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

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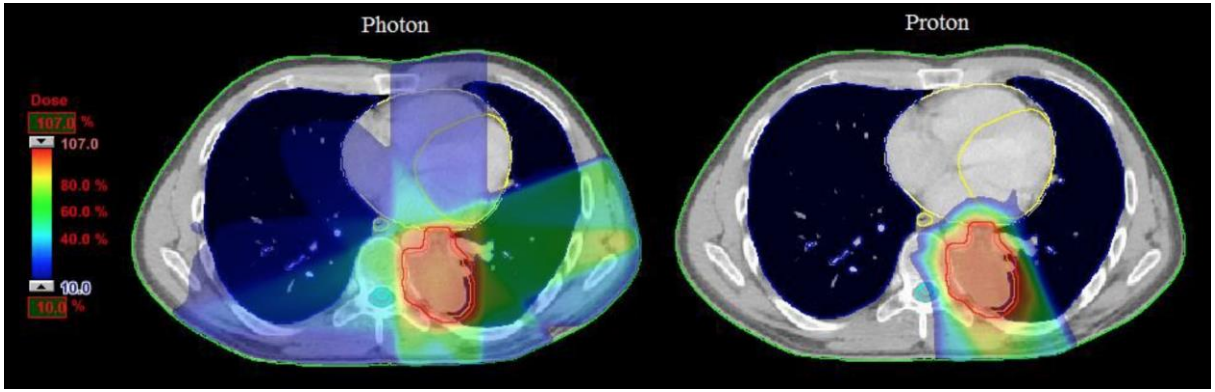
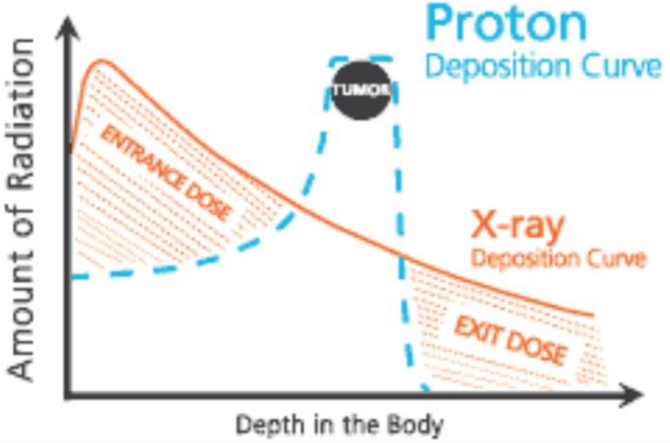
# Introduction

- 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…

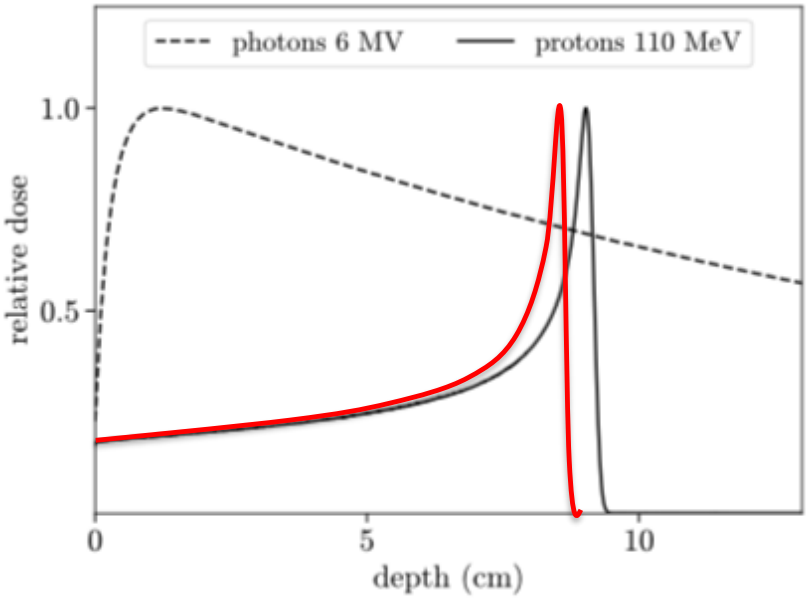
- Increase in the number of patient treated with particle therapy→ Protons



