Trajectory reconstruction for proton computed tomography with machine learning

HUN REN | Wigner

Visegrad Fund

Theory and Experiment in High Energy Physics V4HEP

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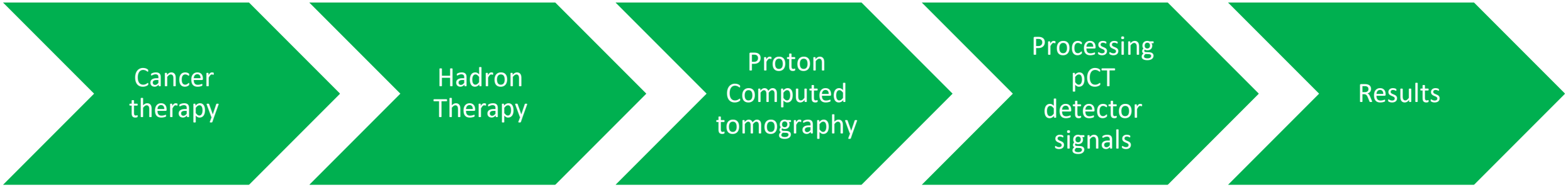
Collaborators: Dr. Papp Gábor, Dr. Bíró Gábor

Bergen pCT collaboration

Nemzeti Kutatási, Fejlesztési és Innovációs Hivatal

Progression of my talk



Cancer therapy

Cancer therapy

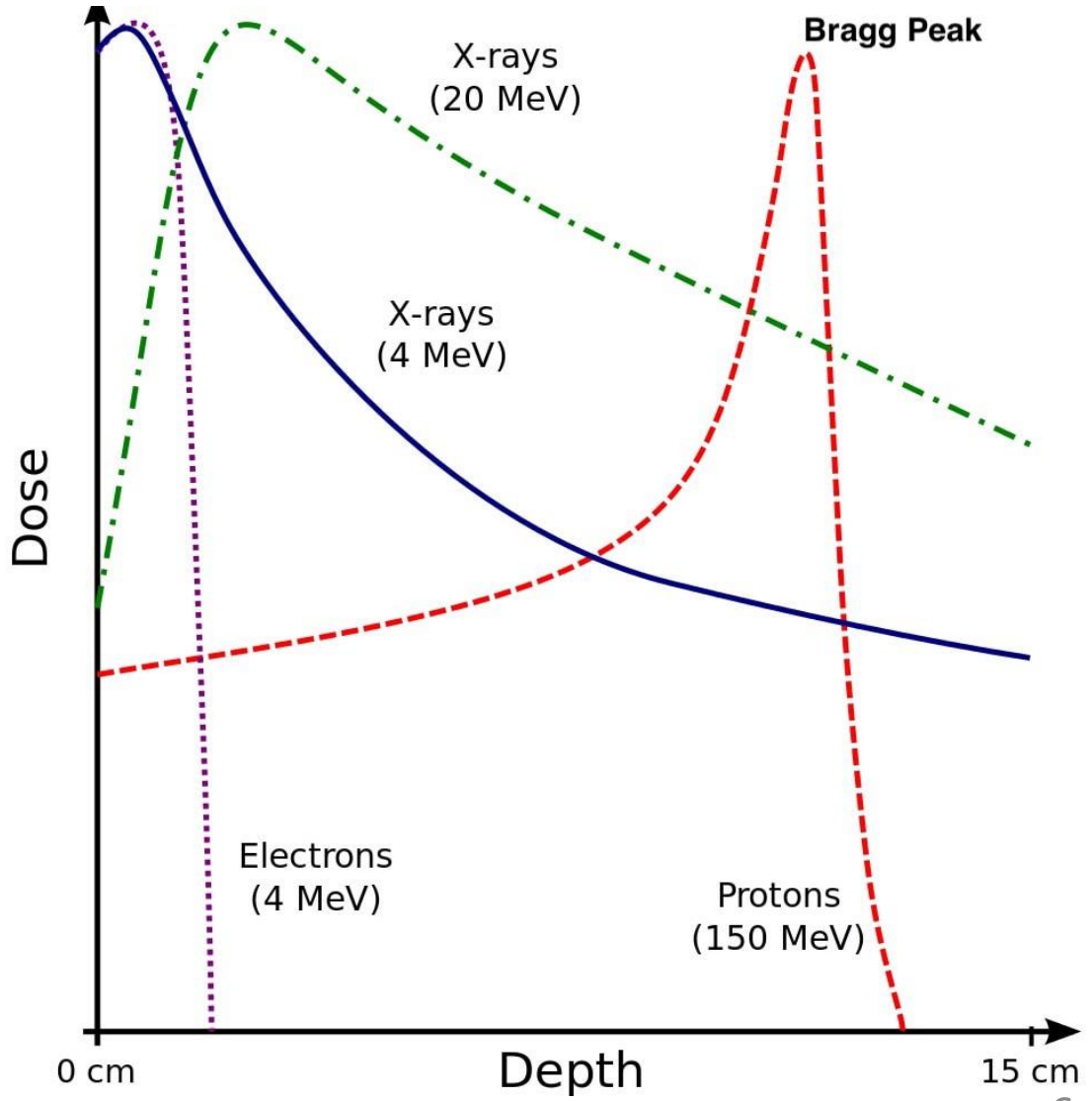
The 3 main methods:

