Neutron DVCS Cross Section Extraction at the CLAS12 Experiment

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CLAS Collaboration Meeting

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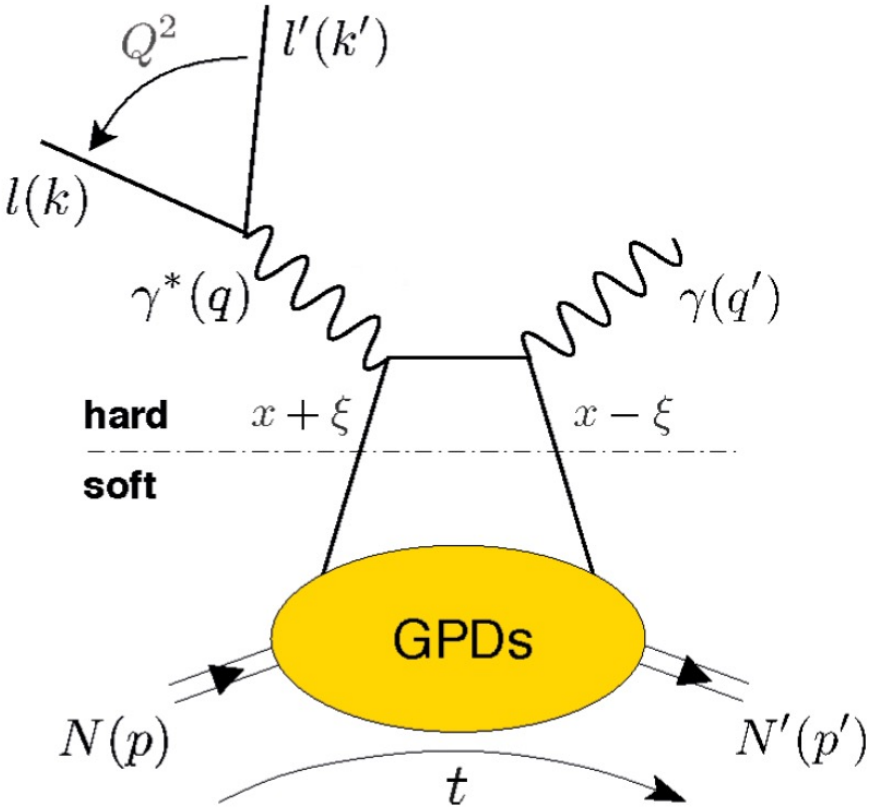
Outline

- Motivation
- Data and MC samples
- PID and fiducial cuts
- Select neutron DVCS (nDVCS) data
- Distributions of nDVCS variables
- Study of π^0 production contamination
- Next to do

Motivation

- The study of multi-dimensional partonic structure of nucleons can provide important information to probe non-perturbative QCD
- Generalized Parton Distributions (GPDs) relate transverse position of partons to longitudinal momentum
- The Deeply Virtual Compton Scattering (DVCS) is one of the cleanest channels to access GPDs
- The measurement of DVCS cross-section from the neutron can provide unique information on GPDs

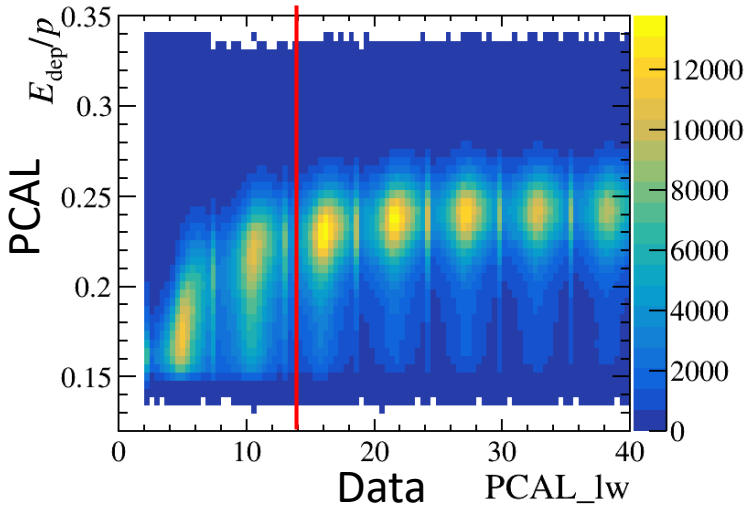


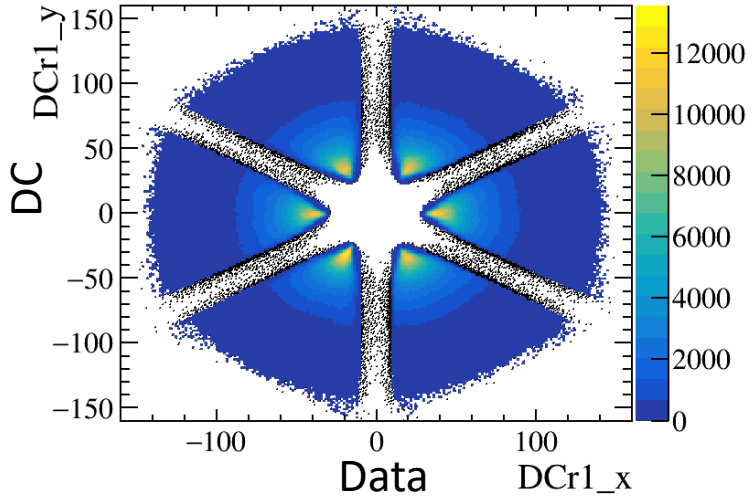
Data and MC samples

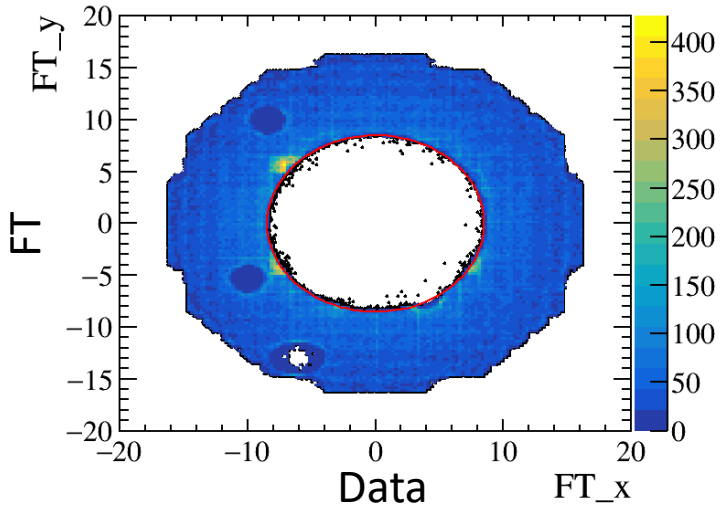
- Data
  - RGB pass2 data, collected by the CLAS12 detector in 2019 spring and 2020 spring
  - 10.6/10.4/10.2 GeV electron beam scattering off an unpolarized liquid deuterium target
- MC
  - 100M DVCS events (nDVCS: 23M events)

Configuration	rgb_spring2019	Software Ver.	gemc/5.4 coatjava/10.0.2
MC Gen Ver.	2.33	Magnetic Field	tor-1.00_sol-1.00
Generator	genepi	Bkg merging	50nA_10599MeV
Target Position	-3.0 cm	Target Length	5 cm
Generator Opt.	--EBeam 10.6 --process 0 -- targ_A 2 --targ_Z 1		

