Status of the development of single shot emittance measurement at SPARC_LAB

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Abstract: In order to measure emittance in single shot, it is necessary to obtain information about beam spot, angular divergence and correlation term. The former and the second terms can be provided by a simultaneous measurement of beam size and Optical Transition Radiation (OTR) angular distribution. The latter is acquired by means of a microlens array, producing several contiguous replicas of OTR angular distribution. We report here the first results and the status of the development of this technique.

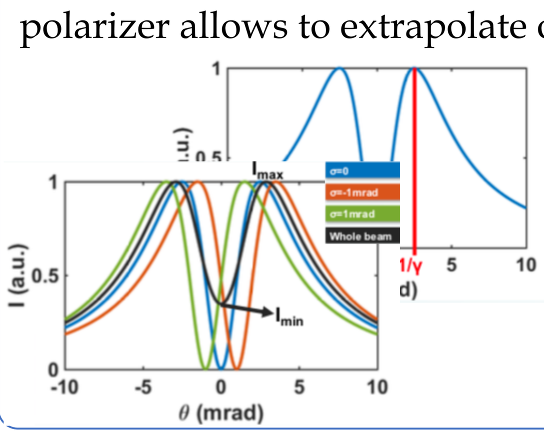
Optical Transition Radiation

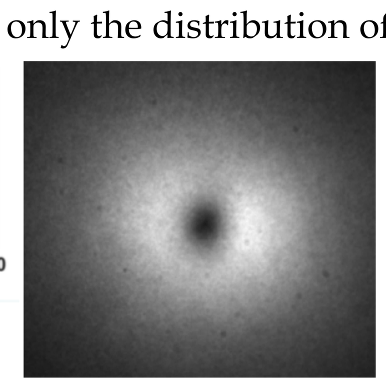
One charged particle passing through the boundary between two media with different optical properties generates **Optical Transition Radiation (OTR)**, according to the equation obtained in relativistic conditions: $\frac{d^2I}{d\omega\, d\Omega} \cong \frac{e^2}{\pi^2 c}\frac{\theta^2}{[\theta^2+\gamma^{-2}]^2}$.

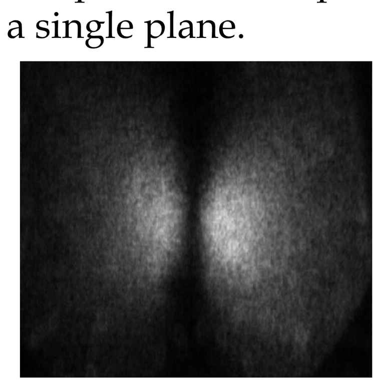
For a **real beam**, the OTRs of each particle add up and generate light with the following **angular distribution**:

$$I = \frac{e^2\beta^2}{\pi^2 c}\left\{\frac{\sqrt{\pi}\,\mu}{\nu}\,\Re e\left[\Theta(z)\left(\frac{1}{2}+\mu\nu z\right)\right]-\mu^2\right\}, \qquad with \begin{cases} z=\mu(\nu+i\theta) \\ \mu = 1/(\sqrt{2}\,\sigma) \\ \nu=\gamma^{-1}\end{cases} .$$

This distribution is valid for both the transverse plane, providing the typical OTR ring, with the middle minimum related to the **divergence of the beam**. Since in the minimum the contributions of the both planes add up, a polarizer allows to extrapolate only the distribution of a single plane.




