



Proton track vs shower reconstruction and BDT variables in the ICARUS detector

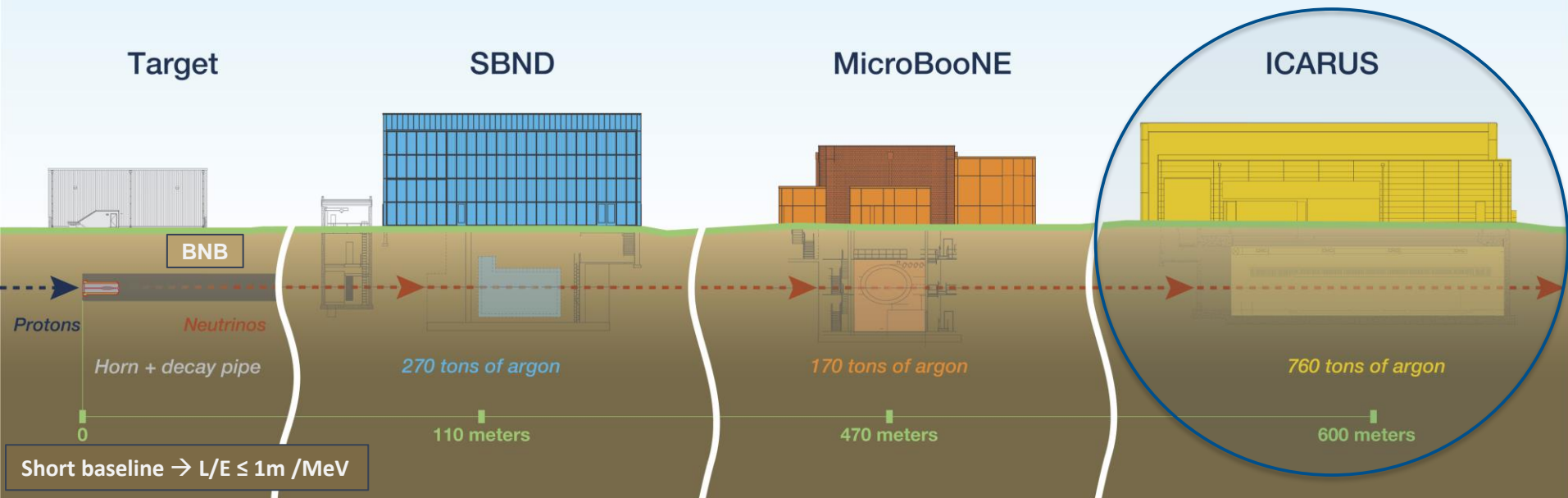
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Italian Summer Student Program @ FNAL – Final reviews 2022

21 September 2022

ICARUS: Imaging Cosmic and Rare Underground Signal

Short-Baseline Neutrino Program at Fermilab



ICARUS is the **Far Detector** in the Short Baseline Neutrino Program (**SBN**) at FNAL.



ICARUS

LAr TPC (Liquid Argon Time Projection Chamber)

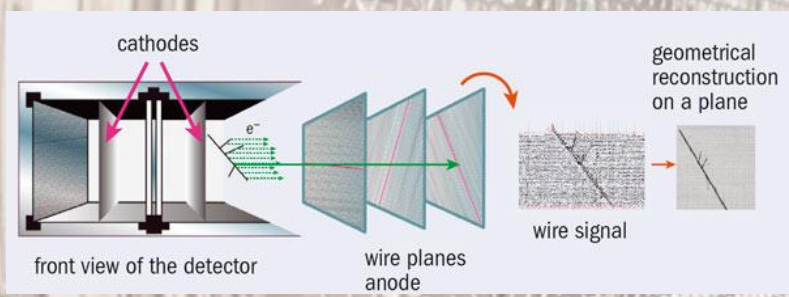
Physics 'goals

Beyond the Standard Model Physics

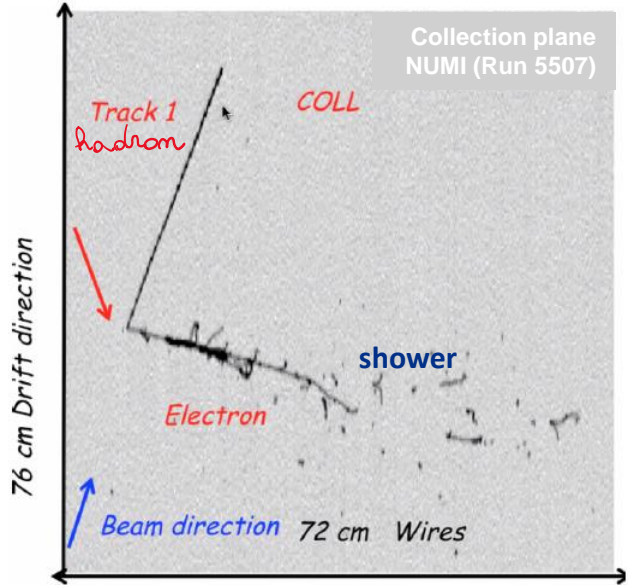
LSND & MiniBooNE anomalies

Neutrino-argon cross section

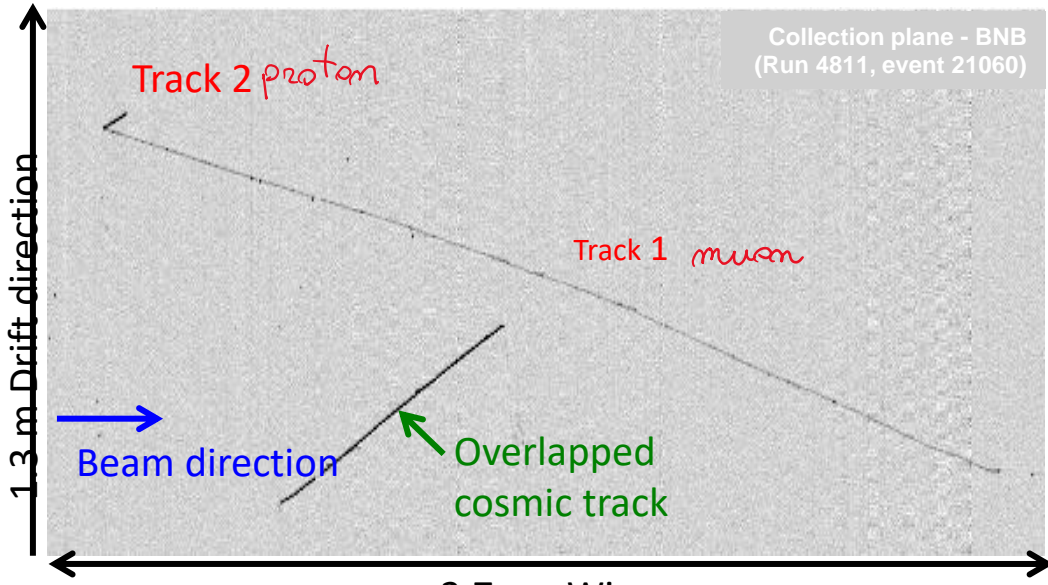
Neutrino-4 anomalies



Candidate ν_e CCQE vs ν_μ CCQE

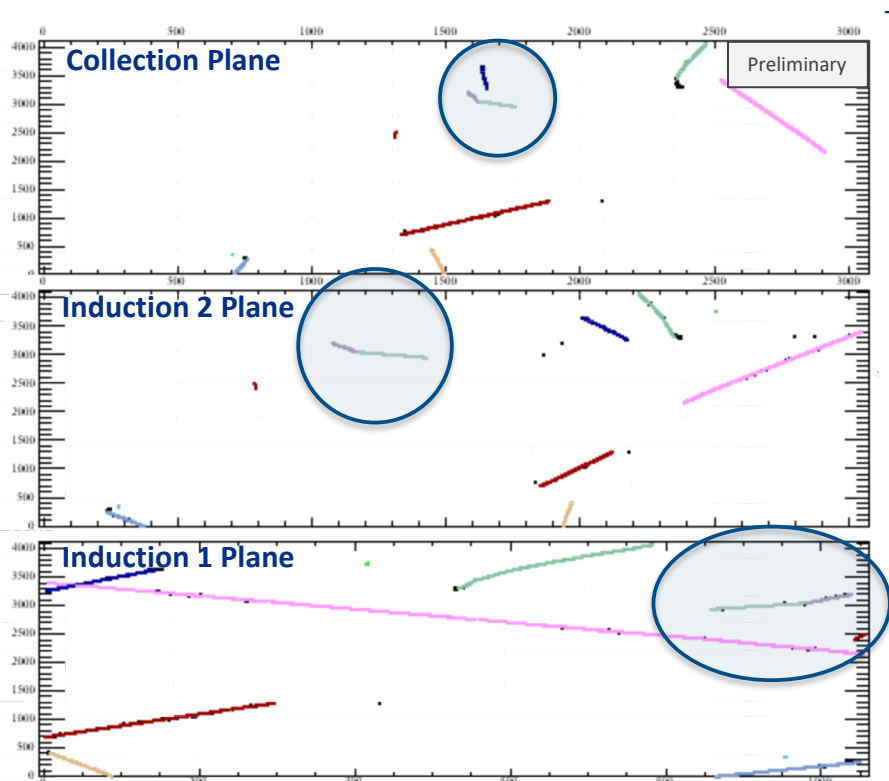


Candidate ν_e interaction from NuMI

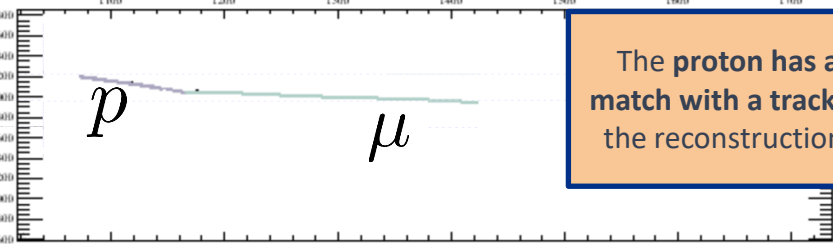
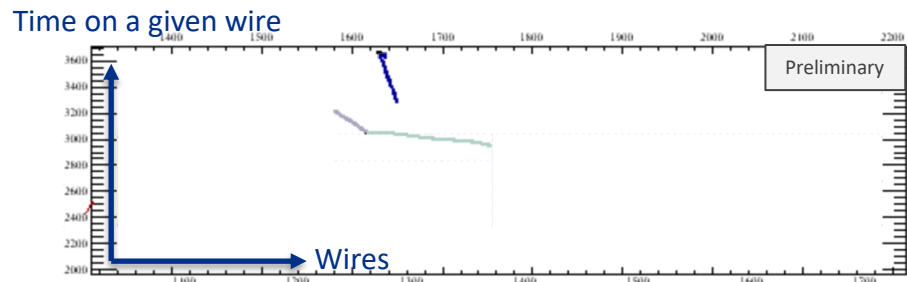


One of the first candidate ν_μ interactions found in BNB.

