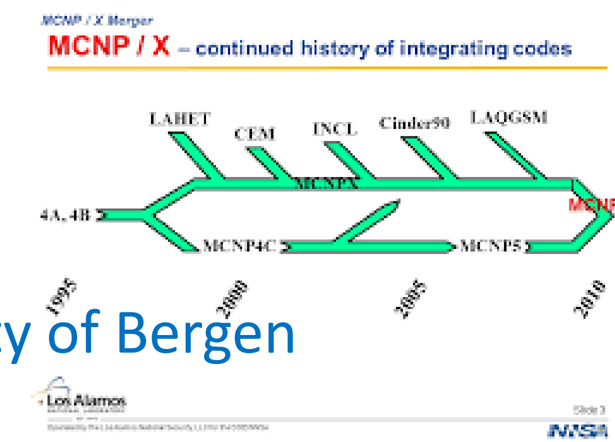
Status of simulations / modeling efforts

Jarle R. Sølie, Helge E. S. Pettersen, Ilker Meric

Western Norway University of Applied Sciences

University of Bergen

Haukeland University Hospital



April 16th 2018

Department of Physics and Technology, University of Bergen

Outline

- Overview of MC codes
  - MC code assessment for proton range
- Analysis toolbox from the FoCal prototype
  - The FoCal prototype
  - Track reconstruction
  - Energy/range reconstruction
  - Beam residual energy reconstruction
- Components of pCT simulations based on a tracking calorimeter
- Simulations / Models of the pCT-DTC design
- Future (very near) plans

Overview of MC codes

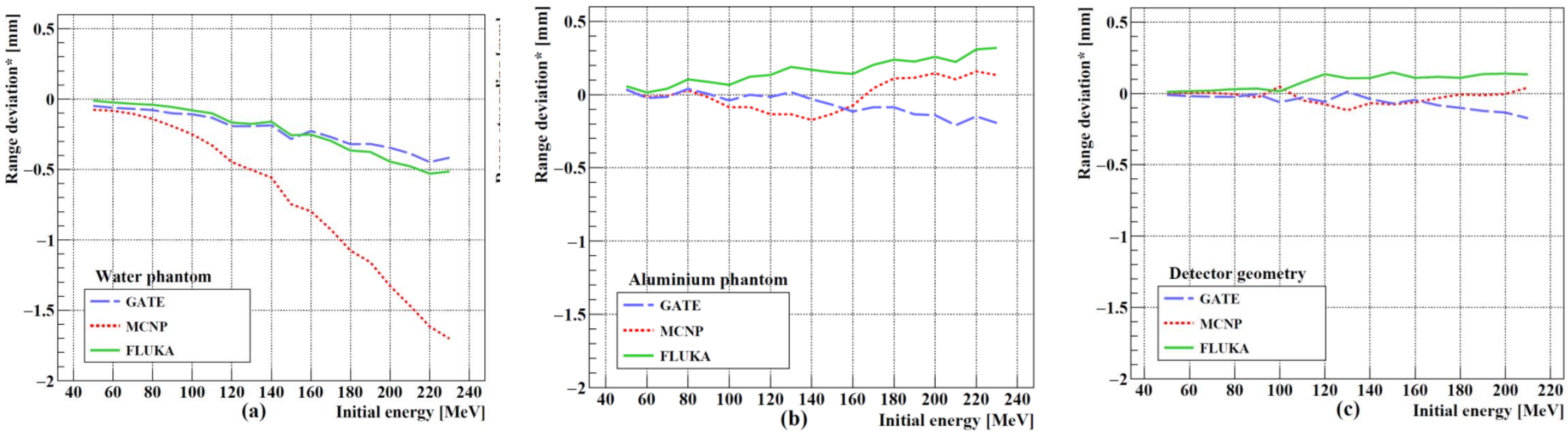
We have access to and expertise in:

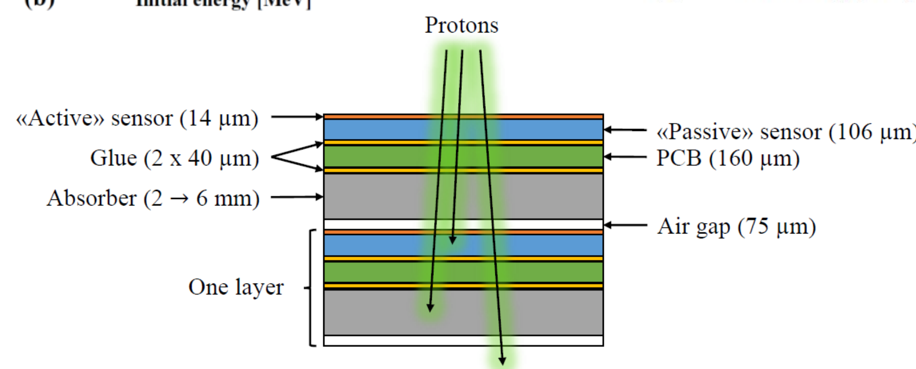
- GATE 7.2 (OpenGATE Collaboration)
  - Open source
  - www.opengatecollaboration.org
- MCNP6.1 (Los Alamos National Laboratory)
  - Quasi-Open source
  - Distributed by RSICC, ORNL (source code and pre-compiled)
  - Difficult to obtain source code
  - Negotiations with RSICC initiated to obtain the latest MCNP6.2 including access to source code
- FLUKA 2011.2c-5 (FLUKA collaboration)
  - Open source
  - www.fluka.org

