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

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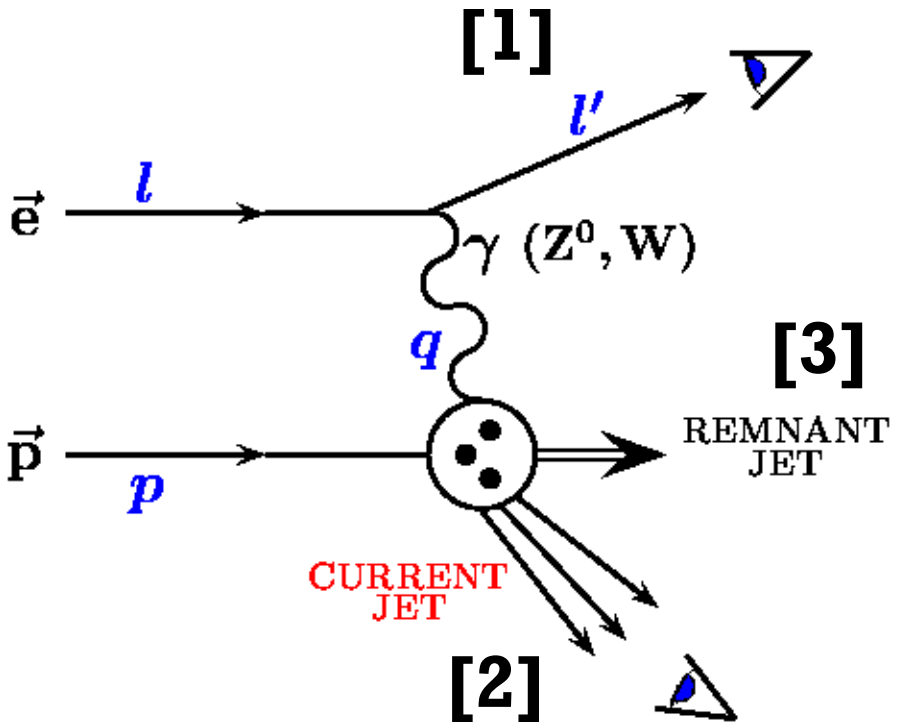
Outline

- 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

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

$Q^2 << M_Z^2$

Polarized structure functions

g_1 , g_2

Quark-Parton Model
QPM

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

Callan-Gross equation

QPM

No g_2 interpretation in QPM

PDFs

Unpolarized pdfs

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

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

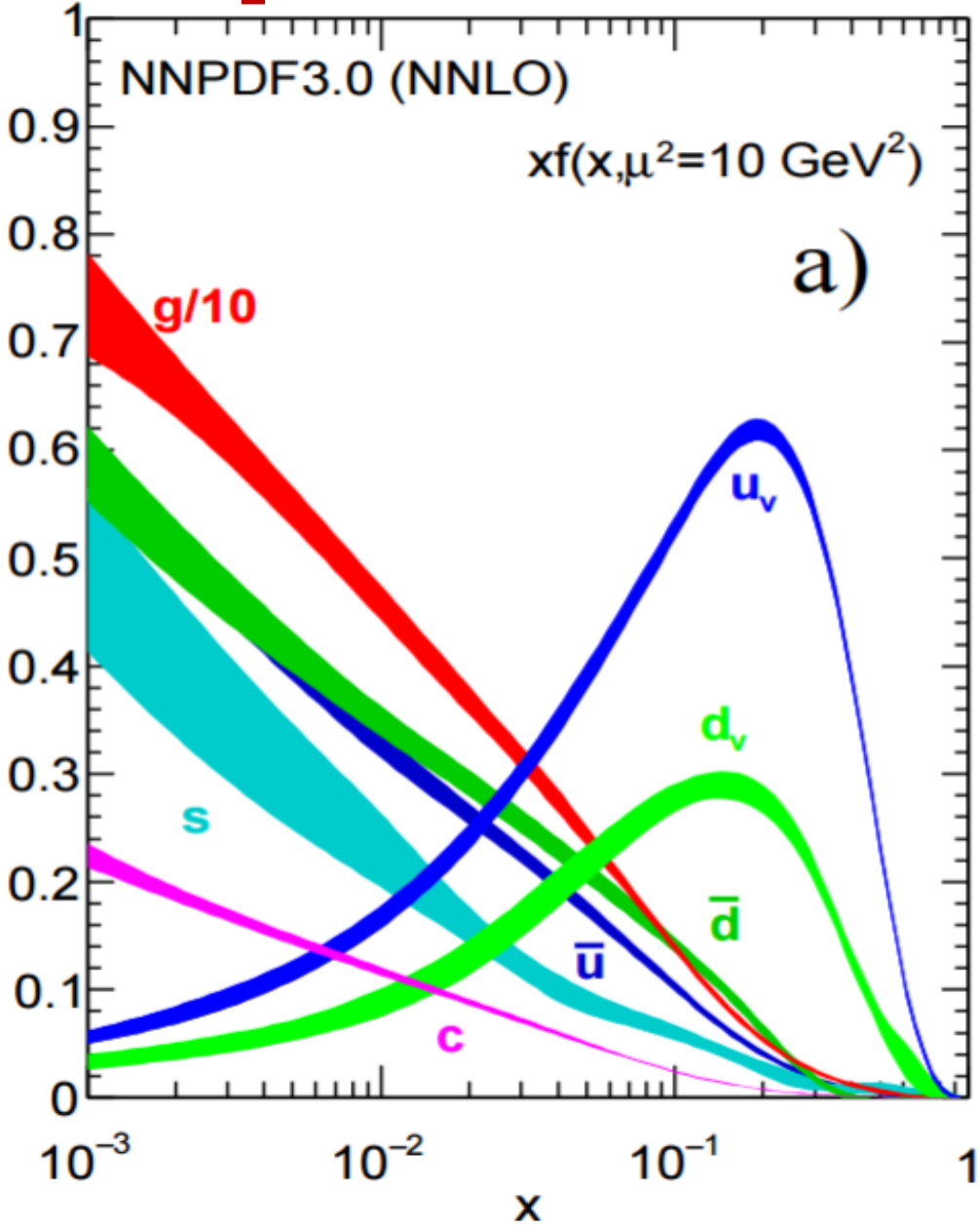
Polarized pdfs

Helicity distribution

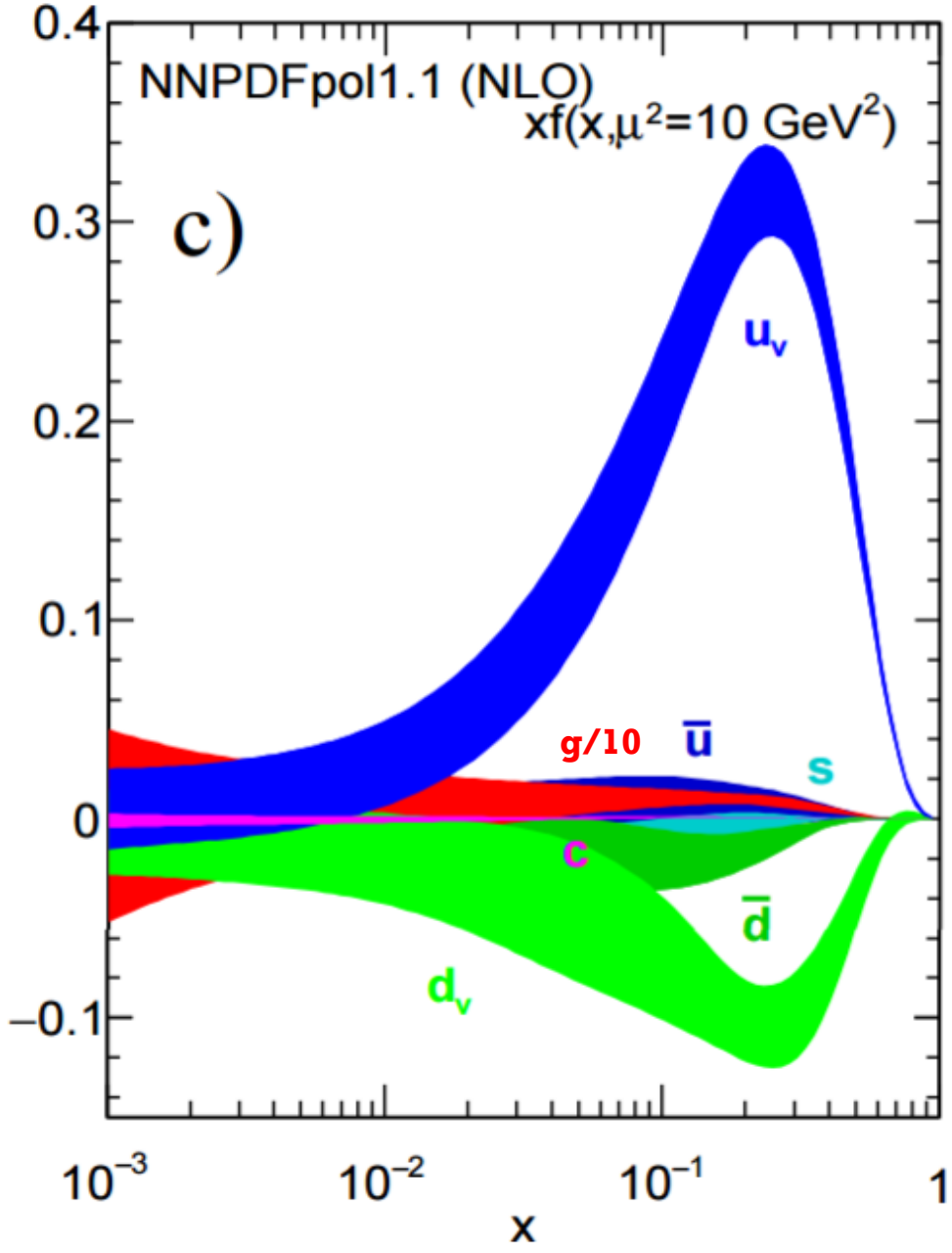
$\Delta q=q^{\uparrow}(x) - q^{\downarrow}(x)$

