The International Linear Collider -
Background Simulations &
Optimizations of the Final-Focus Region

GK Workshop, Bad Liebenzell

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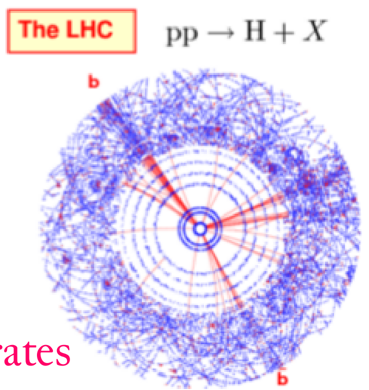
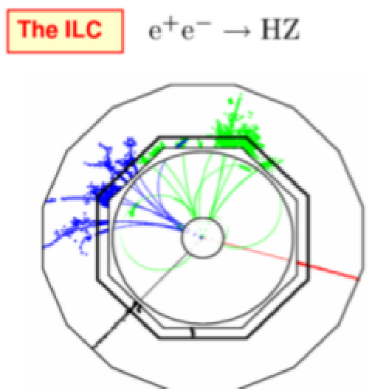
Hadron vs. Lepton Collider

Cleanliness - Democracy - Calculability - Detail

Leptons:





- Small background
- No out-of-time pileup or underlying events
- Small detector occupancy

- e^+e^- annihilation produces pairs of SM and exotics at similar rates (elementary coupling e of photons is the same for all quarks and leptons)
- Model independence
- No triggers

- Point-like elementary particles in initial state
- No systematic uncertainties due to PDFs and QCD corrections

- Reconstruction of complete events
- Due to high energy resolution, particles with small mass difference distinguishable → Peaks are measurable that weren't measurable before

Circular vs. Linear Collider

Circular:

- Synchrotron radiation:

$$P_S = \frac{e^2 c}{6\pi\epsilon_0} \frac{1}{(m_0 c^2)^4} \frac{E^4}{R^2}$$

- Energy loss per turn:

$$\Delta E = \frac{e}{3\epsilon_0 (m_0 c^2)^4} \frac{E^4}{R}$$

- Cost ~ quadratically with E

  (B. Richter 1980)

Linear:

- Not limited by synchrotron radiation
- Cost ~ linear with E + basic costs (dumping rings etc.)

Circular machine?

→ Leptons:

high E loss due to synchrotron radiation

→ Hadrons:

synchrotron radiation less of a problem

Linear collider?

→ Hadrons:

could reach higher E in circular machines

→ Leptons:

perfect for precision measurements!

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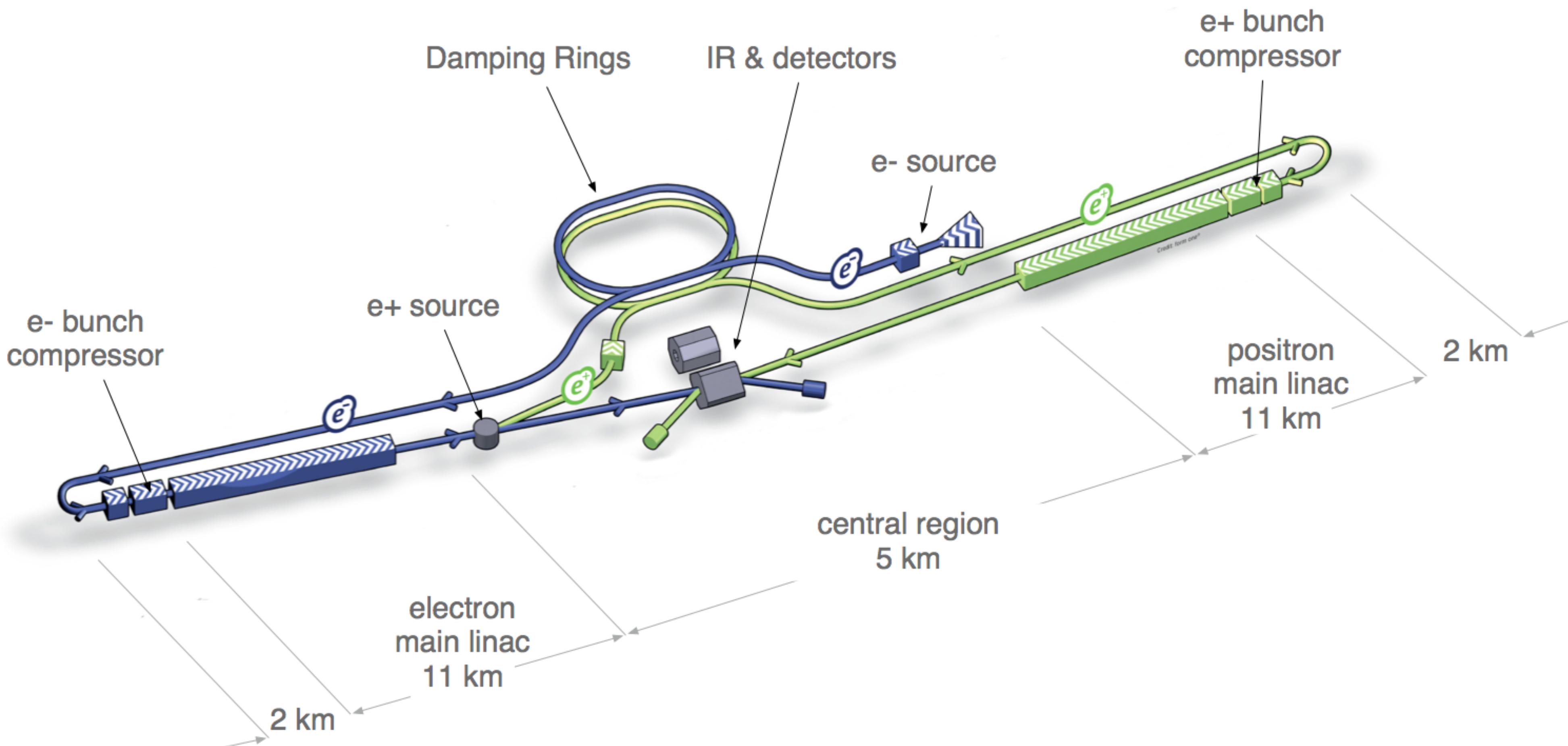
Layout

$e^+ e^-$ linear collider with adjustable center-of-mass energy, and polarized beams



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Candidate Site: The Kitakami Mountains

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In comparison to LHC

Higher luminosity than LHC Run 2 (25ns bunch spacing) due to the tiny bunch sizes (nano-meters)!

