CLIC Magnetic Stray Field Studies

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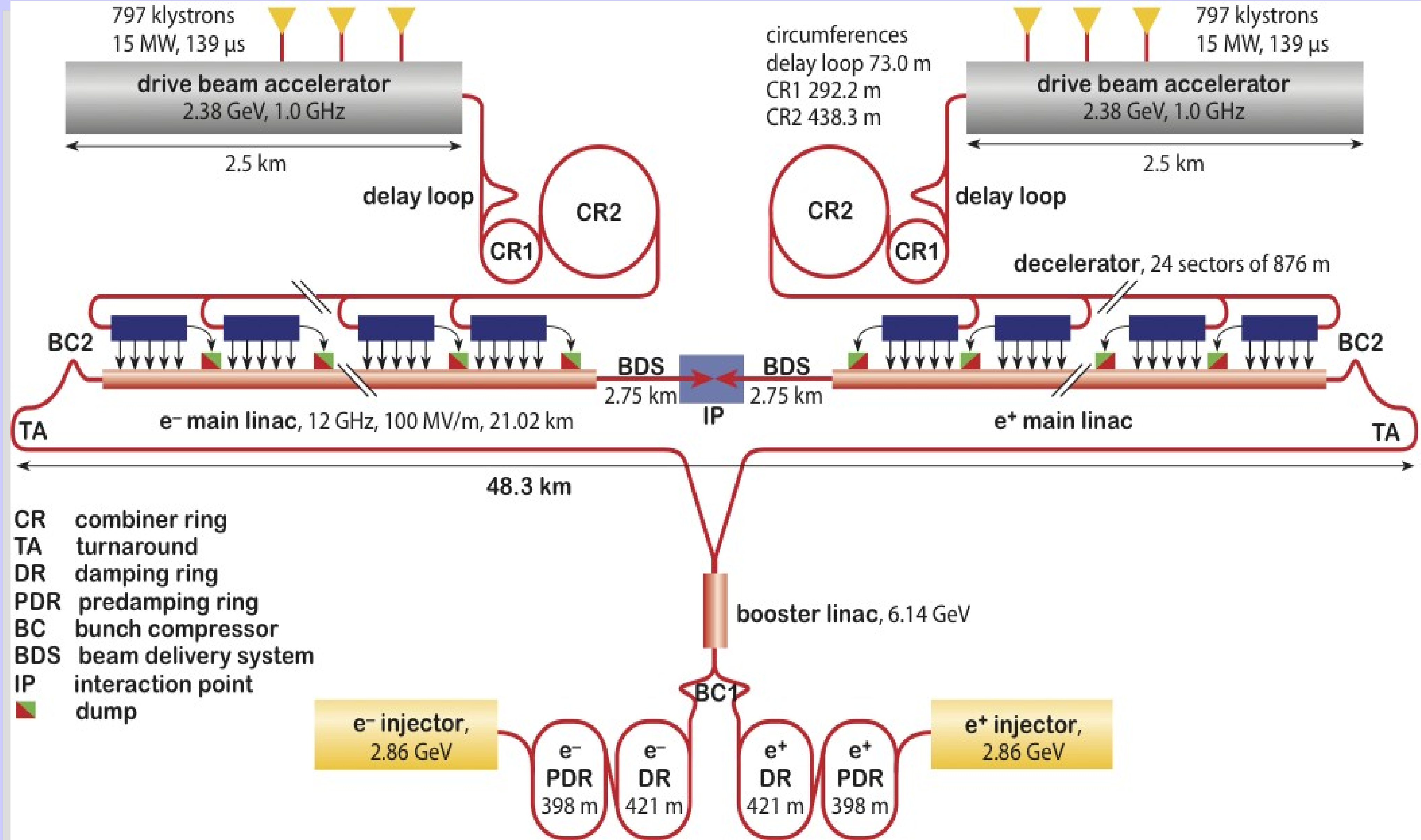
Outline

- Based on IPAC10 paper[1]
- Stray Fields
- Simulations
- Sensitivities / Problem Areas
- Magnetic shielding
- Mitigation techniques

1: Impact of Dynamic Magnetic Fields on the CLIC Main Beam, IPAC 10

CLIC


797 klystrons
15 MW, 139 μs
drive beam accelerator
2.38 GeV, 1.0 GHz
2.5 km
delay loop
CR2
CR1
circumferences
delay loop 73.0 m
CR1 292.2 m
CR2 438.3 m
797 klystrons
15 MW, 139 μs
drive beam accelerator
2.38 GeV, 1.0 GHz
2.5 km
delay loop
CR2
CR1
decelerator, 24 sectors of 876 m
BC2
BDS
2.75 km
BDS
2.75 km
IP
BC2
TA
e⁻ main linac, 12 GHz, 100 MV/m, 21.02 km
e⁺ main linac
TA
48.3 km
CR combiner ring
TA turnaround
DR damping ring
PDR predamping ring
BC bunch compressor
BDS beam delivery system
IP interaction point
dump
booster linac, 6.14 GeV
BC1
e⁻ injector,
2.86 GeV
e⁻
PDR
398 m
e⁻
DR
421 m
e⁺
DR
421 m
e⁺
PDR
398 m
e⁺ injector,
2.86 GeV

