Pull distributions for the primary vertex and an update on Λ_c^+ reconstruction

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Primary Vertex Reconstruction

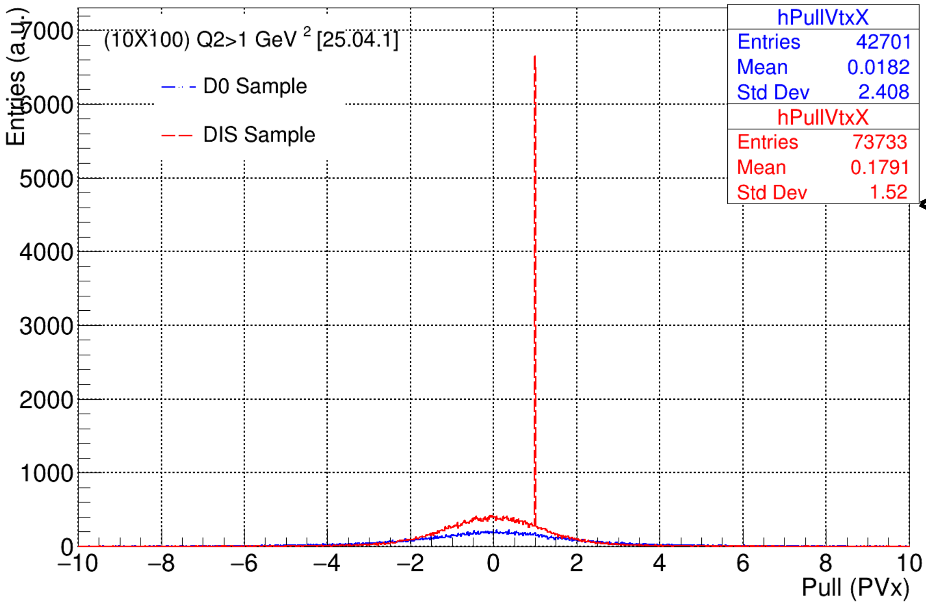
Pull distributions of Primary Vertex

Primary Vertex (PV) Reconstruction:

- **CentralTrackVertices (default)**
- AdaptiveMultiVertexFinder (**in development: Bishoy**)

$$\mathrm{Pull}(V_{x/y/z}) = \frac{V_{x/y/z}(\mathrm{Rec}) - V_{x/y/z}(\mathrm{Mc})}{\sigma_{x/y/z}}$$

ReconstructedChargedParticles≥ 1

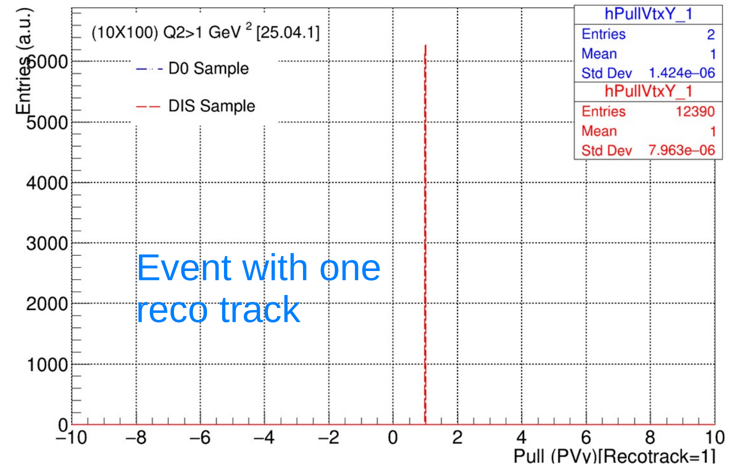


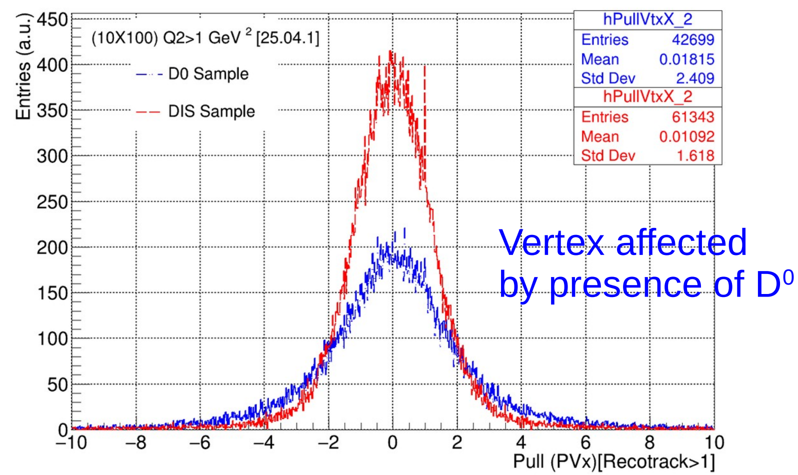
Reco track = 1

Reco track > 1

D⁰ Sample and DIS sample (25.04.1)

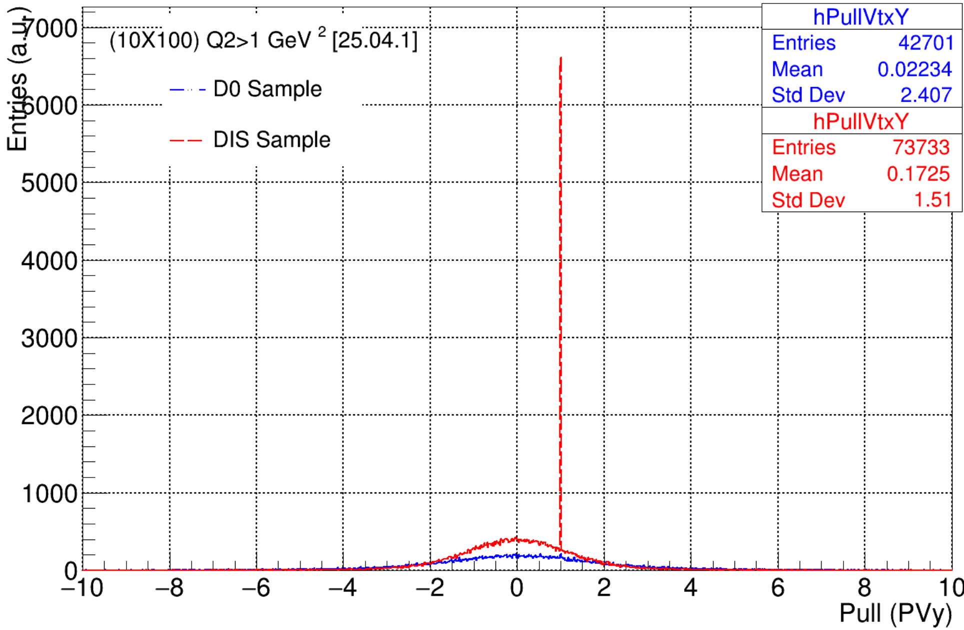
10X100 with $Q^2 > 1\ \mathrm{GeV}^2$ (Few files)