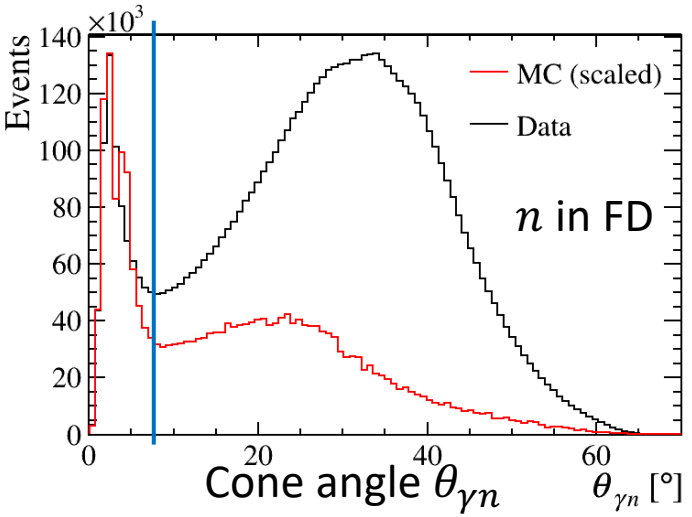
PID and fiducial cuts





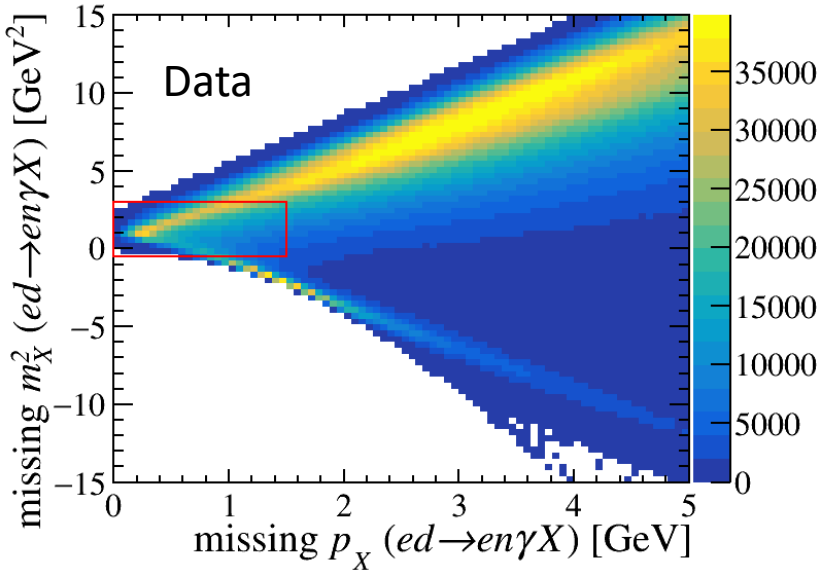


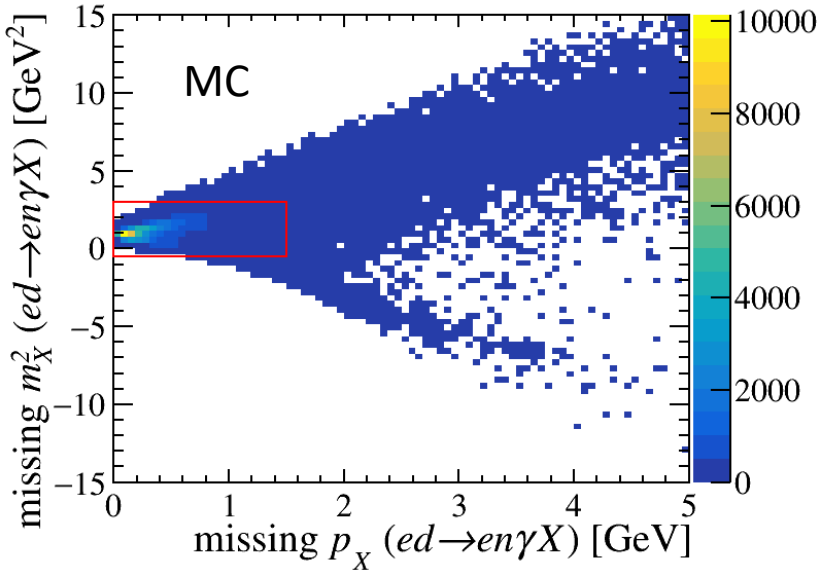
	Electron	Photon	Neutron
PID	11	22	2112
Momentum P	> 1 GeV	> 2 GeV	> 0.3 GeV
Reconstructed in	FD	FD or FT	FD or FT
Fiducial cuts	In FD: PCAL: lv(lw) > 14 DC: edge > 6	In FD: PCAL: lv(lw) > 14	In FD: $\theta_{en} > 12°$ and $\theta_{\gamma n} > 7°$ PCAL or ECin or ECout: lv(lw) > 14
		In FT: $x^2 + y^2 > 72$	In CD: $40° < \theta_n < 150°$



Select nDVCS data

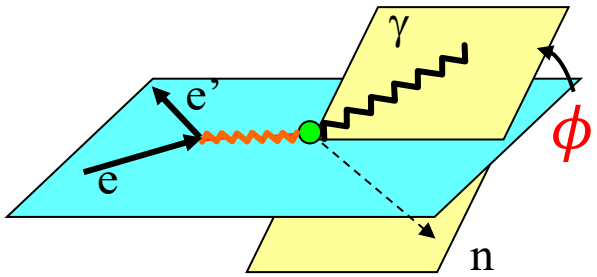
- Select events with at least one electron, one neutron and one photon
  - For cases with more than one combination, select the one with the smallest χ^2-like quantity (defined using exclusivity variables that peak at zero)
- Reaction kinematics: $Q^2 > 1\ \mathrm{GeV}^2$, $W > 2\ \mathrm{GeV}$, $t > -1.9\ \mathrm{GeV}^2$
- Apply pre-selection on missing m_X^2 and p_X of $ed \to en\gamma X$
  - To reduce events from other channels mostly
  - Pre-selection: $-0.5 < m_X^2 < 3\ \mathrm{GeV}^2$, $0 < p_X < 1.5\ \mathrm{GeV}$

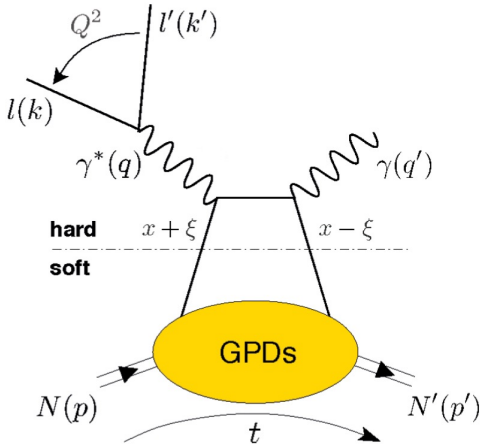


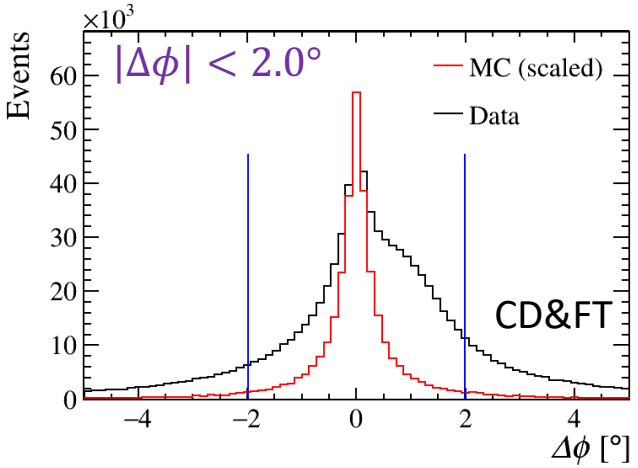


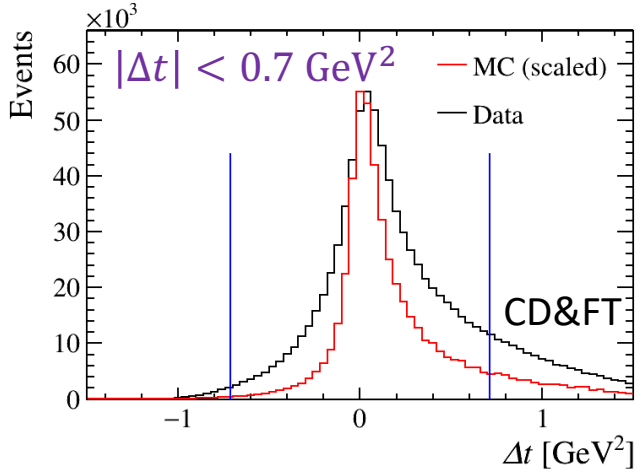
Exclusivity selection

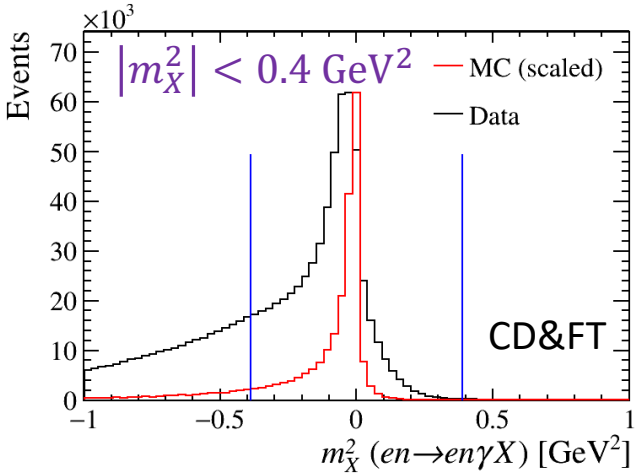
- Criteria determined by comparing data and MC
  - $\sim 2\sigma$ of the MC distribution
- CD&FT (n in CD & γ in FT)

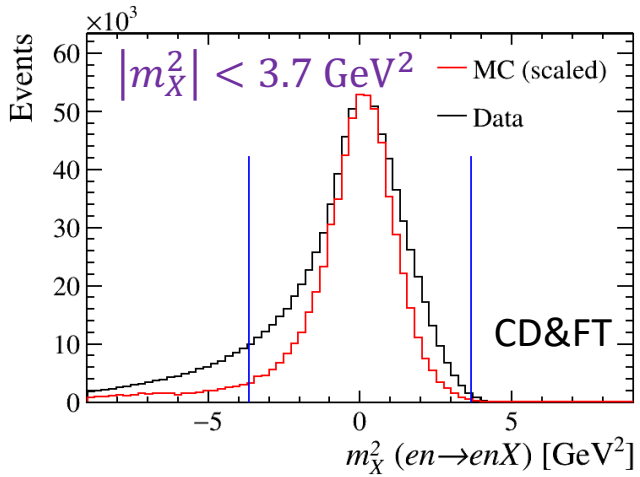










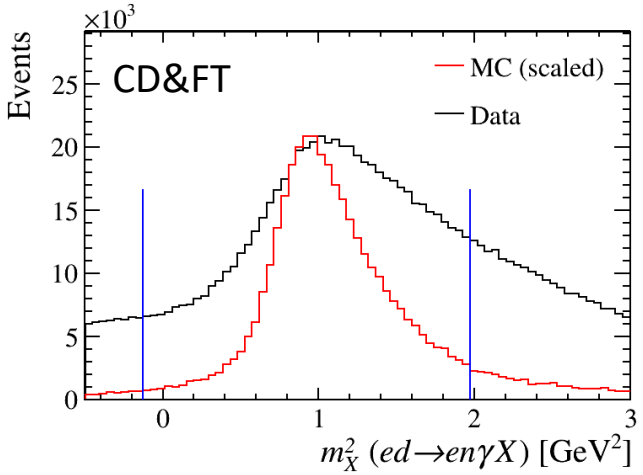


- $\Delta\phi$: difference in ϕ between
  - hadronic plane formed by the neutron and the virtual photon
  - hadronic plane formed by the neutron and the outgoing photon
- Δt: difference in t between
  - t calculated by the neutron
  - t calculated by the photon

