Beam Line Instrumentation/Interface

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MICHIGAN STATE UNIVERSITY

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

Outline

Beamline Layout

Reconstructed Info

How to Use/Access Information

Monitor Glitch + Fix

Monte Carlo -- Momentum Bias/Resolution

Monte Carlo -- Data Product Implementation

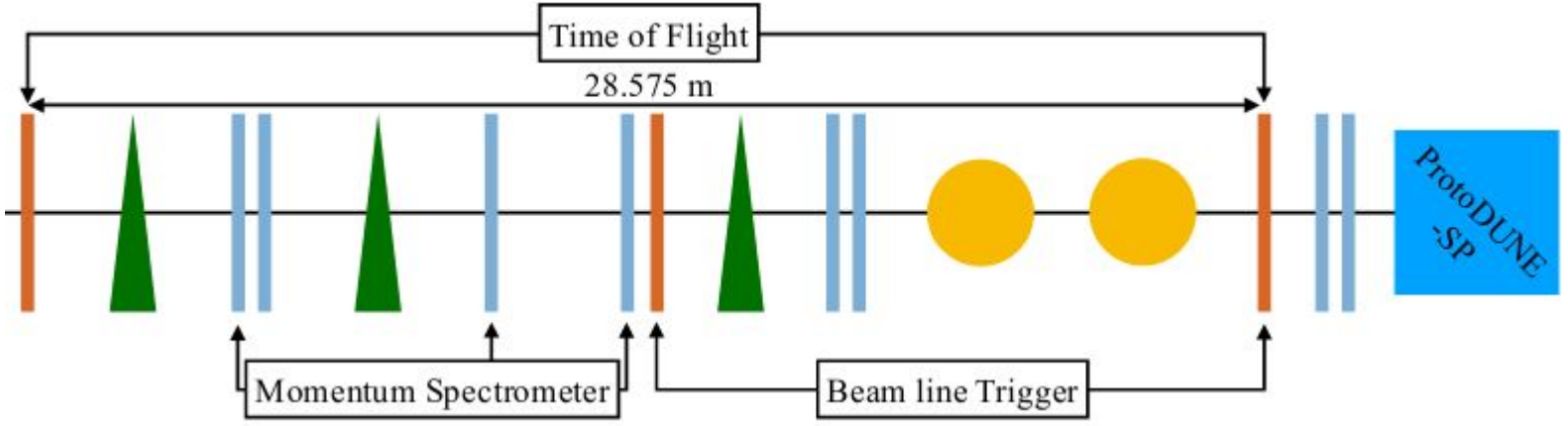
Beam Line Layout

Bending Magnets

Scintillating Fiber Profile Monitors For Momentum/Tracking

Scintillator Planes for Time of Flight (TOF) and Trigger

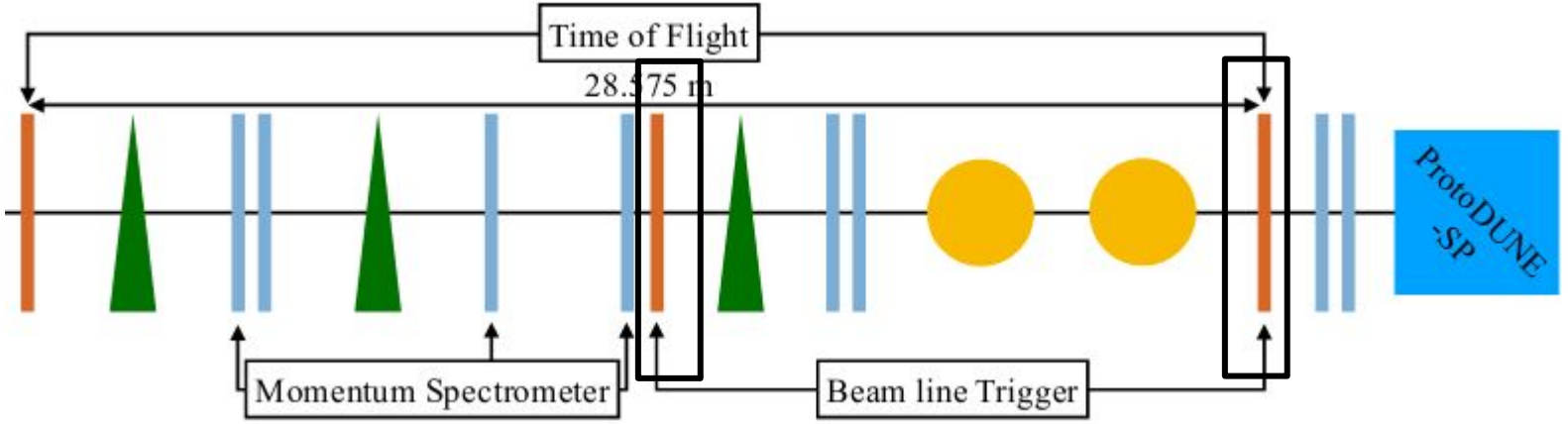
Cerenkov Devices for Particle ID (PID)



General Trigger

Coincident hits between the middle and downstream scintillator planes serve as a General Trigger (GT) for the rest of the beam line

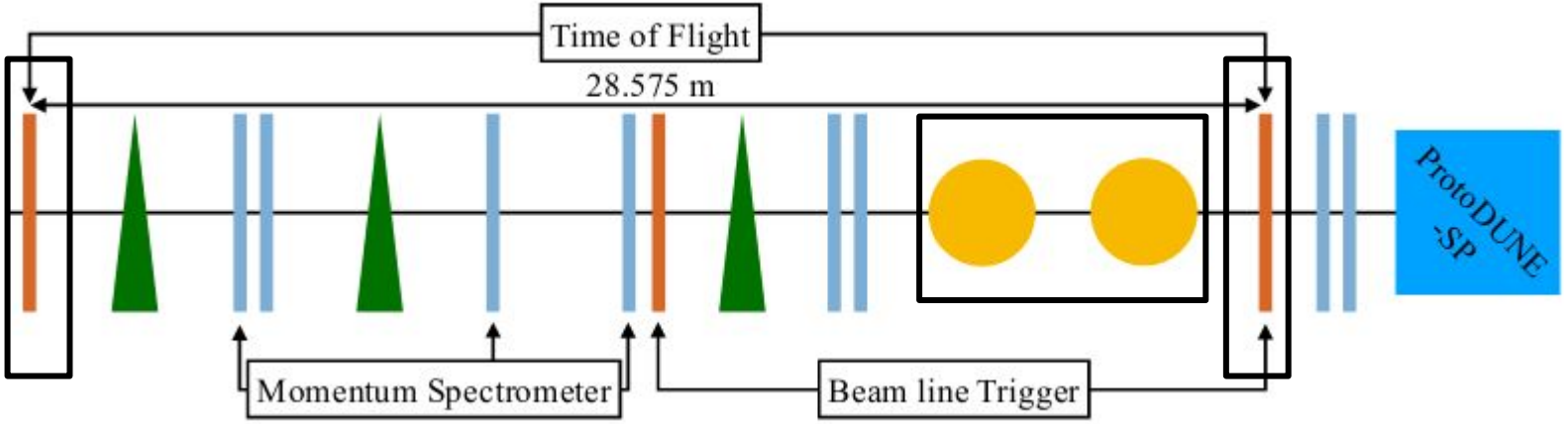
- Data from the other BI components matched to these triggers via timestamps
- A signal is also sent to the PDSP Timing System to produce a trigger for a TPC event



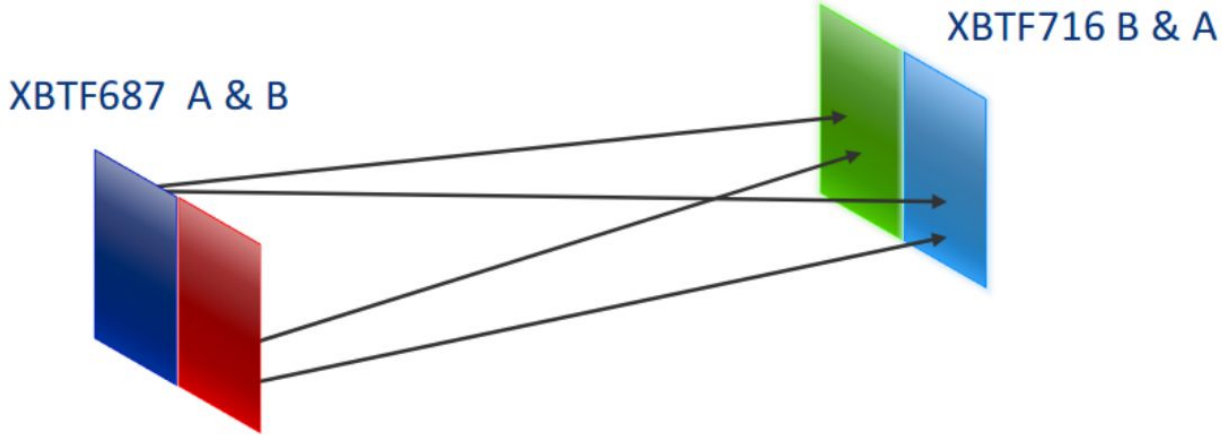
Time of Flight + Cherenkov Detectors

Upstream and downstream scintillator planes matched to GT
→ Difference between timestamps provides TOF measurement

Cherenkov detectors
→ Timestamps searched for match to GT
→ If found: device considered active for the event



