Optimization of the track reconstruction algorithm in a pixel based calorimeter for proton computed tomography

Author:
Alba García Santos

Utrecht University

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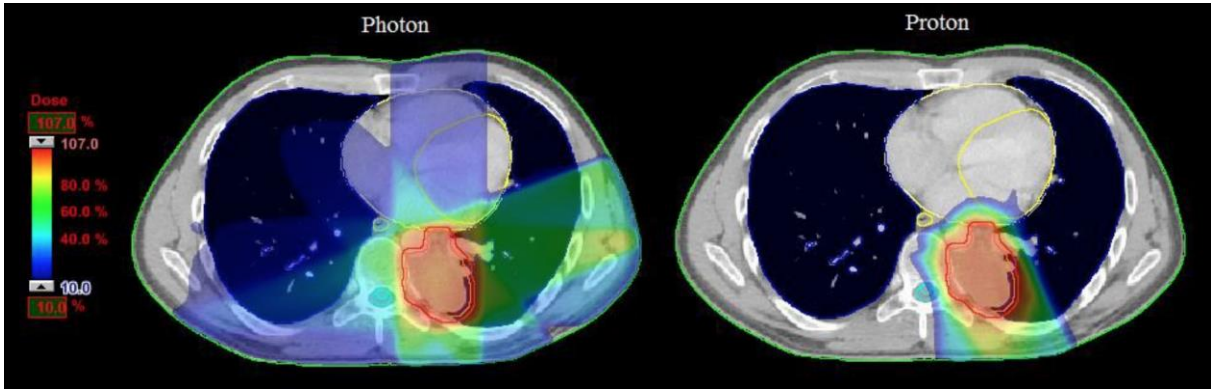
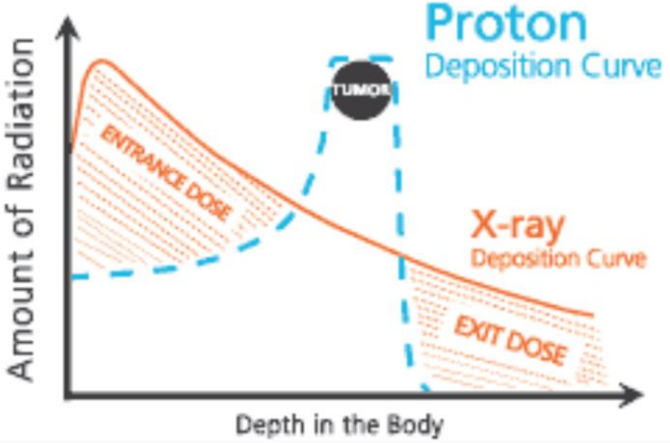
Introduction

- Cancer is a destructive disease, in which tumor cells grow-out-of-control, halting organ function

- Different treatment depending on:
  - cancer type, stage, organs at risk adjacent to the tumor…

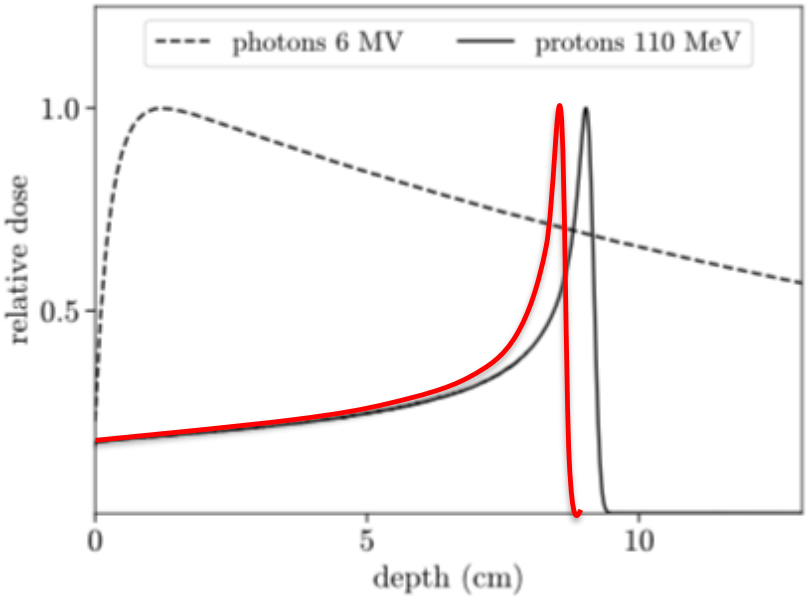
- Increase in the number of patient treated with particle therapy→ Protons