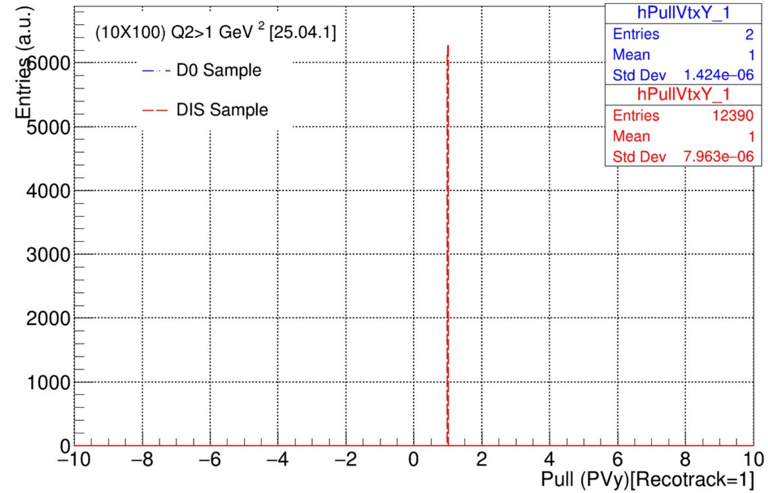


Pull distributions of Primary Vertex

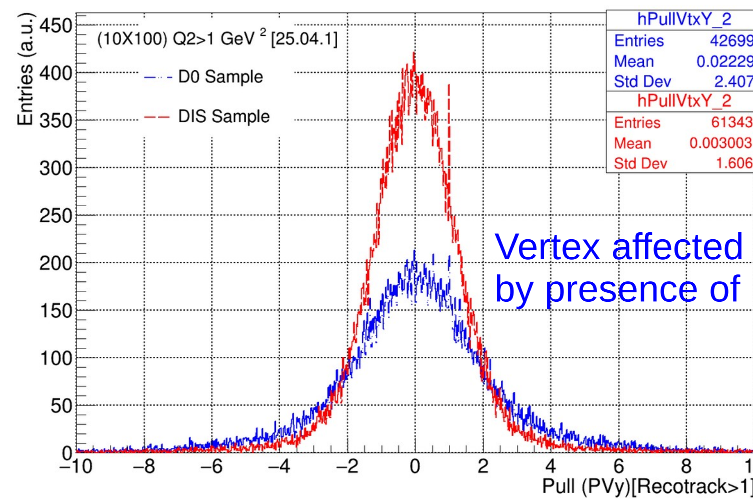
ReconstructedChargedParticles≥ 1



Reco track = 1



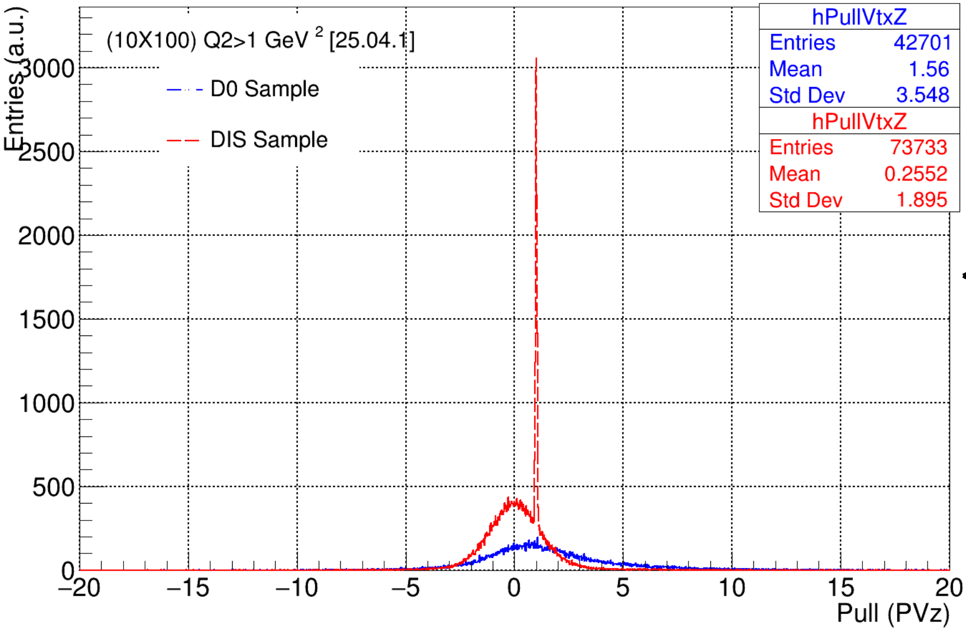
Reco track > 1



Vertex affected by presence of D^0

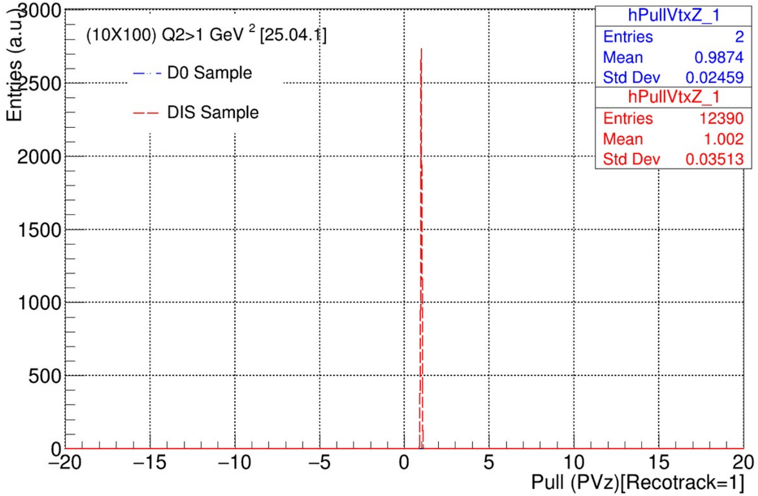
Pull distributions of Primary Vertex

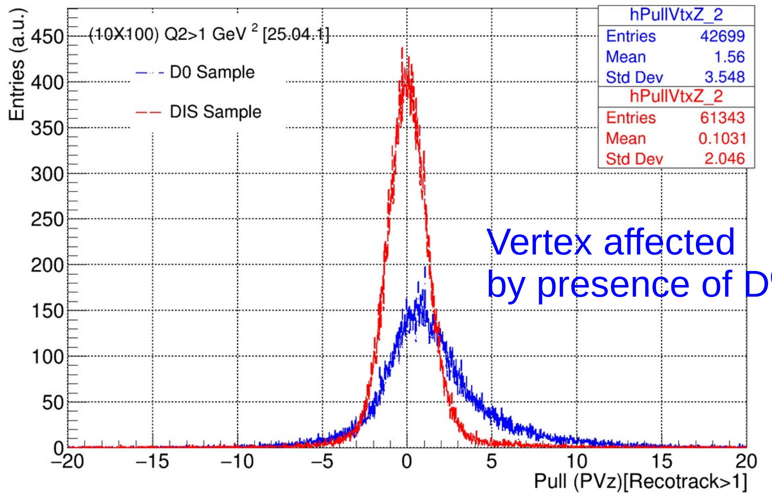
ReconstructedChargedParticles≥ 1



Reco track = 1

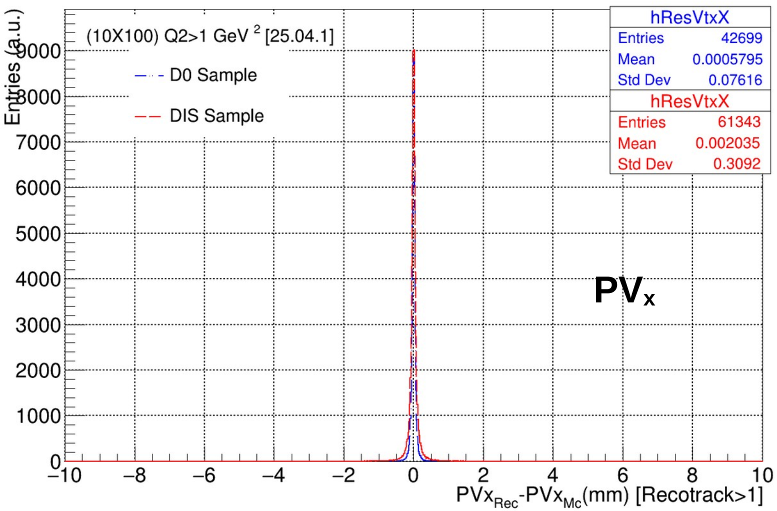
Reco track > 1

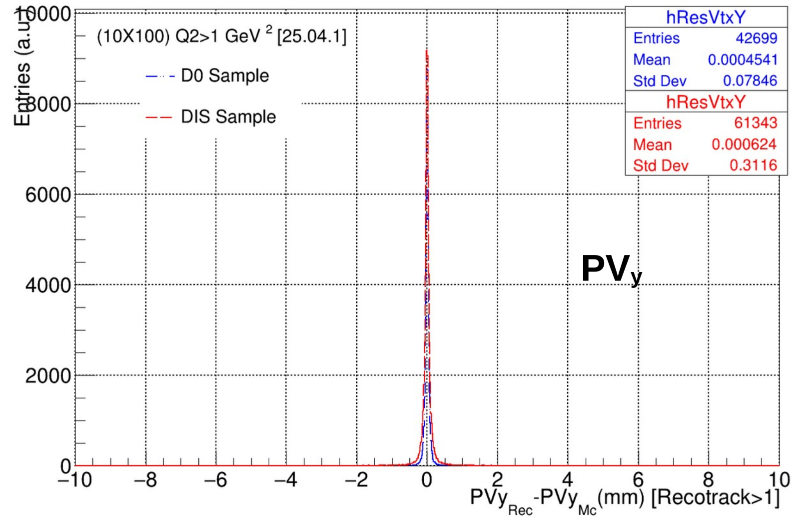


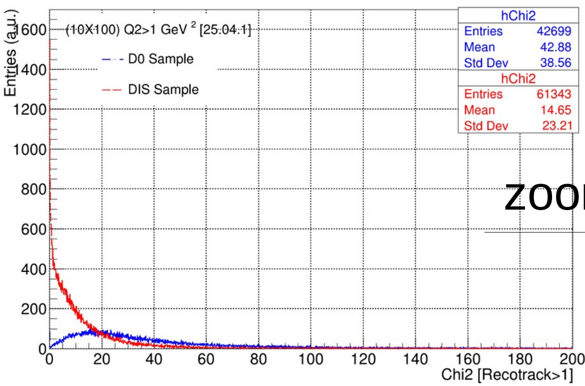


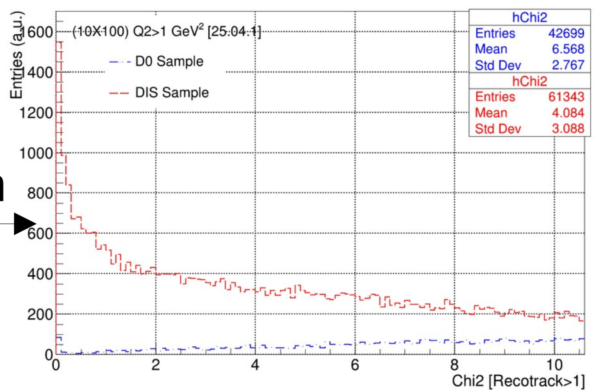
Vertex affected by presence of D^0

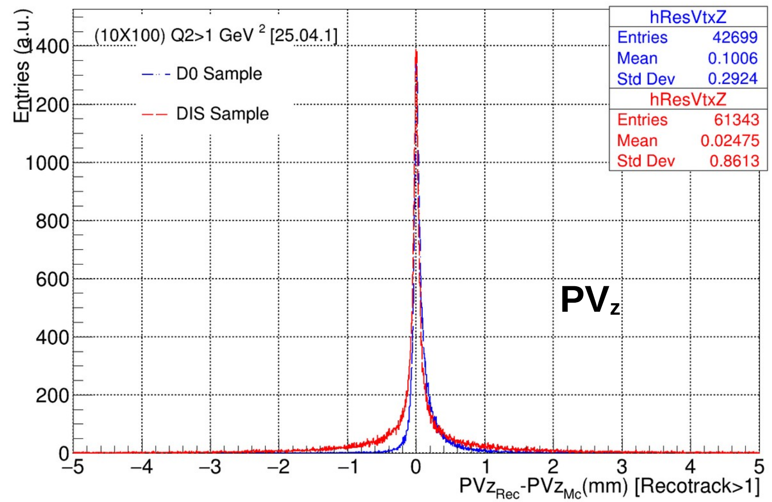
ReconstructedChargedParticles > 1 $\text{Resolution}(V_{x/y/z}) = V_{x/y/z}(\text{Rec}) - V_{x/y/z}(\text{Mc})\,\text{mm}$











Secondary Vertex Reconstruction

Secondary Vertex (Analytical approach)

$$\Lambda_c^+ \rightarrow p K^- \pi^+$$

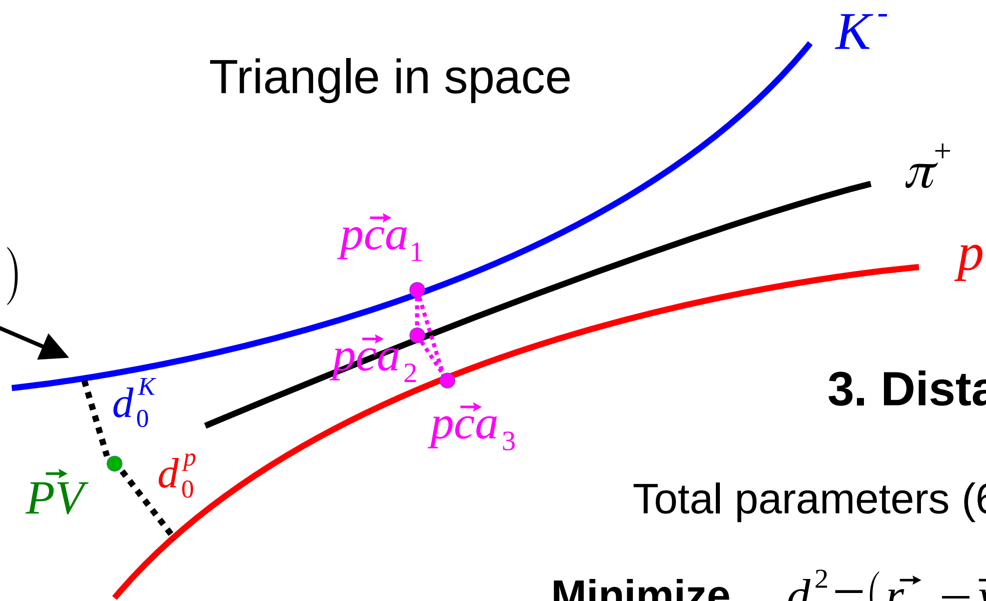
SV studies

My Slides

1. $\vec{SV} = \frac{\vec{pca}_1 + \vec{pca}_2 + \vec{pca}_3}{3}$

Triangle in space

$$\mathrm{Track}_{DCA} = (\vec{r}_0, \vec{p}_0, q)$$

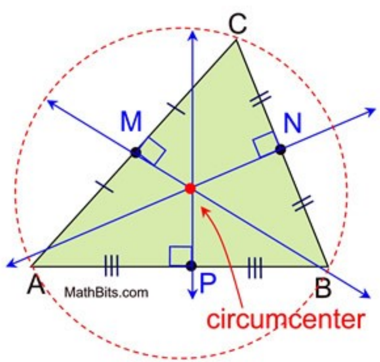


3. Distance2 Minimization

Total parameters (6) = (v_x, v_y, v_z, s_1, s_2, s_3)

Minimize $d^2 = (\vec{r}_{s1} - \vec{v})^2 + (\vec{r}_{s2} - \vec{v})^2 + (\vec{r}_{s3} - \vec{v})^2$

2. CircumCircle Center

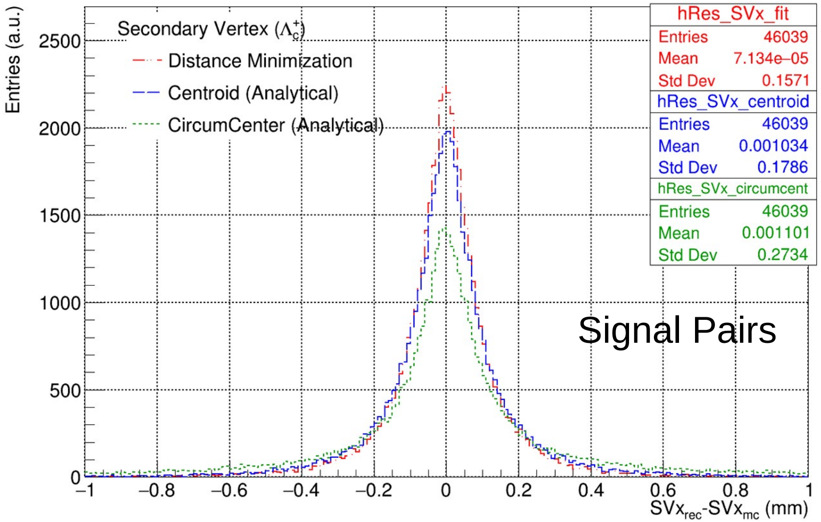


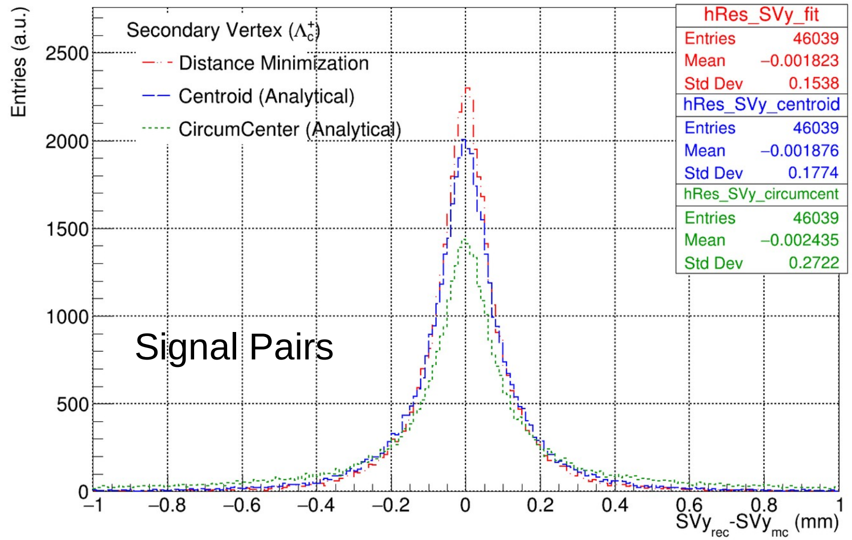
4. Chi2 Minimization

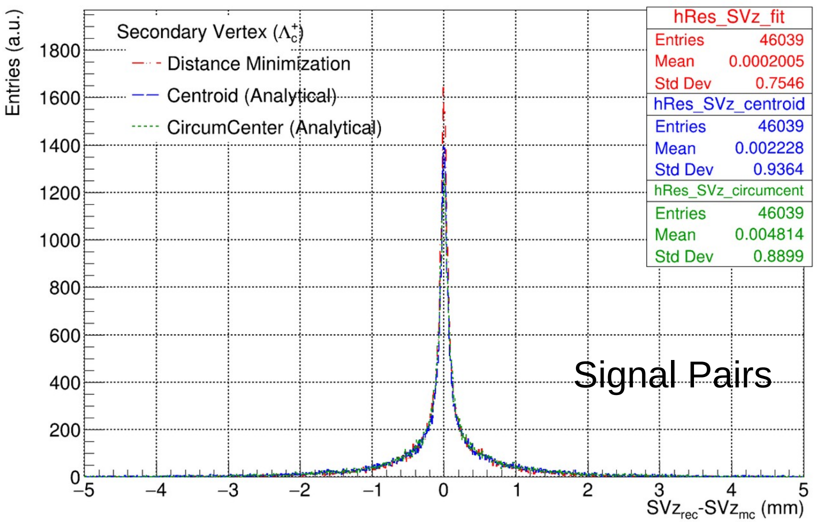
Note: Covariances are taken from DCA to primary vertex

Secondary Vertex (Λ_c)

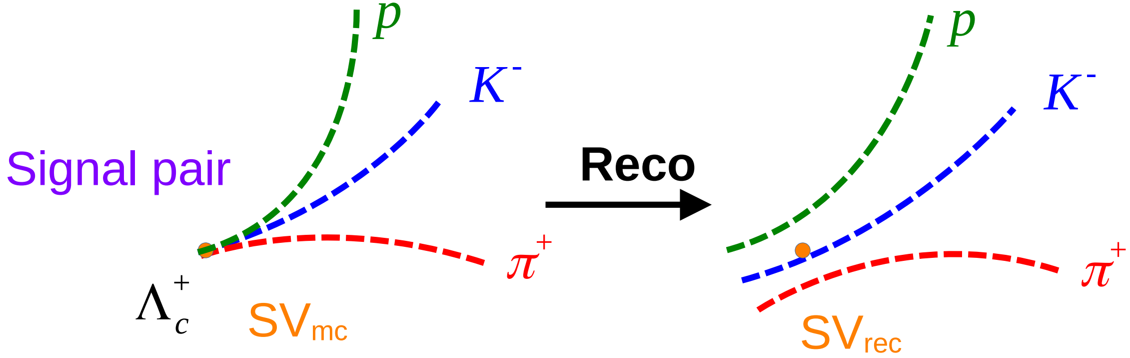
24.12.0







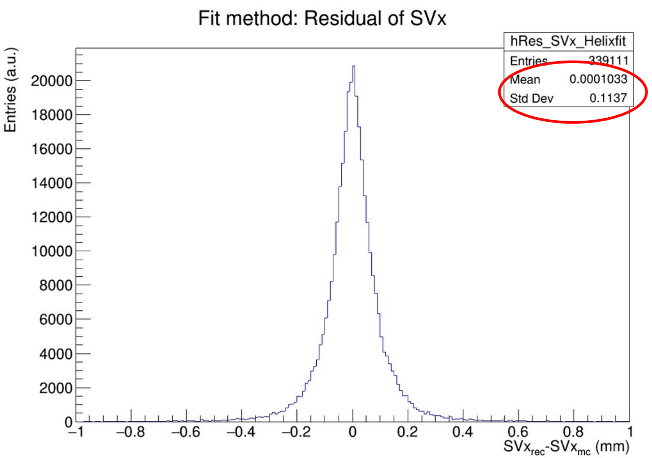
- **Distance minimization** is giving better results w.r.t. other two methods

