Characterization of a 2.7x2.7 cm² particle beam monitor based on a silicon detector segmented in 146 strips

Mohammed Abujami[1,2], Simona Giordanengo[2], Emanuele Data[1,2], Marco Donetti[3], Sara Garbolino[2], Oscar Ariel Martì Villarreal[1,2], Felix Mas Milian[1,4], Anna Vignati[1,2], Roberto Cirio[1,2], Vincenzo Monaco[1,2] and Roberto Sacchi[1,2].

[1]University of Turin, Department of Physics, Turin, Italy;[2]National Institute for Nuclear Physics INFN, Turin division, Turin, Italy;
[3]Centro Nazionale di Adroterapia Oncologica (CNAO), Pavia, Italy; [4]Universidade Estadual de Santa Cruz, DCEt, Ilheus, Brazil.

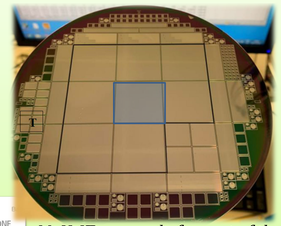
Purpose

The goal of the project is to investigate a **new technology** based on **thin silicon sensors** to overcome the limitation of the ionization chambers currently used for beam monitoring in Particle Therapy. The technology aims at **counting individual protons** at **clinical rates** with a pileup inefficiency below 2%.
A prototype of proton counter was developed by the University of Torino and INFN able to reach up to **10^8 p/s*cm²** counting rate over the whole beam cross-section.

Sensors

Large size Low Gain Avalanche Diodes (LGAD) [1] were produced by Fondazione Bruno Kessler (FBK, Trento, Italy) in the framework of the MoVeIT INFN project for the proton counter.
They feature:

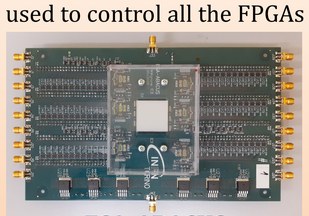
- 45-60 µm active thickness
- 146 strips, 3 mm² area,180 µm pitch
- Total sensitive area 2.7 x 2.7 cm²
- Internal gain ~ 10
- Geometrical efficiency ~ 55% due to interstrip dead area



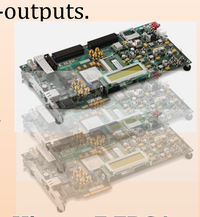
MoVeIT sensors before cut of the wafer

Frontend board

Frontend 24 ch ASIC named ABACUS implementing amplifier-discriminator circuit was developed with counting capability up to 100 MHz [2].
The ESA_ABACUS frontend board houses six ABACUS chips to readout the 144 strips.
Three Xilinx Kintex7 (KC705 Evaluation Kit) FPGAs with main clock of 100 MHz collect the ABACUS outputs and implement counters for each channel. A LabVIEW program is used to control all the FPGAs input-outputs.



ESA_ABACUS



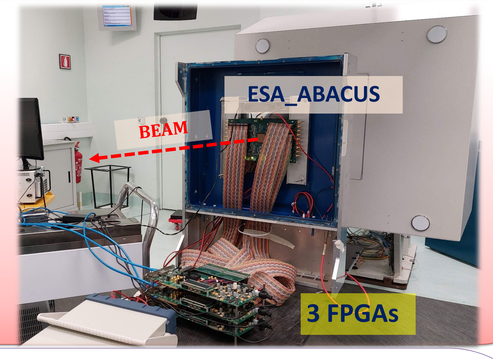
Kintex-7 FPGA

LabVIEW program

Beam test in the Italian CNAO therapy center

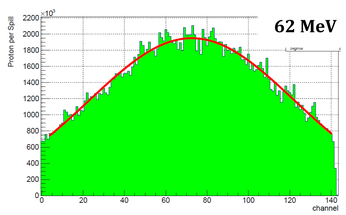
Preliminary tests of the beam monitor were performed with the CNAO clinical proton beams.

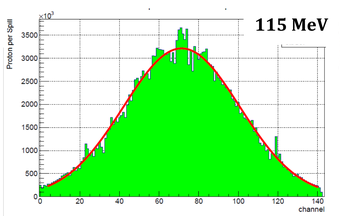
- Beam energies **62, 115, 227 MeV**
- Different fluence rates: clinical (100%, 10^9 p/s*cm²) degraded to 20 and 50%
- Spots of **5*10^8 protons** each (10^8 protons each at 20% degrader)
- Board positioned at the **isocenter**

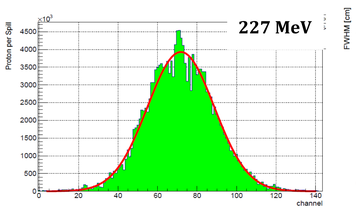


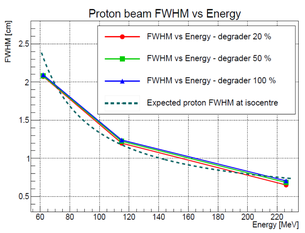
Results and Discussion

Beam profiles
The beam profiles are fitted with a Gaussian function to extract the FWHM. The comparison with the expected values [3] are shown in the right figure.

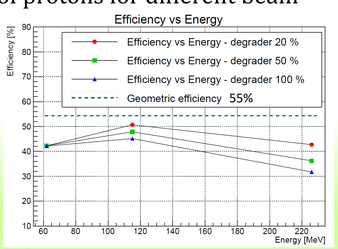






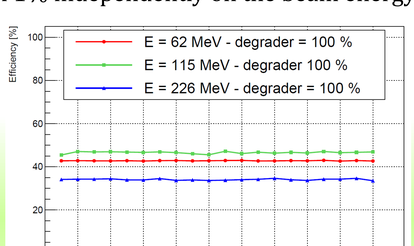


Counting efficiency
The **counting efficiency** was determined comparing the total number of counts with the delivered number of protons for different beam fluences and energies.
- Dashed line corresponds to the expected geometrical efficiency.



Two effects decrease the efficiency:
- the increase of proton fluence rate in the detector channels (**pile-up**)
- at 62 MeV the beam cross section (FWHM 23 mm) is not fully contained

Uniformity in time
Uniformity over 20 identical spills better than 1% independently on the beam energy.



Conclusion

The preliminary tests of the ESA_ABACUS with fluxes larger than the design (< 10^8 p/s*cm²) prove the feasibility of directly measuring the particle rate and the beam shape with a good stability in time.
In these conditions, inefficiencies due to pile-up effect were observed. Further studies are ongoing to mitigate the pile-up effect and other sources of systematic uncertainties.

References
[1] O. M. Villarreal, et al., "Characterization of thin LGAD sensors manufactured at FBK for proton counting in particle therapy", submitted to Nucl. Inst. Meth. A
[2] F. Fausti, et al., "A single ion discriminator ASIC prototype for particle therapy applications" Nucl. Inst. Meth, A 985 (2021)
[3] A. Mirandola, et al., "Dosimetric commissioning and quality assurance of scanned ion beams at the Italian National Center for Oncological Hadrontherapy" –Med. Phys. 42 (9) (2015)

ACKNOWLEDGMENTS
This work was supported by INFN-MoVeIT project and MIUR project «Dipartiemnti di eccellenza»