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

Unpolarized PDFs

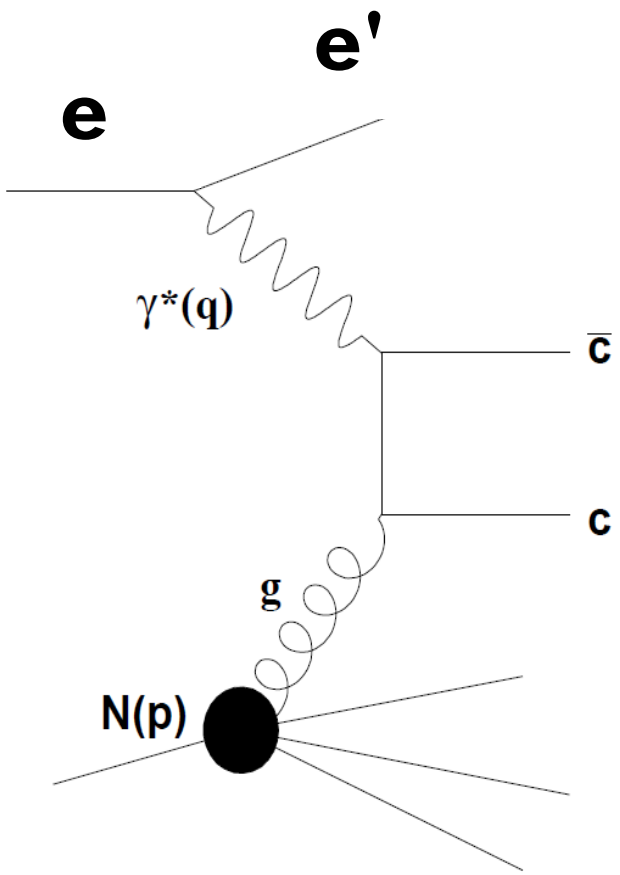


Polarized PDFs



What "heavy flavor" production can contribute

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



Experimental observable: Double spin asymmetry

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

Leading order picture

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

Partonic kinematics

https://inspirehep.net/literature/1231266

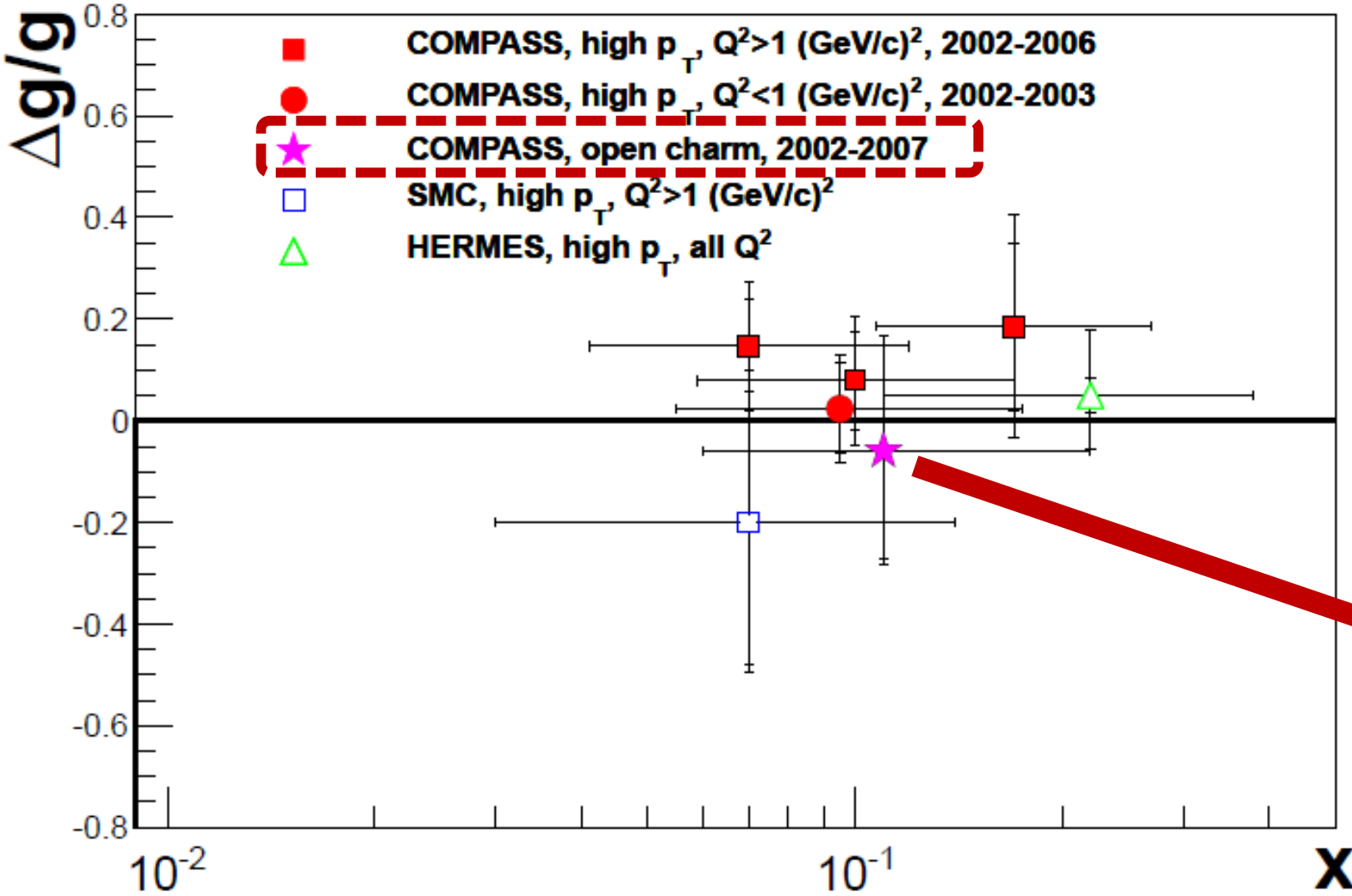
$$d\hat{\sigma} = \frac{\alpha^2 e_q^2 \alpha_s}{x Q^2 (\hat{s}+Q^2)^2} \left\{ \left[2(1-y) + y^2 \left(1 - \frac{2m_l^2}{Q^2} \right) \right] \left[\frac{Q^4 + \hat{s}^2}{(\hat{s}+Q^2)^2} \frac{\tilde{u}^2 + \tilde{t}^2}{2\,\tilde{u}\,\tilde{t}} + \frac{2m^2}{\tilde{u}\,\tilde{t}} \left(\hat{s} - Q^2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

and

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

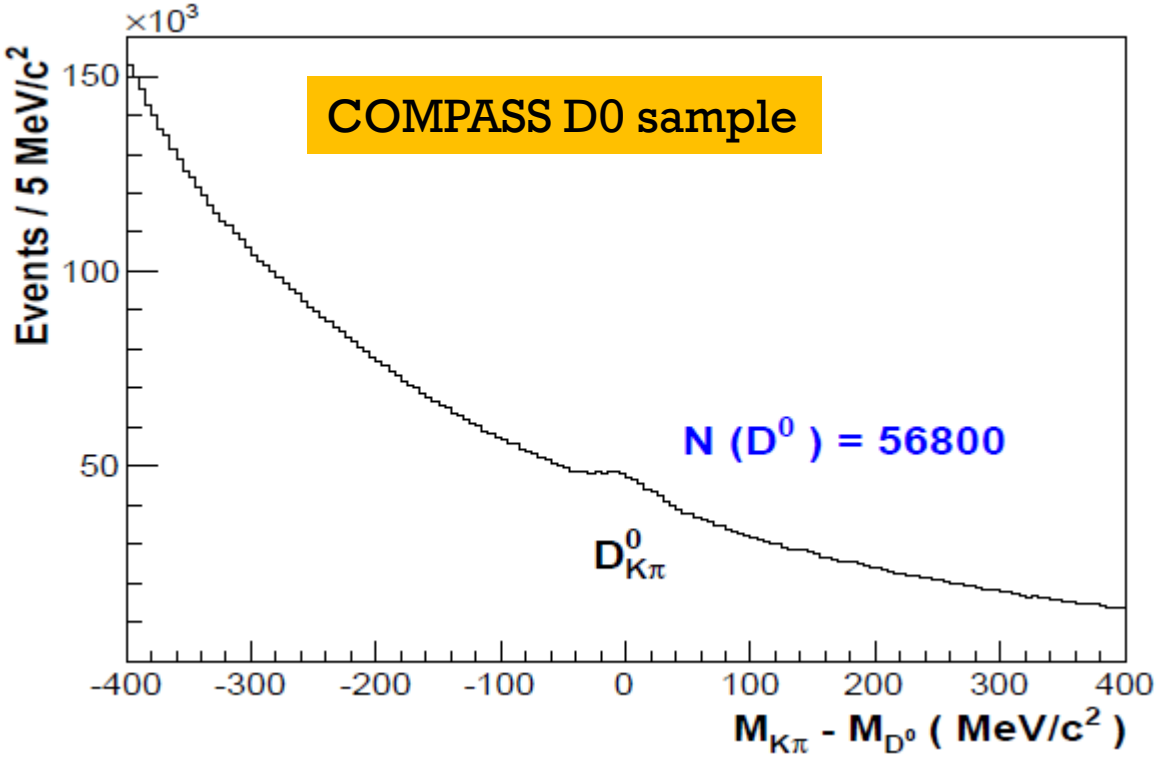
Enable a $\frac{\Delta g}{g}$ measurement

