Update on PreTDR Plots

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hipe4ml package for ML

Ref: https://doi.org/10.5281/zenodo.5070131

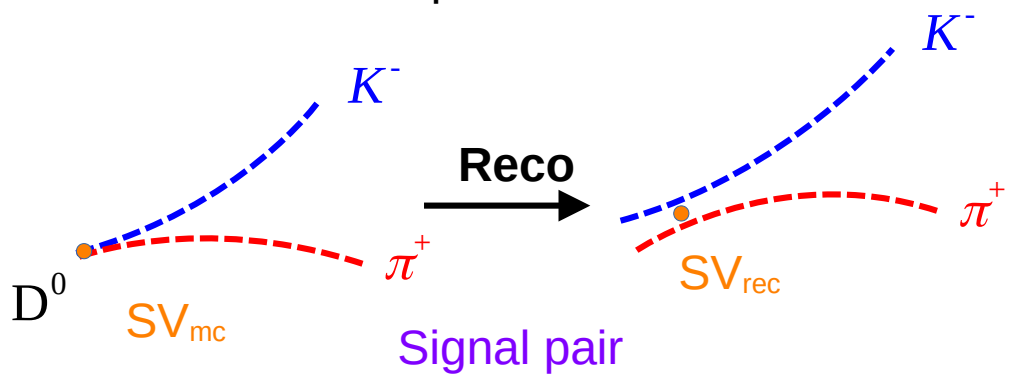
Secondary Vertex Reconstruction

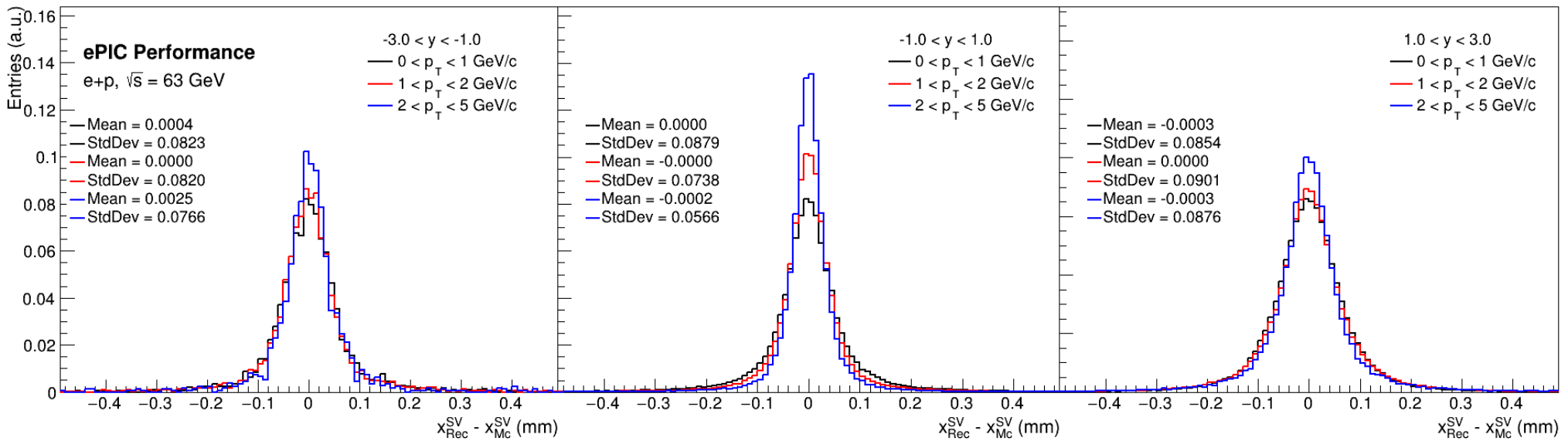
Secondary Vertex (D^0)

25.04.1

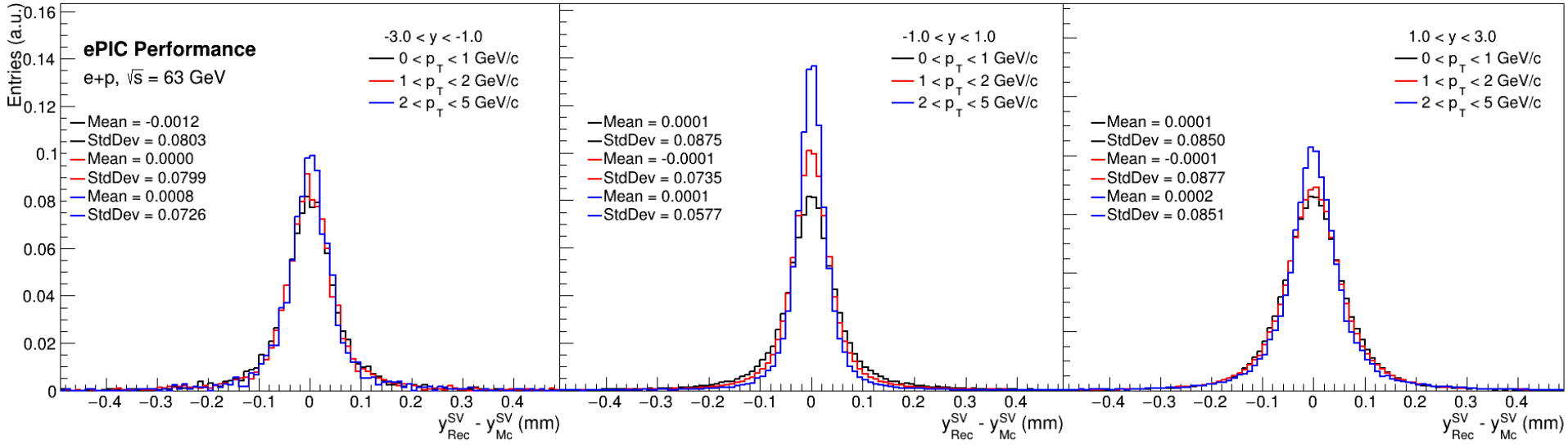
$D^0 \rightarrow K^- \pi^+$

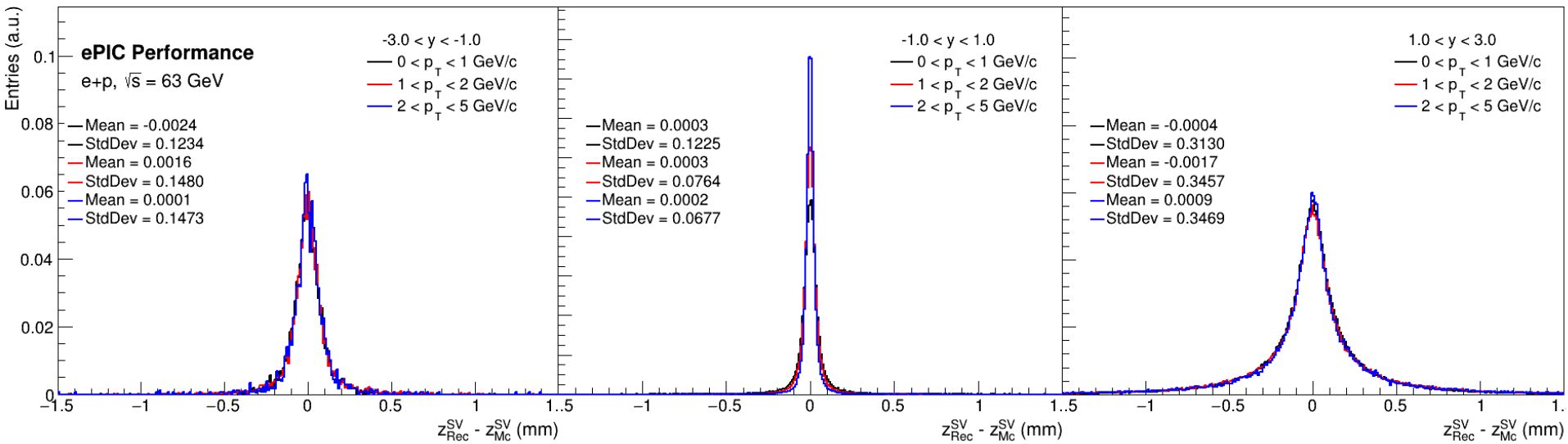
Chi-square minimization



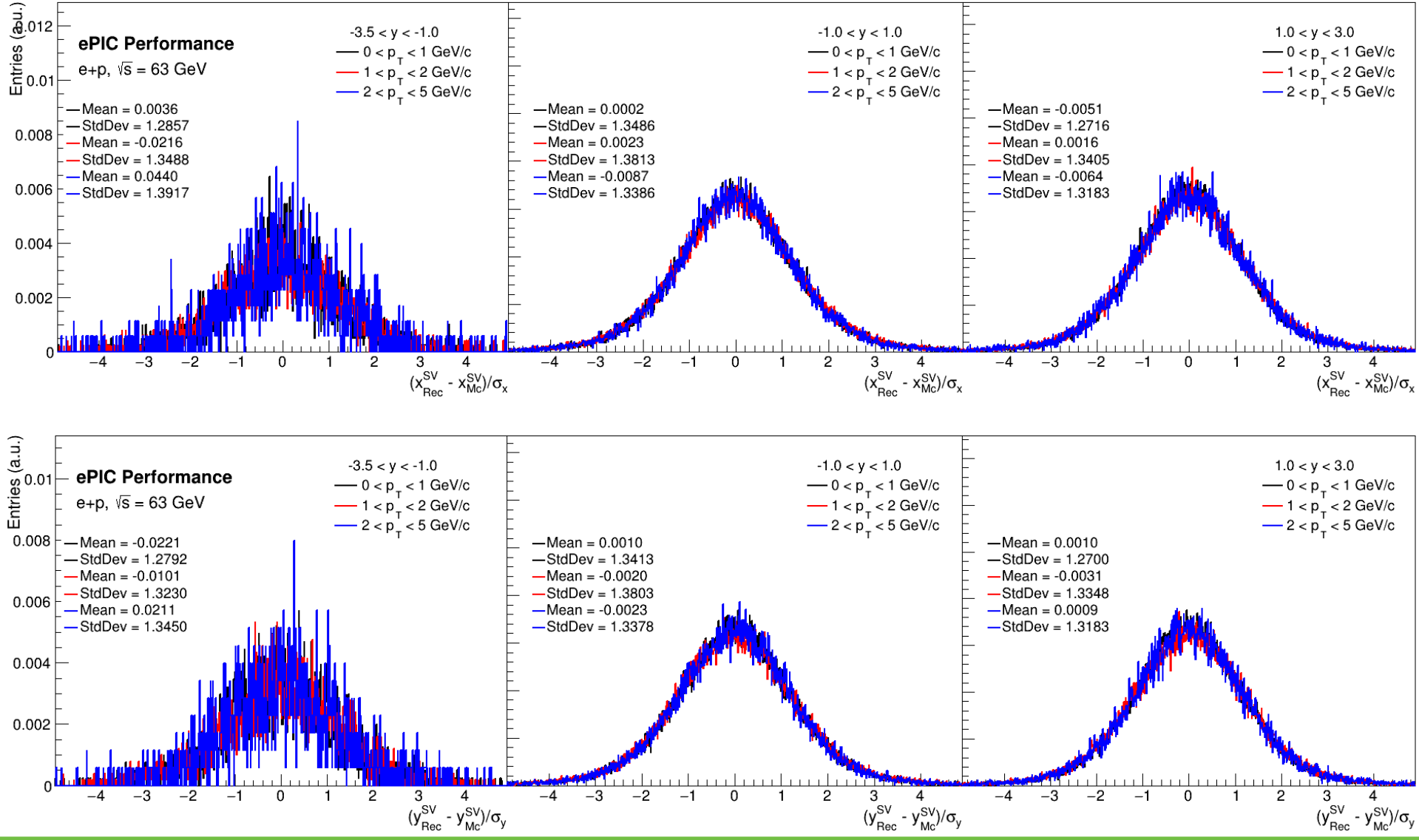


Secondary Vertex (D^0)

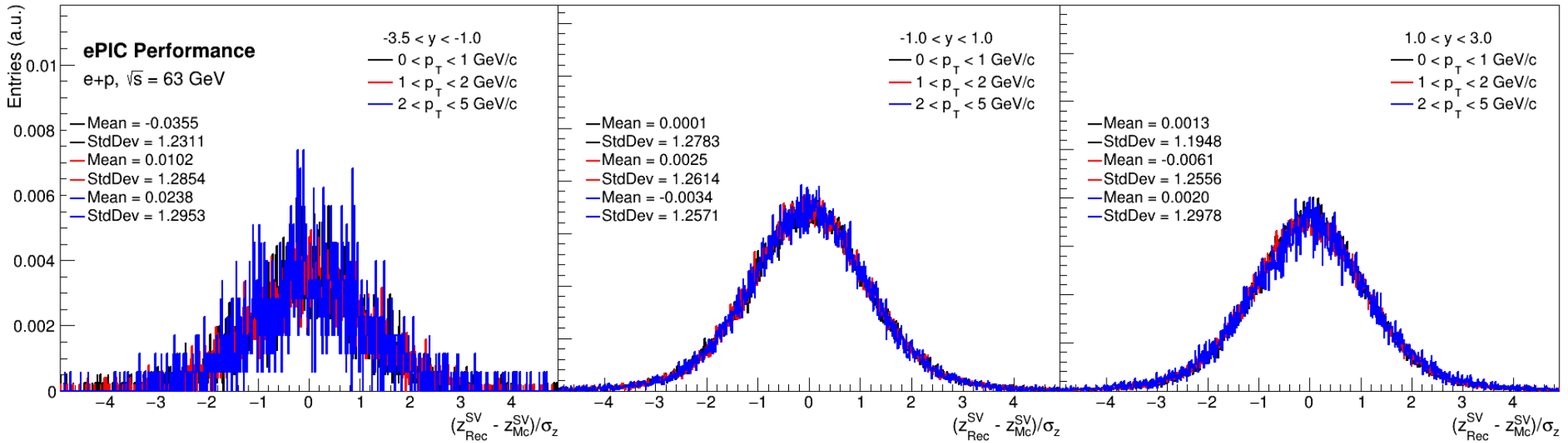




Secondary Vertex (D^0)



Secondary Vertex (D^0)



D^0 meson Reconstruction in ep Collisions

y bins: (-3, -1), (-1, 1), (1,3)

p_T (D meson): (0, 1), (1, 2), (2, 5)

Event Statistics

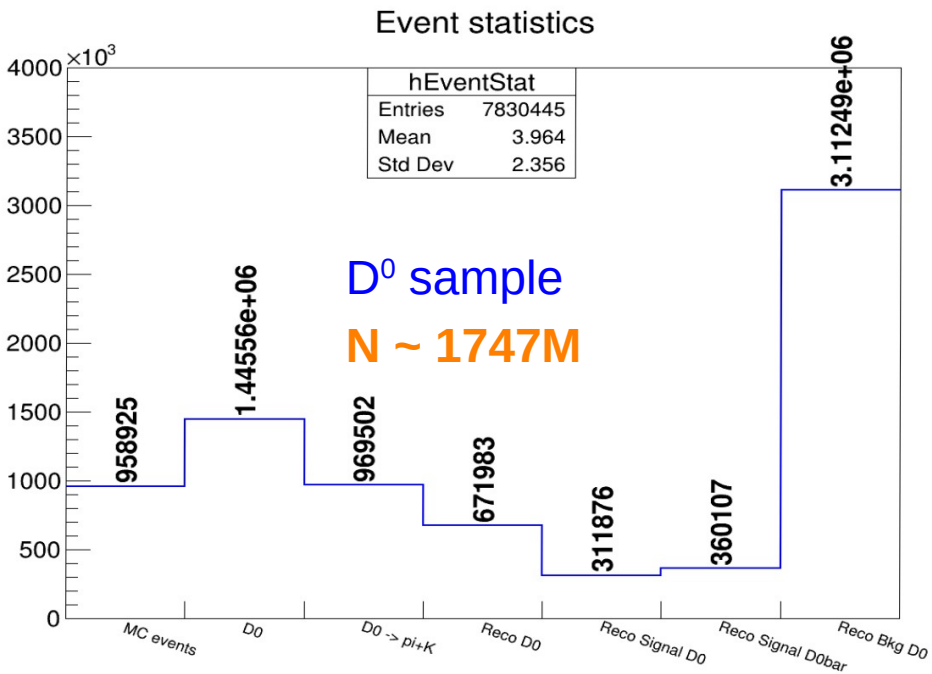
Campaign: 25.04.1

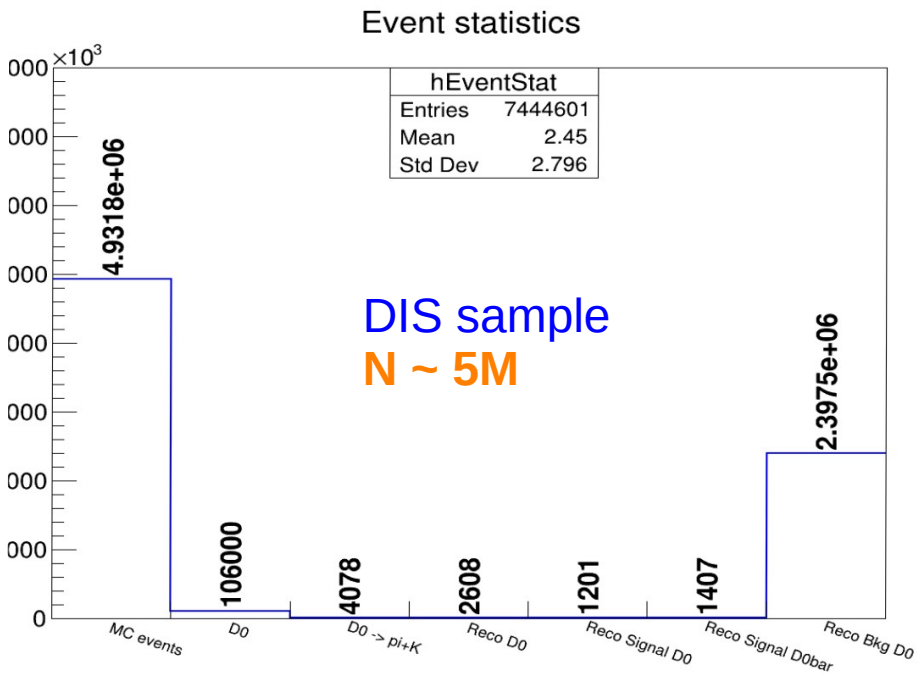
Data Sample: ep collision 10 X 100 with $Q^2 > 1\ GeV^2$

Slide: 12

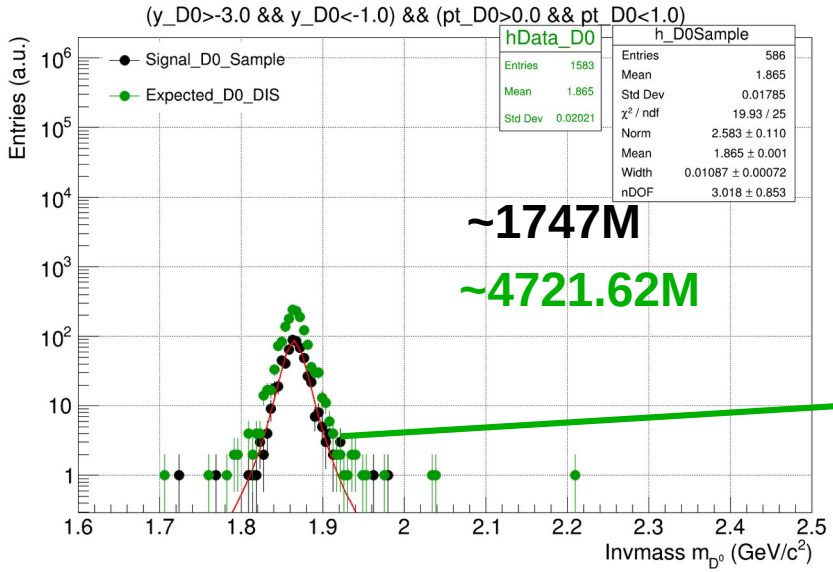
$$N_{events}\left(10\ fb^{-1}\right) \sim 1747 \times 10/3.7 = 4721.62\ M$$

