DVCS Cross-section progress

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CLAS collaboration

Feb.3, DPWG meeting

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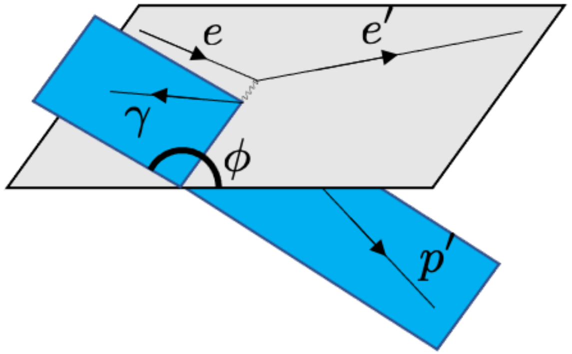
Introduction – Purpose of this work

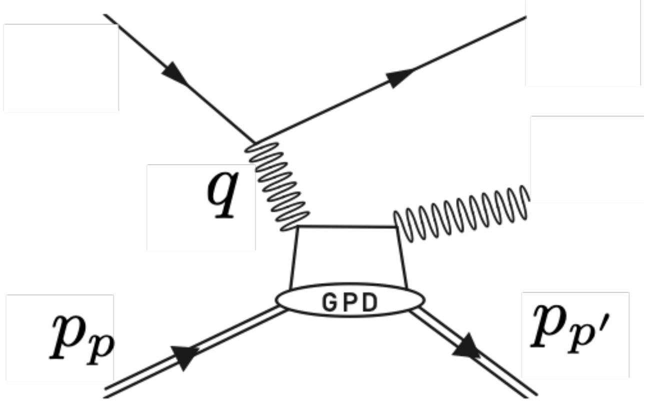
- BH+DVCS unpolarized differential cross section measurement

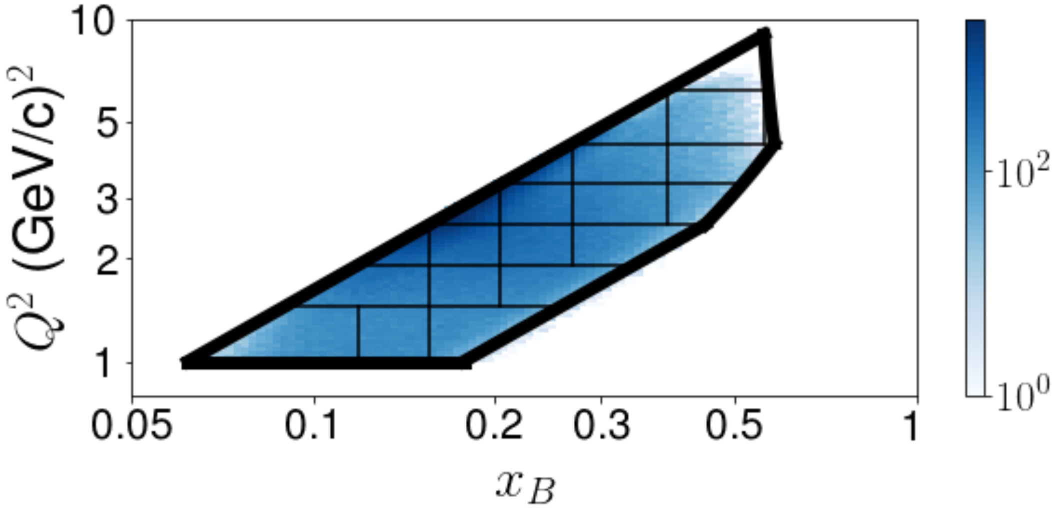
- with RG-A pass1 fall 2018 data
  - with both torus-1 and torus+1 polarity
  - with 10.6 GeV electron beam
  - with liquid hydrogen target (proton)

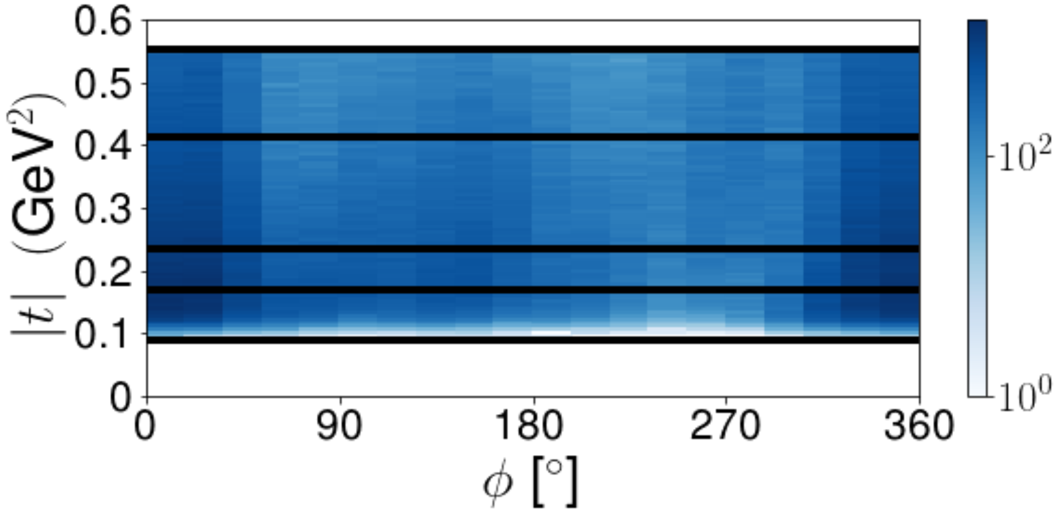
- Primary goal: publish the data points of differential cross-sections

Introduction – Deeply Virtual Compton Scattering









Bjorken x $\quad 0 < x_B \equiv \frac{Q^2}{2p_p \cdot q} < 1$

4-momentum transfer $\quad Q^2 \equiv -q^2 > 1$

Mandelstam variable $\quad t \equiv (p_{p'} - p_p)^2$

angle between scattering planes $\quad \phi$

$$\frac{d\sigma}{dx_B dQ^2 d(-t) d\phi} = \frac{N_{\text{DVCS+BH}}}{L \times \text{Vol}_{\text{bin}}} \frac{1}{\text{F}_{\text{correction}}}$$

Introduction – Data sets

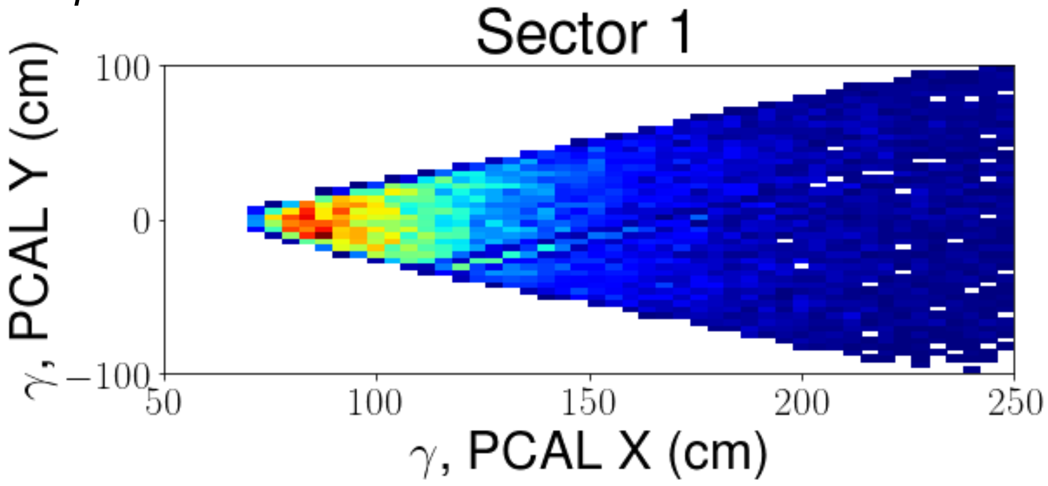
- Experimental Data
  - RG-A Fall 2018 inbending and outbending

- Simulation Data
  - DVCS
    - dvcsgen with BMK approximation and CFF grid from VGG model
    - radiative photons from I. Akushevich and A. Ilyichev, PRD **98** (2018), 013005
  - DVπ^0P
    - aao_rad with structure functions tuned by Valery
  - Both simulation used background merging with the nominal current.

