Heavy-flavor studies for Early Science (ES)

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e+p 10x250: 2.5 fb^{-1} for Λ_c/D^0 ratio
e+p 10x130, e+Au 10x100: 1 fb^{-1} for R_{eAu} vs z_{proj}

What's New?

- Λ_c/D^0 ratio:
  - Inclusion of prediction from PYTHIA 8.316, ALICE pp, 13 TeV, and HERA data (DIS and Photoproduction) at 320 GeV
  - Inclusion of p_T bin: 5-10 GeV/c
- R_{eAu} vs z_{proj}:
  - p_{Tjet} > 3 GeV/c on D^0-in-charged jets
  - Scaling on cross section for e+Au DIS sample

Data Sample

- D^0 Sample, e+p, 10x250, $Q^2 > 1$ GeV^2
  - epic:/RECO/**26.04.1**/epic_craterlake/SIDIS/D0_ABCONV/HFsim-PYTHIA/**pythia8.312-2.0**/ep/10x250/q2_1
- Λc Sample, e+p, 10x250, $Q^2 > 1$ GeV^2
  - epic:/RECO/**26.04.1**/epic_craterlake/SIDIS/Lc_ABCONV/HFsim-PYTHIA/**pythia8.312-2.0**/ep/10x250/q2_1
- **Biased** NC, DIS Sample e+p, 10x250, $Q^2 > 1$ GeV^2 (Biased in different Q^2 bins)
  - Command: rucio did list --short "epic:/RECO/26.04.1/epic_craterlake/DIS/pythia6.428-1.0/NC/noRad/ep/10x250/*"
  - epic:/RECO/**26.04.1**/epic_craterlake/DIS/**pythia6.428-1.0**/NC/noRad/ep/10x250/q2_1to10
  - epic:/RECO/**26.04.1**/epic_craterlake/DIS/**pythia6.428-1.0**/NC/noRad/ep/10x250/q2_10to100
  - epic:/RECO/**26.04.1**/epic_craterlake/DIS/**pythia6.428-1.0**/NC/noRad/ep/10x250/q2_100to1000
  - epic:/RECO/**26.04.1**/epic_craterlake/DIS/**pythia6.428-1.0**/NC/noRad/ep/10x250/q2_1000to10000

Event generator and energy	$Q^2 > 1$	$1 < Q^2 < 10$	$10 < Q^2 < 100$	$1e2 < Q^2 < 1e3$	$1e3 < Q^2 < 1e4$
PYTHIA 8.316, 10x130	5.847e5 pb	5.391e5 pb	4.223e4 pb	1.590e3 pb	1.260e1 pb
PYTHIA 8.316, 10x250	6.556e5 pb	6.054e5 pb	5.291e4 pb	2.322e3 pb	3.686e1 pb
PYTHIA 8.316, 9x130	5.719e5 pb	5.307e5 pb	4.048e4 pb	1.475e3 pb	1.001e1 pb
PYTHIA 8.316, 9x275	6.546e5 pb	6.025e5 pb	5.178e4 pb	2.292e3 pb	3.697e1 pb

Cross section in different Q2 bins: Slides

Current scaling factor

$$f_i = \frac{\sigma(Q_i^2)}{\sigma(Q^2>1)}$$

Λ_c Reconstruction

Signal from Λc sample while combinatorial bkg from DIS Sample

Corrections on signal:

1. Weight factor of 3 for signal for $Q^2 < 5\ GeV^2$
2. Branching Ratio Scaling
3. Scaling to target luminosity 2.5 fb^{-1}

Bkg:

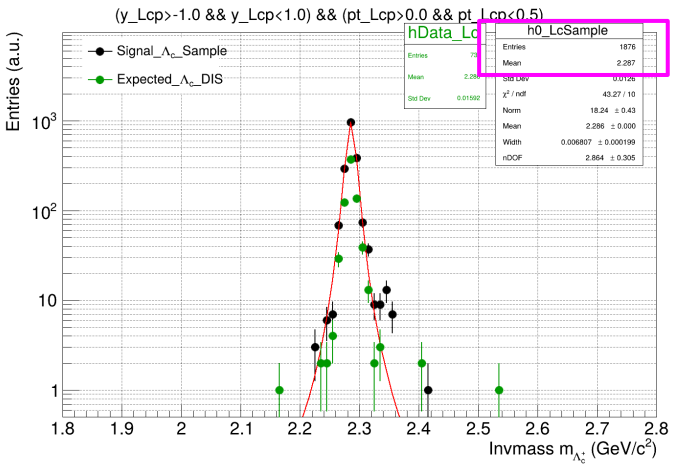
1. Scaling of cross section in each Q^2 bin
2. Scaling to targeted luminosity

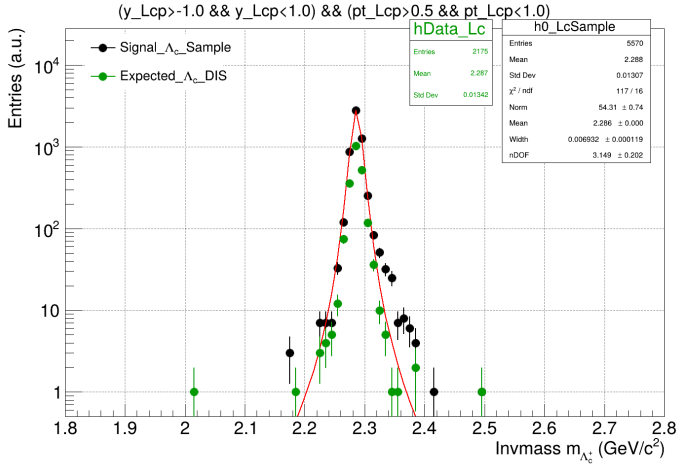
preselection_cuts='(mass_Lcp > 1.8 && mass_Lcp < 2.8) && d0xy_p<10. && d0xy_pi<10. && d0xy_k<10. && chi2 <10.'

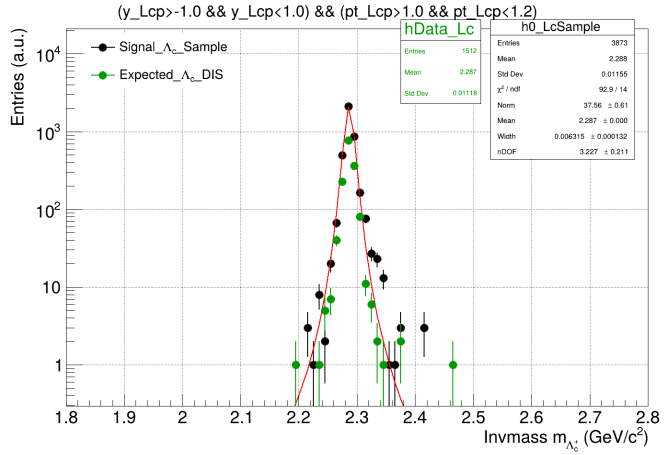
Sampling Signal (-1 < y < 1)

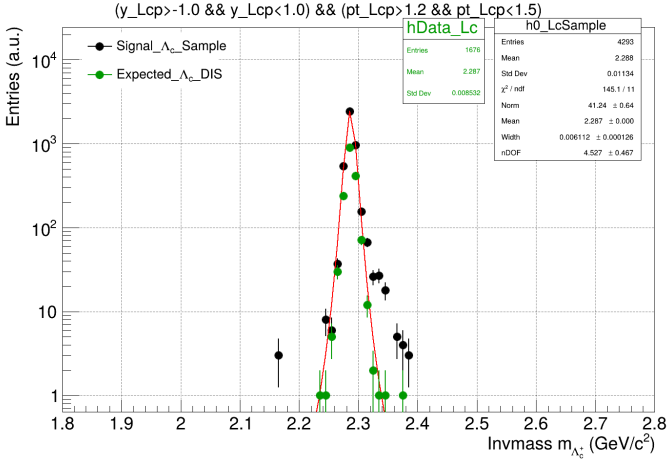
B.R. Scaling = 0.0635/0.0075 ~8.47

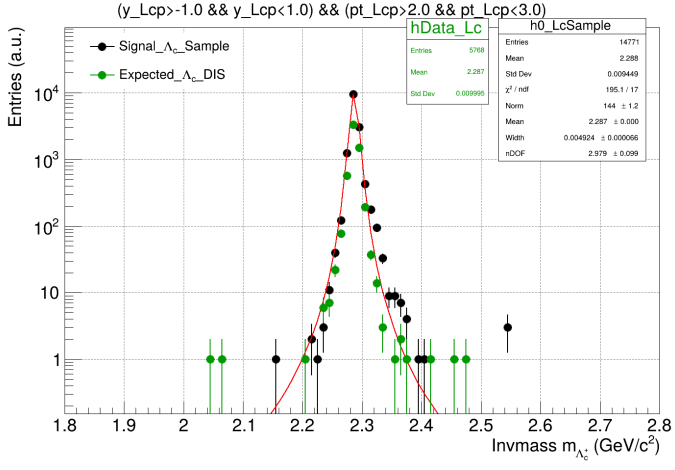
$L_{int} = 54.2\,fb^{-1}$ (Q2 Weighted) $L_{int} = 2.5\,fb^{-1}$

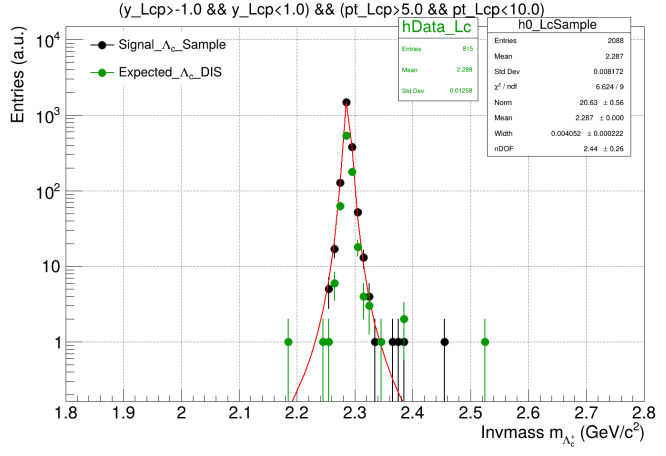








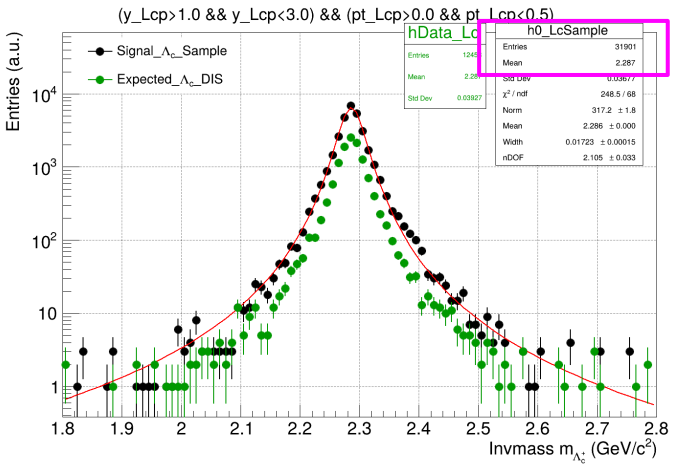


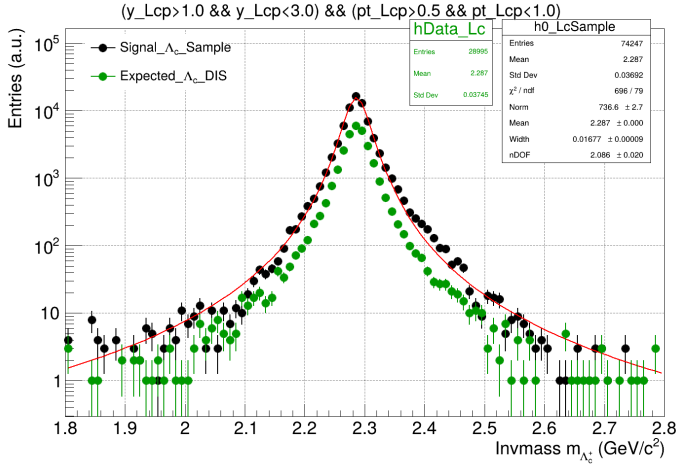


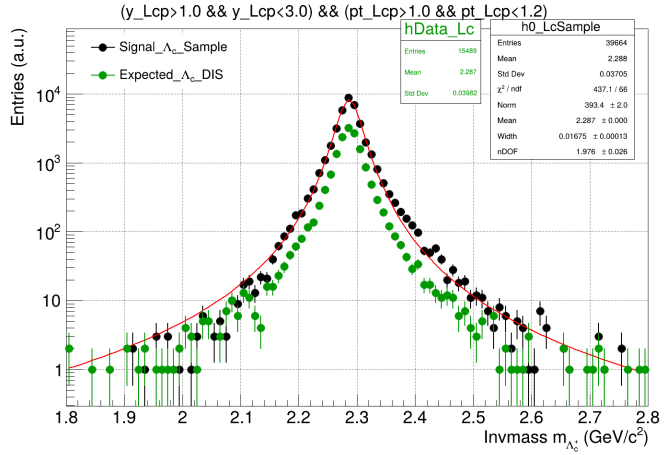
Sampling Signal (1 < y < 3)

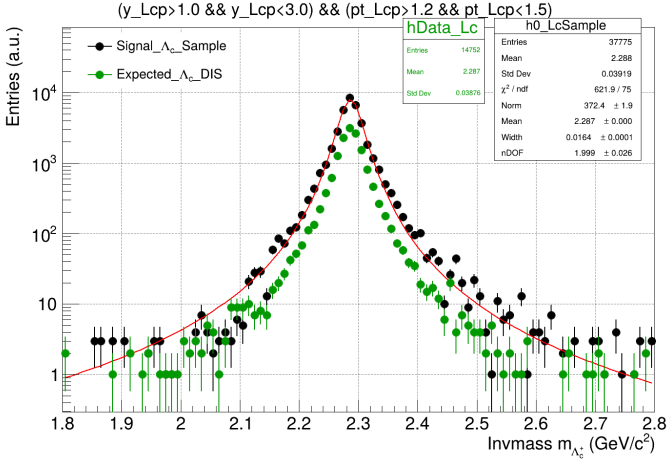
B.R. Scaling = 0.0635/0.0075 ~8.47

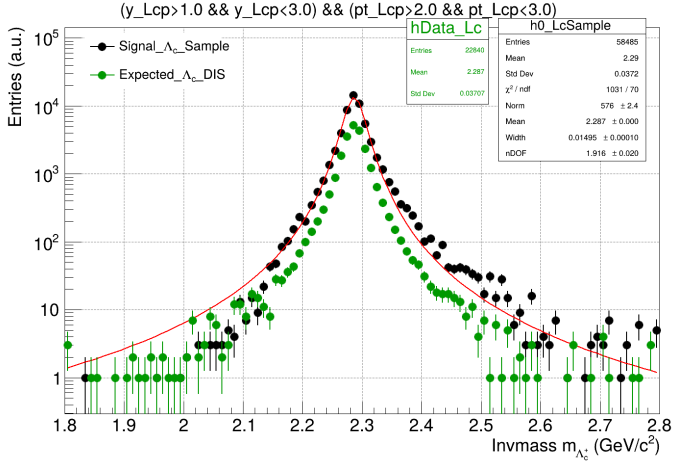
$L_{int} = 54.2\,fb^{-1}$ (Q2 Weighted) $L_{int} = 2.5\,fb^{-1}$

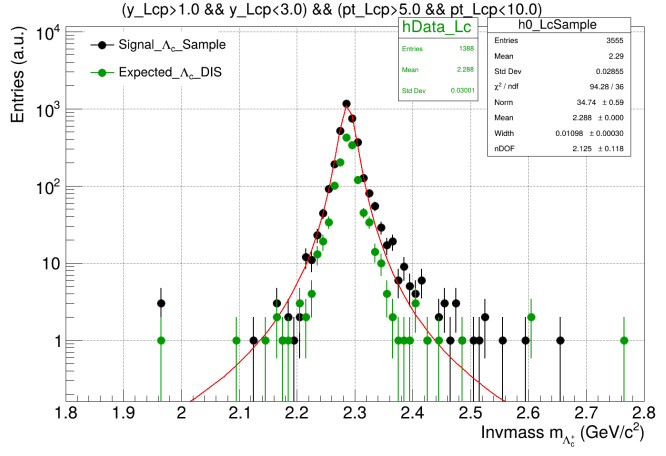








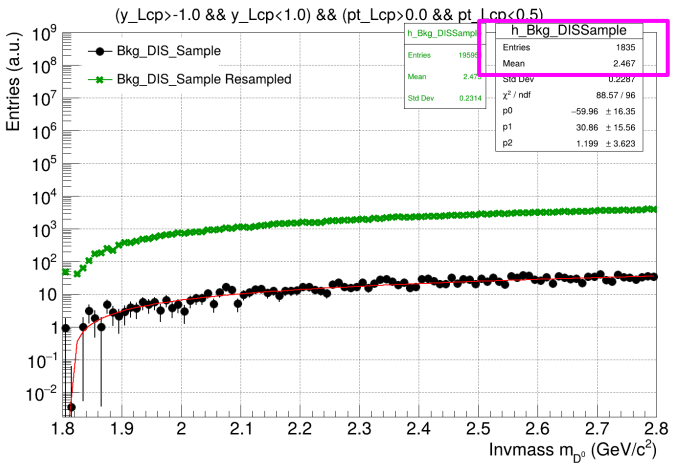


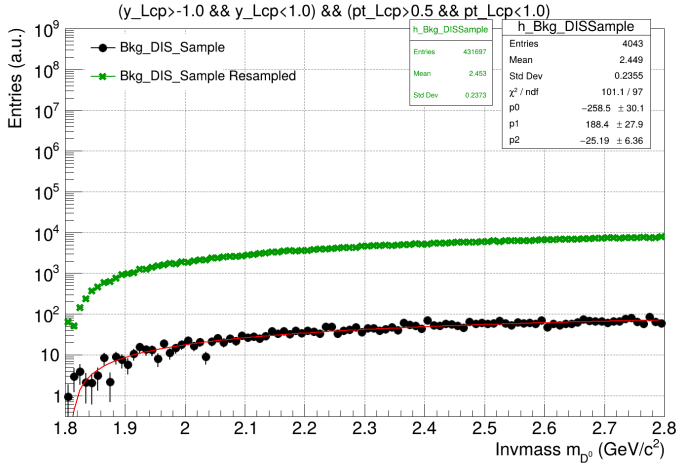


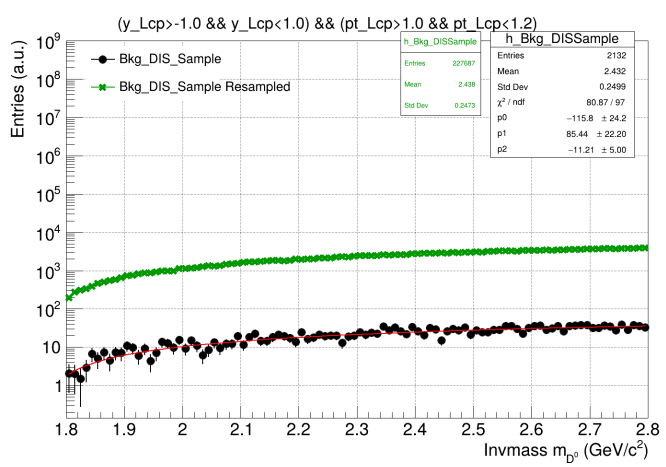
Sampling Background (-1 < y < 1)

