# RGA DVCS Momentum Post-processng

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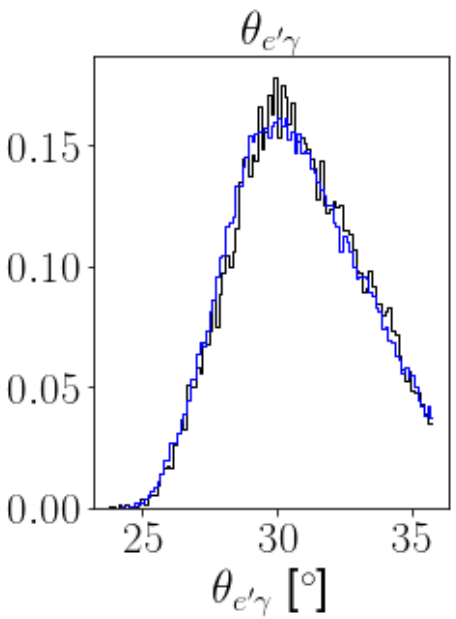
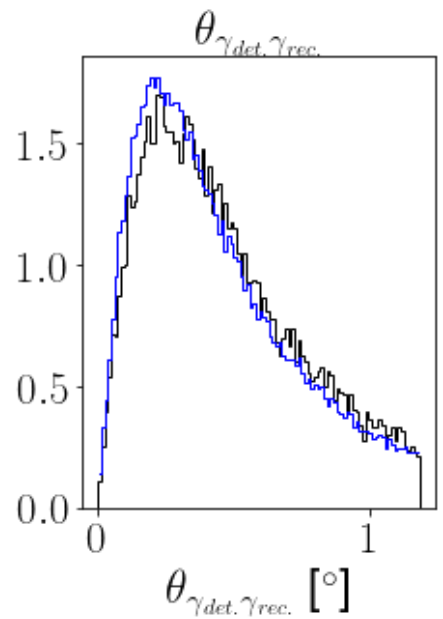
CLAS collaboration

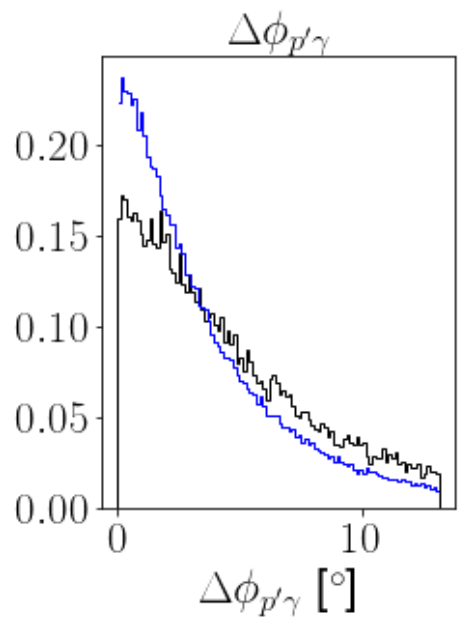
rg-a meeting, Feb. 2

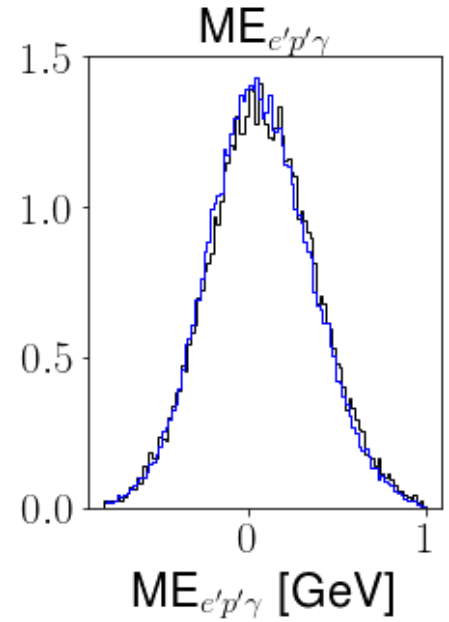
# Useful comments from last meetings

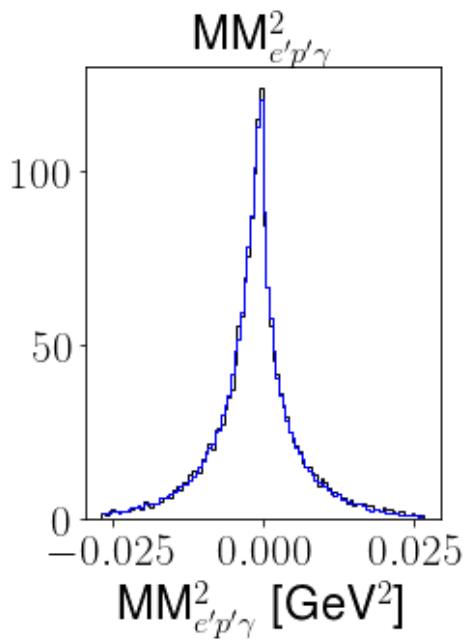
- further details of momentum smearing/ correction.
  - focus of this talk.
- Improve angular variable matching at p and $\gamma$ in the same sector of FD -> next slide.
- List sources of systematic uncertainty -> last slide.
- switch to use proton momentum to get -t, $\phi$ instead of photon
  - photon –t, $\phi$: not valid for radiative events and $\pi^0$ subtraction. -> agreed. done.
- exclude (p, $\gamma$) set when p and $\gamma$ in the same sector of FD
  - excluded protons when protons have calorimeter hits.
- acceptance study with $1\gamma$ and $2\gamma$ events with DVCS rad simulation
  - critical to radiative correction. dpwg meeting tomorrow.
- FD photon fiducial cut with PCAL (X, Y) position -> done.
- save my simulation data in the storage tape for the collaboration
- Comparison with Hall-A unpolarized cross section
  - dpwg meeting tomorrow.