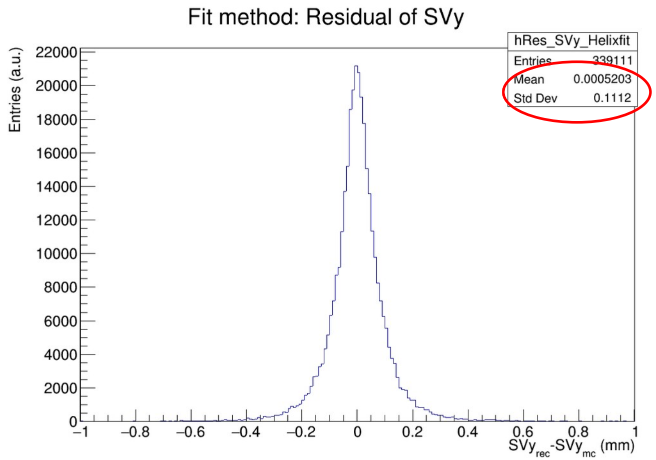


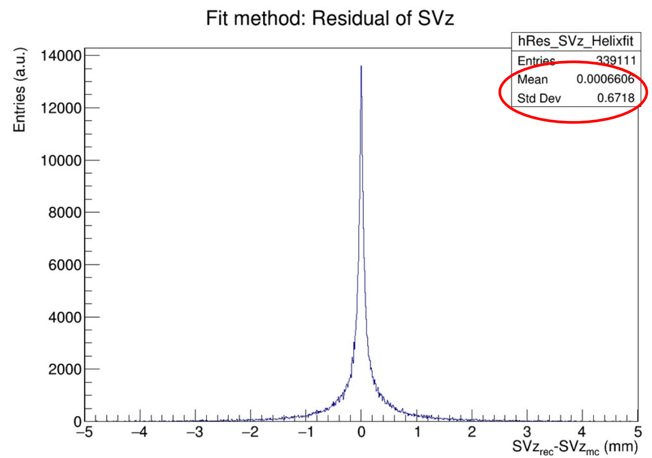
Chi2 minimization

Campaign: 25.07.0

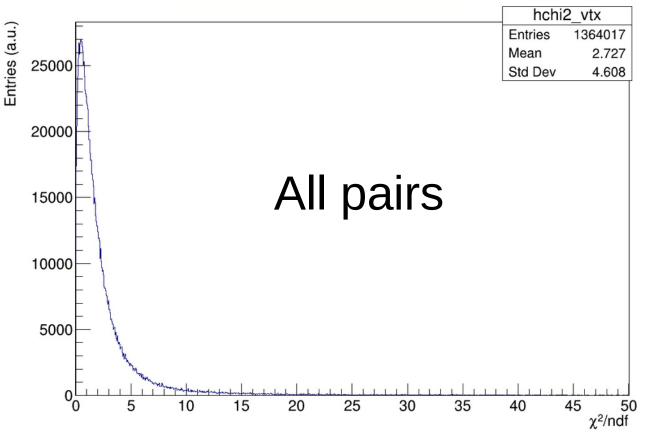
Method used for Λ_c Reconstruction

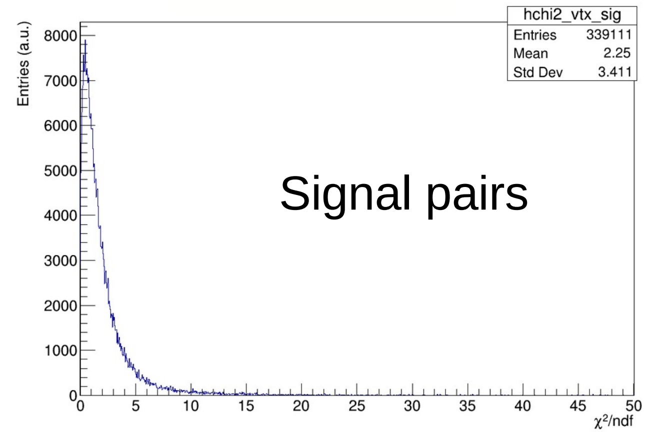


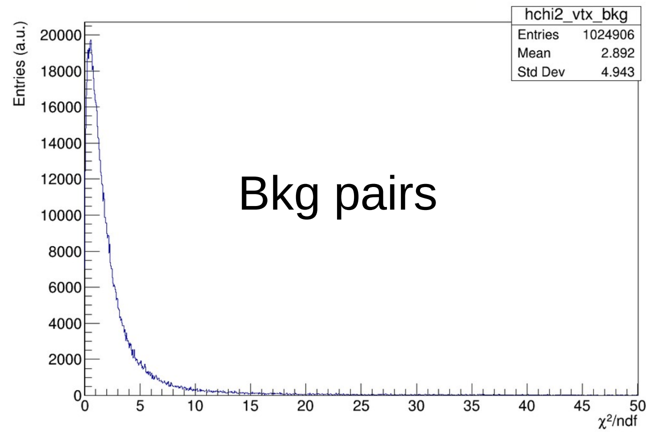




Secondary vertex resolution further improved w.r.t. distance minimization







D^0 meson Reconstruction

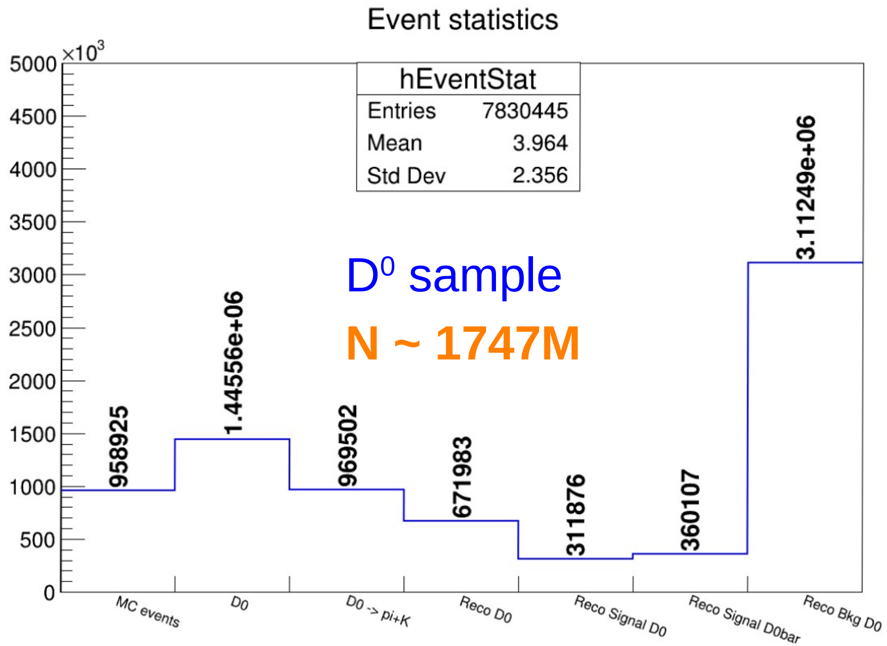
Event Statistics

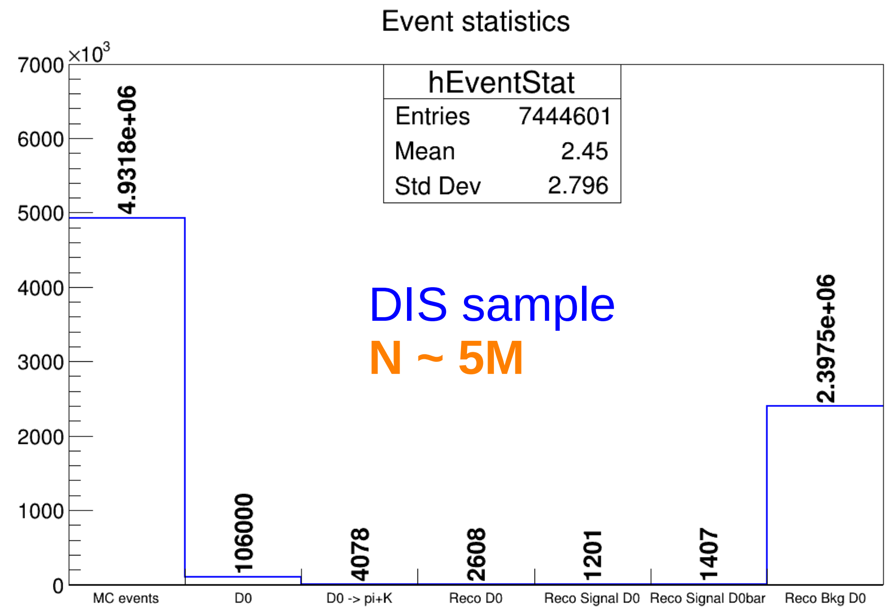
Campaign: 25.04.1

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

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

Real PID



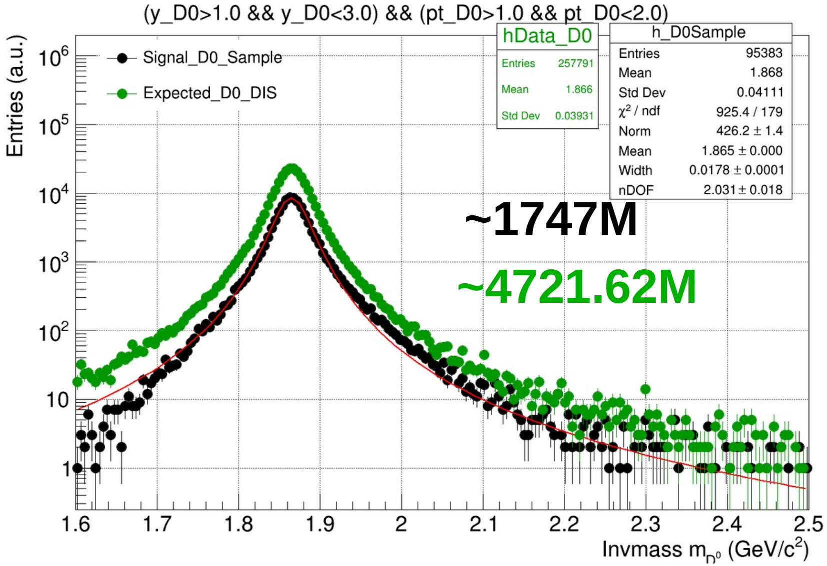


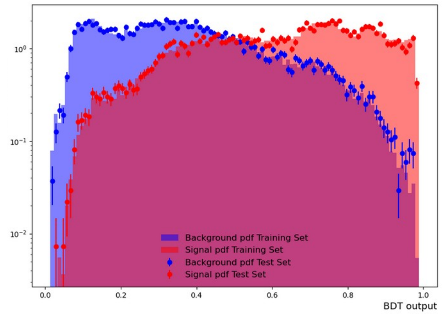
Topological selection for further studies

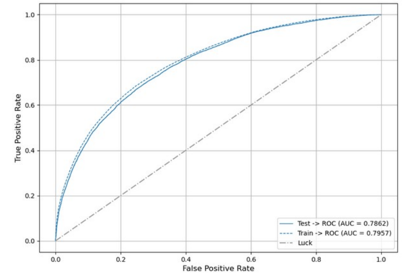
Dimensions are in mm

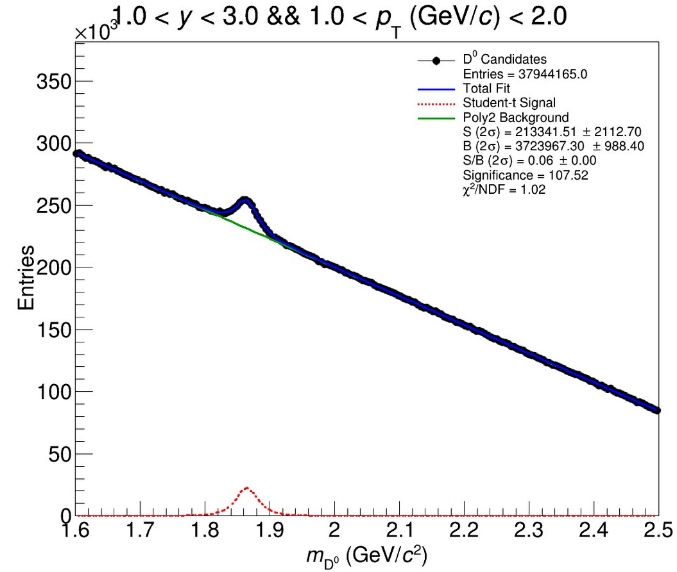
"(mass_D0 > 1.6 && mass_D0 < 2.5) && (d0xy_pi>0.02 && d0xy_pi<10.) && (d0xy_k>0.02 && d0xy_k<10.) && decay_length <100."

