DEEP UNDERGROUND NEUTRINO EXPERIMENT

UNIVERSITY of HOUSTON
YOU ARE THE PRIDE
DEPARTMENT OF PHYSICS

Proton Decay at DUNE FD

$p \rightarrow K + \overline{\nu}$

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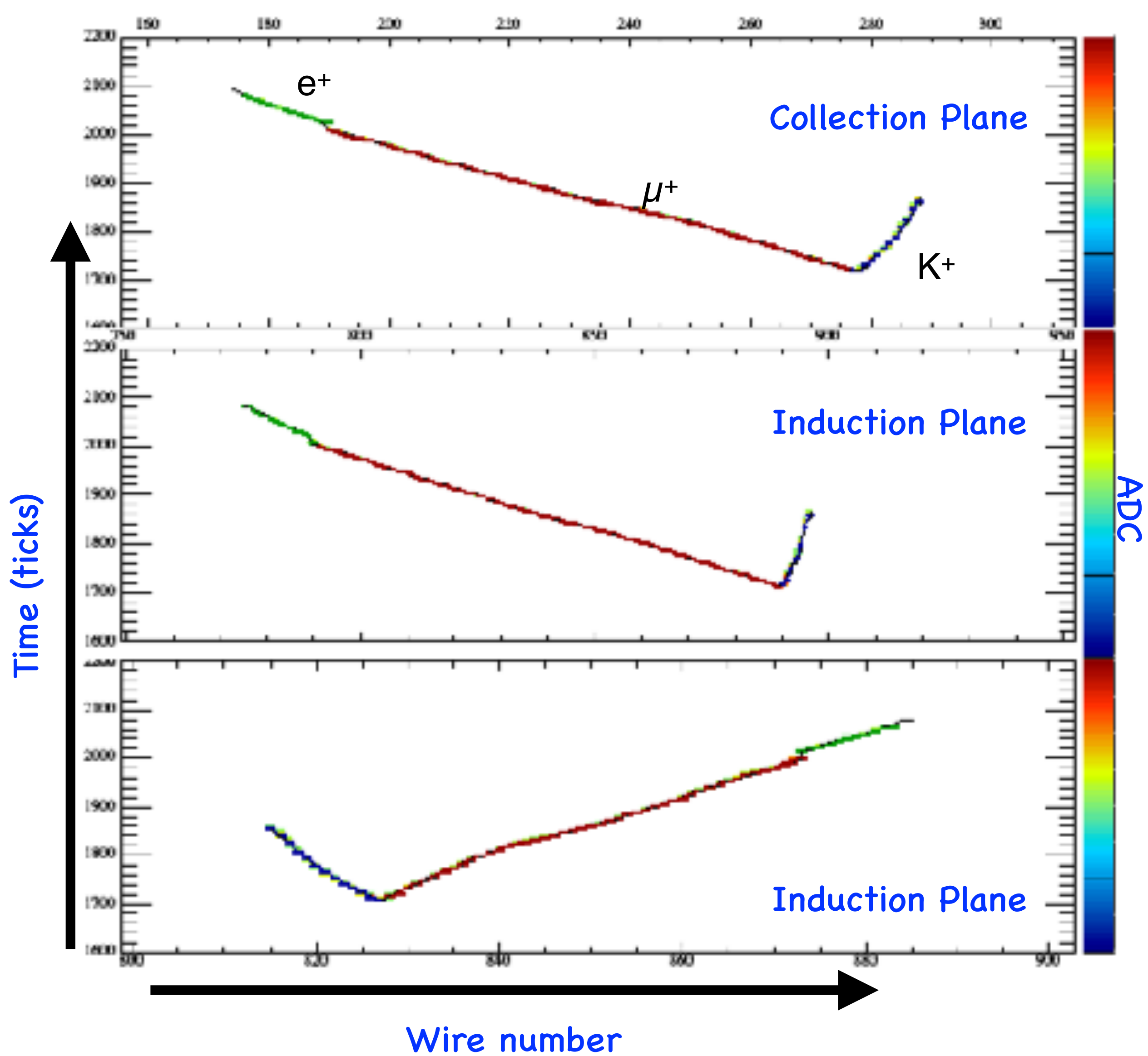
Proton Decay Analysis

Simulation of proton decay at DUNE LArTPC

$p \rightarrow K^{+}\bar{\nu}$ We would focus only on $K \rightarrow \mu^{+} + \nu_{\mu}$ events and atmospheric neutrino events as background

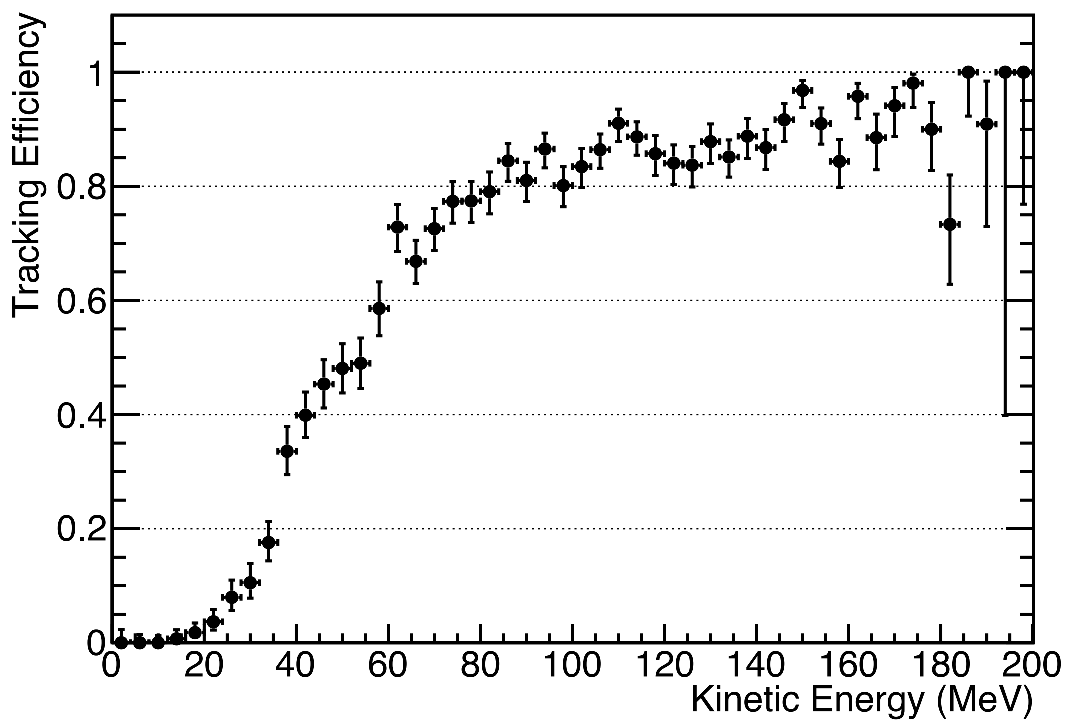


- GENIE 2.12.2
  - Nuclear mode
    - ☑ RFG with short range nucleon-nucleon correlations
    - ☐ No binding energy
    - ☐ No de-excitation photon production for Ar, only for Oxygen (Cherenkov detectors)
  - Kaon-nucleus & GENIE FSI
    - ☑ FSI are simulated using “hA” model
    - ☑ No absorption
    - ☑ Elastic and Inelastic scattering
    - ☐ K^{+} via π is not included
    - ☐ No K^{+} charge exchange
    - ☐ GENIE FSI model never adds or removes K^{+} from the final state

Proton Decay Analysis

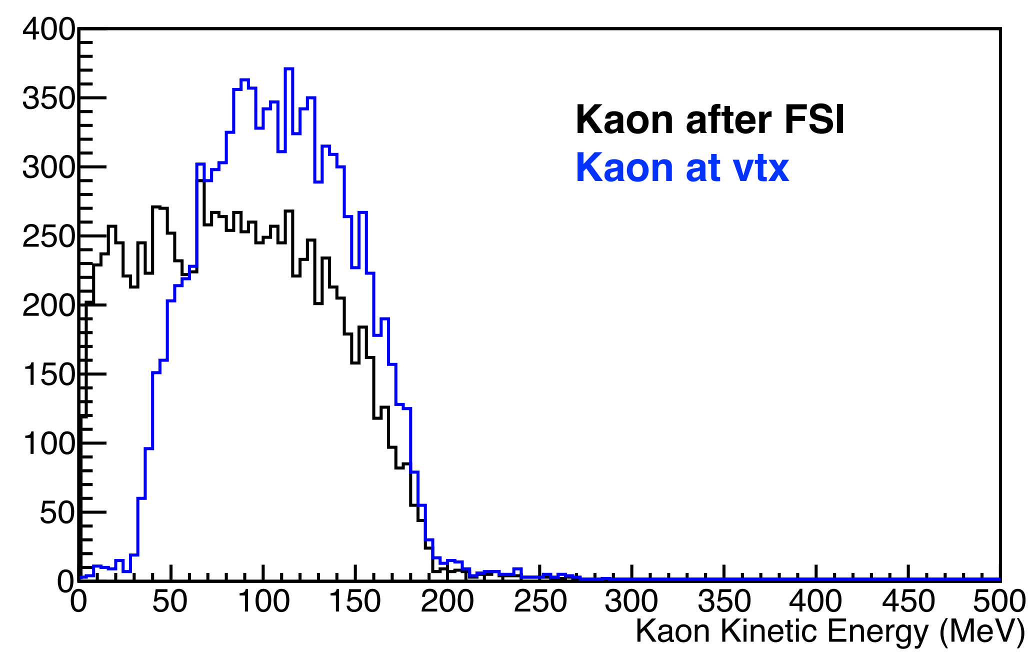
$p \rightarrow K^+ \bar{\nu}$ We would focus only on $K \rightarrow \mu^+ + \nu_\mu$ events

Track Reconstruction

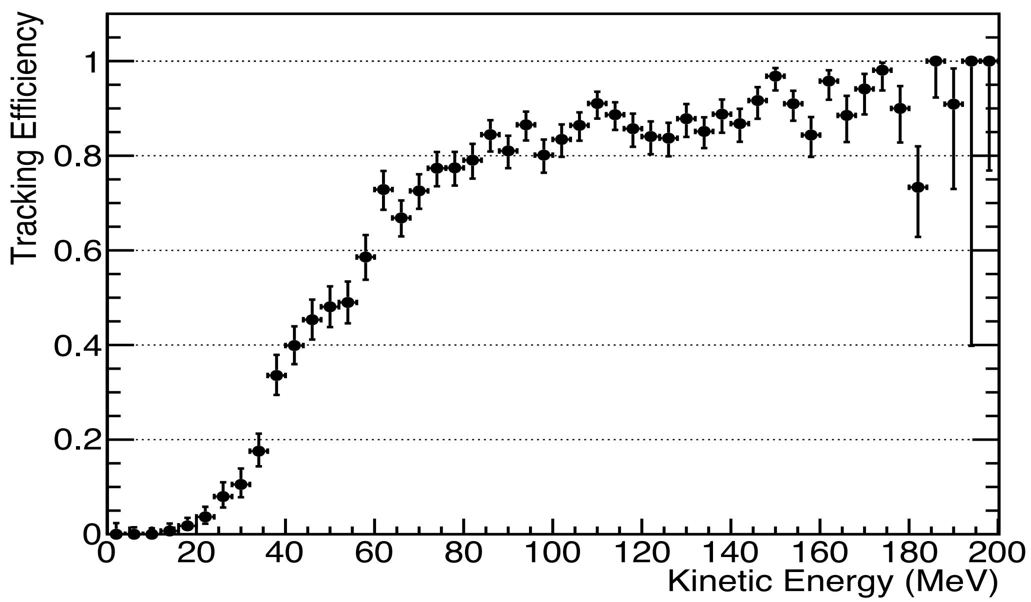


- A MIP looses ~2.1 MeV/cm
- Kaon are heavy ionization particles
- 4 MeV Kaon will travel ~2 cm 2-3 wires
- Kaons below 25 MeV of KE are stubs hard to track them
- FSI modifies the KE spectrum

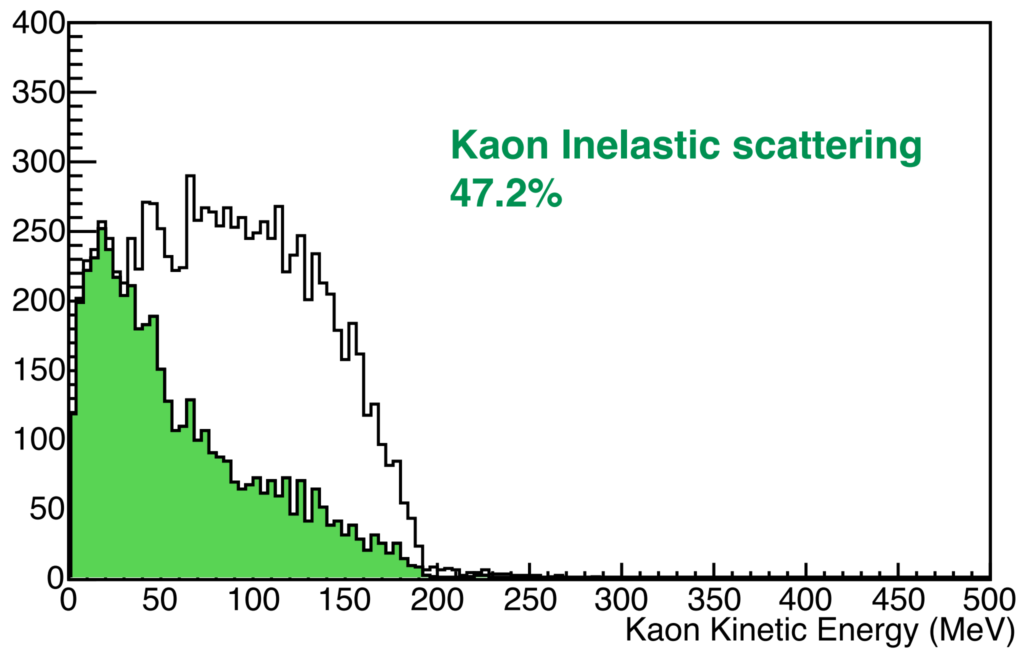
All of this makes Kaon track reconstruction a big challenge

