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CLIC decelerator instrumentation – a first look

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Abstract

The purpose of the decelerator is to extract energy from the CLIC drive beam (via Power ExTracting Structures), and transfer it to the accelerating structures. The transport of the beam through the decelerator lattice must be achieved with very small losses (< 0.1%). The drive beam is characterized by its very large current, and its huge energy spread.

The sensitivity to quadrupole misalignments imply the need for beam-base alignment, which implies that a BPM is provided for each quadrupole – in total ~ 35000 BPMs. In addition, loss monitors, beam profile monitors and final energy spectrometer are instrumentation which are envisaged. The discussion of the required instrumentation is not conclusive, as this is considered a first iteration of the drive beam decelerator requirements.

The attached presentation first goes through the main particularities of the drive beam dynamics, then the instrumentation needs are discussed, and finally a comparison with the TBL is done.

Acknowledgements

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The CLIC decelerator

Instrumentation issues – a first look

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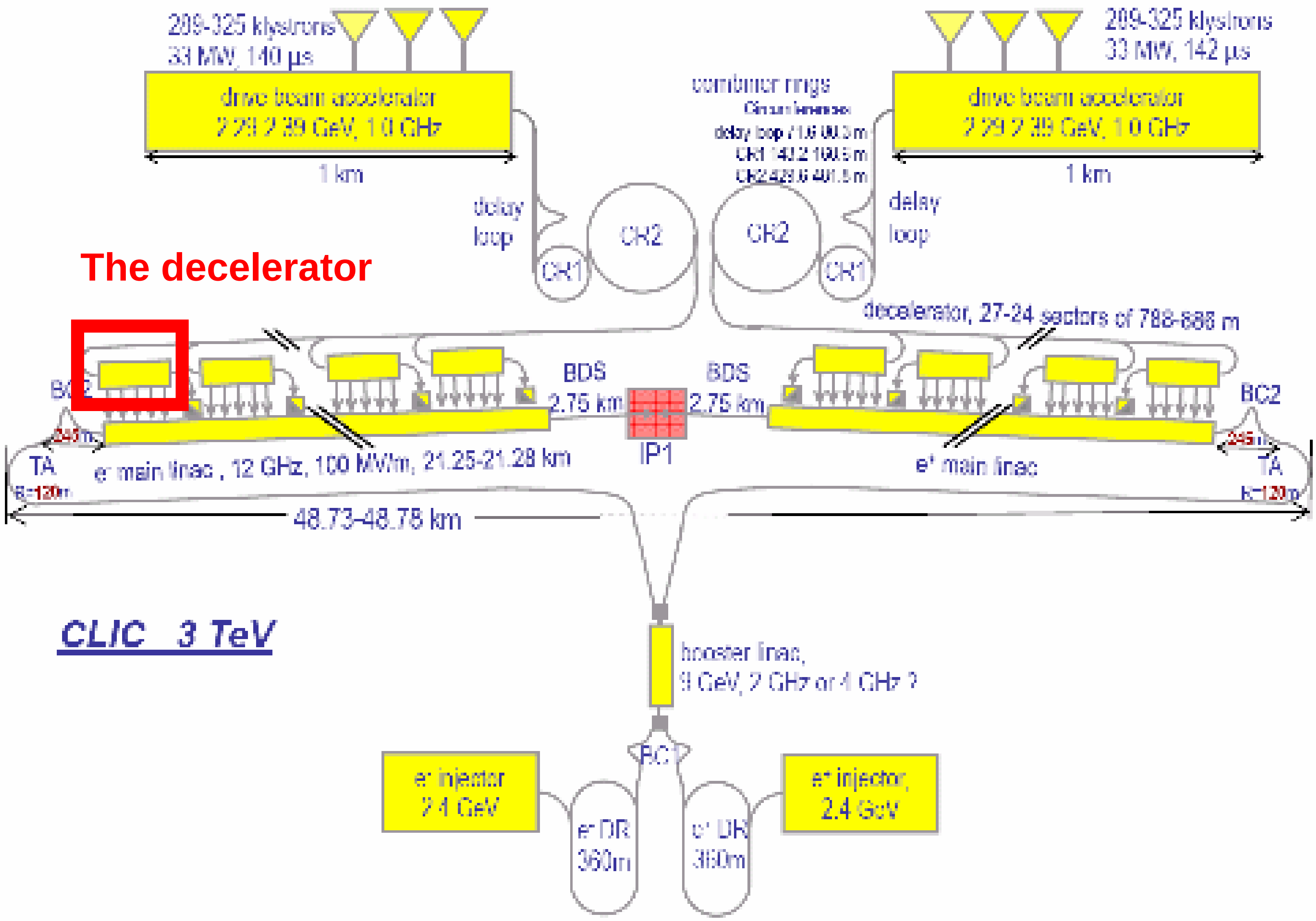
What are we talking about?



