# Trajectory reconstruction for proton computed tomography with machine learning

Zimányi Winter School December 4-8, 2023

Speaker: Dudás Bence

Collaborators: Dr. Papp Gábor, Dr. Bíró Gábor

Bergen pCT collaboration

# Progression of my talk

Cancer therapy → Hadron Therapy → Proton Computed tomography → Processing pCT detector signals → Results

# Cancer therapy

# Cancer therapy

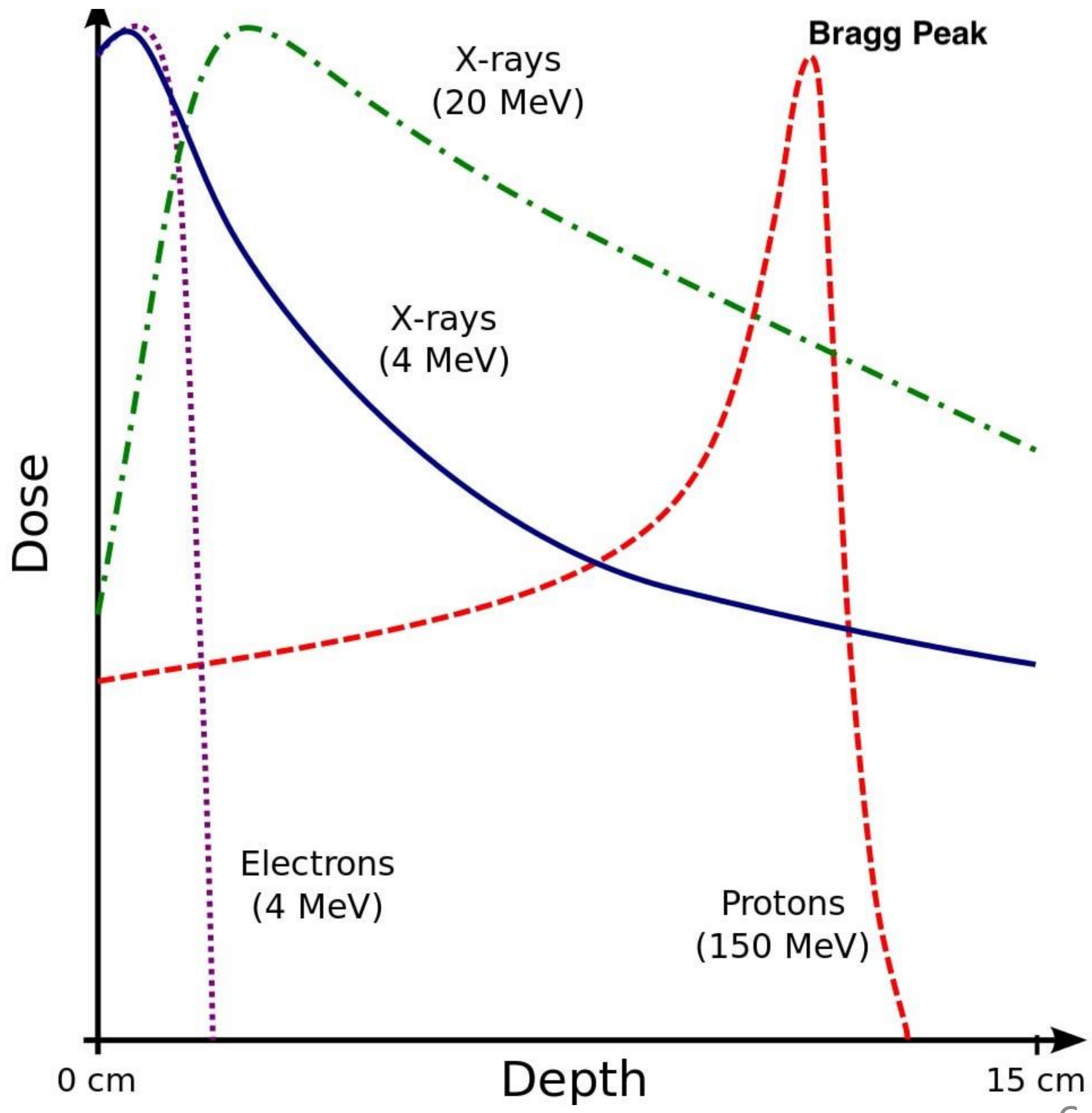
The 3 main methods:

