Beam Profile Monitoring at the Test Beam Line at CTF3

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Outline

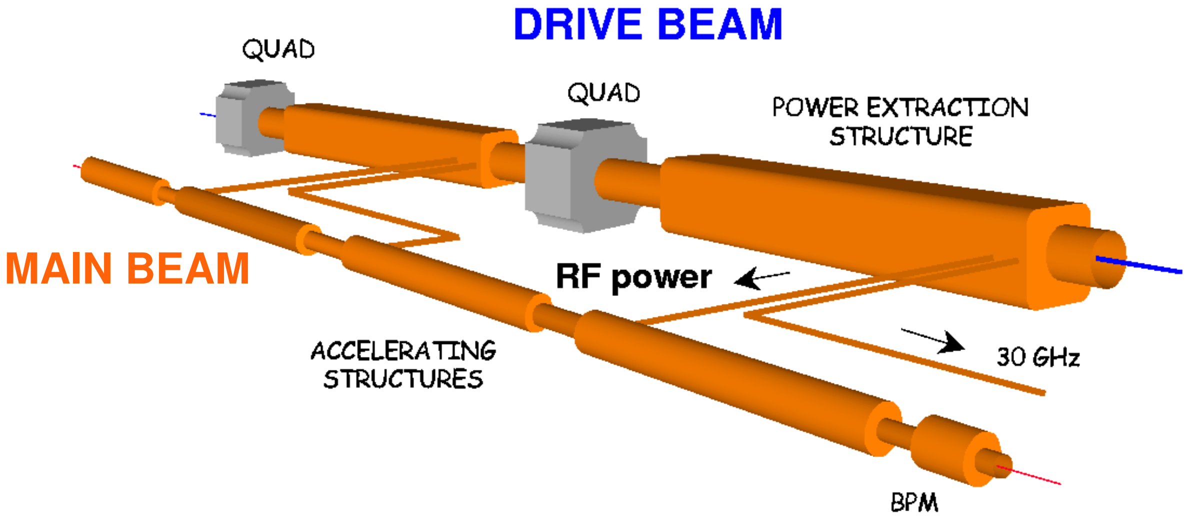
- CLIC and CTF3
- The Test Beam Line (TBL)
    - Goals, layout
    - Beam characteristics
- Profile Monitors
    - Transverse Profile
    - Spectrometry
        - OTR screens
        - Segmented Beam Dump and Single-Slit Beam Dump
        - Instrument performance
- Beam measurements
- Conclusion and Outlook

CLIC and CTF3

- CLIC study for a future linear e^+e^- collider based on two-beam acceleration: high intensity drive beam as RF power source for high energy main beam
- CTF3 - The 3rd CLIC Test Facility for feasibility tests of the RF source: drive beam generation and deceleration, two-beam acceleration

Drive beam (DB):
2.4 GeV --> 0.24 GeV
100 A, 244 ns
12 GHz bunch frequency

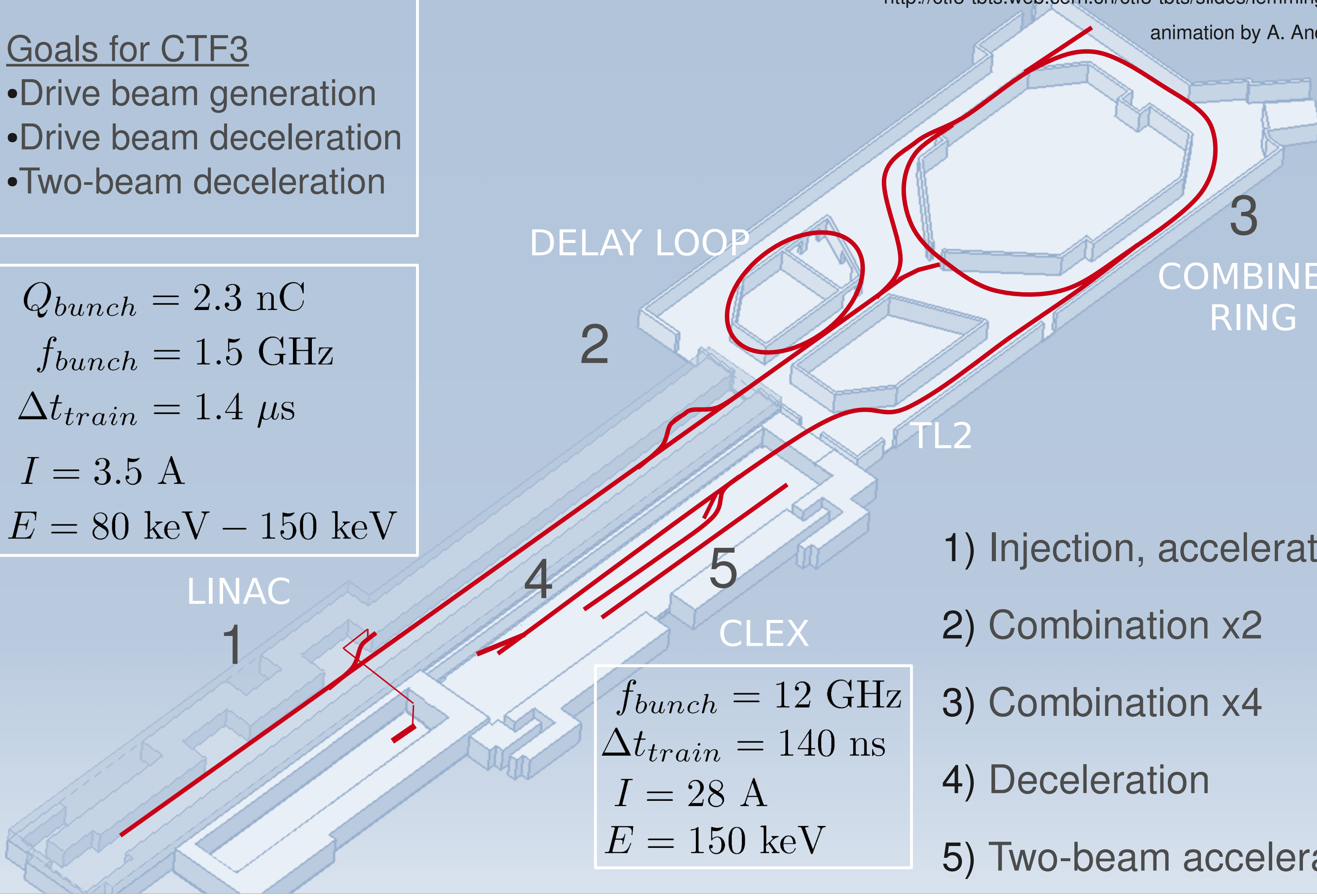
Main beam (MB):
1.5 TeV
1 A, 156 ns
2 GHZ bunch frequency



