Beam-induced Background Simulation Studies for the Cool Copper Collider (C^3)

Second ECFA Workshop on e^+e^- Higgs/EW/Top Factories

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  - *Beam-beam interactions at e^+e^- colliders*
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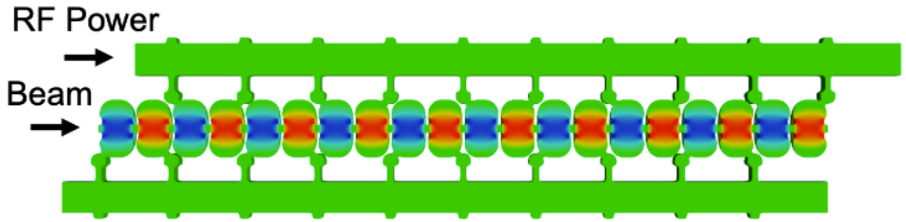
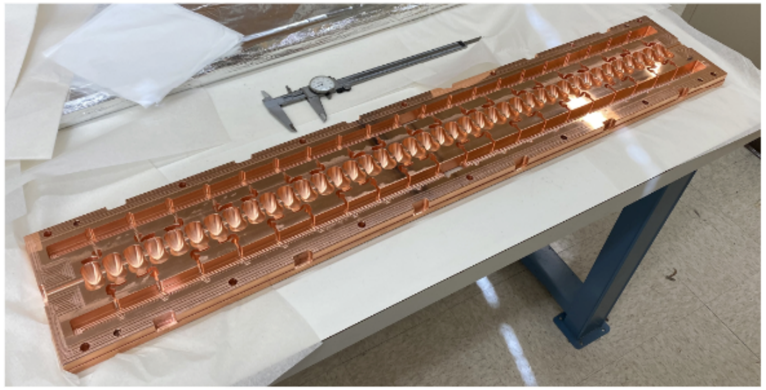
Introduction

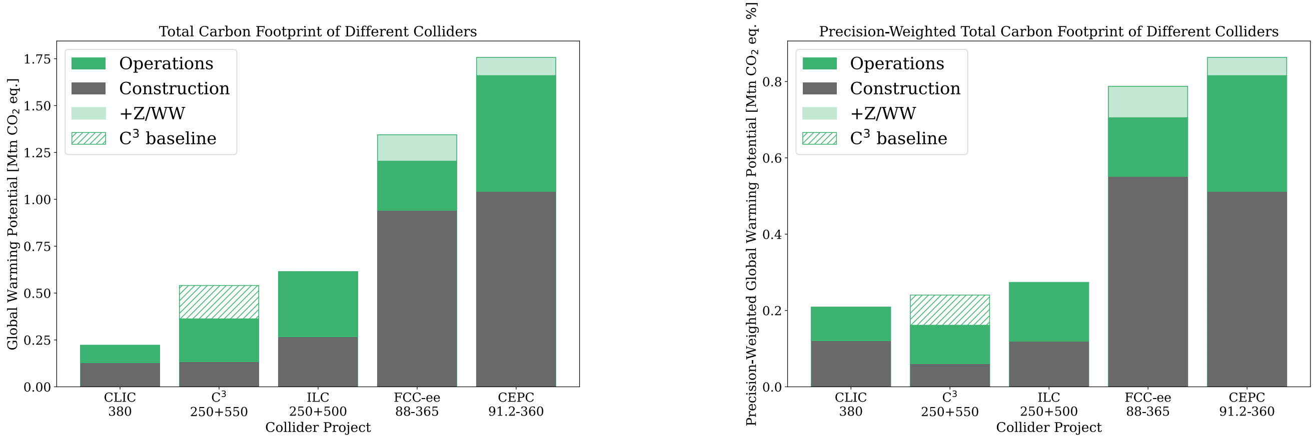
The Cool Copper Collider

- The Cool Copper Collider (C^3) is the newest proposal for a linear e^+e^- collider that relies on normal conducting copper accelerating technology, with a novel cavity design that utilizes distributed coupling.
- In this way, C^3 can achieve cryogenic temperature operation (liquid nitrogen at 77K), lower surface fields and higher accelerating gradients → cost-effective, sustainable, compact 8 km footprint.



Electric field magnitude for equal power from RF manifold





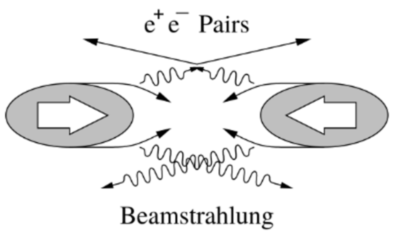
(a) (b)

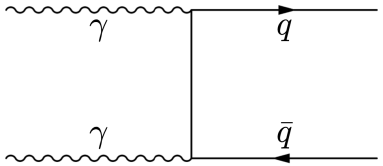
Sustainability Roadmap for C^3: *https://arxiv.org/abs/2307.04084 (accepted in PRX Energy)*

For more information: https://web.slac.stanford.edu/c3/

Beam-Beam interactions at linear e⁺e⁻ colliders

- Nm-sized beams imply very high charge densities at the IP →beam particles from one bunch interact strongly with the opposite bunch, leading to the production of secondary particles, that collectively constitute the **beam-induced background.**





- Background particles are by-products of photons radiated when the two bunches intersect at the IP. Those photons are called **Beamstrahlung (BS)** .
  - Incoherent pair production:
    $\gamma_{BS} e \to e^+e^- e, \quad \gamma_{BS}\gamma_{BS} \to e^+e^-, \quad ee \xrightarrow[\text{(virtual)}]{\gamma_{BS}} eee^+e^-$
  - Hadron photo-production: $\gamma_{BS}\gamma_{BS} \to q\bar{q}$

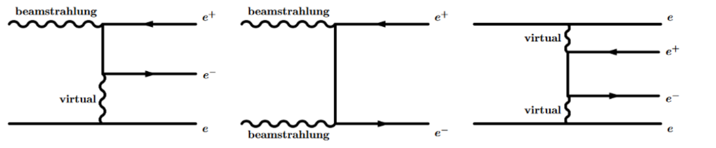
→ $O(10^5)$ ***pairs per BX***

(BX = Bunch Crossing)

→ $O(1)$ ***hadrons per BX***

(more central)

- *Bethe-Heitler (BH)*: interaction of BS photon with a virtual photon
- *Landau-Lifschitz (LL)*: interaction of two virtual BS photons
- *Breit-Wheeler (BW)*: interaction of two BS photons



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

BH: ~ 65 % of the total XS
LL: ~ 30 % of the total XS
BW: ~ 5 % of the total XS

Beam-Beam interactions at linear e^+e^- colliders

C^3

SLAC

The strength of beam-beam interactions and the number of produced BIB particles is expressed through the Ypsilon parameter:

$$\langle \Upsilon \rangle = \frac{5}{6}\frac{N_e r_e^2 \gamma}{\alpha(\sigma_x^* + \sigma_y^*)\sigma_z^*}$$

$$\delta_E = \frac{16\sqrt{3}}{5\pi^{3/2}}\frac{r_e \alpha N_e}{\sigma_x^*}\langle \Upsilon \rangle$$

$$n_\gamma = \frac{12}{\pi^{3/2}}\frac{\alpha^2 \sigma_z^*}{\gamma r_e}\frac{6\langle \Upsilon \rangle}{5}$$

$$\left\langle \frac{E_\gamma}{E_0} \right\rangle = \frac{\delta_E}{n_\gamma}$$

Parameter	Symbol[unit]	CLIC	ILC-250	C^3-250
Geometric Luminosity	$\mathcal{L}_{\mathrm{geom}}$ [x10^{34}/cm^2 s]	0.91	0.53	0.75
Horizontal Disruption	D_x	0.26	0.51	0.32
Vertical Disruption	D_y	13.1	34.5	21.5
Average Beamstrahlung Parameter	$\langle \Upsilon \rangle$	0.17	0.028	0.065
Total Luminosity	$\mathcal{L}$ [x10^{34}/cm^2 s]	1.6	1.35	1.3
Peak luminosity fraction	$\mathcal{L}_{0.01}/\mathcal{L}$	60%	74%	73%
Enhancement Factor	H_D	1.6	2.6	1.7
Average Energy loss	δ_E	6.9 %	2.9 %	3.3 %
Photons per beam particle	n_γ	1.5	2.0	1.3
Average Photon Energy fraction	$\langle E_\gamma/E_0 \rangle$ [%]	4.6 %	1.4 %	2.4 %
Number of incoherent pairs	N_{incoh} [10^4]	6.0	13.4	4.6
Total energy of incoh. pairs	N_{incoh} [TeV]	186	117	57

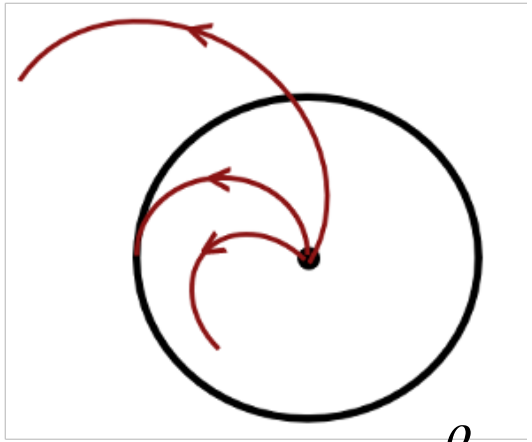
From analytical formulas (first four rows)

From `GuineaPig` simulations (remaining rows)

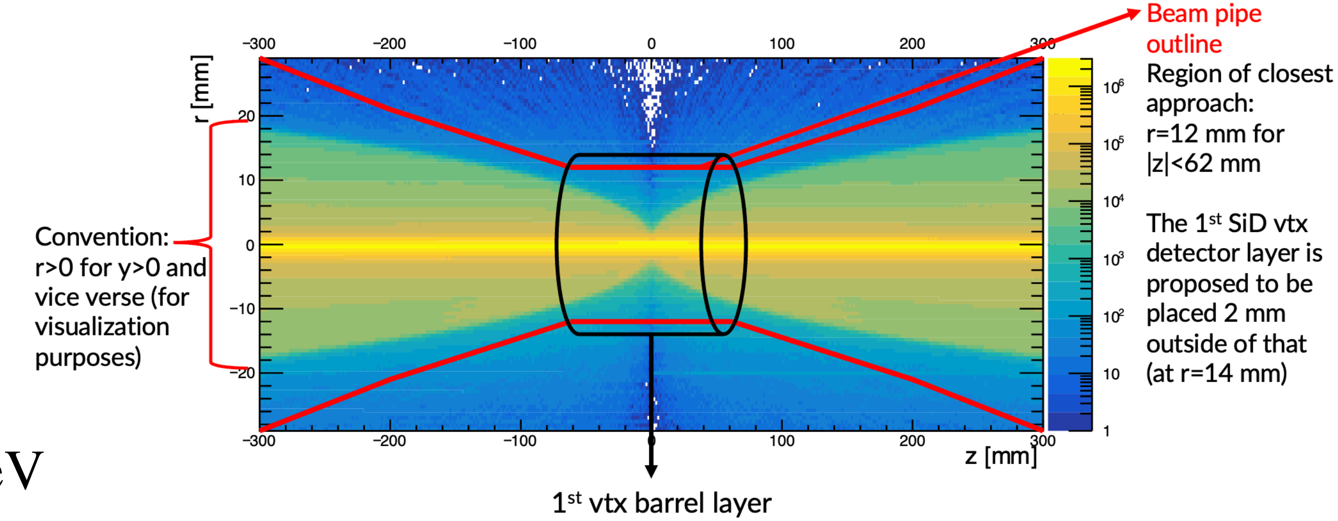
Values of the BS Ypsilon parameter and other related qualities for various future linear e+e- machines

Pair background at linear e^+e^- colliders

- The produced incoherent pairs are mostly boosted in the forward region (low p_T) and are deflected significantly in the strong magnetic field (~T) of the detector. Thus, most of them are "washed" away from the IR within the beam-pipe → **pair background envelope**
- However, those that reach the detector (for C³, $\sim 0.1\ \%$ or ~ 40 particles/BX) can increase its occupancy and impact its performance, compromising the very stringent precision requirements of the experiment.
- The ***vertex barrel detector***, which is the closest to the IP (r=14 mm for the 1st layer of SiD) and is necessary for precise vertexing and tagging, is mostly affected.

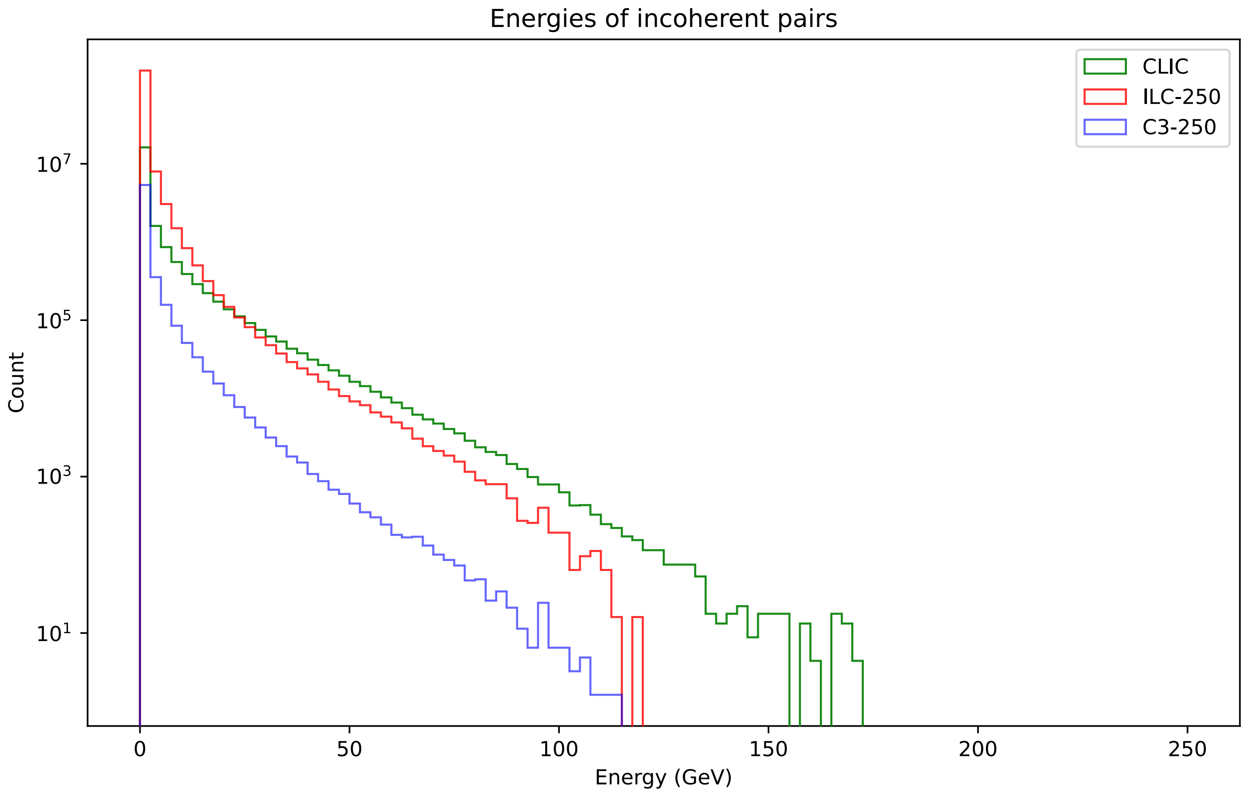


$$p_T^{(\min)}[\text{MeV}] = 0.3 \cdot B[\text{T}] \cdot \frac{\rho}{2}[\text{mm}] \simeq 10\ \text{MeV}$$

