Giornate Romane su “Particelle e Fisica Applicata”

Dipartimenti di Fisica e Matematica

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Development of a diagnostic system for therapeutic proton beam and indirect monitoring of patient released dose

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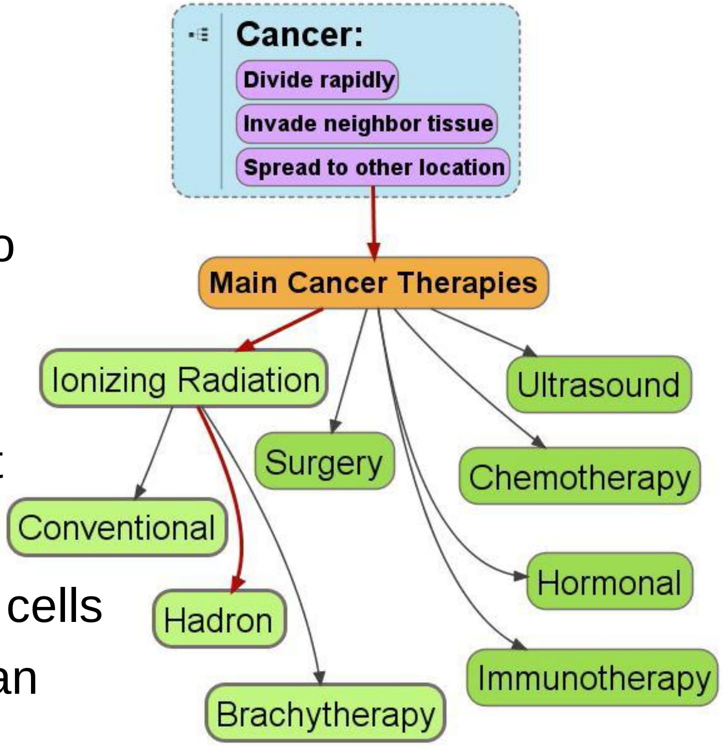
Cancer Relevance

Cancer affects 1/3 of people – first cause of death between 45 and 65 years

- ❑ Multiple Approaches: surgery, chemotherapy, immunotherapy, radiotherapy, hormonal.
- ❑ Approx. 1/4 patients owe their 5 years survival to radiotherapy



Radiotherapy plays a leading role. Radiation is not selective, but it is possible to achieve selectivity:

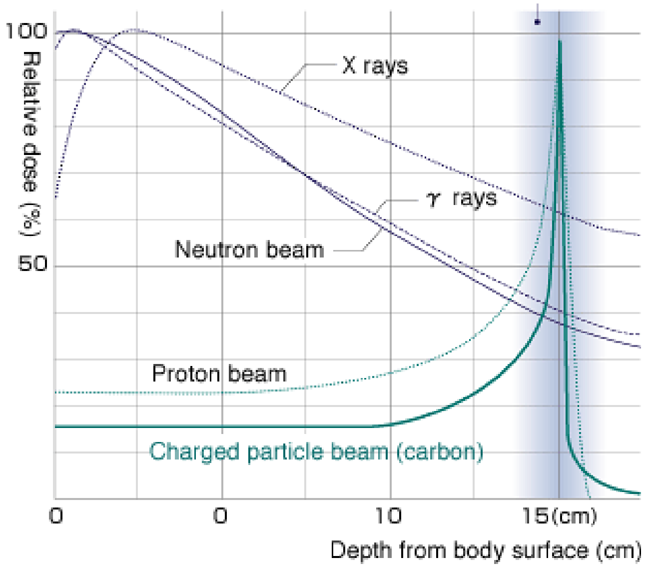
- ❑ Tumor cells are more radiosensitive than normal cells
- ❑ Reparability of malignant cells is less efficient than normal cells
- ❑ Dose delivered can be conformed to diseased tissue

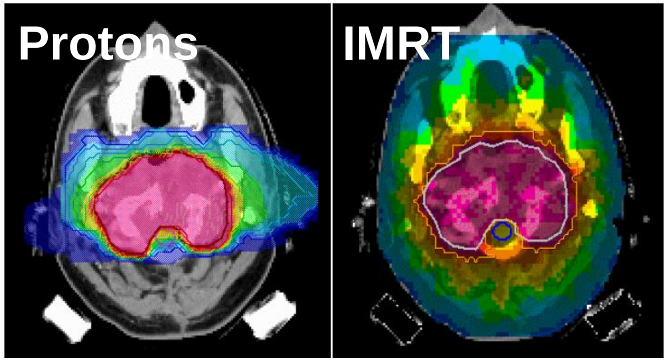
Any additional progress can improve the number of the cured patients and the quality of live: the use of hadrons is presently on of the most promising way in specific cancers

Conventional radiotherapy and hadrontherapy

Modern radiotherapy consists mainly of:

1. **Conventional radiotherapy** with <u>electrons</u> and <u>photons</u> up to 25 MeV
   - ❑ the best choice for the treatment of the shallower tumors (electrons)
   - ❑ high conformation with IMRT
   - ❑ the most diffused option in radiotherapy treatments
2. **Hadrontherapy**
   - ❑ more suitable for radioresistant tumors
   - ❑ higher conformation (intrinsic)
   - ❑ about 40 centers around the world
3. **Others: BNCT, (Pion Therapy)**





G. Kraft, GSI, Biophysik, Darmstadt and J. Debus, DKFZ, Heidelberg

Protontherapy with LINAC

Proton therapy accelerators produce beams with the following main features:

- ❑ energy high enough to reach the deepest tumors (up to 240 MeV)
- ❑ a beam current adequate to achieve treatment times comparable to those of conventional facilities
- ❑ the capability to provide uniform doses to the target volume

Hadrontherapy currently uses synchrotrons, cyclotrons or synchrocyclotrons

LINAC can be considered a valid option:

- ❑ There is no power loss from synchrotron radiation (simpler radioprotection)
- ❑ Injection and extraction are simpler than in circular accelerators
- ❑ LINAC can operate at any duty factor, working at high repetition rate and allowing pulse current modulation
- ❑ Expected to be cheaper

