

D^0 meson Reconstruction and Expected Statistical Precision on Nuclear Modification Factor

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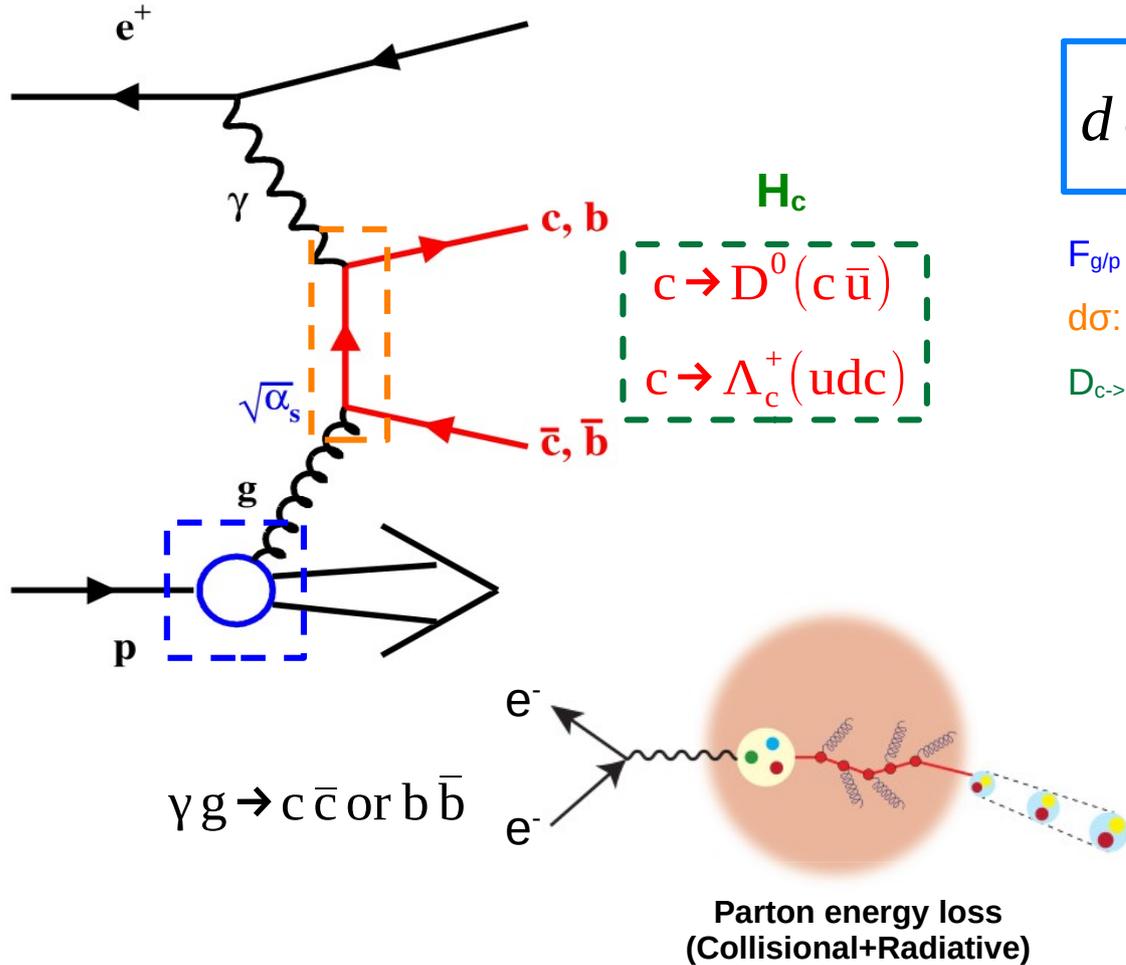


ePIC Physics Forum 24/02/2026

Analysis Note

Photon-Gluon Fusion (PGF) is leading order [LO] mechanism

<https://doi.org/10.1016/j.ppnp.2015.06.002>



QCD Factorization Approach (PGF)

$$d\sigma_{\gamma p \rightarrow H_c X}^{PGF} = F_{g/p} \otimes d\sigma_{\gamma g \rightarrow c\bar{c}} \otimes D_{c \rightarrow H_c}$$

$F_{g/p}(x, \mu^2)$: Parton Distribution Function (PDF)

$d\sigma$: Hard parton scattering cross section for PGF

$D_{c \rightarrow H_c}(z, \mu^2)$: Fragmentation function (Hadronization)

Fragmentation variable: $z = \frac{p_{H_c}}{p_c}$

Hadronization in ep and eA collisions

- R_{eA} vs p_T , x_B , and z
- Shadowing, multiple scattering, gluon saturation
- Energy loss and hadronization in Cold Nuclear Matter (CNM)

➤ Data Sample

$L_{\text{int}} = 10 \text{ fb}^{-1}$

- D0 Sample (e+p) = /volatile/eic/EPIC/RECO/25.10.3/epic craterlake/SIDIS/D0 ABCONV/pythia8.306-1.1/10x100/q2 1/hiDiv/
- DIS Sample (e+p) = /volatile/eic/EPIC/RECO/25.10.0/epic craterlake/DIS/NC/10x100/minQ2 1/
- D0 Sample (e+Au) = /volatile/eic/EPIC/RECO/25.10.3/epic craterlake without zdc/SIDIS/D0 ABCONV/HFsim-BeAGLE/BeAGLE1.03.01-2.0/eAu/10x100/q2 1to10000/
- DIS Sample (e+Au) = /volatile/eic/EPIC/RECO/25.10.2/epic craterlake without zdc/DIS/BeAGLE1.03.02-1.0/eAu/10x100/q2 1to10/

➤ Transverse DCA (DCA_{xy}) distribution w.r.t. MC vertex position (Rongrong Ma)

- **DCA_PrimVsSec**

➤ Code for Secondary Vertex Resolution and D^0 Reconstruction

- **D0 Reconstruction code, ML Framework**

➤ Post-processing Scripts

- **SV_Resolution, Differential_ML_YPt_Invmass** (ep collisions), **Differential_ML_YPt_Invmass** (eAu collisions)
- **Compute_Relative_Uncertainty_eAu**

Reconstruction of D^0 meson

Primary Vertex Reconstruction:

→ CentralTrackVertices

Primary vertex: allows access to the DCA of reconstructed tracks

Secondary vertex: allows access to more topological variables, e.g., decay length, pointing angle ($\cos\theta$), DCA_{D^0} , etc.

Secondary vertex based on χ^2 minimization approach: S. Kumar (Slides)

Topological Variables

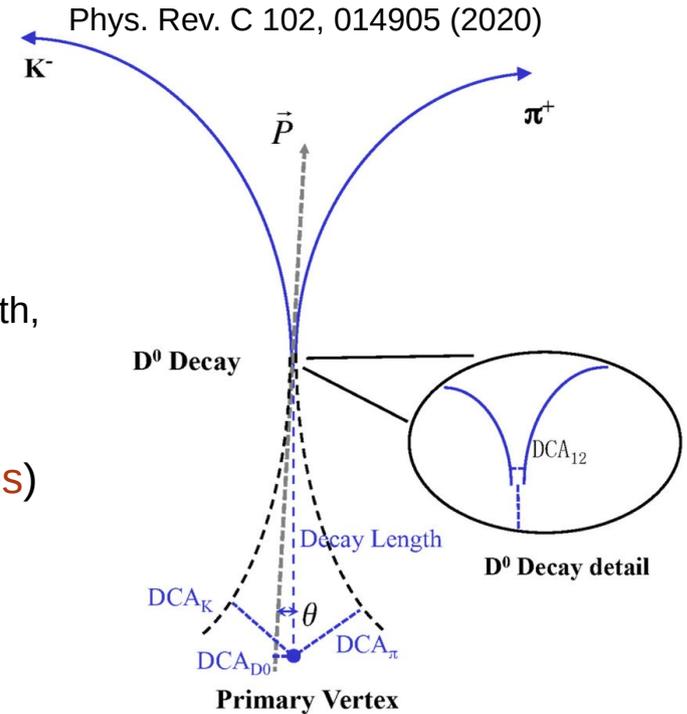
$$\vec{dl} = S\vec{V} - P\vec{V}$$

$$\cos\theta = \frac{\vec{dl} \cdot \vec{p}_{D^0}}{|\vec{dl}| |\vec{p}_{D^0}|}$$

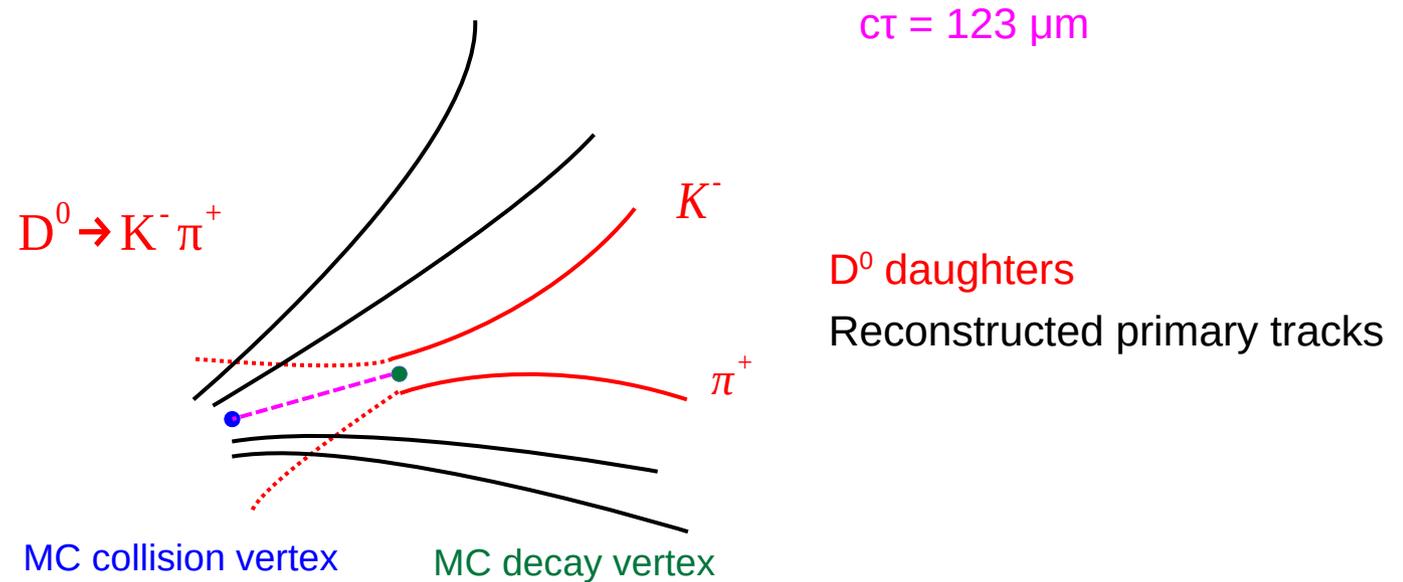
$$DCA_{D^0} = |\vec{dl}| \sin\theta$$

$$\text{Invariant mass: } m_{D^0} = \sqrt{(E_{K^-} + E_{\pi^+})^2 - (\vec{p}_{K^-} + \vec{p}_{\pi^+})^2}$$

Secondary vertex is important for the reconstruction of HF-hadrons



Transverse DCA Resolution w.r.t. MC Vertex (e+p, D⁰ Sample)



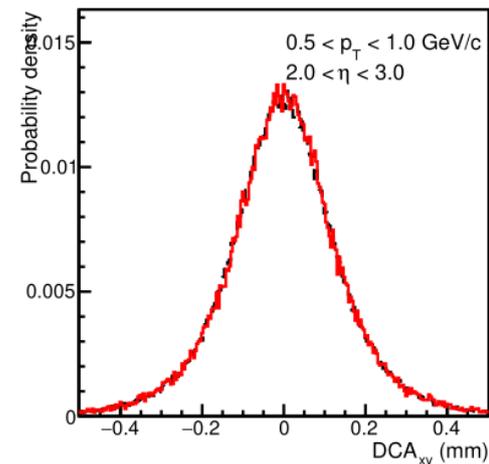
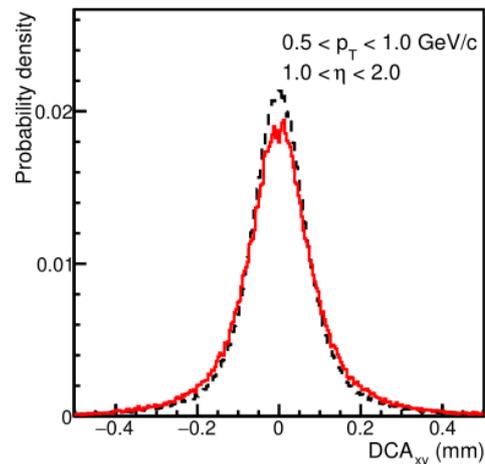
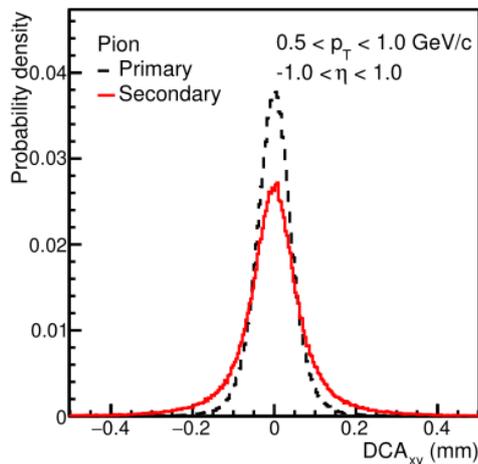
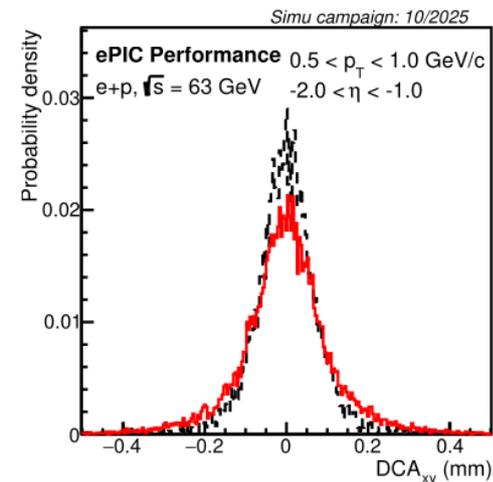
Transverse DCA Distribution (DCA_{xy})

π^- from primary vertex
 $0.5 < p_T < 1.0$ GeV/c

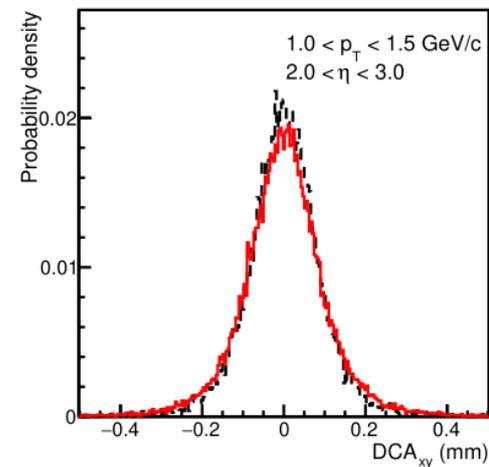
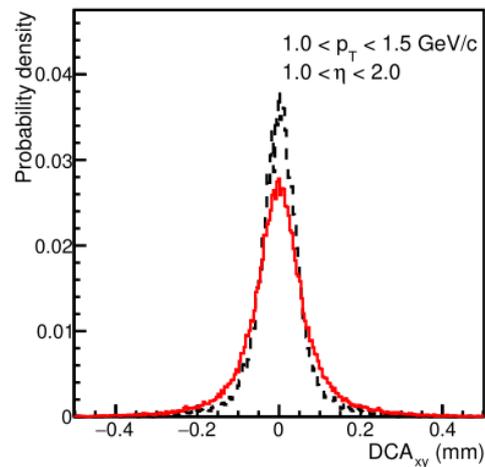
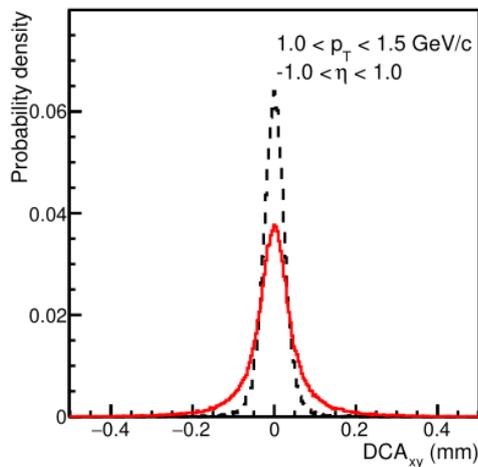
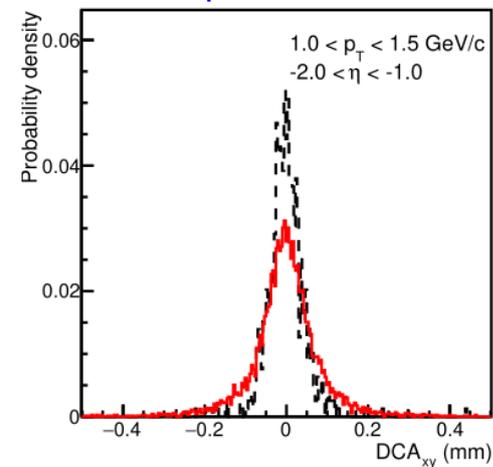
π^- from D^0 decay

Rongrong

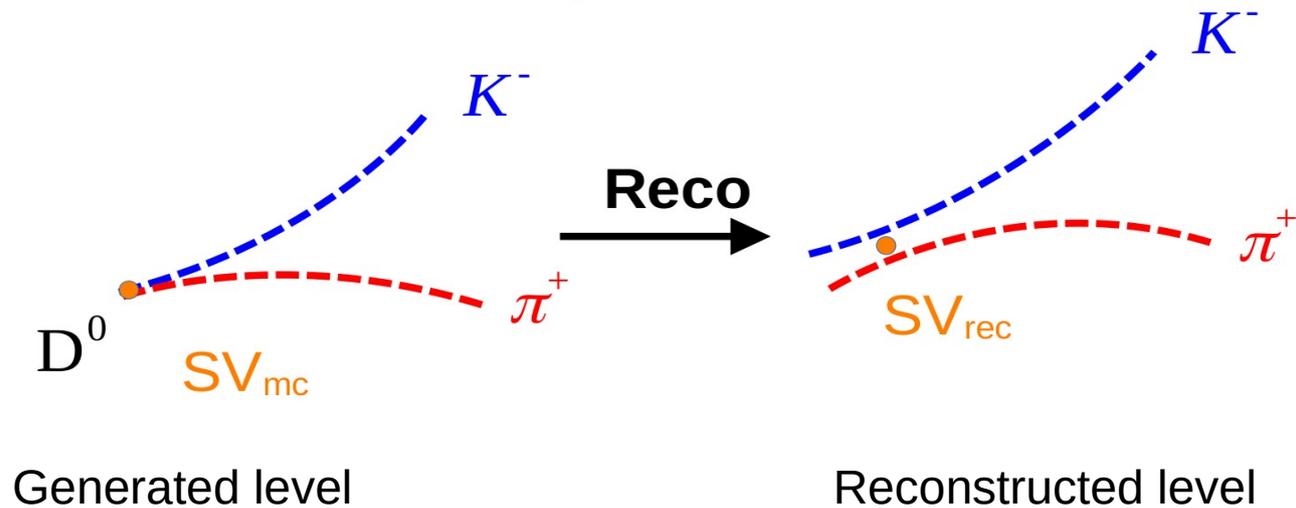
For Approval



$1.0 < p_T < 1.5$ GeV/c

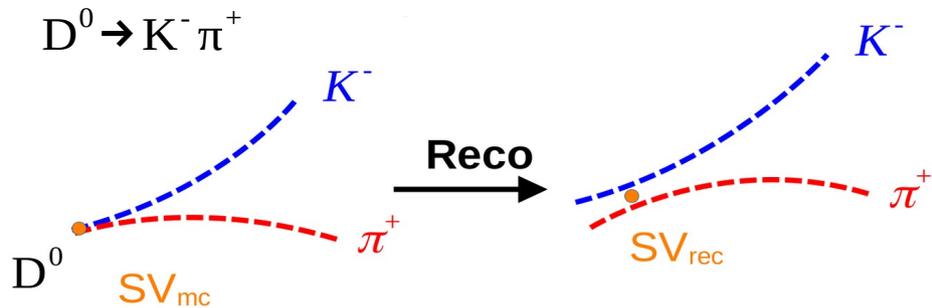


Secondary Vertex Resolution (e+p, D^0 Sample)



Helix Swimming

Method based on STAR experiment which use track parameters to determine the vertex position



