Beam-Induced Background Simulation Studies for the Cool Copper Collider

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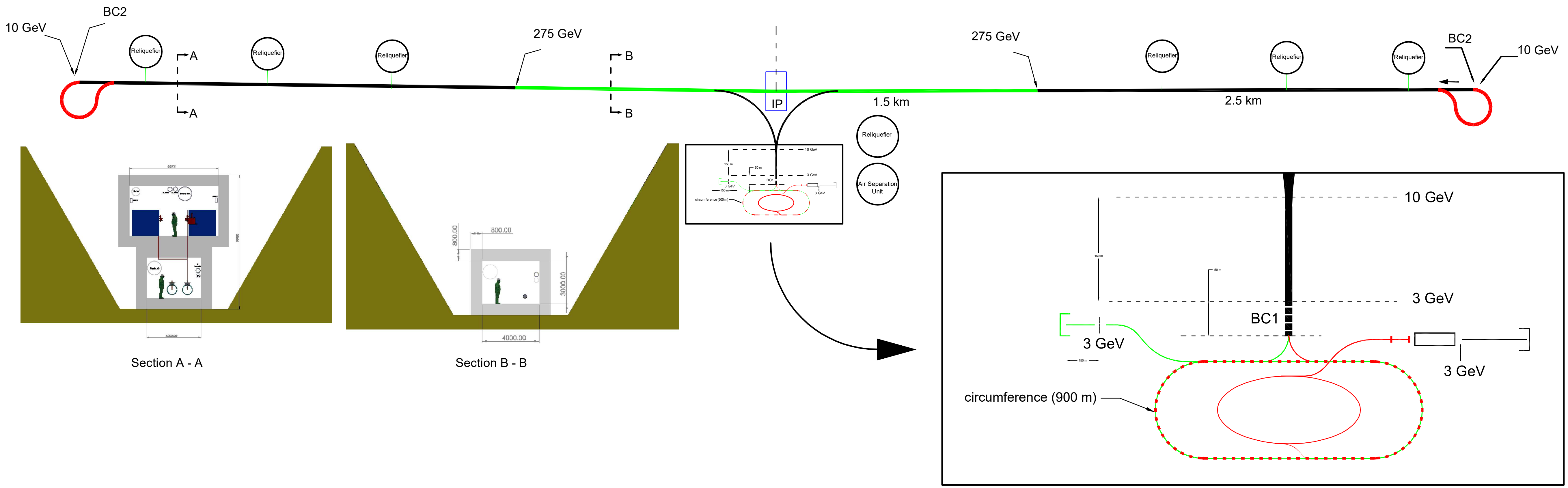
ECFA3 @ Campus des Cordeliers, Paris

10 October 2024

Cool Copper Collider (C3) Introduction



- Compact linear collider concept based on cryogenic copper RF
  - Normal conducting copper at LN2 temperatures
- 250 and 550 GeV physics programs fit in ~8km footprint
- Luminosity production commensurate to ILC
  - Optimizable for power usage (see in D. Ntounis' talk, 2 slots later this session)

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

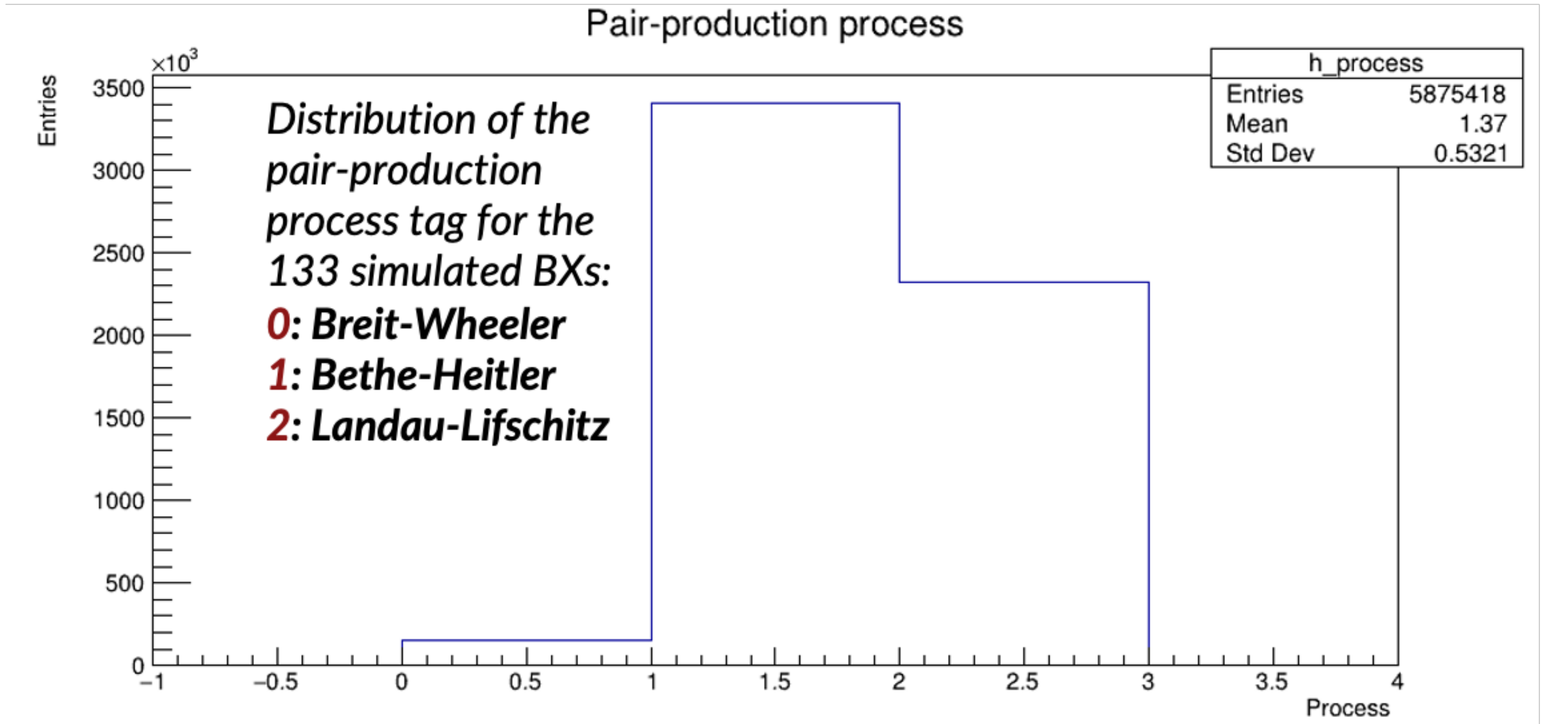
- The emittances on the table are normalized. The transverse beam size is calculated as:

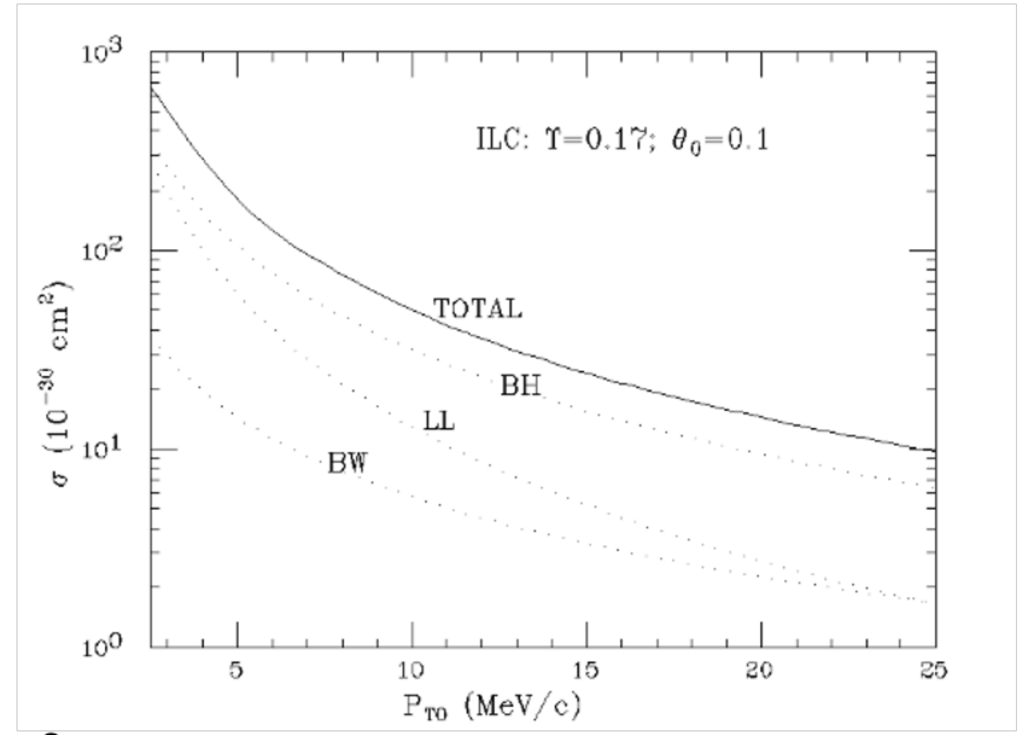
$$\sigma_{x,y}^* = \sqrt{\epsilon_{x,y}^* \beta_{x,y}^*} = \sqrt{\frac{\epsilon_{L,x,y}^* \beta_{x,y}^*}{\gamma}}, \ \gamma = \frac{E}{m_e c^2} = \frac{\sqrt{s}}{2 m_e c^2}$$

	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!