Content

- Particularities of the decelerator beam
- Instrumentation discussion
- Comparison with the TBL

Goal of presentation: **convey beam dynamics of the drive beam decelerator, then discuss (in plenum) the instrumentation issues**

Part 1

Particularities of the decelerator beam

Decelerator BD requirements

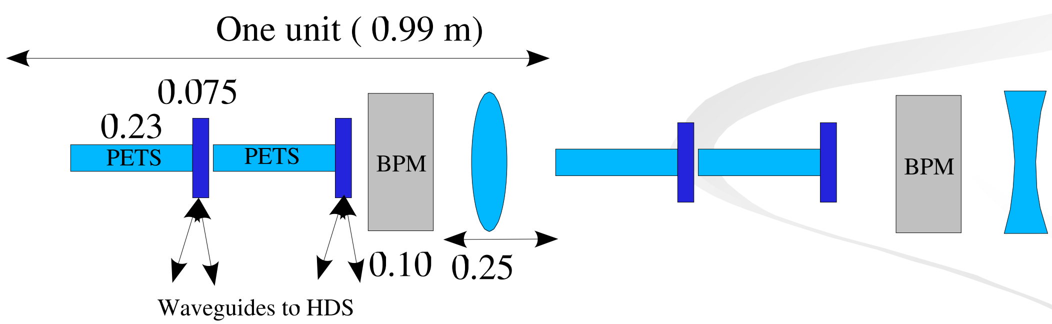
- Deliver required power to accelerating structures
  - → Minimize losses (smaller than 0.1%)
- High power production efficiency
  - → Low final energy → large energy spread

Our target is to transport the beam, the *whole beam*, through the decelerator lattice

The decelerator lattice

(parameters of mid-2007)

- 26 * 2 stations
- 688 units per station



The CLIC drive beam

- High-current, low-energy beam for strong wake field generation

- Initial beam parameters:
  - $E_0 \approx 2.5$ GeV
  - **$I \approx 96$ A**
  - $d = 25$ mm (bunch spacing, $f_b = 12$ GHz)
  - $\tau \approx 300$ ns (3564 bunches)
  - Gaussian bunch, $\sigma_z \approx 1$ mm
  - $\varepsilon_N \approx 150$ µm

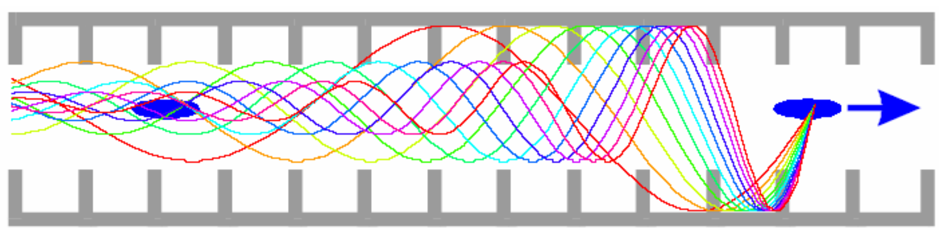
1st particularity of the decelerator beam: huge current

Principle of power generation

- Particles will feel parasitic loss and induce a wake field in the PETS
- The wake field will interact with and further decelerate :

  1) rear part of bunch (**single-bunch** effect)

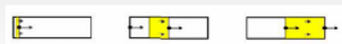
  2) following bunches (**multi-bunch** effect)

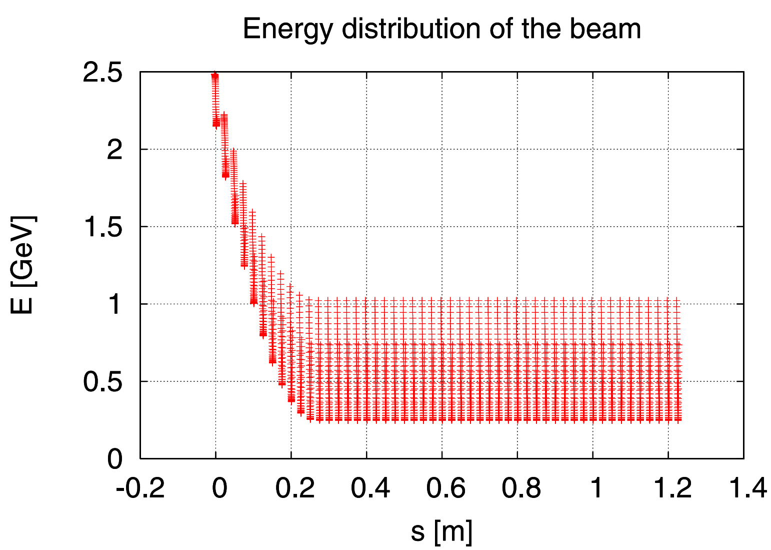


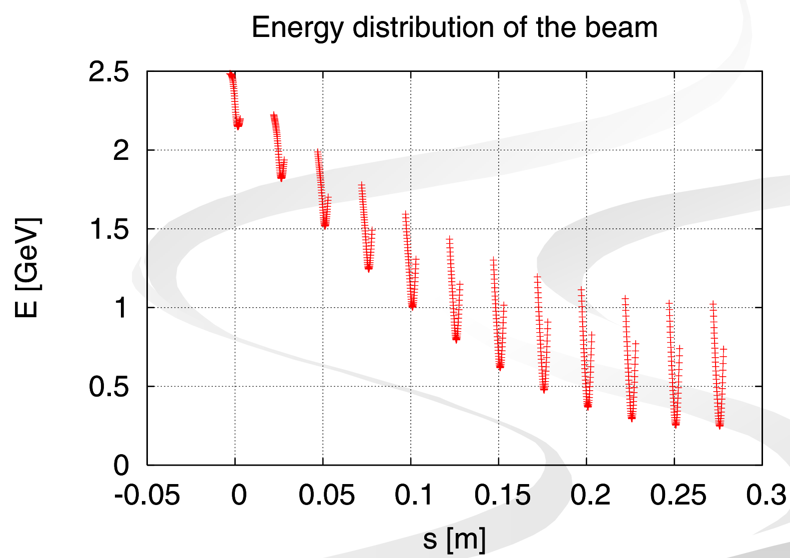
- The integrated effect in a PETS on a witness particle due to a source particle is given by

