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


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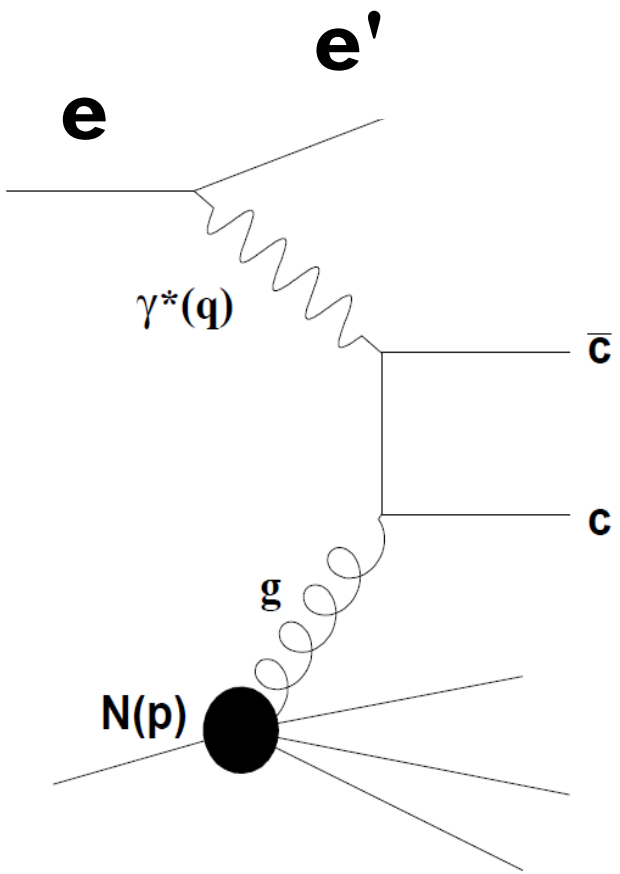
# What "heavy flavor" production can contribute to the proton spin structure study

**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

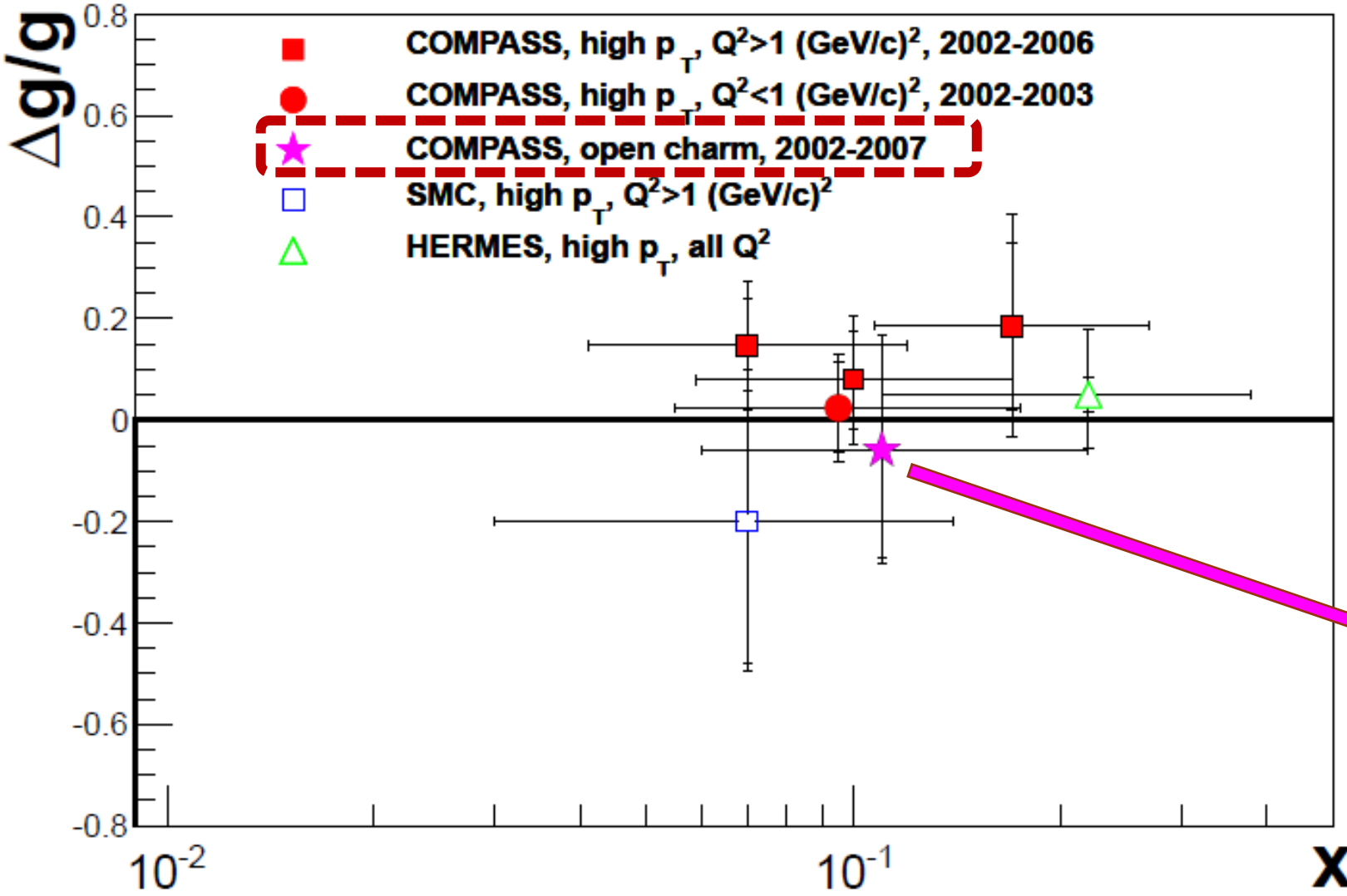
$$d\hat{\sigma} = \frac{\alpha^2 e_q^2 \alpha_s}{x Q^2 (\hat{s}+Q^2)^2} \left\{ \left[ 2(1-y) + y^2 \left( 1 - \frac{2m_l^2}{Q^2} \right) \right] \left[ \frac{Q^4 + \hat{s}^2}{(\hat{s}+Q^2)^2} \frac{\tilde{u}^2 + \tilde{t}^2}{2\,\tilde{u}\,\tilde{t}} + \frac{2m^2}{\tilde{u}\,\tilde{t}} \left( \hat{s}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

