Proton : an imaging tool

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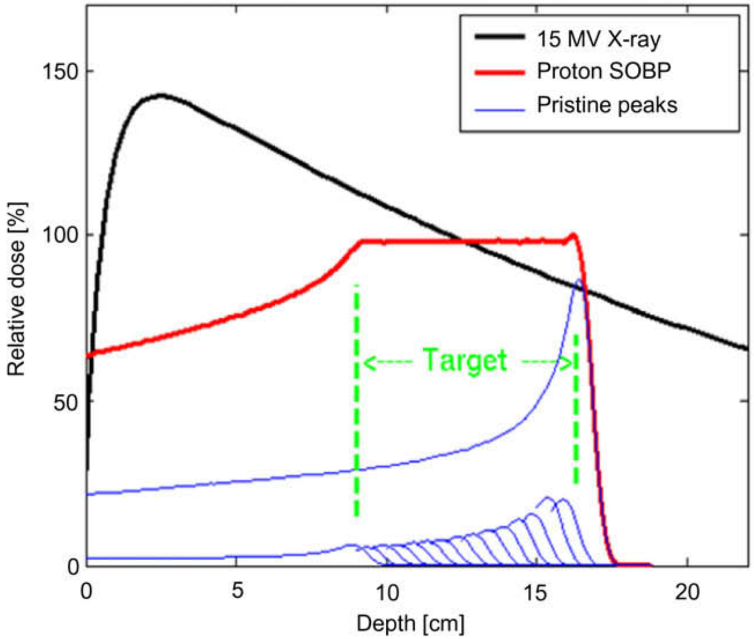
Proton imaging ?



(H.Suit *et al.*, *Proton vs Carbon ion beam …*, 2010)

Protontherapy margins :

- Sharp distal dose falloff ⇔ Bragg peak position
- Uncertainty sources :
  - physical parameters (I_{mean})
  - patient positionning
  - **X-ray CT calibration (HU to stopping power)**
  - …
- Margins ≈ 1-3mm ± 3%

Proton imaging :

- Direct reconstruction of tissues relative stopping power (RSP) from proton energy loss :

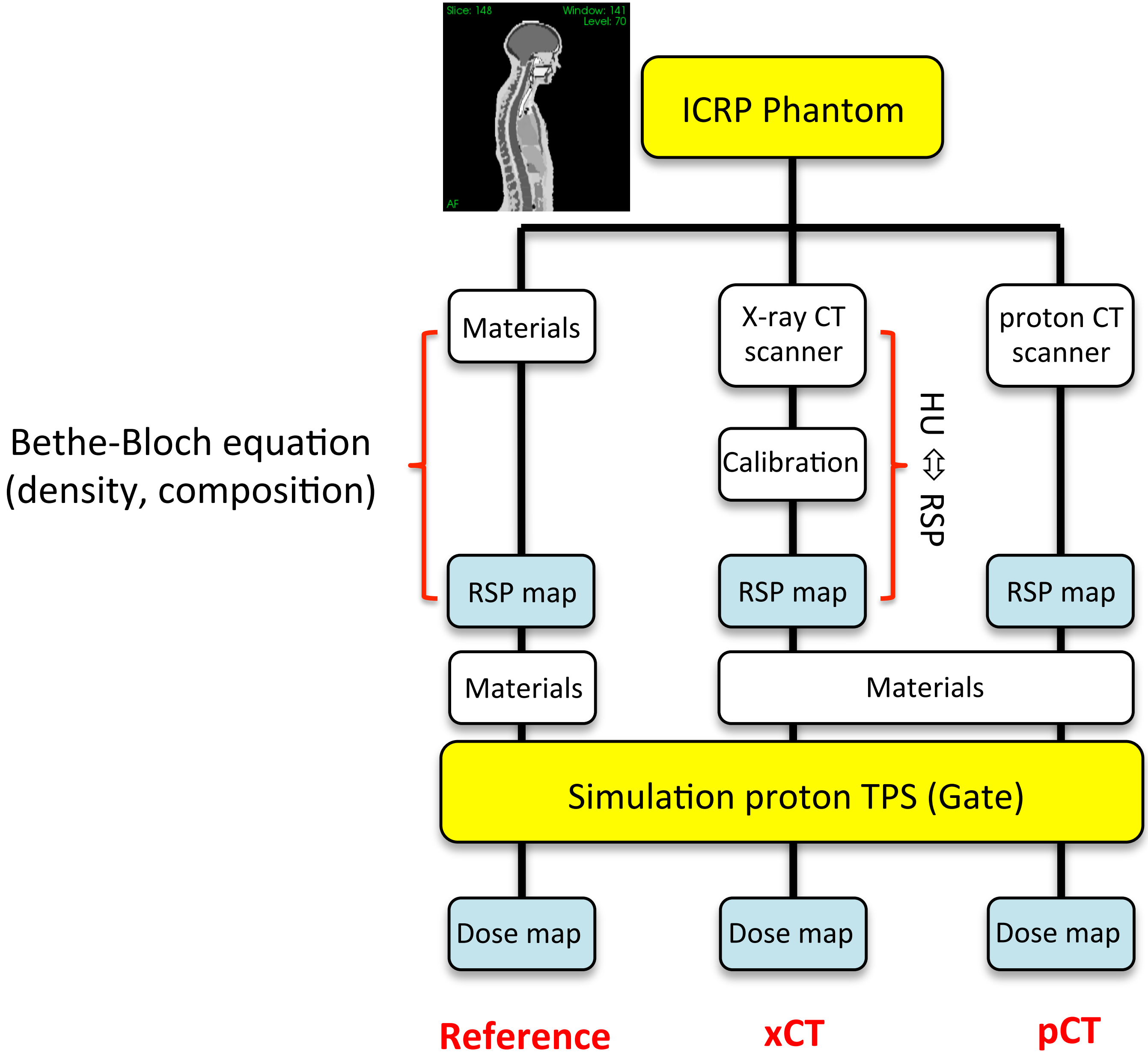
$$\boxed{\int_L \frac{dE/dx_{medium}}{dE/dx_{water}} dl \equiv \int_L \frac{S_{medium}}{S_{water}} dl \equiv WEPL}$$

