



Beam Induced Backgrounds at C3

Lindsey Gray (FNAL), Elias Mettner (UW-Madison), Dimitris Ntounis (SLAC)

With significant help from:

Tim Barklow (SLAC), Juergen Reuter (DESY), Thorsten Ohl (Wuerzburg)

C3 Workshop @ NIKHEF

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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

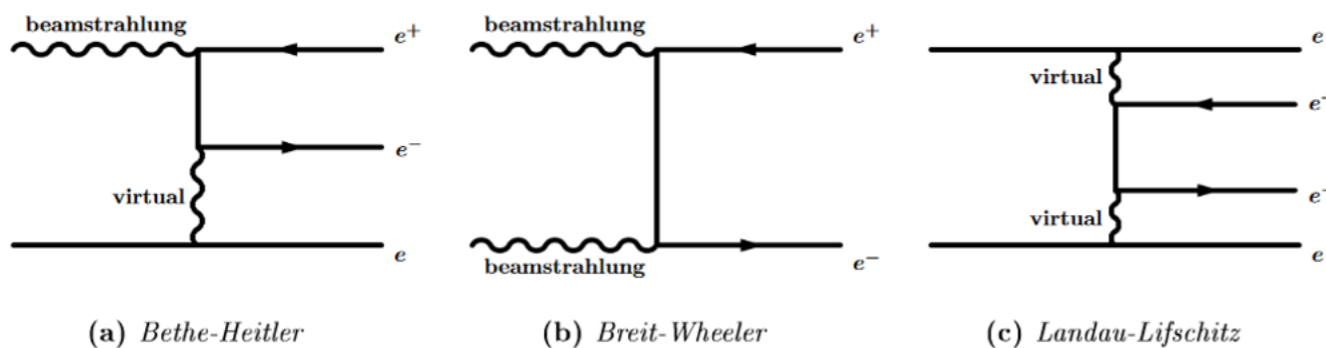
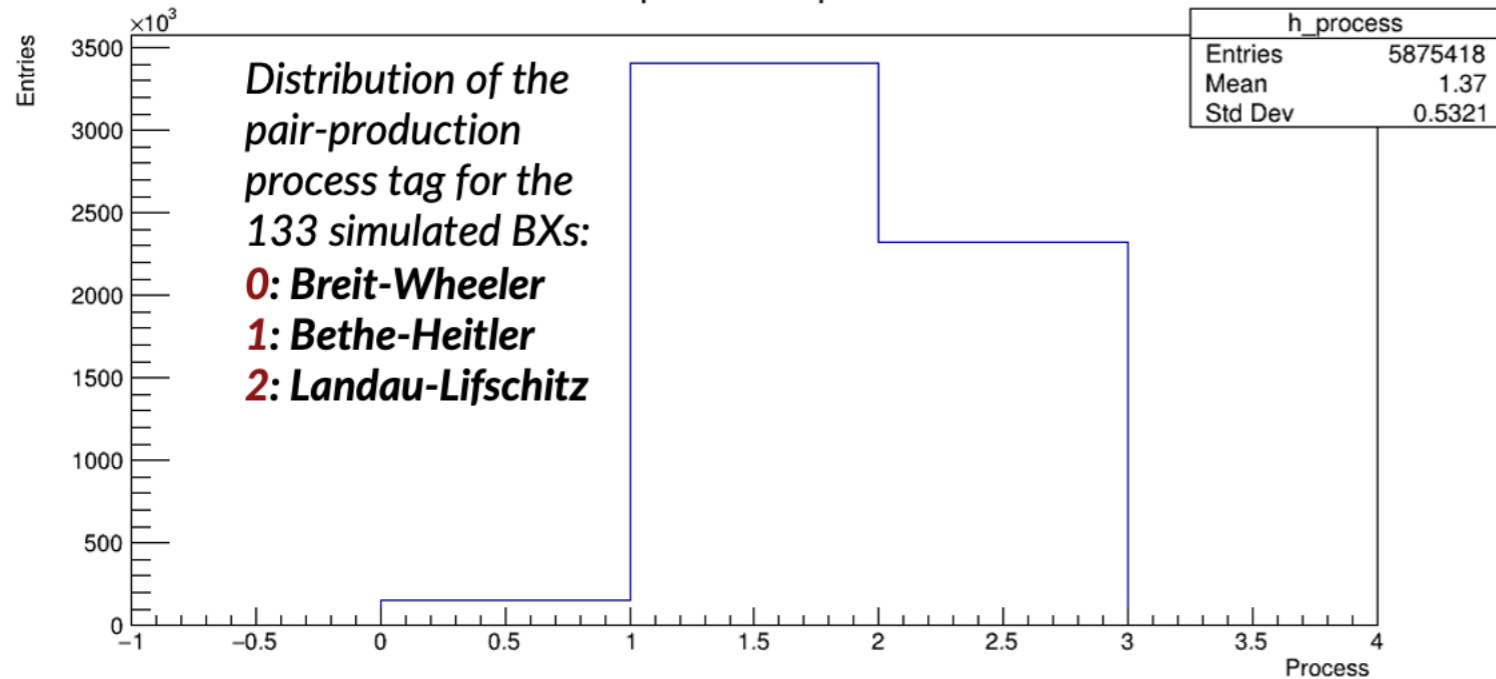
- The emittances on the table are **normalized**. The transverse beam size is calculated as:

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

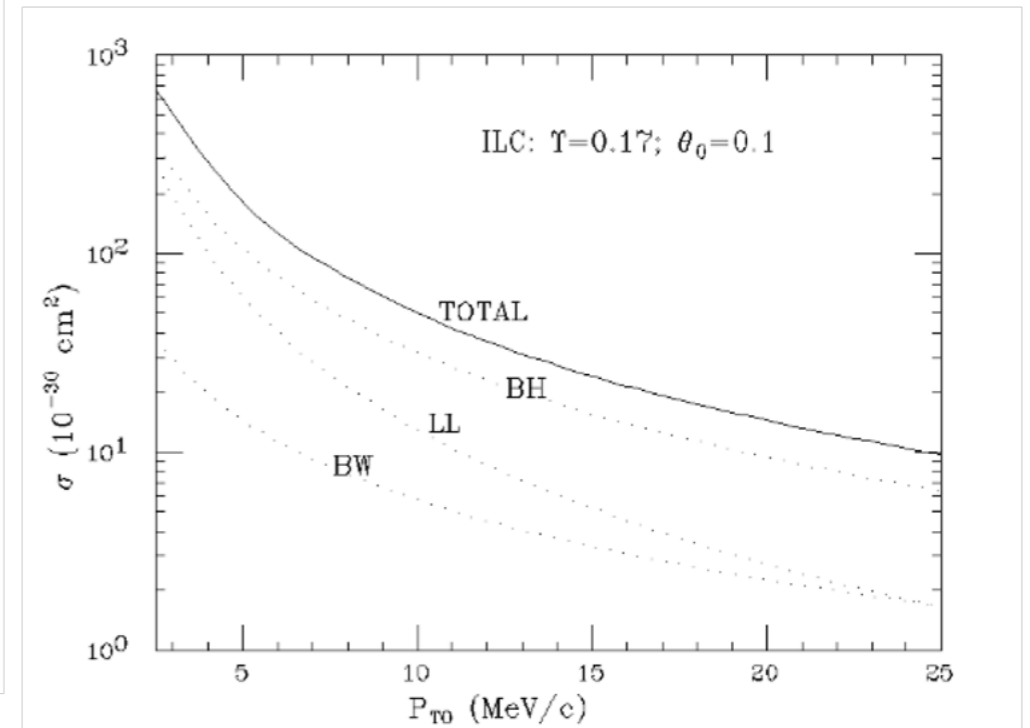
	Initial Tests	Emilio's Values
Energy spread	0.1%	0.3%
Energy spread distribution	Gaussian	Flat
Offset in x direction (nm)	0	5
Offset in y direction (nm)	0	0.2
Waist shift in x direction (μm)	0	0
Waist shift in y direction (μm)	0	Thanks Emilio! 0
Crossing angles (not compensated by crab scheme)	0	0

