Pair Production and Hadron Photoproduction Backgrounds at the Cool Copper Collider (C^3)

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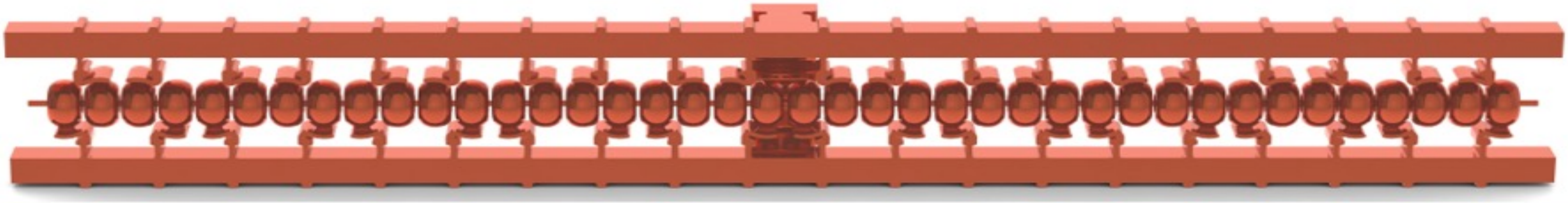

Why a Higgs Factory?

- ❑ Measuring the Higgs couplings precisely is one of the utmost priorities in the field of High Energy Physics!
- ❑ Even at the end of HL-LHC, we would not be able to constrain the Higgs coupling better than a few percent.
