Research and Development in Hadrontherapy
WP4
Real Time, Large Area, Particle Residual Range System

Innovation in Radio and Particle Therapy
M5
Design and realization of detectors devoted to the quality control of therapeutic treatments with charged particles.

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Participants: D. L. Bonanno, D. Bongiovanni, F. Longhitano, N. Randazzo, E. Leonora and G. Gallo (Master Thesis)

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Goals

- Design of a large area (up to 40x40 cm^2) and high spatial resolution (up to 100 microns) imaging device for charged particles based on scintillating optical fibers (Sci-Fi) and a smart read-out strategy with real-time acquisition at high rate (up to 100 MHz).

Applications

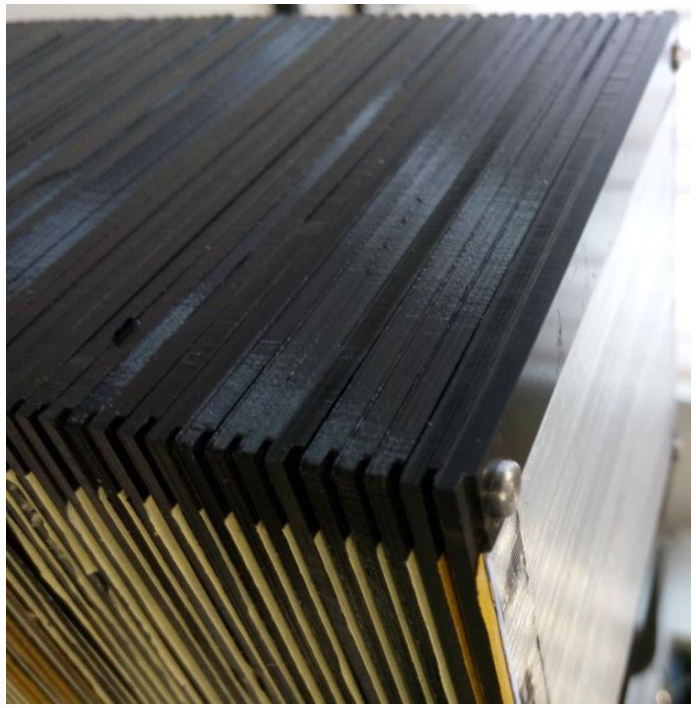
- On line beam diagnostic and monitoring
- 2D or 3D imaging
- Treatment plan verification

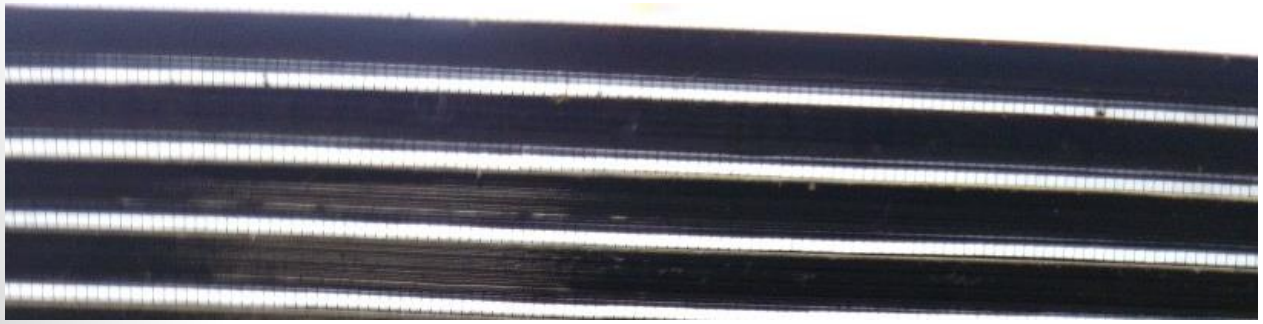
Research activities

- Characterization of Sci-Fi
- Techniques of manipulation, cutting, lapping and optical coupling
- Characterization of sensors: vacuum and solid-state photomultiplier
- Monte Carlo simulations
- Design and construction of the mechanical support for optical coupling (fiber-fiber and fiber-photosensors)
- Design and assembly of front-end electronics
- Design and programming of real-time read-out, acquisition, pre-visualization and analysis system
- Test with radioactive sources, cosmic rays and particle beams

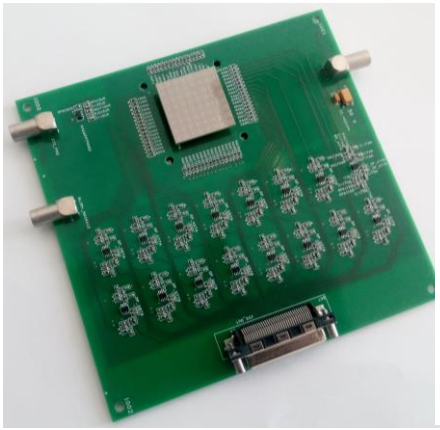
Stato dei lavori – Residual Range

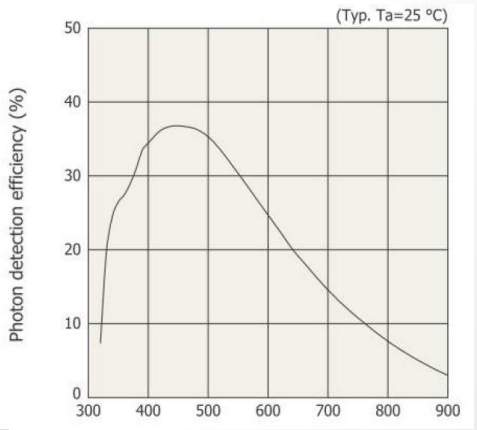
- **Nuovo prototipo costruito e pronto per i test:**
  - Range 3 cm WE – Strati da 0,5 mm
  - FOV 9x9 cm^2
  - MPPC
  - Sistema allineamento con tracciatori e fascio



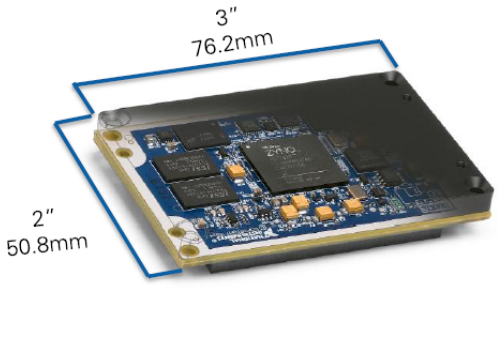


Residual range pronto per l'accoppiamento a front-end con MPPC





Stato dei lavori - Elettronica



Specifications

Processor SoC

Xilinx Zynq-7020
667 MH Dual-Core ARM Cortex-A9
Artix-7 FPGA Fabric

Size and Power

50.8mm x 78.2mm (2 in. X 3 in.)
Typical Power: 3 W to 5 W

Memory

Nonvolatile: 512 MB
DRAM: 512 MB

Operating Temperature

-40 °C to 85 °C Local Ambient

Re-programmable Intelligence on board will allow for:

- composite trigger strategies;
- Slow control;
- Calibration;
- Overall synchronization;
- Gigabit Ethernet to maximize data throughput.