- Surgery
- Chemotherapy
- Radiation therapy

# Hadron therapy

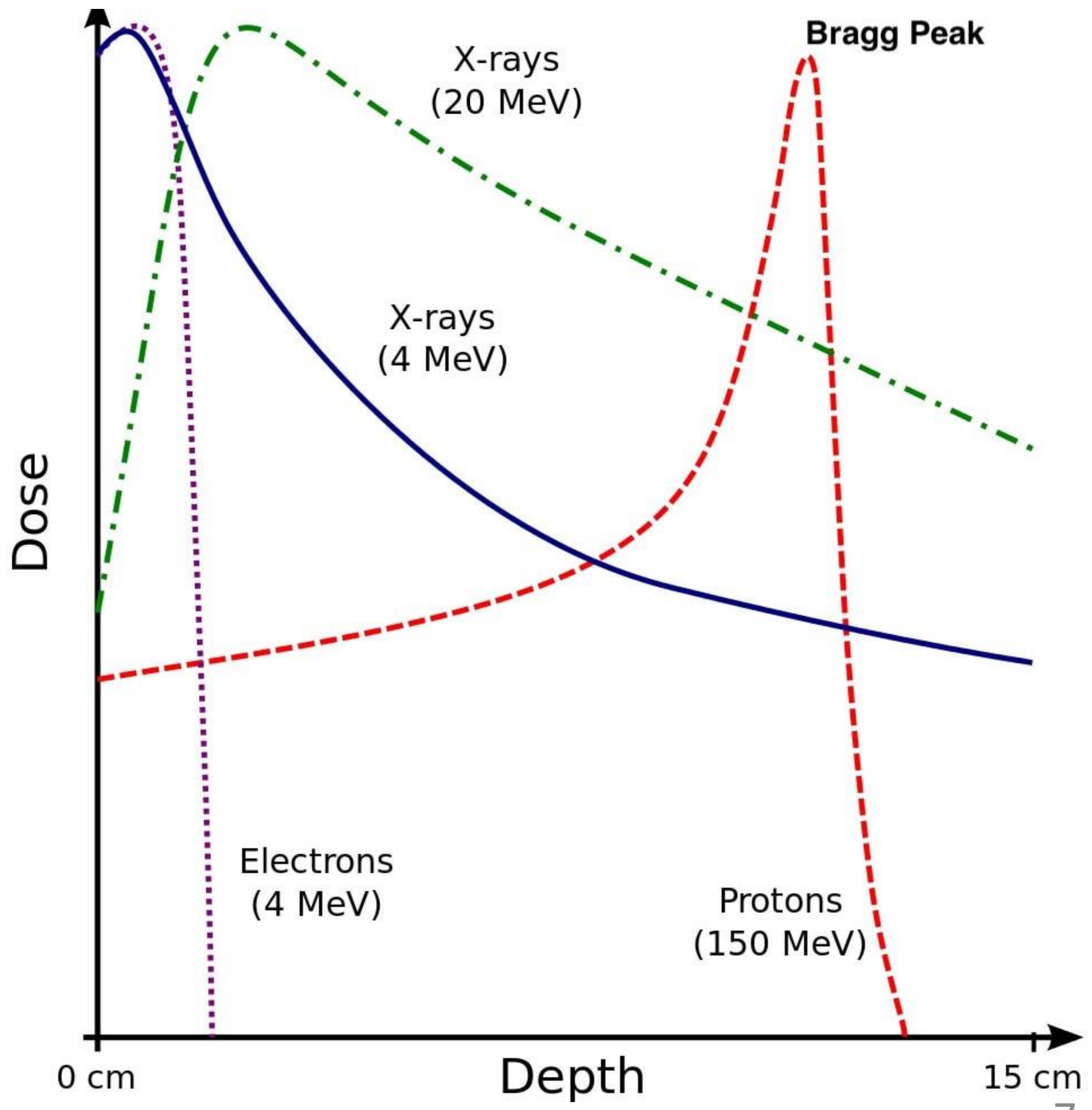
# Hadron(proton) therapy

- Cancer therapy
- Using radiation
- Utilize the Bragg peak of proton
- Ambulant treatment