- ❑ Higgs potential measurement would still remain a challenge by the end of HL-LHC.
- ❑ A Higgs factory is needed to probe the Higgs (self)couplings at a percent level

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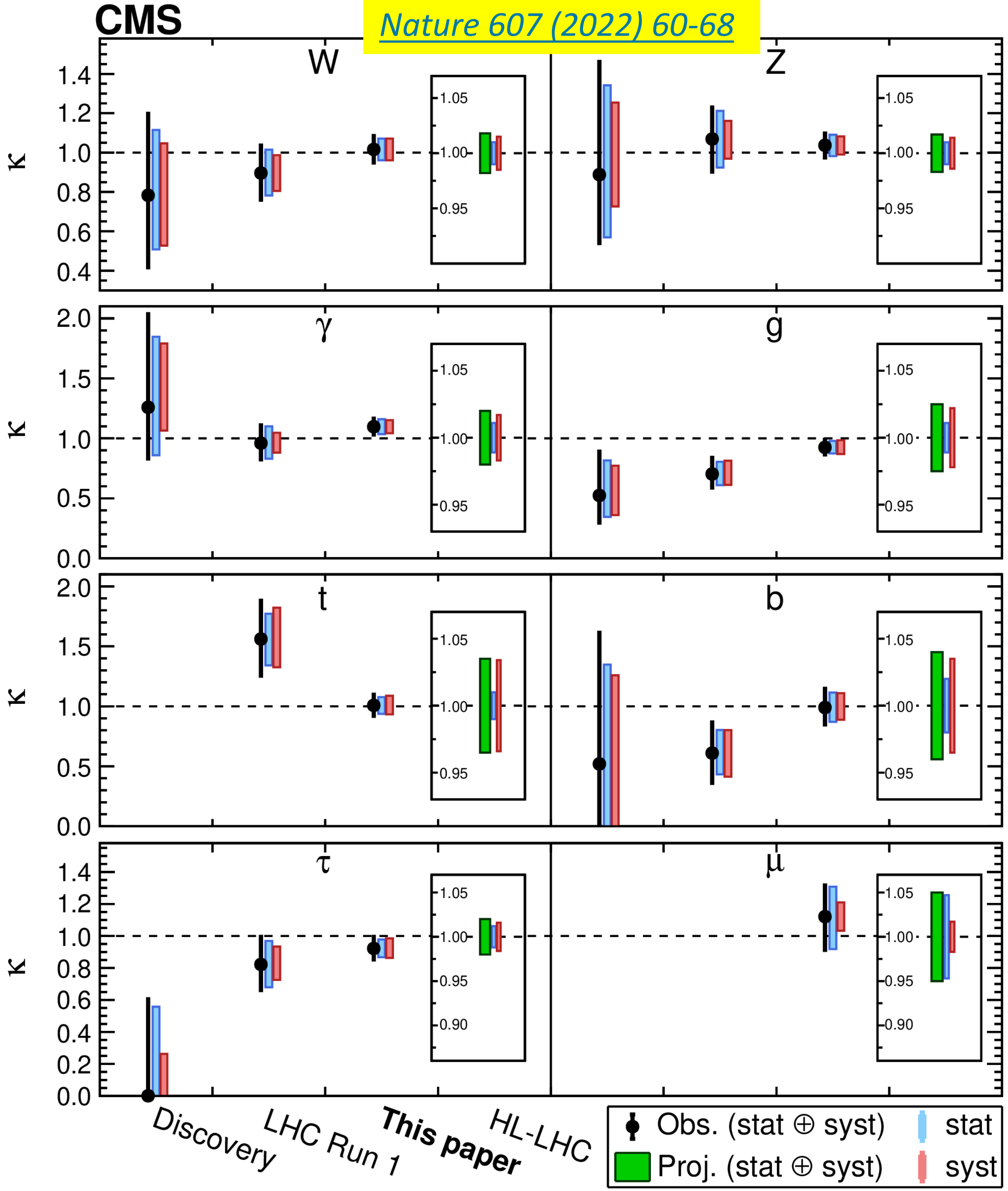
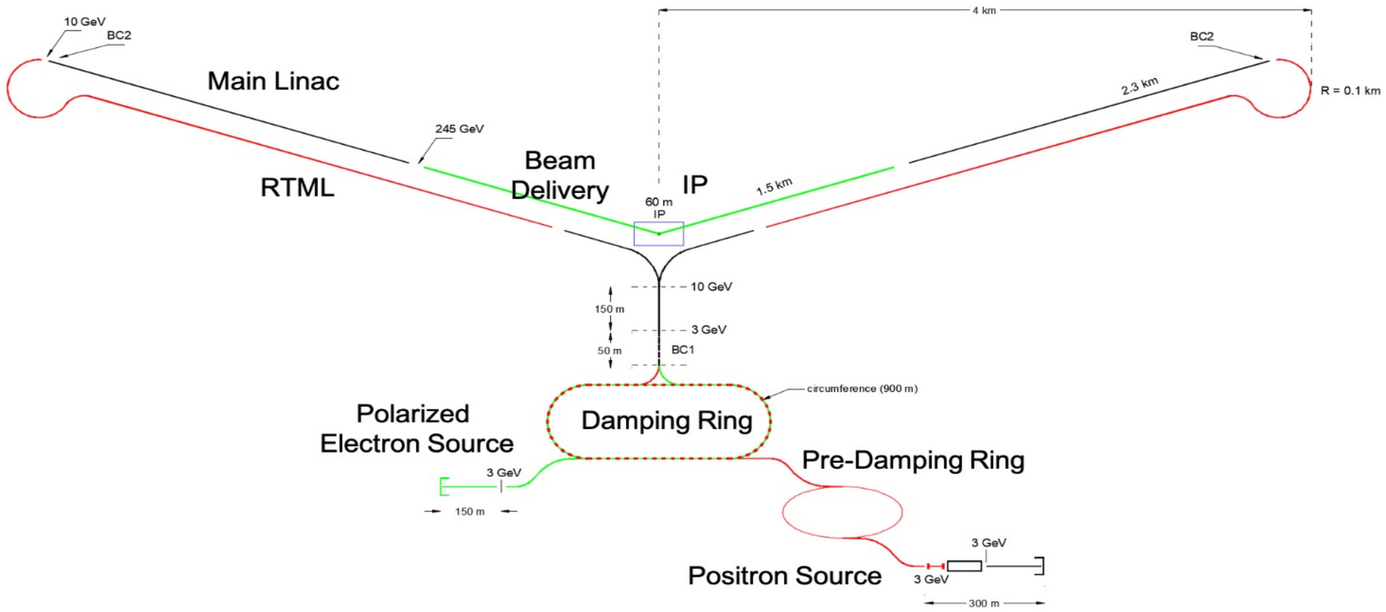
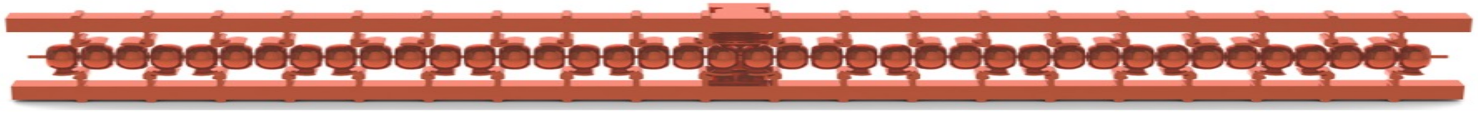


