EIC Particle Identification in Heavy Flavor Study

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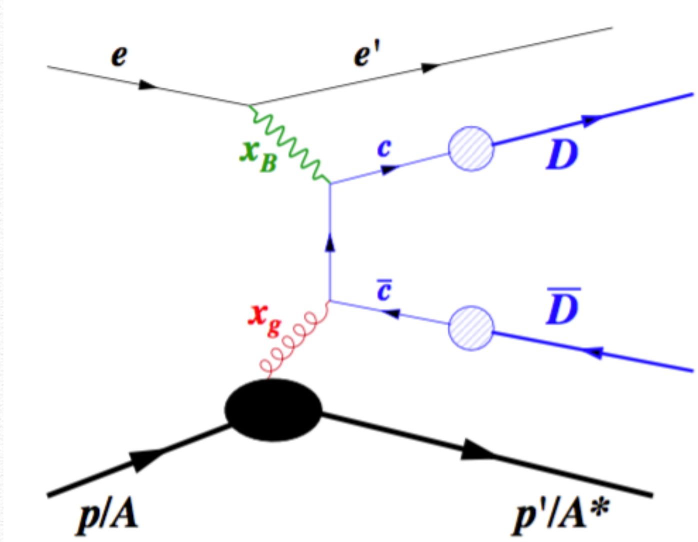
with help & inputs from LBNL memebers, Jin Huang (BNL) and Barak Schmookler (SBU)

Heavy flavor study at EIC

- Heavy flavor sensitive to the gluon dynamics

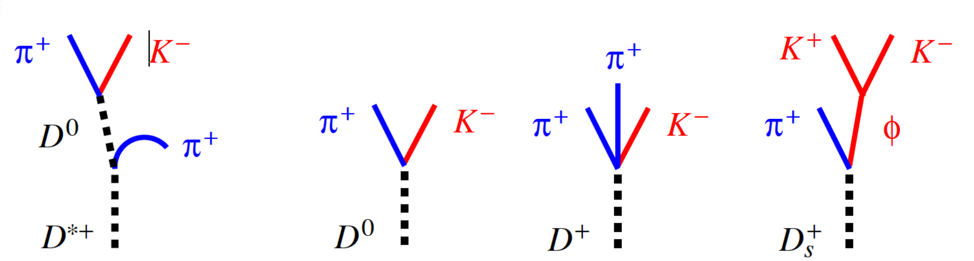


arXiv: 2102.08337

- Inclusive heavy-flavor hadron production in unpolarized $e+p/\mathrm{A}$ collisions to constrain gluon (nuclear) parton distribution functions (PDFs) in nucleons and nuclei, especially in the large Bjorken-x (x_B) region ($x_B \gtrsim 0.1$).
- Heavy-flavor hadron pair (e.g. $D+\overline{D}$) production to constrain gluon transverse momentum dependent (TMD) PDFs in both unpolarized and transversely-polarized experiments.
- Heavy-flavor hadron double spin asymmetry (A_{LL}) measurement to constrain the gluon helicity distributions ($\Delta g/g$).
- Heavy-flavor hadrochemistry (abundance between different heavy-flavor hadron states) studies to better understand heavy-quark hadronization as well as the impact of cold nuclear matter effects in $e+A$ collisions.

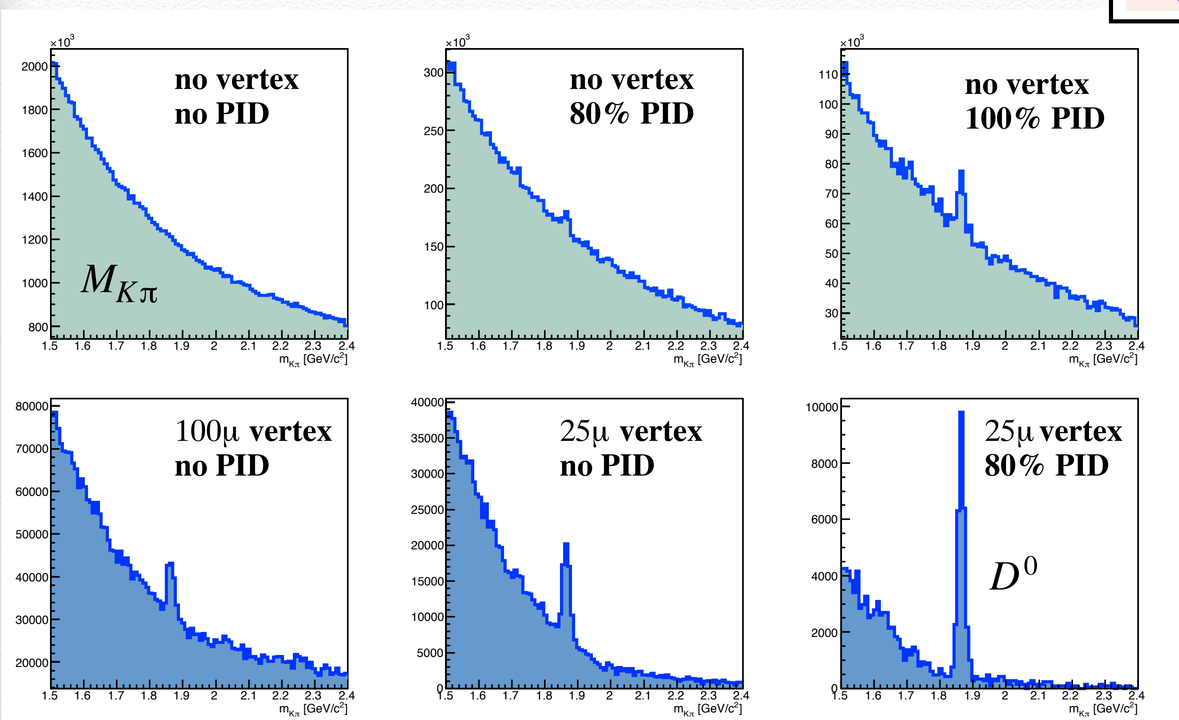
Charm reconstruction with exclusive c hadrons

h_c	f	Decay	BR
D^0	59%	$K^-\pi^+$	3.9%
		$K^-\pi^+\pi^+\pi^-$	8.1%
D^+	23%	$K^-\pi^+\pi^+$	9.2%
D^{*+}	23%	$(K^-\pi^+)_{D0}\ \pi^+_{\text{slow}}$	2.6%
		$(K^-\pi^+\pi^+\pi^-)_{D0}\ \pi^+_{\text{slow}}$	5.5%
D_s^+	9%	$(K^+K^-)_\phi\ \pi^+$	2.3%
Λ_c^+	8%	$pK^-\pi^+$	5.0%



Heavy flavor mass and decay length

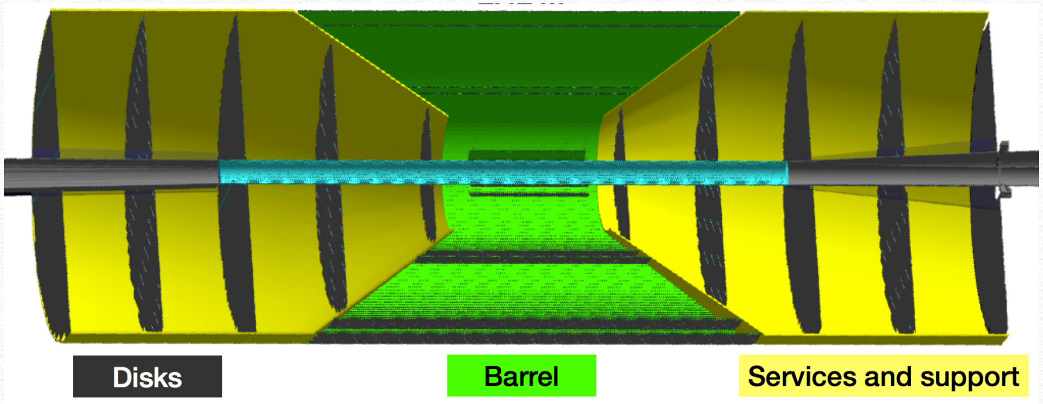
Particle	Mass (GeV/c²)	$c\tau$ decay length
$D^\pm$	1.869	312 micron
D^0	1.864	123 micron
$B^\pm$	5.279	491 micron
B^0	5.280	456 micron