Time Of Flight Channels



Scintintillating planes for TOF have 2 halves → 4 pair-wise combinations

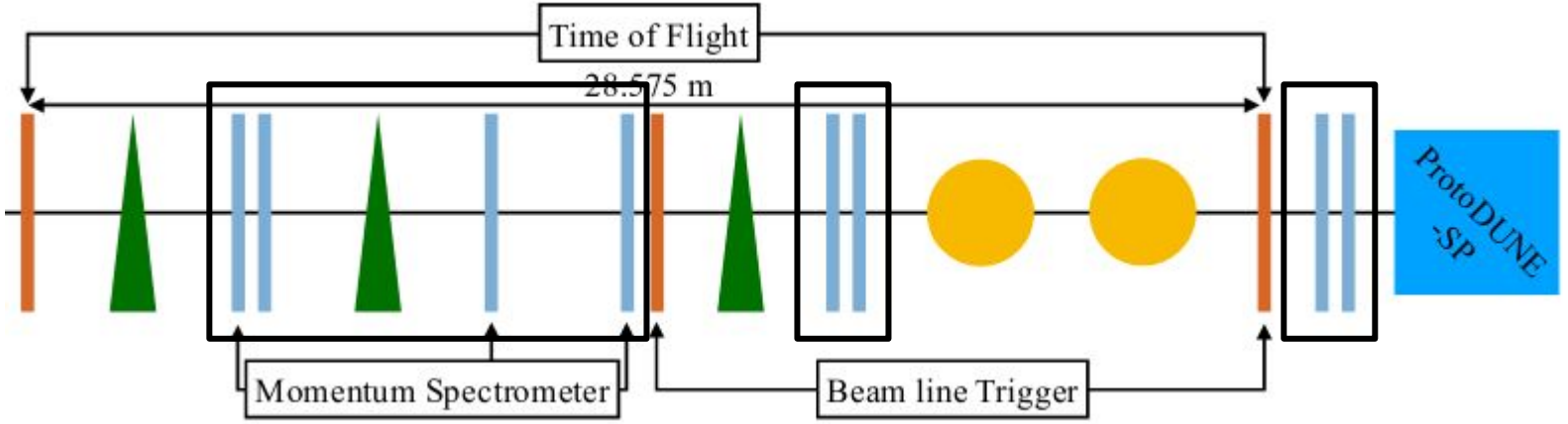
Each channel has their own calibration -- behind the scenes for users

Momentum and Tracking

Use hits in the Fiber Monitors

One set for momentum reconstruction

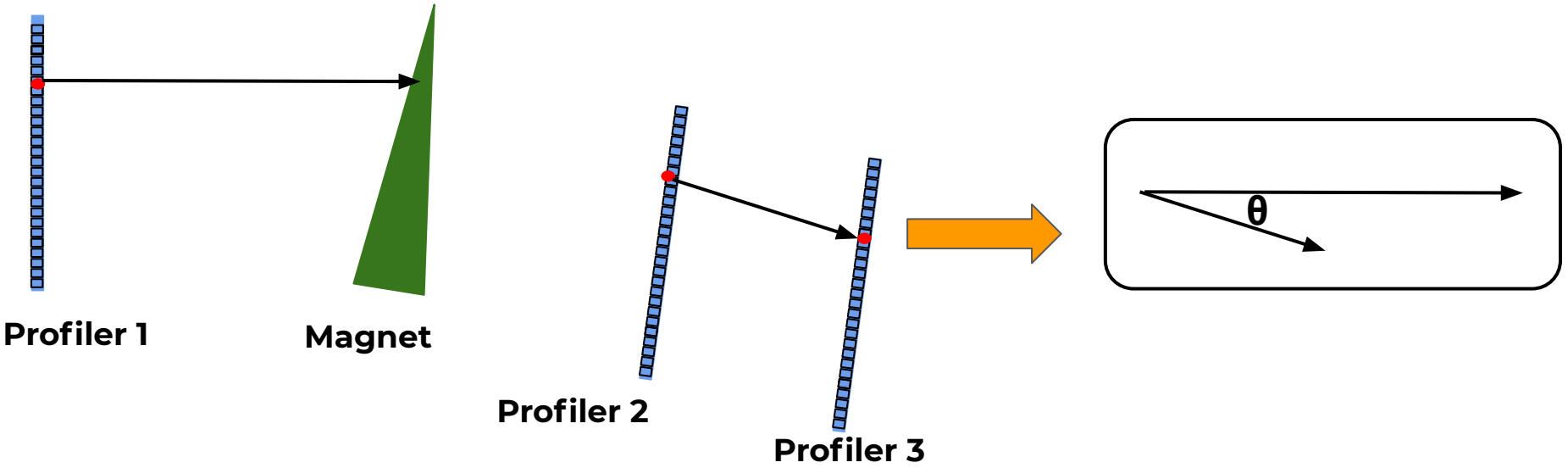
Other set for tracking



Momentum Calculation

Project hit in Profiler 1 to magnet, connect hits in Profilers 2,3
→ Get **θ** between these trajectories

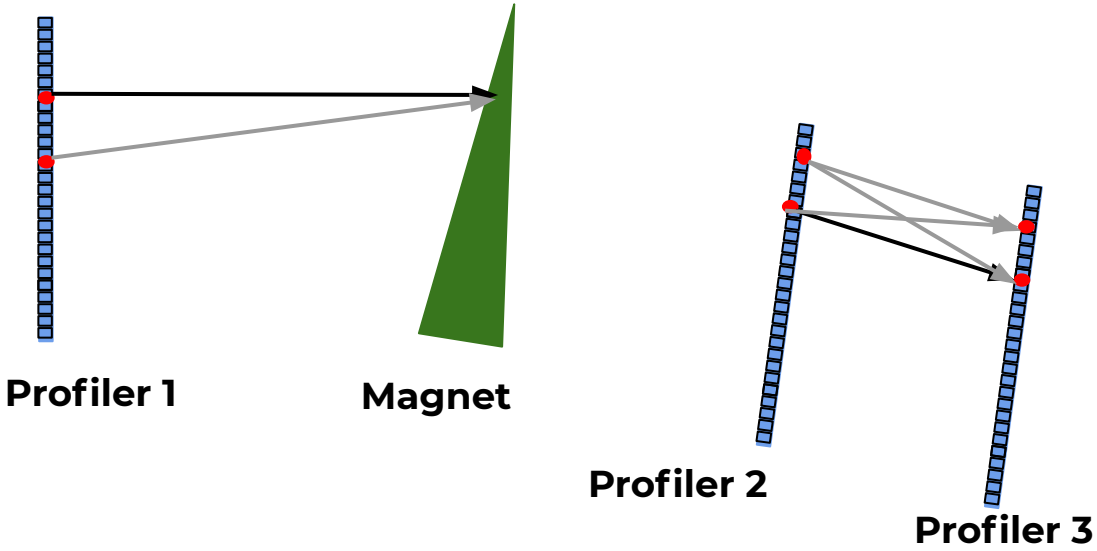
Get current in magnet: $\mathbf{I_B}$
→ Momentum: p ~ f($\mathbf{I_B}$) / **θ**



Multiple Hits

Multiple hits in profilers
→ Multiple trajectories w/ different **θ**

1) Which set of hits to use **2)** Very wrong values for reconstructed momenta
→ Choose events with 1 reconstructed momentum

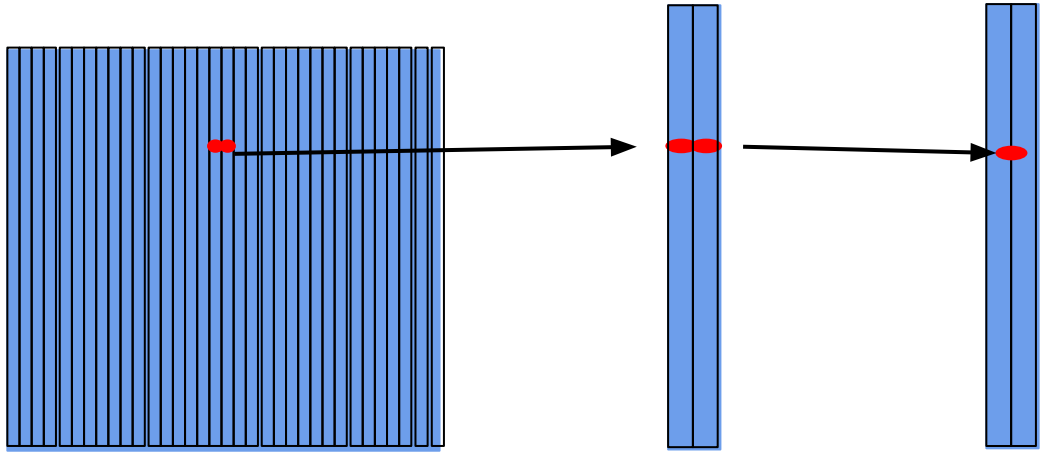


Neighboring Hits

Normally, position of hits in monitors are placed at center of fiber (1mm).
Neighboring hits → Condense to boundary between fibers.

