Micro pattern ionization chamber with adaptive amplifiers as dose delivery monitor for therapeutic proton LINAC

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TOP-IMPLART[1] First Therapeutic Proton LINAC

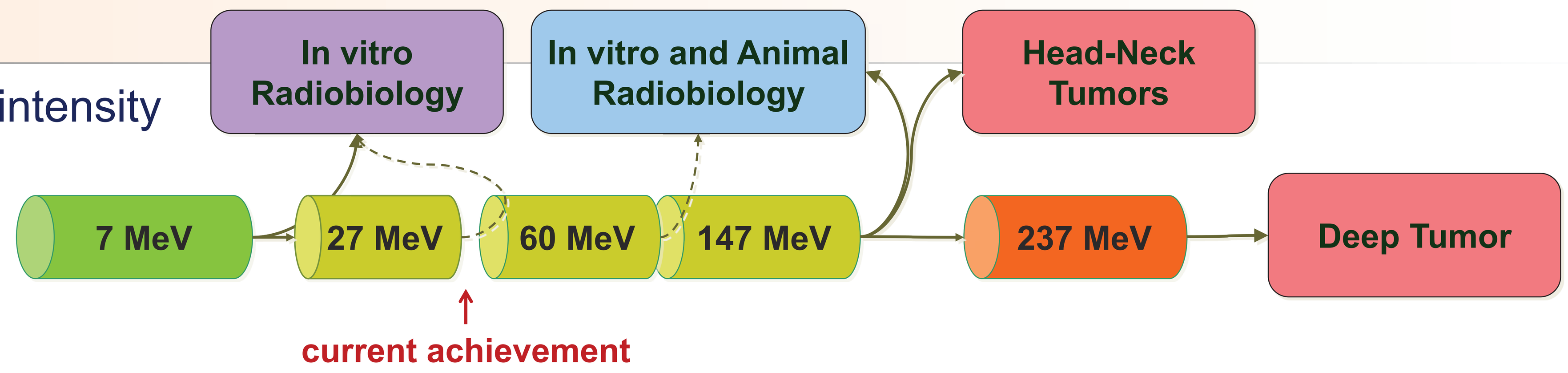
A compact pulsed proton LINAC designed for fully active scanning (3+1)D in intensity (instantaneous released dose), energy (depth) and transverse position (x/y)

Main Pro's:

- **Pulse current modulation**
- **High repetition rate**
- **Negligible radiative power loss**
- **Simpler injection and extraction (respect to circular accelerators)**
- **Modular construction**

Main Con's:

- **Proton/ions need different cavities**
- **No existing clinical systems, so far**



The high proton ballistic precision requires accurate and reliable dose delivery monitor

Pulsed Beam	Dose Delivery Monitor
Energy range: 60-250 MeV	Light and compact detector
Beam cross section: ~1 mm	Good spatial resolution: ~1/10 mm
Peak current: 0.1-10 μA	Wide dynamic range: 10^4 at least
Average current: 10 nA	Good sensitivity: ~100 fC
Pulse width:1-5 μs	Zero dead time
Pulse frequency: 3-100 Hz	Rapid response: < 1ms
	Number of channels: few 100

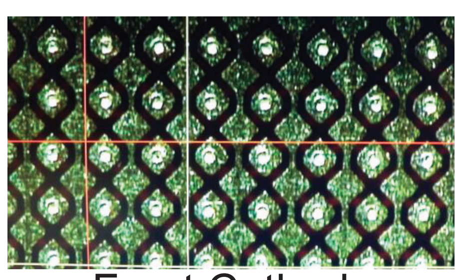
Dose Delivery Monitor

Measure position, direction and intensity profile of each beam pulse. Based on compact transmission, segmented ionization chambers.

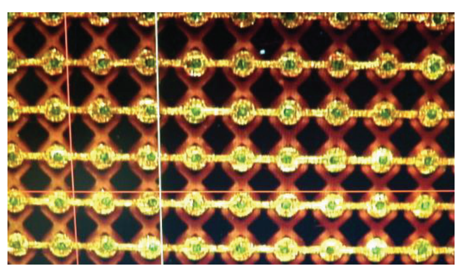
- **Readout plane topology is inspired by recent advances in micro pattern gas detectors, with pad-like x/y design.**
- **Each chamber operates in the ionization regime, collect whole charge and minimize saturation**

Prototype Dose Delivery:
Ionization Chamber
Active area: 7x7 cm^2
Anode – cathode gap: 2 mm
Anode: Al (5μm)
HV bias: 200-400 V
Water Equivalent Thickness : 0.17 mm
Readout:
64x64 adaptive multi gain electronic channels