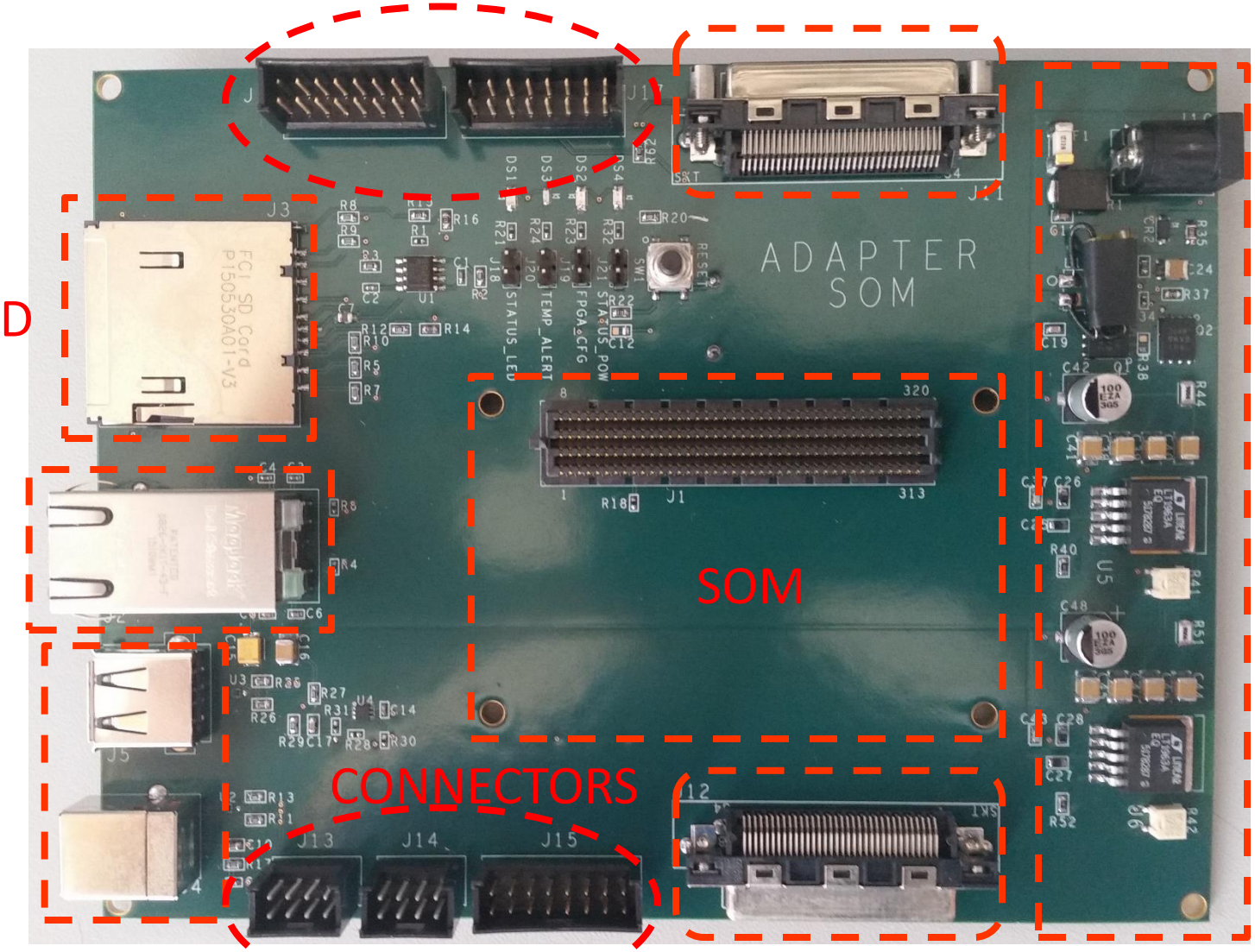
Dedicated Processor I/O
Gigabit Ethernet
USB Host
USB Host/Device
SDHC
Serial TX/RX (console out)

FPGA I/O
16 SE fixed at 3.3V
144 SE/72 diff pairs with IO level selection
3 Banks with user supplied voltage
Configurable Peripherals: Gigabit Ethernet, RS232 x3, RS485 x2, CAN x2

Adapter SOM

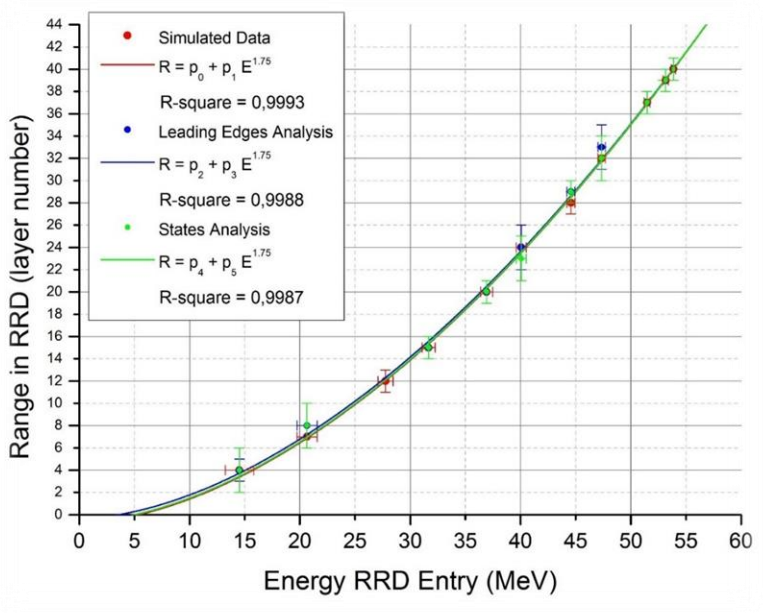
Measured Performance:

- ✓ *Sampling of 128 digital input SE @230MHz*
- ✓ *Sampling of 64 digital input SE @350MHz*