±0.5mm shift in position

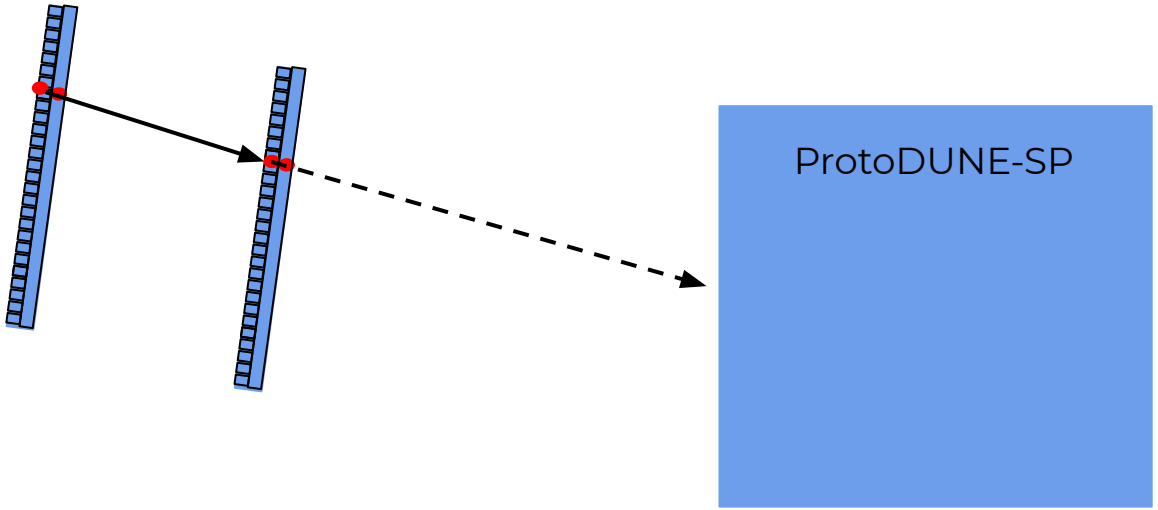
Skews reconstructed values → Choose events with exactly 1 hit in each monitor



Incident Tracks

Last 4 monitors provide 2D positions
→ Project this trajectory toward the TPC face

Multiple hits can produce degenerate tracks
→ Choose events with 1 reconstructed track



How To Access BI Info

ProtoDUNEBeamlineUtils

A utility class is available in protoduneana to help with accessing info

Include in module fcl:

```
1 #include "ProtoDUNEBeamlineUtils.fcl"
2
3 BEGIN_PROLOG
4
5 beamline_reco:
6 {
7     module_type:          "ProtoDUNEBeamlineReco"
8     BeamlineUtils:        @local::standard_protodunebeamlineutils
```

Instantiate in class:

```
70 protoana::ProtoDUNEBeamlineReco::ProtoDUNEBeamlineReco(fhicl::ParameterSet const& pset):
71   EDAnalyzer(pset),
72   fBeamlineUtils(pset.get<fhicl::ParameterSet>("BeamlineUtils")),
73   fDoGlitches( pset.get< bool >( "DoGlitches" ) )
74 {
75   this->reconfigure(pset);
76 }
```

ProtoDUNEBeamlineUtils

GetBeamEvent(art::Event const & evt) Method to get the beam event product from an art::Event

IsGoodBeamlineTrigger(art::Event const & evt) Checks the PDSP trigger type and if the beam trigger is matched to TPC event

HasPerfectBeamMomentum(art::Event const &) **(New!)** Checks if only 1 fiber is active in each fiber monitor of the momentum spectrometer

ProtoDUNEBeamlineUtils

GetPID(art::Event const & evt, double nominal_momentum) Returns a vector of ints representing the possible PDG codes of the beam particle. Need to input reference momentum

GetPIDCandidates(...) Same as above, but returns struct containing bools for each particle type (e, p, pi, mu, K, d -- See backup)

Info from Data Product

Class **beam::ProtoDUNEBeamEvent** (dunetpc)

GetRecoBeamMomenta() Returns vector of possible reconstructed momenta

GetBeamTracks() Returns vector of possible reconstructed tracks

Info from Data Product

GetTOFs() Vector of possible TOFs (multiple matches between fiber bundles in scintillator planes -- See slide 6)

GetTOFChans() Vector of combination of channels for the possible TOF values

Note: Just use **GetTOF()** and **GetTOFChan()** to extract only the first element in each vector.

ProtoDUNEBeamCuts

Class to compare TPC tracks to beam tracks (in protoduneana)

Checks relative position & angle between TPC and beam tracks

Cut values stored in fcl files

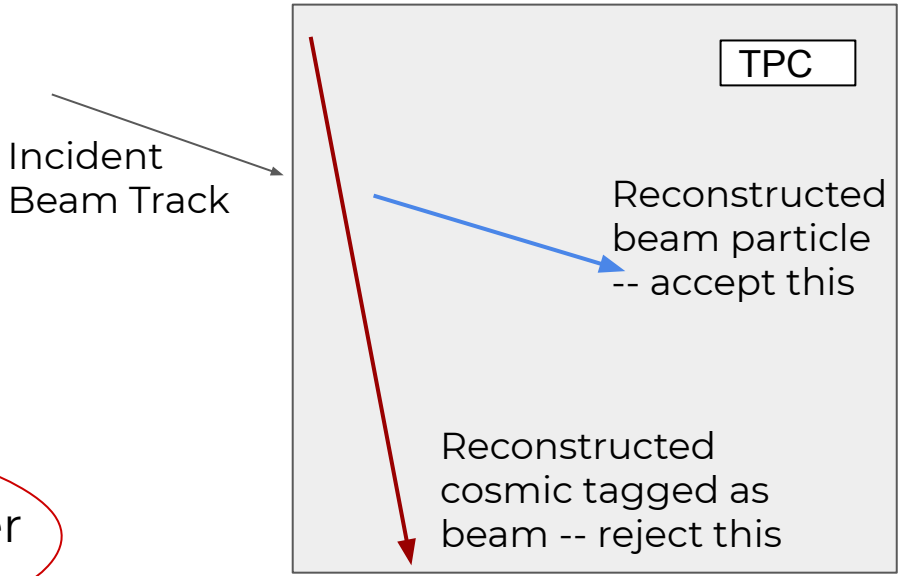
```
3 #
4 #include "ProtoDUNEBeamCuts.fcl"
5 #
```

Instantiate, and pass the track/shower

```
595
596   beam_cuts = protoana::ProtoDUNEBeamCuts( BeamCuts );
597
```

```
1148
1149    reco_beam_passes_beam_cuts = beam_cuts.IsBeamlike( *thisTrack, evt, "1" );
1150
```

Needs reference momentum



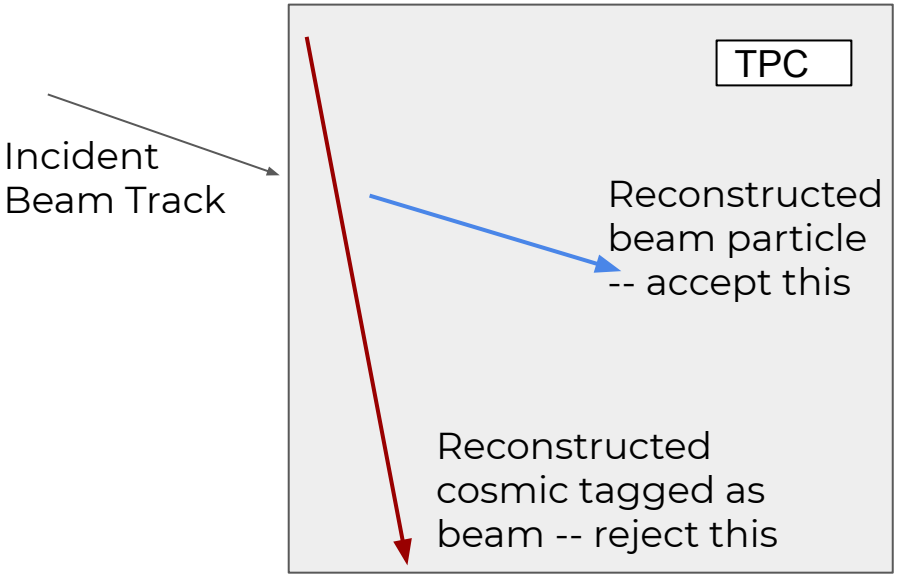
ProtoDUNEBeamCuts

This works for both MC & data

In data, this uses the (reconstructed) BI tracks for comparison

In MC, this uses the true incident tracks

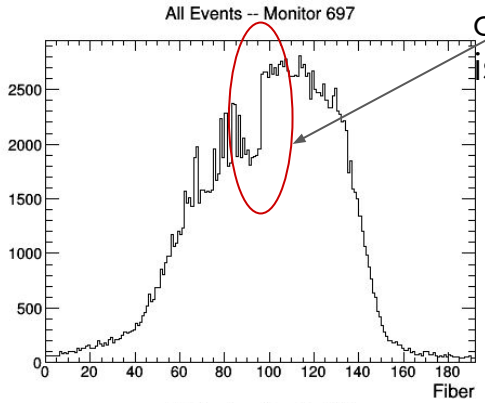
- Implemented BI reconstruction in simulation to be closer to data (More on this later)