The Cool Copper Collider (C^3)

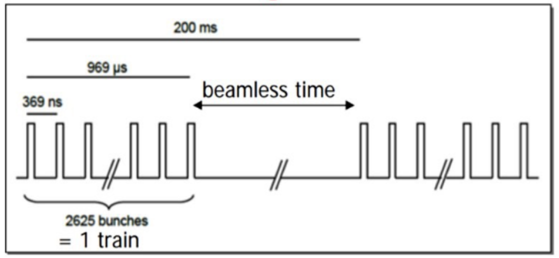


- ❑Newly proposed e^+e^- Higgs factory
- ❑ECM : 250 GeV → 550 GeV → TeV-Scale
- ❑Cold Copper Tech + Distributed RF Coupling → high acceleration gradient



From ILC to C^3 Parameters

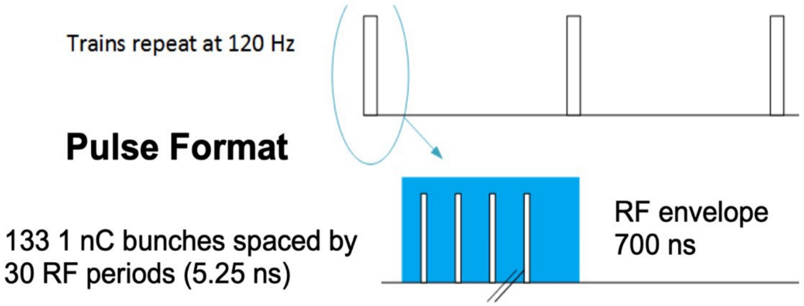
ILC timing structure



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

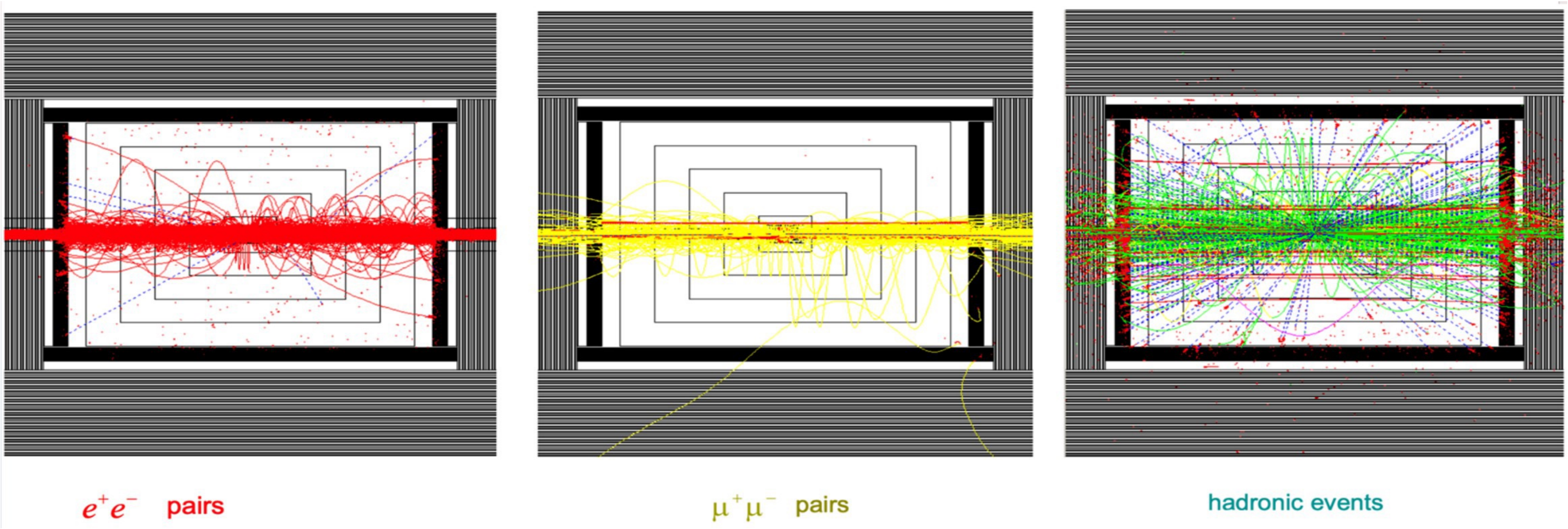
	C^3		ILC	
CM Energy [GeV]	250	550	250	500
Luminosity $[\cdot 10^{34}/\text{cm}^2 s]$	1.3	2.4	1.35	1.8/3.6
Gradient [MeV/m]	70	120	31.5	31.5
Length [km]	8	8	20.5	31
Num. Bunches per Train	133	75	1312	2625
Train Rep. Rate [Hz]	120	120	5	5
Bunch Spacing [ns]	5.26	3.5	554	554/366
Bunch Charge [nC]	1	1	3.2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

C^3 timing structure



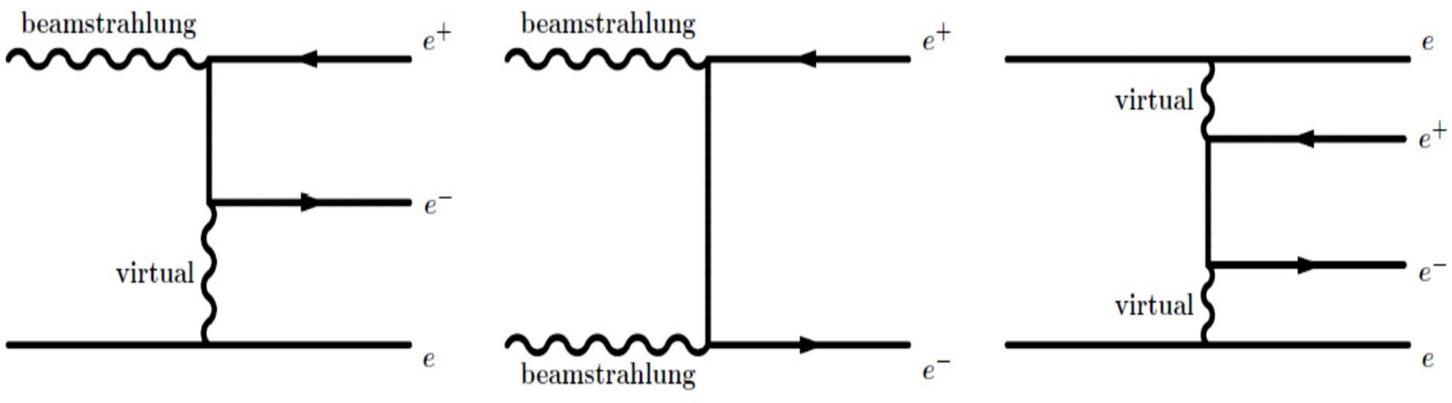
- Key Differences in C^3 design against other linear colliders (ILC):
  - Cooling Technology: Cryogenically-cooled normal-conducting accelerating structure v.s. superconducting RF technology
  - Accelerating Technology: Higher gradients - more compact design.
  - Train Structure: higher train rep. freq., one order fewer bunches/train.
  - Bunch Structure: 2 orders closer + $\sim$3 times smaller particle density.

