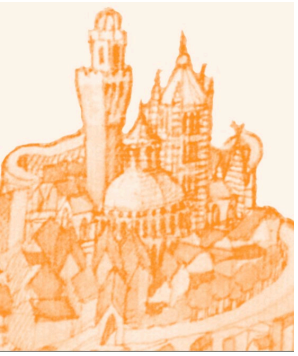

15th Topical Seminar on Innovative Particle and Radiation Detectors

October 14-17, 2019 | Siena (Italy)

(IPRD19)

SCINTILLATOR-BASED SYSTEM FOR TRANSVERSAL DOSE PROFILE RECONSTRUCTION

Ruhani Khanna

(1) Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Sud, Catania, Italy
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(4) DE.TEC.TOR. – Devices and Technologies Torino s.r.l., Torino, Italy
(5) Azienda Ospedaliero-Universitaria Policlinico – Università degli Studi di Catania, Catania, Italy
(6) Institute of Physics ASCR, v.v.i. (FZU), ELI-Beamlines Project, Prague, Czech Republic

INFN Istituto Nazionale di Fisica Nucleare

TIFPA Trento Institute for Fundamental Physics and Applications

DETECTOR DEVICES AND TECHNOLOGIES TORINO

NTU

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DETECTOR DEVICES AND TECHNOLOGIES TORINO

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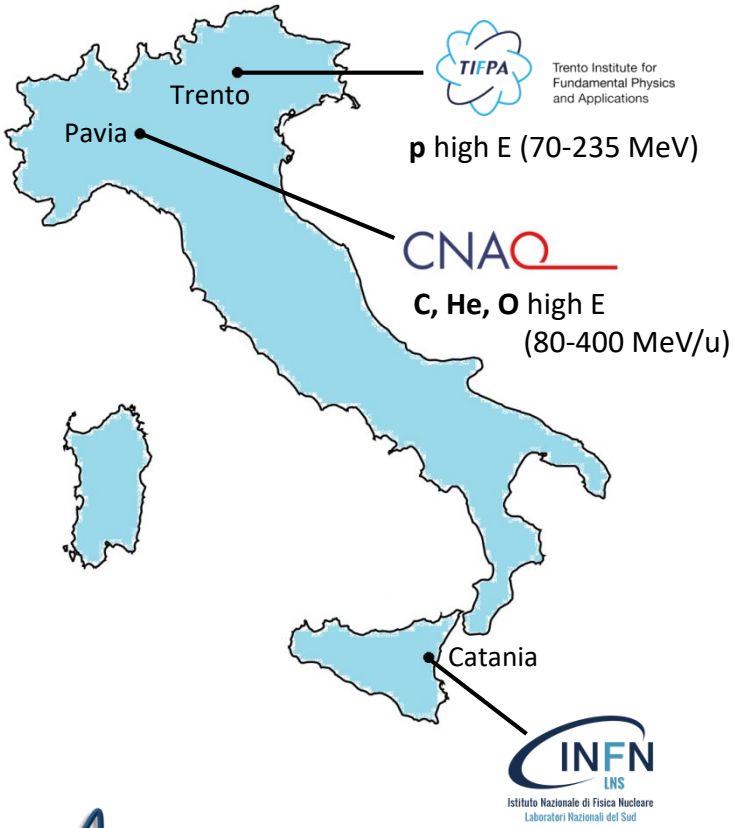
OUTLINE

- Hadrontherapy
- Quality Assurance (QA) tests in proton therapy
- Preliminary characterisation of a scintillator-based beam profiling system designed and realised at INFN-LNS laboratory (Catania, Italy)
- Comparison with reference and commercial detectors (with experimental results)
- Concluding remarks and future perspectives

CATANA protontherapy facility (INFN-LNS, Catania, Italy)

Three particle therapy Facilities:

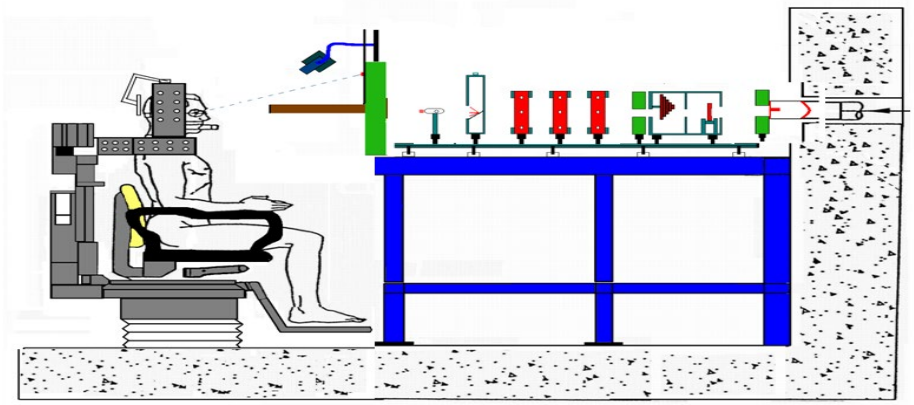


p high E (70-235 MeV)