Track parameters (DCA):

$$(l_0, l_1, \varphi, \theta, q/p) \quad \text{Local}$$



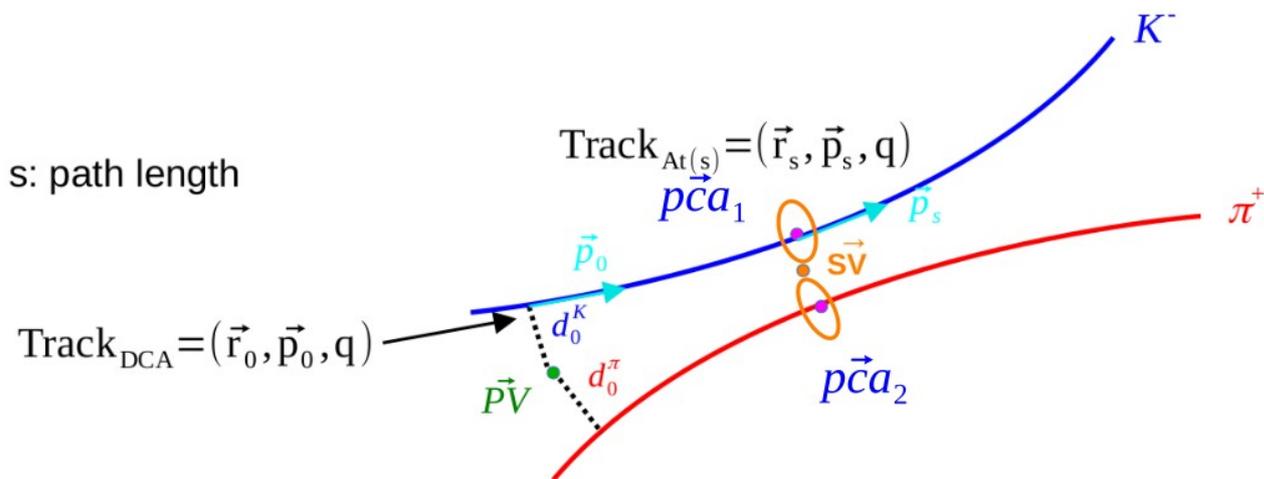
$$(x, y, z, p_x, p_y, p_z) \quad \text{Global}$$

$$\begin{aligned} x &= -l_0 \sin\varphi, \quad y = -l_0 \cos\varphi, \quad z = l_1 \\ p_x &= p \cos\varphi \sin\theta, \quad p_y = p \sin\varphi \sin\theta \\ p_z &= p \cos\theta, \quad q = \text{sign}(q/p) \end{aligned}$$

$$\vec{SV} = \frac{1}{2} (p\vec{ca}_1 + p\vec{ca}_2)$$

Information used: **Track parameters**

Ignores the track **uncertainties**



Implemented in EICRecon (Xin dong, LBL)

Chi-square Minimization

S. Kumar, INFN

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

Considering the tracking errors
Minimization of chi-square

Helix swimming is used for
helix definition

Slides

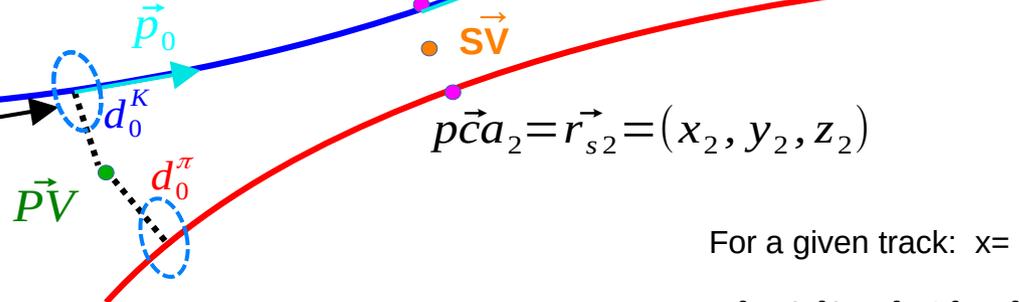
$$\text{Track}_{\text{At}(s)} = (\vec{r}_s, \vec{p}_s, q)$$

$$p\vec{c}a_1 = r_{s_1} = (x_1, y_1, z_1)$$

$$p\vec{c}a_2 = r_{s_2} = (x_2, y_2, z_2)$$

uncertainties

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



For a given track: $x = -l_0 \sin\phi$, $y = l_0 \cos\phi$, $z = l_1$

$$\sigma_x^2 = \sin^2\phi \cdot \sigma_{l_0}^2 + l_0^2 \cos^2\phi \cdot \sigma_\phi^2 + 2 \cdot l_0 \sin\phi \cos\phi \cdot \text{Cov}(l_0, \phi)$$

$$\sigma_y^2 = \cos^2\phi \cdot \sigma_{l_0}^2 + l_0^2 \sin^2\phi \cdot \sigma_\phi^2 - 2 \cdot l_0 \sin\phi \cos\phi \cdot \text{Cov}(l_0, \phi)$$

$$\sigma_z^2 = \sigma_{l_1}^2$$

Parameters: $(v_x, v_y, v_z, s_1, s_2)$

Minimize chi2:

$$\chi^2 = \frac{(x_1 - v_x)^2}{\sigma_{x1}^2} + \frac{(x_2 - v_x)^2}{\sigma_{x2}^2} + \frac{(y_1 - v_y)^2}{\sigma_{y1}^2} + \frac{(y_2 - v_y)^2}{\sigma_{y2}^2} + \frac{(z_1 - v_z)^2}{\sigma_{z1}^2} + \frac{(z_2 - v_z)^2}{\sigma_{z2}^2}$$

Information used: Track parameters and Covariance



Chi-square Minimization

D^0 Sample e+p (10x100, $Q^2 > 1 \text{ GeV}^2$)

Fit Range: Mean +/- 2*StdDev

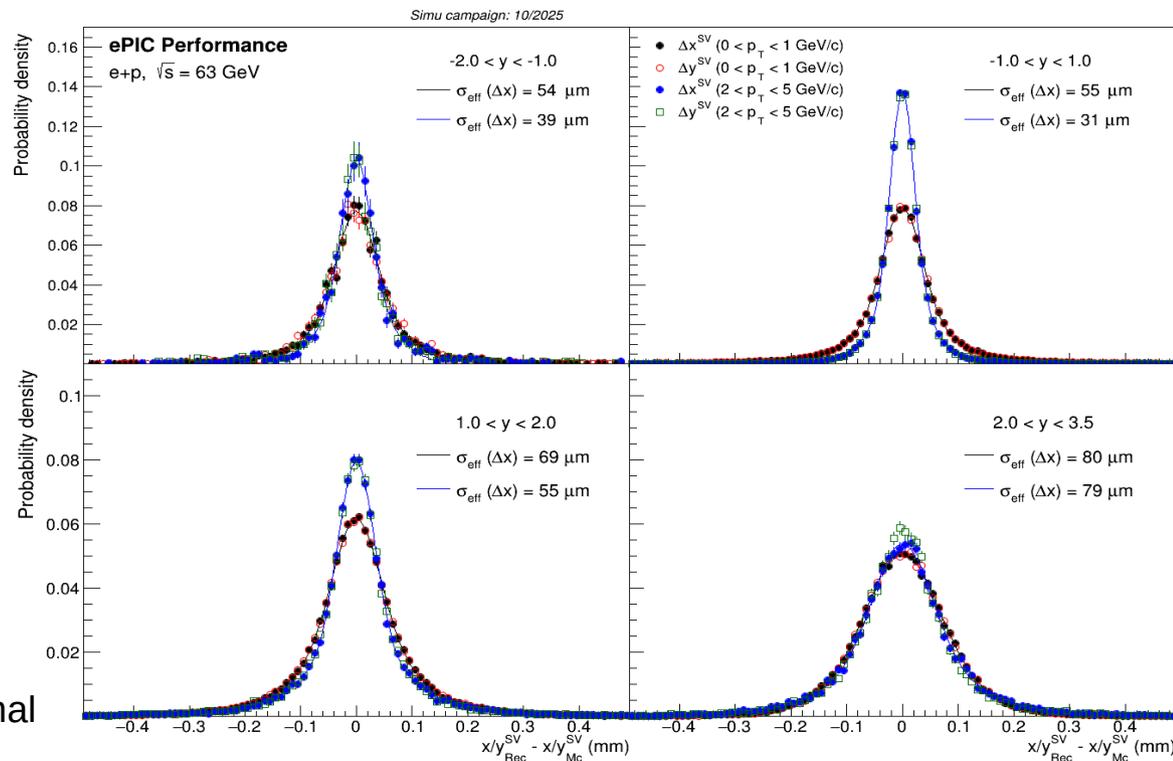
10.2025

Two Gaussian ($A_{\text{core}}, \sigma_{\text{core}}, A_{\text{tail}}, \sigma_{\text{tail}}$)

$$\sigma_{\text{eff}} = \sqrt{\frac{A_{\text{core}}}{(A_{\text{core}} + A_{\text{tail}})} \sigma_{\text{core}}^2 + \frac{A_{\text{tail}}}{(A_{\text{core}} + A_{\text{tail}})} \sigma_{\text{tail}}^2}$$

σ_{eff} decreases as we go at high p_T

Best resolution is achieved at mid-rapidity and high transverse momentum, where DCA resolution is optimal



Pull distributions

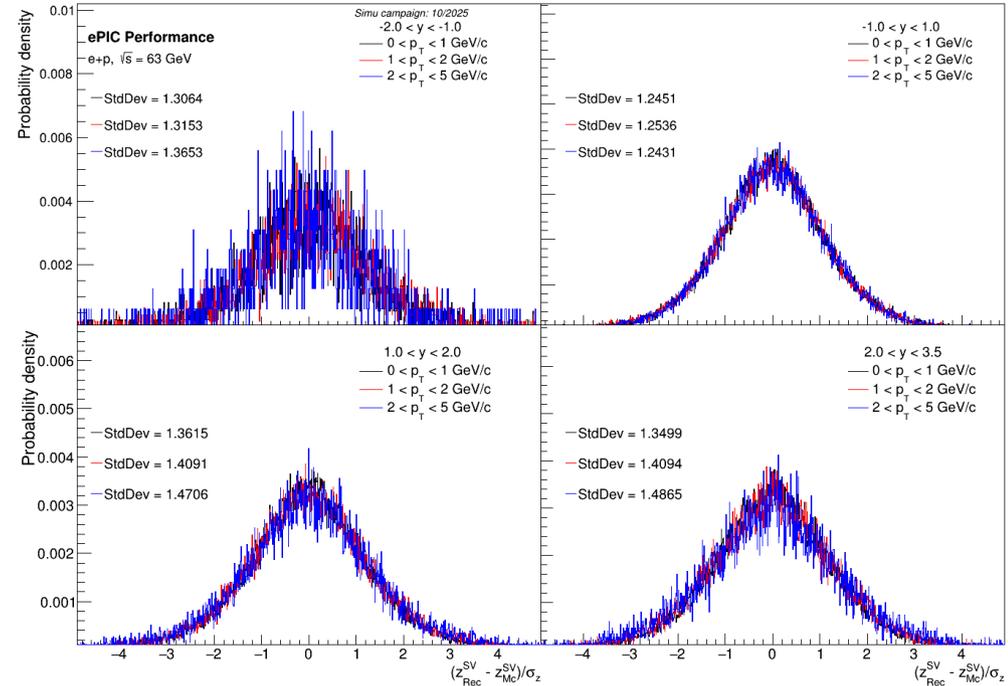
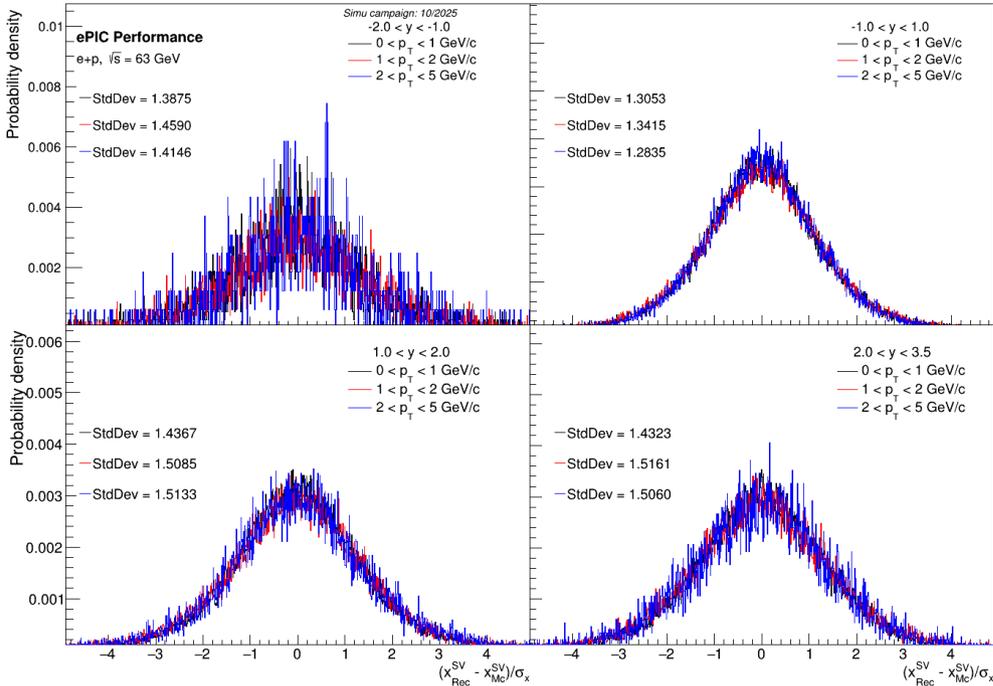
$D^0 \rightarrow K^- \pi^+$

D^0 Sample e+p (10x100, $Q^2 > 1 \text{ GeV}^2$)

10.2025

$$\text{Pulls} = \frac{SV_{\text{rec}}^x - SV_{\text{mc}}^x}{\sigma_x}$$

$$\text{Pulls} = \frac{SV_{\text{rec}}^z - SV_{\text{mc}}^z}{\sigma_z}$$



Pulls are less than 1.5 in most cases

Event Statistics

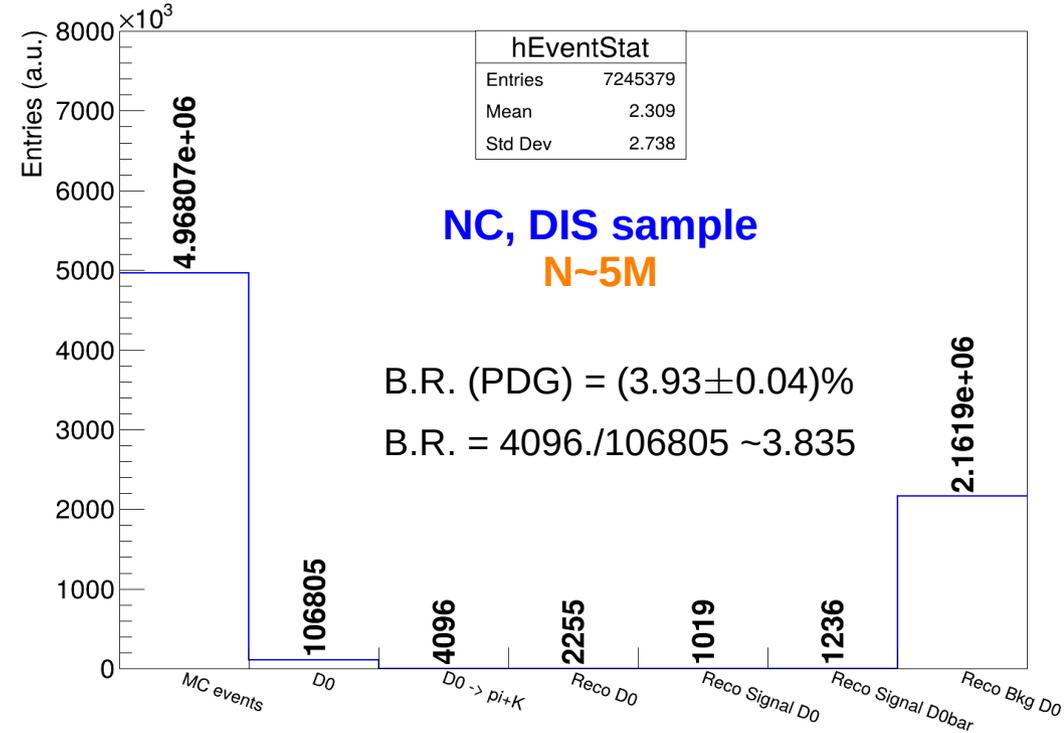
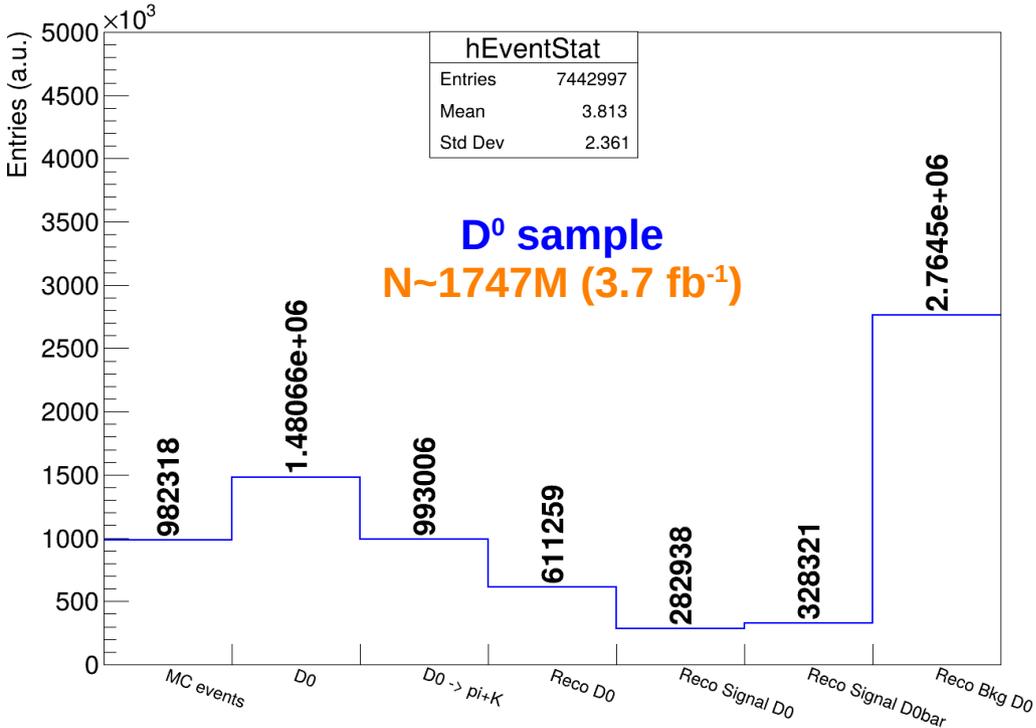
D⁰ sample is produced filtering NC DIS events containing at least a D⁰ → K π⁺ meson

Slide 12

D⁰ Sample e+p (10x100, Q² > 1 GeV²)

Real PID

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

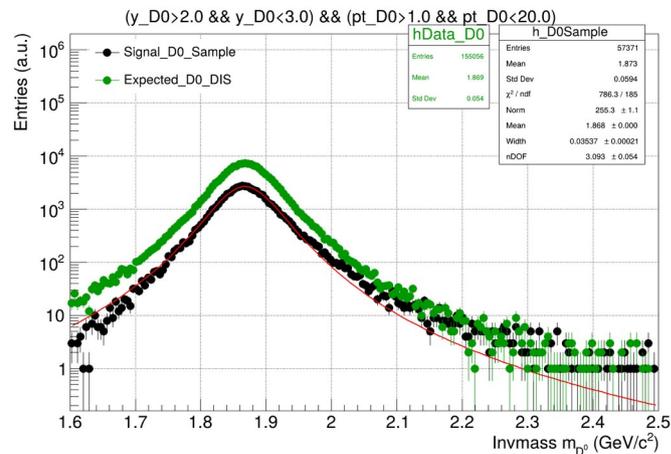
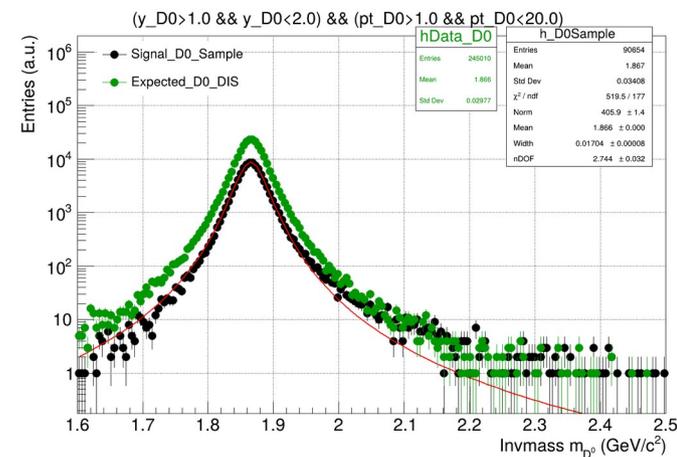
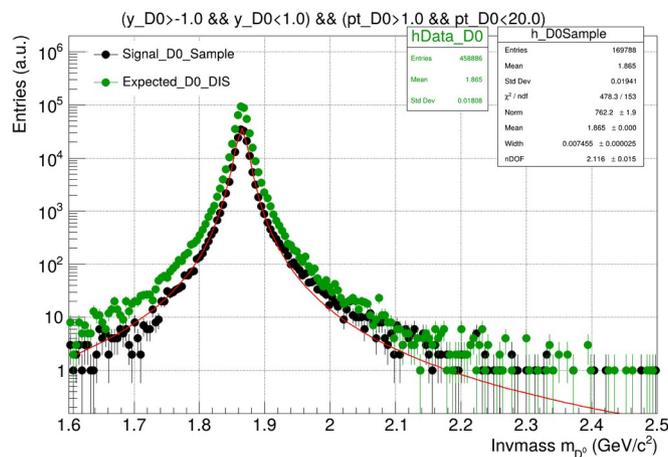
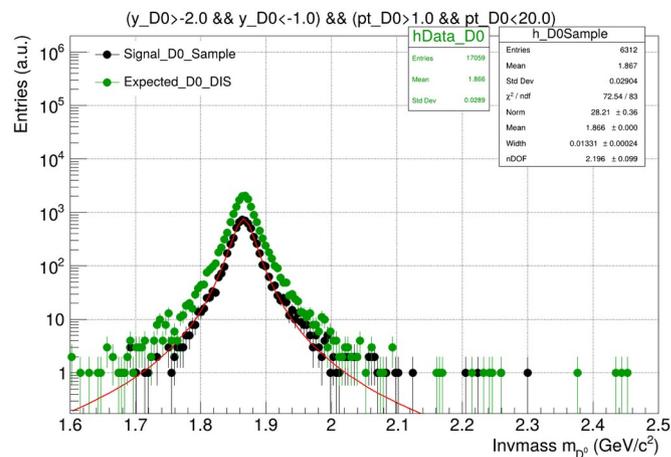