		Baseline 500	LHC 25ns
E_{CM}	[GeV]	500	14 000
n_b		1312	2808
Δt_b	[ns]	554	25
N		2.0×10^{10}	11.5×10^{10}
σ_x^*	[nm]	474	16 700
σ_y^*	[nm]	5.9	16 700
σ_z	[mm]	0.3	0.755
$\mathcal{L}$	[$cm^{-2}\,s^{-1}$]	1.8×10^{34}	1.0×10^{34}

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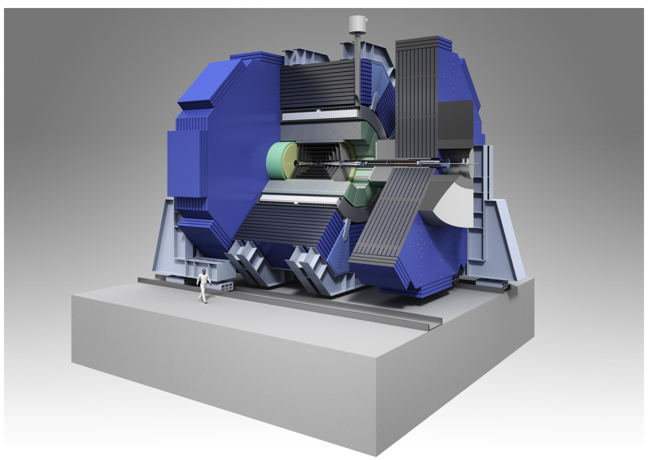
The Detectors

Only one IP but **two** detectors → **push-pull system**!

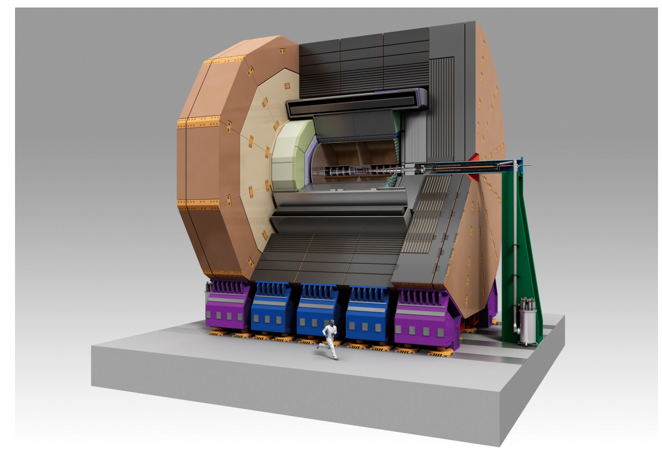
<u>SiD – Silicon Detector</u>

Full silicon vertex & tracker detector system



<u>ILD – International Large Detector</u>

TPC as a tracker system



SiD and ILD are multi-purpose detectors, but what's the difference to the LHC detectors, such as CMS and ATLAS? →

The technology is much more advanced!

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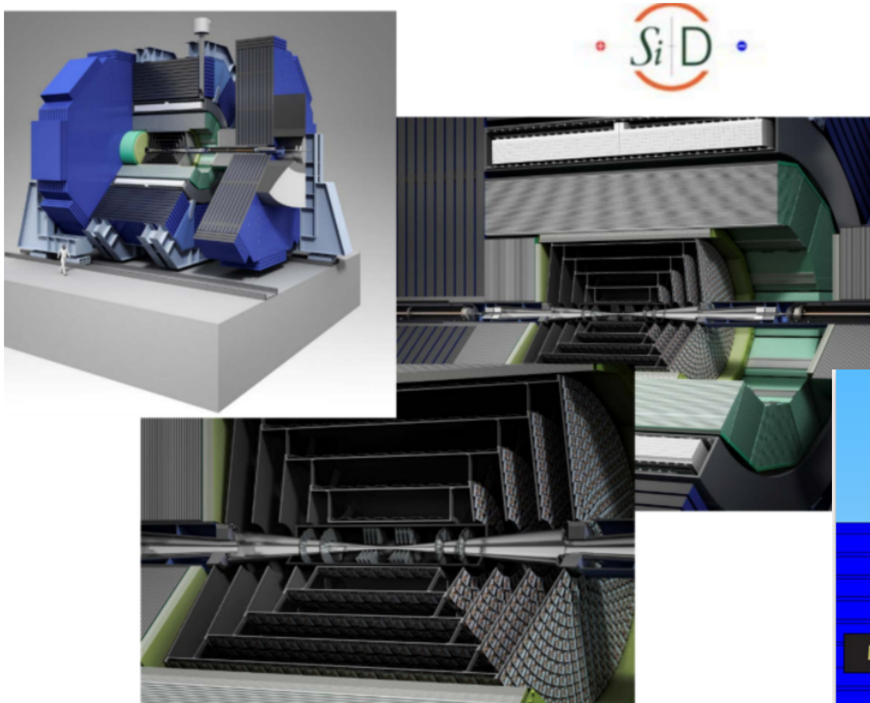
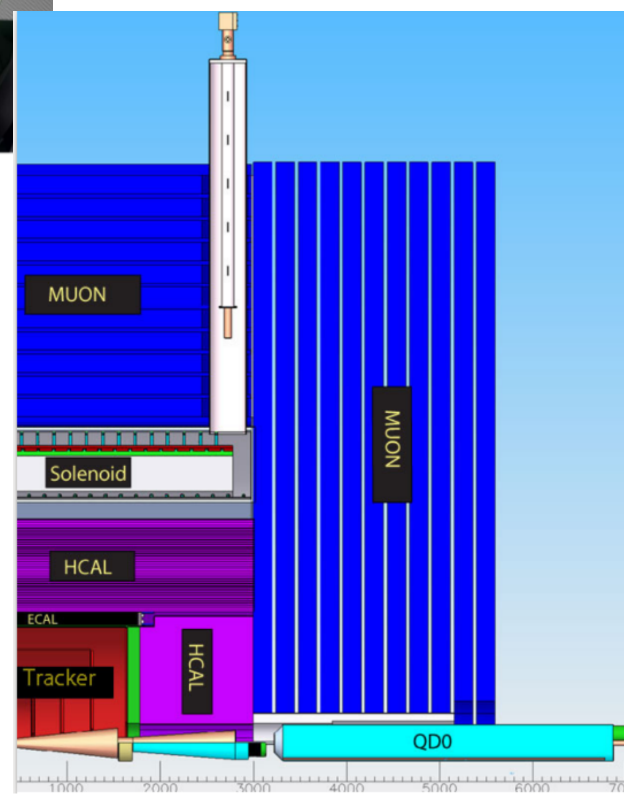
The SiD Detector



