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INFN
Istituto Nazionale di Fisica Nucleare

Proton and x-ray irradiation of silicon devices at the TIFPA-INFN facilities in Trento (Italy)

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ICHEP 2020 Conference

Prague (CZ), July 29th 2020

Outline

Proton irradiation in a medical facility:

- The Trento Proton Therapy Center (TPTC)
- The TPTC cyclotron
- The TPTC experimental area

Silicon sensor proton Irradiation in the TPTC experimental room:

- High fluence-small area irradiations
- Low fluence-large area irradiations
- Preliminary tests

Silicon sensor X-ray irradiation in a medical/biological facility

Future programs

The Trento Proton Therapy Center (TPTC)

The Trento proton Therapy Center (TPTC) Is a medical facility for hadron therapy located in Trento, Italy.
It is operated by the *“Azienda Provinciale per i Servizi Sanitari”* (APSS).
https://protonterapia.provincia.tn.it/eng/?/switchlanguage/to/protonterapia_eng

The facility is equiped with two gantry rooms for patient treatment and a experimental room for physics and biophisics experiments.
Clinical activity started in 2014.

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(* Photo curtesy of the Trento Film Commission)

The TPTC Cyclotron

In the TPTC the proton source for both gantry rooms and the experimental area is a commercial 230 MeV cyclotron produced by IBA.
(https://iba-worldwide.com/)

"The energy of the beam extracted from the cyclotron is 230 MeV and is fixed. The beam extracted from the cyclotron is then focused into a small spot into a variable energy degrader made of graphite, followed by a magnetic analyzer. This energy selection system allows precise tuning of the continuous proton beam, from 60 MeV to 230 MeV, in under a second."

From:
REVIEW ON CYCLOTRONS FOR CANCER THERAPY,
Yves Jongen, IBA, Louvain-la-Neuve, Belgium
Proceedings of CYCLOTRONS 2010, Lanzhou, China.
https://accelconf.web.cern.ch/Cyclotrons2010/papers/frm1cio01.pdf

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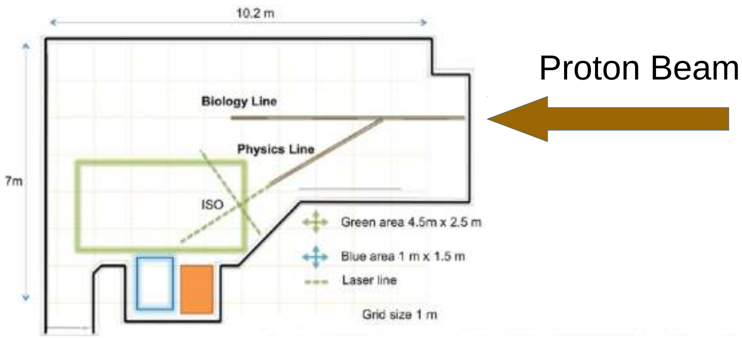
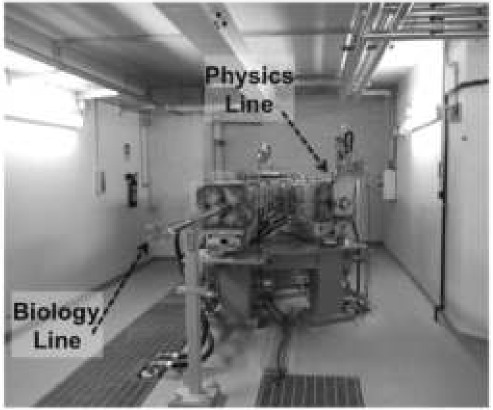
(* Photo by the author)

The TPTC experimental room



In the TPTC facility experimental room, operated by TIFPA-INFN, there are two identical beamlines for “in air” exposition of biological targets (cells), biophysics measurement or particle physics test-beam:

- the “0 degree” or biogical line
- the “30 degree” or physics line



Experimental set-up in the physics line

See ref.1: F. Tommasino et al. NIM A Volume 869, 11 October 2017, Pages 15-20, *Proton beam characterization in the experimental room of the Trento Proton Therapy facility*

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Silicon Sensor Proton Irradiation in the experimental room

High fluence-small area irradiations

Average Fluence on target calculation

Due to the beam delvery system, with the same cyclotron extraction current, the number of protons in the target area changes with the energy (according to table 1 ref. 1).