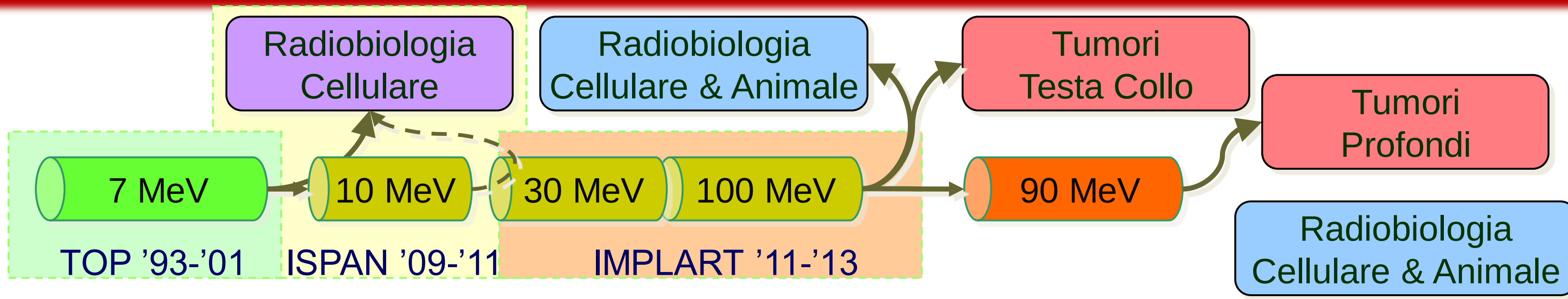
… but

- ❑ The technology is not fully proved for proton-therapy
- ❑ ions can not be accelerated in a proton LINAC

Protontherapy with LINAC: the TOP-IMPLART project

The TOP IMPLART (ENEA - ISS - IFO) project aims to realize an innovative proton therapy facility, based for the first time, on a linear accelerator.

Funding: ISS before 2002, Region after 2009



TOP-IMPLART LINAC features:

- The **active scanning (3+1D)** in
  - **Intensity** (instantaneous released dose)
  - **Energy** (depth)
  - **Transversal Position** (X/Y)

allows a highly conformational therapy ⇒ **need of accurate monitoring of the beam parameters on a pulse by pulse basis**

- The modular implementation allows a modular/progressive development (based on the financial flow)
- The use of widely diffused (3 GHz) radiofrequency technology reduces realization and maintenance costs

Purpose of the current research activity

Development of the beam monitor system for the TOP_IMPLART LINAC with indirect information of dose delivery

- ✓ **Suitable for the monitoring of proton (or electron) beam in other facilities**

The monitoring system design must adhere to the following requirements:

- ❑ The beam parameters (position, intensity profile, direction/emittance) are continuously monitored independently from the beam controls
- ❑ Quick response (faster than beam pulse period)
- ❑ Provide feedback information to correct small deviation from the planned therapeutic treatment
- ❑ Automatic shutdown irradiation in case of large (not recoverable) deviation from planned parameters
- ❑ High reliability

Beam monitor system requirements for the TOP-IMLART LINAC

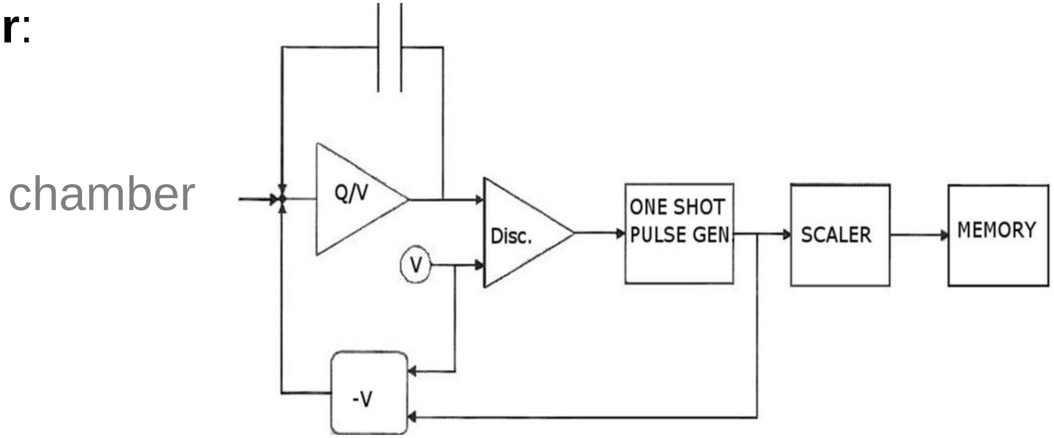
Pulsed beam characteristics		Beam monitor system specifications
Energy in the range	130-250 MeV	Light compact chamber (segmented)
Beam cross section	1-10 mm	Good spatial resolution (~1/10 mm)
Beam current	0.1-10 μA	Wide dynamic range (10^4 at least) for each channel
Average current:	10 nA	Good sensitivity (~100 fC)
Pulse period	1-5 μs	Zero dead time (or near zero)
Pulse frequency (it allows dose repainting without much time demanding)	100-400 Hz	Rapid response (< 1ms)
		Typical channels: few 100

Beam monitor in protontherapy

Beam monitoring systems in proton therapy are commonly based on **couples of ionization chambers**.

The chamber front-end electronics is generally performed by using traditional electronic schemes, e.g. **rate meter**:

Works well on long pulses (order of msec)



- Sensitivity is related to the “quantum” voltage V
- Dynamic range is equal to the maximum number of pulses generated in the time duration of the beam pulse (high performance frequency/converter and scaler ~100 MHz*10µs, the dynamic range does not exceed 1000)

an alternative:

