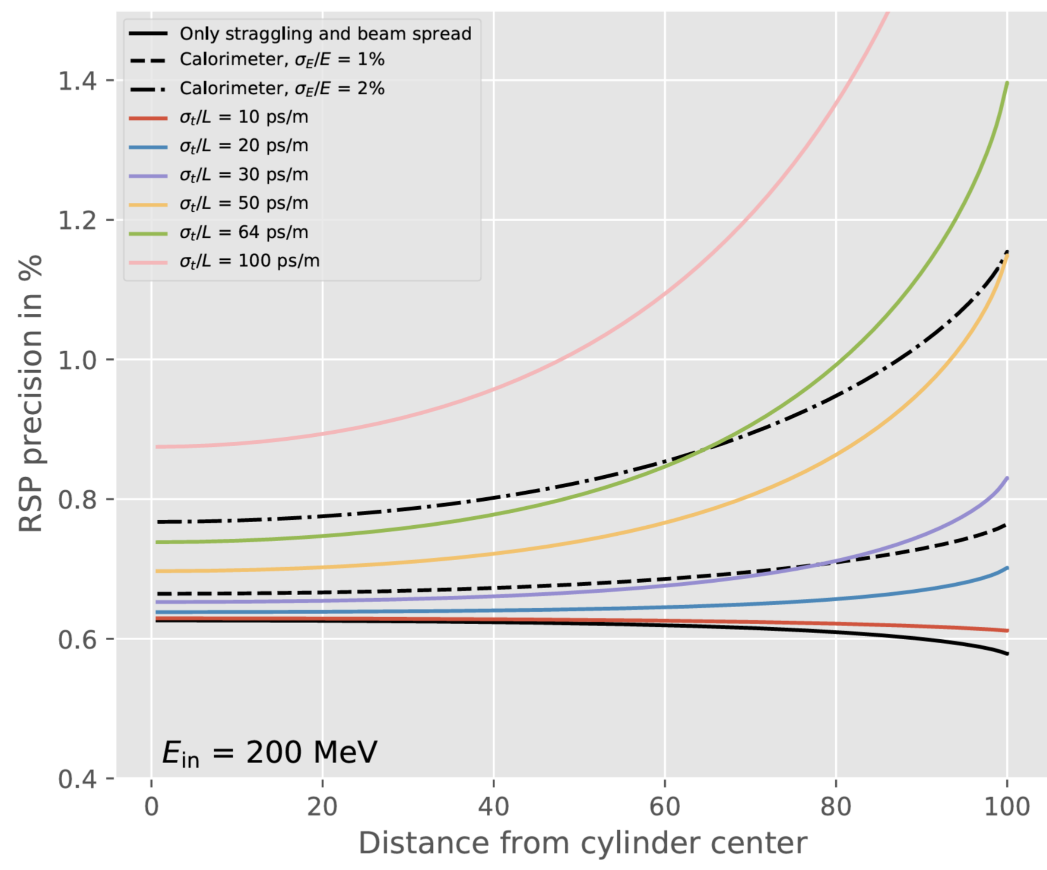
A novel scintillator-based time of flight proton radiography: the TOFpRad project

Y. Dong, R. Anzalone, G. Battistoni, E. Ciarrocchi, M. Francesconi, L. Galli, A. M. Goanta, N. Krah, A. Mereghetti, S. Muraro, M. Pullia, G. Traini, M. Morrocchi
yunsheng.dong@mi.infn.it

Proton radiography: definition and state of the art

Proton radiography is an imaging technique based on the detection of the proton position or trajectory and of its energy loss within an object. Compared to conventional X-ray techniques, **proton radiography provides a direct measurement of proton stopping power**, resulting in an accurate correlation with tissue density without relying on X-ray attenuation. In the framework of proton therapy, this can reduce the range uncertainties and it can be used also for real-time monitoring during treatment sessions.

