Karlsruhe Institute of Technology

Pixel Detector Cluster Rescue

Pixel Detector Cluster Rescue for the Belle II Experiment

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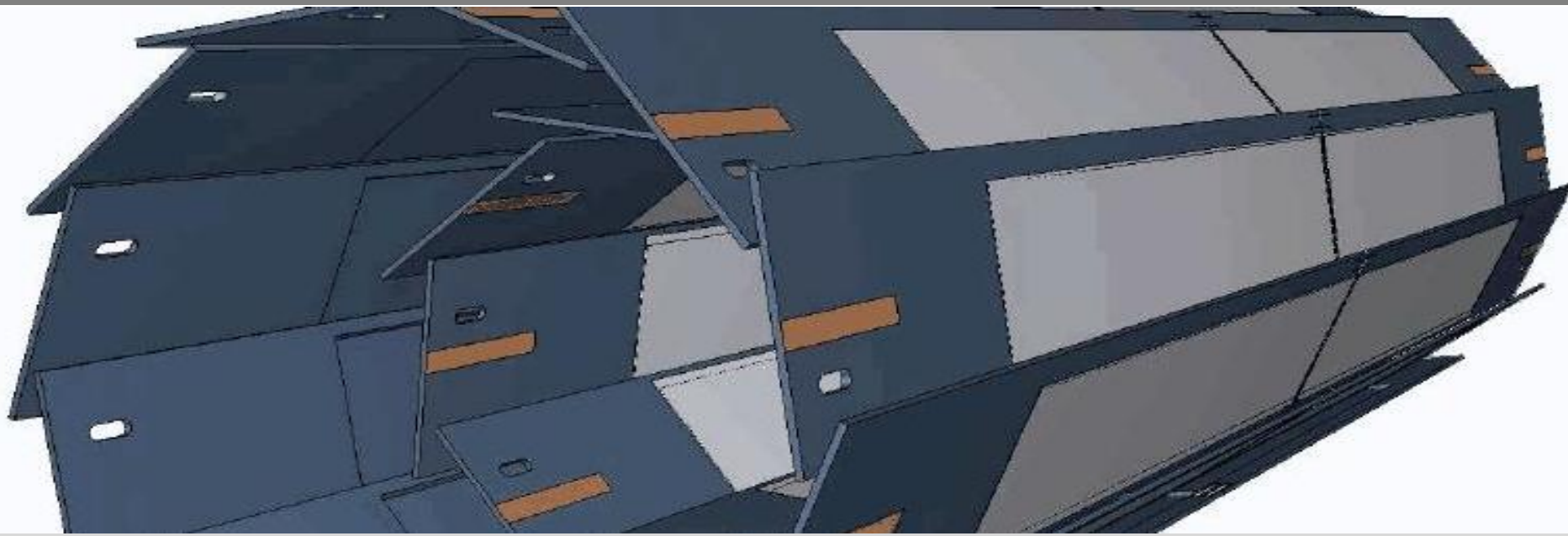
INSTITUT FÜR EXPERIMENTELLE KERNPHYSIK (IEKP)



Overview

- PXD has about 8 million pixels with 3% occupancy and 4 Byte per pixel
  $\rightarrow$ Data rate of about 1 MByte/event
- ONSEN output data rate: 100 kByte/event
- Need data reduction of about 90%

Cluster Rescue via Region of Interest

- Use SVD and CDC hits to extrapolate on PXD
- Define ROI and store all active pixels in this area
- Main mechanism for cluster rescue