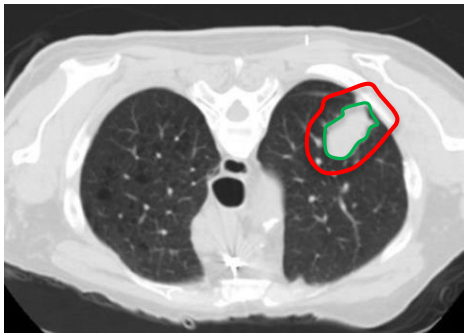


Introduction

- Narrow Bragg peak
  - \+ Localized treatment possible
  - − High susceptibility to uncertainty in the treatment planning



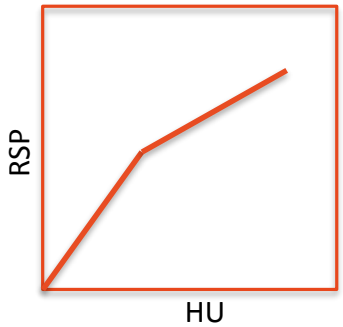
- Safety margins
  - \+ Tumor is fully covered
  - − Increase irradiation of healthy tissue



Institution	Relative margin	Fixed margin	At 20 cm depth
University of Florida Proton Therapy Institute	2.5%	1.5 mm	6.5 mm
Massachusetts General Hospital	3.5%	1 mm	8 mm
MD Anderson Proton Therapy Center	3.5%	3 mm	10 mm
Loma Linda University Medical Center	3.5%	3 mm	10 mm
Roberts Proton Therapy Center	3.5%	3 mm	10 mm

One of the causes of this uncertainty…

CT Hounsfield Units (HU) → (Calibration curve) → Relative Stopping power (RSP) → (Dose calculation) → Treatment planning



- Range uncertainties : ~7%
- Improvement→ Dual Energy CT: ~ 2%
- However, CT artifact→ inaccurate RSP map

Proton CT (~ 0.3%)

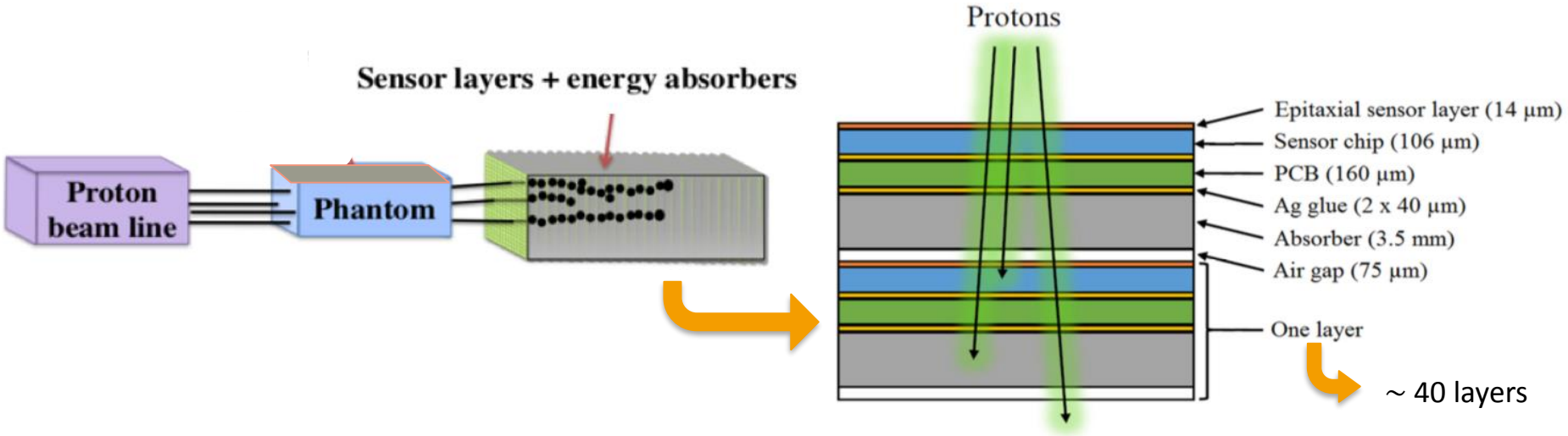
- Direct RSP maps
- No artifacts
- Reduction of imaging dose compare to CT.

Reduction of treatment margins

Proton CT

For RSP maps calculation:

- Using a **Digital Tracking Calorimeter** → many protons' residual energies can be measured at the same time.