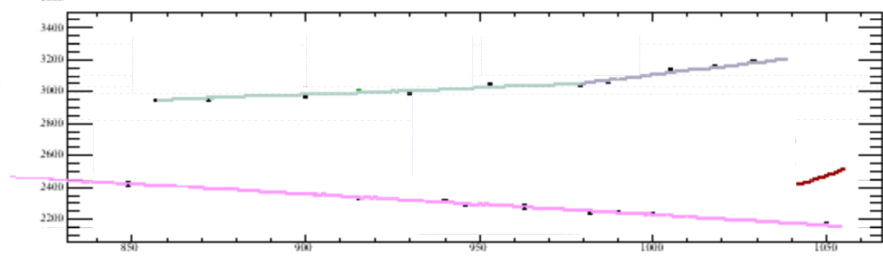
A well reconstructed ν_μ CCQE event on the event display – MC simulated data



Each color is a different track

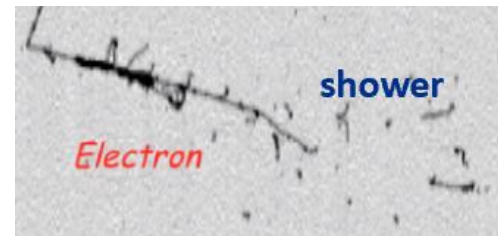
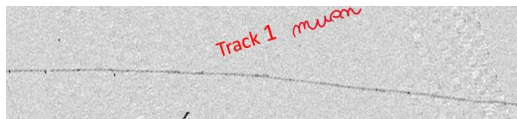
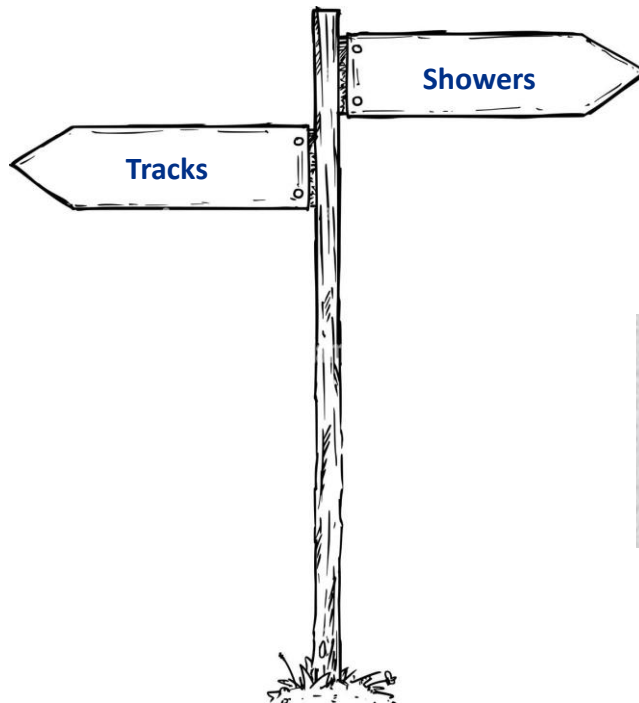


The proton has a match with a track in the reconstruction.

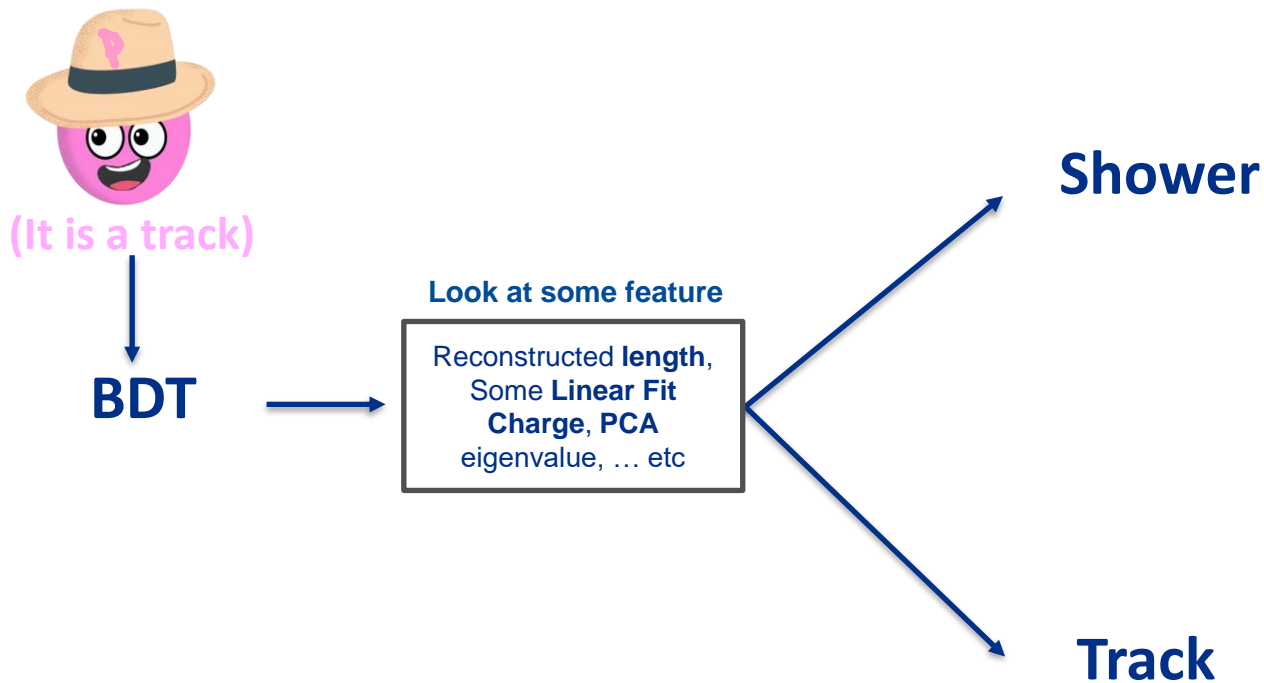


Zoom in

Some particles in our detectors choose the «shower path», others the «track path»



BDT (Boosted Decision Tree)



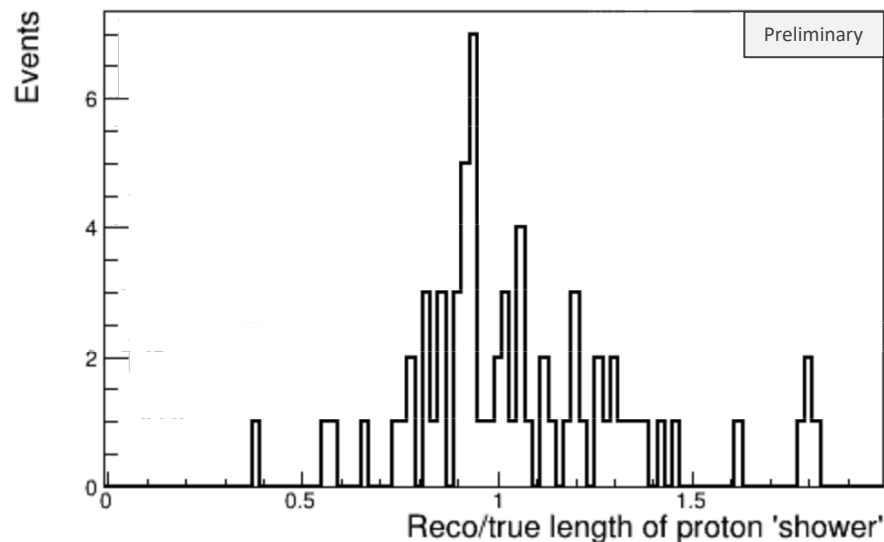
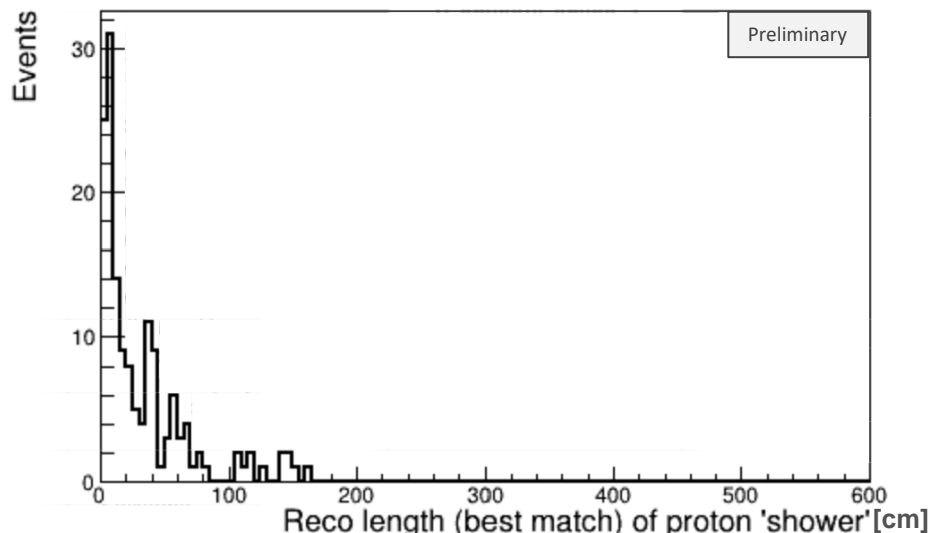
Proton: topology of cut

In order to investigate why the BDT particle identification fails, I'm looking at protons dividing reconstructed events in different categories. If there is more than one proton, I look at the most energetic one