Sampling Signal (D^0 Sample)

Reco invariant mass

e+p collisions

1747M (3.7 fb^{-1})
4721.62M (10 fb^{-1})



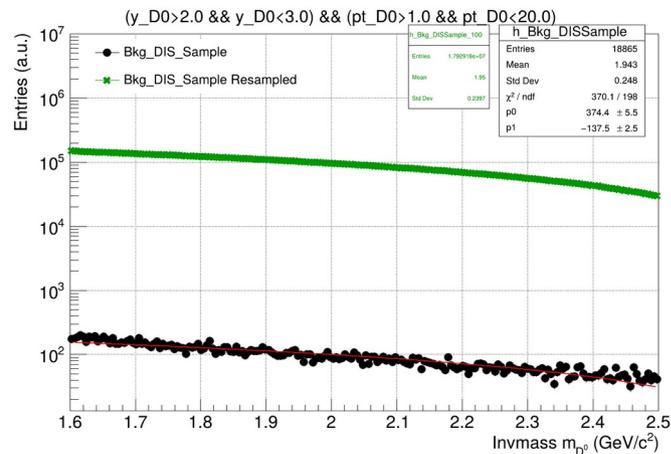
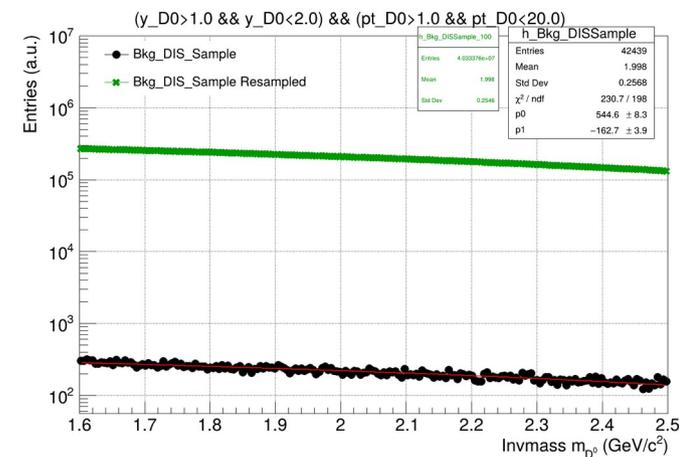
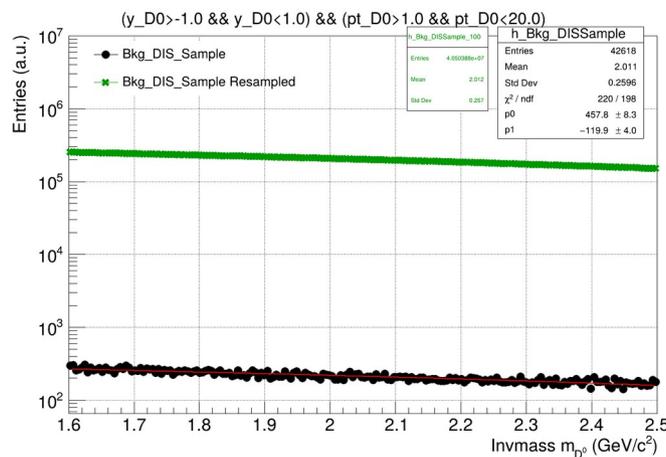
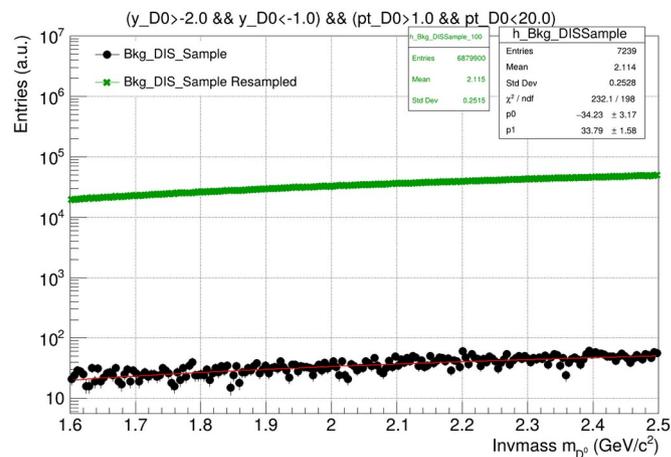
- Applied only Realistic Particle Identification (Real PID)
- For rapidity bins $(-2.0, -1.0)$, $(-1.0, 1.0)$, $(1.0, 2.0)$, $(2.0, 3.0)$
- Signal fitted (3.7 fb^{-1}) with student's function
- Resampling done to 10 fb^{-1}

Sampling Background (DIS Sample)

Reco invariant mass

e+p collisions

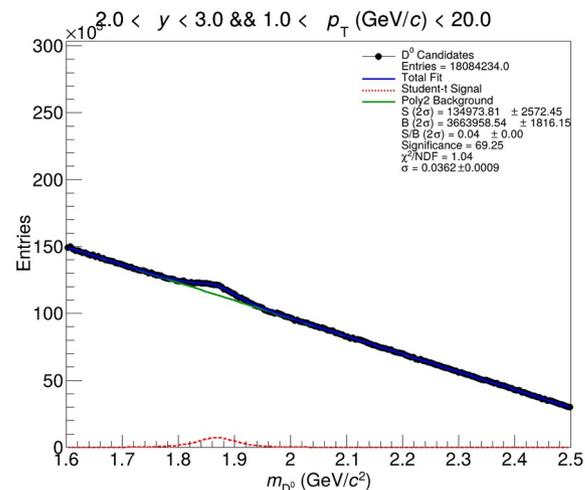
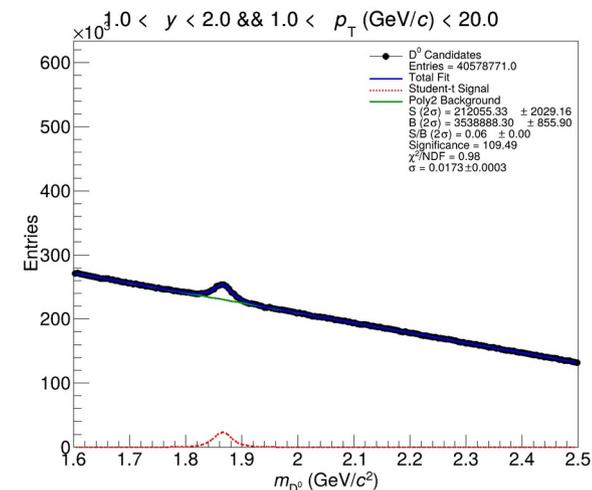
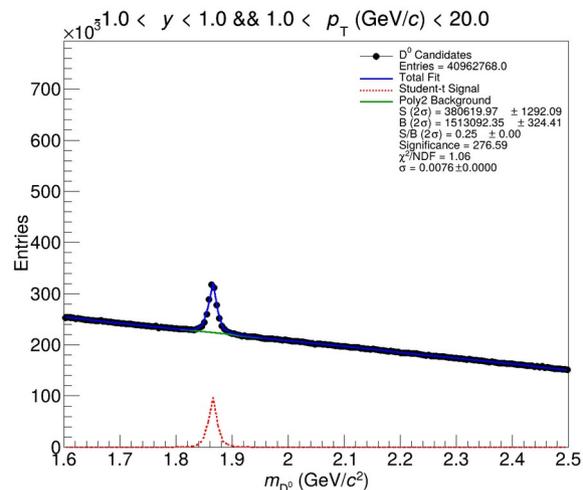
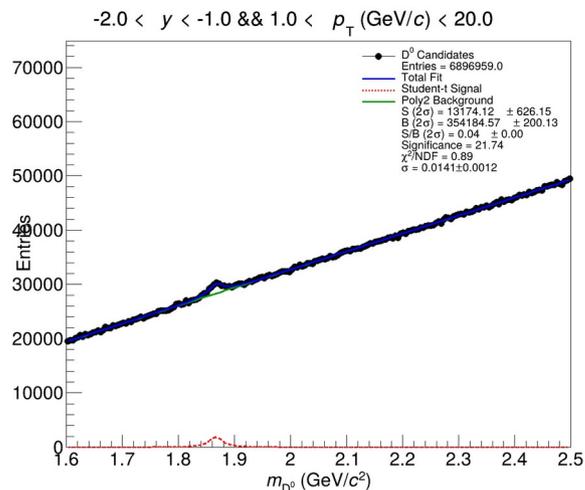
5M
4721.62M (10 fb⁻¹)



- Applied only Realistic Particle Identification (Real PID)
- For rapidity bins (-2.0, -1.0), (-1.0, 1.0), (1.0, 2.0), (2.0, 3.0)
- Bkg fitted (**5M**) with polynomial of order one
- Resampling done to **10 fb⁻¹**

Invariant Mass of D^0 meson

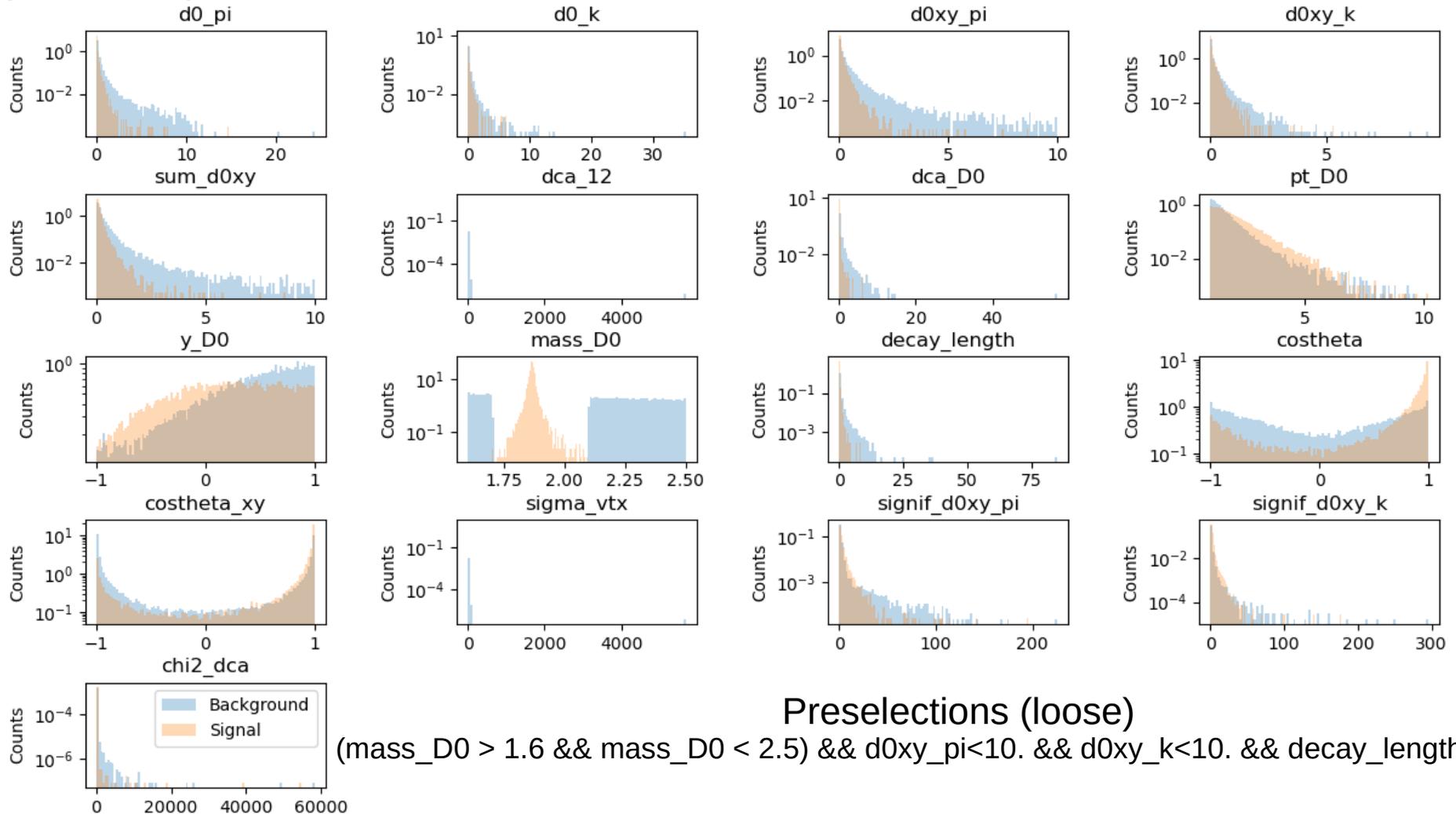
e+p collisions



- Applied only Realistic Particle Identification (Real PID)
- Merged signal and background correspond to 10 fb^{-1}
- Fit function (student + pol1)
- Next to apply topological cuts based on ML approach
- Boosted Decision Trees (BDT) binary classifier (signal and background)
- Training in each rapidity and p_T ($>1 \text{ GeV/c}$) region

Topological Variable Distributions

$-1 < y < 1$ and $p_T > 1$ GeV/c

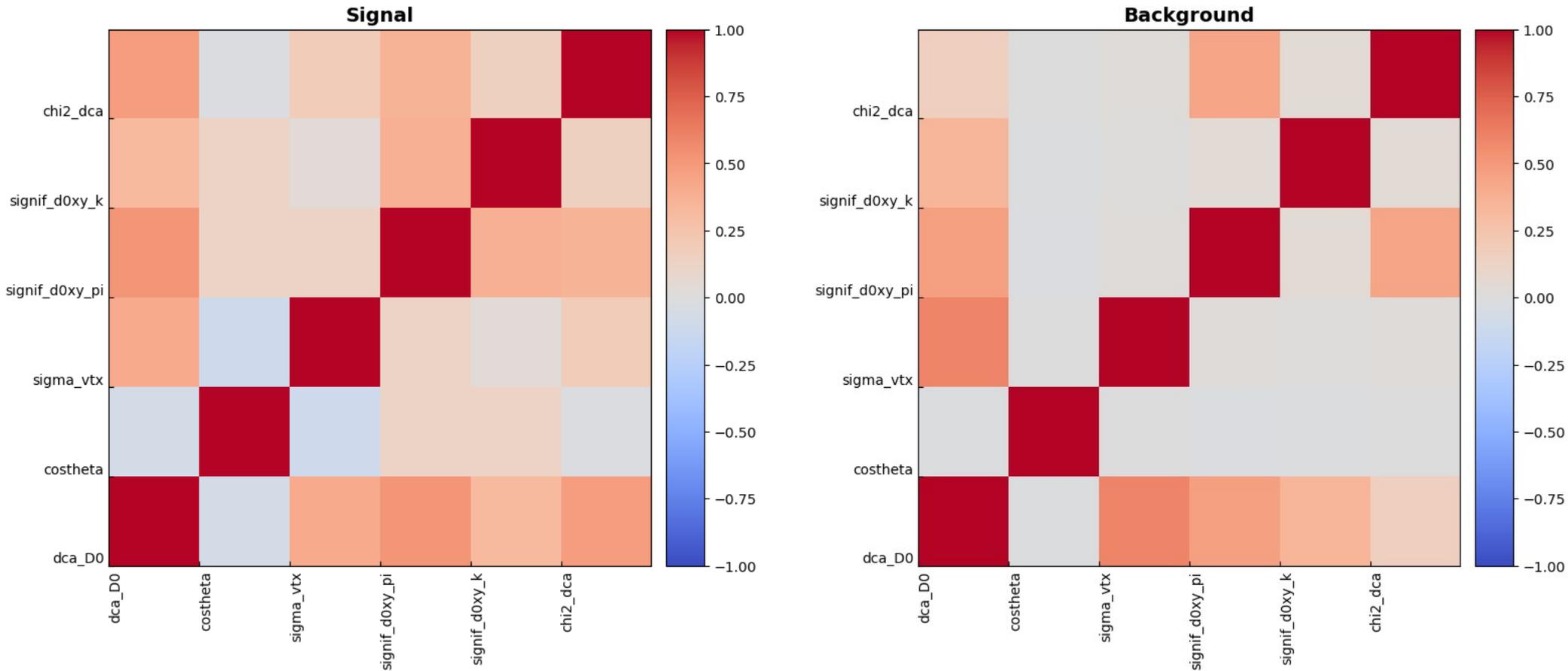


Preselections (loose)
($mass_D0 > 1.6 \ \&\& \ mass_D0 < 2.5$) $\&\& \ d0xy_pi < 10$. $\&\& \ d0xy_k < 10$. $\&\& \ decay_length < 100$.