Guinea Pig and C^3





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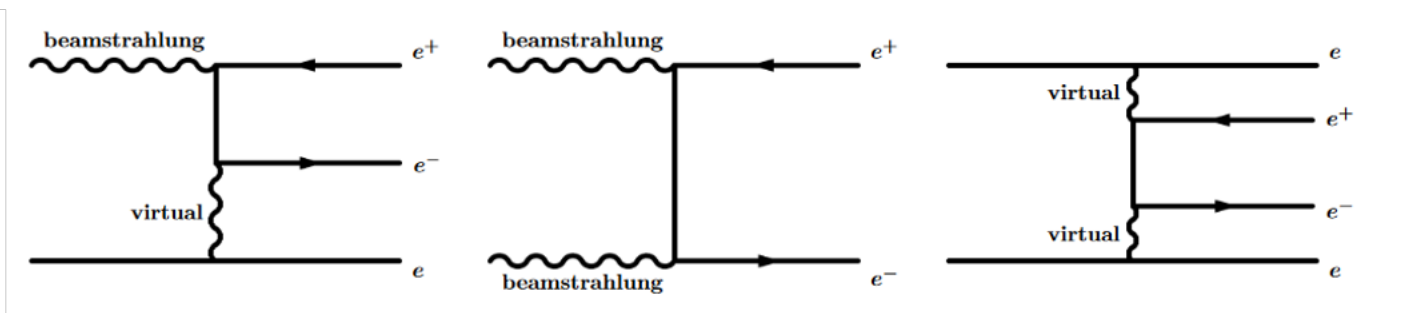
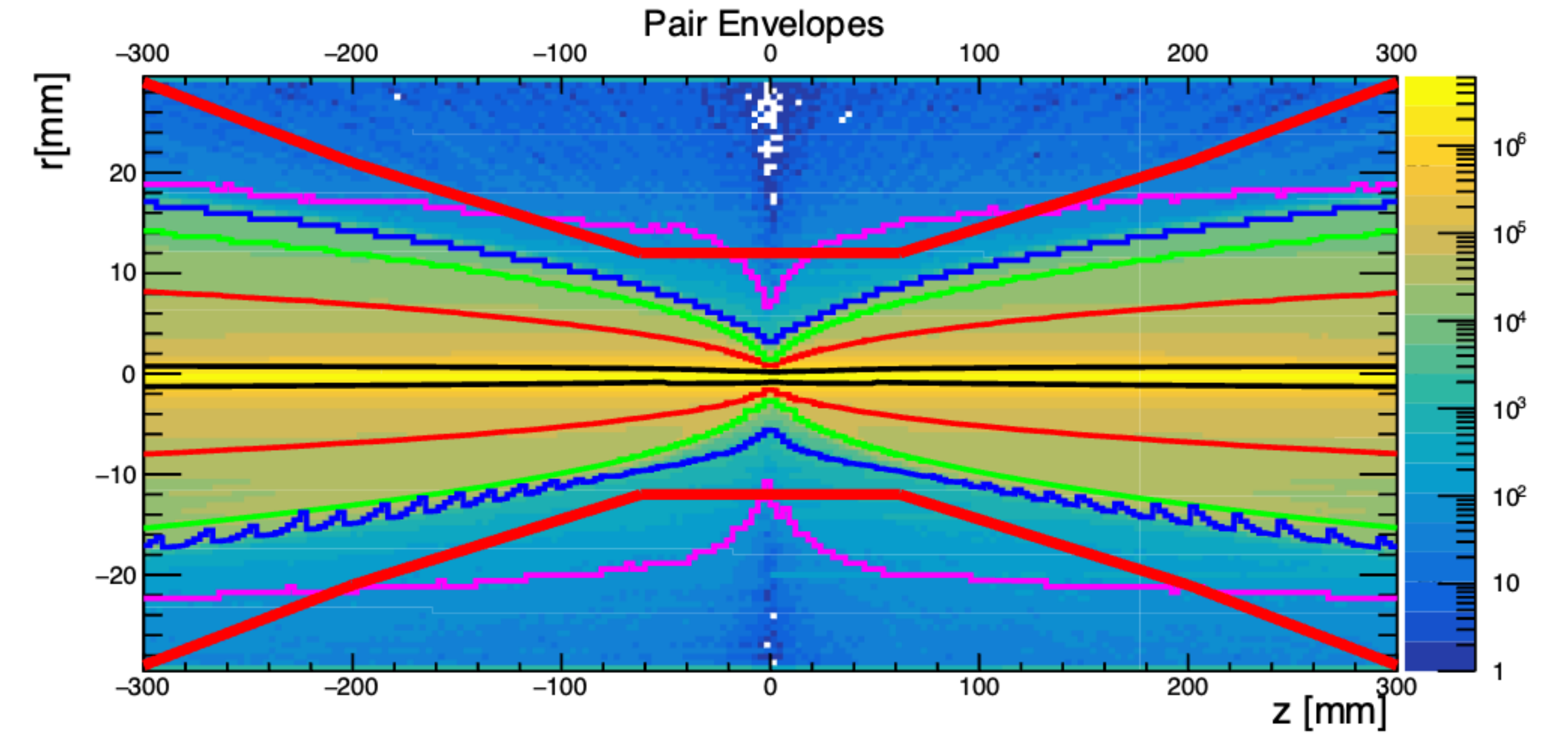


(a) *Bethe-Heitler* (b) *Breit-Wheeler* (c) *Landau-Lifschitz*

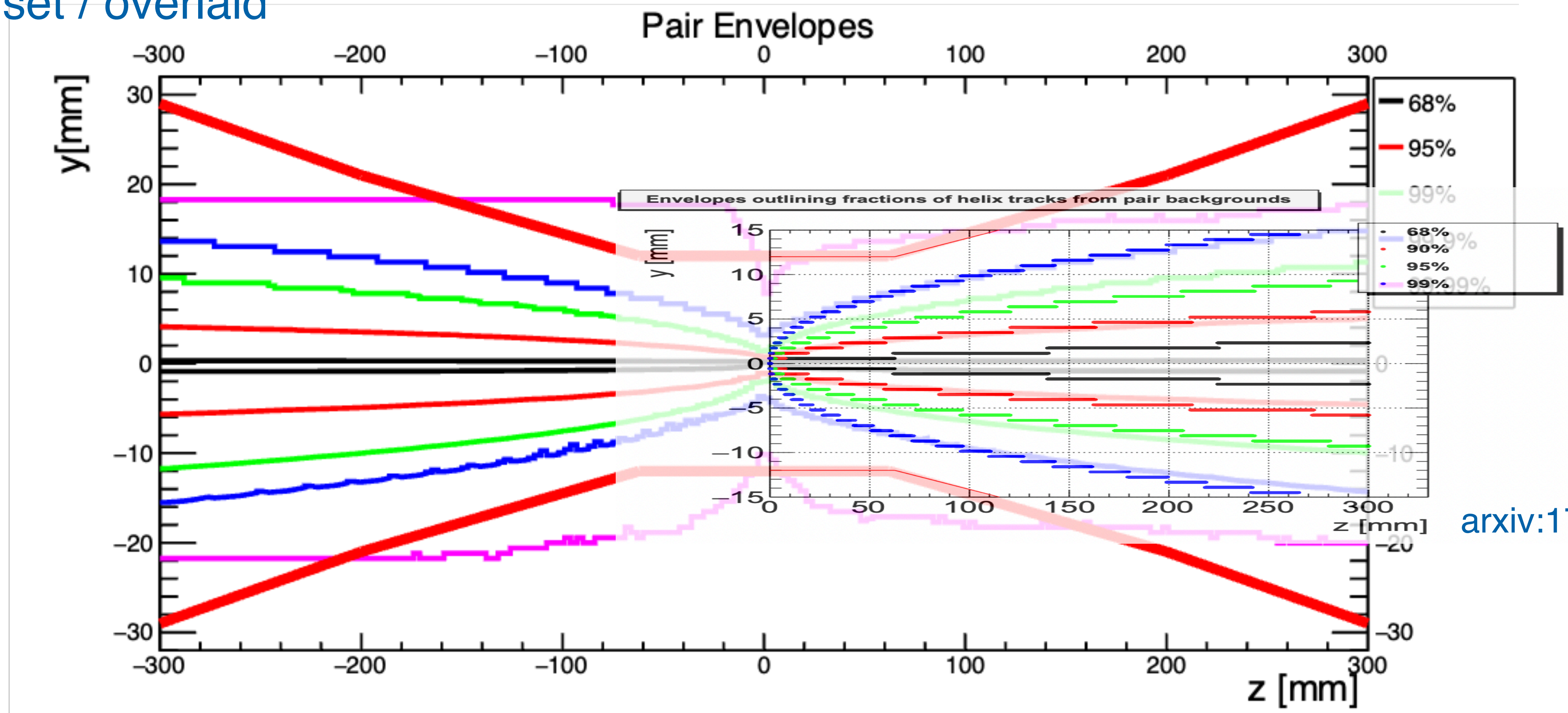
Source: https://bib-pubdb1.desy.de/record/405633/files/PhDThesis_ASchuetz_Publication.pdf

- 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 (better sim. discussed in this talk)