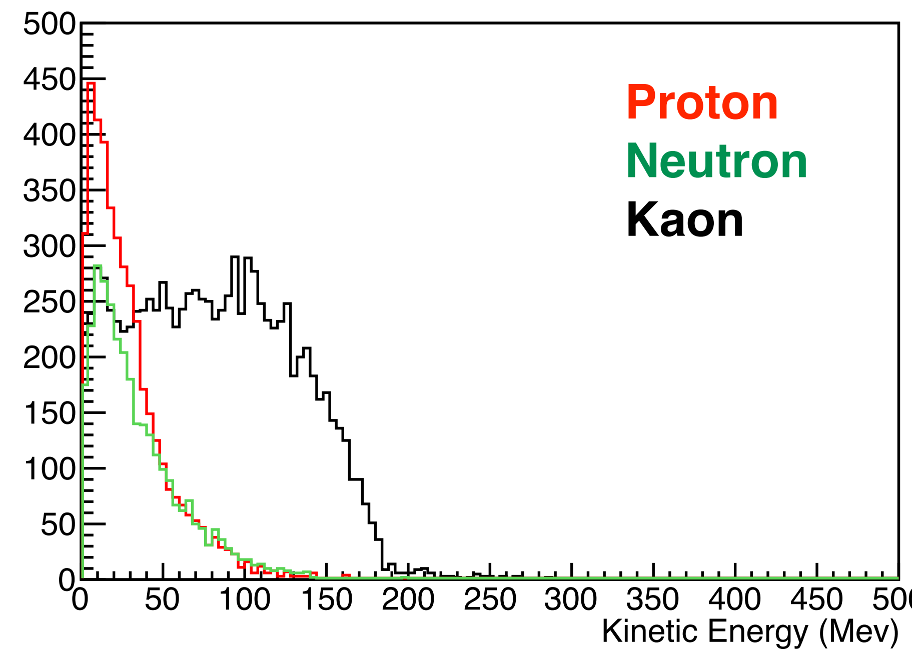


Proton Decay Analysis



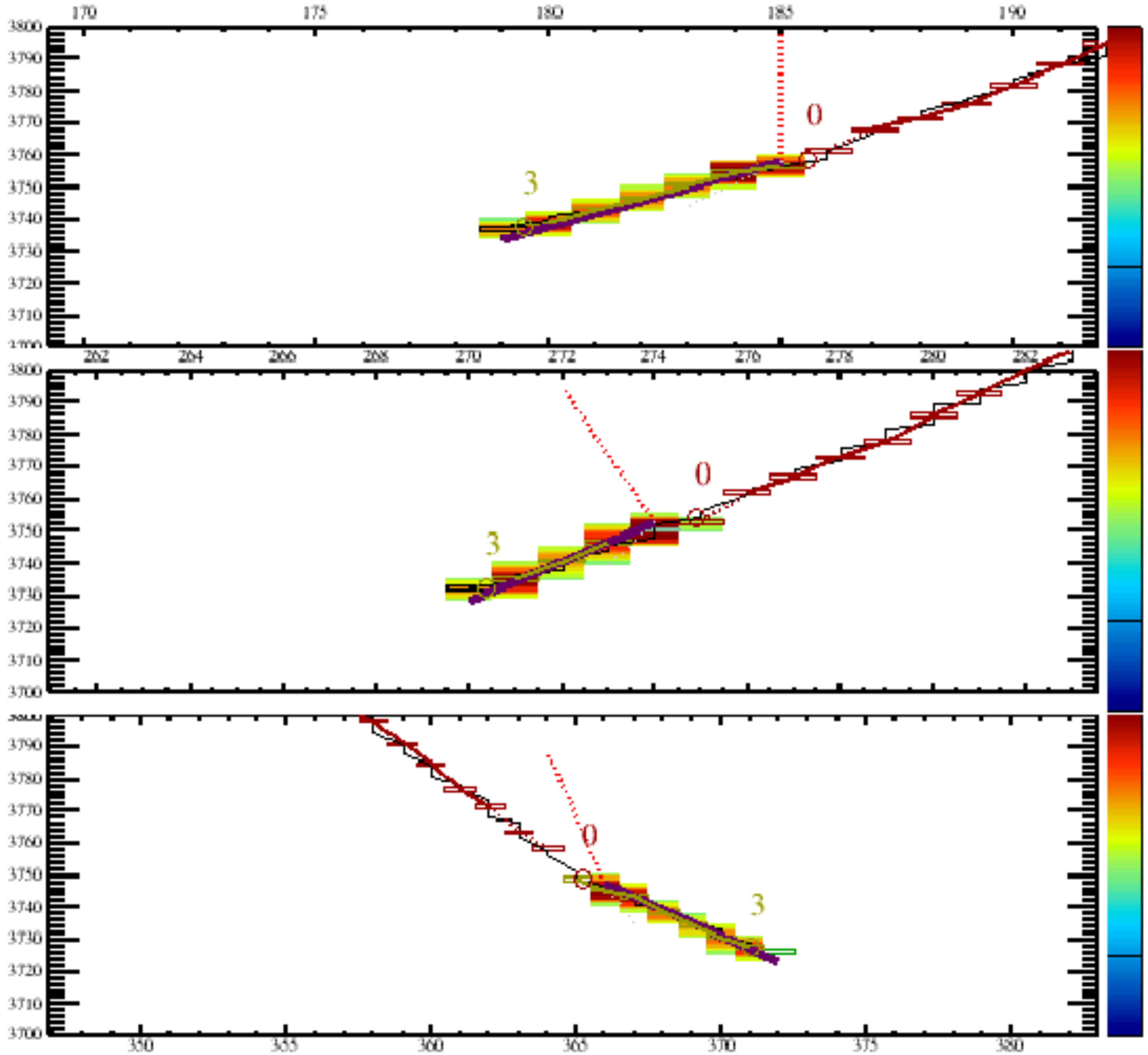
FSI plays a role in tracking efficiency



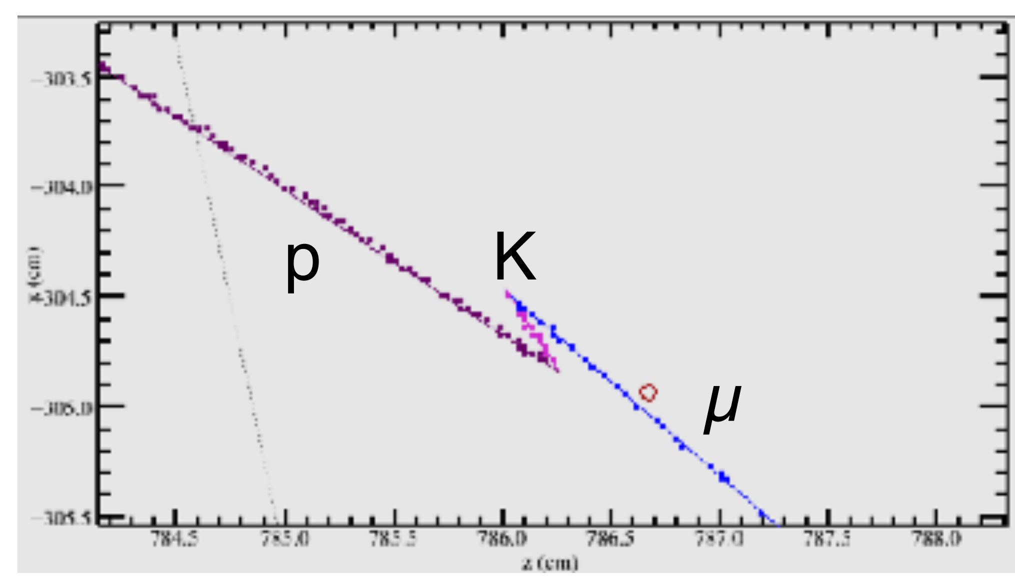


Proton Decay Analysis

Track Reconstruction



K = 15 MeV (KE)
P = 65 MeV (KE)

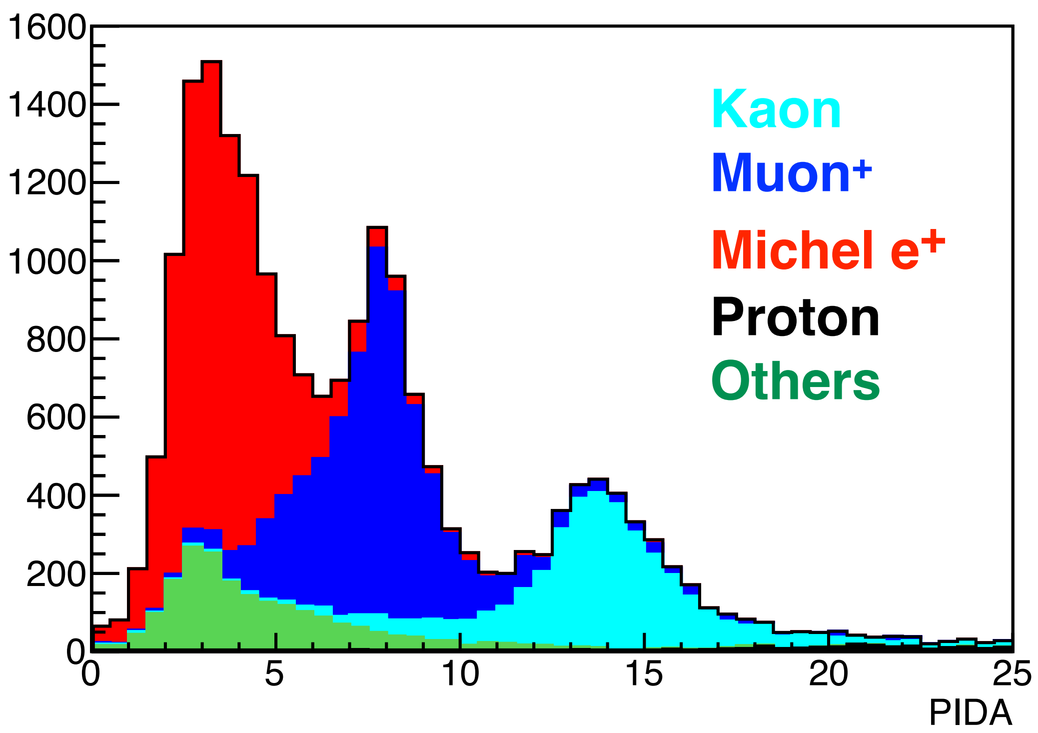


Proton Decay Analysis

Analysis

Far Detector Task Force Report

Requirement	$p \to \bar{\nu} K^+_{\mu 2}$ signal efficiency (%)	Atmospheric ν background rate ($\mathrm{Mton}^{-1} \cdot \mathrm{year}^{-1}$)
None	100.0	2.9×10^5
Kaon tracking efficiency	61.8	N/A
Kaon and muon ID	38.0	9.2×10^3
Not shower-like	30.7	1.0×10^3
Vertex-muon separation	23.2	1.2×10^2