CTF3 – The CLIC Test Facility

Goals for CTF3
- Drive beam generation
- Drive beam deceleration
- Two-beam deceleration

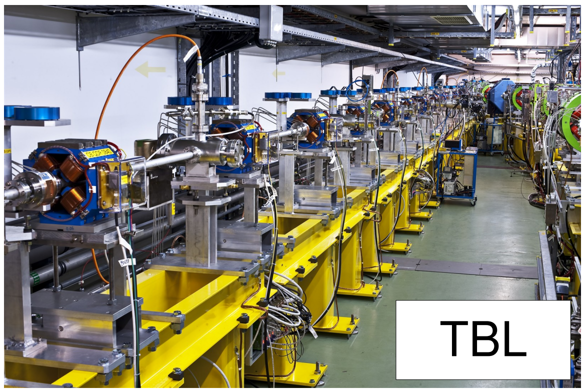
$Q_{bunch} = 2.3$ nC
$f_{bunch} = 1.5$ GHz
$\Delta t_{train} = 1.4\ \mu$s
$I = 3.5$ A
$E = 80$ keV – 150 keV

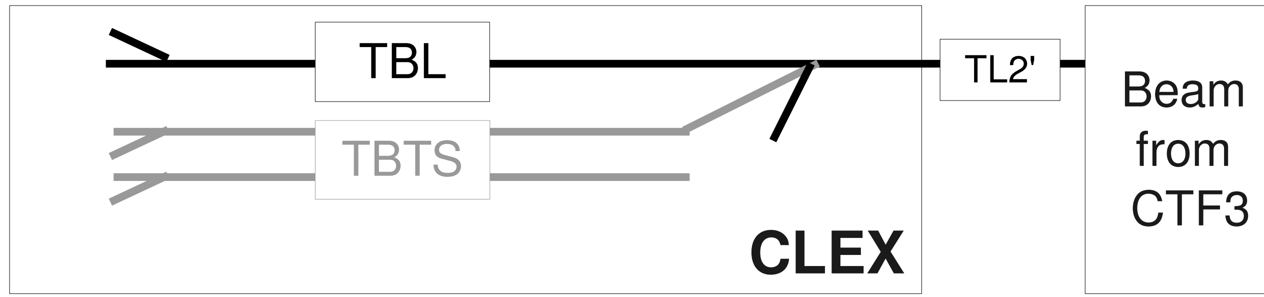


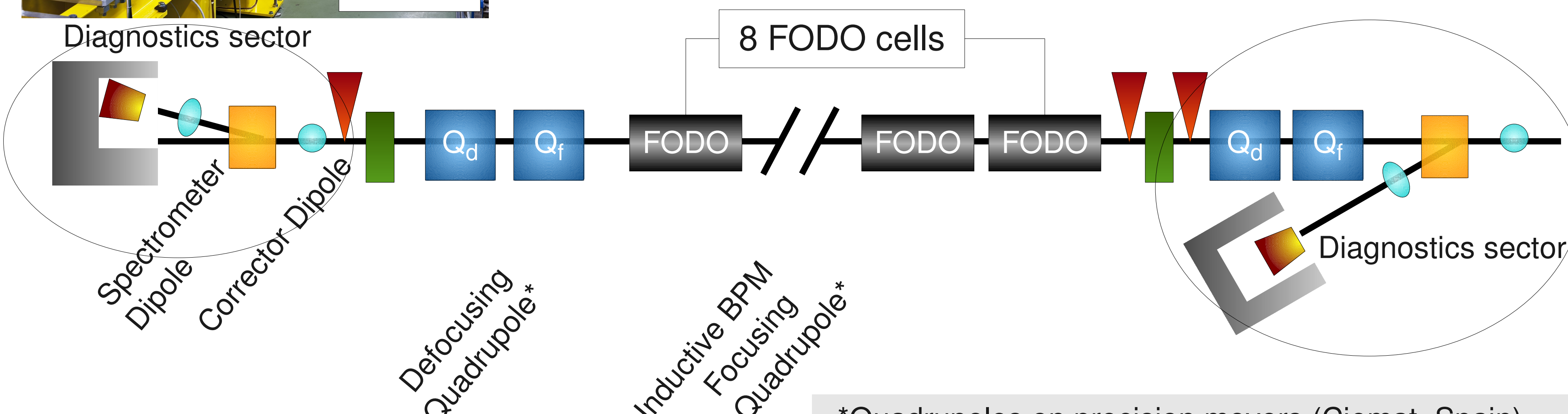
$f_{bunch} = 12$ GHz
$\Delta t_{train} = 140$ ns
$I = 28$ A
$E = 150$ keV

1) Injection, acceleration
2) Combination x2
3) Combination x4
4) Deceleration
5) Two-beam acceleration

The Test Beam Line - TBL







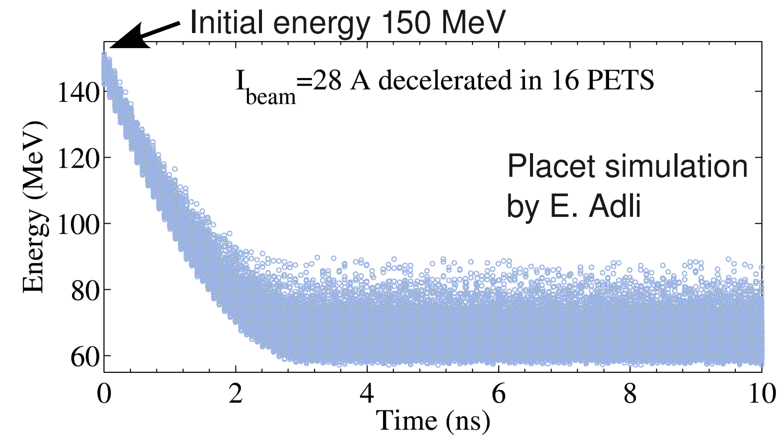
*Quadrupoles on precision movers (Ciemat, Spain)

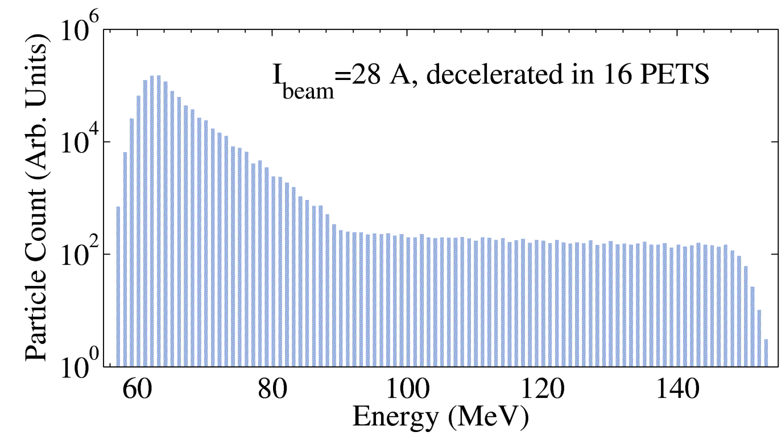
Inductive BPMs: CERN-IFIC-Ciemat collaboration