MC code assessment for proton range

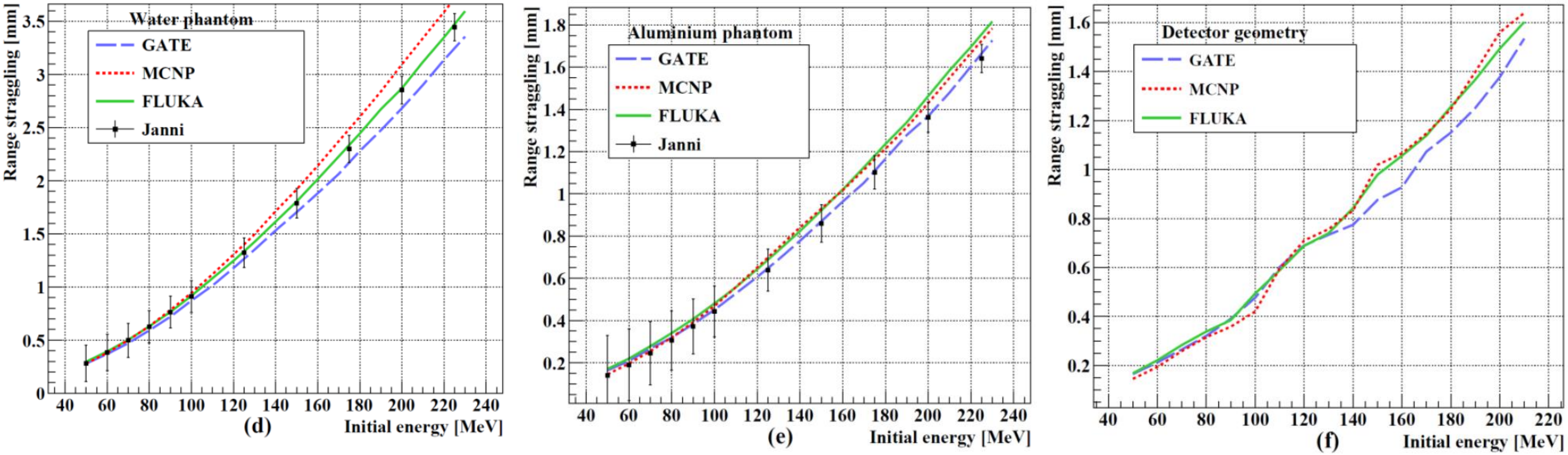
2 Material and methods

Three MC software packages GATE 7.2/Geant4 10.2.2, MCNP6.1 and FLUKA 2011.2c.5 were used to simulate monoenergetic proton beams with energies between 50 – 230 MeV, in 10 MeV increments, as they propagate and come to a complete stop inside different geometry such as a homogeneous water phantom, homogeneous aluminium phantom and the modelled proton tracking detector geometry. The pertinent detector geometry is shown in **Figure 1**.

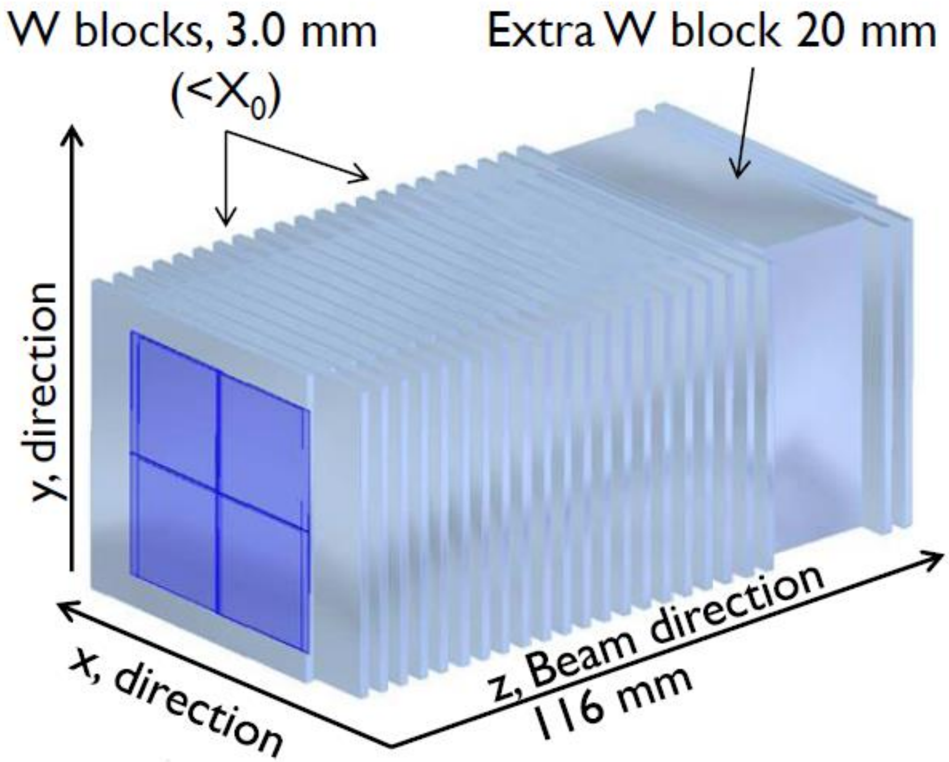


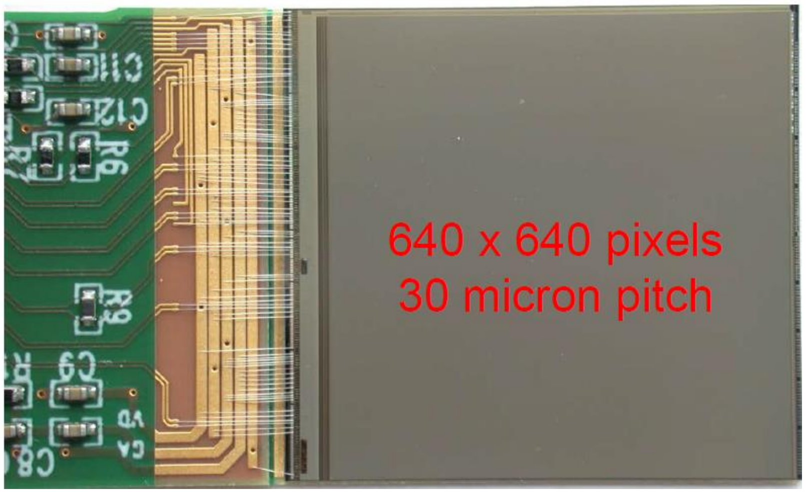


MC code assessment for proton range

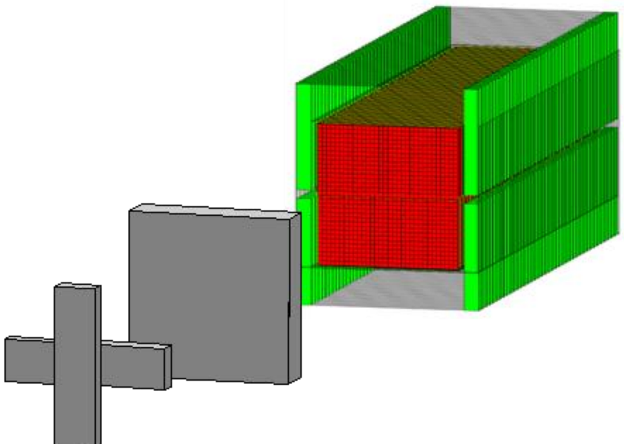


The FoCal prototype





T. Peitzmann, Utrecht University, for the ALICE-FoCal Collaboration
Prototype Studies for a Forward EM Calorimeter in ALICE



- Proton beam tests performed in December 2014 at KVI-CART in Groningen
- Model of FoCal / beam tests implemented in GATE v7.2

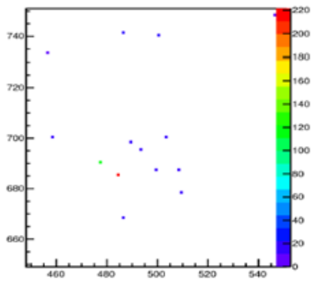
The FoCal prototype

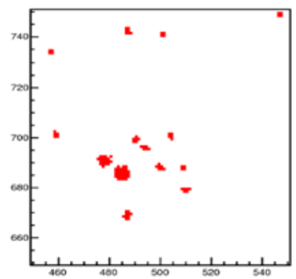
Data readout MC, MC + truth, exp.