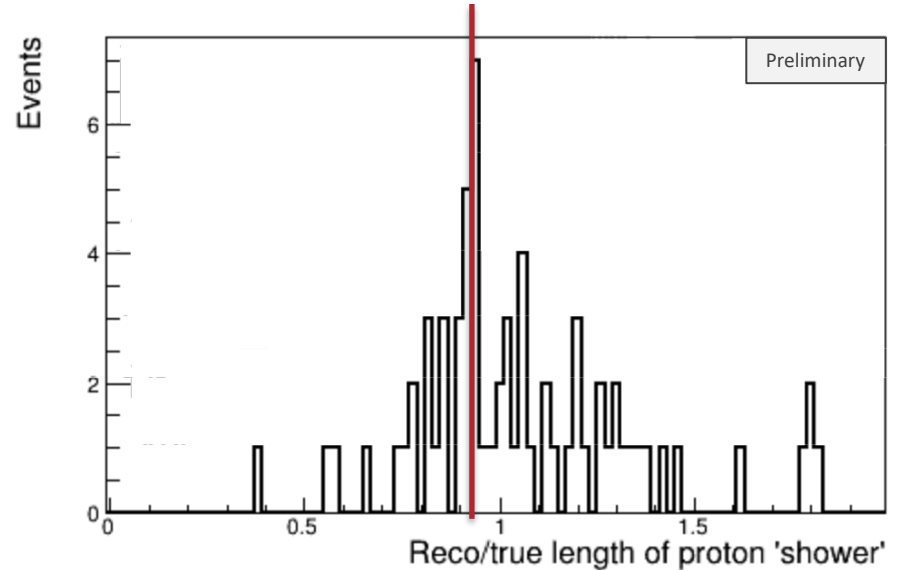
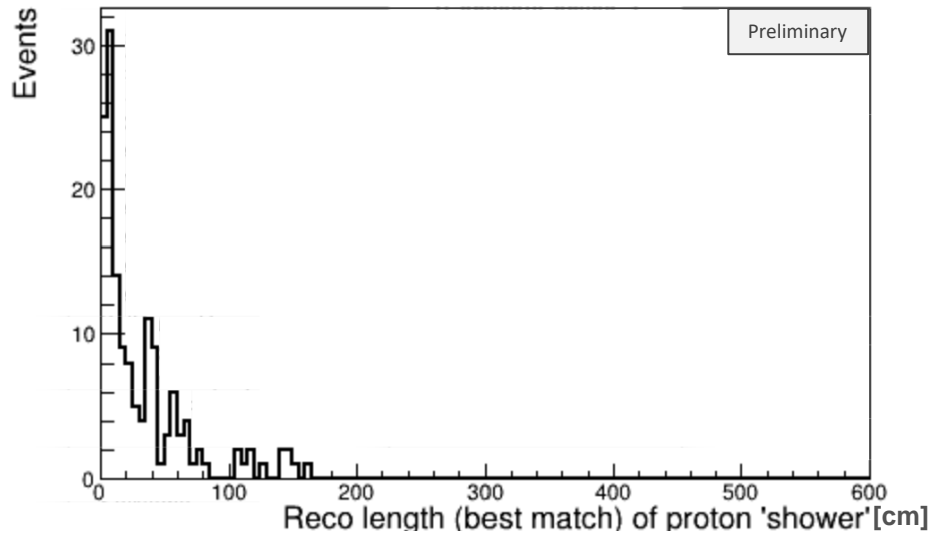
Type of Protons Events	Number	Percentage	
Found only in the reconstructed tracks	2990	80,0%	<input checked="" type="checkbox"/>
Found only in the reconstructed showers	158	4,2%	<input type="checkbox"/>
Found both in reconstructed tracks and showers*	463*	12,4%	<input checked="" type="checkbox"/> <input type="checkbox"/>
Not reconstructed at all	127	3,4%	<input type="checkbox"/> <input type="checkbox"/>
Total	3738	\	

*of which **218** have most of their energy reconstructed as a shower, meaning their best match is a shower

Example of Cut: only match is a shower – MC simulated data

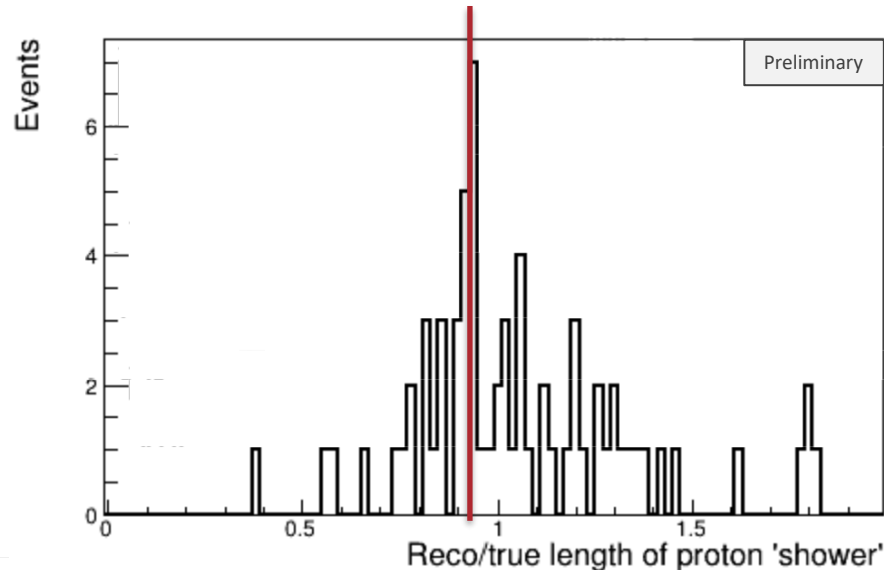
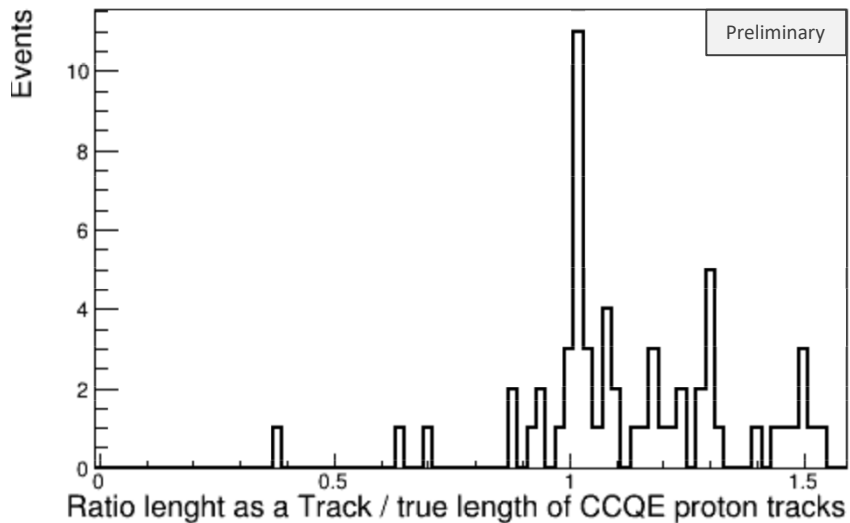


Example of Cut: only match is a shower – MC simulated data



Example of Cut: only match is a shower – MC simulated data

We can look at the reconstruction as a **track** for this sample.

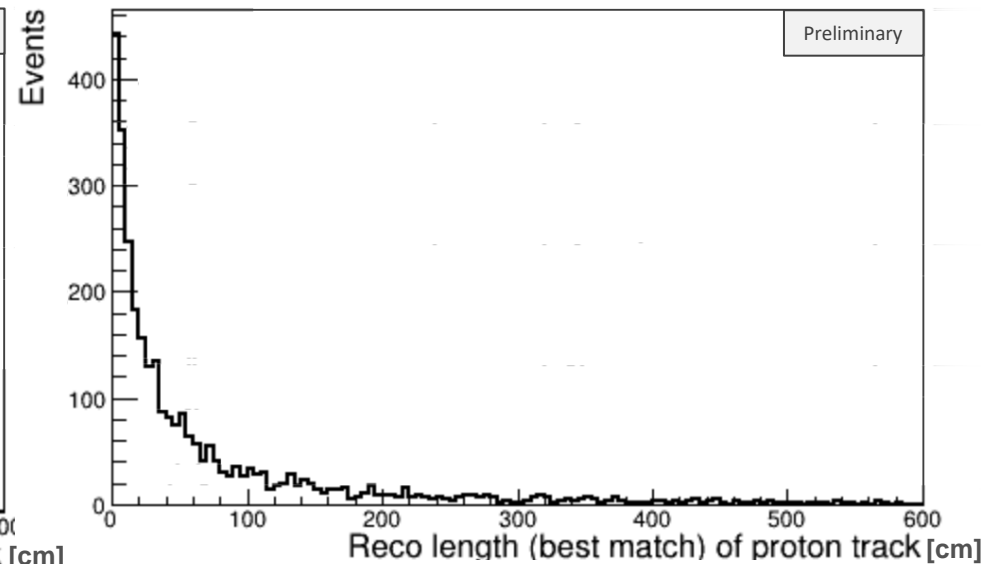
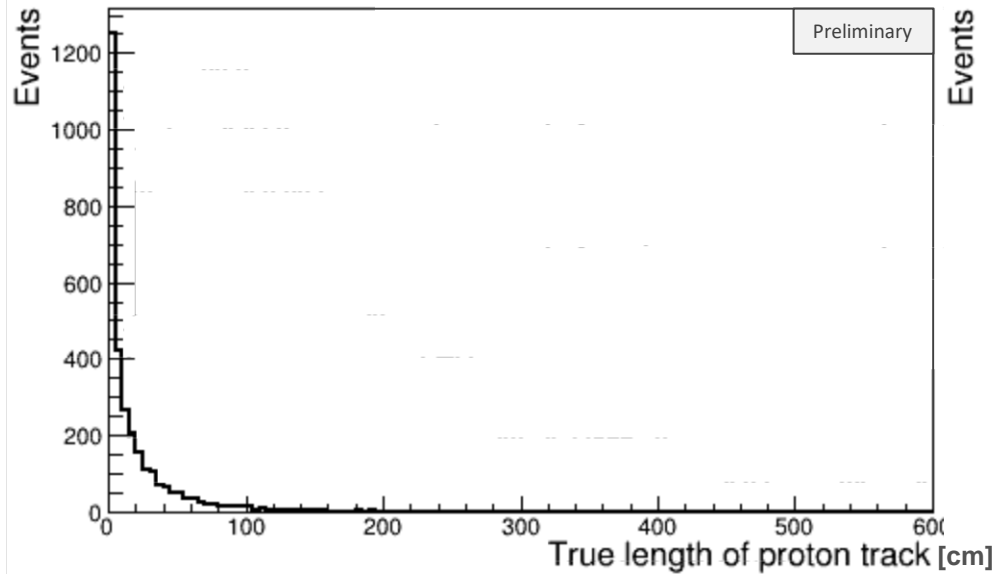


