Magnetic Stray Fields

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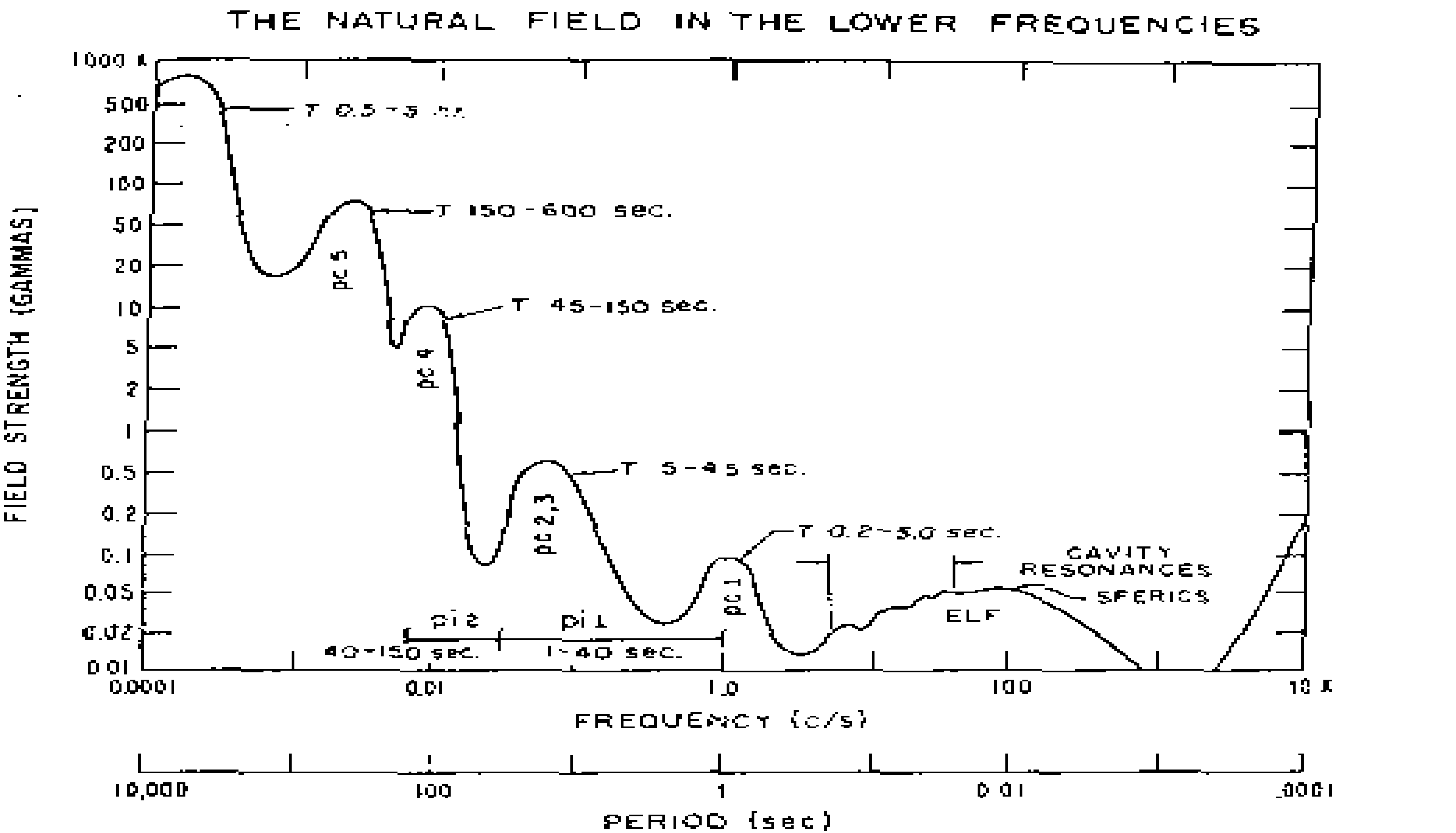
5/10/12

Magnetic stray fields

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

Earth magnetic field (1 gamma = 1 nT)



Power spectrum tunnel?

- Hardly any known measurements
  - J. Frisch, T.O. Raubenheimer, P. Tenenbaum, “Sensitivity to Nano-Tesla Scale Stray Magnetic Fields”, June 2004, SLAC- TN-04-041
  - D. Sergatskov, ILC-CLIC LET Beam Dynamics Workshop, June 2009
- However very important for impact
  - 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
  - Correlations in space?
- (2D-correlation) measurements are needed
  - Tunnel equipment

