Energy Measurements by Means of Transition Radiation in novel Linacs

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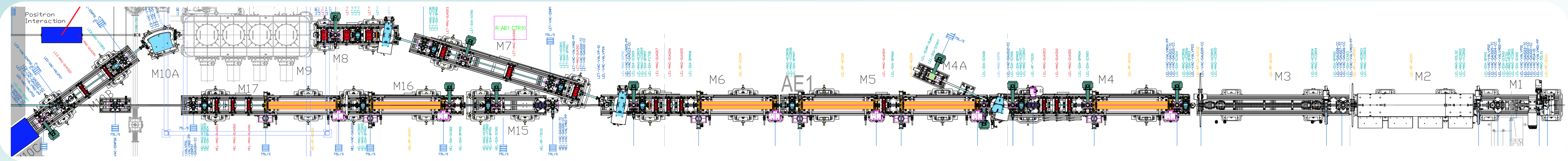
Abstract

Advanced linear accelerator design may use Optical Transition Radiation (OTR) screens to measure beam spot size; for instance, such screens are foreseen in plasma based accelerators (EuPRAXIA@SPARC_LAB) or Compton machines (Gamma Beam Source@ELI-NP). OTR angular distribution strongly depends on beam energy. Since OTR screens are typically placed in several positions along the LINAC to monitor beam envelope, one may perform a distributed energy measurement along the machine. Furthermore, a single shot energy measurement can be useful in plasma accelerators to measure shot to shot energy variations after the plasma interaction. Preliminary measurements of OTR angular distribution of about 100 MeV electrons have been already performed at the SPARC_LAB facility. In this paper, we discuss the sensitivity of this measurement to beam divergence and others parameters, as well as the resolution required and the needed upgrades of conventional OTR diagnostics, using as an example the data collected at SPARC_LAB.

1. Linac layout

The Gamma Beam Source (GBS) machine is an advanced source of up to 20 MeV Gamma Rays based on Compton back-scattering, i.e. collision of an intense high power laser beam and a high brightness electron beam with maximum kinetic energy of about 720 MeV.

The Linac will provide trains of bunches in each RF pulse, spaced by the same time interval needed to recirculate the laser pulse in a properly conceived and designed laser recirculator, in such a way that the same laser pulse will collide with all the electron bunches in the RF pulse, before being dumped. The final optimization foresees trains of 32 electron bunches separated by 16 ns, distributed along a 0.5 μs RF pulse, with a repetition rate of 100 Hz.



2. Optical Transition Radiation

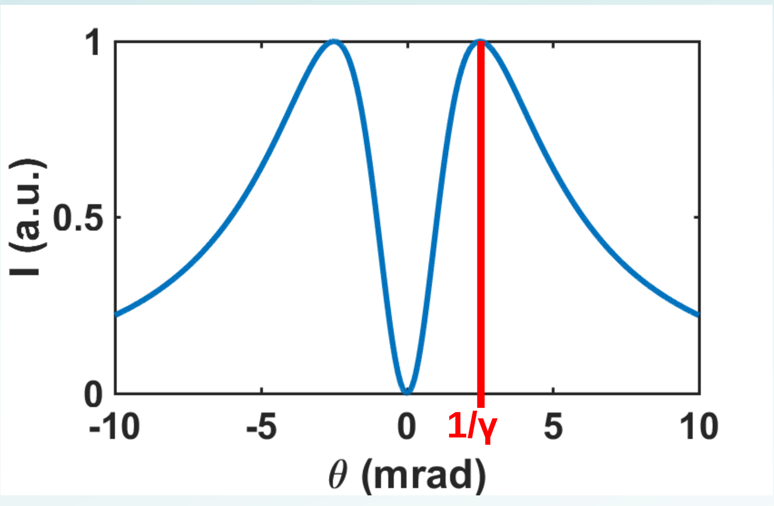
The radiation is emitted when a charged particle beam crosses the boundary between two media with different optical properties [1] (here vacuum and a thin reflecting silicon screen).

Advantages of OTR are the instantaneous emission process enabling fast single shot measurements, and the good linearity (neglecting coherent effects).

Disadvantages are that the process of radiation generation is invasive, i.e. a screen has to be inserted in the beam path, and that the radiation intensity is much lower in comparison to scintillation screens.