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




- No vertex detector to take advantage of decay topology

→ large background

- Low luminosity and finite acceptance

→ limited statistics

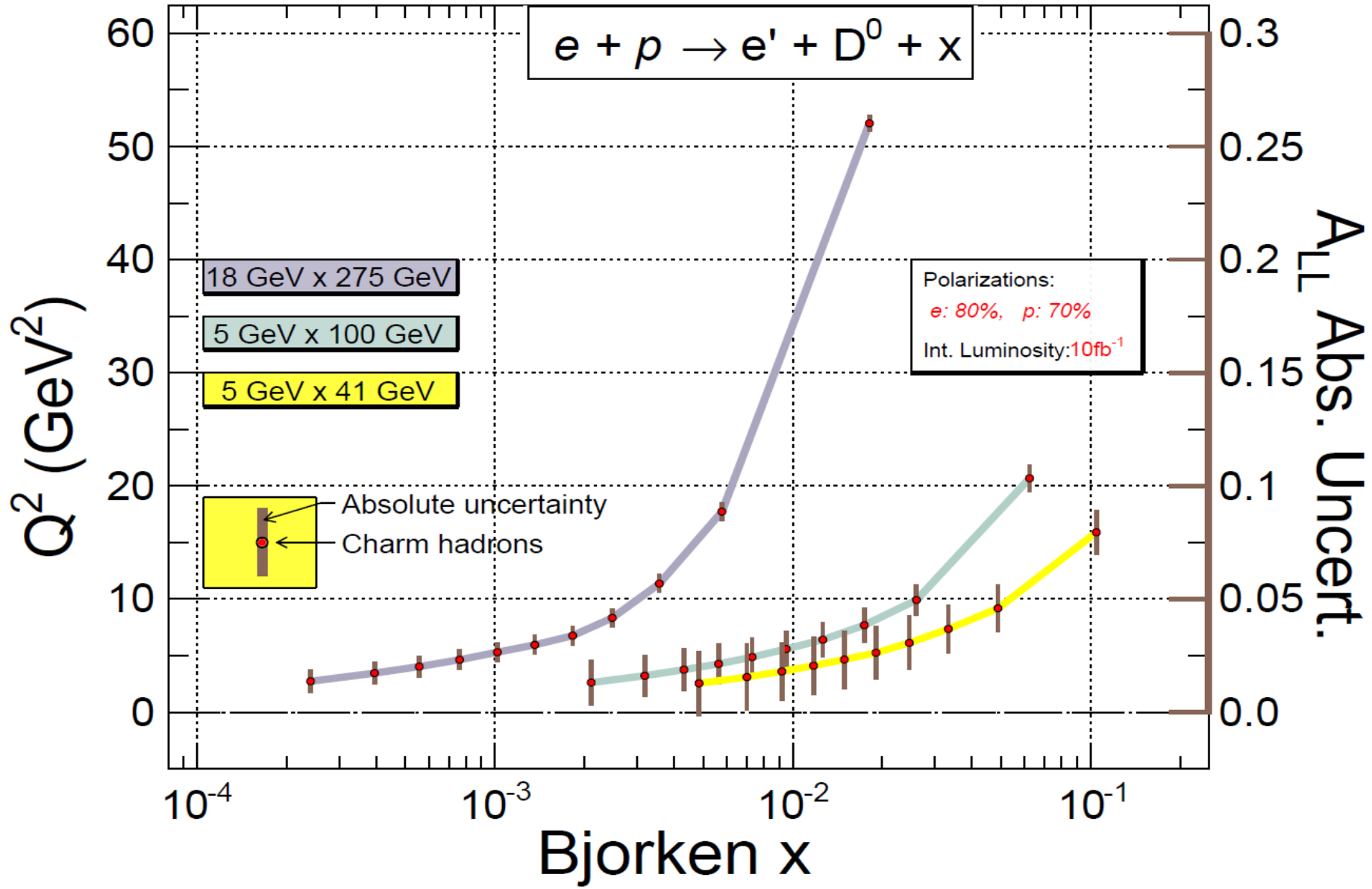
Pioneer work from COMPASS

# Resolution parameters at the EIC

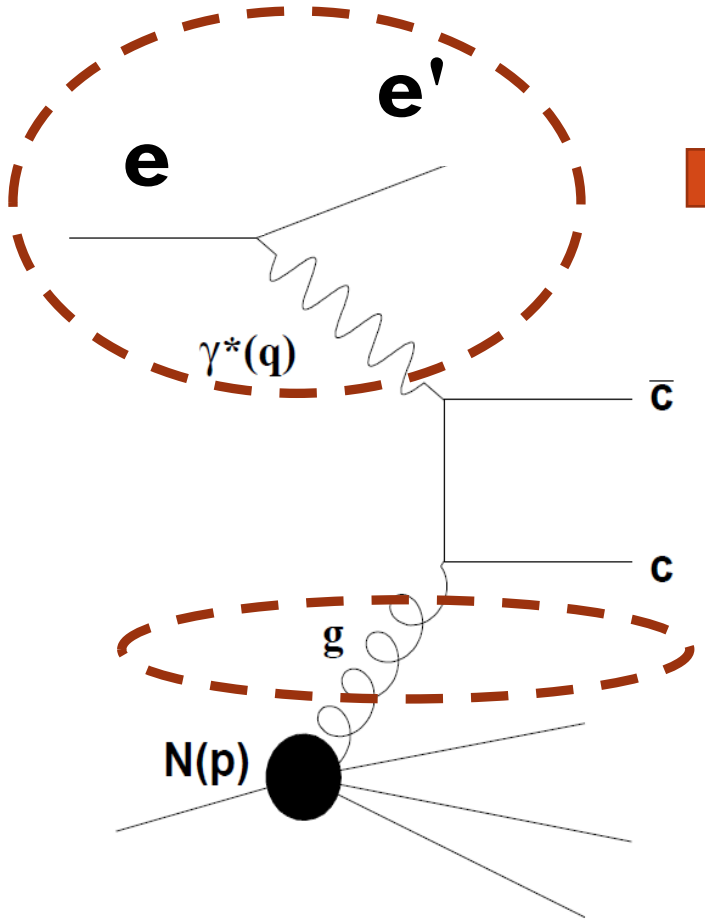
| $\eta$ | $\sigma_p/p$ - 3T (%) | $\sigma_p/p$ - 1.5T (%) | $\sigma(\mathrm{DCA}_{r\phi})$ ($\mu$m) | $p_{\mathrm{max}}^{\mathrm{PID}}$ (GeV/$c$) |
|---|---|---|---|---|
| (-3.0,-2.5) | $0.1 \cdot p \oplus 2.0$ | $0.2 \cdot p \oplus 5.0$ | $60/p_T \oplus 15$ | 10 |
| (-2.5,-2.0) | $0.02 \cdot p \oplus 1.0$ | $0.04 \cdot p \oplus 2.0$ | $60/p_T \oplus 15$ | 10 |
| (-2.0,-1.0) | $0.02 \cdot p \oplus 1.0$ | $0.04 \cdot p \oplus 2.0$ | $40/p_T \oplus 10$ | 10 |
| (-1.0,1.0) | $0.02 \cdot p \oplus 0.5$ | $0.04 \cdot p \oplus 1.0$ | $30/p_T \oplus 5$ | 6 |
| (1.0,2.0) | $0.02 \cdot p \oplus 1.0$ | $0.04 \cdot p \oplus 2.0$ | $40/p_T \oplus 10$ | 50 |
| (2.0,2.5) | $0.02 \cdot p \oplus 1.0$ | $0.04 \cdot p \oplus 2.0$ | $60/p_T \oplus 15$ | 50 |
| (2.5,3.0) | $0.1 \cdot p \oplus 2.0$ | $0.2 \cdot p \oplus 5.0$ | $60/p_T \oplus 15$ | 50 |