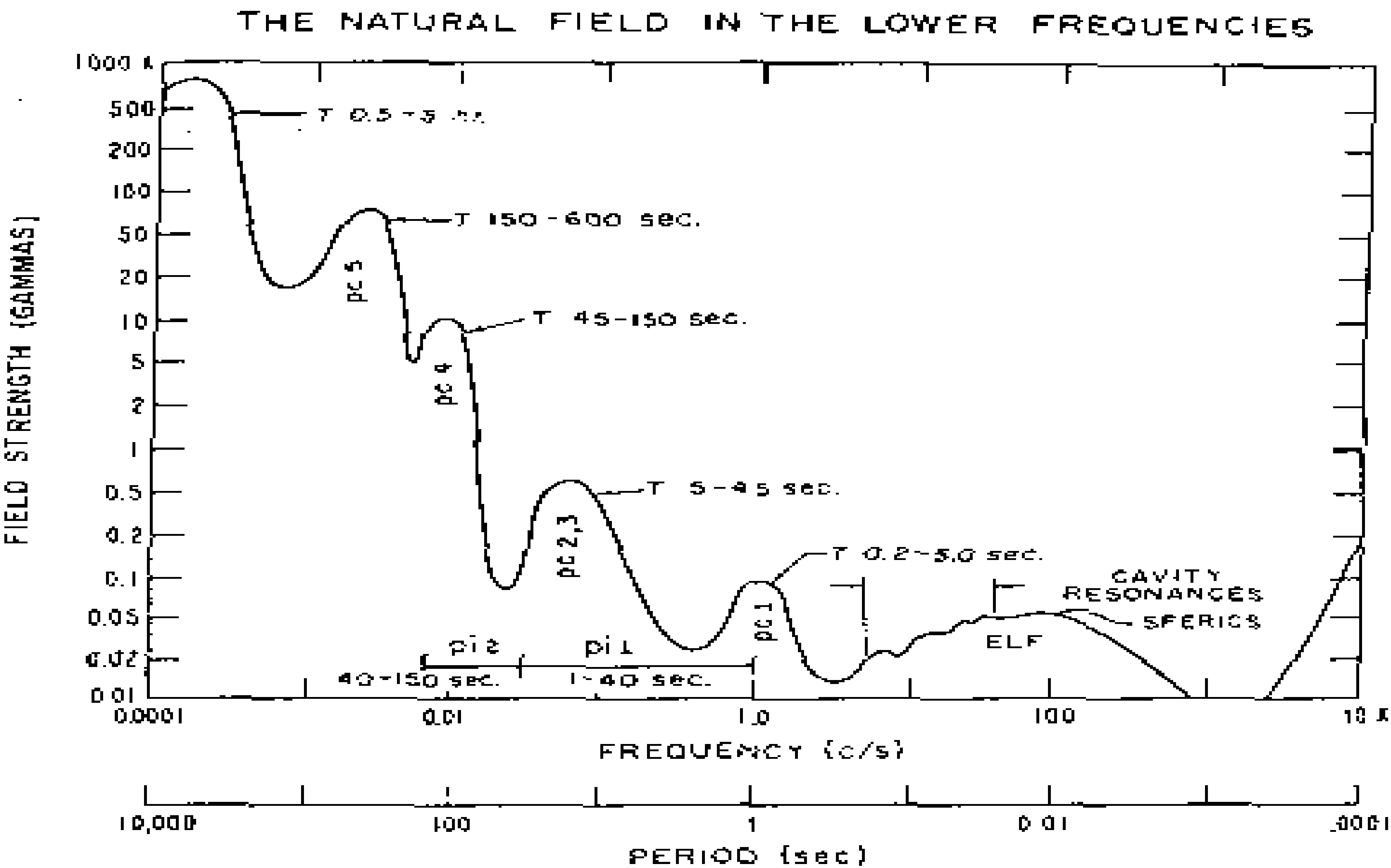
Magnetic stray fields

- Natural (earth, ore deposit)
- Technical field
  - RF cavities / klystrons
  - power lines / sources
  - vacuum pumps
  - trains
  - etc.
- Worry about dynamic fields

Frequencies

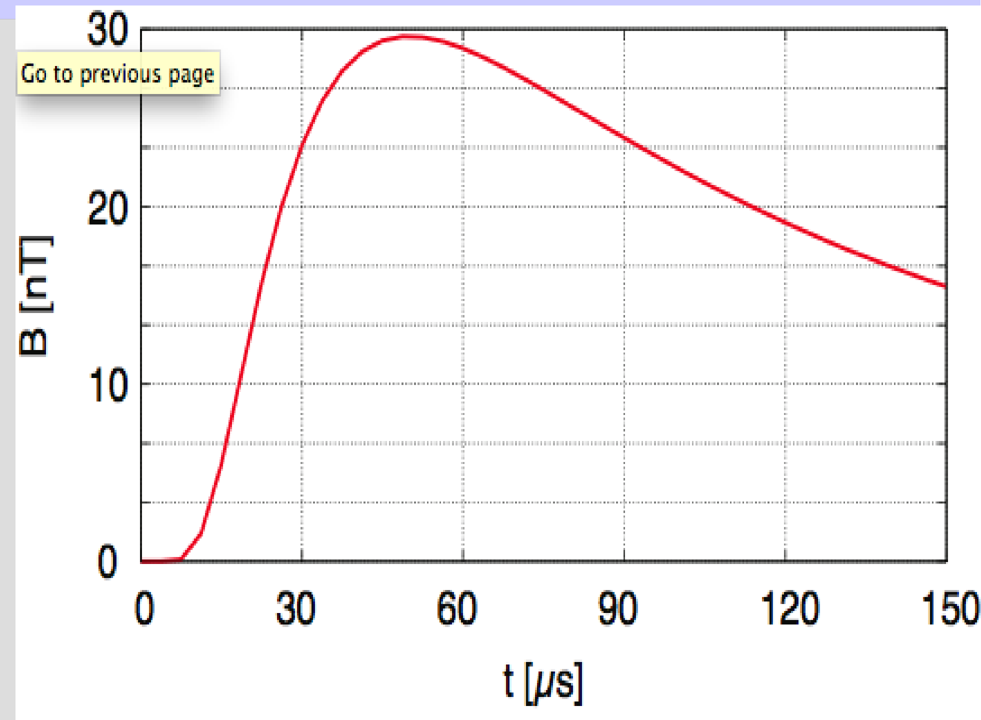
- High frequencies (> kHz) shielded by structures and beam pipe (skin depth ~ $1/\sqrt{f}$)
- Low frequencies (< Hz) reduced by feedbacks
- Harmonics of 50 Hz not seen by the beam