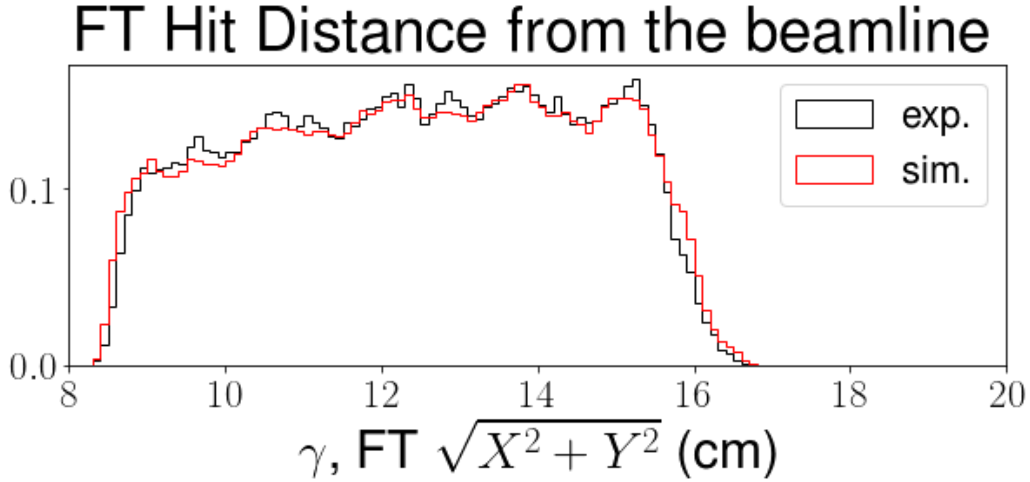
- Configuration
  - (p', γ): (CD, FT), (CD, FD), (FD, FD)
  - torus-1 and torus+1
  - leads to 6 entire configuration with 3 topologies

Method – Particle identification

- PID cuts at RG-A analysis note
  - Relax chi2pid cuts for protons with $p_{p'} < 0.8$ GeV/c
- Photons at Forward Detector
  - Fiducial cut developed by FX



- Protons at Central Detector
  - $\theta_{vertex} < 60°$
- Photons at Forward Tagger
  - Event builder



Method – Kinematic region

- Proton
  - CD
    - 0.3 GeV/c < $p_{p'}$ < 0.8 GeV/c
  - FD, torus-1
    - 0.42 GeV/c < $p_{p'}$ < 0.8 GeV/c
  - FD, torus+1
    - 0.5 GeV/c < $p_{p'}$ < 0.8 GeV/c

- Electron
  - $E_{e'} > 2$ GeV

- Photon
  - $E_{\gamma} > 3$ GeV

Method – Proton energy loss correction

- We know the answer of the measured p and the generated p in MC.
  - measured p: $p_{\text{meas.}}$, $p_{\text{reco.}}$, $p_{\text{rec.}}$, ….
  - generated p : $p_{\text{gen.}}$, p_{truth} ,…
  - correction $\delta p = p_{\text{gen.}} - p_{\text{meas.}}$

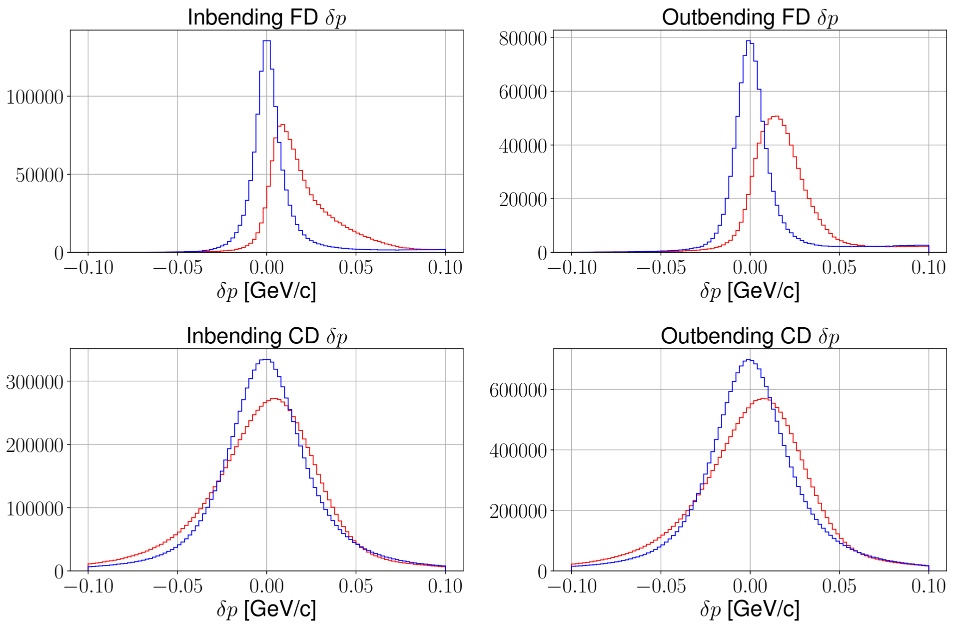
- Corrected θ and ϕ too.
- Details presented at the software meeting.
  - I will finalize and upload the technical note

- p >1 GeV/c, my correction has a negative bias
  - take Andrey's p correction at $p > 1$
  - this work: 0.3 GeV/c < $p_{p'}$ < 0.8 GeV/c

- Applied to both simulation and experimental data.

