Resurrecting Pion Decay In Flight Boosted Decision Tree Code

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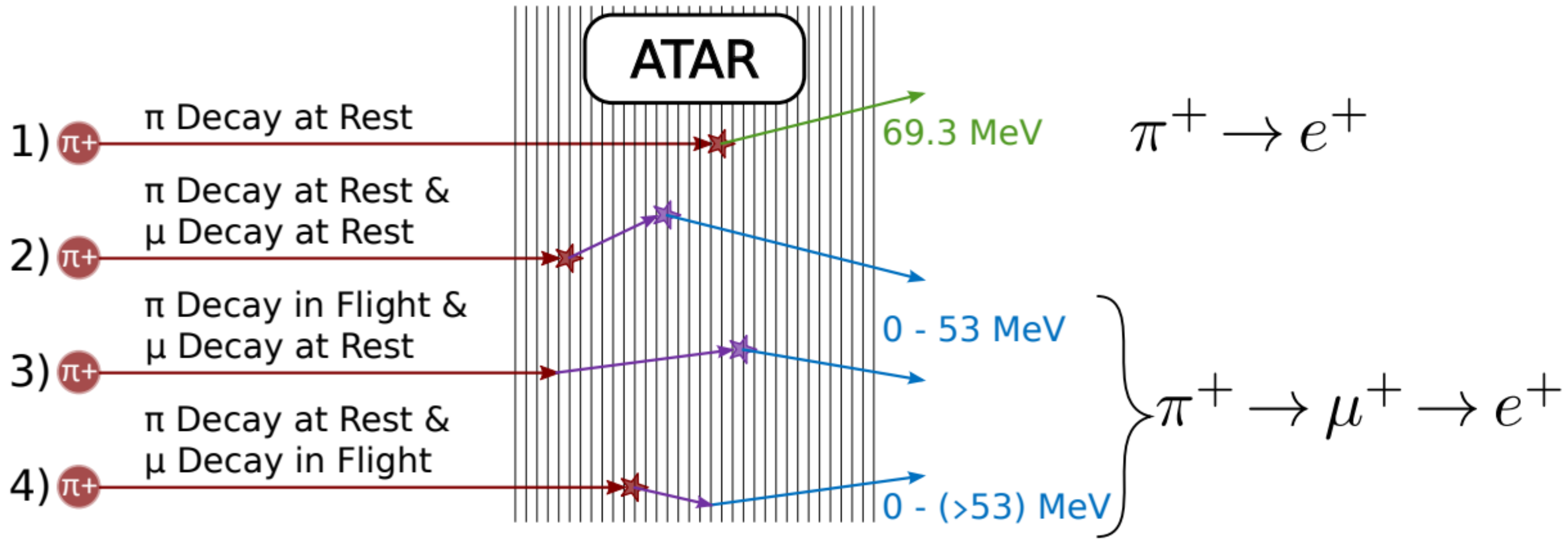
Pion Decay in Flight Introduction

- Pion decay in flight followed by a muon decay at rest is one of the decays that can masquerade as a signal Pienu
- Having the pion decay in flight would mean that the ATAR does not have the Bragg Peak energy deposit of the Pion
- This leaves the kink in the decay as the primary signature of this background

