OTR screen development at CTF3

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presenting the work done by
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Outline

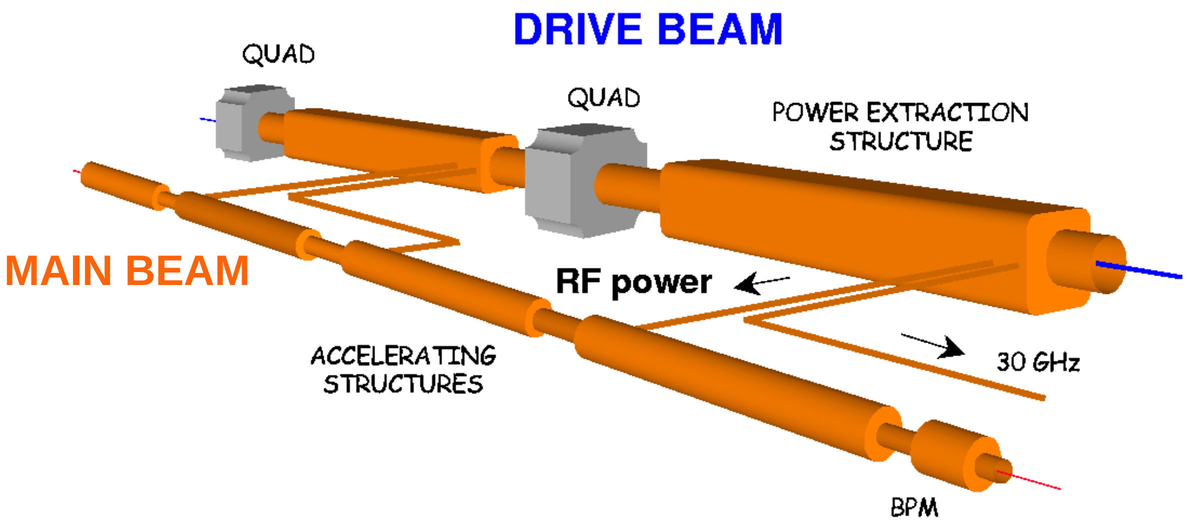
- CLIC and CTF3
    - Beam characteristics, instrumentation requirements
    - Installed equipment
- OTR characteristics
- Studies done on OTR screen systems
    - Thermal/material studies
    - Screen shapes and surfaces
    - Other general improvements
- Planned studies
- Summary

CLIC and CTF3

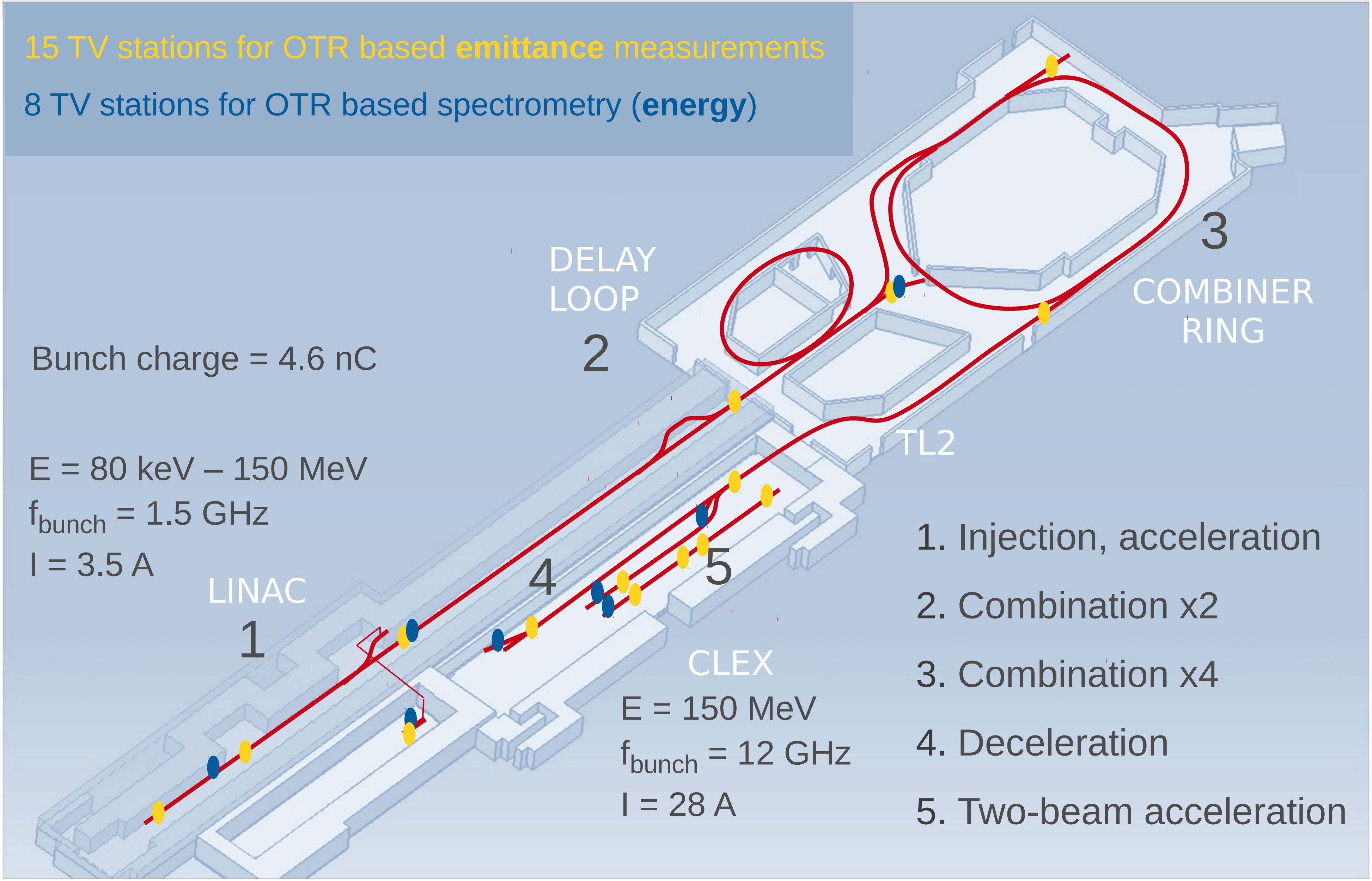
- CLIC study for a future linear e^+e^- collider based on two-beam acceleration: high intensity drive beam as RF power source for high energy main beam
- CTF3 - The 3rd CLIC Test Facility for feasibility tests of the RF source: drive beam generation and deceleration, two-beam acceleration

