Dynamic Electro-magnetic Fields in CLIC

D. Schulte, Ch. Gohil, B. Heilig, E. Marin Lacoma, J. Pfingstner

The Challenge

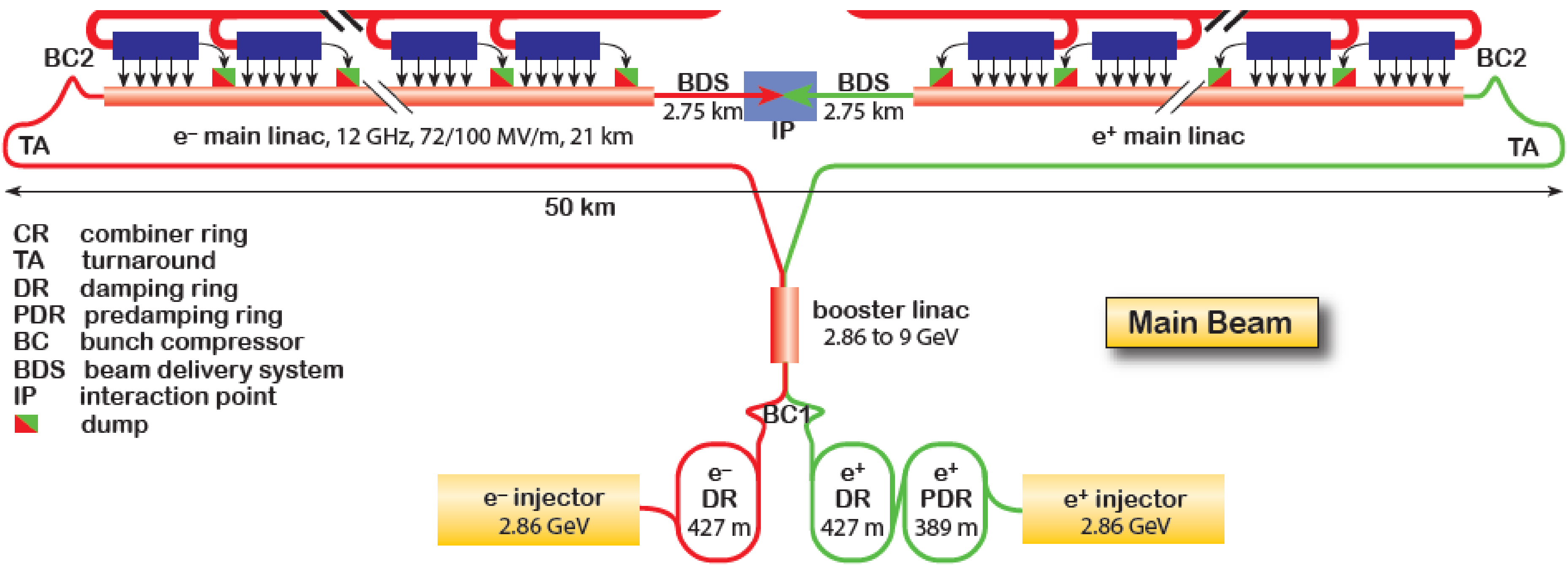
Luminosity determines how many events we produce

Bunch charge

Beam current

$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \frac{1}{\sigma_y}$$

Transverse bunch sizes



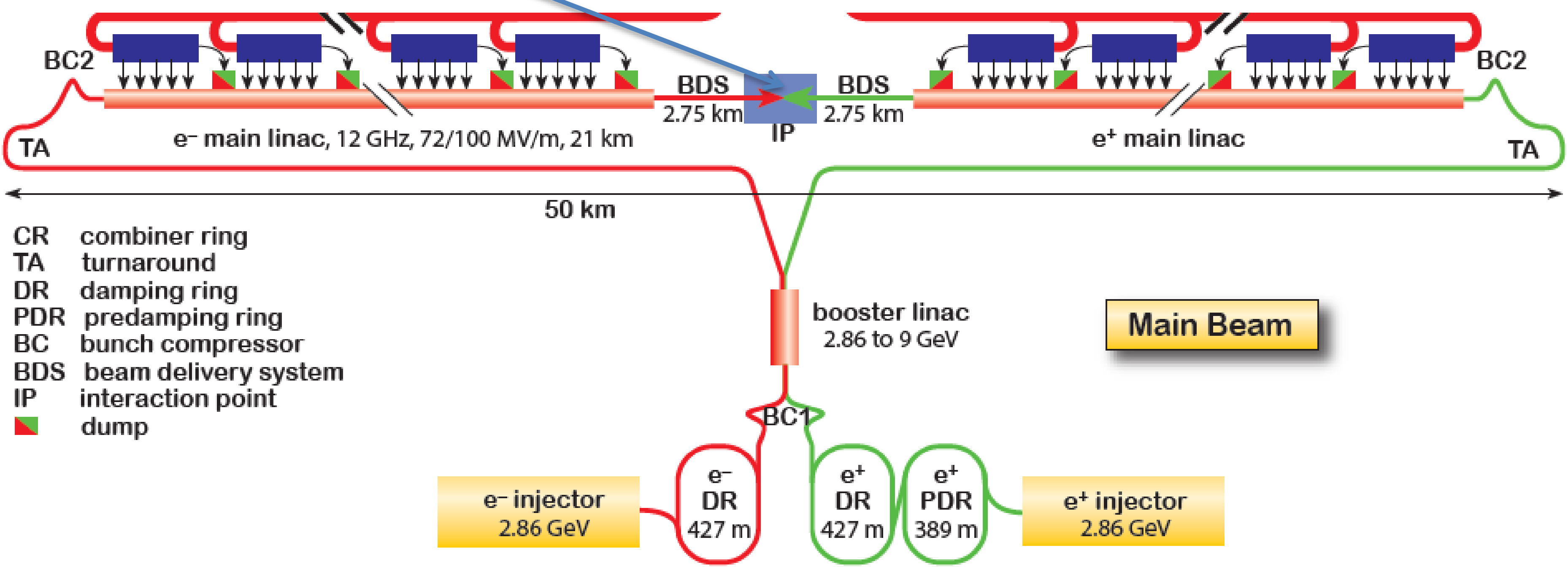
The Challenge

About 40 nm

About 1 nm

$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \frac{1}{\sigma_y}$$

To obtain high luminosity we collide very small bunches at the collision point



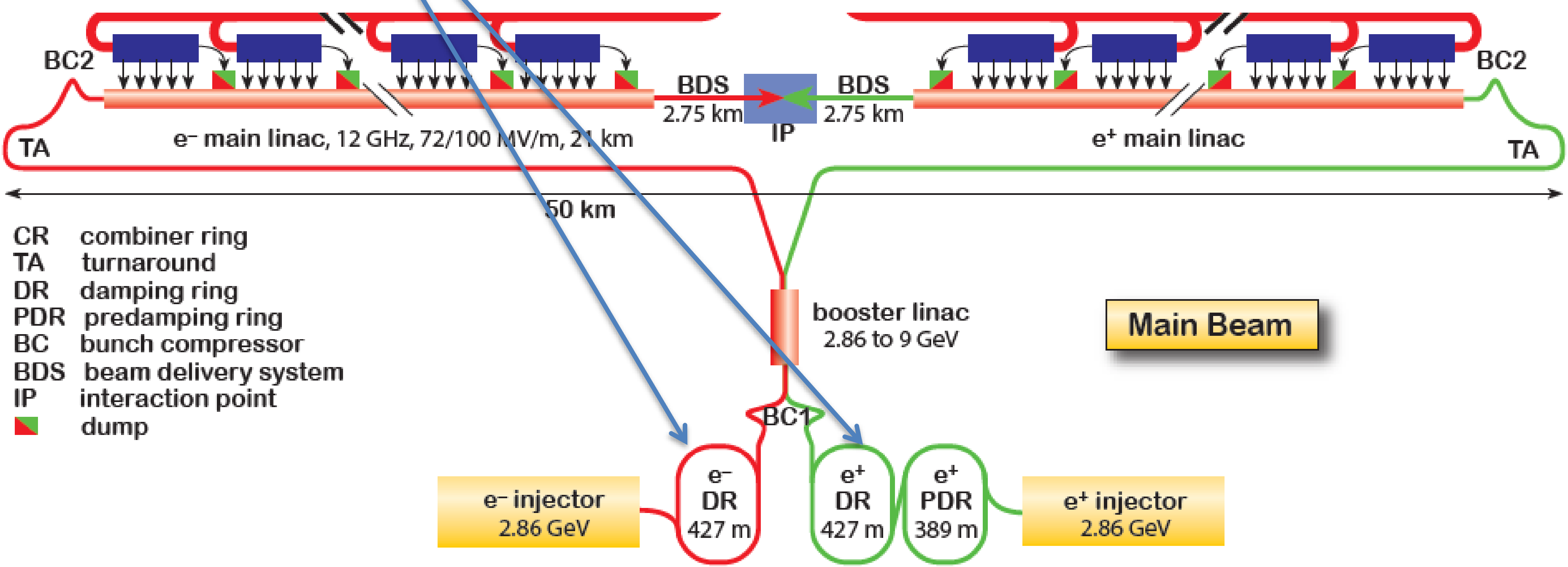
The Challenge

About 40 nm

About 1 nm

Produce a very brilliant beam (small phase space = emittance)

