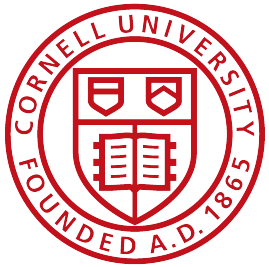


PR #162:

Initial pT3 DNN for LST

Gavin Niendorf

Overview

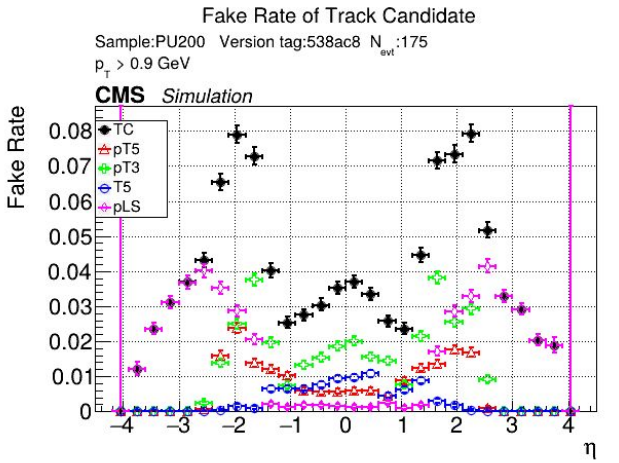
- Adding a pT3 DNN significantly reduces the overall fake rate for LST, especially in the low-pT configuration, with no noticeable increase in timing.
- The low-pT configuration now has a comparable fake rate outside the barrel after adding the additional pT3 DNN cut.
- Attempted to replace some of the existing pT3 cuts with the DNN, but decided to defer this to a future PR.
    - Replacing the existing cuts improved overall efficiency and reduced pLS efficiency (i.e. fewer unmatched pLS's).

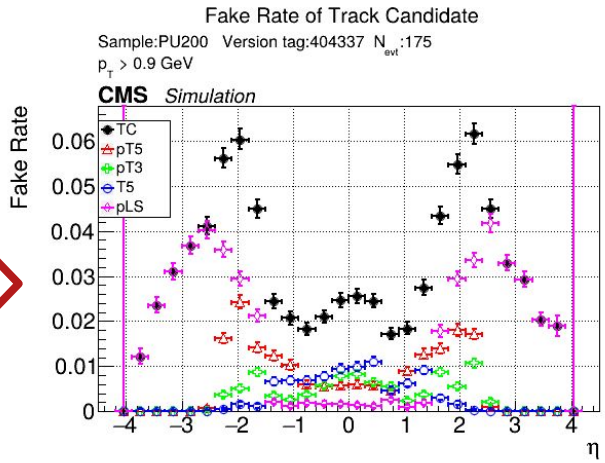
pT3 DNN Overview

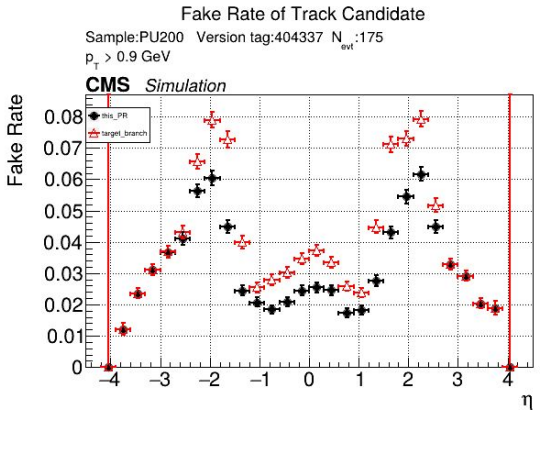
- Six input features: the log of (rPhiChiSquared, tripletRadius, pixelRadius, pixRadiusError, and rzChiSquared), and the absolute value of the pLS Eta.
  - This is the full set of variables used for the pT3 cuts outside of initial cuts that check for dEta/dPhi consistency between the pLS and inner + outer line segments.
- Same number of layers/nodes as T5 and T3 DNN, with only one output node for real/fake probability.
  - Chose signal efficiency cut values at 99.5% (eta bins of 0.25) for pT < 5 and 98% (only one eta bin) for pT > 5.

DNN Fake Rate Reduction, Eta

- pT3 fake rate reduced in the barrel by half with additional DNN cut, and in the region 1 < abs(eta) < 2 by up to a factor of 4.

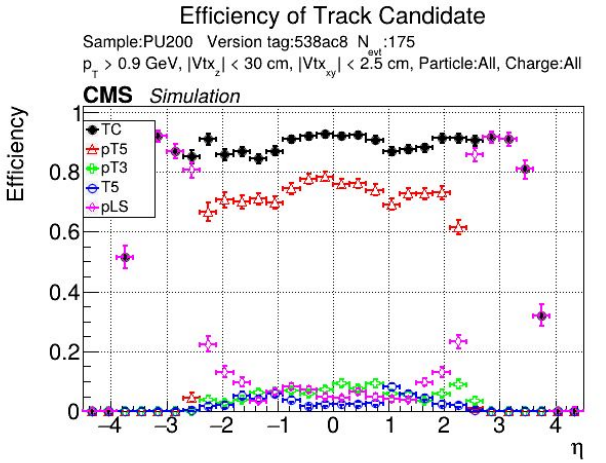


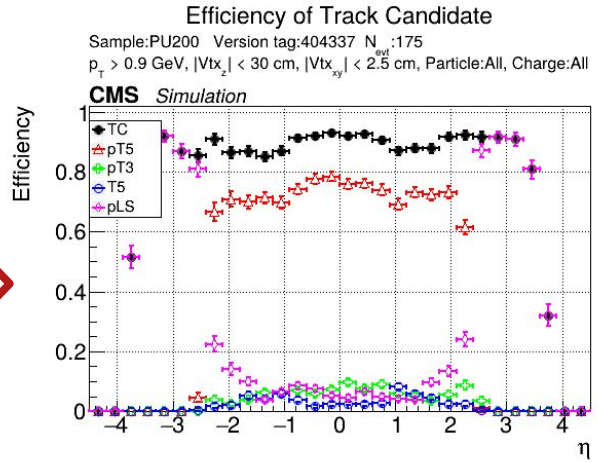


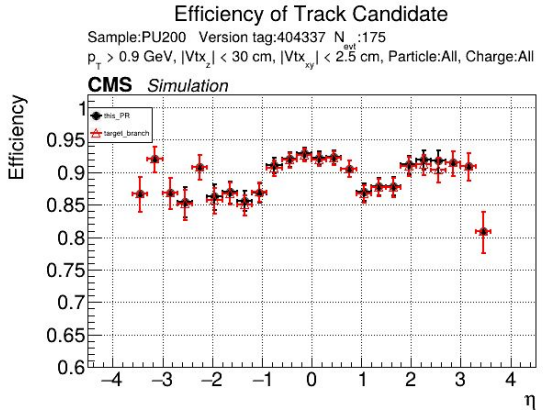


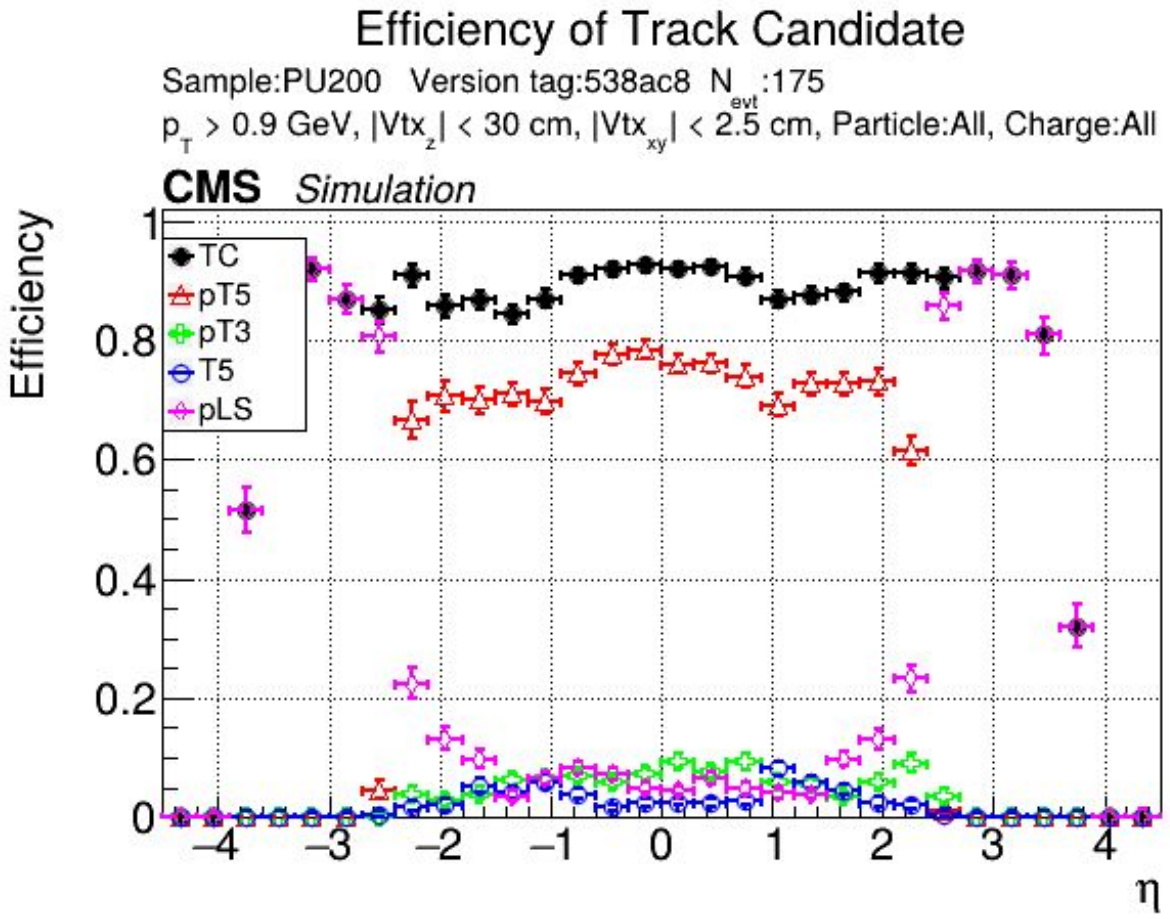
DNN Efficiency Comparison, Eta

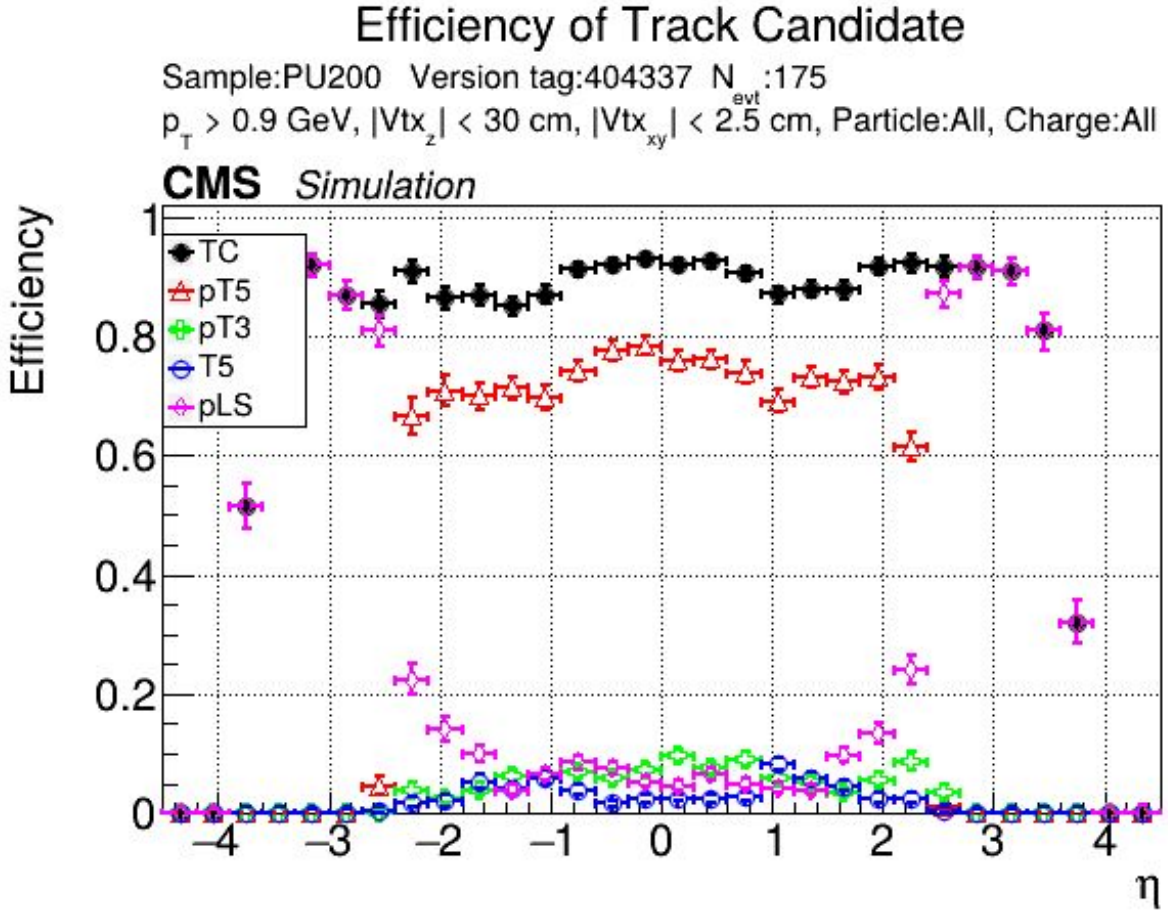
- Small increases in pLS and overall efficiency from reduced fake rate.
  - Fluctuations in pT5 and T5 efficiency are likely from cross-cleaning.