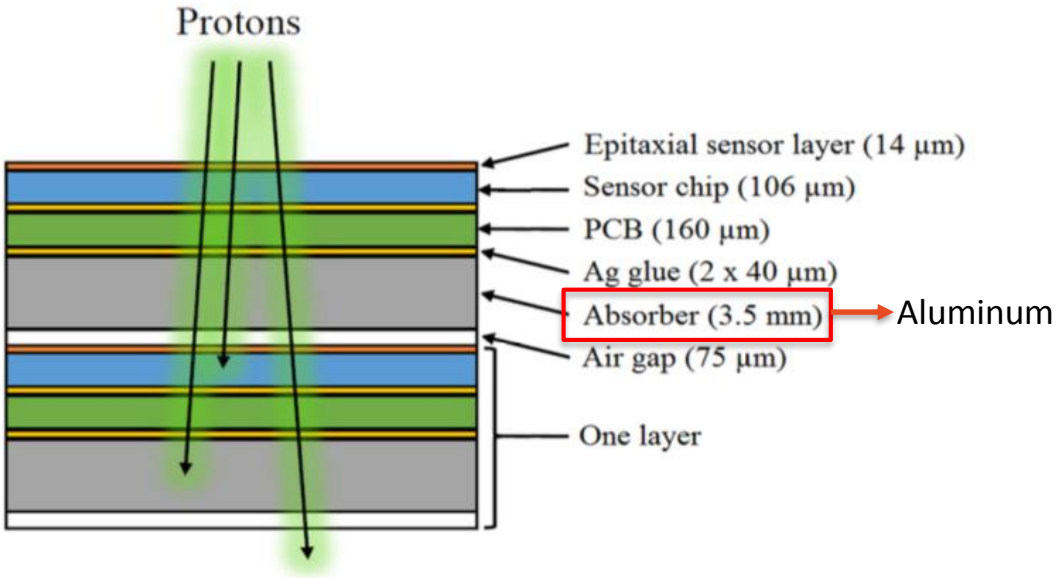


- ALice PIxel Detector (**ALPIDE**) chip:
  - Active area: 15 x 30 mm^2 (1024 x 512 pixel array of 28 x 28 μm^2 pixels).
  - Readout rate: ~ 5-10 μs.
- Used sensors + sensor layer design = ALICE FoCal em calorimeter → Synergy in R&D

Proton CT

For RSP maps calculation:

- Using a Digital Tracking Calorimeter → many proton's residual energies can be measured at the same time .



- Multiple Coulomb scattering → stochastic trajectories
- Proton intensities + high level of scatter between layers → **track reconstruction algorithm**

Research objective

- A proton track reconstruction algorithm has already been developed.
- However, it has some limitations on the track density that can be reconstructed correctly.
- A more efficient algorithm will allow a reduction of the scan time.