The beam energy can be measured by means of observation of OTR angular distribution.

$$\frac{dI^2}{d\omega d\Omega} \propto \frac{\sin^2\theta}{\left(\frac{1}{\gamma^2}+\sin^2\theta\right)^2} \quad (1)$$



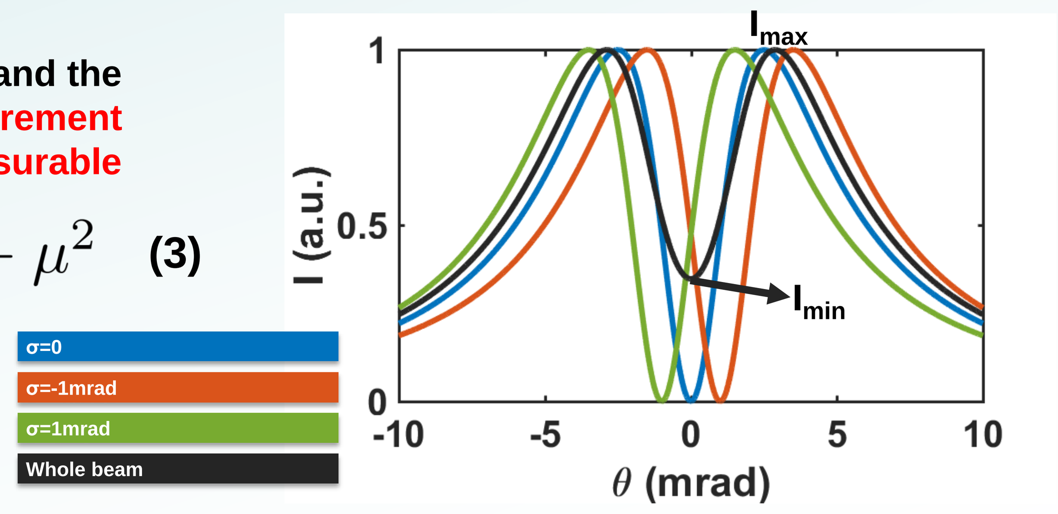
Due to the beam divergence, the angular distribution of the whole beam will be different from 0 at the center; the ratio between the minimum and the maximum intensity is related to the beam divergence. A parameter called visibility defines the reliability of the beam divergence measurement (V>0.1) in analogy with the contrast function. Since the visibility increase with the beam energy, one can also estimate the minimum measurable divergence for a given energy [2].

$$V = \frac{I_{max}-I_{min}}{I_{max}+I_{min}} \quad (2)$$

$$I \propto \int_{-\infty}^{\infty} \frac{(\theta-\xi)^2}{[1/\gamma^2+(\theta-\xi)^2]^2}\exp\left[-\frac{\xi^2}{2\sigma'^2}\right]d\xi = \frac{\sqrt{\pi}\mu}{\nu}\Re\left[\Phi(z)\left(\frac{1}{2}+\mu\nu z\right)\right]-\mu^2 \quad (3)$$

$$\mu = \frac{1}{\sqrt{2}\sigma'} \qquad \Phi(z) = \frac{1-\mathrm{erf}(z)}{\exp[-z^2]} \qquad z = \mu(\nu+i\theta) \qquad \nu = \frac{1}{\gamma} \quad [2]$$

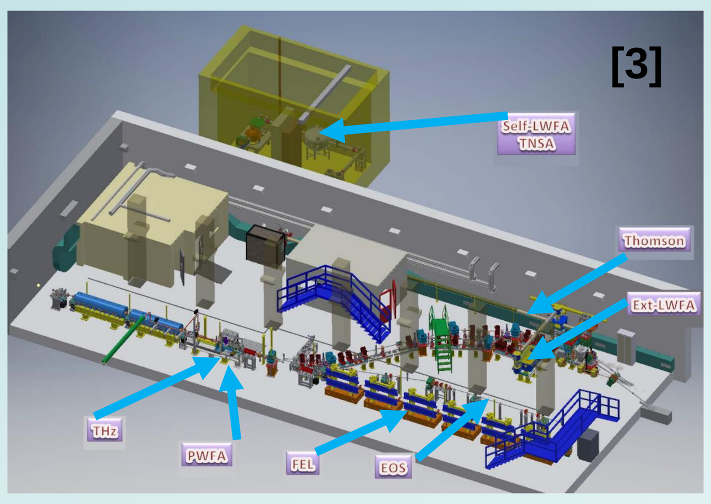
Assuming a Gaussian distribution of the divergences, the beam angular distribution can be written as the convolution between Eq. (1) and the Gaussian distribution as in Eq. (3).