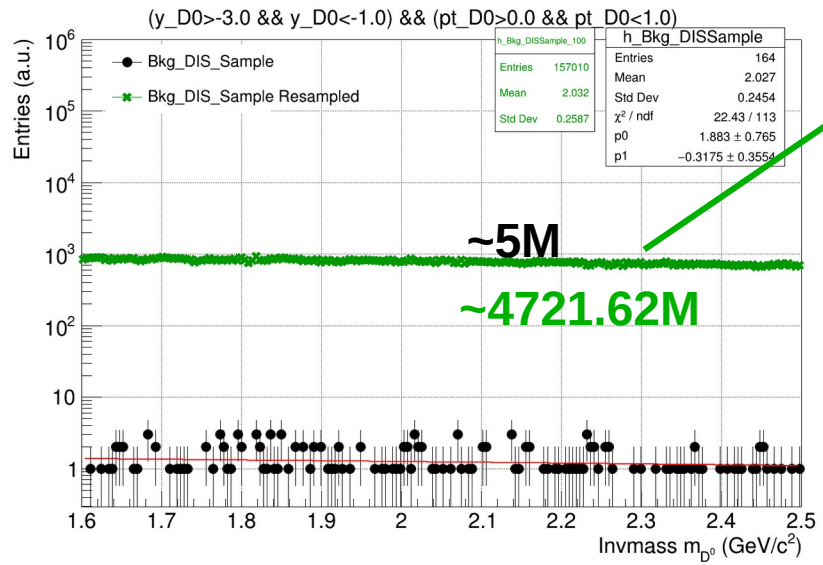
Real PID





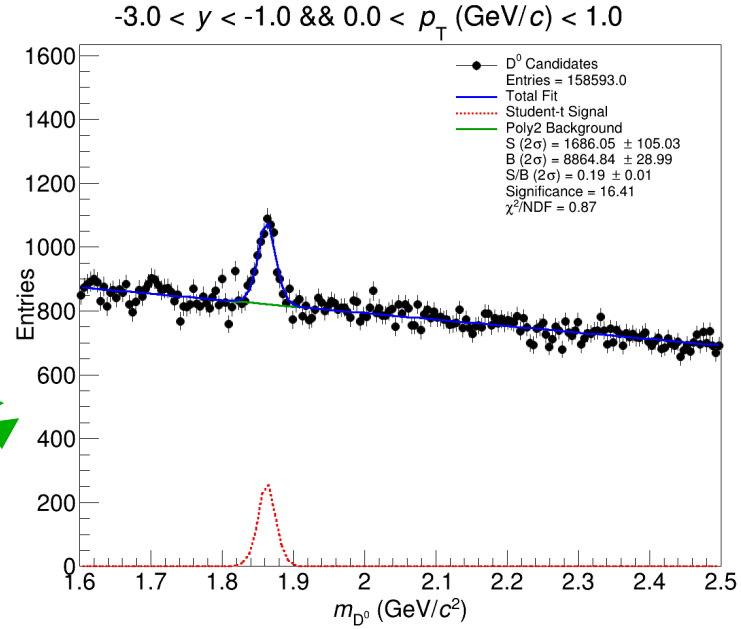
Sampling Signal and Background





-3 < y < -1
&
0 < $p_T(D^0)$ < 1

Sum



No ML due to limited statistics

Topological selection

Real PID

1.6 < mass_D0 < 2.5

20 µm < DCA_{xy}(Pi) < 1 cm

20 µm < DCA_{xy}(K) < 1 cm

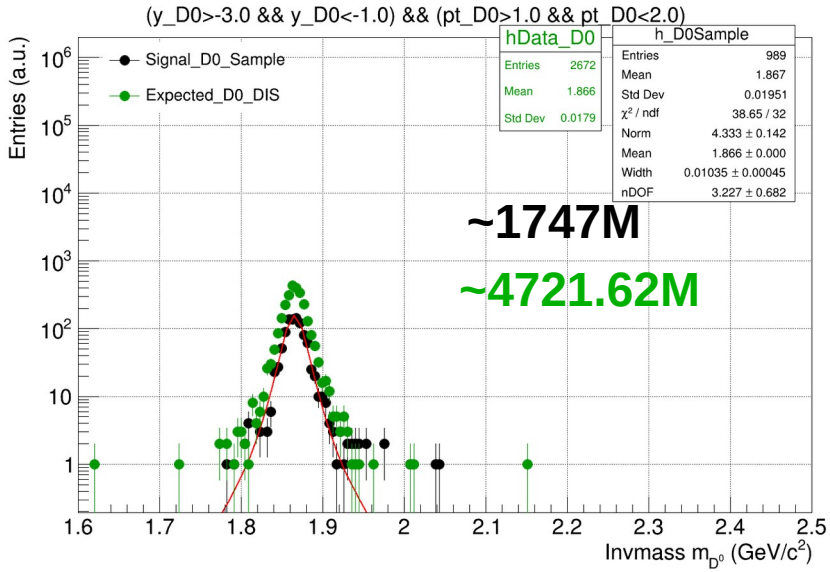
50 µm < Decay length < 10 cm

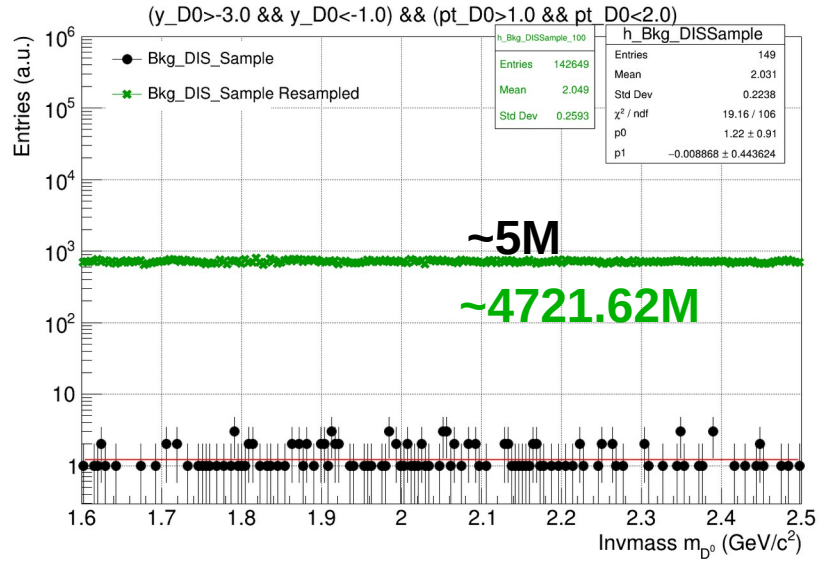
DCA_{12} < 70 µm

DCA_{D0} < 100 µm

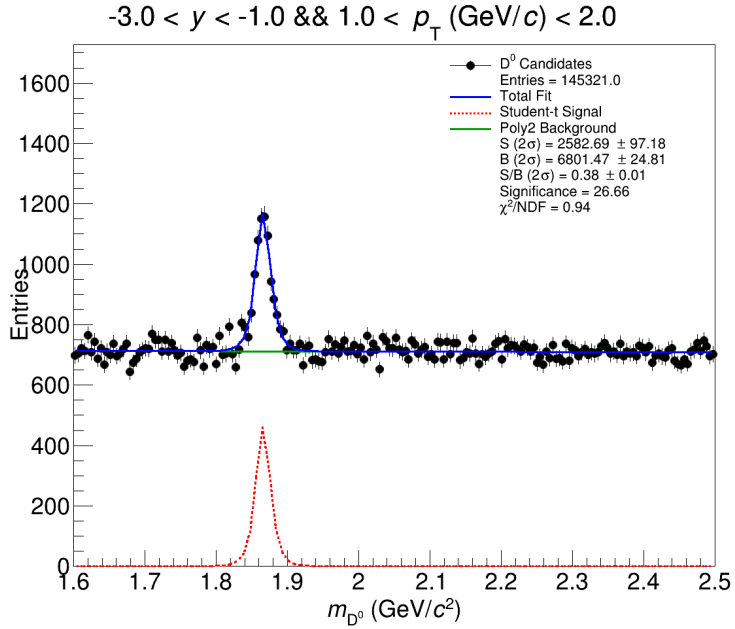
Cosθ > 0.95

Sampling Signal and Background





-3 < y < -1
&
1 < $p_T(D^0)$ < 2



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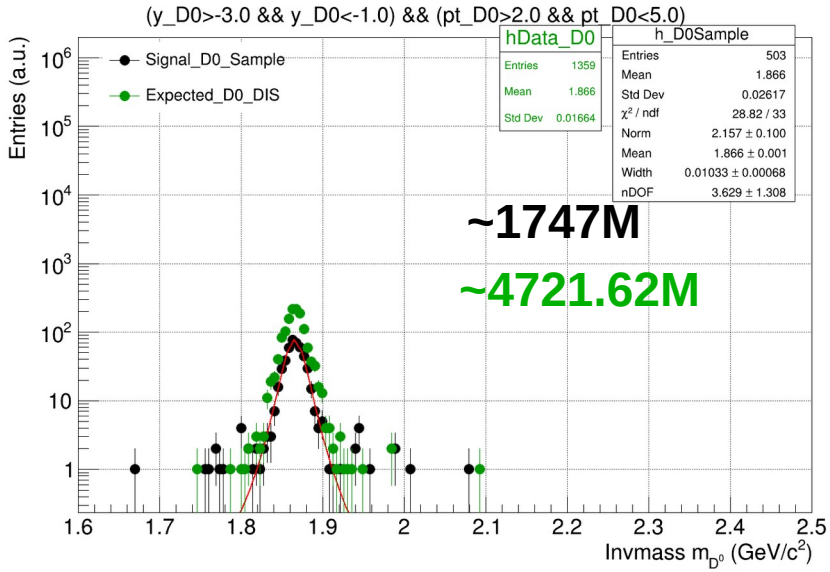
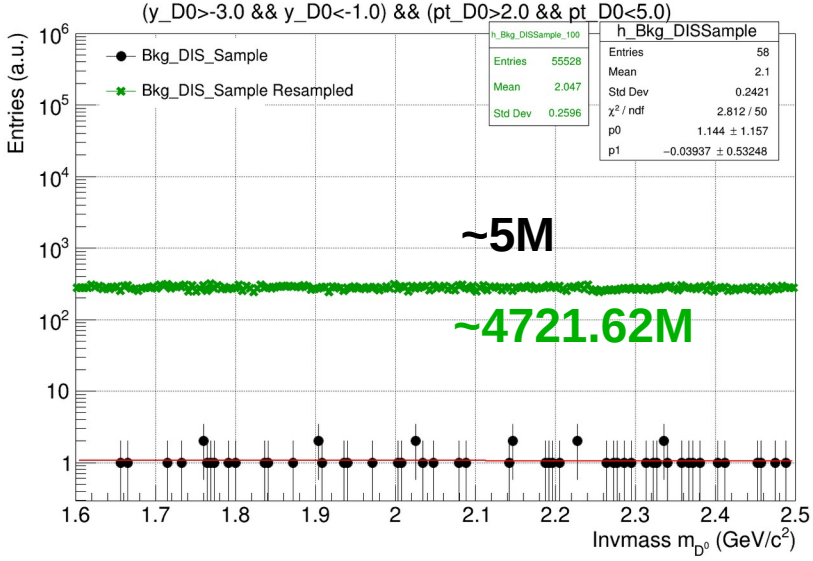
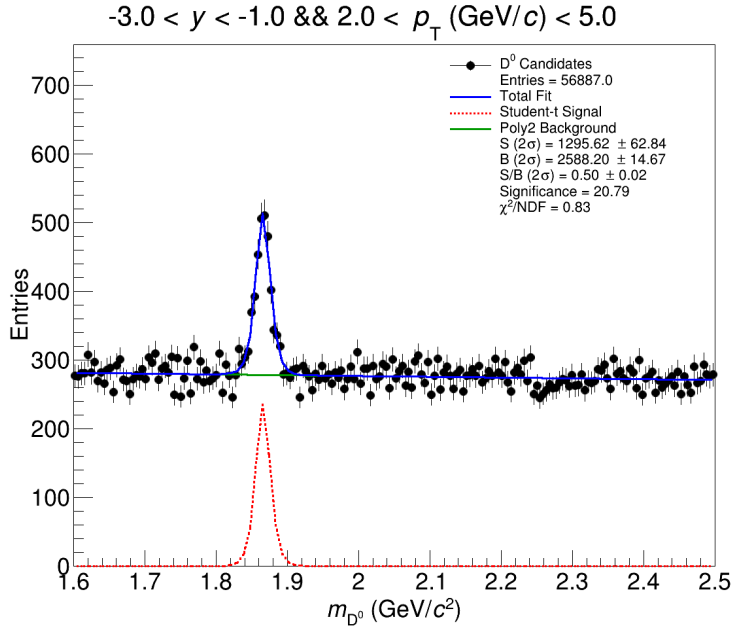
Cosθ > 0.95

Sampling Signal and Background





-3 < y < -1
&
2 < $p_T(D^0)$ < 5



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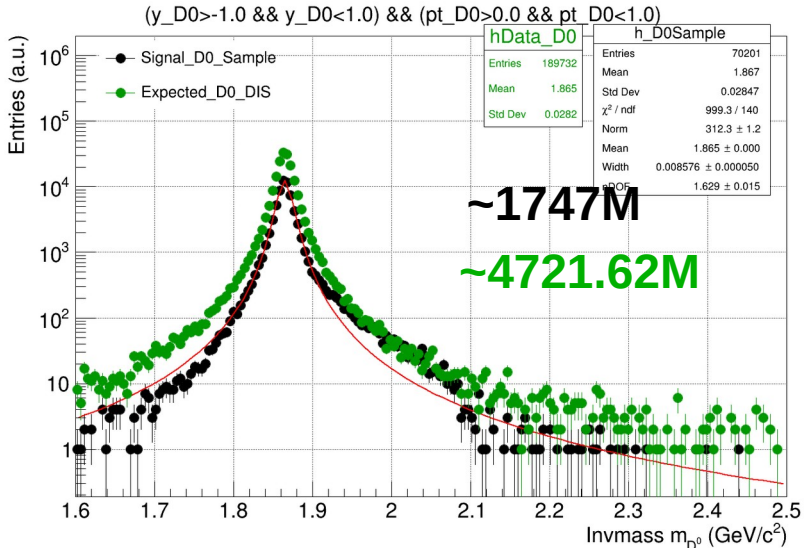
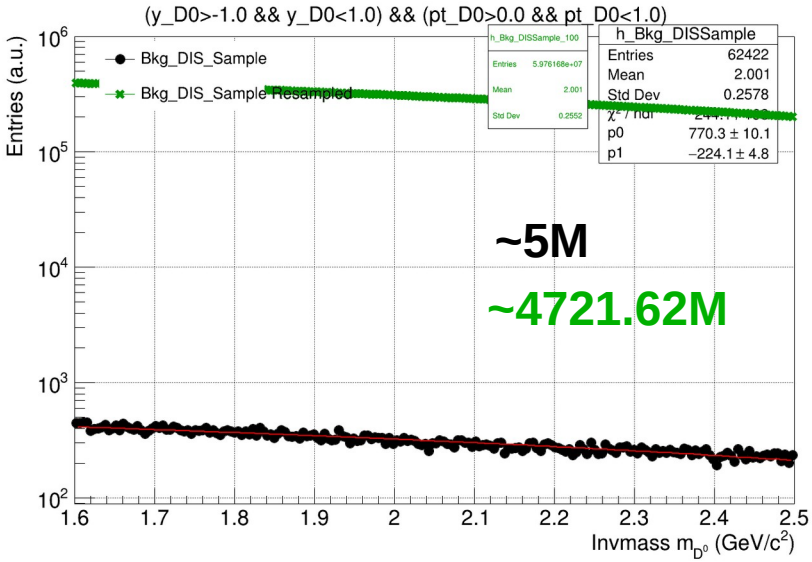
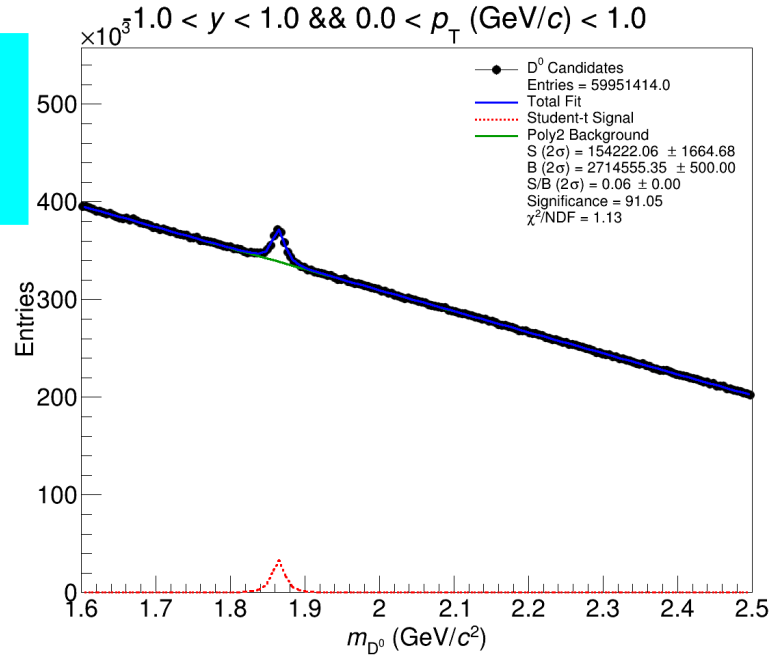
Sampling Signal and Background





-1 < y < 1
&
$0 < p_T(D^0) < 1$



Preselection

Real PID

1.6 < mass_D0 < 2.5

20 µm < DCA_{xy}(Pi) < 1 cm

20 µm < DCA_{xy}(K) < 1 cm

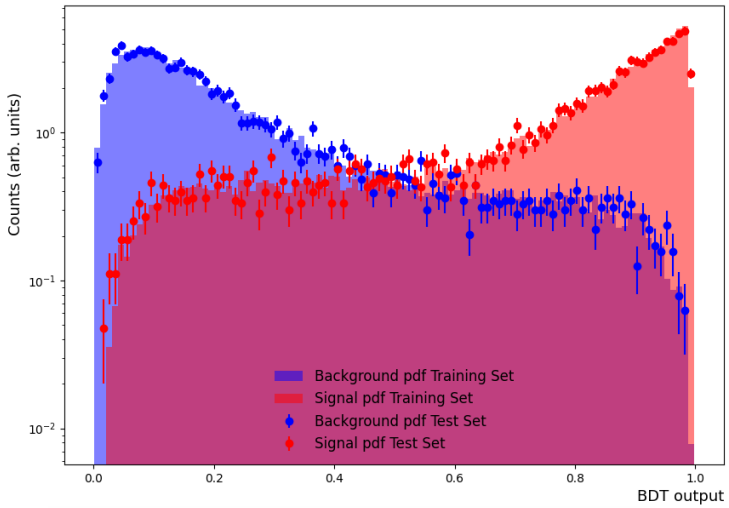
Decay length < 10 cm

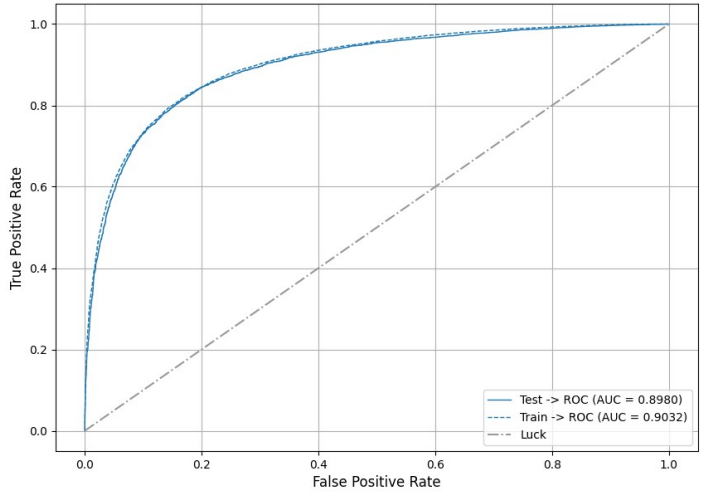
Machine learning

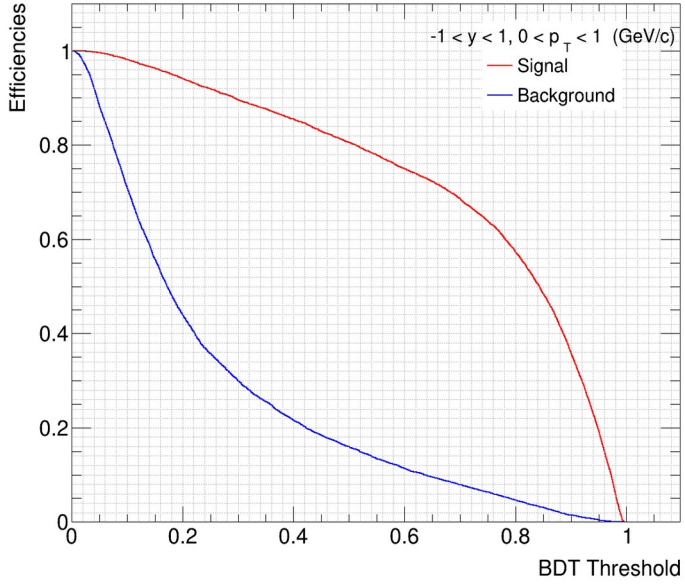
$-1 < y < 1$ & $0 < p_T(D^0) < 1$ GeV/c

Signal: Signal (D^0 Sample) + Signal (DIS Sample)

Bkg: Bkg (DIS Sample)

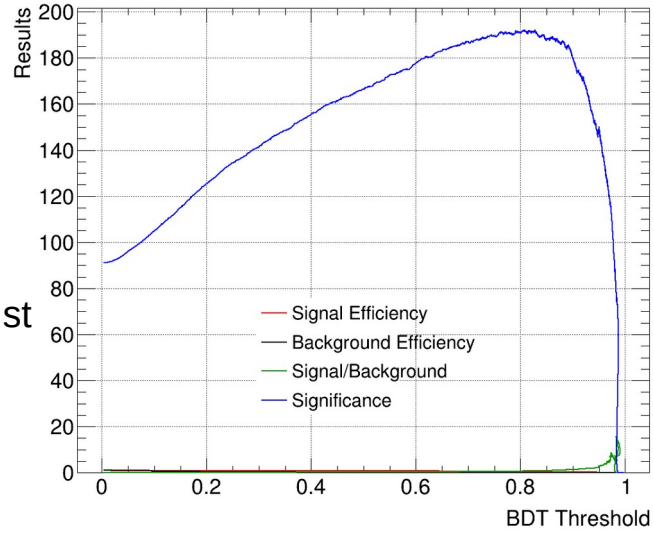




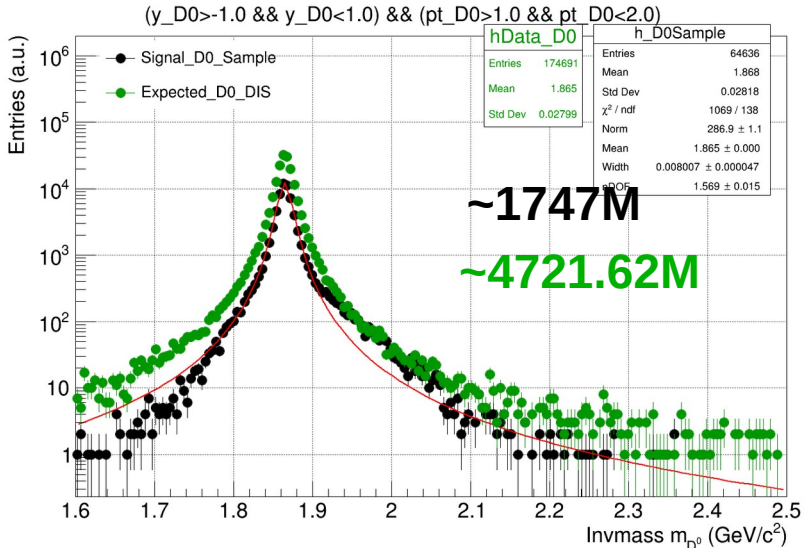


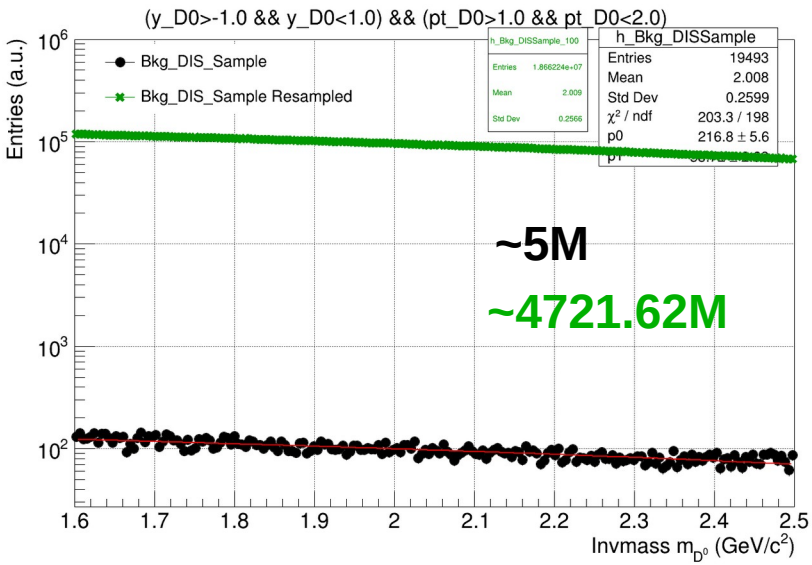
Signal candidates for ML: 31840
Background candidates for ML: 31840

BDT cut =0 is w/o ML and must match with significance of invariant mass plot (previous slide)