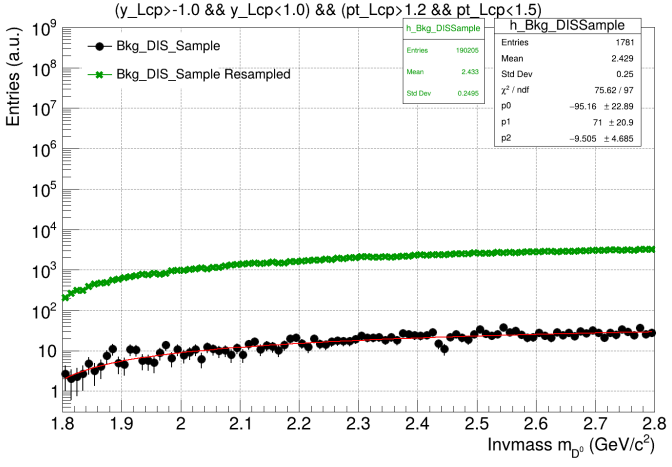
σ_{MB} = 655.6 nb

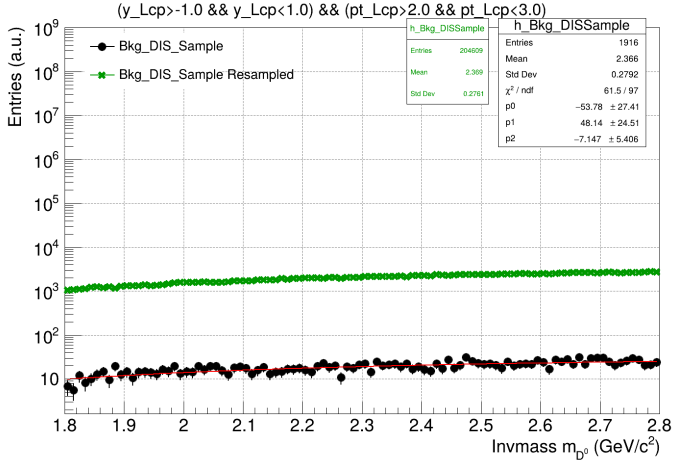
$L_{int} = 0.023412178\,fb^{-1}$ $L_{int} = 2.5\,fb^{-1}$

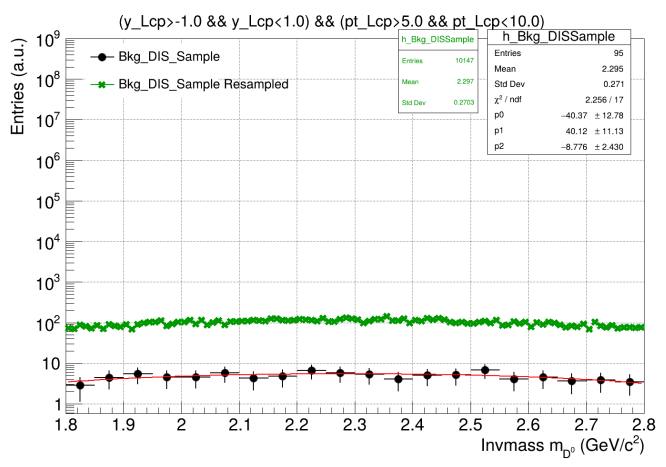








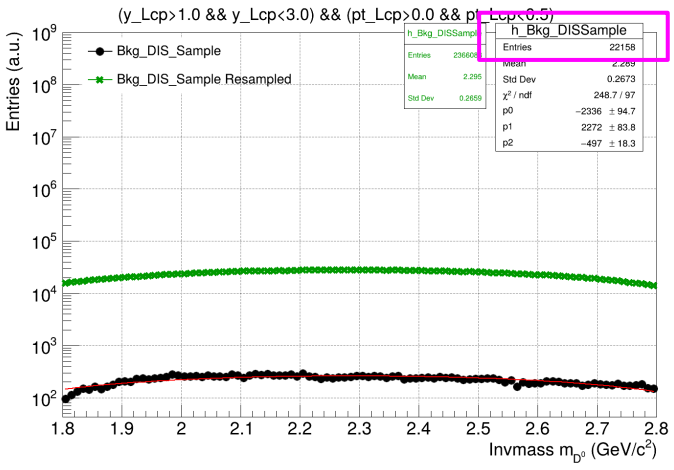


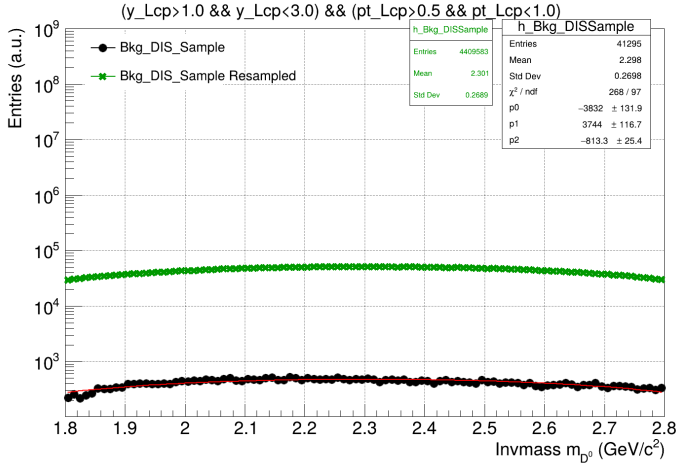


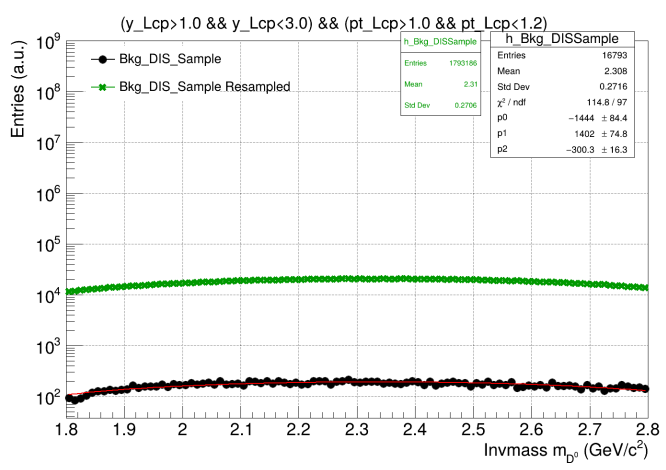
Sampling Background (1 < y < 3)

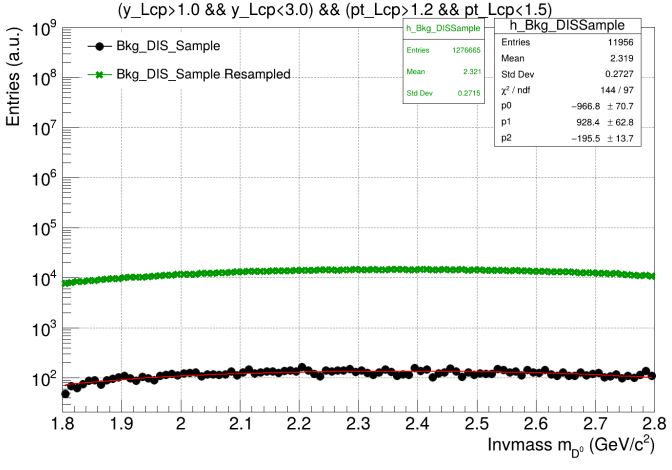
σ_{MB} = 655.6 nb

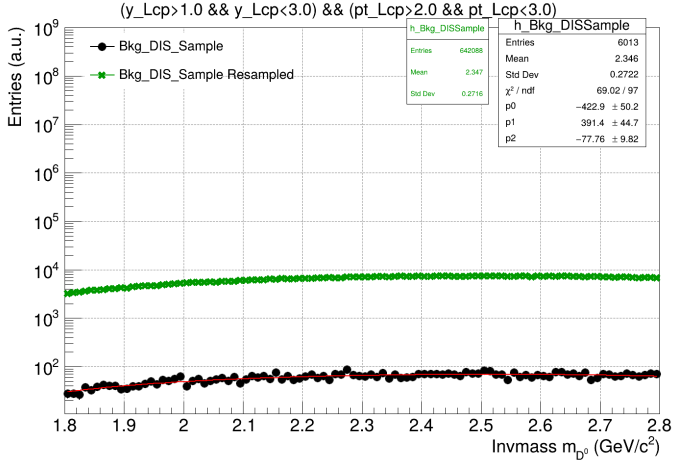
$L_{int} = 0.023412178\,fb^{-1}$ $L_{int} = 2.5\,fb^{-1}$

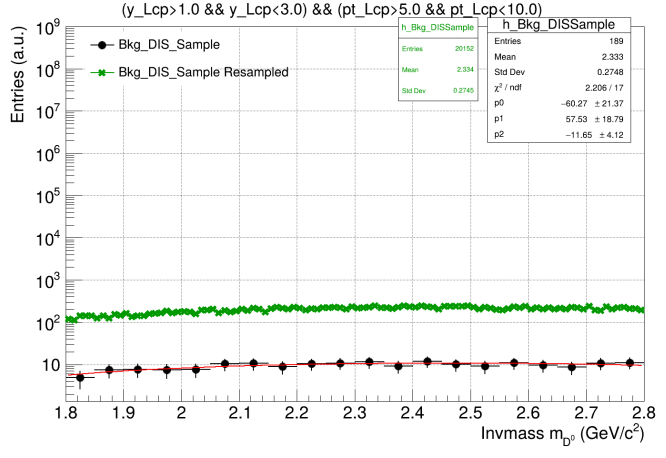






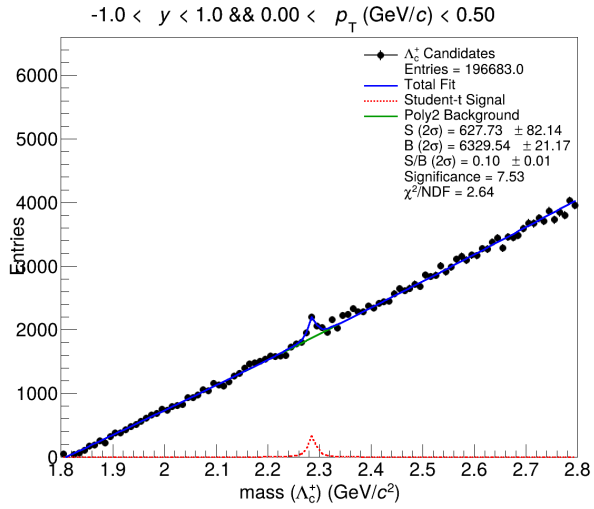


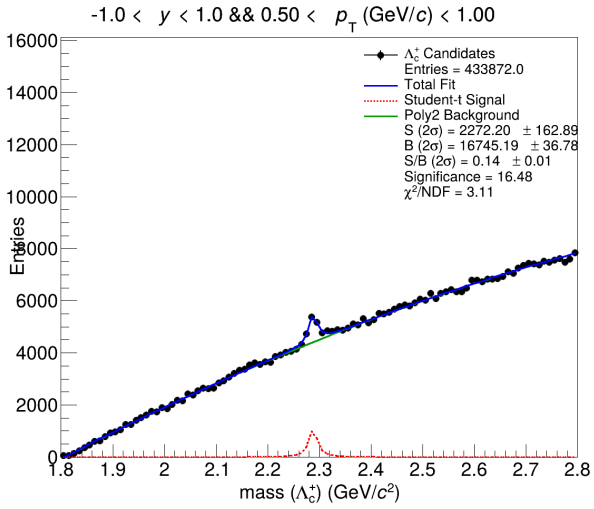


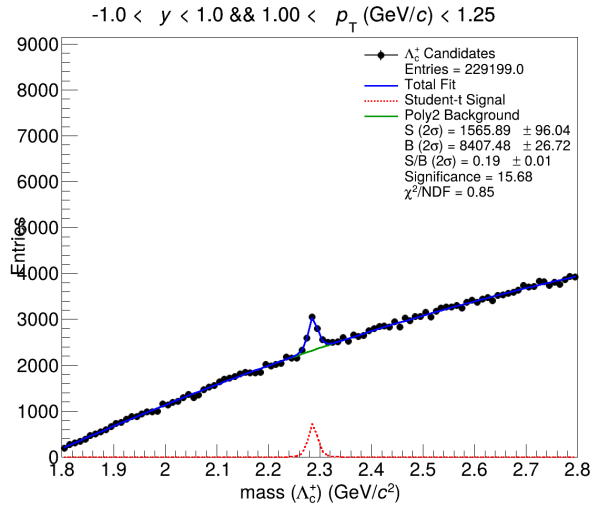


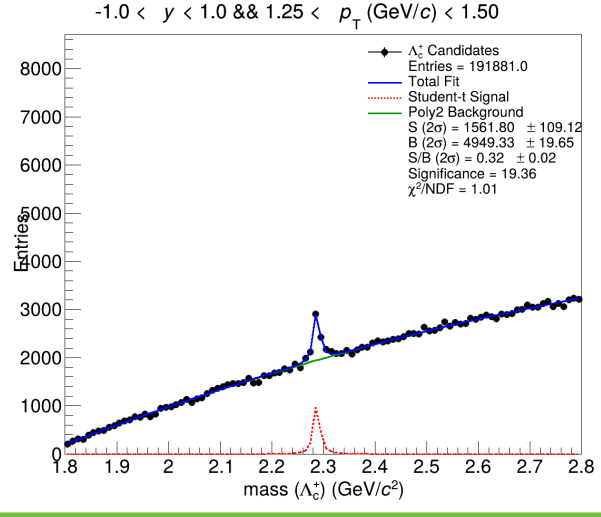
Invariant Mass (Λ_c)

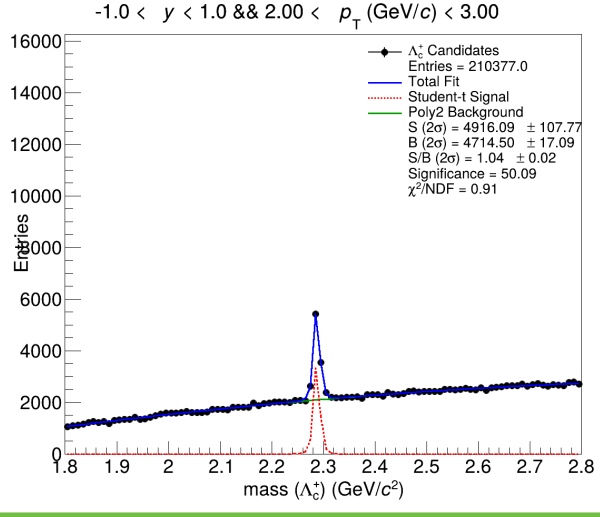
After PID+ Preselection on slide 9

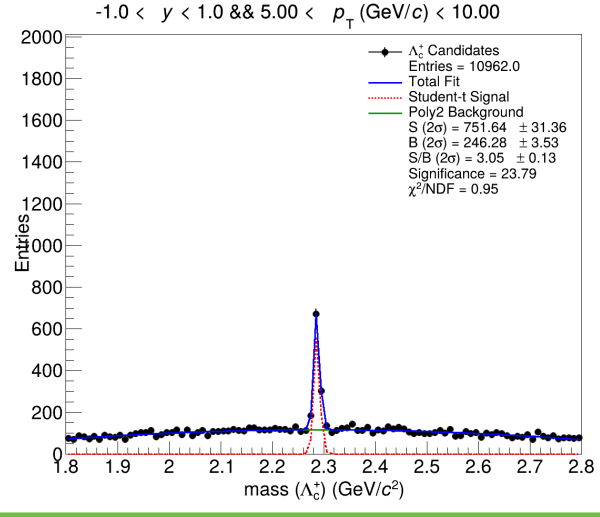






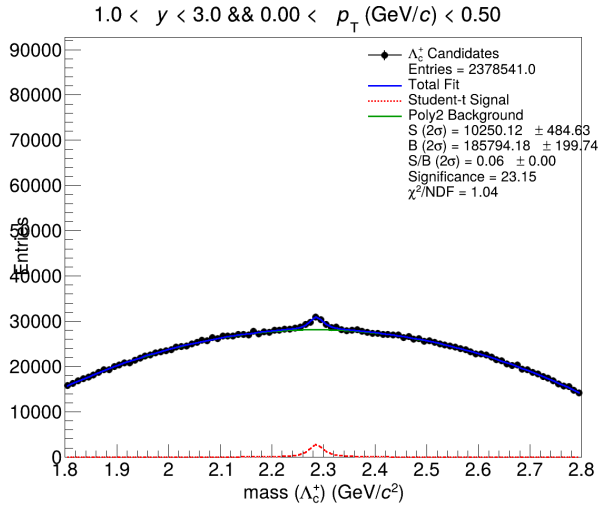


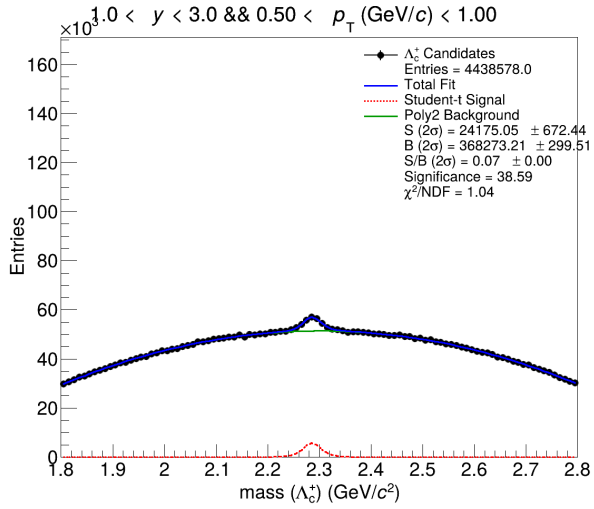


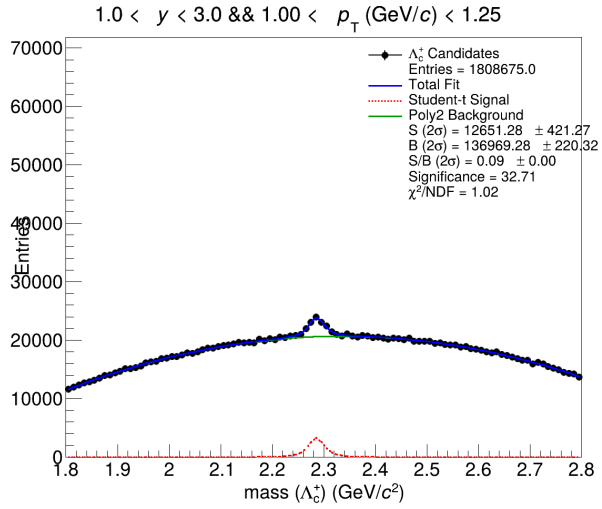


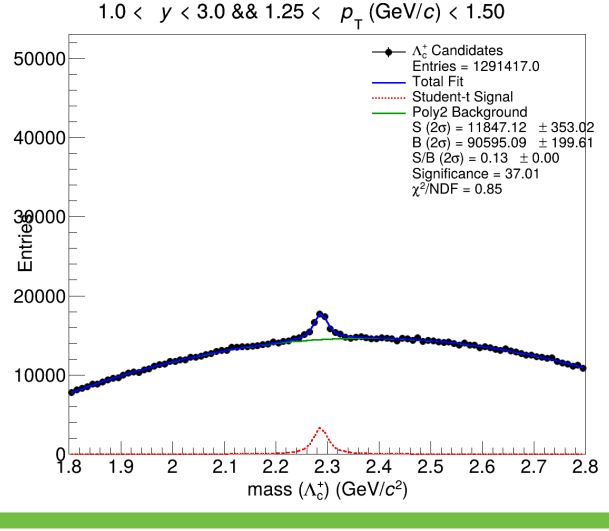
Invariant Mass (Λ_c)