- Two main limits : **spatial resolution** (complex proton path), **reconstruction time**
- **Fast reconstruction algorithm (FBP)** developed at CREATIS
  (S. Rit *et al.*, *Filtered backprojection proton CT…*, 2013)

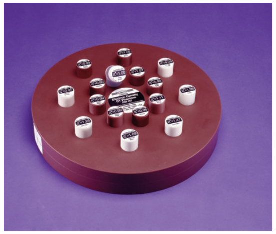
Proton therapy TPS

GATE Monte Carlo Software

Monte Carlo Protontherapy TPS

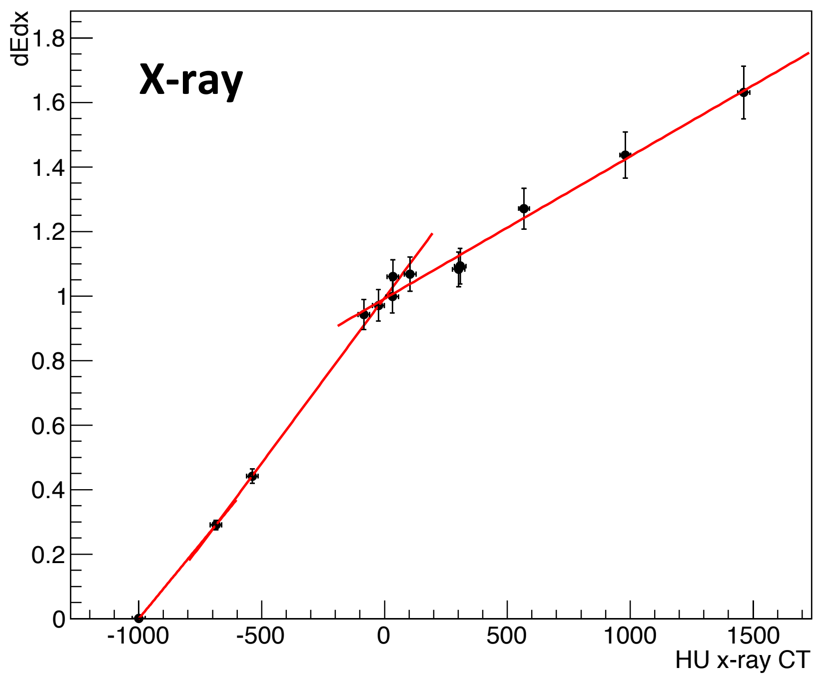


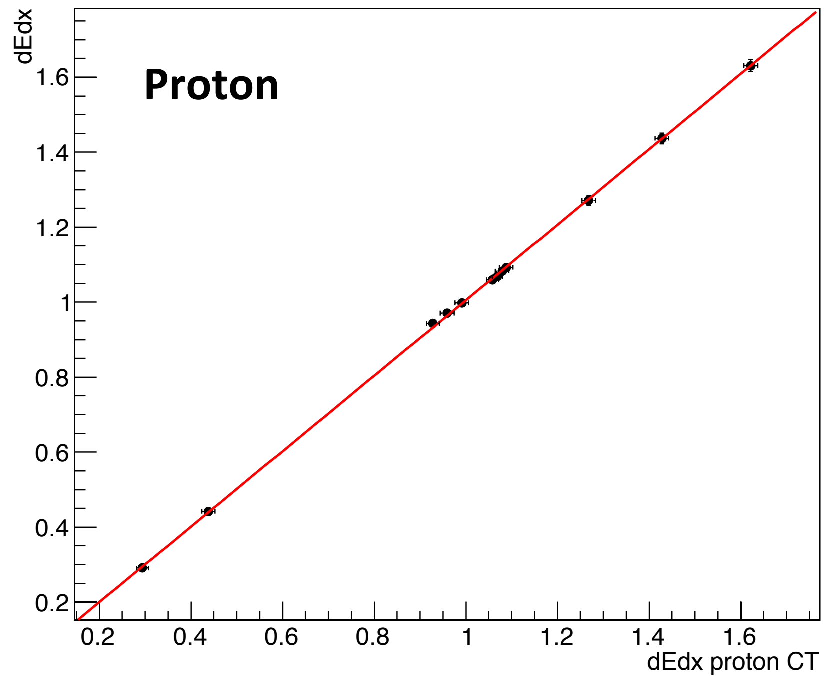
Calibration phantom



Gammex 467

Calibration phantom (Gammex 467)





X-ray CT :

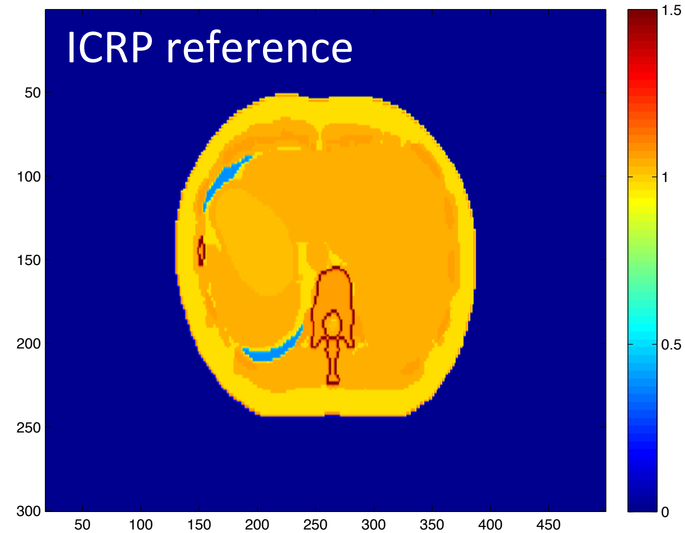
- Fit with 2 or 3 curves (to get a mean deviation between values and fit close to 0)
- Deviation between reconstructed values and fit around **0.1±2.5%**