$$\int_0^{l_{cav}} F_L(z)ds \approx -q_s q_w w_L(z)$$

Simulation results: energy extraction

- PETS longitudinal wake parameters:
  - R'/Q = 2295 Ω/m (linac-convention)
  - f_L=11.99 GHz
  - β_g = 0.453 
- Beam energy profile after lattice: (initial: flat E_0=2.5 GeV)





NB: leading particle always to the left! (PLACET output def.)

2nd particularity of the decelerator: huge energy spread

Energy extraction efficiency: η

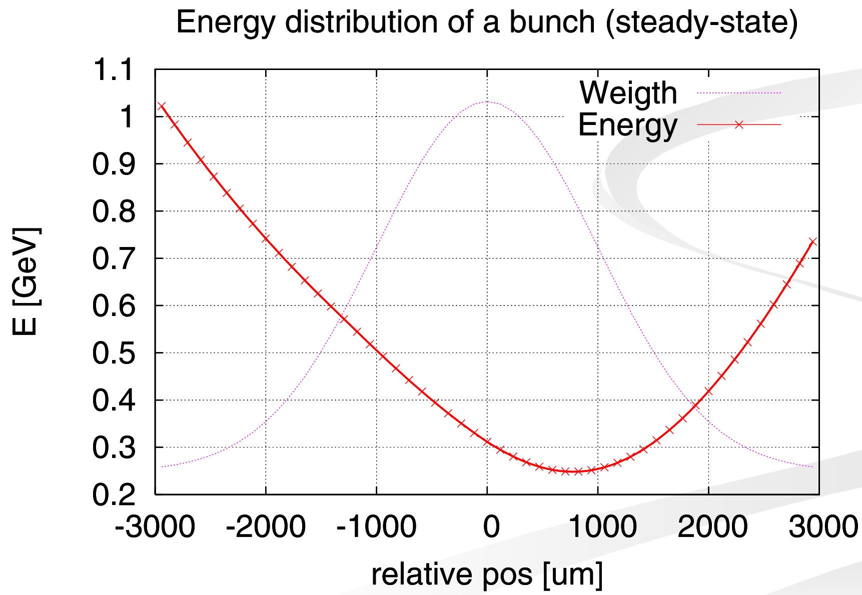
- $\eta = P_{in}/P_{out}$: **steady state** power extraction eff.: $\eta = P[W] \times N / E0[eV] \times I[A]$

- We can express the **steady state** extraction efficiency as:

$$\eta = S \times F(\sigma) \times \eta_{dist}$$

where for current CLIC parameters:

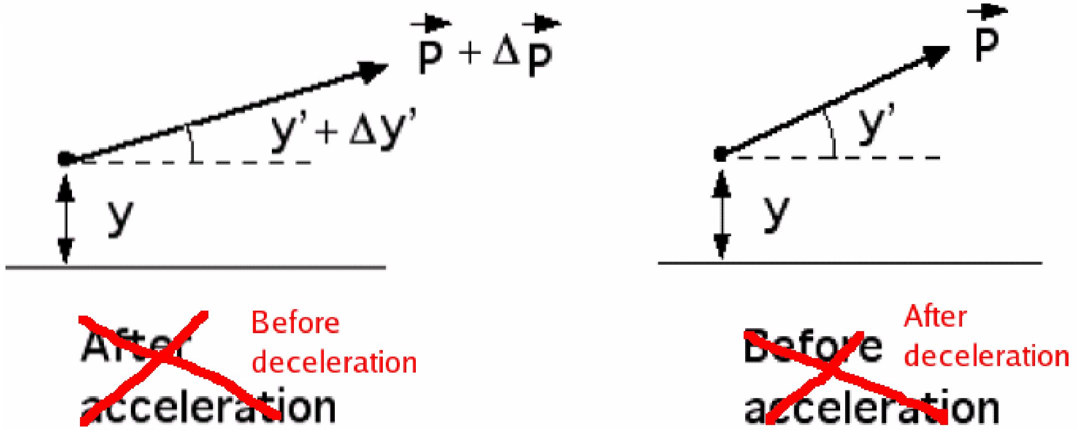
- S = 90.0 % (max energy spread)
- $\eta = S \times F(\sigma) \times \eta_{dist}$ = 90.0 % × 96.9 % × 97.4 % =84.5 %



- (η_{dist} can be improved with detuning: not discussed further here)

Energy spread and beam envelope

- Why is the max. energy spread, S, important?
- In the TBL we will have the effect of *adiabatic undamping*



