Measuring gluon polarization in the nucleon via open charm production at the EIC

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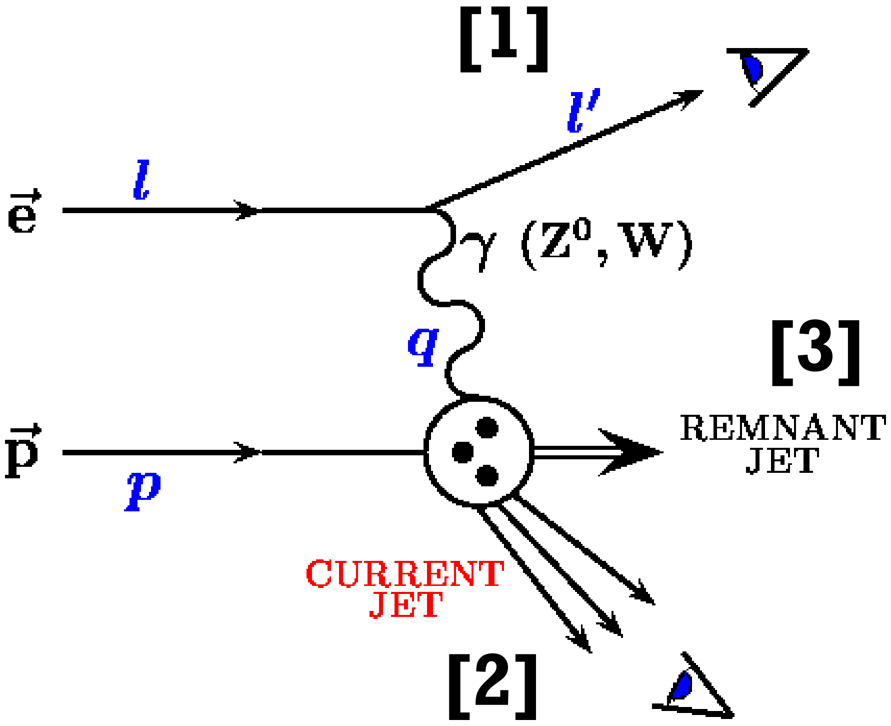
Outline

- Introduction
- Description of the simulation at the EIC
- Results and discussions

Deep inelastic scattering and PDFs



$$Q^2 = -q^2 = sxy$$

$$x = \frac{Q^2}{2p\cdot q}$$

$$y = \frac{p\cdot q}{p\cdot l}$$

$$s = 4E_e E_p$$

$$W = (q+p)^2$$

- Observe scattered electron/muon [1] → inclusive
- Observe current jet [1]+[2] → semi-inclusive
- Observe remnant jet as well [1]+[2]+[3] → exclusive

Experimental observables VS PDFs

Experimental observables

Unpolarized cross section

$Q^2 << M_Z^2$

Unpolarized structure functions

F_1 , F_2

Quark-Parton Model QPM

$$F_2(x) = 2xF_1(x)$$

Callan-Gross equation

PDFs

Unpolarized pdfs

$f_1(x)=q^{\uparrow}(x) + q^{\downarrow}(x)$

$$F_2(x) = x\sum_q e_q^2(f_1^q(x) + f_1^{\bar{q}}(x))$$

A_{LL} , A_{LT} (A_1, A_2)