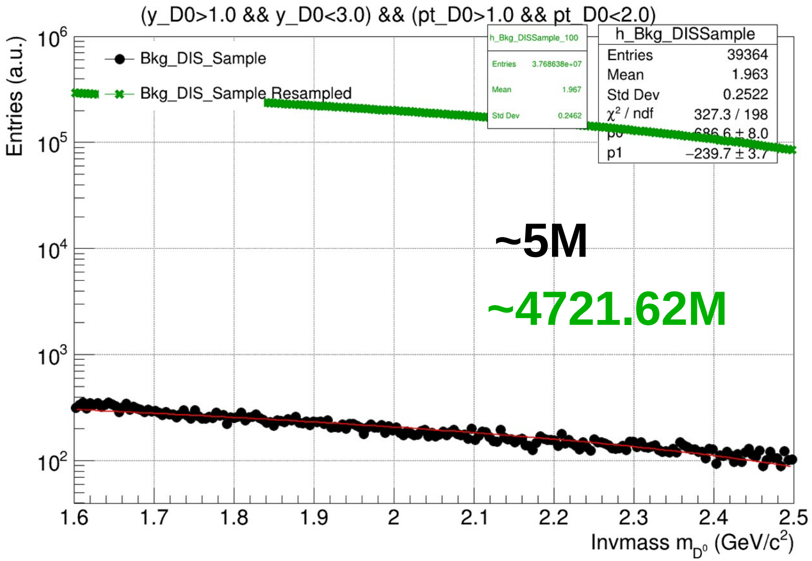
Sampling Signal and Background

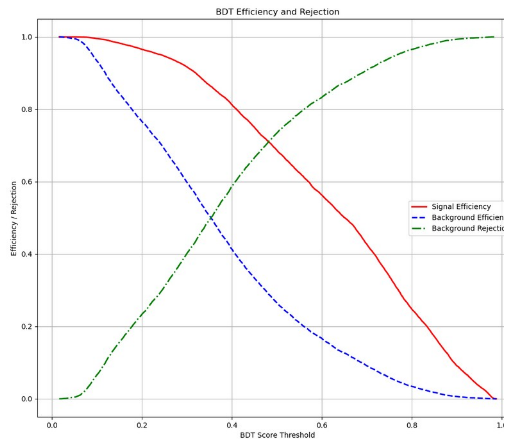


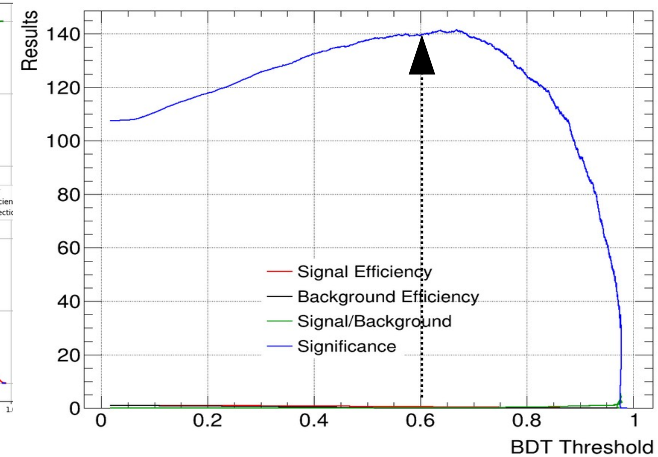




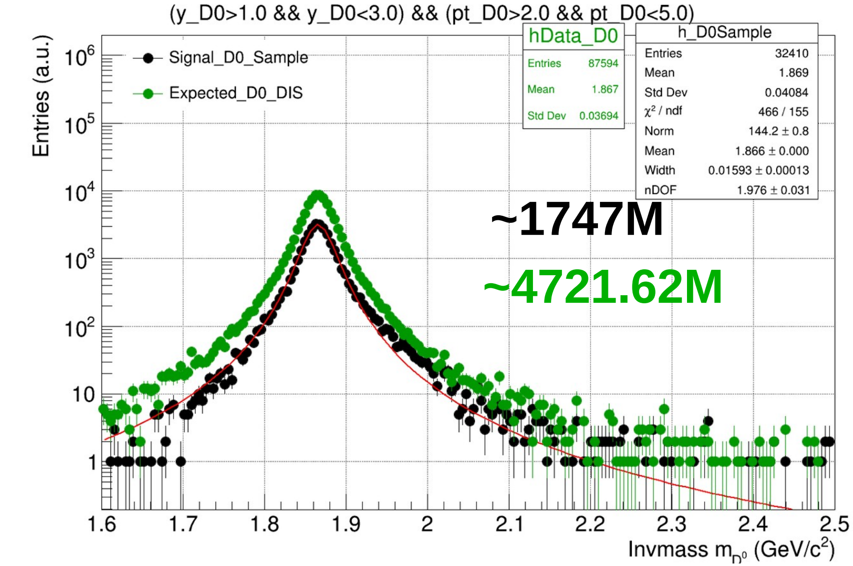


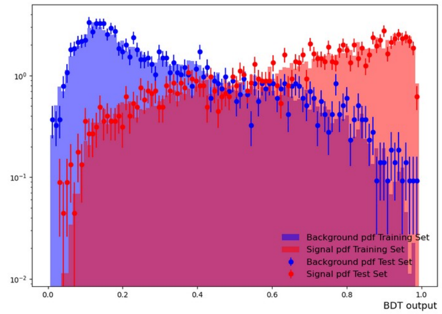


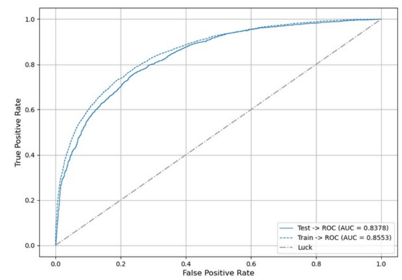


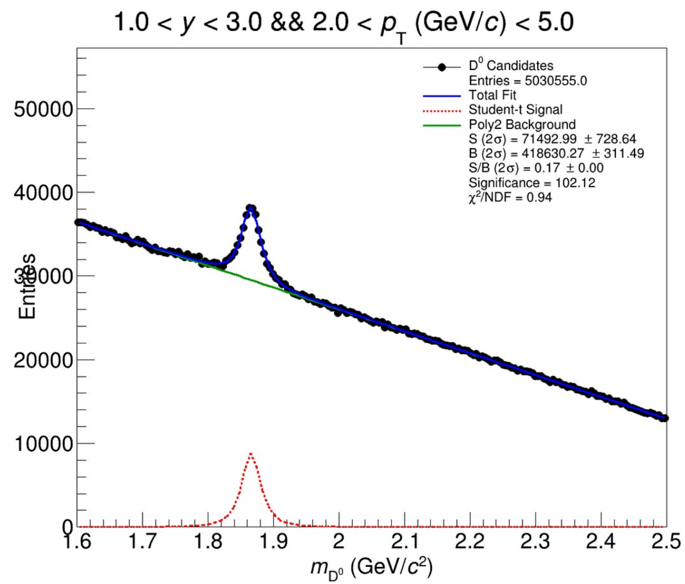


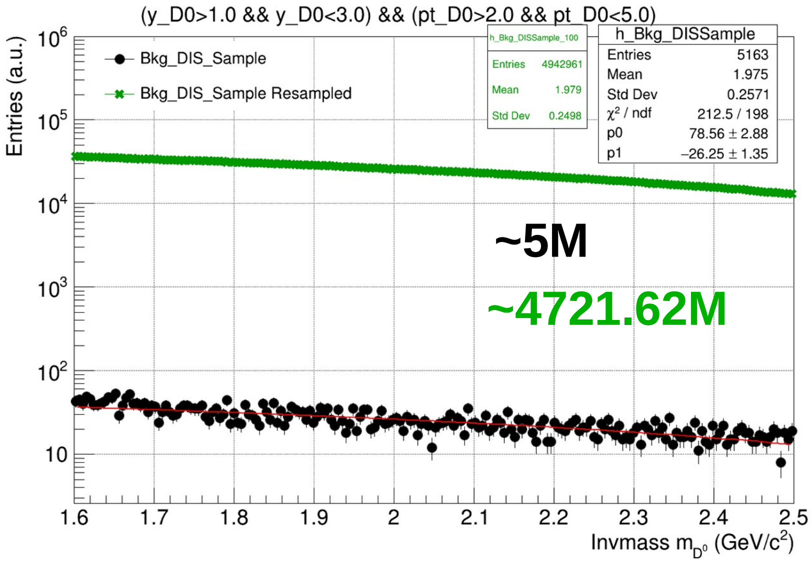
Sampling Signal and Background

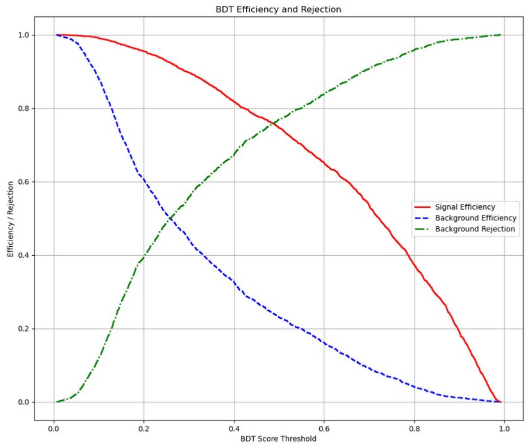


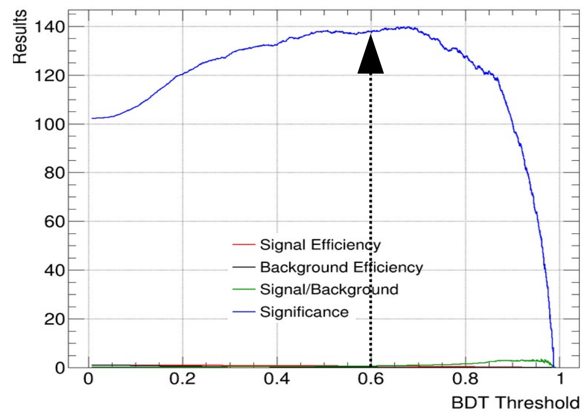




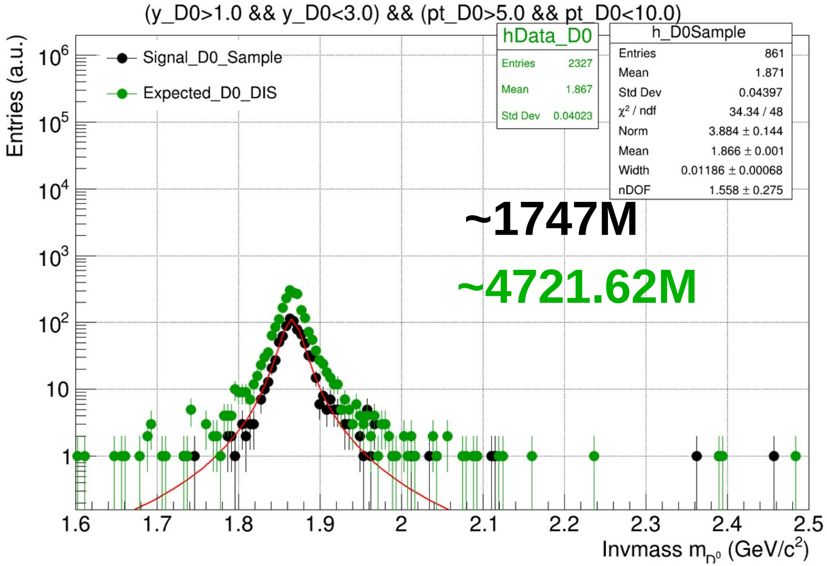


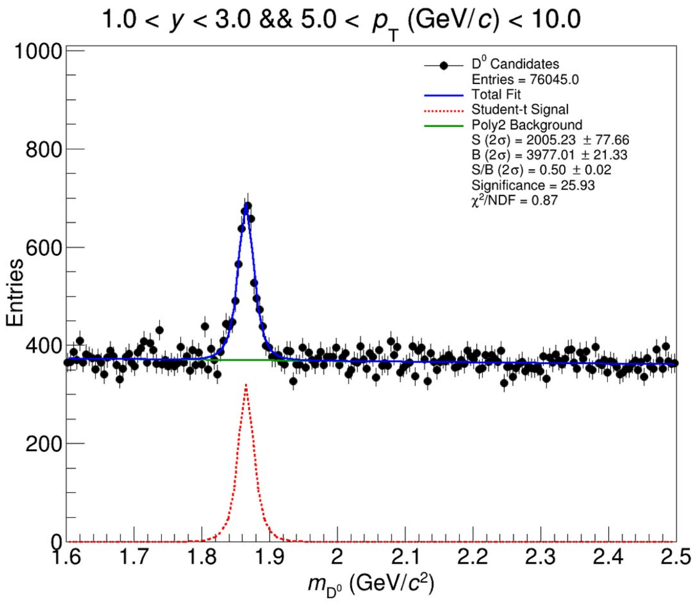


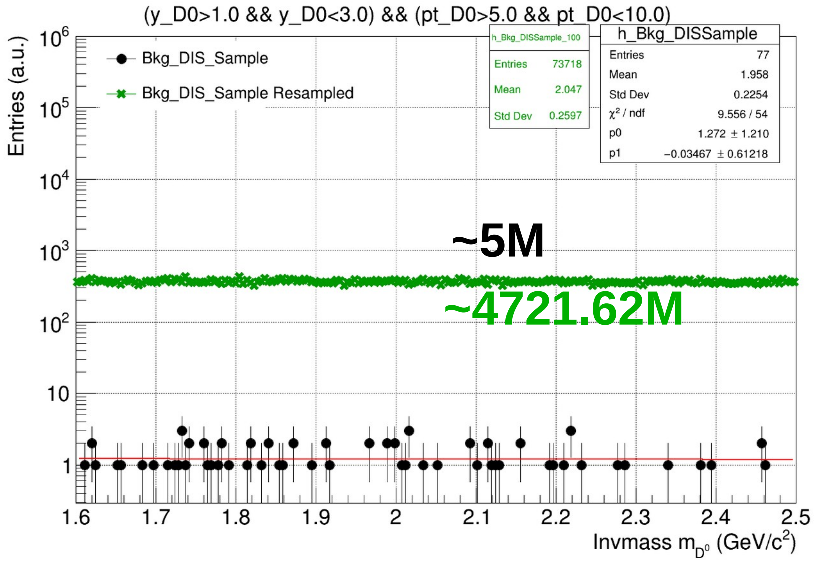




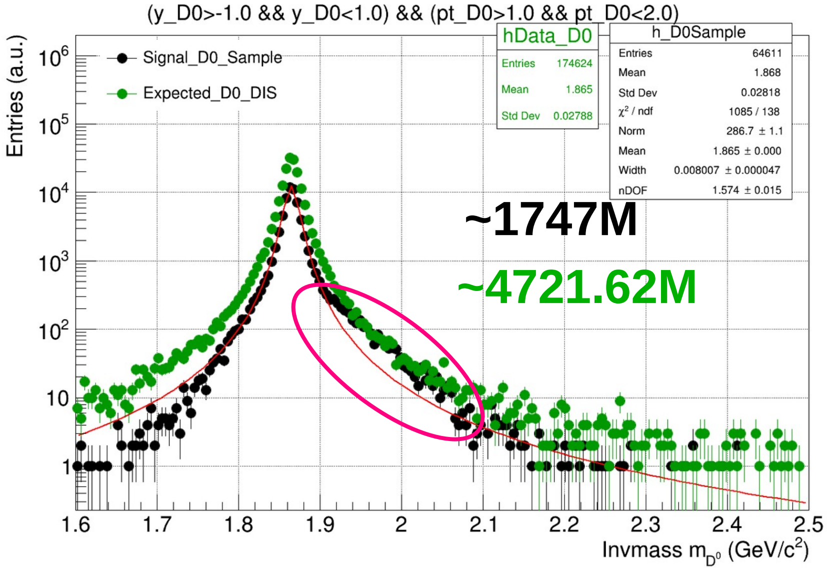
Sampling Signal and Background

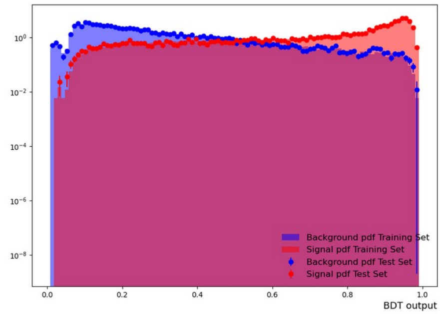


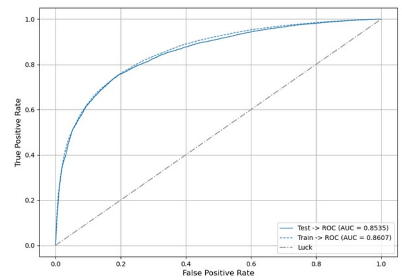


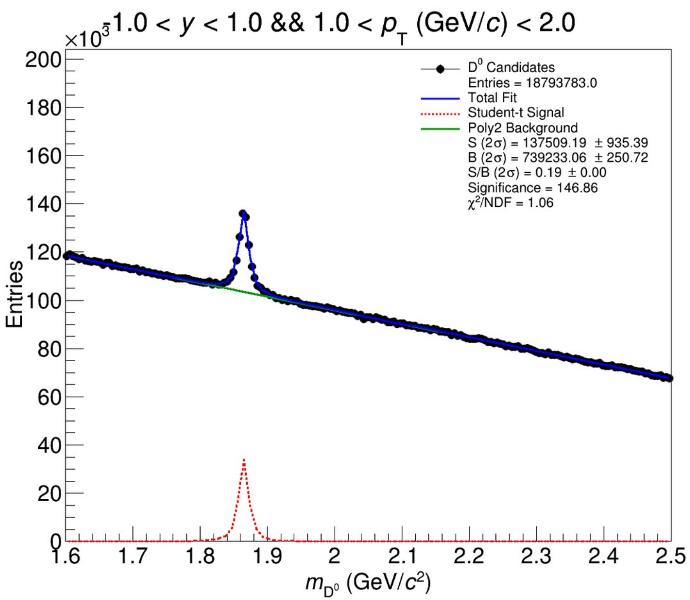


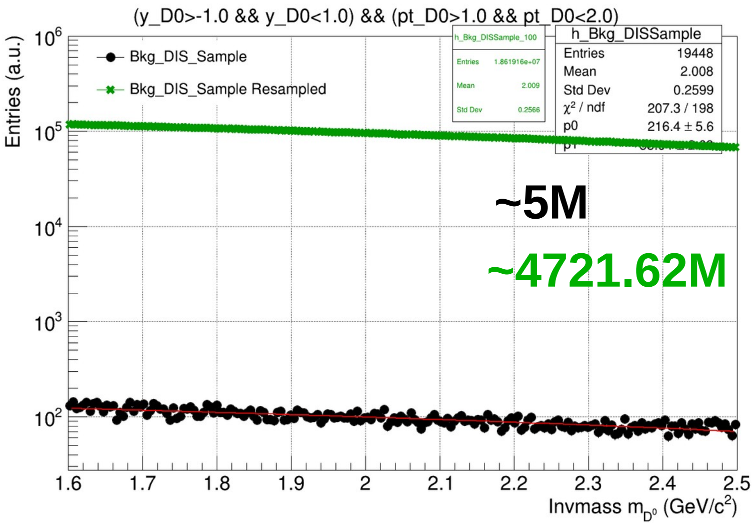
Sampling Signal and Background

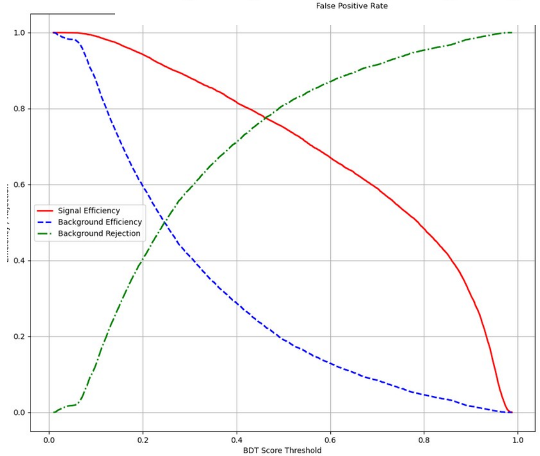


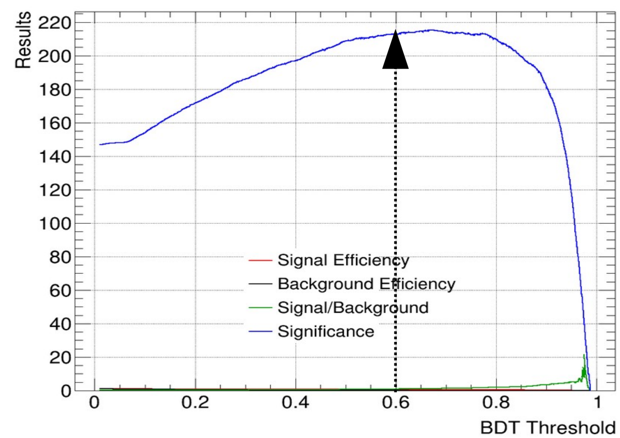












Checks: Truth PID, multi vertex events, mult dependence (done), Mother of D^0 meson (ongoing)

