

FRASCATI BEAM-TEST FACILITY (BTF) HIGH RESOLUTION BEAM SPOT DIAGNOSTICS

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Abstract

The DAFNE Beam Test Facility (BTF) is operational in Frascati since 2003, hosting tens of experimental groups for an average of more than 200 beam-days each year. In the last years the beam diagnostics tools have been completely renewed and the services for the users have been largely improved.

We describe here the new transverse beam diagnostics based on GEM compact time projection chambers (TPC) and MEDIPIX Silicon pixel detectors, the upgraded data acquisition and the data caching system based on MEMCACHED, allowing a straight-forward integration of existing and new sub-systems in the renewed data logging. Results on the optimization of the transverse beam spot and divergence are reported, as well as the real-time diagnostics and feed-back user experience.

INTRODUCTION

The beam parameters of the Beam Test Facility, operational at the Frascati laboratories since 2004 [1], cover a wide range in terms of intensity (from 10^{10} particles/pulse down to the single particle regime) and energy (from 30 to 750 MeV), while the transverse beam spot can be adjusted with beam-line optics and collimators [2].

This requires a high-resolution, efficient, robust, reliable, fast, easily manageable transverse diagnostics detector, with online readout capability in order to be effective in the beam setup phases. As additional requirement, the thickness of the detector should be kept at an acceptable level in order not to spoil the beam spot or alternatively the detector should be easily removable from the beam-line.

TRANSVERSE DIAGNOSTICS

The transverse diagnostics of the BTF beam is an essential tool for the users, especially for detector characterization and calibration purposes.

We have developed both a very light diagnostics, based on micro-pattern gas detectors, namely a compact time-projection chamber (TPC) based on a triple Gas Electron Multiplier (GEM), and a thicker, but higher resolution system based on Silicon pixel detectors with integrated readout.

The two different systems have different limitations and advantages, so that we can choose the best solution depending on the beam parameter required by the users.

GEM TPC

In the framework of the AIDA EU project a triple-GEM TPC has been developed, with the idea of having a very compact and light device, capable of reconstructing in 3D the particle tracks, even though with different resolutions in the three coordinates: if the beam passes in the drift space between the cathode and the first GEM foil, one of the two transverse coordinates will correspond to the drift direction, so that the time of arrival measurement will allow reaching a resolution of the order of 100 μm (limited by the longitudinal diffusion in the drift gap). In our case we have chosen a 4 cm drift length and a standard Ar-CO₂-CF₄ mixture. The other two coordinates are measured by the 128 pads, $3 \times 6 \text{ mm}^2$ over an active area of $50 \times 50 \text{ mm}^2$, smaller with respect to the GEM foils, cathode and anode planes, with standard dimensions $100 \times 100 \text{ mm}^2$, in order to avoid the effect of electric field lines distortion at the edges, even though we have introduced a thin kapton foil with Copper surface all around the drift space as Faraday-cage for a better shaping of the field.

A FPGA allows to easily readout the 128 pad times and quickly transfer the data via Ethernet interface. The online display of the GEM TPC acquired beam profiles is shown in Fig. 1.

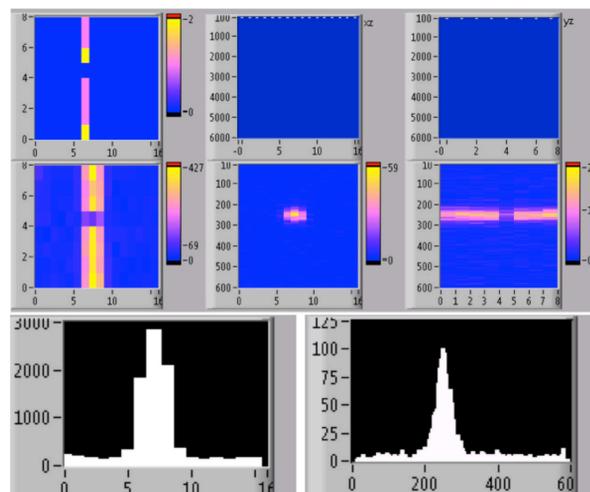


Figure 1: 477 MeV electron beam imaged by the GEM TPC; online display of the six planes view (top) and the two transverse projections (bottom).

FitPIX Silicon Pixel Detectors

In order to achieve a better resolution in both the transverse coordinates, we have implemented MEDIPIX-like Silicon pixel detector with WIDEPPIX FitPIX[®] Kit electronic.

