Impact of Stray Magnetic Fields on Low-Emittance Beam Dynamics

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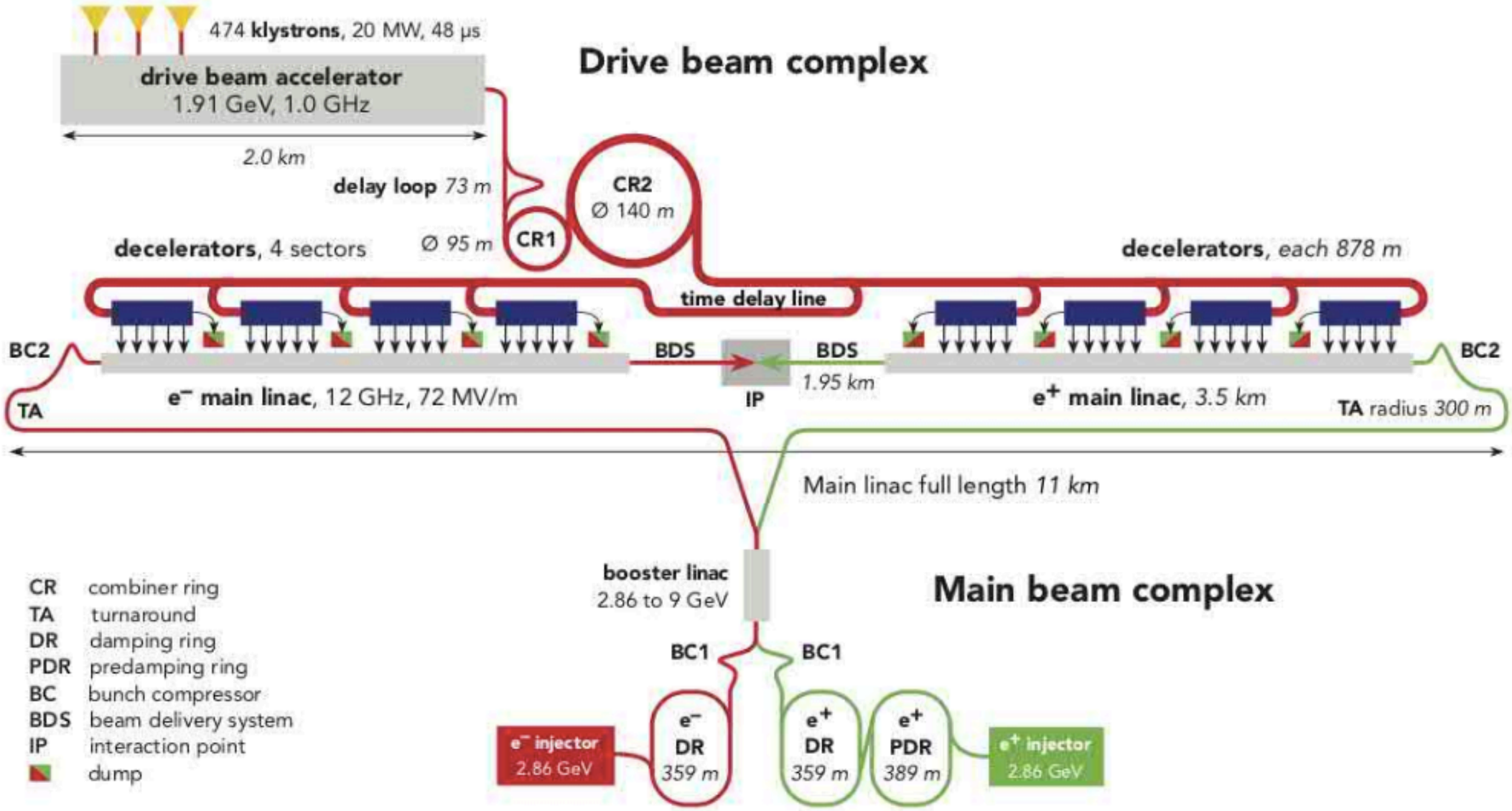
The Compact Linear Collider