Assuming **100 MeV** Protons (see ref. 1 table 1)

Cyclotron extraction current [nA]	Total Proton delivered on target [p/s]
1	1.2 x 10^7 p/s
300	3.6 x 10^9 p/s

For example:
in 20 minutes with a 300 nA extraction current, at 100 MeV energy, **4.32 10^12** total protons are delivered on a target located in the experimental room.
In a beam transverse plane of the target area, protons will be distributed with a gaussian profile intensity.

Average Fluence on target calculation

Also the sigma of the gaussian profile intensity will change with the energy according to table 3 ref. 1.

Assuming **100 MeV** protons:
average sigma = 5.68 mm

Beam spot size estimated from a Gaussian fit on the profiles measured in the X–Y plane

E (MeV)	σ_x (mm)	σ_y (mm)	Asymmetry (%)
70.2	6.93	6.91	0.1
73.9	6.63	6.74	0.8
82.7	6.28	6.41	1.0
90.8	6.04	6.15	0.9
100.0	5.63	5.73	0.8
105.6	5.42	5.63	1.8
112.4	5.26	5.43	1.6
119.0	5.05	5.24	1.9
125.3	4.90	5.09	1.9
131.3	4.70	4.88	1.9
137.2	4.49	4.79	3.2
142.9	4.50	4.62	1.3
148.5	4.39	4.52	1.4
153.9	4.23	4.41	2.0
159.2	4.10	4.31	2.5
164.4	4.02	4.19	2.0
169.4	3.93	4.08	1.8
174.4	3.85	4.07	2.7
179.3	3.76	3.92	2.1
184.1	3.71	3.84	1.7
188.8	3.66	3.83	2.2
193.4	3.57	3.74	2.2
197.9	3.48	3.64	2.3
202.4	3.44	3.52	1.1
206.9	3.33	3.44	1.5
211.2	3.33	3.31	0.4
215.5	3.18	3.19	0.1
219.8	3.10	3.08	0.5
224.0	3.04	2.97	1.0
228.2	2.74	2.72	0.2

Table 3 ref. 1

Average Fluence on target calculation

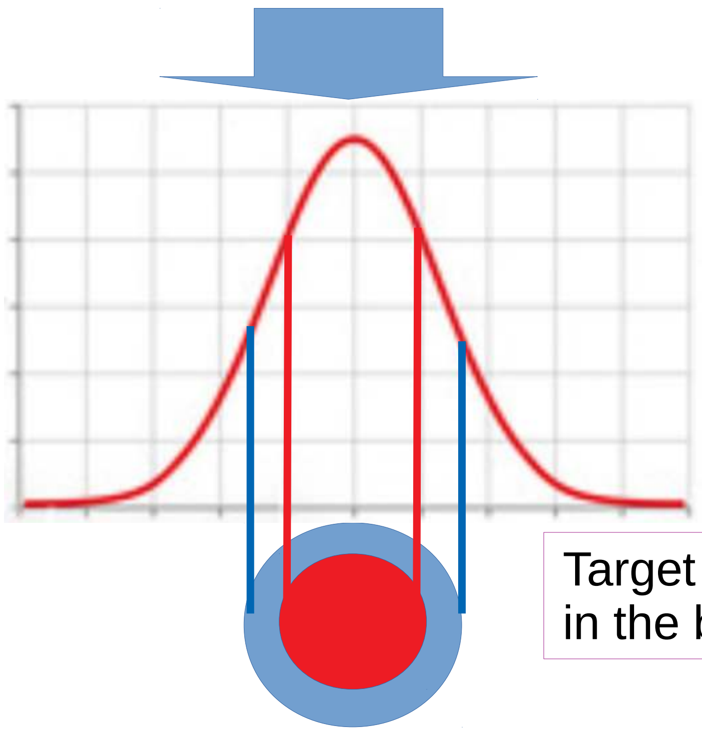
Assuming 20 minutes exposition, 300 nA extraction current, 100 MeV protons:
we have 4.32 10^12 total protons spread in a gaussian intensity profile with sigma = 5.68 mm