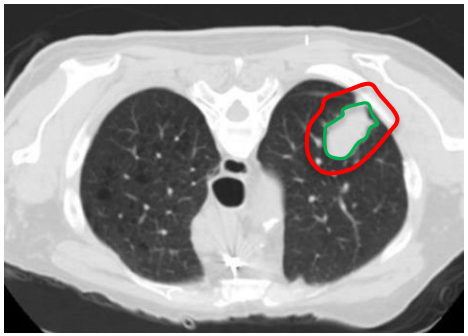



# Introduction

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



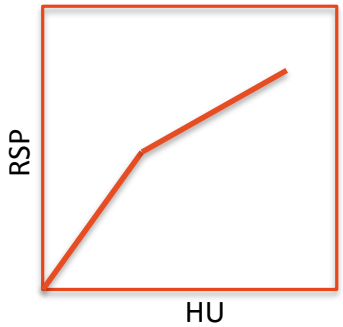

- Safety margins
  - \+ Tumor is fully covered
  - − Increase irradiation of healthy tissue



| 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%)

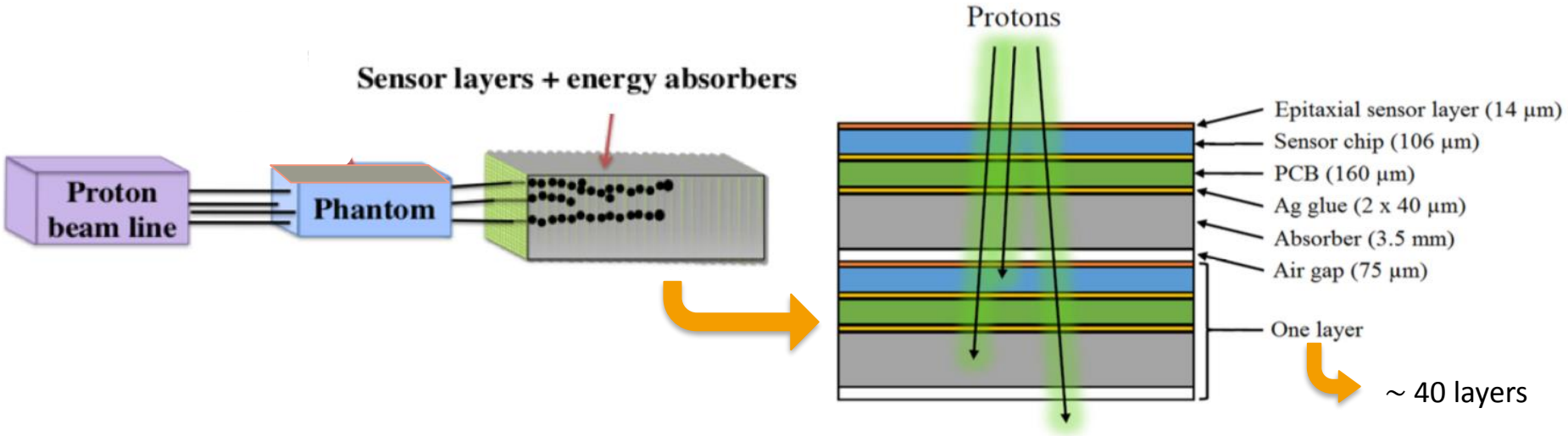
- Direct RSP maps
- No artifacts
- Reduction of imaging dose compare to CT.

