METU-DEFOCUSING BEAM LINE PROJECT AND BEAM OPTICS STUDIES

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ABSTRACT

METU-Defocusing Beam Line (METU-DBL) project aims to perform Single Event Effect (SEE) tests for space, nuclear and medical applications. Turkish Atomic Energy Authority (TAEA) has a 30MeV proton cyclotron at Proton Accelerator Facility (PAF) mainly for radioisotope production and an R&D room for other applications. The proton beam current is variable between 0.1μA to 1.2mA and the beam size is small. METU-DBL, which is being installed in the R&D room, will enlarge the beam size with three quadrupole magnets and reduce the proton flux with scattering foils and collimators in order to have a suitable irradiation area according to ESA ESCC No. 25100 standard. The beam optics studies and particle tracking studies have been performed and will be presented here. Also, the beam parameters have been measured with a beam viewer in the R&D room and the results will be reported. Construction of the METU-DBL preliminary test setup, with two quadrupole magnets, a collimator and a long flight path to allow the beam to blow up, as well as supporting sub-systems, has been completed and the first tests will be performed in October 2017.

KEYWORDS
Beam Line Design, Single Event Effects, Radiation Tests, Beam Optics

1. INTRODUCTION

Spacecraft are exposed to space radiation including cosmic rays, solar particles and trapped particles along their orbits. These particles can damage their electronic cards, vital components or materials by interacting with three different ways; Total Ionizing Dose (TID), Single Event Effect (SEE) and Displacement Damage (DD). Radiation tests of these critical components must be performed before launch. Currently, TID tests can be performed by using Co-60 gamma source in Turkey; however, SEE and DD can not be.

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A cyclotron procured from IBA Company was inaugurated in May 2012 by Turkish Atomic Energy Agency. This cyclotron at Proton Accelerator Facility (PAF) of TAEA can produce protons with 15 to 30 MeV kinetic energy. This facility has four rooms; three of them are reserved for radioisotope production and one is for R&D projects. The 2-D drawing of the R&D room and the adjacent R&D Laboratory can be seen in Figure 1.

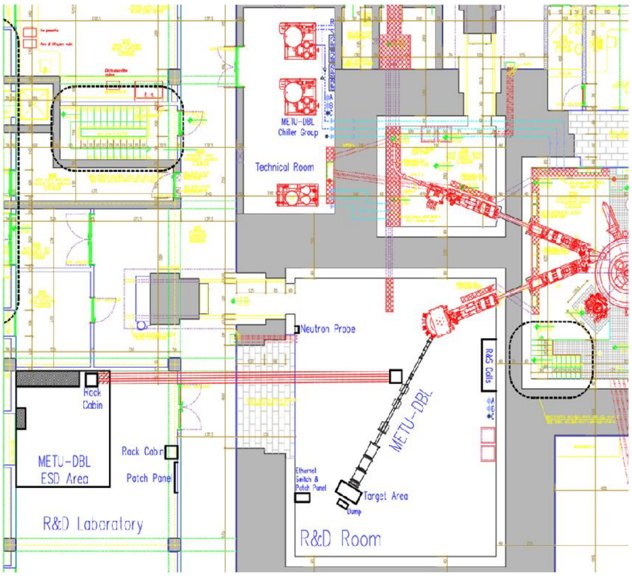

Figure 1. 2-D Drawing of R&D room and the adjacent R&D Laboratory in the TAEA SANAEM PAF. This facility has a 30 MeV cyclotron and four rooms; three of them are reserved for isotope production and one is for R&D projects.

In the facility, the proton beam current is variable between 0.1μA to 1.2mA and beam size in the R&D room is nearly 1mm in both axes. The irradiation conditions of the facility is given in Table I [1].