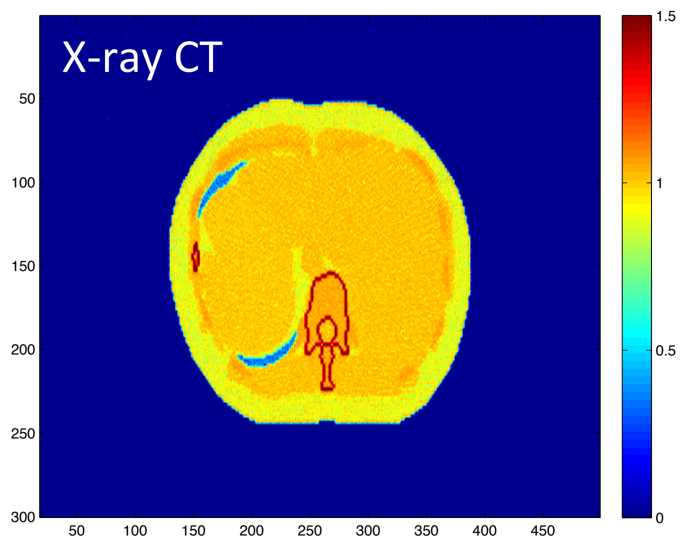
Proton CT :

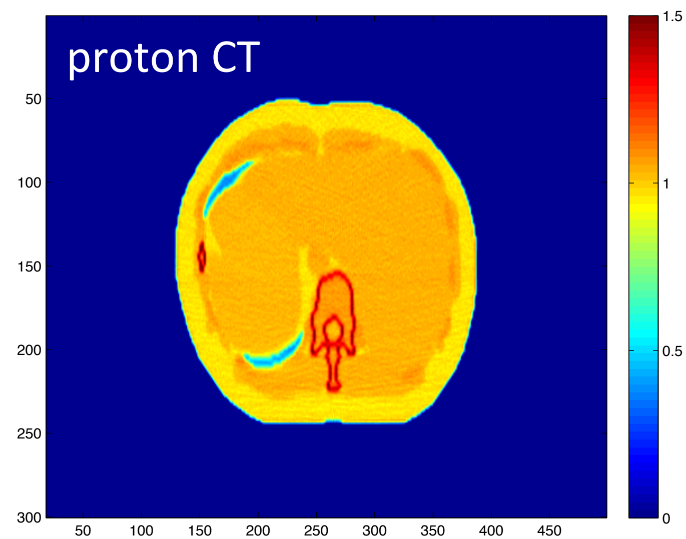
- Fit with 1 curve is sufficient (fit function compatible with y = x ⇔ **no calibration needed**)
- Deviation between reconstructed values and fit around **0.02±0.4%**

Stopping power maps (RSP)

- Reconstructed RSP maps for ICRP reference, X-ray CT and proton CT
- X-ray and proton CT images are produced with an **equal imaging dose** (about 2 mGy)