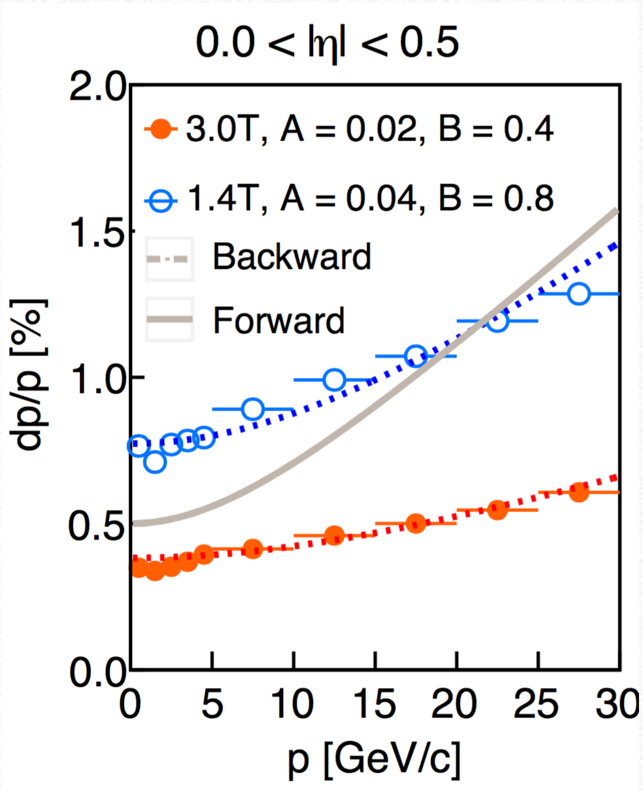


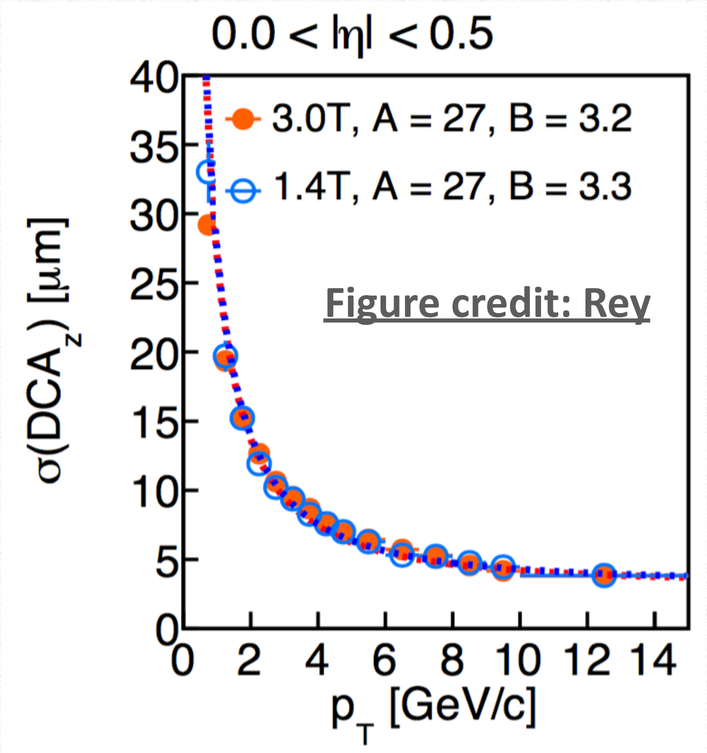
Need good vertexing

Need good PID (K/π/p)

Good vertexing & tracking from All-Si

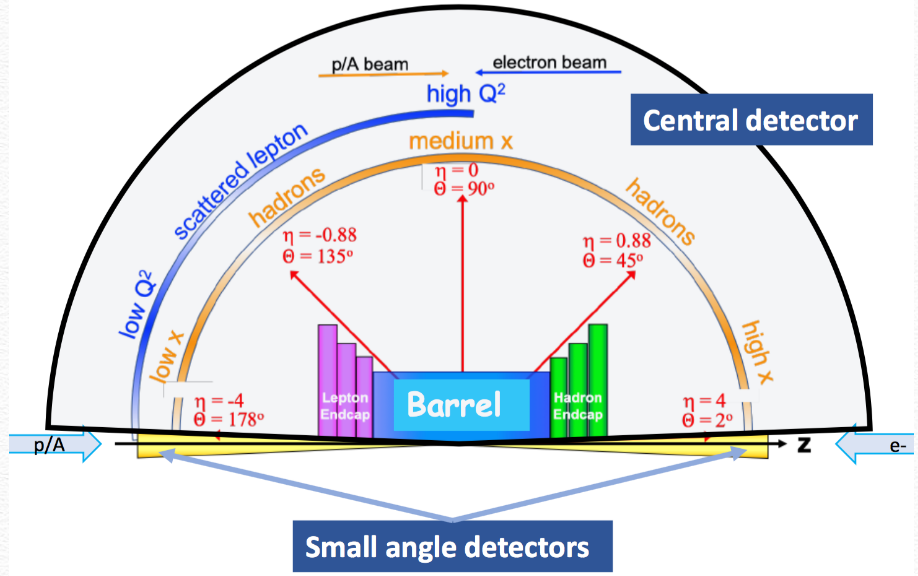






PID at different rapidity

Central Arm Technology	Range (GeV/c)	
	$e - \pi$	π - K
$\frac{dE}{dx}$	0 - 2	0 - 3
$\frac{dE}{dx}$ (Cluster Count)	0 - 10 ??	0 - 15
DIRC	0.00048 - 1	0.47 - 6
TOF (LGAD)	0 - 1	0.00 - 5
HBD	0.0150 - 4.17	N/A



Electron Arm Technology	Range (GeV/c)	
	$e - \pi$	π - K
dRICH (aerogel)	0.0025 - 5	2.46 - 16
dRICH (gas)	0.0127 - 18	12.34 - 60
dRICH (overall)	0.0025 - 18	2.46 - 60
HBD	0.0150 - 4.17	-
mRICH	0.0025 - 2	2.00 - 6
TOF (LAPPD 4m, 5ps)	0 - 3	0.00 - 16
TOF (LAPPD 3m, 10ps)	0 - 1.8	0.00 - 10
TRD	1.0 – 270.0	–

Hadron Arm Technology	Range (GeV/c)	
	$e - \pi$	π - K
CsI RICH	0.0150 - 20	14.75 - 50
dRICH (aerogel)	0.0025 - 5	2.46 - 16
dRICH (gas)	0.0127 - 18	12.34 - 60
dRICH (overall)	0.0025 - 18	2.46 - 60
TOF (LGAD)	0 - 1	0.00 - 5
TOF (LAPPD 4m 5ps)	0 - 2.5	0.00 - 16
TRD	1.0 – 270.0	–