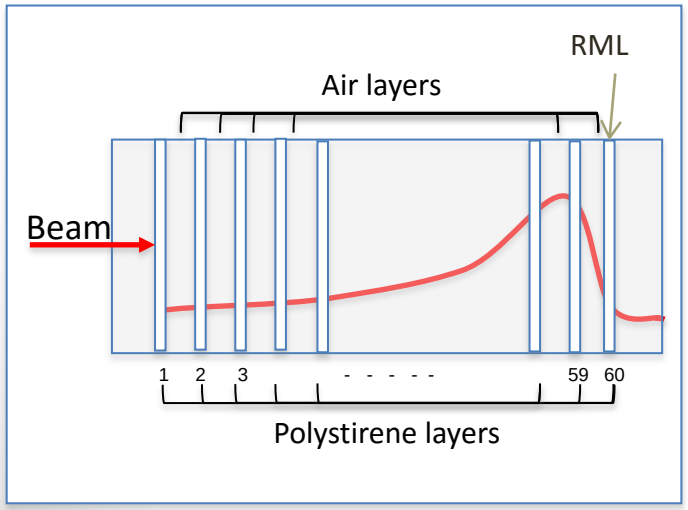


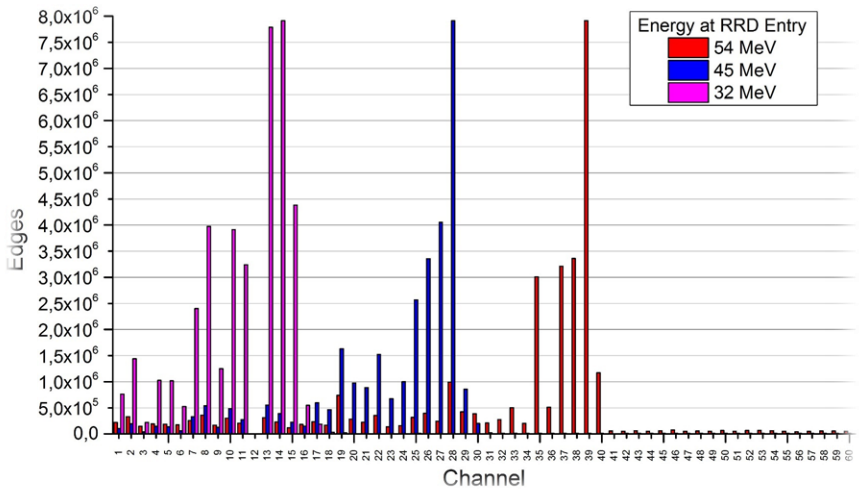
Test Residual Range

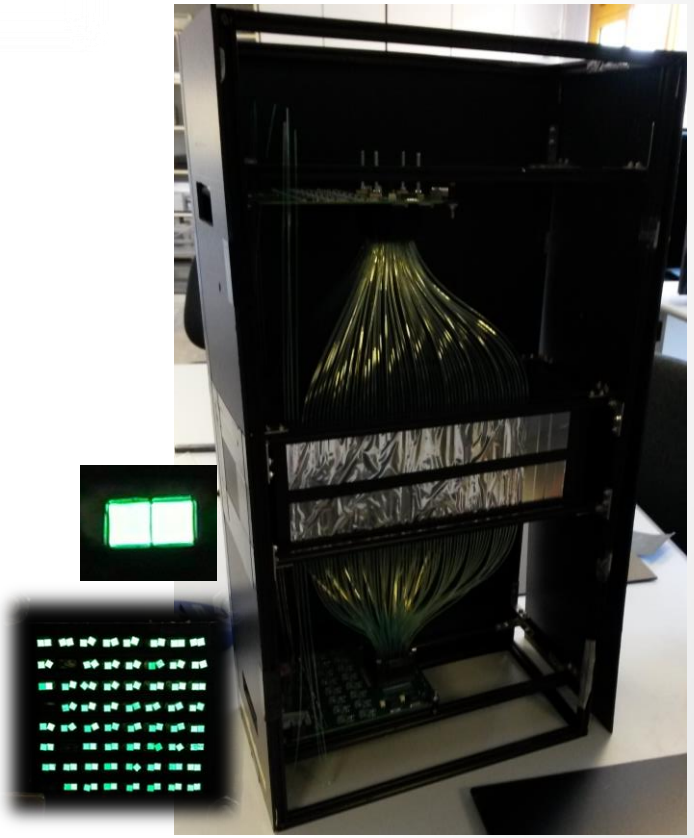
- TRIM and GEANT4 Simulations of a Residual Range detector prototype;
- Catana Beam Line – 62 MeV proton;
- 60 Polystirene Layers 500 μm thick
  + 2 mm Air + 200 μm PVC;
- 90x90 mm^2 area;
- Water equivalence;
- Right Most layer (RML) related to Bragg Peak;
- Energy resolution <3% full range (70 MeV)



Range shifter	Pick of Gauss Fit	sigma	Range	Errore
--	38,80	0,60	40	1
A0	37,81	1,33	39	1
A2	35,46	1,27	37	1
A5	29,48	2,15	33	2
A7	27,73	0,63	29	1
A10	20,93	2,08	24	2
A12	19,06	0,88	20	1
A15	13,73	0,93	15	1
A17	9,40	2,03	11	2
A20	5,40	2,48	8	2
A22	1,96	1,19	4	1







QBERT– Misure con tracciatore

Da interazione con lo staff di CNAO, ideato nuovo sistema:

Qbert (patented).

Profilometro di fascio real-time

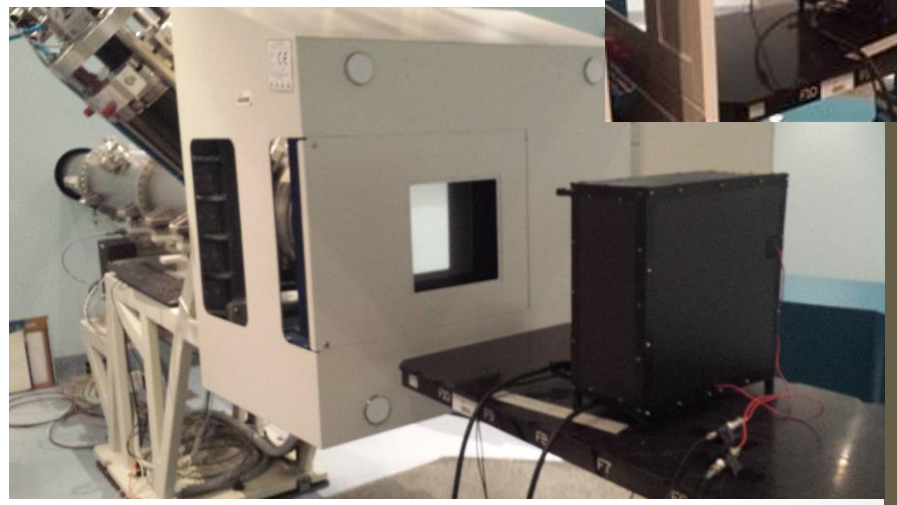
ATTIVITA'

- Deposito domanda di brevetto INFN 7 maggio 2015
- In corso azione di trasferimento tecnologico con PTW
- Prototipo da 7,5x7,5 cm^2 testato a CNAO (novembre) e CATANA (ottobre e febbraio) con successo.

