Proton reconstruction in protoDUNE

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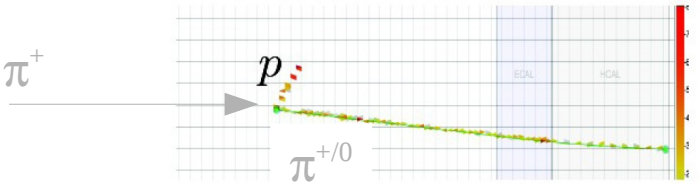
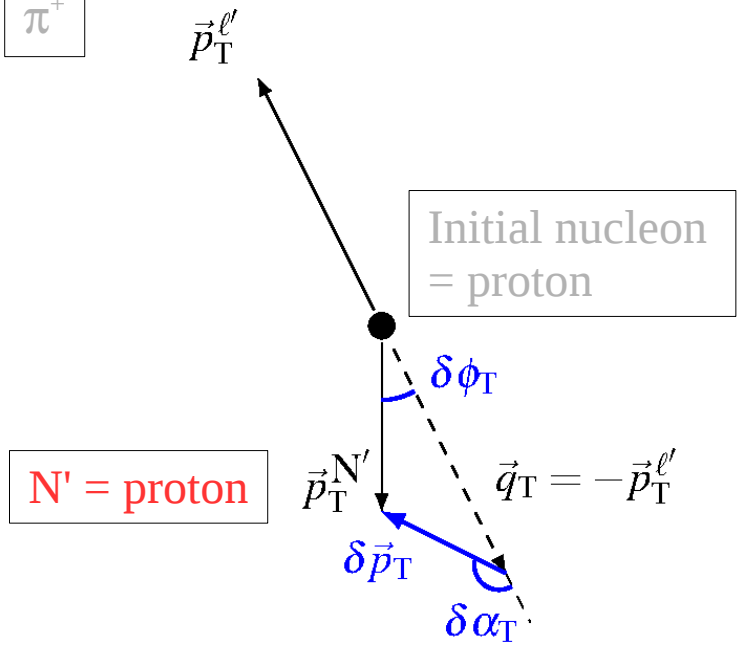
2020 June 4
ProtoDUNE Analysis Meeting

TKI + protoDUNE
– Proton/Neutro initial-state kinematics



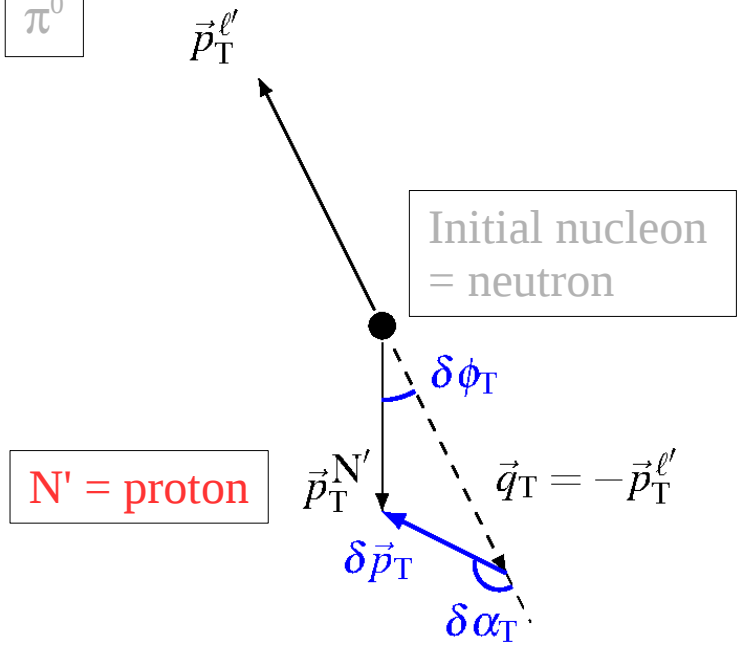
Recap https://indico.fnal.gov/event/43430/

π^+



- Proton Fermi motion observed
- 218 phase-space cut exclusive events / 3263 pi+ beam events = 6.7%

π^0



- Neutron Fermi motion observed
- 260 phase-space cut exclusive events / 3263 pi+ beam events = 8.0%

- Impose kinetic energy threshold for p π+
- require exactly 1 proton above threshold (=remove events with subleading proton above threshold)

Recap

Data set:

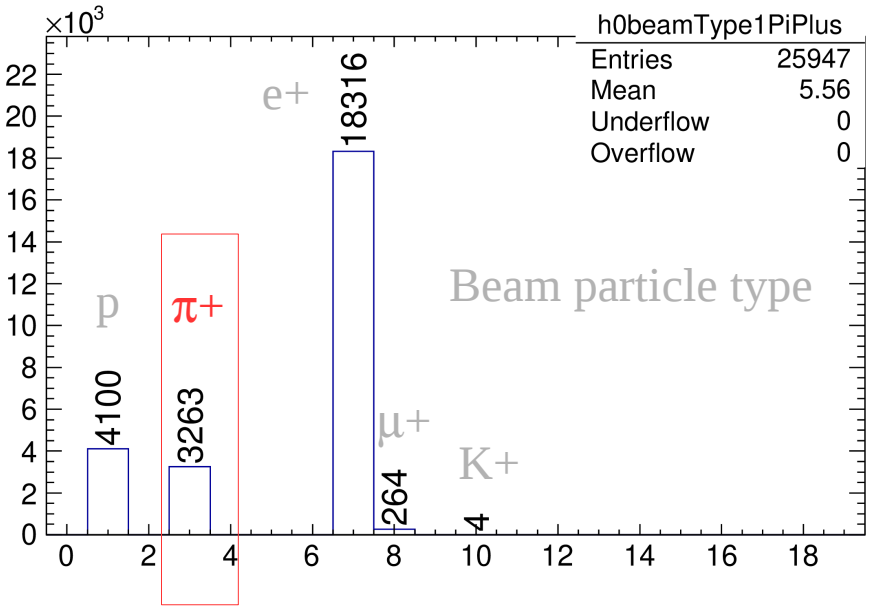
calcuttj_PDSPProd2_MC_1GeV_reco_sce_datadriven_forced_reco

3447 out of all 3486 files finished without error

statistics: the total merged file size is 381M. The merged tree has 25947 entries.

The following **true-level** variables are used:

```
vector<int> *true_beam_daughter_PDG=0x0;
vector<double> *true_beam_daughter_startPx=0x0;
vector<double> *true_beam_daughter_startPy=0x0;
vector<double> *true_beam_daughter_startPz=0x0;
double true_beam_endPx = -999;
double true_beam_endPy = -999;
double true_beam_endPz = -999;
int true_beam_PDG   = -999;
```



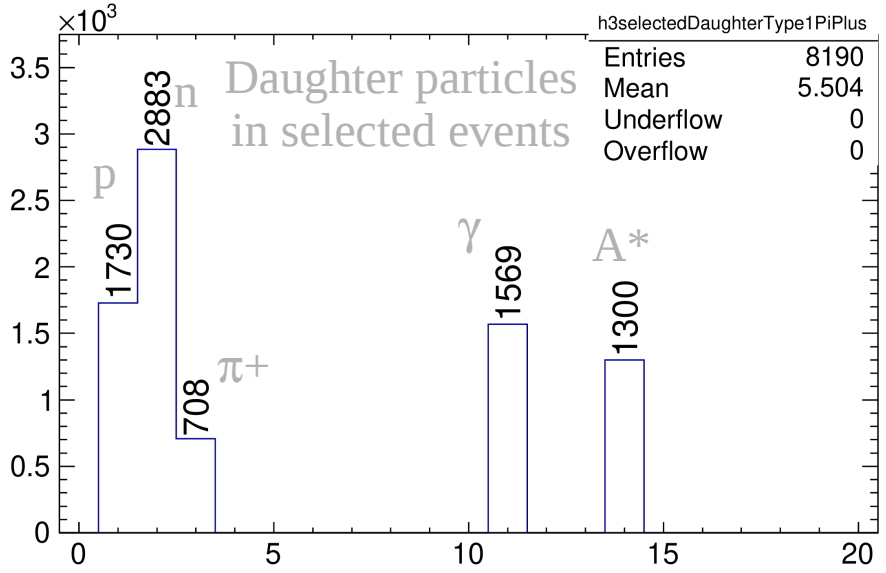
Purpose of this feasibility study:

- Figure out signal definition
- Estimation statistics

3263 pi+ beam events
(3263/25947 = 12.6%)

Q: are these true events AFTER reconstruction?
(That is, already suppressed by 1-efficeincy?)

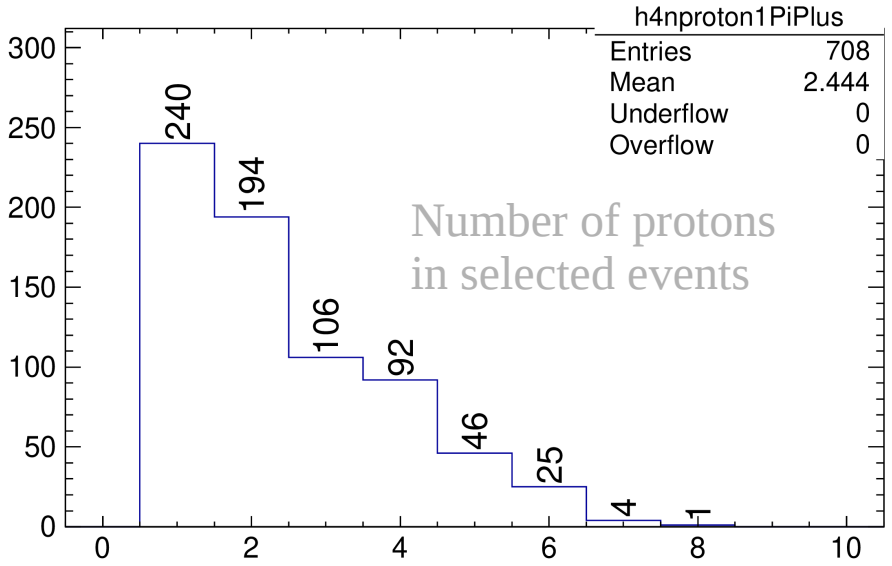
Recap

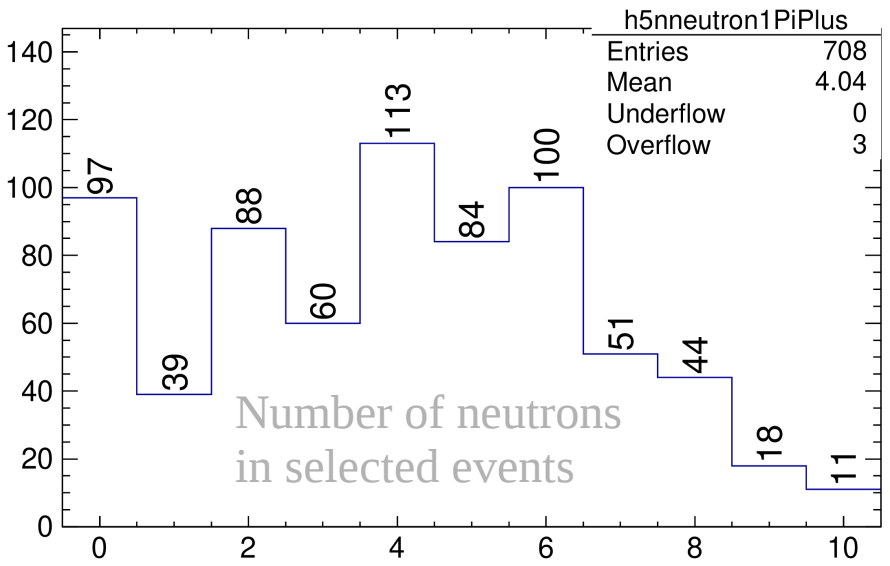


Exclusive pπ+ event selection:

- At least 1 proton (leading proton kinematics used in calculation)
- Exactly 1 π+, no other pions
- Don't care about neutron, gamma, nucleus
- Phase space cut (to be added after a few slides)

→ 708 pπ+ events selected (708/3263= 22%)





Purpose of this study:

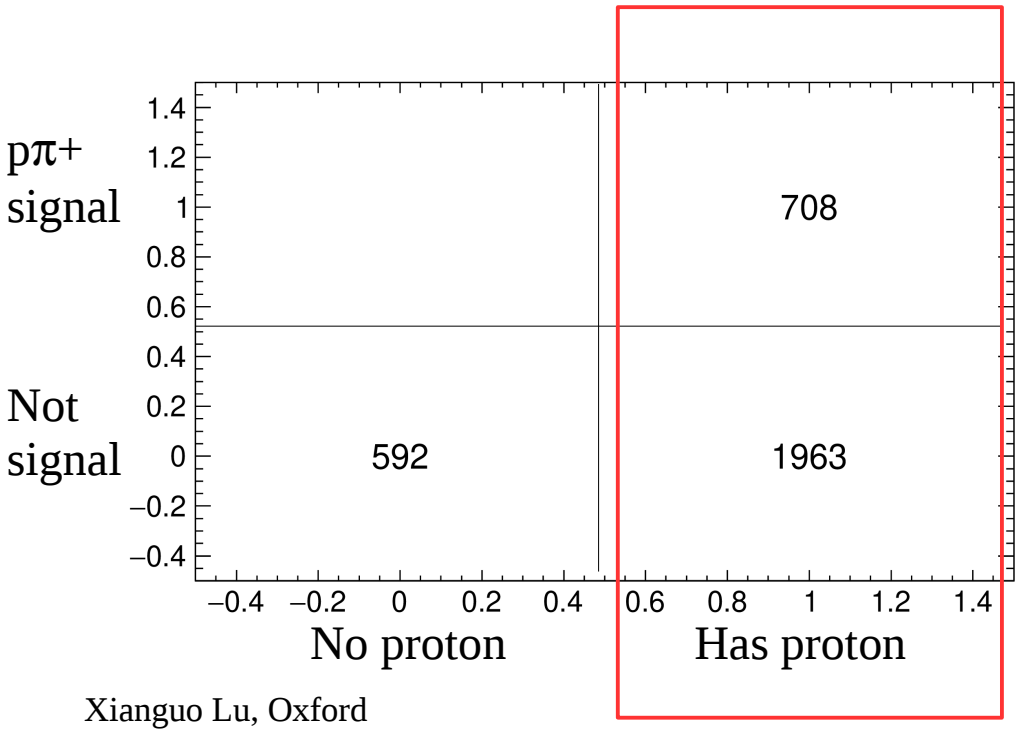
- Check proton reconstruction efficiency and momentum resolution
- Try to improve momentum resolution with ESC proton selection

Data set:

calcuttj_PDSPProd2_MC_1GeV_reco_sce_datadriven_forced_reco

The following **reco-level** variables are used:

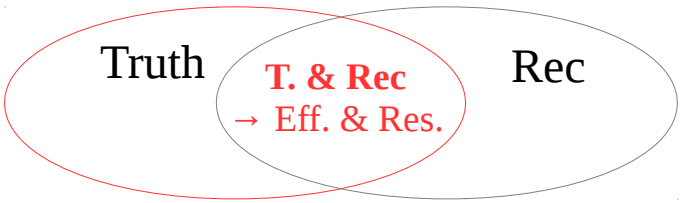
```
vector<int>* true_beam_daughter_ID = 0x0;
vector<int>* reco_daughter_PFP_true_byHits_ID = 0x0;
vector<int>* reco_daughter_allTrack_ID = 0x0;
vector<double>* reco_daughter_allTrack_momByRange_proton = 0x0;
vector<vector<double> >* reco_daughter_allTrack_calibrated_dEdX_SCE = 0x0;
```

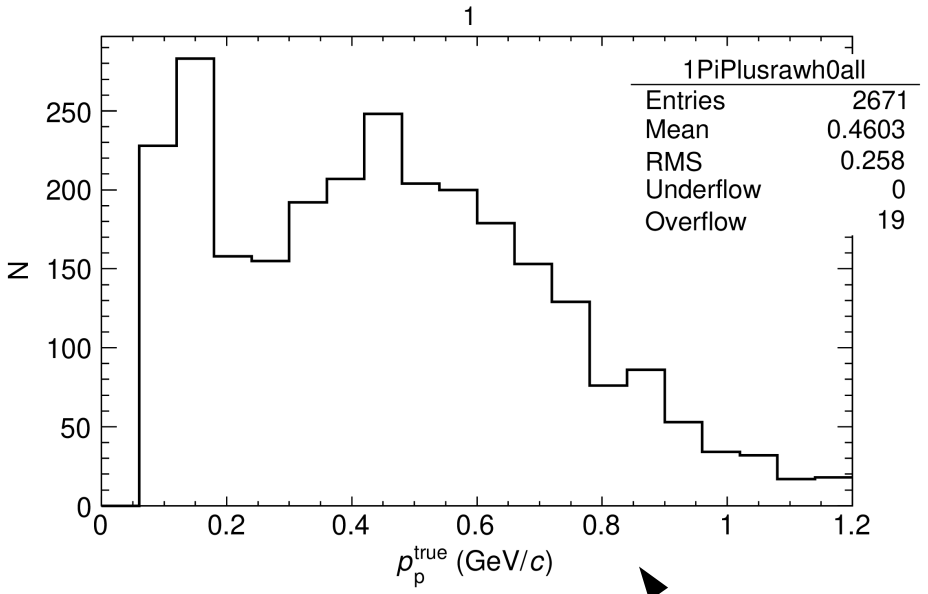


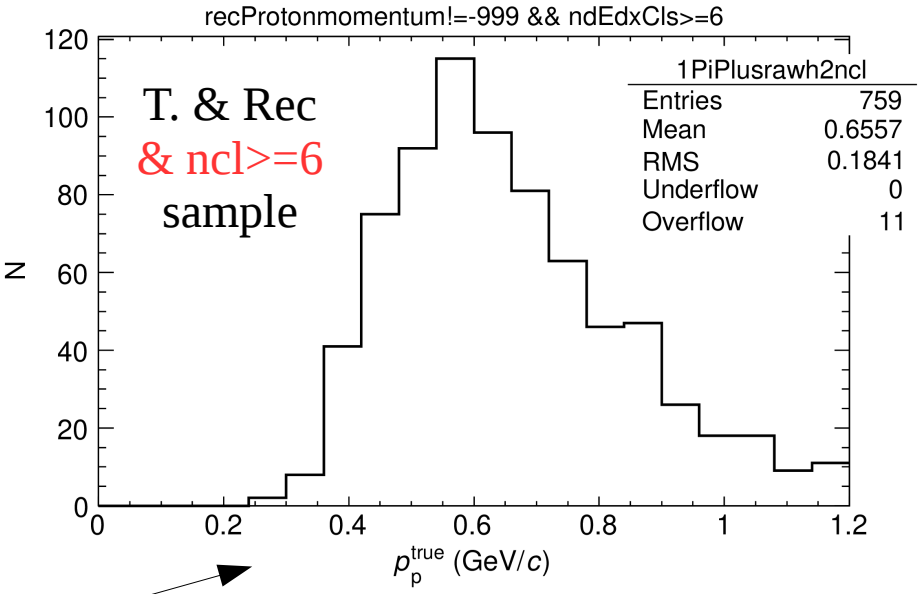
3263 pi+ beam events
(3263/25947 = 12.6%)