The following results are based on this design

# Projections on experimental observable



# A reminder of Photon-Gluon-Fusion




Experimentally measurable

Bjorken x

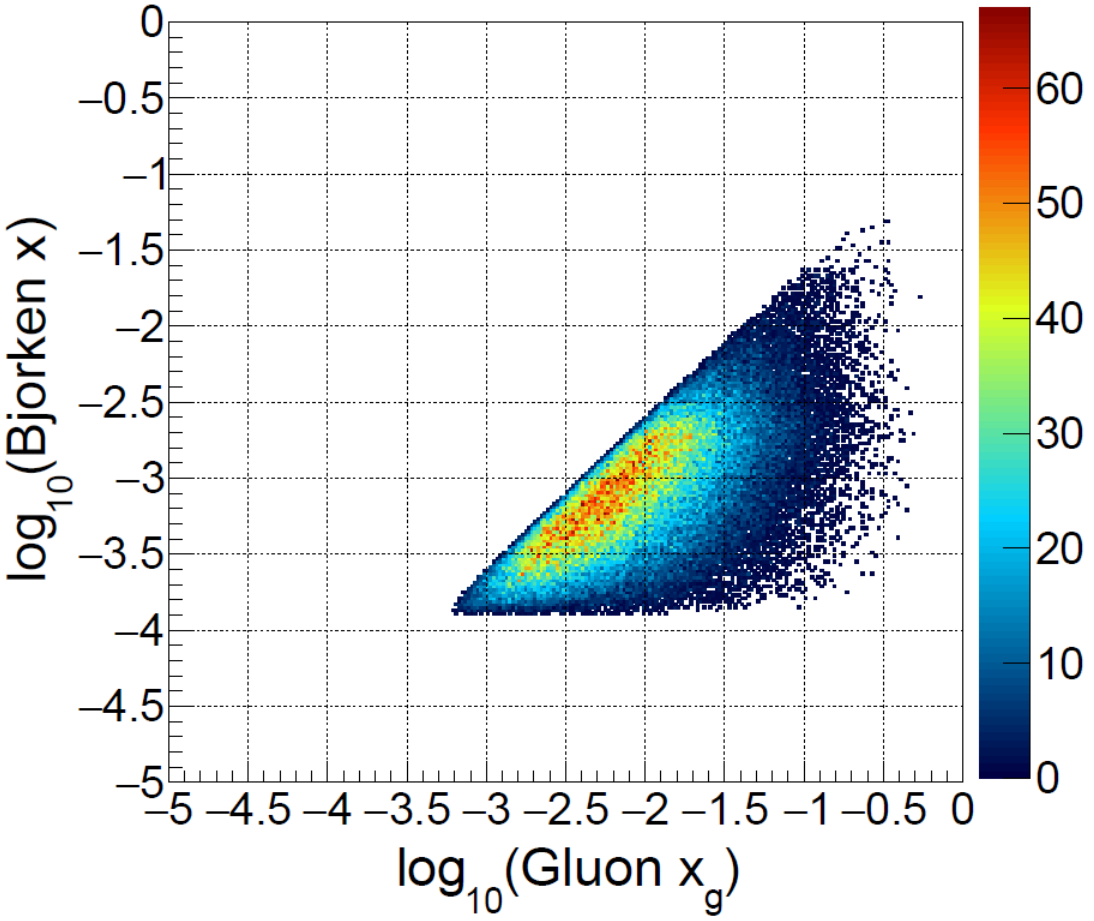
Conversion needed

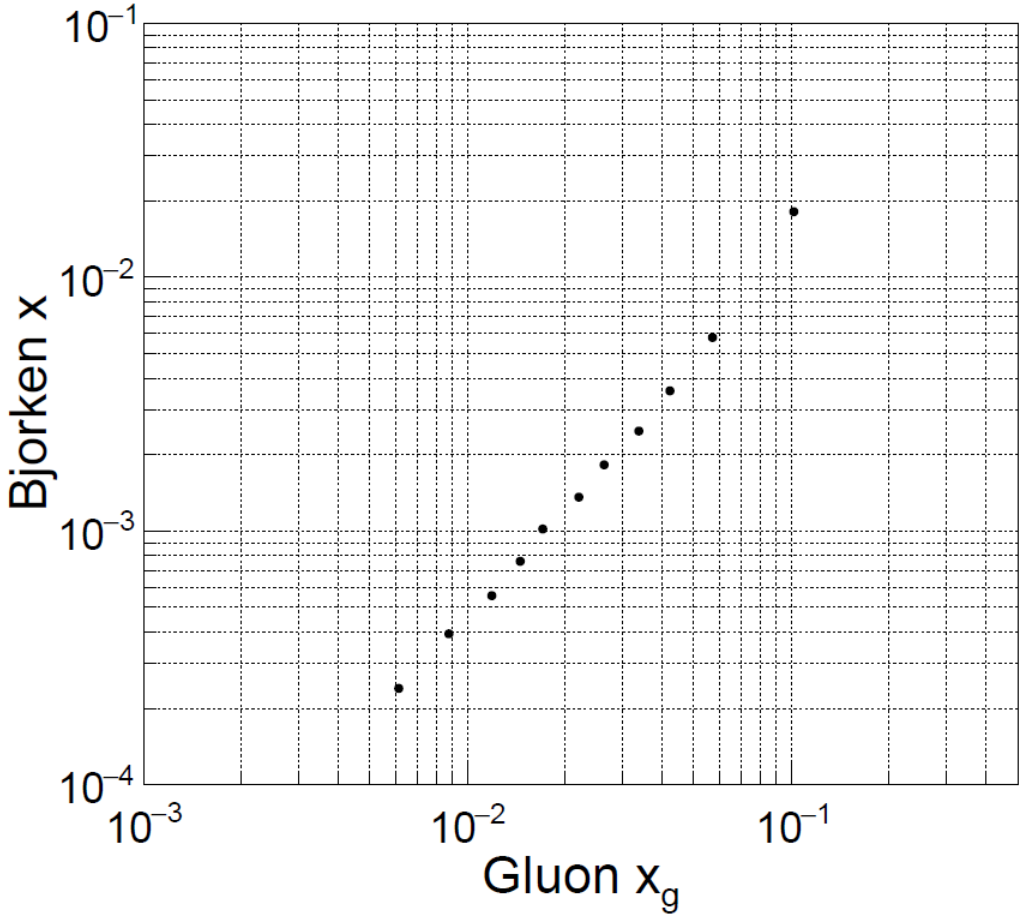
Take advantage of Pythia

Gluon x

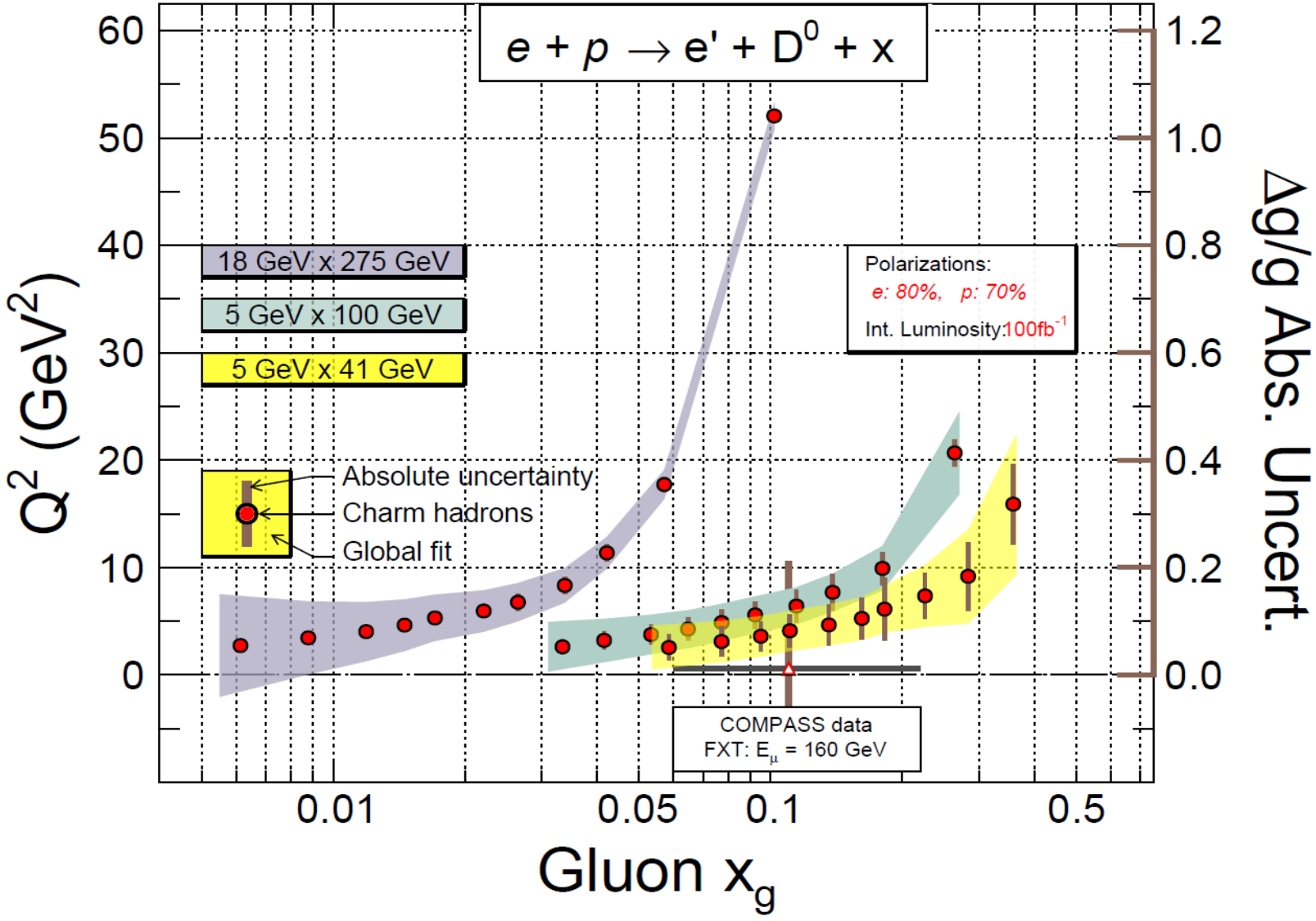
Parton information inside proton

# Conversion from Bjorken x to Gluon x by using Pythia 6.4



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



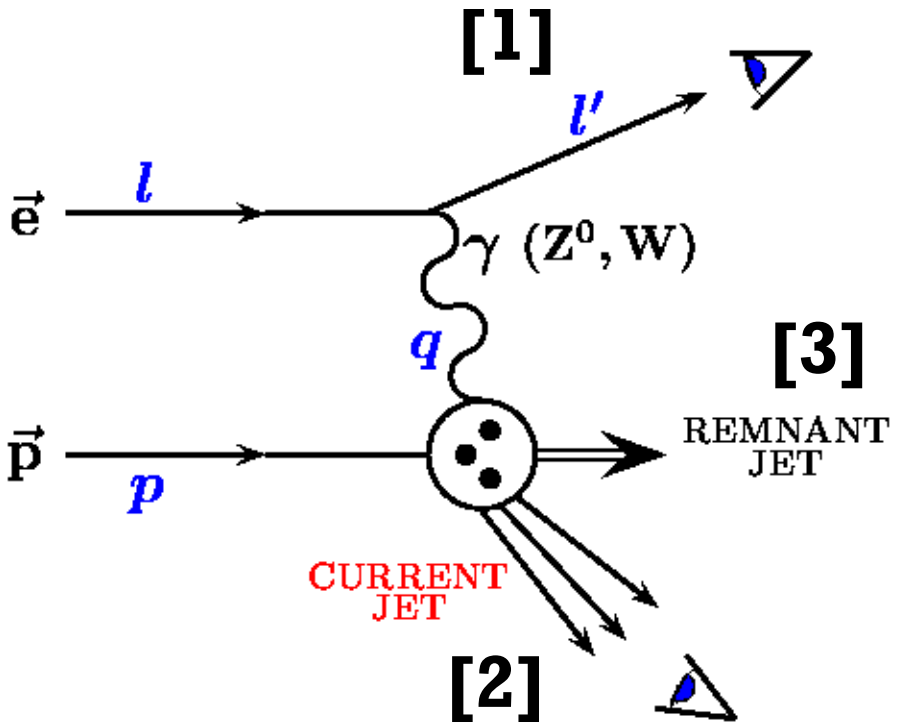
# Summary and discussions

- **$\frac{\Delta g}{g}$ 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:**
**Determination of the parameterization form for the gluon helicity distribution in high x region is an interesting topic**

