The CLIC decelerator

Instrumentation issues – a first look

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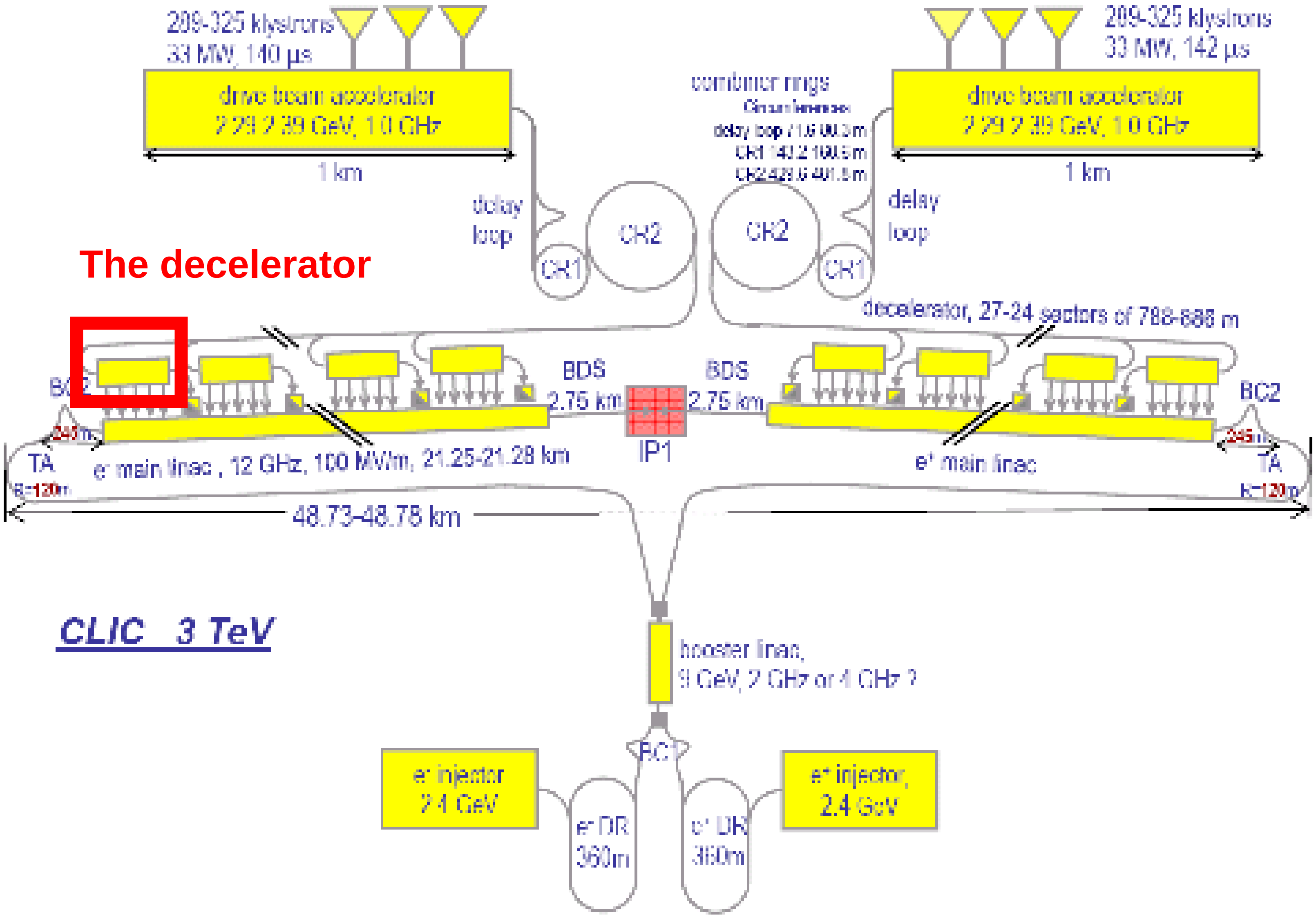
What are we talking about?



CLIC 3 TeV

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

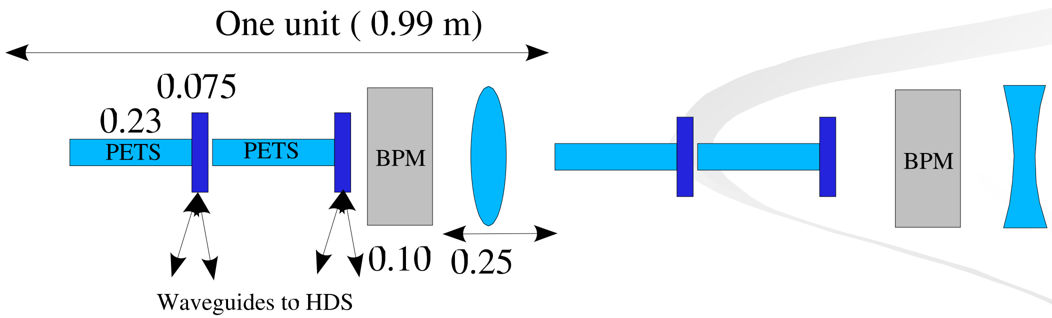
- Deliver required power to accelerating structures
  $\rightarrow$ Minimize losses (smaller than 0.1%)
- High power production efficiency
  $\rightarrow$ Low final energy $\rightarrow$ large energy spread