$Q^2 << M_Z^2$

Polarized structure functions

g_1 , g_2

QPM

No g_2 interpretation in QPM

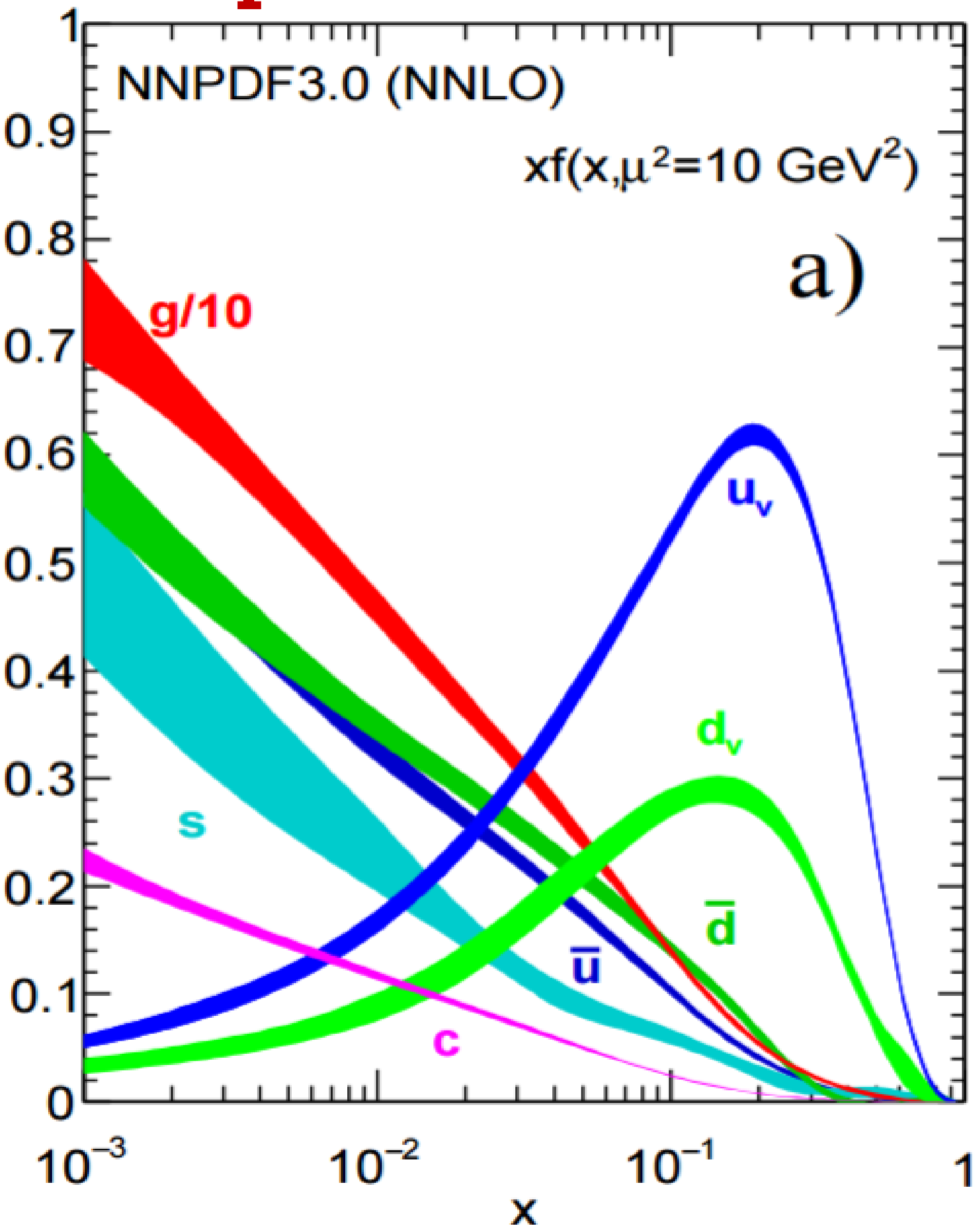
Polarized pdfs

Helicity distribution

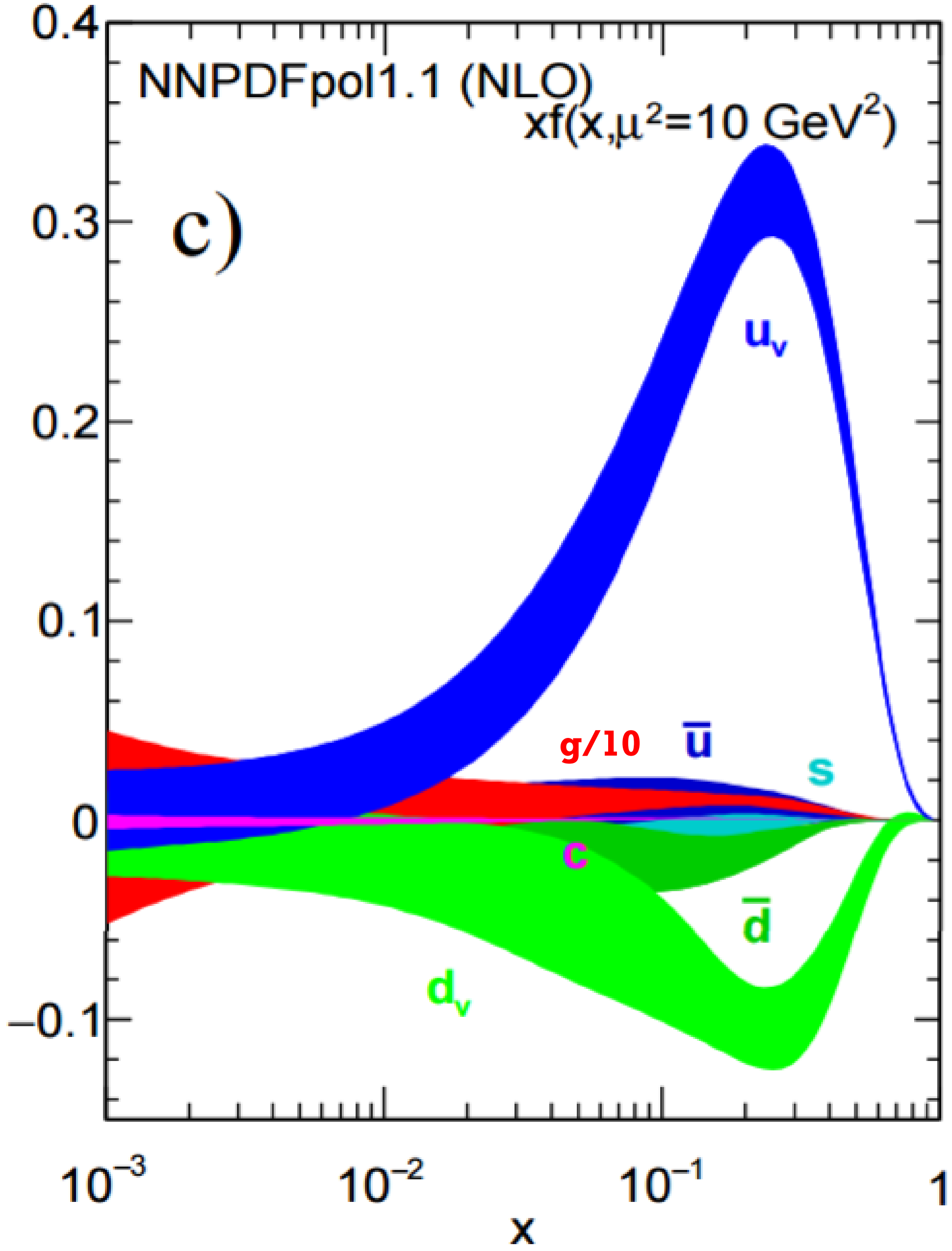
$\Delta q=q^{\uparrow}(x) - q^{\downarrow}(x)$

$$g_1(x) = \frac{1}{2}\sum_q e_q^2 \Delta q(x)$$

Unpolarized PDFs

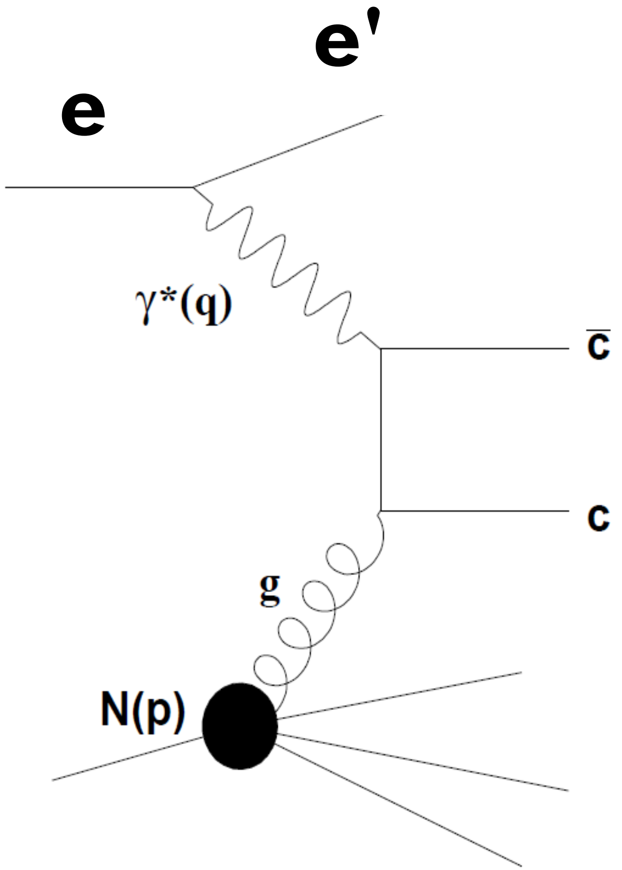


Polarized PDFs



What "heavy flavor" production can contribute

Open Charm "SIDIS": e p→(e' & D0) coincidence + X



Experimental observable: Double spin asymmetry

$$A_{LL}=\frac{d\sigma^{++}-d\sigma^{+-}}{d\sigma^{++}+d\sigma^{+-}}=\frac{1}{P_eP_p}\frac{N^{++}-N^{+-}}{N^{++}-N^{+-}}=\frac{1}{P_eP_p}A_{measure}$$

Leading order picture

$$\boxed{a_{LL}\times\frac{\Delta g}{g}}$$

Partonic kinematics

https://inspirehep.net/literature/1231266

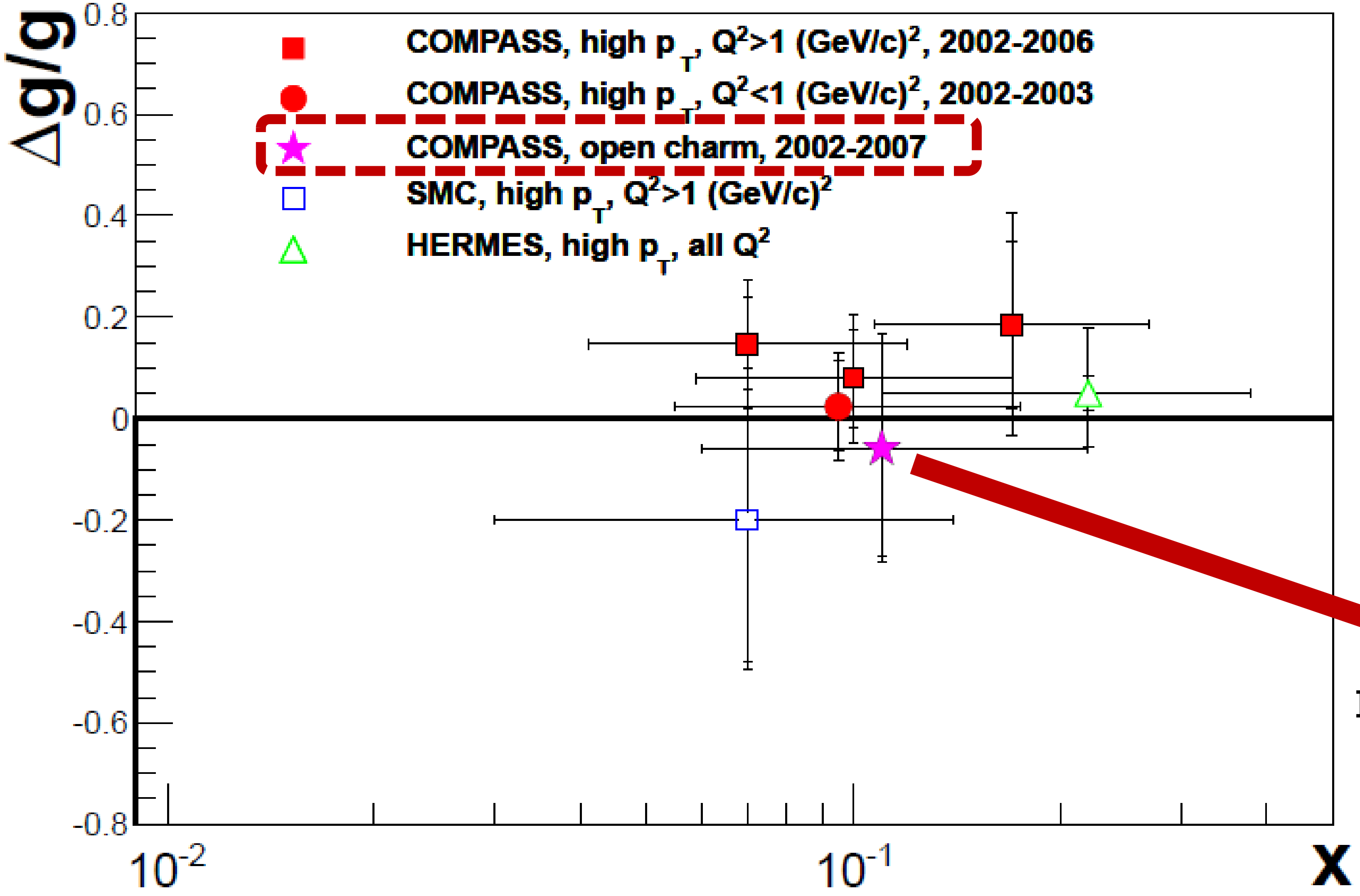
$$d\hat{\sigma} = \frac{\alpha^2 e_q^2 \alpha_s}{xQ^2(\hat{s}+Q^2)^2}\left\{\left[2(1-y)+y^2\left(1-\frac{2m_l^2}{Q^2}\right)\right]\left[\frac{Q^4+\hat{s}^2}{(\hat{s}+Q^2)^2}\frac{\tilde{u}^2+\tilde{t}^2}{2\,\tilde{u}\,\tilde{t}}+\right.\right. \tag{5.8}$$
$$\left.\left.\frac{2m^2}{\tilde{u}\,\tilde{t}}\left(\hat{s}-Q^2+\frac{Q^2(\hat{s}+Q^2)^2}{2\,\tilde{u}\,\tilde{t}}\right)-\frac{2m^4(\hat{s}+Q^2)^2}{\tilde{u}^2\tilde{t}^2}\right]+8(1-y)Q^2\left[\frac{\hat{s}}{(\hat{s}+Q^2)^2}-\frac{m^2}{\tilde{u}\,\tilde{t}}\right]\right\},$$

