METU Defocusing Beamline Project for the First SEE Tests in Turkey and Test Results from the METU-DBL Preliminary Setup

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ABSTRACT

Space radiation can affect performance of electronic components during a satellite's mission. In order to ensure reliable performance, these components must be tested under some types of the radiation. METU Defocusing Beam Line (METU-DBL) project aims to perform Single Event Effect (SEE) tests for space, HiLumi LHC, nuclear and other applications. ESA ESCC No.25100 Standard Single Event Effect Test Method and Guidelines is considered for these SEE tests. Turkish Atomic Energy Authority (TAEA) has a cyclotron which can accelerate protons up to 30 MeV kinetic energy at the Proton Accelerator Facility (PAF) mainly for radioisotope production and for R&D purposes. According to the standard, the proton beam kinetic energy must be between 20MeV and 200MeV. While the proton energy is suitable for SEE tests, the beam size must be 15.40 cm x 21.55 cm and the flux must be between 10^5 p/cm^2/s to at least 10^8 p/cm^2/s according to the standard. The beam size at the entrance of the R&D room is mm-sized and the current is variable between 10μA and 1.2mA. Therefore, a defocusing beam line has been designed to enlarge the beam size and reduce the flux. The beam line has three quadrupole magnets to enlarge the beam size and collimators and scattering foils are used for flux reduction.

Radiation Effects and Standards

Radiation Effects → Total Ionizing Dose; Displacement Damage; Single Event Effects

ESA-SCC No.25100 Standard Single Event Effects Test Method and Guidelines [1]

- Proton kinetic energy: between 20 MeV and 200 MeV.
- Proton flux: ranging from 10^5 p/cm^2/s to at least 10^8 p/cm^2/s
- Radiation area: 15.40 cm x 21.55 cm.
- Radiation at the target: uniform to ±10%.
- Fluence: should be able to reach 10^{11} p/cm^2 for one test

TAEK SANAEM Proton Accelerator Facility [2]

- Inaugurated in May 2012
- Purpose: radioisotope production and also has a room for R&D purposes
- Accelerator: Cyclone30
- Proton kinetic energy: variable, 15 MeV - 30 MeV
- Beam current: 0.1μA - 1.2 mA
- Beam size at the R&D room: 1cm in diameter

METU-DBL Project

Beam size → must be enlarged: 3 quadrupole magnets

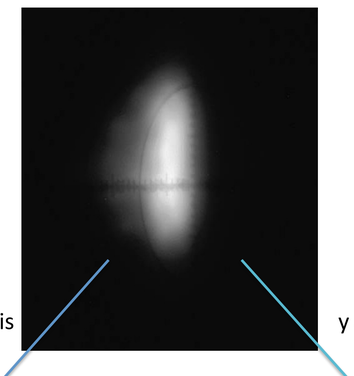
Proton flux → must be reduced: 2 scattering foils and 3 collimators

Total cooling power: 50kW

Vacuum inside beam pipe < 10^{-6} torr

Beam Measurement with Quadrupole Scan Technique

When quadrupole strength right before a beam screen is scanned → beam parameters can be determined. [3]



x axis y axis

Beam matrix for enter point of quadrupole → $\begin{pmatrix} \sigma_{xq}^2 & \langle x_q x_q' \rangle \\ \langle x_q x_q' \rangle & \sigma'^2_{xq} \end{pmatrix}$

Beam matrix for screen → $\begin{pmatrix} \sigma_x^2 & \langle xx' \rangle \\ \langle xx' \rangle & \sigma'^2_x \end{pmatrix}$

$M_D * M_Q = \begin{pmatrix} 1-\frac{1}{f}*l & l \\ -\frac{1}{f} & 1 \end{pmatrix}$

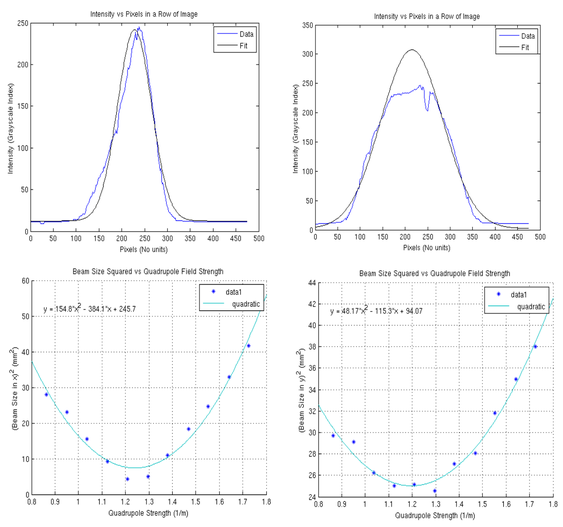
$$\begin{pmatrix} 1-\frac{1}{f}*l & l \\ -1/f & 1 \end{pmatrix}\begin{pmatrix} \sigma_{xq}^2 & \langle x_q x_q' \rangle \\ \langle x_q x_q' \rangle & \sigma'^2_{xq} \end{pmatrix}\begin{pmatrix} 1-\frac{1}{f}*l & -1/f \\ l & 1 \end{pmatrix}=\begin{pmatrix} \sigma_x^2 & \langle xx' \rangle \\ \langle xx' \rangle & \sigma'^2_x \end{pmatrix}$$