The Compact Linear Collider

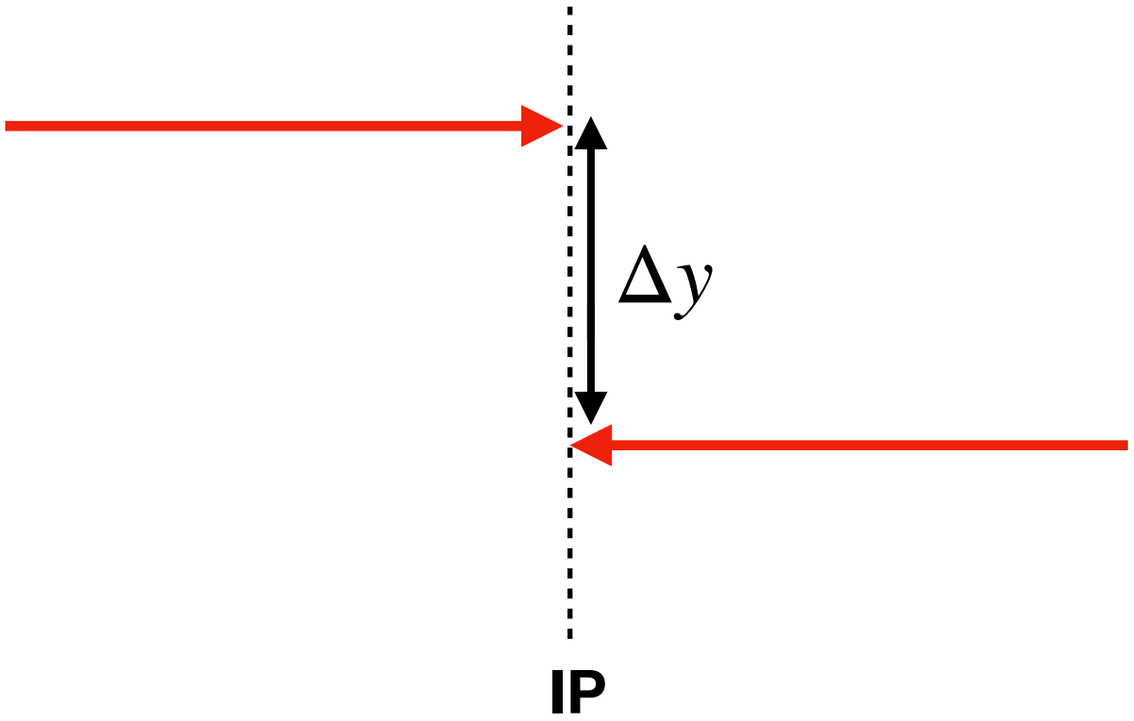


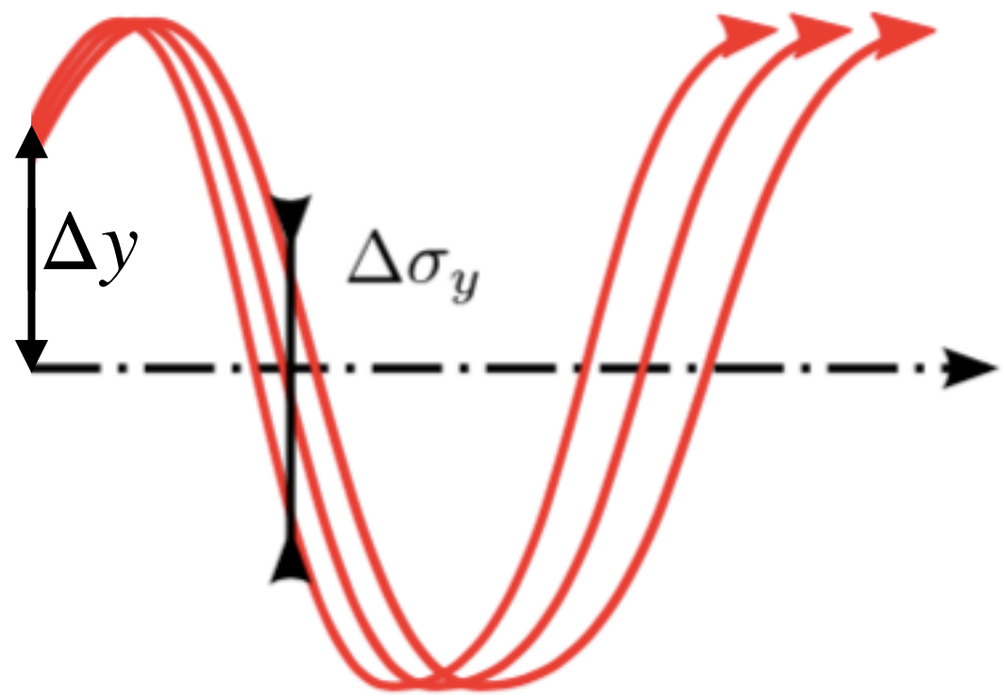
- Proposed e^+e^- collider - first stage at E_{CM}=380 GeV.
- Targets σ_x=150 nm, σ_y=3 nm.

Stray Magnetic Fields

Stray Magnetic Fields

- External (referred to as *stray*) magnetic fields lead to:
  - A beam-beam offset at the IP.
  - Emittance growth.

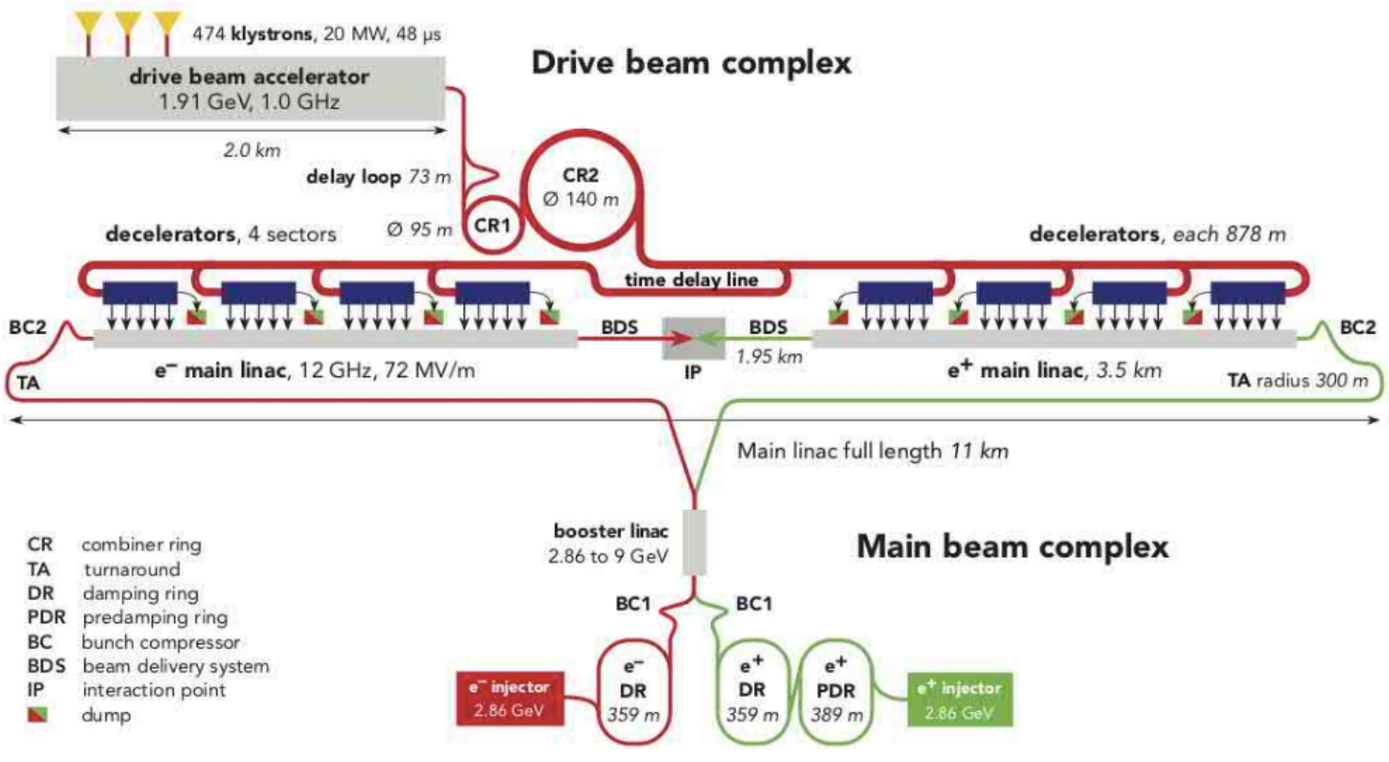




- Only dynamic stray fields are of concern.

Tolerances

- Coherent stray fields:
  - Constant amplitude across a section.
  - Tolerances for 2% luminosity loss:

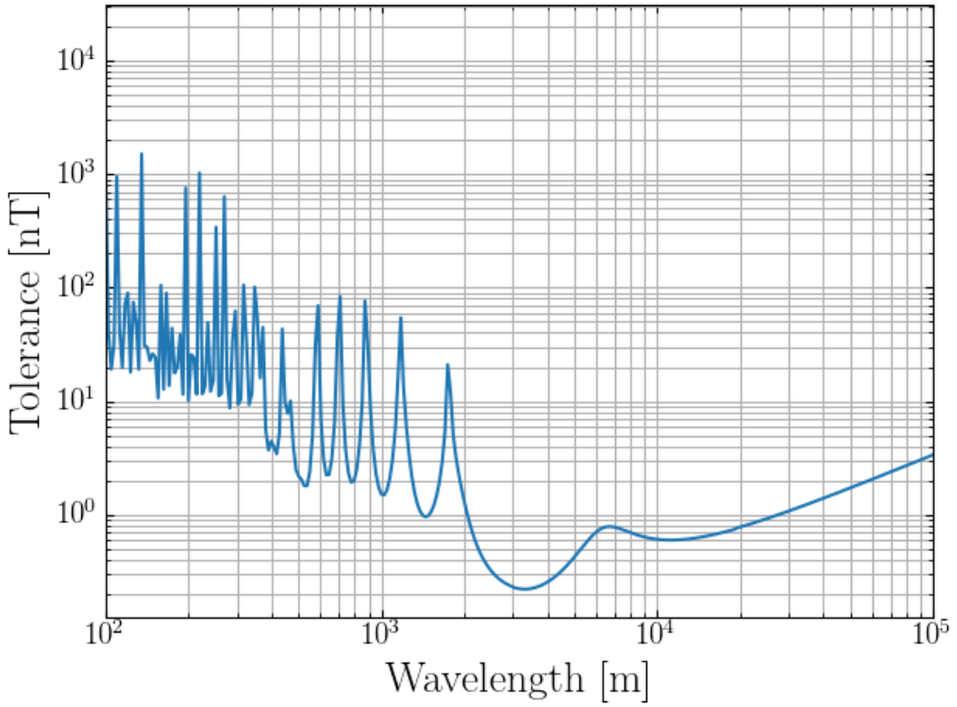


Section	Tolerance (nT)
Long Transfer Line	27
ML	540
BDS	1.3

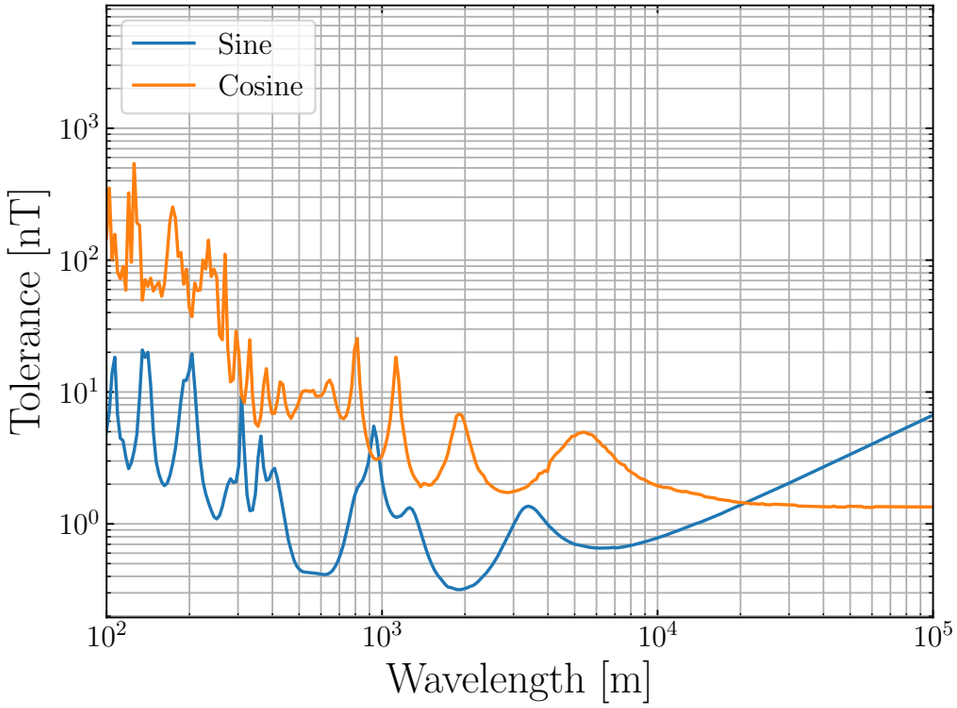
Tolerances

- Sinusoidal stray fields:
  - Tolerances for 2% luminosity loss:

Long Transfer Line



Main Linac + Beam Delivery System



- The tightest tolerance is ~0.1 nT.
- Long wavelength approaches ~1 nT coherent tolerance.

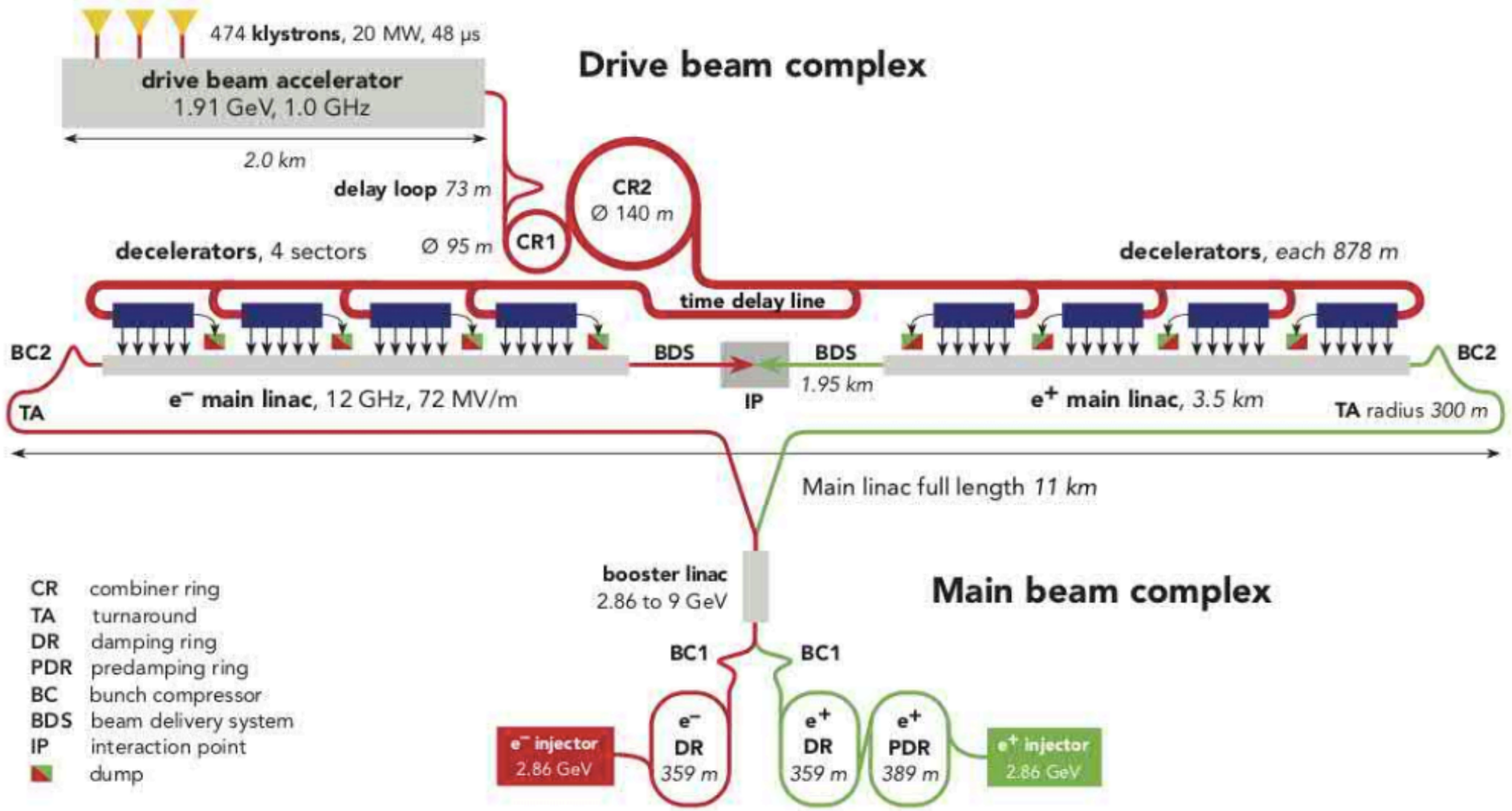
Sources

	Examples	Typical Amplitude	Frequency Range
Natural	Geomagnetic disturbances, Lightening	O(1-100 nT)	< 1 Hz
Environmental	Electrical grid, Railways	O(100 nT)	50 Hz, 16 Hz
Technical	RF, Vacuum systems, Cables	O(μT)	> 1 Hz

- A review of natural sources:
  - **B. Heilig et al., “Natural sources of geomagnetic field variations”. CERN-ACC-2018-028. CLIC-Note-1078.**
  - Are within tolerance or dealt with a beam-based feedback.
- Biggest environmental source is 50 Hz.
  - Looks static to the beam.
- Technical sources pose the greatest risk.