Convincing design:

- Robust and compact
- Full silicon vertex detector and tracker
- 5T solenoid field



Vertex detector:

- Spatial resolution: $< 3\ \mu m$
- Momentum resolution: $\sim 2\text{-}5 \times 10^{-5}$ GeV
- $\sim 0.1\ \%\ X_0$ per layer

Calorimeters:

- highly granular, optimized for Particle Flow
- Jet energy resolution: 3-4 %

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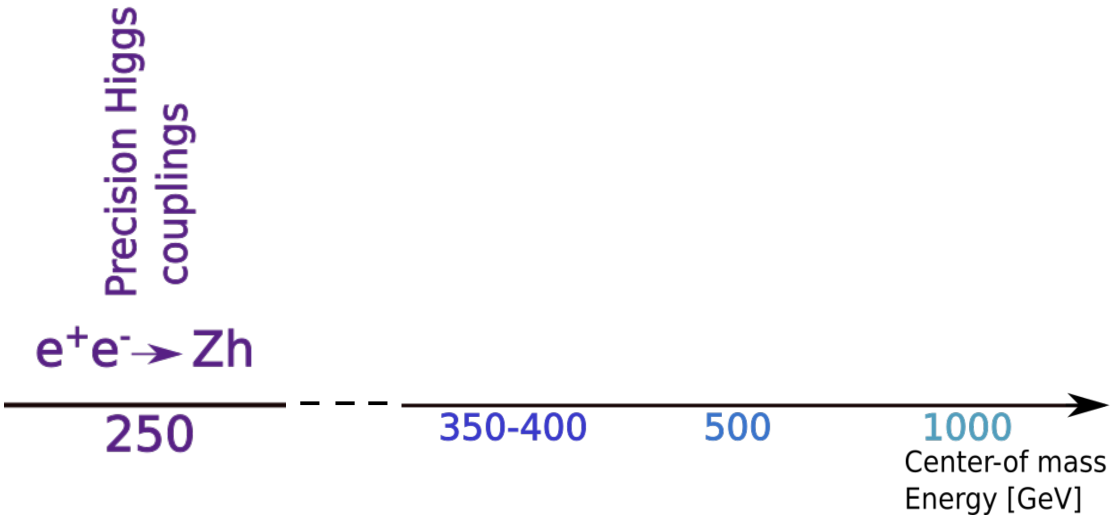
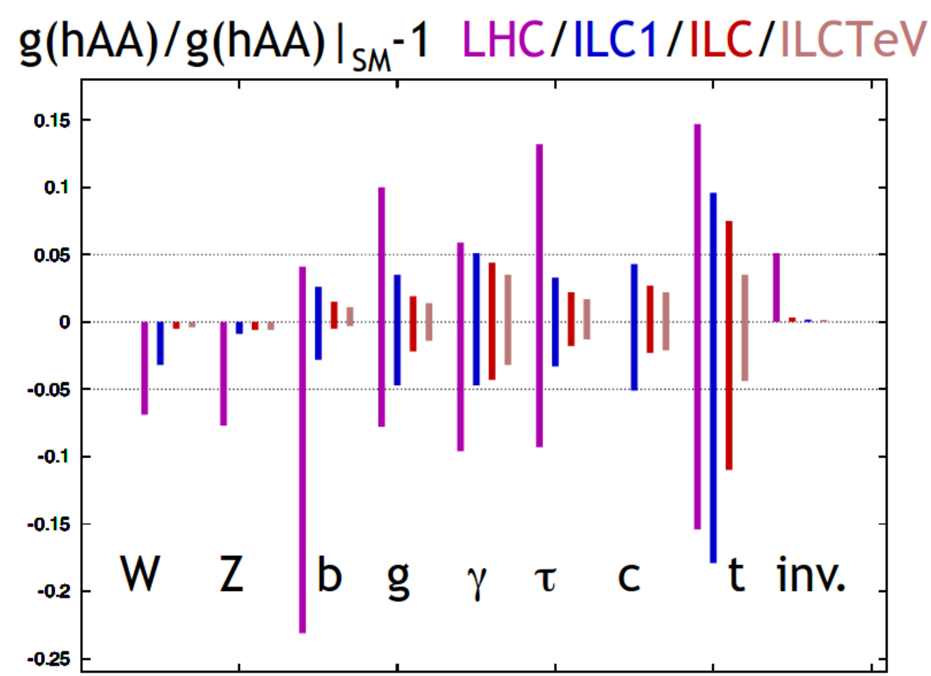
Key Physics Goals



Precision Measurements:

- ILC: Each Higgs coupling will be measured to a percent accuracy, **direct measurement of the global width** of the Higgs
- LHC: **Global fit to all Higgs signals** (plus using theoretical assumptions of the width) → Higgs couplings can never be as precise as at the ILC



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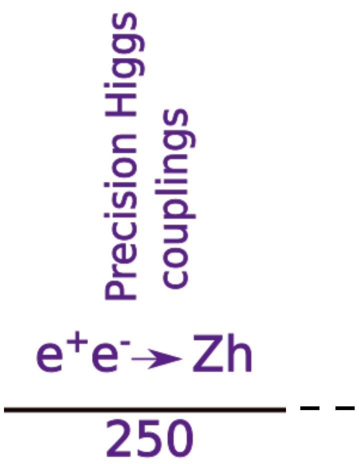
Key Physics Goals



The Japanese government asks for a

significant cost reduction!

To achieve such a dramatic reduction, the full machine needs to be staged:

"ILC250" instead of the ILC with 500 GeV c.o.m energy

Precision Measurements:

- ILC: Each Higgs coupling will be measured to a percent accuracy, **direct measurement of the global width** of the Higgs
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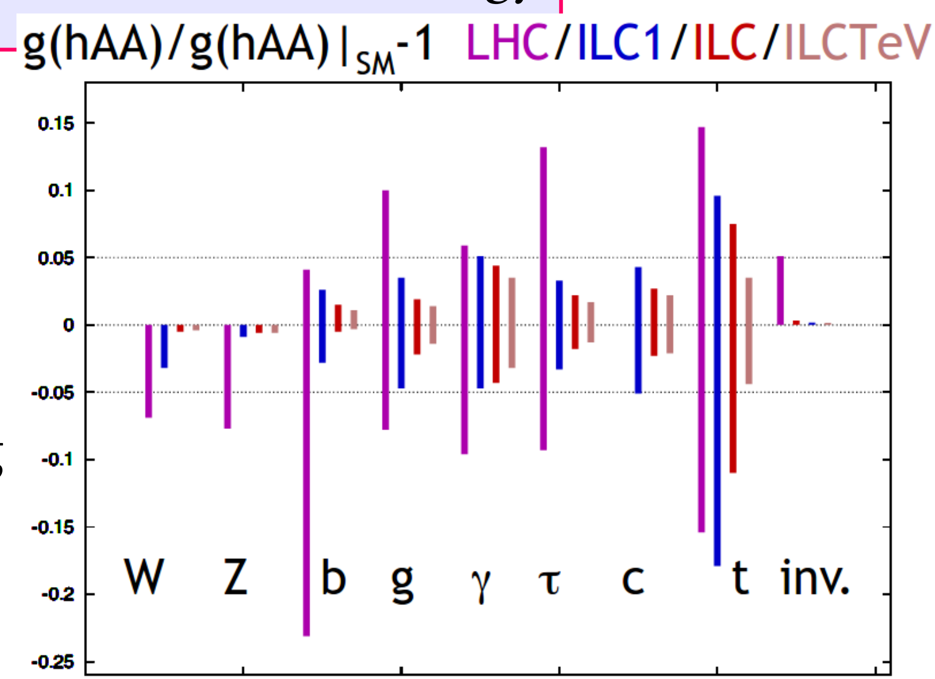

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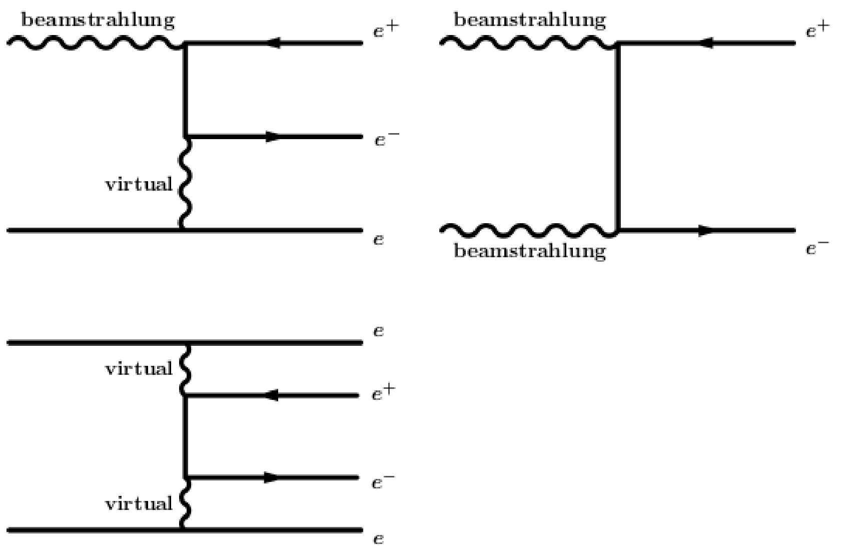
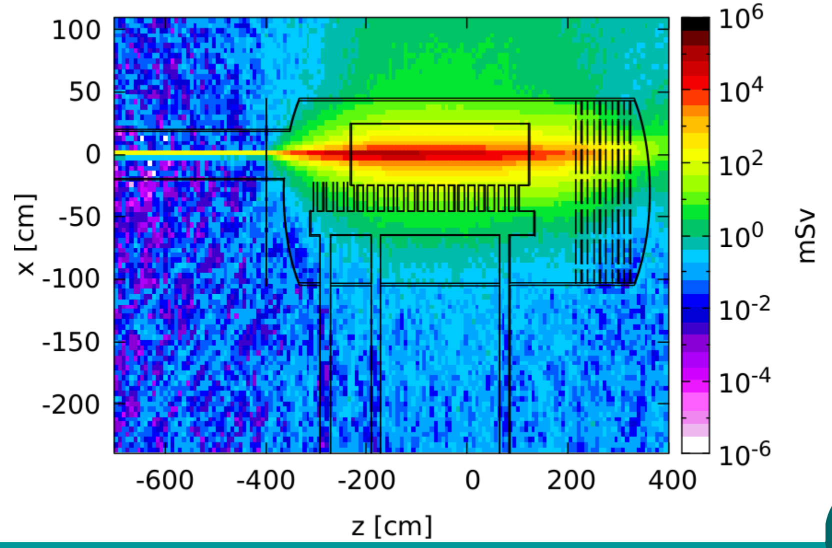
Background Sources & Simulation Tools

The main sources of background:

- <u>Beam-beam interactions</u>
  - **Pair background** → GuineaPig
  - Bhabha scattering → Whizard
  - $\gamma\gamma \rightarrow$ hadrons
- <u>Machine background</u> → Mucarlo
  - Muons from the Beam Delivery System
  - Background from the Final-Focus System (beam halo collimators) → BDSIM
  - **Neutrons from the Main Beam Dumps** → FLUKA





The generated background events are then input to a **Geant4 full detector simulation** of SiD.

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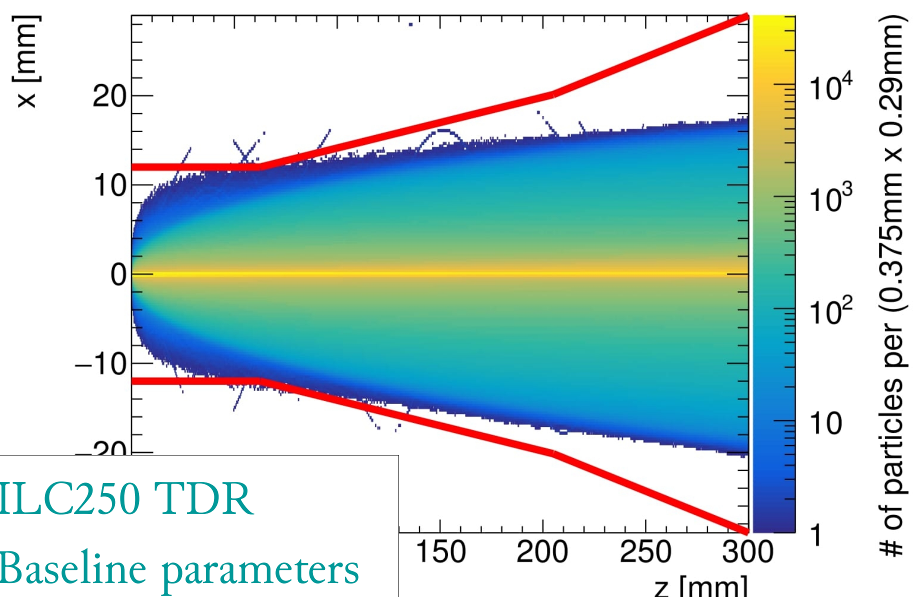
Pair background studies for the ILC250