Beam and Machine background

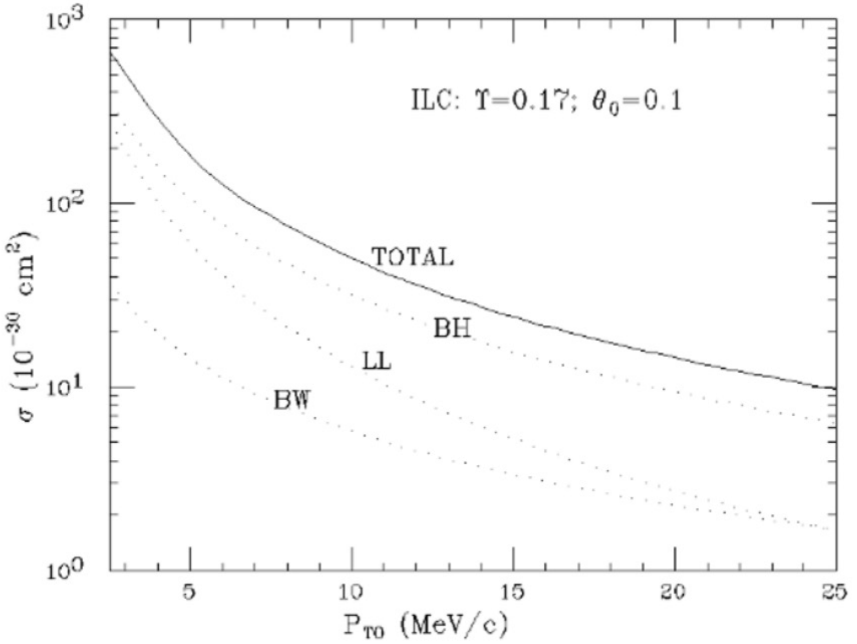


- Various backgrounds originate in the Beam Delivery System or the Interaction Region of C^3
- Can deteriorate detector performance:
  - Beam-induced Backgrounds: secondary e^+e^- pairs, $\gamma\gamma \rightarrow$ hadrons
  - Machine-induced Backgrounds: halo muon, neutron production
- This presentation will focus on the Beam-Induced Backgrounds

e^+e^- Pair Background and Simulation



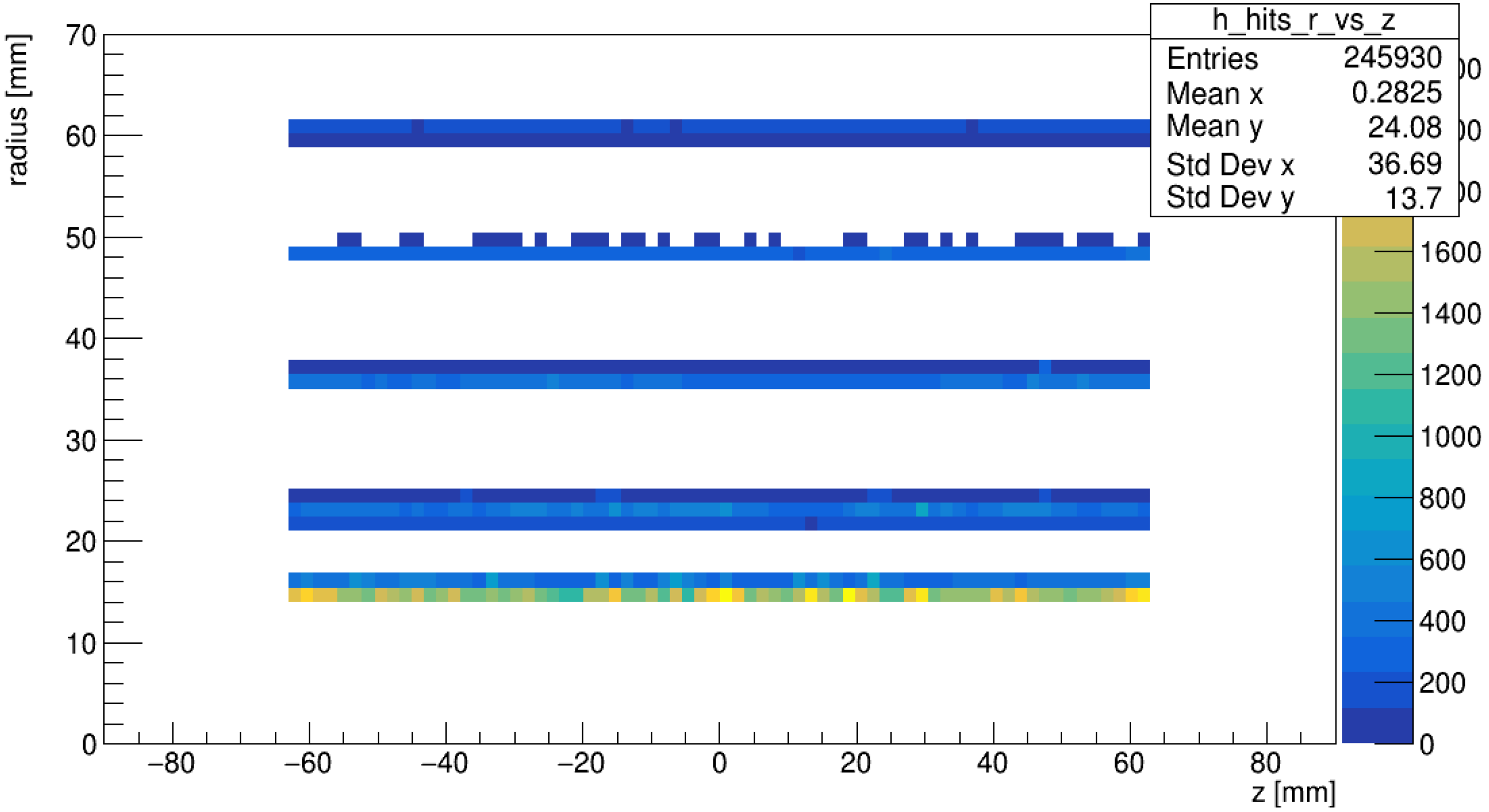
(a) *Bethe-Heitler* (b) *Breit-Wheeler* (c) *Landau-Lifschitz*