- Surgery
- Chemotherapy
- Radiation therapy

Hadron therapy

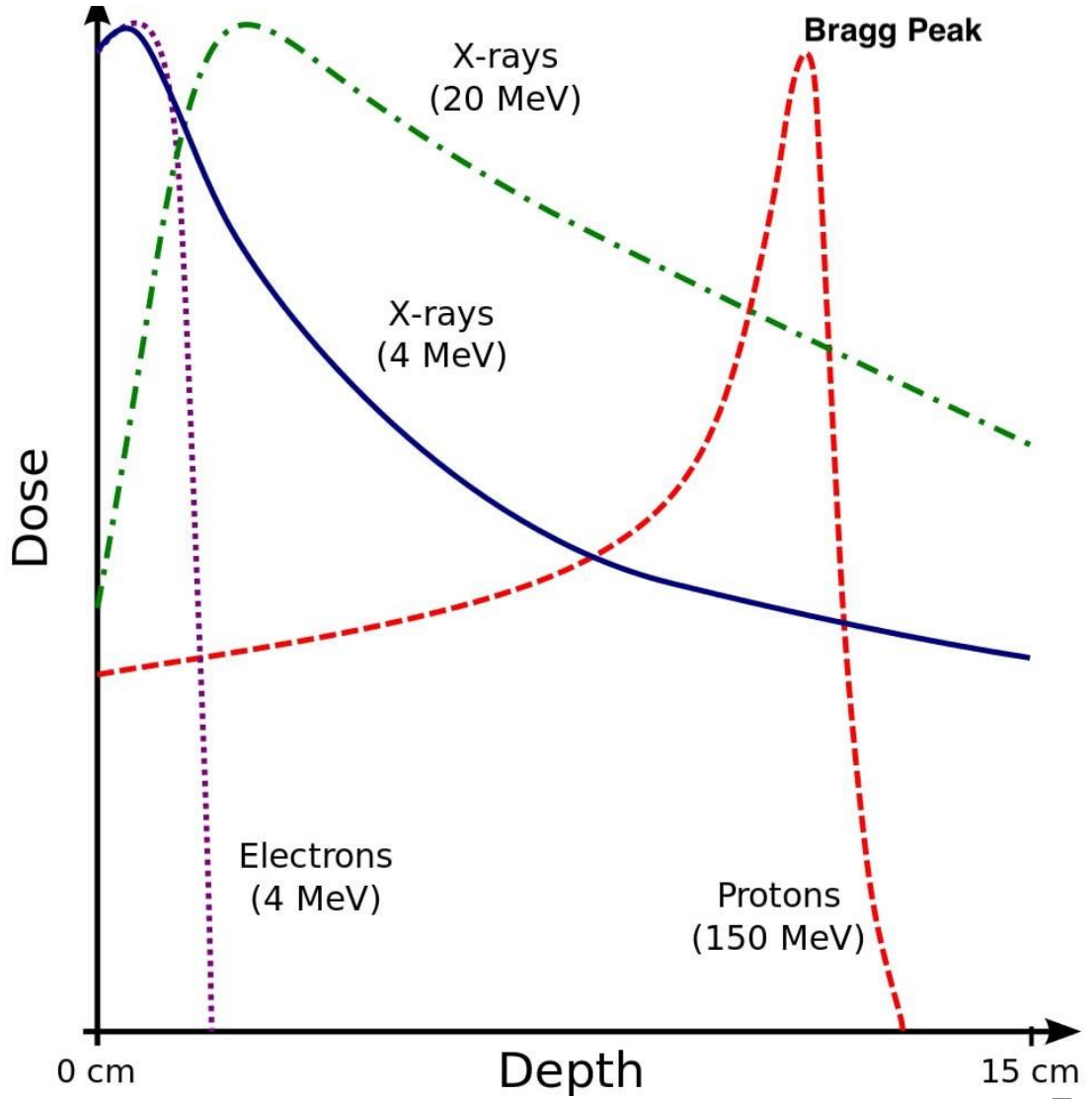
Hadron(proton) therapy

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



Challanges for Hadron therapy