Dynamic 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

Potential mitigation techniques

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

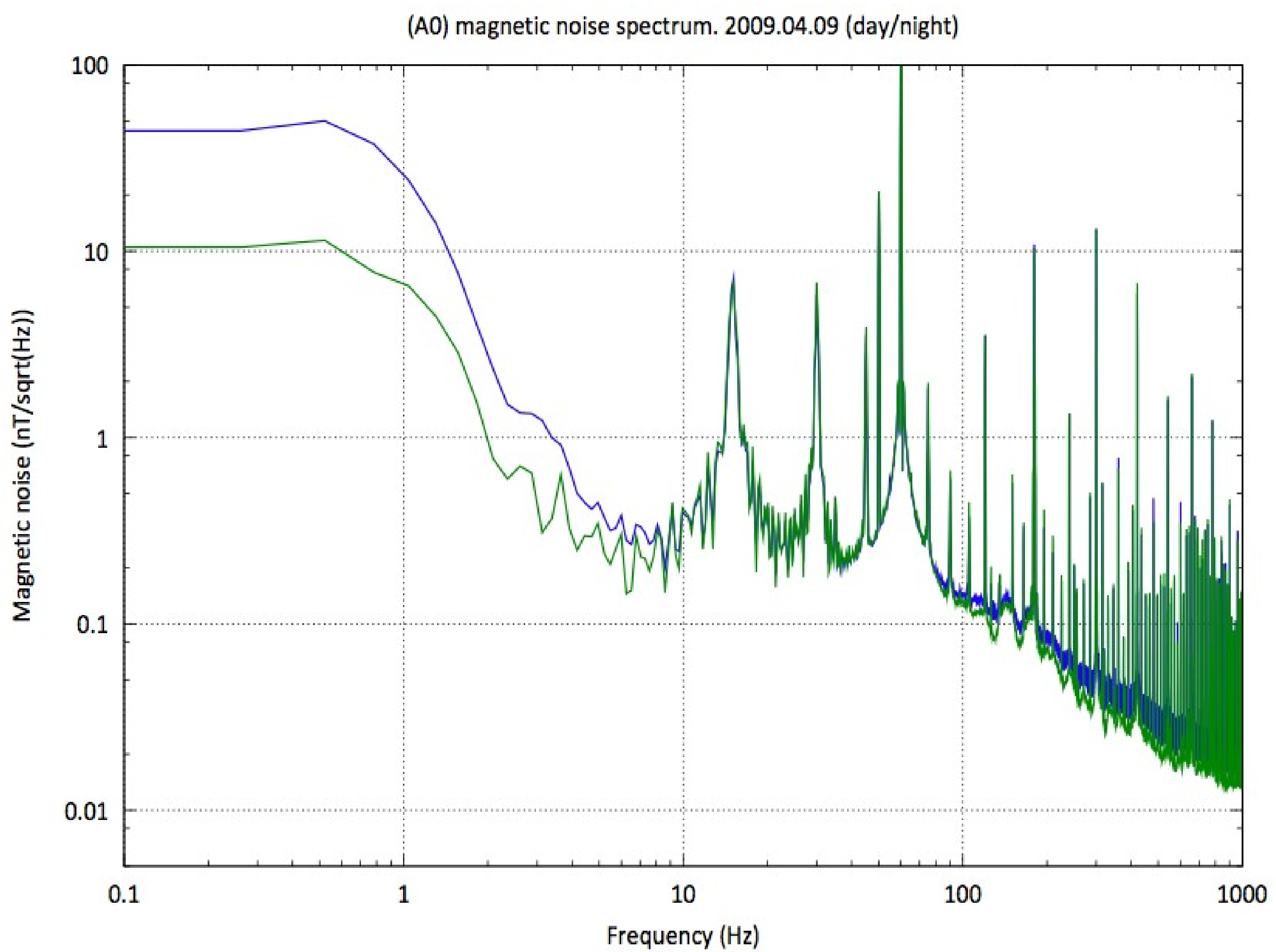
Conclusions

- CLIC sensitive to stray fields in the order of nT
  - Long transfer line most sensitive
  - BDS also affected
- Magnetic shielding will be needed
  - Potential mitigation techniques should be reviewed
  - Feed forward after turnaround is conceived to be essential
- Measurements are needed
  - Tunnel equipment to be measured
- Further reading:

J. Snuverink et al., Impact of Dynamic Magnetic Fields on the CLIC Main Beam, IPAC10

Backup

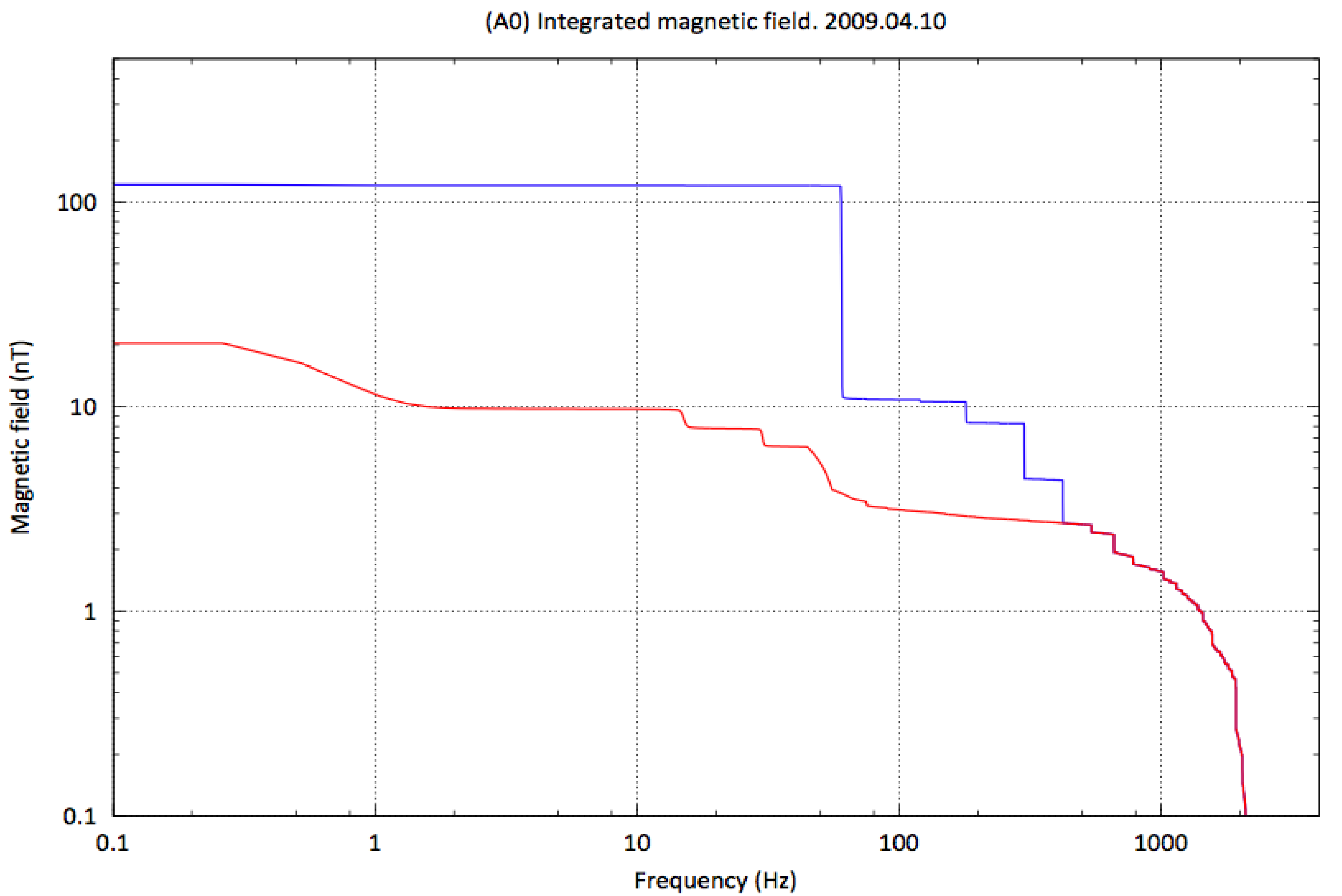
Measurements Fermilab
D. Sergatskov



11am (blue) vs 11pm (green) noise.