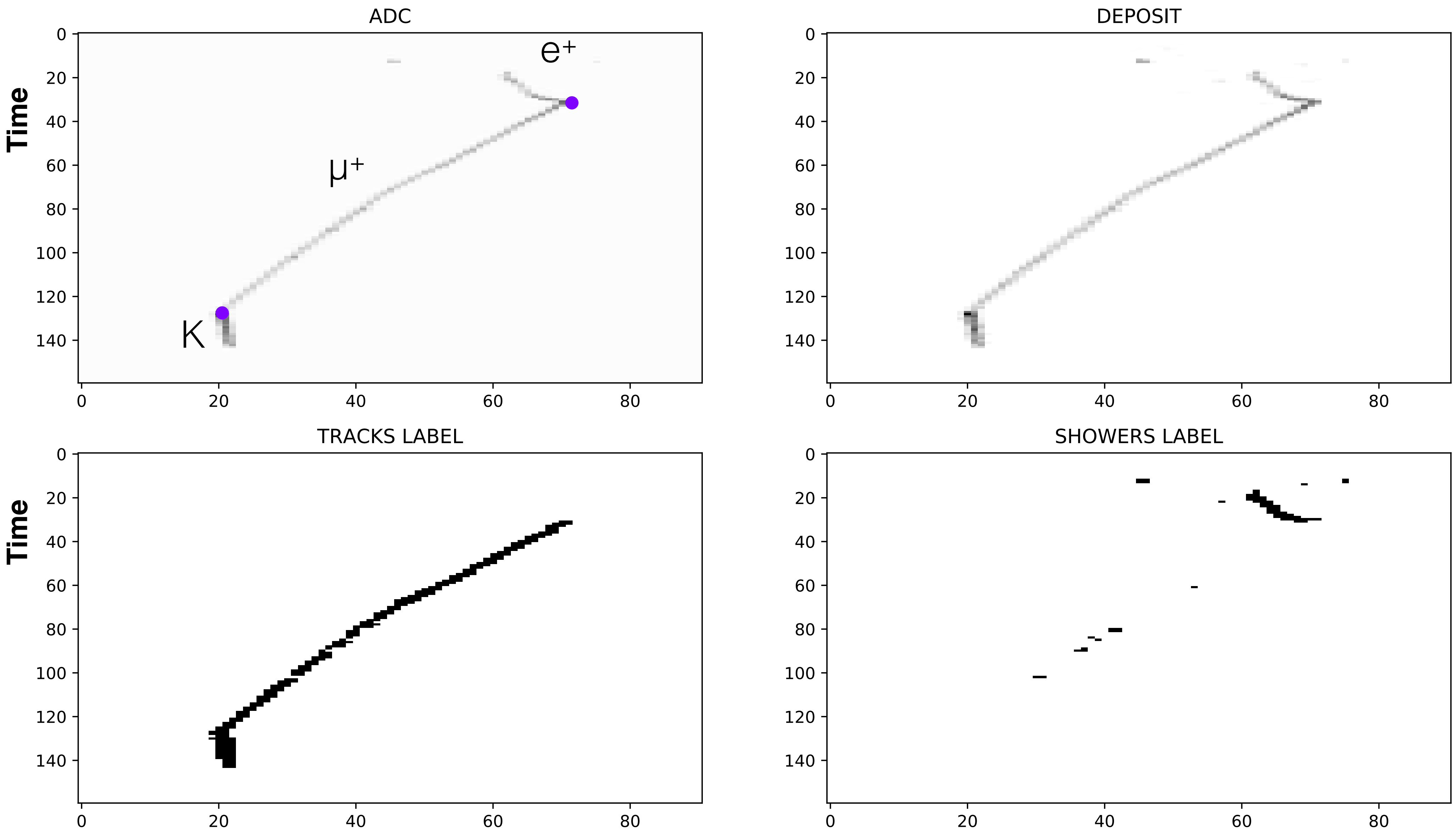


Far from what we promised in CDR

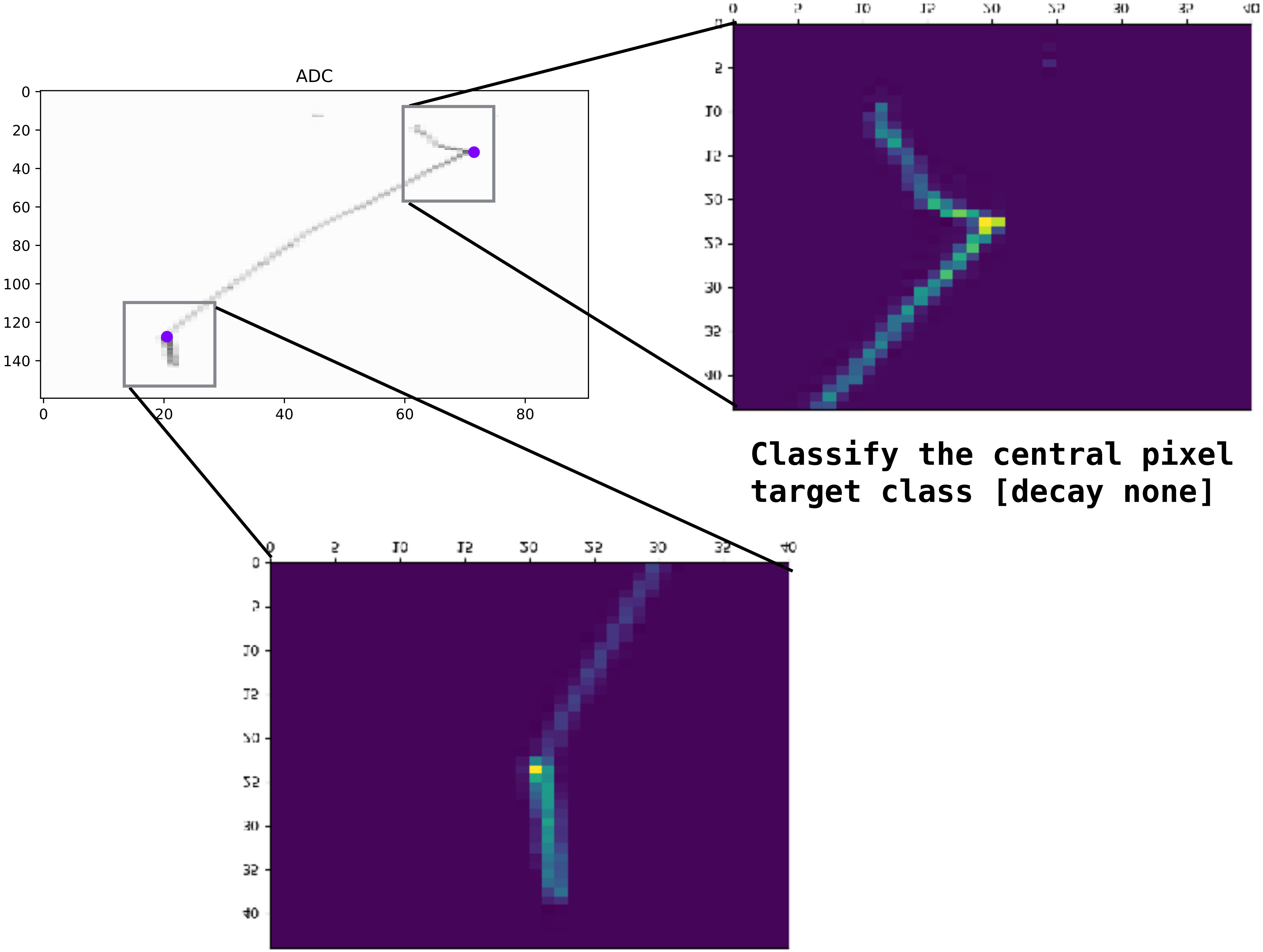
CNN Tools on the Proton Decay Analysis

CNN Tools on the Proton Decay Analysis

- To improve reconstruction
- To improve analysis

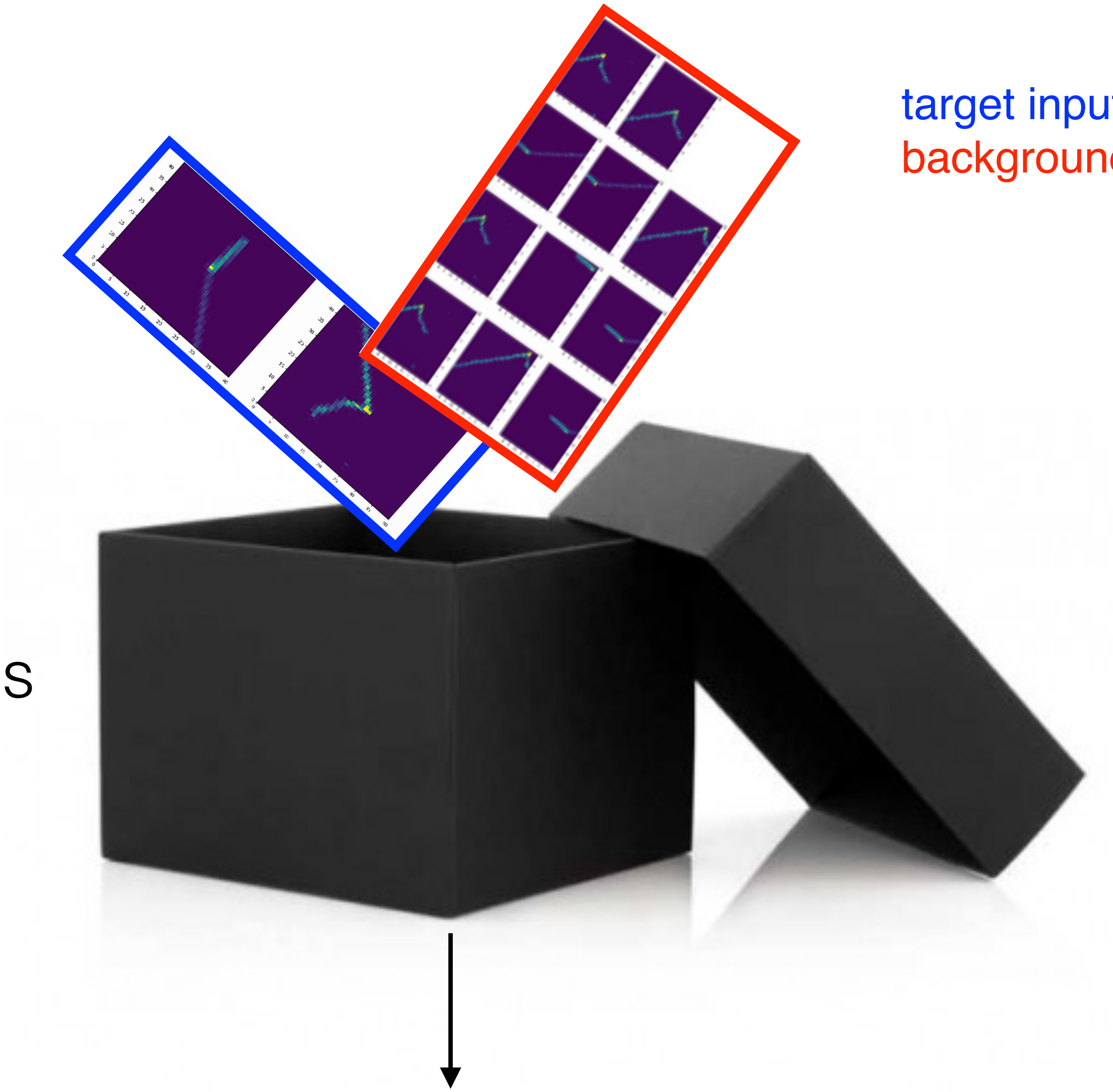


CNN Tools on the Proton Decay Analysis




```
Classify the central pixel
target class [decay none]
```

CNN Tools on the Proton Decay Analysis



target input (decay vertex)
background (random point)

GPUs

convolutional layers
dense layers

Model

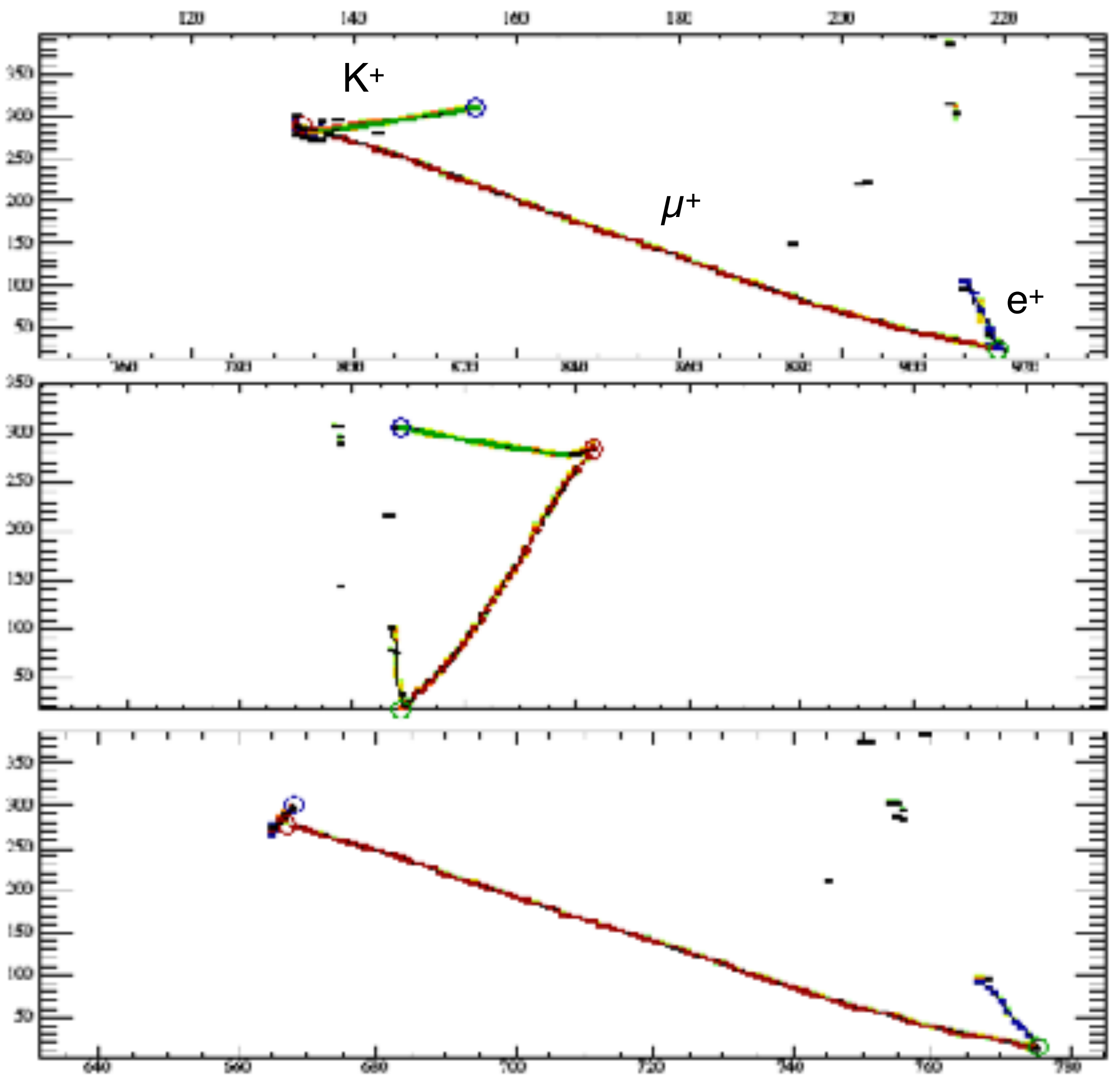
CNN Tools on the Proton Decay Analysis

CNN info

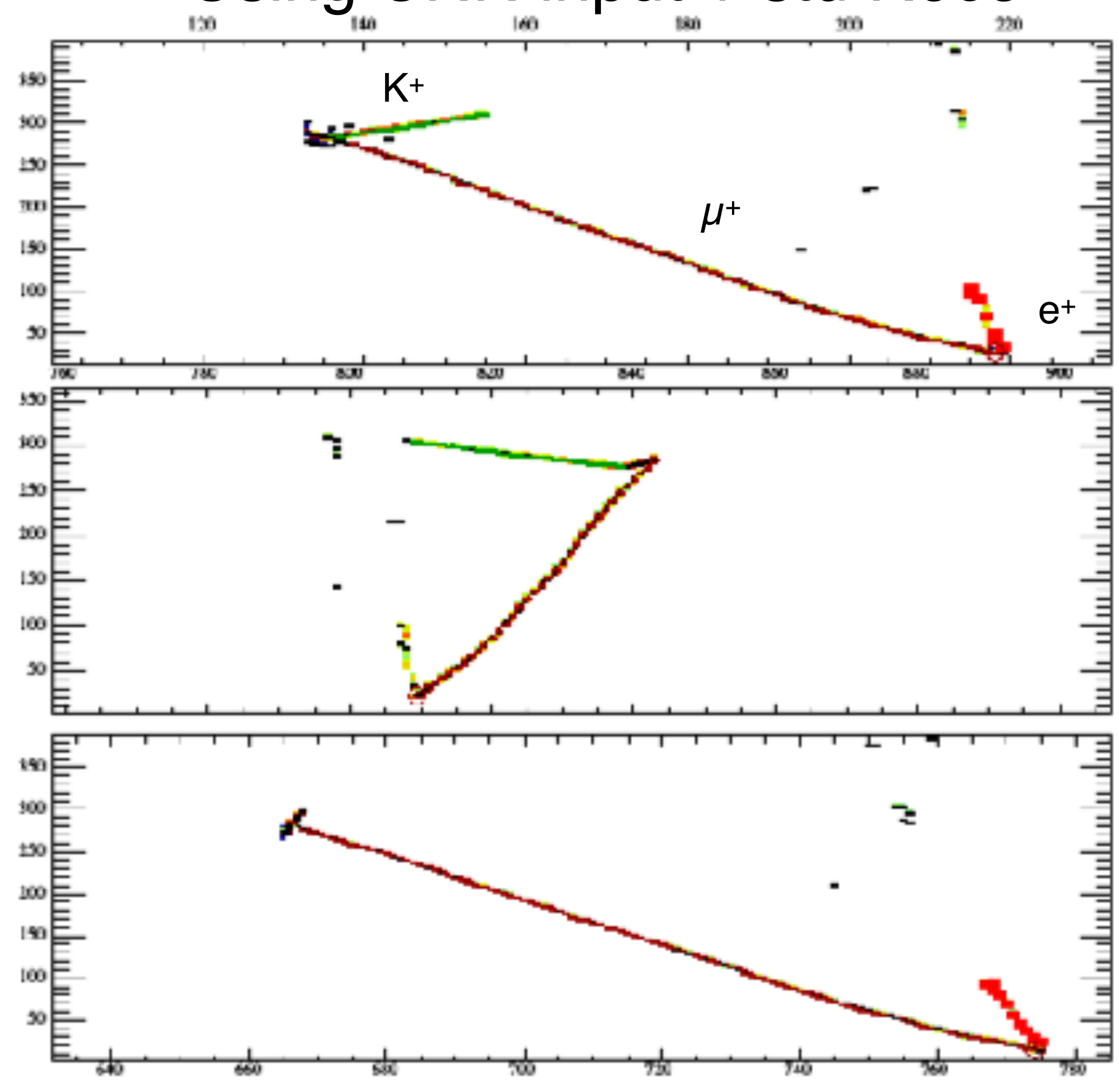
- Track-like hits
  - Do tracks
    - Improves PID
- EM-like hits
  - Do showers
    - Improves Bkgd rejection
- Decay point
  - Do decay vertex
    - Improves selection