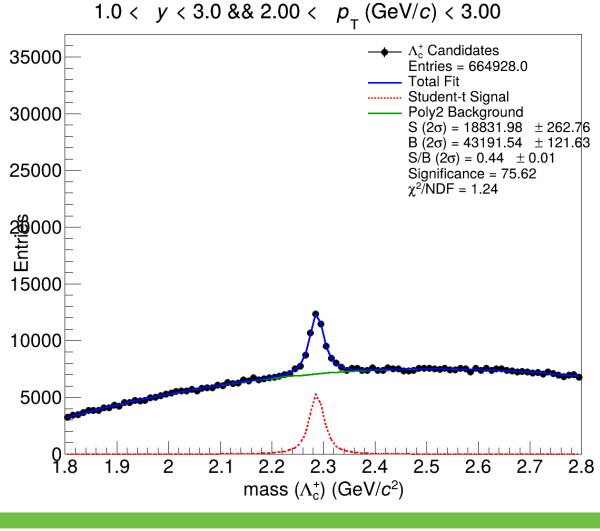
After PID+ Preselection on slide 9

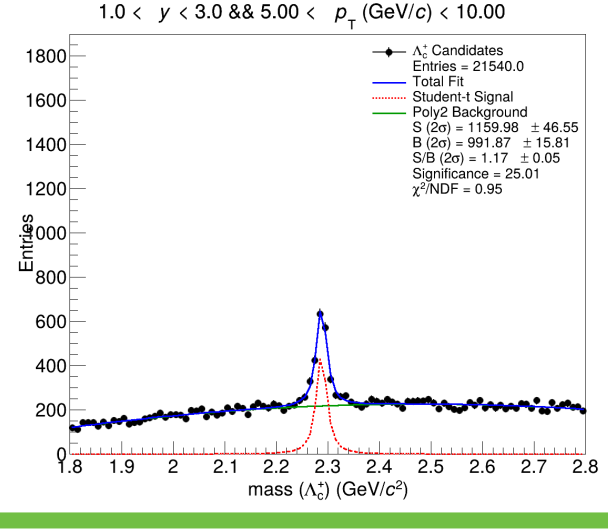




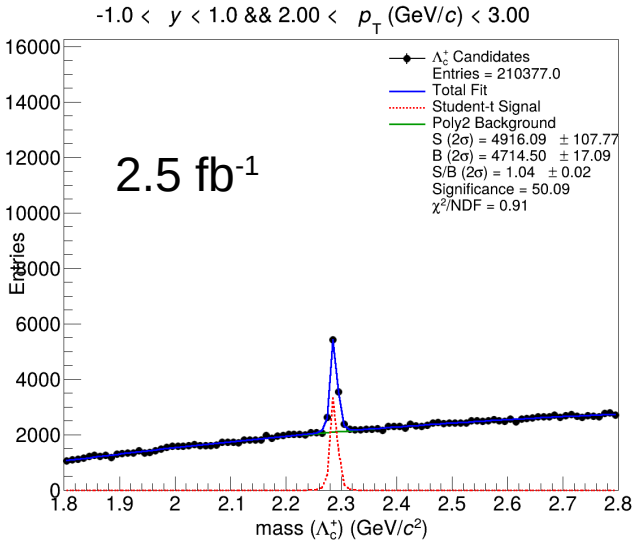


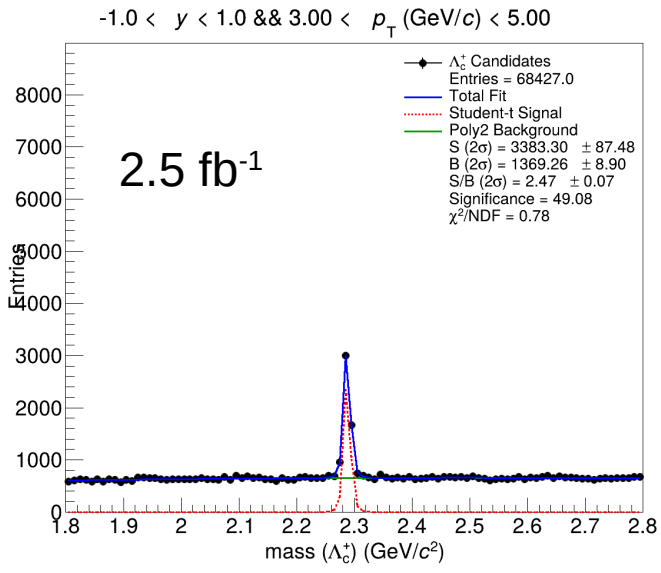




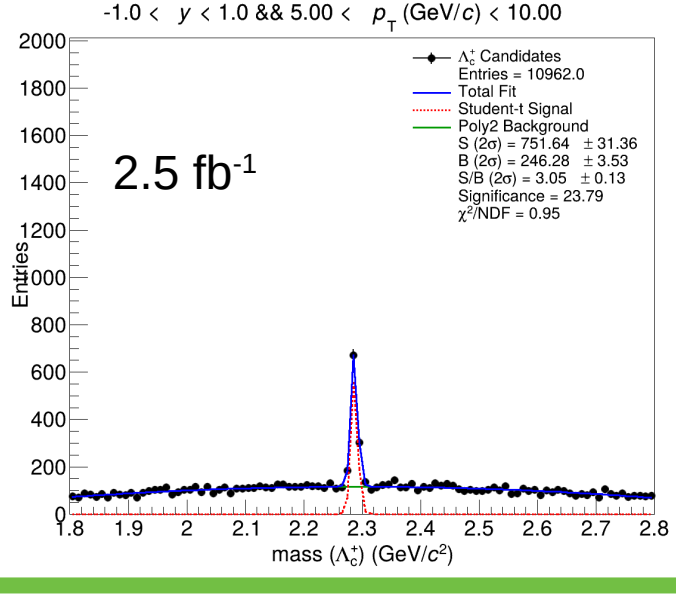


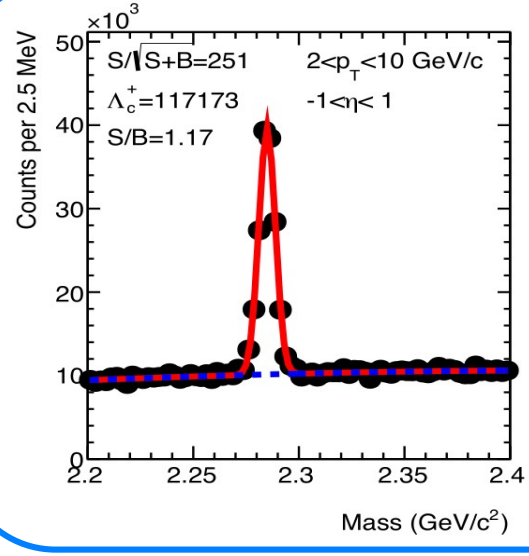
Comparison of Invariant Mass (Λ_c)





PYTHIA 8
e+p: 10x250



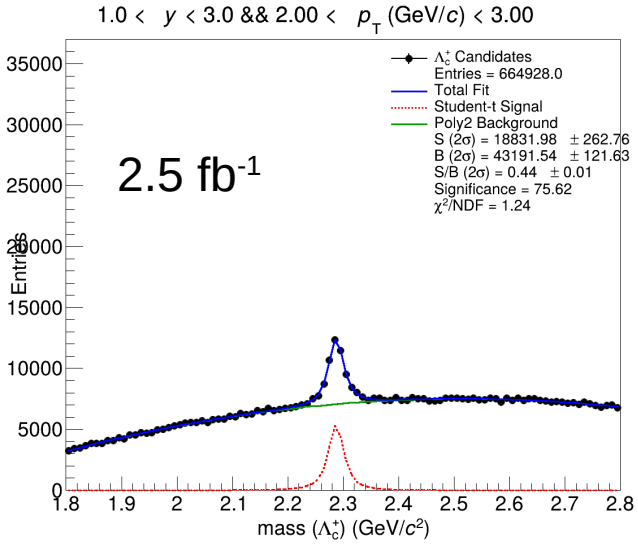


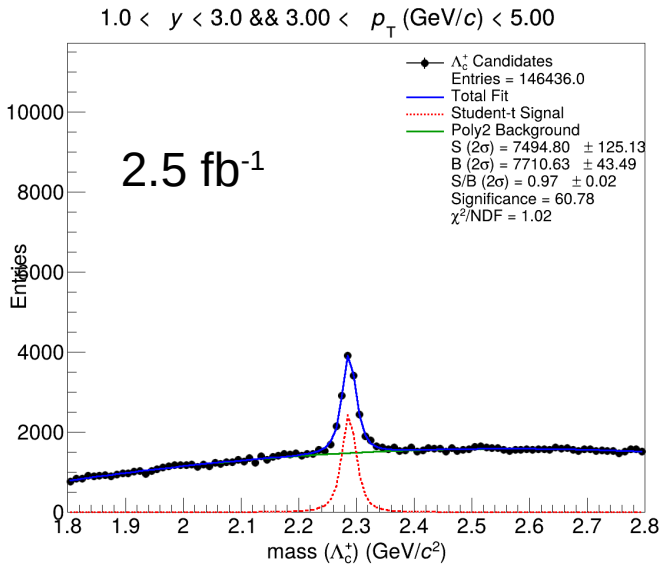
PYTHIA v6.4
e+p: 18x275

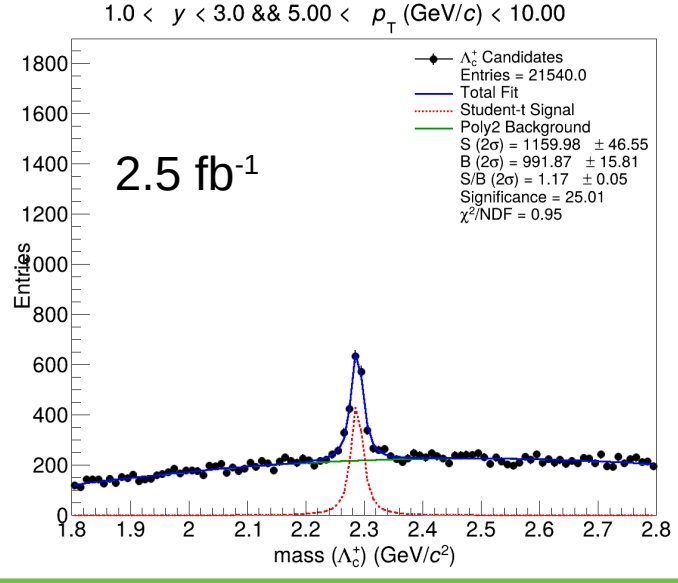
arXiv:2102.08337

Fast simulation
(10 fb^{-1})

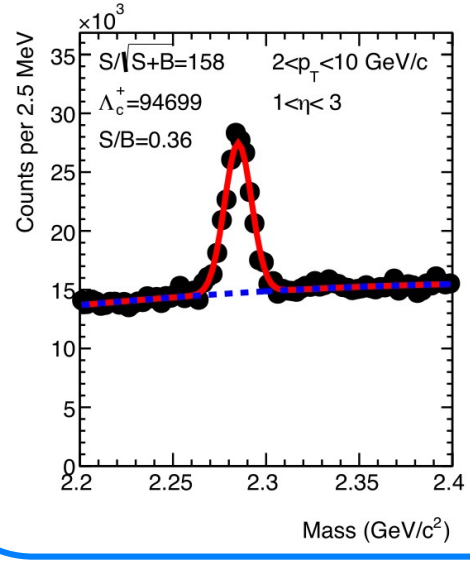
Comparison of Invariant Mass (Λ_c)







PYTHIA 8
e+p: 10x250



PYTHIA v6.4
e+p: 18x275

arXiv:2102.08337

Fast simulation
(10 fb^{-1})

D^0 Reconstruction

Signal from D^0 sample while combinatorial bkg from DIS Sample

Corrections on signal:

1. Weight factor of 3 on signal (Pythia8) for $Q^2 < 5\ GeV^2$
2. Scaling to target luminosity 2.5 fb^{-1}

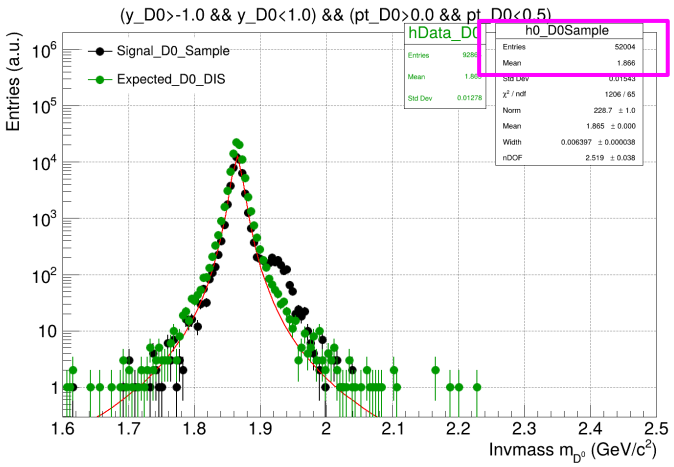
Bkg:

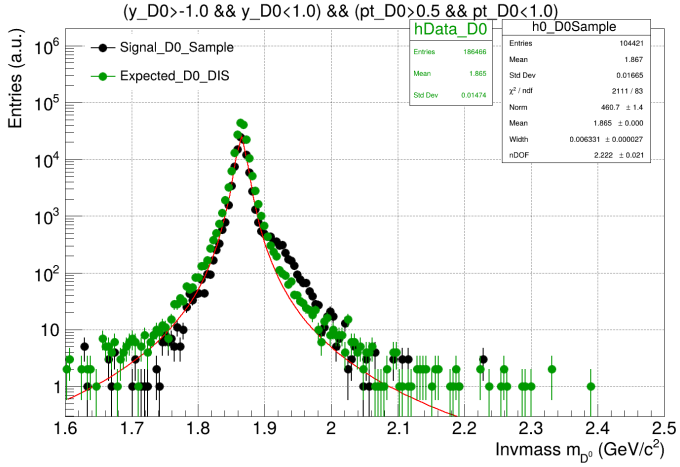
1. Scaling of cross section in each Q^2 bin
2. Scaling to targeted luminosity

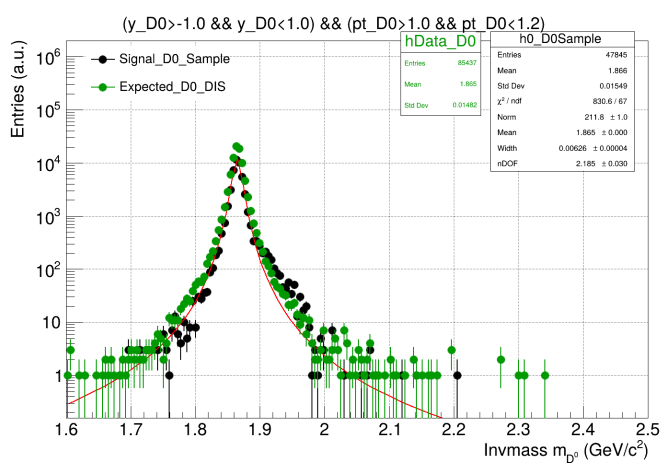
preselection_cuts='(mass_D0 > 1.6 && mass_D0 < 2.5) && d0xy_pi<100. && d0xy_k<100. && decay_length <100.'

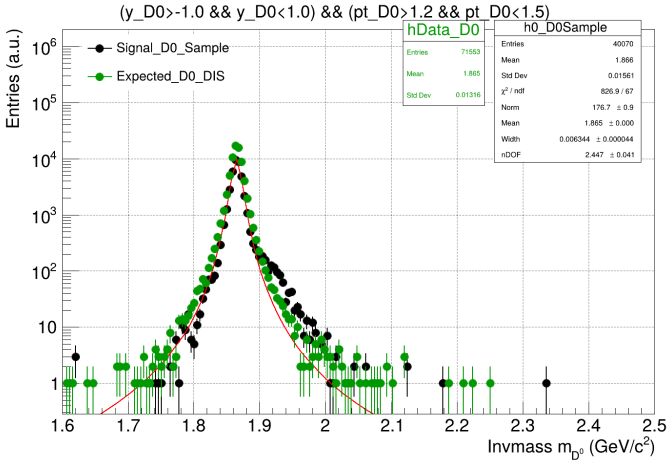
Sampling Signal (-1 < y < 1)

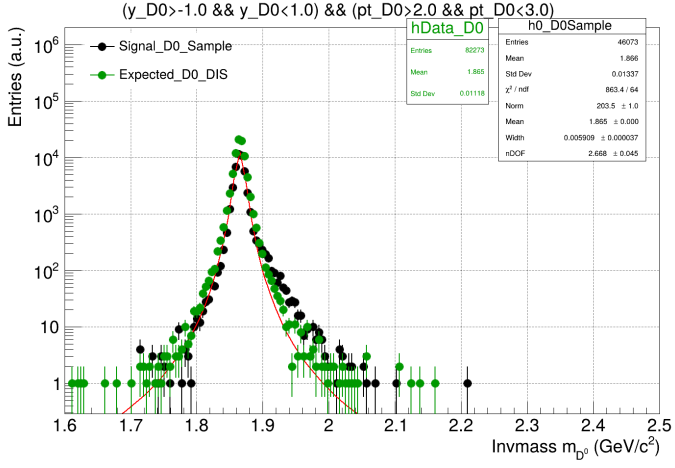
$L_{int} = 1.4\,fb^{-1}$ (Q2 Weighted) $L_{int} = 2.5\,fb^{-1}$

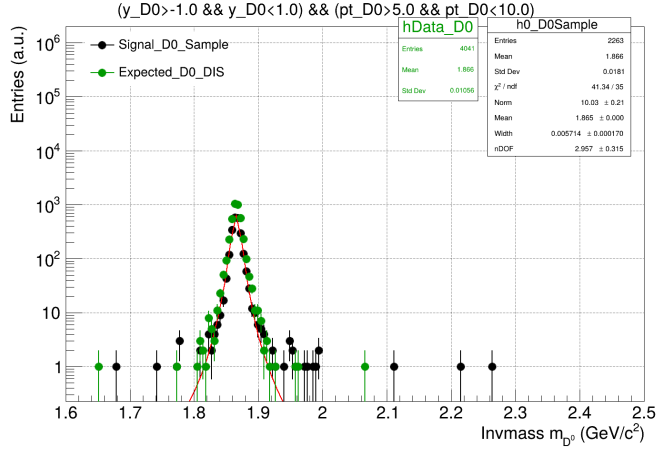






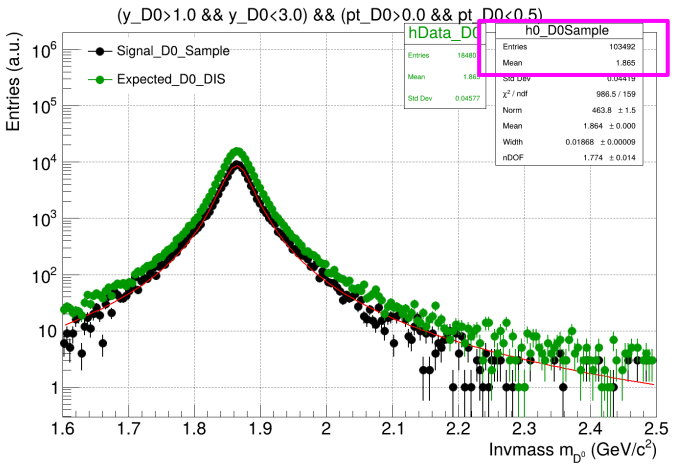


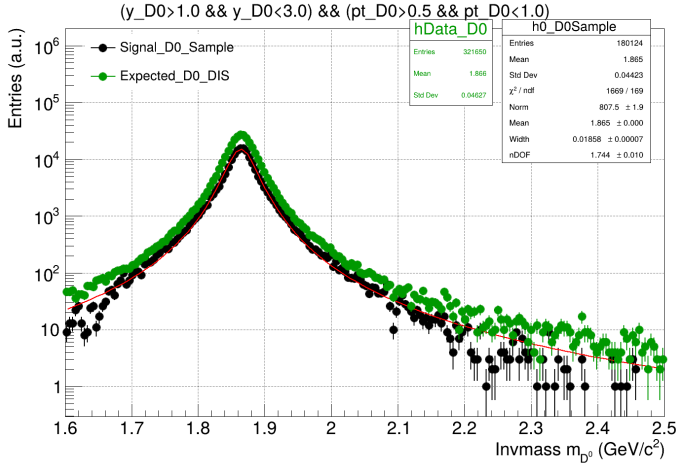


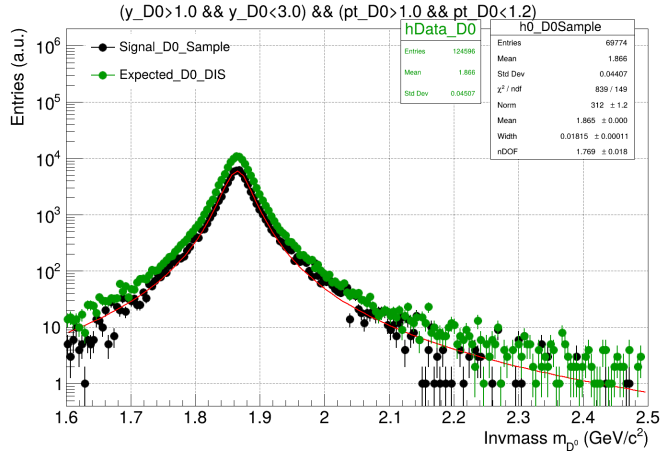


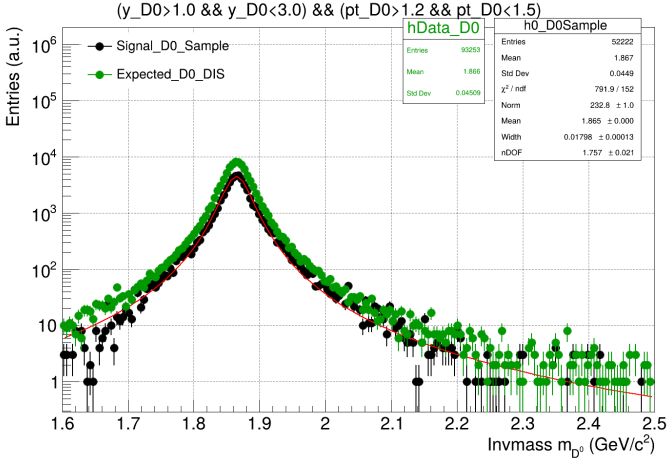
Sampling Signal (1 < y < 3)