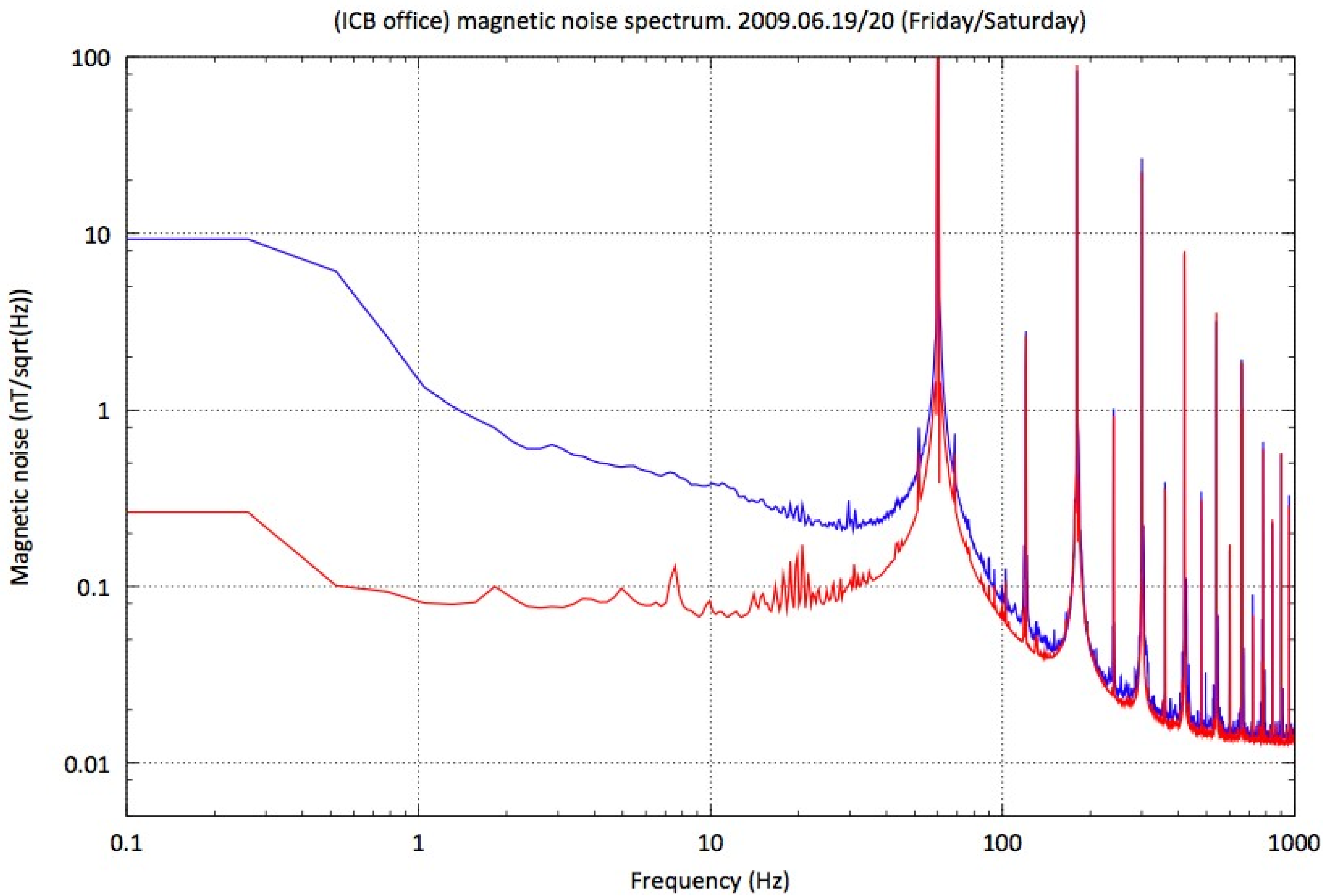
A0 exp. hall (noisy)

Measurements Fermilab
D. Sergatskov



RMS integrated, 24h-averaged noise spectrum. Blue – original, red – with 50 Hz, and 60Hz and its harmonics removed.

