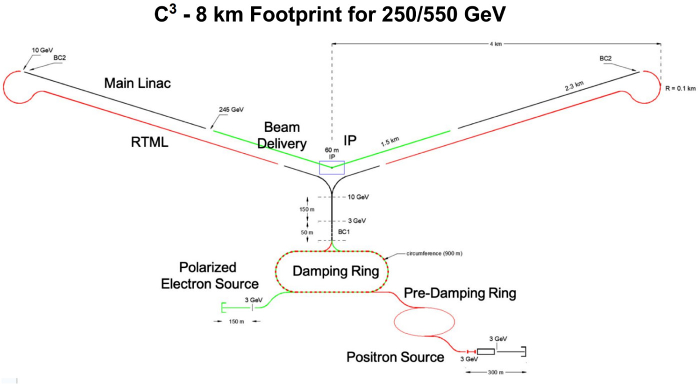
Pair Production and Hadron Photoproduction Backgrounds at the Cool Copper Collider

Elias Mettner, Abdollah Mohammadi, Bryan Nee[1]
Lindsey Gray[2]
Dimitris Ntounis, Caterina Vernieri[3]

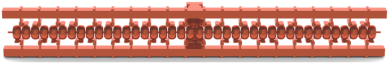
APS April Meeting
3 April 2024

1. University of Wisconsin-Madison
2. Fermi National Accelerator Laboratory
3. Stanford University and SLAC National Accelerator Laboratory

The Cool Copper Collider (C^3)



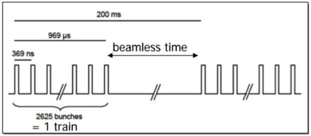
1. Newly proposed e^+e^- Higgs factory
2. E_{CM}: 250 GeV $\rightarrow$ 550 GeV $\rightarrow$ TeV-Scale



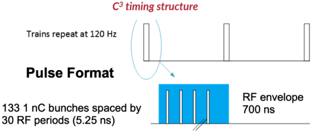
From ILC to C^3 Parameters

	C^3		ILC	
Parameter [Unit]	Value	Value	Value	Value
CM Energy [GeV]	250	550	250	500
Luminosity [$\cdot 10^{34}/\text{cm}^2 s$]	1.3	2.4	1.35	1.8/3.6
Gradient [MeV/m]	70	120	31.5	31.5
Geometric Gradient [MeV/m]	63	108	20.5	31
Length [km]	8	8	20.5	31
Num. Bunches per Train	133	75	1312	2625
Train Rep. Rate [Hz]	120	120	5	5
Bunch Spacing [ns]	5.26	3.5	554	554/366
Bunch Charge [nC]	1	1	3.2	3.2
Crossing Angle[rad]	0.014	0.014	0.014	0.014
Site Power[MW]	$\sim$ 150	$\sim$ 175	111	173/215

ILC timing structure



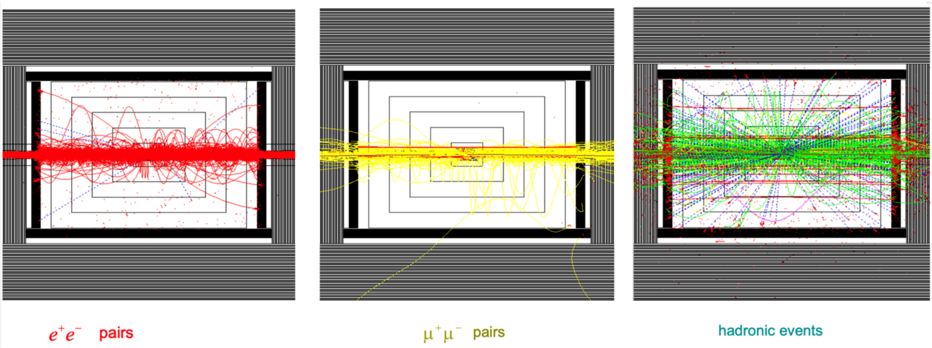
1 ms long bunch trains at 5 Hz
2625 bunches per train
308ns spacing



Key Differences in C^3 design against other linear colliders (ILC):

1. Accelerating Technology: Higher gradients - more compact design.
2. Bunch Structure: 2 orders closer $+ \sim 3$ times smaller particle density.
3. Train Structure: higher train rep. freq., one order fewer bunches/train.