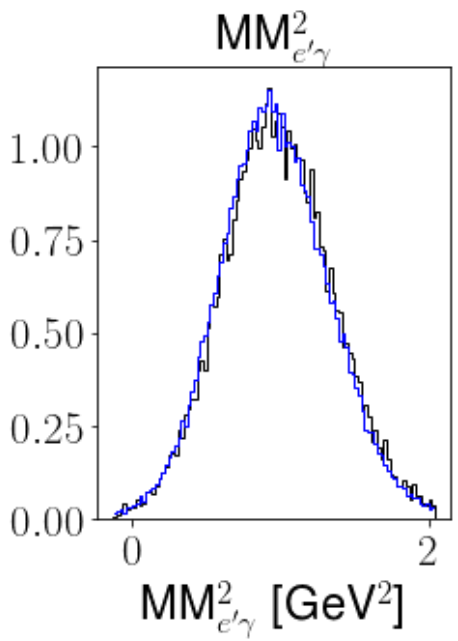


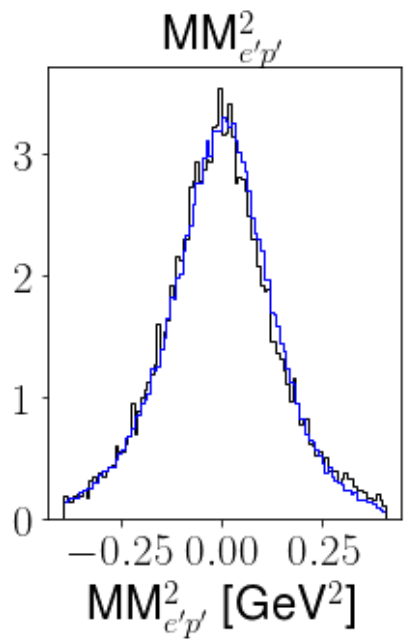



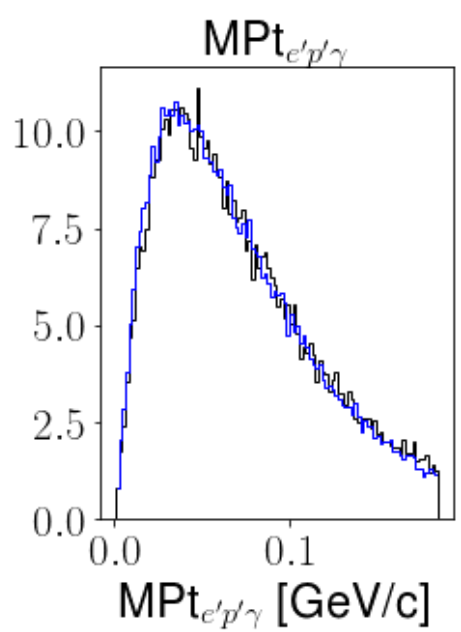



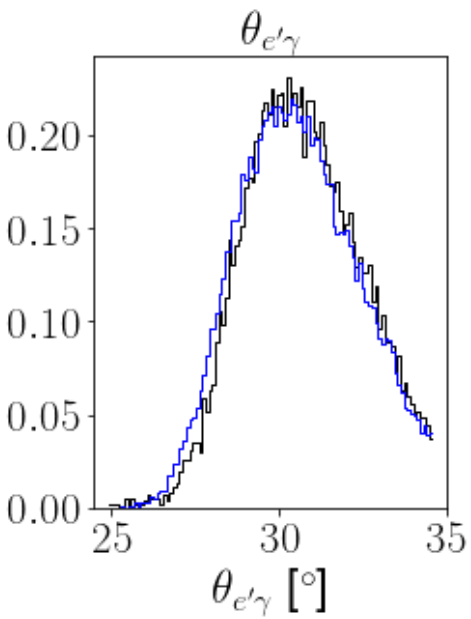



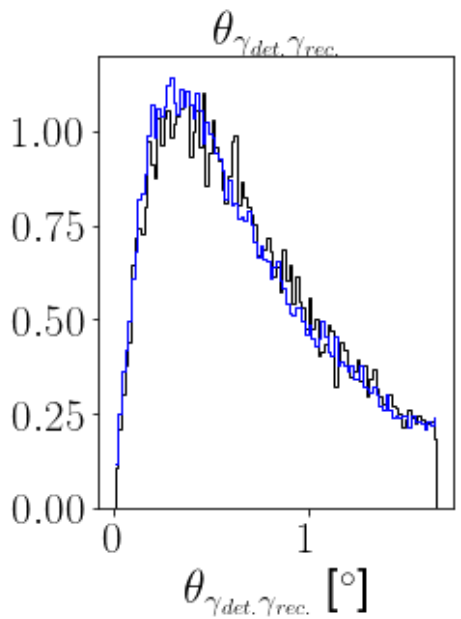



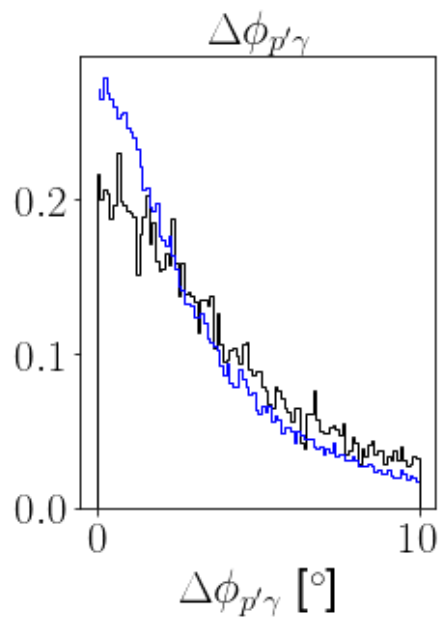

BH+DVCS+Int.+bkg.
Topology: $p$ FD, $\gamma$ FD
Torus polarity: -100%

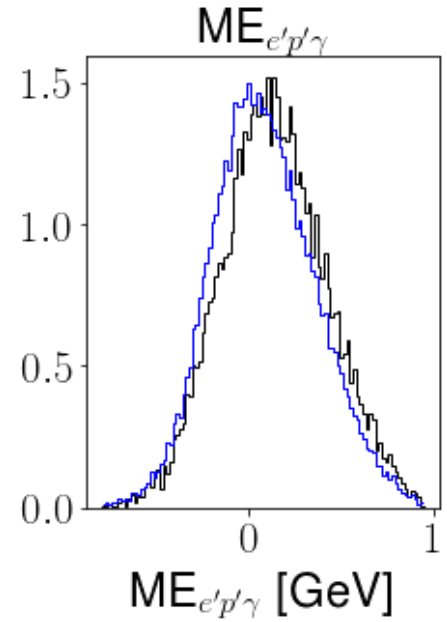
Measured

Monte Carlo

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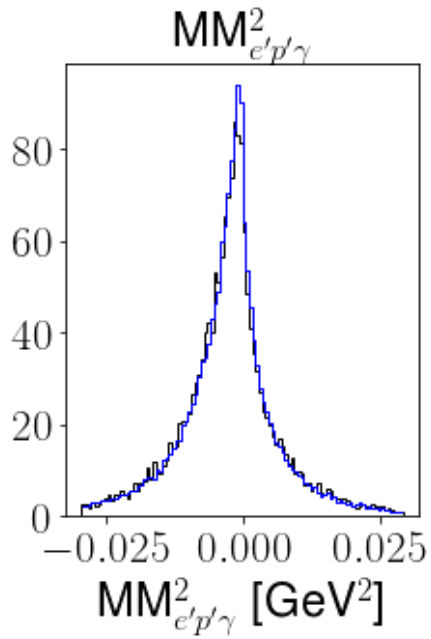
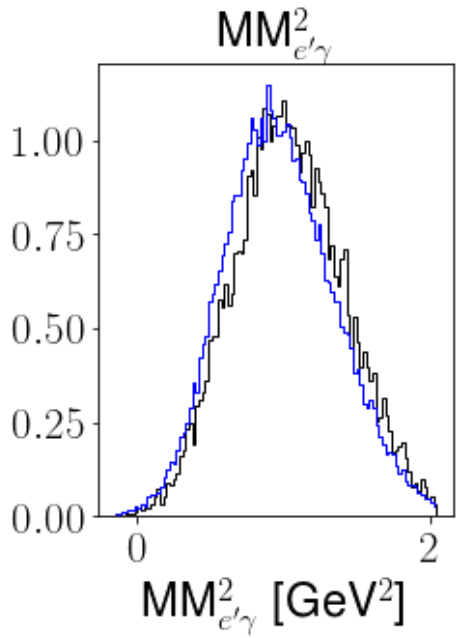
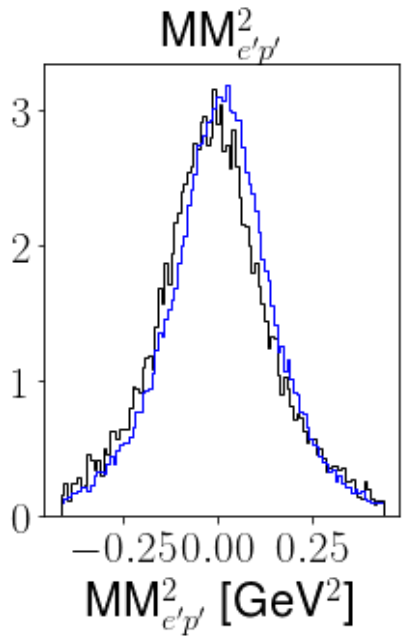
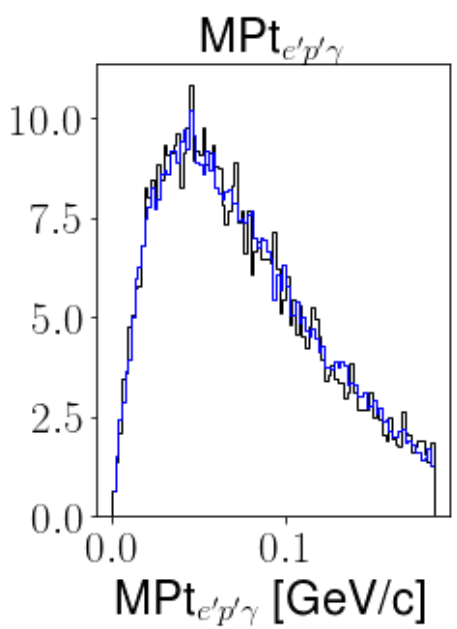


# One-slide summary of pass1 post-processing

- Proton energy loss correction to both experimental and simulation data
- 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: $(p, \theta, \phi) \rightarrow (p + 0.25\ \text{GeV/c}, \theta, \phi)$
    - FD: $(p, \theta, \phi) \rightarrow (p + 0.0045\ p^2, \theta, \phi)$
- Smearing in simulation data
  - Proton
    - CD: $(p, \theta, \phi) \rightarrow (X(p)\%\ \text{smearing}, \theta + 0.8°\ \text{smearing}, \phi + 2.2°\ \text{smearing})$
      - $X(p)\%$ smearing: $p \rightarrow p + gaus(1, X(p)\%) \times p$
      - $0.8°$ smearing: $\theta \rightarrow \theta + gaus(0, 0.8°)$
    - FD: $(p, \theta, \phi) \rightarrow (p + Y(p)\%\ \text{smearing}, \theta, \phi)$
      - $X(p), Y(p)$ has a complex form. but roughly 8% for CD, 6% for FD inbending, 8% for FD outbending
  - Photon
    - FT: $(p, \theta, \phi) \rightarrow (p + 1.4\%\ \text{smearing}, \theta, \phi)$
    - FD: $(p, \theta, \phi) \rightarrow (p + 3.5\%\ \text{smearing}, \theta, \phi)$

# Post-processing: the general principle

- Known facts
  - The simulation distribution is narrower than the experimental distribution.
    -> Momentum smearing at simulation data
  - Not only narrower, there is a shift in some distributions (ex) Missing energy)
    -> Momentum correction at experimental data

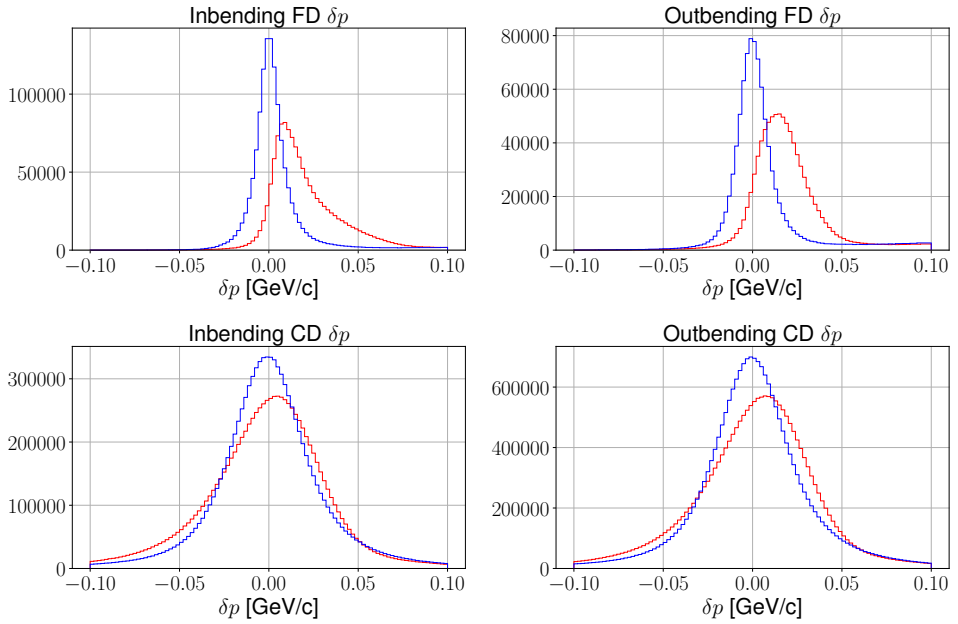
- DVCS experimental distribution?
  - a DVCS candidate is defined as the exclusive $e'p'\gamma$ pair.
  - In simulation, any $e'p'\gamma$ is DVCS or DV$\pi^0$P.
  - In experiment, no clue about the source reaction.
  - The experimental data exists based on the exclusive event selection cuts.
  - The event selection cut is from a priori knowledge of the simulation
  - By definition, momentum correction is an iterative procedure.

# 0. Proton energy loss correction

- We know the truth and observed momentum values in MC.
  - measured $p$: $p_{meas.}$, $p_{reco.}$, $p_{rec.}$ , ….
  - generated $p$ : $p_{gen.}$, $p_{truth}$ ,…
  - correction $\delta p = p_{gen.} - p_{meas.}$
- Corrected $\theta$ and $\phi$ too.
- $p$>1 GeV/c, my correction has a negative bias
  - take Andrey's $p$ correction at $p$>1
- Presented at the software meeting.
  - I will finalize and upload the technical note
- Applied to both simulation and experimental data.

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

before this correction
after this correction



# 1. Momentum Smearing and Correction Procedure

- goal: adjust proton and photon 3d momentum in order to
  - match DVCS($e'p'\gamma$) distributions for all topologies ($p'\gamma$: CDFT, CDFD, FDFD)
  - match DV$\pi^0$P($e'p'\gamma\ \gamma$) distributions for all topologies ($p'\gamma\gamma$ : CDFTFT, CDFDFD, FDFDFD)
  - distributions: particle 3d momentum, exclusivity variables

- DVCS
  - CD proton: almost 0 background/ FD proton: nonnegligible background (30%)
  - only one photon exists.
- DV$\pi^0$P
  - pure (0 background)
  - has two photons that often touches different kinematic region. -> difficult to use for the photon correction study.
  - used for the validation

- The photon correction/smearing should be the same for both torus polarities
- The CD proton correction/smearing should be the same for both torus polarities

# 1. Momentum Smearing and Correction Procedure

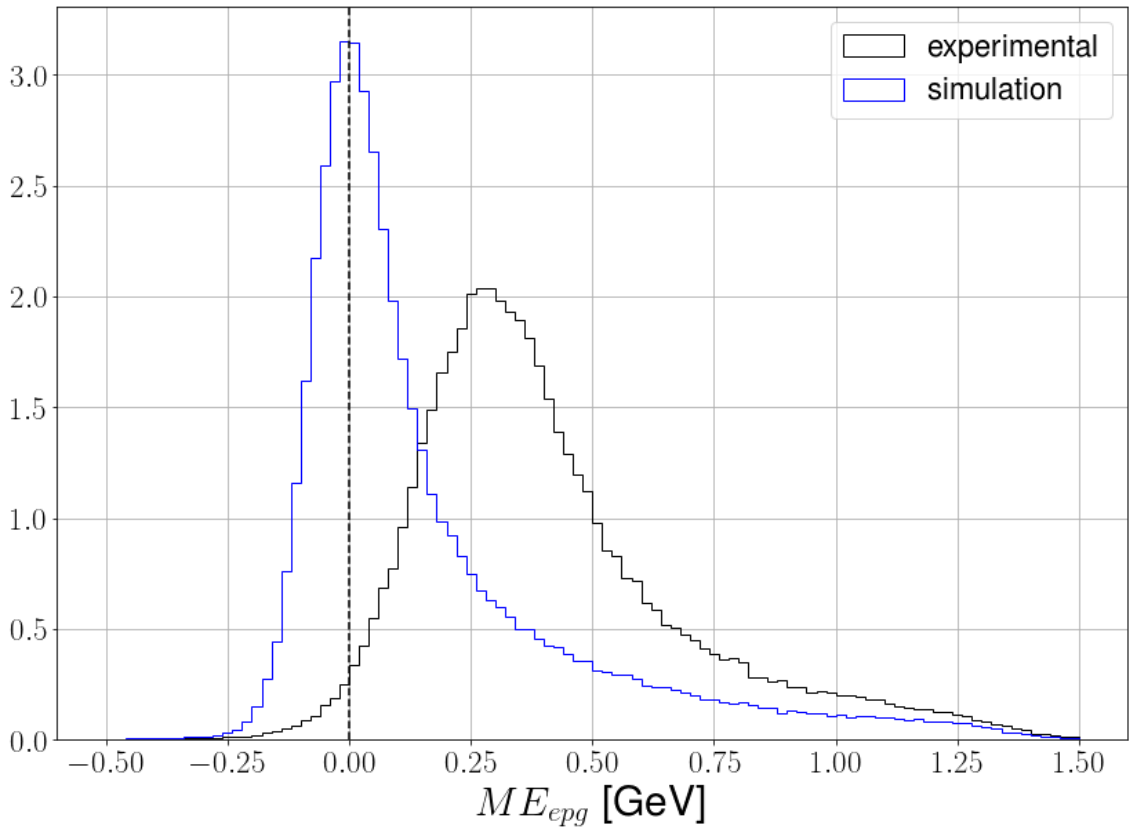
- These simple facts lead to a reasonable procedure
  - $p'\gamma$:CDFT → CDFD → FDFD
  - $\gamma$ : FT → FD
  - $p'$: CD → FD
  - Only FD proton is torus sensitive. Start with inbending data set -> expand to outbending.