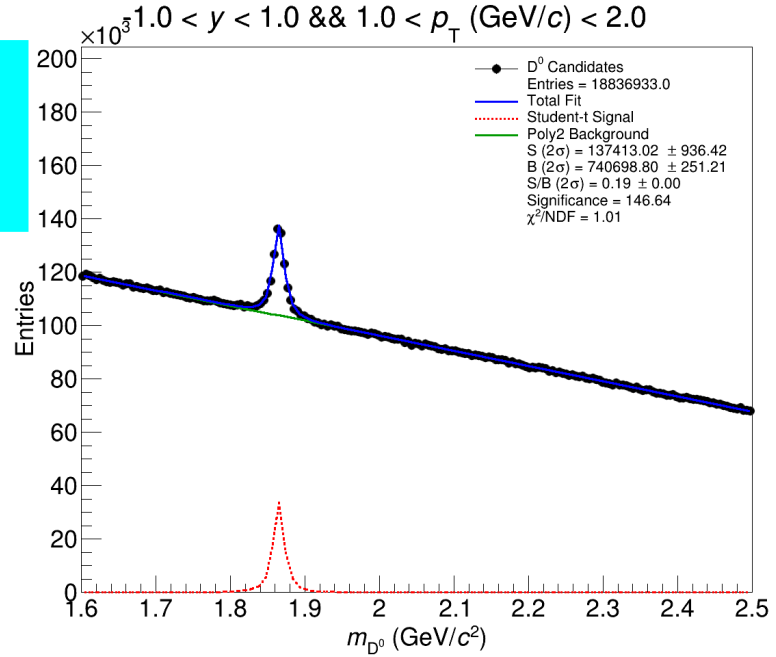


Sampling Signal and Background





-1 < y < 1
&
1 < $p_T(D^0)$ < 2



Preselection

Real PID

1.6 < mass_D0 < 2.5

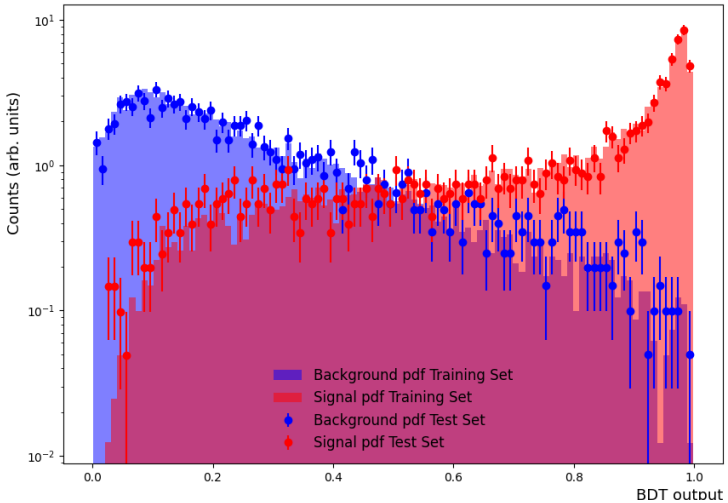
20 µm < DCA_{xy}(Pi) < 1 cm

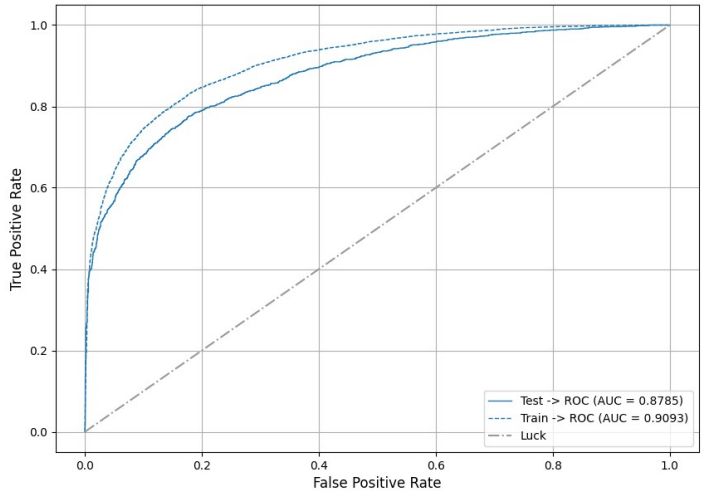
20 µm < DCA_{xy}(K) < 1 cm

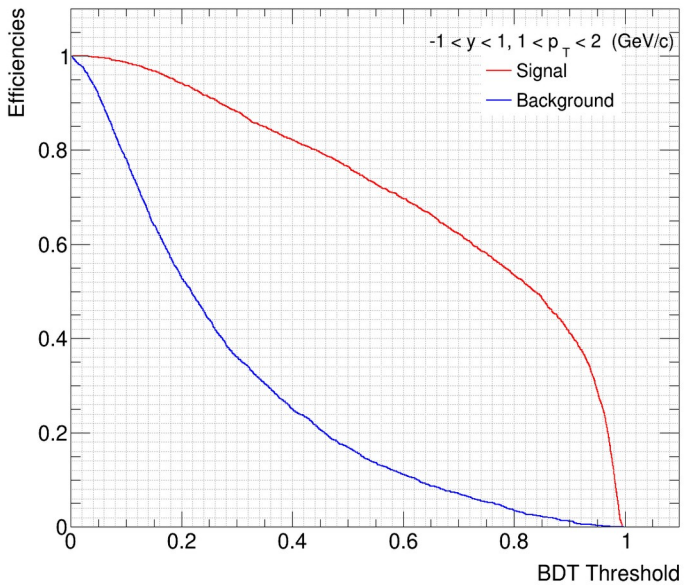
Decay length < 10 cm

Machine learning

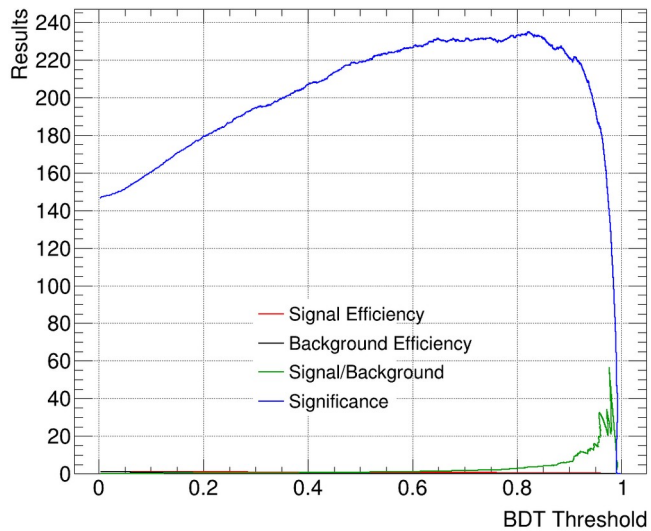
$-1 < y < 1$ & $1 < p_T(D^0) < 2$ GeV/c



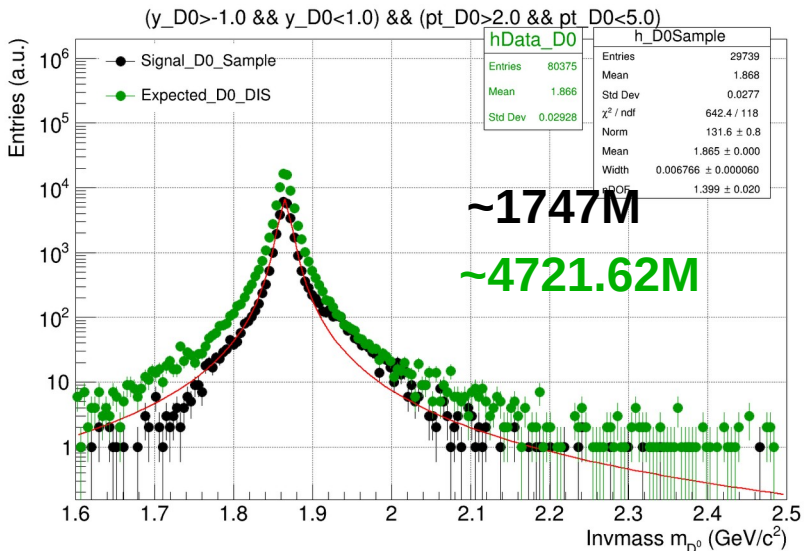


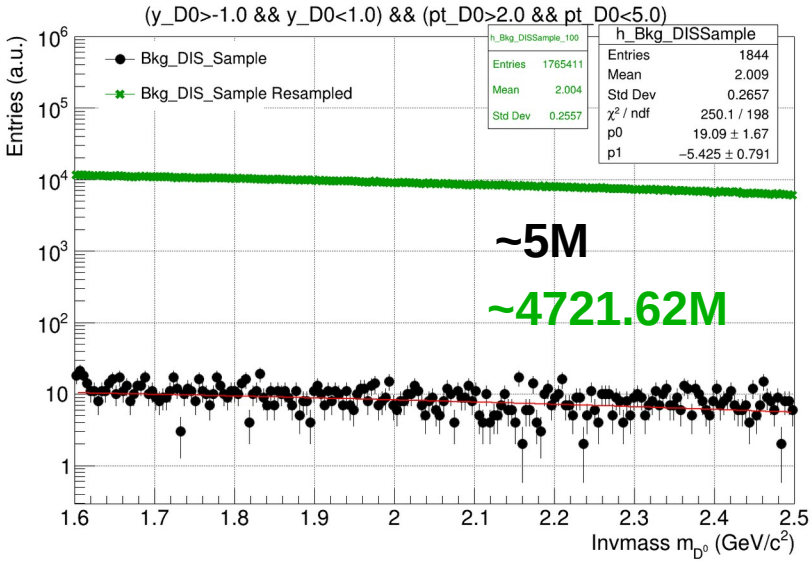


Signal candidates: 10142
Background candidates: 10142

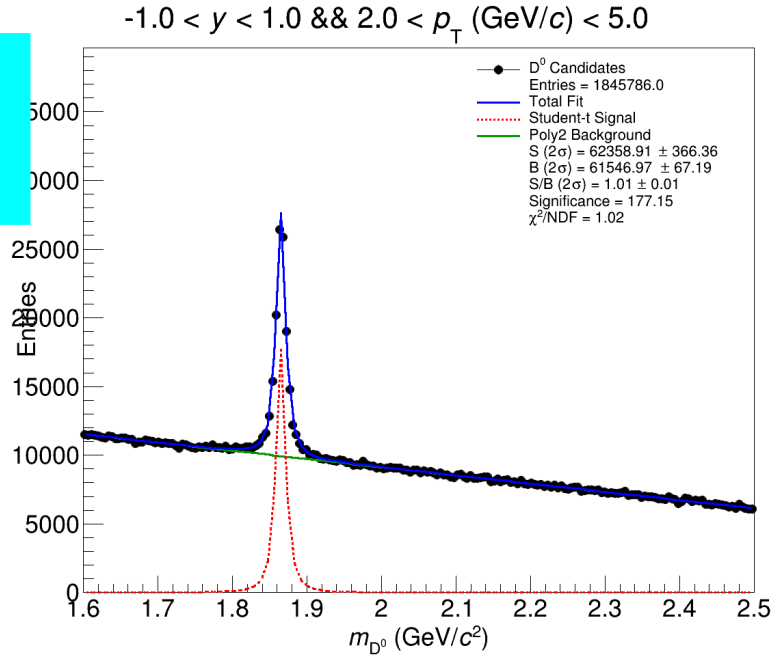


Sampling Signal and Background





-1 < y < 1
&
2 < $p_T(D^0)$ < 5



Preselection

Real PID

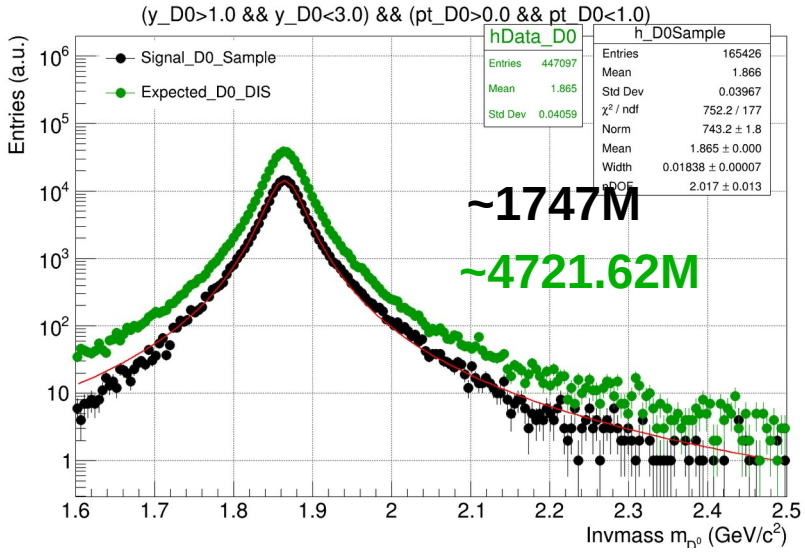
1.6 < mass_D0 < 2.5

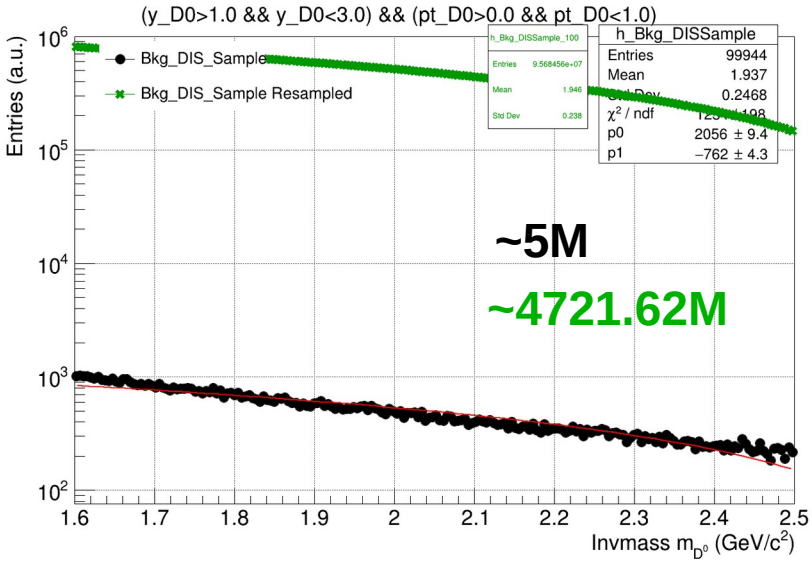
20 µm < DCA_{xy}(Pi) < 1 cm

20 µm < DCA_{xy}(K) < 1 cm

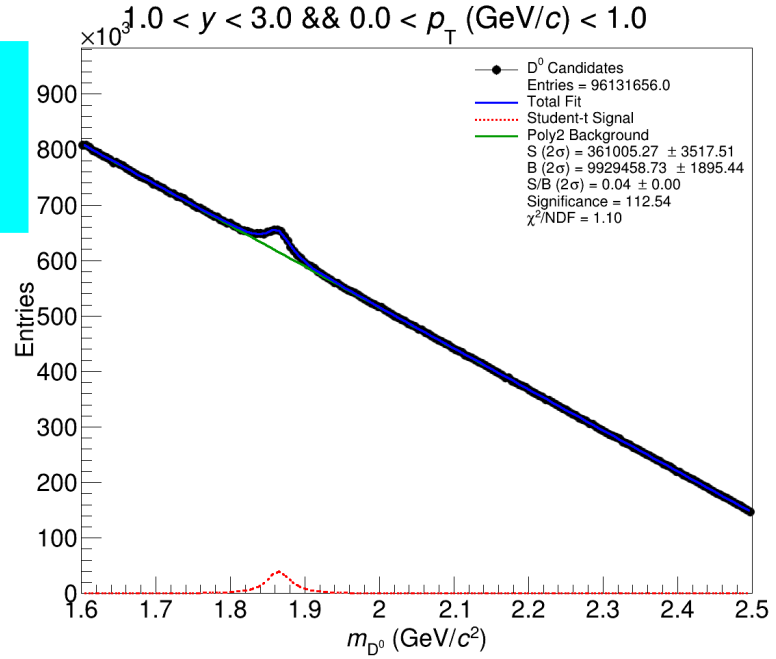
Decay length < 10 cm

Sampling Signal and Background





$1 < y < 3$
&
$0 < p_T(D^0) < 1$



Preselection

Real PID

$1.6 < \text{mass\_D0} < 2.5$

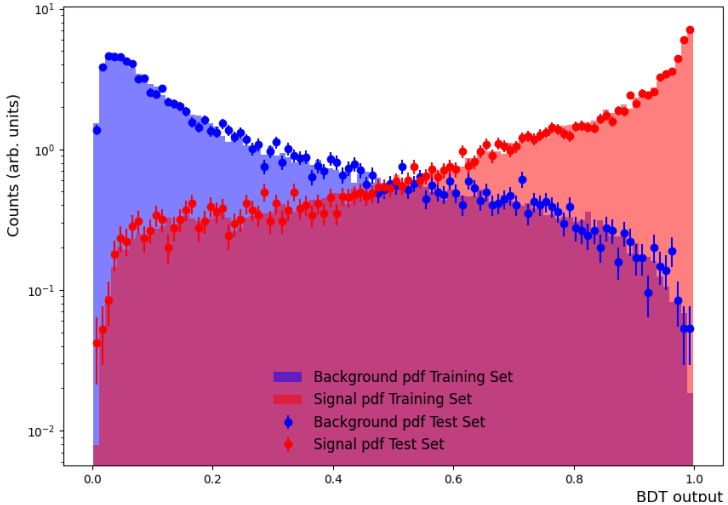
$20\ \mu m < DCA_{xy}(Pi) < 1\ cm$

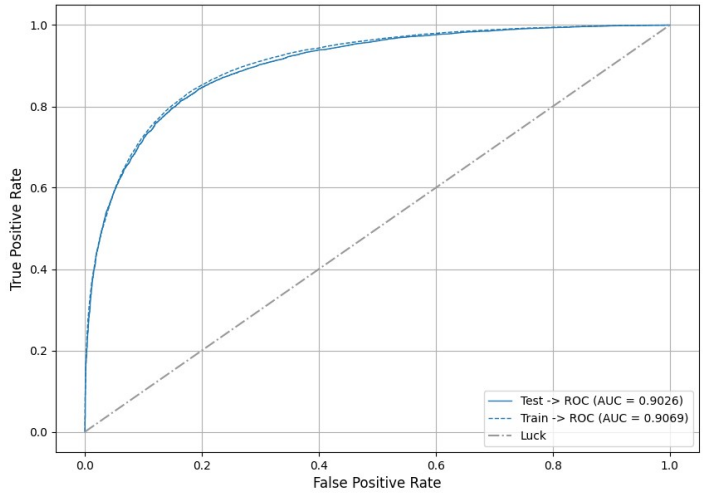
$20\ \mu m < DCA_{xy}(K) < 1\ cm$

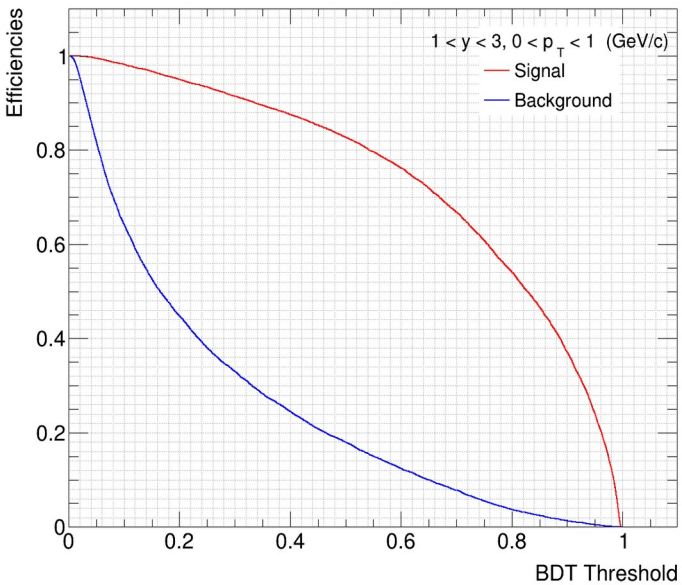
Decay length < 10 cm

Machine learning

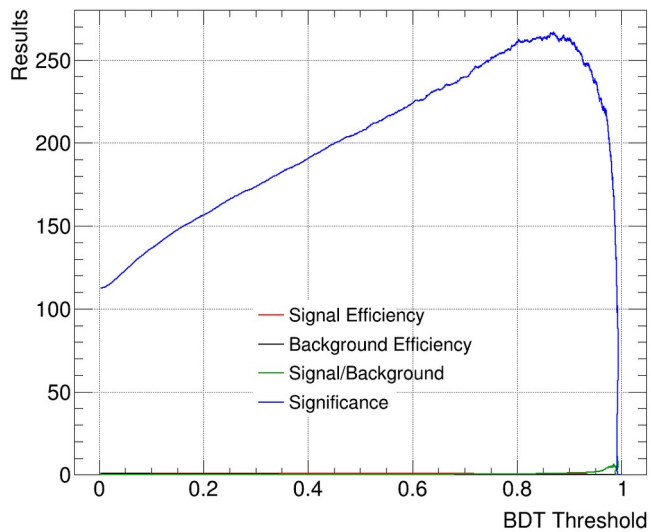
$1 < y < 3$ & $0 < p_T(D^0) < 1$ GeV/c



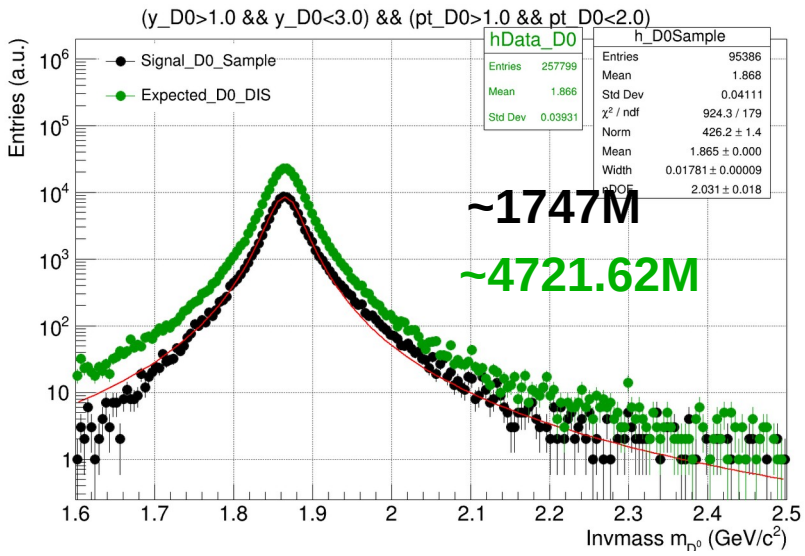


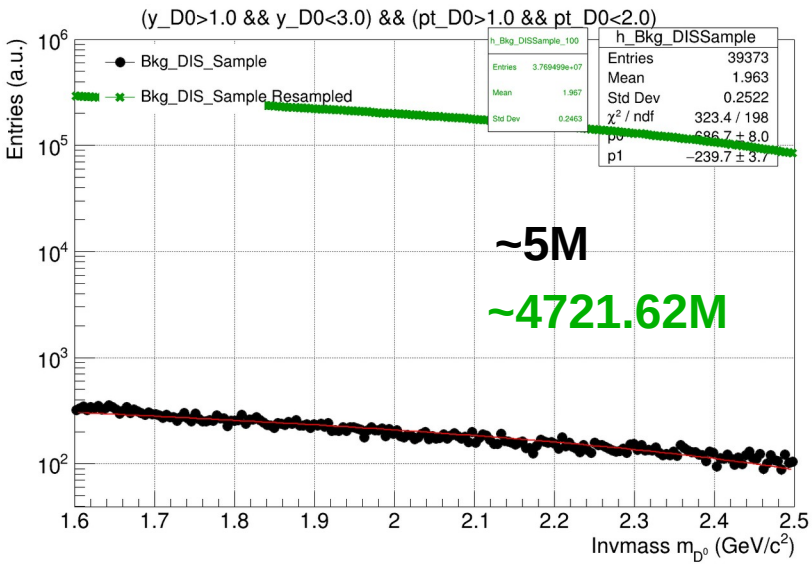


Signal candidates: 47403
Background candidates: 47403

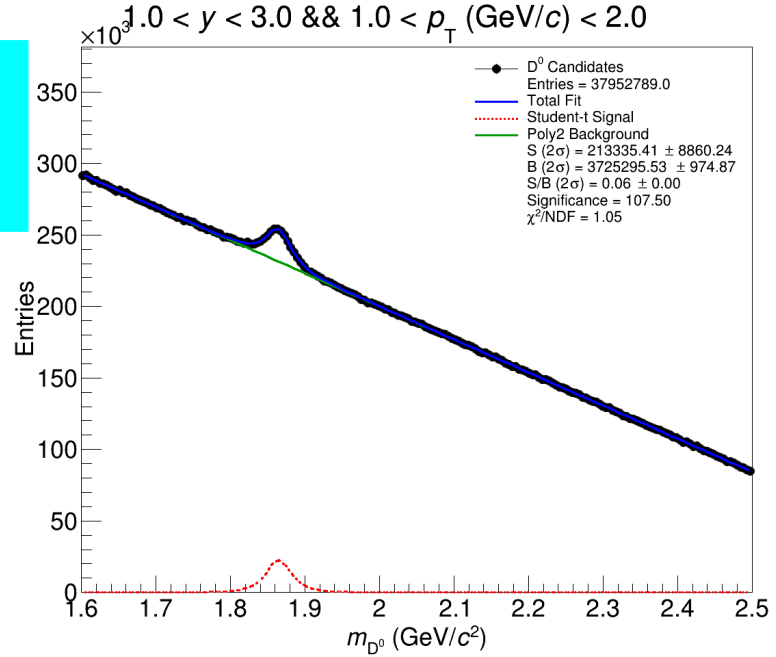


Sampling Signal and Background





$1 < y < 3$
&
$1 < p_T(D^0) < 2$



Preselection

Real PID

1.6 < mass_D0 < 2.5

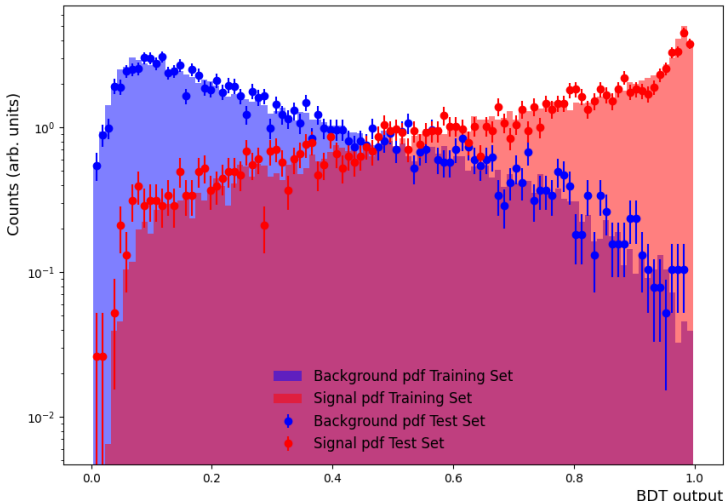
20 µm < DCA_{xy}(Pi) < 1 cm

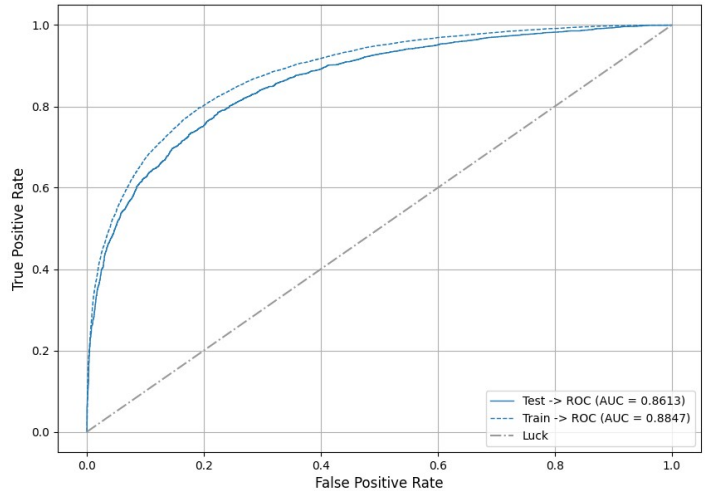
20 µm < DCA_{xy}(K) < 1 cm

Decay length < 10 cm

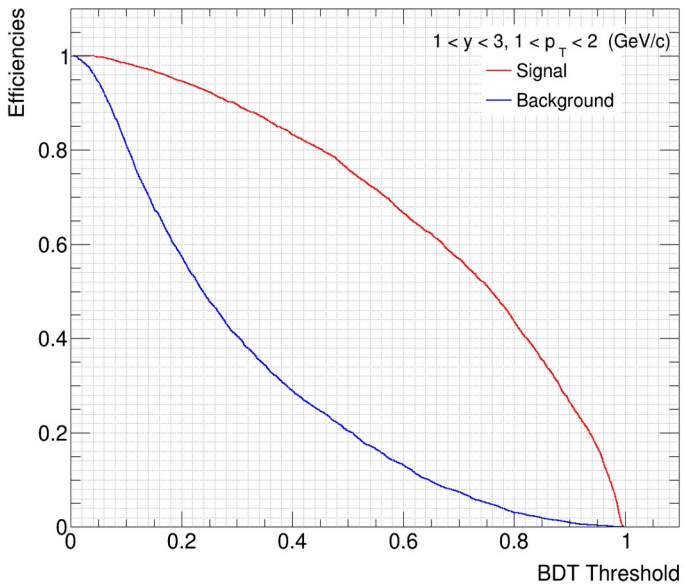
Machine learning

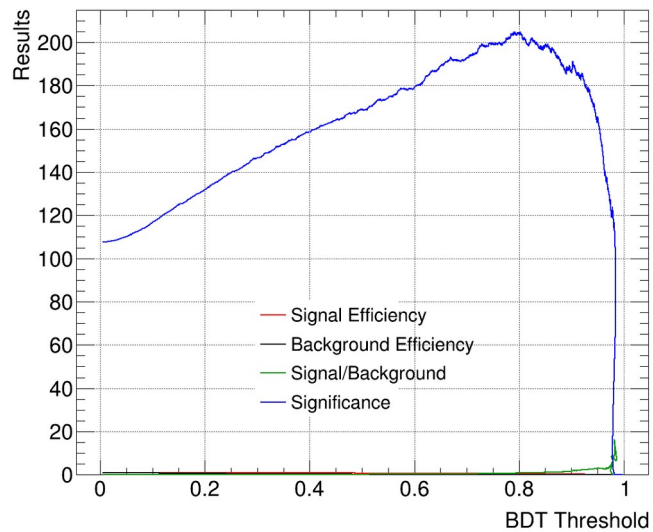
$1 < y < 3$ & $1 < p_T(D^0) < 2$ GeV/c



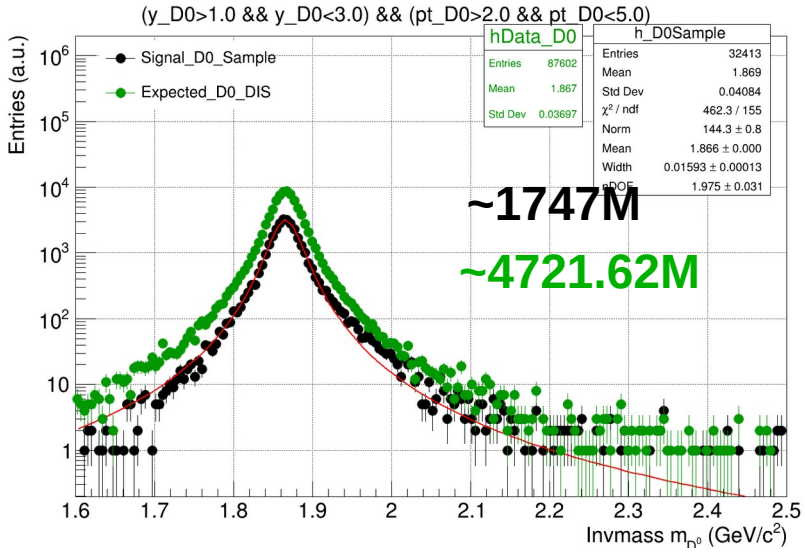


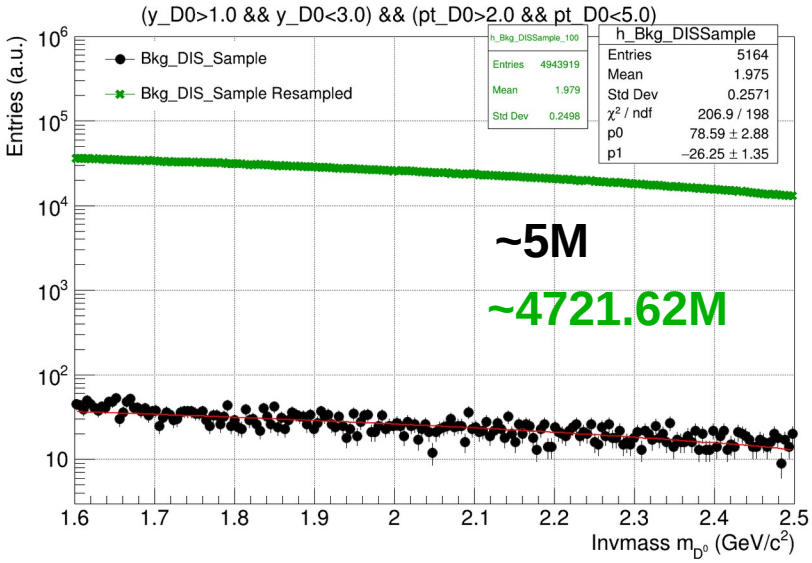
Signal candidates: 19244
Background candidates: 19244



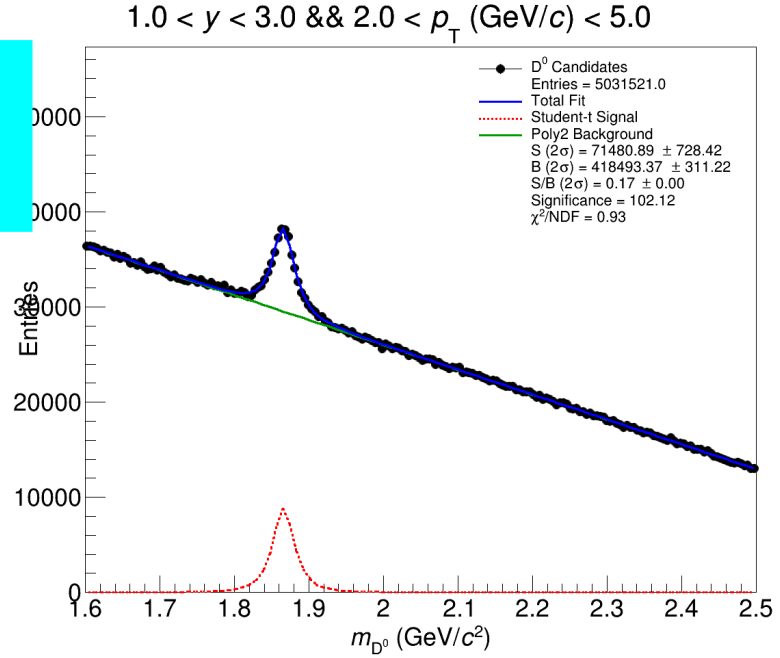


Sampling Signal and Background





$1 < y < 3$
&
$2 < p_T(D^0) < 5$



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Decay length < 10 cm

D^0 meson Reconstruction in eAu Collisions

y bins: (-3, -1), (-1, 1), (1,3)

p_T (D meson): (0, 1), (1, 2), (2, 5)

Event Statistics

Campaign: 25.04.1

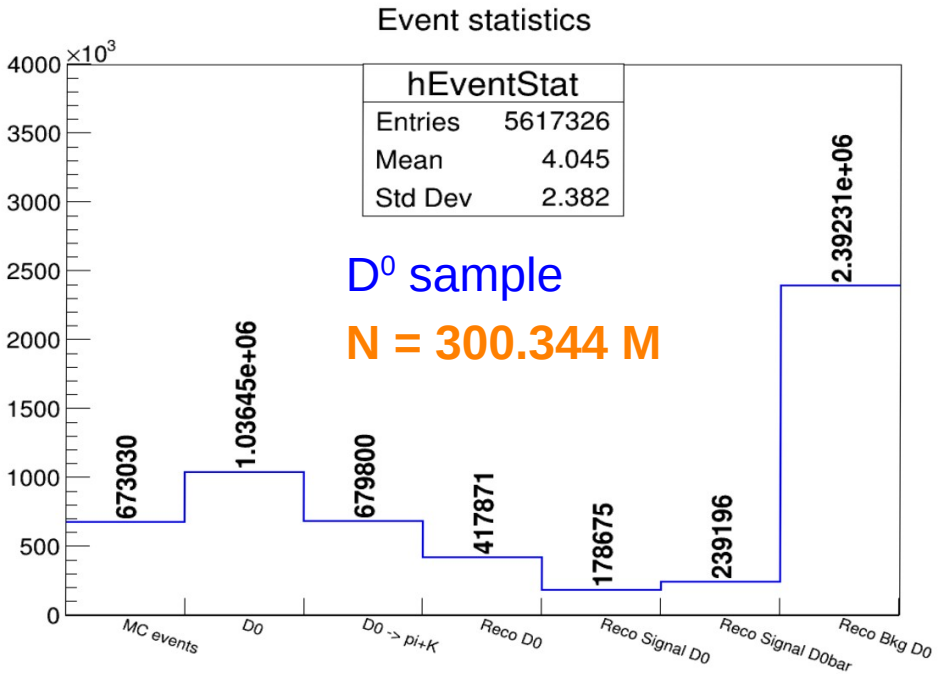
Data Sample: eAu collision 10 X 100 with $Q^2 > 1\ GeV^2$