RICH detectors have firing threshold at low momentum

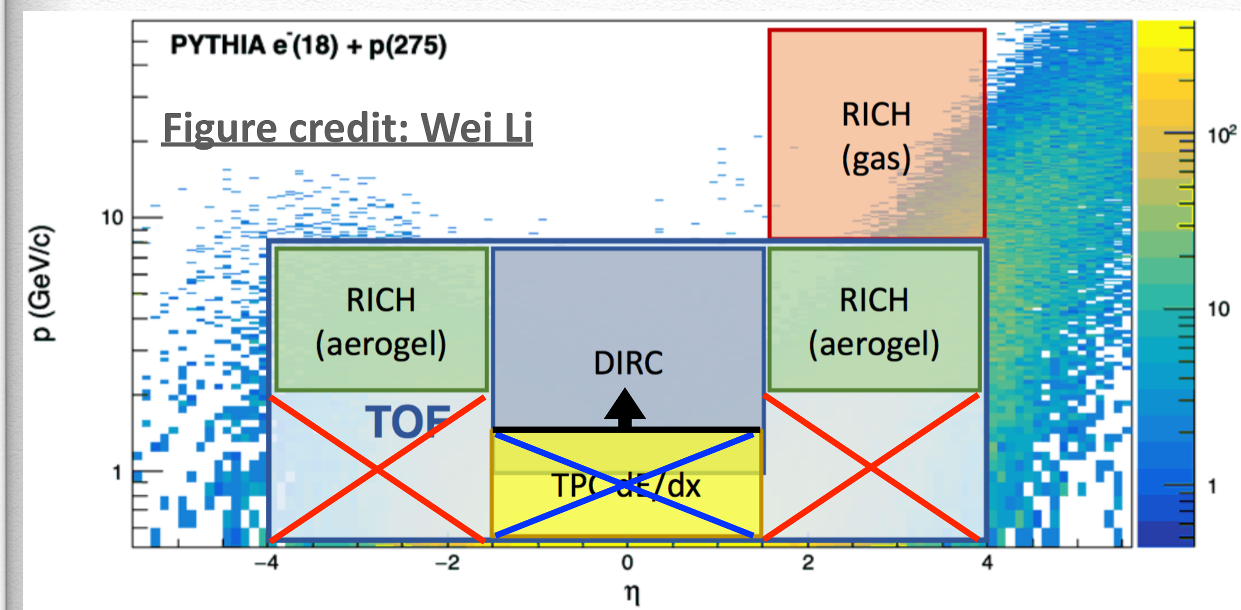
Low p threshold for RICH detectors

Deterctor Matrix	
Barrel	**< 6 GeV**
Forward	**< 10 GeV**
Backward	**< 50 GeV**

EICUG YR

radiator	index	Threshold (GeV/c) e	π	K	p
quartz (DIRC)	1.473	0.00048	0.13	0.47	0.88
aerogel (mRICH)	1.03	0.00207	0.57	2.00	3.80
aerogel (dRICH)	1.02	0.00245	0.69	2.46	4.67
C_2F_6 (dRICH)	1.0008	0.01277	3.49	12.34	23.45
CF_4 (gRICH)	1.00056	0.01527	4.17	14.75	28.03

Table 11.23: Table of Cherenkov thresholds for various media.



No TOF in current Beast or EIC-sPHENIX

No dE/dx in All-Si concept

Magnetic field can affect the low p_T range

Detector effects — PID

- Using fast simulation to check the detector effects on D0 and Λ_c reconstruction
- Particle identification (PID)
  - No PID
  - Detector Matrix (DM) PID: no low p cutoff (can be covered by TPC and TOF)
  - DIRC+dRICH: with low p cutoff (1.4T and 3T), including or excluding mis-identified particles
  - Caveat: assume perfect electron ID, ignore muons

Detector effects — PID

- Fast simulation for DIRC and dRICH
  - If particles can not reach DIRC ($p_T >$ 0.19GeV for 1.4T, 0.40GeV for 3T), can be smaller if put DIRC closer to All-Si
  - If particles momentum is below the firing threshold for π/K/p

Veto mode: if track momentum above pion threshold but not firing the detector, then it cannot be pion

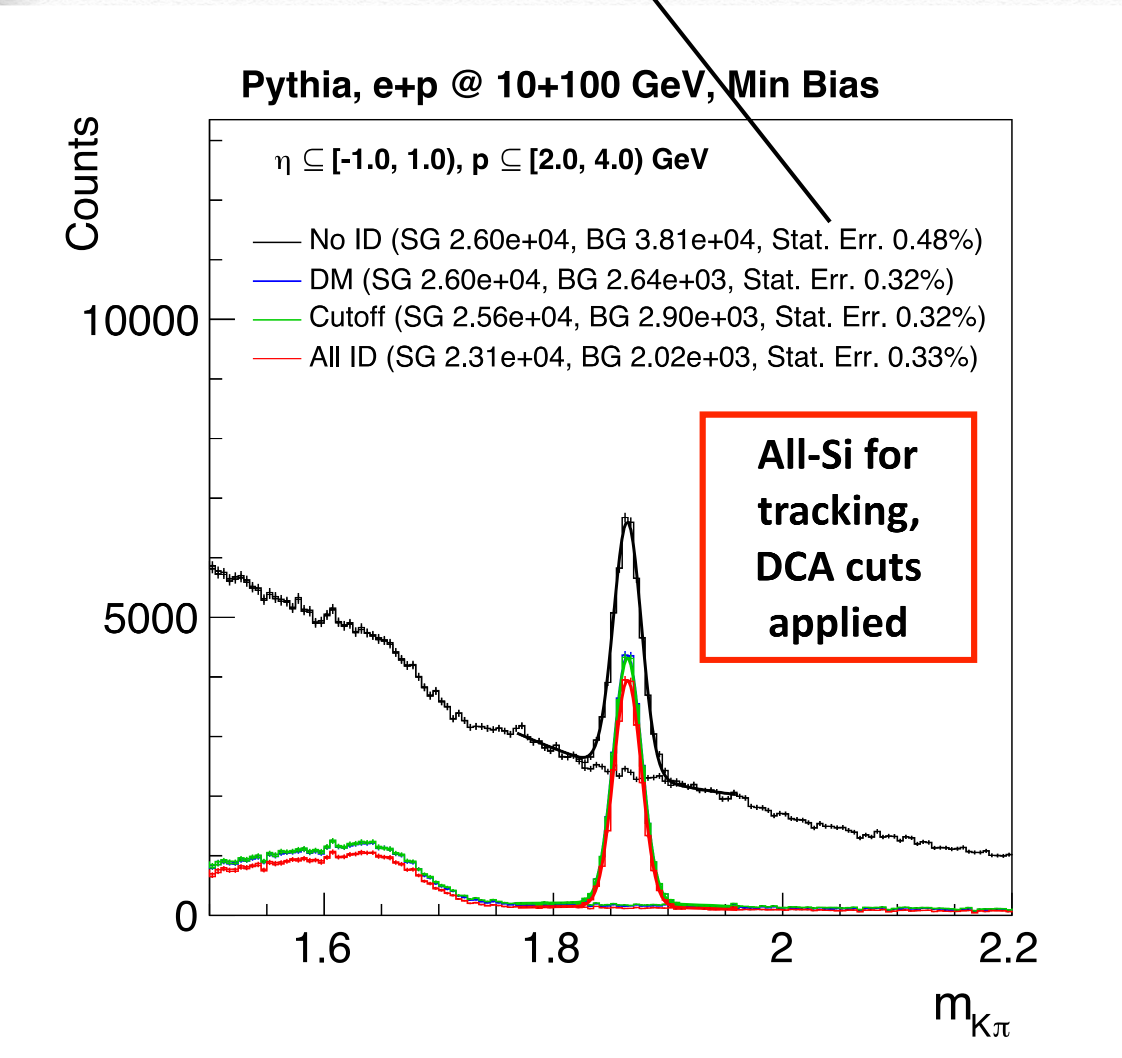
True particle	Pion	Kaon	Proton
p < 0.13 (0.69)	prob(π/K/p) = 0.7, 0.2, 0.1		
p < 0.47 (2.46)	prob(π/K/p) = 1, 0, 0	prob(π/K/p) = 0, 0.6, 0.4	
p < 0.88 (4.67)		prob(π/K/p) = 0, 1, 0	prob(π/K/p) = 0, 0, 1
p < 6 (50)			

probability assigned according to multiplicity of different charged particles

D^0

Stat. Err. = sqrt(SG+BG)/SG
= sqrt(1+BG/SG)/sqrt(SG)