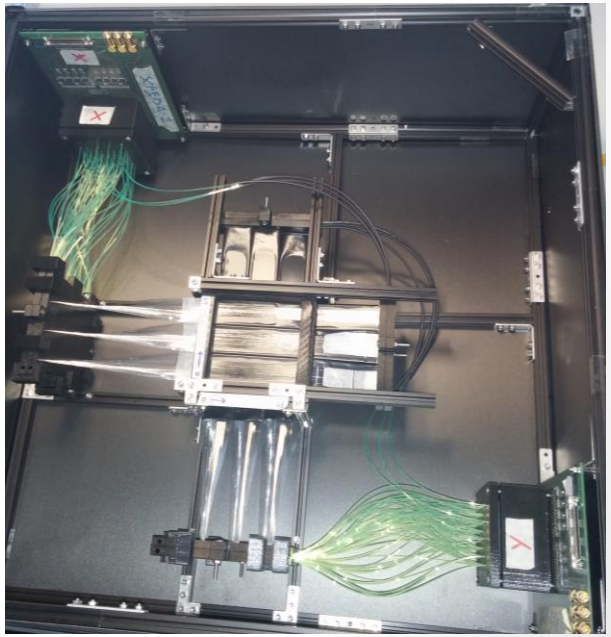
STATO

- In corso analisi dati delle misure a CNAO:
  - Confronto con log del sistema monitor CNAO su:
  - Posizione spot e fluenza.
- Acquistate nuove fibre, in arrivo a Luglio (ritardo di 3 mesi).
- Costruzione completata del frame di supporto del nuovo prototipo con FOV da 8x8 cm^2.
- Previsto test a CNAO e TIFPA.

Tracciatore a CNAO



Tracciatore – QBeRT

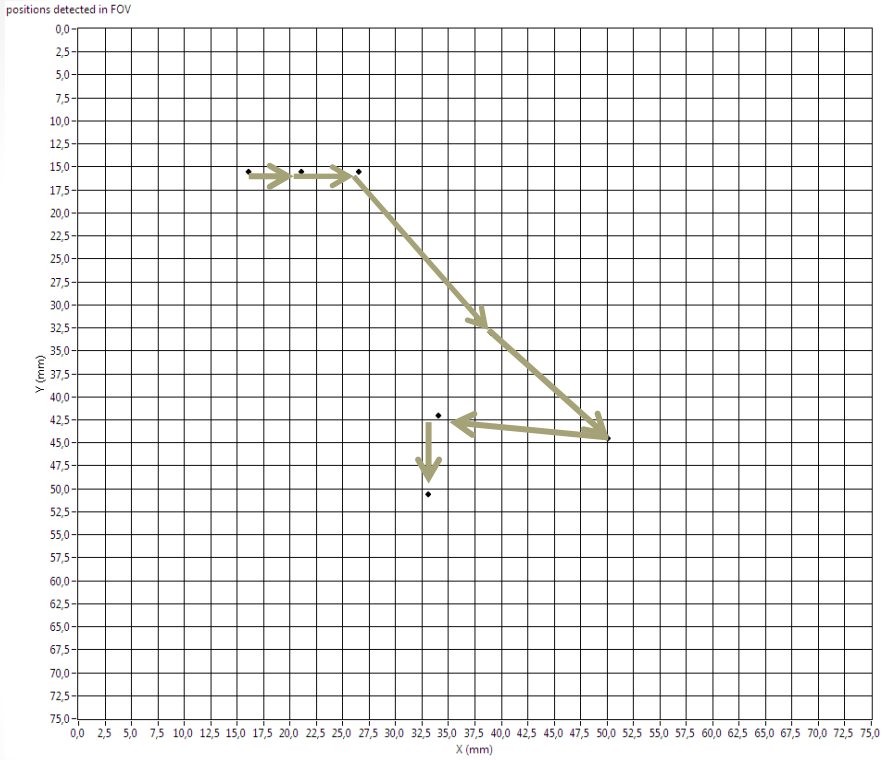


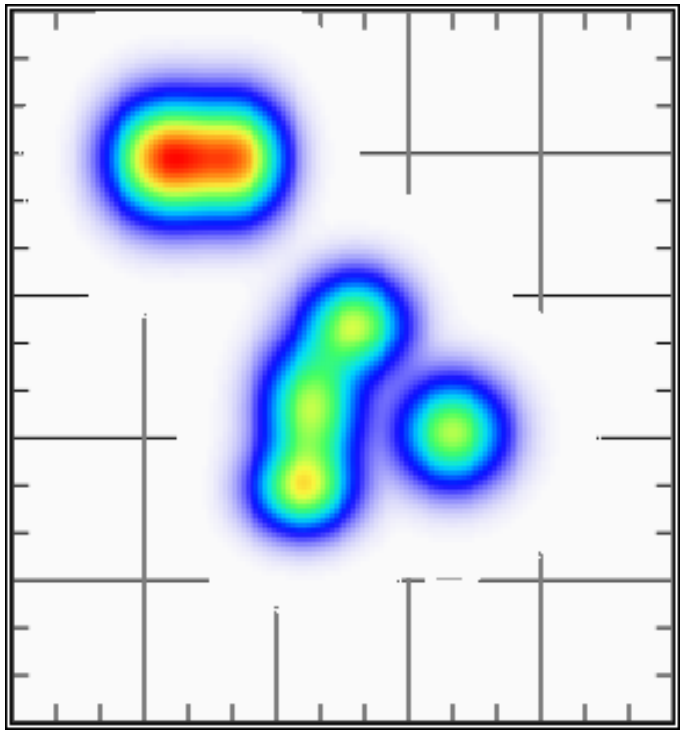
Stato dei lavori - TRACCIATORI

QBERT CATANA – Misure con tracciatore

CATANA - Posizione spot fascio Protoni 62 MeV collimato a 5 mm

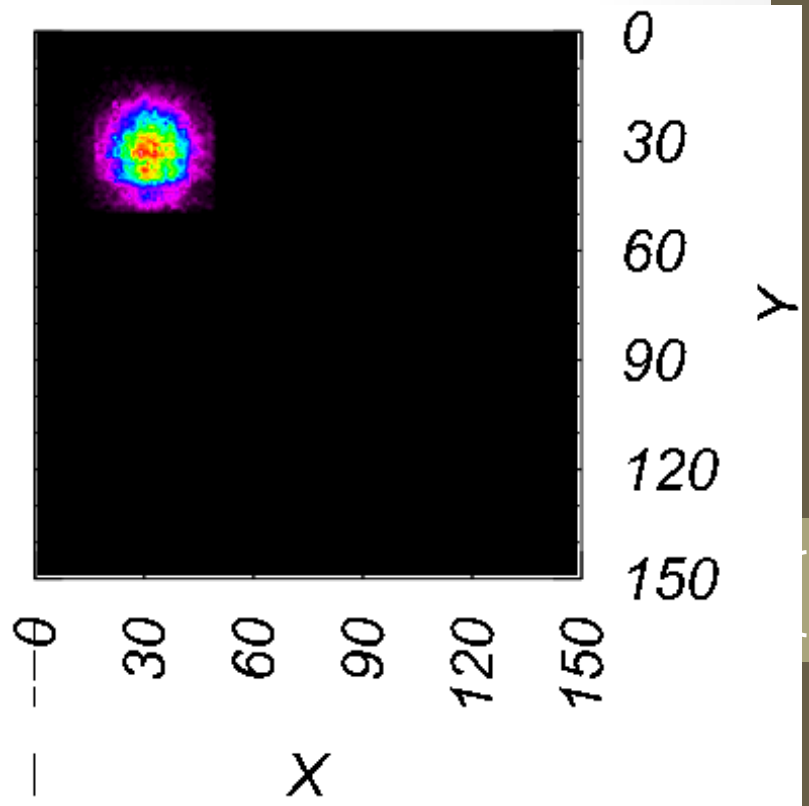
Spostamento micrometrico della sedia e verifica posizione ricostruita





