ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-TUPA007

# STATUS OF A LOW-ENERGY ELECTRON TRANSVERSE MOMENTUM MEASUREMENT DEVICE (TRAMM) AT INFN LASA

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*Abstract*

To advance in the characterization of photocathodes for high brightness sources, the measurement of the thermal emittance plays a key role. The TRAnsverse Momentun Measurement device developed at INFN LASA will allow equipping our photocathode laboratory with an advance device able giving in quasi on-line feedback during the photocathode growth process. This paper reports on the status of the apparatus and its latest achievements.

## INTRODUCTION

In e+-e- colliders and Free Electron Lasers (FELs), the quality of the beam is often referred as the beam Brightness:

$$B = \frac{N_{part}}{A\Sigma} \approx \frac{I_{peak}}{\epsilon_x \epsilon_y} \tag{1}$$

where $I_{peak}$ is the beam peak current and $\epsilon_i$ the transverse beam emittances along the x-y transverse plane. For colliders, high average (and peak) Brightness translates into high Luminosity, which determines that more collisions take place at the interaction point. In Free Electron Lasers, low beam emittance (hence high brightness) is required to extract high peak power photon beams. Moreover, low thermal emittance is necessary to obtain hard X-ray radiation, since $\epsilon$ limits the minimum wavelength achievable.

Keeping into account the previous arguments, to obtain a high-Brightness electron beam one should consider minimizing the emittance of that beam. Generally, this quantity is the result of several contributions:

$$\epsilon = \sqrt{\epsilon_{RF}^2 + \epsilon_{sc}^2 + \epsilon_{rough}^2 + \epsilon_{unif}^2 + \epsilon_{th}^2 + ...} \tag{2}$$

the first terms are related to the RF field and to space charge effects. The following terms exist because the electron source (photocathode) exhibits a certain surface roughness and non-uniformity. The last term $\epsilon_{th}$, known as thermal emittance, is the intrinsic value of $\epsilon$ determined only by the material of the photocathode.

The thermal emittance is an unavoidable effect, and it represents the lower limit for the overall emittance of beam, according to the Liouville's theorem. This means that the emittance can only be degraded during the beam propagation and the lowest value achievable is that at the generation, $\epsilon_{th}$.

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## THERMAL EMITTANCE MEASUREMENT AT INFN LASA

Over the years, we have developed a robust and reliable deposition procedure and deposited more than 150 $Cs_2Te$ photocathodes, used as electron sources in high brightness injectors.

The developed process allows growing film with high Quantum Efficiency (QE - number of emitted electrons per impinging photon), low dark current, long lifetime. Nevertheless, we are still missing an on-line monitoring of the thermal emittance. This parameter, up to now, is measured only when the photocathode is used in an RF gun by standard techniques as quadrupole scan, slits or pepper pot. Nevertheless, the possibility of measuring the thermal emittance during the deposition of the photocathode will allow improving photocathode quality and, possible, develop new growing techniques.

For these reasons, based on the idea developed at Lawrence Berkeley National Lab (LBNL) [1], we designed [2,3] and assembled an instrument for transverse momentum measurements that we plan to finally installed as a standard diagnostic tool in our photocathode deposition systems.

## MEASUREMENT PRINCIPLE

As written before, the measurement of transverse emittance in beam lines is done mainly by using slits, pepper pots, solenoid or quadrupole scans to mention some of them. For low energy electrons, one idea is to measure the electron energy spectrum resolved in angle and then reconstruct, from these data, the beam diverge [4] or to exploit the conversion of the electron transverse velocity in a measurable displacement on a screen as done here.

The basic principle is as follows: photoemitted electrons by a light beam are accelerated by a grid that create a uniform electric field in the volume between the photocathode front surface and the grid itself. The electrons are accelerated to few keV in few hundreds of nanosecond [3].

The space between the grid and the electron detector is a free field region where the transverse momentum $p_x$ of the electrons determines the displacement of the electron position L from the center towards the side as given by the following expression

$$L = \frac{p_x}{mc}(2g + d)\sqrt{\frac{mc^2}{2eV}} \tag{3}$$

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where V is the accelerating voltage between photocathode and grid.

Figure 1 shows the main parameters of the TRAMM layout, in particular $d$ is the distance grid-detector and, g the distance photocathode-grid.

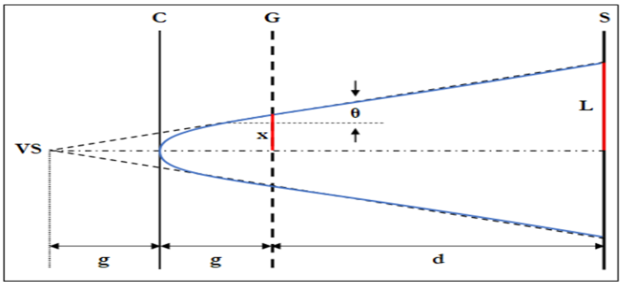


Figure 1: Schematics of the TRAMM experiment. Photocathode is placed at position C, grid in G and the front face of the electron multiplier at S.