- ***decrease with increasing SG***
- ***descrease with descreasing BG***



No PID: pairing all the charged hadron with opposite charge

DM PID: pairing $K^-\pi^+$ or $K^+\pi^-$

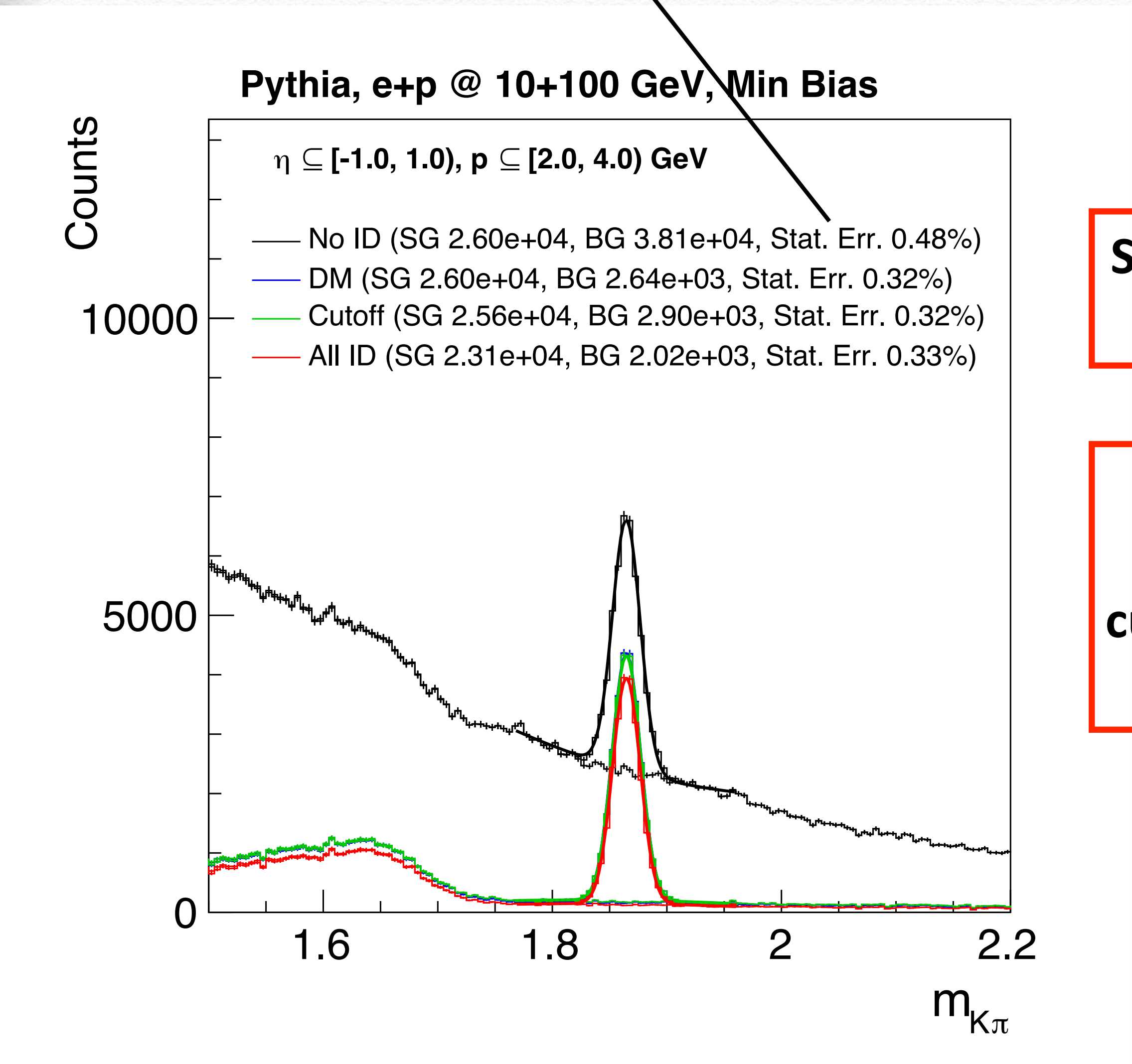
Cutoff: with low p cutoff, pairing identified π with tracks most likely to be K (prob(K)>0.5)

All ID: with low p cutoff, only pair identified particles

D^0 at mid-rapidity

Stat. Err. = sqrt(SG+BG)/SG
= sqrt(1+BG/SG)/sqrt(SG)

- ***decrease with increasing SG***
- ***descrease with descreasing BG***



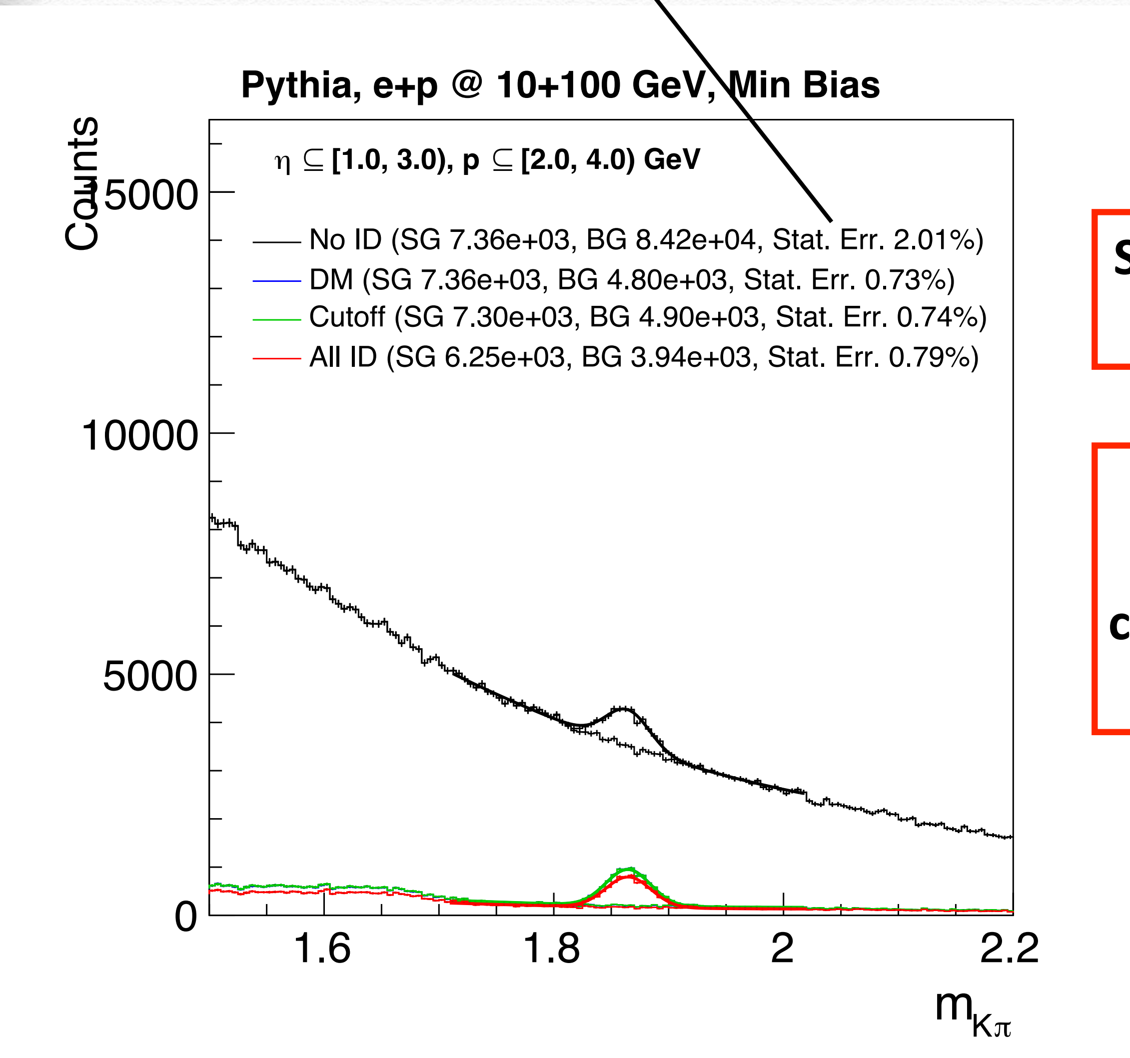
Stat. Err. improves from NO PID to with PID

Stat. Err. become worse from DM PID to PID with low p cutoff, however the effect is not significant

D^0 at forward-rapidity

Stat. Err. = sqrt(SG+BG)/SG
= sqrt(1+BG/SG)/sqrt(SG)