Imaging Spot fascio

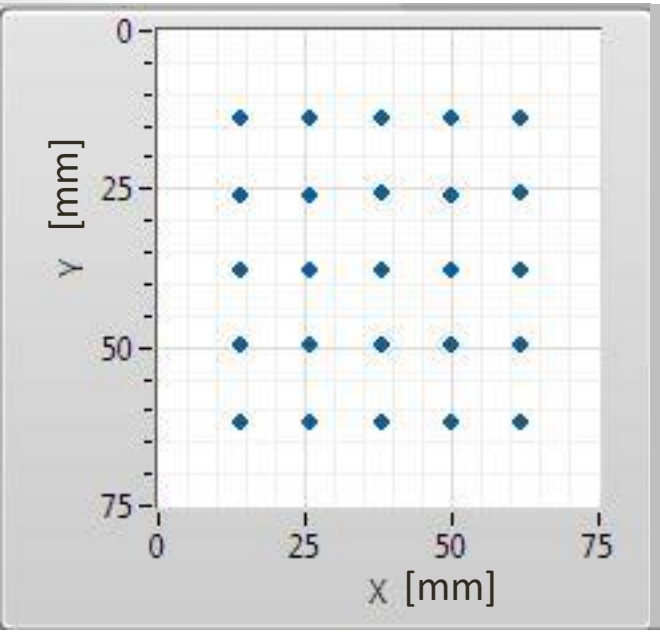
Massima intensità CATANA

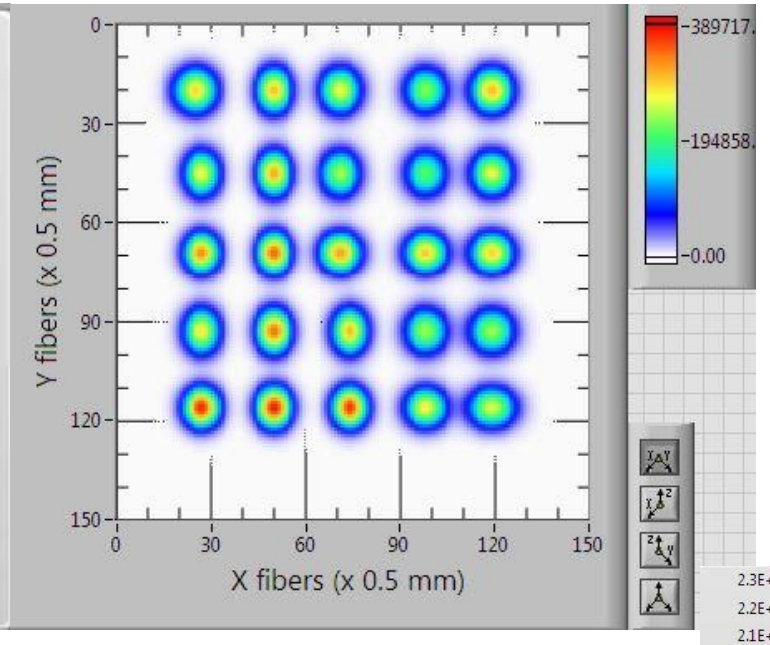


Canali non calibrati

QBERT CNAO – Misure con tracciatore (non calibrato)

Pattern di spot Carbonio 400 AMev da controllo >10^8 per spill e misurato

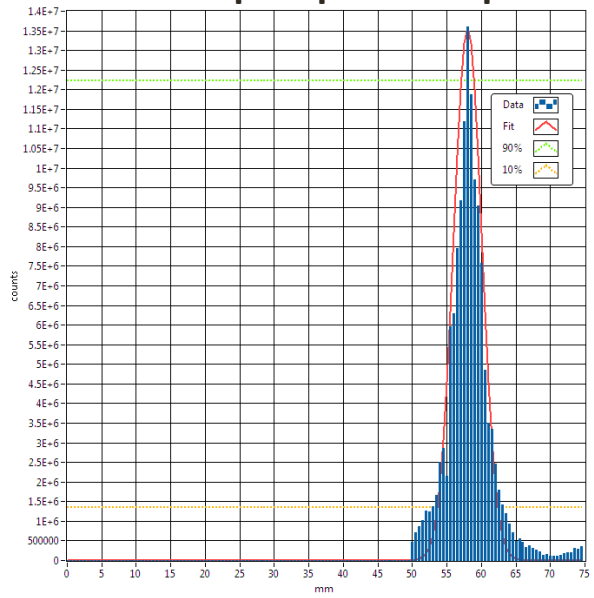




Da Sala controllo viene impostato un pattern di posizioni dello spot eseguito in un numero di spill funzione del numero di particelle previste per spot.

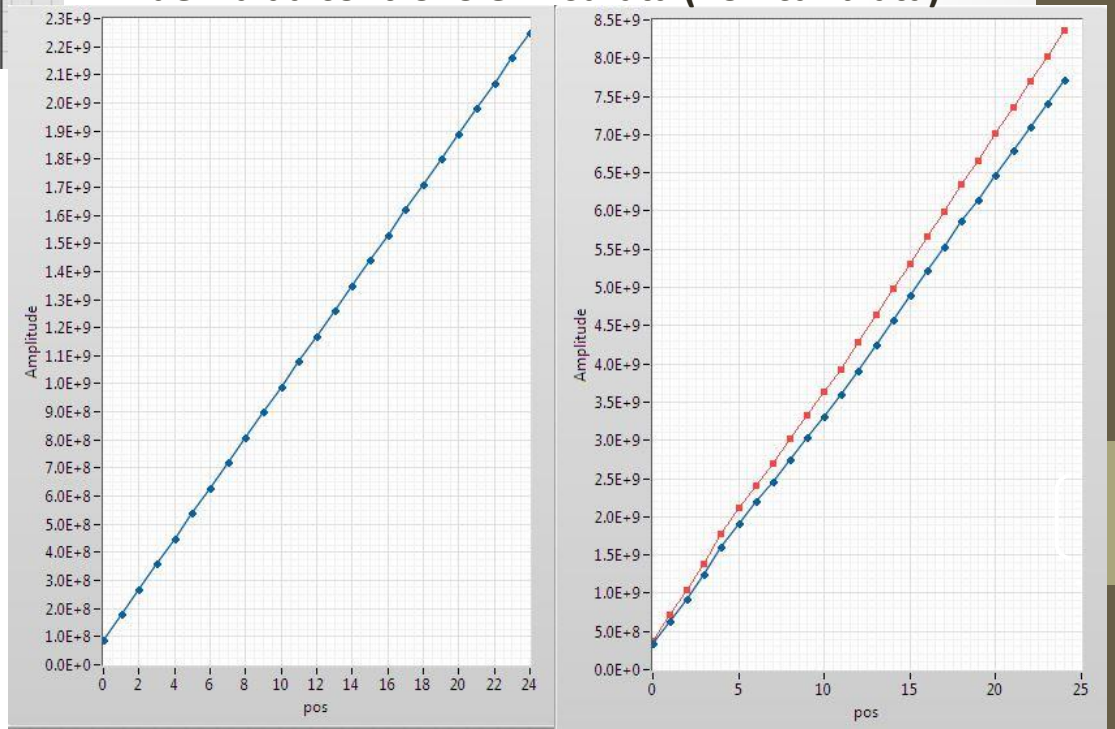
Il tracciatore sincronizzato alla macchina acquisisce e ricostruisce in tempo reale la posizione dello spot, i profili e la fluenza.