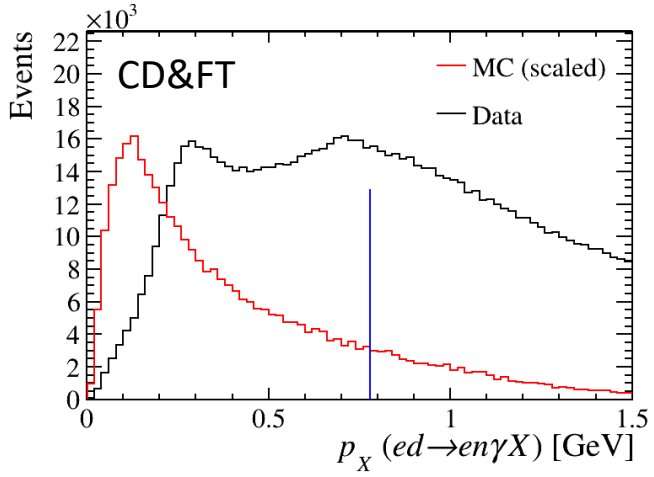
Other topologies (CD&FD, FD&FT, FD&FD) are presented in backup slides

Exclusivity selection

- Criteria determined by comparing data and MC
  - $\sim 2\sigma$ of the MC distribution
- CD&FT (n in CD & γ in FT)

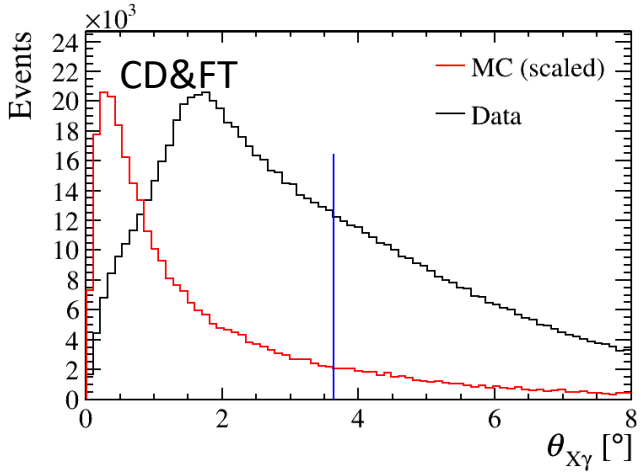


$-0.1 < m_X^2 < 2.0\ \mathrm{GeV}^2$



$p_X < 0.8\ \mathrm{GeV}$

- $\theta_{X\gamma}$: cone angle formed by the missing photon X ($en \to enX$) and the outgoing photon γ



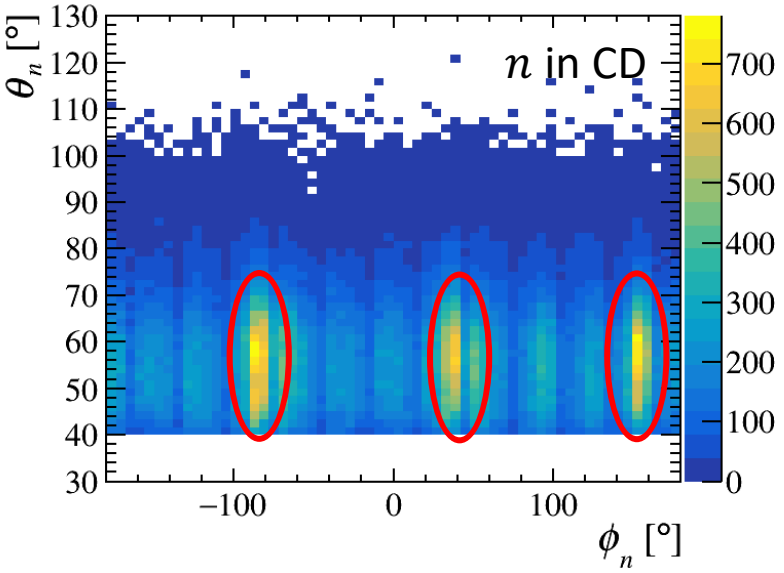
$\theta_{X\gamma} < 3.6°$

- After the exclusivity selection
  - $N = 4.11\times10^5$ for CD&FT
  - $N = 0.85\times10^5$ for CD&FD
- The data and MC distributions are very different
  - mainly due to the protons that are misidentified as neutrons, discussed in the later slides

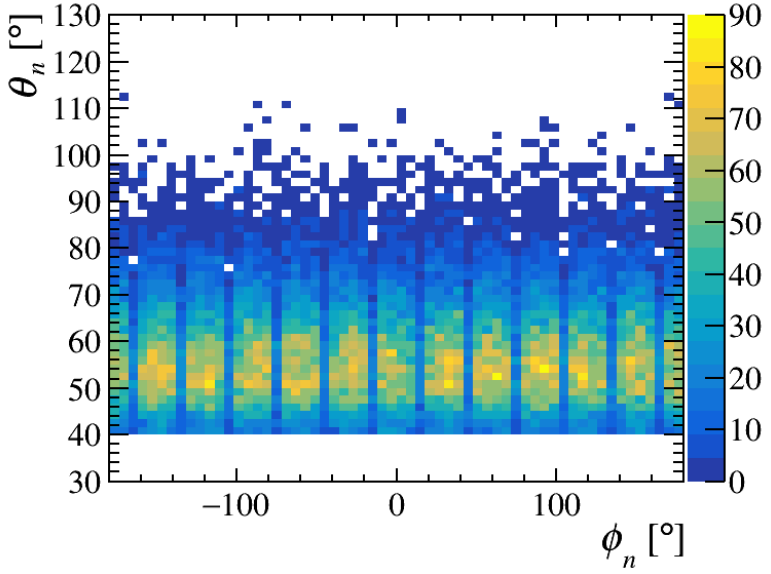
Proton misidentified as neutron in CD

- The tracking system (CVT) in CD has dead or low-efficiency regions
- Protons: no tracks in CVT but hits in CND
  - ➢ Misidentified as neutrons
- Reproduce distributions in MC mixing pDVCS and nDVCS (both reconstructed as nDVCS)