$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \frac{1}{\sigma_y}$$



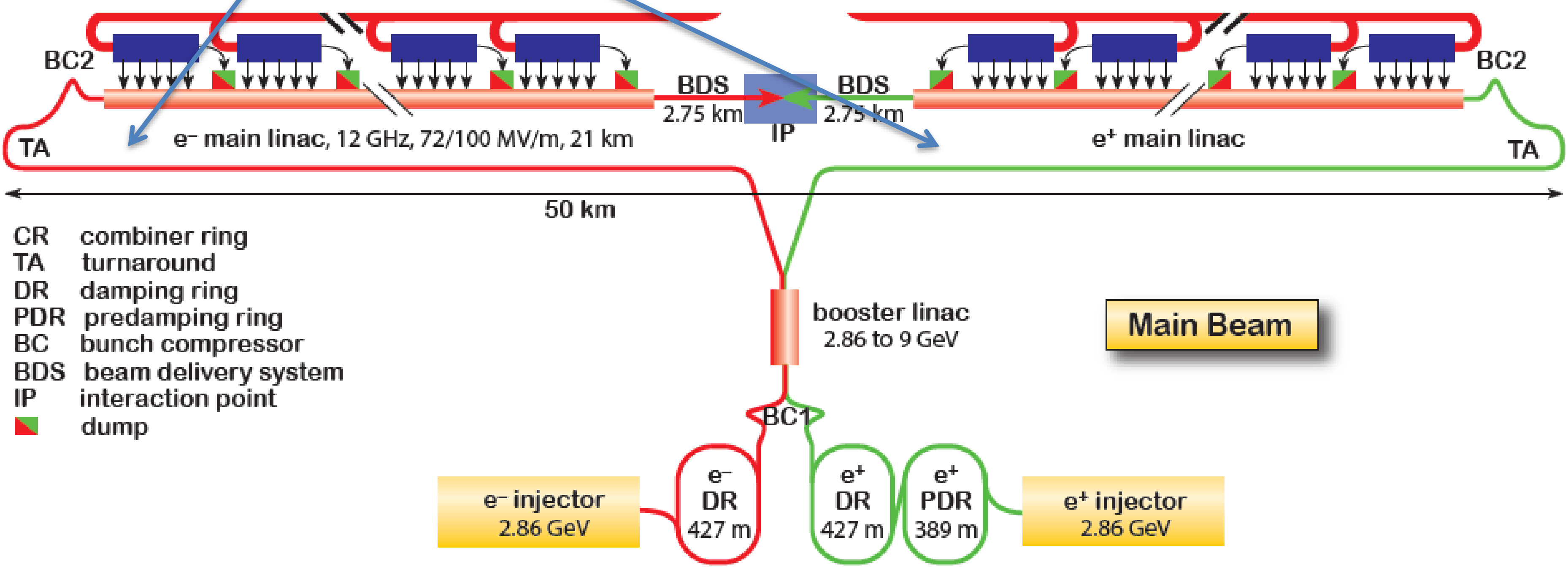
The Challenge

About 40 nm

About 1 nm

Preserve the brilliance
And control the trajectory

$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \frac{1}{\sigma_y}$$



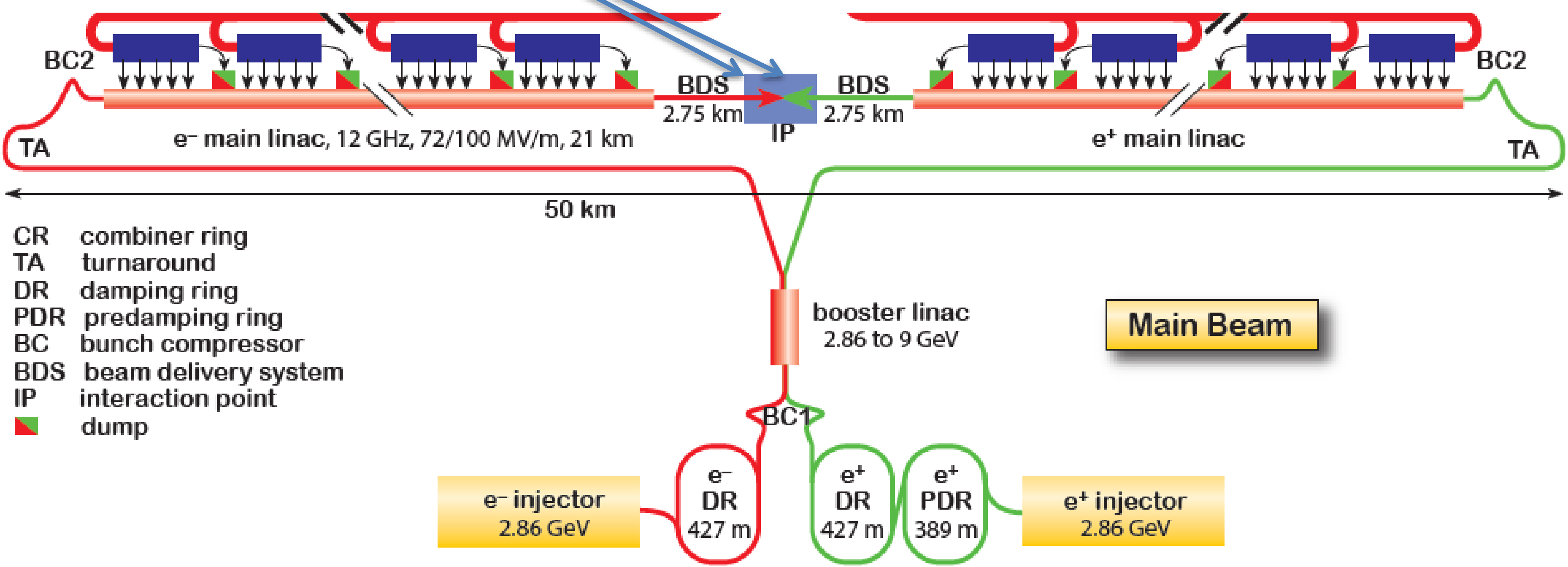
The Challenge

About 40 nm

About 1 nm

Squeeze beam with a telescope to minimal size

$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \frac{1}{\sigma_y}$$



The Challenge

We loose 1% of the luminosity if the beams miss by more than 0.2 nm

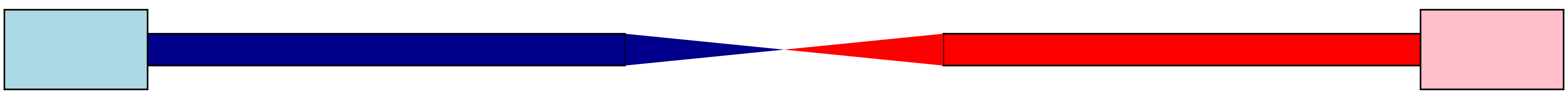
Beam jitter < 0.2 RMS beam size

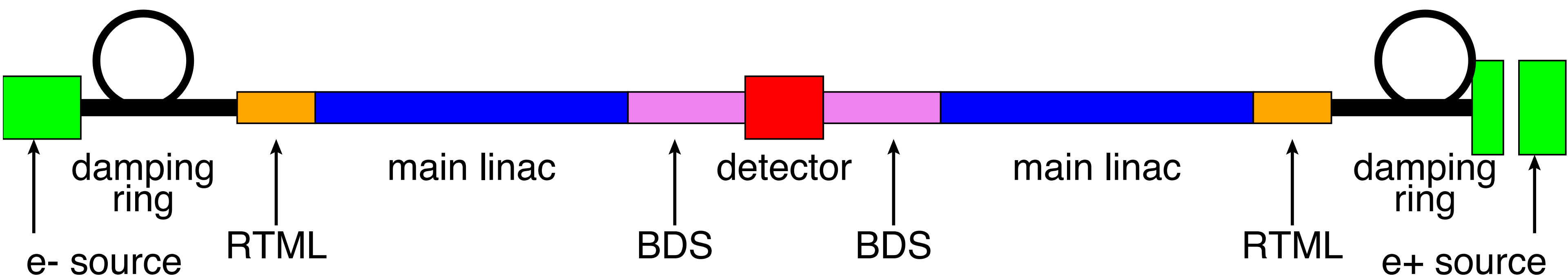
Or if their size increases by 1 % (i.e. emittance increases by 2%)

About 40 nm

About 1 nm

$$\mathcal{L} \propto H_D \frac{N}{\sigma_x} N n_b f_r \frac{1}{\sigma_y}$$

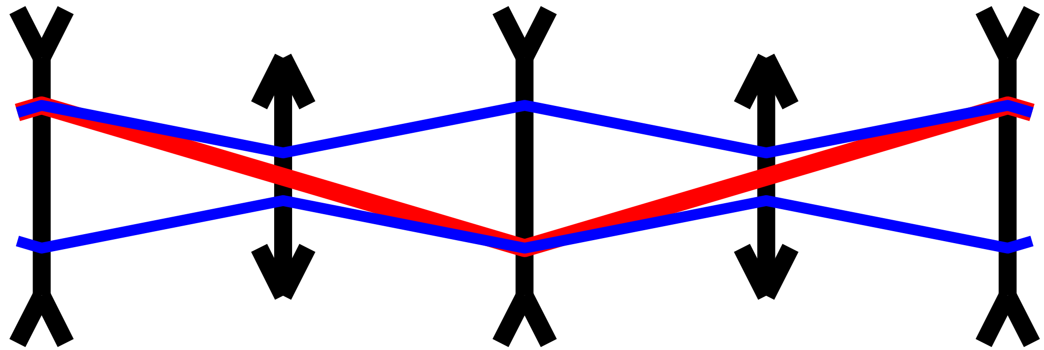




Note: Beam Transport

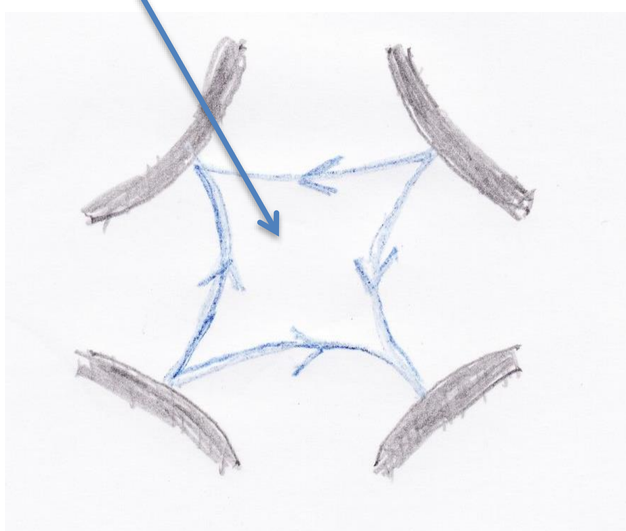
The beams are guided by magnets from the damping ring to the collision point

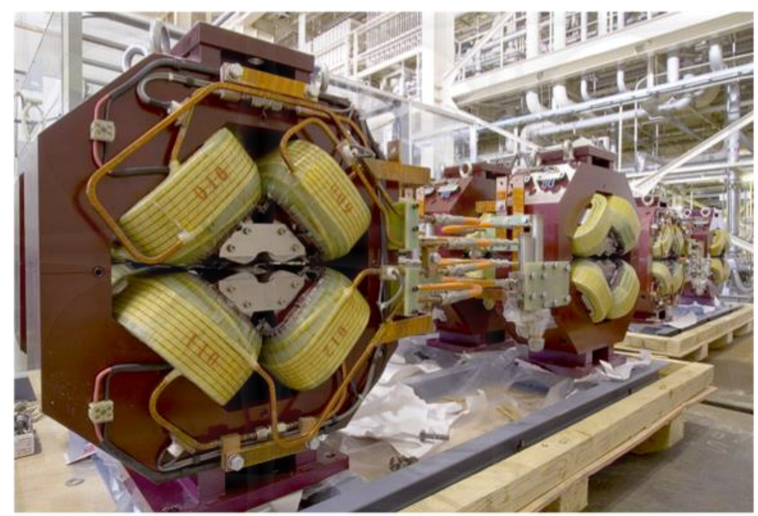
Quadrupoles act like optical lenses



Horizontal field proportional to vertical offset
$\Rightarrow$ Gives vertical force

Beam size changes, jitter scales with beam size





Issues from Magnetic Fields

- Small magnetic or electric fields can change the beam trajectory
  - An oscillation around the nominal trajectory starts

  $\Rightarrow$ The beams can miss at the collision point

  $\Rightarrow$ The beam quality can be degraded

- Static (or slow) fields are to a large extent corrected
  - Static fields are tuned out initially
  - Slow variations are cured by the beam-based feedback

  $\Rightarrow$ The most urgent concern are varying fields

- The spatial distribution of the fields is also critical
  - An oscillation excited at one location might be cured or amplified by the additional kick at another position