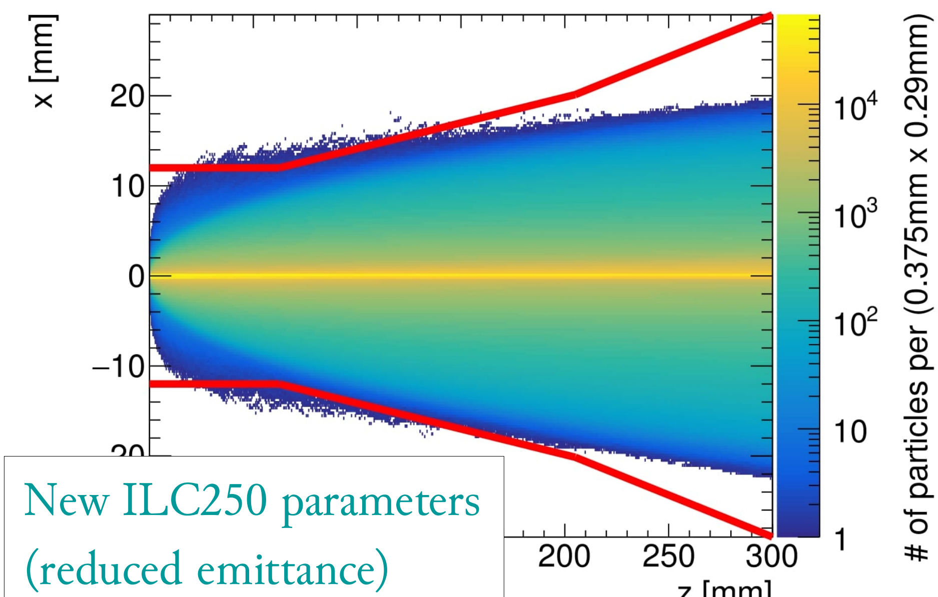
New beam parameter sets: Increasing the lumi by **reducing the beam emittance** → Stronger beam-beam interactions, **more background**!

Pair background density in a 5T solenoid field

- The pair background particles spiral in the magnetic field, and have a characteristic envelope.
- The broader the envelope, the more particles reach the inner most layers of the detector



ILC250 TDR
Baseline parameters



New ILC250 parameters
(reduced emittance)

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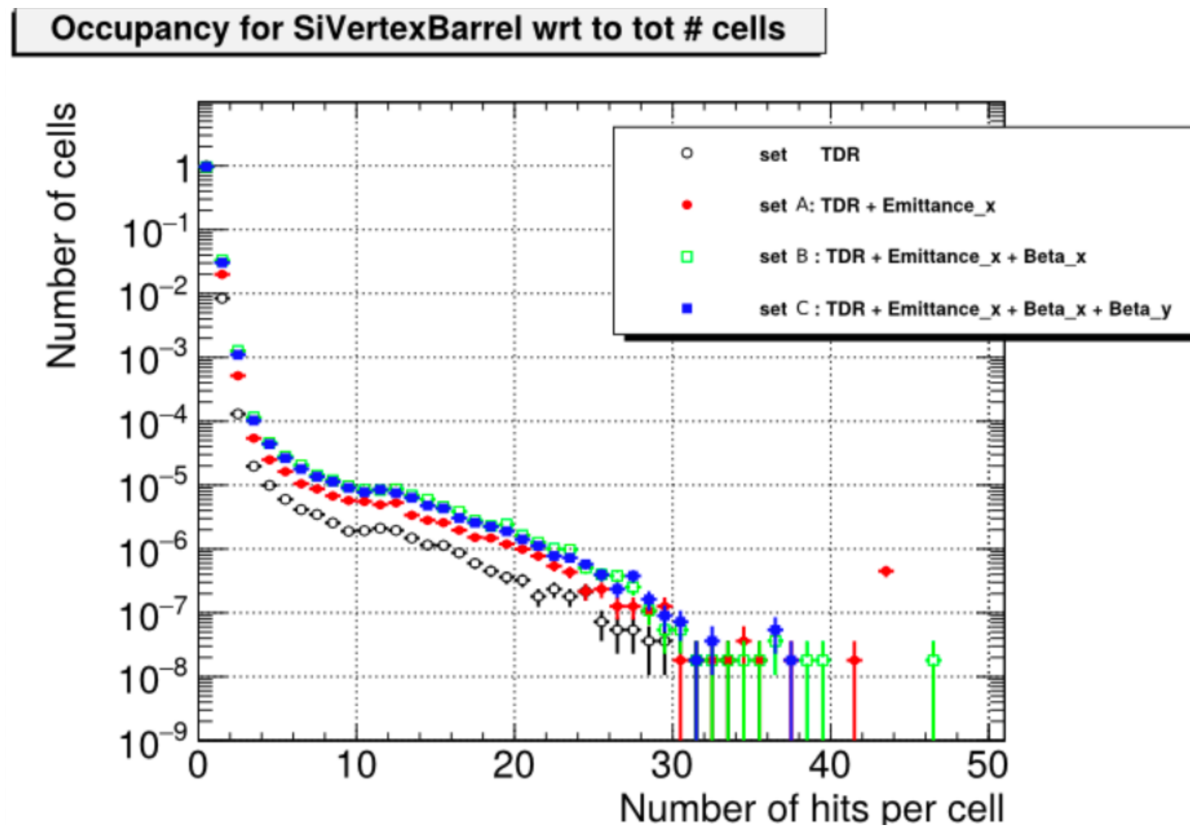
Pair background studies for the ILC250

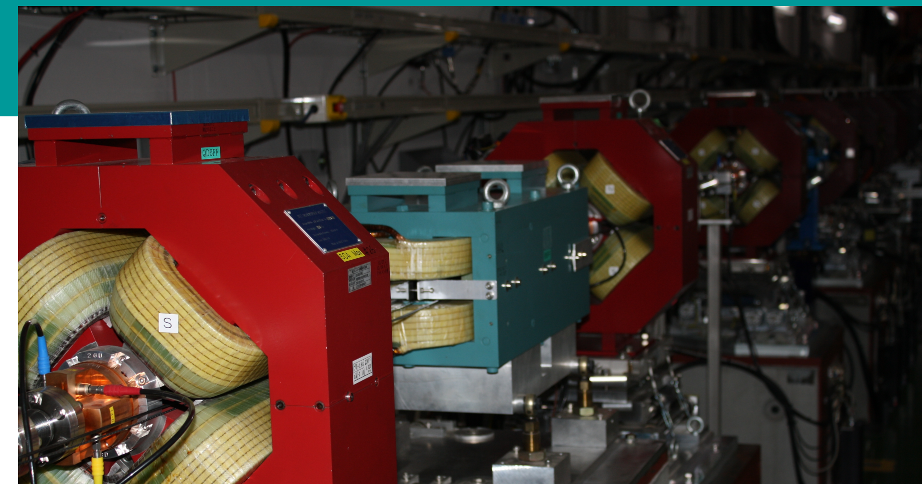
SiD Vertex Detector Occupancy

Number of cells containing a certain amount of hits, normalized by the total number of cells of the vertex detector.