Fraction of protons hitting
a radius R circle:
1-e^[-0.5*(R/sigma)^2]

R_{red} 2.5 mm ==> fraction =0.0923
R_{blue} 3 mm ==> fraction =0.1302

Average Fluence:
fraction of protons/circle area

incoming beam



Beam intensity profile

Target area
in the beam transverse plane

Calculation of average fluence for radius R circular targets

Irradiation Time:
20 minutes

Proton Energy:
100 MeV

Extraction Current:
300 nA

R [mm]	Fraction of beam on a R target	Total Protons on a R target [total number]	Average Fluence [p/cm^2]
1.0	1.54%	6.64*10^10	2.11*10^12
1.5	3.43%	14.80*10^10	2.09*10^12
2.0	6.01%	25.97*10^10	2.07*10^12
2.5	9.23%	39.88*10^10	2.03*10^12
3.0	13.02%	56.24*10^10	1.99*10^12
3.5	17.29%	74.70*10^10	1.94*10^12
4.0	21.96%	94.87*10^10	1.89*10^12

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Silicon Sensor Proton Irradiation in the experimental room

High fluence-small area irradiations: considerations

- This setup can be used for small sensors irradiation like SiPM or small chip.
- The energy of 100 MeV is a compromise between beam intensity on target (increasing with energy) and beam spread on target (decreasing with energy).
- Since silicon radiation bulk damage for 100 MeV protons is ~ 1 MeV neutron equivalent this set-up can be used for irradiation studies on silicon sensors for medical or space applications.

First two preliminary tests were performed in late 2019 on FBK SiPM showing very promising results.
Measurements will resume with the reopening of the facility experimental room expected for September 2020.

Silicon Sensor Proton Irradiation in the experimental room

Low fluence-large area irradiations

Low fluence-large area irradiations

Since 2018 the biological line in the experimental room of the TPTC can be equiped with a device, called *Dual Ring(**)*, able to perform a scattering spread of the proton beam.
The device can be used in two configurations able to produce a uniform beam on a 5 cm radius or a 10 cm radius circular area.

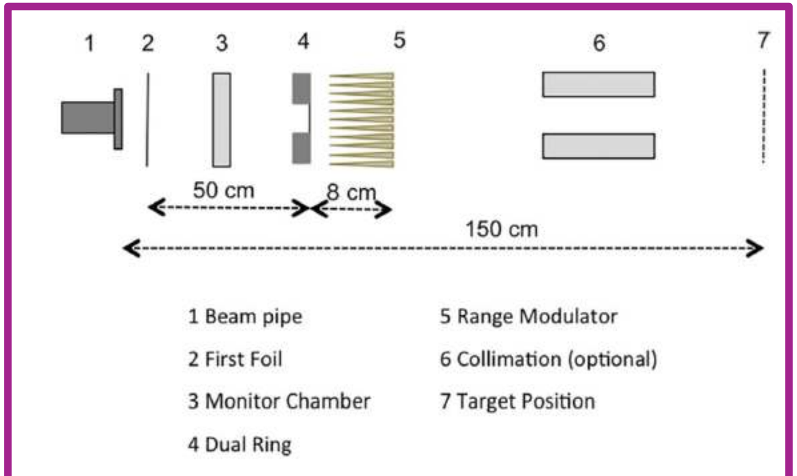
The device was realized to perform irradiations on biological cell flasks but can be also used for large area electronics and chip irradiations of device for medical and space applications not requiring high fluences.

The device is designed to work at the fixed proton energy of 148 MeV.