# Backups

# 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

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

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

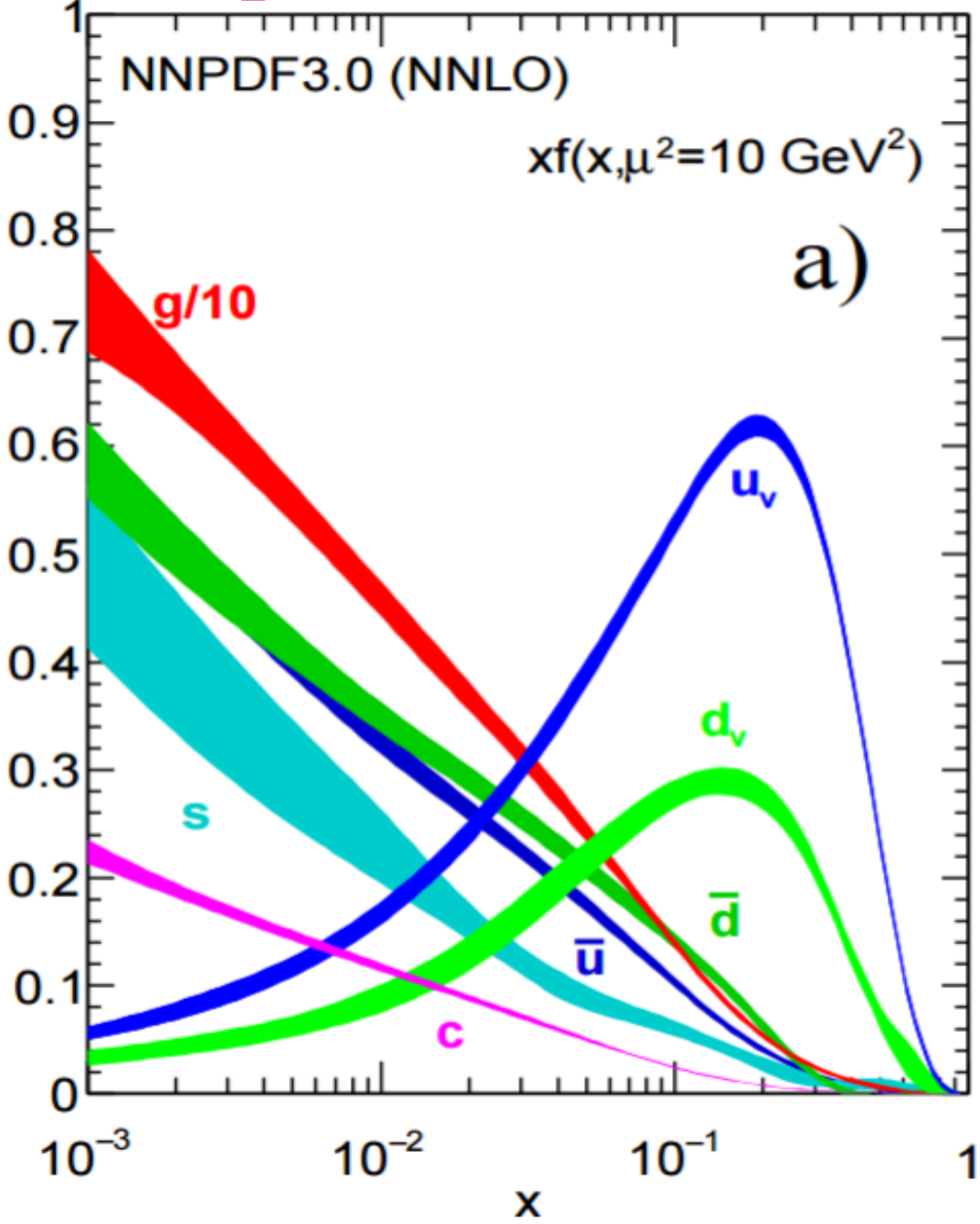
## Polarized pdfs

Helicity distribution

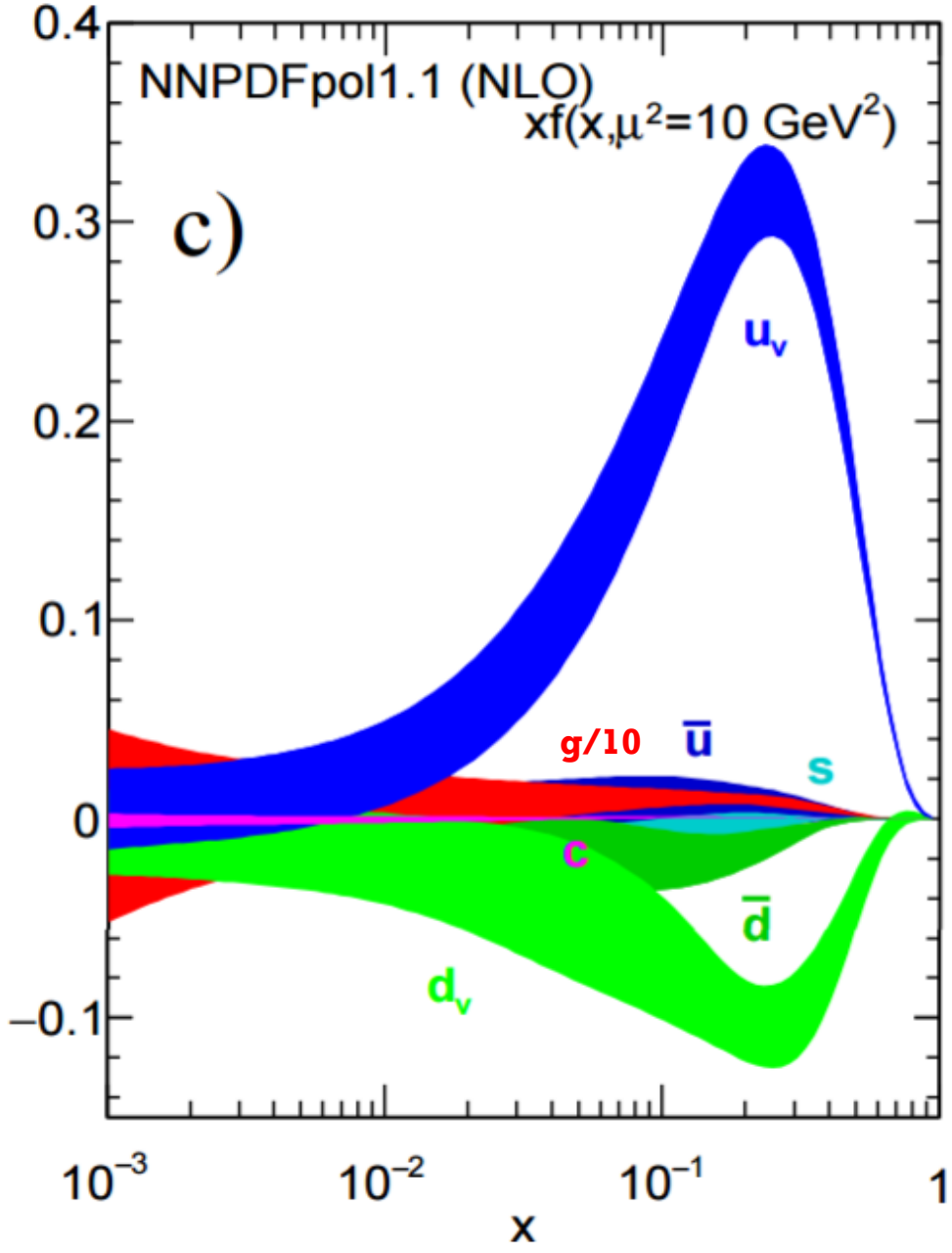
$\Delta q=q^{\uparrow}(x) - q^{\downarrow}(x)$

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

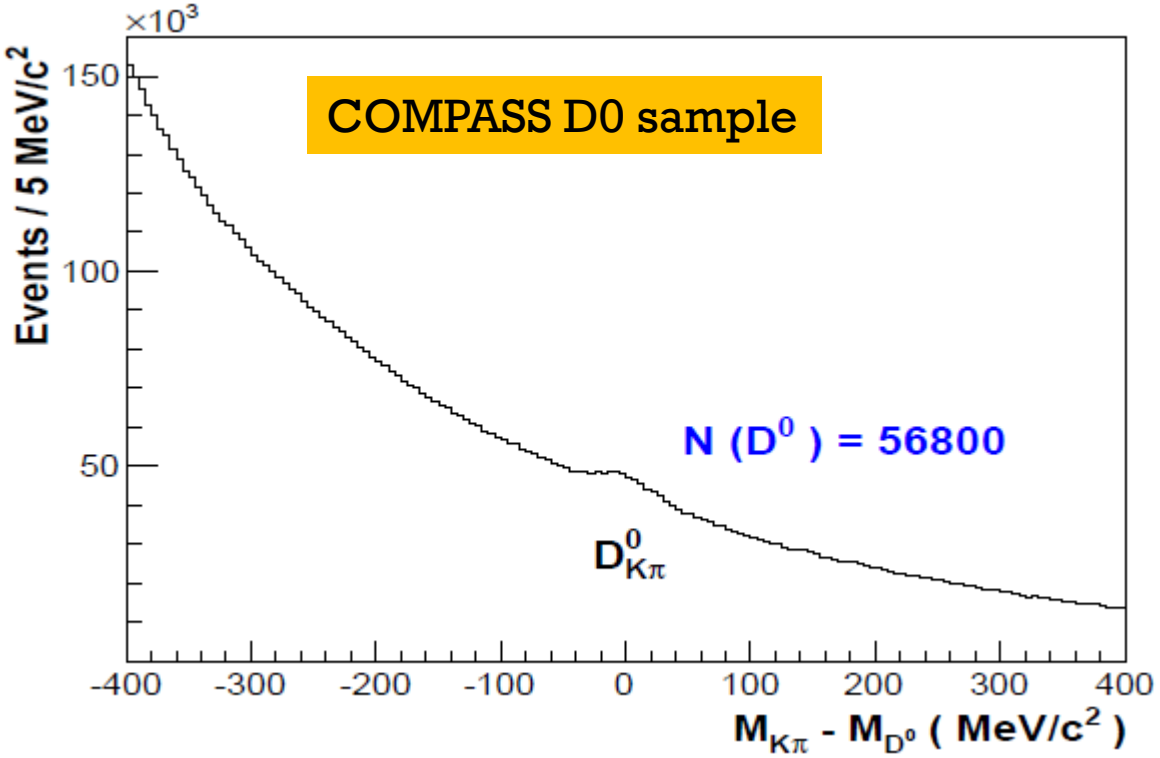
# Unpolarized PDFs

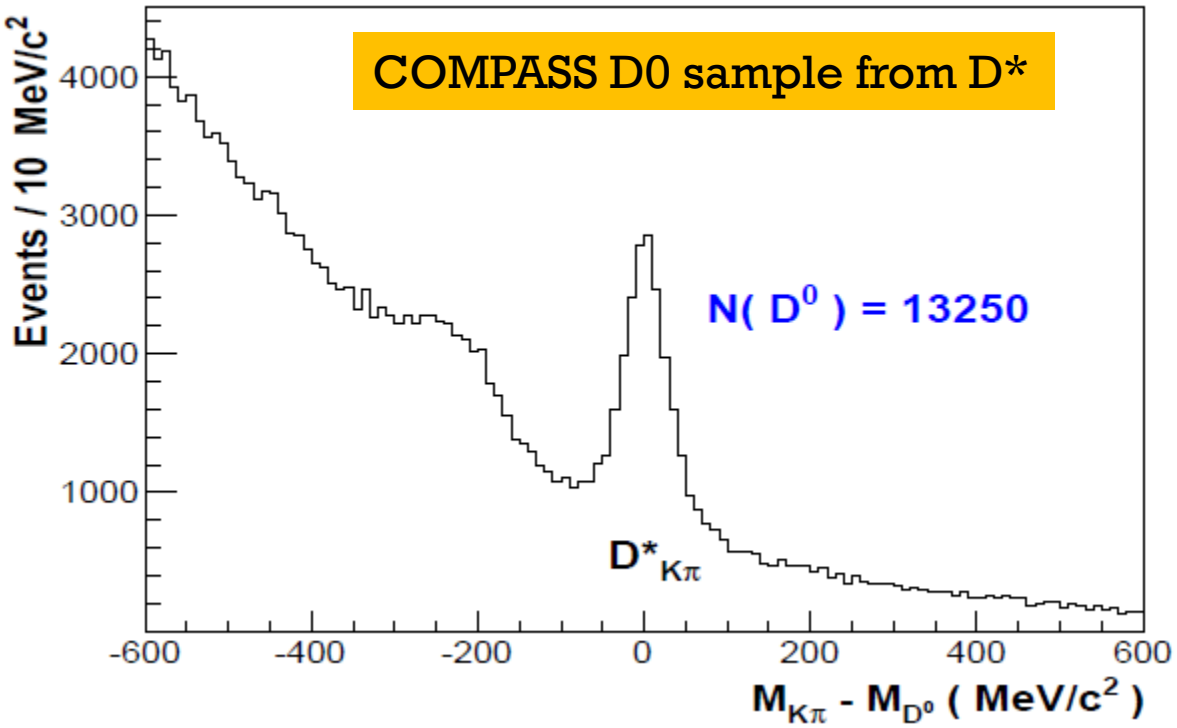



# Polarized PDFs



# Limitations at COMPASS




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

# Outline

- Introduction

- Description of the simulation at the EIC

- Results and discussions

# Strategy of the simulation

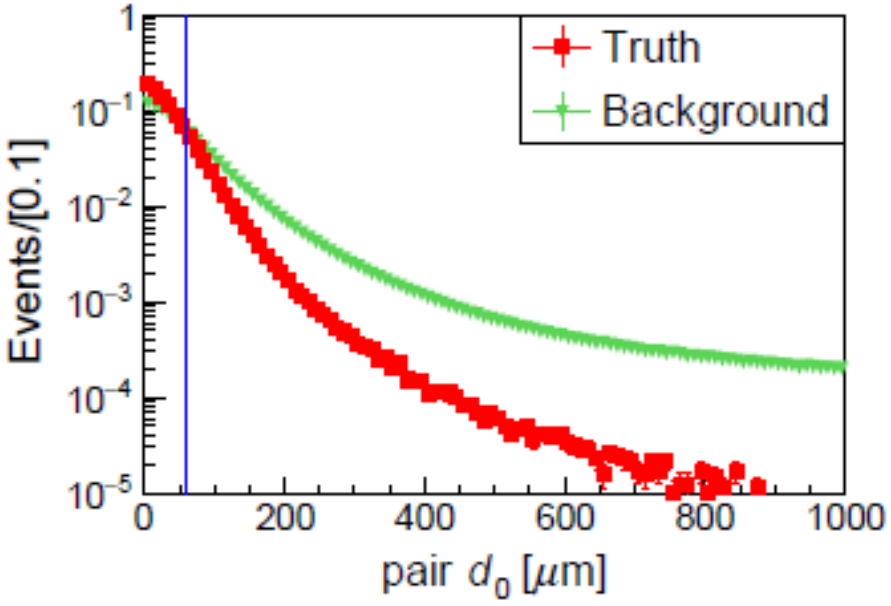
Events generated using PythiaeRHIC (Pythia 6.4)