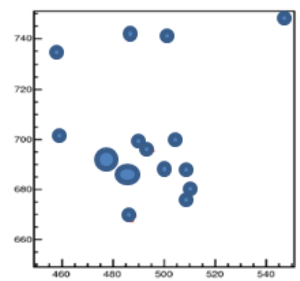
Pixel diffusion modelling (MC only)

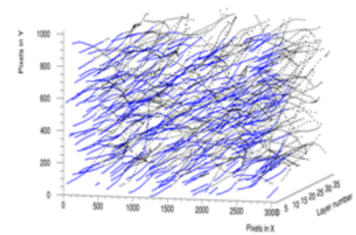
Cluster identification

Proton track reconstruction





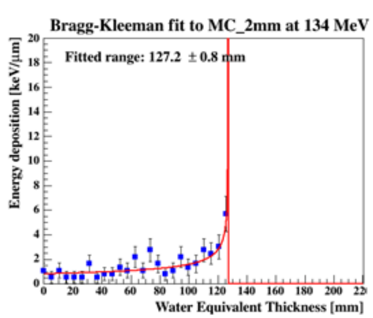


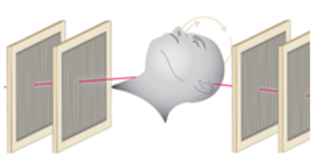


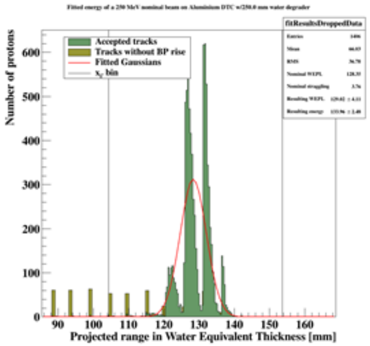
Individual track – energy loss fitting

If 3D reconstruction: MLP estimation

Residual range calculation







Details of the data analysis

Details of the data analysis (charge diffusion, clustering, tracking etc…) are thorougly explained in our 2017 NIMA paper

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH

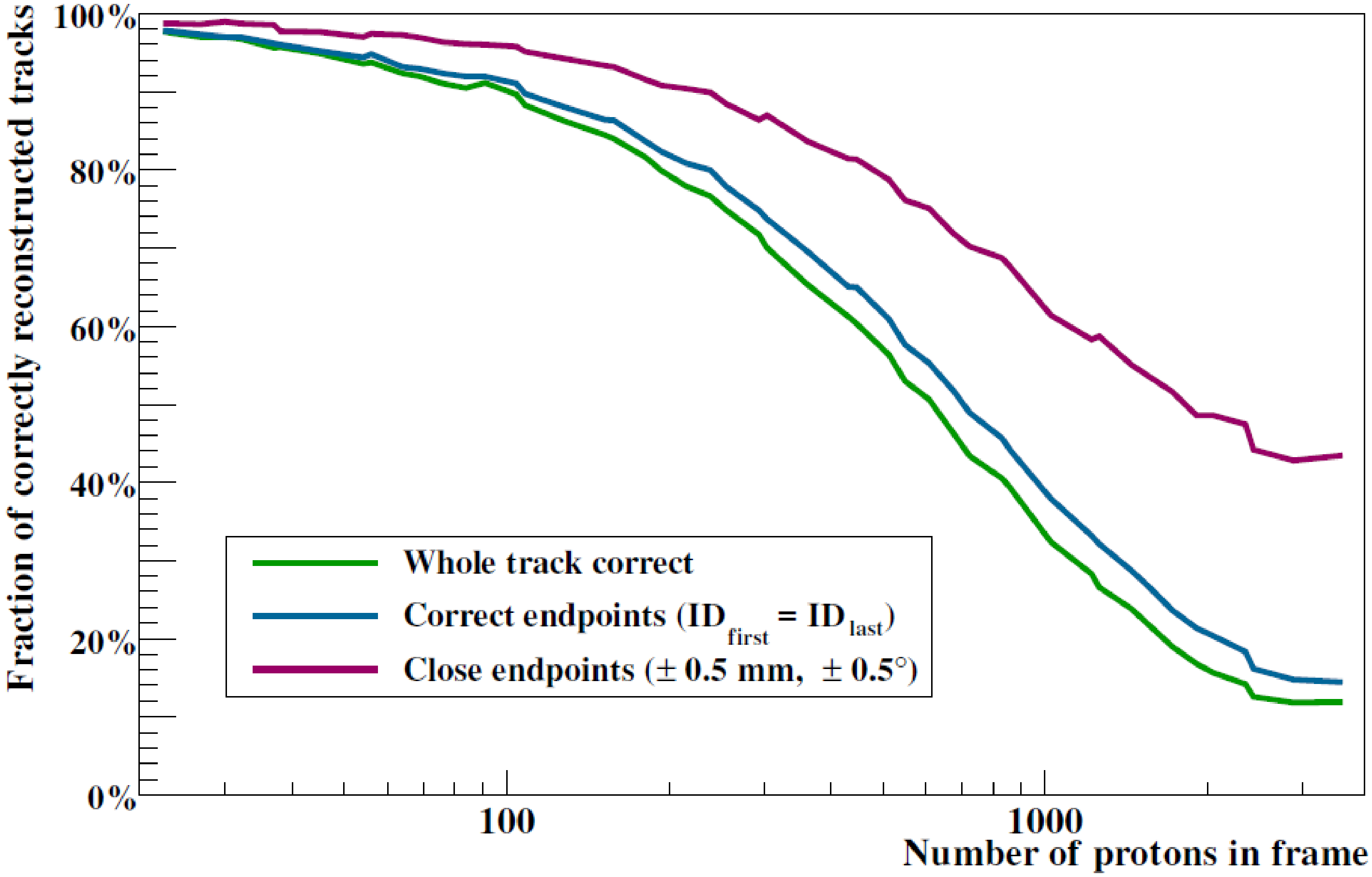
Proton tracking in a high-granularity Digital Tracking Calorimeter for proton CT purposes