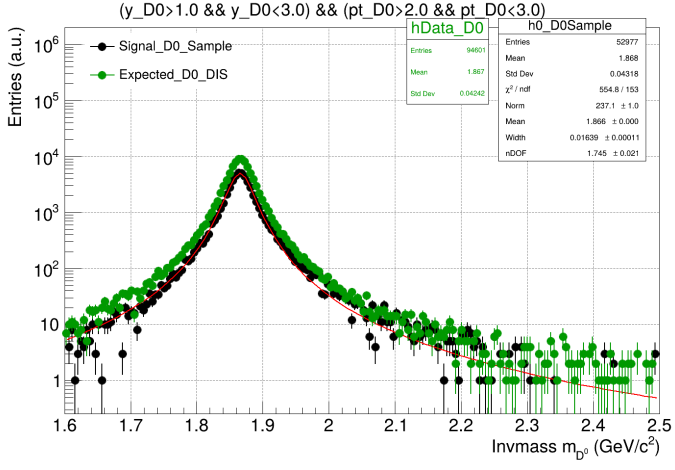
$L_{int} = 1.4\,fb^{-1}$ (Q2 Weighted) $L_{int} = 2.5\,fb^{-1}$

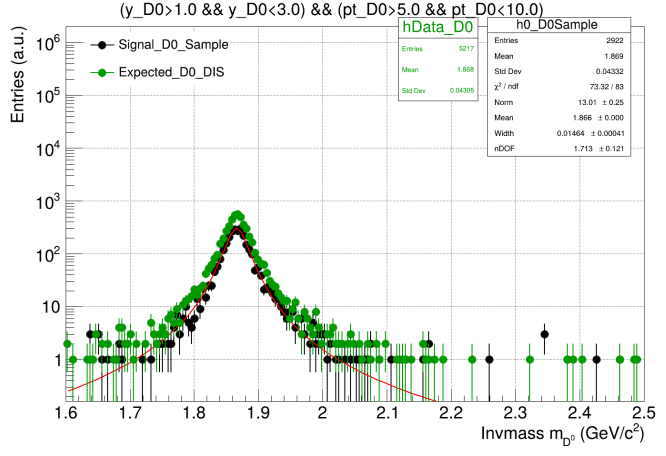








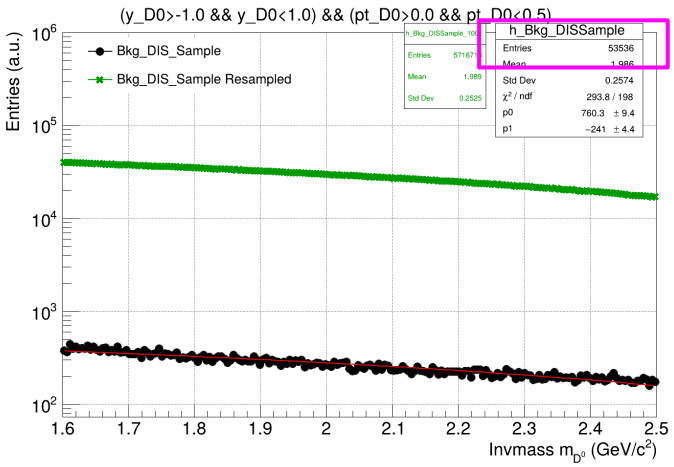


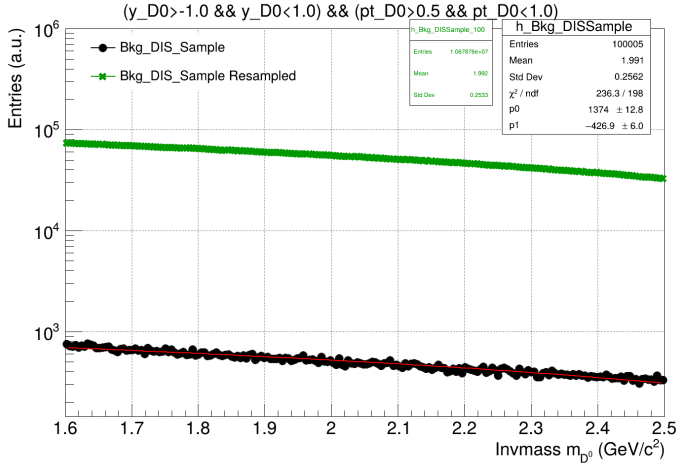


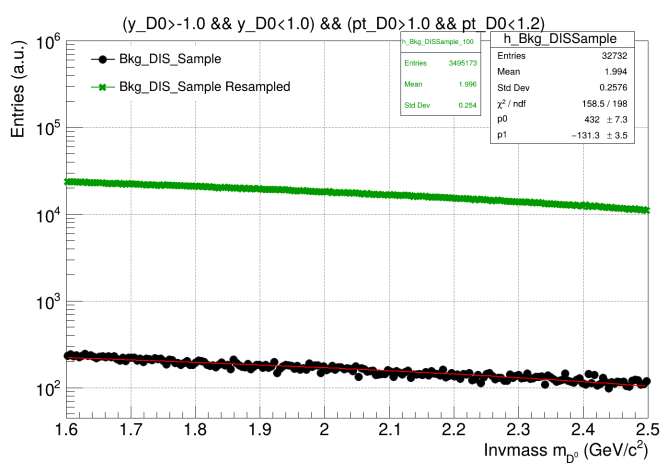
Sampling Background (-1 < y < 1)

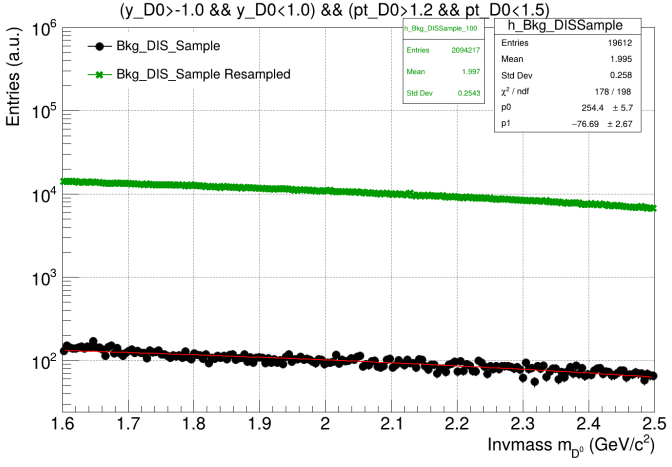
σ_{MB} = 655.6 nb

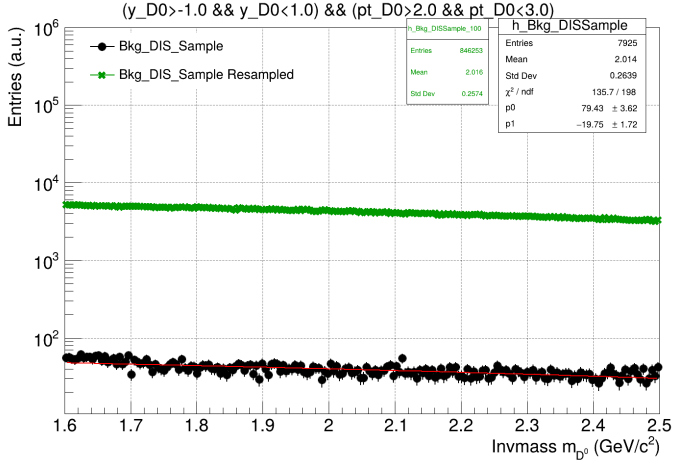
$L_{int} = 0.023412178\,fb^{-1}$ $L_{int} = 2.5\,fb^{-1}$

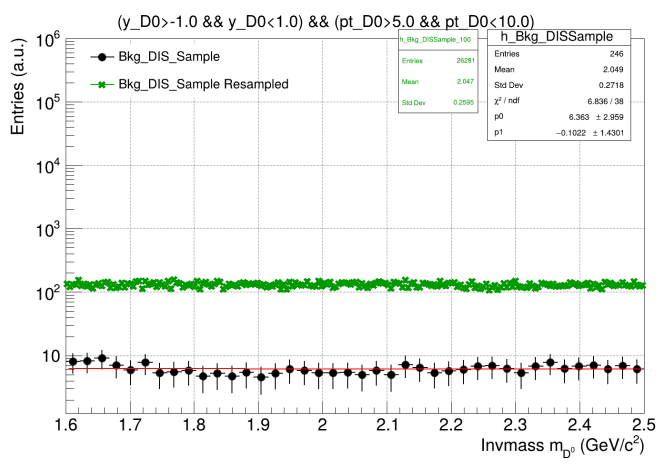










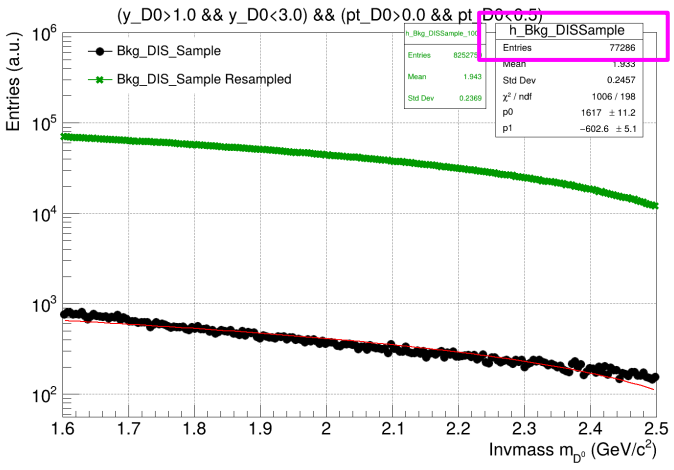


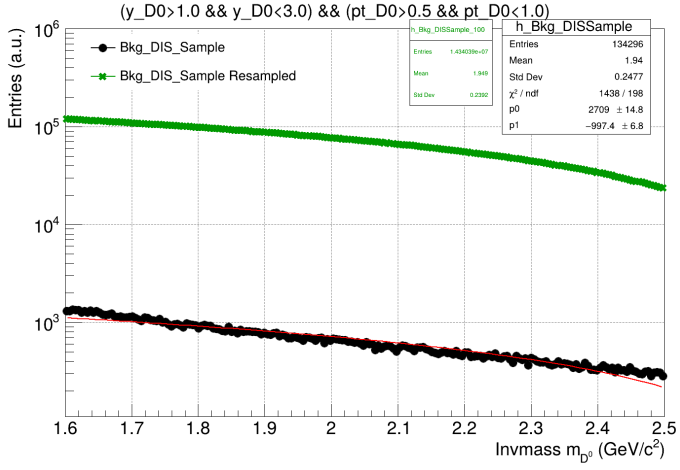
Sampling Background (1 < y < 3)

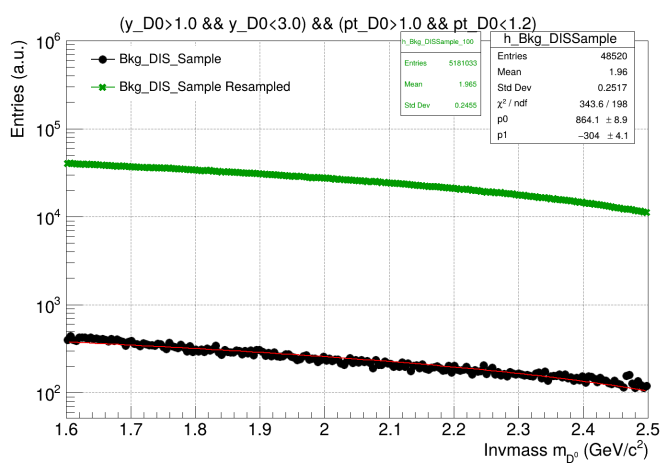
σ_{MB} = 655.6 nb

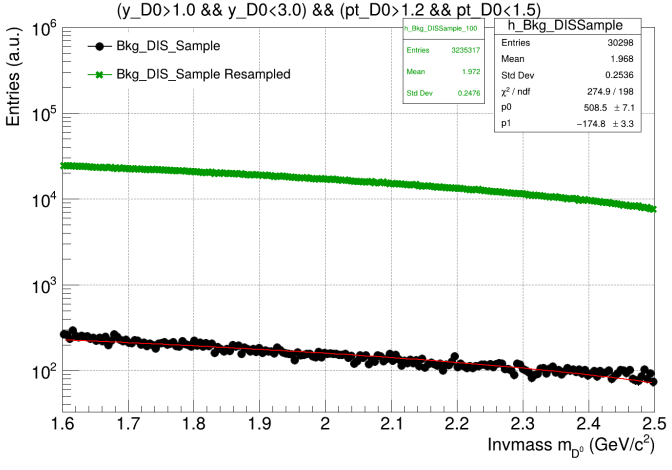
$L_{int} = 0.023412178\,fb^{-1}$

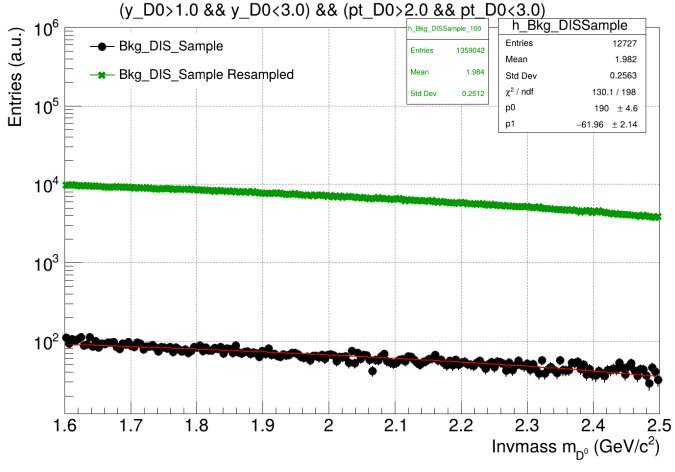
$L_{int} = 2.5\,fb^{-1}$

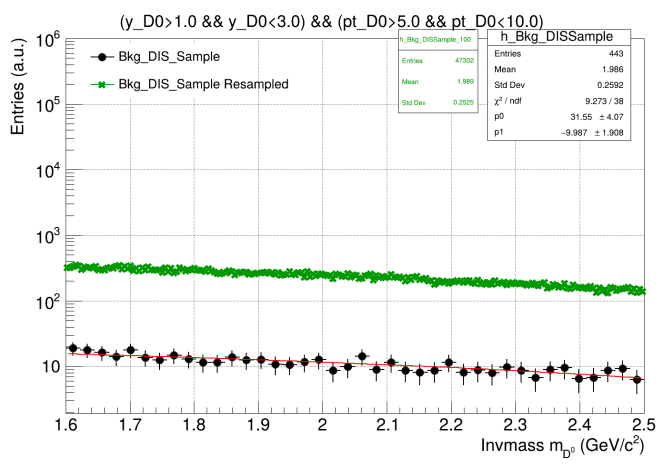






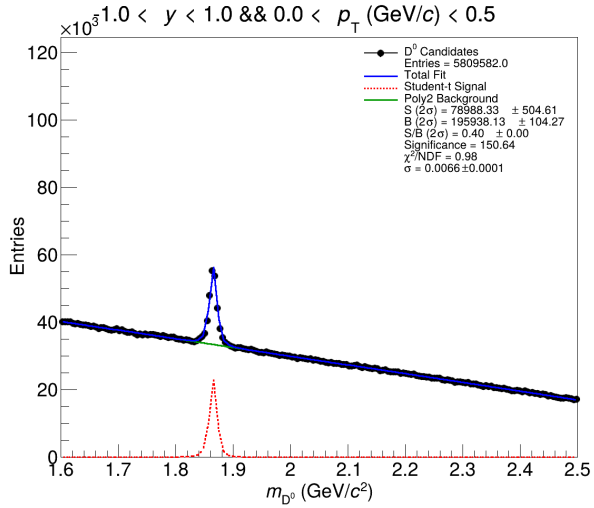


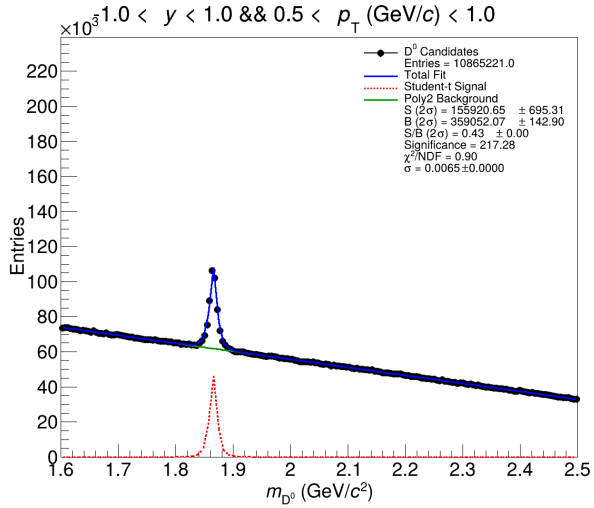


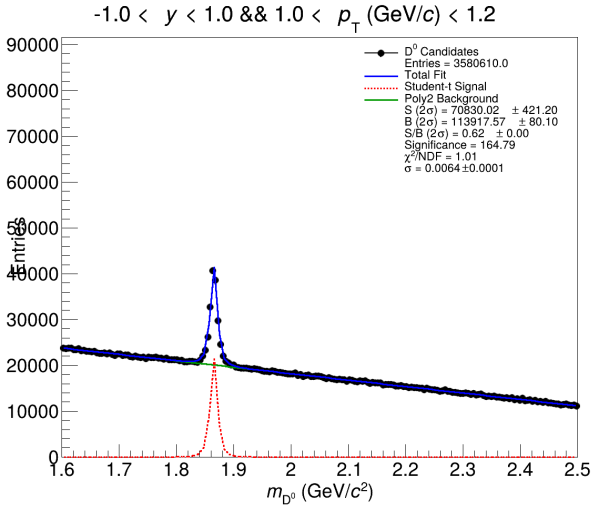


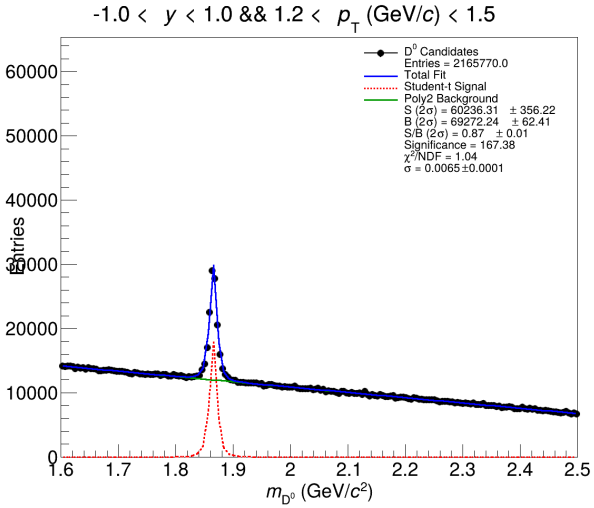
Invariant Mass (D^0)