PETS – Power Extraction and Transfer Structure

The Decelerated Beam

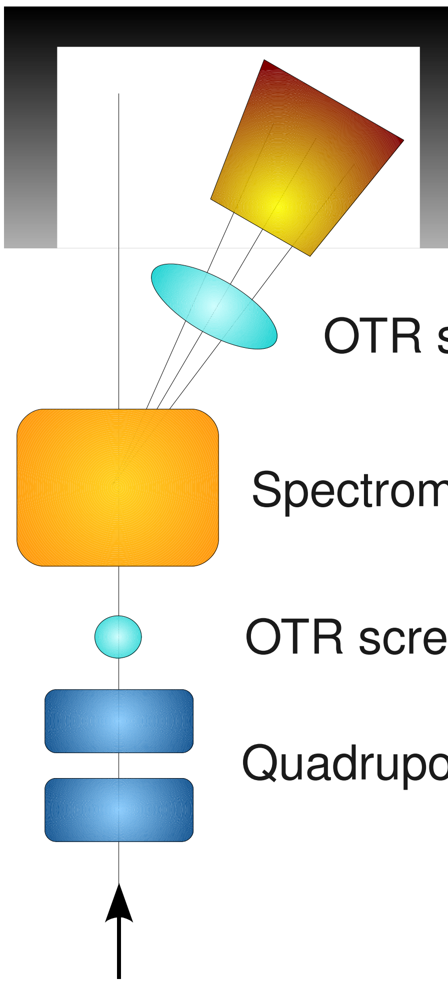
- 8 FODO cells, space for 2 PETS in each cell. 9 PETS installed so far.
- For fully combined beam, I=28 A, 5.2 MeV deceleration per PETS.
- Very large energy spread, asymmetric distribution. $\sigma_E = 6\%$ (single bunch)
- The filling time of the PETS leads to a 3 ns long high-energy transient.



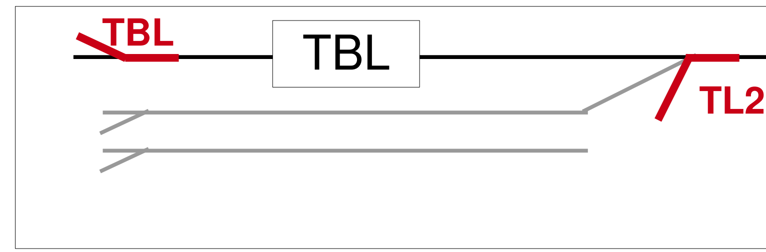


PETS
- High-impedance structure
- Strong wakefield built up coherently with the beam passage

Profile Measurements in TBL



Diagnostics sectors:



Single-slit/Segmented Beam Dump — for time-resolved spectrometry

OTR screen — for high resolution, average spectrometry

Spectrometer dipole

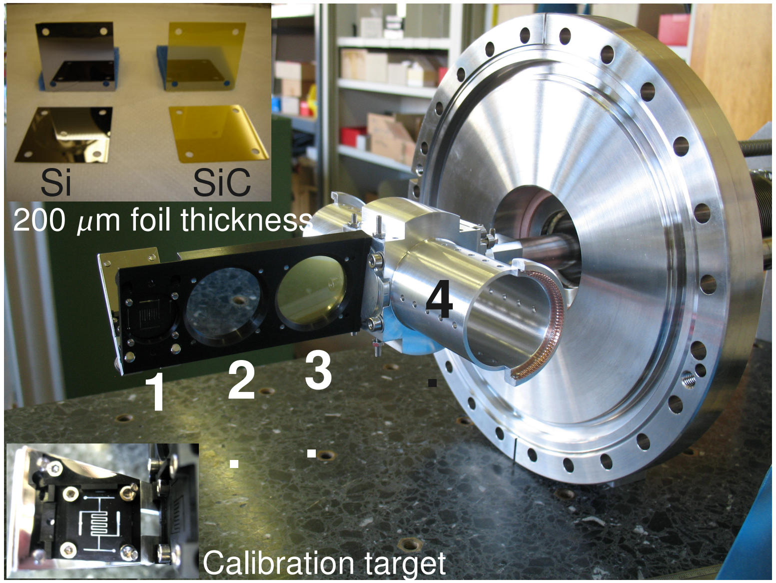
OTR screen — for transverse profile: Emittance (quadrupole scans) and optics matching

Quadrupole magnets

Screens for transverse profiling

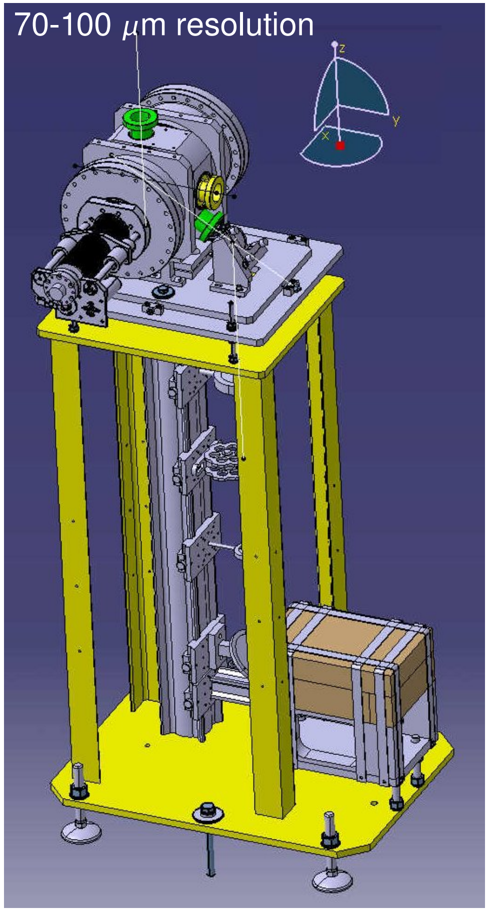
Several improvements of the systems for transverse profile measurements:

- Screen - beam angle 15° to minimize field depth errors
- Reduced length and complexity of optical line (view port at an angle, two mirrors, one achromatic lens, filters for light attenuation, CCD camera)
- Special shielding designed for the camera – radiation huge problem at CTF3.