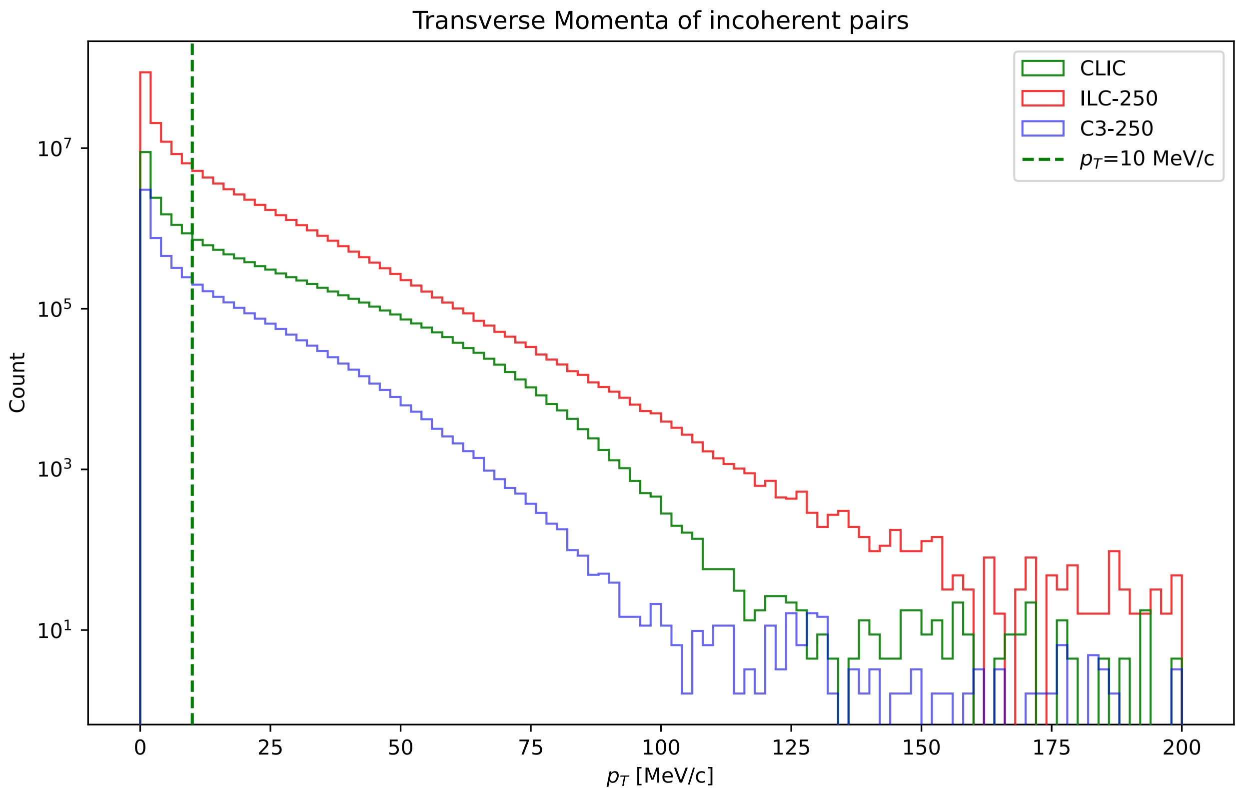


Pair background at linear e^+e^- colliders

Energy



Transverse Momentum (p_T)

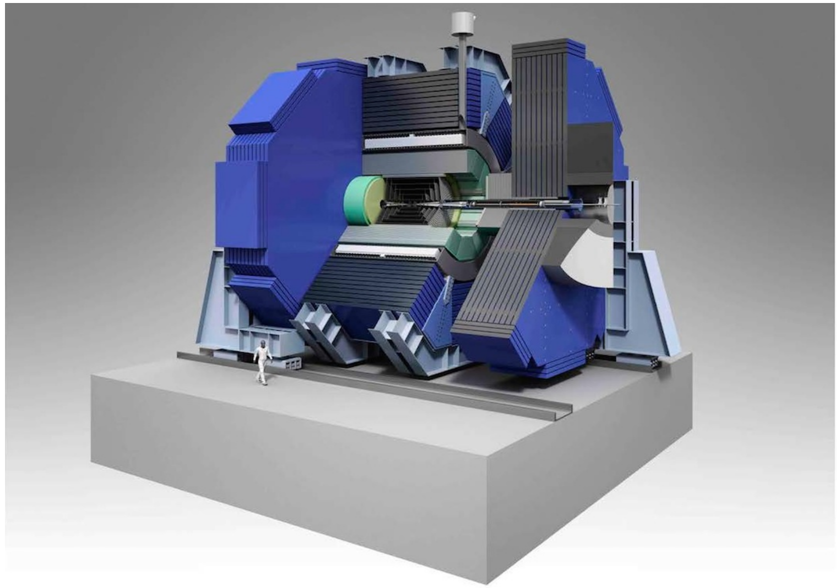


- Energy and p_T distributions of incoherent pairs for CLIC,ILC and C^3, as simulated with `GuineaPig`.
- Each histogram has been normalized to the expected number of pair particles for an entire bunch train

Simulation Tools

For all C^3 studies, we are making an effort to use well-established and/or modern software tools, to guarantee modularity, preservation and reusability of our code:

- For the simulation of beam-beam interactions, the tools **GuineaPig++** and **CAIN v2.4.2** have been used and their results cross-validated.
- For full detector simulation with GEANT4, **DD4hep** is used.
- The SiD detector geometry (02_v04) is ported from **k4geo** (lcgeo).



Links

GUINEA-PIG
Key4hep
DD4hep
k4geo

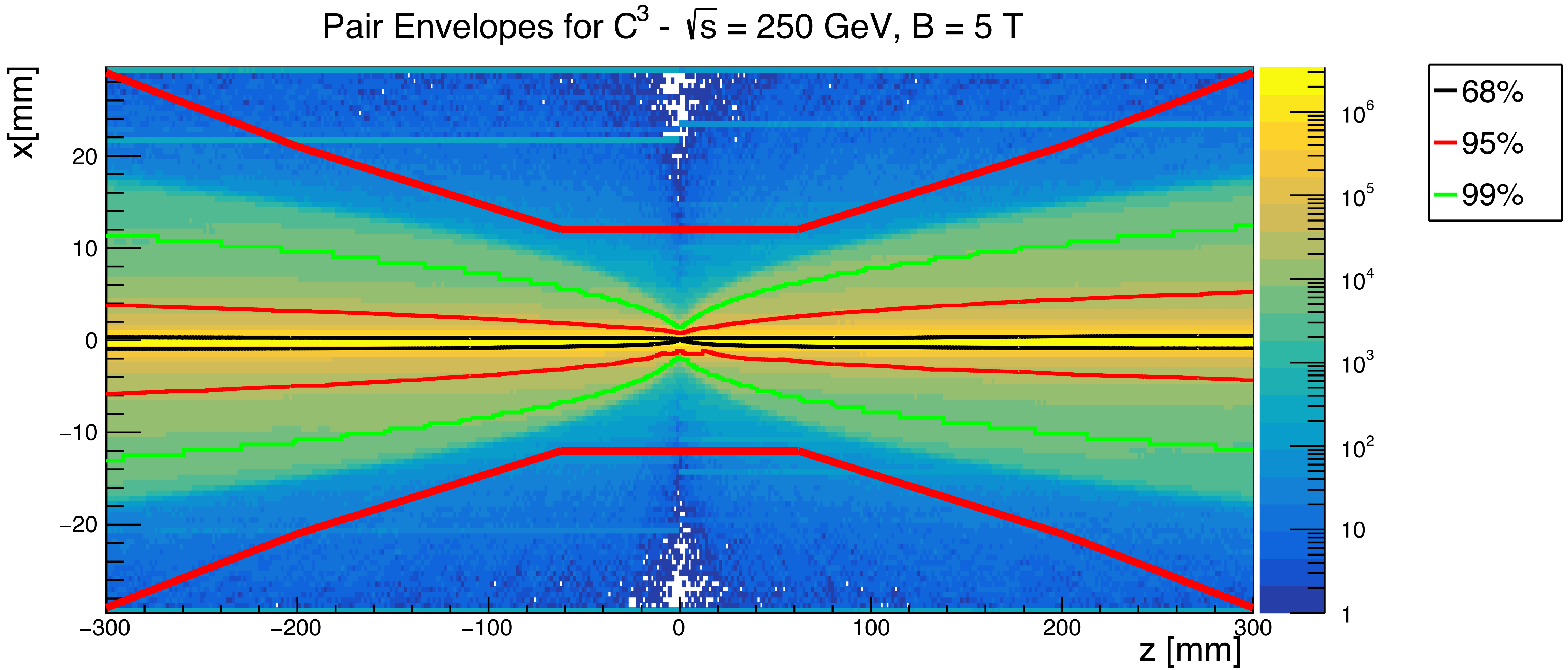
* *Also: efforts with MUCARLO ongoing to simulate the halo muon background*

Occupancy Studies for C^3

Pair Background Envelopes

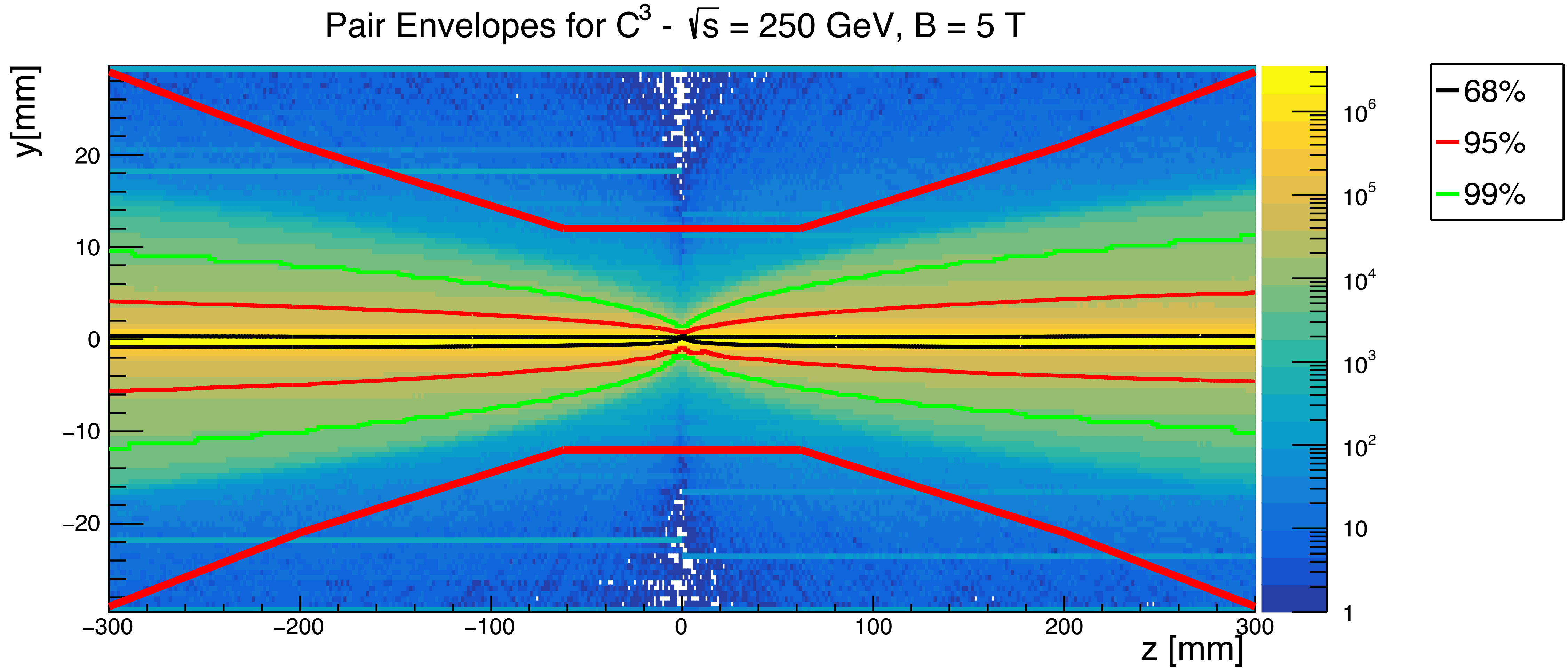
The pair background envelopes for C³ are well contained within the beam-pipe.

x vs z



The pair background envelopes for C³ are well contained within the beam-pipe.