# Challanges for Hadron therapy

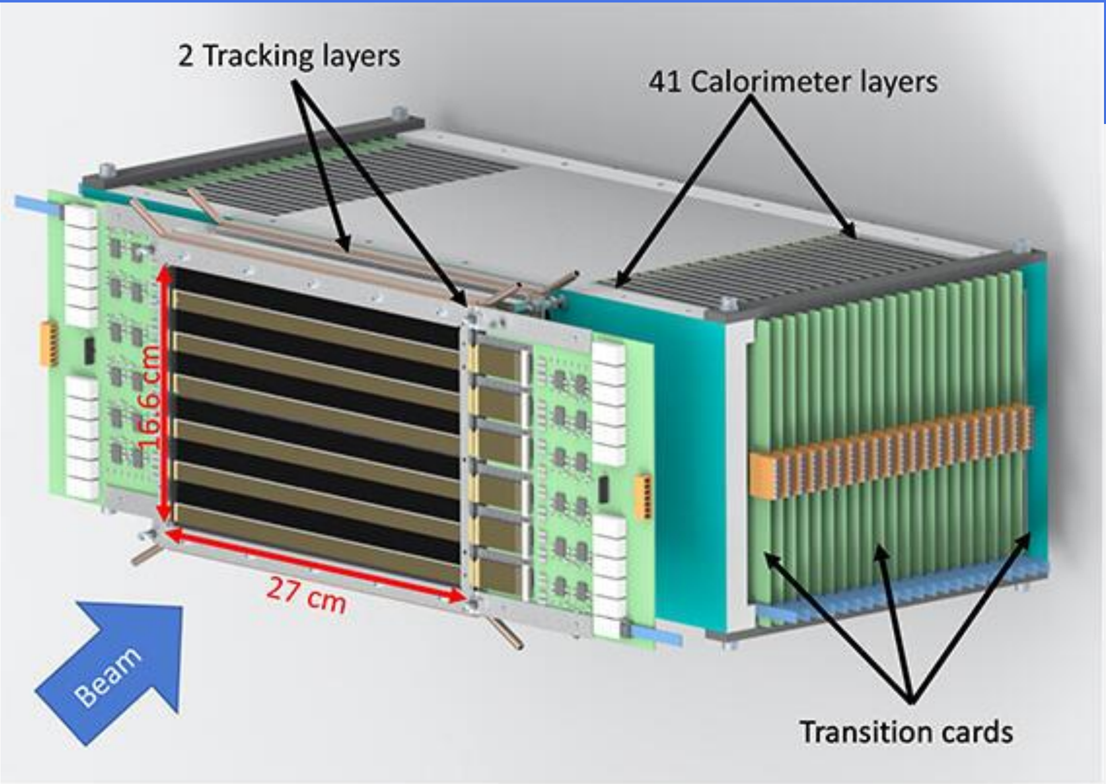
- Traditional tomography was not made for protons
- Hadron therapy needs map of stopping power
- Data processing needs to be fast for ambulant treatment