CrossMark

H.E.S. Pettersen[a,b,*], J. Alme[b], A. Biegun[e], A. van den Brink[c], M. Chaar[b], D. Fehlker[b], I. Meric[d], O.H. Odland[a], T. Peitzmann[c], E. Rocco[c], K. Ullaland[b], H. Wang[c], S. Yang[b], C. Zhang[c], D. Röhrich[b]

[a] Department of Oncology and Medical Physics, Haukeland University Hospital, Postbox 1400, 5021 Bergen, Norway
[b] Department of Physics and Technology, University of Bergen, Postbox 7803, 5020 Bergen, Norway
[c] Nikhef, Utrecht University, Postbox 41882, 1009 DB Amsterdam, The Netherlands
[d] Department of Electrical Engineering, Bergen University College, Postbox 7030, 5020 Bergen, Norway
[e] Kernfysisch Versneller Instituut, University of Groningen, NL-9747 AA Groningen, The Netherlands

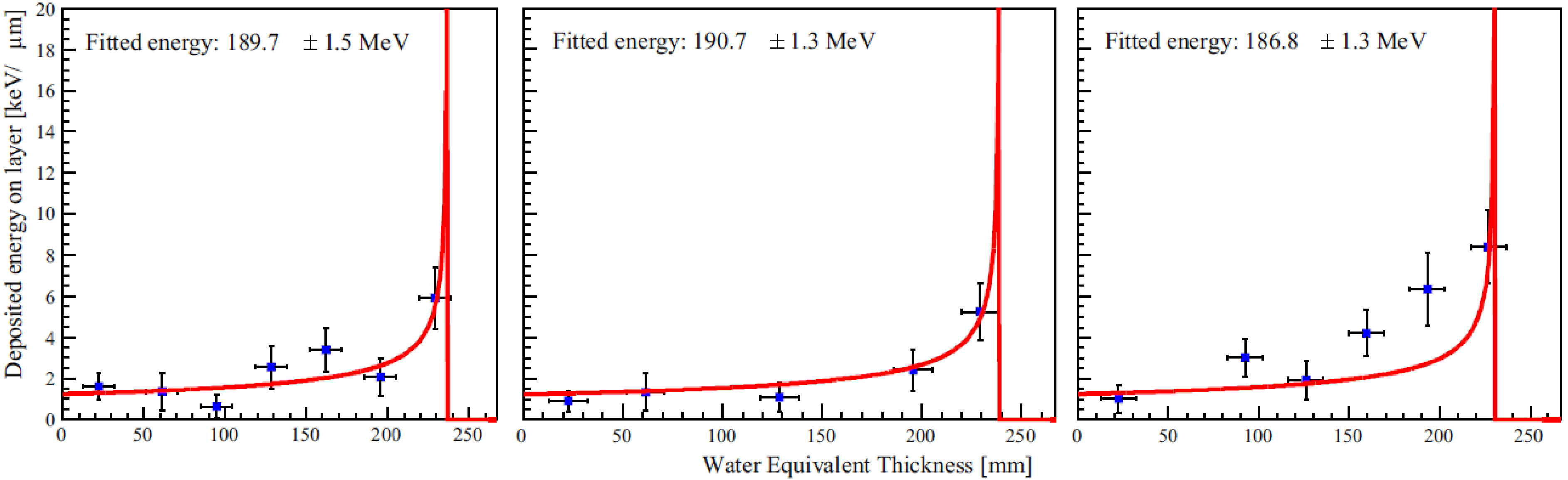
Track reconstruction



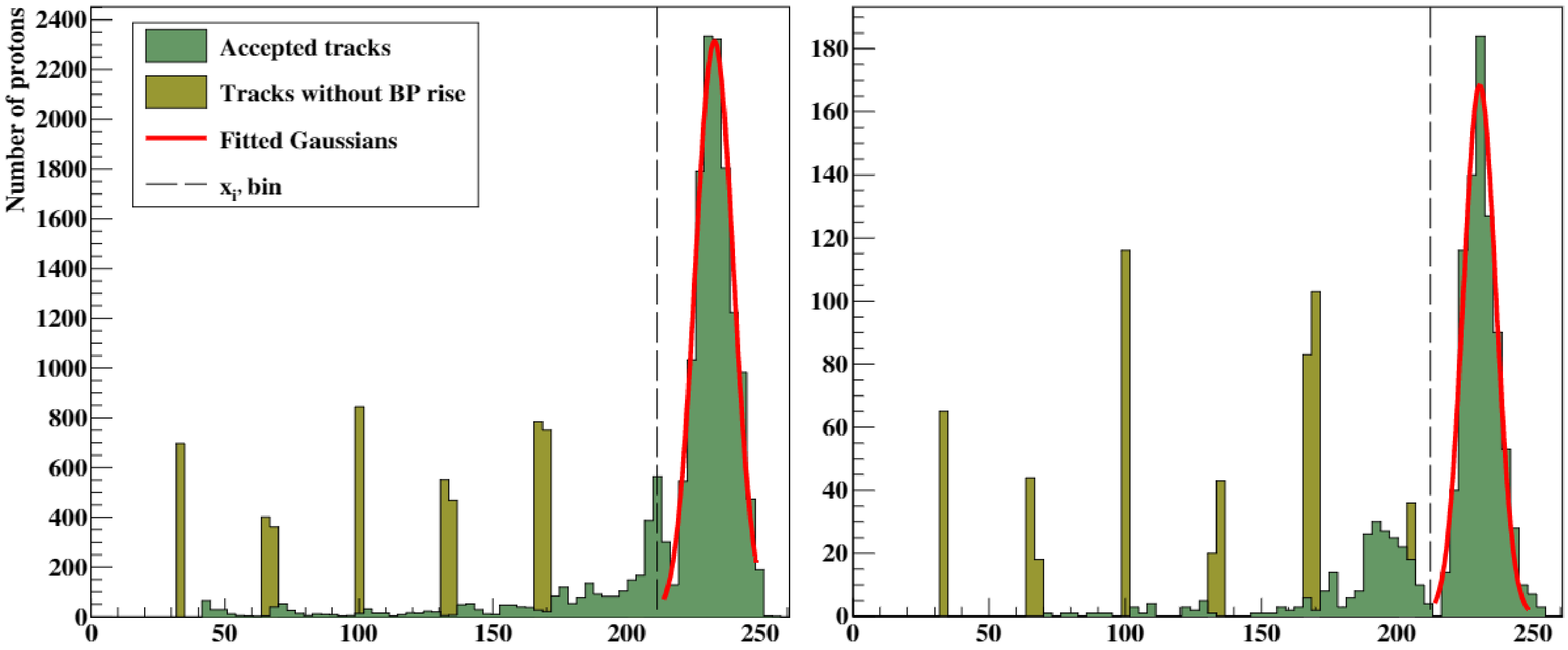
Energy / range reconstruction

- Upon identification of proton tracks, perform a Bragg-curve fit (from Bortfeld) to the resulting data