**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.

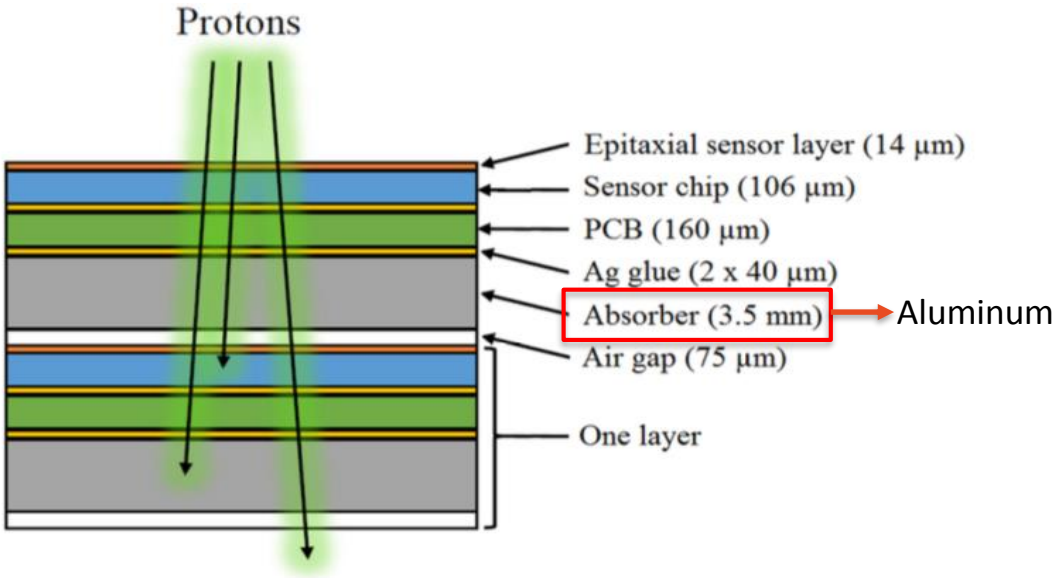



- ALice PIxel Detector (**ALPIDE**) chip:
  - Active area: 15 x 30 $mm^2$ (1024 x 512 pixel array of 28 x 28 $\mu m^2$ pixels).
  - Readout rate: ~ 5-10 $\mu s$.
- Used sensors + sensor layer design = ALICE FoCal em calorimeter → Synergy in R&D