$\delta p = p_{\text{gen.}} - p_{\text{meas.}}$

before this correction
after this correction



Method – Momentum correction

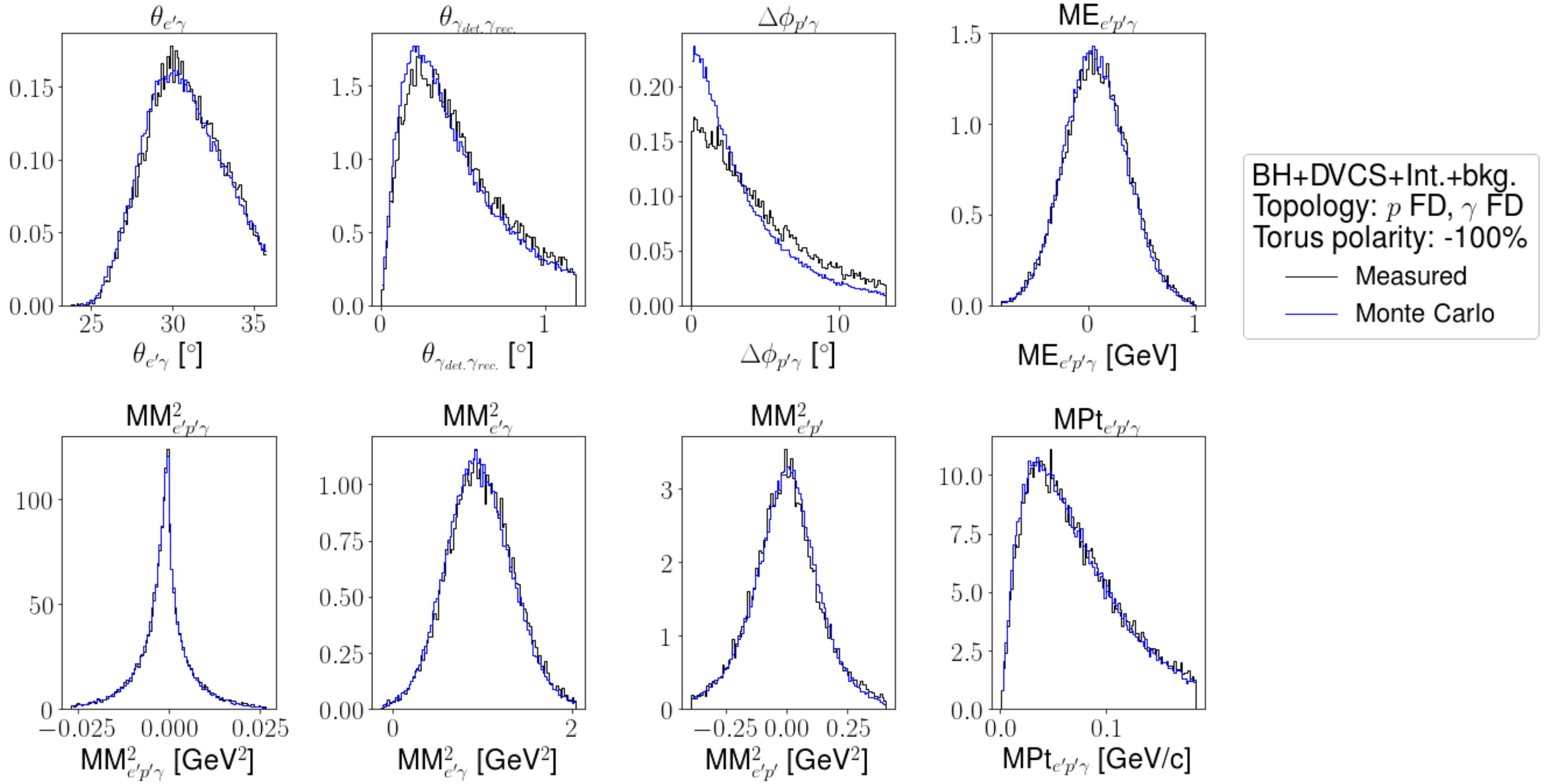
- Details presented at rg-a meeting yesterday.
- Correction in experimental data (all units in GeV/c and degrees)
  - Proton
    - CD: $(p, \theta, \phi) \rightarrow (p + 0.01, \theta - 0.5°, \phi)$
    - FD inbending: $(p, \theta, \phi) \rightarrow (p + A(p), \theta, \phi)$, $A(p) = 58.62\,(p - 0.42)^{4.355}\, e^{-10.038(p-0.42)}$
    - FD outbending: $(p, \theta, \phi) \rightarrow (p - 0.02, \theta + B(\theta), \phi)$, $B(\theta) = 0.05(|\theta-27| + (\theta-27))$
  - Photon
    - FT: $(p, \theta, \phi) \rightarrow (p + 0.25$ GeV/c, $\theta, \phi)$
    - FD: $(p, \theta, \phi) \rightarrow (p + 0.0045\, p^2, \theta, \phi)$

- Smearing in simulation data
  - Proton
    - CD: $(p, \theta, \phi) \rightarrow$ (X(p)% smearing, θ+ 0.8° smearing, ϕ + 2.2° smearing)
      - X(p)% smearing: $p \rightarrow p + gaus(1, X(p)\%) \times p$
      - 0.8° smearing: $\theta \rightarrow \theta + gaus(0, 0.8°)$
    - FD: $(p, \theta, \phi) \rightarrow$ (p + Y(p)% smearing, θ, ϕ)
      - X(p), Y(p) has a complex form. but roughly 8% for CD, 6% for FD inbending, 8% for FD outbending
  - Photon
    - FT: $(p, \theta, \phi) \rightarrow$ (p + 1.4% smearing, θ, ϕ)
    - FD: $(p, \theta, \phi) \rightarrow$ (p + 3.5% smearing, θ, ϕ)

Method – Exclusivity Variables

- Simulation-to-data matching for all topologies and all polarities presented at the rg-a meeting.

- Invariant mass
  - DVπ^0P: $IM_{\gamma\gamma}$
- Missing masses
  - DVCS: $MM^2_{e'p'}$, $MM^2_{e'p'\gamma}$, $MM^2_{e'\gamma}$
  - DVπ^0P: $MM^2_{e'p'}$, $MM^2_{e'p'\gamma\gamma}$, $MM^2_{e'\gamma\gamma}$
- Missing Energies
  - DVCS:, $ME_{e'p'\gamma}$
  - DVπ^0P: $ME_{e'p'\gamma\gamma}$



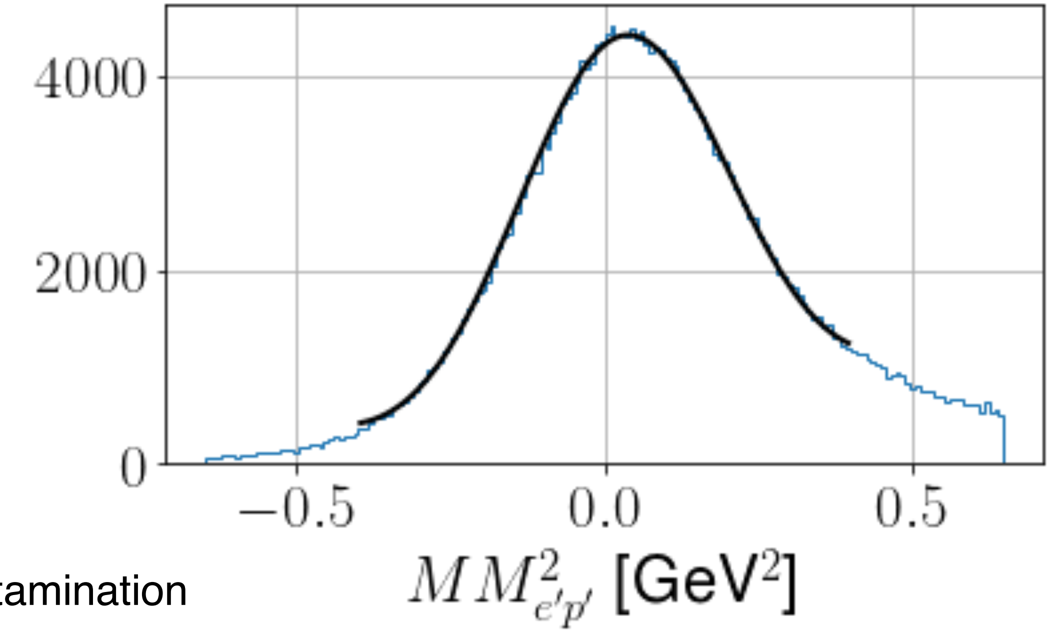
- Angular variables
  - DVCS: $\theta_{\gamma X}$, $\Delta\phi_{p'\gamma}$ (X = beam + target – e' – p'), $\theta_{e'\gamma}$ (not exclusivity variable, but important for the radiation)
  - DVπ^0P: $\theta_{\pi X}$, $\Delta\phi_{p'\pi}$ (X = beam + target – e' – p')

Method – Exclusivity Cuts

- Fit the distributions to get 3σ range for each topology and polarity

- Sequentially fit one variable at one time
  - Marco's question at dpwg meeting: Wouldn't one cut affect another distribution? Yes.
  - But if we iterate on 3σ cuts, we'll end up losing too many events.
  - Fix the order of fitting, apply cuts at only one time upon the previous cut.
  - Separately do this for each channel/ topology/ polarity.