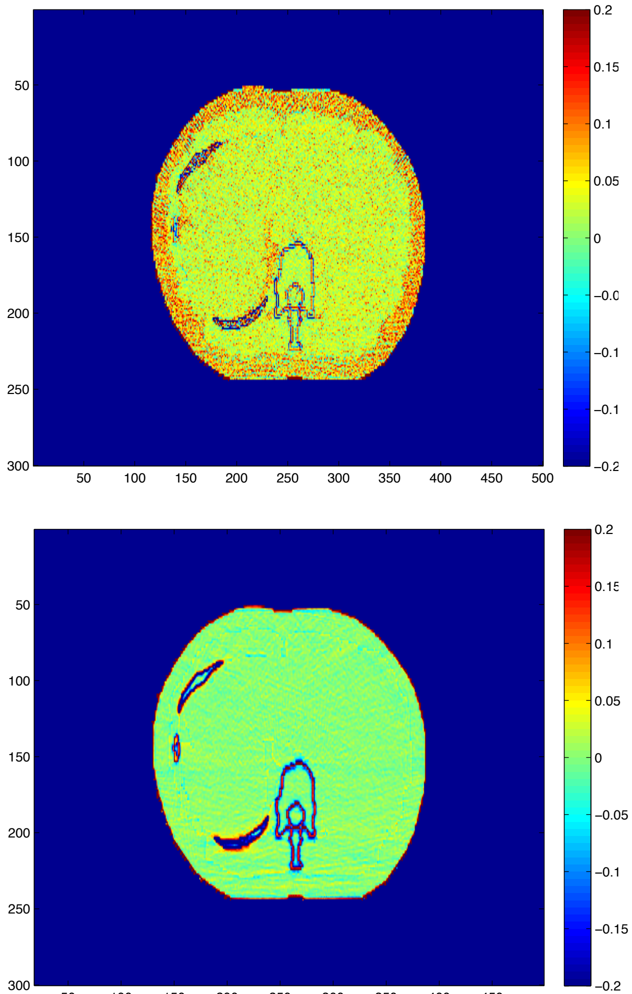




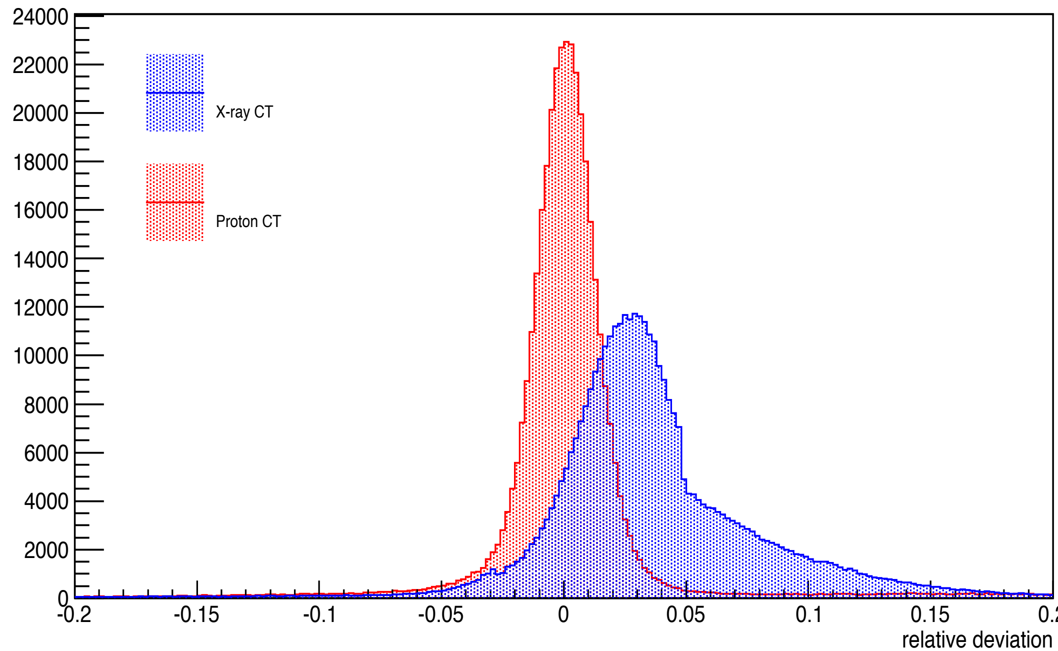


RSP maps deviation

- Compute **voxel by voxel relative deviation** between xCT/pCT and reference map
- Apply analysis on **10** uncorre