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 ≈ 96 A**
  - d = 25 mm (bunch spacing, f_b = 12 GHz)
  - $\tau \approx 300$ ns (3564 bunches)
  - Gaussian bunch, $\sigma_z \approx 1$ mm
  - $\varepsilon_N \approx 150\ \mu$m

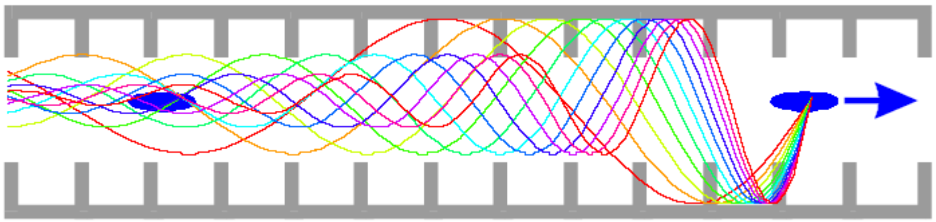
1st particularity of the decelerator beam: huge current

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)

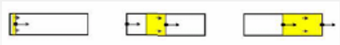
  2) following bunches (**multi-bunch** effect)

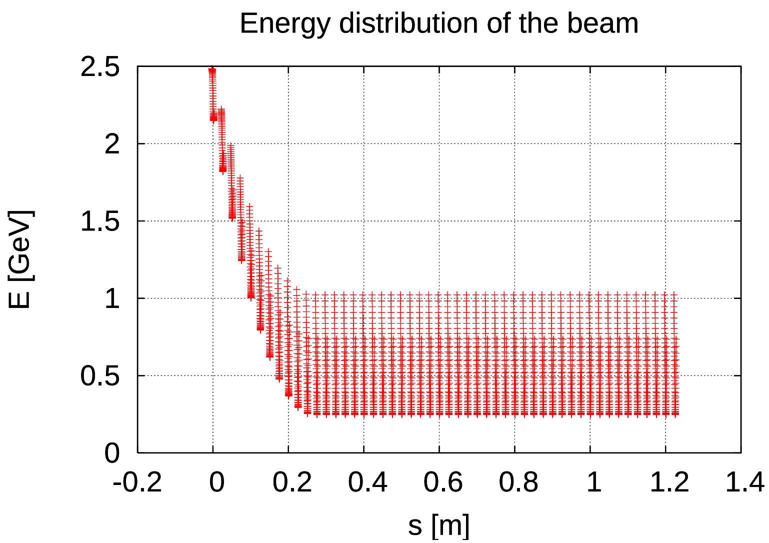


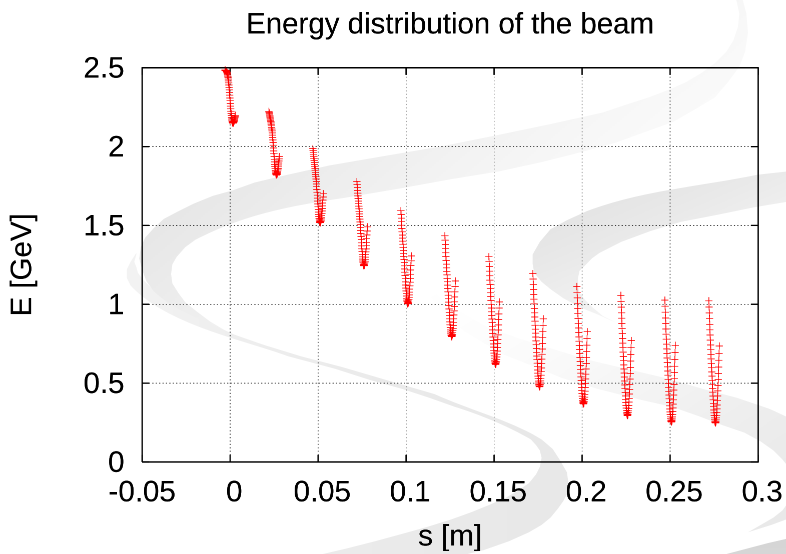
- The integrated effect in a PETS on a witness particle due to a source particle is given by