Table I. Irradiation Conditions according to TAEK SANAEM PAF Properties [1]

Beam Parameters	Value
The energy range	15 - 30 MeV
The beam current	0.1μA - 1.2 mA
The beam size	1 mm × 1 mm

The aim of the METU- DBL project is to realize some types of SEE tests in the R&D room of TAEA SANAEM PAF by using protons of kinetic energy between 15 to 30 MeV. For this project, ESA/SCC No: 25100 standard Single Event Effects Test Method and Guidelines has being followed and the requirements of this standard are given in Table II [2]. To satisfy the requirements, the available maximum kinetic energy 30 MeV and the minimum stable current 1μA has been studied in detail for performing SEE tests. 30 MeV is in the desired range; however, beam size is very small and beam current is very high at the desired target area. Thus, METU-DBL must enlarge the beam size and decrease the beam flux.

Table II. Irradiation Conditions according to ESA/SCC No: 25100 standard Single Event Effects Test Method and Guidelines [2]

Beam Parameters	Range
The energy range	20 - 200 MeV
The flux range	10^5 p/cm^2/s to at least 10^8 p/cm^2/s
The beam size at target position	15.40 cm × 21.55 cm
The uniformity of beam at target position	±10%
The fluence	10^{11} p/cm^2 for one test

2.1. METU-DBL Project

METU-DBL project will perform a limited range of SEE tests in the R&D room of TAEA SANAEM PAF. This project, supported by the Ministry of Development was initiated in August 2015. Currently, four quadrupole magnets and a beam screen are available on the beamline that leads from the cyclotron to the R&D room. Procurement of a 5-port switching magnet to allow for 5 different experiments to be installed in the R& D room has been started and this magnet will arrive in March 2018. To make maximal use of the time until that date, a pretest setup has been installed and will be uninstalled before March 2018.. METU-DBL which is an 8m long beam line, will follow after the end of this 5-port magnet. METU-DBL has three quadrupole magnets to enlarge the beam size and some collimators with different apertures to reduce the number of particles. Also, it has two titanium foils to scatter the particles to obtain the required uniformity at target area and a helium section between these foils to cool them.

2.1.1. METU-DBL Final Design

METU-DBL design satisfying all requirements of the ESA ESCC-25100 standard can be found in Figure 2. At the end of the 5-port switching magnet, a beam stopper and a vacuum valve will be placed in the first drift distance. The beam stopper will be used for protecting the system from functional faults of the accelerator. The vacuum valve separates the vacuum systems of TAEA PAF and METU to prevent a local loss of vacuum to traverse the full beamline. Then, two titanium foils are used to scatter the beam and then to obtain a uniform beam distribution at the target area. A helium section is located between these foils to cool them and to further separate the vacuum systems of TAEA PAF and METU. A conic collimator with variable conic apertures ranging from 1mm to 9 mm is used to reduce the flux and to provide different fluxes at the target area for different needs of users. A second collimator with 10 mm square aperture is placed to protect the ensuing quadrupole magnets from particles scattered by the collimator. Then, three quadrupole magnet are used to expand the beam to the desired size, 15.40 cm × 21.55 cm. Two of them were commercially procured from Scanditronix. The last is under construction at the Sönmez Transformer Company in Turkey and will be tested at CERN. Finally, the last collimator shapes the beam for the target area to the desired beam area. A titanium window separates the vacuum of the beamline from the air outside. According to the ESA-ESCC 25100 standard, SEE tests must be performed in air. After the target area, a dump system consisting of aluminum and graphite stops the beam after irradiation and prevents creating extra dose in the R&D room.