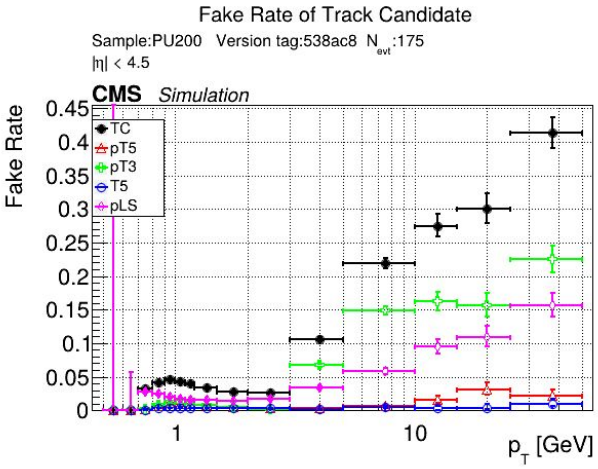


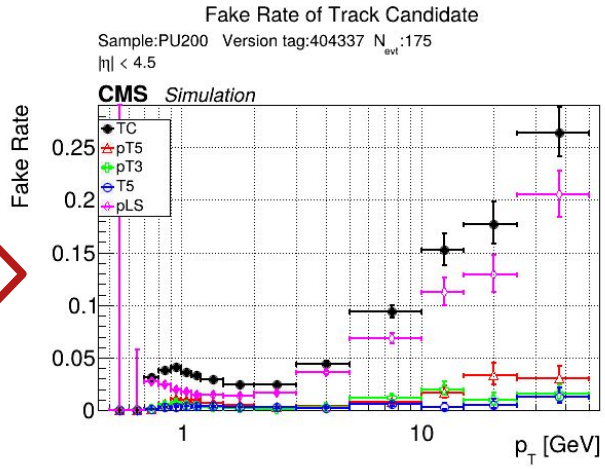

Efficiency of Track Candidate
Sample:PU200 Version tag:538ac8 N_evt:175
p_T > 0.9 GeV, |Vtx_z| < 30 cm, |Vtx_xy| < 2.5 cm, Particle:All, Charge:All
CMS Simulation
Efficiency
TC
pT5
pT3
T5
pLS
1
0.8
0.6
0.4
0.2
0
−4
−3
−2
−1
0
1
2
3
4
η

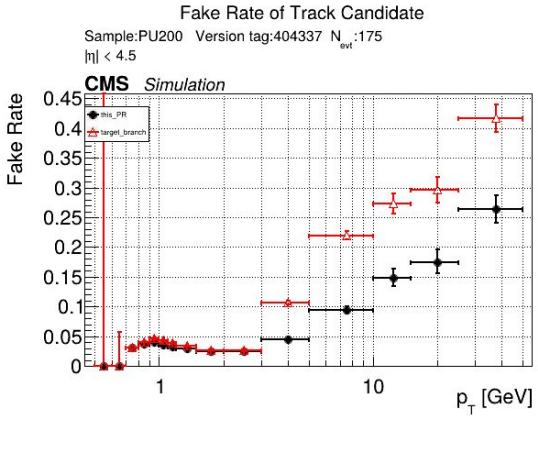

Efficiency of Track Candidate
Sample:PU200 Version tag:404337 N evt :175
p T > 0.9 GeV, |Vtx z| < 30 cm, |Vtx xy| < 2.5 cm, Particle:All, Charge:All
CMS Simulation
Efficiency
TC
pT5
pT3
T5
pLS
1
0.8
0.6
0.4
0.2
0
−4
−3
−2
−1
0
1
2
3
4
η

DNN Fake Rate Reduction, pT

- Large reduction in fake rate at high pT. The pT3 fake rate is now comparable to other objects.

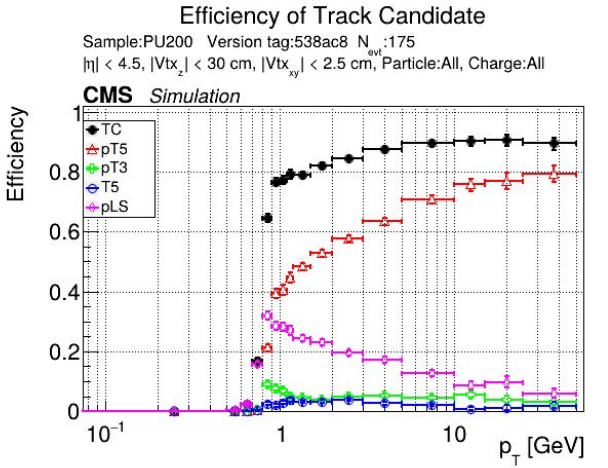


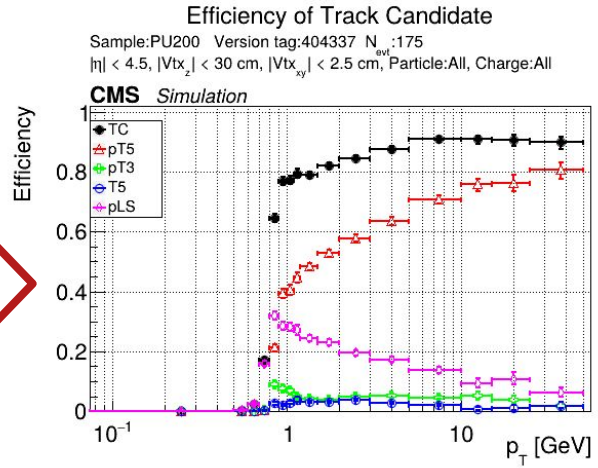


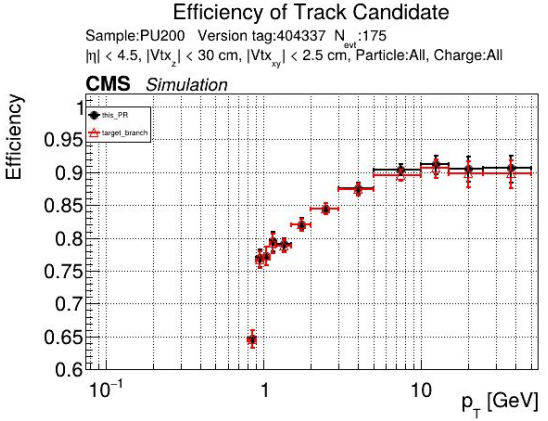


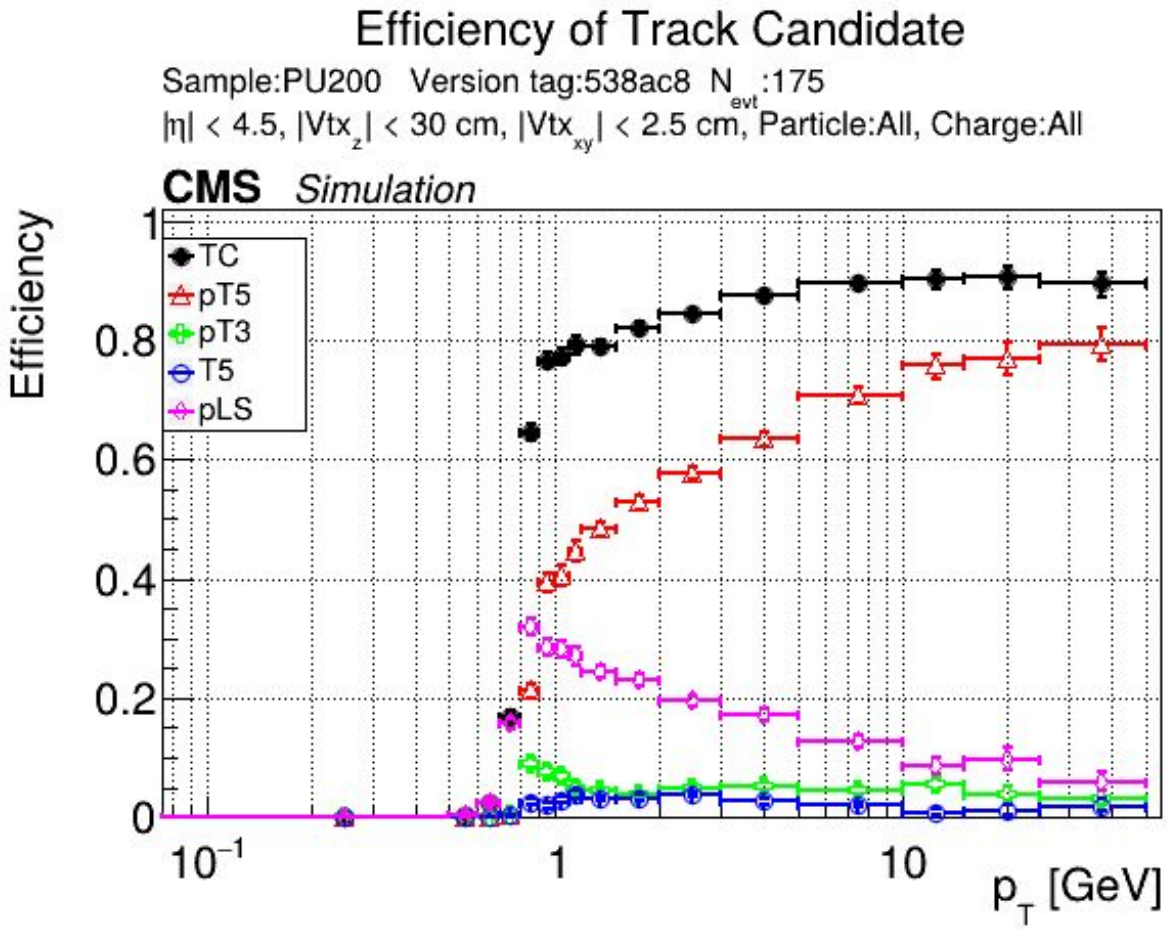
DNN Efficiency Comparison, pT

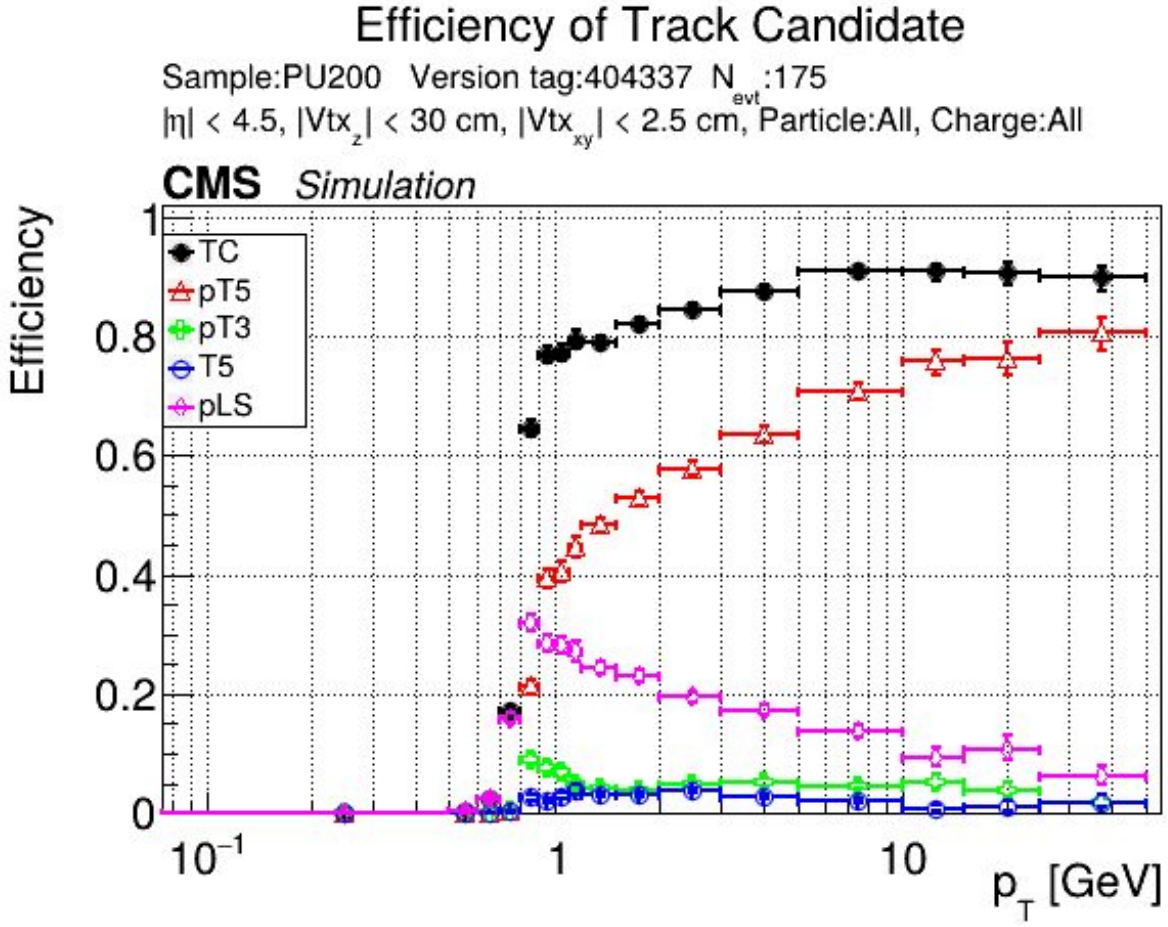
- Small increases in pLS and overall efficiency from reduced fake rate.
  - Fluctuations in pT5 and T5 efficiency are likely from cross-cleaning.