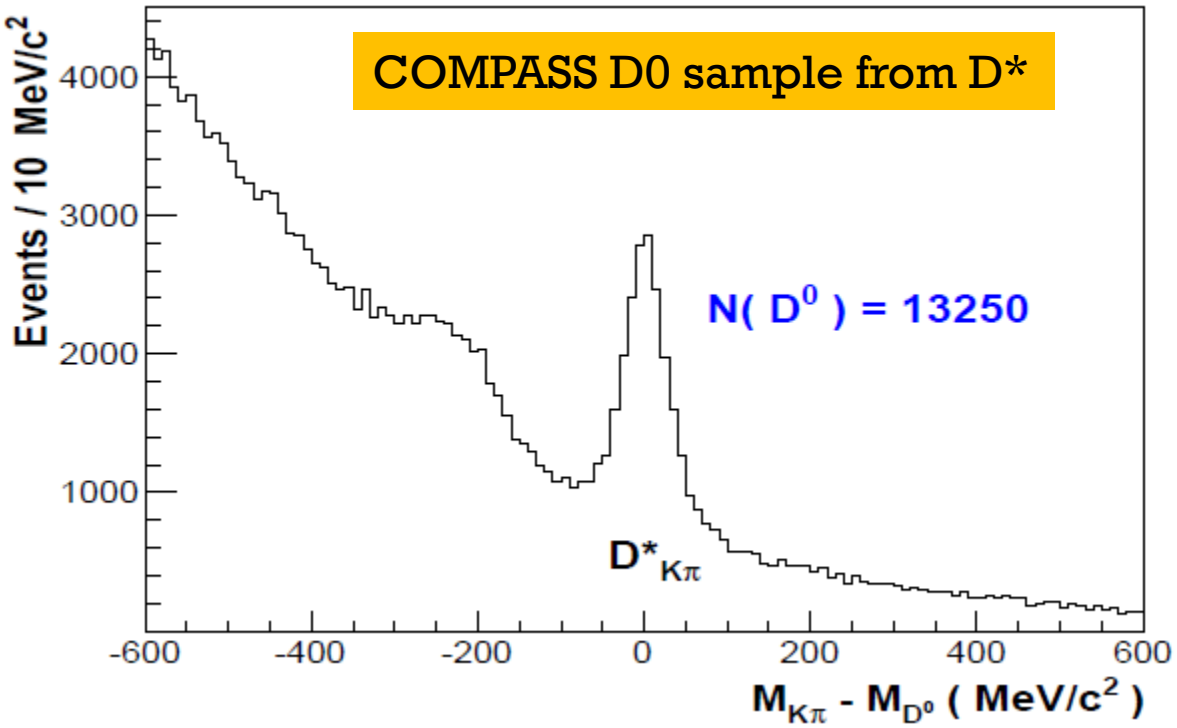
First measurement from COMPASS



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

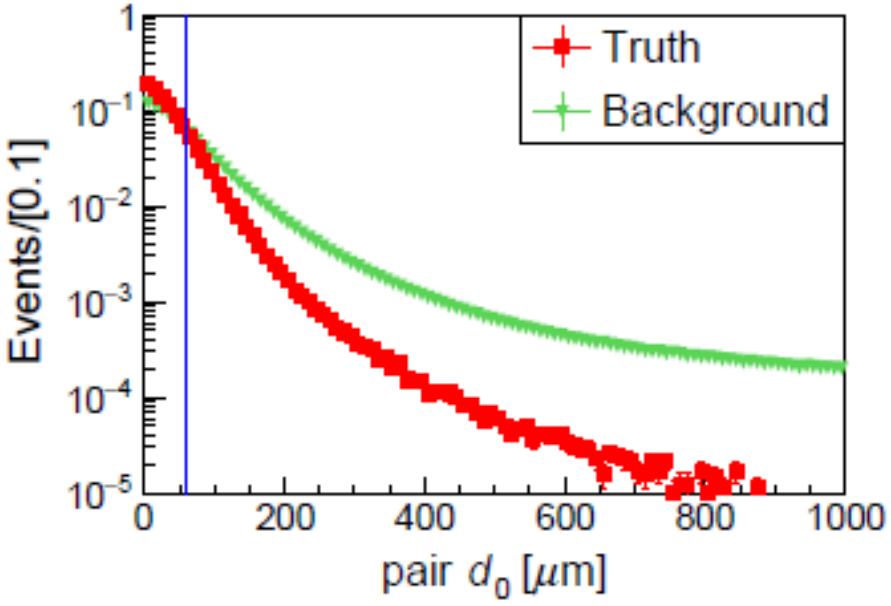
Events generated using PythiaeRHIC (Pythia 6.4)

Smear event by event according to the "detector matrix" ("fastsim" w.r.t. detector matrix)

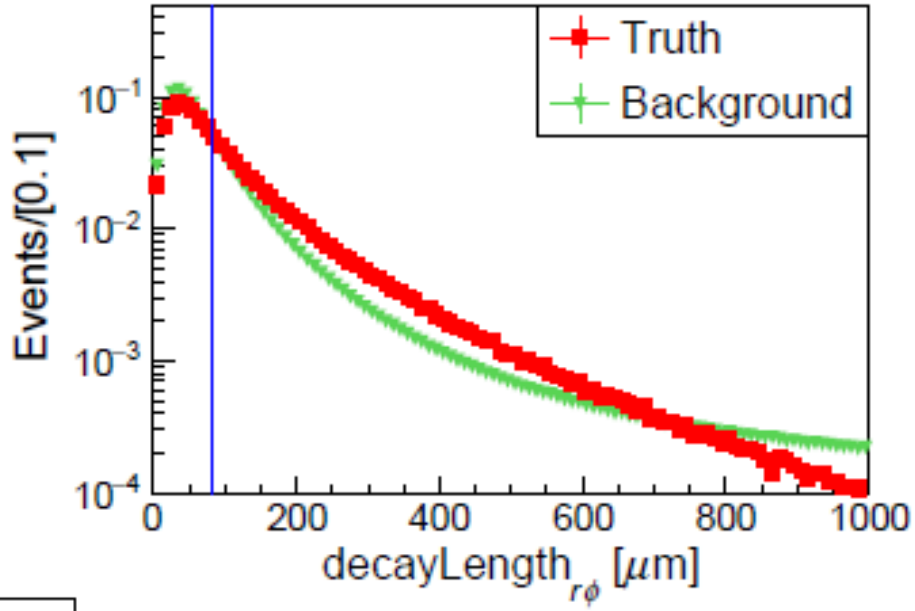
Search Pion&Kaon pair $D^0 \xrightarrow{3.89\%} K^-\pi^+$

Reconstructed D0

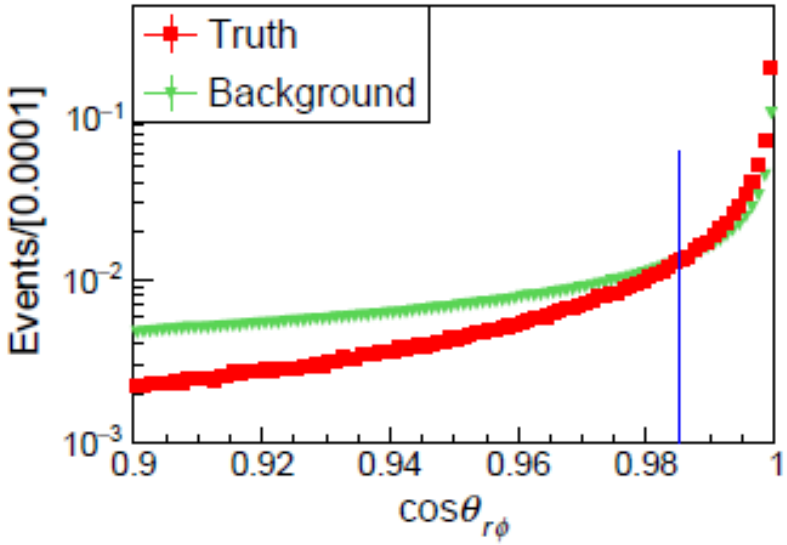
Optimization of D^0 decay topology cuts



Pion&kaon pair DCA



D0 decay length



D0 VS pion&kaon pair angle

Summary of cuts

(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

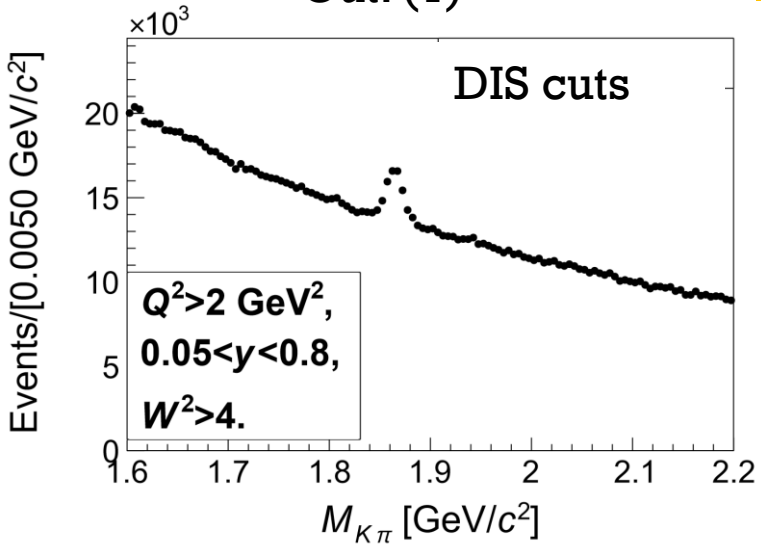
Selection criteria	18 GeV×275 GeV	5 GeV×100 GeV	5 GeV×41 GeV
pion+kaon pair DCA	$< 60\ \mu m$	$< 60\ \mu m$	$< 60\ \mu m$
$decayLength_{r\phi}$	$> 80\ \mu m$	$> 70\ \mu m$	$> 70\ \mu m$
$\cos\theta_{r\phi}$	> 0.985	> 0.983	> 0.981