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

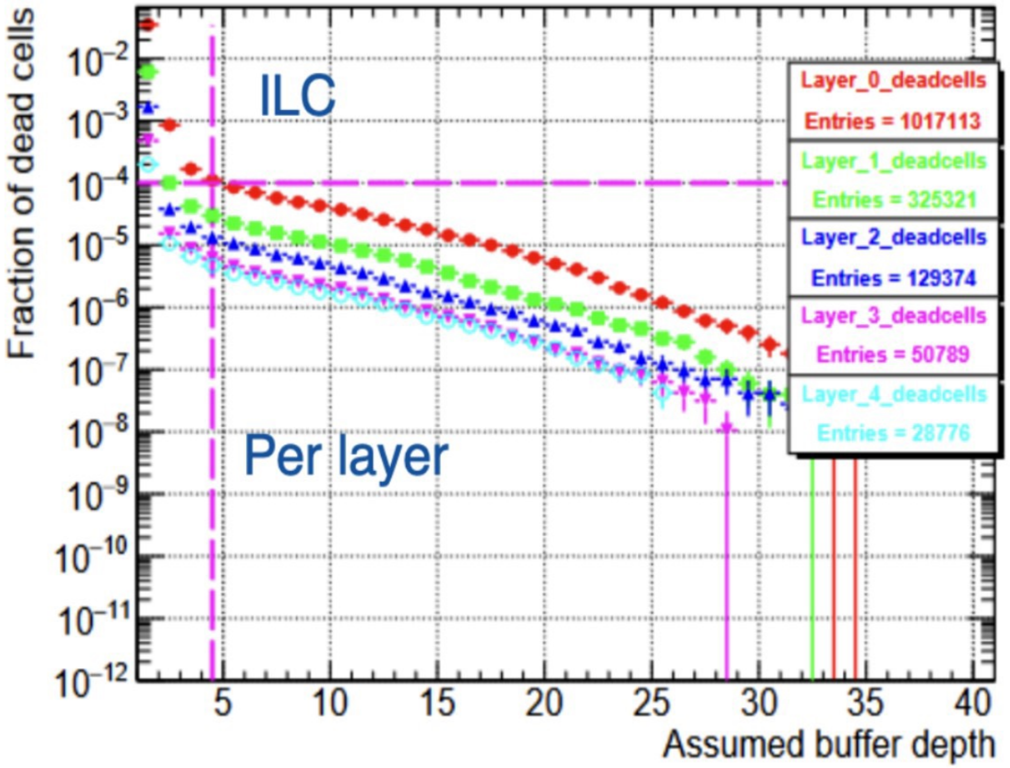
- This background comes from the generation of virtual photons as bunches pass through each other or from hard bremsstrahlung
  - Around 10^5 pairs / bunch crossing expected with C^3
  - Most are deflected, but a small fraction reach detector
- Simulation of background using GUINEA-PIG
  - Interaction with detector, simulated by Geant4 thru Detector Description Toolkit for High Energy Physics (DD4hep)