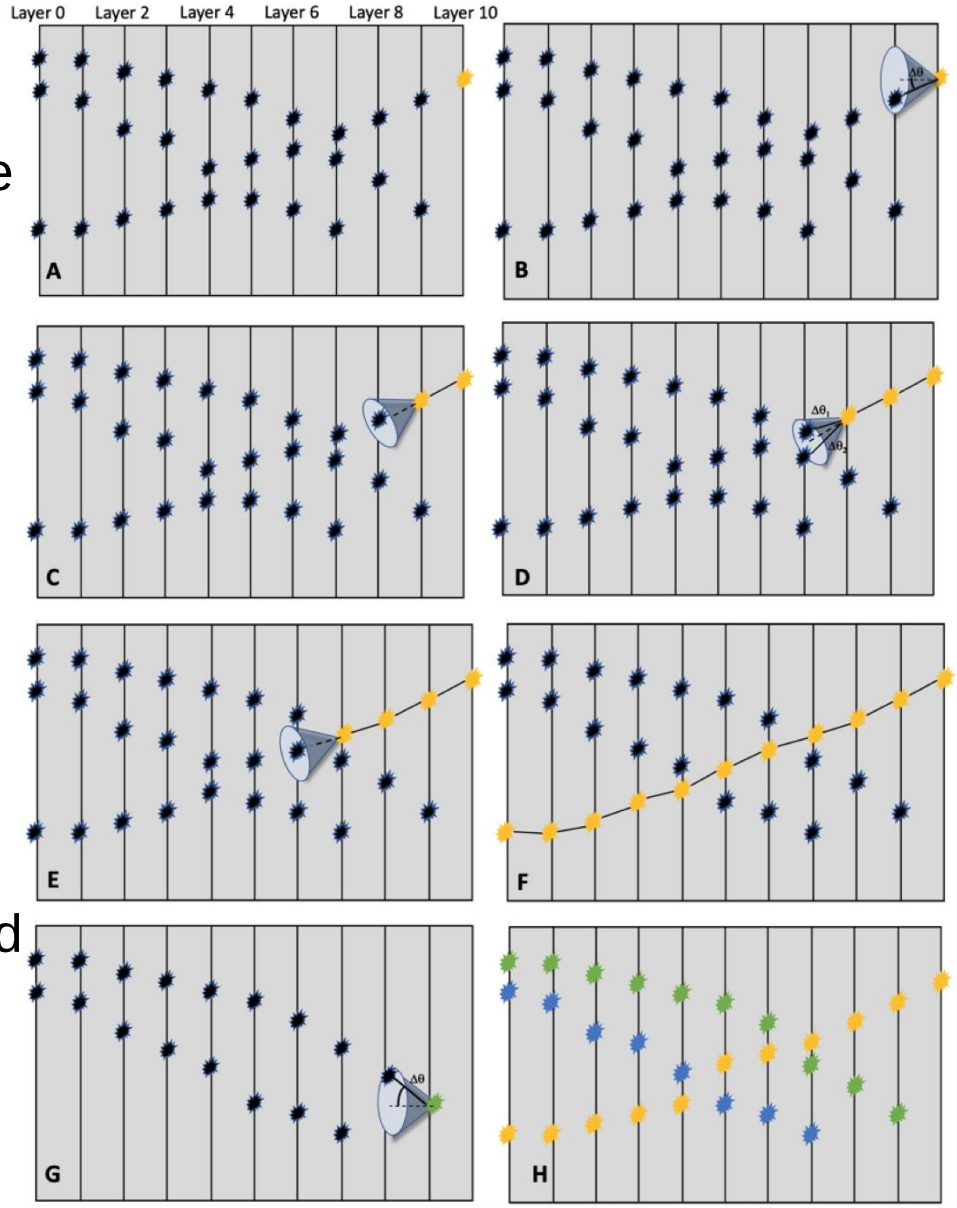
Optimization of the current method

Current Algorithm

- Based on the track-following scheme
- Search cone size depends on S_{max}
  - Determine the of curvature
  - Constant value
- S_n is calculated for each candidate

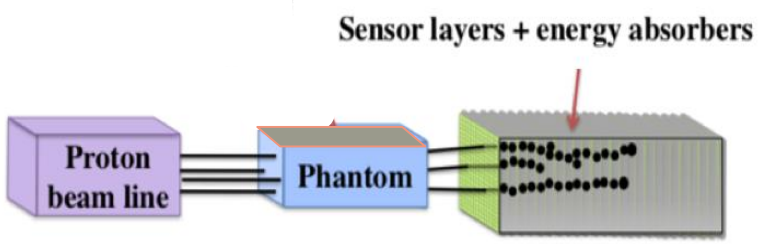
$$S_n = \sqrt{\sum_{n}^{layer} (\Delta\theta layer)^2}$$

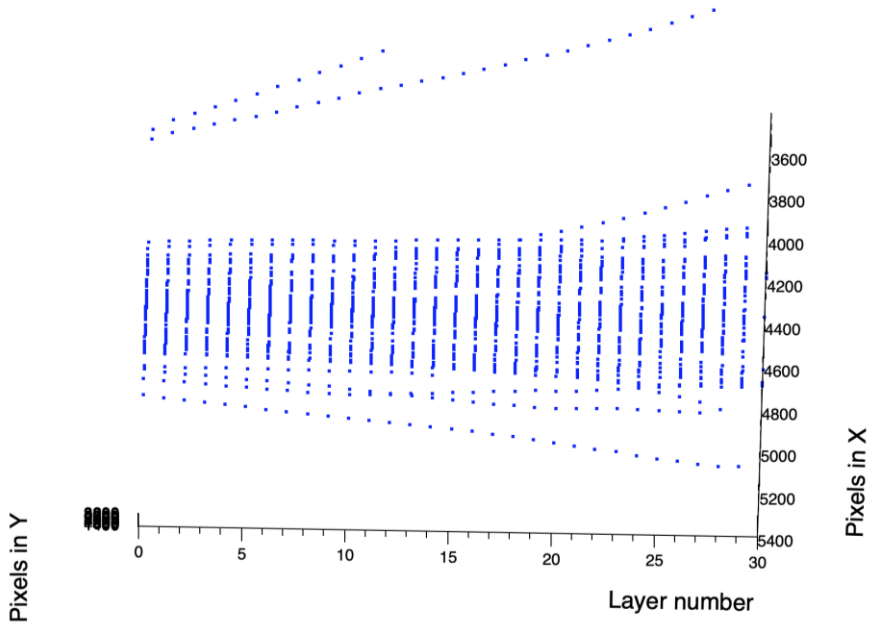
- If $S_n < S_{max}$ → the candidate is added to the track