C, He, O high E (80-400 MeV/u)

p, C, He, O low E (80 MeV/u)

Collaboration



CATANA (Centro di AdroTerapia e Applicazioni Nucleari Avanzate) protontherapy facility since 2002 at INFN-LNS

Beam: monochromatic H_2^+ (62 MeV) accelerated by a SC

Plastic absorbers: wheeled modulators and range shifters

Radiotherapeutic treatment: ocular diseases

- choroidal melanoma
- iris melanoma
- macular degeneration

Patients treated: more than 500

% of success: loco-regional cancer control in 97% of cases

Beam profiling: non real-time monitoring

- silicon diodes
- radiochromic films (EBT3 type)

QA in Proton therapy

QA tests
- Safe and accurate treatment assurance
- Frequent, reproducible, precise dosimetric checks

Methods (Radiation detectors):
- Ionisation chamber
- Silicon diodes
- Photodiodes
- Radiographic and radiochromic film

Drawbacks:
- Expensive
- Time consuming
- Manual results

Radiographic film

Silicon Diode

Lynx

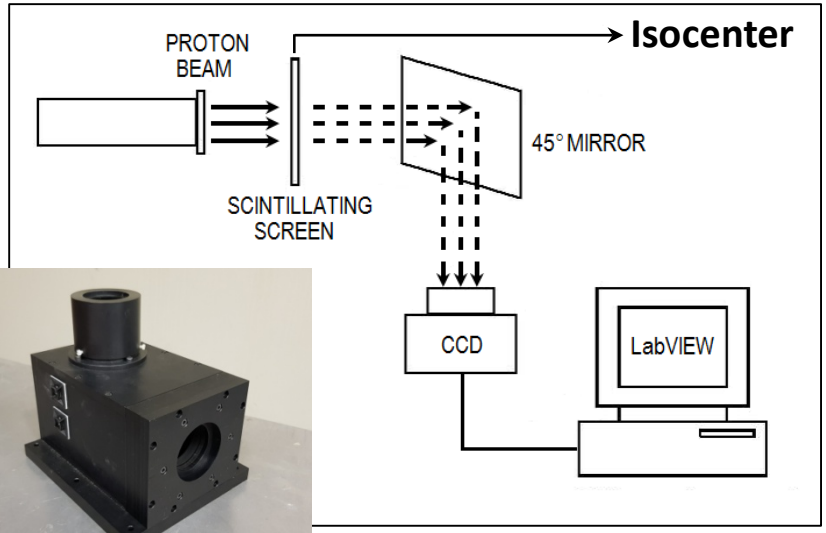
Timepix silicon detector

References

www.Iba-dosimetry.com

Cirrone G.A.P. et al., Deep Characterization of o Fast Monitoring System for Radiotherapeutic Proton Beams Based on Scintillating Screens and a CCD camera, IEEE Nuclear Science Symposium, 2004

NEW BEAM PROFILING SYSTEM



Prototype

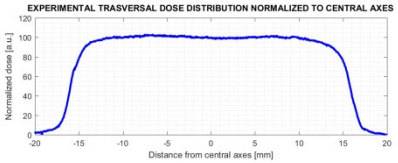
LabView dedicated software for real-time data acquisition and processing. Suitable MATLAB routines allow for data analysis:

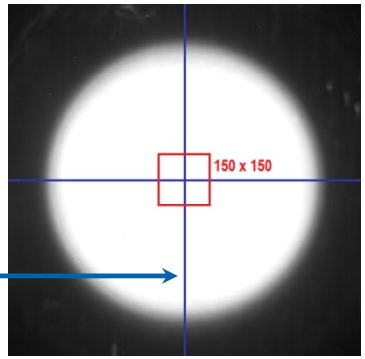
- Radiation field (FWHM)
- Lateral penumbras
- Field Ratio
- Flatness and Asymmetry
- 2-D contour plot

Acquisition and processing time: max 30 sec

System very preliminary characterisation in terms of:

- Response dependence on the dose rate and the number of the acquired frames (ROI)
- Short-term stability