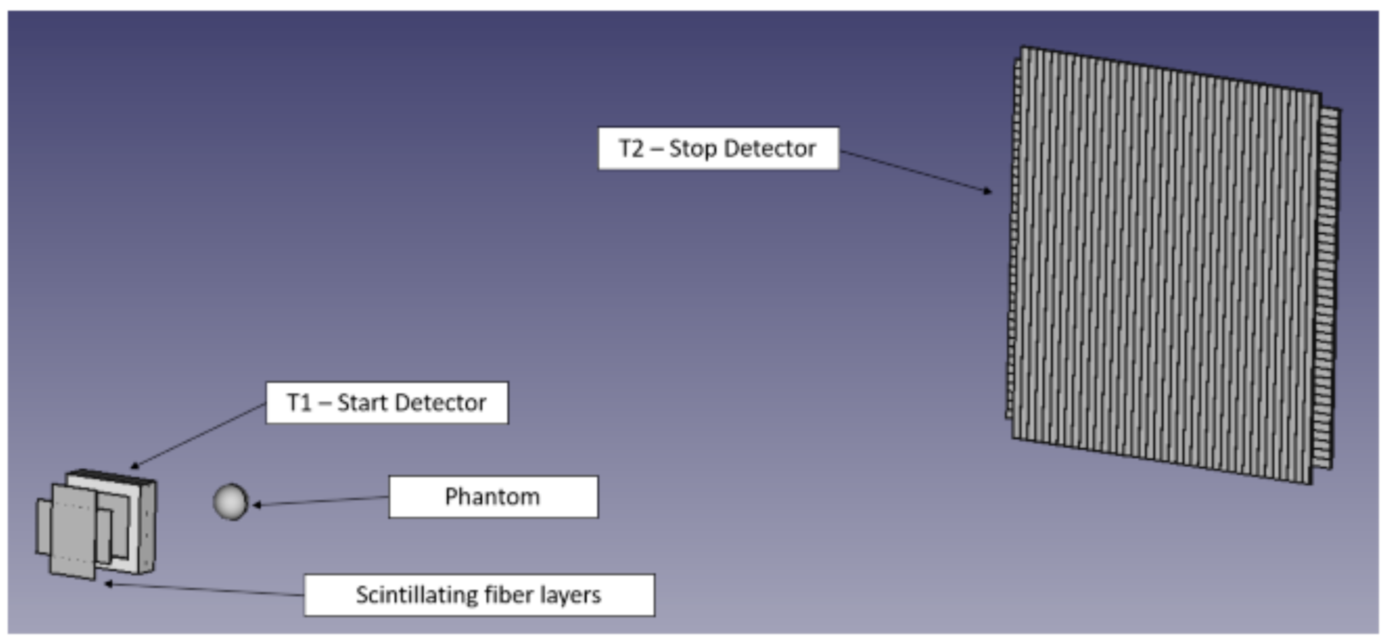
Existing proton imaging devices are typically based on the measurement of the particle residual kinetic energy with a calorimeter. One of the main drawbacks is due to the limited rate capability ($\lesssim$10kHz), which is generally too slow to be clinically acceptable. **Recently, different studies have been conducted to explore the possibility to retrieve the proton kinetic energy by measuring their Time Of Flight (TOF), showing that this approach can increase the energy resolution maintaining a high rate capability.**



Relative Stopping Power precision estimated with TOF and calorimeter based systems with different time and energy resolutions of a 200 MeV proton beam impinging on a water cylinder with 20 cm diameter.

Nils K. et al, *Relative stopping power precision in time-of-flight proton CT*, Physics in Medicine & Biology, 67, 165004, DOI 10.1088/1361-6560/ac7191

THE TOFPRAD project

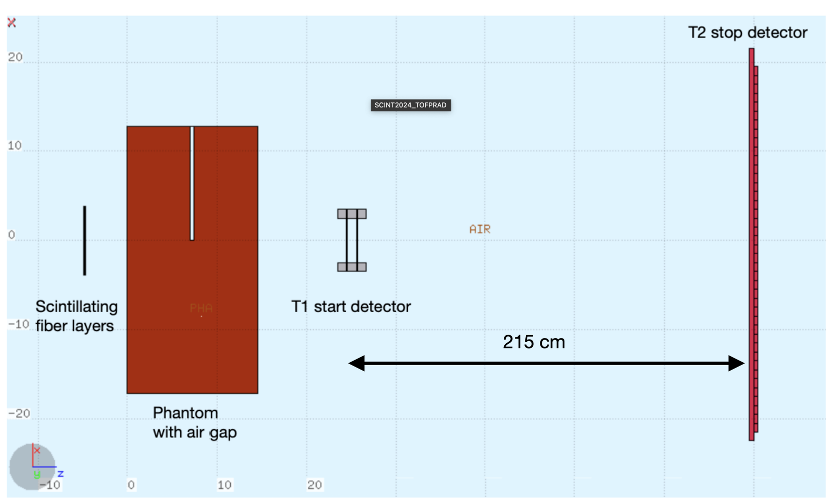


The TOFpRad project aims to assess the viability of a proton radiography system based on the TOF approach by realising a prototype consisting of two fast plastic scintillator detectors for the TOF measurement and a set of layers of plastic scintillator fibres for tracking purposes, both read with SiPMs.

The choice of such technology allows to develop a **low-cost system**, while ensuring an **excellent time resolution as well as a larger rate capability** with respect to inorganic scintillators typically used in the calorimetric approach.