- ***decrease with increasing SG***
- ***descrease with descreasing BG***



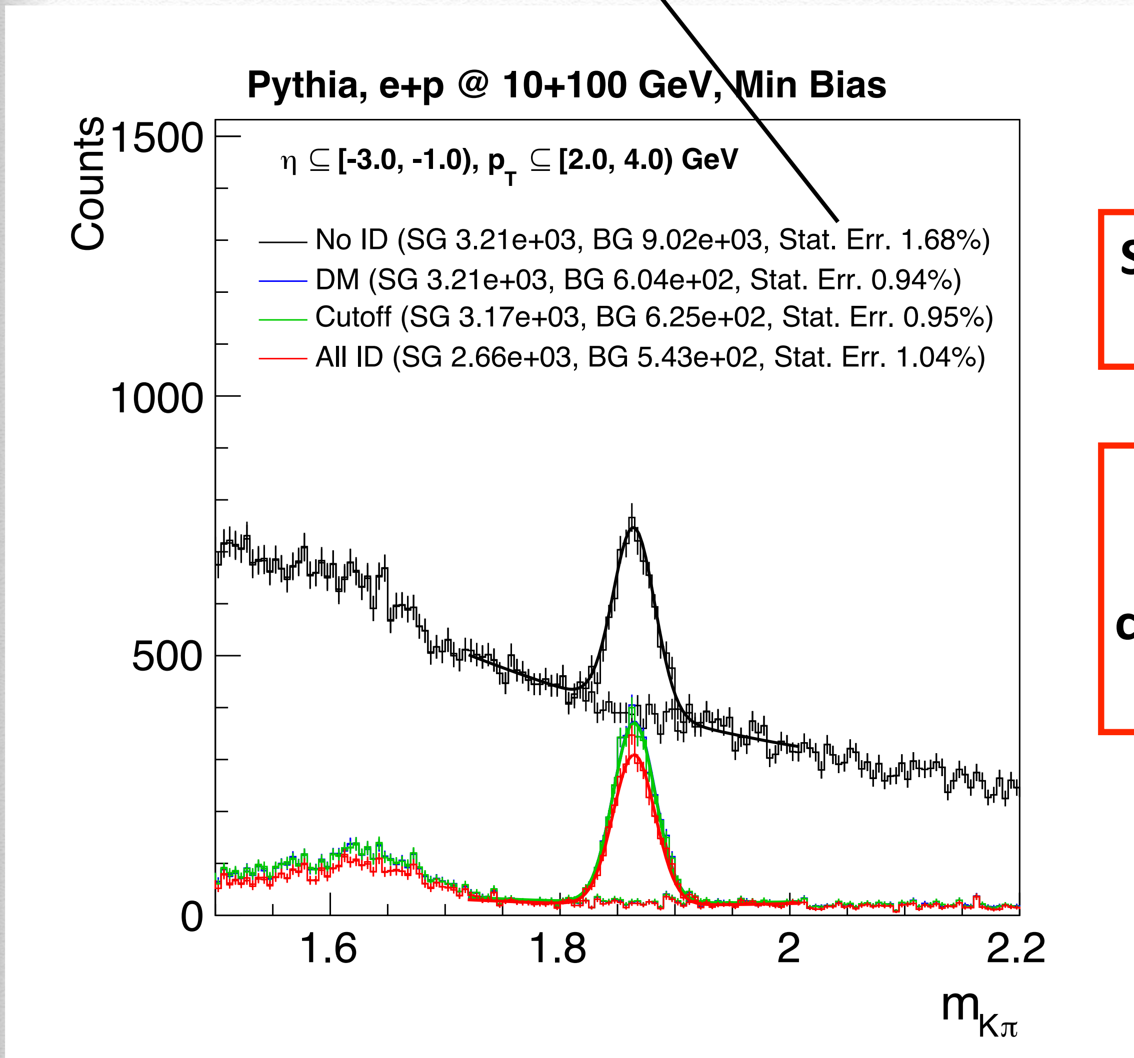
Stat. Err. improves from NO PID to with PID

Stat. Err. become worse from DM PID to PID with low p cutoff, however the effect is not significant

D^0 at backward-rapidity

Stat. Err. = sqrt(SG+BG)/SG
= sqrt(1+BG/SG)/sqrt(SG)

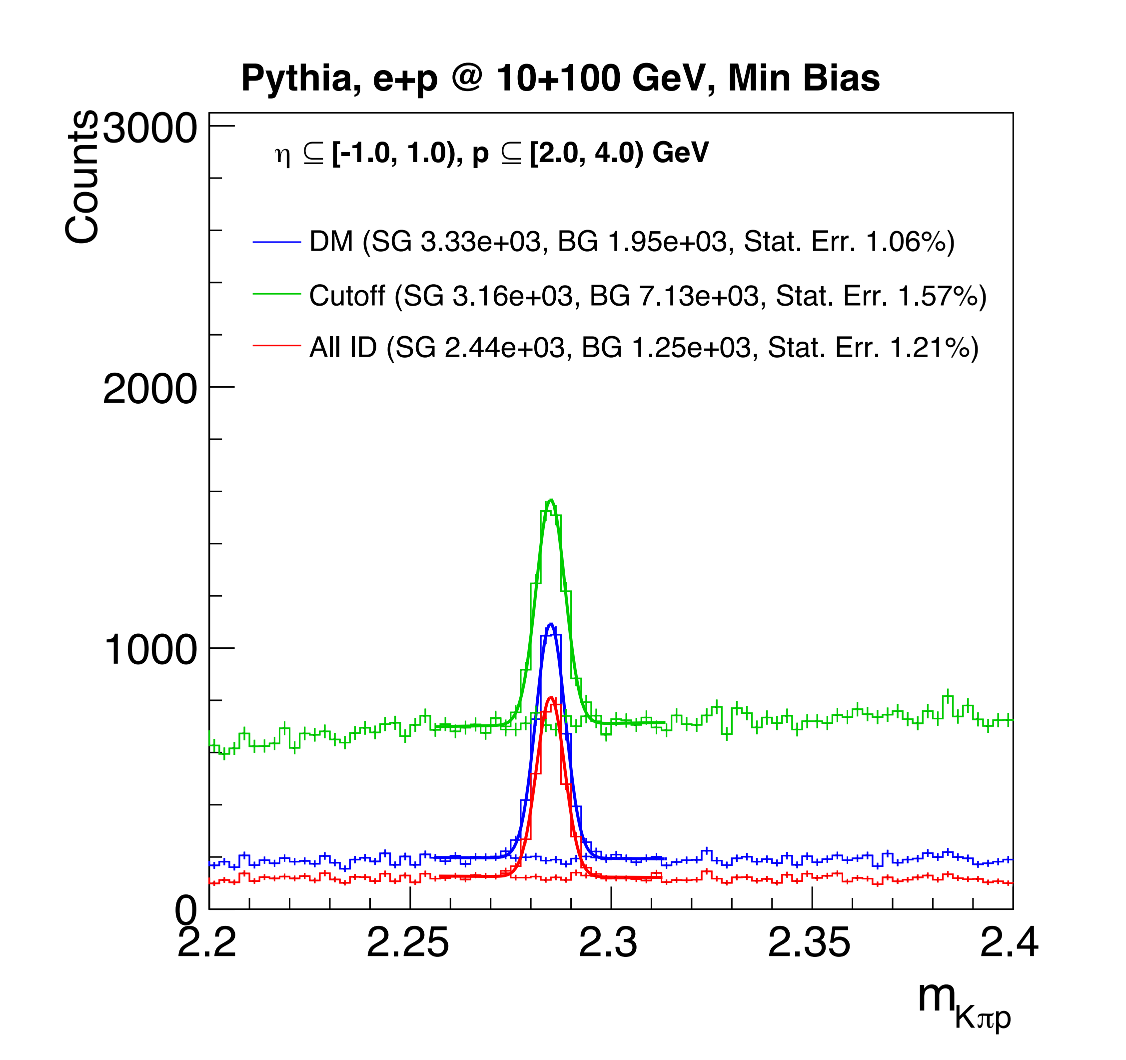
- ***decrease with increasing SG***
- ***descrease with descreasing BG***



Stat. Err. improves from NO PID to with PID

Stat. Err. become worse from DM PID to PID with low p cutoff, however the effect is not significant