2671 events have protons
(2671/3263 = 82%)

Look into proton true sample, find the reconstructed protons



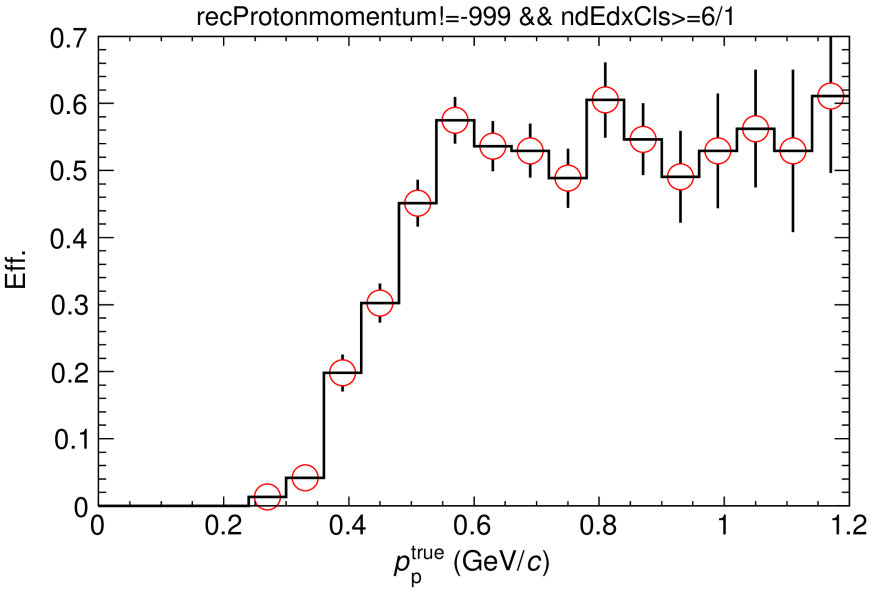


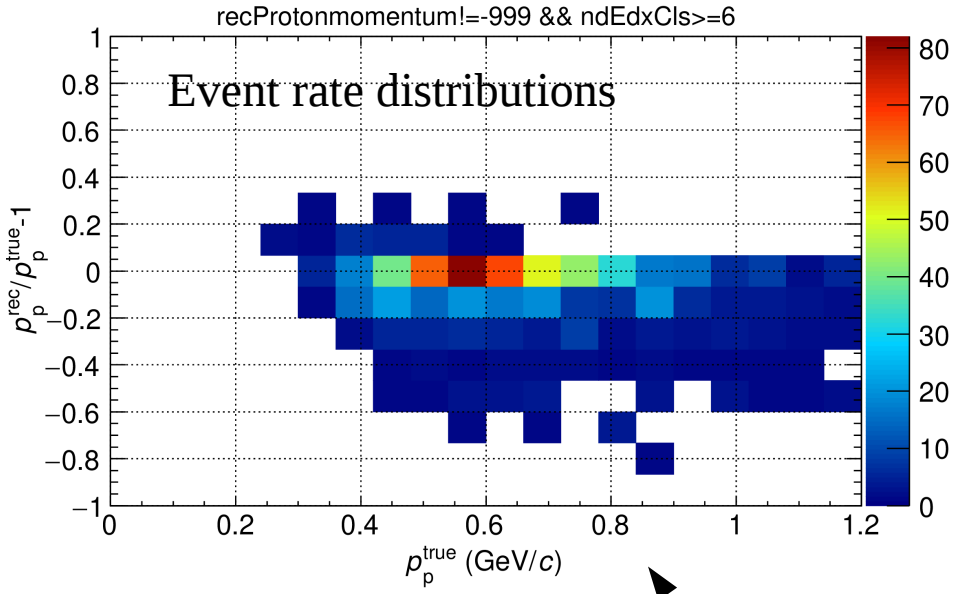


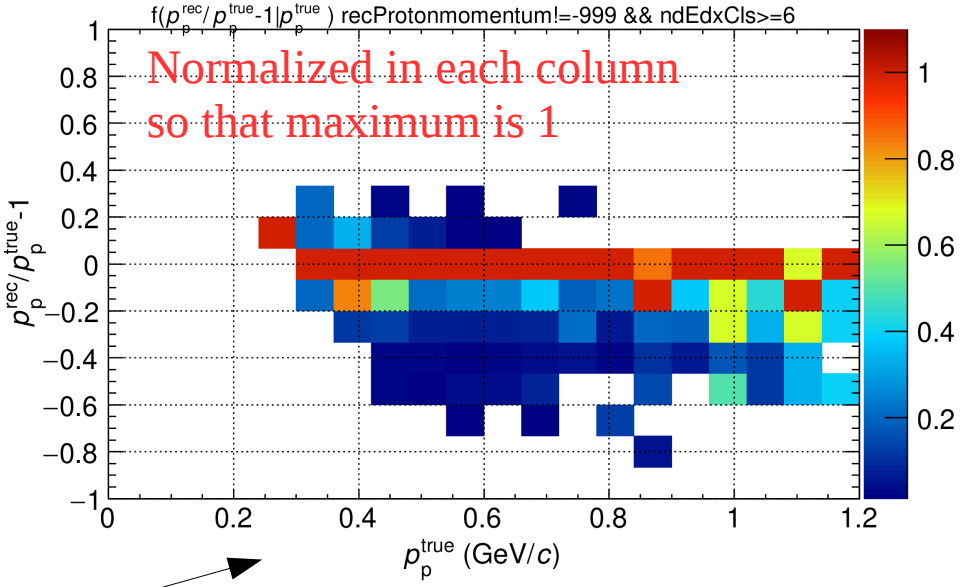
True leading proton momentum distribution

- Require number of dEdx cluster >= 6
  (motivation see later slides)

  Reconstruction efficiency
  - Onset at 0.2 GeV/c
  - Saturates at 55% from 0.5 GeV/c



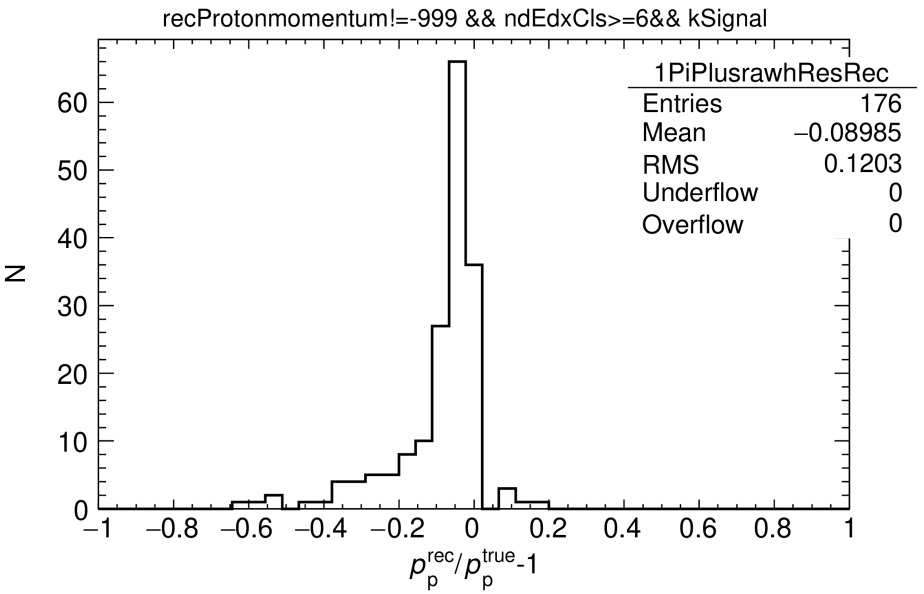




T. & Rec & ncl>=6 sample:
Resolution for leading proton momentum as a function of truth momentum

T. & Rec & ncl>=6 & signal sample:
“Integrated” resolution

- 9% bias
- 12% RMS

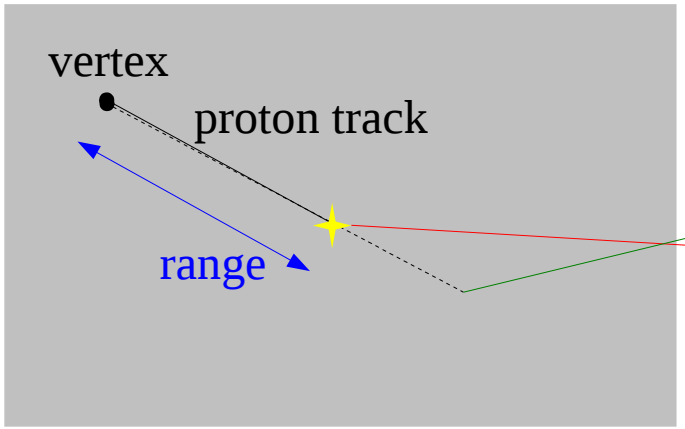


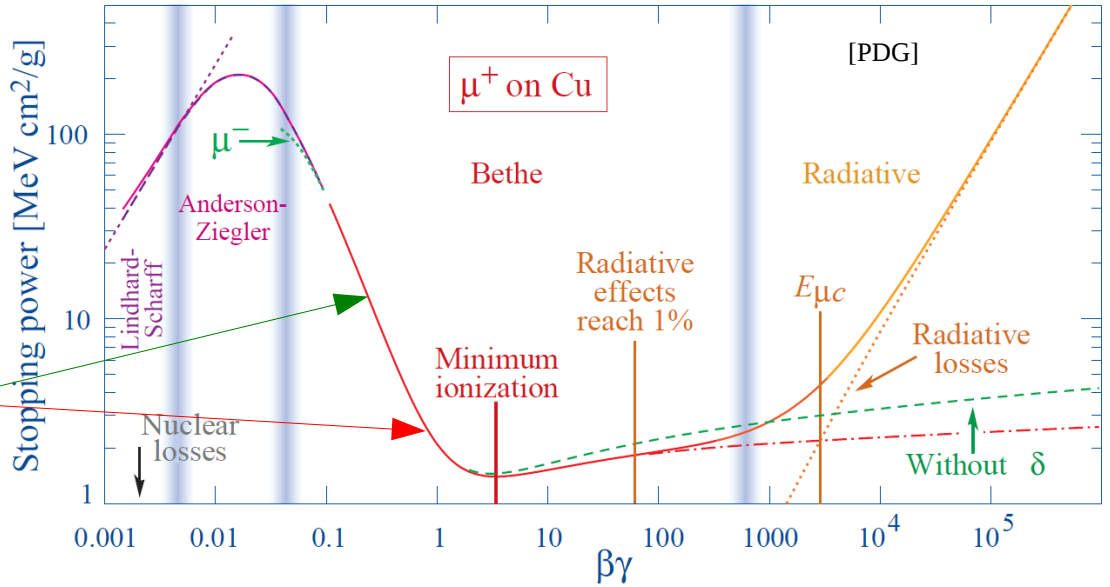
Event Selection

MINERvA Archive

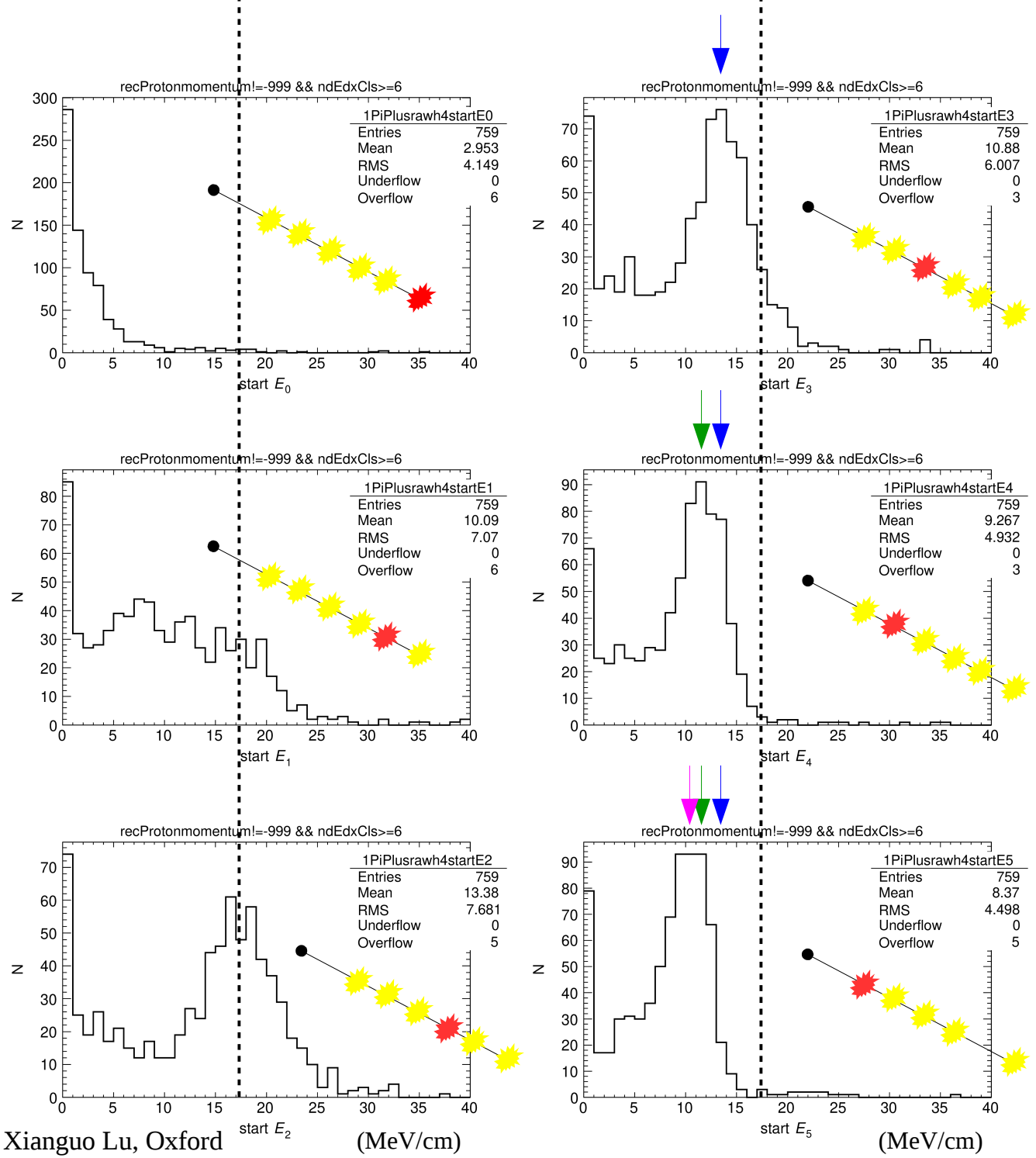
- One muon candidate track matched to a MINOS track
- At least one proton candidate (particle identification using dE/dx along the track)
  - Elastically Scattered Contained (ESC) proton selection → new development
- Vertex in tracker
- Michel electron (from pion-muon-electron decay chain) tag to remove pion production
- Cut on energy far from vertex (unattached visible energy) to remove events with untracked pions

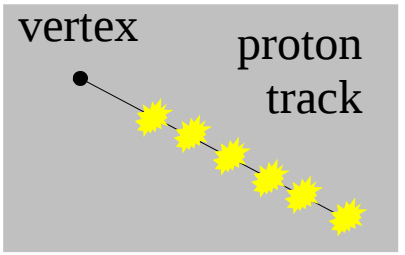
Homogeneous non-magnetized tracker
Momentum by range