(**)A detailed description can be found in ref. 2:
F. Tommasino et al. Physica Medica 58 (2019) 99–106

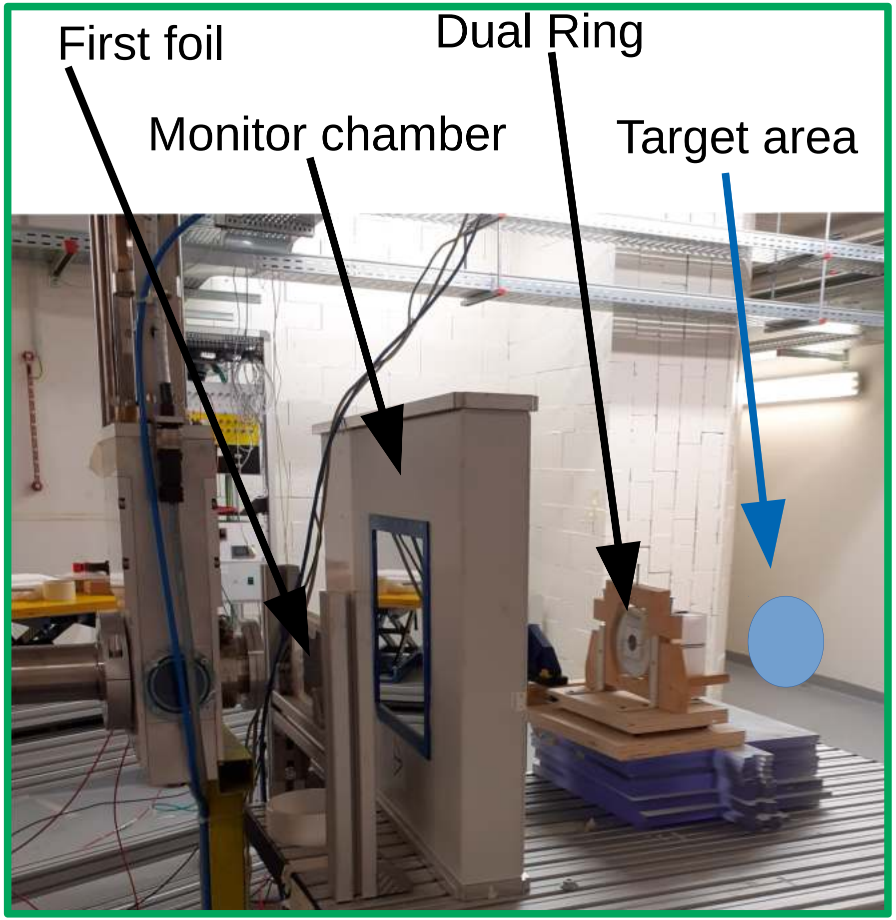
Low fluence-large area irradiations

Dual Ring Schematic View



(See ref. 2: F. Tommasino et al. Physica Medica 58 (2019) 99–106)

Dual Ring Implemented Set-Up



Proton beam

First irradiation on a small board for space application is scheduled for October 2020. Stay tuned for results.

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Silicon Sensor X-ray irradiation in a medical/biological facility