Correlation Matrix

$-1 < y < 1$ and $p_T > 1$ GeV/c

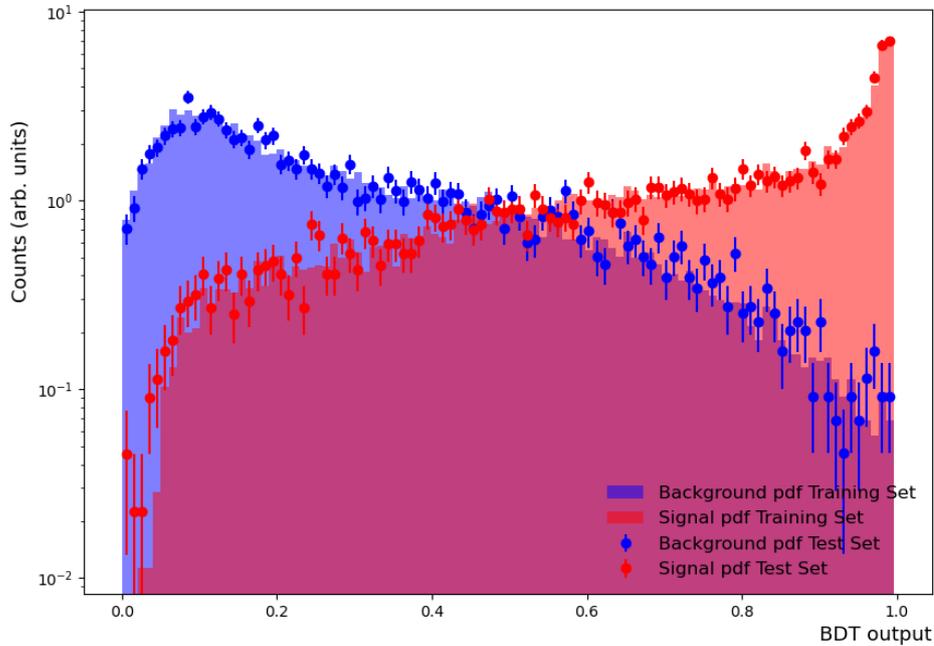
Features used in the ML



$-1 < y < 1$ and $p_T > 1$ GeV/c

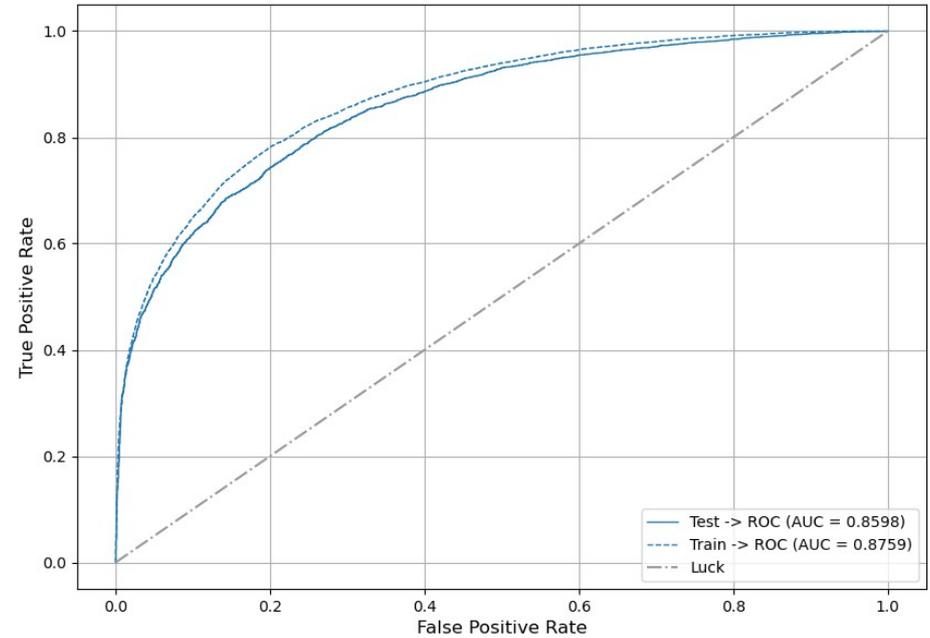
Training (80%)+ Test (20%) sample

Good compatibility between training/test data



BDT model is able to separate **signal** and **background**

Receiver Operating Characteristic (ROC) curve



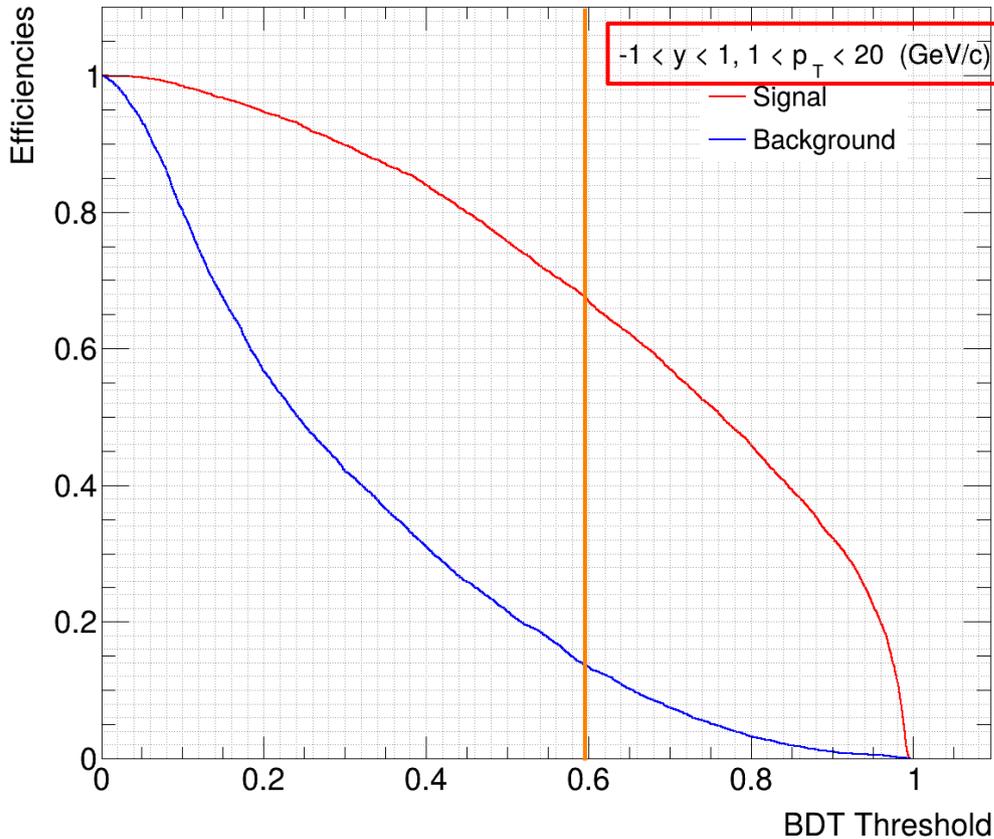
ROC Score ~ 0.86

ML Framework: S. Kumar

Invariant Mass of D^0 meson with ML

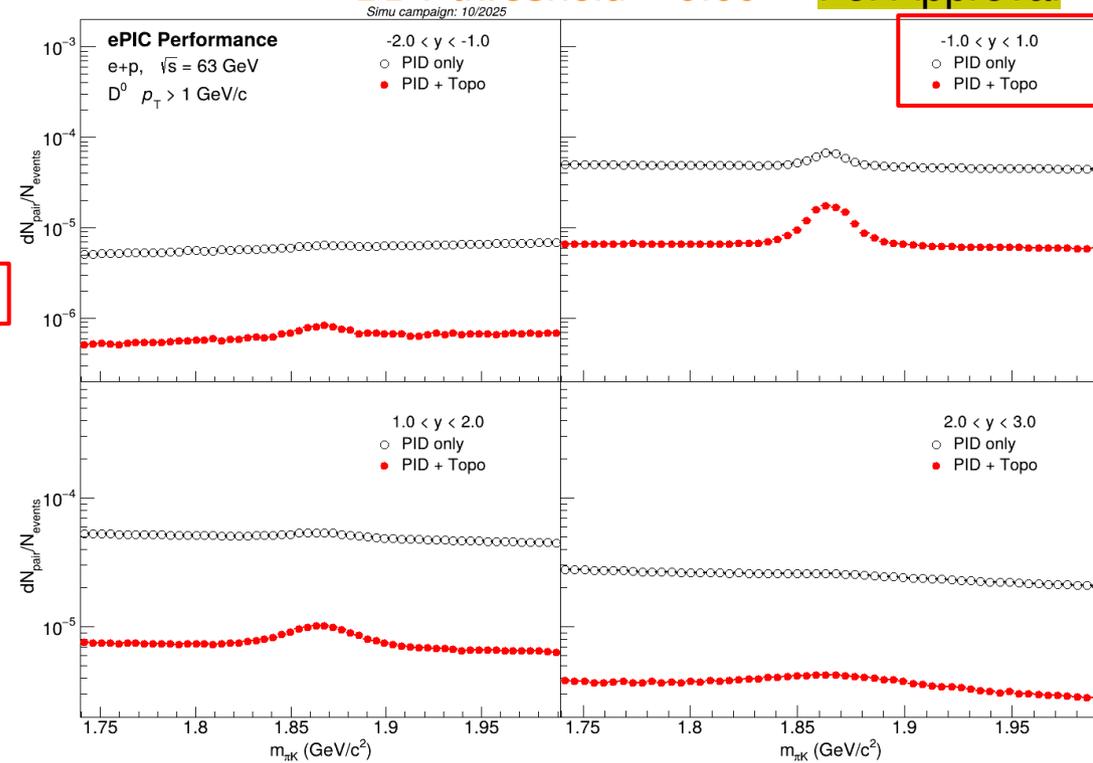
Model trained for each rapidity and $p_T > 1$ GeV/c

BDT threshold > 0.60



BDT threshold = 0.60

For Approval



PID Only: using only PID information

PID +Topo: using PID+ Topological cuts with ML

Substantial suppression of the background with ML

Event Statistics

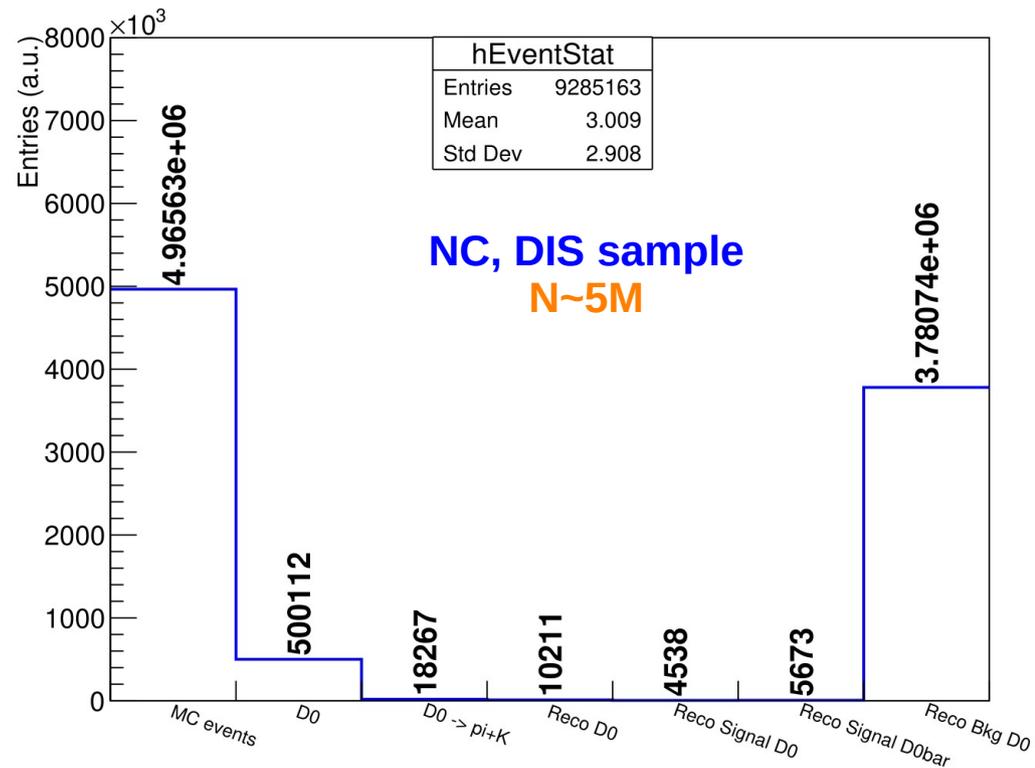
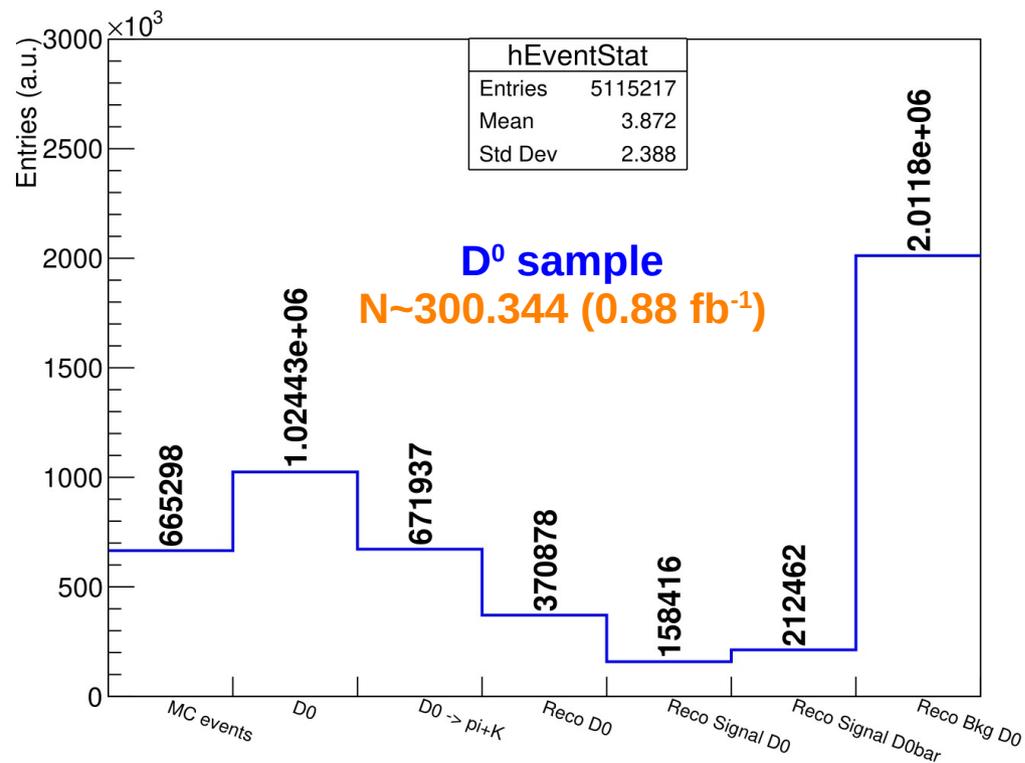
D^0 sample is produced filtering NC DIS events containing at least a $D^{0D0} \rightarrow K\pi^+$ meson

Slide 12

D^0 Sample e+Au (10x100, $Q^2 > 1 \text{ GeV}^2$)

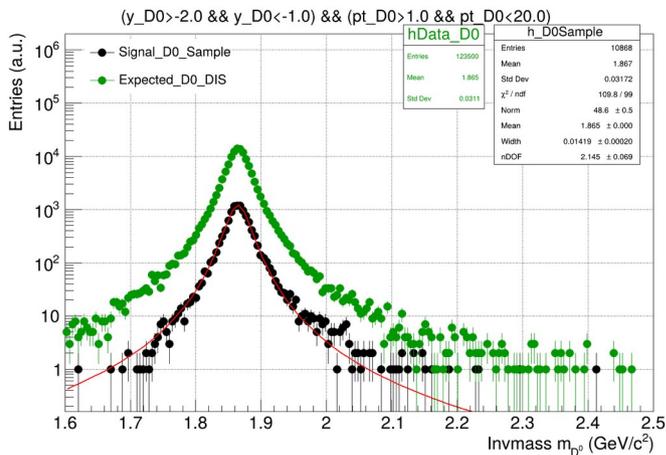
Real PID

$$N_{\text{events}} (10 \text{ fb}^{-1}) = 300.344 \times 10 / 0.88 = 3413 \text{ M}$$

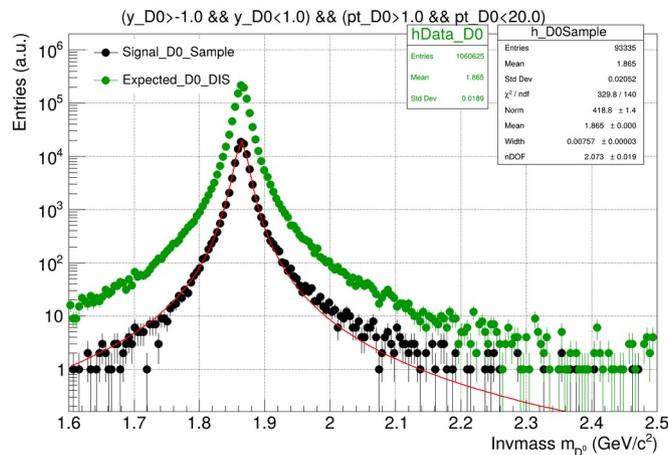


Sampling Signal (D^0 Sample)

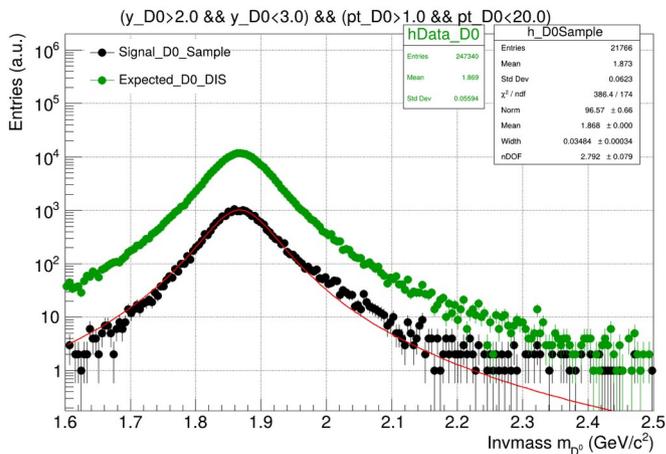
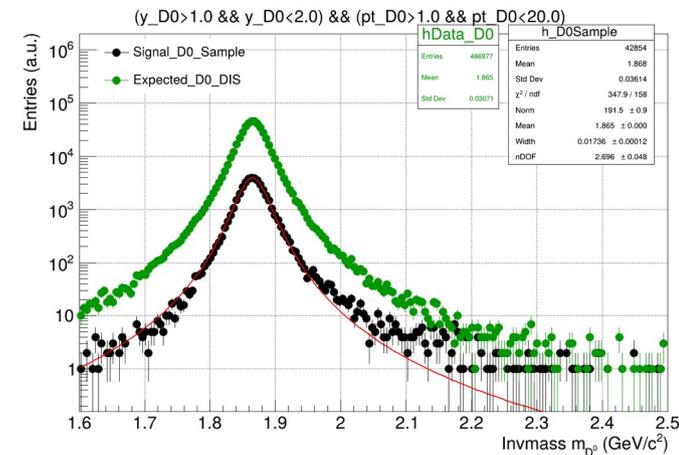
Reco invariant mass



e+Au collisions



300.344M (0.88 fb⁻¹)
3413M (10 fb⁻¹)



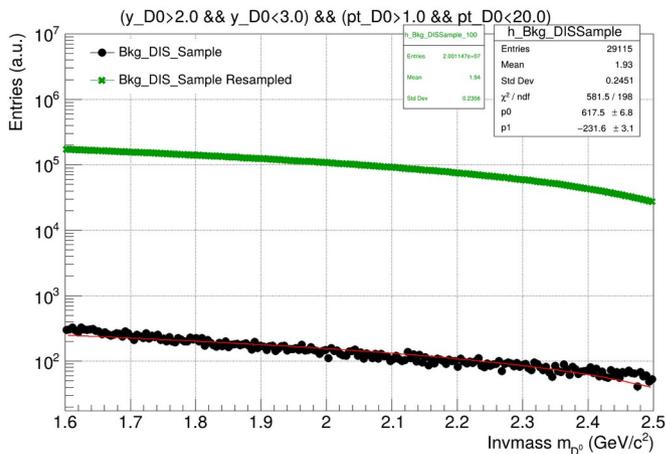
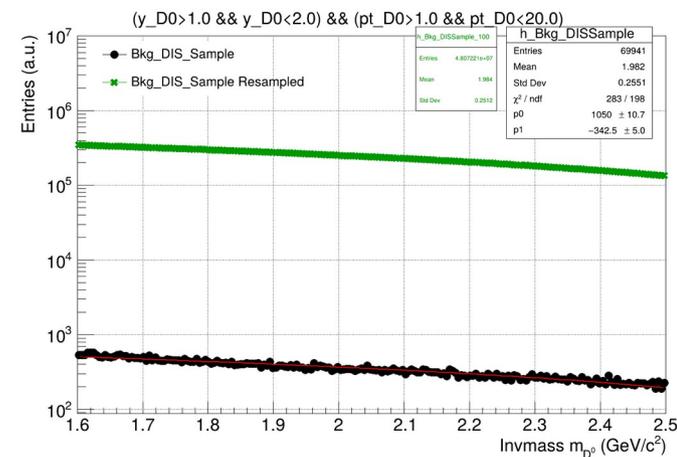
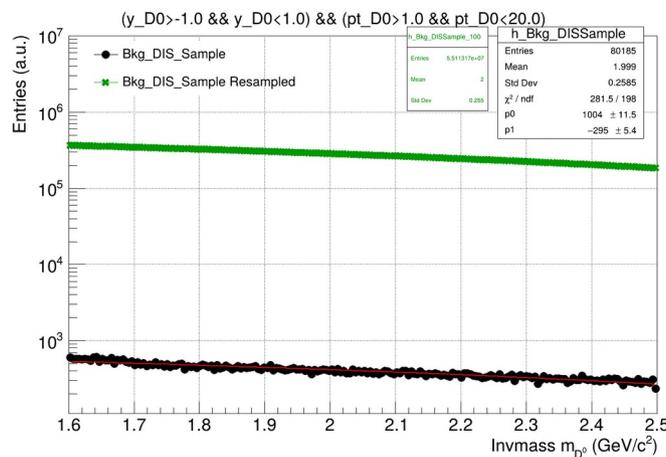
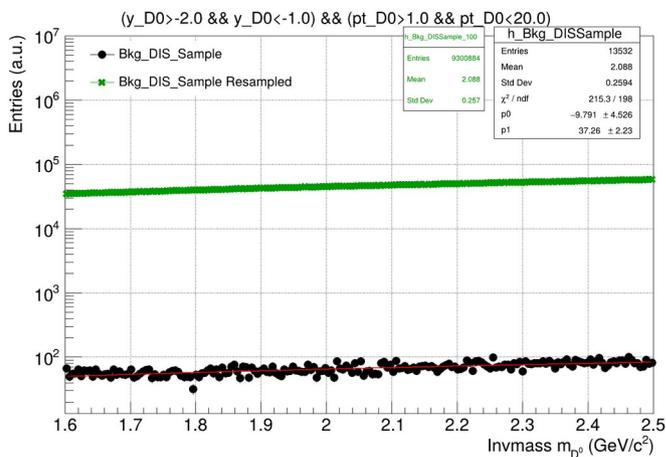
- Applied only Realistic Particle Identification (Real PID)
- For rapidity bins (-2.0, -1.0), (-1.0, 1.0), (1.0, 2.0), (2.0, 3.0)
- Signal fitted (0.88 fb⁻¹) with student's function
- Resampling done to 10 fb⁻¹

Sampling Background (DIS Sample)