What has been done? Look for a **sample of “good events”** as a reference to **compare the BDT’s variable** of the difference cut topology

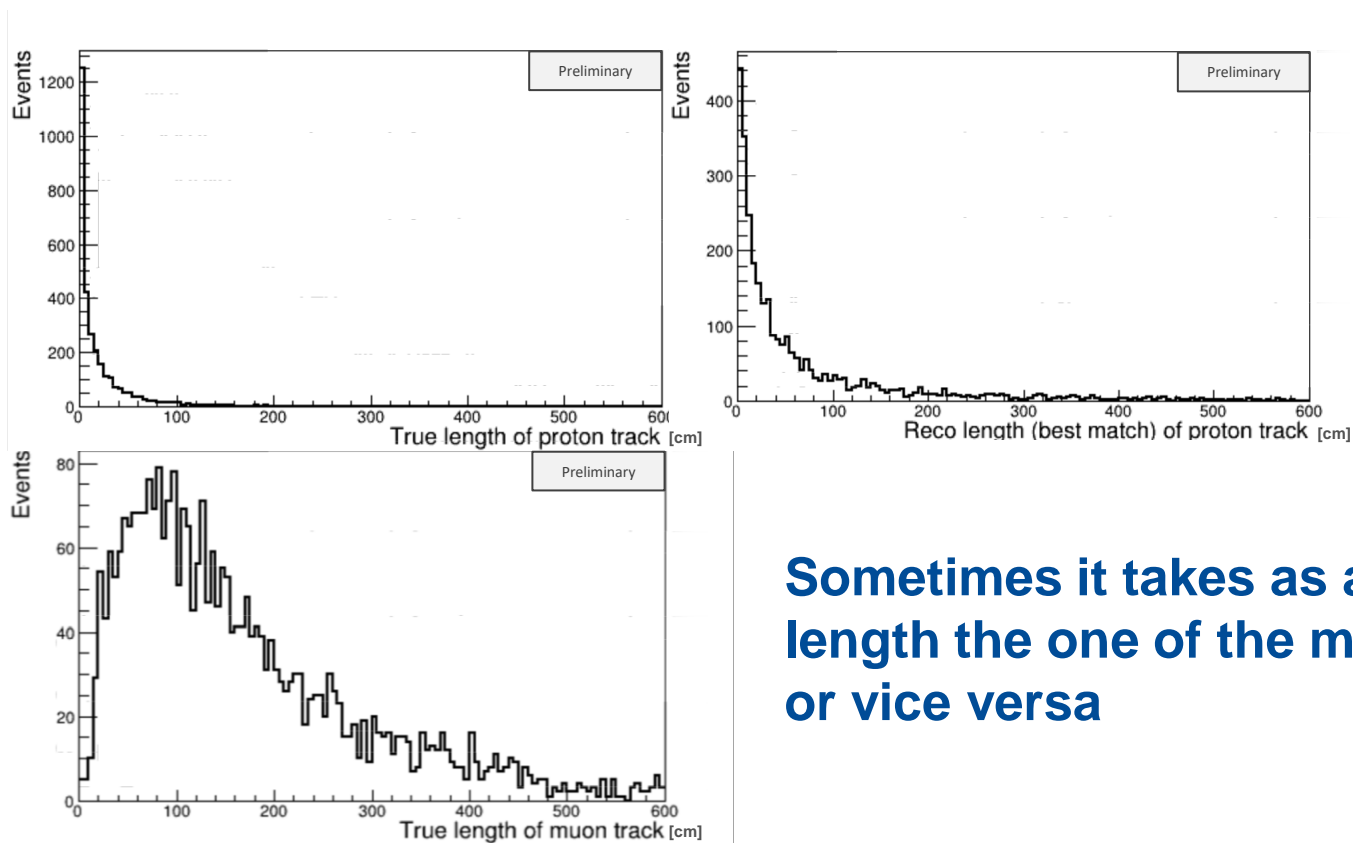
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Total	3738	\

→ **Is this the right choice?**

Example of Cut: only match is a Track – MC simulated data



Only match is a Track – MC simulated data




Sometimes it takes as a length the one of the muon or vice versa

What has been done? Look for a **sample of “good events”** as a reference to **comparing the BDT’s variable** of the difference cut topology

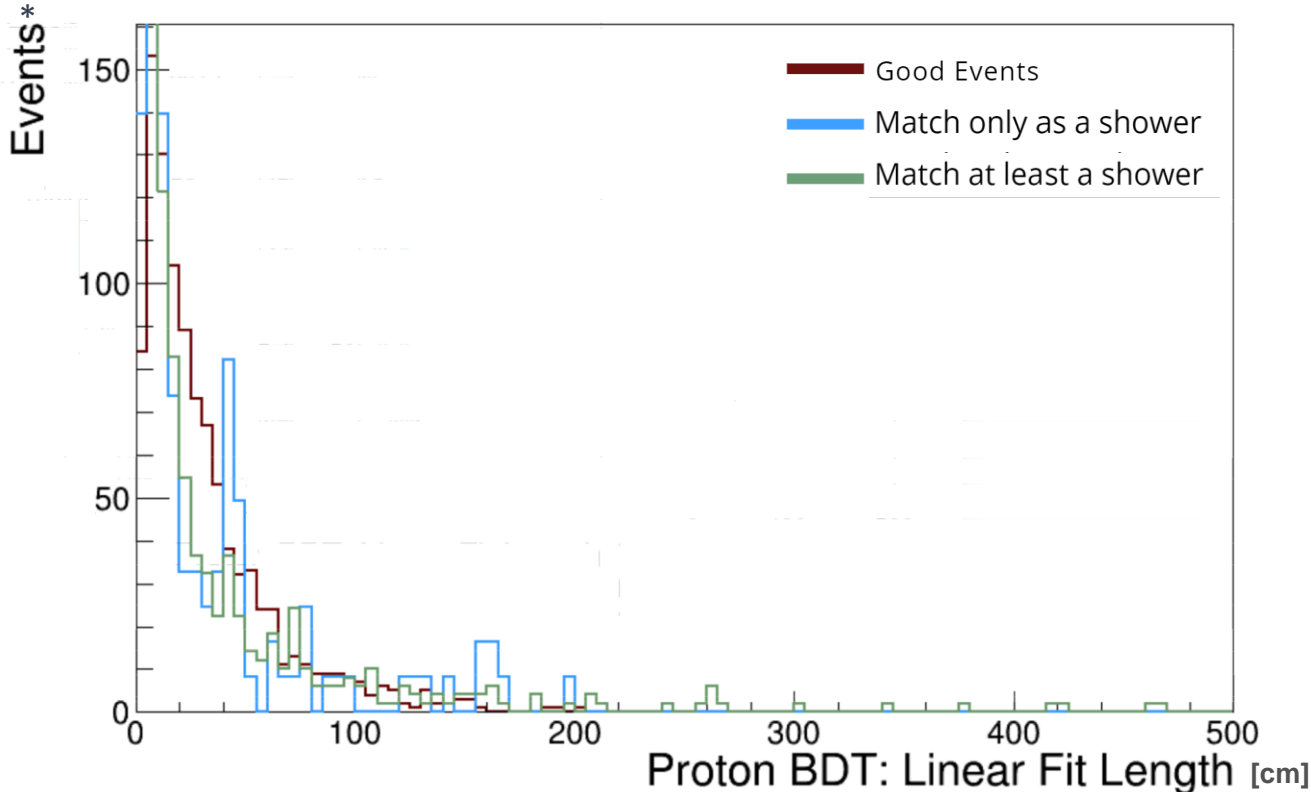
Type of Protons Events	Number	Percentage
Found only in the reconstructed tracks	2990	80,0%
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→ **Is this the right choice?**

What has been done? Look for a **sample of “good events”** as a reference to **comparing the BDT’s variable** of the difference cut topology

Type of Protons Events	Number	
Found only in the reconstructed tracks	2990	-
Reconstructed proton length == reconstructed muon length	883	-
Muon not reconstructed as a track	25	-
Completeness and Purity < 90% for proton	899	-
Completeness and Purity < 90% for muon	164	=
Good Sample:	1019	 Good Events

BDT's variables



Proton: topology of cut

Type of Protons Events	Number	Percentage
Found only in the reconstructed tracks	2990	80,0%
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Not reconstructed at all	127	3,4%
Total	3738	\

— Match only as a shower

— Match at least a shower

Run 11 SubRun 18 Event 8 (best match is a shower) - MC simulated data

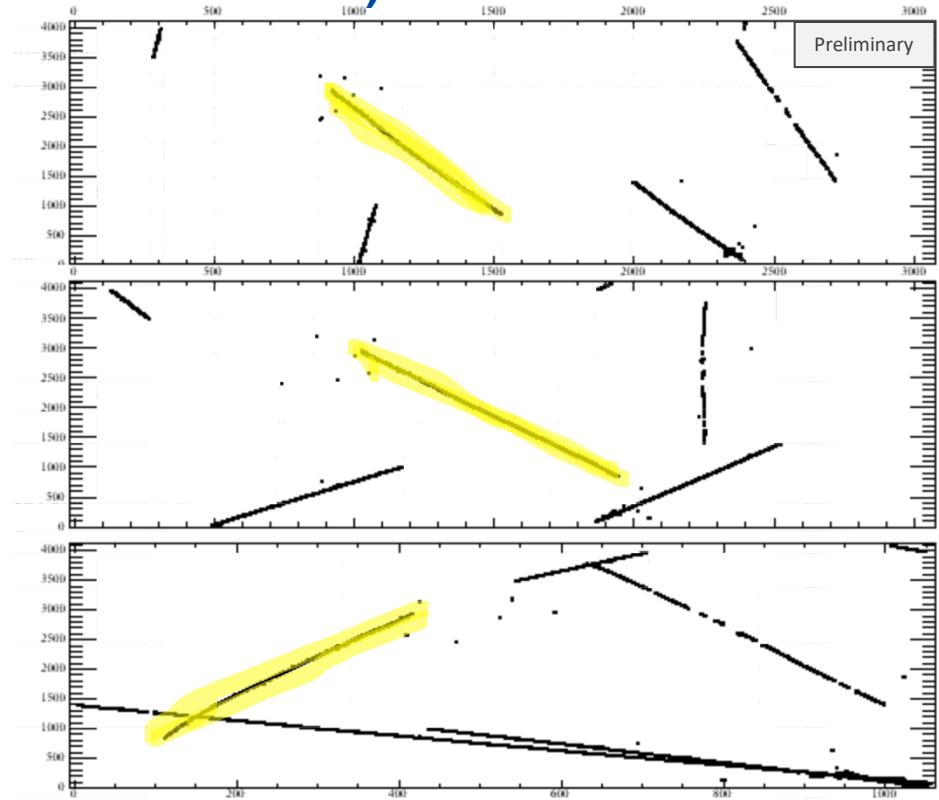
PROTON

xStart **228.152** xEnd 226.29
yStart **-57.5873** yEnd -56.7188
zStart **-631.652** zEnd -632.641
length 2.28083
Reco length (as a Shower) 2.81928
Egen 0.987579
Edep 0.0493066
EMatchBest 0.0417645