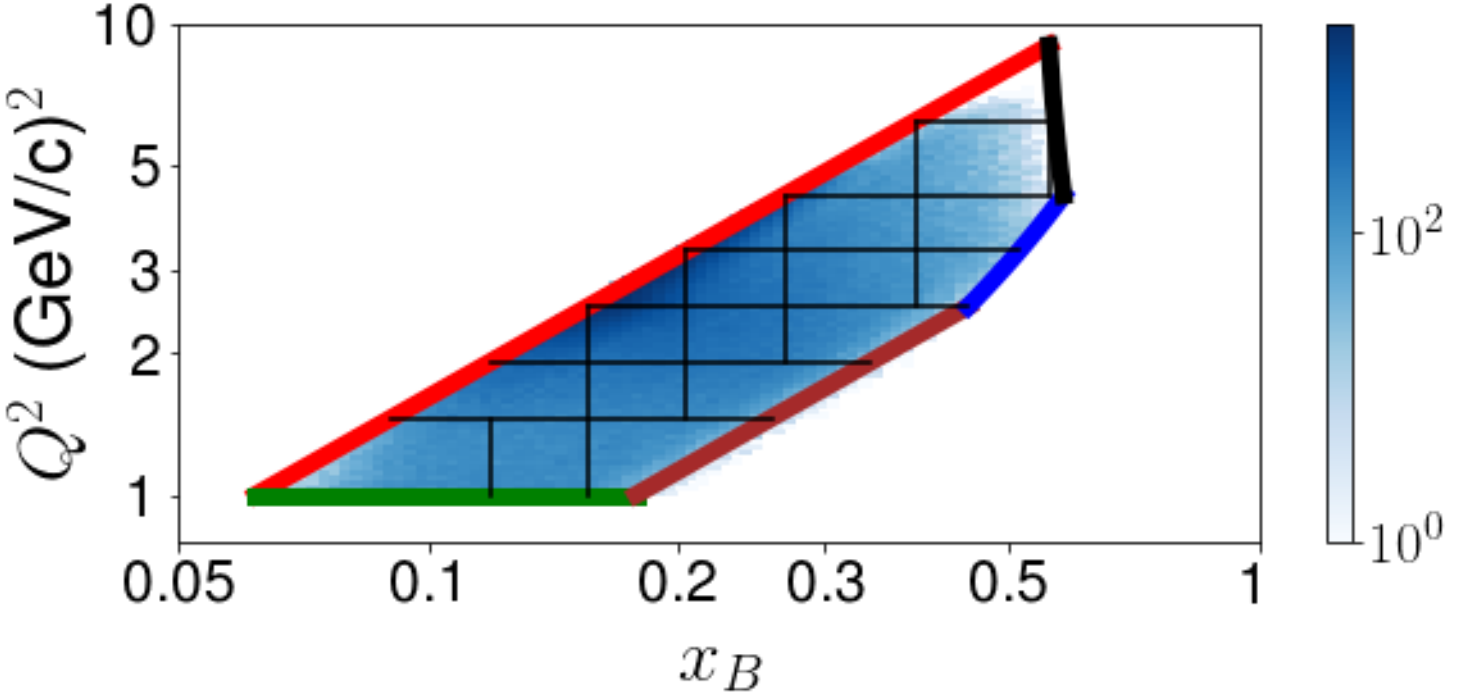
- Ex) (p', γ)=(CD, FT), torus -1
  - With DVCS simulation data without any exclusivity cut.
  - Fit $MM^2_{e'p'}$ with gaussian + quadratic function
  - -0.528 $(GeV/c)^2 < MM^2_{e'p'} < 0.601$ $(GeV/c)^2$
  - Then, apply this cut on the data set
  - Then, fit $MM^2_{e'\gamma}$



- (p', γ)=(FD, FD)'s case
  - cuts on (70% DVCS + 30% DVπ^0P) simulation due to high contamination

Method – (Q^2, x_B) binning

- Kinematic constraints
    - red: $E_{e'} > 2$ GeV
    - brown: $E_\gamma > 3$ GeV
    - green: $Q^2 > 1$ (GeV/c)^2
    - blue: $W > 2$ GeV
    - black: $p_{p'} < 0.8$ GeV/c

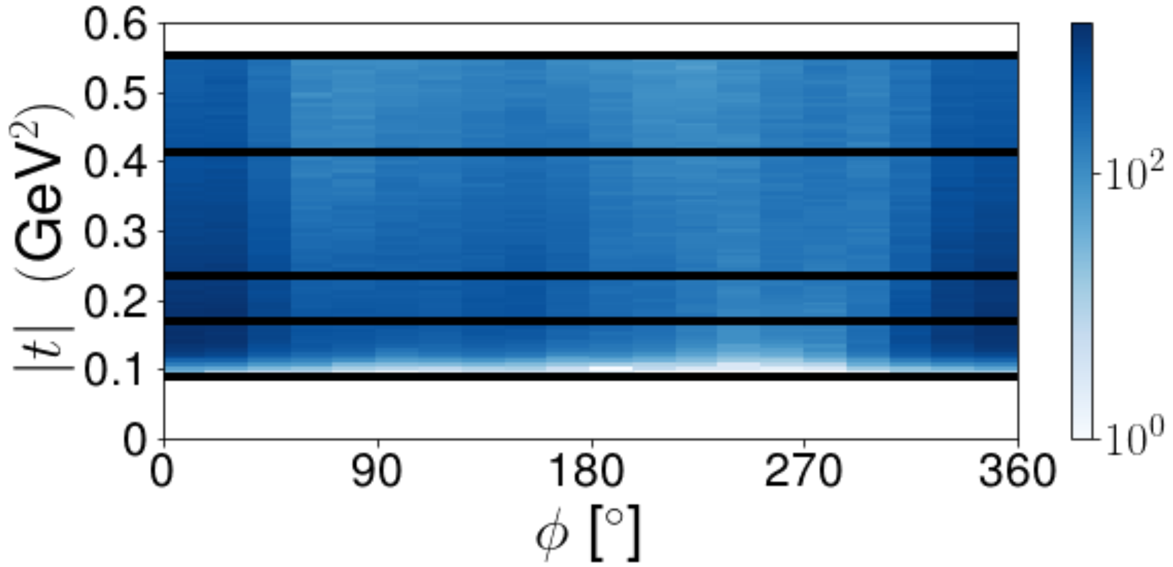


- bin in Q^2 first
    - in logarithmic scale
    - respect the curve intersections
    - ground floor occupied with the outbending data
    - top floor doesn't have many statistics. 6 bins

- bin in x_B
    - in logarithmic scale
    - with an effort to share x_B bin edges over different Q^2 bins
    - 2–4 bins up to Q^2