Reco invariant mass

e+Au collisions

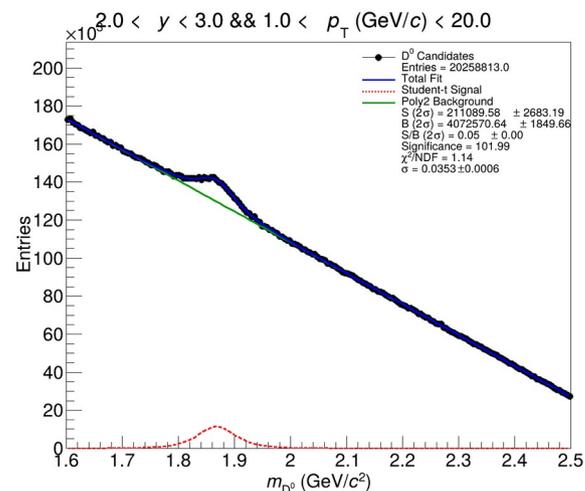
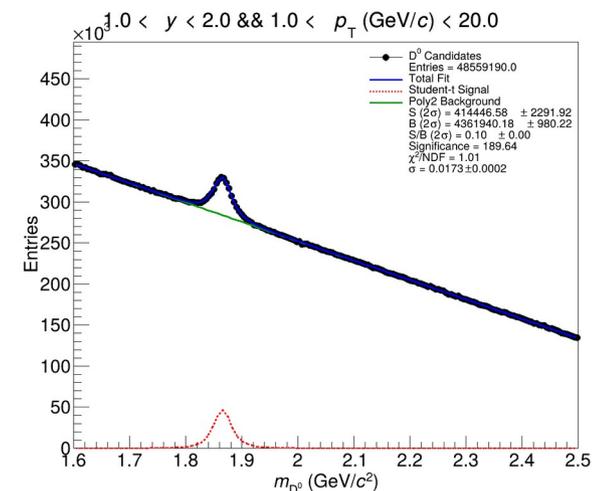
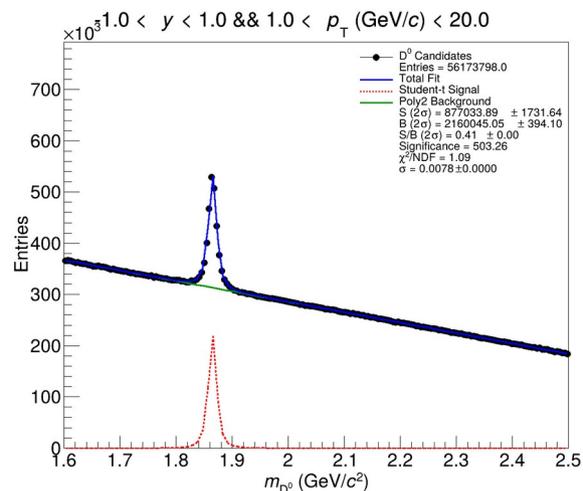
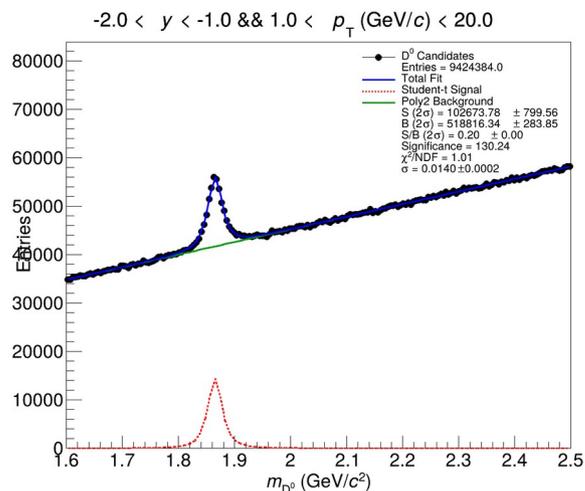
5M
3413M (10 fb⁻¹)



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Invariant Mass of D^0 meson

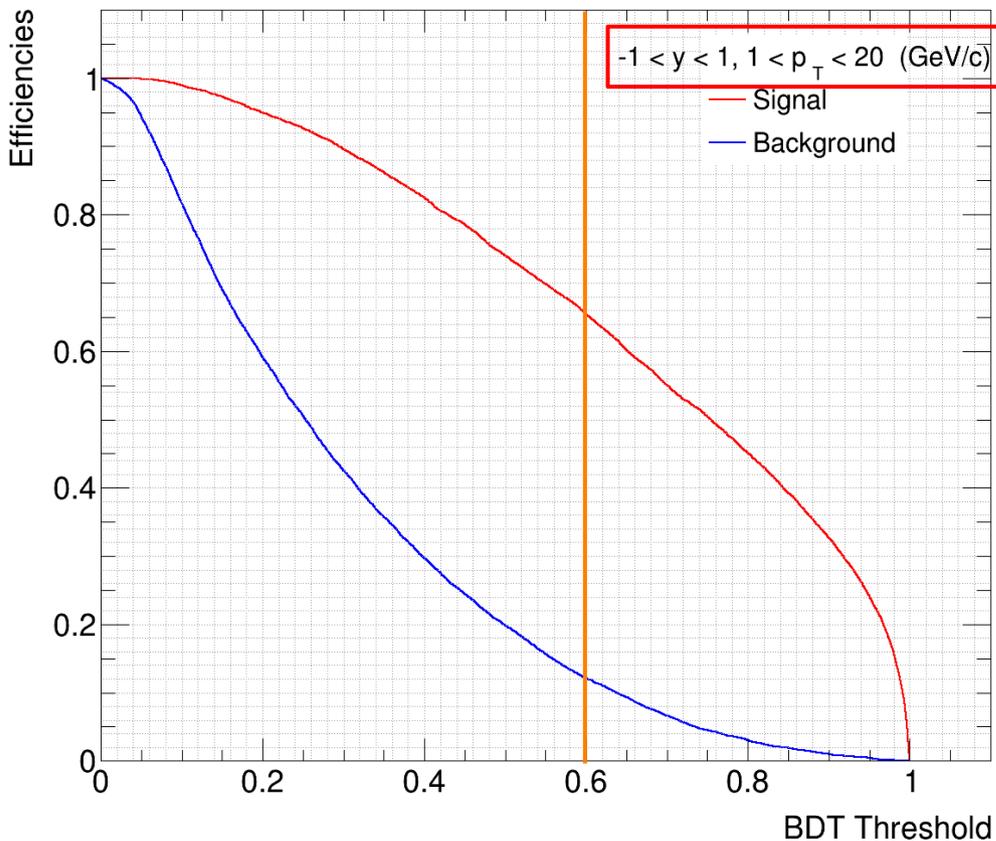
e+Au collisions



- Applied only Realistic Particle Identification (Real PID)
- Merged signal and background correspond to 10 fb^{-1}
- Fit function (Student's t-function + pol1)
- Next to apply topological cuts based on ML approach
- Boosted Decision Trees (BDT) binary classifier (signal and background)
- Training in each rapidity and p_T ($>1 \text{ GeV}/c$) region

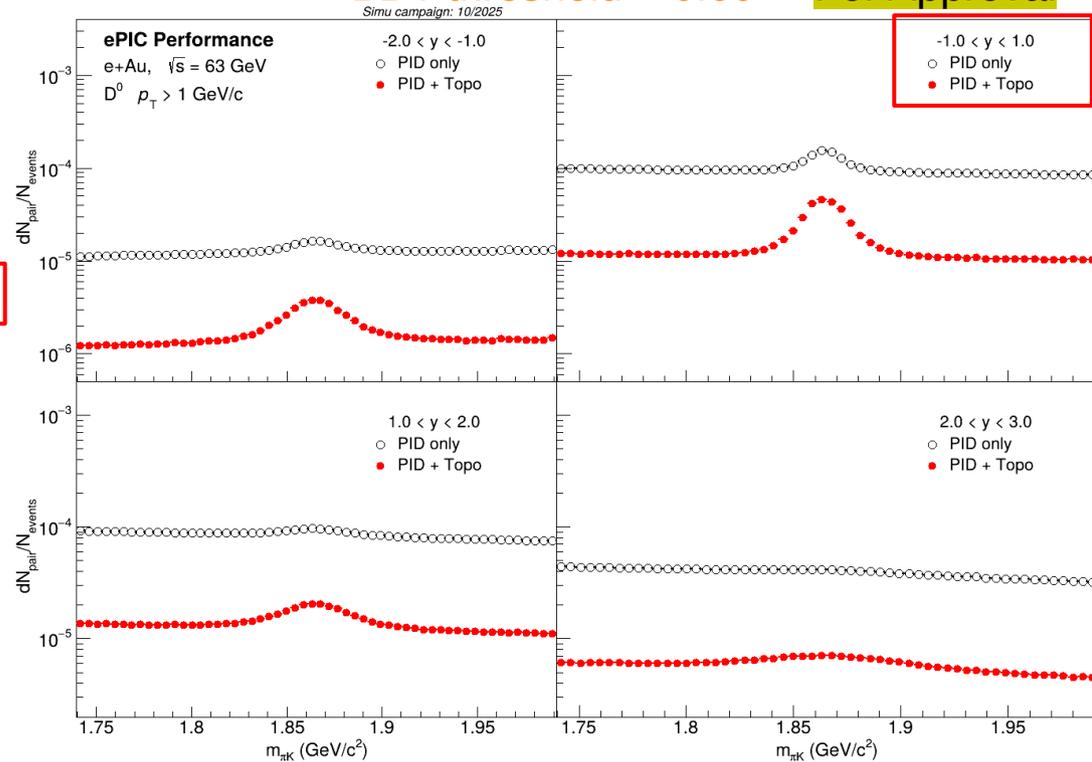
Model trained for each rapidity and $p_T > 1$ GeV/c

BDT threshold > 0.60



BDT threshold = 0.60

For Approval



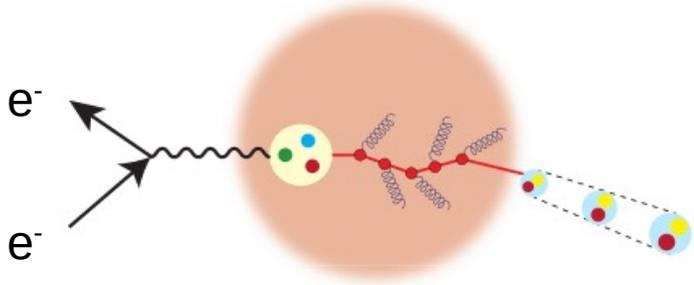
PID Only: using only PID information

PID +Topo: using PID+ Topological cuts with ML

Substantial suppression of the background with ML

Relative Statistical Uncertainty on Nuclear Modification Factor

Topological features and ML



$$R_{eA} = \frac{\sigma_{eA}}{A \times \sigma_{ep}}$$

Energy loss and Hadronization

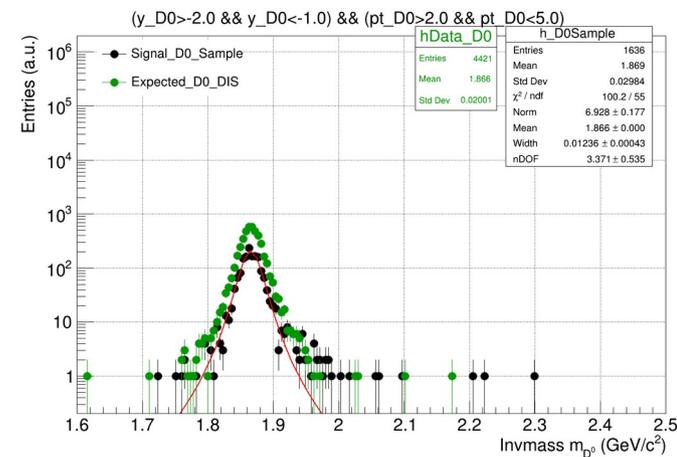
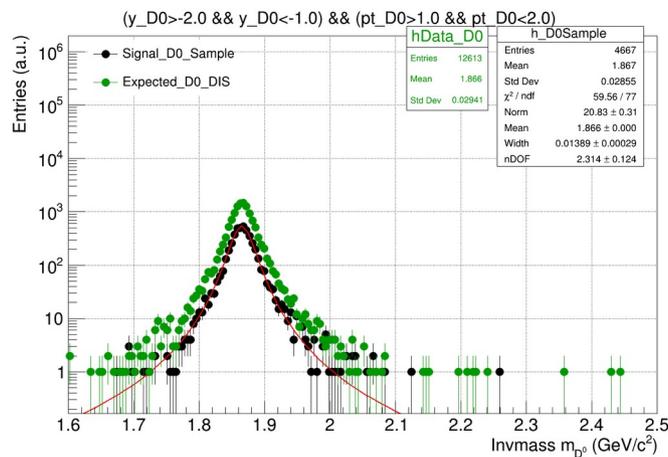
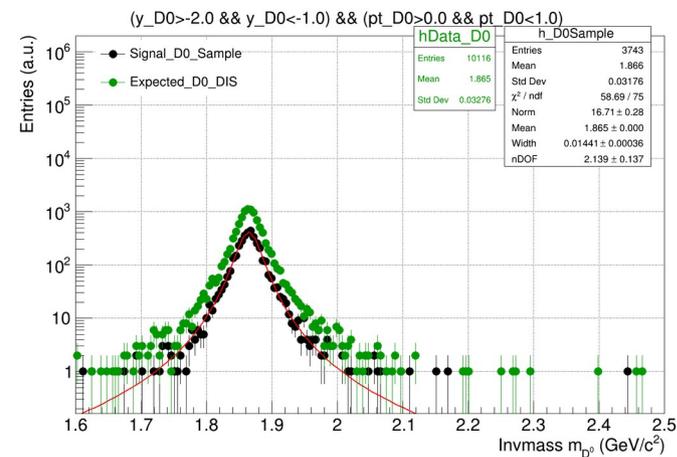
- Phase space
 - Rapidity bins: (-2.0, -1.0), (-1.0, 1.0), (1.0, 3.0)
 - p_T bins: (0.0, 1.0), (1.0, 2.0), (2.0, 5.0), (5.0,10.0) GeV/c
- Preselection Cuts (loose)
 - (mass_D0 > 1.6 && mass_D0 < 2.5) && d0xy_pi<100. && d0xy_k<100. && decay_length <100."
- Sampling Signal (D⁰ sample) and Background (DIS Sample) in each rapidity and p_T bins
- Training ML models in different rapidity bins
 - Backward rapidity: $-2 < y < -1$, $p_T > 0$ GeV/c
 - Mid rapidity: $-1 < y < 1$, $p_T < 1$ GeV/c and $p_T > 1$ GeV/c
 - Forward rapidity: $1 < y < 3$, $p_T < 1$ GeV/c and $p_T > 1$ GeV/c
- Optimization of ML Performance via Maximum Significance
- Estimation of relative statistical uncertainty with ML for ep and eAu in each y bin and p_T range
- Statistical projection of R_{eAu} for $L_{int} = 10 \text{ fb}^{-1}$

Sampling Signal (D^0 Sample)

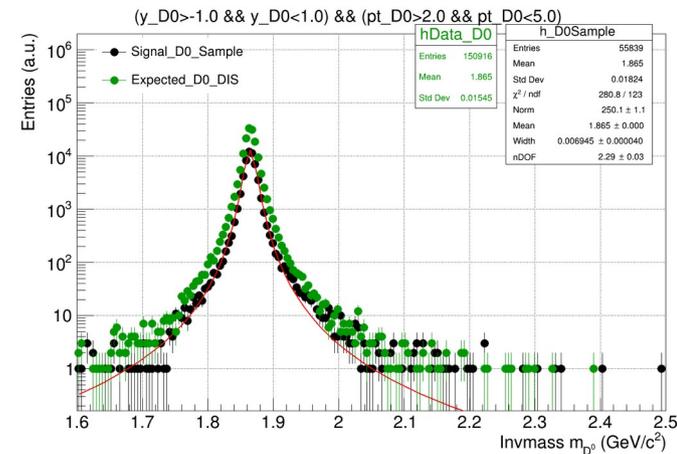
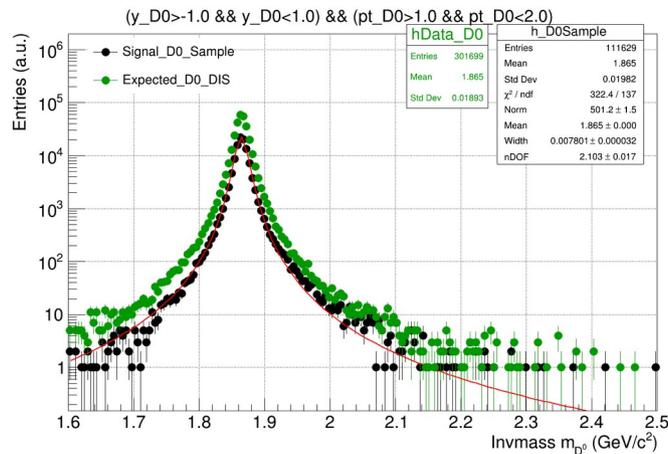
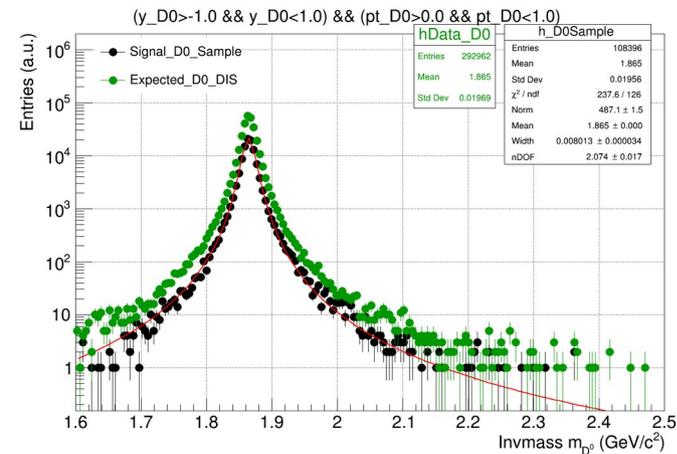
Backward rapidity

$e+p$ collisions

1747M (3.7 fb⁻¹)
4721.62M (10 fb⁻¹)



Mid rapidity

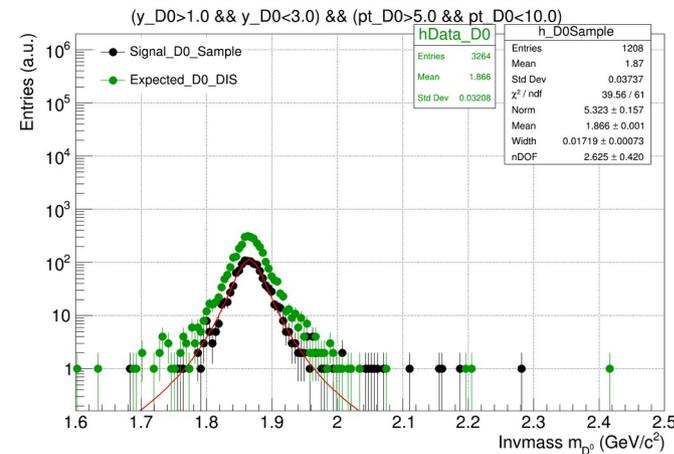
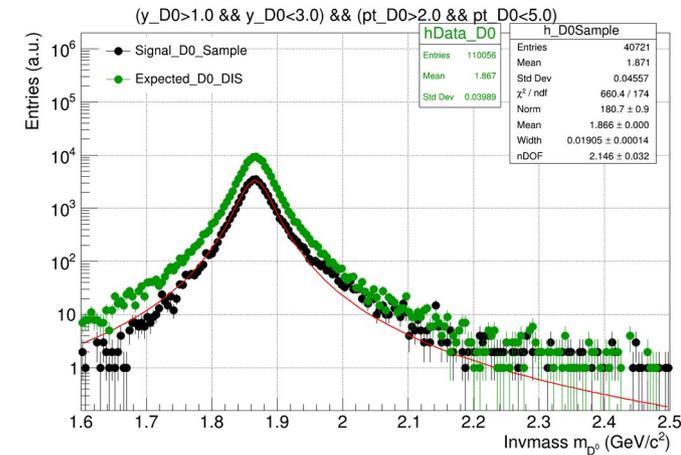
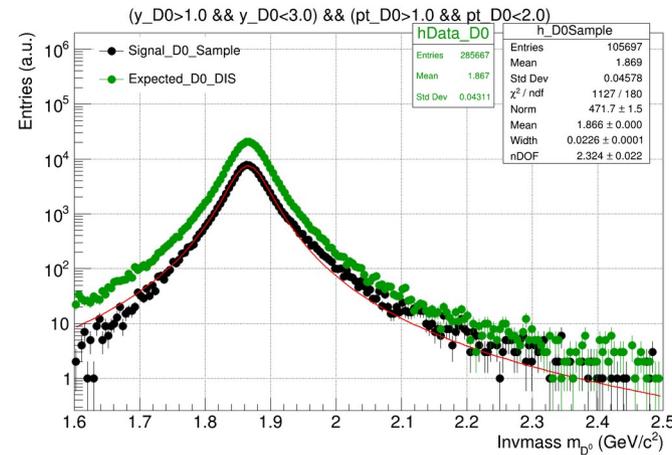
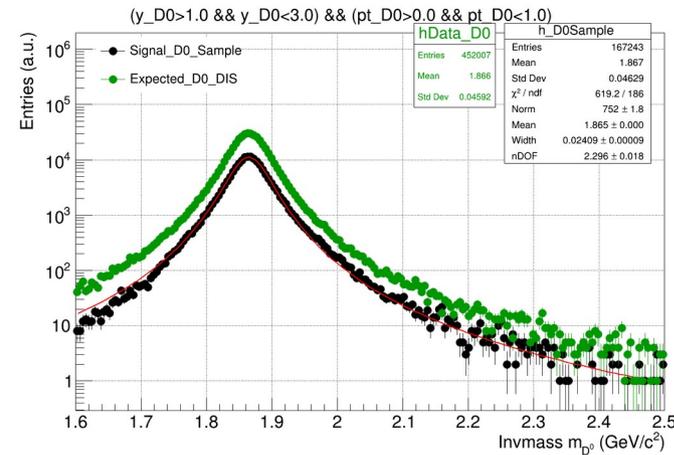


Sampling Signal (D^0 Sample)

Forward rapidity

e+p collisions

1747M (3.7 fb^{-1})
4721.62M (10 fb^{-1})