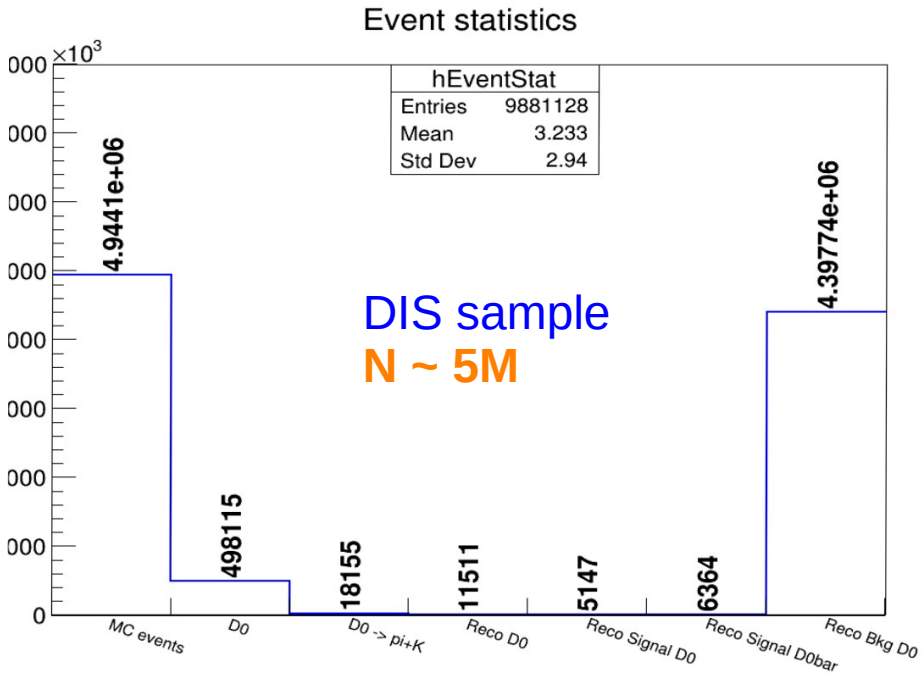
Real PID

$$N_{events}(0.88\,fb^{-1}) = 0.88\,fb^{-1} \times 0.3413\,\mu b = 300.344\,M$$

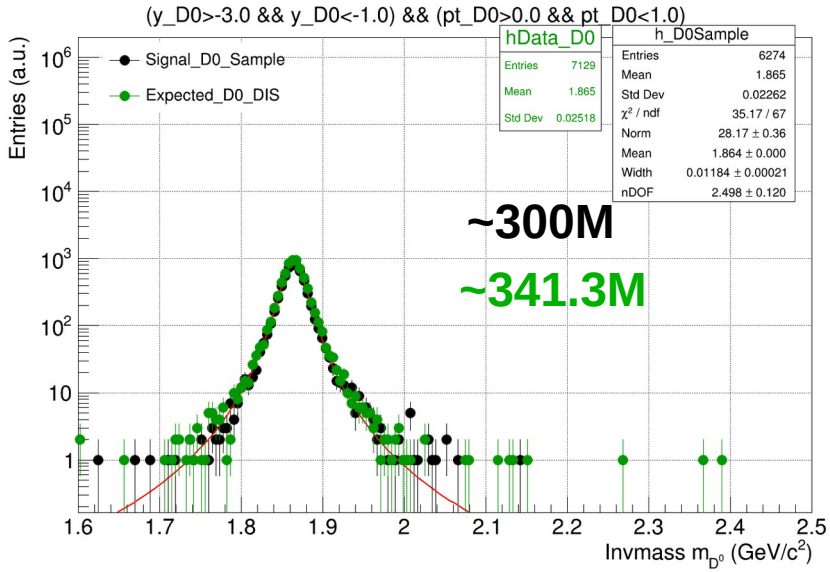
Slide: 18

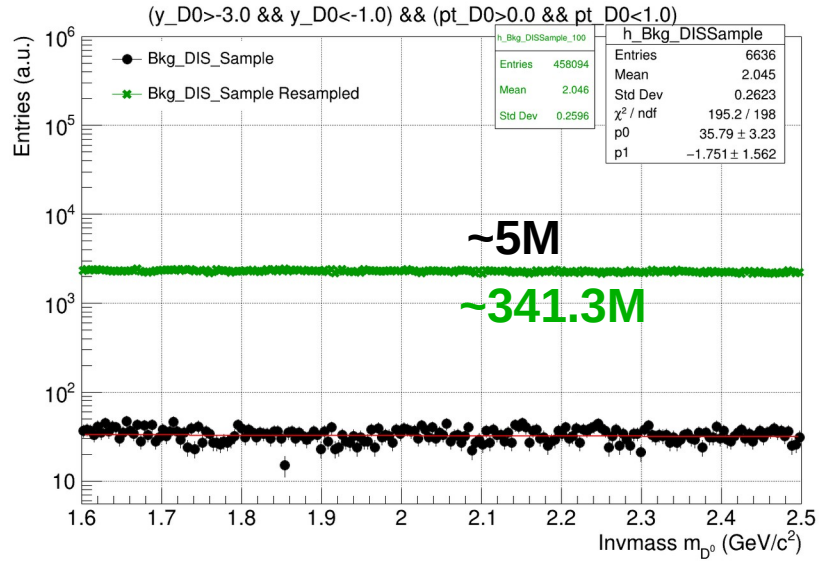
$$N_{events}(1.0\,fb^{-1}) = 341.3\,M$$



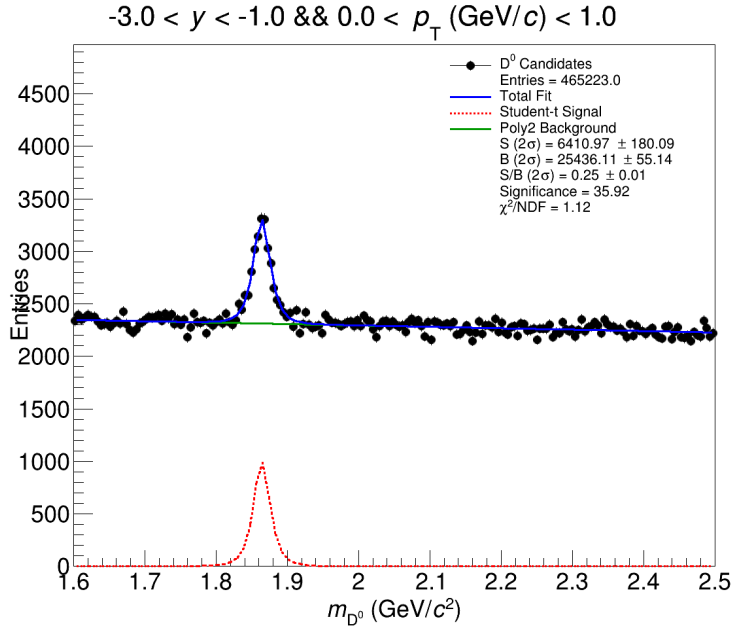


Sampling Signal and Background





-3 < y < -1
&
0 < $p_T(D^0)$ < 1



No ML due to limited statistics

Topological selection

Real PID

1.6 < mass_D0 < 2.5

20 µm < DCA_{xy}(Pi) < 1 cm

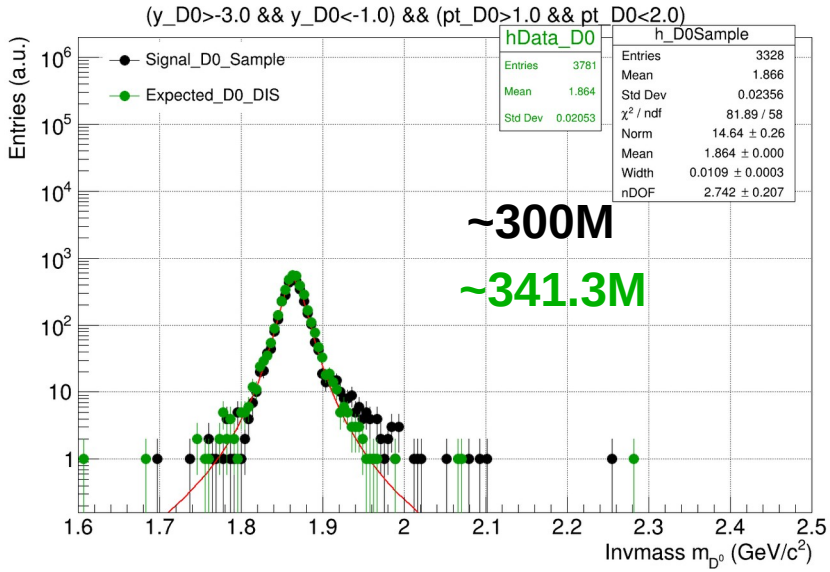
20 µm < DCA_{xy}(K) < 1 cm

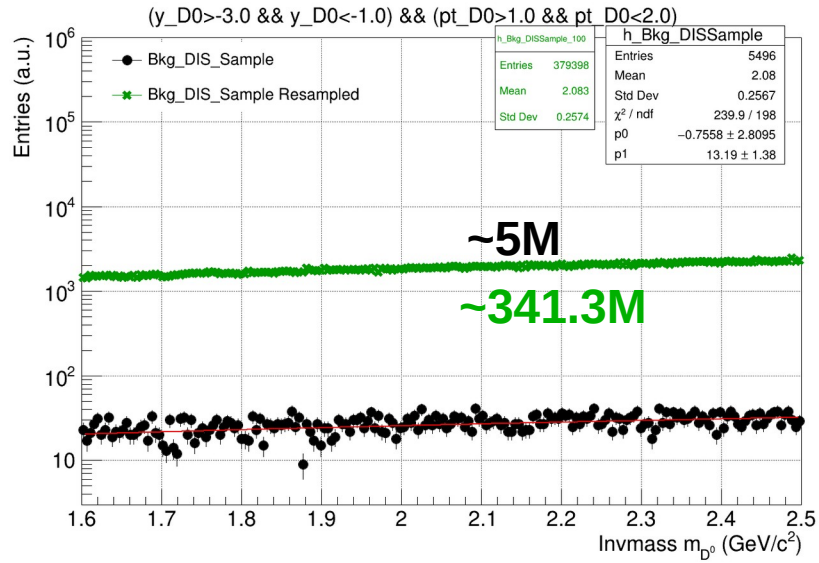
Decay length < 200 µm

DCA_{12} < 200 µm

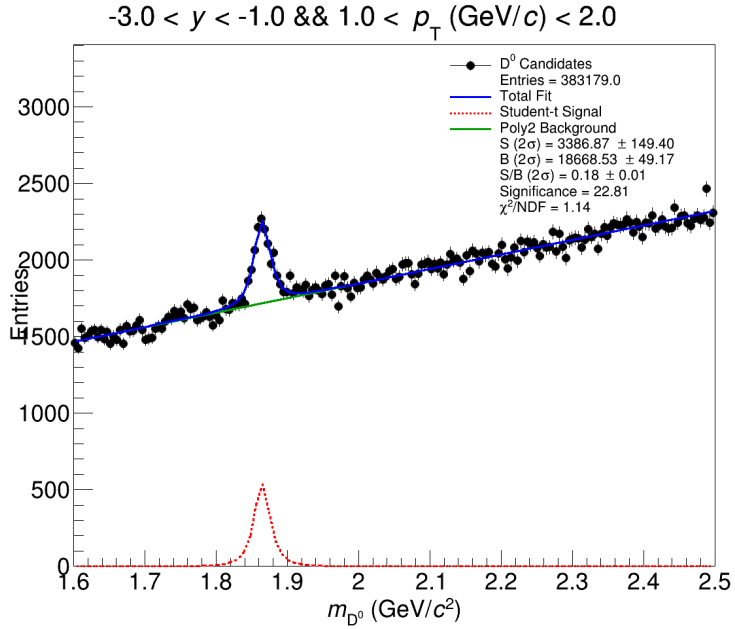
DCA_{D0} < 100 µm

Sampling Signal and Background





-3 < y < -1
&
1 < $p_T(D^0)$ < 2



No ML due to limited statistics

Topological selection

Real PID

1.6 < mass_D0 < 2.5

20 µm < DCA_{xy}(Pi) < 1 cm

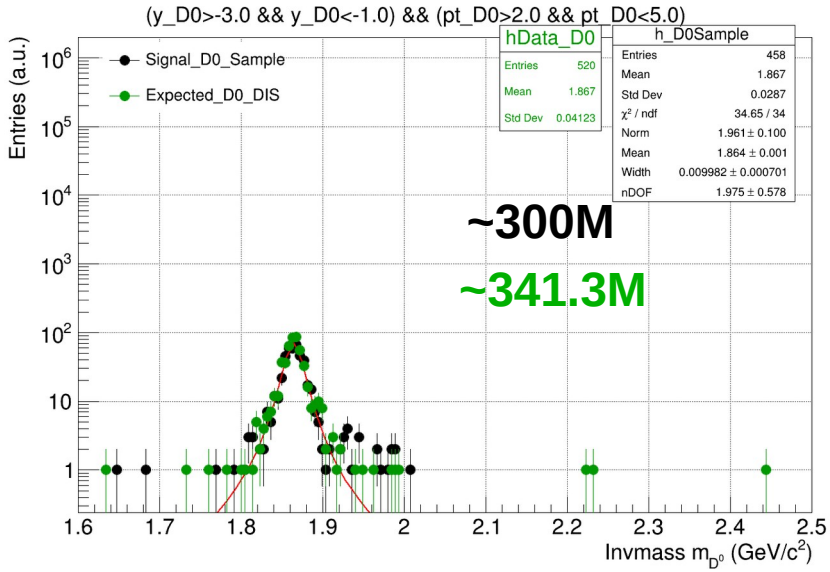
20 µm < DCA_{xy}(K) < 1 cm

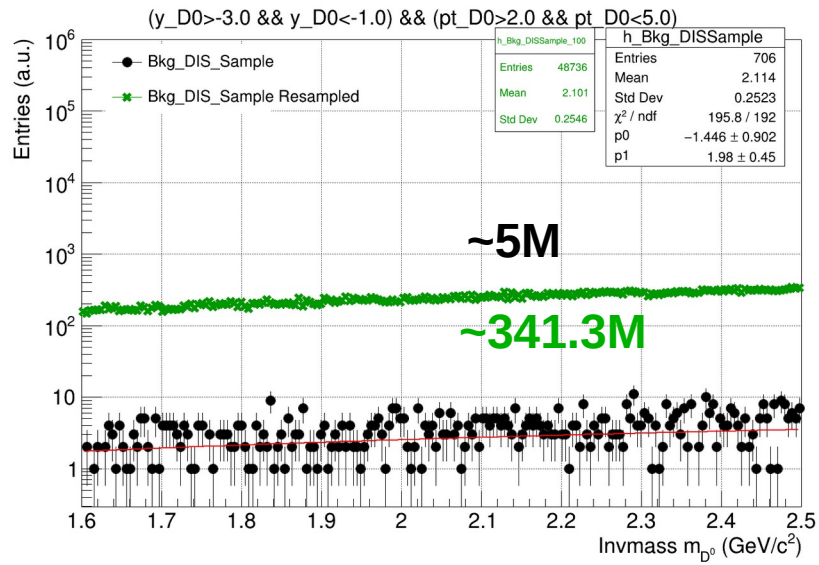
Decay length < 200 µm

DCA_{12} < 200 µm

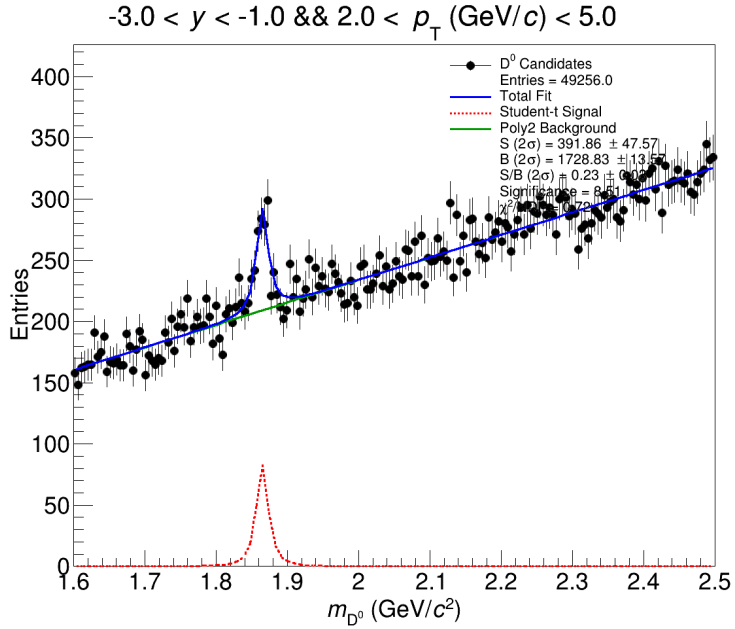
DCA_{D0} < 100 µm

Sampling Signal and Background





-3 < y < -1
&
2 < $p_T(D^0)$ < 5



No ML due to limited statistics

Topological selection

Real PID

1.6 < mass_D0 < 2.5

20 μm < DCA_{xy}(Pi) < 1 cm

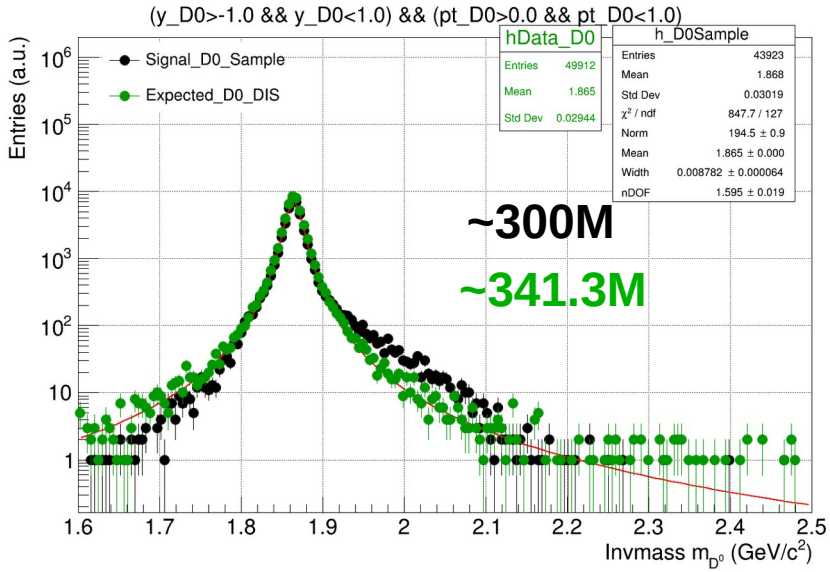