Screen system with four different positions:

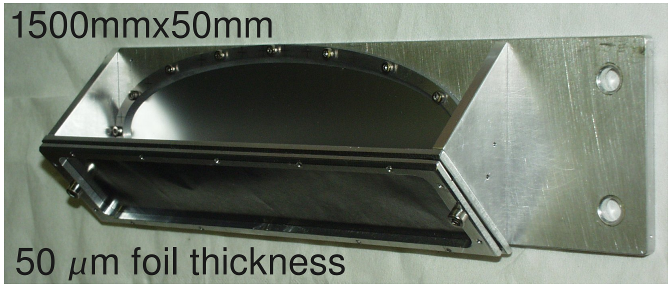
1. Calibration target
2. Highly reflective screen (Si)
3. Less reflective, thermally resistant screen (SiC)
4. Replacement chamber to reduce beam impedance while not in use.



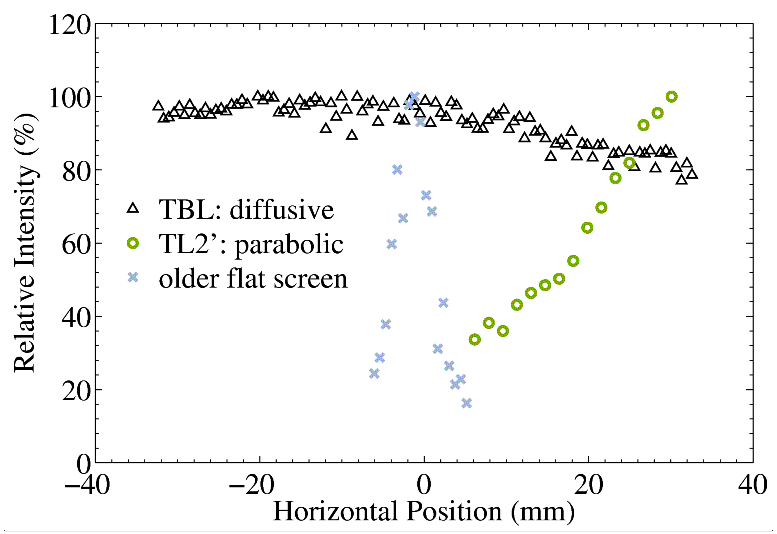
Screens for spectrometry

- Non-movable 50 μm Al screens; Parabolic or diffusive
- Carbon foil (50 μm) for blocking synchrotron radiation
- 400 μm spatial resolution --> better than 0.2% on energy spread.
- CCD camera with 20 ms integration time: single-shot, averaged over each pulse

- Large beams – vignetting problem
- Intense beams – sacrifice light intensity in order to reduce vignetting
- Density filters for light attenuation



Fixed Al screen, 50 μm
- parabolic or diffusive
Carbon foil, 50 μm
- block synchrotron radiation

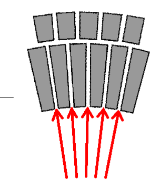


See poster by B. Bolzon, "*Performances of Imaging Screens at the CLIC Test Facility 3*" for more details.

Segmented Beam Dump

- Detection principle same as Faraday cup: stop particle and measure absorbed charge as current.
- Horizontal segmentation gives spectrometric profile

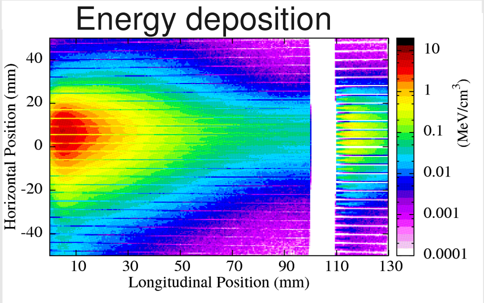
- Design based on FLUKA simulations of electromagnetic showers
- Material and geometry optimized for TBL.

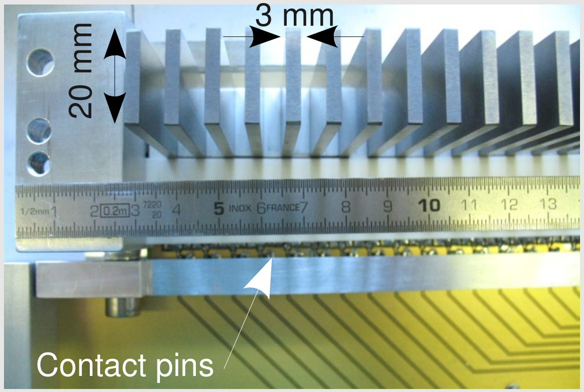


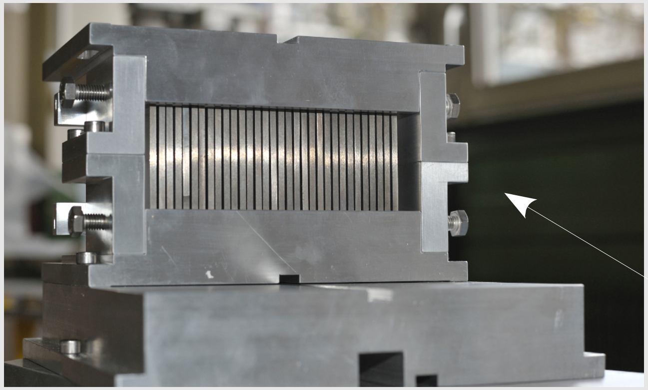
New concentric geometry

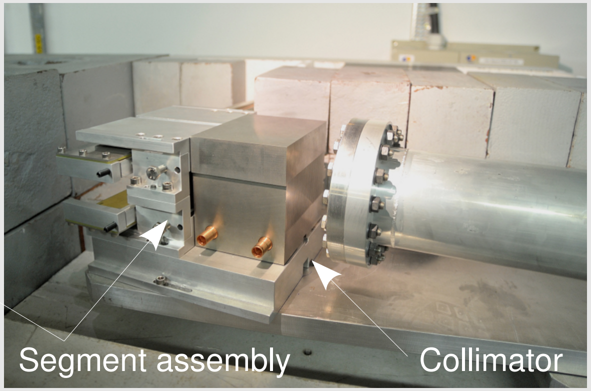
- 32 tungsten segments, 1 mm alumina spacers
- Semi-rigid cables attached to readout PCB
- 20dB signal attenuation
- SIS 3320 ADCs (250 MS/s)

- Water-cooled collimator as thermal buffer
- 32 slits 400 μm wide
- 100 mm long
- Material: Inermet (high tungsten content)