Small Excursion: Ground Motion

- A similar issue exists due to the motion of the ground
  - The ground motion moves the magnets
  - They kick the beam
  - The trajectory changes
  - We lose luminosity

- This problem has been studied in detail and solutions have been developed

  $\Rightarrow$ A good model for the new activity

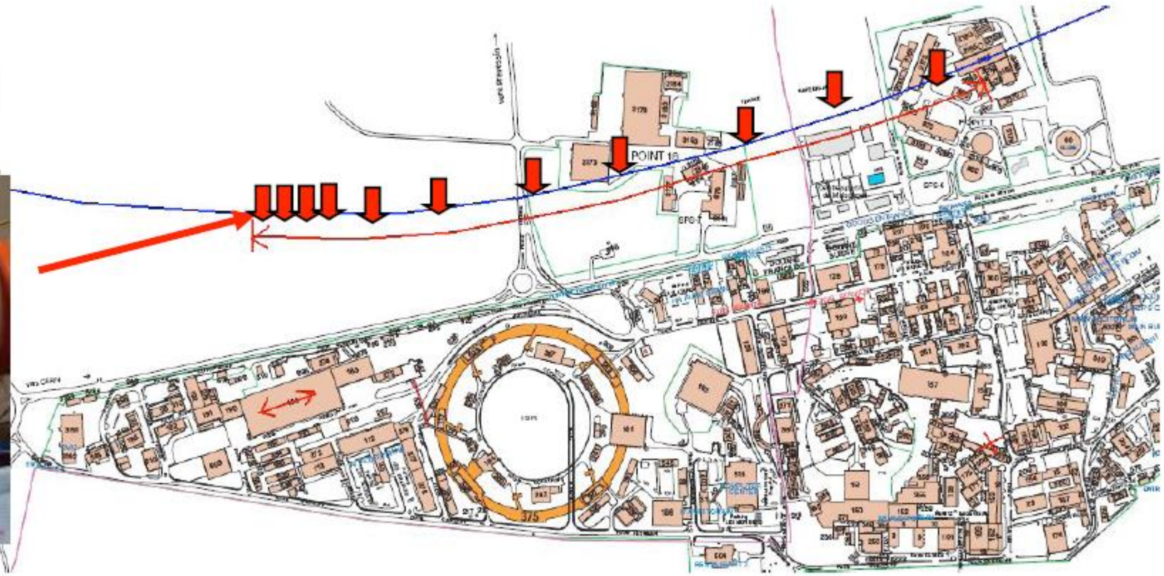
  $\Rightarrow$ Will show what we did

Measurements Performed

K. Artoos and M. Guinchard, CLIC Workshop (16 October 2008)

LHC Measurements

LHC DCUM 1000
~ 80 m under ground



Measurements: 0 1 2 3 4 5 6 7 8 9 10 12 20 30 38 54 108 198 306 412 509 604 706 960 (m)

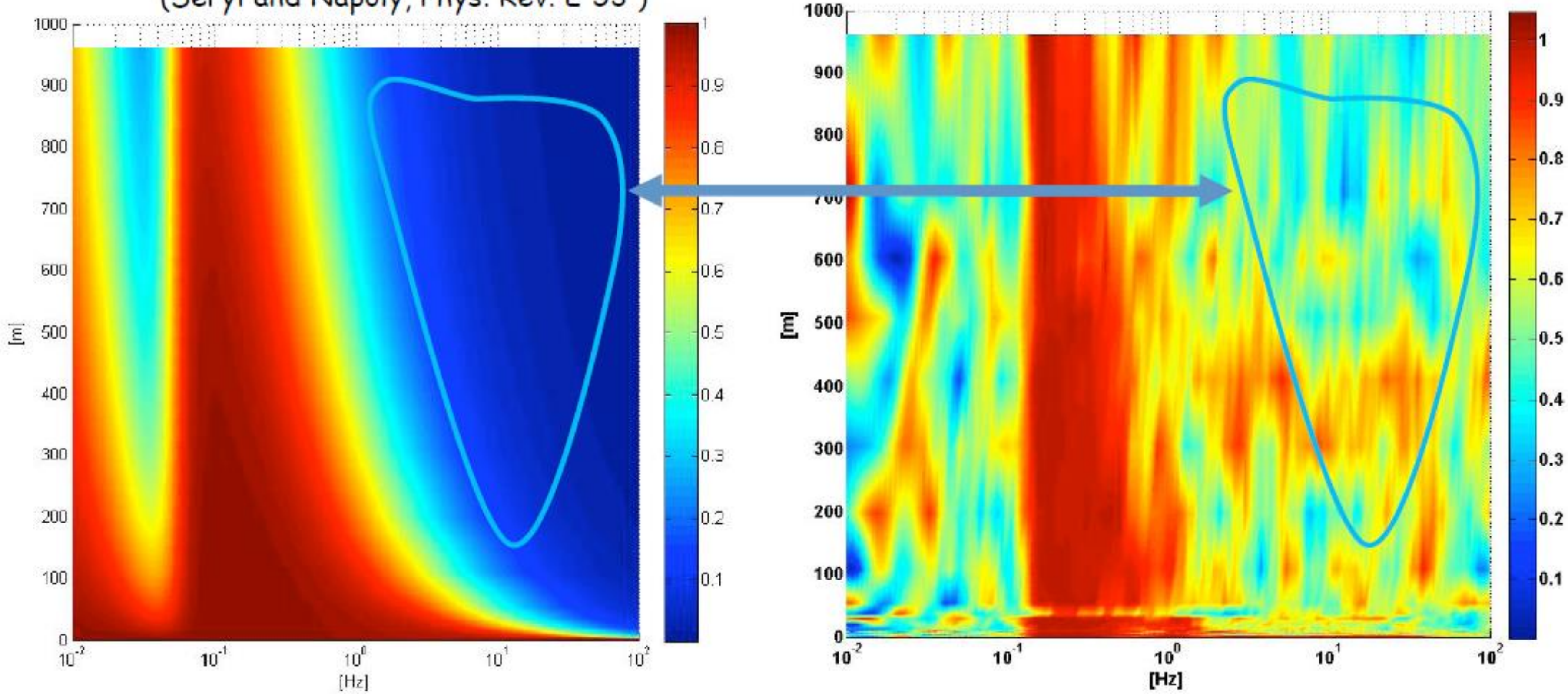
Specific features :
- Synchronous measurements
- LHC systems in operation, night time
- Multi-directional

Ground Motion Spectrum

Coherence using a theoretical model

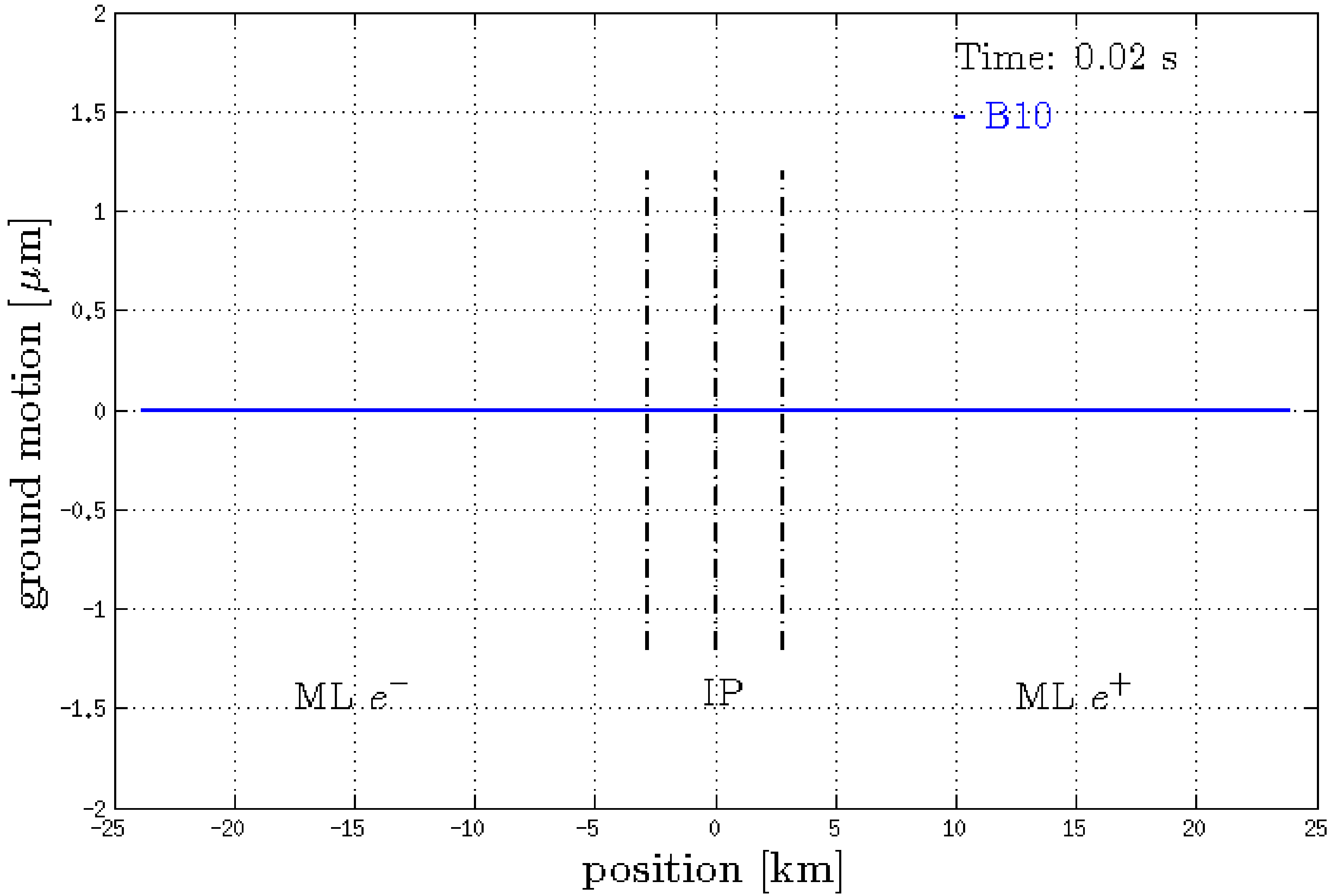
(Seryi and Napoly, Phys. Rev. E 53)