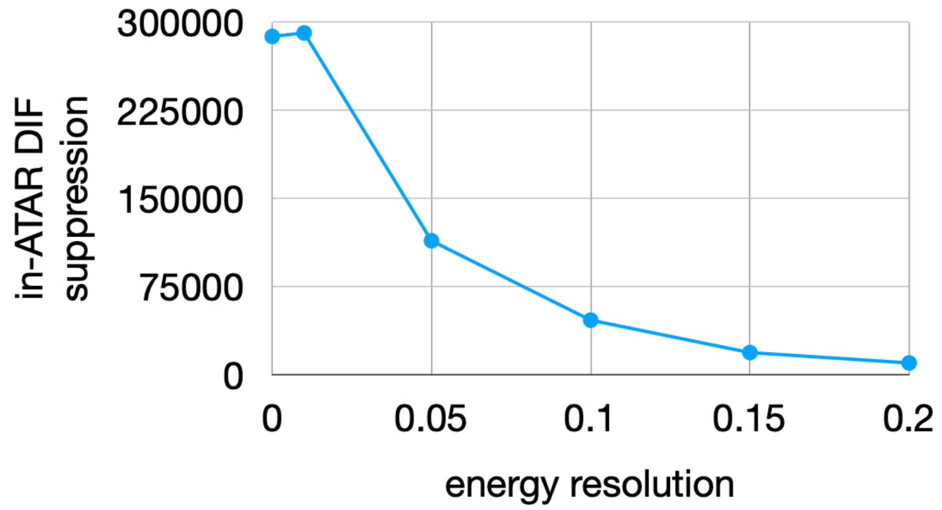


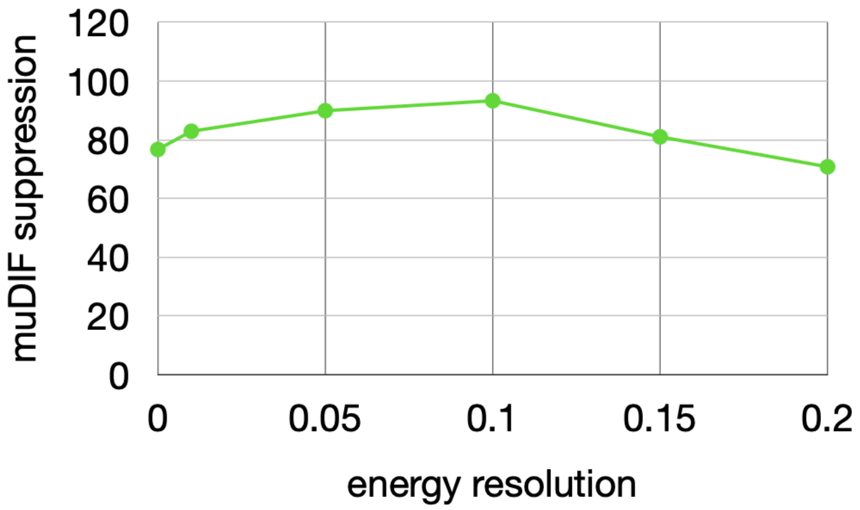
The Target: Vincent's PiDIF Code

nominal (120 μm layer thickness)

energy resolution	in-ATAR DIF suppression	#in-ATAR DIF / #pienu
0%	288,000	3.0e-05
1%	291,000	3.0e-05
5%	114,000	7.7e-05
10%	46,400	1.9e-04
15%	18,800	4.7e-04
20%	9,960	8.8e-04

energy resolution	muDIF suppression	#in-ATAR DIF / #pienu
0%	76.7	6.1e-04
1%	82.9	5.6e-04
5%	89.9	5.2e-04
10%	93.3	5.0e-04
15%	81	5.8e-04
20%	70.8	6.6e-04



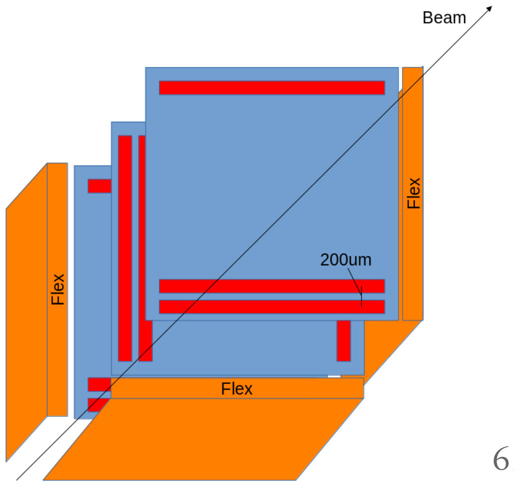


* No dead material included
* Fraction of pienu event in tail region not yet considered