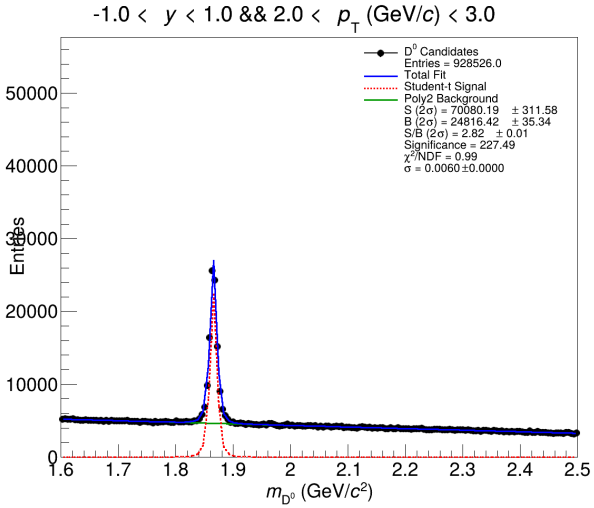
After PID+ Preselection on slide 9

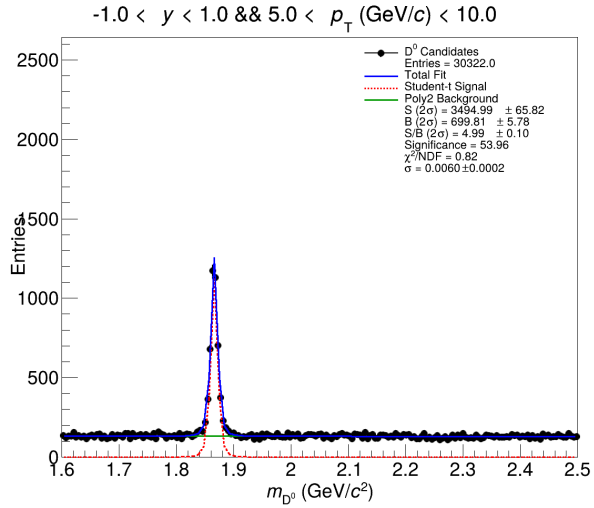






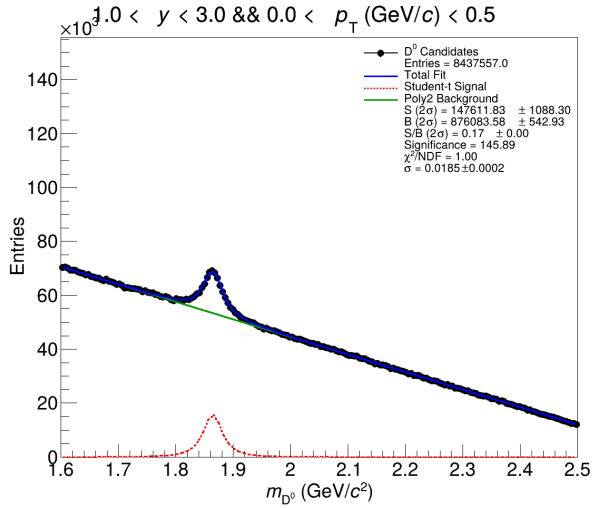


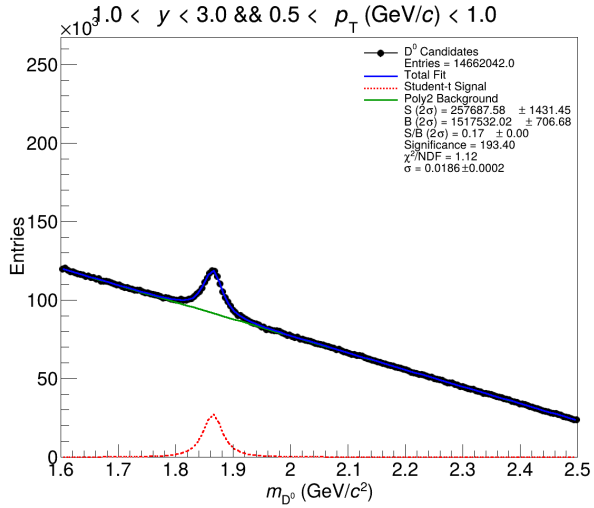


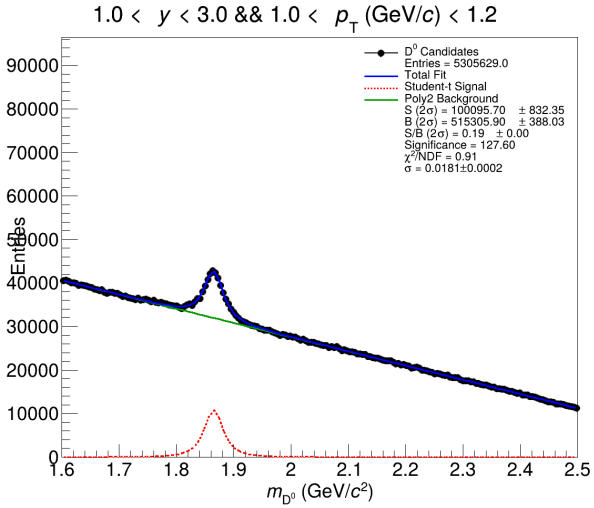


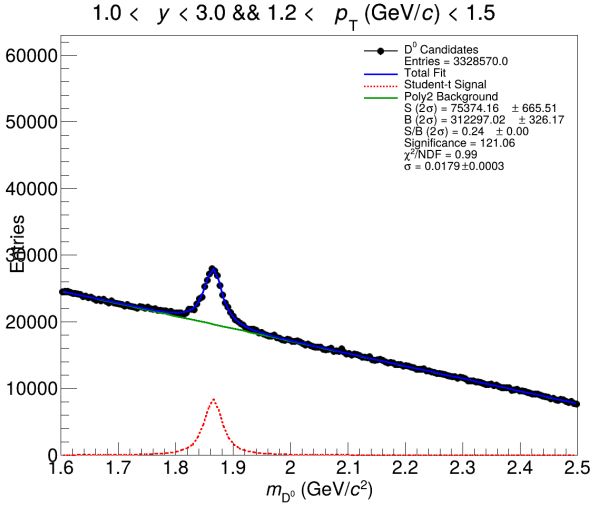
Invariant Mass (D^0)

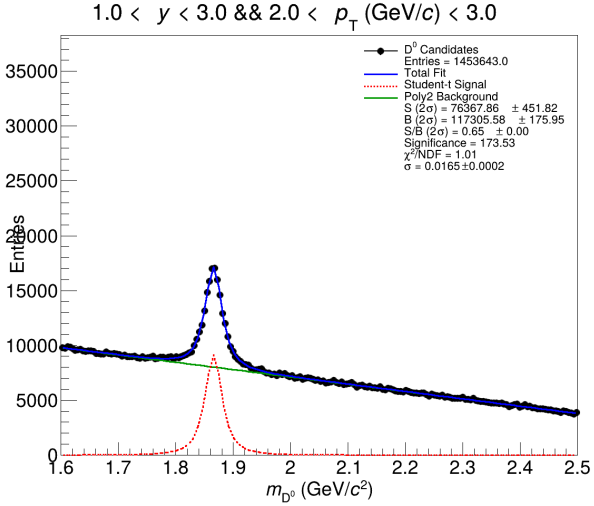
After PID+ Preselection on slide 9

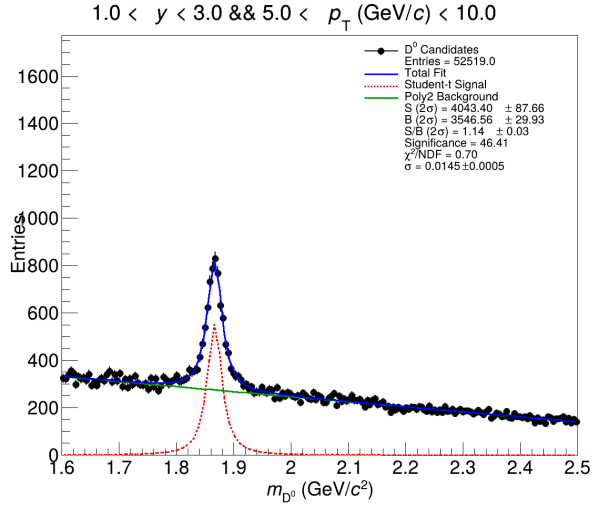








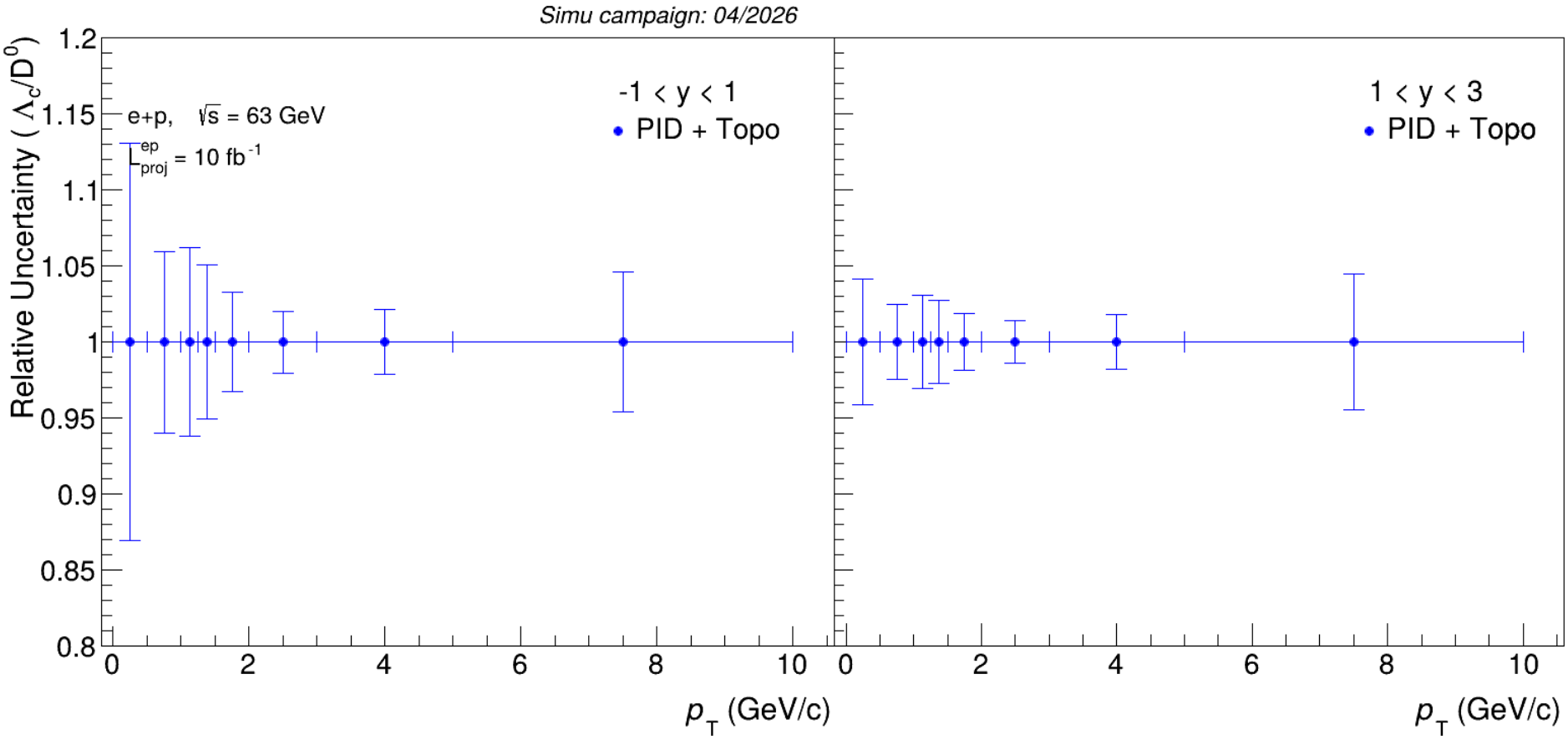




Machine Learning

Train the model in two bins (p_T < 1 and p_T > 1 GeV/c) at mid and forward rapidities
Maximization of Significance

Statistical Projection for Λ_c/D^0 ratio

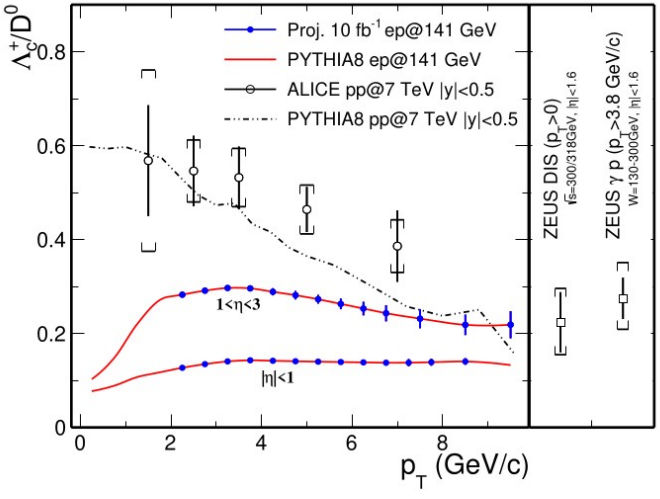


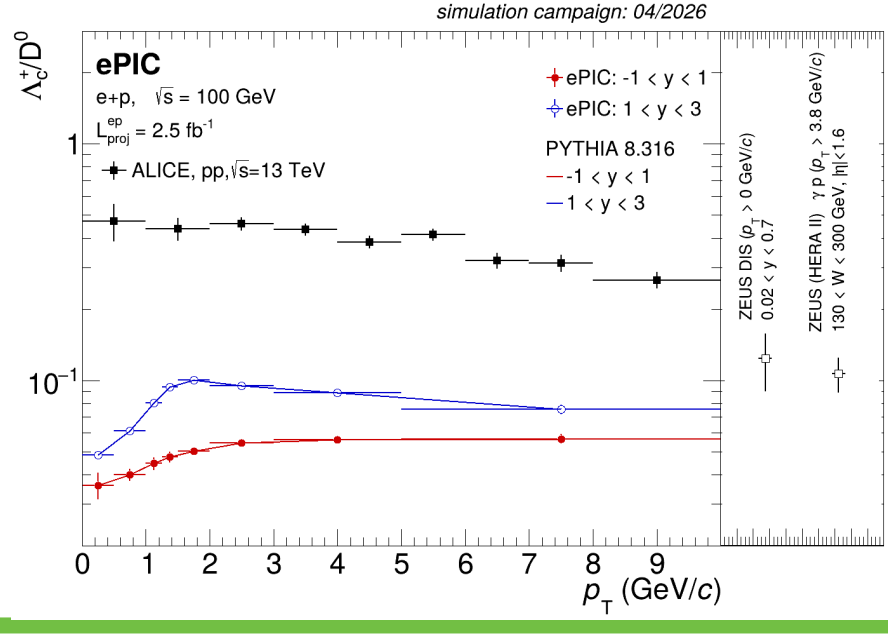
Statistical Projection for Λ_c/D^0 ratio

JHEP12(2023)086 https://arxiv.org/pdf/2011.06079

REACTION	PP --> LAMBDAC + X
REACTION	PP --> D0 + X
SQRT(S)	13000 GEV
YRAP	-0.5 TO 0.5
p_T [GeV/c]	Λ_c^+/D^0
0.0 - 1.0	0.472 ±0.086 stat ±0.059 syst ±0.021 systBR
1.0 - 2.0	0.438 ±0.049 stat +0.043 -0.044 syst ±0.021 systBR
2.0 - 3.0	0.459 ±0.03 stat ±0.043 syst ±0.021 systBR
3.0 - 4.0	0.434 ±0.025 stat ±0.038 syst ±0.02 systBR
4.0 - 5.0	0.385 ±0.023 stat ±0.029 syst ±0.017 systBR
5.0 - 6.0	0.413 ±0.024 stat +0.032 -0.031 syst ±0.019 systBR
6.0 - 7.0	0.321 ±0.024 stat ±0.025 syst ±0.015 systBR
7.0 - 8.0	0.314 ±0.026 stat ±0.027 syst ±0.014 systBR
8.0 - 10.0	0.266 ±0.021 stat ±0.023 syst ±0.012 systBR
10.0 - 12.0	0.249 ±0.033 stat ±0.023 syst ±0.011 syst
12.0 - 24.0	0.141 ±0.023 stat +0.015 -0.016 syst ±0.006 systB

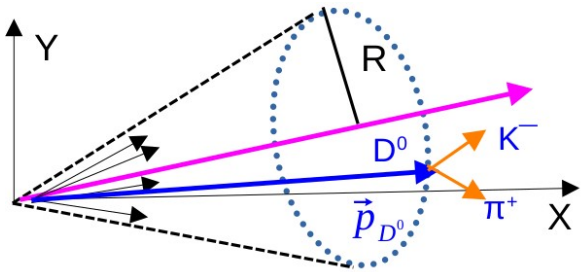
	$\Lambda_c^+/D^0 \pm$ stat. $\pm$ syst.	System	$\sqrt{s}$ (GeV)	Notes
ALICE	$0.51 \pm 0.04 \pm 0.04^{+0.01}_{-0.02}$	pp	5020	$p_T > 0, \lvert y \rvert < 0.5$
ALICE	$0.42 \pm 0.03 \pm 0.06^{+0.05}_{-0.03}$	p–Pb	5020	$p_T > 0, -0.96 < y < 0.04$
CLEO [16]	$0.119 \pm 0.021 \pm 0.019$	e^+e^-	10.55	
ARGUS [15, 17]	0.127 ± 0.031	e^+e^-	10.55	
LEP average [18]	$0.113 \pm 0.013 \pm 0.006$	e^+e^-	91.2	
ZEUS DIS [21]	$0.124 \pm 0.034^{+0.025}_{-0.022}$	e^-p	320	$1 < Q^2 < 1000$ GeV^2, $0 < p_T < 10$ GeV/c, $0.02 < y < 0.7$
ZEUS γp, HERA I [19]	$0.220 \pm 0.035^{+0.027}_{-0.037}$	e^-p	320	$130 < W < 300$ GeV, $Q^2 < 1$ GeV^2, $p_T > 3.8$ GeV/c, $\lvert\eta\rvert < 1.6$
ZEUS γp, HERA II [20]	$0.107 \pm 0.018^{+0.009}_{-0.014}$	e^-p	320	$130 < W < 300$ GeV, $Q^2 < 1$ GeV^2, $p_T > 3.8$ GeV/c, $\lvert\eta\rvert < 1.6$





R_{eAu} vs fragmentation (z_{proj}) for D^0-tagged jets

Signal for D^0 sample while combinatorial bkg from DIS Sample



Corrections on signal:

1. Weight factor of 3 on signal (Pythia8) for $Q^2 < 5$ GeV^2
2. Projection in different rapidity bins
3. Scaling to target luminosity 1.0 fb^{-1}

Bkg:

1. Scaling to targeted luminosity (1.0 fb^{-1})
2. Cross section scaling for **biased** DIS sample
3. Projection in different eta and z bins
4. Training in ML: 0 < z < 0.6 and 0.6 < z < 1

preselection_cuts='(mass_D0 > 1.6 && mass_D0 < 2.5) && d0xy_pi<100. && d0xy_k<100. && decay_length <100.'