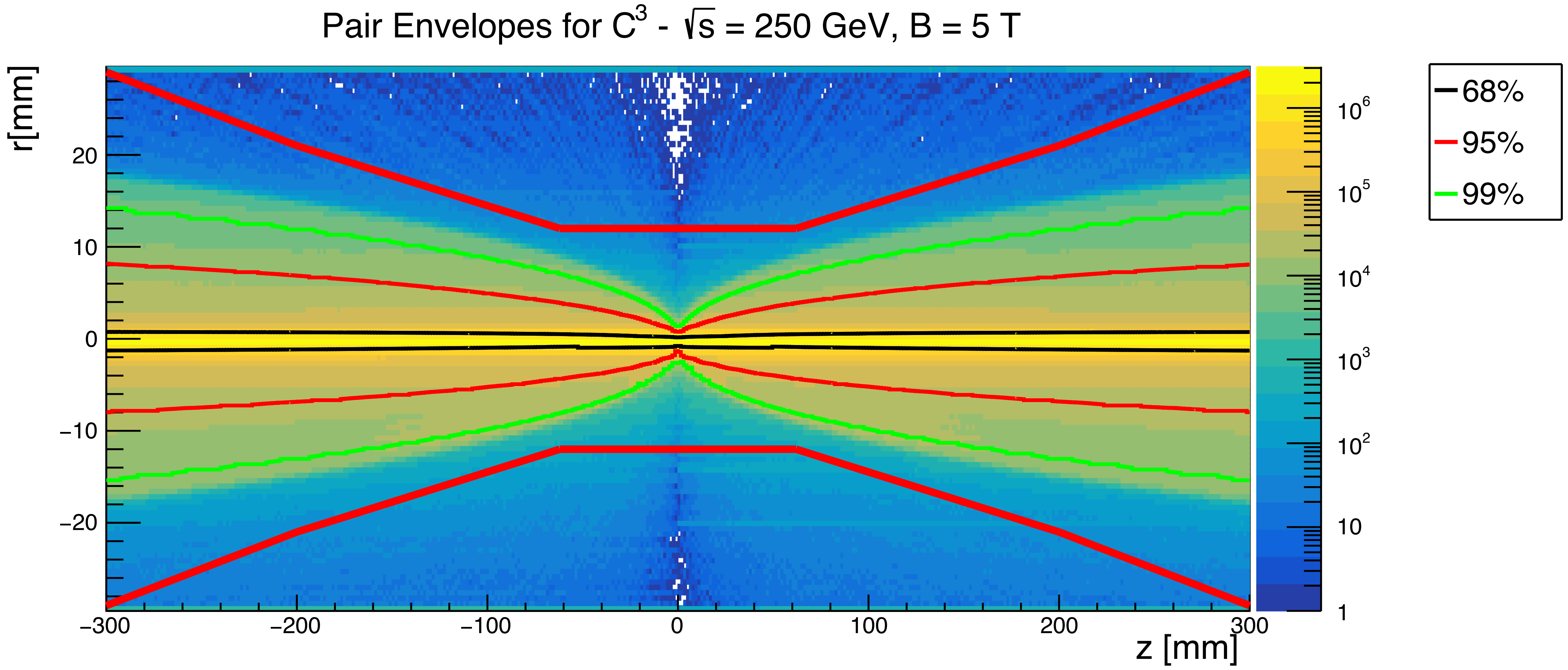
y vs z



Pair Background Envelopes

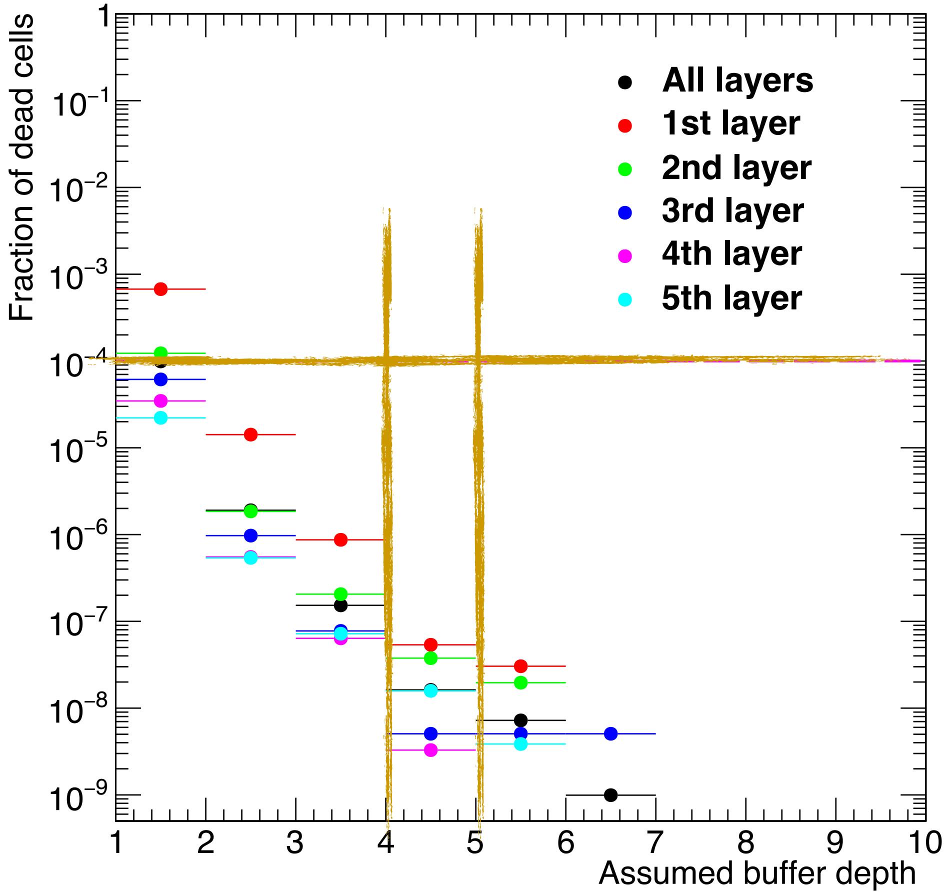
The pair background envelopes for C³ are well contained within the beam-pipe.

r vs z



Pair background occupancy

- We define the detector **occupancy** as the fraction of dead cells, i.e. cells with a number of hits ≥ the available number of buffers (called **buffer depth**).
- In the current readout schemes, hits will be stored in the buffer system and read out after each bunch train.
- To estimate the occupancy, we run full detector simulations for all pair background particles for a full C^3 bunch train (133 BXs).
- For ILC detectors, an occupancy upper limit of 10^{-4} and buffer depth of 4 has been proposed.
- *The occupancy in the SiD vertex barrel for the C^3 beam structure is well within that limit.*



Occupancy in the vertex barrel as a function of assumed buffer depth for C^3-250.

Timing Studies for C^3

Beam Parameters related to timing

- **ILC:** One train every 200 ms (5 Hz) with 1312 bunches/train.
- Each bunch is separated by 369 ns.
- In the remaining time until the next train arrives, the detector has to read out the analog signals and do the digital processing.

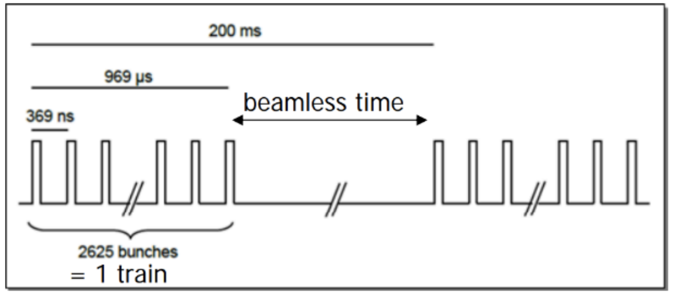
- **C^3:** One train every 8.3 ms (120 Hz) with 133 bunches/train.
- Each bunch is separated by 5.25 ns.
- In the remaining time until the next train arrives, the detector has to read out the analog signals and do the digital processing.

- **Comparison:** C^3 will record $O(10)$ times fewer bunches than ILC, leading to reduced occupancy. But, the readout will have to take place ~25 times faster.

Collider	NLC[16]	CLIC[10]	ILC[18]	C^3	C^3
CM Energy [GeV]	500	380	250 (500)	250	550
σ_z [μm]	150	70	300	100	100
β_x [mm]	10	8.0	8.0	12	12
β_y [mm]	0.2	0.1	0.41	0.12	0.12
ϵ_x [nm-rad]	4000	900	500	900	900
ϵ_y [nm-rad]	110	20	35	20	20
Num. Bunches per Train	90	352	1312	133	75
Train Rep. Rate [Hz]	180	50	5	120	120
Bunch Spacing [ns]	1.4	0.5	369	5.26	3.5

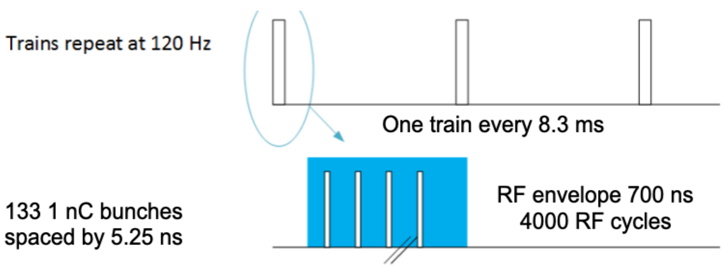
Caterina Vernieri et al 2023 JINST 18 P07053

ILC timing structure



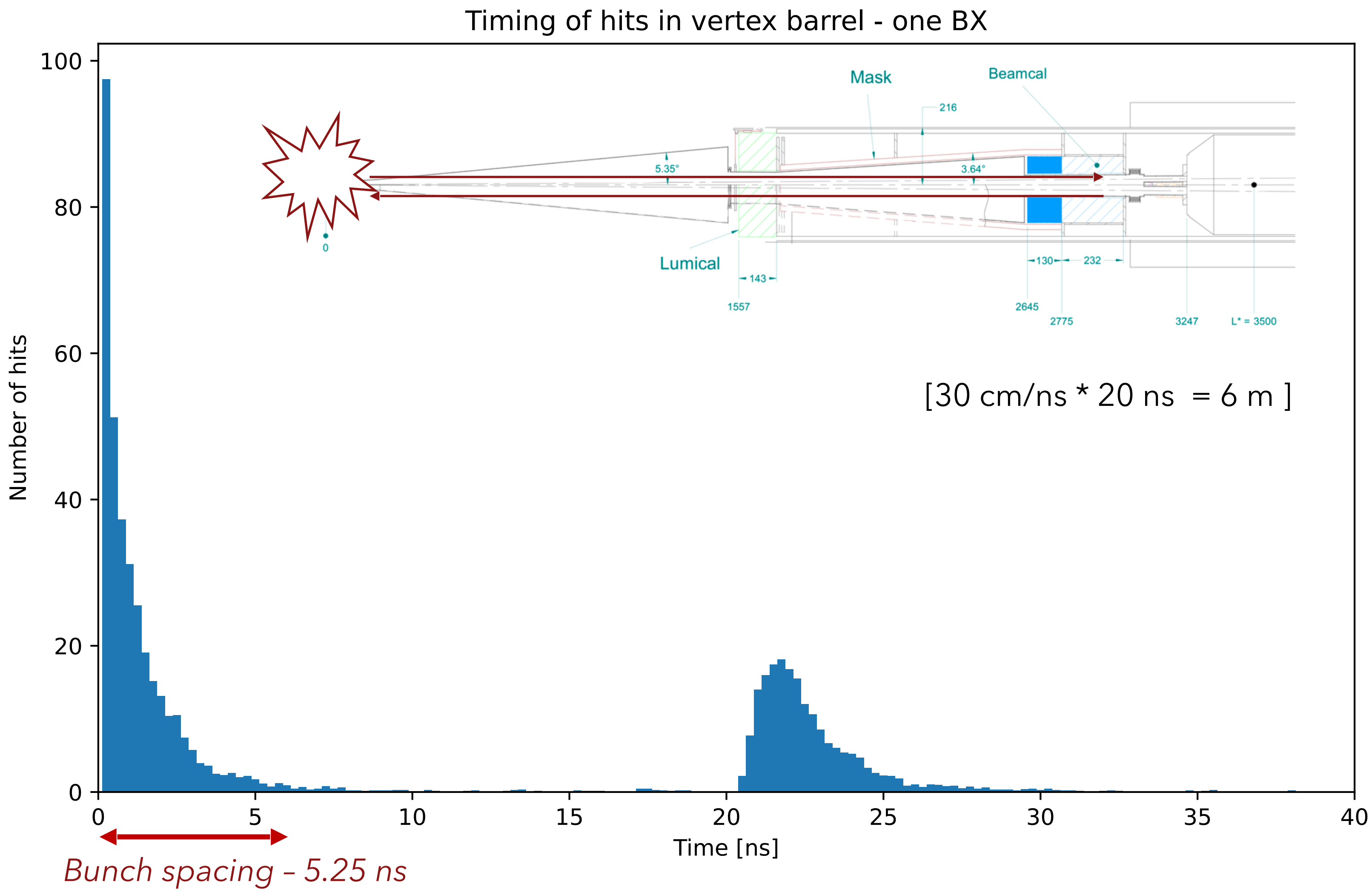
1 ms long bunch trains at 5 Hz
308ns spacing