- which variable impacts on which exclusivity variables?
  - Invariant mass
    - DV$\pi^0$P: $IM_{\gamma\gamma}$
  - Missing masses
    - DVCS: $MM^2_{e'p'}$, $MM^2_{e'p'\gamma}$, $MM^2_{e'\gamma}$
    - DV$\pi^0$P : $MM^2_{e'p'}$, $MM^2_{e'p'\gamma\gamma}$, $MM^2_{e'\gamma\gamma}$
  - Missing Energies
    - DVCS:, $ME_{e'p'\gamma}$
    - DV$\pi^0$P: $ME_{e'p'\gamma\gamma}$
  - Angular variables
    - DVCS: $\theta_{\gamma X}$ , $\Delta\phi_{p'\gamma}$ (X = beam + target – e' – p')
    - DV$\pi^0$P : $\theta_{\pi X}$ , $\Delta\phi_{p'\pi}$ (X = beam + target – e' – p')

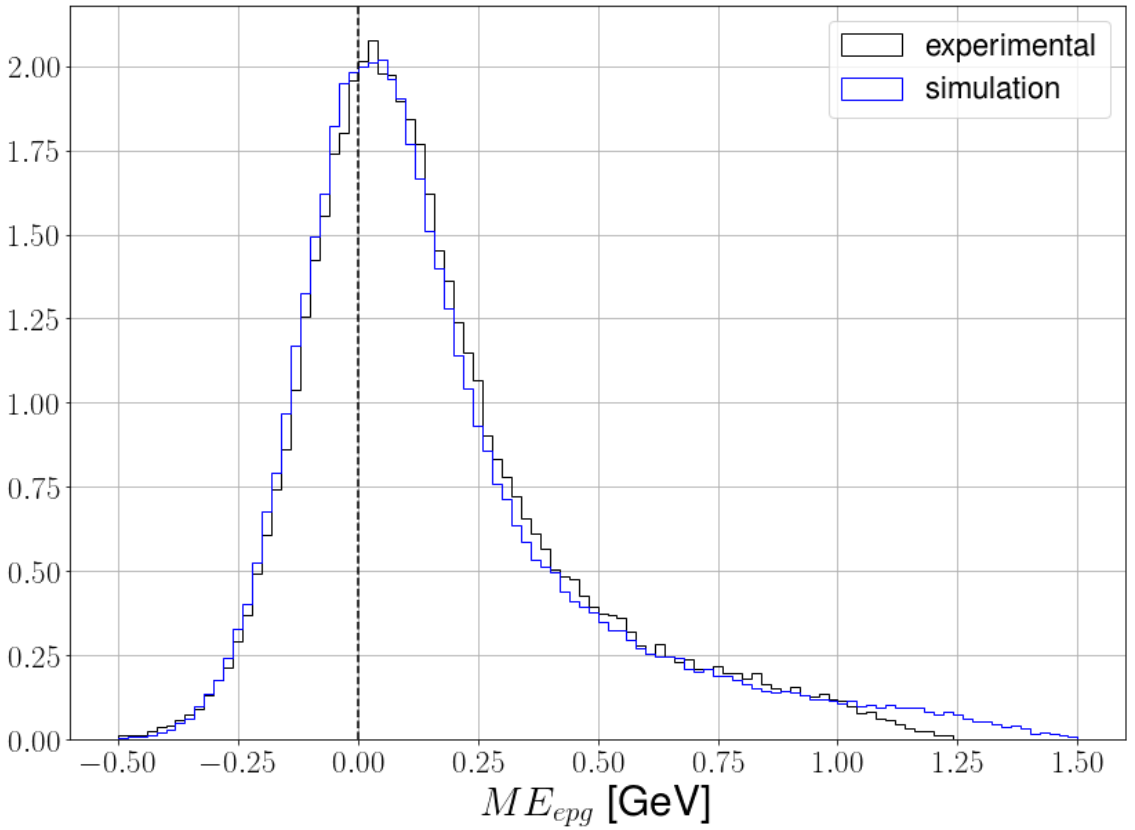
# 2-1. FT photon momentum using DVCS ($p'\gamma$: CDFT)

experimental data: $p_\gamma \rightarrow p_\gamma$ + 250 MeV.
simulation data: $p_\gamma \rightarrow p_\gamma + gaus(1, 1.4\%) \times p_\gamma$

$ME_{e'p'\gamma}$ before correction and smearing



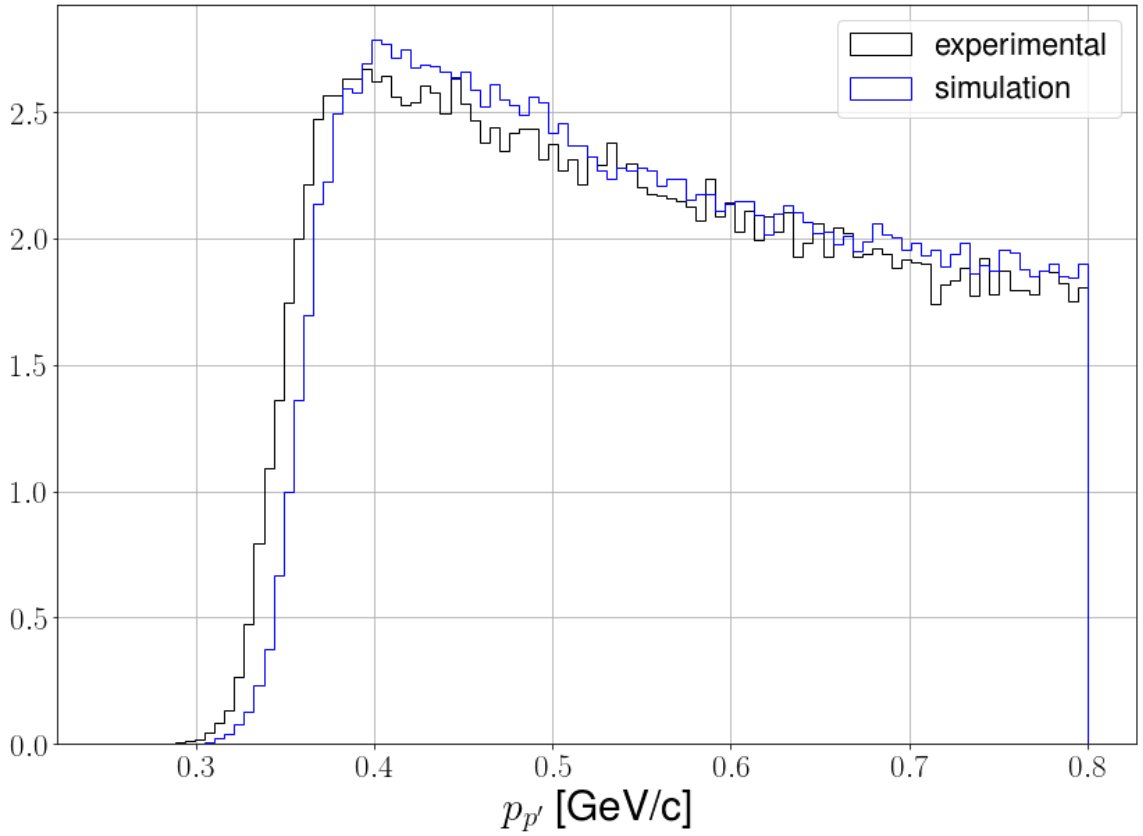

$ME_{e'p'\gamma}$ after correction and smearing



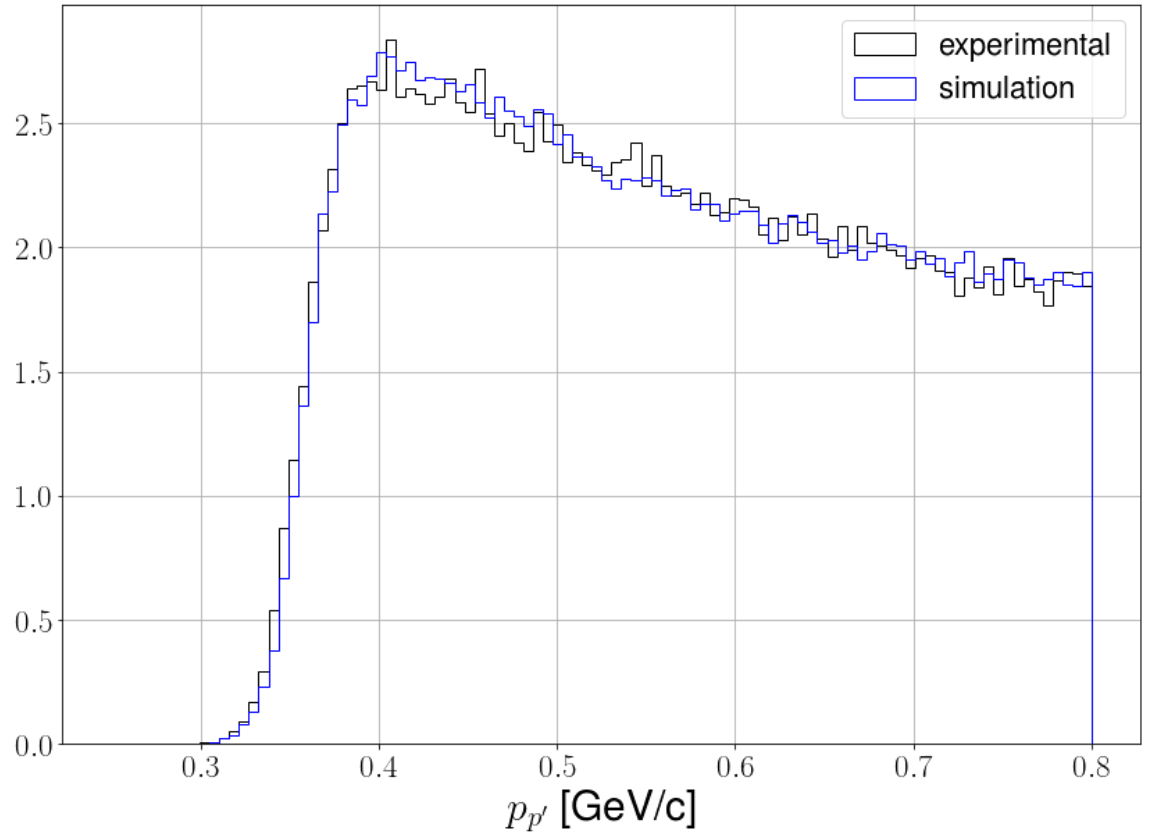
# 2-2. CD proton momentum using DVCS ($p'\gamma$: CDFT)

experimental data: $p_{p'} \rightarrow p_{p'}$ + 10 MeV/c.