# 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.

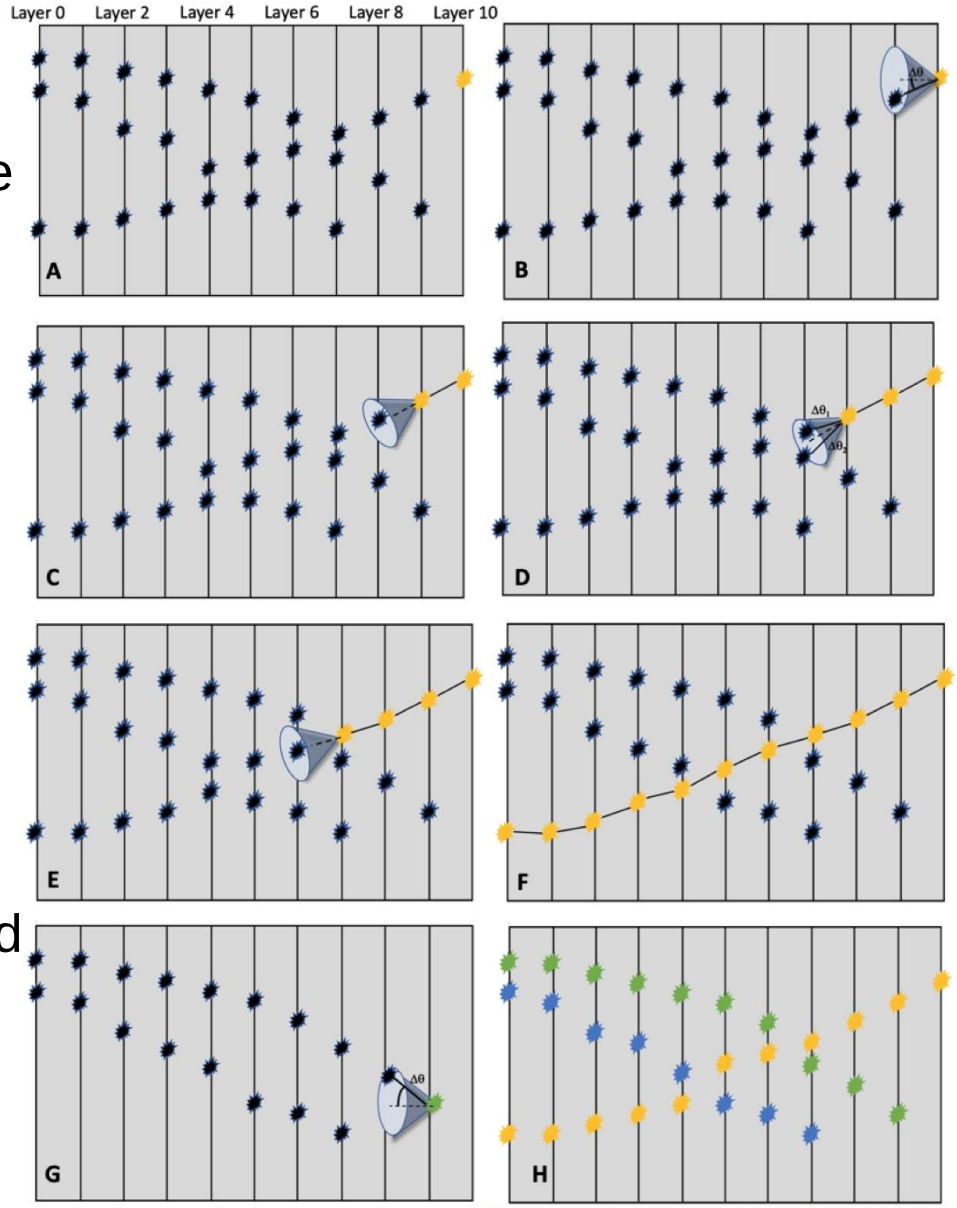
**Optimization of the current method**

# 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

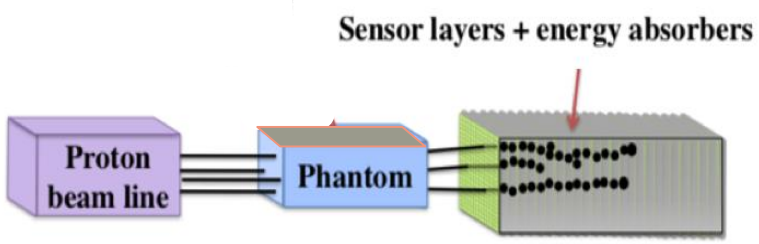
$$S_n = \sqrt{\sum_{n}^{layer} (\Delta\theta layer)^2}$$

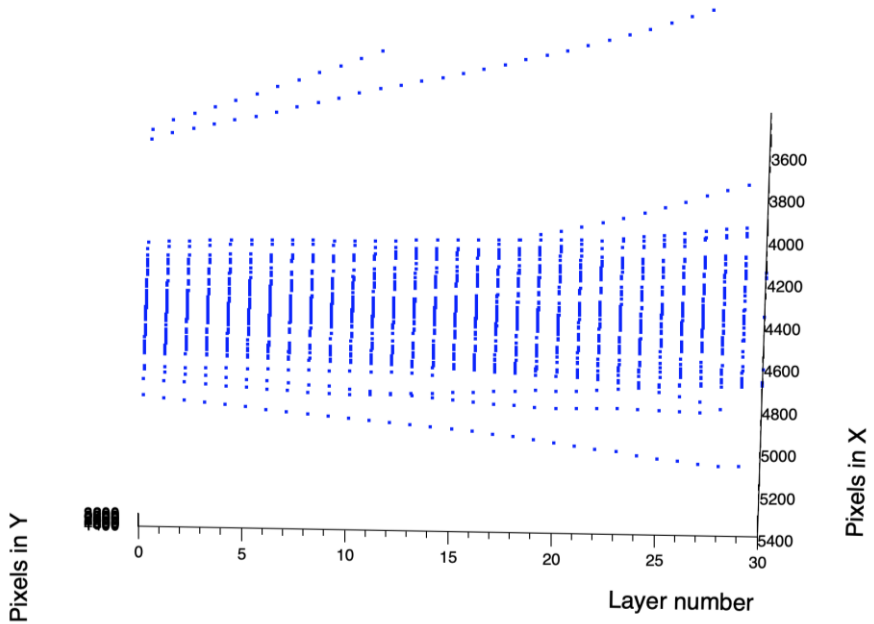
- If $S_n < S_{max}$ → the candidate is added to the track