and

$$d\Delta\hat{\sigma} = \frac{\alpha^2 e_q^2 \alpha_s}{xQ^2(\hat{s}+Q^2)^2}\, y\left(2-y-\frac{2y^2m_l^2}{Q^2}\right)\frac{\tilde{u}^2+\tilde{t}^2}{2\,\tilde{u}\,\tilde{t}}\left[\frac{Q^2-\hat{s}}{\hat{s}+Q^2}+\frac{2\,m^2(\hat{s}+Q^2)}{\tilde{u}\,\tilde{t}}\right], \tag{5.9}$$

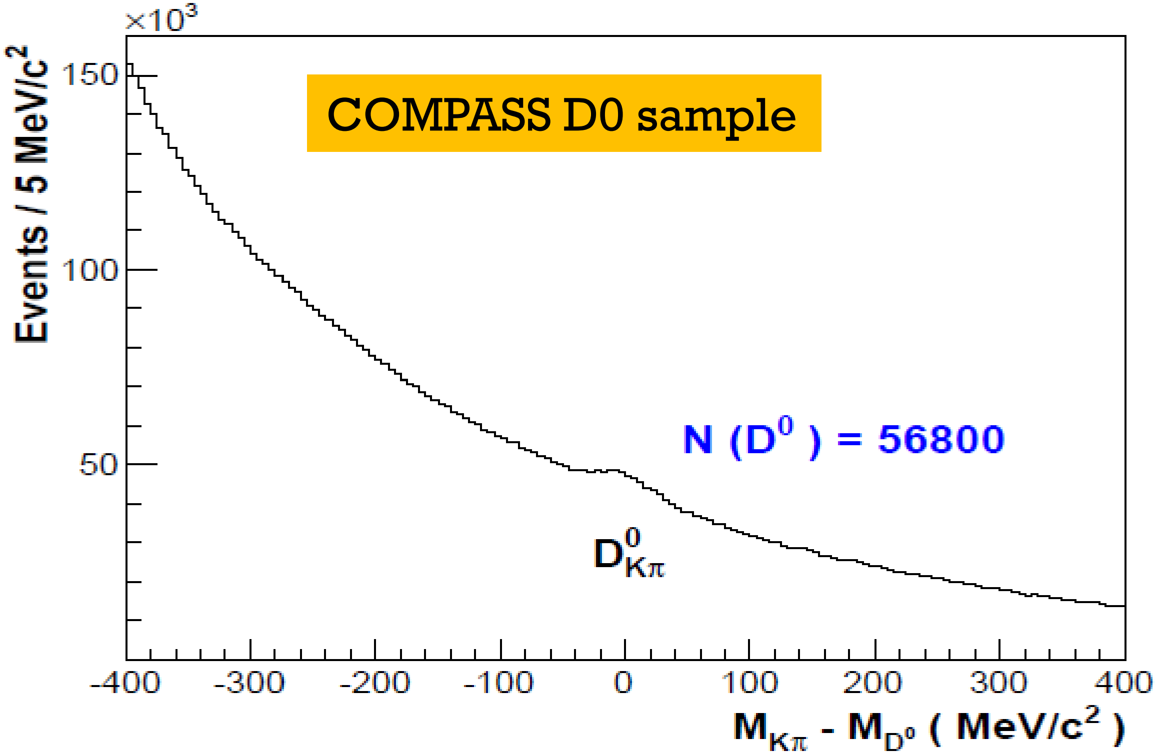
Enable a $\frac{\Delta g}{g}$ measurement

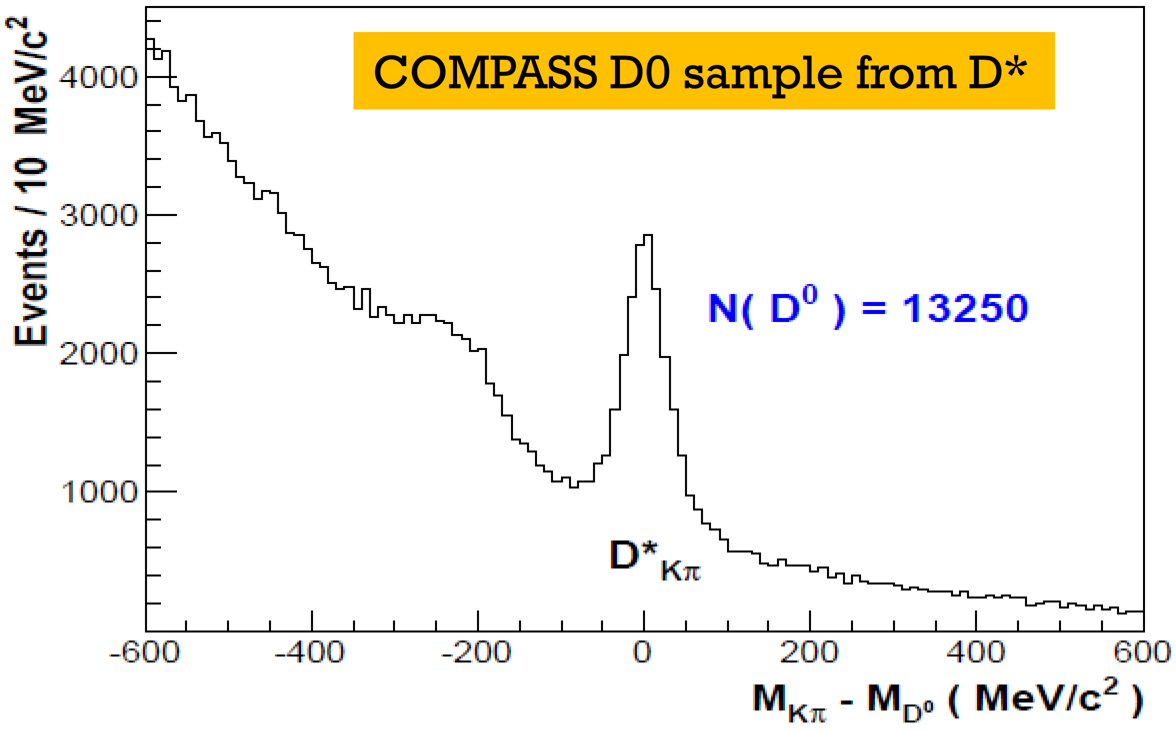
First measurement from COMPASS



Pioneer work from COMPASS

Limitations at COMPASS





- No vertex detector to take advantage of decay topology → large background
- Low luminosity and finite acceptance → limited statistics

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Strategy of the simulation

Events generated using PythiaeRHIC (Pythia 6.4)

⇩

Smear event by event according to the "detector matrix" (Sooraj's "fastsim" at LBNL)

⇩

Search Pion&Kaon pair $\quad D^0 \xrightarrow{3.89\%} K^-\pi^+$

⇩

Reconstructed D0

First look at the sample: Cut flow study

(1)

$Q^2 > 2GeV^2$
$0.05 < y < 0.8$
$W^2 > 4\ GeV^2$

(2)

Truth PID
+
Charge selection
Pi+&K- or Pi-&K+

(3)

D0 decay topology

(4)

PID acceptance cuts

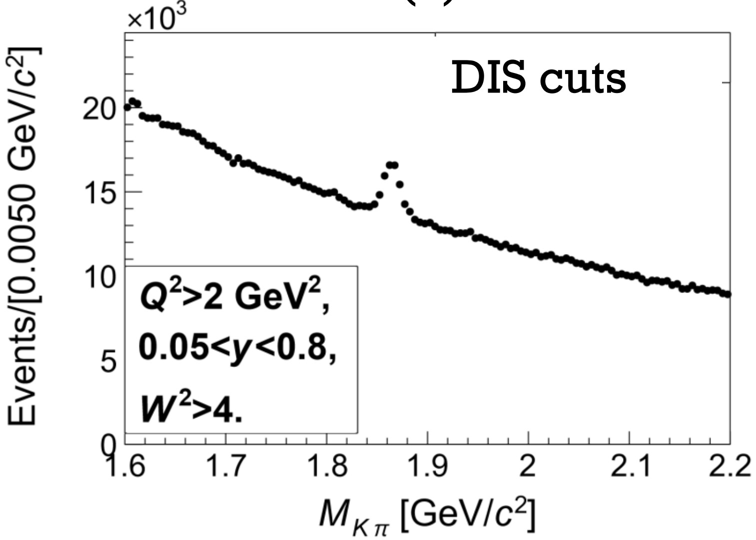
Refer to Sooraj's talk:
- Cuts on decay topology: $\cos(\theta_{r\phi}) > 0.98$, $dL > 40\ \mu m$, pair $d_0 < 150\ \mu m$