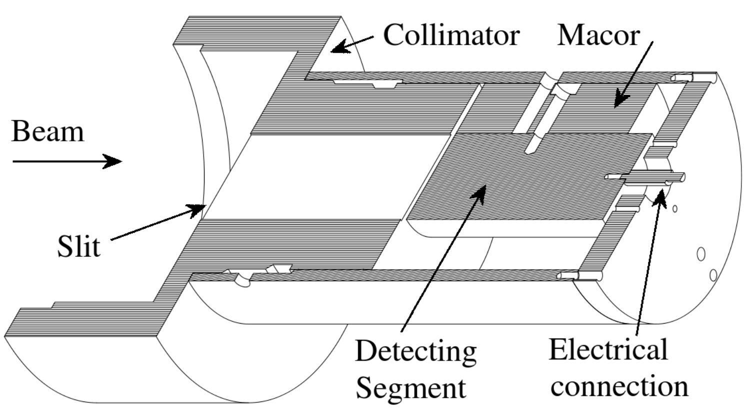


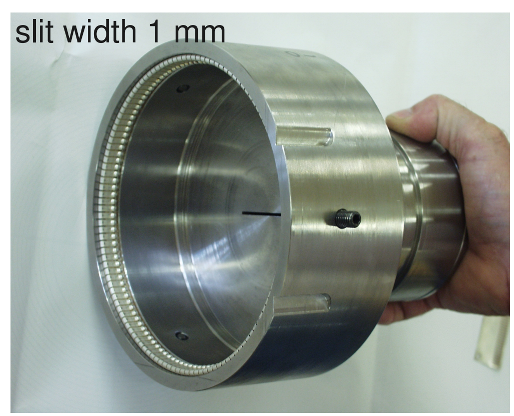


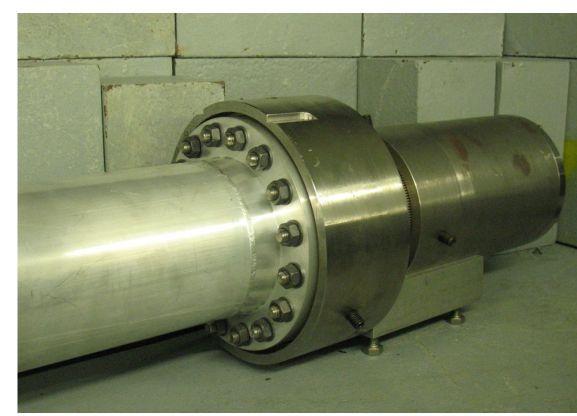


Single-slit Beam Dump

- Same principle as the Segmented dump: absorb particles in metallic block, measure as current.
- Use a single slit, 1 mm wide, to sample the beam. Operated in multi-shot mode through a dipole scan.
- Sampling at 100MS/s gives time-resolved beam spectrum.
- Used for characterization of the incoming beam.







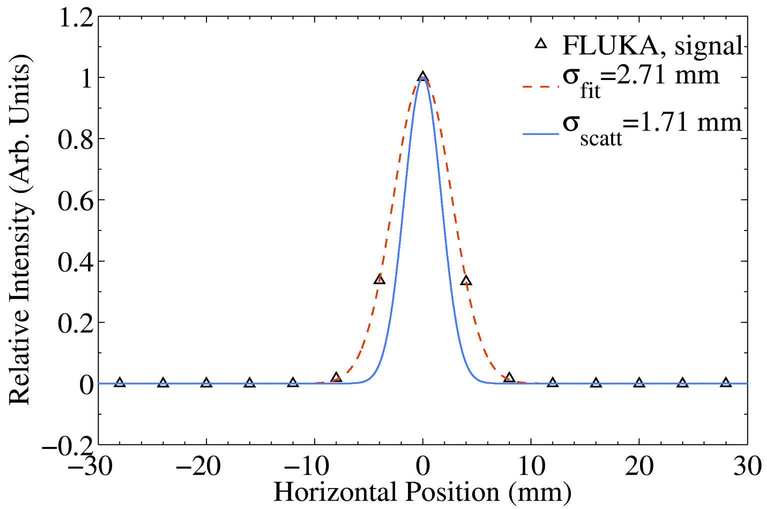
Segmented Dump Performance

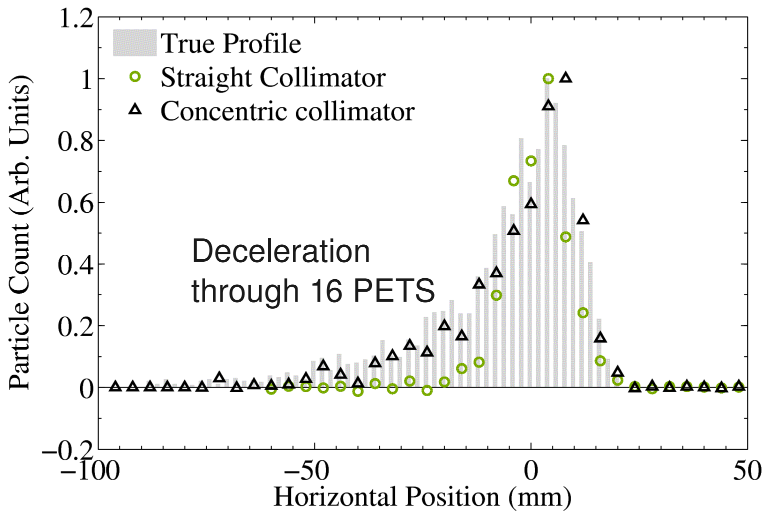
Final design used in FLUKA simulations:

- 1σ resolution of 2.71 mm expected from particle crosstalk between segments
- 1σ beam broadening of 1.71 mm due to scattering from OTR screen, carbon foil and vacuum window.

$$\sigma_{res} \geq \sqrt{\sigma_{scatt}^2 + \sigma_{part}^2} = 3.2 \text{ mm}$$

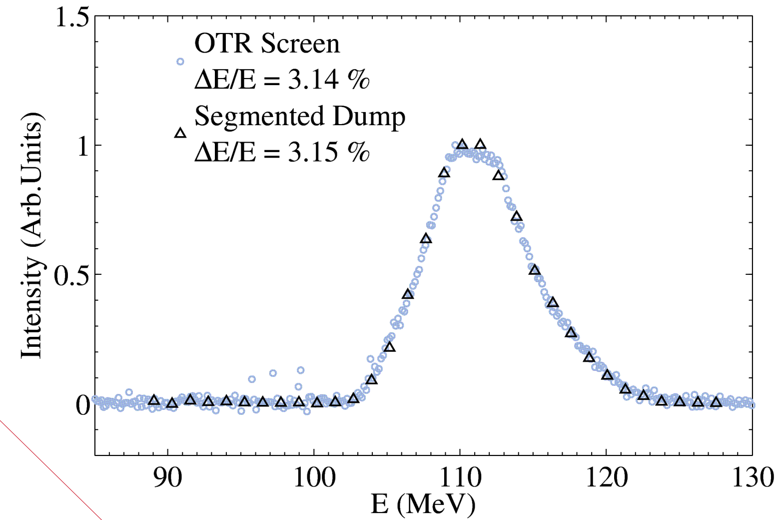
- Beam distribution from Placet reconstructed with 4% overestimation of the energy spread (rms), to be compared with a 56% underestimation with straight collimator geometry.



