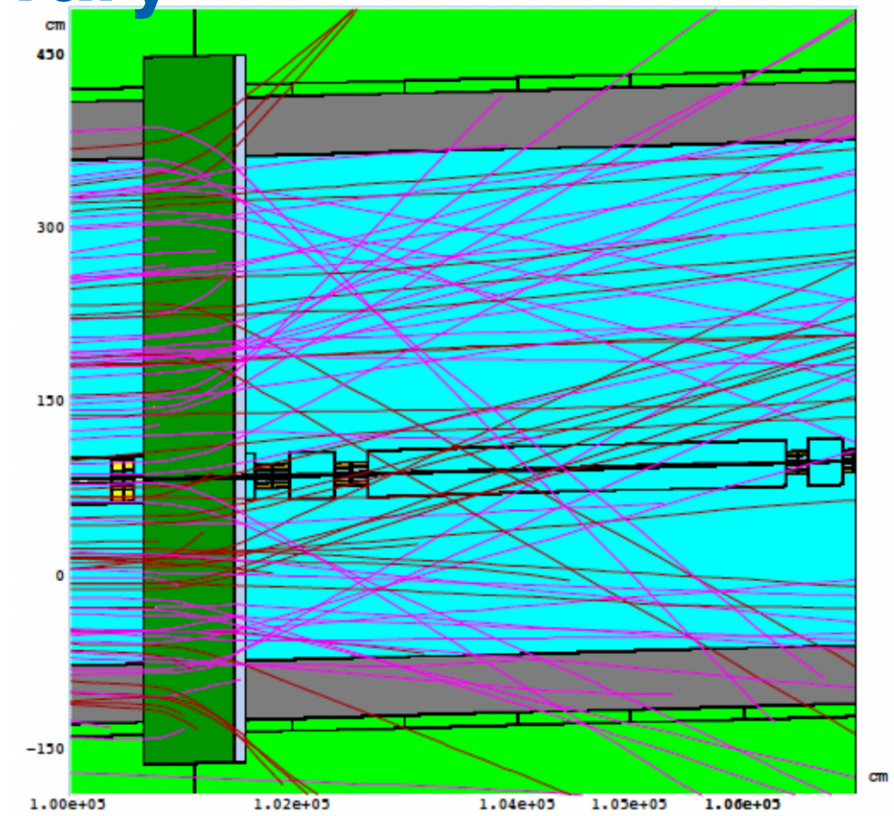
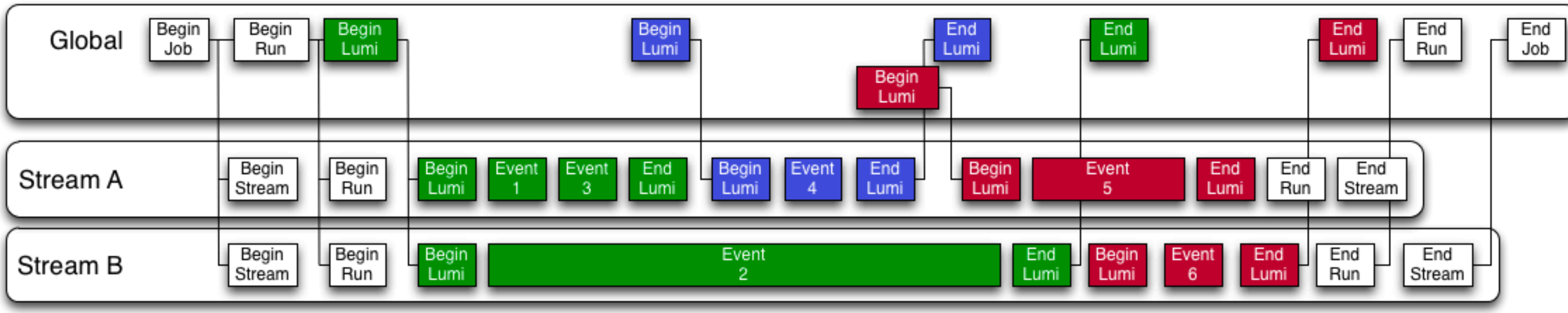
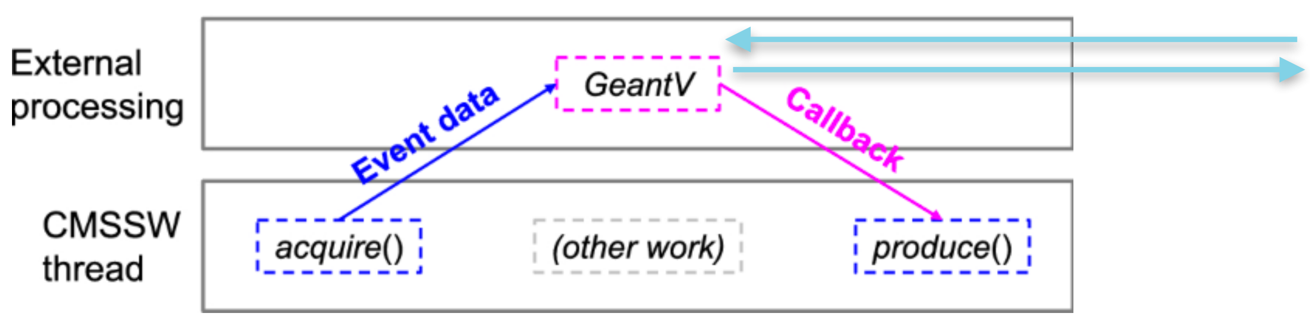