Pseudo-rapidity region	PID Momentum upper limit (GeV)
<-1	7
[-1, 1)	5
[1, 2)	8
[2, 3)	20
Otherwise	Not analyzed yet

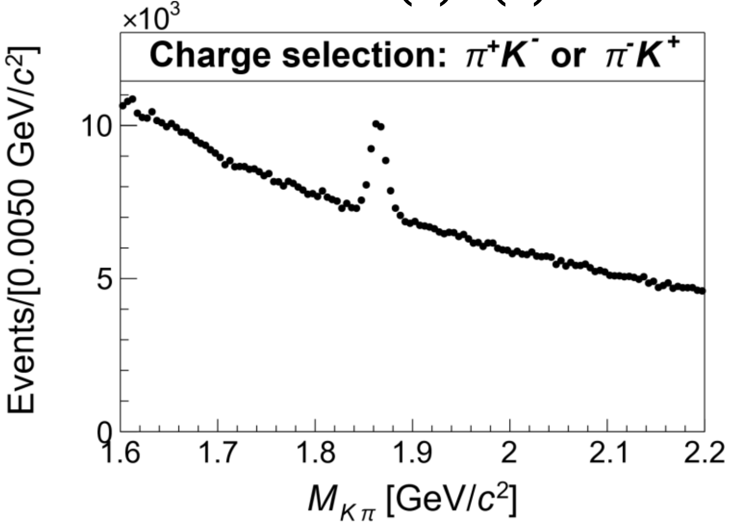
Cut flow study

18 GeV x 275 GeV

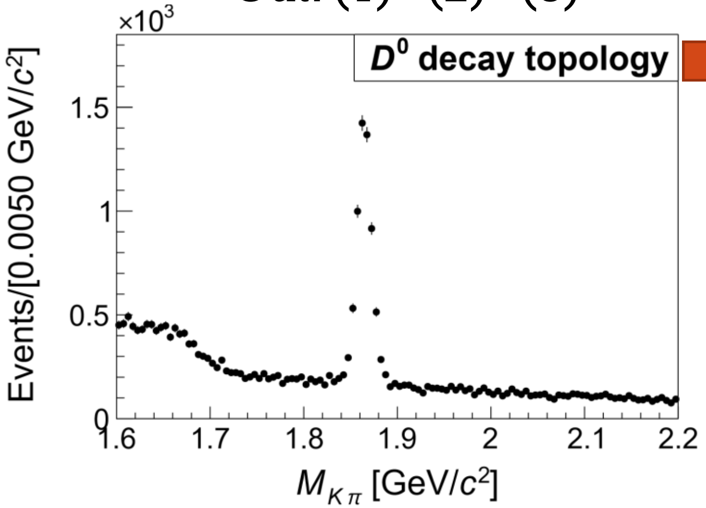
Cut: (1)



Cut: (1)+(2)

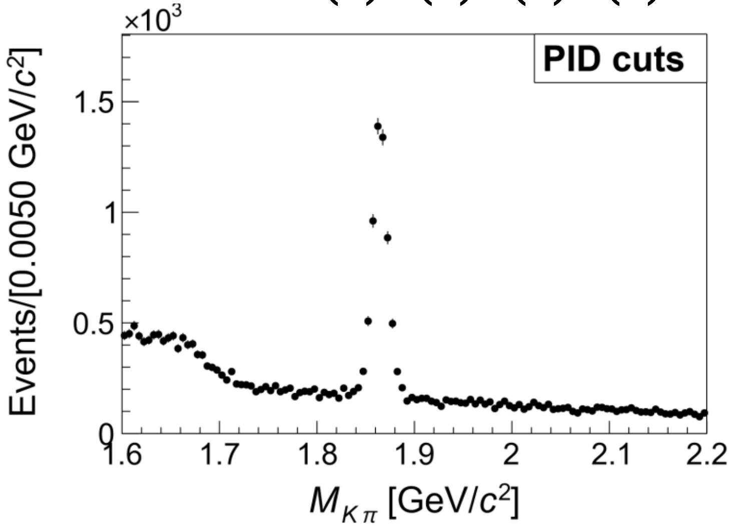


Cut: (1)+(2)+(3)



