Meson Structure Program at EicC (some updates)

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Workshop "Parton Distribution Functions at A Crossroad"
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Motivations

- The pion and kaon are Goldstone bosons, of quite light masses. **Measuring their structures are helpful in checking the Emergent Hadron Mass (EHM) mechanism in Continuum Schwinger Function Methods (CSM)**, and the interplay between EHM and Higgs Boson mechanism. [J. Arrington et al, J. Phys. G: Nucl. Part. Phys. 48 (2021) 075106]

Understand the strong interaction

- **The pion and kaon play the important roles in nuclear physics** as the key nuclear fore carriers.

The most fundamental meson

- **Experimentally, there are TOO few data on the pion and kaon structures** (form factor and structure function). Some Drell-Yan data from CERN & Fermilab decades ago, and the pion form factor data at low Q^2 from JLab and CERN pion-electron scattering. Very scarce data for the kaon structure.

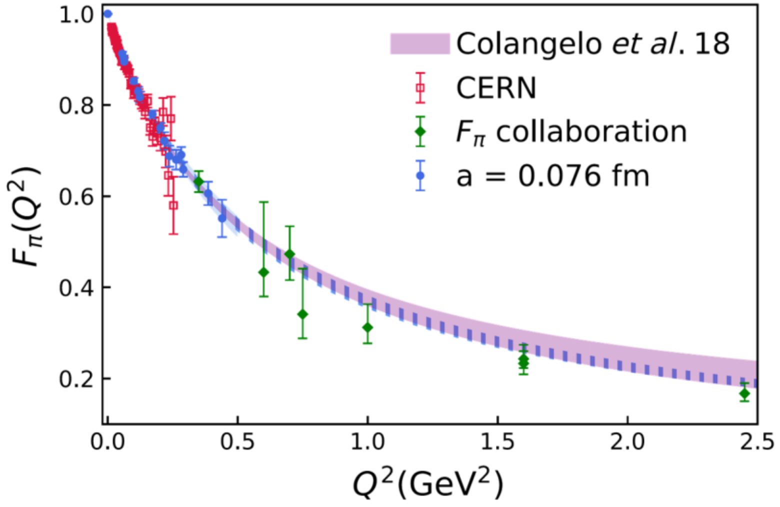
Much fewer data compared to proton

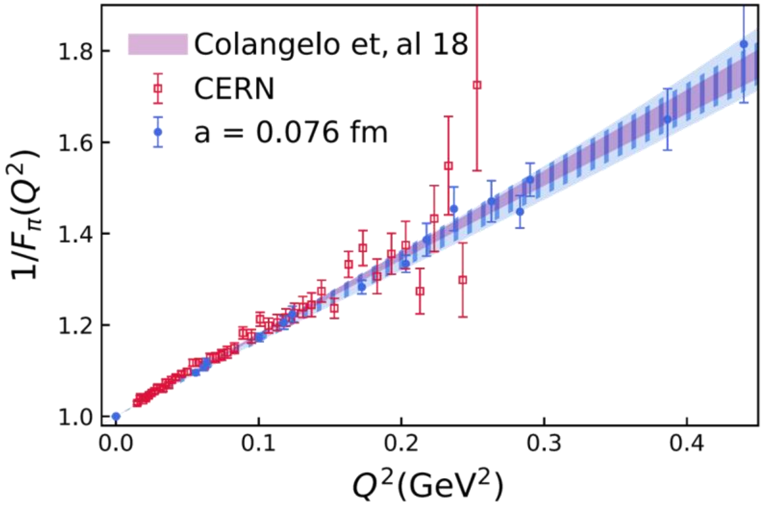
- ……

Motivations

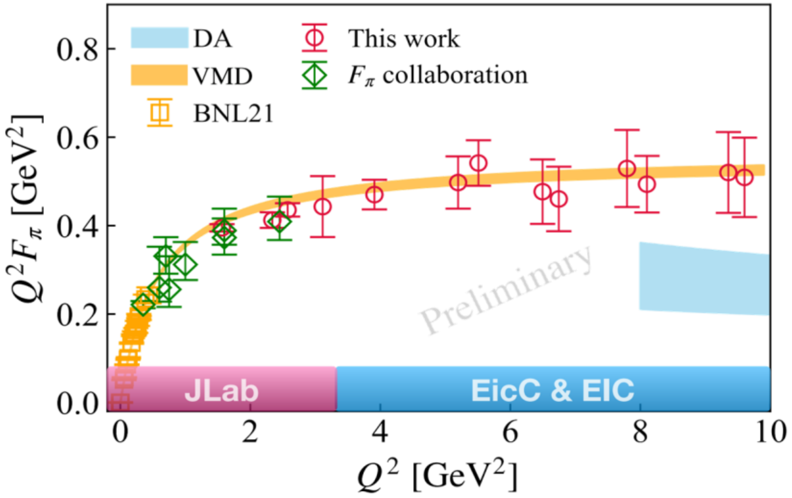
Understanding the internal meson structure and the dynamics in Lattice QCD

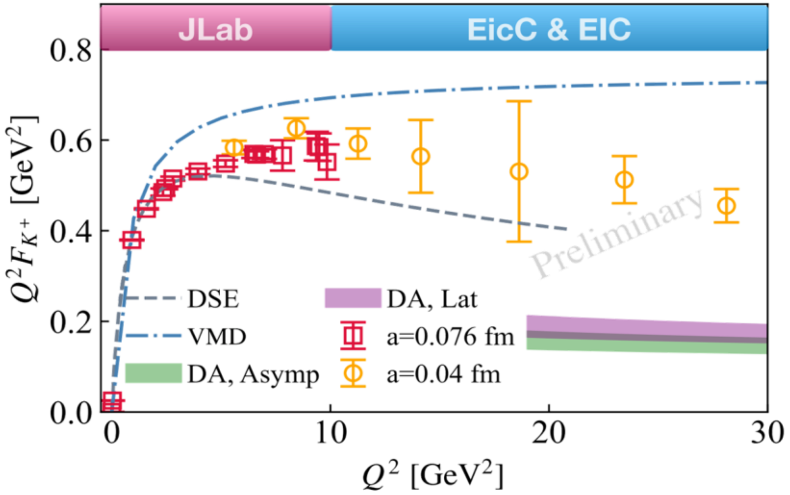
Fast advancement





[X. Gao, et al, Phys. Rev. D 104 (2021) 114515]





From Qi SHI's (**CCNU & BNL**) presentation at Lattice2023.

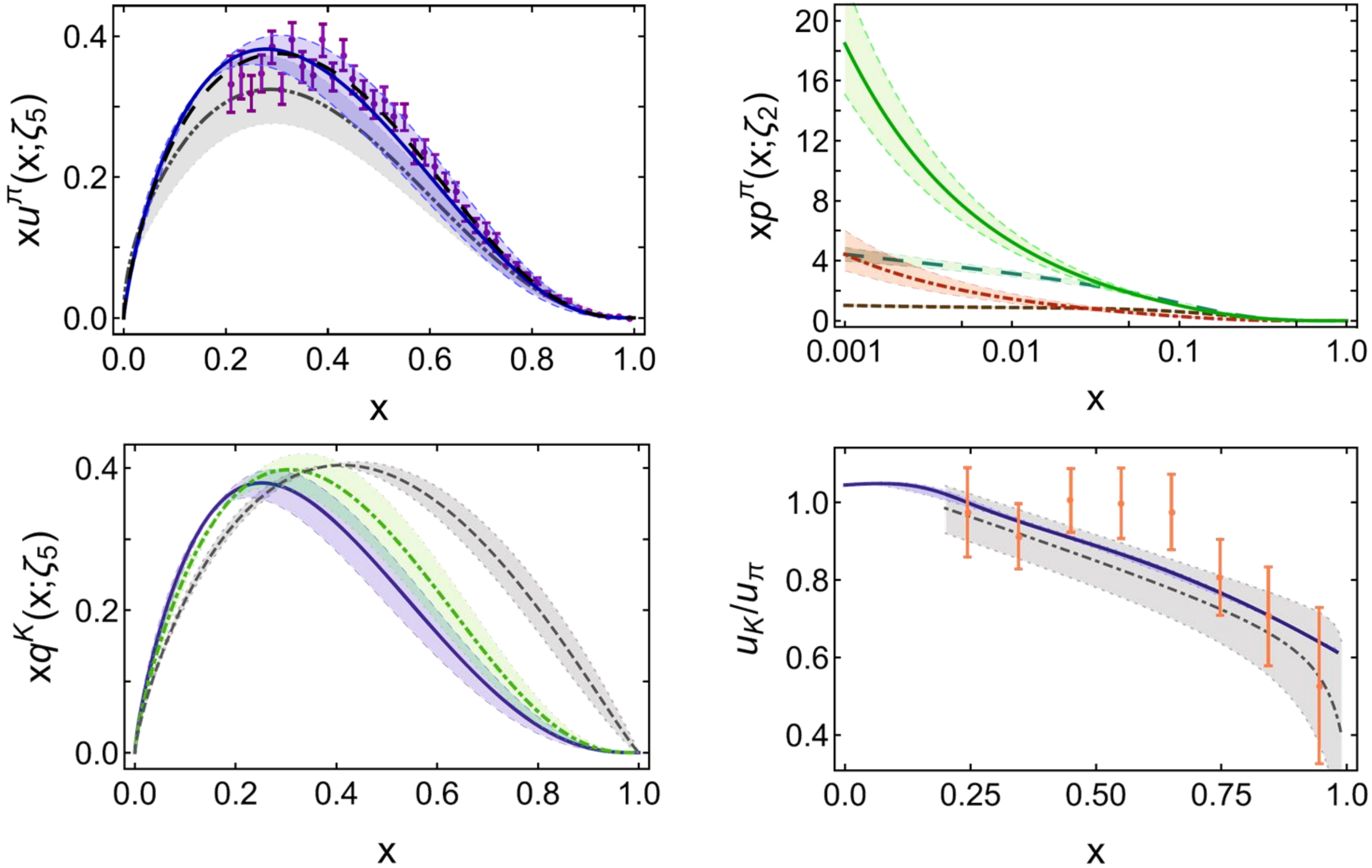
Also **DSE** predictions: [Lei Chang et al, Phys. Rev. Lett. 111 (2013) 141802; Fei Gao et al, Phys. Rev. D 96 (2017) 034024]

Instanton prediction: [E. Shuryak et al, PRD 103 (2021) 054028]

Many other predictions ……

Motivations

Understanding the internal meson structure and the dynamics in DSE/CSM



Fast advancement

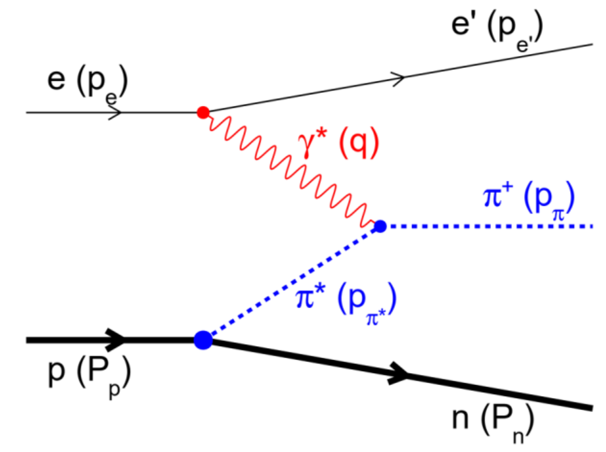
[M. Ding et al, Phys. Rev. D 101 (2020) 054014; Zh.-F. Cui et al, Eur. Phys. J. A 57 (2021) 5; Zh.-F. Cui et al, Eur. Phys. J. C 80 (2020) 1064;T. Nguyen et al, Phys. Rev. C 83 (2011) 062201; Chen Chen et al, Phys.Rev.D 93 (2016) 074021; Chao Shi et al, Phys.Rev.D 98 (2018) 5, 054029]

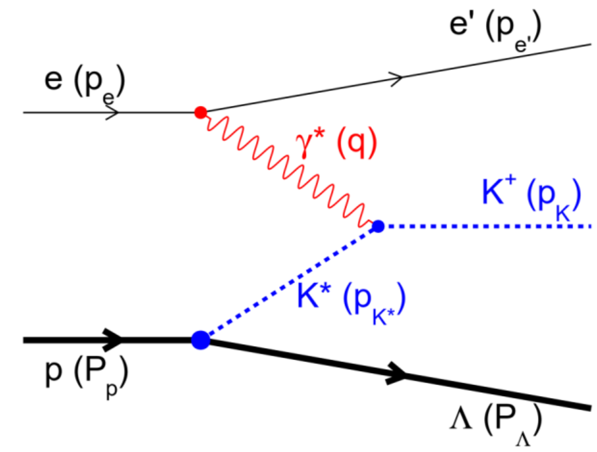
Reviews: [C. D. Roberts et al, Prog. Part. Nucl. Phys. 120 (2021) 103883; J. Arrington et al, J. Phys. G: Nucl. Part. Phys. 48 (2021) 075106]

Also **LQCD** predictions: [X. Gao et al, Phys. Rev. Lett. 128 (2022) 142003; H.-W. Lin et al, Phys. Rev. D 103 (2021) 014516; Z. Fan, H.-W. Lin, Phys. Lett. B 823 (2021) 136778; A. Salas-Chavira et al, Phys. Rev. D 106 (2022) 094510]**……**

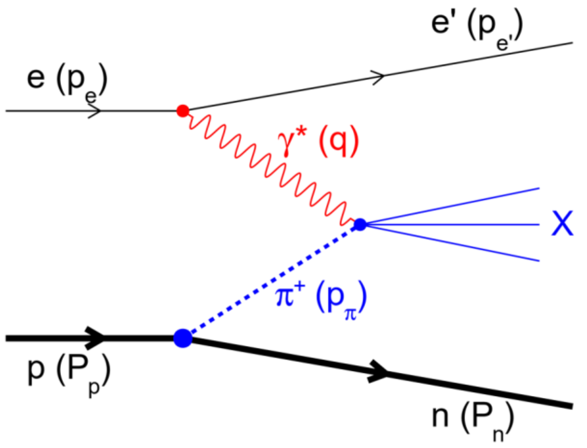
Sullivan Process and Event Generator

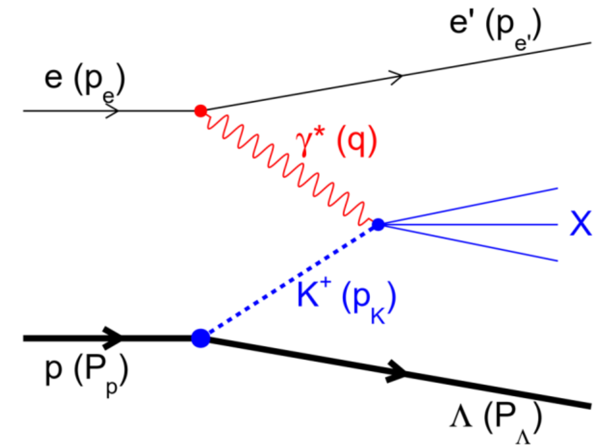
Sullivan processes at small t (<0.6/0.9 GeV2) is sensitive to pion and kaon structures.





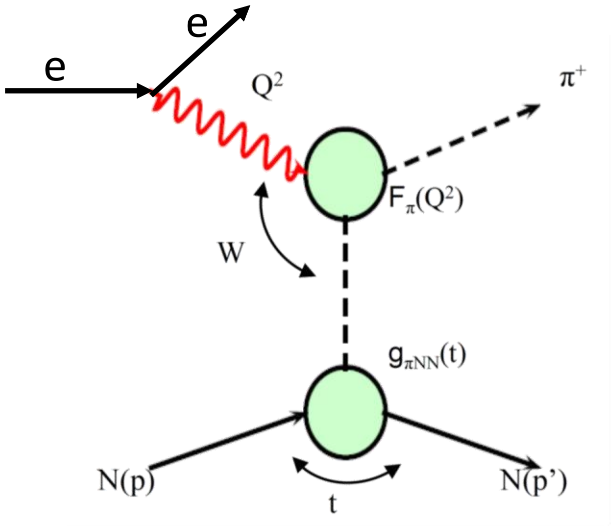
Exclusive processes for meson form factor measurements.





Leading baryon semi-inclusive deep inelastic scattering processes for meson structure measurements.

Sullivan Process and Event Generator



Pion form factor measurement

To write an event generator and to estimate the statistics, we adapt the π-pole model for the differential cross-section:

$$\frac{d^3\sigma}{dQ^2 dx_B dt} = \Gamma(Q^2, x_B, s)\left[\frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt}\right]$$

$$\Gamma(Q^2, x_B, s) = \frac{\alpha y^2 (1-x_B)}{2\pi x_B (1-\epsilon) Q^2}$$

$$\epsilon = \frac{1 - y - \frac{Q^2}{4E^2}}{1 - y + \frac{y^2}{2} + \frac{Q^2}{4E^4}}$$

$$N\frac{d\sigma_L}{dt} = 4\hbar c (e g_{\pi NN}(t))^2 \frac{-t}{(t-m_\pi^2)^2} Q^2 F_\pi^2(Q^2)$$

Pion pole and pion form factor

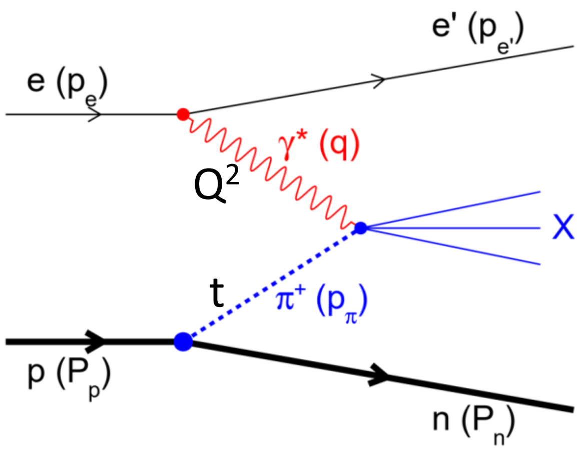
$$N = 32\pi (W^2 - m_p^2)\sqrt{(W^2 - m_p^2)^2 + Q^4 + 2Q^2(W^2 + m_p^2)}$$

$$g_{\pi NN}(t) = g_{\pi NN}(m_\pi^2)\left(\frac{\Lambda_\pi^2 - m_\pi^2}{\Lambda_\pi^2 - t}\right)$$

$$F_\pi(Q^2) = \frac{1}{1 + Q^2/\Lambda_\pi^2}$$

Comparisons to EIC generator is made by Weizhi. The event distributions show a little difference while the phase-space shapes are the same.

Sullivan Process and Event Generator



leading neutron of large rapidity

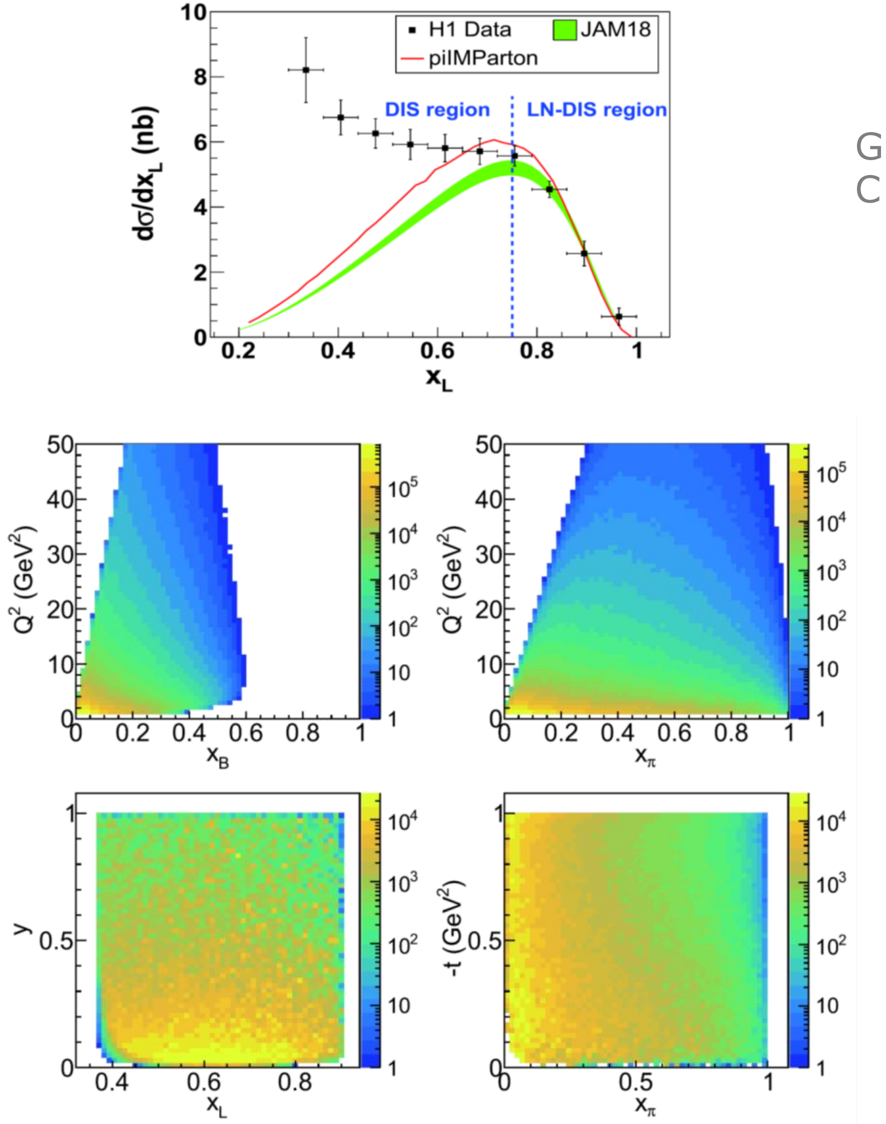
$$Q^2 \equiv -q^2, \quad x_B \equiv \frac{Q^2}{2P_p \cdot q}, \quad y \equiv \frac{P_p \cdot q}{P_p \cdot P_e}$$

$$x_L \equiv \frac{P_n \cdot q}{P_p \cdot q}, \; t \equiv (P_p - P_n)^2 = p_{\pi^*}^2 \quad x_\pi \equiv \frac{Q^2}{2p_\pi \cdot q} = \frac{x_B}{1-x_L}$$

$$\frac{d^4\sigma(ep \to enX)}{dx_B dQ^2 dx_L dt} = \frac{4\pi\alpha^2}{x_B Q^4}\left(1 - y + \frac{y^2}{2}\right) F_2^{LN(4)}(Q^2, x_B, x_L, t)$$

$$= \frac{4\pi\alpha^2}{x_B Q^4}\left(1 - y + \frac{y^2}{2}\right) F_2^{\pi}\left(\frac{x_B}{1-x_L}, Q^2\right) f_{\pi^+/p}(x_L, t)$$

pion SF **pion flux**

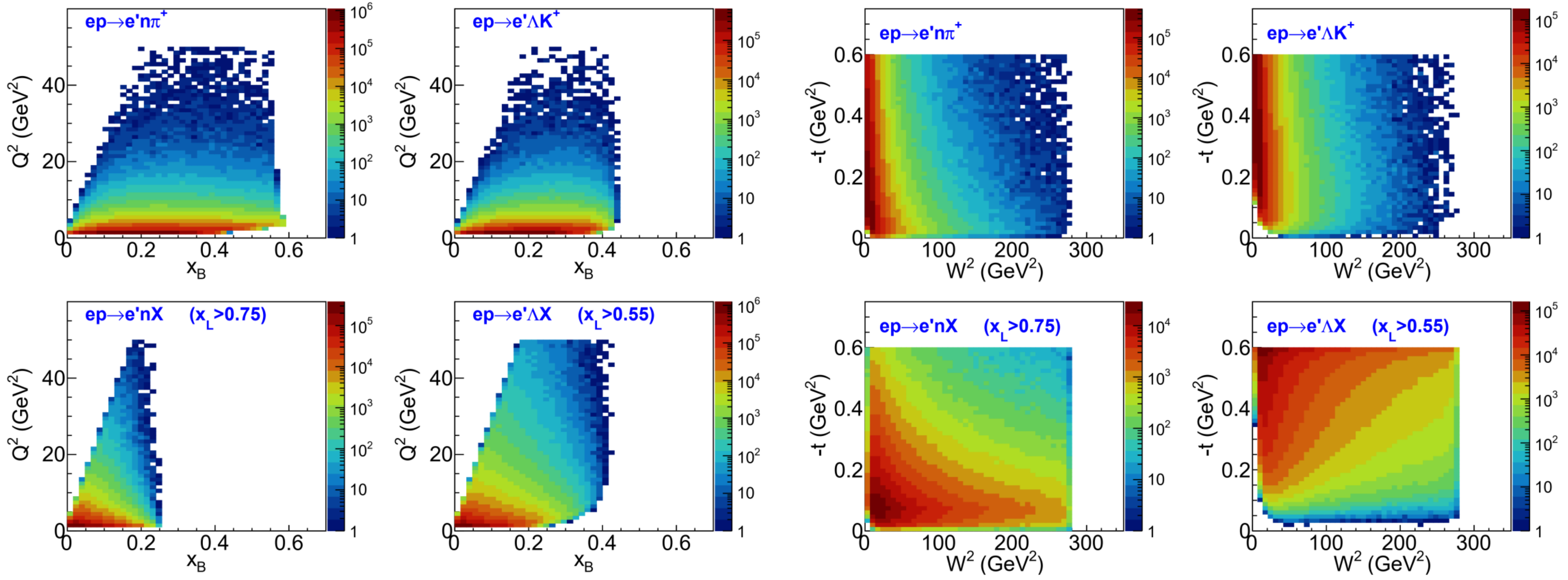


G. Xie et al., Chin. Phys. C 45, 053002 (2021)

Comparisons to EIC generator (RAPGAP) is made by Jixie. The cross sections and event distributions are very similar.

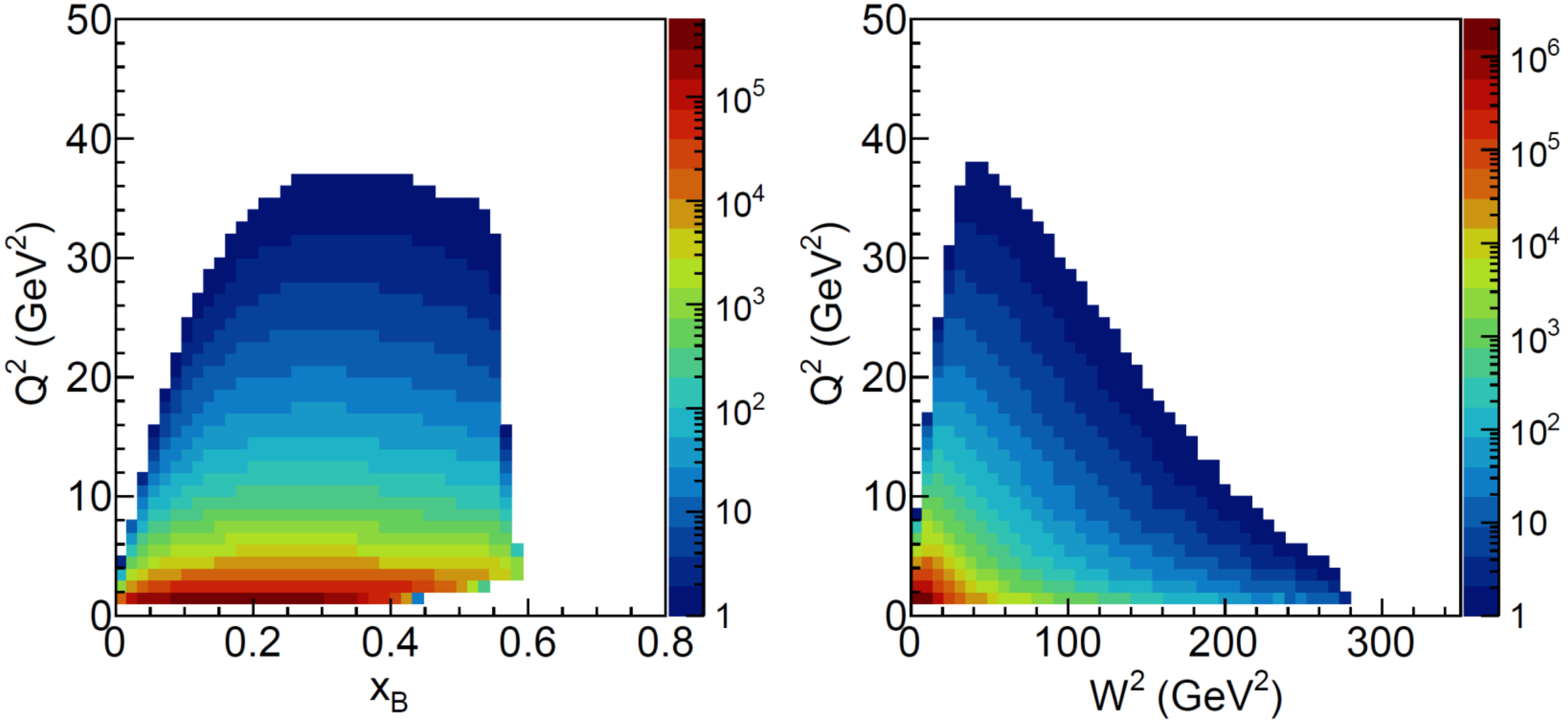
Sullivan Process and Event Generator

Distributions of the invariant kinematics Q^2, x_B, t, W^2 in the region of interests for various kinds of Sullivan processes.



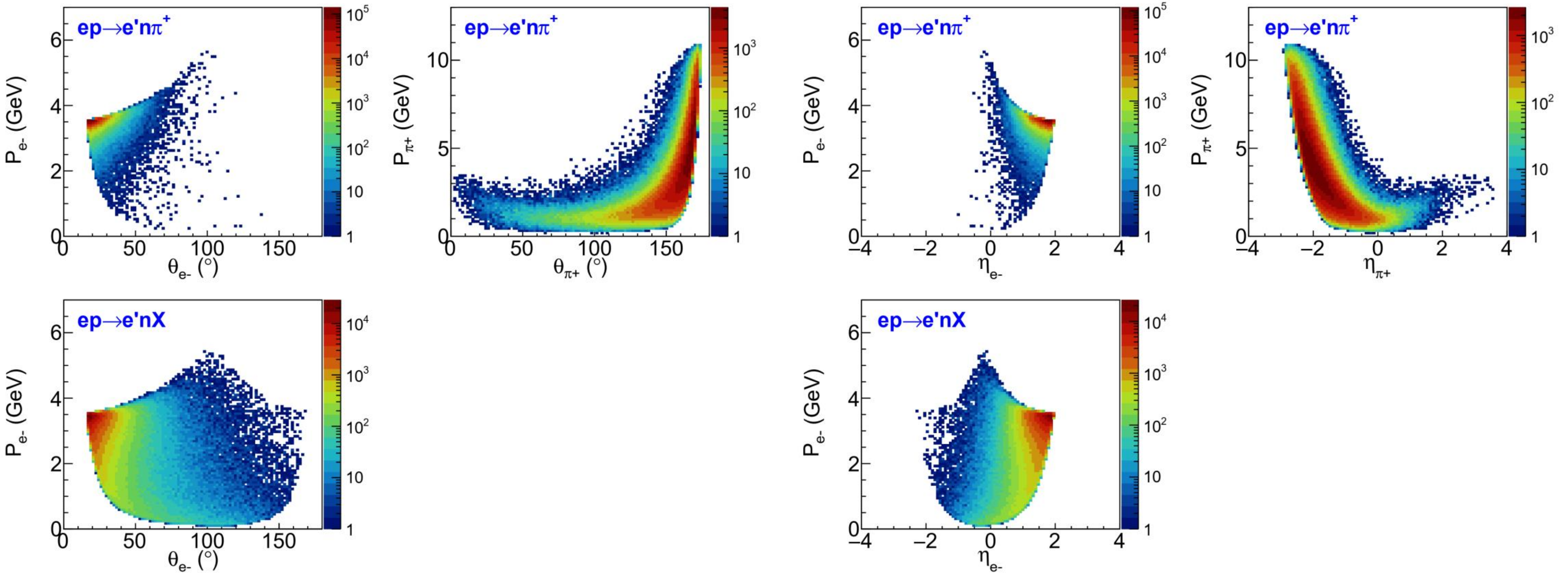
Pion FF Experiment at EicC

Cross-section weighted distributions of the invariant kinematics




```
PionExculsiveElectroproduction demp_pion;
demp_pion.SetQ2max(50);
demp_pion.SetQ2min(1);
demp_pion.SetxBmax(0.8);
demp_pion.SetxBmin(0.001);
demp_pion.SetTmax(0.6);
demp_pion.SetTmin(0.01);
```

