CTF3 screen development

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LCWS, Granada, Spain, 27 September 2011

Outline

1. OTR screens installed in CTF3

2. Vignetting effect

3. Screen scan measurements

4. Large energy spread

5. Conclusion

1. OTR screens installed in CTF3

Locations of the OTR screens at CTF3

15 TV stations for OTR based emittance measurements

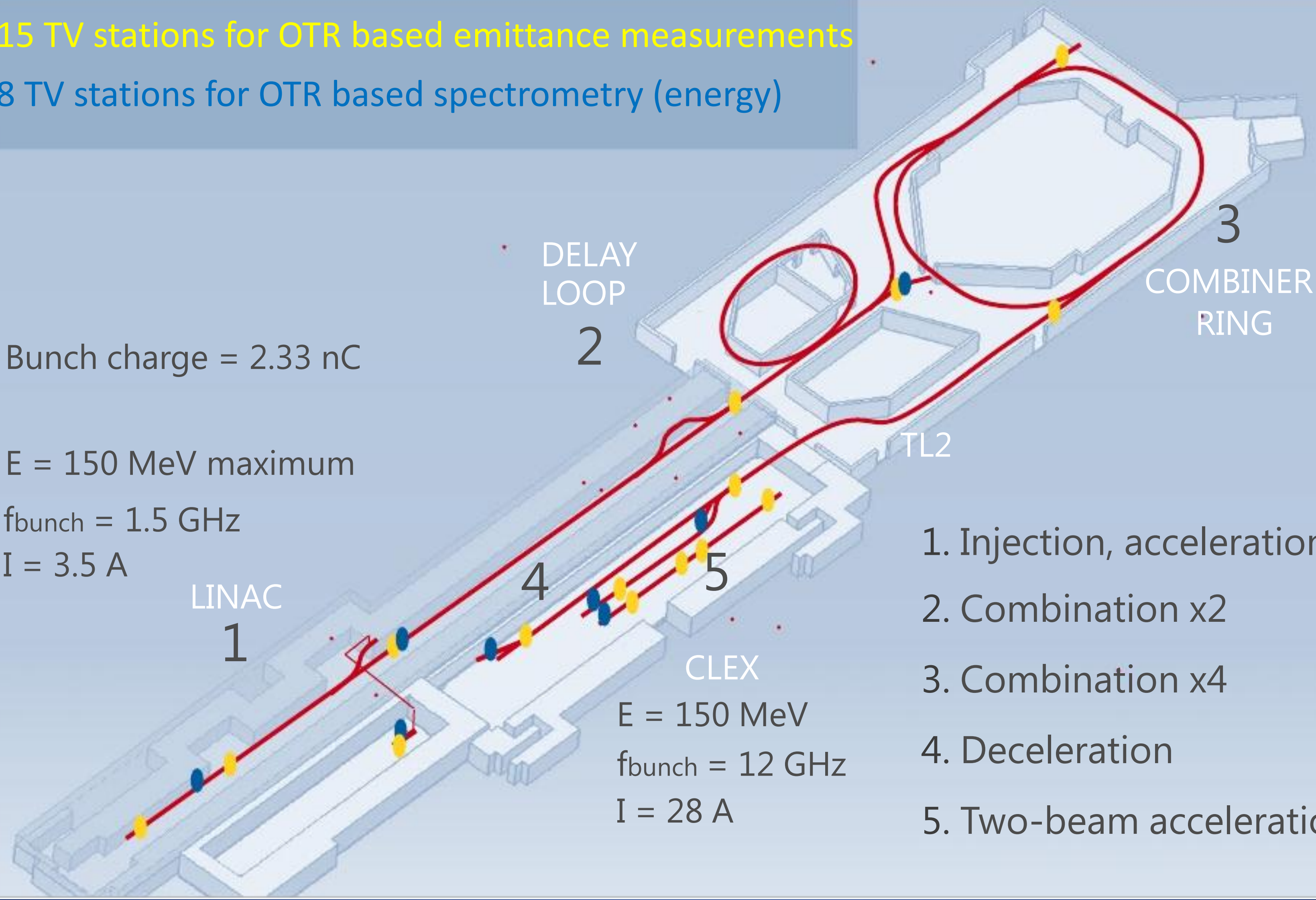
8 TV stations for OTR based spectrometry (energy)

Bunch charge = 2.33 nC

E = 150 MeV maximum

f_{bunch} = 1.5 GHz

I = 3.5 A



E = 150 MeV

f_{bunch} = 12 GHz

I = 28 A

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

Choice of OTR for CTF3

- ✓ Beam intensity: from 3.5 A during 1.4 μs, to 28 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.

Requirements of OTR at CTF3

- ✓ Small beam size typically of the order of few mm:
  - ➢ High thermal load due to the high charge

- ✓ For quad scan measurements, beam size can increase consequently
- ✓ In the spectrometer lines, large beam size of the order of ~ cm
  - ➢ Large vignetting factor can decrease the accuracy of measurements

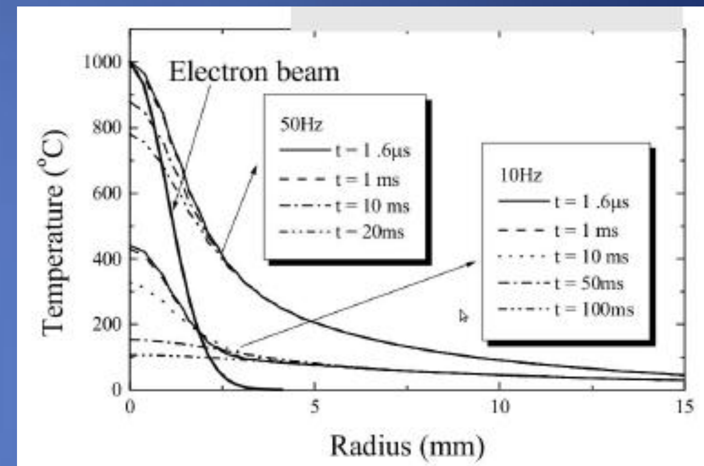
➔ **Measurements of the linearity in position for all of the CTF3 screens due to problems of acceptance and vignetting**

- ✓ Test Beam Line (TBL) at CTF3: a small-scale test of the CLIC decelerator.
  - ➢ High energy spread: need to investigate the accuracy of measurements

Screen damages

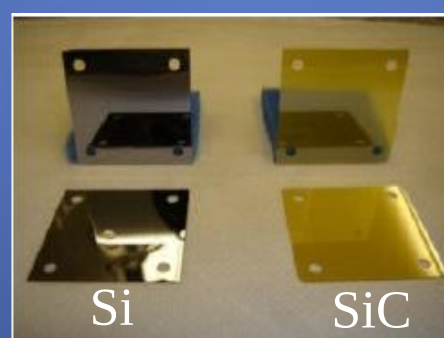
- ✓ CTF3 high intensity electron beam constitutes a high thermal load on intrusive devices – even OTR screens

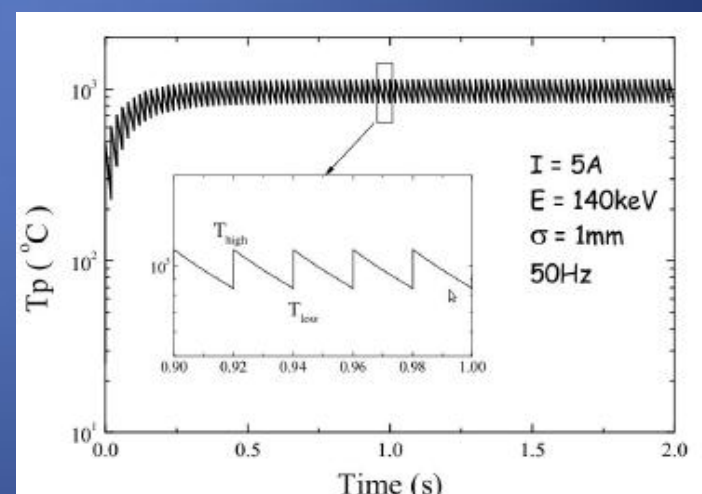
- ✓ Solution: Thermally resistant materials as radiators, at the expense of total light intensity (reflectivity). Specific heat capacity, melting temperature, and thermal conductivity key properties.