Single lens OTR


Hor-polarized single lens OTR

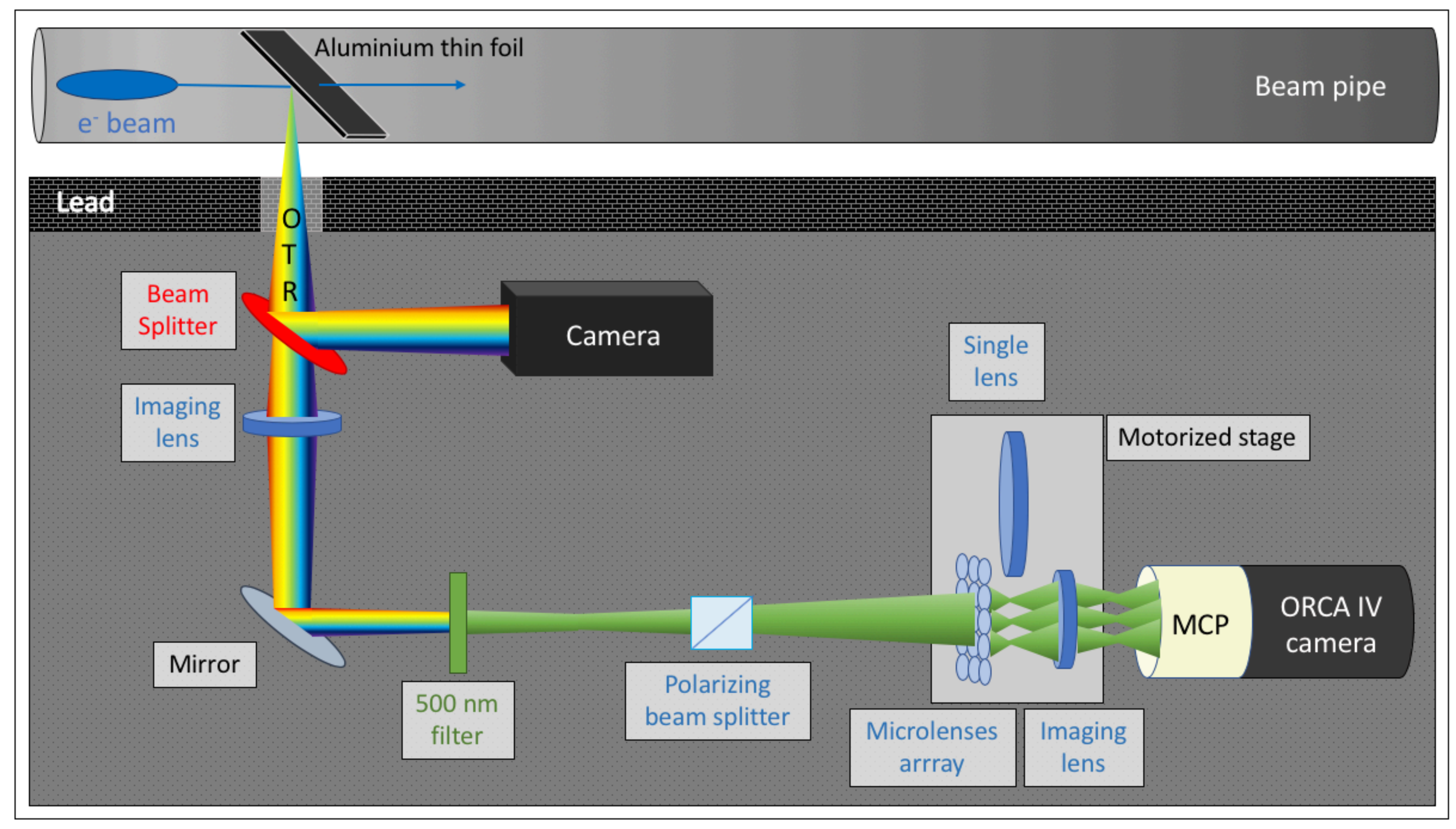
Goal and setup

The final goal is to measure the beam **emittance in single shot**, hence the knowledge of the beam spot, the beam divergence and correlation is needed, according to:

$$\varepsilon_{rms} = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle}$$

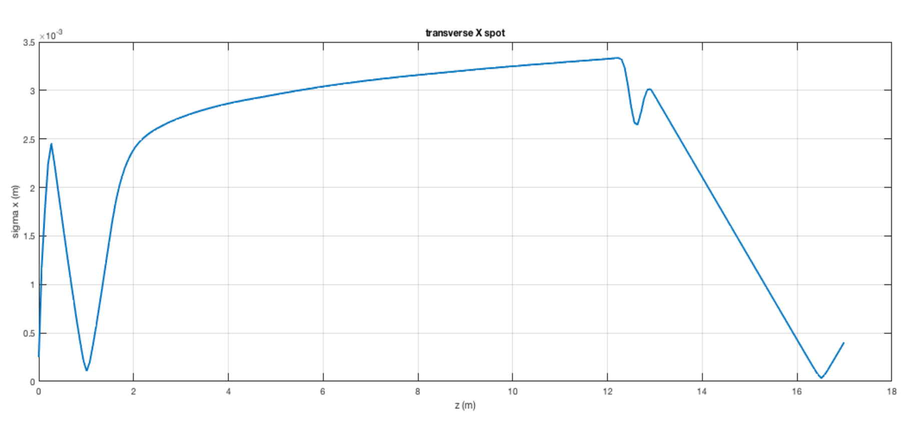
The OTR, by means of a Beam Splitter, provides the former and the light to extrapolate the latters. The filtered light passes through a microlenses array, creating an OTR pattern from which divergence and correlation are computed.

This work is a **proof of principle** to verify if it is possible to extrapolate the emittance value by means of this techinque.



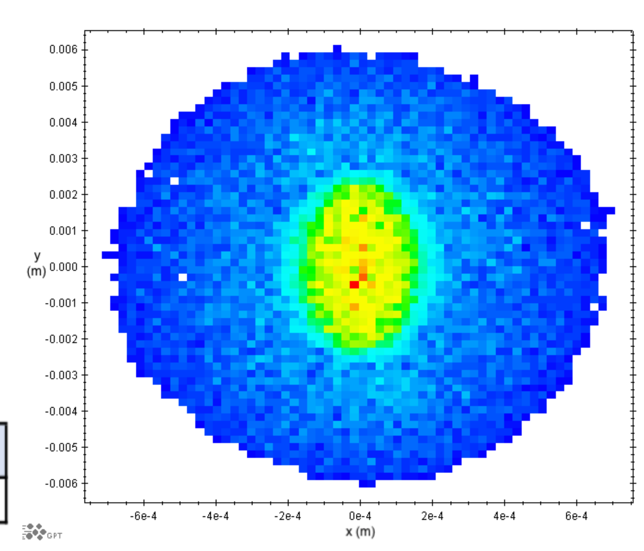
Simulations: GPT

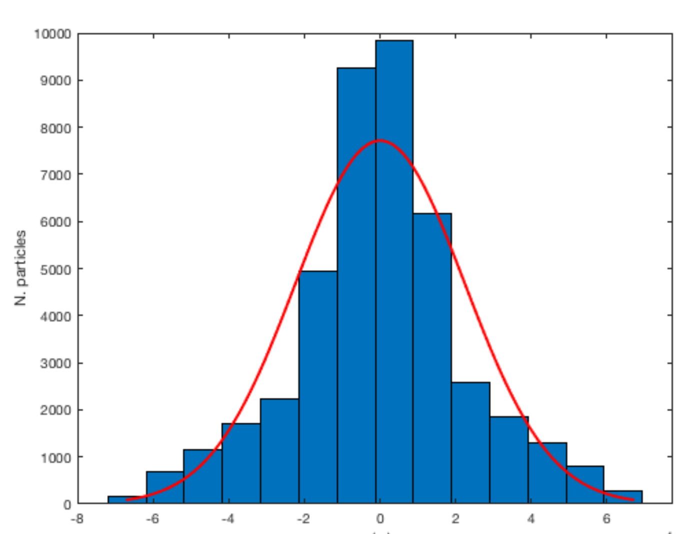
Since the proof of principle allows to use any working point of the beam generating OTR, a **configuration achievable in SPARC_LAB** was used: a totally characterized beam was simulated **start-to-end** on the **General Particle Tracer (GPT)** simulation tool, starting from the gun, up to the thin Aluminium foil, whereby the OTR starts to propagate. Since the polarized light let us to retrieve the emittance one transverse plane per time, in this simulation the x plane will be taken in account.