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

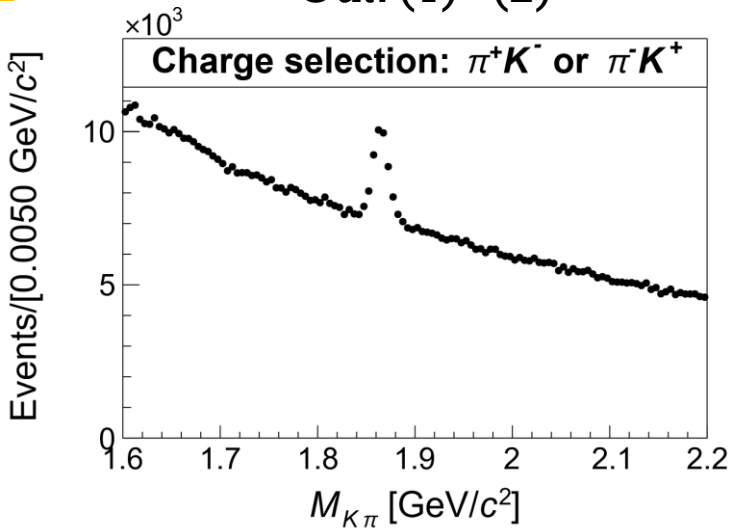
Cut flow study

18 GeV x 275 GeV

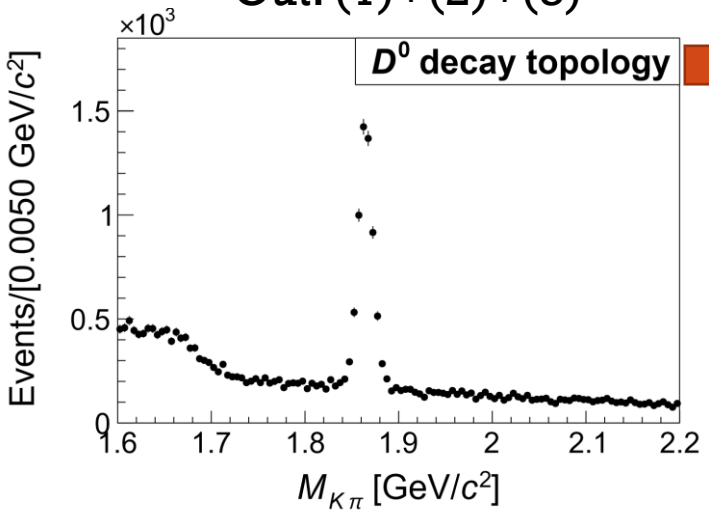
Cut: (1)



Cut: (1)+(2)



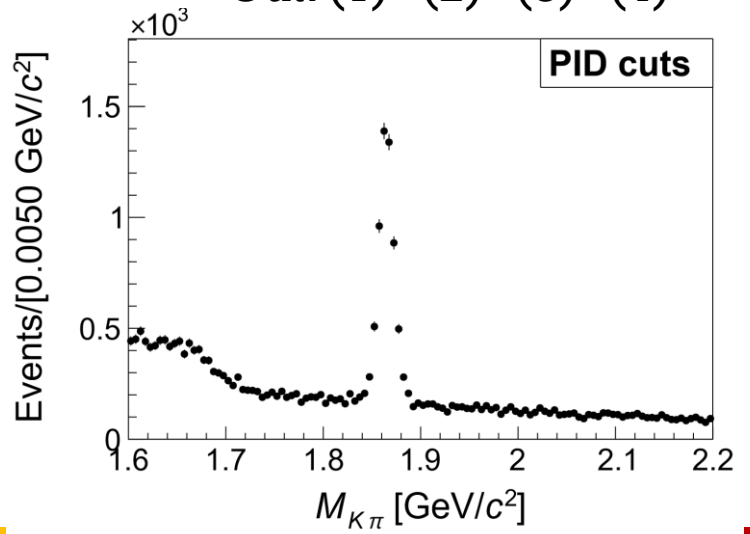
Cut: (1)+(2)+(3)