Earth magnetic field



Drive Beam

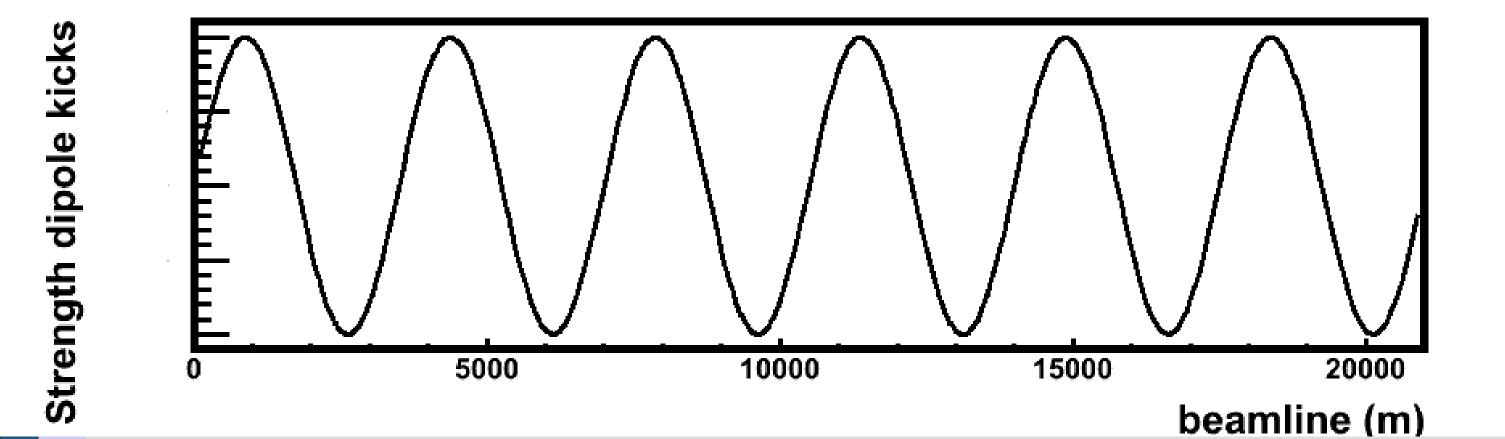
- Stray field source unique for CLIC
- 243.7 ns, 101 A
- 0.5 m from main linac
- Field 'seen' by next main linac pulse (20ms later): 20 pT



Magnetic field induced by a drive beam at r=0.5m with 2mm copper shielding

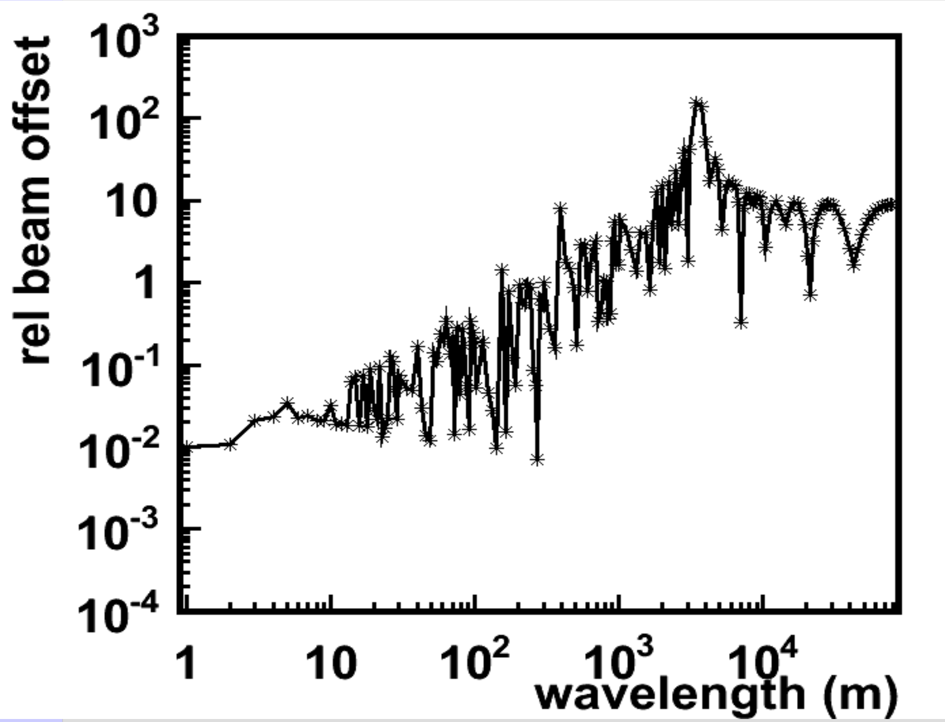
Transfer line beam (3 m from drive beam) receive kicks of 5 nT (static effect), fluctuations much lower