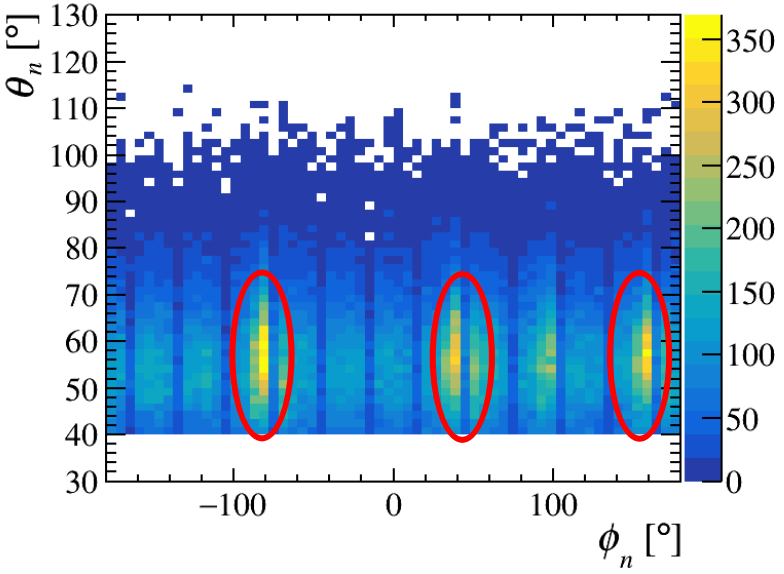
Data



Only nDVCS MC

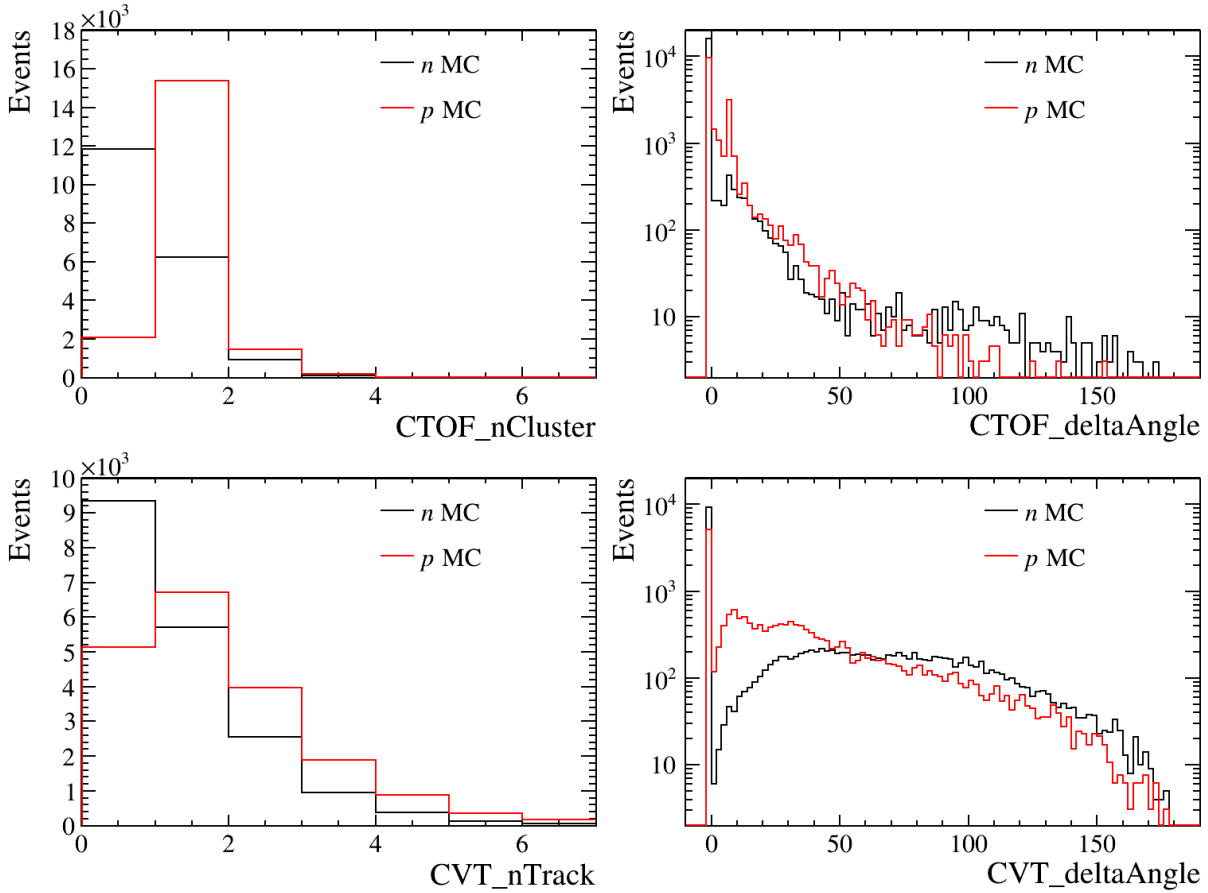


Mix pDVCS and nDVCS MC



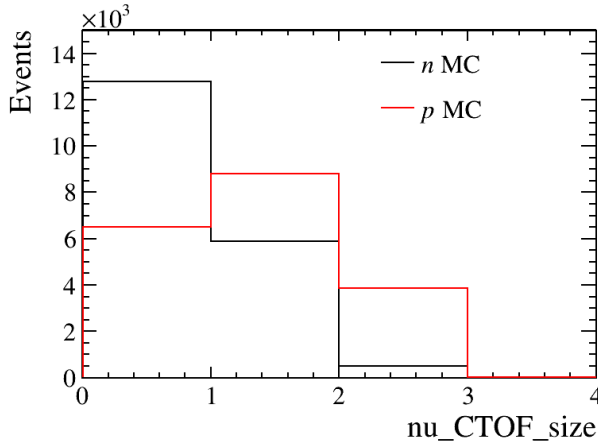
TMVA training

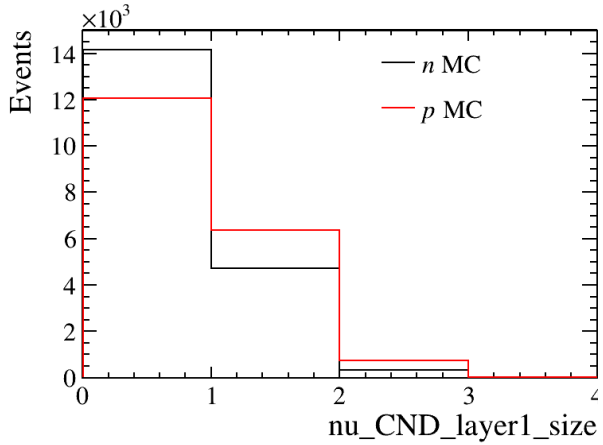
- Training and test sample:
  - MC with pure neutron target
  - MC with pure proton target
- Training variables (only use info at CTOF, CVT and CND)
  - Number of clusters at CTOF (most distinguishable)
  - Smallest cone angle between the CTOF cluster and $n(p)$ track
  - Number of tracks at CVT
  - Smallest cone angle between the CVT track and $n(p)$ track

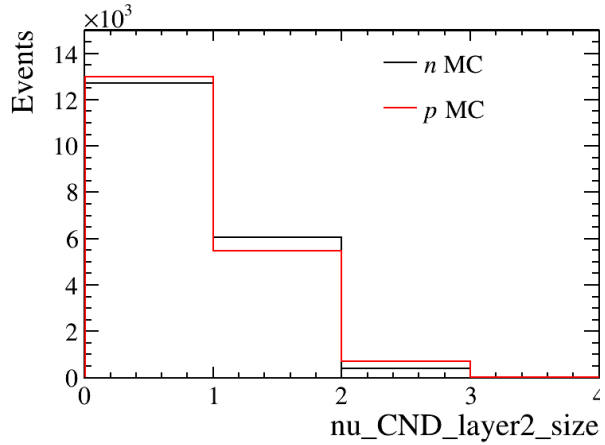


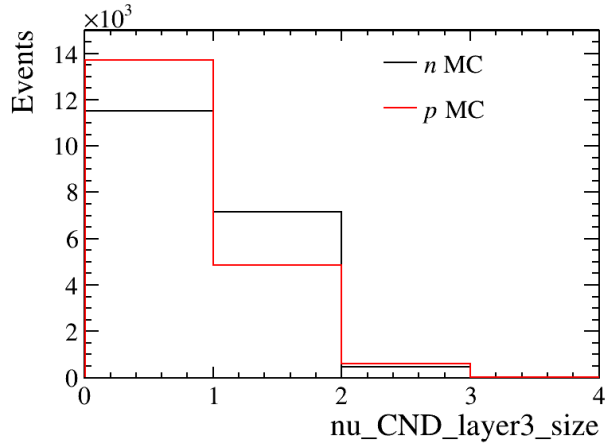
TMVA training

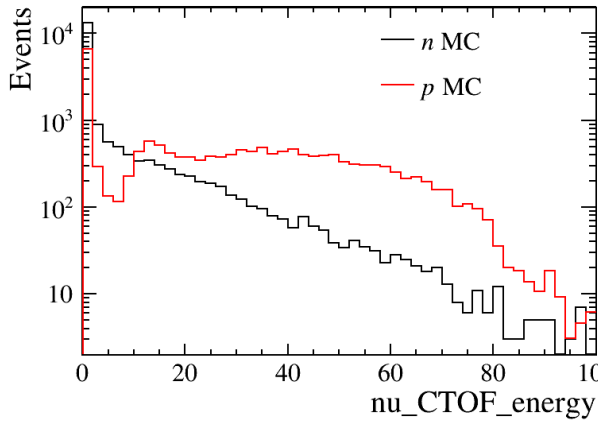
- Number of hits for the $n(p)$ cluster at CTOF and three layers of CND
- Deposit energy at CTOF and three layers of CND