$p_{p'}$ before correction



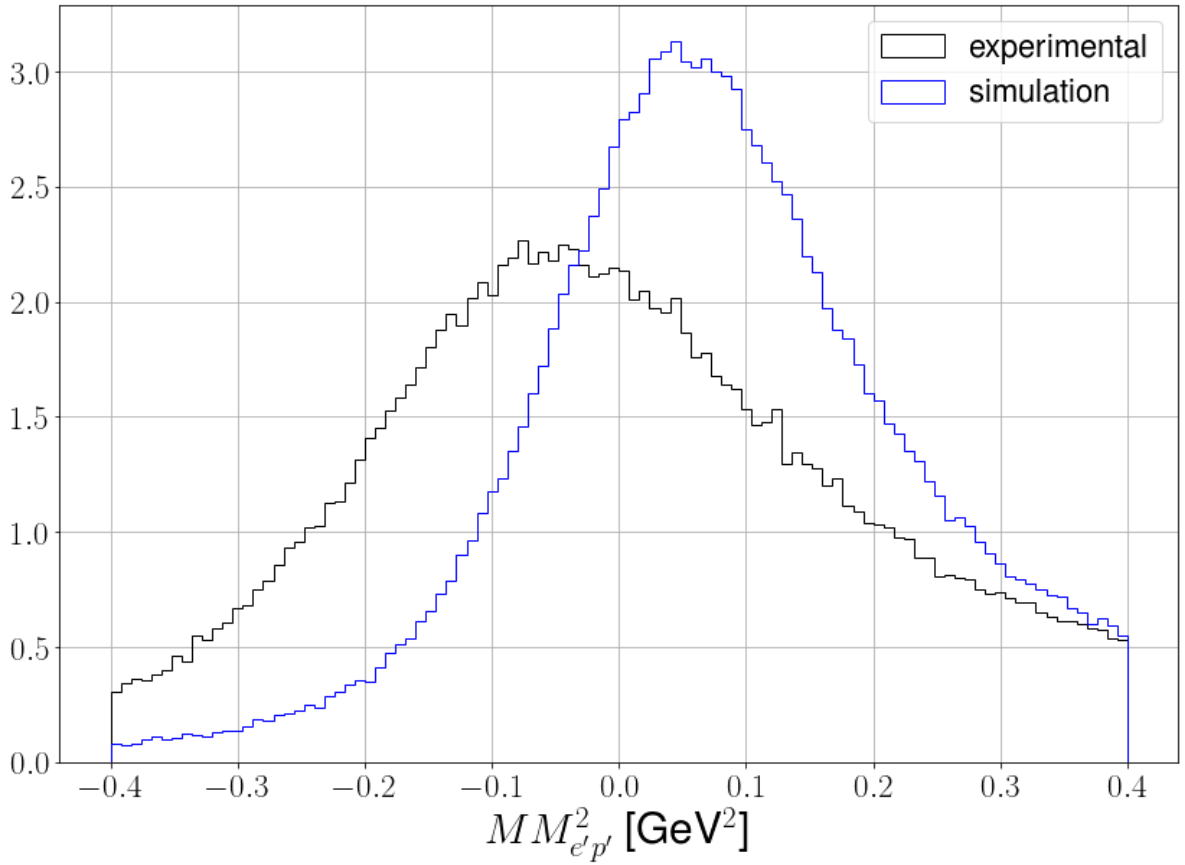

$p_{p'}$ after correction



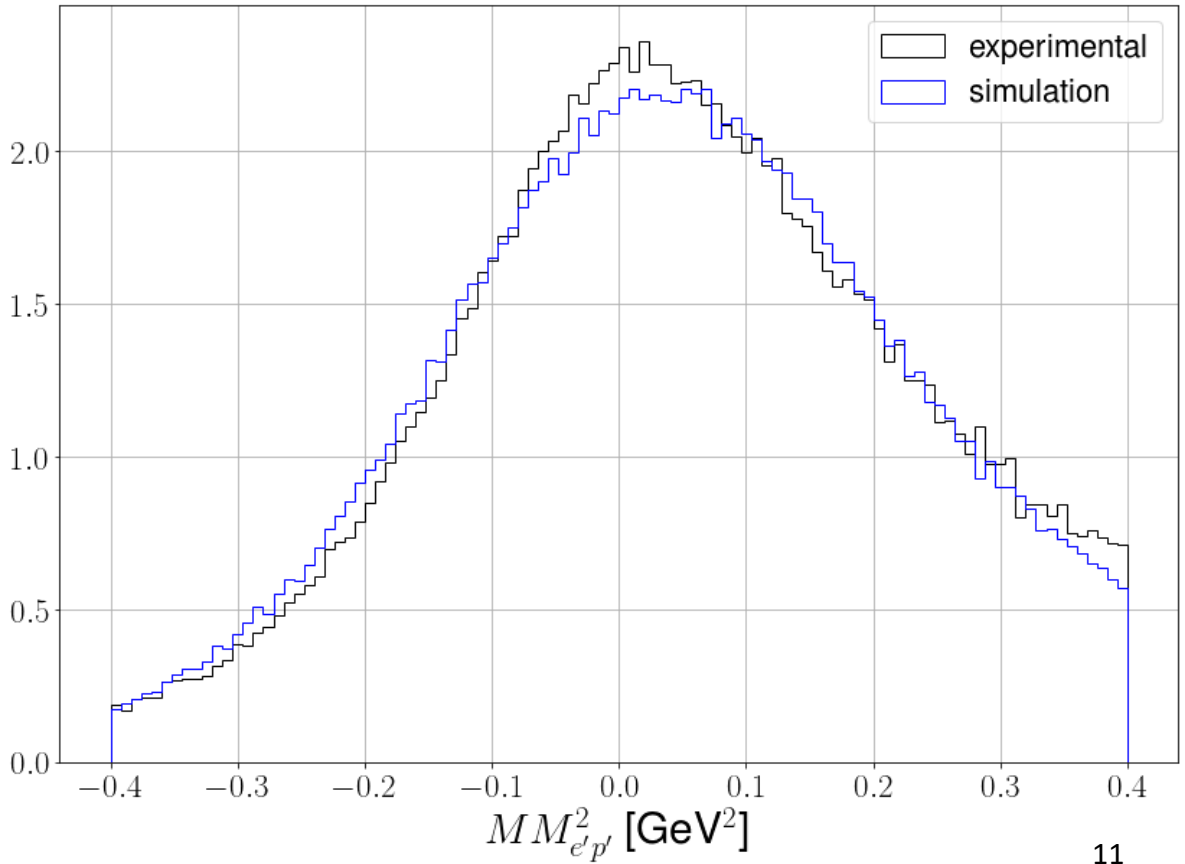
# 2-2. CD proton momentum using DVCS ($p'\gamma$: CDFT)

experimental data: $\theta_{p'} \rightarrow \theta_{p'} - 0.5$
simulation data: $p_{p'} \rightarrow p_{p'} + gaus(1, X(p)\%) \times p_{p'}$
X($p$) has a complex form. but roughly 8%.

$MM^2_{e'p}$ before correction



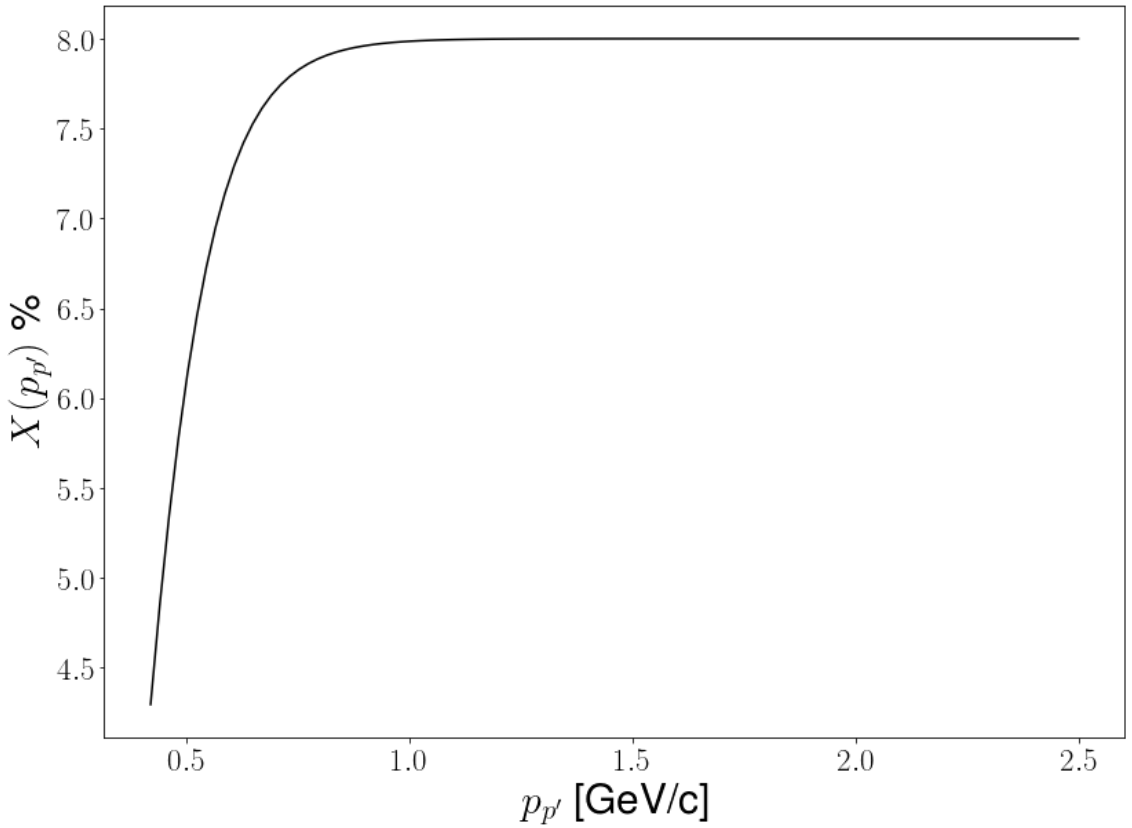

$MM^2_{e'p}$ after correction

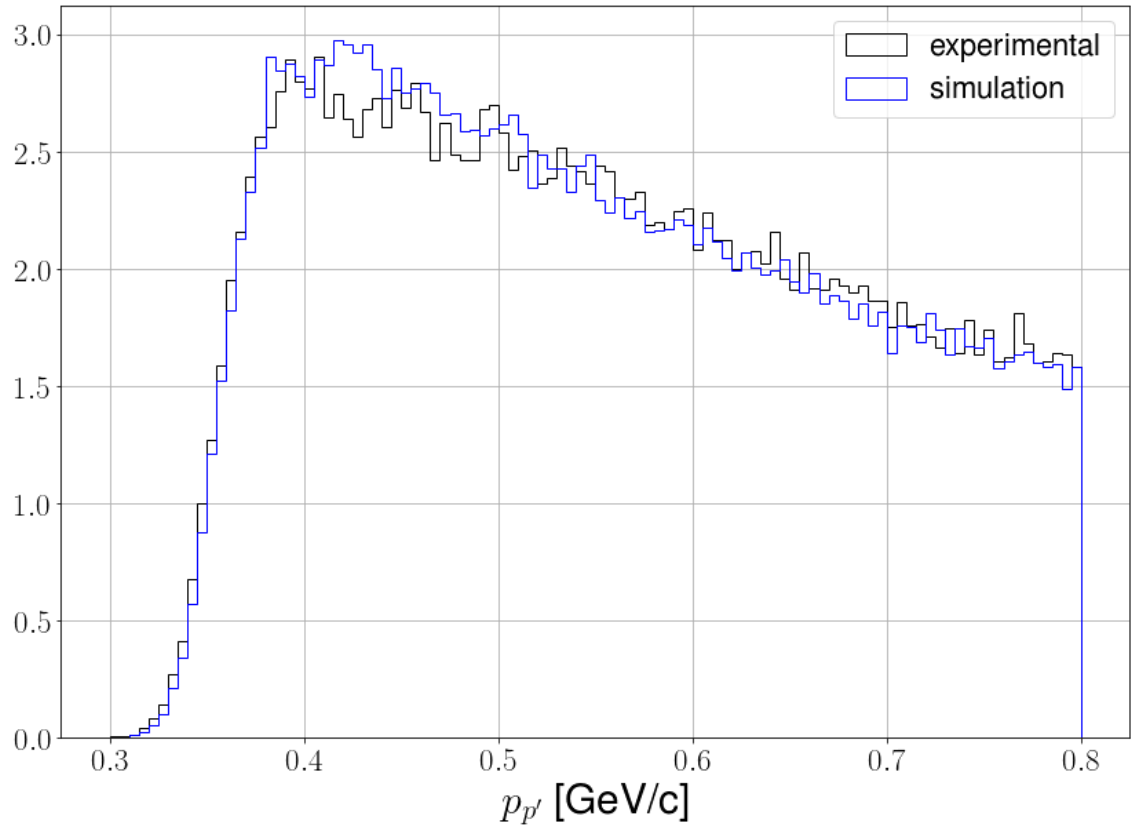


# 2-2. CD proton momentum using DVCS ($p'\gamma$: CDFT)

X(*p)* has a complex form. but roughly 8%.