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

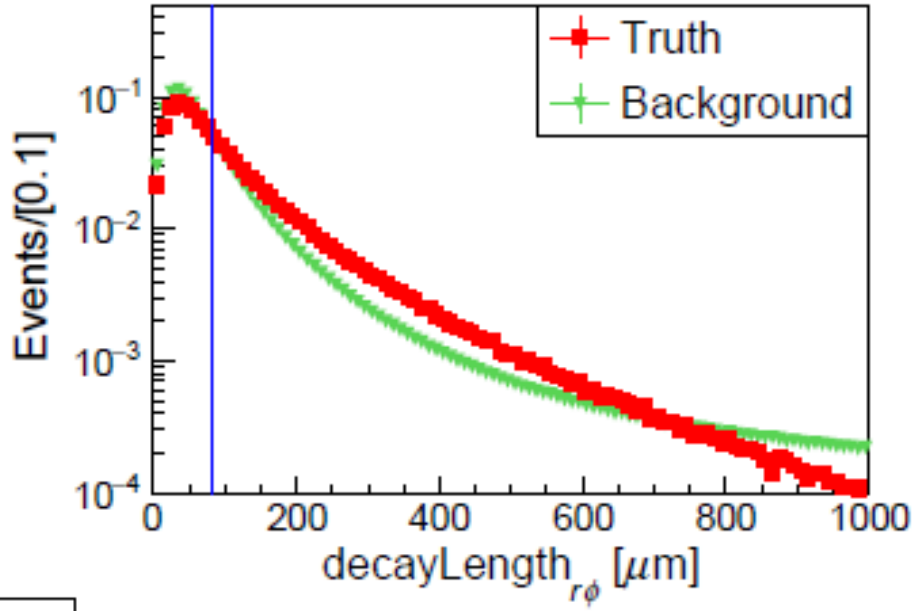
Search Pion&Kaon pair $D^0 \xrightarrow{3.89\%} K^-\pi^+$

Reconstructed D0

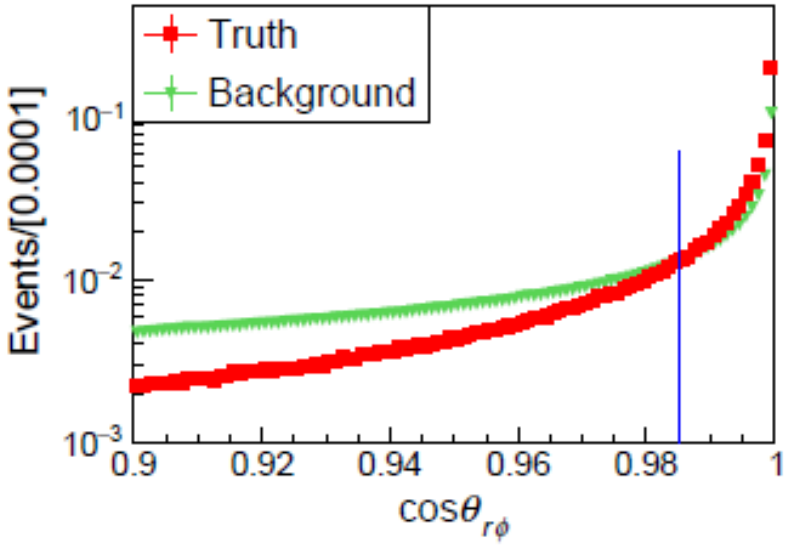
# Optimization of $D^0$ decay topology cuts




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**

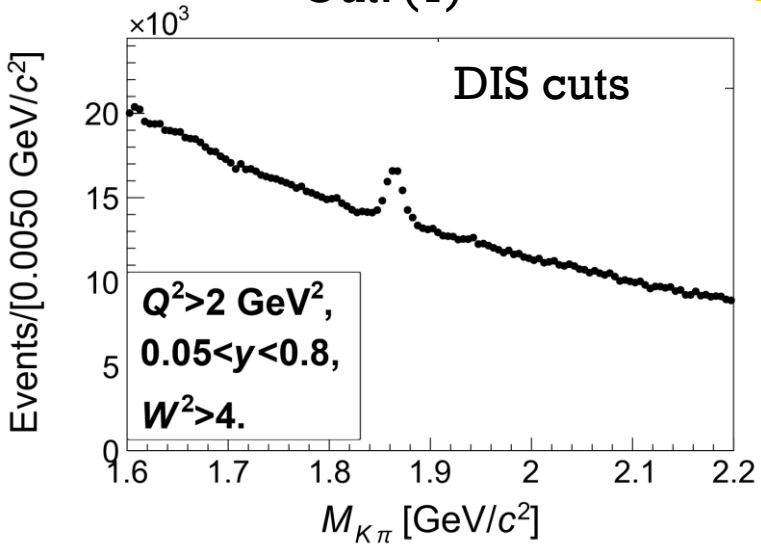
| Selection criteria | 18 GeV×275 GeV | 5 GeV×100 GeV | 5 GeV×41 GeV |
|---|---|---|---|
| pion+kaon pair DCA | $< 60\ \mu m$ | $< 60\ \mu m$ | $< 60\ \mu m$ |
| $decayLength_{r\phi}$ | $> 80\ \mu m$ | $> 70\ \mu m$ | $> 70\ \mu m$ |
| $\cos\theta_{r\phi}$ | $> 0.985$ | $> 0.983$ | $> 0.981$ |

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

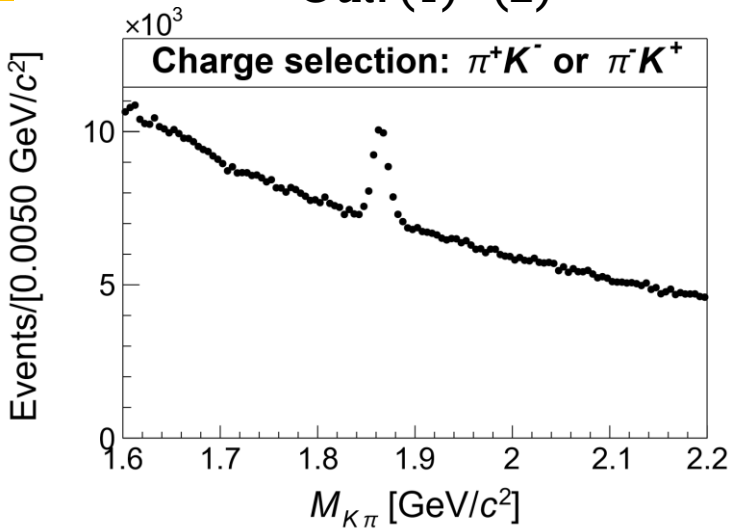
# Cut flow study

18 GeV x 275 GeV

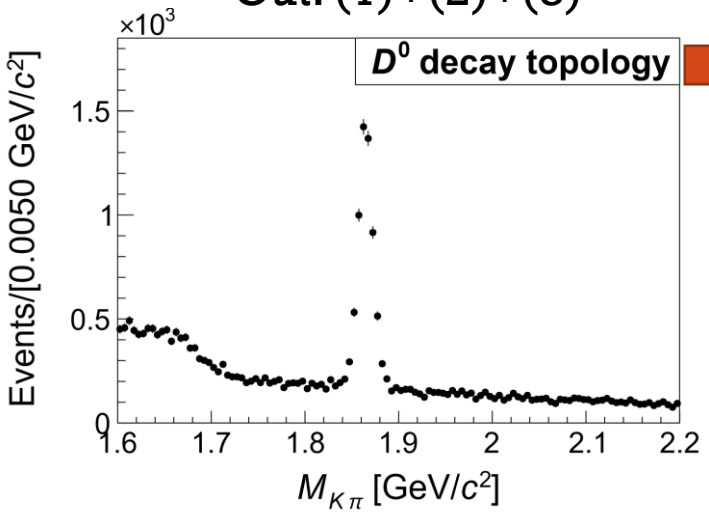
Cut: (1)




Cut: (1)+(2)



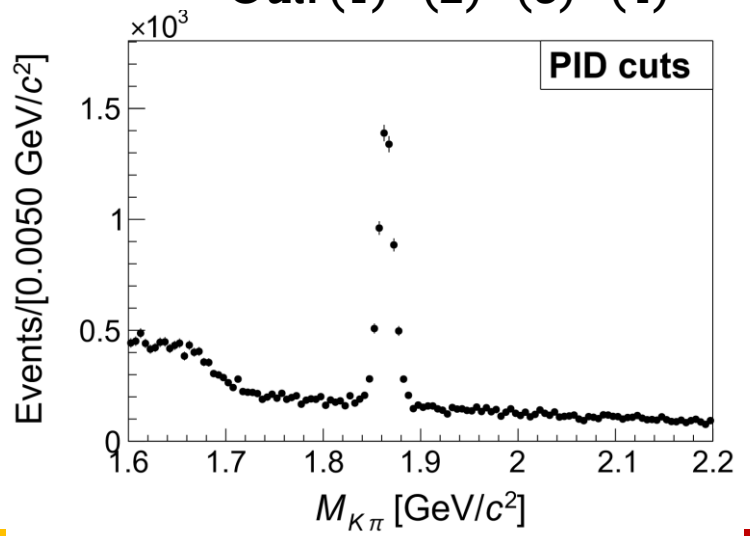

Cut: (1)+(2)+(3)