Guinea Pig and C³

Pair-production process



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

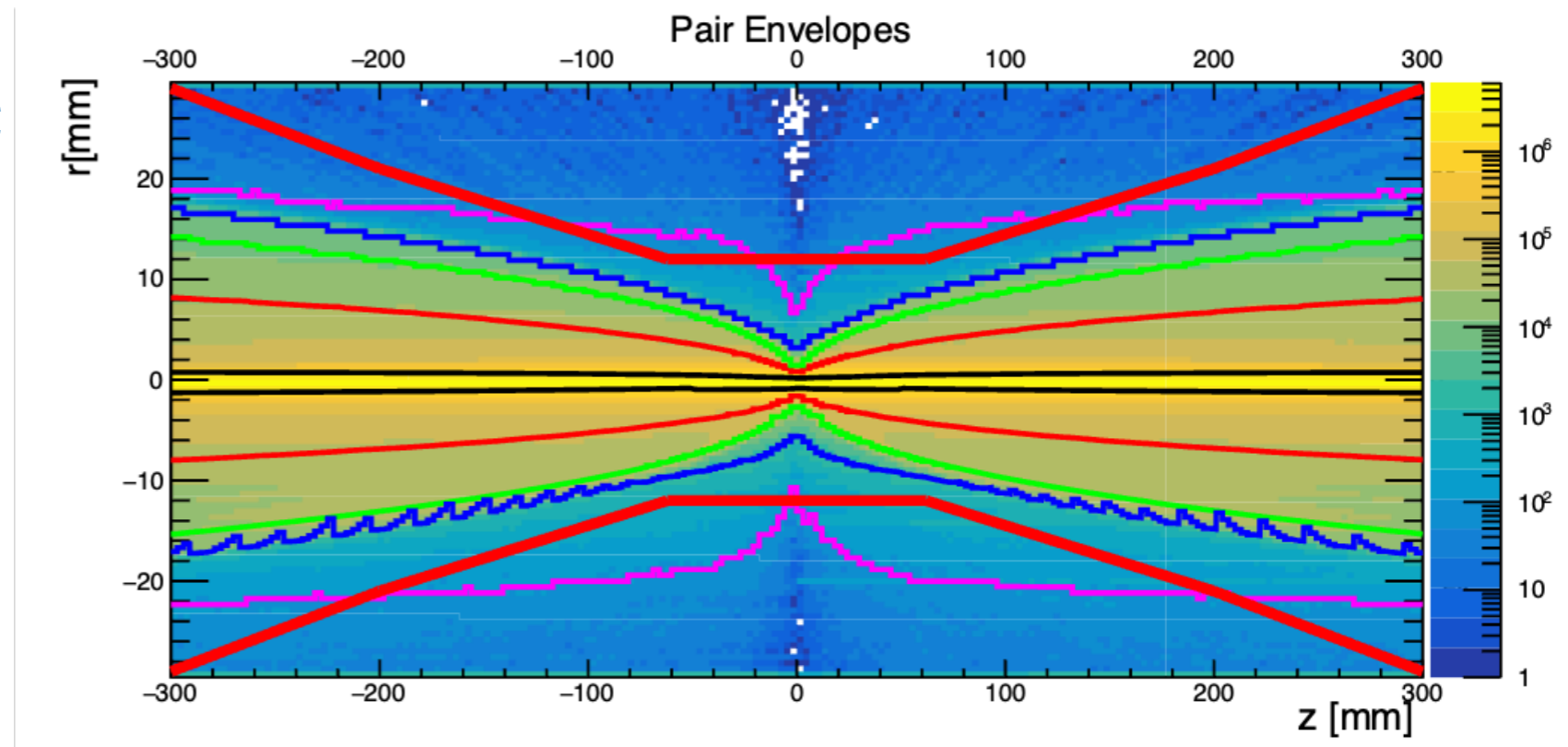


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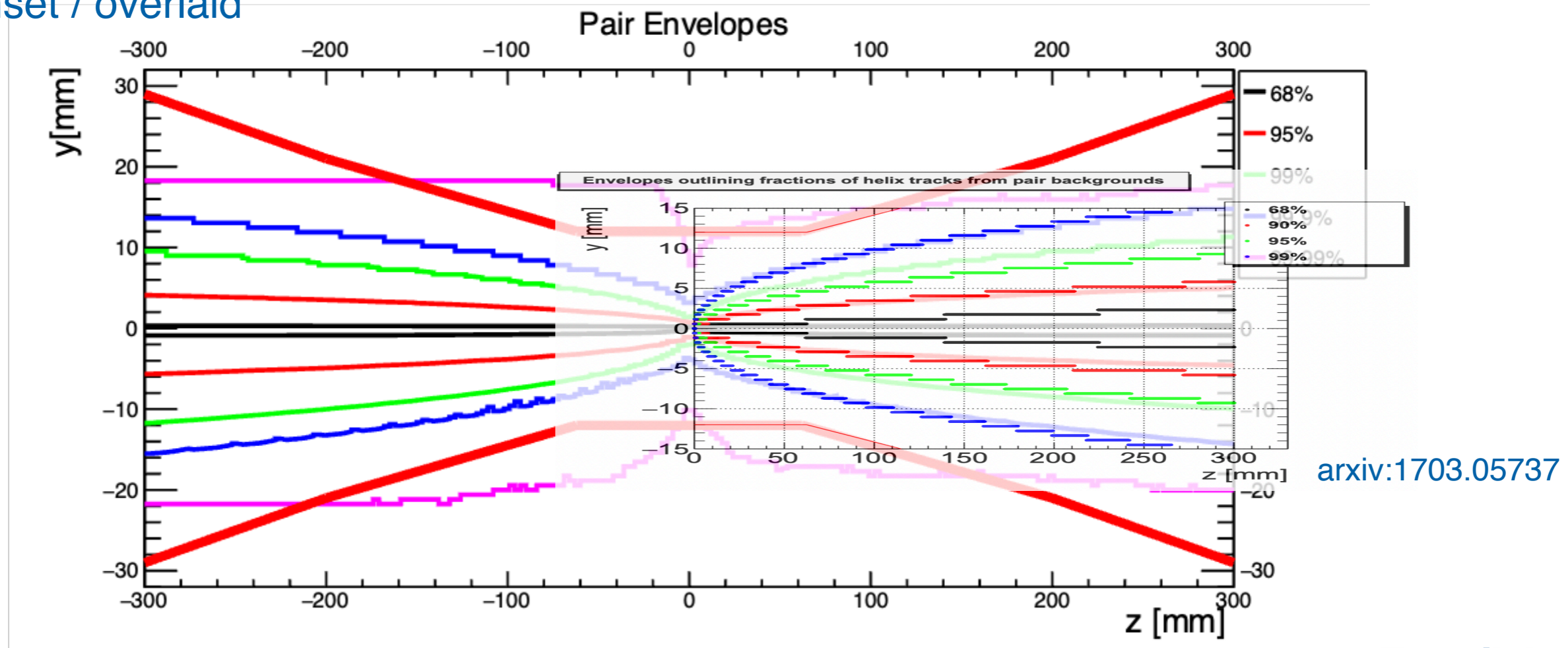
<https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.44.2209&rep=rep1&type=pdf>

- 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 (better sim. discussed in this talk)

Envelope Plots a la ILC

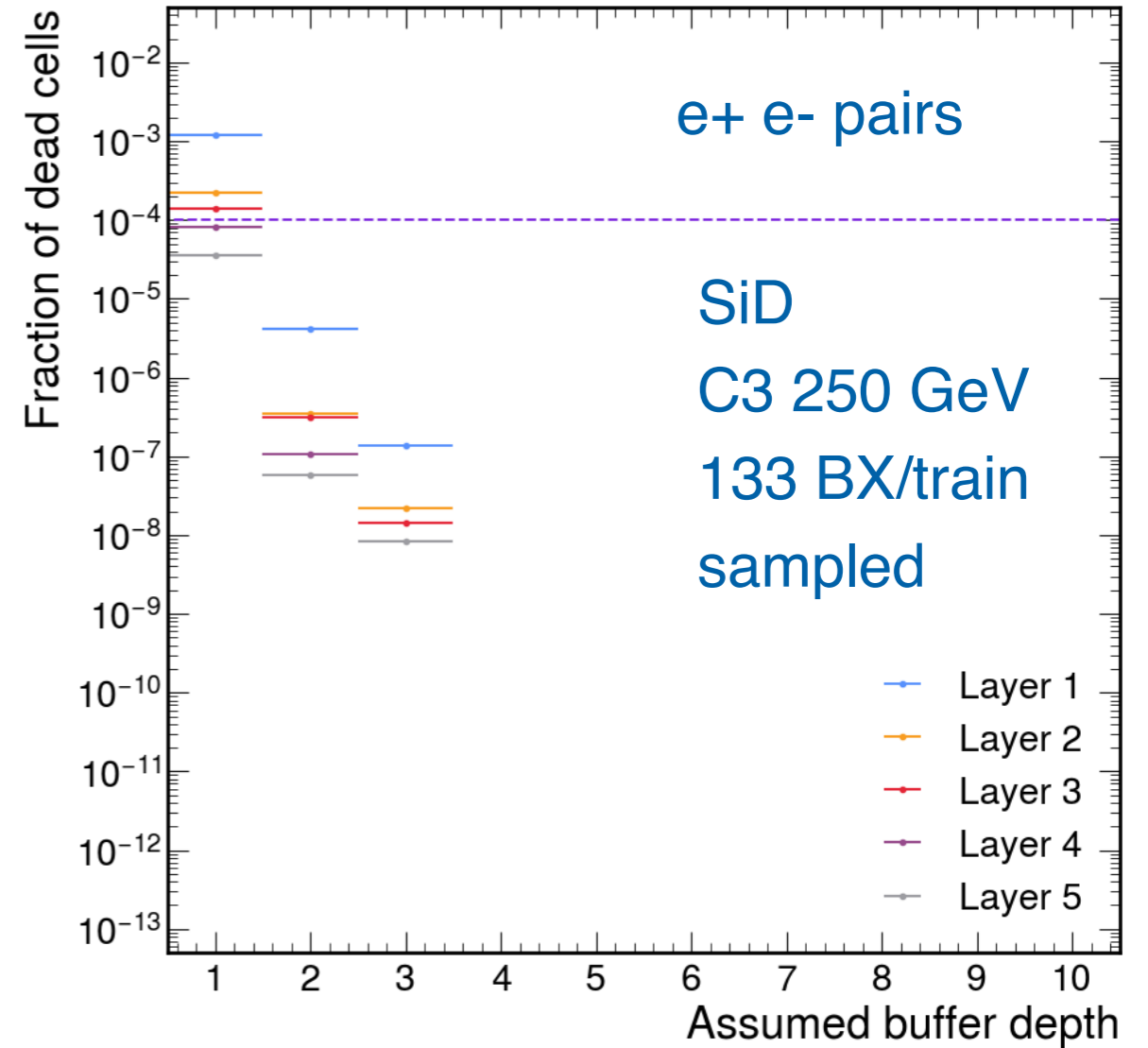
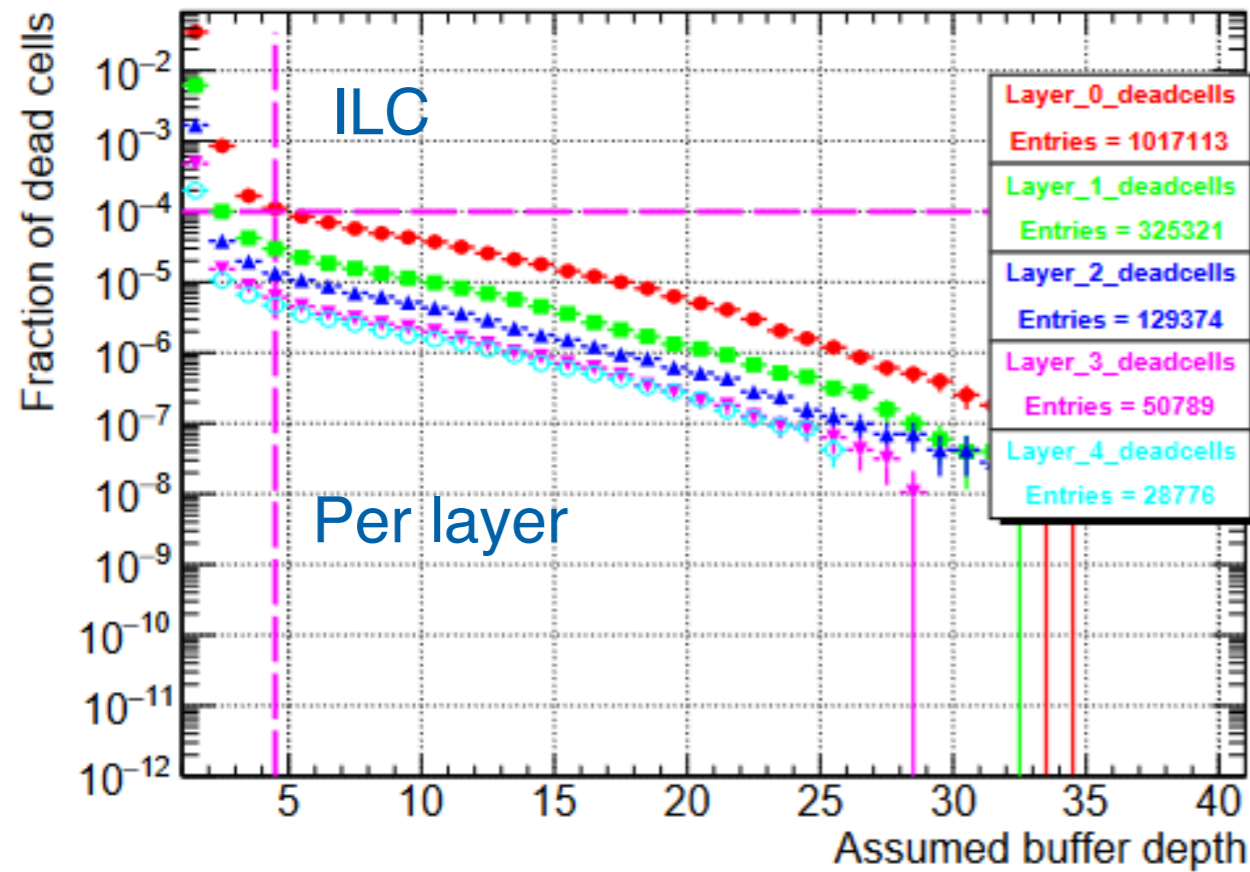


ILC inset / overlaid



arxiv:1703.05737

Preliminary Results for C³



- 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.
- Confirms baseline expectation that C³ ~ ILC/10