Method – | t | binning

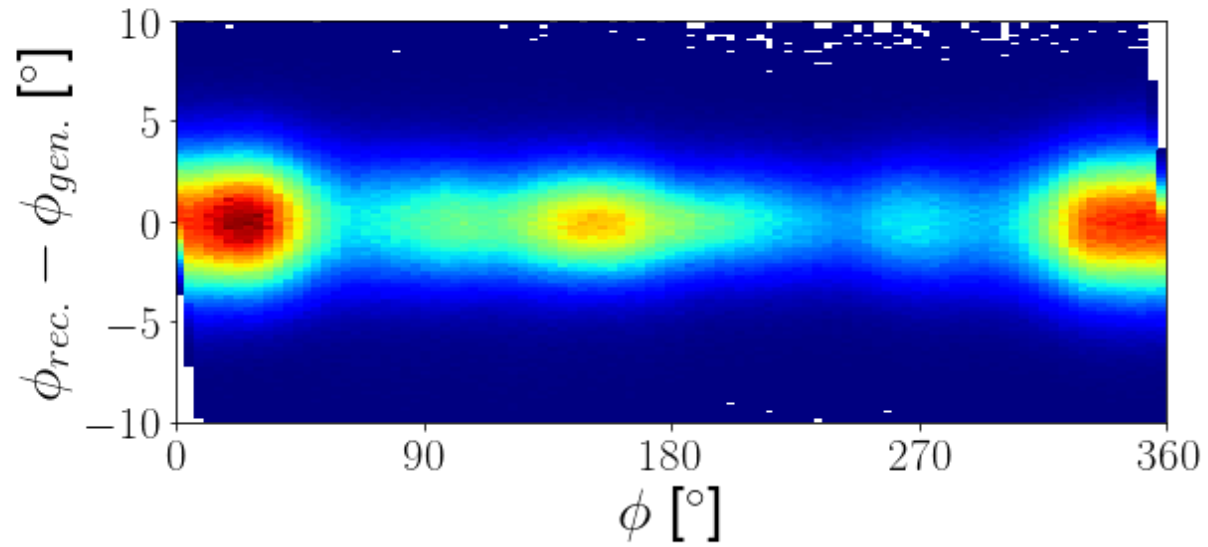
- Proton Kinematics revisited
  - CD
    - 0.3 GeV/c < $p_{p'}$ < 0.8 GeV/c
  - FD, torus-1
    - 0.42 GeV/c < $p_{p'}$ < 0.8 GeV/c
  - FD, torus+1
    - 0.5 GeV/c < $p_{p'}$ < 0.8 GeV/c

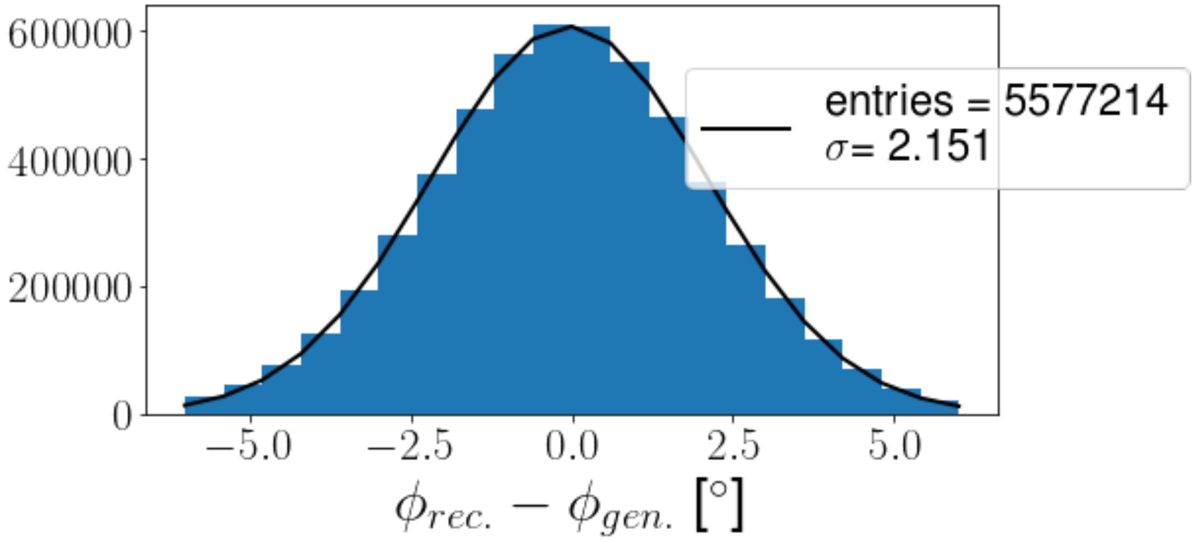


- p = [0.3, 0.42, 0.5, 0.8] ~ | t | = [0.088, 0.168, 0.234, 0.553]
- One more edge at | t | = 0.414 GeV^2
- 4 bins