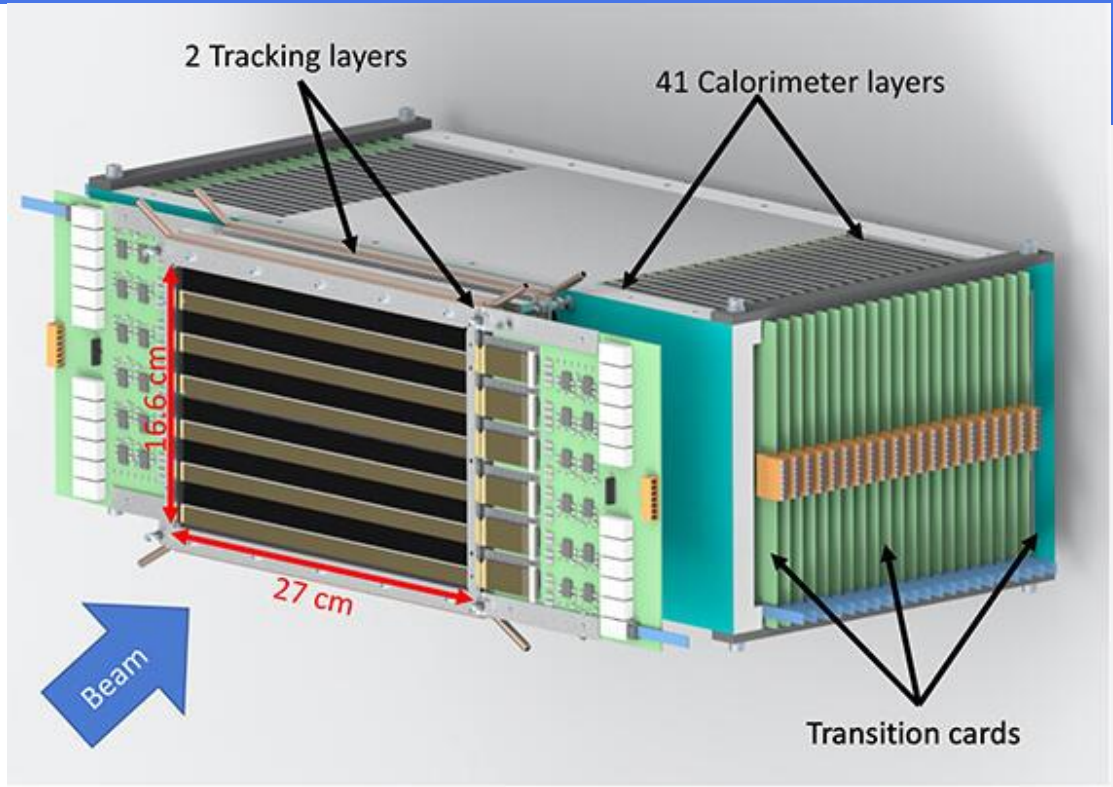
- Traditional tomography was not made for protons
- Hadron therapy needs map of stopping power
- Data processing needs to be fast for ambulant treatment