20 μm < DCA_{xy}(K) < 1 cm

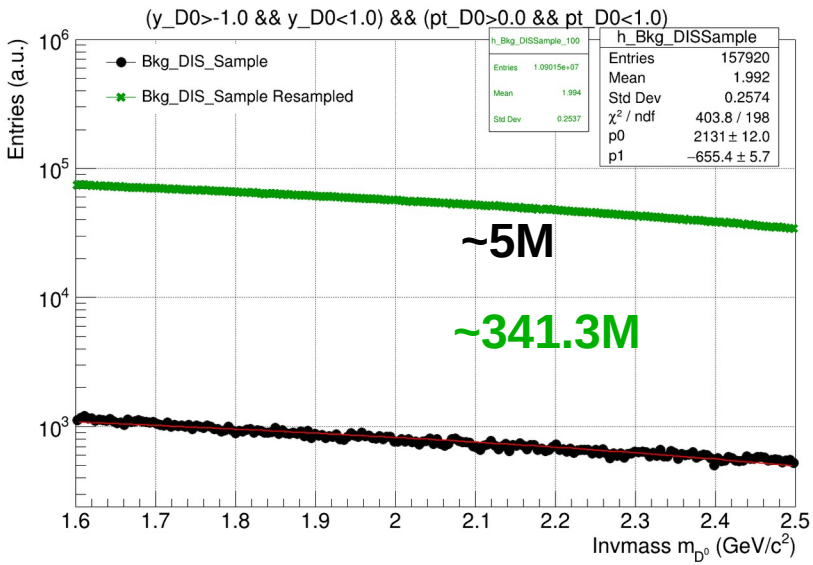
Decay length < 200 μm

DCA_{12} < 200 μm

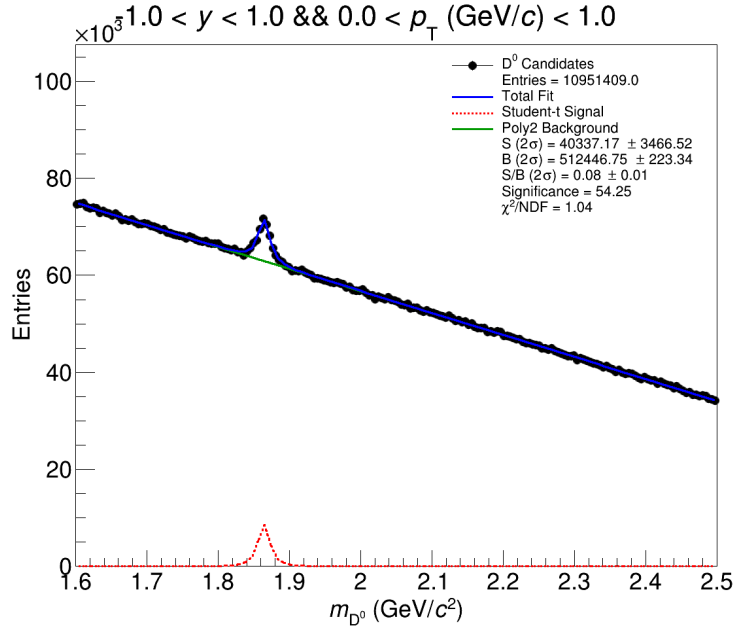
DCA_{D0} < 100 μm

Sampling Signal and Background





-1 < y < 1
&
$0 < p_T(D^0) < 1$



Preselection

Real PID

1.6 < mass_D0 < 2.5

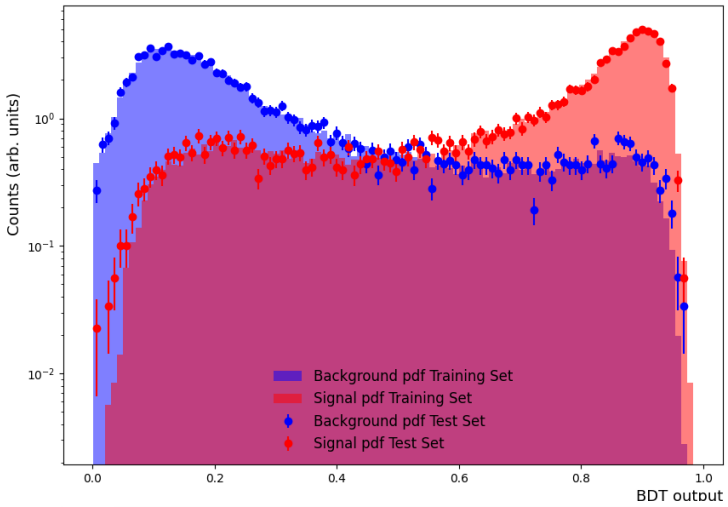
20 µm < DCA_{xy}(Pi) < 1 cm

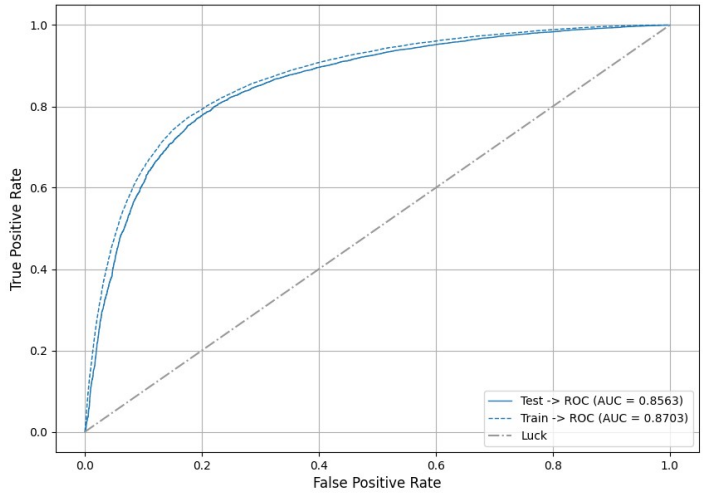
20 µm < DCA_{xy}(K) < 1 cm

Decay length < 10 cm

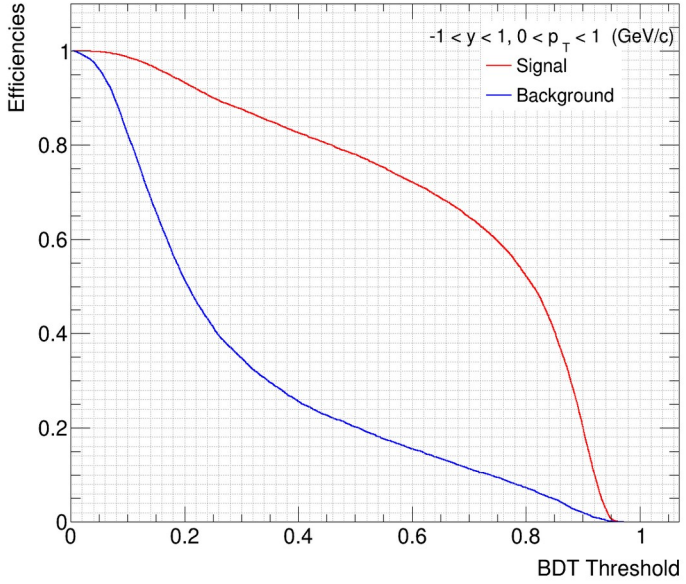
Machine learning

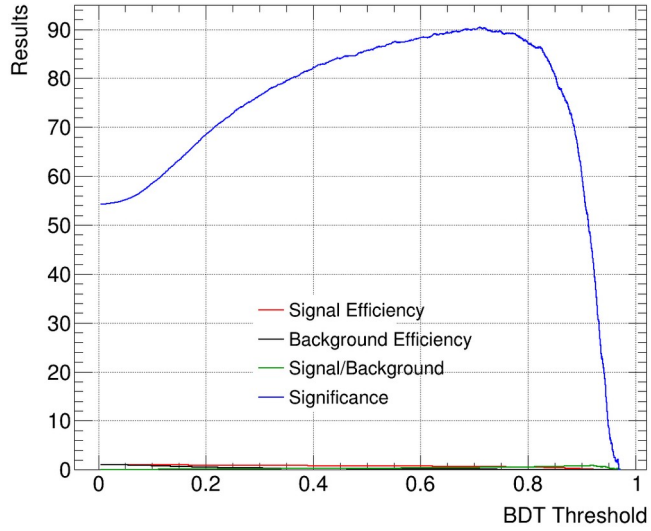
$-1 < y < 1$ & $0 < p_T(D^0) < 1$ GeV/c



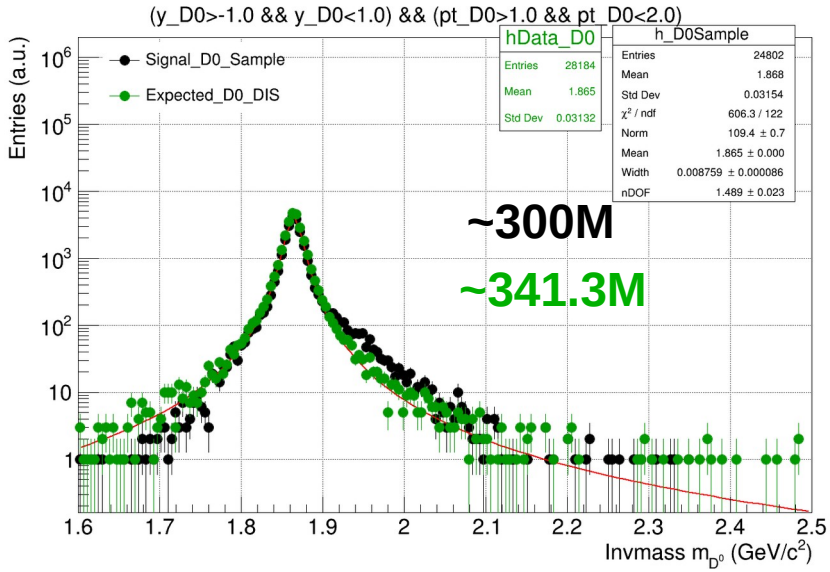


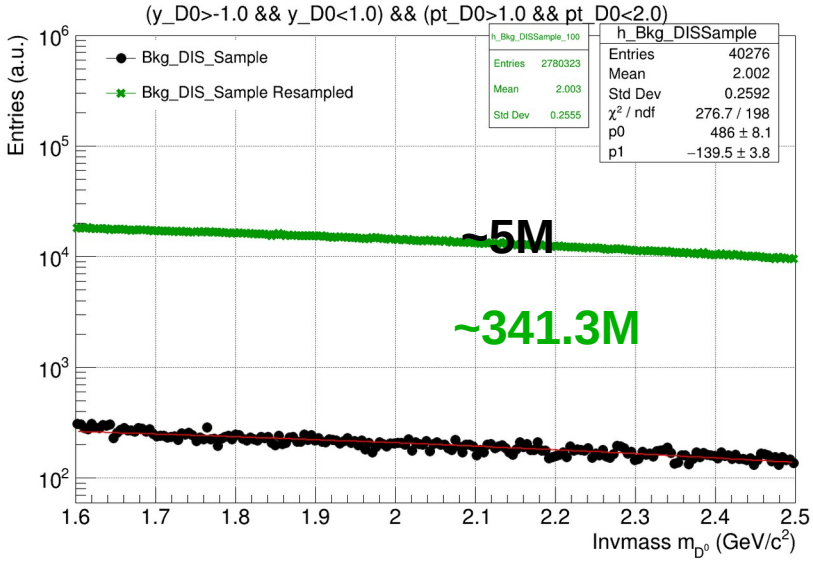
Signal candidates: 45179
Background candidates: 45179



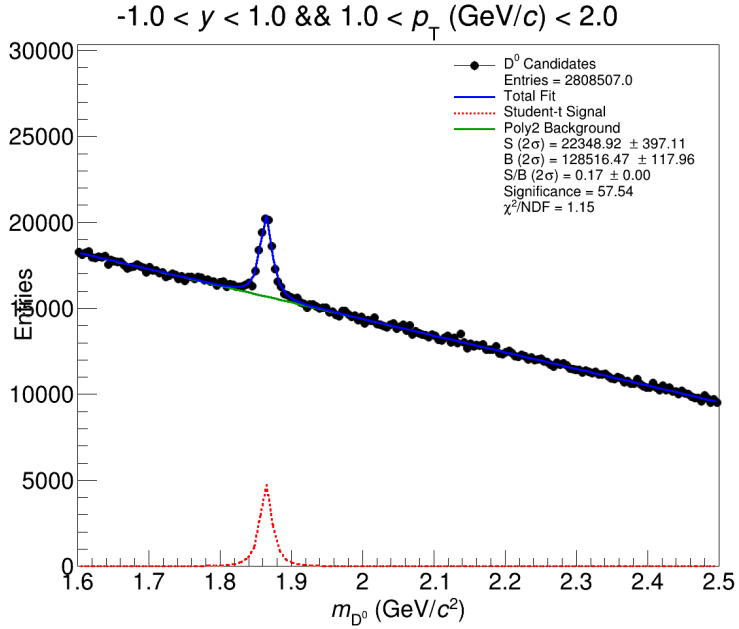


Sampling Signal and Background





-1 < y < 1
&
1 < $p_T(D^0)$ < 2



Preselection

Real PID

1.6 < mass_D0 < 2.5

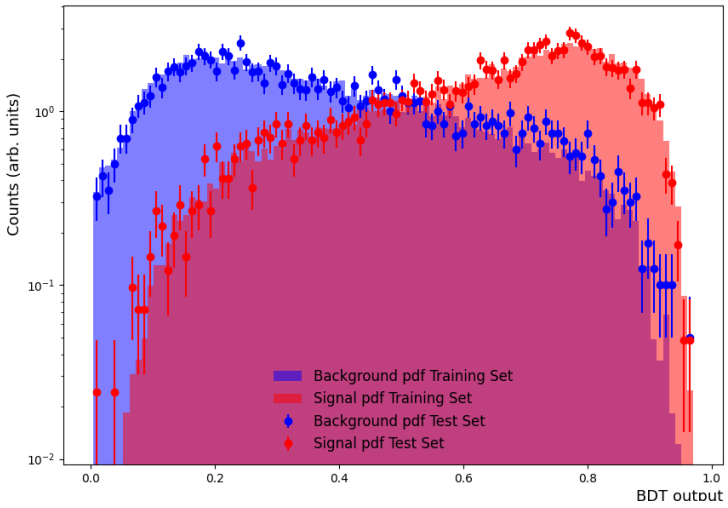
20 µm < DCA_{xy}(Pi) < 1 cm

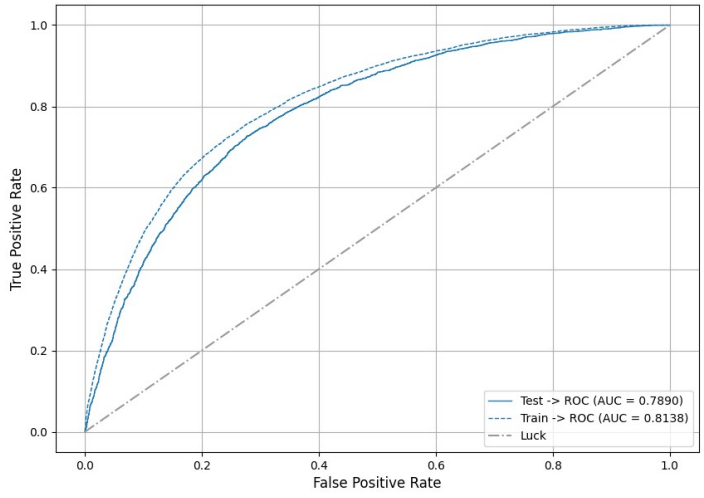
20 µm < DCA_{xy}(K) < 1 cm

Decay length < 10 cm

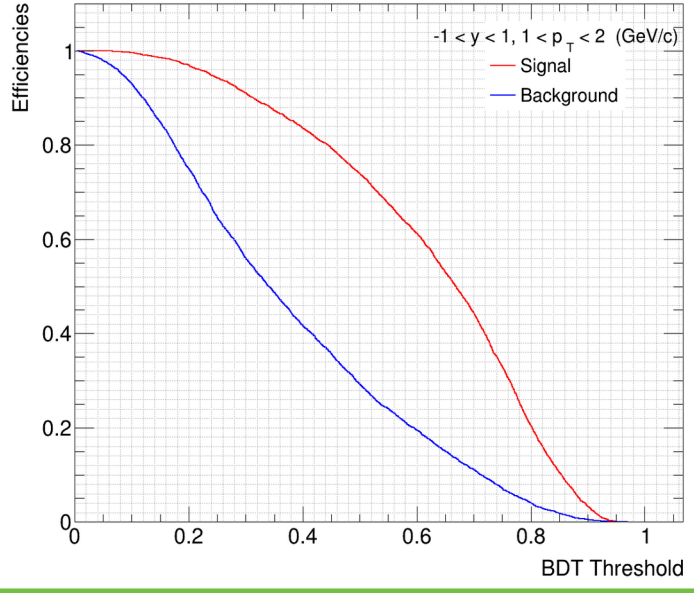
Machine learning

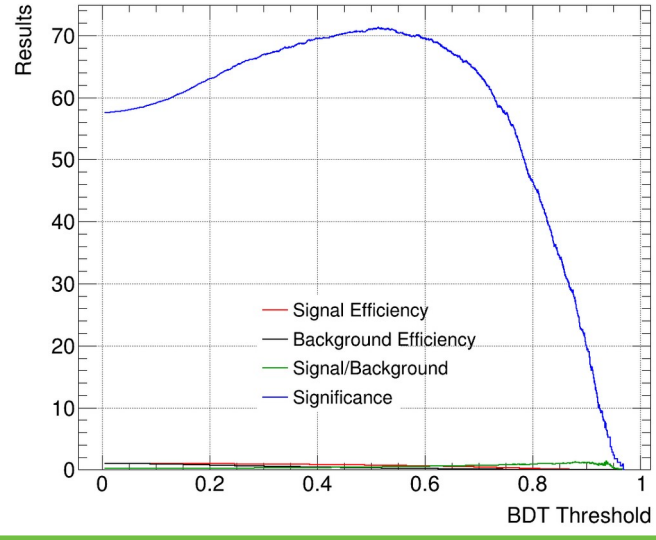
$-1 < y < 1$ & $1 < p_T(D^0) < 2$ GeV/c



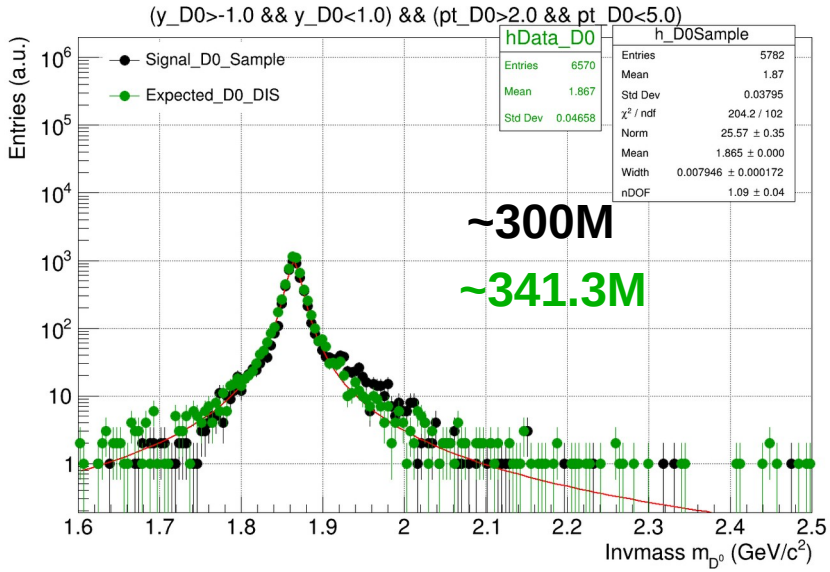


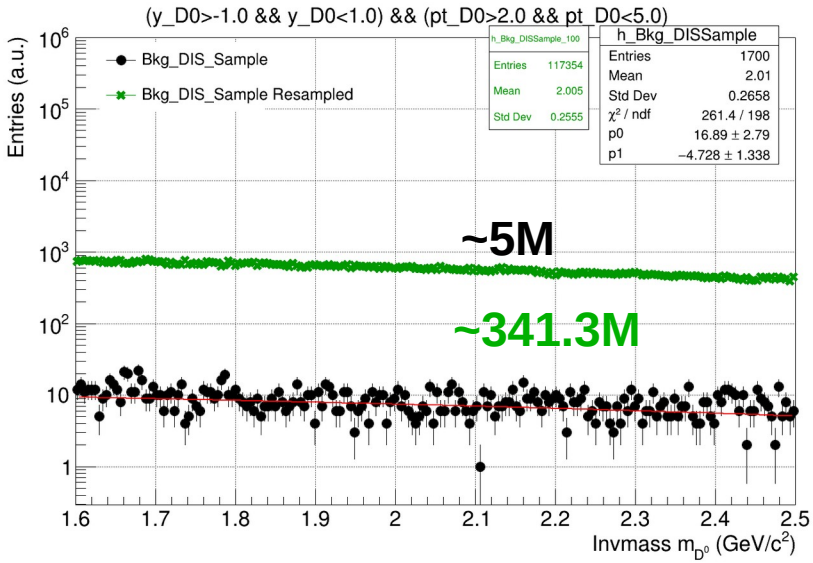
Signal candidates: 21031
Background candidates: 21031