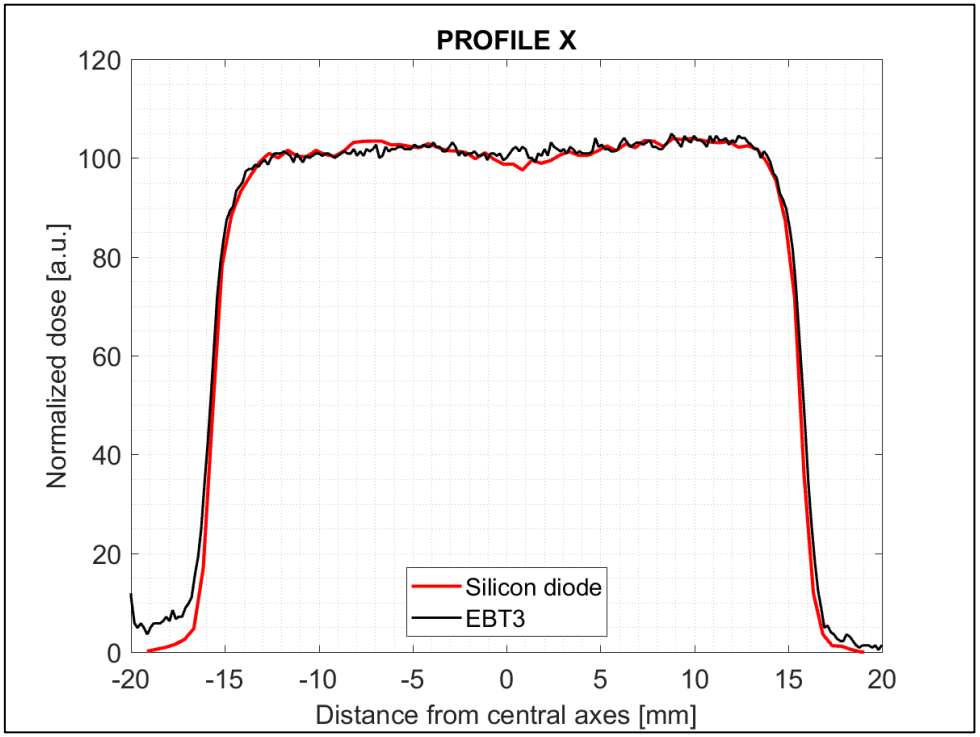


References

Cirrone G.A.P. et al., A Fast Monitoring system for Radiotherapeutic Proton Beams Based on Scintillating Screens and a CCD camera, IEEE Transaction on Nuclear Science, vol. 51, n. 4, 2003

Cirrone G.A.P. et al., Deep Characterization of o Fast Monitoring System for Radiotherapeutic Proton Beams Based on Scintillating Screens and a CCD camera, IEEE Nuclear Science Symposium, 2004

COMPARISON WITH REFERENCE DETECTORS @ INFN-LNS

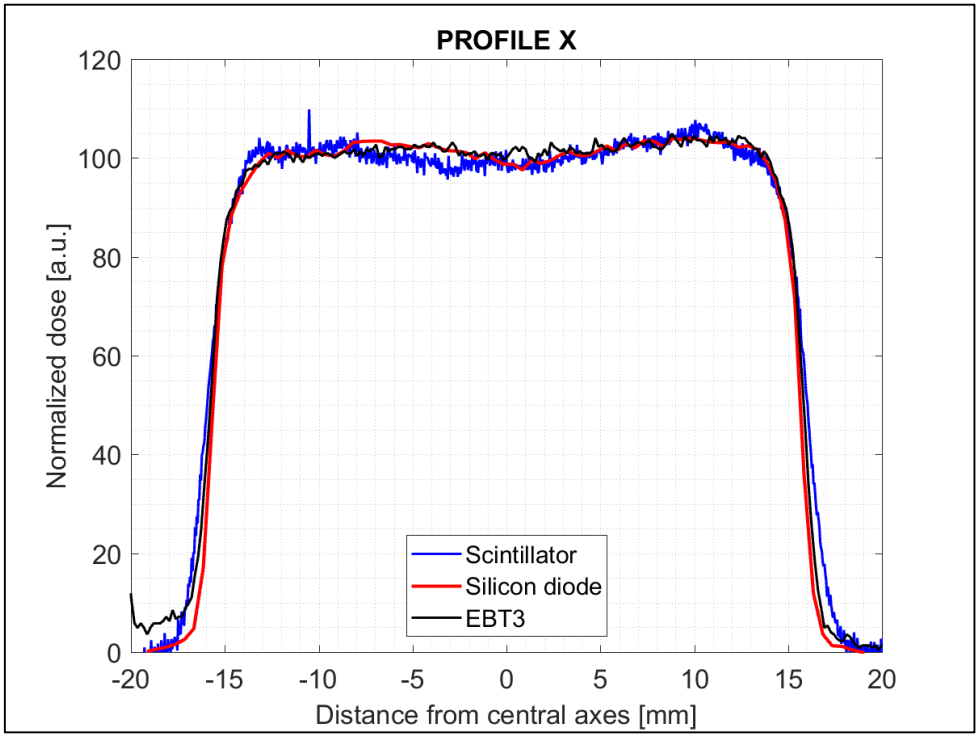


Beam Energy: 62 MeV protons
Position: Isocenter (17 cm from the beam exit)
Collimator diameter: 30 mm
Exposure time: 30 ms

- EBT3 radiochromic film (thickness 0.2 mm)
- Silicon diode

Profile X	EBT3 Radiochromic film	Silicon diode
FWHM [mm]	31.665	31.700
90/50 Ratio	0.930	0.937
Left Penumbra [mm]	1.220	1.260
Right Penumbra [mm]	1.185	1.210
Flatness [%]	3.802	3.813
Asymmetry [%]	105.430	105.512

COMPARISON WITH REFERENCE DETECTORS @ INFN-LNS



Beam Energy: 62 MeV protons
Position: Isocenter (17 cm from the beam exit)
Collimator diameter: 30 mm
Exposure time: 30 ms

- EBT3 radiochromic film (thickness 0.2 mm)
- Silicon diode
- INFN scintillator-based beam profiling system (thickness 1 mm)