Proton Computed Tomography

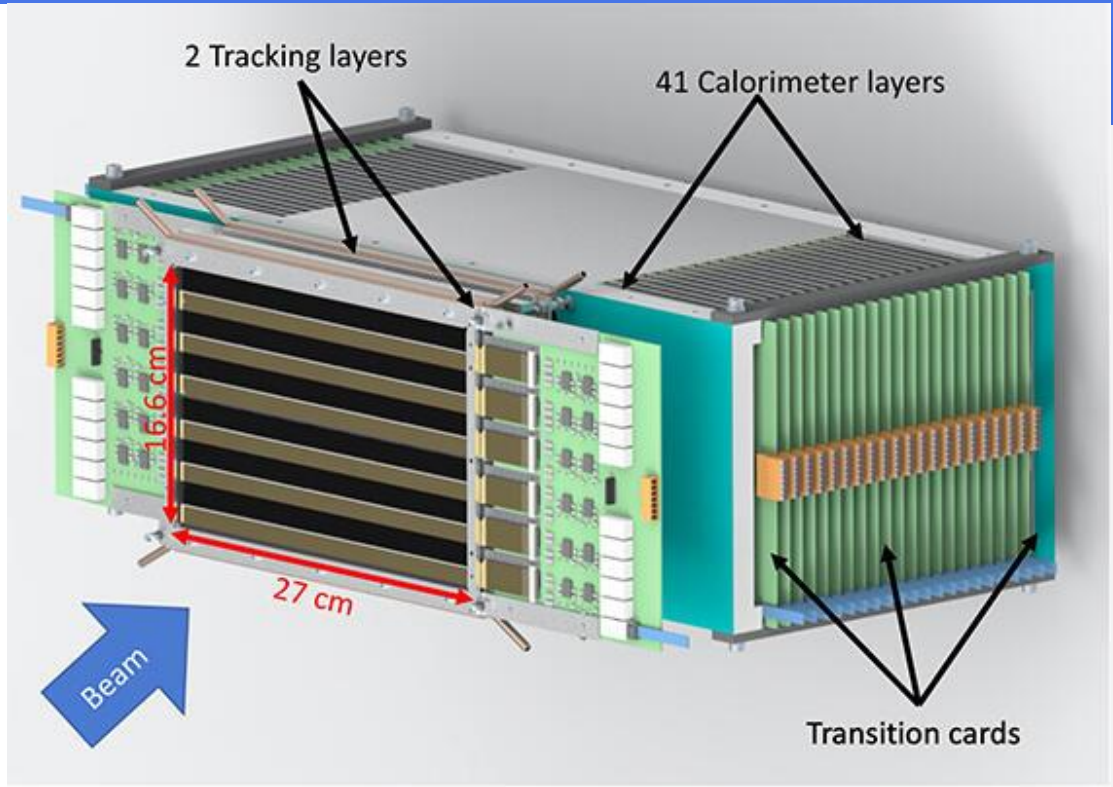
Proton computed tomography(PCT)

- 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
- 9216 pixel in X axis, 6144 pixel in Y axis