3. SPARC_LAB Data

Conventional Techniques (spectrometer and quadrupole scan)

	E (MeV)	Q (pC)	σ'_x (mrad)	σ'_y (mrad)
Data set 1	**110.82** (0.07)	108 (3)	**0.52** (0.03)	**0.66** (0.02)
Data set 2	**123.1** (0.04)	120 (4)	**1.1** (0.09)	**1.04** (0.09)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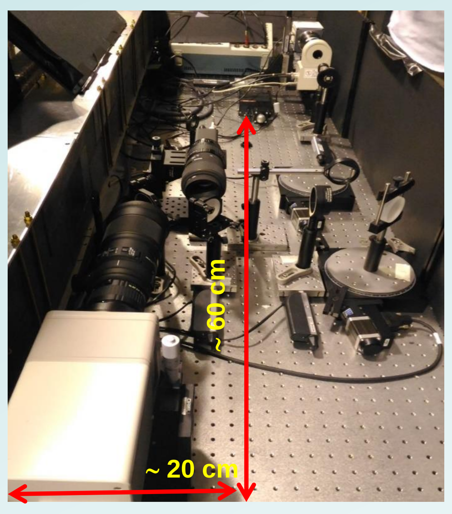
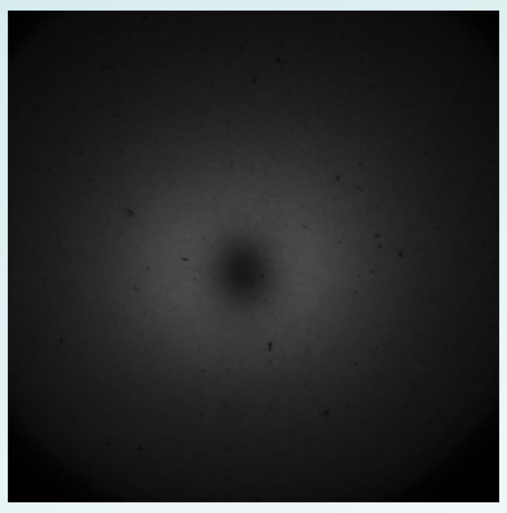




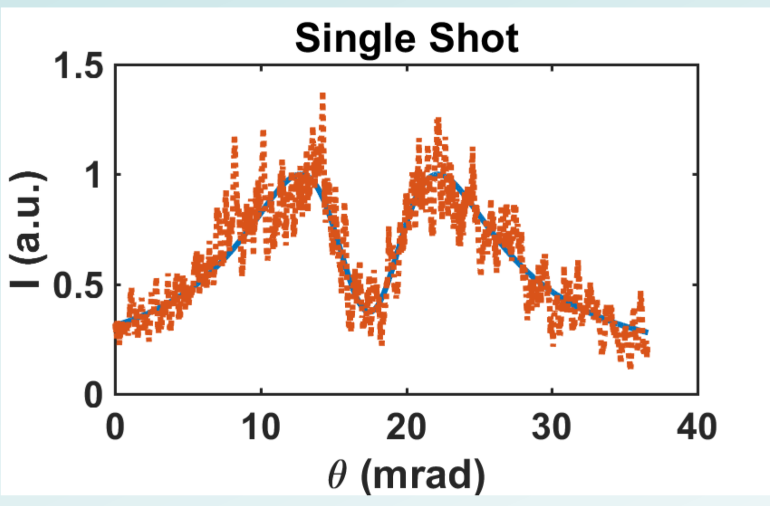
Focal length equal to 400mm. Pixel size equal to 6.5μm. Therefore each pixel is 16.25μrad