Measurements Fermilab
D. Sergatskov

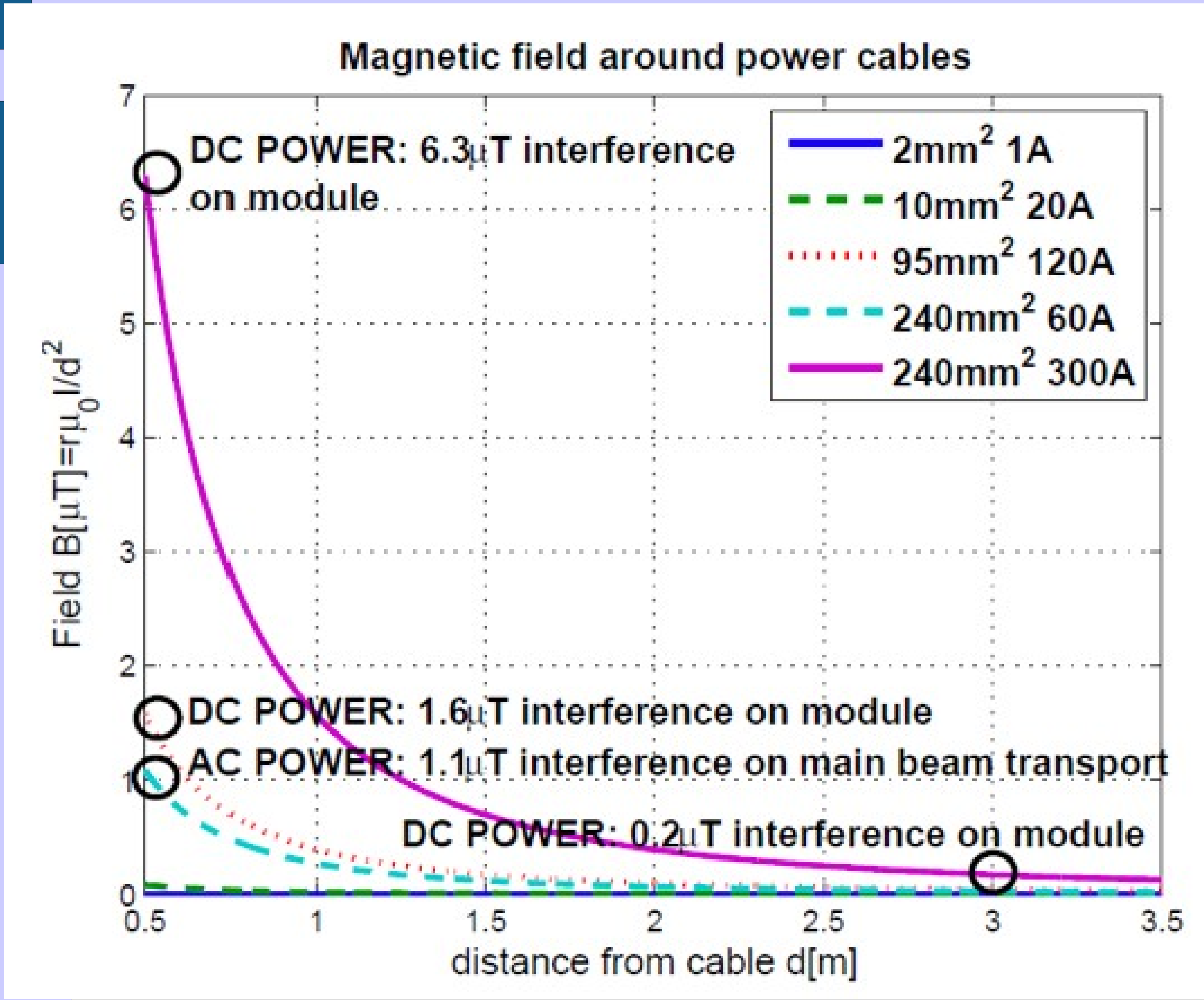


Blue – Friday, red -- Saturday

Office

(quiet)

CLIC Power Cables

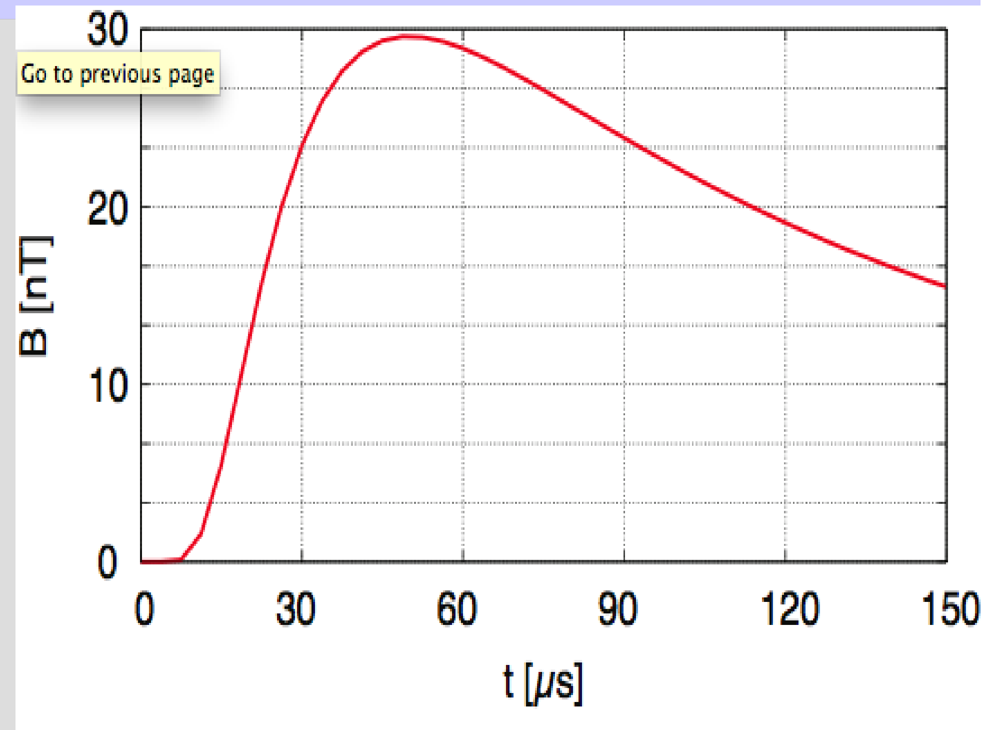


Power cabling scheme (unshielded) optimised to reduce magnetic fields in tunnel

D. Siemaszko & S. Pittet

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



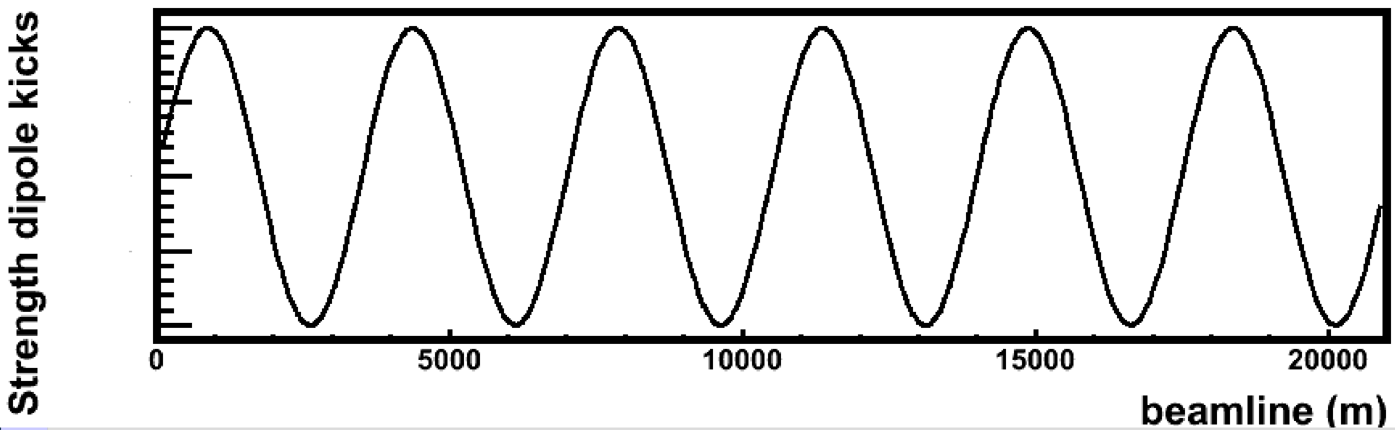
Magnetic field induced by a drive beam at r=0.5m with 2mm copper shielding