Deviation xCT (top) and pCT (bottom) wrt reference

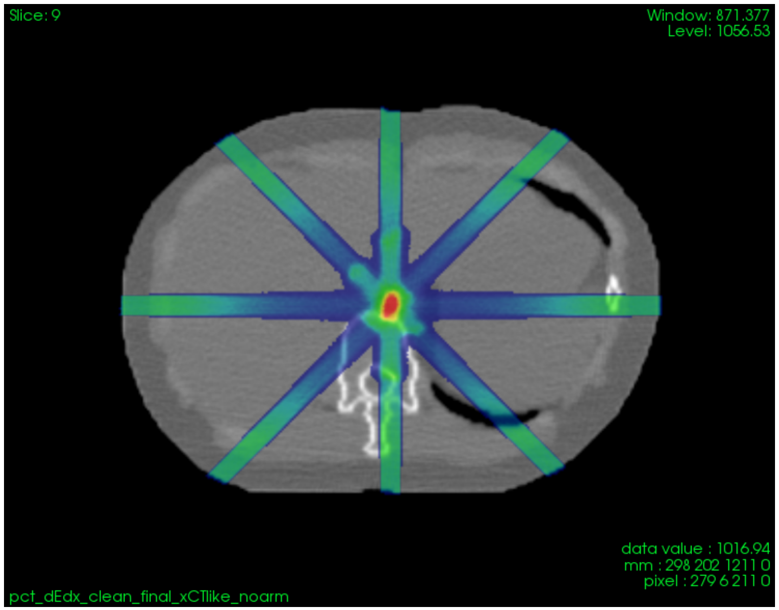


- Deviation : xCT $\longrightarrow$ **μ = 3.6%, σ = 4.4%**
  pCT $\longrightarrow$ **μ = 0.1%, σ = 3.3%**