σ x (mm)	σ x' (mrad)	α x	β x (m)	$\mathcal{E}n$ x (mm mrad)	Energy (MeV)
0.25	0.77	-8.5	2.8	7.2	160

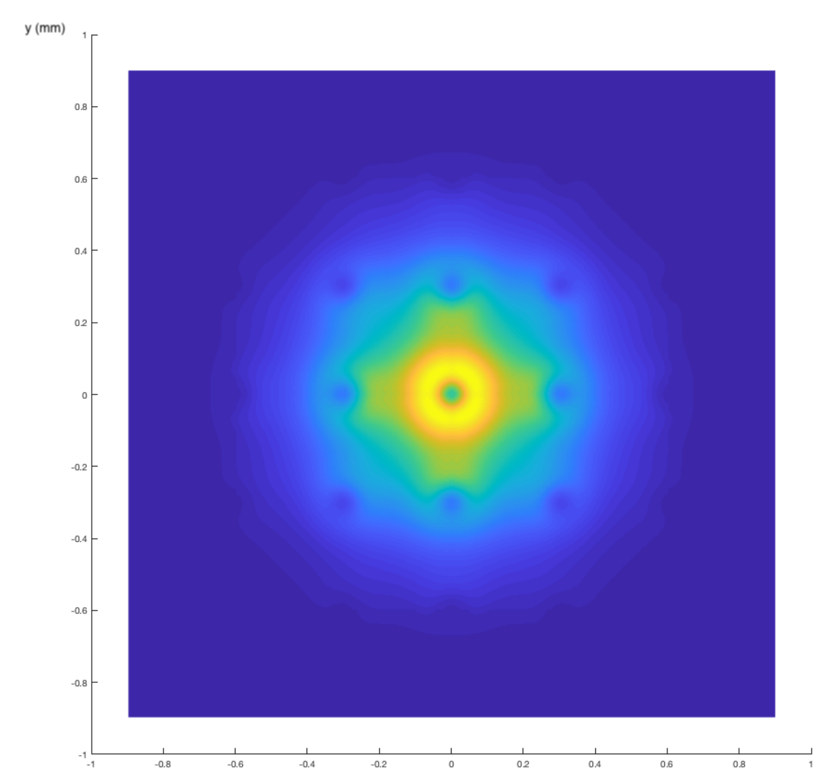
Transport inside SPARC linac and configuration at the end.


Beam spot at the end of linac

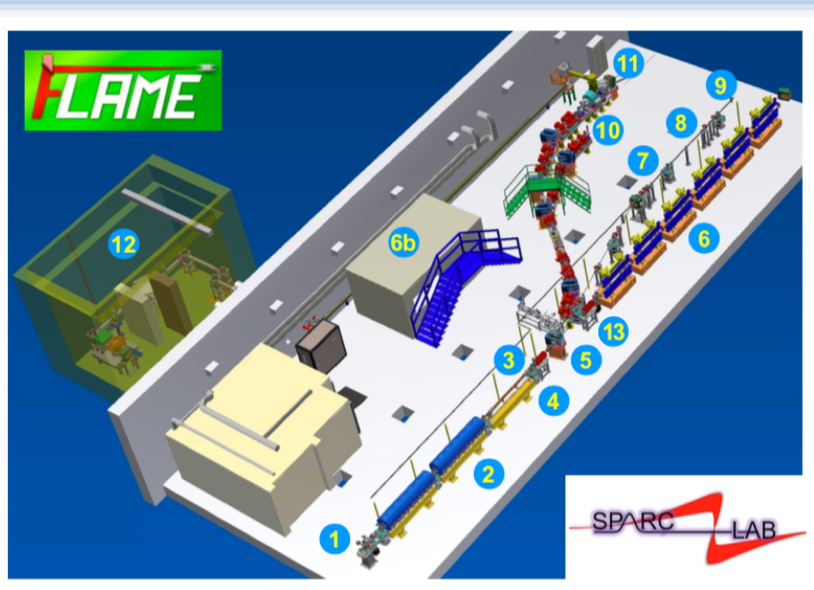

X profile of the spot.