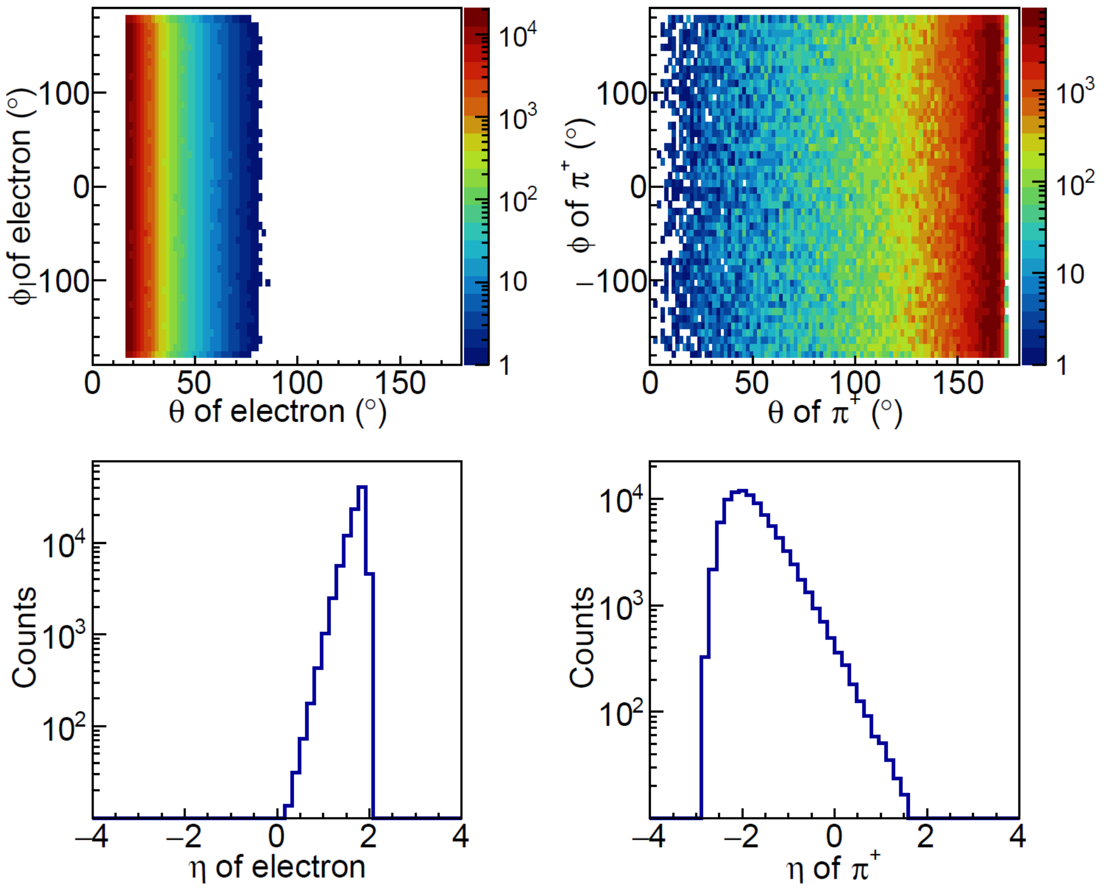
Pion FF Experiment at EicC



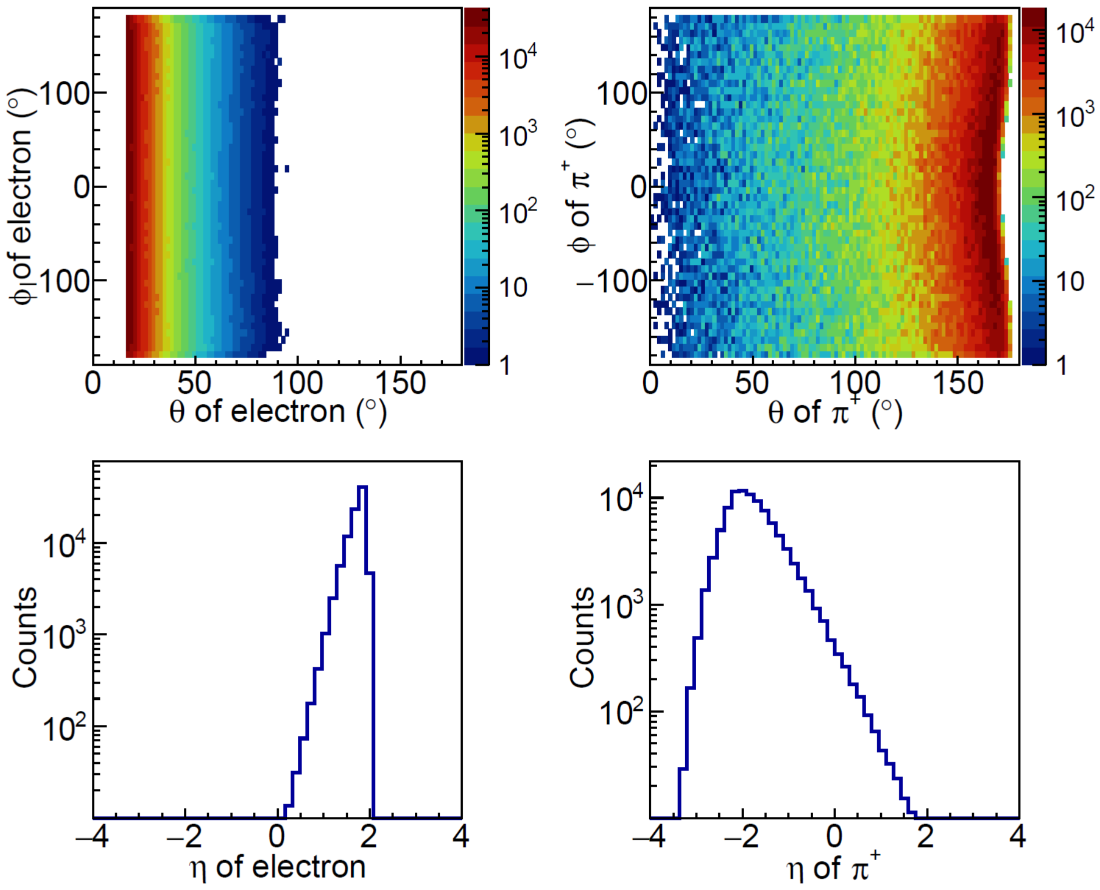
Pion FF Experiment at EicC

Cross-section weighted kinematical distributions of the final electron and pion

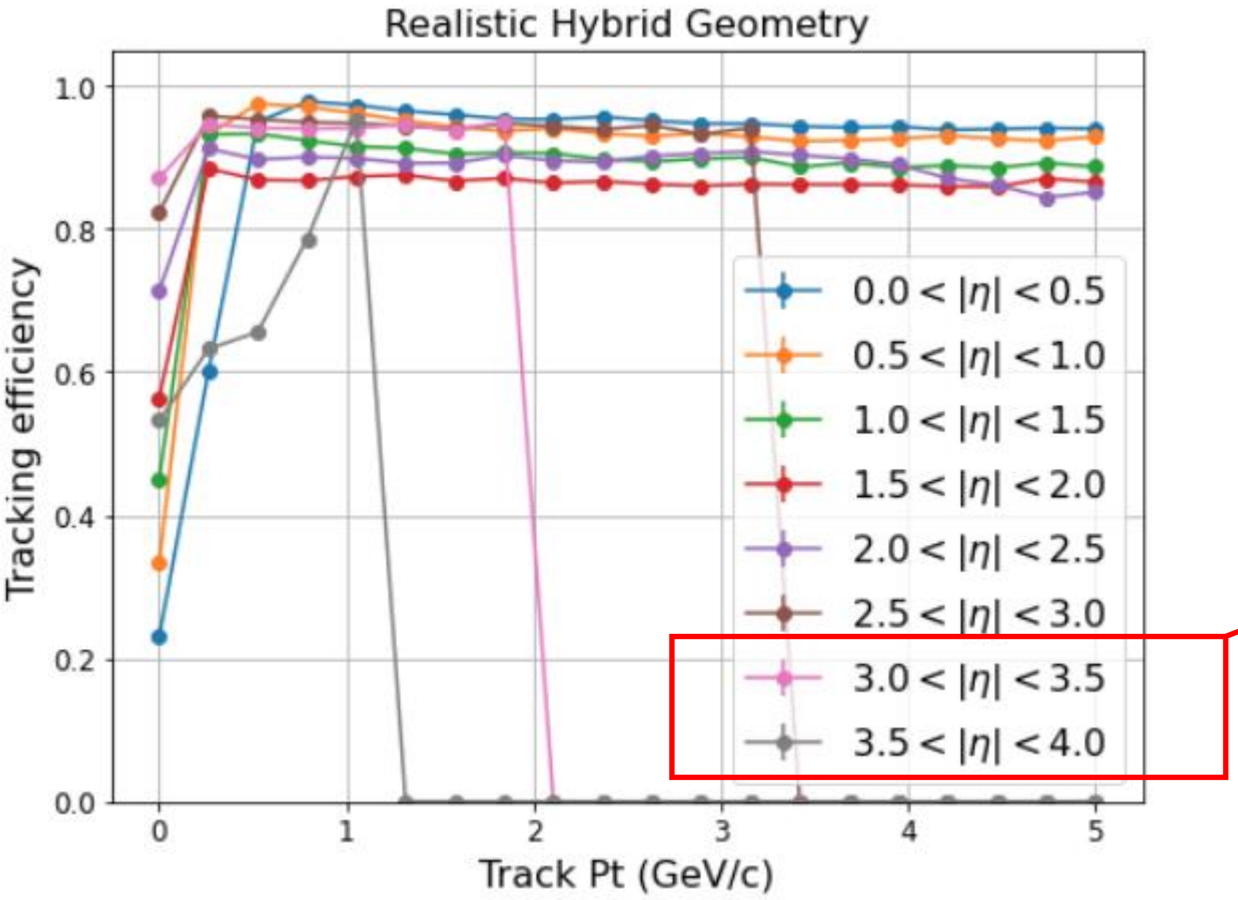
No beam crossing



Beam crossing angle 50 mrad



Pion FF Experiment at EicC

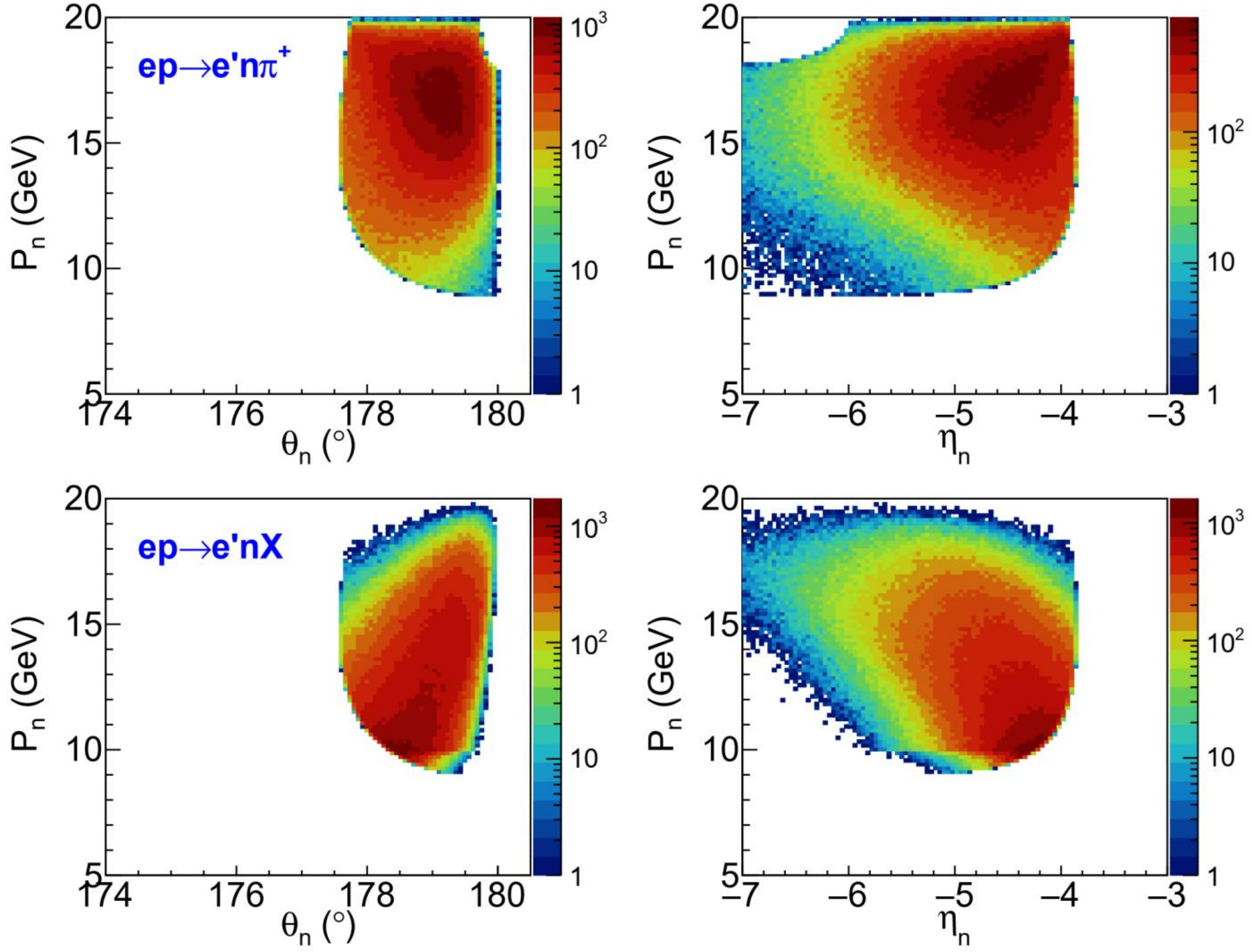


The left plot shows the efficiencies of the central tracking system at different pseudo rapidity's, which is taken from the tracking R&D group.

It is important to collect the π^- from the charged decay of forward Lambda baryon.

Pion FF Experiment at EicC

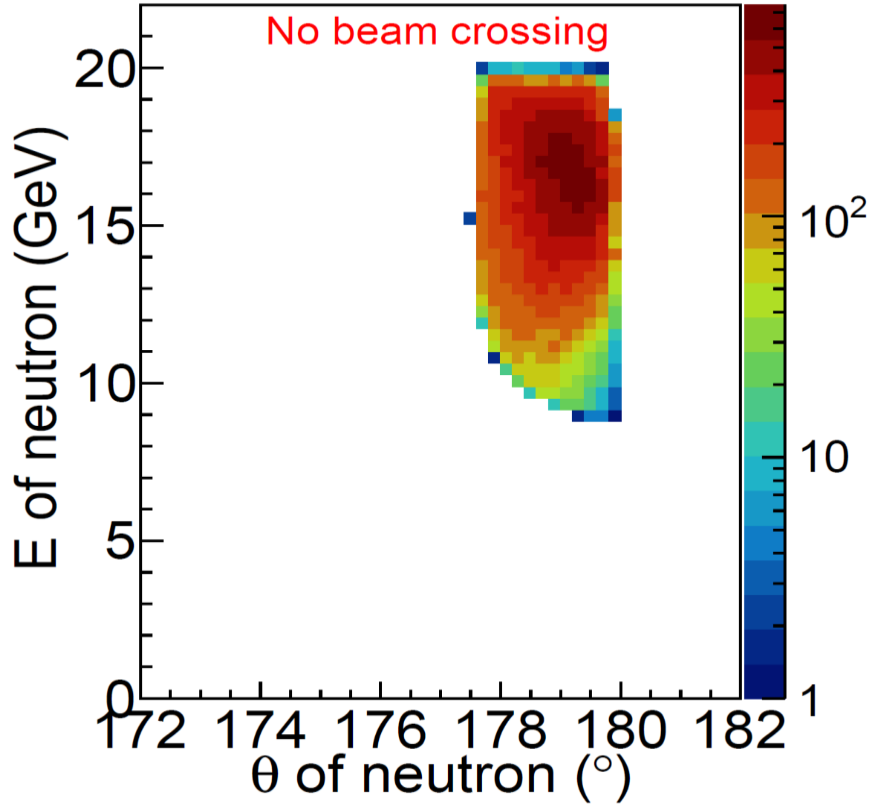
No beam crossing

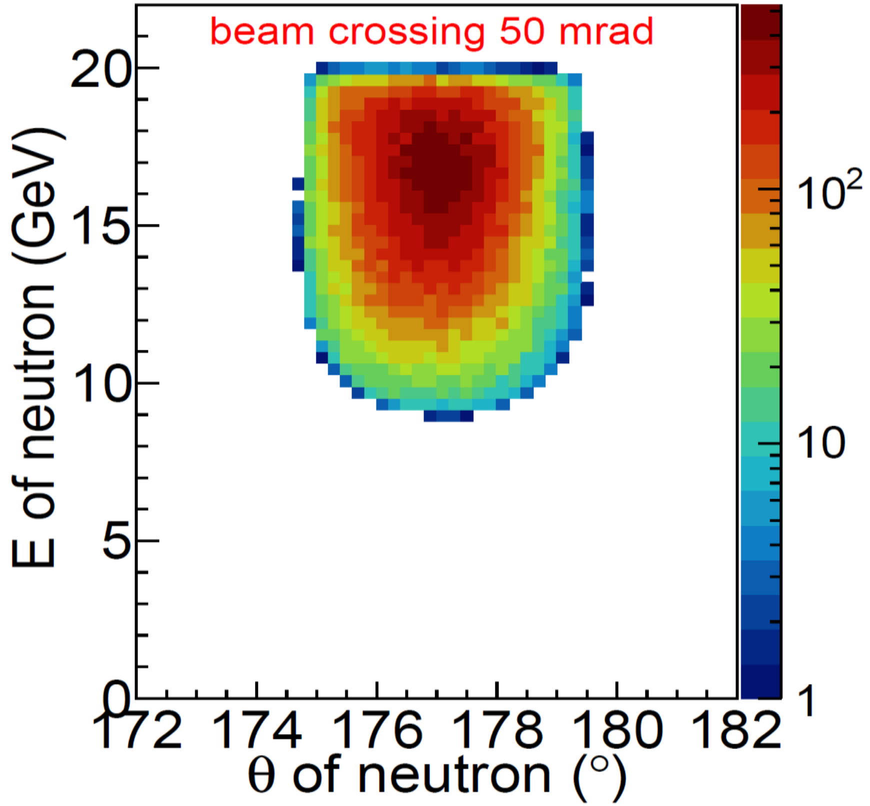


In pion form factor experiment, the forward neutrons have higher energies and smaller scattering angles, comparing to the pion structure function experiments.

Pion FF Experiment at EicC

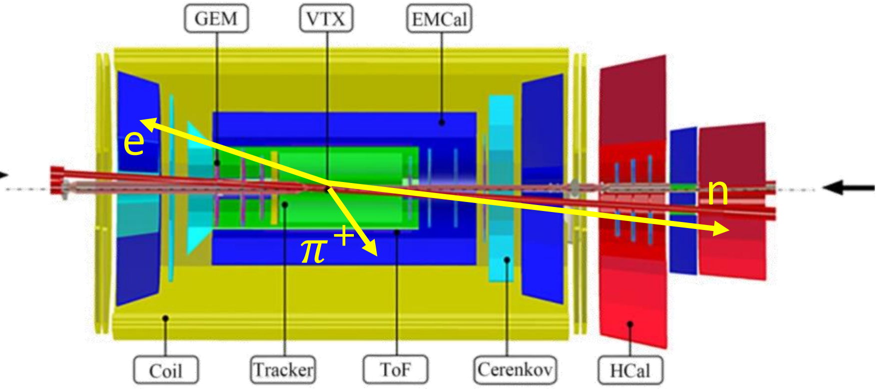
Cross-section weighted kinematical distributions of the final neutron





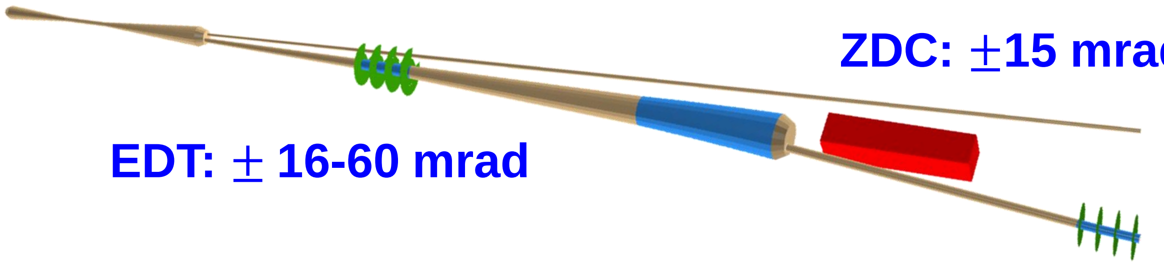
Pion FF Experiment at EicC

20 GeV
Proton beam



3.5 GeV
Electron beam

Int. luminosity 50 fb^{-1}



$35\%/\sqrt{E/\mathrm{GeV}}$ 1 cm resolution

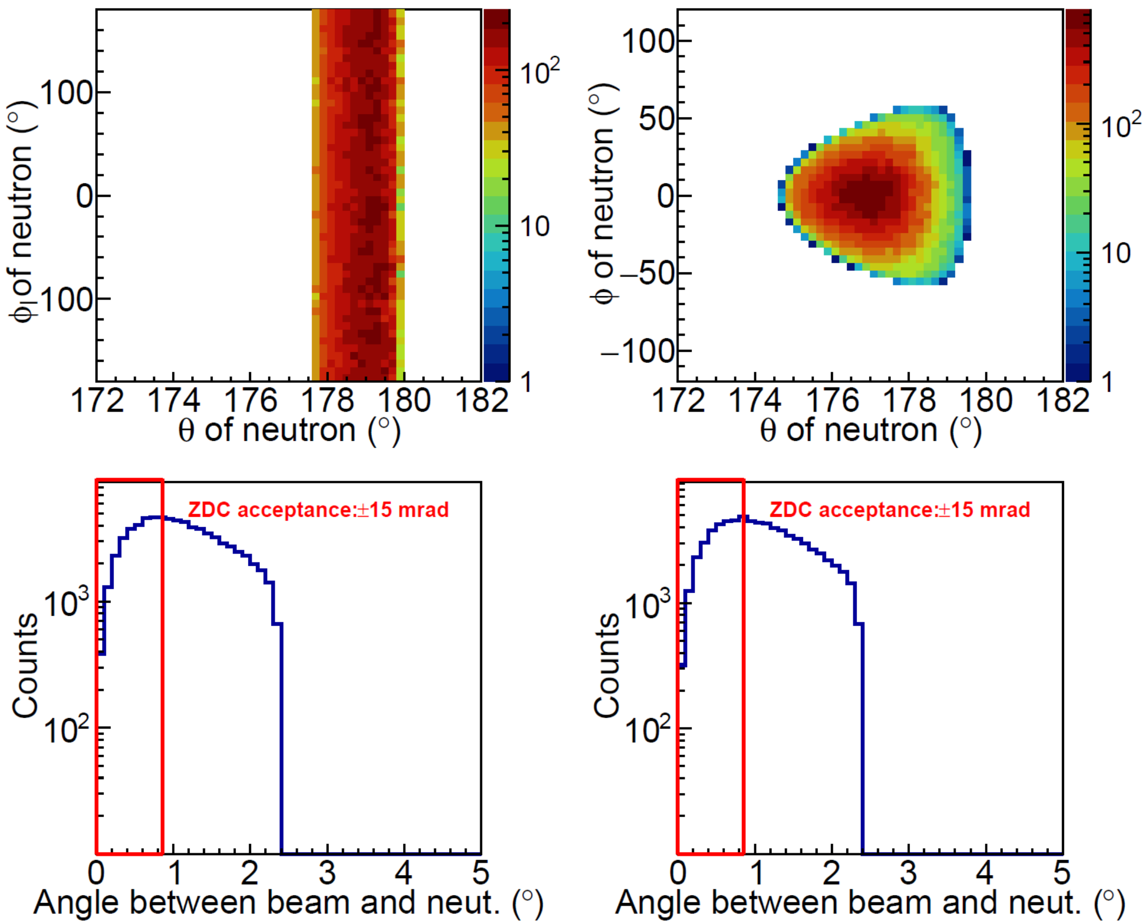
t的相对误差19%左右。

The final-state electron and pion go to the central rapidity region due to the elastic scattering between the electron and the "pion cloud". Neutron as a spectator goes to the small angle very close to the proton beam.

Forward neutron detector is needed!

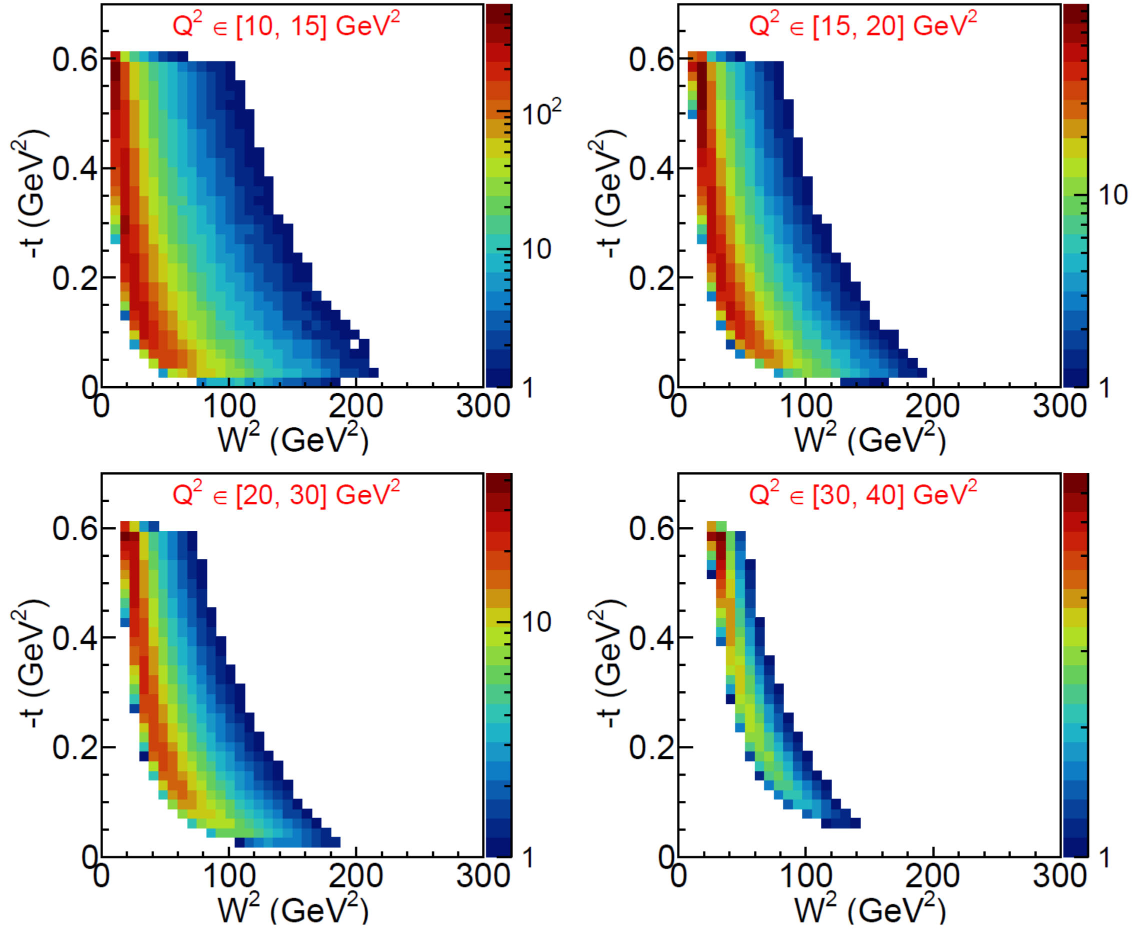
Pion FF Experiment at EicC

Cross-section weighted kinematical distributions of the final neutron

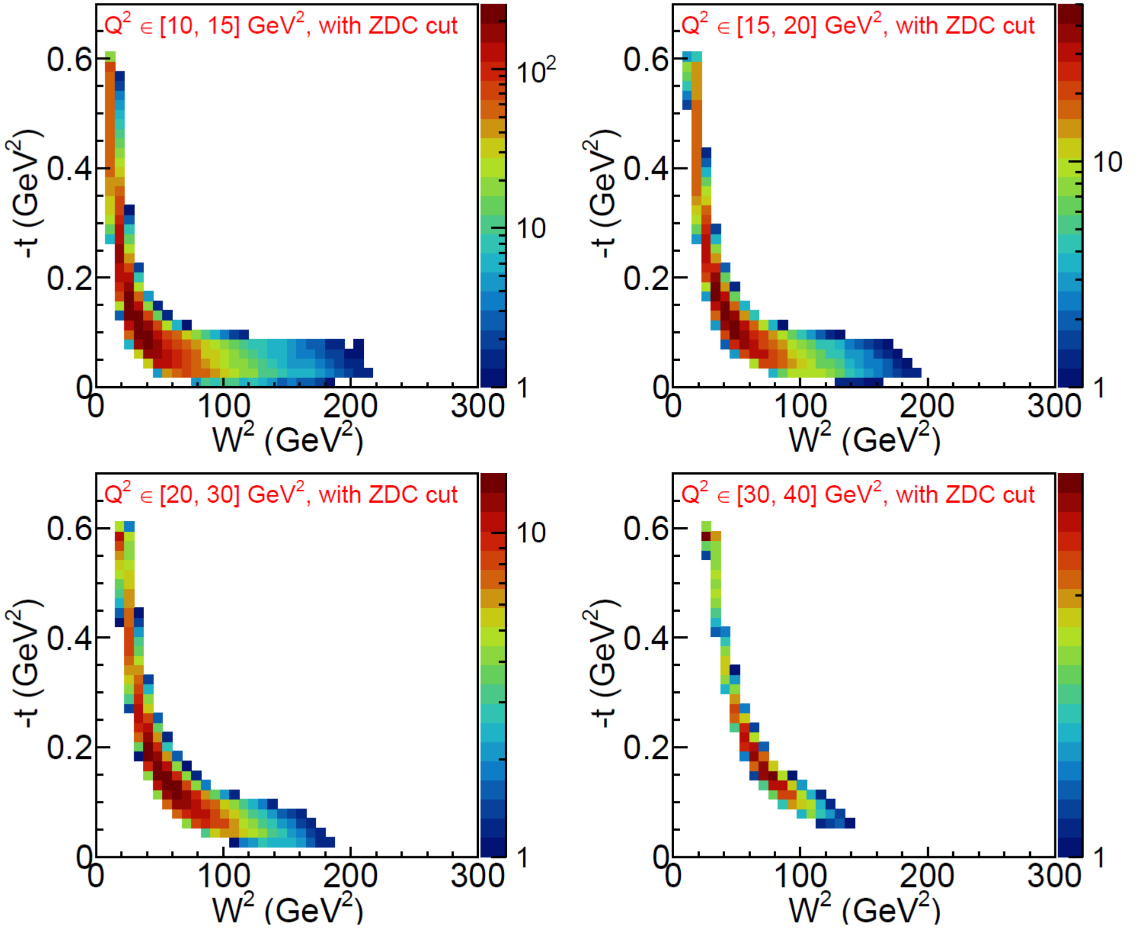


Pion FF Experiment at EicC

Without ZDC cut



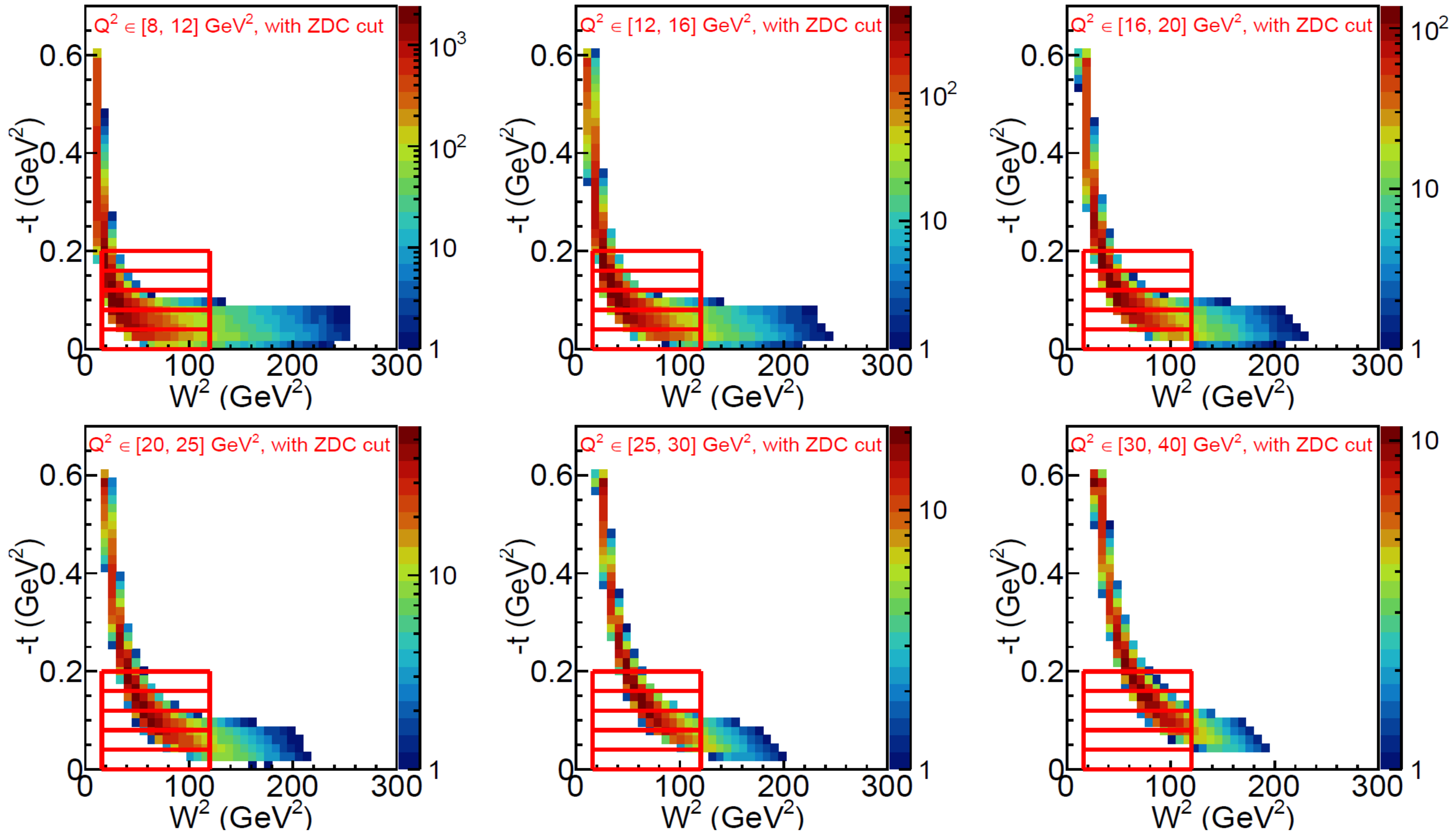
With ZDC cut



Pion FF Experiment at EicC

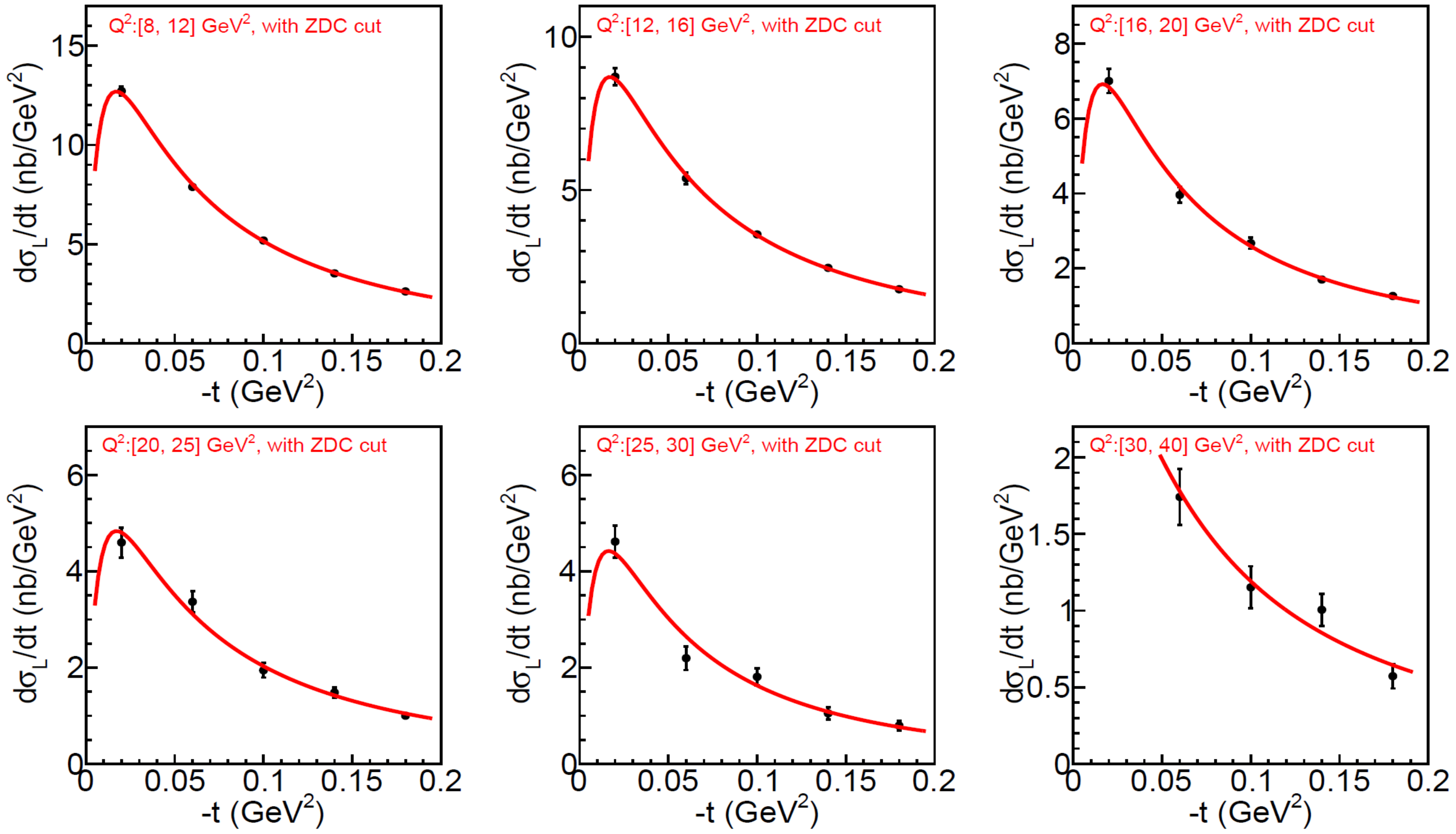
Binning and stat. error estimation

$$N_{\rm i} = \epsilon L \overline{\sigma}_{\rm i} \Delta Q^2 \Delta t \Delta W^2 \frac{\partial x_{\rm B}}{\partial W^2}$$



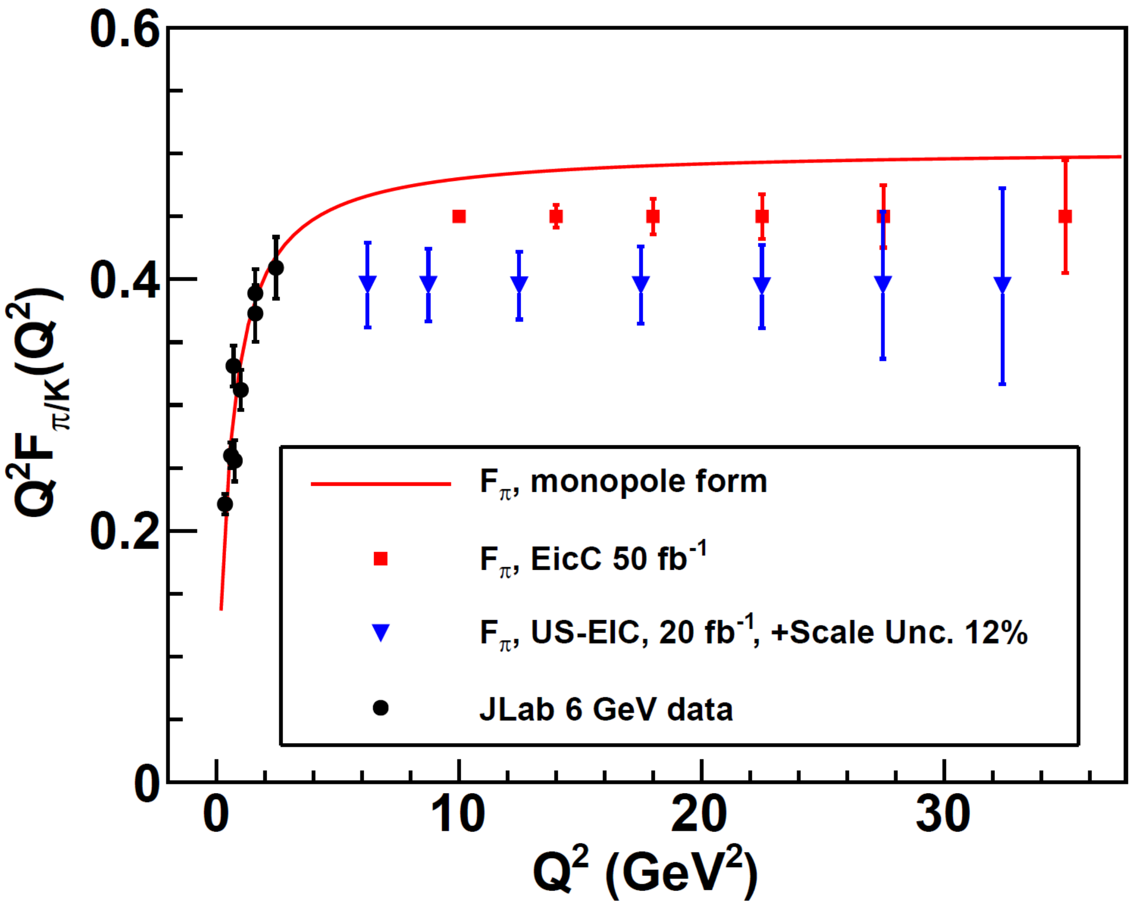
Pion FF Experiment at EicC

Pion Form Factor is extracted from the model-dependent fits of longitudinal cross section.