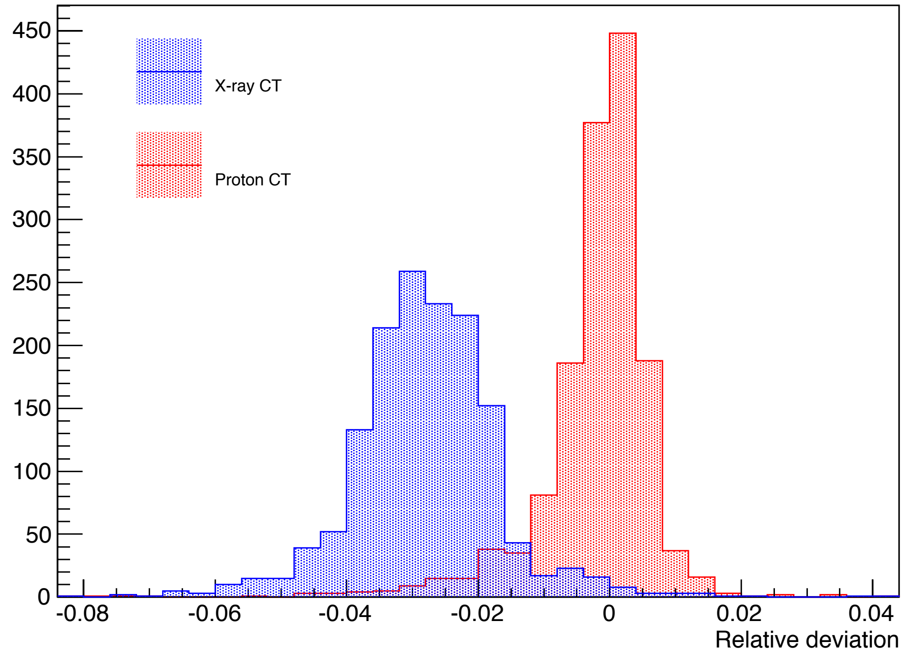
- Proton imaging enables :
  - a **more reliable** RSP reconstruction ($\mu_{dev} \approx 0$)
  - a **more precise** RSP reconstruction (σ_{dev})

Proton beam dosimetry

- Convert voxel RSP values into **Monte-Carlo materials** with right stopping power
- Compare **Bragg peak position** with reference (ICRP) one



Energy deposition for multiple proton beams



→ Bragg peak position for proton beams with E = 140 MeV (2mm size each) :

- proton CT : **Δref = 0.2 ± 1.0%**
- x-ray CT : **Δref = 2.8 ± 1.1%**

Proton CT scanner

Experimental developments

Specifications

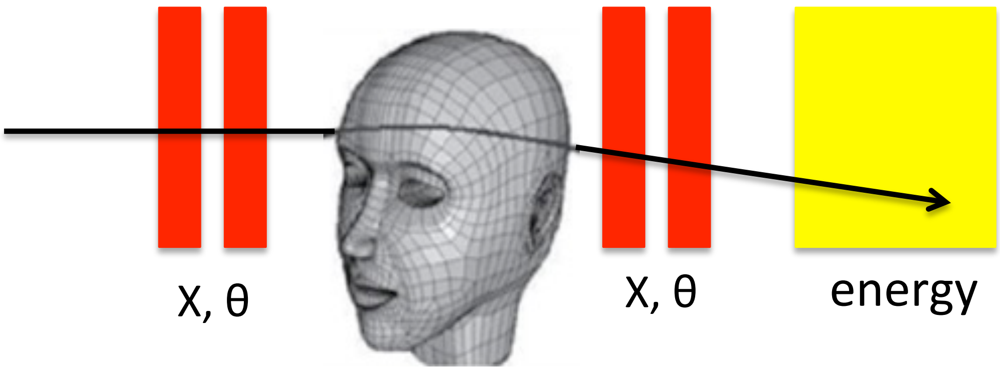
Image reconstruction constraints :