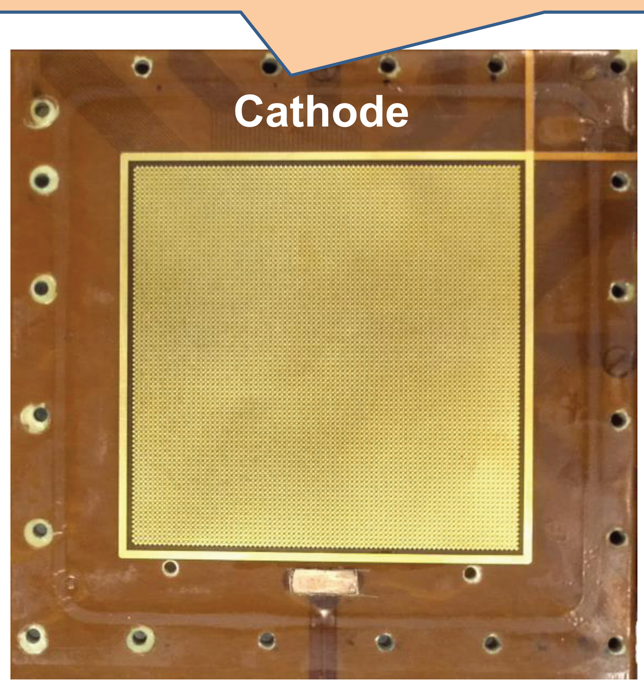
Cathode: kapton (50 μm) with Cu pads (15 μm) on the internal side, connected by Cu strips (15 μm) on both sides; pitch: 875 μm (final goal ~400 μm), pad interspace: 120 μm; 80 strips on each axis.