Proton Decay Analysis

Standard Reconstruction



Using CNN input + std Reco

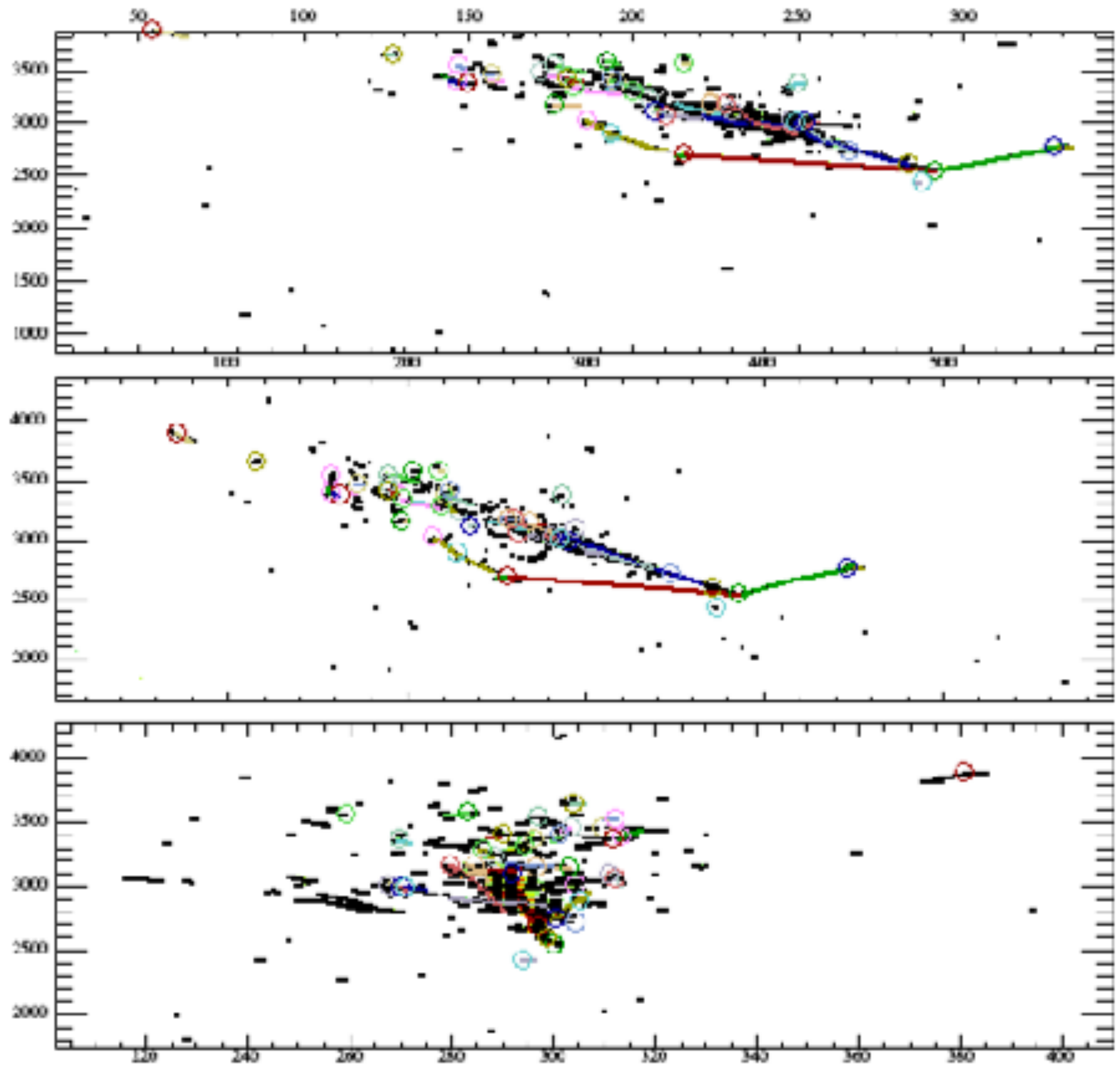


Kaon track
Muon track
Michel electron track

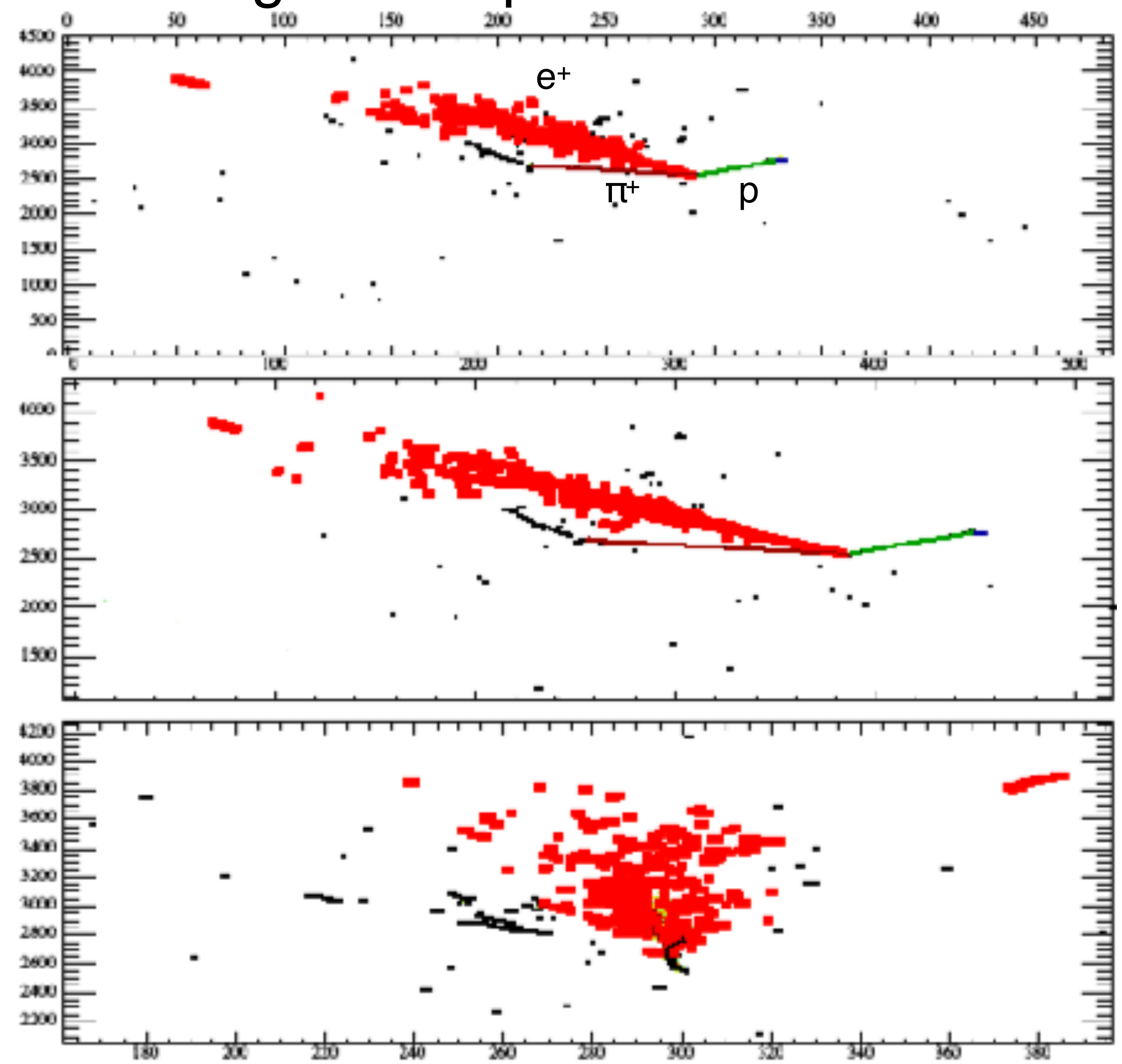
Kaon track
Muon track
Muon decay vertex
Michel electron shower