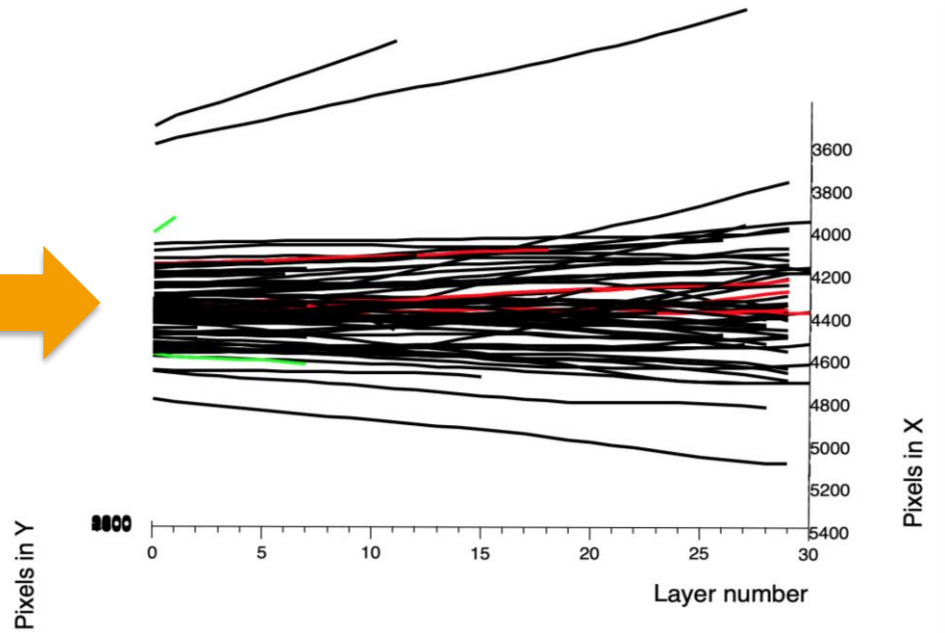


Current Algorithm

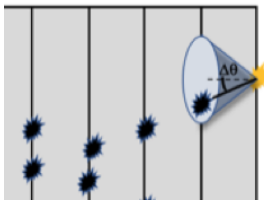
Geant4
+
GATE







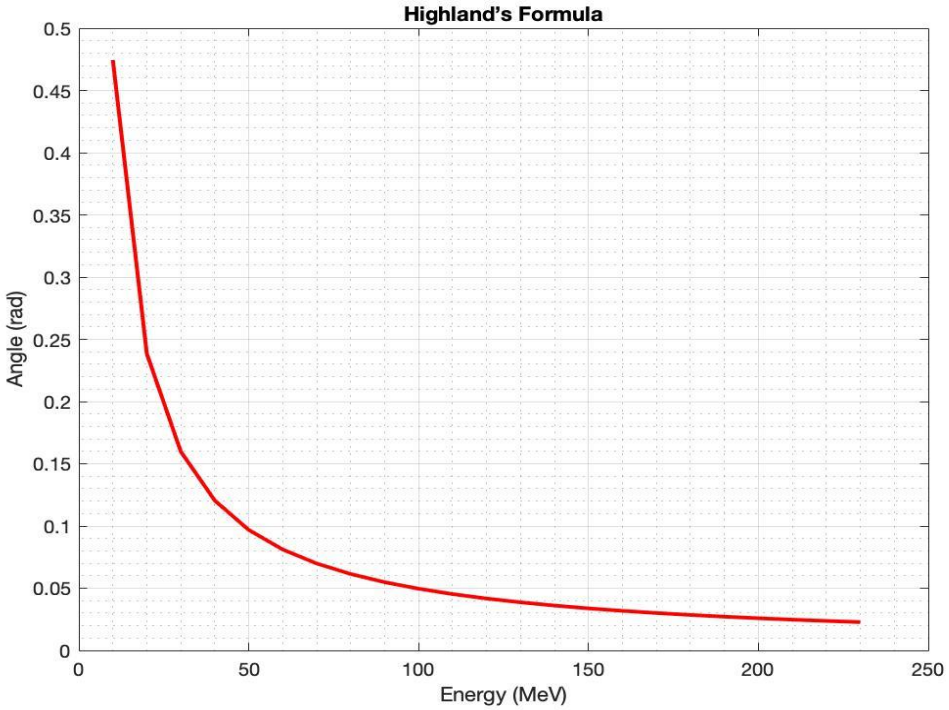
Idea 1: Variable S_{max}



- Calculate expected scatter →Highland's Formula

$$\theta_0 = \frac{14.1\,\text{MeV}}{p_1 v_1}\sqrt{\frac{x}{X_0}}\left(1+\frac{1}{9}\log_{10}\frac{x}{X_0}\right)$$

- *x: target length (3.5mm Al)*
- *X_0: radiation length of the target material (Al)*
- *P_1v_1: proton's kinematic properties for momentum and velocity.*