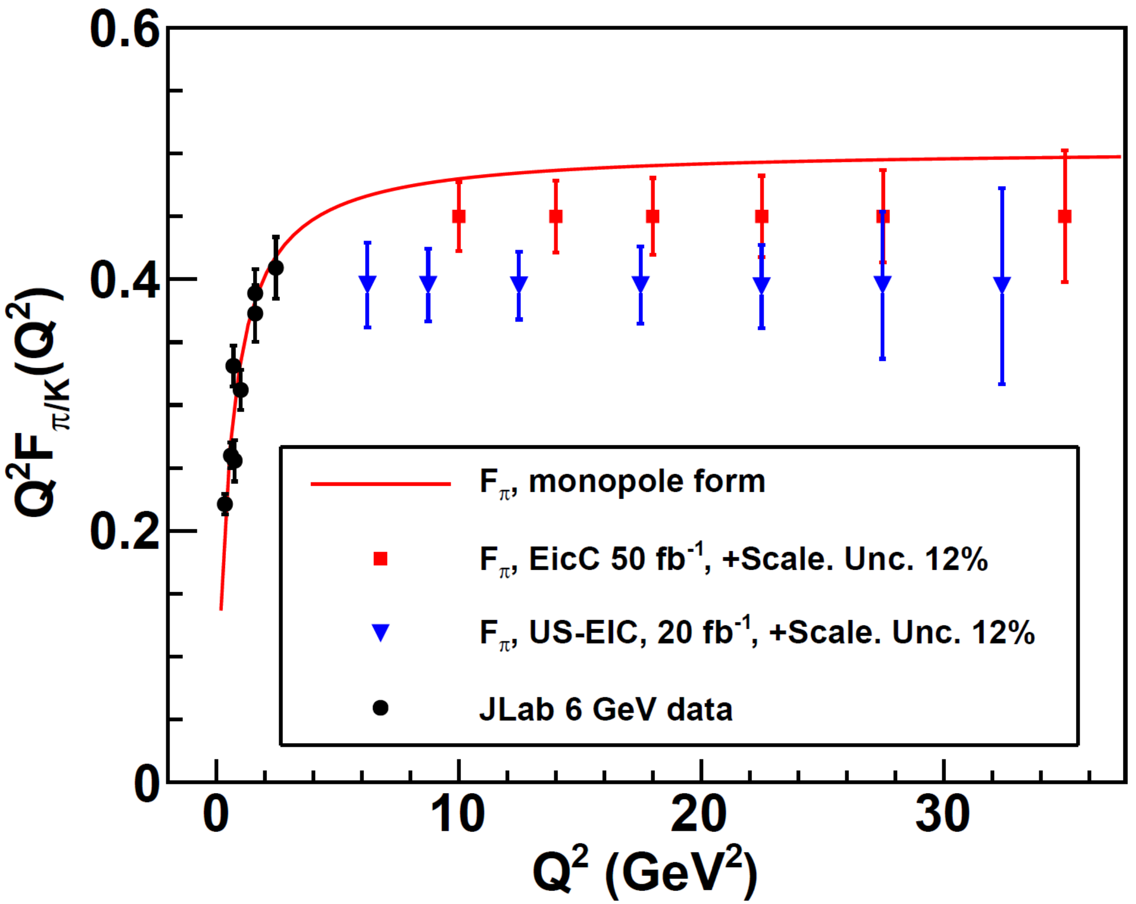


Pion FF Experiment at EicC

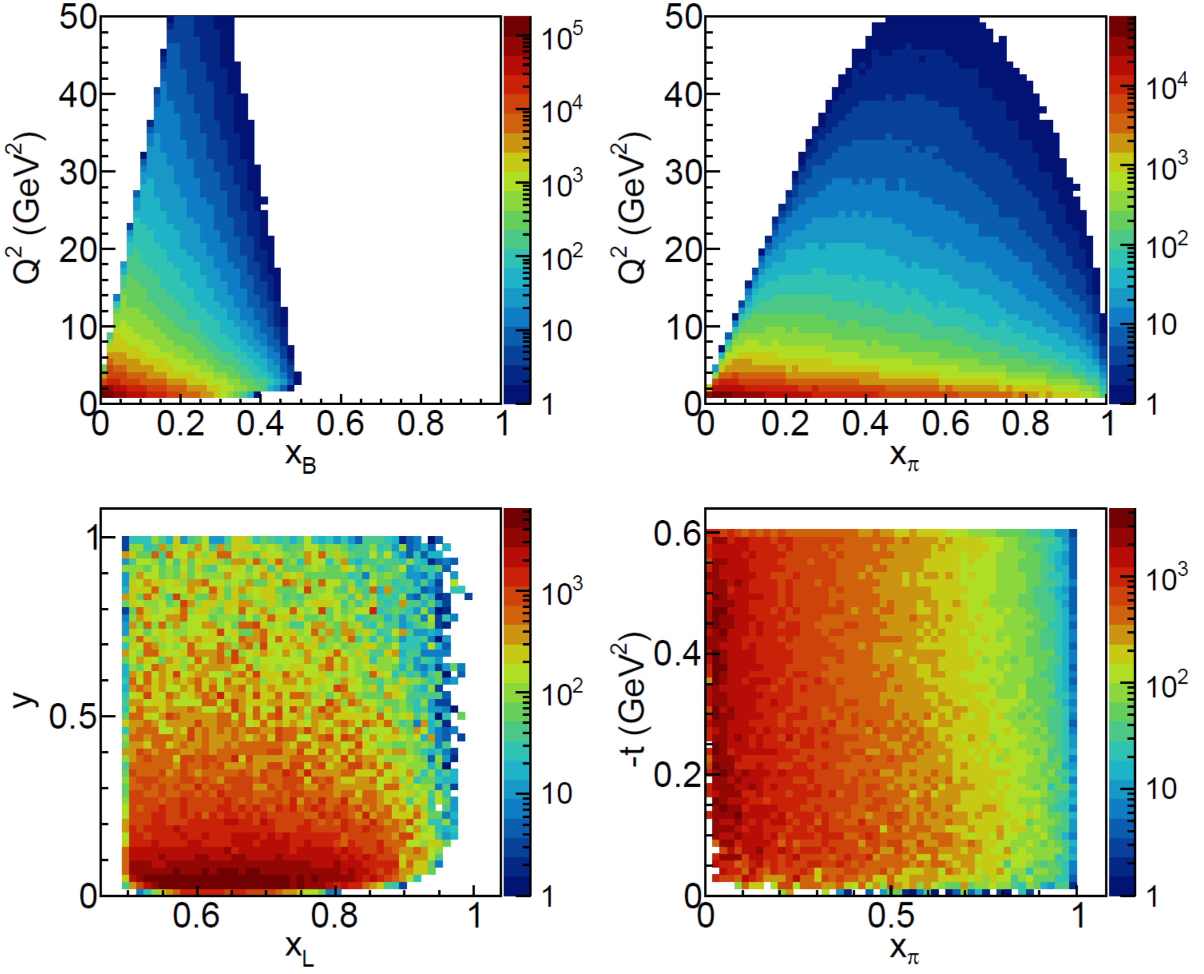
Stat. error only



Stat. error plus some sys. error



Pion SF Experiment at EicC



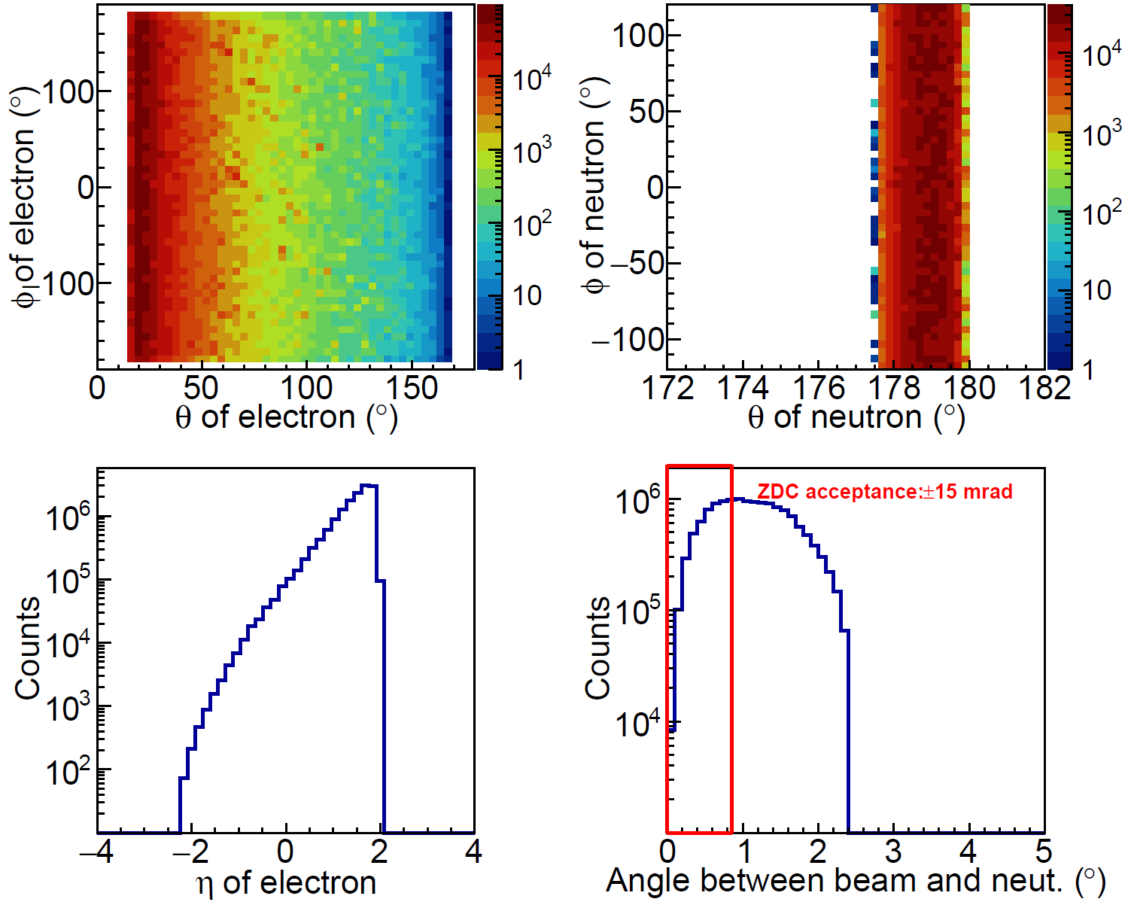
Cross-section weighted distributions of the invariant kinematics

```
TaggedN_DIS dis;
dis.SetQ2max(50);
dis.SetQ2min(1);
dis.SetxBmax(0.8);
dis.SetxBmin(0.001);
dis.SetTmax(0.6);
dis.SetTmin(0.01);
dis.SetxLmax(0.995);
dis.SetxLmin(0.5);
```

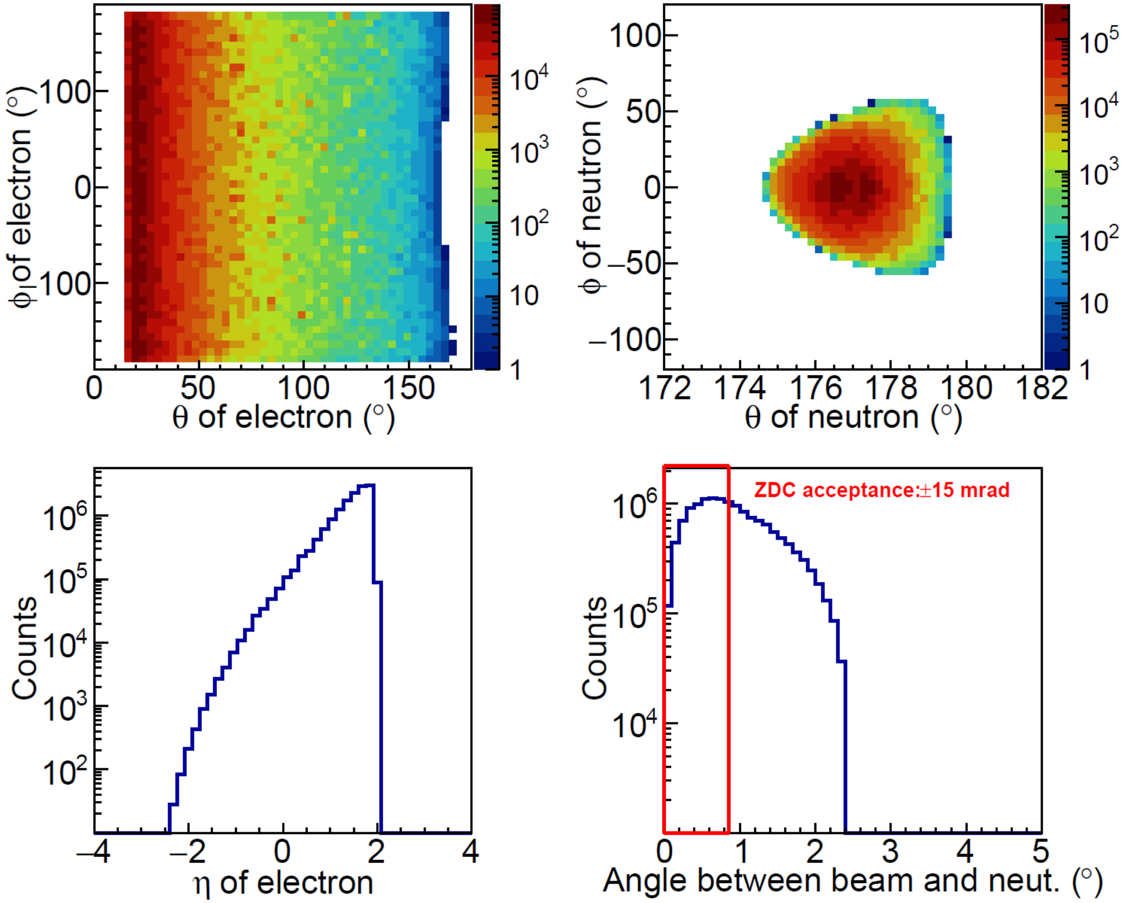
Pion SF Experiment at EicC

Cross-section weighted kinematical distributions of the final electron and neutron

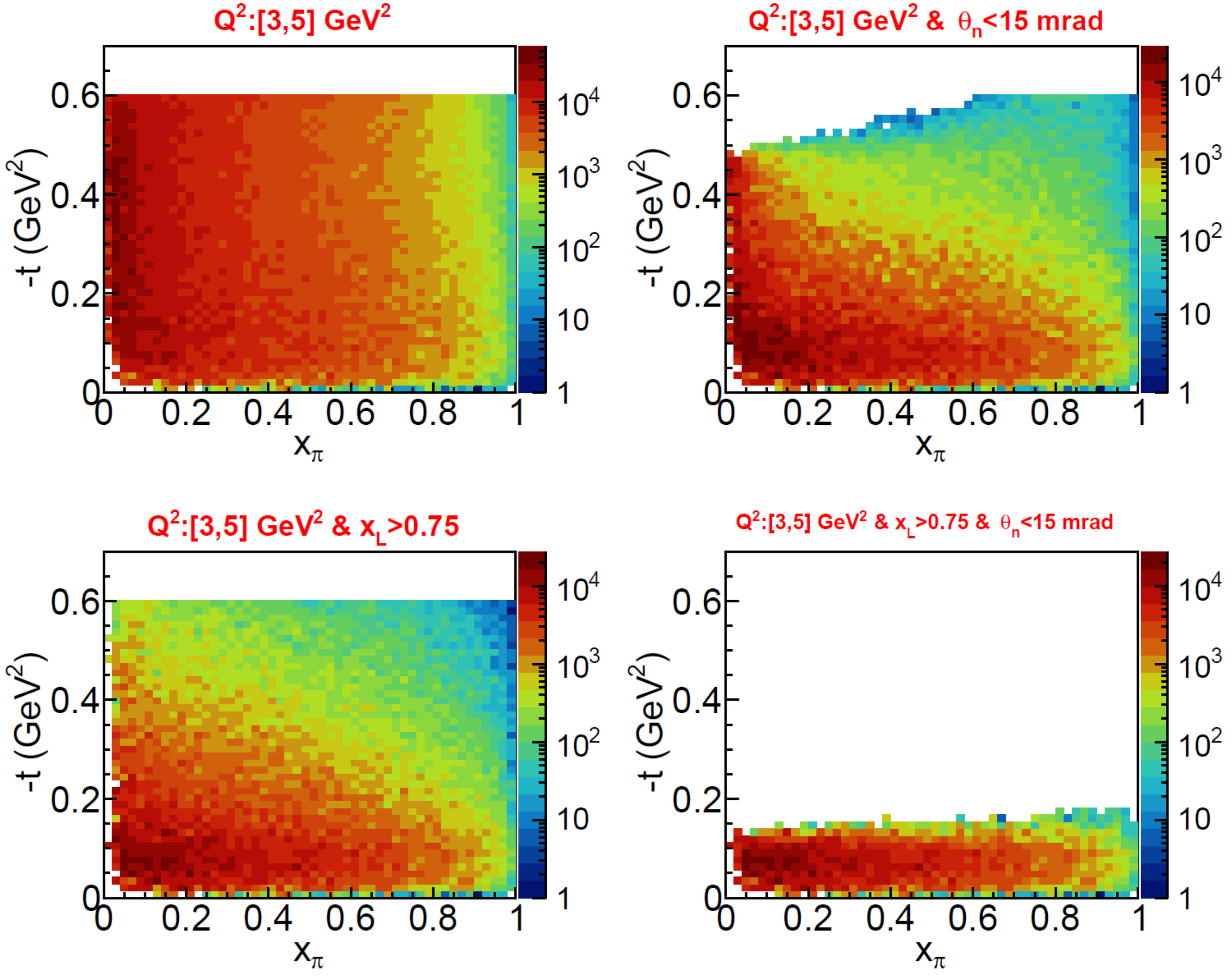
No beam crossing



Beam crossing angle 50 mrad



Pion SF Experiment at EicC



ZDC cut: $\theta_n < 15$ mrad
Leading-neutron Cut (picking up high energy neutron): $x_L > 0.75$

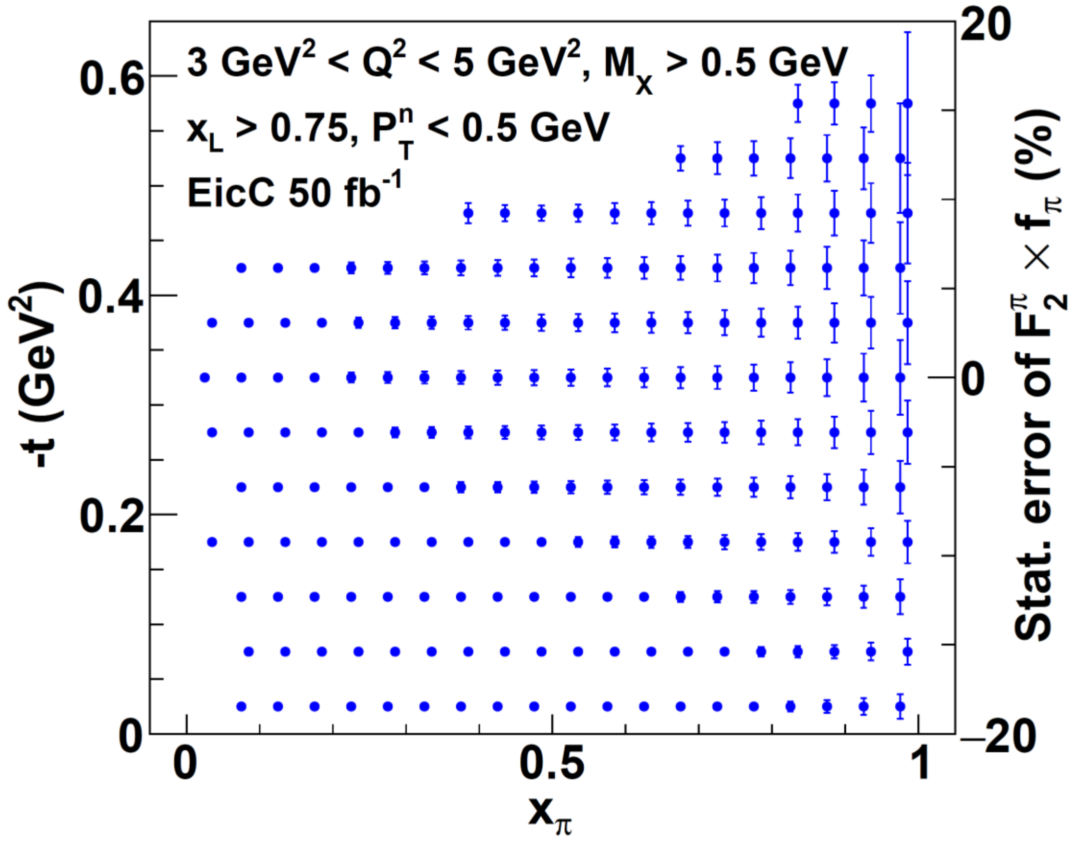
The combination of the above strict cuts reduces t-range significantly.

Pion SF Experiment at EicC

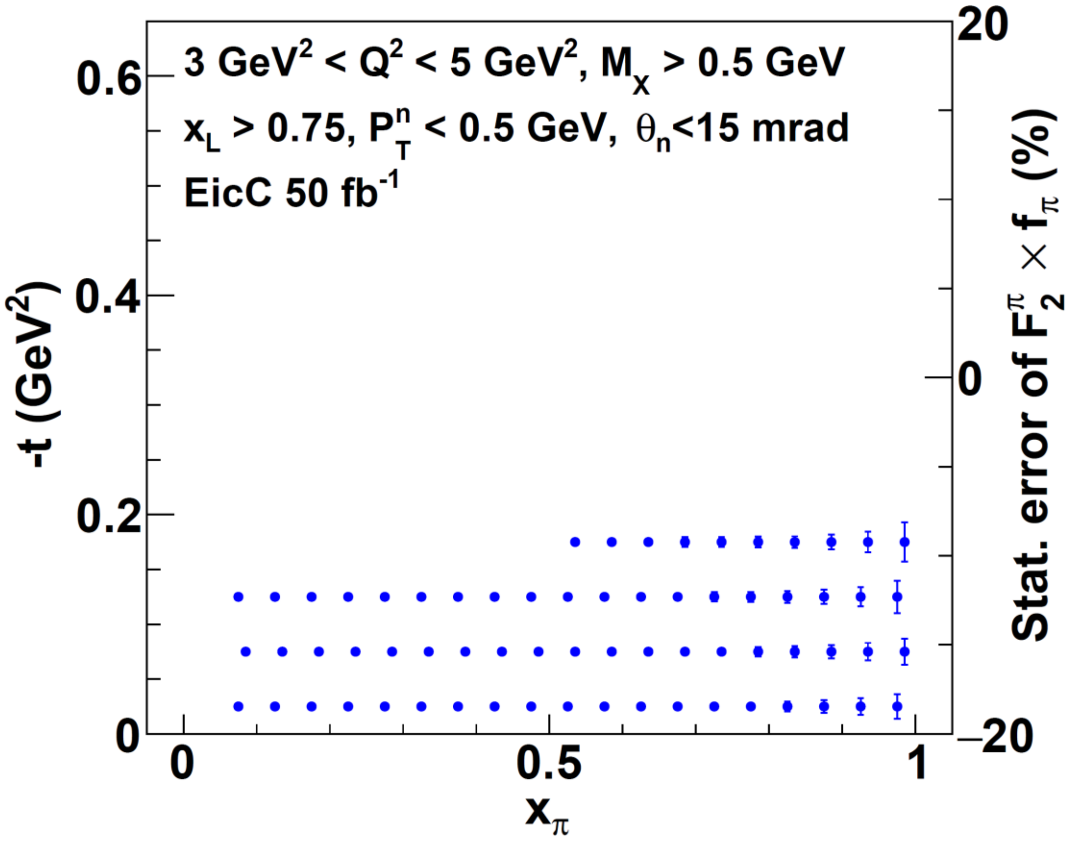
Binning and stat. error estimation

$$N_{\mathrm{i}} = \epsilon L \overline{\sigma}_{\mathrm{i}} \Delta x_{\pi} \Delta Q^2 \Delta x_{\mathrm{L}} \Delta t (1 - x_{\mathrm{L}})$$

$$\epsilon = 50\%$$



Previous simulation result



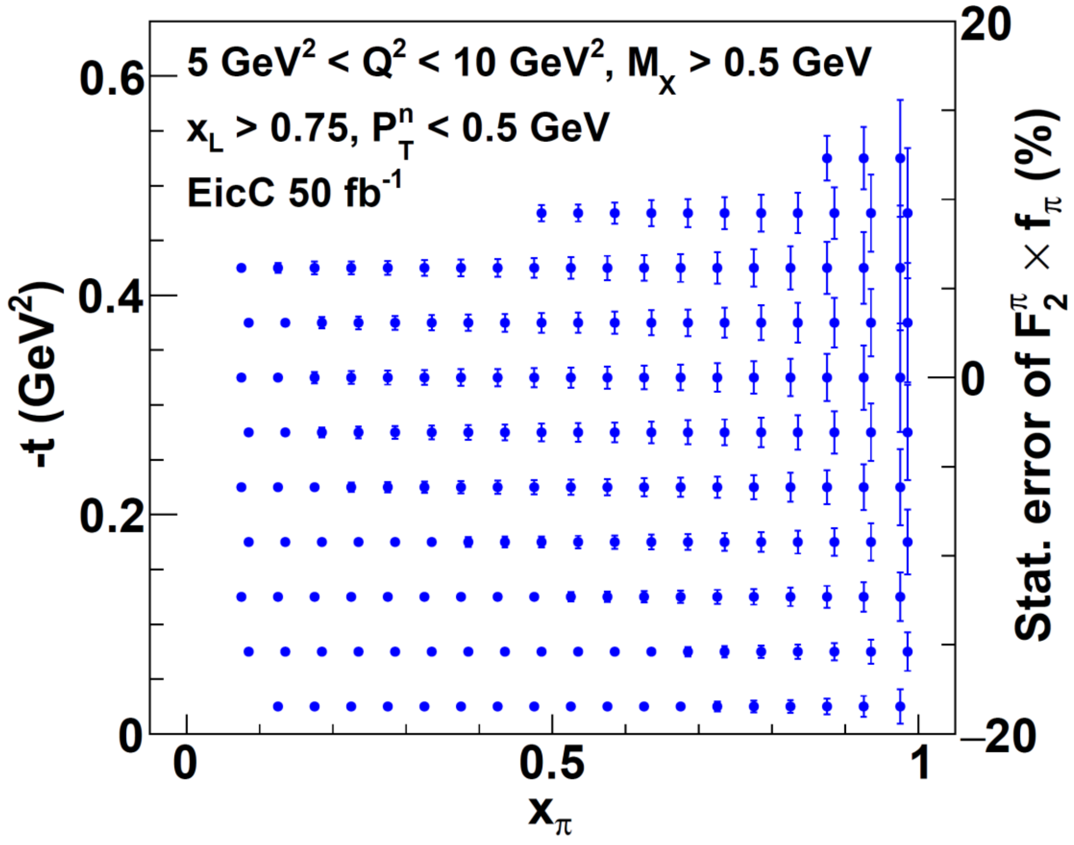
Up-to-date simulation result

Pion SF Experiment at EicC

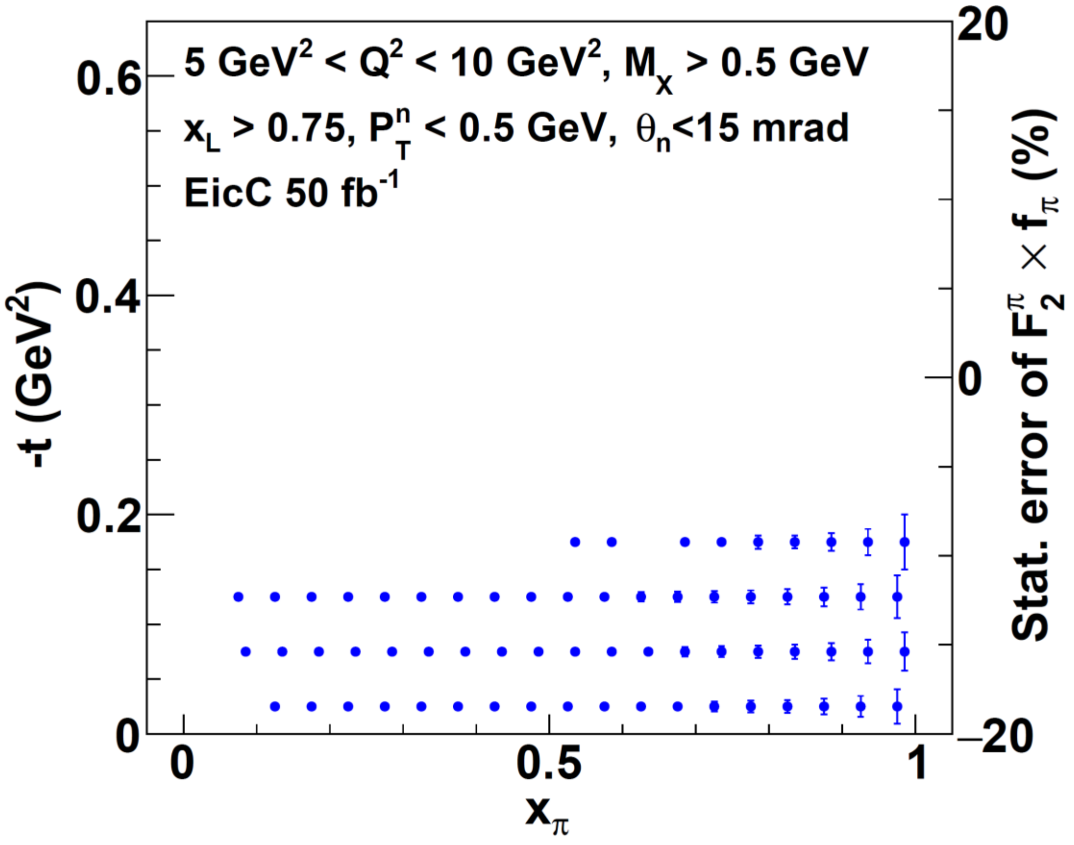
Binning and stat. error estimation

$$N_{\mathrm{i}} = \epsilon L \overline{\sigma}_{\mathrm{i}} \Delta x_{\pi} \Delta Q^2 \Delta x_{\mathrm{L}} \Delta t (1 - x_{\mathrm{L}})$$

$\epsilon = 50\%$



Previous simulation result



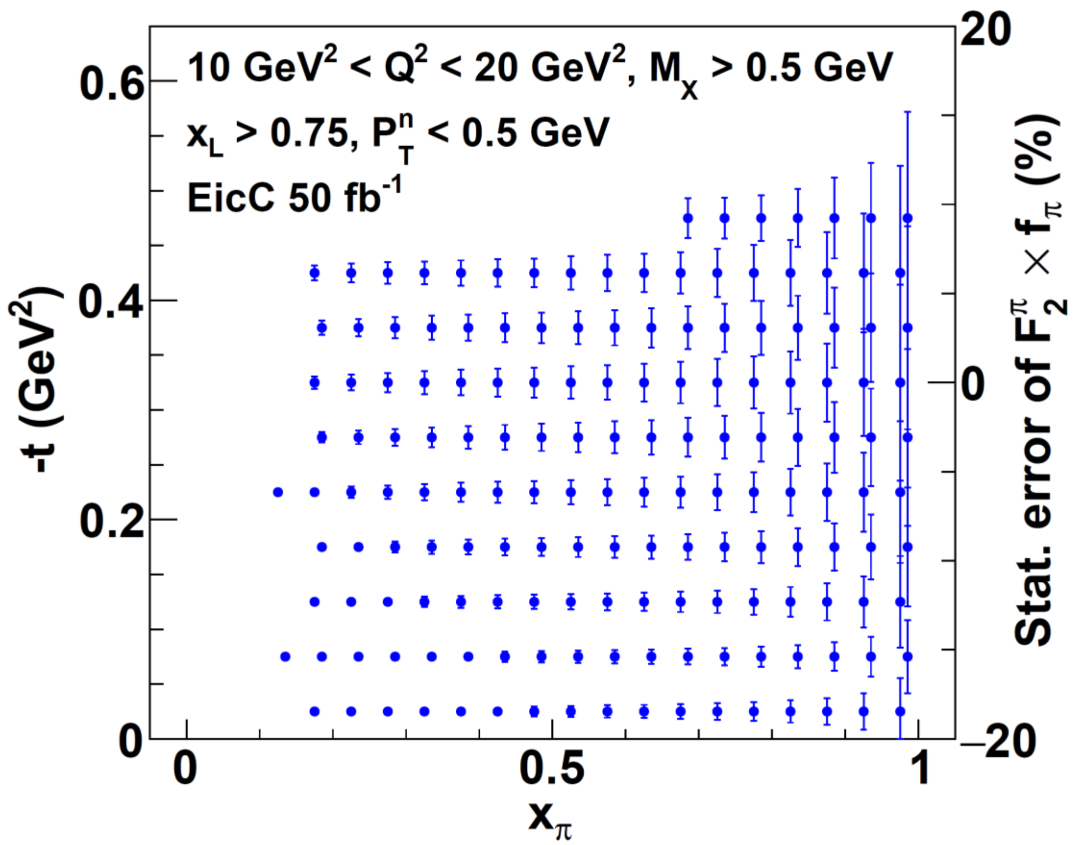
Up-to-date simulation result

Pion SF Experiment at EicC

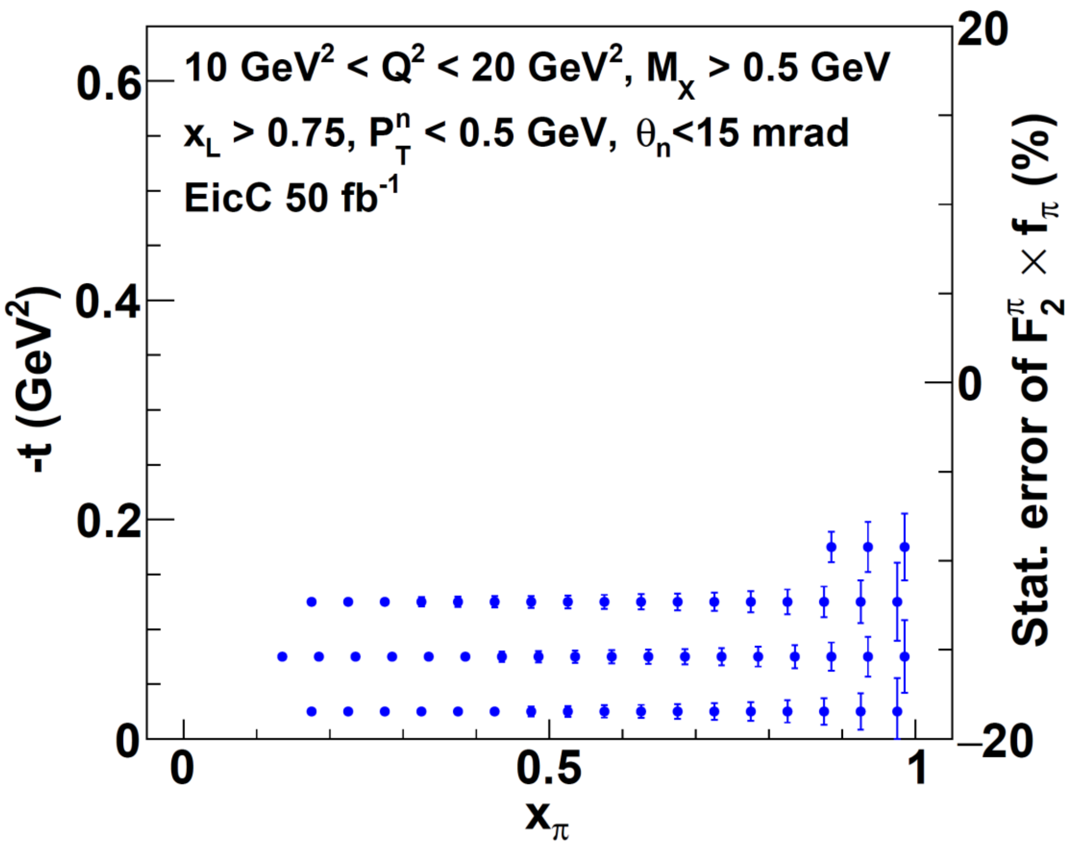
Binning and stat. error estimation

$$N_{\rm i} = \epsilon L \overline{\sigma}_{\rm i} \Delta x_\pi \Delta Q^2 \Delta x_{\rm L} \Delta t (1 - x_{\rm L})$$

$\epsilon = 50\%$



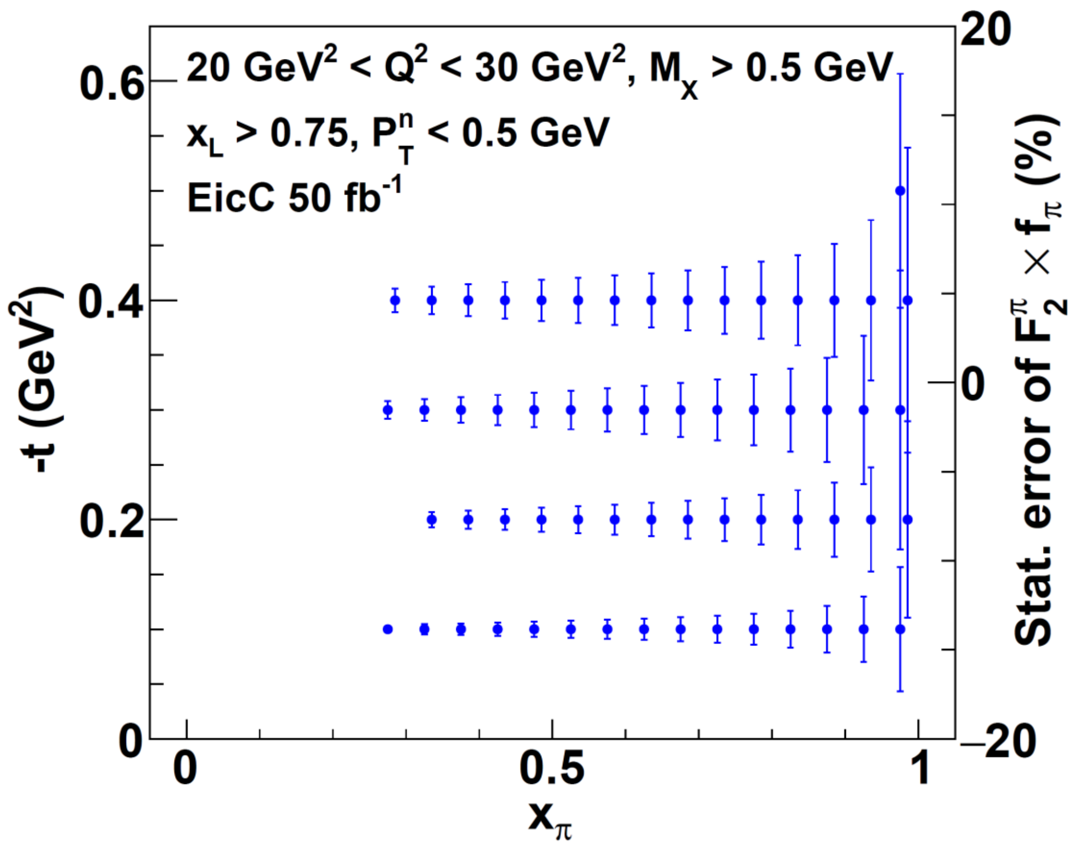
Previous simulation result



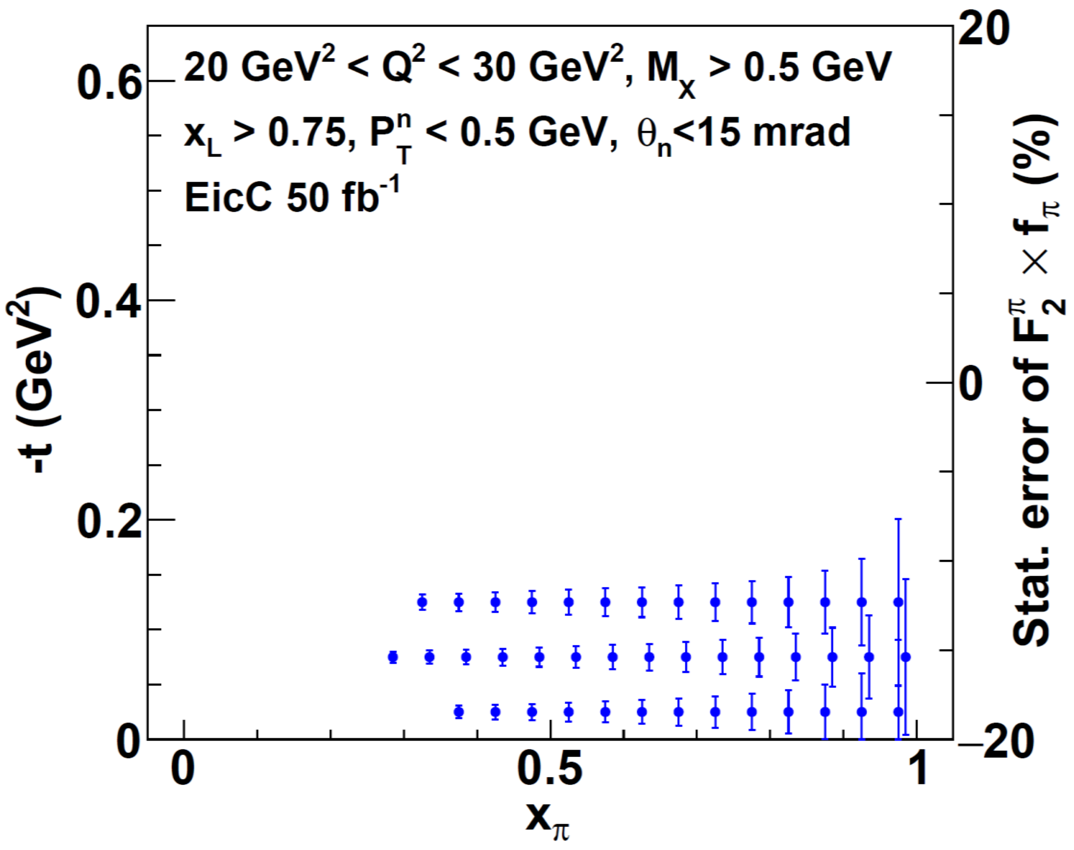
Up-to-date simulation result

Pion SF Experiment at EicC

Binning and stat. error estimation $N_i = \epsilon L \overline{\sigma}_i \Delta x_\pi \Delta Q^2 \Delta x_L \Delta t (1 - x_L)$ $\epsilon = 50\%$