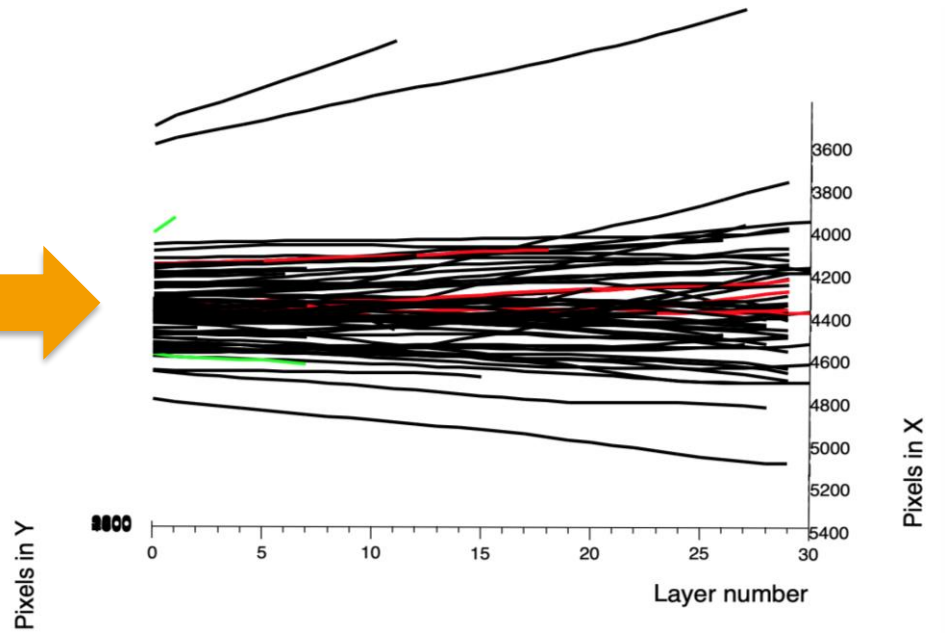


# Current Algorithm

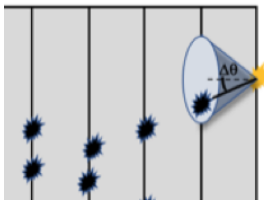
Geant4
+
GATE



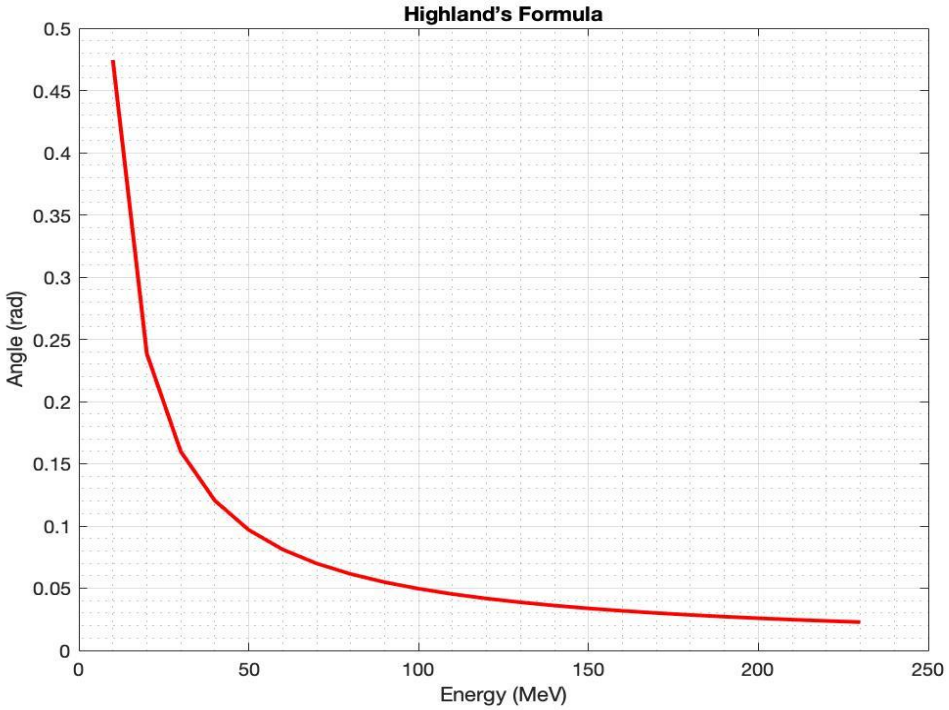
# Idea 1: Variable $S_{max}$



- 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