# Proton Computed Tomography

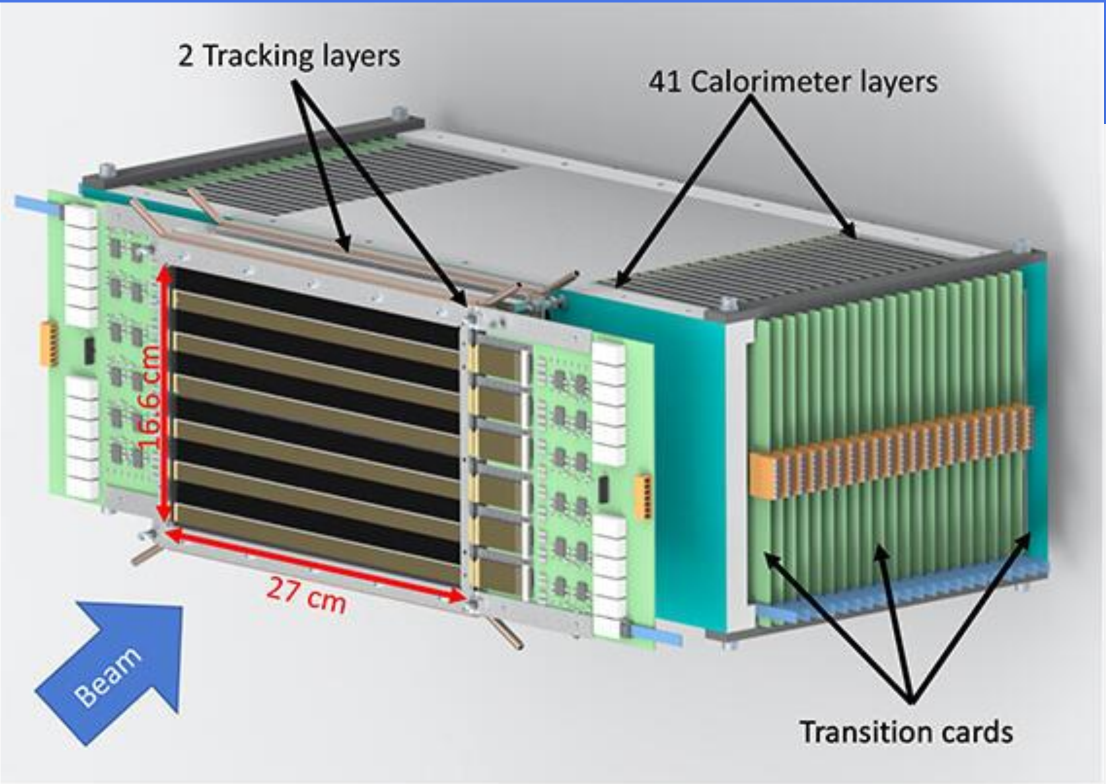
# Proton computed tomography(PCT)

- High energy (200 MeV) protons beamed through a phantom
- These are scattered on the particles of the phantom
- The detector measures position of the hits and energy deposition (by the clusters of the hits)
- Detector layers are ALICE ALPIDE chips



# Proton computed tomography(PCT)

- The detector signals processed
- Reconstruct the trajectories based on the position and energy deposit of the hits
- Extract initial angles and kinetic energy
- Rotate and translate the system around the phantom
- Get a 3D map



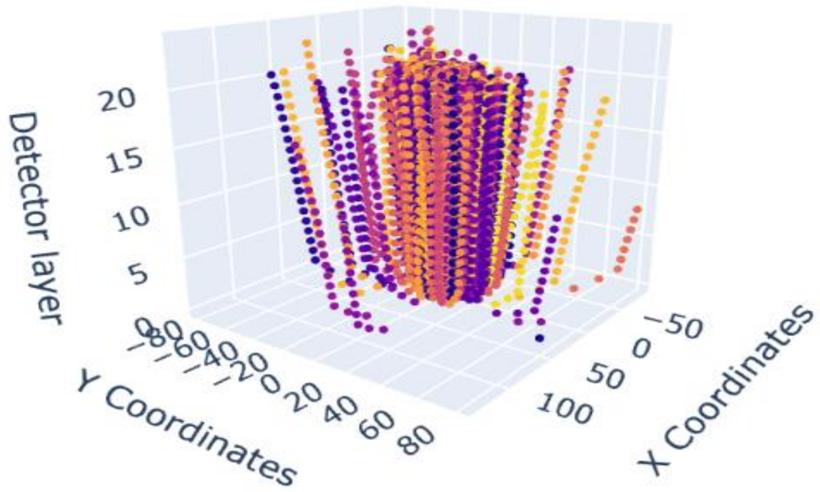
# Data processing with machine learning

- To predict angle we need to reconstruct the trajectories
- For the image reconstruction:
  - Scattering angles
  - Initial kinetic energy
- Do not need all the trajectories, only the reliably reconstructed ones
- Reconstructing particle path with traditional algorithms takes too much computational time

- Deep Neural Networks can evaluate fast
- Learn complex connections between data