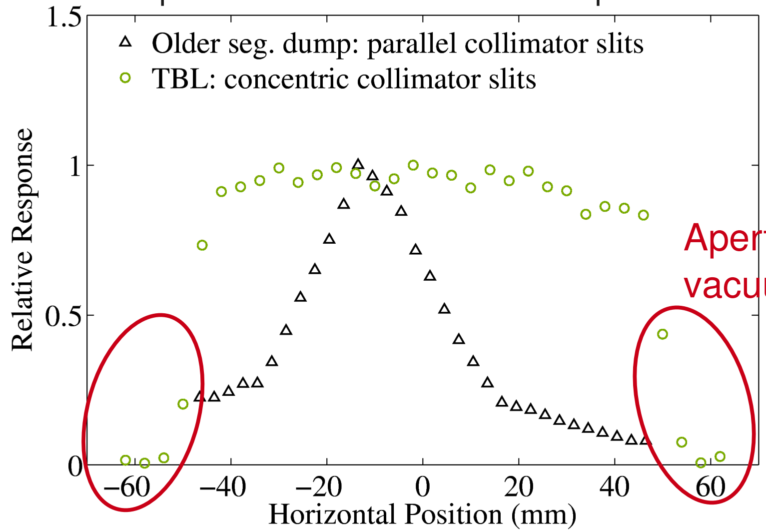


Beam-Based Performance Studies

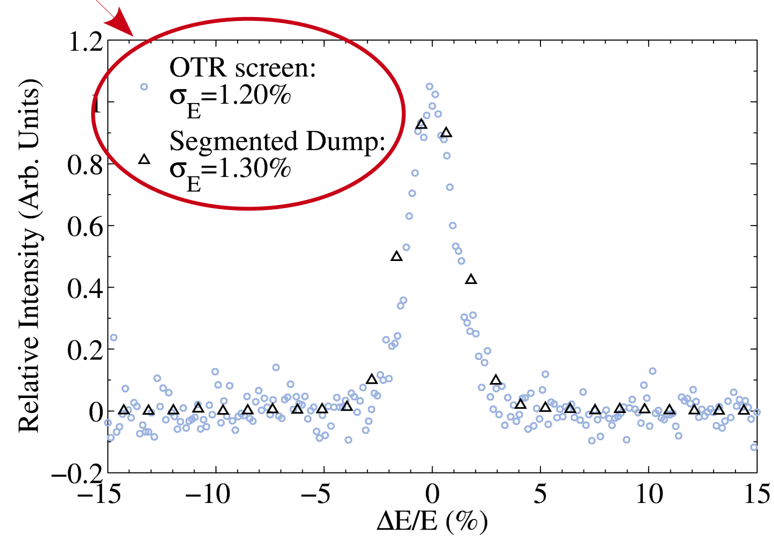
- Cross-calibration with OTR screen:
  - Good agreement when energy spread is large
  - Worse for smaller beams: measured resolution 1.3%
- Response curve shows big improvement of a concentric collimator geometry.



Response curve calculated from dipole scan

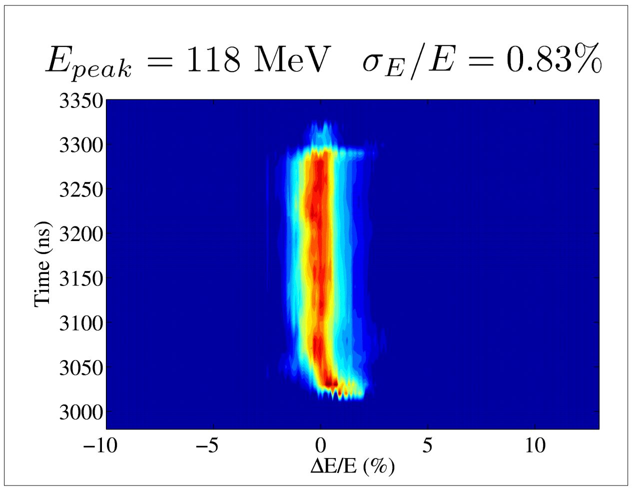


Aperture restriction from vacuum chamber

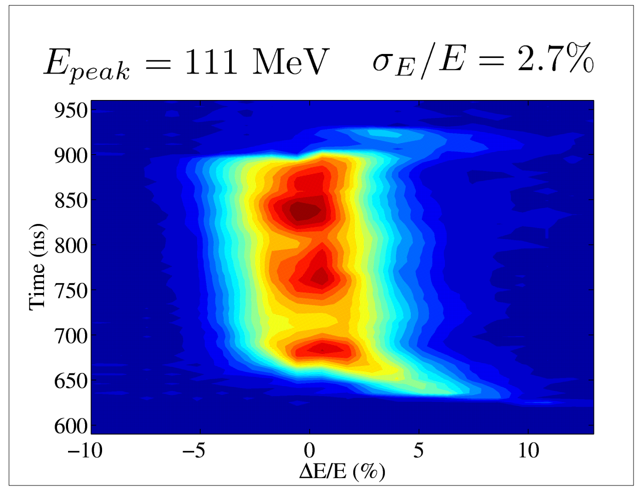


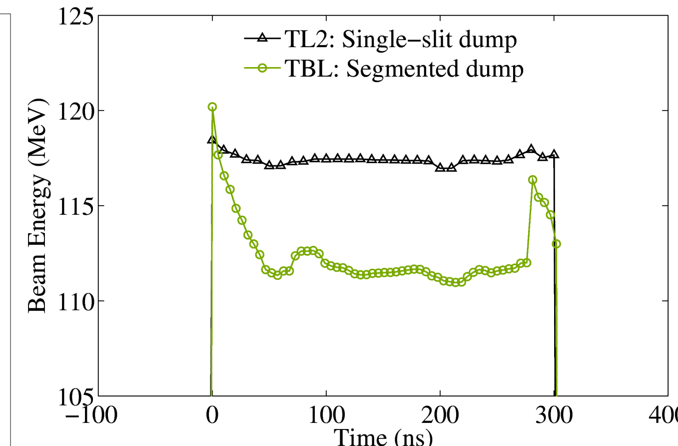
Beam Measurements

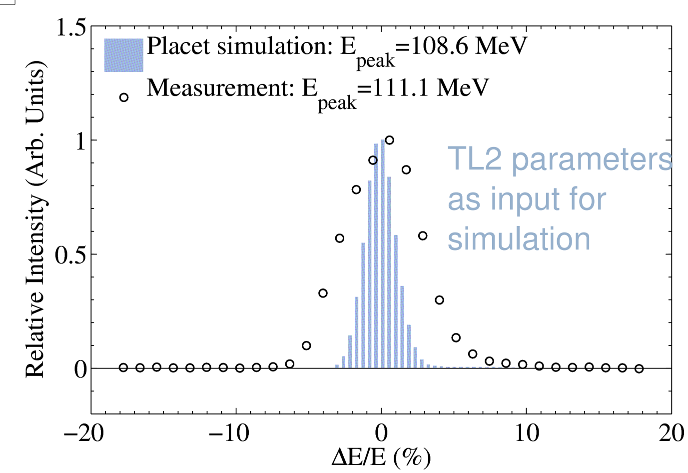
TL2':