C³ Timing Structure



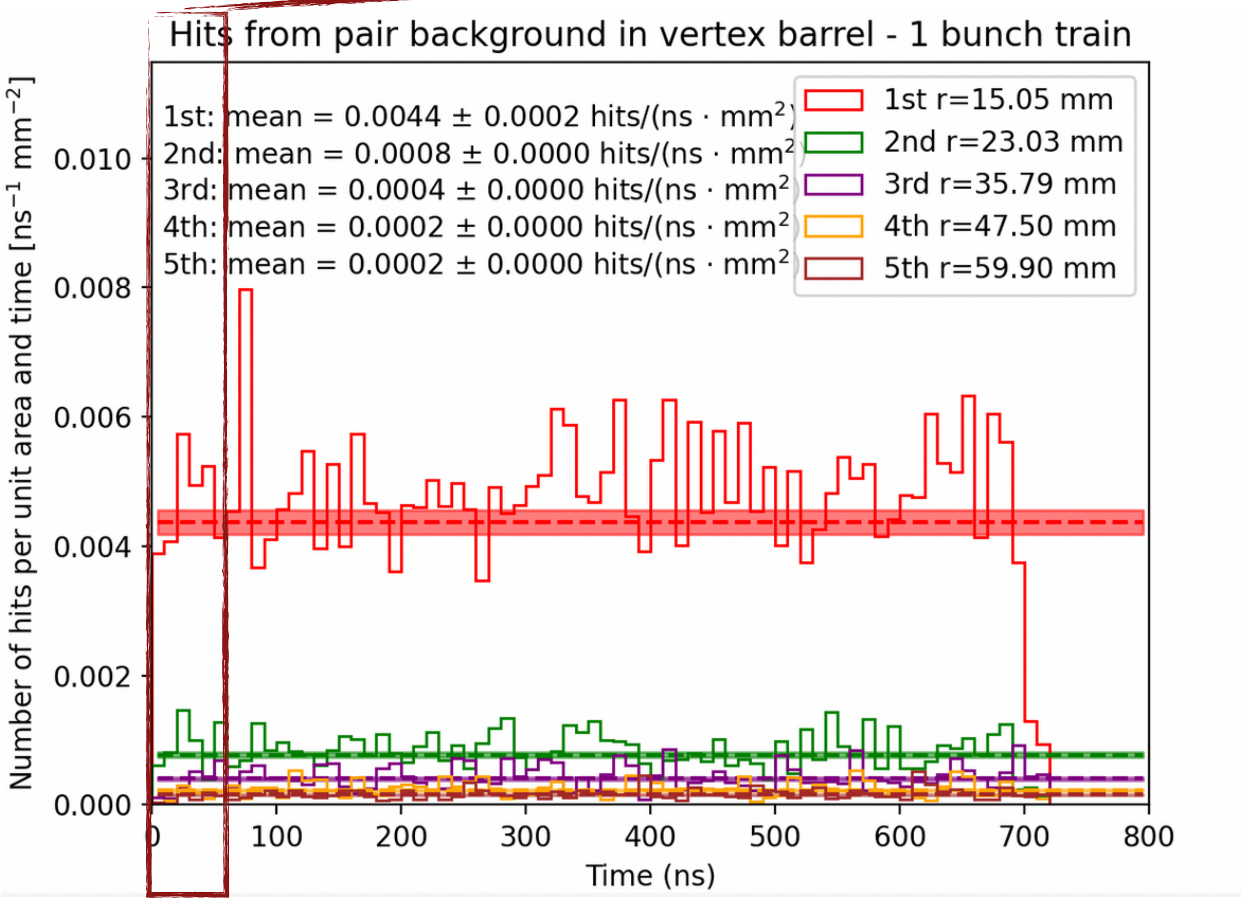
Time distribution within each BX

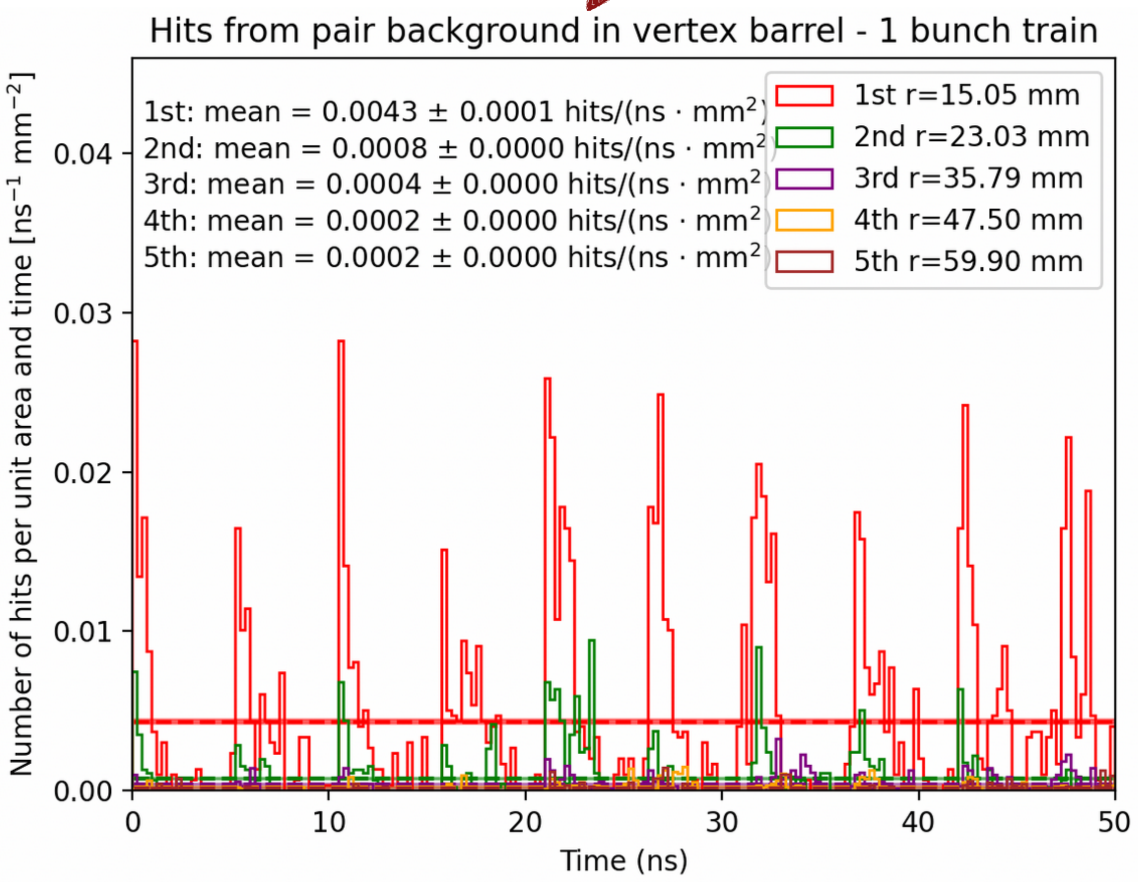
- Time distribution of hits in the vertex barrel within a single BX.
- Most hits contained in time within the bunch spacing.
- The secondary peak at ~20-25 ns is due to backscattering from the BeamCal.



Time distribution over a train - vertex barrel

Time distribution of hits per unit time and area: on average, we anticipate $\sim 4.4 \cdot 10^{-3}$ hits/(ns $\cdot$ mm^2) $\simeq 0.023$ hits/mm^2/BX in the 1st layer of the vertex barrel detector, within the limits set for SiD from previous studies for ILC.

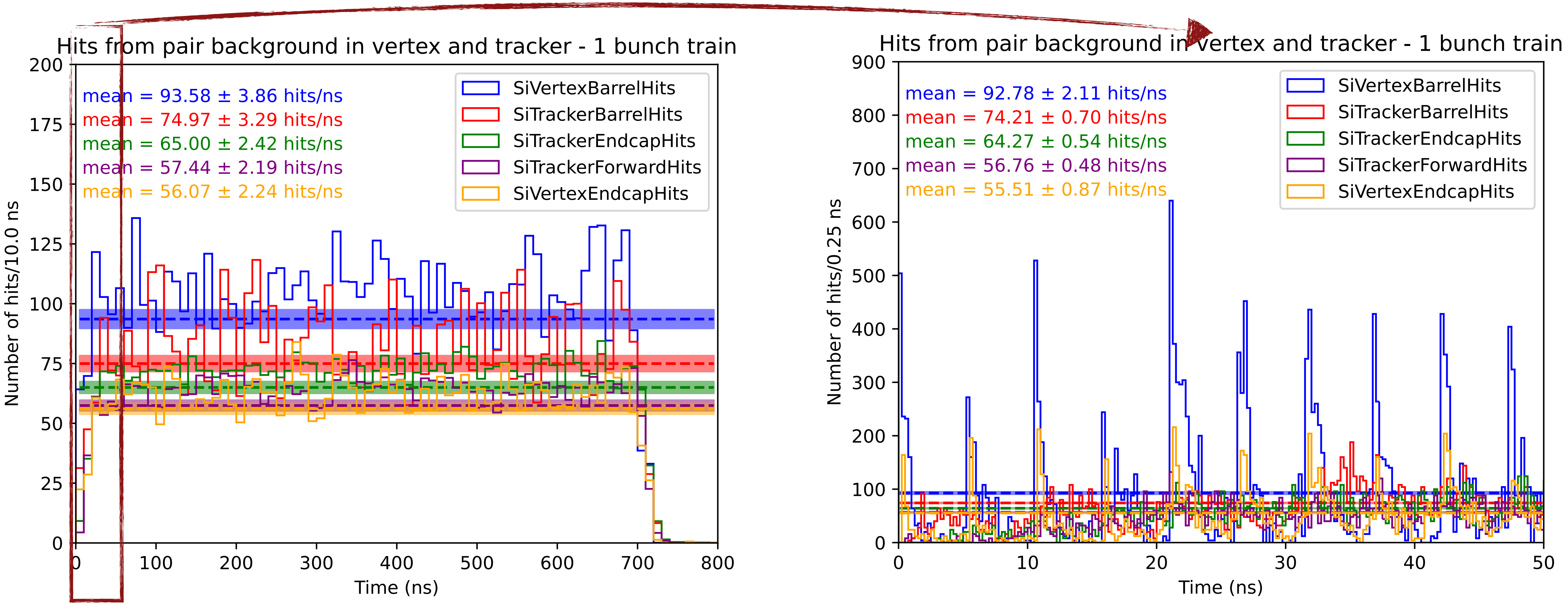




Time distribution over a train - vertex & tracker

Time distribution of hits per unit time in the various vertex and tracker subdetectors.

Peak structure follows bunch spacing for vertex detectors, becomes more diffuse for tracker.



Conclusions

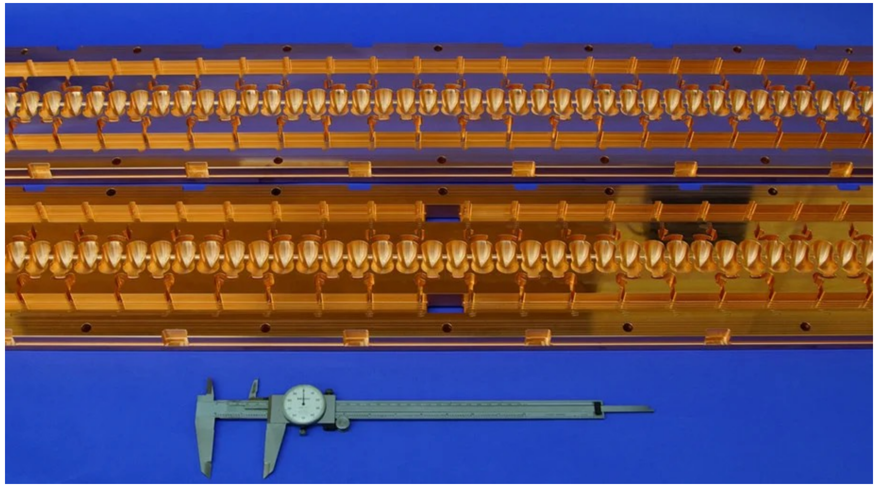
Conclusions

- We presented an overview of the ongoing studies for the beam-induced pair background at C^3.

- All results so far, in terms of the resulting detector occupancy and time-structure of the hits, indicate that the beam-background at C^3 is comparable with ILC.
- This further validates the statement that C^3 could utilize ILC-like detector designs.

- Many more studies are underway to fully simulate, characterize and combine all sources of background at C^3 and evaluate their impact on detector design and Physics reach.

*See **Lindsey Gray**'s talk on out-of-time pileup mixing!*



We are looking forward to incorporating more Key4hep tools in our simulation pipeline, as well as to further synergies with the Future Collider community.

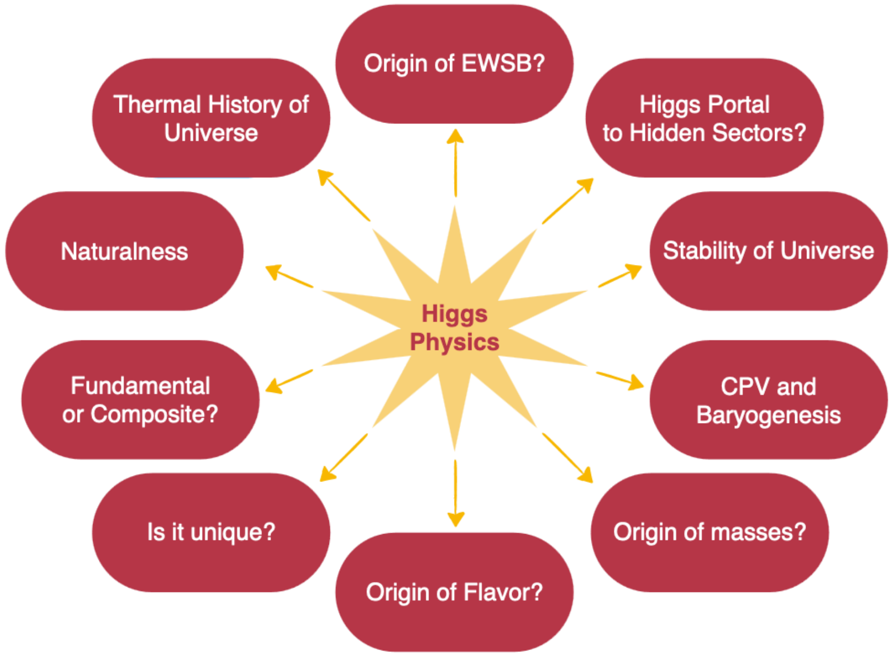
Thank you for your attention

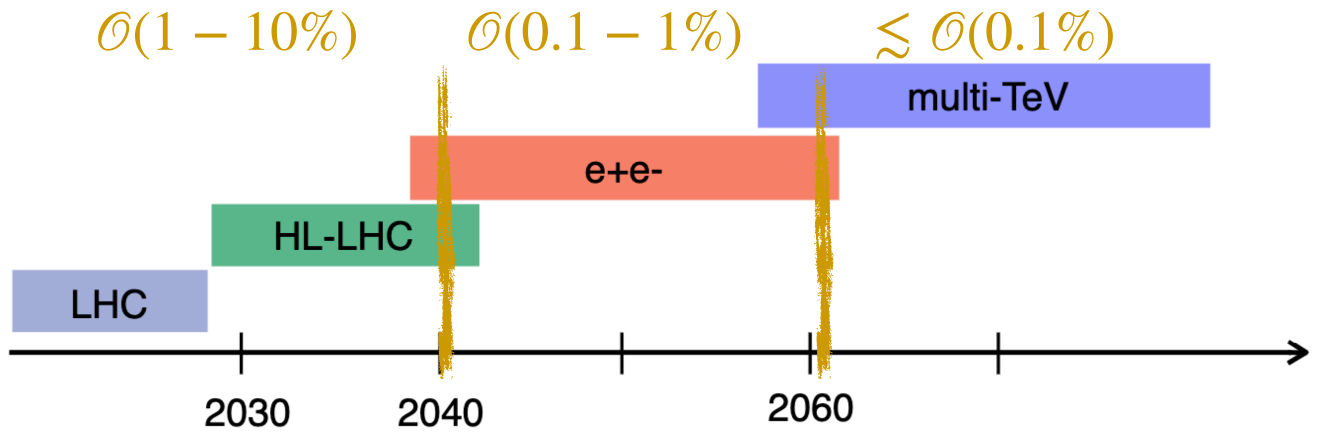
Stay tuned!

Backup

Benefits of e^+e^- colliders

- The Higgs boson is the latest experimentally verified addition to the SM and a pathway to answering many fundamental questions in Particle Physics and beyond.
- This requires measurements of its properties with precision at the percent and sub percent level, which lies beyond the capabilities of HL-LHC.

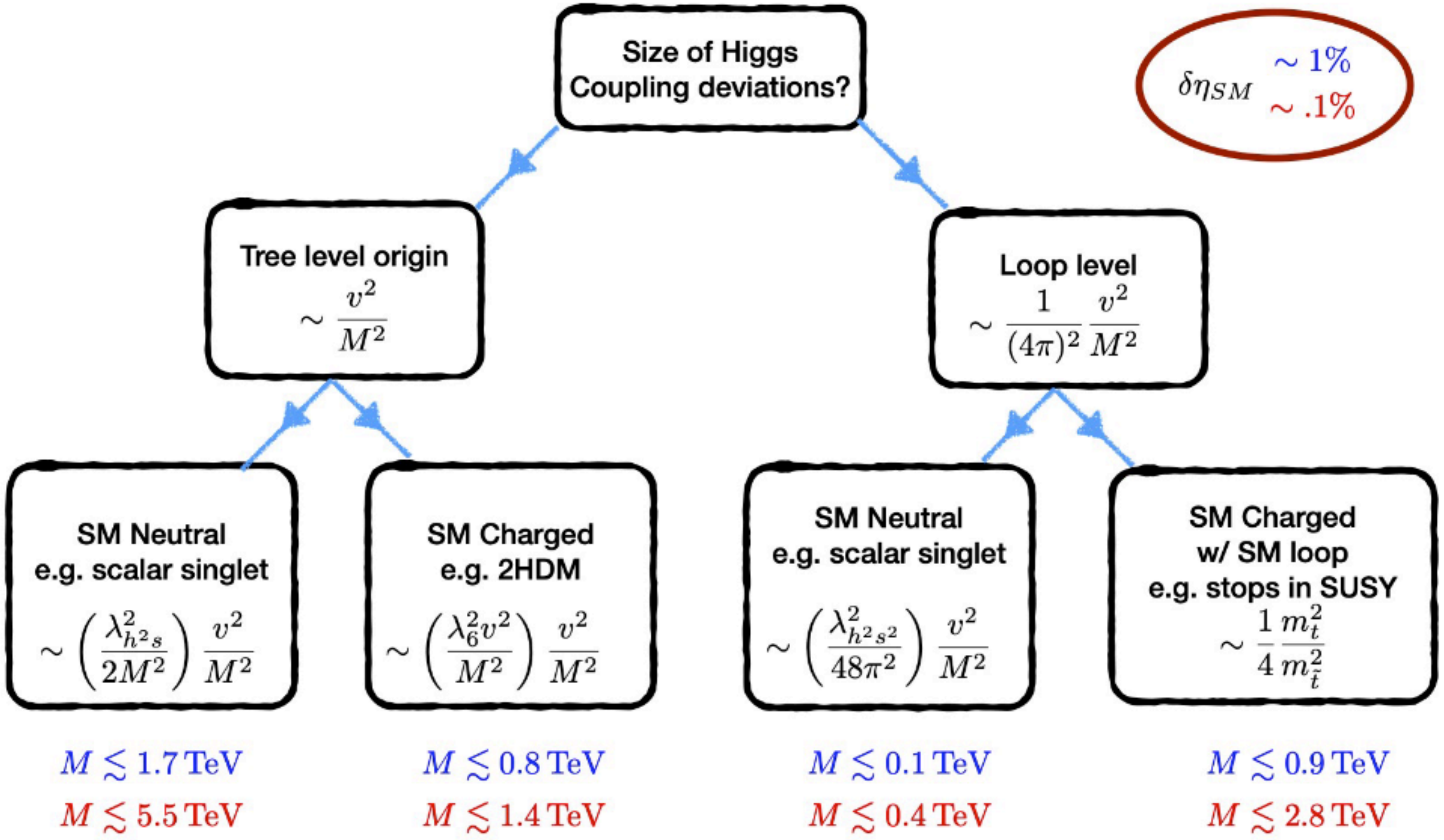




Snowmass EF01 & EF02 Report

Benefits of e⁺e⁻ colliders

- Higgs precision measurements at the percent and sub-percent level enables tests of new Physics at the **TeV** scale.

