Simulation of Beam- and Machine-induced Backgrounds for the Cool Copper Collider

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INTERNATIONAL WORKSHOP ON LINEAR COLLIDERS

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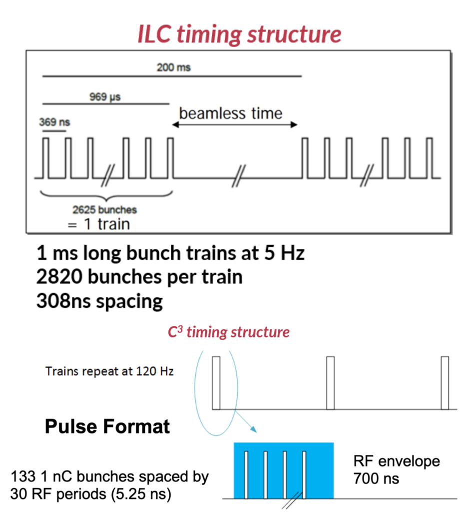
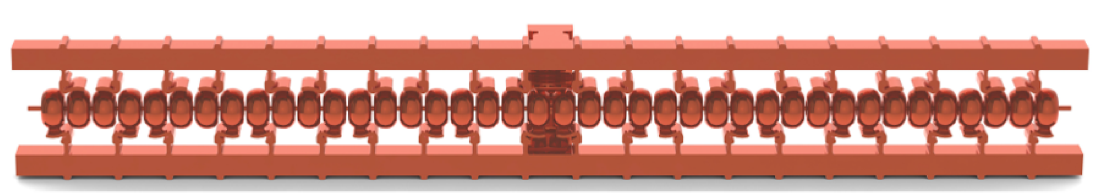
The Cool Copper Collider (C^3)

- The Cool Copper Collider(C^3) has been proposed as an e^+e^- Higgs Factory with a 250 GeV collision energy and based on a technology that offers the option for an upgrade to 550 GeV, with possible extensions to the TeV-scale.
- Some key differences in the proposed C^3 design with respect to ILC are:
  - Accelerating Technology: NC Cu distributed coupling vs Nb SC RF cavities $\rightarrow$ higher gradients - more compact design.
  - Bunch Structure: bunches spaced two orders of magnitude closer together with ~ 3 times smaller particle density.
  - Train Structure: higher train repetition frequency with an order of magnitude fewer bunches per train.
- Despite these differences, the target center-of-mass energy and instantaneous luminosity for C^3 and ILC are very similar.

	C^3		ILC	
Parameter [Unit]	Value	Value	Value	Value
CM Energy [GeV]	250	550	250	500
Luminosity $[\cdot 10^{34}/\mathrm{cm}^2 s]$	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

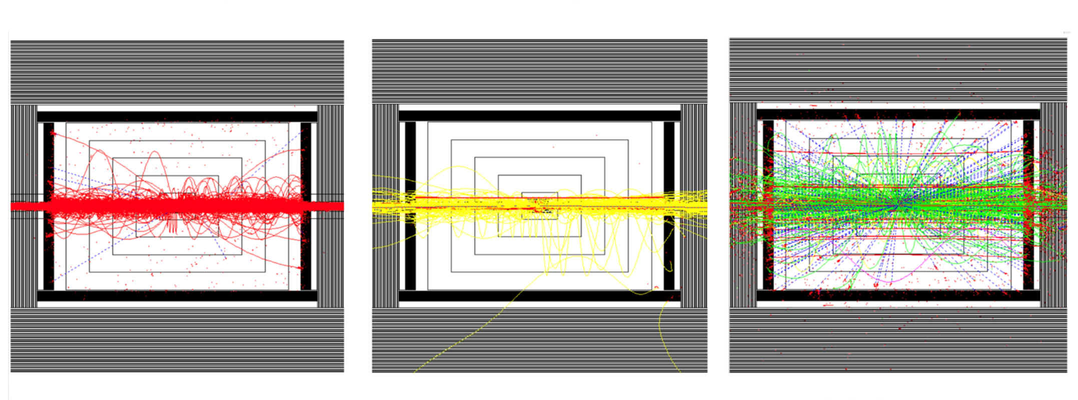
Table 1: Beam parameters for C^3 and ILC . The final focus parameters for C^3 are preliminary[1].