Beam and Machine Backgrounds



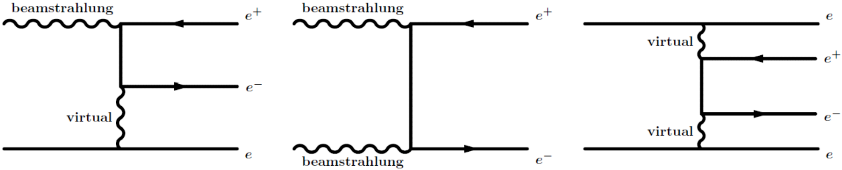
Various backgrounds originate in the BDS or the IR of C^3

Can deteriorate detector performance:

1. Beam-induced Backgrounds: secondary e^+e^- pairs, $\gamma\gamma \rightarrow$ hadrons
2. Machine-induced Backgrounds: halo muon, neutron production

This presentation will focus on the Beam-Induced Backgrounds

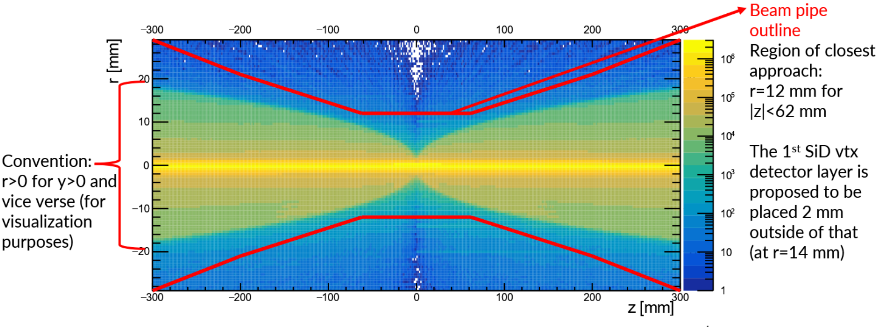
e^+e^- Pair Background



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

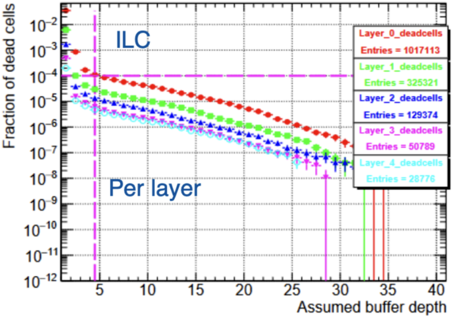
1. Beamstrahlung photons produce forward-boosted incoherent e^+e^- pairs
   - Around 10^5 pairs / bunch crossing expected with C^3
   - Most are deflected, but a small fraction reach detector
2. Simulation of background using GUINEA-PIG
   - Interaction w/ detector simulated by Geant4 thru DD4hep - SiD-like

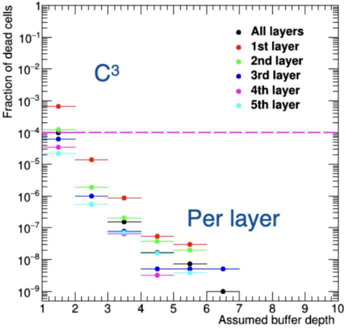
Pair Background Simulation



- For comparison:
  1. ILC TDR includes all backgrounds, C3 only incoherent pairs
  2. ILC bunch train is 10x longer than C3