Profilo X tipico per uno spot



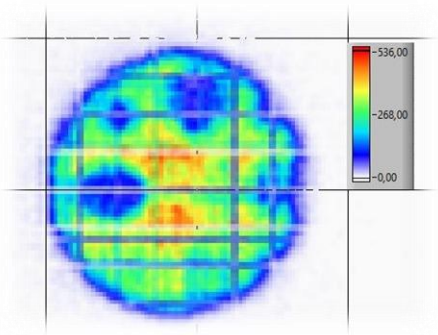
Buona proporzionalità della fluenza, misurata simultaneamente dai due strati x e y del tracciatore

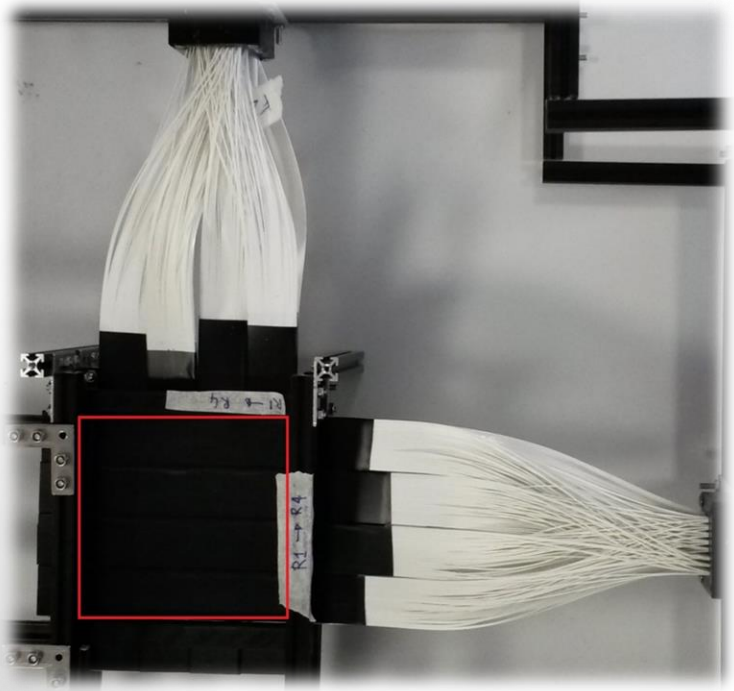
Fluenza da controllo e misurata (non calibrata)

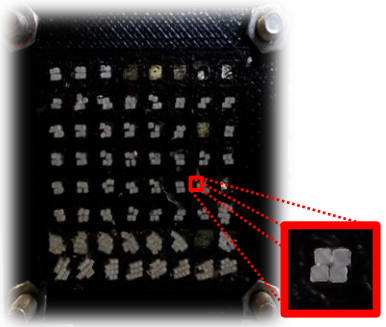


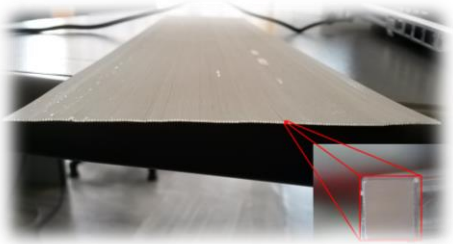
Test QBERT profilometer

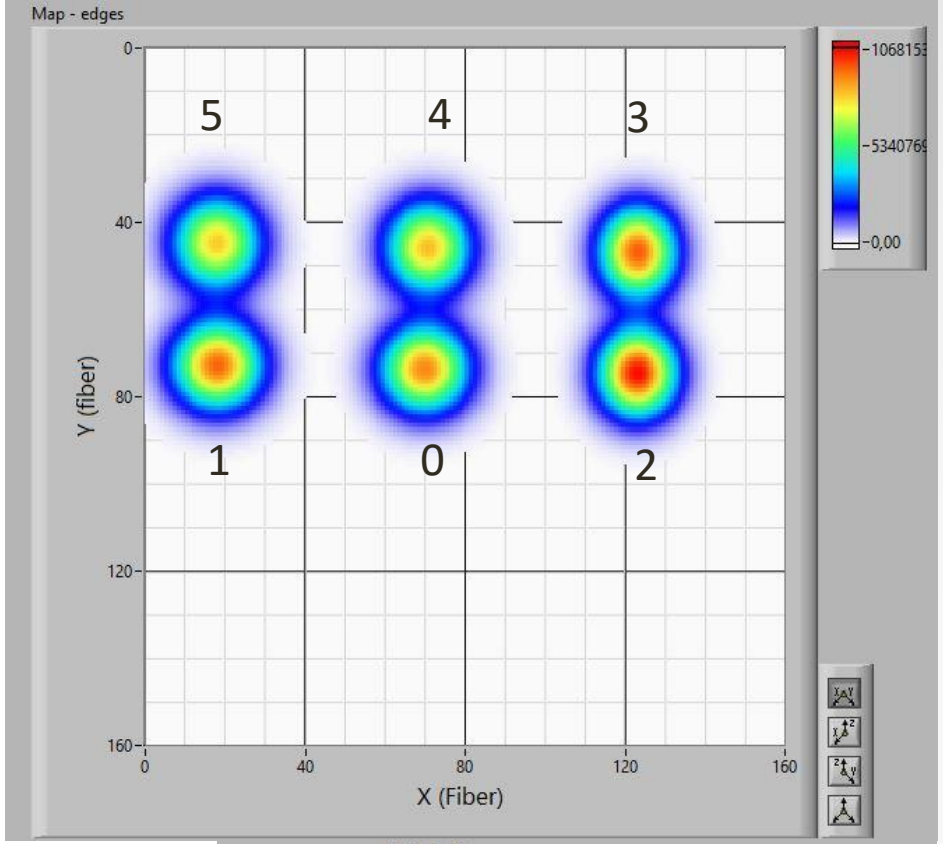
- Catana Beam Line – 62 MeV proton;
- 4 Polystirene Layers 500 μm thick, 1 mm WE ;
- 80x80 mm^2 area;
- Real Time measurement of beam position, size and fluence.
- Real Time imaging