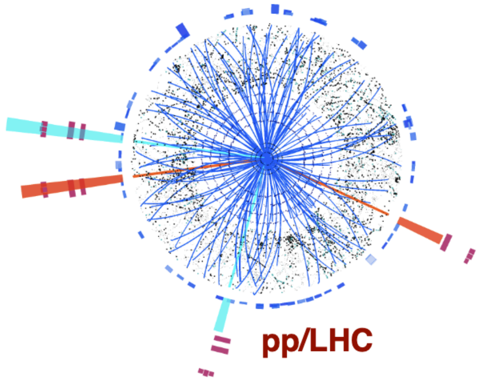


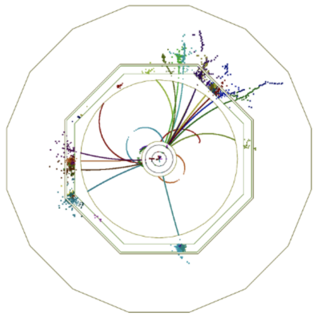
Conservative Scaling for Upper Limit on Mass Scale Probed by Higgs Precision

[Snowmass EF01 & EF02 Report]

Benefits of e^+e^- colliders

- Electron-positron colliders are precision machines that can serve as **Higgs factories**. They offer:
  - *A well-defined initial state*
  - *A "clean" and trigger less experimental environment*
  - *Longitudinal polarization (only possible at linear machines) → increases sensitivity to EW observables, suppresses backgrounds, controls systematics*


pp/LHC


e^+e^-

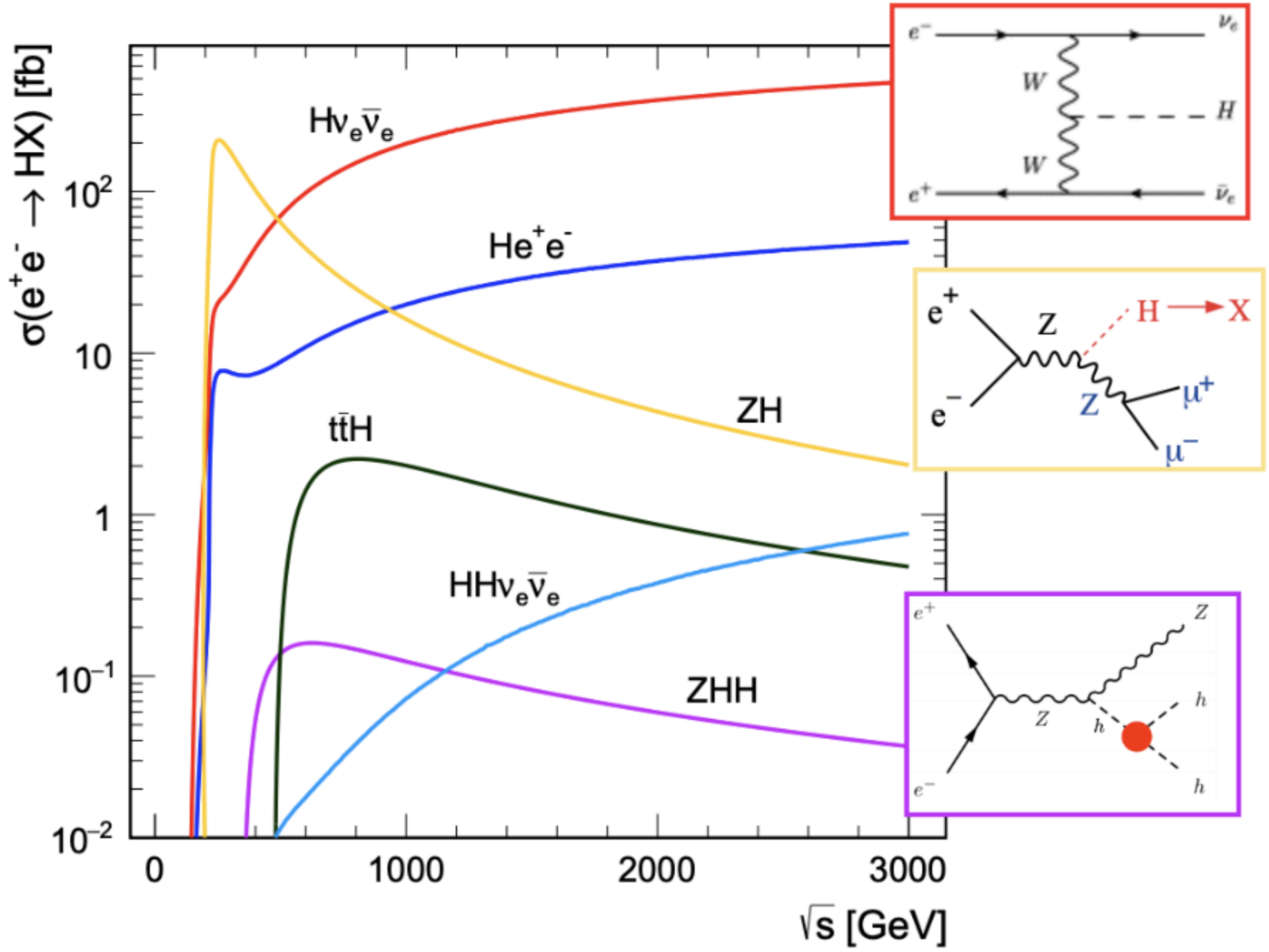
$\sim O(10^{-1})\,\%$ Level precision

Relative Precision (%)	HL-LHC	CLIC-380	HL-LHC + ILC-250/C^3-250	HL-LHC + ILC-500/C^3-550	FCC 240/360	CEPC-240/360
hZZ	1.5	0.34	0.22	0.17	0.17	0.072
hWW	1.7	0.62	0.98	0.20	0.41	0.41
$hb\bar{b}$	3.7	0.98	1.06	0.50	0.64	0.44
$h\tau^+\tau^-$	3.4	1.26	1.03	0.58	0.66	0.49
hgg	2.5	1.36	1.32	0.82	0.89	0.61
$hc\bar{c}$	-	3.95	1.95	1.22	1.3	1.1
$h\gamma\gamma$	1.8	1.37	1.36	1.22	1.3	1.5
$h\gamma Z$	9.8	10.26	10.2	10.2	10	4.17
$h\mu^+\mu^-$	4.3	4.36	4.14	3.9	3.9	3.2
$ht\bar{t}$	3.4	3.14	3.12	2.82/1.41	3.1	3.1
hhh	50	50	49	20	33	-
Γ_{tot}	5.3	1.44	1.8	0.63	1.1	1.1

$\sim \mathcal{O}(1)\,\%$ Level precision

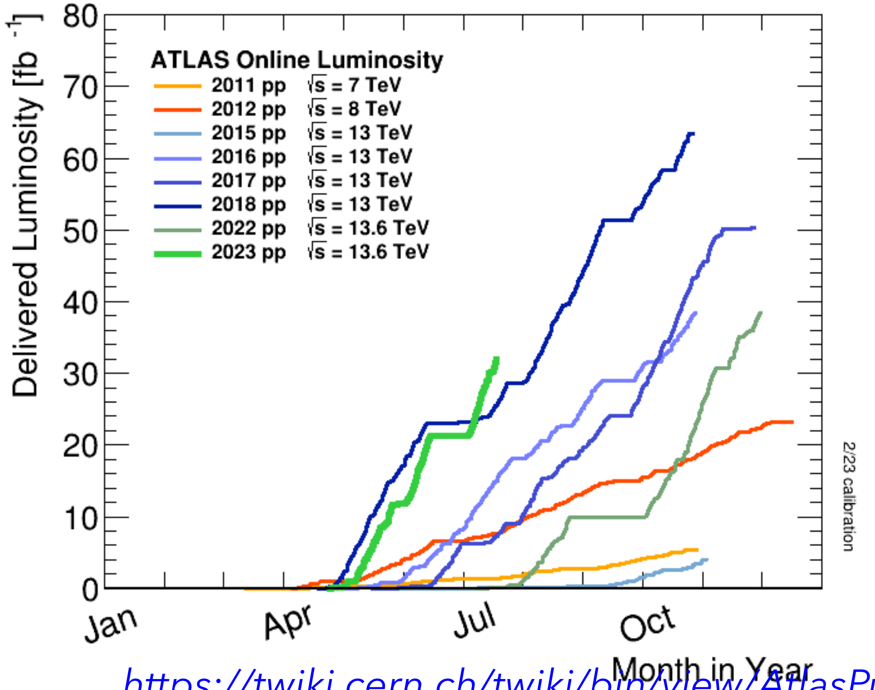
Benefits of e+e- colliders

- At e+e- machines, Higgs bosons are produced mainly through the ZH process at $\sqrt{s} \simeq 250$ GeV.
- This process allows model-independent determination of the Higgs width and BRs using the recoil technique.
- At higher energies, above ~ 500 GeV:
  - $\nu\nu H$ dominates, with ttH also becoming accessible
  - Direct double Higgs production can be probed with ZHH

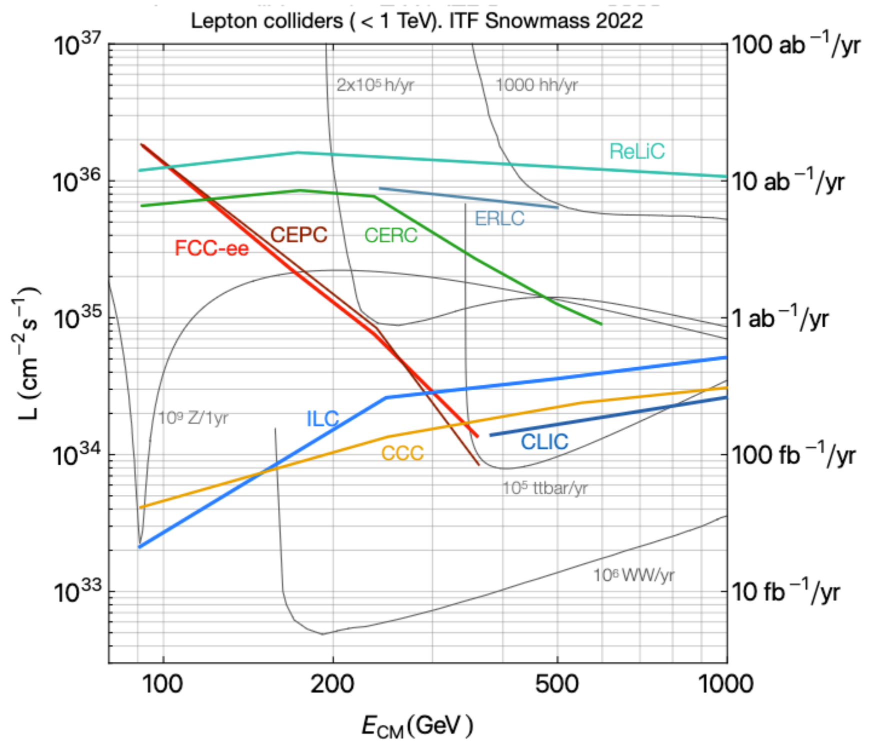


Beam Parameters for linear e^+e^- colliders

- The typical instantaneous luminosity requirement for any high-energy collider is $\sim 10^{34}\ \mathrm{cm^{-2}\ s^{-1}} \simeq 0.86\ (\mathrm{fb})^{-1}/\mathrm{day} \simeq 150\ (\mathrm{fb})^{-1}/\mathrm{year}$ for 180 days of data-taking per year.
- For example, the instantaneous luminosity for LHC Run 3 is $\sim 2 \cdot 10^{34}\ \mathrm{cm^{-2}\ s^{-1}}$ (but the integrated luminosity for 2022/23 is only $\sim 70\ (\mathrm{fb})^{-1}$ due to extensive downtime periods.
- For circular machines, this luminosity goal is typically achieved by recirculating the beams at very high frequencies.
- For linear machines, the two beams are dumped after each crossing and so, to achieve the luminosity goals, the beams have to be focused to nm size.



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun3



https://arxiv.org/abs/2208.06030

Beam Parameters for linear e+e- colliders

- To reach the luminosity goals for linear colliders, flat beams with $\sigma_x^* \gg \sigma_y^*$ and $\sigma_y^* \sim$ nm are required.
- Power pulsing is used with trains of $\sim O(10^2)$ bunches that repeat at frequencies of $10^1 - 10^2$ Hz.
- *Why are nm size beams necessary and why are flat beams used?*

Parameter	Symbol[unit]	NLC [3]	CLIC [4]	ILC-250 [5]	ILC-500 [5]	C^3-250 [6]	C^3-550 [6]
CM Energy	$\sqrt{s}$[GeV]	500	380	250	500	250	550
RMS bunch length	σ_z^* [μm]	150	70	300	300	100	100
Horizontal beta function at IP	β_x^* [mm]	10	8.2	13	22	12	12
Vertical beta function at IP	β_y^* [mm]	0.2	0.1	0.41	0.49	0.12	0.12
Normalized horizontal emittance at IP	ϵ_x^* [nm]	4000	950	5000	5000	900	900
Normalized horizontal emittance at IP	ϵ_y^* [nm]	110	30	35	35	20	20
RMS horizontal beam size at IP	σ_x^* [nm]	286	149	516	474	210	142
RMS vertical beam size at IP	σ_y^* [nm]	6.7	2.9	7.7	5.9	3.1	2.1
Num. Bunches per Train	n_b	90	352	1312	1312	133	75
Train Rep. Rate	f_r [Hz]	180	50	5	5	120	120
Bunch Spacing	[ns]	1.4	0.5	554	554	5.26	3.5
Bunch Charge	Q[nC]	1.36	0.83	3.2	3.2	1	1
Bunch Population	$N_e[10^9$ particles]	8.49	5.18	20.0	20.0	6.24	6.24
Beam Power	P_{beam} [MW]	5.5	2.8	2.63	5.25	2	2.45
Final RMS energy spread	%	0.38	0.35	~ 0.1	~ 0.1	~ 0.1	~ 0.1
Crossing Angle	θ[rad]	0.020	0.0165	0.014	0.014	0.014	0.014
Crab Angle	θ[rad]	0.020/2	0.0165/2	0.014/2	0.014/2	0.014/2	0.014/2
Gradient	[MeV/m]	37	72	31.5	31.5	70	120
Effective Gradient	[MeV/m]	29	57	21	21	63	108
Shunt Impedance	[M Ω/m]	98	95			300	300
Effective Shunt Impedance	[MΩ/m]	50	39			300	300
Site Power	[MW]	121	168	125	173	~ 150	~ 175
Length	[km]	23.8	11.4	20.5	31	8	8
L*	[m]	2	6	4.1	4.1	4.3	4.3

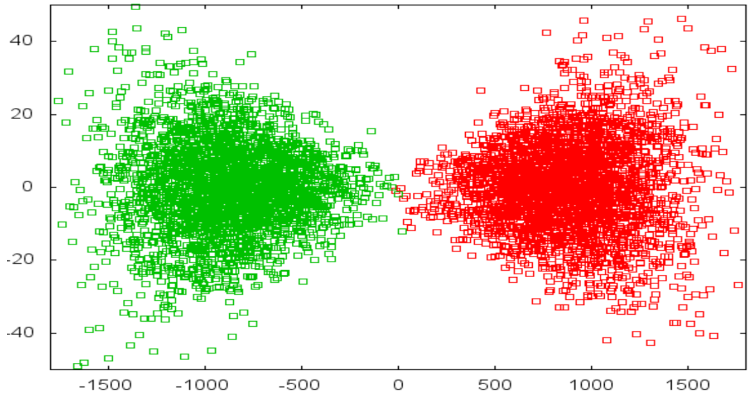
Beam Parameters for linear e+e- colliders

- The instantaneous luminosity at a linear collider is given by: $\mathscr{L} = H_D \frac{N_e^2 n_b f_r}{4\pi\sigma_x^*\sigma_y^*}$

where:

- N_e is the number of particles per bunch
- n_b is the number of bunches per bunch train
- f_r is the train repetition rate and
- $\sigma_{x,y}^*$ are the horizontal and vertical, respectively, RMS beam sizes at the IP.
- H_D is an enhancement factor that accounts for the effects of beam-beam interactions. It has typical values of 1.5-2.