SiD is confident that the occupancy can be accommodated in the design of the pixel detector.
→ **Green light for changes of the machine parameters!**

Conclusion



Realizing a new particle accelerator does not only mean **unfathomable CPU time of calculations and simulations**, but also **hands-on work at prototypes** of accelerator machines and detector components!

The ILC is ready to go!
Young scientists are needed to make it happen, and then to do great physics at the ILC. :)

Backup

1. ILC beam parameters
2. ILC250 stage
3. ILC Main Beam Dump simulations

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In comparison to LHC

		Baseline 500	Lumi Upgrade	TeV Upgrade	LHC 25ns
E_{CM}	[GeV]	500	500	1000	14 000
n_b		1312	2625	2450	2808
Δt_b	[ns]	554	366	366	25
N		2.0×10^{10}	2.0×10^{10}	1.74×10^{10}	11.5×10^{10}
q_b	[nC]	3.2	3.2	2.7	18.4
σ_x^*	[nm]	474	474	481	16 700
σ_y^*	[nm]	5.9	5.9	2.8	16 700
σ_z	[mm]	0.3	0.3	0.25	0.755
$\mathcal{L}$	[cm^{-2} s^{-1}]	1.8×10^{34}	3.6×10^{34}	3.6×10^{34}	1.0×10^{34}

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ILC250 beam parameter sets

Going from ILC500 to ILC250: New beam parameters under discussion in order to increase the luminosity:

		TDR Baseline	Set (A)	Set (B)	Set (C)
E_{CM}	[GeV]	250	250	250	250
n_b		1312	1312	1312	1312
N		2.0×10^{10}	2.0×10^{10}	2.0×10^{10}	2.0×10^{10}
ϵ_x^*	[µm]	10	**5**	**5**	**5**
ϵ_y^*	[nm]	35	35	35	35
β_x^*	[mm]	13	13	**9.19**	**9.19**
β_y^*	[mm]	0.41	0.41	0.41	**0.58**
$\mathcal{L}$	[$\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$]	0.8×10^{34}	1.37×10^{34}	1.97×10^{34}	1.80×10^{34}

Work in progress...

Reduced emittance leads to stronger beam-beam interactions, and therefore to increased e^+e^- pair background.

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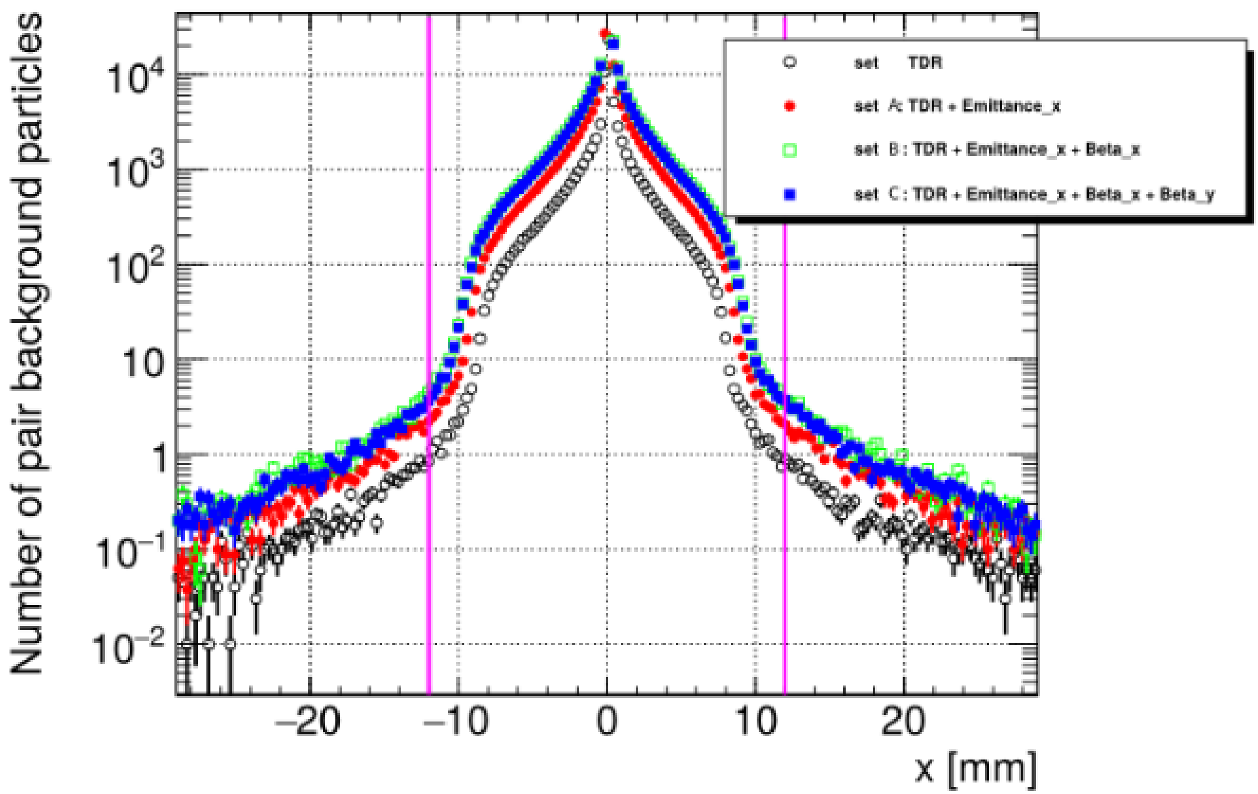
ILC250 beam parameter sets