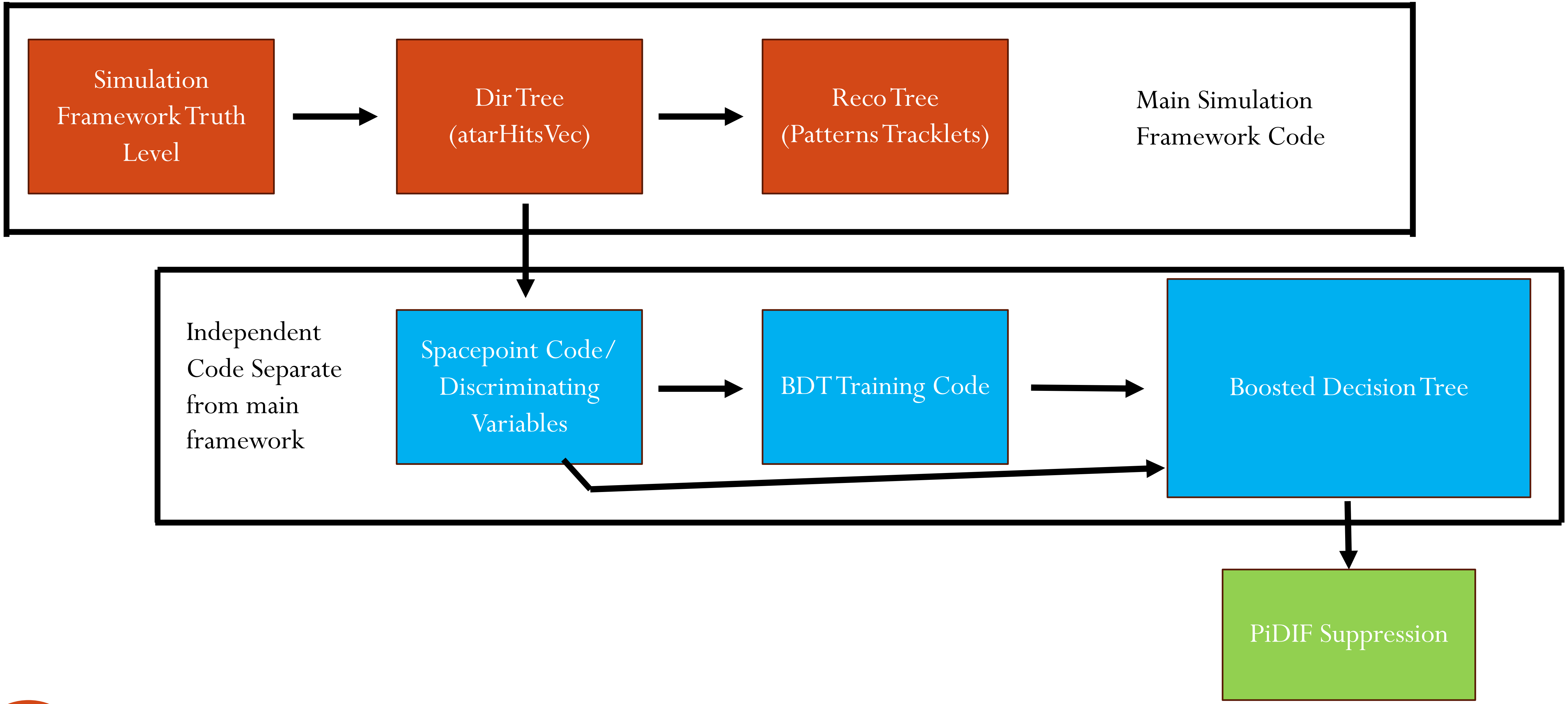
These studies were created before current day major simulation framework elements were implemented

In time hits and cuts

- The pion decay in flight variables defined on the "on time hits"
- On time hits are all hits within a 0.7 ns time window of whatever the first hit of the event that the ATAR registered
  - This was a semi arbitrary time cut, but should probably be scanned to see if this affects PiDIF suppression
- Historically considered an energy cut, where the majority of energy deposited must be in the middle sections of the ATAR aka Box Cut