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

Turnaround + Feedforward

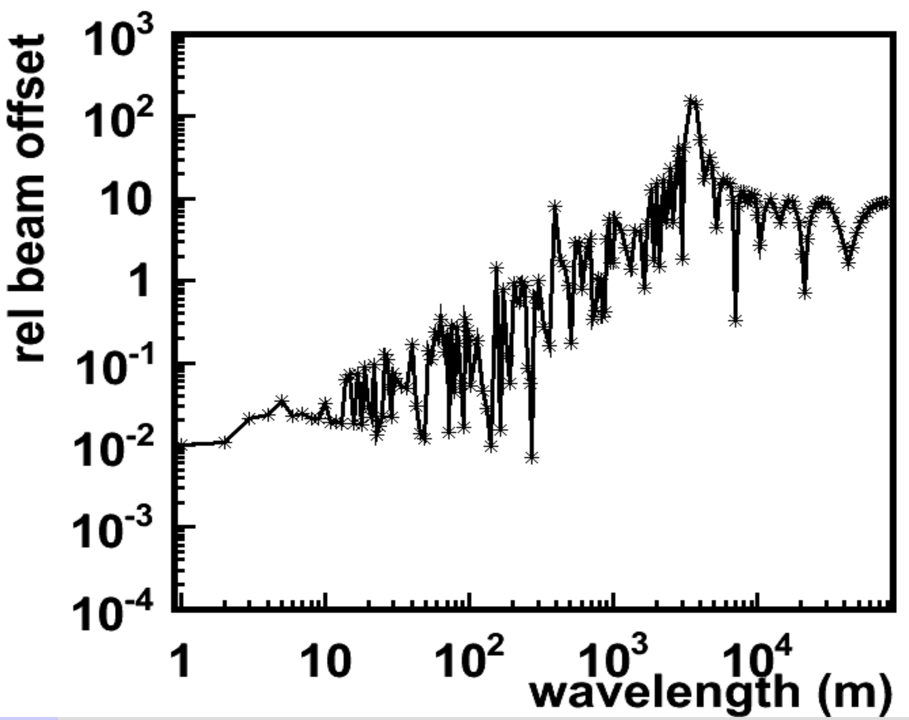
- A feed forward system after the turnaround loop can almost fully correct the beam offset in the transfer line
- Problem:
  - emittance growth in turnaround loop due to beam offset
- Overcome partly by latest lattice design

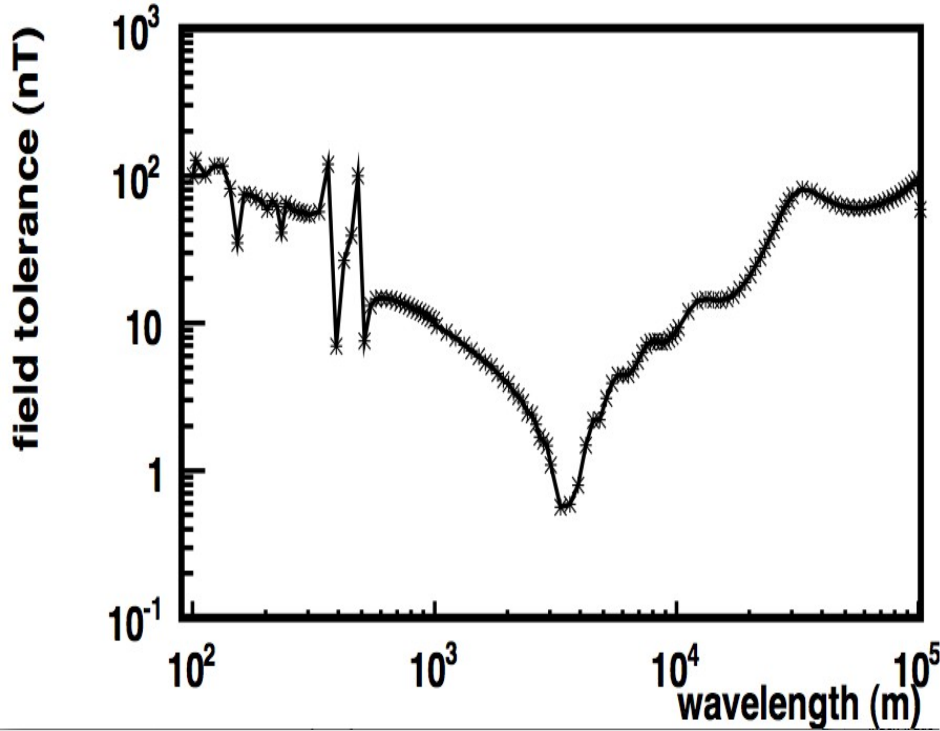
Simulations (example RTML)