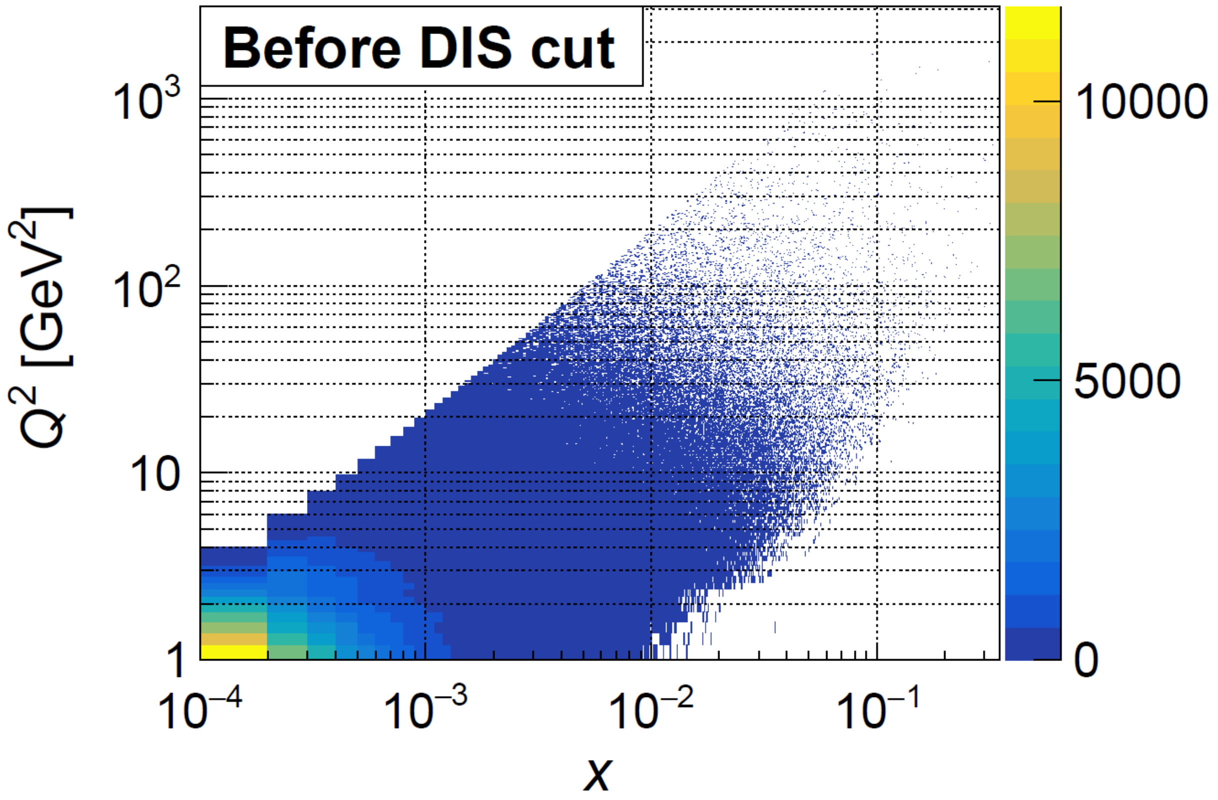
Most powerful cut

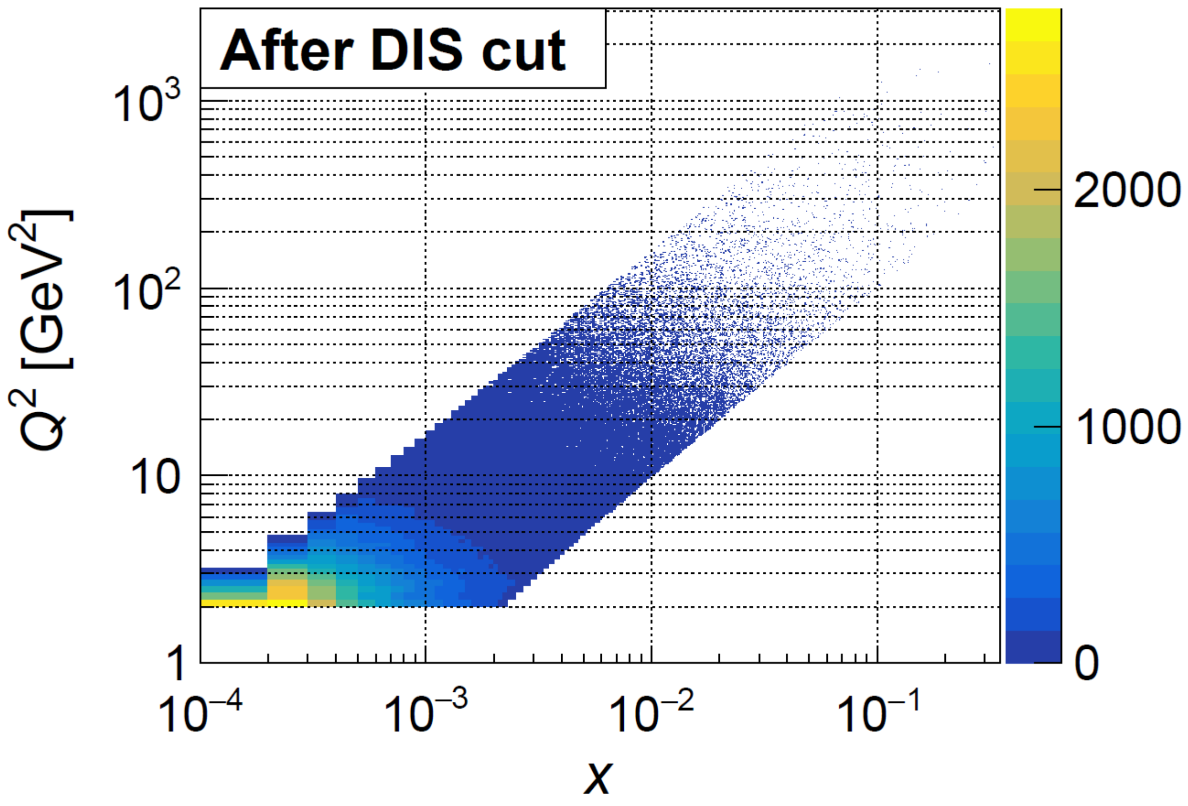
Cut: (1)+(2)+(3)+(4)