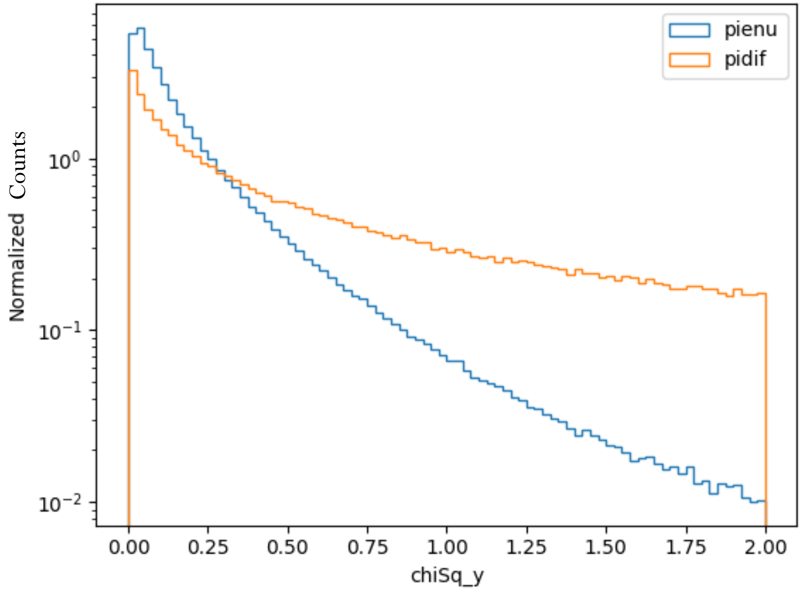


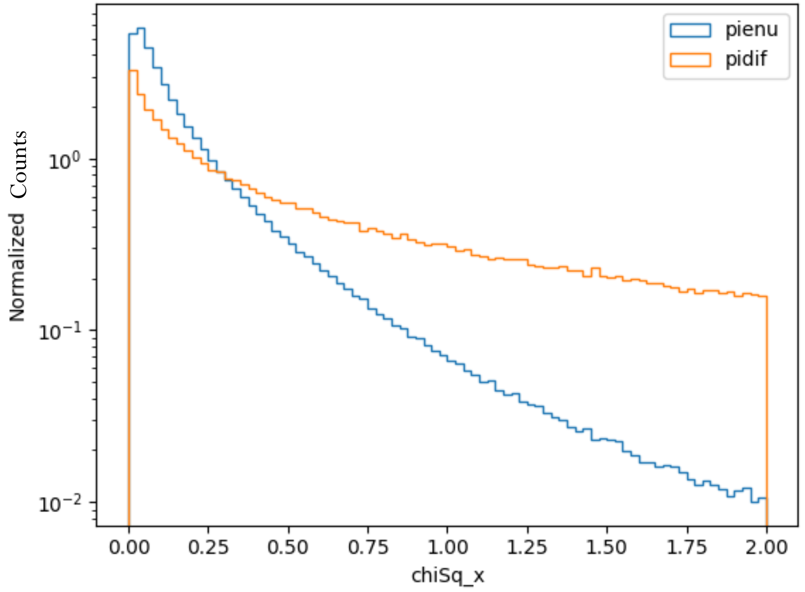
The Method: Using a Boosted Decision Tree (BDT) for PiDIF



The Discriminating Variables: Example Chi Squares

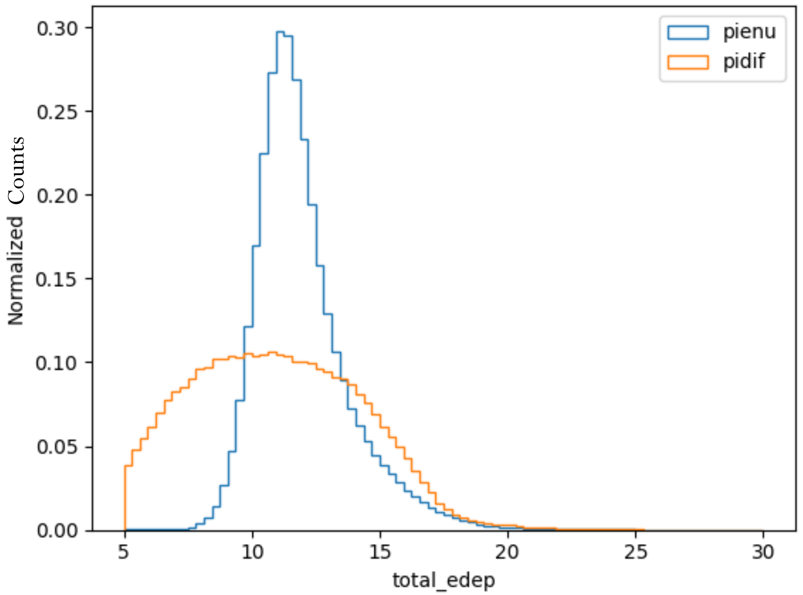
- One of the main markers of a pion decay in flight event is a kink in the path of the in time hits
- Two of the boosted decision tree discriminating variables are calculated by first doing a linear fit of the in time hits
- The chi square of the two lines are then calculated yz and yx
- It is expected the chi square of a PiDIF event would be worse