Data Sample

- D^0 Sample, e+p, 10x130, $Q^2 > 1$ GeV^2
  - epic:/RECO/**26.04.1**/epic_craterlake/SIDIS/D0_ABCONV/HFsim-PYTHIA/pythia8.312-2.0/ep/10x130/q2_1
- D^0 Sample, e+Au, 10x100, $Q^2 > 1$ GeV^2 (Pythia6)
  - epic:/RECO/**26.04.1**/epic_craterlake_without_zdc/SIDIS/D0_ABCONV/HFsim-BeAGLE/BeAGLE1.03.01-2.0/eAu/10x100/q2_1to10000
- **Biased** NC, DIS Sample e+p, 10x130, $Q^2 > 1$ GeV^2 (Biased in different Q^2 bins)
- NC, DIS Sample e+Au, 10x100, **Q^2: 1-100 GeV^2**

Cross section in different Q2 bins: Slides

Current scaling factor

$$f_i = \frac{\sigma_i}{\sigma(Q^2>1)}$$

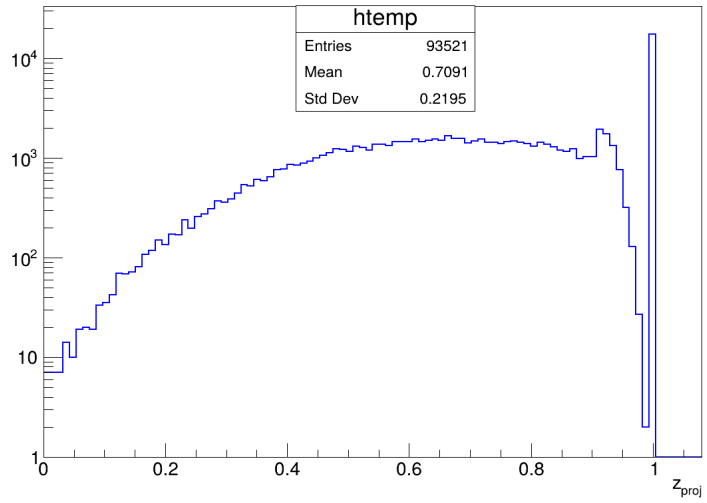
Event generator and energy	**$Q^2 > 1$**	**$1 < Q^2 < 10$**	**$10 < Q^2 < 100$**	**$1e2 < Q^2 < 1e3$**	**$1e3 < Q^2 < 1e4$**
PYTHIA 8.316, 10x130	5.847e5 pb	5.391e5 pb	4.223e4 pb	1.590e3 pb	1.260e1 pb
PYTHIA 8.316, 10x250	6.556e5 pb	6.054e5 pb	5.291e4 pb	2.322e3 pb	3.686e1 pb
PYTHIA 8.316, 9x130	5.719e5 pb	5.307e5 pb	4.048e4 pb	1.475e3 pb	1.001e1 pb
PYTHIA 8.316, 9x275	6.546e5 pb	6.025e5 pb	5.178e4 pb	2.292e3 pb	3.697e1 pb

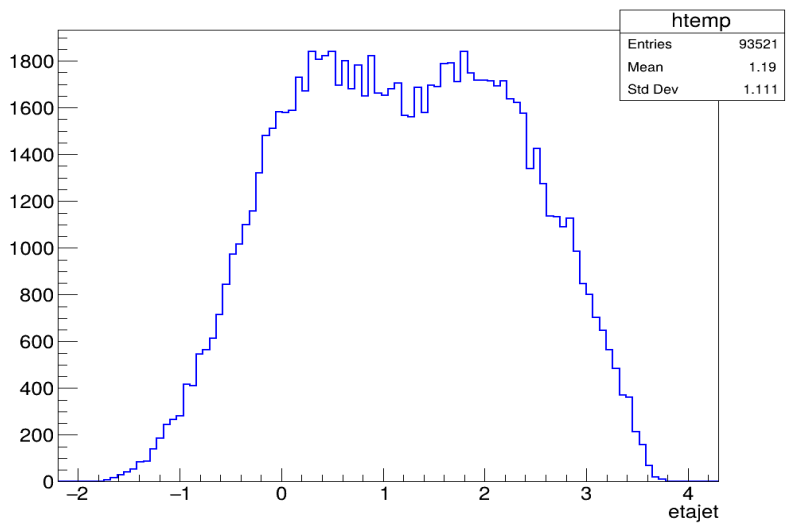
Fragmentation Variable (z)

e+p, 10x130, D^0 sample, **Biased** DIS sample

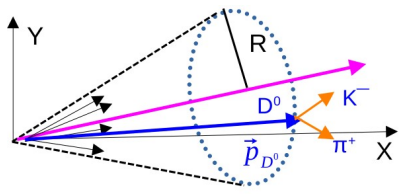
Signal pairs from D^0 Sample

z {pTjet>3}





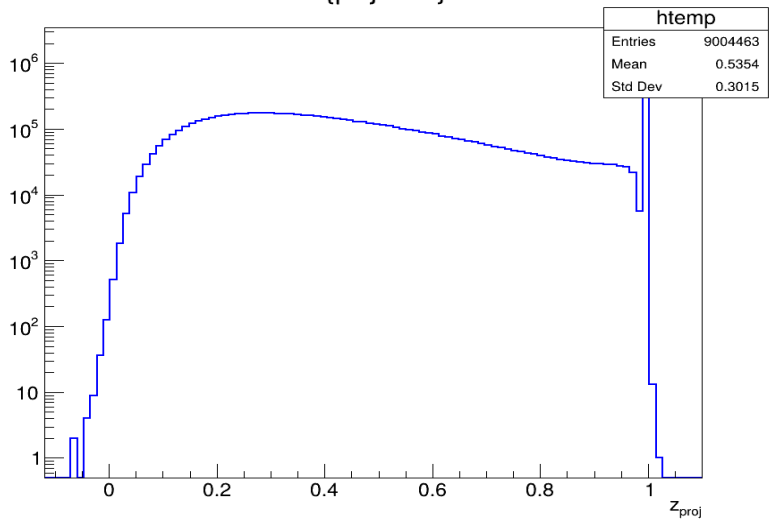
Anti-k_T, R = 1,
$p_{Tjet} > 3$ GeV/c

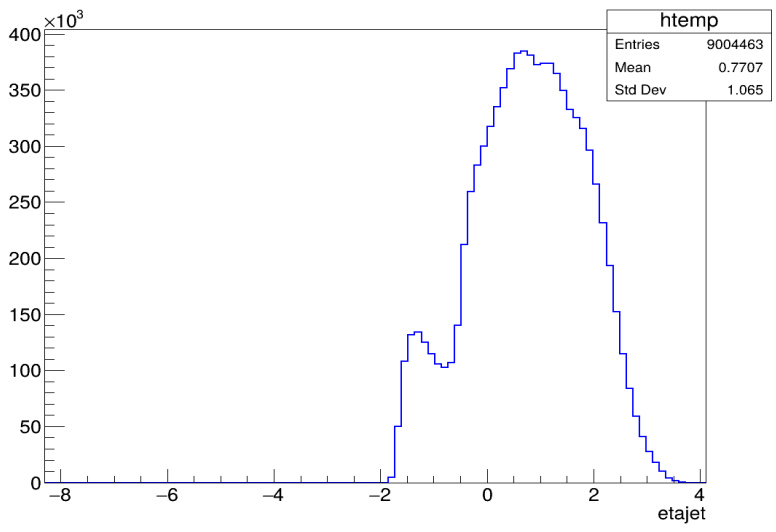


$$z = z_{proj} = \frac{\vec{p}_{D0}.\vec{p}_{jet}}{p_{jet}^2}$$

Bkg pairs from DIS

z {pTjet>3}



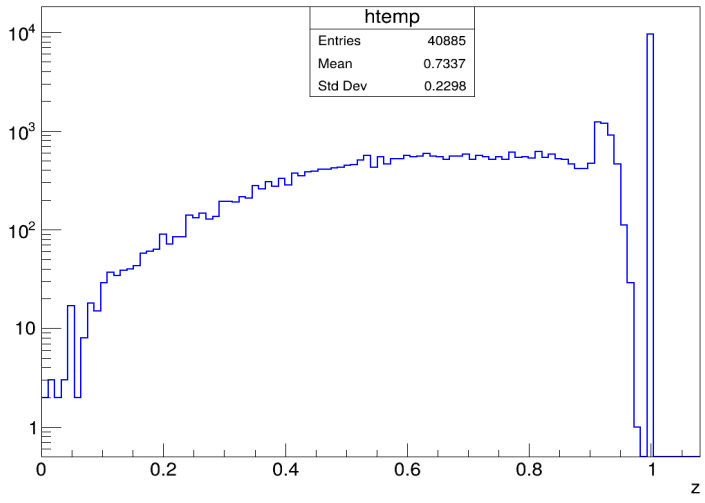


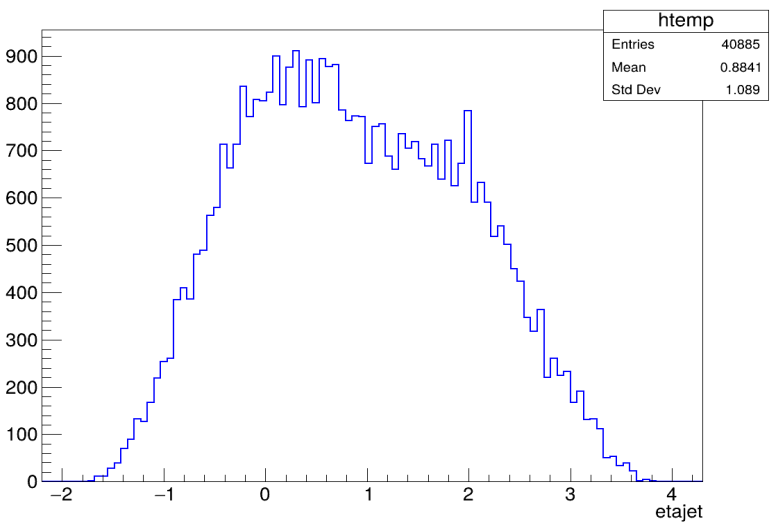
Fragmentation Variable (z)

e+Au, 10x100, D^0 sample, **Biased** DIS sample

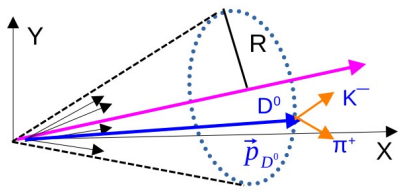
Signal pairs from D^0 Sample

z {pTjet>3}





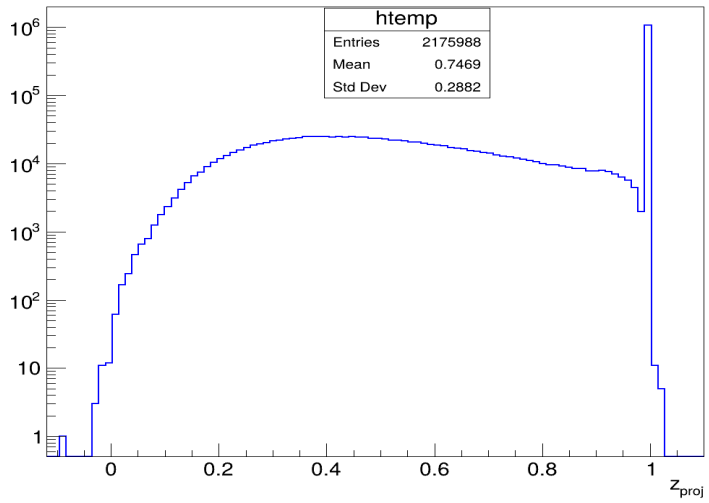
Anti-k_T, R = 1,
$p_{Tjet} > 3$ GeV/c

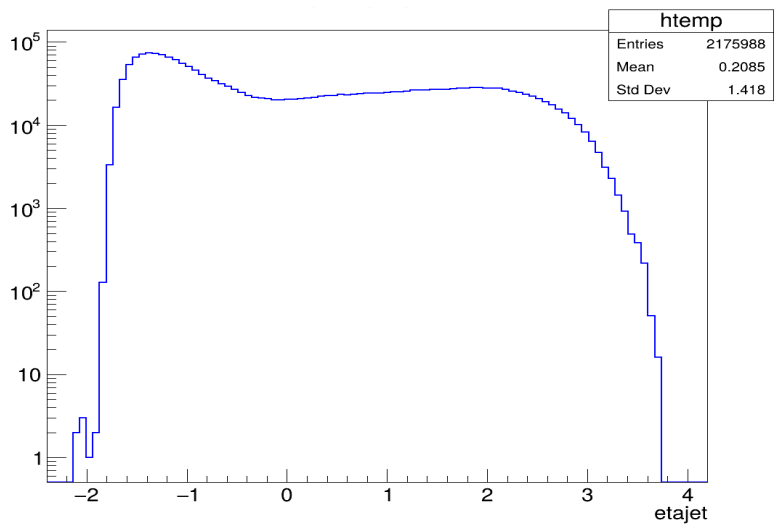


$$z = z_{proj} = \frac{\vec{p}_{D0.}\vec{p}_{jet}}{p_{jet}^2}$$

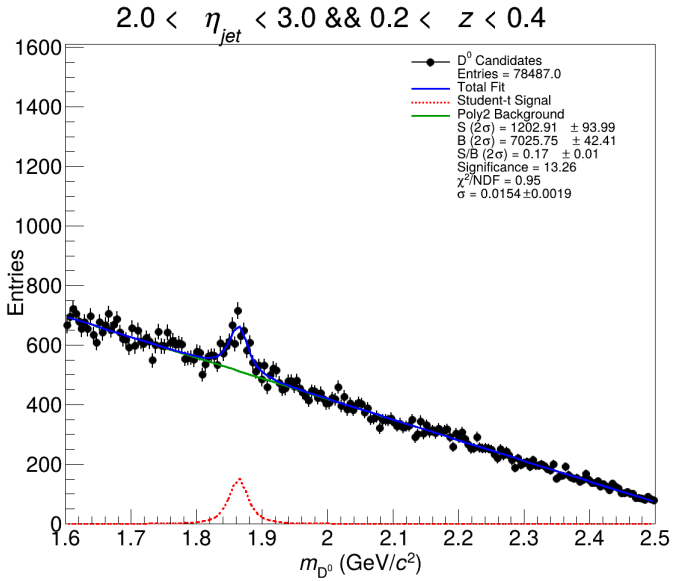
Bkg pairs from DIS

z {pTjet>3}





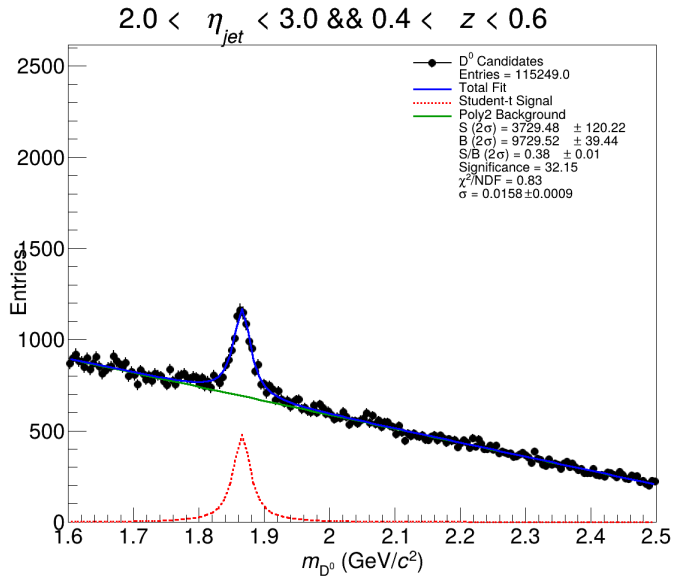
Invariant Mass Spectra (e+p)

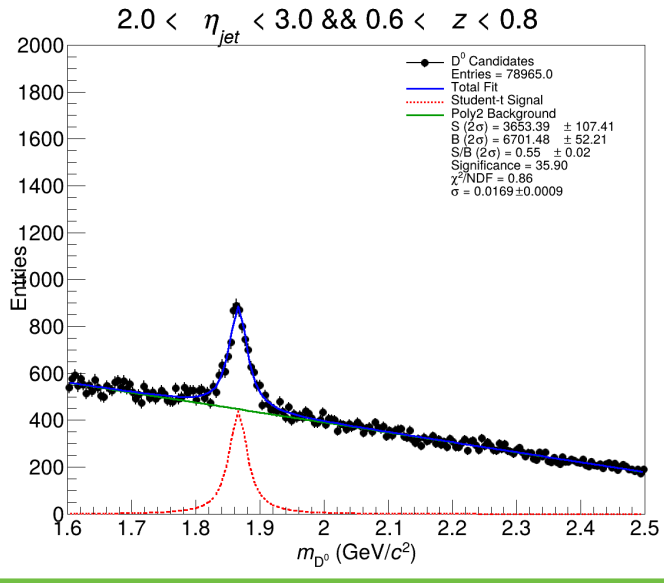


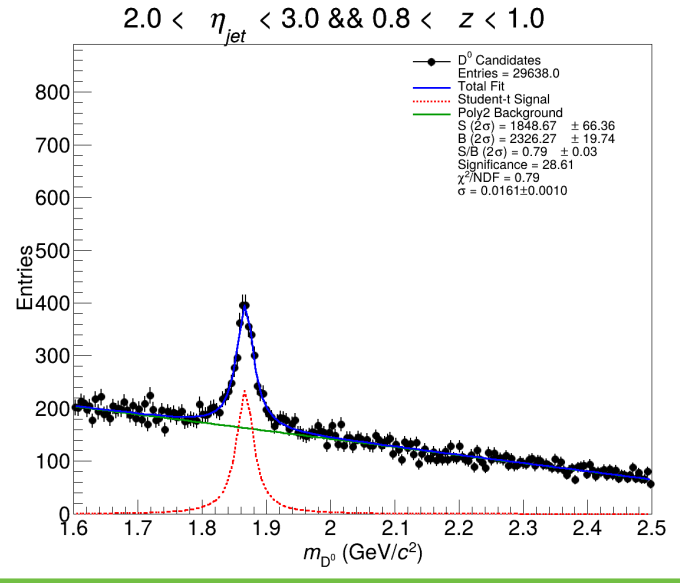
After PID+ Preselection

$$z = z_{proj} = \frac{\vec{p}_{D0.}\vec{p}_{jet}}{p^2_{jet}}$$

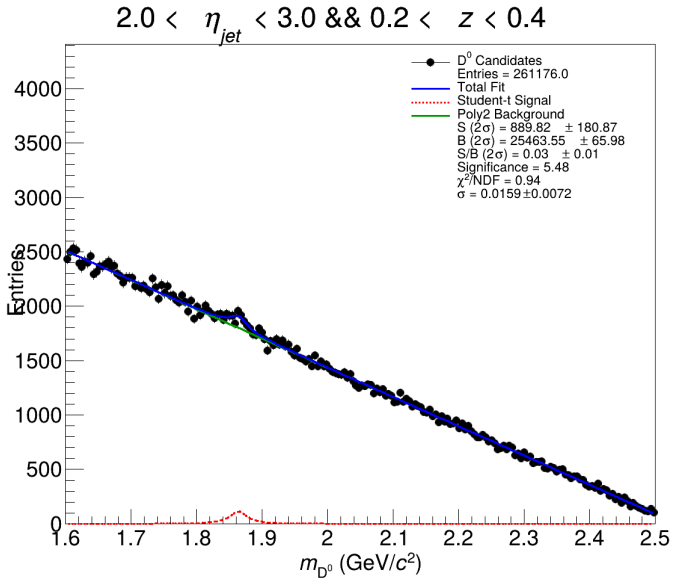
D^0-jet reconstruction
Gurtaj, Lokesh, Rongrong, Shyam







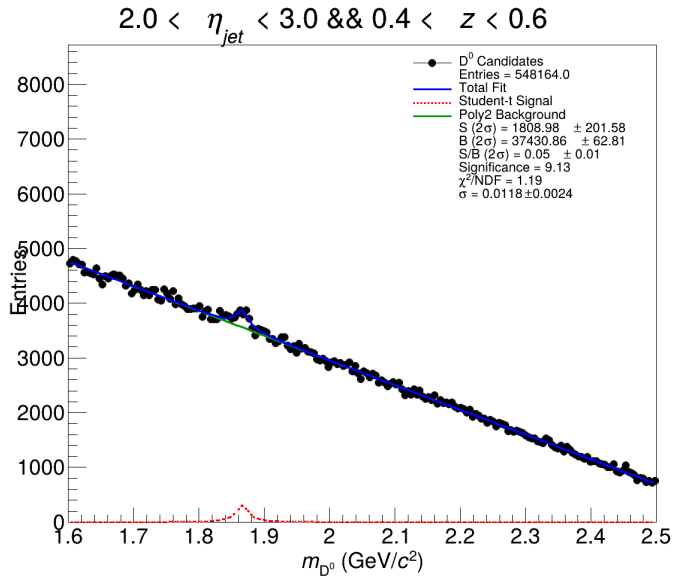
Invariant Mass Spectra (e+Au)

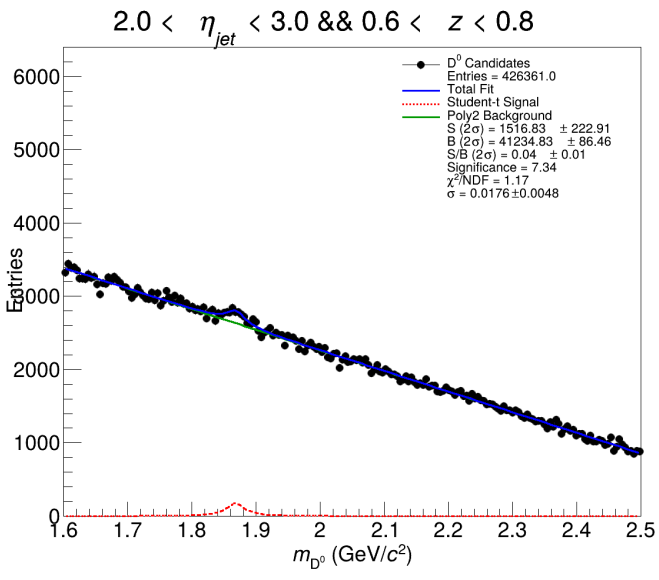


After PID+ Preselection

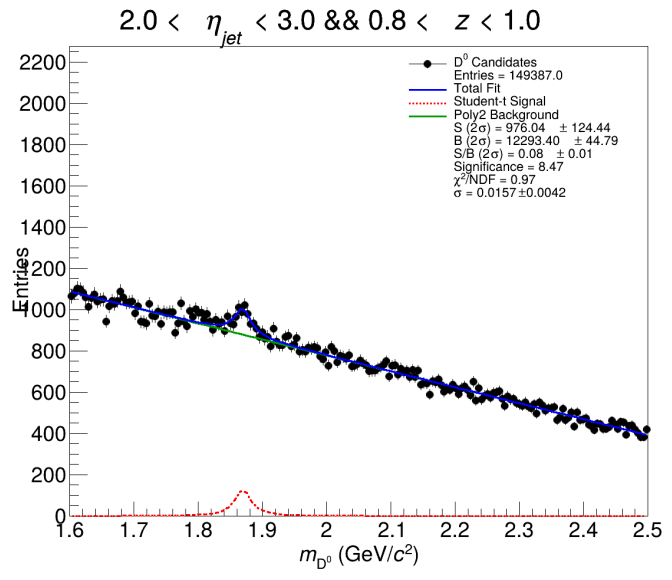
$$z = z_{proj} = \frac{\vec{p}_{D0.}\,\vec{p}_{jet}}{p_{jet}^2}$$