Envelope Plots a la ILC

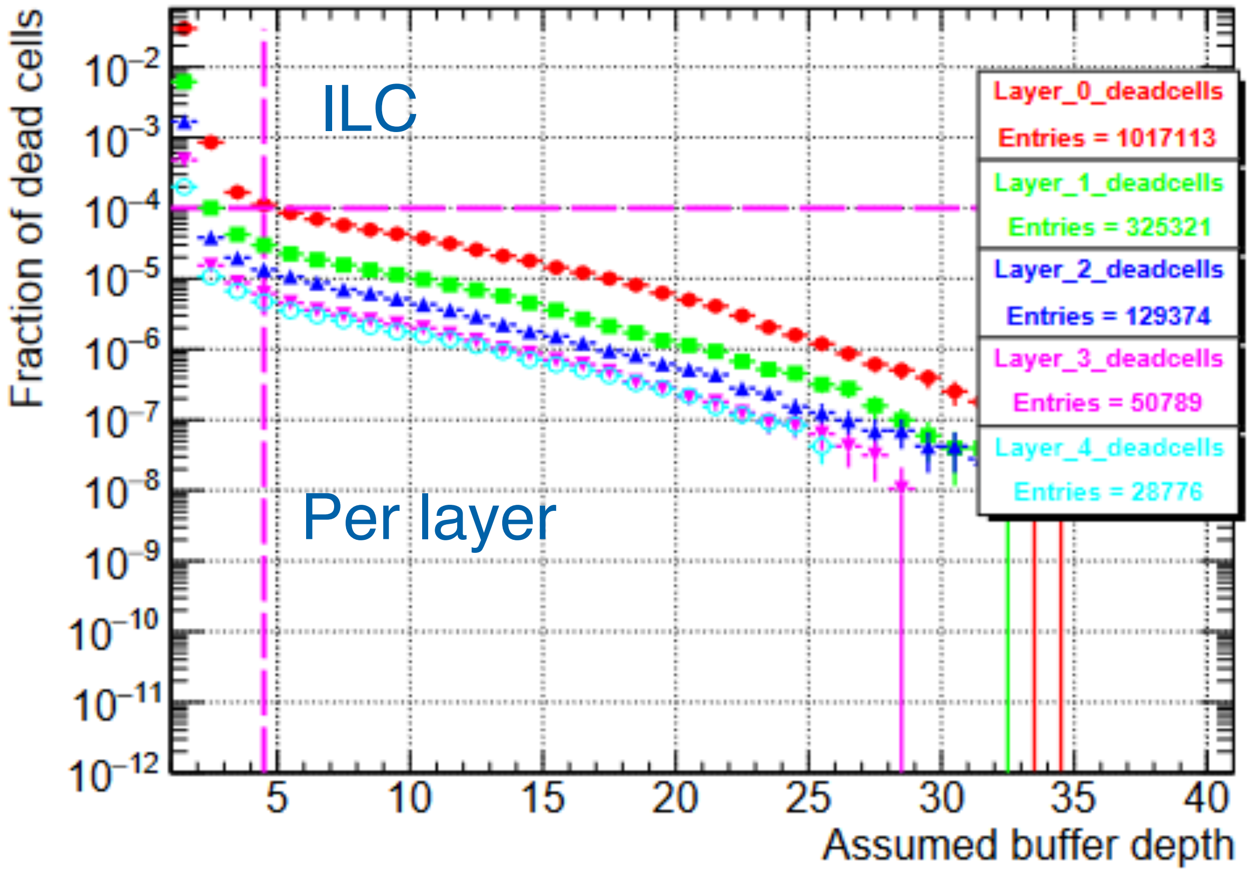


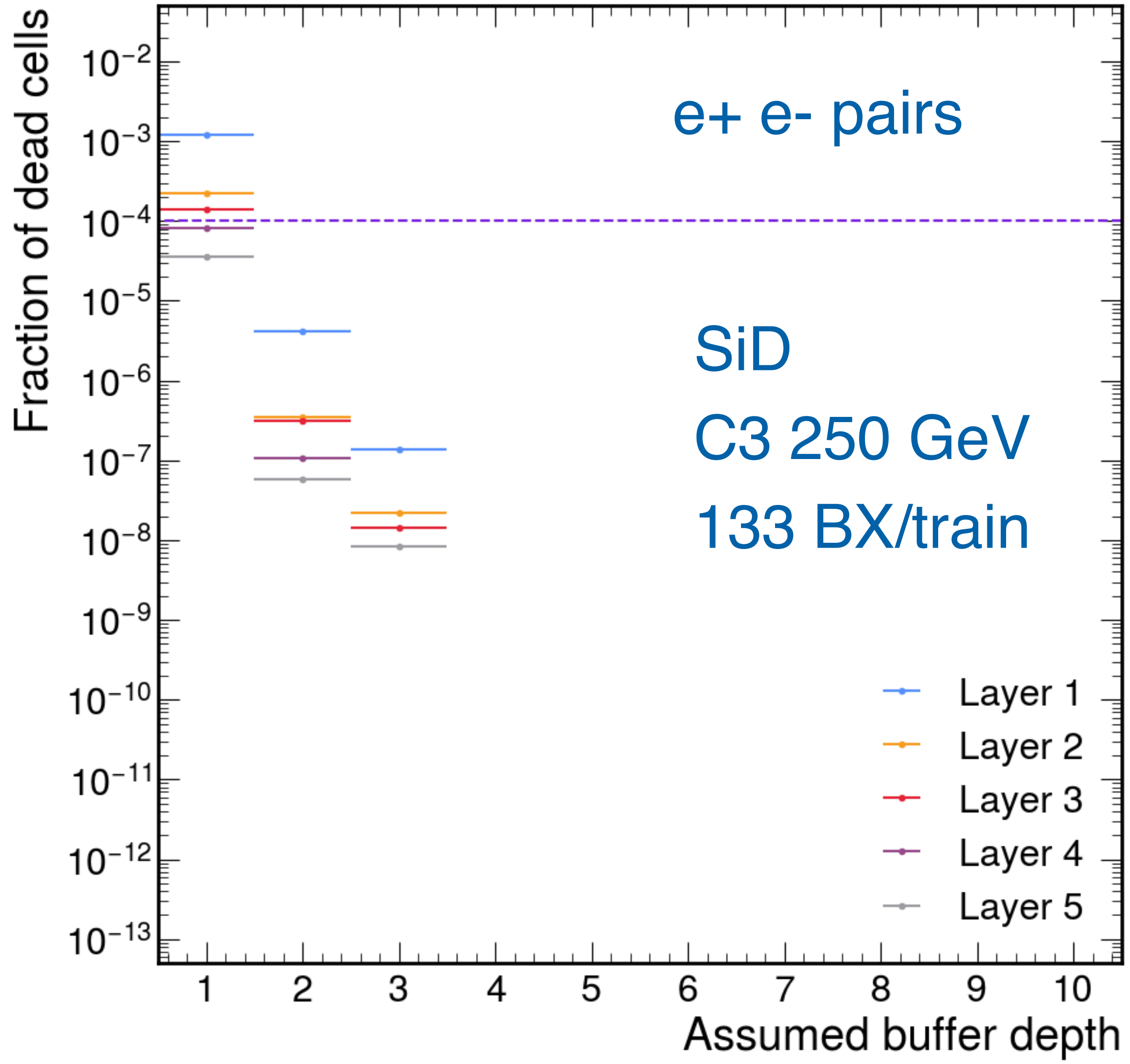
ILC inset / overlaid



arxiv:1703.05737

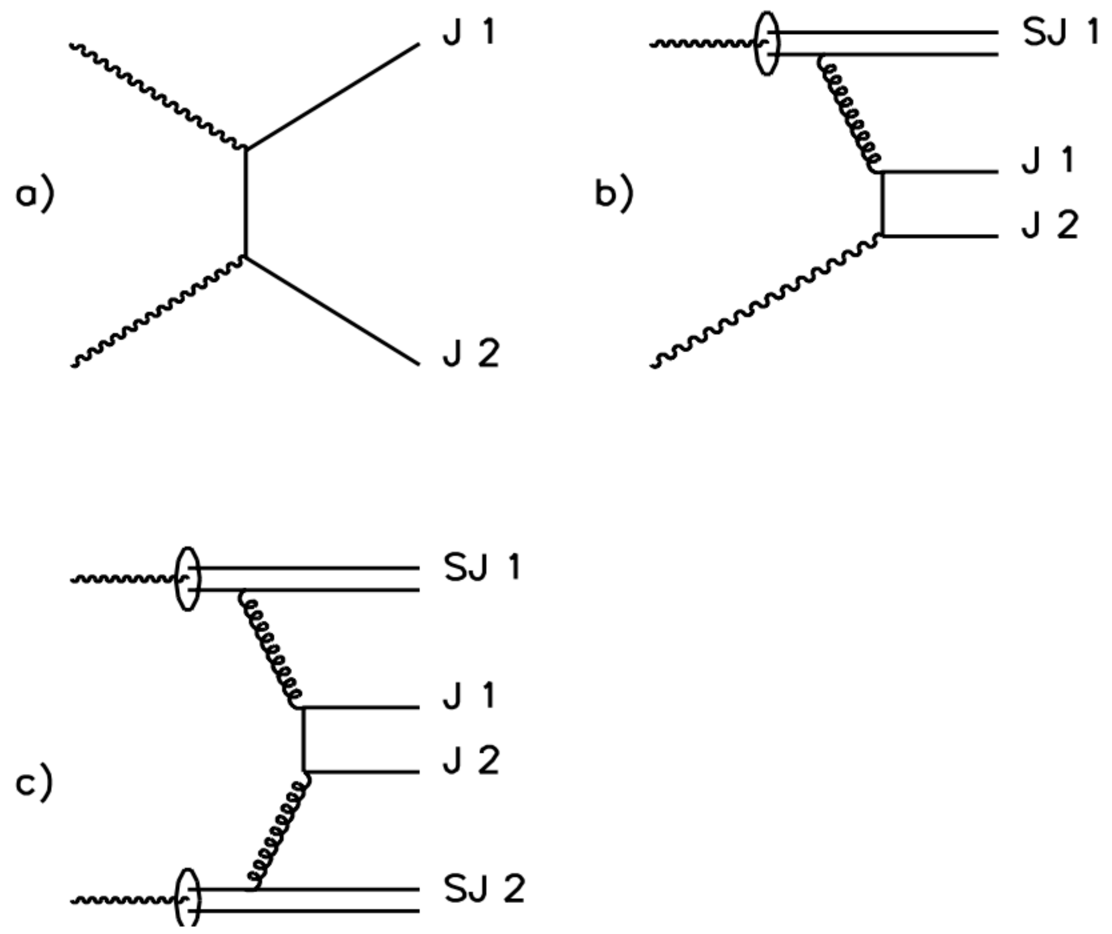
Preliminary Results for C^3





- 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 C^3 ~ ILC/10
  - Difference to A. Schütz thesis (left) appears to be statistics or detector configuration

Hadron Photoproduction: Introduction



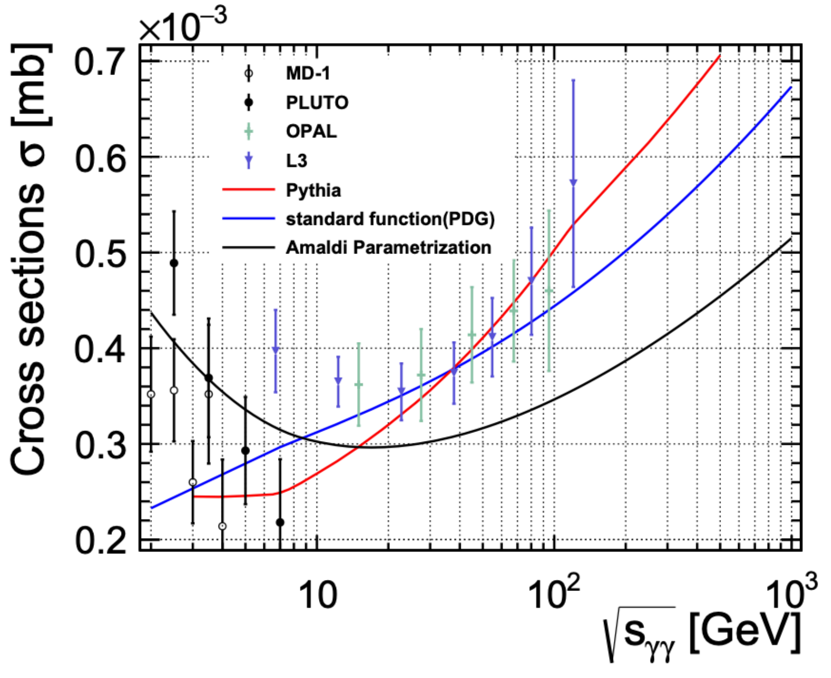


FIG. 2: Comparison of cross sections for $\gamma\gamma \rightarrow$ hadron processes as a function of centre of mass energy obtained from Amaldi parameterization [3], Standard paramerization [8] in PDG, Pythia and data from LEP [1], PETRA [6] and VEPP [5]

- 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 ~10% of pair background at calorimeters, more central than e+ e- pair bkg.!
- Given the c.o.m. range over which we're producing events there are many details to consider

Hadron Photoproduction: Spectra and Generators

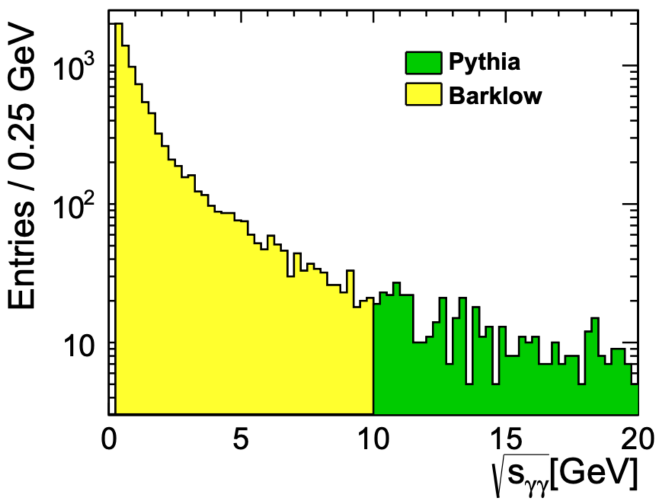


FIG. 1: Energy spectrum of $\gamma\gamma \to$ low p_T hadron events as a function of centre-of-mass energy. The figure shows the energy cutoff of 10 GeV below which the events are generated by the Barklow generator. Above 10 GeV the events are generated by Pythia.