The FitPIX is a 300 μm thick Silicon detector with 256×256 , 55 μm pitch pixels, for an active area of approximately $14 \times 14 \text{ mm}^2$. The readout is performed with USB interface; we have used the standard PIX-ETPRO software but we have also developed a suite of custom software packages, in order to reach the maximum readout speed of about 80 frames/s, so that we can real-time read and reconstruct beam profiles at the full 50 Hz rate of the BTF beam.

Moreover, in order to have a completely arbitrary access to live data at the maximum frame-rate, we have implemented a new software architecture with a typical producer-consumer layout, implementing data caching on MEMCACHED server, to allow more than one different consumers at the same time. A more detailed description of the hardware and software of our custom implementation is given in [3].

An example of real-time acquisition and display (using a custom LabVIEW interface) of FitPIX detectors, retrieving data at the full 49 Hz rate, is shown in Fig. 2 for a typical BTF beam (intermediate intensity, 450 MeV electrons, approximately 1% momentum spread, about $\sigma_y=0.5 \text{ mm}$ spot, almost flat horizontal distribution) is shown in Fig. 2.

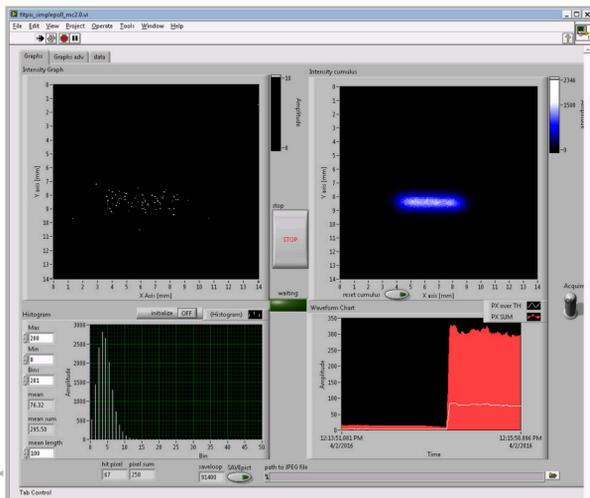


Figure 2: Example of real-time display with a LabVIEW interface of a FitPIX with a typical 450 MeV, intermediate “single electron” beam. Top: on the left a single frame is displayed, while on the right the cumulative beam spot distribution is shown; bottom: the multiplicity distribution and the pulse-by-pulse particle count are displayed.

Up to three FitPIX devices are routinely used in the facility (as shown in Fig. 3), in general the up-stream one is permanently mounted on a linear stage, remotely controlled, in order to be easily moved in and out of the beam for a quick feedback to the users.

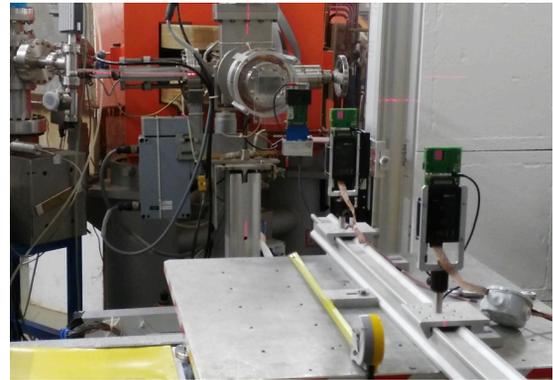


Figure 3: Three FitPIX detectors mounted on the BTF beam line for the transverse spot characterization and tracking tests.

The development of the track reconstruction software with multiple FitPIX detectors is under way, in order to realize an easily manageable Silicon pixel tracking system, even though with the limitation of a significant multiple scattering effect due to the not negligible amount of material (at least 1 mm of Silicon plus approximately 1 m of air), as described in the following section.

BEAM SPOT CHARACTERIZATION AND OPTIMIZATION

We have performed a number of studies of transverse beam spot in a wide range of beam parameters, e.g. at different selected energies and by optimizing the beam-line optics according to different requirements: “pencil” beam, e.g. the smallest possible spot; low-divergence; round beam; highest possible uniformity “flat” beam, very elongated aspect-ratio “knife” beam; etc.

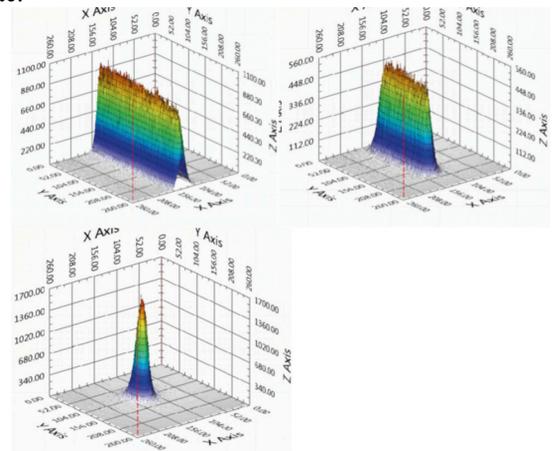


Figure 4: FitPIX display of 450 MeV electron beam for different beam energy spread, translating in different horizontal beam sizes due to the dispersion introduced by the last transport dipole in the BTF line.