MUON

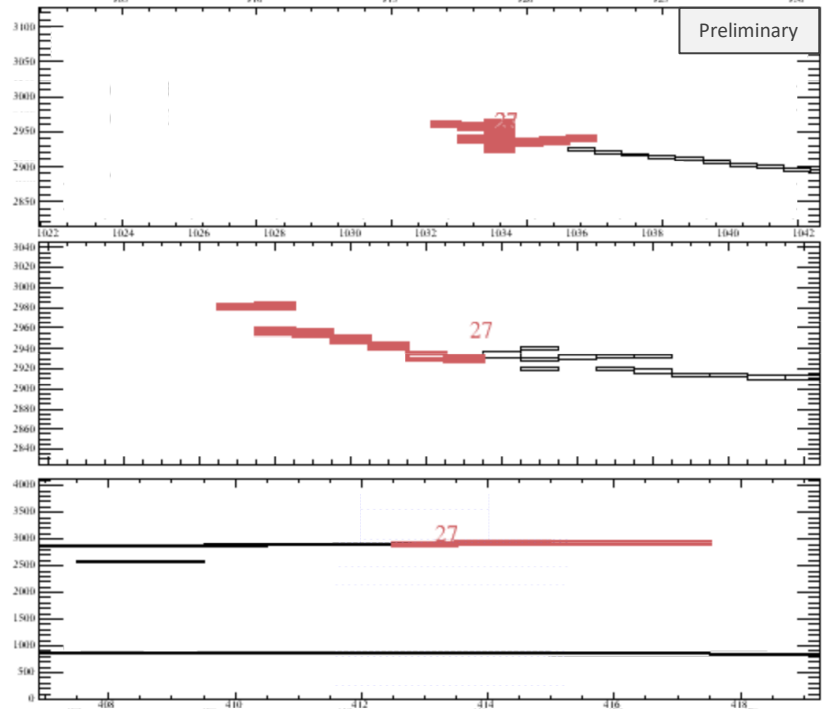
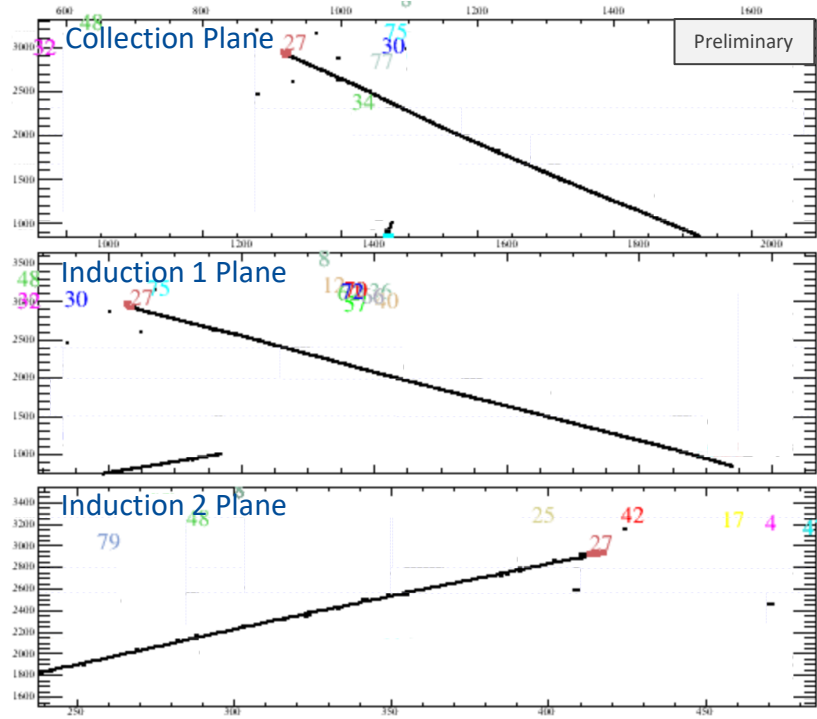
xStart **228.152** xEnd 358.49
yStart **-57.5873** yEnd -148.399
zStart **-631.652** zEnd -370.186
length 306.284
reco_length_Best 304.793
Egen 1.28524
Edep 0.667817
EMatchBest 0.535782

VERTEX
POSITION



Angle between muon and proton: 2.55302 radians

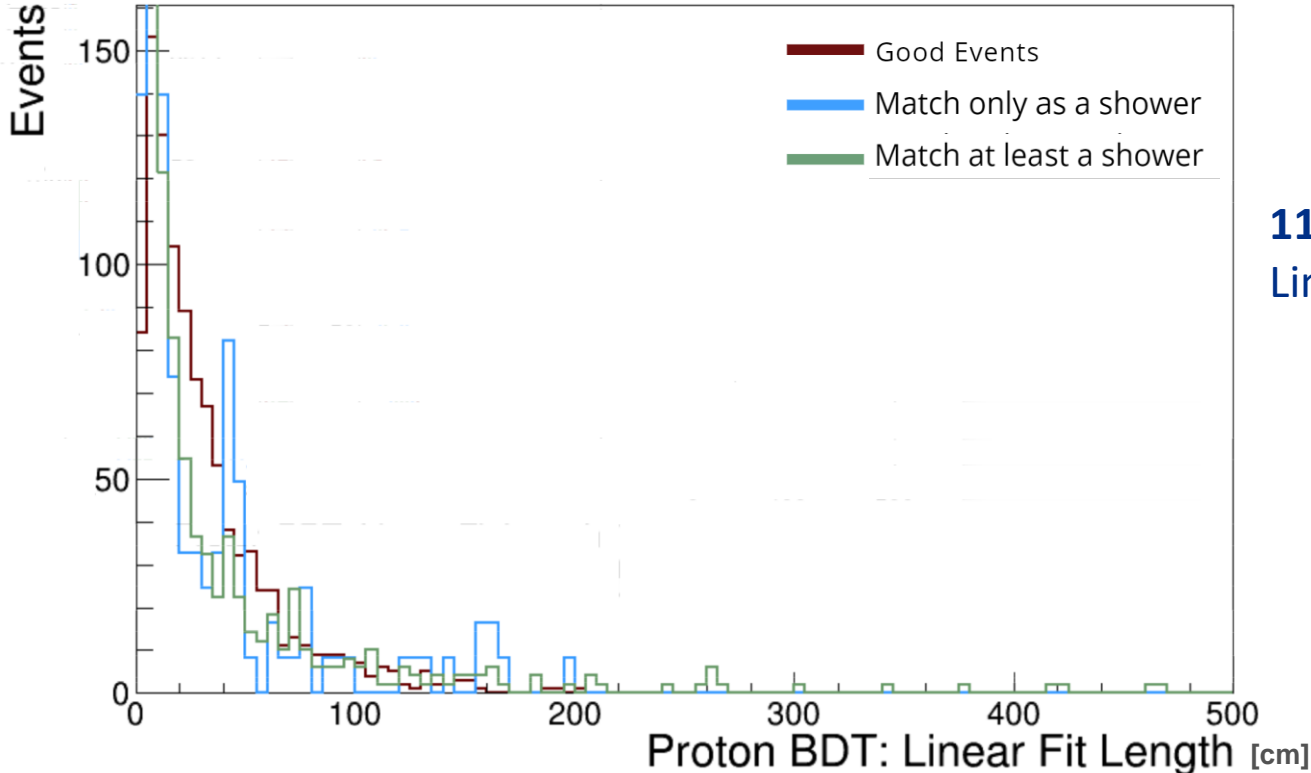
Run 11 SubRun 18 Event 8 (best match is a shower) - MC simulated data



The red particle is the proton reconstructed as a shower



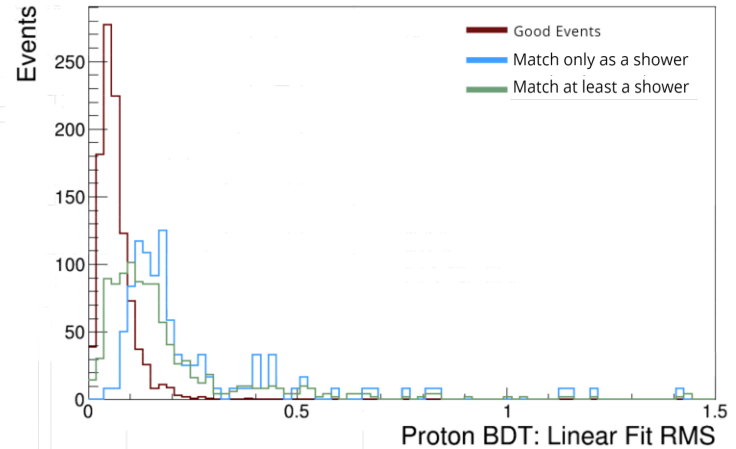
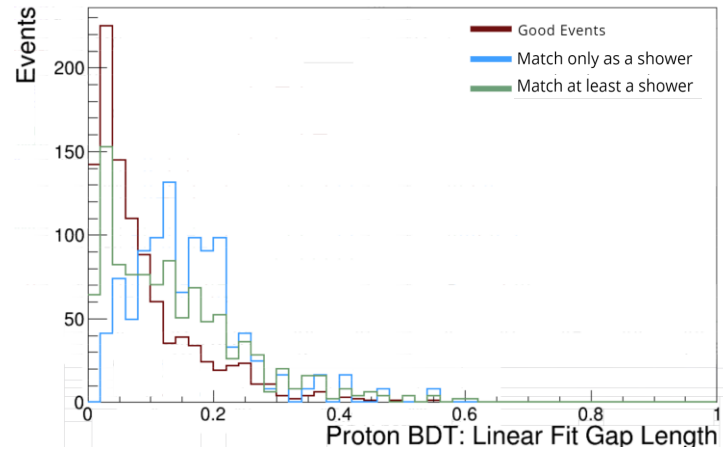
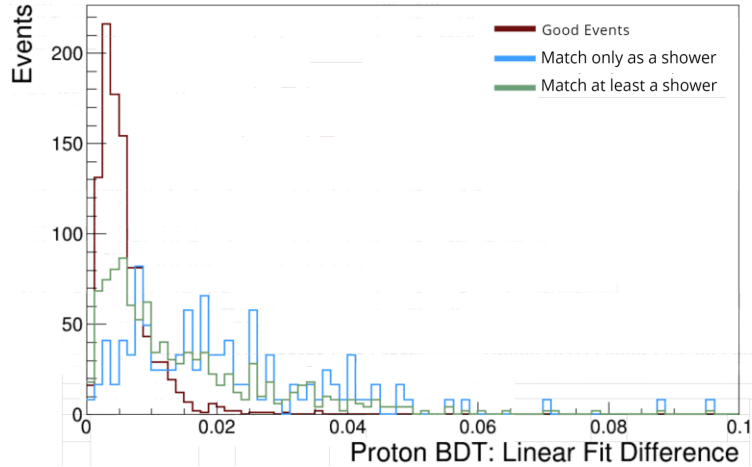
BDT's variables