$$R = \alpha\, E^{p}$$

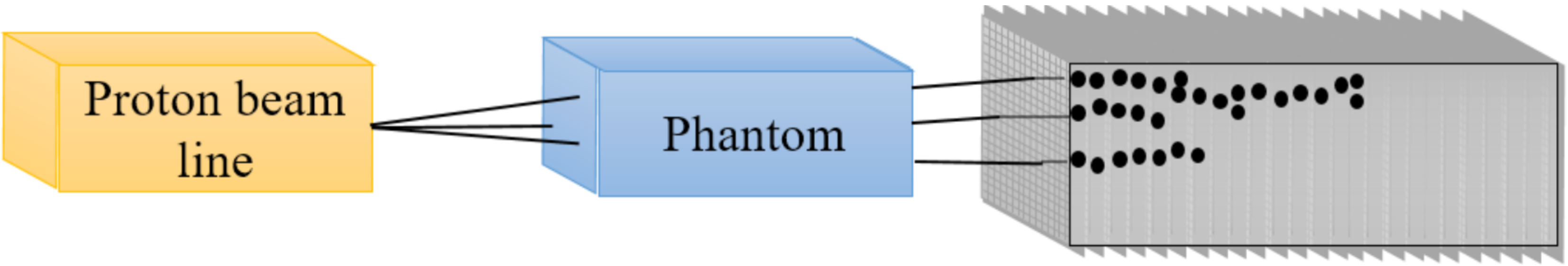


Beam residual energy/range reconstruction



Left: *188 ± 3 MeV from a 188 MeV MC simulated mono-energetic beam.*
Right: *187 ± 3 MeV from the 188 MeV beam taken during the KVI Groningen beam test.*

Components of pCT simulations

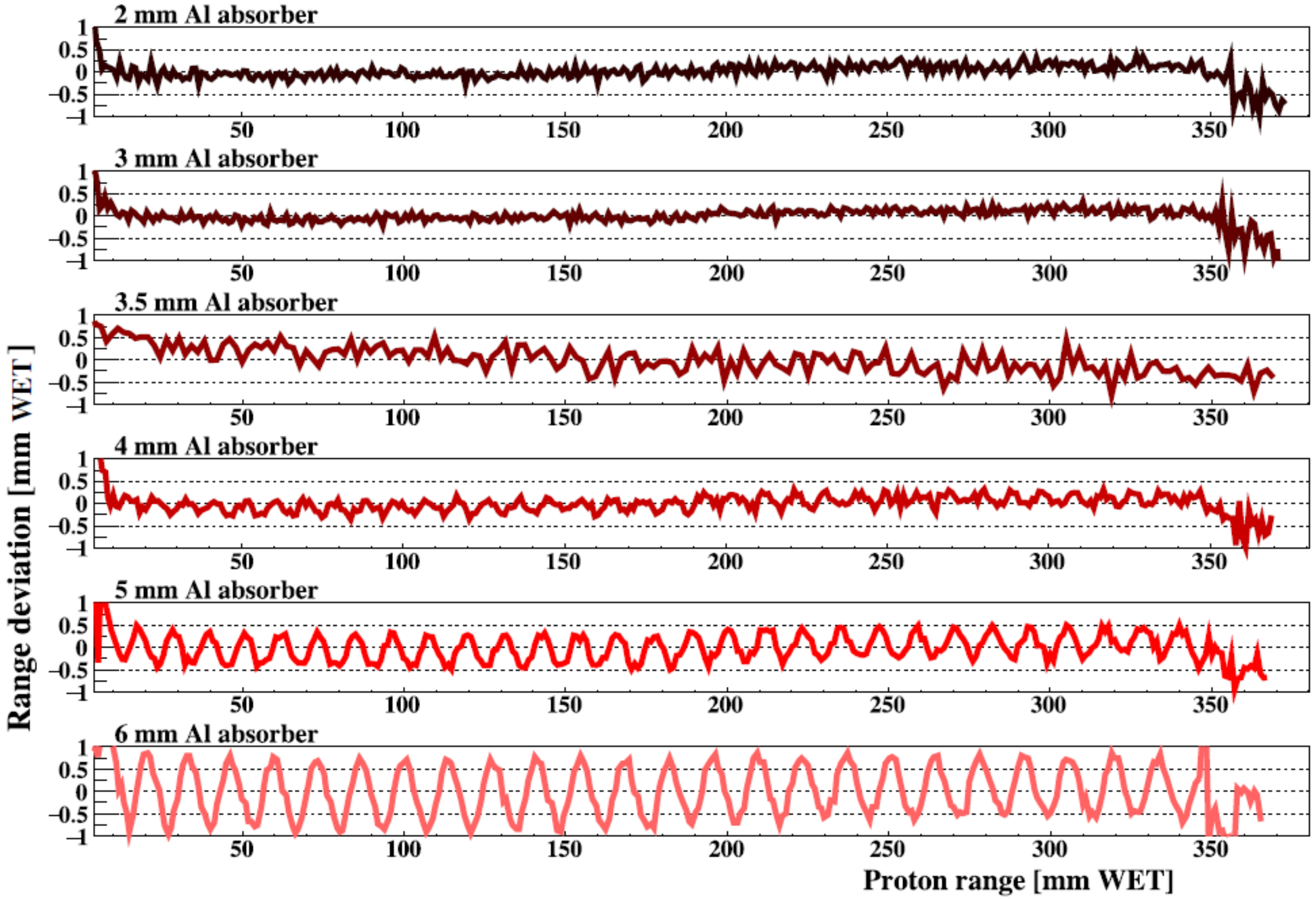


Schematic setup of the variable geometry used for the design optimization. In order to obtain a spectrum of different proton beams to hit the DTC, the thickness of the energy degrading water phantom is modulated from 0 cm to the maximum range of the 250 MeV beam, which is approximately 38 cm.