Proton stopped on the fly have smaller dE/dx
→ Cut on dEdx from track end point

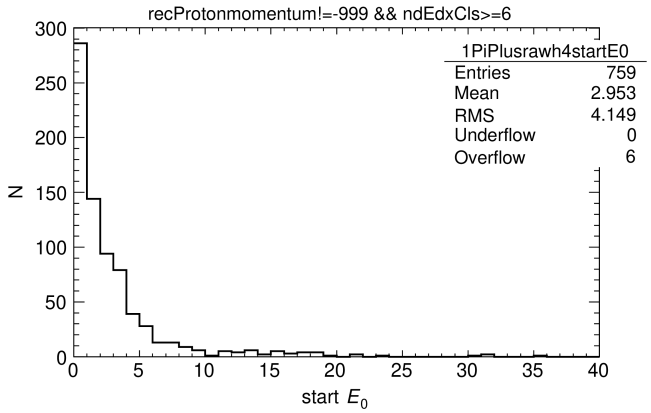


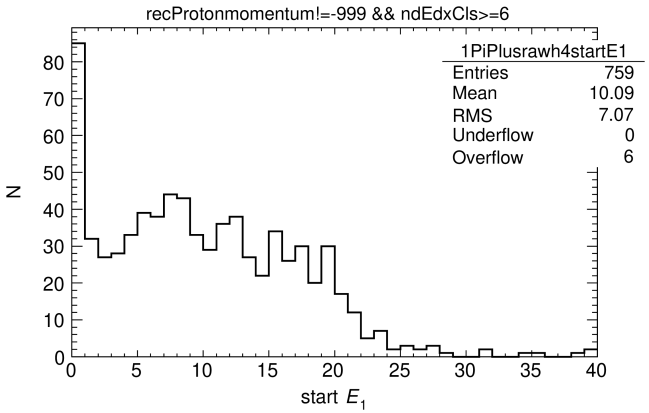


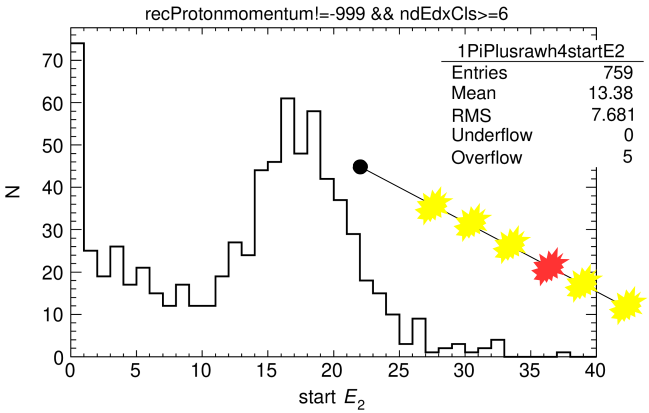
E0 and E1 look “weird” due half-dead proton not traversing the full “cluster length”

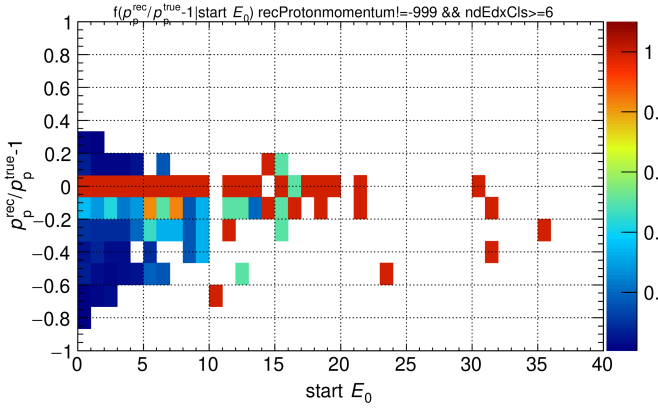
(MeV/cm) (MeV/cm)

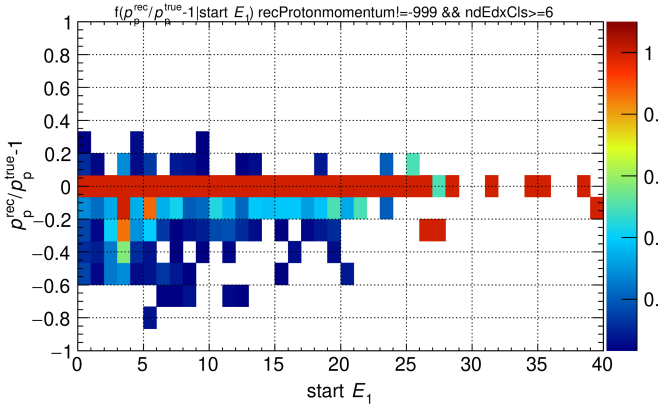
T. & Rec & ncl>=6 sample:
Resolution for leading proton momentum as a function of startE0,1,2

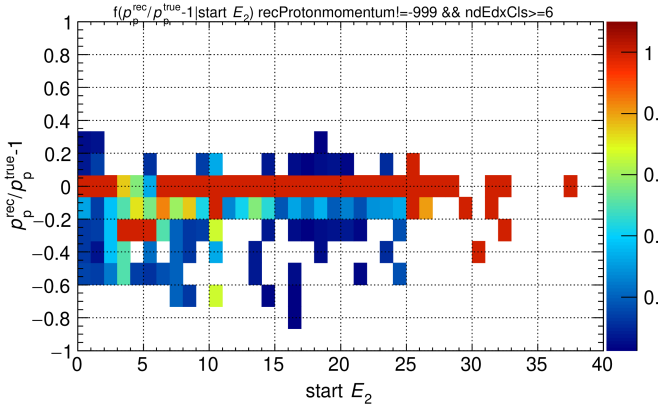




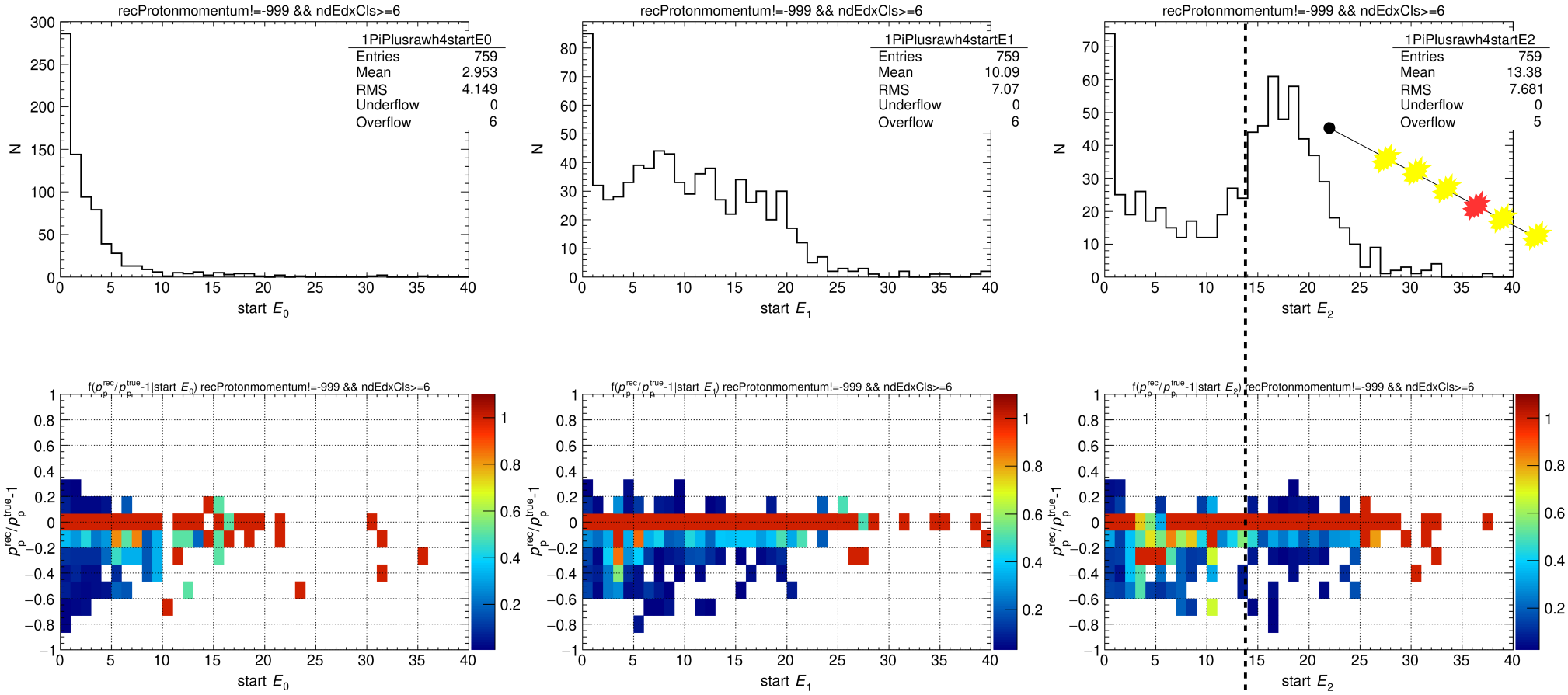








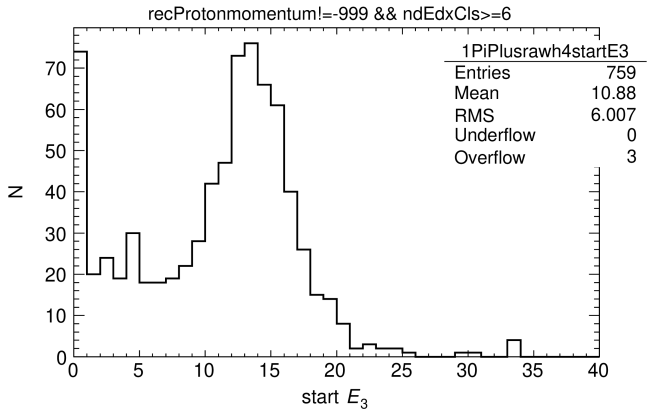
T. & Rec & ncl>=6 sample:
Resolution for leading proton momentum as a function of startE0,1,2

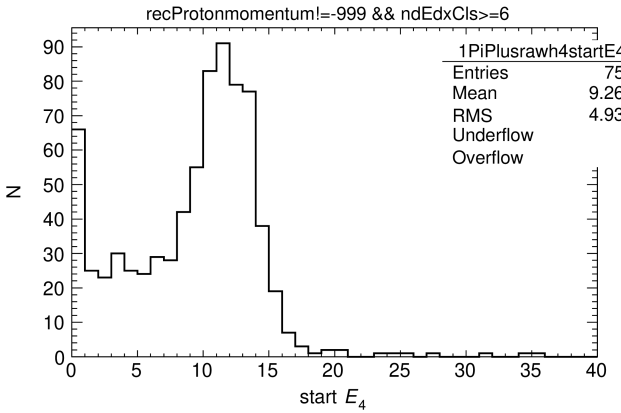


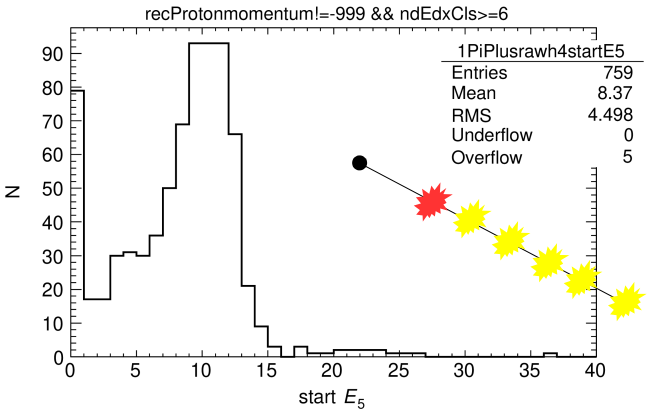
Can require startE2 > 10 to improve resolution

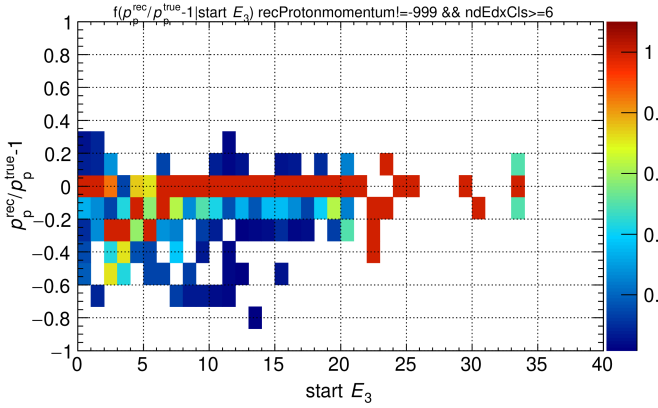
Bad | Good
resolution

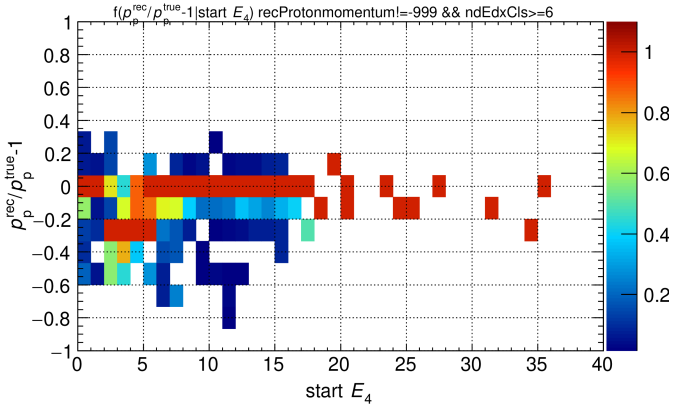
T. & Rec & ncl>=6 sample:
Resolution for leading proton momentum as a function of startE3,4,5