Profile X	EBT3 Radiochromic film	Silicon diode	Scintillator-based system
FWHM [mm]	31.665	31.655	31.970
90/50 Ratio	0.930	0.937	0.921
Left Penumbra [mm]	1.220	1.250	1.575
Right Penumbra [mm]	1.185	1.210	1.530
Flatness [%]	3.802	3.813	4.798
Asymmetry [%]	105.430	105.512	106.502

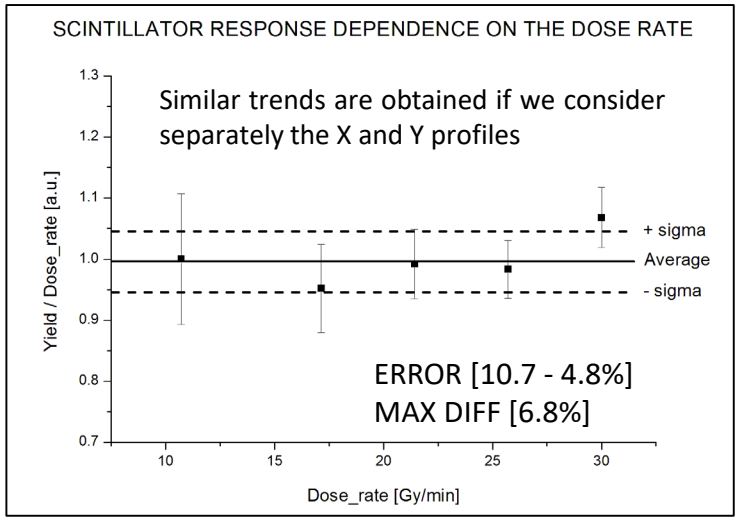
PRELIMINARY CHARACTERIZATION OF THE 2-D SCINTILLATOR-BASED SYSTEM

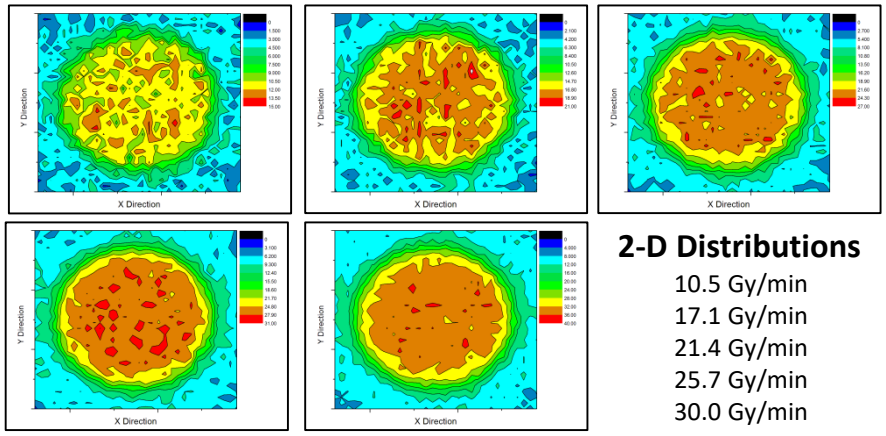
- Scintillator response dependence on the dose rate
- Scintillator response dependence on the number of acquired frames
- Short-term stability