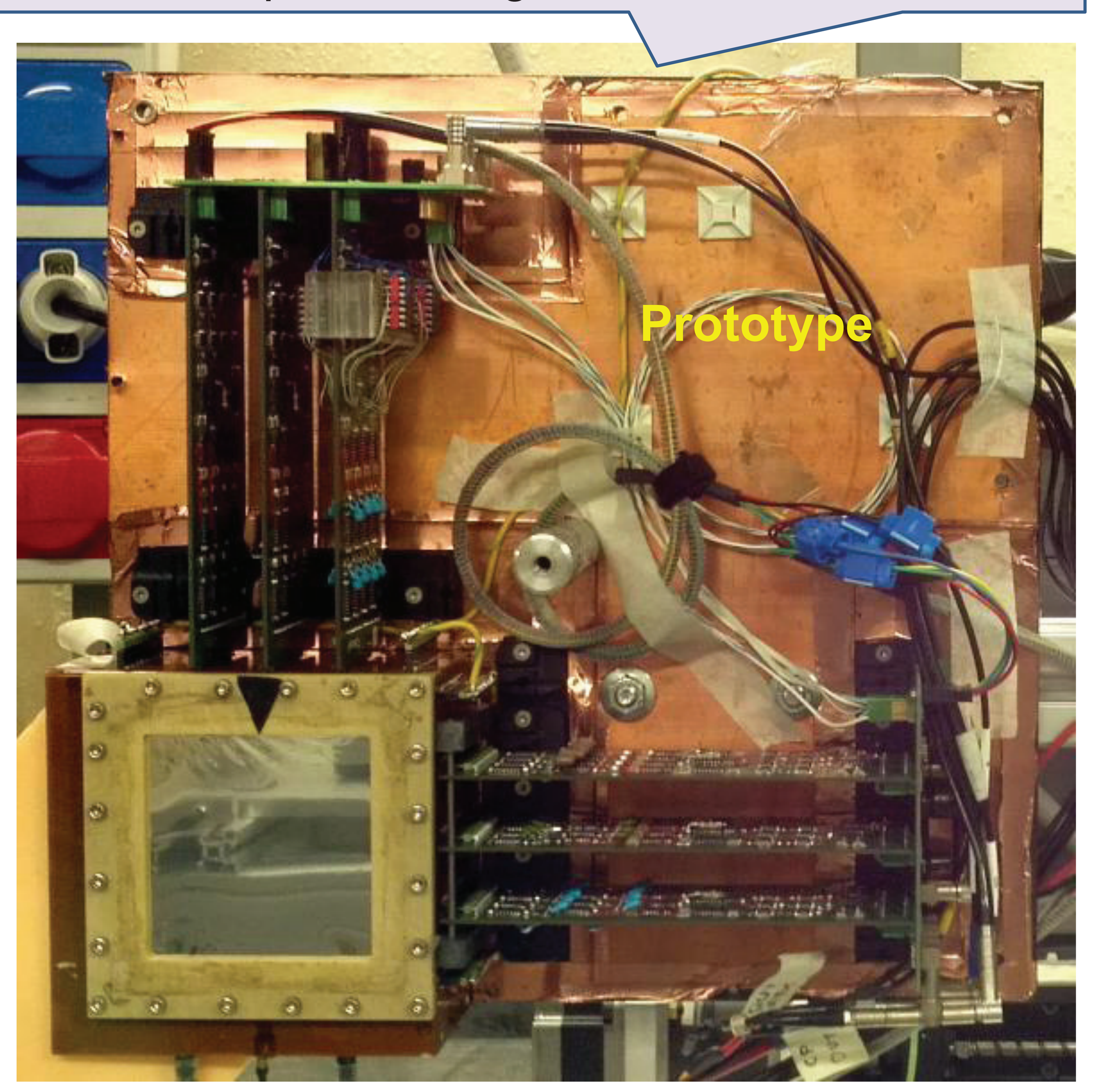


Front Cathode

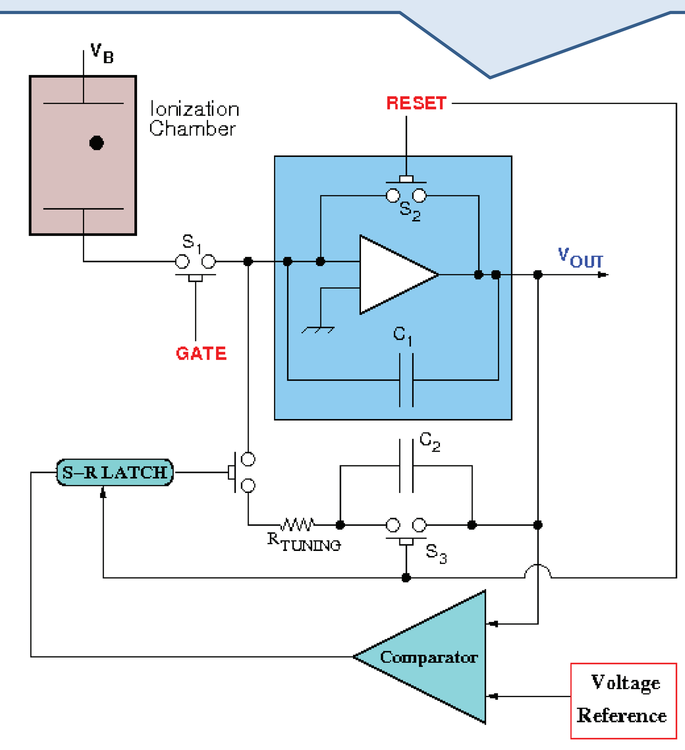


Back Cathode



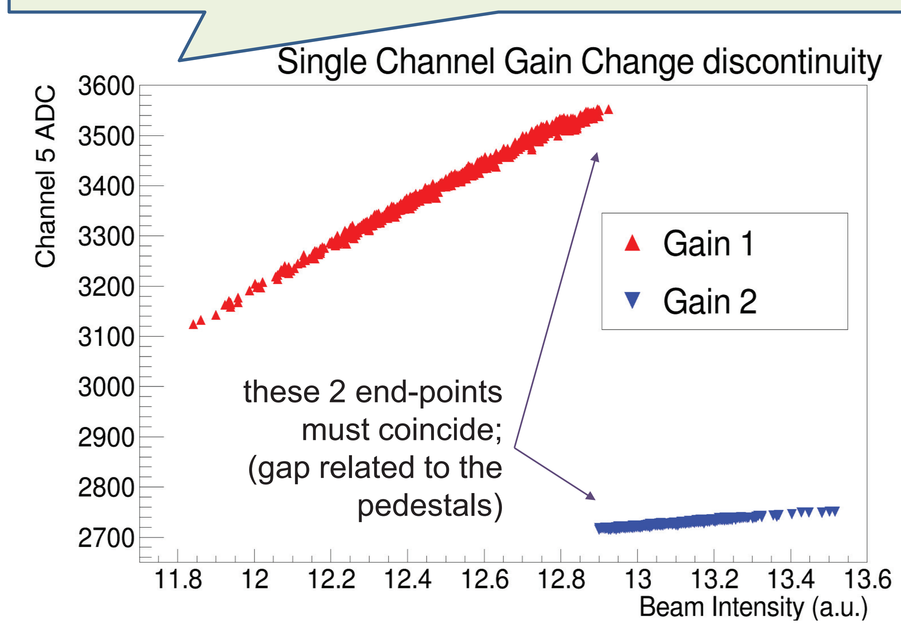


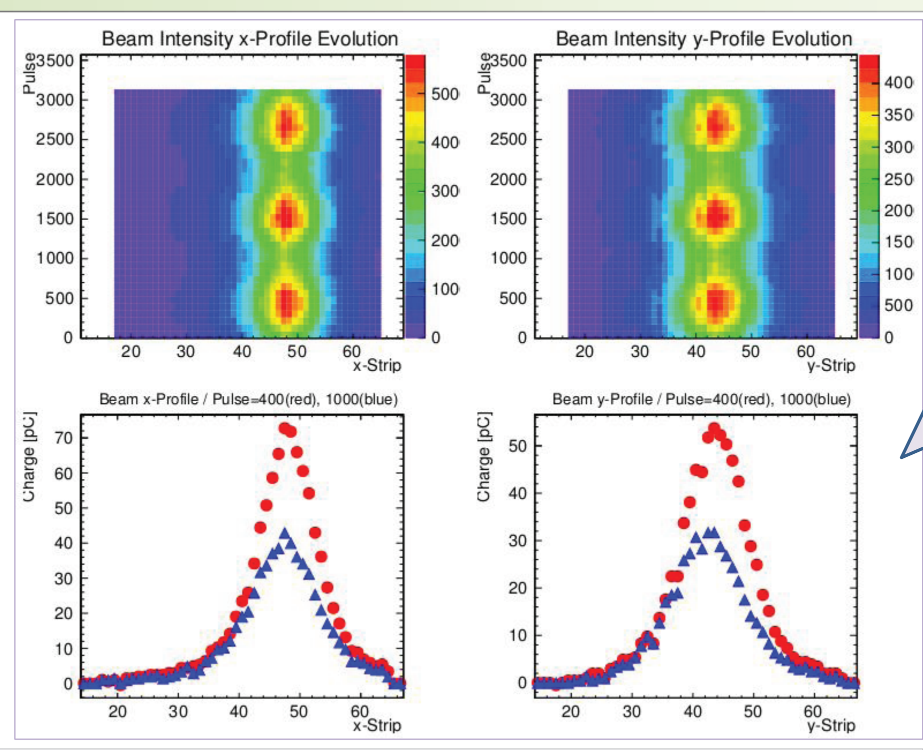
Readout electronics:
based on peculiar multi gain adaptive amplification mechanism to obtain larger dynamic range and quick response: when the voltage V_{out} on