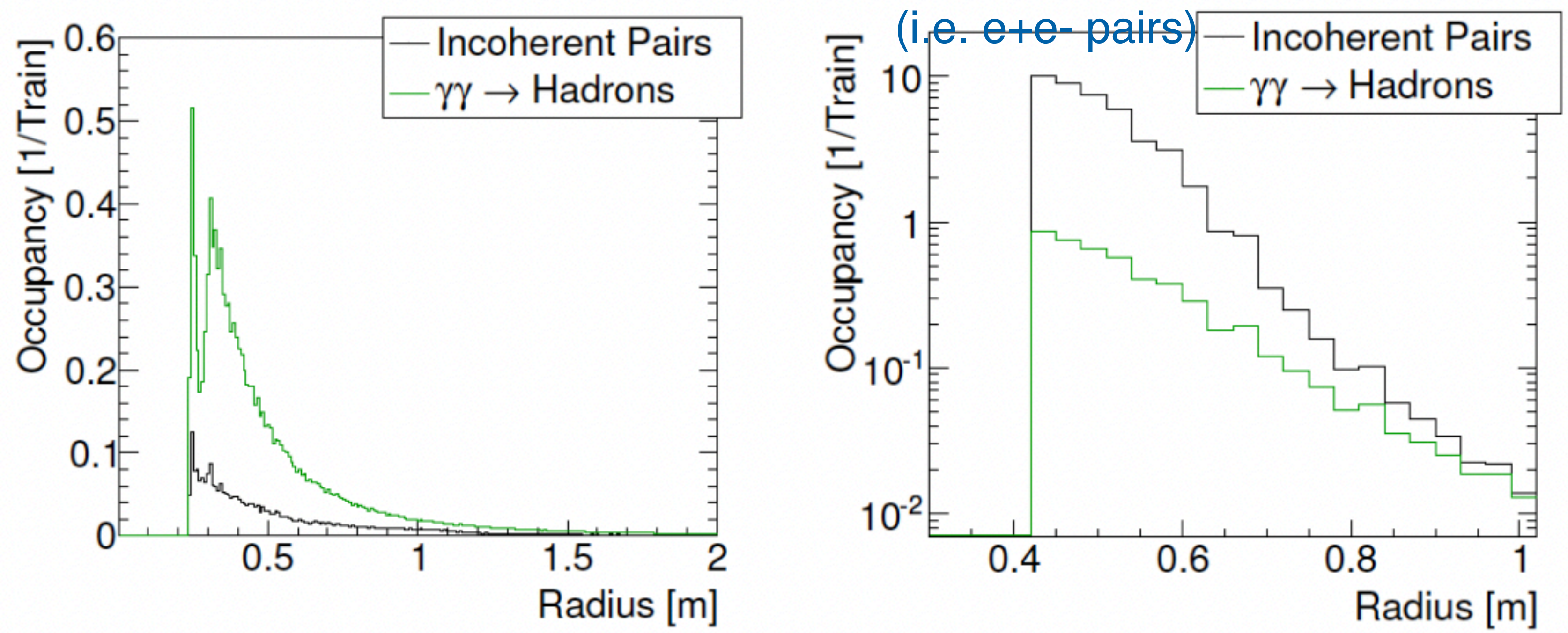
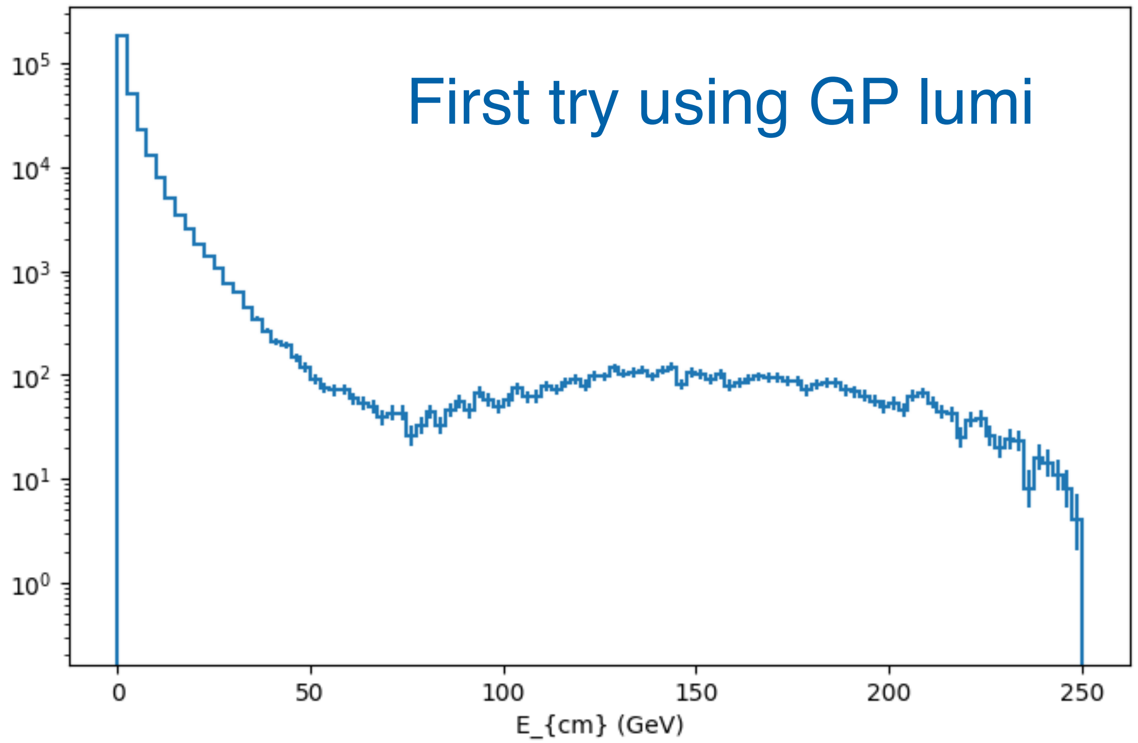
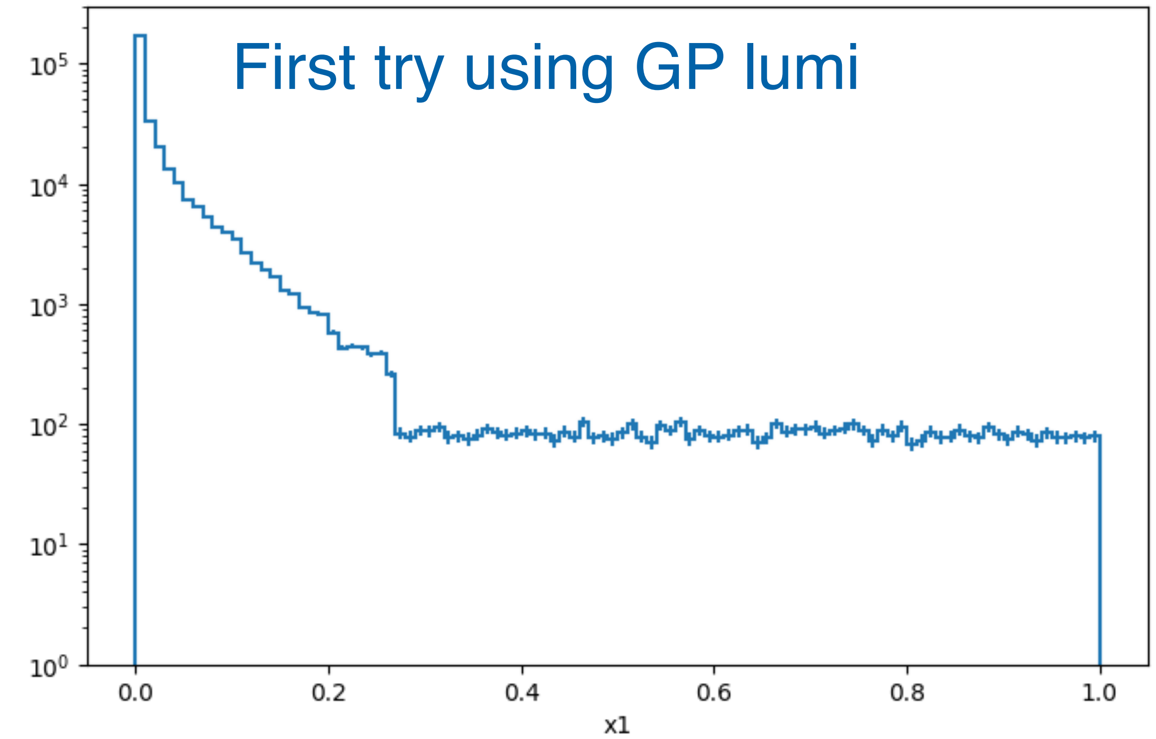