Simulated by grid of dipole kickers with 1m distance

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

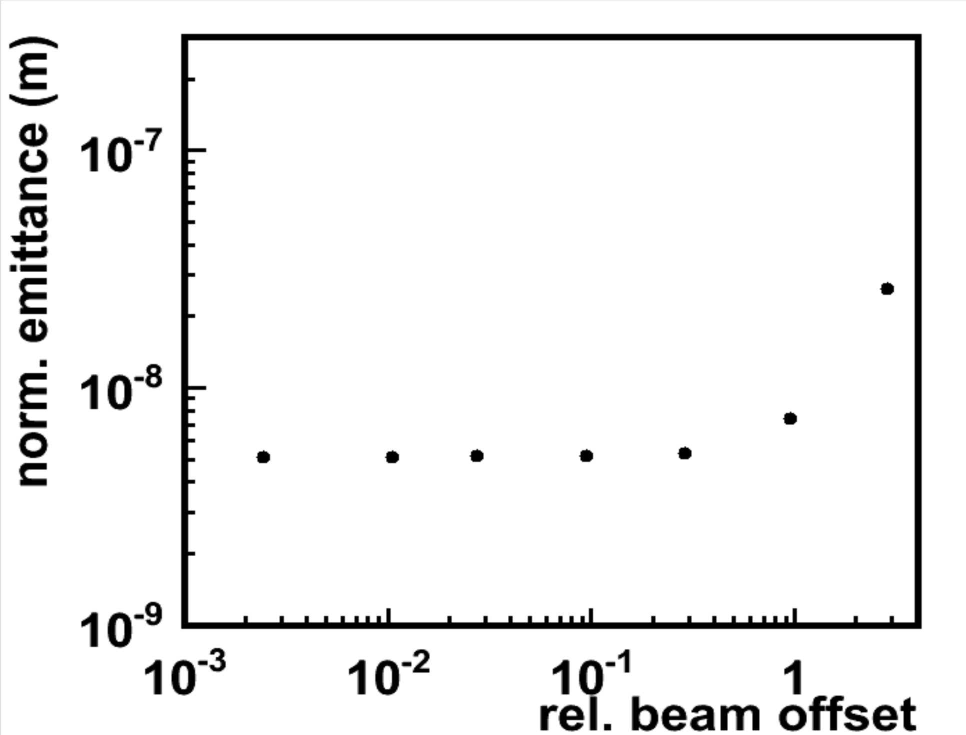




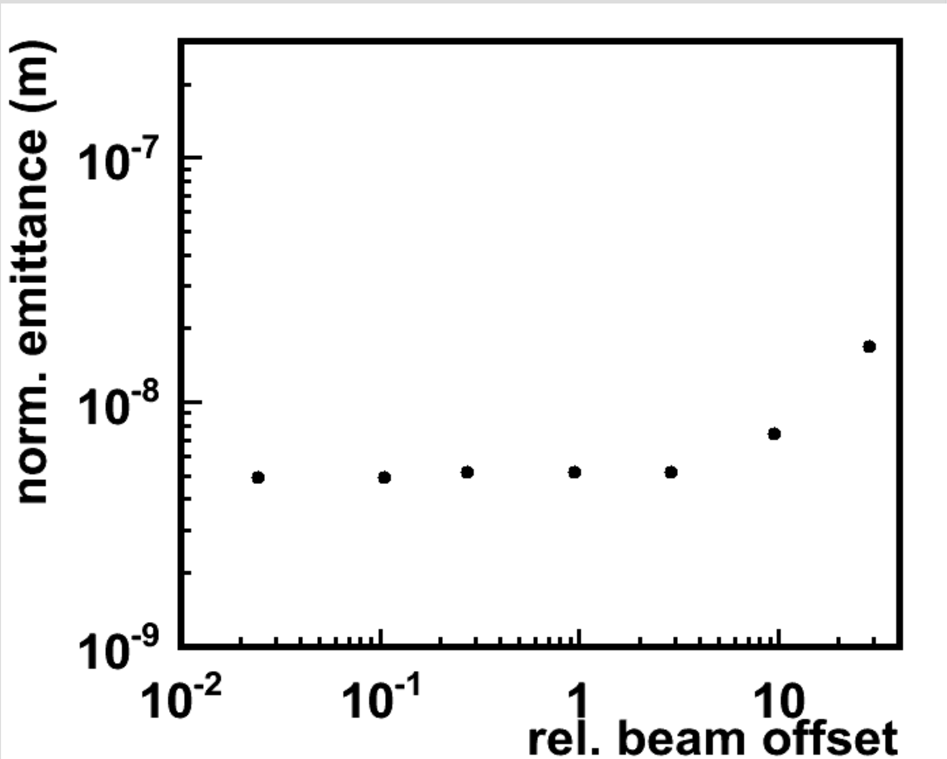
Sensitive to magnetic stray fields of ~ 1 nT