Hadron Photoproduction: Introduction

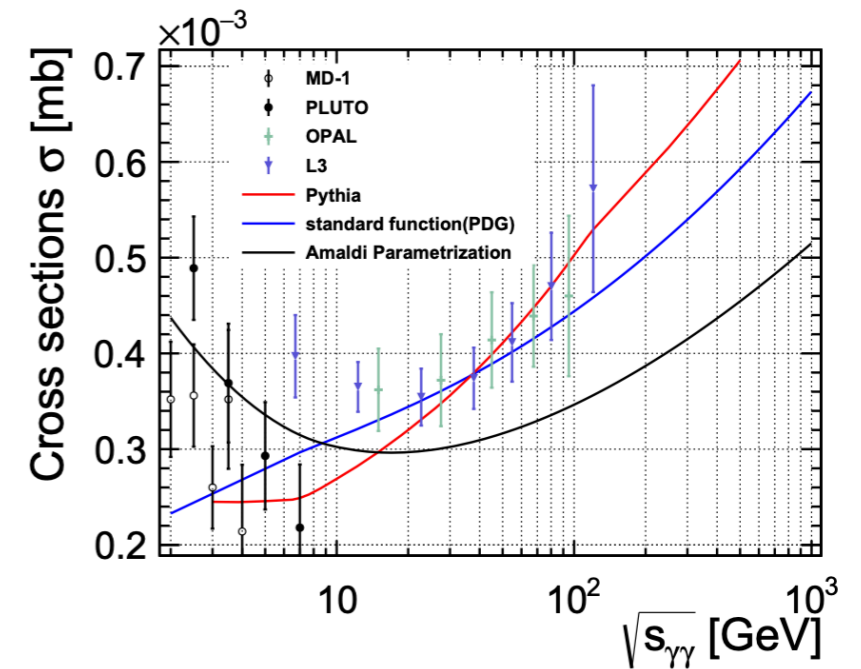
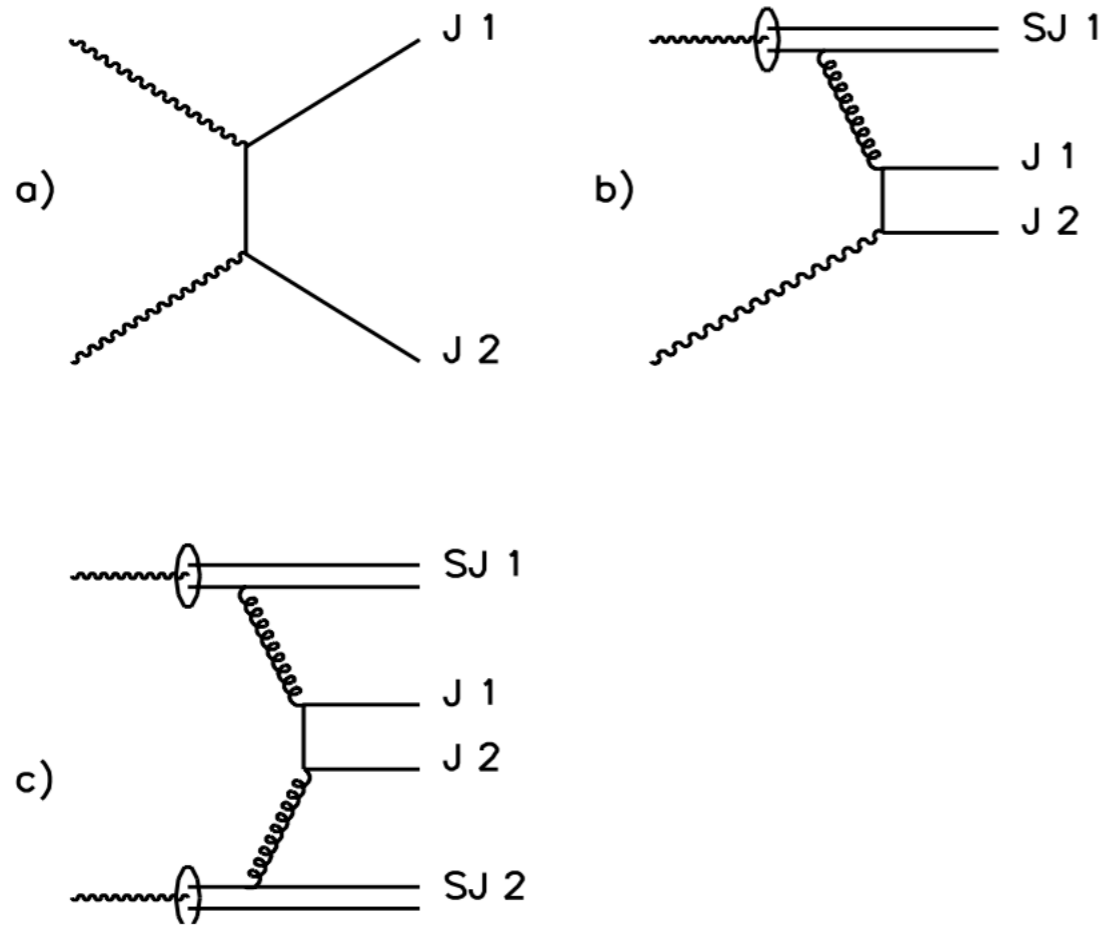


FIG. 2: Comparison of cross sections for $\gamma\gamma \rightarrow$ hadron processes as a function of centre of mass energy obtained from Amaldi parameterization [3], Standard parameterization [8] in PDG, Pythia and data from LEP [1], PETRA [6] and VEPP [5]

- Diagrams have similar topology to electron-positron background but include the possibility that the virtual photons pair-produce quarks
- Given smaller coupling to quarks and requirement for internal conversion this background is smaller
 - Measurements indicate $\sim 10\%$ of pair background at calorimeters, more central than e^+e^- !
- Given the c.o.m. range over which we're producing events there are many details to consider

Hadron Photoproduction: Spectra and Generators

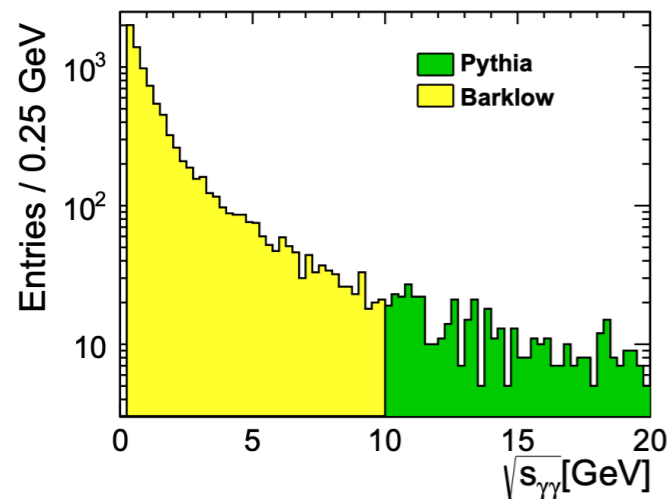


FIG. 1: Energy spectrum of $\gamma\gamma \rightarrow$ low p_T hadron events as a function of centre-of-mass energy. The figure shows the energy cutoff of 10 GeV below which the events are generated by the Barklow generator. Above 10 GeV the events are generated by Pythia.

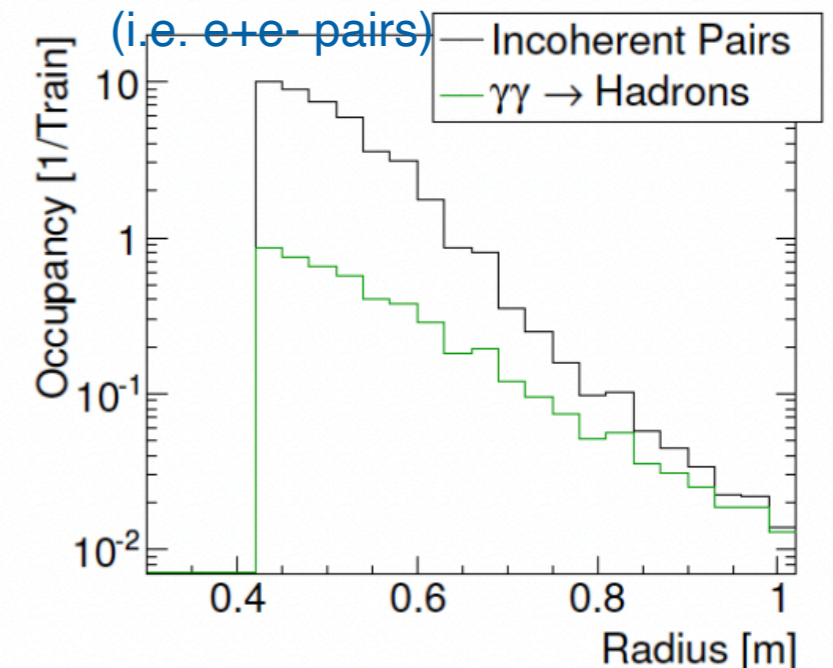
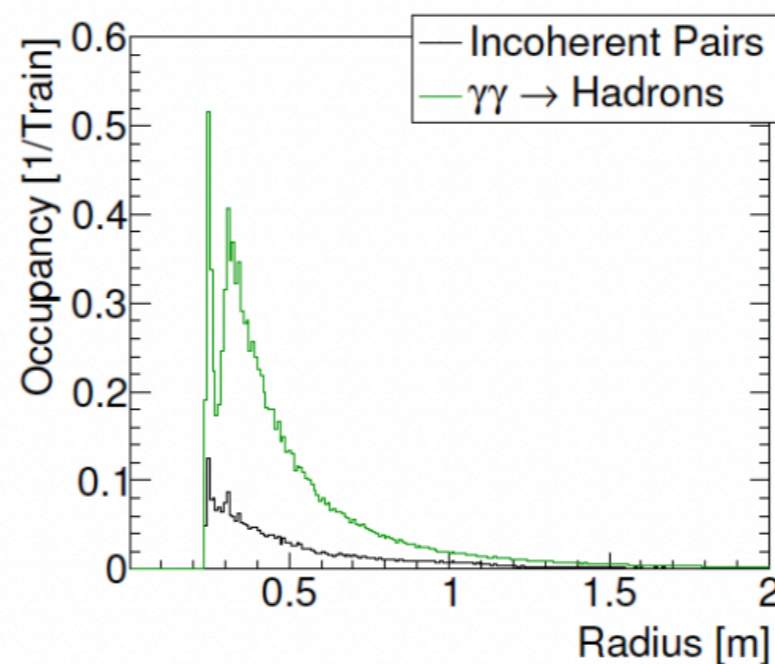
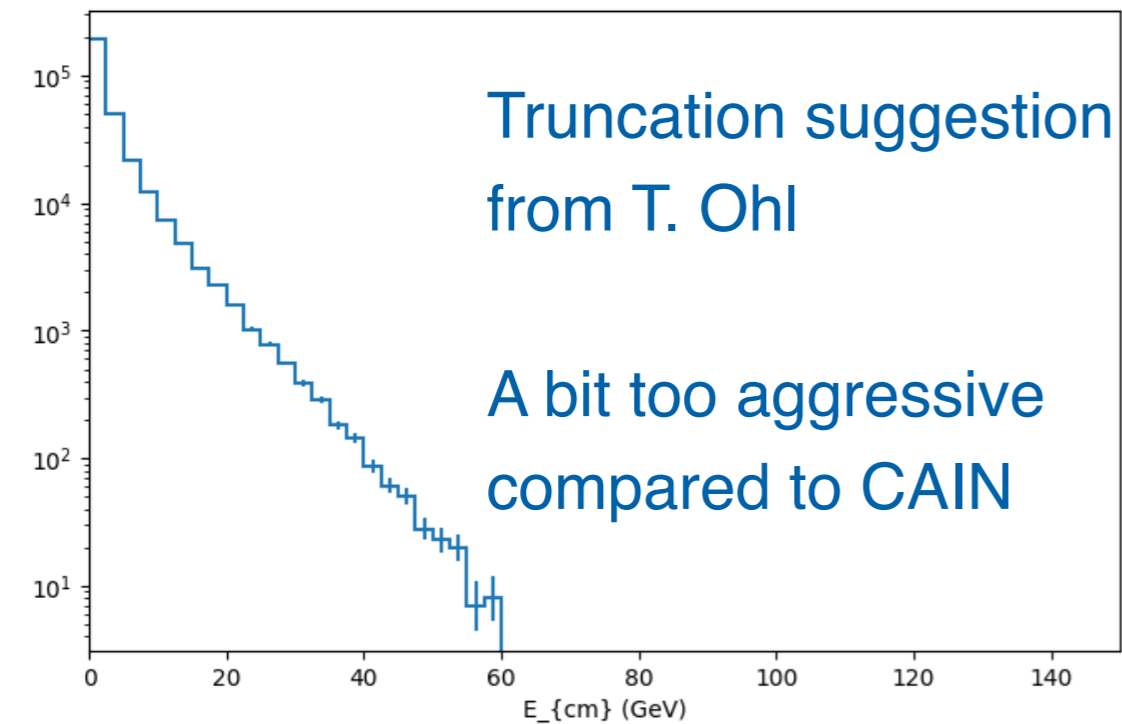
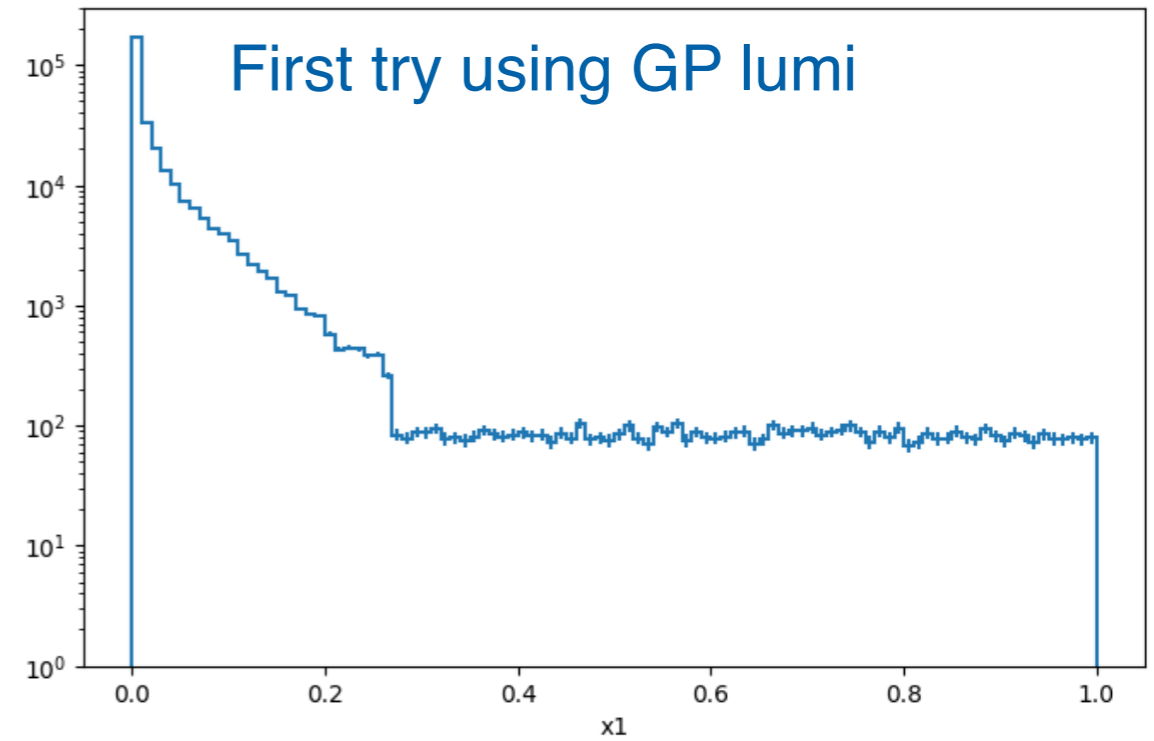
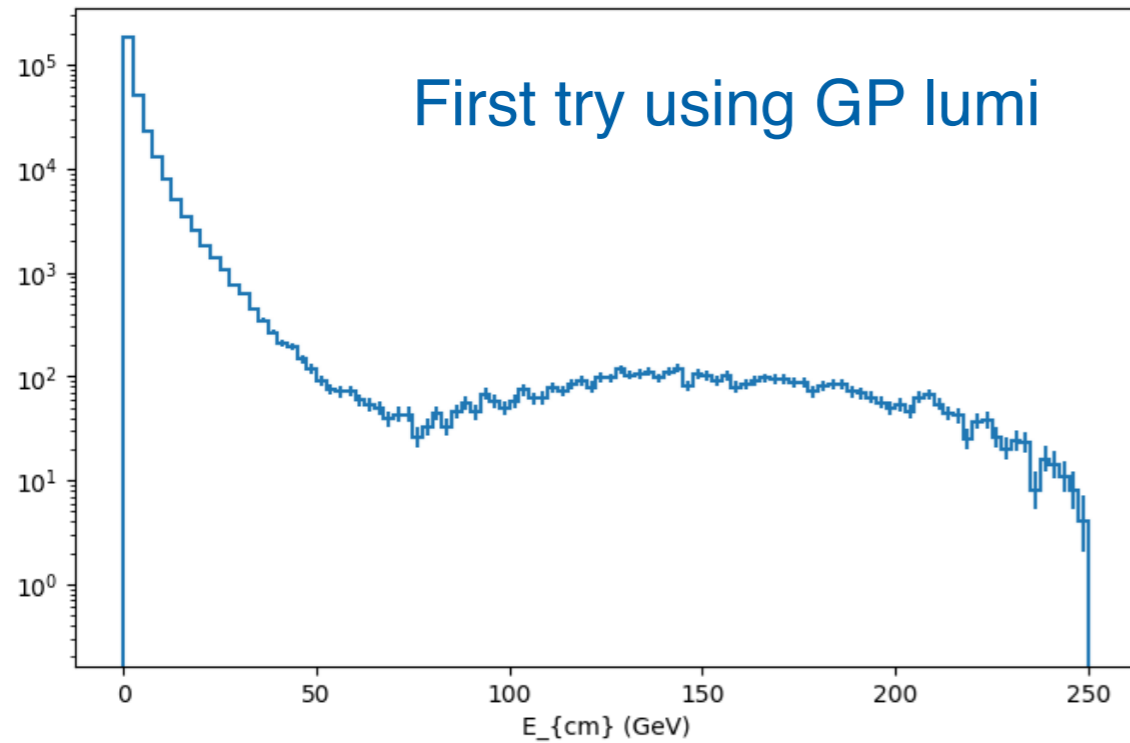