- Beam-line
- Trackers
- Phantom
- Proton track / energy reconstruction in DTC

- Most-likely path
- Image / RSP reconstruction

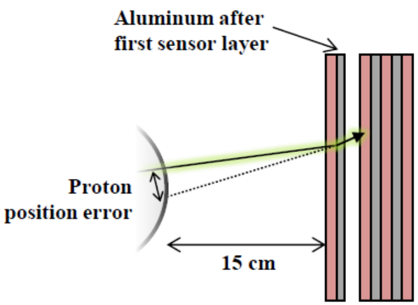
Simulations / Models of the pCT-DTC design

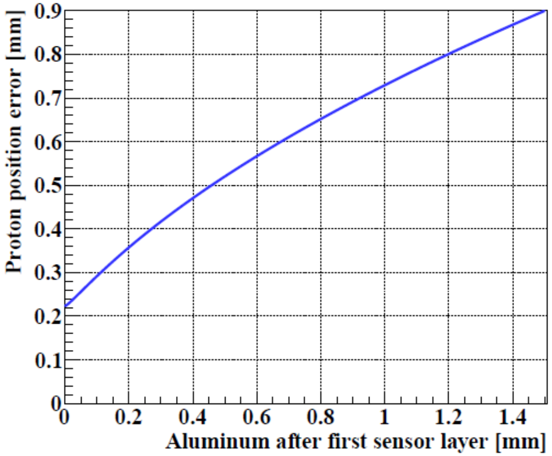


Simulations / Models of the pCT-DTC design

Absorber thickness [mm]	2	2.5	3	3.5	4	4.5	5	5.5	6
Layers needed (230 MeV)	66.6	55.2	47.1	41.1	36.5	32.8	29.7	27.2	24.4
Layers needed (200 MeV)	52.8	43.8	37.4	32.6	29	26	23.6	21.6	20

- Number of layers needed for 230 and 200 MeV proton beams.
- Also added a margin corresponding to 3 times the range straggling





- The Al-absorber thickness should be < 450 µm to keep lateral deflection < 0.5 mm

Future (very near) plans

- Implement and test the MLP algorithms (cubic splines and/or more sophisticated Bayesian statistics)
  - PhD-candidate Jarle R. Sølie to visit HIT during May, June and July 2018
  - First MLP results expected during or soon after
  - Important to establish expected uncertainties in the MLP when front-trackers are removed
- Set-up a full simulation and data-analysis chain including:
  - Track and energy reconstruction
  - MLP
  - Image (or RSP) reconstruction
- For this, we need some serious computational power!

A dedicated HPC – Cluster

- 2 nodes (ThinkSystem SD530) – current config.
  - 2 CPUs (Intel Xeon Gold 6136 3.0GHz Processor) in each node
  - 64 GB of memory (upgradable if needed)
  - NVIDIA Tesla M60 GPU in each node
  - Most likely a 500 GB SSD for the OS and 10 TB of HDD for storage
  - Total of 96 cores
  - SSH connection will be set-up (no access problems)
  - Hopefully, installed and operational before the summer
- Will allow us to obtain e.g. all projections in a matter of <u>hours.</u>

Thank you for your attention

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MC code assessment for proton range

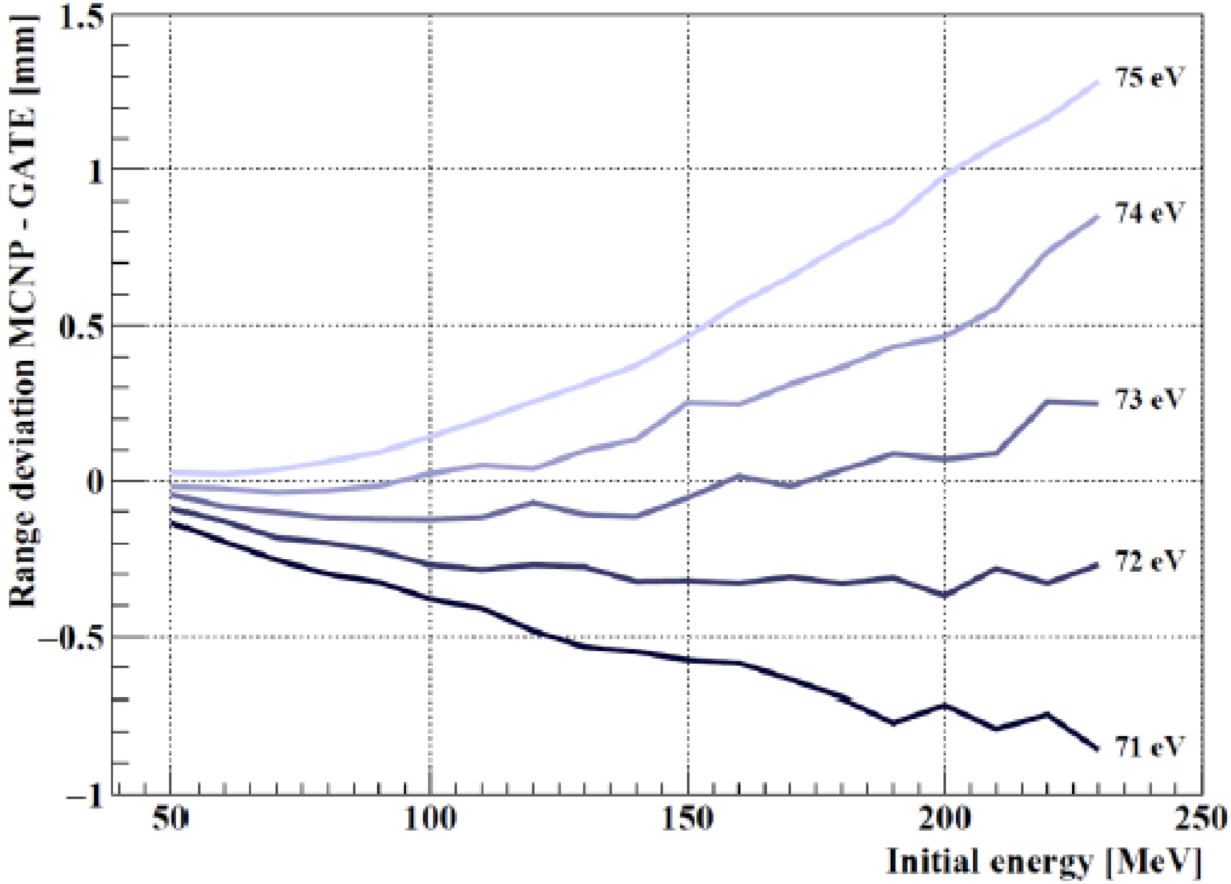
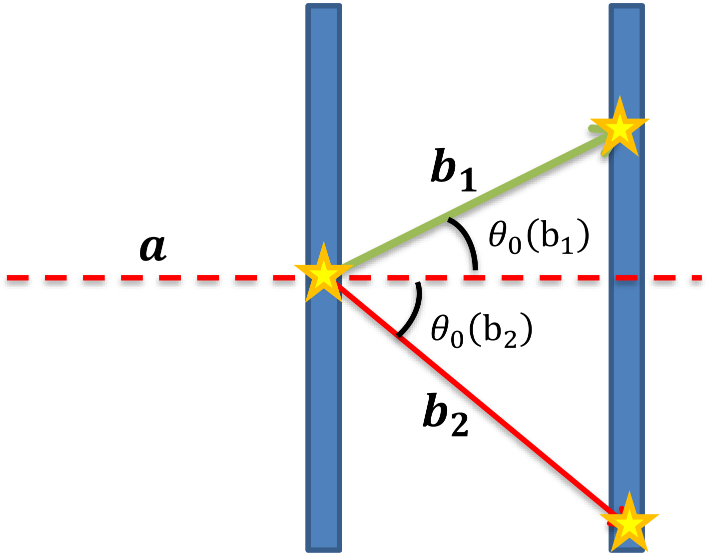