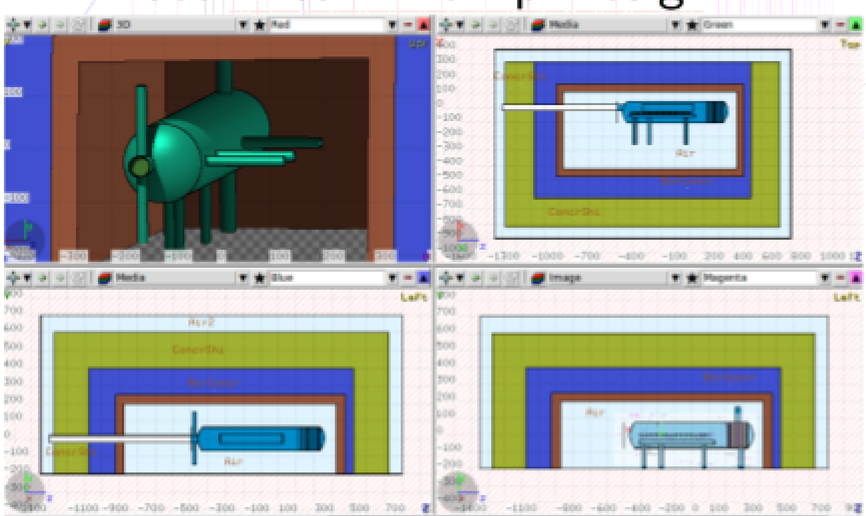
The envelopes are in all schemes well contained within the beam pipe. Less than 10 particles per bunch crossing are to be expected outside the beam pipe.

Simulation of the ILC Main Beam Dumps

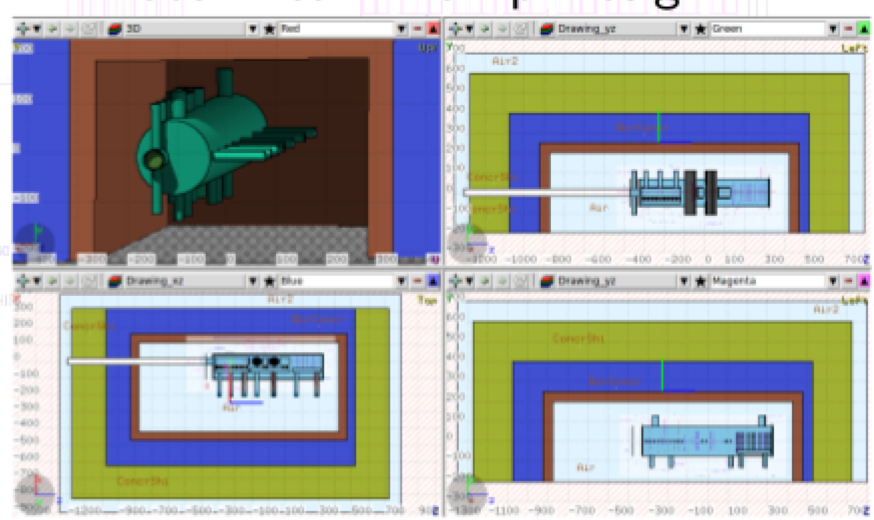
The 17 MW[1] beam is dumped into a water tank after collision.
The activation of the dump surrounding will permit access to the dump area. Neutrons ($\lesssim 10^{10}\,\mathrm{cm}^{-2}\,\mathrm{yr}^{-1}$) are emitted that irradiate the surroundings, and travel back towards the detectors. [7]

Goal: Simulating the energy deposition, irradiation, and background particles

Water Beam Dump Design 1



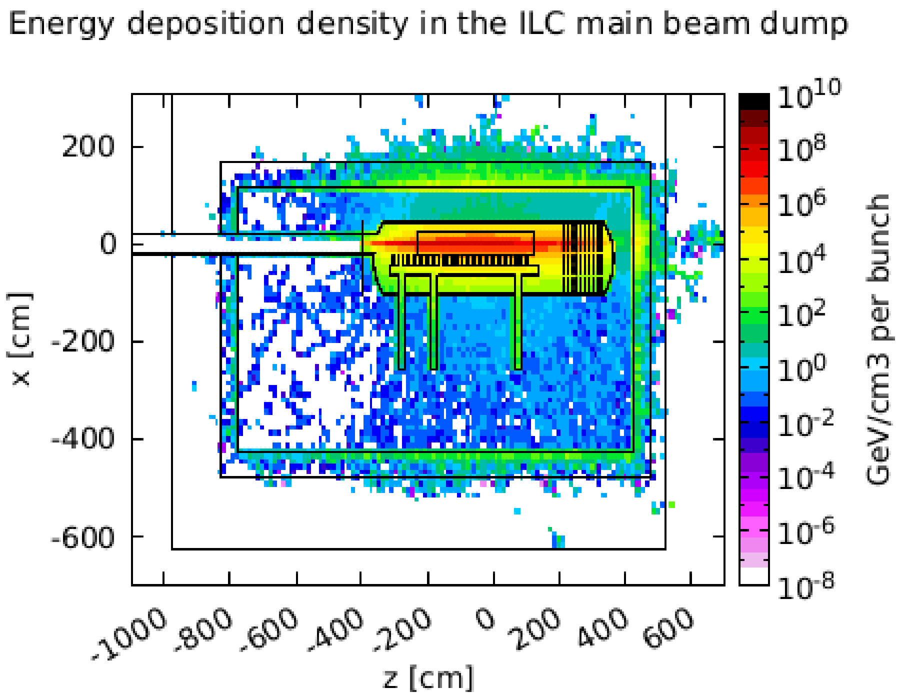
Water Beam Dump Design 2



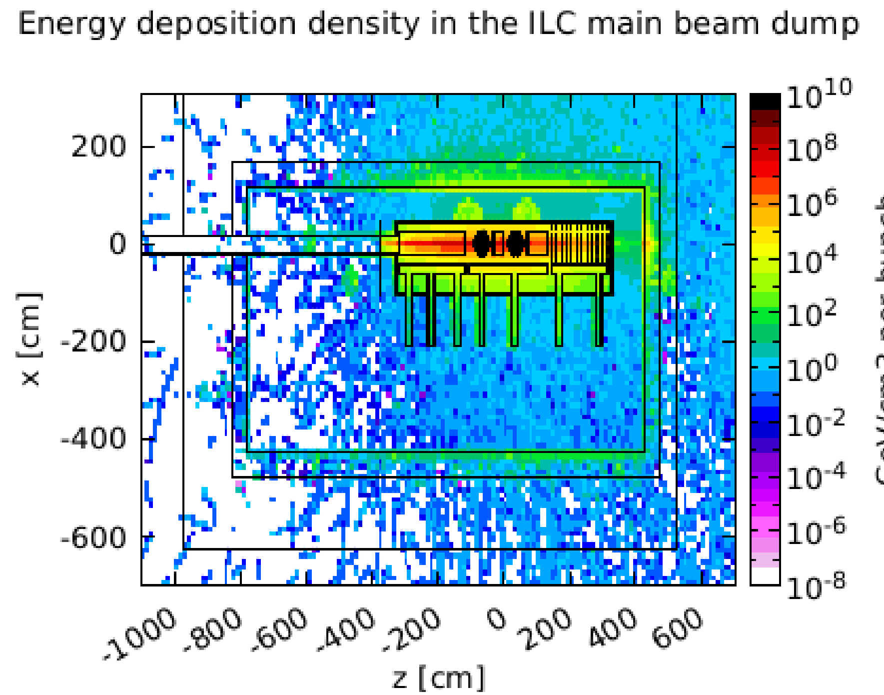
[1] 13.7 MW average beam power + 20% margin