Experimental setup

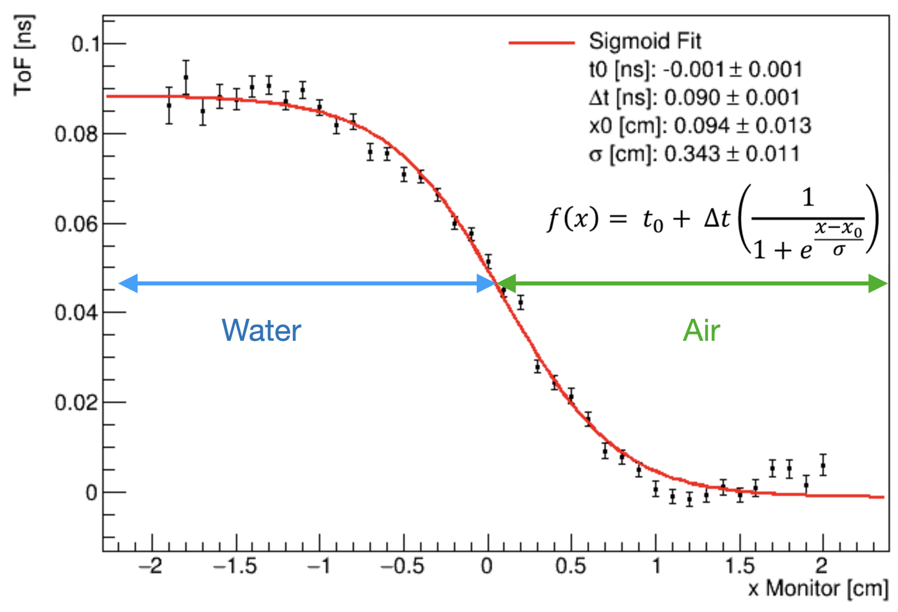
A preliminary TOF measurement system has been developed and tested at CNAO (Pavia) with protons to prove the capability of the TOF system to detect an air gap of the order of a few millimetres located in a water equivalent phantom.



MC simulation by means of FLUKA (left) and picture (right) of the TOFpRad project preliminary experimental setup tested at CNAO.

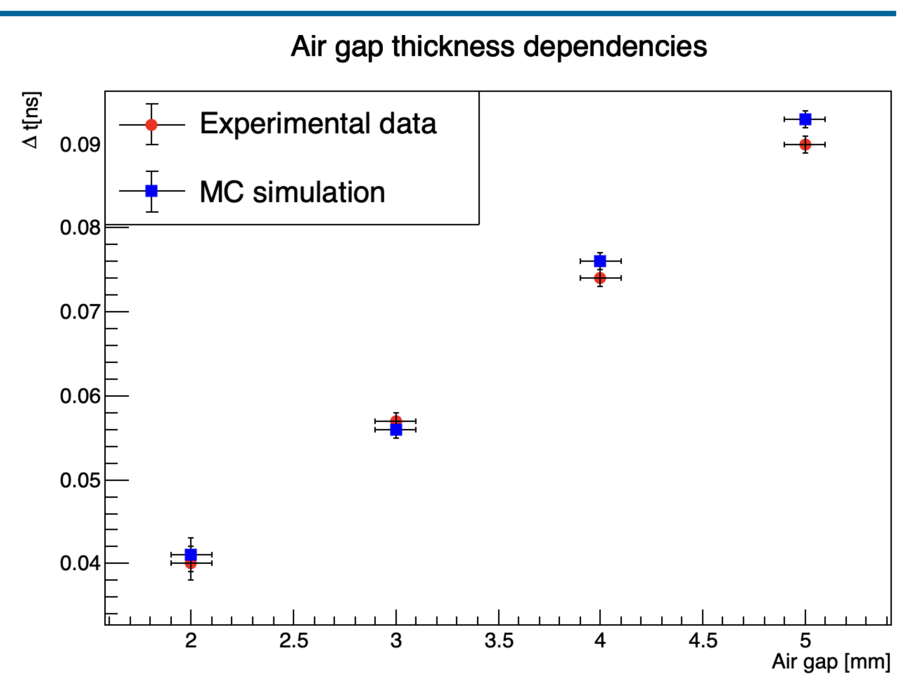
- Incident proton beam @ 226.91 MeV for the data taking and at lower energies (up to 62.73 MeV) for the TOF calibration
- Two orthogonal planes of scintillating fiber layers with a thickness of 1 mm adopted to measure the initial particle position
- A 14.5 cm thick water-equivalent phantom with air gaps of varying thicknesses (2-10 mm) positioned at different depths and across half of the transverse section within the water phantom
- Two layers of EJ-232 plastic scintillator 500 μm thick read with SiPMs and used as the TOF start time detector
- Two orthogonal layers of EJ-200 plastic scintillating bars (20 bars of 44x2x0.3 cm^3 each) read with SiPMs on both sides and adopted as the final TOF measurement station

Preliminary experimental results



- The TOF measurement system has been calibrated varying the beam energy and using a full water equivalent phantom without any air gap
- The TOF vs beam position measurements has been fitted with a sigmoid function, extracting the main parameters

- **Δt parameter increases with increasing air gap size**
- Other parameters are not related to the gap size
- There is a good agreement between data and MC simulations conducted by means of the FLUKA software



Conclusions and future perspectives

- **The preliminary setup is able to detect an air gap of few millimeters in a water equivalent phantom**
- A new prototype is under development to enhance the DAQ rate capability to be compatible with the clinical requirements
- First tests with part of the new apparatus in few months at CNAO