Simulations: Zemax OpticStudio

The whole **optical setup** was simulated on **Zemax OpticStudio**: step by step the OTR, created by the simulated beam was transported through the optical elements to obtain the microlens OTR pattern and the polarized one. In the setup, the former lens allows to have the imaging of the beam spot light on the microlenses array, wheraeas the latter lead the focal plane of the microlenses to the Micro Channel Plate (MCP) and then to the camera.


OTR microlenses pattern

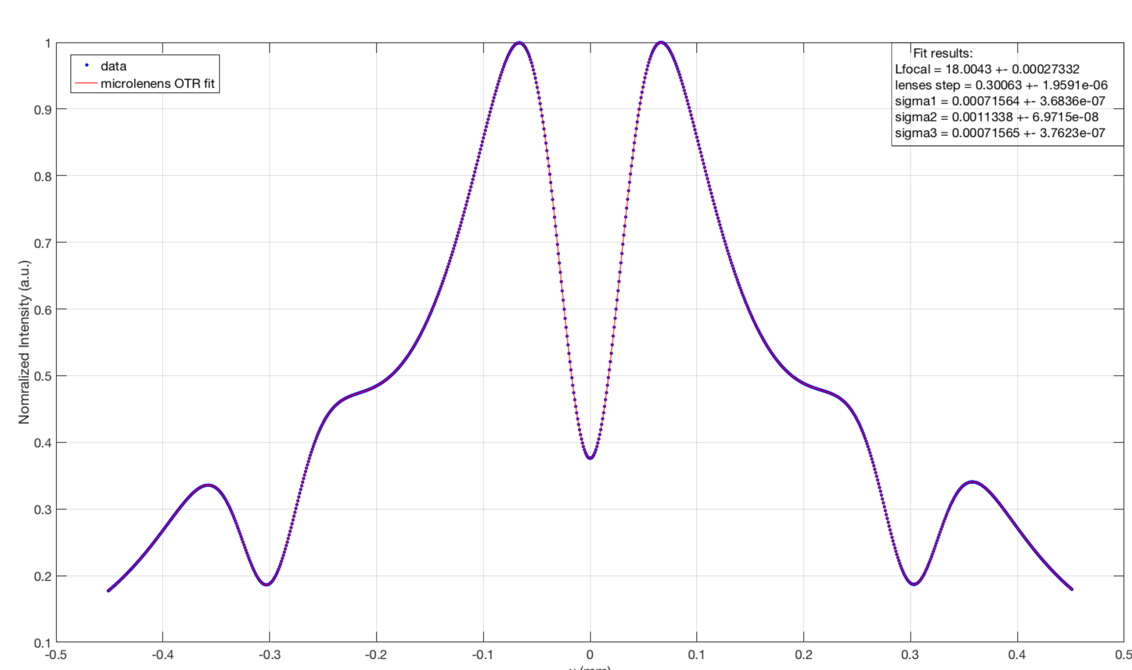
SPARC_LAB



SPARC_LAB (*Sources for Plasma Accelerators and Radiation Compton with Lasers And Beams*) is a test-facility based on the 180 MeV SPARC electron linac and the 300 TW FLAME laser system. Bunch with charge up to 1 nC are produced by a laser hitting on the photo-cathode of a RF-gun (1). After that, there are three accelerating sections (2) and a THz radiation source (3). A Plasma Wakefield Acceleration (PWFA) experiment is located upstream the THz station. Four beamlines follow the RF Deflector (4) and the main dipole (5). They are devoted to: Free Electron Laser (FEL, 6) both in SASE and seeded (6b) schemes; beam diagnostics (7) based on THz radiation (8) and Electro-Optical Sampling (9); Laser Wake-Field Acceleration (LWFA) by external injection (10); X-rays source by Thomson scattering (11) between the e-beam and the FLAME laser (12). Before the FEL (13) is located the optical table with the experimental setup of this single shot diagnostic measurement.

Test for angular distribution reconstruction

The working point is chosen to **reconstruct properly the angular distribution of the lenses**, to retrieve the divergences of each one, hence the correlation. The distribution comes from simulation, hence no background noise is considered.