Figure 5 *Range deviation between MCNP6 and five separate simulations using GATE/Geant4 as a function of the initial proton energy. All five GATE/Geant4 simulations were performed using different values for the Ionization Potential in the 71 - 75 eV span.*

Track reconstruction

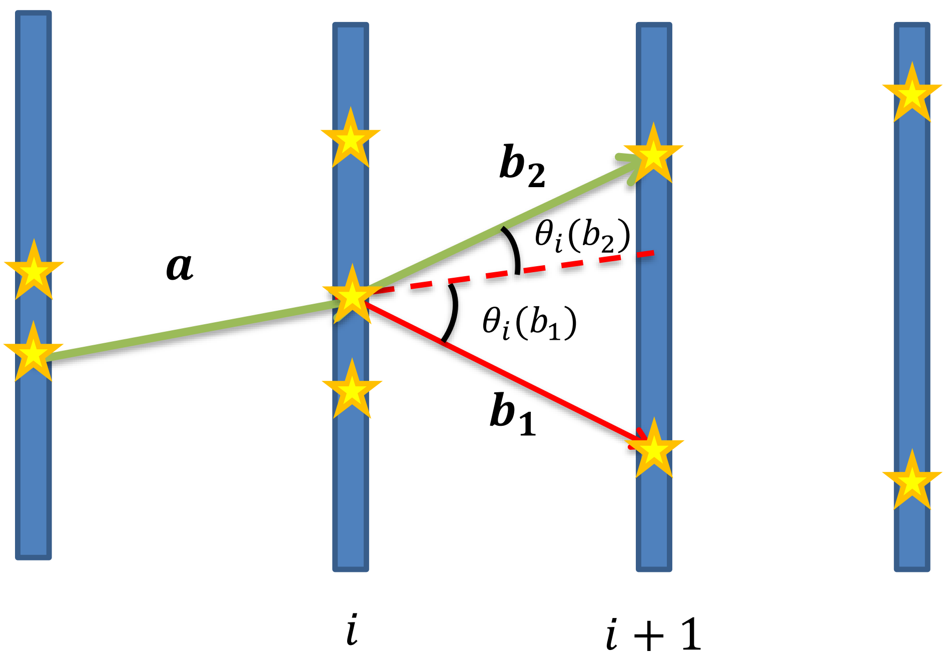
1. Use all hits in first layer as seeds
2. Test all seeds against hits in next layer:
    1. Evaluate: Find change in direction θ_0 in first sensor layer (assume parallel beam here) against all hits in next layer
    2. Compare θ_0 against a threshold value: If below, keep the hit in next layergiving rise to lowest θ_0: Here it's $\boldsymbol{b_1}$.



$$\theta_0(\boldsymbol{x}) = \cos^{-1}\left[\frac{\boldsymbol{a}\cdot\boldsymbol{x}}{|\boldsymbol{a}|\cdot|\boldsymbol{x}|}\right]$$

Track reconstruction cont.

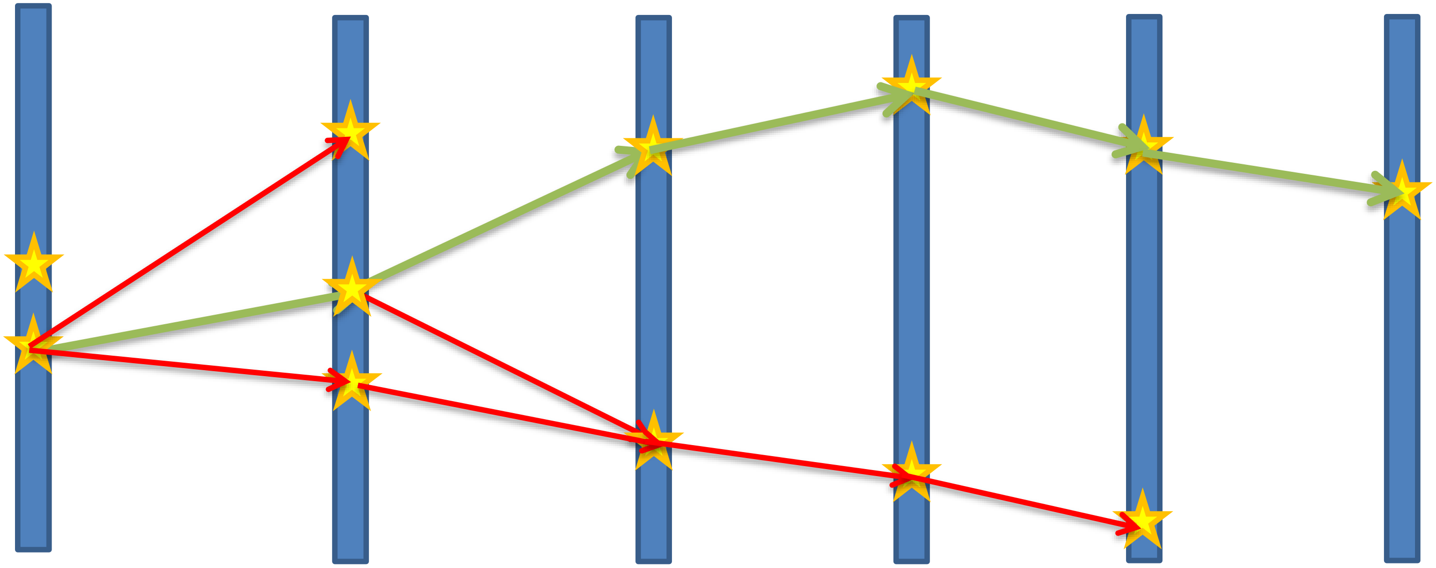
1. For all next layers, find angular change θ_i and append the hit with «lowest-scattering» cluster.