Method – Binning ϕ

- Obviously the most important binning for the model study



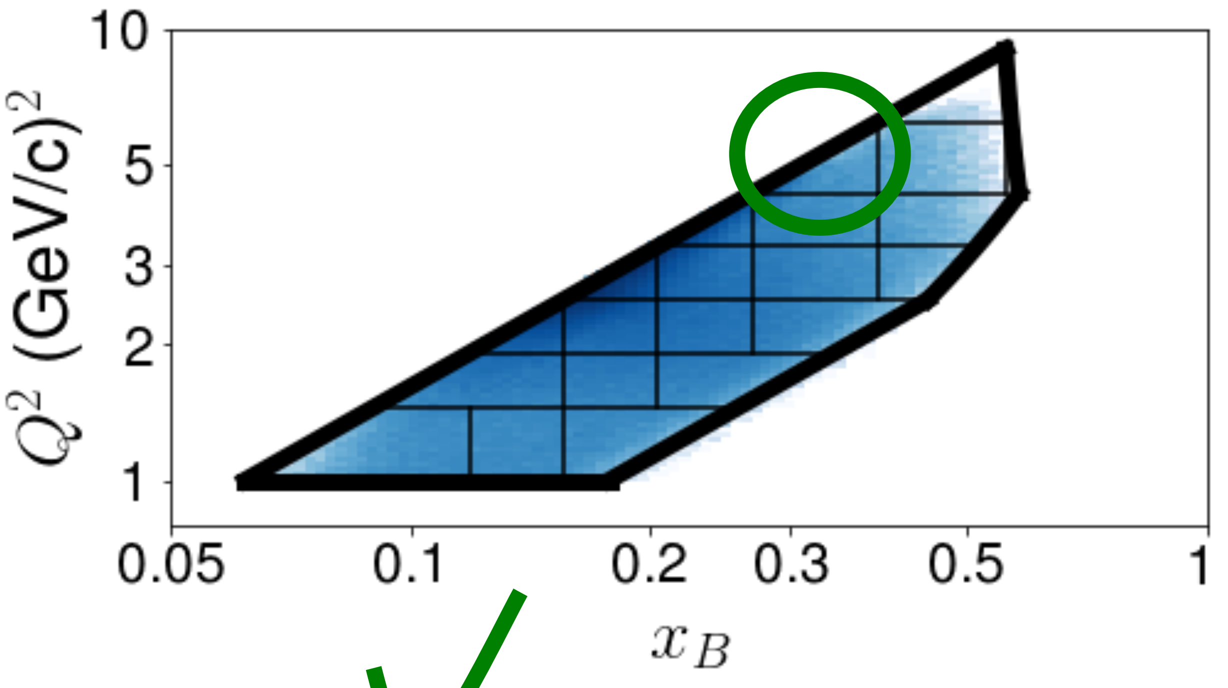


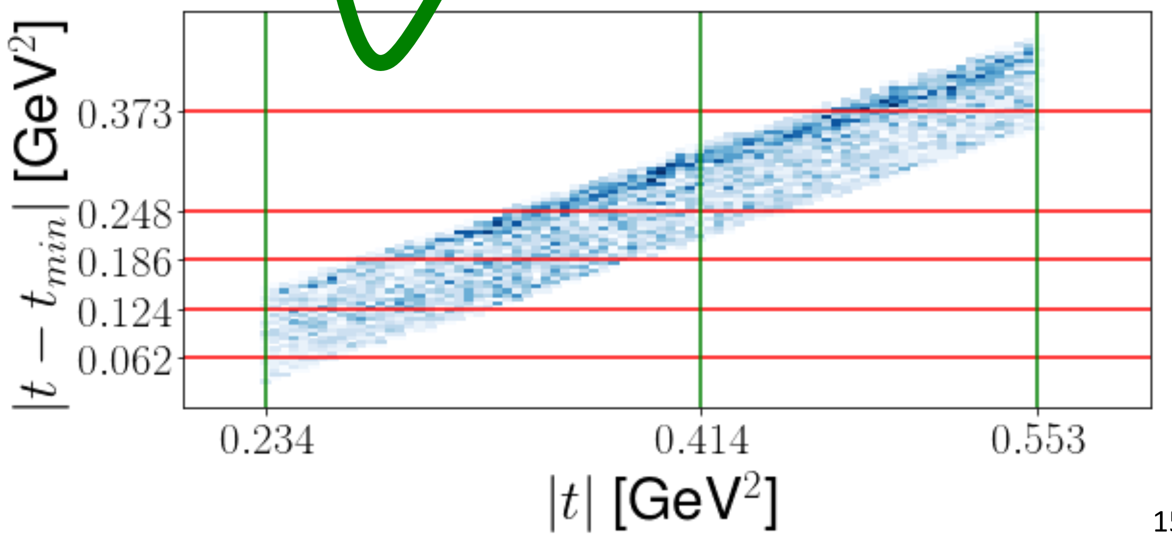
- $\phi \in [0°,72°)$, $[288°–360°)$: bin size 12°
- $\phi \in [72°, 288)$: bin size 24°
  - passes [168°, 192°)
- 21 bins

Result – the closest bin to compare with Hall A

A. Stefanko, Ph.D. thesis (2020), Hall A

Setting	x_B	Q^2 (GeV^2)	E_{beam} (GeV)	t_{min} (GeV^2)	t_{max} (GeV^2)
361	0.36	3.200	6.663	-0.163	-0.69
362	0.36	3.600	8.517	-0.165	-0.54
363	0.36	4.470	10.617	-0.167	-0.54
481	0.48	2.700	4.485	-0.321	-0.58
482	0.48	4.365	8.843	-0.344	-0.72
483	0.48	5.334	8.843	-0.351	-0.71
484	0.48	6.900	11.023	-0.359	-0.96
601	0.60	5.541	8.517	-0.661	-1.47
602	0.60	6.100	8.517	-0.671	-1.24
603	0.60	8.400	10.617	-0.700	-1.41
604	0.60	9.000	10.617	-0.706	-1.28





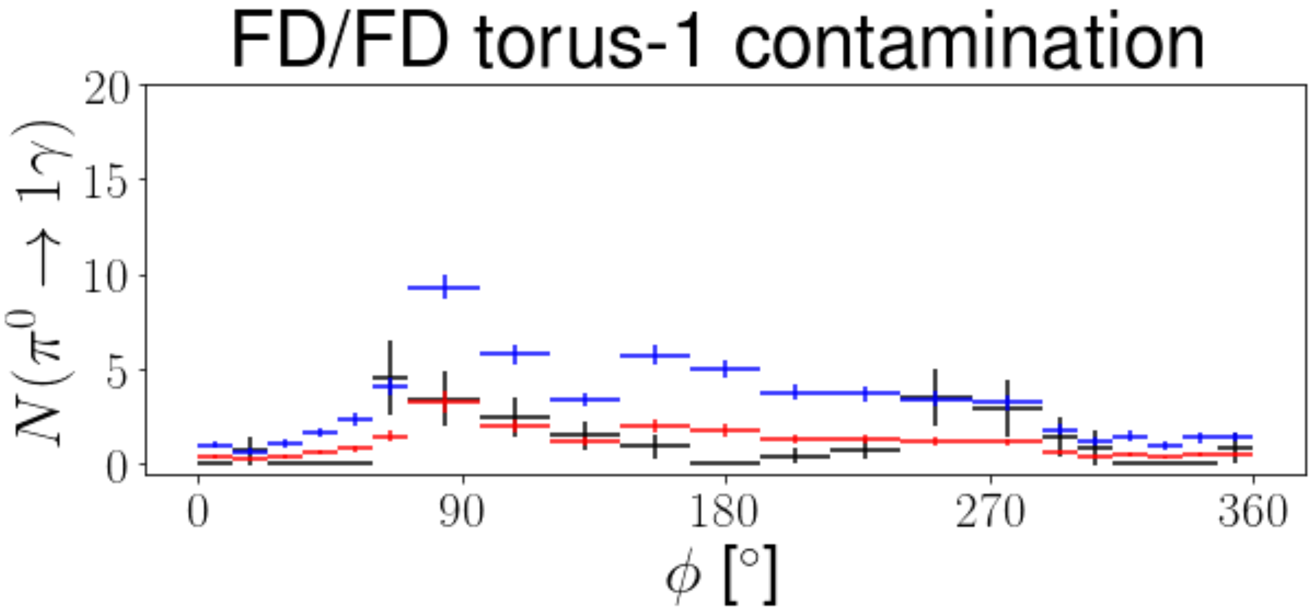
Result – π^0 contamination

- $(\pi^0 \rightarrow 1\gamma)_{\text{Exp.}} = (\pi^0 \rightarrow 1\gamma)_{\text{Sim.}} \dfrac{(\pi^0 \rightarrow 2\gamma)_{\text{Exp.}}}{(\pi^0 \rightarrow 2\gamma)_{\text{Sim.}}}$

- Denote $\dfrac{(\pi^0 \rightarrow 2\gamma)_{\text{Exp.}}}{(\pi^0 \rightarrow 2\gamma)_{\text{Sim.}}}$ as R