$P_z = P + \Delta P$

$P_y = y'P$

$P_z = P$

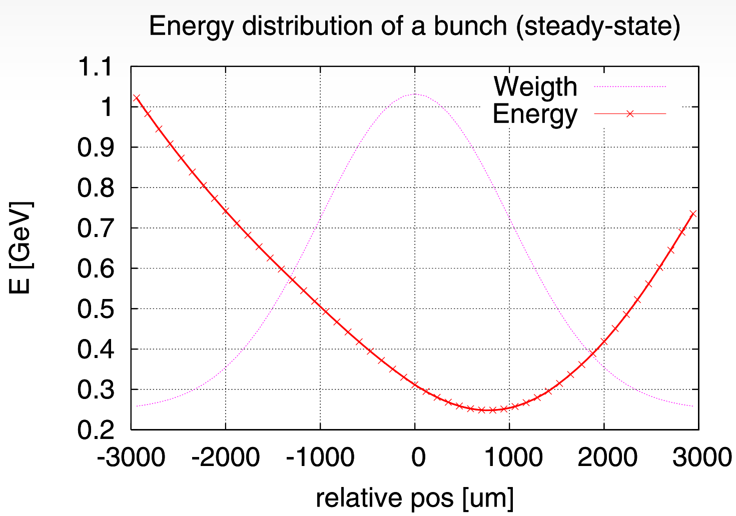
$P_y = y'P$

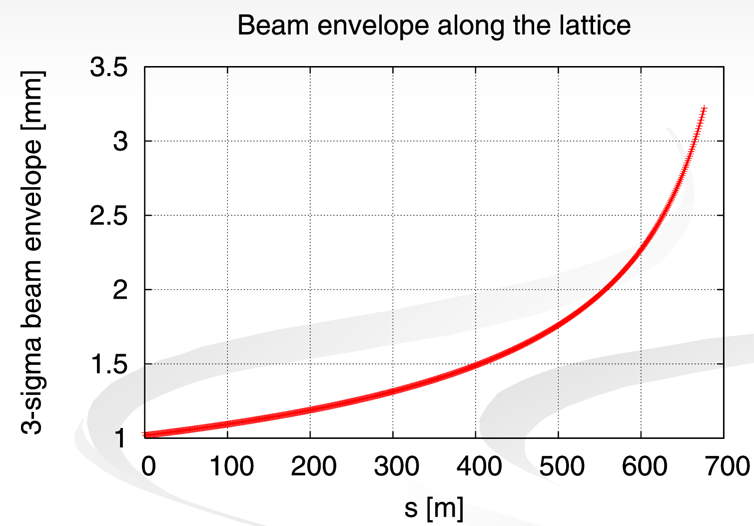
(fig: A. Chao)

- The divergence, y'=dy/ds, and ultimately also beam envelope, will increase with decreasing energy

Beam envelope along the lattice

- Thus, beam envelope along the lattice $r_{ad} \propto 1/\sqrt{\gamma}$



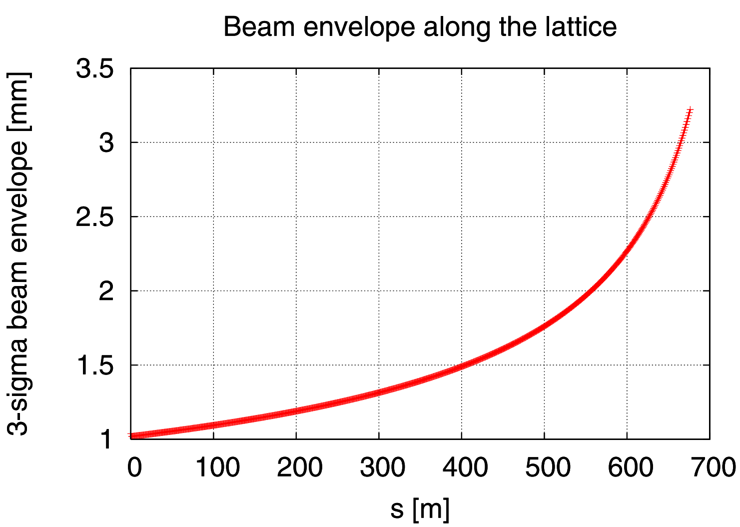


Beam envelope due to adiabatic undamping alone

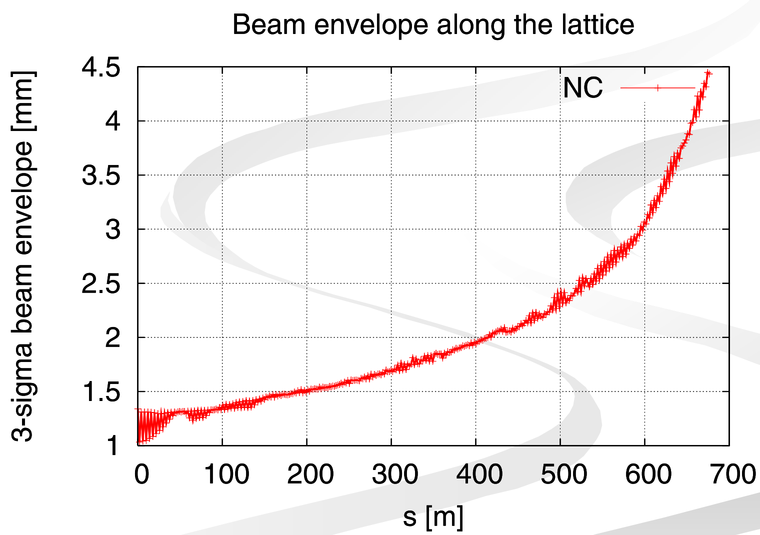
$$r_{ad} = \sqrt{3^2 \sigma_x^{\,2} + 3^2 \sigma_y^{\,2}} \approx 3 \cdot 2 \sqrt{L_{FODO/2} \varepsilon_N /(1-S)\gamma_0}$$