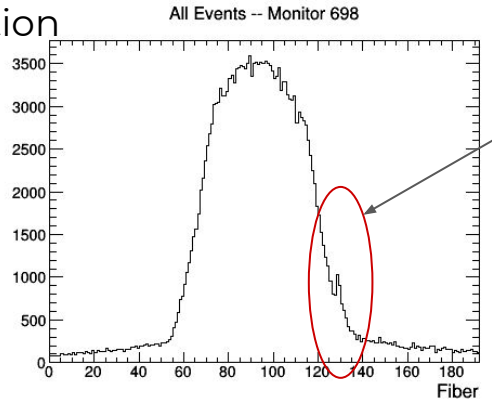


Recent Updates
Fiber Monitor Glitch

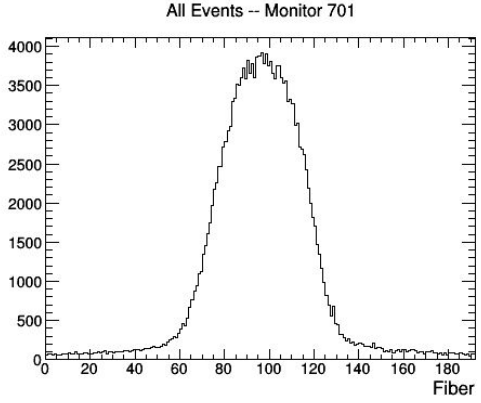
Fiber Monitor Issues

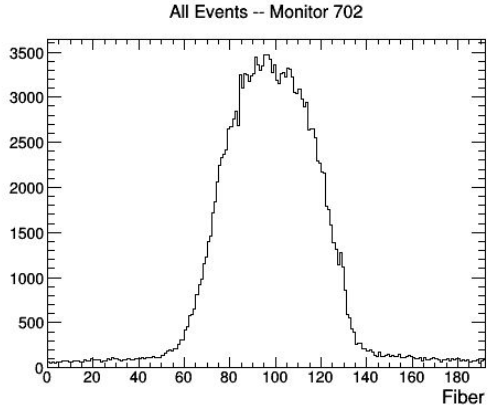
Comes from configuration issues





Software glitch



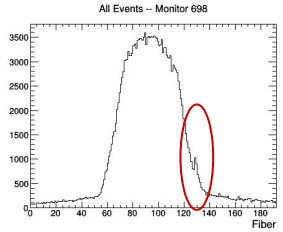


Software Bug

Fiber output → 6 sets of bits (words)

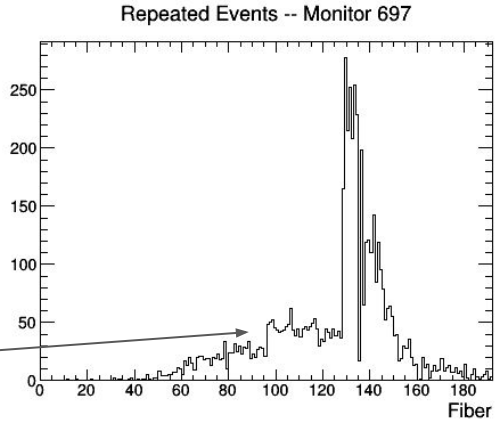
Smoking gun: multiple cases of immediately repeated fibers in the last 2 words

Smokier gun: same 2 fibers are repeated



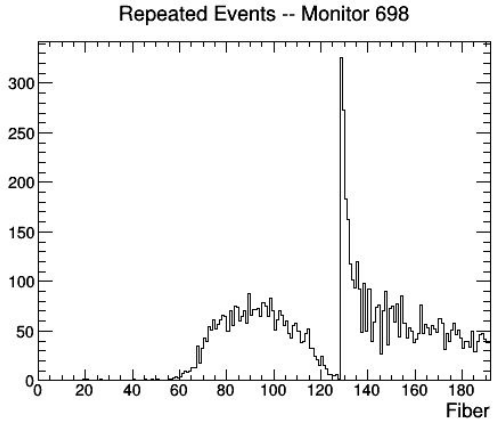
[1539840498.9030044]	-1	-1	-1	-1	[10]	-1			
[1539840498.9506893]	-1	-1	-1	[15]	-1	-1			
[1539840498.9829087]	-1	-1	-1	-1	[7]	-1			
[1539840499.022586]	-1	-1	-1	[11]	-1	-1			
[1539840499.0870402]	-1	-1	-1	[24]	[20, 5]		-1		
[1539840499.1382678]	-1	-1	[29]	-1	[20, 5]		-1		
[1539840499.1408312]	-1	-1	-1	[30]	-1	-1			
[1539840499.1610453]	-1	-1	[10]	-1	-1	-1			
[1539840499.198975]	-1	-1	-1	-1	[2]	-1			
[1539840499.2412484]	-1	-1	-1	[13]	-1	-1			
[1539840499.2881212]	-1	-1	-1	[13]	-1	-1			
[1539840499.3942833]	-1	[21]	[17, 9]		-1	-1	-1		
[1539840499.4199429]	-1	-1	-1	-1	[1]	-1			
[1539840499.4612713]	-1	-1	[22]	-1	[1]	-1			
[1539840499.480137]	-1	-1	[13]	-1	-1	-1			
[1539840499.496152]	-1	-1	-1	[27]	-1	-1			

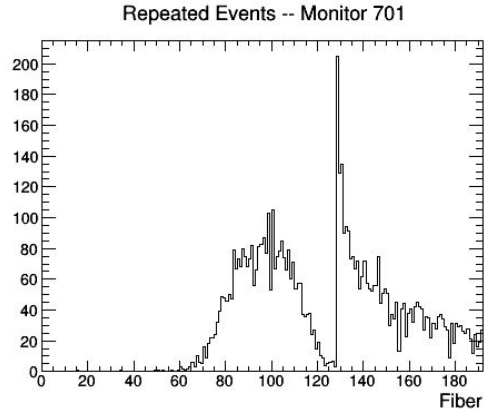
Repeated Fibers

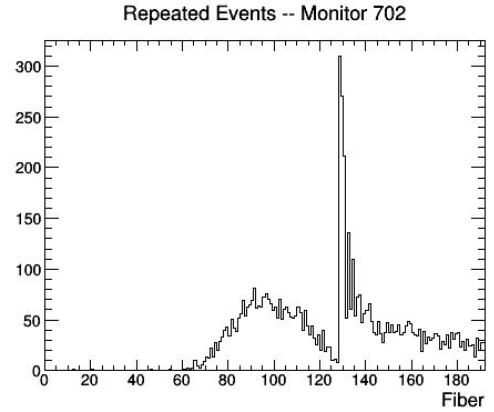


This ‘jump’ is related to the other issue

Last 2 words are more likely to be repeated immediately





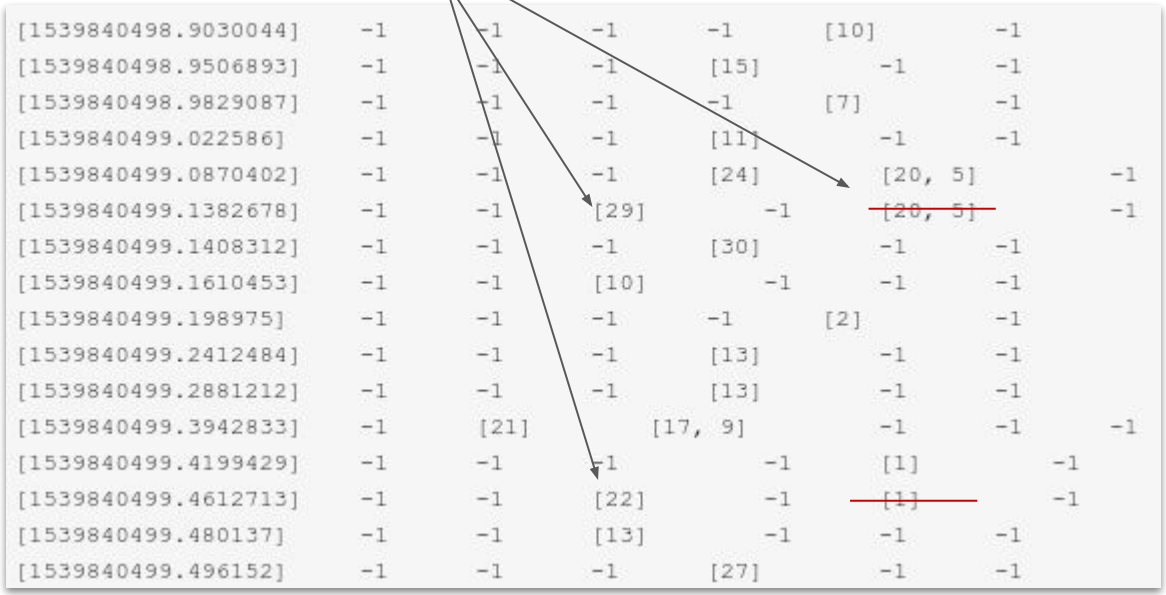


Mitigating the issue

Software workaround:

For each monitor acquisition/trigger in the spill:

1. Check if any active fibers from words 5 & 6 were repeated from the previous trigger
2. Mask these/throw them out
3. Treat any other active fibers as “truly” active



[1539840498.9030044]	-1	-1	-1	-1	[10]	-1	
[1539840498.9506893]	-1	-1	-1	[15]	-1	-1	
[1539840498.9829087]	-1	-1	-1	-1	[7]	-1	
[1539840499.022586]	-1	-1	-1	[11]	-1	-1	
[1539840499.0870402]	-1	-1	-1	[24]	[20, 5]		-1
[1539840499.1382678]	-1	-1	[29]	-1	[20, 5]		-1
[1539840499.1408312]	-1	-1	-1	[30]	-1	-1	
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[1539840499.2412484]	-1	-1	-1	[13]	-1	-1	
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[1539840499.3942833]	-1	[21]	[17, 9]		-1	-1	-1
[1539840499.4199429]	-1	-1	-1	-1	[1]	-1	
[1539840499.4612713]	-1	-1	[22]	-1	[1]	-1	
[1539840499.480137]	-1	-1	[13]	-1	-1	-1	
[1539840499.496152]	-1	-1	-1	[27]	-1	-1	

