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Using Allpix^2 for proton computed tomography

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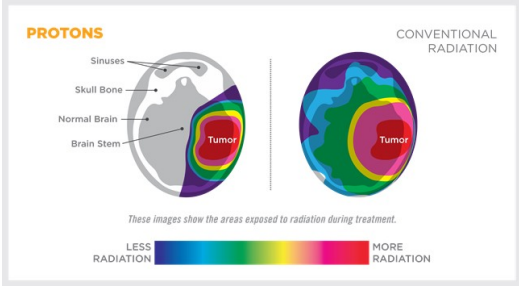
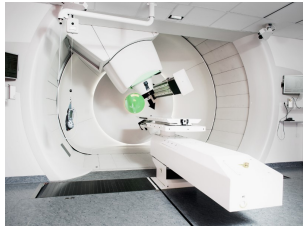
2. Allpix^2 Workshop

Proton therapy

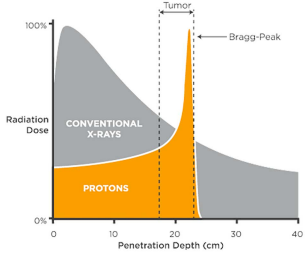
- Proton therapy uses the energy deposition of protons to irradiate tumors
  - Advantage: Less damage for healthy tissue due to different energy deposition



[The National Association for Proton Therapy: Provision Brain Graphic]



[Primo Medico: Proton Therapy Essen]

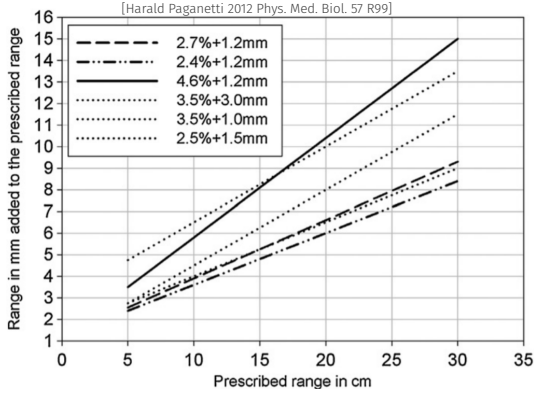


[Provision Cares Cancer Network]

Proton computed tomography

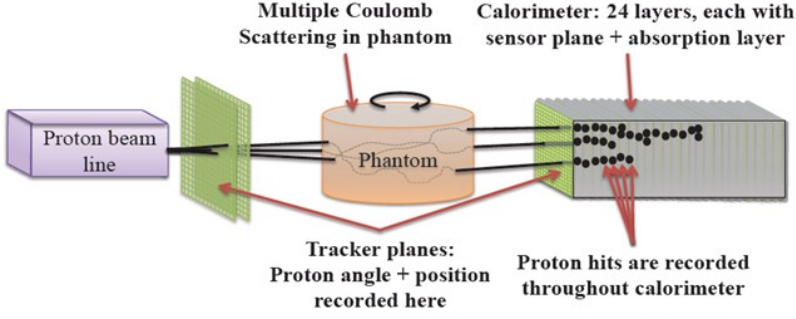
- CT scan necessary for irradiation plan
- Using X-ray CT scans causes uncertainties for the irradiation plan
  - Safety margin increases with travel distance

[Harald Paganetti 2012 Phys. Med. Biol. 57 R99]



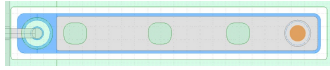
Proton computed tomography

- Track reconstruction is necessary in creating proton computed tomography scans
- Using Allpix^2 to simulate proton beam and telescope

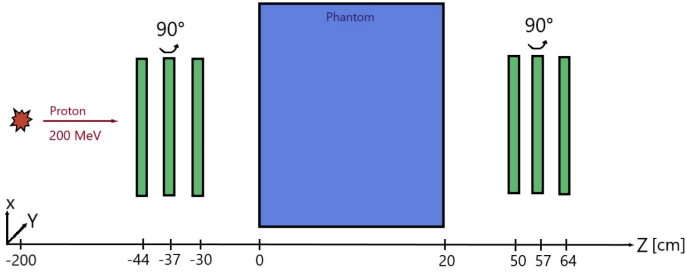


Proton beam setup

- Telescope setup: 6 ×IBL planar sensors



- Middle sensor of triplets is rotated by 90° to increase resolution in horizontal direction
- Protons events are simulated with the Allpix^2 framework [arXiv:1806.05813]