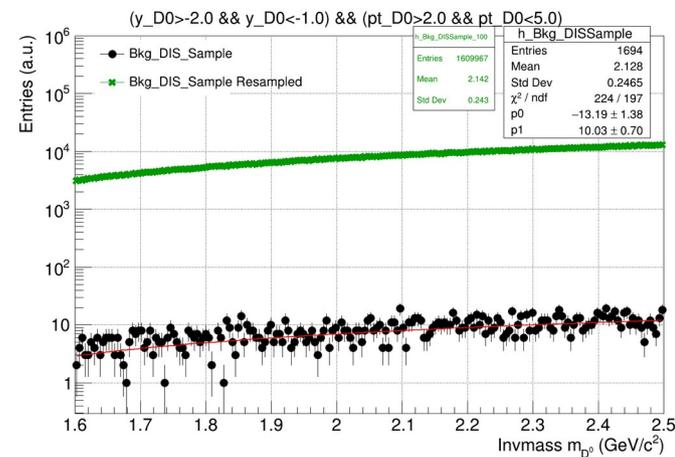
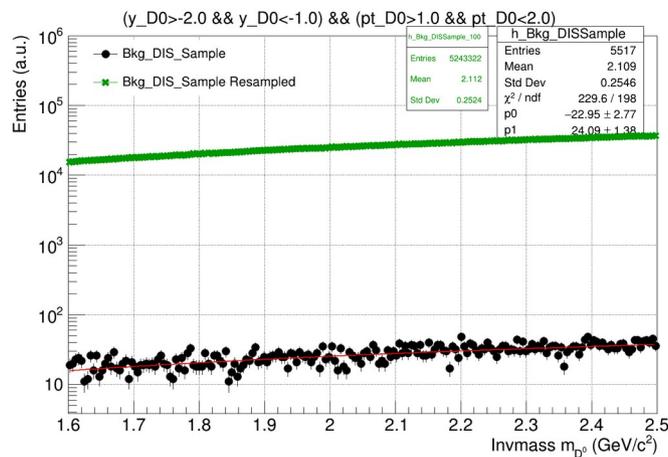
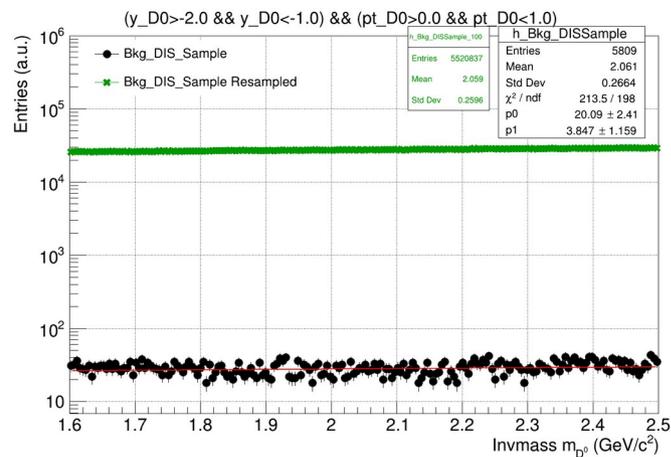
- D^0 sample after applying preselection in e+p collisions
- The sampling at forward rapidity in different p_T bins
- Signal fitted with a Student's t-function
- The distribution (**green**) is sampled to 10 fb^{-1}

Sampling Background (DIS Sample)

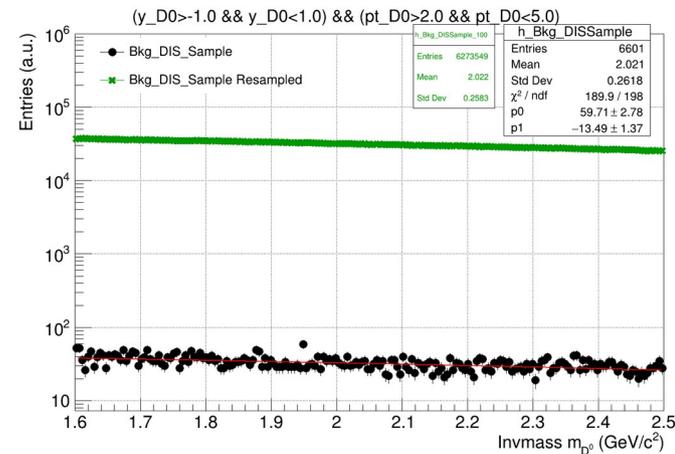
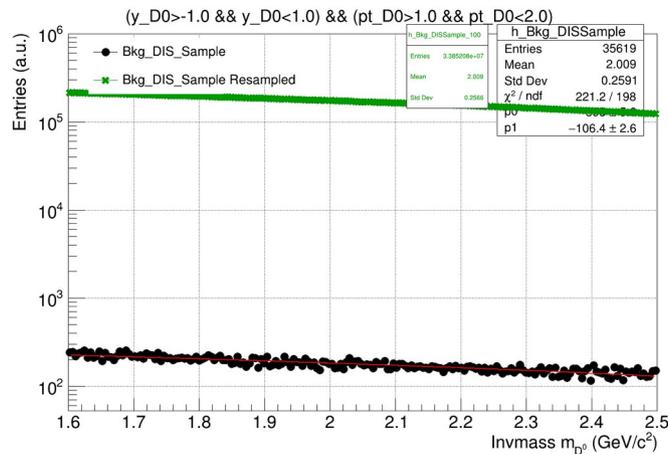
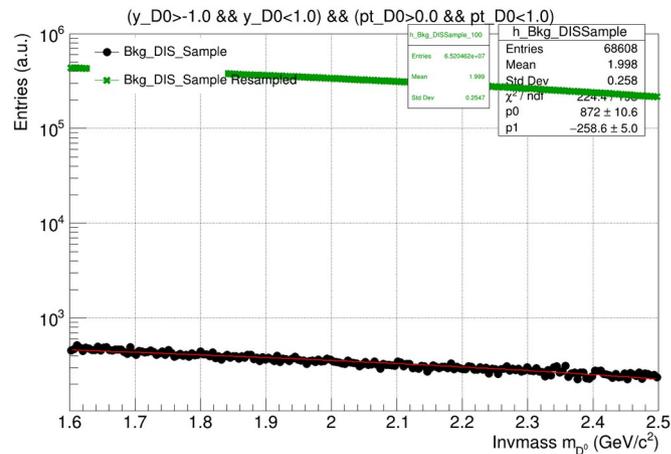
Backward rapidity

e+p collisions

5M
4721.62M (10 fb⁻¹)



Mid rapidity

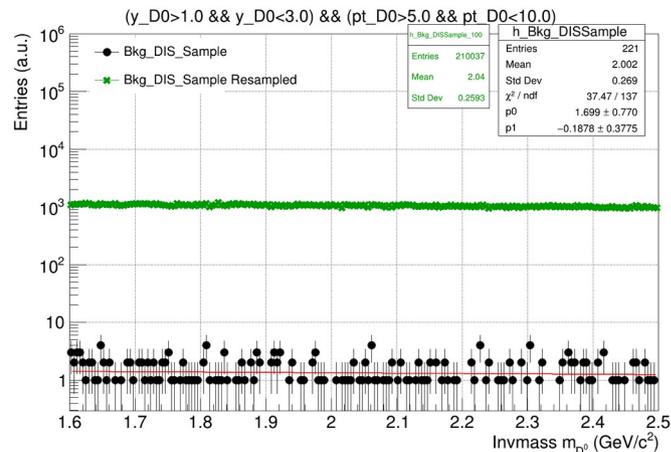
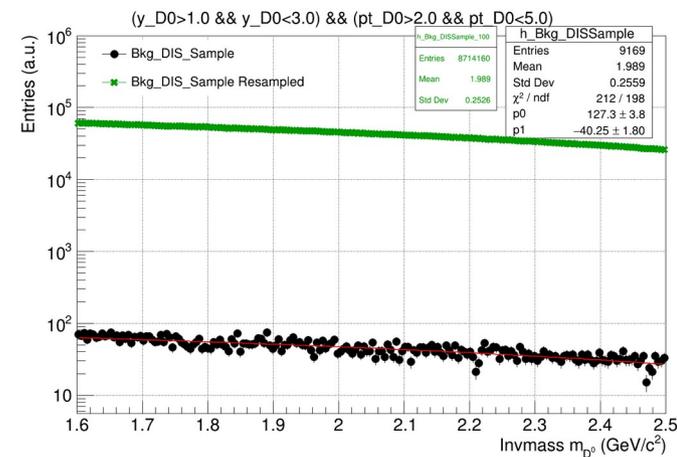
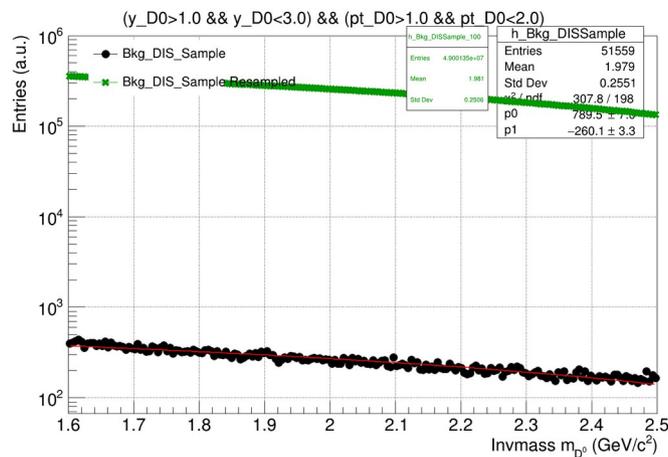
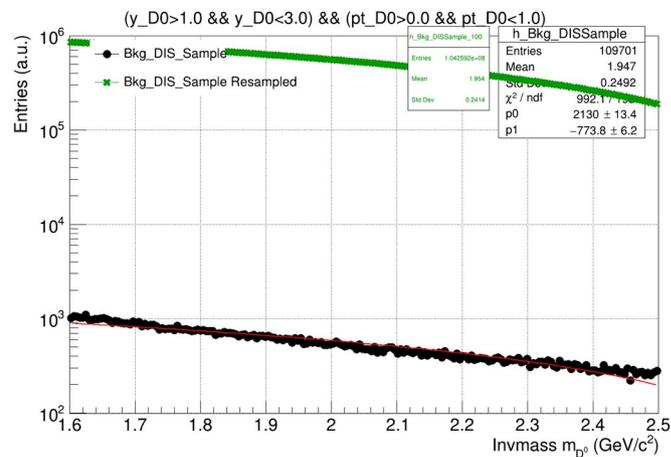


Sampling Background (DIS Sample)

Forward rapidity

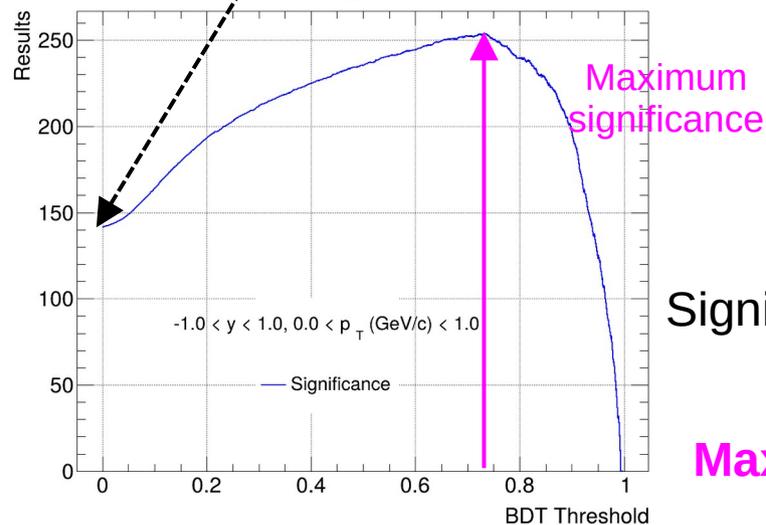
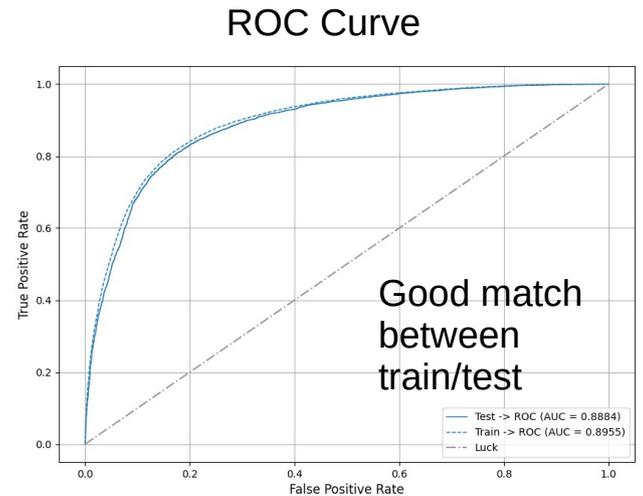
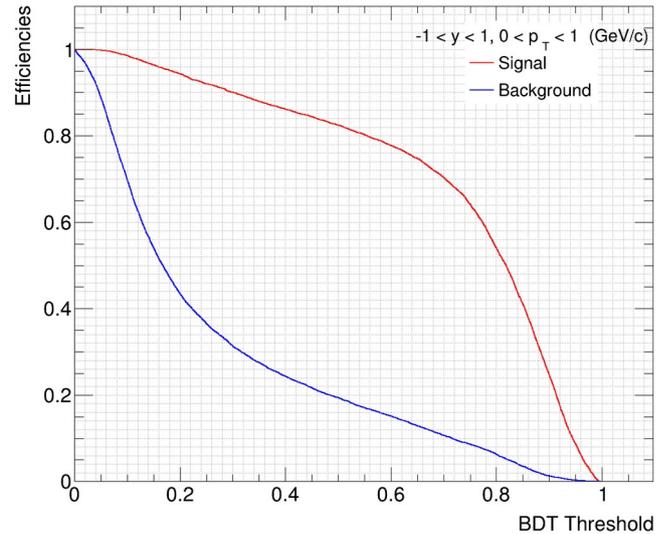
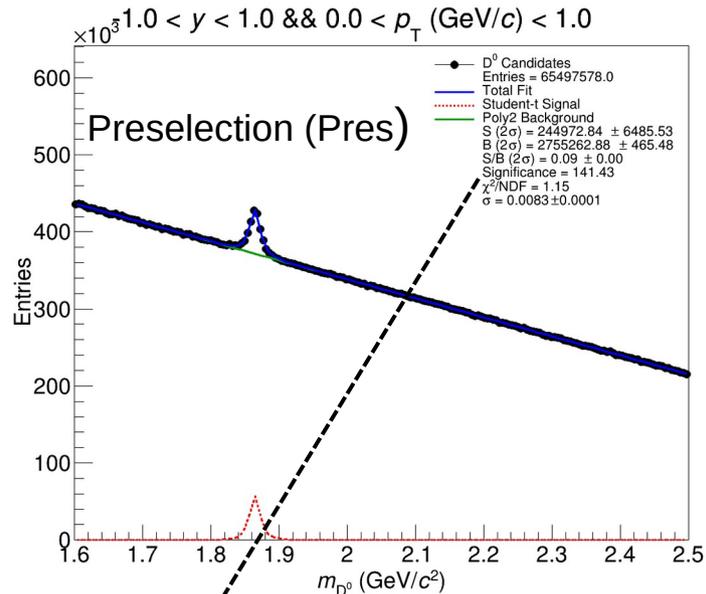
e+p collisions

5M
4721.62M (10 fb⁻¹)



- DIS sample after applying preselection in e+p collisions
- The sampling at forward rapidity in different p_T bins
- Signal fitted with pol1 distribution
- The distribution (**green**) is sampled to 10 fb⁻¹

Invariant Mass Distribution (e+p)



$$\left(\frac{S}{B}\right)_{\text{BDT Thr}} = \left(\frac{S}{B}\right)_{\text{Pres}} \times \left(\frac{\epsilon_{\text{sig}}}{\epsilon_{\text{bkg}}}\right)_{\text{BDT Thr}}$$

Significance

$$\left(\frac{S}{\sigma_S}\right)_{\text{Pres}} = \frac{S}{\sqrt{S+B}}$$

ML

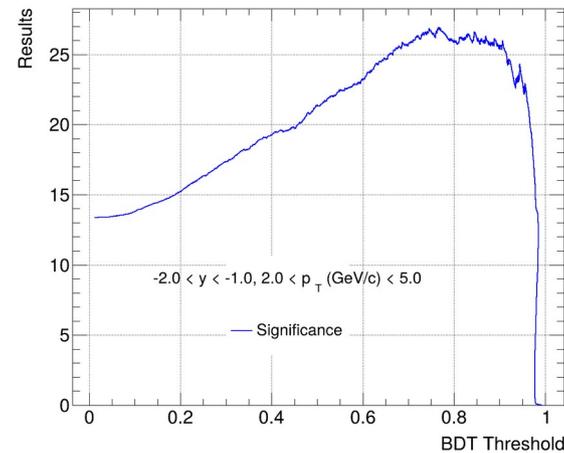
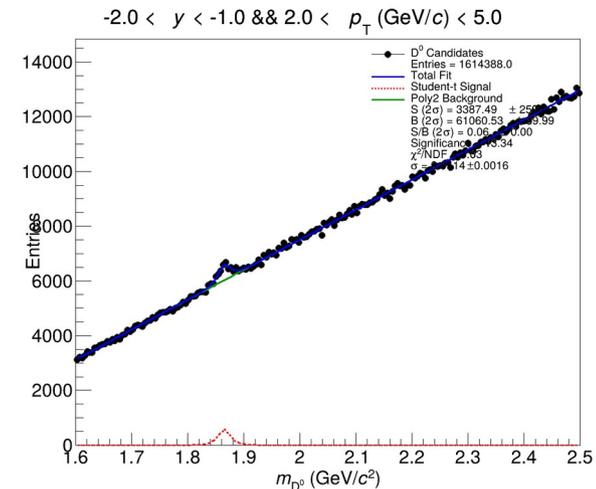
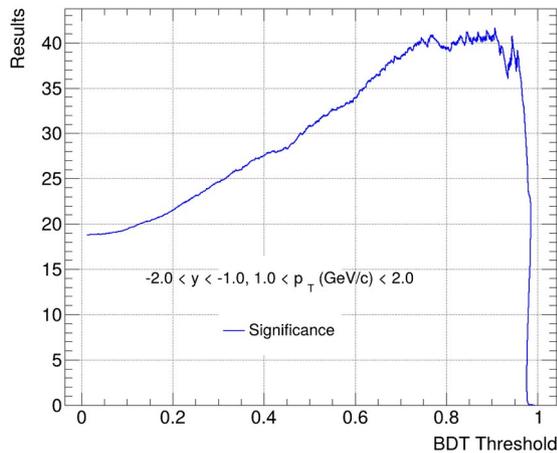
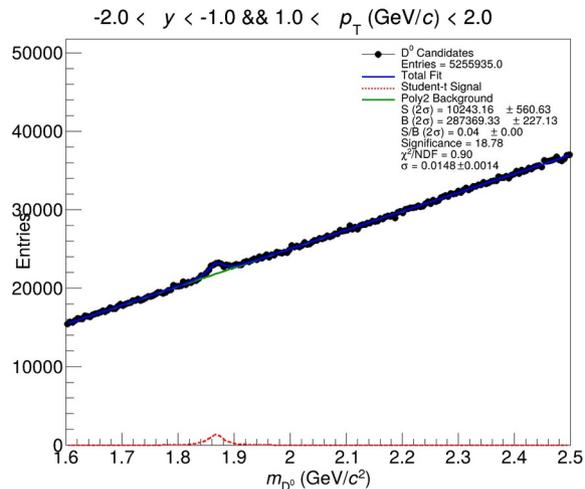
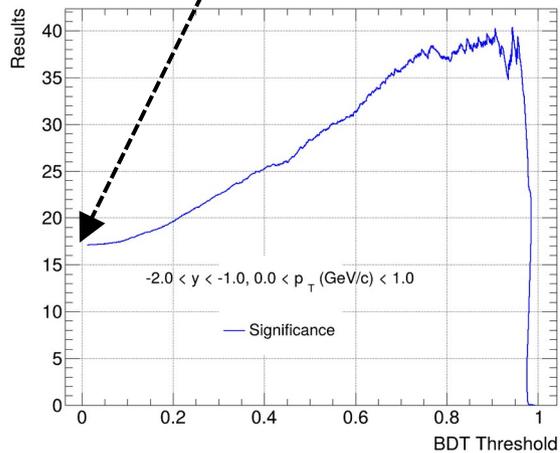
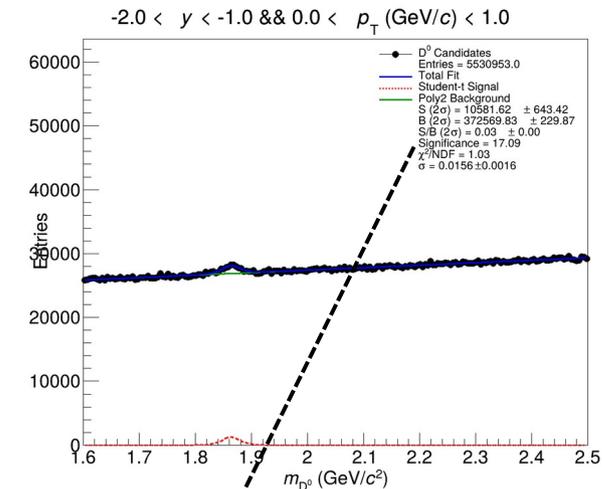
$$\left(\frac{S}{\sigma_S}\right)_{\text{BDT Thr}} = \frac{S \times \epsilon_{\text{sig}}}{\sqrt{S \times \epsilon_{\text{sig}} + B \times \epsilon_{\text{bkg}}}}$$

Maximum significance → Minimum relative uncertainty σ_s/S

Invariant Mass Distribution (e+p)