Simulation of the ILC Main Beam Dumps

Design 1



Design 2

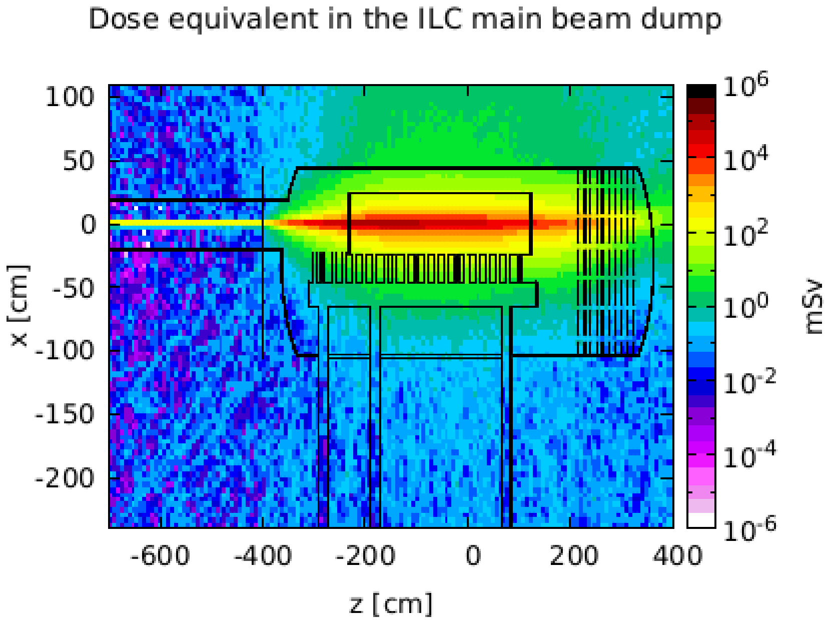


Shielding walls seem to stop particles fluxes well, but large scattering in Design 2 at high water pressure sections leads to energy deposition outside the walls.

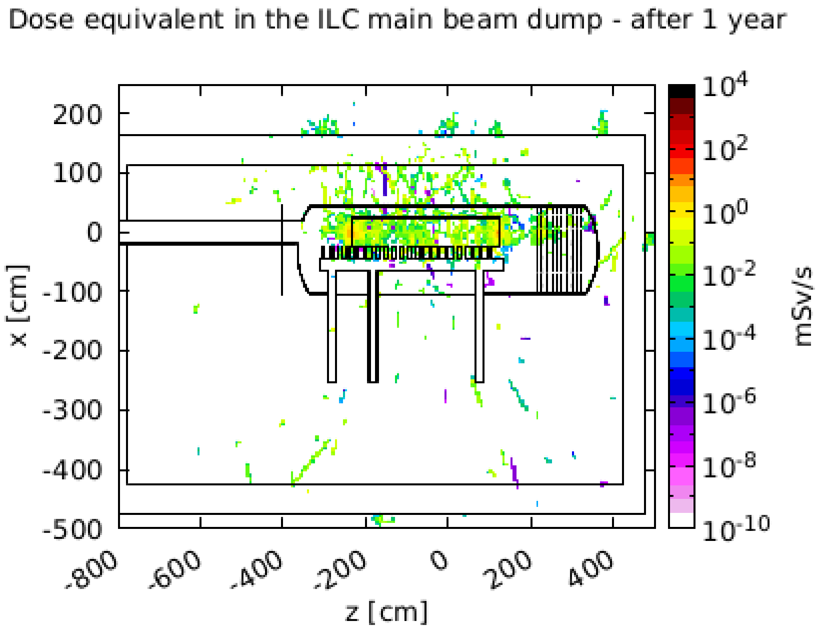
Simulation of the ILC Main Beam Dumps

After one month of beam operation, the beam is turned off.

Instantaneous

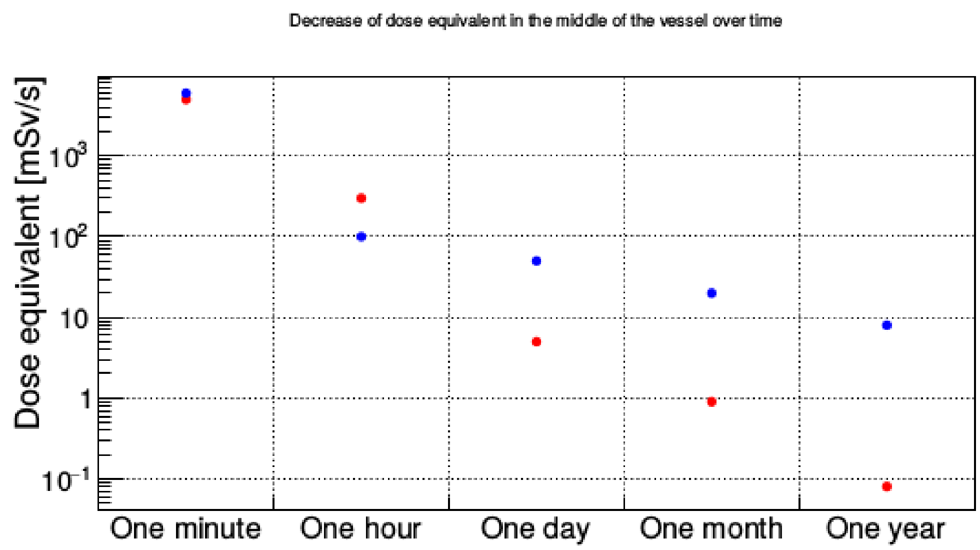


After 1 year



Simulation of the ILC Main Beam Dumps

The dose rate measured at the longitudinal shower maximum inside the vessel over time:



After one year, the dose rate drops to $\sim$ **0.1 mSv/s** for Design 1 and to $\sim$ **10 mSv/s** for Design 2.