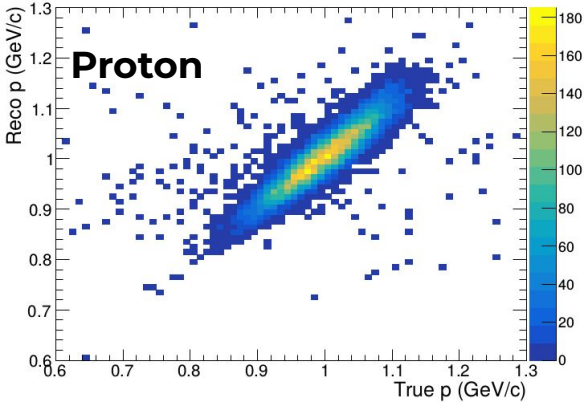
Mitigation Results

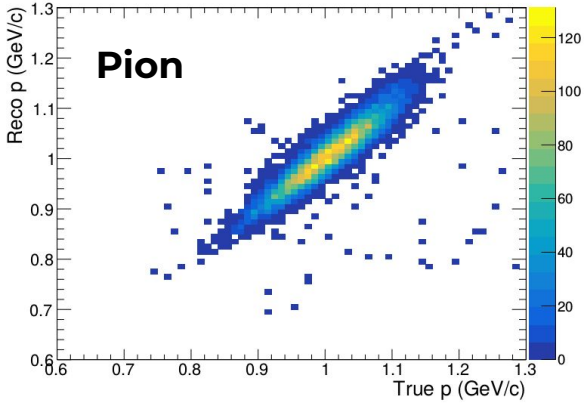
Run	Single Track	Single Momentum	Both Good
5387	66% → 88%	88% → 95%	59% → 84%
5824	70% → 82%	88% → 89%	64% → 75%
5770	69% → 87%	90% → 94%	63% → 82%

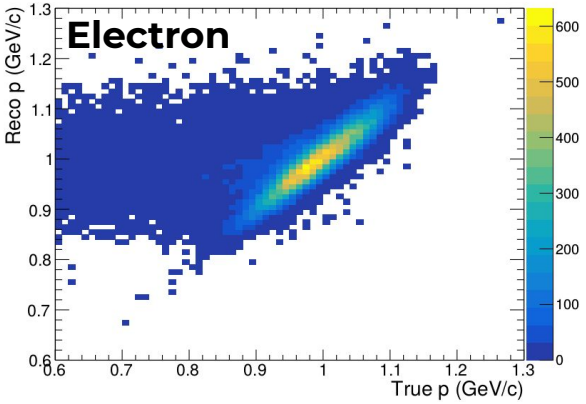
Note: Percentages above are relative to the total number of pion-like triggers in 5387, 5770 or e-like triggers in 5824

Recent Updates
Momentum Systematics

True to Reco -- 1 GeV (NP04 Front)







Note:
True: @ NP04 Front

Momentum Smearing

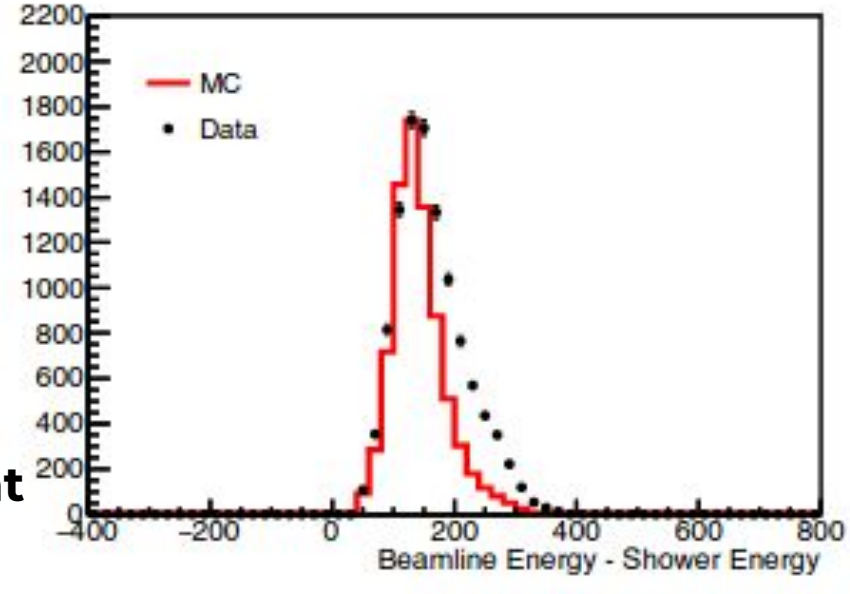
Peter's talk: Comparisons of true to reco offer smearing matrices which can be used within analyses

Alternative: comparing MC and data in reco space

- Requires having the reconstructed beam momentum for MC (next slide)

Data vs. MC

Aaron Higueira showed differences between data and MC for the electron analysis



Want to have the reconstructed beam momentum within MC to compare ‘apples-to-apples’

- Implement **ProtoDUNEBeamEvent** in MC event generator

BI Info in Monte Carlo

Simulation files from the CERN beam group serve as input for the event generator

Material of full beam line is simulated -- Can use this to create simulated **ProtoDUNEBeamEvent** products

Positions in Fiber Monitors converted to Fibers → Momentum + Tracks

Difference in simulated time at Scintillating Planes → Time of Flight

Cherenkov response not simulated → Can just use efficiencies?

Implemented in event generator → Will be included next production

Summary

The beam line provides users with information to assist in beam-related analyses

- Various tools are available to make this easy
- Bug reports + suggestions for improvement always welcome

A (hidden) bug was discovered and mitigated

- Significantly improves data quality

Beam line simulations provides users with more-direct comparisons to data

- **ProtoDUNEBeamEvent** implemented for next MC production

Thanks for listening

Backup Slides

PossibleParticleCands struct

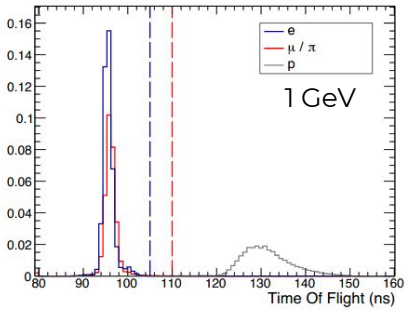
Struct returned by **ProtoDUNEBeamlineUtils::GetPIDCandidates(...)**

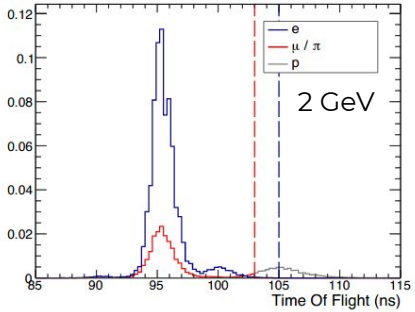
```
38  struct PossibleParticleCands {
39    public:
40      bool electron = false;
41      bool muon = false;
42      bool pion = false;
43      bool kaon = false;
44      bool proton = false;
45      bool deuteron = false;
46
```

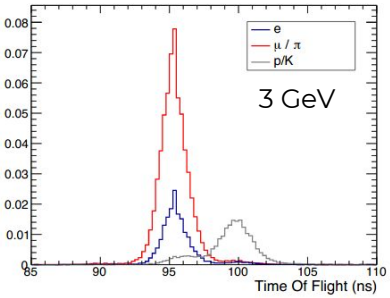
Can cast to string for easy printing, and can get vector of ints using **getPDGCodes()** method

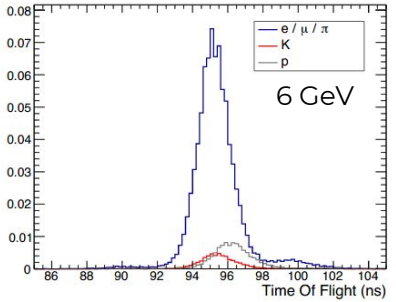
PID Logic

		Momentum (GeV/c)			
		1	**2**	**3**	**6 - 7**
e	TOF (ns)	0, 105	0, 105	–	–
	XCET-L	1	1	1	1
	XCET-H	–	–	1	1
μ / π	TOF (ns)	0, 110	0, 103	–	–
	XCET-L	0	0	0	1
	XCET-H	–	–	1	1
K	TOF (ns)	–	–	–	–
	XCET-L	–	–	0	0
	XCET-H	–	–	0	1
p	TOF (ns)	110, 160	103, 160	–	–
	XCET-L	0	0	0	0
	XCET-H	–	–	0	0