Proton Decay Analysis

Standard Reconstruction



Using CNN input + std Reco



a lot

ν_e —> e+p+π+n

proton track

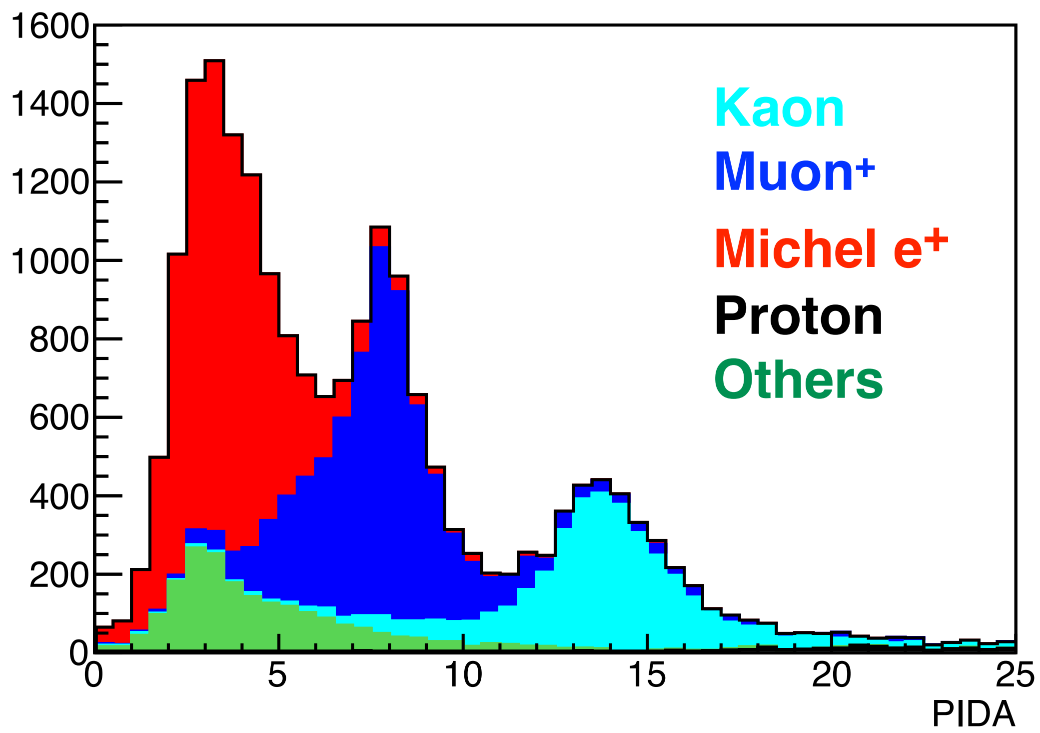
pion track

electron shower

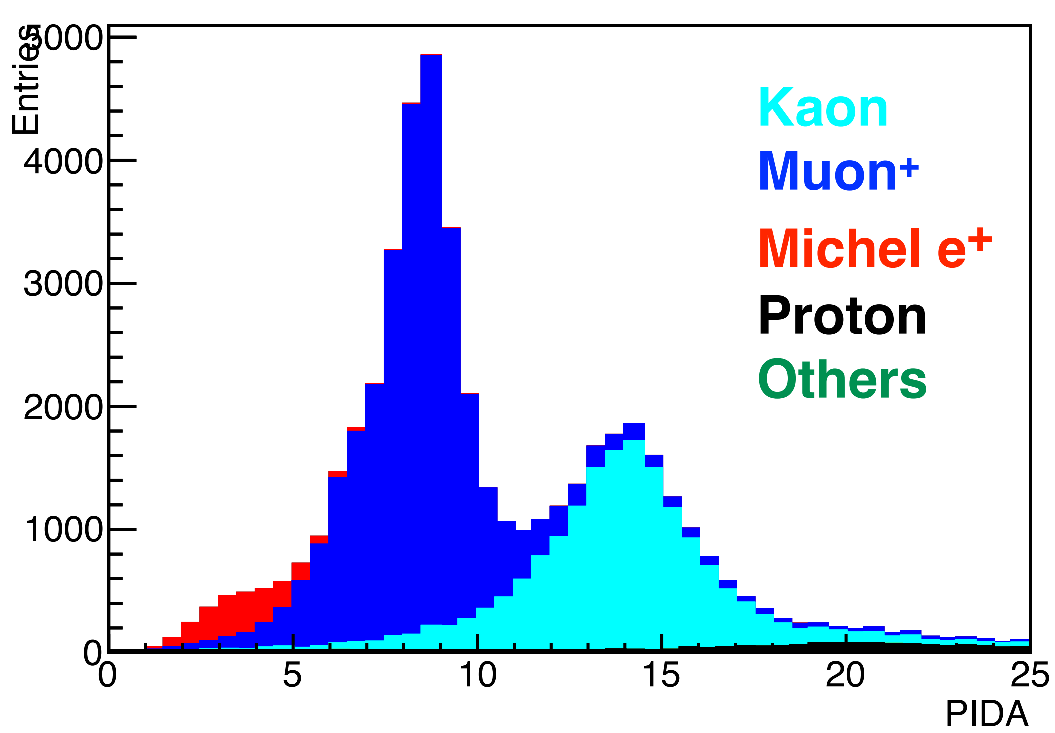
Proton Decay Analysis

Only on K → $\mu^+ + v_\mu$ events

Before using CNN



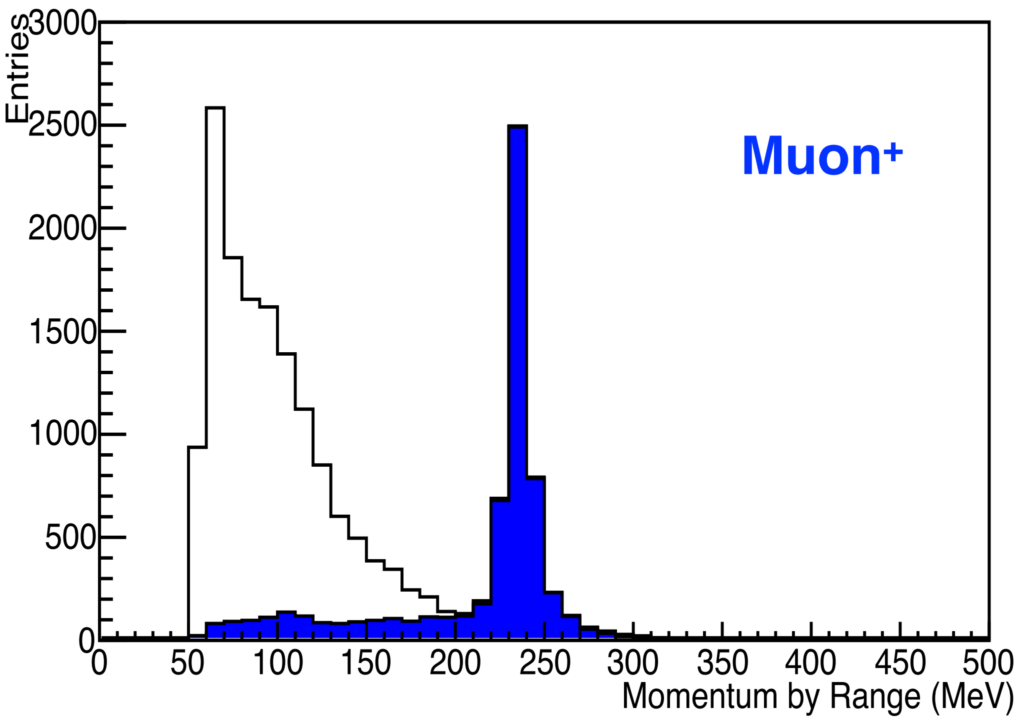
After using CNN



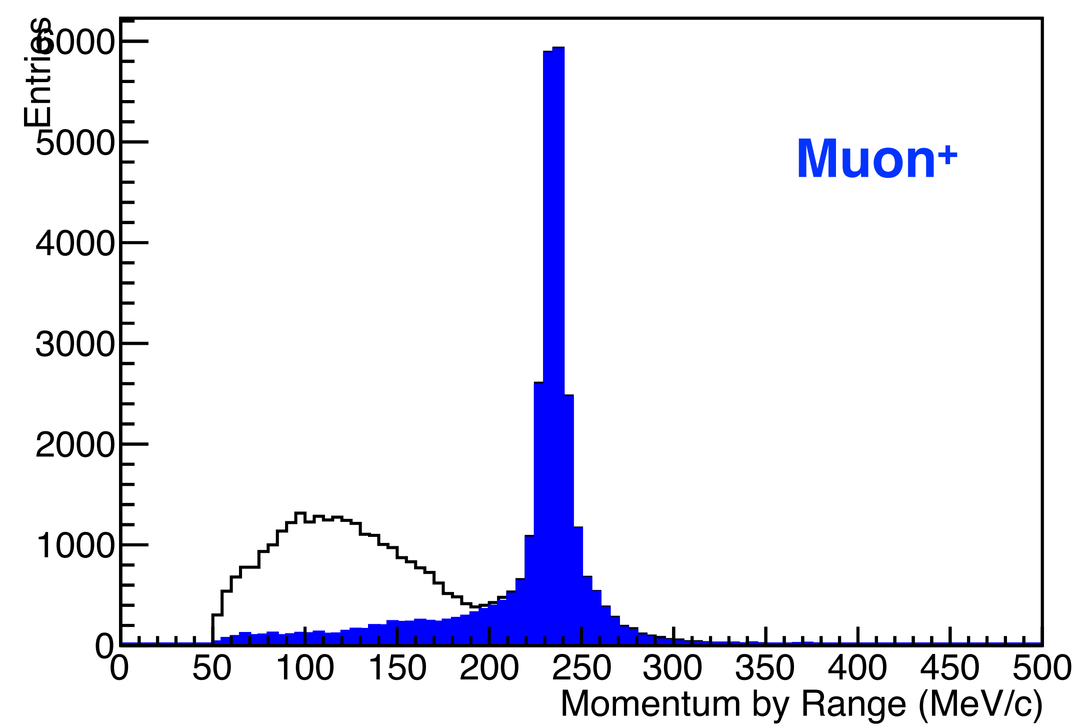
Proton Decay Analysis

Only on K → $\mu^+ + \nu_\mu$ events

Before using CNN



After using CNN



$$p_\mu = \frac{m_k^2 - m_\mu^2}{2m_k} = 239 \text{ MeV}$$

Proton Decay Analysis

TMVA

Toolkit for Multivariate Data Analysis

ROOT
Data Analysis Framework

MVA for Proton Decay

Machine learning (supervised training)

Boosted Decision Tree (BDT)

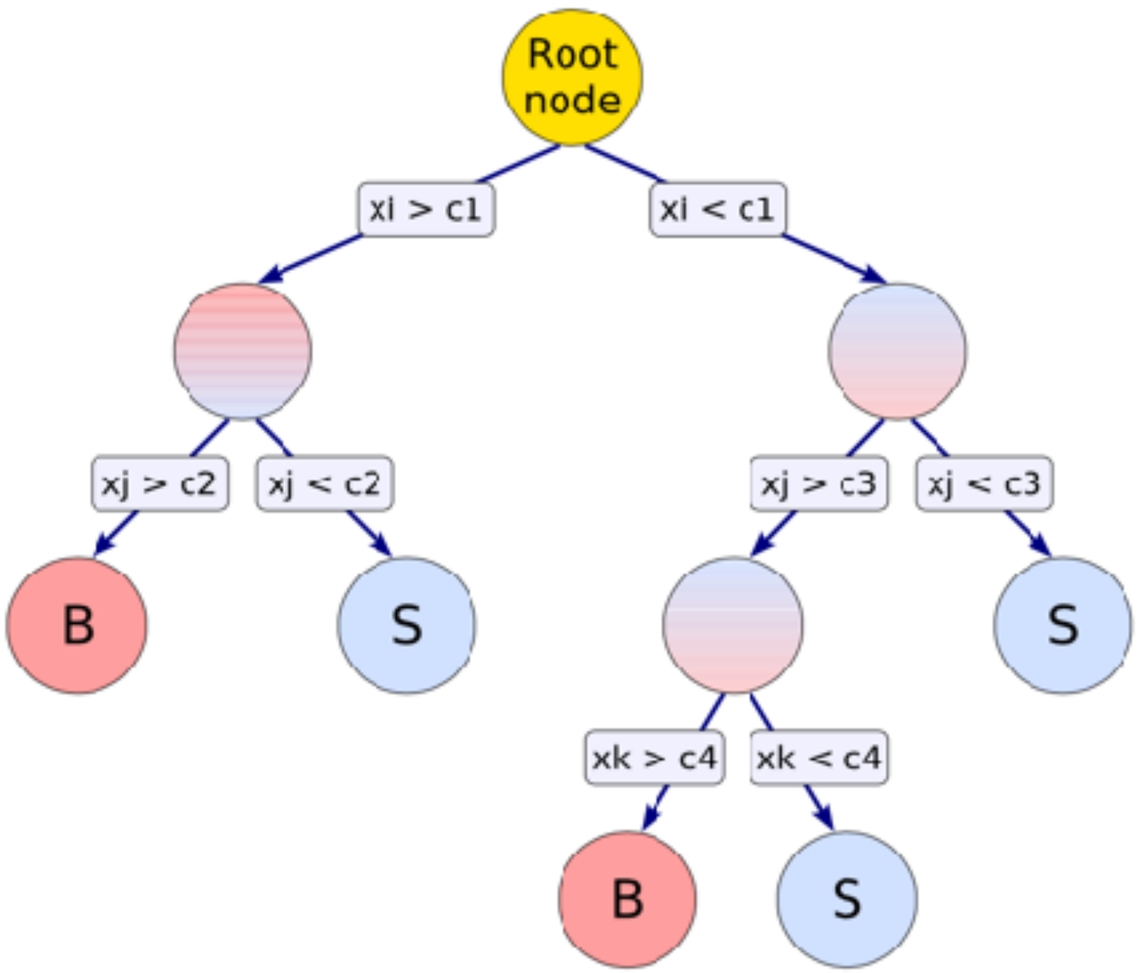
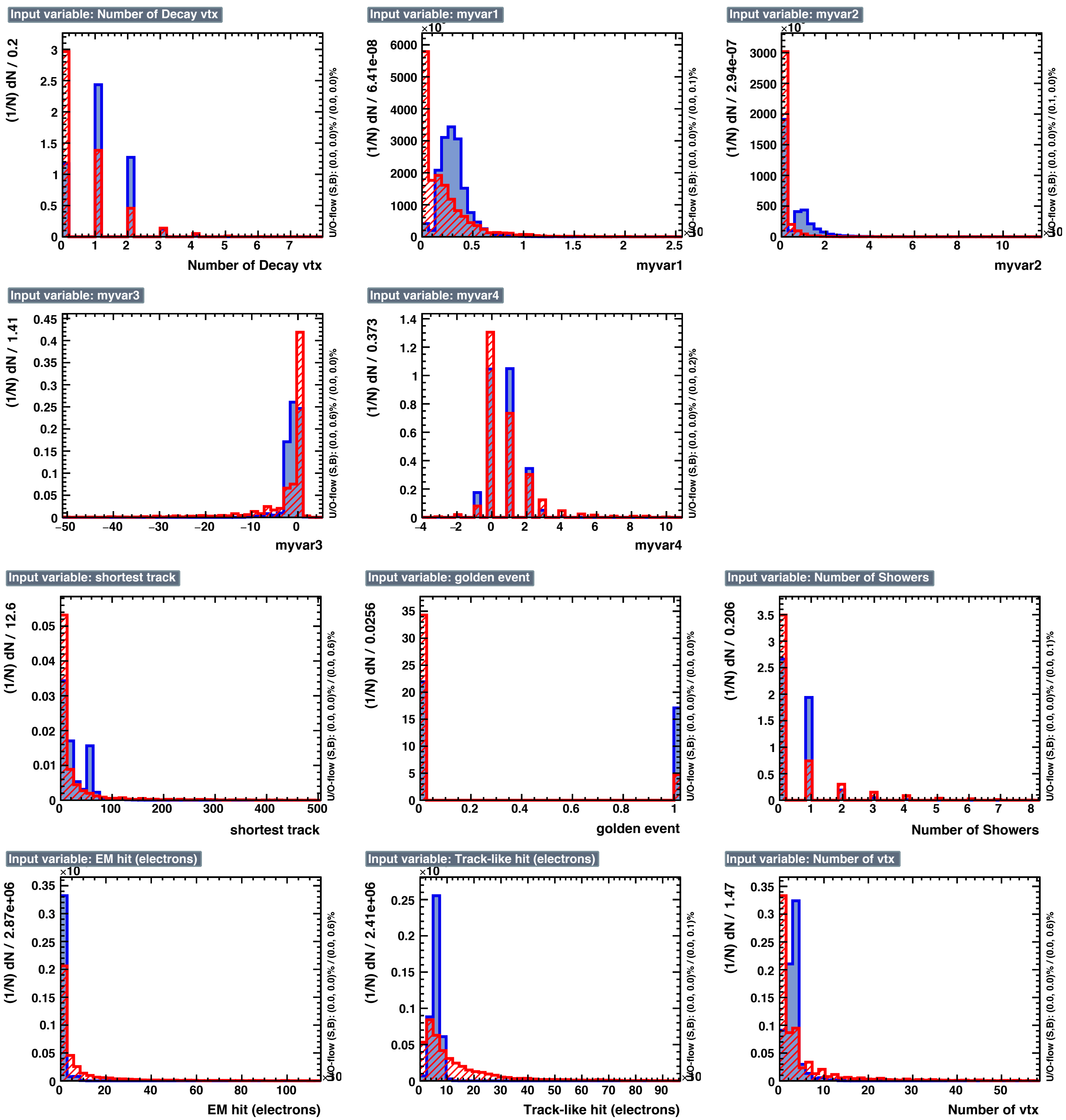


Fig. TMVA user guide

the boosting (forest)

$$O(x) = \sum_i l(\hat{y}_i, y_i) + \sum_t \Omega(f_t)$$

MVA for Proton Decay



Signal:

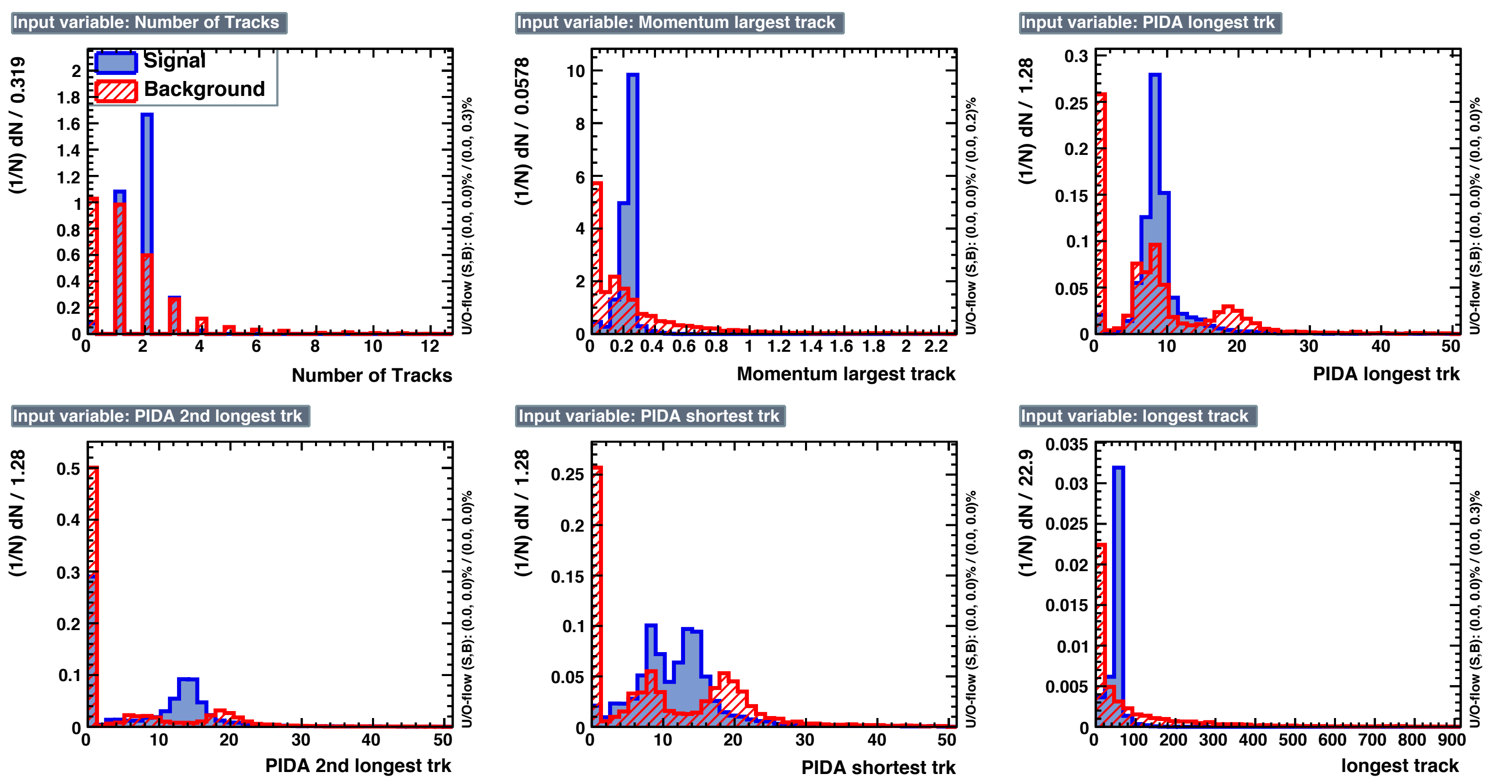
$K \rightarrow \mu^{+} + \nu_{\mu}$ events