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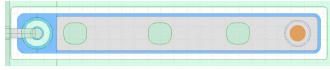

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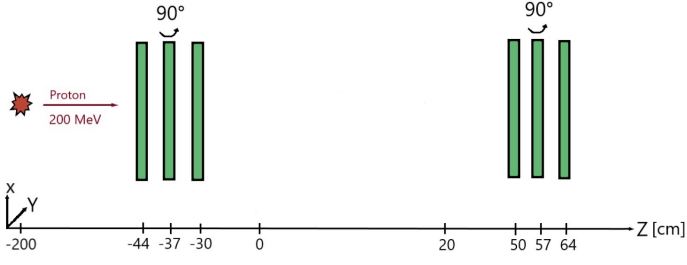
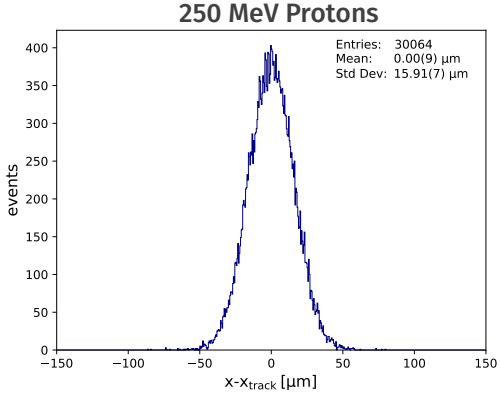
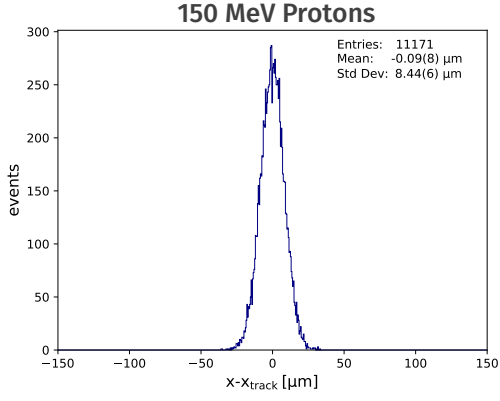


Performance test: Energy

- Simulations with proton energies used for proton computed tomography
- Significant amount of particles can not be reconstructed due to stronger scattering

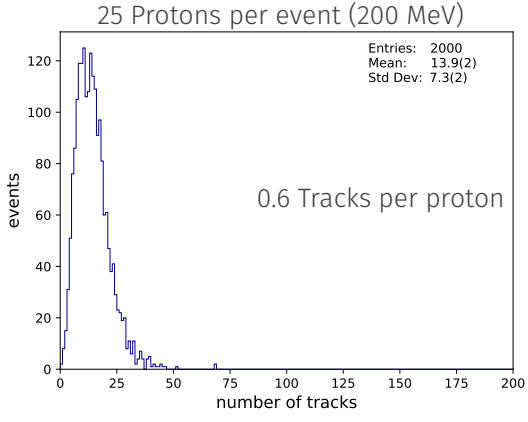


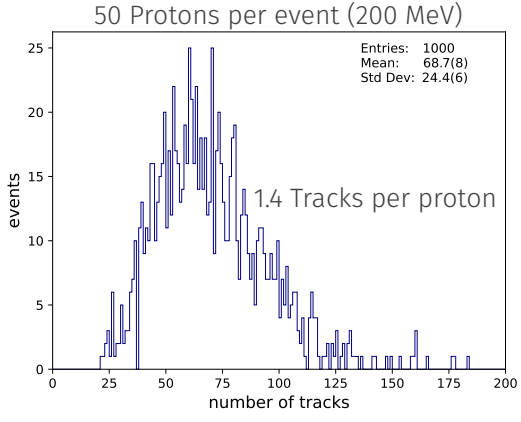


- Smaller statistics can be countered by taking more data $\longrightarrow$ More radiation damage