The position of the electron after the free field region is measured by an electron multiplier (MCPs in our case) and a electron/light converter (phosphor) that allows the acquisition of the electron position by a proper image acquisition system.

At the end of all these operations, the transverse momentum of the emitted electrons is then given by

$$\epsilon_n = \sigma_{x,y}\sqrt{\frac{< p_{x,y}^2}{mc}} \tag{4}$$

where $\sigma_{x,y}$ is the r.m.s light spot size on the photocathode.

The design of TRAMM for the photocathode preparation systems we have at LASA needs to be compatible with the UHV conditions required to maintain the photoemissive properties of the photocathodes. The vacuum quality plays a crucial role not only during the deposition process, but also in preserving the film QE and also to limit a shortening of the photocathode lifetime. These considerations transform in proper choice of the materials installed in the system as well as in the proper choice of the vacuum pumping system. To satisfy the latter, a SAES NEXTorr™ pump that combines a Non Evaporable Getter (NEG) pump with a Sputter Ion Pump (SIP) that, besides the advantage to preserve the vacuum condition also in case of power failure, it provides the proper pumping speed and vacuum composition necessary to gaurantee the photocathode performances.

Another critical component is the illumination system that needs to produce a light spot on the cathode with minimal dimensions, to minimize the transverse momentum calculation error, while maintaining a sufficient light power to allow the emission of the necessary number of electrons for the detection system. To achieve these requirements, we have opted for the Eq-77 Laser Driven Light Source (LDLS™) from Energetiq with open output, coupled with off-axis parabolic mirrors to produce a stigmatic and μm size spot on the photocathode front surface, independent from the selected light wavelength.

## STATUS OF THE PROJECT

The project was initiated in the COVID time and we have suffered and we are suffering till now delays. The following sections report on the status of the different aspects of the project.

### *Mechanical and Vacuum Components*

All the mechanical components have been prepared and assembled. The last component we have prepared has been the Fine 1000 Copper grid that has been ”glued” while trying to keep it as straight as possible to maximize the uniformity of the electric field. The mechanics has been all checked in particular the operation of the manipulator necessary to bring the photocathode into TRAMM. This manipulator has a different operation principle with respect to the manipulator we usually used in our systems, In fact, in the TRAMM case the photocathode has to be left into TRAMM to allow high voltage polarization. Minor alignments and adjustments have been necessary to bring the system in operation.

### *Optical System*

At present, the optical system is the part of the TRAMM project that is more affected by the consequences of the COVID and later developments. Indeed, we have designed the system to include a monochromator that still needs to be delivered. This clearly has slowed down the development of this part. We have recently redesign partially the light beam line to allow some first experiments. In particular, we have work on bringing the light on the photocathode, through the grid, and studied the resulting effects.

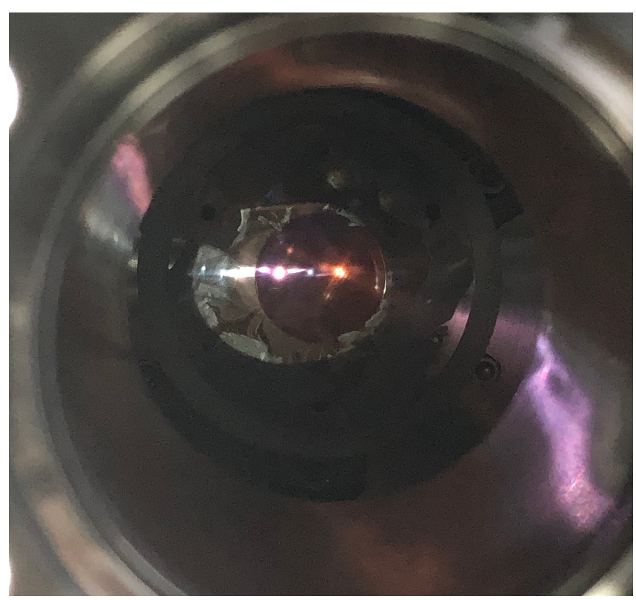

Figure 2: View on the grid from the MCP side. Visible on the grid are the three spots corresponding, from left to right, to incoming beam (bright), beam on photocathode (light blue) and reflected beam (orange).

Figure 2 shows the grid illuminated by the spot light as seen from the electron multiplier detector. On the grid,

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three spots are visible, corresponding respectively to the incoming beam, the small diffusion from the photocathode and the beam reflected from the photocathode. Being the photocathode mirror-like are visible also other reflections such as from the grid as fainter side orange spots.