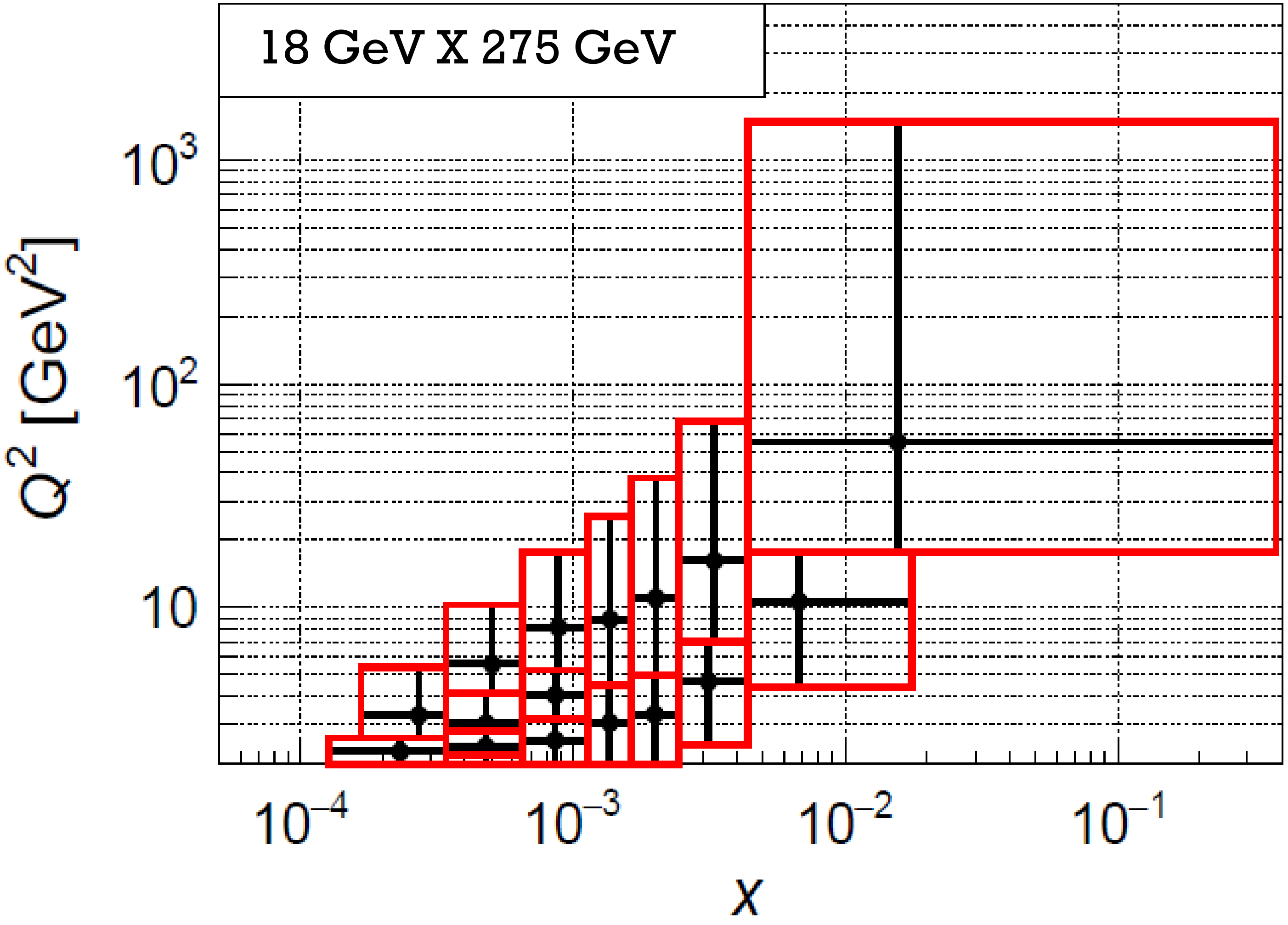
Bjorken x VS Q^2 coverage

18 GeV x 275 GeV

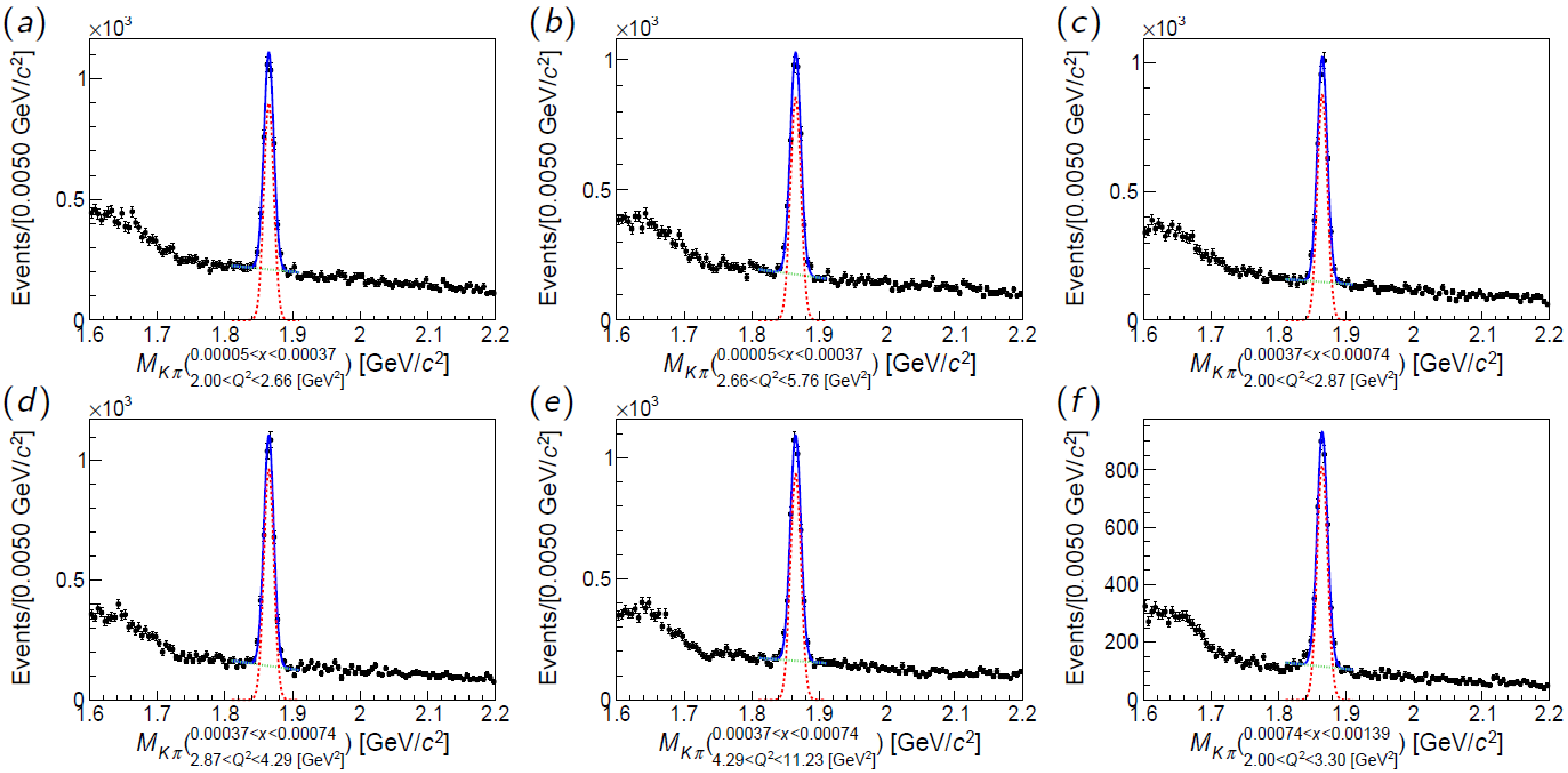




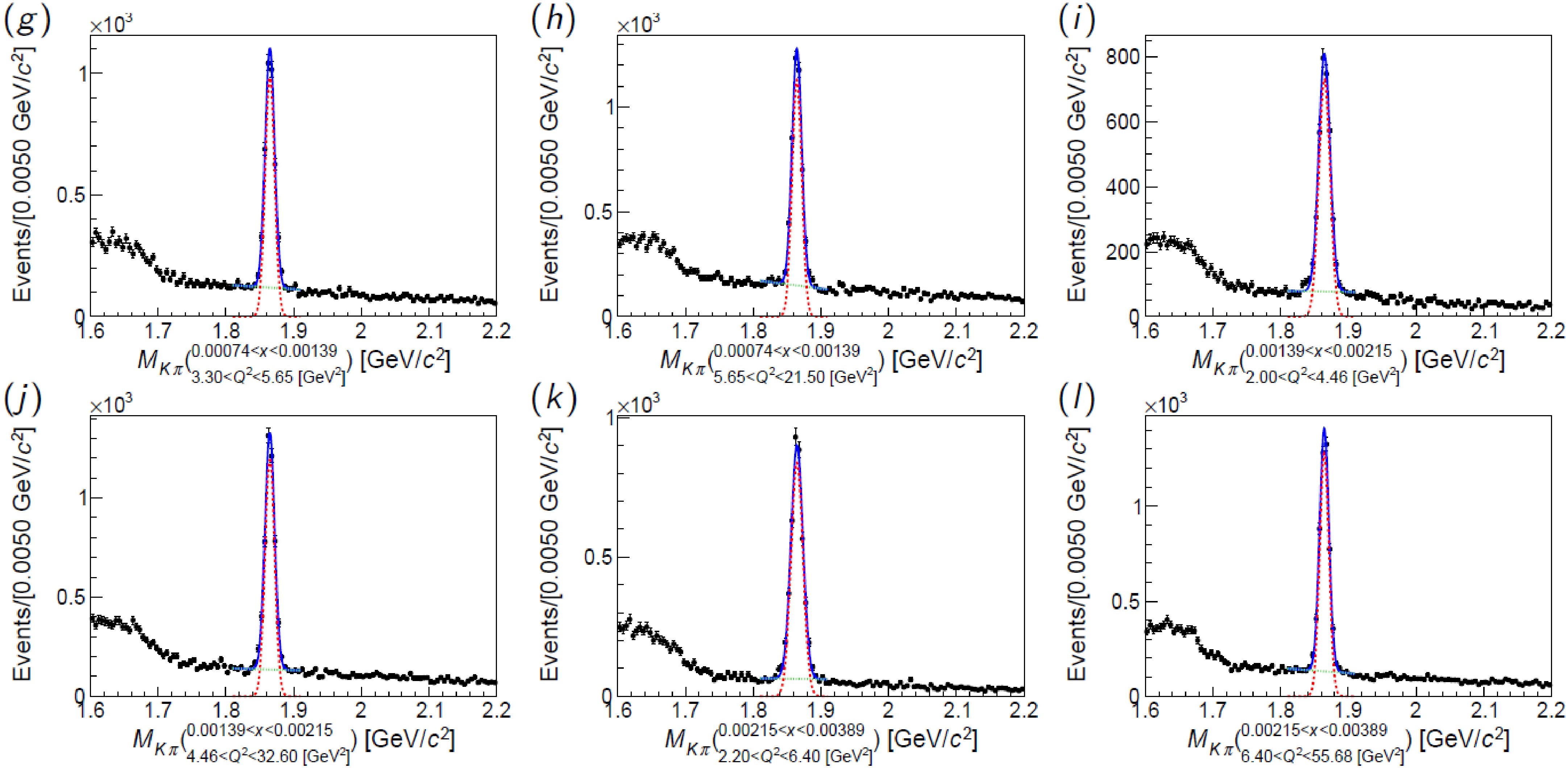
Binning on x-Q^2



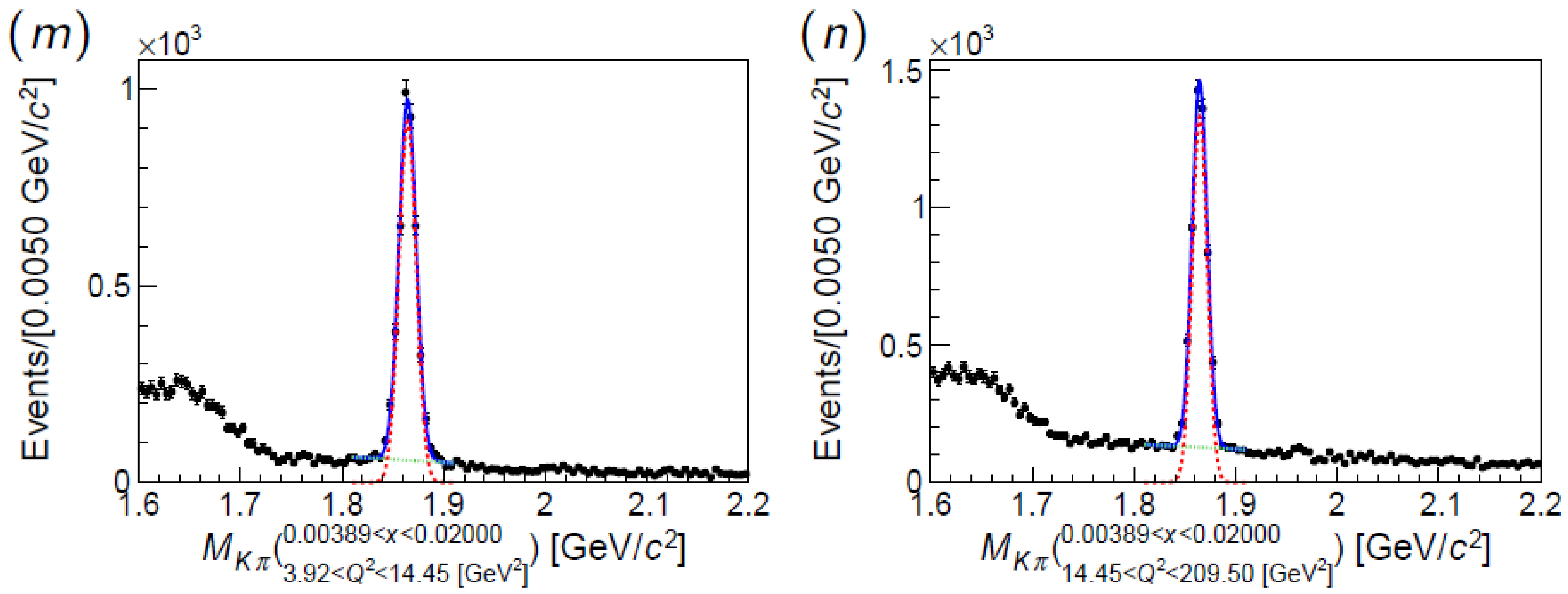
Events in each bin (18 GeV x 275 GeV)



Events in each bin (18 GeV x 275 GeV)



Events in each bin (18 GeV x 275 GeV)