- ✓ Intensified camera where necessary.

- ✓ Si and SiC tested successfully.



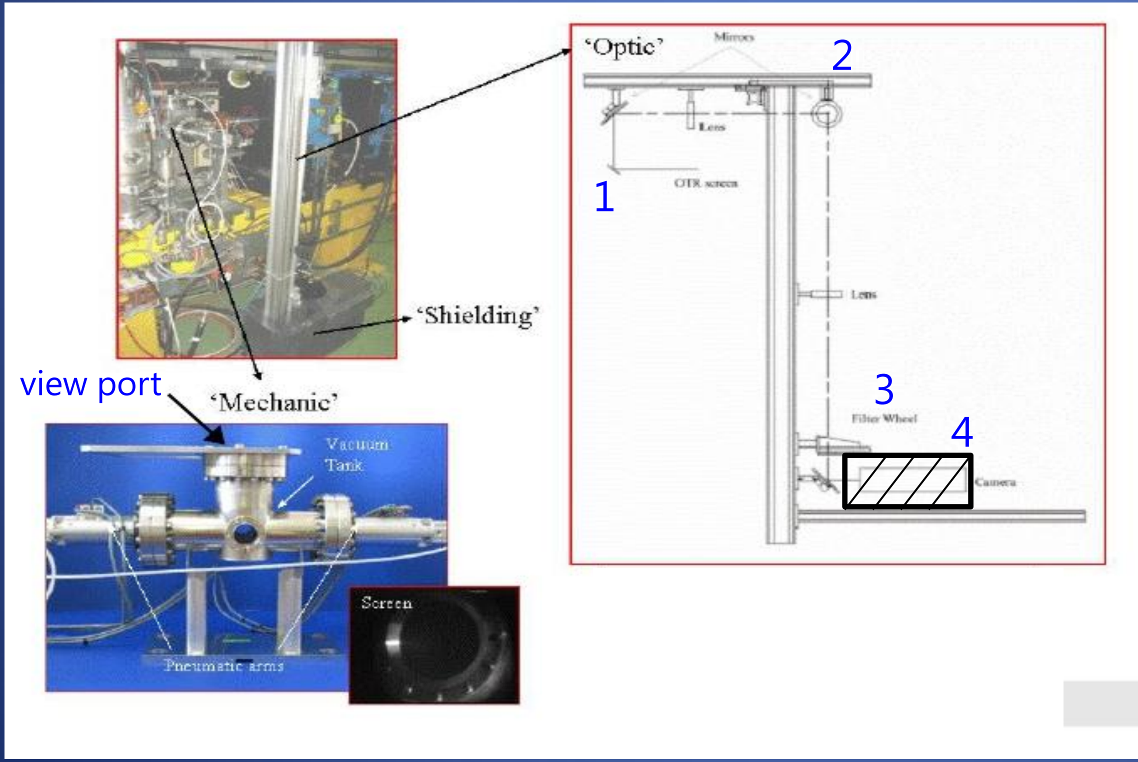


OTR screen system at CTF3

✓ In the past: radiation hard cameras directly on top of the tank

✓ Optics of "all" systems was modified in order to replace these types of cameras by CCD cameras to improve the sensitivity of the measurement

➢ "Standard" system (subject to local variation)



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 and shielding

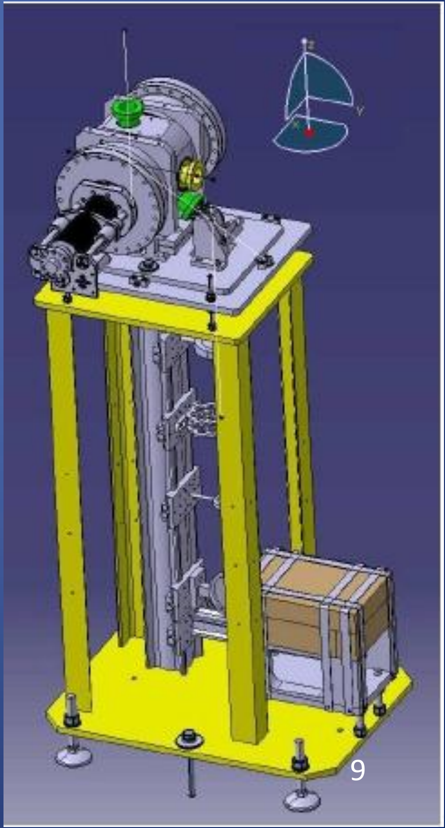
Resolution 70-200µm

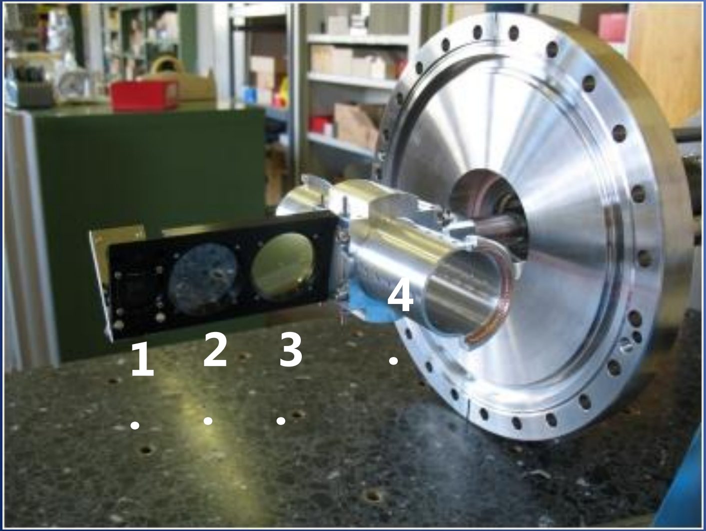
N.B: in this scheme, the line is said "long" (1.5m) since the light is first transported to the top and then go down to the camera (old system)

OTR based emittance measurements

- ✓ Beam size typically of the order of few mm:
  - ➢ Active size of the screens: diameter of 3cm

- ✓ Improved design for high current (28-30A) when the beam is combined
  - ➢ Special shielding designed for the camera – huge radiation at CTF3.
  - ➢ Screen - beam angle reduced to minimize field depth errors
  - ➢ Shorter lines and better alignment designed: the light is transported directly down to the camera (less lenses and mirrors)
    ➔ Less light losses (vignetting)





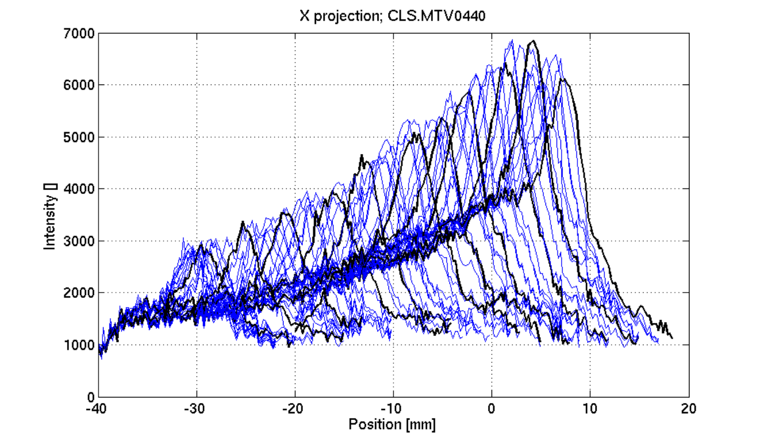
Screen system with four different positions:

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 size typically of the order of 1 cm:
  - ➢ Active size of the screens: 10cm*4cm

- ✓ Synchrotron radiation can increase highly the background for energies above 80MeV and makes the beam profile to be much asymmetric

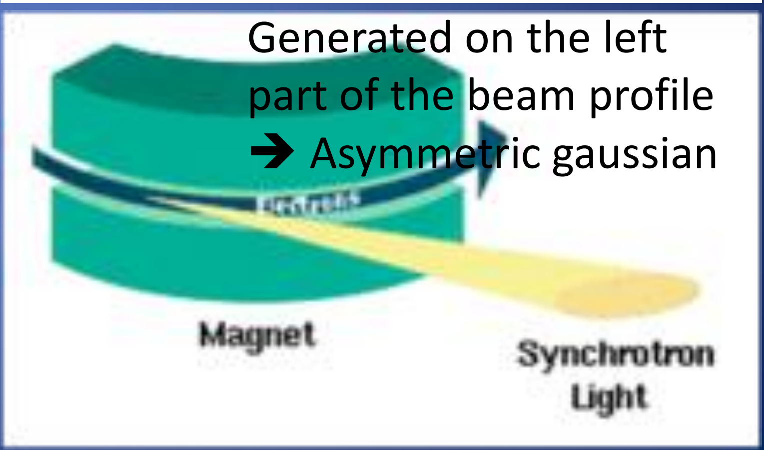


Beam energy	# SR photons/e	# OTR photons/e
50MeV	1.5E-09	7.7E-03
80MeV	5.0E-04	8.6E-03
100MeV	**4.0E-03**	**9.0E-03**

- ✓ All systems for spectrometry have fixed aluminum screens

- ✓ New standard: block synchrotron radiation using a carbon foil


50 µm foil thickness



2. Vignetting effect

Angular distribution of OTR emission

✓ 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.

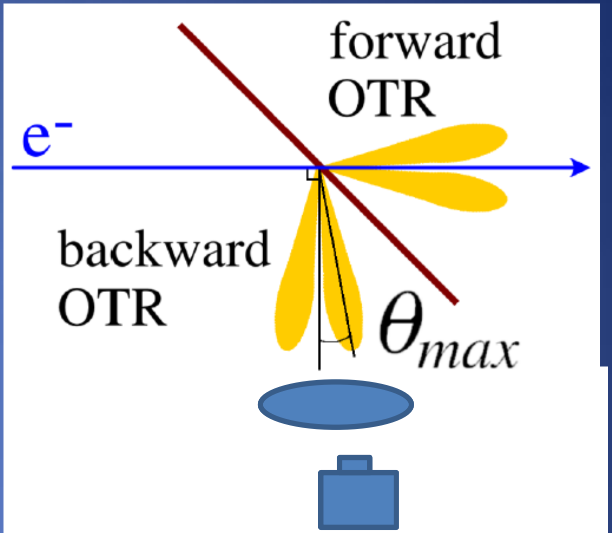
✓ For ultra-relativistic particles:

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

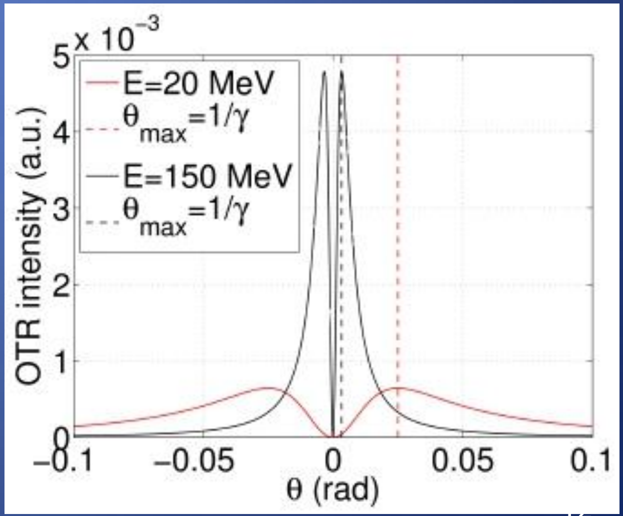
$$\frac{d^2 I}{d\omega . d\Omega} = \frac{q^2}{\pi^2 c} \frac{\theta^2}{\left(\gamma^{-2} + \theta^2\right)^2} \bullet R$$

➢ By differentiating this equation: $\theta_{\max} = \gamma^{-1}$

➔ **Emitted light cone gets narrower with increasing beam energy.**

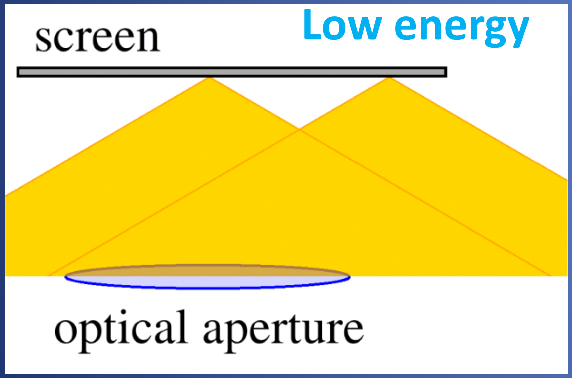


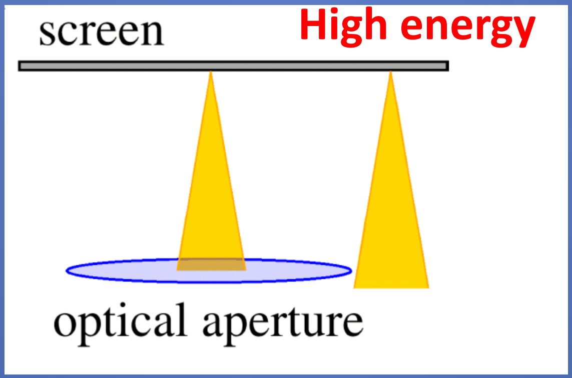
Angular distribution of OTR emission

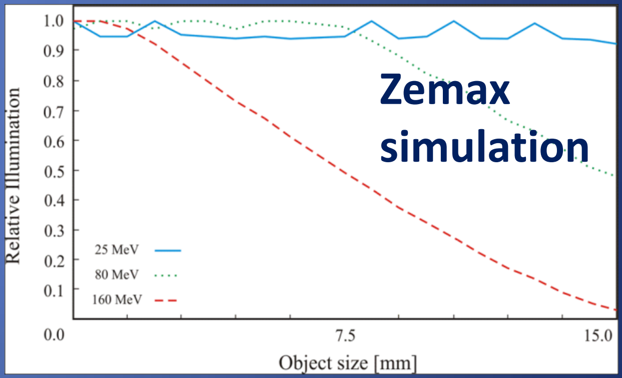


Vignetting effect

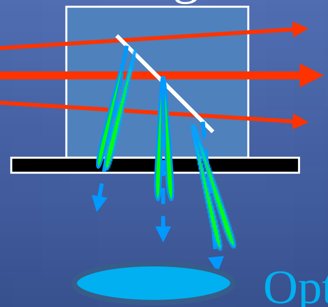
- ✓ In optics: less light collected from the edges of a system.
- ✓ Here: less light collected from the edges of the screen due to finite optical aperture of the optical system (the first lens being a strong limiting factor) and the screen size
- ✓ The effect is stronger for higher beam energy, due to the distribution of the OTR emission.