We have made use of the light source and two optical mirrors to bring the light on the cathode. Two pinholes have been also used to clean the light beam from some side spots (see Fig. 3).

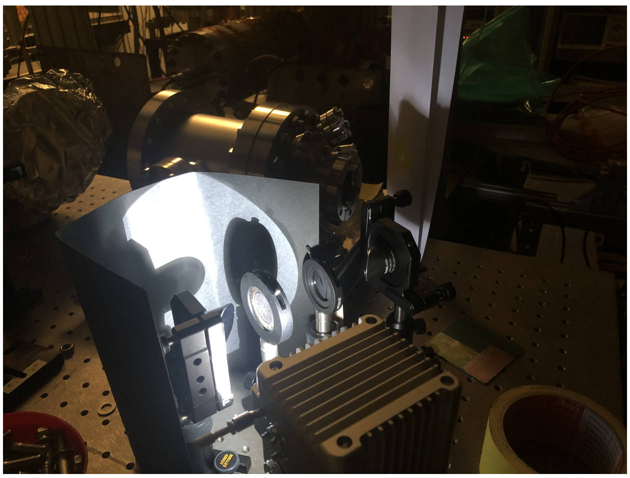

Figure 3: Top view of the layout we used for first measurement with light. Visible are LDLS light source, the two off-axis parabolic mirrors, apertures to clean the light beam and vacuum chamber. On the left, the paper screen used for reflected beam experiments.

The reflected beam will be used to align the light spot on the photocathode when the system will be in vacuum conditions. For these reasons, it is important to understand the behaviour and the pattern of the reflected beam and related the observed figure to the light spot size and alignment on the photocathode while the system is still in air.

Fig. 4 shows the observed pattern of the reflected beam. Interesting to note are the many small spots visible. The are presented only when the photocathode plug is located in the position to be measured in TRAMM system (front plug polished surface in C position, as sketched in Fig. 1), meaning that they are a usable parameter for the alignment. We interpret the number of spots as a measurement of the light beam size on the grid, being the spots representative of the hole present in the grid. Remembering that the grid is a 1000 grid (i. e. the holes in the grid are typically 10 µm to 20 µm in size and are spaced about 20 µm to 30 µm apart).

### *Electron Detection and Acquisition System*

The electrons coming from the photocathode will be amplified by a pair of Micro Channel Plates (MCPs) and the signal then converted into visible light by a phosphor screen by a Hamamtsu UHV compatible detector assembly. A CCD camera with proper optics will acquire the image. This image will be then process by a dedicated software based on LabVIEW to calculate the dimension of the beam and, from

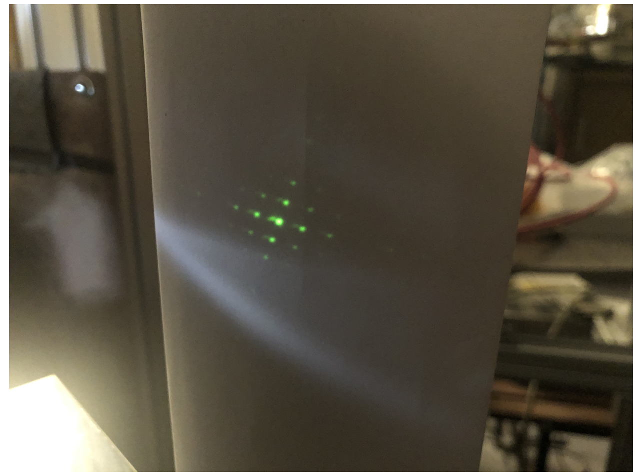

Figure 4: Light pattern measured at $\lambda$ = 543 nm after the beam passed through the grid, it was reflected from the mirror-like front face of the plug and passed the second time the grid. The number of spots is used to evaluate the light spot size. This pattern is not present if the photocathode is not in its proper position.

that, the size of the beam. As said before, to avoid further deconvolution processing in case of a significant electron source dimension, we try to keep the spot on the cathode as small as reasonable achievable. The size of the beam and its distribution is the input for the reconstruction routine we are developing to get finally the beam transverse momentum.

## CONCLUSION

The measurement of the thermal emittance in photocathodes is becoming a key parameter to characterize them. The availability of a device to be used during production opens the possibility to use it to better tailor the photocathode growing process by using it as a feedback parameter.

At INFN LASA we are developing TRAMM to perform such kind of photocathode characterization. The project has been delayed due to COVID and its following consequences. Nonetheless, we are slowly progressing in all the components of the project and we expect to have first measurements from metal surface by Summer 2023.

## ACKNOWLEDGEMENTS

We acknowledge the support of the INFN ”Commissione Scientifica Nazionale 5”.

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