Background:

Atmospheric events

- Number of dcy vtx
- golden event
- Track-like hits
- EM-like hits
- Number of showers
- Total shower energy
- N tracks/trk-like hits
- N showers/em-like hits
- N trks - N vtx

MVA for Proton Decay



Signal:

$K \rightarrow \mu^{+} + \nu_{\mu}$ events

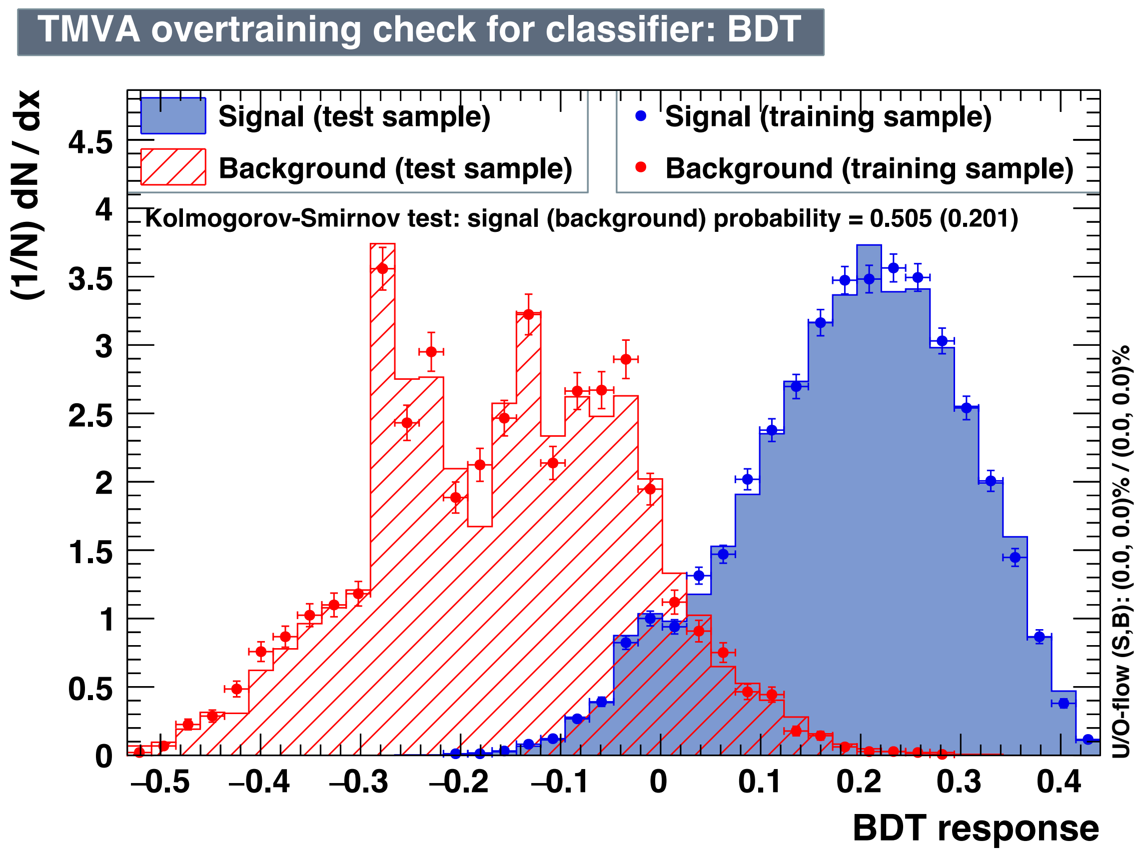
Background:

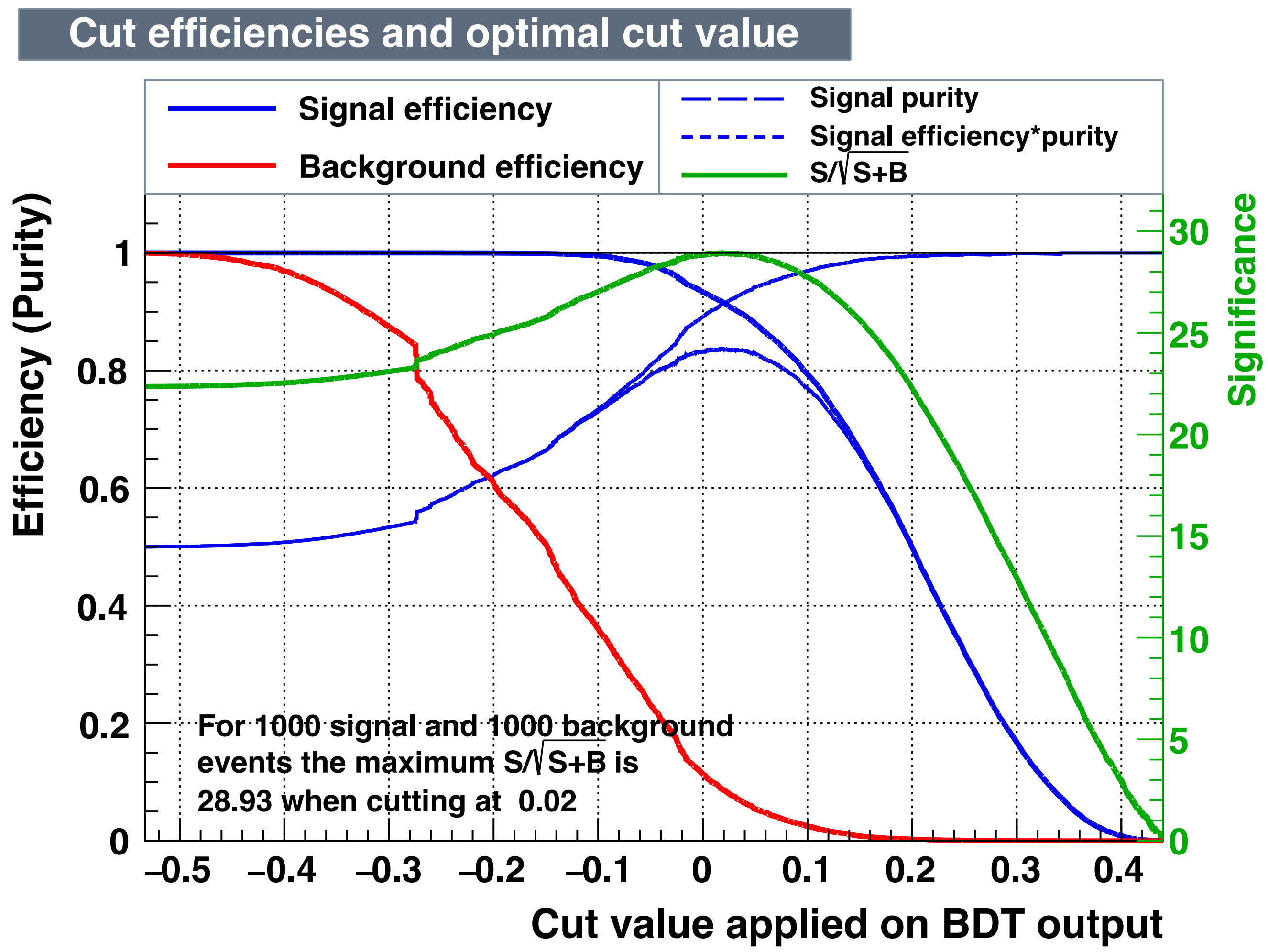
Atmospheric events

- Number of tracks
- PIDA
- Track length
- P by range

MVA for Proton Decay

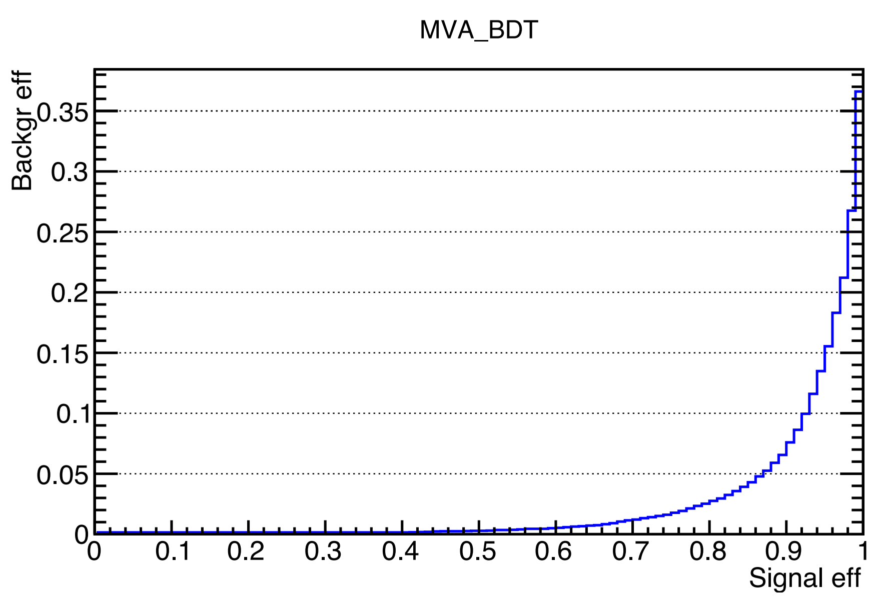
Boosted Decision Tree (BDT)

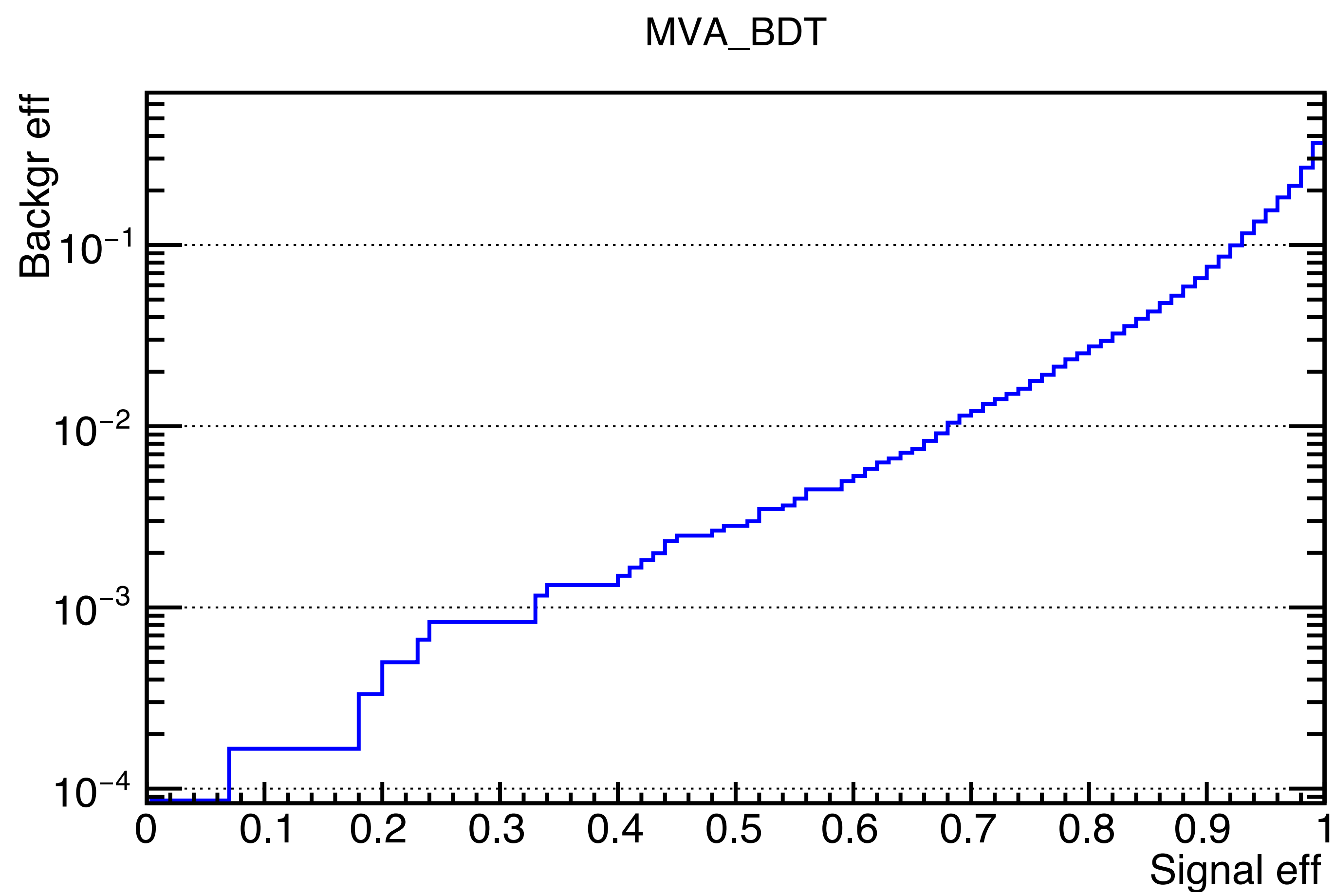




MVA for Proton Decay

Boosted Decision Tree (BDT)