$\boldsymbol{\theta_i(b_1) > \theta_i(b_2) \rightarrow}$ **Use** $\mathbf{b_2}$

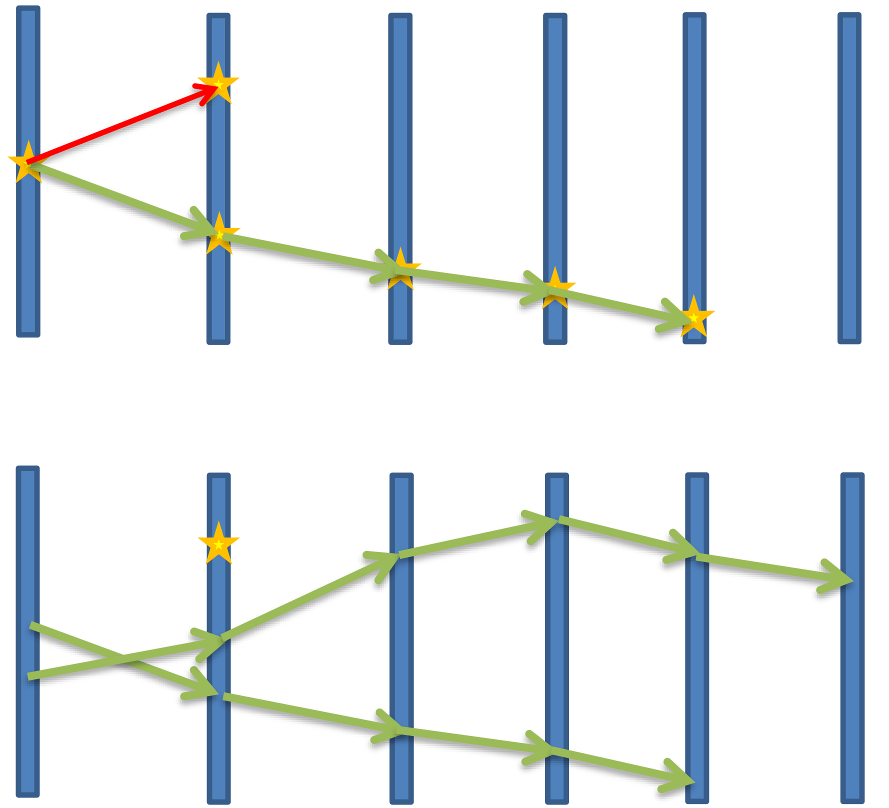
Track reconstruction cont.

1. When a few tracks are made from the same seed pair, find the best one using different scoring criteria (total angular change, length, existence of Bragg Peak, etc.)
2. Keep the track (green) and remove all hits connected to it



Track reconstruction cont.

1. Redo the tracking on the reduced data until all tracks are reconstructed



Beam residual energy/range reconstruction

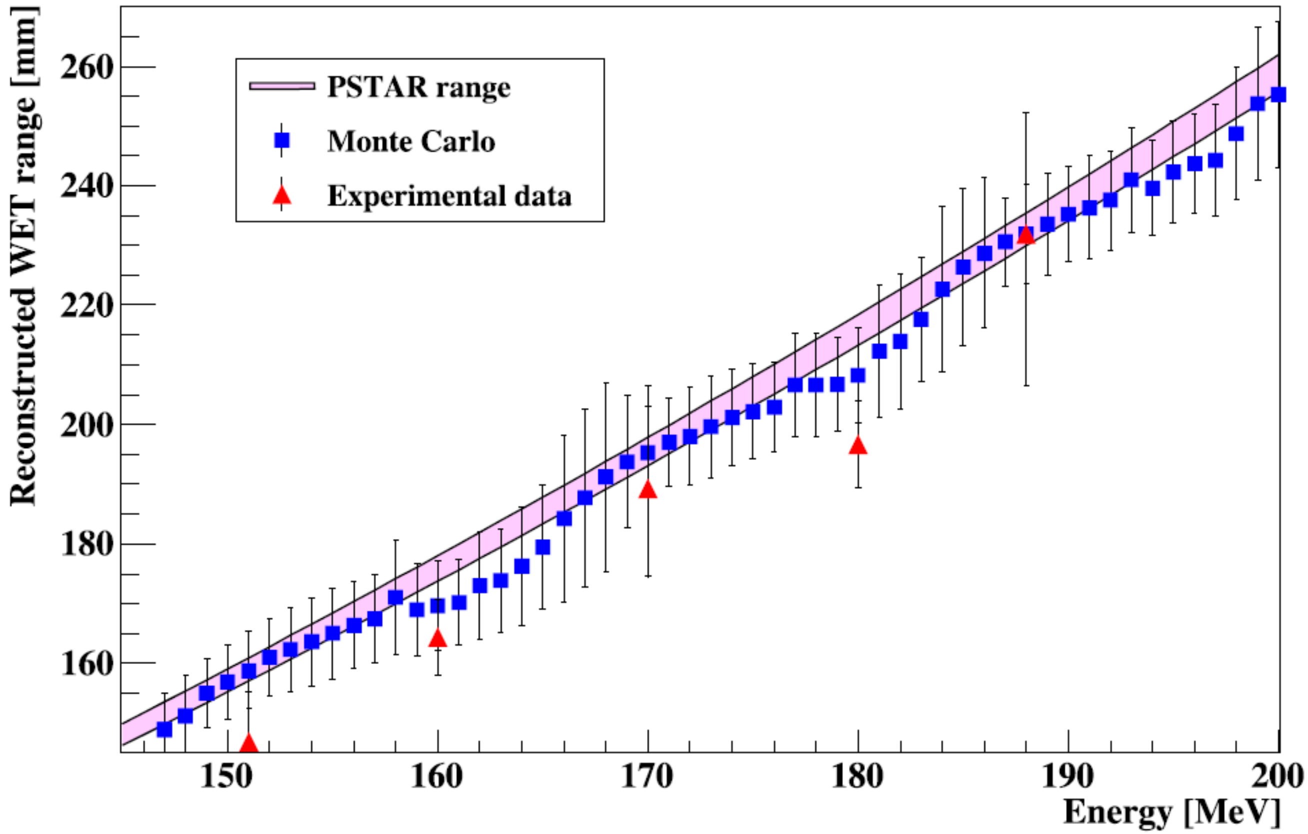


Figure 4.23: *Reconstructed WET ranges of proton beams with different energies, with data from both the MC simulations and from the experimental measurements. The PSTAR (water) range is displayed using a band representing the expected range straggling. From Pettersen et al. (2017).*

Simulations / Models of the pCT-DTC design