As an example, in Fig. 4 the effect of the dispersion introduced by the last BTF line dipole on the beam size is shown: a larger momentum spread of the beam (due to different settings in the collimator system [1]) translates in a larger beam spot in the bending coordinate (in this case the horizontal one). This effect is very easily

and precisely measured by means of the FitPIX diagnostics.

Thanks to our custom software, we have the possibility of reconstructing the beam profiles on a pulse by pulse basis, running the FitPIX acquisition at full frame rate and storing the live data on the MEMCACHED system. With a simple LabVIEW interface we can display in real-time the main spot parameters (average position, size, etc.), as shown in Fig. 5.

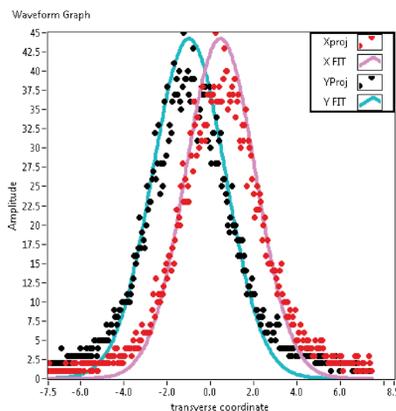


Figure 5: Real-time reconstructed transverse profiles and Gaussian fit for a 100 MeV electron beam.

With high-statistics data acquisition we can also study the tails of the electron or positron beam, in the different configuration, this is particularly relevant for instance for the PADME experiment [4-5], demanding a small spot (<1 mm), low divergence beam (<1 mrad), with the lowest possible halo. As an example, in Fig. 6 the distribution of an optimized beam, 700 MeV electrons, is shown (in logarithmic scale), showing the effect of a lower energy tail on one side in the bending coordinate.

The most important contribution to the beam size and divergence is the multiple scattering on the 0.5 mm thick Beryllium window at the exit of the BTF vacuum beam-pipe. This can be seen measuring the beam spot at different beam energies, given that we can keep

constant the beam momentum spread, in order not to change the horizontal size due to the effect of the last dipole dispersion described above.

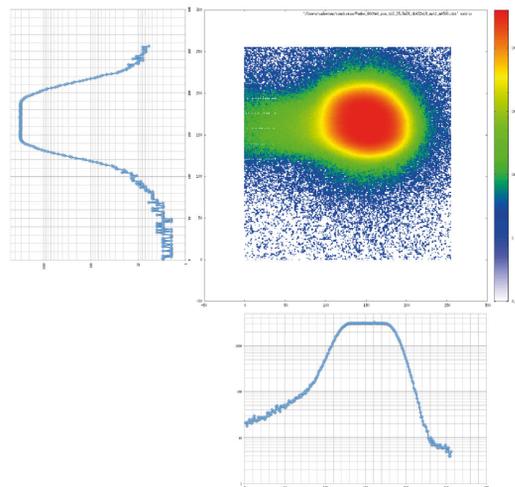


Figure 6: High statistics image of a 700 MeV electron beam in the transverse coordinates (logarithmic scale).

The 2D beam spots with horizontal (x) and vertical (y) profiles with Gaussian fits at 30, 60, 90, 120 and 150 MeV electron energies are shown in Fig. 7, while in Fig. 8 we show the fitted transverse size $\sigma = \sqrt{\sigma_x^2 + \sigma_y^2}$, as a function of the momentum, together with the calculation of the multiple scattering contribution due to the Be window material only.

Low energy beams are also required for electron irradiation, with the additional requirement of keeping an uniform intensity (within 10%) over a large (order of few cm²) area. Even though a single FitPIX active area is limited to 2 cm², thanks to the full efficiency we can obtain real-time maps of the irradiation field, as shown in Fig. 9, where a 1.7×10^6 electrons/s, 50 MeV beam is shown in a $\pm 25\%$ intensity range.