Performance test: Track density

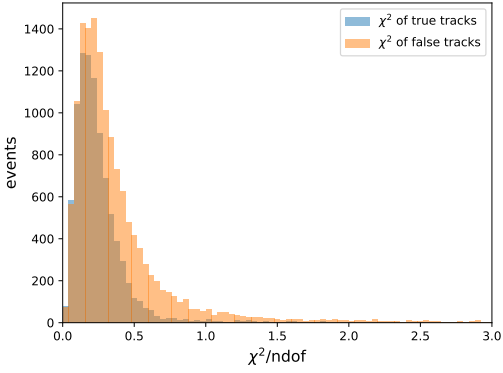
- Simulations with proton densities used for proton computed tomography
- More particles per event lead to higher amount of tracks with false cluster combinations

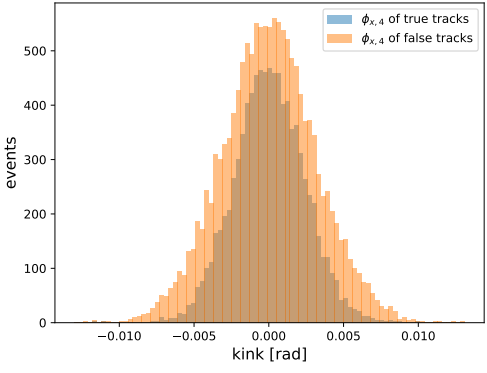




Separating features

- Reject false tracks by implementing cuts on track features
- 100000 Protons (200 MeV), 10 protons per event
- Useful features: χ^2 value, kink angles $\phi_{x,3}$ and $\phi_{x,4}$



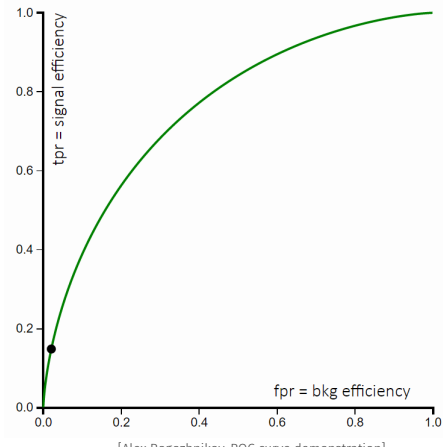


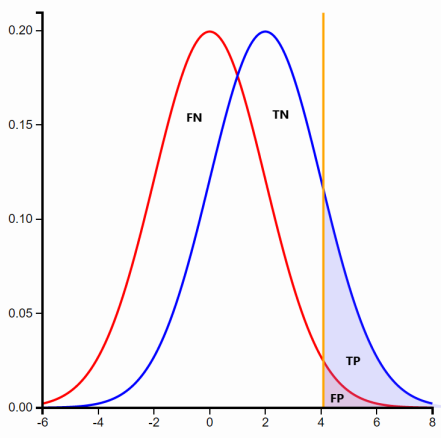
ROC curve

- Evaluate classification ⟶ ROC curve
- Each cut describes one point of the curve

tpr = TP/(TP + FN)

fpr = FP/(FP + TN)





[Alex Rogozhnikov, ROC curve demonstration]

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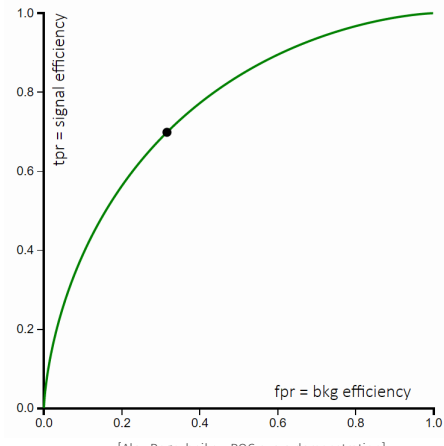