- Because $\mathscr{L} \sim \frac{1}{\sigma^*}$, higher luminosities are achieved the more focused the more focused the beams are.



Beam-beam interactions cause further "pinching" of the bunches, resulting in increased luminosity. This "pinch-effect", as well as additional related mechanisms, are parametrized with H_D.

Beam-Beam interactions at linear e+e- colliders

The strength of beam-beam interactions and the number of produced BIB particles is expressed through the Ypsilon parameter:

$$\langle Y \rangle = \frac{5}{6} \frac{N_e r_e^2 \gamma}{\alpha(\sigma_x^* + \sigma_y^*)\sigma_z^*}$$

$$D_{x,y} = \frac{2N_e r_e \sigma_z^*}{\gamma \sigma_{x,y}^*(\sigma_x^* + \sigma_y^*)}$$

This explains the choice of flat beams: For $\sigma_x^* \gg \sigma_y^*$, $\langle Y \rangle \simeq \frac{5}{6} \frac{N_e r_e^2 \gamma}{\alpha \sigma_x^* \sigma_z^*}$ and for large enough $\sigma_x^* \sim O(10^2)$ nm, one can limit the BS without sacrificing the luminosity, which is still achieved for small enough σ_y^*:

$$\mathscr{L} = H_D \frac{N_e^2 n_b f_r}{4\pi \sigma_x^* \sigma_y^*}$$

TABLE IV: Luminosity and beam-induced background related quantities for various linear collider proposals. The horizontal line after the fourth row separates the quantities in those calculated (top) and simulated from `GuineaPig` (bottom).

Parameter	Symbol[unit]	CLIC	ILC-250	C^3-250
Geometric Luminosity	$\mathscr{L}_{\text{geom}}$ [x10^{34}/cm^2 s]	0.91	0.53	0.75
Horizontal Disruption	D_x	0.26	0.51	0.32
Vertical Disruption	D_y	13.1	34.5	21.5
Average Beamstrahlung Parameter	$\langle Y \rangle$	0.17	0.028	0.065
Total Luminosity	$\mathscr{L}$ [x10^{34}/cm^2 s]	1.6	1.35	1.3
Peak luminosity fraction	$\mathscr{L}_{0.01}/\mathscr{L}$	60%	74%	73%
Enhancement Factor	H_D	1.6	2.6	1.7
Average Energy loss	δ_E	6.9 %	2.9 %	3.3 %
Photons per beam particle	n_γ	1.5	2.0	1.3
Average Photon Energy fraction	$\langle E_\gamma/E_0 \rangle$ [%]	4.6 %	1.4 %	2.4 %
Number of incoherent pairs	N_{incoh} [10^4]	6.0	13.4	4.6
Total energy of incoh. pairs	N_{incoh} [TeV]	186	117	57

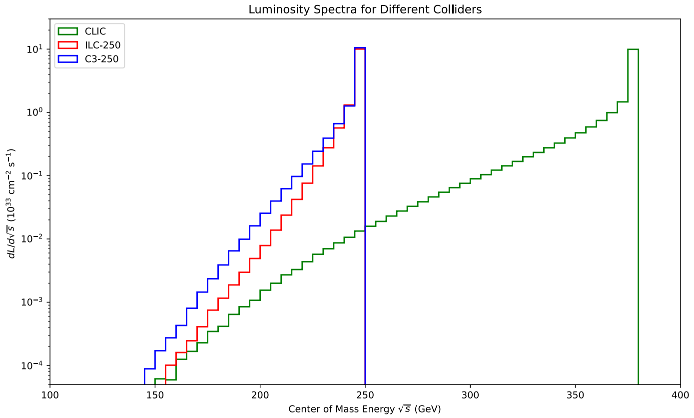
Values of the BS Ypsilon parameter and other related qualities for various future linear e+e- machines

Beam-Beam interactions at linear e^+e^- colliders

- The effects of beam-beam interactions on the experiments can be split in **two categories**:

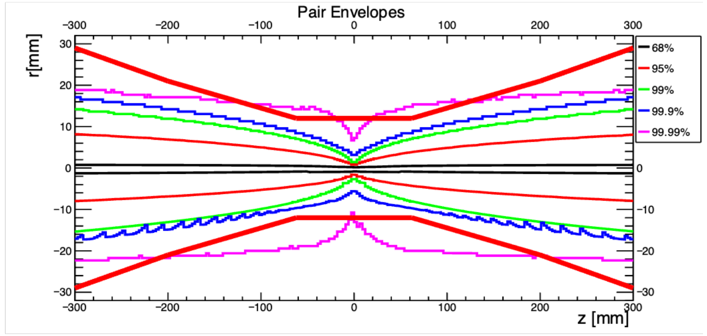
Physics Analyses

- BS widens the luminosity spectrum considerably
- Enables collisions at lower $\sqrt{s}$
- Softens initial state constraints -> important for kinematic fits
- Need to unfold the luminosity spectrum for measurements.
- Photoproduced jets affect clustering performance, JER, JES



Detector Performance

- High flux in vertex barrel and forward sub detectors
- Increase in detector occupancy –> might miss interesting Physics (HS) events!
- –> impacts detector design decisions, e.g. radius of 1st vertex barrel layer, buffer depth etc.



Luminosity spectra for linear e⁺e⁻ colliders

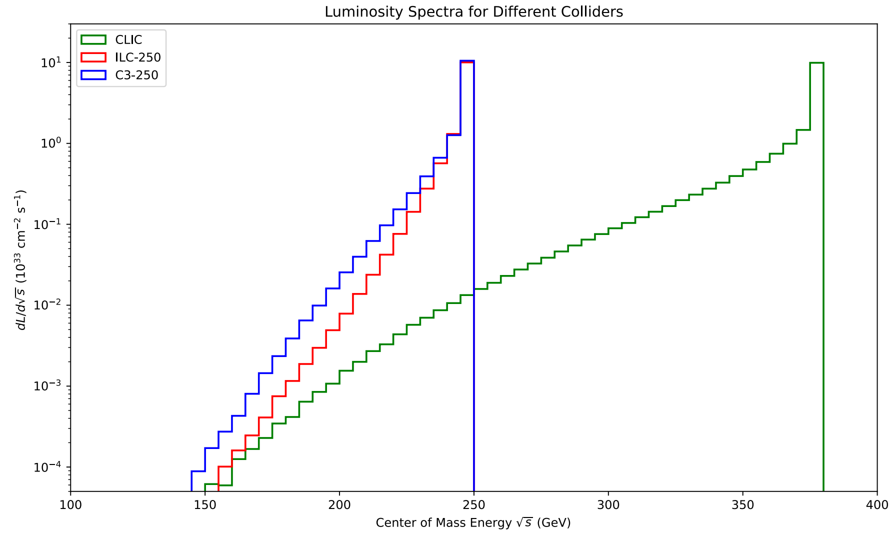
- Luminosity smearing is a convolution of:
  - Natural beam energy spread $\sim O(0.1)\ \%$
  - Initial State Radiation (ISR)
  - Beamstrahlung (BS)

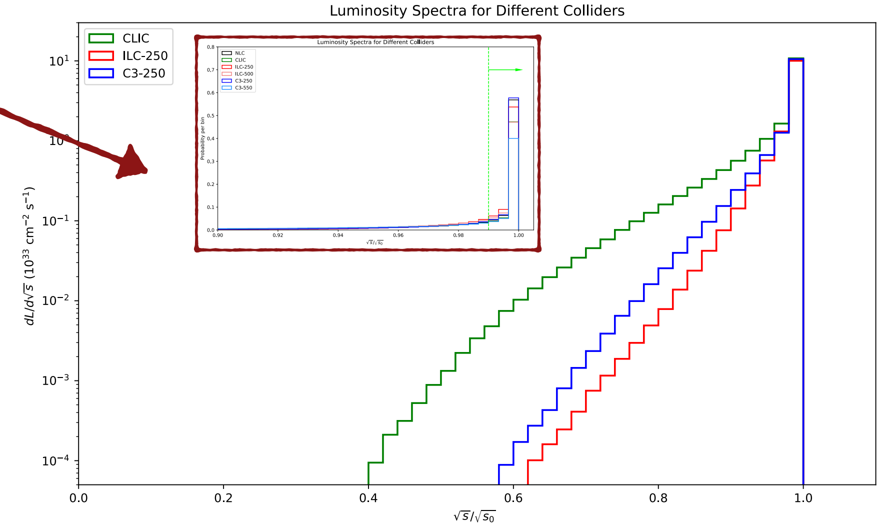
- One usually optimizes the beam parameters to achieve at least $\sim 60\,\%$ of the luminosity in the top $1\,\%$ of the $\sqrt{s}$.

$$x_{1,2} = \frac{E_{1,2}}{E_{\text{beam}}},\ x = \frac{\sqrt{s}}{\sqrt{s_0}} = \sqrt{x_1 x_2}$$

$$\mathscr{L}(x) = \iint_0^{x_{\max}} dx_1 dx_2 \delta(x - \sqrt{x_1 x_2}\mathscr{L}(x_1, x_2)$$

$$\sigma_{\text{eff}} = \int_0^{x_{\max}} dx \mathscr{L}(x)\sigma(x\sqrt{s_0})$$

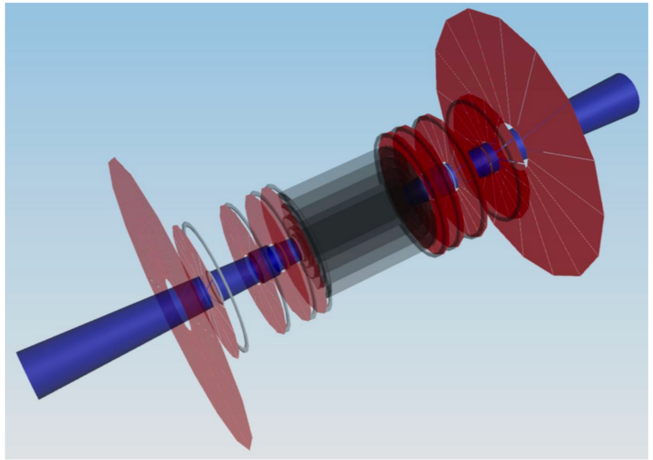




Typical detector dimensions for e^+e^- colliders

- Vertex Barrel:

Layer	Inner radius [mm]	Outer radius [mm]
1st	13	17
2nd	21	25
3rd	34	38
4th	46.6	50.6
5th	59	63



Dimensions in cm

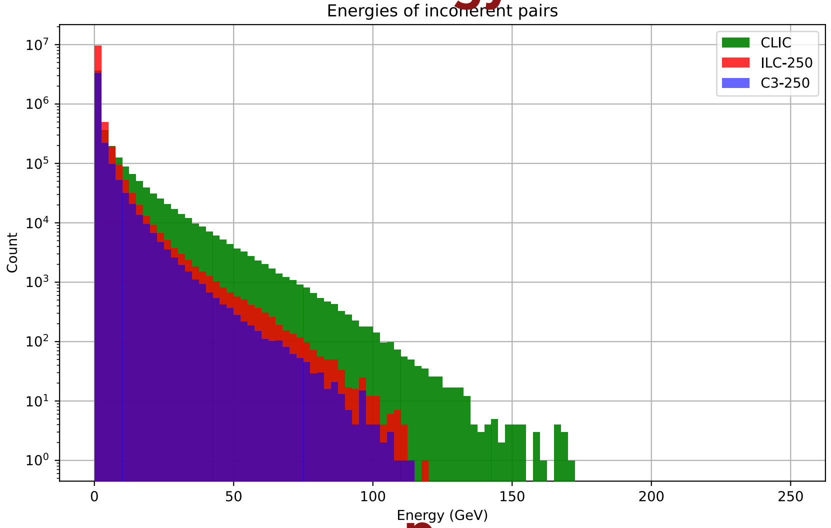
Barrel	Technology	Inner radius	Outer radius	z extent
Vertex detector	Silicon pixels	1.4	6.0	+/- 6.25
Tracker	Silicon strips	21.7	122.1	+/- 152.2
ECAL	Silicon pixels-W	126.5	140.9	+/- 176.5
HCAL	RPC-steel	141.7	249.3	+/- 301.8
Solenoid	5 Tesla SC	259.1	339.2	+/- 298.3
Flux return	Scintillator-steel	340.2	604.2	+/- 303.3
Endcap	**Technology**	**Inner z**	**Outer z**	**Outer radius**
Vertex detector	Silicon pixels	7.3	83.4	16.6
Tracker	Silicon strips	77.0	164.3	125.5
ECAL	Silicon pixel-W	165.7	180.0	125.0
HCAL	RPC-steel	180.5	302.8	140.2
Flux return	Scintillator/steel	303.3	567.3	604.2
LumiCal	Silicon-W	155.7	170.0	20.0
BeamCal	Semiconductor-W	277.5	300.7	13.5

https://pages.uoregon.edu/silicondetector/sid-dimensions.html

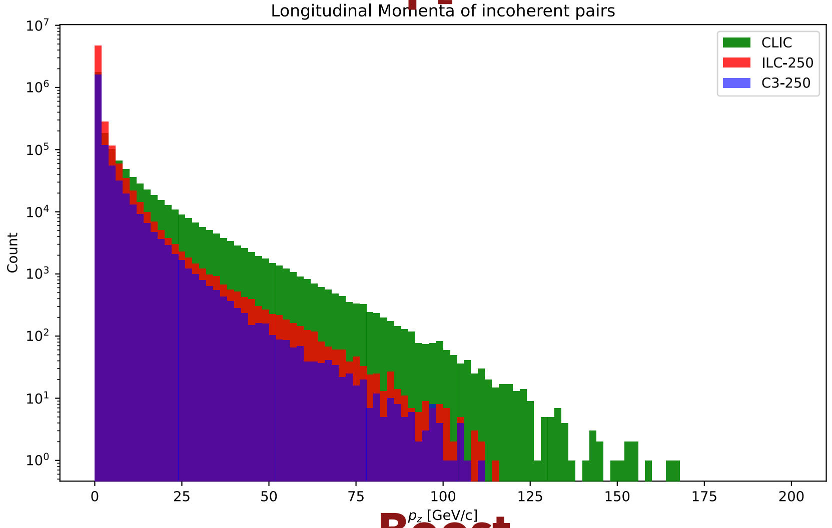
***SiD geometry version SiD_o2_v4 used in our simulations**