Λ_c at mid-rapidity



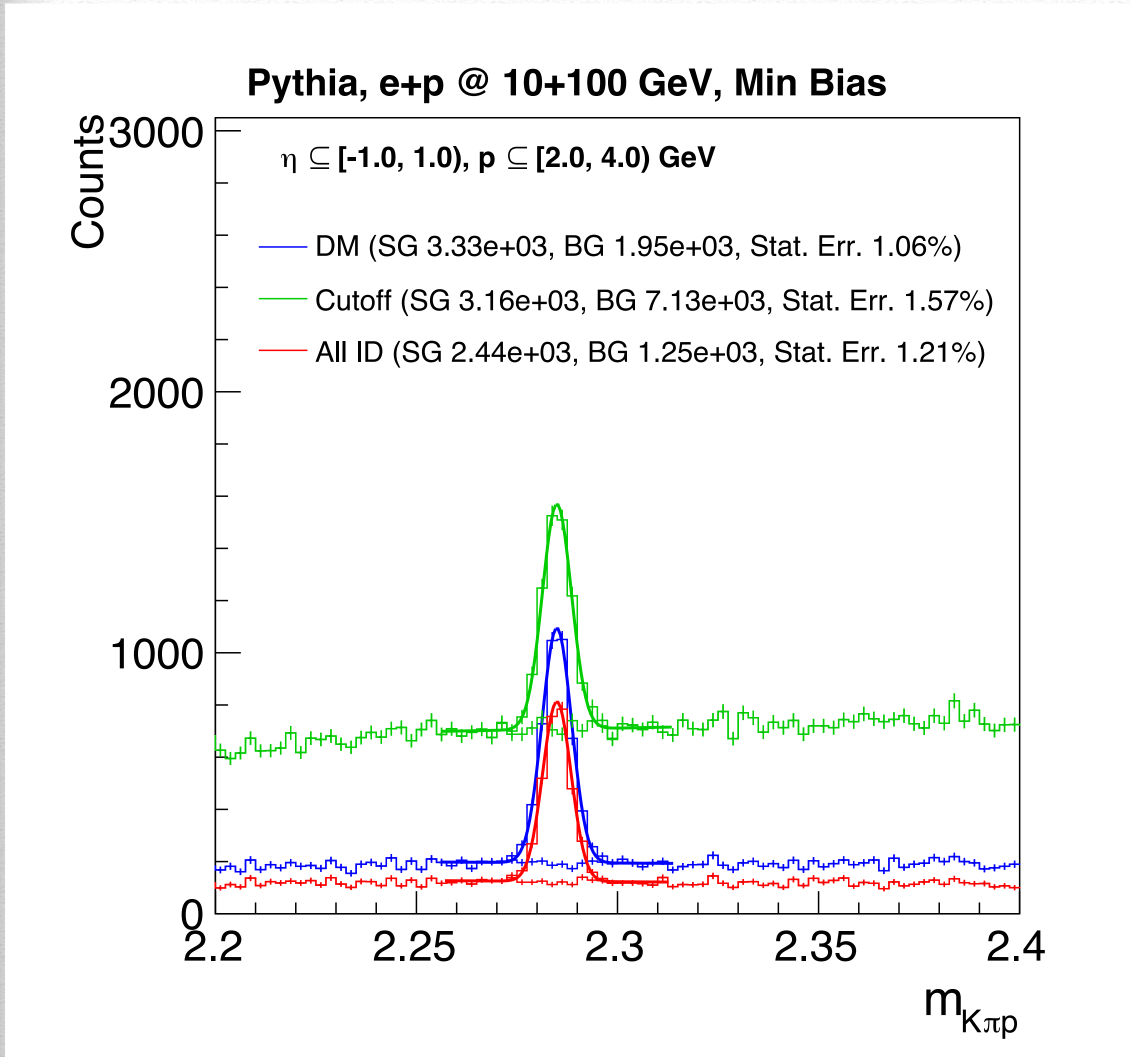
No PID: pairing all the charged hadron with opposite charge

DM PID: pairing $K^-\pi^+p+$ or $K^+\pi^-p-$

Cutoff: with low p cutoff, pairing identified π with tracks most likely to be K (prob(K)>0.5) and tracks that can be p (prob(p)>0.1)

All ID: with low p cutoff, only pair identified particles

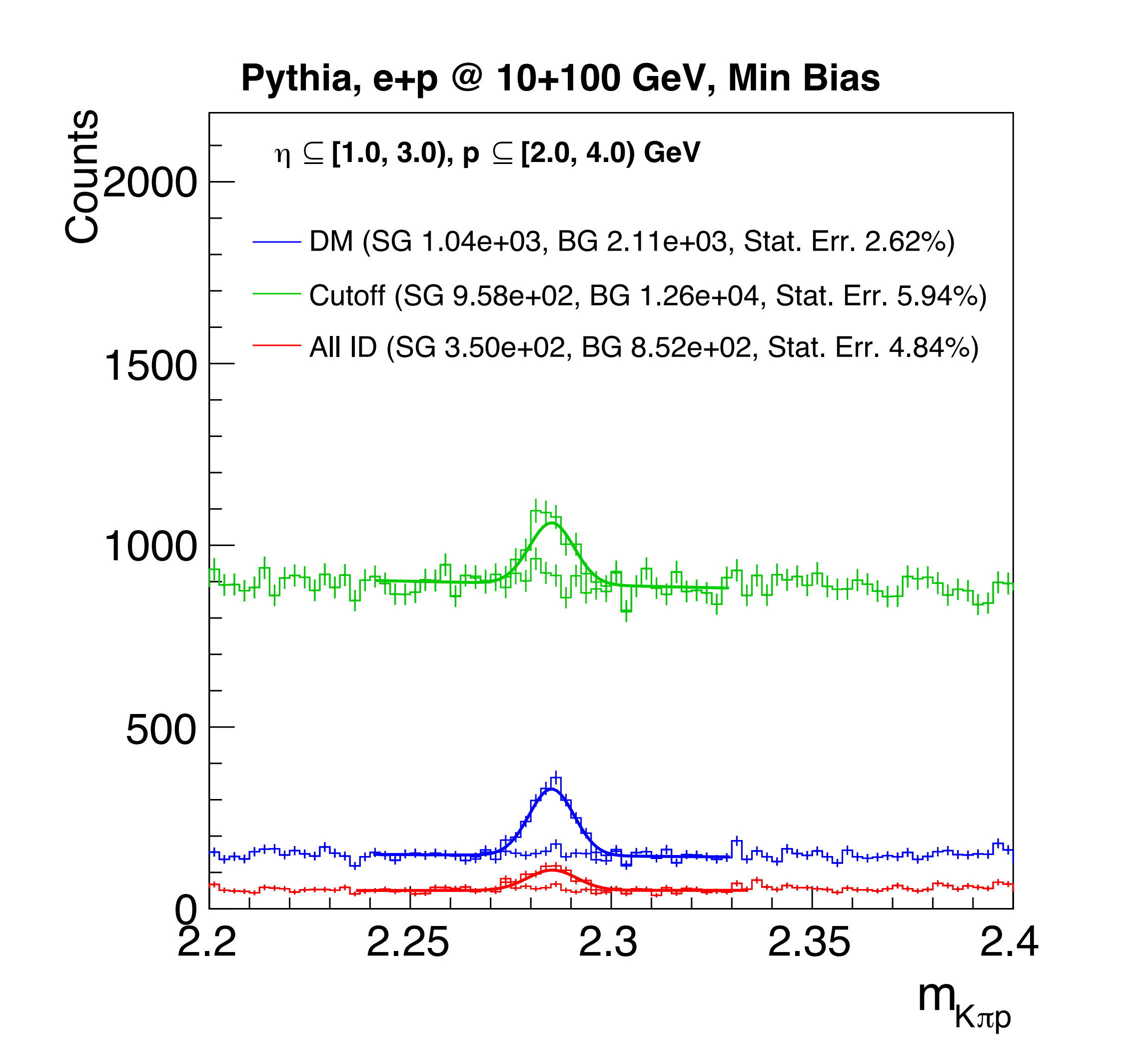
Λ_c at mid-rapidity



Comb. bkg too big when NO PID

Stat. Err. become worse from DM PID to PID with low p cutoff, ~50% effect in forward-rapidity