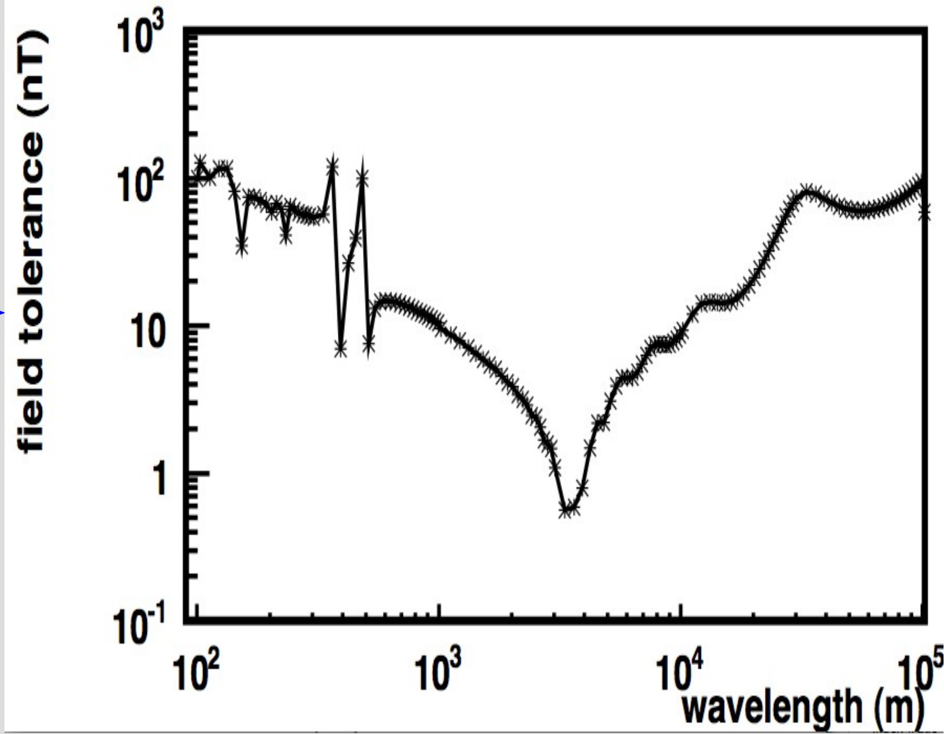
Simulations (example RTML)