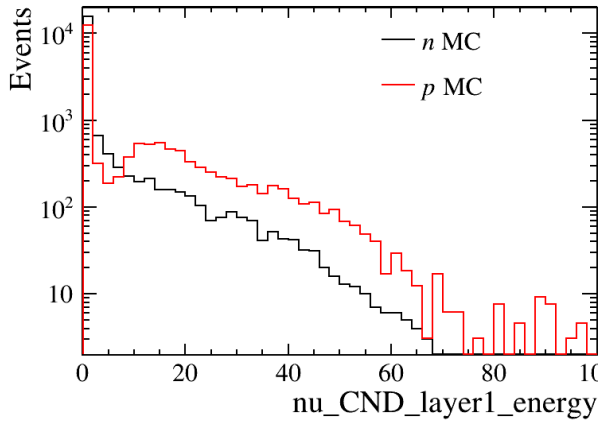


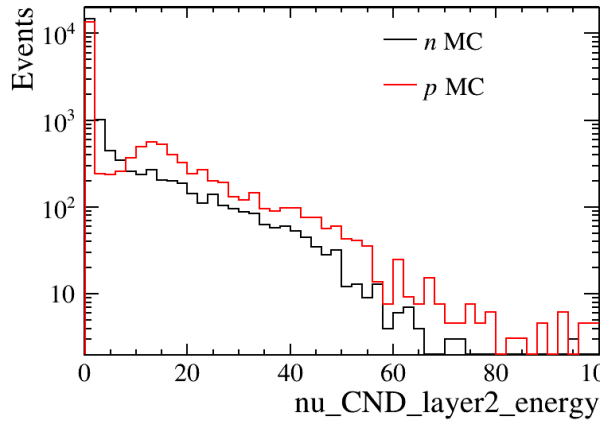


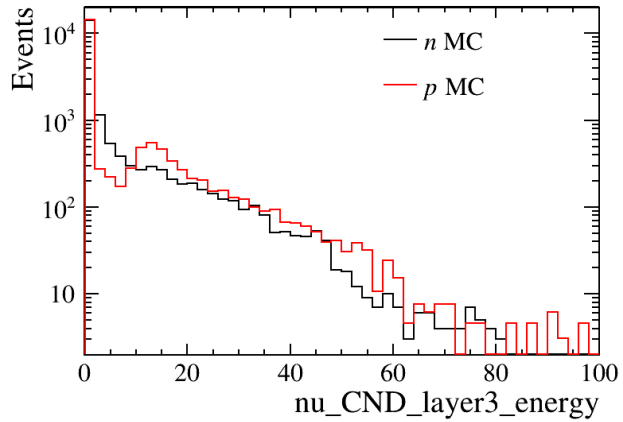






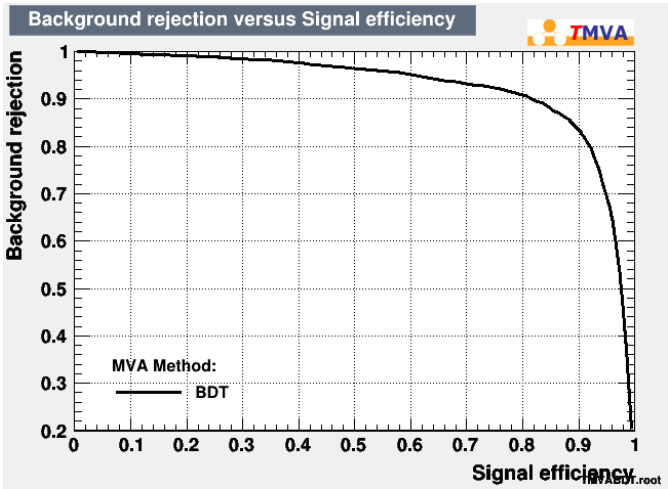


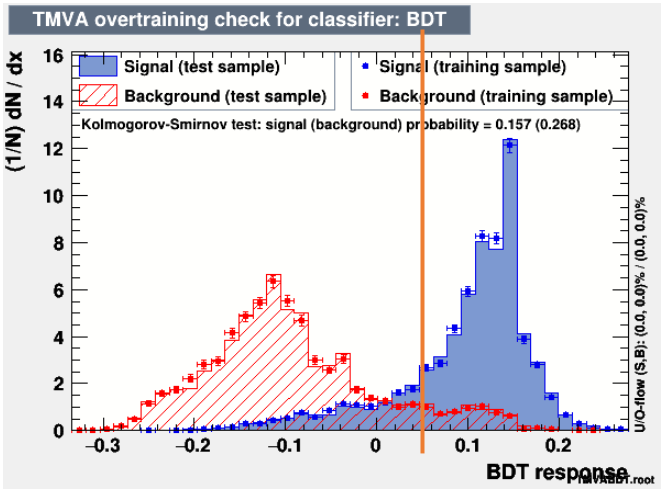


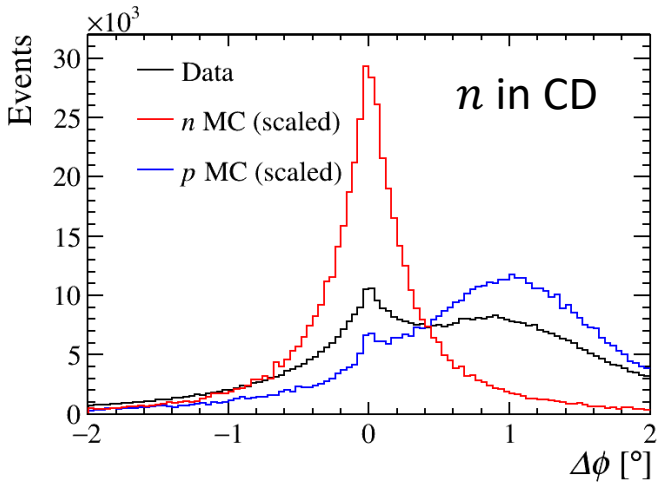


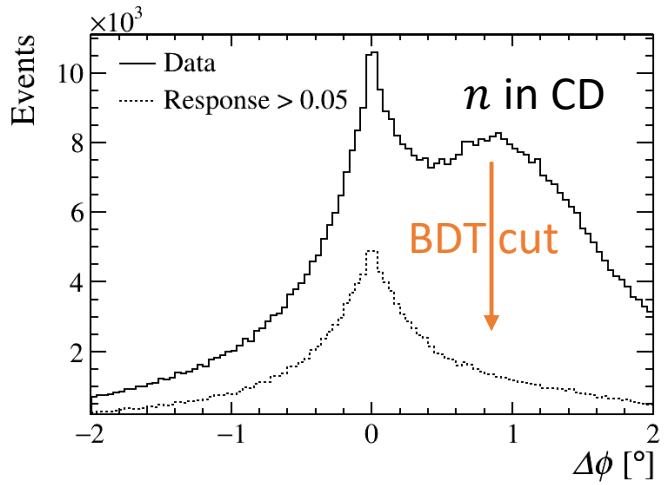
Boosted Decision Tree (BDT) classifier

- Selection:
  - BDT response > 0.05 (to be tuned)
- $N = 4.96\times10^5$ for n in CD (CD&FT + CD&FD)
- $N = 1.43\times10^5$ after the BDT response selection



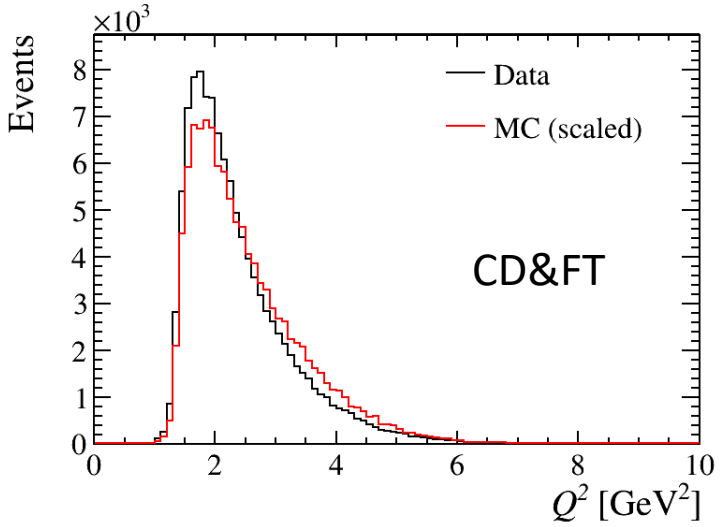


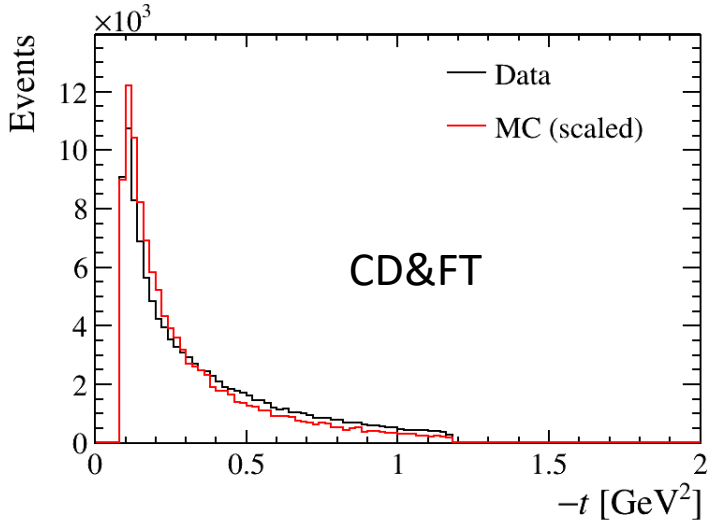


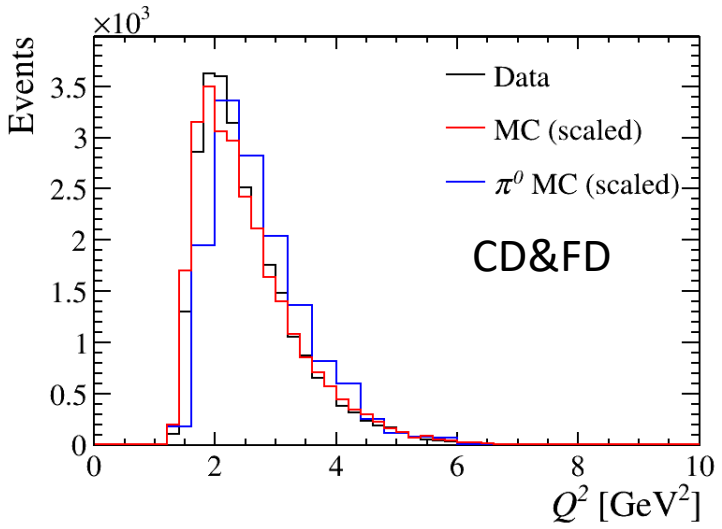


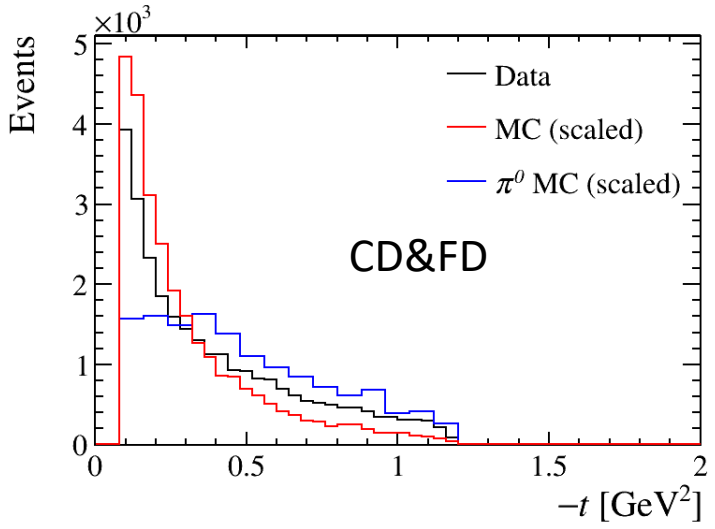
Distributions of nDVCS variables

- Remain backgrounds:
  - Proton misidentified as neutron
    - Mostly reduced by BDT
  - π^0 production contamination
    - $en \rightarrow en\pi^0(\rightarrow \gamma\gamma)$
    - Mainly for γ in FD
    - π^0 MC: 45M events reconstructed as DVCS