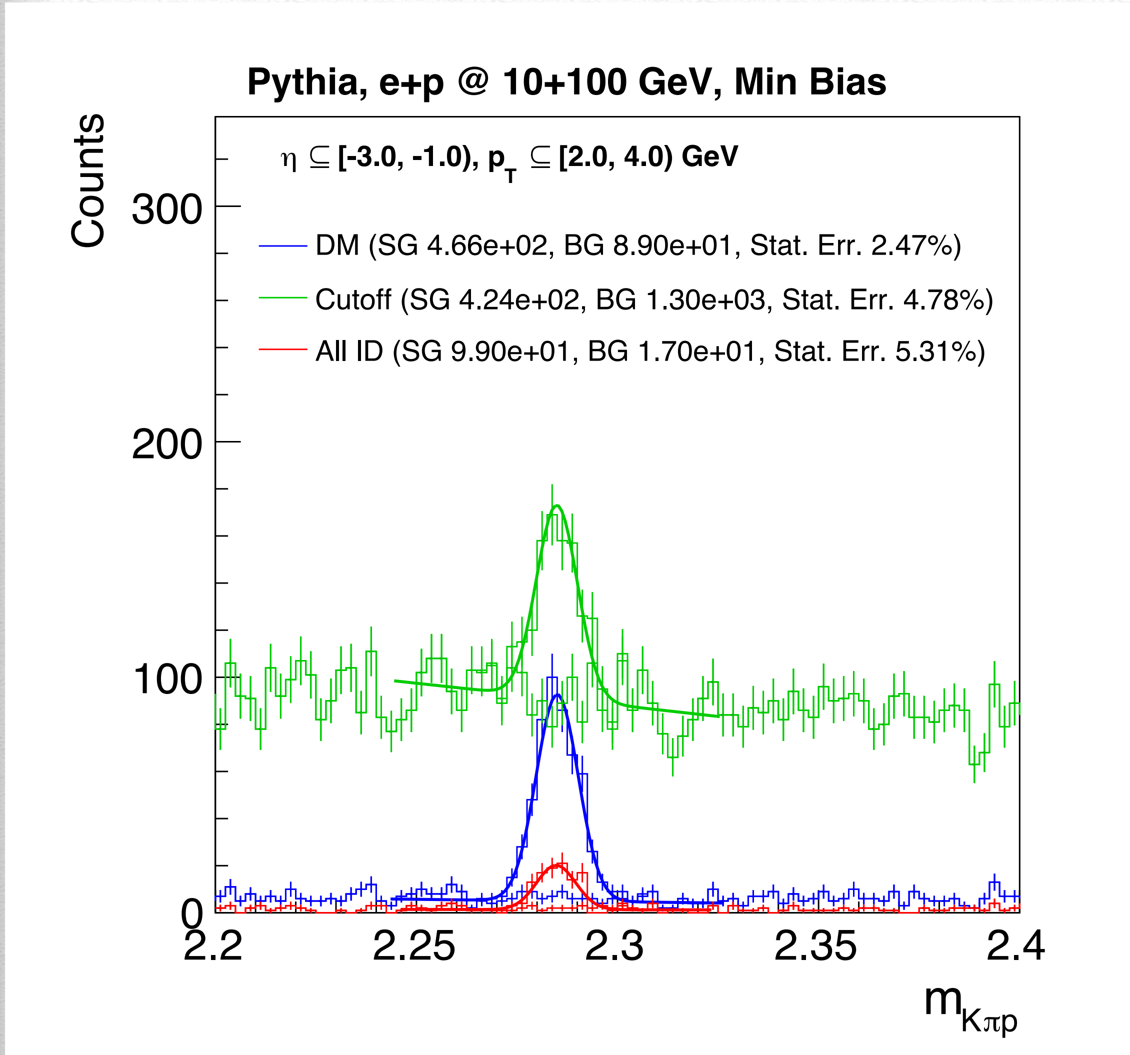
Λ_c at forward-rapidity



Comb. bkg too big when NO PID

Stat. Err. become worse from DM PID to PID with low p cutoff, ~200% effect in forward-rapidity

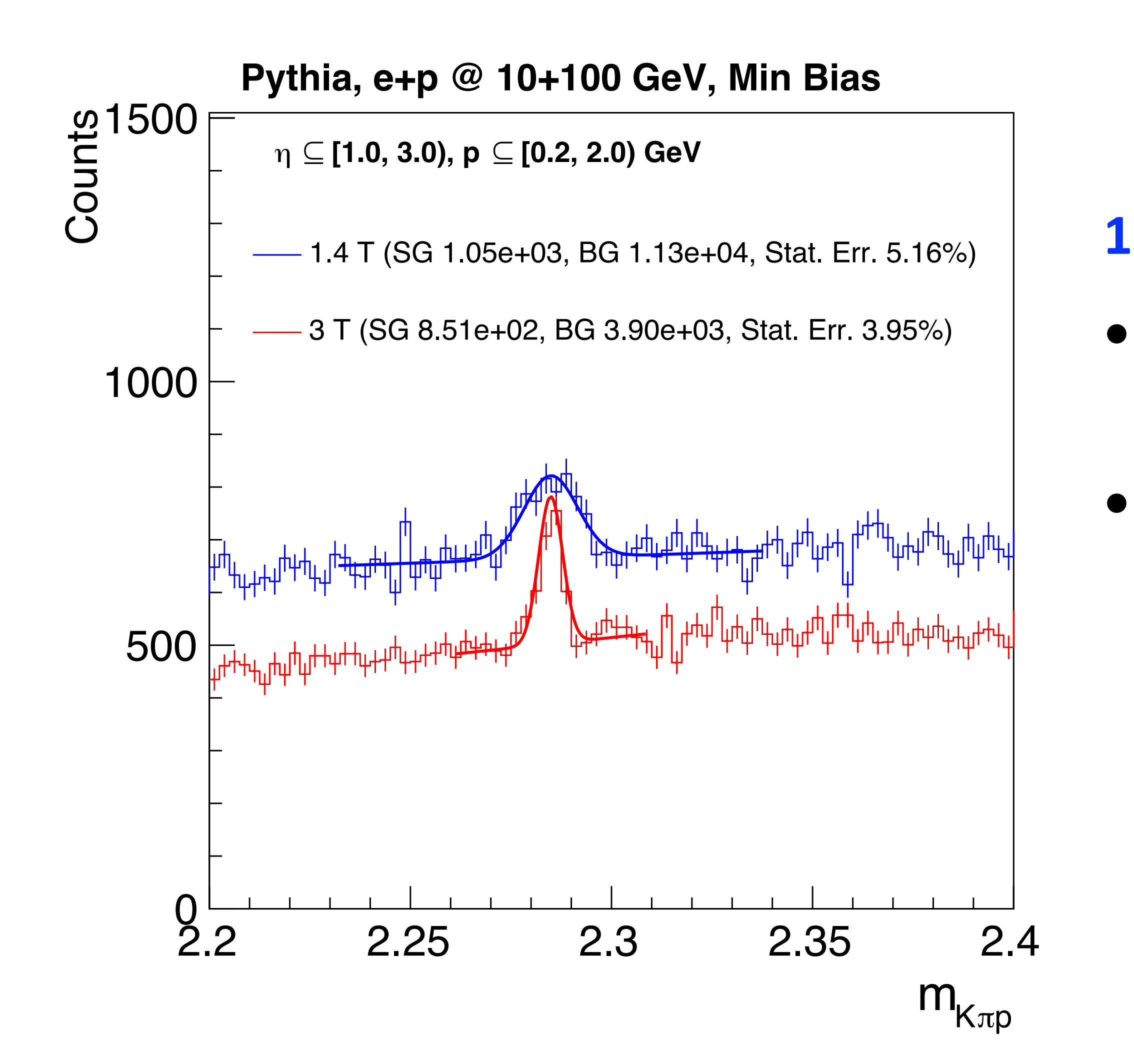
Λ_c at backward-rapidity



Comb. bkg too big when NO PID

Stat. Err. become worse from DM PID to PID with low p cutoff, ~200% effect in backward-rapidity