Regulate X(*p)* at the threshold to keep the good matching of $p_{p'}$

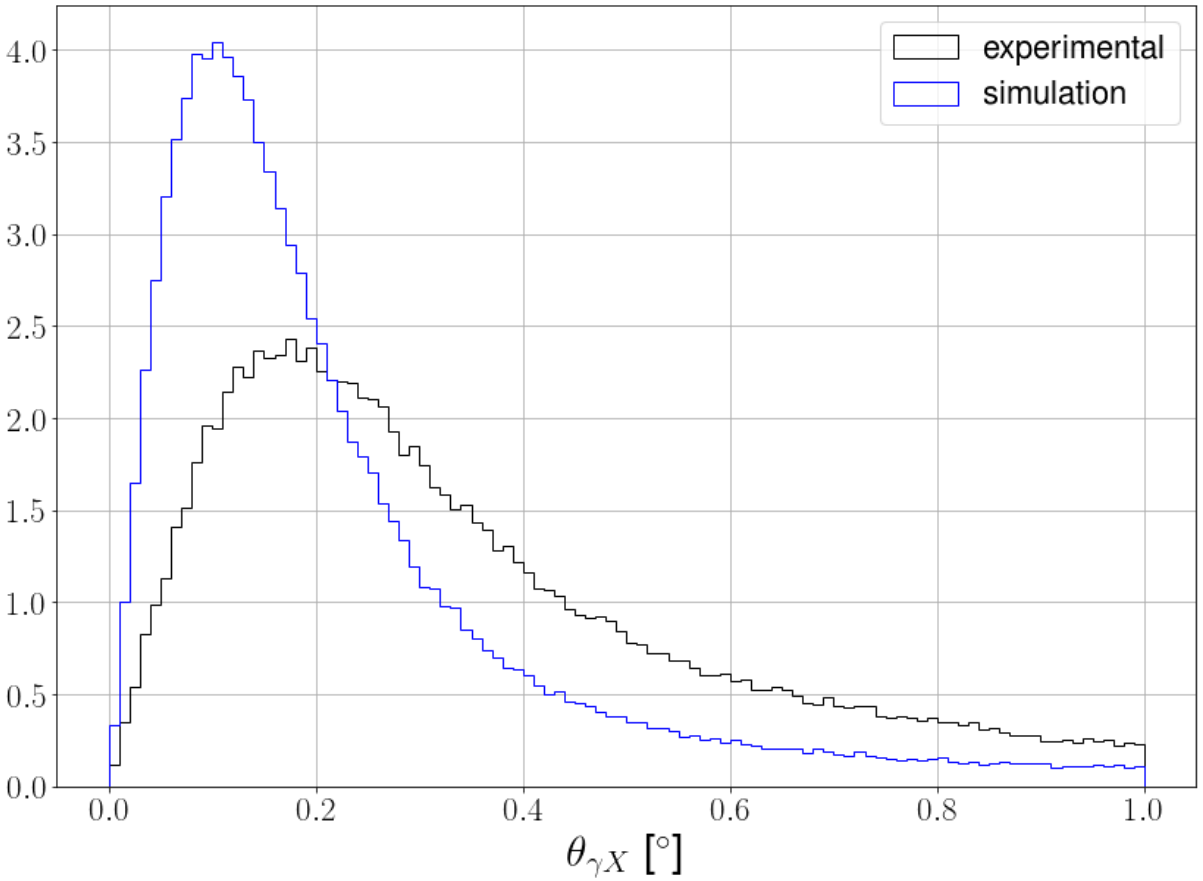


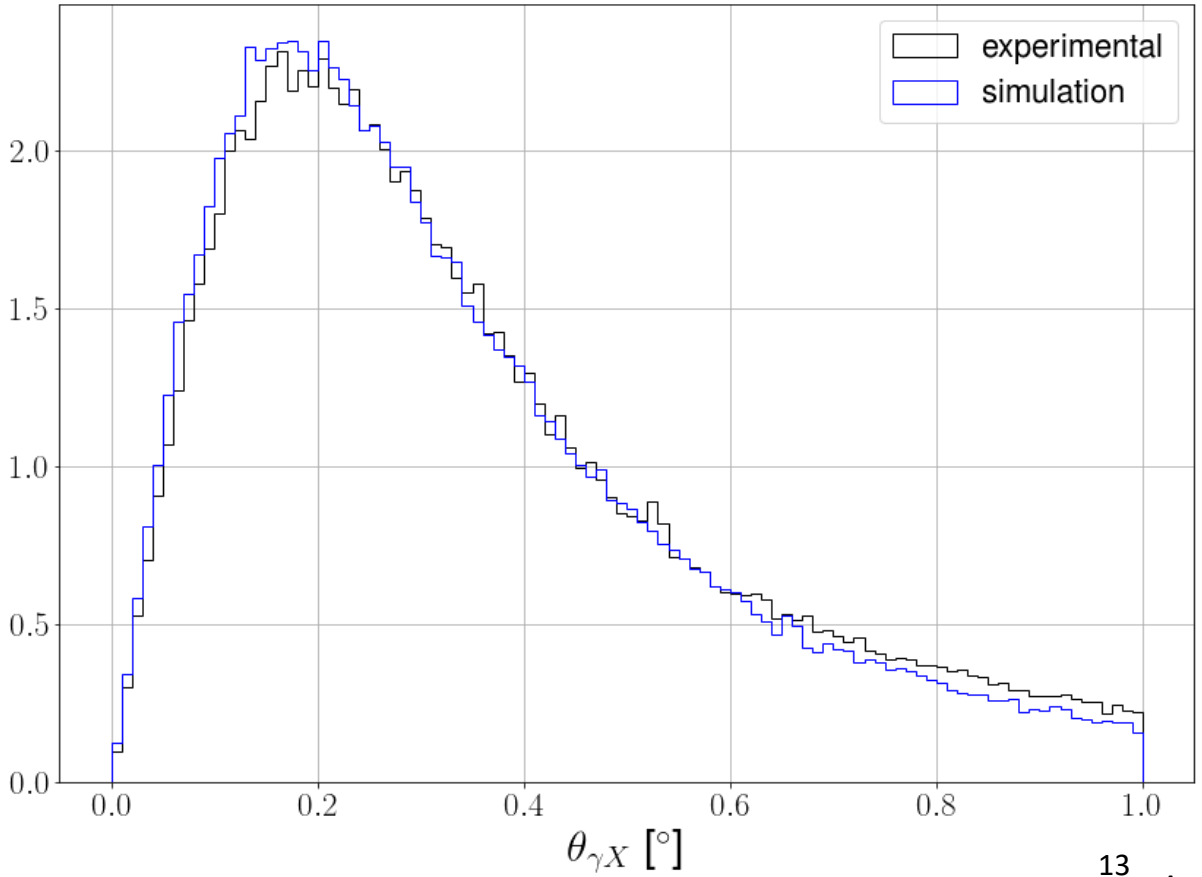
# 2-2. CD proton momentum using DVCS ($p'\gamma$: CDFT)

simulation data: $\theta_{p'} \rightarrow \theta_{p'} + gaus(0, 0.8°)$

$\theta_{p'}$ before correction



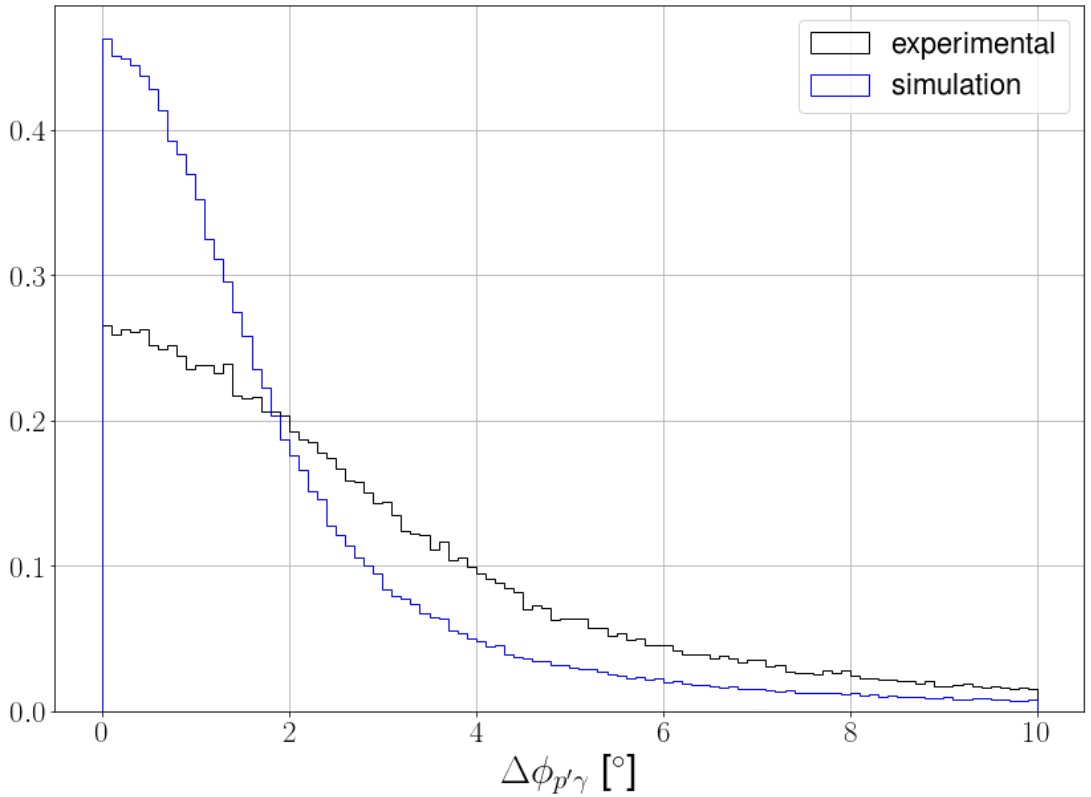

$\theta_{p'}$ after correction



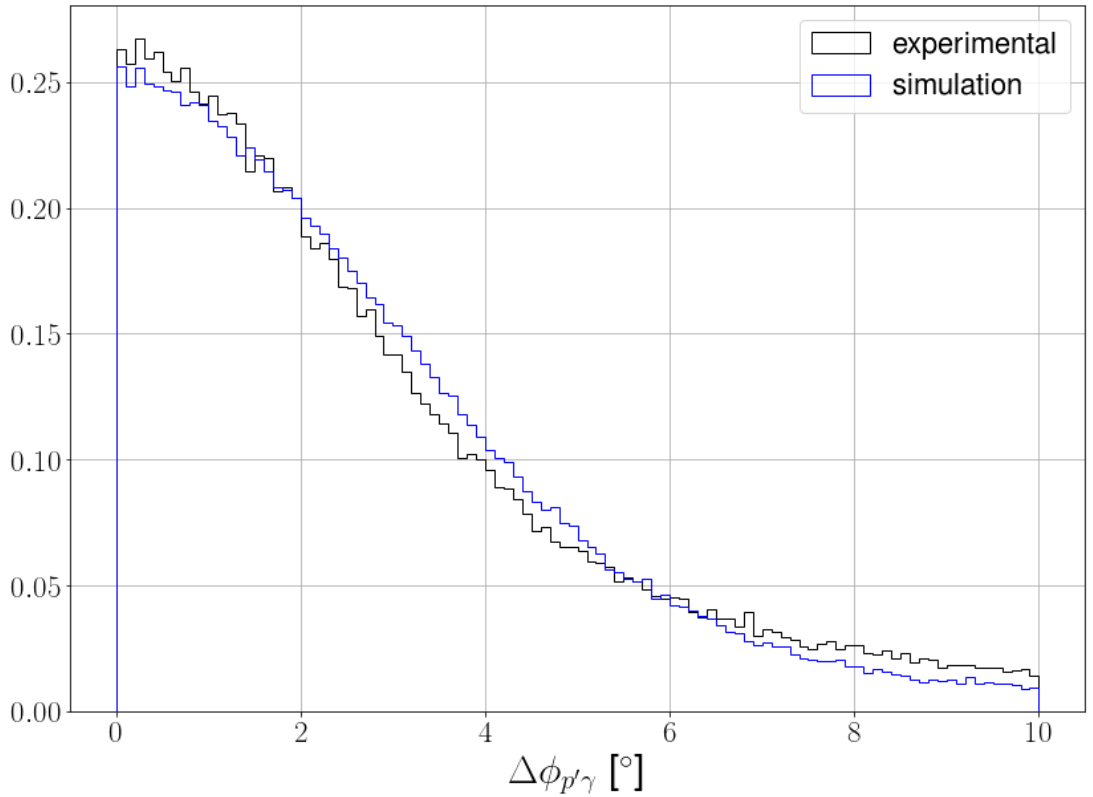
# 2-2. CD proton momentum using DVCS ($p'\gamma$: CDFT)