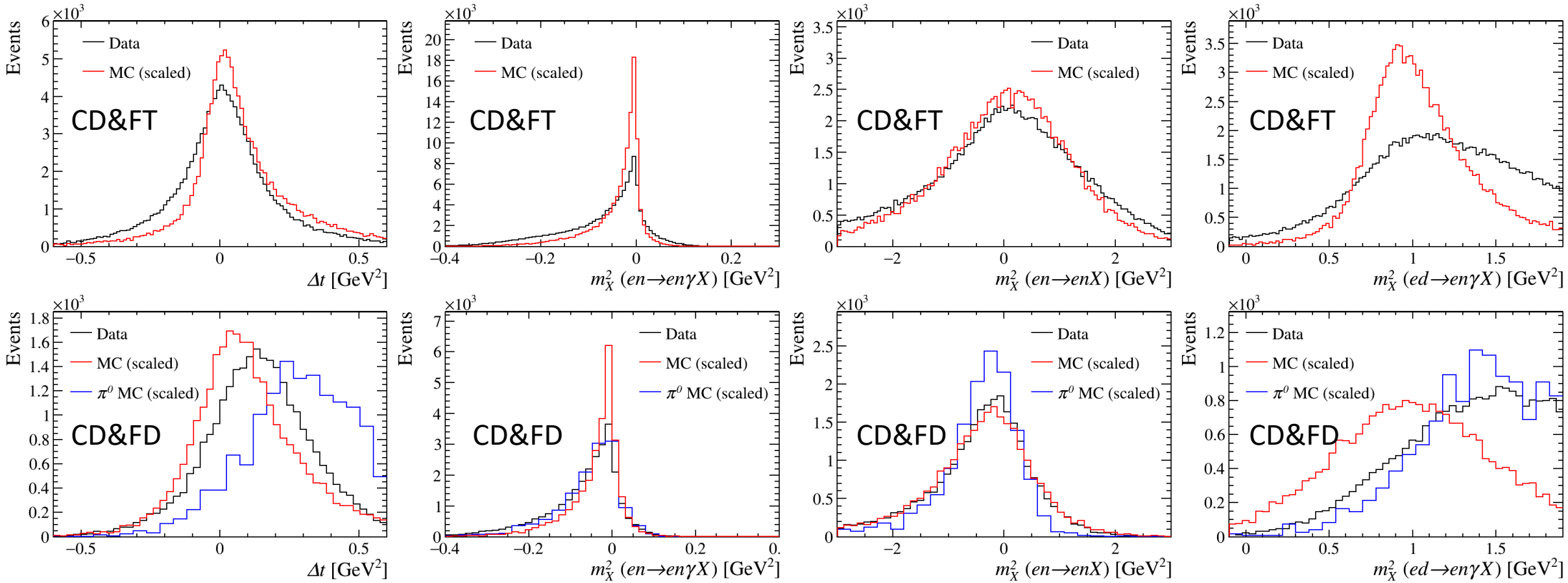








Distributions of nDVCS variables

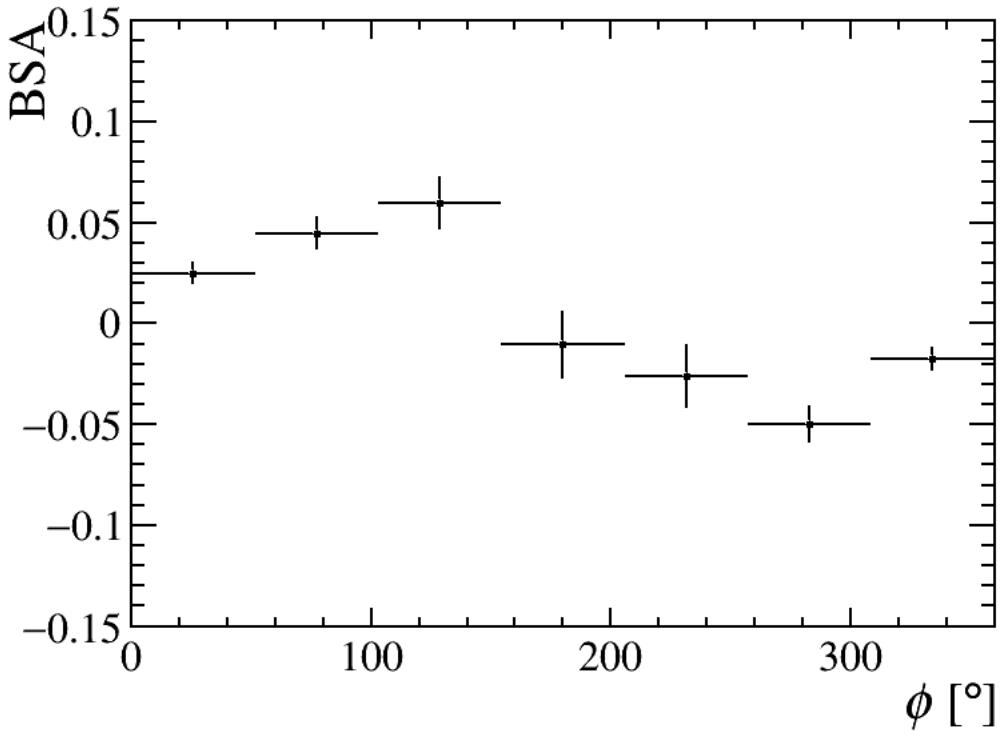


- Need more π^0 MC to study the π^0 production contamination
- The difference between data and MC is also due to their different resolution
- The study of other topologies (FD&FT, FD&FD) is ongoing

Raw beam-spin asymmetry as a check

$$BSA = \frac{1}{P}\frac{N^+ - N^-}{N^+ + N^-}$$

- P is the average beam polarization
- N^+ is the nDVCS yield for positive helicity
- N^+ is the nDVCS yield for negative helicity
- Extract BSA using nDVCS events
  - only for n in CD
  - after the BDT response selection
  - π^0 production contamination remains
- The BSA has the expected sinusoidal shape, and its amplitude is on the order of a few percent
  - consistent with the recent CLAS12 measurement



Study of π^0 production contamination

- $en \to en\pi^0(\to \gamma\gamma)$ background subtraction:
  - $N_{\mathrm{DVCS}} = N_{\mathrm{en}\gamma} - N_{en\pi^0} \times f^{\mathrm{MC}} = N_{\mathrm{en}\gamma} - N_{en\pi^0} \times \frac{N^{\mathrm{MC}}_{en\pi^0(1\gamma)}}{N^{\mathrm{MC}}_{en\pi^0(2\gamma)}}$

Partially reconstructed $en\pi^0(1\gamma)$ and passed DVCS selection

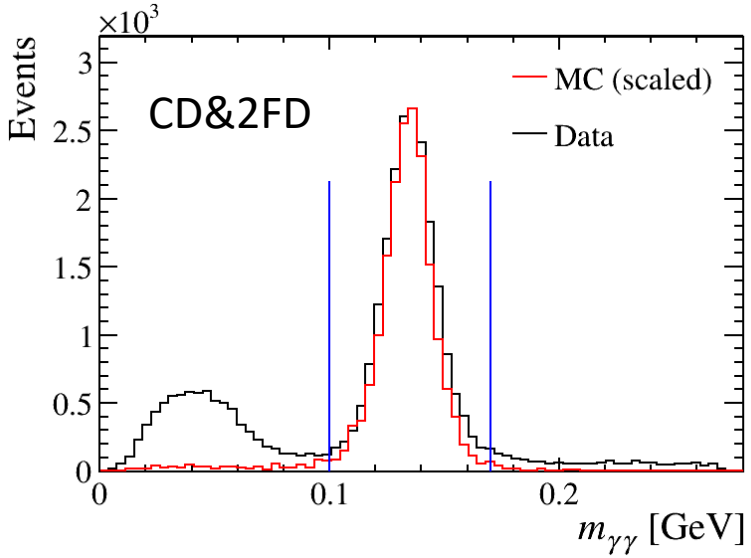
Fully reconstructed $en\pi^0(2\gamma)$ and passed π^0 production selection

- Select π^0 production data
  - PID and fiducial cuts:
    - $p_e > 1\ \mathrm{GeV}, p_n > 0.3\ \mathrm{GeV}, p_\gamma > 0.3\ \mathrm{GeV}$
    - Same fiducial cuts for the nDVCS selection
  - Select events with at least one electron, one neutron and two photons with $0 < m_{\gamma\gamma} < 0.28\ \mathrm{GeV}$
    - For cases with more than one combination, select the one with the smallest χ^2-like quantity (defined using exclusivity variables that peak at zero)
  - Reaction kinematics:
    - $Q^2 > 1\ \mathrm{GeV}^2$, $W > 2\ \mathrm{GeV}, t > -1.9\ \mathrm{GeV}^2$
  - Pre-selection before determining the exclusivity cuts:
    - $-0.5 < m_X^2 < 3\ \mathrm{GeV}^2, 0 < p_X < 1.5\ \mathrm{GeV}$ for $ed \to en\gamma\gamma X$

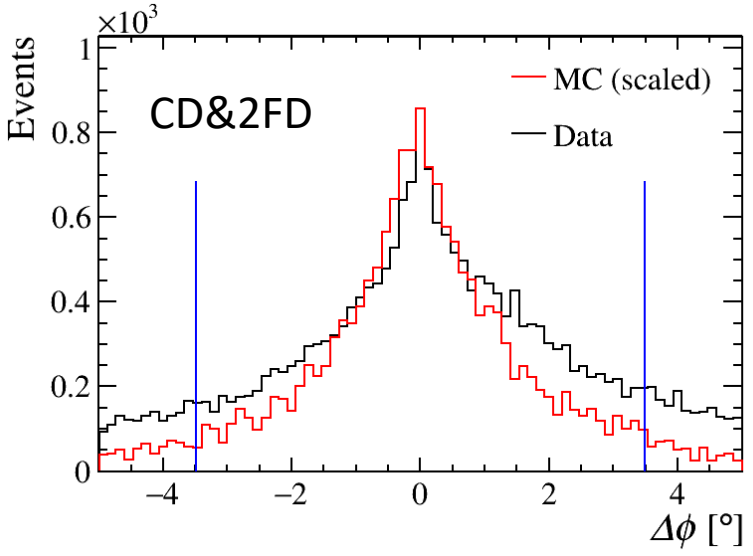
Exclusivity selection of π^0 production

- Criteria determined by comparing data and MC
  - $\sim 2\sigma$ of the MC distribution
- π^0 production MC
  - 45M events, but not enough to get the distribution for all topologies
  - Need more MC to tune the selection criteria