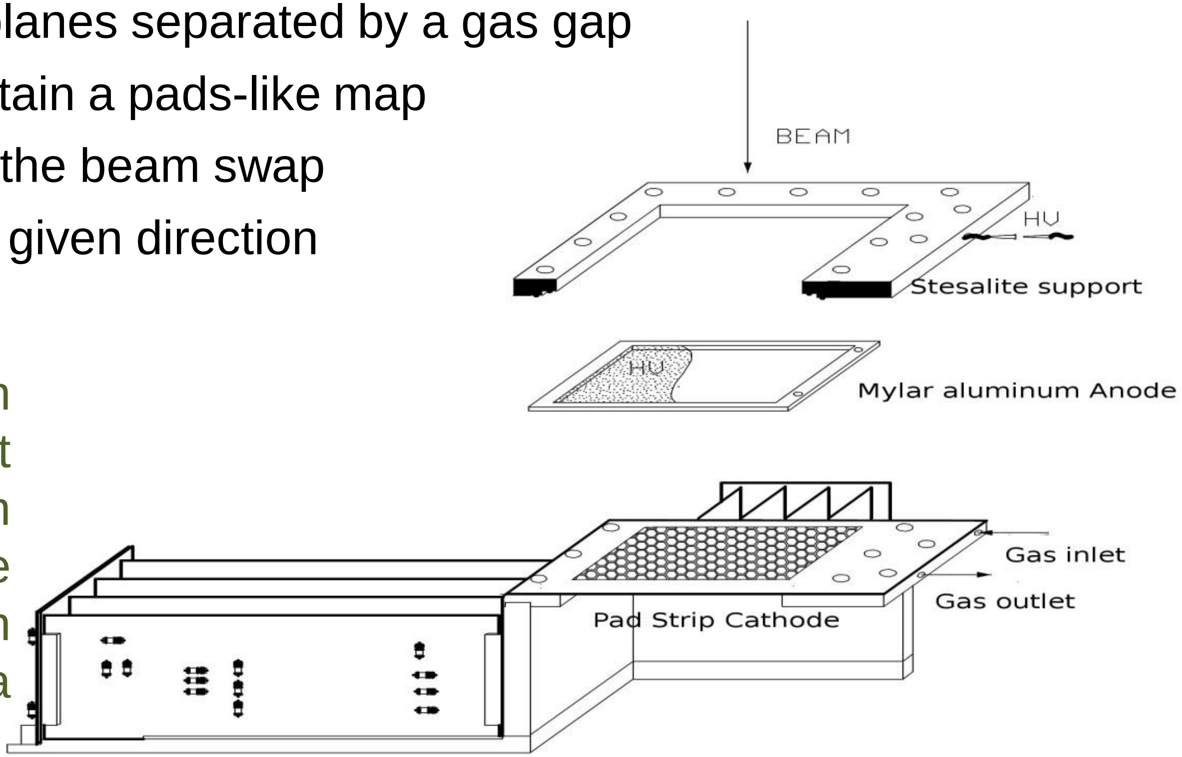
- Charge amp and good performance ADC converters (limited by the input stage saturation, the ADC bit number, achieving the dynamic range of ~1000)

The beam monitor developed for the TOP-IMPLART LINAC

The TOP-IMPLART monitor system is based on 2D segmented ionization chamber driven by a dedicated front end electronics designed to OVERCOME limitations of the traditional electronics schemes (ratemeter, charge amp and ADC converters):

- the prototype consists of 2 planes separated by a gas gap
- the anode is engraved to obtain a pads-like map
- active surface able to cover the beam swap
- pads are connected along a given direction
- dedicated electronics

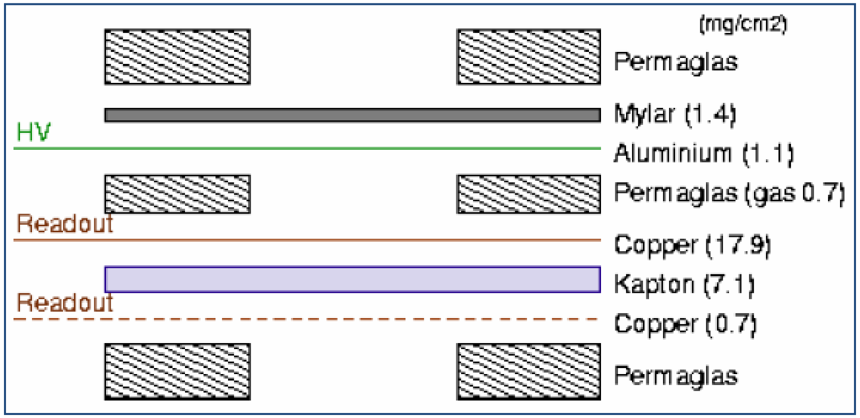
The chamber has been designed according to recent developments in micro pattern gaseous detectors and the readout foil has been produced by Rui De Oliveira at TS-DEM, CERN

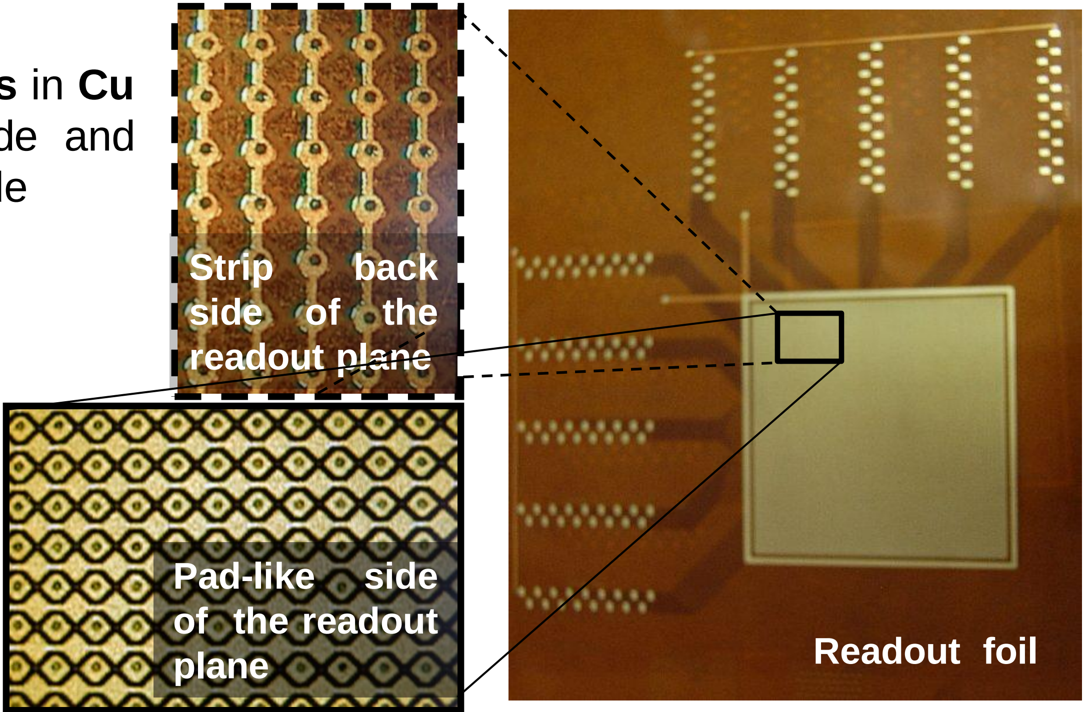


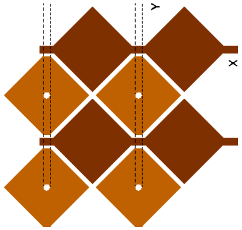
The ionization chamber

The chamber operates in ionization region and has the following characteristics:

- **GAP** between anode and cathode: **2mm**
- Anode and cathode **ACTIVE AREA**: **7x7cm^2**
- **ANODE:** Al (**5µm**)
- **CATHODE**: Kapton (**50 µm**) with **PADs** in **Cu** (**15 µm**) on the beam incidence side and **STRIPs** in **Cu** (**15 µm**) on the other side
  - **PITCH:** **875 *µm***
  - **Gap between pad**: 120 *µ*m
- **CHANNELS:** **80 x 80**
- **BIAS:** **300 V**



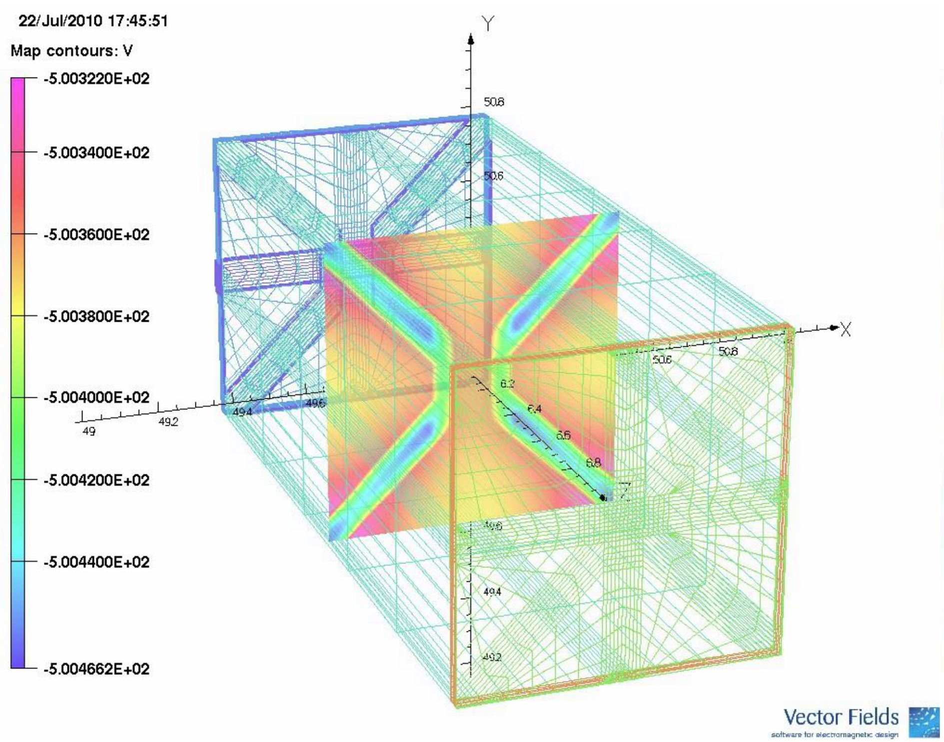


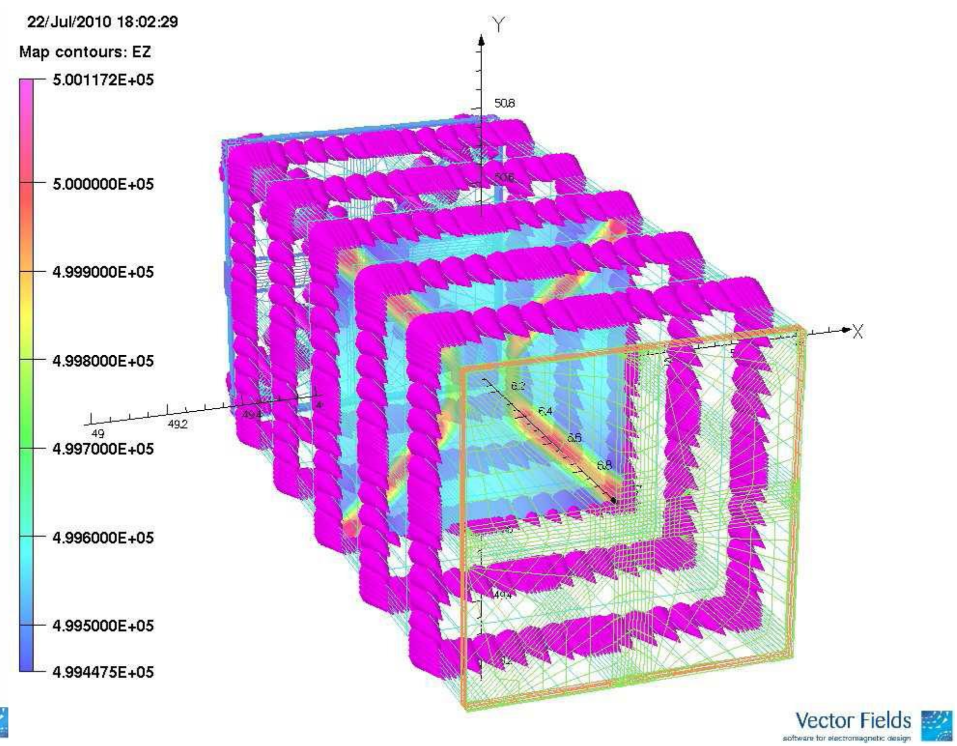


Simulation of the chamber Electrostatic Field

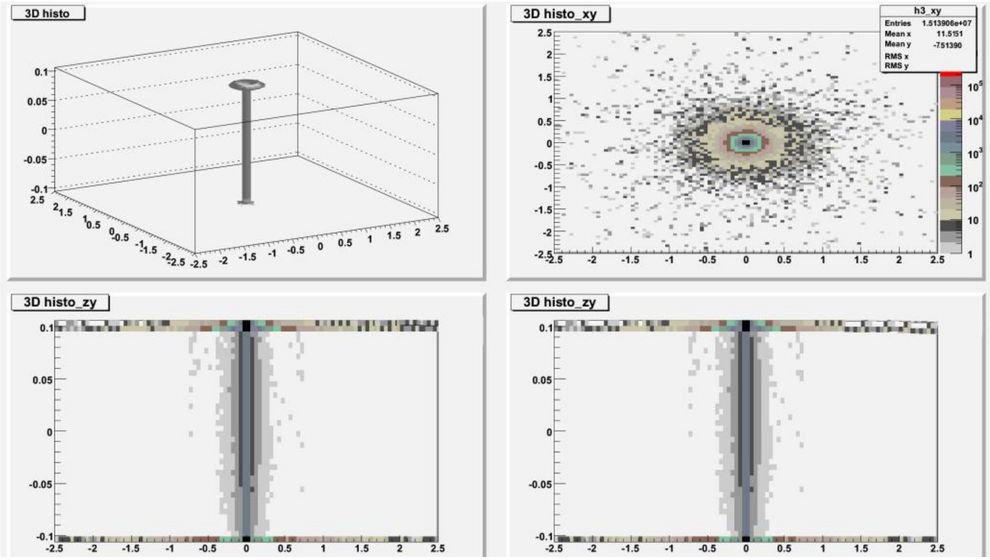
OPERA (OPerating environment for Electromagnetic Research and Analysis) simulation of the chamber field