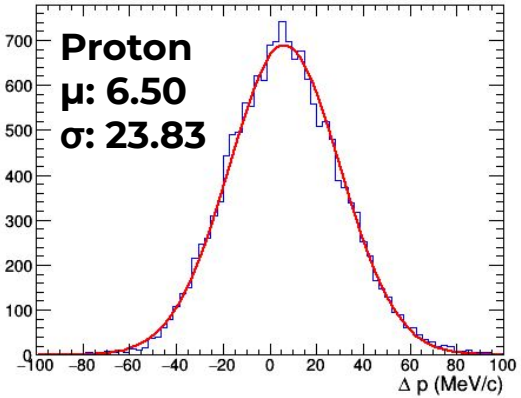


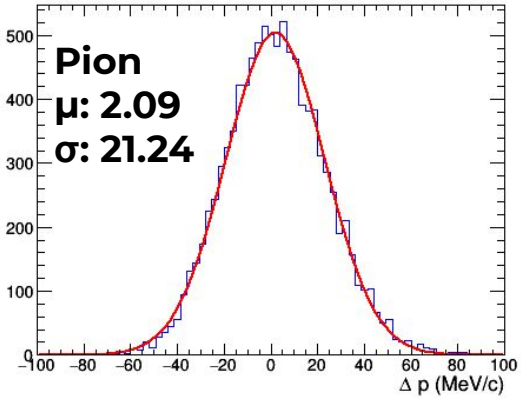


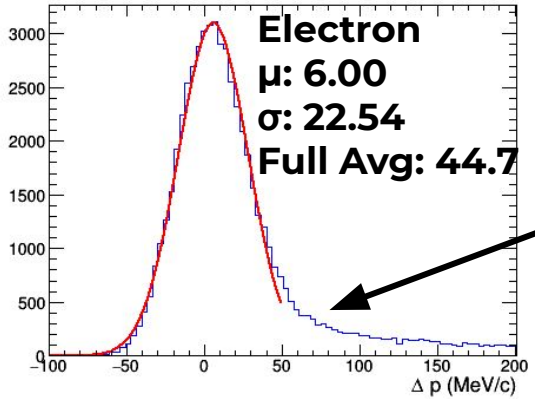




Resolution + Bias -- 1 GeV (NP04 Front)





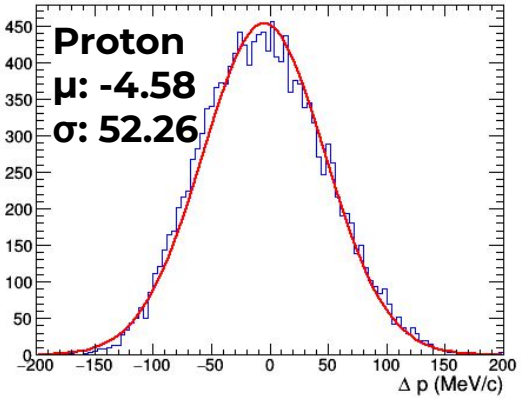


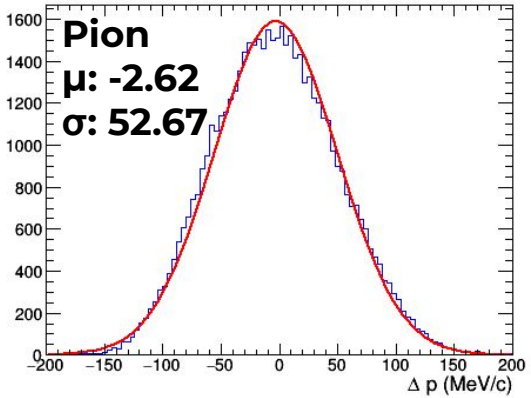
Source of data-MC discrepancies in Aaron's studies

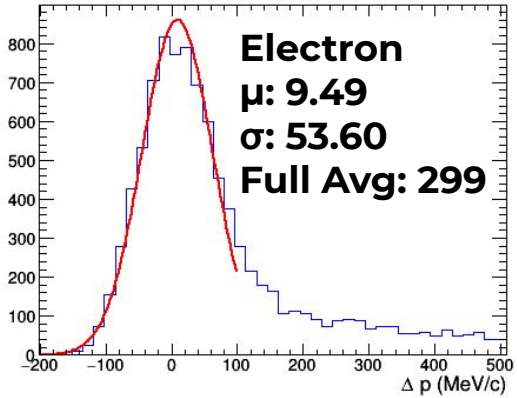
See full range of distribution in backup

Note:
p = Reconstructed - True (@ NP04 Front)

Resolution + Bias -- 3 GeV (NP04 Front)

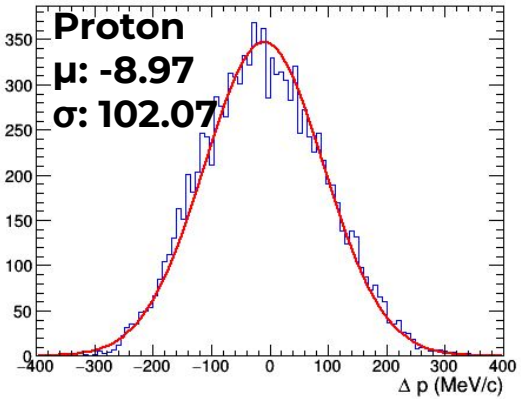


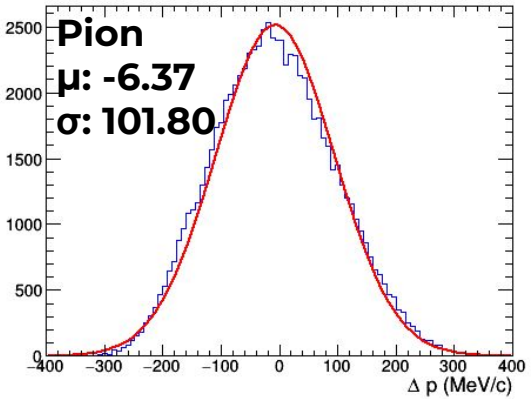


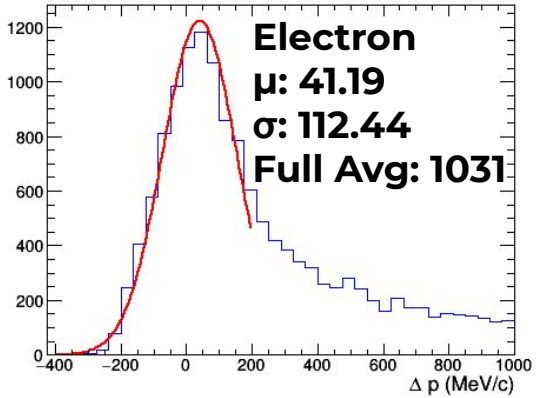


Note:
p = Reconstructed - True (@ NP04 Front)

Resolution + Bias -- 6 GeV (NP04 Front)

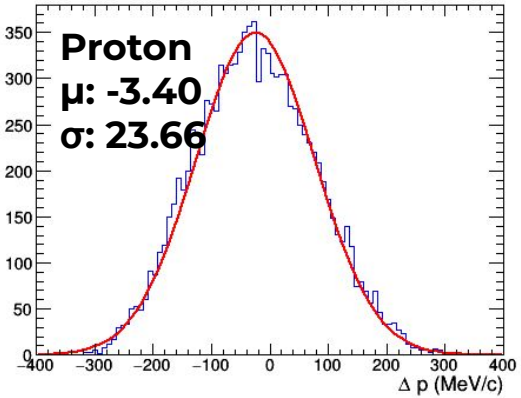


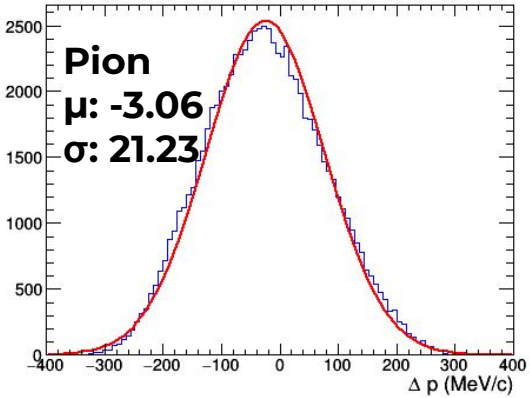


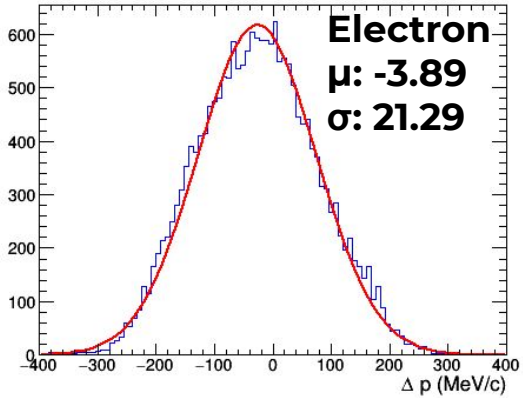


Note:
p = Reconstructed - True (@ NP04 Front)

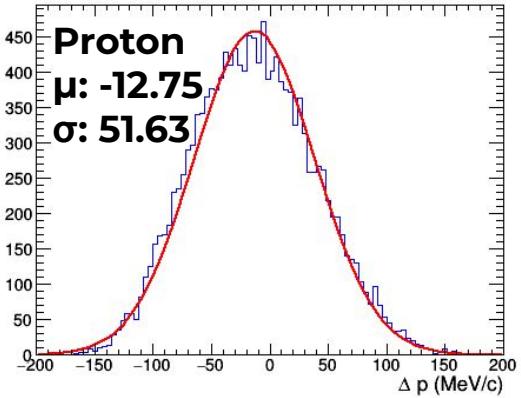
Resolution + Bias -- 1 GeV (At BPROF1)