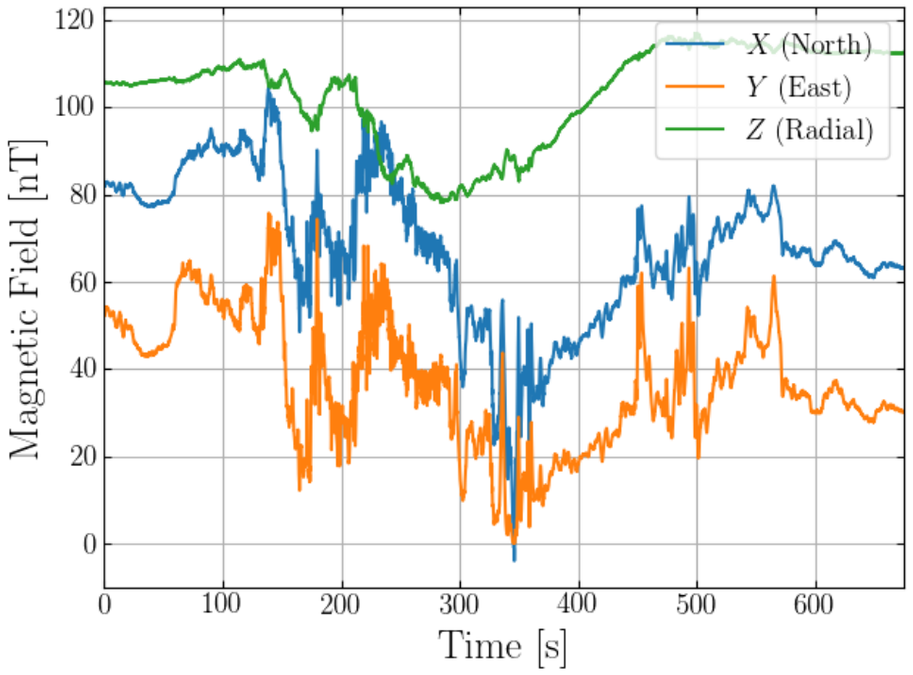
Integrated Simulations

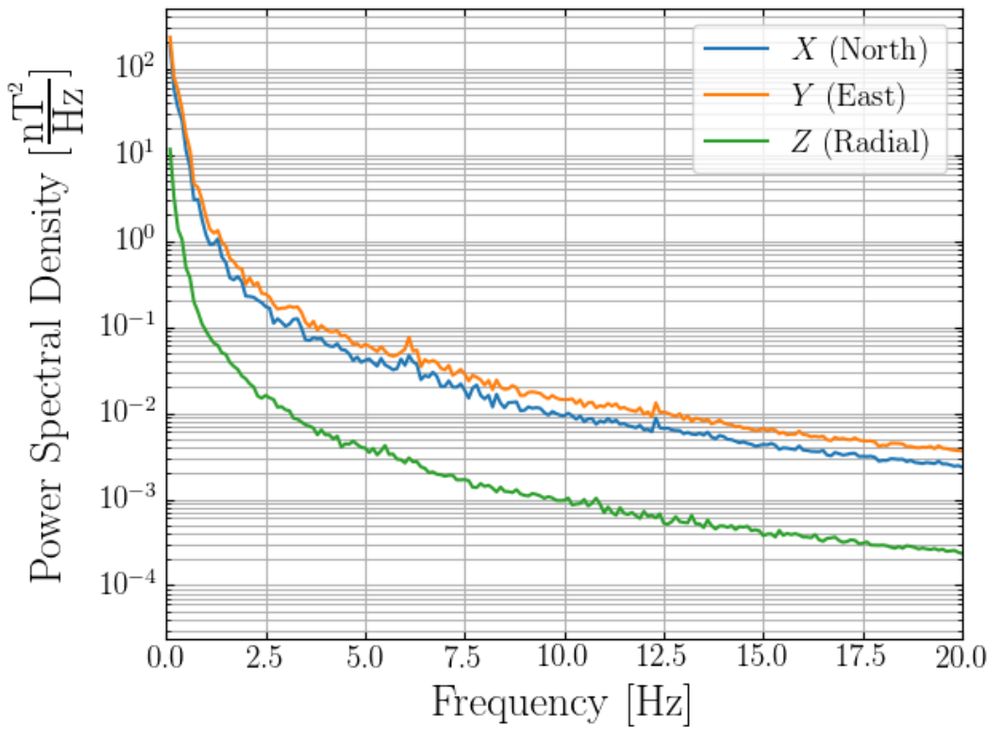
Integrated Simulations



- The RTML, ML and BDS were integrated into a single simulation in PLACET.
- Luminosity was calculated with GUINEA-PIG.

Geomagnetic Disturbances





- Measured on 08/06/14 in Tihany, Hungary.
- Fluctuations O(10 nT) over seconds.
- Coherent variations across the accelerator.
- Measurement provided by B. Heilig.
- Typical occurrence is monthly.
- Lasts a few hours.