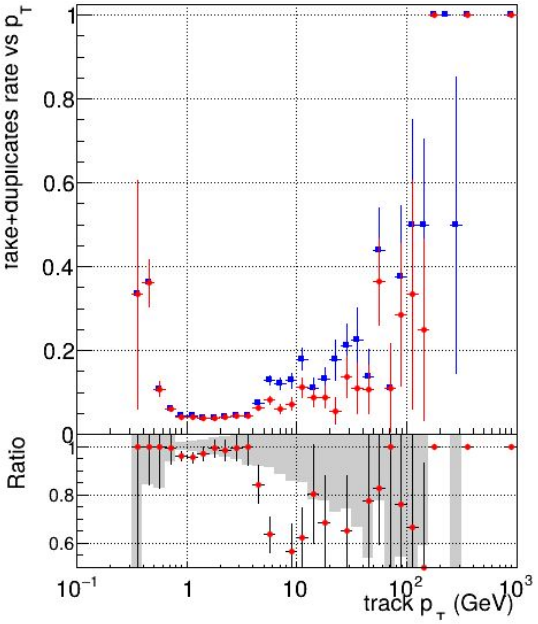


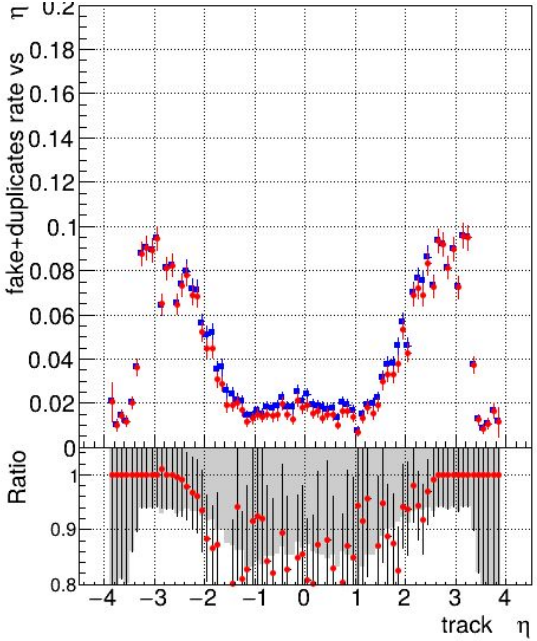

Efficiency of Track Candidate
Sample:PU200 Version tag:538ac8 N_evt:175
|η| < 4.5, |Vtx_z| < 30 cm, |Vtx_xy| < 2.5 cm, Particle:All, Charge:All
CMS Simulation
Efficiency
TC
pT5
pT3
T5
pLS
1
0.8
0.6
0.4
0.2
0
10^-1
1
10
p_T [GeV]


Efficiency of Track Candidate
Sample:PU200 Version tag:404337 N_evt:175
|η| < 4.5, |Vtx_z| < 30 cm, |Vtx_xy| < 2.5 cm, Particle:All, Charge:All
CMS Simulation
Efficiency
TC
pT5
pT3
T5
pLS
1
0.8
0.6
0.4
0.2
0
10^-1
1
10
p_T [GeV]

DNN Fake Rate Reduction, CMSSW

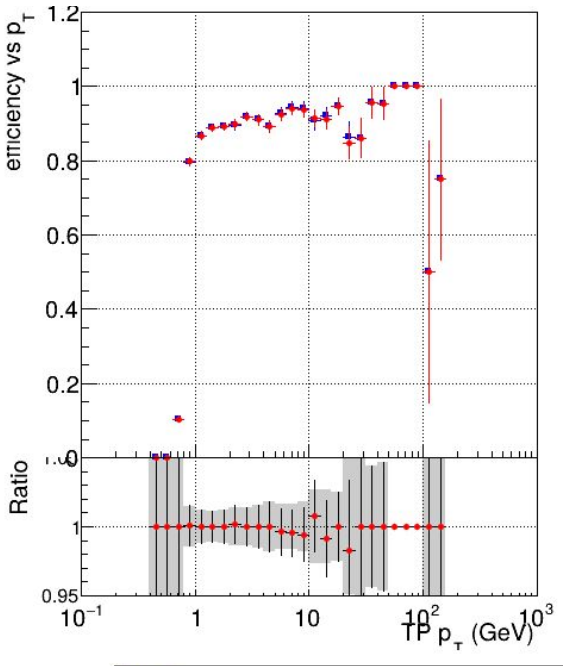
- Similar reductions in fake rate at high pT and in eta also observed in CMSSW performance plots.

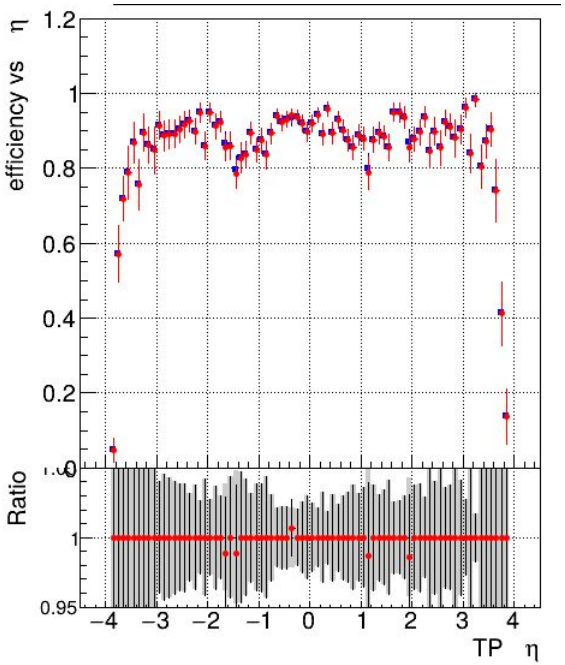




DNN Efficiency Comparison, CMSSW

- Negligible differences in efficiency in the CMSSW comparison plots.





Timing Differences

- No noticeable differences in timing on L40 GPU or on CPU.

Current Timing

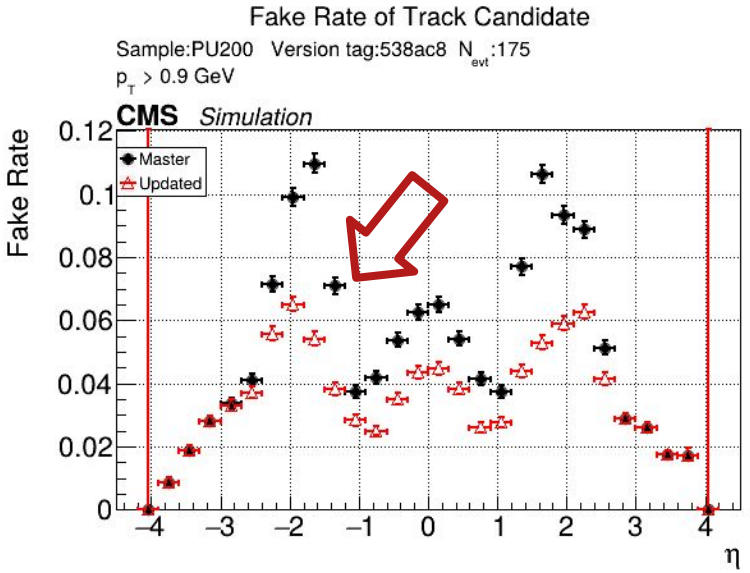
```
Total Timing Summary
Average time for map loading = 326.331 ms
Average time for input loading = 6668.28 ms
Average time for lst::Event creation = 0.00152134 ms
   Evt    Hits       MD       LS       T3       T5       pLS      pT5      pT3      TC       Reset    Event    Short            Rate
   avg     0.8      0.3      0.2      1.4      0.5      0.2      0.6      0.3      0.6      0.0      4.9      3.8+/-  0.8      5.2      explicit[s=1]
   avg     1.0      0.4      0.3      1.6      0.5      0.3      0.7      0.4      0.7      0.0      6.0      4.7+/-  1.0      3.2      explicit[s=2]
   avg     1.4      0.6      0.5      2.0      0.8      0.4      1.0      0.5      1.0      0.0      8.3      6.5+/-  2.0      2.2      explicit[s=4]
   avg     2.1      0.9      0.7      2.4      1.0      0.6      1.4      0.7      1.4      0.0      11.3     8.5+/-  3.3      2.0      explicit[s=6]
   avg     2.6      1.2      0.8      2.7      1.3      0.9      1.9      0.9      1.8      0.0      14.1     10.6+/- 4.6      1.9      explicit[s=8]
```

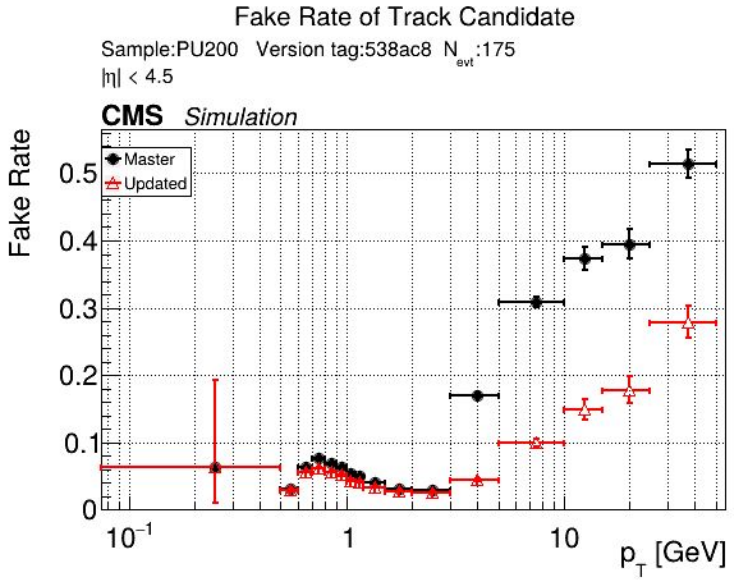
This PR Timing

```
Total Timing Summary
Average time for map loading = 320.709 ms
Average time for input loading = 6673.98 ms
Average time for lst::Event creation = 0.000987734 ms
   Evt    Hits       MD       LS       T3       T5       pLS      pT5      pT3      TC       Reset    Event    Short            Rate
   avg     0.8      0.3      0.2      1.4      0.4      0.2      0.6      0.3      0.6      0.0      4.8      3.8+/-  0.8      5.2      explicit[s=1]
   avg     1.0      0.4      0.3      1.6      0.5      0.3      0.7      0.4      0.7      0.0      6.0      4.7+/-  1.0      3.2      explicit[s=2]
   avg     1.4      0.6      0.5      2.0      0.7      0.5      1.0      0.5      1.0      0.0      8.4      6.5+/-  2.0      2.2      explicit[s=4]
   avg     1.9      0.9      0.7      2.4      1.0      0.7      1.4      0.7      1.4      0.0      11.1     8.5+/-  3.5      2.0      explicit[s=6]
   avg     2.7      1.1      0.9      2.8      1.3      0.8      1.9      0.9      1.7      0.0      14.0     10.5+/- 4.5      1.9      explicit[s=8]
```

Low-pT Config Fake Rate Changes

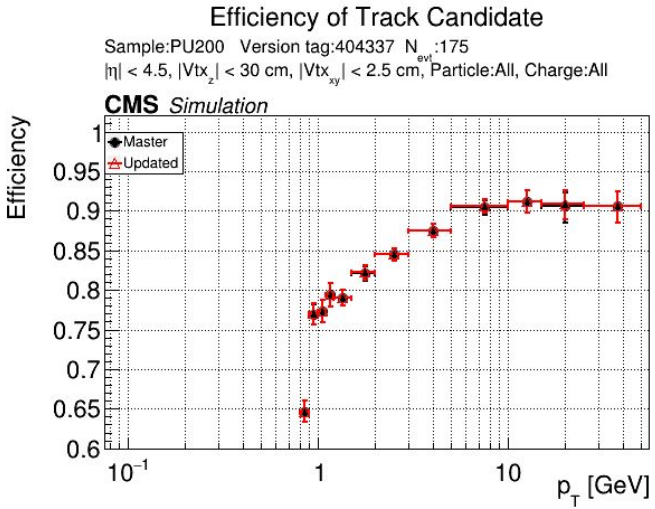
- Low-pT config fake rate is now comparable to normal config outside of barrel after including pT3 DNN cut.
- Efficiency and fake rate for low-pT config should be roughly similar after occupancies PR (#147) is merged and tightCutFlag is moved over to T5 DNN.