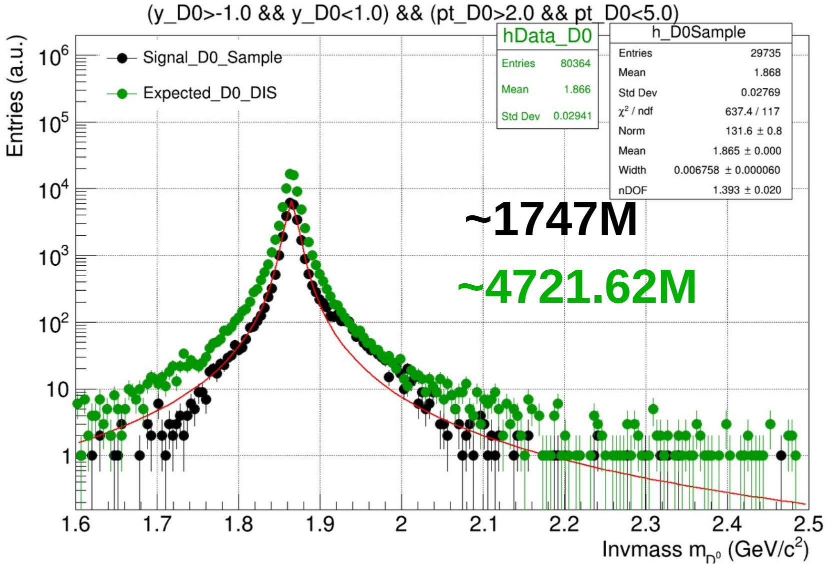
HF Hadrons in D0 Sample

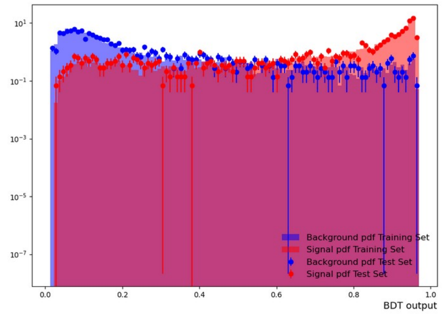
```
==============Event No = 0====================
---------Generated HF Hadrons list-------------
Particle PDG: 421.0        Particle Name = D0
Particle PDG: -413.0       Particle Name = D*-
Particle PDG: -421.0       Particle Name = D0_bar

==============Event No = 1====================
---------Generated HF Hadrons list-------------
Particle PDG: 423.0        Particle Name = D*0
Particle PDG: -4122.0      Particle Name = Lambda_c-
Particle PDG: 421.0        Particle Name = D0

==============Event No = 2====================
---------Generated HF Hadrons list-------------
Particle PDG: -423.0       Particle Name = D*0_bar
Particle PDG: 421.0        Particle Name = D0
Particle PDG: -421.0       Particle Name = D0_bar

==============Event No = 3====================
---------Generated HF Hadrons list-------------
Particle PDG: -421.0       Particle Name = D0_bar
Particle PDG: 421.0        Particle Name = D0

==============Event No = 4====================
---------Generated HF Hadrons list-------------
Particle PDG: 431.0        Particle Name = D_s+
Particle PDG: -413.0       Particle Name = D*-
Particle PDG: -421.0       Particle Name = D0_bar

==============Event No = 5====================
---------Generated HF Hadrons list-------------
Particle PDG: 4122.0       Particle Name = Lambda_c+
Particle PDG: -423.0       Particle Name = D*0_bar
Particle PDG: -421.0       Particle Name = D0_bar

==============Event No = 6====================
---------Generated HF Hadrons list-------------
Particle PDG: 423.0        Particle Name = D*0
Particle PDG: -421.0       Particle Name = D0_bar
Particle PDG: 421.0        Particle Name = D0
```

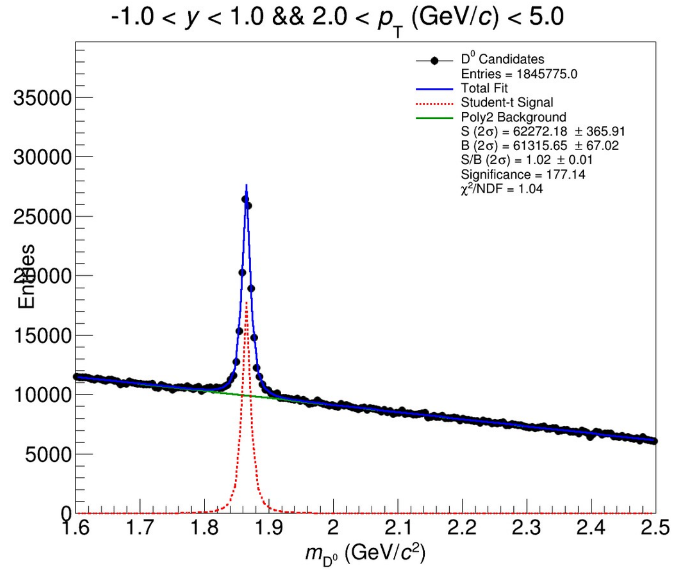
pythia8.306-1.1_D0_10x100_hiDiv_q2_1_run01.0000.eicrecon.edm4eic.root

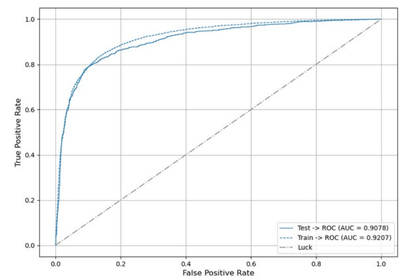
```
==============Event No = 7====================
---------Generated HF Hadrons list-------------
Particle PDG: 413.0        Particle Name = D*+
Particle PDG: 421.0        Particle Name = D0
Particle PDG: -421.0       Particle Name = D0_bar

==============Event No = 8====================
---------Generated HF Hadrons list-------------
Particle PDG: 423.0        Particle Name = D*0
Particle PDG: -413.0       Particle Name = D*-
Particle PDG: 421.0        Particle Name = D0
Particle PDG: -421.0       Particle Name = D0_bar

==============Event No = 9====================
---------Generated HF Hadrons list-------------
Particle PDG: 421.0        Particle Name = D0
Particle PDG: -411.0       Particle Name = D-

==============Event No = 10====================
---------Generated HF Hadrons list-------------
Particle PDG: 431.0        Particle Name = D_s+
Particle PDG: -421.0       Particle Name = D0_bar

==============Event No = 11====================
---------Generated HF Hadrons list-------------
Particle PDG: 421.0        Particle Name = D0
Particle PDG: -413.0       Particle Name = D*-
Particle PDG: -411.0       Particle Name = D-

==============Event No = 12====================
---------Generated HF Hadrons list-------------
Particle PDG: 421.0        Particle Name = D0
Particle PDG: -421.0       Particle Name = D0_bar

==============Event No = 13====================
---------Generated HF Hadrons list-------------
Particle PDG: 423.0        Particle Name = D*0
Particle PDG: 421.0        Particle Name = D0
Particle PDG: -413.0       Particle Name = D*-
Particle PDG: -421.0       Particle Name = D0_bar

==============Event No = 14====================
---------Generated HF Hadrons list-------------
Particle PDG: -411.0       Particle Name = D-
Particle PDG: 421.0        Particle Name = D0

==============Event No = 15====================
---------Generated HF Hadrons list-------------
Particle PDG: 4122.0       Particle Name = Lambda_c+
Particle PDG: -423.0       Particle Name = D*0_bar
Particle PDG: -421.0       Particle Name = D0_bar

==============Event No = 16====================
---------Generated HF Hadrons list-------------
Particle PDG: 423.0        Particle Name = D*0
Particle PDG: -423.0       Particle Name = D*0_bar
Particle PDG: 421.0        Particle Name = D0
Particle PDG: -421.0       Particle Name = D0_bar

==============Event No = 17====================
---------Generated HF Hadrons list-------------
Particle PDG: 433.0        Particle Name = D*_s+
Particle PDG: -423.0       Particle Name = D*0_bar
Particle PDG: 431.0        Particle Name = D_s+
Particle PDG: -421.0       Particle Name = D0_bar

==============Event No = 18====================
---------Generated HF Hadrons list-------------
Particle PDG: -421.0       Particle Name = D0_bar
Particle PDG: 413.0        Particle Name = D*+
Particle PDG: 421.0        Particle Name = D0

==============Event No = 19====================
---------Generated HF Hadrons list-------------
Particle PDG: 423.0        Particle Name = D*0
Particle PDG: -413.0       Particle Name = D*-
Particle PDG: 421.0        Particle Name = D0
Particle PDG: -421.0       Particle Name = D0_bar

==============Event No = 20====================
---------Generated HF Hadrons list-------------
Particle PDG: 411.0        Particle Name = D+
Particle PDG: -421.0       Particle Name = D0_bar
```