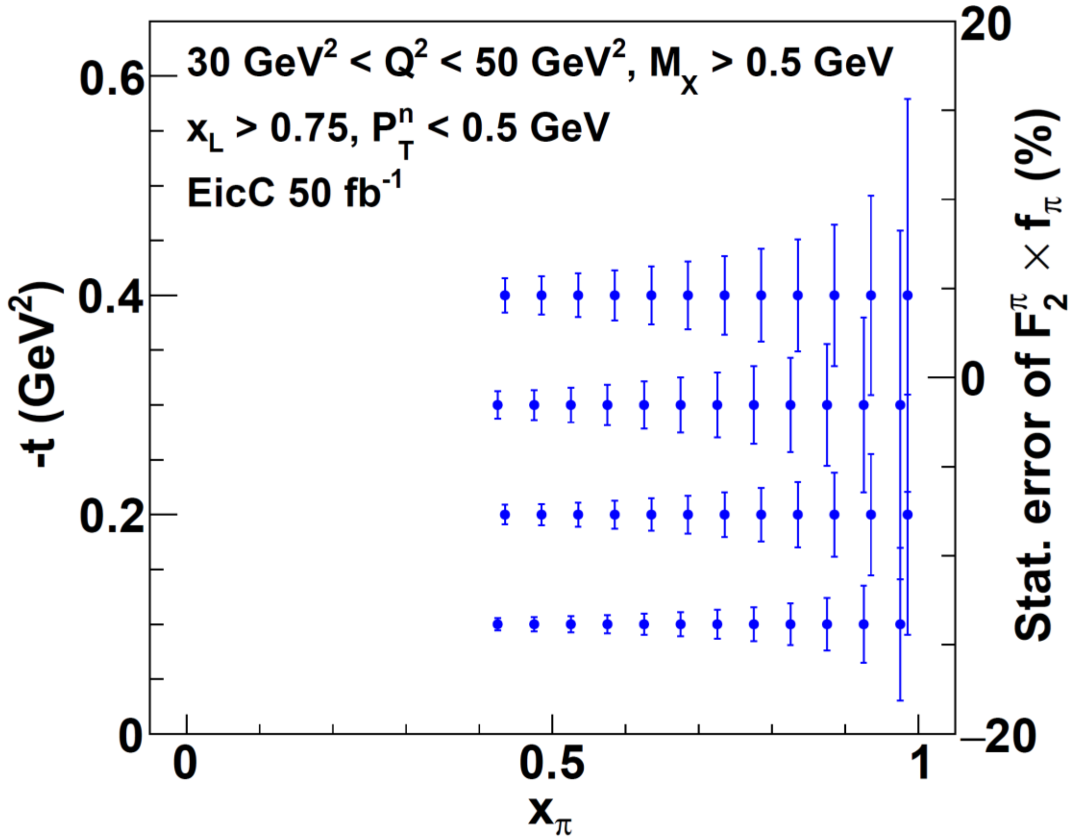
Previous simulation result



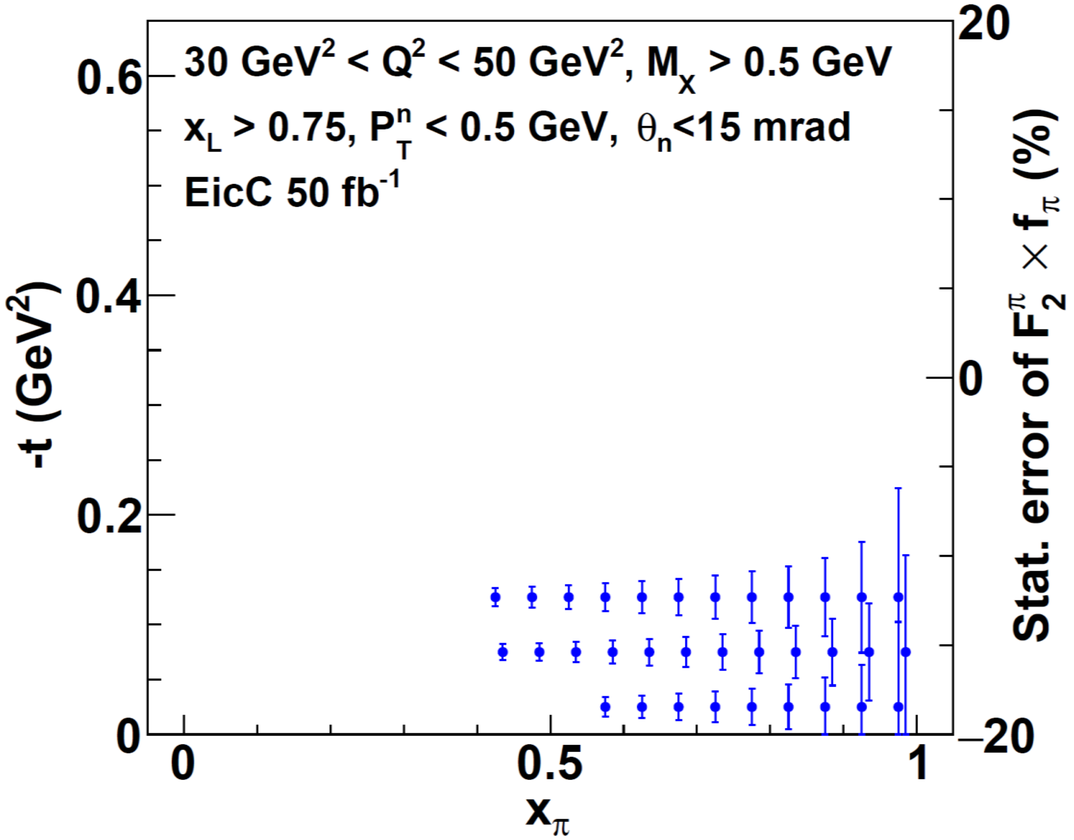
Up-to-date simulation result

Pion SF Experiment at EicC

Binning and stat. error estimation $N_{\rm i} = \epsilon L \overline{\sigma}_{\rm i} \Delta x_\pi \Delta Q^2 \Delta x_{\rm L} \Delta t (1 - x_{\rm L})$ $\epsilon = 50\%$

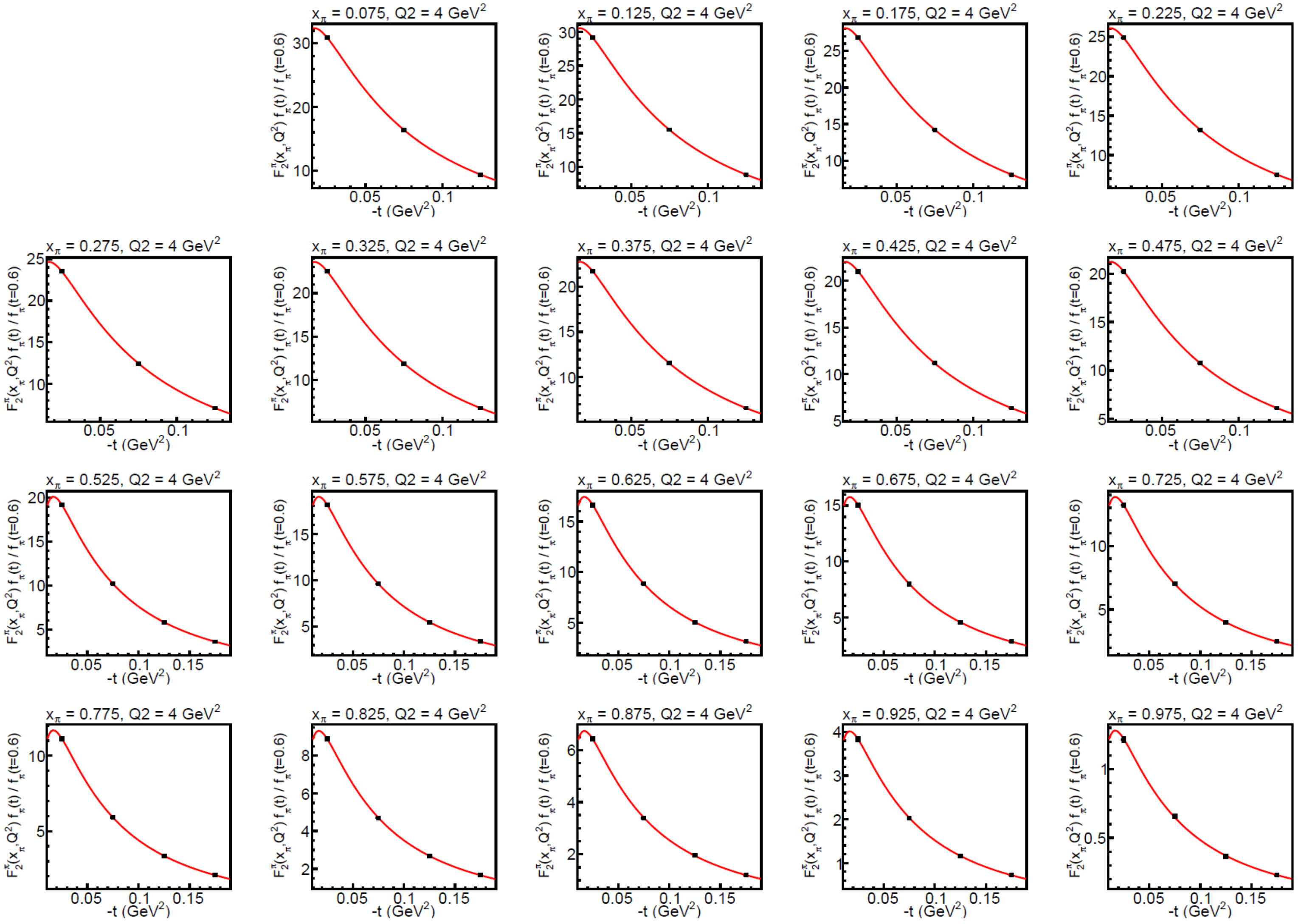


Previous simulation result



Up-to-date simulation result

Pion SF Experiment at EicC

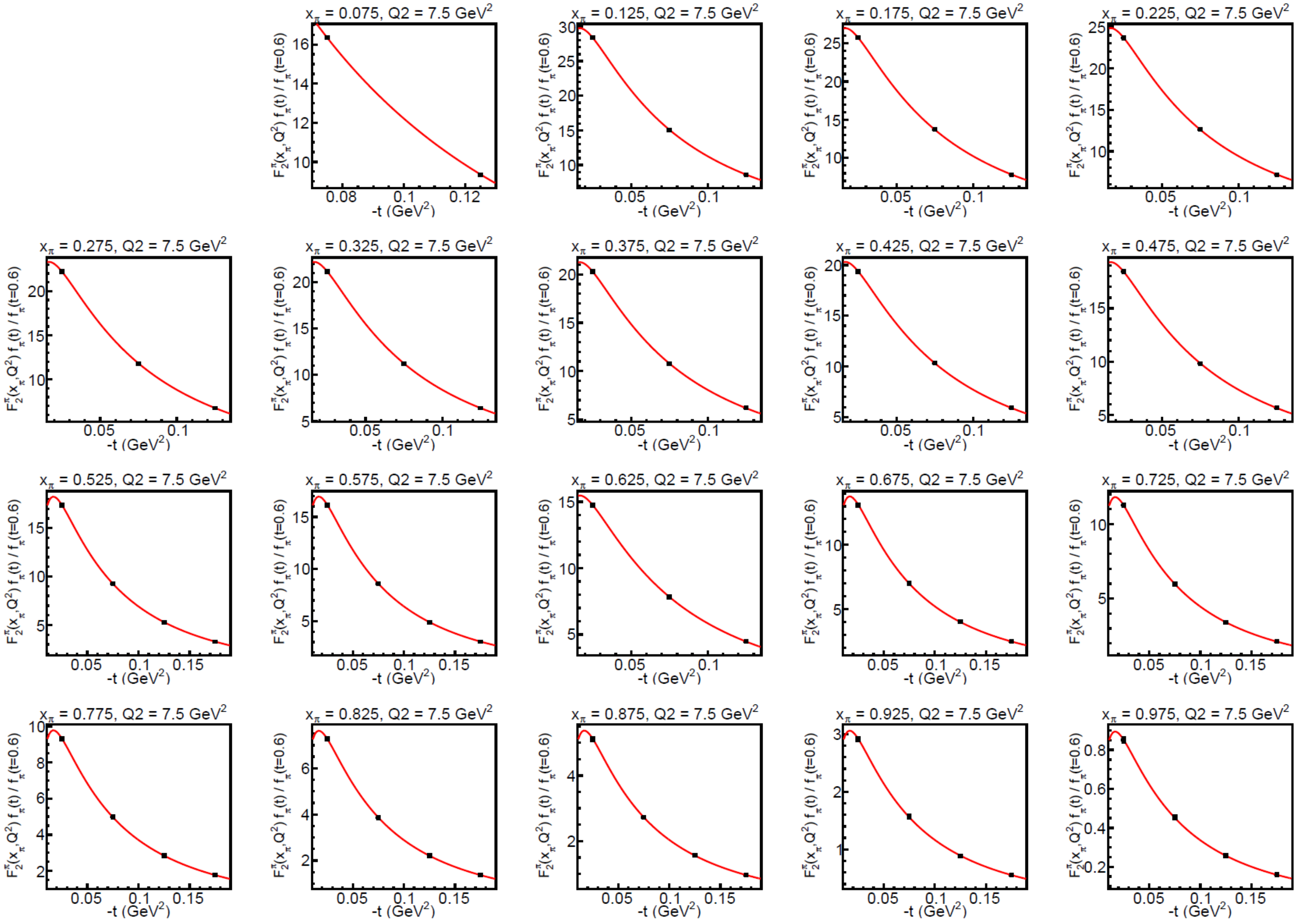


Fitting $F_2^{\pi} \times f_{\pi}$ in different x_{π} bins, Q^2: [3, 5] GeV^2

The pion flux f_{π} is t-dependent:

$$f_{\pi^+/p}(x_L, t) = \frac{1}{2\pi}\frac{g_{pn\pi}^2}{4\pi}(1 - x_L)\frac{-t}{(m_\pi^2 - t)^2}\exp\left(R_{n\pi}^2\frac{t - m_\pi^2}{1 - x_L}\right)$$

Pion SF Experiment at EicC

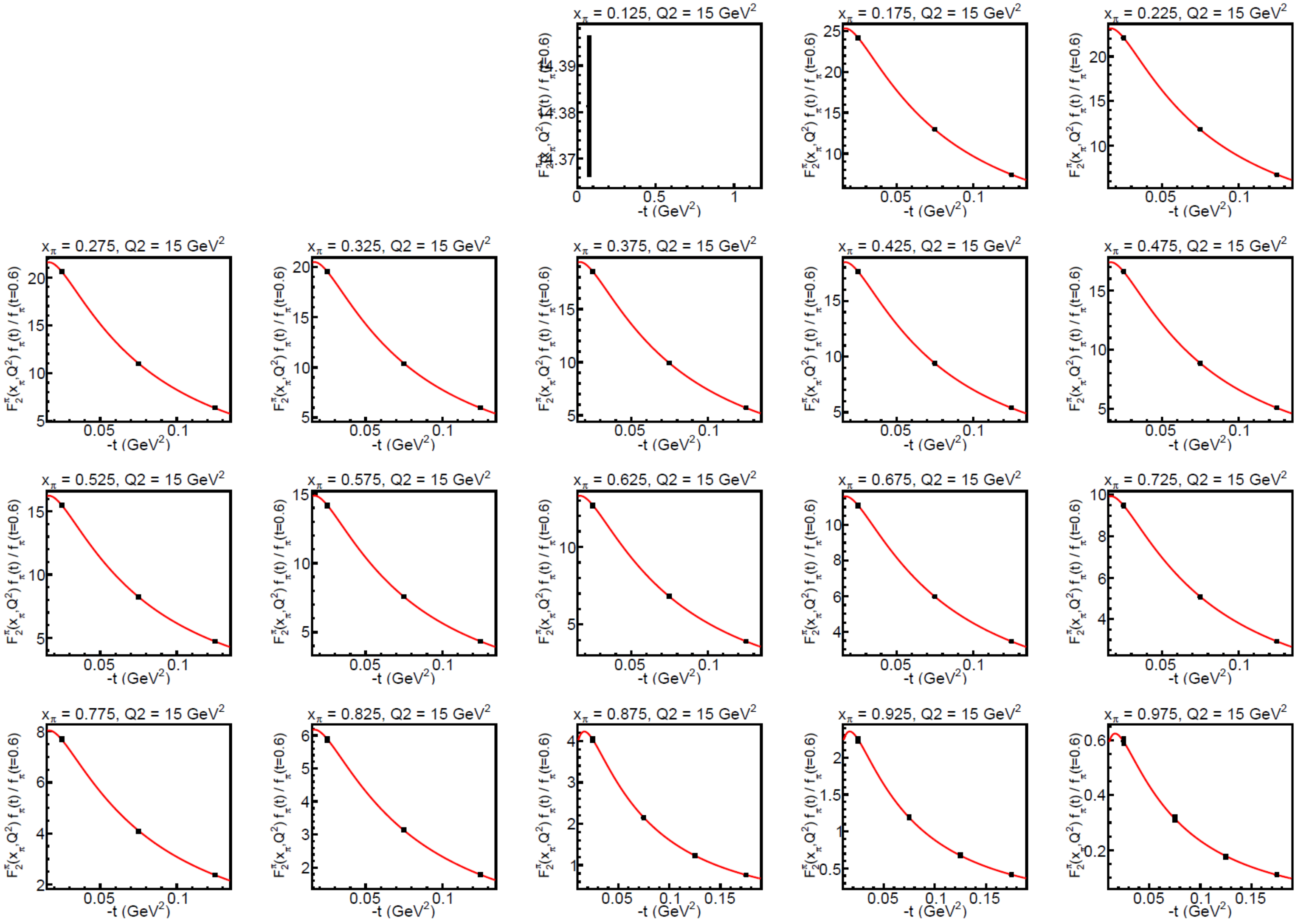


Fitting $F_2^\pi \times f_\pi$ in different x_π bins, Q^2: [5, 10] GeV^2

The pion flux f_π is t-dependent:

$$f_{\pi^+/p}(x_L, t) = \frac{1}{2\pi}\frac{g_{pn\pi}^2}{4\pi}(1-x_L)\frac{-t}{(m_\pi^2-t)^2}\exp\left(R_{n\pi}^2\frac{t-m_\pi^2}{1-x_L}\right)$$

Pion SF Experiment at EicC

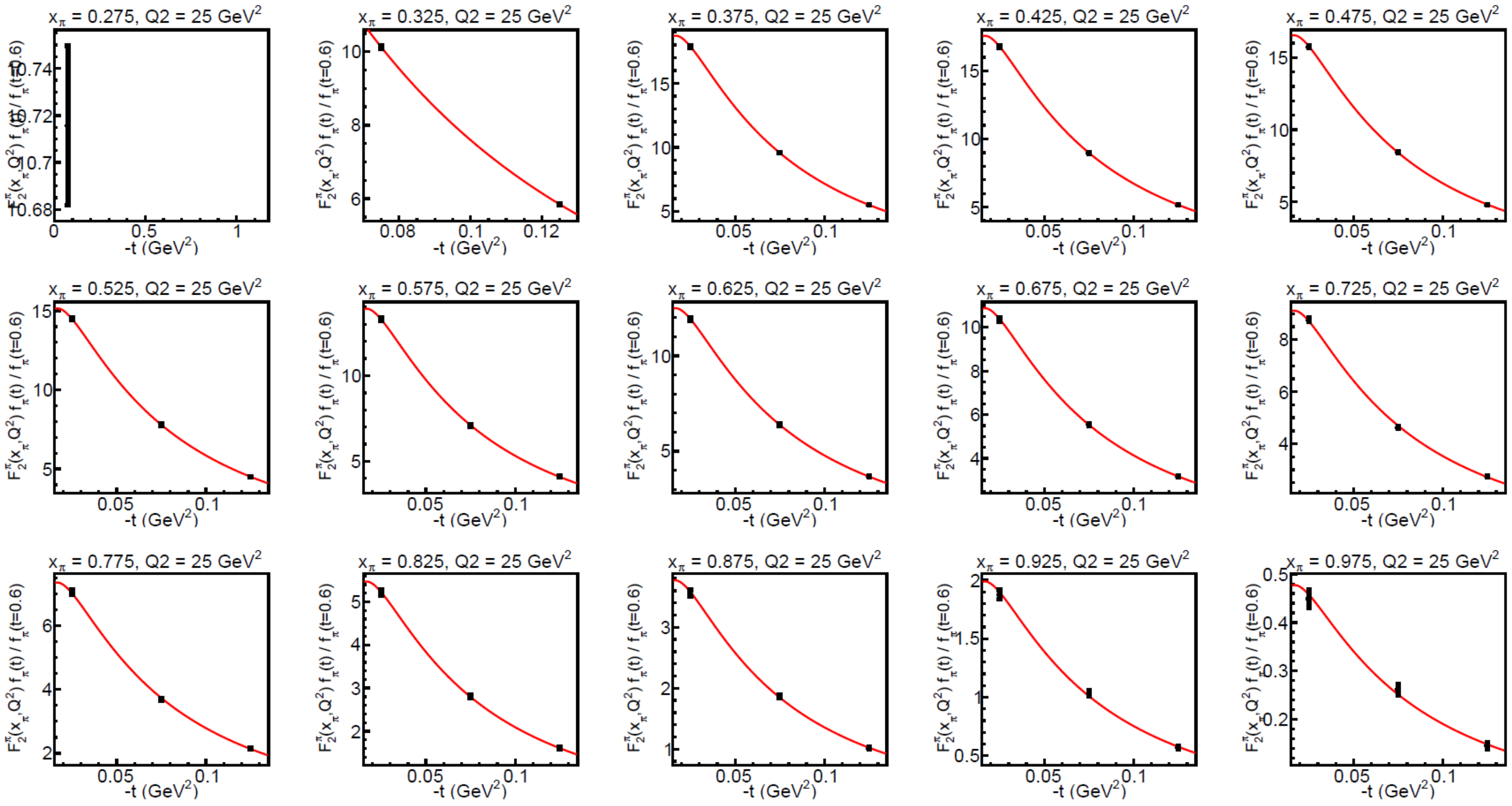


Fitting $F_2^{\pi} \times f_{\pi}$ in different x_{π} bins, Q^2: [10, 20] GeV^2

The pion flux f_{π} is t-dependent:

$$f_{\pi^+/p}(x_L, t) = \frac{1}{2\pi}\frac{g_{pn\pi}^2}{4\pi}(1-x_L)\frac{-t}{(m_\pi^2-t)^2}\exp\left(R_{n\pi}^2\frac{t-m_\pi^2}{1-x_L}\right)$$

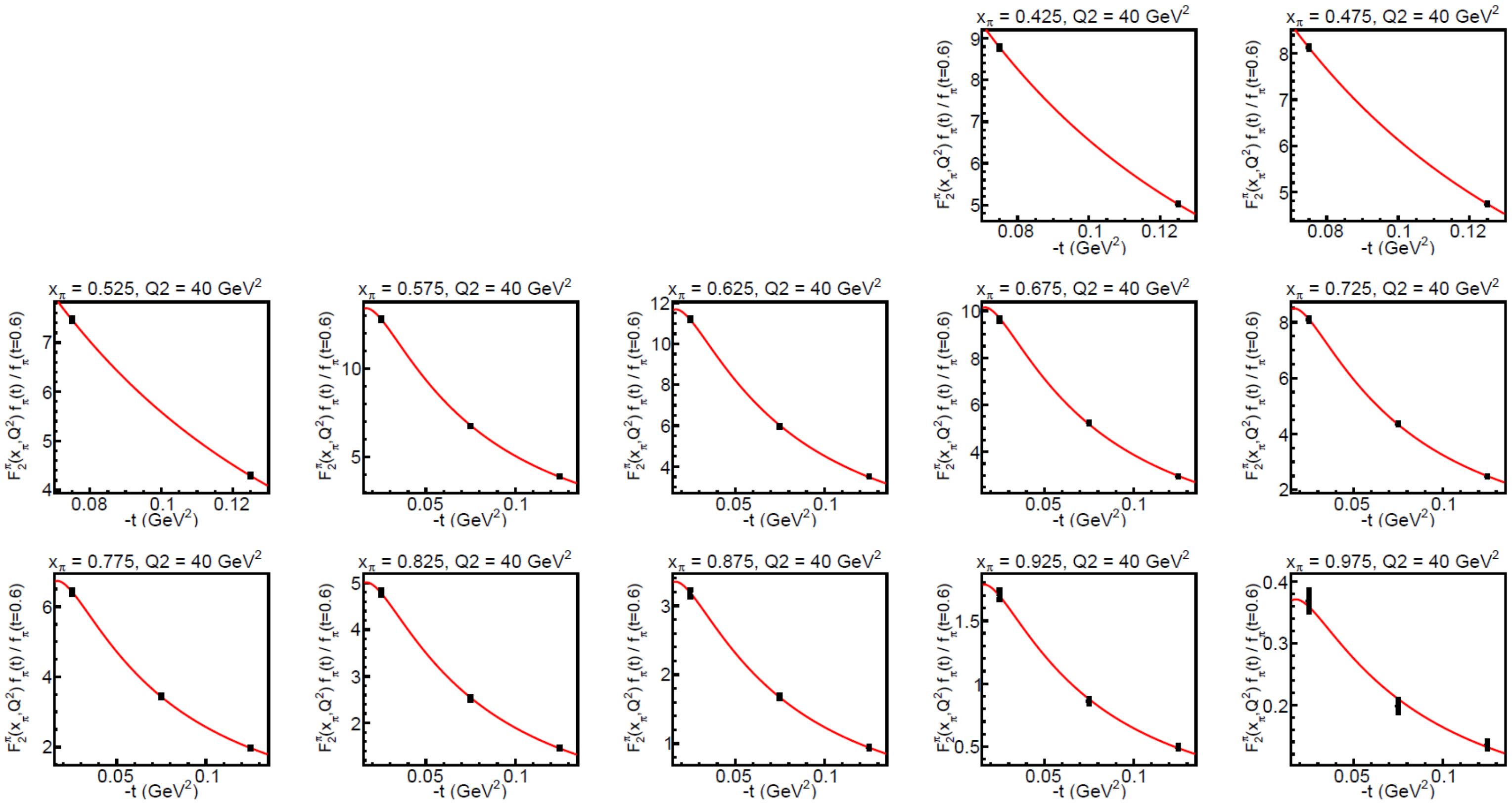
Pion SF Experiment at EicC



Fitting $\mathbf{F_2^\pi} \times \mathbf{f_\pi}$ in different $\mathbf{x_\pi}$ bins, Q^2: [20, 30] GeV^2

The pion flux $\mathbf{f_\pi}$ is t-dependent:

$$f_{\pi^+/p}(x_L,t) = \frac{1}{2\pi}\frac{g_{pn\pi}^2}{4\pi}(1-x_L)\frac{-t}{(m_\pi^2-t)^2}\exp\left(R_{n\pi}^2\frac{t-m_\pi^2}{1-x_L}\right)$$



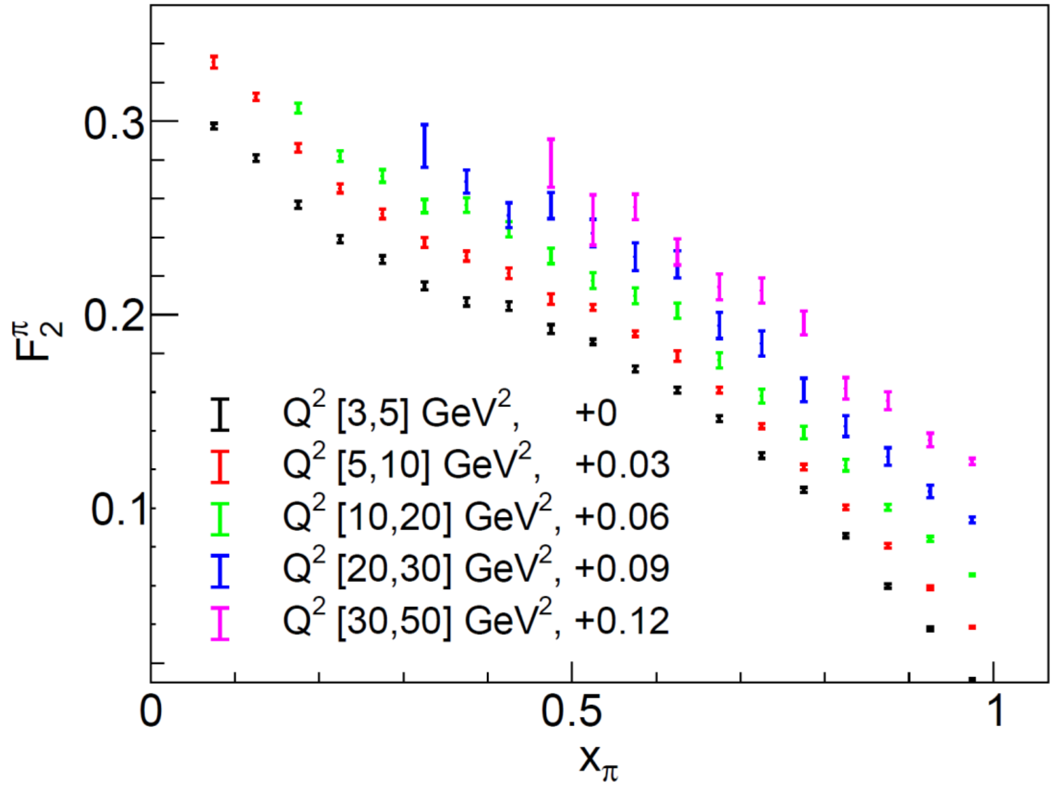
Fitting $\mathbf{F_2^\pi \times f_\pi}$ in different $\mathbf{x_\pi}$ bins, Q^2: [30, 50] GeV^2

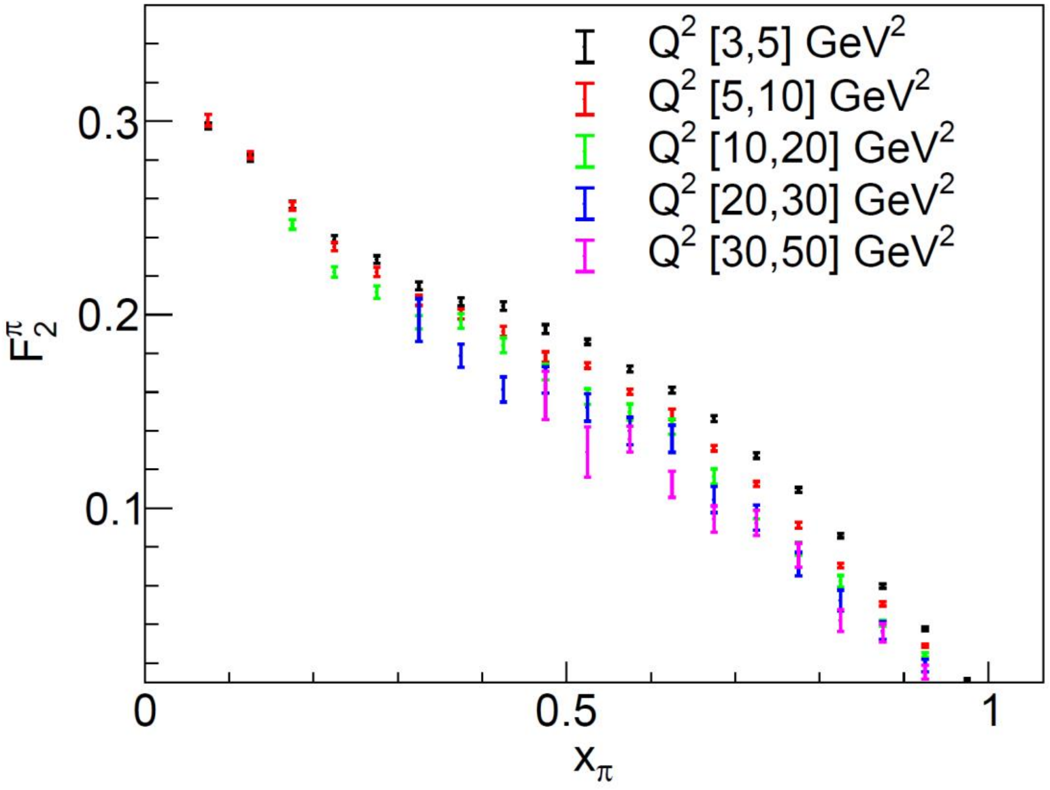
The pion flux $\mathbf{f_\pi}$ is t-dependent:

$$f_{\pi^+/p}(x_L, t) = \frac{1}{2\pi}\frac{g_{pn\pi}^2}{4\pi}(1-x_L)\frac{-t}{(m_\pi^2-t)^2}\exp\left(R_{n\pi}^2\frac{t-m_\pi^2}{1-x_L}\right)$$

Pion SF Experiment at EicC

F_2^π are extracted from the model-dependent fits of the differential cross sections above.





Pion SF Experiment at EicC

QCD fit of the pseudo F_2^π data

Parametrization of initial PDF: same as JAM's input (π^+ meson)

JAM collaboration, Phys. Rev. Lett. 121 (2018) 15, 152001

$Q_0^2 = 1.0$ GeV^2

$$q_v^\pi \equiv u_v^{\pi^+} = u^{\pi^+} - \bar{u}^{\pi^+} = \bar{d}_v^{\pi^+} = \bar{u}_v^{\pi^-} = d_v^{\pi^-}$$

$$q_s^\pi \equiv \bar{u}^{\pi^+} = d^{\pi^+} = s^{\pi^+} = \bar{s}^{\pi^+}$$

$$f(x_\pi, Q_0^2; \boldsymbol{a}) = \frac{N}{B(2+\alpha,\beta)} x_\pi^\alpha (1-x_\pi)^\beta$$

$$\int_0^1 v(x)\mathrm{d}x = 2, \int_0^1 x(v(x) + S(x) + g(x))\mathrm{d}x = 1.$$

Evolution with Q^2: DGLAP evolution equation at NNLO

Utilize the package qcdnum18.00

M. Botje, Comput. Phys. Commun. 182 (2011) 490, arXiv:1005.1481, Erratum arXiv:1602.08383 (2016)

Pion SF Experiment at EicC

QCD fit of the pseudo F_2^π data

Fitting: least-square method, Utilize the "minuit" package

$$\chi^2 = \sum_i^N \frac{(D_i - T_i)^2}{\sigma_i^2}$$

TMinuit in ROOT

Error analysis method: Hessian matrix

$$(\Delta X)^2 = \Delta\chi^2 \sum_{i=1}^{n}\sum_{j=1}^{n} \frac{\partial X}{\partial a_i} C_{ij}(a) \frac{\partial X}{\partial a_j}$$

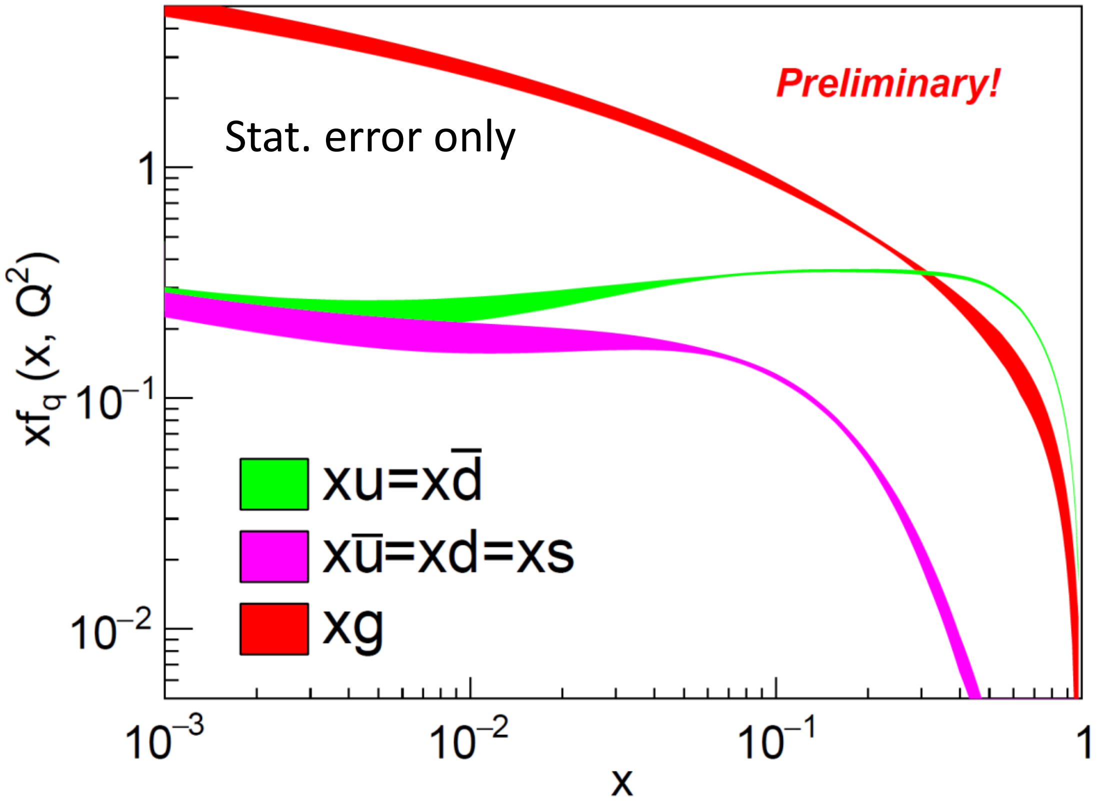
$$C_{ij}(a) = (H^{-1})_{ij}$$

$$\Delta\chi^2 = \chi^2 - \chi_0^2 = \sum_{i=1}^{n}\sum_{j=1}^{n} \boxed{H_{ij}} (a_i - a_i^0)(a_j - a_j^0)$$

C. Han et al., Eur. Phys. J. C 81, 302 (2021); J. Pumplin et al., Phys. Rev. D 65, 014013 (2001); A.D. Martin et al., Eur. Phys. J. C 28, 455–473 (2003)

Pion SF Experiment at EicC

QCD fit of the pseudo F_2^{π} data



Systematic errors would be dominant!

One sees that the quark distributions are precisely determined with only the EicC pseudo-data, in the x range above 0.05. One also nds that the pion gluon distribution is given by the QCD evolution equations.

Nonperturbative input:

$$xq_v^{\pi} = 2.35x^{1.0}(1-x)^{1.34}$$

$$xq_s^{\pi} = 1.32x^{0.48}(1-x)^{9.36}$$

$$xg^{\pi} = 3.25x^{0.03}(1-x)^{15}$$

ZDC Performance and Sys. Errors

Current ZDC performance and the spatial resolution requirement

How the energy and angular resolutions of ZDC affect the resolution of the t variable:

$$t = (P_\mathrm{p} - P_\mathrm{n})^2 \approx 2E_\mathrm{p}E_\mathrm{n}(cos(\theta) - 1)$$
$$(\text{with, } E_\mathrm{p} \approx p_\mathrm{p} \text{ and } E_\mathrm{n} \approx p_\mathrm{n})$$

$$\delta t = \frac{\partial t}{\partial E_\mathrm{n}}\delta E_\mathrm{n} + \frac{\partial t}{\partial \theta}\delta\theta$$
$$\frac{\delta t}{t} = \frac{\delta E_\mathrm{n}}{E_\mathrm{n}} + \frac{sin(\theta)}{1 - cos(\theta)}\delta\theta$$

$$\frac{\delta E_\mathrm{n}}{E_\mathrm{n}} = \frac{47\%}{\sqrt{E_\mathrm{n}}} + 2.5\%$$

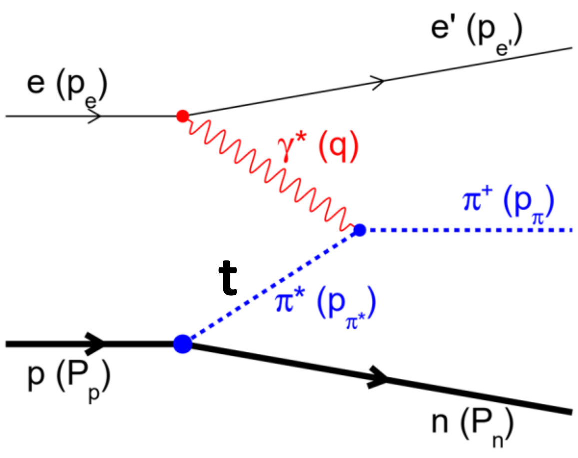
$$\frac{\delta E_\mathrm{n}}{E_\mathrm{n}} \approx 14.5\% \text{ for 15 GeV neutron}$$

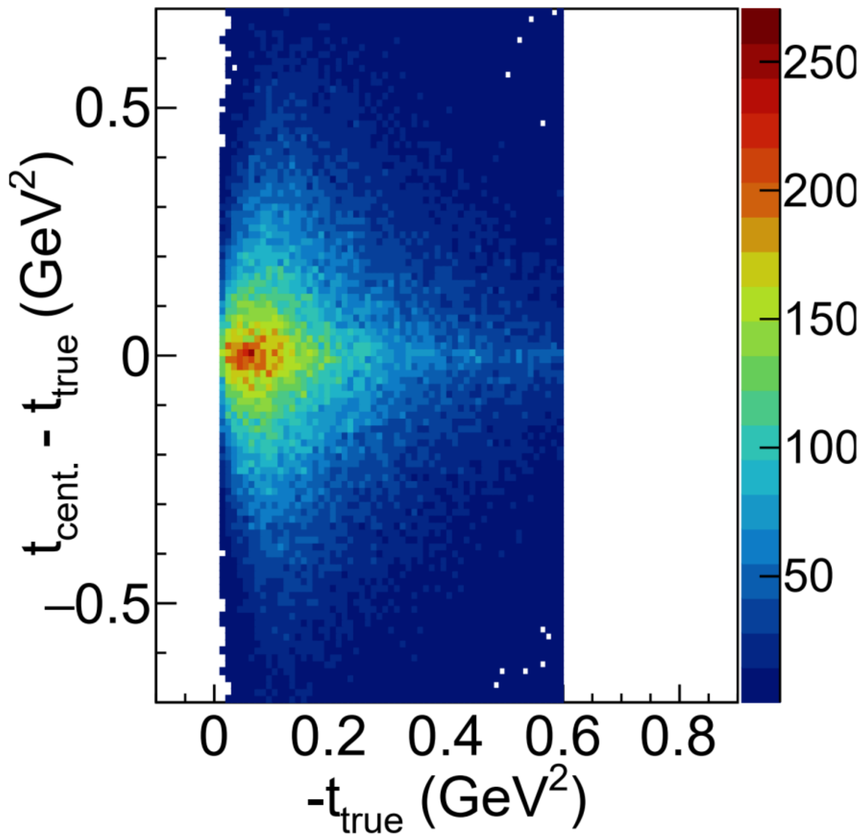
$$\frac{sin(\theta)}{1 - cos(\theta)}\delta\theta \text{ is suggested to be around } 14.5\%$$

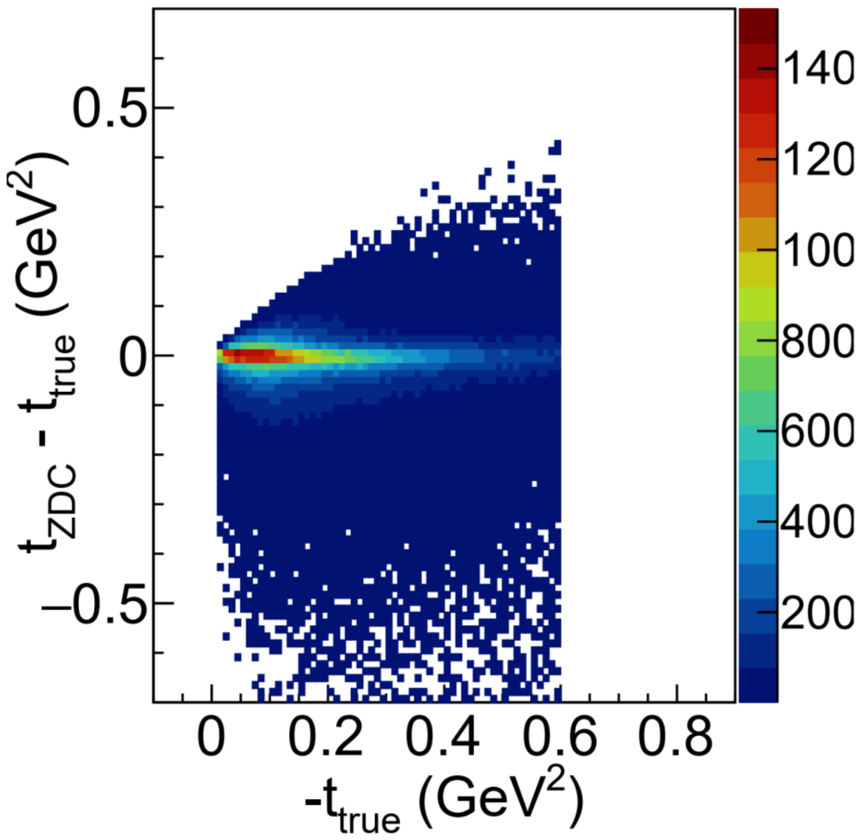
At θ~7 mrad, the angular resolution δθ should be around 0.00051. **And the position resolution should be around 12 m × δθ = 0.6 cm.**

This kind of position resolution is very challenging!