Calculated from measurement



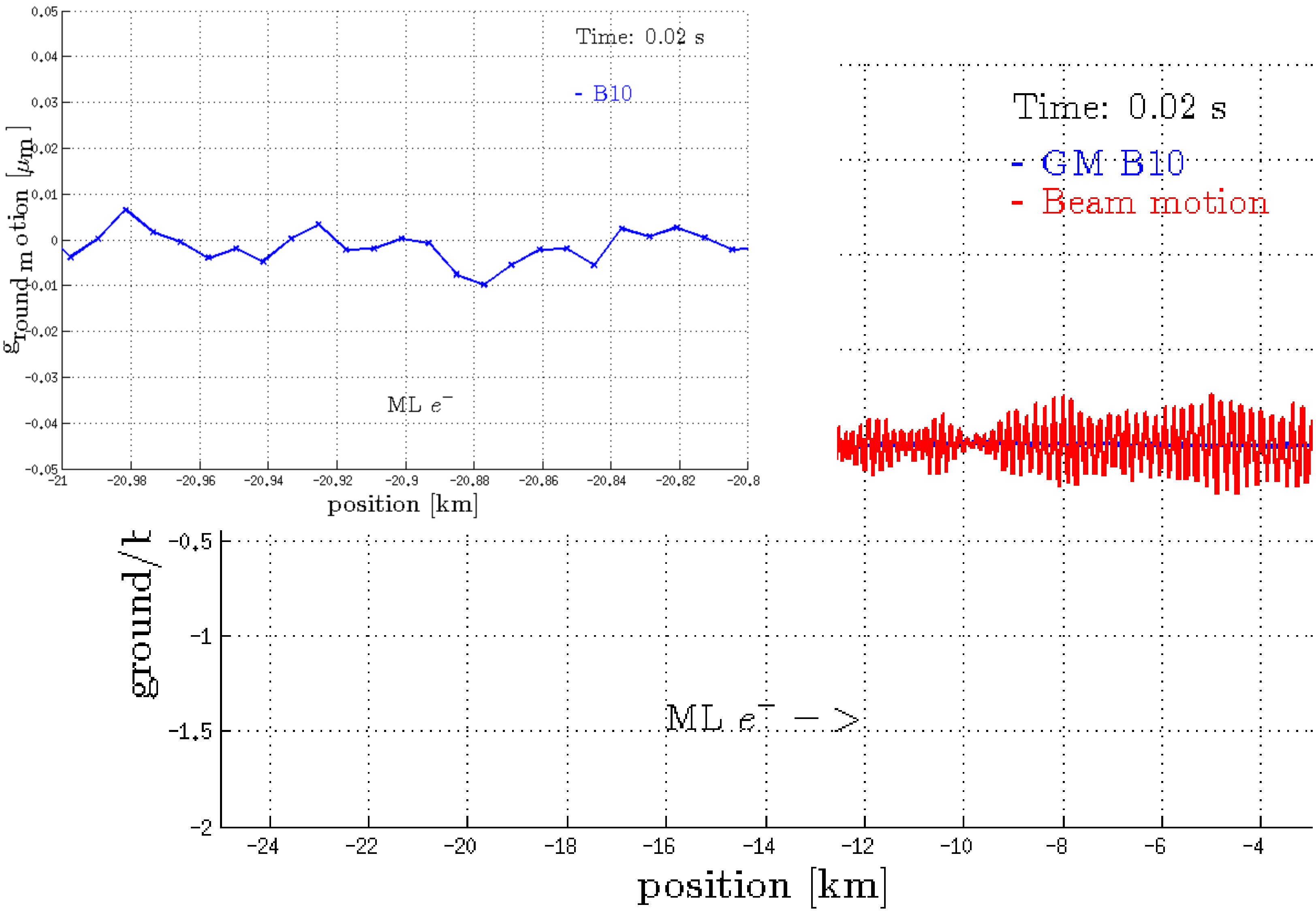
$$y(s,t) = \sum_{k,l}^{N_k,N_l} C_{kl} \left[\sin(\omega_k t)\sin(k_l s + \phi_{kl}) + (\cos(\omega_k t) - 1)\sin(k_l s + \psi_{kl}) \right]$$

Ground Motion at CLIC



J. Pfingstner

Resulting Beam Jitter



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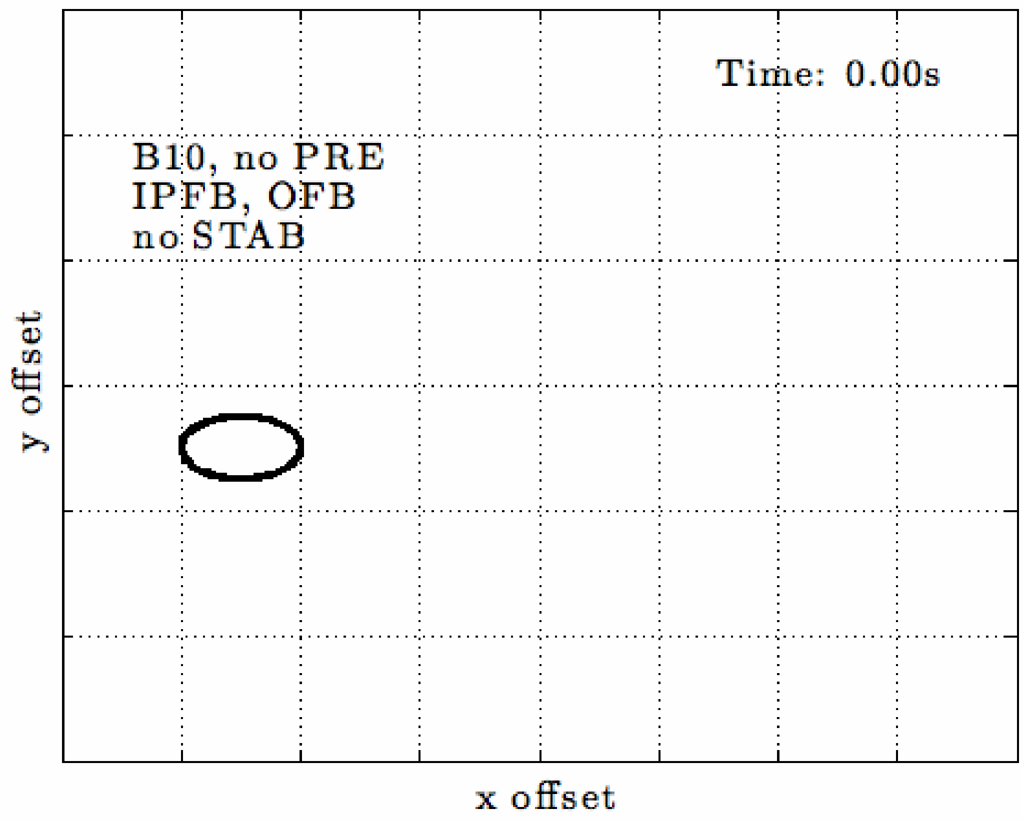
Beams at Collision



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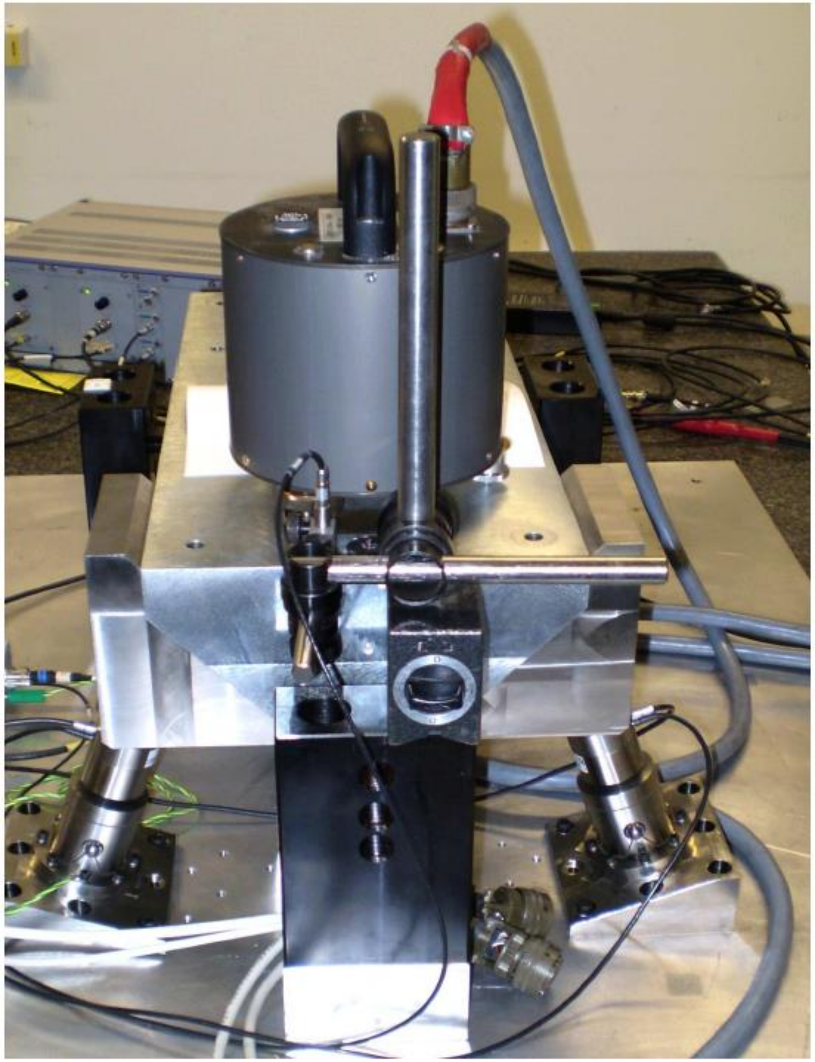
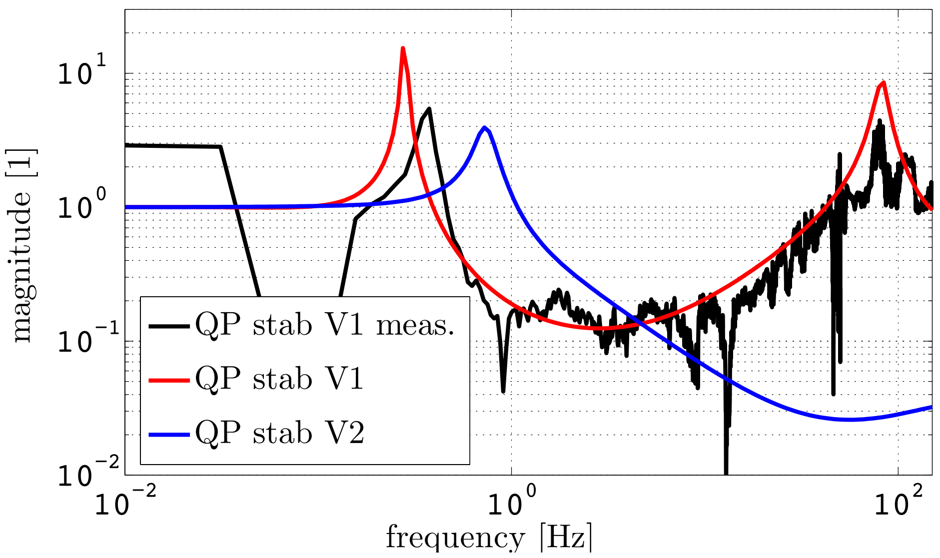
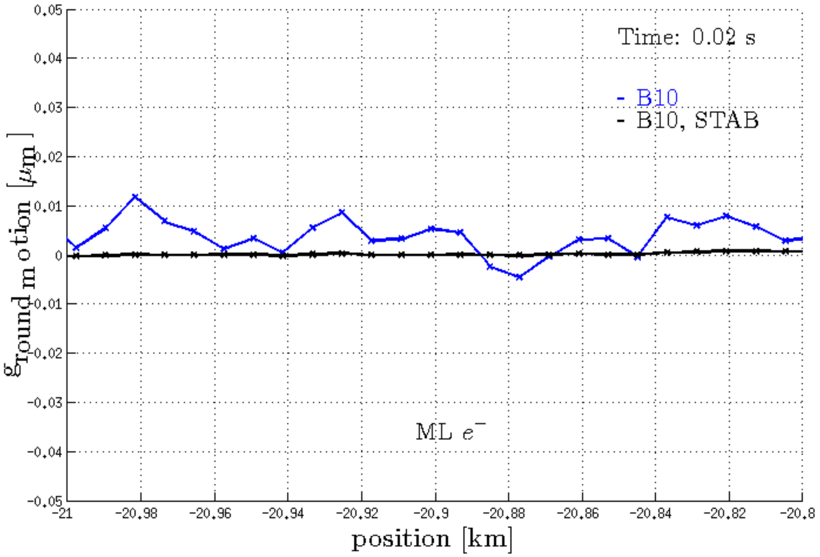
Stabilisation System