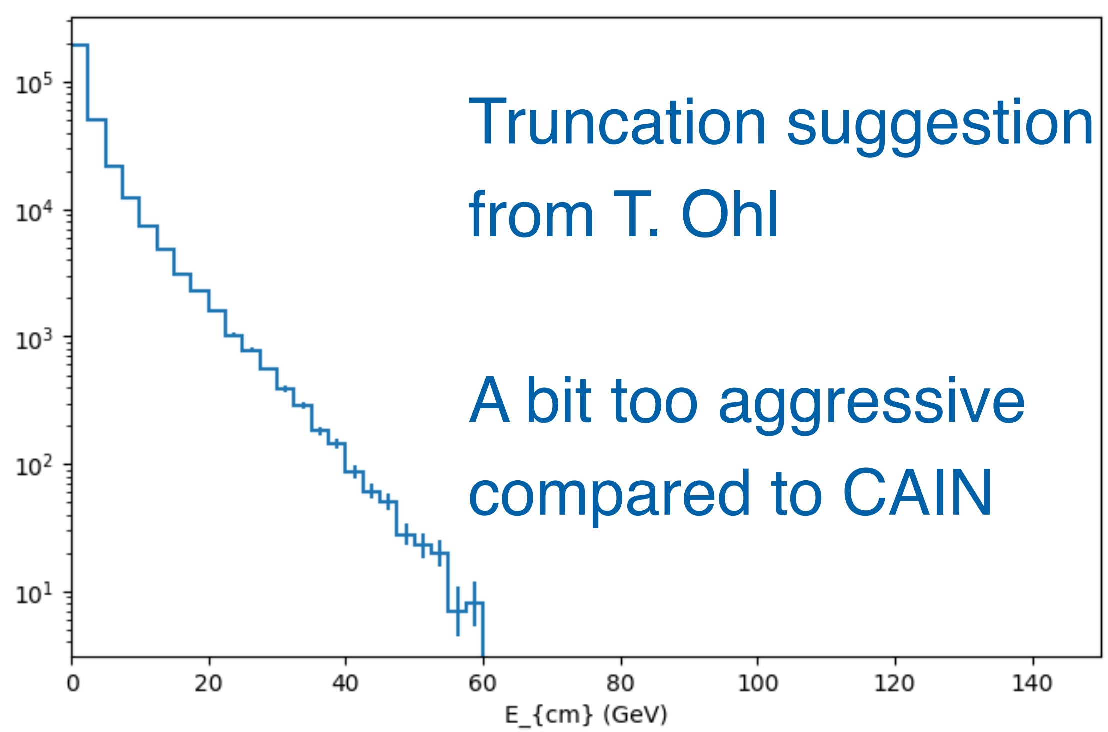
Figure 14. The radial distribution of the train occupancy per pad in ECal (left) and per cell in HCal (right) endcap [10].

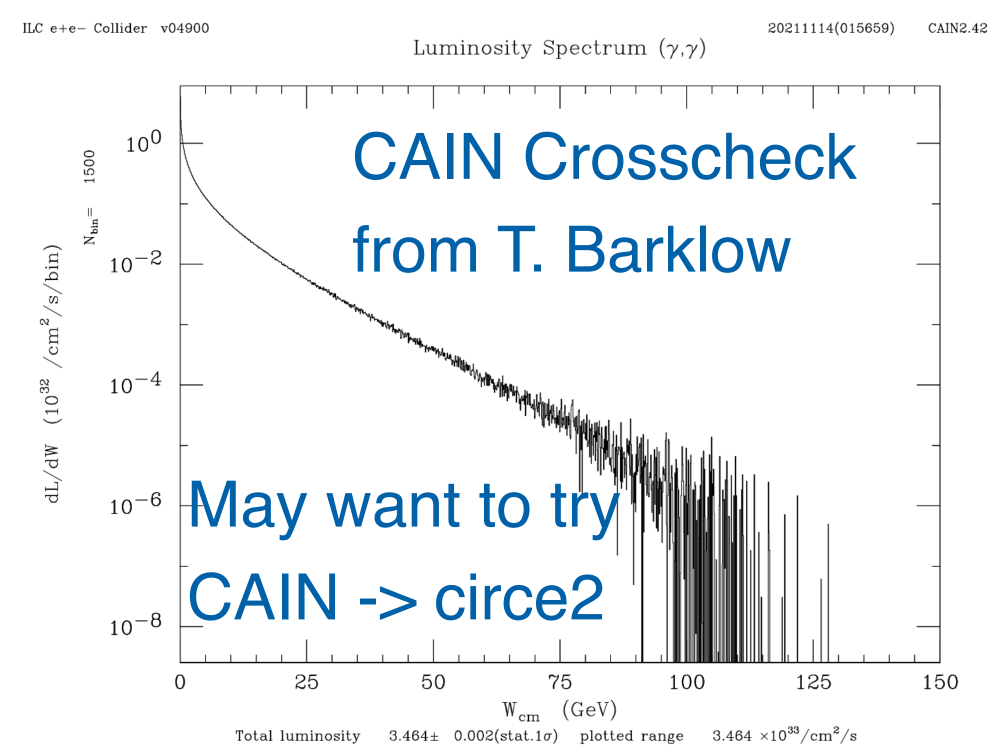
- Hadron Backgrounds in Pythia5.7 -> Pythia6, Whizard 1 -> Whizard 3
  - Previous hadron background simulation libraries generated in pythia6 but most of the configuration lost to history (generated/mixed events available but for ILC)
  - We did find this but difficult to get it all running again
- Today's results using Tim's updated generator, looking at vertex detector
  - Now released in latest Whizard
  - GP -> circe2 -> Whizard 3 generation pipeline smooth and reproducible

Generating Correct Spectra









Using updated Barklow Generator

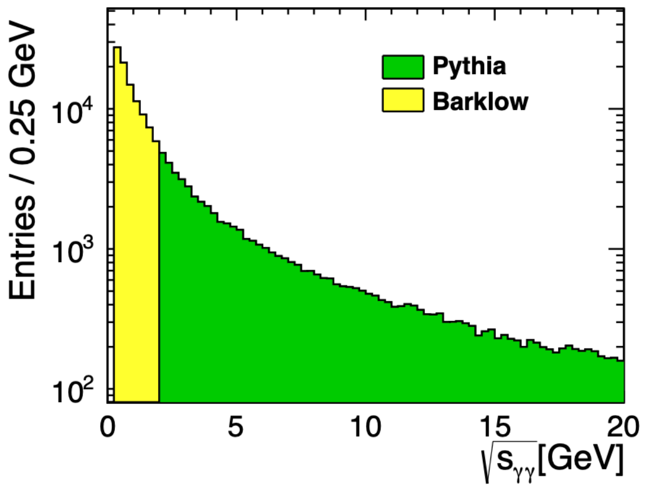
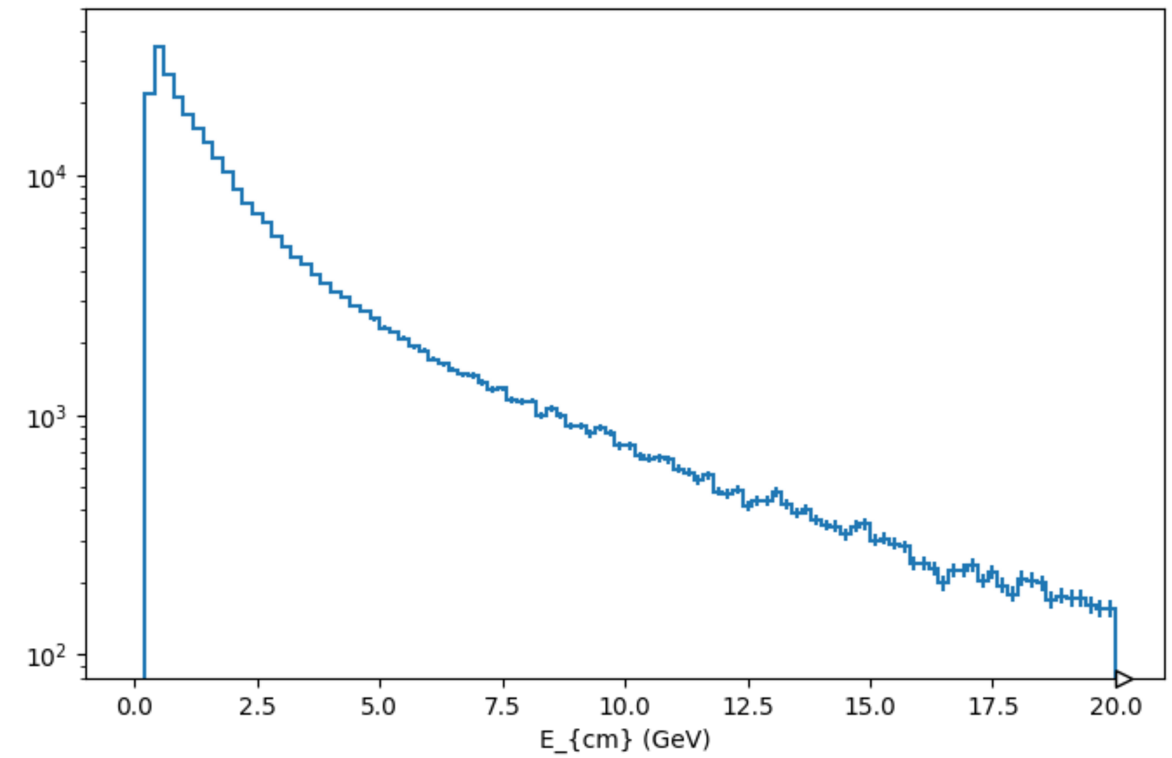


Figure 5.10.: The number of $\gamma\gamma \to$ low p_T hadron events as a function of $\gamma\gamma$ centre-of-mass energy. The figure shows the changed energy cutoff of 10 GeV to 2 GeV below which the events are generated by Barklow generator and above it the events are generated by Pythia. The events are produced at a centre-of-mass energy 500 GeV for ~150k 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.
- This generator is now integrated and distributed in latest Whizard 3

Comparing Per-event Averages

Sasikumar Thesis

$\gamma\gamma$ Background

The $\gamma\gamma \to$ 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 $< N > = 1.05$ 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

ILC TDR

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

Source	#particles per bunch	$< E >$ (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
$\gamma\gamma \to$ 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