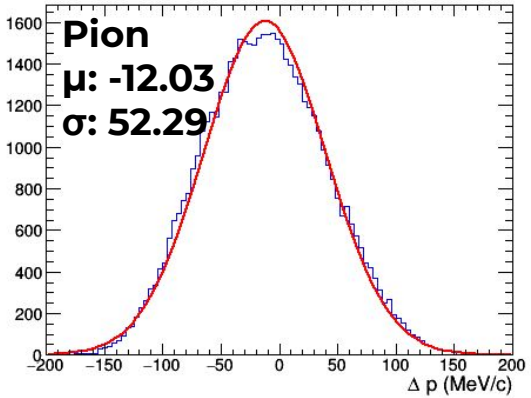


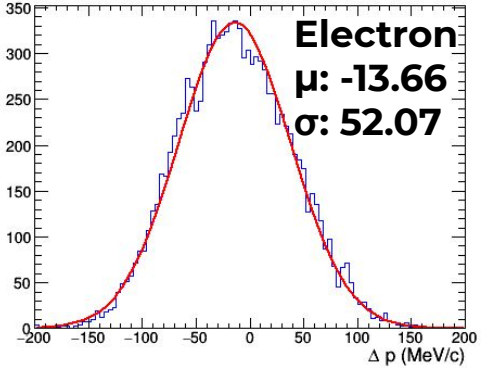




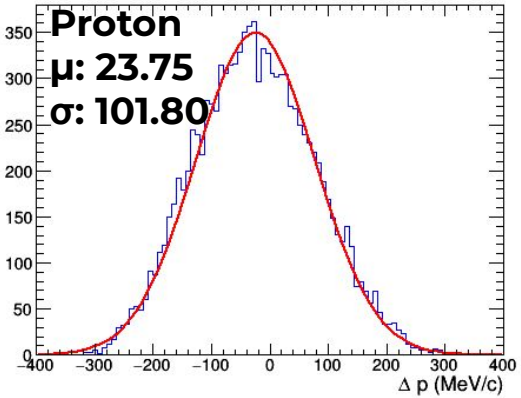
Resolution + Bias -- 3 GeV (At BPROF1)

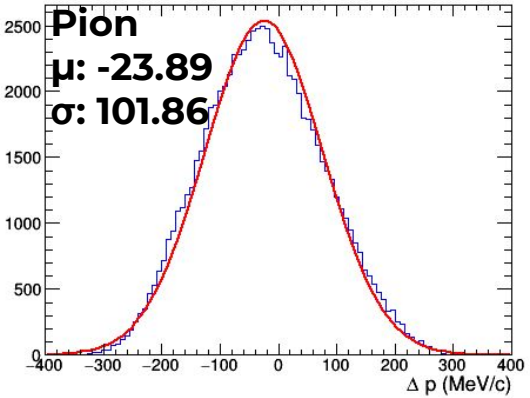


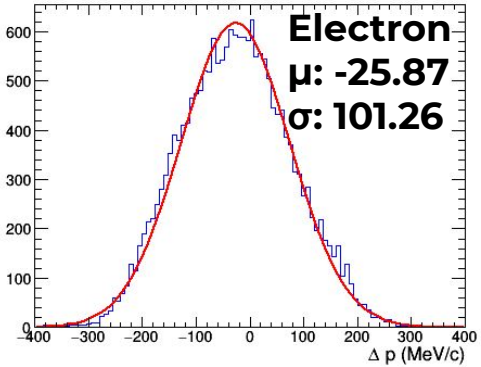




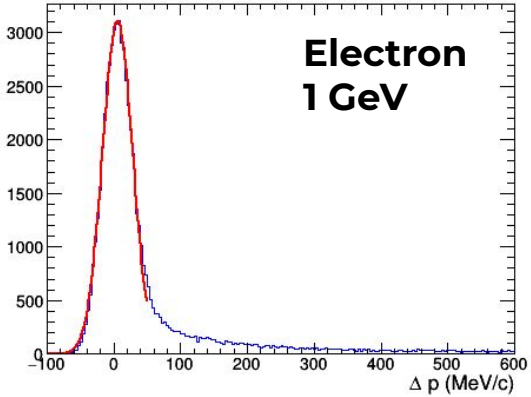
Resolution + Bias -- 6 GeV (At BPROF1)

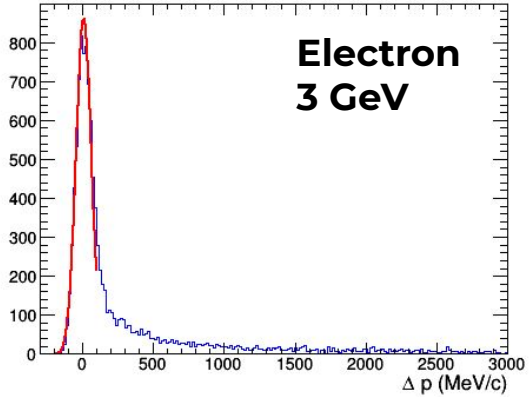


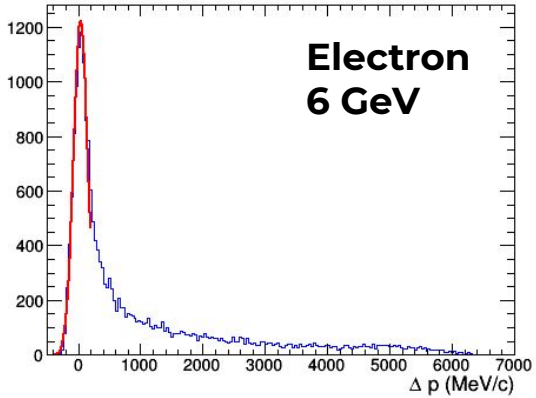




Extended Electron Distributions







Introduction

The ProtoDUNE beam line provides various reconstructed info to be used within analysis

- Next slides detail this info and how to access it

Beam line simulation serves as input for event generation in MC. Also provides info to compare reconstructed info between data and MC

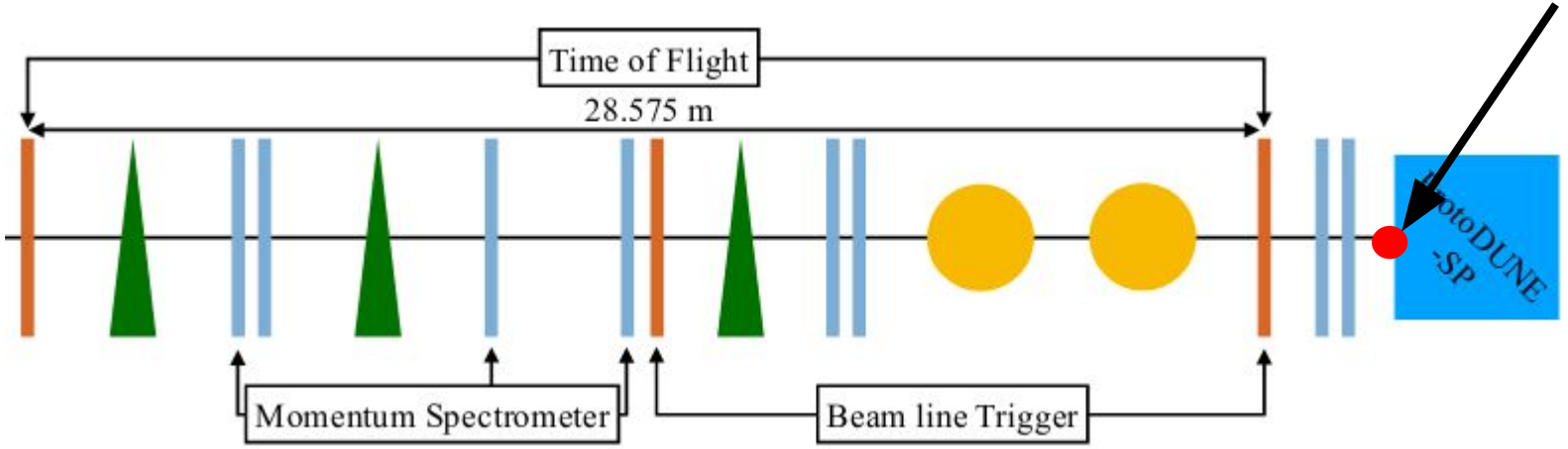
- Can be used to understand our resolution/bias on the reconstructed momentum
- Make sure we're correctly comparing between data & MC

Event Generator

Looking at dunetpc/dune/EventGenerator/ProtoDUNEBeam_module.cc

```
755             fGoodParticleTree->GetEntry(spill.fGoodIndex);
756             pos = ConvertCoordinates(fGoodNP04front_x/10.,fGoodNP04front_y/10.,fGoodNP04front_z/10.,baseTime + fGoodNP04front_t);
757             mom = MakeMomentumVector(fGoodNP04front_Px/1000.,fGoodNP04front_Py/1000.,fGoodNP04front_Pz/1000.,(int)fGoodNP04front_PDGid);
```