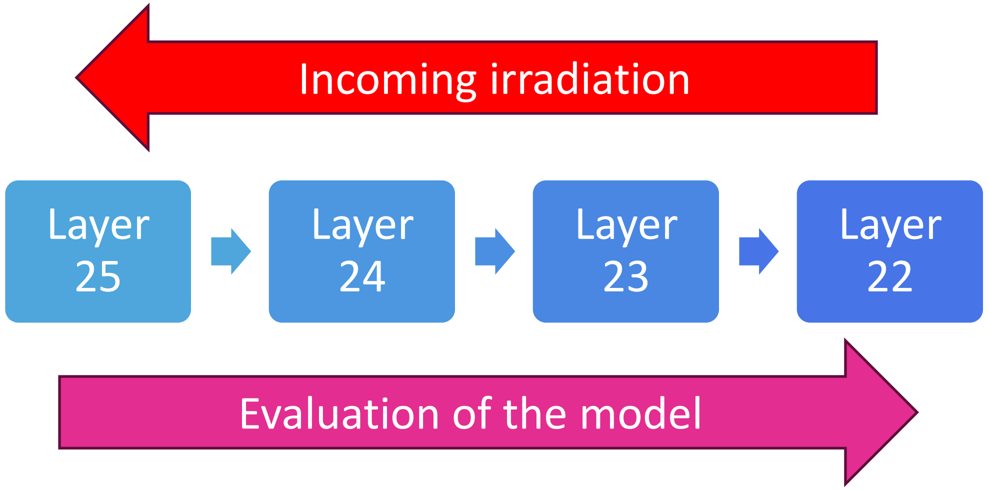
# Data structure

- Using data simulated from openGate(Geant4 medical extension)
  - Therefore tracking information is available
  - Large number (O(1e5)) of events may be generated
- Measurment is done in frames with 100-200 primaries (event)
- For every detector layer:
  - middle of every hit (X,Y coordinate)
  - size (energy deposition)