Beam & Machine Backgrounds

- The benefits of a clean collision environment that an e^+e^- collider offers can only be fully exploited with the use of highly granular & extremely precise detectors.
- The design of such detectors has to account for various backgrounds that originate in the BDS or the IR and which can deteriorate detector performance:
  - Beam-induced Backgrounds: secondary e^+e^- pair background and $\gamma\gamma \rightarrow$ hadrons from beam-beam interactions in the IR.
  - Machine-induced Backgrounds: halo muon production from beam-collimator interactions in the BDS, neutron production in the beam dumps.
- These backgrounds have been studied extensively for ILC and are currently under study for C^3 as well, with the purpose of informing detector and BDS design.

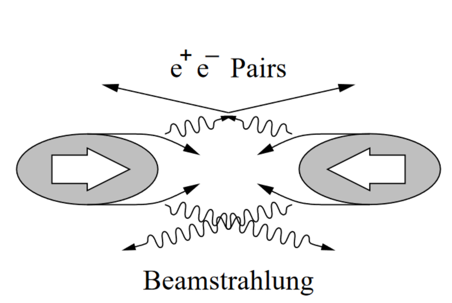


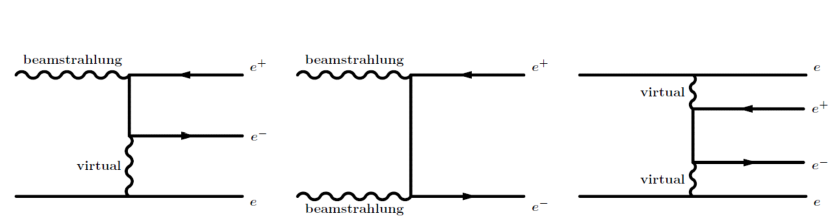
e^+e^- Pair Background

The nm-size beams required for e^+e^- colliders imply that the colliding bunches have very high space charge, creating strong electric fields that attract and accelerate particles in the opposite bunch, leading to the radiation of photons, called beamstrahlung, in the interaction region.

Beamstrahlung photons can produce incoherent e^+e^- pairs, through interactions with other, real or virtual, photons. Around 10^5 such pairs are expected per bunch crossing for C^3. These additional e^+e^- are boosted in the forward direction and are deflected from the strong B-field of the detector solenoid. However, a small fraction of those secondaries reaches the detector and increases the occupancy.