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

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

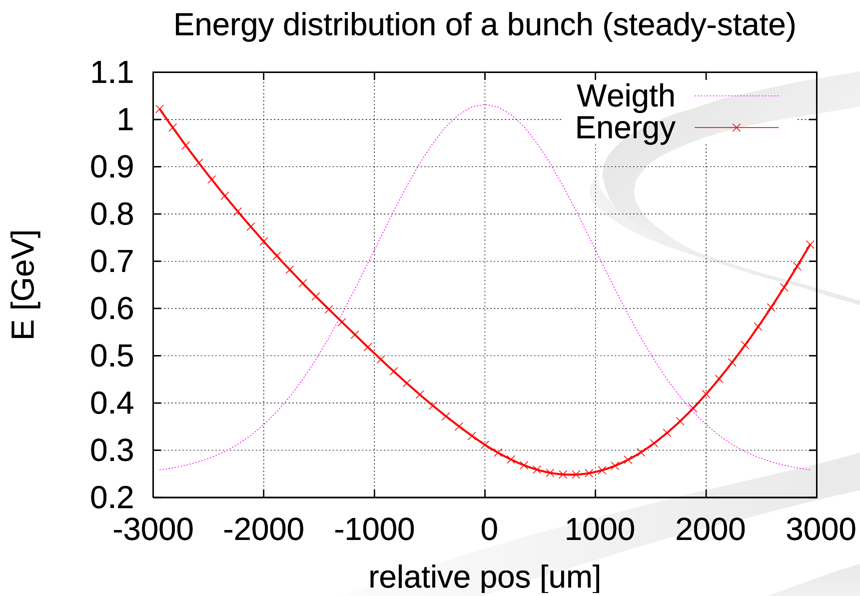
- $\eta = P_{in}/P_{out}$: **steady state** power extraction eff.: $\eta = P[W] \times N / E0[eV] \times I[A]$

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

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

where for current CLIC parameters:

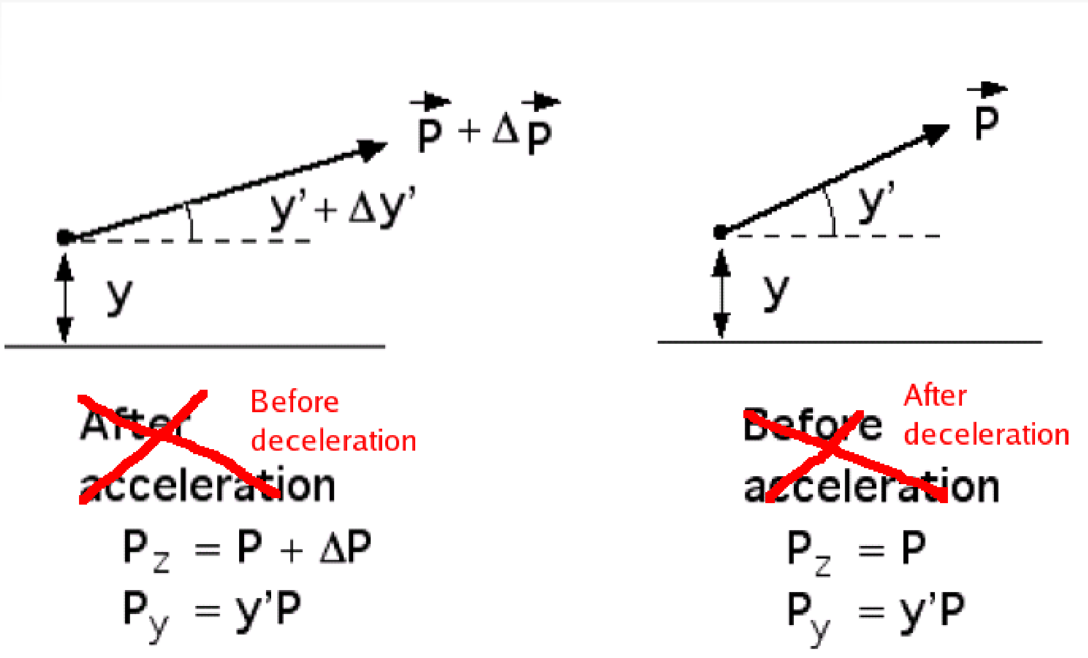
- S = 90.0 % (max energy spread)
- $\eta = S \times F(\sigma) \times \eta_{dist}$ = 90.0 % $\times$ 96.9 % $\times$ 97.4 % =84.5 %