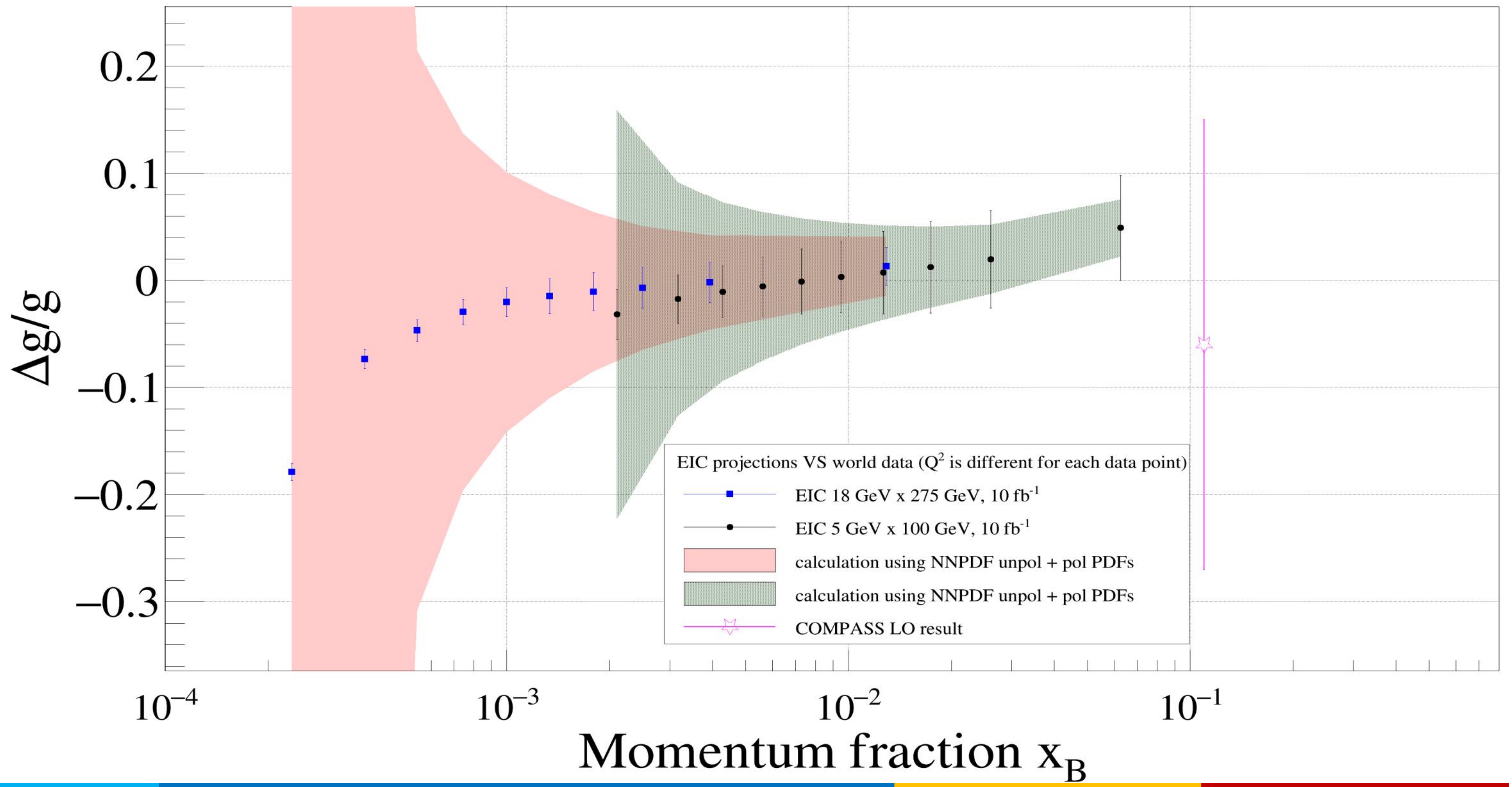


In general, signal is quite significant in each bin

Fitting results (18 GeV x 275 GeV)

$x_{\min}$	$x_{\max}$	$Q^2_{\min}$	$Q^2_{\max}$	N_{Signal}	$N_{\text{Background}}$	a_{LL}
0.00005	0.00034	2.00	2.62	2910^{+76}_{-75}	1653^{+208}_{-202}	-0.246
0.00005	0.00034	2.62	5.43	2866^{+74}_{-74}	1486^{+198}_{-194}	-0.431
0.00034	0.00065	2.00	2.82	2934^{+71}_{-70}	1206^{+176}_{-172}	-0.118
0.00034	0.00065	2.82	4.13	3082^{+72}_{-71}	1144^{+175}_{-171}	-0.199
0.00034	0.00065	4.13	10.27	3122^{+75}_{-74}	1333^{+188}_{-184}	-0.467
0.00065	0.00113	2.00	3.16	2698^{+68}_{-67}	954^{+164}_{-159}	-0.065
0.00065	0.00113	3.16	5.24	3094^{+68}_{-68}	920^{+153}_{-149}	-0.162
0.00065	0.00113	5.24	17.62	3494^{+75}_{-74}	1182^{+178}_{-174}	-0.410
0.00113	0.00164	2.00	4.46	2749^{+66}_{-65}	785^{+143}_{-146}	-0.055
0.00113	0.00164	4.46	25.47	3501^{+73}_{-71}	1008^{+161}_{-158}	-0.278
0.00164	0.00245	2.00	4.94	2918^{+68}_{-67}	700^{+148}_{-144}	-0.043
0.00164	0.00245	4.94	37.95	3674^{+73}_{-73}	975^{+157}_{-153}	-0.240
0.00245	0.00439	2.43	7.00	3218^{+68}_{-67}	542^{+136}_{-131}	-0.044
0.00245	0.00439	7.00	67.52	3952^{+76}_{-74}	958^{+156}_{-153}	-0.221
0.00439	0.38368	4.39	17.81	3863^{+71}_{-71}	552^{+132}_{-127}	-0.055
0.00439	0.38368	17.81	1560.12	4487^{+82}_{-81}	1195^{+178}_{-174}	-0.208

Projections VS existing knowledge on PDFs



Summary and discussions

- $\frac{\Delta g}{g}$ measurement is feasible at the EIC taking advantage of good vertex and PID detectors
  - Different from relying on QCD fits to inclusive and SIDIS double spin asymmetry measurements

- A LO projection study was done

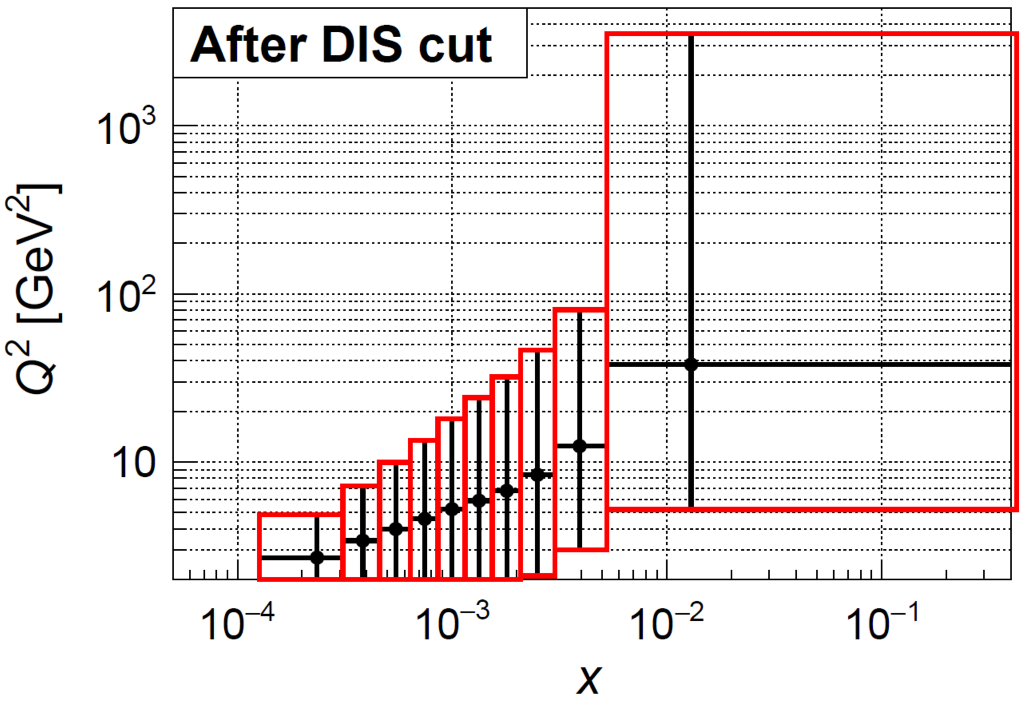
- **Double spin asymmetry in the e'&D0 coincidence channel can be nicely measured at the EIC**, to interpret the data at LO or NLO depends on the theoretical inputs
  - I will be more than happy to discuss and collaborate with whoever is interested in this topic at the EIC