D⁰-jet reconstruction
Gurtaj, Lokesh, Rongrong, Shyam



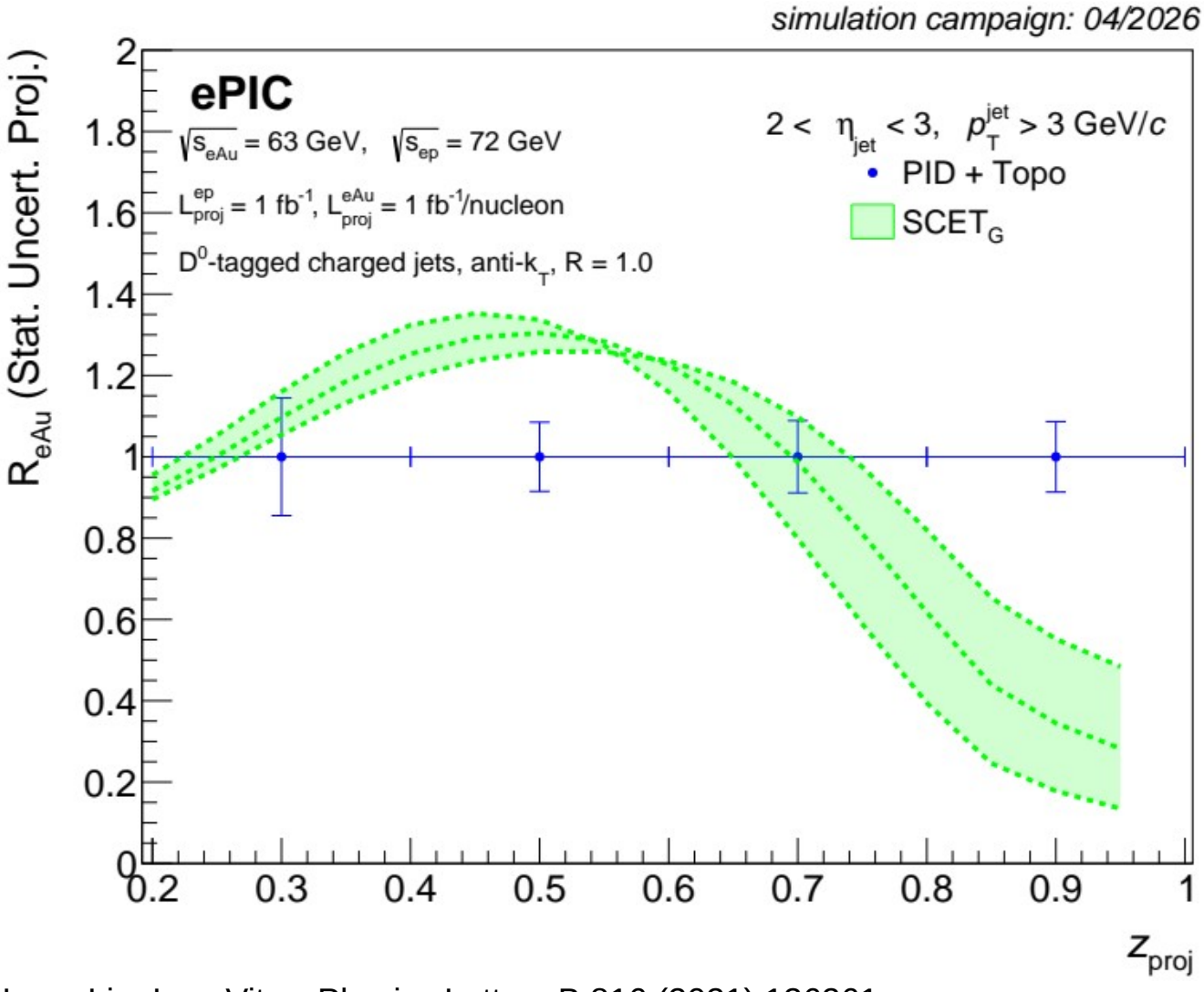


Older results: **No scaling on cross section**



Nuclear Modification Factor (R_{eAu})

After PID+ Preselection + ML



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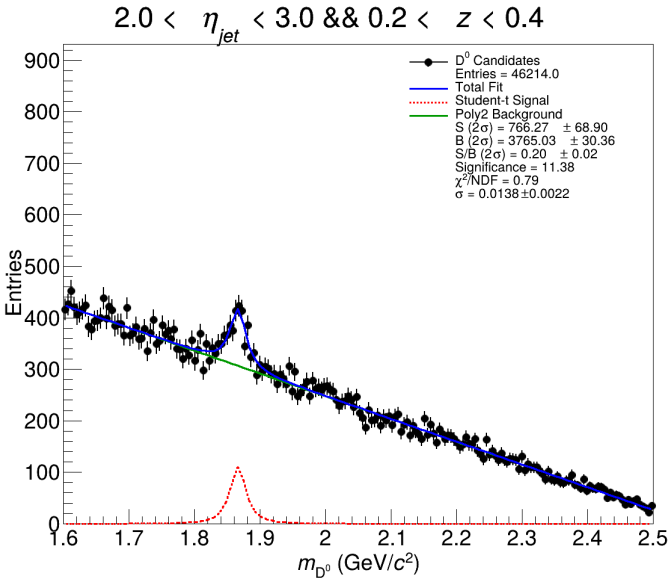
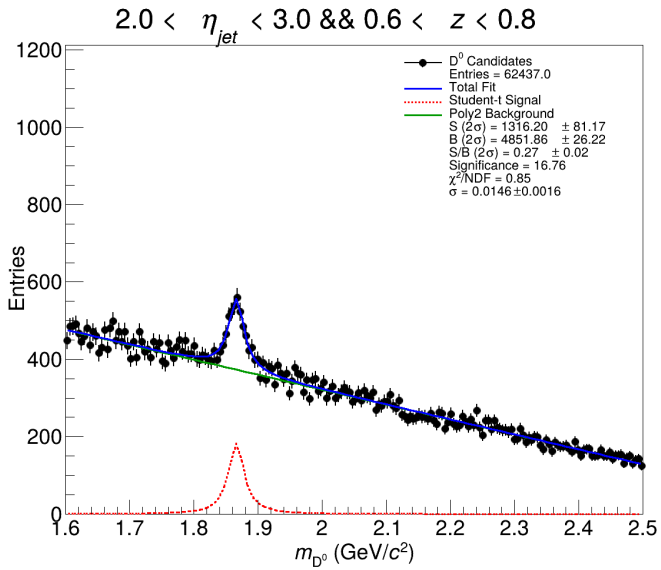
Invariant Mass Spectra (e+Au)





After PID+ Preselection

$$z = z_{proj} = \frac{\vec{p}_{D0.}\,\vec{p}_{jet}}{p_{jet}^2}$$

D⁰-jet reconstruction
Gurtaj, Lokesh, Rongrong, Shyam

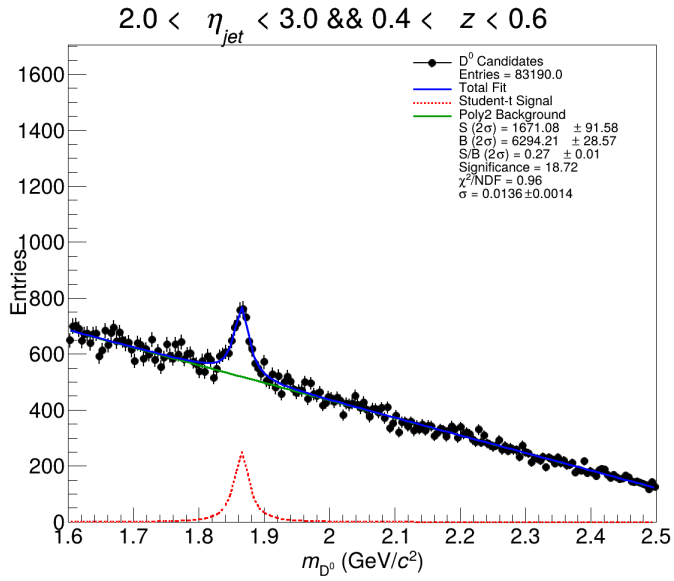
$$L_{\text{int}}(\text{sim}) = \frac{N_{DIS}}{\sigma_{MB}(Q^2>1)}$$

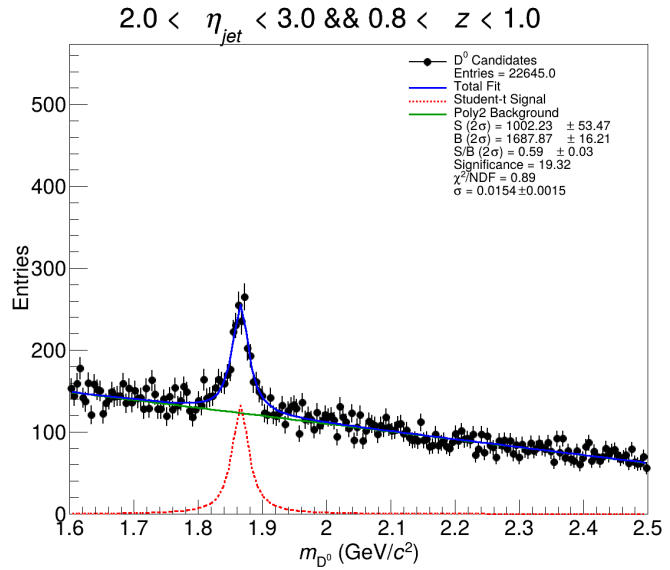
Q_i bins: 1-10, 10-100

$$f_i = \frac{\sigma(Q_i^2)}{\sigma(Q^2>1)}$$

Slide 5

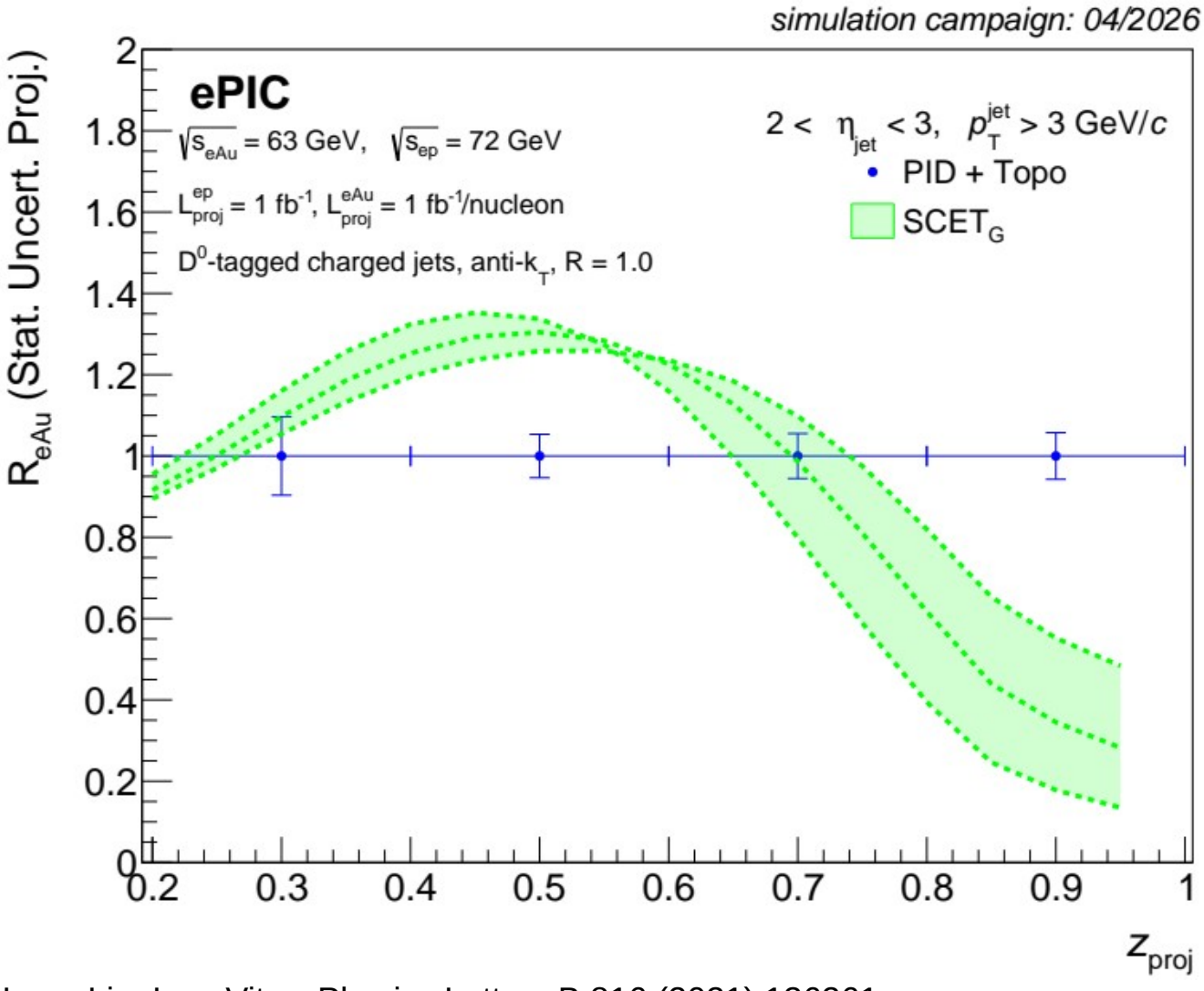
Scaling on cross section





Nuclear Modification Factor (R_{eAu})

After PID+ Preselection + ML



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Summary and Future Plan

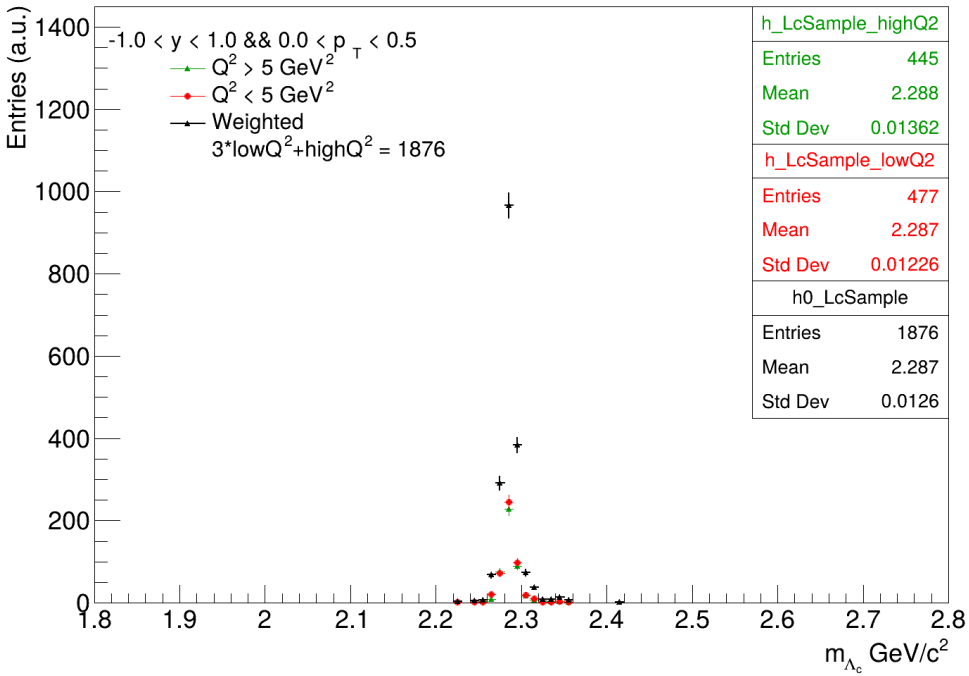
- Λ_c^+/D^0 ratio is included in ES report
- Result of R_{eAu} vs z_{proj} is also included on ES report
- Next simulate proper sample in July campaign to avoid cross section scaling
- Analysis cross-checks in progress

Thank you for your attention!

Applying weight factor on Signal (Checks)

Weight factor of 3 on signal for $Q^2 < 5$ GeV^2

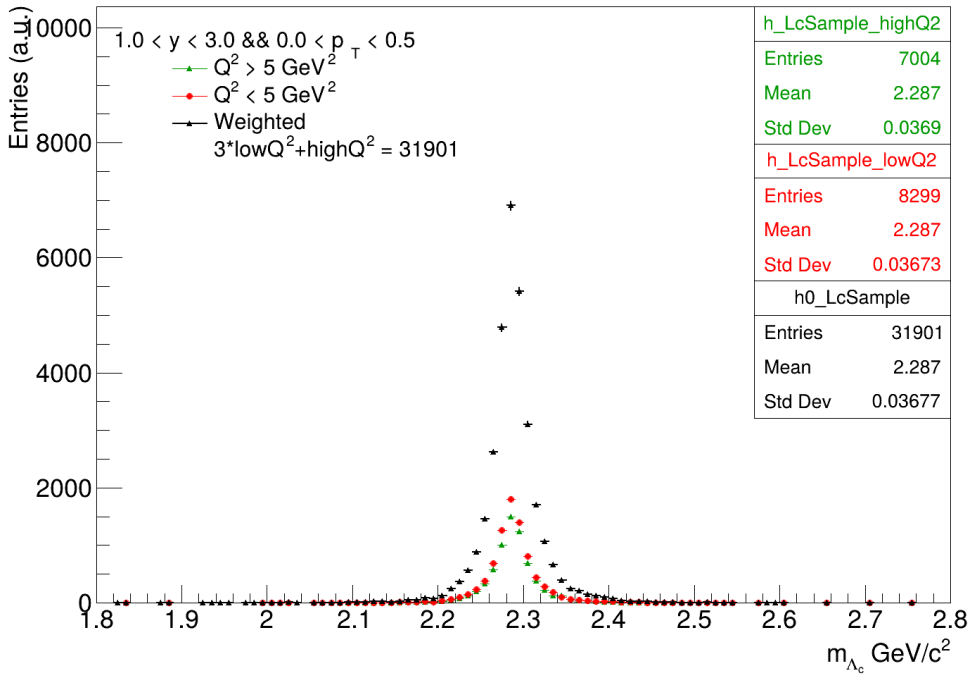
Mid rapidity



bin 47 x=2.265 low=20+/-4.47214 high=8+/-2.82843
weighted=68+/-8.24621

bin 48 x=2.275 low=72+/-8.48528 high=76+/-8.7178
weighted=292+/-17.088

Forward rapidity



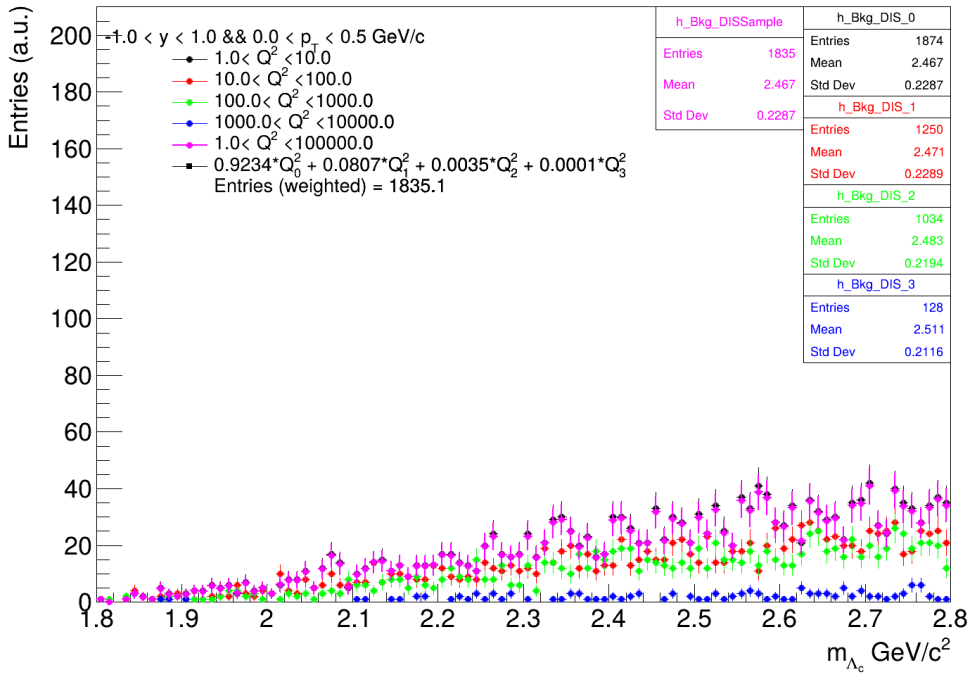
bin 47 x=2.265 low=683+/-26.1343 high=574+/-23.9583
weighted=2623+/-51.2152