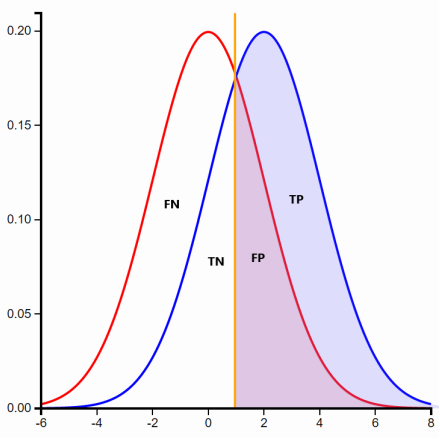

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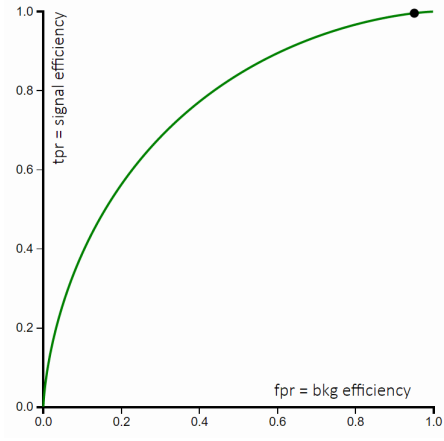
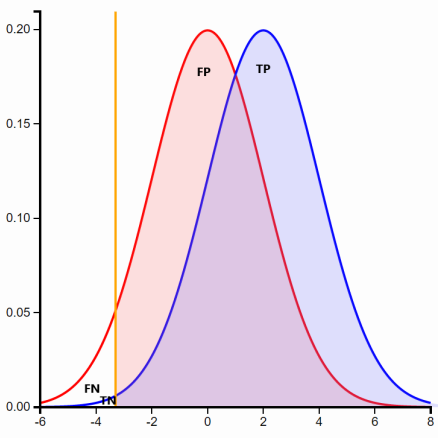




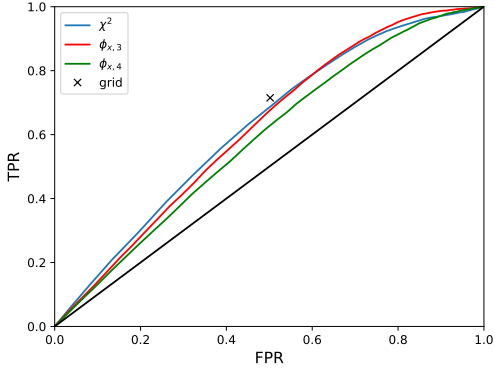
[Alex Rogozhnikov, ROC curve demonstration]

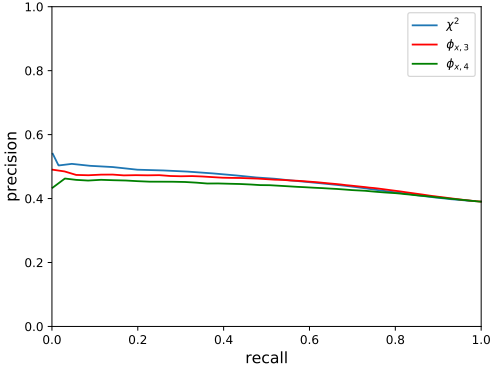
Feature cuts results

- Precision: Classifying false tracks as false
- Recall: Finding all true tracks

Recall = TP/(TP + FN)

Precision = TP/(TP + FP)

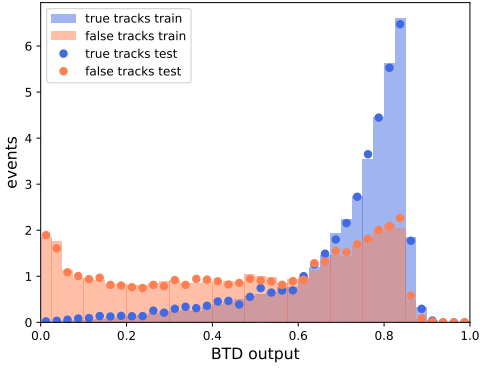


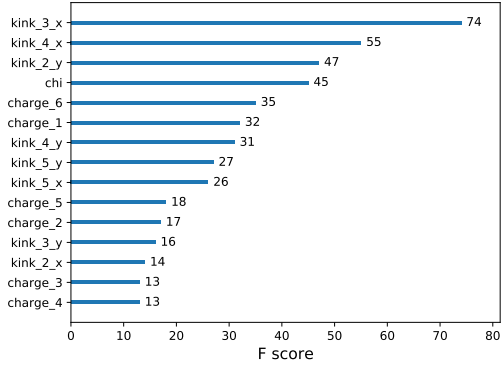


- How does a machine learner perform in comparison?