Emittance growth in TA due to beamoffset

Old Lattice



New Lattice

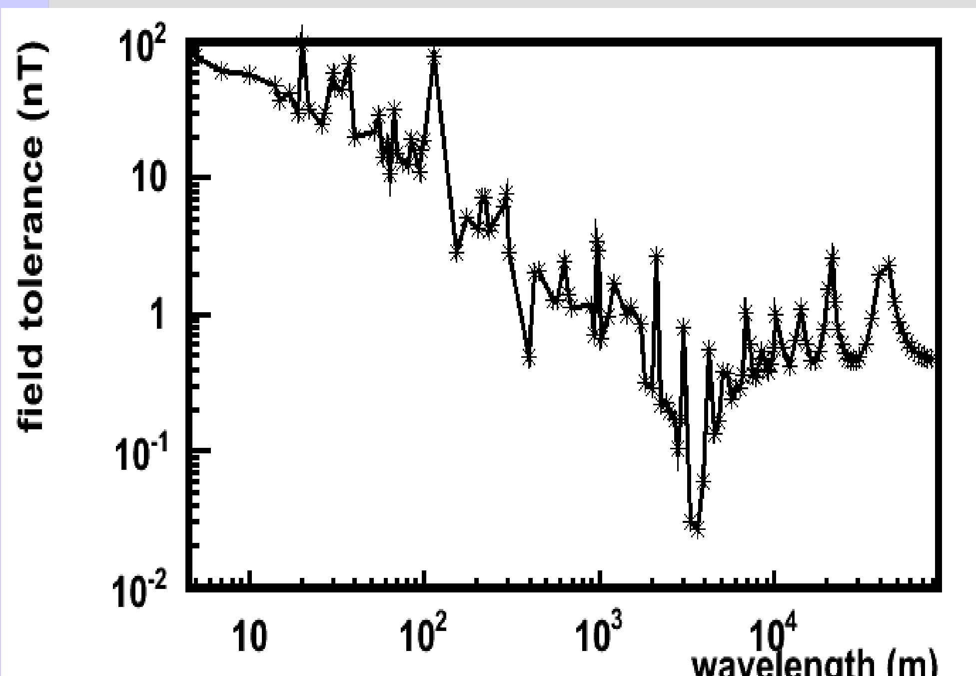


Factor 10 improvement

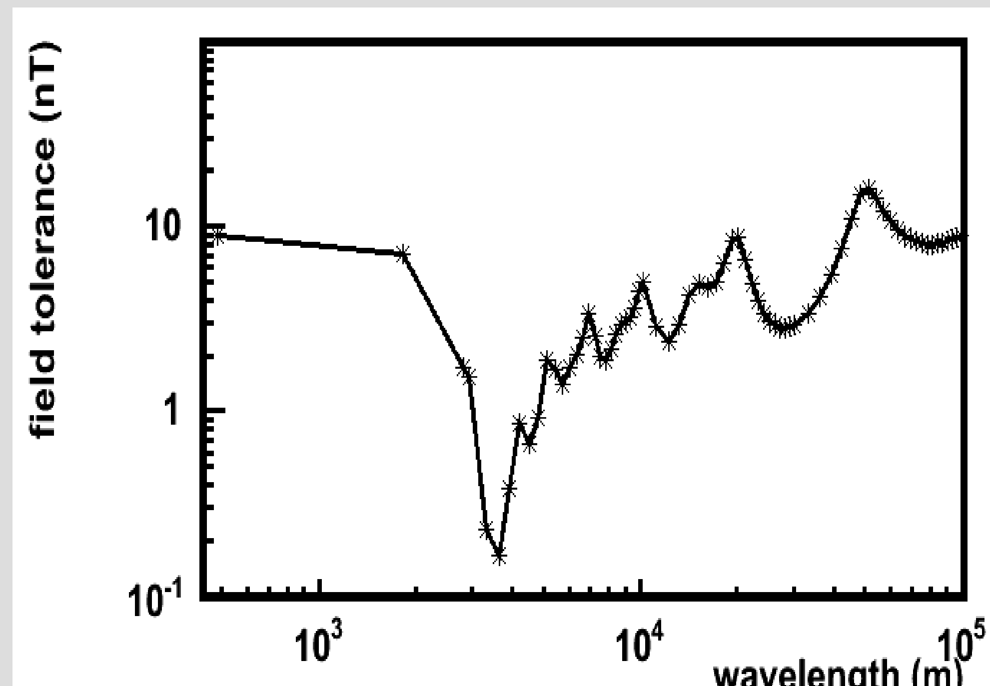
1 beam offset ≈ 10 μm

Sensitivity strayfields RTML + TA Emittance

Old Lattice

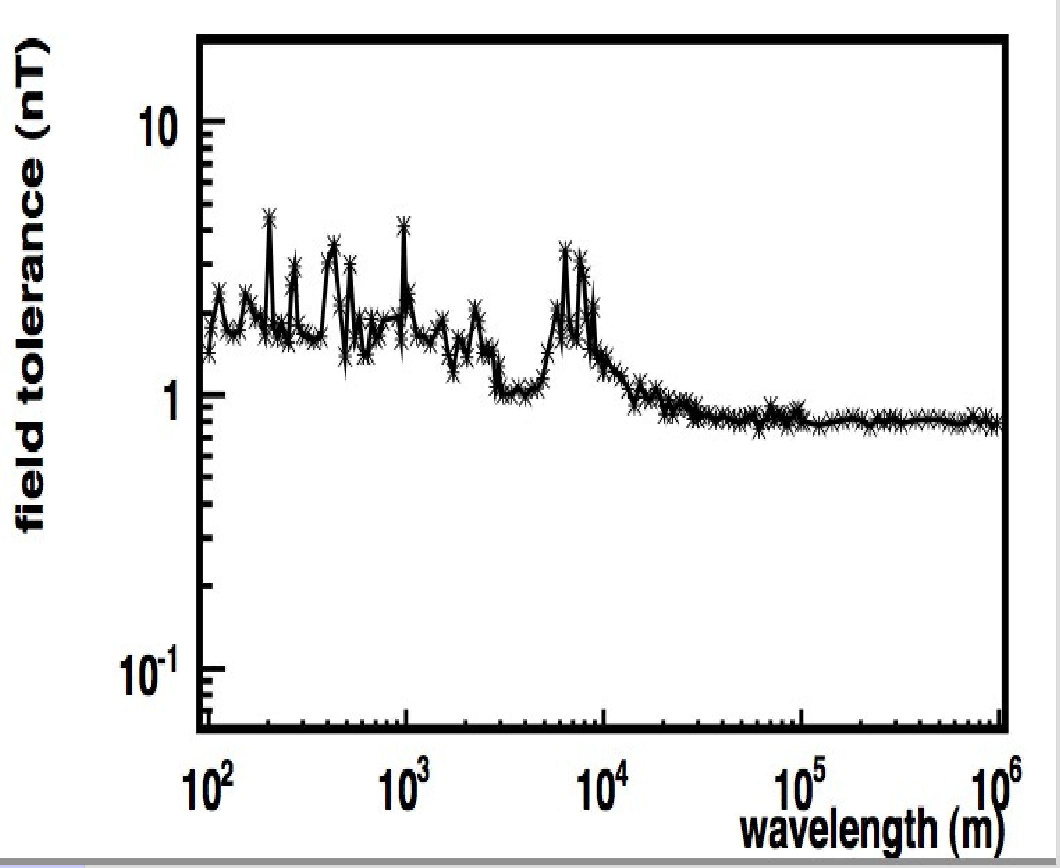


New Lattice

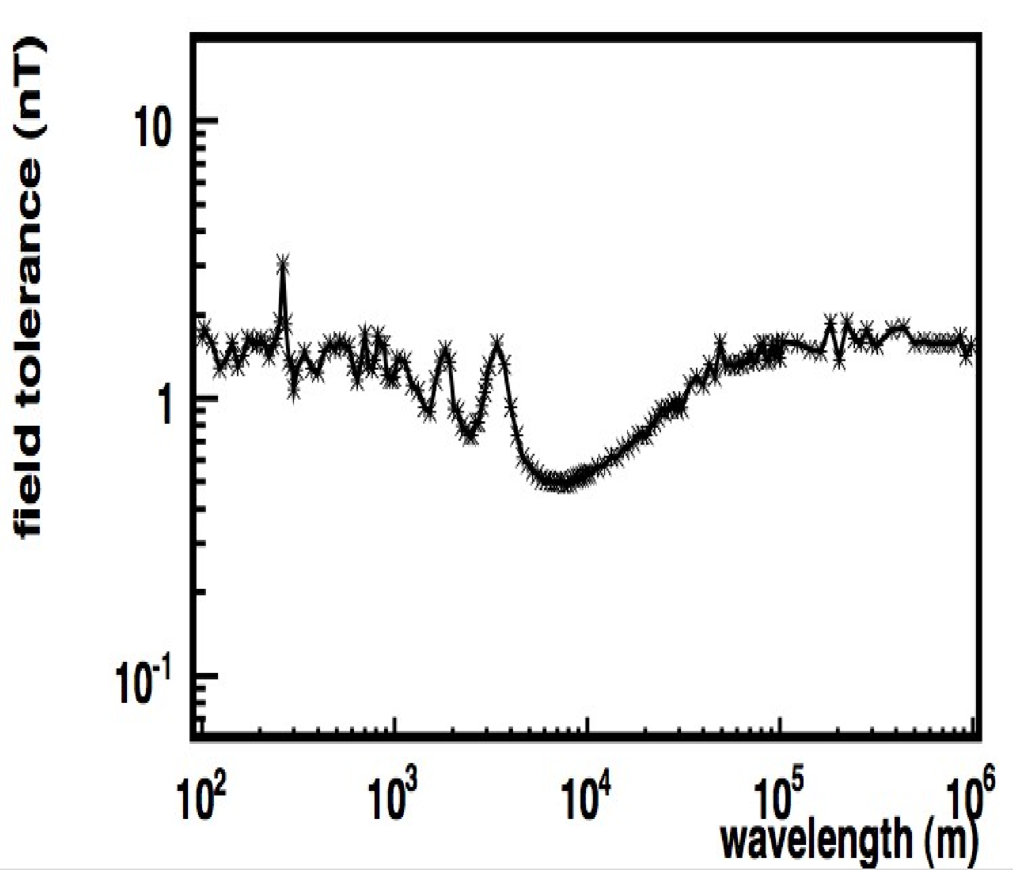


BDS sensitivity

symmetric wrt IP



anti-symmetric wrt IP



Magnetic shielding 1

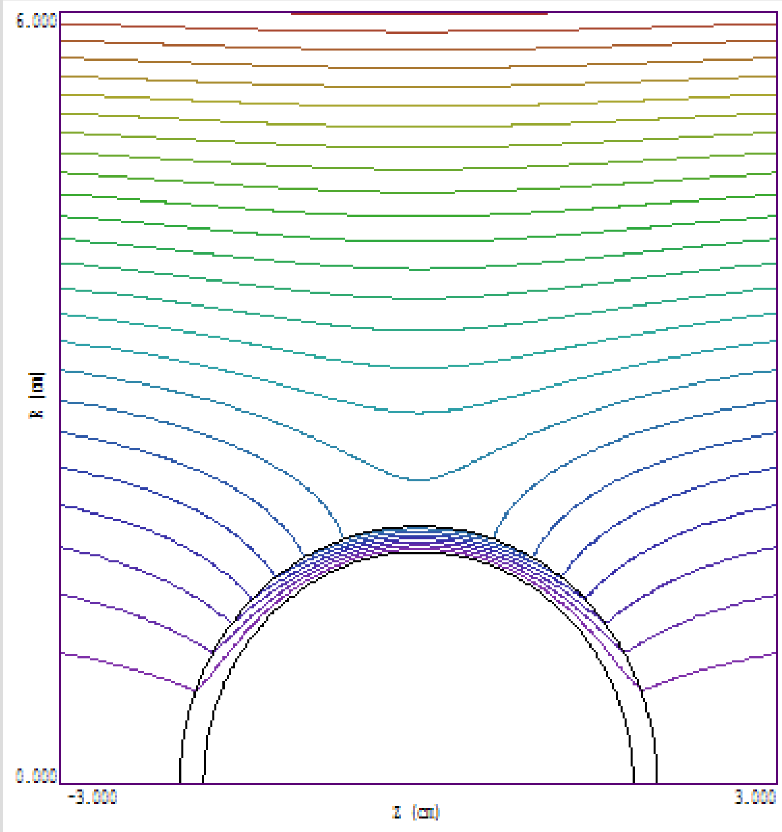
- varying magnetic waves induce eddy currents in conductors which cancel the field
- skin depth: depth on which an electromagnetic wave flows through a material