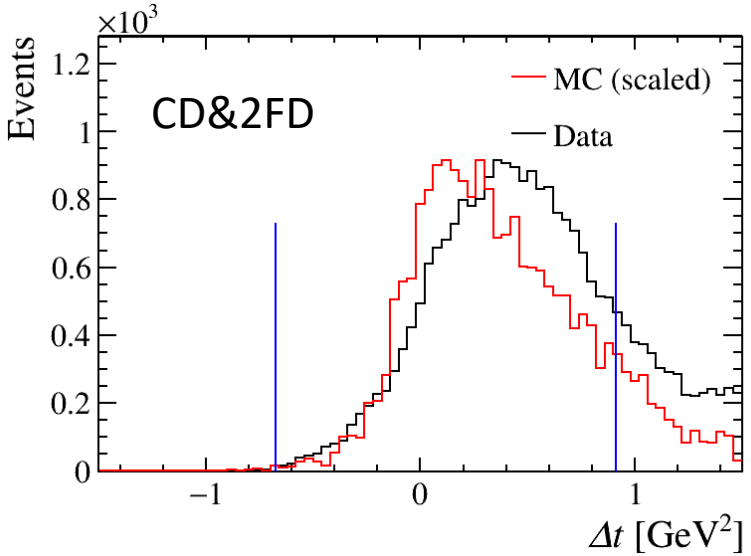
CD&2FD: n in CD and 2 γ in FD



$0.10 < m_{\gamma\gamma} < 0.17$ GeV



$|\Delta\phi| < 3.5°$

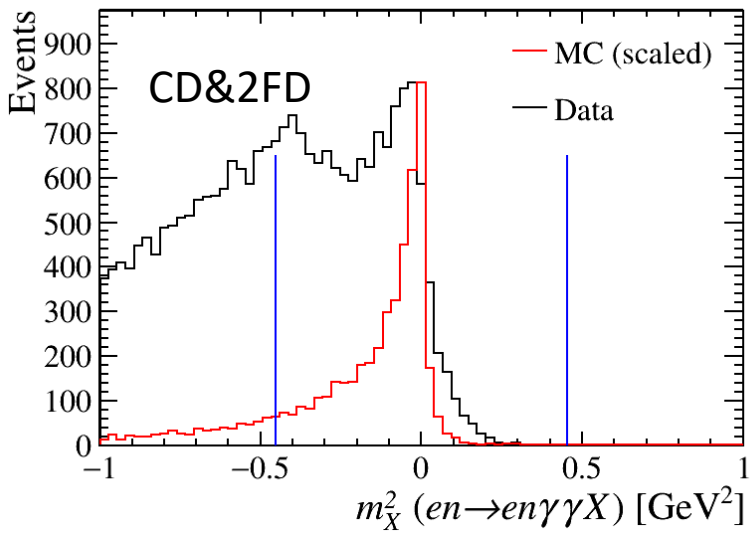


$|\Delta t| < 0.8$ GeV^2

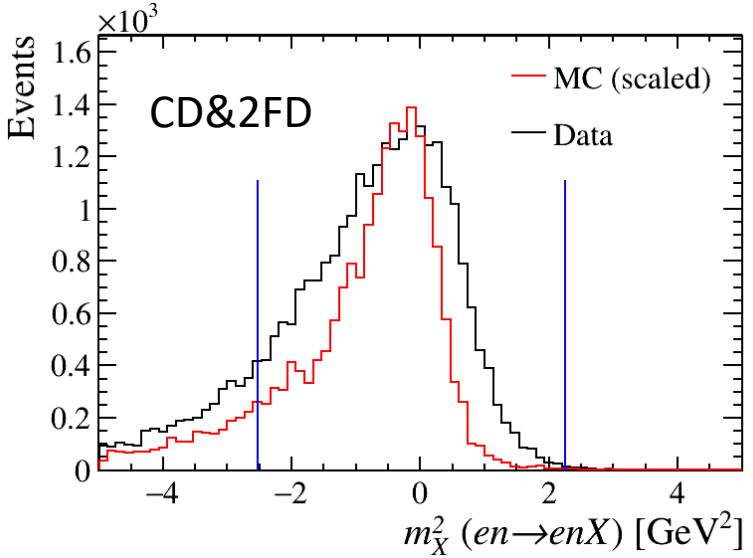
Exclusivity selection of π^0 production

- Criteria determined by comparing data and MC
  - $\sim 2\sigma$ of the MC distribution
- π^0 production MC
  - 45M events, but not enough to get the distribution for all topologies
  - Need more MC to tune the selection criteria

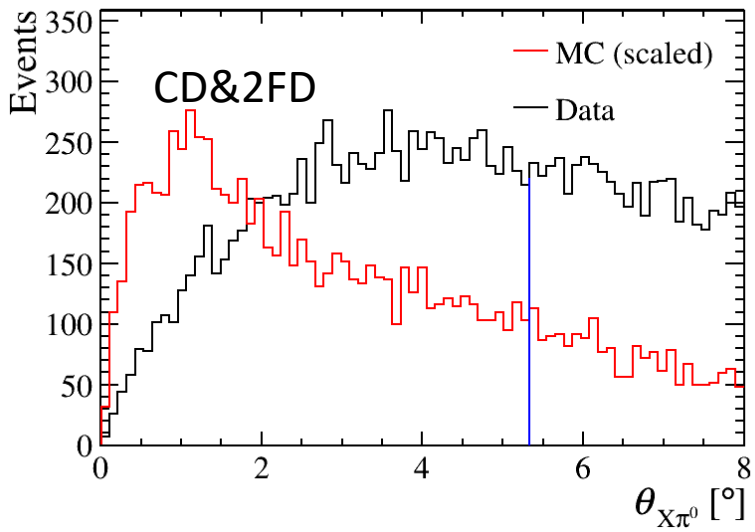
CD&2FD: still have fake neutrons



$|m_X^2| < 0.45$ GeV^2



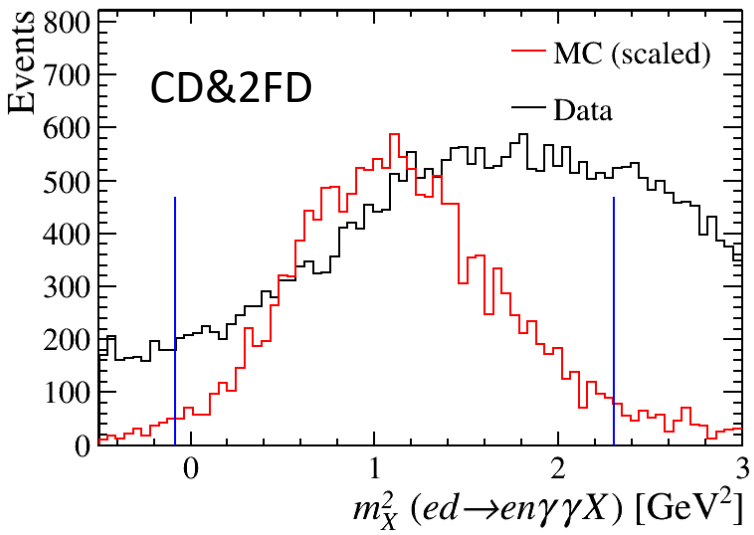
$|m_X^2| < 2.4$ GeV^2



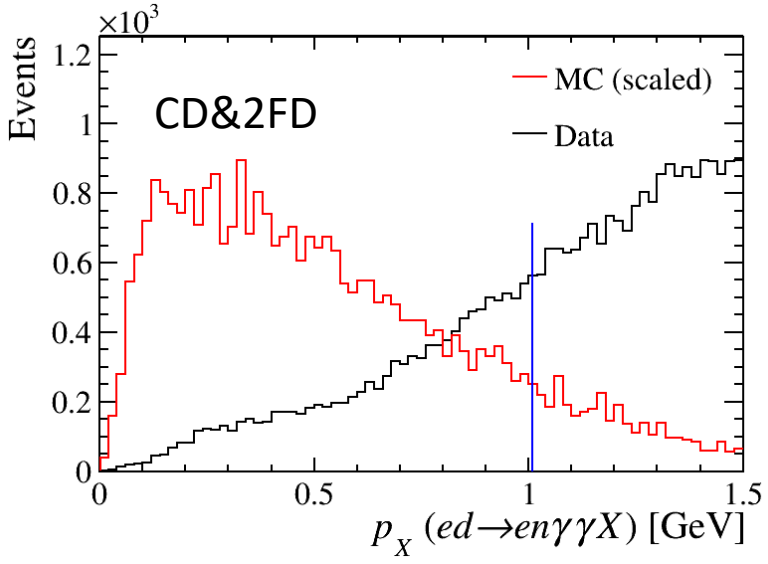
$\theta_{X\pi^0} < 5.3°$

Exclusivity selection of π^0 production

- Criteria determined by comparing data and MC
  - $\sim 2\sigma$ of the MC distribution
- π^0 production MC
  - 45M events, but not enough to get the distribution for all topologies
  - Need more MC to tune the selection criteria