XGBoost

- Using Boosted Decision trees from XGBoost library
- Training data set: 400000 protons (200 MeV, 10 per event)
- Test data set: 100000 protons (200 MeV, 10 per Event)
- Probability distribution of true and false tracks different



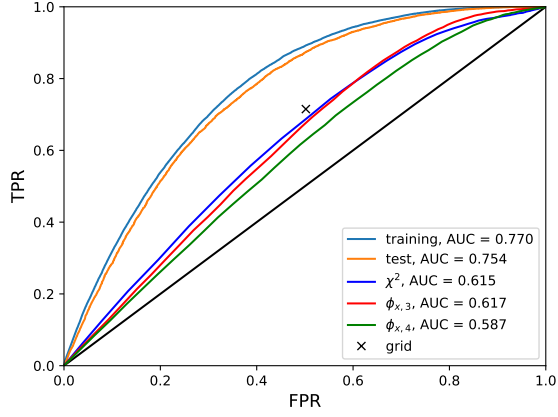


ROC curves result

tpr = TP/(TP + TN)

fpr = FP/(FP + FN)

- Area Under Curve (AUC) is a good measure to evaluate ROC curves
  - Higher AUC means higher tpr, lower fpr
- AUC of the learner is higher
  $\longrightarrow$ Better classification

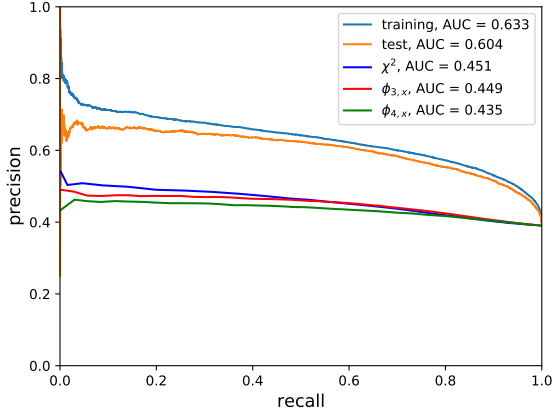


Precision-Recall curves

Recall = TP/(TP + FN)

Precision = TP/(TP + FP)

- Precision is stable for most recall values
  - High recall achievable
- AUC of the learner is higher
  $\longrightarrow$ Higher precision scores



Summary and Outlook

- Track reconstruction of simulated low energy protons with high track density
- Low energy particles cause problems in track reconstruction due to stronger scattering
  - More particles get deflected
  - Standard deviation of residuals decreases
- High track densities cause a combinatorics problem
  - Many unwanted false tracks decrease the resolution of the ct image
- Classification with a boosted decision tree is superior to 1D cuts on track features

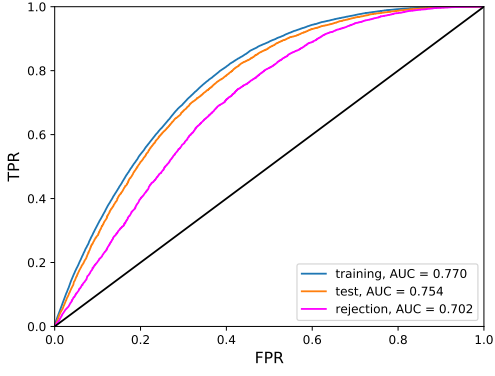
Outlook:

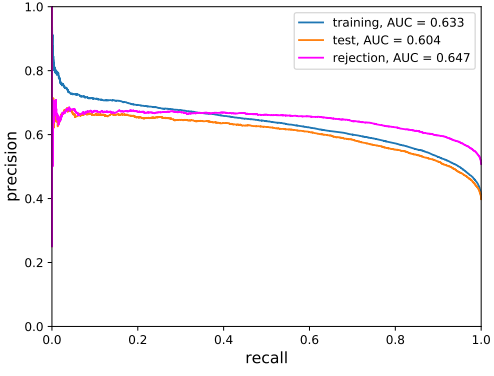
- Advanced track finding Algorithm: Tracking Multiplet
- Further rejection of false tracks by discarding all but one tracks from associated clusters

Backup

Further rejection

- Rejecting all but one track from cluster on first and last plane
- Only keeping track with highest probability of being true





- Precision increases, but FPR increases too due to the decrease of true negative tracks