- Relative variation of the potential in the middle of the gap less than 0,03%
- Relative variation of the field in the middle of the gap about 0,13%



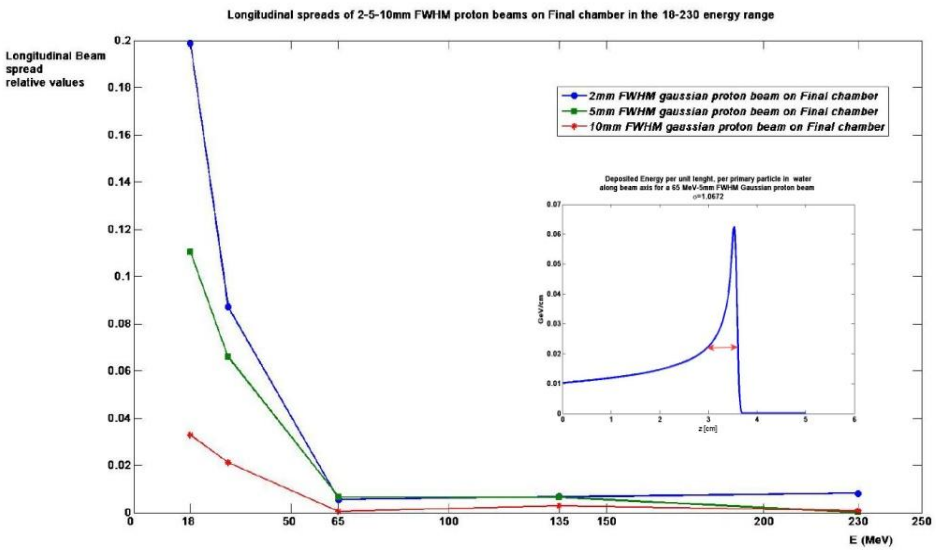


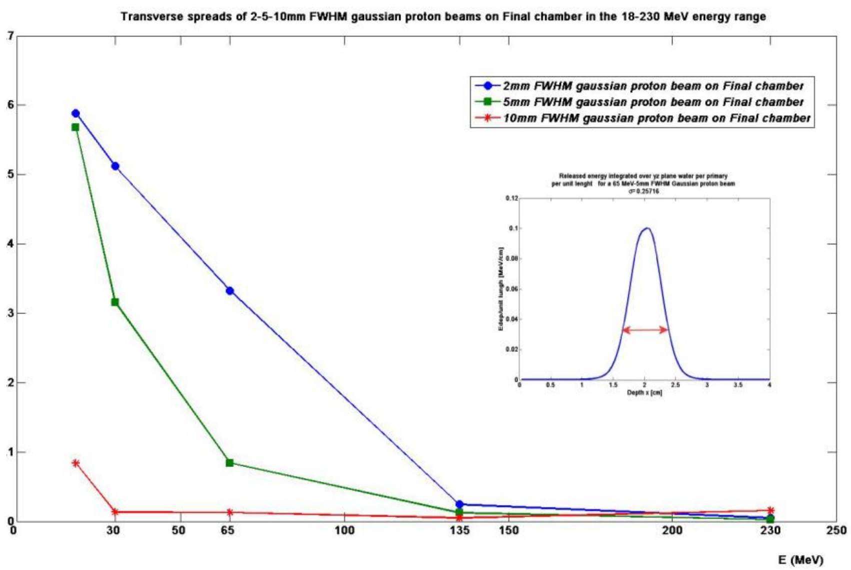
Simulation of the perturbation effect induced by the chamber on the dose delivery



Fluka Simulation on water phantom.

- Longitudinal relative variation of the Bragg peak spread less than 1% above 65 MeV
- Transversal relative variation of the Bragg peak spread less than 3% above 135 MeV





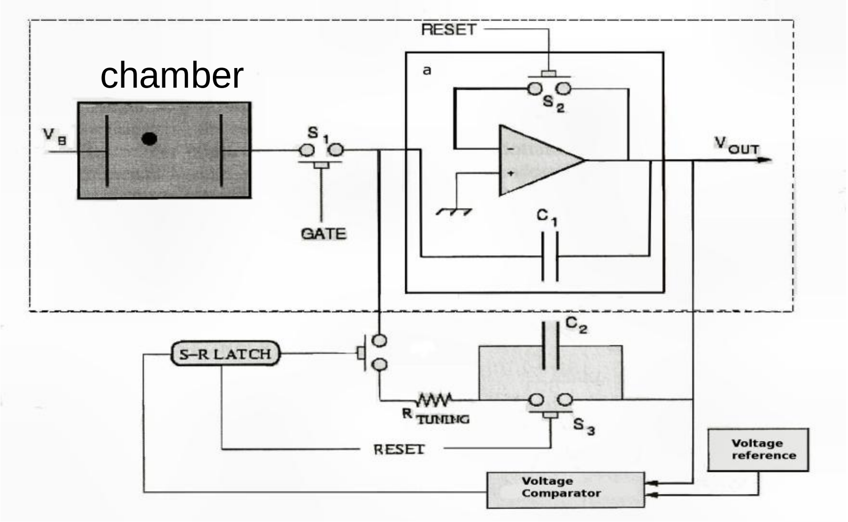
The readout electronics

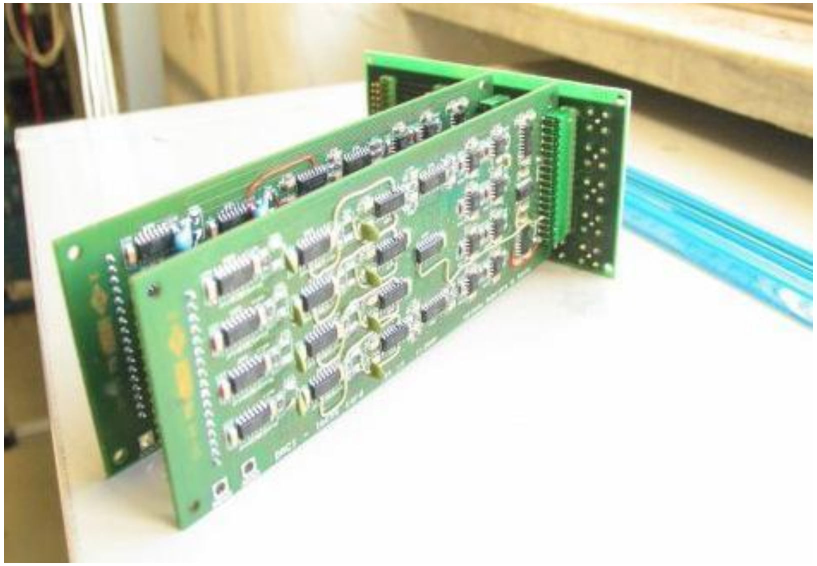
Based on a “dual range” trans-impedance amplifier with “sample and hold” mechanism (able to ensure an adequate charge dynamic range and sensitivity).