Simulated by grid of dipole kickers with 1m distance

Tolerance (2% lumi loss): vert. emitt growth 0.4 nm

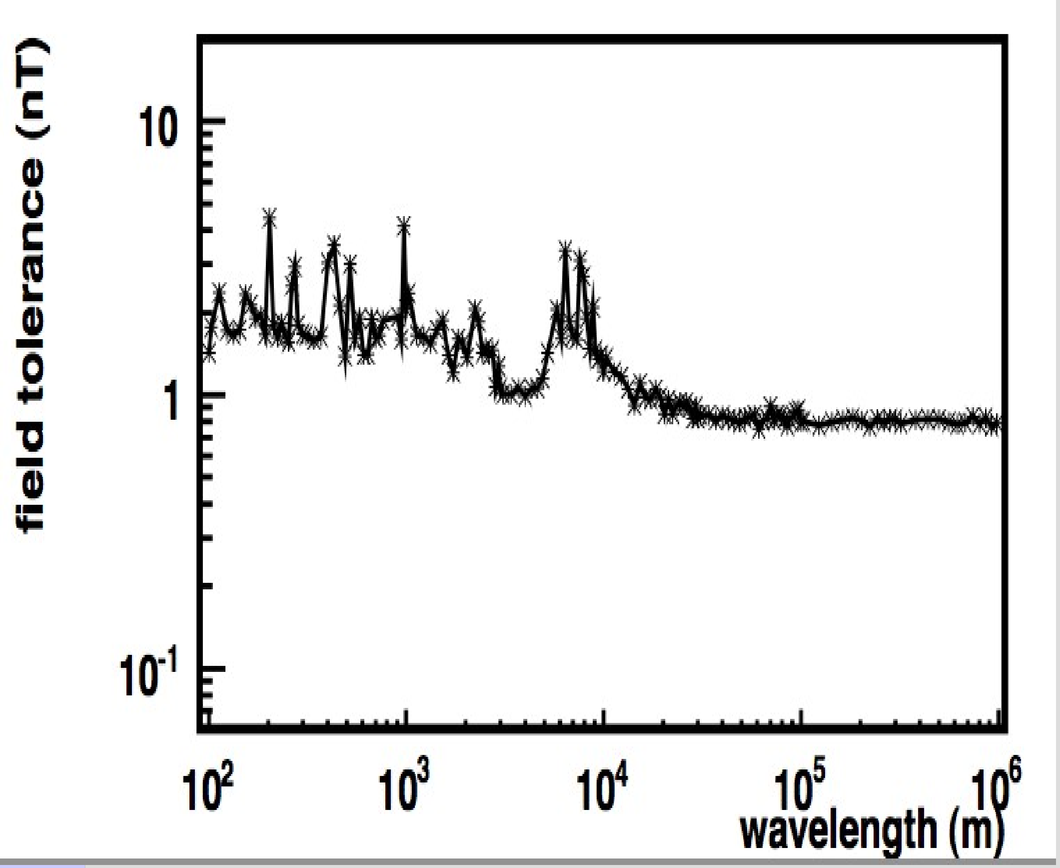




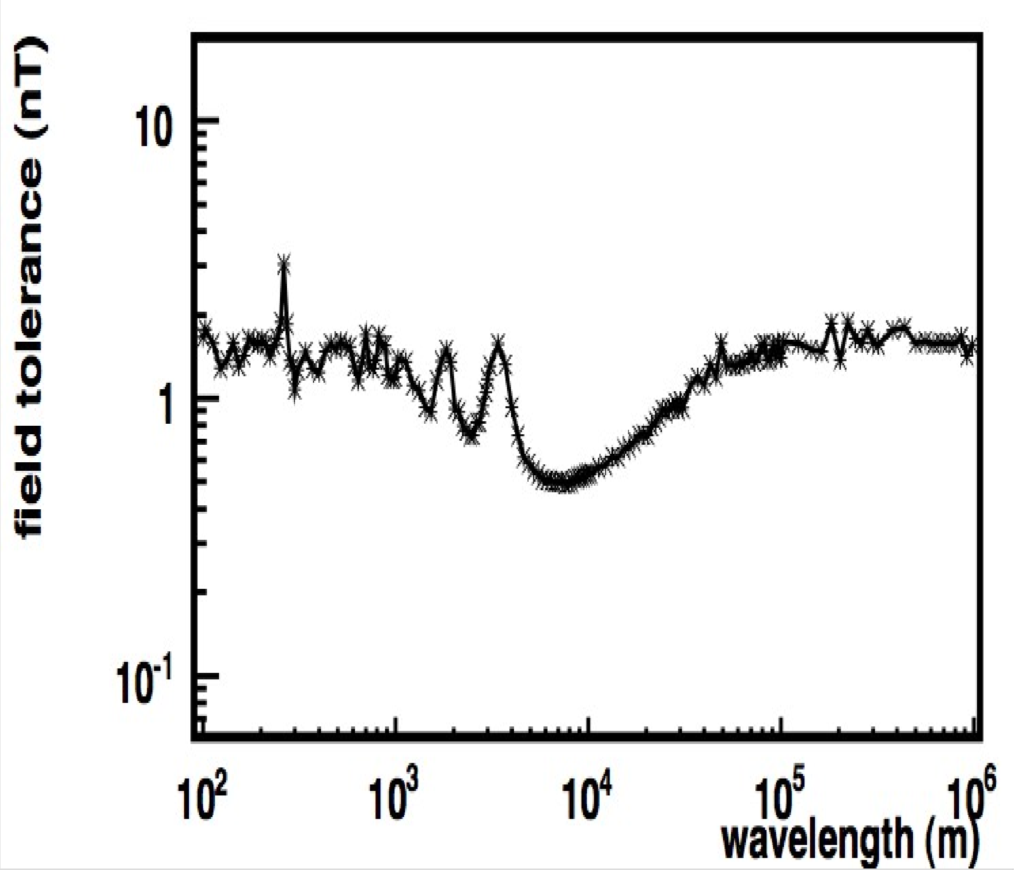
Sensitive to magnetic stray fields of ~ 1 nT

BDS sensitivity

symmetric wrt IP



anti-symmetric wrt IP



Sensitivities (uncorrected)

- Tolerances for a 2% lumi loss

	resonances	random fluctuations
Transfer line	0.1 nT*	10 nT/m*
Main linac	10 nT	50 nT/m
Main linac + BDS	1 nT	10 nT/m

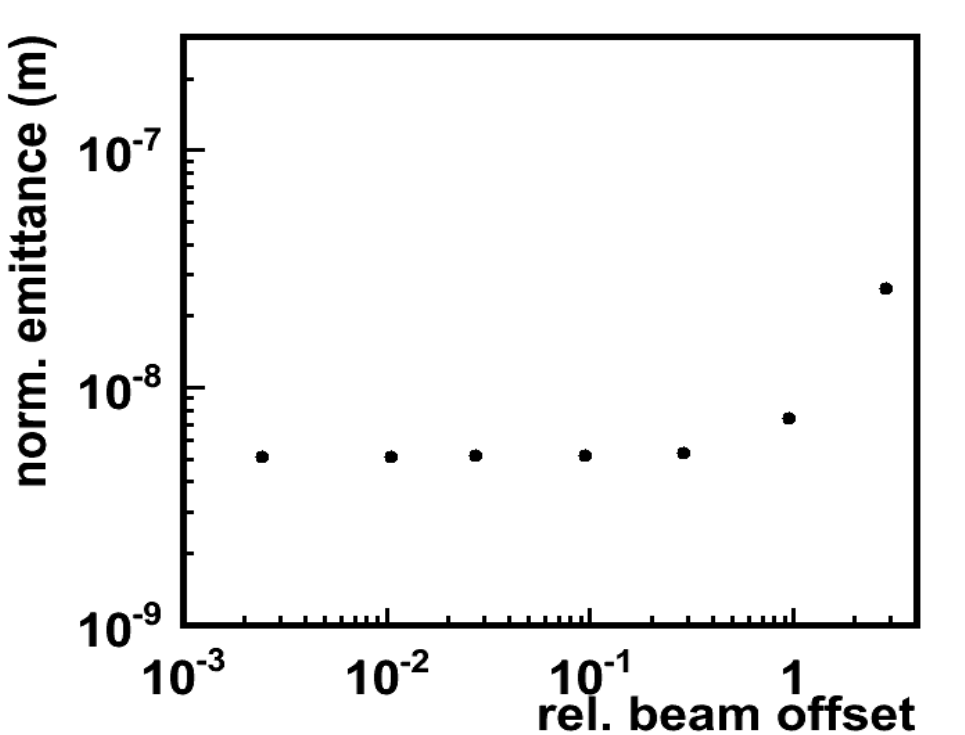
* = beam offsets in the transfer line will be corrected for with a feed forward system after the turnaround loop