- ✓ The effect is also enhanced if the beam angle is stronger



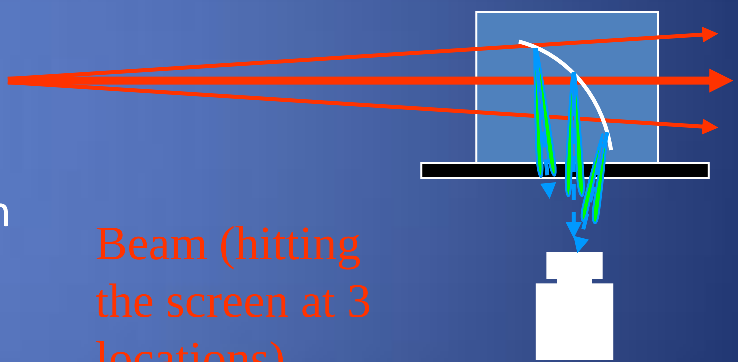
Mitigation

✓ Mitigating the effect means removing the correlation between position on the screen and the amount of light seen by the camera.

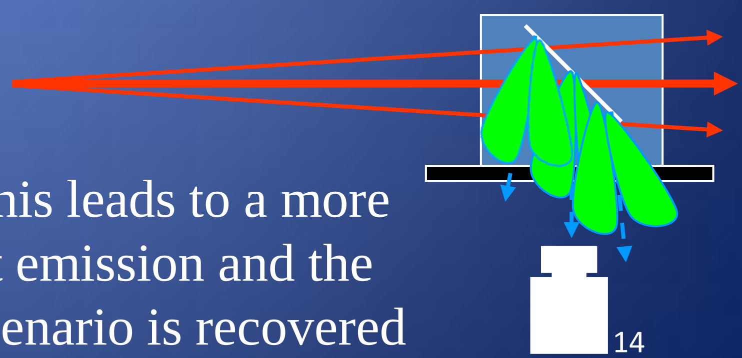
✓ Two ways: concentrate the light (parabolic screens) or diffuse the light (diffusive screens).

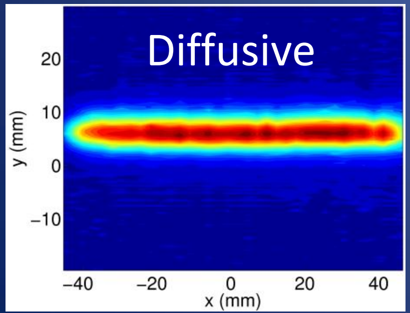
- Parabolic screen: it is possible to – already from the emission point – concentrate the light onto the optical aperture.

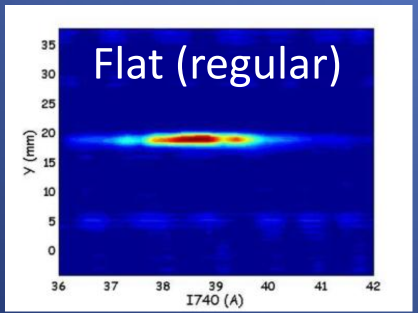
Curvature: $z=x^2/f$ (f: distance between the screen and the first lens)



- Diffusive screen: A depolished screen will diffuse the generated light.





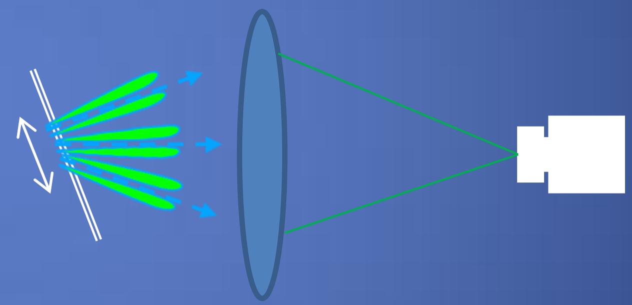


On average, this leads to a more isotropic light emission and the low energy scenario is recovered

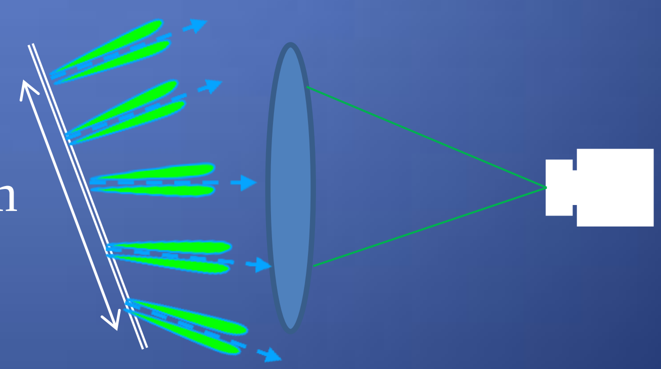
Mitigation

- ✓ The effect should be higher in the spectrometer lines since the beam size is larger
  - ➢ The optical acceptance decreases rapidly as the beam position changes
  - ➢ Parabolic and diffusive screens have been tested in such lines at CTF3

✓ Emittance screen: beam size ~ 5mm



✓ Spectrometer screen: beam size ~ few cm



3. Screen scan measurements

Goal of these measurements

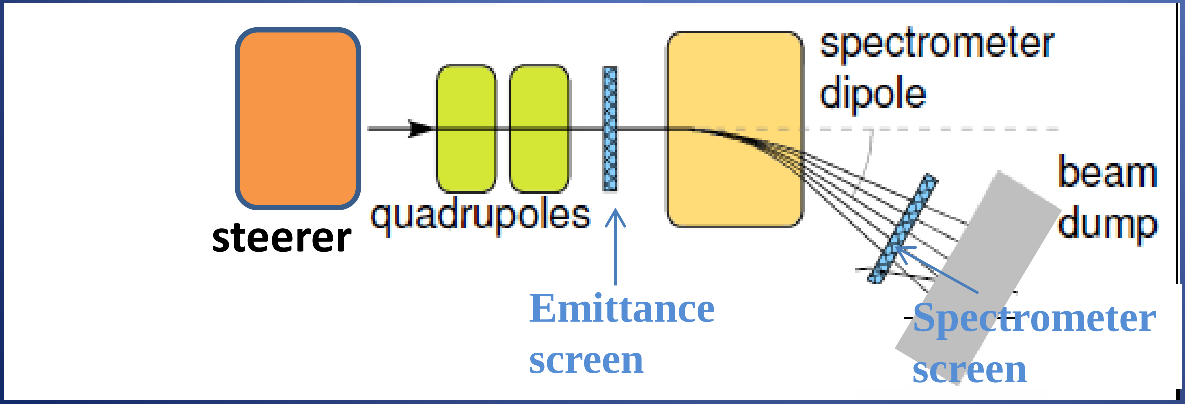
✓ OTR: perfectly linear with beam charge (no saturation)

✓ Analysis of the linearity in position for all of the CTF3 screens due to the problems of vignetting

✓ The screens have been characterized using a dipole scan technique

✓ The dipole current is increased by small steps, moving the beam across the screen (for each screen, 2 scans: in X and Y directions)

✓ For each setting an image is acquired. Assuming constant beam properties, these images will help quantifying the variation in response across the screen.

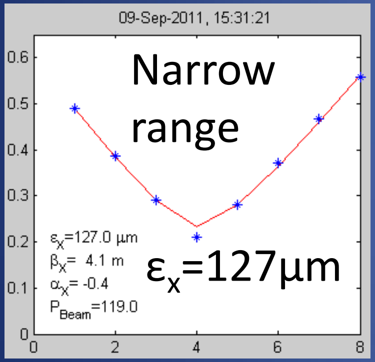


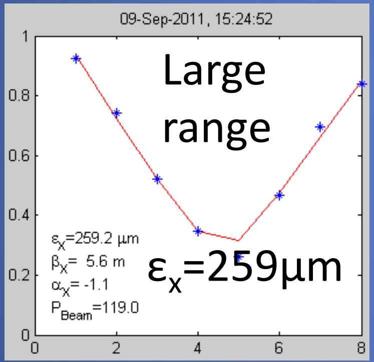
Goal of these measurements

For emittance screens

✓ Since the beam size is relatively small (order of few mm) for the emittance screens, the vignetting effect should not be very high

➢ Try to apply a correction on the beam size for all the screens from these measurements (instead of changing standard flat screens by other screens)





➔ Important in the linac for quad scan measurements:
-Large range on quad current: large beam size
➔ Vignetting effect underestimating beam size!!
➔ Emittance overestimated!!