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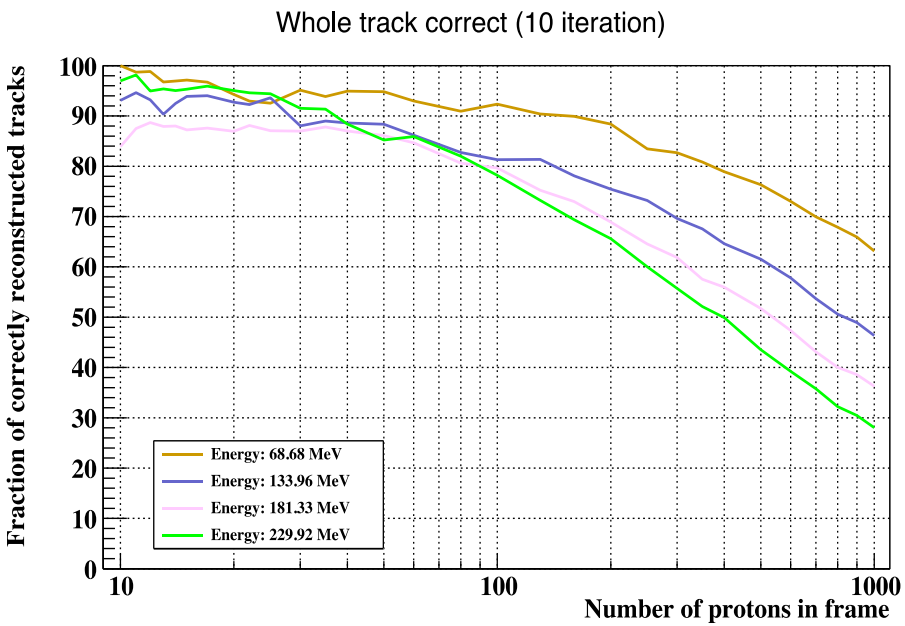
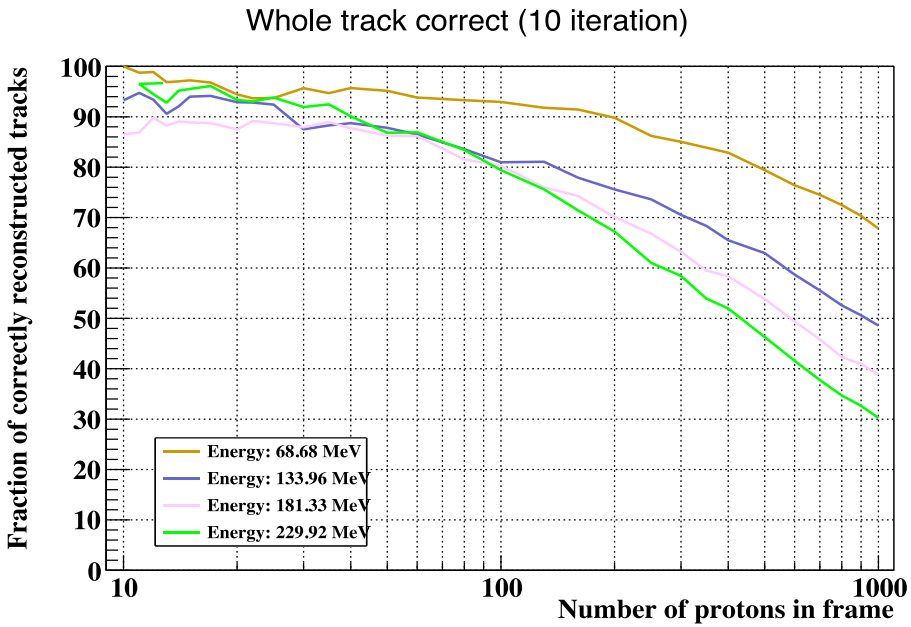
# Efficiency

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

Using constant $S_{max}$ (current algorithm)