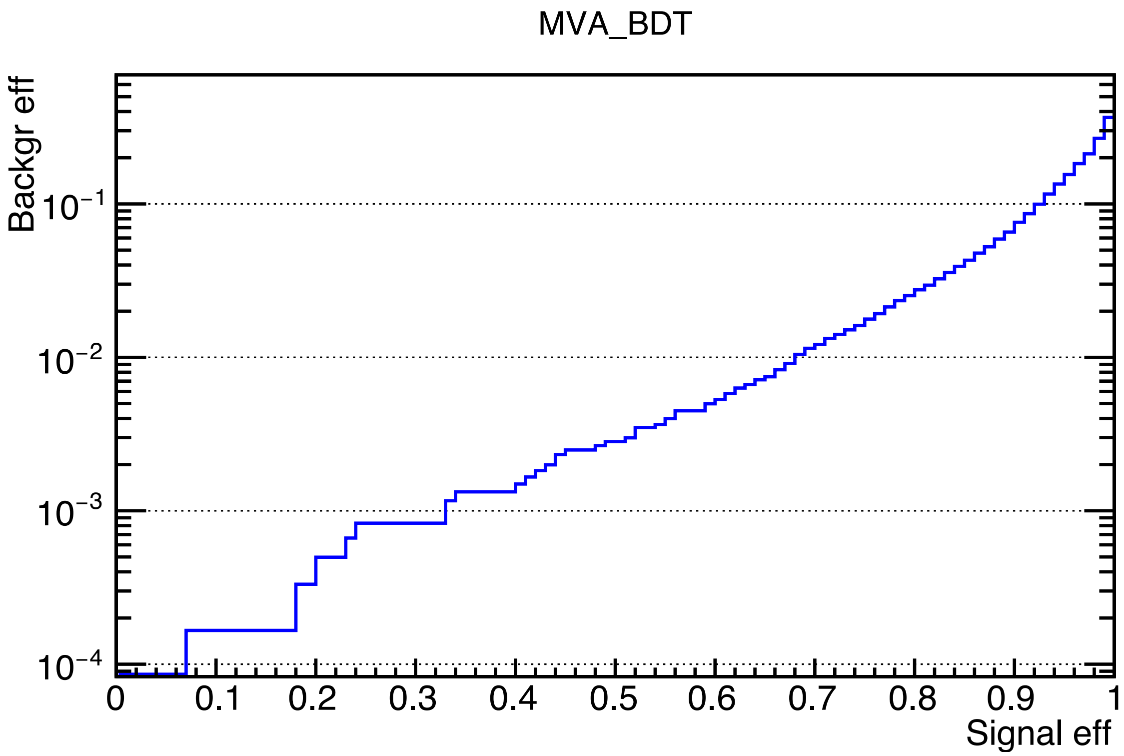




MVA for Proton Decay

Boosted Decision Tree (BDT)

Signal	Background Mton^{-1} year^{-1}
100%	2.9 x 10^5
60%	1421
50%	783
30%	232
20%	95



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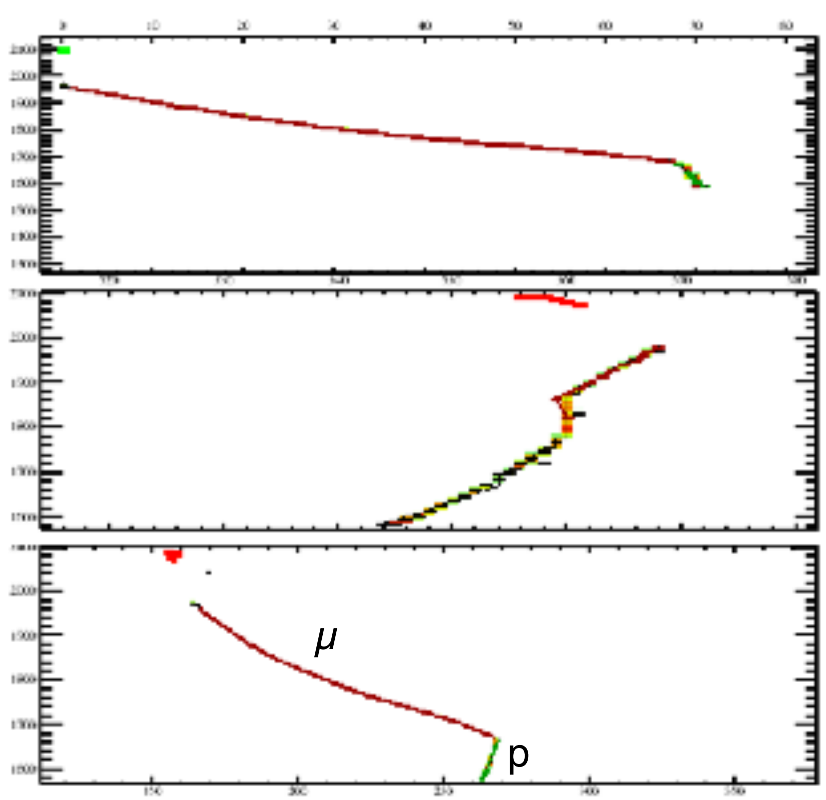
Far Detector Task Force Report

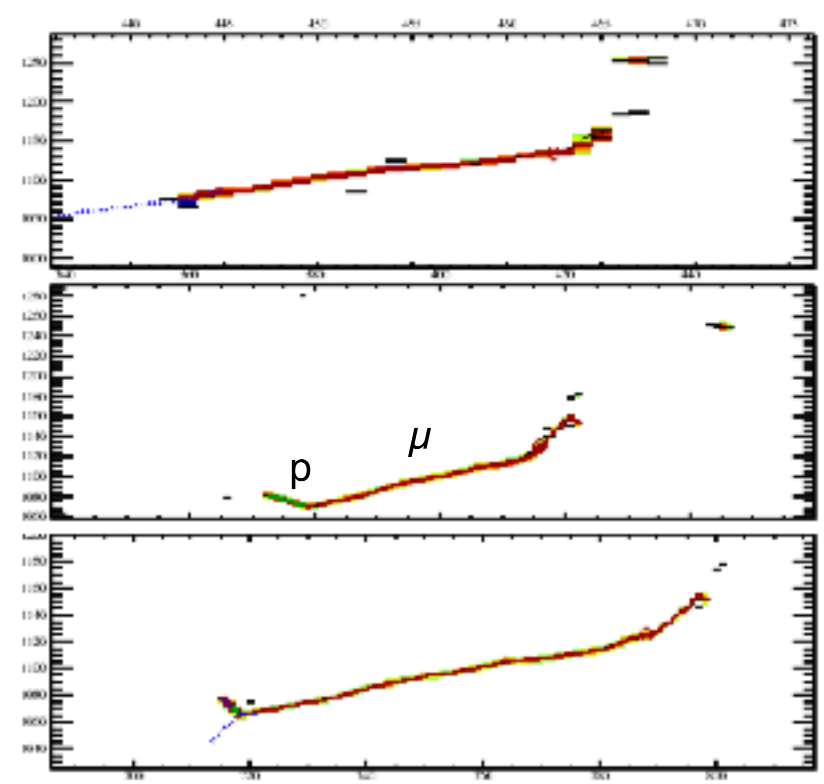
MVA for Proton Decay

Boosted Decision Tree (BDT)

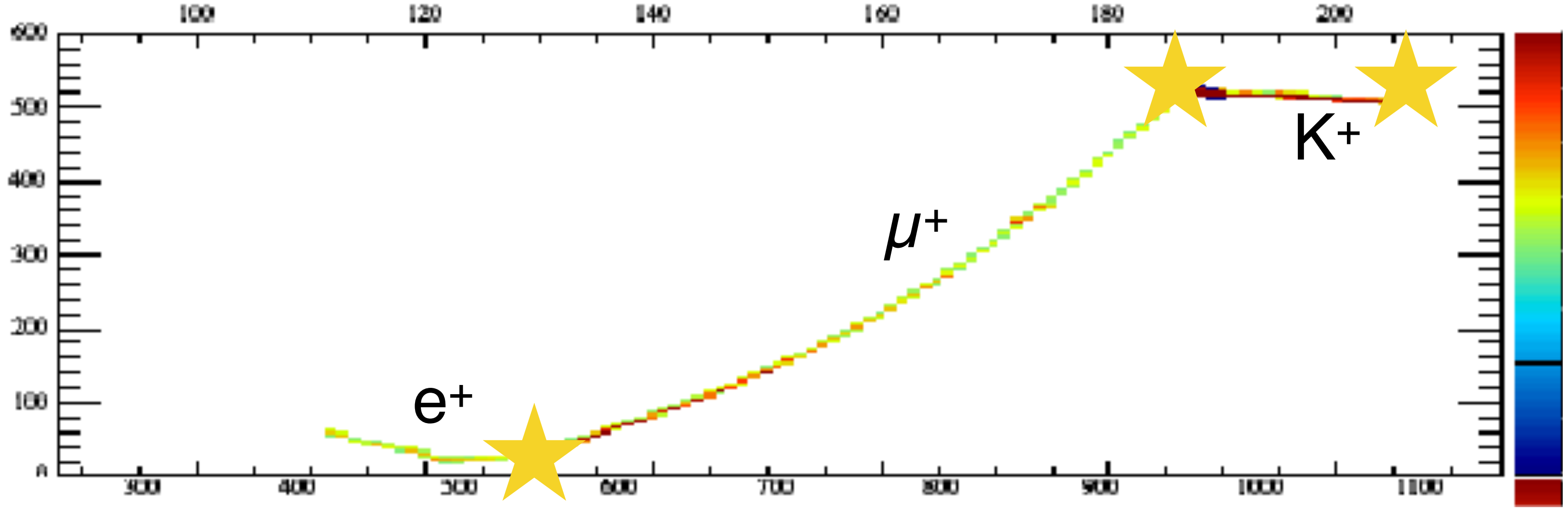
Signal	**Background Mton^{-1} year^{-1}**
100%	2.9 x 10^5
50%	**783**
20%	95

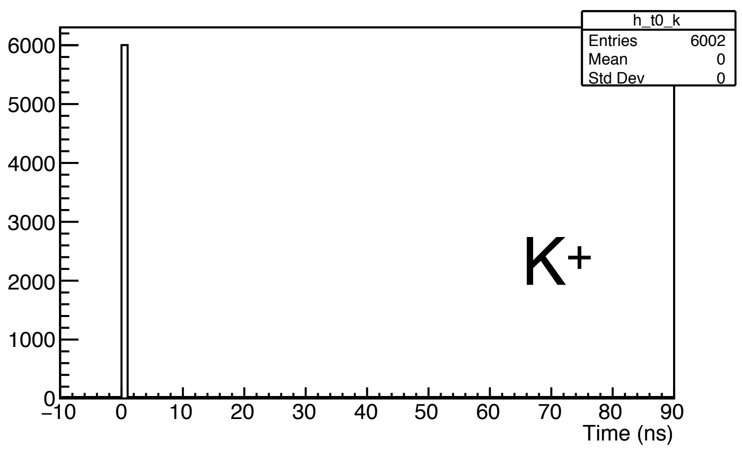
Background events are ν_μ CCQE

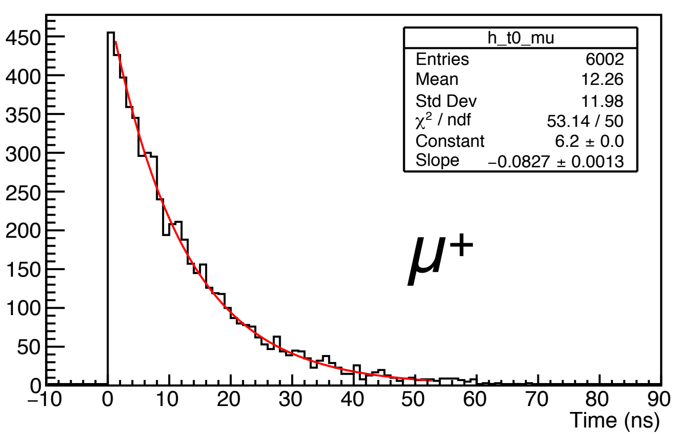


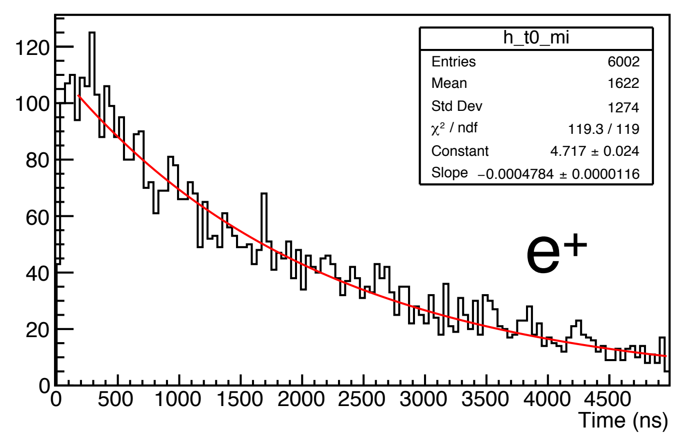


Photon Detector System & Proton Decay





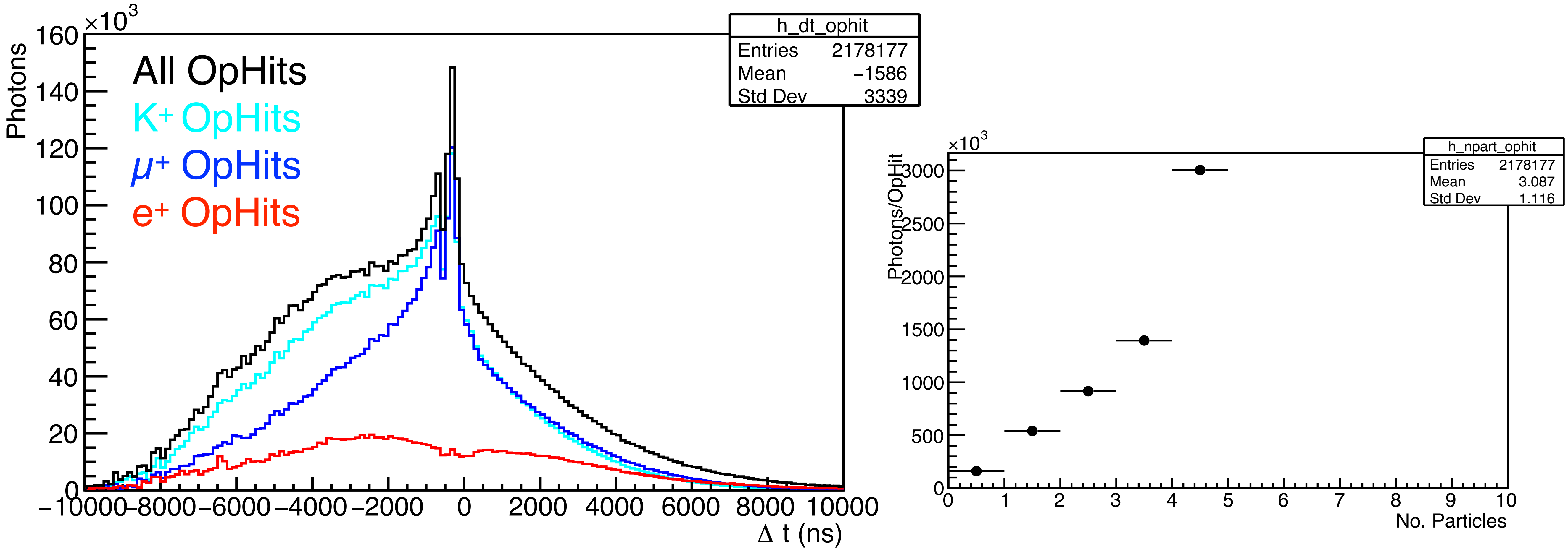




- Since the propagation of photons is much faster than the drifting of ions along the electric field light provides a references for a T0
- A PDS provides also a trigger system for non-beam events
- For a proton decay, $k^+ \longrightarrow \mu^+ \longrightarrow e^+$ a perfect PDS would have 3 “flashes” i.e. one per each decay