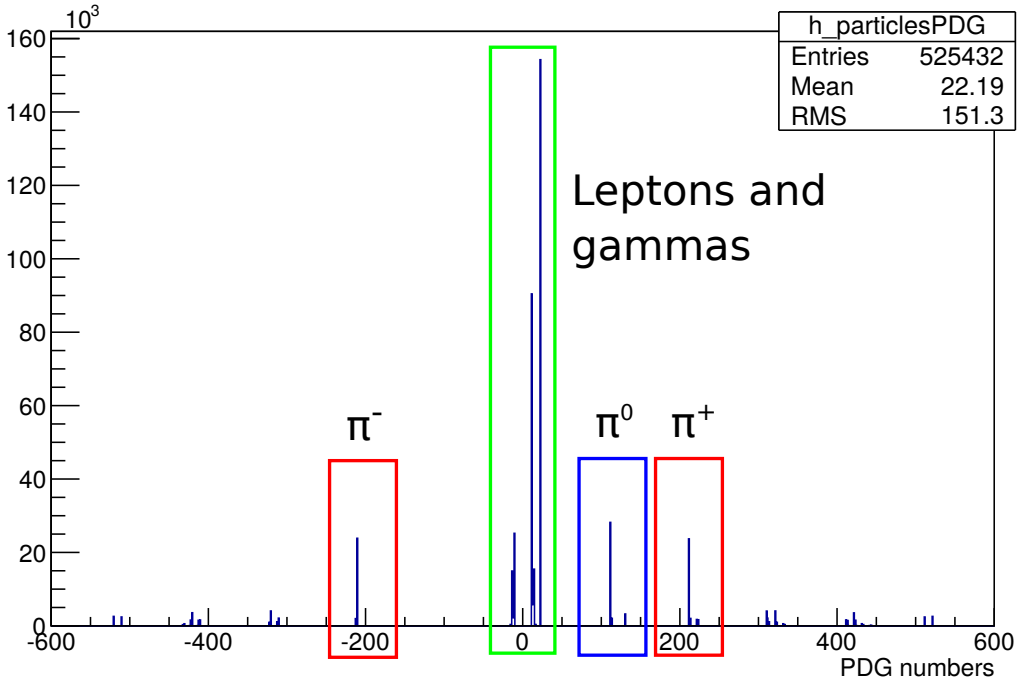
Neural Network

- Train NN on signal PXD cluster parameters
- Implementation on FPGAs by Steffen Baehr (ITIV)
- Try to complement missed clusters by ROI

Which clusters do we want to rescue?