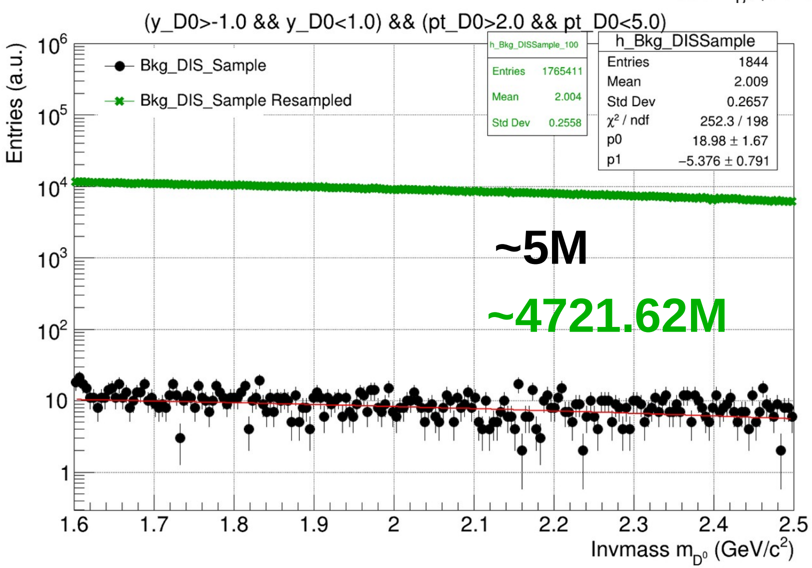
Sampling Signal and Background

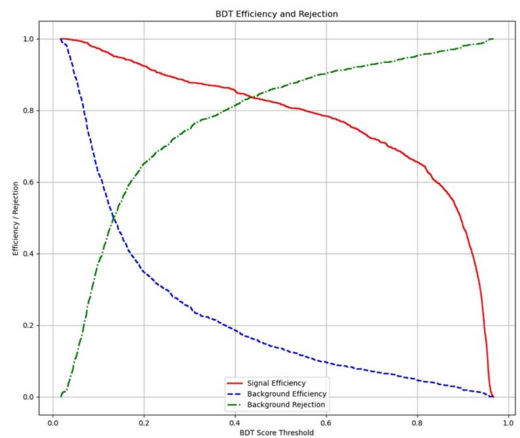


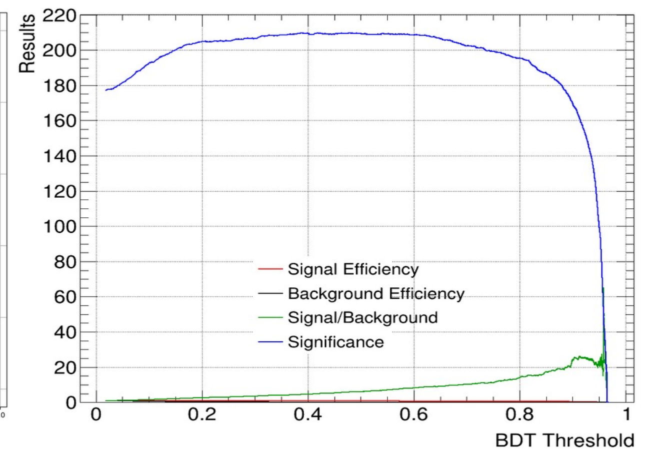




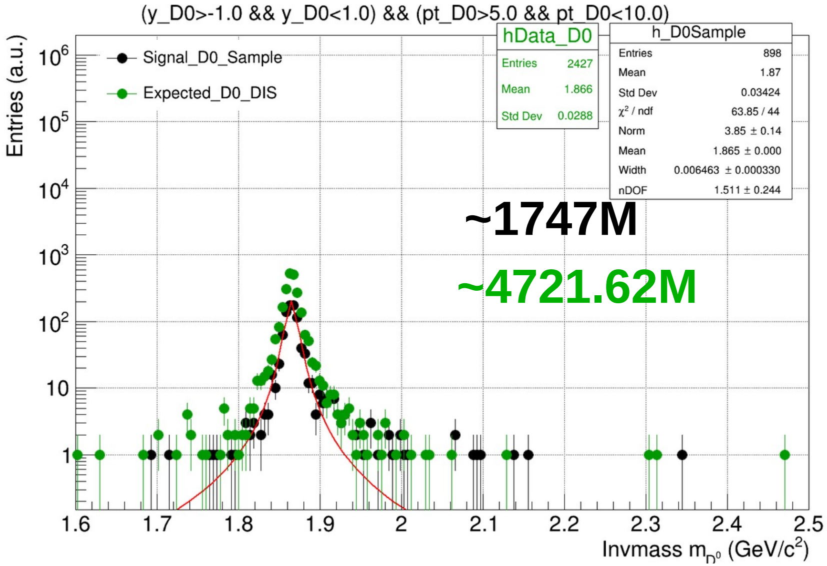


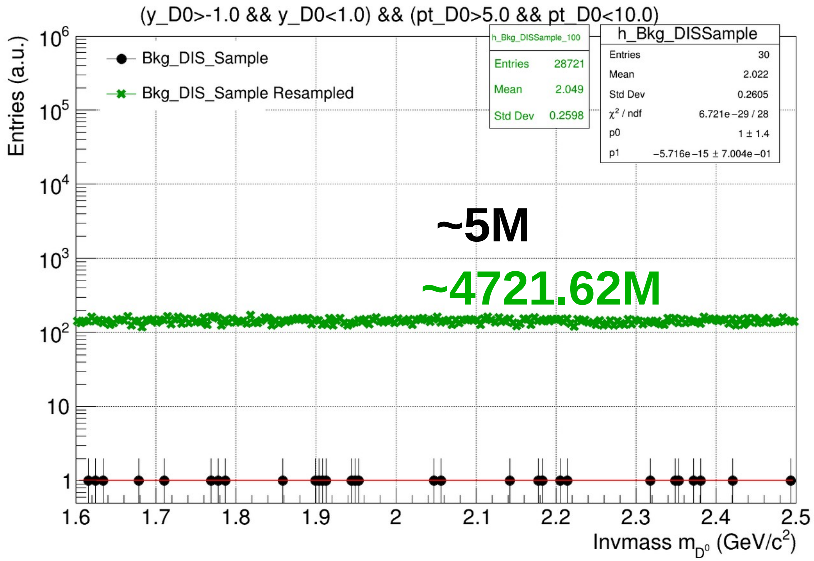


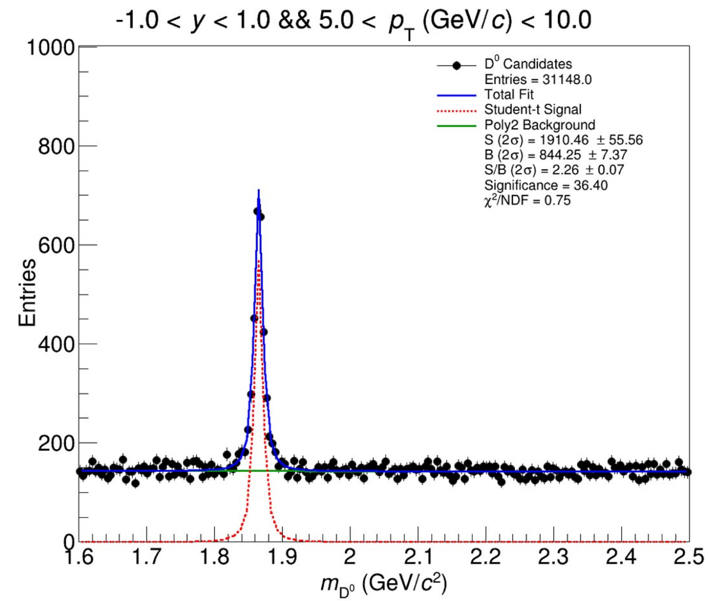




Sampling Signal and Background







Λ_c baryon Reconstruction

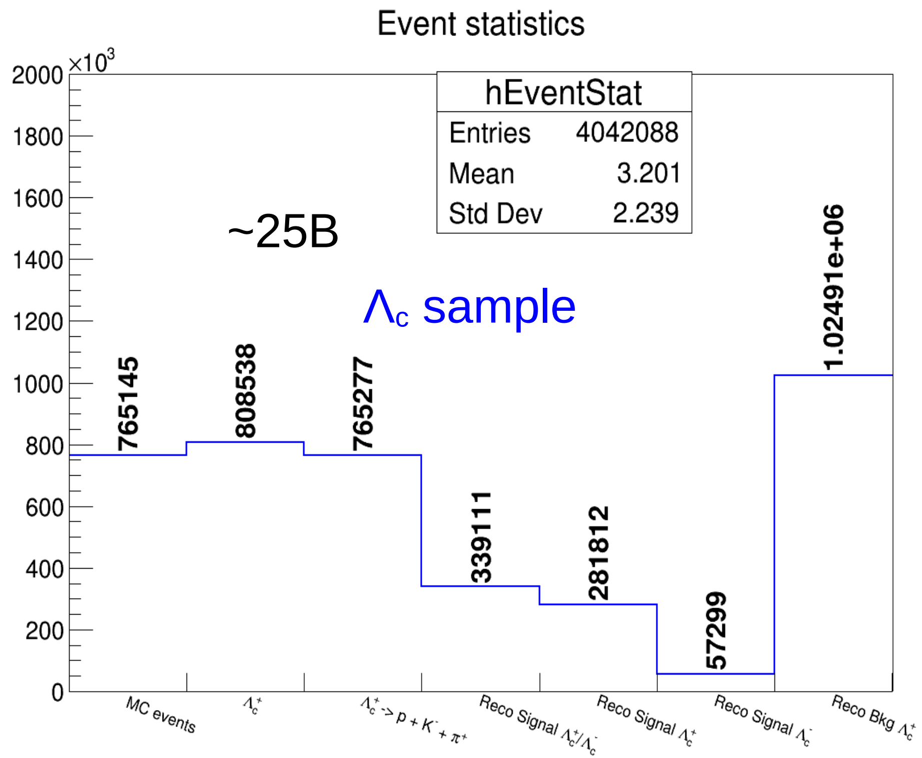
Particle	Mass (GeV/c^2)	cτ (µm)
$D^{\pm}$	1.869	312
D^0	1.864	123
$B^{\pm}$	5.279	491
B^0	5.280	456
Λ_c^+	2.286	60

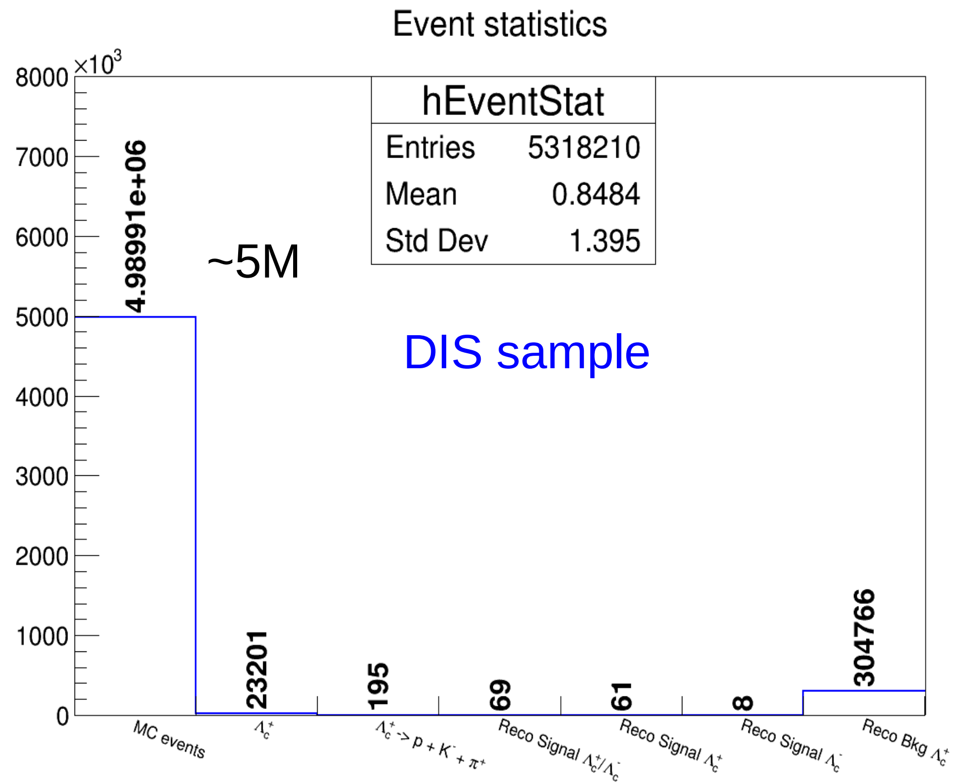
Campaign: 25.07.0 Data Sample: ep collision 10 X 100 with $Q^2 > 1\ GeV^2$

$$N_{events}\left(10\ fb^{-1}\right) = 10\times10^3\ pb^{-1}\times4.527\times10^5\ pb$$