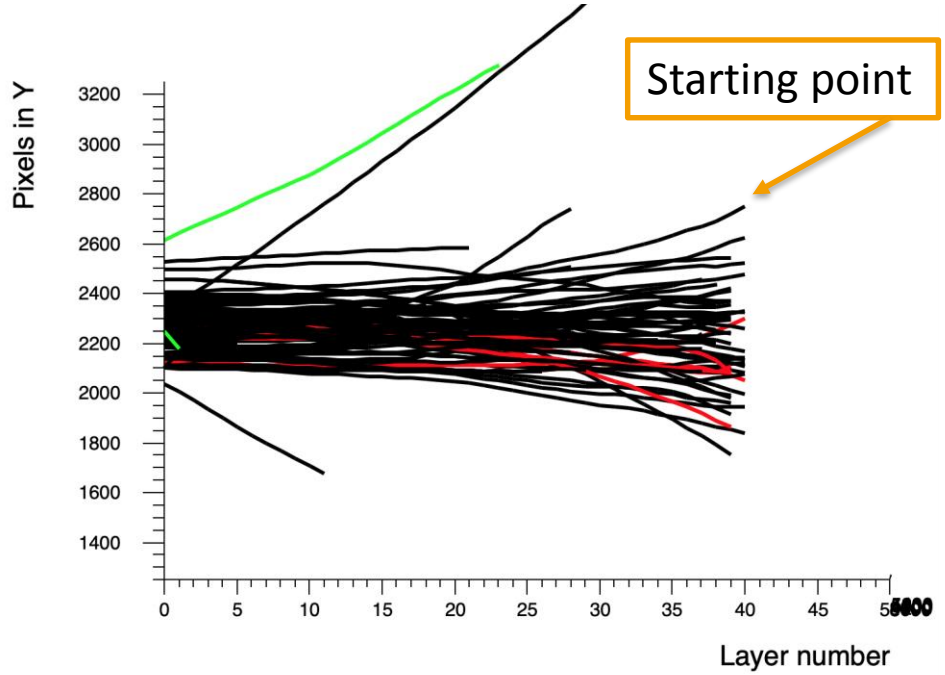


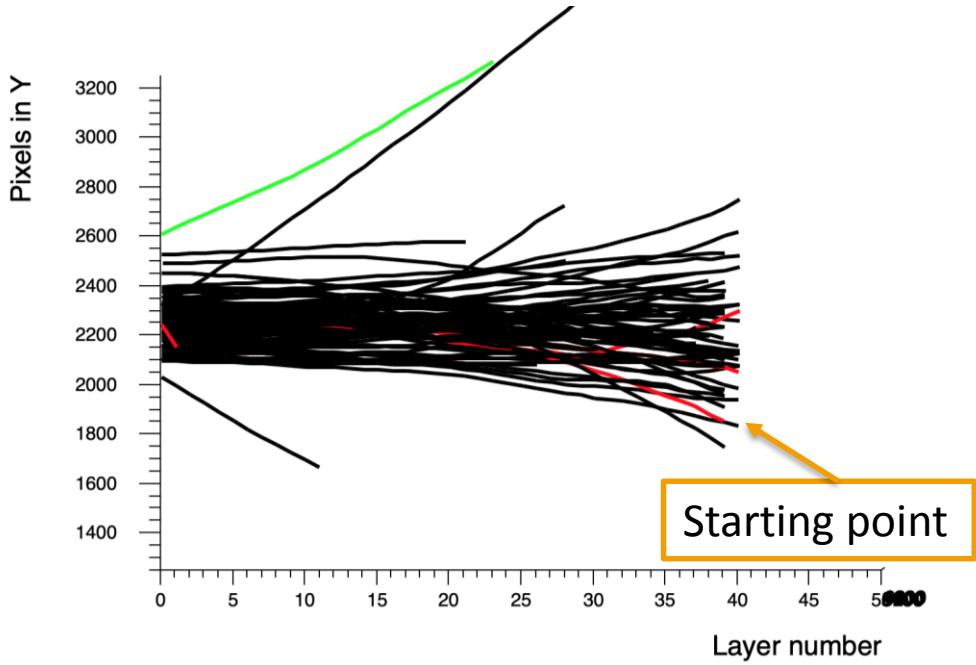

Using Highland's formula



# Idea 1: Variable $S_{max}$

**Different starting point = Different efficiency**

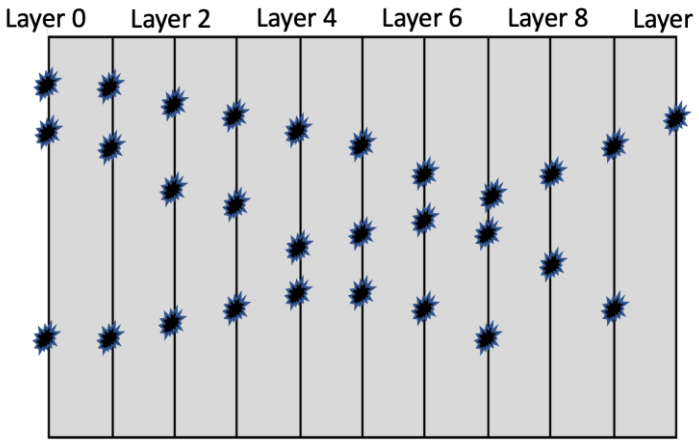


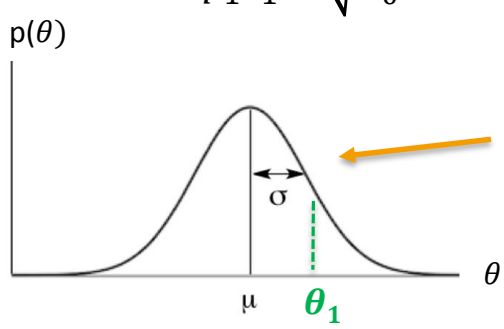

| Tracks with same first/last ID | All clusters same ID | Tracks with close match (0.5mm,1 degree) on first/last cluster |
|---|---|---|
| 84.96% | 75.22% | 96.4% |

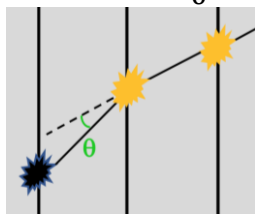