Geomagnetic Disturbances

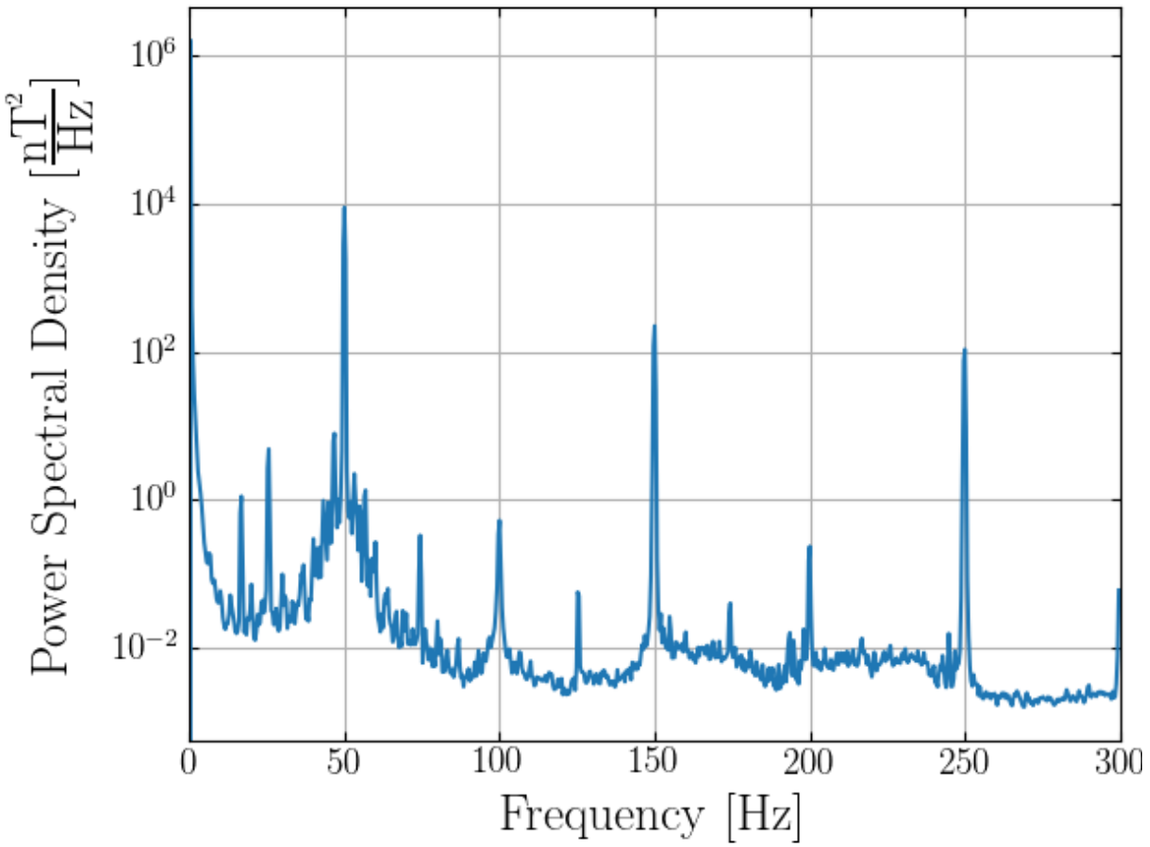
	Luminosity Loss (%)
Direct Effect	16
Beam Pipe	16
Beam Pipe + Beam-Based Feedback	2.1

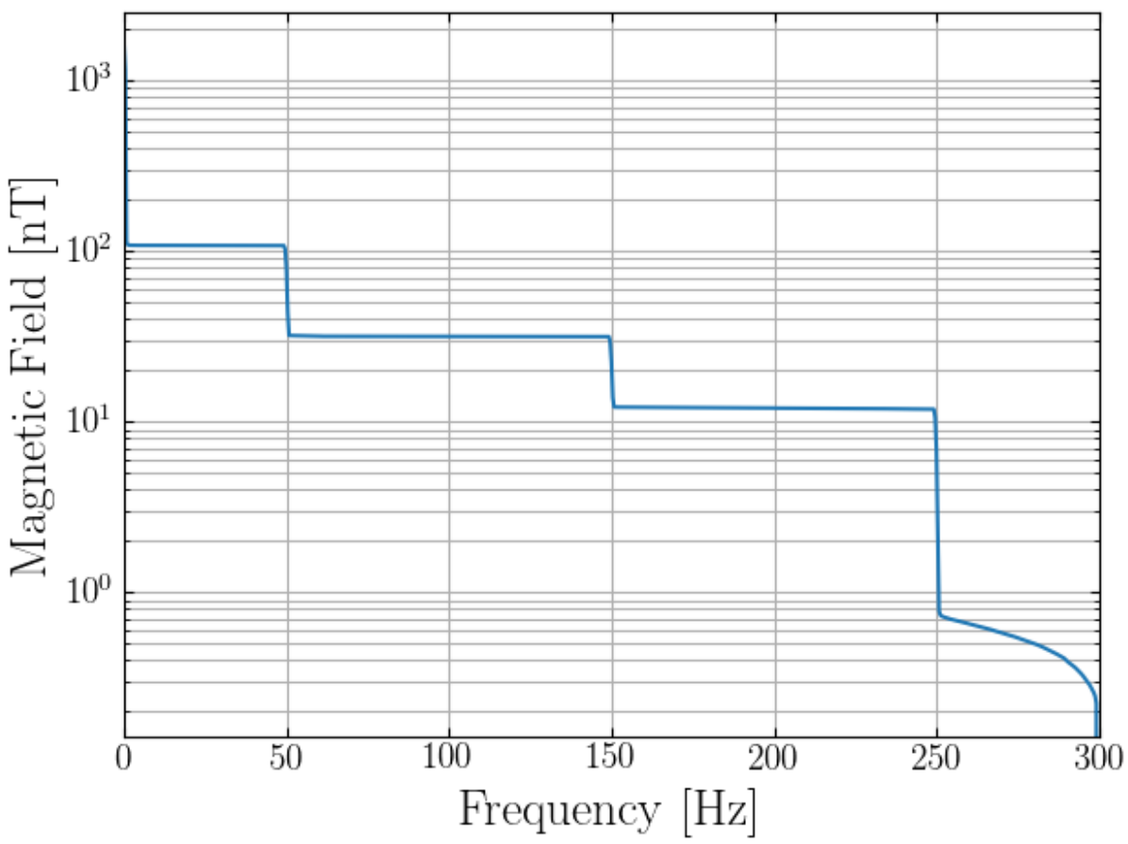
- Simulation of 500 bunch trains (10 s).
- Acceptable performance loss without specific mitigation.

Mitigation

LHC Tunnel Measurement

- Need a realistic power spectrum for CLIC.
  - Campaign to measure stray fields at CERN on-going.
- LHC tunnel near Point 2 (average over 8 locations - 31/01/18):



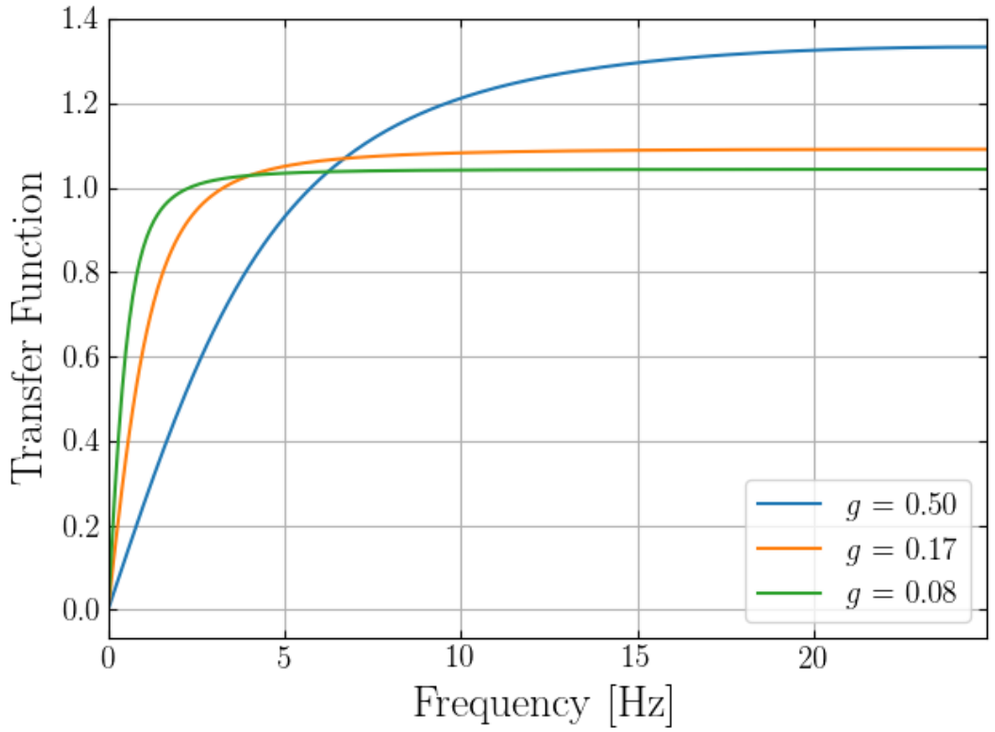


- Contains environmental and some technical sources.