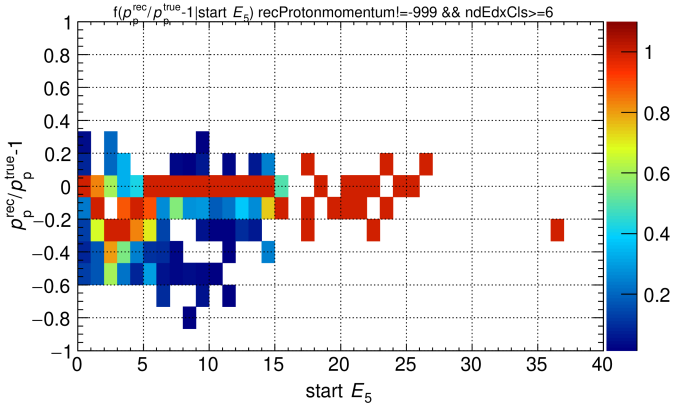




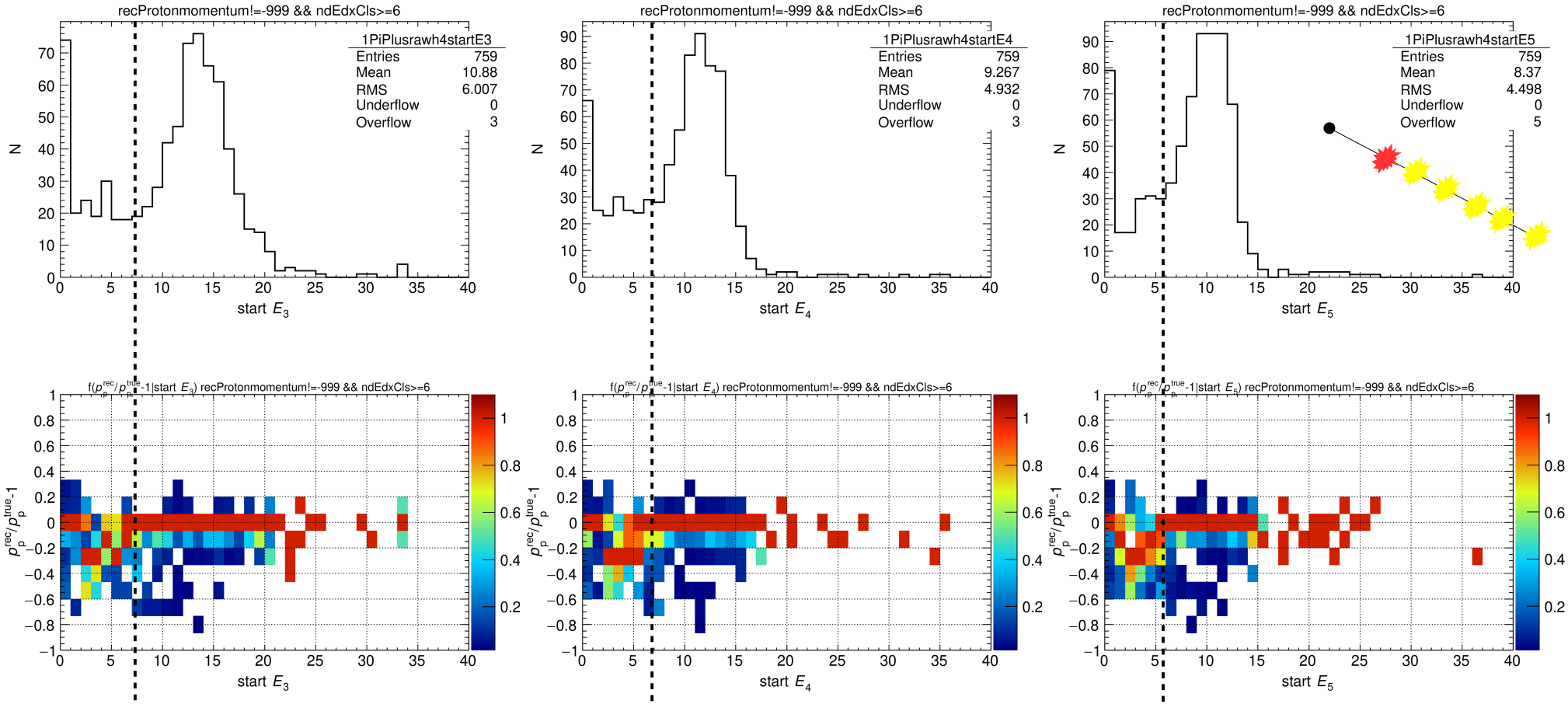








T. & Rec & ncl>=6 sample:
Resolution for leading proton momentum as a function of startE3,4,5



Bad resolution | Good

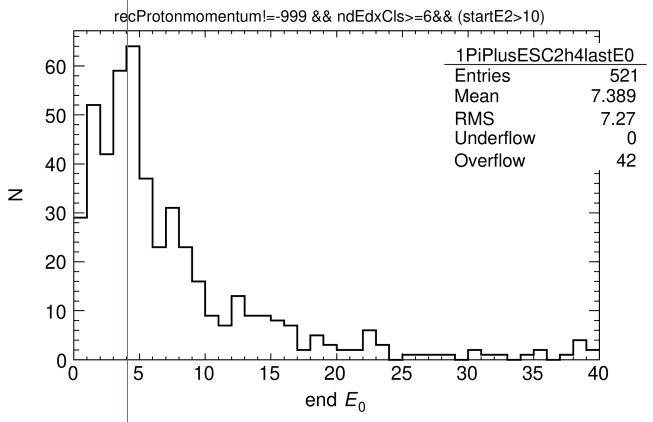
Bad resolution | Good

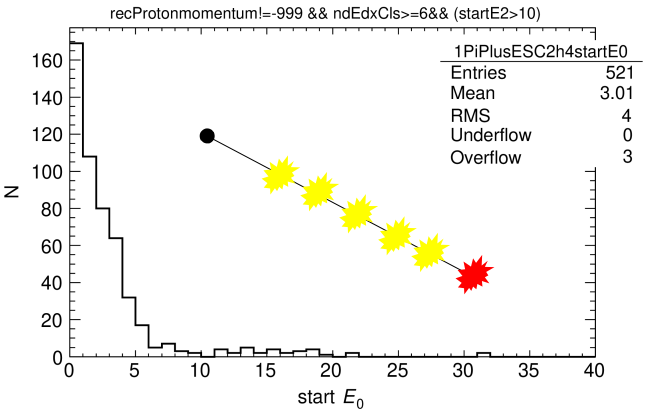
Bad resolution | Good

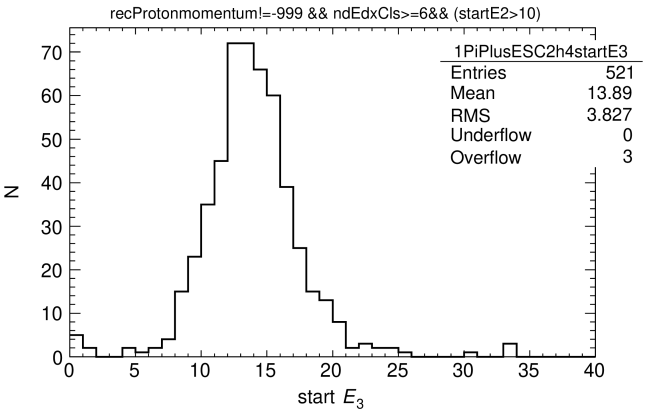
Events with low dEdx at track end all have bad resolution

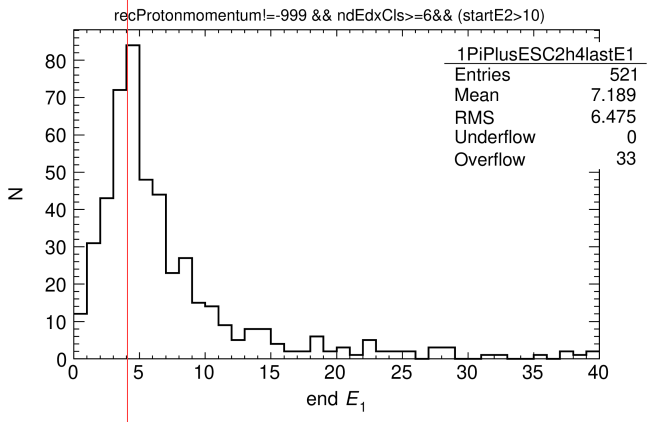
Start of track endE0,1,2

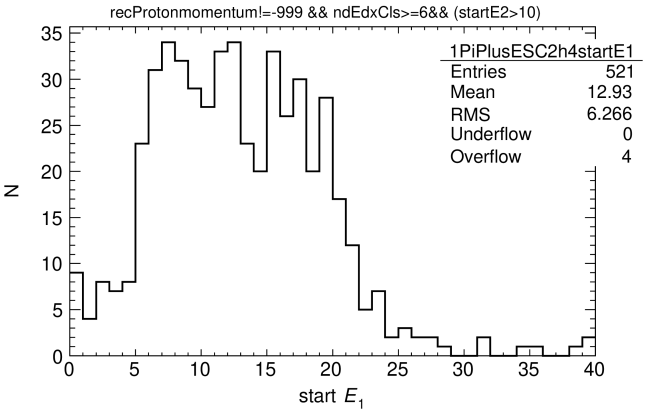
End of track startE0,1,2,3,4,5

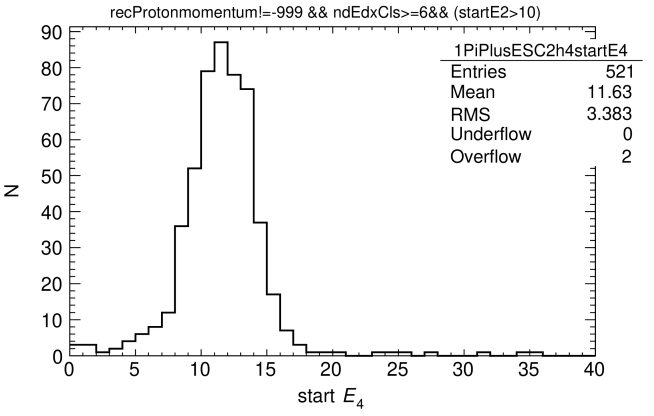


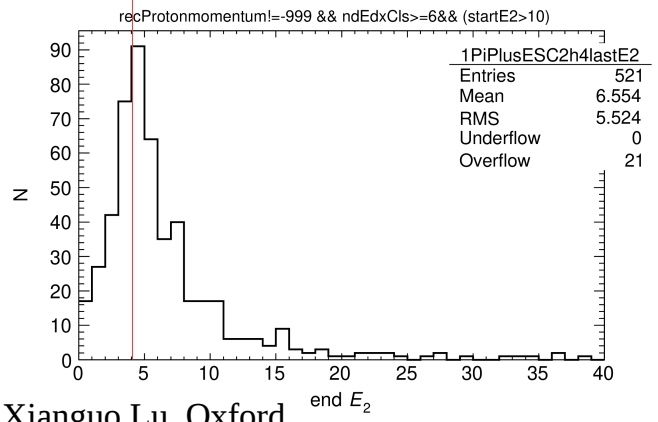


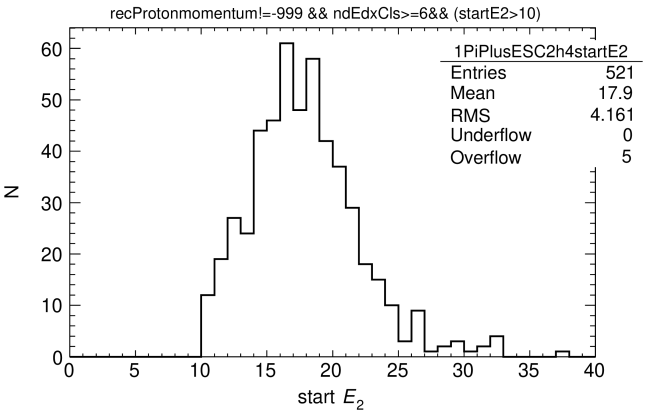


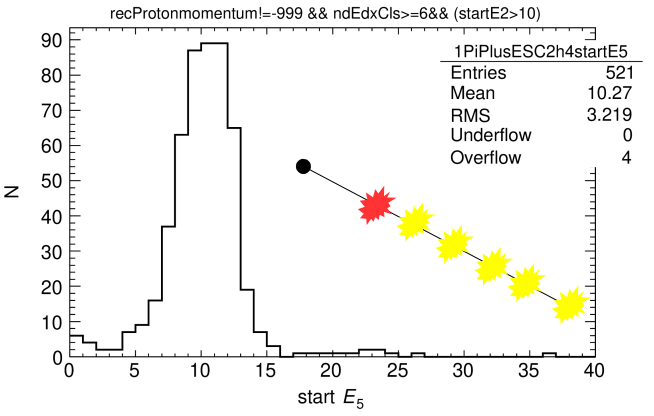












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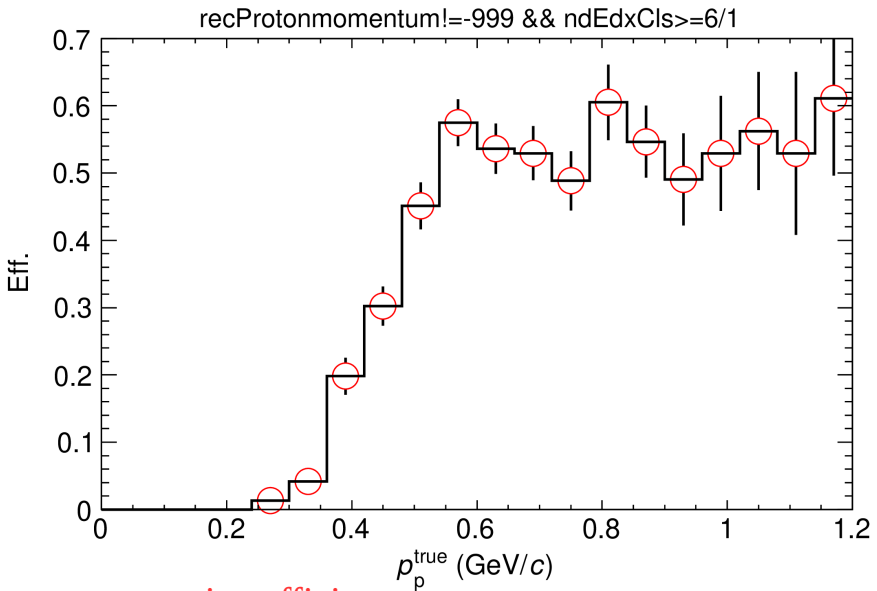
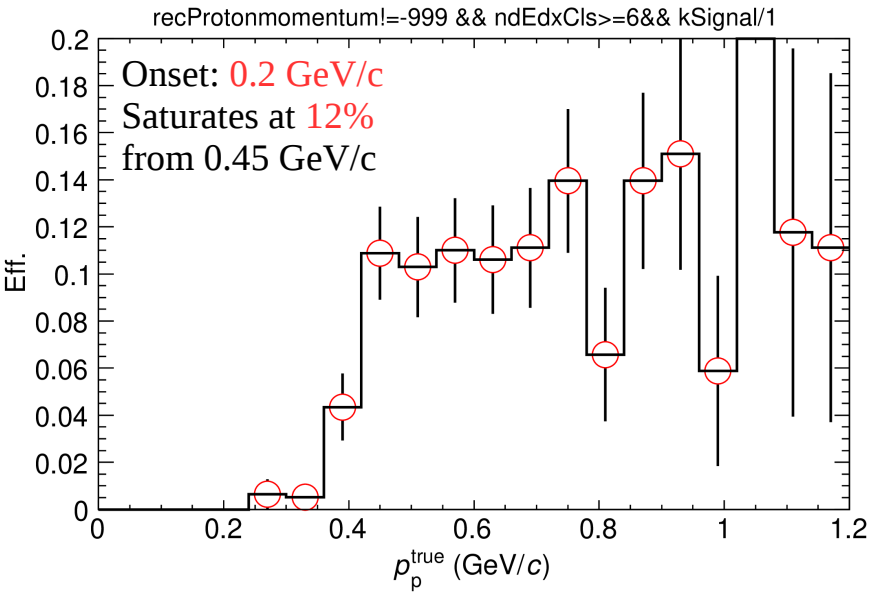
After applying startE2>10 cut: all look much more reasonable