Most powerful cut

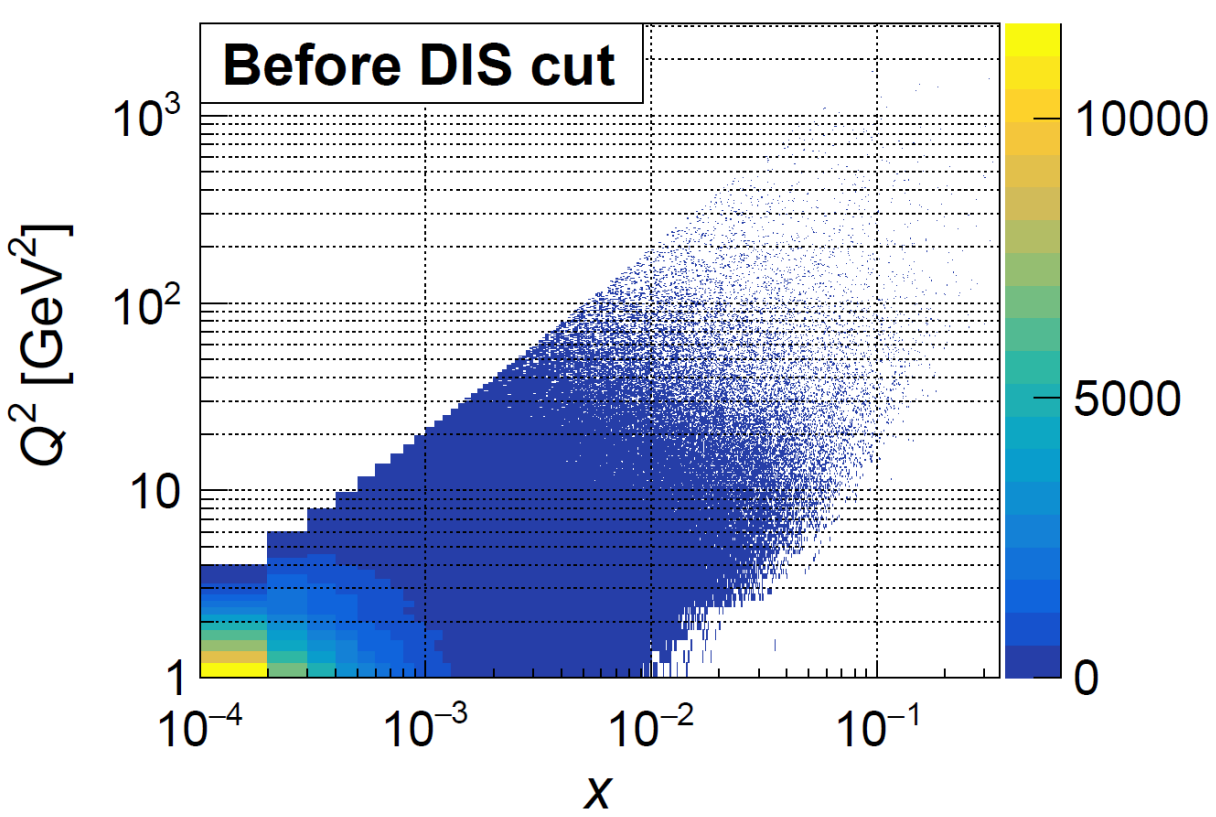
A good vertex detector is crucial

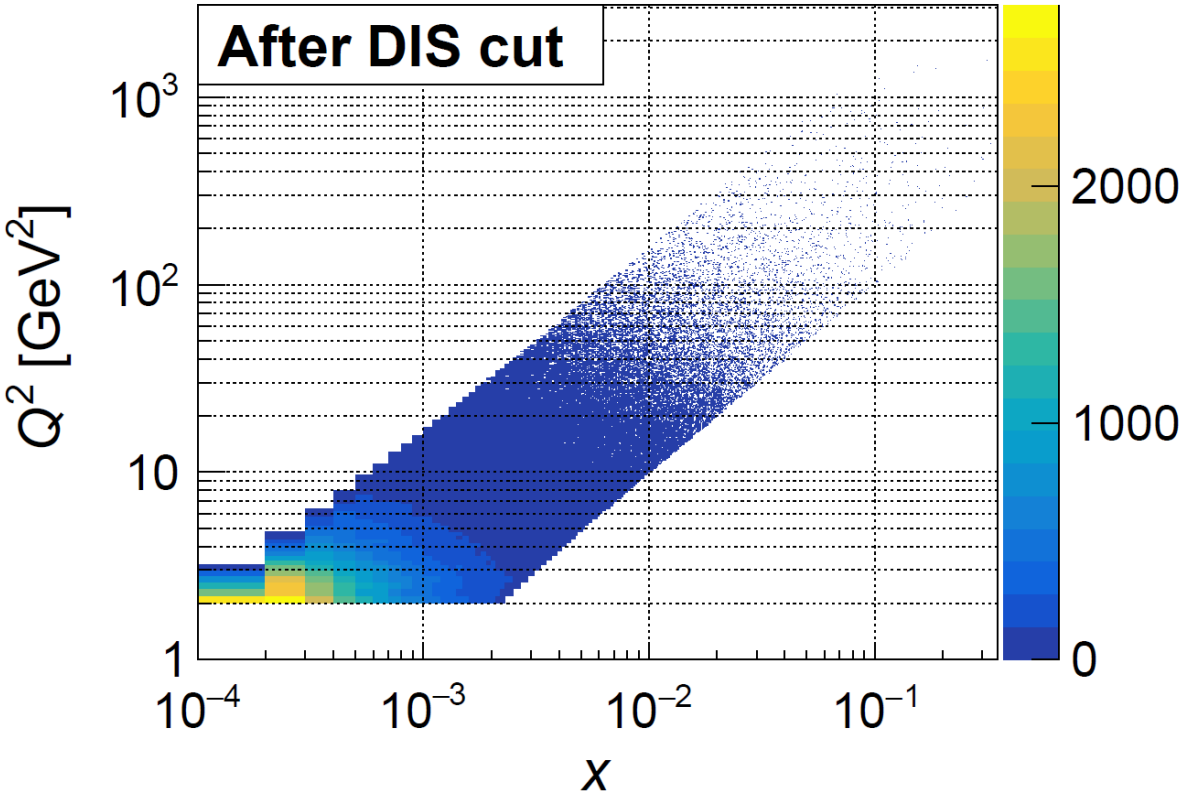
Cut: (1)+(2)+(3)+(4)



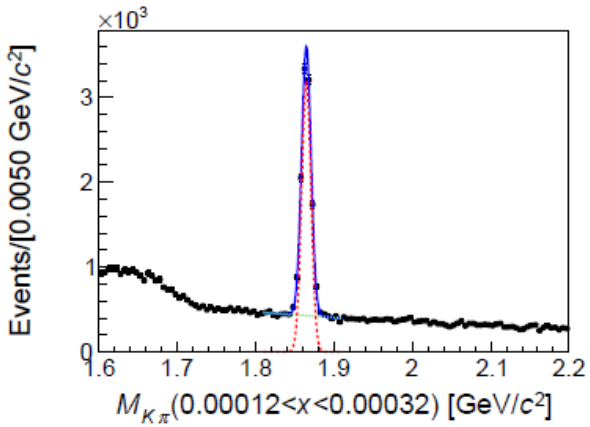
Bjorken x VS Q^2 coverage

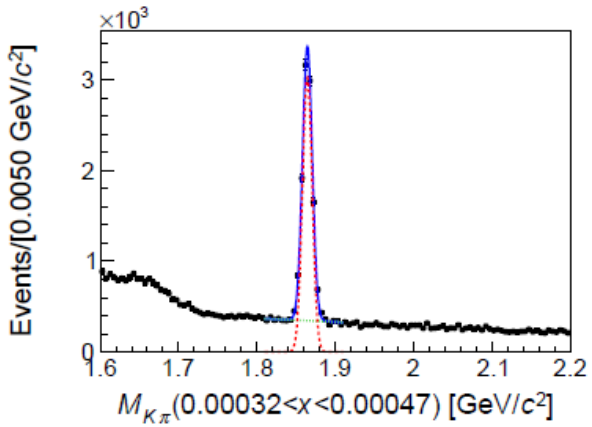
18 GeV x 275 GeV

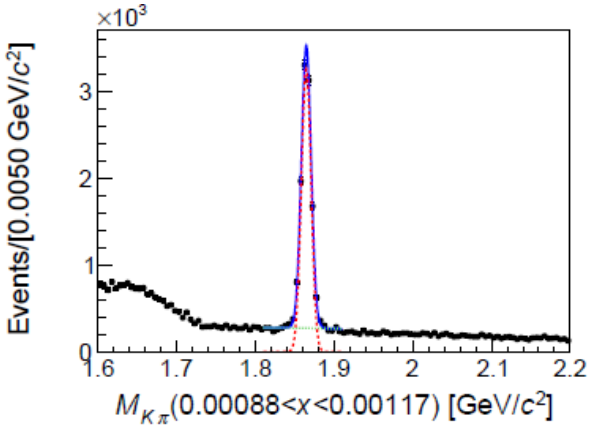


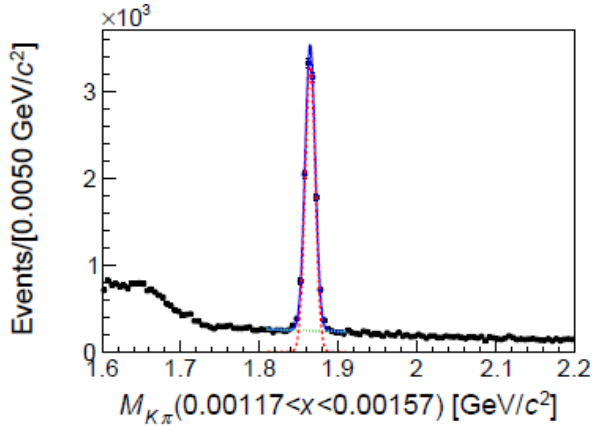


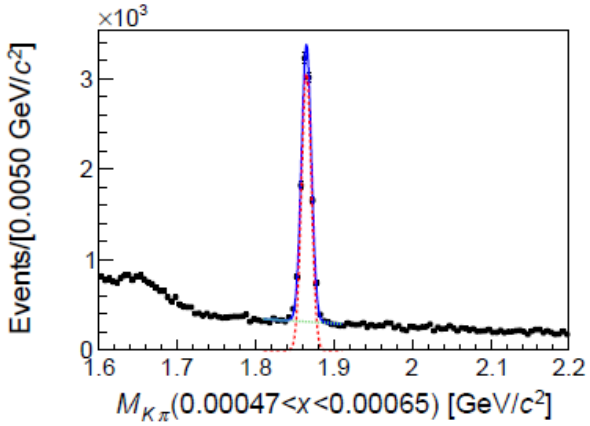
Fitting to the D0 mass spectrum bin by bin