The **readout electronics** prototype controls 64 channels (but it is possible cascade several backplanes) and consists of:

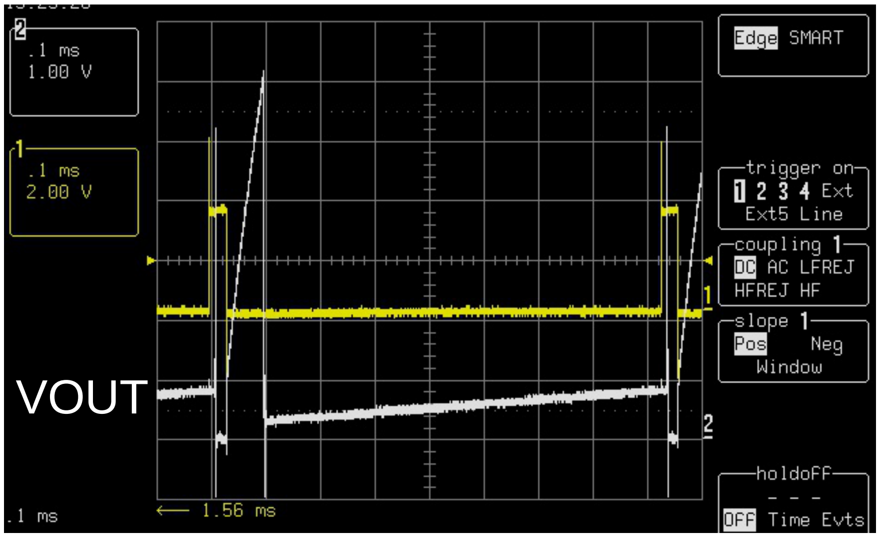
- 4 **front-end cards** (1 card/16 channels), made of 2 two main blocks:
  - the input stage with the trans-impedance amplifier and dual range logic
  - the multiplexing logic that route the collected charges into a single ADC
- a **passive backplane** which provides power supply and distributes the signals between front-end and controller