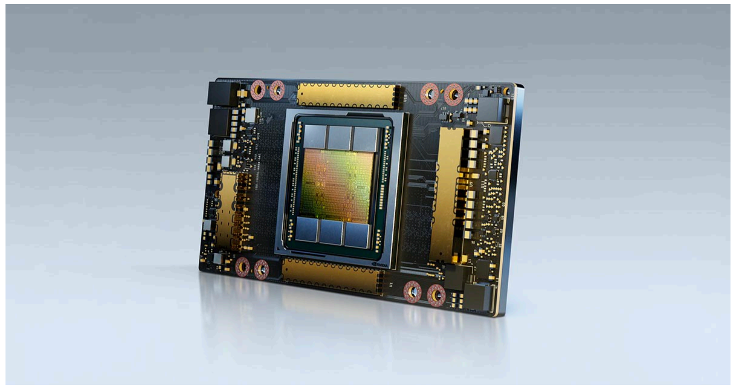
Figure 2. Muon tracks in the spoiler region [3].

- Hadron Backgrounds in Pythia5.7 -> Pythia8
  - Previous hadron background simulation libraries generated in pythia6 but most of the configuration lost to history (generated/mixed events available but for ILC)
  - Talked with Pythia authors to get modernized versions of photoproduction workflow
  - Will harmonize (as best we can) with the tuning used for ILC studies provided by Tim
- Muon Machine Backgrounds code is more or less lost (or difficult to use)!
  - Unmaintained fortran code which is difficult to get ahold of these days
  - May need to re-build this from scratch if we would like to include this in our library of backgrounds for event simulation (would like to include properly in simulation)

Planning for an updated simulation & reconstruction framework







- Modern processors designed around multiple cores
- Linear collider software will need to address this
  - Despite drastically different computing needs compared to LHC experiments
- Modern techniques coupled with hardware accelerators allows us to create more detailed reconstructions and improve C3 physics outcome.

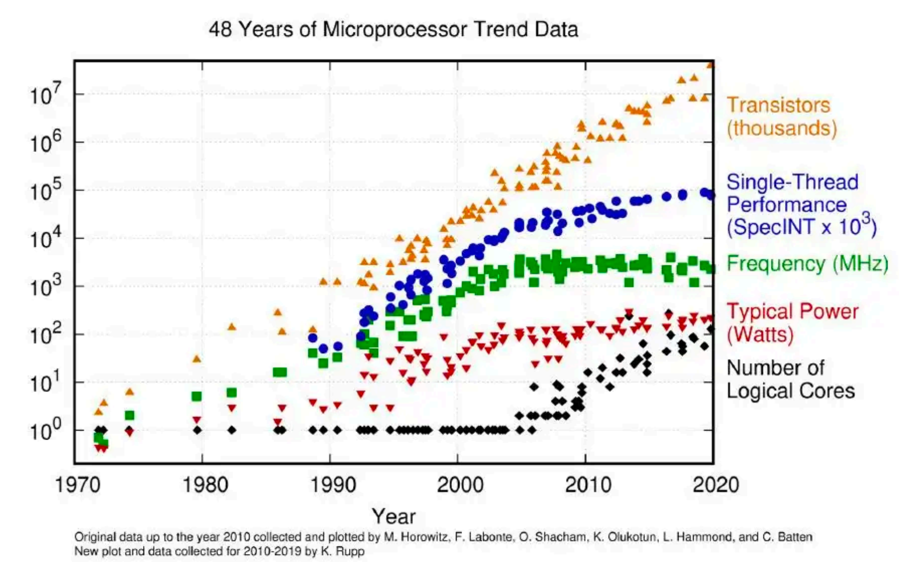


Figure 3. 48 Years of Microprocessor Trend Data. Source: K. Rupp.