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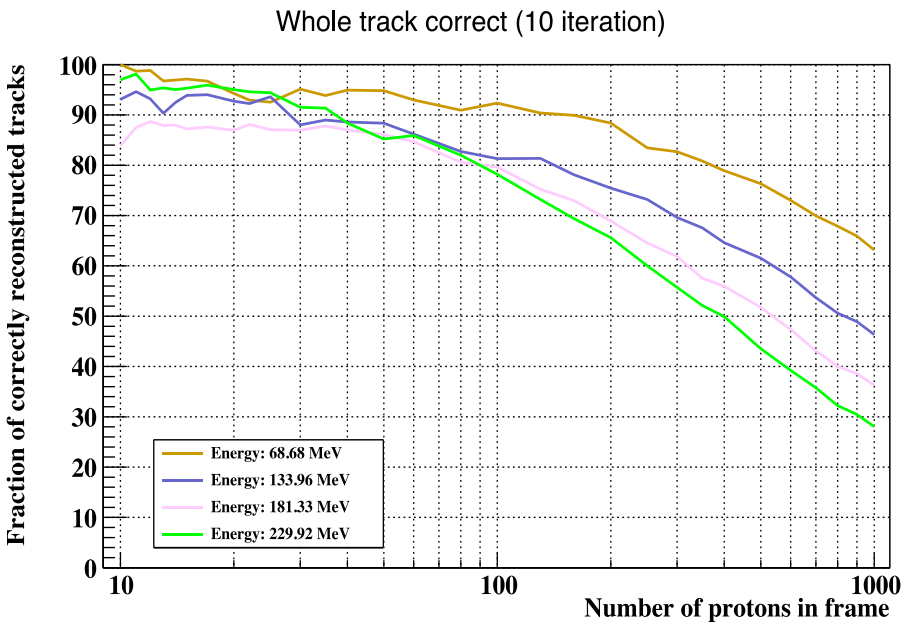
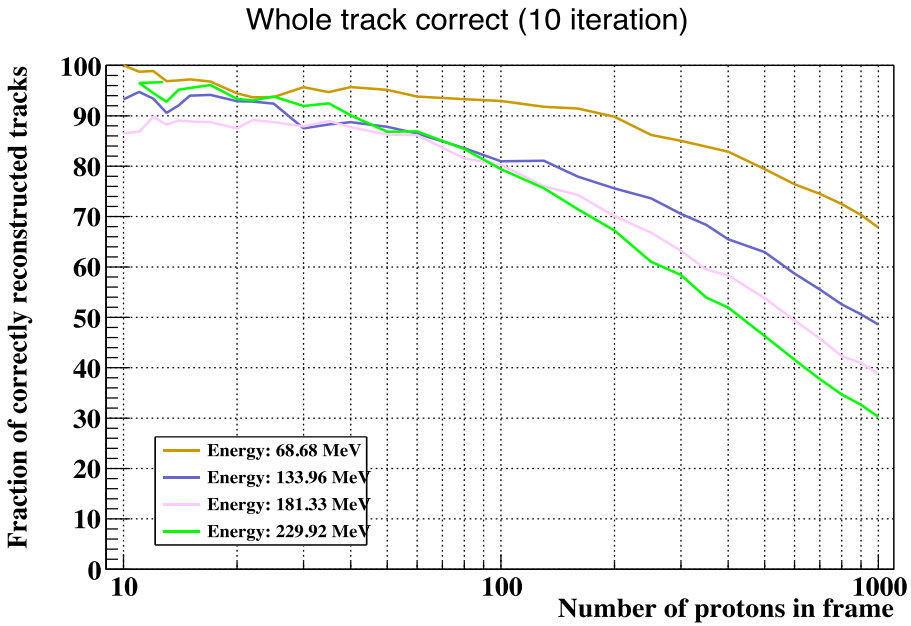
Efficiency

- Only marginal improvement of the algorithm by using Highland's formula

Using constant S_{max} (current algorithm)