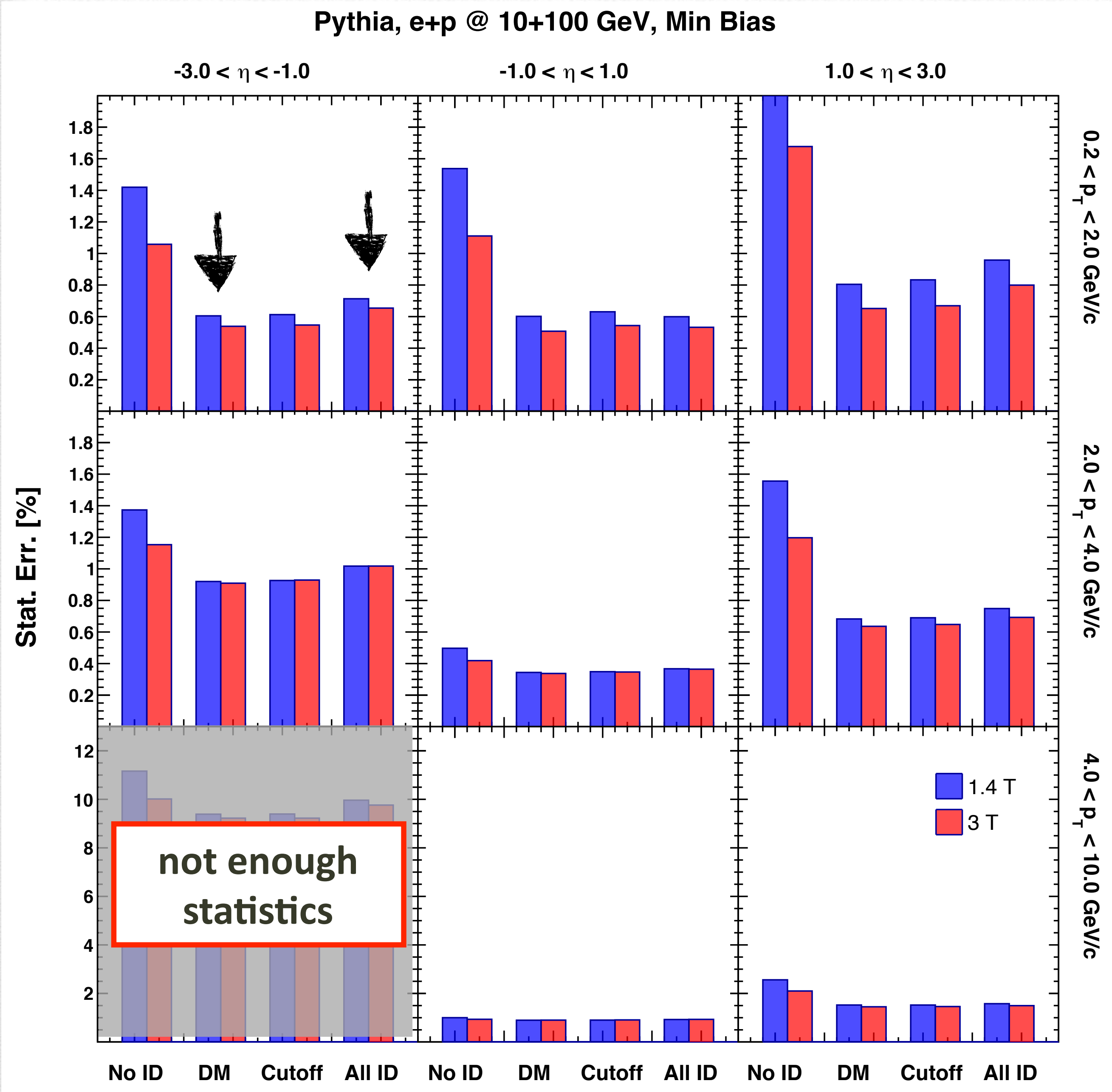
Effect of magnetic field



1.4T to 3T

- **SG drops because of the acceptance**
- **BG drops because of a better momentum resolution (narrower signal region) and fewer low p_T tracks**

D^0



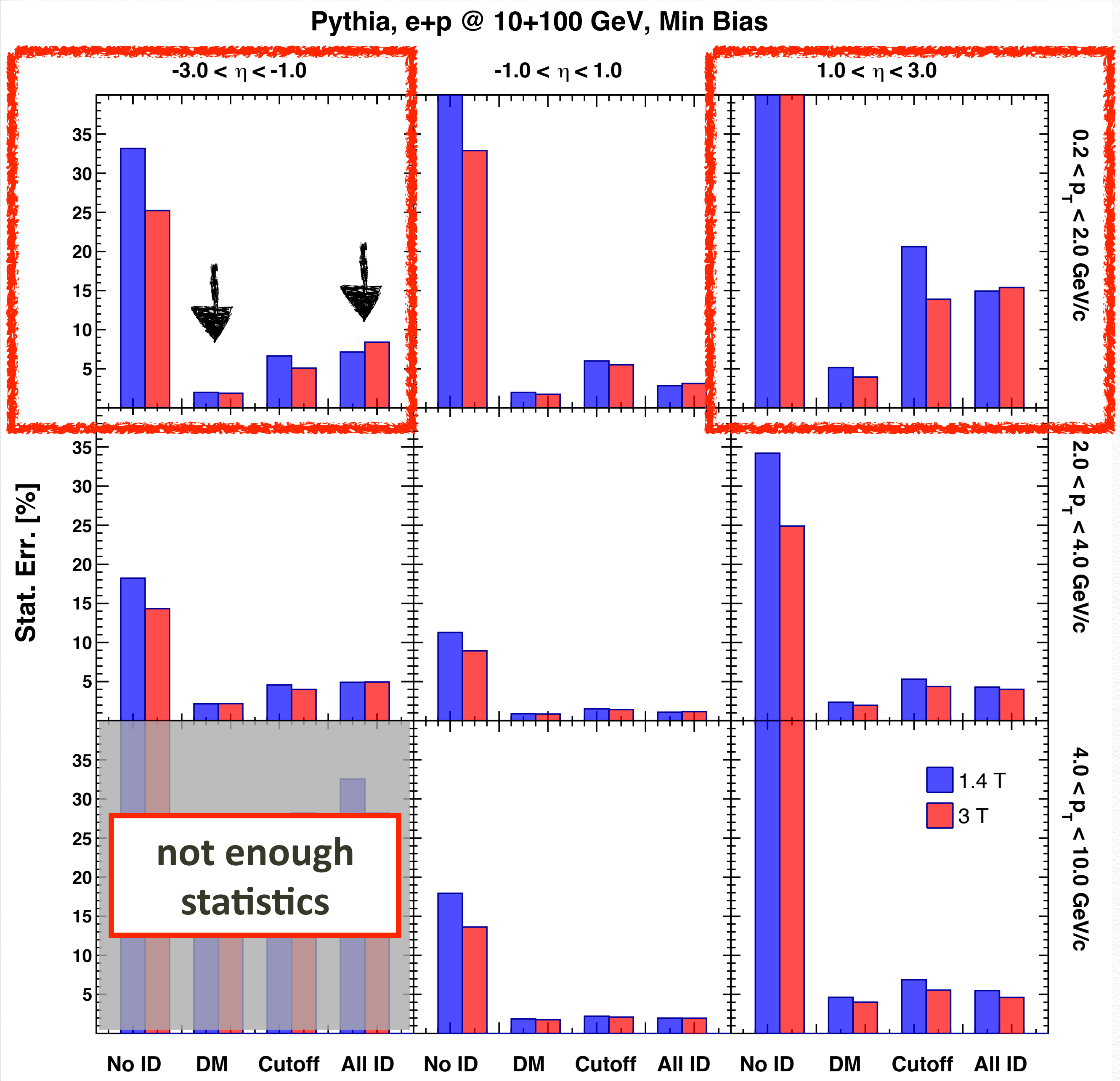
Low p cutoff using DIRC+dRICH as PID does not affect D^0 significantly

Larger effect at $|\eta|>1$

larger effect at low p_T

3T has slightly better precision comparing to 1.4T

Λc



Low p cutoff using DIRC+dRICH as PID affect Λc significantly

Larger effect at |η|>1

larger effect at low p_T

3T has slightly better precision comparing to 1.4T

Future steps

- Finer binning at low p_T to check the low p_T reach of D^0 and Λc
- Impact on more differential measurements & spin measurements
- Re-visiting track reconstruction efficiency at low momentum (optimize tracker geometry + track finding algorithm) — Rey's study
- Study impact of TOF in the barrel region and hadron going direction

Thanks!