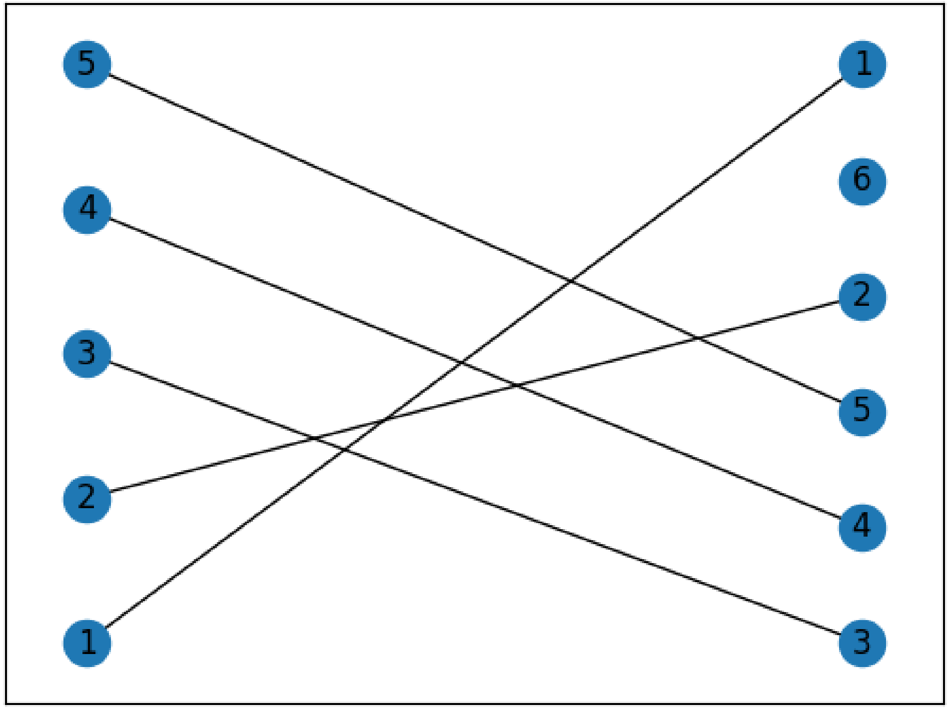
# Methods

- From last layer iterate through the whole detector system



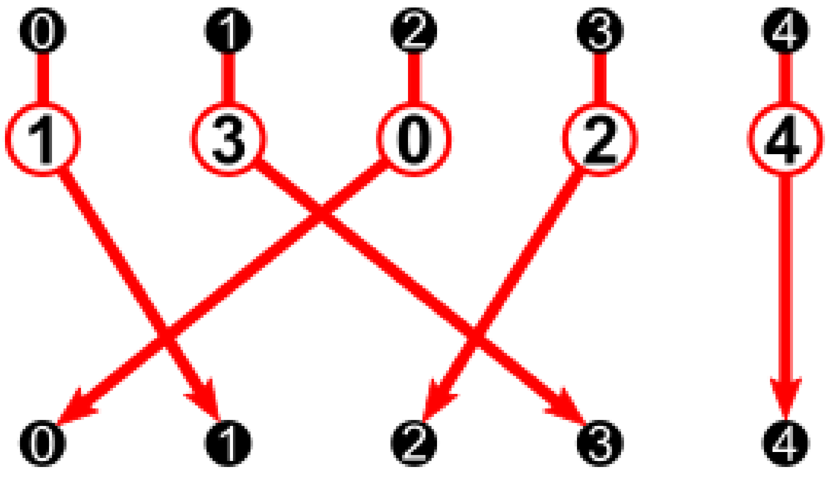
# Methods

- From last layer iterate through the whole detector system
- Try to connect the next layer with the previous ones while using results from the previous connections, using a transformer architecture



# Methods

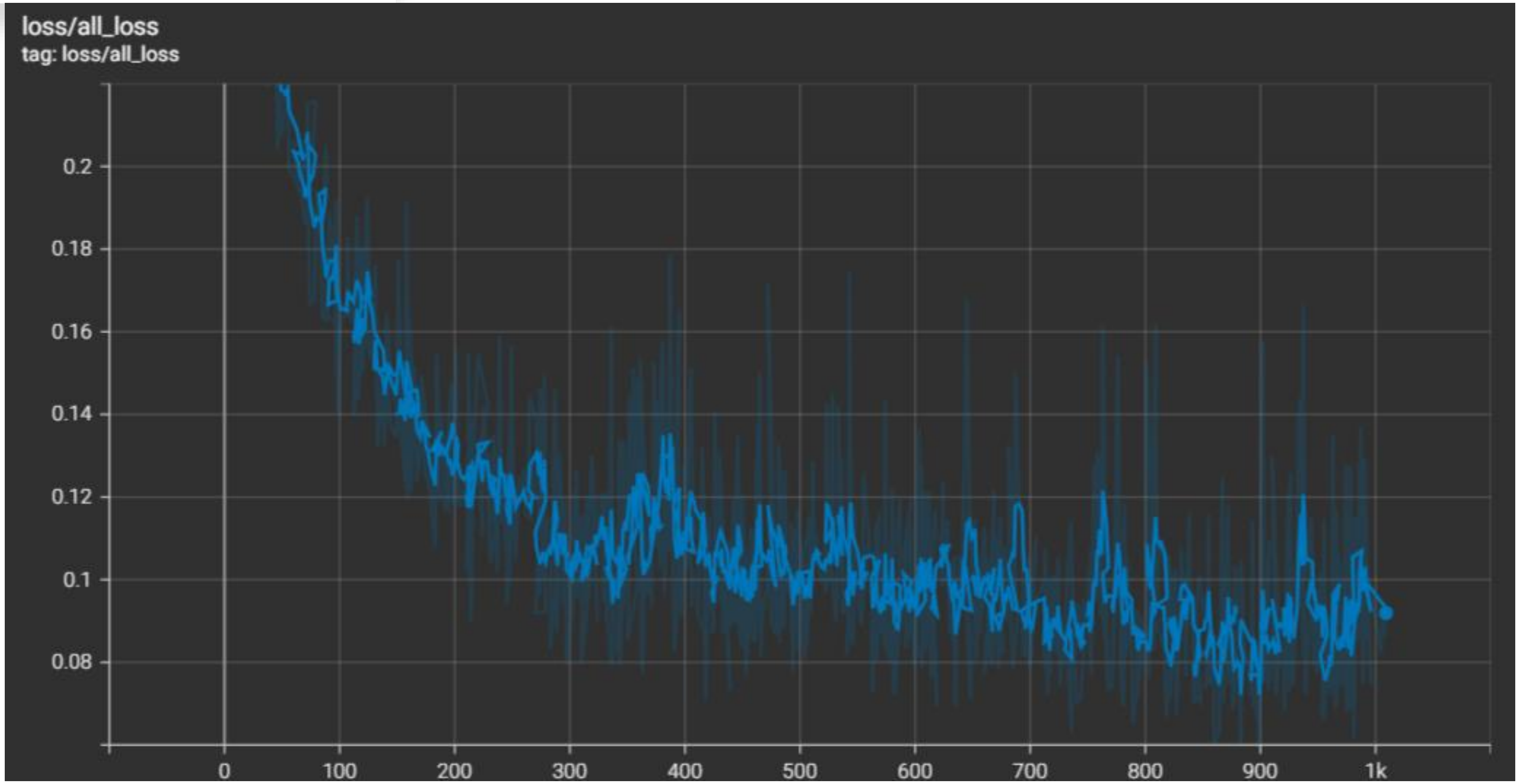
- From last layer iterate through the whole detector system
- Try to connect the next layer with the previous ones while using results from the previous connections, using a transformer architecture
- Randomly change the order of every data point (x,y,energy) after each layer