- (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*

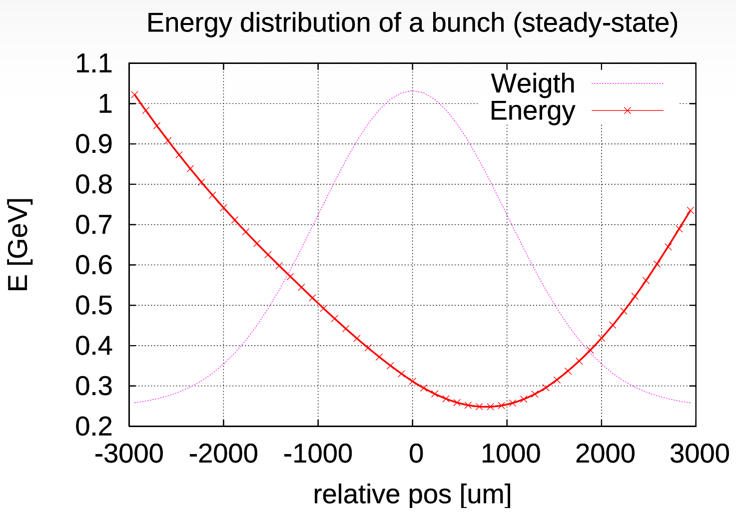


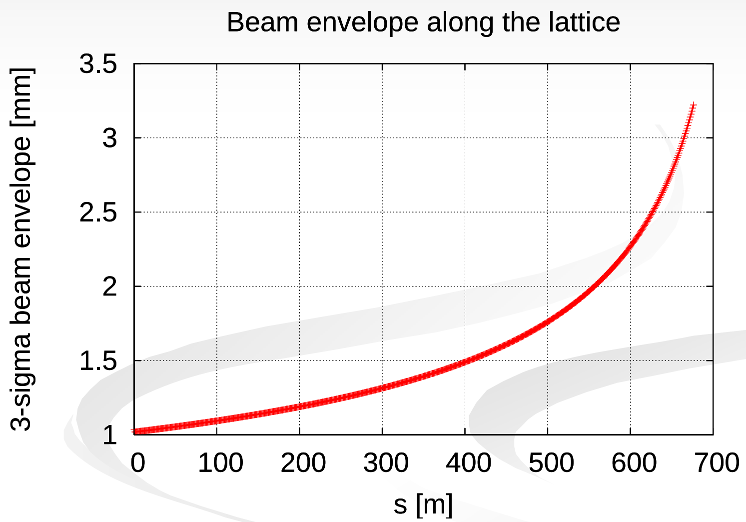
(fig: A. Chao)

- 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 $r_{ad} \propto 1/\sqrt{\gamma}$



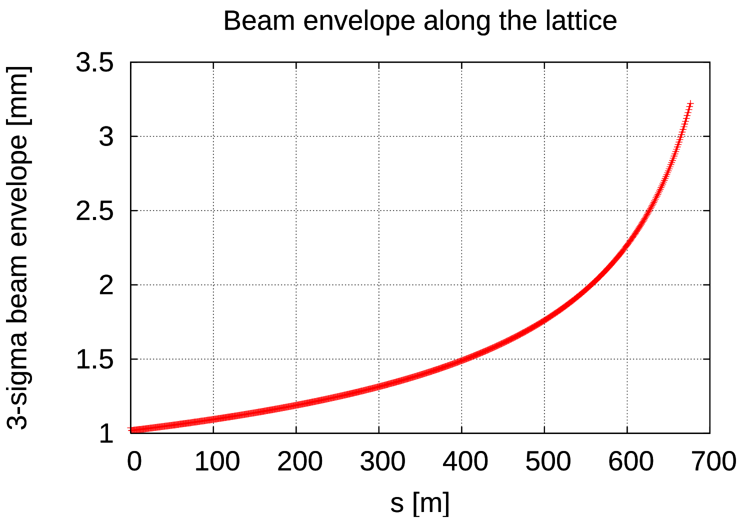


Beam envelope due to adiabatic undamping alone

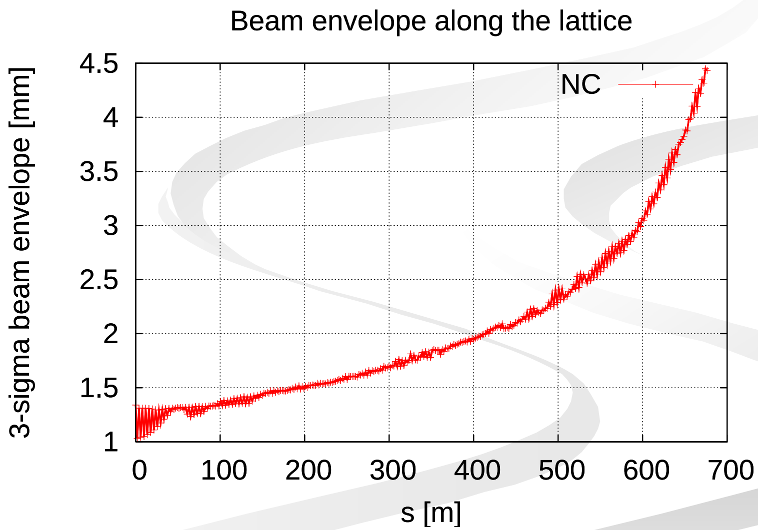
$$r_{ad} = \sqrt{3^2 \sigma_x{}^2 + 3^2 \sigma_y{}^2} \approx 3 \cdot 2\sqrt{L_{FODO/2} \varepsilon_N / (1-S)\gamma_0}$$