Misalignment: PETS

- Misalignment and beam jitter will introduce growth of beam envelope due to transverse wakes
- Effect on beam envelope for PETS misalignment of 200 um:



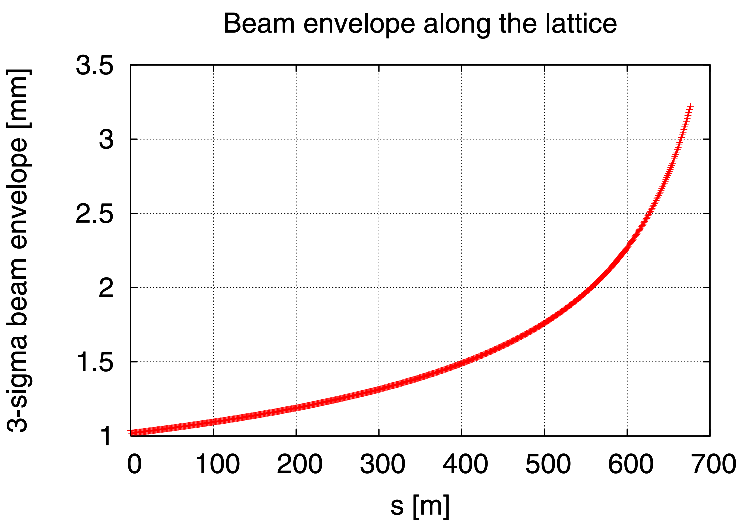
Adiabatic effects alone



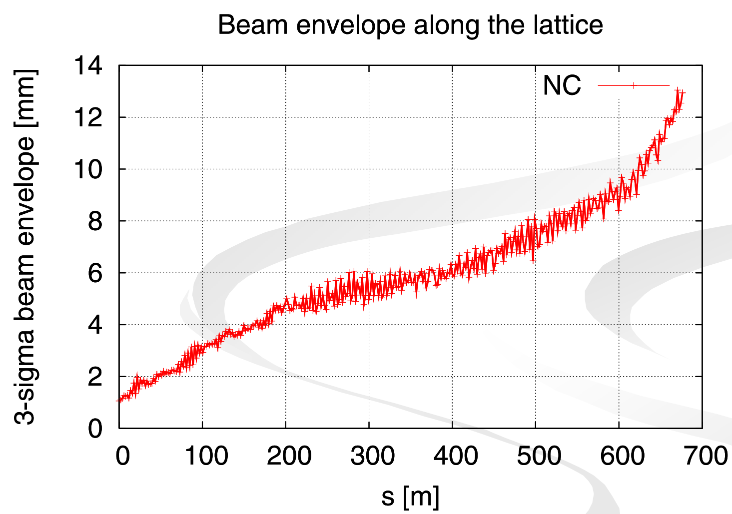
With PETS misalignment

Misalignment: quads

- Misalignment of quadruples will introduce growth of beam envelope due to kicks
- Effect on beam envelope for quadrupole misalignment of 20 um:



Adiabatic effects alone

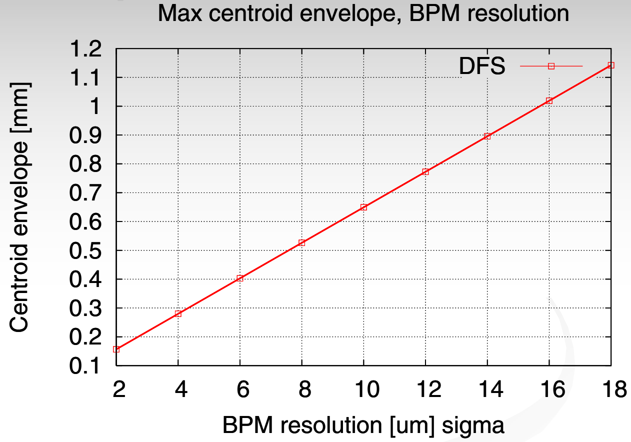


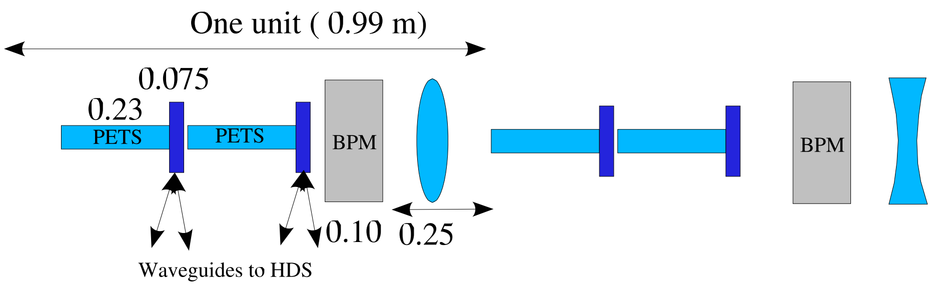
With quadrupole misalignment

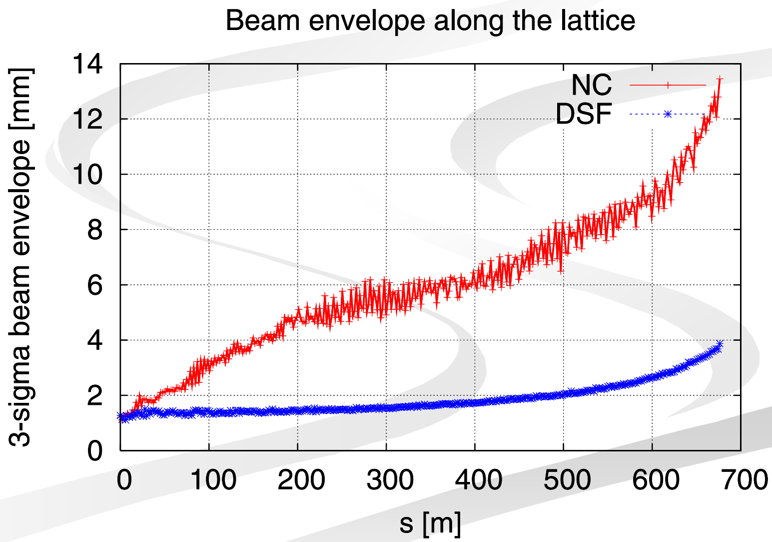
3rd particularity of the decelerator: large beam size

Beam-based alignment

- Predicted pre-alignment accuracy of quads is not acceptable for operation
- Beam-based alignment required
- Foreseen methods
  - 1-to-1 steering (for initial correction)
  - Dispersion Free Steering







- Both methods require one BPMs for each quadrupole

Part 2

Decelerator instrumentation – a first look

Decelerator: BPMs

The need for beam-based alignment implies:

- One BPM per quadrupole
- Total number of BPMs: ~ 26 * 2 * 688 = ~ 36000
- Current: ~ 100 A
- BPM resolution requirement derived from dispersion-free steering: at least ~10um
- Beam envelope (~99.9%) might reach close to PETS aperture limit of 11.5 mm. (at start of decelerator envelope size: ~1 mm)
  - Centroid signal / range of BPM: few millimeters
  - But signal from halo-particles must be taken into account
- Available length for BPMs: $\approx$ 10 cm
- Time resolution: ~ 10 ns (fraction of train length)

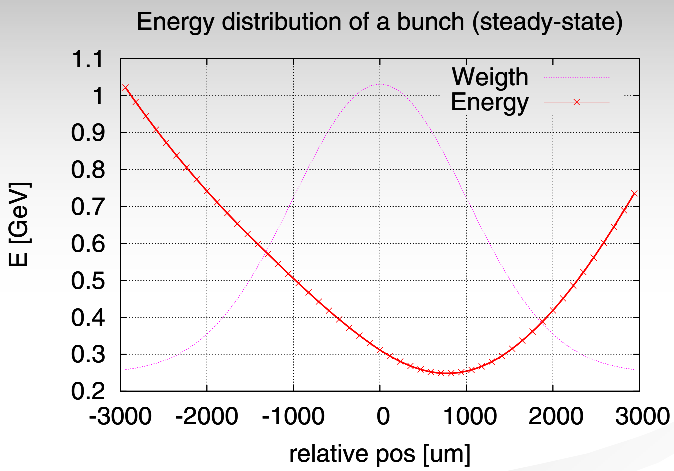
Decelerator: loss monitors

- Required: loss monitors
  - Ensuring beam transport with minimal losses is crucial
  - Installation frequency of these components is TBD
  - Keeping instrumentation small is of concern (in the current design: zero length is foreseen for such instrumentation, except of PETS-free units)

- Desirable: instrumentation to measure transverse beam size (frequency of these components TBD)

Decelerator: other instrumentation

- Measurement of beam energy at the end of the lattice (spectometer/ dump-measurement)



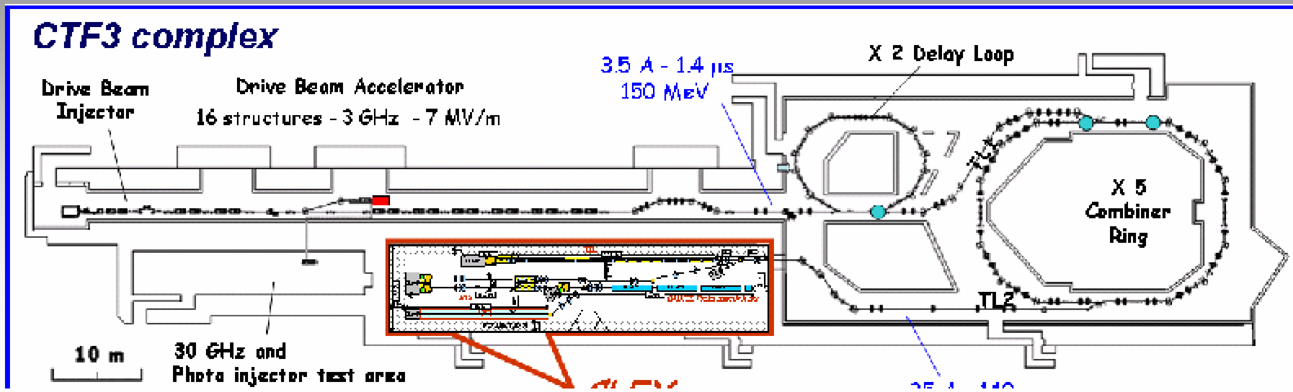
- Phase-monitors for synchronization drive beam and main beam