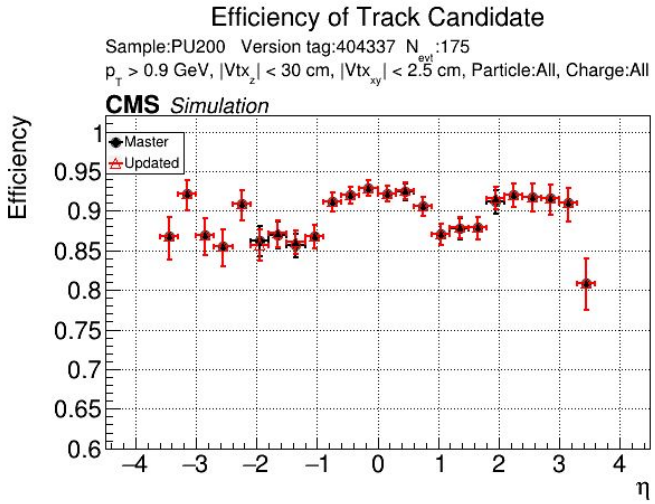


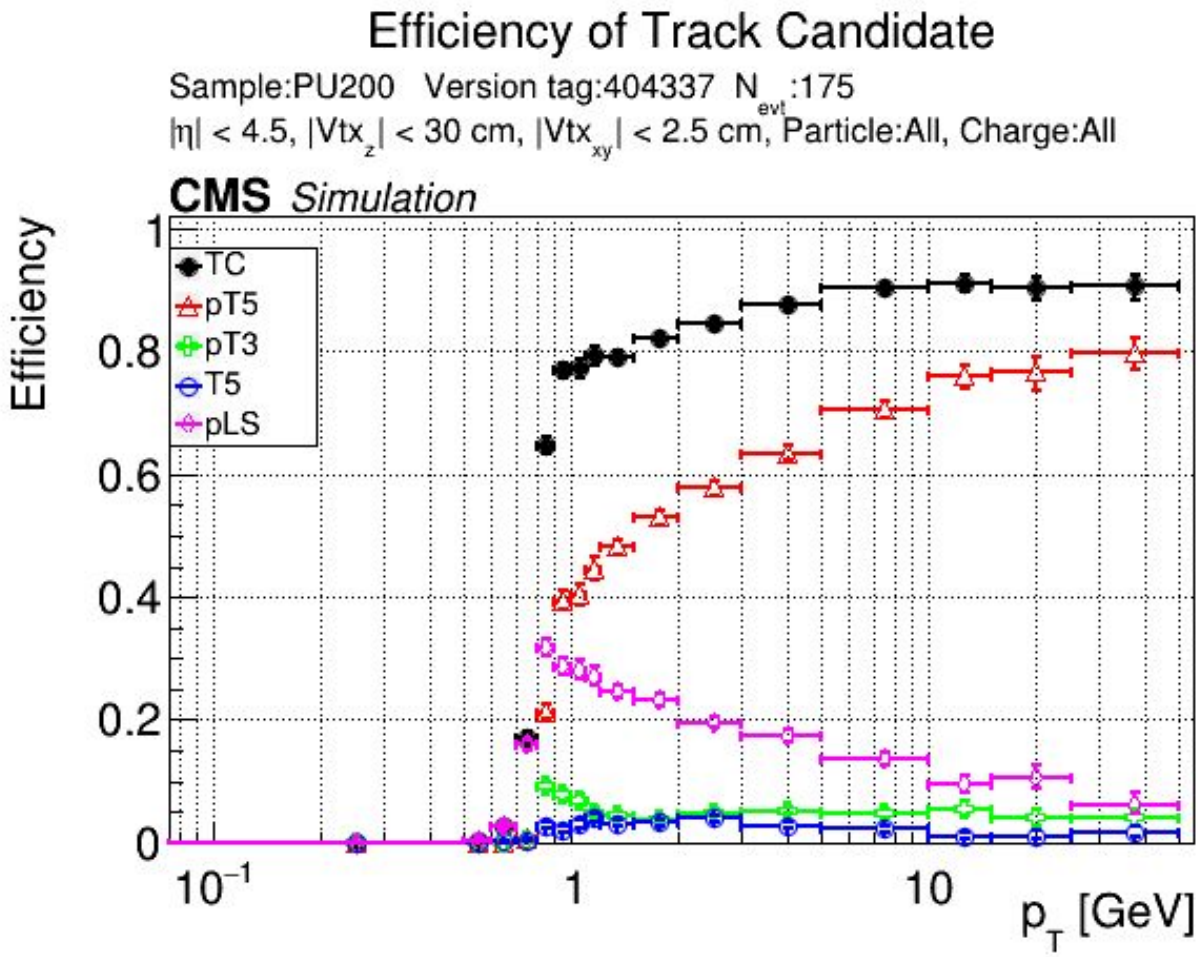


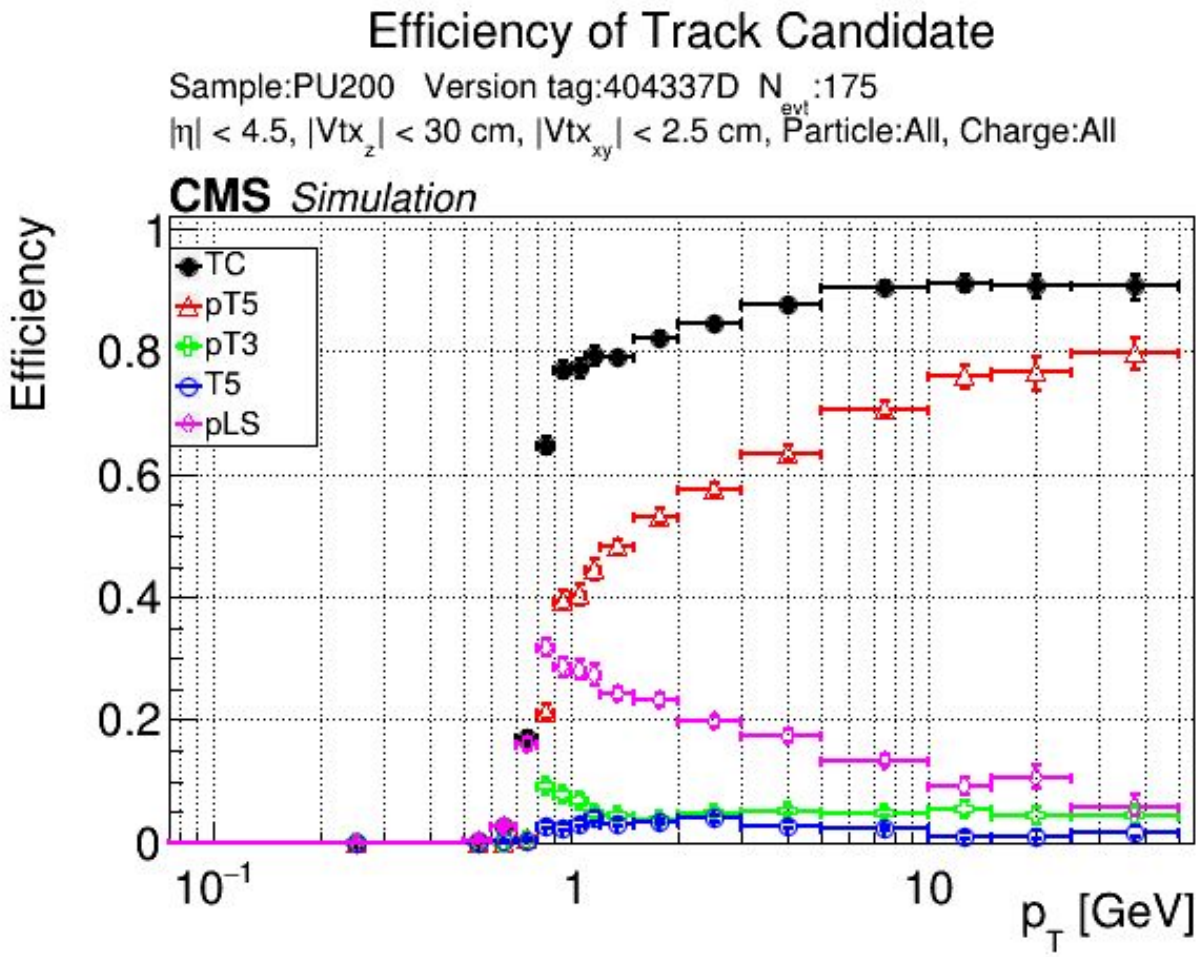
Turning on pT3 DNN for pT5's, Efficiency

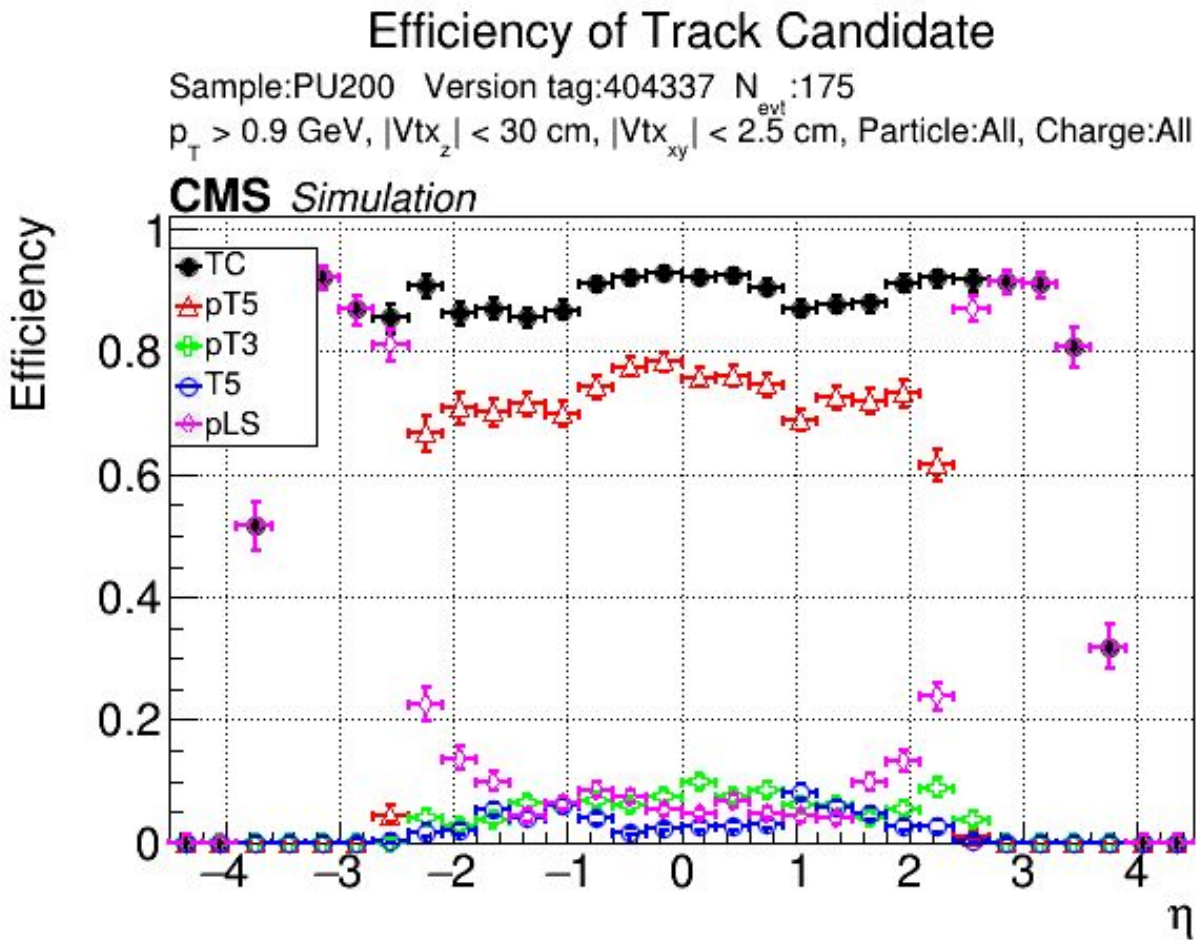
- pT3 DNN has negligible effect on efficiency, and most of the changes are likely from result of cross cleaning.
- Black is before, Red is after turning on pT3 DNN for pT5's for plots below.