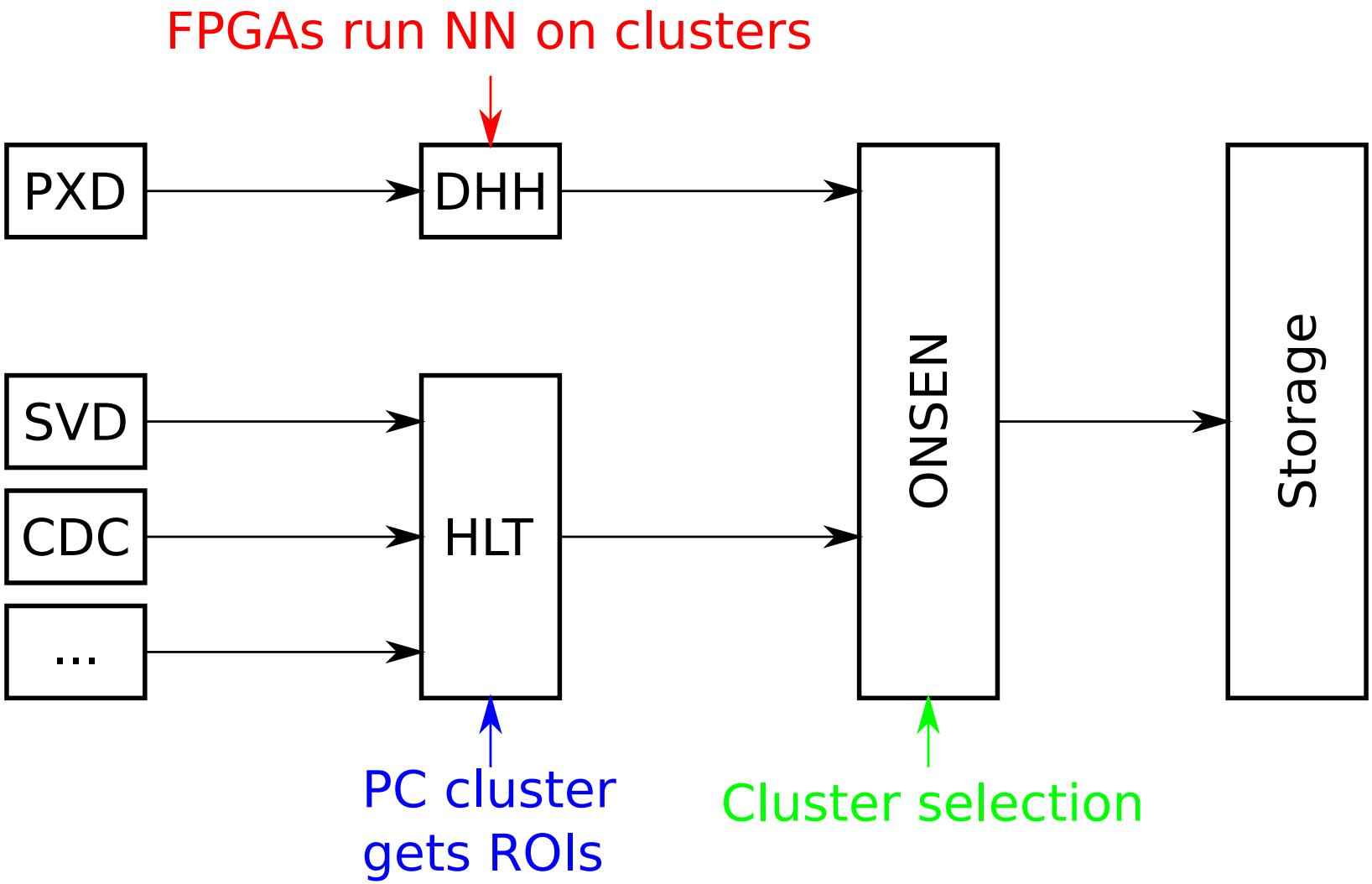
Signal cluster definition

- At least one relation to particle with whitelisted PDG number
- Actual whitelist contains ± 211 ($\pi^{\pm}$)