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



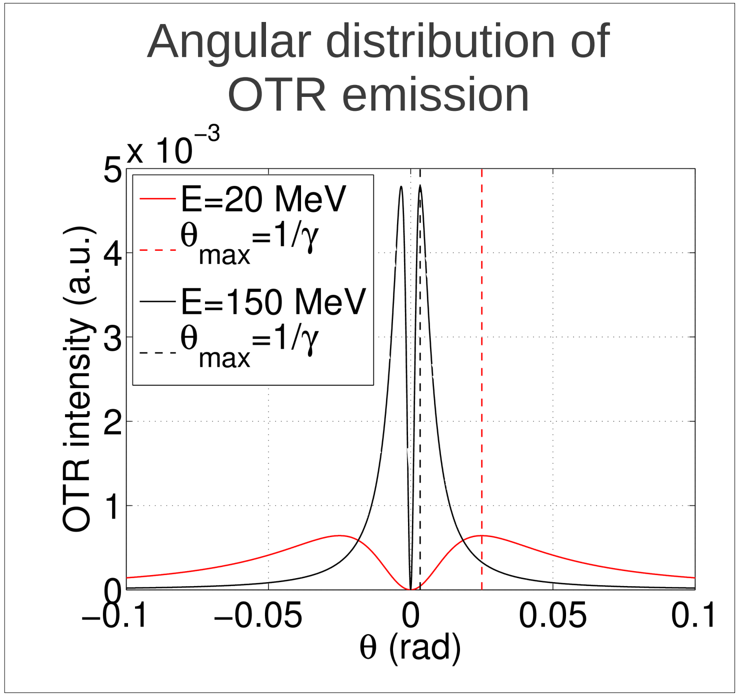
CTF3 – The CLIC Test Facility

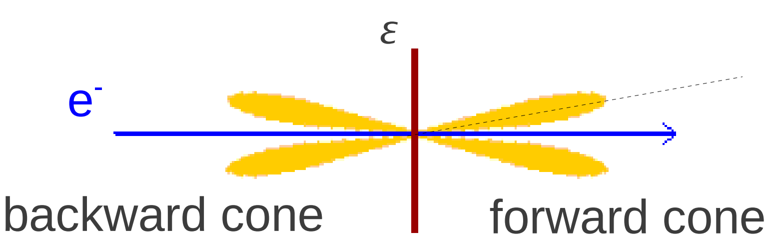


OTR properties

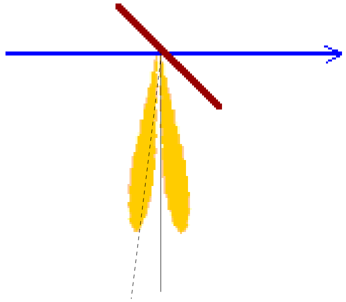
- OTR emitted when a charged particle goes from a medium to another with different dielectric properties.
- Radiation is emitted in forward and backward direction, of which the latter is generally used due to easier extraction.
- For ultra-relativistic particles:

$$N_{OTR} \propto \log(\gamma) \qquad \frac{d^2 I}{d\omega d\Omega} = \frac{q^2}{\pi^2 c} \frac{\theta^2}{(\gamma^{-2} + \theta^2)^2}$$