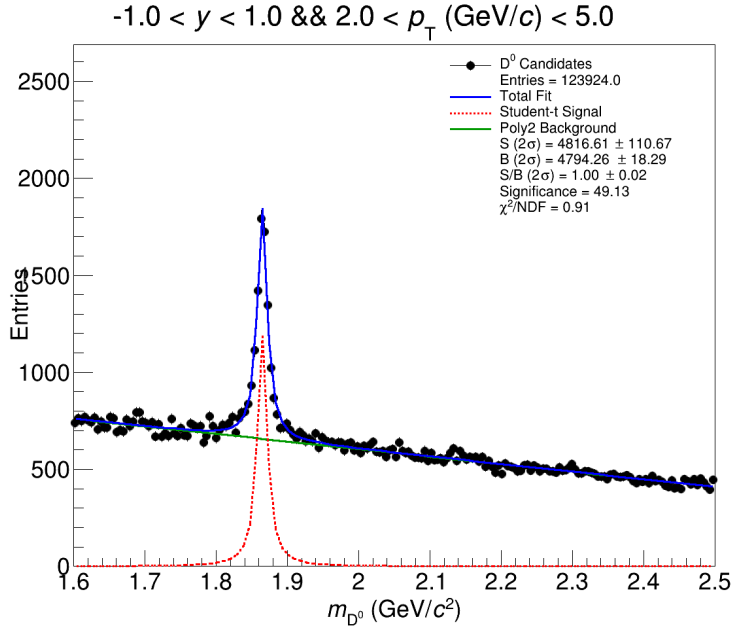


Sampling Signal and Background





-1 < y < 1
&
2 < $p_T(D^0)$ < 5



Preselection

Real PID

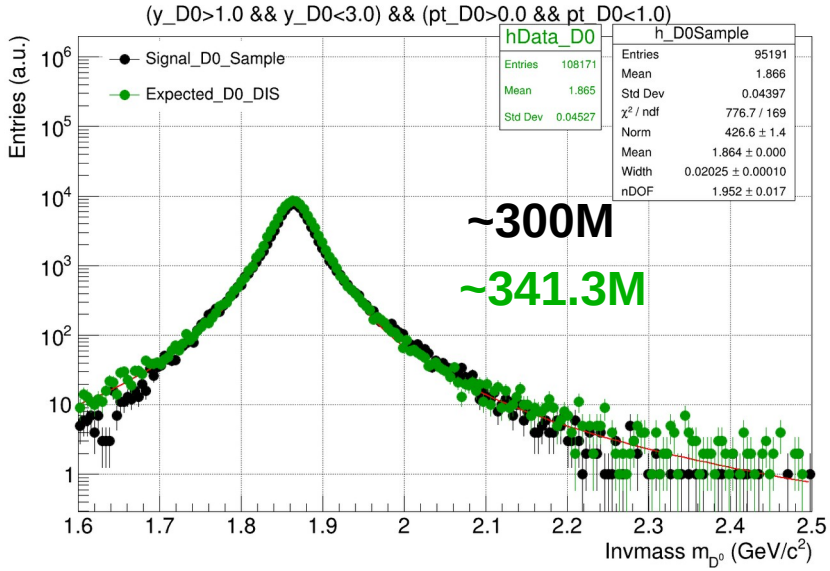
1.6 < mass_D0 < 2.5

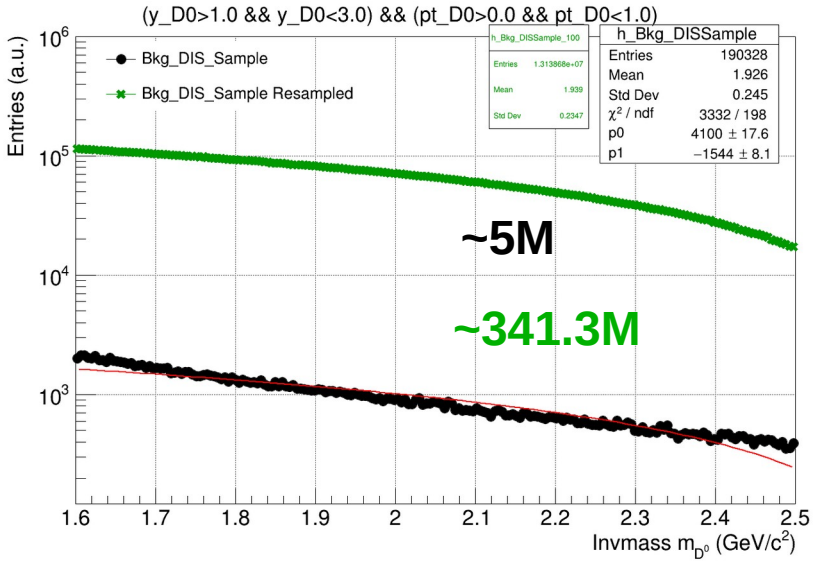
20 µm < DCA_{xy}(Pi) < 1 cm

20 µm < DCA_{xy}(K) < 1 cm

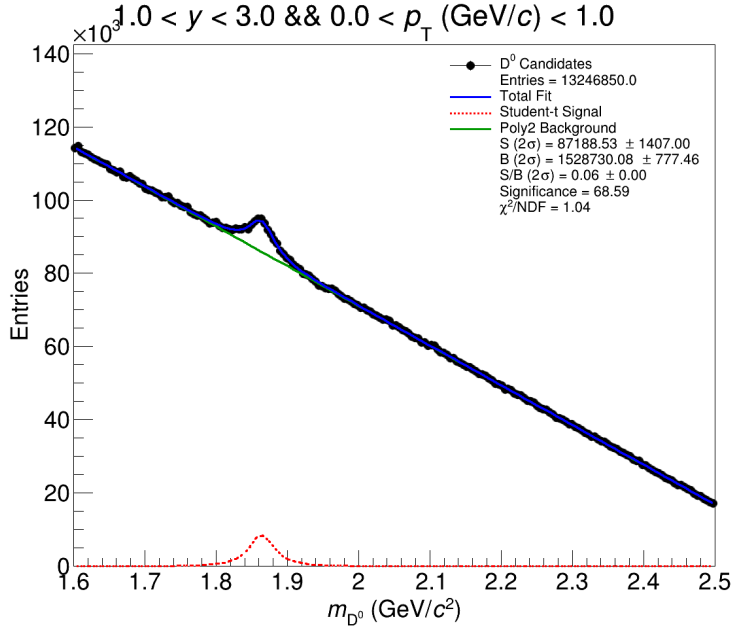
Decay length < 10 cm

Sampling Signal and Background





1 < y < 3
&
0 < $p_T(D^0)$ < 1



Preselection

Real PID

1.6 < mass_D0 < 2.5

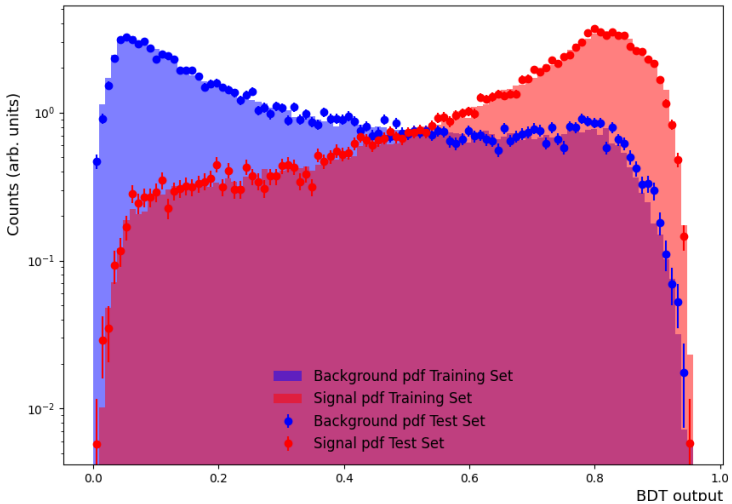
20 µm < DCA_{xy}(Pi) < 1 cm

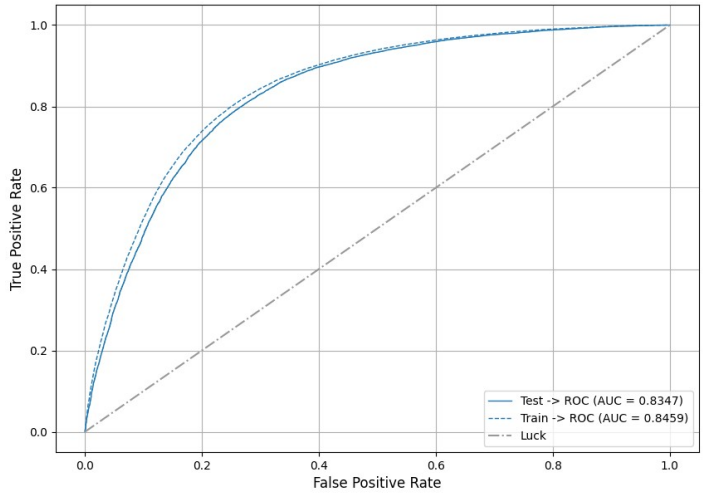
20 µm < DCA_{xy}(K) < 1 cm

Decay length < 10 cm

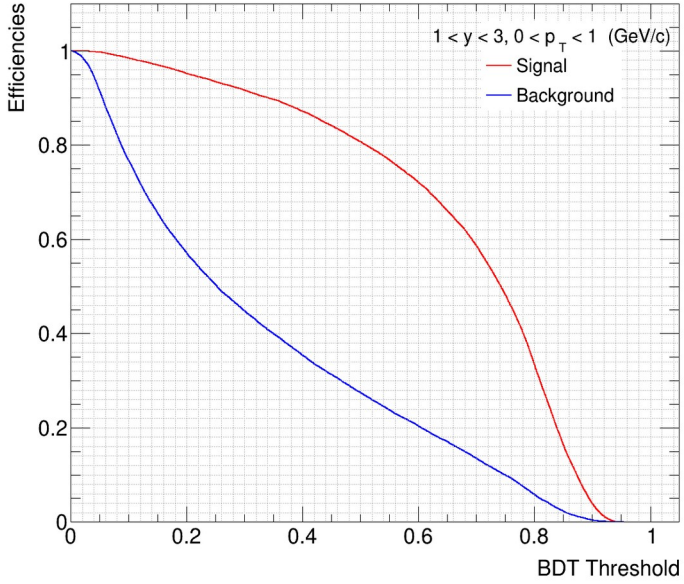
Machine learning

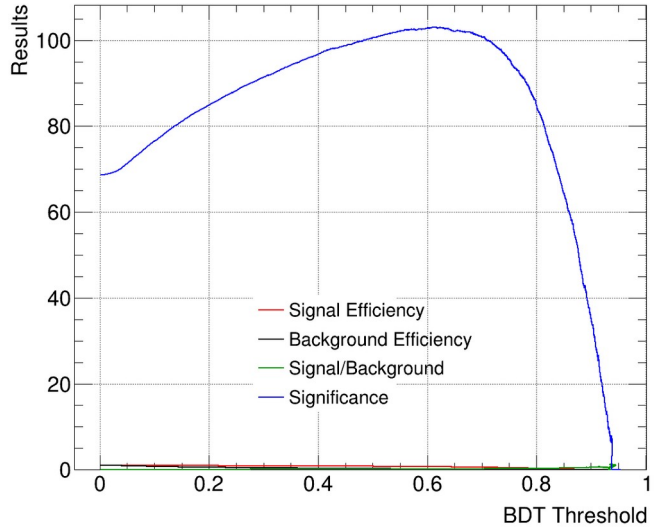
$1 < y < 3$ & $0 < p_T(D^0) < 1$ GeV/c



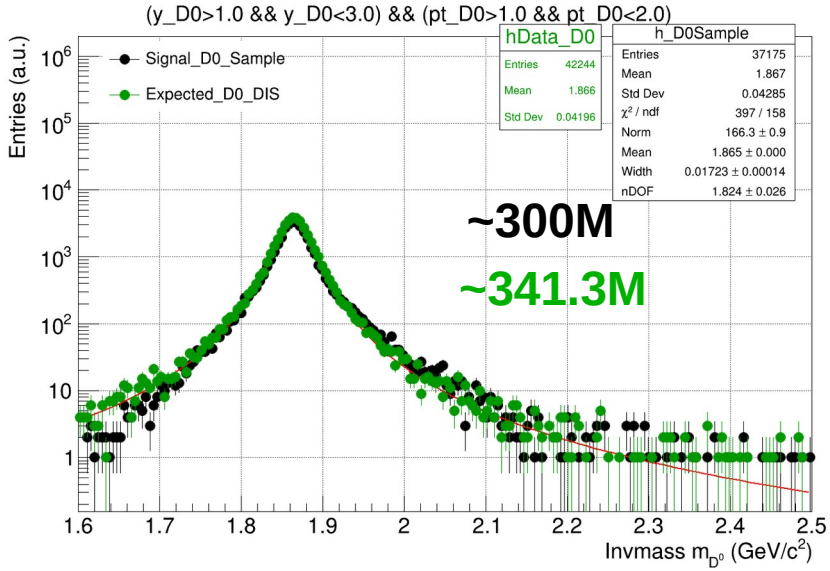


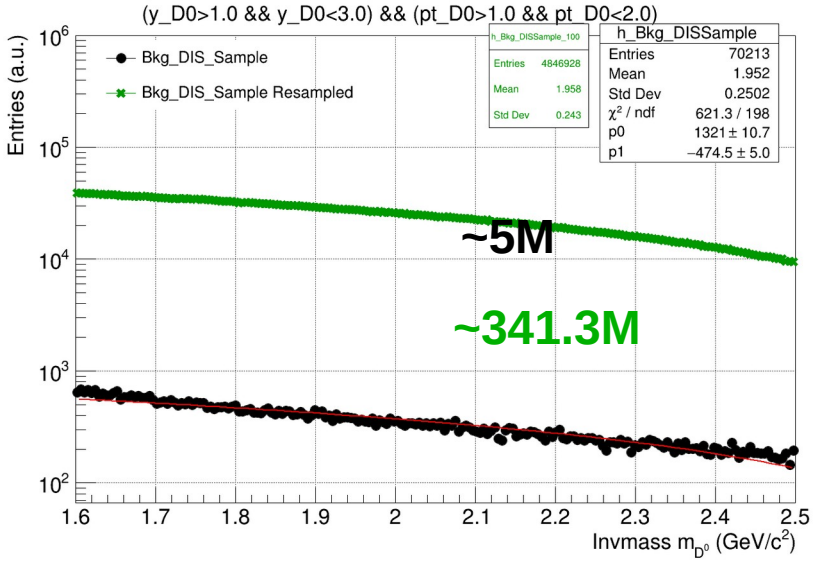
Signal candidates: 90050
Background candidates: 90050



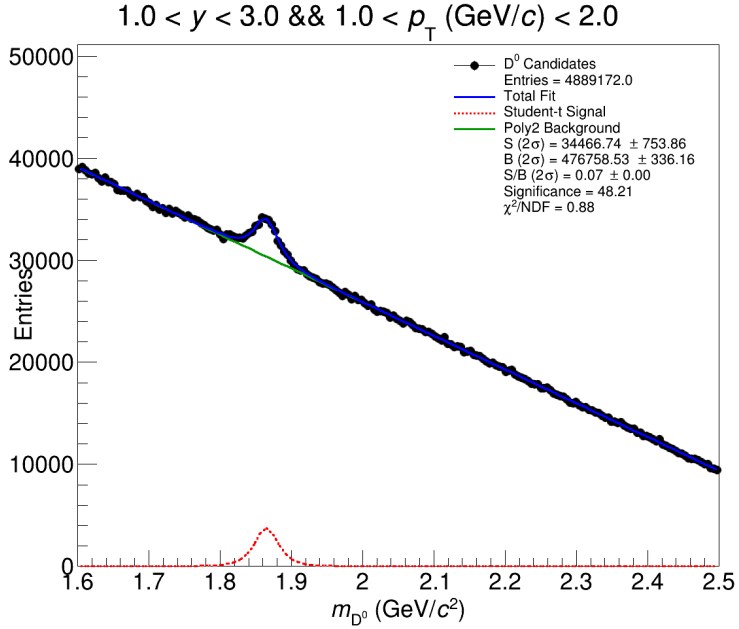


Sampling Signal and Background





$1 < y < 3$
&
$1 < p_T(D^0) < 2$



Preselection

Real PID

$1.6 < \text{mass\_D0} < 2.5$

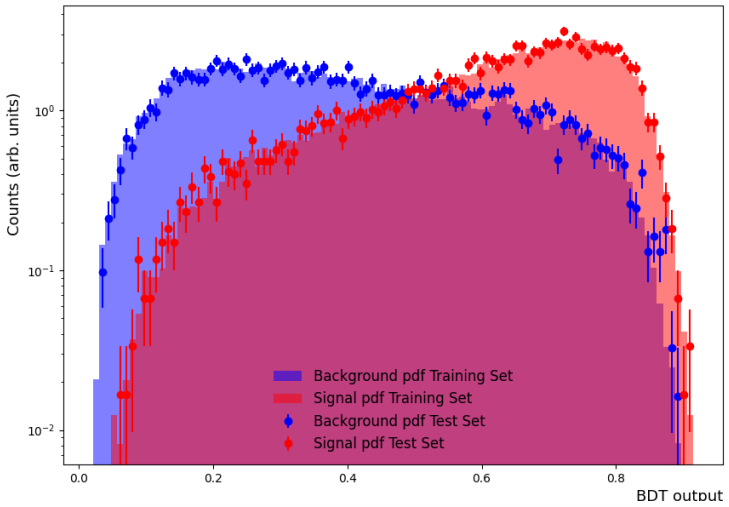
$20\ \mu m < DCA_{xy}(Pi) < 1\ cm$

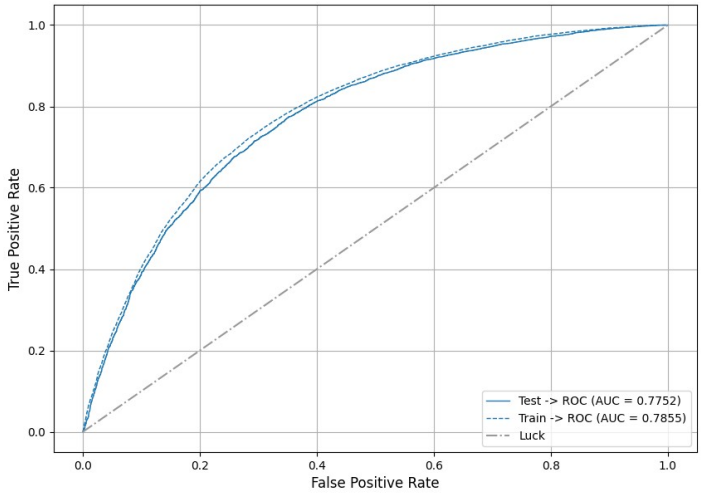
$20\ \mu m < DCA_{xy}(K) < 1\ cm$

Decay length < 10 cm

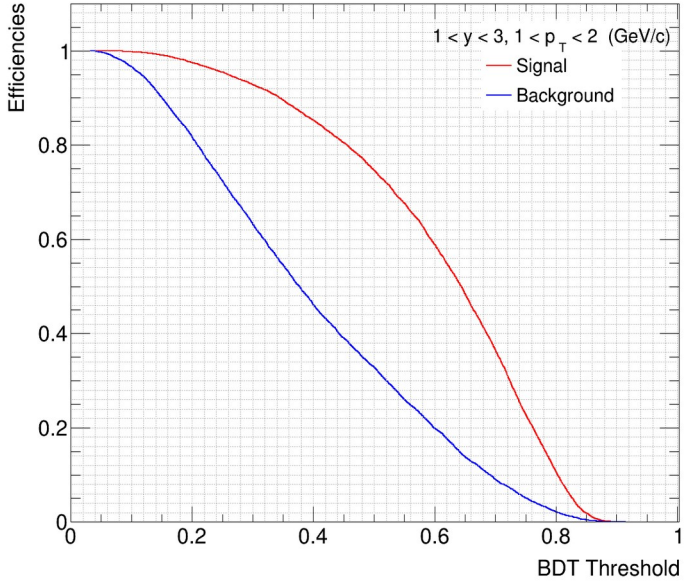
Machine learning

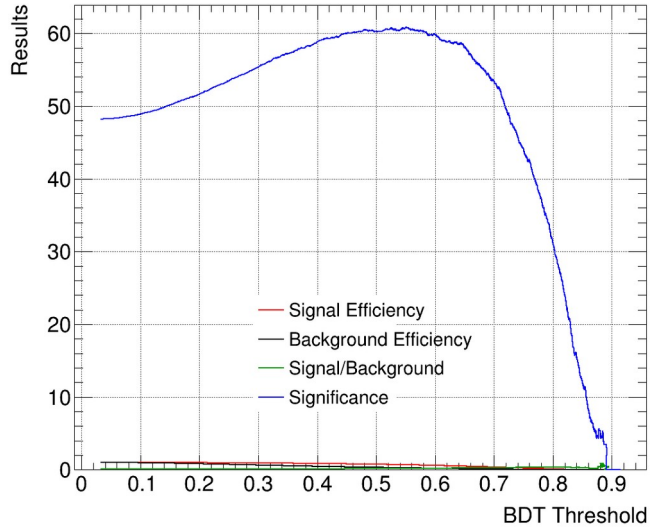
$1 < y < 3$ & $1 < p_T(D^0) < 2$ GeV/c



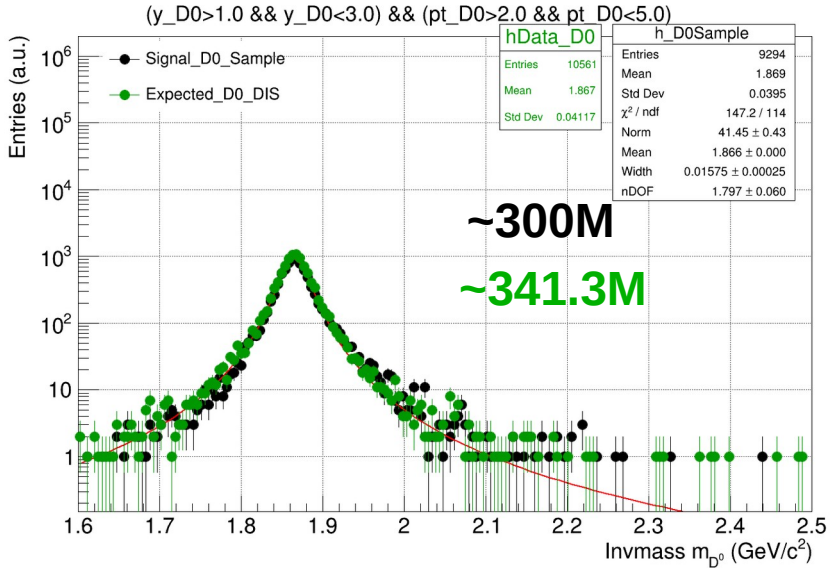


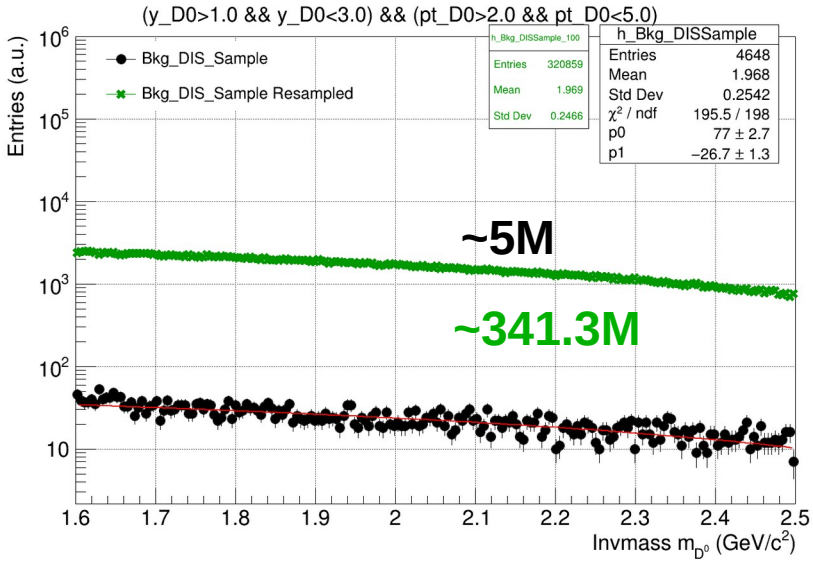
Signal candidates: 33909
Background candidates: 33909



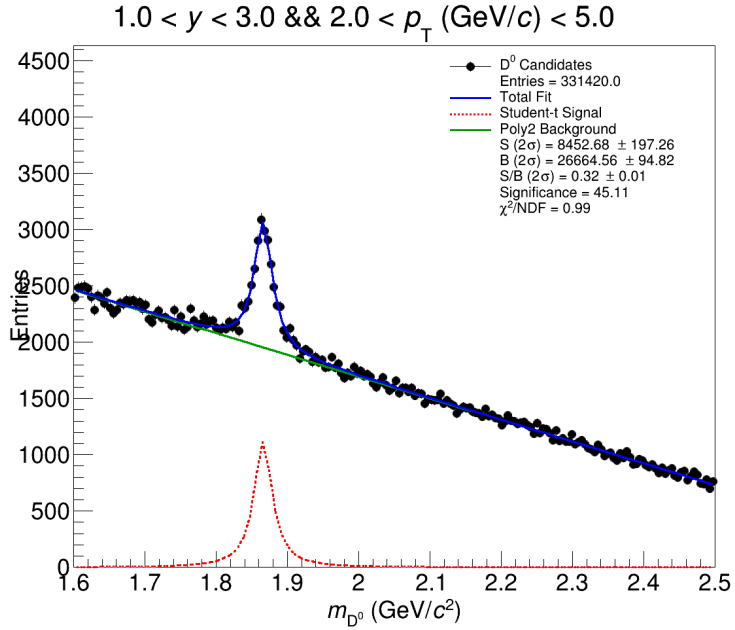


Sampling Signal and Background





$1 < y < 3$
&
$2 < p_T(D^0) < 5$



Preselection

Real PID

$1.6 < \text{mass\_D0} < 2.5$

$20\ \mu m < DCA_{xy}(Pi) < 1\ cm$

$20\ \mu m < DCA_{xy}(K) < 1\ cm$

Decay length < 10 cm

Relative Uncertiaties w/o ML

-->(ymin, ymax) = (-3,-1)-->(ptmin, ptmax) = (0,1)-------
eAu: S=6410.9653 B=25436.1113 S/sqrt(S+B)) =35.9243 Inverse Significance = 0.0278 rel sigma(S)/S =0.0278
ep: S=1686.0507 B=8864.8350 S/Sqr(S+B) =16.4144 Inverse Significance = 0.0609 rel sigma(S)/S=0.0609
(relative uncertainty after adding in quadrature = 0.0670 = 6.6980%)

-->(ymin, ymax) = (-3,-1)-->(ptmin, ptmax) = (1,2)-------
eAu: S=3386.8691 B=18668.5332 S/sqrt(S+B)) =22.8056 Inverse Significance = 0.0438 rel sigma(S)/S =0.0438
ep: S=2582.6934 B=6801.4741 S/Sqr(S+B) =26.6609 Inverse Significance = 0.0375 rel sigma(S)/S=0.0375
(relative uncertainty after adding in quadrature = 0.0577 = 5.7703%)

-->(ymin, ymax) = (-3,-1)-->(ptmin, ptmax) = (2,5)-------
eAu: S=391.8584 B=1728.8330 S/sqrt(S+B)) =8.5092 Inverse Significance = 0.1175 rel sigma(S)/S =0.1175
ep: S=1295.6207 B=2588.1956 S/Sqr(S+B) =20.7897 Inverse Significance = 0.0481 rel sigma(S)/S=0.0481
(relative uncertainty after adding in quadrature = 0.1270 = 12.6982%)