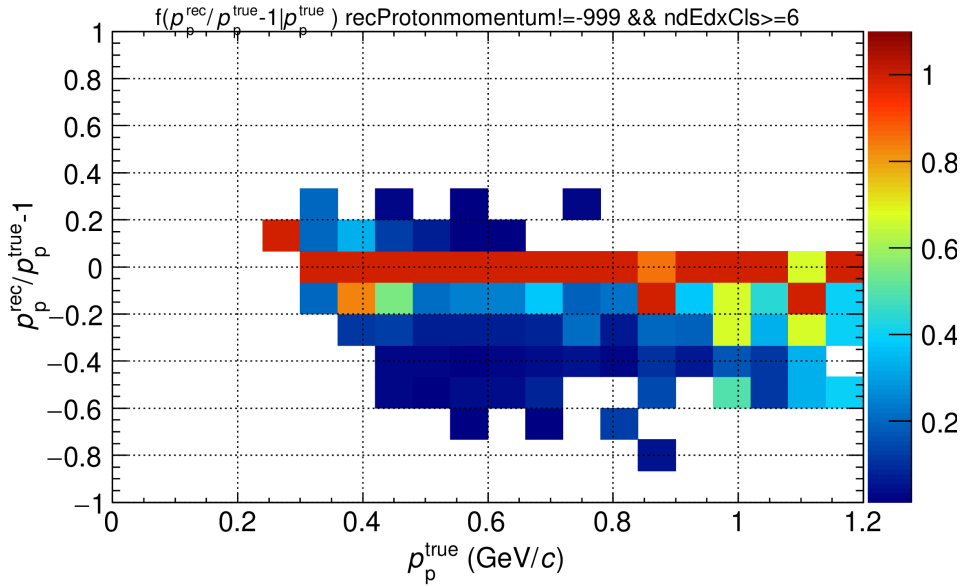


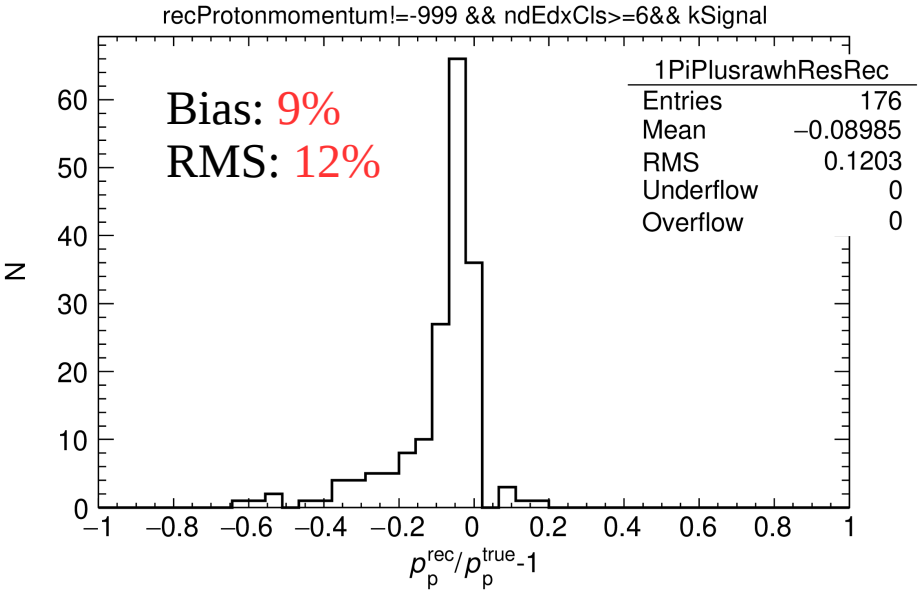
Proton reconstruction efficiency

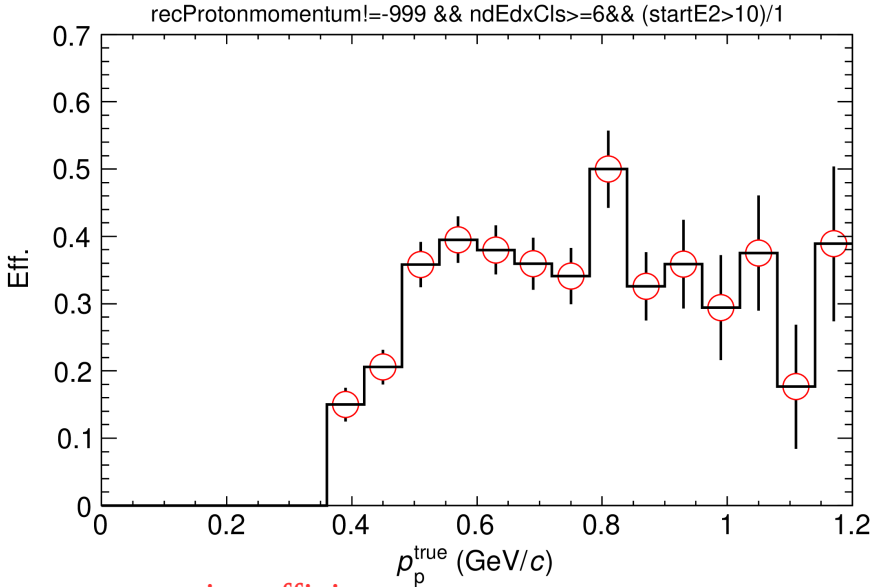


pπ+ TKI signal efficiency

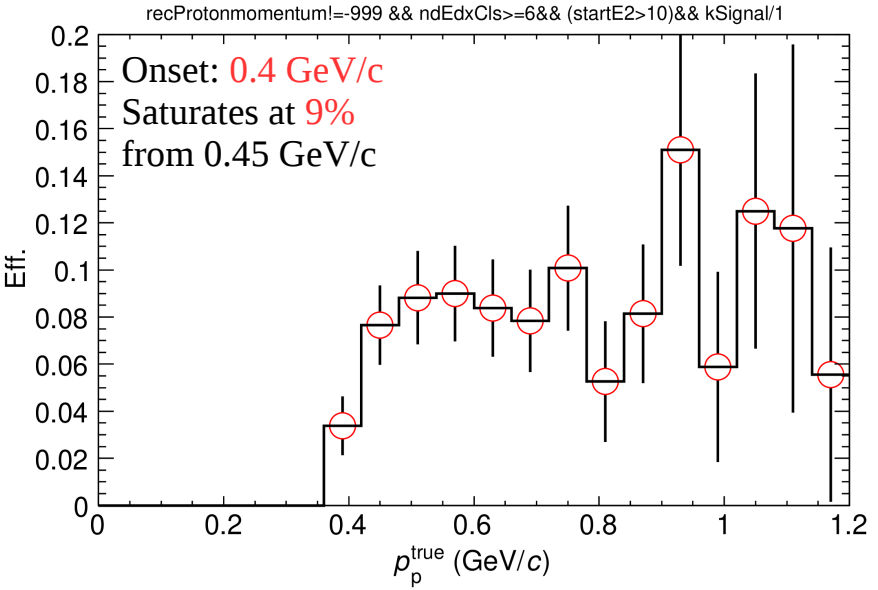
Before ESC proton selection





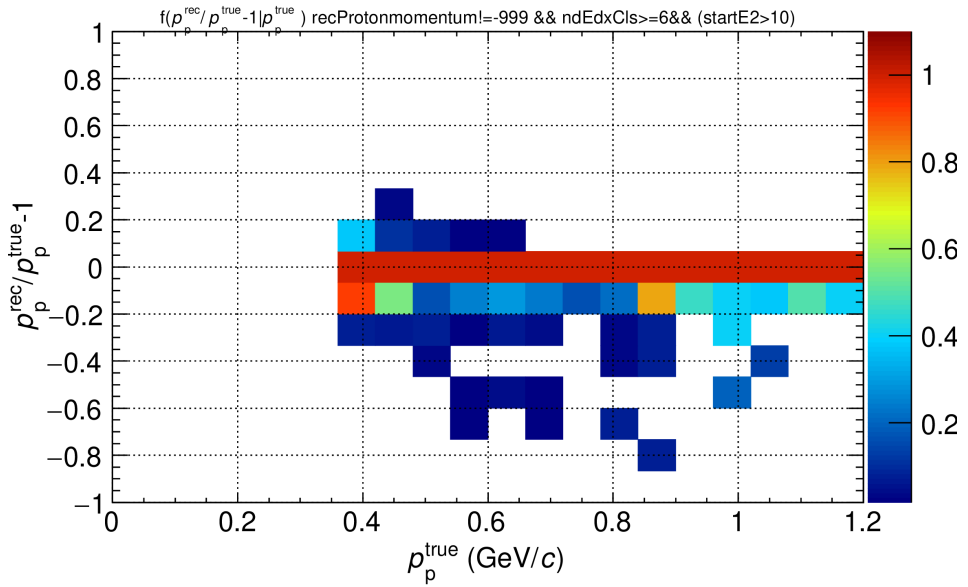


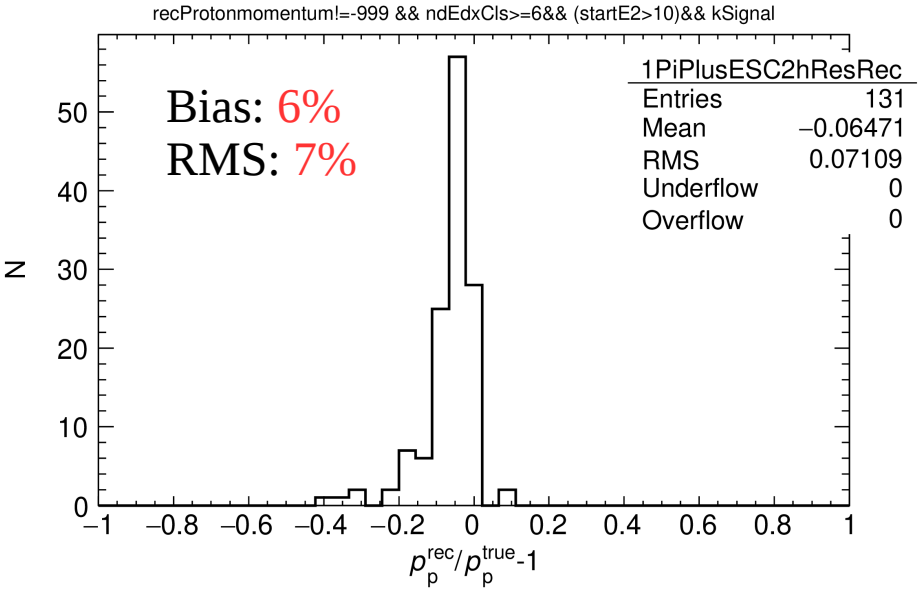
Proton reconstruction efficiency

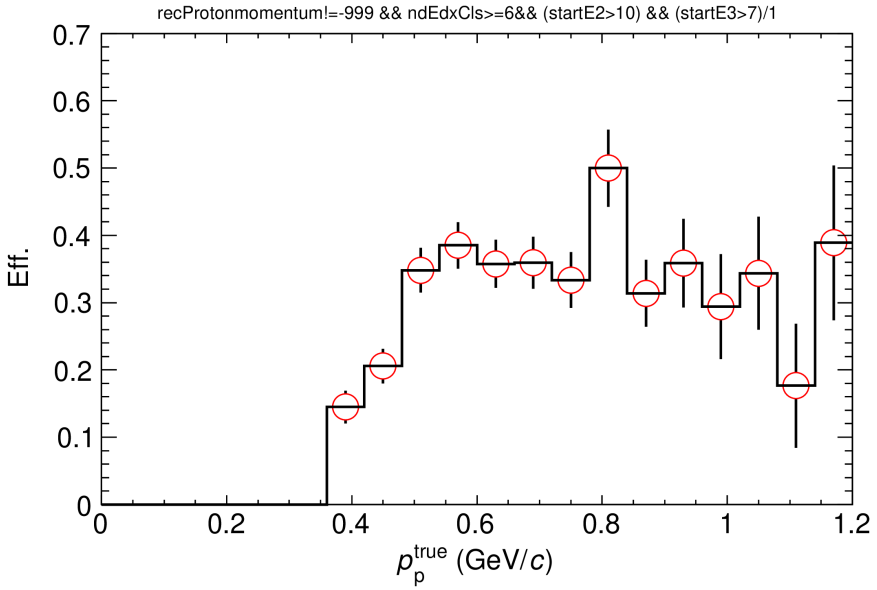


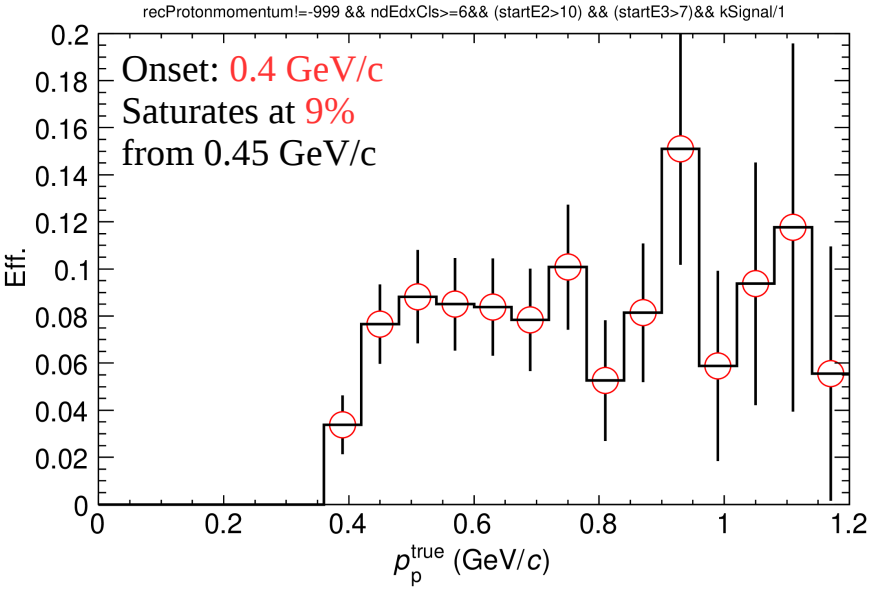
pπ+ TKI signal efficiency

After applying startE2>10 cut

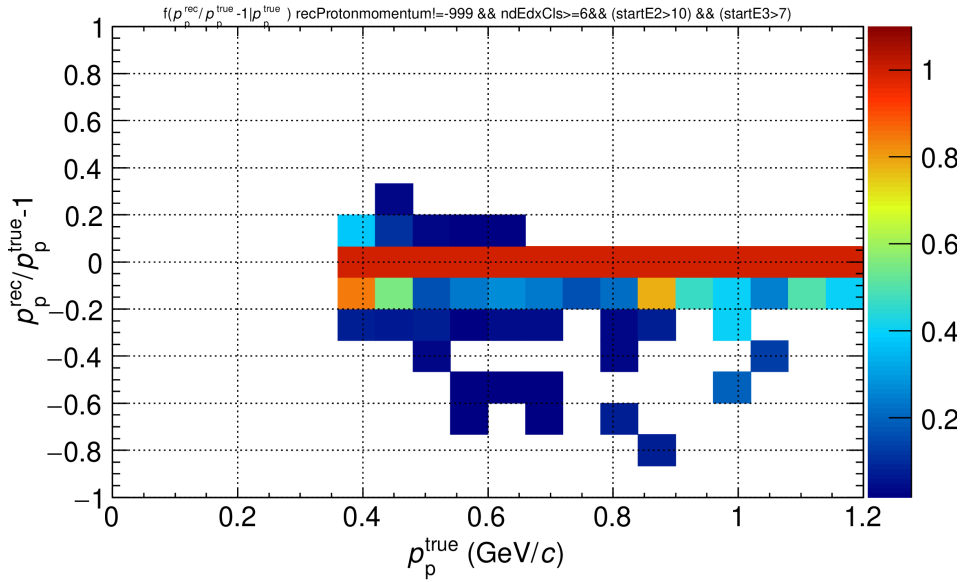


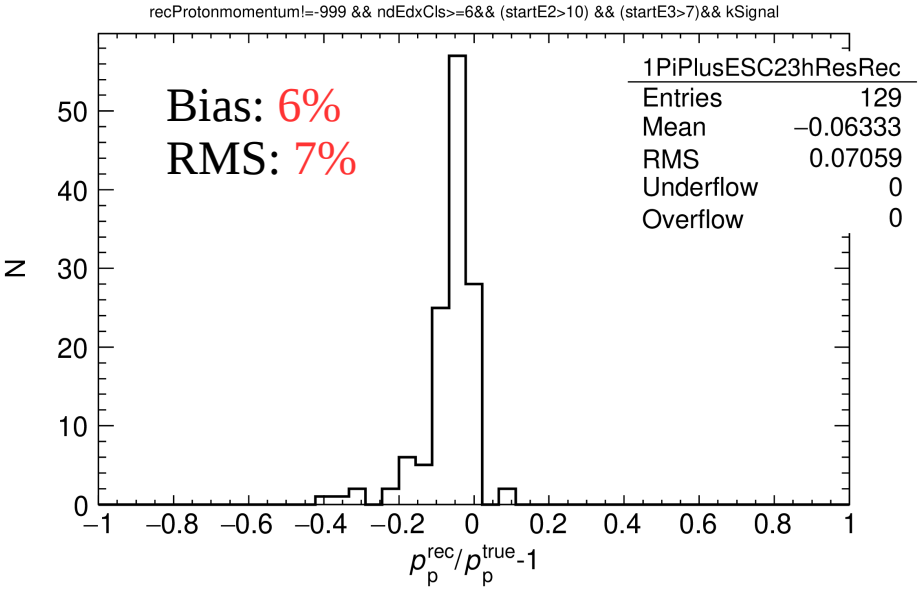


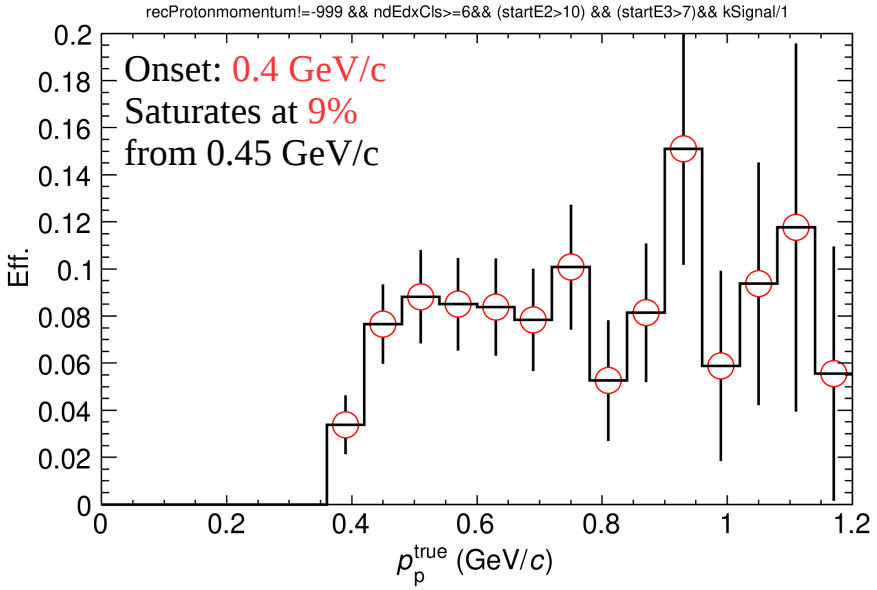




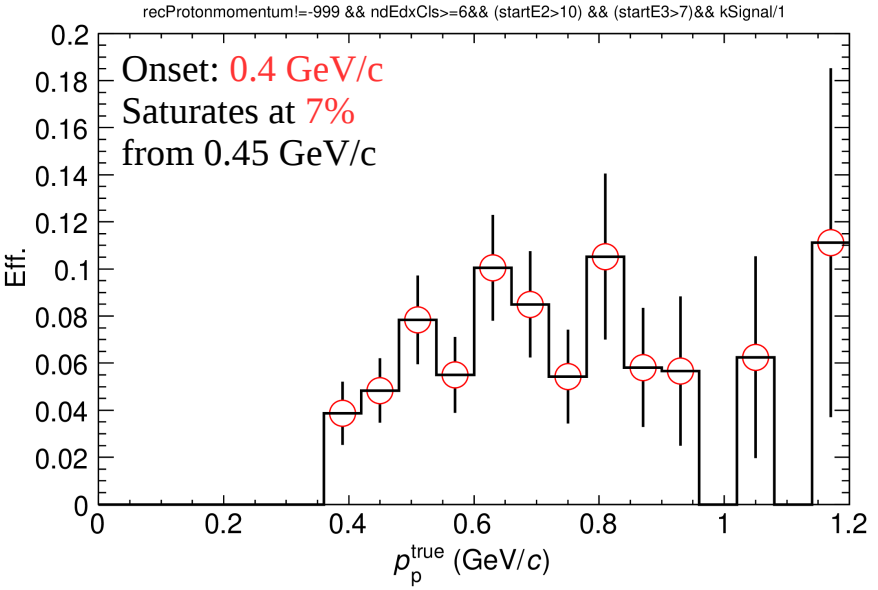
After applying startE2>10 & startE3 >7 cuts to select **ESC** protons
(startE3 is just for clean-up)