Turnaround + Feedforward

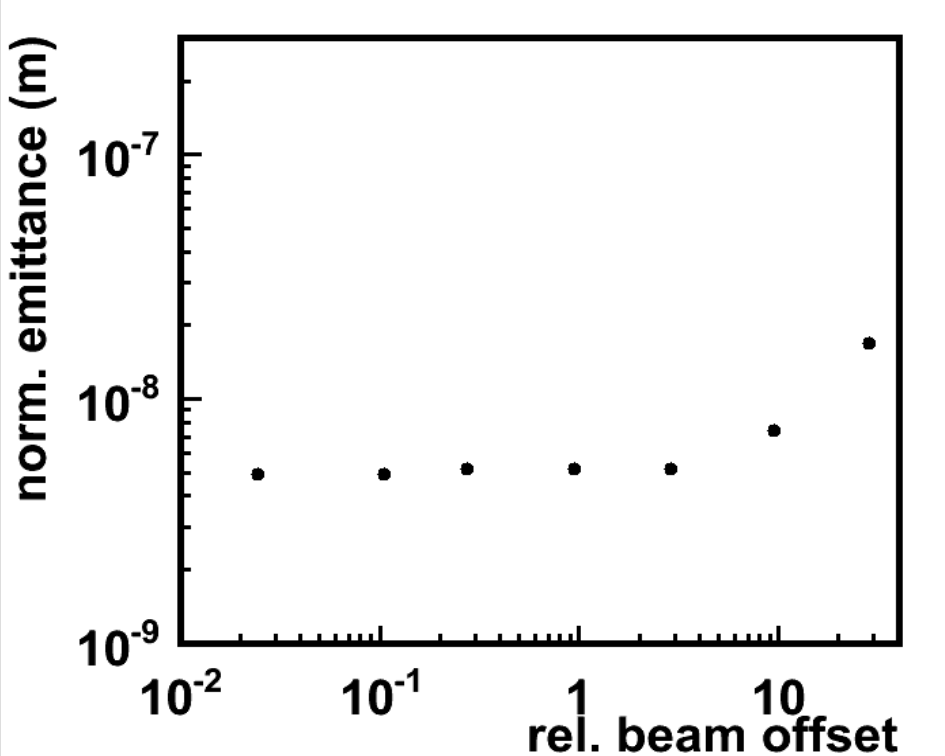
- A feed forward system after the turnaround loop can almost fully correct the beam offset in the transfer line
- Problem:
  - emittance growth in turnaround loop due to beam offset
- New lattice design by Frank Stulle (morning talk)

Emittance growth in TA due to beamoffset

Old Lattice



New Lattice

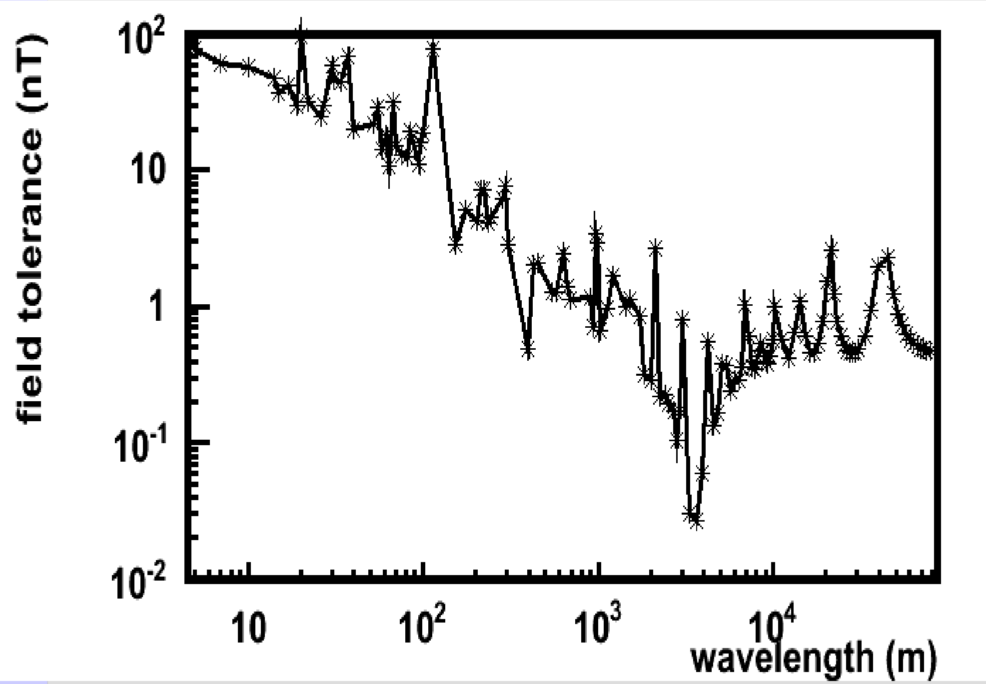


Factor 10 improvement

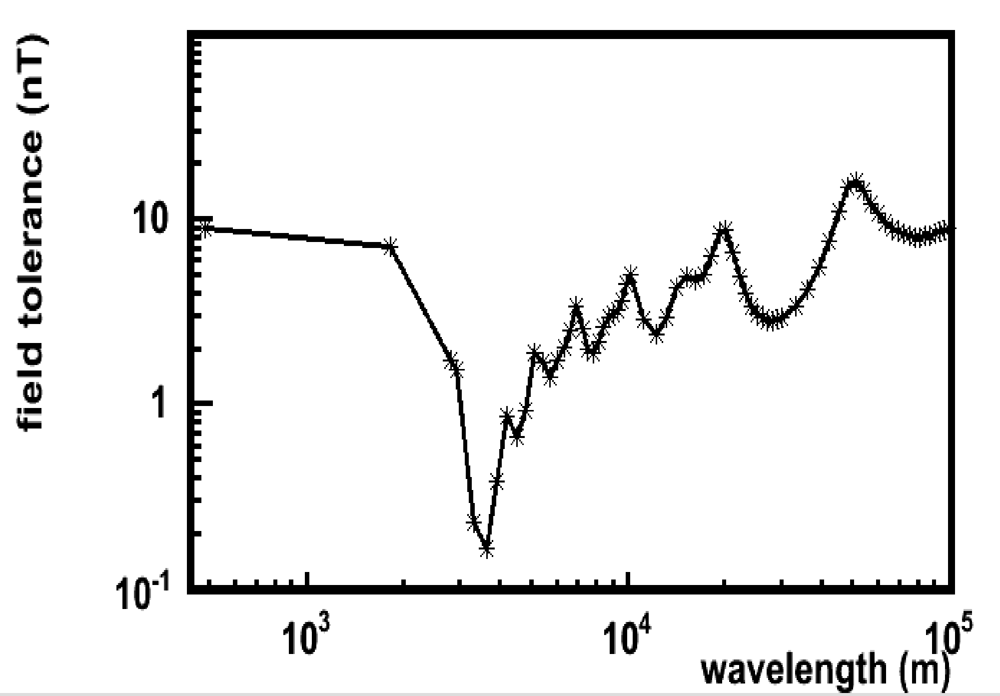
1 beam offset ≈ 10 μm

Sensitivity strayfields RTML + TA
Emittance

Old Lattice



New Lattice



Potential mitigation techniques

- Stronger focusing (RTML)
- Avoid resonances
- Feed forward
- Shielding beamline
- Shielding sources
- Active compensation