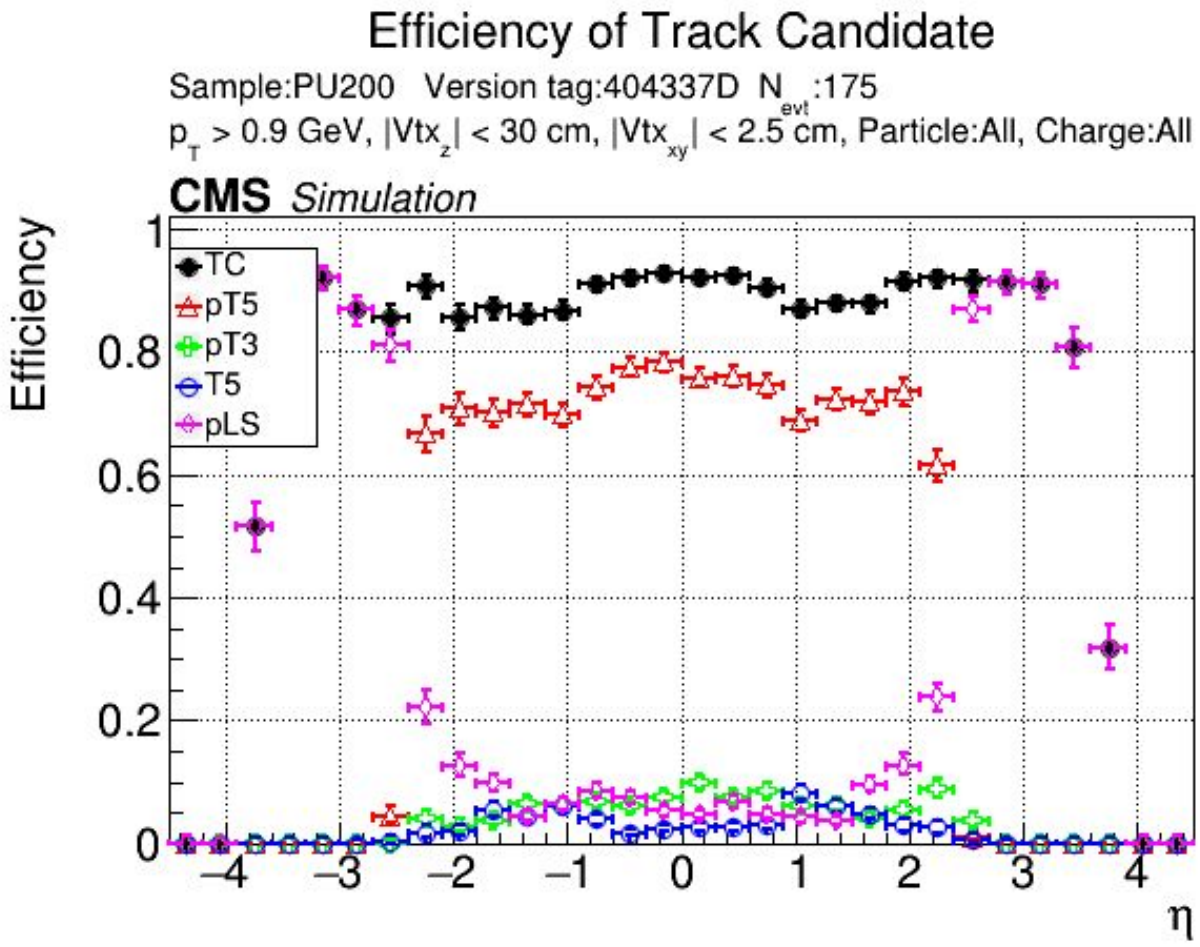





Efficiency of Track Candidate
Sample:PU200 Version tag:404337 N_evt:175
|η| < 4.5, |Vtx_z| < 30 cm, |Vtx_xy| < 2.5 cm, Particle:All, Charge:All
CMS Simulation
Efficiency
TC
pT5
pT3
T5
pLS
1
0.8
0.6
0.4
0.2
0
10^-1
1
10
p_T [GeV]

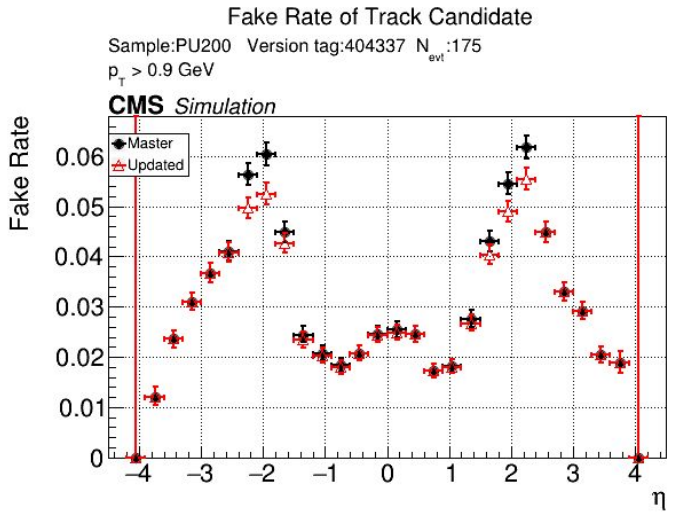

Efficiency of Track Candidate
Sample:PU200 Version tag:404337D N_evt:175
|η| < 4.5, |Vtx_z| < 30 cm, |Vtx_xy| < 2.5 cm, Particle:All, Charge:All
CMS Simulation
Efficiency
TC
pT5
pT3
T5
pLS
1
0.8
0.6
0.4
0.2
0
10^-1
1
10
p_T [GeV]

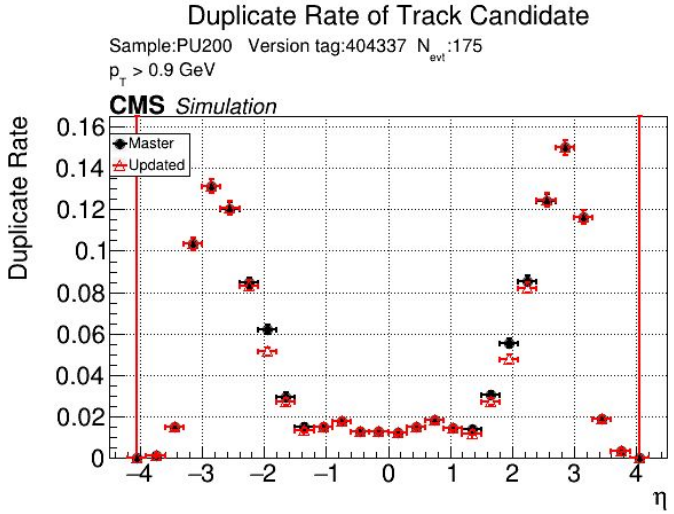

Efficiency of Track Candidate
Sample:PU200 Version tag:404337 N_evt:175
p_T > 0.9 GeV, |Vtx_z| < 30 cm, |Vtx_xy| < 2.5 cm, Particle:All, Charge:All
CMS Simulation
Efficiency
TC
pT5
pT3
T5
pLS
1
0.8
0.6
0.4
0.2
0
−4
−3
−2
−1
0
1
2
3
4
η


Efficiency of Track Candidate
Sample:PU200 Version tag:404337D N_evt:175
p_T > 0.9 GeV, |Vtx_z| < 30 cm, |Vtx_xy| < 2.5 cm, Particle:All, Charge:All
CMS Simulation
Efficiency
TC
pT5
pT3
T5
pLS
1
0.8
0.6
0.4
0.2
0
−4
−3
−2
−1
0
1
2
3
4
η

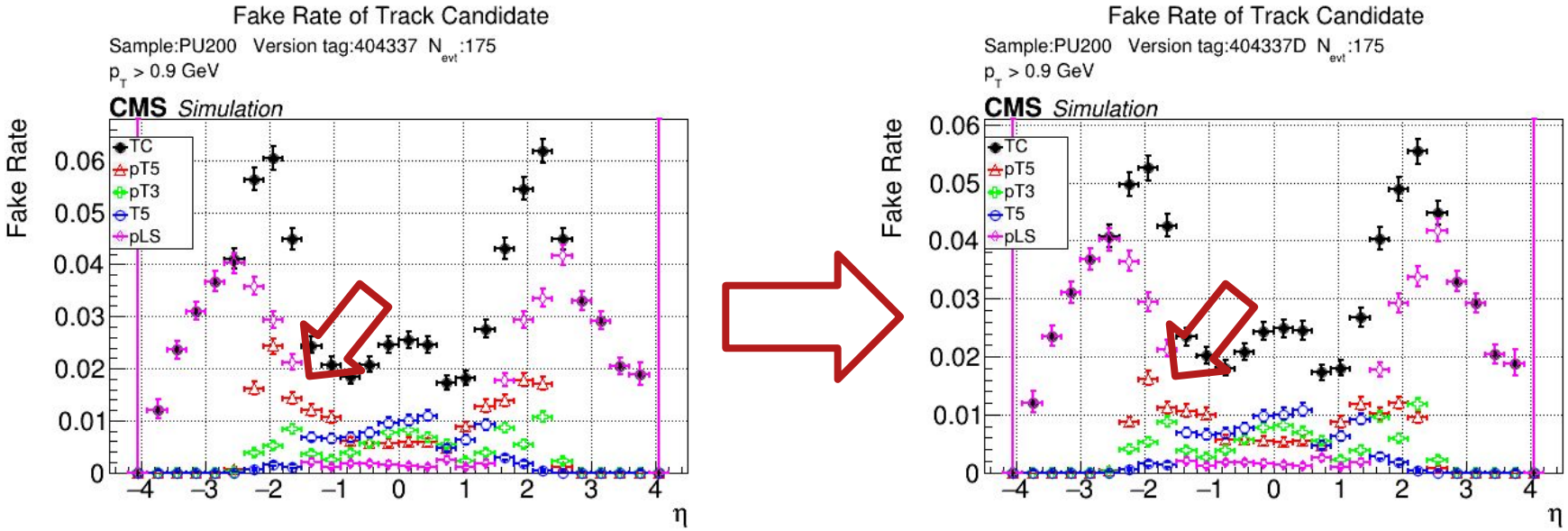
Turning on pT3 DNN for pT5's, FR + DR

- Duplicate rate goes down a bit, and fake rate goes down as well.
- Black is before, Red is after turning on pT3 DNN for plots below.