✓ Help also to analyse misalignments and screen damages

✓ Comparison between different energies, between short and long lines, between screens of different materials…

✓ To understand all these results, need to perform optics simulations… not yet done… but some examples of measurements are shown

Goal of these measurements

For spectrometer screens

- ✓ Beam size relatively large (order of cm) for spectrometer screens
    - ➢ Vignetting effect should be important

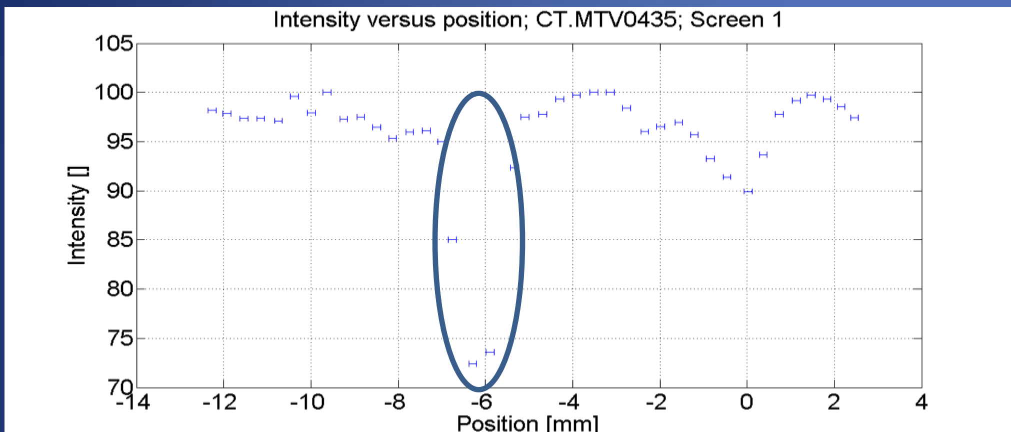
➔ Parabolic and diffusive screens have been installed in CTF3

- ✓ Screen scan measurements can reveal which system is the most efficient

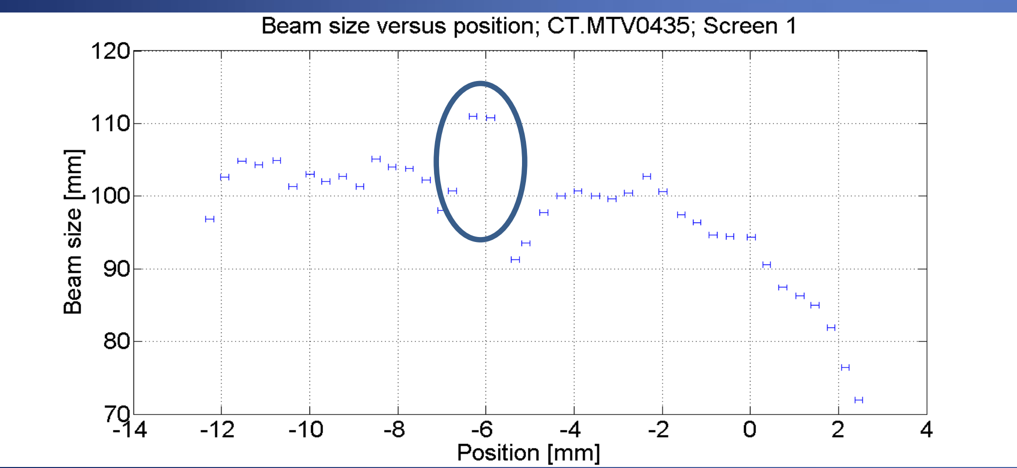
Emittance screen

Investigation of damage

- ✓ Damage observed on the screen at the position -6mm due to high charge



- ➢ Fall of the light intensity of 30%

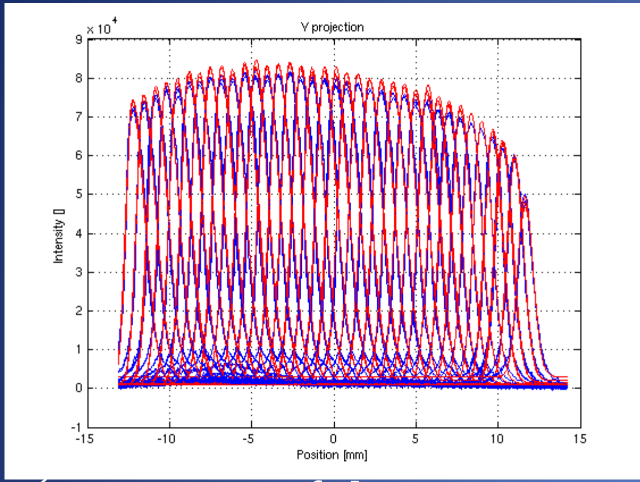


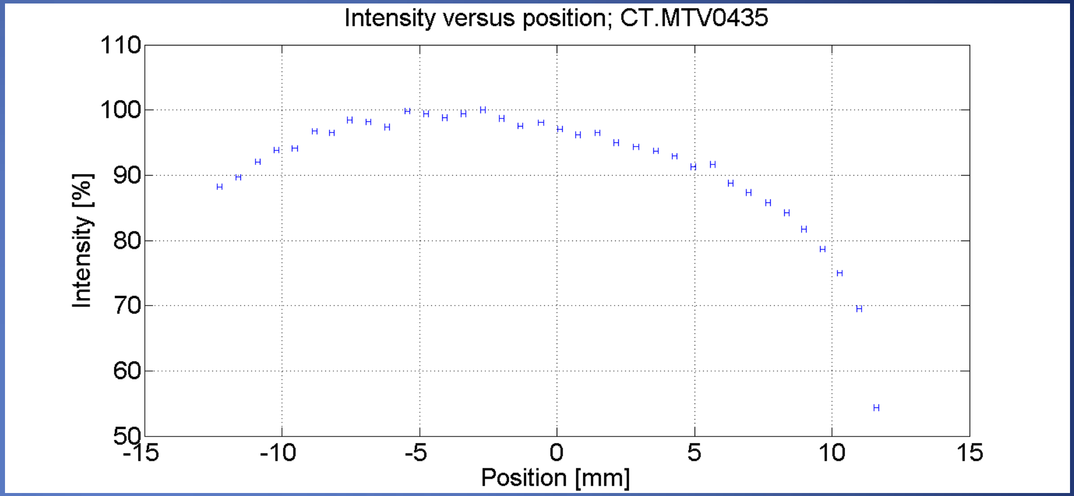
- ➢ Increase of the beam size of 10%

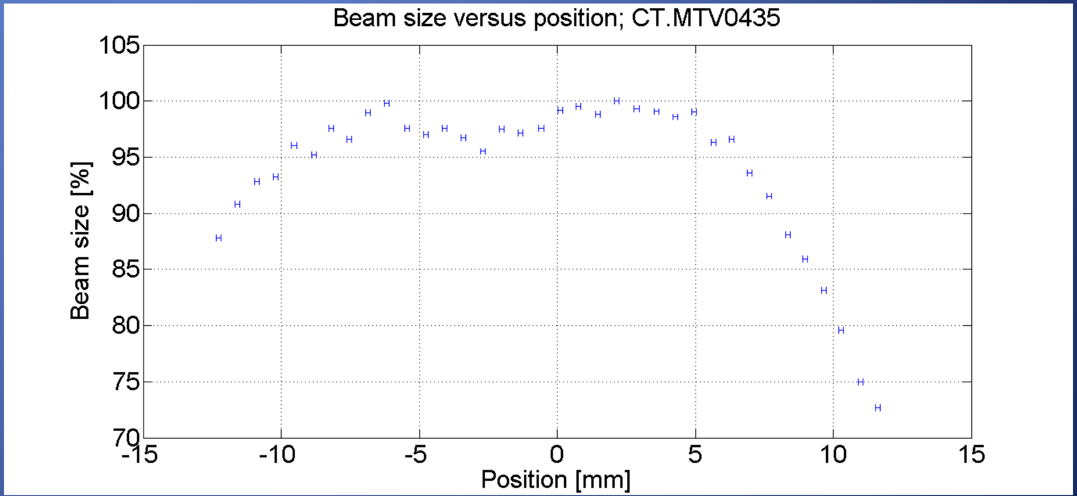
➔ **Screen scan: Good tool to observe screen damage and to know the impact on the measured beam size**