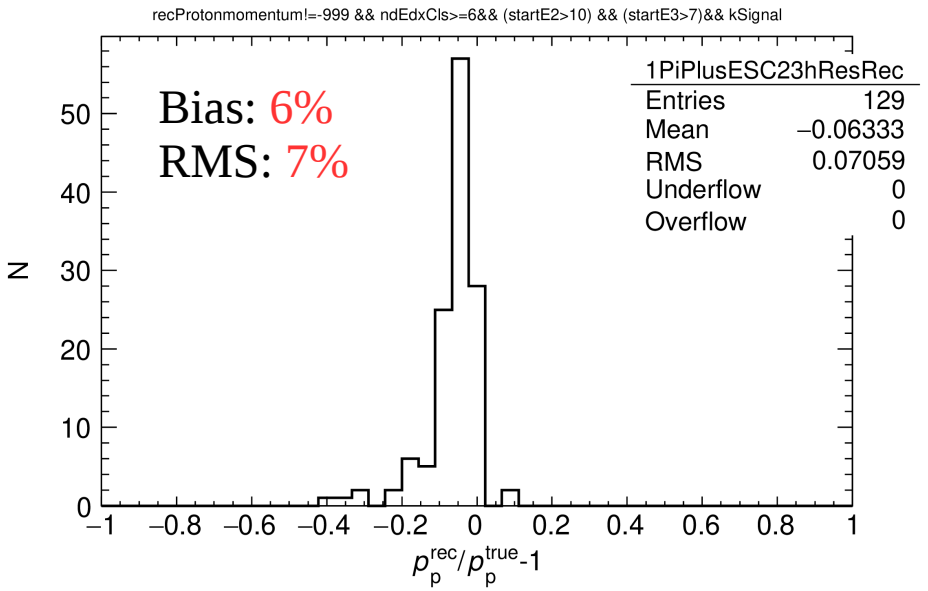


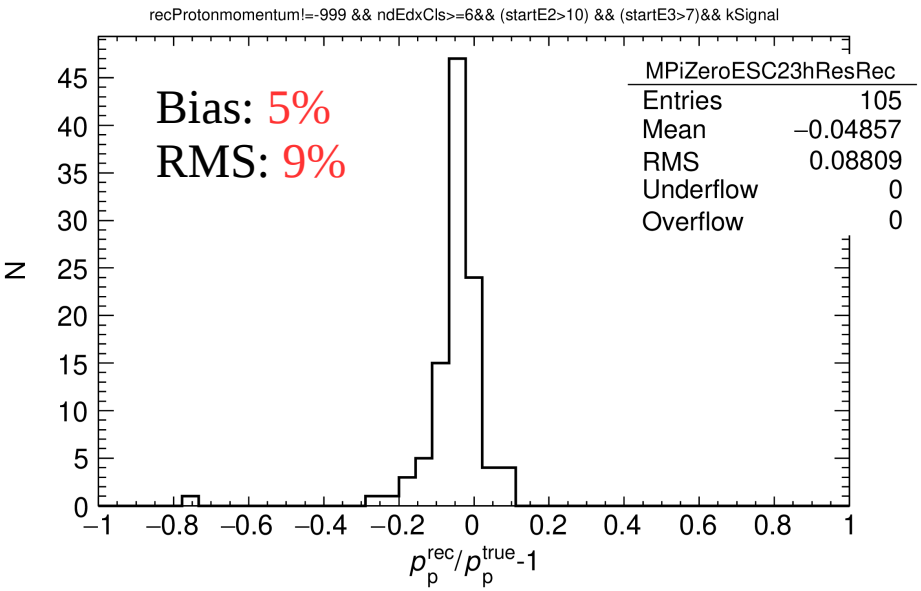


pπ+ elastic channel



pπ0 charge-exchange channel





After **ESC** proton selection

Summary and discussions

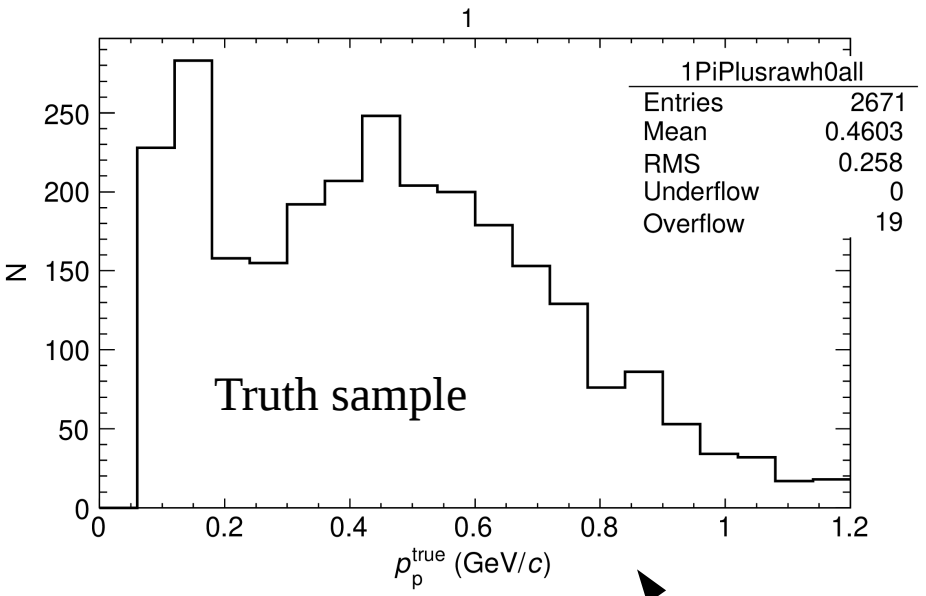
1. Looked at proton reconstruction efficiency and momentum resolution using Jake's sample
   - Efficiency onset at ~0.2 GeV/c, saturate at 55% for pi+ beam events, and ~10% for pπ signal events (denominator all pi+ beam events)
   - Signal sample proton momentum bias 9%, resolution 12%

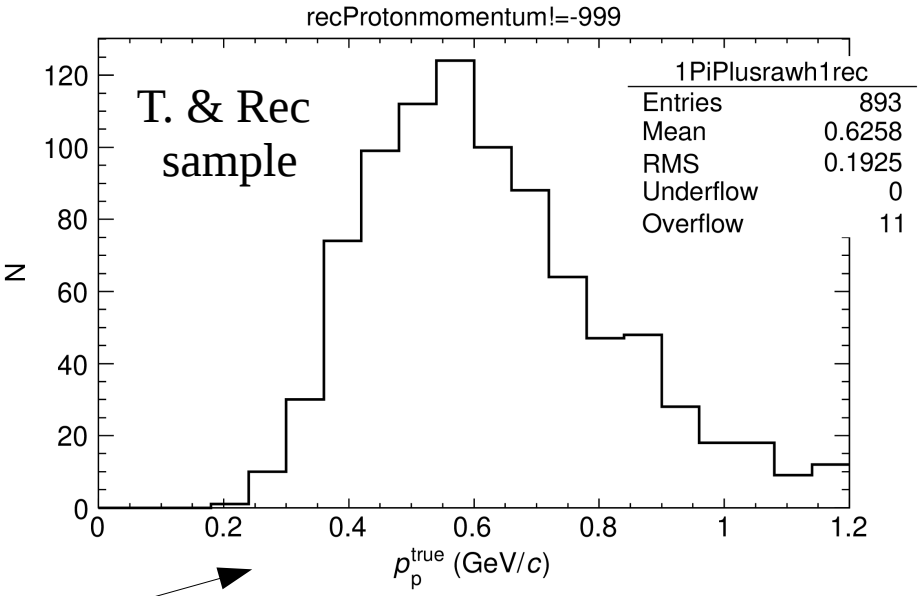
2. The proton momentum resolution can be improved by **ESC** (Elastically Scattered Contained) protons selection
   - Efficiency onset at ~0.4 GeV/c, saturate at ~8% for pπ signal events (denominator all pi+ beam events)
   - Signal sample proton momentum bias 5%, resolution ~8%.

3. Reconstruction efficiency for signal events (denominator true signal events): 40~60%

4. Need some investigation on dE/dx to further improve resolution.

BACKUP

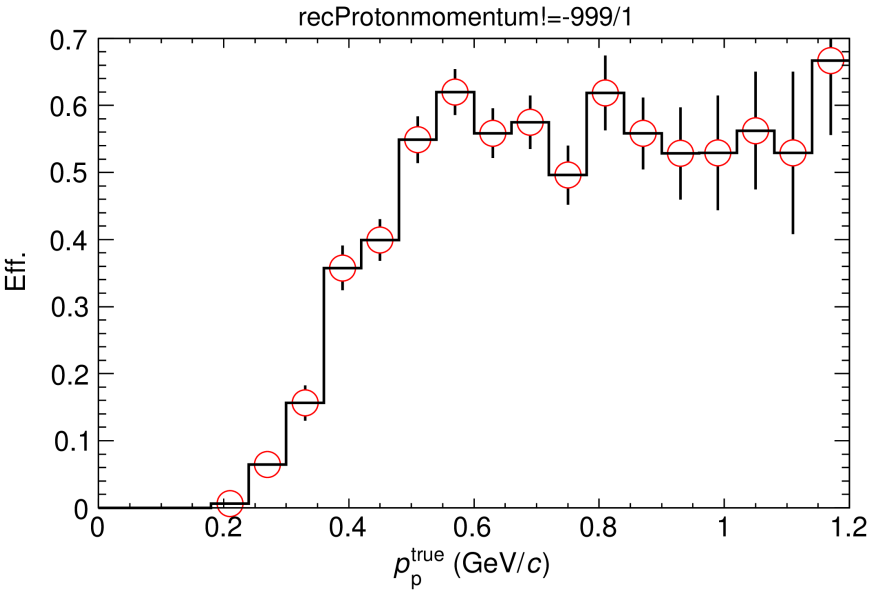


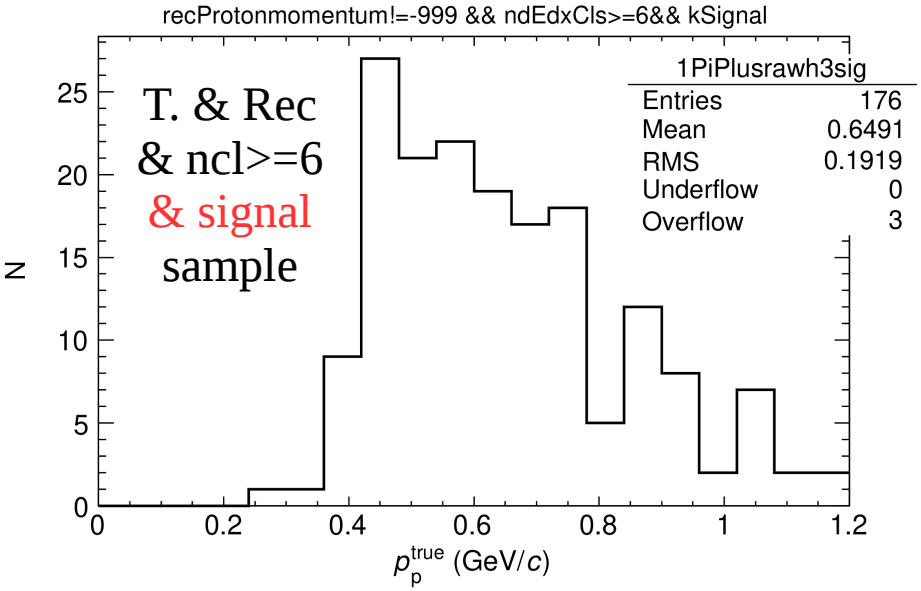


True leading proton momentum distribution

Reconstruction efficiency

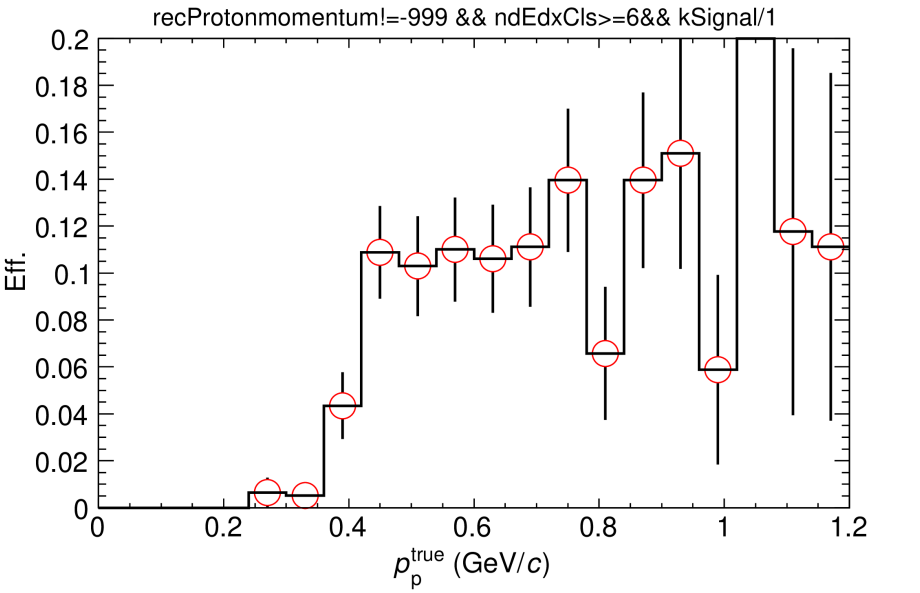
- Onset at 0.2 GeV/c
- Saturates at 55% from 0.5 GeV/c





- Require number of dEdx cluster >= 6
- Requires to be signal events

Reconstruction efficiency
- Onset at 0.2 GeV/c
- Saturates at 12% from 0.45 GeV/c

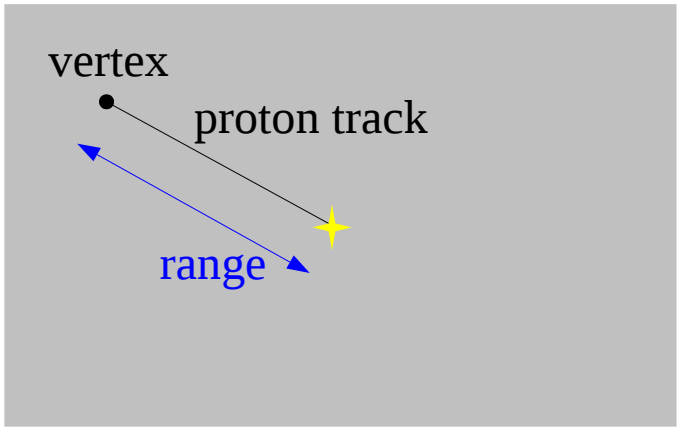


Event Selection

Archive

- One muon candidate track matched to a MINOS track
- At least one proton candidate (particle identification using dE/dx along the track)
  - Elastically Scattered Contained (ESC) proton selection → new development
- Vertex in tracker
- Michel electron (from pion-muon-electron decay chain) tag to remove pion production
- Cut on energy far from vertex (unattached visible energy) to remove events with untracked pions

Homogeneous non-magnetized tracker
Momentum by range



Momentum-range correlation best known when the track has “peaceful” end: stopped elastically

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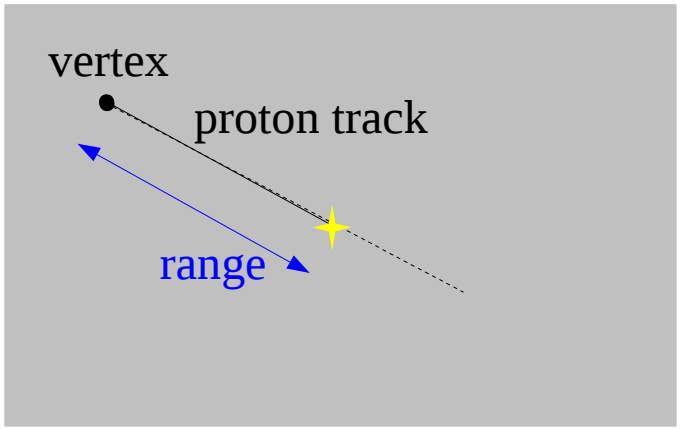
Homogeneous non-magnetized tracker
Momentum by range



Momentum-range correlation best known when the track has "peaceful" end: stopped elastically

If track ends on the fly due to inelastic interaction in detector (e.g. p A → n A')
Range can only be measured prematurely → large bias in momentum estimation

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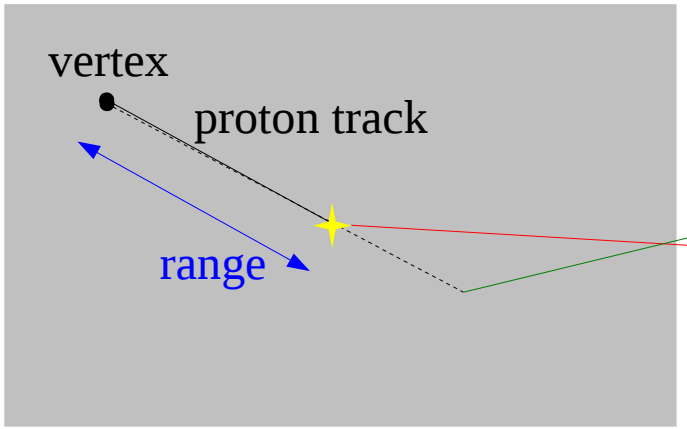
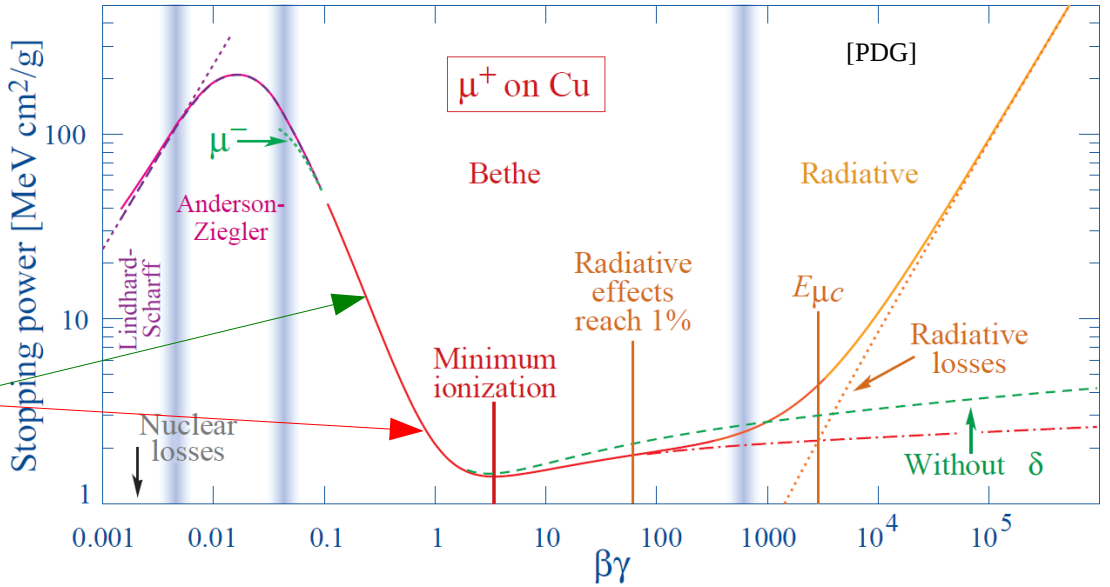
Homogeneous non-magnetized tracker
Momentum by range