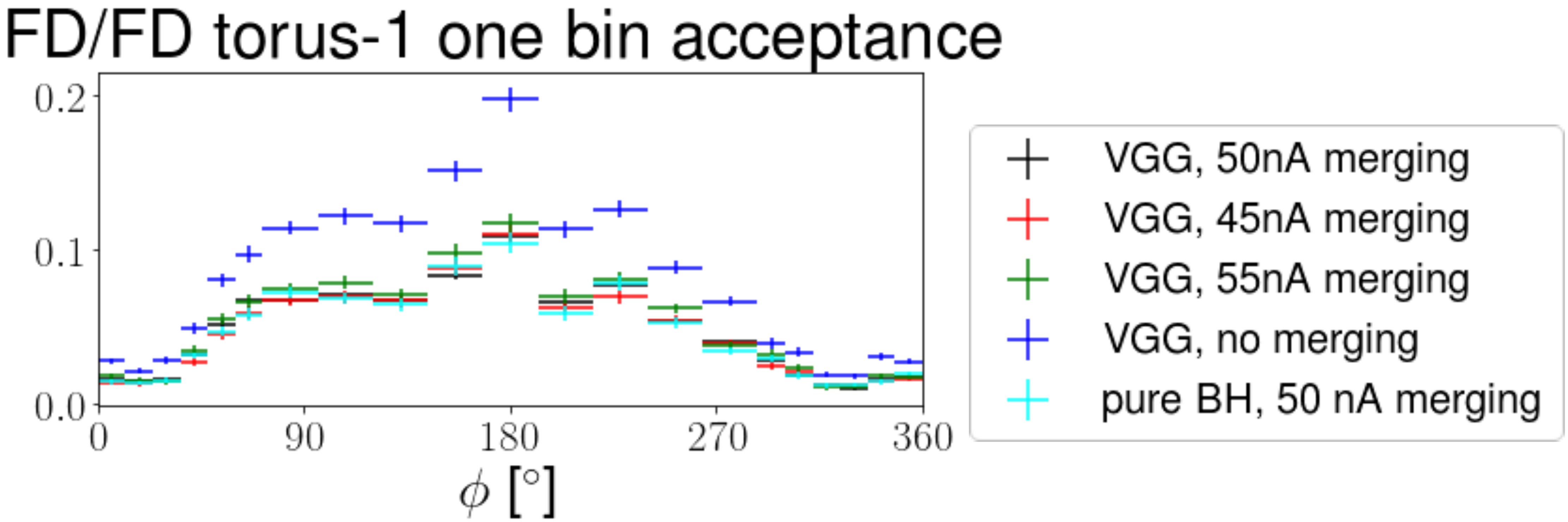
  - R(Q^2, x_B, $|t|$, ϕ)
    - minimum model dependence
    - maximum statistical uncertainty
  - R(Q^2, x_B, $|t|$)
    - model dependence over ϕ profile
  - R
    - max model dependence
    - small statistical uncertainty

  - averaging each R
    - source of systematic uncertainty



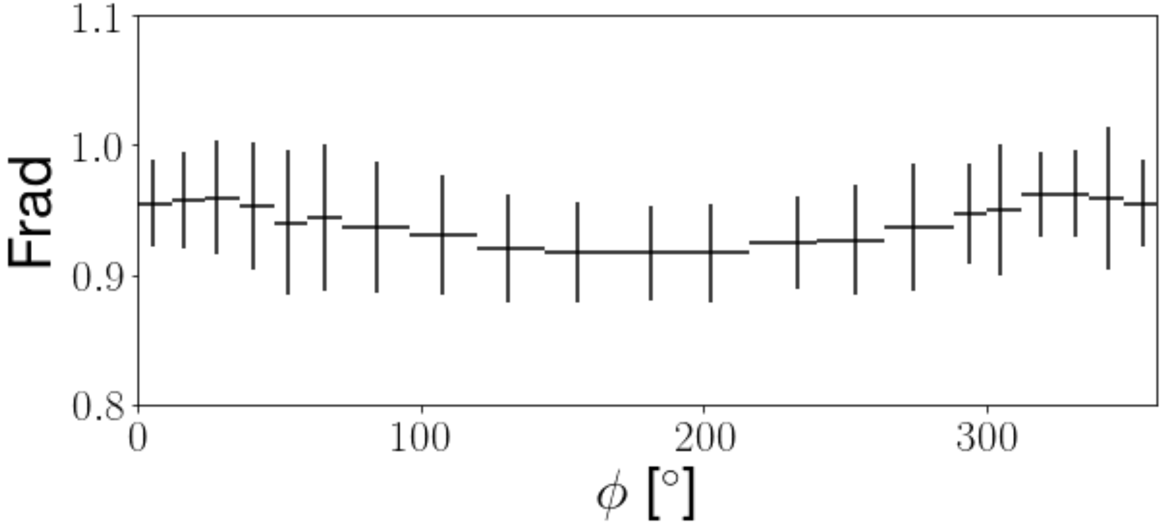
Result – Acceptance

- FD reconstruction efficiency with background merging
- Model dependence study
  - DVCS with VGG model
  - pure BH simulation



Result – Radiative corrections

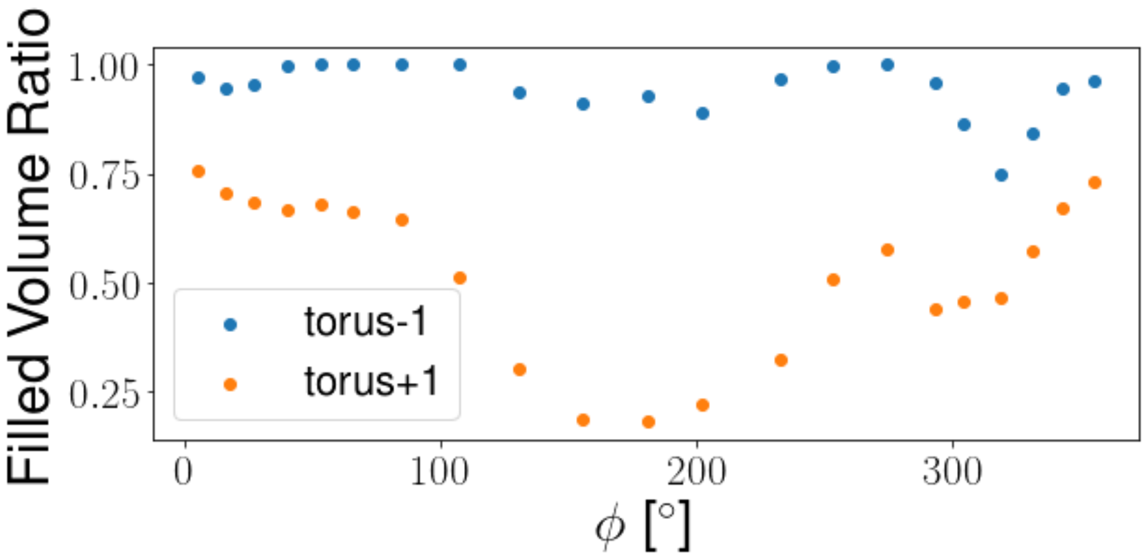
- nonrad. events: no radiative photon
- rad. events
  - s-peak: peak approximation with photon toward the beam electron
  - p-peak: peak approximation with photon toward the scattered electron
  - sensitive to exclusivity cuts
- Frad = $(\sigma_{non} + \sigma_s + \sigma_p) / \sigma_{Born}$



- Take $((1-f_s) N_s + (1-f_p)N_p)/ N_{non}$ as a source of systematic uncertainty
  - observed $N_{obs.}$: $N_{non} + f_sN_s + f_pN_p$ (f_s, f_p: fractional acceptances)
  - generated $\propto N_{non} + N_s + N_p$