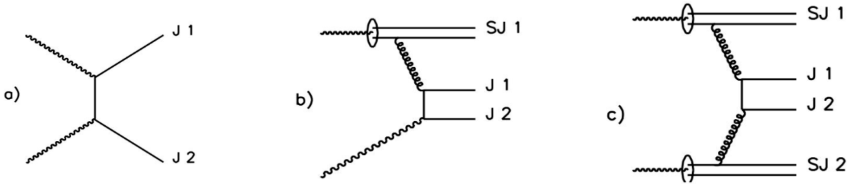
Pair Background Simulation





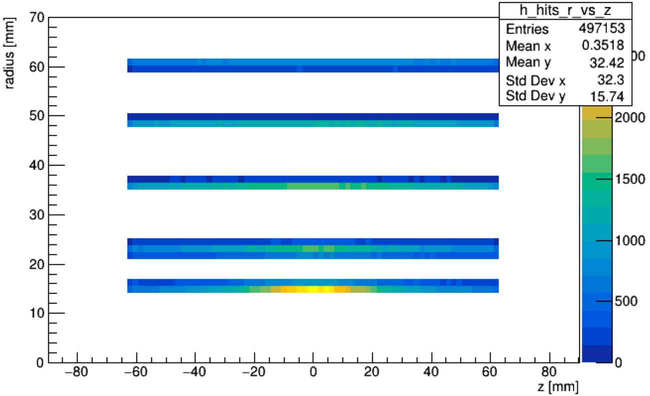
- For comparison:
  1. ILC TDR includes all backgrounds, C3 only incoherent pairs
  2. ILC bunch train is 10x longer than C3

Hadron Photoproduction Background



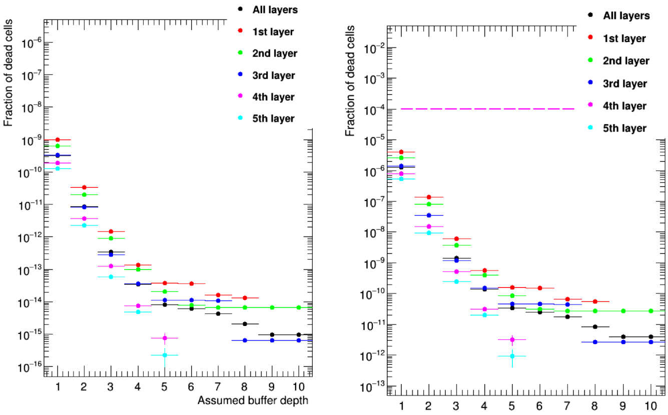
- Beamstrahlung photons can also produce a hadronic background
  1. rate $\sim 10^5$ smaller than the e^+e^- pair background
  2. More central than incoherent pairs, may still impact reconstruction
- PYTHIA used for simulation of processes above $\sqrt{s_{\gamma\gamma}} > 2$ GeV
  1. Interfaced w/ detector through Geant4/DD4hep
  2. $\sqrt{s_{\gamma\gamma}} < 2$ GeV: use WHIZARD/CIRCE (Slide 10)

Hadron Photoproduction Simulation



- For comparison:
  1. Only $\gamma\gamma \to$ hadrons occupancy (Not overlaid with incoherent pairs)
  2. Summed with incoherent pair occupancy: tail seen in ILC plot appears

Occupancy Results With Pythia



- For comparison:
  1. Only $\gamma\gamma \to$ hadrons occupancy (Not overlaid with incoherent pairs)
  2. Summed with incoherent pair occupancy: tail seen in ILC plot appears

Further Simulation with CIRCE and WHIZARD

1. $\sqrt{s_{\gamma\gamma}} < 2\ \mathrm{GeV}$: Pythia does not simulate this part of the spectrum
2. Alternate workflow: GUINEA-PIG $\rightarrow$ CIRCE $\rightarrow$ WHIZARD
3. Previous simulation from GUINEA-PIG utilized
4. CIRCE: Output successfully tailored for C3 after some consideration
   - CIRCE had a bug when processing low-event GPig data
   - This was fixed in a later release
5. : WHIZARD: Successful simulation with C3 but further modifications needed

Key Takeaways

1. C^3 is a compact, upgradable, and sustainable Higgs Factory proposal
2. Contribution from e^+e^- pairs and $\gamma\gamma \rightarrow$ hadron backgrounds is manageable
3. The ILC is a valid reference for C^3 studies, with $C^3 \sim$ ILC $/10$.
4. Generation of full hadron background processes is slow but steady
5. Future Steps:
   - Finish hadron background generation
   - Expand data production and investigate further backgrounds
   - Utilize further ILC studies for reexamination within the context of C3