Pair background at linear e⁺e⁻ colliders

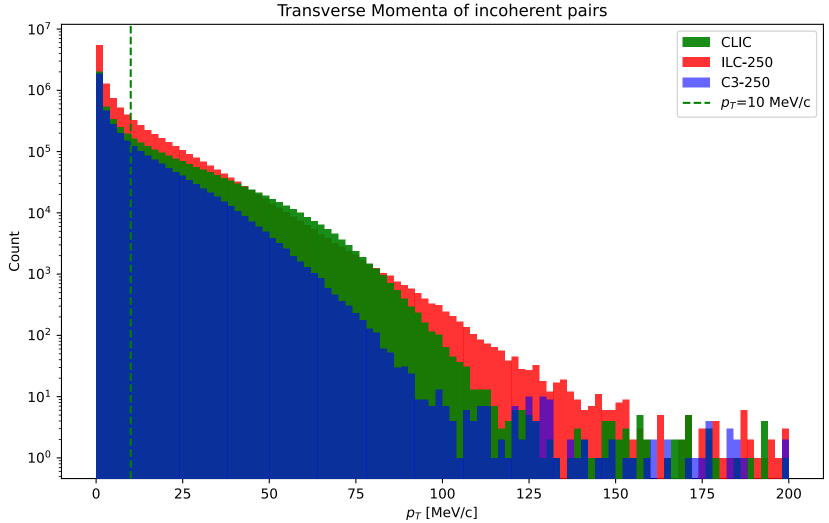
Energy



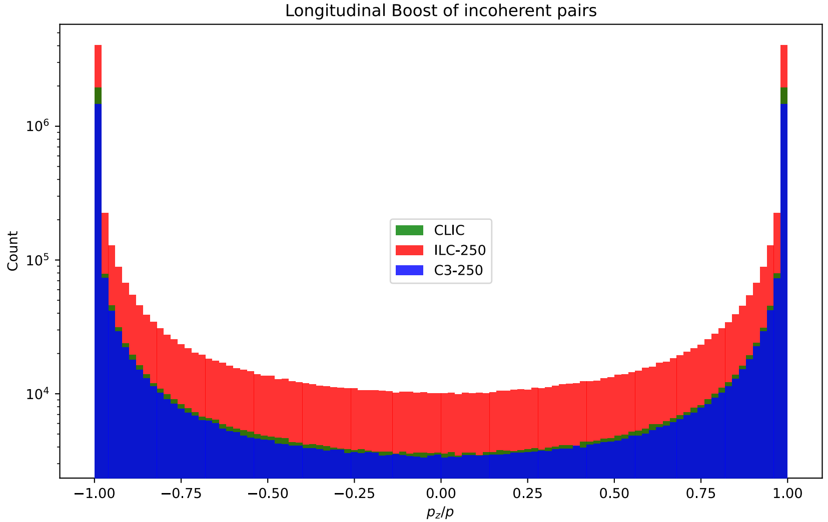
p_z



p_T



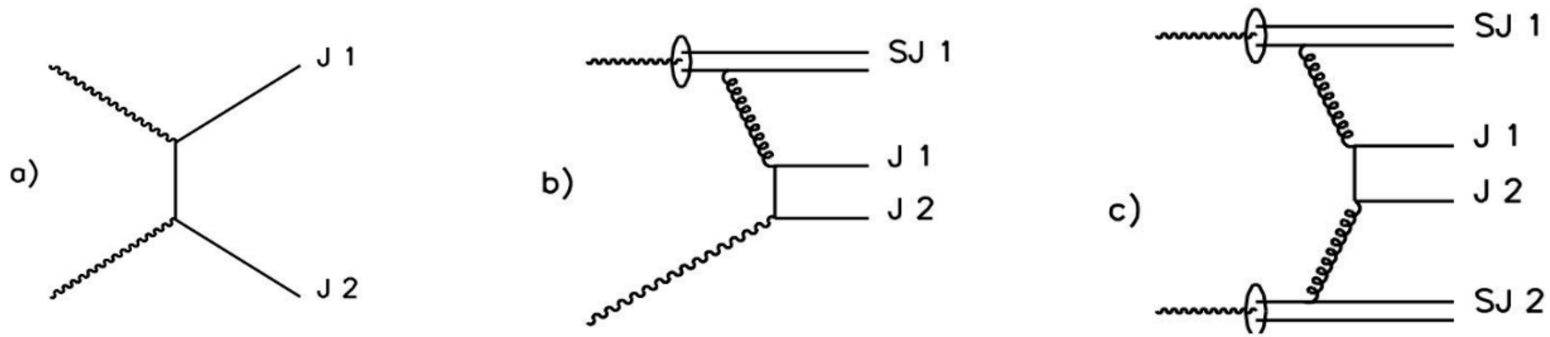
Boost

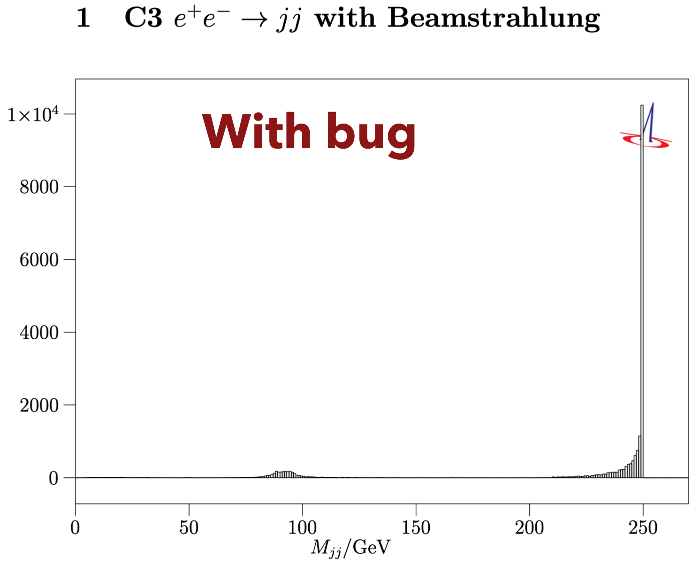


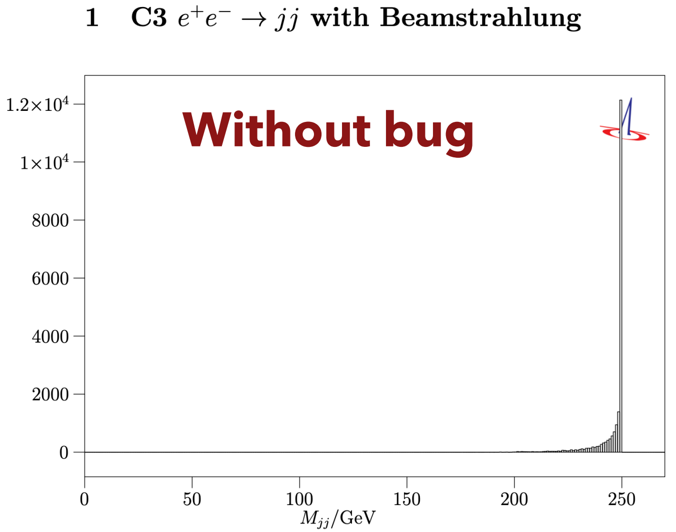
Statistics corresponds to 80 BXs for all colliders

Hadron Photoproduction Background

- Use Pythia for $\sqrt{s_{\gamma\gamma}} \gtrsim 10\ \text{GeV}$, WHIZARD below that.
- A bug was found in CIRCE that was creating a secondary peak at $M_{jj} \simeq M_Z$ due to radiative return being included in a region where GuineaPig events are too few.
- Thanks to *Thorsten Ohl* for helping debug this!







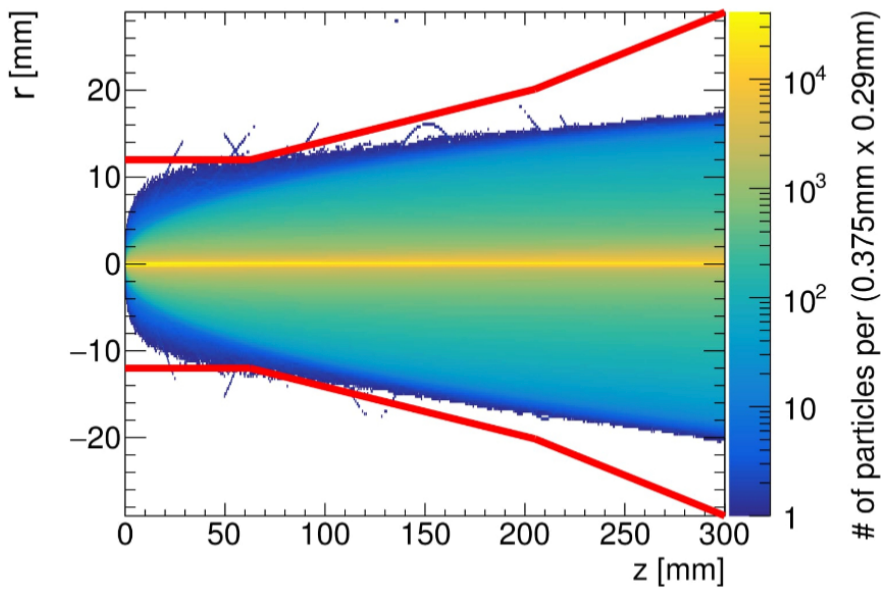
Work by Elias Mettner, Lindsey Gray

Pair Background Envelopes

Results shown here correspond to $\sqrt{s} = 250\ \text{GeV}\ ,\ B = 5\ \text{T}$ *(uniform)*

ILC - Previous results

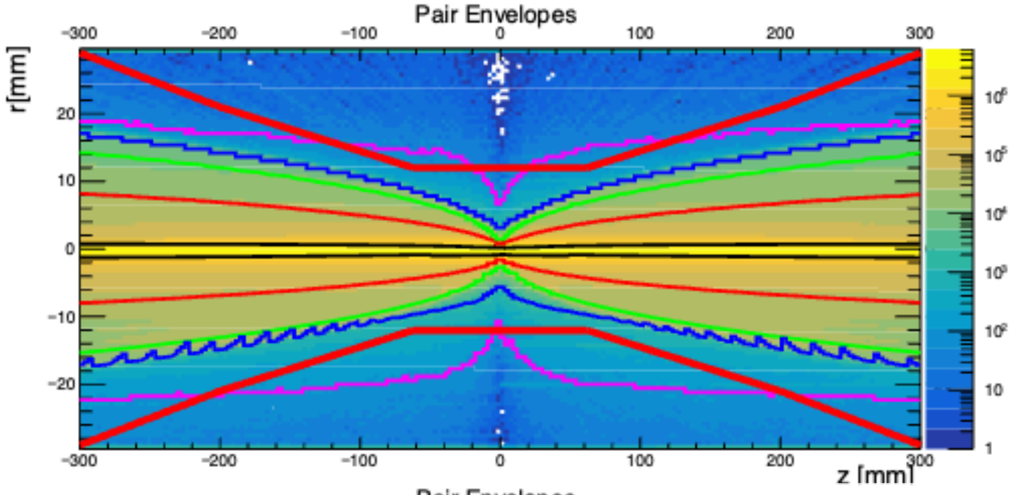
r vs z

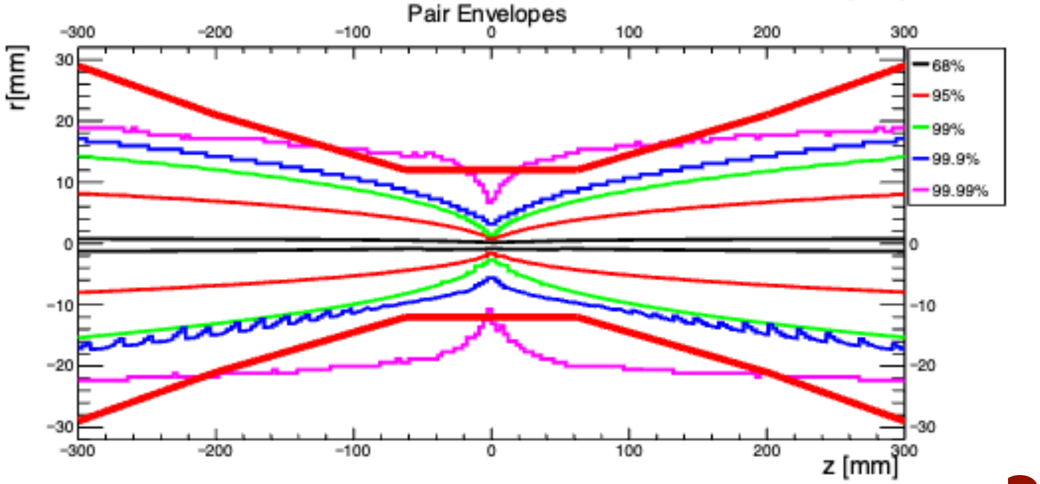


From [Anne Schutz's PhD thesis](#) (2018)