-->(ymin, ymax) = (-1,1)-->(ptmin, ptmax) = (0,1)-------
eAu: S=40337.1719 B=512446.7500 S/sqrt(S+B)) =54.2535 Inverse Significance = 0.0184 rel sigma(S)/S =0.0184
ep: S=154222.0625 B=2714555.2500 S/Sqr(S+B) =91.0538 Inverse Significance = 0.0110 rel sigma(S)/S=0.0110
(relative uncertainty after adding in quadrature = 0.0215 = 2.1456%)

-->(ymin, ymax) = (-1,1)-->(ptmin, ptmax) = (1,2)-------
eAu: S=22348.9199 B=128516.4688 S/sqrt(S+B)) =57.5389 Inverse Significance = 0.0174 rel sigma(S)/S =0.0174
ep: S=137413.0312 B=740698.8125 S/Sqr(S+B) =146.6402 Inverse Significance = 0.0068 rel sigma(S)/S=0.0068
(relative uncertainty after adding in quadrature = 0.0187 = 1.8670%)

-->(ymin, ymax) = (-1,1)-->(ptmin, ptmax) = (2,5)-------
eAu: S=4816.6113 B=4794.2568 S/sqrt(S+B)) =49.1315 Inverse Significance = 0.0204 rel sigma(S)/S =0.0204
ep: S=62358.9062 B=61546.9688 S/Sqr(S+B) =177.1546 Inverse Significance = 0.0056 rel sigma(S)/S=0.0056
(relative uncertainty after adding in quadrature = 0.0211 = 2.1122%)

-->(ymin, ymax) = (1,3)-->(ptmin, ptmax) = (0,1)-------
eAu: S=87188.5234 B=1528730.1250 S/sqrt(S+B)) =68.5882 Inverse Significance = 0.0146 rel sigma(S)/S =0.0146
ep: S=361005.2812 B=9929459.0000 S/Sqr(S+B) =112.5372 Inverse Significance = 0.0089 rel sigma(S)/S=0.0089
(relative uncertainty after adding in quadrature = 0.0171 = 1.7074%)

-->(ymin, ymax) = (1,3)-->(ptmin, ptmax) = (1,2)-------
eAu: S=34466.7383 B=476758.5312 S/sqrt(S+B)) =48.2052 Inverse Significance = 0.0207 rel sigma(S)/S =0.0207
ep: S=213335.4219 B=3725295.5000 S/Sqr(S+B) =107.4955 Inverse Significance = 0.0093 rel sigma(S)/S=0.0093
(relative uncertainty after adding in quadrature = 0.0227 = 2.2735%)

-->(ymin, ymax) = (1,3)-->(ptmin, ptmax) = (2,5)-------
eAu: S=8452.6797 B=26664.5605 S/sqrt(S+B)) =45.1060 Inverse Significance = 0.0222 rel sigma(S)/S =0.0222
ep: S=71480.8828 B=418493.3750 S/Sqr(S+B) =102.1182 Inverse Significance = 0.0098 rel sigma(S)/S=0.0098
(relative uncertainty after adding in quadrature = 0.0242 = 2.4236%)

Relative Uncertiaties w ML

-->(ymin, ymax) = (-1,1)-->ptmin, ptmax) = (0,1)-------
eAu (ML): S/sqrt(S+B) =90.4785 Inverse Significance = 0.0111 rel sqrt(S+B)/S =0.0111
ep (ML): S/sqrt(S+B) =192.0742 Inverse Significance = 0.0052 rel sqrt(S+B)/S=0.0052
(relative uncertainty after adding in quadrature = 0.0122 = 1.2217%)

-->(ymin, ymax) = (-1,1)-->ptmin, ptmax) = (1,2)-------
eAu (ML): S/sqrt(S+B) =71.3640 Inverse Significance = 0.0140 rel sqrt(S+B)/S =0.0140
ep (ML): S/sqrt(S+B) =235.2795 Inverse Significance = 0.0043 rel sqrt(S+B)/S=0.0043
(relative uncertainty after adding in quadrature = 0.0146 = 1.4643%)

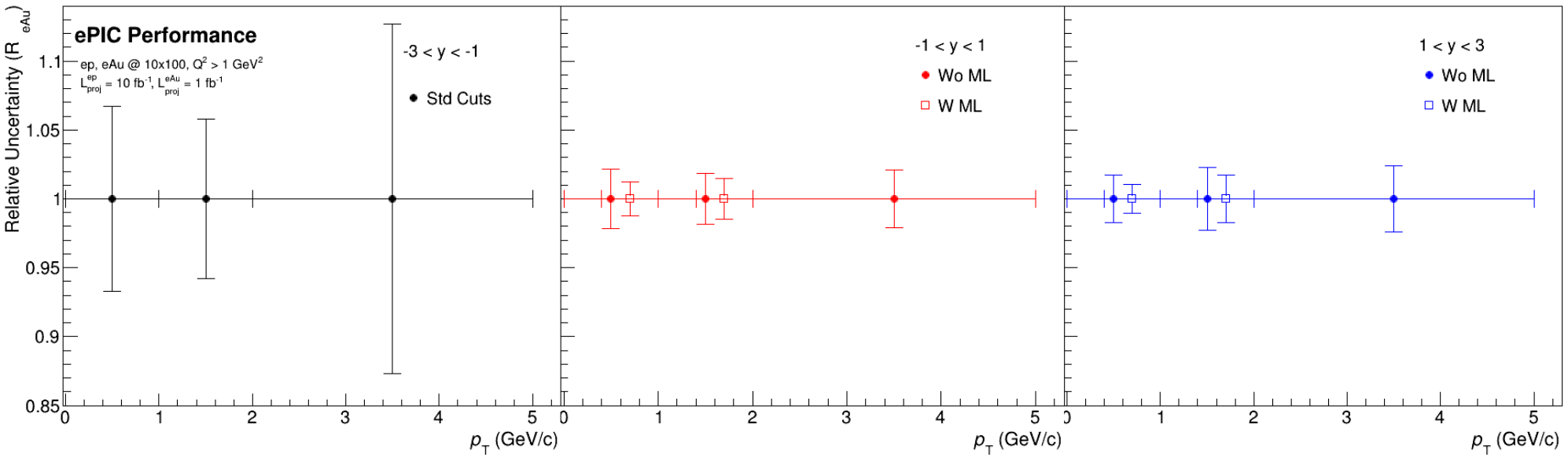
-->(ymin, ymax) = (1,3)-->ptmin, ptmax) = (0,1)-------
eAu (ML): S/sqrt(S+B) =103.0463 Inverse Significance = 0.0097 rel sqrt(S+B)/S =0.0097
ep (ML): S/sqrt(S+B) =266.8802 Inverse Significance = 0.0037 rel sqrt(S+B)/S=0.0037
(relative uncertainty after adding in quadrature = 0.0104 = 1.0403%)

-->(ymin, ymax) = (1,3)-->ptmin, ptmax) = (1,2)-------
eAu (ML): S/sqrt(S+B) =60.8581 Inverse Significance = 0.0164 rel sqrt(S+B)/S =0.0164
ep (ML): S/sqrt(S+B) =204.7588 Inverse Significance = 0.0049 rel sqrt(S+B)/S=0.0049
(relative uncertainty after adding in quadrature = 0.0171 = 1.7142%)

Statistical Projections (R_{eAu})

Data Sample: ep, eAu collision 10 X 100 with $Q^2 > 1$ GeV^2

$$\text{Rel. Uncertainity}\left(R_{eAu}\right) = \sqrt{\left(\frac{\sigma(S)}{S}\right)^2_{eAu} + \left(\frac{\sigma(S)}{S}\right)^2_{ep}}$$



Invariant mass w/o and with ML

ep (10x100), $Q^2 > 1$ GeV^2

Cut-outlier removal

Real PID

1.6 < mass_D0 < 2.5

DCA_{xy}(Pi) < 10 cm

DCA_{xy}(K) < 10 cm

Decay length < 10 cm

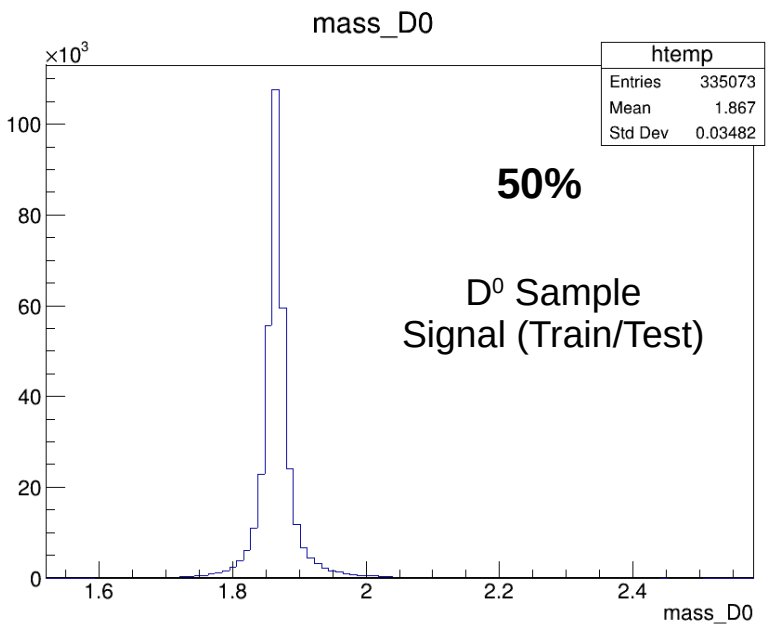
y bins: (-1, 1), (1,3)

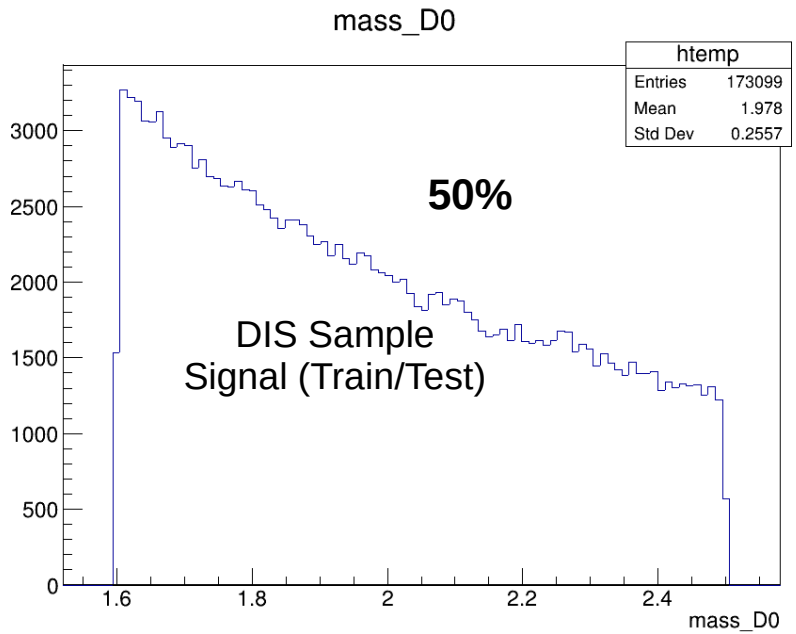
p_T (D meson) > 0

y: (-3, -1) limited with statistics

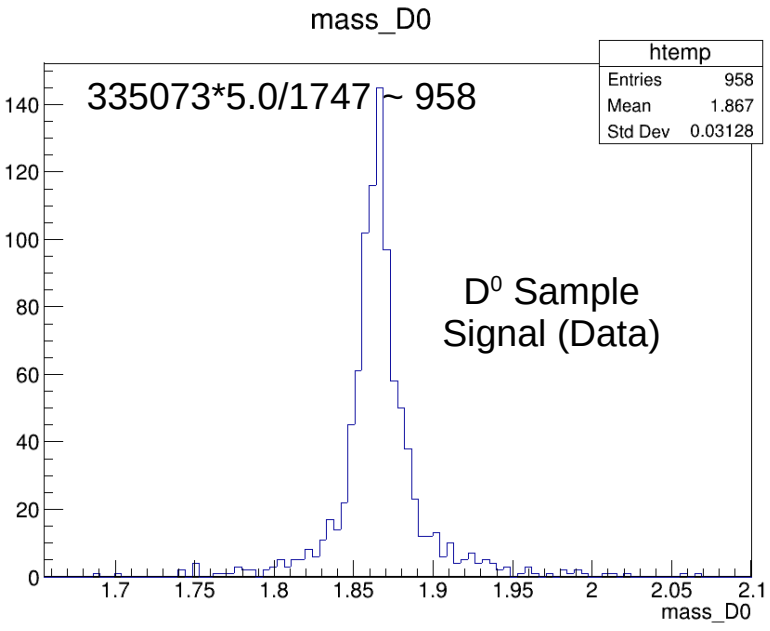
Split Scheme: Train/Test (50%) and 50% for application

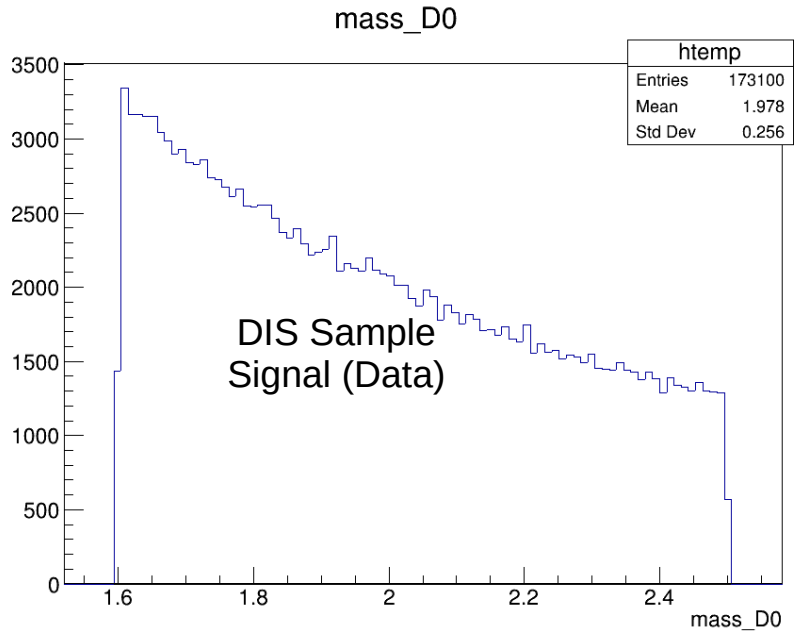
Training/Test = 50%

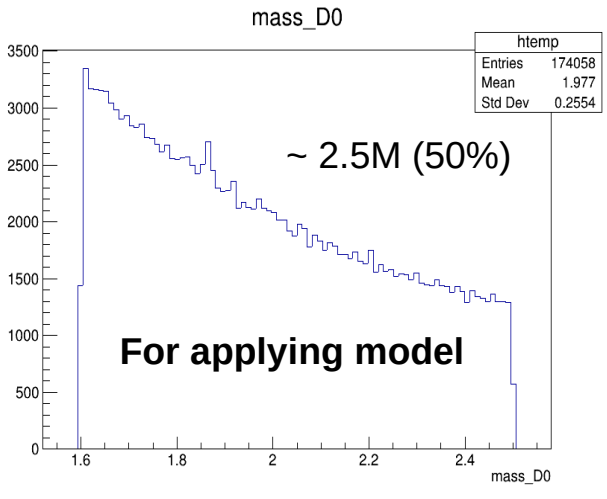




Invariant mass w/o and with ML







Invariant mass w/o and with ML

eAu (10x100), $Q^2 > 1$ GeV^2

Cut-outlier removal

Real PID

1.6 < mass_D0 < 2.5

DCA_{xy}(Pi) < 10 cm

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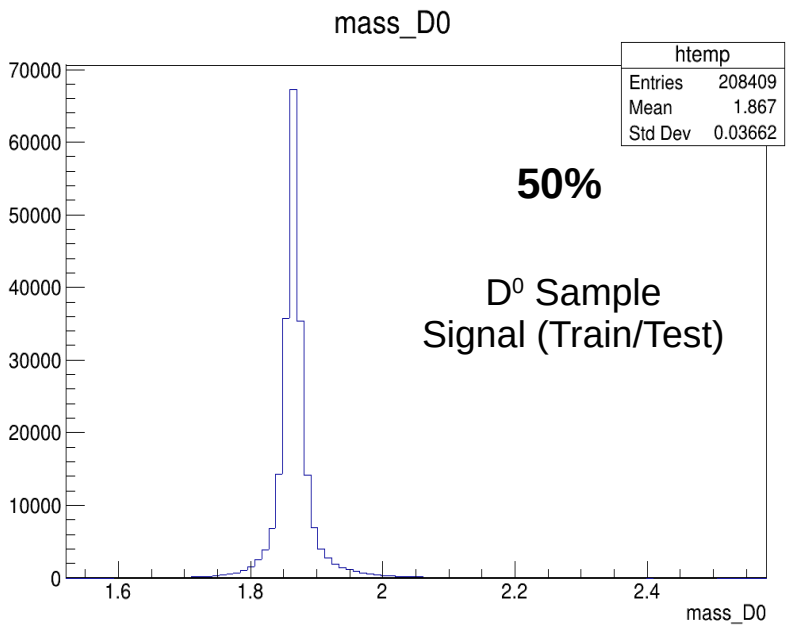
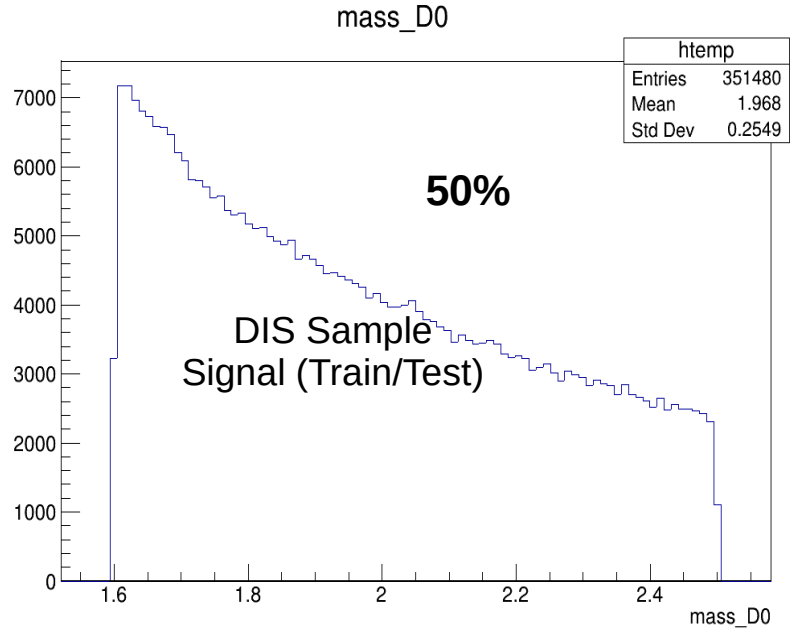
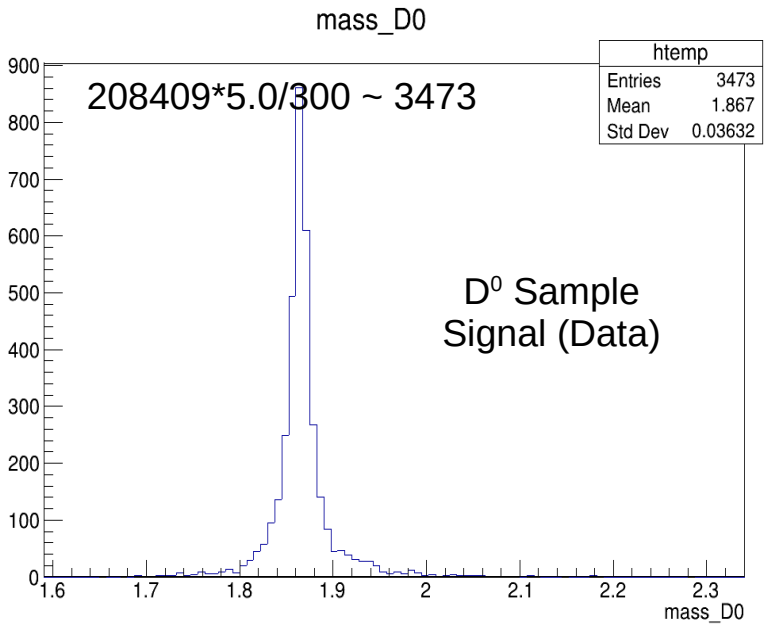
Split Scheme: Train/Test (50%) and 50% for application

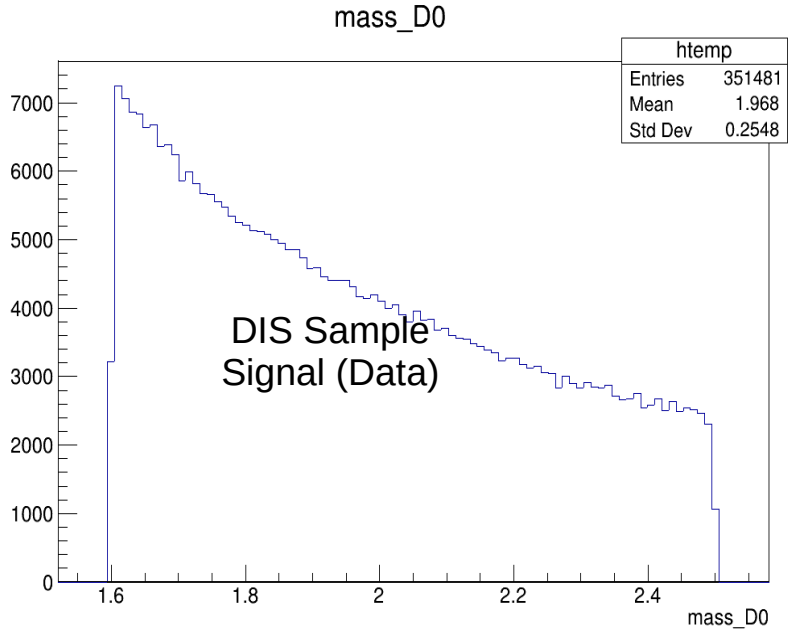
Training/Test = 50%

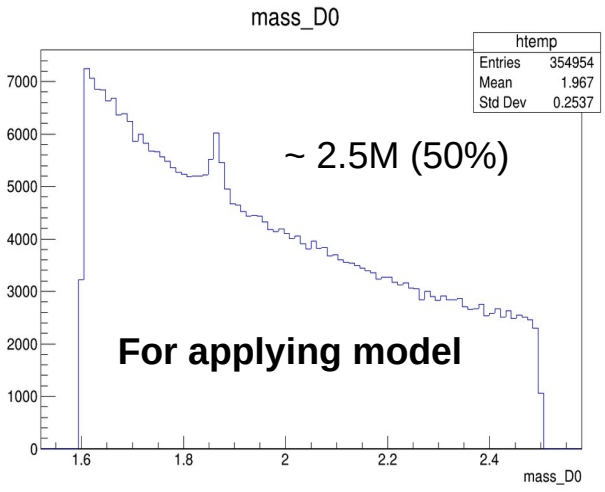




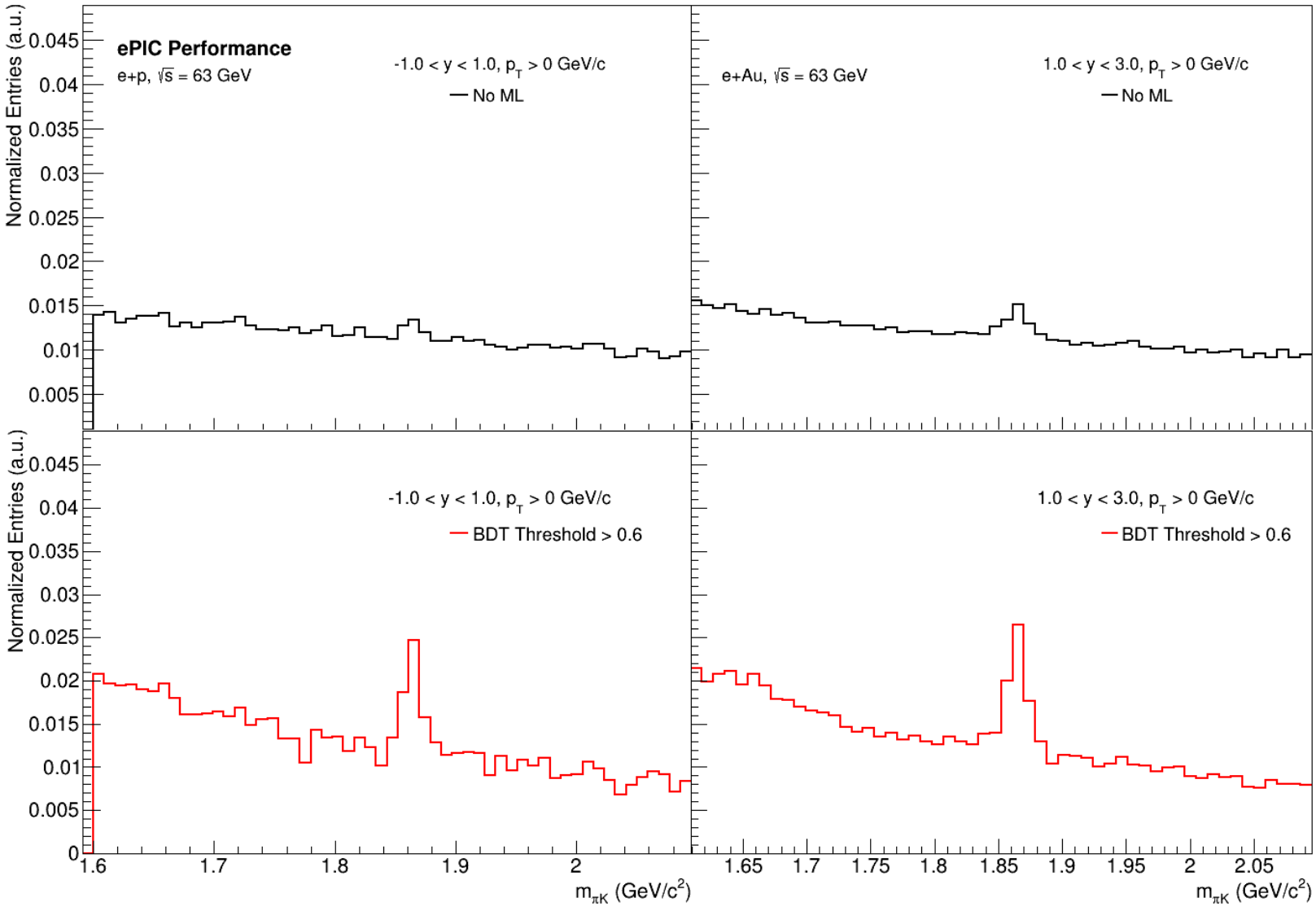
Invariant mass w/o and with ML







Invariant mass w/o and with ML



Summary

- Presented the results to be included in preTDR
- Need to include the text in preTDR
- Further need to produce with October Campaign

Thank you for your attention!