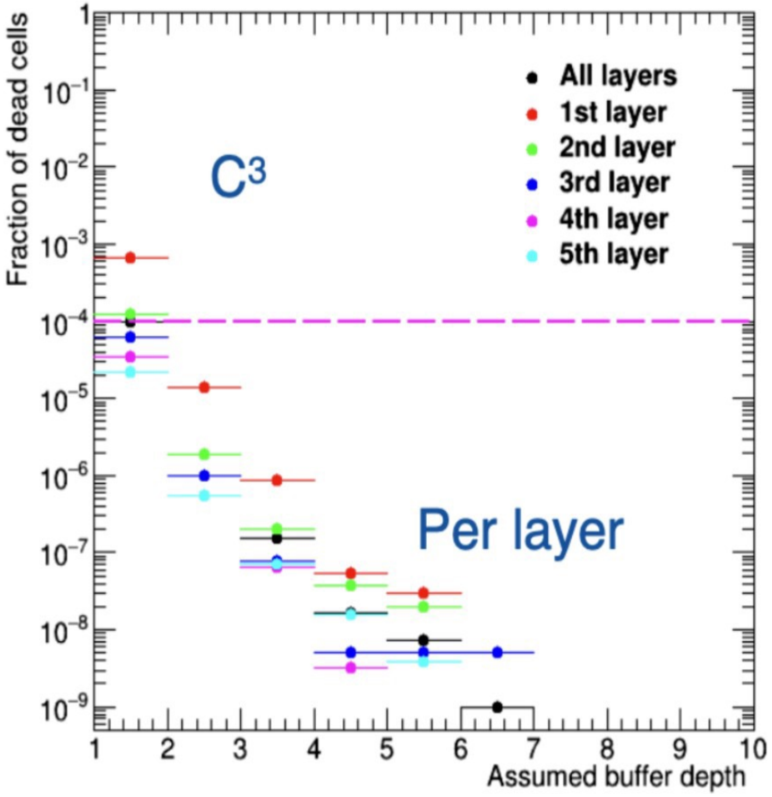
e^+e^- Pair Background Occupancy



- Visualization of occupancy within 5 tracker layers (hits/mm^2)
- Background clearly impacts the entire first layer

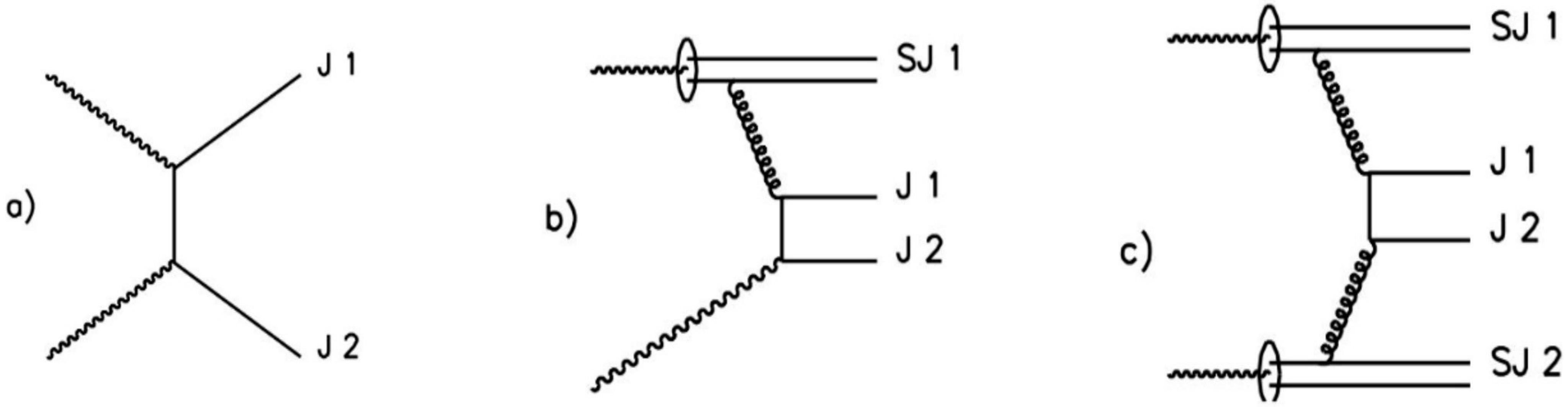
e^+e^- Pair Background Occupancy





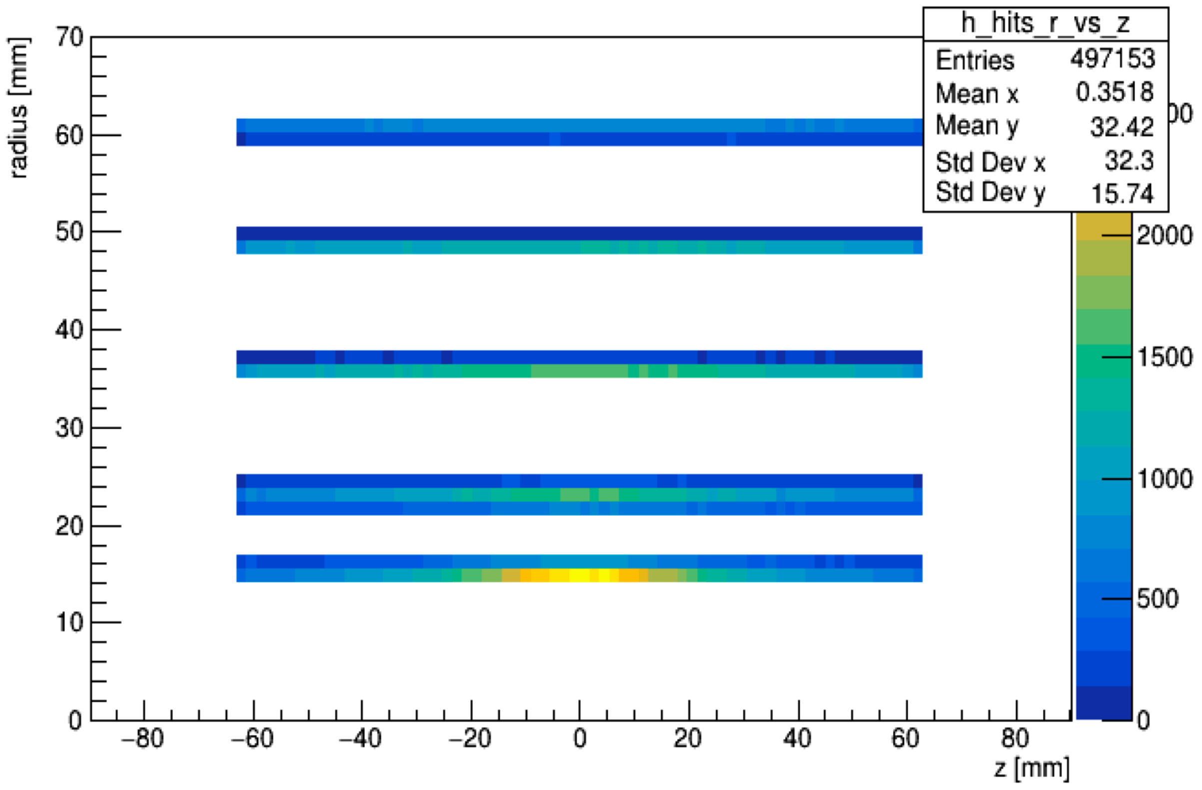
- Above: Fraction of cells unable to accumulate more data
- For comparison
  - ILC plot includes all backgrounds, C^3 only incoherent pair
  - ILC bunch train is 10x longer than C^3