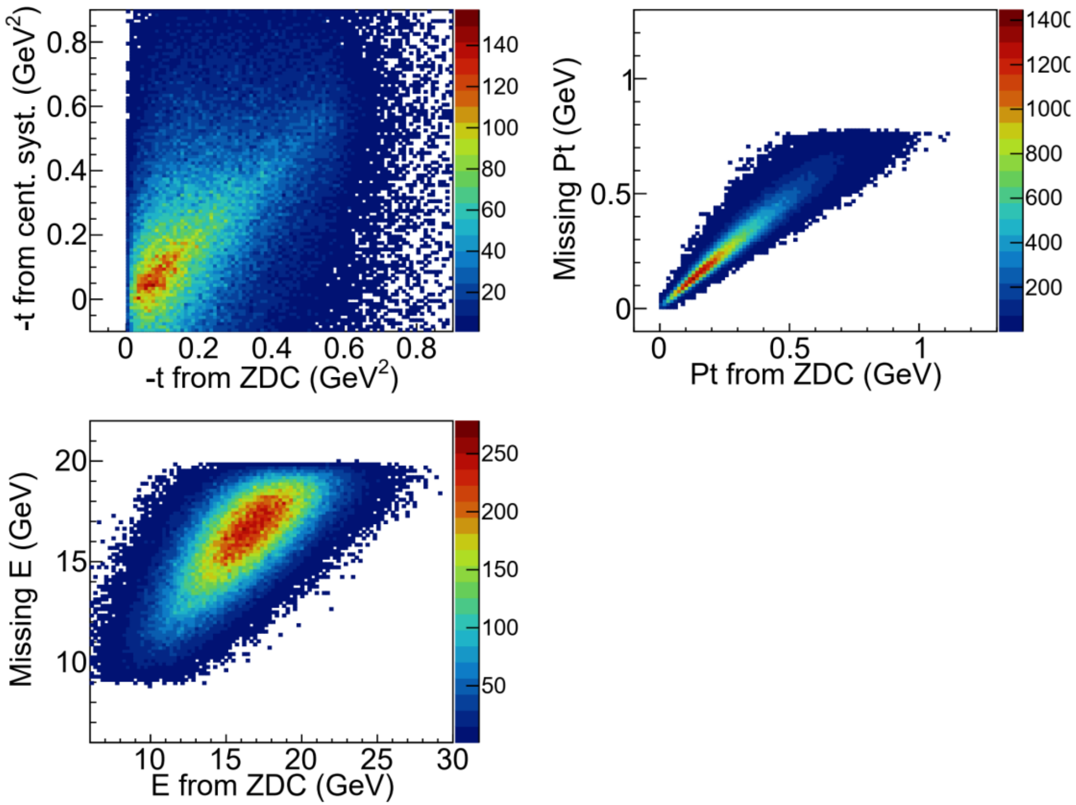
ZDC Performance and Sys. Errors

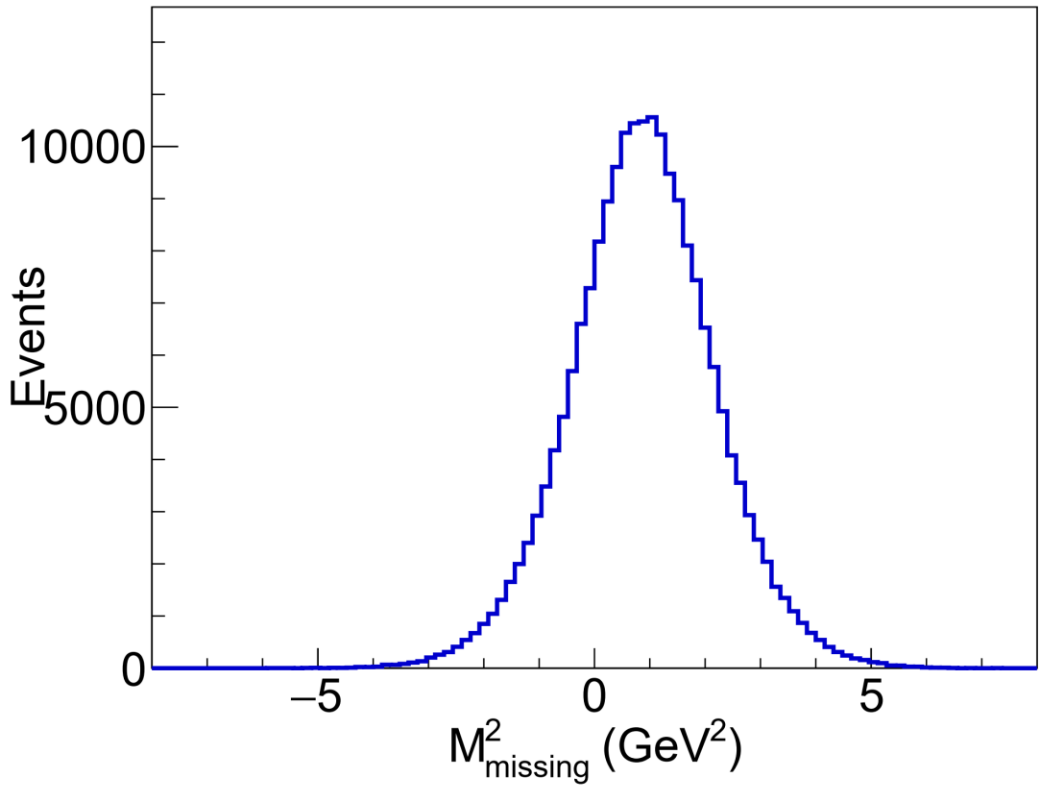






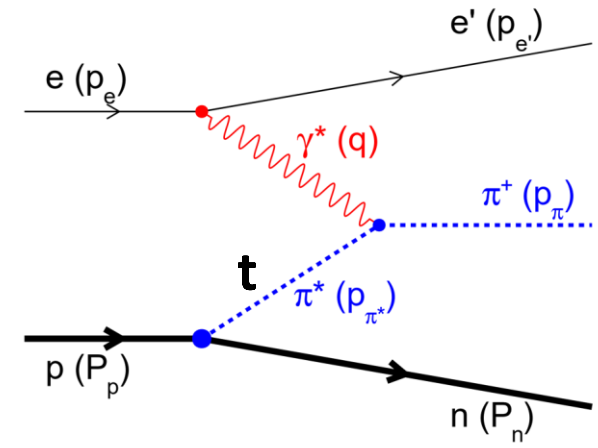
ZDC Performance and Sys. Errors

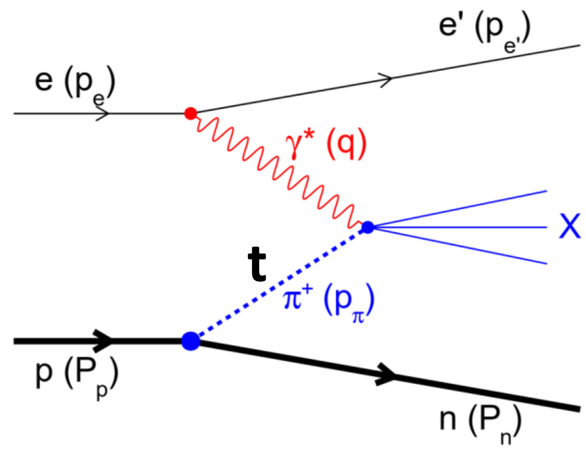




With the central detector, the neutron information also can be given with the missing-particle method.

Systematic Uncertainties from ZDC Resolutions

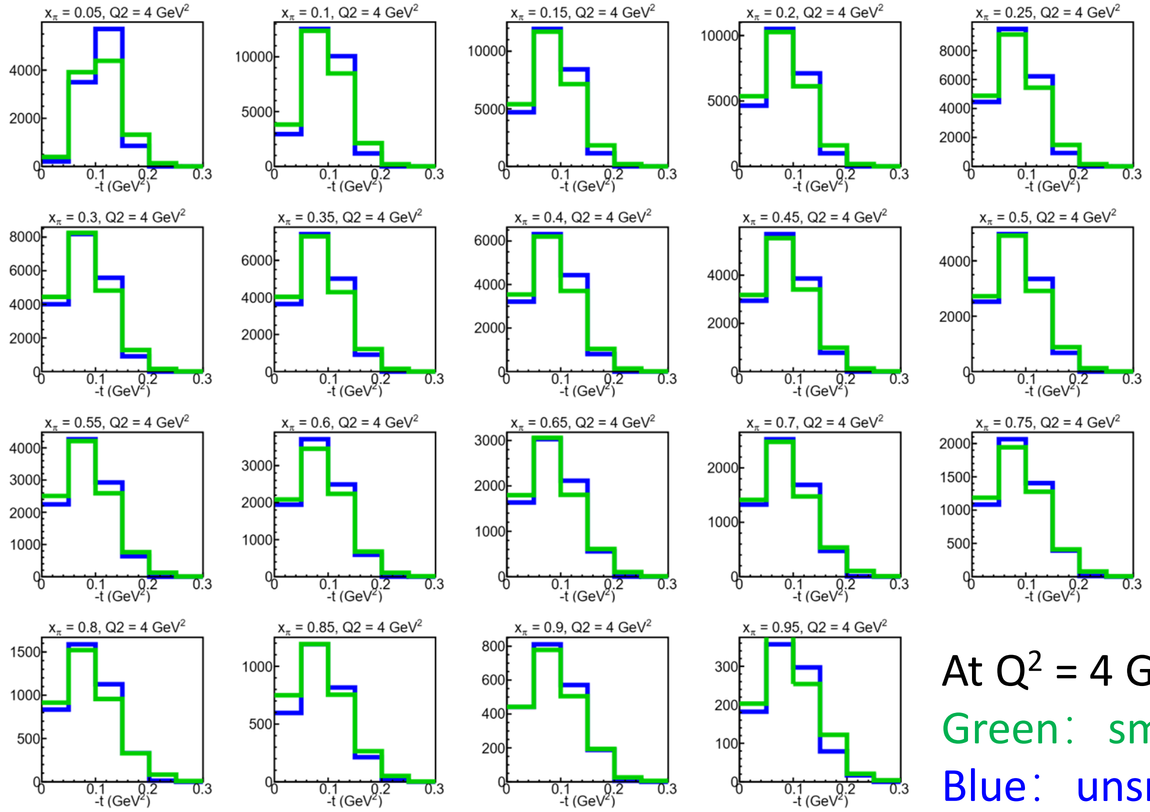




For the form factor experiment, the momentum transfer t also can be evaluated with the virtual photon and final pion.

Need more studies!

For the structure function experiment, the t can only be measured with ZDC. Thus ZDC introduces more uncertainties to the pion structure functions.



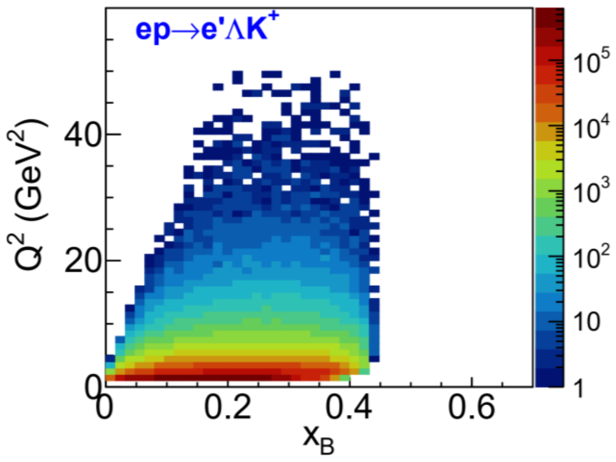
The typical resolution of t:
$\sqrt{2} \times 14.5\%$ **= 21%**

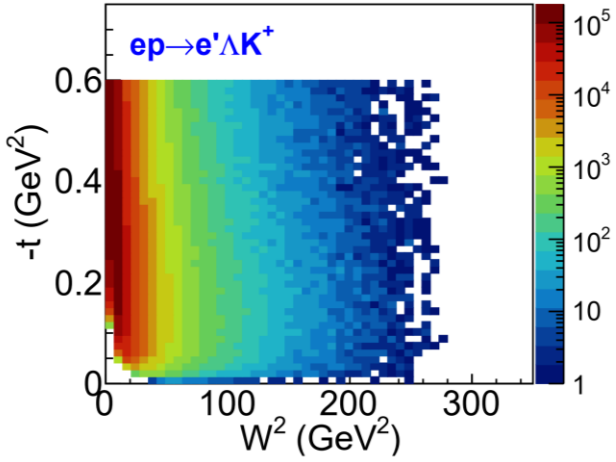
Preliminary MC study shows that the systematic uncertainty from the resolution of t is 6-19% for the pion structure function.

At Q^2 = 4 GeV^2
Green： smeared
Blue： unmeasured

Kaon FF Experiment at EicC

The invariant kinematical distributions of $\mathbf{ep} \rightarrow \mathbf{eK^{+}\Lambda}$ from the event generator






```
KaonExclusiveElectroproduction demp_kaon;
demp_kaon.SetTmax(0.6);  demp_kaon.SetTmin(0.01);
demp_kaon.SetQ2max(50); demp_kaon.SetQ2min(1);
demp_kaon.SetxBmax(0.8); demp_kaon.SetxBmin(0.001);
demp_kaon.SetElecBeamEnergy(3.5); demp_kaon.SetProtBeamEnergy(20);
demp_kaon.SetBeamCrossAngle(0.0);

demp_kaon.SetOutputFileName("DEMP-kaon-pole-at-EicC.root");
demp_kaon.SetEvtFileOutput(1);
demp_kaon.SetQuiet(1);
demp_kaon.SetSamplingMode(1);
demp_kaon.Generate(10000000);
```

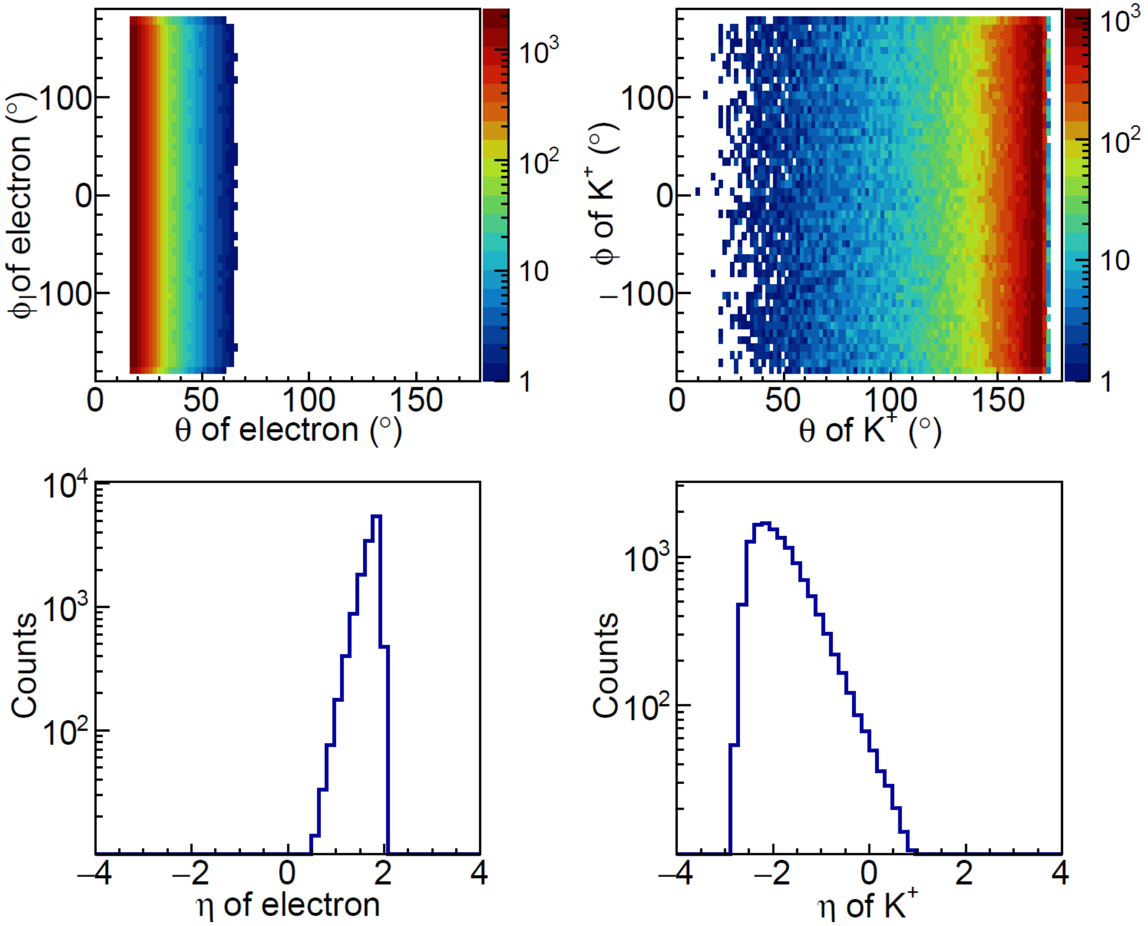
The evt file can be easily used in the EicCRoot and geant4 simulations.

```
0       7
  N      Id      Ist     M1      M2      DF      DL      px        py        pz        E         t        x        y        z
  0      11      1       -1      -1      -1      -1      -0.275297 1.14401 -3.31999 3.52234 0 0 0 0
  1      321     1       -1      -1      -1      -1      0.628167 -0.733735 4.47504 4.60464 0 0 0 0
  2      2212    1       -1      -1      -1      -1      -0.304412 -0.354582 11.7698 11.8163 0 -0.17107 -0.1989 7.42851
  3      -211    1       -1      -1      -1      -1      -0.0484579 -0.0556922 3.55318 3.55668 0 -0.17107 -0.1989 7.42851
  4      2112    1       -1      -1      -1      -1      -0.376788 -0.374849 14.2433 14.2841 0 -0.17107 -0.1989 7.42851
  5      22      1       -1      -1      -1      -1      0.0713131 -0.0310818 0.888843 0.892241 0 -0.17107 -0.1989 7.42851
  6      22      1       -1      -1      -1      -1      -0.0473955 -0.00434271 0.190813 0.19666 0 -0.17107 -0.1989 7.4285
1       7
  N      Id      Ist     M1      M2      DF      DL      px        py        pz        E         t        x        y        z
  0      11      1       -1      -1      -1      -1      -0.465765 -1.19213 -3.29303 3.53301 0 0 0 0
  1      321     1       -1      -1      -1      -1      0.450413 0.950829 4.31165 4.46553 0 0 0 0
```

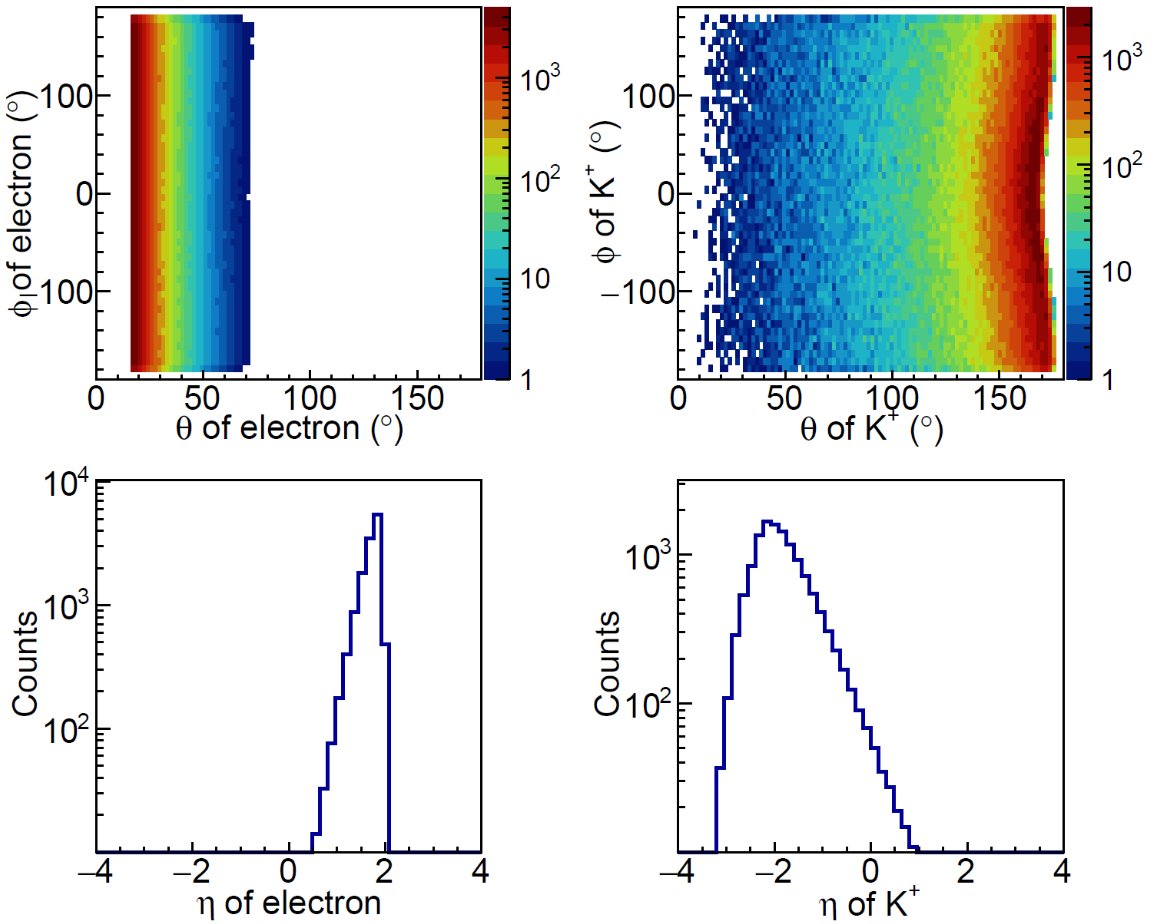
Kaon FF Experiment at EicC

Cross-section weighted kinematical distributions of the final electron and kaon

No beam crossing

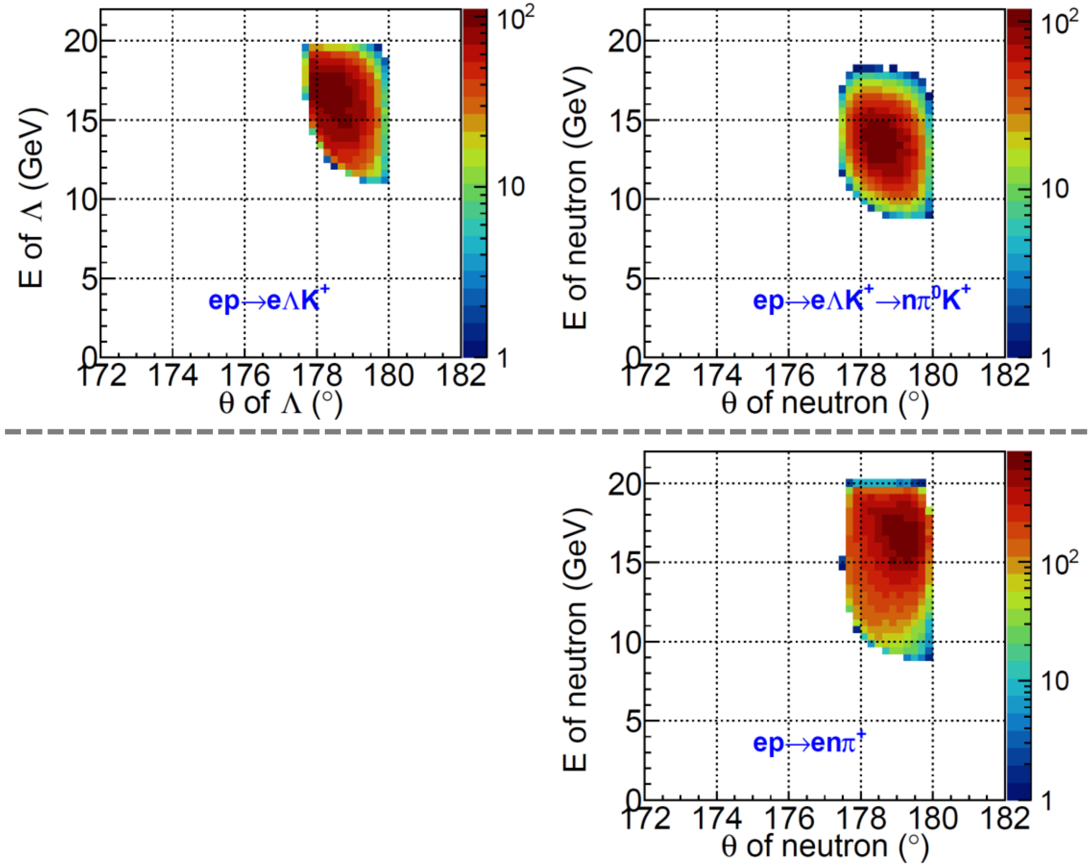


Beam crossing angle 50 mrad

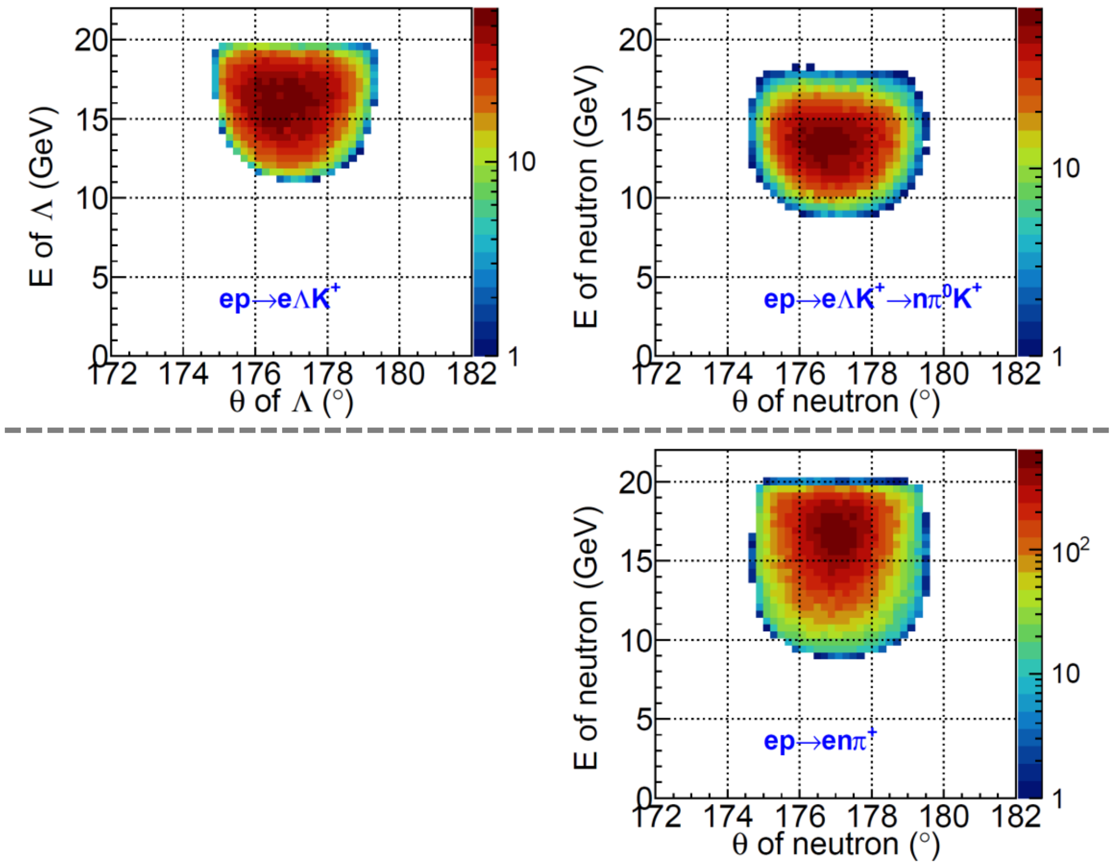


Kaon FF Experiment at EicC

No beam crossing



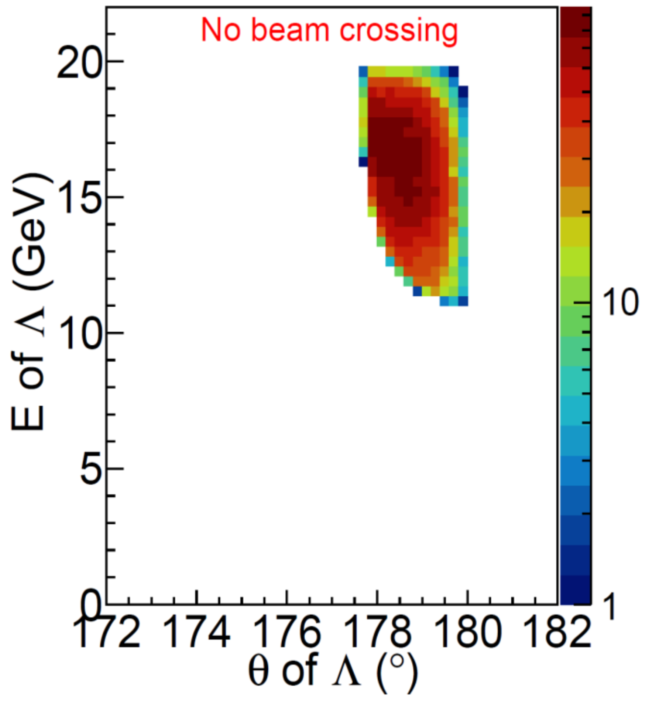
Beam crossing angle 50 mrad = 2.865 deg

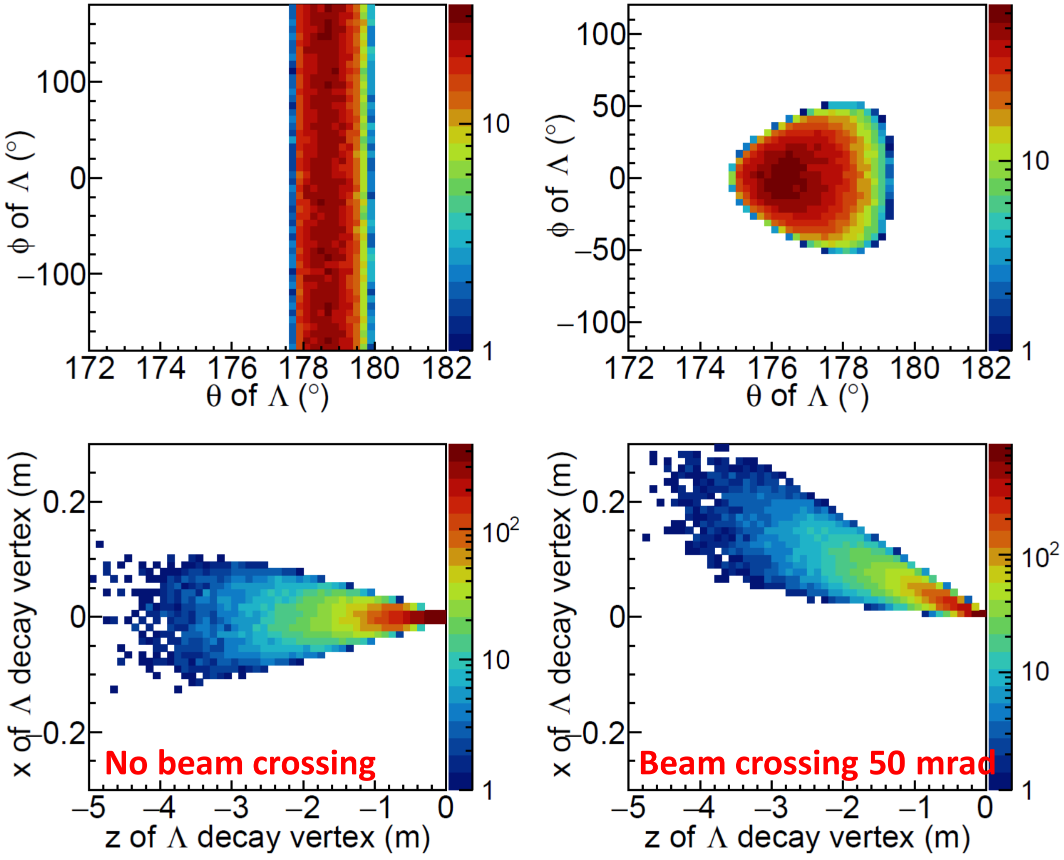


For exclusive kaon production in the kaon pole model, **the final baryons (Lambda and its decay) have larger scattering angle and wider distributions.**

Kaon FF Experiment at EicC

Cross-section weighted distributions of energy, angle, decay vertex of Lambda

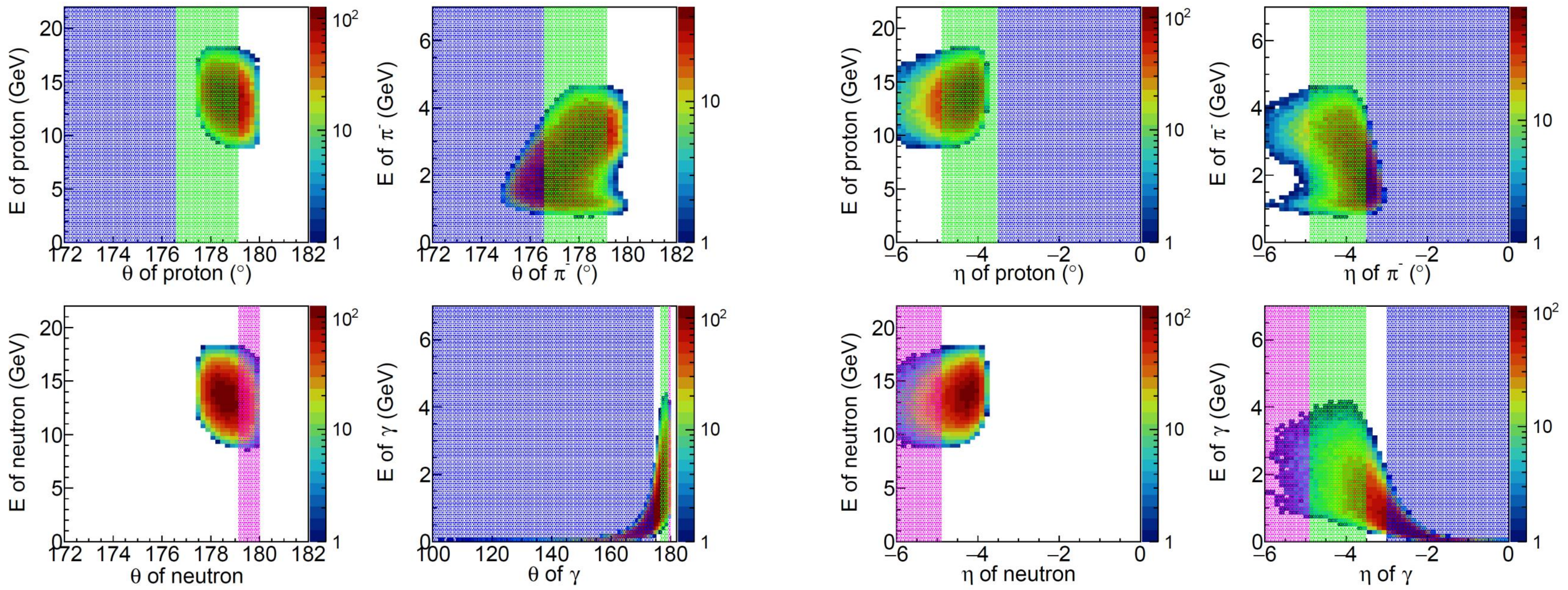




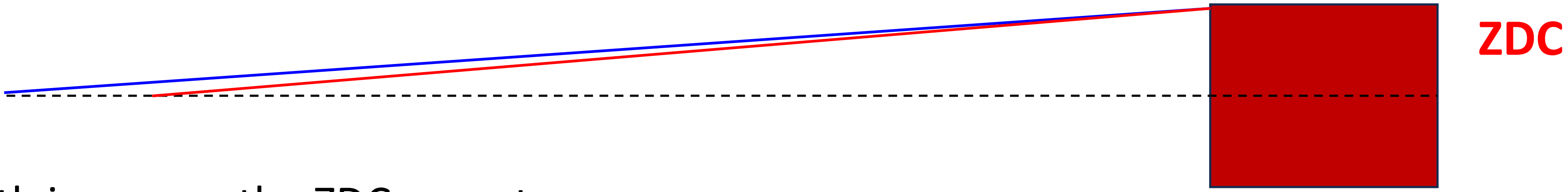
Kaon FF Experiment at EicC

Blue: center detector system
Green: EDT
Magenta: ZDC

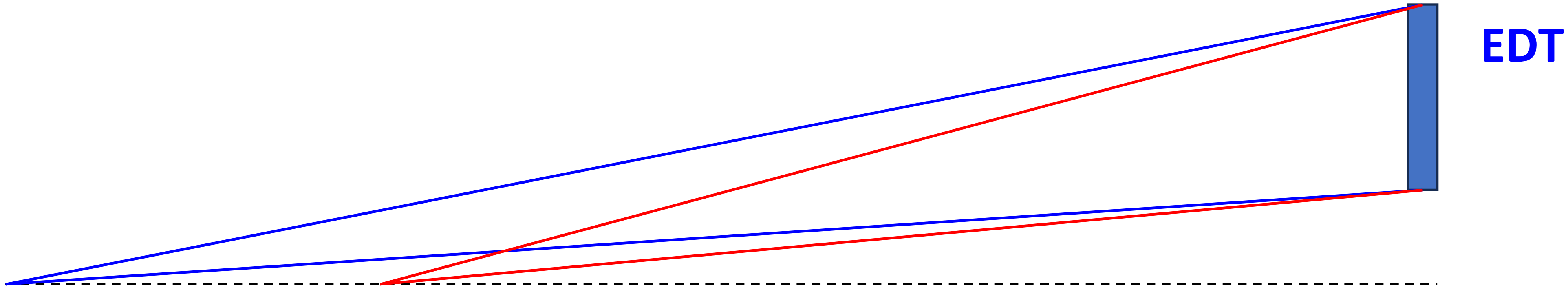
Kinematical distributions of Lamba decays ($p\pi^-$, $n\gamma\gamma$)



Kaon FF Experiment at EicC



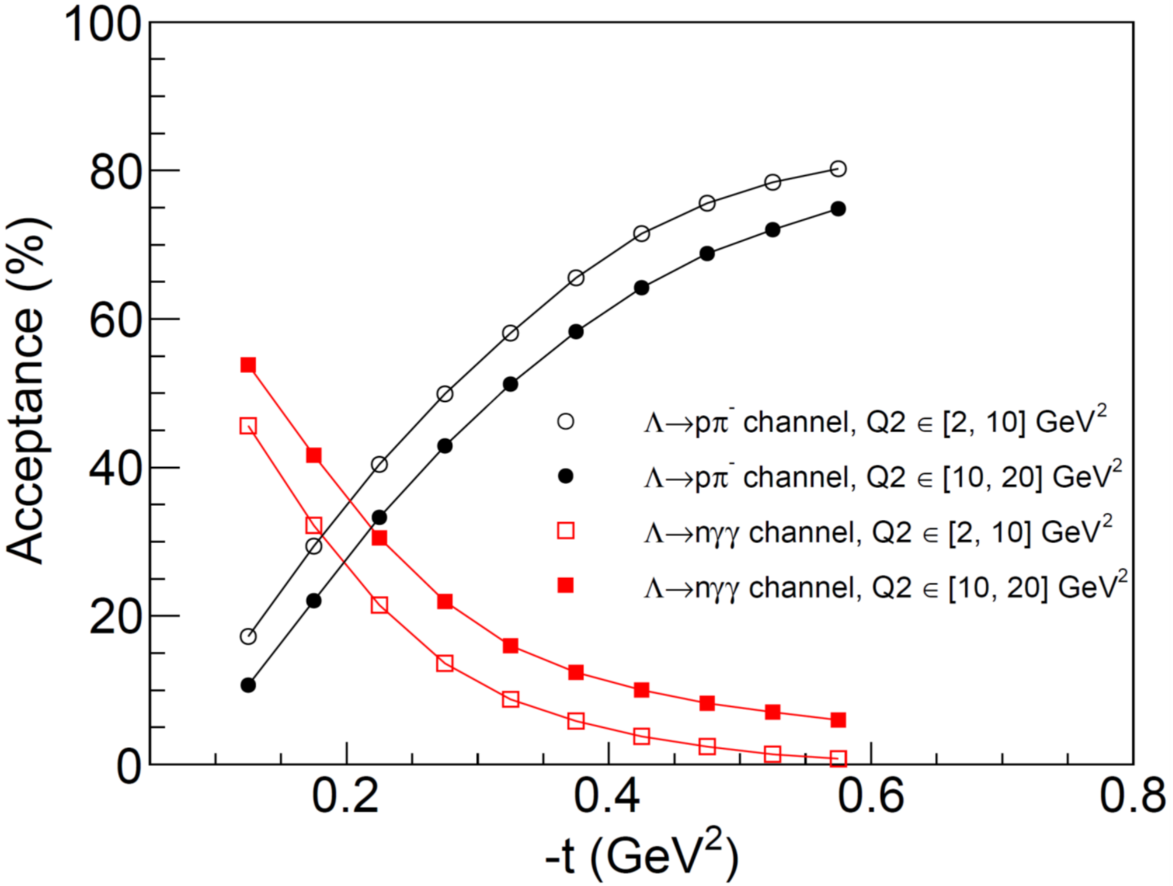
Long Λ decay length increases the ZDC acceptance.