11:18:12
LinearFitLength: 4.09 cm



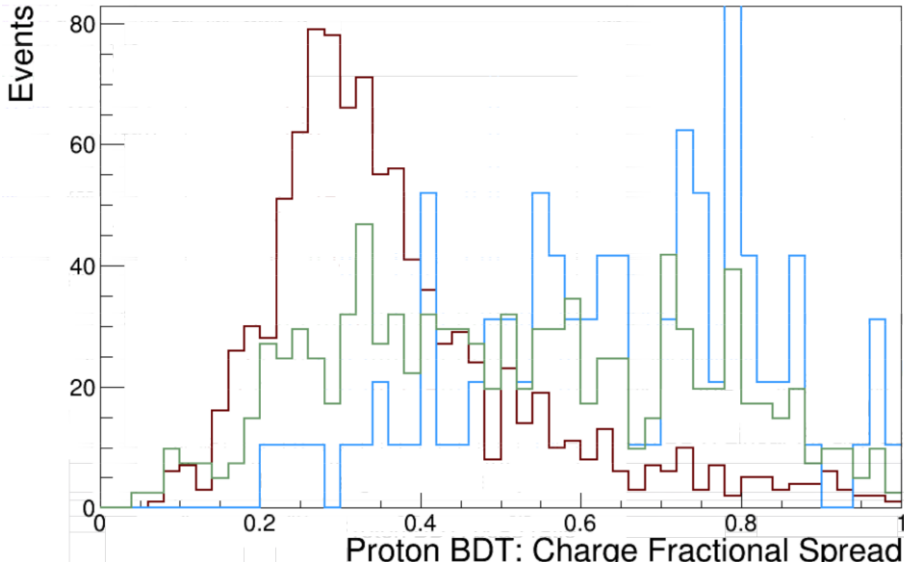
BDT's variables



11:18:12

LinearFitDifference: 0.03
LinearFitGapLength: 0.18
LinearFitRMS: 0.29

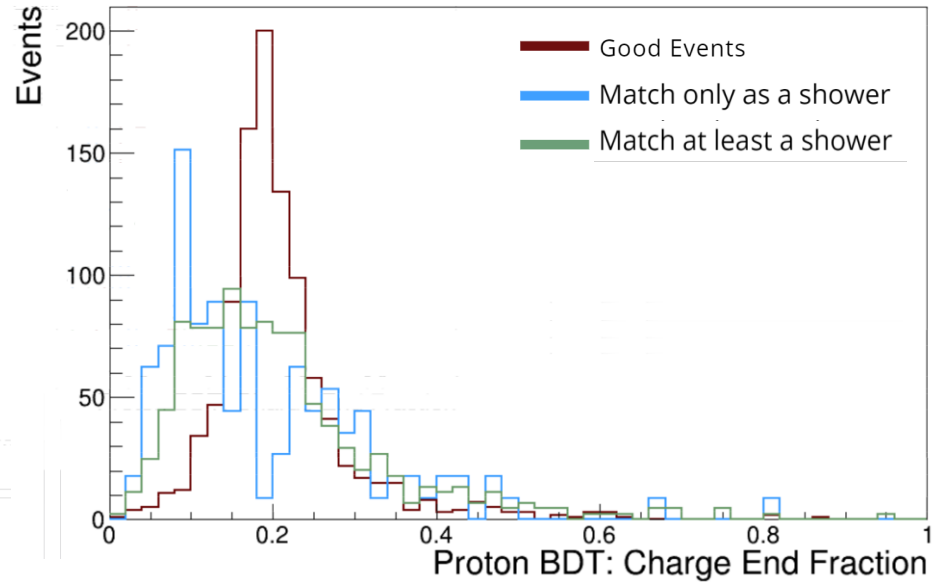
BDT's variables



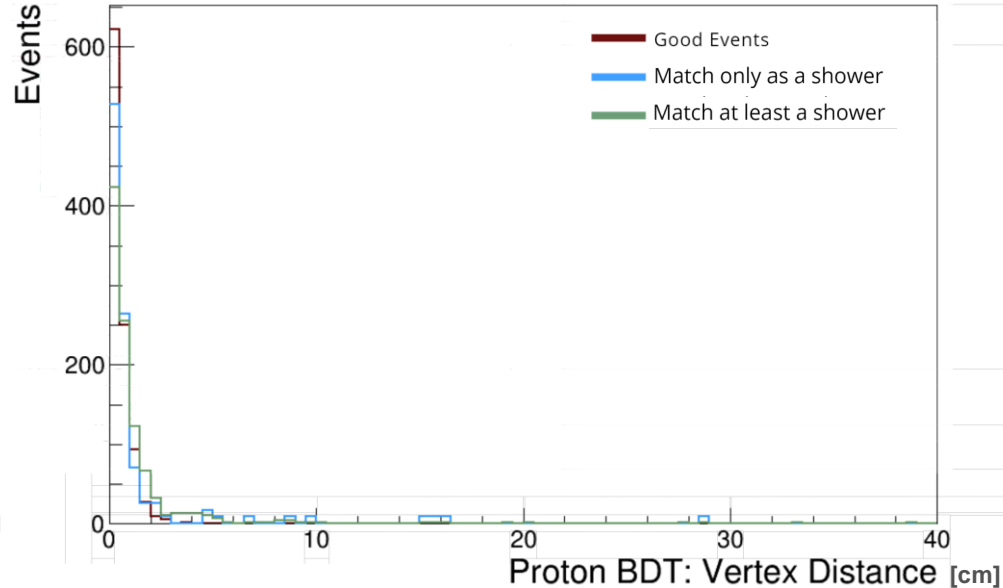
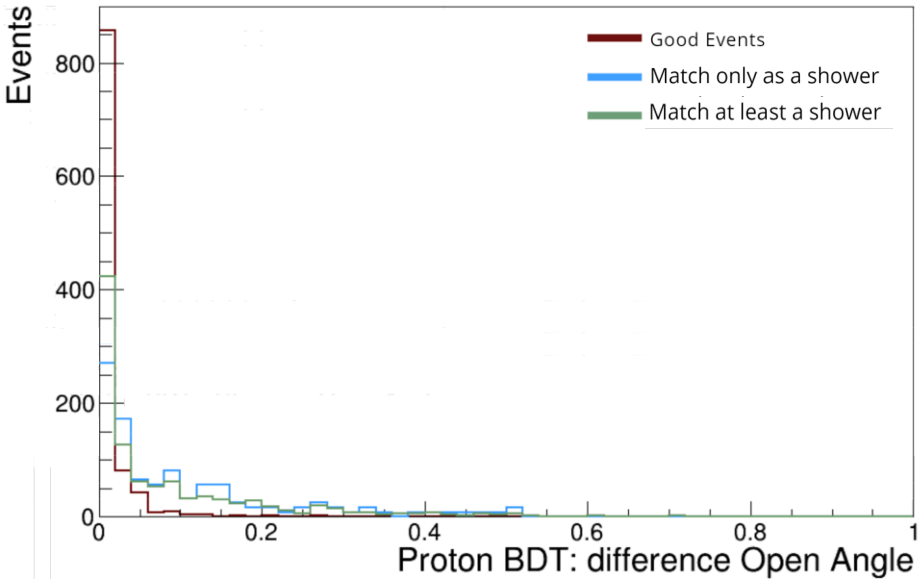
11:18:12

ChargeEndFraction : 0.23

ChargeFractionalSpread: 0.59



BDT's variables

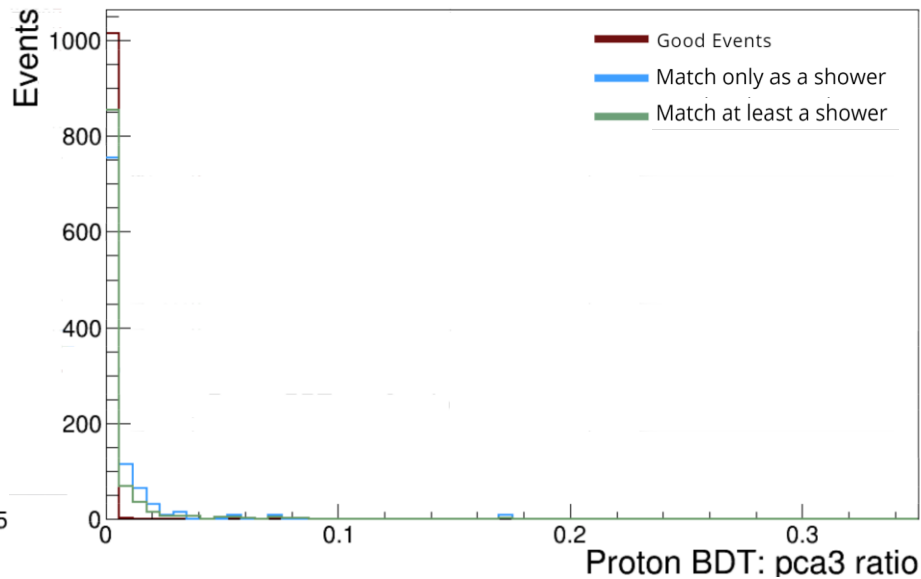
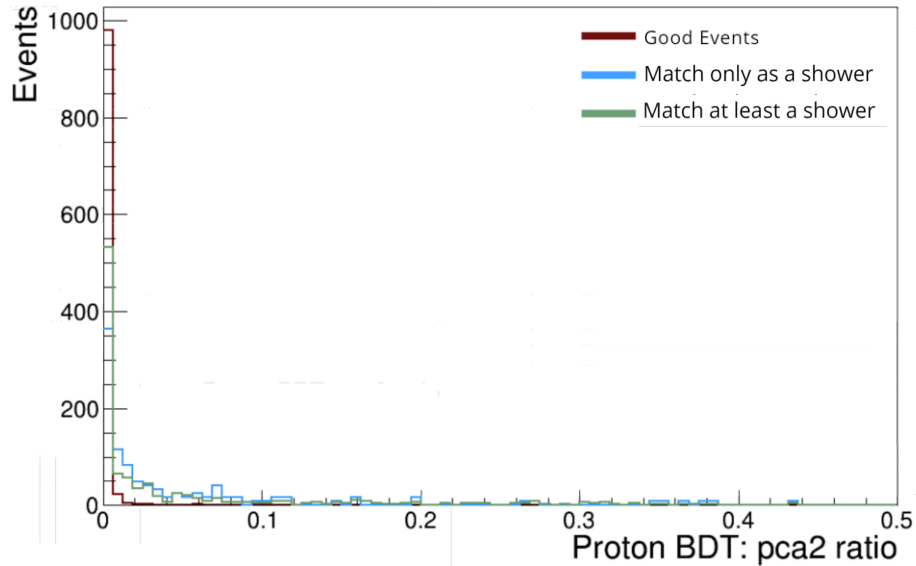