Planning for an updated simulation & reconstruction framework

- I suggest we investigate and build around the non-collaboration port of CMSSW “Stitched”
  - Contains all the essentials needed to build a modern, multithreaded framework from code that is battle hardened for (HL-)LHC data and simulation.

README.md

Stitched

Stitched is an export of the CMSSW Framework packages and a minimal set of data packages needed for testing the Framework.

Building and running with spack

- Clone spack and cmssw-spack and run build

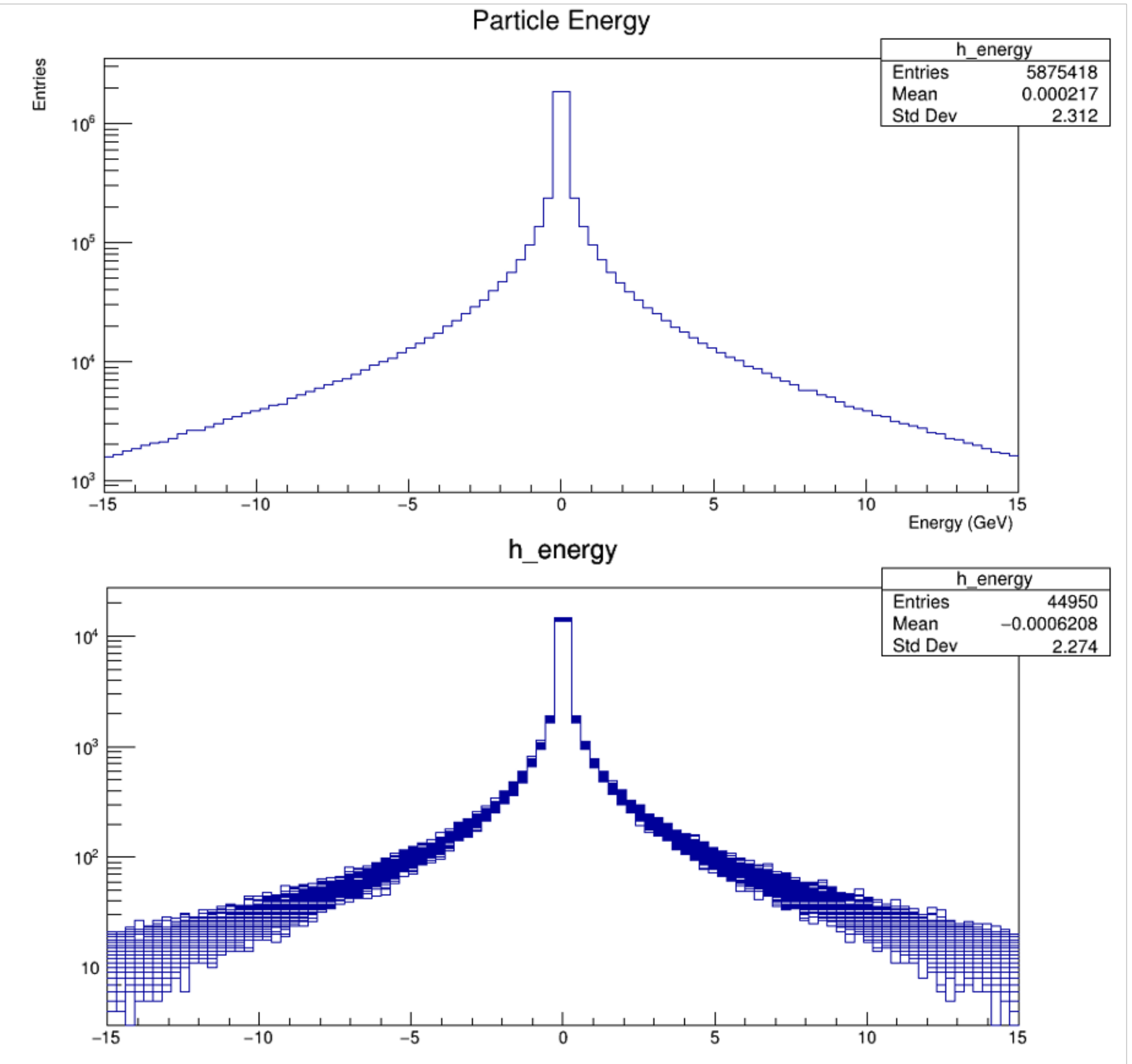
```
git clone https://github.com/spack/spack.git
source spack/share/setup-env.sh
spack compiler add
cd spack/var/spack/repos
git clone -b stitched https://github.com/gartung/cmssw-spack.git
spack repo add $PWD/cmssw-spack
mkdir -p ~/.spack/cray
cd -
spack install stitched
spack activate py-setuptools
spack activate py-six
spack activate py-future
```