Long Λ decay length reduces the EDT acceptance.

Kaon FF Experiment at EicC

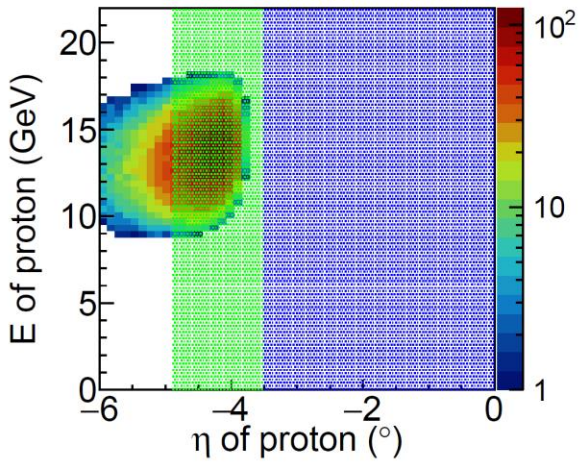
The left plot shows the acceptances of the channel $\mathbf{ep \to eK^{+}\Lambda}$ by measuring the decay protons and decay neutrons. The proton channel and neutron channel are complementary.



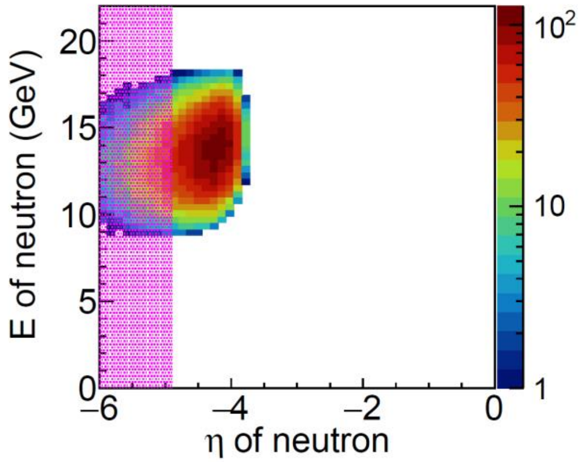
Blue: center detector system

Green: EDT   Magenta: ZDC

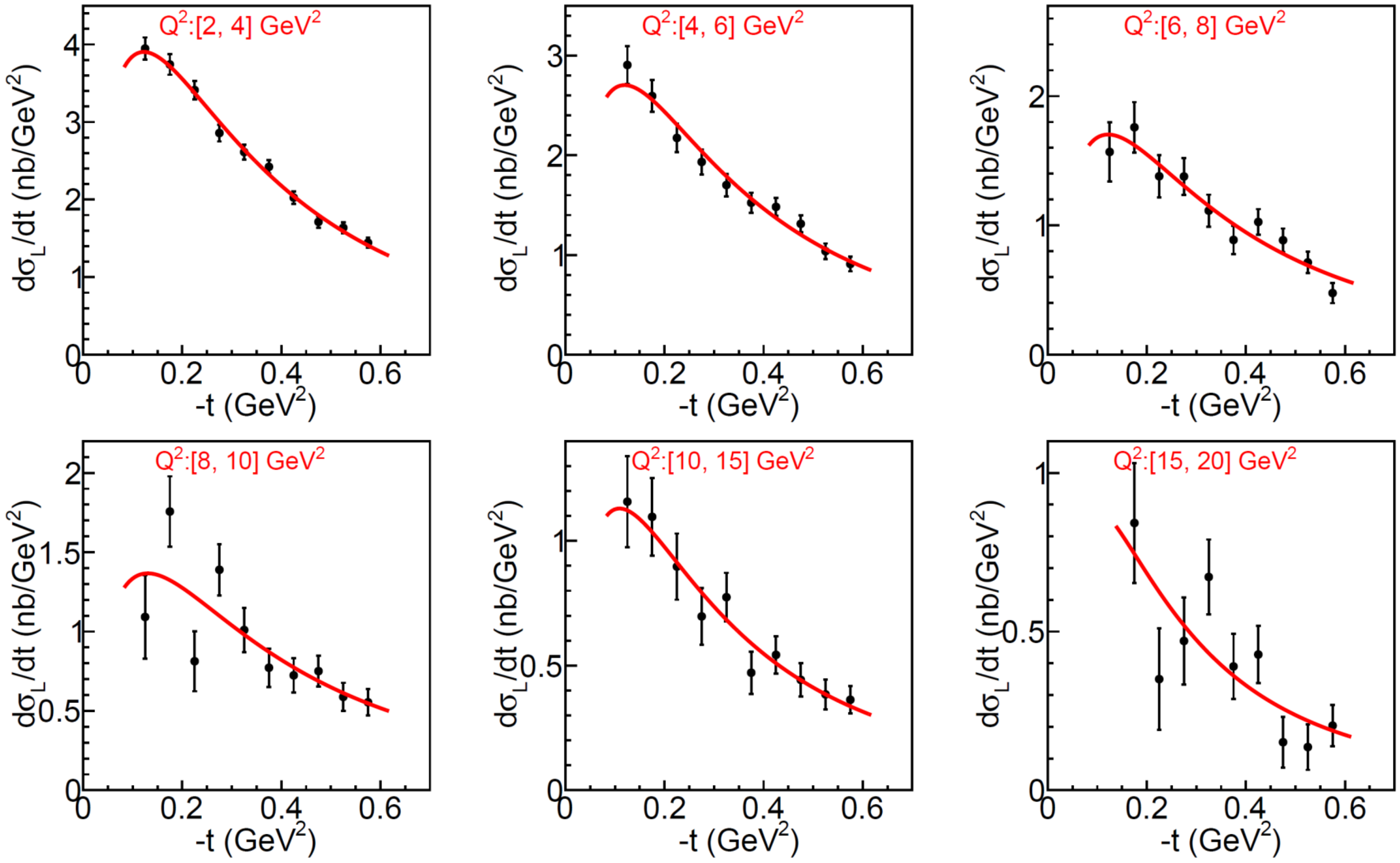
For a little higher |t| events



For very low |t| events



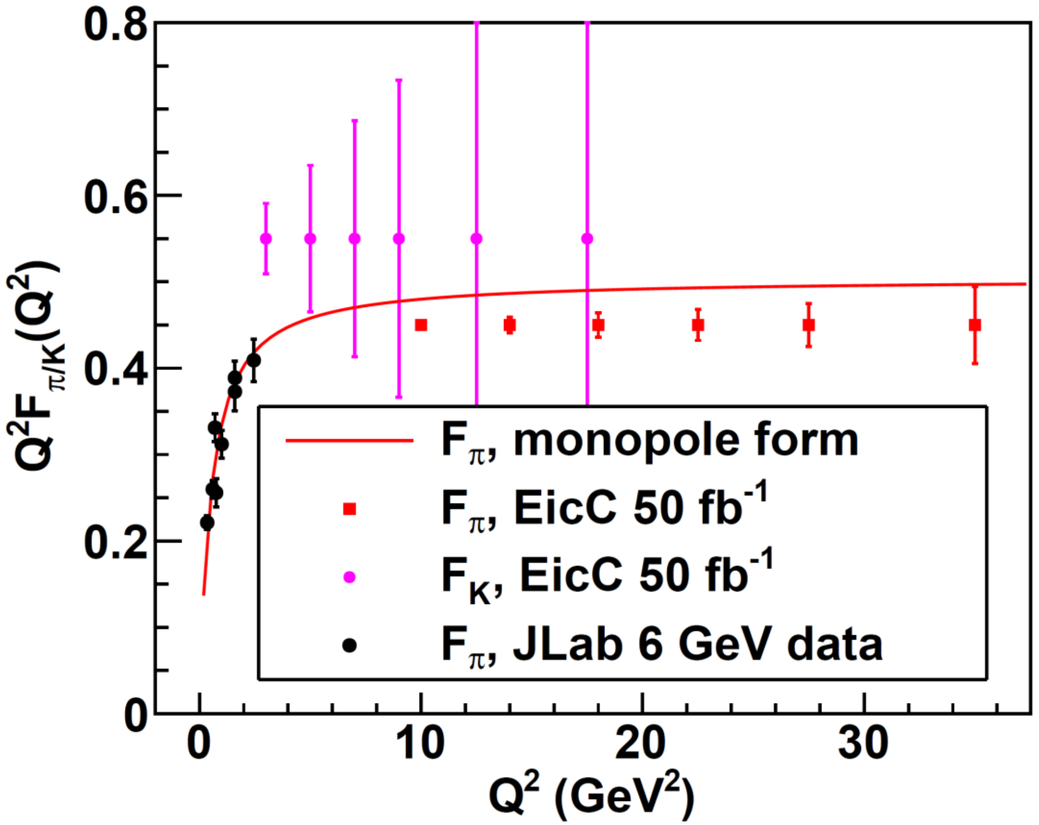
Kaon FF Experiment at EicC



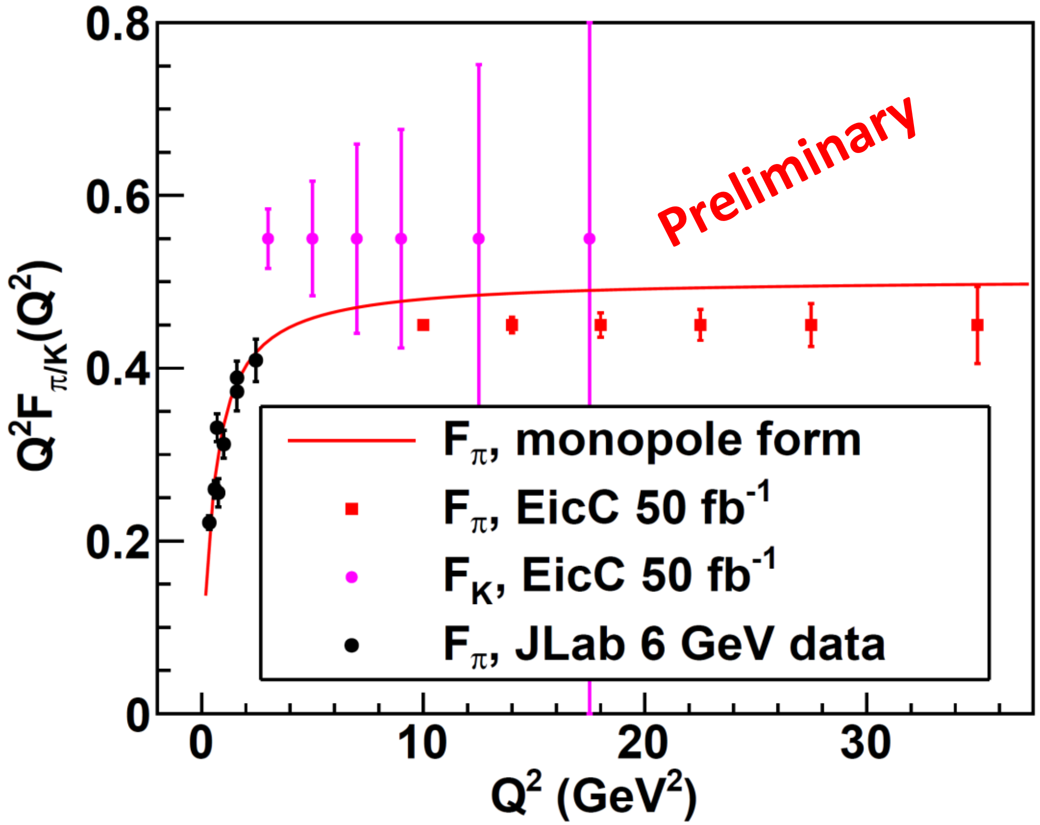
The differential cross sections of $ep \to eK^+\Lambda$ in different Q^2 bins, from measurements of both the proton decay channel and the neutron decay channel of Lambda.

Kaon FF Experiment at EicC

Tagging proton decay channel only



Tagging both proton and neutron decay channels



这里仅仅展示了统计误差预测的初步结果。统计误差会和模型有关，需要更多结果横向比较。
对于Pion的形状因子实验，系统误差可能是主要的误差来源。

Advertisement

https://github.com/rong-wang-impcas/tagged-neutron-DIS

https://github.com/rong-wang-impcas/DEMP-generator-pion-pole-model

https://github.com/rong-wang-impcas/tagged-Lambda-DIS

https://github.com/rong-wang-impcas/DEMP-generator-kaon-pole-model

Keep on updating!

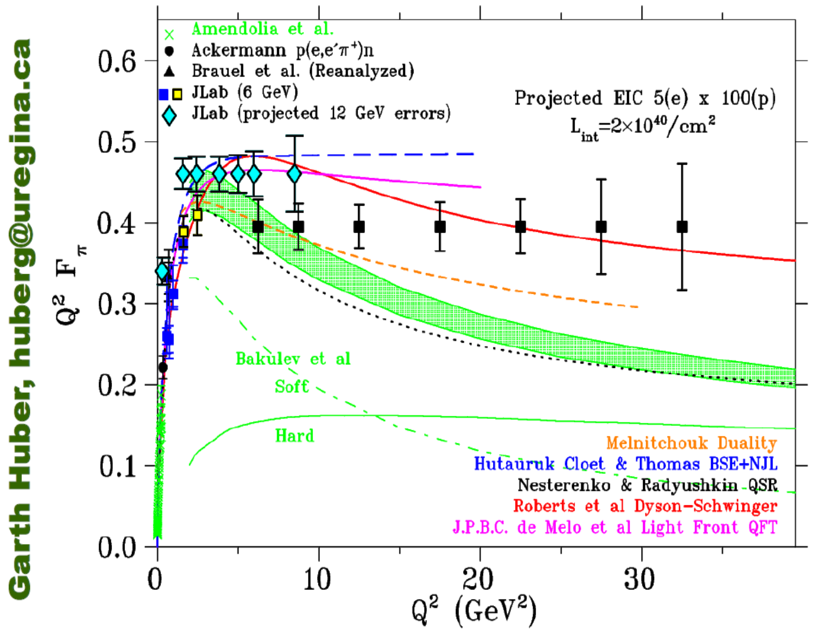
```
PionExclusiveElectroproduction demp_pion;
demp_pion.SetOutputFileName("DEMP-pion-pole-at-EicC.root");
demp_pion.SetEvtFileOutput(1);

demp_pion.SetElecBeamEnergy(3.5);
demp_pion.SetProtBeamEnergy(20);
//demp_pion.SetBeamCrossAngle(0.05);
demp_pion.SetSamplingMode(1);
demp_pion.Generate(20000);
```

Options for output ROOT and evt files

Just modifying the following functions, the users can apply any models they like.

```
double dsigmaT();
double dsigmaL();
double dsigmaTT();
double dsigmaLT();
double d4sigma_dQ2dxBdtdPhi(double Q2, double xB, double t, double Phi);
double d3sigma_dQ2dxBdt(double Q2, double xB, double t);
```

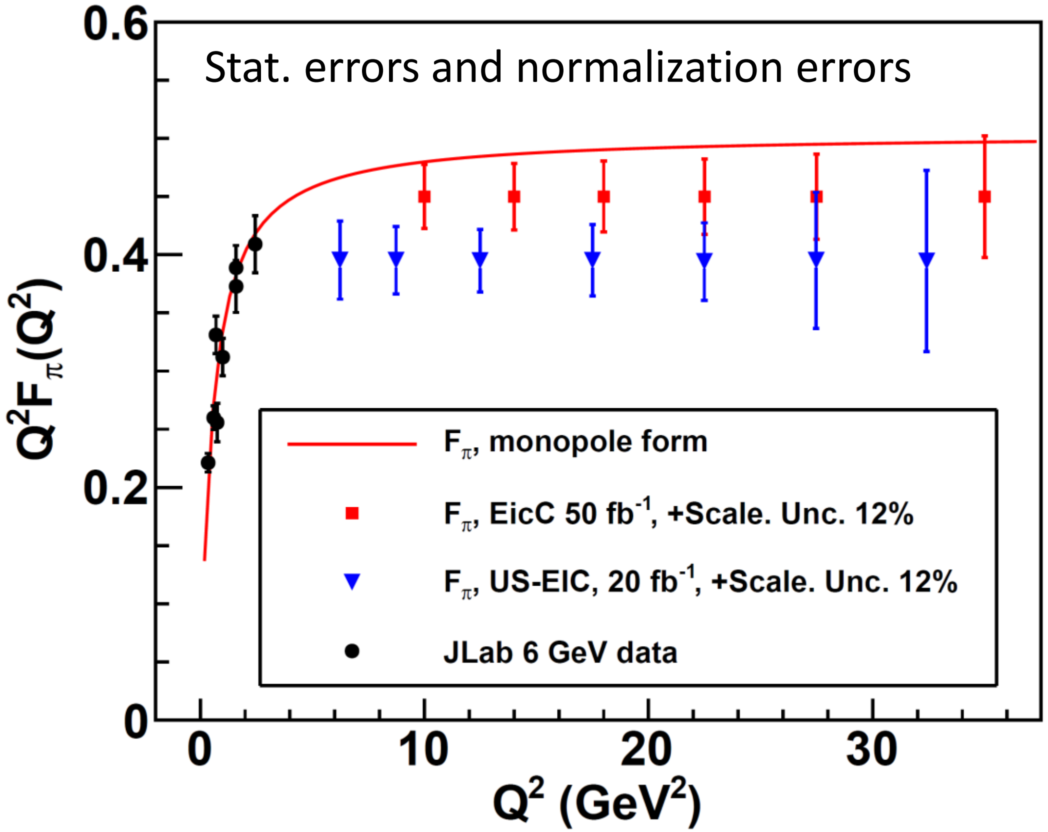
Summary



Assumptions:

- 5(e^-) x 100(p)
- Integrated L=20 fb^{-1}/yr
- Clean identification of exclusive $p(e,e'\pi^+n)$ events
- t reconstruction resolution based on ECCE detector design
- Syst. Unc: 2.5% pt–pt and 12% scale
- $R=\sigma_L/\sigma_T$ =0.013–0.14 at lowest $-t$ from VR model, and $\delta R=R$ syst. unc. in model subtraction to isolate σ_L.
- π pole dominance at small $-t$ confirmed in ^{2}H π^-/π^+ ratios.

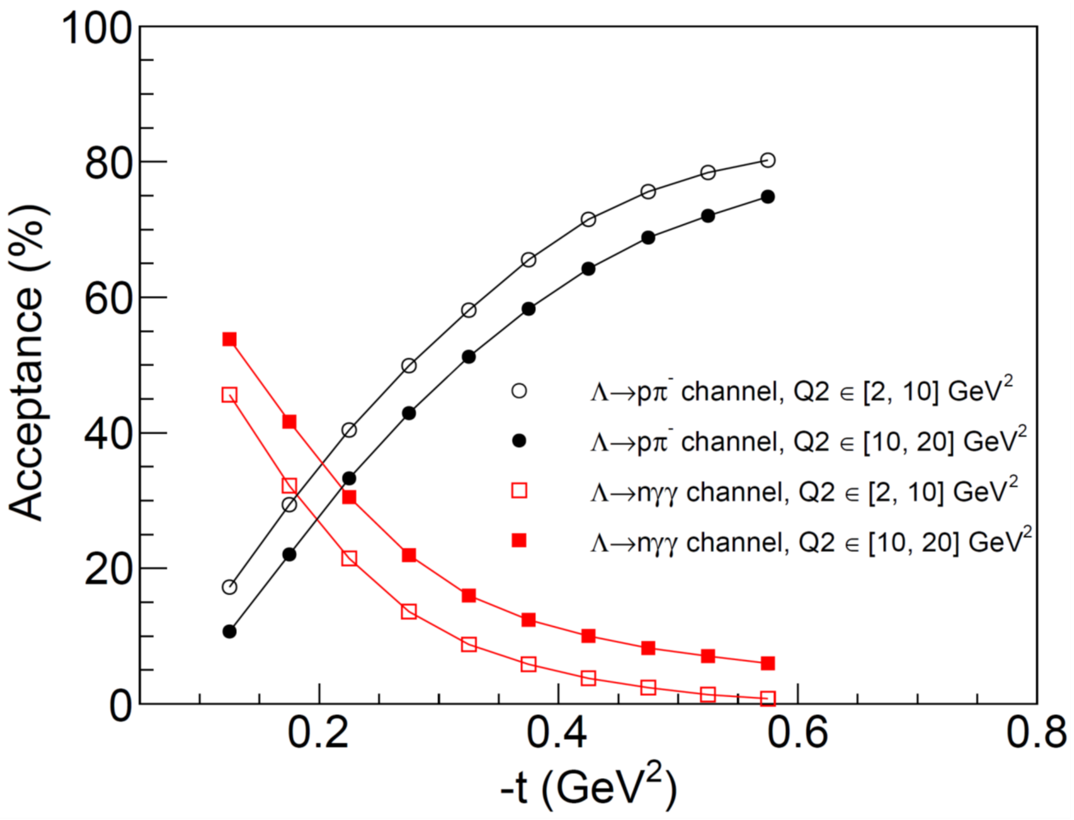
Garth Huber's slide for US-EIC (2022-04-29)

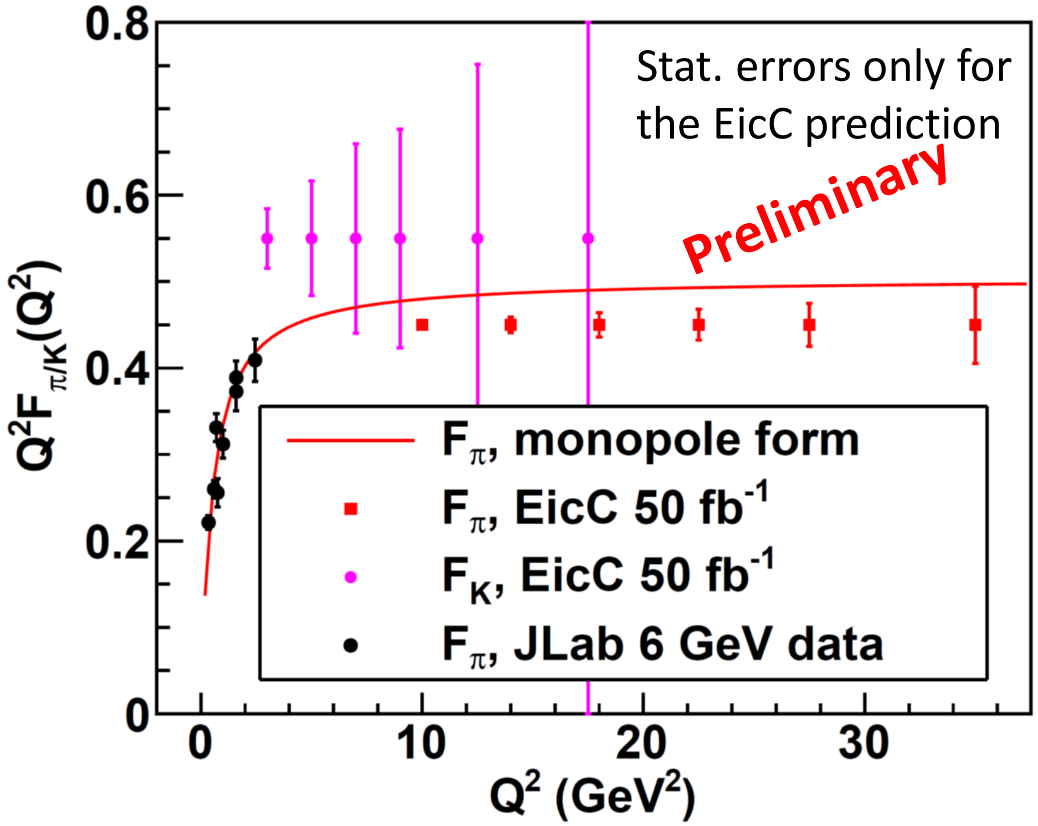


Up-to-date simulation result
With realistic ZDC acceptance

Systematic uncertainty dominates for the measurement!

Summary

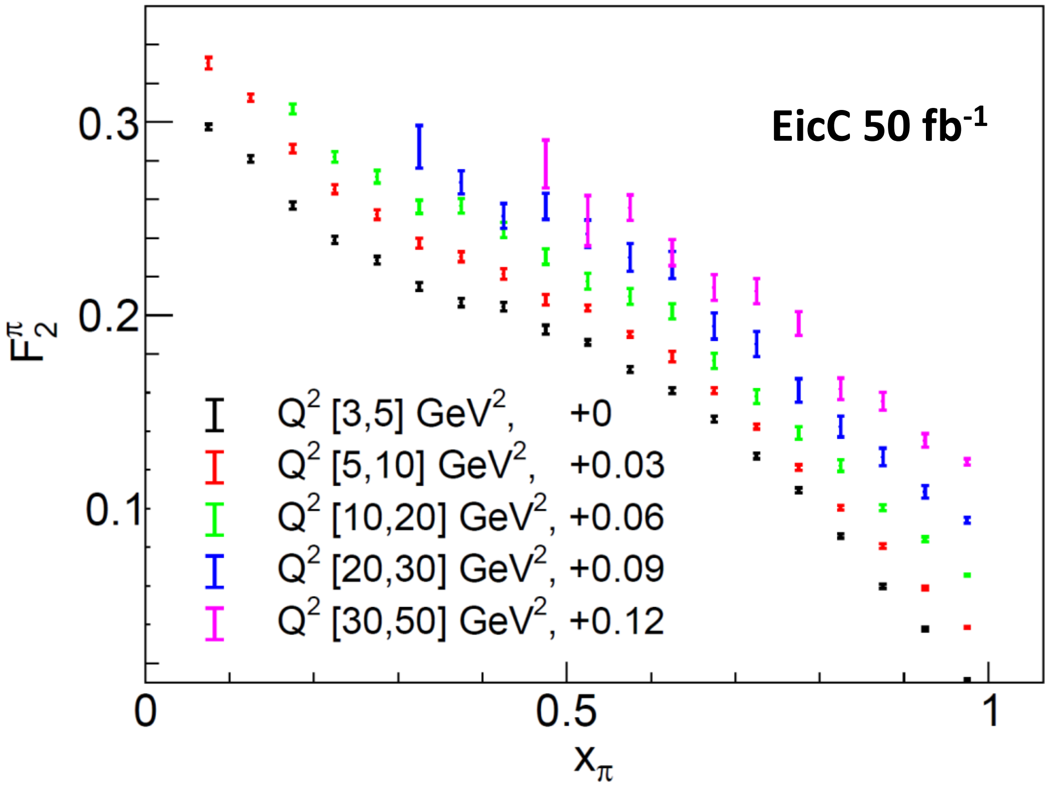




Acceptance for the deep exclusive kaon production process $ep \rightarrow eK^+\Lambda$ at EicC. This result should have small model dependence, as it is pure geometric.

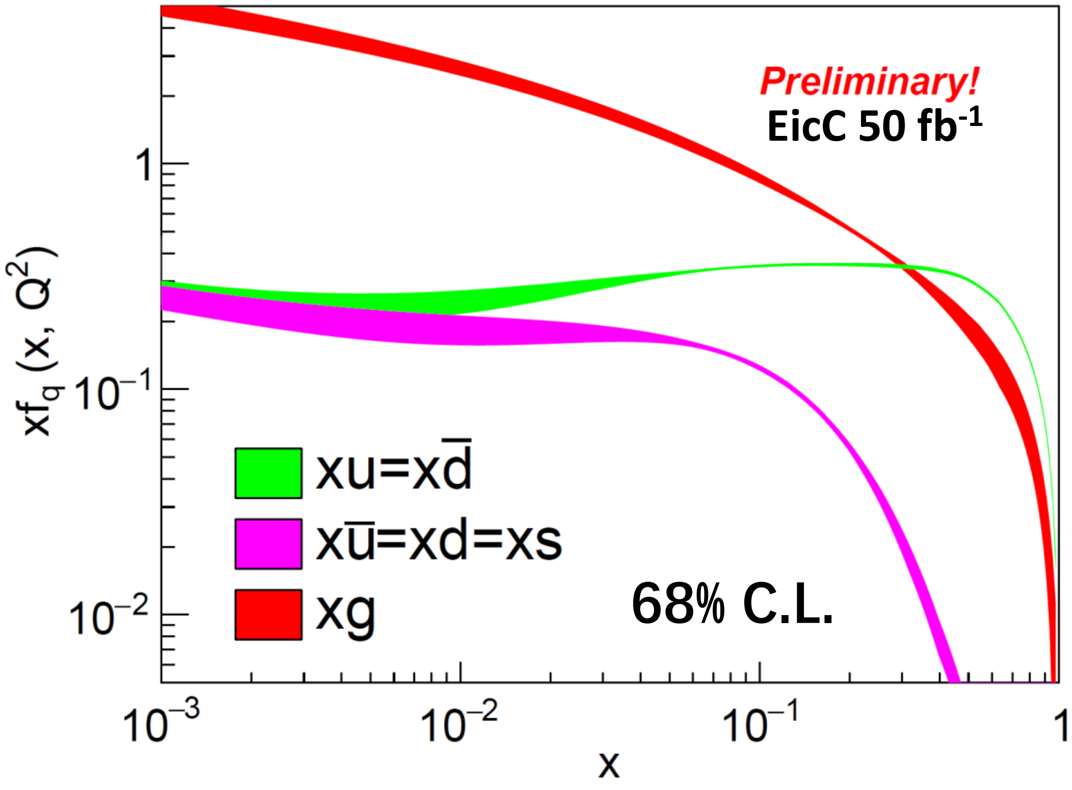
The statistic error projection for the kaon form factor at EicC, updated with the current designs of ZDC and EDT. This result is model-dependent.

Summary



Pion structure function extracted from differential cross sections (stat. errors only)

[Please find more information from the talk in the last CDR workshop and R. Wang, W. Xiong, Y. Liang, X. Chen, Few Body Syst. 64 (2023) 28]



Pion PDFs determined by a QCD analysis of the pseudo-data (for π^+ meson, at $Q^2 = 10$ GeV²)

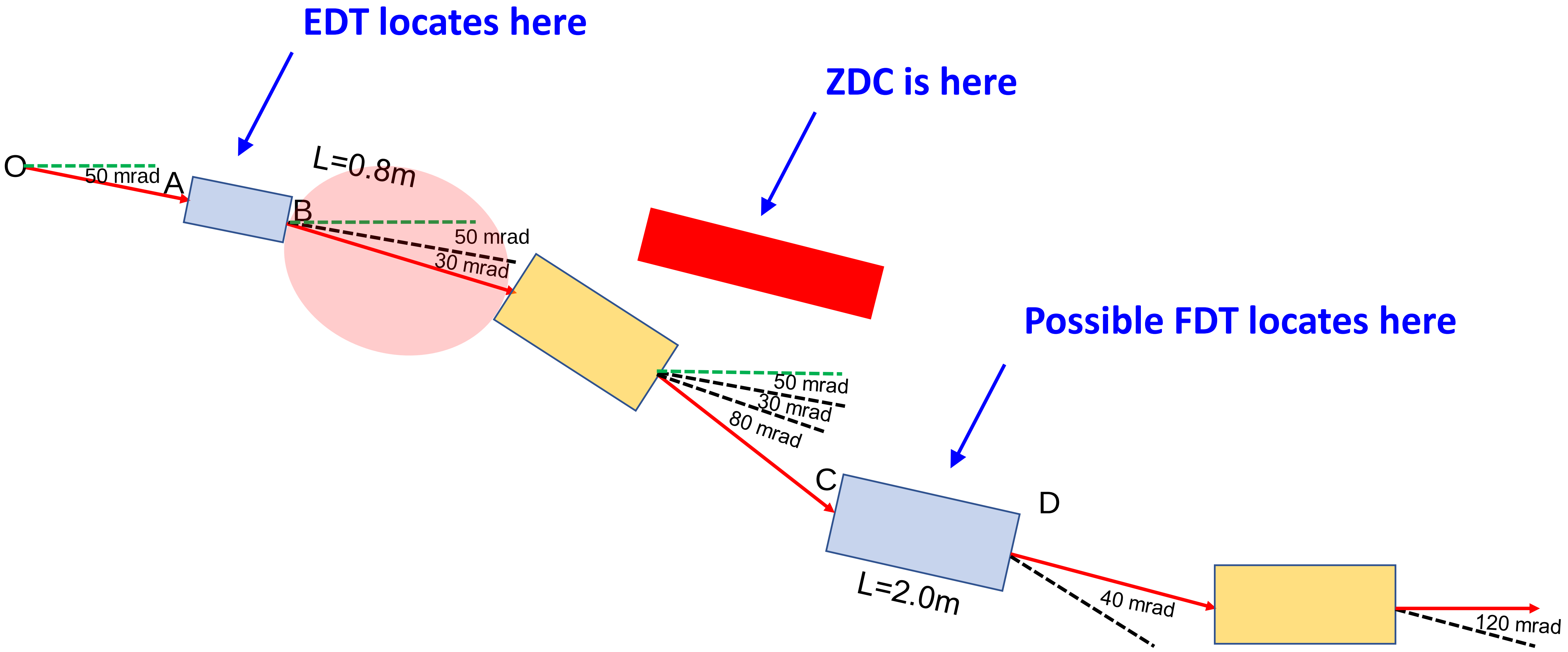
Summary and Outlook

- The feasibilities of the meson structure experiments at EicC are studied, and the statistical error projections are given.

- Controlling the systematical errors are very challenging. Without any corrections, the systematic errors from ZDC would be around 20%. We need more studies on the ZDC performance in the future.

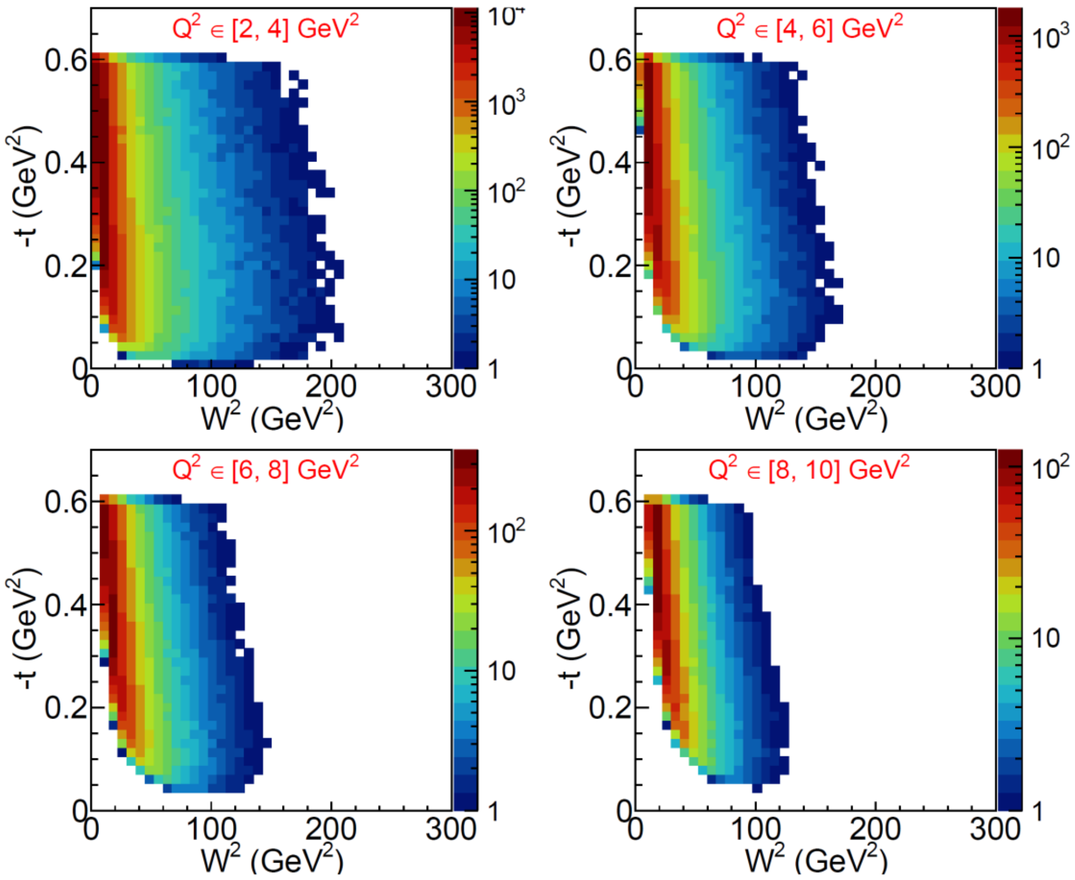
- The systematic uncertainty from the background contamination also should be studied in the future.