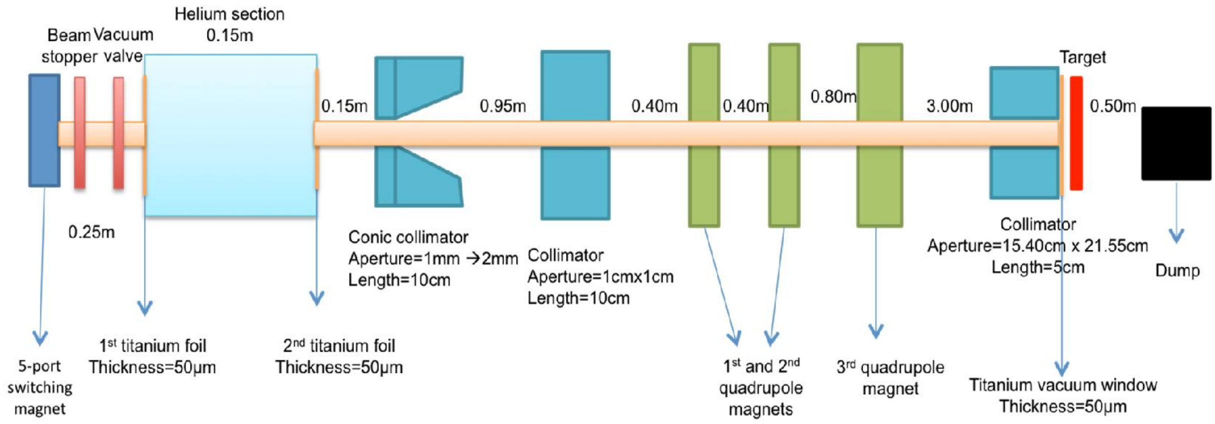

Figure 2. Schematic of METU-DBL Design Satisfying All Requirements of the ESA ESCC-25100 Standard. The beam stopper will be used for protecting the system from functional faults of the accelerator. The vacuum valve separates the vacuum systems of TAEA PAF and METU to prevent a local loss of vacuum to traverse the full beamline. Two titanium foils are used to scatter the beam and then to obtain a uniform beam distribution at the target area. A helium section is located between these foils to cool them and to further separate the vacuum systems of TAEA PAF and METU. A conic collimator with variable conic apertures ranging from 1mm to 9 mm is used to reduce the flux and to provide different fluxes at the target area for different needs of users. A second collimator with 10 mm square aperture is placed to protect the ensuing quadrupole magnets from particles scattered by the collimator. Then, three quadrupole magnets are used to expand the beam to the desired size, 15.40 cm × 21.55 cm. the last collimator shapes the beam for the target area to the desired beam area. A titanium window separates the vacuum of the beamline from the air outside.

METU-DBL has been simulated in detail using G4Beamline and TURTLE. Both programs give consistent results which demonstrate that at the target area of METU-DBL, all requirements of ESA ESCC No. 25100 standard are satisfied. The final kinetic energy is 29.1 ± 0.2 MeV and the final flux is 1.5×10^5 p/cm^2/s by using theconic collimator with 1mm to 2mm conic aperture. Also, the uniformity of the beam in x is 4.6% and in y in 7.5% which are less than 10%. In addition, the desired beam area is obtained at the target area, seen in Figure 3.

2.1.2. METU-DBL Preliminary Design

Before the arrival of the 5-port switching magnet in March 2018, pre-tests of METU-DBL and its supporting sub-systems will be performed using a METU-DBL preliminary setup. This setup has been constructed out of already available beam elements to gain some practical and technical experience and to test some components even though the requirements may not be satisfied at the end of this setup. Two commercial quadrupole magnets were procured from Scanditronix. A collimator and some parts of beam pipes was also produced by Turkish companies, as well as the cooling and vacuum sub-systems.

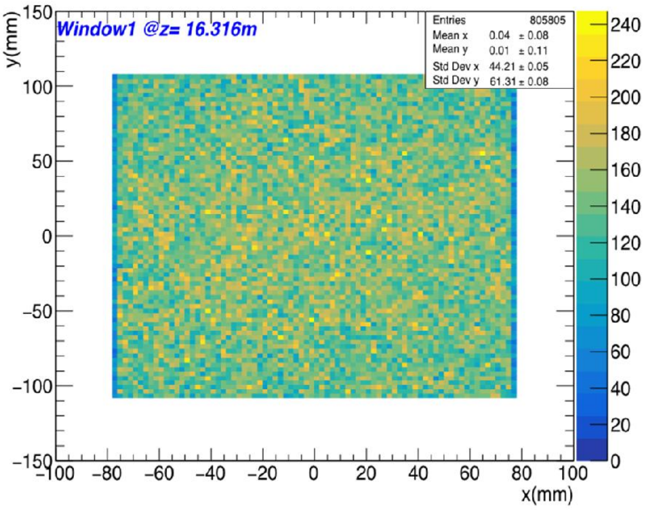

Figure 3. METU-DBL Final Beam Distribution at the Target Area as obtained from TURTLE. This area is 15.40 cm × 21.55 cm which is the required beam size according to the ESA ESCC No. 25100 standard. Its uniformity in x is 4.6% and in y is 7.5% which are less than the allowed 10%. Also, the final kinetic energy is 29.1 ± 0.2 MeV and the final flux is 1.5 x 10^5 p/cm^2/s by using the conic collimator with 1mm to 2mm aperture.