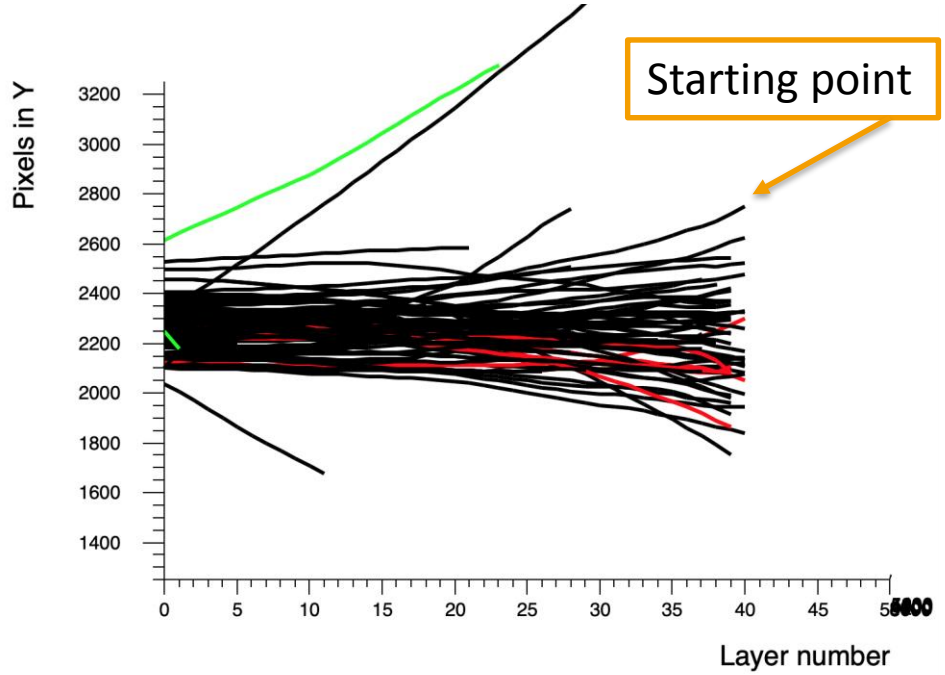


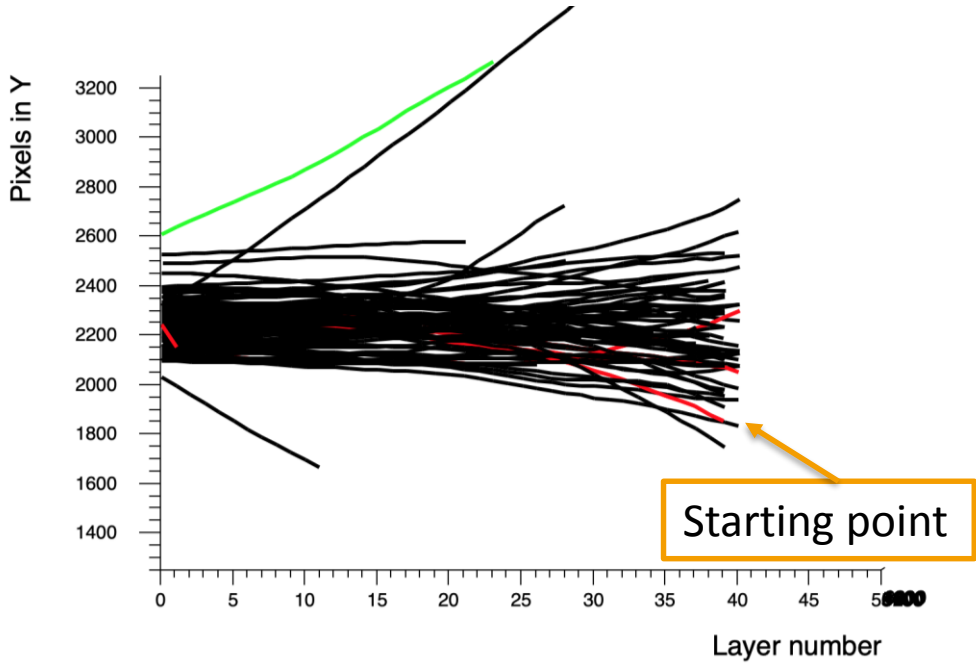
Using Highland's formula



Idea 1: Variable S_{max}

Different starting point = Different efficiency

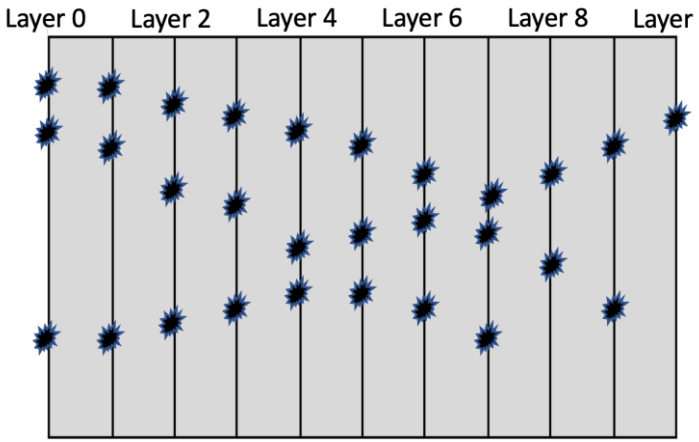




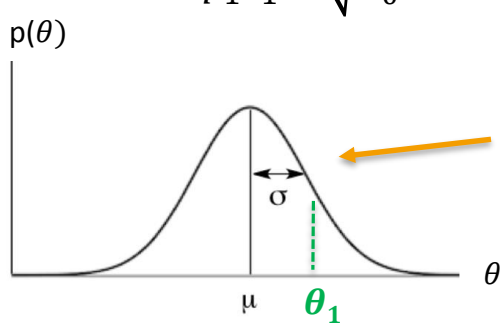
Tracks with same first/last ID	All clusters same ID	Tracks with close match (0.5mm,1 degree) on first/last cluster
84.96%	75.22%	96.4%