| Tracks with same first/last ID | All clusters same ID | Tracks with close match (0.5mm,1 degree) on first/last cluster |
|---|---|---|
| 90.09% | 81.08% | 98.2% |

# Idea 2: Calculate best scenario

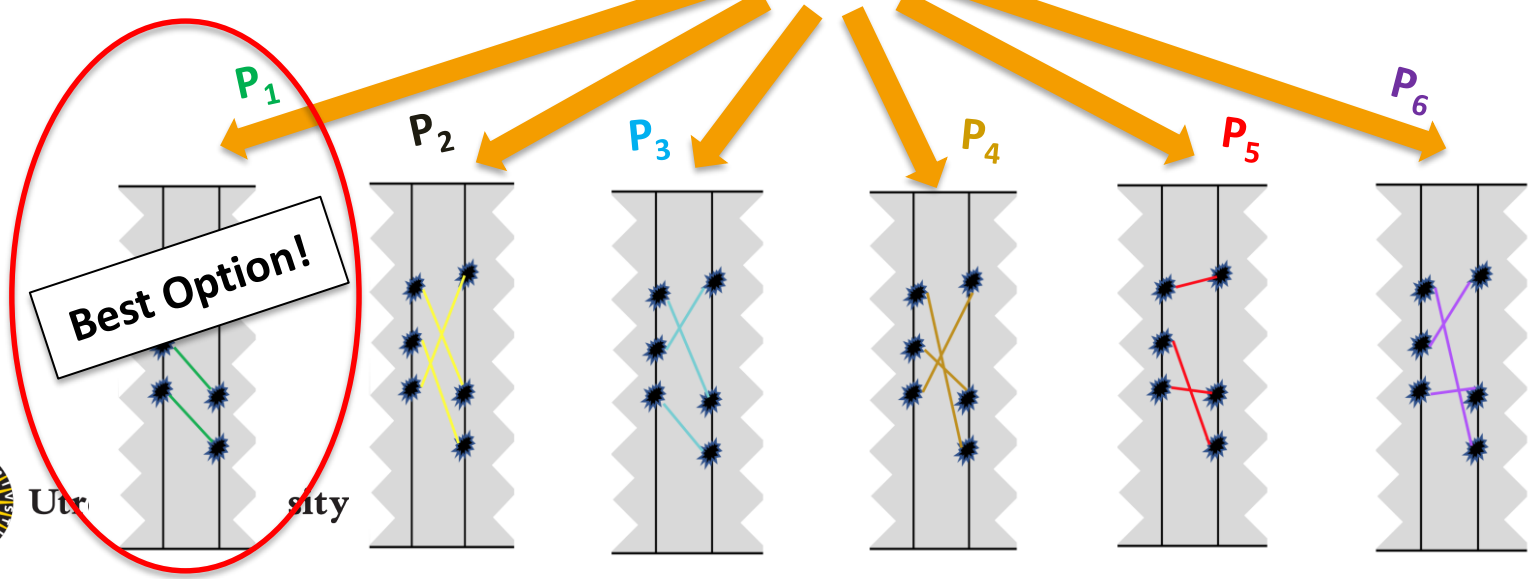



$$\sigma = \frac{14.1\ MeV}{p_1 v_1}\sqrt{\frac{x}{X_0}}\left(1 + \frac{1}{9}log_{10}\frac{x}{X_0}\right)$$




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



# 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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