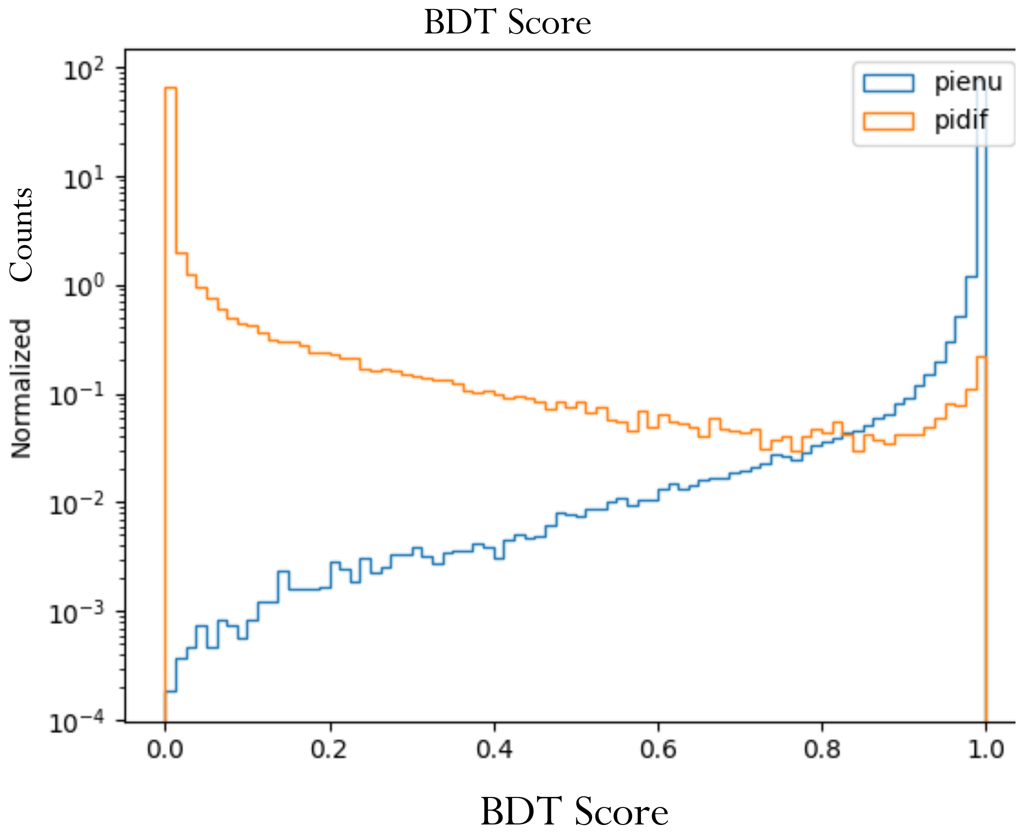


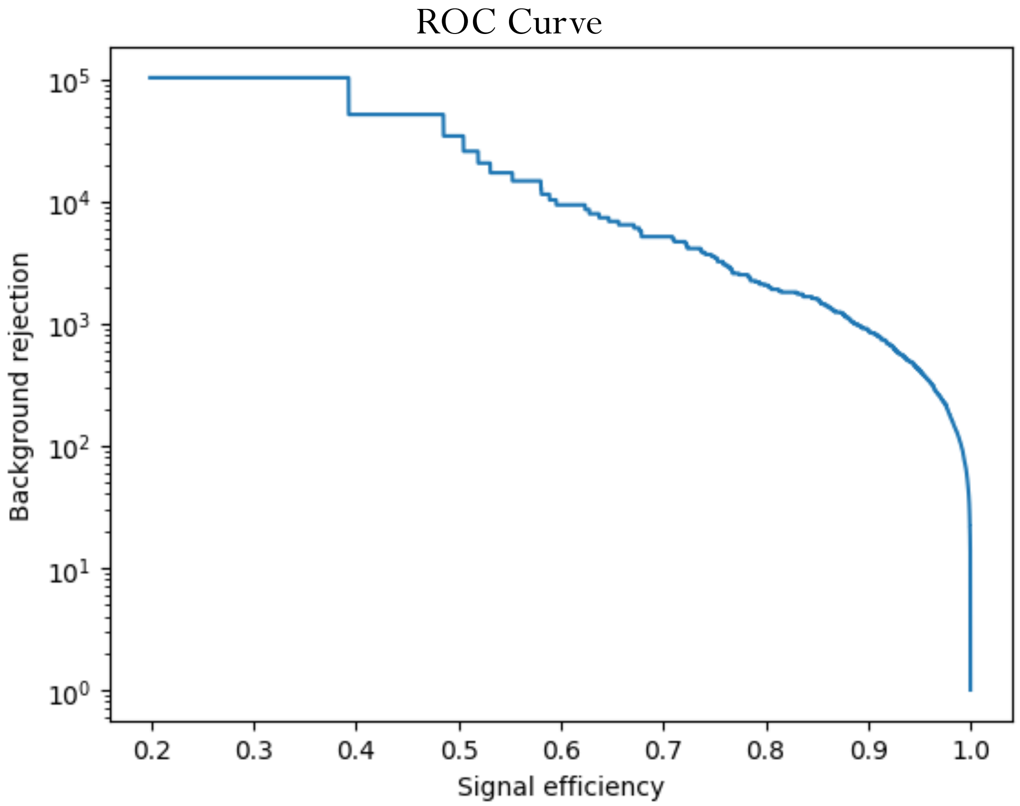
The Discriminating Variables: Total Energy in ATAR