Hadron Photoproduction Background and Simulation



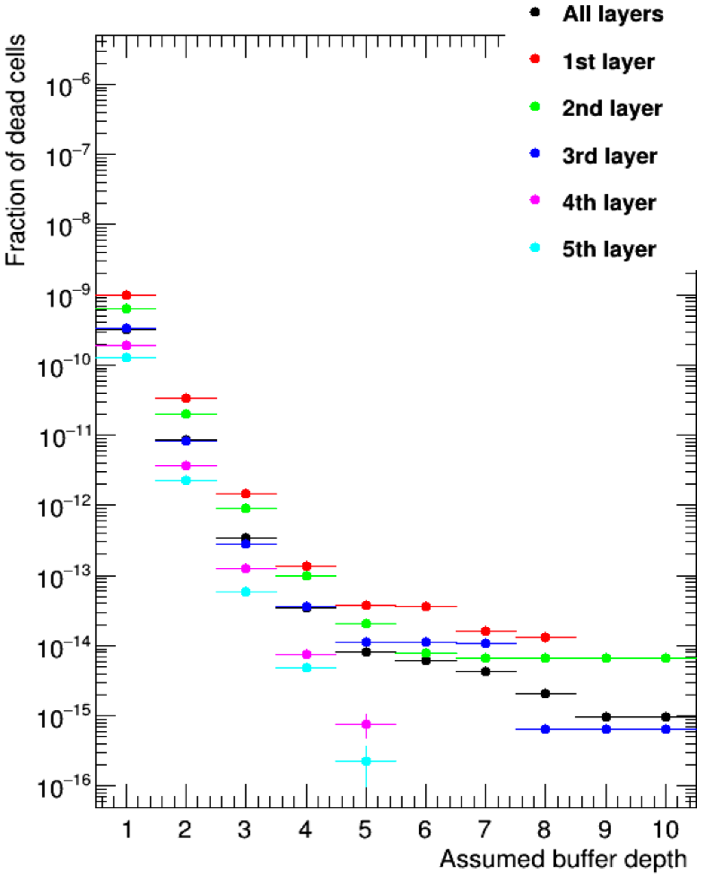
- Beamstrahlung photons can also produce a hadronic background at smaller rate than the $e^{+}e^{-}$ pair background
  - More central than incoherent pairs, may still impact reconstruction
- PYTHIA used for simulation of processes above $\sqrt{s_{\gamma\gamma}} > 2$ GeV
  - Interfaced w/ detector through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

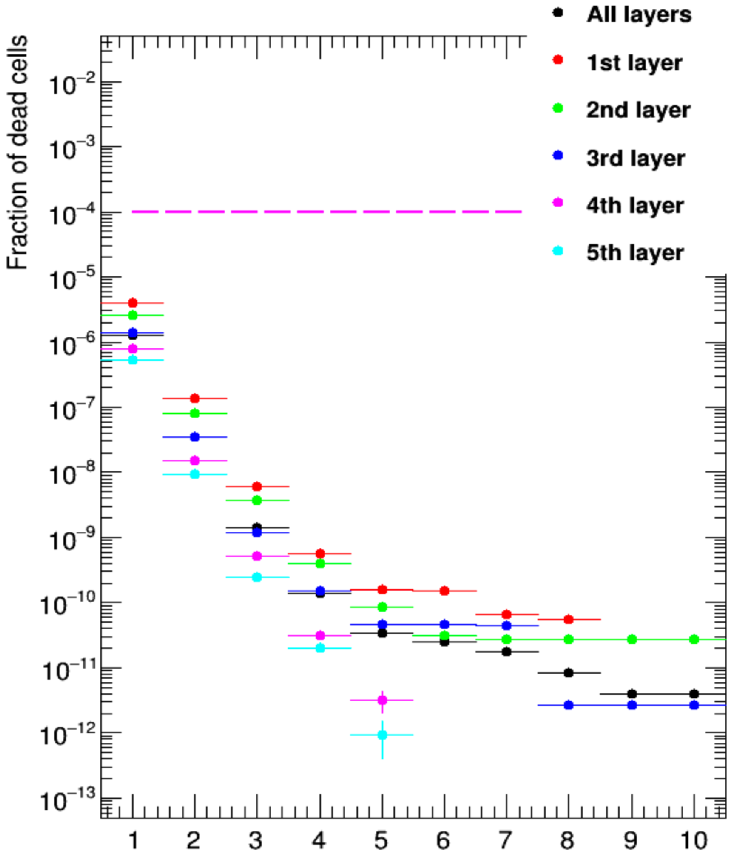
Hadron Photoproduction Occupancy



- Above: Visualization of occupancy within 5 tracker layers (hits/mm2)
- Significantly more central than Pair Production background