Method – bin volume

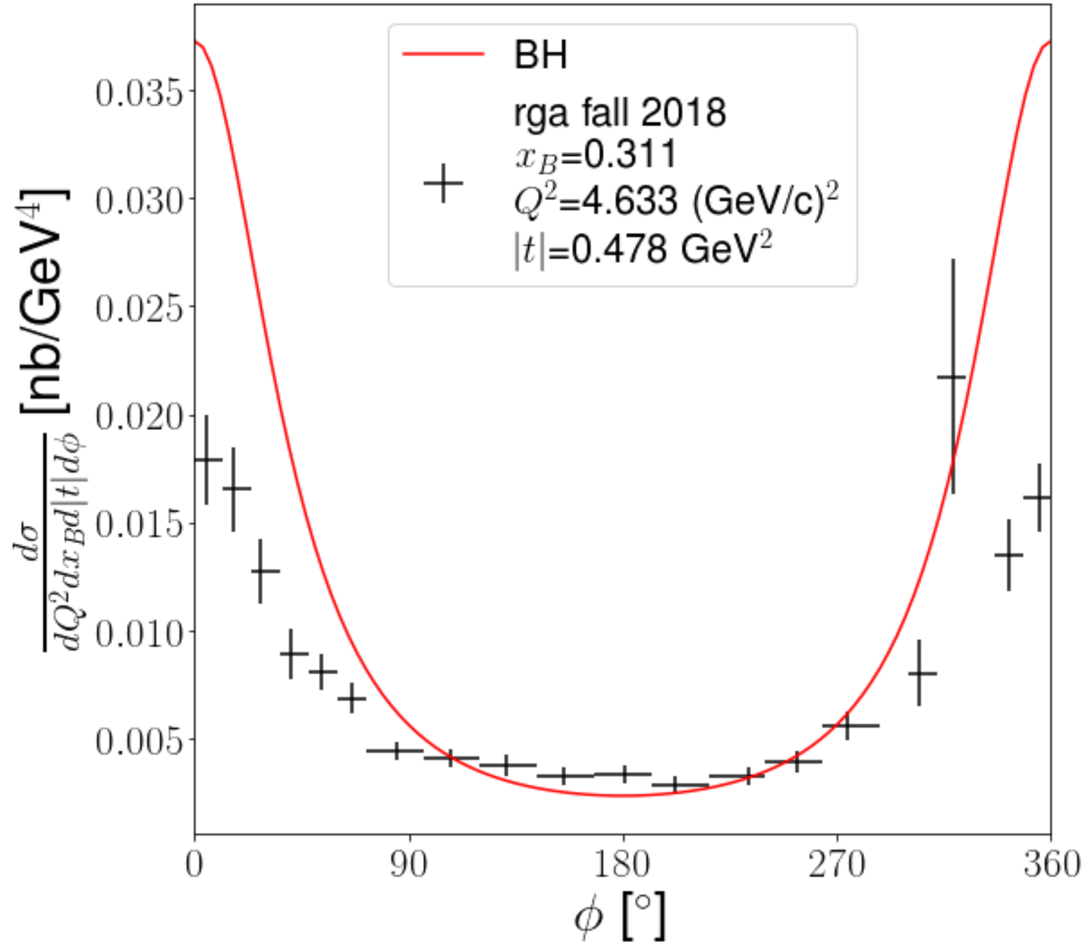
- 1. Some bins are partially filled
  - Divide one (Q^2, x_B, | t |, ϕ) bin into small sub-bin pieces (6 X 6 X 6 X 6 for trial)
  - Count how many bins are occupied

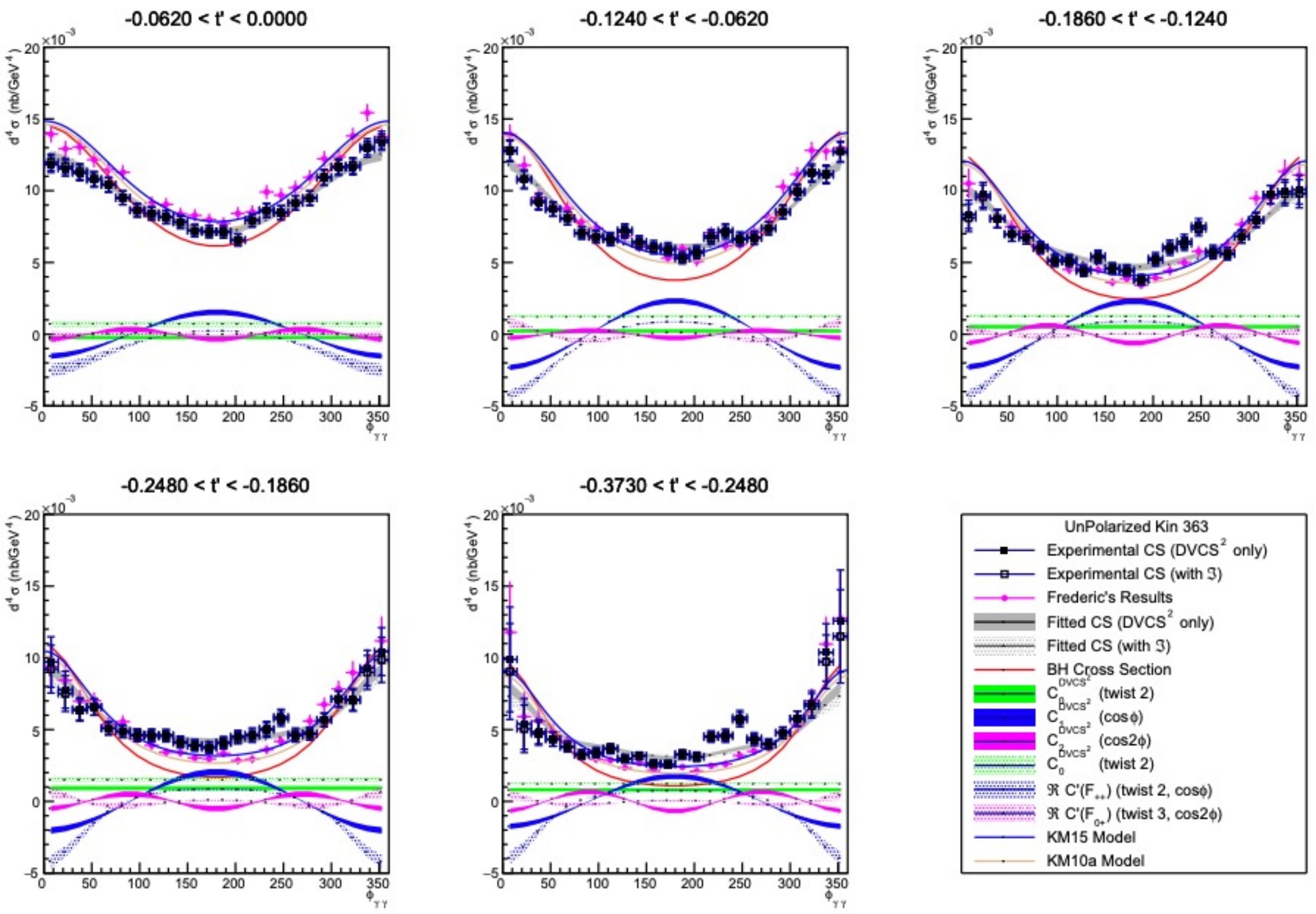


- 2. Some bins have data points unevenly spread
  - Report <Q^2>, <x_B>, <| t |>, <ϕ> as weighted average with BH cross section

Result – unpolarized cross section

Setting	x_B	Q^2 (GeV^2)	E_{beam} (GeV)	t_{min} (GeV^2)	t_{max} (GeV^2)
363	0.36	4.470	10.617	-0.167	-0.54





M. Rashad, Ph.D. thesis (2020), Hall A

Discussion – other sources of systematic unc.

- Bin migration
  - N(bin i) = $Acc_{rec}(\text{bin } i)^{-1}\, n_{obs}(\text{bin } i)$
  - N(bin i) =? $Acc_{gen}(\text{bin } i)^{-1}\, n_{truth}(\text{bin } i)$
  - $n_{truth}(\text{bin } i) = P(\text{truth bin } i \mid \text{observed bin } j)\, n_{obs}(\text{bin } j)$
  - Differences can enable systematic uncertainty estimation
  - Likely to overestimate the uncertainty

- Cut selection
  - Fit each distribution to get 3σ range for each topology and polarity
  - Try wider and narrower cuts
  - Quantify the effects at the yield and the acceptance

- Contamination dependence on the beam current

Conclusion

- The progress report of DVCS analysis is presented.

- Proposed timeline
  - February – Analysis note
  - March – Collaboration meeting
  - April – APS April + Draft of manuscript