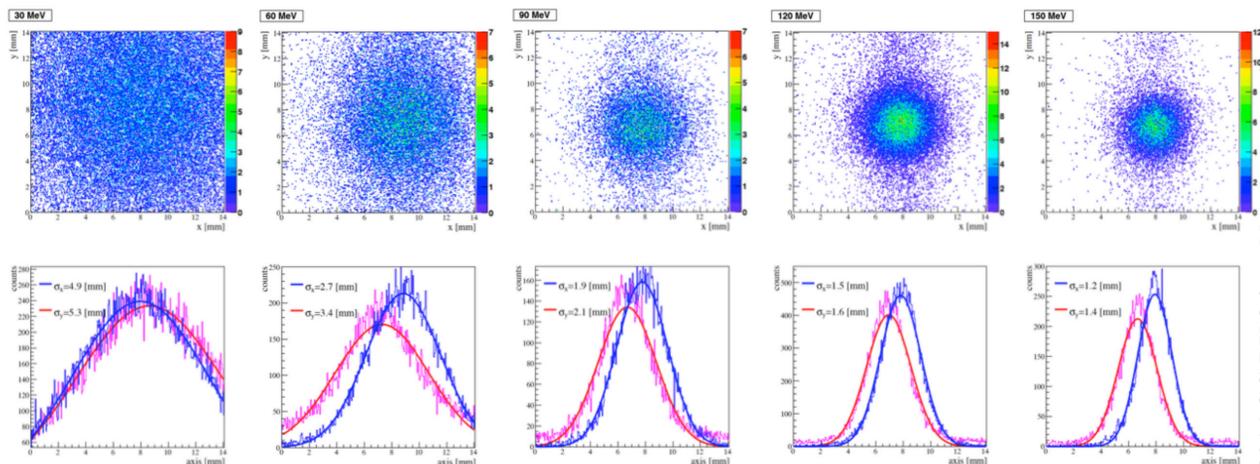


Figure 7: Beam transverse spot imaged by a FitPIX detector at different beam energies, from left to right 30, 60, 90, 120 and 150 MeV electrons (online display).

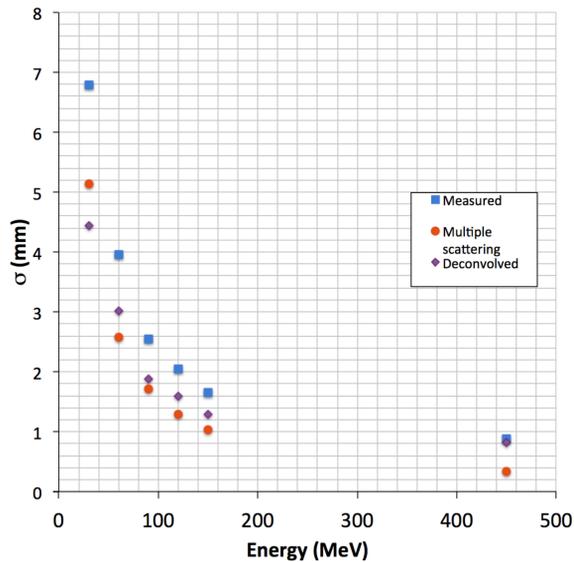


Figure 8: Measured beam transverse size $\sigma = \sqrt{(\sigma_x^2 + \sigma_y^2)}$ as a function of the electron beam energy. The computed contribution of the multiple scattering on the Beryllium window is also shown.

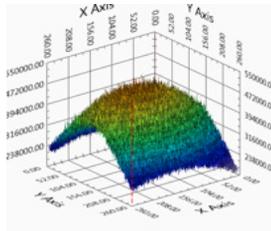


Figure 9: Beam distribution of 50 MeV electrons, 3.5×10^3 /pulse, during a test BTF irradiation run.

CONCLUSIONS

The transverse beam spot diagnostics developed in the last years is a fundamental tool for characterizing and optimizing the BTF beam, and for quickly responding to the users requirements in terms of beam spot size, position, divergence, etc. The constant improvement of both the detectors hardware and software now allow us a reliable, real-time, full-speed readout of multiple FitPIX devices.

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REFERENCES

- [1] G. Mazzitelli, A. Ghigo, F. Sannibale, P. Valente and G. Vignola, *Nucl. Instrum. Meth. A* 515 (2003) 524-542.
- [2] B. Buonomo, C. Di Giulio, L. G. Foggetta and P. Valente, "The Frascati LINAC Beam-Test Facility (BTF) Performance and Upgrades", Proceedings of IBIC 2016, Barcelona, Spain, TUPG29.
- [3] B. Buonomo, C. Di Giulio, L. G. Foggetta and P. Valente, "A Hardware and Software Overview on the New BTF Transverse Profile Monitor", Proceedings of IBIC 2016, Barcelona, Spain, WEPG73.
- [4] M. Raggi and V. Kozhuharov, *Adv. High Energy Phys.* 2014 (2014) 959802.
- [5] M. Raggi, V. Kozhuharov and P. Valente, *EPJ Web Conf.* 96, 01025 (2015).