Emittance screen

Investigation of vignetting and alignment







- ✓ Decrease of the intensity when approaching the screen edges
- ✓ Beam profile modified

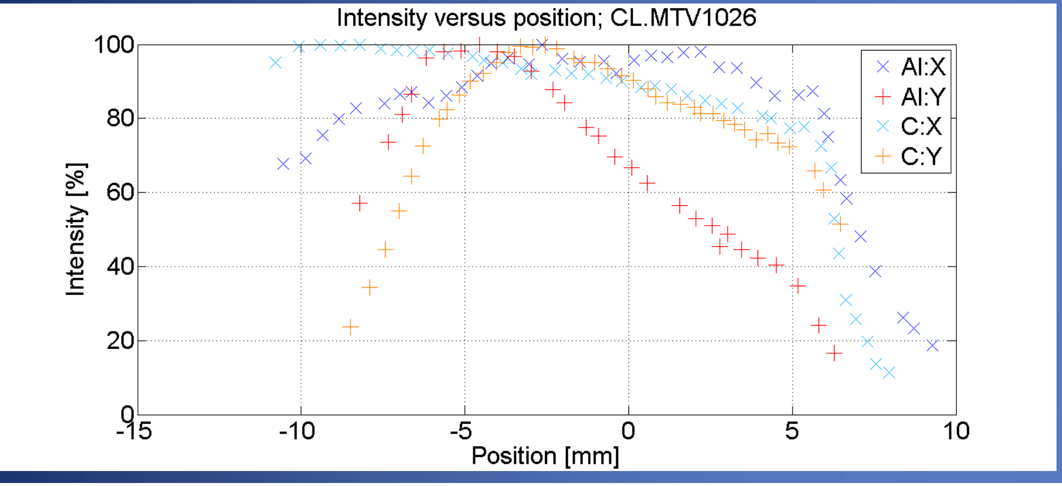
  ➔ Beam size underestimated at the screen edges
- ✓ However, beam size constant within 5% in the range of 1cm

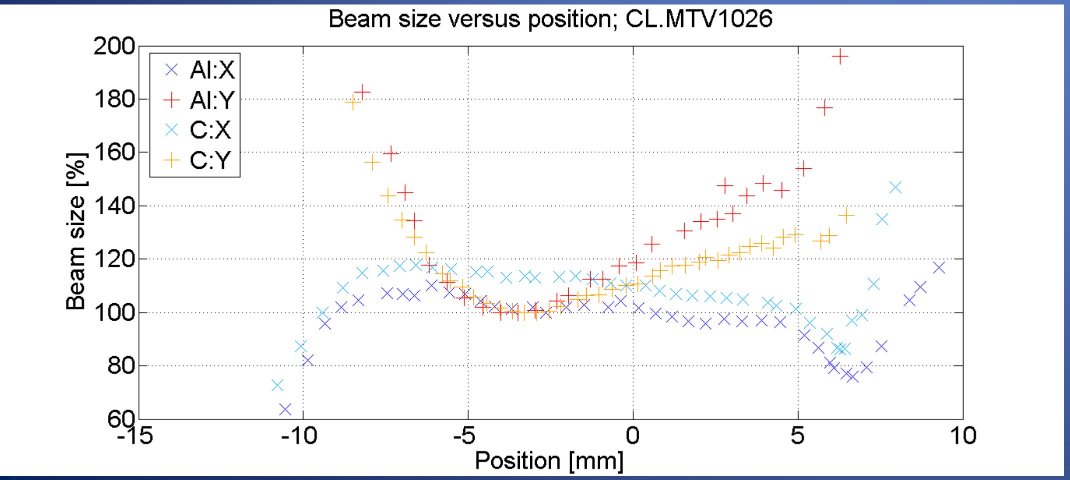
➔ Should be easy to apply a correction on the beam size from the measured intensity

Emittance screen

Investigation of vignetting and alignment

- ✓ For this screen system (CL.MTV1026), there are two screens (Al and C) whose mechanical supports are similar

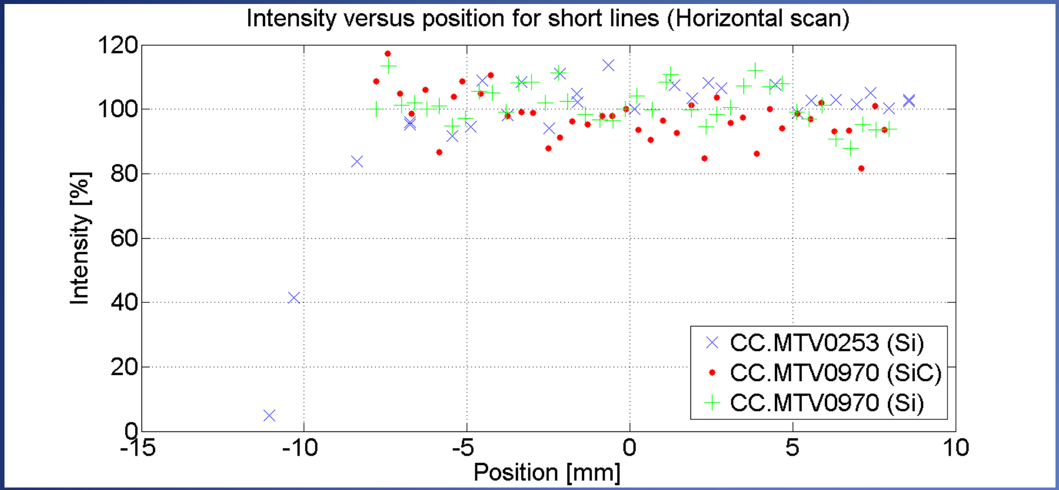


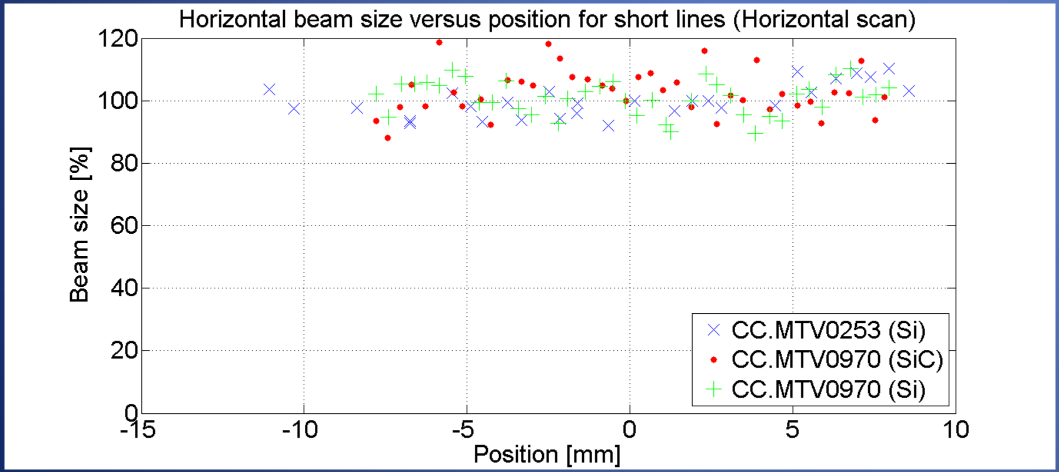


- ✓ The maximum of light intensity is off-centered (vignetting effect is also present)
- ✓ The behavior is similar on both screens for light intensity and beam size evolution
- ✓ Tilt of the wole tank? (not only of one screen support)
  - ➢ Need to check the alignment
  - ➢ Very good tool to analyse misalignment