TBL:





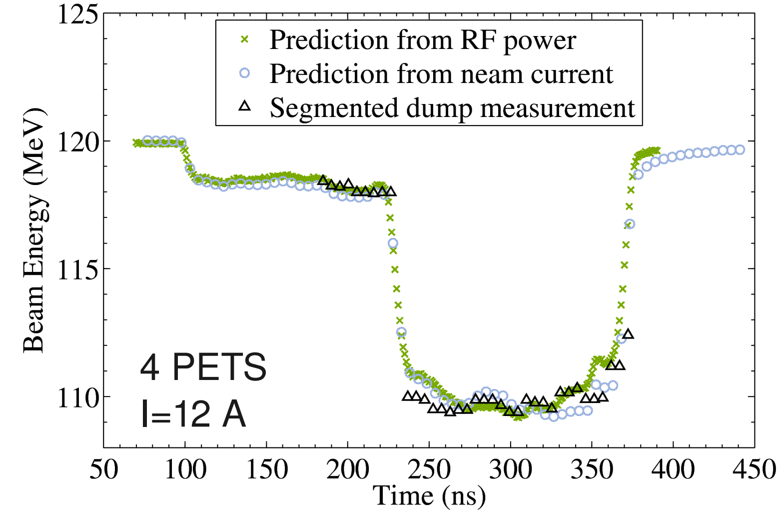


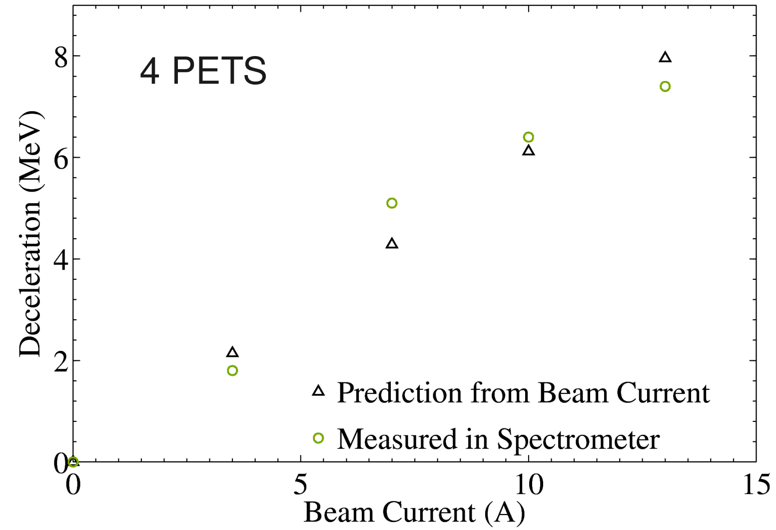
- Deceleration
    - slit dump (TL2') – segmented dump (TBL)
    - compared with RF signals/BPMs
- Increase of energy spread
    - measurement – simulation
- Emittance blow-up and matching

Beam Measurements

- Measure beam current
  - Adjust by “form factor” for bunch length and bunch combination efficiency
- Measure RF output power from PETS
  - 15% error marginal on calibration of RF signals
- Correlate with energy measurements
  - ~2% error on absolute energy

Reasonable results so far (4 PETS). To be continued for 9 PETS and higher beam current.





Conclusions and Outlook

- Beam profile monitors for TBL designed, installed and commissioned
  - New segmented beam dump perform as expected with temporal resolution of 5 ns and 1.3% resolution on energy spread.
- Continue beam measurements at TBL
  - higher beam current
  - more PETS
- Time-resolved energy measurements for the CLIC Drive Beam:
  - higher energy, higher intensity, larger energy spread, higher repetition rate
  - Time-resolved spectrometry based on Cerenkov radiation

Beam Profile Monitoring at the Test Beam Line at CTF3

Further reading:

"Commissioning Status of the Decelerator Test Beam Line in CTF3"
MOP018, LINAC'10, Tsukuba (2010), S. Doebert *et al.*
"A Study of the Beam Physics in the CLIC Drive Beam Decelerator"
PhD thesis, University of Oslo, Norway (2009), E. Adli
"*Spectrometry in the Test Beam Line at CTF3*"
MOPE60, IPAC'10, M Olvegaard *et al.*

Extra slides

Large energy spread beams

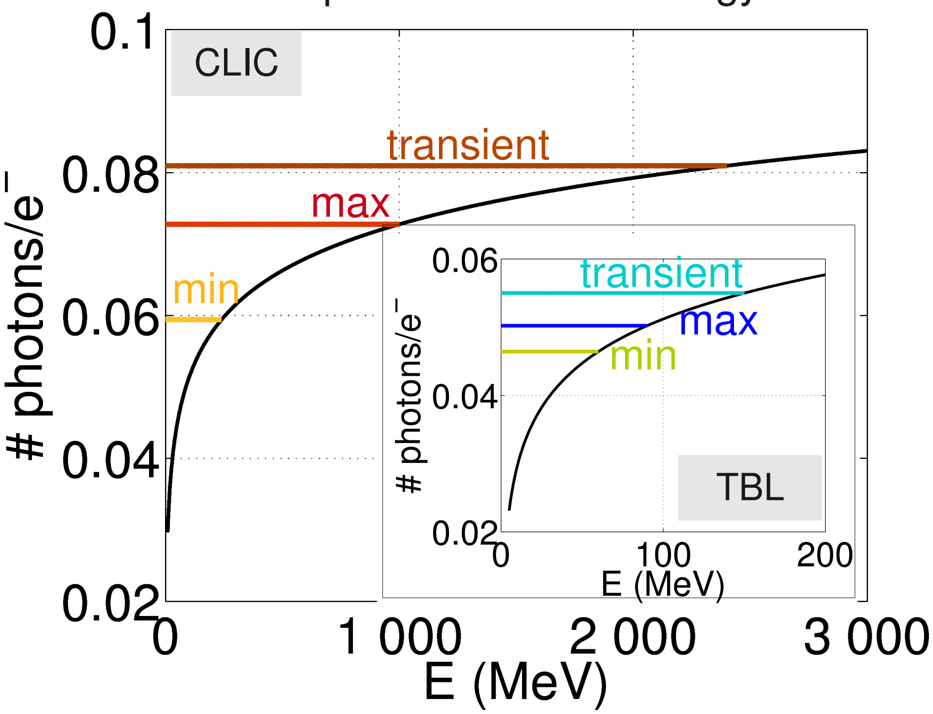
- The beam in the CLIC Drive Beam decelerator will go from initial energy 2.4 GeV to 0.24 GeV (90 % energy extraction), with a large intra-bunch energy spread.
- Test Beam Line (TBL) at CTF3 a small-scale test of the CLIC decelerator: 57% energy extraction.
- OTR characteristics:

$$N_{OTR} \propto \log(\gamma) \qquad \theta_{max} = \gamma^{-1}$$

  - To be investigated: how "wrong" we measure transverse profile using standard OTR screens.