$$\theta_{max} = \gamma^{-1}$$

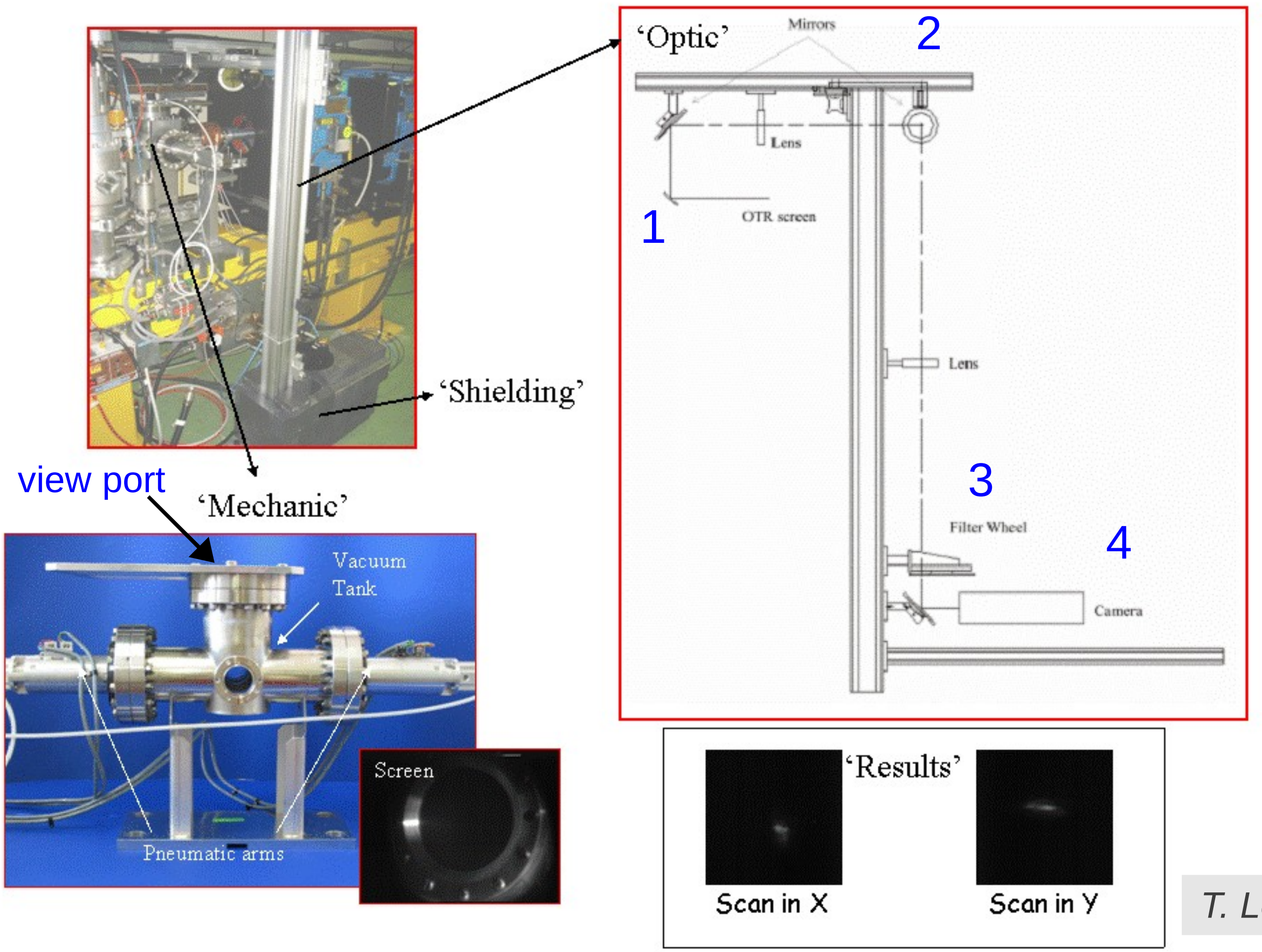


Why OTR?

- Beam intensity: from 4 A during 1.4 μs, to 32 A, 140 ns. Beam size ~1 mm, pulse repetition rate up to 5 Hz
  - *Thermal load too high for scintillating screens*
  - *High intensity compensates for lower light yield*
- Up to coherence, perfectly linear with beam charge (no saturation)
- Femto-second time resolution possible
  - *Allows for longitudinal profile imaging (bunch length)*
- Due to properties of the emitted light, it can be used to determine several beam properties.

OTR screen system at CTF3

“Standard” system (subject to local variations)