bin 48 x=2.275 low=1261+/-35.5106 high=1006+/-31.7175
weighted=4789+/-69.2026

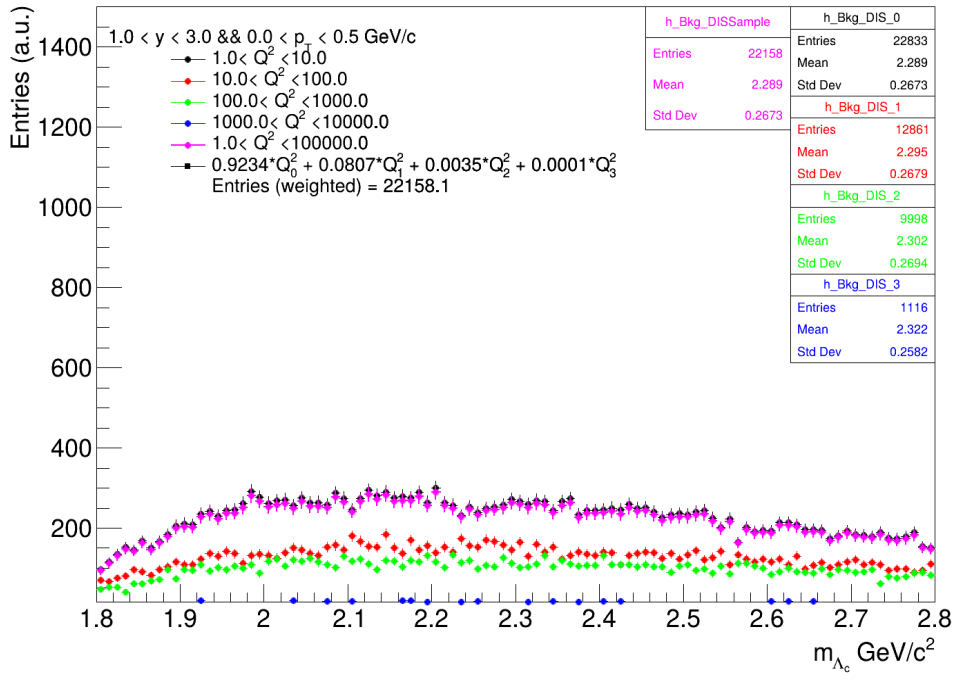
Applying scaling factor on Bkg (Checks)

Weight factor according to cross section

Mid rapidity



Forward rapidity



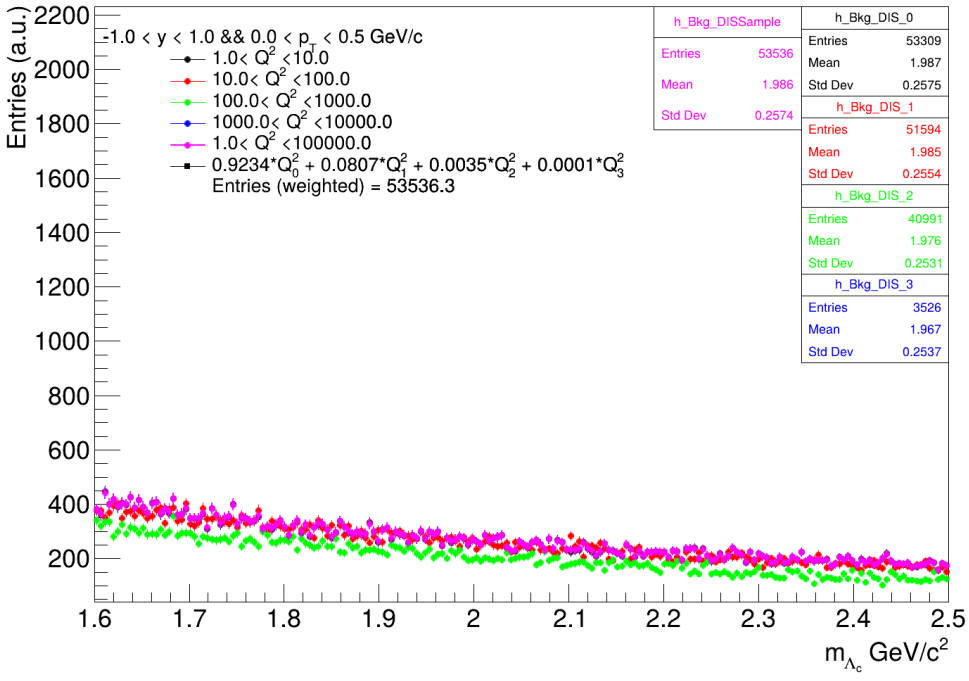
Event generator and energy	$Q^2 > 1$	$1 < Q^2 < 10$	$10 < Q^2 < 100$	$1e2 < Q^2 < 1e3$	$1e3 < Q^2 < 1e4$
PYTHIA 8.316, 10x130	5.847e5 pb	5.391e5 pb	4.223e4 pb	1.590e3 pb	1.260e1 pb
PYTHIA 8.316, 10x250	6.556e5 pb	6.054e5 pb	5.291e4 pb	2.322e3 pb	3.686e1 pb
PYTHIA 8.316, 9x130	5.719e5 pb	5.307e5 pb	4.048e4 pb	1.475e3 pb	1.001e1 pb
PYTHIA 8.316, 9x275	6.546e5 pb	6.025e5 pb	5.178e4 pb	2.292e3 pb	3.697e1 pb

$$f_i = \frac{\sigma(Q_i^2)}{\sigma(Q^2>1)}$$

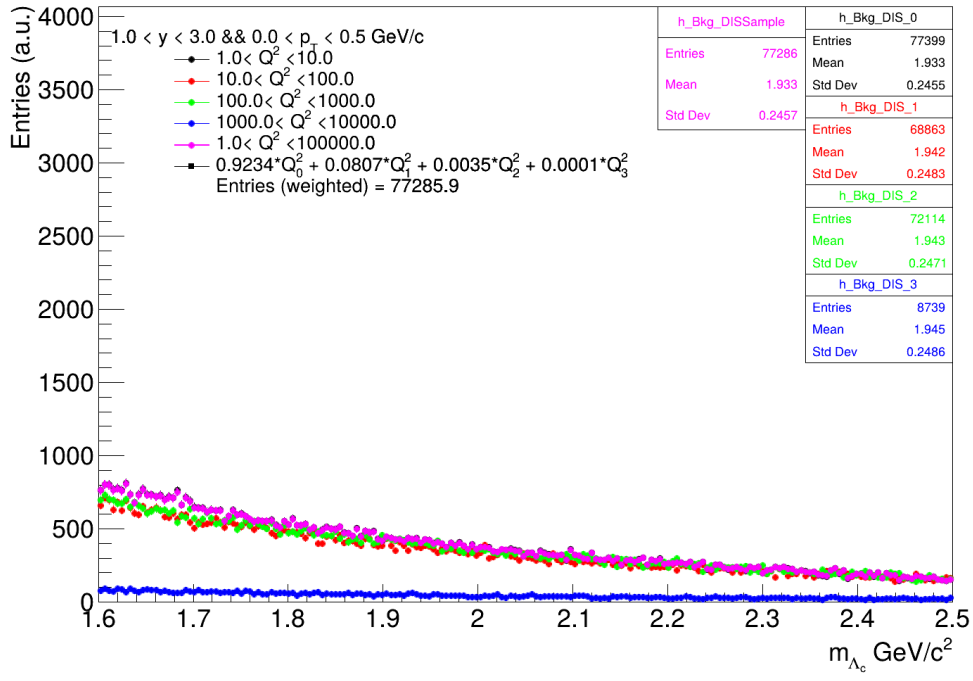
Applying scaling factor on Bkg (Checks)

Weight factor according to cross section

Mid rapidity



Forward rapidity

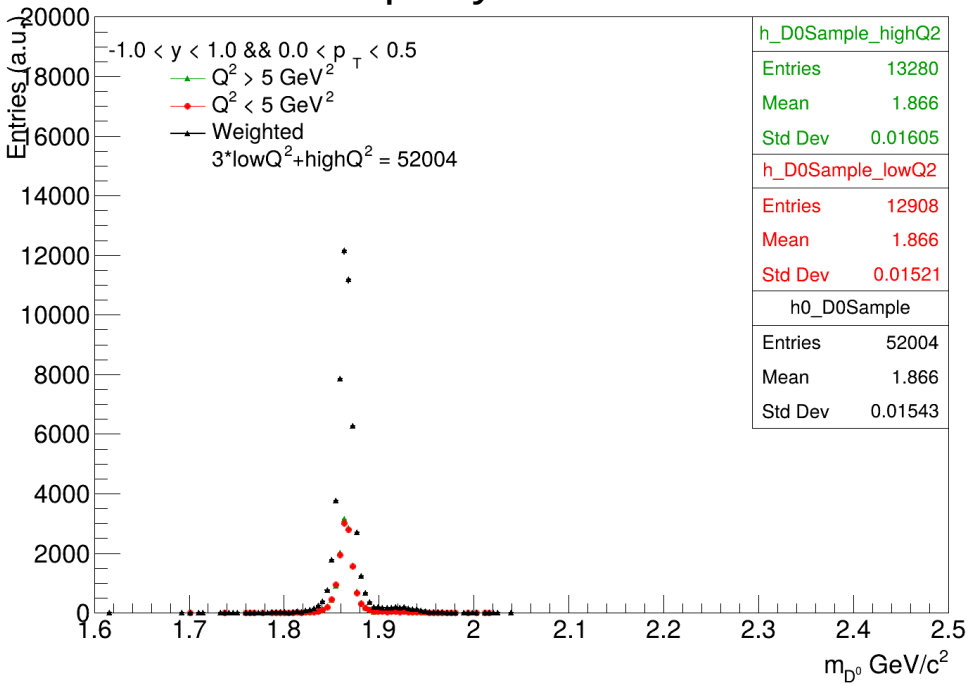


Event generator and energy	**$Q^2 > 1$**	**$1 < Q^2 < 10$**	**$10 < Q^2 < 100$**	**$1e2 < Q^2 < 1e3$**	**$1e3 < Q^2 < 1e4$**
PYTHIA 8.316, 10x130	5.847e5 pb	5.391e5 pb	4.223e4 pb	1.590e3 pb	1.260e1 pb
PYTHIA 8.316, 10x250	6.556e5 pb	6.054e5 pb	5.291e4 pb	2.322e3 pb	3.686e1 pb
PYTHIA 8.316, 9x130	5.719e5 pb	5.307e5 pb	4.048e4 pb	1.475e3 pb	1.001e1 pb
PYTHIA 8.316, 9x275	6.546e5 pb	6.025e5 pb	5.178e4 pb	2.292e3 pb	3.697e1 pb

Applying weight factor on Signal (Checks)

Weight factor of 3 on signal for $Q^2 < 5$ GeV^2

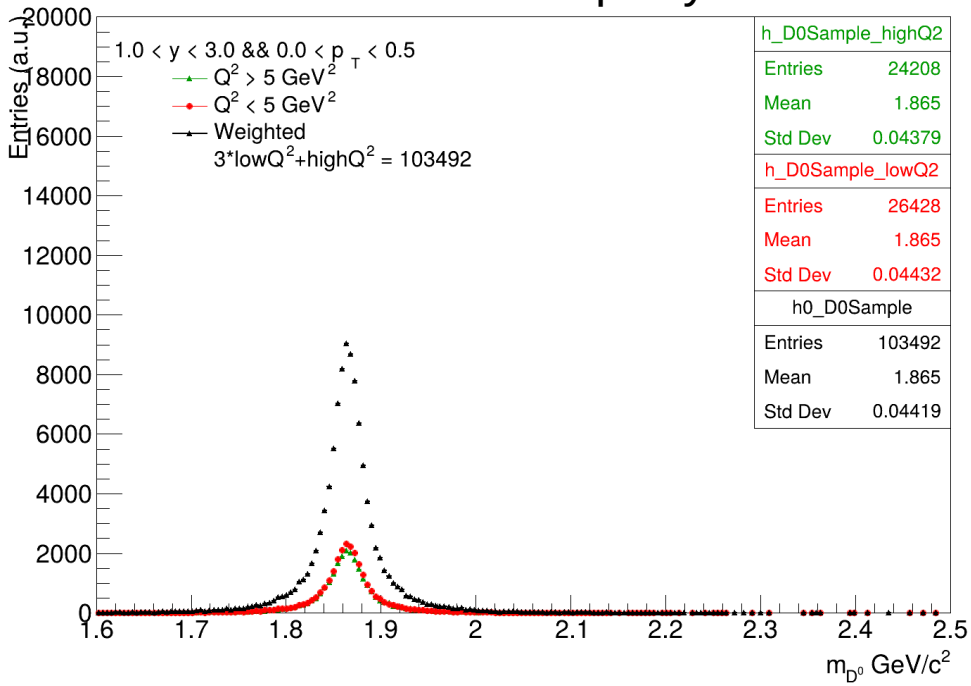
Mid rapidity



bin 48 x=1.81375 low=15+/-3.87298 high=11+/-3.31662
weighted=56+/-7.48331

bin 49 x=1.81825 low=8+/-2.82843 high=8+/-2.82843
weighted=32+/-5.65685

Forward rapidity



bin 48 x=1.81375 low=266+/-16.3095 high=246+/-15.6844
weighted=1044+/-32.311

bin 49 x=1.81825 low=281+/-16.7631 high=261+/-16.1555
weighted=1104+/-33.2265

Invariant Mass (Λ_c)

Fast simulation (10 fb^{-1})

$\sqrt{s} = 141\,GeV$

arXiv:2102.08337

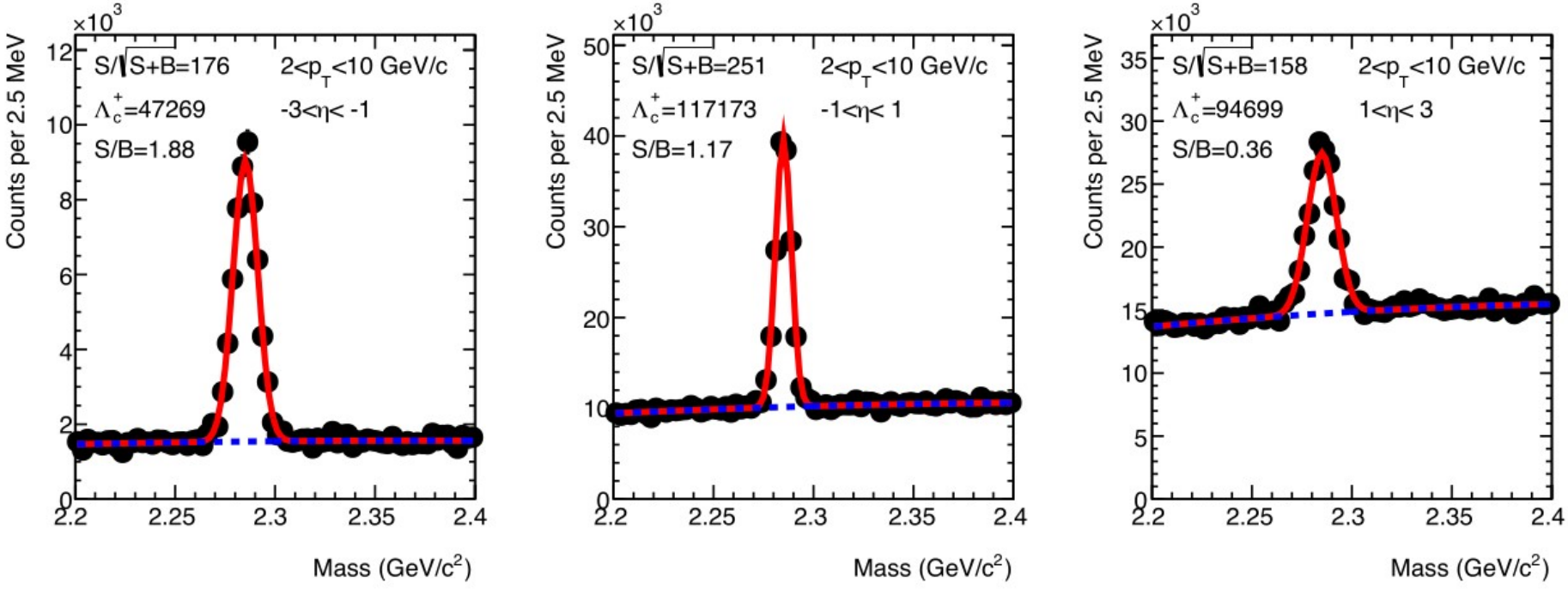
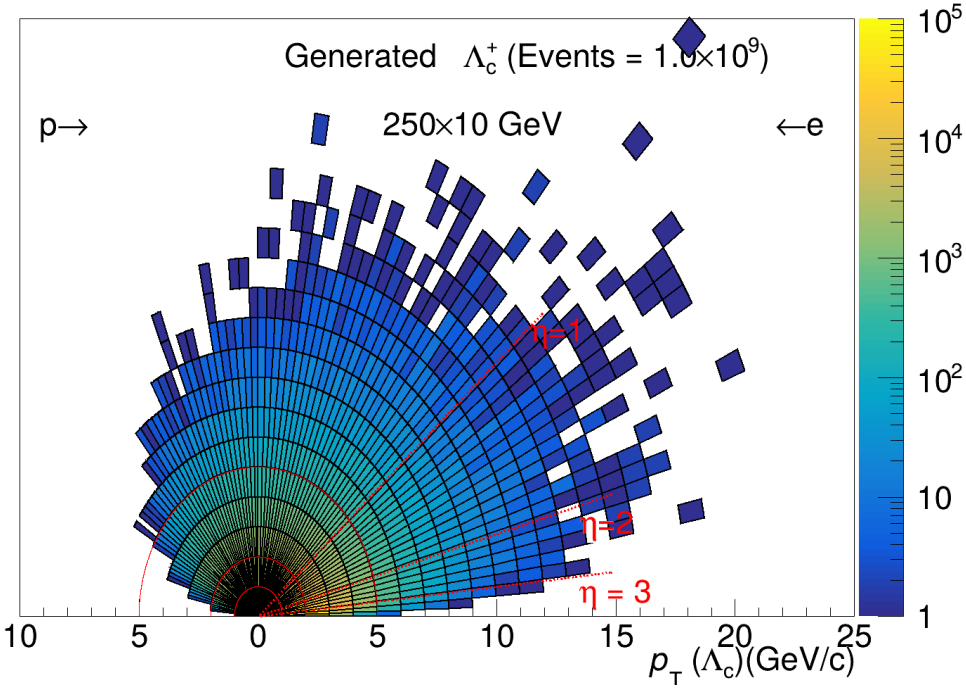


FIG. 39. Invariant-mass distributions of $pK^-\pi^+$ triplets in Λ_c^+ reconstruction in $2 < p_T < 4\,\mathrm{GeV}/c$ from DIS e+p (18×275 GeV) collisions based on a PYTHIA v6.4 + fast simulation in the $-3 < \eta < -1$ (left), $-1 < \eta < 1$ (middle) and $1 < \eta < 3$ (right) regions, respectively.

Phase Space (PYTHIA8316 Simulation)

main41_D0_from_piK_NoEtaCut.cc



main41_LcToPiKp.cc