Emittance screen

Investigation of vignetting and alignment for short lines



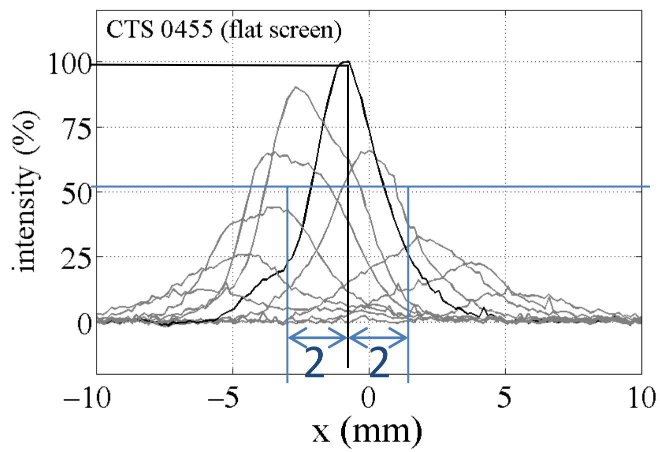


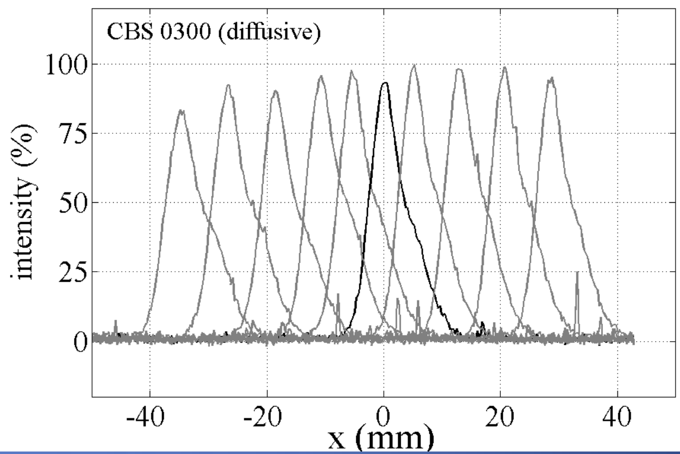
- ✓ No vignetting observed with short lines contrary to long lines
- ✓ Beam size stays relatively constant

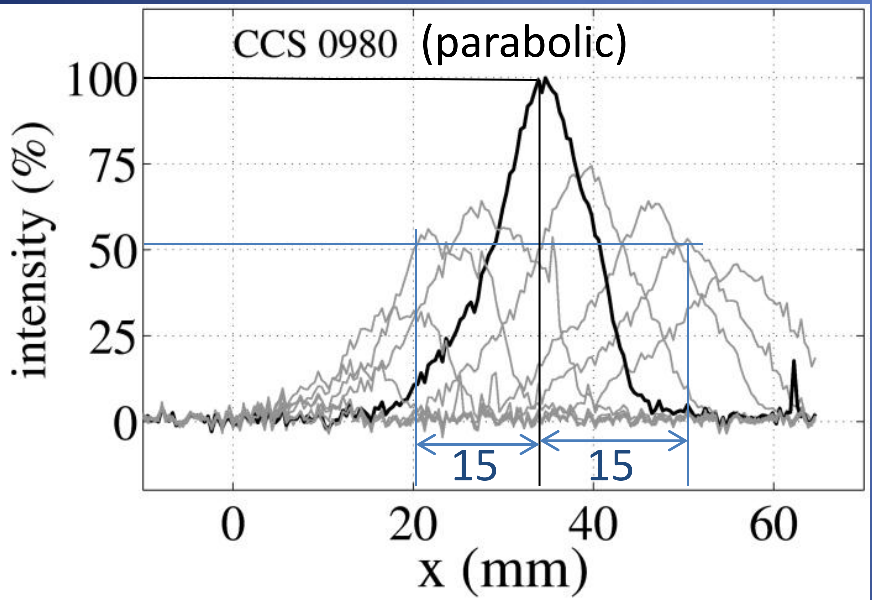
➔ **Differences between short and long lines seem to be clear in these measurements (less lenses/mirrors and design for accurate alignment help a lot!)**

Spectrometer screen

- ✓ Horizontal projection of the beam image for different beam positions:







- ✓ Intensity loss of 50% from the screen center:
  - With standard flat screen: +-2mm
  - With parabolic screen: +-15mm
- ✓ With diffusive screen: light loss of intensity even at the edges of the screen

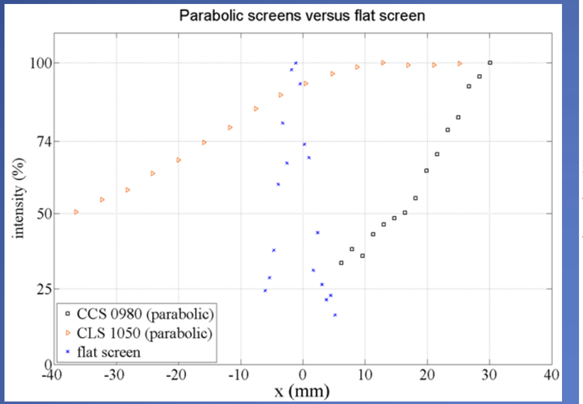
Spectrometer screen

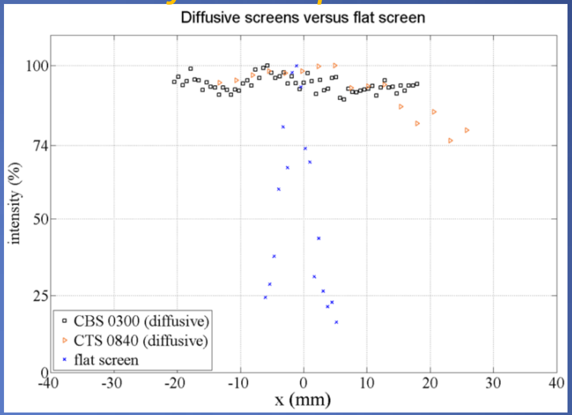
PARABOLIC

DIFFUSIVE

Total light intensity as a function of beam position

✓ The vignetting effect is reduced compared to standard flat screens.



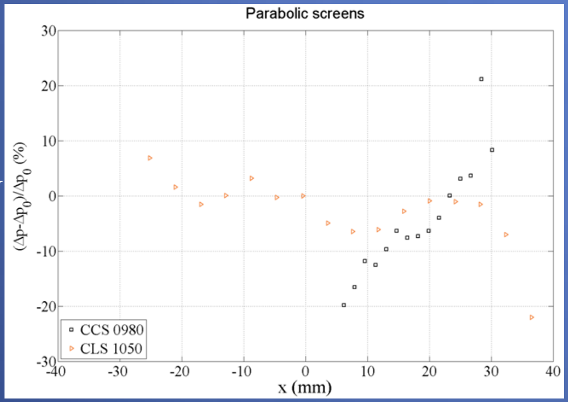


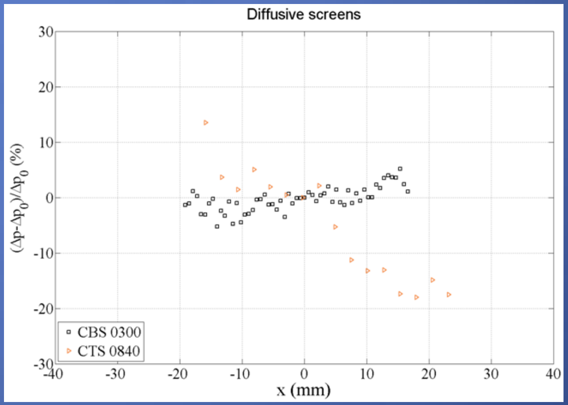
✓ The vignetting effect is efficiently reduced compared to a standard flat screen.