BEAM PROFILING SYSTEM CHARACTERIZATION / 1

Scintillator response dependence on the dose rate

- **Range [10.5 – 30.0 Gy/min]**

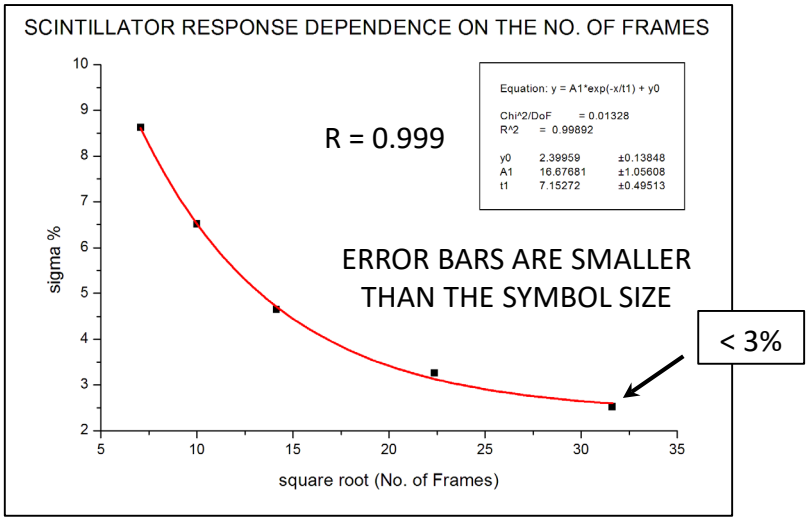


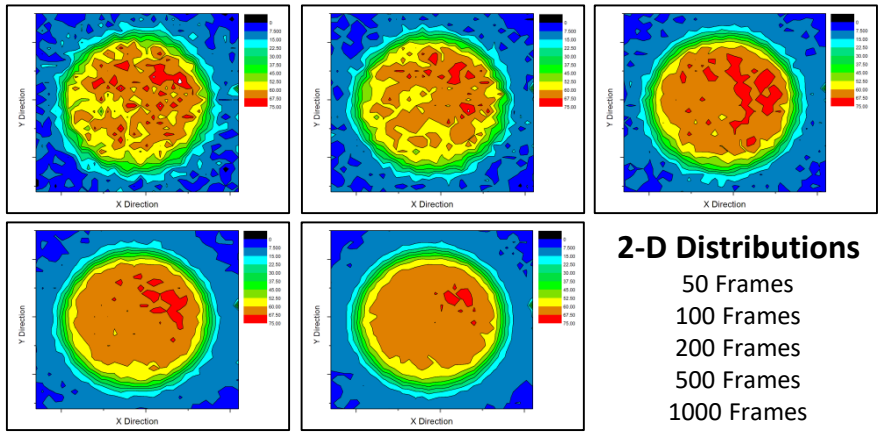


2-D Distributions
10.5 Gy/min
17.1 Gy/min
21.4 Gy/min
25.7 Gy/min
30.0 Gy/min

Scintillator response dependence on the number of frames

- **Range [50 – 1000 Frames]**



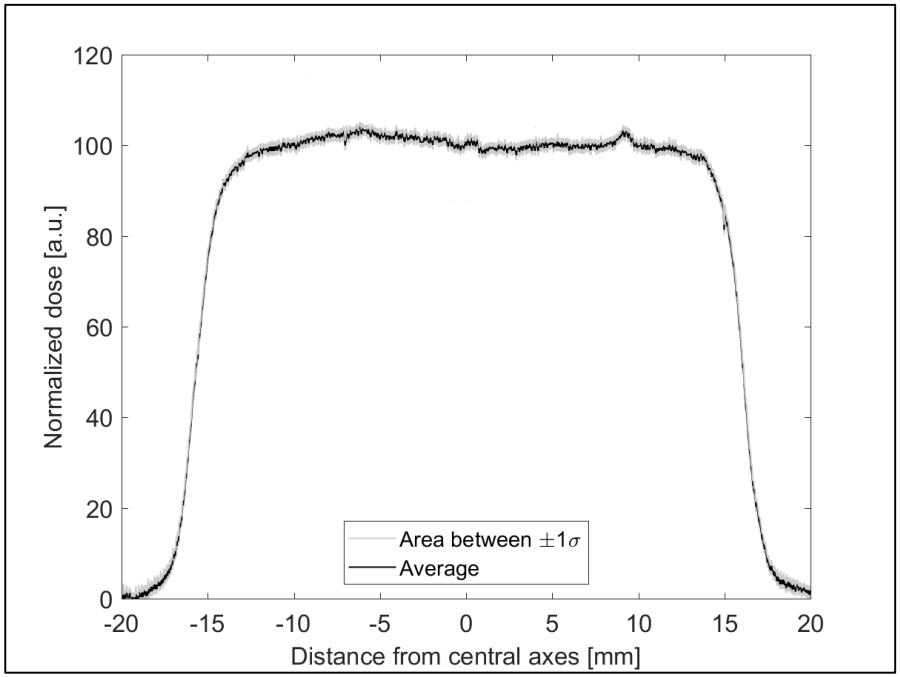


2-D Distributions
50 Frames
100 Frames
200 Frames
500 Frames
1000 Frames

BEAM PROFILING SYSTEM CHARACTERIZATION / 2

Short-term stability

The short-term stability, calculated as the percentage ratio of the SD to the mean CCD output, was evaluated performing eight consecutive irradiations with identical dose-rate values and resulted to be **smaller than 0.9%** .



<PROFILE X>

FWHM:	**31.737 ± 0.052 mm**	**[ERROR 0.2%]**
90/50 Ratio:	**0.901 ± 0.007 %**	**[ERROR 0.8%]**
Right penumbra:	**1.548 ± 0.032 mm**	**[ERROR 2.0%]**
Left penumbra:	**1.678 ± 0.038 mm**	**[ERROR 2.3%]**
Asymmetry:	**104.889 ± 1.542 %**	**[ERROR 1.5%]**