	CLIC	TBL
E_{min}	240 MeV	60 MeV
E_{max}	1.0 GeV	90 MeV
$E_{transient}$	2.4 GeV	150 MeV
Light yield variation	37%	15%

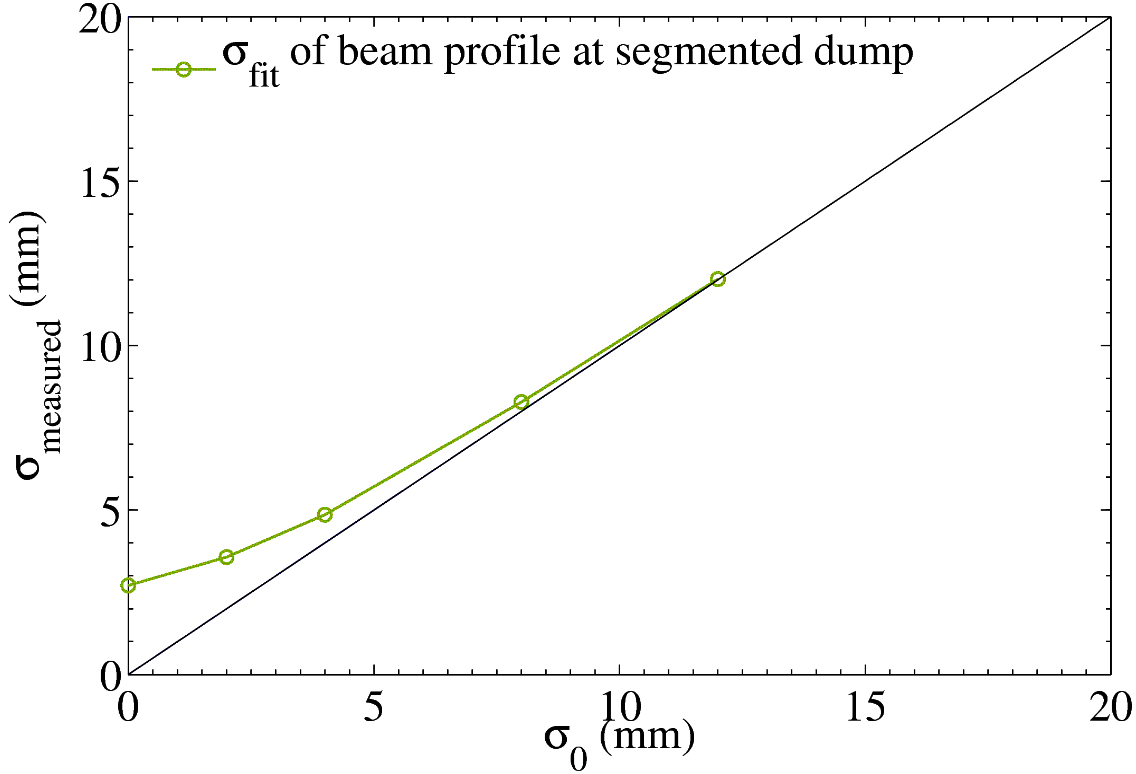
OTR photons - beam energy



Broadening from scattered particles

- Broadening from particle crosstalk between segments and from scattering in foils is a systematic effect that can be compensated for.

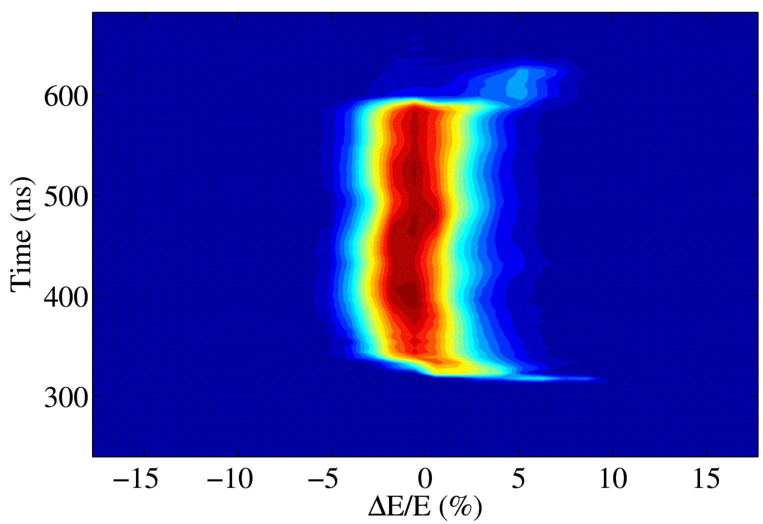
FLUKA simulation of beam distributions as measured by segmented beam dump: beam width of measured distribution as a function of true width



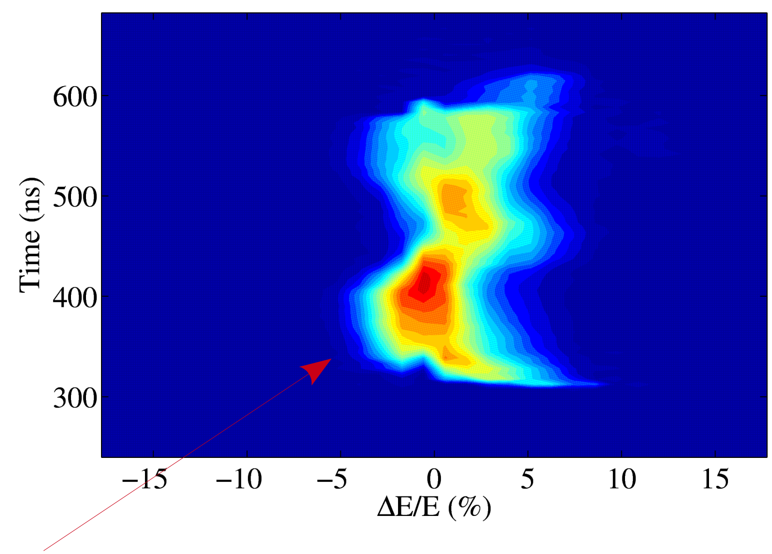
Single-shot 1-0 Multi-shot

Single-shot important to capture rapid changes (such as a breakdown in a PETS) and to avoid sensitivity to them.

$$I_{beam} = 11.5\ \mathrm{A}$$
$$E_{peak} = 108.9\ \mathrm{MeV}$$



$$I_{beam} = 11.0\ \mathrm{A}$$
$$E_{peak} = 110.3\ \mathrm{MeV}$$



Breakdown in PETS?