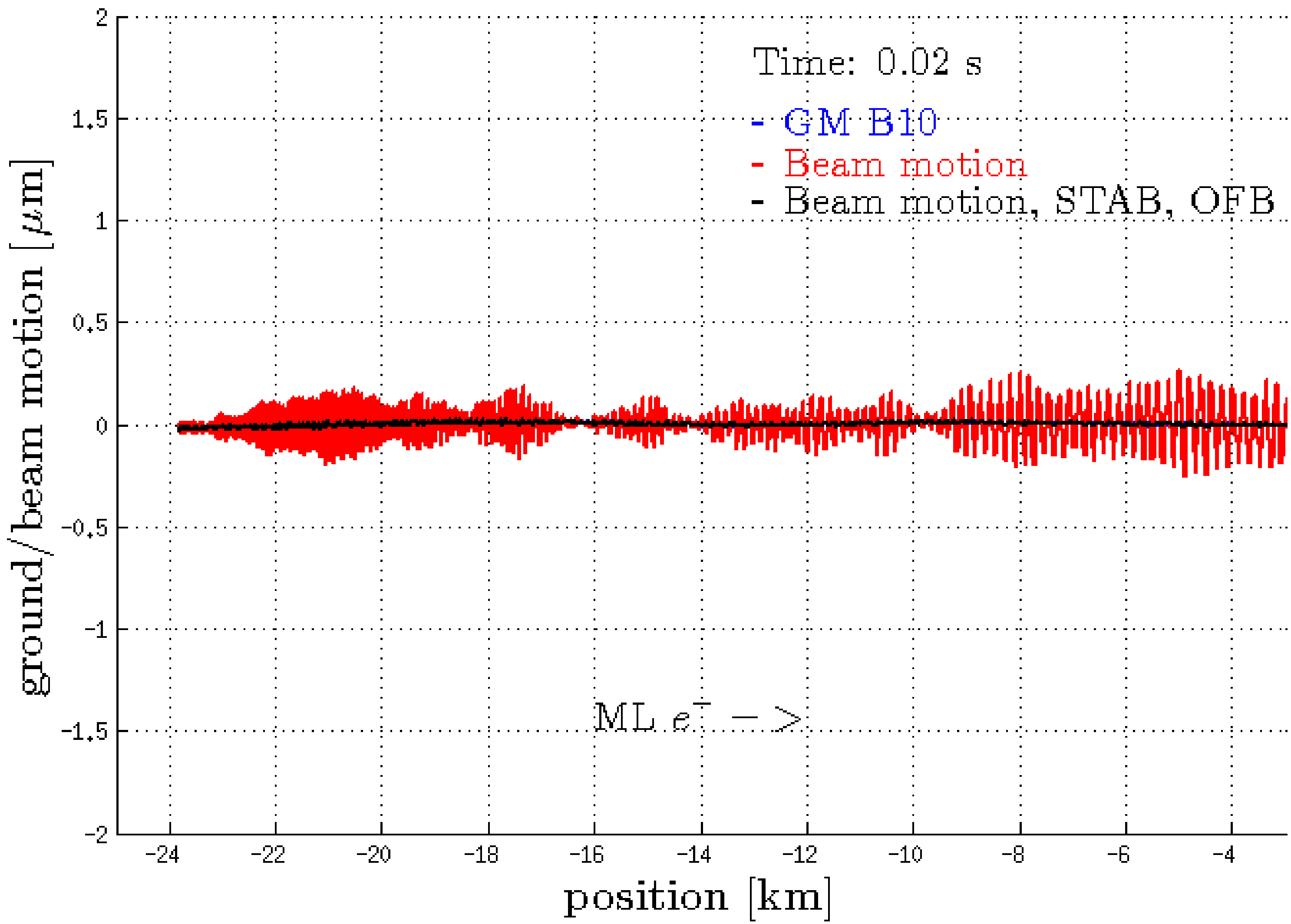
K. Artoos et al.





J. Snuverink, et al.

Impact of Stabilisation on Beam



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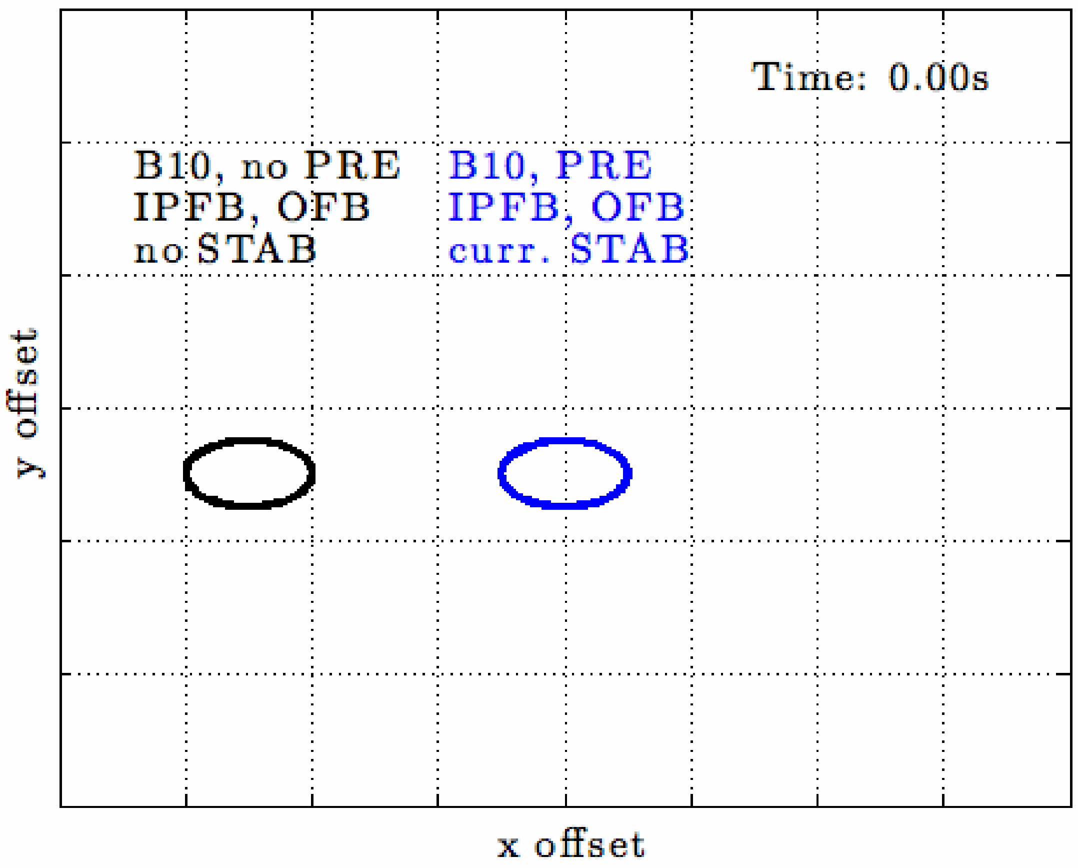
Beam at Collision



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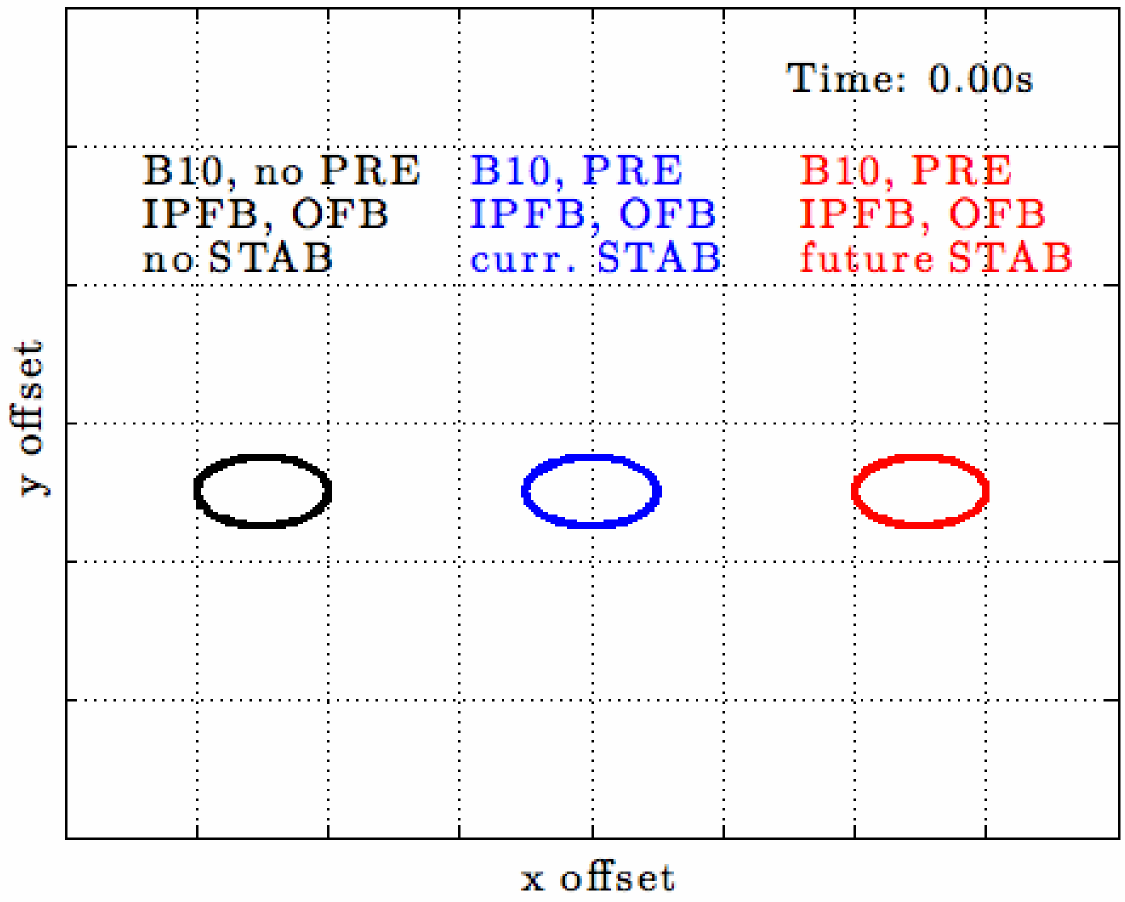
Beam at Collision