$\sigma_x^2 = a_x(1/f)^2 + b_x(1/f) + c_x$

$a = l^2\ \sigma_{xq}^2$

$b = 2\,l\,\sigma_{xq}^2 + 2\,l^2 \langle x_q x_q' \rangle$

$c = \sigma_{xq}^2 + 2\,l\,\langle x_q x_q' \rangle + l^2\ \sigma'^2_{xq}$



4th QUADRUPOLE LENGTH: 0.244 m

SCREEN

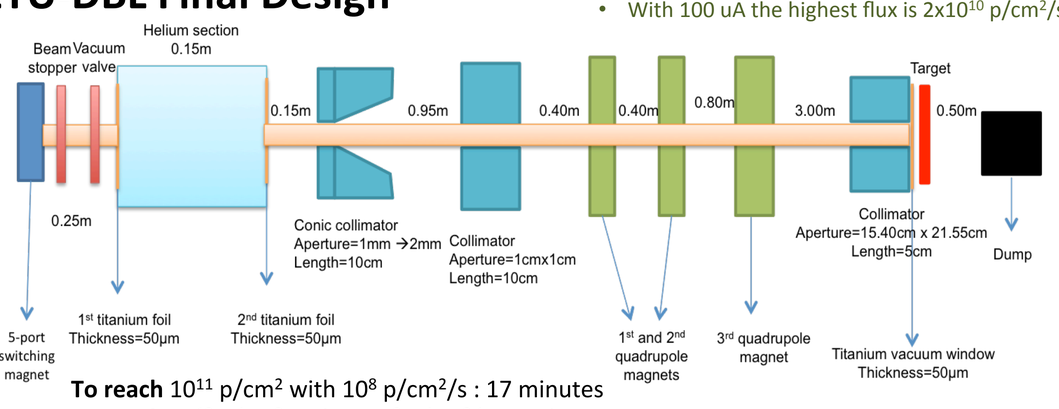
2.DRIFT: 1.722 m

- Beam Parameters;

σ_x (mm)	$\sigma_{x'}$(mrad)	cor_x(mmmrad)
7.2252	5.0241	0.9490
σ_y(mm)	$\sigma_{y'}$(mrad)	cor_y(mmmrad)
4.0305	7.7319	-0.9266

METU-DBL Final Design

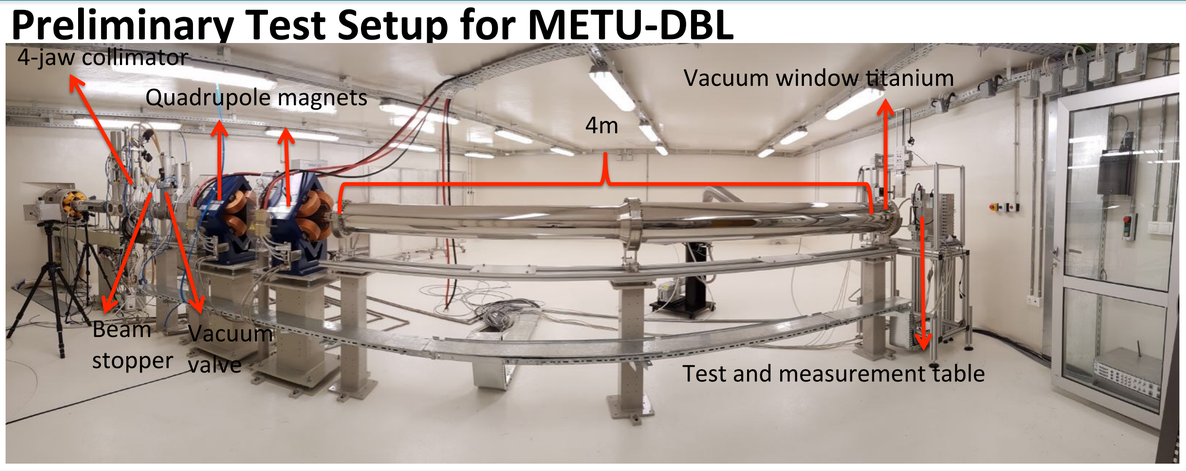
- With 0.1 uA the lowest flux is 5x10^5 p/cm^2/s
- With 100 uA the highest flux is 2x10^{10} p/cm^2/s



To reach 10^{11} p/cm^2 with 10^8 p/cm^2/s : 17 minutes

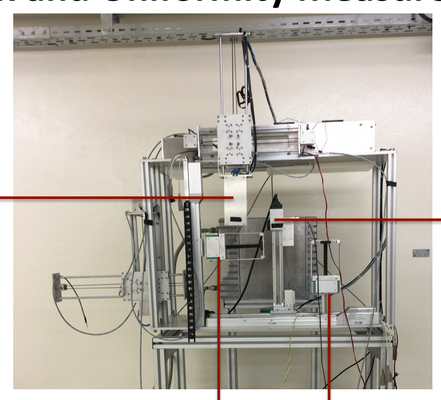
To reach 10^{13} p/cm^2 with 2x10^9 p/cm^2/s : 1.4 hours