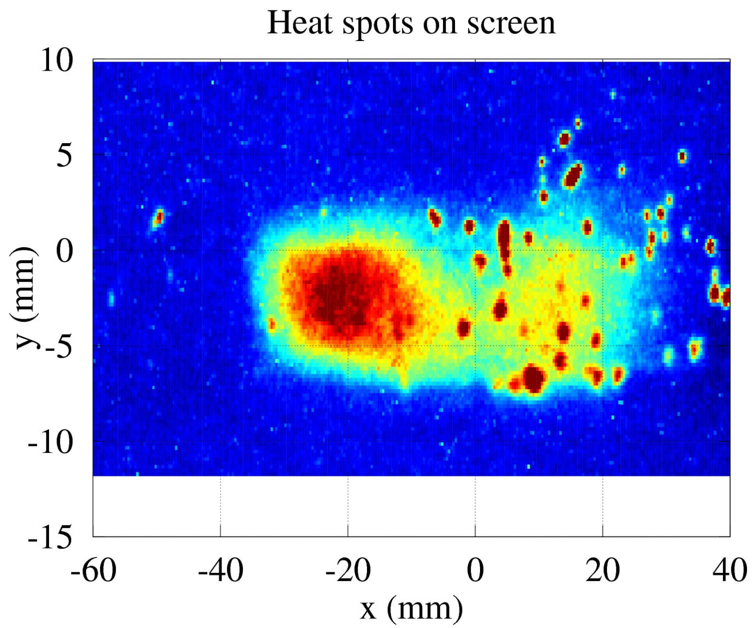


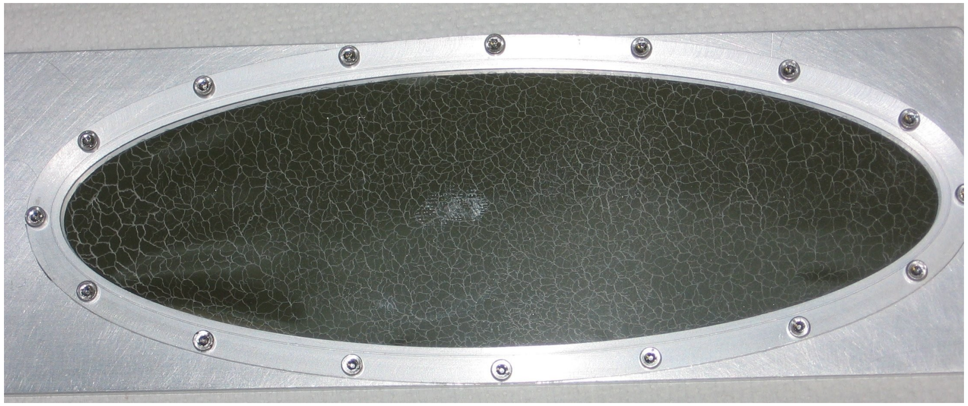
1. Tilted screen(s) inside a vacuum tank
2. View port, mirrors and achromat lenses
3. Filter wheel for light attenuation
4. CCD camera, digitization box.

Resolution 70-200 μm.

T. Lefevre

Screen damages



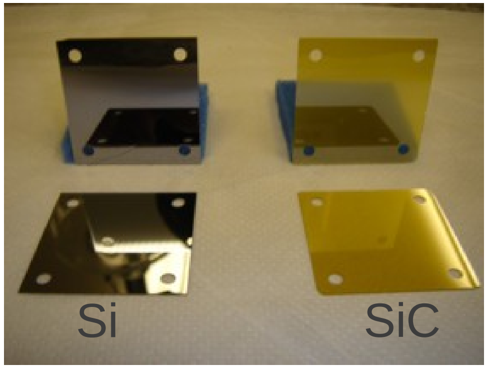


Spectrometer screen in PHIN - the photoinjector test facility for CLIC

- “hot spots” on the screen observed even when the beam is not there
- A closer look at the screen shows clear damages
- Reason? Most likely thermal load.

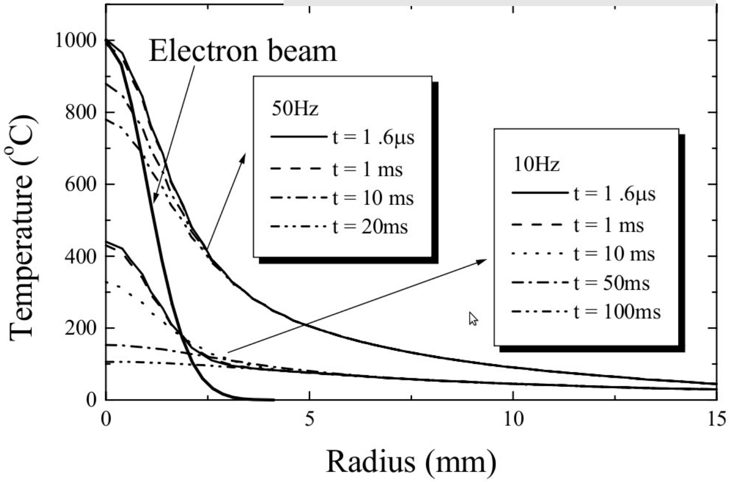
Thermal considerations

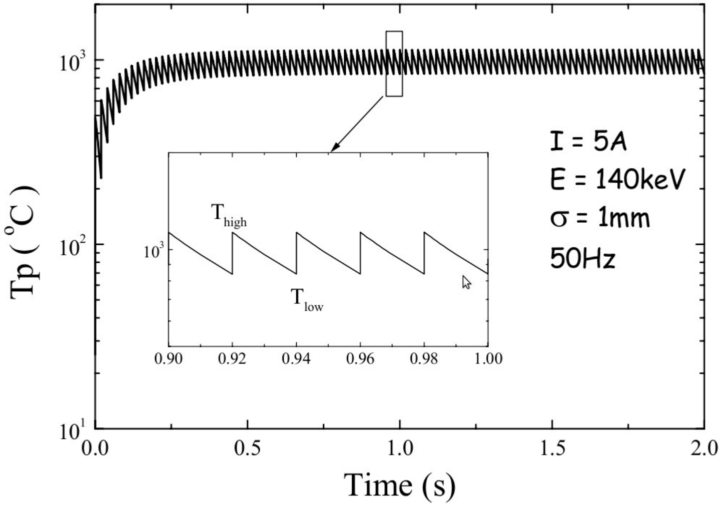
- CTF3 high intensity electron beam constitutes a high thermal load on intrusive devices – even OTR screens.
- Solution: Thermally resistant materials as radiators, at the expense of total light intensity (reflectivity). Specific heat capacity, melting temperature, and thermal conductivity key properties.
- Intensified camera where necessary.
- Si, SiC and C tested successfully.