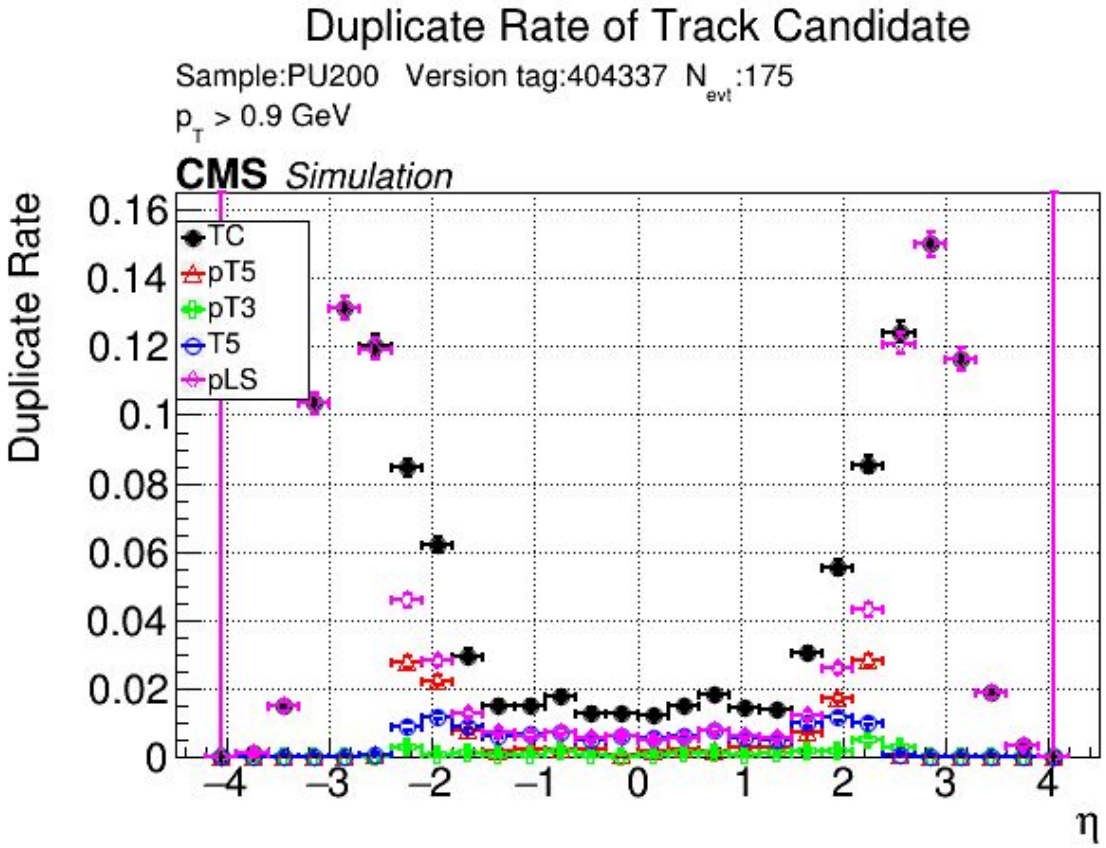




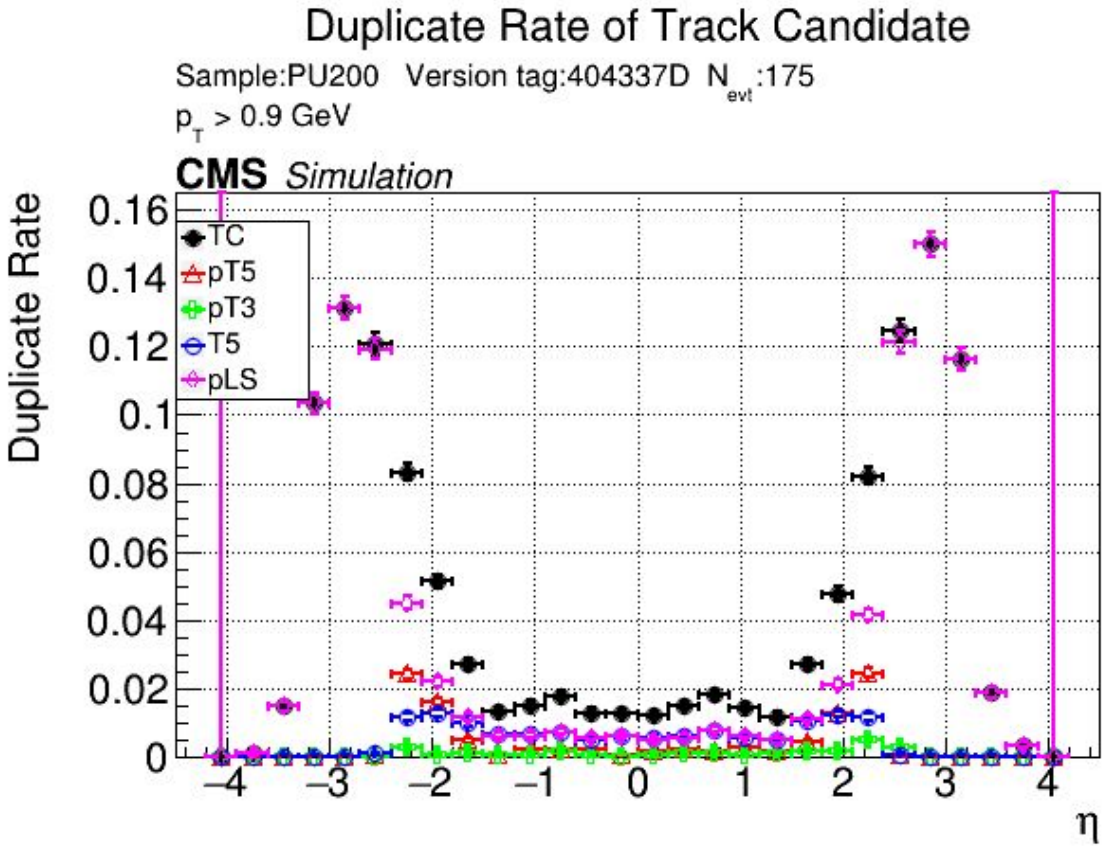
Turning on pT3 DNN for pT5's, FR



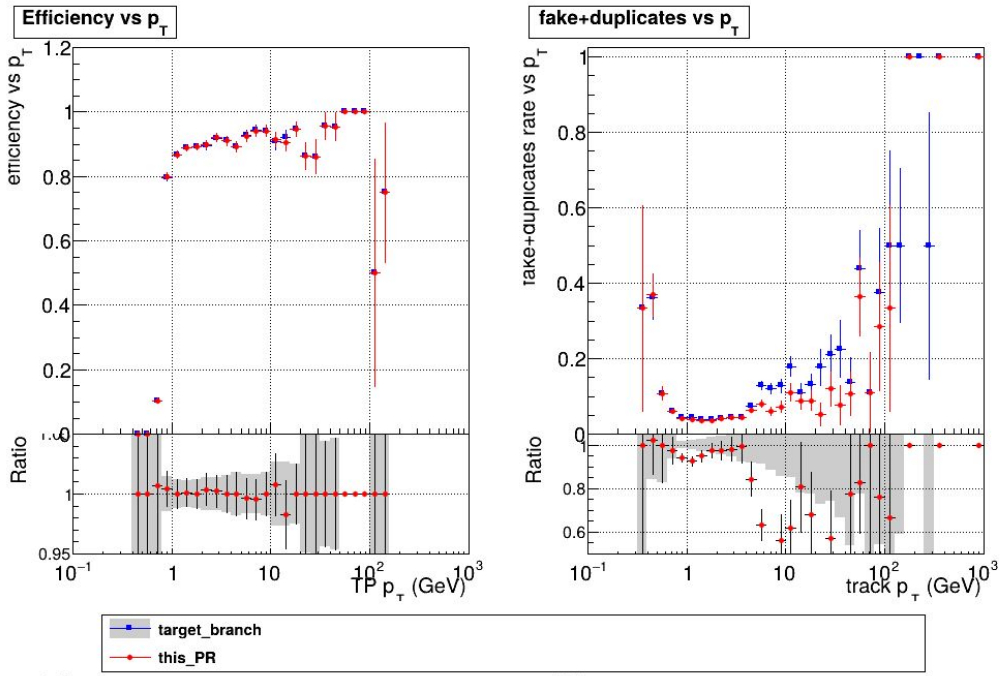
Turning on pT3 DNN for pT5's, DR



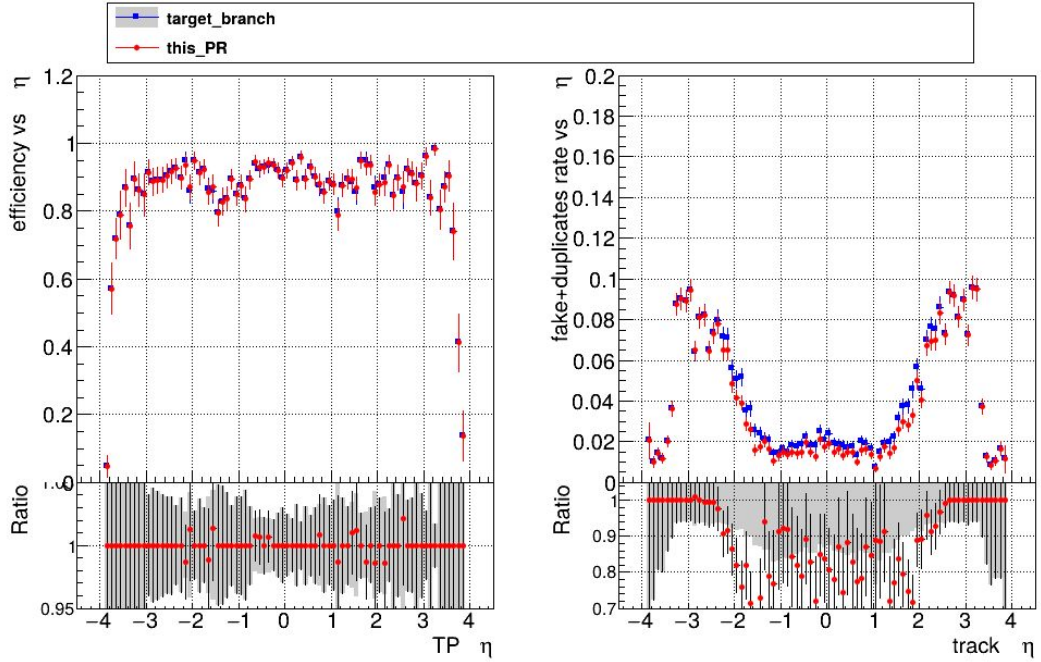
Turning on pT3 DNN for pT5's, DR



Turning on pT3 DNN for pT5's, CMSSW

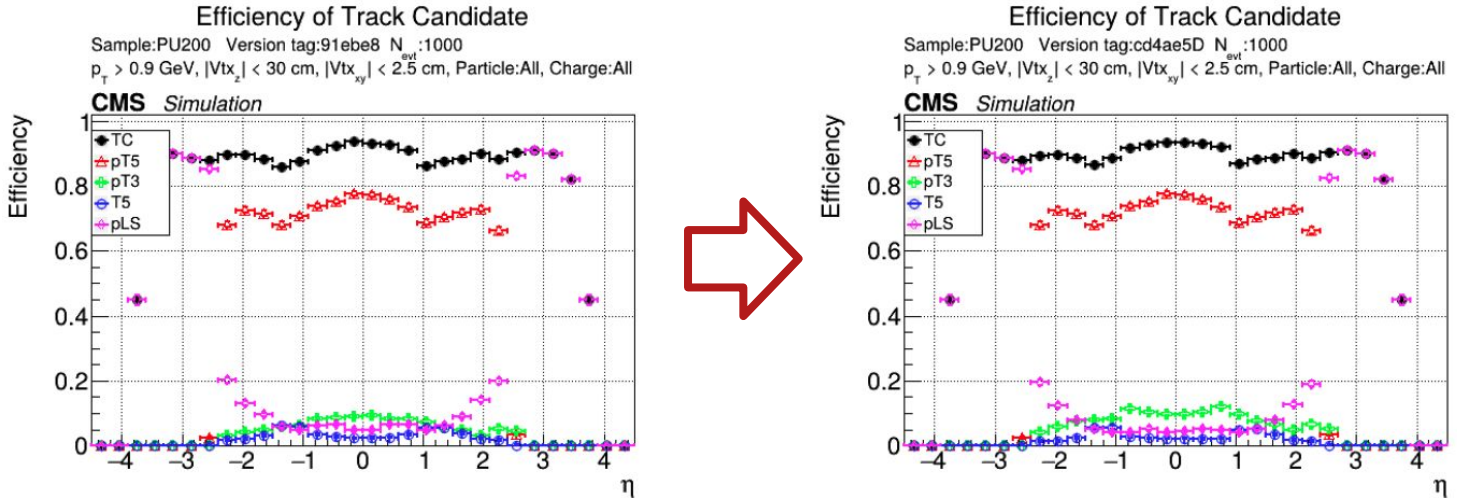


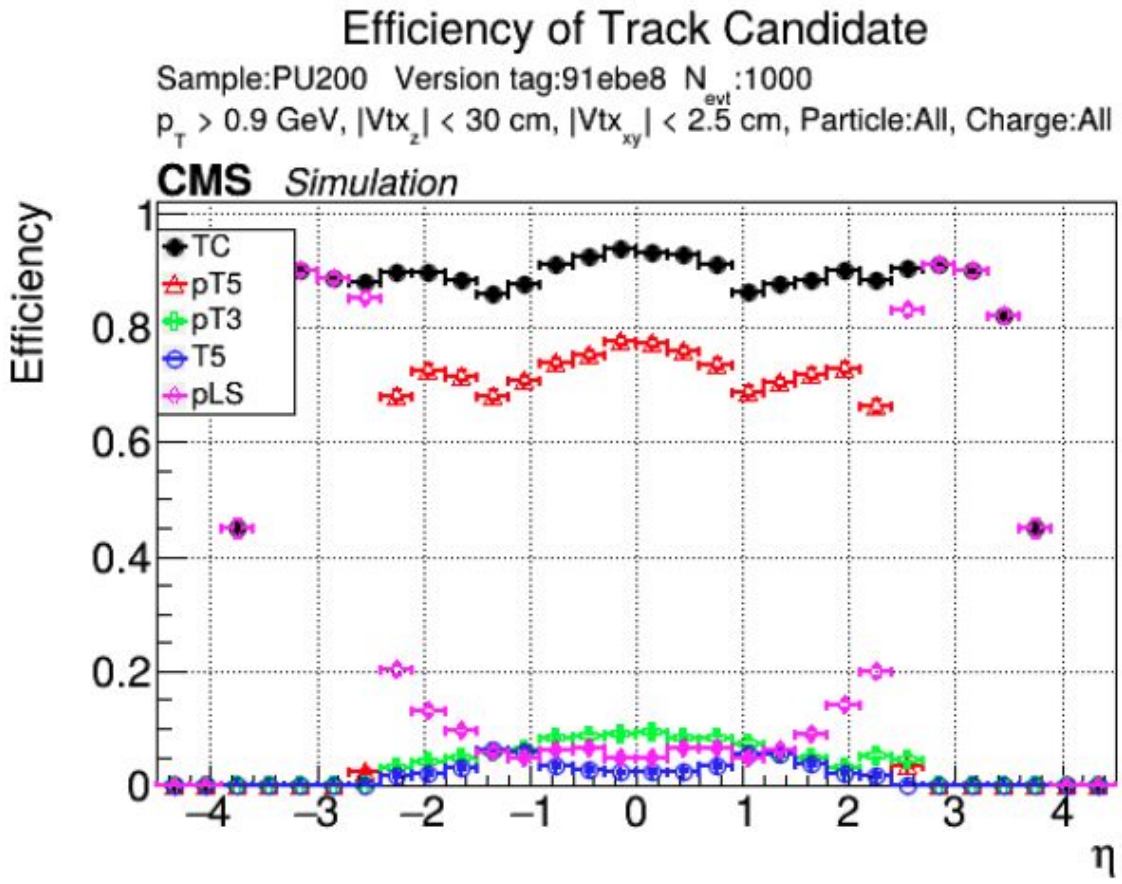
Turning on pT3 DNN for pT5's, CMSSW

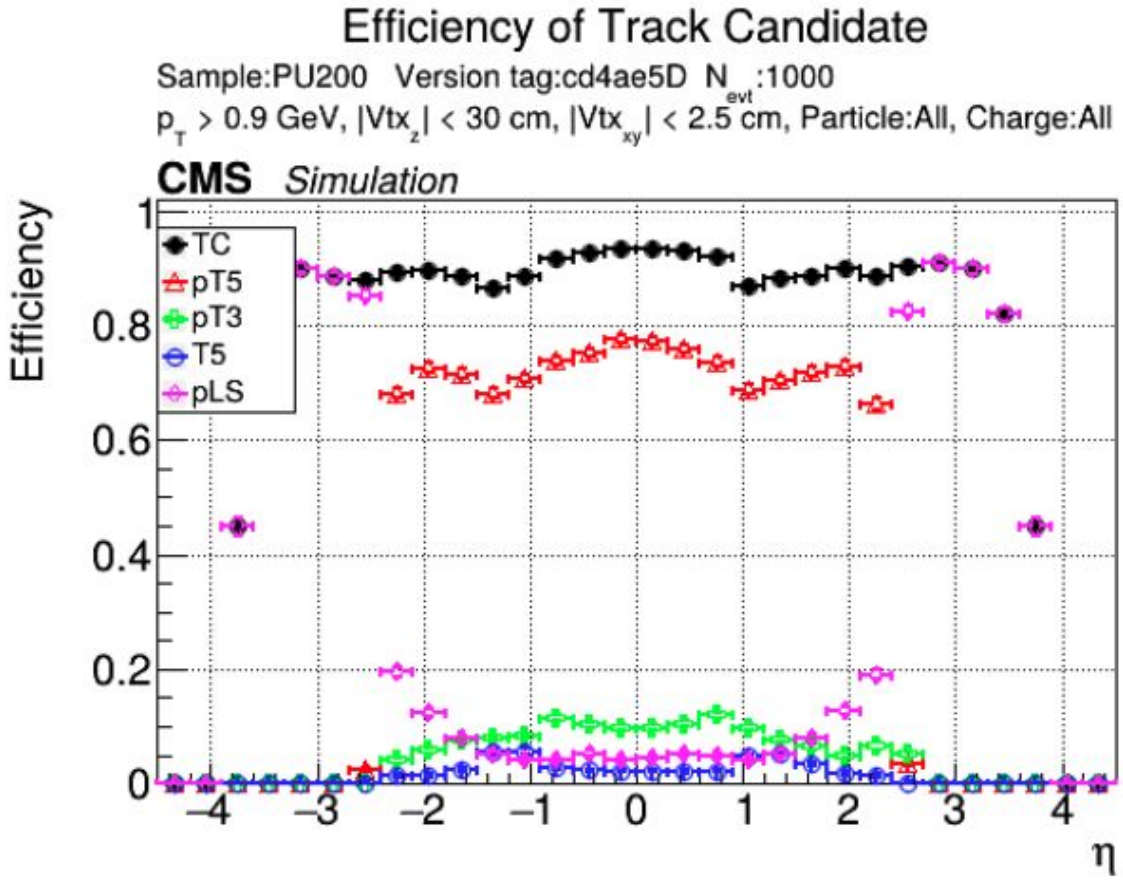


Replacing Existing pT3 Cuts

- Attempted to replace the existing pT3 chi-squared cuts with just a single cut on the DNN.
  - Increased pT3 efficiency, decreased pLS efficiency (i.e. less unmatched pLS tracks in TC collection).
- Will merge this in a follow-up PR, need to do some additional checks on “real” pT3 tracks used for training and method to choose cut values.




Efficiency of Track Candidate
Sample:PU200 Version tag:91ebe8 N_evt:1000