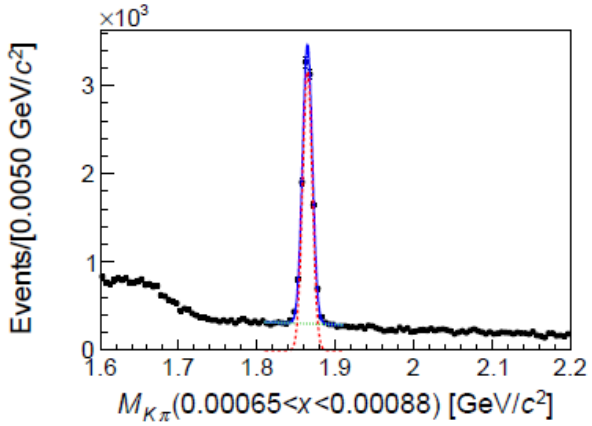


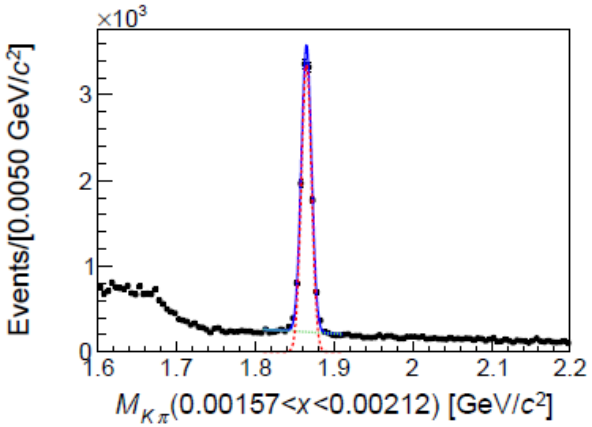


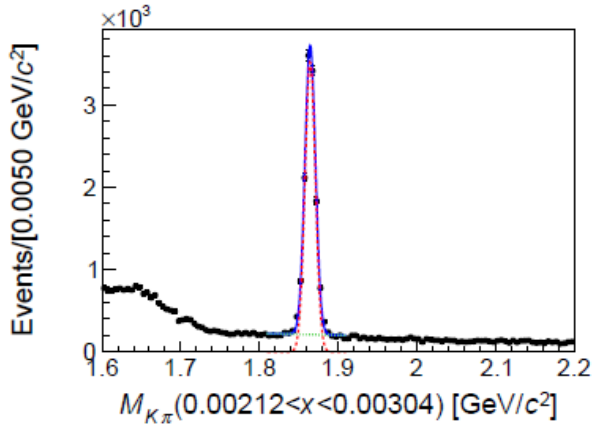






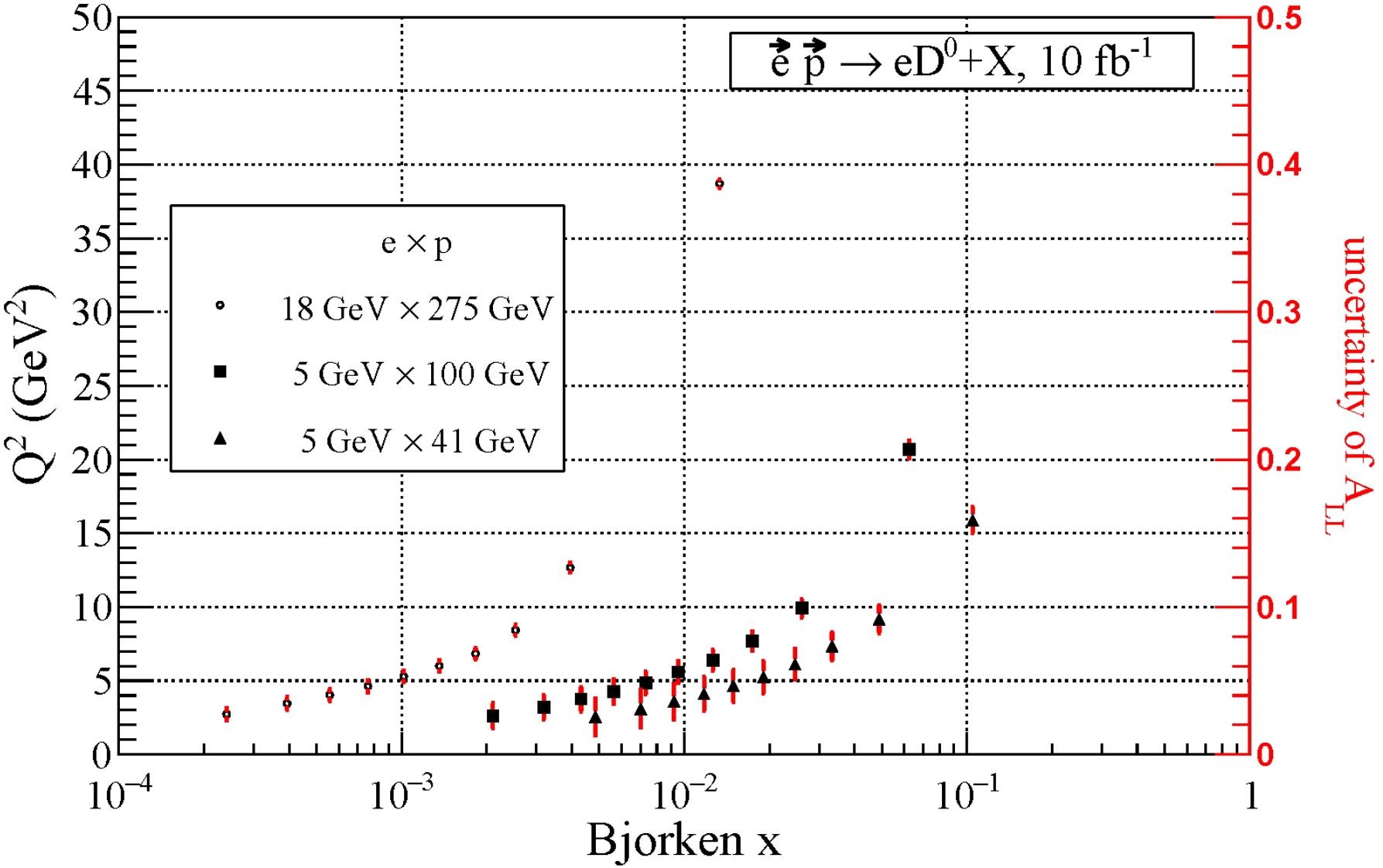




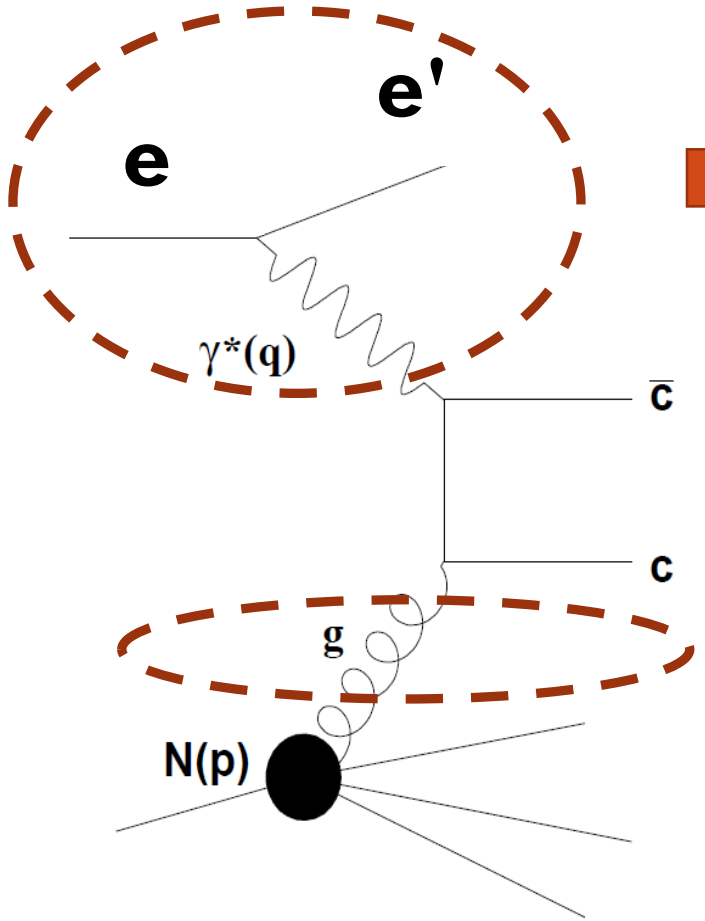


In general, signal is quite significant in each bin

Projections on experimental observable



A reminder of Photon-Gluon-Fusion



Experimentally measurable

Bjorken x

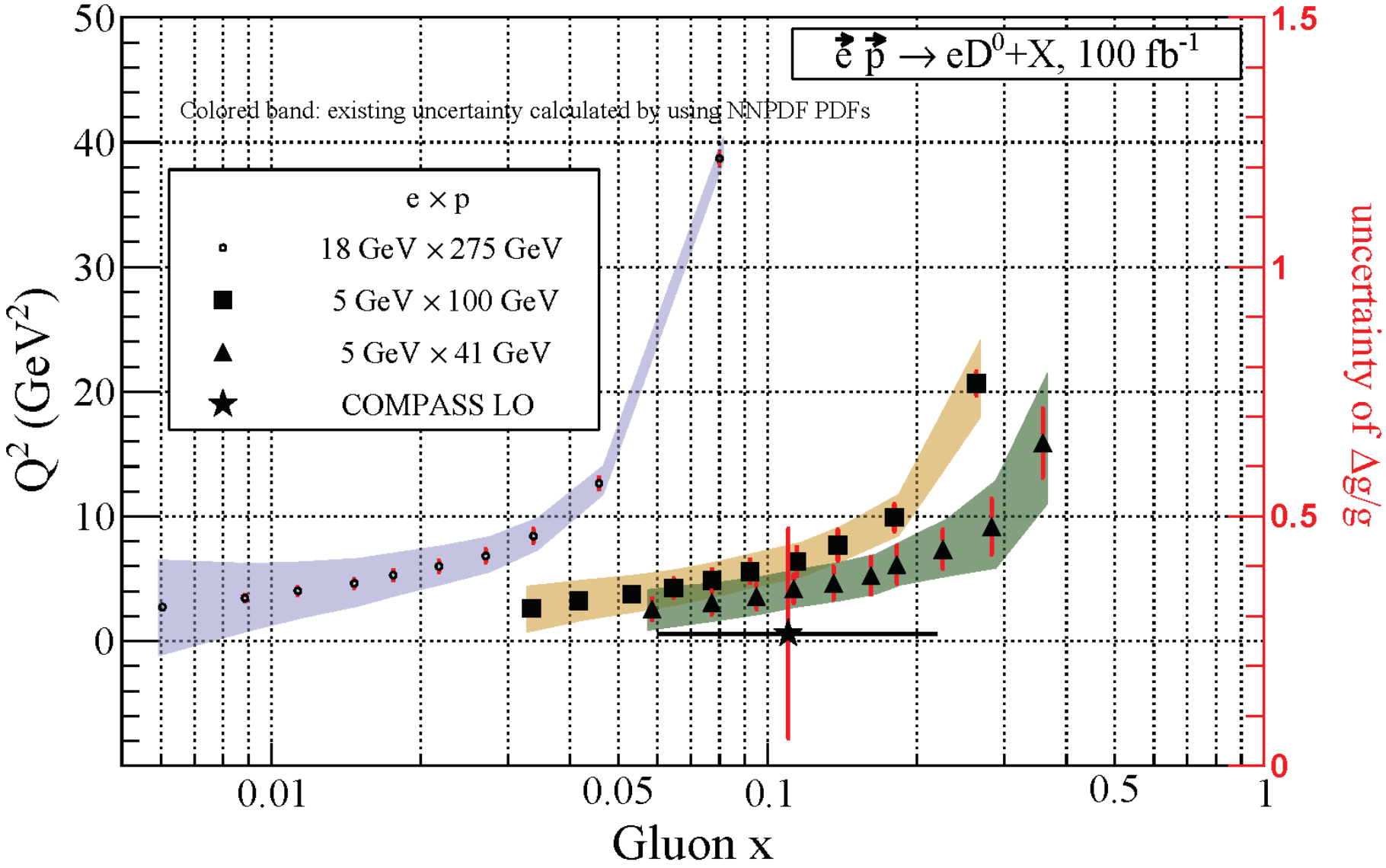
Conversion needed

Take advantage of Pythia

Gluon x

Parton information inside proton

Projections on $\frac{\Delta g}{g}$



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 fit to inclusive and SIDIS double spin asymmetry measurements
  - Measuring gluon polarization from a different angle, **direct measurement bin by bin in some sense**, could be used as a crosscheck on the complicated QCD fit
  - The precision in the overlap region ($0.03<x<0.3$) can be improved by combining measurements at different energy configurations