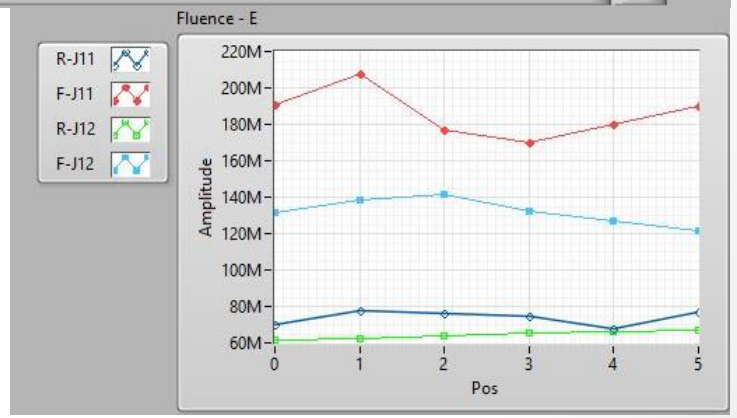




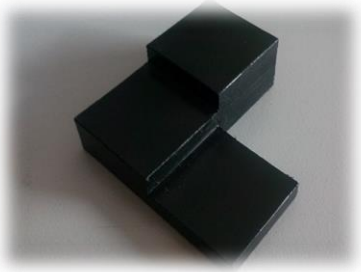


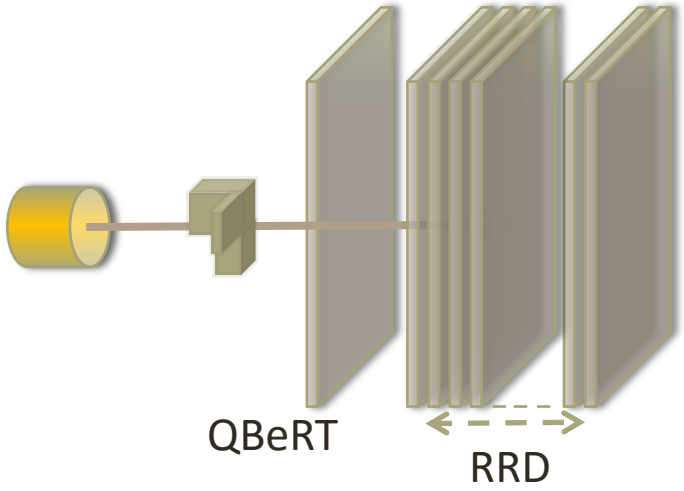


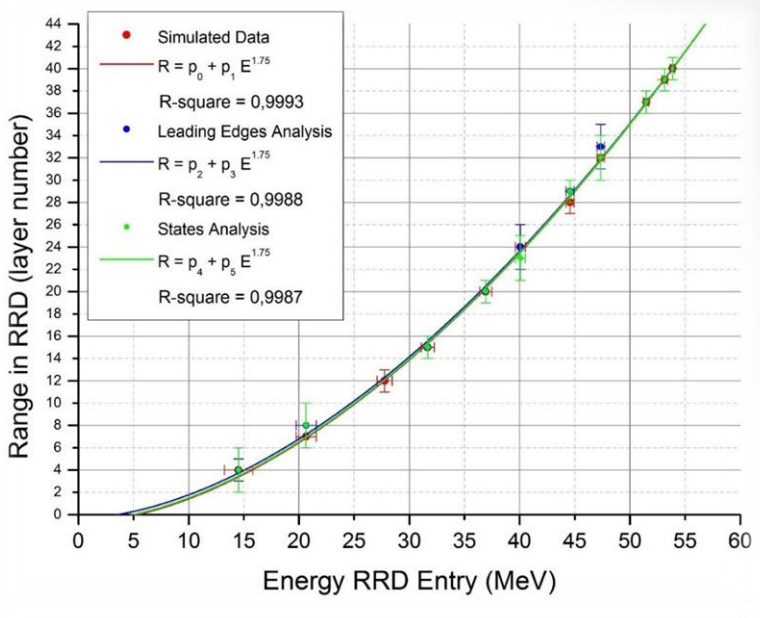




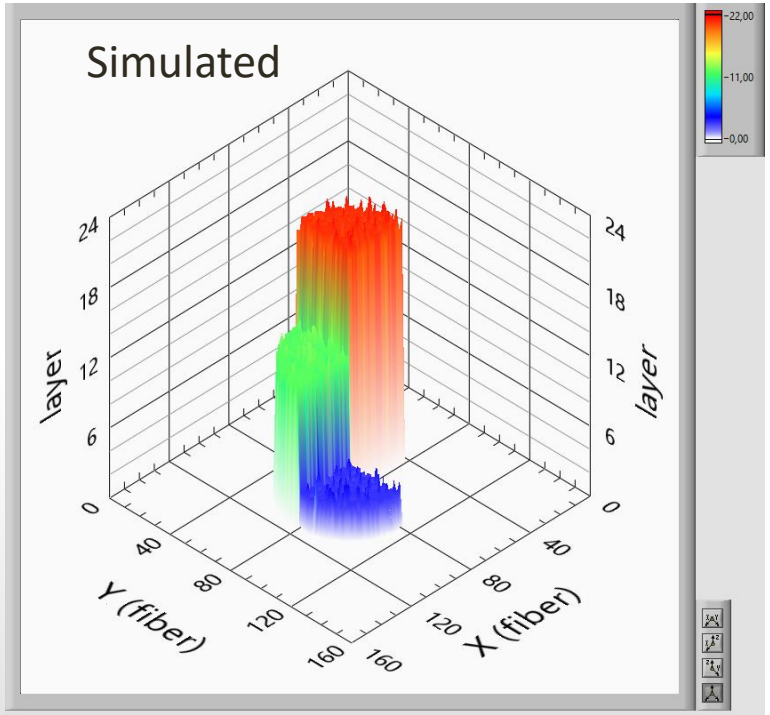
Radiography QBERT+RRD



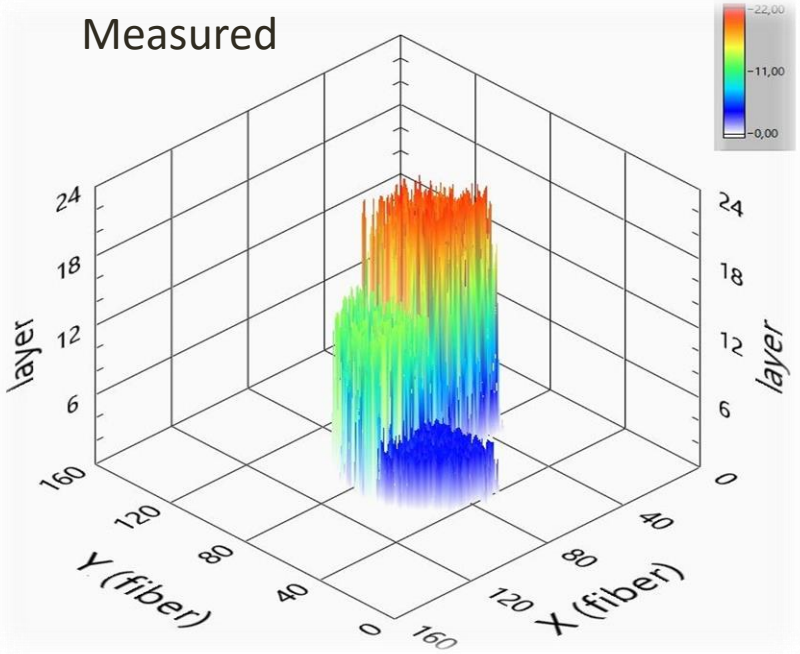




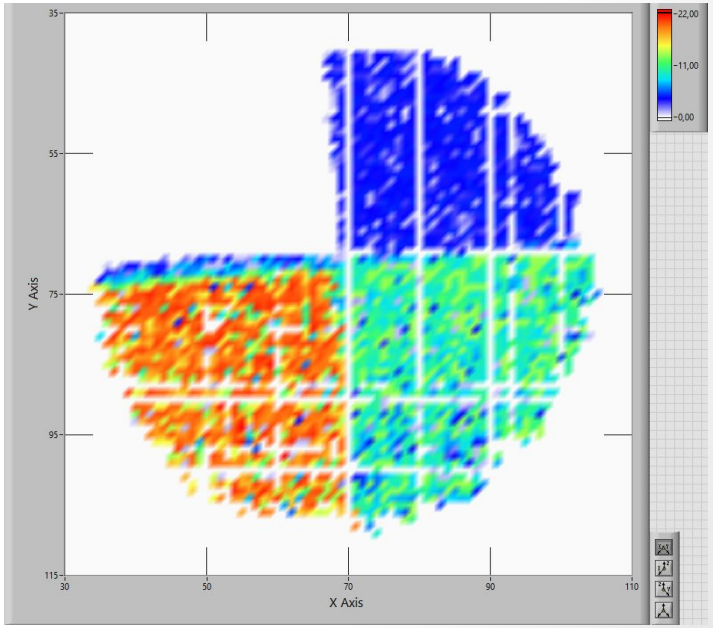
Simulated



Measured



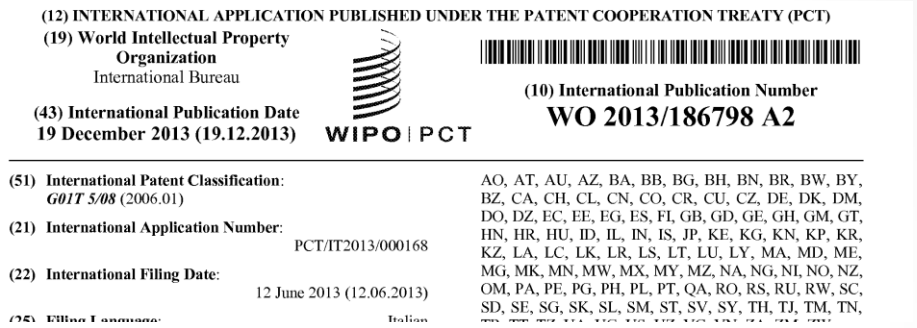
Measured



Trasferimento Tecnologico

- Brevetto internazionale INFN
  - Residual range e metodo compressione canali

- Domanda di brevetto INFN
  - Profilometro di fascio real-time
  - In atteso del rapporto scientifico
    da parte dell'ufficio brevetti europeo



(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
19 December 2013 (19.12.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/186798 A2

(51) International Patent Classification:
G01T 5/08 (2006.01)

(21) International Application Number:
PCT/IT2013/000168

(22) International Filing Date:
12 June 2013 (12.06.2013)

(25) Filing Language: Italian

AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,

- Interesse di PTW su acquisizione brevetti, azione in corso

Conferences and proceedings

- Conference: IEEE Nuclear Science Symposium / Medical Imaging Conference Record (NSS/MIC) / 19th Room-Temperature Semiconductor X-ray and Gamma-ray Detector Workshop Location: Anaheim, CA Date: OCT 29-NOV 03, 2012 Sponsor(s): IEEE
- 15th International workshop on radiation Imaging detectors, Parigi 2013
- 19th Real Time Conference, May 26-30 2014, Nara - Japan

Publications

- "OFFSET3: A Real-Time Particle Tracker Based On Scintillating Optical Fibers" – D. Lo Presti et alter – IEEE TRANSACTIONS ON NUCLEAR SCIENCE,VOL.62,NO.3,JUNE 2015 1135
- "A real-time, large area, high space resolution particle radiography system" D. Lo Presti et alter - JOURNAL OF INSTRUMENTATION Volume: 9 Article Number: C06012 Published: JUN 2014