$$N_{events}\left(10\ fb^{-1}\right) = 4.527\ B$$

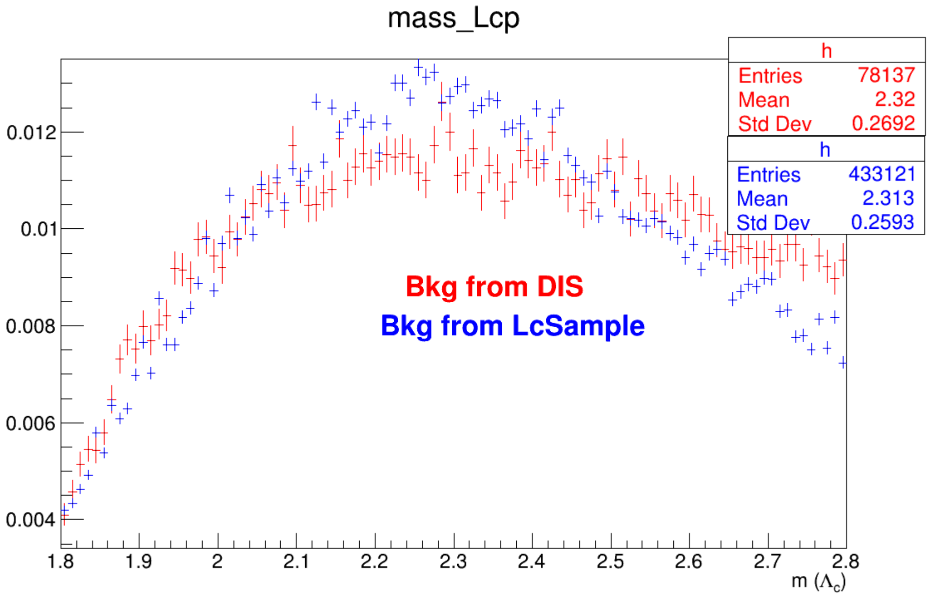
Truth PID



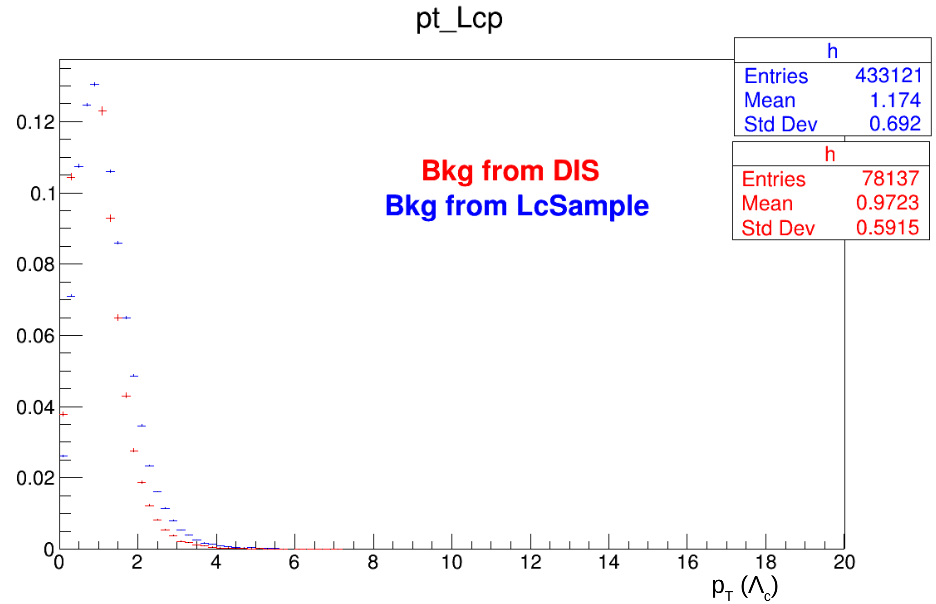


Background distributions

Mass distribution

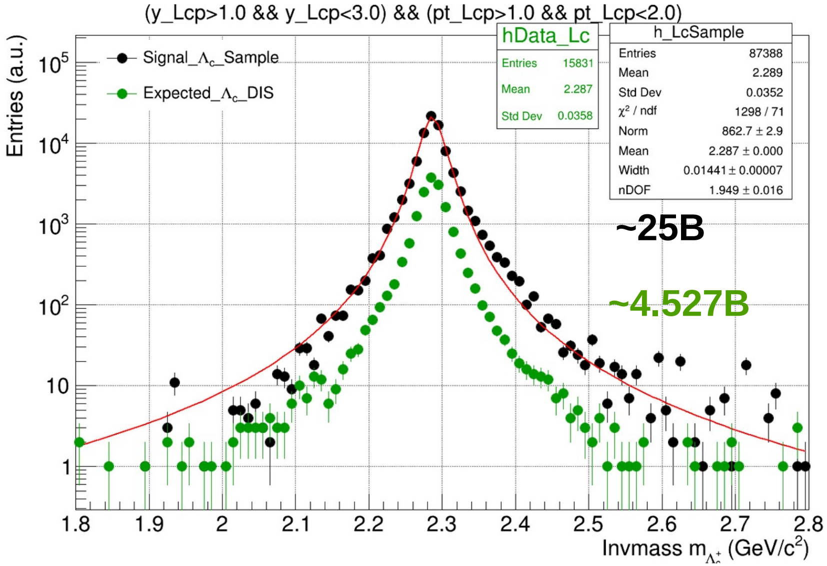


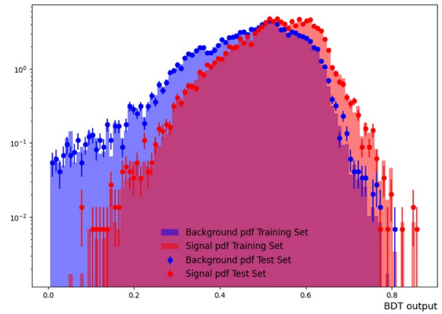
Momentum distribution

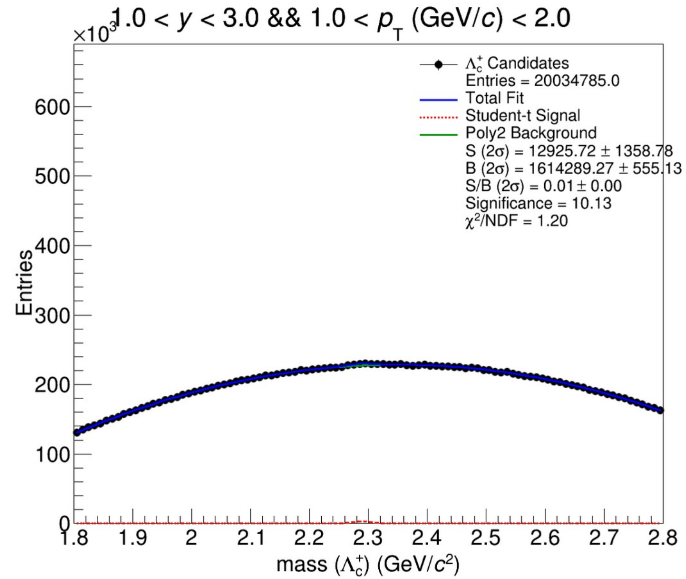


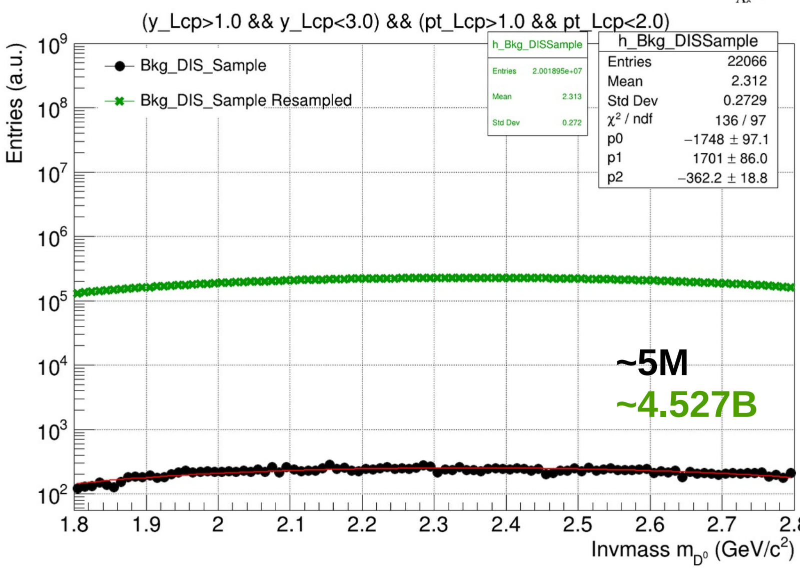
Merged the two background for ML

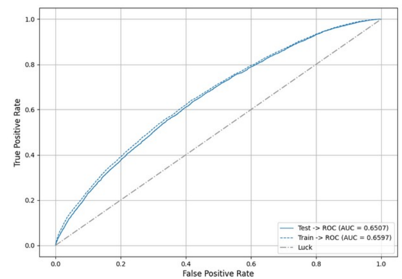
Sampling Signal and Background

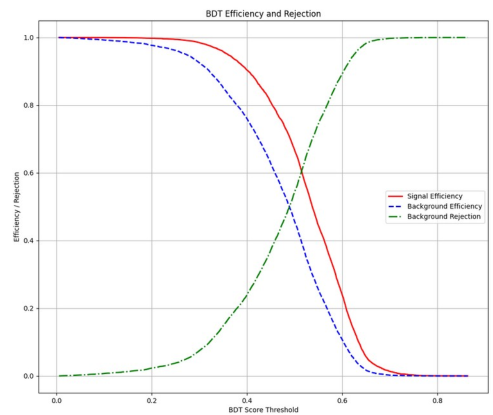




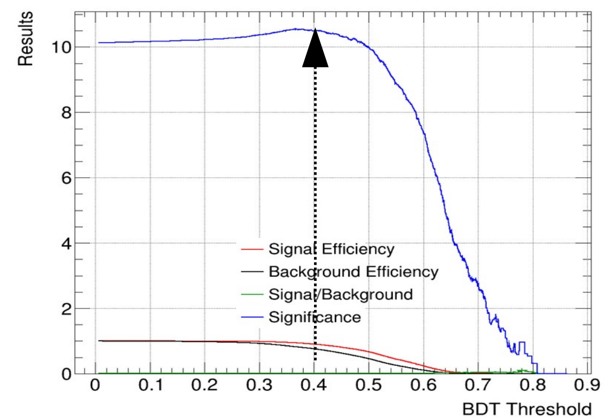




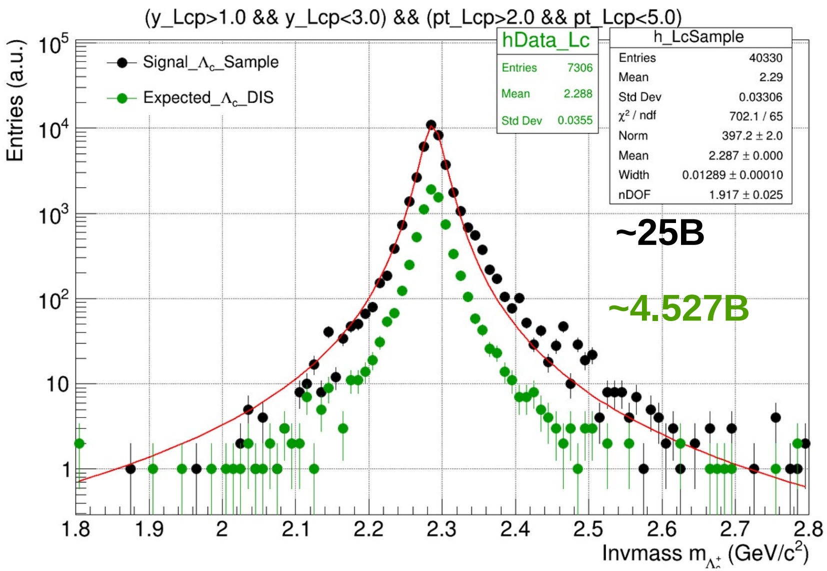


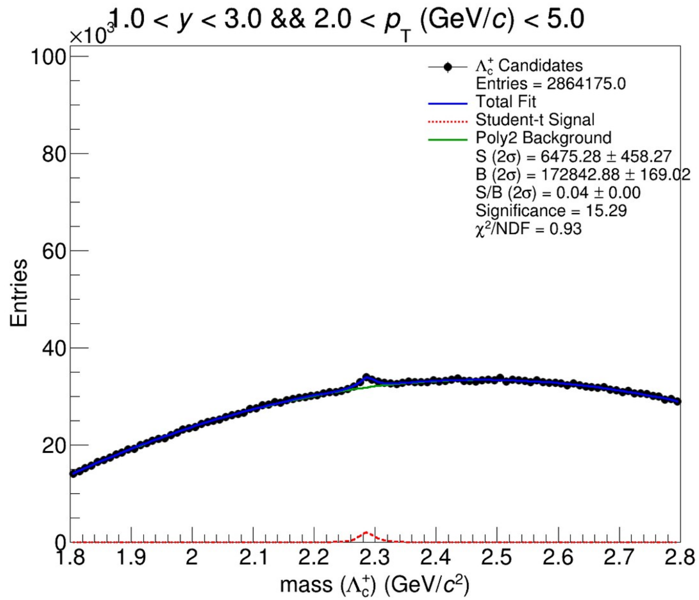


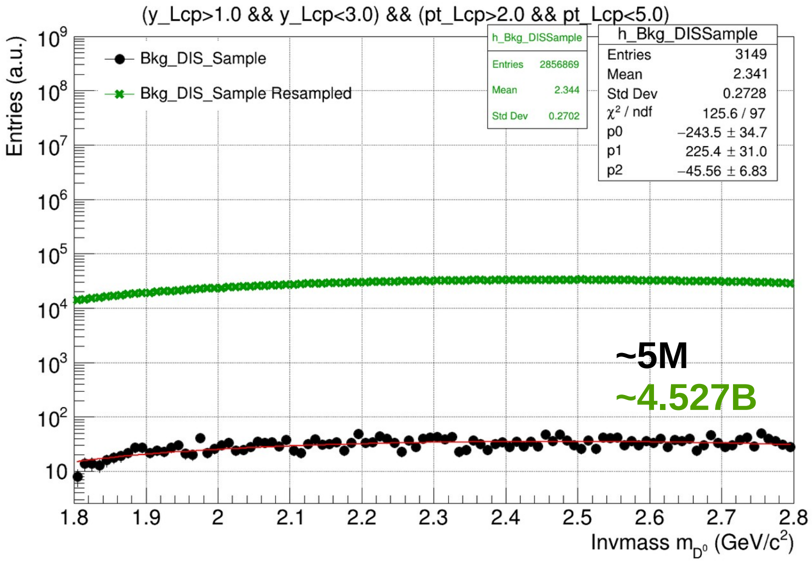
For future use: $S(d0_T) = \dfrac{d0_T}{\sigma(d0_T)}$



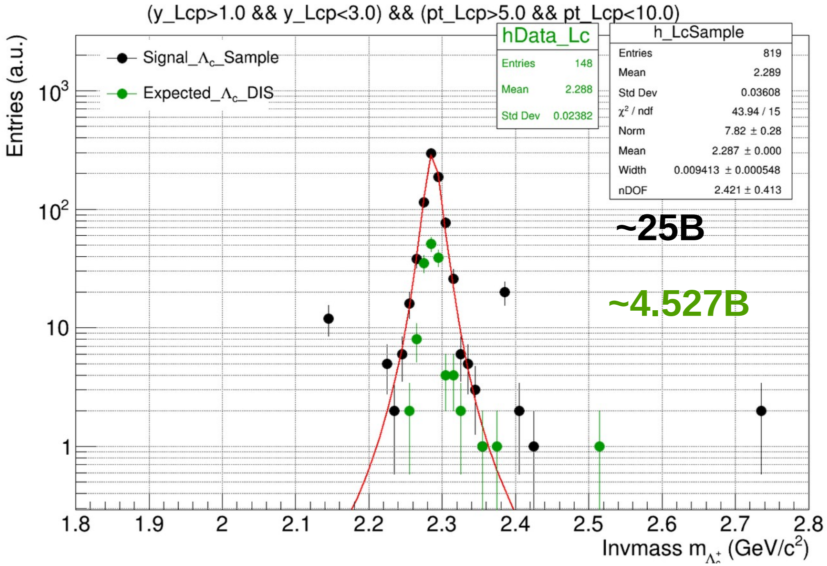
Sampling Signal and Background

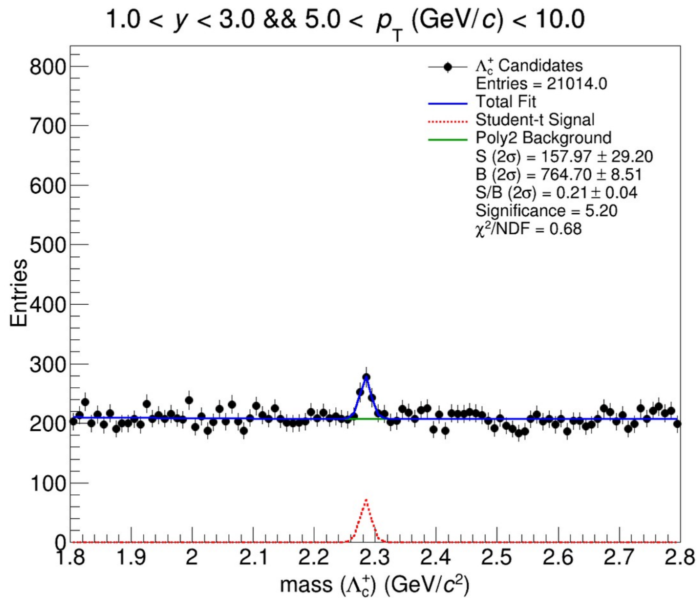


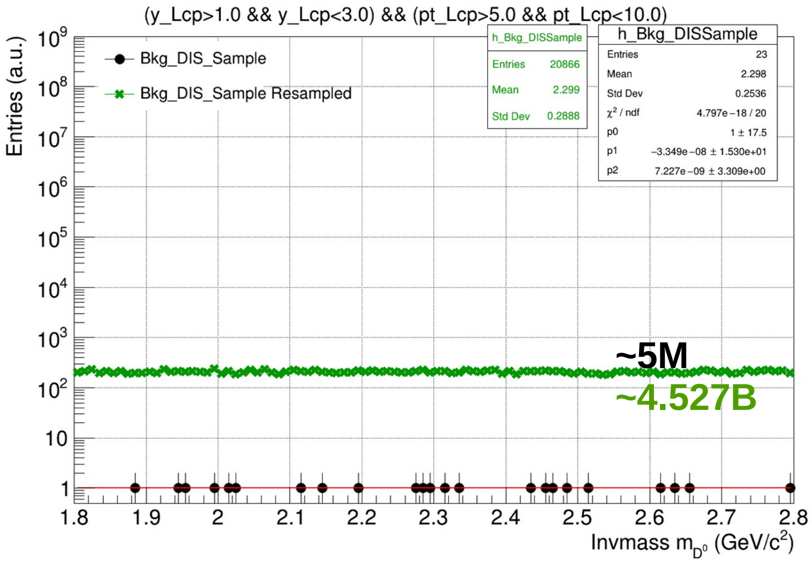


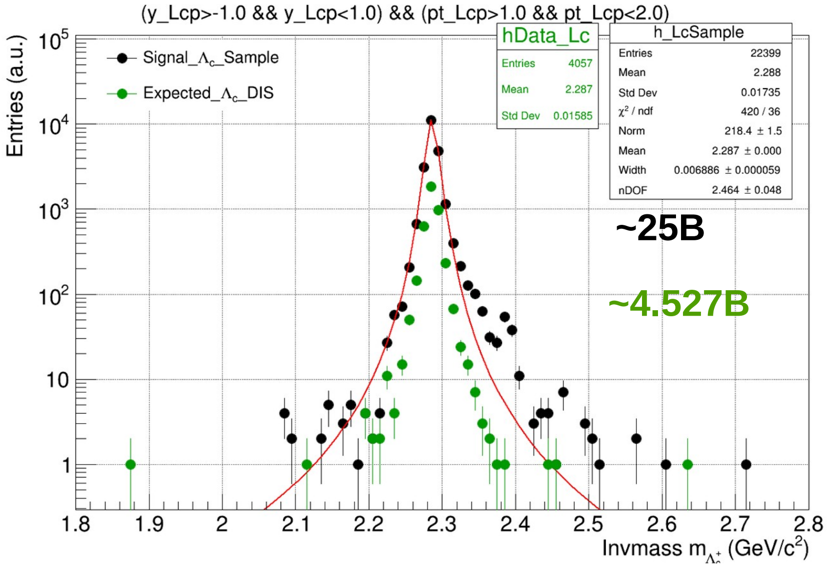


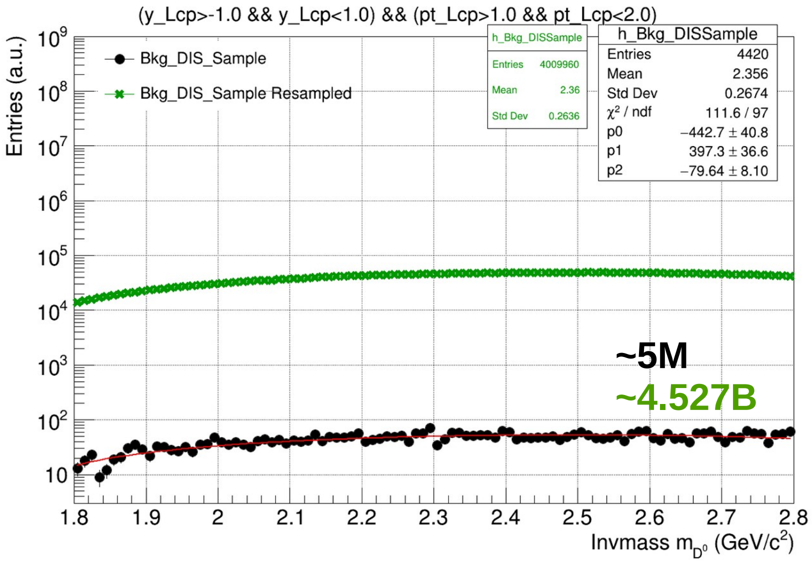
Sampling Signal and Background

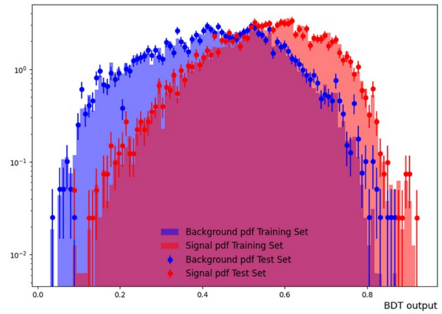


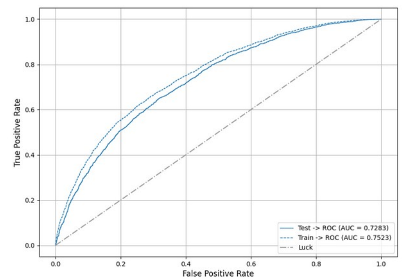


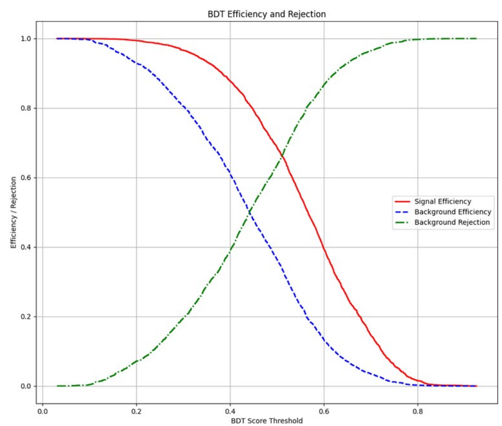


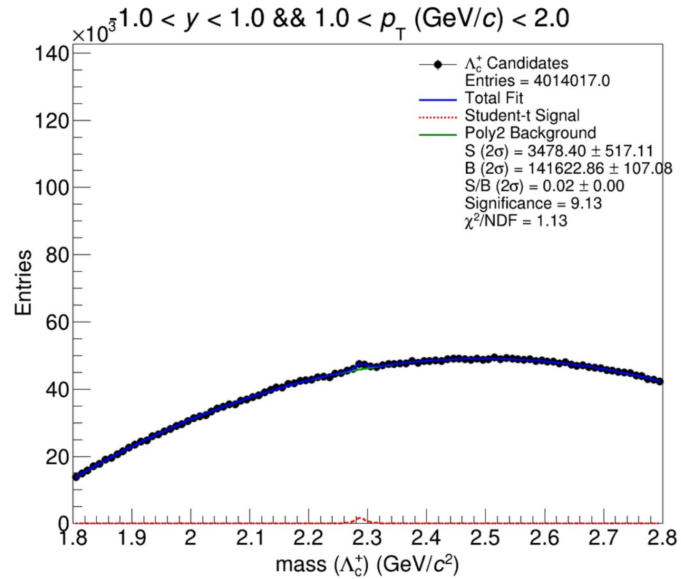

(y_Lcp>-1.0 && y_Lcp<1.0) && (pt_Lcp>1.0 && pt_Lcp<2.0)
Signal_Λc_Sample
Expected_Λc_DIS
hData_Lc
Entries 4057
Mean 2.287
Std Dev 0.01585
h_LcSample
Entries 22399
Mean 2.288
Std Dev 0.01735
χ² / ndf 420 / 36
Norm 218.4 ± 1.5
Mean 2.287 ± 0.000
Width 0.006886 ± 0.000059
nDOF 2.464 ± 0.048
~25B
~4.527B
Entries (a.u.)
Invmass m_Λc+ (GeV/c²)