p_T > 0.9 GeV, |Vtx_z| < 30 cm, |Vtx_xy| < 2.5 cm, Particle:All, Charge:All
CMS Simulation
Efficiency
TC
pT5
pT3
T5
pLS
1
0.8
0.6
0.4
0.2
0
−4
−3
−2
−1
0
1
2
3
4
η


Efficiency of Track Candidate
Sample:PU200 Version tag:cd4ae5D N_evt:1000
p_T > 0.9 GeV, |Vtx_z| < 30 cm, |Vtx_xy| < 2.5 cm, Particle:All, Charge:All
CMS Simulation
Efficiency
TC
pT5
pT3
T5
pLS
1
0.8
0.6
0.4
0.2
0
−4
−3
−2
−1
0
1
2
3
4
η

Conclusions

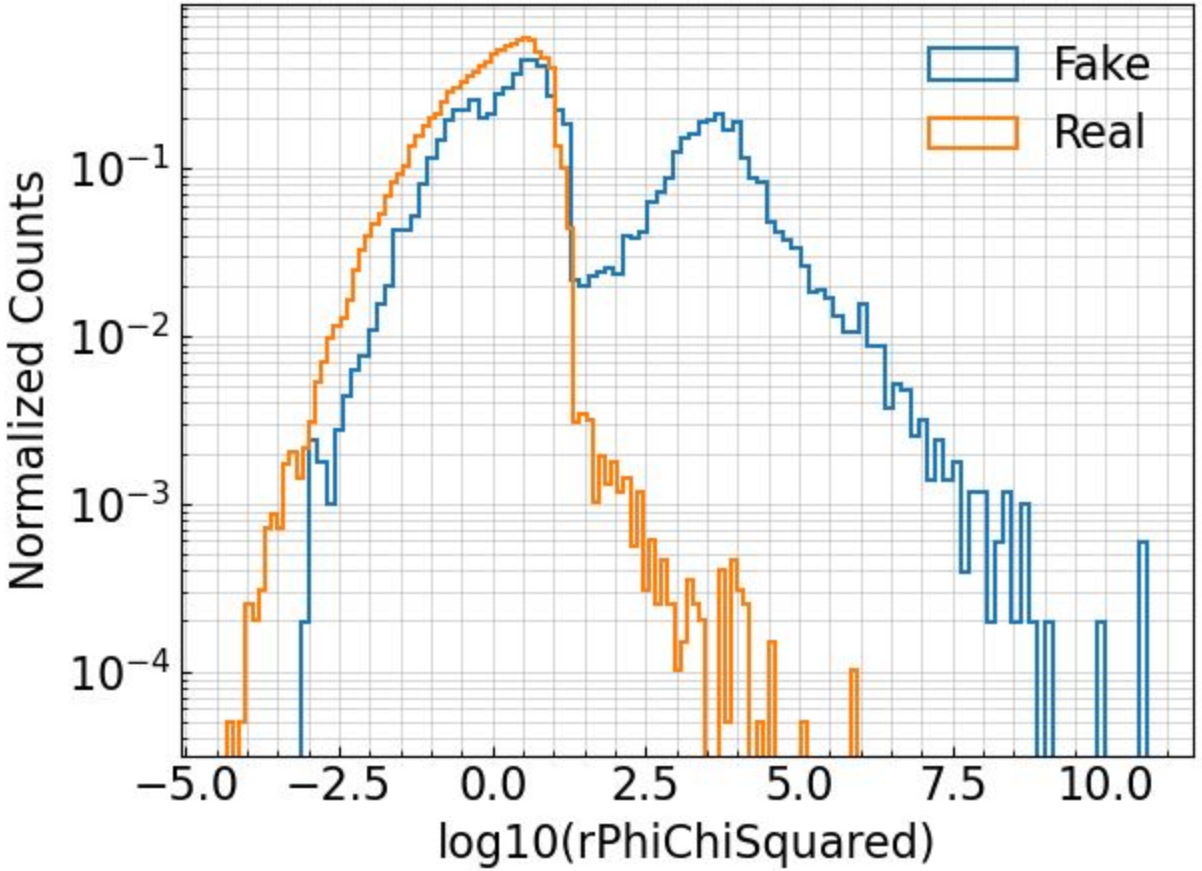
- pT3 DNN reduces overall fake rate of LST with negligible differences in timing and overall efficiency.
    - Makes the low-pT configuration fake rate comparable to the normal configuration outside the barrel.
- Plan to replace the existing chi-squared cuts with a single cut on the DNN in a future PR for improved efficiency.
- Also planning to replace the tightCutFlag for T5’s with the DNN while working on the embeddings.