Proton stopped on the fly have smaller dE/dx
→ Cut on dEdx from track end point

Event Selection

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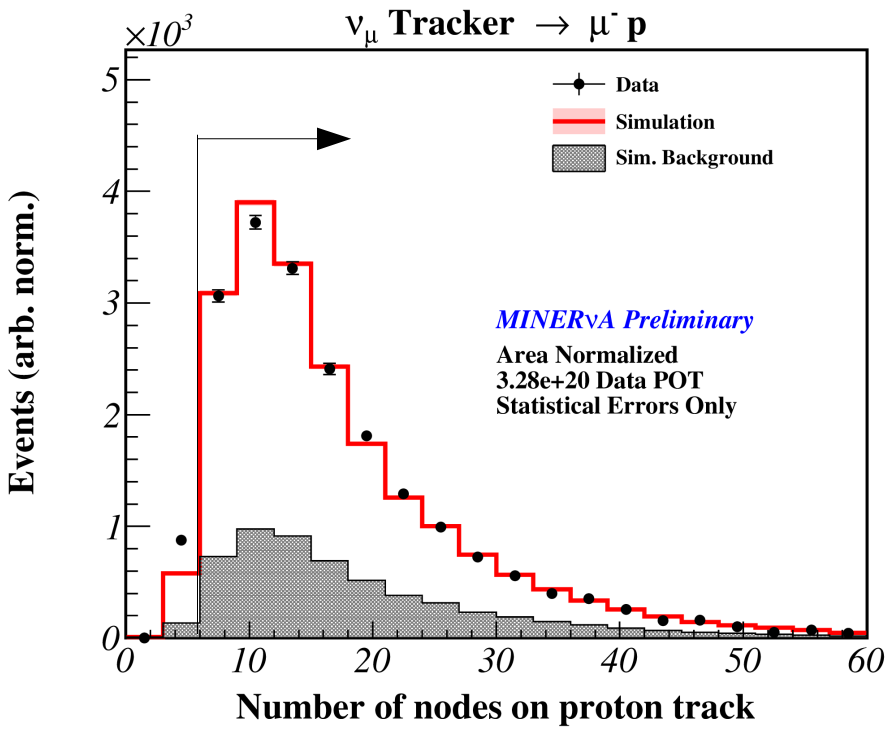
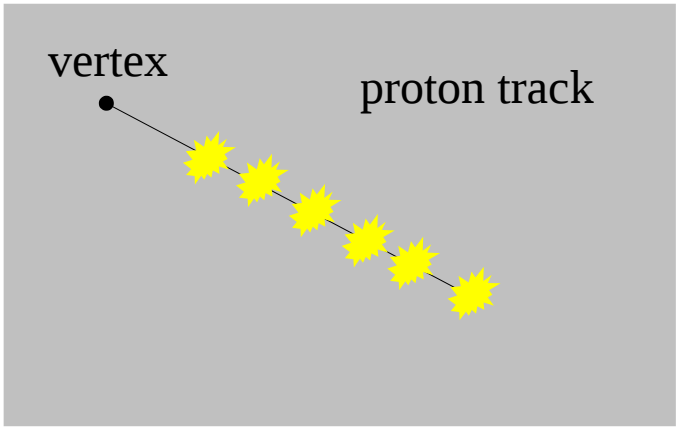


- Require at least 6 dE/dx nodes from track end point



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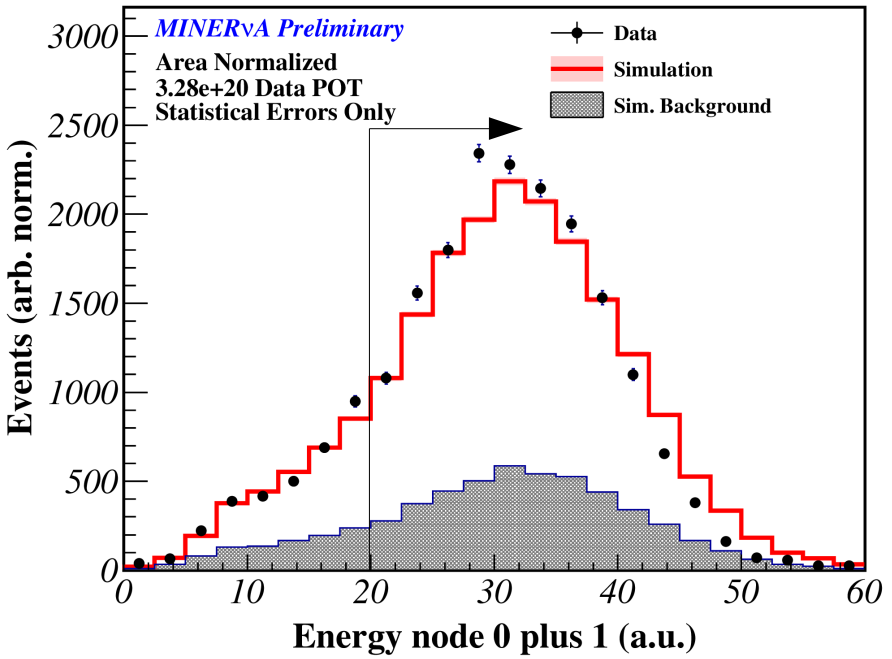
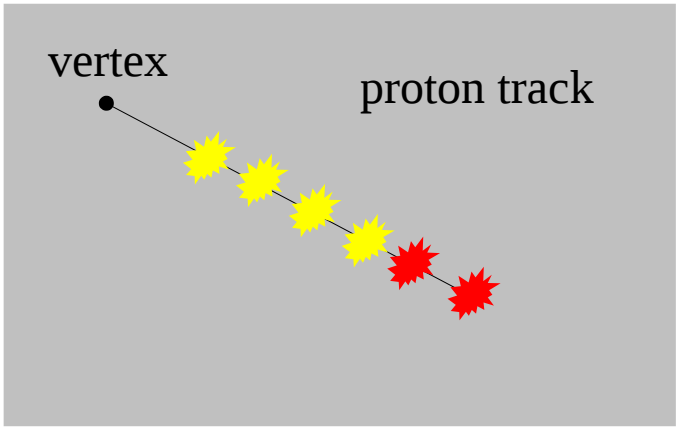


- Require at least 6 dE/dx nodes from track end point
- Cut on summed dE/dx of last two nodes (node 0 and 1 correlated)



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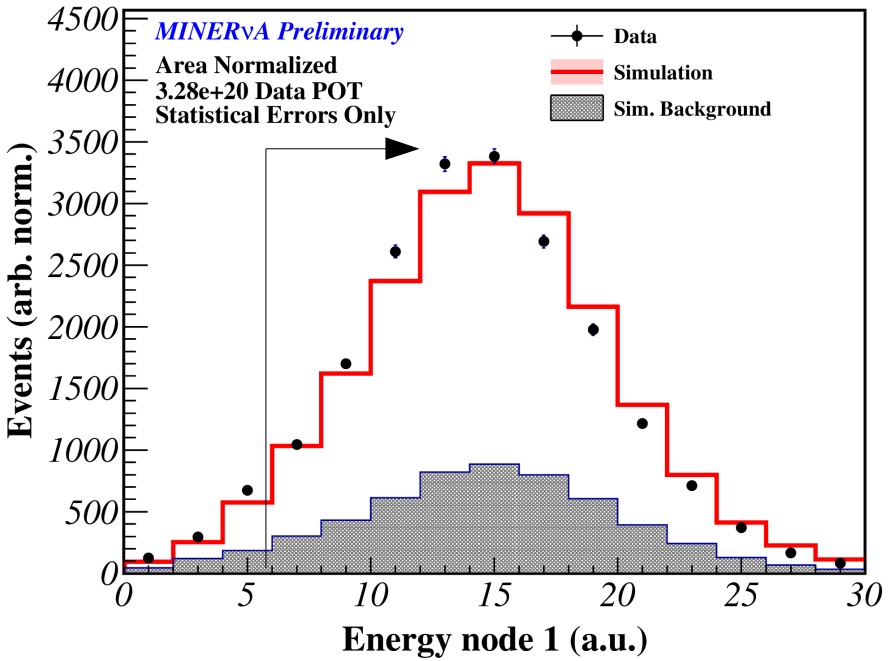
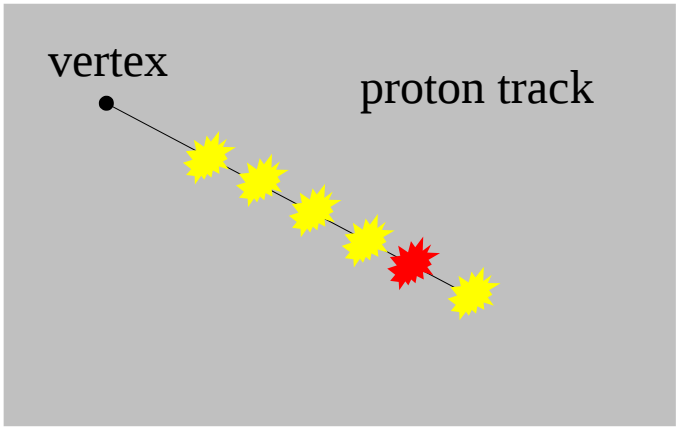


- Require at least 6 dE/dx nodes from track end point
- Cut on summed dE/dx of last two nodes (node 0 and 1 correlated)
- Cut on individual nodes (node 1-5)



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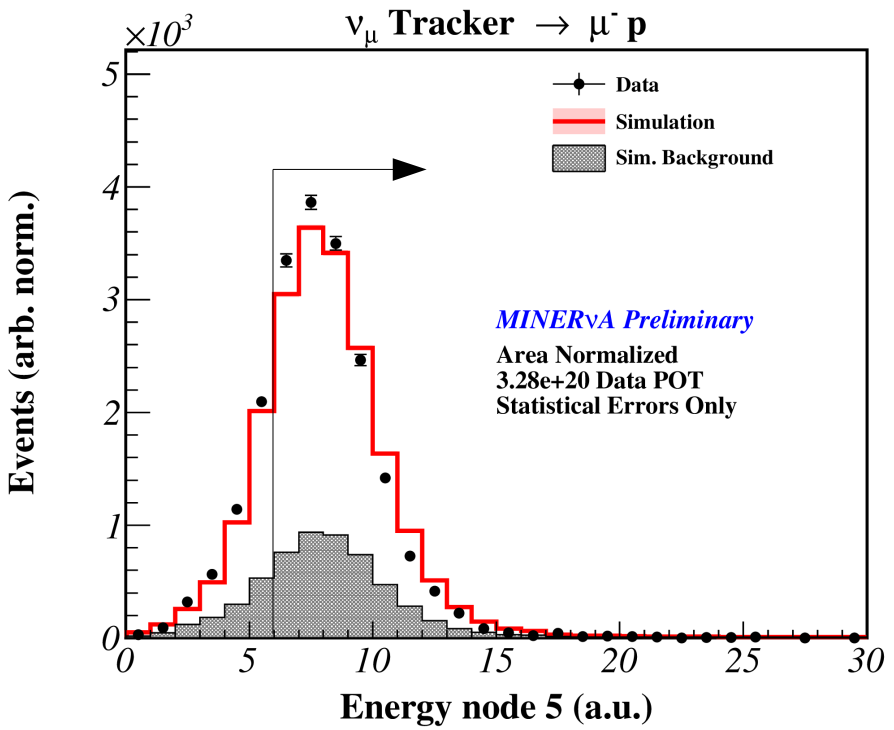

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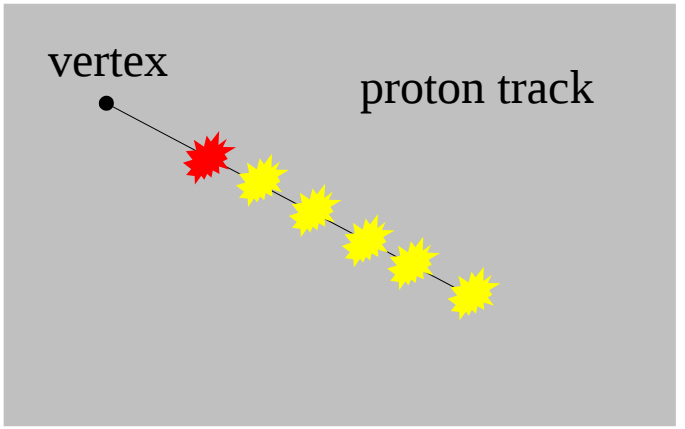

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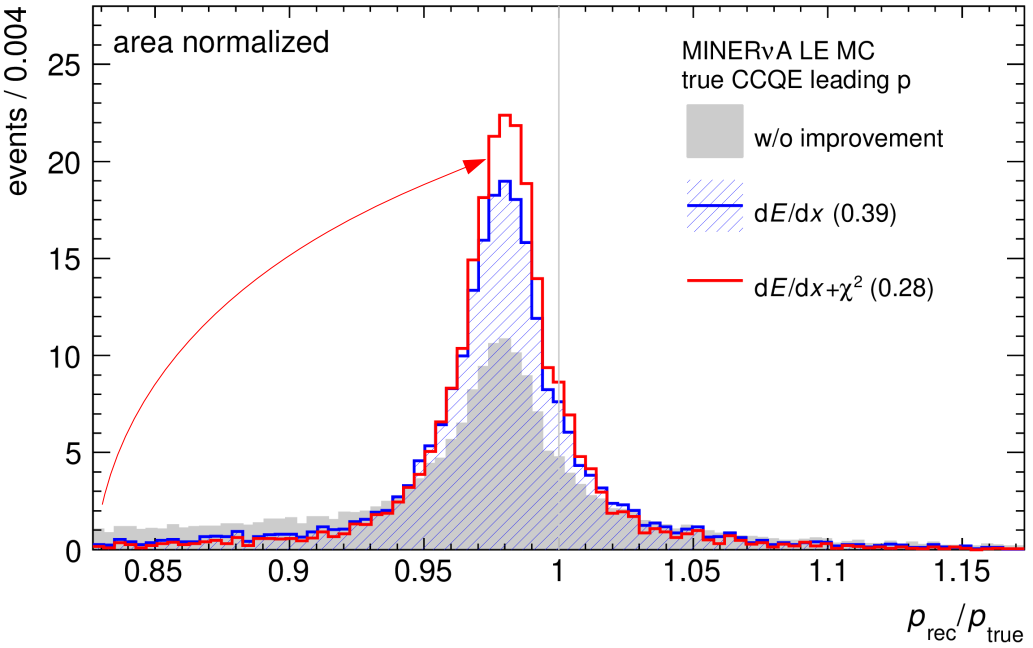


*dE/dx+cleanup cut efficiency 30-40-20%@0.6-0.75-1 GeV/c

ESC proton selection:

- Cut efficiency ~ 40%
- Reconstructed momentum spread much reduced @ 0.7 – 1.1 GeV, resolution 3% ~ 2%
- 5-10% uncertainty in efficiency

Clean-up cuts to improve proton and muon momentum resolution:

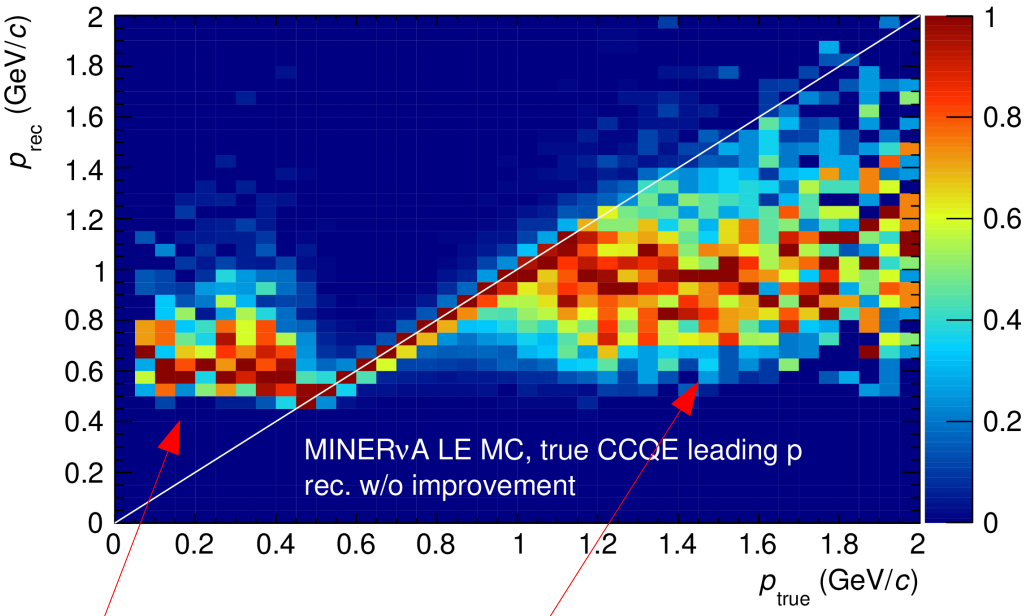
- proton dE/dx profile χ^2
- number of MINOS track nodes

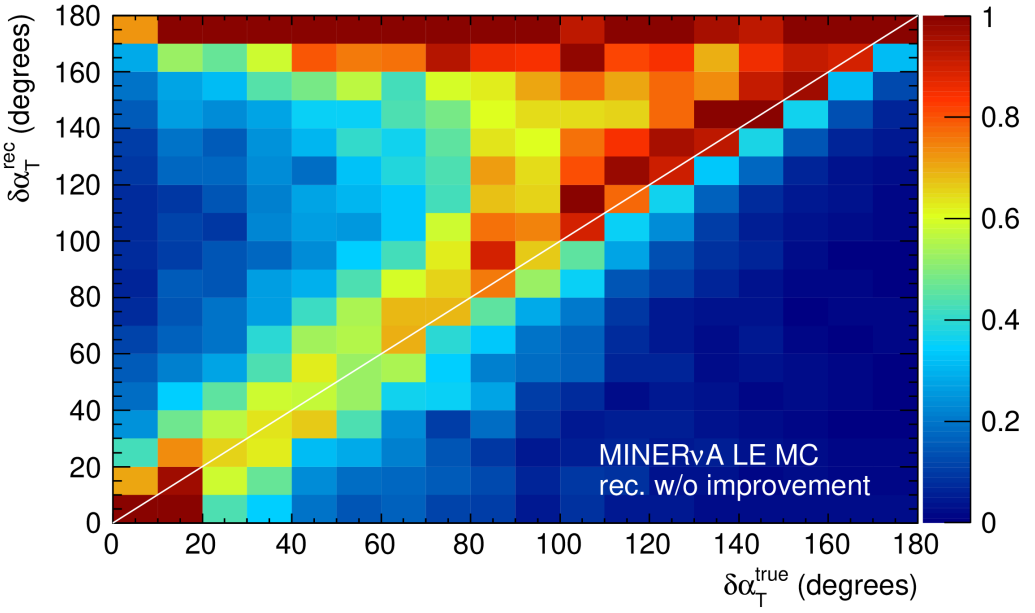
Also need to correct pT scales of both muon and protons.