200 μm foil thickness

E. Bravin & T. Lefevre

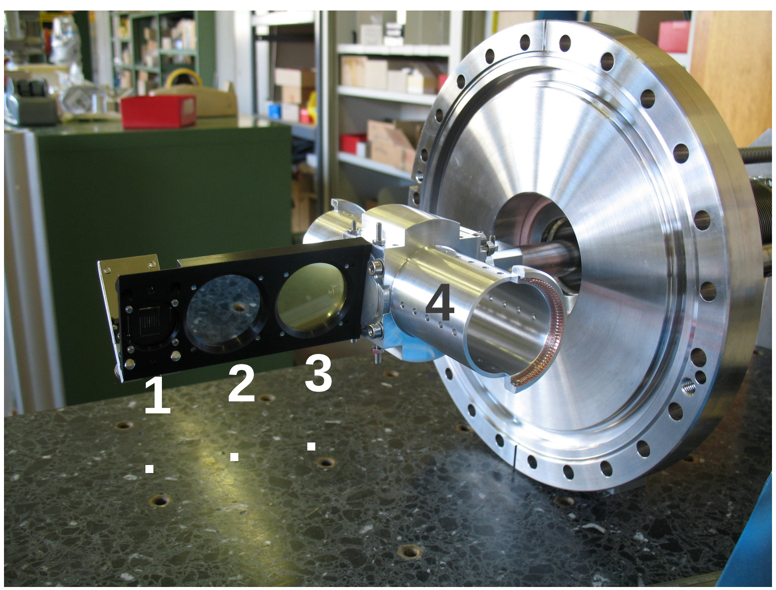




Screens for transverse profiling

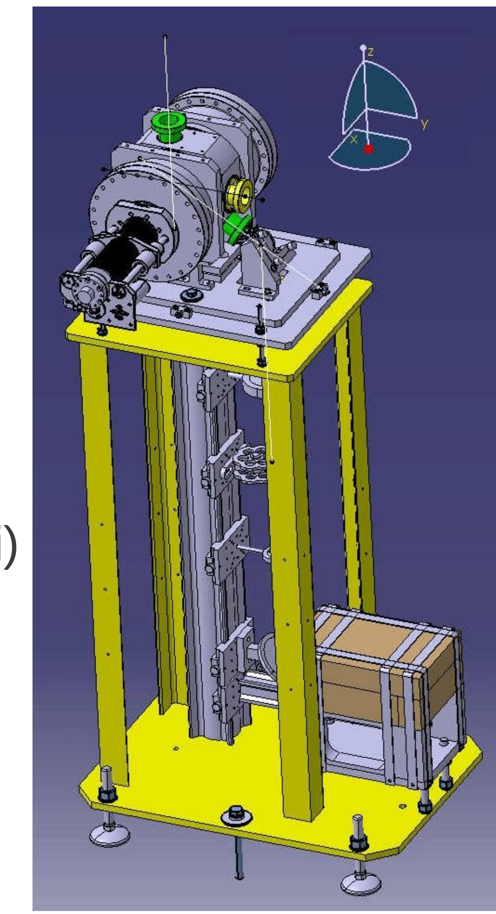
<u>Several improvements of the systems for transverse profile measurements:</u>

- Screen - beam angle 15° to minimize field depth errors
- Simpler design with view port at an angle, followed by mirror which directs the beam towards the CCD camera on the floor through a lens, filters for light attenuation, and another mirror.
- Special shielding designed for the camera – radiation huge problem at CTF3.



Screen system with four different positions:

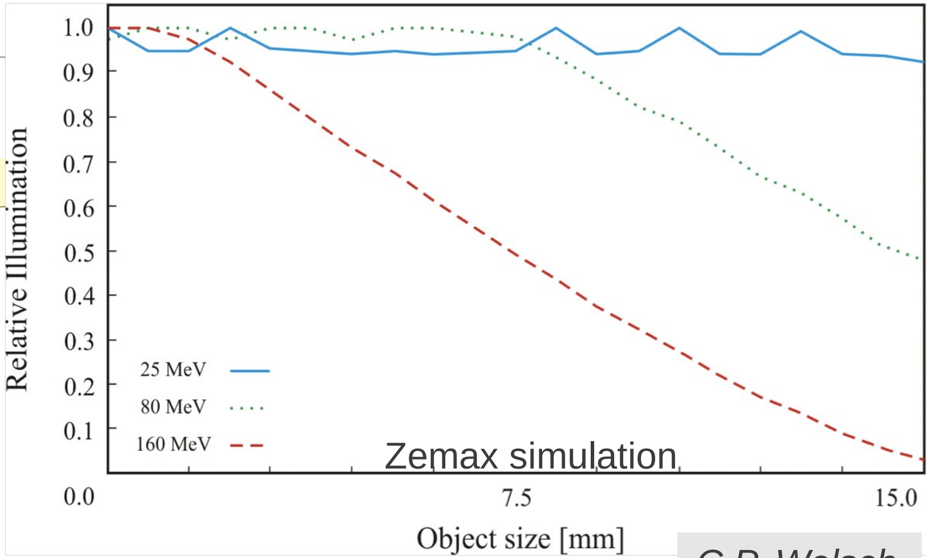
1. Calibration target
2. Highly reflective screen (Si)
3. Less reflective, thermally resistant screen (SiC)
4. Replacement chamber to reduce beam impedance while not in use.



Screens for spectrometry

Beam energy	# SR photons/e$^-$	# OTR photons/e$^-$
50 MeV	1.5E-09	7.7E-03
80 MeV	5.0E-04	8.6E-03
100 MeV	4.0E-03	9.0E-03

50 μm foil thickness



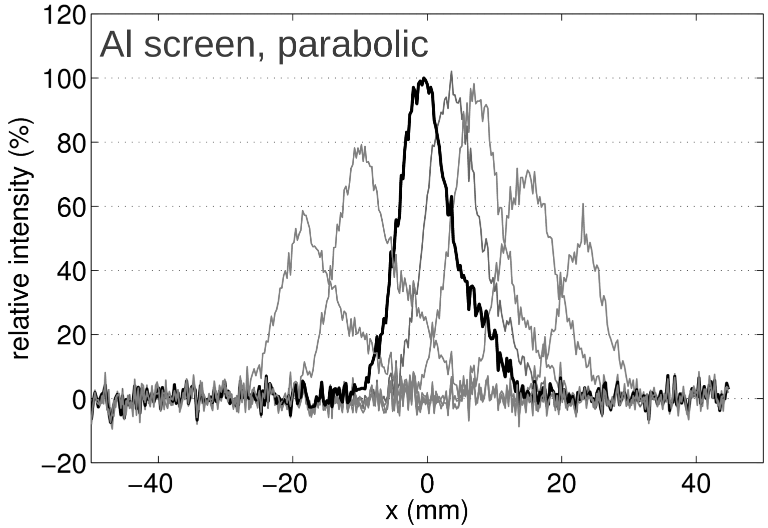
C.P. Welsch

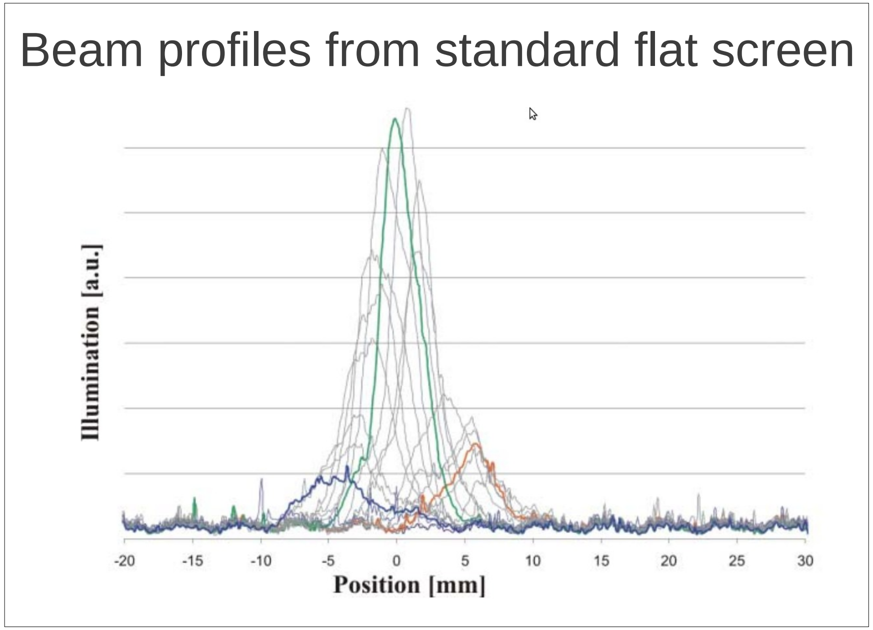
- All systems for spectrometry have fixed aluminum screens
- New standard: block synchrotron radiation using a carbon foil
- Extensive investigation on how to improve linearity of the complete system: relative amount of light reaching the camera decreases rapidly as the beam hits the edge (worse for high beam energy)

Parabolic screen

- An initial focusing of the light reduces vignetting effects on the screen edges.
- Screen support with parabolic shape: $$y = \frac{x^2}{f}$$