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



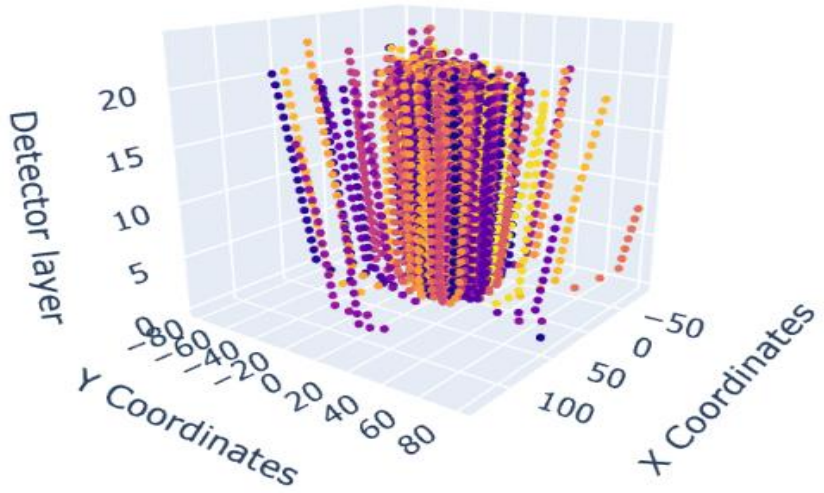
Data processing with machine learning

- 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

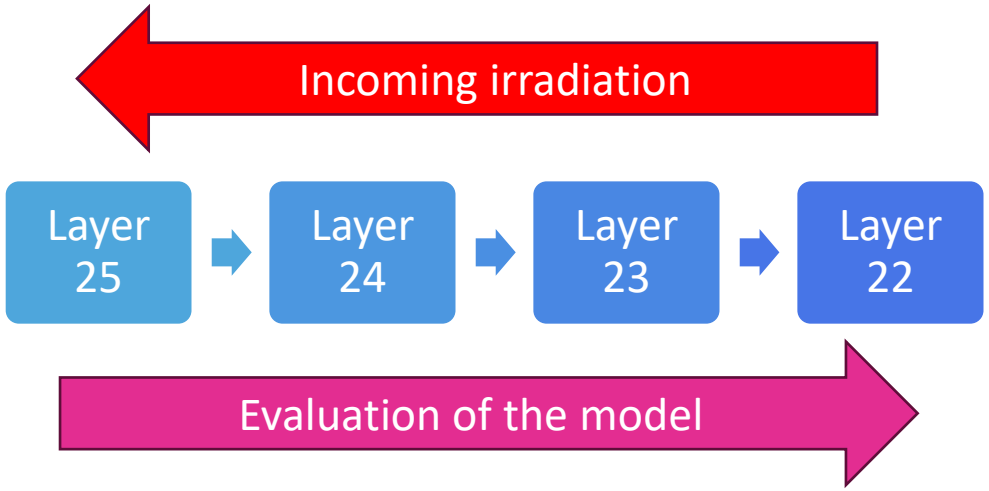
Data structure

- 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)



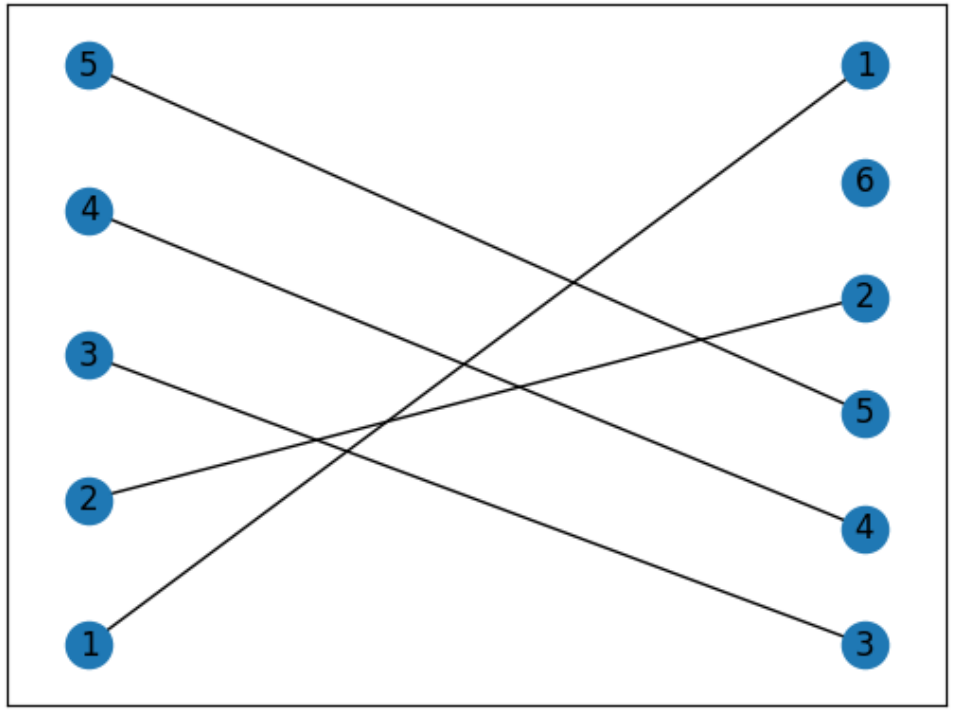
Methods

- From last layer iterate through the whole detector system.