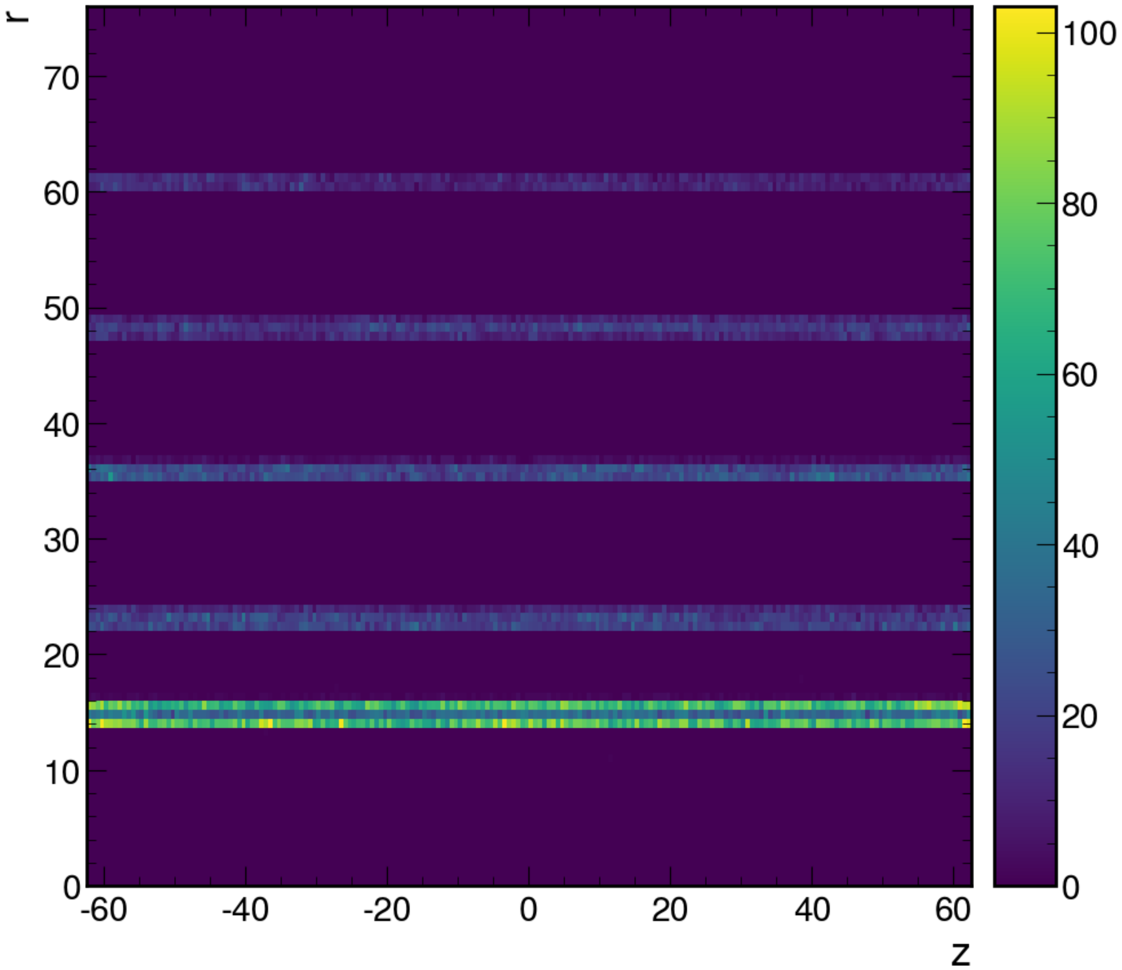
- Have had some inconsistencies between calculations
  - In particular gamma-gamma luminosities out of GP not consistent with CAIN or the Circe2 derivation of the gg luminosity from GP (!!)
- However, after a bit of digging and trying various combinations the recipe which appears consistent to reproduce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

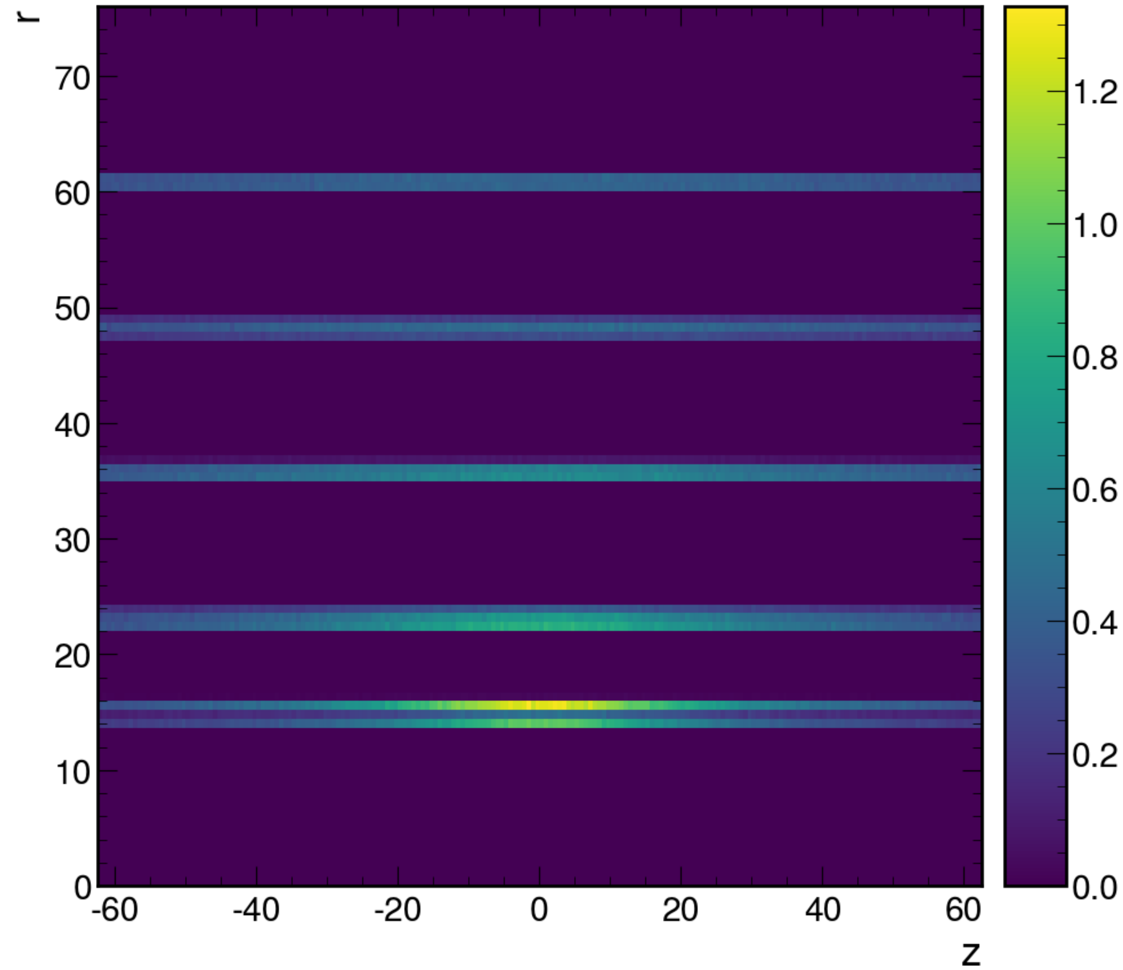
Bunch Trains

LG ILC 500: 1.4 evt/BX	→	LG ILC 500: 1846.8 evt/train (1312 bx)
LG ILC 250: 0.27 evt/BX		LG ILC 250: 495.9 evt/train (1312 bx)
LG C3 250: 0.52 evt/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)

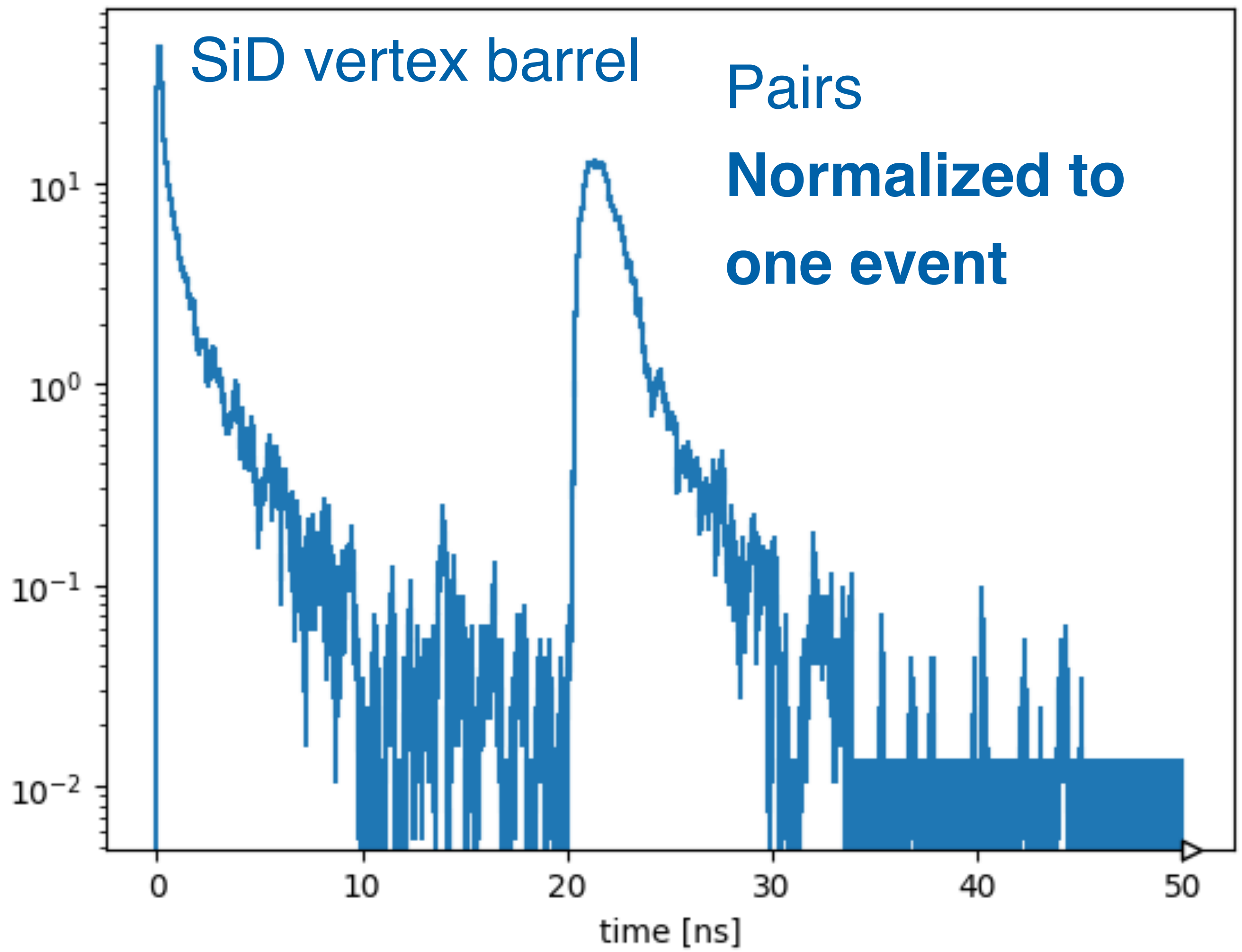
Occupancy Structure: Pairs vs. Hadron-photoproduction (I)