Beam-Based Feedback

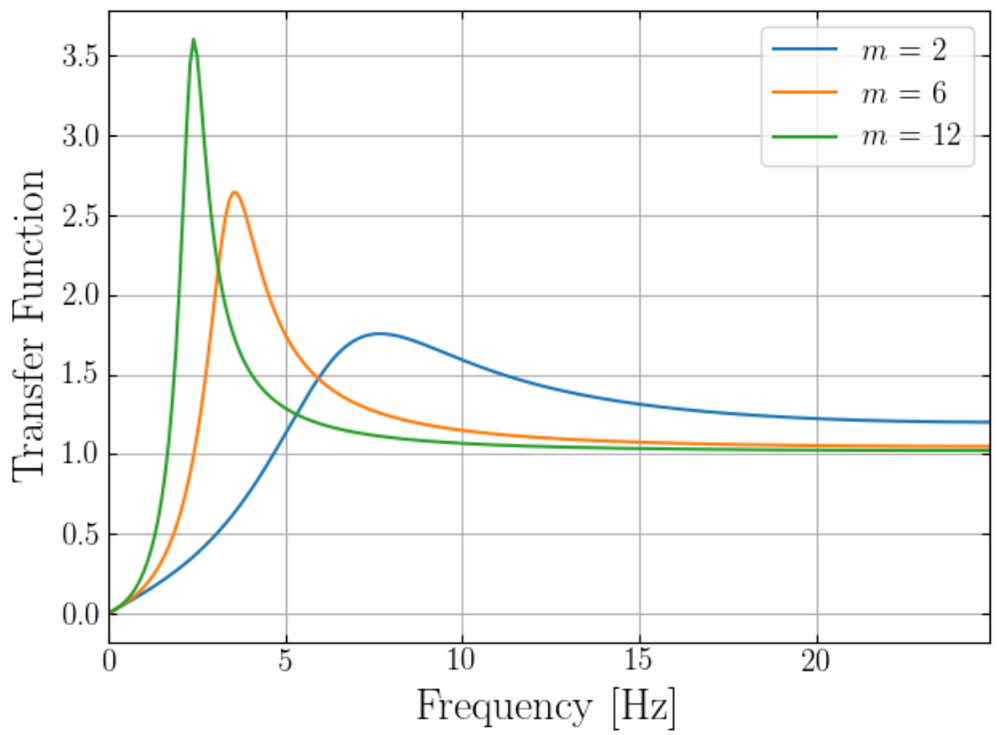
- Actively correct the beam trajectory.
- Different algorithms available:

Deadbeat



$$\Delta y_{n+1} = \Delta y_n - g y_n$$

Recursive

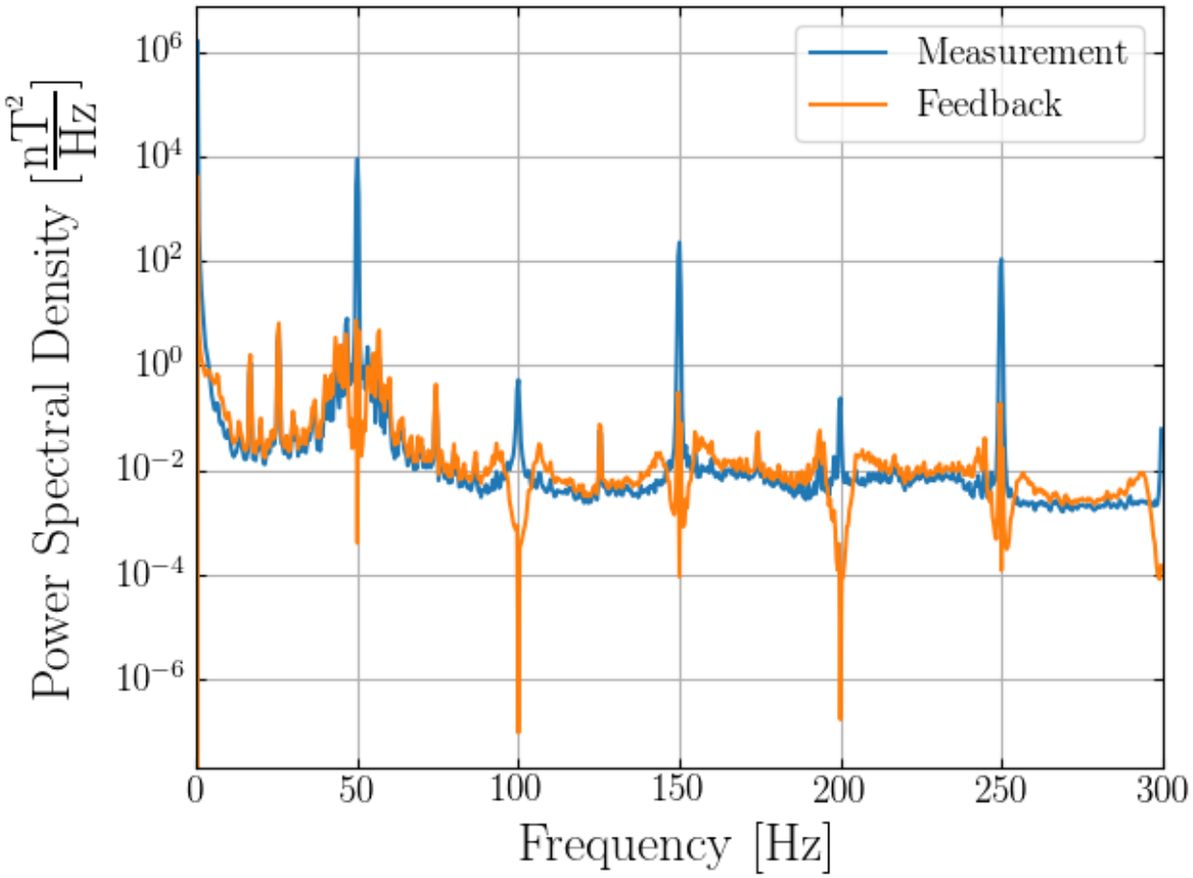


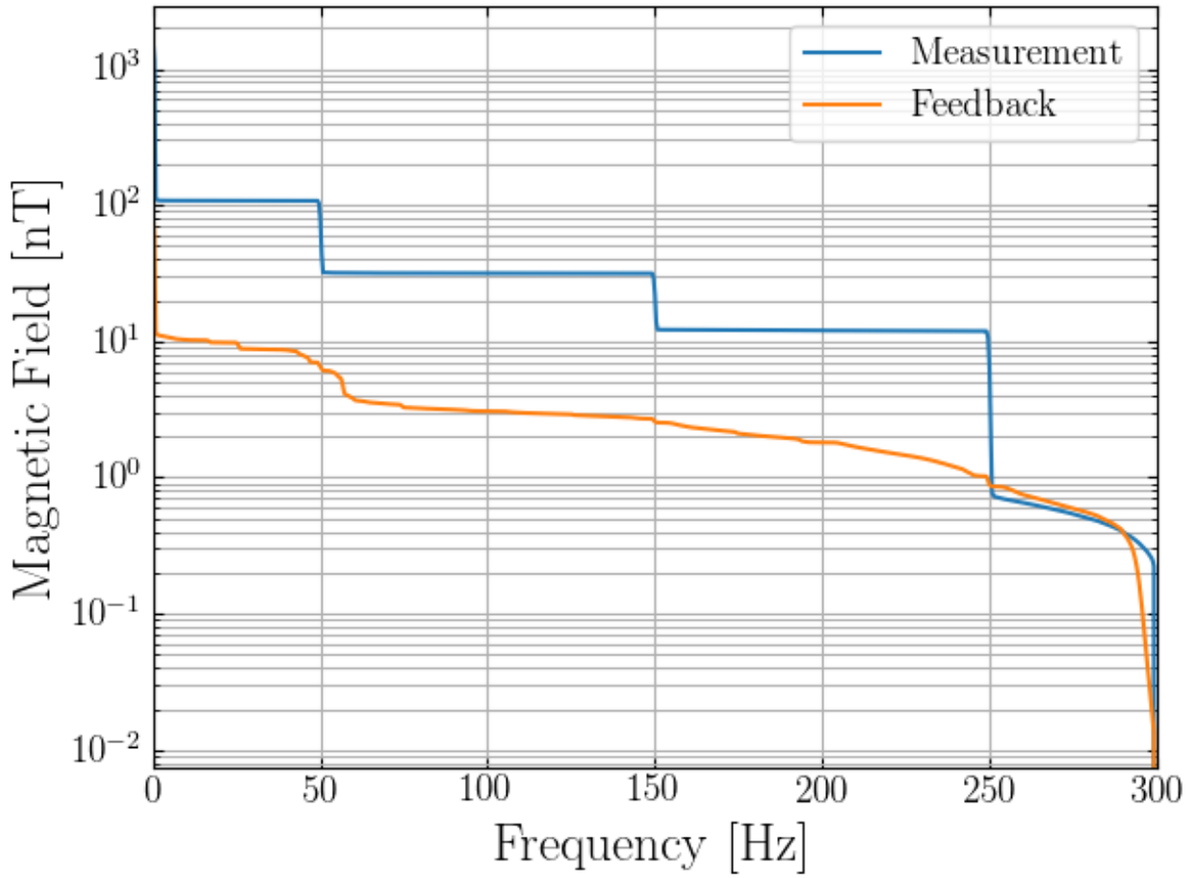
$$\Delta y_{n+1} = \Delta y_n - a_n$$

$$a_n = \frac{1}{m} y_n + \left(1 - \frac{1}{m}\right) a_{n-1}$$

Beam-Based Feedback

- Effect of current feedback system (recursive, *m*=2.5):





- Largest contributions (50 Hz harmonics) removed.
- Magnetic field of ~10 nT remains.

Passive Shielding

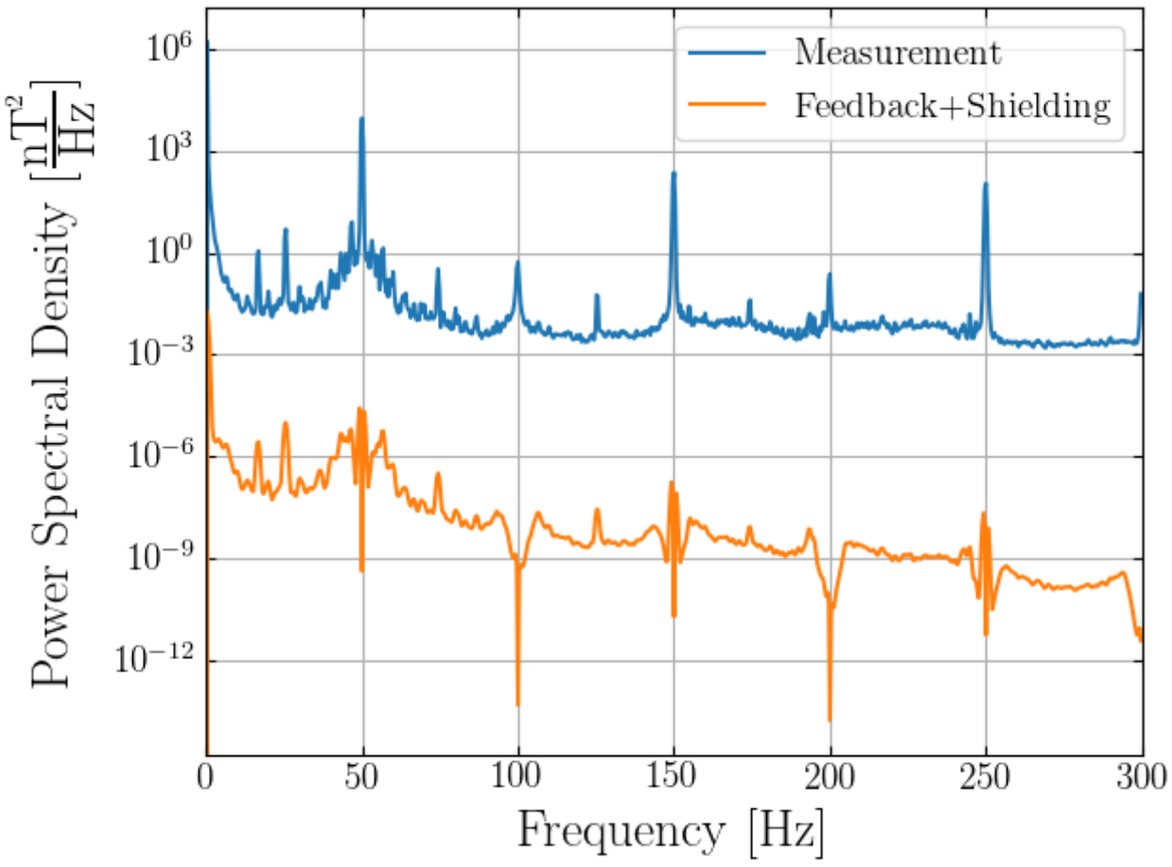
- Use a metallic coating to shield the beam pipe.
- Effectiveness depends on:
  - Material properties, shield geometry and external field.