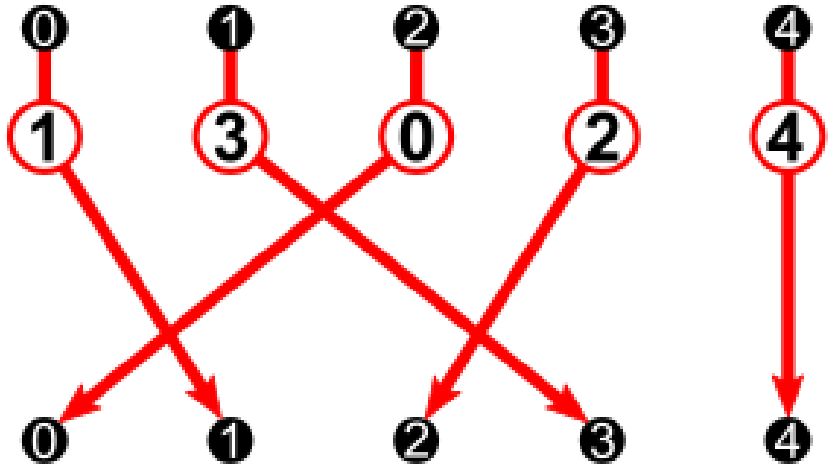
Methods

- From last layer iterate through the whole detector system.
- Try to match detector hits in between detector layers.



Methods

- From last layer iterate through the whole detector system.
- Try to match detector hits in between detector layers.
- Randomly change the order of every data point (x,y,energy) after each layer.



Matching

Sinkhorn algorithm

- We want to connect elements of X with elements of Y
- The Sinkhorn operator:

$$S(X,Y)_{i,j} = e^{\frac{\sqrt{X_i^2 - Y_j^2}}{T}}$$

- T is a constant parameter, often called temperature

Normalize the operator

- $S(X,Y)_{i,j}$ operator gives us transformed distances
- We need to convert this to probability
- $P(X,Y)_i = \sum_j S(X,Y)_{i,j} \cong 1$
- After normalizing the rows the sum of columns will not be 1

Normalize the operator

3.813014	1.1846079	1.1926202
9.104467	4.32391	5.296152
4.1251545	5.4451103	7.04003

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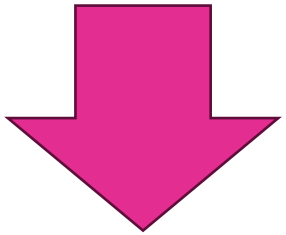

0.8733873	0.06305282	0.06356005
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0.04312247	0.16141844	0.79545933

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- We need to convert this to probability
- $P(X,Y)_i = \sum_j S(X,Y)_{i,j} \cong 1$
- After normalizing the rows the sum of columns will not be 1
- Repeat iterations until the sum of rows is 1 and the sum of columns is 1 also

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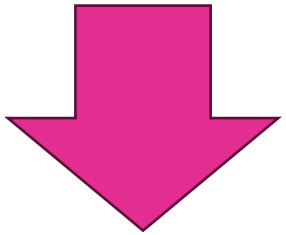
0.9703301	0.00814235	0.02152728
0.04312247	0.16141844	0.79545933



0.2894971	0.5115175	0.19898538
0.70675534	0.14515041	0.14809425
0.00374754	0.34333208	0.6529203

Sinkhor algorithm with deep learning

- In order to gain better results the distance matrix is transformed with a neural network:

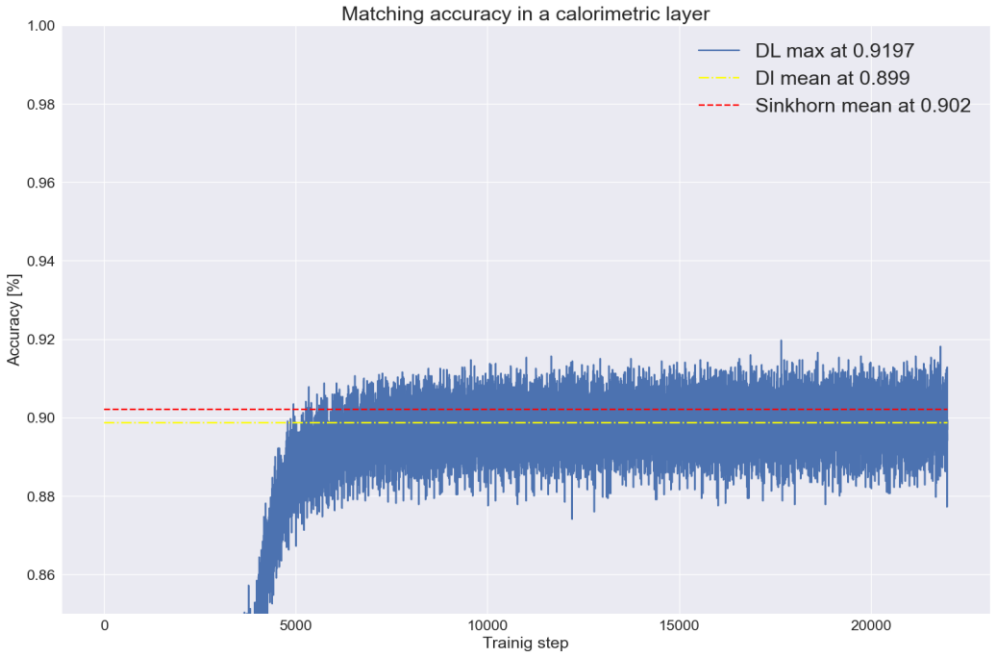
$$\widetilde{D}(X,Y)_{i,j} = h\left(\sqrt{X_i^2 - Y_j^2}\right)$$

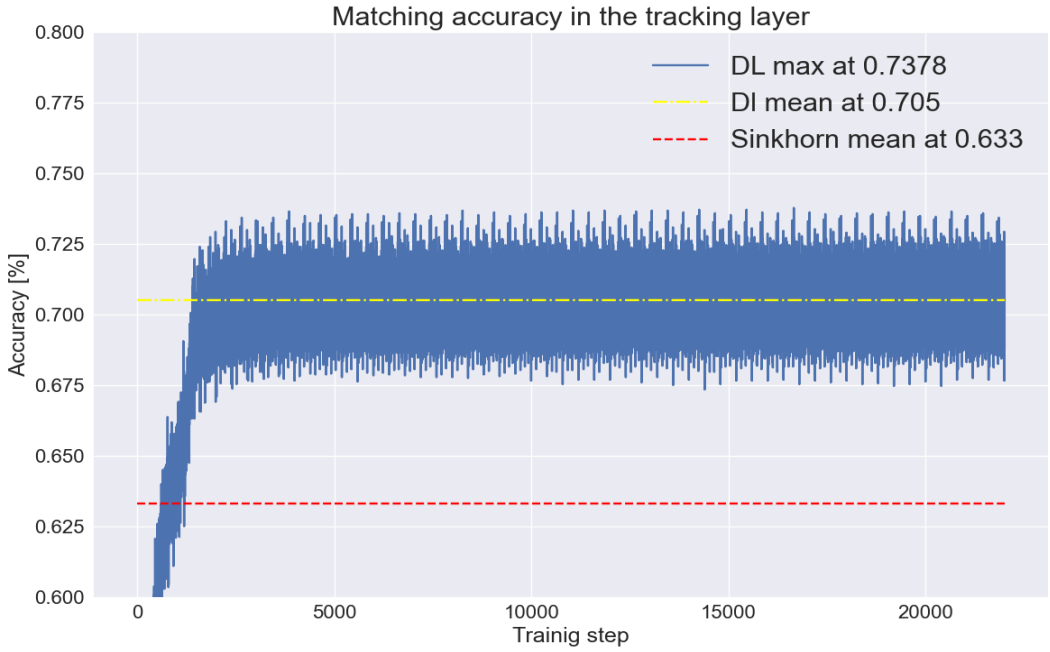
- Then the Sinkhorn operator in this case:

$$S(X,Y)_{i,j} = e^{\frac{\widetilde{D}(X,Y)_{i,j}}{T}}$$

Results

Accuracy in different layers





Summary & outlook

The application of Deep Learning for trajectory reconstruction looks promising (the Bergen pCT has achieved overall 87% accuracy with similar methods). Our approach is less accurate in the current state.

- Get better matching in the tracking layers
- Be able to reconstruct particle trajectories
- Predict initial kinetic energy of the protons

Supporters:

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- 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