Thanks

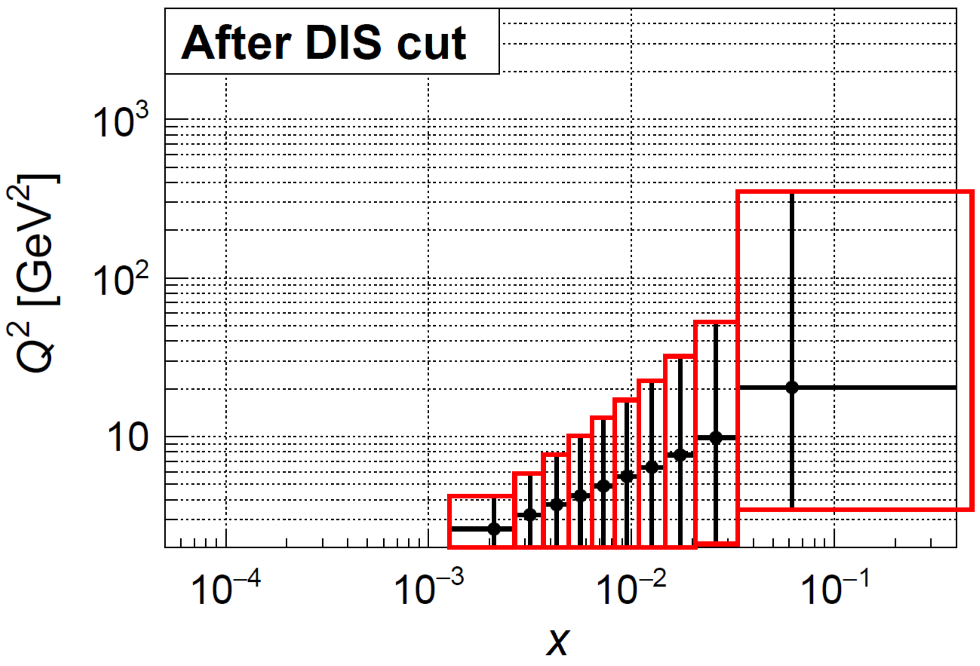
Backups

1D bining on Bjorken x

18 GeV x 275 GeV



5 GeV x 100 GeV



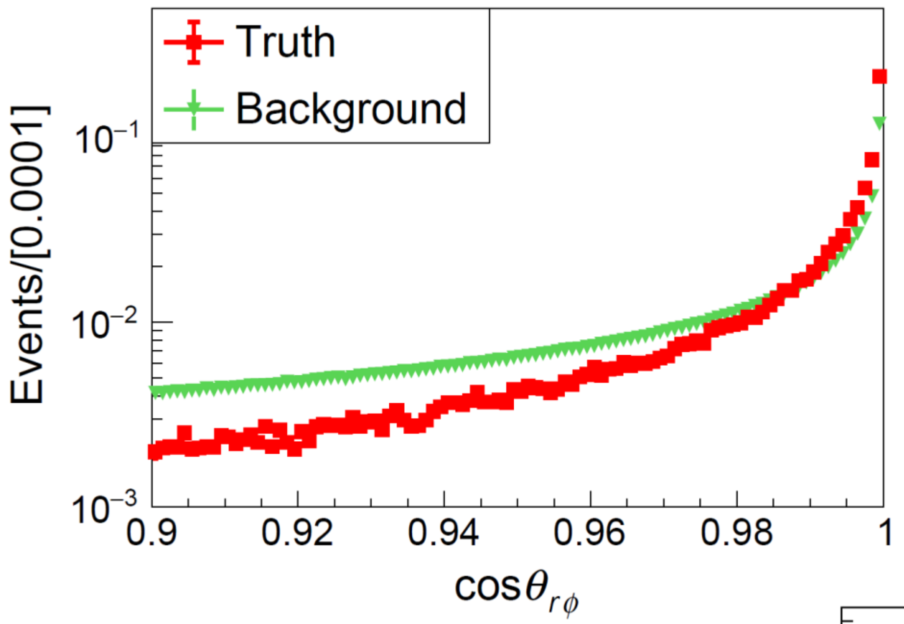
D^0 reconstruction

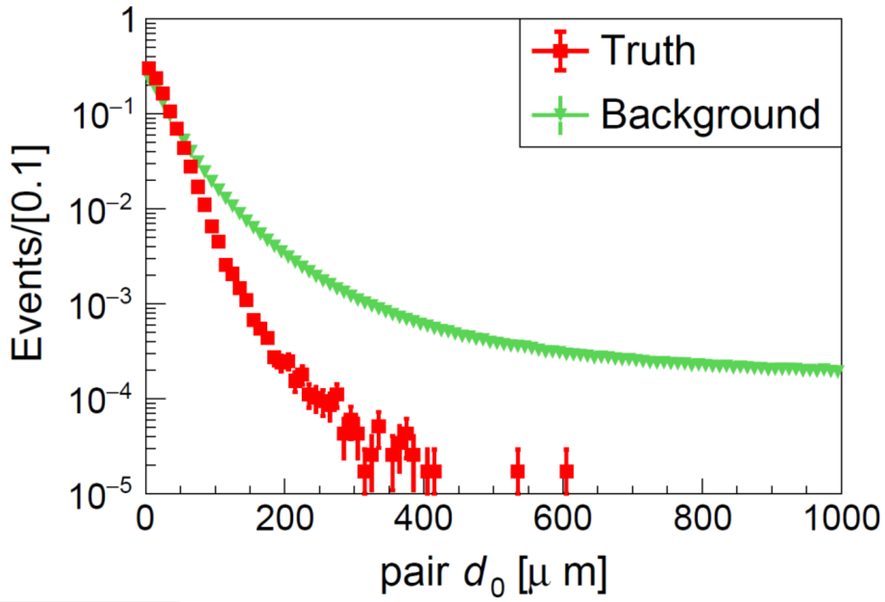
Pseudorapidity range				Momentum resolution		vertex resolution
-3.5 to -3.0		Central Detector	Backward Detector	σ_p/p ~ 0.1%⊕0.5%	~5% or less X	TBD
-3.0 to -2.5						
-2.5 to -2.0				σ_p/p 0.1%⊕0.5%		
-2.0 to -1.5				σ_p/p 0.05%⊕0.5%		
-1.5 to -1.0						
-1.0 to -0.5			Barrel	σ_p/p ~0.05%×p+0.5%		σ_{xyz} ~ 20 μm, $d_0(z)$ ~$d_0(r\Phi)$ ~ $20/p_T$GeV μm + 5 μm
-0.5 to 0.0						
0.0 to 0.5						
0.5 to 1.0						
1.0 to 1.5			Forward Detectors	σ_p/p ~0.05%×p+1.0%		TBD
1.5 to 2.0						
2.0 to 2.5						
2.5 to 3.0				σ_p/p ~ 0.1%×p+2.0%		
3.0 to 3.5						

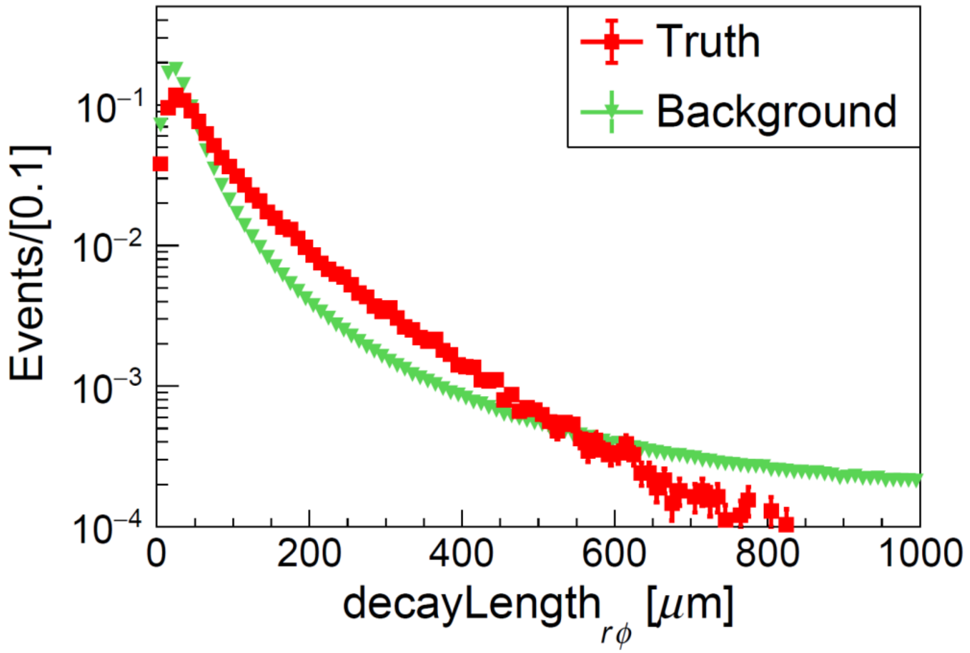
PID

π/K/p	
p-Range (GeV/c)	Separation
≤ 7 GeV/c	≥ 3 σ
≤ 5 GeV/c	
≤ 8 GeV/c	
≤ 20 GeV/c	
≤ 45 GeV/c	

- How fastsim is implemented:
  - Smear the momenta of final state particles according to the momentum resolution in the above table
  - Using the smeared momentum, smear the vertex position of tracks according to the vertex resolution given above
  - Fold in the primary vertex resolution when reconstructing topological variables


Truth
Background
Events/[0.0001]
10^{-1}
10^{-2}
10^{-3}
0.9
0.92
0.94
0.96
0.98
1
$\cos\theta_{r\phi}$


Truth
Background
Events/[0.1]
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
200
400
600
800
1000
pair d_0 [μ m]


Truth
Background
Events/[0.1]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
200
400
600
800
1000
$\mathrm{decayLength}_{r\phi}$ [μm]