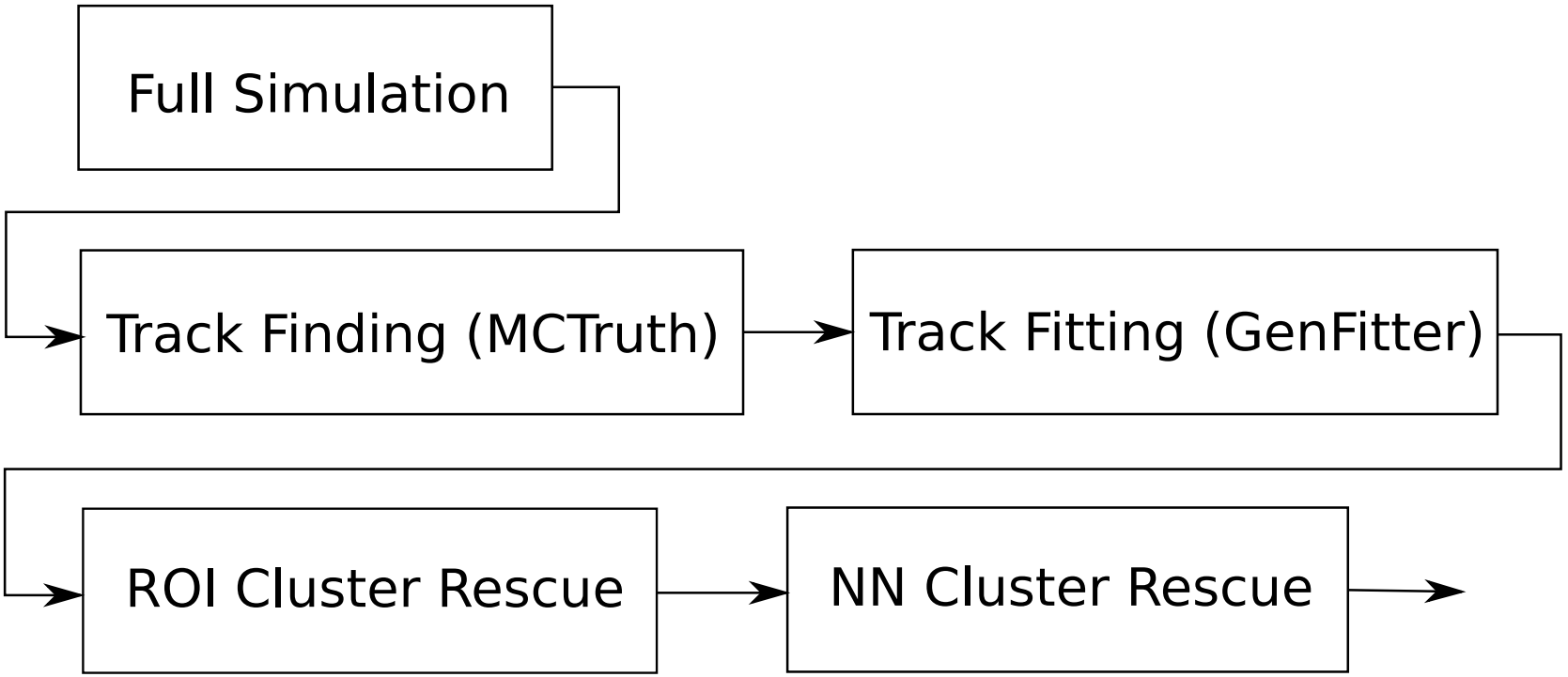


PDG numbers histogram of full simulation

PXD Data Flow



basf2 Steering



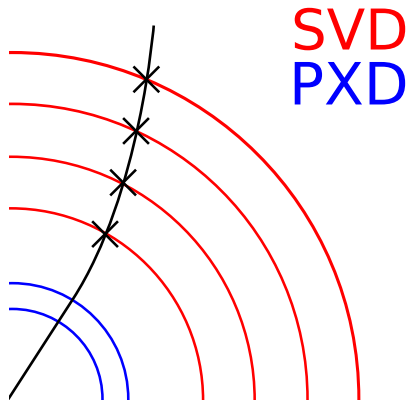
Cluster Rescue via Region of Interest

Implementation

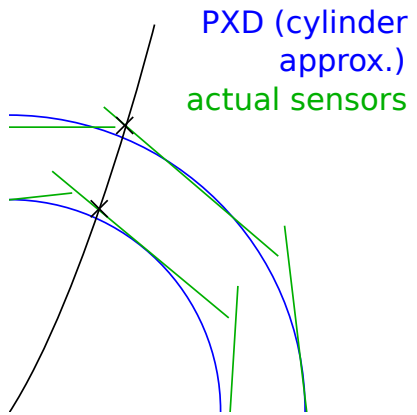
1) Rough extrapolation on PXD layers (cylinder approx.)
2) Find possible sensors in track range via geometry information
3) Get ROIs via exact extrapolation on sensor planes

ROI Cluster Rescue Parameters

- Scale factor for Kalman fitter uncertainties
- Maximum ROI size
- Tolerance for sensor finding



rough extrapolation



exact extrapolation

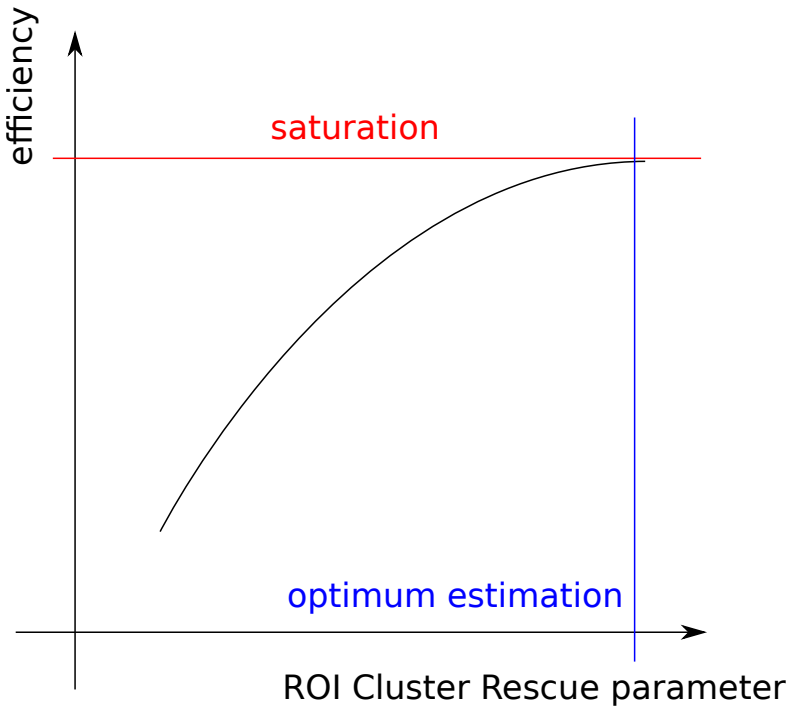
ROI Cluster Rescue Parameter Optimization

Method

- Hold all parameters except one
- Generate cluster rescue efficiency plot
- Choose value next to saturation

Results

- Mean cluster size is 1x2 pixels
- Square with maximum of 140x140 pixels as ROI
- Square with about 32x32 pixels as mean ROI size
- About 3.5 ROIs per track