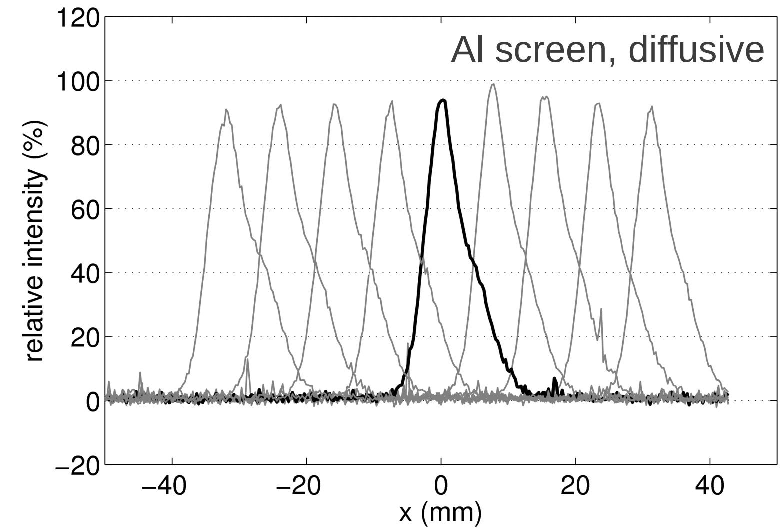
where f is distance to the first lens.





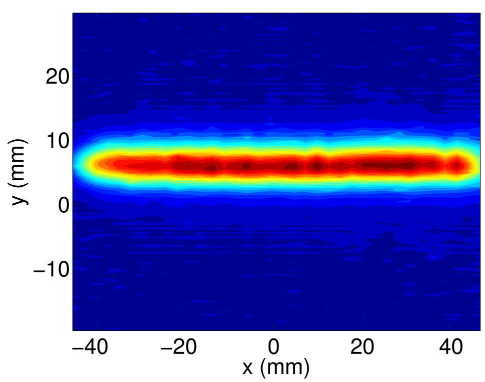
Diffusive screen

- Intentional (and controlled!) reduction of the screen reflectivity can minimize non-linear effects in the system due to vignetting in lenses.
- Non-blanc surface increases angular divergence of OTR emission – same amount of light reaches the camera independent on beam position on screen.

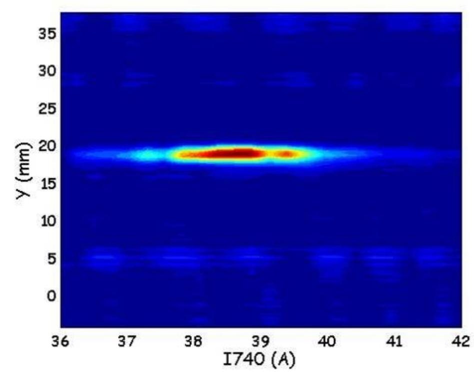


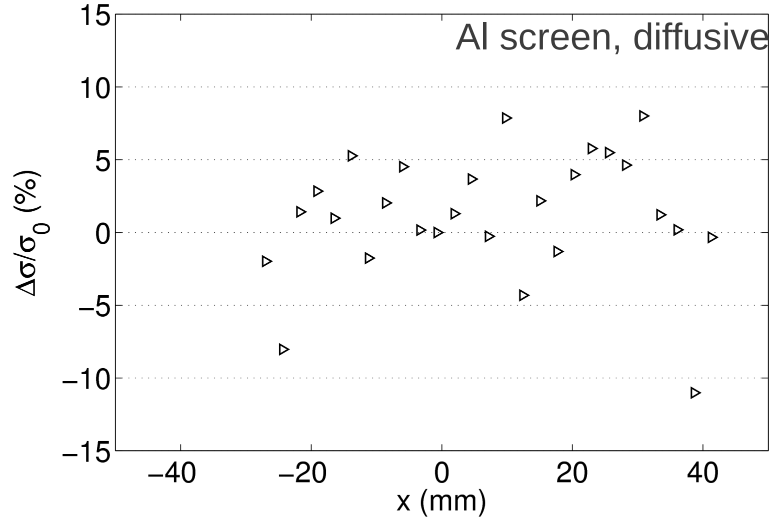
Intensity during a scan over the screen:

New diffusive screen



Regular flat screen

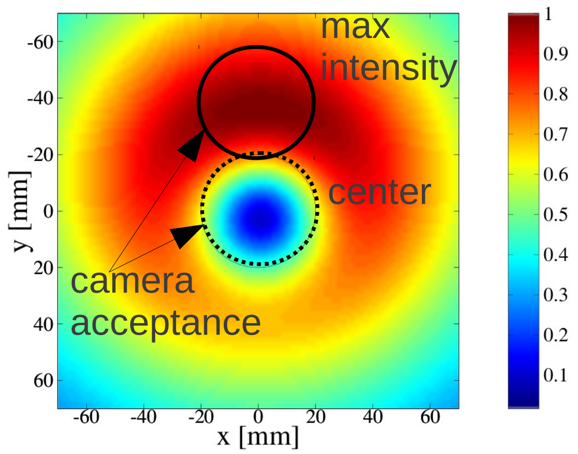




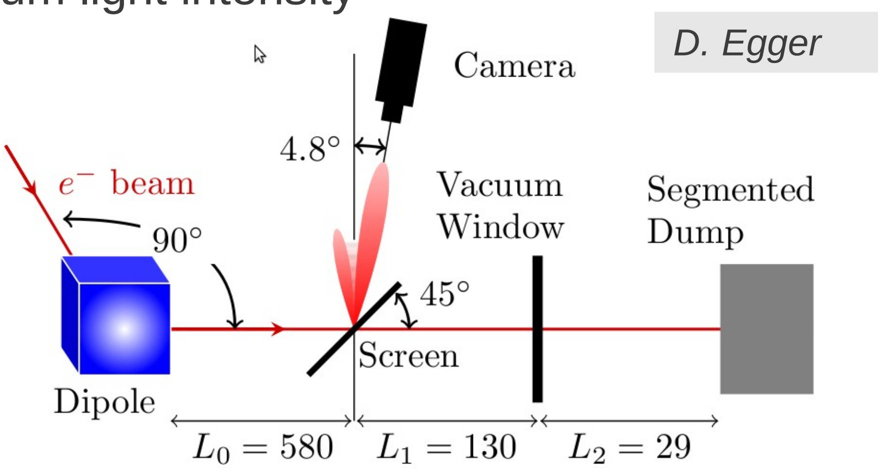
OTR for low energy e⁻

- For low energy, OTR emission highly asymmetric. Camera at an angle to catch the most intense part.
- Place camera not in image plane to capture angular distribution of OTR emission: possible to determine beam divergence and energy.

OTR distribution from a 5.5 MeV e⁻ beam.



Camera placed to catch maximum light intensity



What's next?

- Extrapolate from CTF3 to CLIC parameters
  - Drive Beam: higher energy, higher intensity, larger energy spread
  - Main beam: higher energy, smaller beam size, shorter bunches
- Error in size/emittance due to energy spread?
- Develop cheap and robust systems

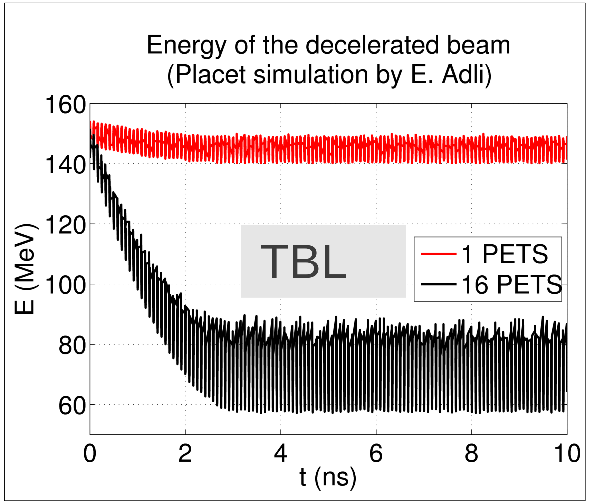
Large energy spread beams

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

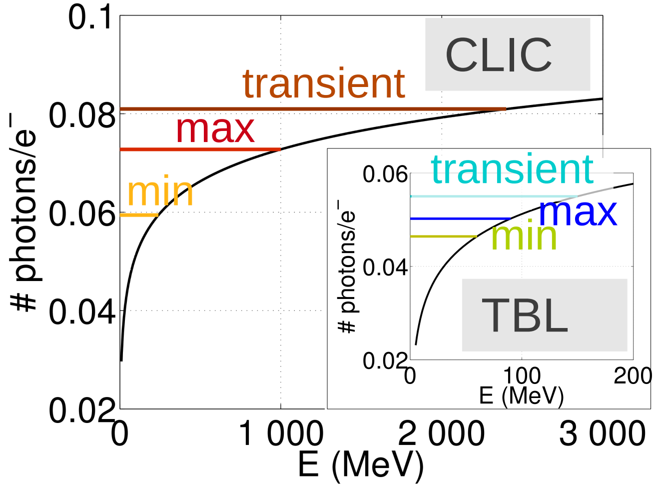
$$N_{OTR} \propto \log(\gamma)$$

	CLIC	TBL
E_{min}	240 MeV	60 MeV
E_{max}	1.0 GeV	90 MeV
$E_{transient}$	2.4 GeV	150 MeV

- high energy transient
- 6% (1σ) intra-bunch energy spread



OTR photons - beam energy



Summary

- OTR screens important tool in everyday operation of CTF3
  - Enough light intensity, better for high intensity beams.
- Improvement of the overall performance of the OTR screen systems
  - Thermally resistant materials as radiators increase life time
  - Parabolic and diffusive screens recovers performance losses when going to higher beam energy and improves reliability of energy measurement
- Next step: focus on OTR based diagnostics for beams of large energy spread

OTR screen development at CTF3

Further reading:

- *Optimization of OTR screen surface materials and OTR screen geometry at CTF3,* C.P. Welsch et al.
- *OTR studies for the high charge CTF3 beam,* E. Bravin et al.
- *Studies of OTR angular distribution at CTF2,* E. Bravin et al.
- *CTF3 Injector Profile Monitor*, C. Bal, et al.