the feedback capacitor C_1 of the trans-impedance amplifier becomes larger than the precise voltage reference, the analogue switch inserts in parallel an additional capacitor C_2 with larger capacitance. Switch is recorded.



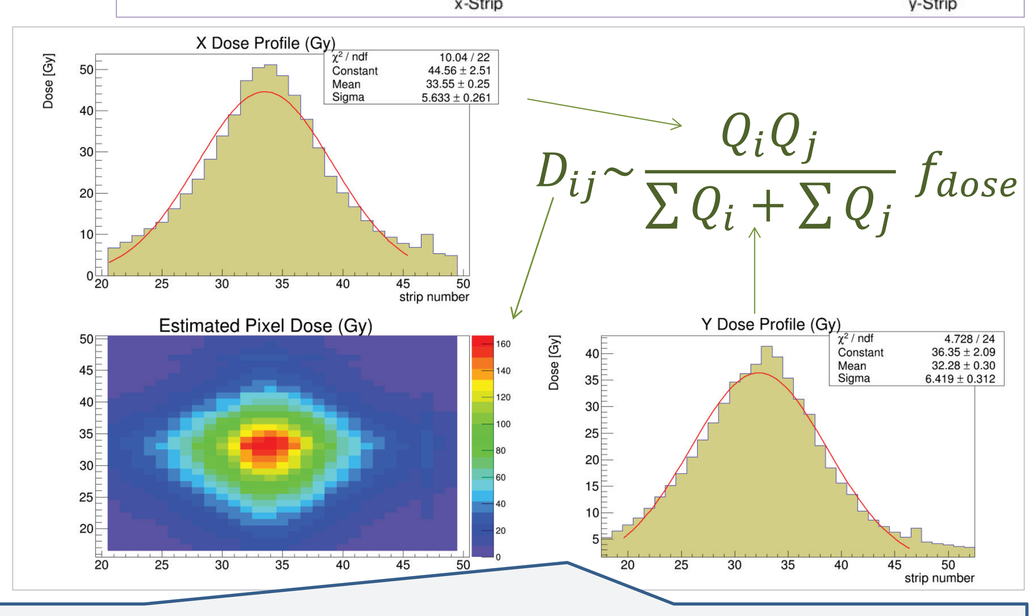
Prototype, first calibration and characterization on TOP-IMPLART 27 MeV proton beam