In addition, a test and measurement table was produced to hold and move samples and particle dedectors in and out of the target area. A 3-D drawing of METU-DBL preliminary setup including all available beam elements can be seen in Figure 4.

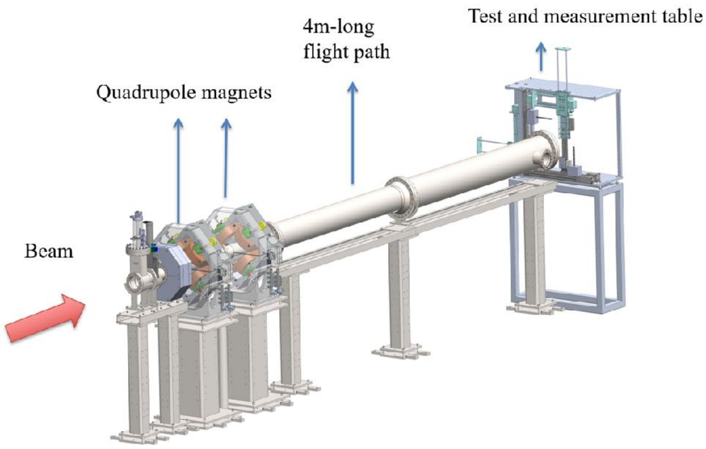

Figure 4. 3-D Drawing of METU-DBL Preliminary Design. It has two commercial quadrupole magnets from Scanditronix and a collimator to protect them. After a 4m-long flight path, the test and measurement table is located at the end of the beam line.

At the end of METU-DBL preliminary setup, while not all of the requirements of the ESA ESCC No. 25100 standard are satisfied, a uniform beam area, 8 cm × 6 cm at the center can still be obtained and the final area can be seen in Figure 5. The final kinetic energy is 29.7 ± 0.3 MeV and also the flux is 3.4 x 10^9 p/cm^2/s, which is already interesting for some users.

The construction of METU-DBL preliminary setup was completed in July 2017. The cooling system of METU-DBL was installed in the cooling room of TAEA PAF, as seen in Figure 6. The cooling water of METU-DBL comes from the main chiller of TAEA PAF. The cooling system of METU-DBL includes two heat exchangers, two pumps, a water tank and a resin tube to filter radioactive elements.

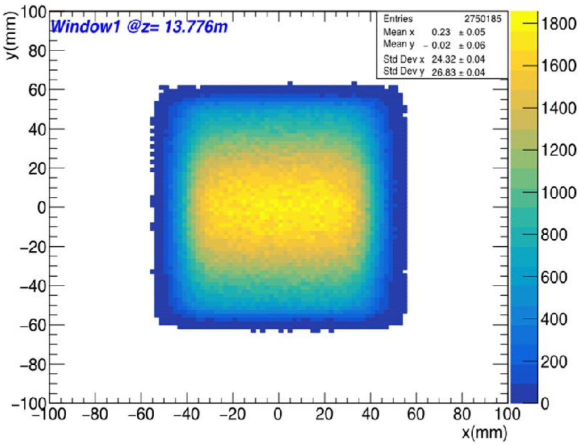

Figure 5. Final Beam Distribution at the Target Area METU-DBL Preliminary Design from TURTLE. It has a 8 cm × 6 cm uniform area. The final kinetic energy is 29.7 ± 0.3 MeV and also the flux is 3.4 x 10^9 p/cm^2/s.