<PROFILE Y>

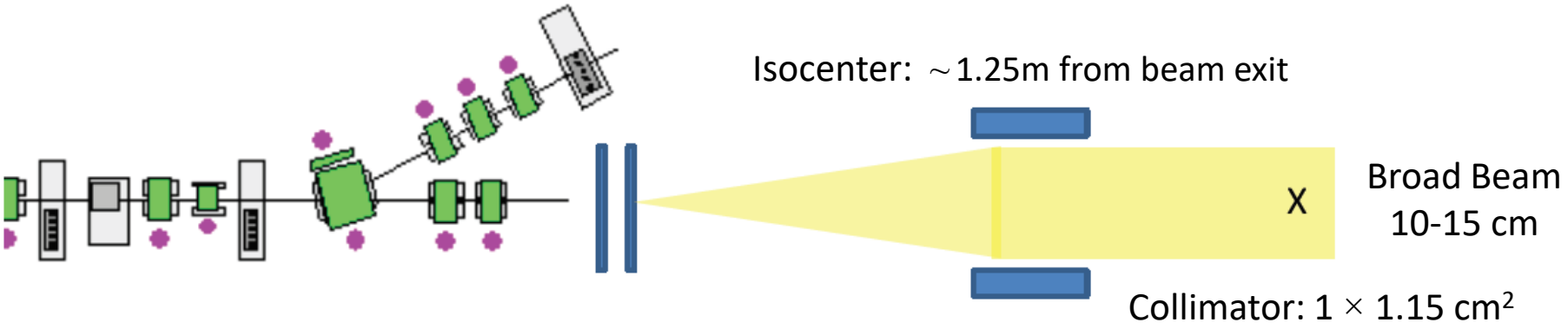
FWHM:	**31.901 ± 0.027 mm**	**[ERROR 0.1%]**
90/50 Ratio:	**0.873 ± 0.008 %**	**[ERROR 0.9%]**
Right penumbra:	**1.951 ± 0.034 mm**	**[ERROR 1.7%]**
Left penumbra:	**2.028 ± 0.051 mm**	**[ERROR 2.5%]**
Asymmetry:	**103.623 ± 2.013 %**	**[ERROR 1.9%]**

Uncertainty on the estimation of the beam parameters < 2.5%

Comparison with other commercial detectors

- Scintillator comparison with reference detector
- Scintillator comparison with other commercial detectors

COMPARISON WITH OTHER DETECTORS @ TIFPA

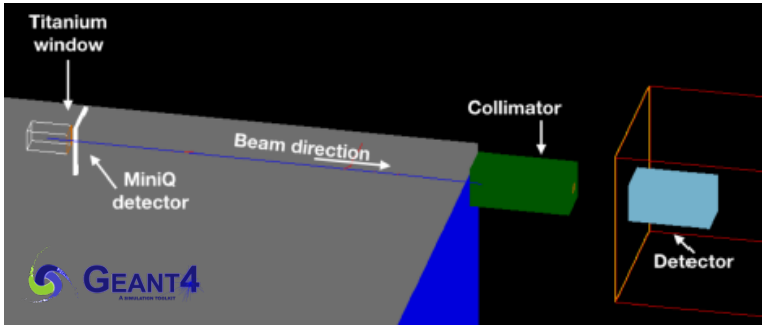


Ion beam: monochromatic H_2^+ (100 MeV)
Beam current: 20-150 nA

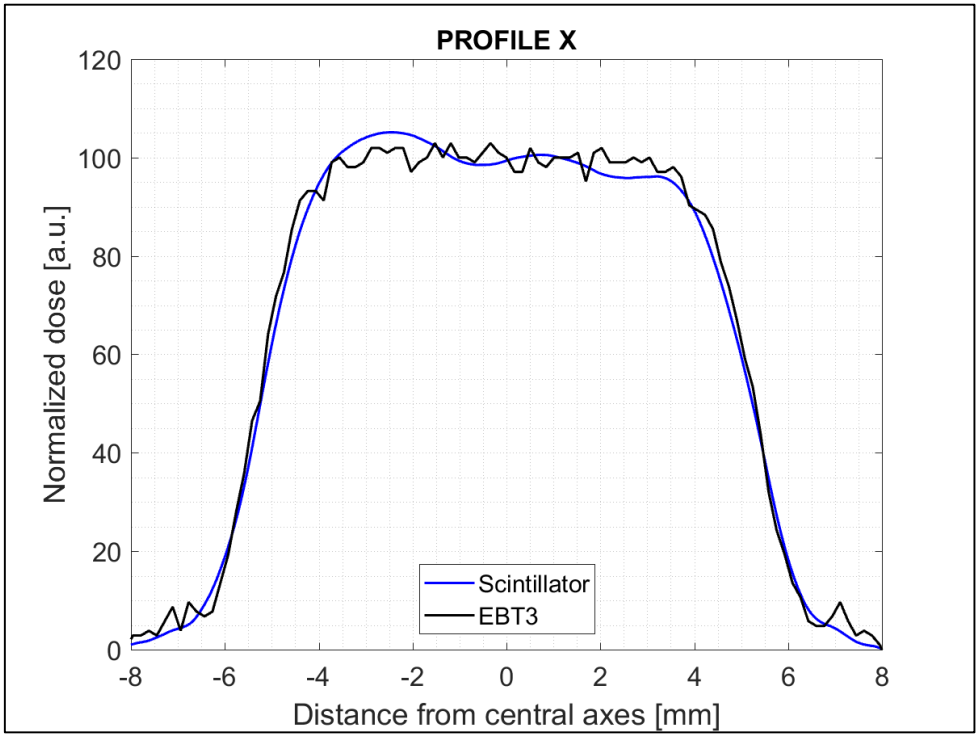
- **INFN beam profiling system** (active surface area 50 × 50 mm²)
- **Radiochromic films** (EBT3 type, scan resolution 150 dpi)
- **Timepix silicon detector** (256 × 256 pixels, pixel size 55 × 55 μm)
- **Lynx** (IBA Dosimetry GmbH, Germany, active surface area 300 × 300 mm²)