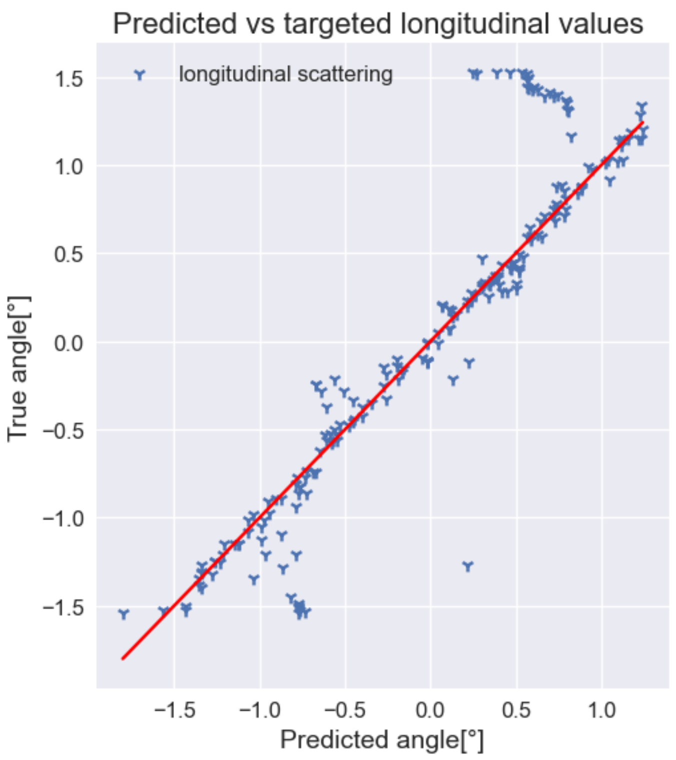
# Results

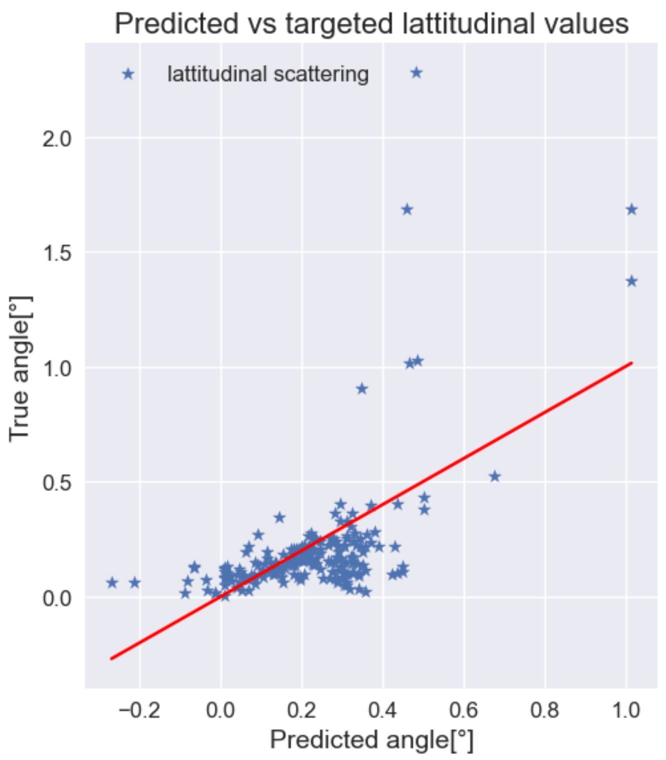
# Learning curve

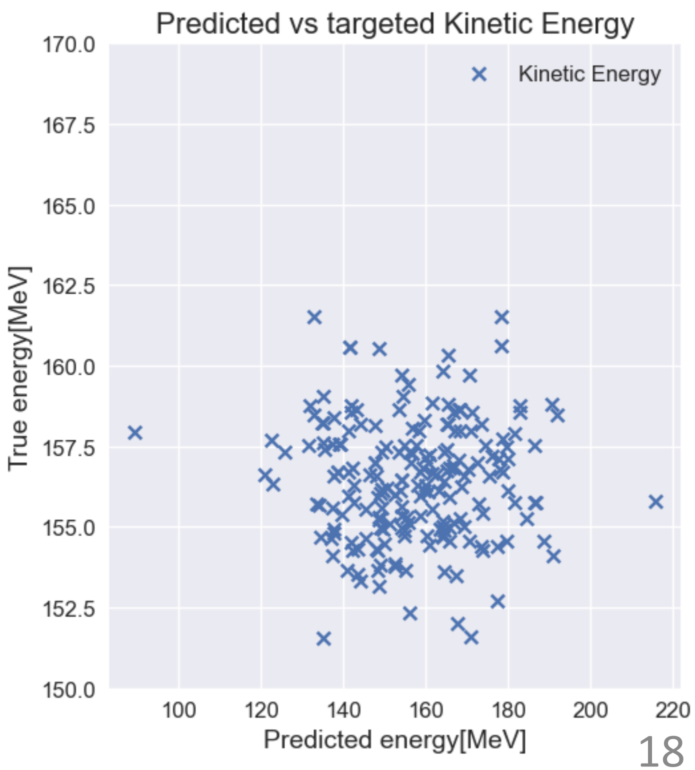
- Training for 1000 epochs
- Training data size for one phantom is around 100,000 event
- Target dimension is normalized (every values is in the same scale) for better learning properties
- Loss is mean squared error
- Mean of the three target prediction values



# Results


Predicted vs targeted longitudinal values
longitudinal scattering
True angle[°]
Predicted angle[°]
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−1.5
−1.0
−0.5
0.0
0.5
1.0


Predicted vs targeted lattitudinal values
lattitudinal scattering
True angle[°]
Predicted angle[°]
2.0
1.5
1.0
0.5
0.0
−0.2
0.0
0.2
0.4
0.6
0.8
1.0


Predicted vs targeted Kinetic Energy
Kinetic Energy
True energy[MeV]
Predicted energy[MeV]
170.0
167.5
165.0
162.5
160.0
157.5
155.0
152.5
150.0
100
120
140
160
180
200
220

# Summary & outlook

Summary:
The application of Deep Learning for trajectory reconstruction looks promising (the Bergen pCT has achieved 87% accuracy with similar methods) and fast enough.

Outlook:
- Get better results with the energy section
- Make the model more general
- Evaluate on real detector data

Supporters:
- Hungarian Artificial Intelligence Laboratory, under the ID: RF-2.3.1-21-2022-00004
- OTKA K135515
- Doktoranduszi Kivállósági Ösztöndíj Program
- Wigner Scientific Computer Laboratory

# Thank you for your attention

# Resources


- https://www.uwa.edu.au/study/courses/master-of-surgery
- https://www.timesofisrael.com/major-israeli-hospital-admits-giving-cancer-patients-expired-chemotherapy-drugs/
- https://www.saferradiationtherapy.com/radiation-therapy-2/
- https://builtin.com/artificial-intelligence/transformer-neural-network
- https://study.com/academy/lesson/bipartite-graph-definition-applications-examples.html
- Johan Alme et all, *A High-Granularity Digital Tracking Calorimeter Optimized for Proton CT*, Frontiers in Physics (2020), doi: 10.3389/fphy.2020.568243
- Robert P Johnson, *Review of medical radiography and tomography with proton beams,* Rep. Prog. Phys. **(81)** (2018) 016701, doi: 10.1088/1361-6633/aa8b1d.
- M. Mager et all, *ALPIDE, the Monolithic Active Pixel Sensor for the ALICE ITS upgrade,* Elsevier **434-438** (2016), doi 10.1016/j.nima.2015.09.057
- H.E.S. Pettersen et all, *Design optimization of pixel-based range telescope for proton computed tomography,* Physica Medica **87-97** (2019) doi:https://doi.org/10.1016/j.ejmp.2019.05.026