- Proton **direction / position** before and after the patient (proton path)
- Proton **energy** before and after the patient (stopping power)
- Acquisition **proton by proton**

Clinical constraints :

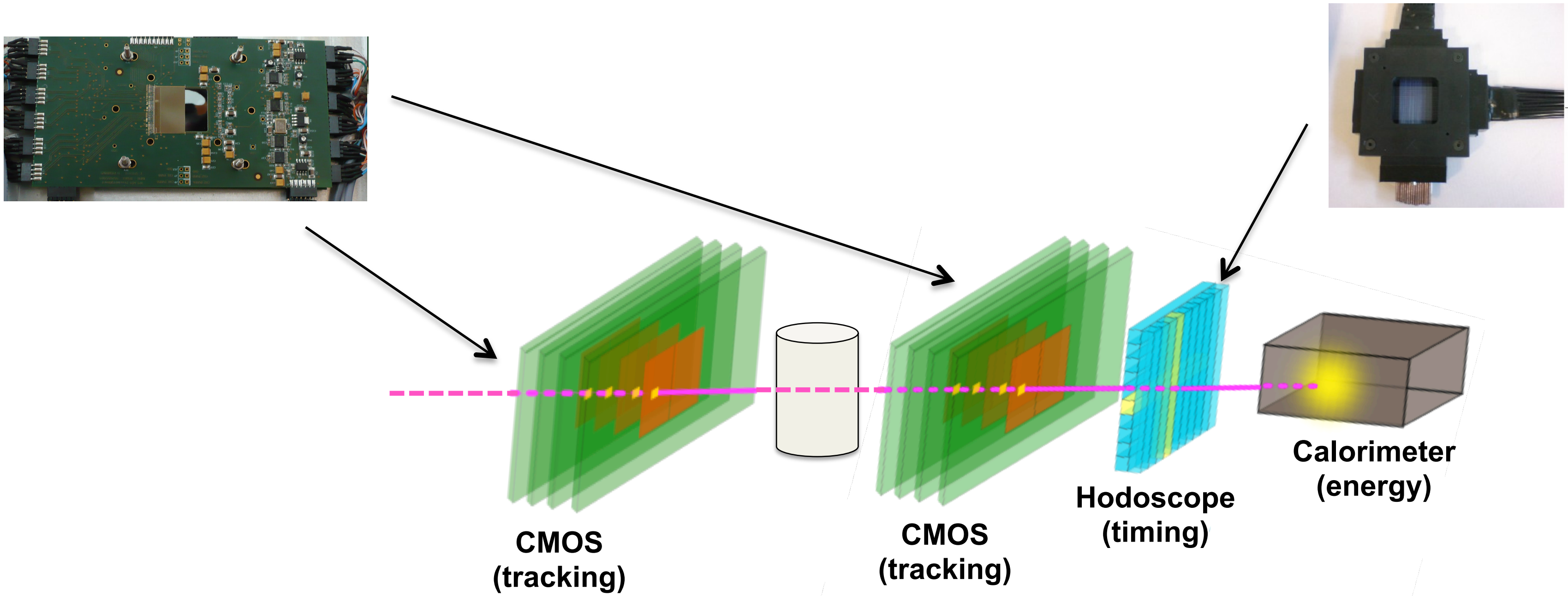
- Maximum proton beam energy (about 250 MeV)
- Gantry features (available space, rotation, …)
- Acquisition time (high rate ⇔ short time)

⟶ **build a first prototype to study specifications constraints**



Schematic view of a proton CT scanner

Prototype

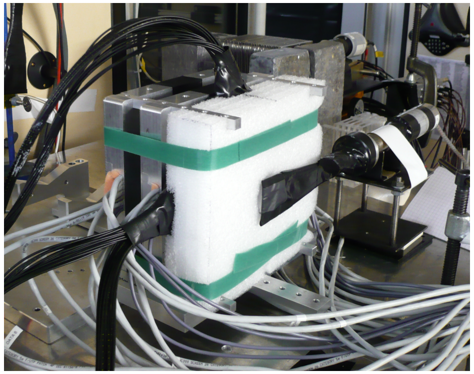


- **CMOS** silicon trackers to measure proton position / direction
  ✓excellent spatial resolution (≈µm)
  ✗ Slow readout time (≈100 µs) ⬄ limited acquisition rate