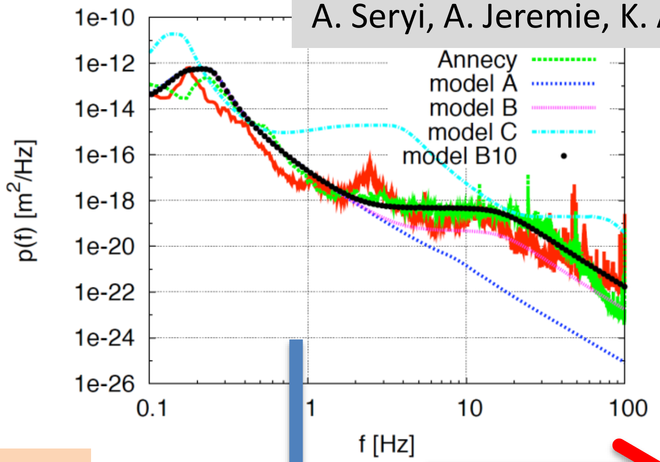
J. Pfingstner

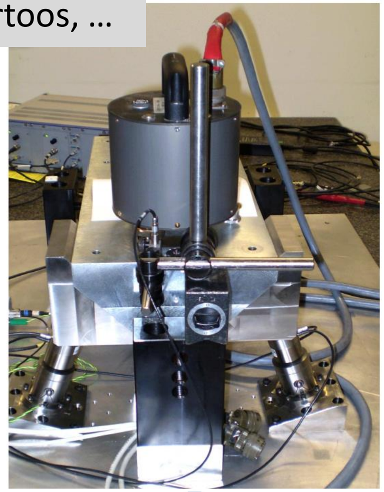
Ground Motion and Active Stabilisation

Ground motion and jitter could easily destroy CLIC luminosity (jitter tolerance of 0.2nm): considered feasibility issue

Establish strategy to convincingly demonstrate feasibility
Make hardware teams to support this
Make fighting teams work together

A. Seryi, A. Jeremie, K. Artoos, …

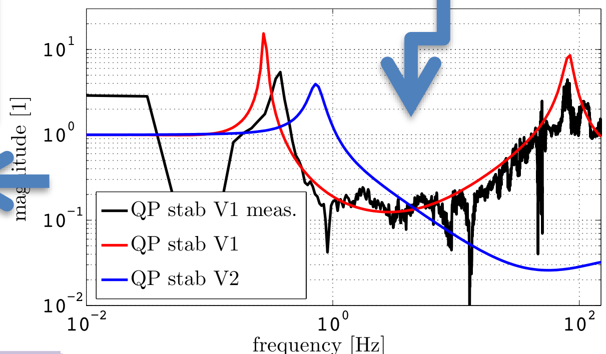


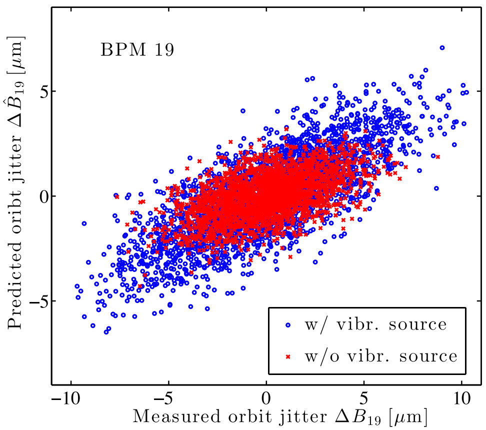


Beam-based feedback

J. Pfingstner,
J. Snuverink, D.S.,…

PLACET
GUINEA-PIG





Feed-forward

J. Pfingstner,
K. Artoos,
A. Jeremie,
R. Tomas,
D.S., …

Conclusion:
Performance target met with stabilisation

Strategy and conclusion endorsed by advisory committee

Stray Field Work Programme

- Understand (and model) sources
  - Natural
  - Environmental, e.g. trains, …
  - Technical, e.g. accelerator components
- Understand (and model) transfer to beam
  - Field at the beam is important
  - E.g. beam pipe can modify field
  - E.g. steel in walls of tunnel
  - …
- Understand (and model) impact on the beam
  - Here we have the tools
- Develop (and model) mitigation methods
- Make performance predictions
- Validate methods
- Choose most effective and cost effective method(s)

Here, we need to learn more

Based on models can predict collider performance

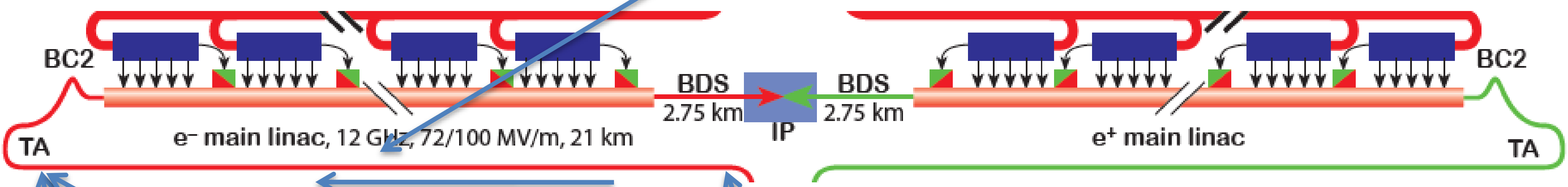
Experiments to develop and verify models including mitigation methods

Spatial Distribution

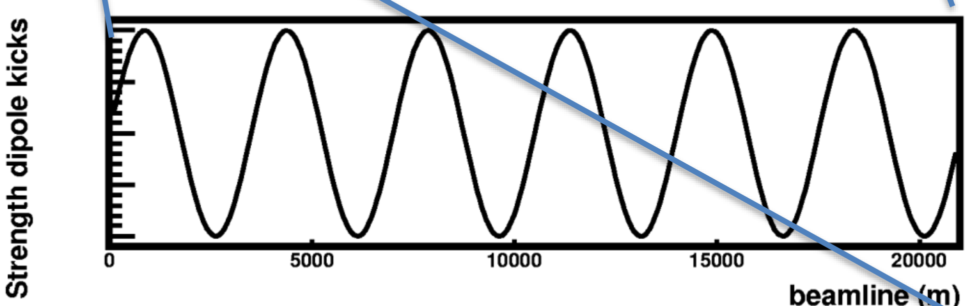
- The sensitivity of the beam depends very strongly on the local distribution of the field
  - It is more sensitive at some points than at others
  - In most regions it has a specific wavelength that is most critical
- First approximation:
  - The fields are constant in time but we did not apply a correction yet
  - E.g. think of a small perturbation that happened right now

Spatial Distribution Example

We study the line that transports the main beam to the beginning of the linac



Beam direction



We apply a field with a given wavelength

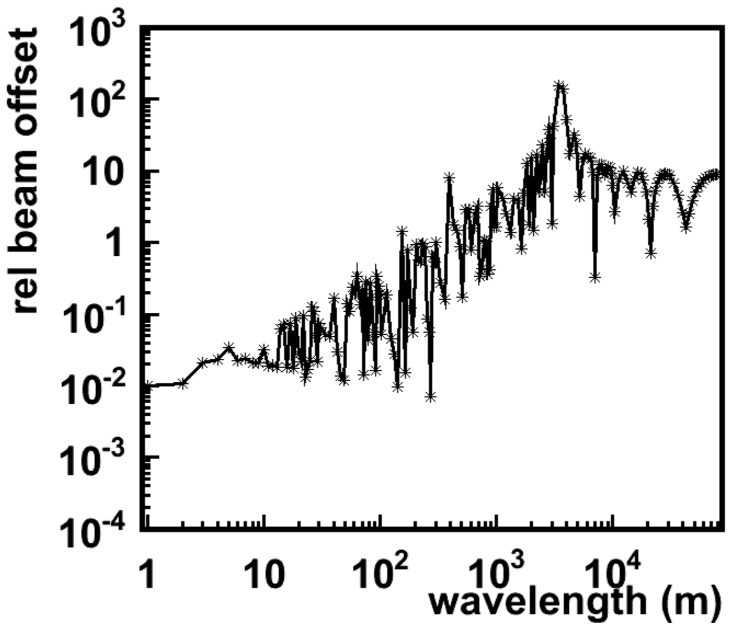
And study the beam trajectory

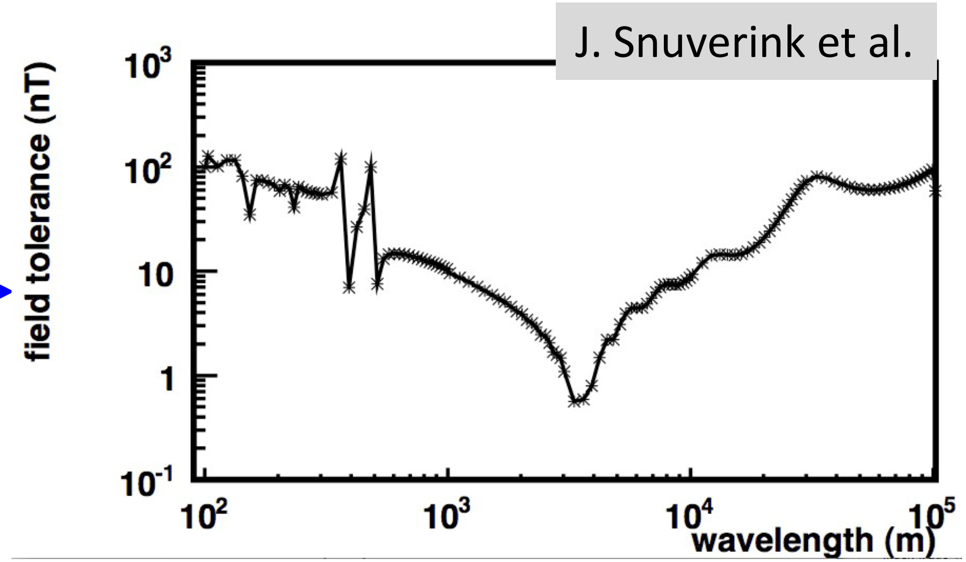
Note: we assume the field does not change while beam is passing (microseconds)

We determine the beam offset/emittance increase at the end of the line

$\Rightarrow$ Ch. Gohil for more detail

Spatial Distribution Example





From the determined offset we calculate the allowed tolerance to have an acceptable effect

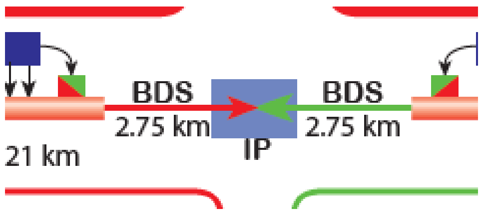
$$y(s)'' + \frac{1}{\beta(s)^2} y(s) = 0$$