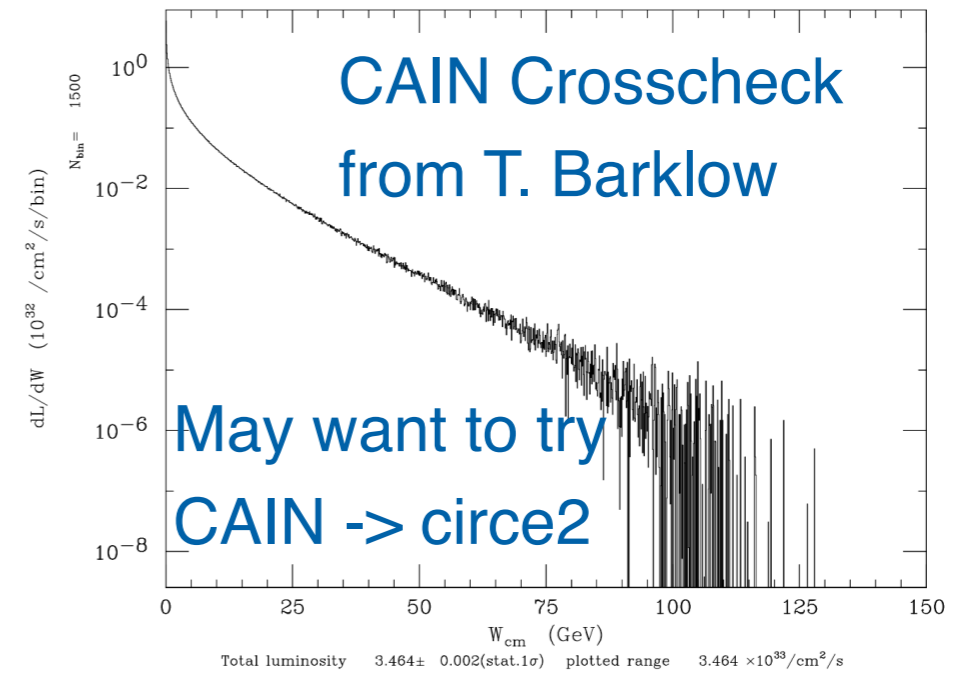
Figure 14. The radial distribution of the train occupancy per pad in ECal (left) and per cell in HCal (right) endcap [10].

- Hadron Backgrounds in Pythia5.7 -> Pythia6, Whizard 1 -> Whizard 3
 - Previous hadron background simulation libraries generated in pythia6 but most of the configuration lost to history (generated/mixed events available but for ILC)
 - We did find this but difficult to get it all running again
- Today's results using Tim's updated generator, looking at vertex detector
 - Now released in latest Whizard
 - GP -> circe2 -> Whizard 3 generation pipeline smooth and reproducible
 - Some remain questions on units and meaning of numbers
 - Nevertheless, achieving rough reproducibility
 - Would like to extend to include pythia8 (talked to Steve Mrenna)
 - requires some legwork, fortran -> C++, interface changes

Generating Correct Spectra



ILC e+e- Collider v04900 20211114(015659) CAIN2.42



Using updated Barklow Generator

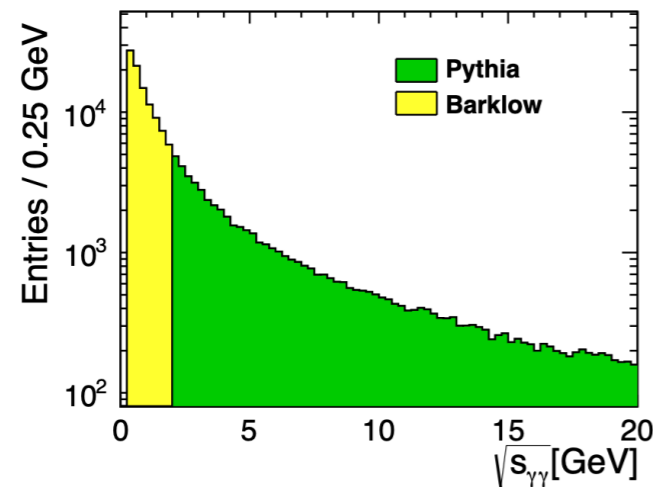
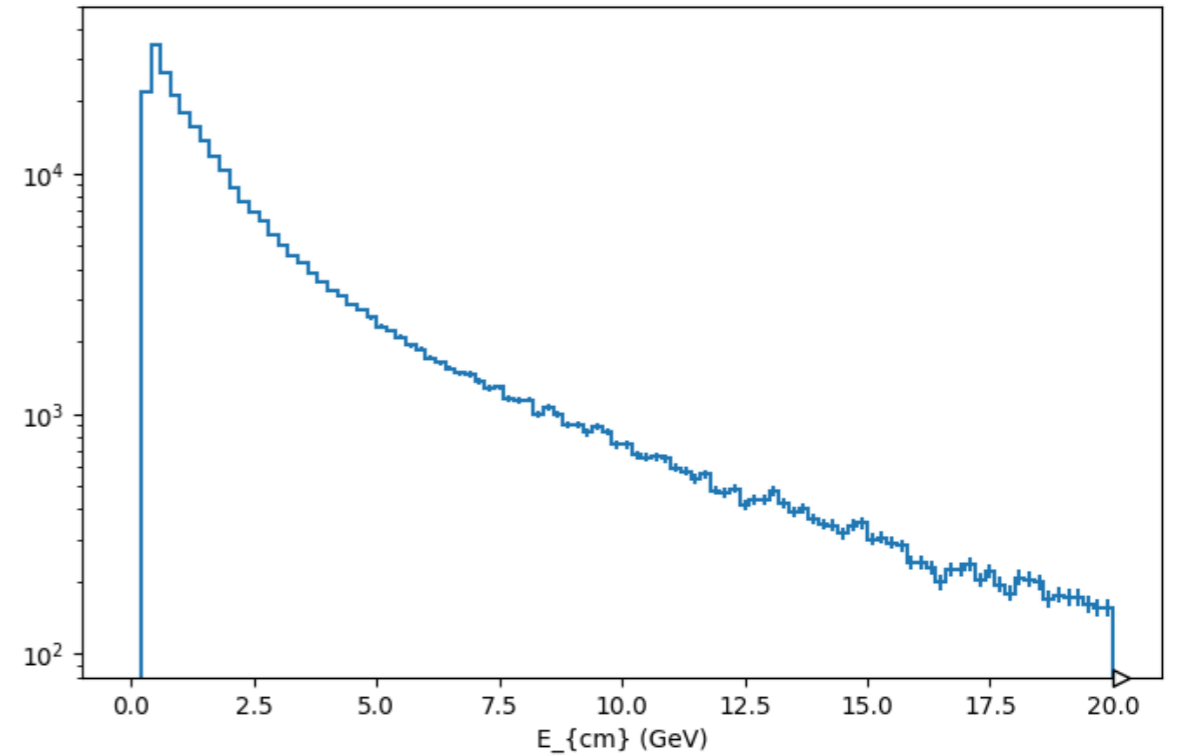


Figure 5.10.: The number of $\gamma\gamma \rightarrow$ low p_T hadron events as a function of $\gamma\gamma$ centre-of-mass energy. The figure shows the changed energy cutoff of 10 GeV to 2 GeV below which the events are generated by Barklow generator and above it the events are generated by Pythia. The events are produced at a centre-of-mass energy 500 GeV for ~ 150 k events.



Sasikumar Thesis

LG ipython notebook

- Generated 300k events
 - Had to find a random seed that didn't crash (!!)
 - Otherwise distributions look physical, event records consistent and reasonable
- Finally have results ready for event overlay, etc.

Comparing Per-event Averages

Sasikumar Thesis

$\gamma\gamma$ Background

The $\gamma\gamma \rightarrow$ low p_T hadron backgrounds receive contributions from real beamstrahlung photons and virtual photons from e^+ and e^- bunches. Their cross sections highly depend on the centre-of-mass energy of e^+e^- collisions. $\gamma\gamma$ backgrounds occur at a rate of $\langle N \rangle \approx 1.05$ events per bunch crossing at a centre of mass energy 500 GeV as will be explained in section 5.3.2. The particles produced in these interactions are typically very low p_T hadrons which appear mostly in the forward direction of the detector. These events act as a pile-up to any other physics processes. Especially, for processes which decay into very low p_T particles these backgrounds are very important. This thesis mainly focuses on developing an alternative method from the standard existing methods to remove these backgrounds. More details about these backgrounds are given in Chapter 5 and in Section 6.2.2.

e^+e^- Pair Backgrounds

Table I-1.3
Background sources for
the nominal 500 GeV
beam parameters.