Gain Change Calibration:
Each gain state has its own pedestal value which needs to be measured to correctly estimate the collected charge and then the beam intensity.
The (base) gain_1 pedestal is directly measured by the conventional procedure (run without beam).
The pedestal of gain_2 state is estimated imposing the continuity conditions on the collected charge of each channel near the threshold region; figure show the raw ADC without pedestals subtraction.

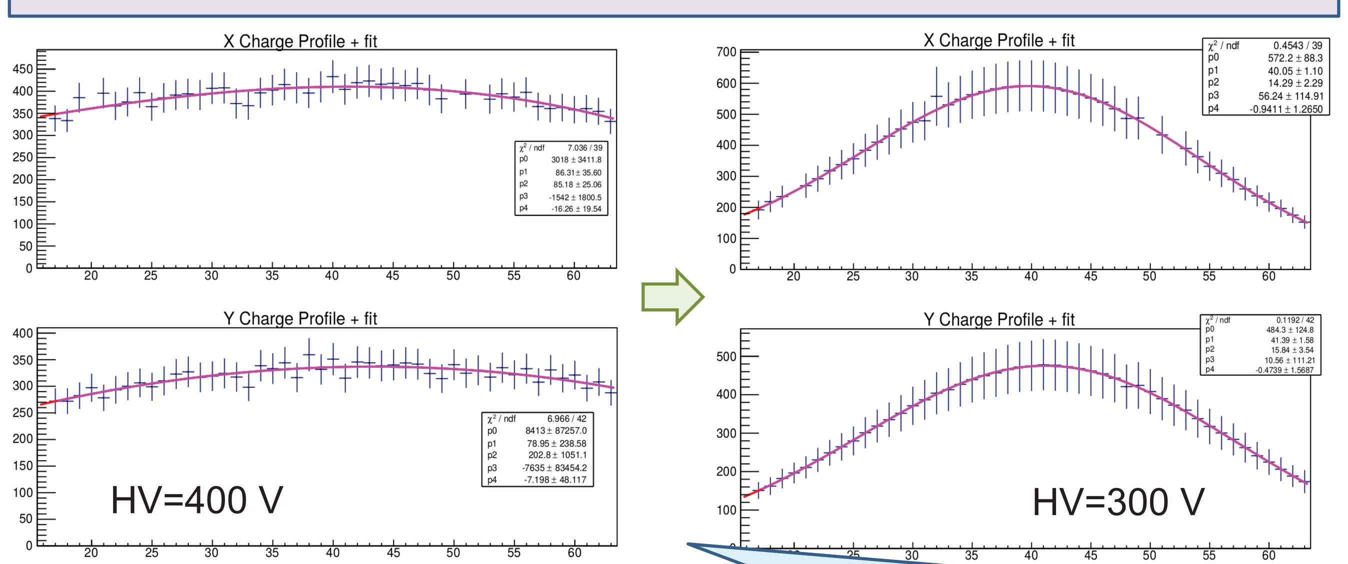




Single pulse intensity monitor:
The dose delivery monitor measure the profile of each beam pulse (10 Hz in the example). Upper plots show the evolution of the beam intensity for each consecutive pulse (an oscillation of about 2 m is present in the recorded beam); lower plots x and y beam profiles for the maximum and minimum intensity pulse.



$$D_{ij} \sim \frac{Q_i Q_j}{\sum Q_i + \sum Q_j} f_{dose}$$



Channel response Equalization:
Left: equalization factors as ratio of the measured strip charge over the corresponding Gaussian fit of almost flat beam profiles;
Right: the equalization factors are applied on data of different run showing pretty good results (large error bars due to pulse to pulse beam fluctuations), also at different chamber high voltage and geometrical conditions.

Dosimetric Calibration (in progress):small gafchromic films and alanine pills used to measure delivered dose; registered charge of the chamber expected proportional to the dose (factor depending on gas density). 1-dim profiles are combined to get a 2-dim intensity cross section (under specific assumptions on beam shape) to account for different irradiation fields.

Reference:

[1] C. Ronsivalle et al, "*The TOP-IMPLART Project*", Eur. Phys. J. Plus (2011) 126: 68, 1-15.

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