11:18:12

Vertex Distance:0.03

DifferenceOpenAngle:1.02

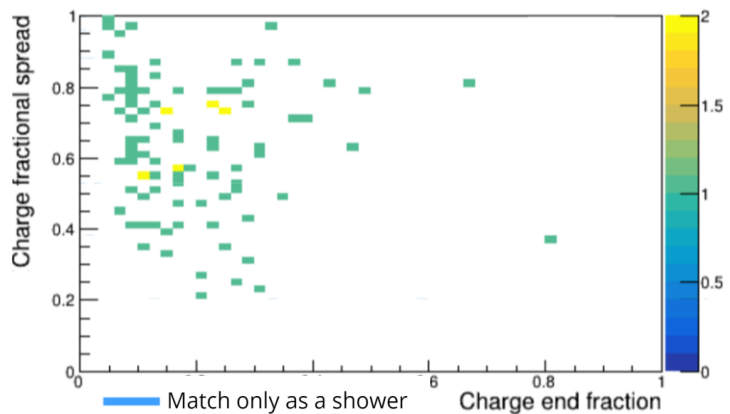
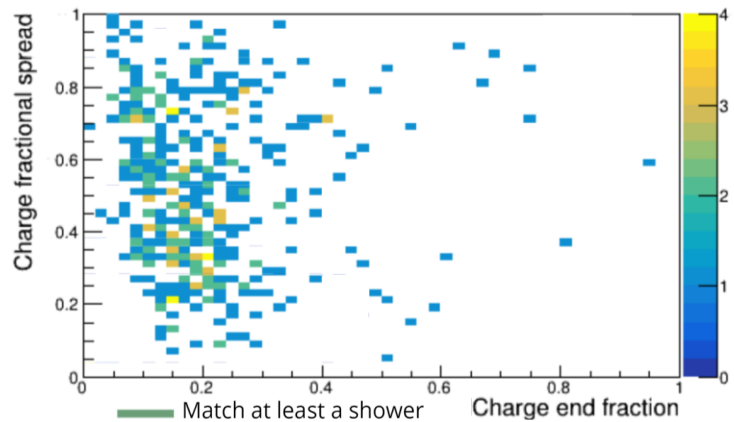
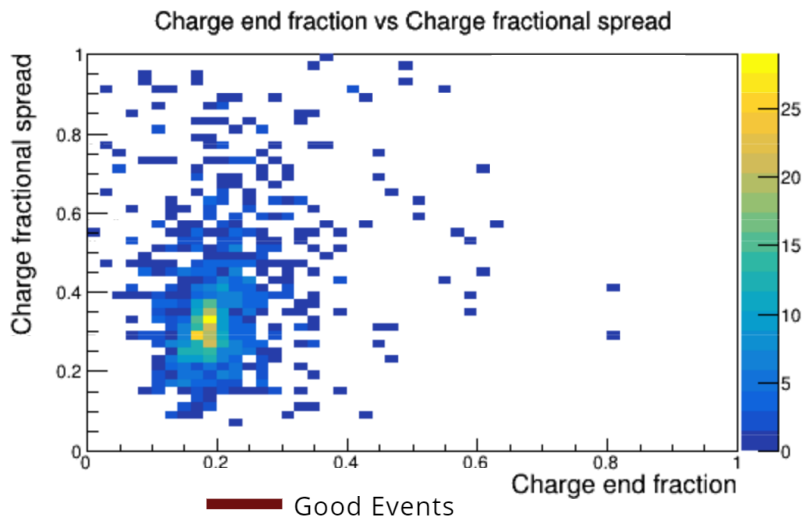
BDT's variables



11:18:12

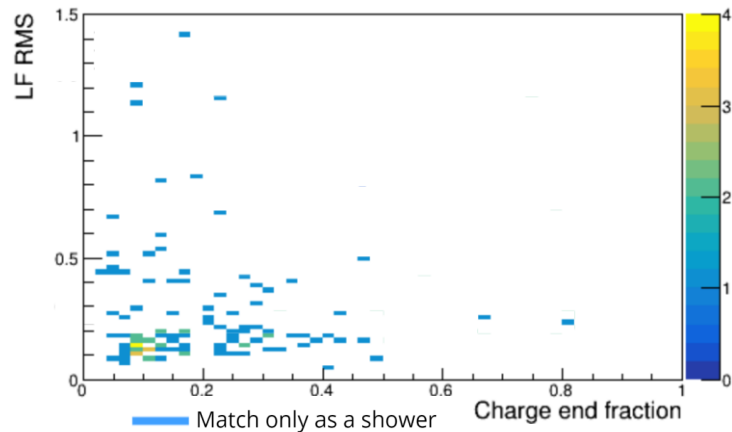
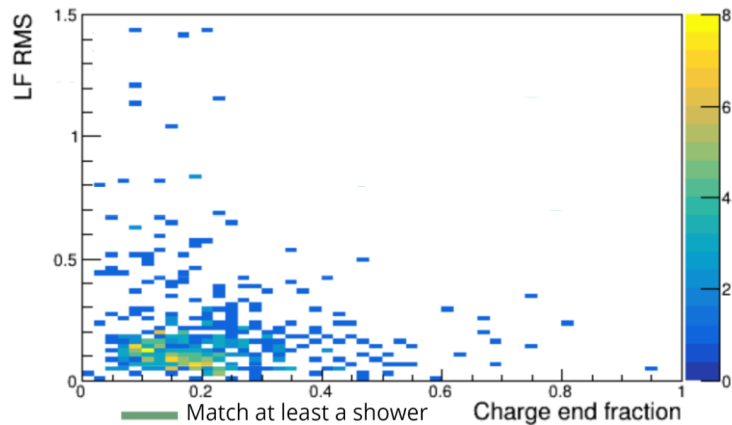
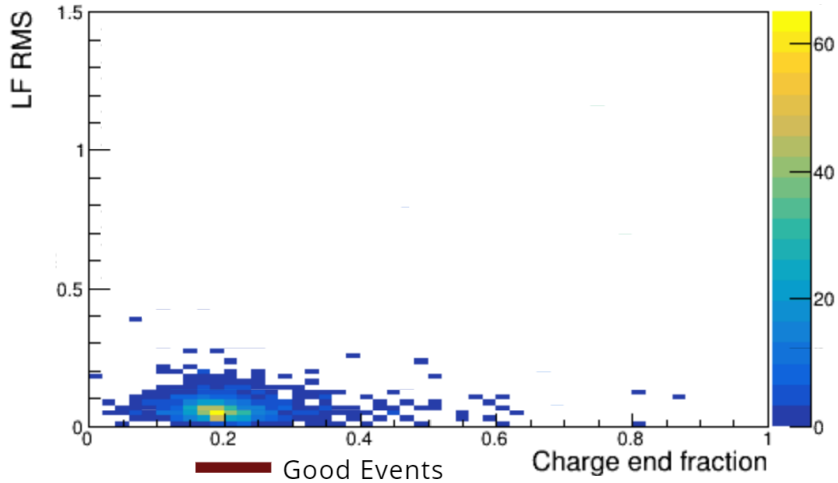
pca2ratio: 0.01

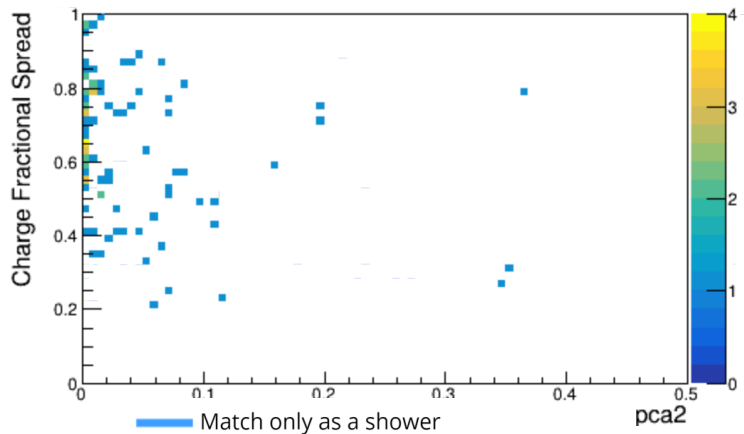
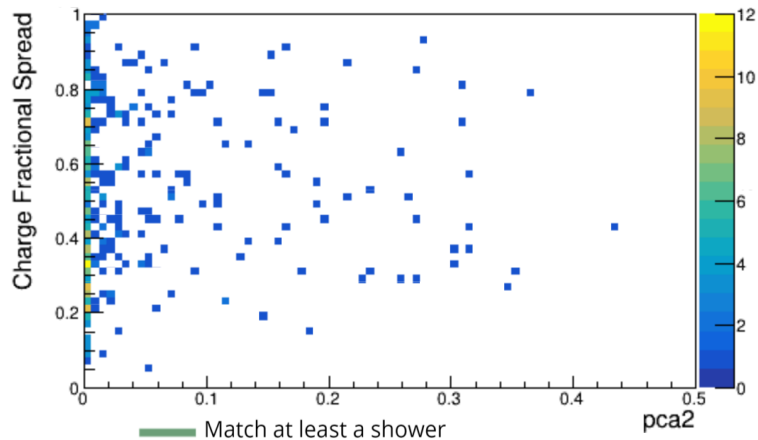
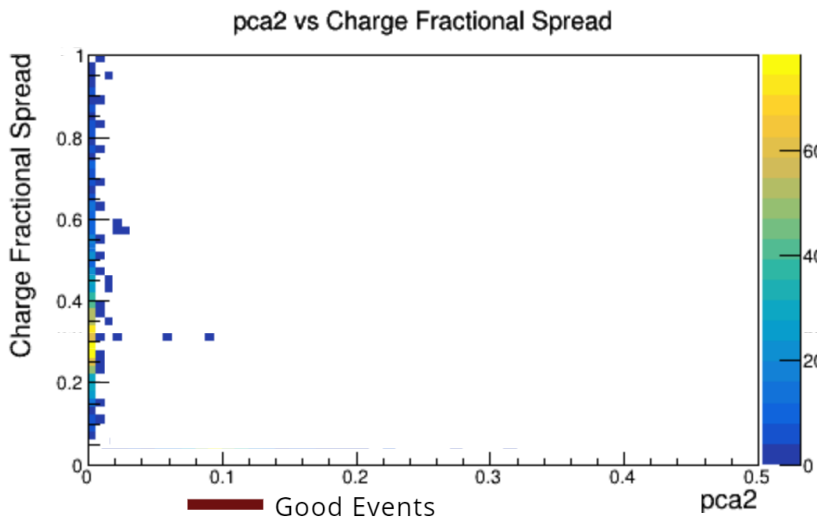
pca3ratio: 0.33