The vacuum system of METU-DBL was also constructed and tested. The current vacuum level of the METU-DBL pretest setup is 10^{-5} torr. Both the cooling and the vacuum systems have been proportioned according to the final METU-DBL setup and experience gained during the pre-test phase is important for the commissioning of the full system.

Figure 6. Cooling System of METU-DBL in the Cooling room of TAEA PAF. The cooling water of METU-DBL comes from the main chiller of TAEA PAF. The cooling system of METU-DBL includes two heat exchangers, two pumps, a water tank and a resin tube.

The construction and installation of the METU-DBL preliminary setup in R&D room at TAEK SANAEM PAF was finished, seen in Figure 7.

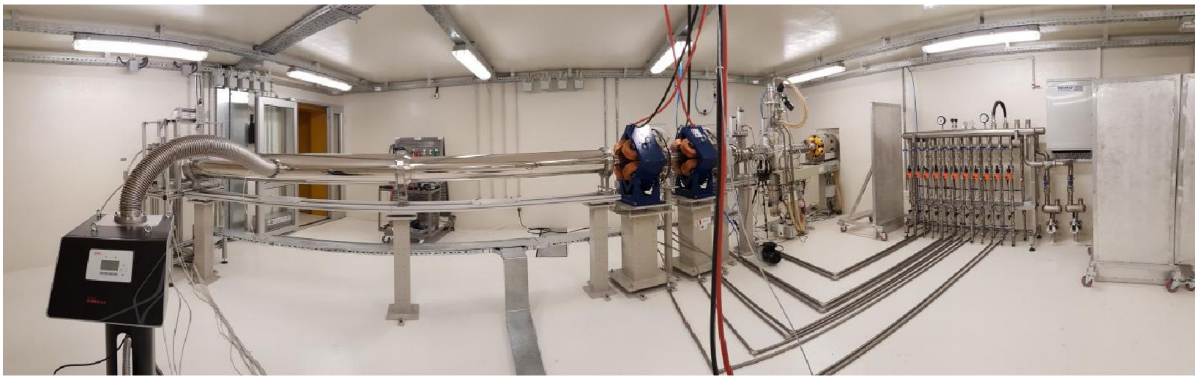

Figure 7. METU-DBL Preliminary Setup as installed in the R&D room at TAEK SANAEM PAF. Two blue quadrupole magnets are followed by a 4m long flight path. The cooling water is distributed from the station on the left wall, while the power of the magnets are distributed from a ceiling tray. The vacuum system can be seen on the far left.

2.1.3. Beam Measurement Studies

All simulations for METU-DBL have performed for a given initial parameters. Beam measurements were performed with an existing Al_20_3 screen which can be moved in and out of the beamline and a sensitive CCD camera procured by the METU-DBL project to verify them. However, the centre of the existing beam screen was burnt due to high use and measurements could only be performed a not damaged part of the screen as seen in Figure 8. Quadrupole Scan Method [3] was employed to obtain beam parameters at the measurement position. The magnetic field of last quadrupole before the screen was changed systematically in steps and beam size in x and y was measured from the screen at each magnetic field setting. The x and y profiles of the beam as seen from the camera and fitted Gaussians to extract the width of the beam is shown in Figure 9.

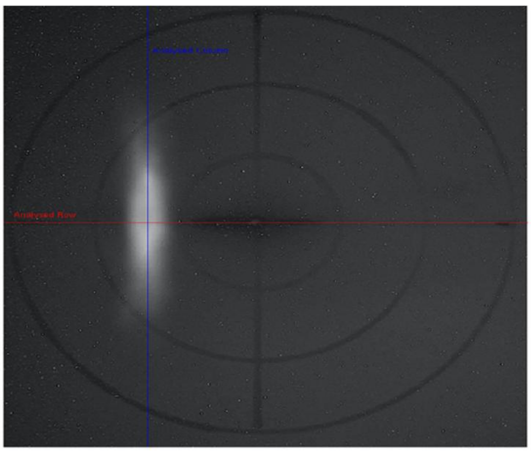

Figure 8. Beam Hitting the existing Al_20_3 screen in the beamline leading to the R&D room