Magnetic shielding 1

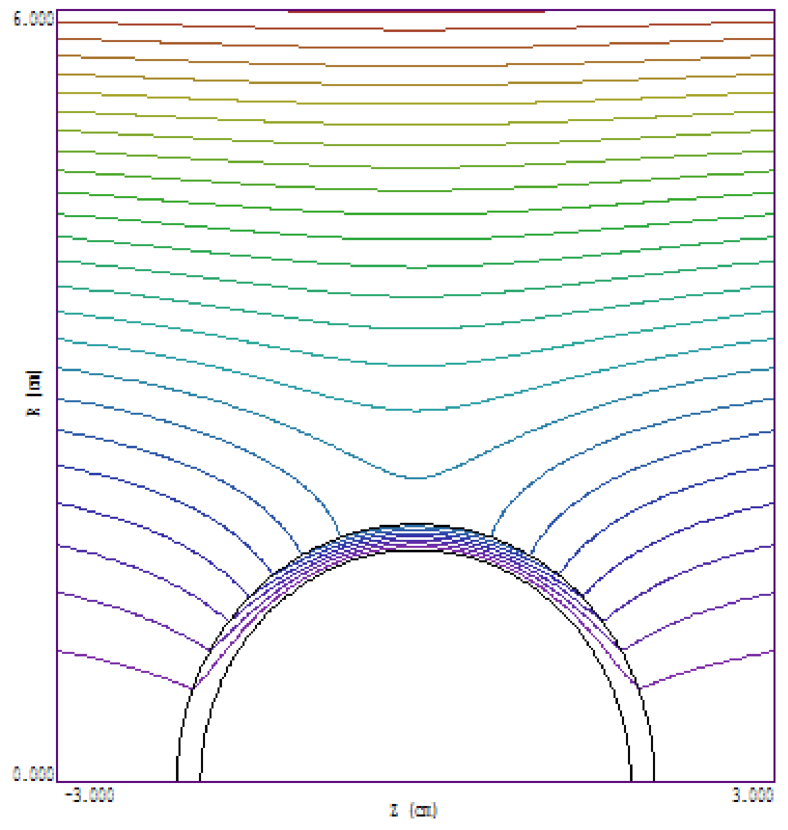
- varying magnetic waves induce eddy currents in conductors which cancel the field
- skin depth: depth on which an electromagnetic wave flows through a material

$$\delta = \sqrt{\frac{\rho}{(\pi \mu f)}}$$

- effective for high frequencies (> kHz)

Magnetic shielding 2

- in addition to eddy current shielding some materials can redirect magnetic field lines
- lower frequencies, but less effective for low (or high) field strengths
- rel. magnetic permeability
  - steel (100-4k)
  - mu-metal (Ni-Fe alloy) 20k-100k
- expensive
- several layers may be needed to achieve required level



Magnetic Shielding 3

- Helmholtz coils
  - produces nearly uniform field in one direction
  - can be used to cancel existing fields
    - fast measurement needed
    - 3 coils
  - lower frequencies (< kHz)
  - sub-pT level reached dedicated experiments (very low noise)

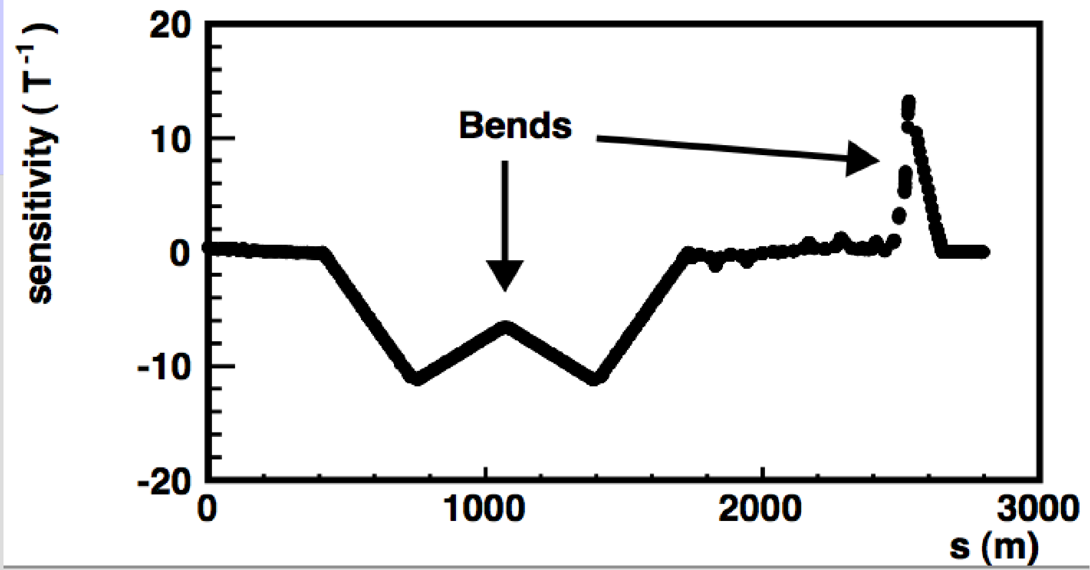
- Superconductors
  - Meissner effect: perfect shielding