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:



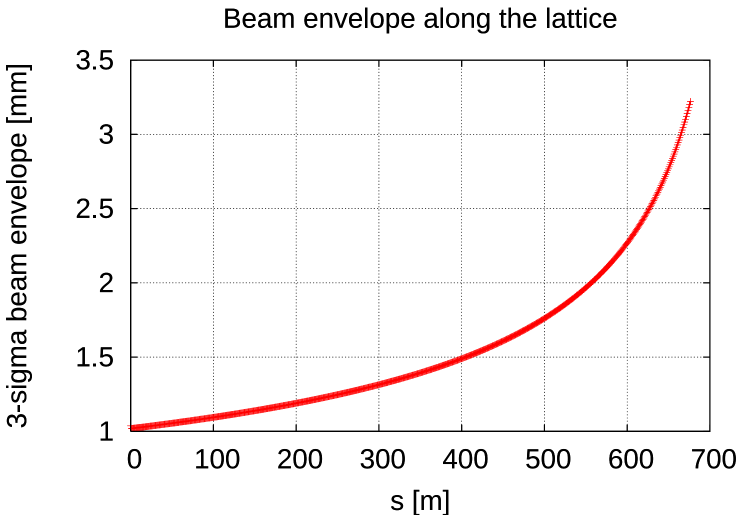
Adiabatic effects alone



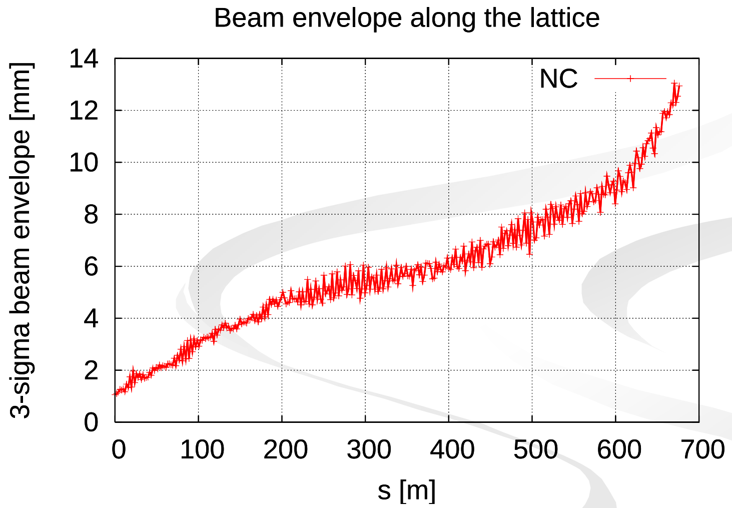
With PETS misalignment

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

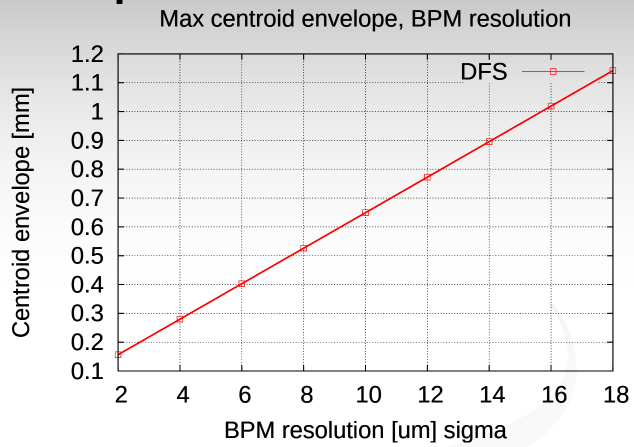


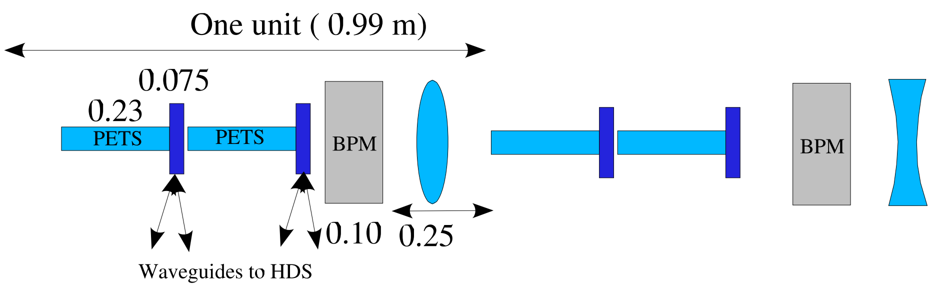
With quadrupole misalignment

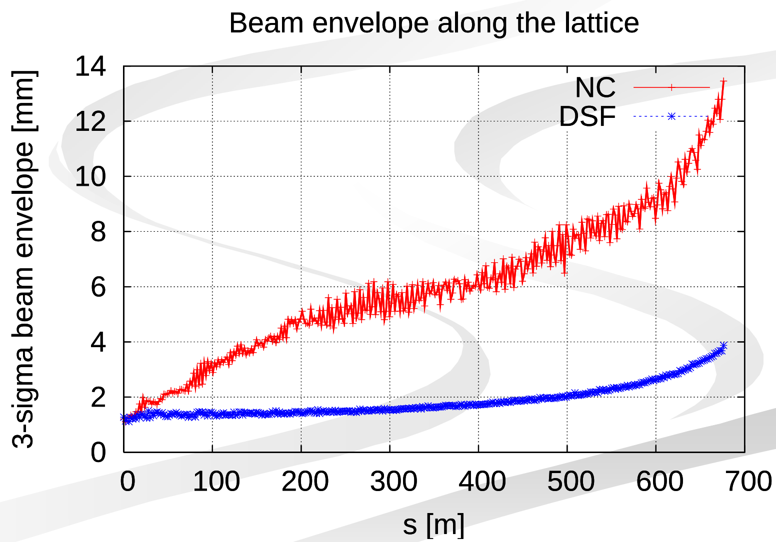
3rd particularity of the decelerator: large beam size

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

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: ~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: ≈ 10 cm