simulation data: $\phi_{p'} \rightarrow \phi_{p'} + gaus(0, 2.2°)$

$\Delta\phi_{p'\gamma}$ before correction



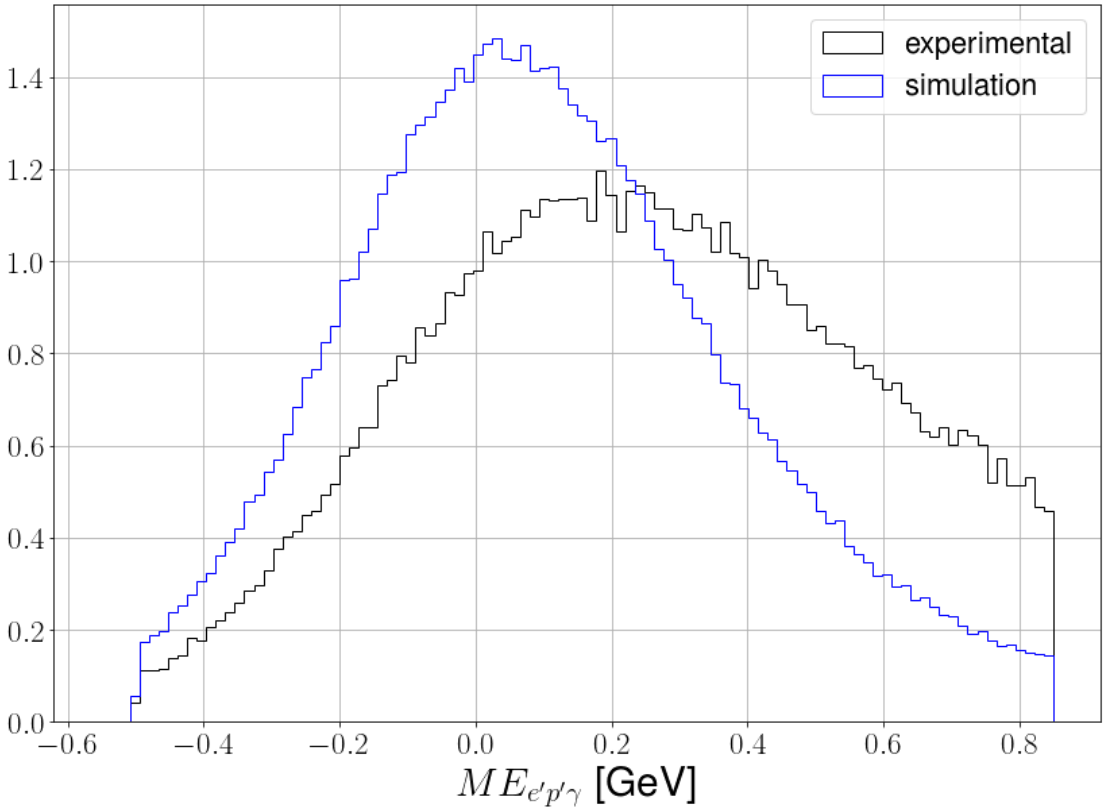

$\Delta\phi_{p'\gamma}$ after correction



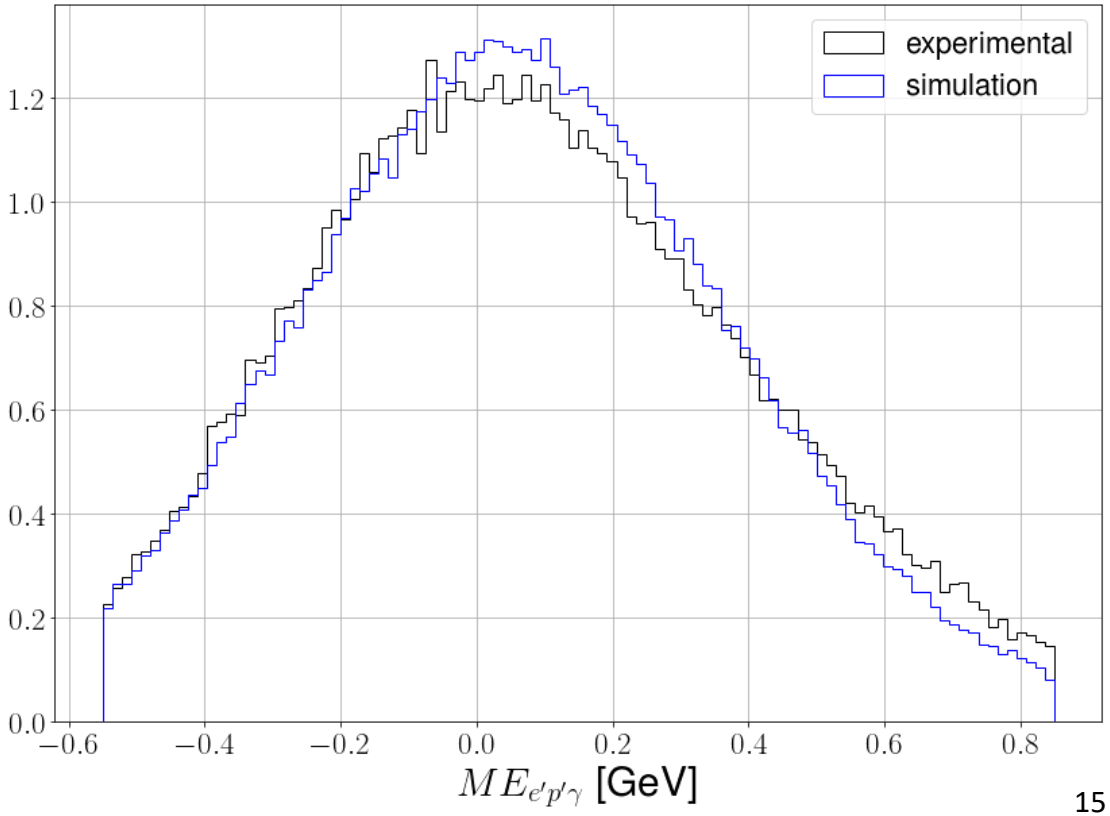
# 2-3. FD photon momentum using DVCS ($p'\gamma$: CDFD)

experimental data: $p_\gamma \rightarrow p_\gamma + 0.0045\, p_\gamma^2$
simulation data: $p_\gamma \rightarrow p_\gamma + gaus(1, 3.5\%) \times p_\gamma$

$ME_{e'p'\gamma}$ before correction and smearing




$ME_{e'p'\gamma}$ after correction and smearing



# 2-4. FD proton momentum using DV$\pi^0$P ($p'\gamma\gamma$ : FDFDFD)

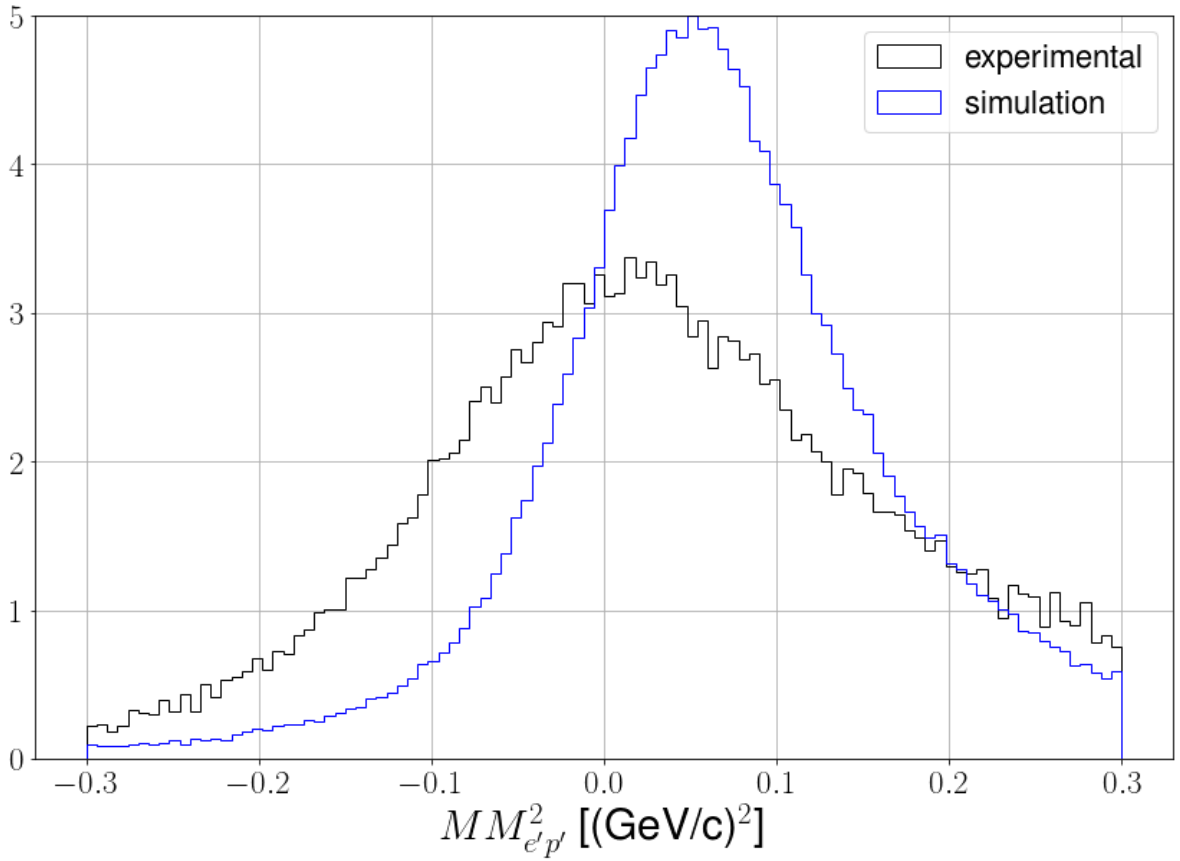
experimental data: $p_{p'} \rightarrow p_{p'}$ + A($p$).

simulation data $p_{p'} \rightarrow p_{p'}$ + *gaus*(1, Y($p_{p'}$)) × $p_{p'}$

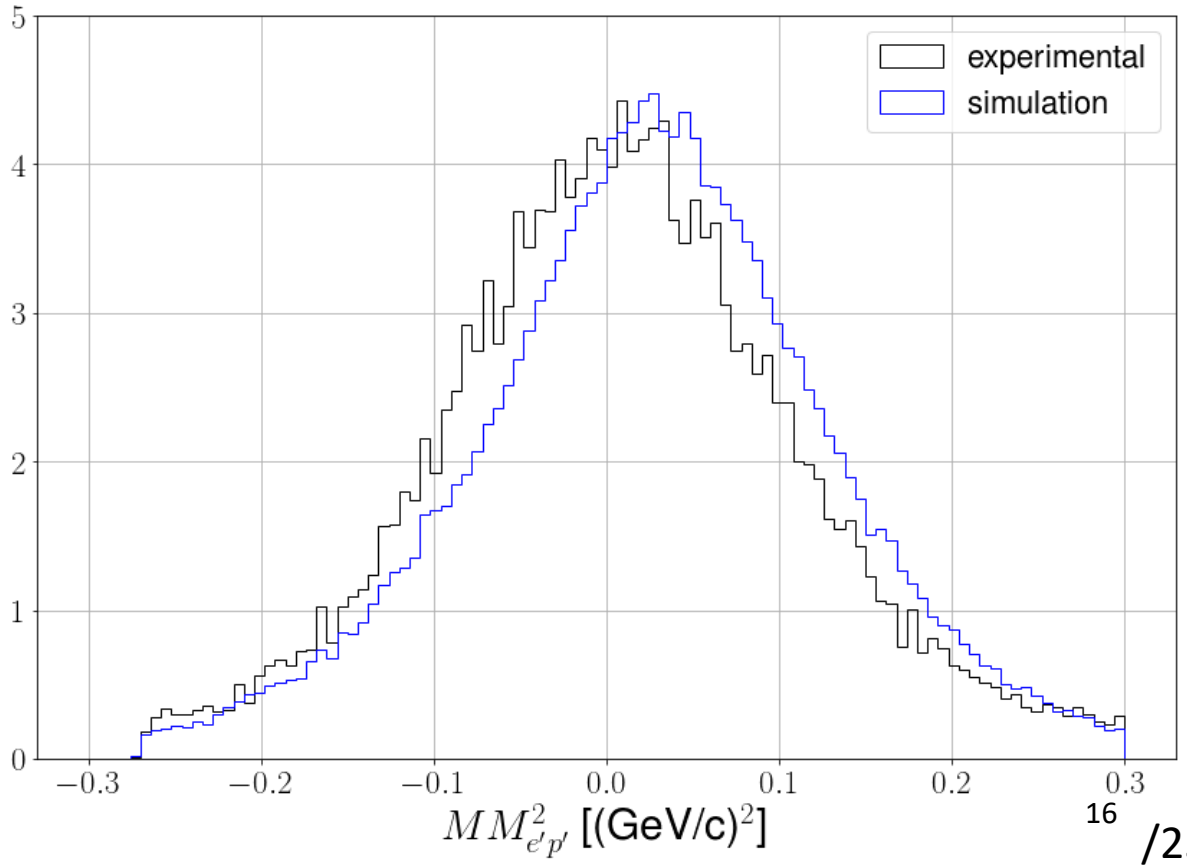
A($p$) = 58.62 ($p$ - 0.42)$^{4.355}$ $e^{-10.038(p-0.42)}$ (inbending), -0.02 (outbending)

Y($p$) has a complex form. but roughly 6% (inbending), and 8% (outbending).

$MM^2_{e'p}$ before correction (inbending)




$MM^2_{e'p}$ after correction (inbending)



# 2-4. FD proton momentum using DV$\pi^0$P ($p'\gamma\gamma$ : FDFDFD)

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simulation data $p_{p'} \rightarrow p_{p'} + gaus(1, Y(p_{p'})) \times p_{p'}$