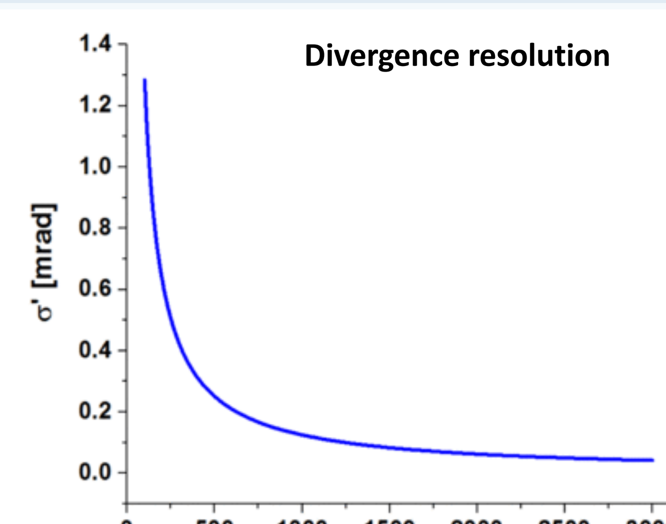


From the fit results the divergence of each lens is estrapolated; thus the quantities $\langle x'^2\rangle$ and $\langle xx'\rangle$ in the emittance formula can be computed. By means of the spot, obtained by the beam transport (by the camera, for what concern the experimental setup), the normalized emittance, retrieved by the algorithm, is:

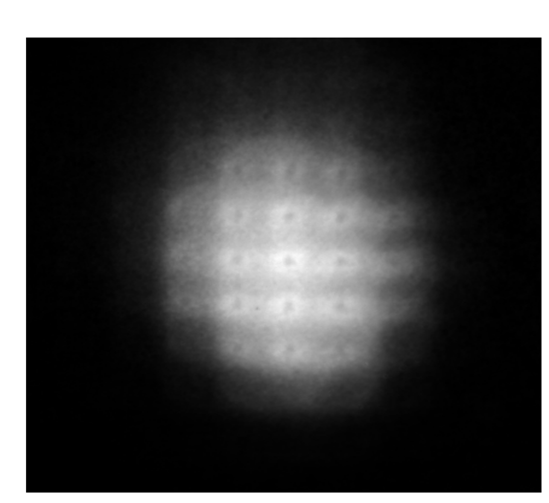
$$\varepsilon_{n,rms} = \langle\beta\gamma\rangle\,\varepsilon_{rms} = 7.196\ mm\ mrad\ \approx\ \varepsilon_{n,rms}{}^{(GPT)} = 7.2\ mm\ mrad\,.$$

The algorithm estimates an emittance value **in agreement** with the simulated one.

Divergence resolution



The **divergence resolution as function of energy** (i.e. relativistic γ) is shown in this plot. Since at SPARC_LAB the maximum beam energy is below 200 MeV, there is the need to have high divergence beam in the measurement point. Some **data** has been already acquired, as shown in next figure, but the divergence was $\sigma_{x'} \sim 0.1\ mrad$, below the resolution for beam with $E = 160\ MeV$.



References

- V. L. Ginzburg and I. M. Frank. "*Radiation of a uniformly moving electron due to its transition from one medium into another.*" Zh. Eksp. Teor. Fiz. 9 (1945): 353-362.
- A. Cianchi et al., "*Transverse emittance diagnostics for high brightness electron beams*", Nuclear Instruments and Methods in Physics Research Section A, 2016.
- F. G.Bisesto et al.,"*Zemax simulations describing collective effects in transition and diffraction radiation*", Optics Express, vol. 26, no. 4, p. 5075, 2018.
- M. Ferrario et al. "*SPARC_LAB present and future.*" Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 309 (2013): 183-188.

Conclusions and next steps

- The emittance value of the simulated beam is retrieved by the developed algorithm, that reconstructs well the angular distribution of the OTR passing through the microlenses.
- In the next month a new data acquisition campaign will be conducted, in order to reproduce the beam configuration of the simulation and acquire the related data.