**Most powerful cut**

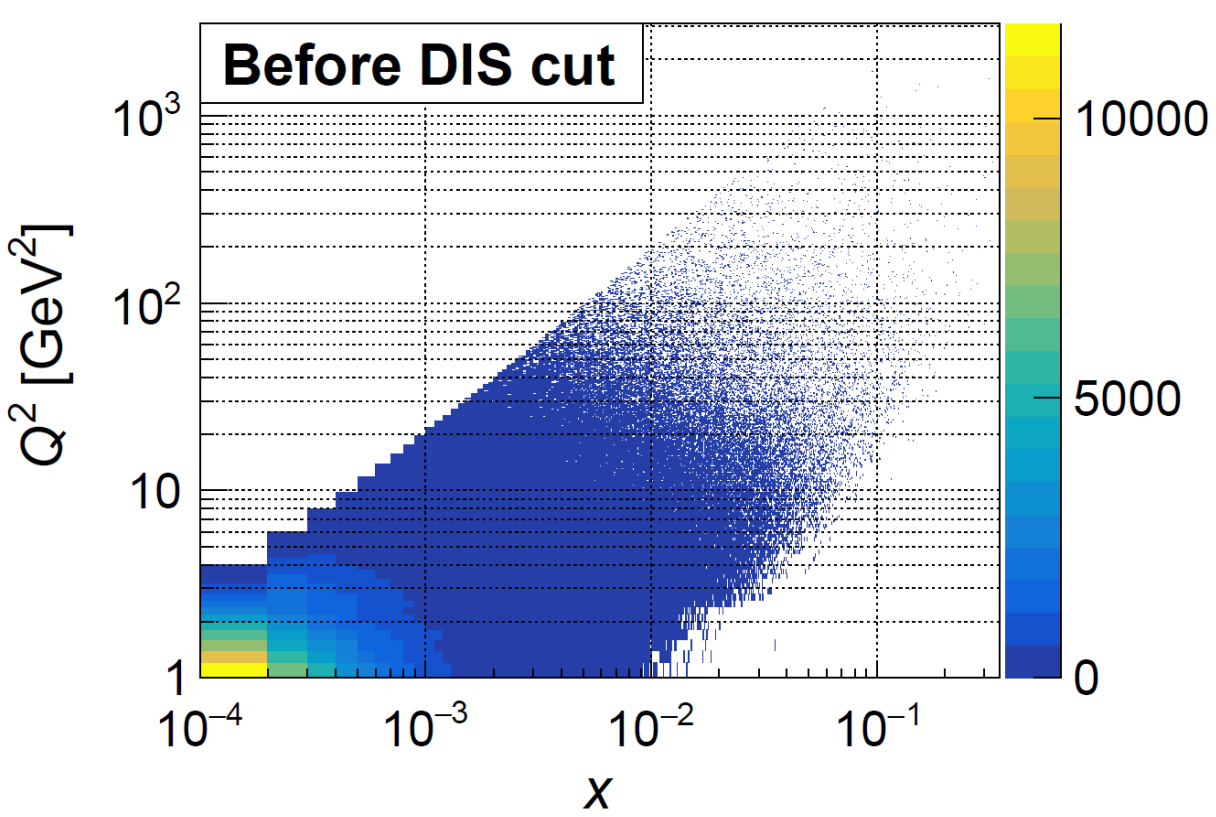
**A good vertex detector is crucial**

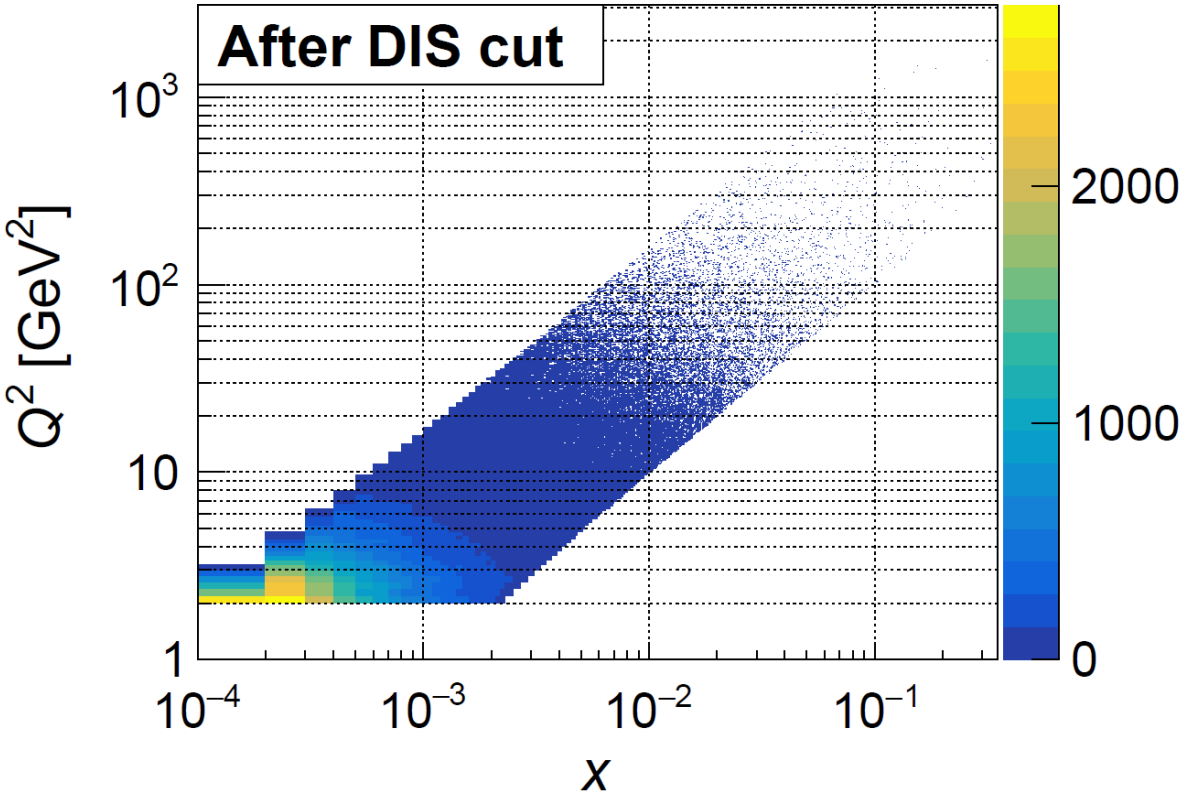
Cut: (1)+(2)+(3)+(4)



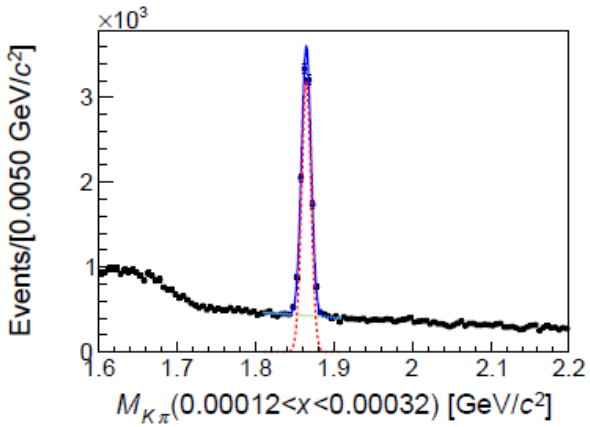
# Bjorken x VS $Q^2$ coverage

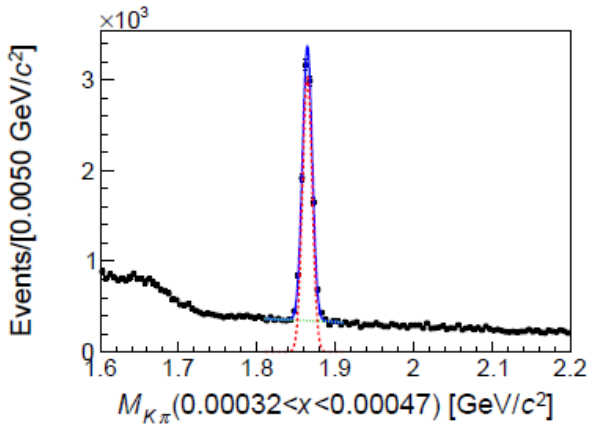
**18 GeV x 275 GeV**

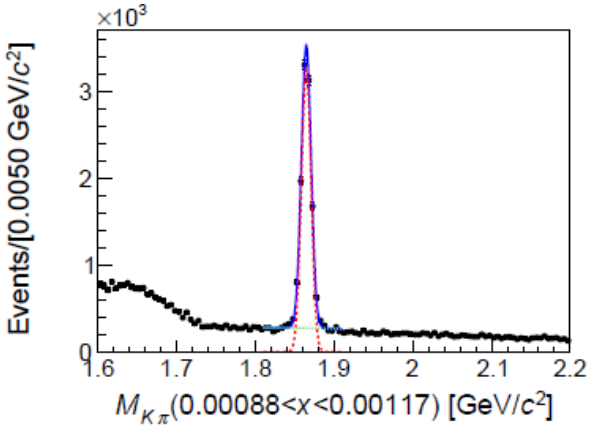


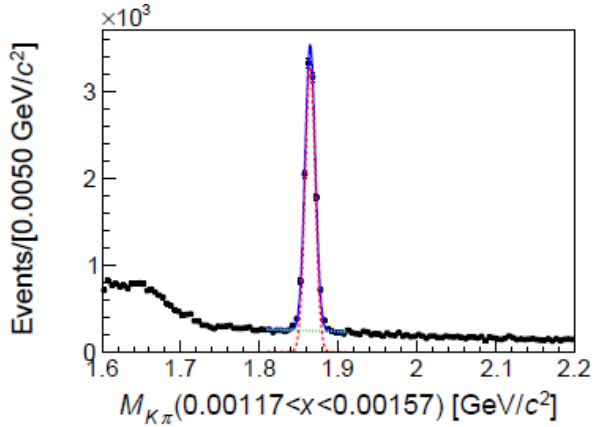



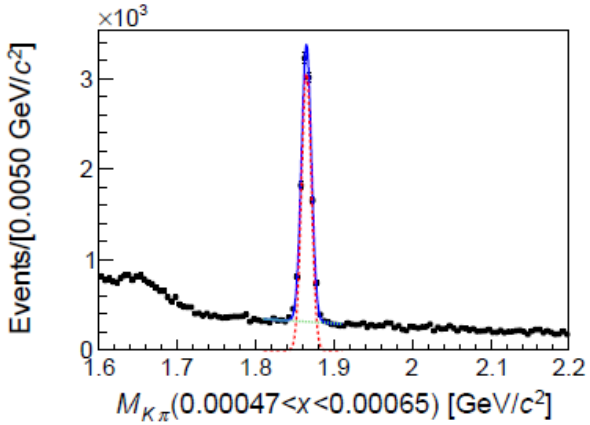
# Fitting to the D0 mass spectrum bin by bin