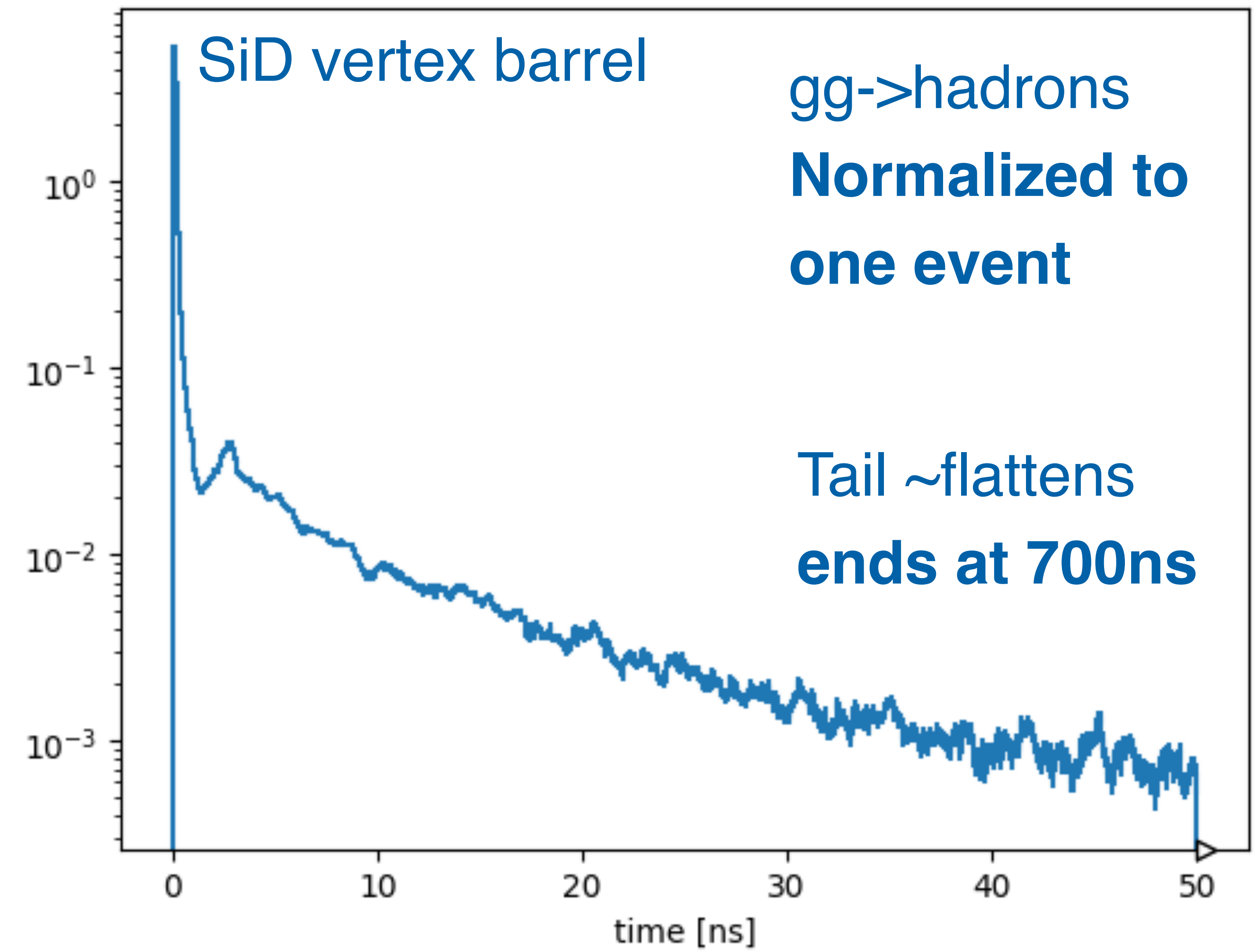




- Left: 133 BX of e+ e- pairs, Right: 100k gg->hadrons events scaled to 69.2
  - 1 bunch train of C3 250
- gg->hadrons much more central, pairs mostly forward (outside acceptance)
  - XS: gg->hadrons ~0.3 ub, pairs -> 16 mb
- Expect maximally ~1% effect of gg->hadrons in vertex occupancy

Time Structure of Pairs and Hadron Photoproduction (I)

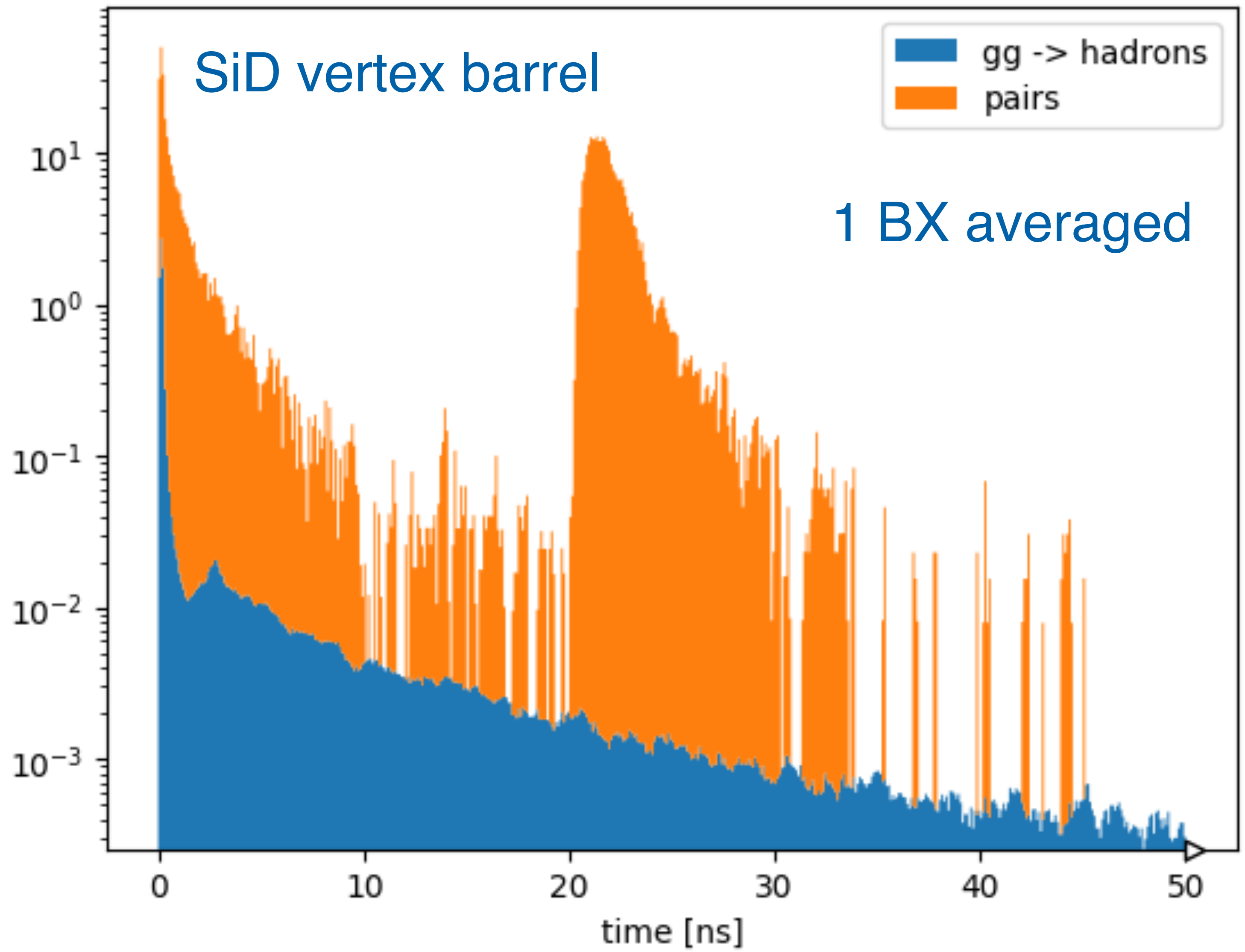




- Marked time structure to pairs background
  - Forward production of pairs backsplashes off of beamcal, returns to vertex detector
  - Beating pattern between backsplash and primary particles depending on bunch spacing!
  - 5.25ns 133 BX trains -> every 4th event has backsplash of 4 events prior!
- Hadrons background more smooth (it's central!), consistent with calorimeter backsplash and slow shower remnants propagating in detector
  - **but** this spectrum is only peaked in for primary production, tail persistent over multiple BX, more complex implications (aside: 25ns spacing at FCC will help but its worth a look!)