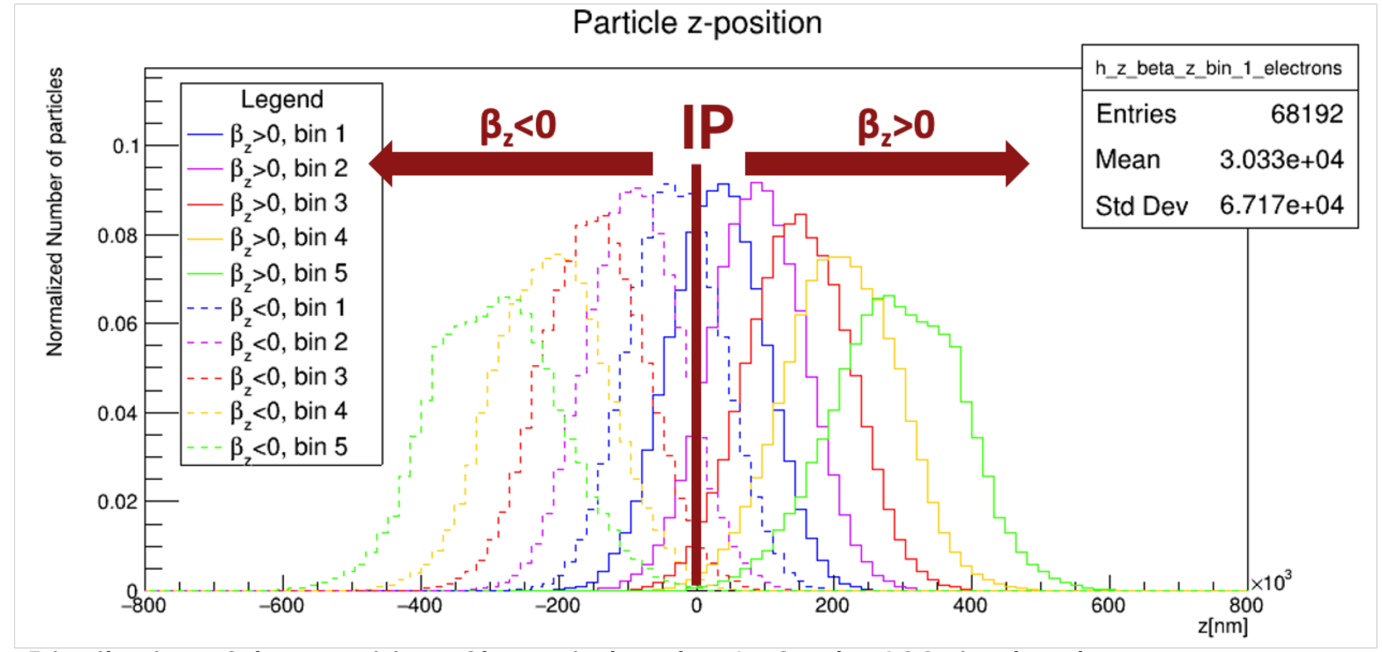
Conclusions / Plans

- Very close beam-profile match between C^3 and ILC 250 (and 500)
  - For a full C^3 bunch train
- 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
- We should focus now on detector optimization, working out electronics, and building the experiment we want
  - It's time to build out our software framework and address the specificities of C^3 together!
  - A modern framework that can leverage contemporary computing hardware will benefit us and others significantly in this effort.
  - We would like to coordinate heavily with ILCSoft developers to make this real
- 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 β_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 C^3 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