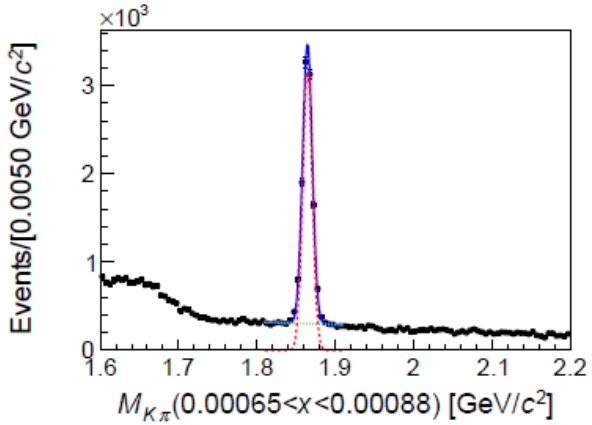


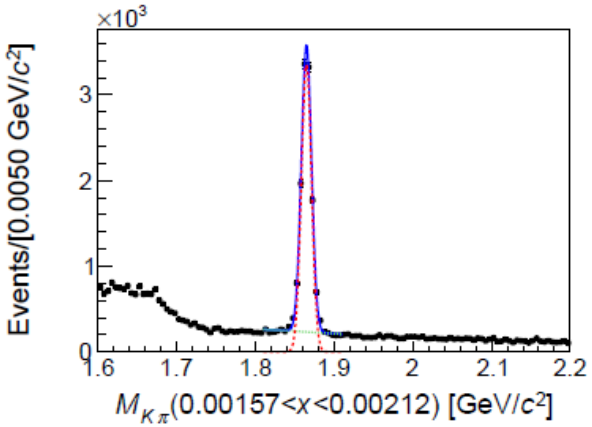



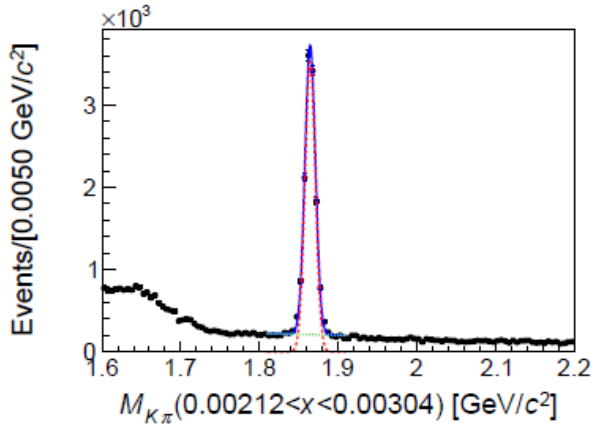



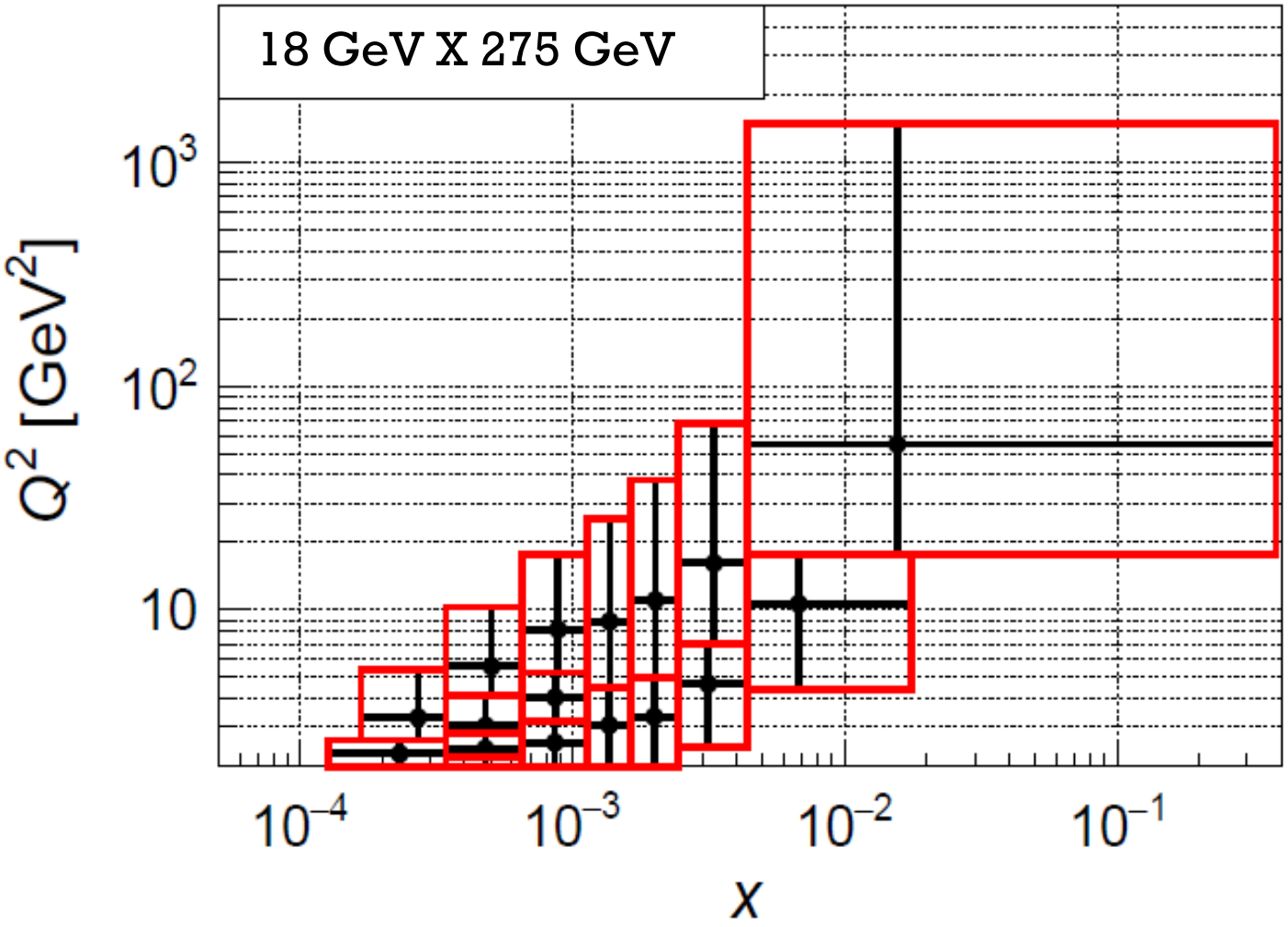




**In general, signal is quite significant in each bin**

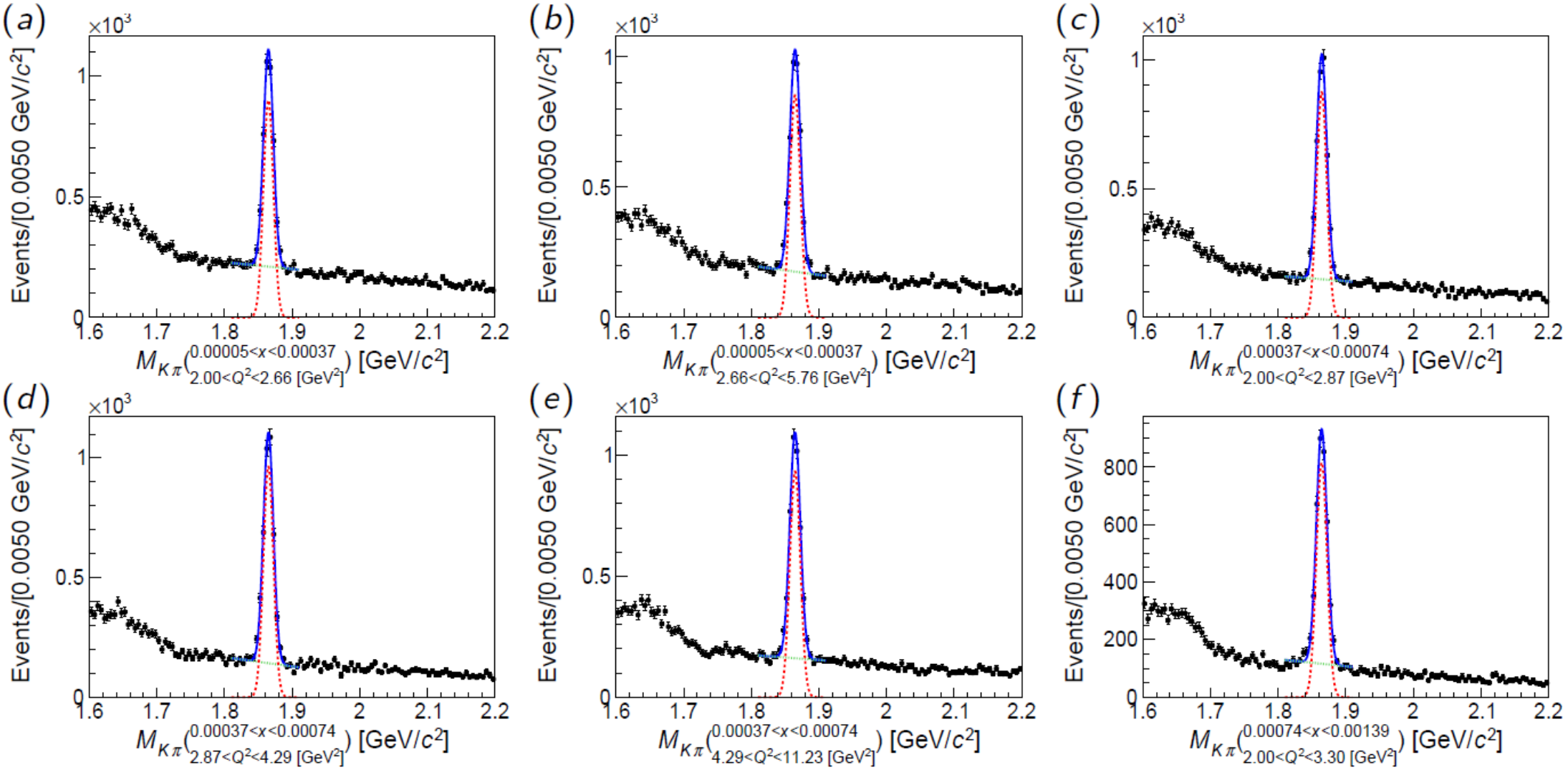
| $\eta$ Region | Detector Matrix ($\mu$m) | LBNL ($\mu$m) |
|---|---|---|
| -3.0< $\eta$ <-2.5 | $30/p_T \oplus 40$ | $30/p_T \oplus 10$ |
| -2.5< $\eta$ <-2.0 | $30/p_T \oplus 20$ | $30/p_T \oplus 10$ |
| -2.0< $\eta$ <-1.0 | $30/p_T \oplus 20$ | $25/p_T \oplus 10$ |
| -1.0< $\eta$ <1.0 | $20/p_T \oplus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