✓ Maximum of light intensity when the beam is off-centered

➢ Misalignment on both screens certainly

Measured momentum spread, deviation from reference





✓ Best performance with CBS0300, possibly due to differences in the optical lines

➢ Further studies to perform (including Zemax simulations)

Conclusion

Harder requirements for manufacturing and alignment. Parabolic screens should only be considered where light intensity is an issue.

In terms of manufacturing and installation, this is a less complicated improvement, compared to parabolic screens. Where the light density allows it, diffusive screens should be the primary choice.

4. Large energy spread

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 an initial energy of 2.4 GeV to 0.24 GeV (90 % energy extraction), with a large intra-bunch energy spread.

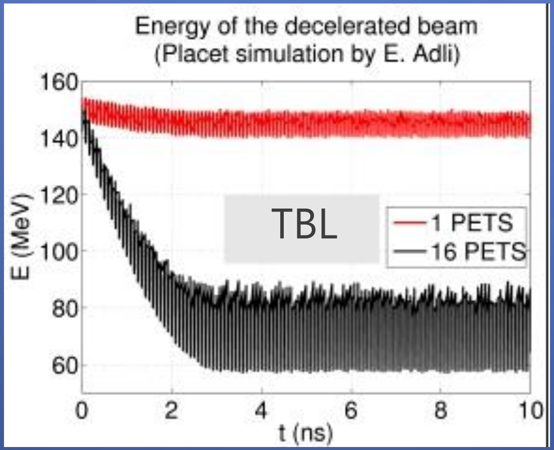
✓ Test Beam Line (TBL) at CTF3: a small-scale test of the CLIC decelerator.

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

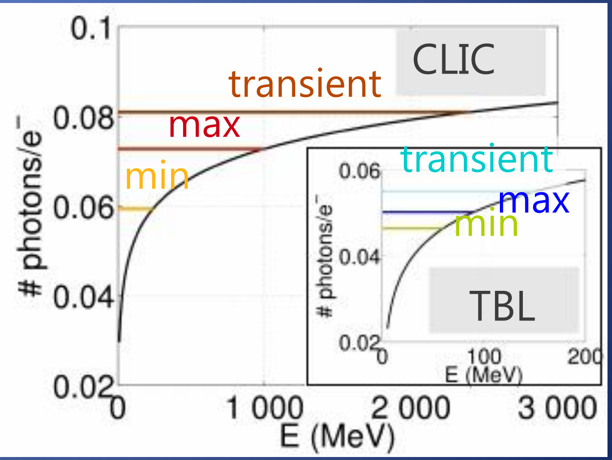
$$N_{OTR} \propto \log(\gamma)$$

	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



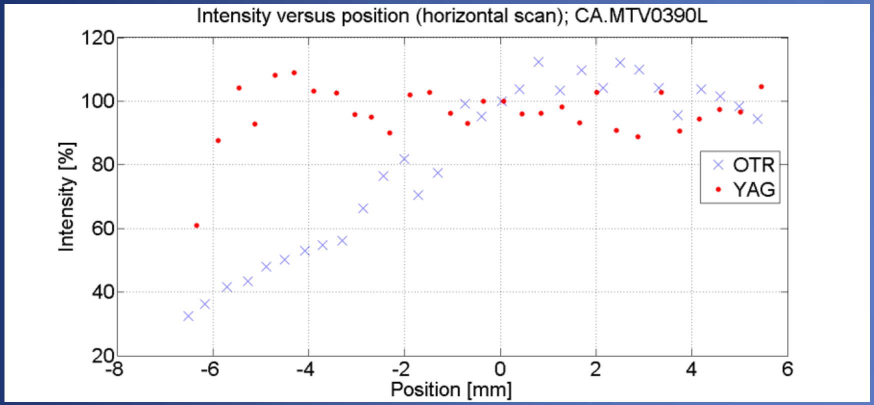
#OTR photons – beam energy

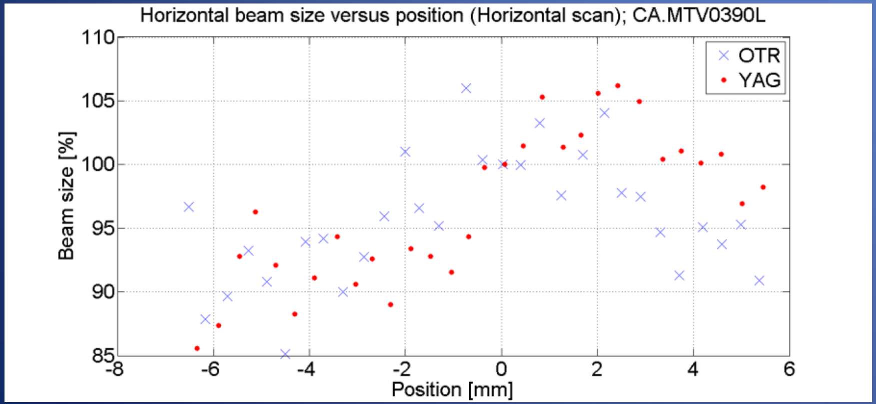


Large energy spread beams

Comparison between scintillating screens (YAG) and OTR

- ✓ For this screen system (CA.MTV0390), there are two types of screens, YAG and OTR, whose mechanical supports are similar





- ✓ In terms of light intensity, scintillating screens are much more stable than OTR screens as expected
- ✓ However, in terms of beam size accuracy, OTR screens are as good as YAG screens (+-10% of variation over a range of 12mm)

➔ YAG could be a good compromise: almost not sensitive to beam energy fluctuations

5. Conclusion

- ✓ OTR screens important tool in everyday operation of CTF3
  - ➢ Enough light intensity, better for high intensity beams

- ✓ OTR screens will be a basic tool for imaging system as well as for emittance measurements in CLIC

- ✓ Screen scan measurements performed on all the screens of CTF3 to analyze vignetting effects, misalignments, damages…

- ✓ For emittance screens: deeper studies must be done with optics simulation
  - ➢ However, first studies show that vignetting effect does not have a big impact on the beam size (except on the very edges of the screen)
  - ➢ Calibration versus position will be anyway done thanks to these studies (very important for quad scan measurements in the linac)
  - ➢ These studies will help to identify misaligned and damaged screens

- ✓ For spectrometer screens: parabolic and diffusive screens recover performance which decreases with standard flat screens when going to higher beam energy
  - ➢ Parabolic screen: no light losses but manufacturing and alignment are tricky
  - ➢ Diffusive screen: very easy to install and should be the primary choice when light density allows it

- ✓ Next step: focus on OTR based diagnostics for beams of large energy spread

ANNEXES

Emittance screen

Spectrometer screen

Screens	Screen type	Materials	Energy (MeV)	Current (A)
CT.MTV0435	flat	Si, SiC	118.5	3.5
CL.MTV0500	flat	Al,C	18.5	3.5
CL.MTV1026	flat	Al, C	65.4	3.5
CC.MTV0253	flat	Si, SiC	118.5	3.5
CC.MTV0970	flat	Si, SiC	118.5	3.5
CA.MTV0390L	flat		170-180	3.5
CTS.MTV0550	flat	Si, SiC		3.5
CLS.MTV0440	flat	Al		3.5
CLS.MTV1050	parabolic	Al	60-75	3.5
CTS.MTV0840	diffusive	Al	100-150	7
CCS.MTV0980	parabolic	Al	100-150	28
CMS.MTV0630	parabolic	Al	100-150	28
CBS.MTV0300	diffusive	Al	60-150	28