Backup: Ion Forward Detector Complex

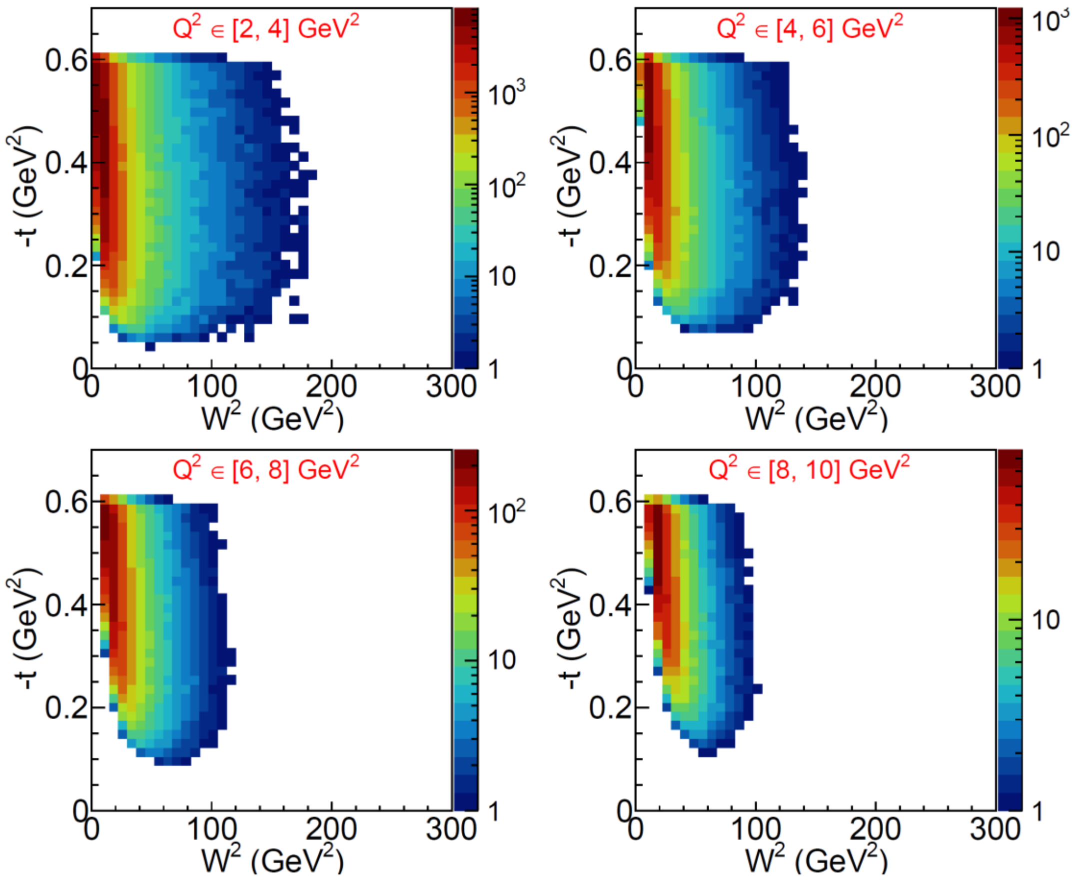


Backup: Kaon FF Experiment at EicC

Without detector acceptance

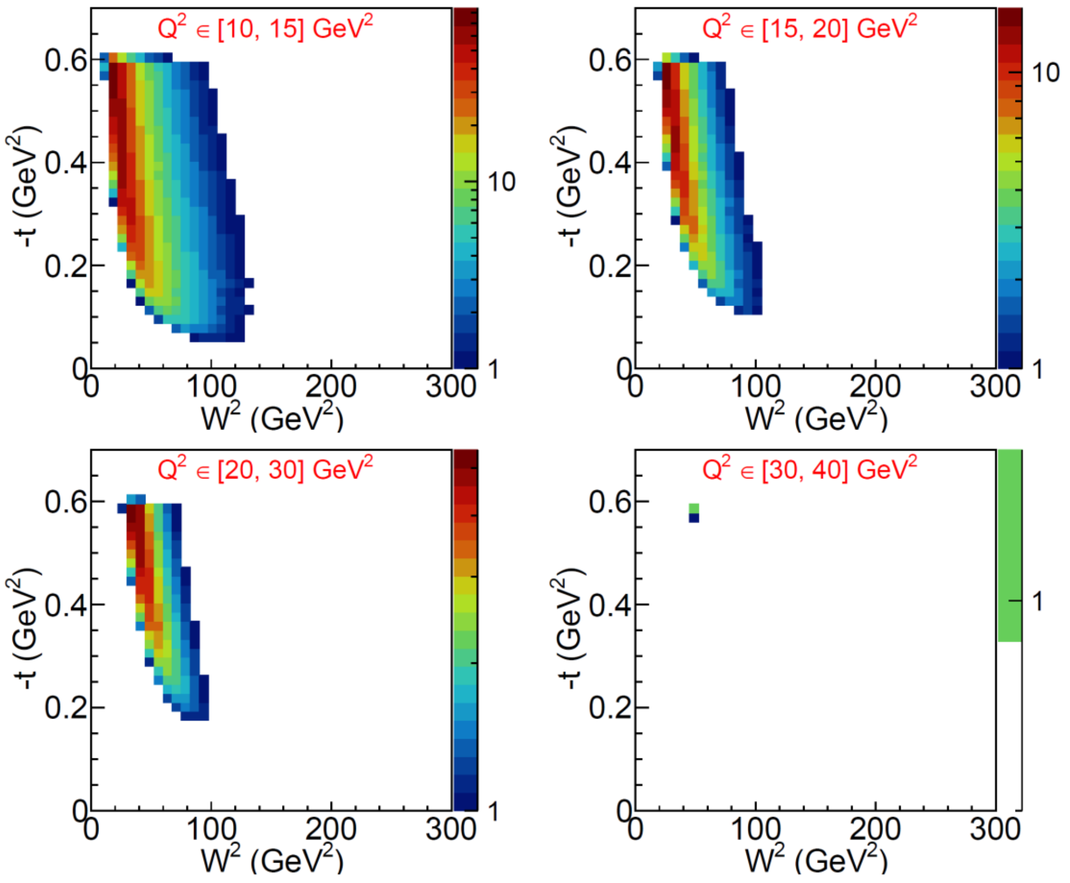


With detector acceptance

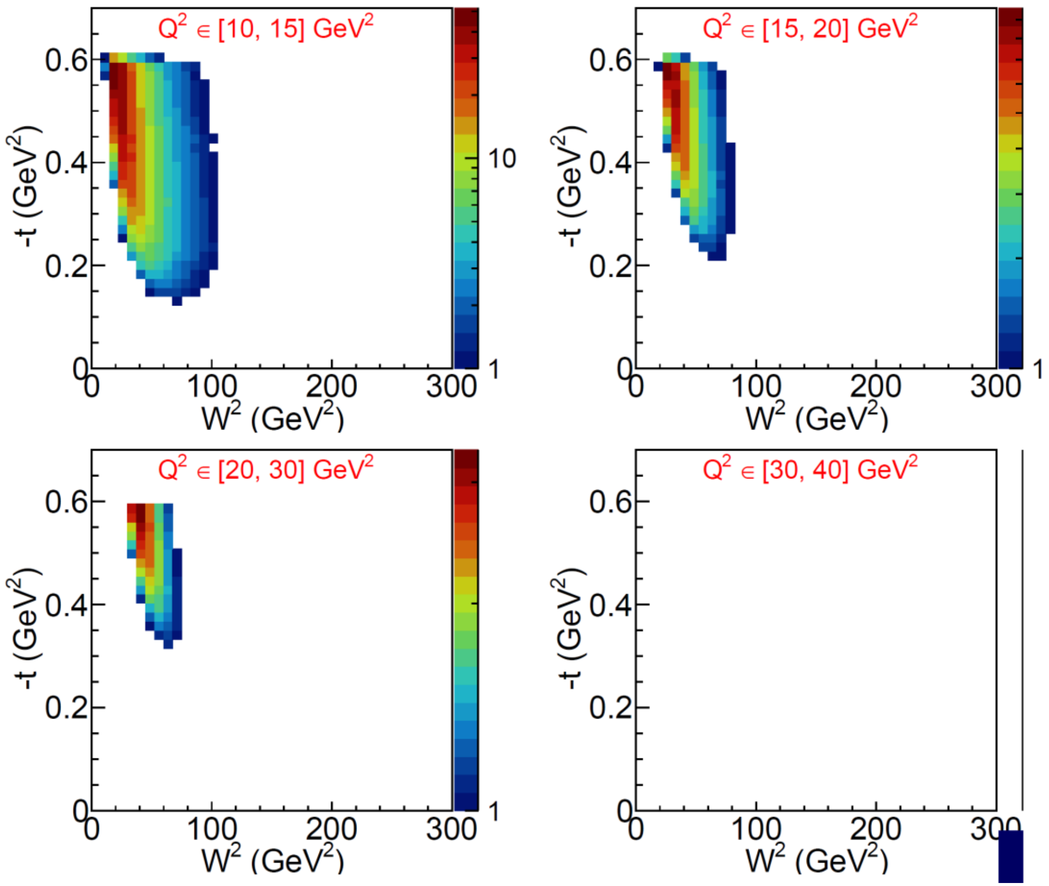


Backup: Kaon FF Experiment at EicC

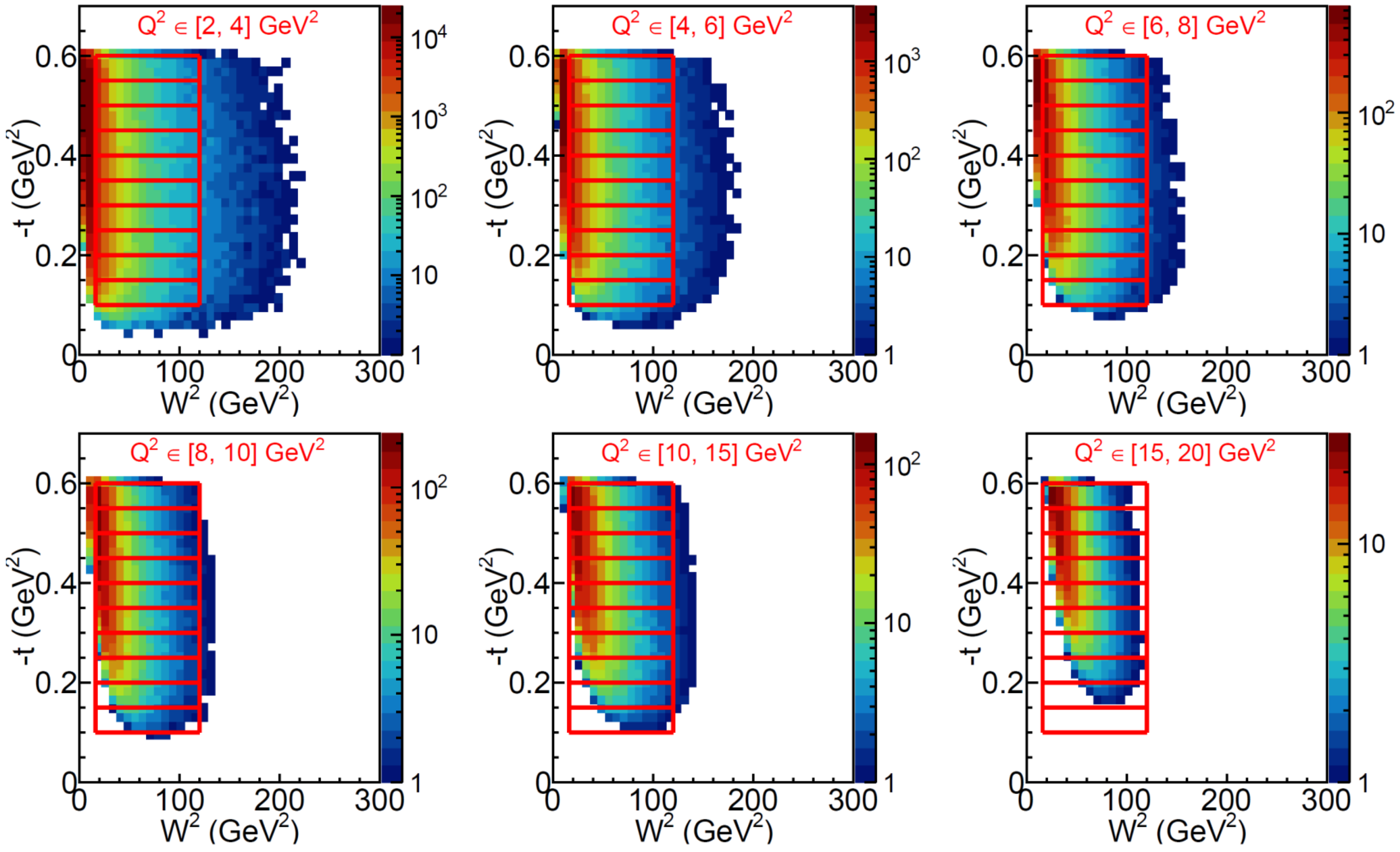
Without detector acceptance



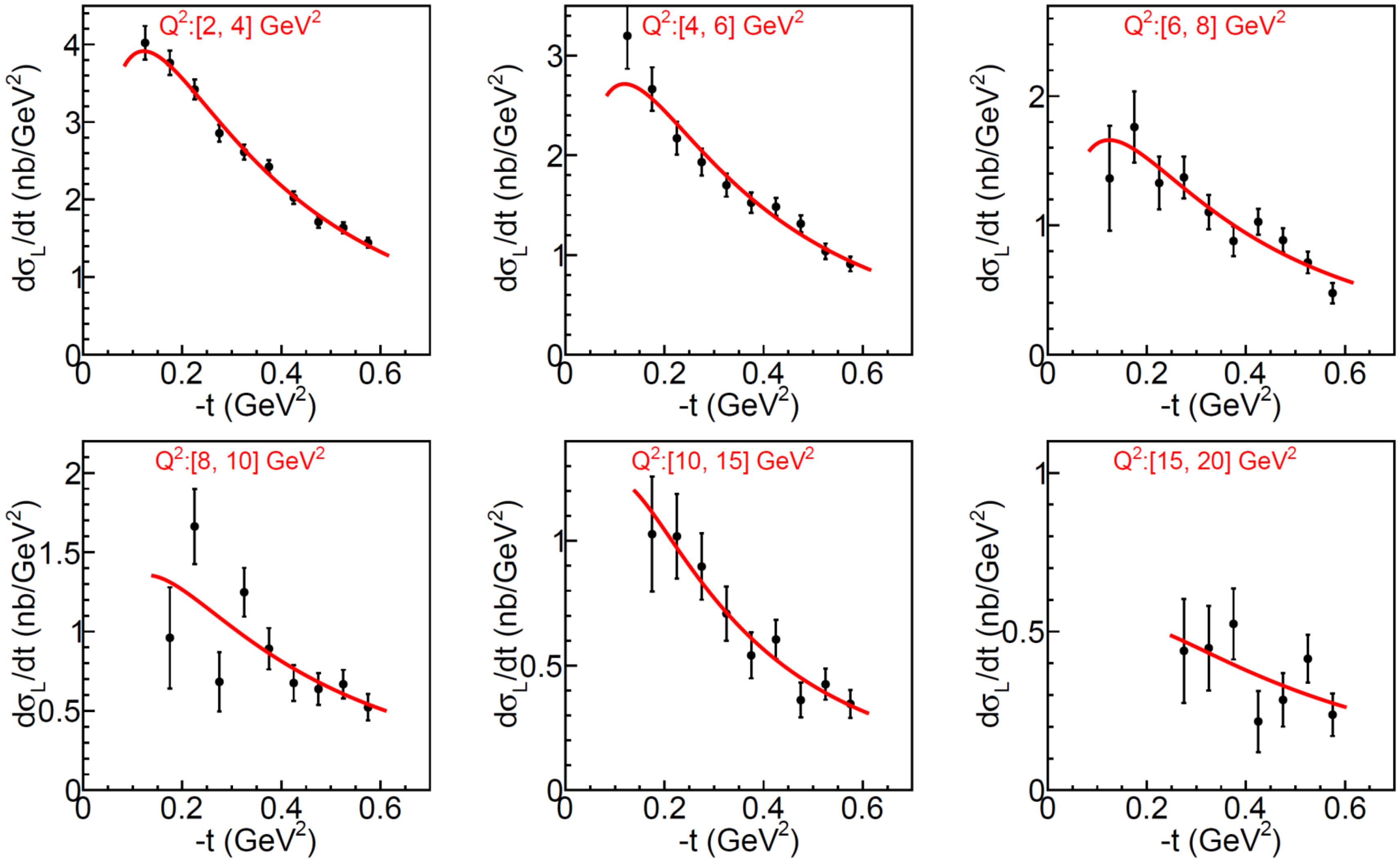
With detector acceptance



Backup: Kaon FF Experiment at EicC

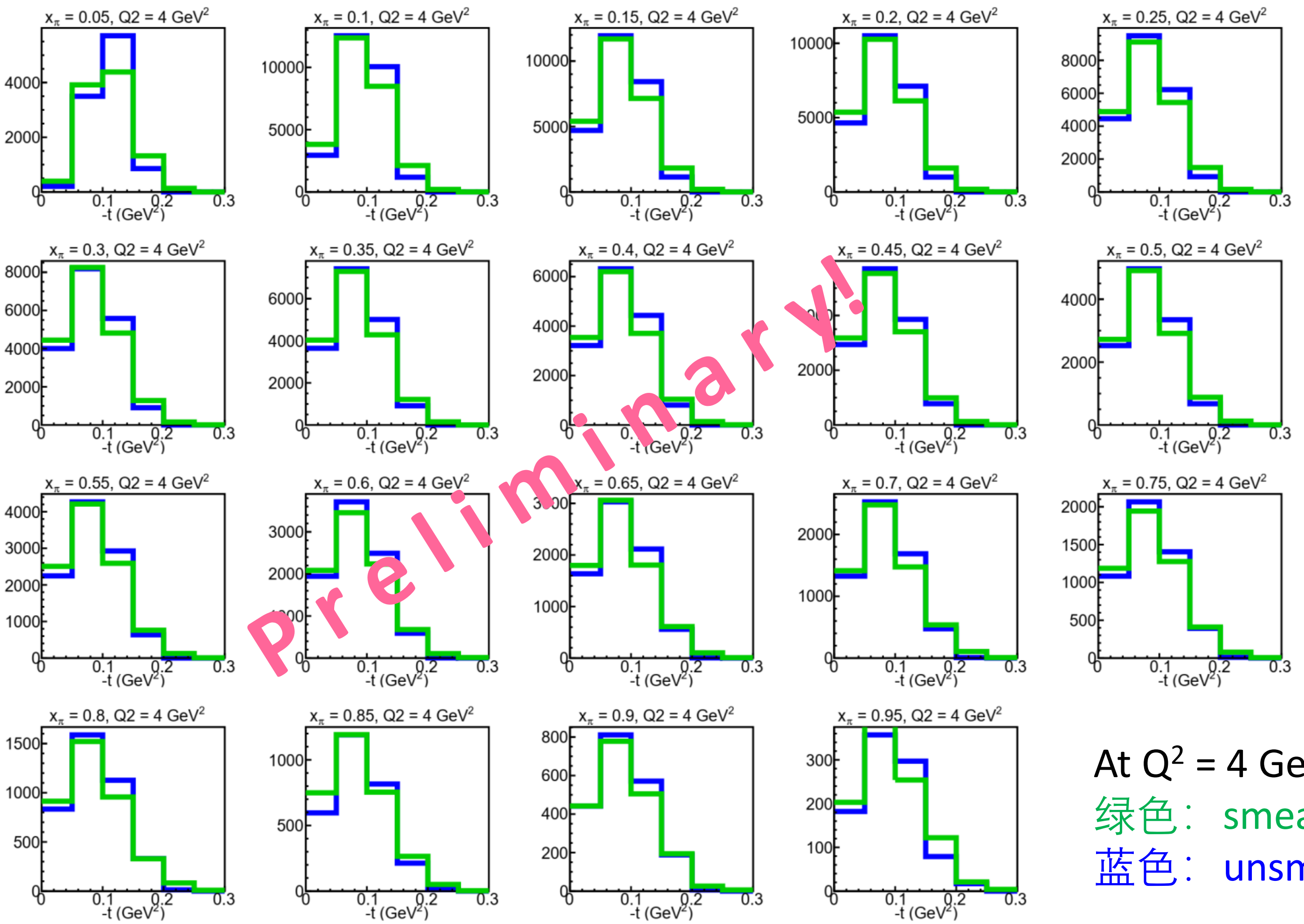


Backup: Kaon FF Experiment at EicC



The differential cross sections of $\mathbf{ep \rightarrow eK^{+}\Lambda}$ in different $\mathbf{Q^2}$ bins, from measurements of only the proton decay channel of Lambda.

Backup: ZDC Resolution Induced Uncertainty on the pion SF Extraction



At Q^2 = 4 GeV^2

绿色： smeared

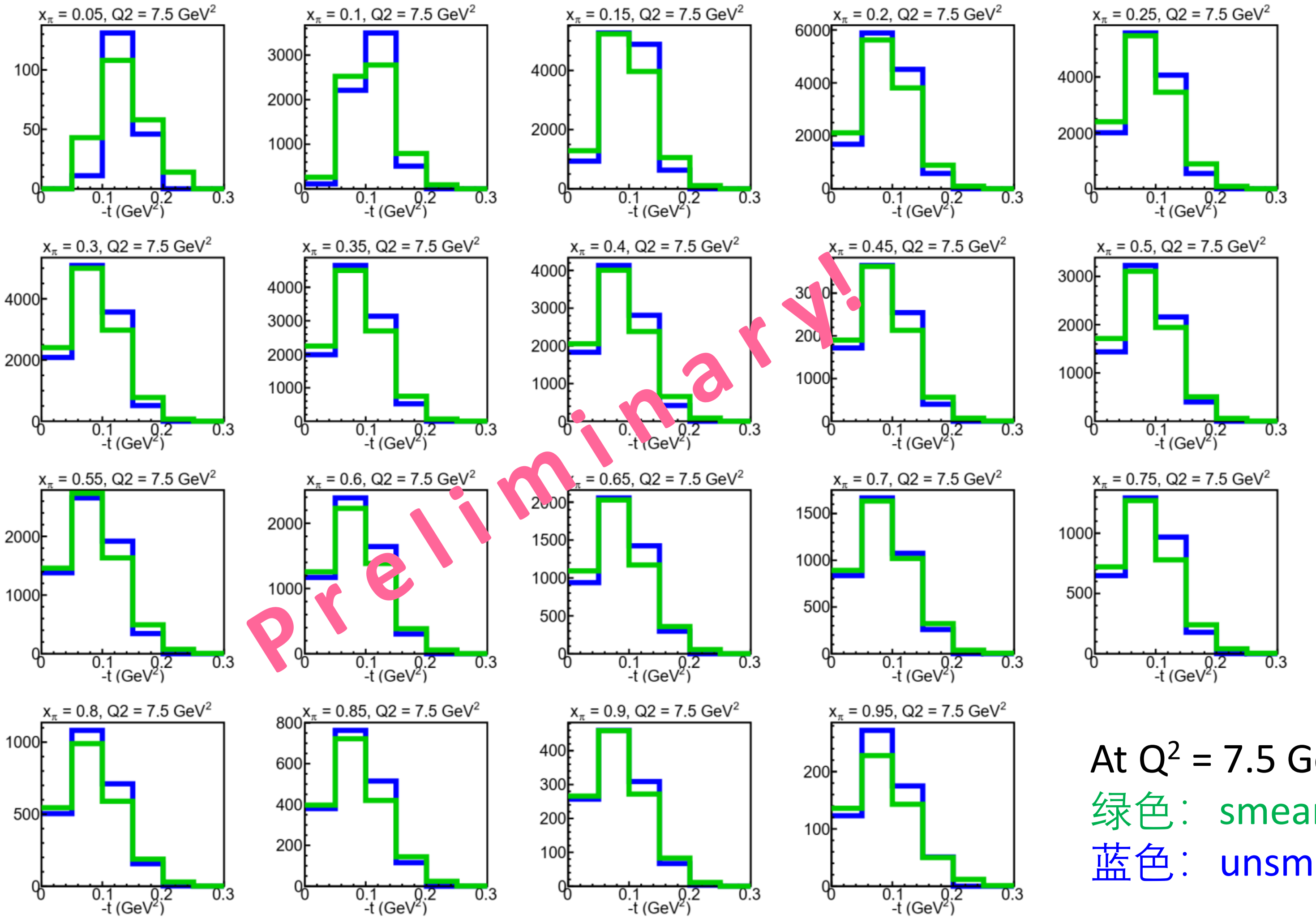
蓝色： unmeared

Q^2 = 4 GeV^2

典型的动量转移t的相对误差为$\sqrt{2} \times 14.5\% = 21\%$

初步MC研究表明，由于我们ZDC测量到的t的范围较小，t变量21%的相对误差导致提取到的结构函数有6-19%的系统误差！

Backup: ZDC Resolution Induced Uncertainty on the pion SF Extraction



At Q^2 = 7.5 GeV^2

绿色： smeared

蓝色： unsmeared

Q^2 = 7.5 GeV^2

典型的动量转移t的相对误差为$\sqrt{2} \times 14.5\% = 21\%$

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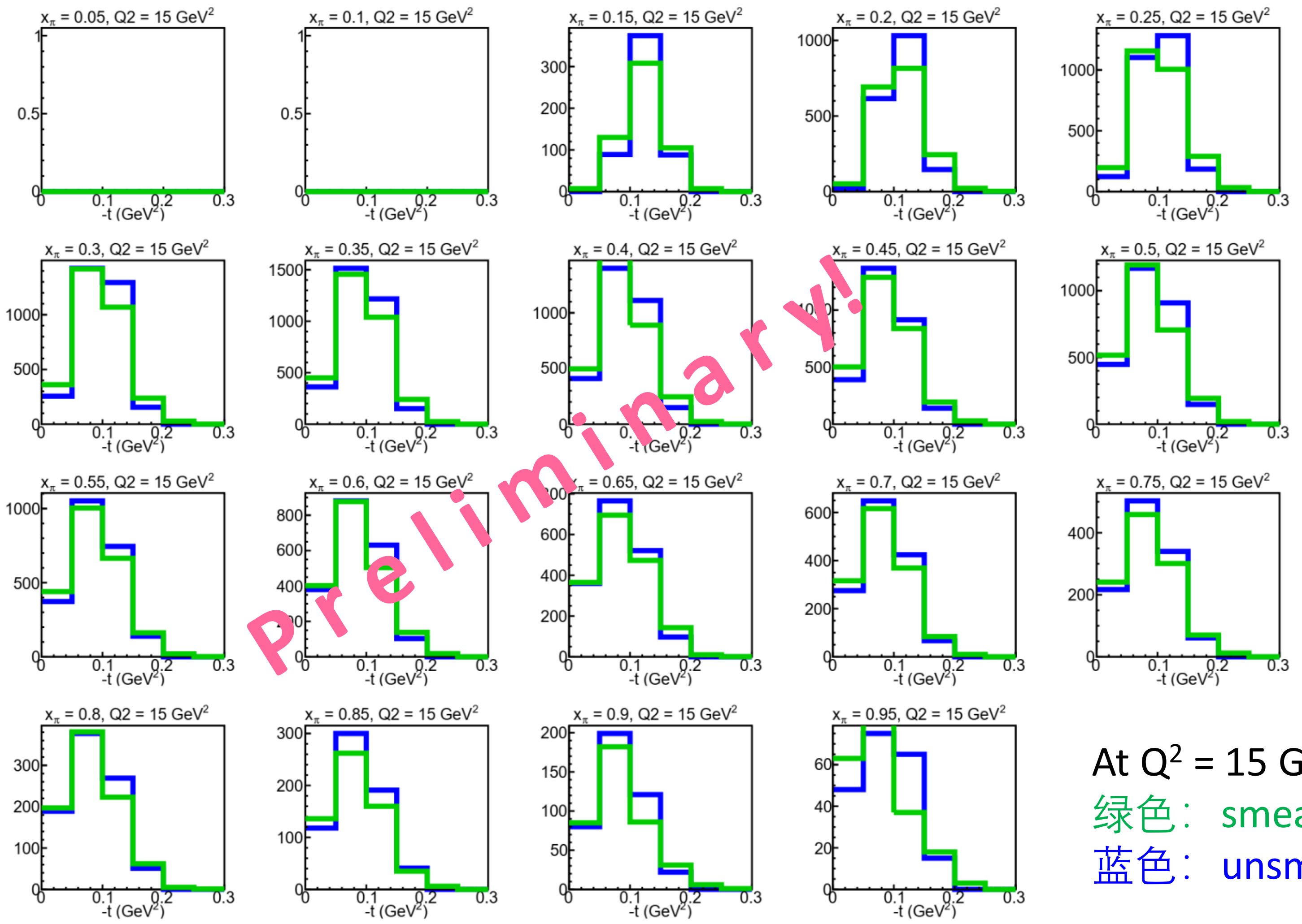
Backup: ZDC Resolution Induced Uncertainty on the pion SF Extraction