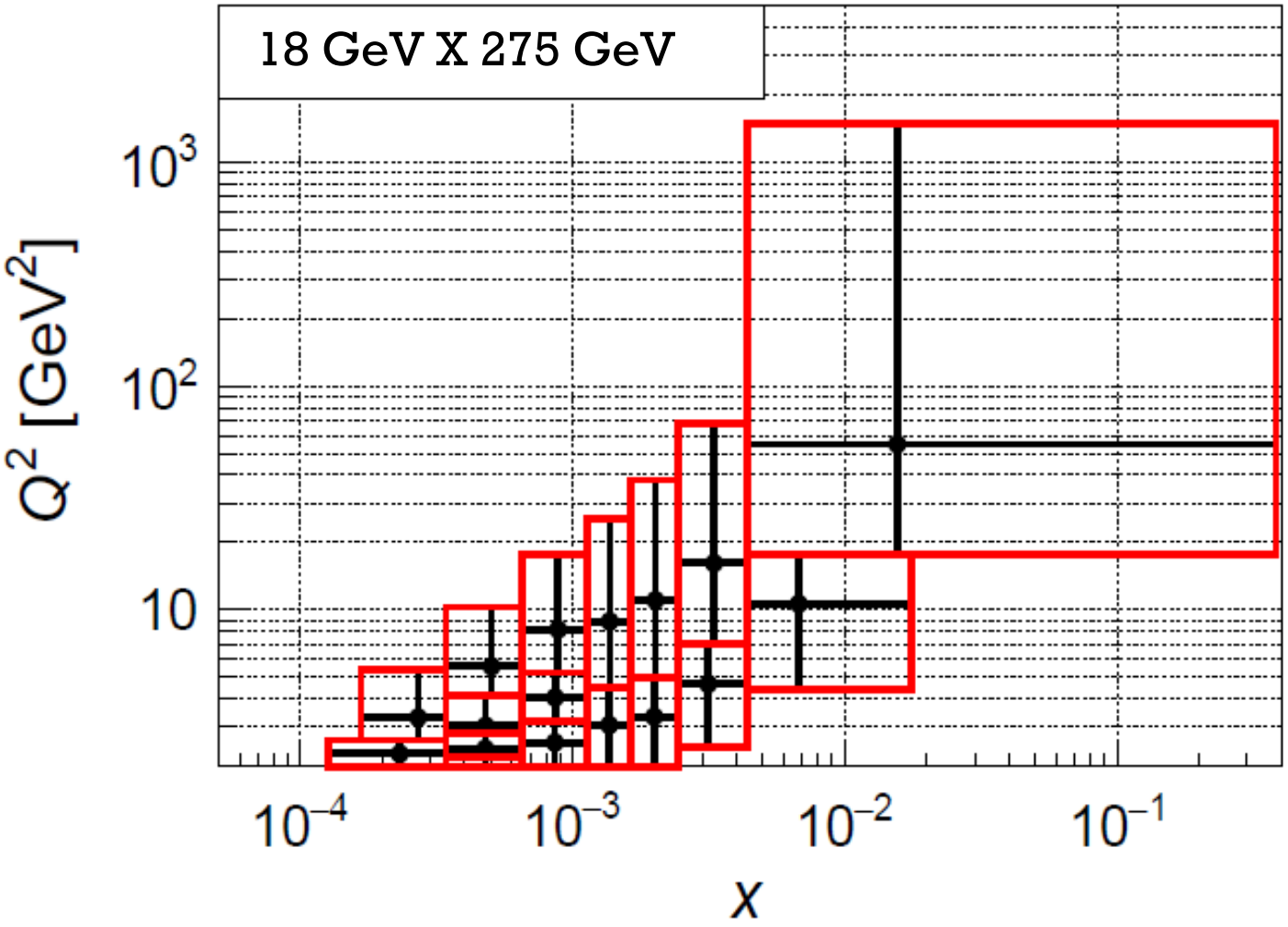
A reminder: gluon polarization in high x region is an interesting topic by itself

Backups

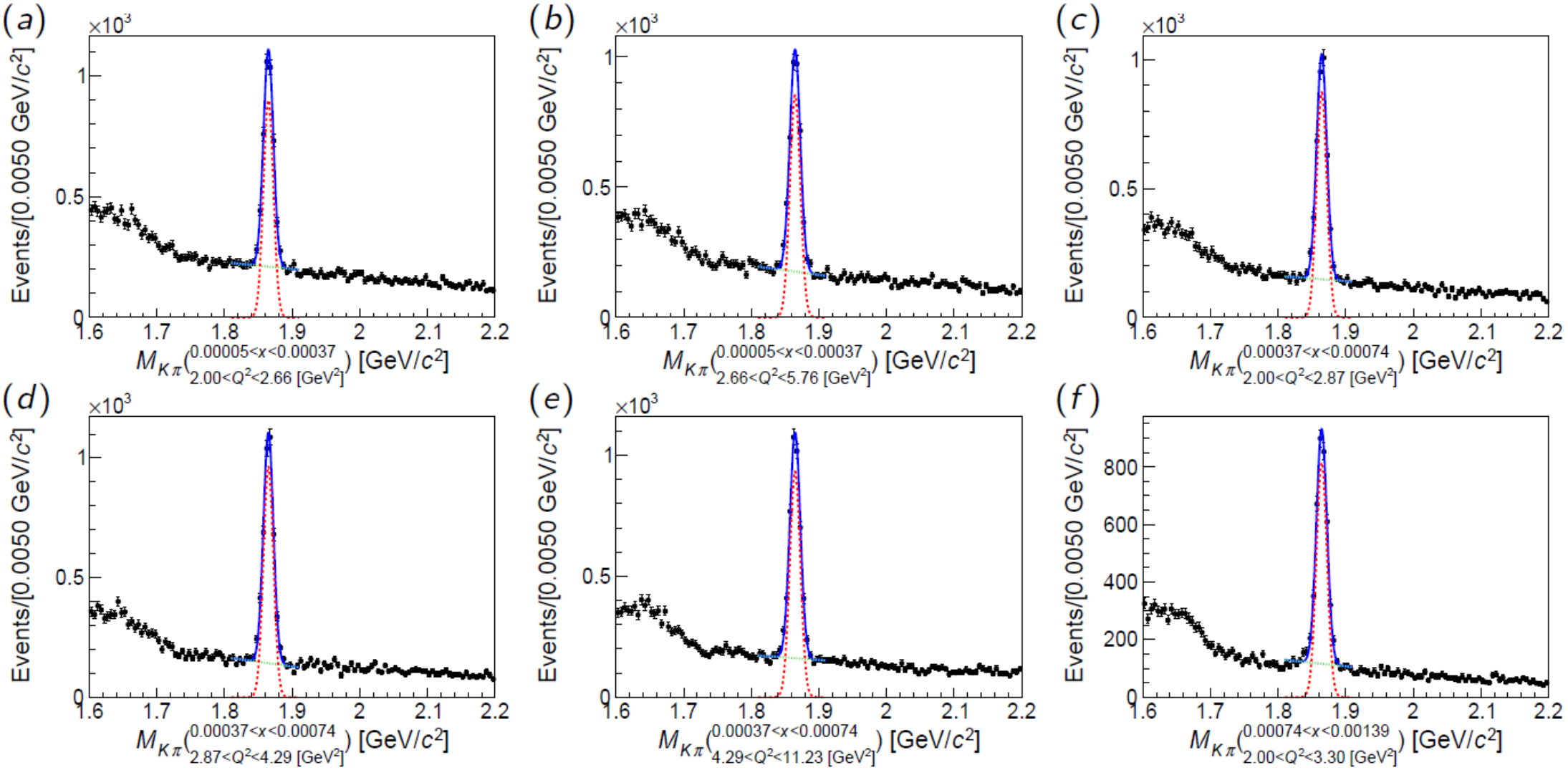
η Region	Detector Matrix (μm)	LBNL (μm)
-3.0< η <-2.5	$30/p_T \oplus 40$	$30/p_T \oplus 10$
-2.5< η <-2.0	$30/p_T \oplus 20$	$30/p_T \oplus 10$
-2.0< η <-1.0	$30/p_T \oplus 20$	$25/p_T \oplus 10$
-1.0< η <1.0	$20/p_T \oplus 5$	$20/p_T \oplus 5$
1.0< η <2.0	$30/p_T \oplus 20$	$25/p_T \oplus 10$
2.0< η <2.5	$30/p_T \oplus 20$	$30/p_T \oplus 10$
2.5< η <3.0	$30/p_T \oplus 40$	$30/p_T \oplus 10$
3.0< η <3.5	$30/p_T \oplus 60$	N/A

η Region	Resolution (%)
-3.5< η <-2.5	$0.1 \cdot p \oplus 0.5$
-2.5< η <-2.0	$0.1 \cdot p \oplus 0.5$
-2.0< η <-1.0	$0.05 \cdot p \oplus 0.5$
-1.0< η <1.0	$0.05 \cdot p \oplus 0.5$
1.0< η <2.5	$0.05 \cdot p \oplus 1.0$
2.5< η <3.5	$0.1 \cdot p \oplus 2.0$