Photon Detector System & Proton Decay

- Optical flashes (OpFlashes) are a collection of optical hits (OpHits)
- Look at OpHit to see if we can optimize OpFlash reco for proton decay events



- The PDS cannot discriminate decays (due to timing resolution and mechanism of scintillation in LAr)

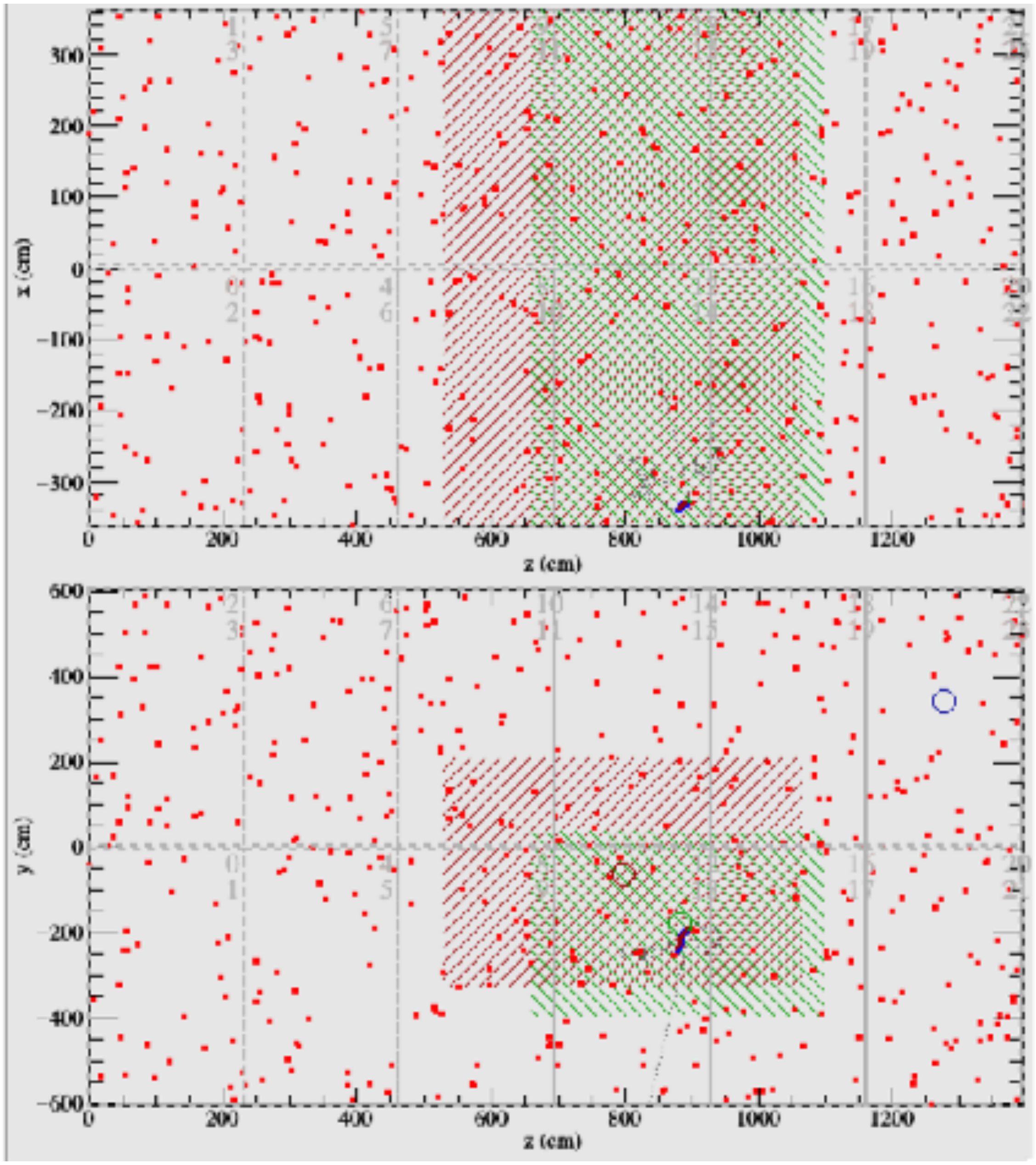
Photon Detector System & Proton Decay

- Optical flashes (OpFlashes) are a collection of optical hits (OpHits)
- Look at OpHit to see if we can optimize OpFlash reco for proton decay events

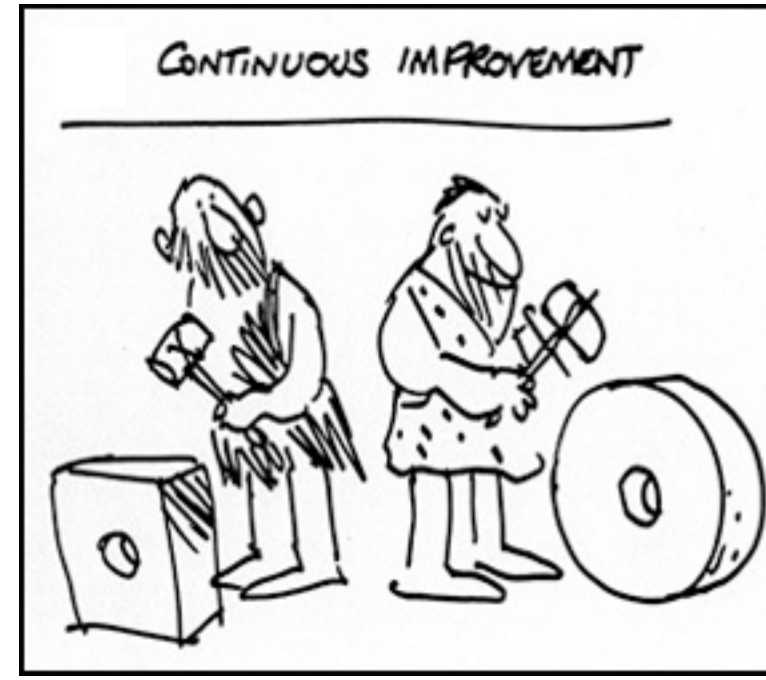
✦ Select the most intense OpFlash and require that OpFlash yz center overlap with the yz muon-like track vertex

✤ If we assume that additional radiological background is one order of magnitude below the intrinsic ^{39}Ar background at any place in the active volume of the TPC

✤ Then, from this preliminary studies it seems that we can handle ^{39}Ar background and we are cover from additional radiological background (i.e. we can search for NDK)



Comments



- We have done significant progress
- More improvements to the reconstructions are needed
  - Track reconstruction (try 2nd gen of trajcluster)
  - Decay vertex ID, improve model
  - Shower reco & shower energy (current alg doesn’t handle pretty well low energy shower)
- How far we want to go before TDR?
- Systematics? GENIE FSI
- Cosmogenic background?

The End

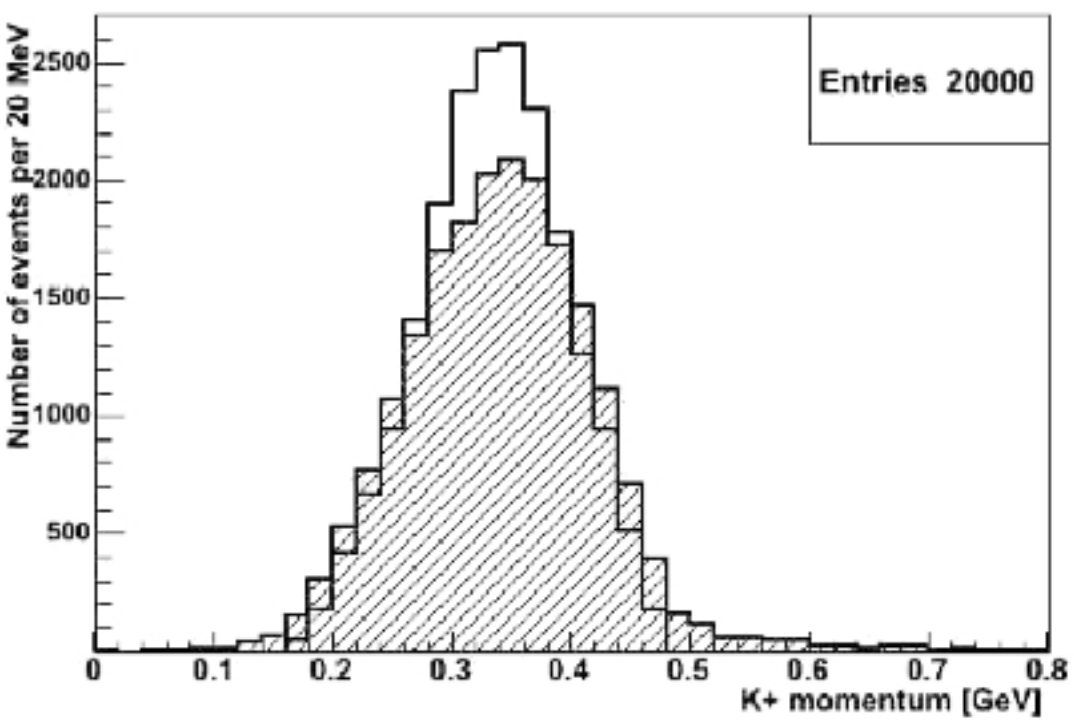
Workflow to Generate your CNN model

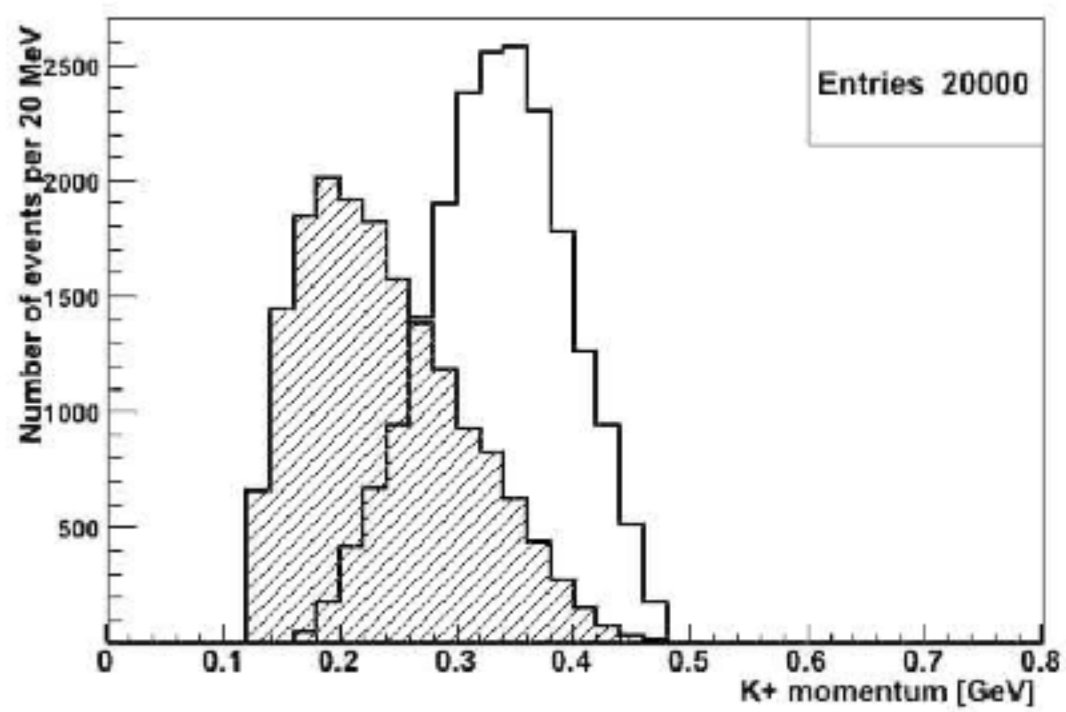
1) Generate your sample background and signal
2) Dump the ADC info for further processing and training
   Output- This would produce adc map synced with pdg map
3) Prepare data
   input: patch ~20x20cm of deconvoluted ADC
   output: vector of 3 values: [had_int decay pi0decay(gammaConv)]
4) Training your model
   GPU machine, *thanks to Center for Advance Computing & Data Systems UH*
5) Dump Keras model into a pure C++ model
6) Run ParticleDecayId_module.cc
   Uses hits and spacepoints from track with CNN info to produces vertices

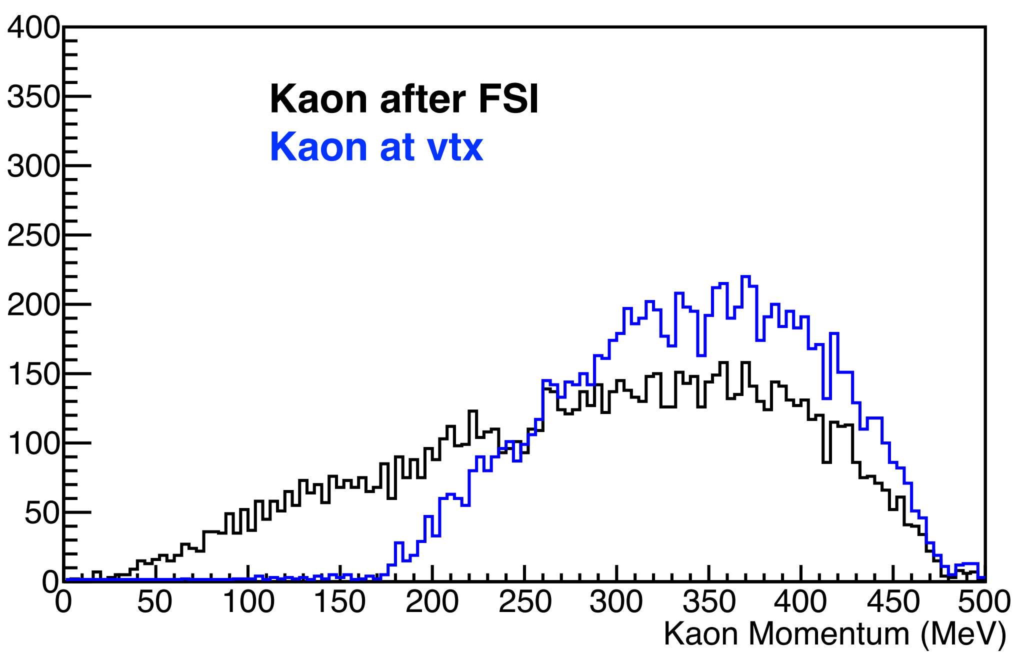
K+ and LAr

- Kaon-nucleus

D. Stefan, Artur M. Ankowski
Acta Physica Polonica B Vol. 40 (2009)







- Fluka & GEANT4 simulation
- Fermi vs Spectral Functions
- Bertini cascade model w &w/o
- 2.0 % of K are lost due charge exchange
- Overall the result is similar to GENIE