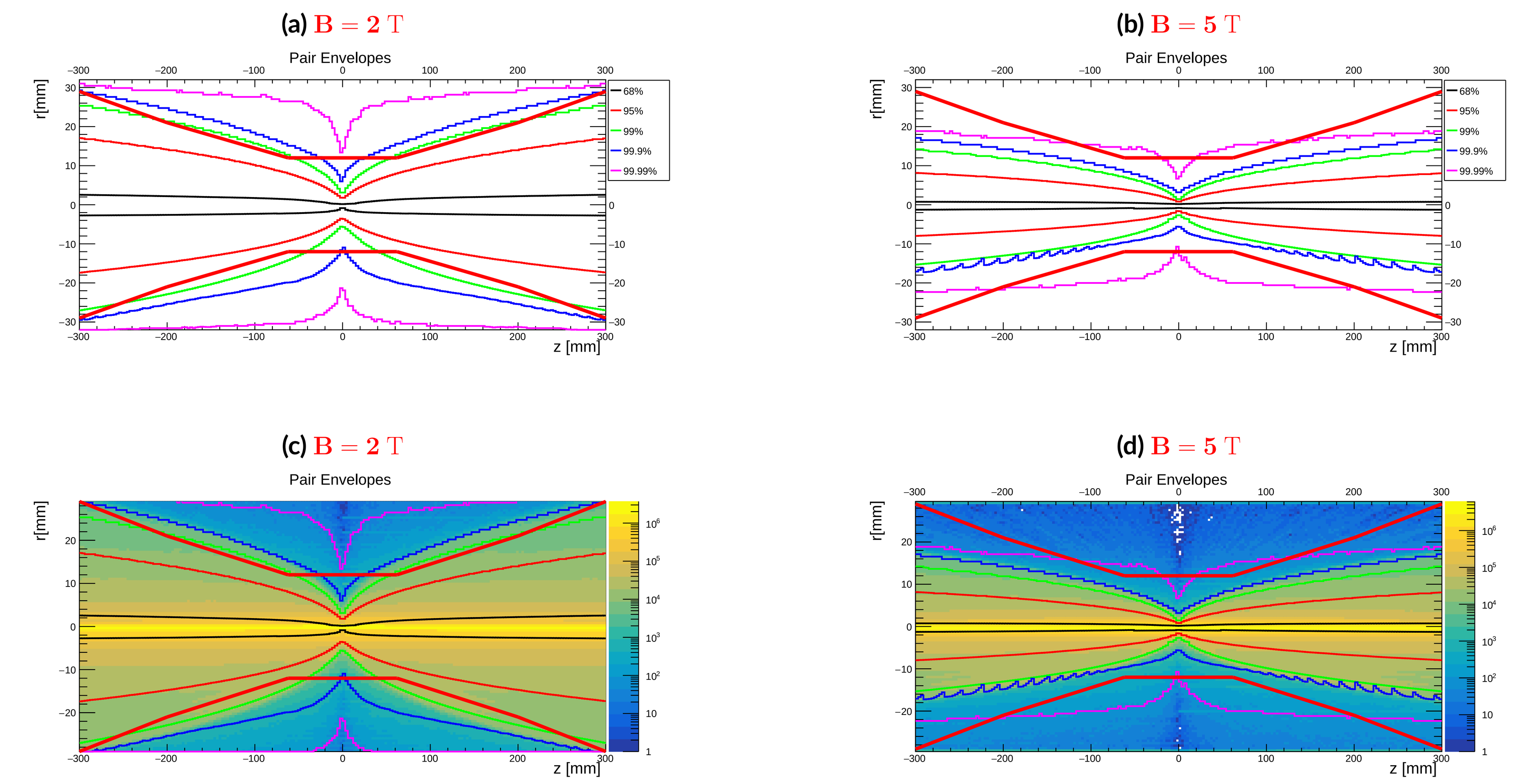
The simulation of this important beam-induced background is performed using the GUINEA-PIG[4] generator, and the interaction of the produced particles with the detector is carried out in Geant4 through DD4hep, assuming an SiD-like detector.

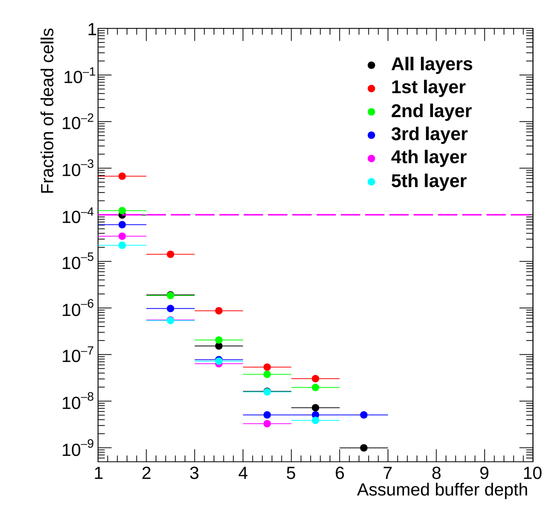




(a) Bethe-Heitler (b) Breit-Wheeler (c) Landau-Lifschitz

Simulation Results:



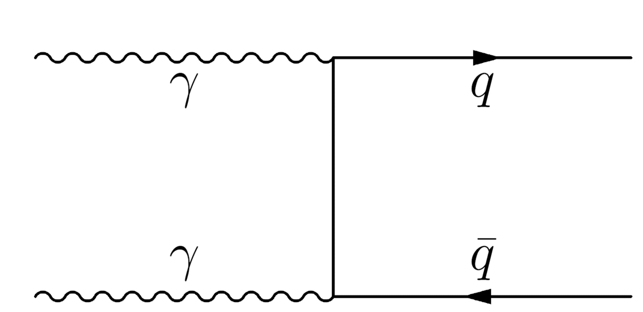


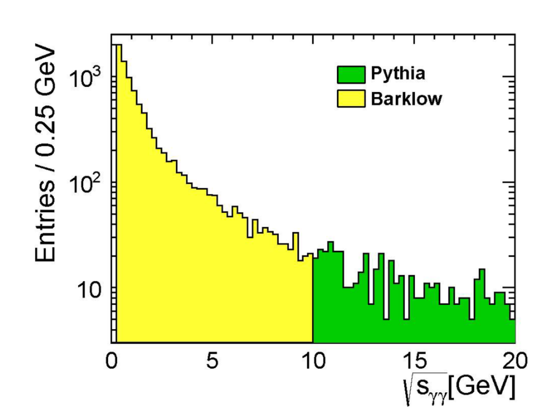
Figures (a),(b) show the envelopes at various levels of the hit density of the secondaries e^+e^- in the vertex detector as they get deflected away from the IP due to the magnetic field of a solenoid with field strength 2T and 5T respectively. For reference, the beamline has also been drawn in red. Figures (c),(d) contain the same information and additionally show the hit density of the e^+e^- pairs. Finally, the plot on the left shows the occupancy in the vertex detector, defined as the fraction of cells with hits equal to or larger than the assumed buffer depth, as a function of buffer depth.

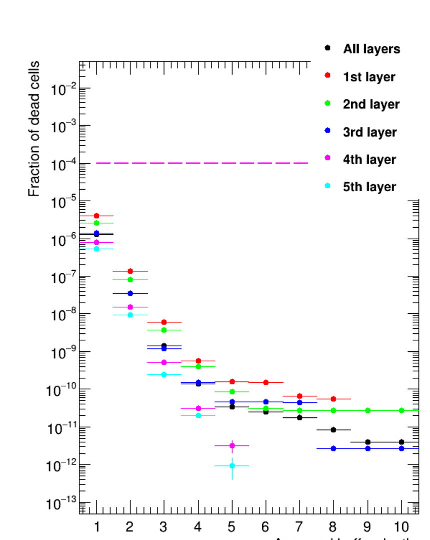
Hadron Photoproduction Background

The interaction of beamstrahlung photons can also produce a hadronic background, at a rate $\sim 10^5$ smaller than the e^+e^- pair background. These hadrons are more central than incoherent pairs and can have an impact on reconstruction, especially jet clustering.

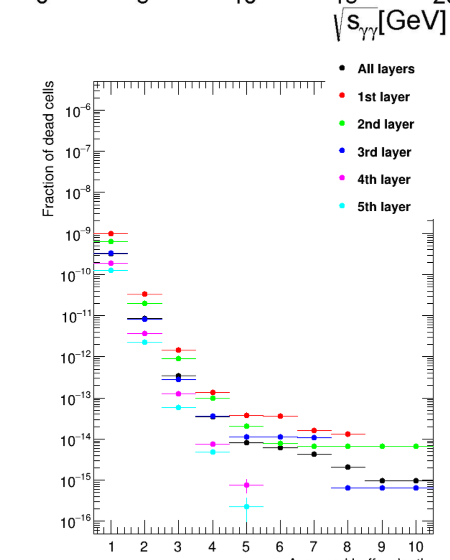
PYTHIA was used for the simulation of the $\gamma\gamma \rightarrow$ hadrons processes above $\sqrt{s_{\gamma\gamma}} > 10$ GeV and a dedicated generator [2] will be used for lower energies, to account for cross-section mismodelling effects. The produced hadrons were then interfaced with the detector through Geant4/DD4hep.