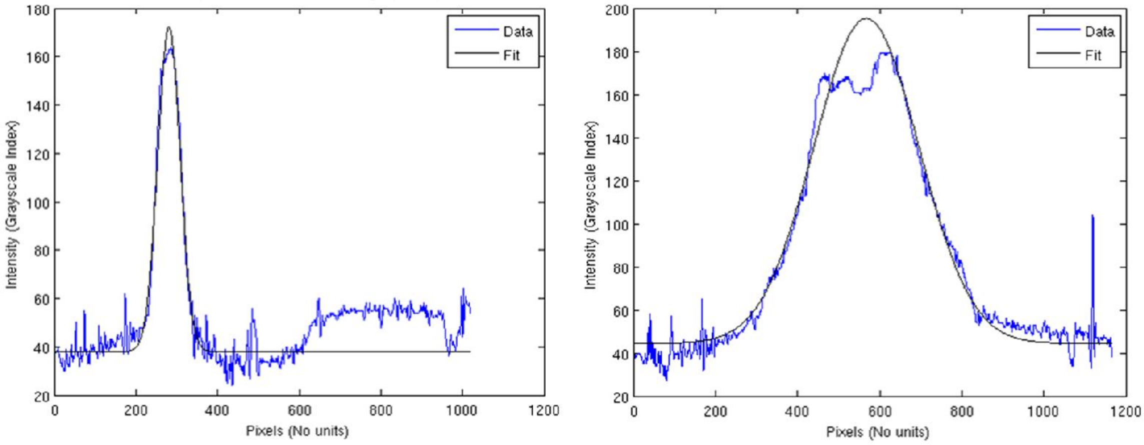

Figure 9. x and y profiles of the beam on the screen as seen from the camera and fitted Gaussians to extract the width of the beam

The σ_x^2 and σ_y^2 versus magnetic field strengths were plotted and quadratic fits were applied to these plots. However, the behavior was observed not to be quadratic and in addition, the beam shifted in position with different magnetic field settings. This was understood to be due to the fact that the beam was not centered through the beam elements. To correctly apply the method, the beam must go through center of the all beam elements. However, the existing screen does not allow for a centered experiment and a new commercial screen was ordered and will be installed in November 2017.

A new stationary beam screen system was designed under the METU-DBL project. A new Al_20_3 beam screen was produced by Yıldız Technical University in Turkey and later was demarcated every centimeter by co-centric circles using a powerful CO_2 laser with a small focus. A mechanical design including cooling and vacuum connections and screen holder, can be seen in Figure 10. This screen system also acts as a beam stopper and must be cooled accordingly.

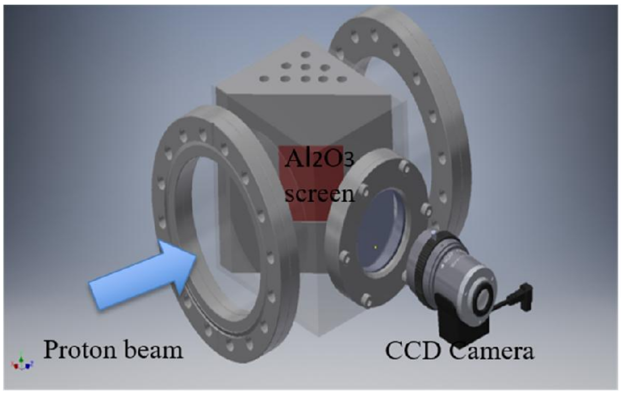

Figure 10. 3-D Drawing of a new stationary beam screen system including cooling and vacuum connections and a screen holder

This beam screen system was produced and integrated at the end of the available beamline in the R&D room, as seen in Figure 11. When the beam hits the Al_20_3 screen and the video can be recorded from the METU-DBL camera. A photo of beam hitting the screen almost in the center can be seen in Figure 12.