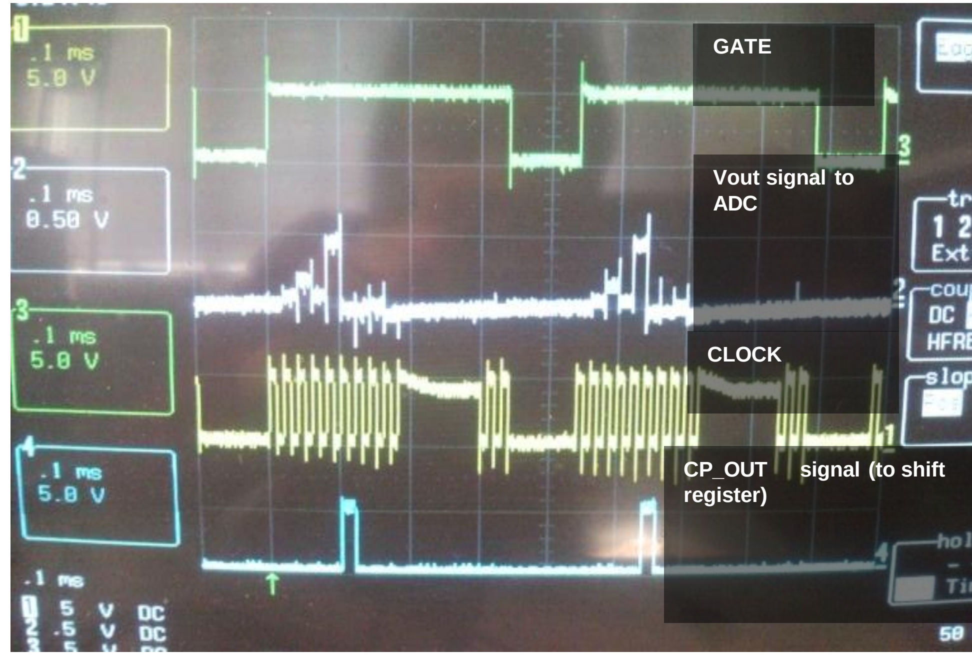
Dual Range logic

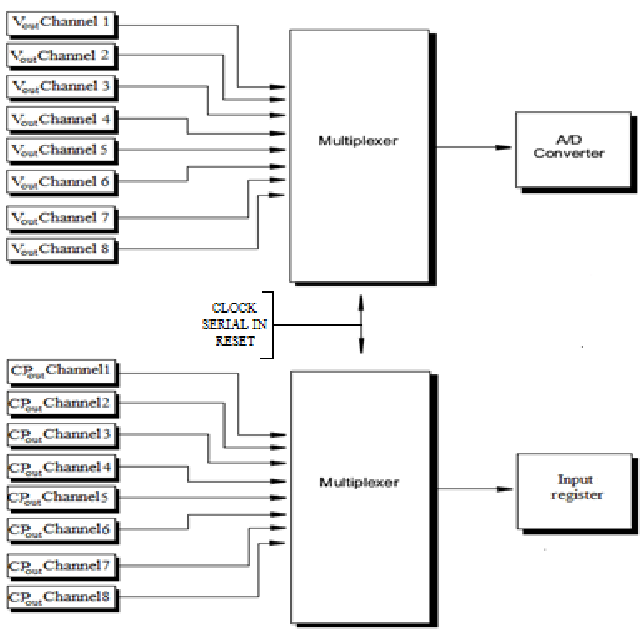




Dual Input Regime and MUX



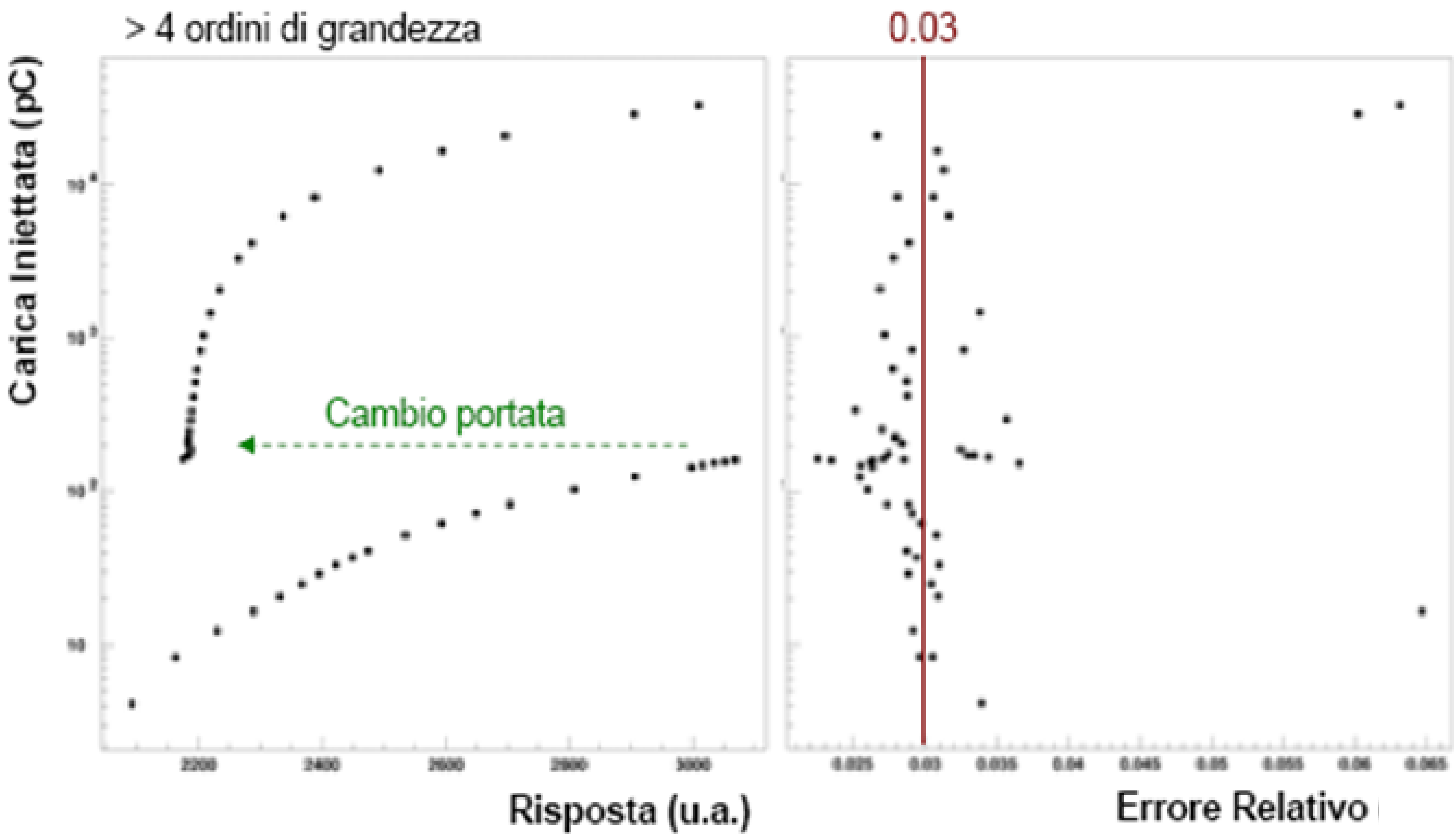




Multiplexer/ADC DAQ System

- Single channel charge is stored on the trans-impedance capacitance (sampled and hold)
- Analog values (up to 64) are multiplexed on a single ADC