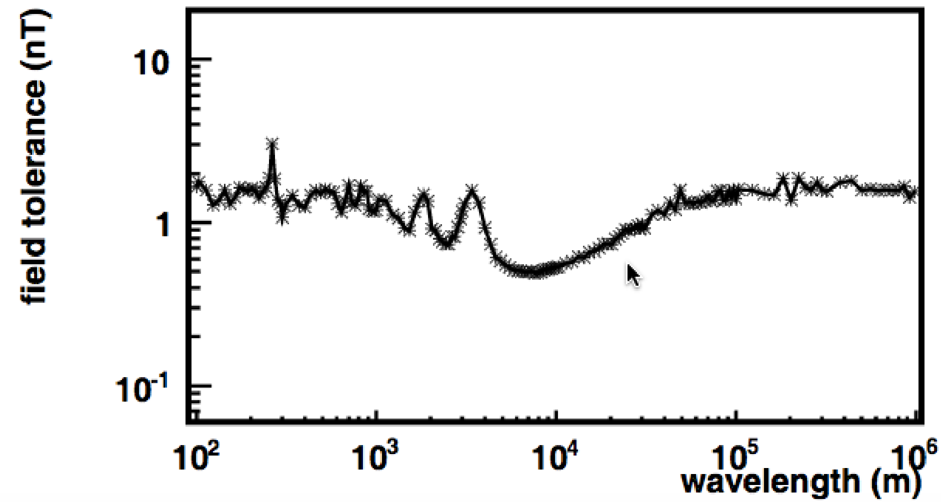
The tolerance depends strongly on the wavelength of the field

$$y(s)'' + \frac{1}{\beta(s)^2} y(s) = F(s)$$

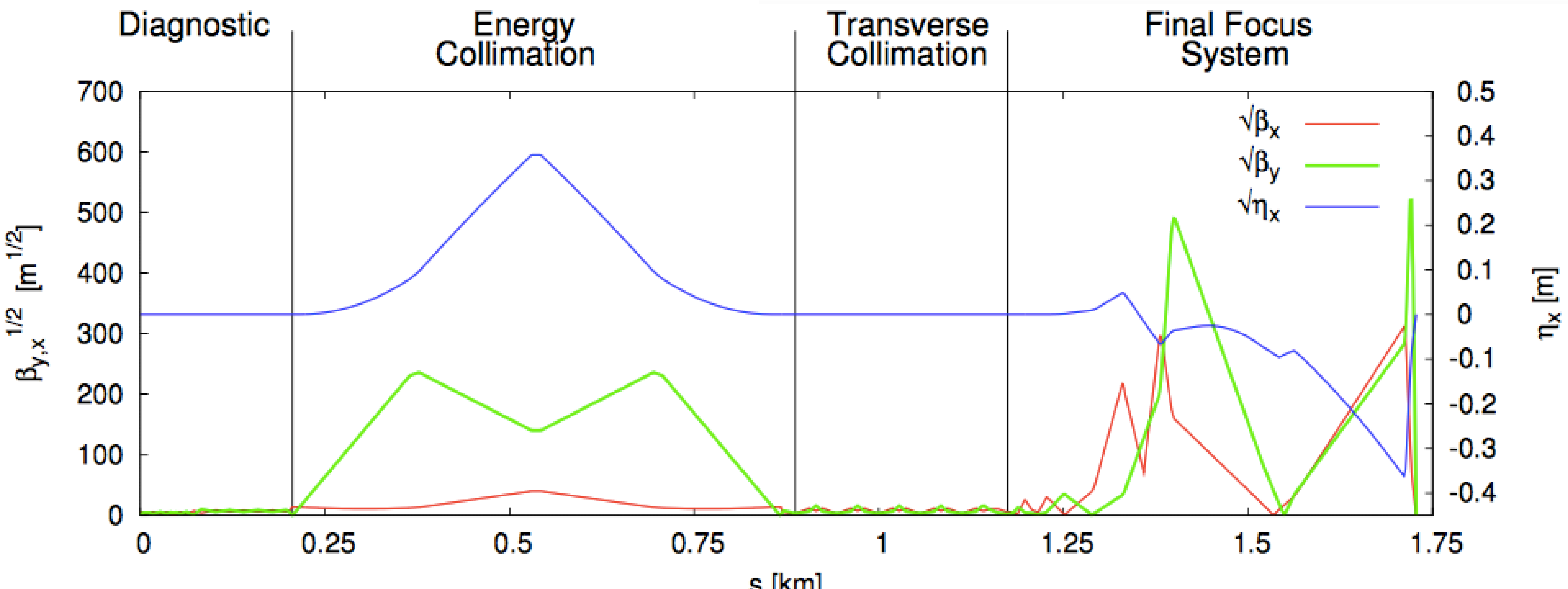
The guiding magnets lead to a specific wavelength for trajectory oscillations

Beam Delivery System

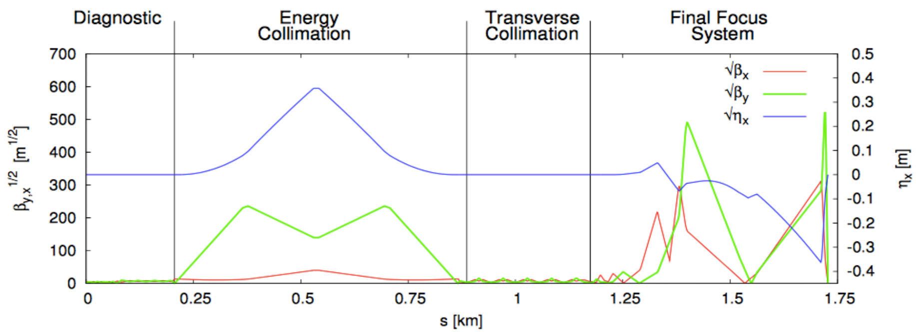




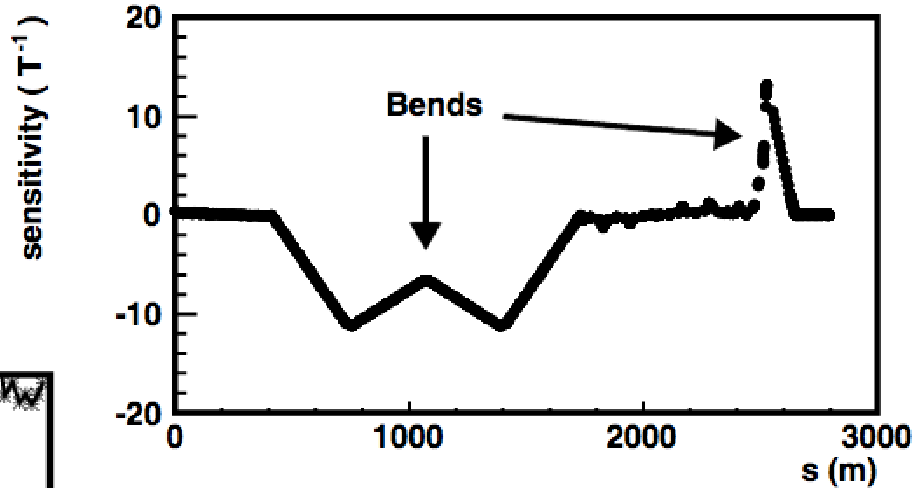
Anti-symmetric fields:
Beams move in opposite directions

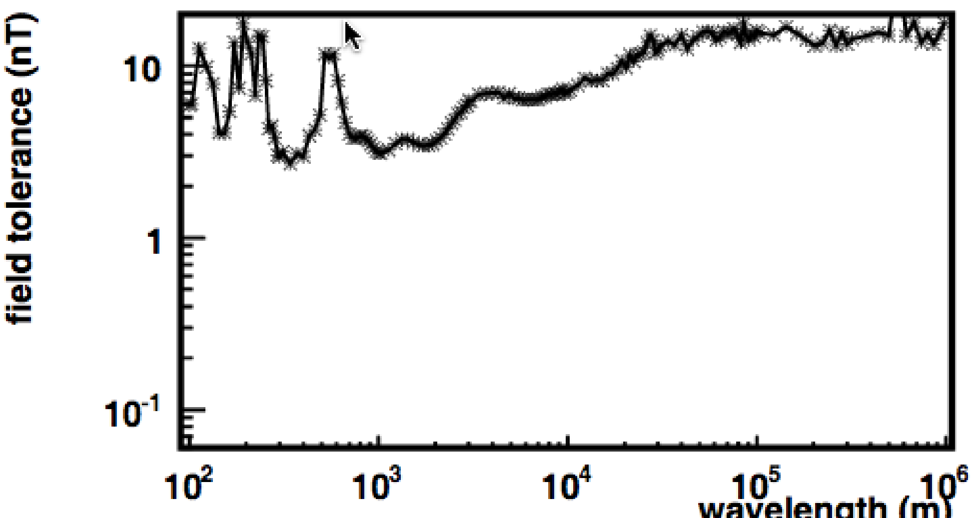


Impact of Shielding



Shielding sensitive regions helps





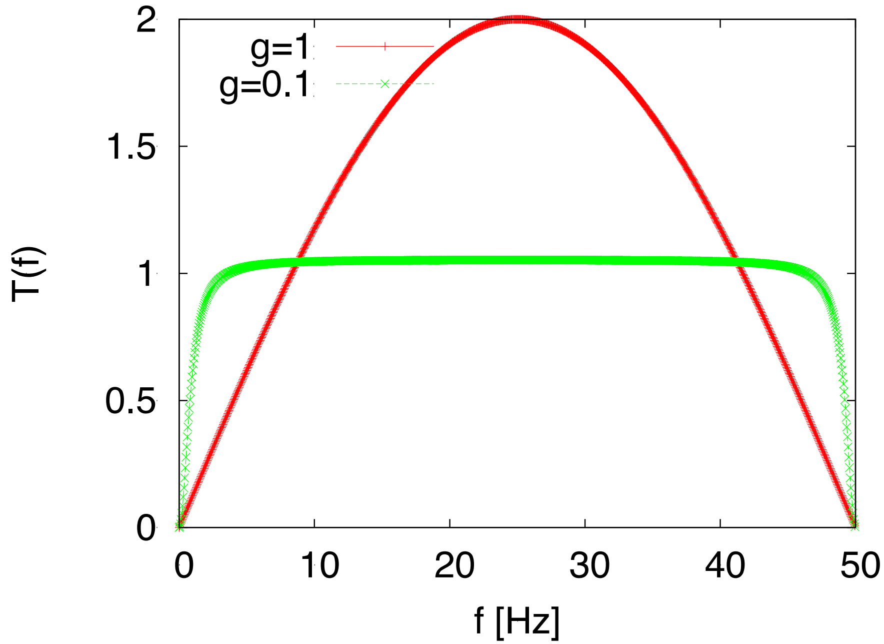
How much do normal magnets shield?
Superconducting magnets?
Superconducting coating on beampipe?
Active compensation?
...?