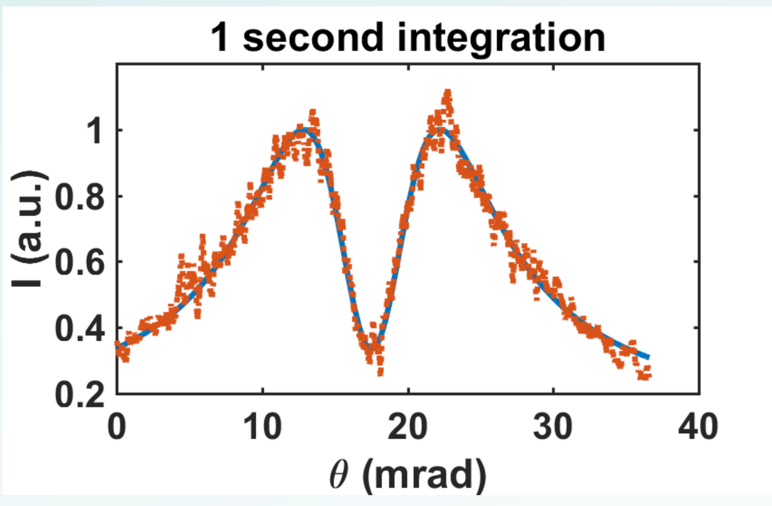
Fit Results

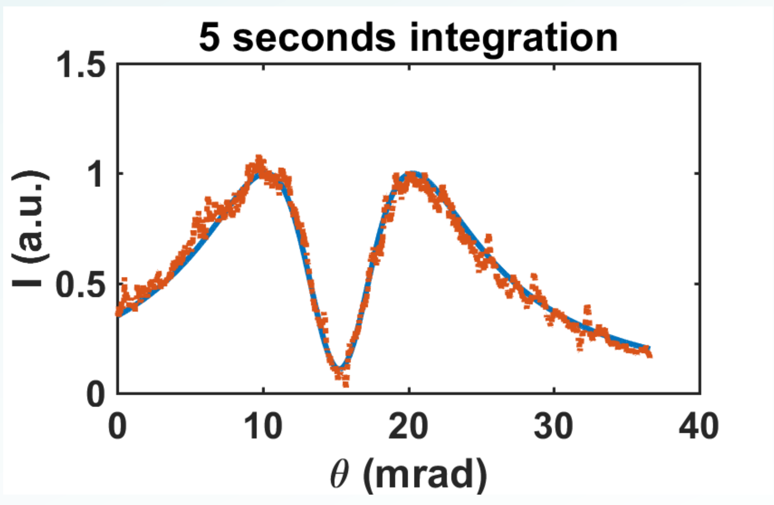
	Data set 1	Data Set 2
E (MeV)	105.35 (2.04)	122.13 (2.04)
σ'_x (mrad)	0.72 (0.21)	1.4 (0.1)
σ'_y (mrad)	0.74 (0.17)	1.3 (0.1)

	Data set 1	Data Set 2
E (MeV)	108.33 (1.53)	123.66 (1.02)
σ'_x (mrad)	0.75 (0.09)	1.3 (0.05)
σ'_y (mrad)	0.77 (0.08)	1.2 (0.04)

	Data set 1
E (MeV)	109.87 (0.55)
σ'_x (mrad)	0.72 (0.04)
σ'_y (mrad)	0.78 (0.06)







The energy is well predicted by the fit; especially for the higher energy data set.

Due to the lack of visibility, see Eq. (2), the divergences are overestimated: at higher energy (i.e. 180 MeV) these parameters could be better estimated [2].

The accuracy is higher with conventional techniques (i.e. spectrometer and quadrupole scan); the OTR angular distribution, at this energies, is a complementary technique useful for a distributed measurement.

4. Conclusions

The OTR could be a very useful diagnostic tool in order to measure the beam energy.

Due to the fact that the OTR screen are placed all along the machine, a distributed energy measurement can be performed; the energy jitter shot to shot could also be evaluated during the commissioning stage of the machine or after plasma interaction if the signal to noise ratio (SNR) is high enough (i.e. high energy, high charge). Indeed the data analysis shows a strong dependence of the uncertainty to the SNR.

New distributed measurements are foreseen especially to evaluate the performances of the accelerating structures at the ELI-GBS facility during the commissioning stage. Using a gated camera (Hamamatsu Orca4), it's foreseen the measurement also of a single bunch of the pulse train.

References

[1] V. Ginzburg, et al., "*Radiation of a uniformly moving electron due to its transition from one medium into another*", Zhurnal eksperimentalnoi i teoreticheskoi fiziki, 1946

[2] A. Cianchi, et al., "*Transverse emittance diagnostics for high brightness electron beams*", NIM A, 2016

[3] M. Ferrario, et al., "*SPARC_LAB present and future*", NIM A, 2013

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