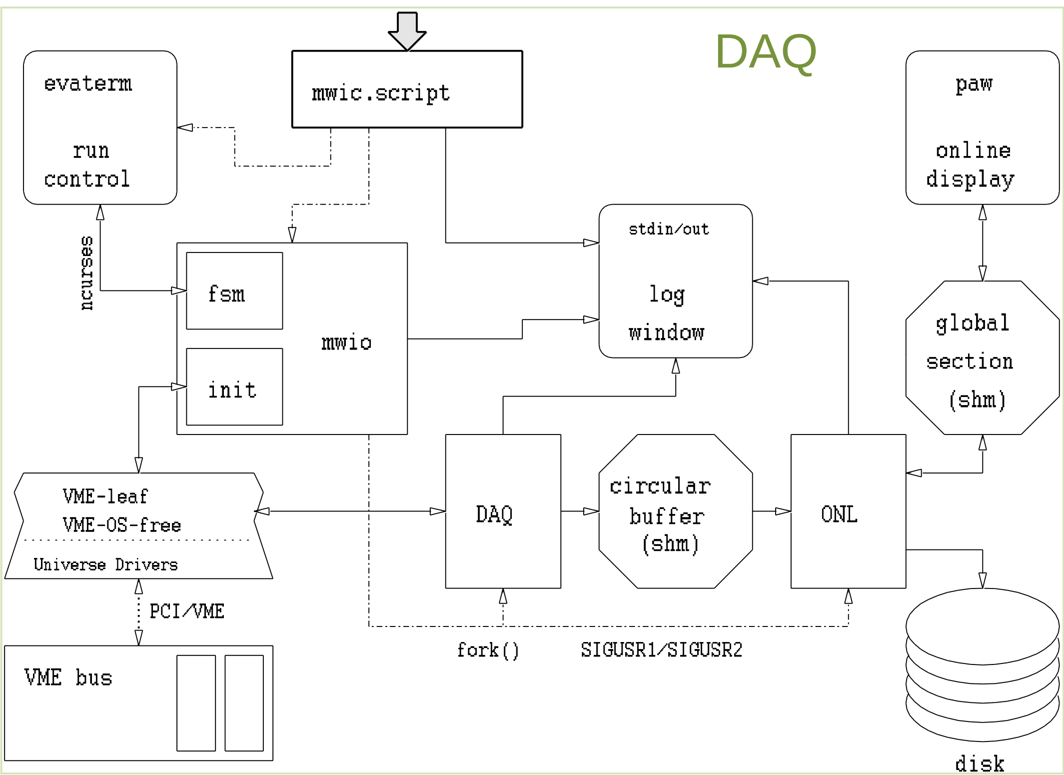
Dual Regime performance

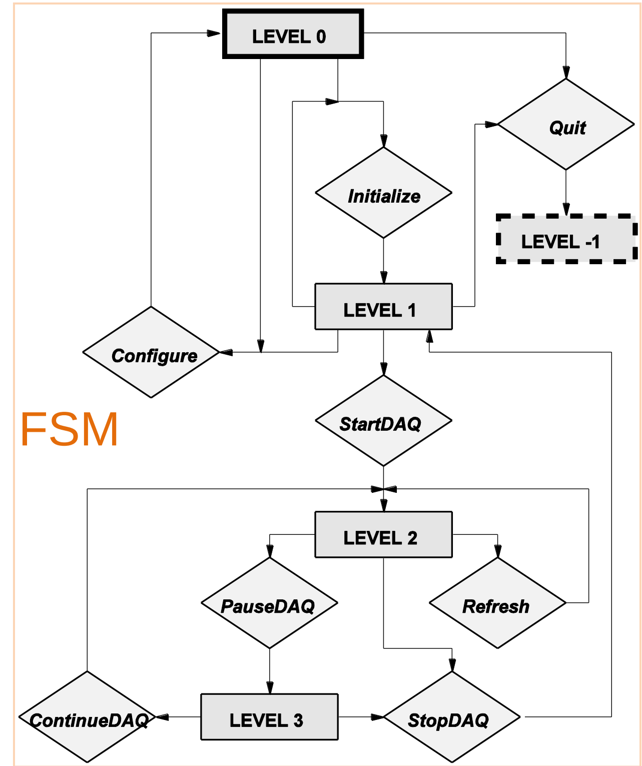


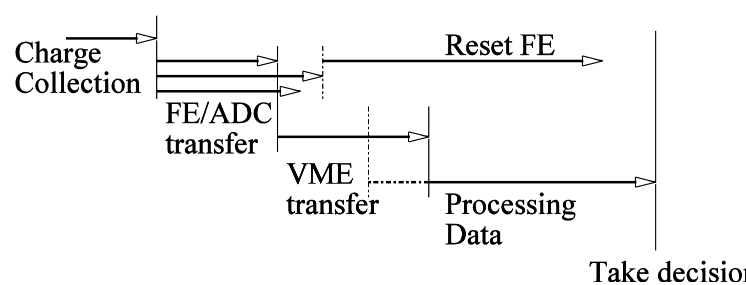
- ❑ Input dynamic range larger than 10^4 (from about 2 pC to tens of nC)
- ❑ Relative sensitivity less than 3% (minimum absolute sensitivity of 70 fC)

The data acquisition and processing system

The DAQ system is based on VME standard components, managed by a modular software in C. Software use reliable FSM, multithreads and shared buffers used by the processing algorithms that produce the feedback to the beam control system within ms.







Current activity

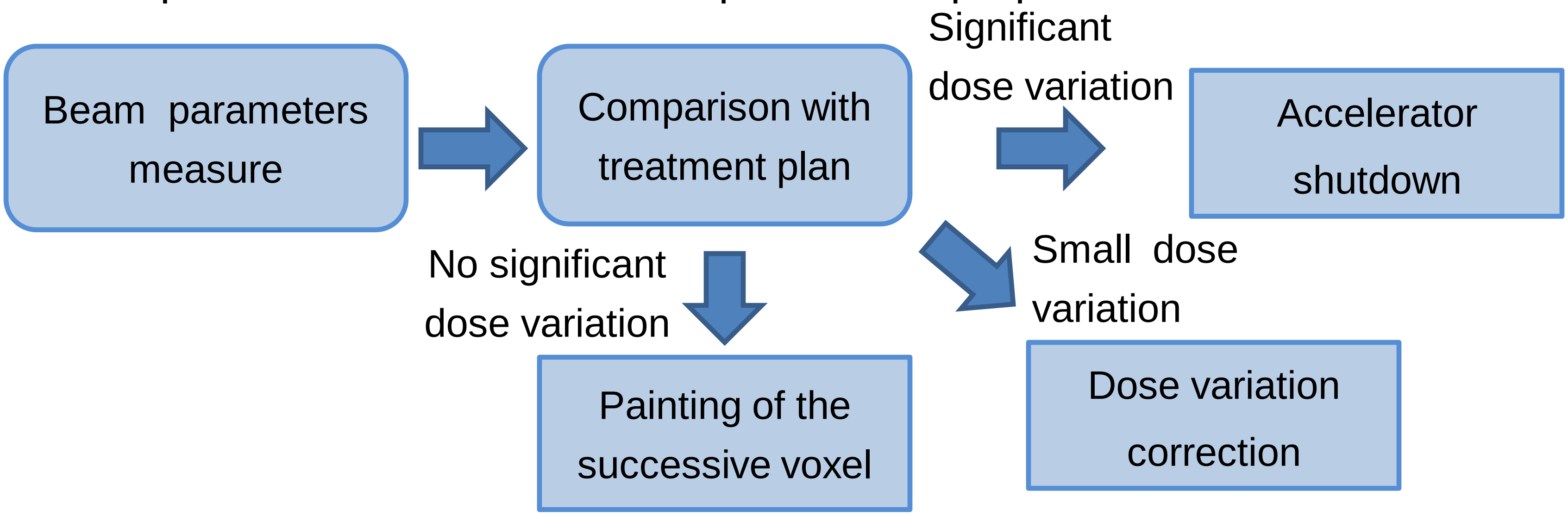
- Lab test almost completed on electronics prototype
- DAQ software ready, processing to be optimized
- Chamber under construction

- Finalization of the chamber prototype
- Characterization with rad source and under test beams (X ray and charged beam)
- Tests and characterization under the TOP proton beam (up to 20 MeV)
- Realization of a chamber telescope (with 3 chambers, at least)

- Electronics control system miniaturization with the use of a microcontroller which will replace the VME modules
- Further development of the acquisition and processing software

Link with patient monitor and “analytical” TPS

- The monitor system must check the consistency of the assessed dose with the planned dose in real time to provide the proper feedback:



- A feedback system + patient monitor (e.g. movement) + a fast Treatment Plan System (using an analytical formulation of the dose distribution):
  - evaluate, in real-time, the actual delivered dose,
  - calculate in real time, the dose correction (if any) for the next pass

Considerazioni finali

- Tanto più localizzato è il rilascio di dose, tanto più precisi debbono essere gli strumenti per la sua pianificazione, controllo e verifica

- Un sistema di protonterapia in grado di competere con le tecniche più avanzate di radioterapia convenzionale deve integrare un **sistema dinamico** di rilascio del fascio

- L'utilizzo ottimale di un tale sistema richiede lo sviluppo e "fine tuning" di un gran numero di componenti fondamentali: **TPS, Radiobiologia, Dosimetria, Diagnostica, Sala Trattamento, Imaging …**