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

- 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)

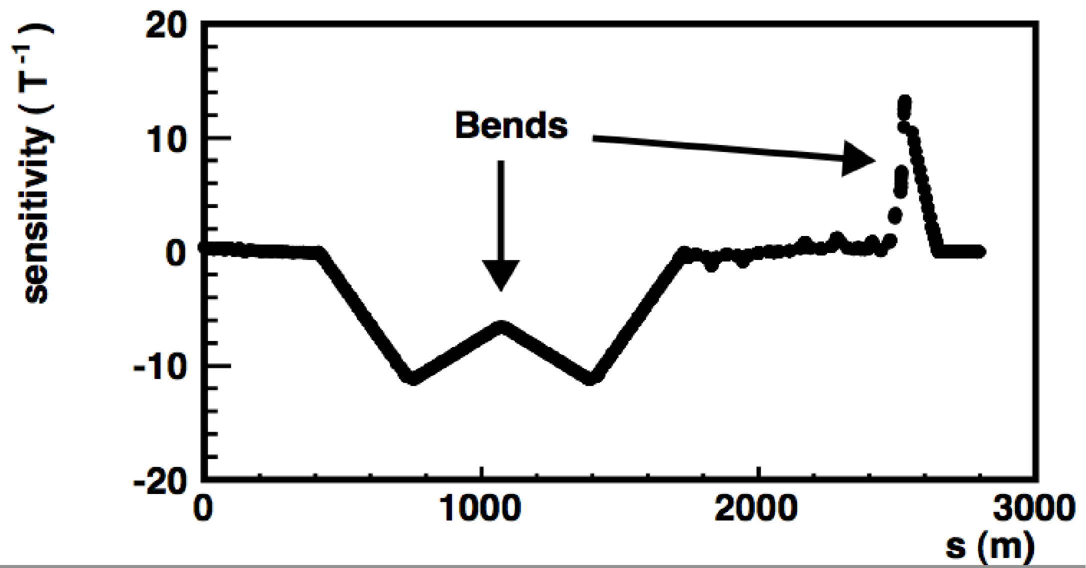
- Superconductors
  - Meissner effect: perfect shielding

Shielding beamline: passive

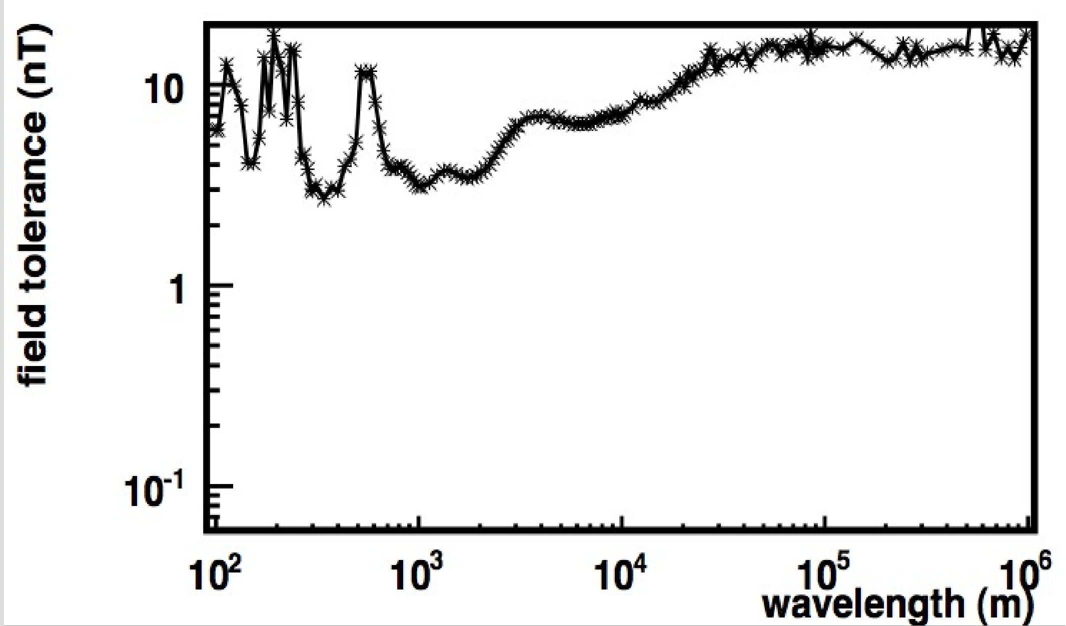
- natural shielding from beampipe
- current design beampipe:
  - transfer line 1.5 mm copper (about f > 2 kHz shielded)
  - main linac:
    - copper coated stainless steel 0.3 mm (f > ~3 kHz shielded)
    - copper RF structures 20 mm thick (f > 10 Hz shielded)
  - note that main linac consists of 80% 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