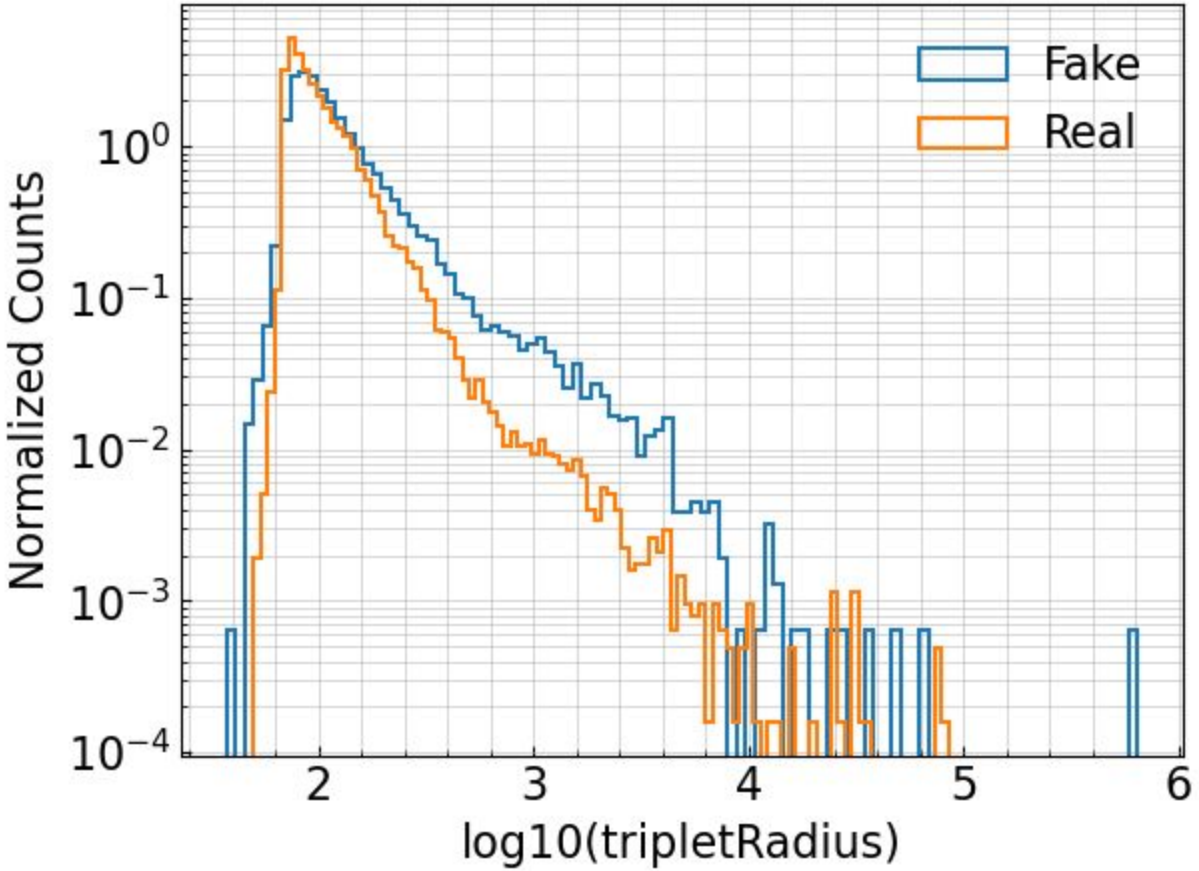
Backup

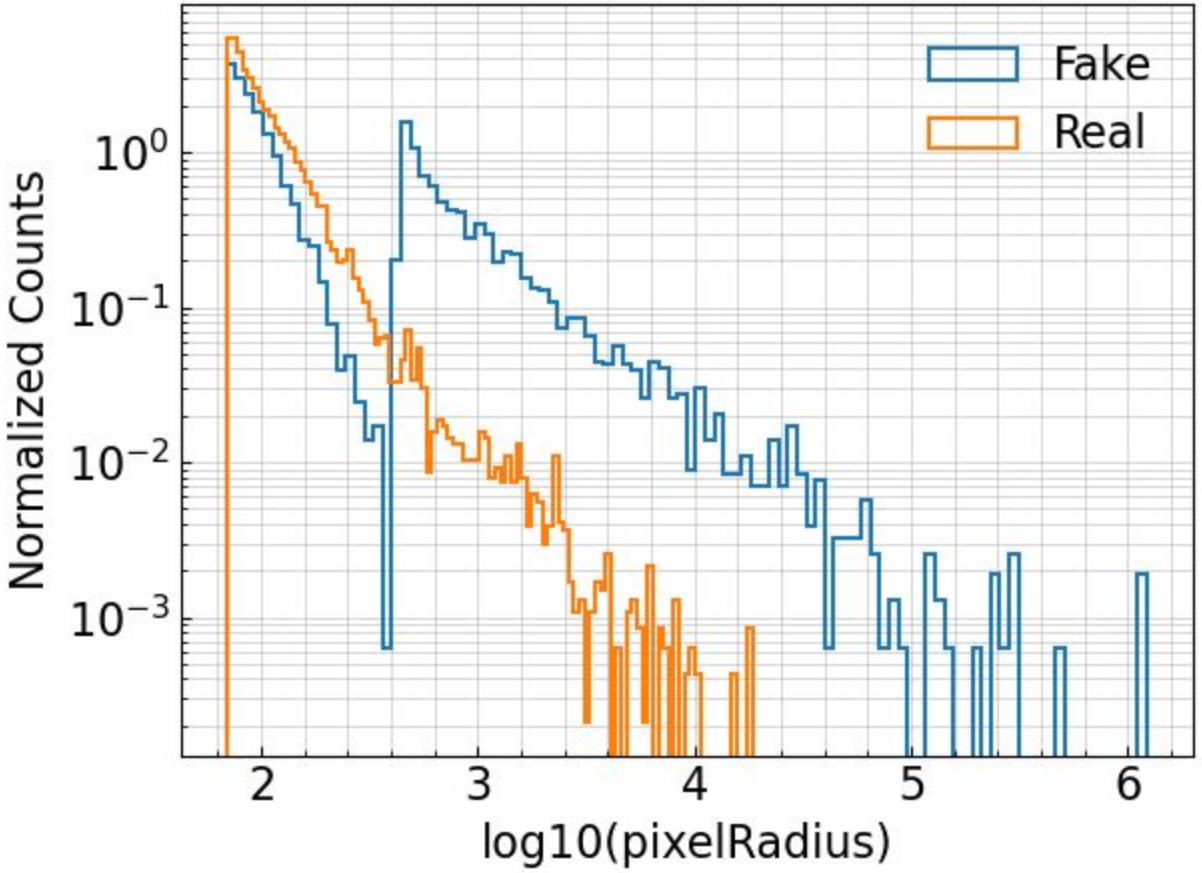
Feature Importances

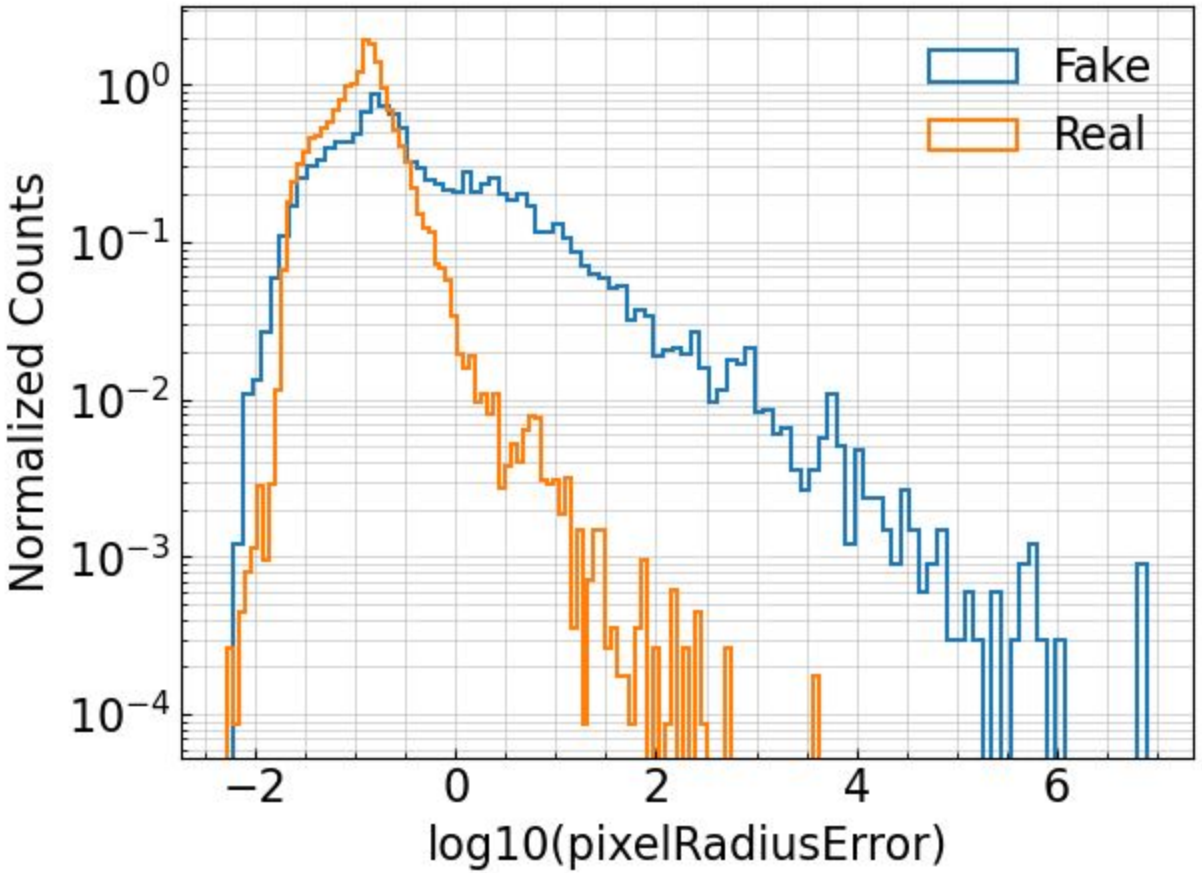
```
features = np.array([
    np.log10(pt3_rPhiChiSquared),
    np.log10(pt3_trip_rad),
    np.log10(pt3_pix_rad),
    np.log10(pt3_pixRadError),
    np.log10(pt3_rzChiSquared),
    np.abs(pt3_eta)/eta_max
])
```

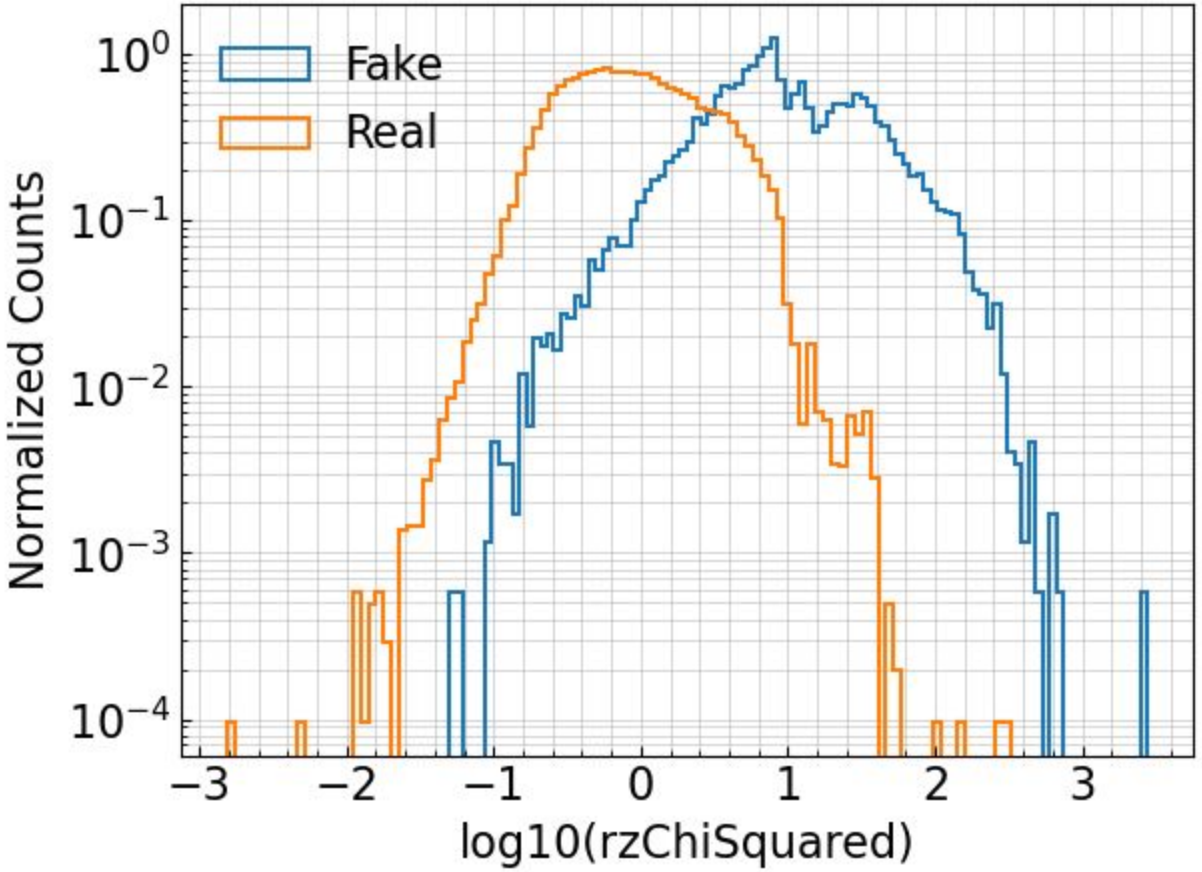
```
Feature importances:
Feature 2 importance: 0.1705
Feature 1 importance: 0.1614
Feature 3 importance: 0.0985
Feature 5 importance: 0.0871
Feature 4 importance: 0.0293
Feature 0 importance: 0.0219
```

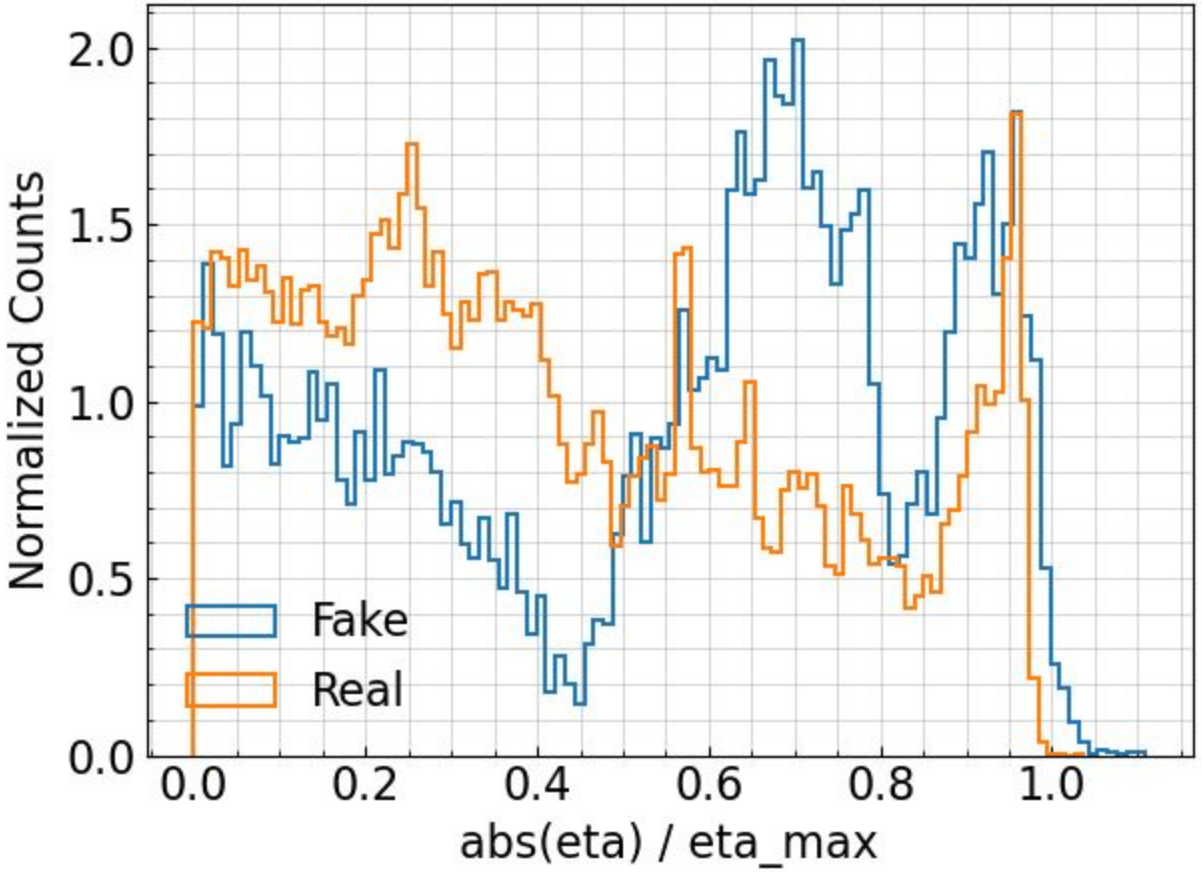

Fake
Real
Normalized Counts
10^{-1}
10^{-2}
10^{-3}
10^{-4}
−5.0
−2.5
0.0
2.5
5.0
7.5
10.0
log10(rPhiChiSquared)


Fake
Real
Normalized Counts
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
2
3
4
5
6
log10(tripletRadius)


Fake
Real
Normalized Counts
10^{0}
10^{-1}
10^{-2}
10^{-3}
2
3
4
5
6
log10(pixelRadius)


Fake
Real
Normalized Counts
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
−2
0
2
4
6
log10(pixelRadiusError)


Fake
Real
Normalized Counts
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
−3
−2
−1
0
1
2
3
log10(rzChiSquared)


Normalized Counts
2.0
1.5
1.0
0.5
0.0
Fake
Real
0.0
0.2
0.4
0.6
0.8
1.0
abs(eta) / eta_max