At Q^2 = 15 GeV^2

绿色： smeared

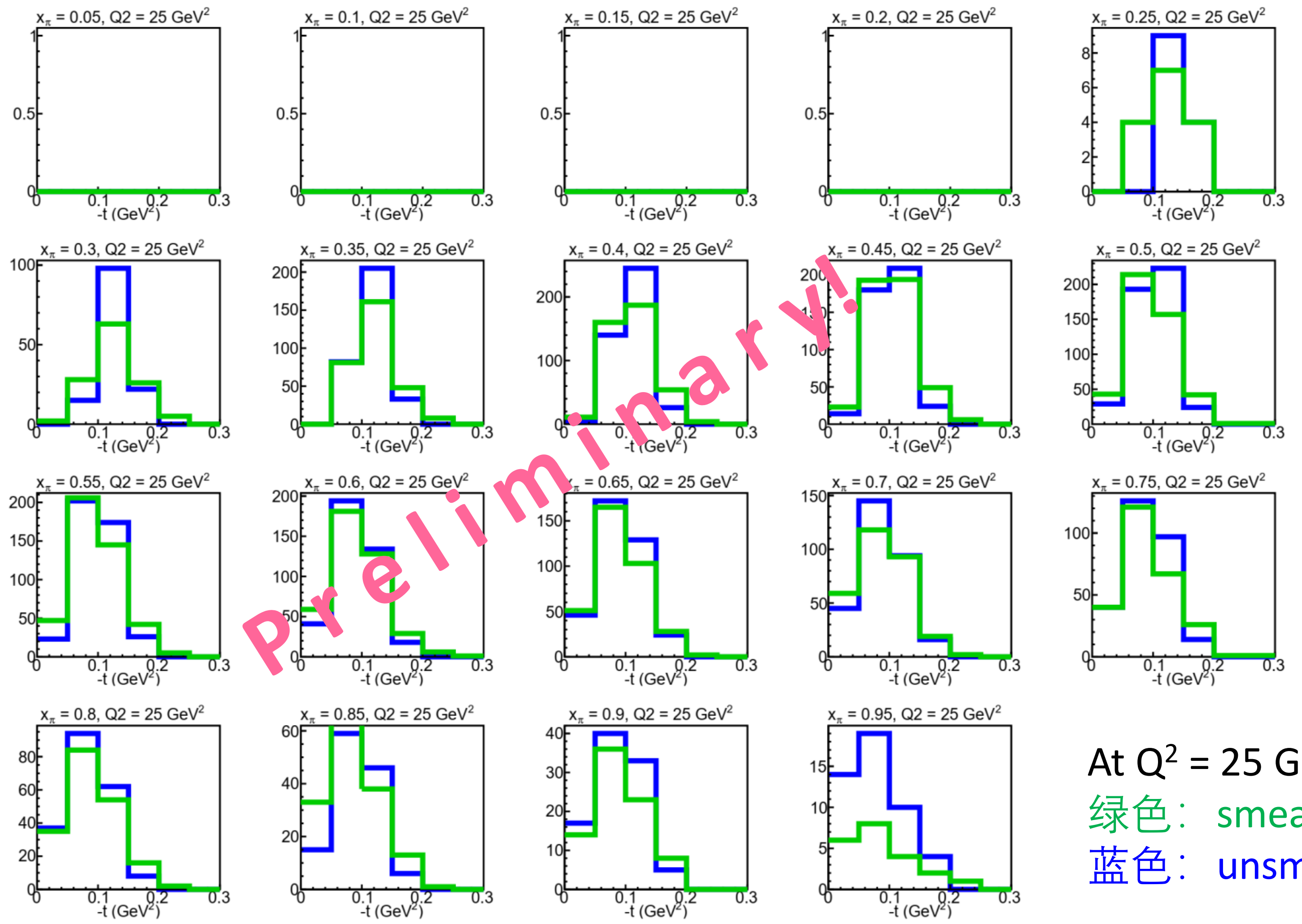
蓝色： unsmeared

Q^2 = 15 GeV^2

典型的动量转移t的相对误差为$\sqrt{2} \times 14.5\% = 21\%$

初步MC研究表明，由于我们ZDC测量到的t的范围较小，t变量21%的相对误差导致提取到的结构函数有7-22%的系统误差！

Backup: ZDC Resolution Induced Uncertainty on the pion SF Extraction



At Q^2 = 25 GeV^2

绿色： smeared

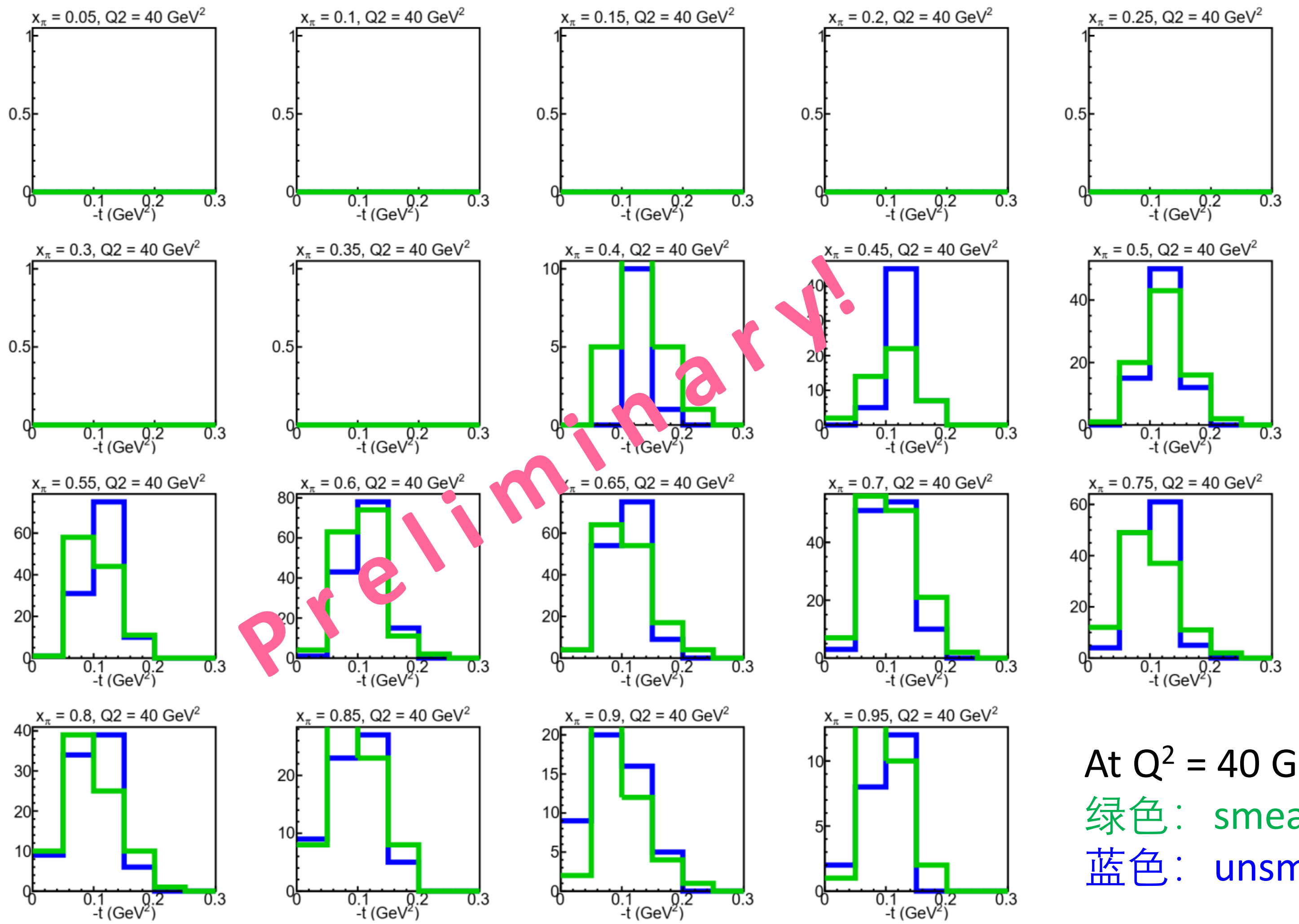
蓝色： unsmeared

Q^2 = 25 GeV^2

典型的动量转移t的相对误差为$\sqrt{2} \times 14.5\% = 21\%$

初步MC研究表明，由于我们ZDC测量到的t的范围较小，t变量21%的相对误差导致提取到的结构函数有10-60%的系统误差！

Backup: ZDC Resolution Induced Uncertainty on the pion SF Extraction



At Q^2 = 40 GeV^2

绿色： smeared

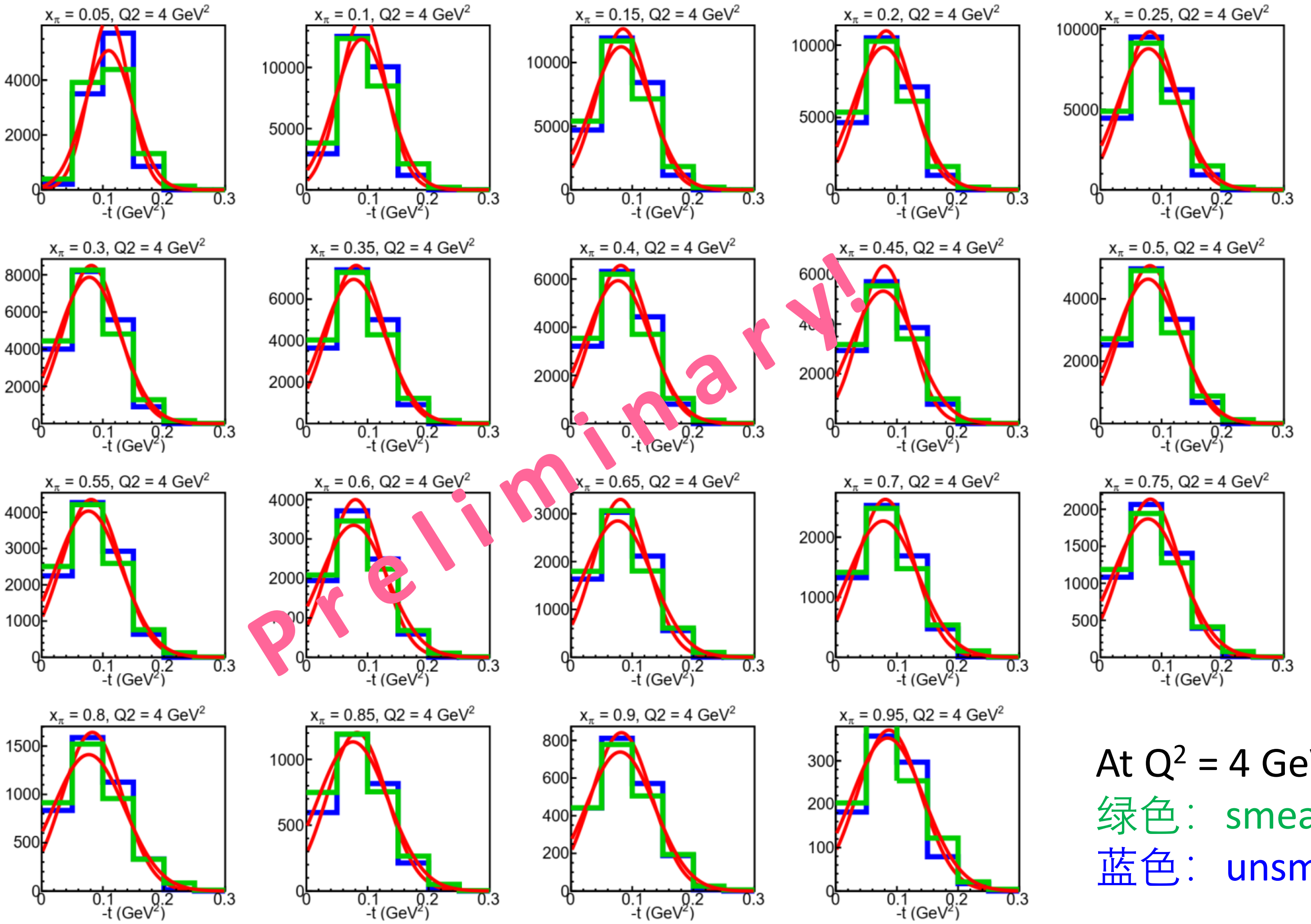
蓝色： unsmeared

Q^2 = 40 GeV^2

典型的动量转移t的相对误差为$\sqrt{2} \times 14.5\%$ = 21%

初步MC研究表明，由于我们ZDC测量到的t的范围较小，t变量21%的相对误差导致提取到的结构函数有10-50%的系统误差！

Backup: ZDC Resolution Induced Uncertainty on the pion SF Extraction



At Q^2 = 4 GeV^2

绿色： smeared

蓝色： unsmeared

Q^2 = 4 GeV^2

典型的动量转移t的相对误差为$\sqrt{2} \times 14.5\% = 21\%$

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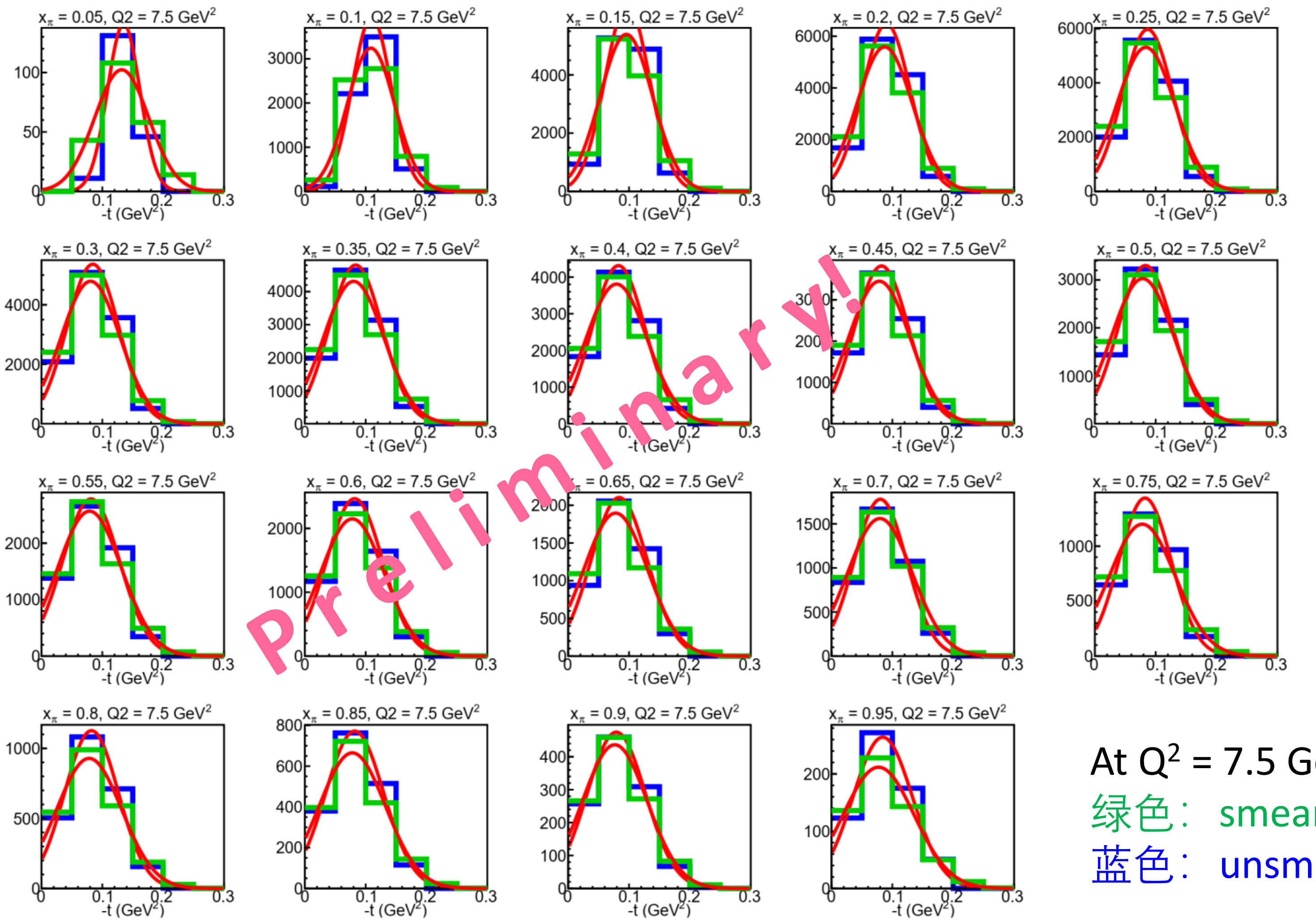
Backup: ZDC Resolution Induced Uncertainty on the pion SF Extraction



At Q^2 = 7.5 GeV^2
绿色： smeared
蓝色： unsmeared

Q^2 = 7.5 GeV^2

典型的动量转移t的相对误差为$\sqrt{2} \times 14.5\% = 21\%$

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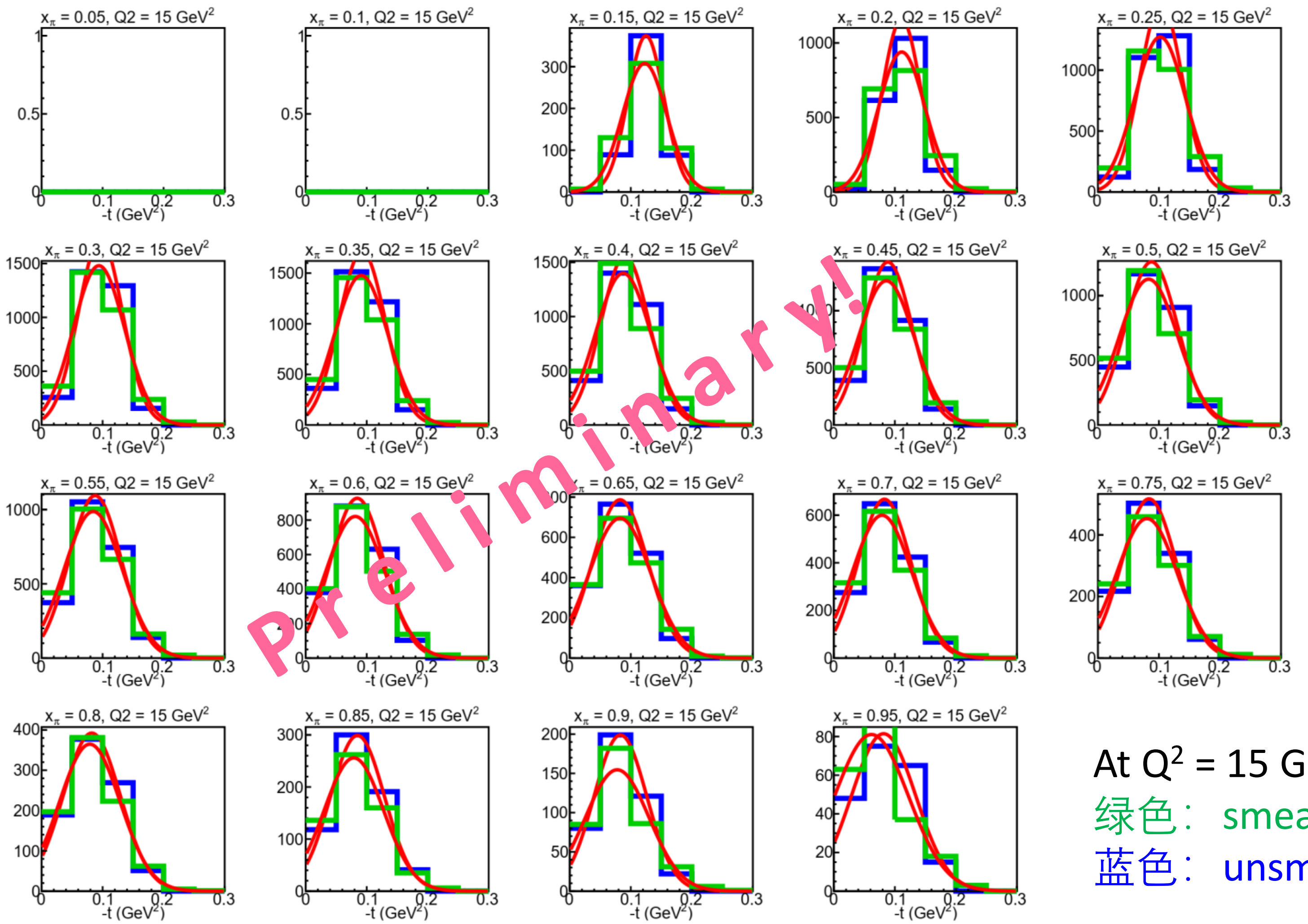
Backup: ZDC Resolution Induced Uncertainty on the pion SF Extraction



At Q^2 = 15 GeV^2
绿色： smeared
蓝色： unsmeared

Q^2 = 15 GeV^2

典型的动量转移t的相对误差为$\sqrt{2} \times 14.5\% = 21\%$

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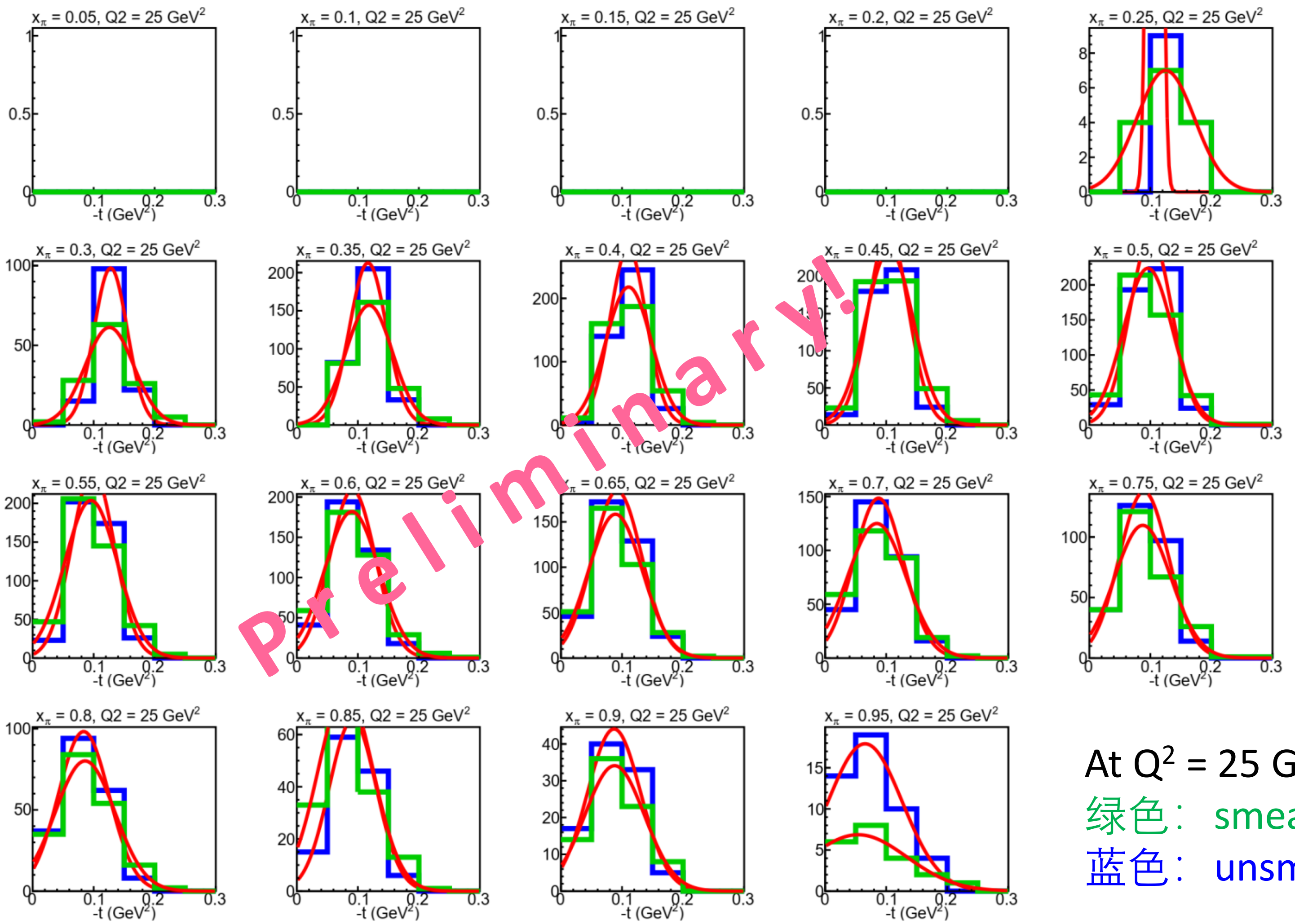
Backup: ZDC Resolution Induced Uncertainty on the pion SF Extraction



At Q^2 = 25 GeV^2
绿色： smeared
蓝色： unsmeared

Q^2 = 25 GeV^2

典型的动量转移t的相对误差为$\sqrt{2} \times 14.5\% = 21\%$

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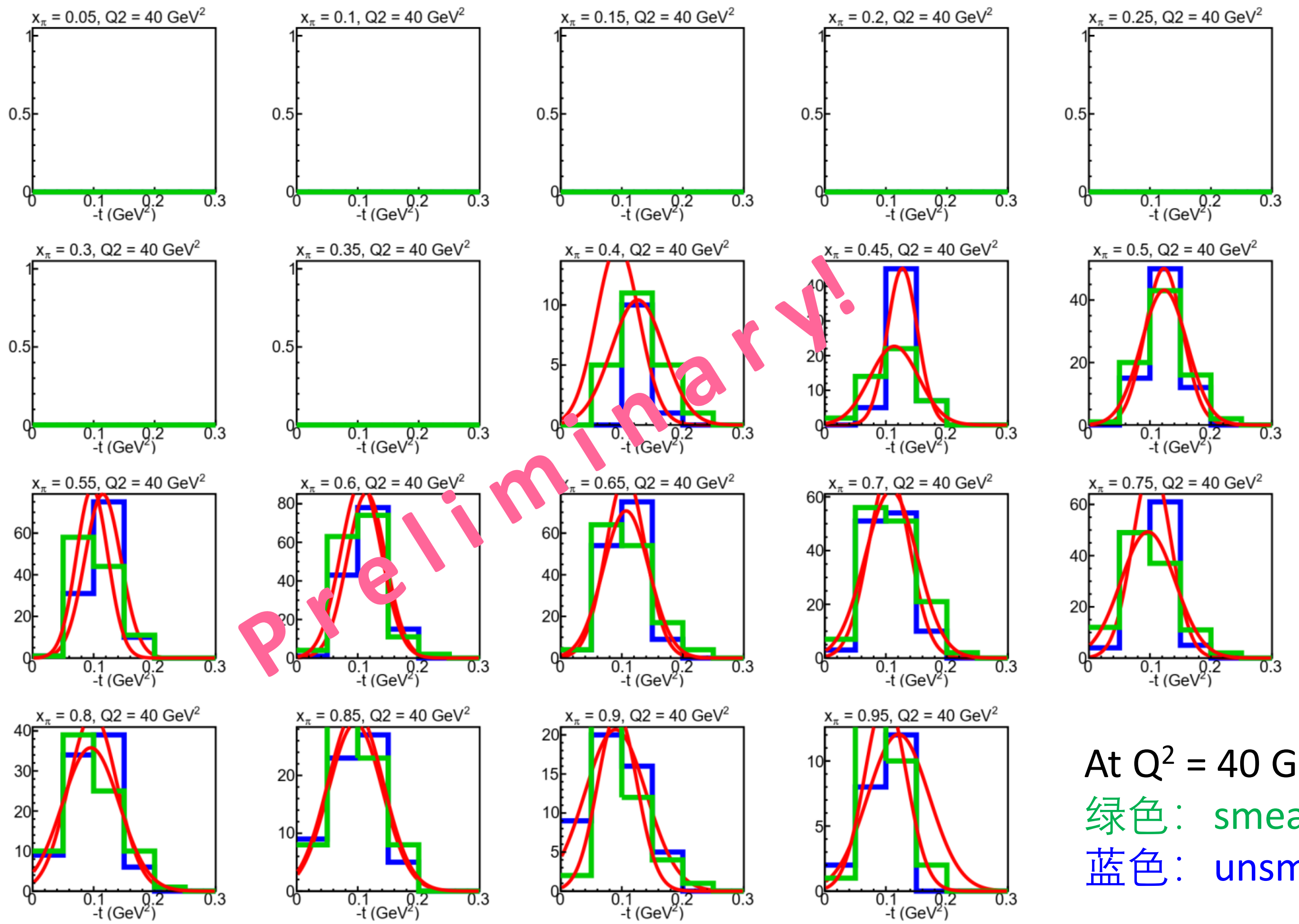
Backup: ZDC Resolution Induced Uncertainty on the pion SF Extraction



At Q^2 = 40 GeV^2

绿色： smeared

蓝色： unsmeared

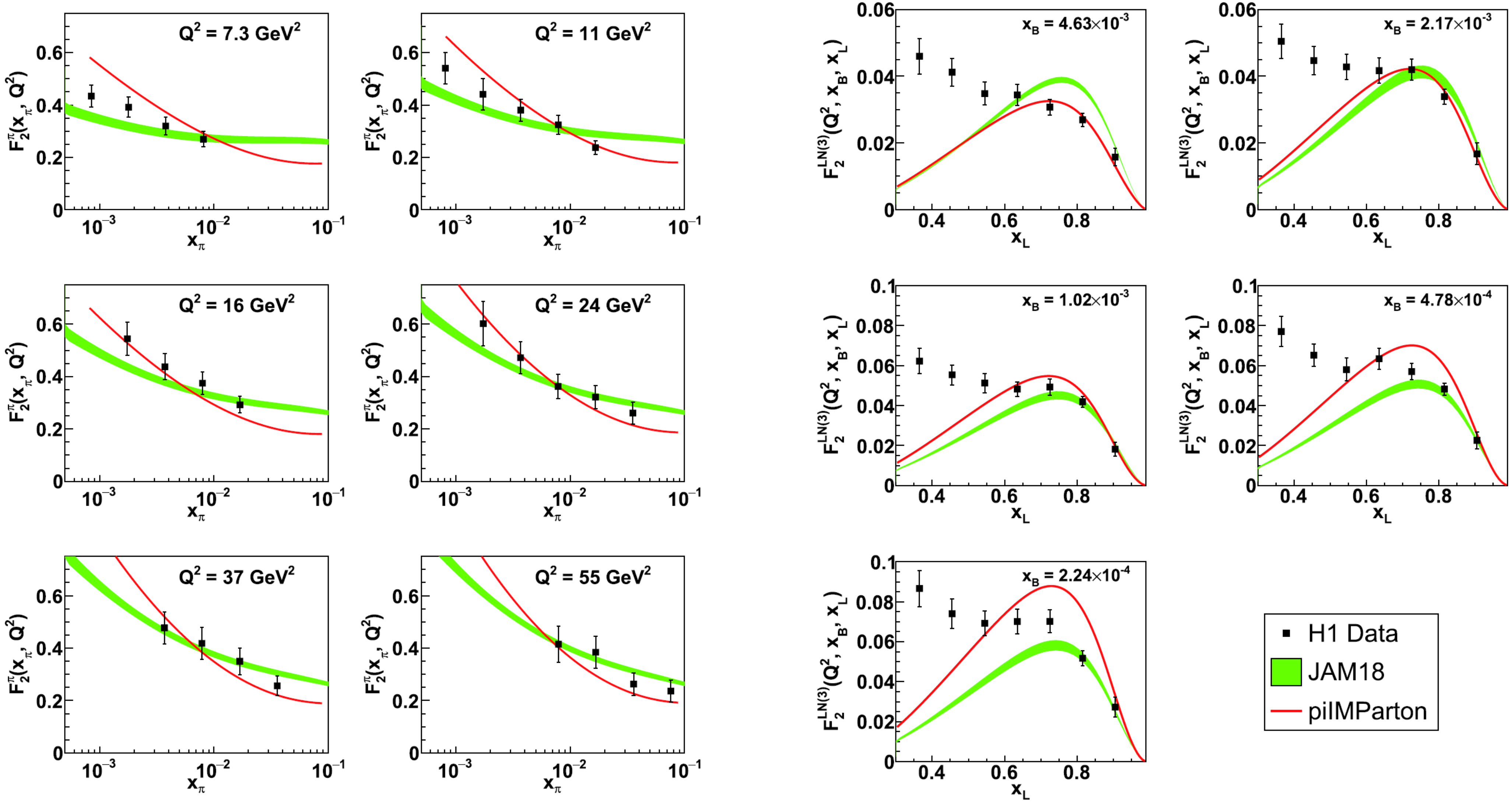
Q^2 = 40 GeV^2

典型的动量转移t的相对误差为$\sqrt{2} \times 14.5\% = 21\%$

初步MC研究表明，由于我们ZDC测量到的t的范围较小，t变量21%的相对误差导致提取到的结构函数有10-50%的系统误差！

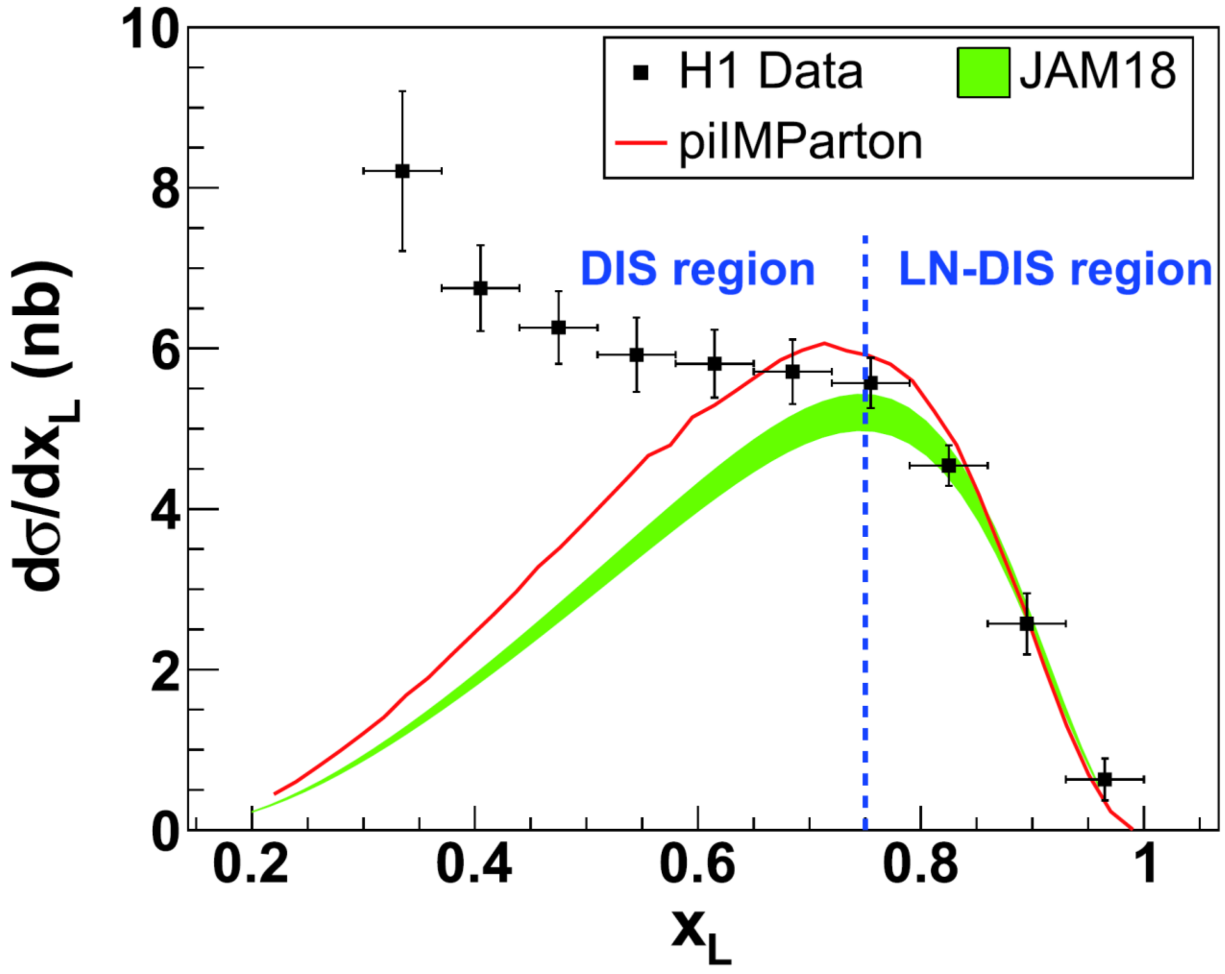
Backup: Justifications of the MC Models

LN DIS产生器

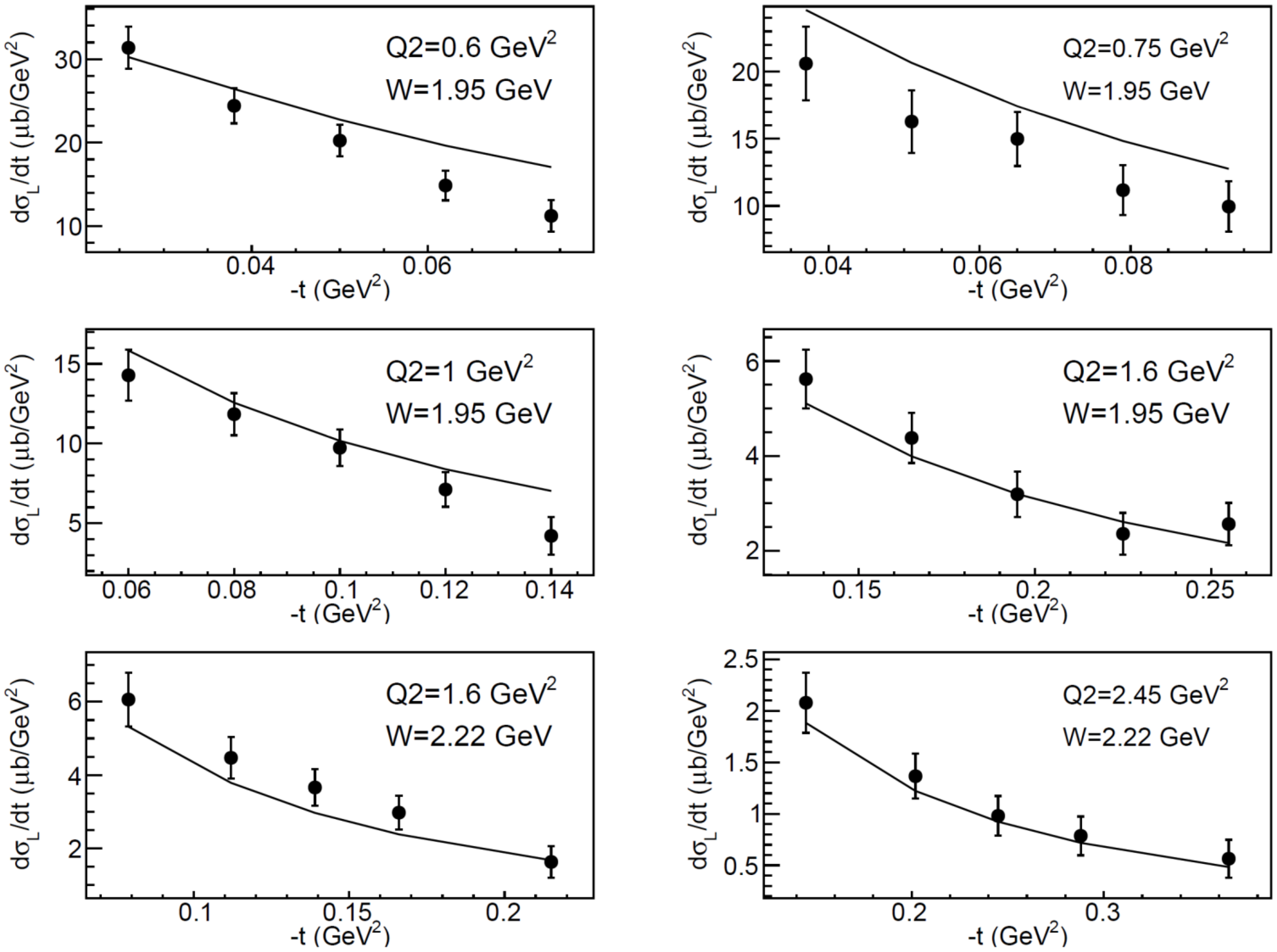


Backup: Justifications of the MC Models

LN DIS产生器



Backup: Justifications of the MC Models

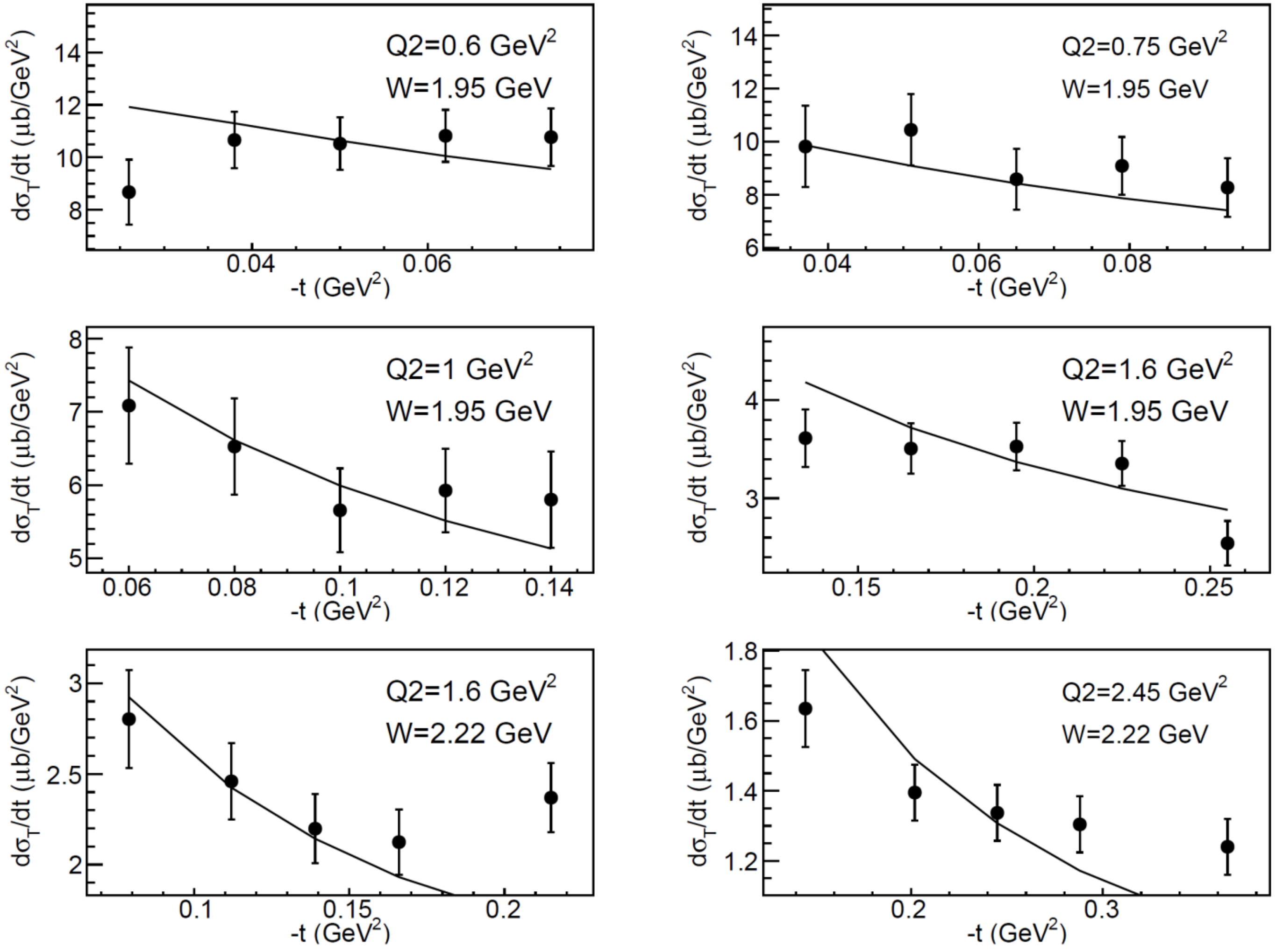


Deep Exclusive Pion Production产生器

我们的π-pole模型与
纵向截面实验数据比较

数据来自 JLab Fpi collaboration,
Phys. Rev. C 78 (2008) 045202

Backup: Justifications of the MC Models



Deep Exclusive Pion Production产生器

参数化的横向截面模型
与横向截面实验数据比

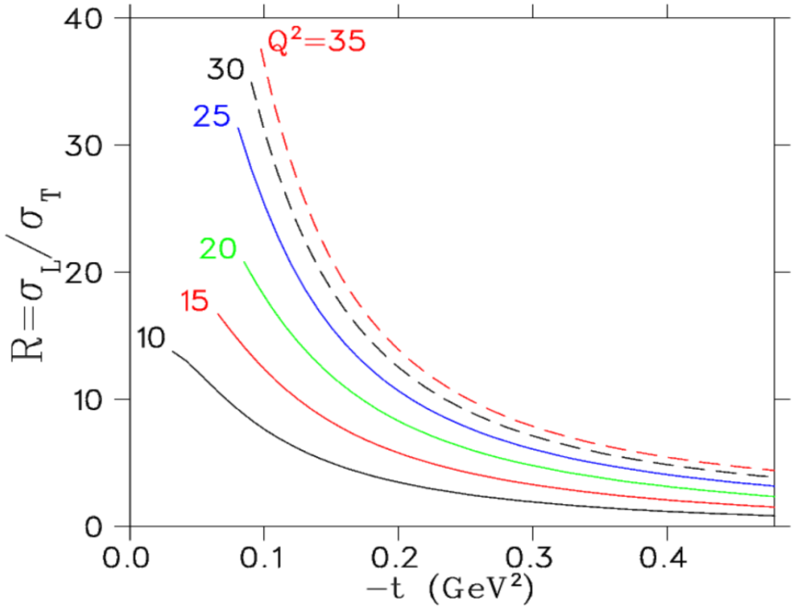
模型A:

参数化的模型和实验数据均来自
Phys. Rev. C 78 (2008) 045202

$$\frac{d\sigma_T}{dt} = \left(\frac{0.74}{Q^2} + \frac{1.25}{Q^4} + \frac{0.57|t|}{(|t| + m_\pi^2)^2}\right)\frac{8.54}{(W^2 - m_N^2)^2}$$

Backup: Justifications of the MC Models

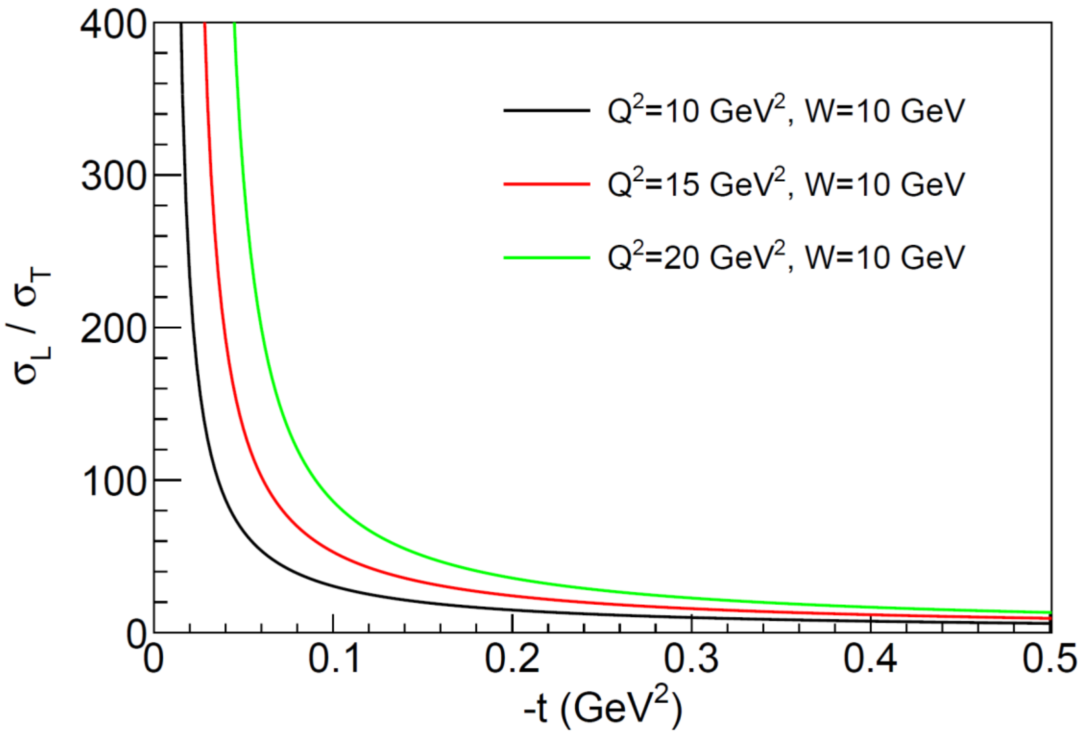
In the hard scattering regime, QCD scaling predicts $\sigma_L \propto 1/Q^6$ and $\sigma_T \propto 1/Q^8$.



- T. Vrancx, J. Ryckebusch, PRC **89**(2014)025203.
- Predictions are for ε>0.995 Q^2, W kinematics shown earlier.

Deep Exclusive Pion Production产生器

模型B: 刘天博、俞子涵的计算



Backup

Number of Parameters	Confidence level (probability contents desired inside hypercontour of $\chi^2 = \chi^2_{min} + \mathrm{UP}$)				
	50%	70%	90%	95%	99%
1	0.46	1.07	2.70	3.84	6.63
2	1.39	2.41	4.61	5.99	9.21
3	2.37	3.67	6.25	7.82	11.36
4	3.36	4.88	7.78	9.49	13.28
5	4.35	6.06	9.24	11.07	15.09
6	5.35	7.23	10.65	12.59	16.81
7	6.35	8.38	12.02	14.07	18.49
8	7.34	9.52	13.36	15.51	20.09
9	8.34	10.66	14.68	16.92	21.67
10	9.34	11.78	15.99	18.31	23.21
11	10.34	12.88	17.29	19.68	24.71
	If FCN is $-\log(\text{likelihood})$ instead of χ^2, all values of UP should be divided by 2.				

Table 7.1: Table of UP for multi-parameter confidence regions

From minuit manual