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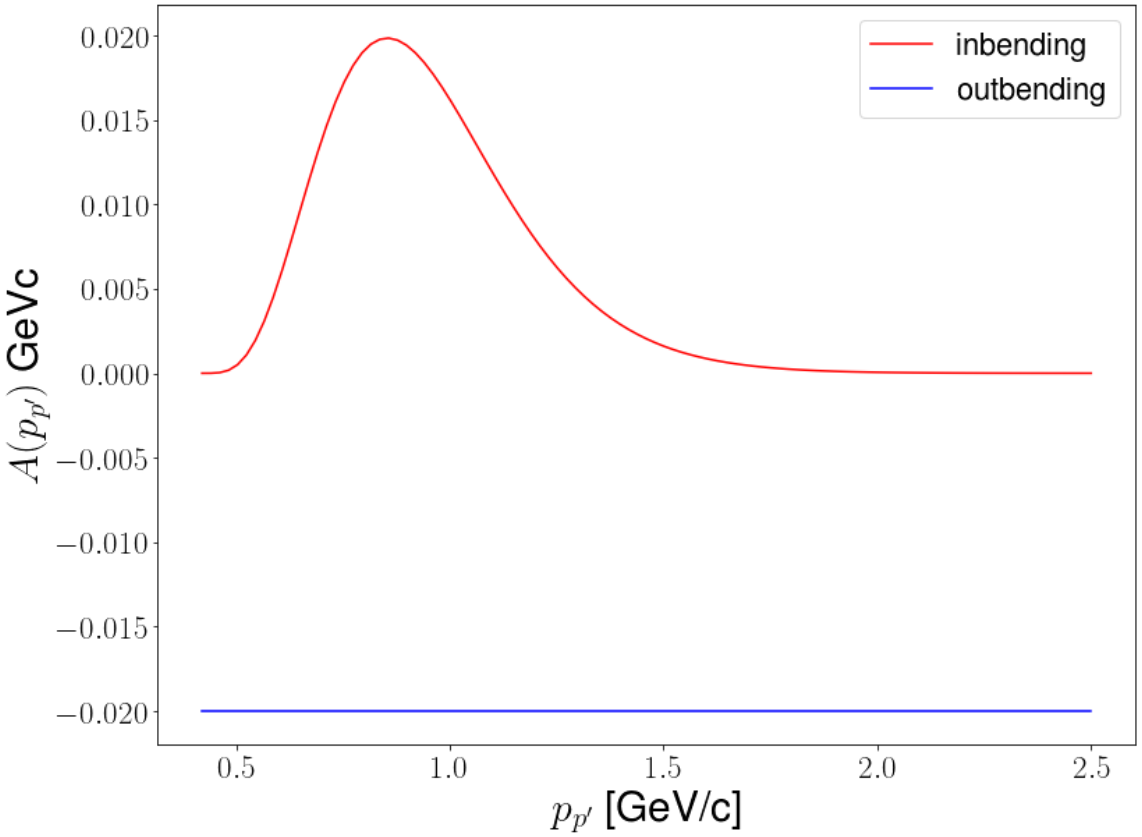
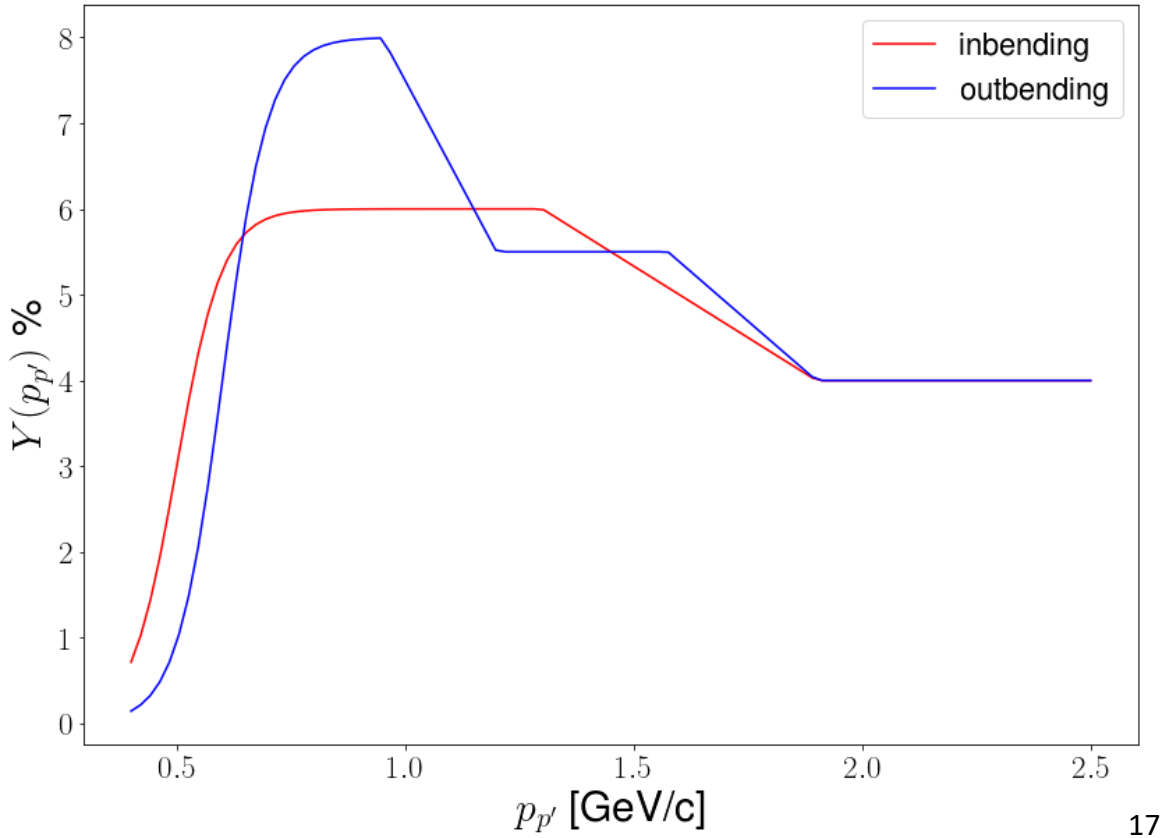


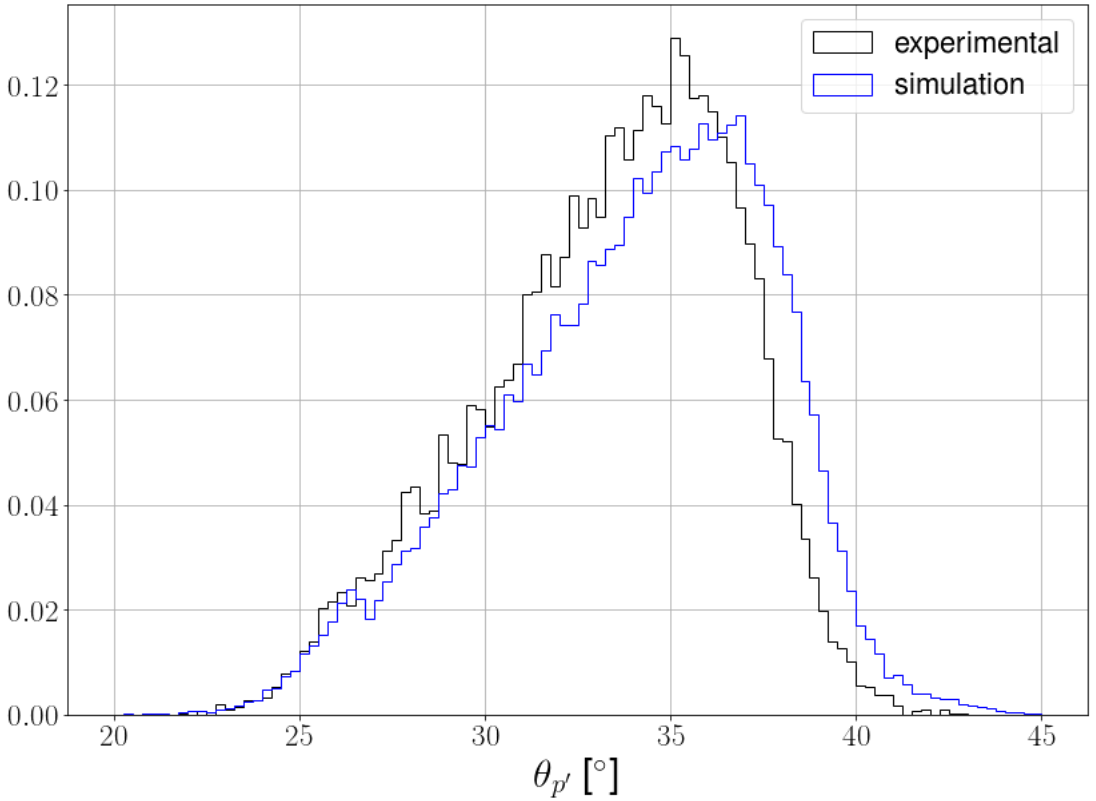



# 2-4. FD proton momentum using DV$\pi^0$P ($p'\gamma\gamma$ : FDFDFD)

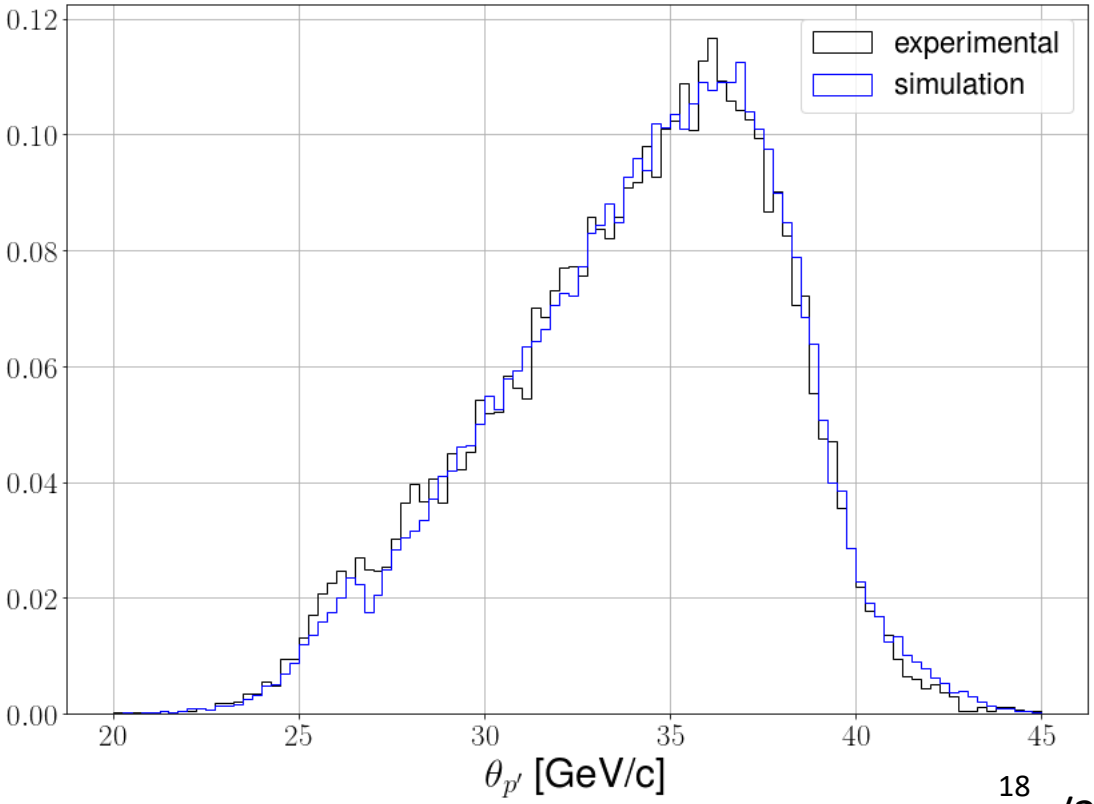
experimental data: $\theta_{p'}$ -> $\theta_{p'}$ + B($p$).

B($p$) = 0 (inbending), 0.05(|$\theta_{p'}$-27| +($\theta_{p'}$-27) ) (outbending)

$\theta_{p'}$ before correction (outbending)




$\theta_{p'}$ after correction (outbending)

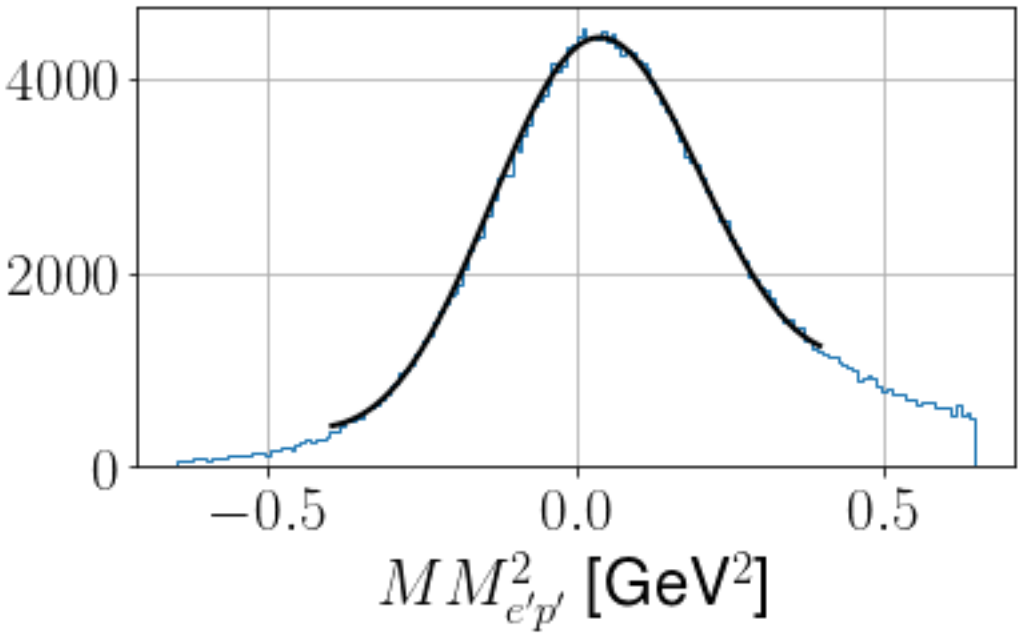


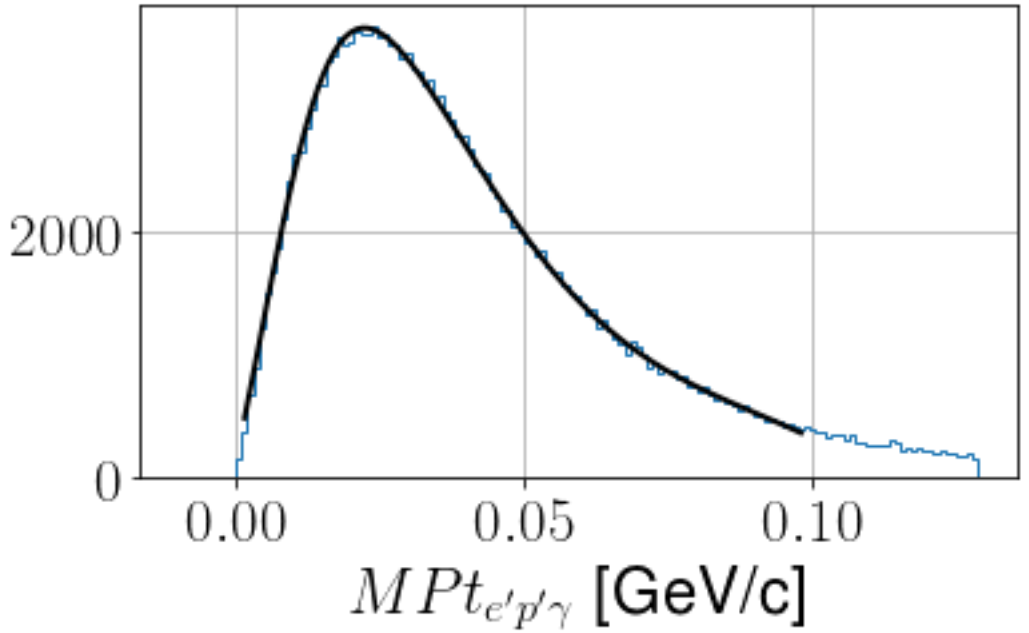
# One-slide summary revisited.