ILC TDR

Source	#particles per bunch	$\langle E \rangle$ (GeV)
Disrupted primary beam	2×10^{10}	244
Bremstrahlung photons	2.5×10^{10}	244
e^+e^- pairs from beam-beam interactions	75k	2.5
Radiative Bhabhas	320k	195
$\gamma\gamma \rightarrow$ hadrons/muons	0.5 events/1.3 events	-

D. Ntounis ILC 500: 1.2 evt/BX

LG ILC 500: 1.4 evt/BX

LG ILC 250: 0.27 evt/BX

LG C3 250: 0.52 evt/BX

- Have had some inconsistencies between calculations
 - In particular gamma-gamma luminosities out of GP not consistent with CAIN or the Circe2 derivation of the gg luminosity from GP (!!)
- However, after a bit of digging and trying various combinations the recipe which appears consistent to reproduce published numbers is
 - gg lumi from circe2 + XS out of Whizard is highly ~reproducible
- ILC bunches longer than C3 bunches by $\sim 3x$ so C3 background should be larger per bunch, calculation confirms

Bunch Trains

LG ILC 500: 1.4 evt/BX

LG ILC 250: 0.27 evt/BX

LG C3 250: 0.52 evt/BX



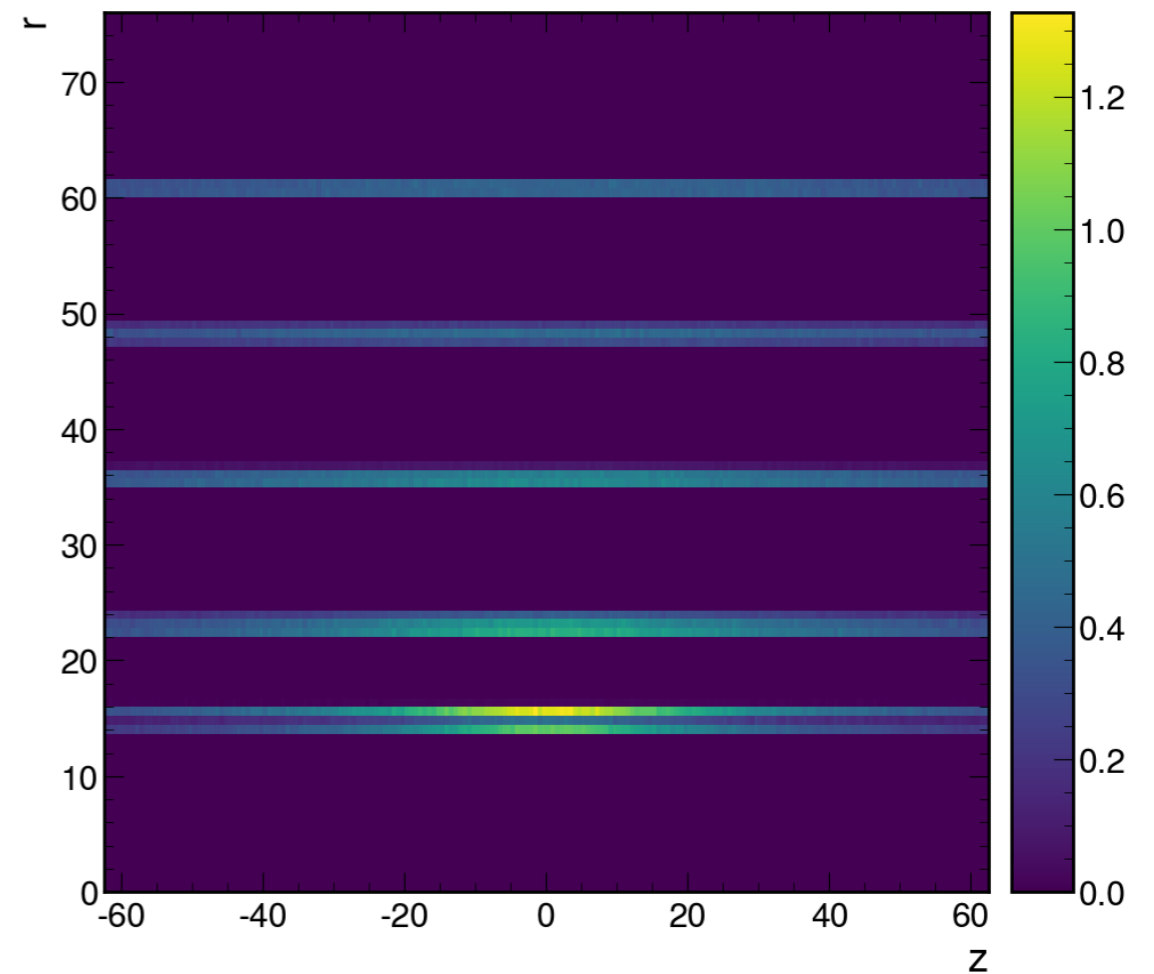
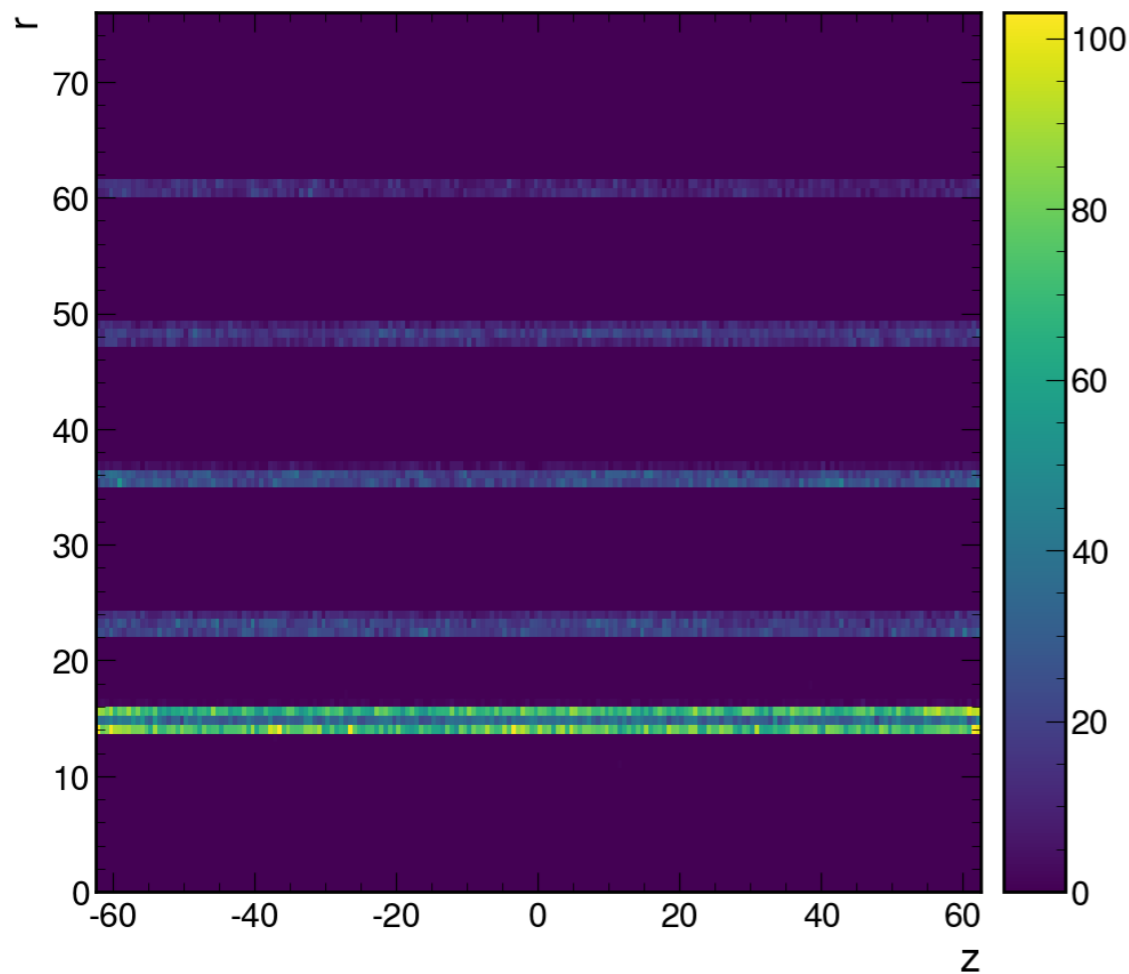
LG ILC 500: 1846.8 evt/train (1312 bx)

LG ILC 250: 495.9 evt/train (1312 bx)

LG C3 250: 69.2 evt/train (133 bx)

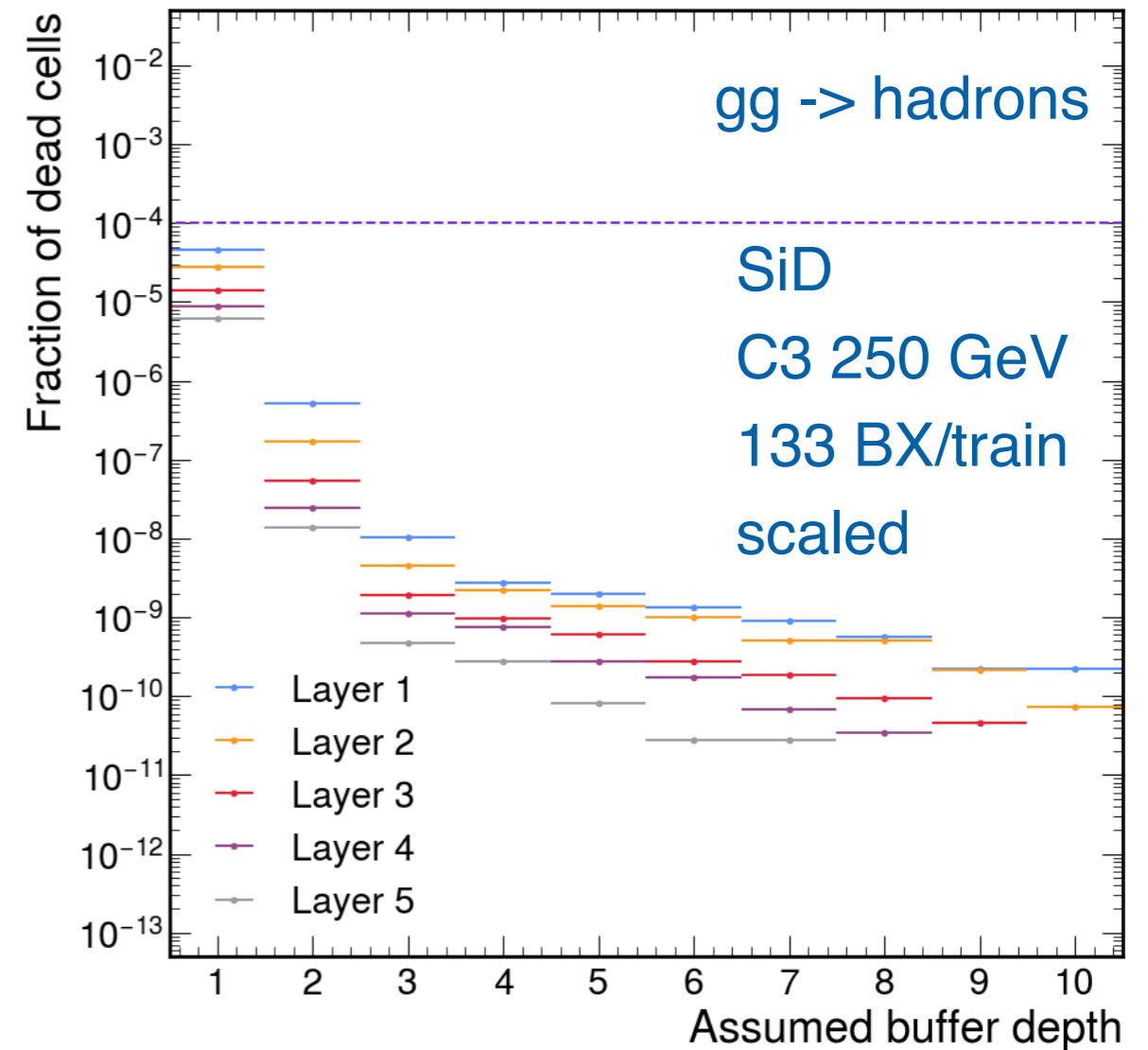
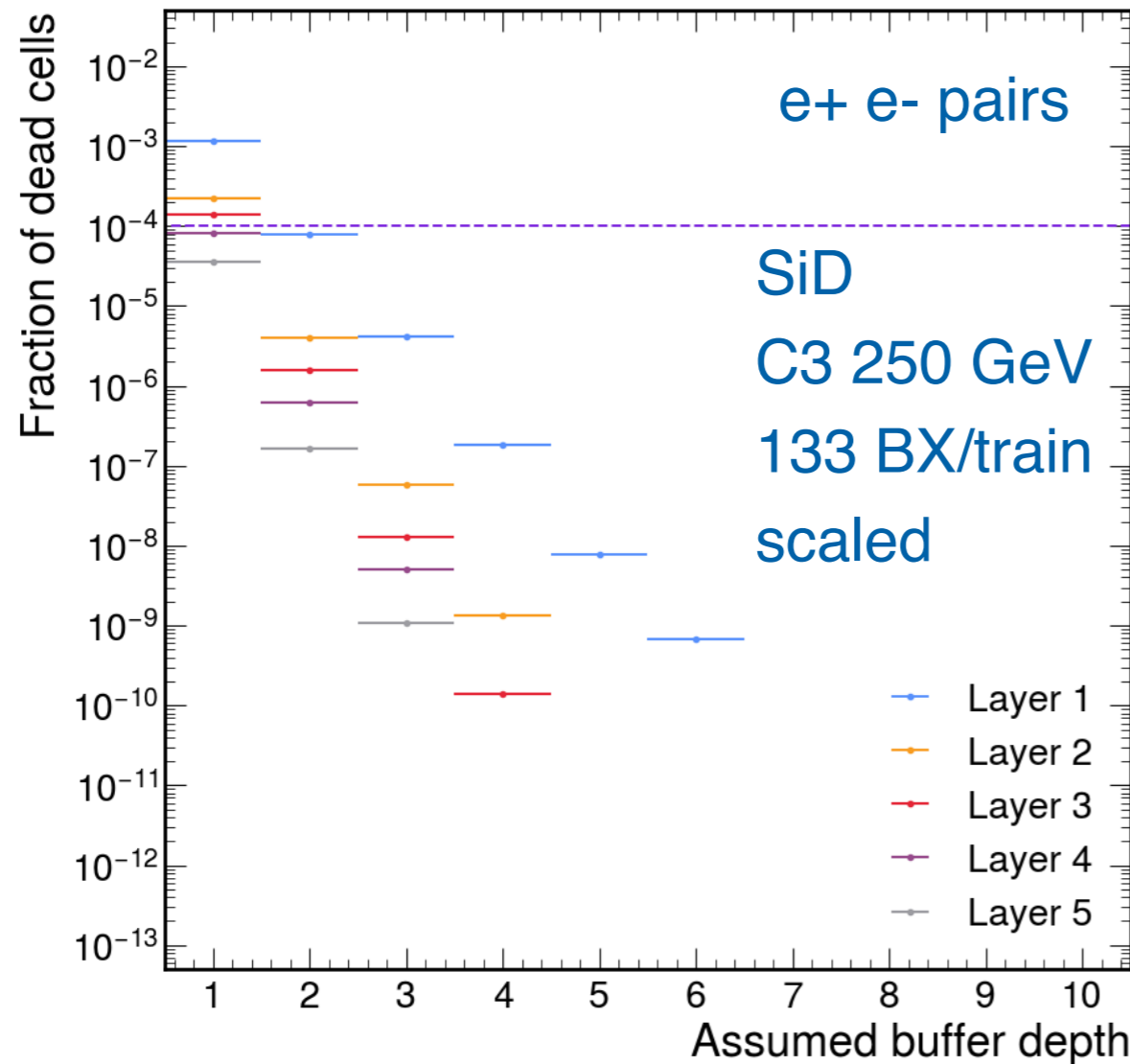
- As with most things C3 the 10x shorter bunch trains saves a lot of pain
 - Per train occupancies from hadron photoproduction will be negligible atop pair background
 - This re-raises the old question about why the occupancy tail for C3 looks so different
 - Need to do the occupancy study with more bunches
 - suspect it's integrating distribution tails with more events, 10x smaller C3 train beneficial
 - This significantly eases memory requirements in calorimeters, vertex detector
- Diminishing returns with more populated trains
 - Should consider carefully (though more lumi is certainly more desirable)