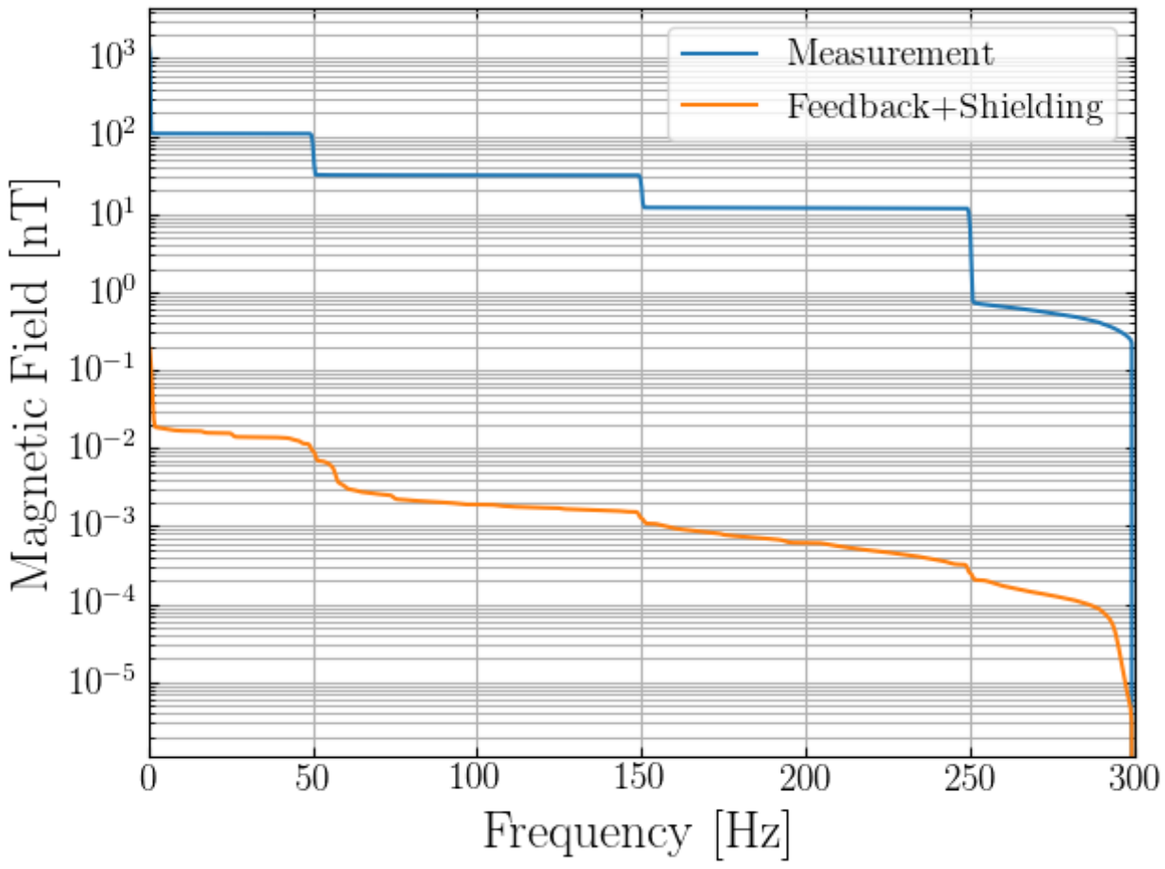
- An analytical model is outlined in:

J. F. Hoburg, “A Computational Methodolgy and Results for Quasistatic Multilayered Magnetic Shielding”, IEEE TRANSACTIONS ON ELECTROMAGNETIC COMPATIBILITY, VOL 38, (1996).

Passive Shielding

- Effect of a 1 mm mu-metal coating:





- Magnetic field within the tightest tolerance of 0.1 nT.

Summary

- CLIC has very tight tolerances O(nT).

- Integrated simulations:
  - Natural source do not pose a serious danger.

- A measurement campaign to characterise stray fields is on-going.

- Mitigation techniques are being investigated:
  - Beam-based feedback and passive shielding.

- Thank you! Questions?

Back Up Slides

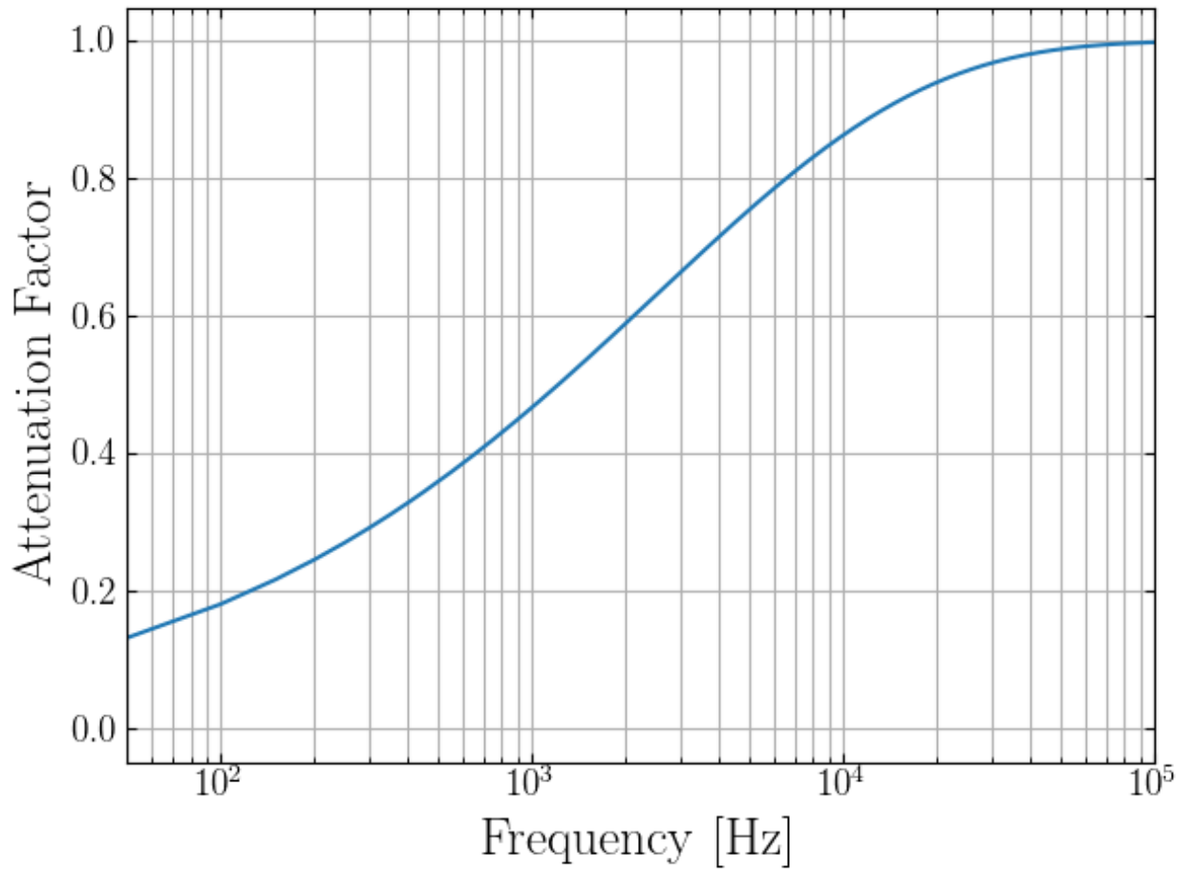
Attenuation from the Earth

- Earth conductivity is 1-50 mS/m.
  - Use 10 mS/m.

- Non-magnetic Earth:
  - Rel. permeability is 1.

- Skin depth for 50 Hz is ~710 m.

- Attenuation of 50 Hz at 100 m is <u>13%</u>.



$$B(d) = B_0 \exp\left(-\frac{d}{\delta}\right) \qquad \delta = \sqrt{\frac{2}{\omega\mu\sigma}}$$