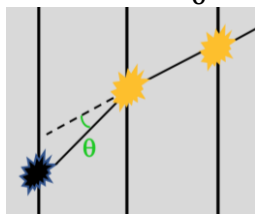
Tracks with same first/last ID	All clusters same ID	Tracks with close match (0.5mm,1 degree) on first/last cluster
90.09%	81.08%	98.2%

Idea 2: Calculate best scenario

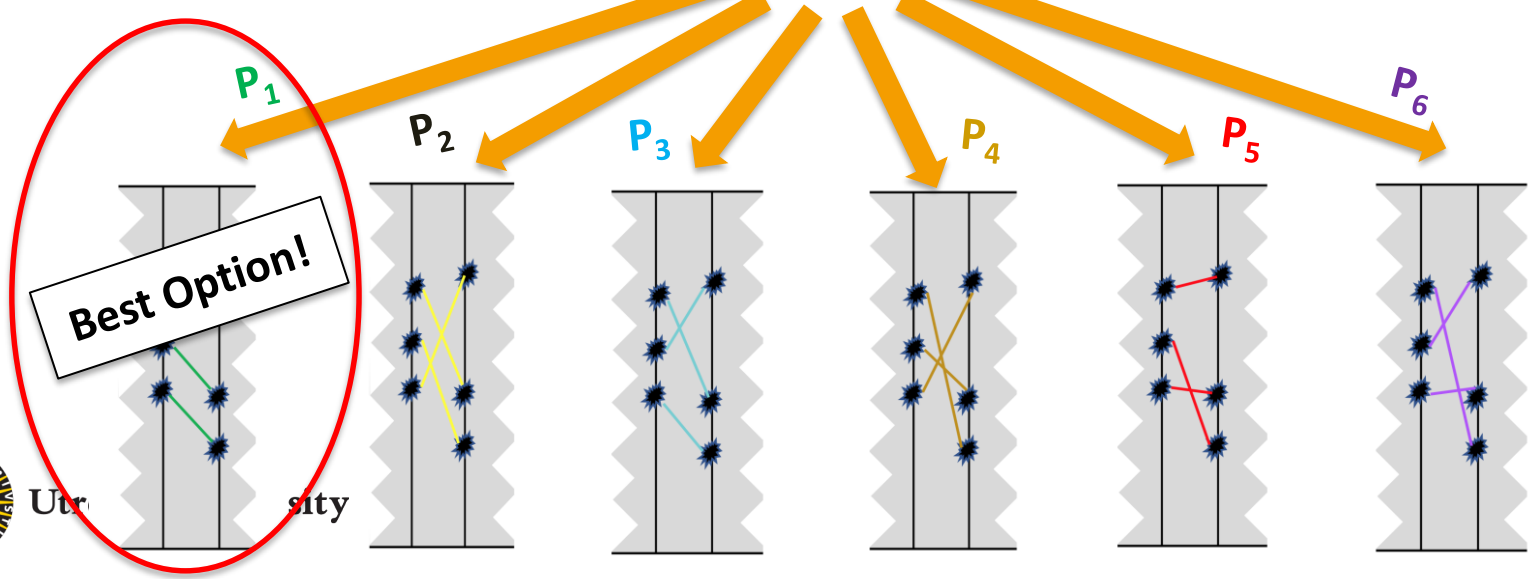


$$\sigma = \frac{14.1\ MeV}{p_1 v_1}\sqrt{\frac{x}{X_0}}\left(1 + \frac{1}{9}log_{10}\frac{x}{X_0}\right)$$





$$P_{Total} = P_{\theta_1} * P_{\theta_2} * \ldots * P_{\theta_n}$$



Conclusions

- Proton therapy treatment can optimize the dose delivery to patient
- The use of a proton CT will increase the accuracy of the treatment planning
- To this end, protons' residual energies can be measured using Digital Tracking Calorimeter → many protons can be detected at the same time
- However, protons follow stochastic trajectories in the detector→ track reconstruction algorithm.
- The current track reconstruction algorithm has some limitation, especially at higher beam intensities
- Optimization of this algorithm → better performance
  - Idea 1: Adapt the algorithm to the expected scatter depending on the energy
    - Small improvement
    - Low robustness
  - Idea 2: Calculate the best scenario per layer
    - More robust
    - More computationally expensive
    - Better results???

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