Binning on x-Q^2



Events in each bin (18 GeV x 275 GeV)



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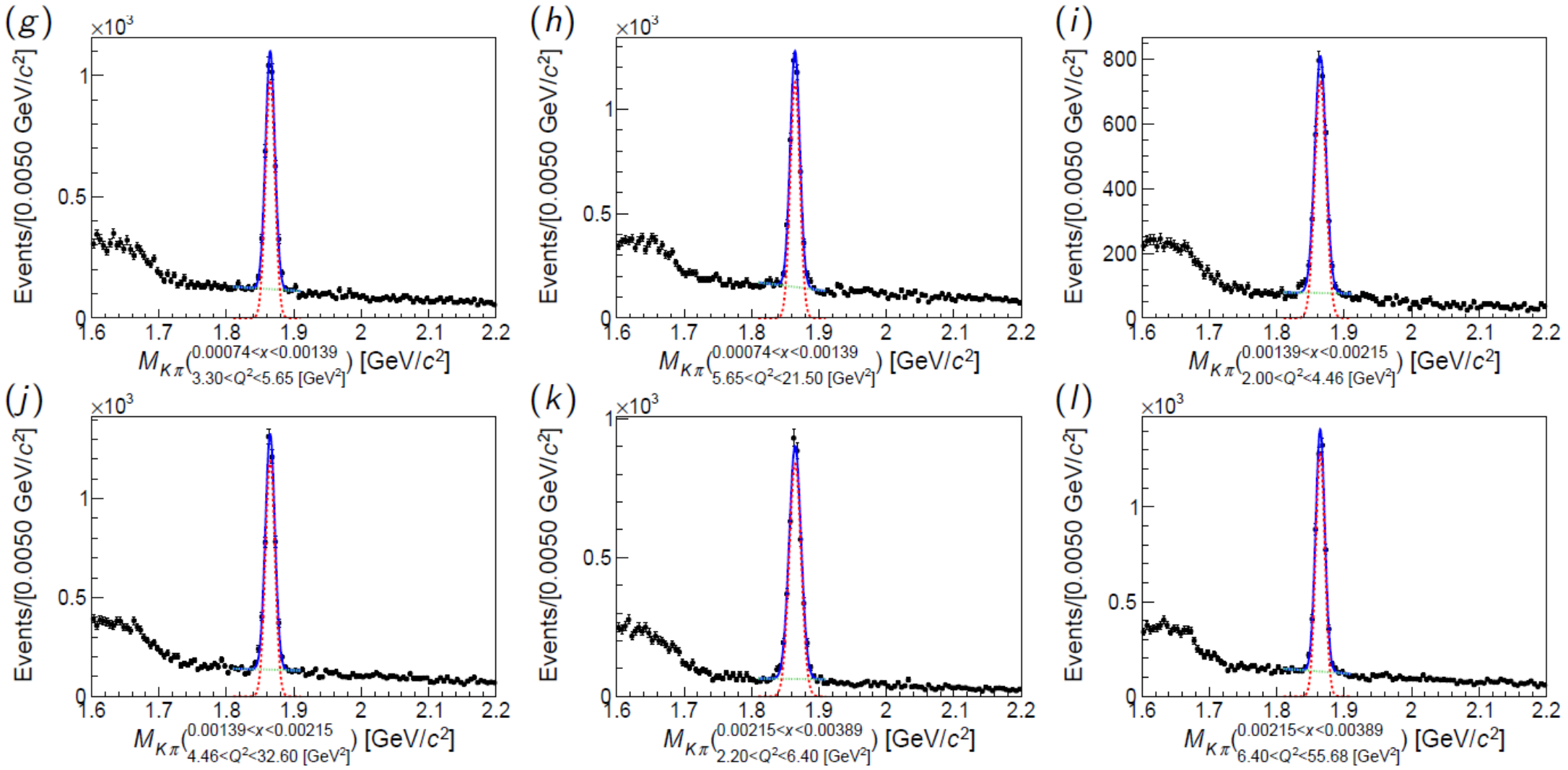

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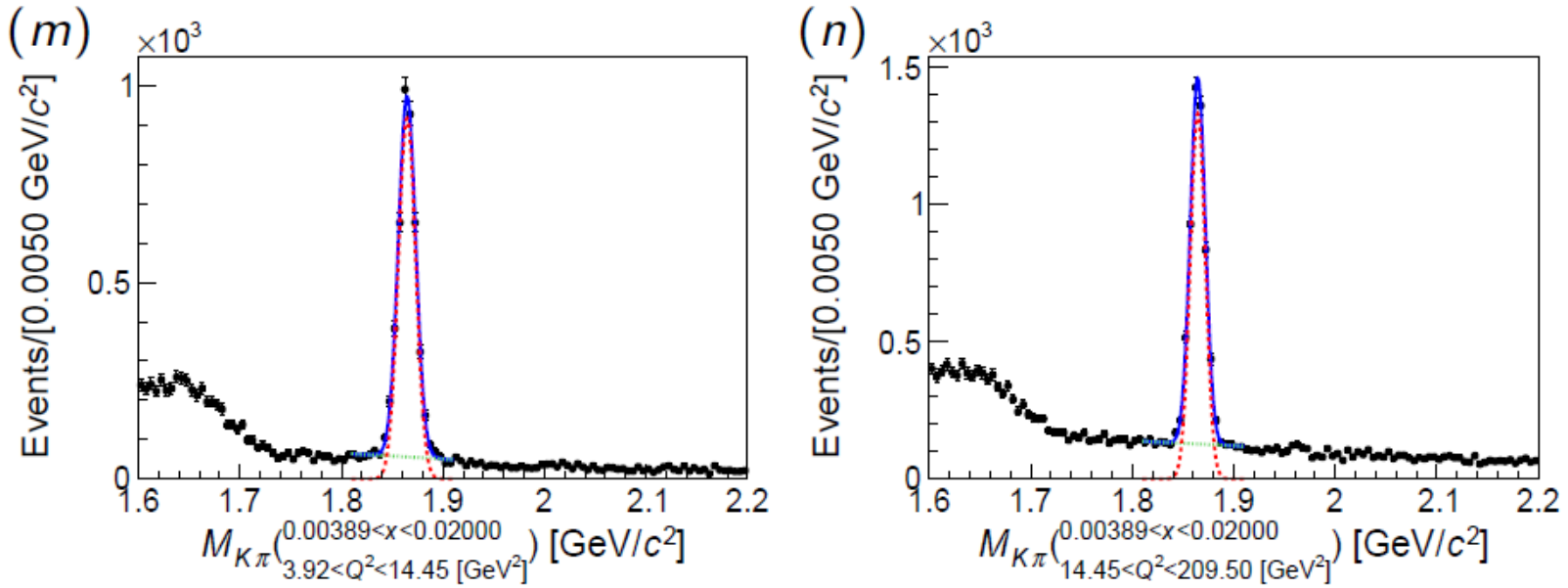
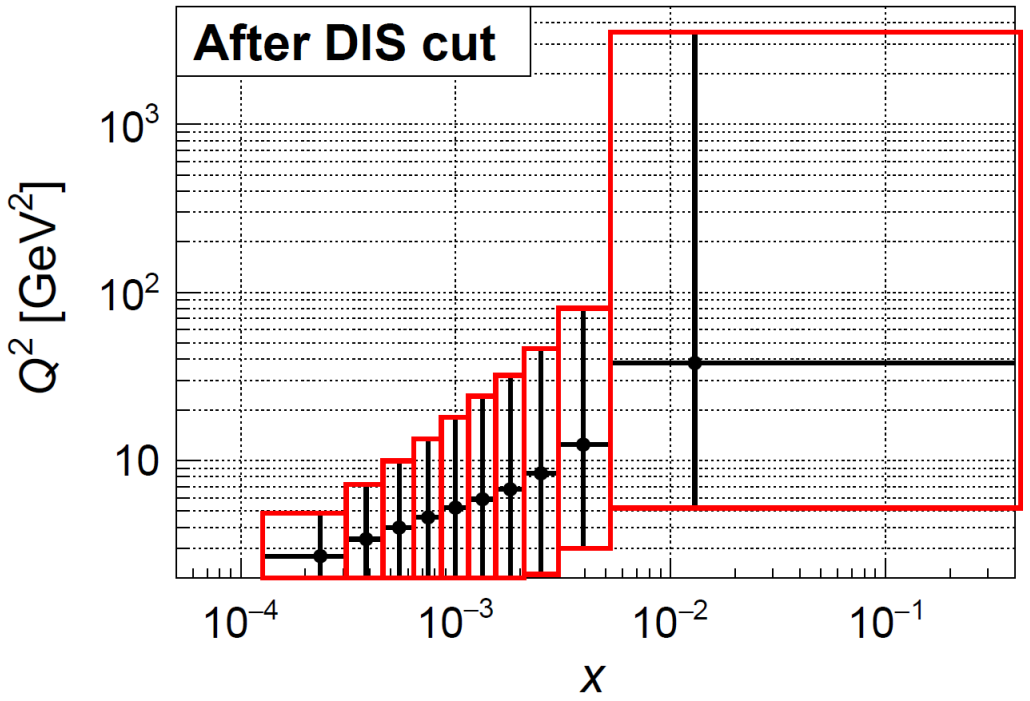


In general, signal is quite significant in each bin

1D bining on Bjorken x

18 GeV x 275 GeV



5 GeV x 100 GeV