Cluster Rescue via Neural Network

NN Training Toolchain

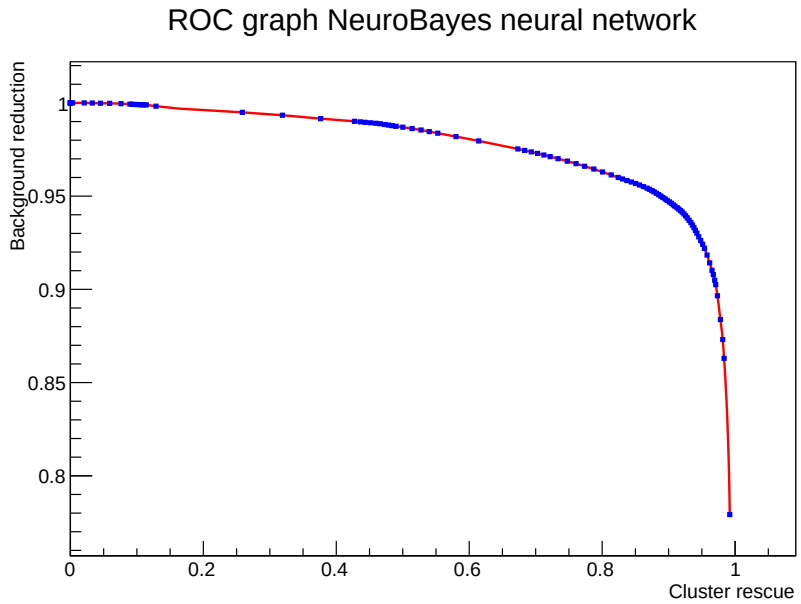
1) Extract training variables from signal and background ROOT files (basf2 module)
2) Use NeuroBayes teacher (stand-alone program)

Implementation

- Simple NeuroBayes expert application

NN Cluster Rescue Parameters

- NeuroBayes expertise file
- Classification threshold



Background reduction vs. Cluster rescue

ROC information created from NeuroBayes analysis output via ROOT script

Neural Network Training Variables

- Signal: Signal clusters with related particle Pt less than 65 MeV (Christian Pulvermacher diploma thesis)
- Background: Given background simulation data

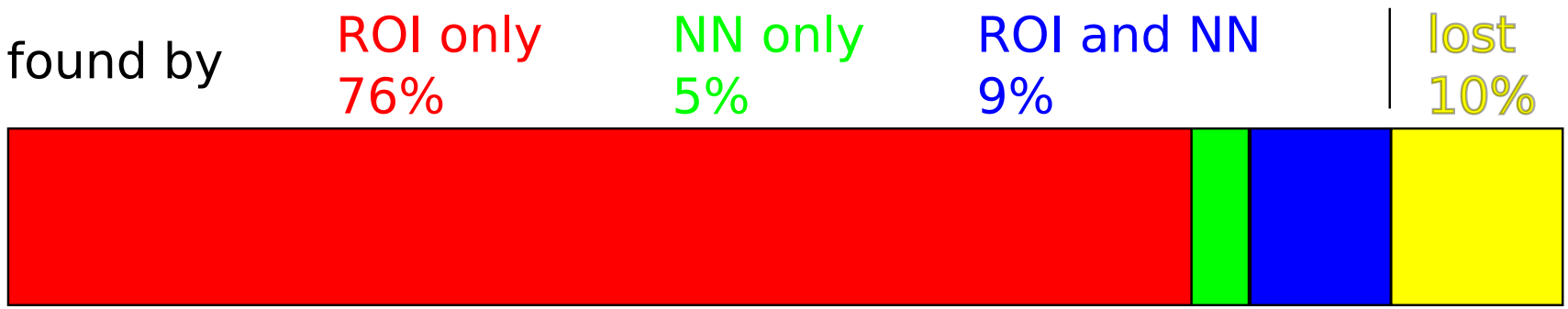
nrank	nvar	additional signif	only this var	loss when removed	global corr. to others [%]	
1	5	674.34	674.34	185.35	94.0	pixelChargeMean 14 #5
2	2	245.22	618.64	212.81	87.0	pixelChargeSum 14 #2
3	8	212.32	179.91	237.59	52.2	clusterSizeU 14 #8
4	7	181.09	222.81	121.19	73.0	clusterSize 14 #7
5	4	64.38	670.26	42.30	98.3	pixelChargeMax 14 #4
6	12	53.45	113.59	55.96	13.1	layerNumber 14 #12
7	9	35.38	255.38	35.62	71.7	clusterSizeV 14 #9
8	6	15.59	611.91	6.42	97.3	pixelChargeVar 14 #6
9	3	5.29	279.95	5.33	87.9	pixelChargeMin 14 #3
10	10	3.67	14.32	3.67	3.5	clusterStartU 14 #10
11	11	0.15	24.12	0.15	4.2	clusterStartV 14 #11