Occupancy Structure: Pairs vs. Hadron-photoproduction (I)



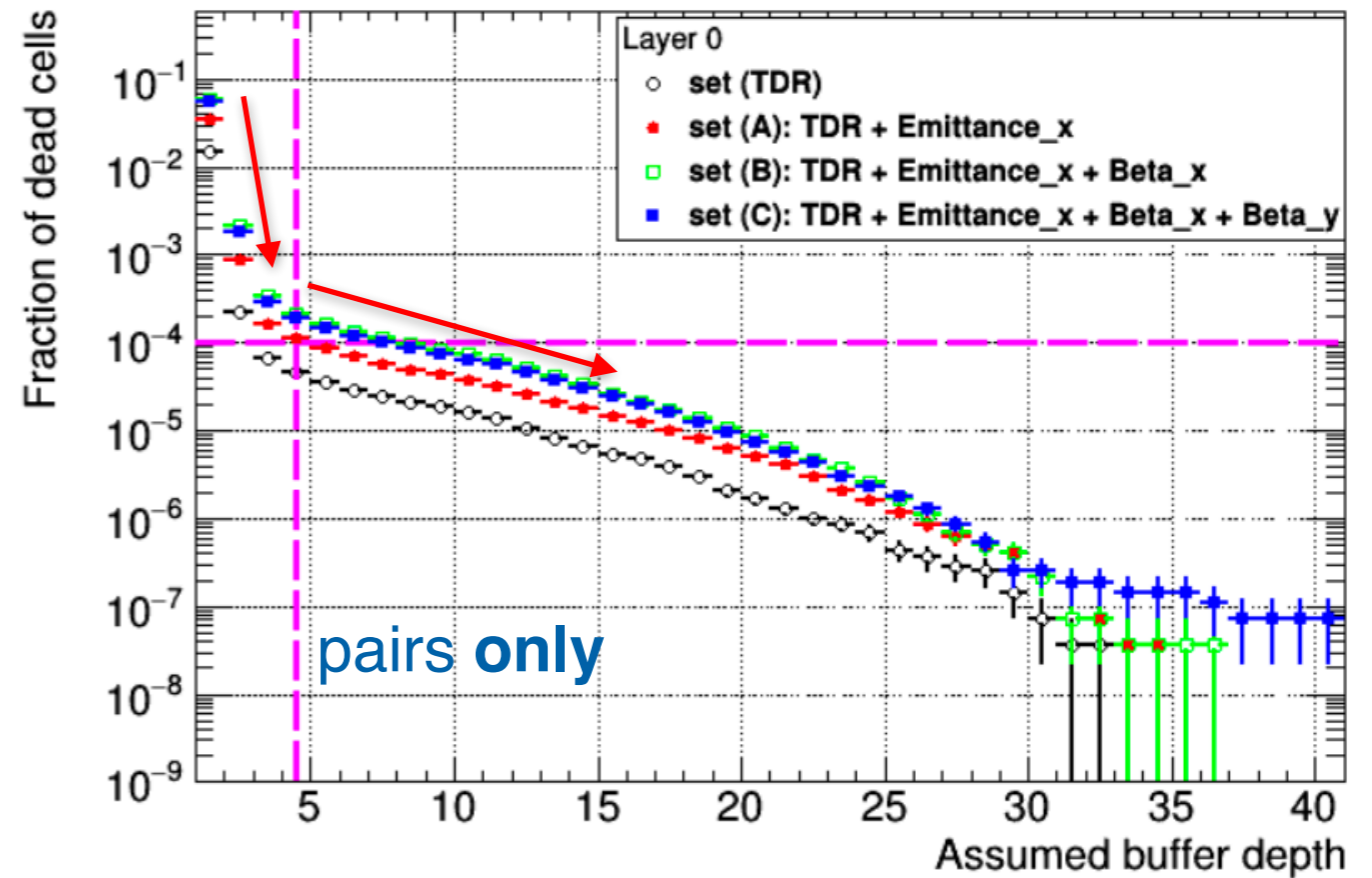
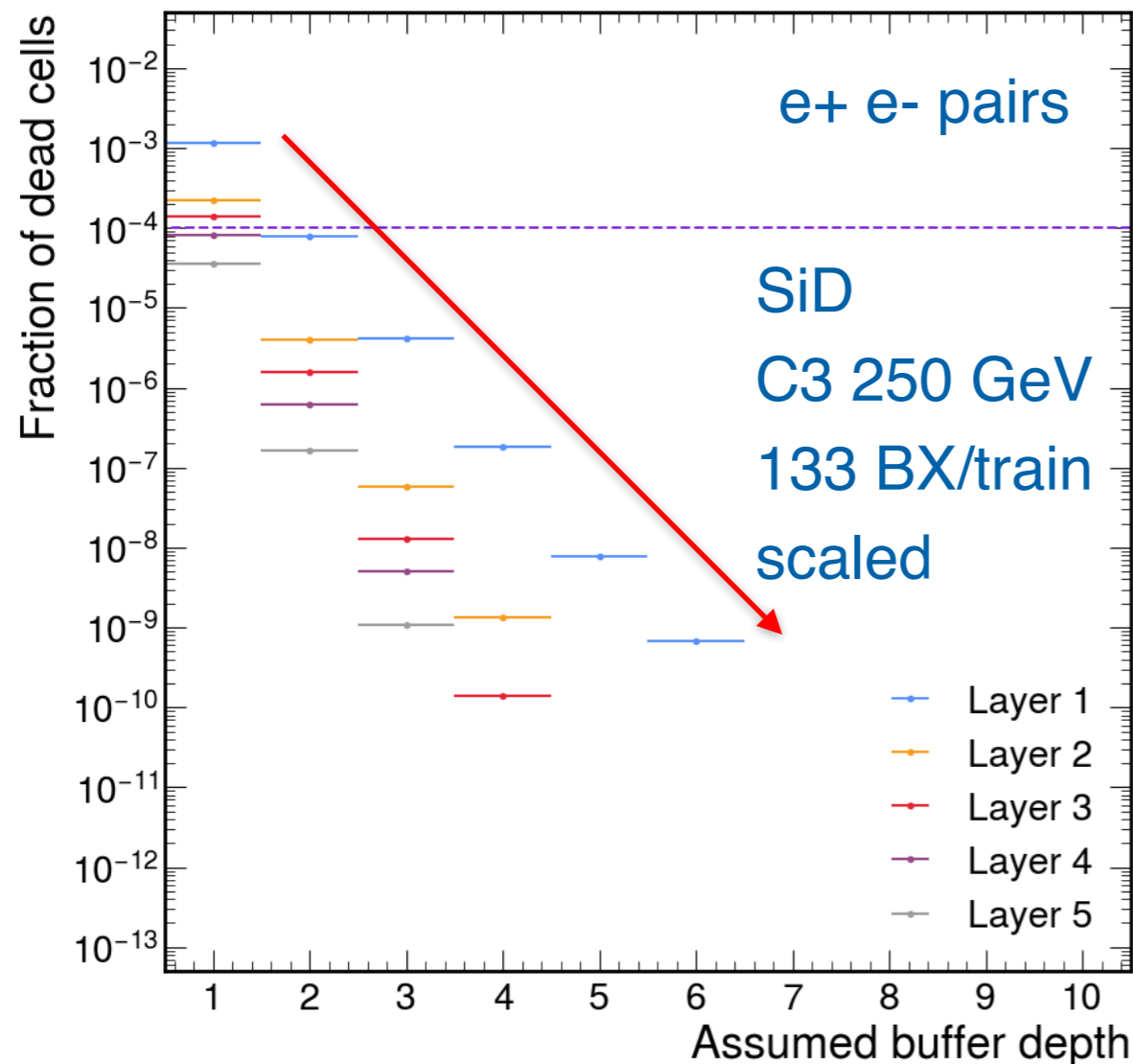
- Left: 133 BX of e^+e^- pairs, Right: 100k $gg \rightarrow \text{hadrons}$ events scaled to 69.2
 - 1 bunch train of C3 250
- $gg \rightarrow \text{hadrons}$ much more central, pairs mostly forward (outside acceptance)
 - XS: $gg \rightarrow \text{hadrons} \sim 0.3 \text{ ub}$, pairs $\rightarrow 16 \text{ mb}$
- Expect maximally $\sim 1\%$ effect of $gg \rightarrow \text{hadrons}$ in vertex occupancy

Occupancy Structure: Pairs vs. Hadron-photoproduction (II)



- Pairs plot made with 13300 BX of C3 250 pairs data, scaled to 133 BX train
 - 13300 was generated by adding random phi rotation to GEANT hit positions
- Hadrons plot made with 100k events, scaled to 69.2 events/train
 - 100k events out of Whizard w/Barklow into GEANT
- However, this scaling is a bit naïve