Optimization based on maximum significance

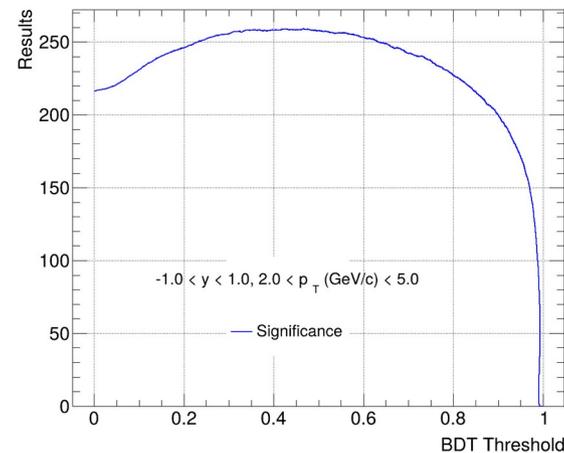
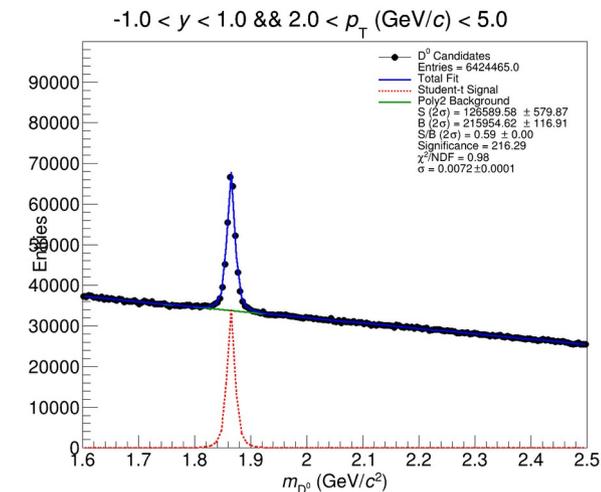
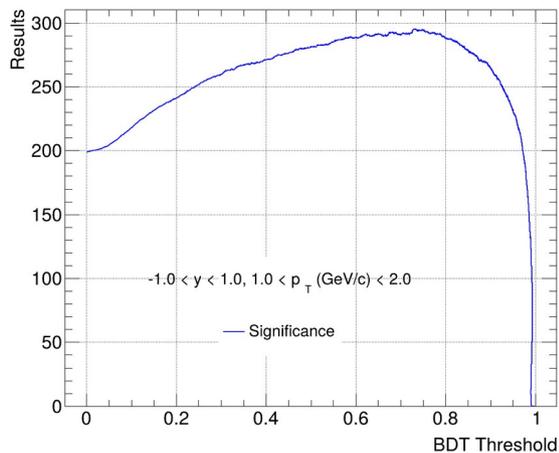
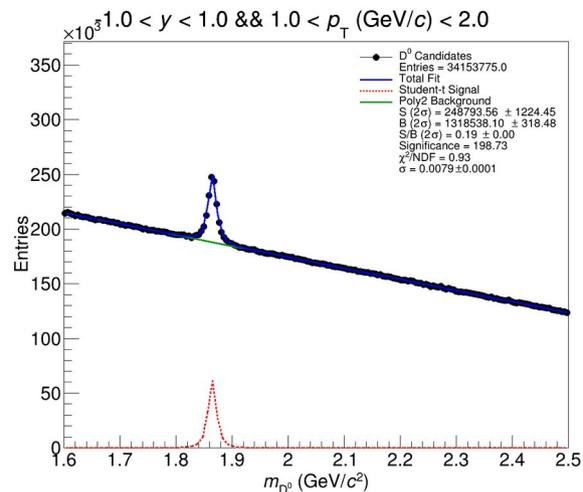
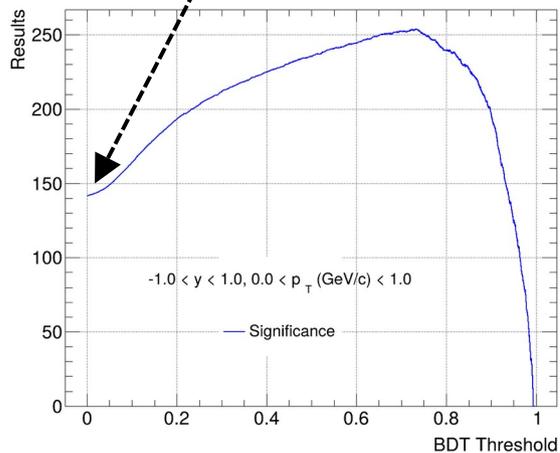
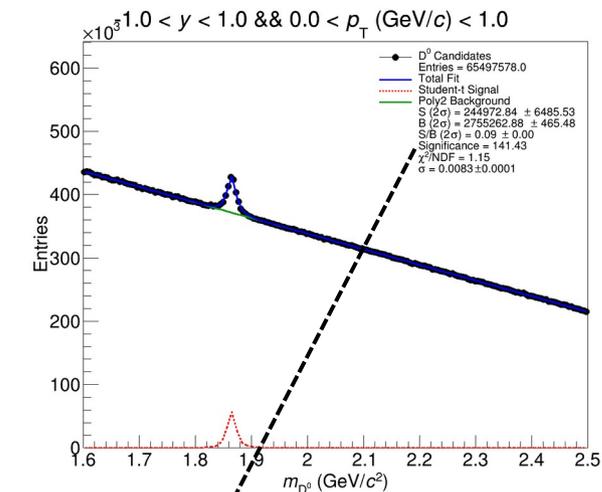
Backward rapidity (Preselections)



Invariant Mass Distribution (e+p)

Optimization based on maximum significance

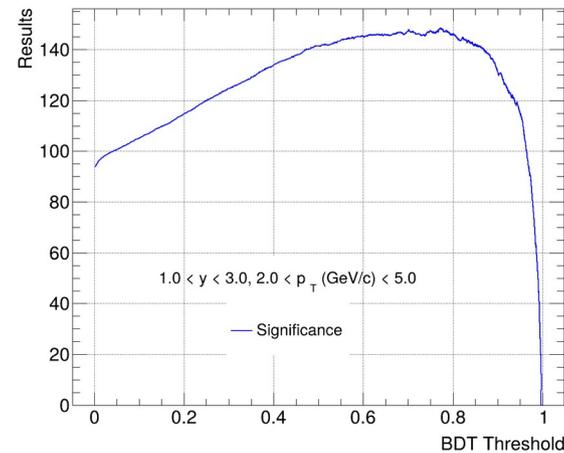
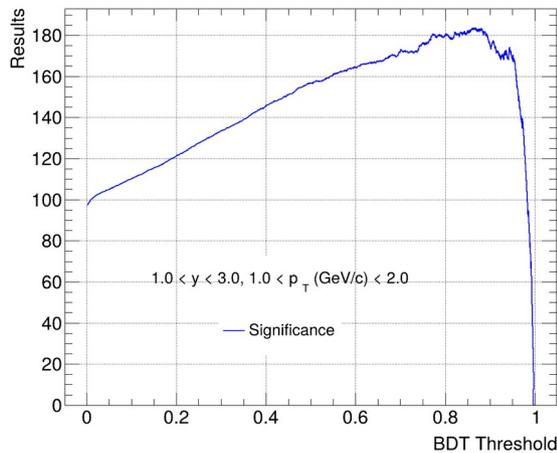
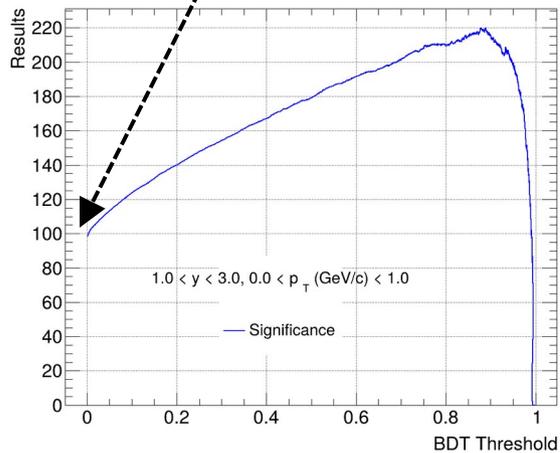
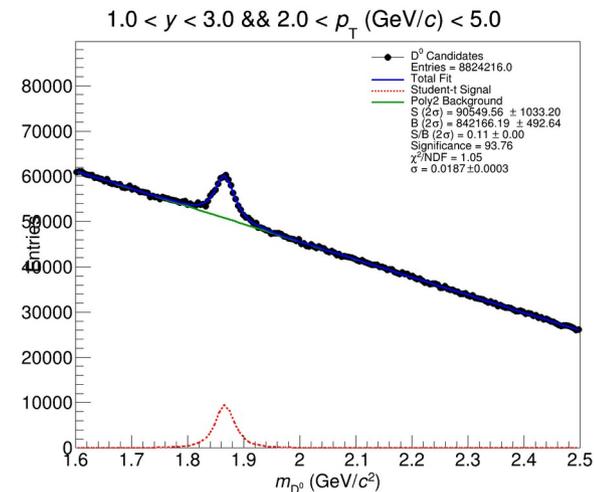
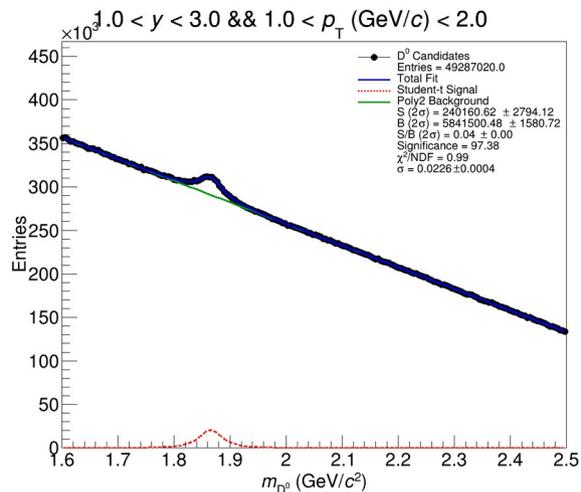
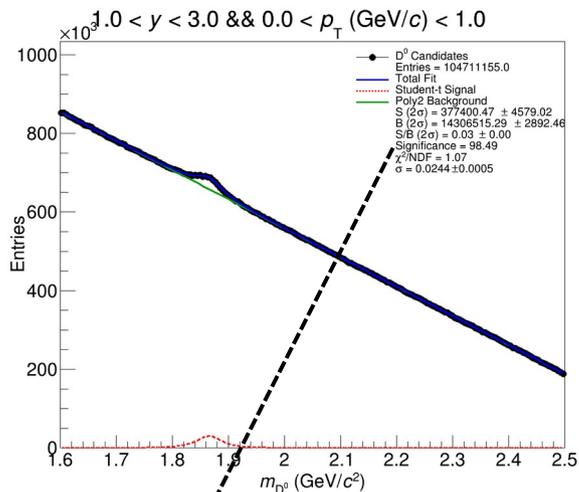
Mid rapidity (Preselections)



Invariant Mass Distribution (e+p)

Optimization based on maximum significance

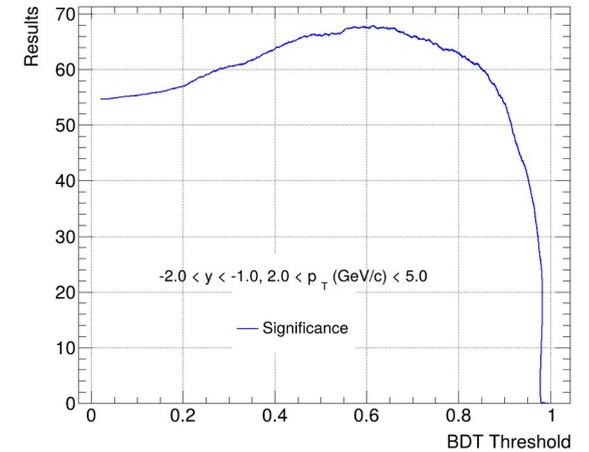
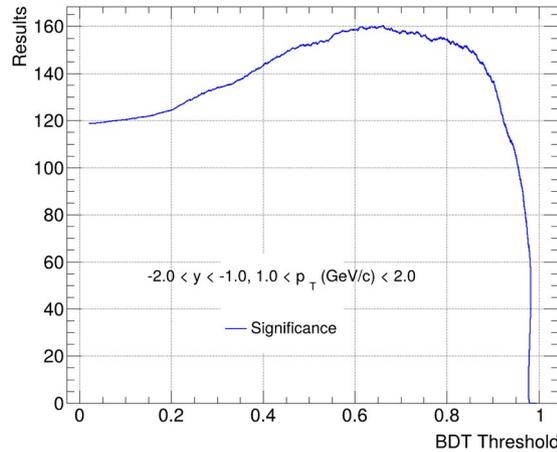
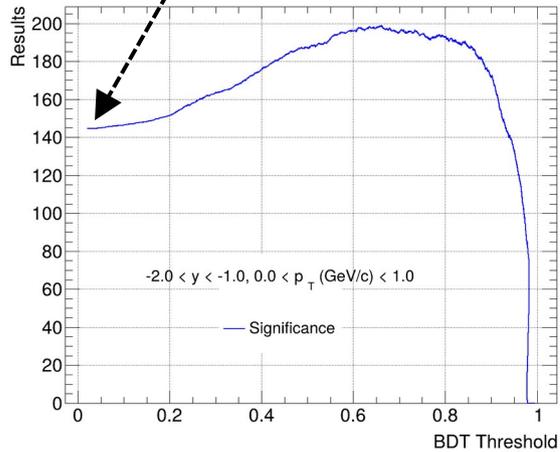
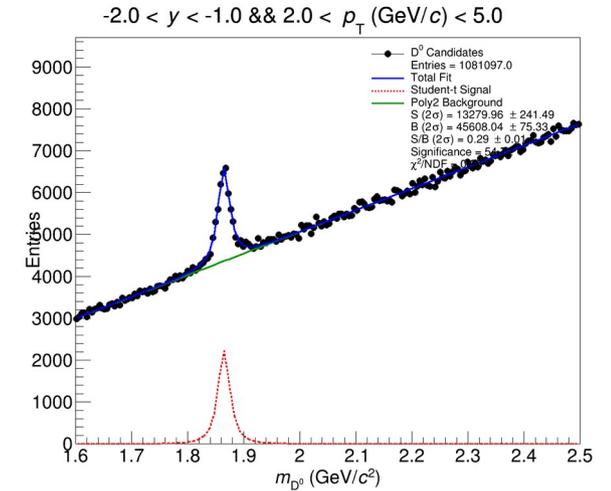
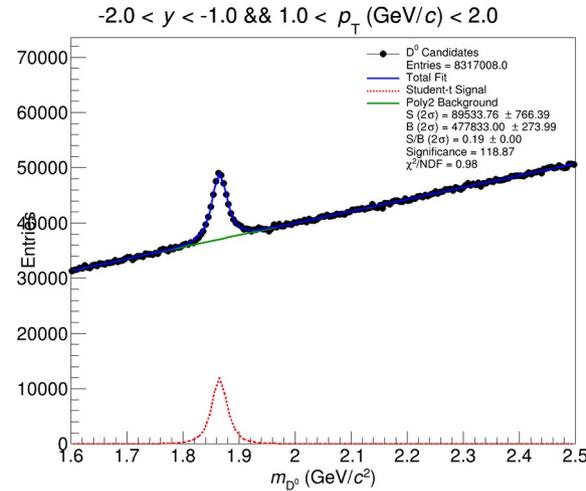
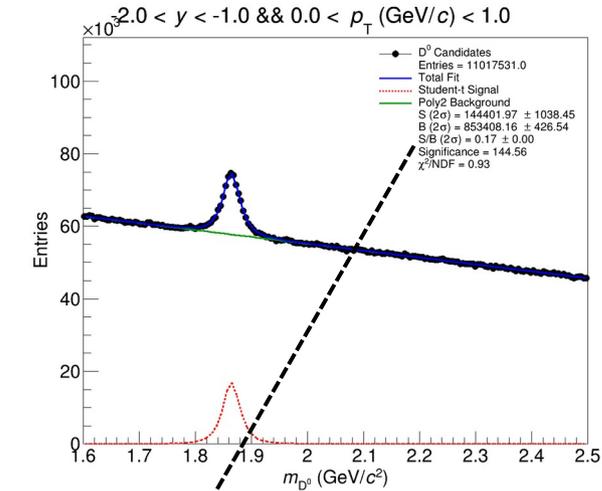
Forward rapidity (Preselections)



Invariant Mass Distribution (e+Au)

Backward rapidity (Preselections)

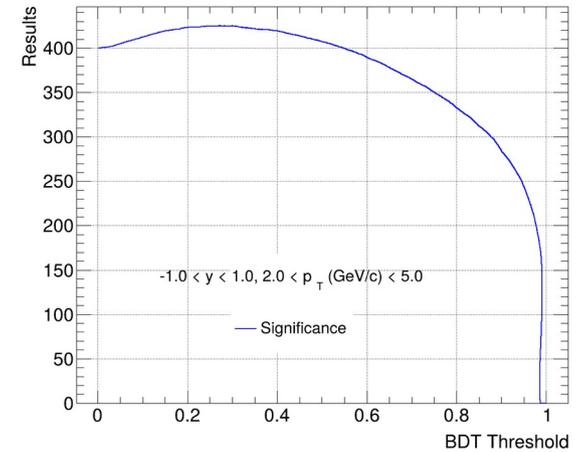
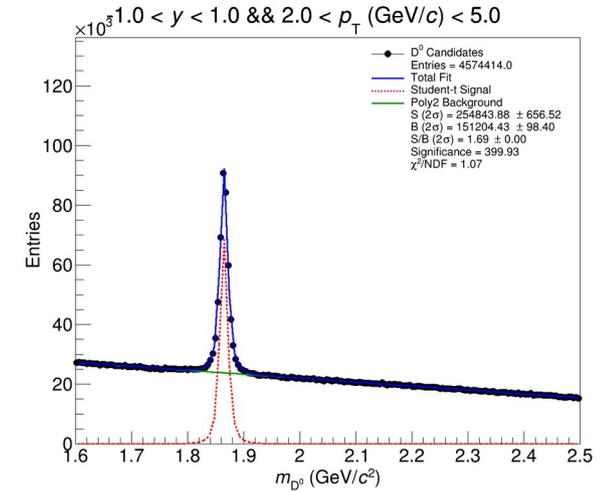
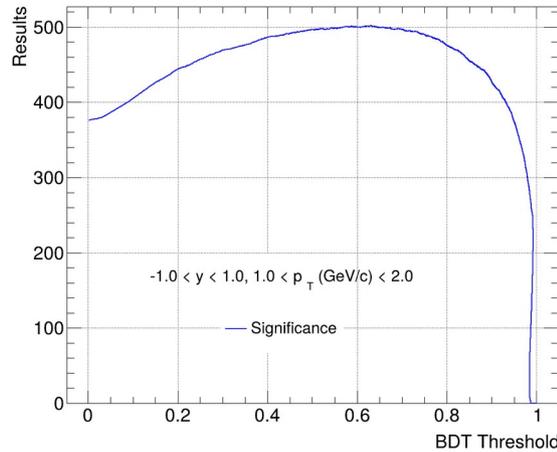
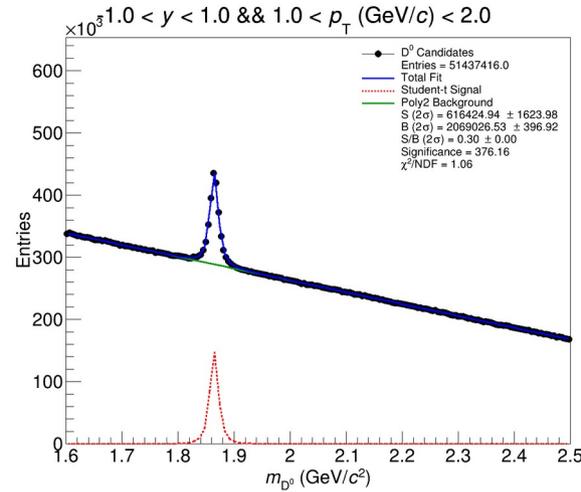
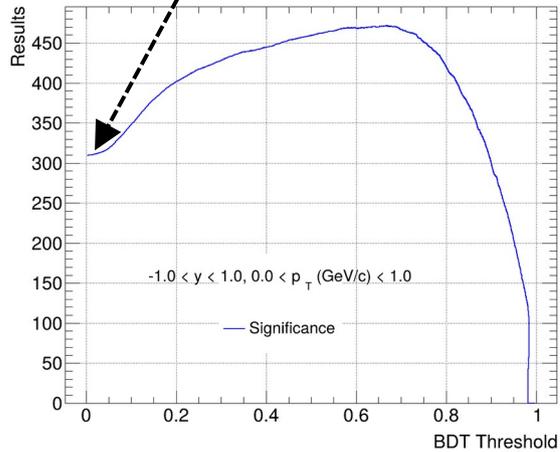
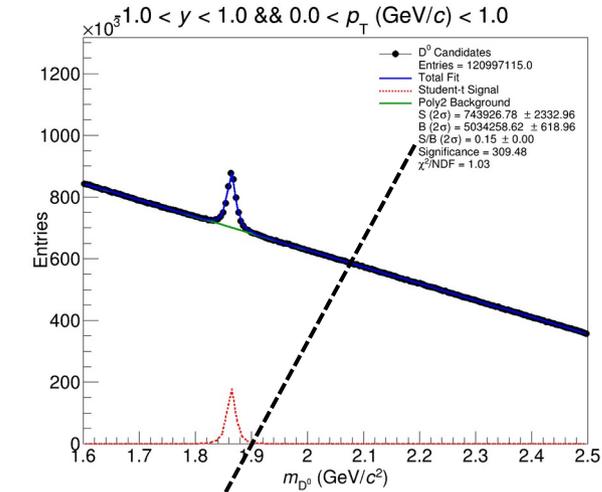
Optimization based on maximum significance