(Discussion / input from instrument workgroup here)

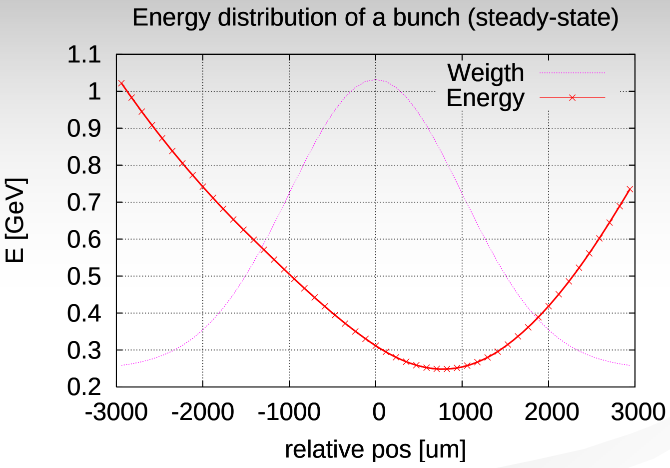
Beam profile monitors / loss monitors

- Requirement: transport with minimal losses
- Desirable: instrumentation to measure transverse beam size
- Desirable: loss monitors
  - 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)

(Discussion / input from instrument workgroup here)

Other instrumentation

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



- Phase-monitors for synchronization drive beam and main beam

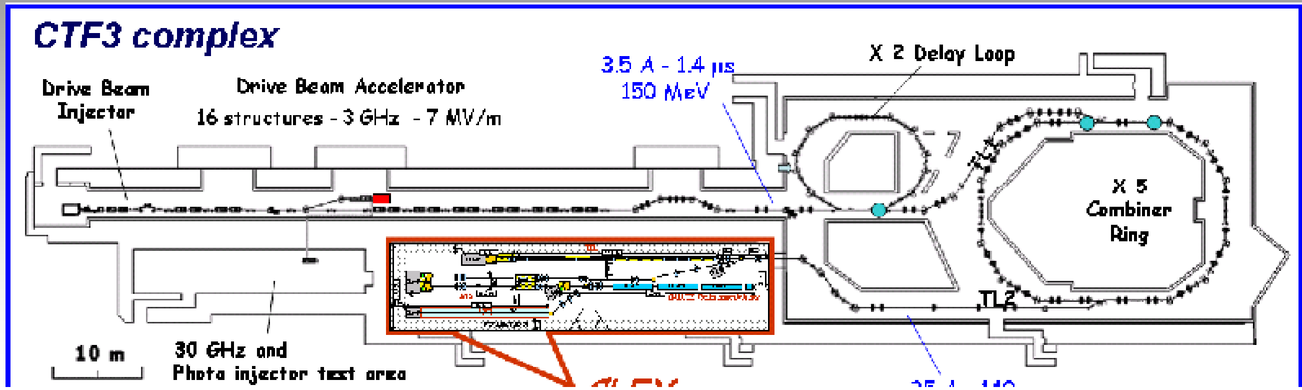
- Entrance (feedback to BC) and possibly exit: bunch length/long. emittance measurement