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

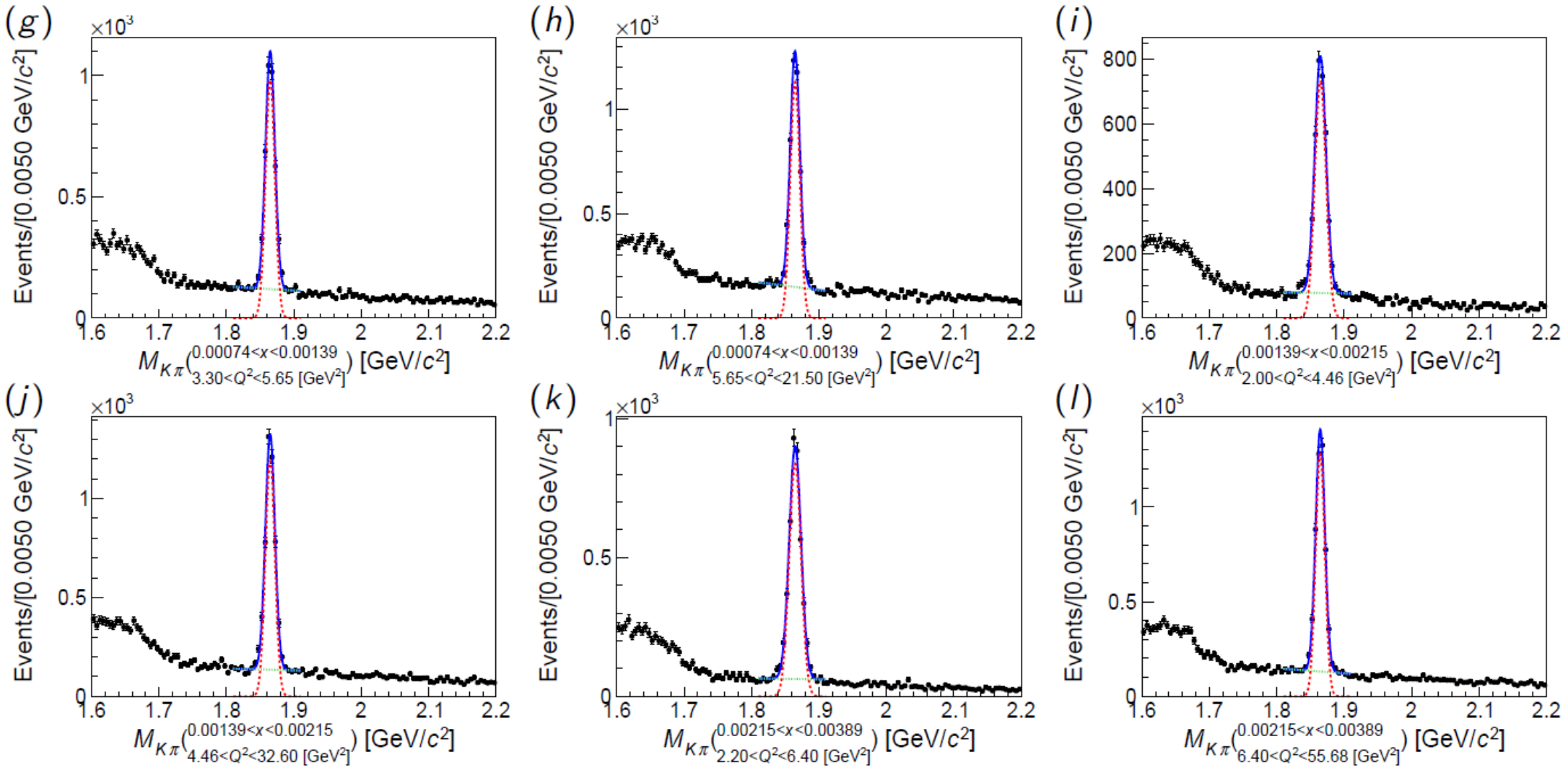
# Binning on x-$Q^2$



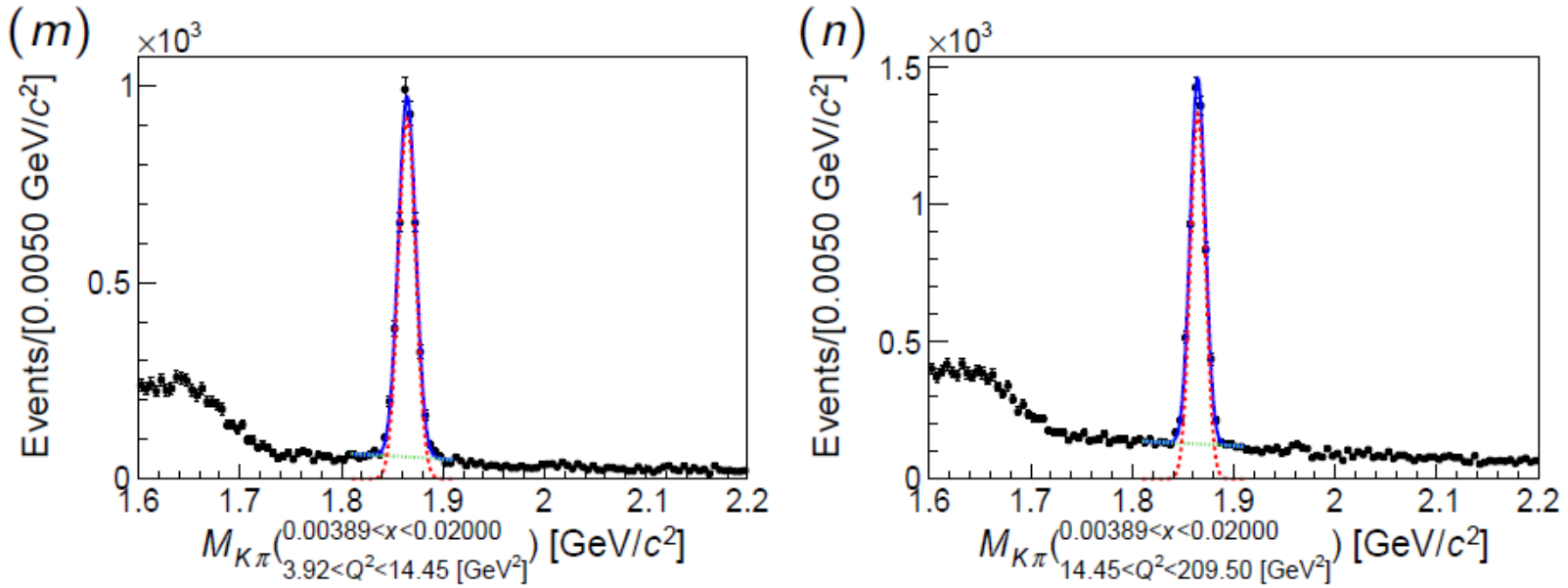
# Events in each bin (18 GeV x 275 GeV)



# Events in each bin (18 GeV x 275 GeV)



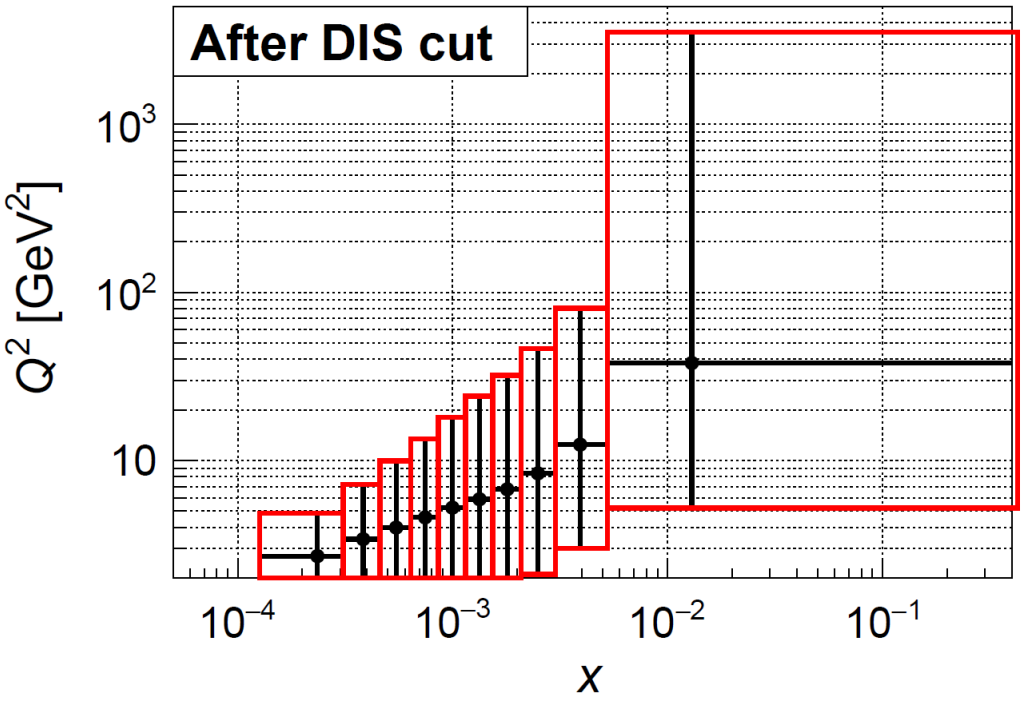
# Events in each bin (18 GeV x 275 GeV)




In general, signal is quite significant in each bin

# 1D bining on Bjorken x

18 GeV x 275 GeV




5 GeV x 100 GeV