Hadron Photoproduction Occupancy





- ❑ Above: Fraction of cells unable to accumulate more data + rescaling
- ❑ Rescaling is done to include the contributions from $\sqrt{s}_{\gamma\gamma} < 2$ GeV

Summary

- C^3 is a compact, upgradable, and sustainable Higgs Factory proposal
- Contribution from e^+e^- pairs and $\gamma\gamma\rightarrow$ hadron backgrounds is manageable
- The ILC is a valid reference for C^3 studies. Modern clocking and timing performance means that C^3 ~ ILC/10 where beam-based background's impact on performance considerations are concerned
- Generation of full hadron background processes is slow but steady
- Future Steps:
  - Finish hadron background generation
  - Expand data production and investigate further backgrounds
  - Utilize further ILC studies for re-examination within the context of C^3

- *While with the most recent P5 report, the construction of an on-shore e^+e^- collider is not foreseeable in near future, the report calls out the possible R&D test facility efforts for cold copper phase-2.*
- *Studies of machine and beam induced backgrounds, prevalent in all Higgs factories, provides insight into the low-rate backgrounds that are pertinent in the large datasets of future e^+e^- machines.*

Back up

Hadron photo production for $\sqrt{s_{\gamma\gamma}} < 2$ GeV

- $\sqrt{s_{\gamma\gamma}} < 2$ GeV: Pythia does not simulate this part of the spectrum
- Alternate workflow: GUINEA-PIG → CIRCE → WHIZARD
- Previous simulation from GUINEA-PIG utilized
- 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
- WHIZARD: Successful simulation with C3 but further modifications needed

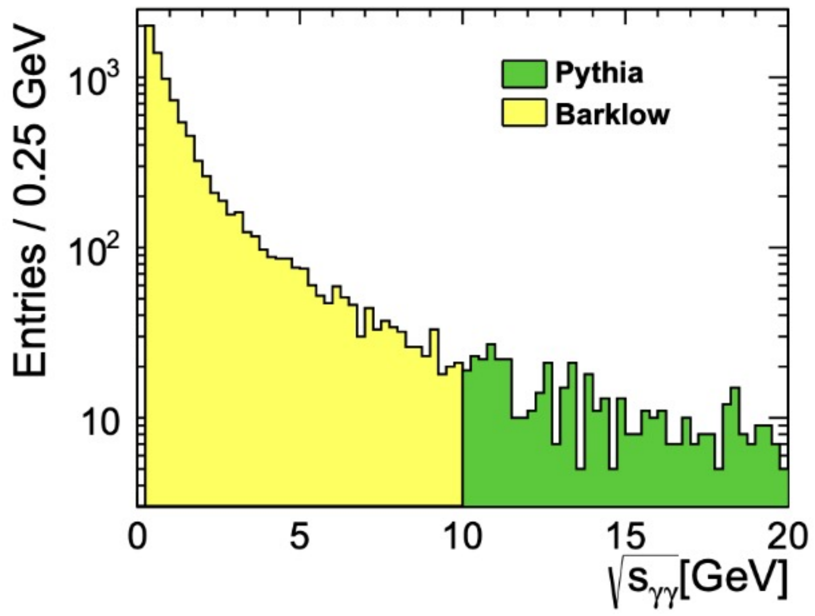


FIG. 1: Energy spectrum of $\gamma\gamma \rightarrow$ low p_T hadron events as a function of centre-of-mass energy. The figure shows the energy cutoff of 10 GeV below which the events are generated by the Barklow generator. Above 10 GeV the events are generated by Pythia.

Precision for the Higgs couplings obtained w/ different accelerators

2209.03472v1

Higgs Coupling (%)	HL-LHC	ILC250 + HL-LHC	ILC500 +HL-LHC	ILC1000 + HL-LHC	FCC-ee + HL-LHC	CEPC240 + HL-LHC	CEPC360 +HL-LHC	CLIC380 + HL-LHC	CLIC3000 +HL-LHC
hZZ	1.5	.22	.17	.16	.17	.074	.072	.34	.22
hWW	1.7	.98	.20	.13	.41	.73	.41	.62	1
$hb\bar{b}$	3.7	1.06	.50	.41	.64	.73	.44	.98	.36
$h\tau^+\tau^-$	3.4	1.03	.58	.48	.66	.77	.49	1.26	.74
$hgg.$	2.5	1.32	.82	.59	.89	.86	.61	1.36	.78
$hc\bar{c}$	-	1.95	1.22	.87	1.3	1.3	1.1	3.95	1.37
$h\gamma\gamma$	1.8	1.36	1.22	1.07	1.3	1.68	1.5	1.37	1.13
$h\gamma Z$	9.8	10.2	10.2	10.2	10	4.28	4.17	10.26	5.67
$h\mu^+\mu^-$	4.3	4.14	3.9	3.53	3.9	3.3	3.2	4.36	3.47
$ht\bar{t}$	3.4	3.12	2.82	1.4	3.1	3.1	3.1	3.14	2.01
Γ_{tot}	5.3	1.8	.63	.45	1.1	1.65	1.1	1.44	.41