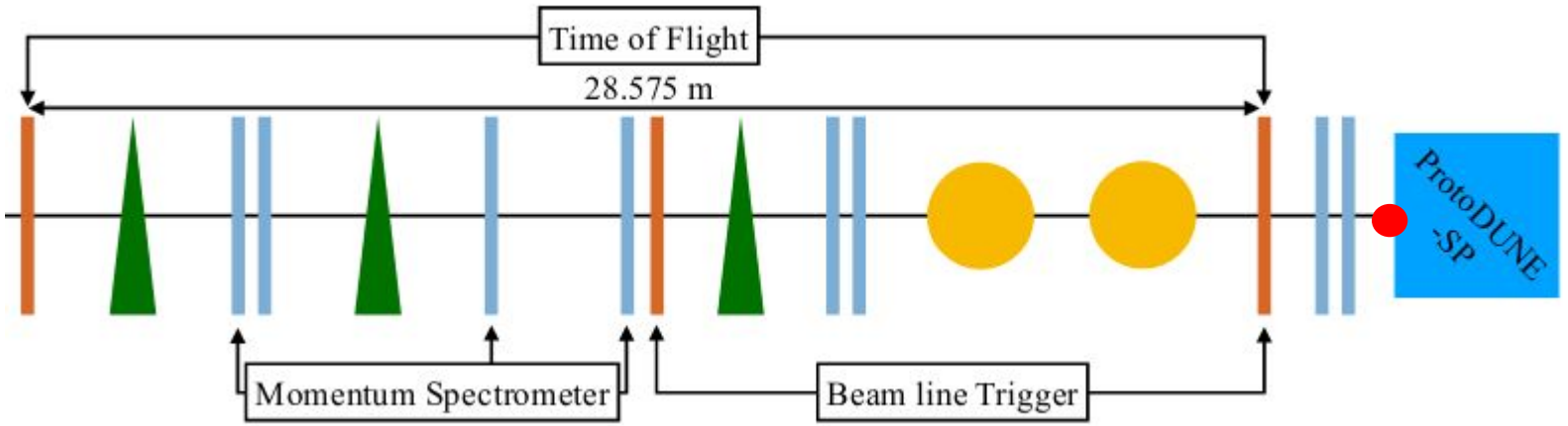
The momentum comes from that as simulated at the front of the TPC



Event Generator -- Energy loss

Our MC events are produced at a point where energy loss has already been considered

Motivates us to consider the difference between the momentum **at this point** and **as measured in the spectrometer**

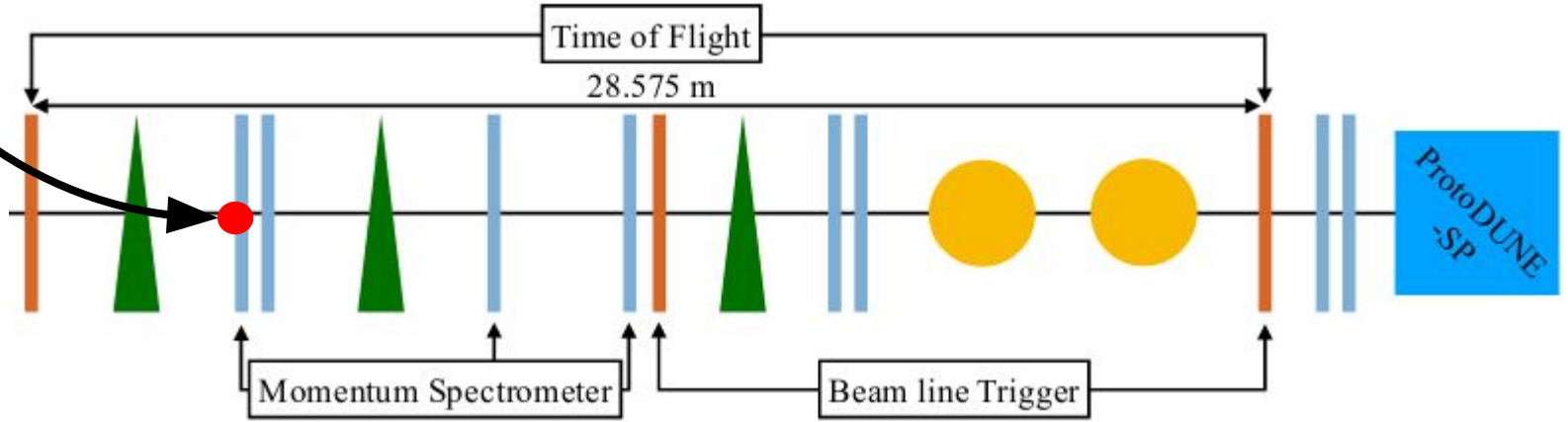


Momentum Calculation -- Resolution

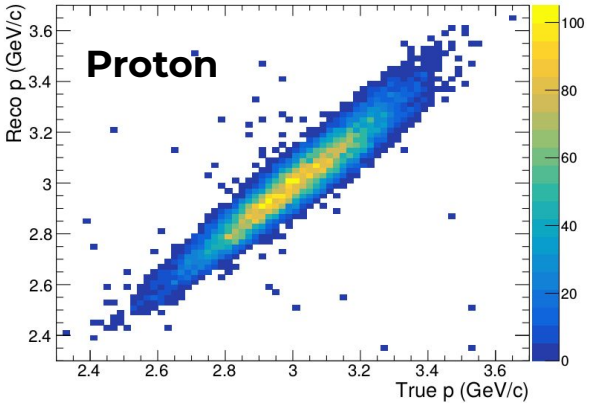
An additional effect to consider is the inherent resolution (+ bias) on the spectrometer measurement as compared to the true momentum at the spectrometer

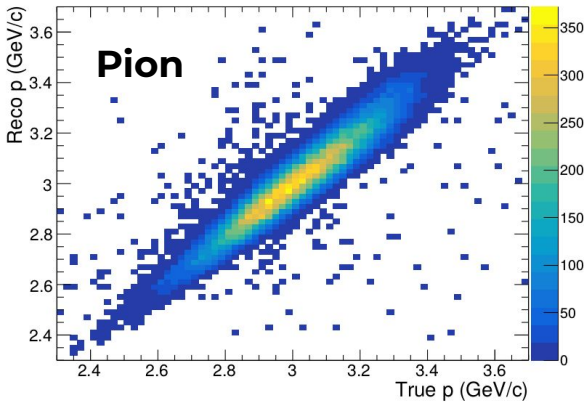
This effect is ‘folded in’ with the energy loss

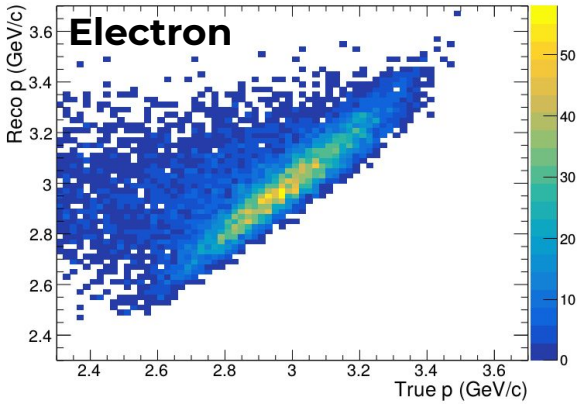
See backup for these plots alone



True to Reco -- 3 GeV (NP04 Front)

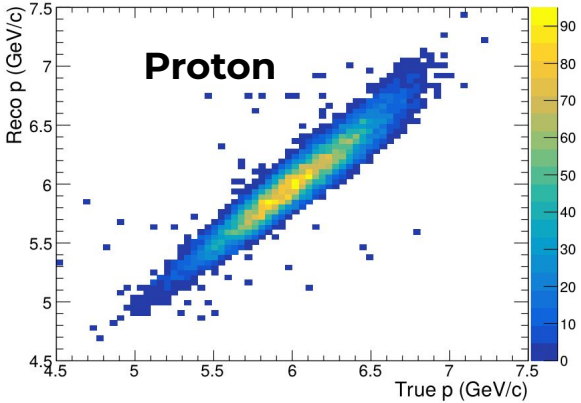


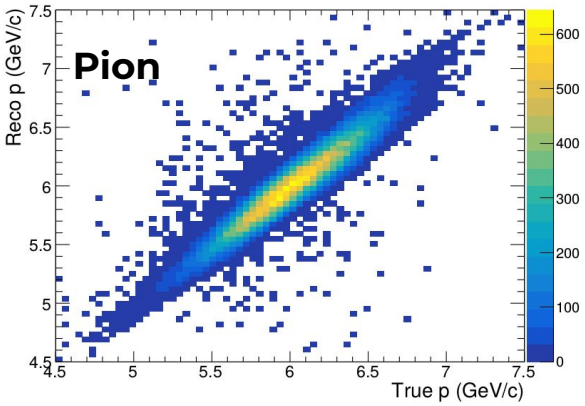


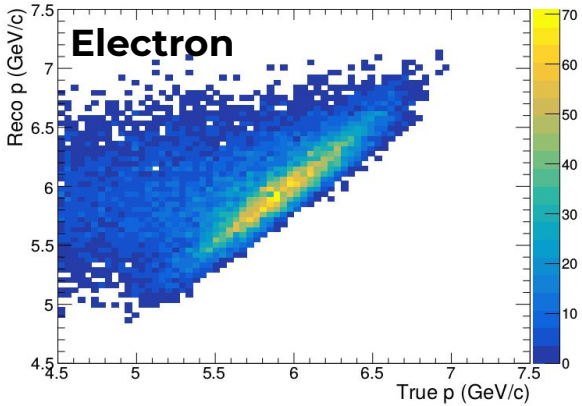


Note:
True: @ NP04 Front

True to Reco -- 6 GeV (NP04 Front)







Note:
True: @ NP04 Front