Charge end fraction vs LF RMS





Summary

- Looked to a Set of MC simulated in order to clarify the proton reconstruction (as a shower or as a track)
- Looked at the BDT variables to understand the situation.

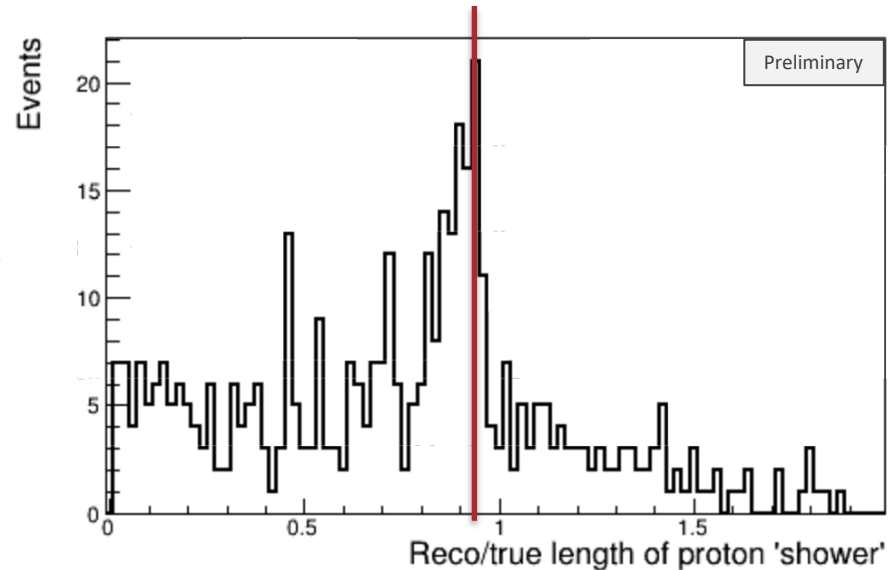
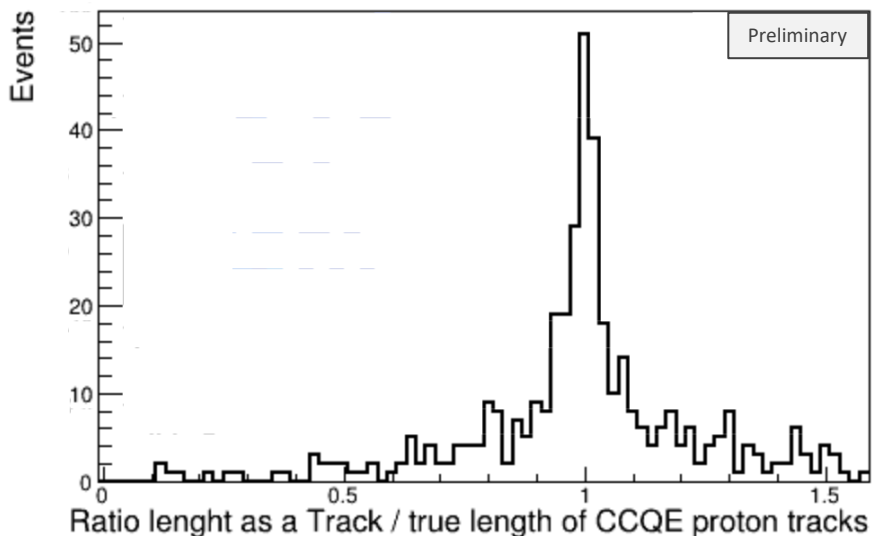
For the next few days:

- Look at the track fit and *get **the calorimetry proton chi2** (a variable that looks at the dE/dx along the particle and calculates a chi2 comparison of the found dE/dx versus the expectation for different particles)*;
- Looking at the BDT variables for some sample of real data;

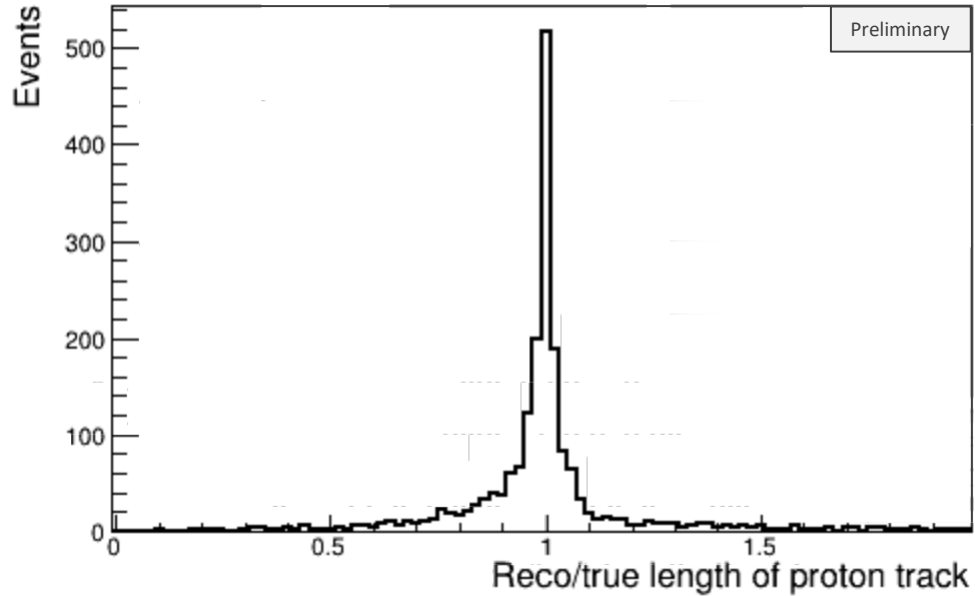
Thank you for your attention

Backup

Example of Cut: match at least a shower – MC simulated data



Example of Cut: only match is a track – MC simulated data



Track Score BDT

- The BDT uses 10 input variables:
 - Length — estimate of length of the reco particle
 - Sliding Linear Fit: *Estimate of difference with respect to a straight line (/ length)*
 - Sliding Linear Fit: *Estimate of largest gap on the 3 planes (/ length)*
 - Sliding Linear Fit: *Estimate of RMS w.r.t. the fit (/ length)*
 - Vertex distance: *Distance from interaction vertex (reco) to start of reco particle*
 - Difference in “opening” angle & “closing” angle (from 2 points at beginning & end of particle)
 - Principal Component Analysis: *secondary eigenvalue / primary* (estimate of how linear)
 - Principal Component Analysis: *tertiary eigenvalue / primary* (estimate of how linear)
 - Charge: *fractional spread* (using spread in values and mean value)
 - Charge: *fraction near the end of particle* (using charge near end and total)

- Matched_hits: $\text{hits}_{\text{MC particle}} \cap \text{hits}_{\text{reco tracks}}$

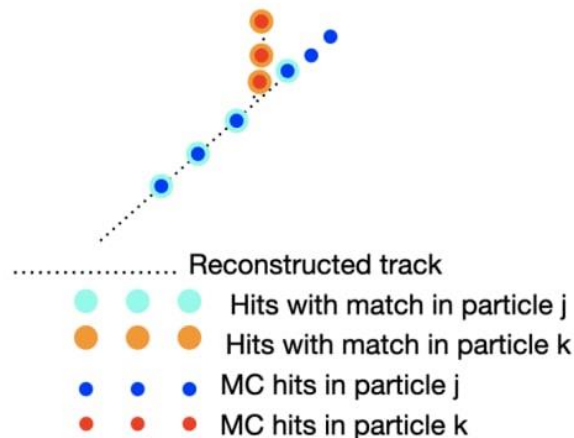
[particle $j \rightarrow 4$, particle $k \rightarrow 3$]

- Purity: $\frac{\text{Matched hits}}{\text{hits}_{\text{reco tracks}}}$

[particle $j \rightarrow 4/7$, particle $k \rightarrow 3/7$]

- Completeness: $\frac{\text{Matched hits}}{\text{hits}_{\text{MC particle}}}$

[particle $j \rightarrow 4/6$, particle $k \rightarrow 3/3$]



For each true particle the **best match** is identified as the reconstructed track with the highest energy from the matched hits

11

References

- [1] Chrisitan Farnese || 20 July 2022 || Neutrino Search with the Icarus Detector
- [2] José I. Crespo-Anadón || 20 July 2022 || The MicroBooNE Experiment
- [3] B. Howard || 20 April 2022 || Neutrino hunting with ICARUS at Fermilab B
- [4] B. Howard || 25 April 2022 || Brief update on track vs shower BDT scores
- [5] P. Machado, O. Palmara, D. Schmitz || Annu. Rev. Nucl. Part. Sci. (1019). Doi: 10.1146
- [6] A.P. Serebrov, R.M. Samoilov, M.E. Chaikovskii || Doi:10.48550
- [7] F. Poppi || FNAL 55° Annual Users Meeting|| ICARUS spreads its wings