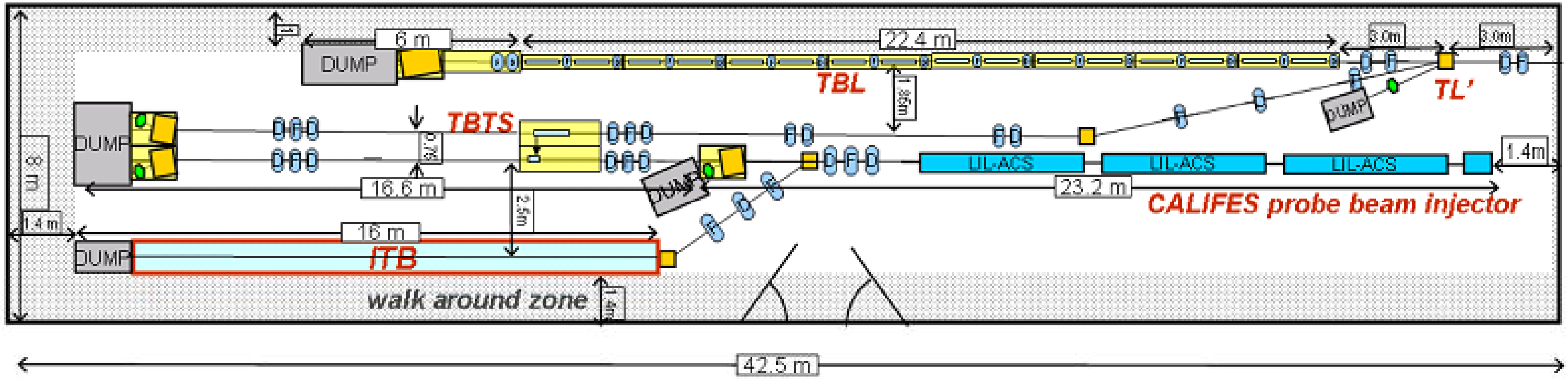
(Discussion / input from instrument workgroup here)

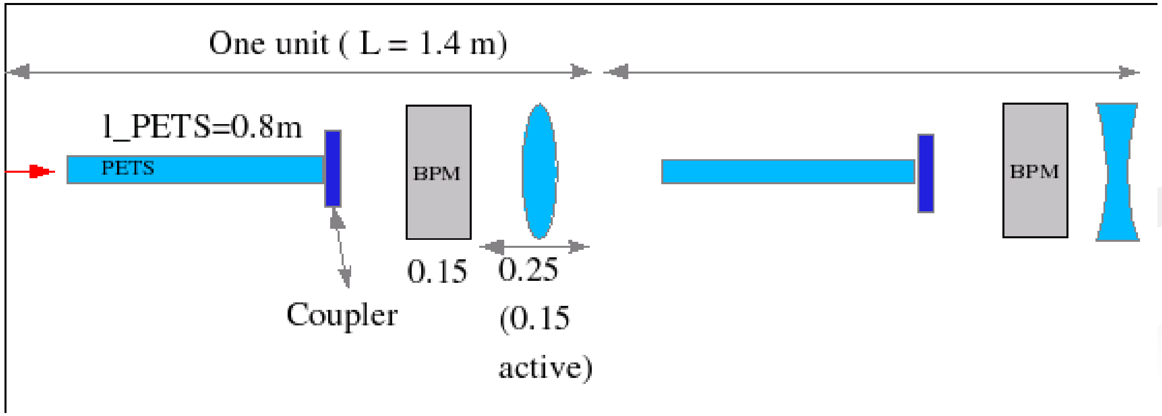
Part 3

The Test Beam Line

TBL: the test of the decelerator





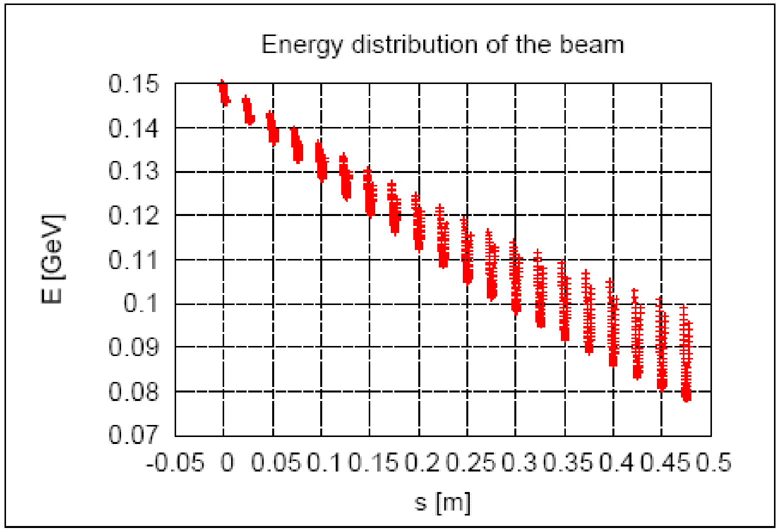


Lattice:

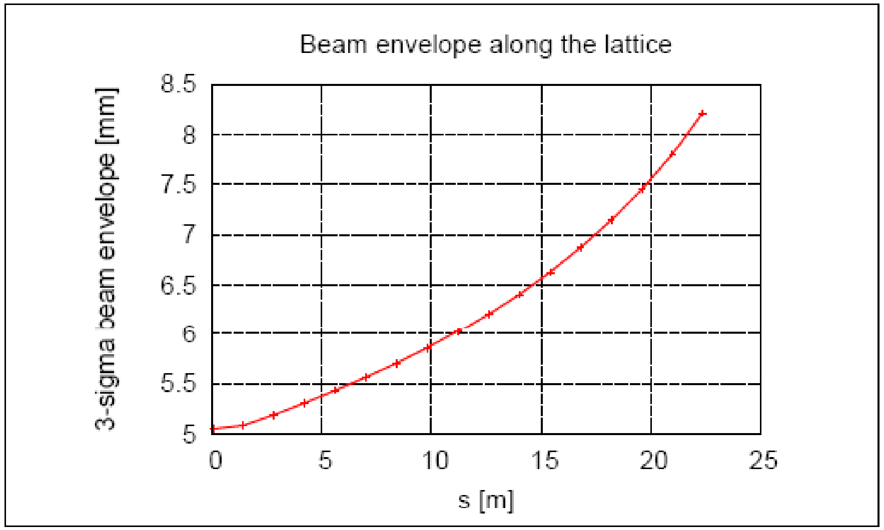
16 units of one of each:

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

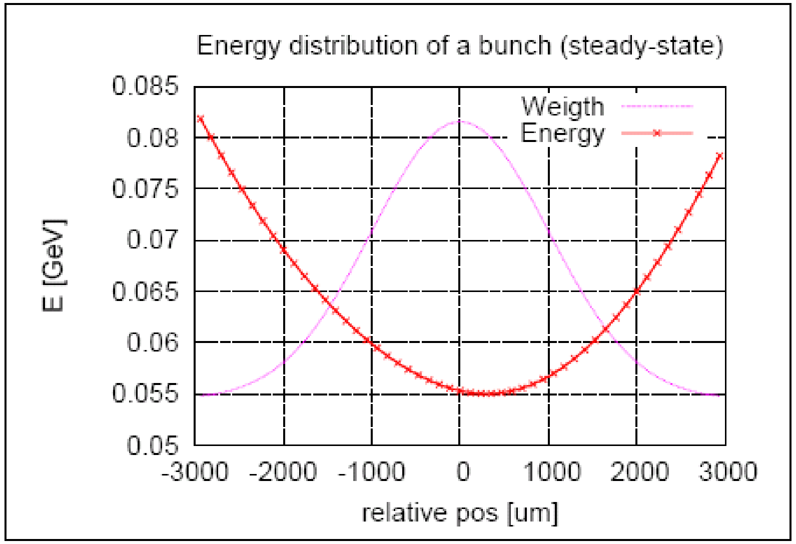
Beam dynamics of TBL



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**

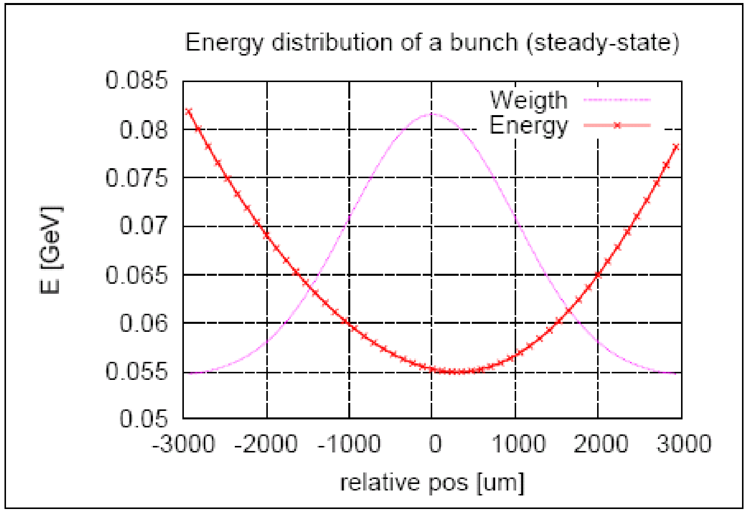
However, the TBL will show the same beam dynamics effects as the CLIC decelerator:

*** 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