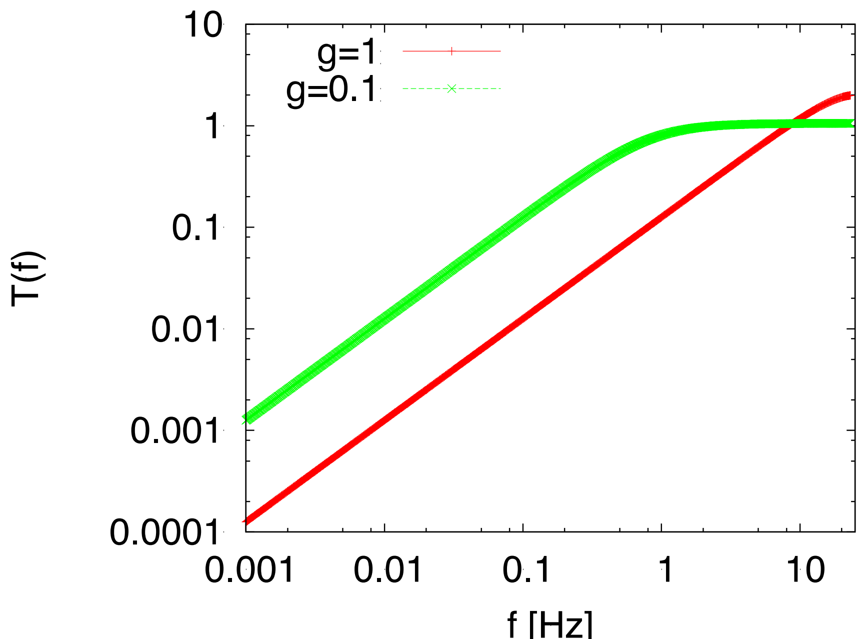
Beam-based Feedback

Beam pulses are 150 ns long
⇒ Cannot do much within one pulse
⇒ At some location can use feed-forward

We measure the trajectory for every beam pulse (every 20 ms) and apply correction before the next pulse

Show simple model of feedback to show amplification of trajectory jitter in one point





Beam-based feedback amplifies high frequencies and reduces low frequency trajectory motion by factor T(f)

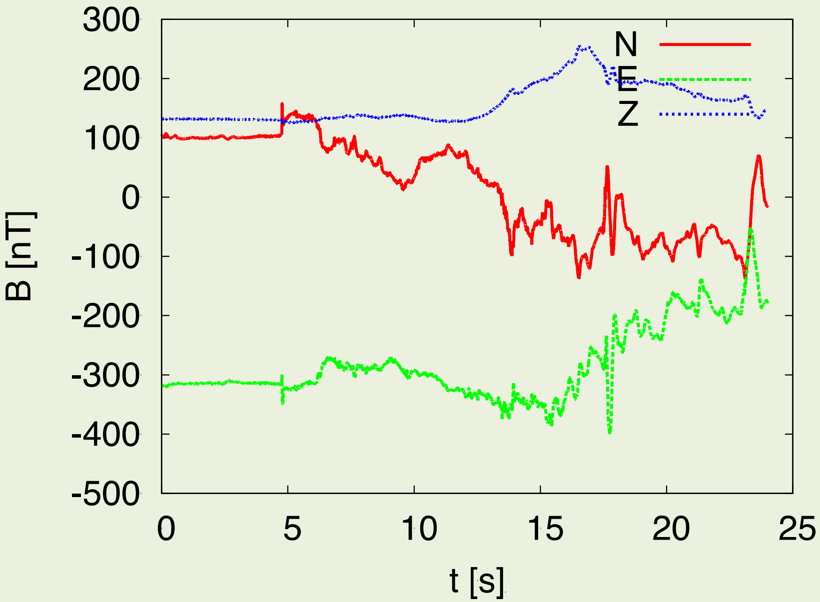
Frequencies well below 0.1 Hz matter less

Note:CLIC operates locked to the power grid (50 Hz) to minimise grid impact

Sources of Fields

Natural sources, e.g. magnetic storms
⇒ Seems OK

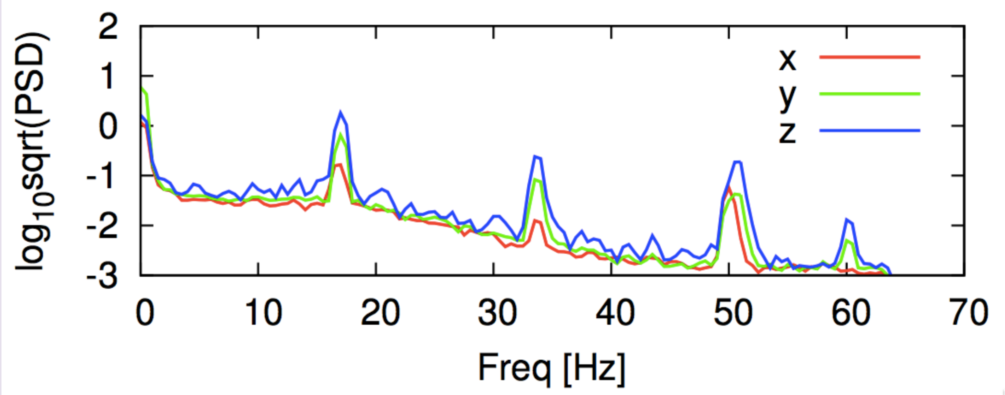
⇒ Ch. Gohil for more detail



Thanks to B. Heilig for the data

Environmental sources, e.g. power lines, trains
How does it propagate into the tunnel? How to best mitigate it?

B. Heilig et al.



Example measurement on the surface
Note: can use feedback using the pulse three timesteps ago

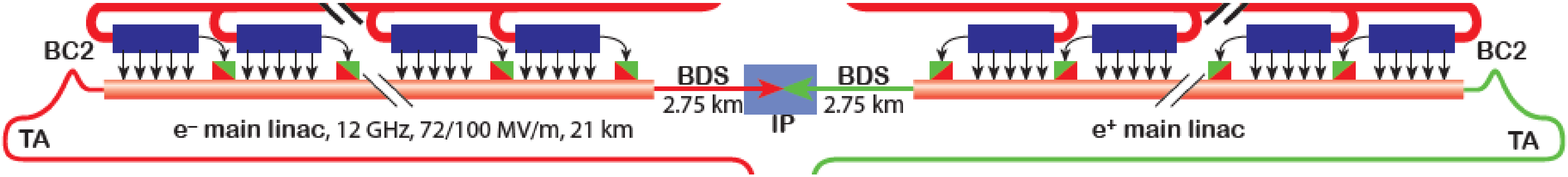
Accelerator sources, e.g. cables, kickers, magnets, vacuum pumps, beams, RF equipment
This is expected to be the main focus

Propagation of Fields

- Propagation of fields from sources to beam is important
  - To understand the impact on the beam
  - Materials can shield
  - But could also transfer field

- Might be difficult to model
  - Small fields
  - Complex geometries
  - Difficult materials (superconductor?, ferromagnetic, …)

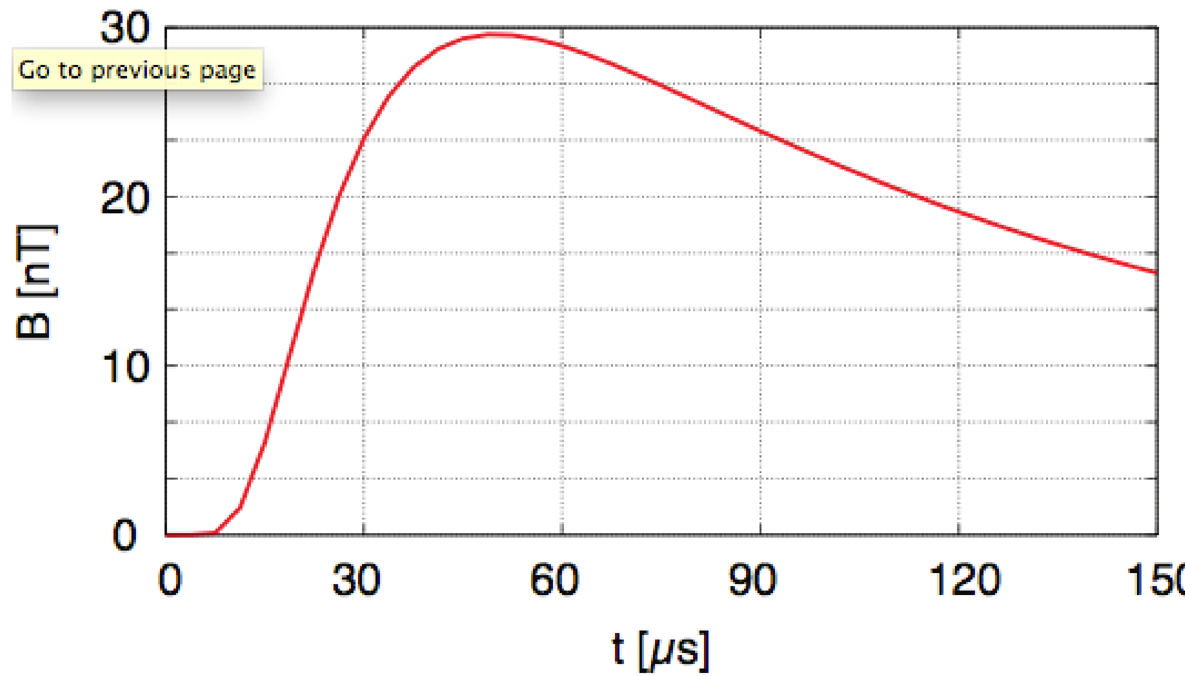
Example of Field Propagation



Outgoing 250 ns drive beam pulses produce fields that penetrate beam pipe

Time dependence of field outside of 2 mm copper pipe in 0.5 m distance (actual distance is much larger)

Main beam will see fields



But to first order the same field from one pulse to the next

$\Rightarrow$ Seems OK

Mitigation Methods

- Eliminate sources
  - Natural sources seem to be OK, even in sun storm
  - More on environmental and technical sources, e.g. design of components
- Develop passive protection
  - E.g. shielding (components?, the whole tunnel?, …)
- Develop active protection
  - Local feedback to keep fields stable
- Beamline design
  - Stronger focusing, adjustment of phase advance
- Develop compensation
  - Measure fields and apply compensating kicks to the beam
- Finally, chose best solution based on efficiency and cost

Measurement Capabilities

- Measurement capabilities are instrumental to identify all relevant sources
- And to validate our mitigation methods
- Measuring in real time is important for feedback on magnetic fields
  - Radiation hardness might be required
- Particular challenge might be short bursts of field (O(150 ns)) caused by beam or equipment
- Also measurements in quieter sites should be foreseen

Conclusion

- Dynamic magnetic fields can affect the CLIC beam
  - Some nT at Hz

⇒ Ch. Gohil

- Natural field sources seem to be low enough
- More work on technical and environmental sources
  - How do … nnel? How m… best be mitigate…
  - Which … to best remove …

Field level is new for us

- Collect existing expertise
- Explore novel approaches

Room for exciting R&D and clever ideas

Your help is welcome

- A wide range of mitigation methods can be considered
  - Have to identify the best choice of methods to limit the field fluctuations and mitigate their effect