- "Development of a Real-Time, Large Area, High Spatial Resolution Particle Tracker Based on Scintillating Fibers" – D. Lo Presti et al. - Advances in High Energy Physics 03/2014; 2014. **invited**
- "OFFSET: Optical Fiber Folded Scintillating Extended Tracker" - D Lo Presti et alter - Nuclear Instruments and Methods in Physics Research A. 01/2014; 737:195-202.
- "Design and Characterization of a Real Time, Large Area, High Spatial Resolution Particle Tracker Based on Scintillating Fibers" - D Lo Presti et al. - Biomedical Engineering Research. 12/2013; 2(4):159-174. **invited**
- "Development of a scintillation-fiber detector for real-time particle tracking" - D. Lo Presti et alter - JOURNAL OF INSTRUMENTATION Volume: 8 Article Number: P04015 Published: APR 2013
- "A Real Time, Large Area, High Spatial resolution Tracker based on square scintillating fibers " D. Lo Presti et alter - 2012 IEEE NUCLEAR SCIENCE SYMPOSIUM AND MEDICAL IMAGING CONFERENCE RECORD (NSS/MIC) Book Series: IEEE Nuclear Science Symposium Conference Record Pages: 1244-1249 Published: 2012

Tesi

2015 – G. Gallo – «Realizzazione e caratterizzazione di un sistema per imaging con particelle cariche e qualifica del piano di trattamento in adroterapia"
2014 – C. Pugliatti – «Particle scintillating trackers: Design and read-out of real-time, large area, highly segmented detectors»- PHD
2013 – P. Barone – «PREDATE – Particle Residual Energy and Tracker Enhancement» – laurea triennale in fisica.
2013 - G. Petringa – "Studio per la realizzazione di una radiografia con protoni in tempo reale" - laurea triennale in fisica.

Conclusioni

- Tracker/Profilometer e Residual Range detector pronti
- Campagna di misure, CNAO e TIFPA, analisi e dati e presentazione risultati – 2016
- Trasferimento tecnologico in corso