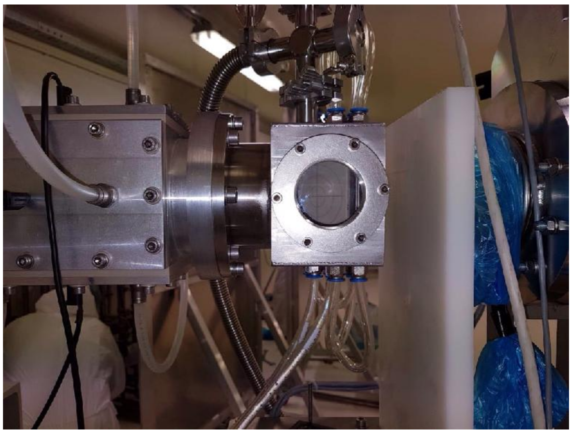

Figure 11. METU-DBL Stationary beam screen system with Al_2O_3 Screen Produced in Turkey, installed at the end of the available beamline in the R&D room.

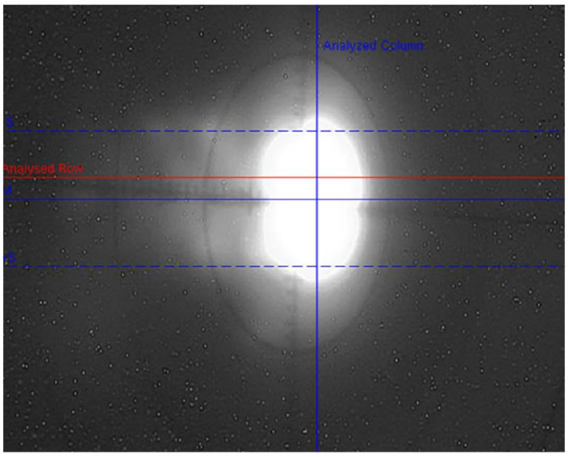

Figure 12. Beam hitting the screen produced in Turkey, almost centrally. Centimeter and axes demarcations on the screen can be used to calibrate the beam size.

While the beam was centered during this study, the METU camera had not yet been calibrated by the date of the conference. By using the image of the beam, x and y distributions of the beam can be analyzed and quadratic fits can be applied. As an example from the first beam measurement with this screen, y profile of the beam on the screen as seen from the camera and fitted Gaussians to extract the width of the beam can be seen in Figure 13. The camera was saturated and was calibrated after the ANS conference and the ensuing quadrupole magnet scan results are being prepared for publication elsewhere.

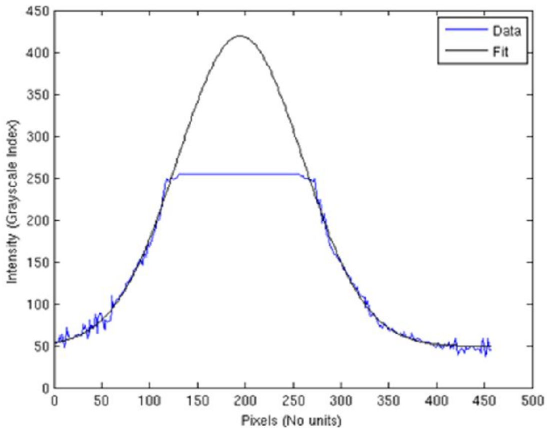

Figure 13. y profile of the beam on the METU screen as seen from the camera and fitted Gaussian to extract the width of the beam

3.CONCLUSIONS

METU-DBL Tests with the final setup are scheduled to start in August 2018. During SEE tests, the test procedure of the ESA-ESCC 25100 Standard will be followed. As a part of the project, the first SEE tests will be performed for solar panels of the IMECE satellite, Li-Ion battery and its control card of the IMECE satellite and multi-layer Insulation (MLI) of the IMECE satellite. The METU-DBL preliminary setup construction and installed is complete and radiation tests will start in October 2017. It will be performed for electronic components & cards, solar cells, pin diodes.
Beam measurement studies have been carried with METU-DBL beam screen system. After doing beam measurement with more different magnetic field strength, better quadratic fits will be obtained from analysis. By using obtained coefficients from fits, beam parameters at the measurement point will be found. Then, initial parameters will be found by using beam elements and drift matrices multiplication. According to new initial parameters, all simulations for METU-DBL will be repeated.

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