(a)

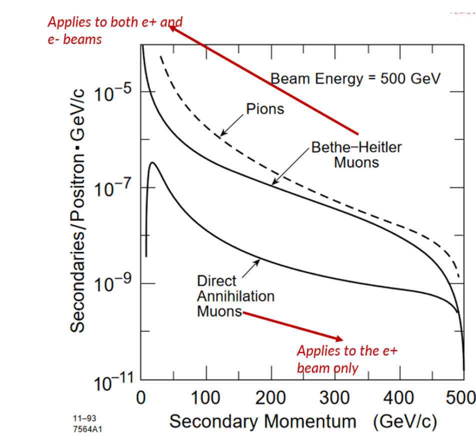


(b)

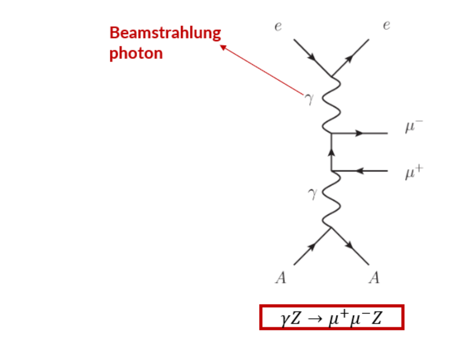
Figure 7: Occupancy in the vertex detector as a function of buffer depth for the hadron photoproduction background. For (a) Only the generated events with $\sqrt{s_{\gamma\gamma}} > 10$ GeV were used for the estimation of the occupancy. Even after rescaling to the total hadron photoproduction cross-section in (b), the occupancy remains well below 10^{-4} but has longer tails than the e^+e^- pair background.

Halo Muon Background

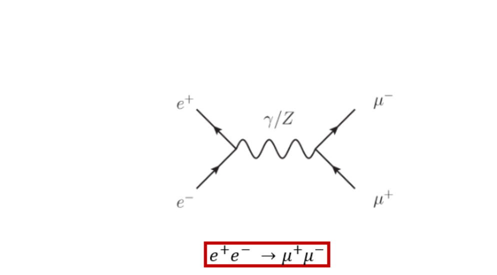
The beam halo muon background is produced from interactions of particles in the beam halos with material in the accelerator structure, particularly collimators in the BDS. Muons are penetrating enough that they can travel upstream and reach the detector, thus contributing to an increase in the overall occupancy.



(a) Muon production processes at a 1 TeV e^+e^- collider. From: [3]



(b) Bethe-Heitler production of muon pairs. Main production mechanism (cross-section enhanced by Z^2.)



(c) Direct annihilation of e^+ with atomic e^-. This process takes place in the e^+ beam and leads to a larger number of muons being produced in the e^+ vs e^- beam.

The simulation of the muon flux is carried out using MUCARLO [3], which semi-analytically generates muons in the BDS from beam halo interactions, and then tracks their trajectories up to the IR.

In the context of ILC, MUCARLO was used to inform the placement of magnetized spoilers in the BDS and a magnetized wall outside of the detector hall to deflect and/or absorb the incoming muons. It was demonstrated that, with these additions, the muon flux in the detector can be reduced by 1-2 orders of magnitude.