- Scintillating fibers **hodoscope** to tag protons in time
  apply geometrical tracking to associate tracks from CMOS to Hodoscope

- **$LaBr_3$ calorimeter** to measure proton energy

Beam test



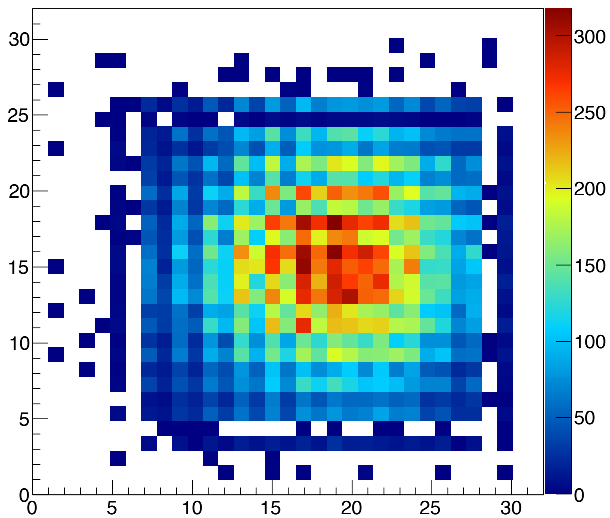
GANIL avril 2014

Test prototype under beam conditions :

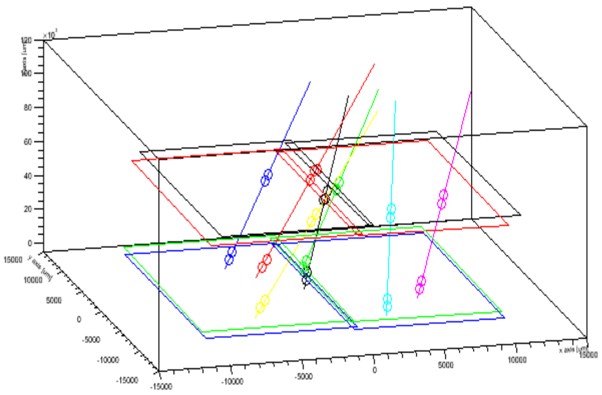
- Detectors responses
- Electronic behaviour
- Coupling CMOS / Hodoscope / Calorimeter

→ tests with carbon and secondary proton beam

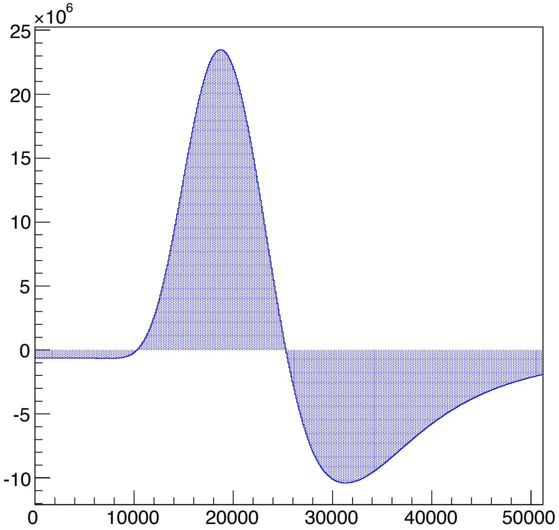
→ actual acquisition rate ≈ 15 kHz



Protons tracks (Hodoscope)



Protons tracks (CMOS)



Protons energy (calorimeter)

Summary / Outlook

Proton Scanner Prototype :

- Define a first prototype to improve experimental specifications
- Succesful beam tests…data acquisition proton by proton at 15 kHz
- Higher rate expected soon…to gain between one and two order of magnitude

Proton therapy TPS :

- Monte Carlo is a useful tool to quantify clinical interest of new imaging technics
- One can reproduce a full protontherapy TPS from imaging to dose distribution
- Other clinical tests in progress (ex : dental titanium implant to test metal artefacts)