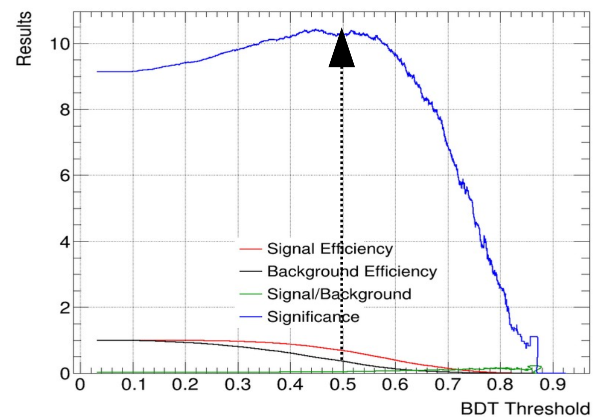

(y_Lcp>-1.0 && y_Lcp<1.0) && (pt_Lcp>1.0 && pt_Lcp<2.0)
Bkg_DIS_Sample
Bkg_DIS_Sample Resampled
h_Bkg_DISSample
Entries 4009960
Mean 2.36
Std Dev 0.2636
h_Bkg_DISSample
Entries 4420
Mean 2.356
Std Dev 0.2674
χ² / ndf 111.6 / 97
p0 −442.7 ± 40.8
p1 397.3 ± 36.6
p2 −79.64 ± 8.10
~5M
~4.527B
Entries (a.u.)
Invmass m_D0 (GeV/c²)


Background pdf Training Set
Signal pdf Training Set
Background pdf Test Set
Signal pdf Test Set
BDT output

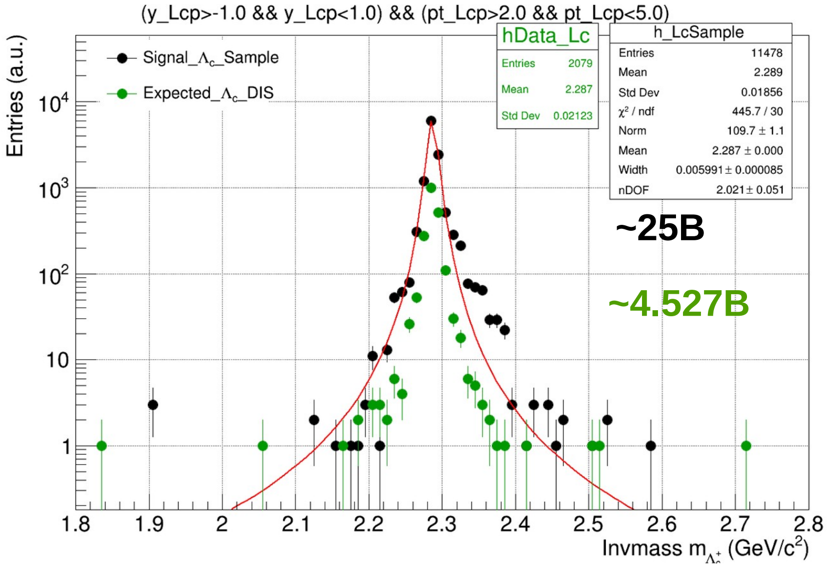

Test -> ROC (AUC = 0.7283)
Train -> ROC (AUC = 0.7523)
Luck
True Positive Rate
False Positive Rate

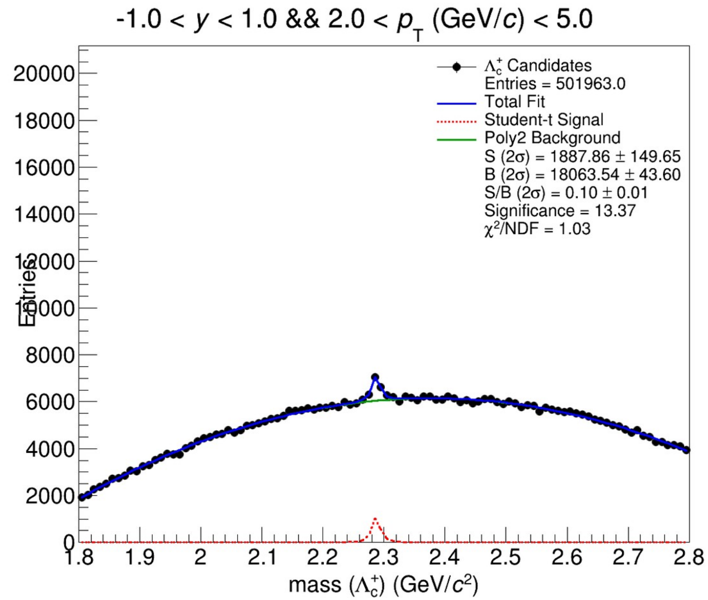

BDT Efficiency and Rejection
Signal Efficiency
Background Efficiency
Background Rejection
Efficiency / Rejection
BDT Score Threshold

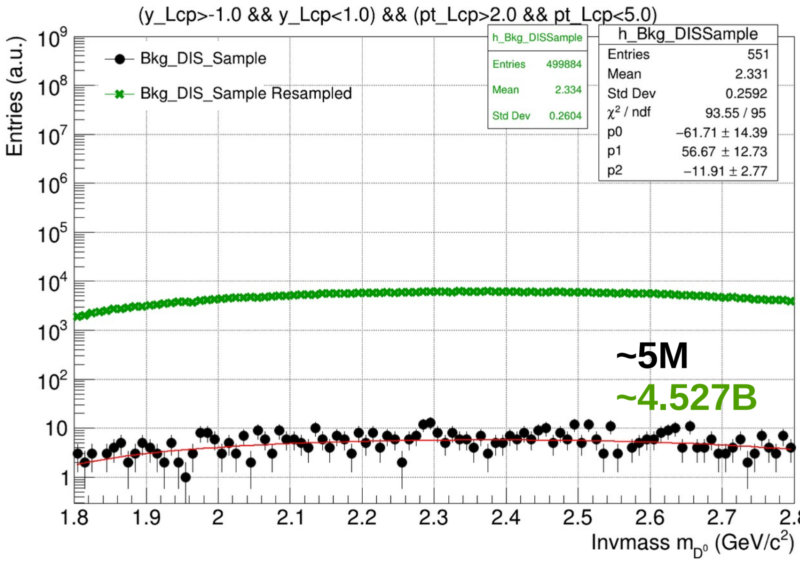

-1.0 < y < 1.0 && 1.0 < p_T (GeV/c) < 2.0
×10³
Λc+ Candidates
Entries = 4014017.0
Total Fit
Student-t Signal
Poly2 Background
S (2σ) = 3478.40 ± 517.11
B (2σ) = 141622.86 ± 107.08
S/B (2σ) = 0.02 ± 0.00
Significance = 9.13
χ²/NDF = 1.13
Entries
mass (Λc+) (GeV/c²)


Signal Efficiency
Background Efficiency
Signal/Background
Significance
Results
BDT Threshold

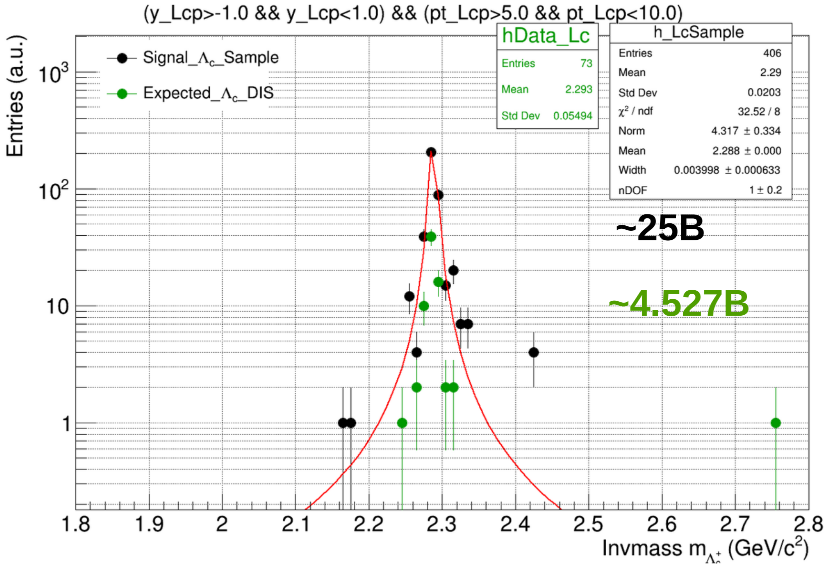
Sampling Signal and Background

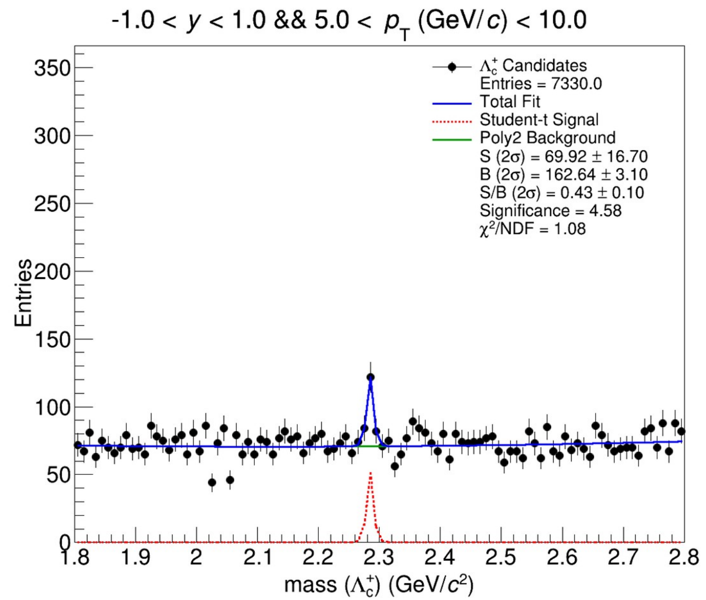


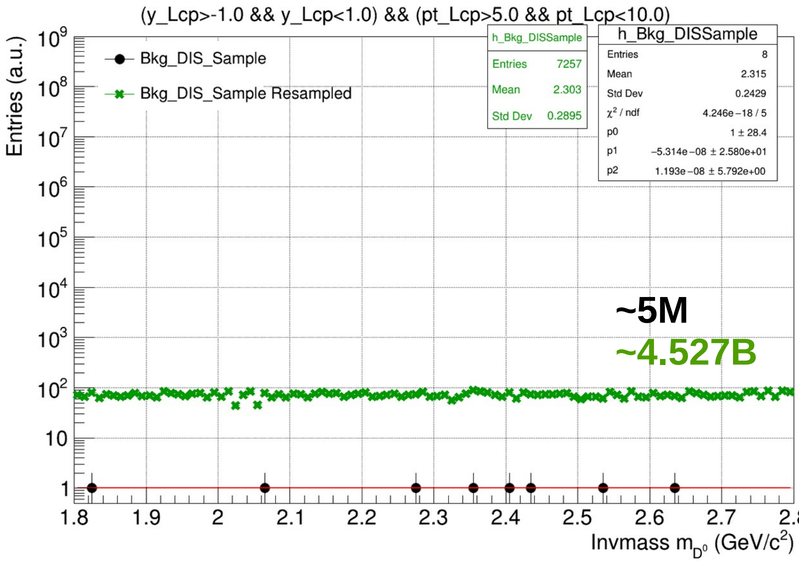




Sampling Signal and Background







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

$$\text{Rel. Uncertainity}_{\text{No ML}} = \frac{\sqrt{S_{\text{No ML}} + B_{\text{No ML}}}}{S_{\text{No ML}}}$$

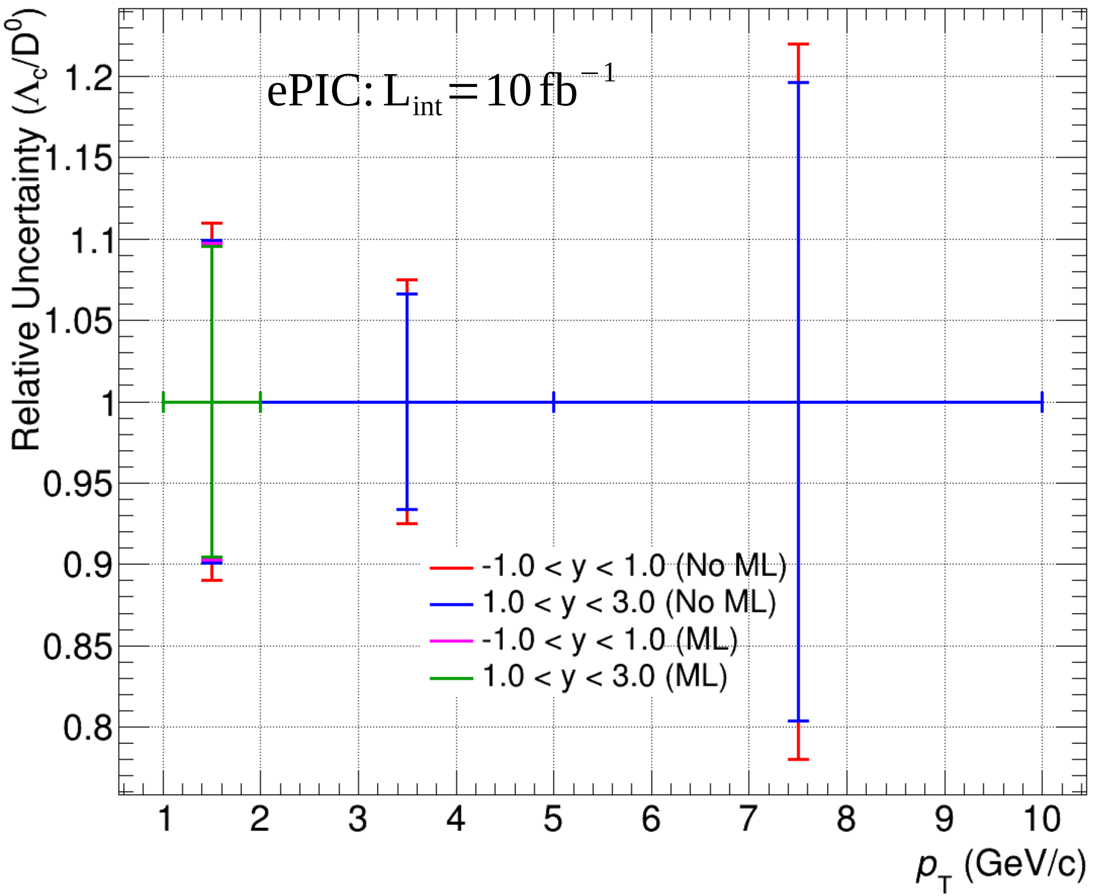
$$\text{Rel. Uncertainity}_{\text{BDT Cut}} = \frac{\sqrt{S_{\text{No ML}} \times \epsilon_{\text{Signal}} + B_{\text{No ML}} \times \epsilon_{\text{Background}}}}{S_{\text{No ML}} \times \epsilon_{\text{Signal}}}$$

-1 <y < 1 and 1 < p_T < 2 GeV/c

epsil_D0_Sig = 0.670802; // BDT Cut 0.600021 0.670802
epsil_D0_Bkg = 0.129204; // BDT Cut = 0.600021 0.129204
epsil_Lcp_Sig = 0.686461; // BDT Cut = 0.500087 0.686461
epsil_Lcp_Bkg = 0.365076; // BDT Cut = 0.500087 0.365076

1 <y < 3 and 1 < p_T < 2 GeV/c

epsil_D0_Sig = 0.562838; // BDT Cut = 0.600076 0.562838
epsil_D0_Bkg = 0.166655; // BDT Cut = 0.600076 0.166655
epsil_Lcp_Sig = 0.903848; // 0.400069 0.903848
epsil_Lcp_Bkg = 0.760462; // 0.400069 0.760462



Summary

- First study of the pull distributions for the primary vertex
- χ^2 minimization provides a further improvement in the resolution of the secondary vertex
- Preliminary results obtained for the projected statistical uncertainties of the Λ_c/D^0 ratio
- Further to use real PID for Λ_c and extract the projected uncertainties
- Particle identification will significantly enhance the Λ_c reconstruction once available
- Additional studies and optimizations are foreseen in the future

Thank you for your attention!

Covariance Matrix

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

For each fitted track we get track parameters and covariance matrix

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

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] = 3.89044e-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)

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

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

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