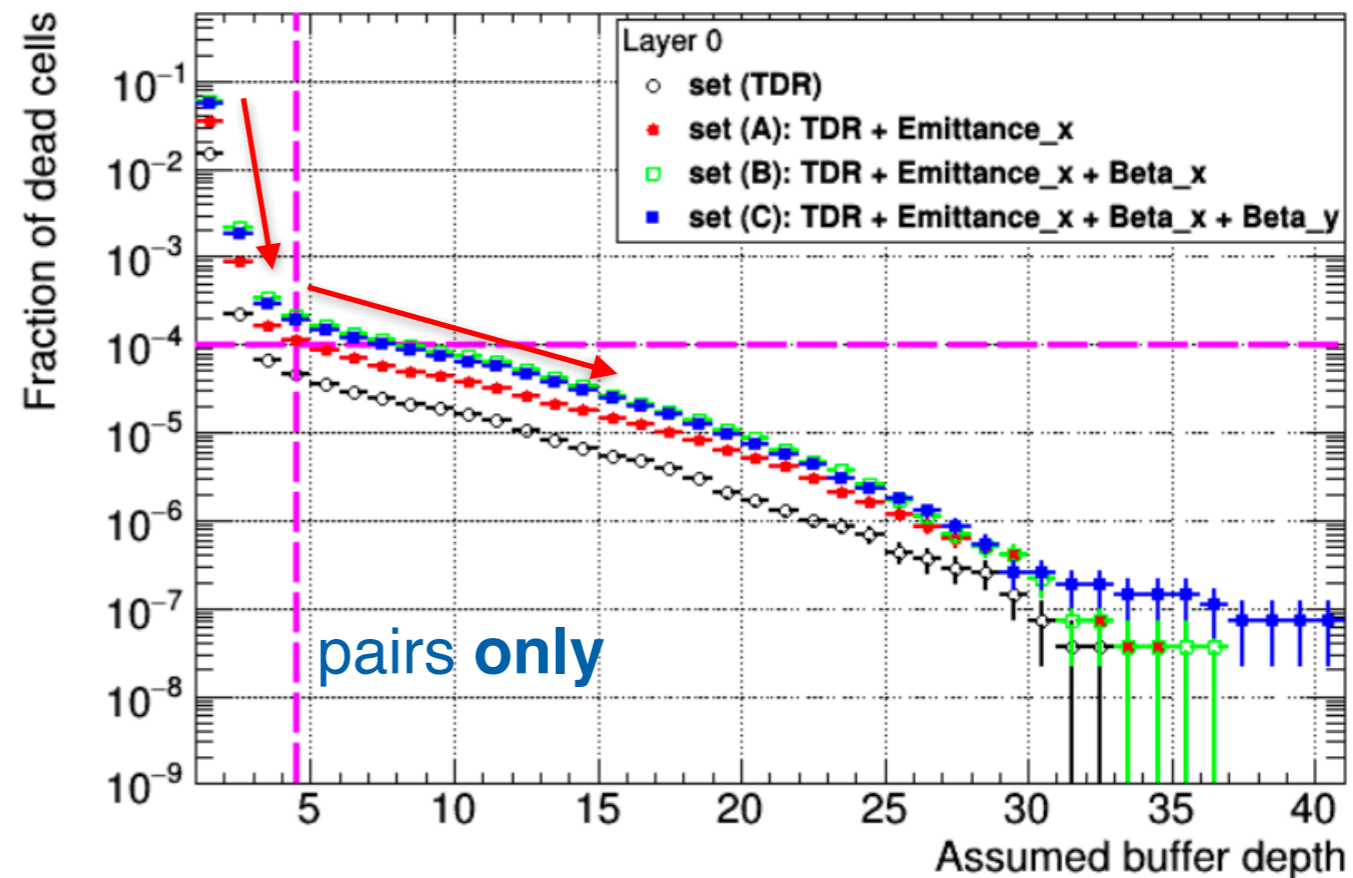
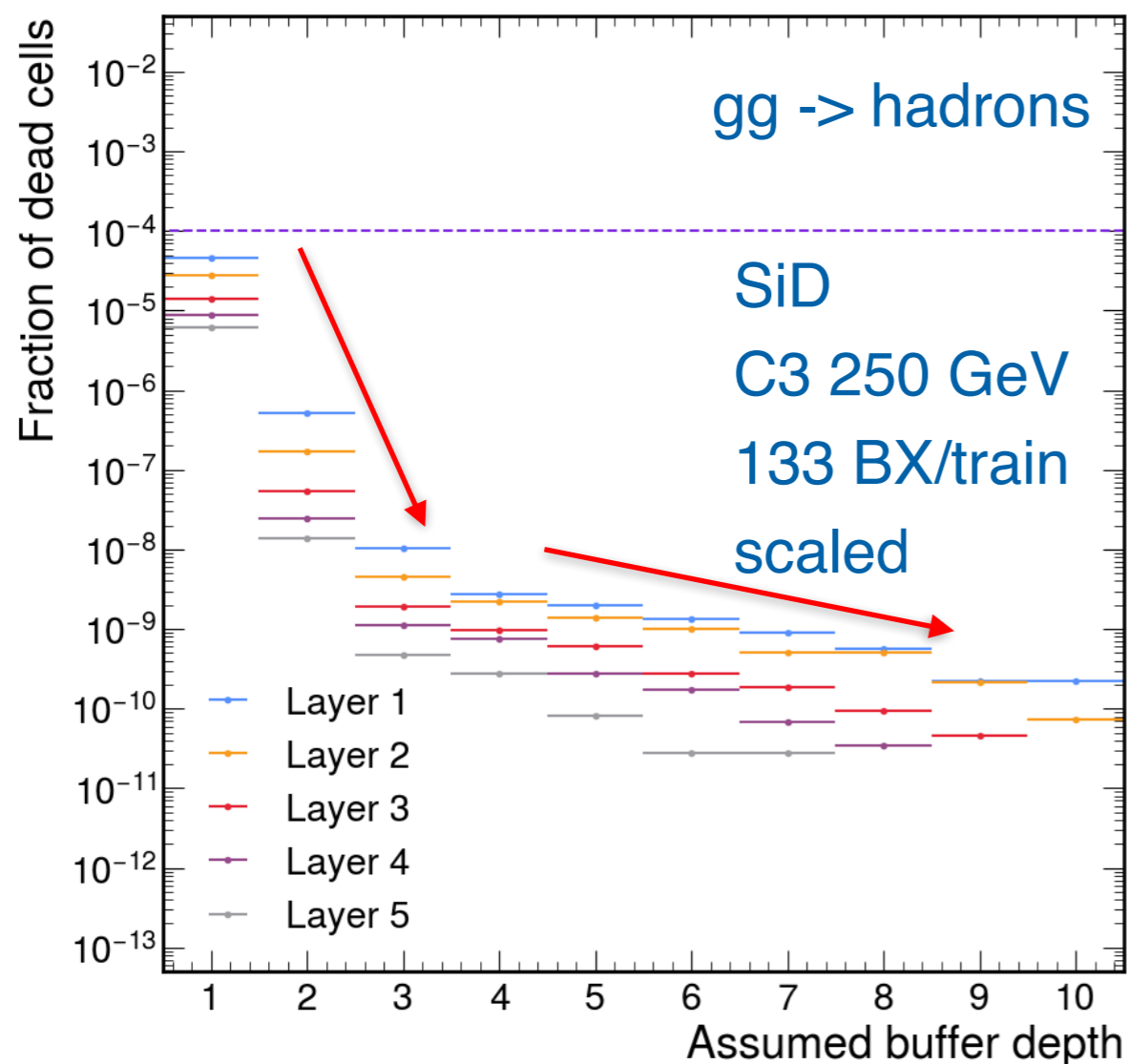
Head Scratcher: The knee in Anne Schütz's plot for ILC!



(c) *SiD vertex detector barrel, fraction of dead cells*

- C3 simulated BXs show a markedly different structure from older ILC results
 - There is no 'knee' at all for C3 pairs events
 - Even after generating 100x more events from phi rotations (this should over-estimate!)
- Exploring naïve scaling to try to explain knee in AS thesis plots

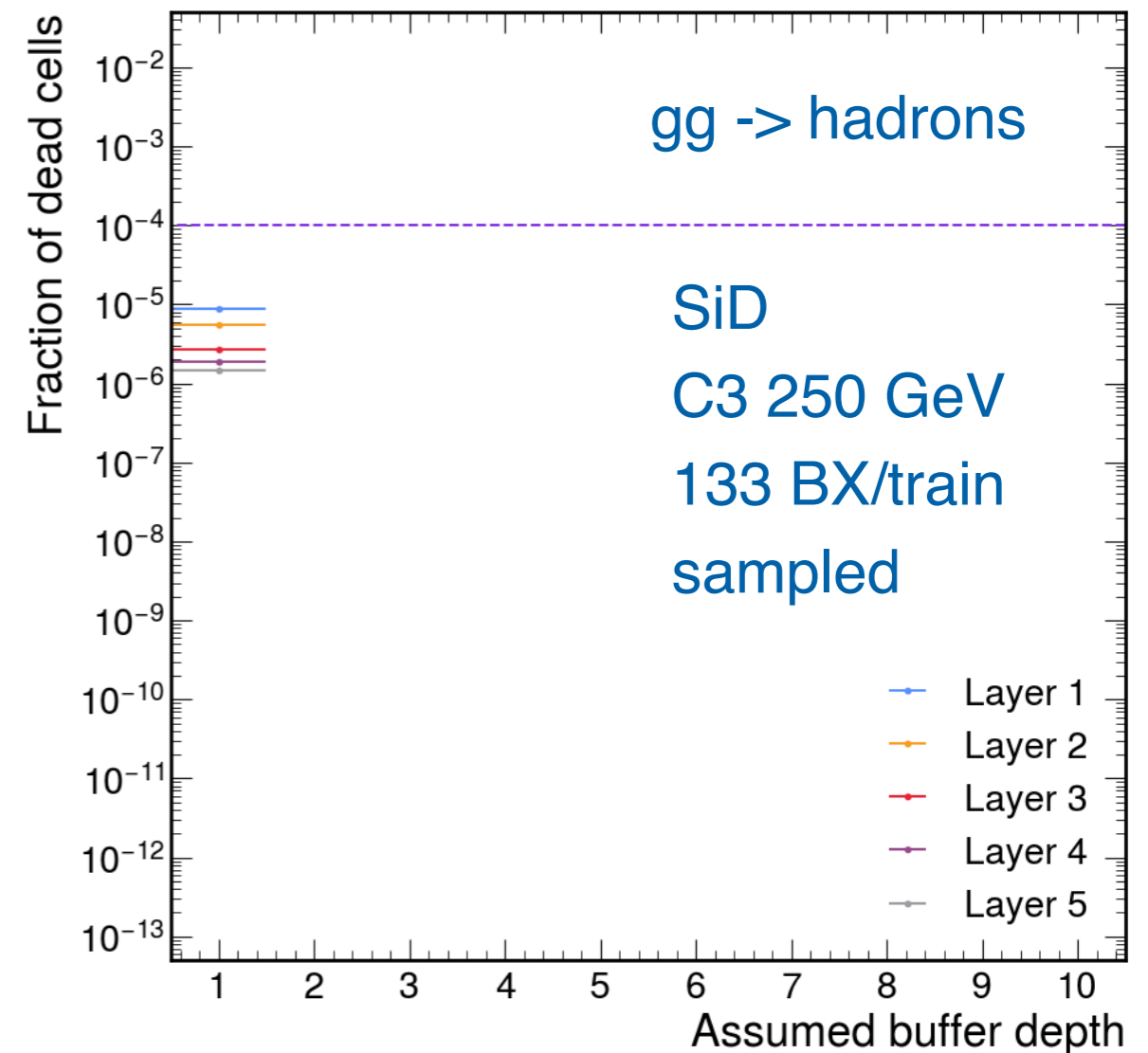
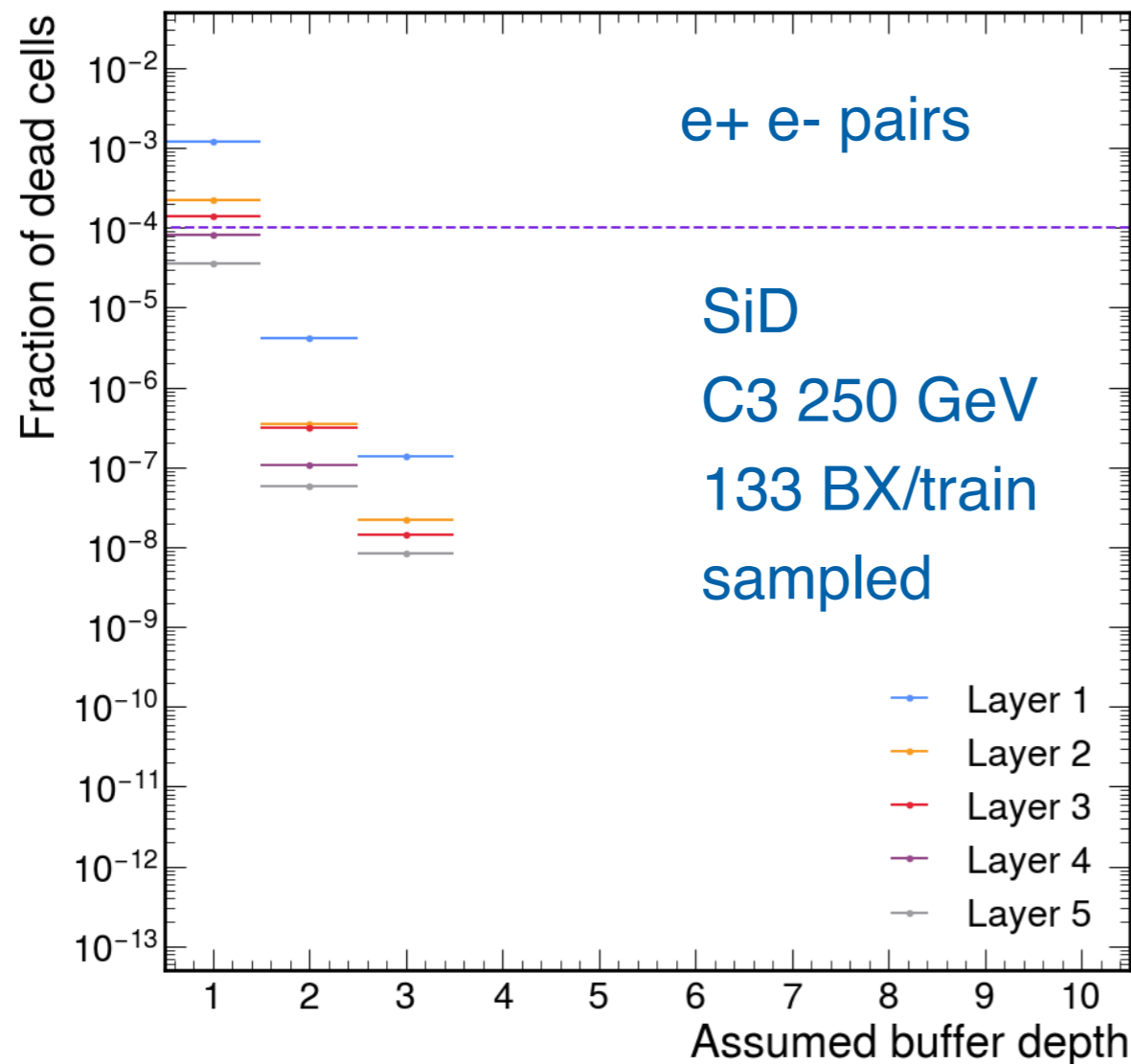
Head Scratcher? How I made the $gg \rightarrow$ hadrons histogram