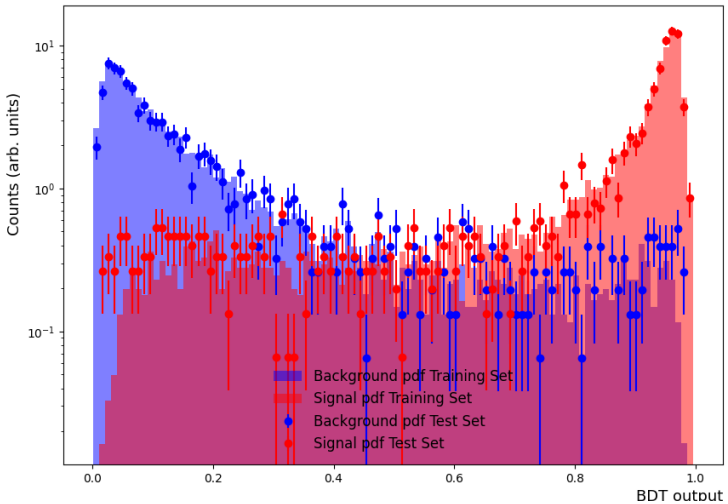
Machine learning (Checks)

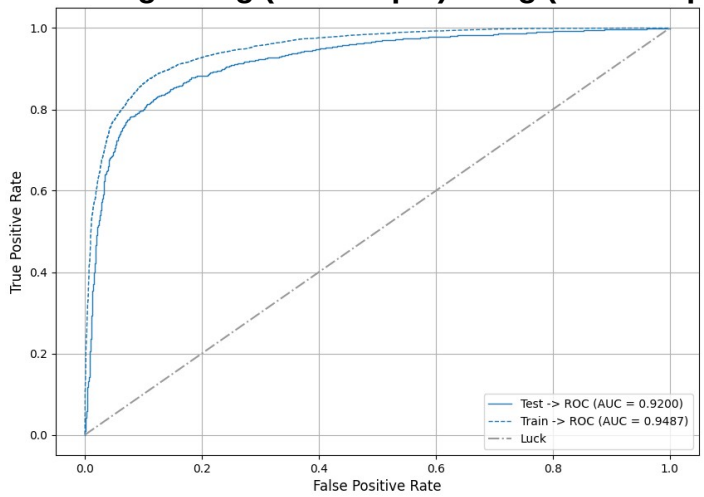
$-1 < y < 1$ & $2 < p_T(D^0) < 5$ GeV/c

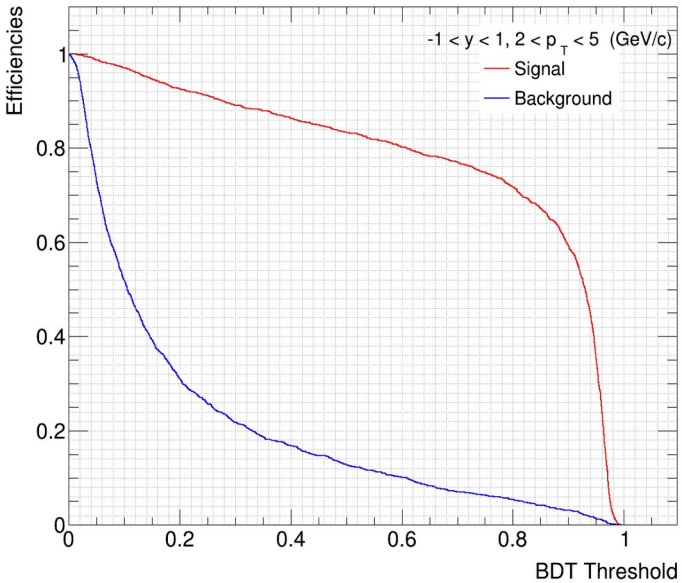
ep 10x100, $Q^2>1$

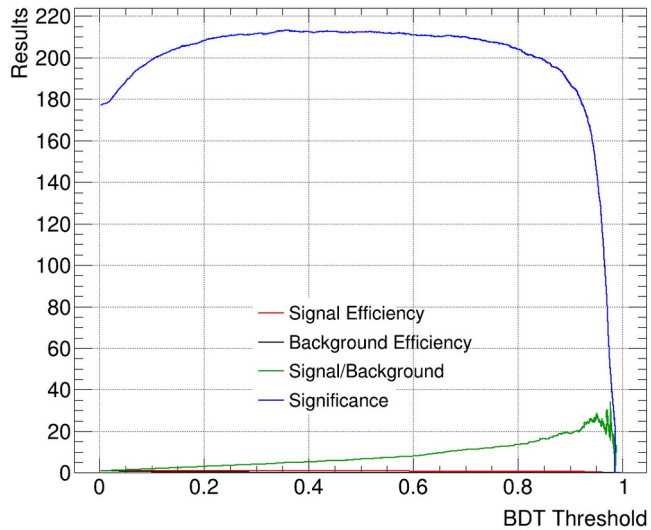
Signal: Signal (D^0 Sample) + Signal (DIS Sample)

Bkg: Bkg (D0 Sample) +Bkg (DIS Sample)









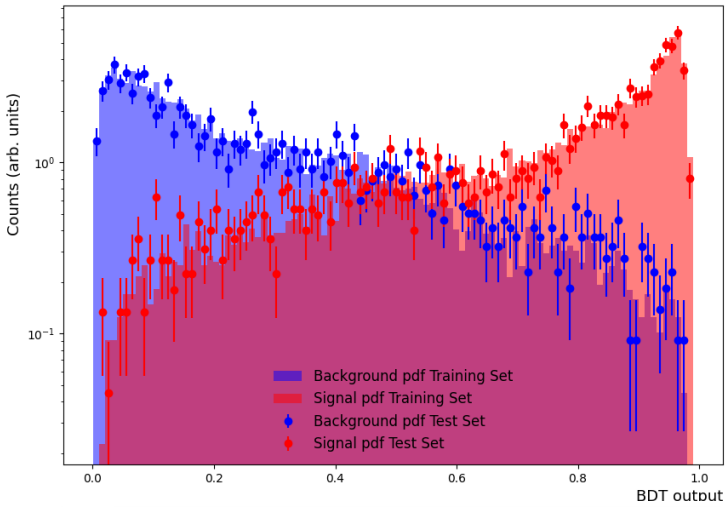
Machine learning (Checks)

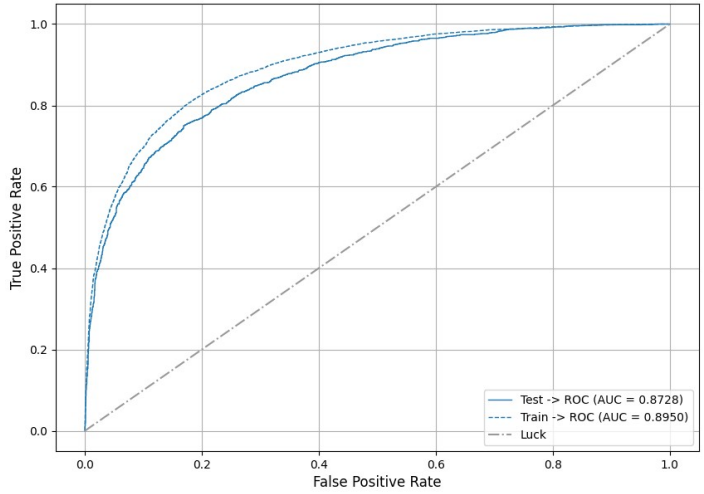
$1 < y < 3$ & $2 < p_T(D^0) < 5$ GeV/c

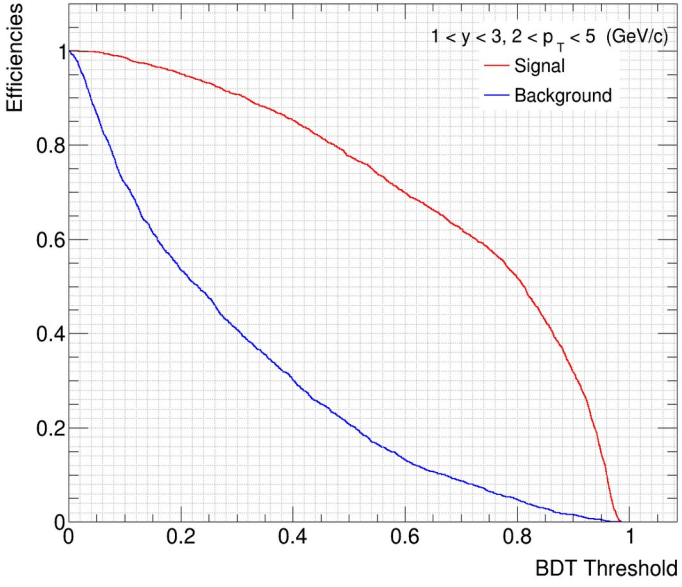
ep 10x100, $Q^2>1$

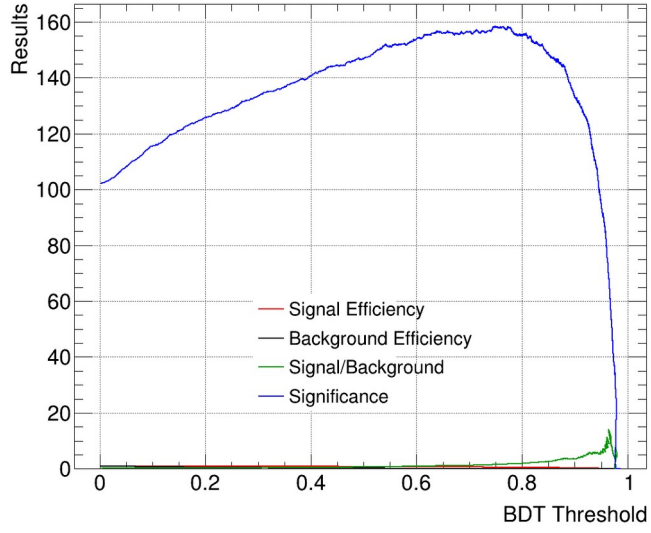
Signal: Signal (D^0 Sample) + Signal (DIS Sample)

Bkg: Bkg (D0 Sample) +Bkg (DIS Sample)









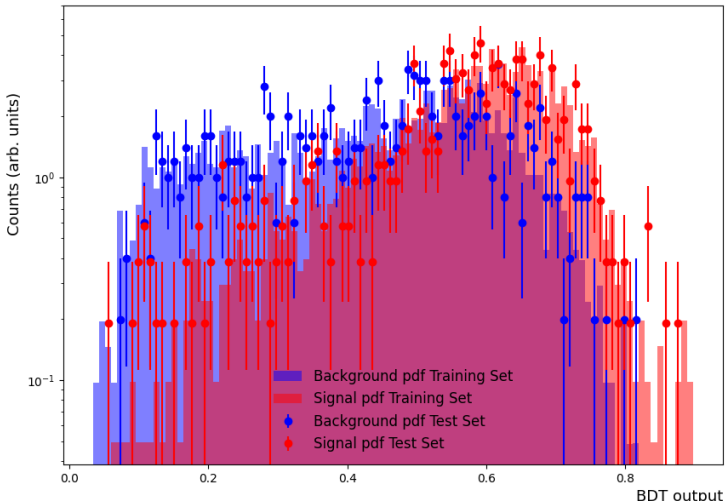
Machine learning (Checks)

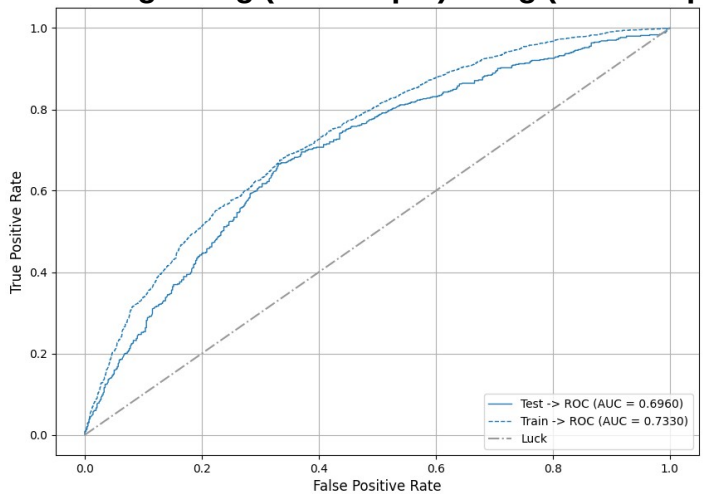
$-1 < y < 1$ & $2 < p_T(D^0) < 5$ GeV/c

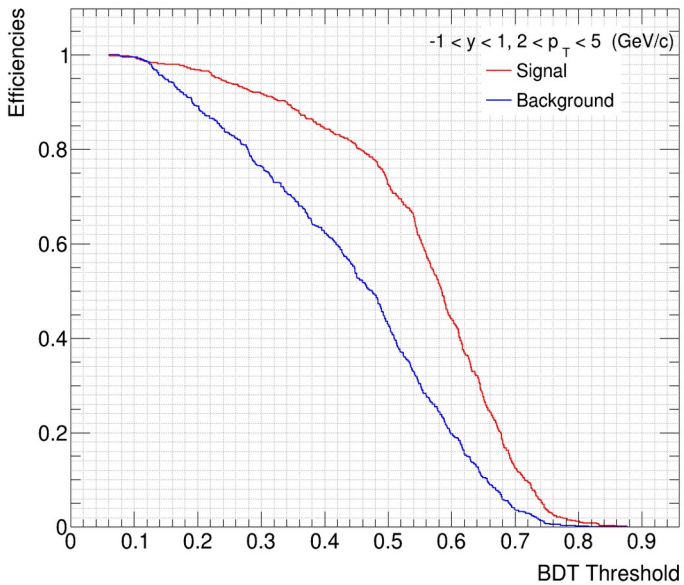
eAu 10x100, $Q^2>1$

Signal: Signal (D^0 Sample) + Signal (DIS Sample)

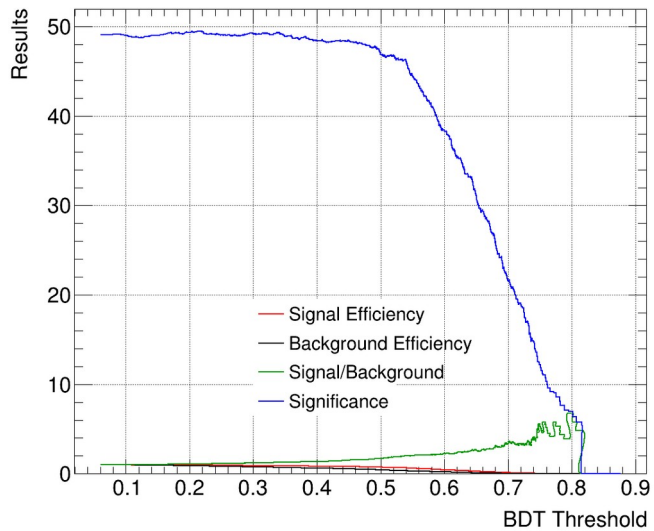
Bkg: Bkg (D0 Sample) +Bkg (DIS Sample)







Limited Statistics



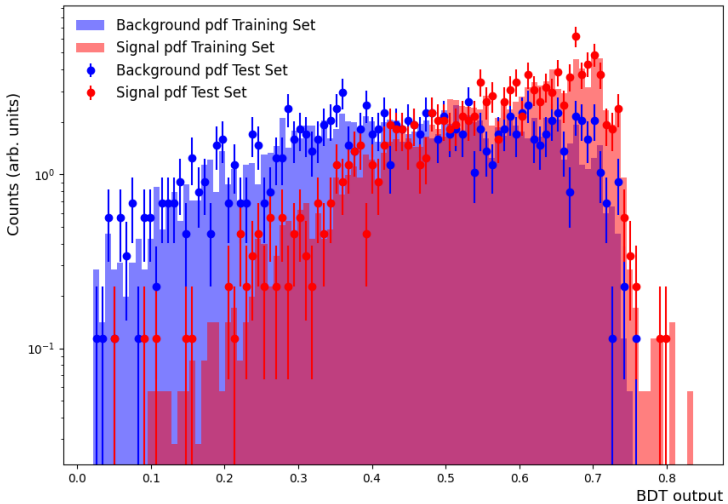
Machine learning (Checks)

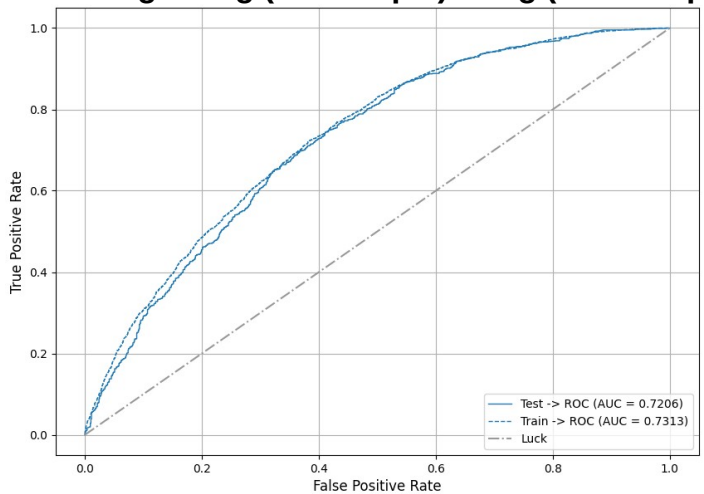
$1 < y < 3$ & $2 < p_T(D^0) < 5$ GeV/c

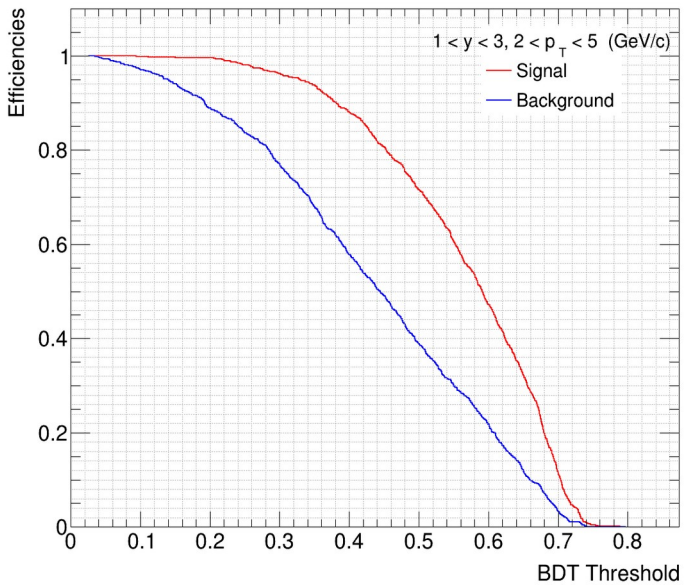
eAu 10x100, $Q^2>1$

Signal: Signal (D^0 Sample) + Signal (DIS Sample)

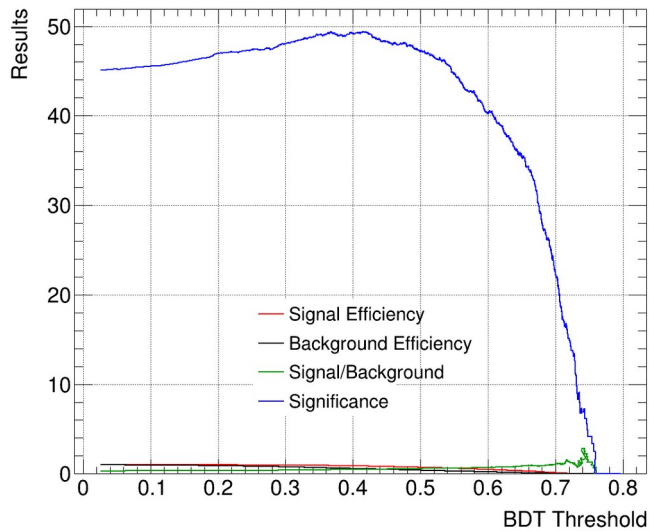
Bkg: Bkg (D0 Sample) +Bkg (DIS Sample)







Limited Statistics



Covariance Matrix

Track Parameters $(l_0, l_1, \phi, \theta, q/p, time)$

For each fitted track we get track parameters and covariance matrix

$$
\begin{array}{c} \\ l_0 \\ l_1 \\ \phi \\ \theta \\ q/p \\ time \end{array}
\begin{array}{c}
\begin{array}{cccccc} l_0 & l_1 & \phi & \theta & q/p & time \end{array} \\
\begin{bmatrix}
\sigma^2(l_0) & \mathrm{cov}(l_0,l_1) & \mathrm{cov}(l_0,\phi) & \mathrm{cov}(l_0,\theta) & \mathrm{cov}(l_0,q/p) & \mathrm{cov}(l_0,t) \\
. & \sigma^2(l_1) & \mathrm{cov}(l_1,\phi) & \mathrm{cov}(l_1,\theta) & \mathrm{cov}(l_1,q/p) & \mathrm{cov}(l_1,t) \\
. & . & \sigma^2(\phi) & \mathrm{cov}(\phi,\theta) & \mathrm{cov}(\phi,q/p) & \mathrm{cov}(\phi,t) \\
. & . & . & \sigma^2(\theta) & \mathrm{cov}(\theta,q/p) & \mathrm{cov}(\theta,t) \\
. & . & . & . & \sigma^2(q/p) & \mathrm{cov}(q/p,t) \\
. & . & . & . & . & \sigma^2(t)
\end{bmatrix}
\end{array}
$$

Symmetric matrix: Independent entries = n(n+1)/2 = 6*7/2 = 21

```
Processing ReadCovarianceArray_new.C...
Event 0, number of tracks: 8
  Track 0 covariance:
    cov[0] = 0.0104456
    cov[1] = 2.366e-06
    cov[2] = 0.0103324
    cov[3] = -0.000289634
    cov[4] = 7.52669e-07
    cov[5] = 8.04972e-06
    cov[6] = -8.12589e-07
    cov[7] = 0.000284166
    cov[8] = 4.50984e-08
    cov[9] = 7.82997e-06
    cov[10] = 0.000153944
    cov[11] = 7.02629e-07
    cov[12] = -4.94218e-06
    cov[13] = 5.14138e-09
    cov[14] = 0.00011838
    cov[15] = -1.41347e-06
    cov[16] = -3.20263e-06
    cov[17] = 3.89944e-08
    cov[18] = -8.82041e-08
    cov[19] = 2.242e-09
    cov[20] = 0.000333566
```

Cov[0] = cov(l0, l0)
Cov[1] = cov(l0, l1)
Cov[2] = cov(l1, l1)
Cov[3] = cov(l0, φ)
cov[4] = cov(l1, φ)
cov[5] = cov(φ, φ)
cov[6] = cov(l0, θ)
cov[7] = cov(l1, θ)
cov[8] = cov(φ, θ)
cov[9] = cov(θ, θ)
cov[10] = cov(l0, q/p)

Cov[11] = cov(l1, q/p)
Cov[12] = cov(φ, q/p)
Cov[13] = cov(θ, q/p)
Cov[14] = cov(q/p, q/p)
Cov[15] = cov(l0, time)
Cov[16] = cov(l1, time)
Cov[17] = cov(φ, time)
Cov[18] = cov(θ, time)
Cov[19] = cov(q/p, time)
Cov[20] = cov(time, time)

$\sigma_{l0} = \sqrt{(Cov[0])}$ $\sigma_{l1} = \sqrt{(Cov[2])}$

$\sigma_{\phi} = \sqrt{(Cov[5])}$ $\sigma_{\theta} = \sqrt{(Cov[9])}$

$\sigma_q/p = \sqrt{(Cov[14])}$