Invariant Mass Distribution (e+Au)

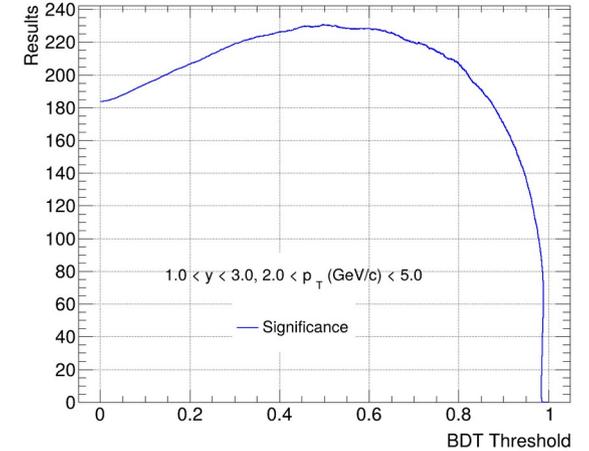
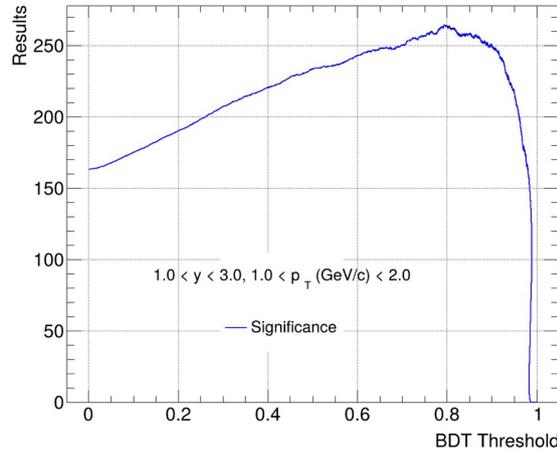
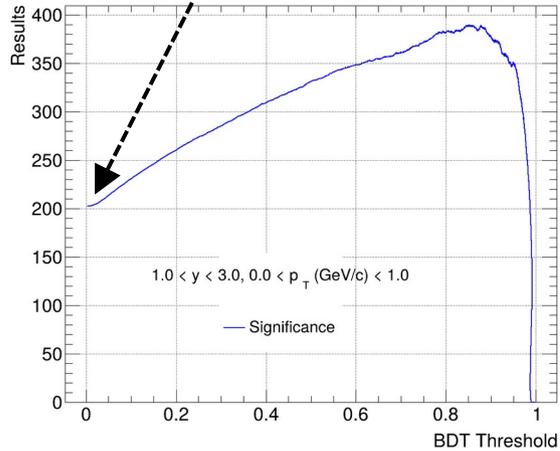
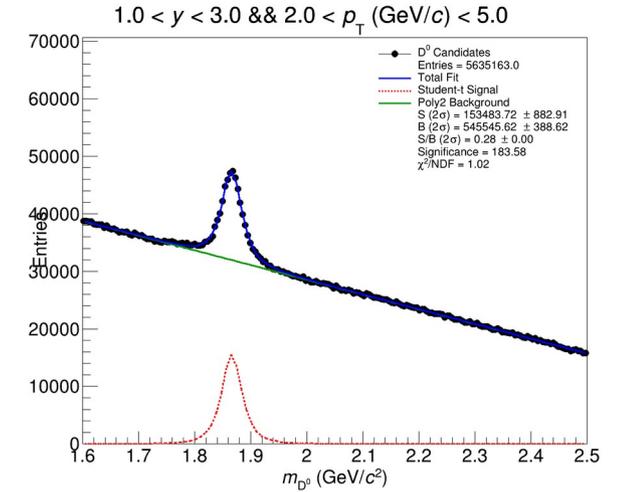
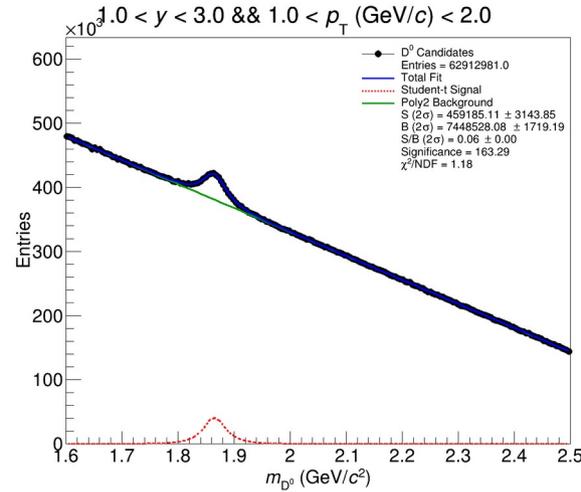
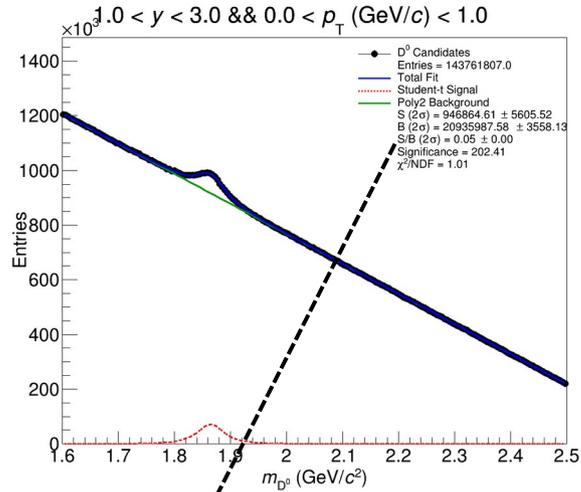
Optimization based on maximum significance

Mid rapidity (Preselections)



Forward rapidity (Preselections)

Optimization based on maximum significance



Relative Statistical Uncertainty (Preselection)

Relative Statistical Uncertainty on R_{eAu}

$$\frac{\sigma_{R_{eAu}}}{R_{eAu}} = \sqrt{\left(\frac{\sigma_S}{S}\right)_{ep}^2 + \left(\frac{\sigma_S}{S}\right)_{eAu}^2}$$

-->(ymin, ymax) = (-2,-1)-->(ptmin, ptmax) = (0,1)-----

eAu: S=144401.9688 B=853408.1875 S/sqrt(S+B) =144.5603 Inverse Significance = 0.0069 rel sigma(S)/S =0.0069
ep: S=10581.7500 B=372566.3438 S/Sqr(S+B) =17.0952 Inverse Significance = 0.0585 rel sigma(S)/S=0.0585
(relative uncertainty after adding in quadrature = 0.0589 = 5.8904%)

-->(ymin, ymax) = (-2,-1)-->(ptmin, ptmax) = (1,2)-----

eAu: S=89533.7656 B=477833.0000 S/sqrt(S+B) =118.8652 Inverse Significance = 0.0084 rel sigma(S)/S =0.0084
ep: S=10243.1553 B=287368.6562 S/Sqr(S+B) =18.7762 Inverse Significance = 0.0533 rel sigma(S)/S=0.0533
(relative uncertainty after adding in quadrature = 0.0539 = 5.3919%)

-->(ymin, ymax) = (-2,-1)-->(ptmin, ptmax) = (2,5)-----

eAu: S=13279.9648 B=45608.0352 S/sqrt(S+B) =54.7247 Inverse Significance = 0.0183 rel sigma(S)/S =0.0183
ep: S=3387.5637 B=61062.7539 S/Sqr(S+B) =13.3437 Inverse Significance = 0.0749 rel sigma(S)/S=0.0749
(relative uncertainty after adding in quadrature = 0.0771 = 7.7138%)

-->(ymin, ymax) = (-1,1)-->(ptmin, ptmax) = (0,1)-----

eAu: S=743926.8125 B=5034258.5000 S/sqrt(S+B) =309.4813 Inverse Significance = 0.0032 rel sigma(S)/S =0.0032
ep: S=244972.8438 B=2755263.0000 S/Sqr(S+B) =141.4296 Inverse Significance = 0.0071 rel sigma(S)/S=0.0071
(relative uncertainty after adding in quadrature = 0.0078 = 0.7774%)

-->(ymin, ymax) = (-1,1)-->(ptmin, ptmax) = (1,2)-----

eAu: S=616424.9375 B=2069026.5000 S/sqrt(S+B) =376.1591 Inverse Significance = 0.0027 rel sigma(S)/S =0.0027
ep: S=248793.5625 B=1318538.1250 S/Sqr(S+B) =198.7278 Inverse Significance = 0.0050 rel sigma(S)/S=0.0050
(relative uncertainty after adding in quadrature = 0.0057 = 0.5691%)

-->(ymin, ymax) = (-1,1)-->(ptmin, ptmax) = (2,5)-----

eAu: S=254843.8906 B=151204.4375 S/sqrt(S+B) =399.9313 Inverse Significance = 0.0025 rel sigma(S)/S =0.0025
ep: S=126589.5781 B=215954.6250 S/Sqr(S+B) =216.2916 Inverse Significance = 0.0046 rel sigma(S)/S=0.0046
(relative uncertainty after adding in quadrature = 0.0053 = 0.5256%)

-->(ymin, ymax) = (-1,1)-->(ptmin, ptmax) = (5,10)-----

eAu: S=5992.3066 B=1103.3960 S/sqrt(S+B) =71.1371 Inverse Significance = 0.0141 rel sigma(S)/S =0.0141
ep: S=4569.1343 B=7420.9136 S/Sqr(S+B) =41.7276 Inverse Significance = 0.0240 rel sigma(S)/S=0.0240
(relative uncertainty after adding in quadrature = 0.0278 = 2.7784%)

-->(ymin, ymax) = (1,3)-->(ptmin, ptmax) = (0,1)-----

eAu: S=946864.6250 B=20935988.0000 S/sqrt(S+B) =202.4118 Inverse Significance = 0.0049 rel sigma(S)/S =0.0049
ep: S=377400.4688 B=14306515.0000 S/Sqr(S+B) =98.4876 Inverse Significance = 0.0102 rel sigma(S)/S=0.0102
(relative uncertainty after adding in quadrature = 0.0113 = 1.1292%)

-->(ymin, ymax) = (1,3)-->(ptmin, ptmax) = (1,2)-----

eAu: S=459185.1250 B=7448528.0000 S/sqrt(S+B) =163.2910 Inverse Significance = 0.0061 rel sigma(S)/S =0.0061
ep: S=240160.6250 B=5841500.5000 S/Sqr(S+B) =97.3847 Inverse Significance = 0.0103 rel sigma(S)/S=0.0103
(relative uncertainty after adding in quadrature = 0.0120 = 1.1956%)

-->(ymin, ymax) = (1,3)-->(ptmin, ptmax) = (2,5)-----

eAu: S=153483.7188 B=545545.6250 S/sqrt(S+B) =183.5755 Inverse Significance = 0.0054 rel sigma(S)/S =0.0054
ep: S=90549.5547 B=842166.1875 S/Sqr(S+B) =93.7587 Inverse Significance = 0.0107 rel sigma(S)/S=0.0107
(relative uncertainty after adding in quadrature = 0.0120 = 1.1976%)

-->(ymin, ymax) = (1,3)-->(ptmin, ptmax) = (5,10)-----

eAu: S=2241.6250 B=2089.0767 S/sqrt(S+B) =34.0631 Inverse Significance = 0.0294 rel sigma(S)/S =0.0294
ep: S=3016.8118 B=15817.9443 S/Sqr(S+B) =21.9821 Inverse Significance = 0.0455 rel sigma(S)/S=0.0455
(relative uncertainty after adding in quadrature = 0.0541 = 5.4142%)

Relative Statistical Uncertainty (Machine Learning)

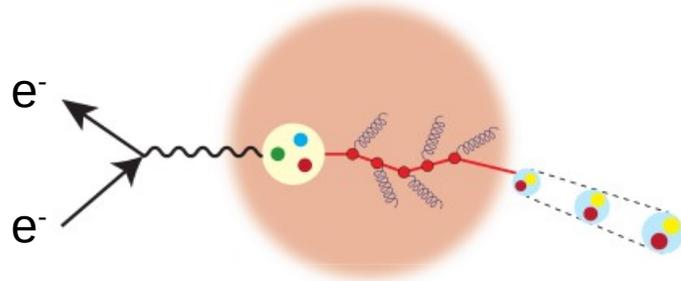
Relative Statistical Uncertainty on R_{eAu}

$$\frac{\sigma_{R_{eAu}}}{R_{eAu}} = \sqrt{\left(\frac{\sigma_S}{S}\right)_{ep}^2 + \left(\frac{\sigma_S}{S}\right)_{eAu}^2}$$

Optimization based on
Maximum significance

-->(ymin, ymax) = (-2,-1)-->ptmin, ptmax) = (0,1)-----
eAu (ML): S/sqrt(S+B) =198.7415 Inverse Significance = 0.0050 rel sqrt(S+B)/S =0.0050
ep (ML): S/sqrt(S+B) =40.3121 Inverse Significance = 0.0248 rel sqrt(S+B)/S=0.0248
(relative uncertainty after adding in quadrature = 0.0253 = 2.5312%)
-->(ymin, ymax) = (-2,-1)-->ptmin, ptmax) = (1,2)-----
eAu (ML): S/sqrt(S+B) =160.2739 Inverse Significance = 0.0062 rel sqrt(S+B)/S =0.0062
ep (ML): S/sqrt(S+B) =41.6596 Inverse Significance = 0.0240 rel sqrt(S+B)/S=0.0240
(relative uncertainty after adding in quadrature = 0.0248 = 2.4802%)
-->(ymin, ymax) = (-2,-1)-->ptmin, ptmax) = (2,5)-----
eAu (ML): S/sqrt(S+B) =67.8824 Inverse Significance = 0.0147 rel sqrt(S+B)/S =0.0147
ep (ML): S/sqrt(S+B) =26.9013 Inverse Significance = 0.0372 rel sqrt(S+B)/S=0.0372
(relative uncertainty after adding in quadrature = 0.0400 = 3.9985%)
-->(ymin, ymax) = (-1,1)-->ptmin, ptmax) = (0,1)-----
eAu (ML): S/sqrt(S+B) =471.6258 Inverse Significance = 0.0021 rel sqrt(S+B)/S =0.0021
ep (ML): S/sqrt(S+B) =254.0291 Inverse Significance = 0.0039 rel sqrt(S+B)/S=0.0039
(relative uncertainty after adding in quadrature = 0.0045 = 0.4471%)
-->(ymin, ymax) = (-1,1)-->ptmin, ptmax) = (1,2)-----
eAu (ML): S/sqrt(S+B) =501.7971 Inverse Significance = 0.0020 rel sqrt(S+B)/S =0.0020
ep (ML): S/sqrt(S+B) =295.3255 Inverse Significance = 0.0034 rel sqrt(S+B)/S=0.0034
(relative uncertainty after adding in quadrature = 0.0039 = 0.3929%)
-->(ymin, ymax) = (-1,1)-->ptmin, ptmax) = (2,5)-----
eAu (ML): S/sqrt(S+B) =425.2099 Inverse Significance = 0.0024 rel sqrt(S+B)/S =0.0024
ep (ML): S/sqrt(S+B) =259.1516 Inverse Significance = 0.0039 rel sqrt(S+B)/S=0.0039
(relative uncertainty after adding in quadrature = 0.0045 = 0.4519%)
-->(ymin, ymax) = (-1,1)-->ptmin, ptmax) = (5,10)-----
eAu (ML): S/sqrt(S+B) =74.0549 Inverse Significance = 0.0135 rel sqrt(S+B)/S =0.0135
ep (ML): S/sqrt(S+B) =49.6580 Inverse Significance = 0.0201 rel sqrt(S+B)/S=0.0201
(relative uncertainty after adding in quadrature = 0.0242 = 2.4246%)
-->(ymin, ymax) = (1,3)-->ptmin, ptmax) = (0,1)-----
eAu (ML): S/sqrt(S+B) =389.9544 Inverse Significance = 0.0026 rel sqrt(S+B)/S =0.0026
ep (ML): S/sqrt(S+B) =220.0056 Inverse Significance = 0.0045 rel sqrt(S+B)/S=0.0045
(relative uncertainty after adding in quadrature = 0.0052 = 0.5219%)
-->(ymin, ymax) = (1,3)-->ptmin, ptmax) = (1,2)-----
eAu (ML): S/sqrt(S+B) =264.6940 Inverse Significance = 0.0038 rel sqrt(S+B)/S =0.0038
ep (ML): S/sqrt(S+B) =183.6558 Inverse Significance = 0.0054 rel sqrt(S+B)/S=0.0054
(relative uncertainty after adding in quadrature = 0.0066 = 0.6627%)
-->(ymin, ymax) = (1,3)-->ptmin, ptmax) = (2,5)-----
eAu (ML): S/sqrt(S+B) =230.6253 Inverse Significance = 0.0043 rel sqrt(S+B)/S =0.0043
ep (ML): S/sqrt(S+B) =148.5929 Inverse Significance = 0.0067 rel sqrt(S+B)/S=0.0067
(relative uncertainty after adding in quadrature = 0.0080 = 0.8006%)
-->(ymin, ymax) = (1,3)-->ptmin, ptmax) = (5,10)-----
eAu (ML): S/sqrt(S+B) =41.6490 Inverse Significance = 0.0240 rel sqrt(S+B)/S =0.0240
ep (ML): S/sqrt(S+B) =31.4945 Inverse Significance = 0.0318 rel sqrt(S+B)/S=0.0318
(relative uncertainty after adding in quadrature = 0.0398 = 3.9808%)

Relative Statistical Uncertainty (Machine Learning)



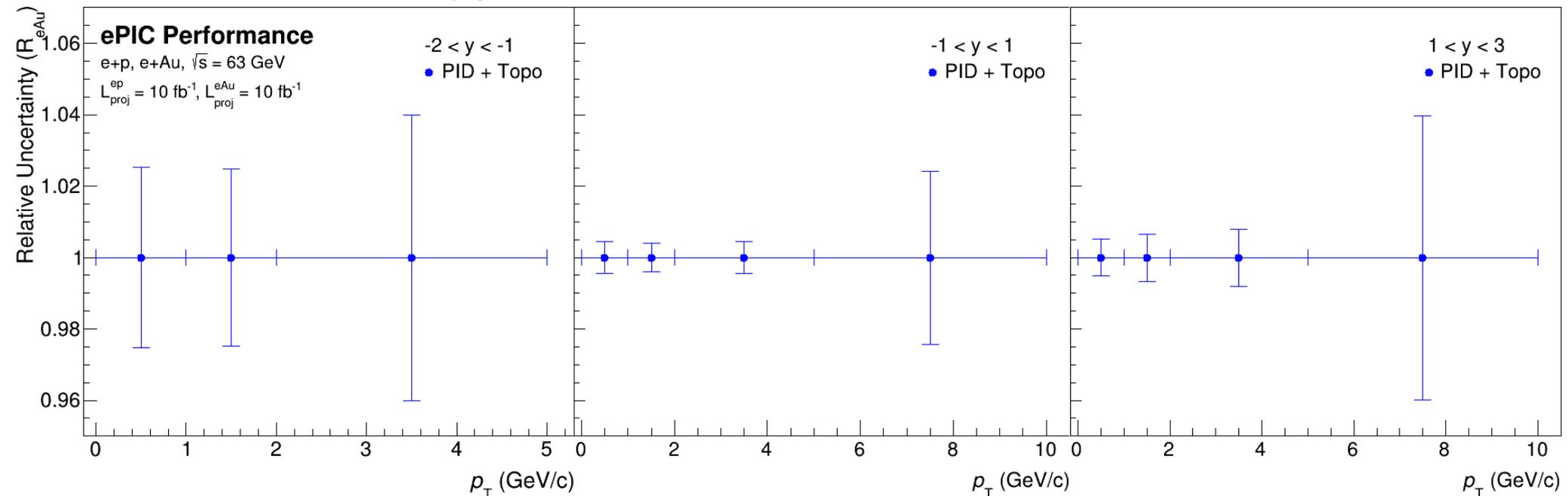
Energy loss and Hadronization

Relative Statistical Uncertainty on R_{eAu}

$$\frac{\sigma_{R_{eAu}}}{R_{eAu}} = \sqrt{\left(\frac{\sigma_S}{S}\right)_{ep}^2 + \left(\frac{\sigma_S}{S}\right)_{eAu}^2}$$

For Approval

Simu campaign: 10/2025



Summary and Future Plan

- The performance studies for the D^0 meson have been reported from the October campaign
- The ML method provides substantial suppression of the background
- The uncertainty of the nuclear modification factor is small, suggesting that the probe of cold nuclear matter effects as a function of p_T can be performed with good precision
- Future Steps (Early Science)
 - Λ_c^+ reconstruction and statistical projection of the Λ_c^+/D^0 ratio (the first version is already ready; [see slides](#))
 - Projected statistical uncertainty on R_{eAu} as a function of the fragmentation variable (z)
 - Performance studies of B and D_s^+ meson reconstruction

Thank you for your attention!

e+p sample

Signal D^0 meson (D^0 sample)

Bkg D^0 meson (DIS Sample)