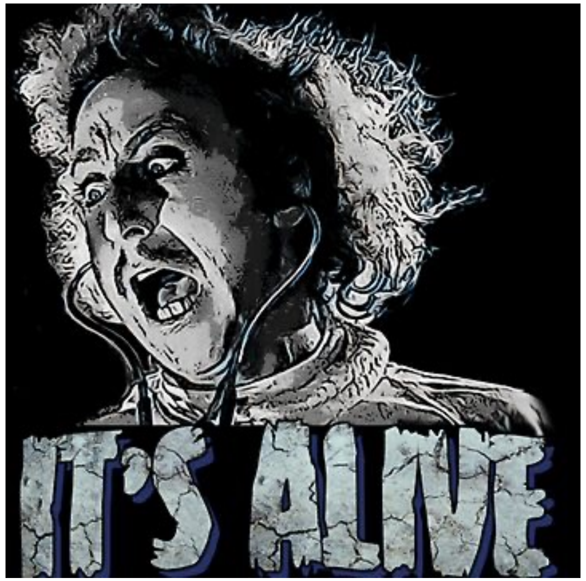
- It's interesting that the total energy deposited in the ATAR is such a good discriminating variables
- This simulation was done assuming 0% energy resolution, and thus this observation agrees with Vincent's results



PiDIF BDT



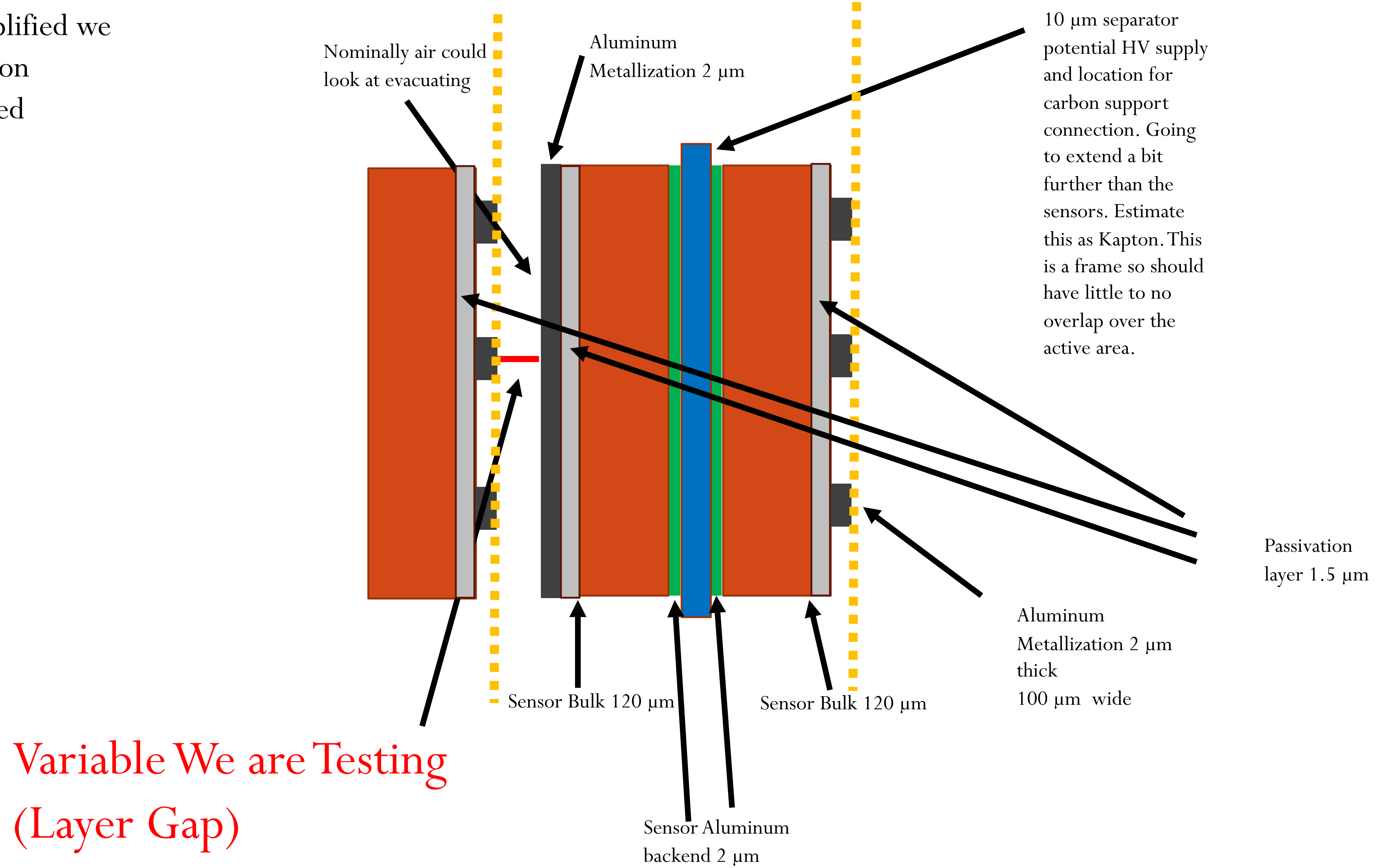




First Pion Decay in Flight Results since the original results from Vincent. Data from the main simulation framework, but the scripts are offboard (slide 5)

ATAR Optimization: One Example Study

By simplified we mean non staggered



x24 of what is inside the orange dashed lines

ATAR Optimization Side quest MuDiF Suppression

Dead Material Quantity	MuDif Events	Pienu Events	Signal Tag (Positive Rate)	Background Tag (False Positive Rate)	Suppression
40 µm	253630	839111	0.1161	0.005216	22.26
25 µm	240473	839287	0.1151	0.004466	25.78
5 µm	222921	839745	0.1162	0.003652	31.82
0 µm	218295	839510	0.1167	0.003715	31.42
No Dead Material	204664	850081	0.1176	0.002257	52.081

For Raw Events

- For pienu pion decay (kPitar) at rest in ATAR
- For MuDIF pion decay at rest (kPitar) muon decay in flight (kMudif)
- Chi square of the fit to the initial hits can't be infinite
- Greater than 70 percent of the event's energy must be inside the central region of the ATAR

To determine muon decay in flight suppression

- The energy of the first five delayed hits must be less than 0.05 MeV (within 1 ns of the final positron hit time)

Comparative Vincent Results

energy resolution	muDIF suppression	#in-ATAR DIF / #pienu