C³ - Our results

r vs z

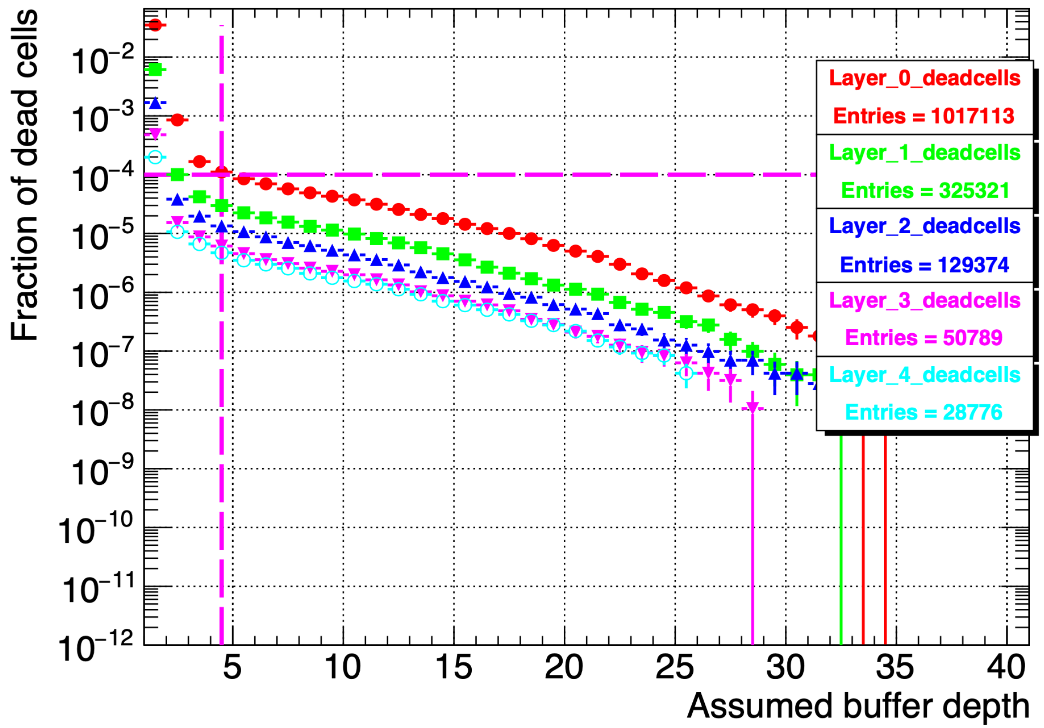




Pair background occupancy

Results shown here correspond to $\sqrt{s} = 250$ GeV, full detector (SiD) sim

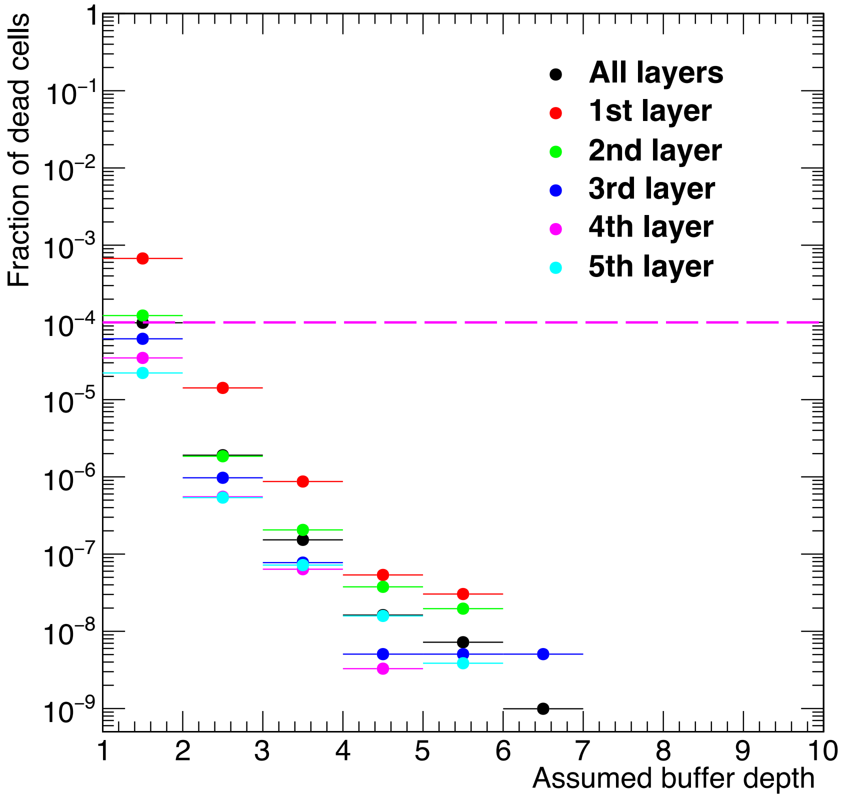
ILC - Previous results



(b) *Set (A), fraction of dead cells*

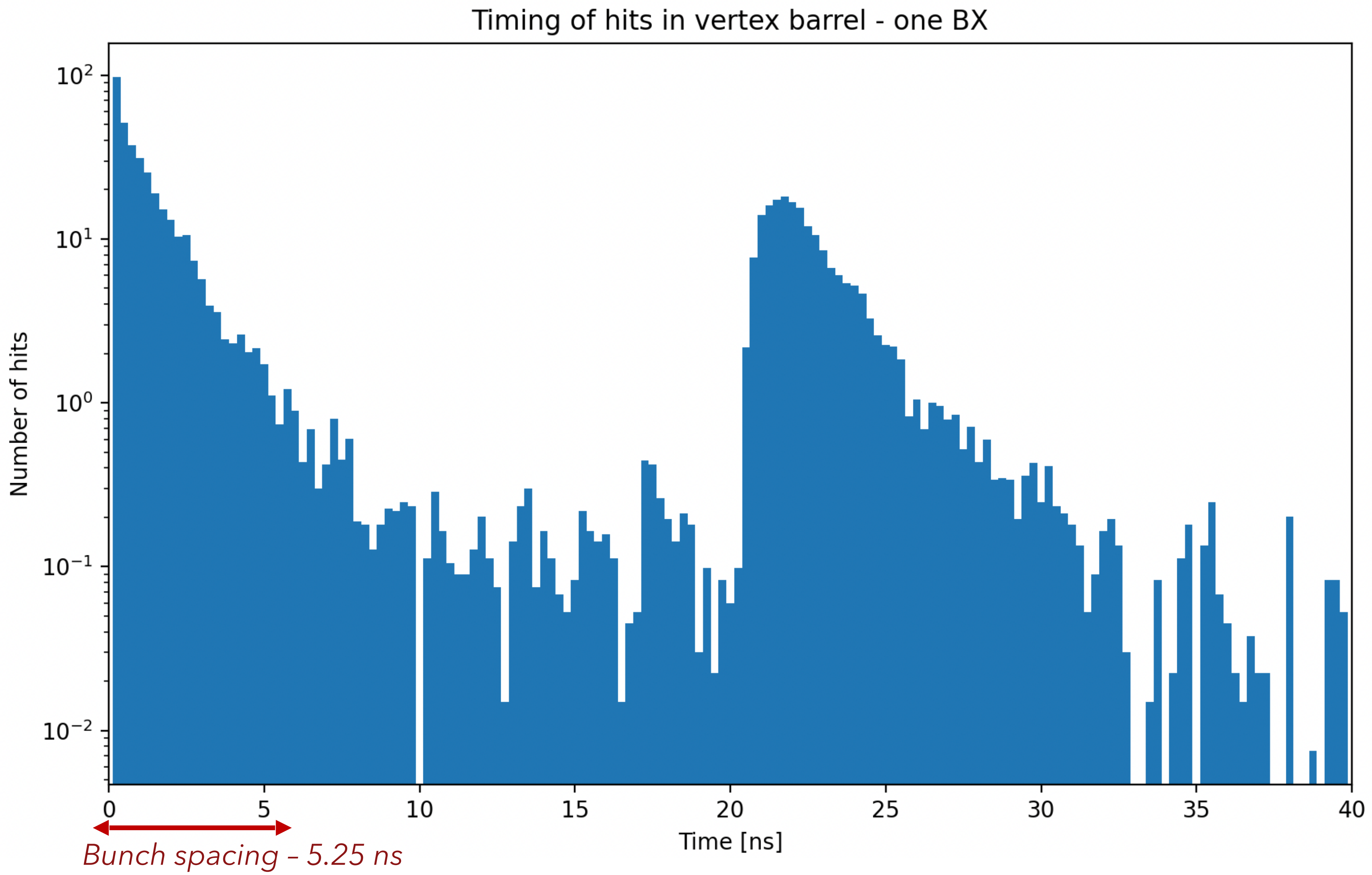
From [Anne Schutz's PhD thesis] (2018)

C³ - Our results



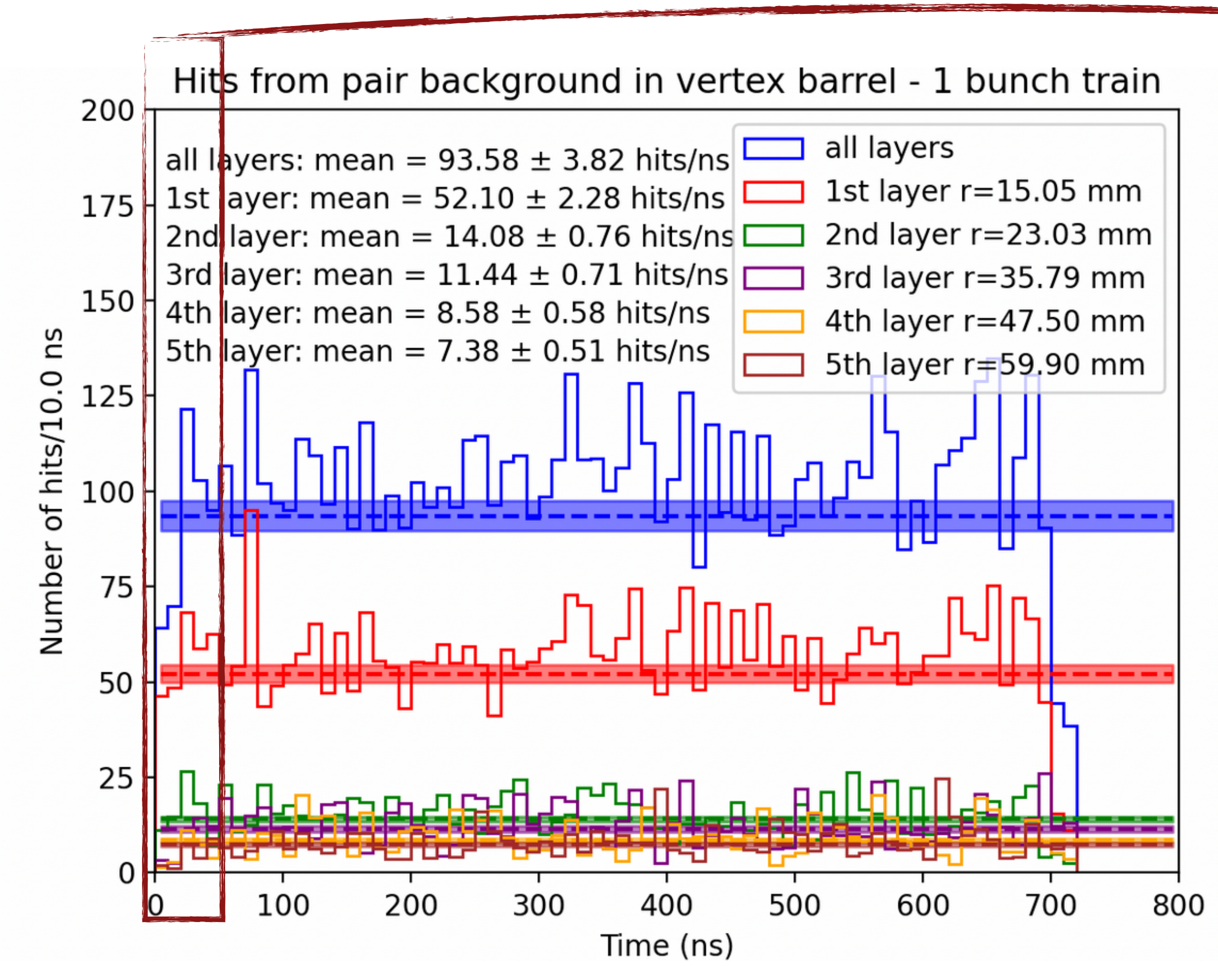
Time distribution within each BX

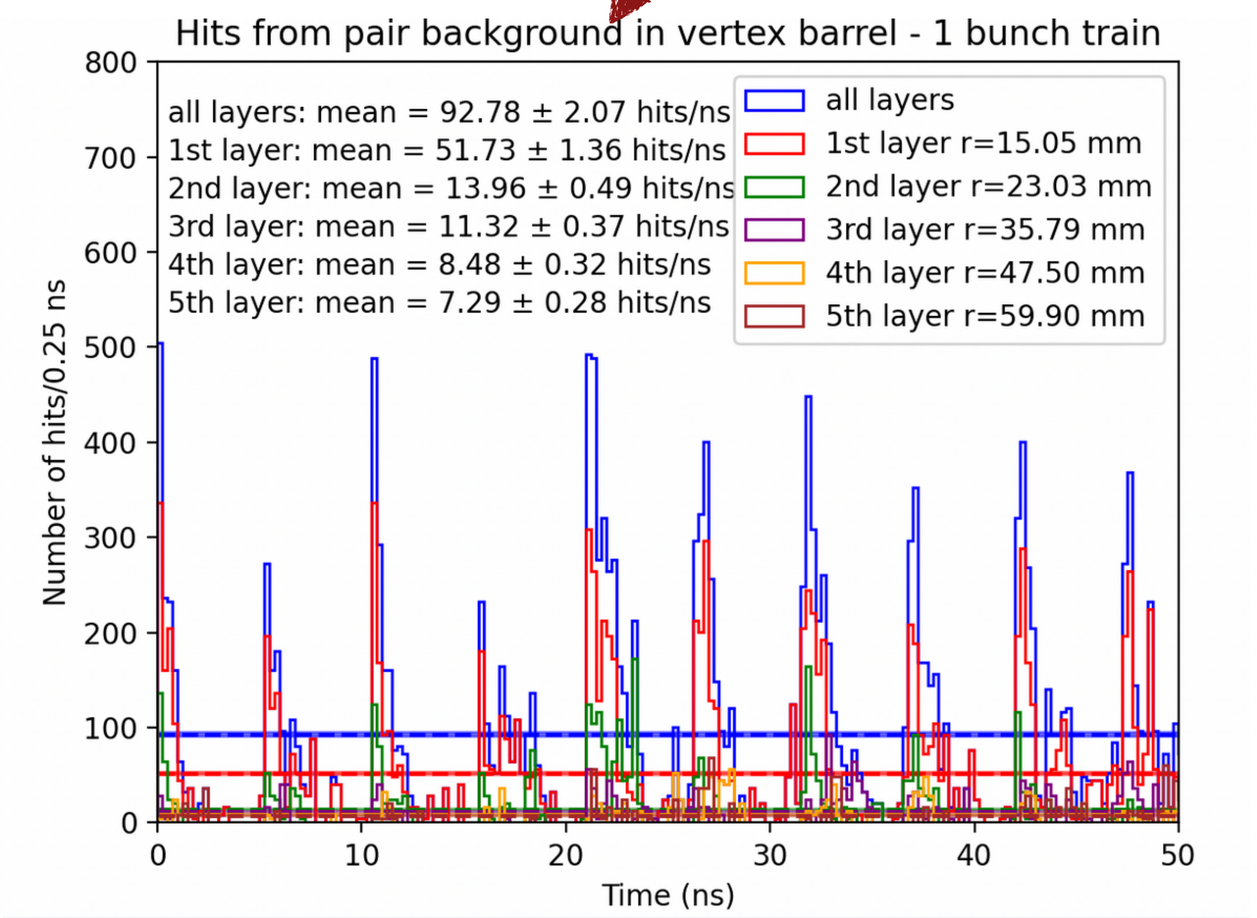
- Time distribution of hits in the vertex barrel within a single BX.
- Most hits contained in time within the bunch spacing.
- The secondary peak at ~0-25 nsec is due to backscattering from the BeamCal.



Time distribution over a train - vertex barrel

Time distribution of hits per unit time: on average, we anticipate ~ 90 hits/ns in the vertex barrel detector.





SiD background flux rate

- Preliminary Studies indicate that the pair background particle flux is within the limits set in the SiD DOE Final Report: https://www.osti.gov/biblio/1182602

- Our estimate for the flux in the innermost layer of the vertex detector is :

$0.043\ \text{hits}/(\text{ns} \cdot \text{mm}^2) \cdot (5.25\ \text{ns/BX}) =$ **$0.023\ \text{hits/mm}^2\text{/BX}$**

- We are currently in the process of validating our results and repeating the studies for all subdetectors.

> The highest hit rates and occupancies result from the estimated 0.03 hits/mm^2/ bunch crossing for the innermost layer, for a bunch train pixel occupancy approaching 10 percent. The time information (i.e., bunch crossing number) reduces this occupancy to $<< 10^{-4}$ per pixel giving considerable headroom should occupancies be higher than expected.