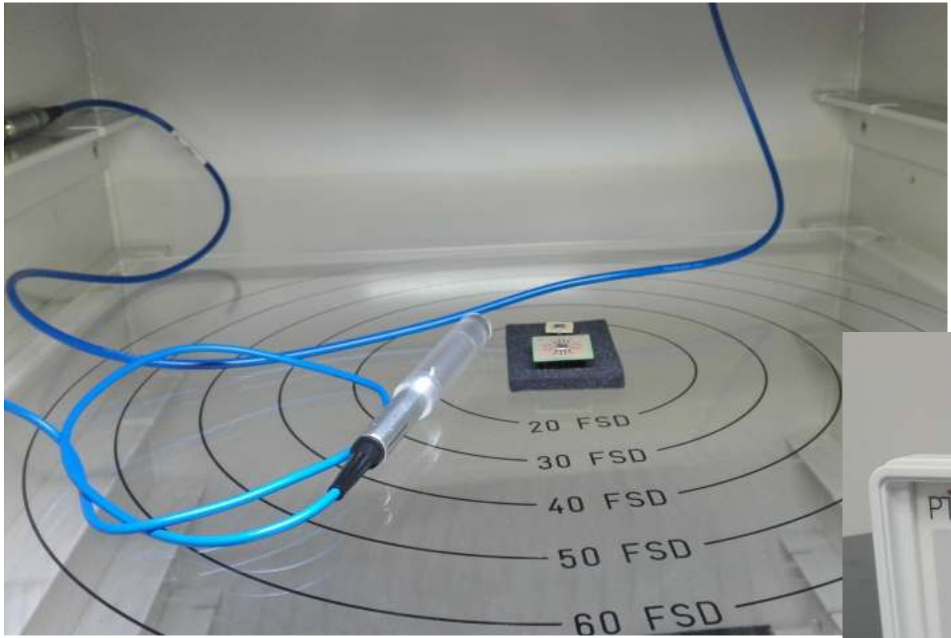
In the TIFPA facility is also available a 195 kV x-ray tube with tungsten anode, already used for biological irradiations.

Tube voltage can be set down to 40 kV and used also for irradiation on silicon detectors.

Silicon Sensor X-ray irradiation in a medical/biological facility

For biological irradiations measurements of absorbed dose is performed using a calibrated Farmer Chamber.

Studies are ongoing for the construction of a silicon diode dose measurement system.



Preliminary x-ray irradiation on SiPM and test structures

Future programs

The experimental area of the Trento Proton Theraphy Center, designed for physics and biophysics experiment, is also a place where proton irradiation on silicon sensors can be performed in order to study bulk radiation damage on small/medium size innovative sensors. The beam intensity available allows tests for medical or space devices requiring fluences order of ~ 10^13 particle/cm^2

In the TIFPA-INFN laboratories studies are ongoing in order to perform also surface silicon damage test on innovative silicon sensors using an already available x-ray tube.

Stay tuned for new results!

References

TIFPA-INFN web site:
https://www.tifpa.infn.it/

Beam time applications:
http://www.tifpa.infn.it/sc-init/med-tech/p-beam-research/

References:

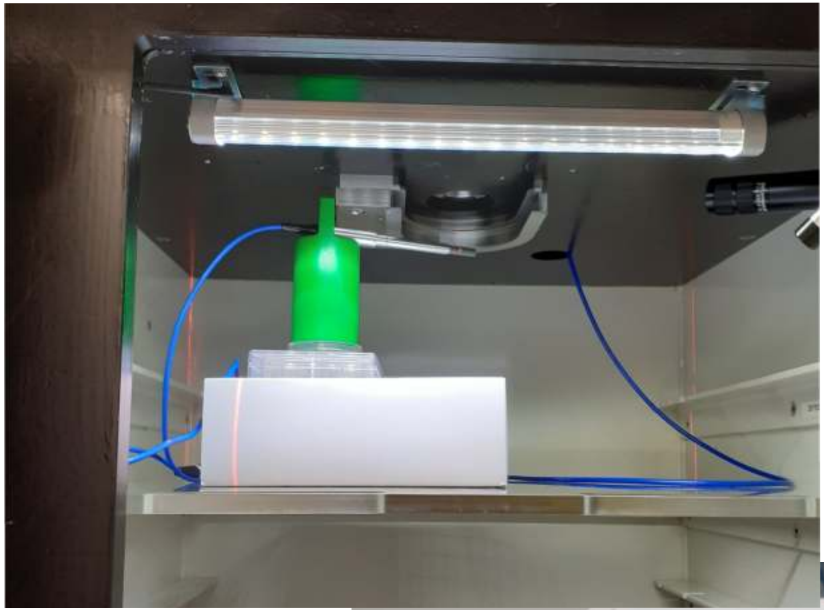
1) F. Tommasino et al. NIM A Volume 869, 11 October 2017, Pages 15-20, *Proton beam characterization in the experimental room of the Trento Proton Therapy facility*
2) F. Tommasino et al. Physica Medica 58 (2019) 99–106, *A new facility for proton radiobiology at the Trento proton therapy centre: Design and implementation.*