0%	76.7	6.1e-04
1%	82.9	5.6e-04
5%	89.9	5.2e-04
10%	93.3	5.0e-04
15%	81	5.8e-04
20%	70.8	6.6e-04

ATAR Optimization PiDIF Suppression

Dead Material Quantity	PiDif Events	Pienu Events	Signal Tag (Positive Rate)	Background Tag (False Positive Rate)	Suppression
40 µm	377654	902659	117601	2	24601
25 µm	359435	902922	152125	1	60558
5 µm	333740	903168	147687	1	54574
0 µm	329681	903159	143782	3	17495
No Dead Material	307294	915072	307294	1	73488

For Raw Events

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- For PiDif pion decay at rest (kPidif) muon decay in flight (kMudar)
- Chi square of the fit to the initial hits can't be infinite
- Greater than 70 percent of the event's energy must be inside the central region of the ATAR

To determine pion decay in flight suppression

- The BDT score of the event must be >0.9999

Comparative Vincent Results

energy resolution	in-ATAR DIF suppression	#in-ATAR DIF / #pienu
0%	288,000	3.0e-05
1%	291,000	3.0e-05
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Moving to Full Implementation into Framework

- Working on implementing pion decay in flight BDT variables directly into framework
- Model training will remain offboard the framework for now potential to bring the BDT directly into the framework
    - Some similar software was created in ATLAS

```
enum PidifNess {
  stop_zpos,
  maxE_zpos,
  total_edep,
  chiSq_x,
  chiSq_y,
  prestop_edep_planeN,
  prestop_edep_planeNminus1,
  prestop_edep_planeNminus2,
  prestop_edep_planeNminus3,
  prestop_edep_planeNminus4,
};
```