NON-CLINICAL BEAM

(GEANT4 simulation of the experimental setup)



COMPARISON WITH REFERENCE DETECTORS @ TIFPA-INFN

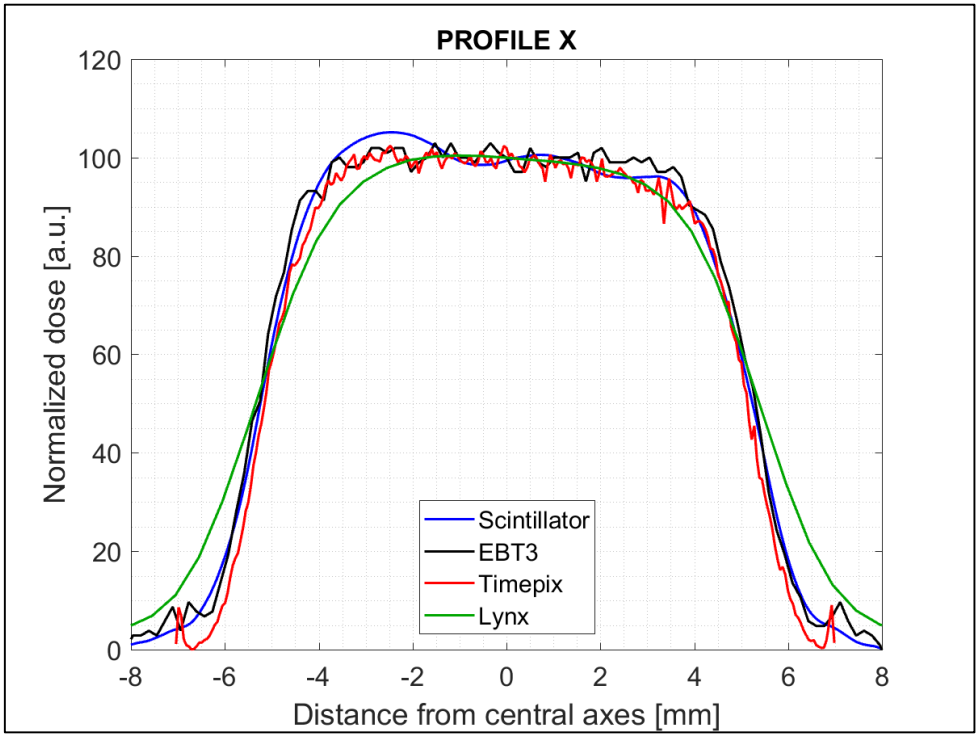


Beam Energy: 100 MeV protons
Position: Isocenter (1.25 m from the beam exit)
Collimator diameter: 1 × 1.15 cm^2
Exposure time: 30 ms

- EBT3 radiochromic film (thickness 0.2 mm)
- INFN scintillator-based beam profiling system (thickness 1 mm)

Profile X	EBT3 Radiochromic film	Scintillator-based system
FWHM [mm]	10.460	10.535
90/50 Ratio	0.793	0.768
Left Penumbra [mm]	1.220	1.295
Right Penumbra [mm]	1.370	1.400
Flatness [%]	4.125	4.314
Asymmetry [%]	101.978	103.003

COMPARISON WITH REFERENCE DETECTORS @ TIFPA-INFN



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Exposure time: 30 ms

- EBT3 radiochromic film (thickness 0.2 mm)
- INFN scintillator-based beam profiling system (thickness 1 mm)
- Timepix silicon detector
- Lynx, IBA dosimetry

Profile X	EBT3 Radiochromic film	Scintillator-based system	Timepix	Lynx, IBA
FWHM [mm]	10.460	10.535	10.450	10.750
90/50 Ratio	0.793	0.768	0.765	0.656
Left Penumbra [mm]	1.220	1.295	1.260	2.340
Right Penumbra [mm]	1.370	1.400	1.385	2.350
Flatness [%]	4.125	4.314	3.695	0.825
Asymmetry [%]	101.978	103.003	102.864	101.343

TECHNOLOGIC TRANSFER AGREEMENT

DETECTOR
DEVICES AND TECHNOLOGIES TORINO

CONTRATTO DI CONCESSIONE DI LICENZA NON ESCLUSIVA DI KNOW-HOW

(rif. cod. TTC2_19LNS_021)

TRA

Istituto Nazionale di Fisica Nucleare (di seguito INFN), C.F. 84001850589,P.I. 04430461006,con sede in Frascati, via Enrico Fermi, n. 40, in persona del Direttore Generale Bruno Quarta autorizzato ai sensi dell'art. 25 del "Disciplinare per la tutela, lo sviluppo, la valorizzazione delle conoscenze dell'INFN"

E

DE.TEC.TOR. Devices & Technologies Torino S.r.l. (di seguito "DETECTOR"), P.I 10170150014, con sede legale in via Lungo Dora Voghera 36/A, 10153 Torino - Italy, in persona del Legale Rappresentante, Dott. Giuseppe Pitta,

di seguito anche indicate separatamente come "Parte" e congiuntamente come "Parti".