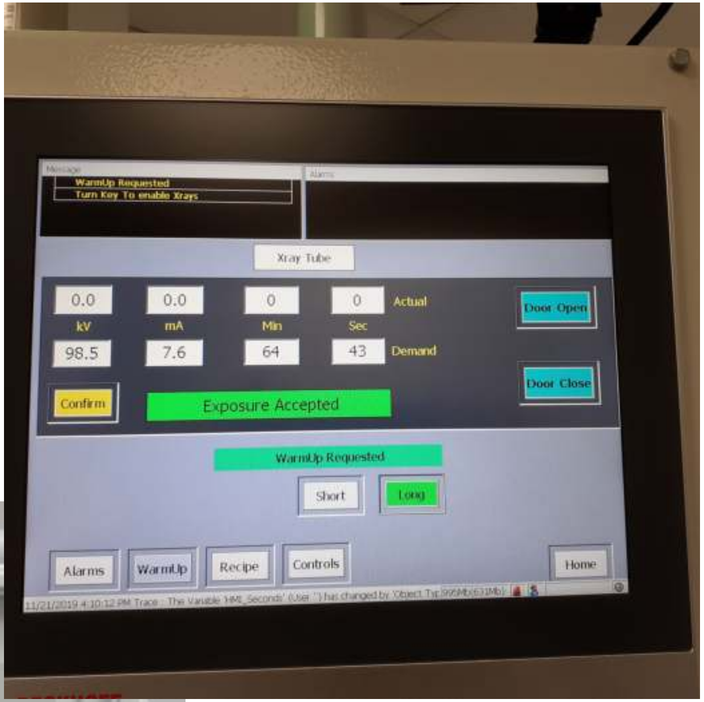
Back-up slides

Table 1 ref. 1

Table 1
Nominal and effective values of the beam energy and corresponding range and maximum flux. The former refer to the energy at the cyclotron exit while the latter are measured in the experimental room at the Isocenter position. Flux measurements in the last column refer to 1 nA beam extraction current. The extraction current can be increased up to 320 nA, and the flux can scale consequently.

Nominal values		Effective valuesat ISO		Flux (p/s)
E (MeV)	R90 (g/cm^2)	*E* (MeV)	R90 (g/cm^2)	
70.2	4.1	68.5	3.9	3.8×10^6
73.9	4.5	72.4	4.3	–
82.7	5.5	82.3	5.4	7.5×10^6
90.8	6.5	89.5	6.3	9.9×10^6
100.0	7.5	98.6	7.5	1.2×10^7
105.6	8.5	104.2	8.3	–
112.4	9.5	11.2	9.3	2.1×10^7
119.0	10.5	117.8	10.3	2.8×10^7
125.3	11.5	124.1	11.3	–
131.3	12.5	130.3	12.3	2.7×10^7
137.2	13.5	136.1	13.3	–
142.9	14.5	141.7	14.2	3.6×10^7
148.5	15.5	147.1	15.2	–
153.9	16.5	152.7	16.2	4.6×10^7
159.2	17.5	158.0	17.2	5.5×10^7
164.4	18.5	163.1	18.2	–
169.4	19.5	168.1	19.2	7.4×10^7
174.4	20.5	173.4	20.2	–
179.3	21.5	178.2	21.2	9.0×10^7
184.1	22.5	182.8	22.2	–
188.8	23.5	187.4	23.2	1.1×10^8
193.4	24.5	192.3	24.2	–
197.9	25.5	196.8	25.2	–
202.4	26.5	201.1	26.1	1.4×10^8
206.9	27.5	205.6	27.1	–
211.2	28.5	210.0	28.1	1.7×10^8
215.5	29.5	214.2	29.1	–
219.8	30.5	218.4	30.1	2.0×10^8
224.0	31.5	222.9	31.2	–
228.2	32.5	227.4	32.3	2.3×10^8





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