Preliminary Test Setup for METU-DBL

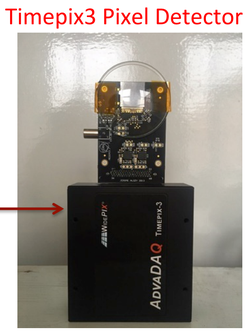


Detectors for The Flux and Uniformity Measurement

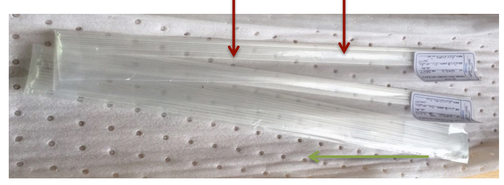
Diamond Detector



Timepix3 Pixel Detector



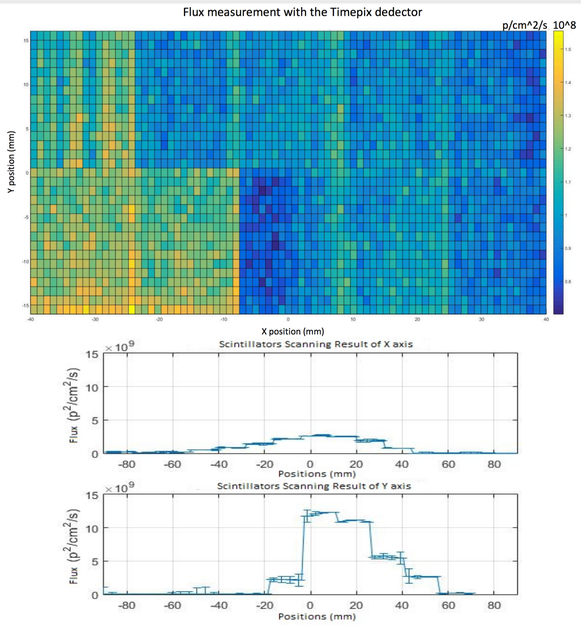
Output signal is sampled using A/D converter connected to an FPGA. A Matlab code in Labview counts the protons and measures the flux.



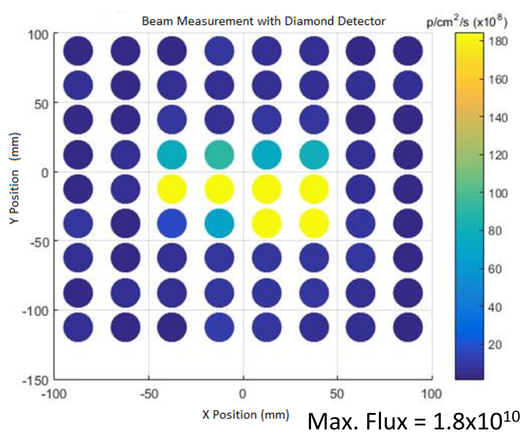
Advadaq readout card gives time over threshold and time of arrival information. These two info are used for calculating flux.

Scintillator Fibers, readout by photodiodes (not shown)

Photons converted to electrical signals using a photodiode. Signals are amplified and digitized before transmitted to Labview for flux measurement.



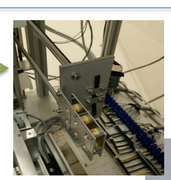
Timepix3 detector gave a data overflow error for fluxes above 10^9 p/cm^2/s. This measurement was taken from the edge of proton beam, where the flux is 10^8 p/cm^2/s.

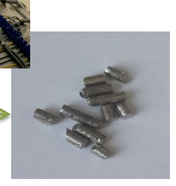


Max. Flux = 1.8x10^{10} p/cm^2/s

Preliminary tests →

- Silicon based photodiodes
- Solar cells and cover glasses
- Readout buffers and GaNFET
- Silicon detectors
- Composite materials
- Bulk metallic glasses
- Li-Ion batteries





- ✓ Preliminary tests were performed with 0.1uA proton beam current
- ✓ Some devices were live during tests and instant measurements were taken with detectors
- ✓ Secondary dose is monitored constantly
  - Neutron dose < 0.82±0.02 mSv
  - Electron + photon dose <6.64±0.30 mSv

Acknowledgement

- This project is a METU and CERN collaboration (no: KR2890) with financial support provided by the Ministry of Development of Turkey (Grant no: 2015K121190).
- Thanks to colleagues from TAEA SANAEM Proton Accelerator Facility.

References

1. Single Event Effects Test Method and Guidelines, ESA ESCC Basic Specification No. 25100
2. TAEK SANAEM, Proton Accelerator Facility Booklet, Ankara, 2012
3. Green, A. T. & Shin, Y.M., Implementation of Quadrupole Scan Emittance Measurement at Fermilab's Advance Superconducting Test Accelerator (ASTA), 2015, Proceedings of IPAC2015
4. M. B. Demirköz et al, Pretest Setup Installation of the METU-DBL Project to Perform Space Radiation Tests, RAST Proceedings 2017, DOI: 10.1109/RAST.2017.8002927