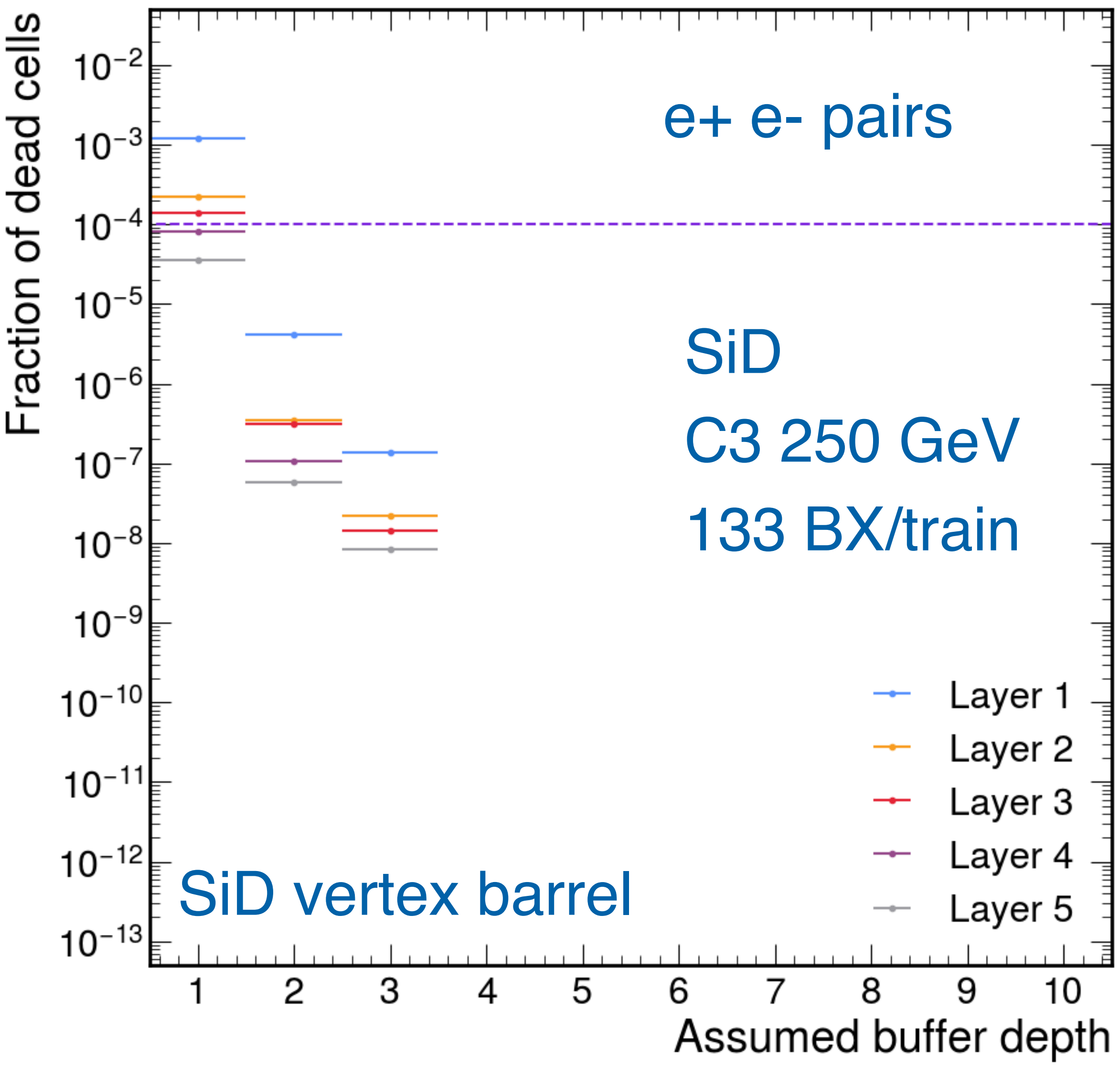
Fermilab

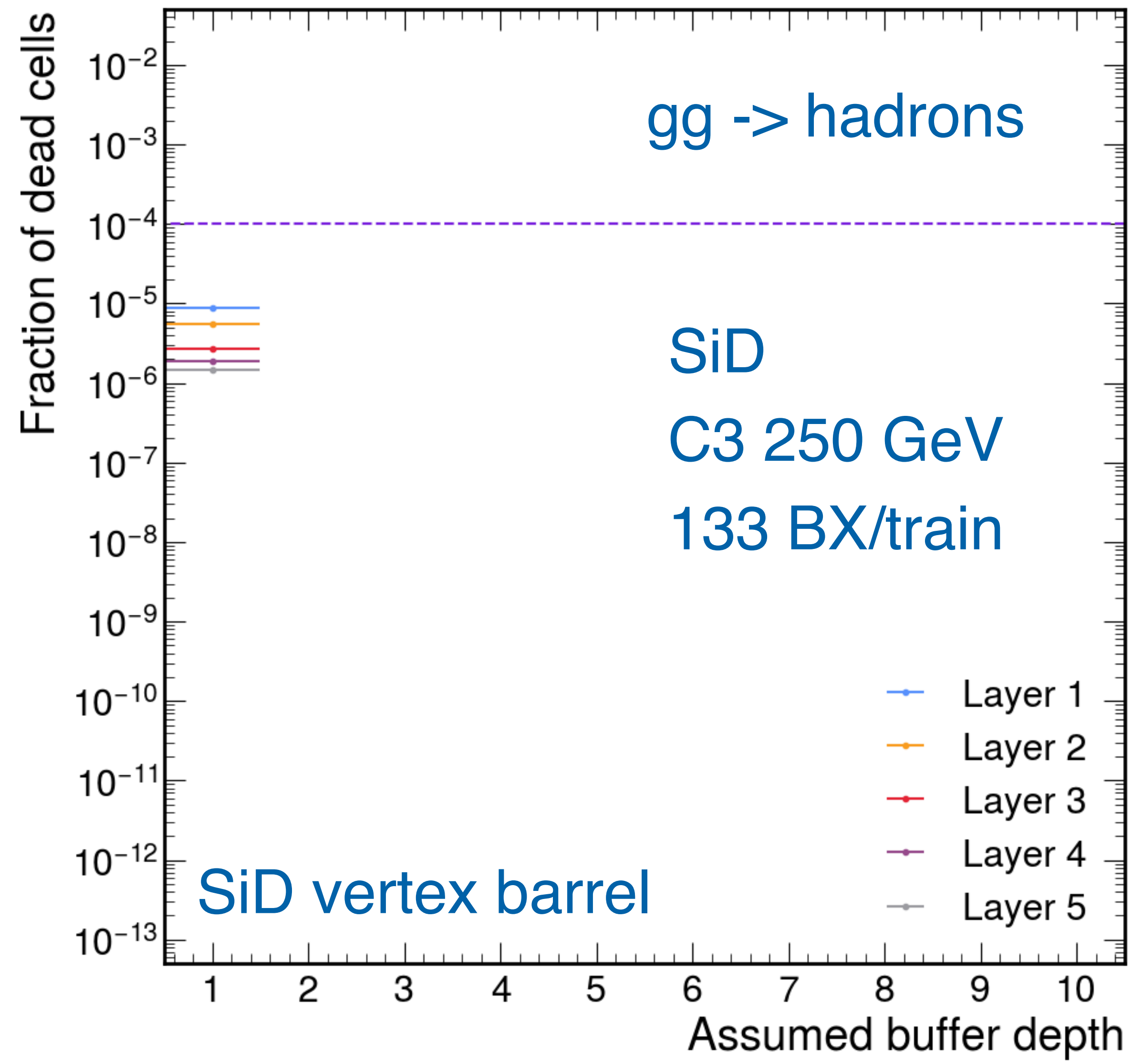
Time Structure of Pairs and Hadron Photoproduction (II)



- Hadron photoproduction has ~0.1-1% effect compared to pairs when in-time with that background
  - ~50% effect out of time with the two major components, from long tail
  - Very different patterns concerning out of time pileup!
- We'll see in a moment this corresponds to ~5e-6 occupancy effects at C3
  - The answer is different in the calorimeters (but no time to discuss today)

Breakdown of detector occupancies

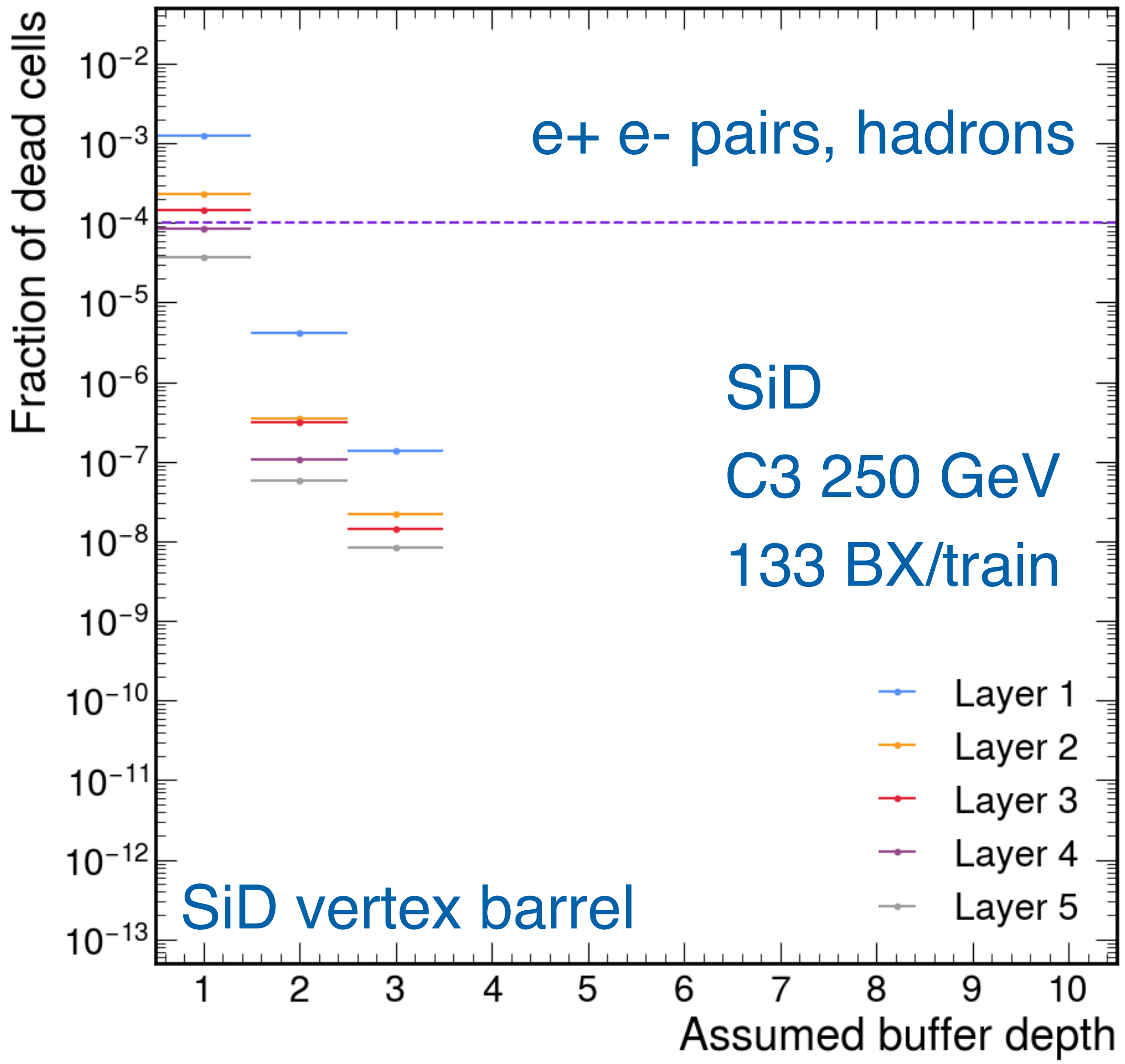




- Hadrons background ~1% effect at single-buffer occupancy, as expected

- Pair background only gives lax constraints on memory requirements in the vertex detector

Total Occupancy



- Fully overlaid bunch train from C3, all backgrounds
- Vertex detector occupancies at C3 quite favorable compared to ILC
  - This is driven only by the bunch train length
  - Follow up studies to do concerning the time structures of these backgrounds
- Can likely be much more aggressive in luminosity delivery at C3

Concluding remarks / Next Steps

- We finally have the gg -> 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
- gg-> hadrons background has rather different space/time occupancy structure compared to pairs
  - Expected from rather different kinematics compared to pairs
  - Very long time-constants make it important for event overlay / pileup mixing
  - Impacts on calorimetry should be investigated at all colliders due to long tails and central production
- Package up instructions for FCC, Muon Collider folks
  - Hadron photoproduction background now in distributed, maintained package: Whizard 3
  - 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 MuC conditions
  - Some interesting studies to do in both these cases, especially considering FCC rates