PREMESSO CHE:

- L'Istituto Nazionale di Fisica Nucleare è Ente pubblico nazionale di ricerca che promuove, coordina ed effettua la ricerca scientifica nel campo della fisica nucleare, subnucleare, astroparticellare e delle interazioni fondamentali, nonché la ricerca e lo sviluppo tecnologico pertinenti alle attività in tali settori prevedendo forme di sinergia con altri enti di ricerca e il mondo dell'impresa.
- INFN nell'ambito delle proprie attività di ricerca istituzionali ha sviluppato delle conoscenze nell'ambito dei dispositivi di monitoraggio di fasci di particelle, in particolare per l'acquisizione e l'analisi quantitativa e clinicamente rilevante, di distribuzioni di dose trasversale di fasci di protoni;
- DETECTOR nasce come spin-off dell'Università degli Studi di Torino ed opera nel campo dell'adroterapia, un'avanzata forma di radioterapia per il trattamento dei tumori mediante l'utilizzo di protoni e ioni carbonio. Nello specifico, DETECTOR progetta e produce rivelatori di particelle, impiegati nei centri di trattamento radioterapico per monitorare i parametri del fascio terapeutico e per misure di verifica e calibrazione dei fasci di particelle;
- DETECTOR è interessata ad utilizzare il know-how e il software sviluppati da INFN nel campo del monitoraggio e profilazione di fasci di particelle, nonché le competenze dell'INFN in materia, come meglio specificato nell'allegato A (nel seguito, per brevità, il Know-How).
- DETECTOR ha pertanto richiesto una licenza d'uso non esclusivo nel settore medicale del Know-How dell'INFN al fine di ingegnerizzare e commercializzare un dispositivo volto alla

Pag 1 di 9

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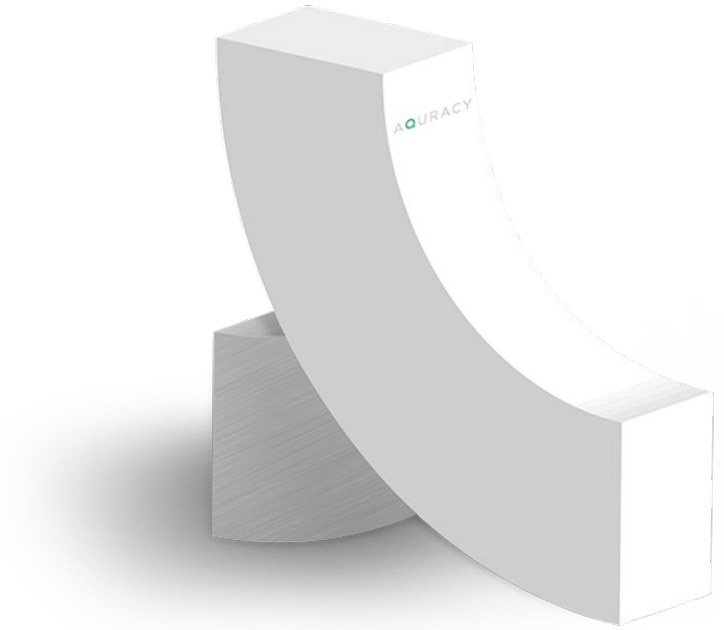
https://detector-group.com/aquracy/



AQURACY

June, 2019

CONCLUDING REMARKS AND FUTURE PERSPECTIVES

The presented device appears to be a promising quality control system for radiotherapeutic proton beam thanks to its suitable characteristics:

- The relative differences of the beam quality parameters are acceptable, if compared with those obtained with others widely-used detectors, especially at **100 MeV**
- Linear response in a **wide dose rate** range (useful for protontherapy treatments);
- **Validation**: It's acquisition and processing time is less than 30 seconds against 15 mins of routine systems at CATANA facility;

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- The relative differences of the beam quality parameters are acceptable, if compared with those obtained with others widely-used detectors, especially at **100 MeV**
- Linear response in a wide dose rate range (useful for protontherapy treatments);
- It's acquisition and processing time is less than 30 seconds against 15 mins of routine systems at CATANA facility;

FUTURE PERSPECTIVES

- Measurements at higher energies are ongoing (other ion beams)
- A deeper characterization, together with its optimisation in terms of materials and set-up configuration (smaller), is necessary in order to further improve the performances of the system.
- Development of a 'large-field' system for broader beams

THANK YOU FOR YOUR ATTENTION

Left to right: Roberto Catalano, Giovanni Manno, Emilio Zappalà, Antonio Russo, Gustavo Messina, Pablo Cirrone, Milene Ficarra, Gaetano Savoca, Cristina Guarrera, Giusi Larosa, Antonio Amato, Giada Petringa, Giacomo Cuttone, Ruhani Khanna, Giuseppe Fustaino, Beatrice Cagni, Chidera Opara, Daniele Rizzo, Salvo Tudisco, Nelly Puglia, Marco Calvaruso, Luigi Minafra, Francesco Cammarata, Giorgio Russo, Piero Lojacono