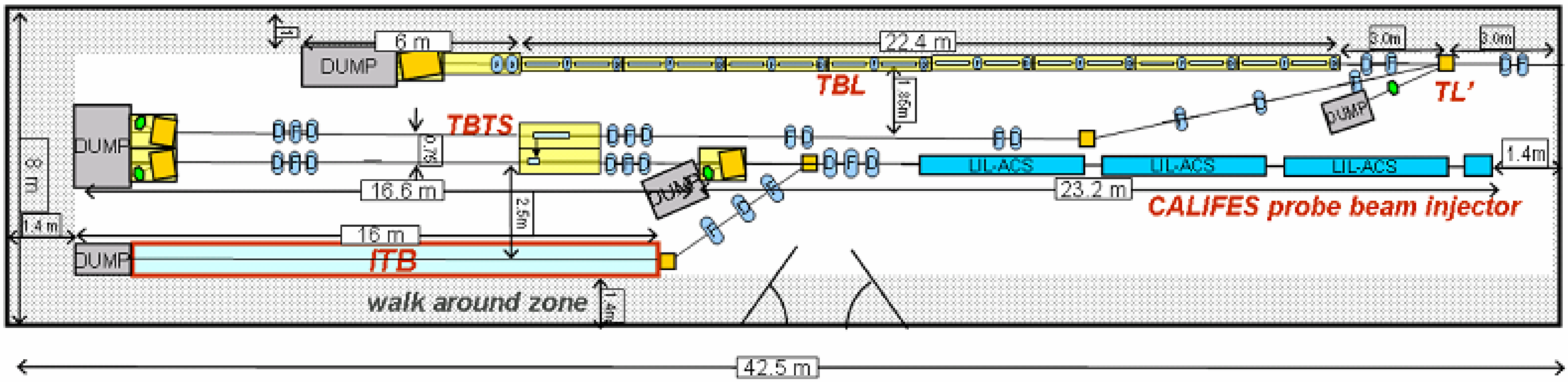
- Entrance (feedback to BC) and possibly exit: bunch length/long. emittance measurement

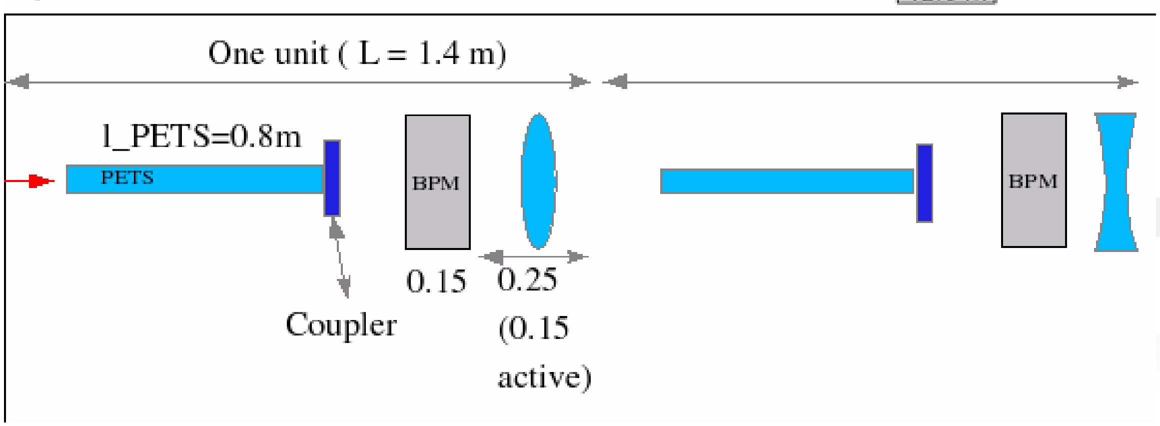
Part 3

The Test Beam Line

TBL: the test of the decelerator





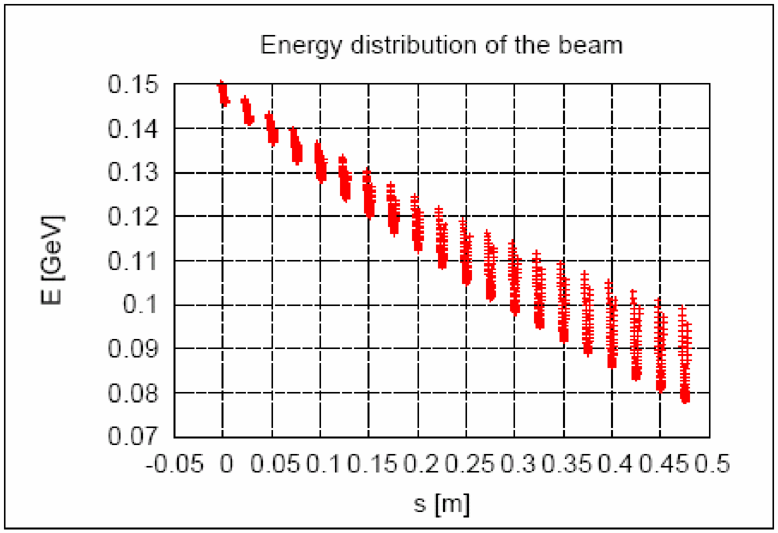


Lattice:

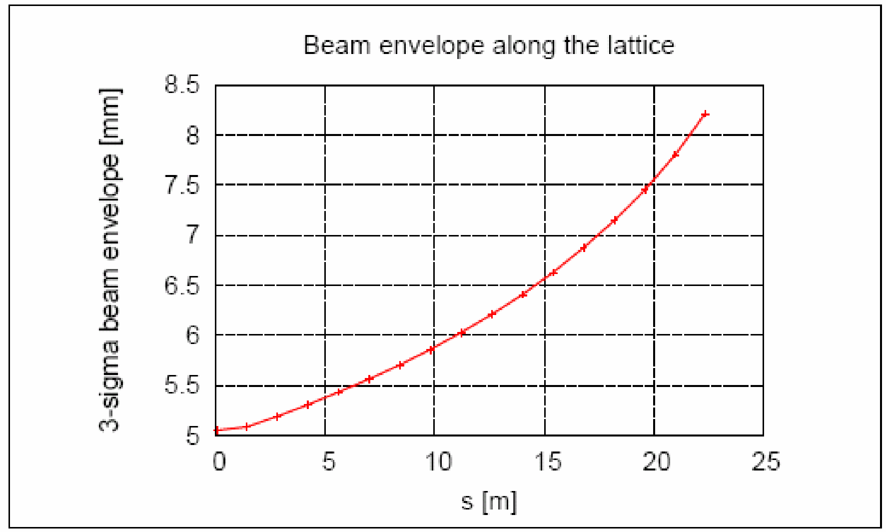
16 units of one of each:

- **PETS + coupler**
- **Quad**
- **BPM**

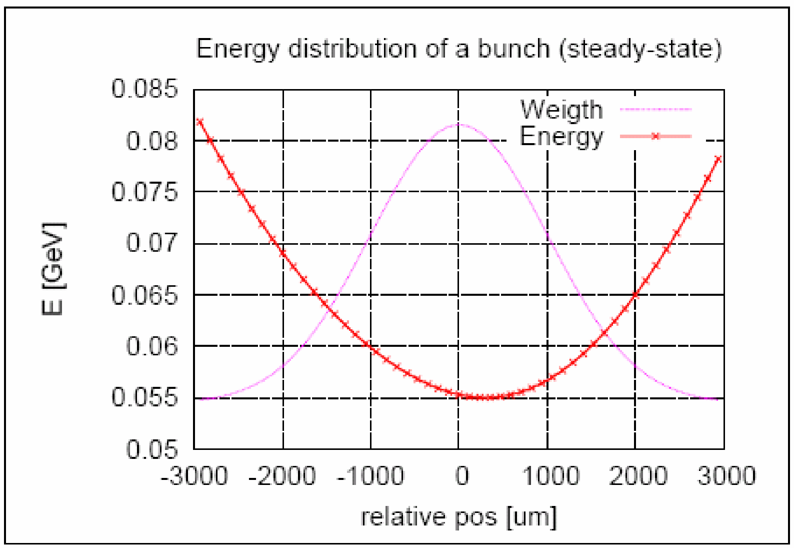
Beam dynamics of TBL



Beam energy after lattice



3-σ beam envelope along lattice (adiabatic effects alone)



Steady state bunch energy profile

Different parameter range:

*** E0 ~ 150 MeV, I ~ 30 A, τ ~ 140 ns**

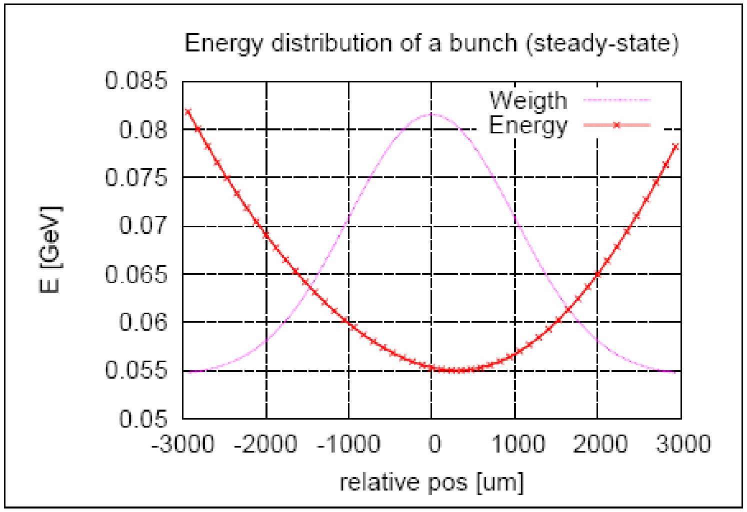
However, the TBL will show the same beam dynamics effects as the CLIC decelerator:

*** envelope growth**

*** decelerated energy profile**

Instrumentation for the TBL

- BPMs: one per quad, resolution ~ 10 um and dynamic range of up to ~ PETS aperture limit (?)
- Spectrometer: here good energy measurement at end of lattice is very important (benchmarking of model and code)
  - ...with z-dependence? Ideas?
- Profile / loss monitors
  - beam size at end of lattice?



Steady state bunch energy profile