Data Rate Estimation and NN Working Point

- Assume 50 tracks per event
- About 180000 ROI pixels per event with 3% occupancy
  → 5000 pixels tagged as signal by ROI Cluster Rescue per event
  → Generates data rate of about 20 kByte/event
- Data rate of about 80 kByte/event free for NN Cluster Rescue
  → Need NN with background reduction rate of about 92%
  → Defines working point in NN ROC
- NN working point with 95% cluster rescue efficiency

Performance

- Single efficiency of NN on clusters with related particle Pt $<$ 65 MeV: 95%
- Single efficiency of ROI Cluster Rescue on clusters with related track: 94%
- Combined efficiency of NN and ROI on simulation data: 90%

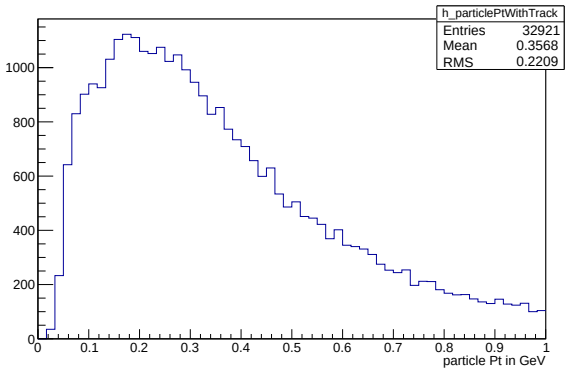


Where goes the lost 10%?

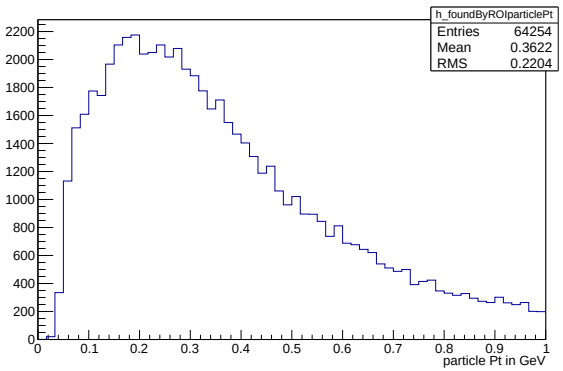
- Particles with no track as main influence
- Mean number of clusters per event with relation cluster $\rightarrow$ valid particle: 15.03
- Mean number of clusters per event with relation cluster $\rightarrow$ valid particle $\rightarrow$ track: 13.66
- $1 - 13.66/15.03 \approx 9\%$ of signal clusters with no attached track
- Cut on maximum combined efficiency of ROI on $91\% \times 94\% \approx 86\%$

Why we don’t rescue more with the NN?

ROI Cluster Rescue

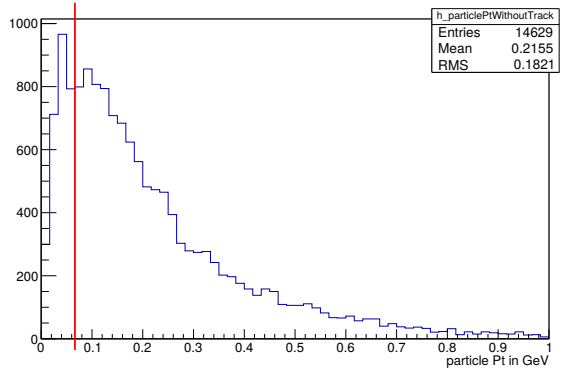


Particle Pt with related track

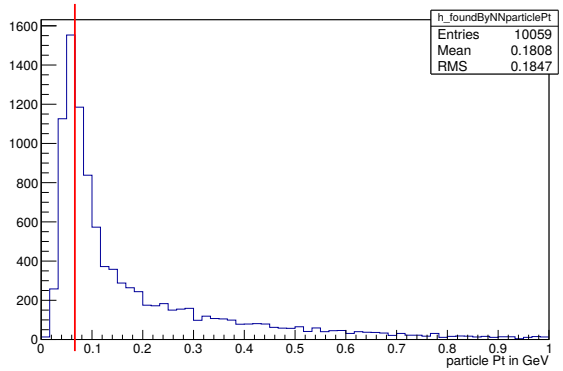


Partice Pt found by ROI

NN Cluster Rescue



Particle Pt without related track



Particle Pt found by NN