Event Selection

Archive

- One muon candidate track matched to a MINOS track
- At least one proton candidate (particle identification using dE/dx along the track)
  - Elastically Scattered Contained (ESC) proton selection → new development
- Vertex in tracker
- Michel electron (from pion-muon-electron decay chain) tag to remove pion production
- Cut on energy far from vertex (unattached visible energy) to remove events with untracked pions

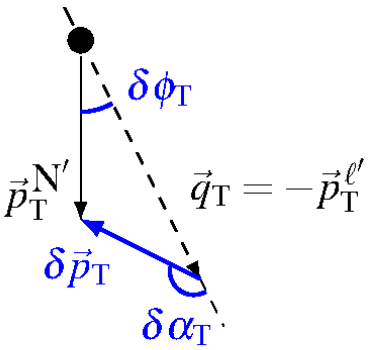




Short track around vertex

Inelastic scattered protons

Reconstructed as a function of true quantity before ESC proton selection for proton momentum and $\delta\alpha_T$



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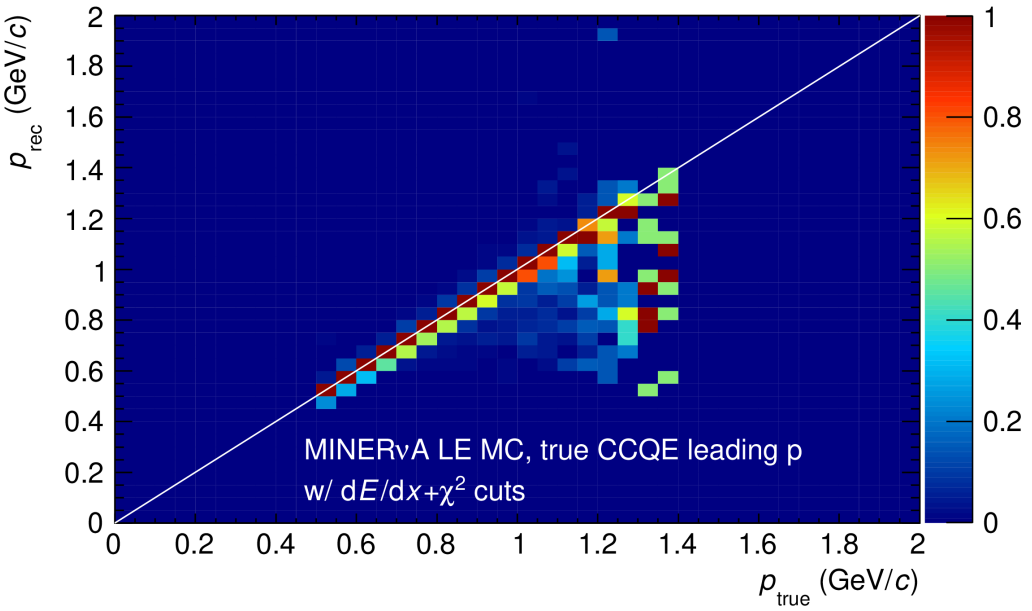
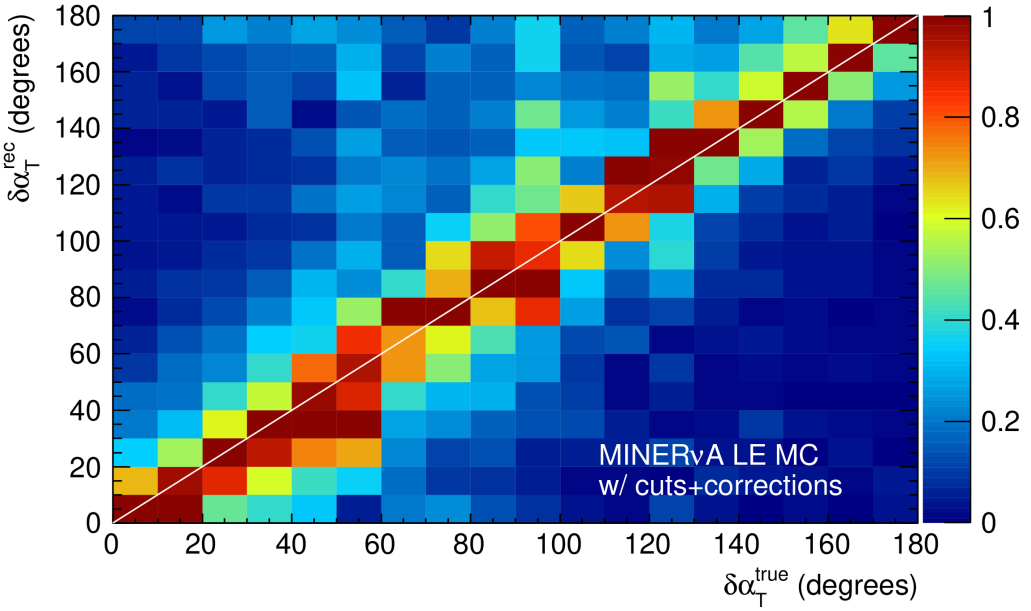
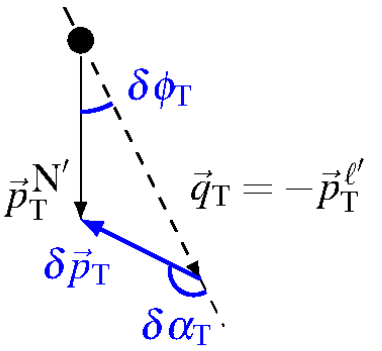




Reconstructed as a function of true quantity after ESC proton selection and pT-scale correction (only applied to derived variables) for proton momentum and $\delta\alpha_T$



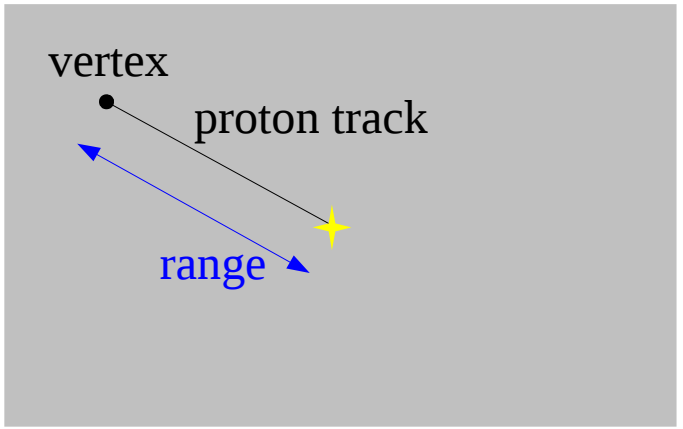
Start to look at and try to understand protoDUNE dE/dx:

- Using calibrated dE/dx with SCE
- Test the dE/dx array first → which one contains the Bragg peak?

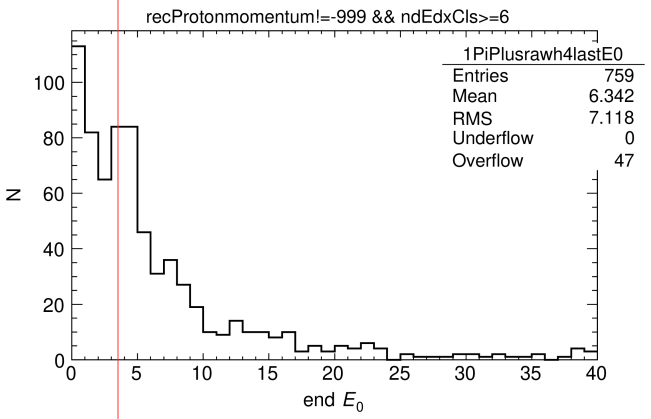
`(*reco_daughter_allTrack_calibrated_dEdX_SCE)[itrack][icluster]`

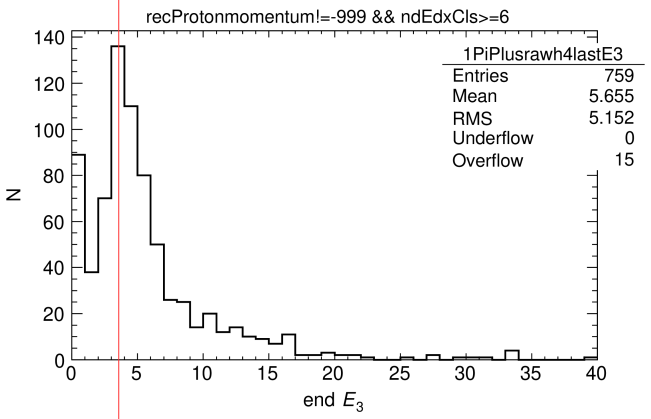
Start of array: `startE0, startE1, …, startE5: [icluster=0], [1], …, [5]`

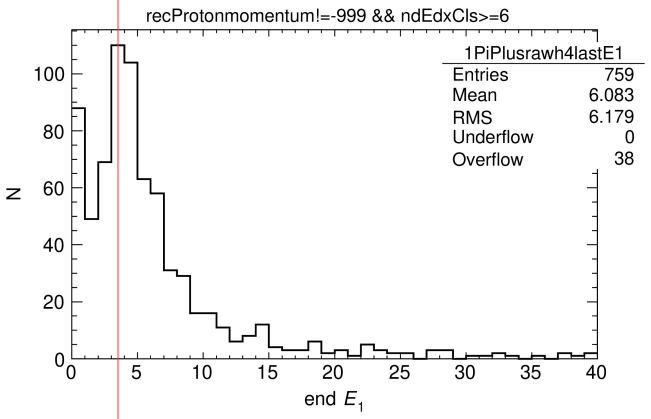
End of array: `endE0, endE1, …, endE5: [icluster=Ncluster-1], [Ncluster-2], …, [Ncluster-6]`

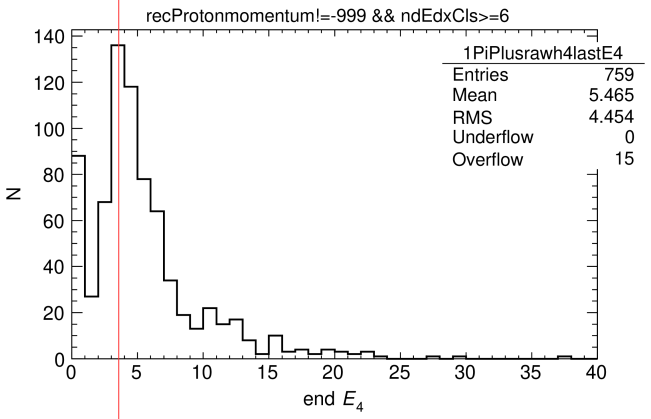


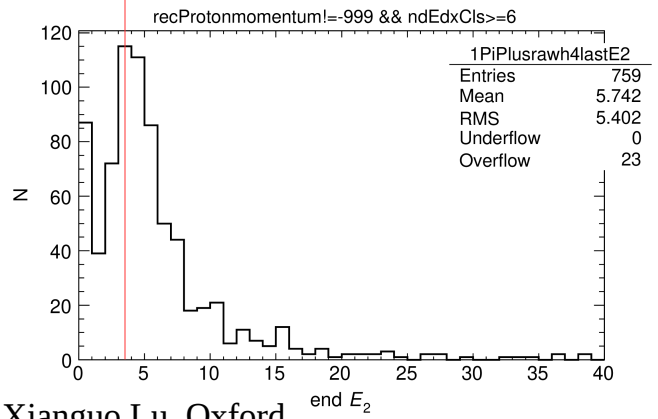
Track end = start of array or end of array?

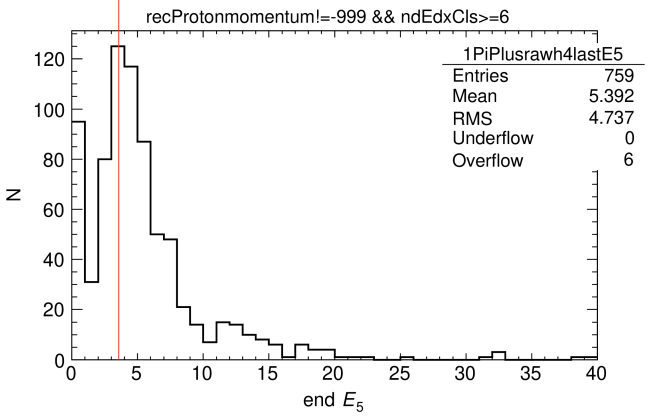








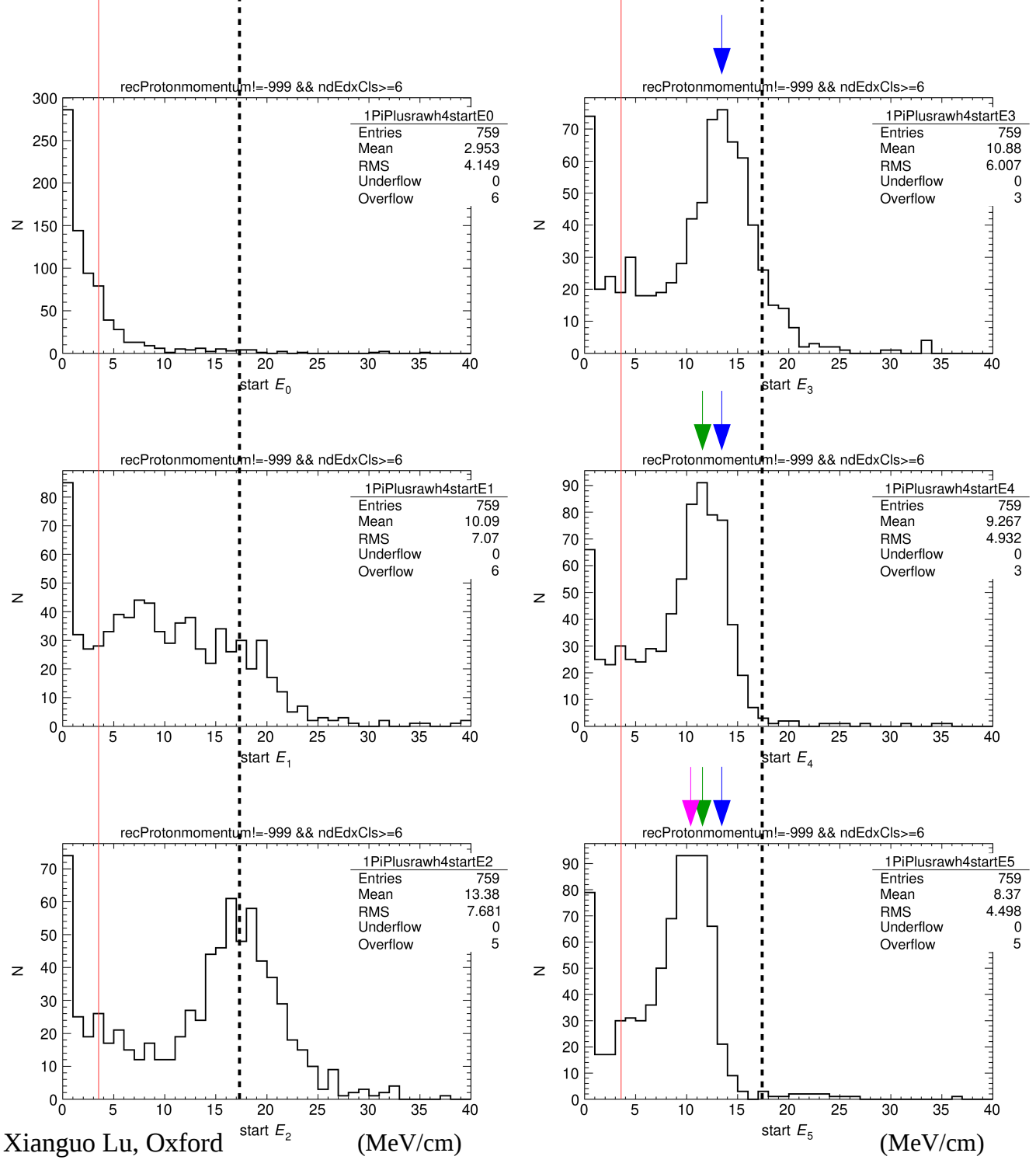




End of array:

`endE0, endE1, …, endE5:`
`[icluster=Ncluster-1],`
`[Ncluster-2], …,`
`[Ncluster-6]`

all have same dE/dx
→ not track end



(MeV/cm)

(MeV/cm)

Start of array:

`startE0, startE1, …, startE5:`
`[icluster=0], [1], …, [5]`

Seems to have Bragg peak
→ also dE/dx decrease as [icluster] increase
→ Start of array is the track end

E0 and E1 look “weird” due half-dead proton not traversing the full “cluster length”
→ need to check correlations like E0:E1, E1:E2, E2:E3, ...
→ E0 and E1 can be used by combining them like E0*=E0+E1+E2

END