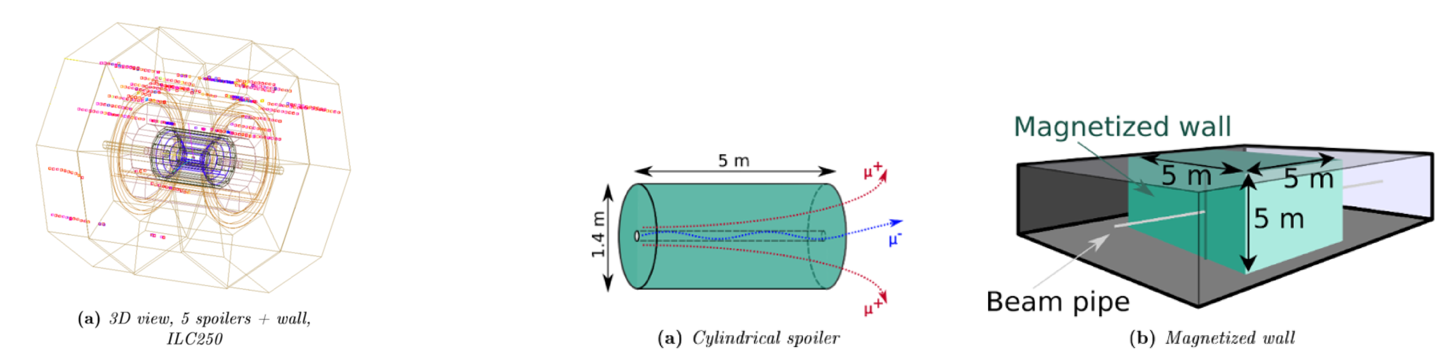
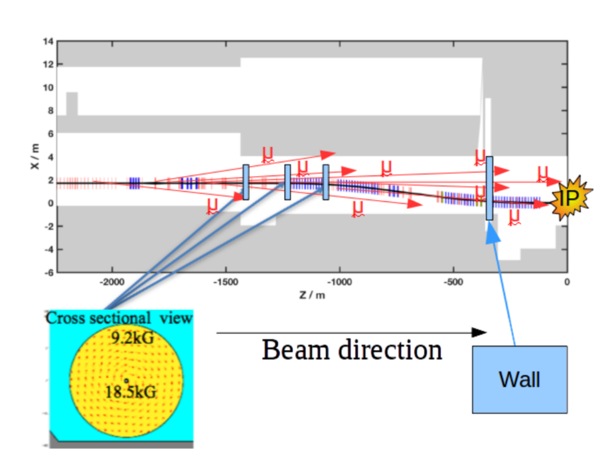


Figure 9: *Left*: detector hits from MUCARLO simulated muons at the ILC. *Middle, right*: schematics of a cylindrical spoiler and a magnetized wall that could be used for muon background reduction [5].



Scenario	Muons per bunch crossing in a detector with 6.5 m radius					
	ILC500			ILC250		
	positron line	electron line	total	positron line	electron line	total
No Spoilers	71.6	58.5	130.1	21,1	17,2	38.3
5 spoilers	2.3	2	4.3	0.73	0.57	1.3
5 spoilers + wall	0.34	0.26	0.6	0.016	0.014	0.03

(a) Table of number of halo muons per bunch crossing that reach the IR for ILC for different shielding scenarios. From: [2]

Relevant Talks at LCWS 2023

Physics and Detectors Track 2 : Analysis and Reconstruction

- Lindsey Gray, Collider Background Studies, Th 18 May 2023, 08:50
- Elias Mettner, Pair Production and Hadron Photoproduction Backgrounds at C^3, Th 18 May 2023, 13:30
- Dimitris Ntounis, Muon Backgrounds from Beam Interactions with the Accelerator Structure at C^3, Th 18 May 2023, 13:45

References

[1] M. Bai, T. Barklow, R. Bartoldus, M. Breidenbach, P. Grenier, Z. Huang, M. Kagan, J. Lewellen, Z. Li, T. W. Markiewicz, E. A. Nanni, M. Nasr, C.-K. Ng, M. Oriunno, M. E. Peskin, T. G. Rizzo, J. Rosenzweig, A. G. Schwartzman, V. Shiltsev, E. Simakov, B. Spataro, D. Su, S. Tantawi, C. Vernieri, G. White, and C. C. Young. C³: A "cool" route to the higgs boson and beyond, 2021.

[2] T. Barklow, L. d'Hautuille, C. Milke, B. Schumm, A. Schütz, M. Stanitzki, and J. Strube. A study of the impact of high cross section ilc processes on the sid detector design, 2016.

[3] L. Keller and G. White. Simulation of muon background at the ilc, 2019.

[4] D. Schulte. Study of Electromagnetic and Hadronic Background in the Interaction Region of the TESLA Collider, 1997. Presented on Apr 1997.

[5] A. Schütz. *Optimizing the design of the Final-Focus region for the International Linear Collider*. PhD thesis, KIT, Karlsruhe, Hamburg, 2018.