- 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: $(p, \theta, \phi) \rightarrow (p + 0.25\ \text{GeV/c}, \theta, \phi)$
    - FD: $(p, \theta, \phi) \rightarrow (p + 0.0045\ p^2, \theta, \phi)$
- Smearing in simulation data
  - Proton
    - CD: $(p, \theta, \phi) \rightarrow (X(p)\%\ \text{smearing}, \theta + 0.8^\circ\ \text{smearing}, \phi + 2.2^\circ\ \text{smearing})$
      - $X(p)\%$ smearing: $p \rightarrow p + gaus(1, X(p)\%) \times p$
      - $0.8^\circ$ smearing: $\theta \rightarrow \theta + gaus(0, 0.8^\circ)$
    - FD: $(p, \theta, \phi) \rightarrow (p + Y(p)\%\ \text{smearing}, \theta, \phi)$
      - $X(p)$, $Y(p)$ has a complex form. but roughly 8% for CD, 6% for FD inbending, 8% for FD outbending
  - Photon
    - FT: $(p, \theta, \phi) \rightarrow (p + 1.4\%\ \text{smearing}, \theta, \phi)$
    - FD: $(p, \theta, \phi) \rightarrow (p + 3.5\%\ \text{smearing}, \theta, \phi)$

# Event Selections

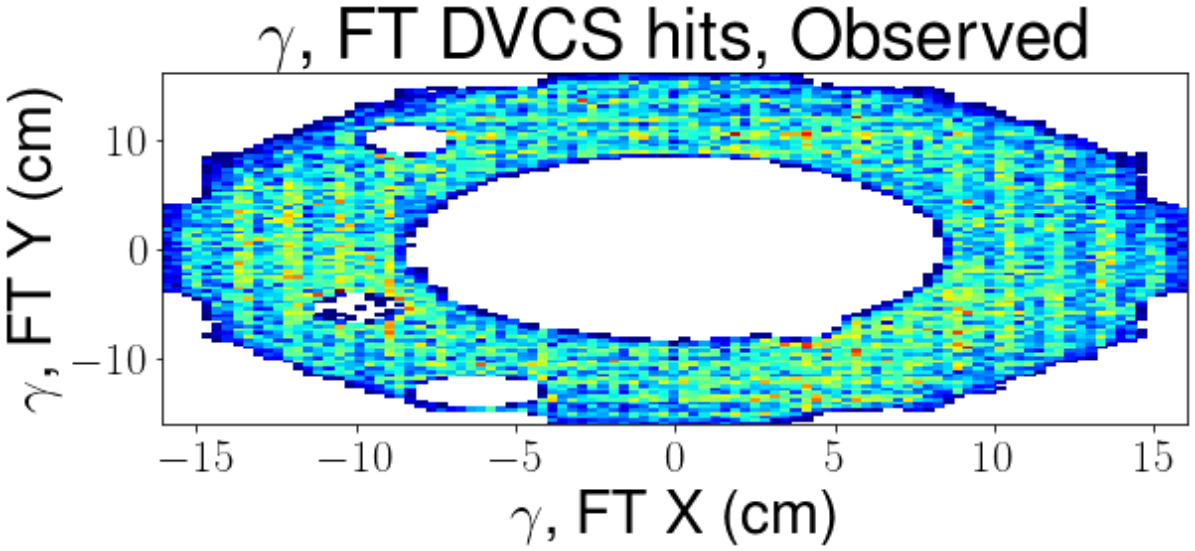
- Fit 3$\sigma$ region from simulation for each topology
  - used fitting function: normal (gaussian), skew normal, half normal
  - ex) $p'\gamma$: CDFT

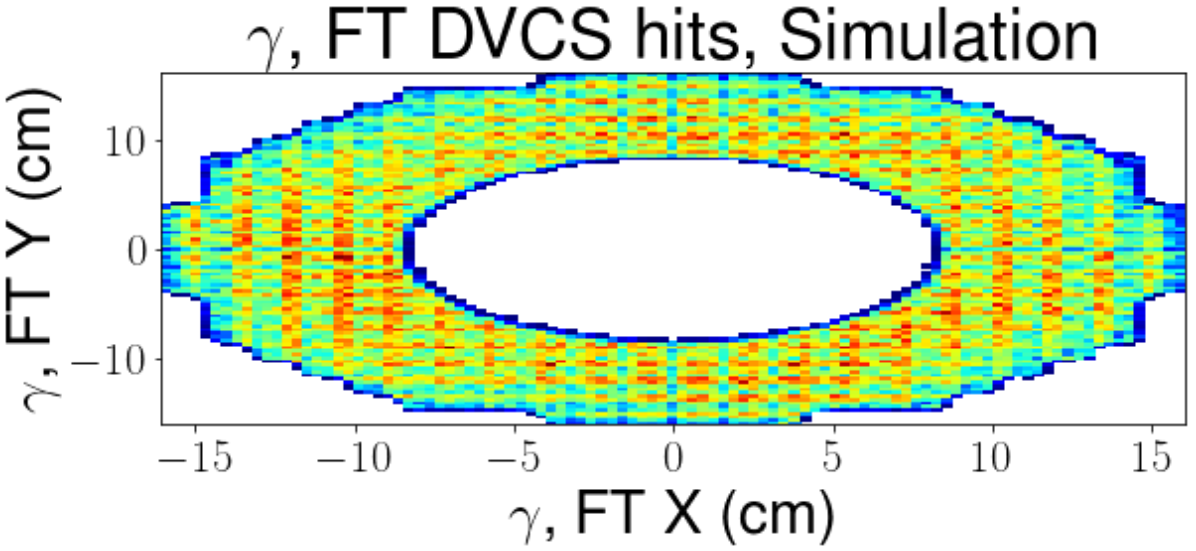


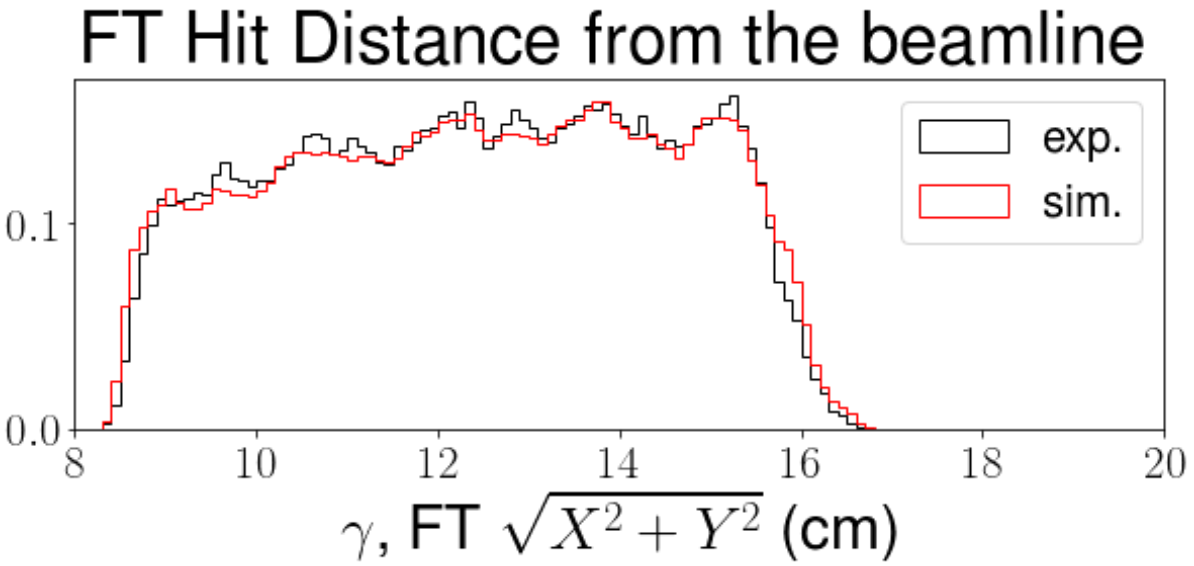



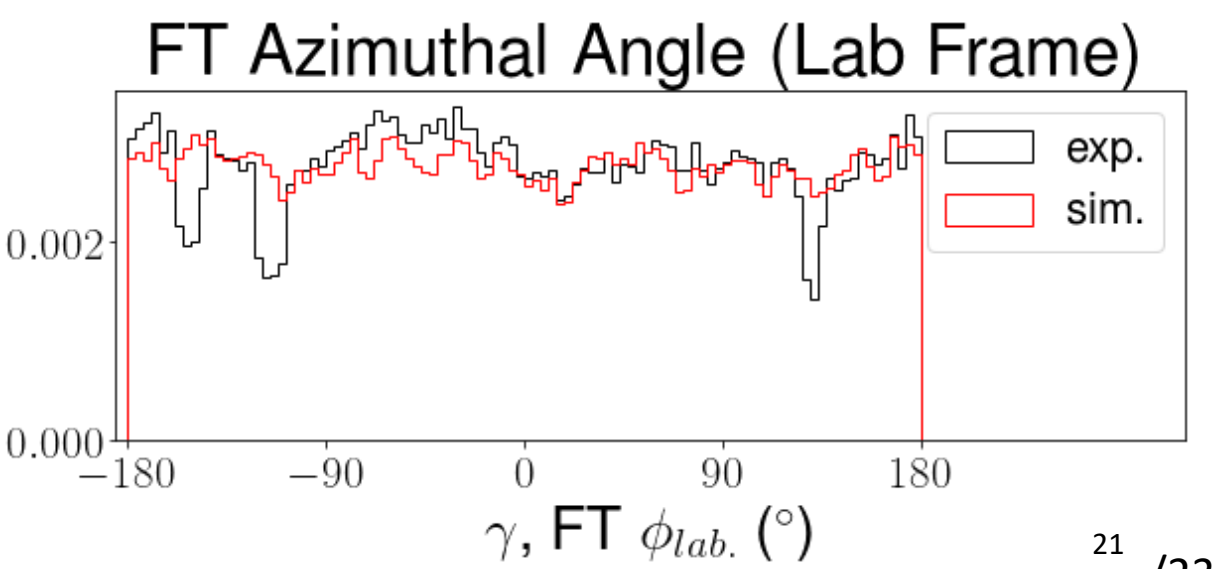

- For $p'\gamma$ : FDFD case, it is important to develop cuts on mixture of DVCS and DV$\pi^0$P profile!
  - contamination is non-negligible.
  - i.e., make normlized distributions from 70% DVCS and 30% DV$\pi^0$P

# Minor issue with FT



# Sources of systematic uncertainty

- My works
  - $\pi^0$ contamination
  - radiative correction
  - model dependence
  - bin volume effects
  - bin migration
  - cut selection
  - FD reconstruction efficiency vs. beam current (background merging)
  - relative efficiencies among different topologies

- global efficiency ratio of exp. to sim.
  - Need some helps!

# Conclusion

- The momentum correction and smearing has been performed
  - in order for a good simulation-to-data matching with pass1 data
  - effectively works well for both channels DVCS and DV$\pi^0$P
  - sequentially developed (CDFT -> CDFD -> FDFD)
  - iteratively developed
    - applied, verified and tested for all exclusivity variables
  - for all topology and torus polarity

- FD angular resolution matching improved after changing the cuts
  - discussion with FX