(c) *SiD vertex detector barrel, fraction of dead cells*

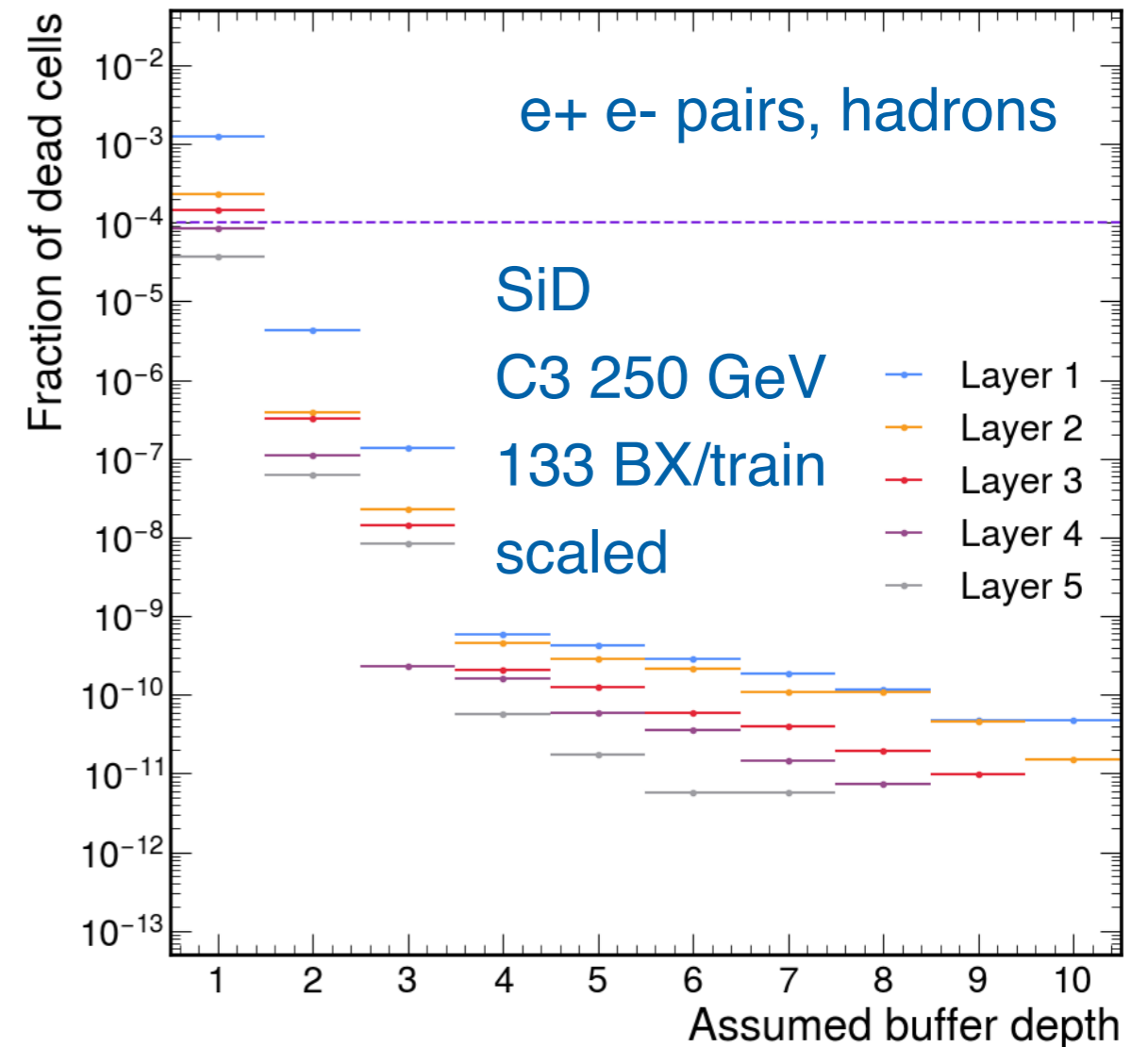
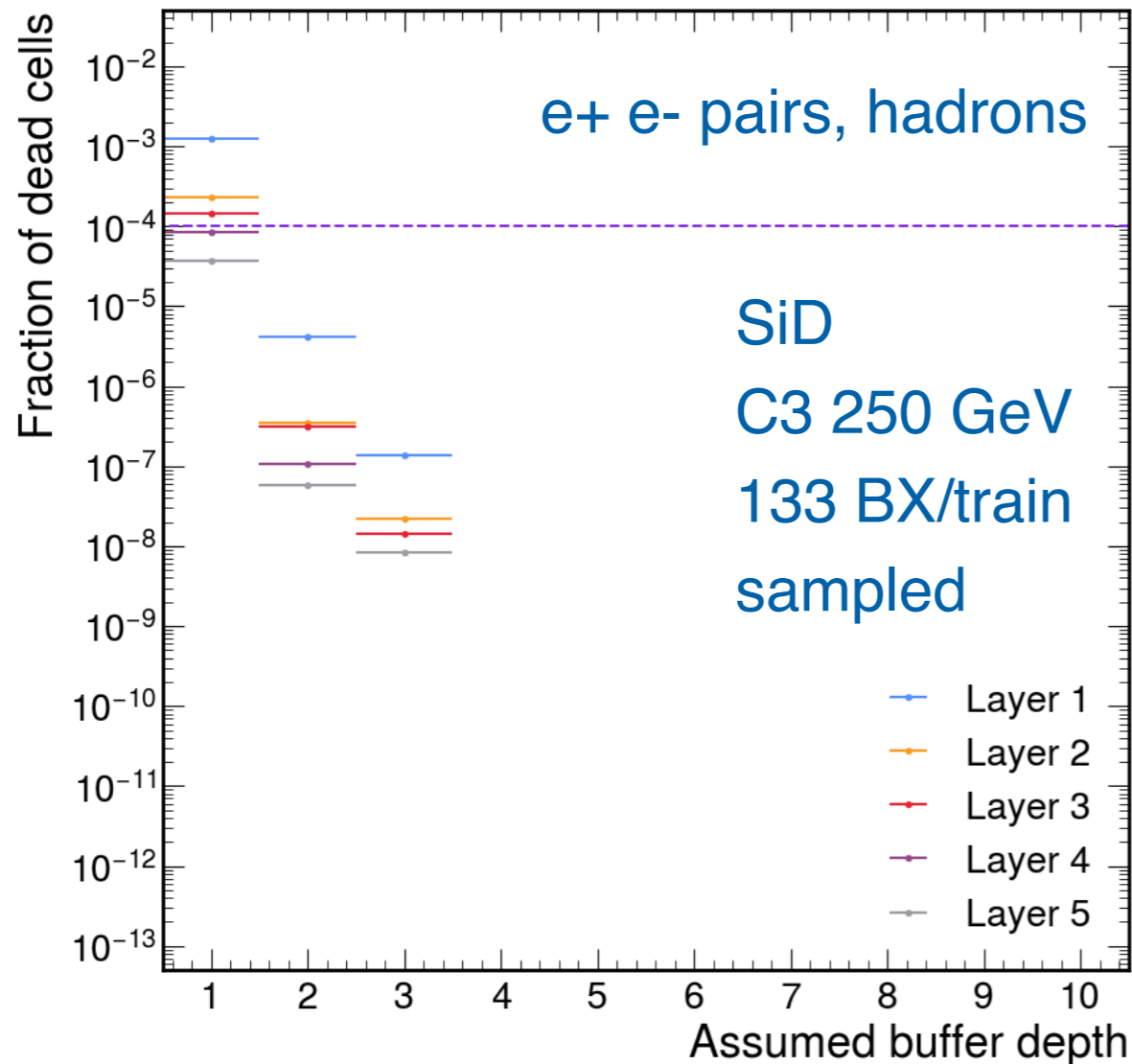
- Qualitative argument: knee forms *simply* from larger event multiplicity?
 - If you keep filling the histogram the probability that you hit an already hit cell increases the more you overfill, especially with $M_{gg} > 3$ GeV (complex hadron spectra / jets)
- Attempted to replicate pair background through phi rotations but no knee appears
 - Left at square one once again... Will look into detector effects?
 - That or the plots in the thesis contain a considerably overestimated $gg \rightarrow$ hadrons component

Head Scratcher: gg->hadrons trivial BVTX background?



- Sampling one bunch train of gg->hadrons yields ~1e-5 additional occupancy
 - No tails in buffer depth, counting by hand not enough events to get full depth of 2 or larger
 - Higher energy gg->hadron events more collimated/jet-like may show occasional larger buffer depth tails. Never to extend of pairs background though

Total Occupancy



- Sampled occupancy distribution matches expectations from slide 8
- Scaled occupancy distribution explores deeper tails but is manifestly incorrect from how the average occupancy is calculated
- Working on code to sample and average over all events correctly

Concluding remarks / Next Steps

- We finally have the $gg \rightarrow$ hadrons background, and results appear trustable
 - Need to track down remaining questions concerning provenance of luminosity
 - It does not appear to appreciably change the answer for C3 that we got from pairs for the vertex detector
 - Calorimeters likely have some interesting data in them
- There are still questions about the occupancy tail shape compared to A. Schütz thesis
 - The details of filling the original plots are lost to time
 - However, details point to original plots being scaled down from larger number of total BX to get sufficient statistics (unlikely), or changes in detector thresholds
 - A correct strategy is to fill 1 train per histogram until events exhausted and average those histograms to determine the occupancy
- Package up instructions for FCC, Muon Collider folks
 - Muon Collider has specialized GP for muon bunches
 - $e^+ e^-$ pair background is enormous! (Huge boost factor, large bunch population)
 - Hadron photoproduction should also be rather pronounced in these conditions
 - Some interesting studies to do in both these cases, especially considering FCC rates