Shielding beamline: passive

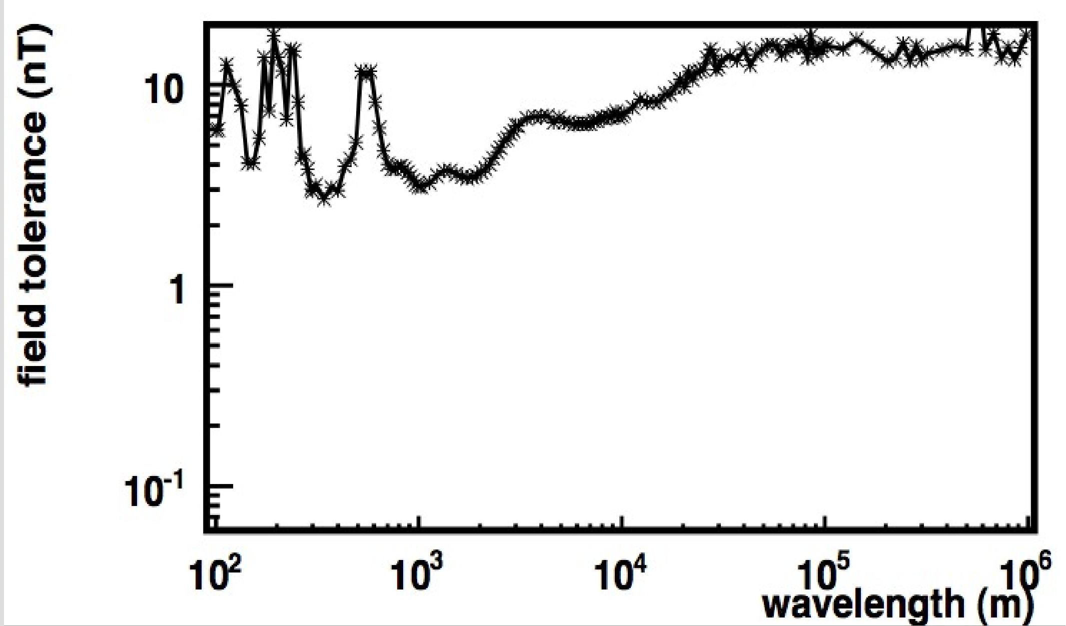
- natural shielding from beampipe
- current design beampipe:
  - transfer line 1.5 mm copper (about f > 2 kHz shielded)
  - main linac:
    - copper coated stainless steel 0.3 mm (f > ~3 kHz shielded)
    - copper RF structures 20 mm thick (f > 10 Hz shielded)
  - note that main linac consists of 80% RF structures
- additional shielding with e.g. several layers of mu-metal
  - difficult due to low field strengths

BDS: collimation bends

- BDS sensitivity caused by collimation bends
- Shielding these regions would reduce sensitivity factor 10
- Could be done with superconducting bends



anti-symmetric wrt IP
factor 10 improvement



Shielding the sources

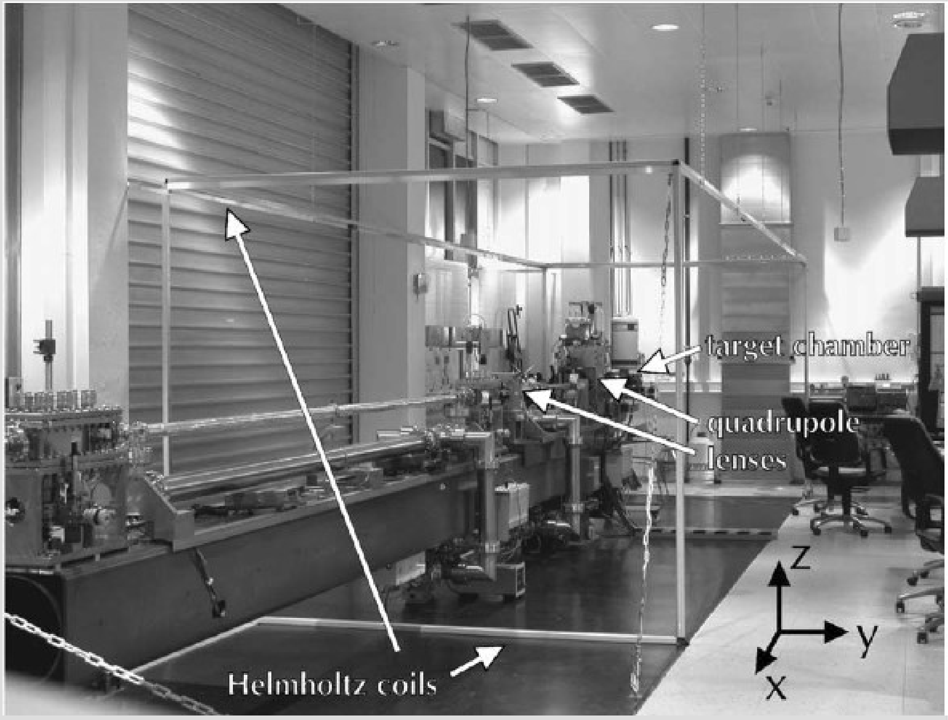
- Similar to passive shielding
  - lower skin depth, increase thickness
  - high permeability materials

- Easier due to stronger fields
- Easier to implement

- More shielding
- More different components

Shielding beamline: active

- Helmholtz coils
- Used at LIPSION (Leipzig, 2 MeV proton beam)
  - reduction from 1.5 μT -> 10 nT
  - improvements possible
- RTML and ML shielded at same time
- Space constraint in tunnel



Conclusions

- CLIC sensitive to stray fields < nT
  - Transfer line most sensitive
  - BDS also affected
- Magnetic shielding is needed
- Potential mitigation techniques have been presented
- Feed forward after turnaround is conceived to be essential
- Measurements are needed