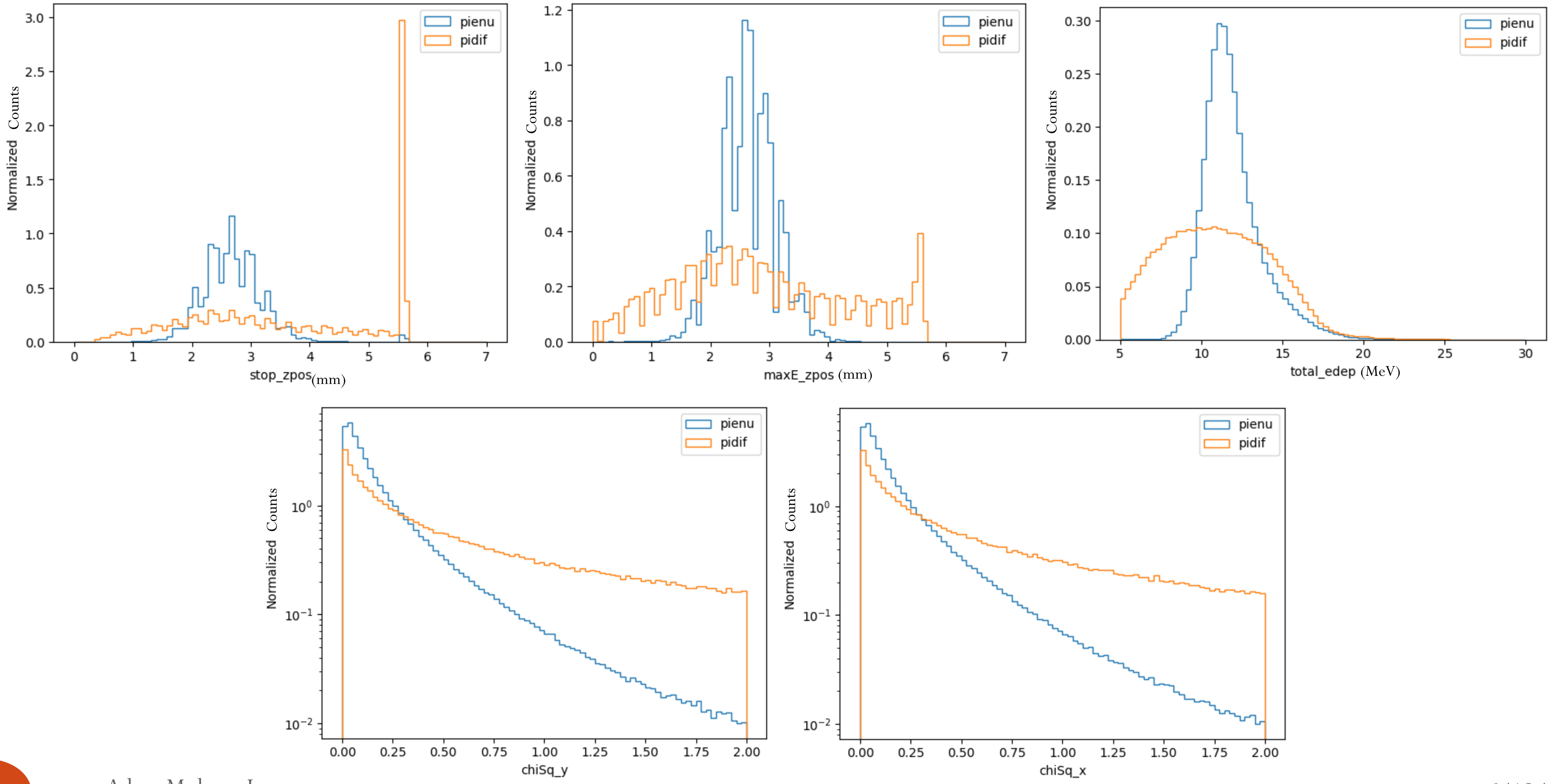
Conclusion/Future Work

- The Pion Decay in Flight boosted decision tree algorithm has entirety been resurrected and brought back into the modern era
- The results of my studies are pretty consistent with Vincent's results
- The BDT continues to show that seemingly high levels of PiDIF suppression are possible

- Future work is a bit of question to the wider collaboration?
  - Waveform Reconstruction?
  - ATAR Optimization/smearing studies?
  - Full Experimental Sensitivity Study?

Back Up

The Discriminating Variables



The Discriminating Variables