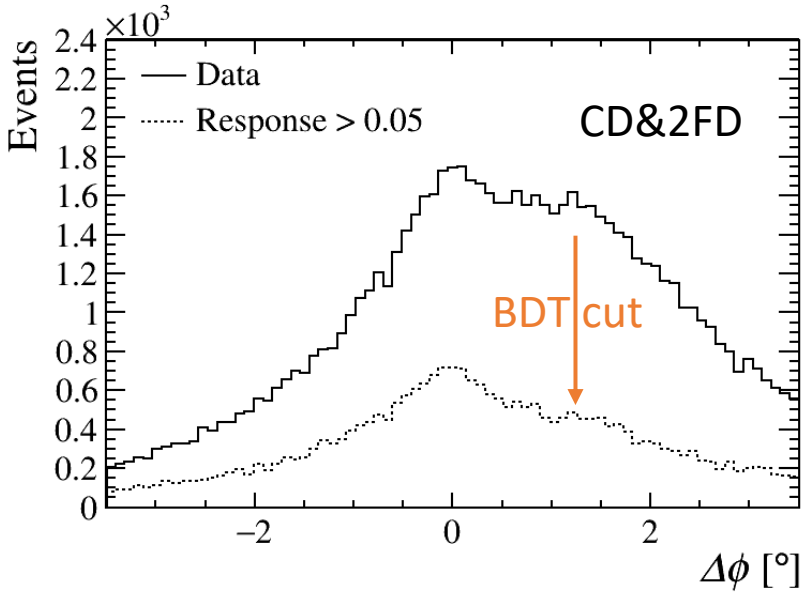
$-0.1 < m_X^2 < 2.3$ GeV^2

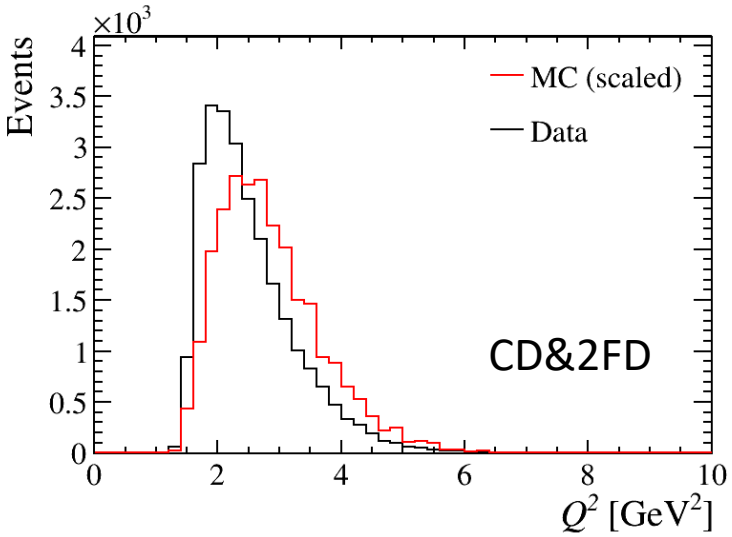


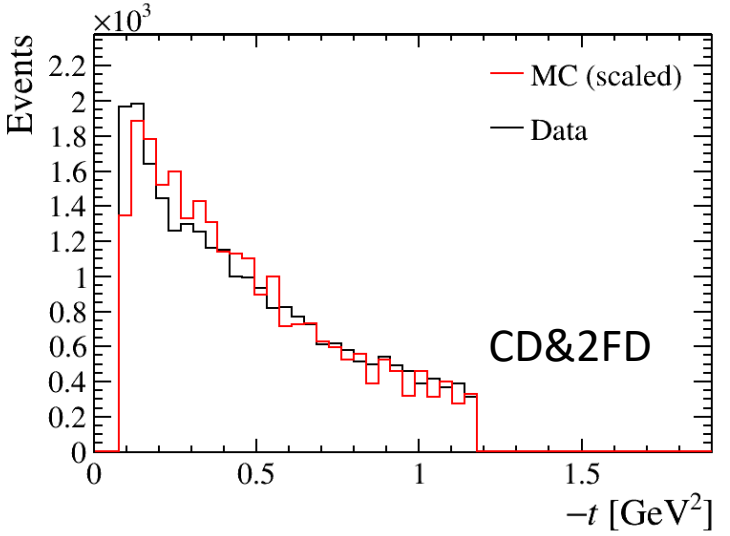
$p_X < 1.0$ GeV

Distributions of π^0 production variables

- CD&2FD: n in CD and 2 γ in FD
  - After the exclusivity slection, still have protons misidentified as neutrons
  - Apply the BDT cut

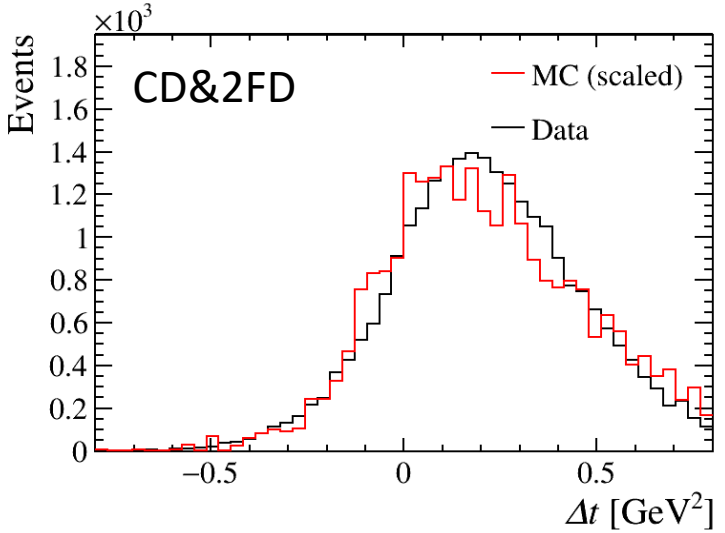


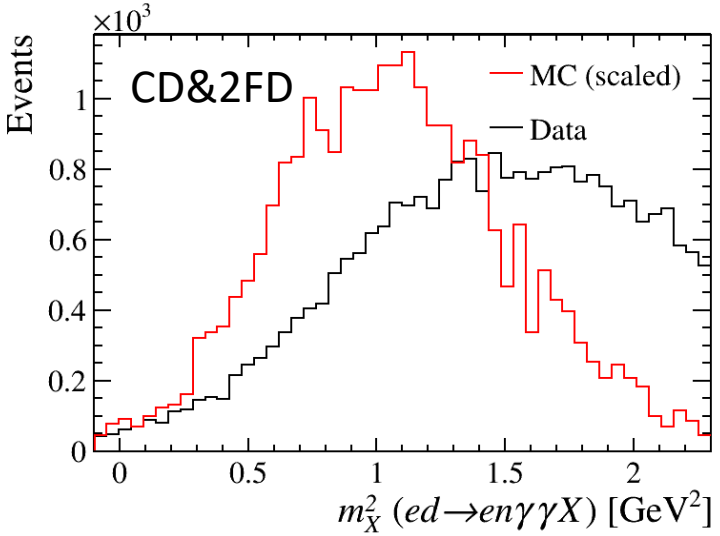


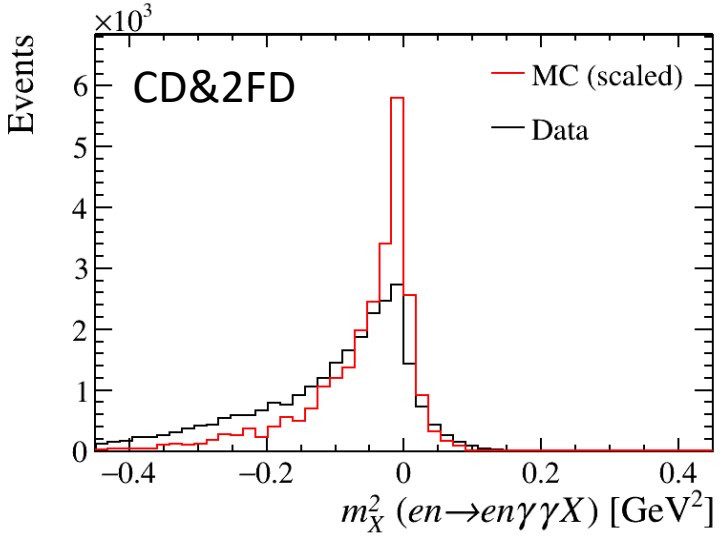


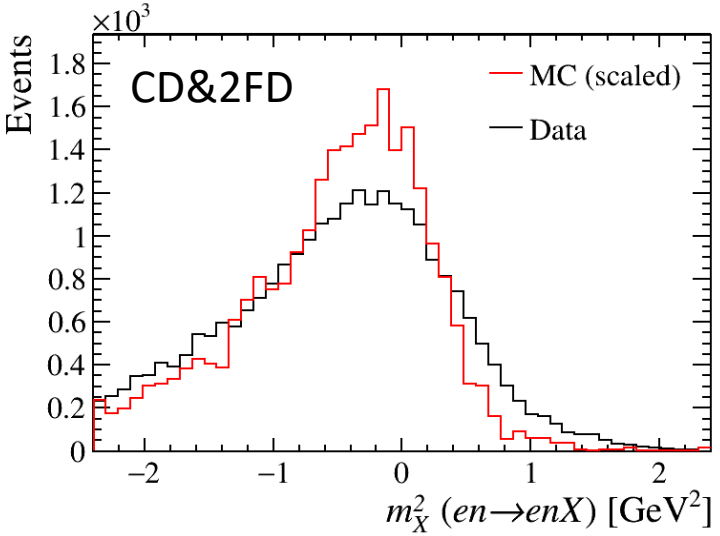
Distributions of π^0 production variables

- CD&2FD:
  n in CD and 2 γ in FD
- The difference between data and MC maybe is due to their different resolution
- Maybe need momentum correction
- Need more MC to tune the selection criteria and study all topologies









Next to do

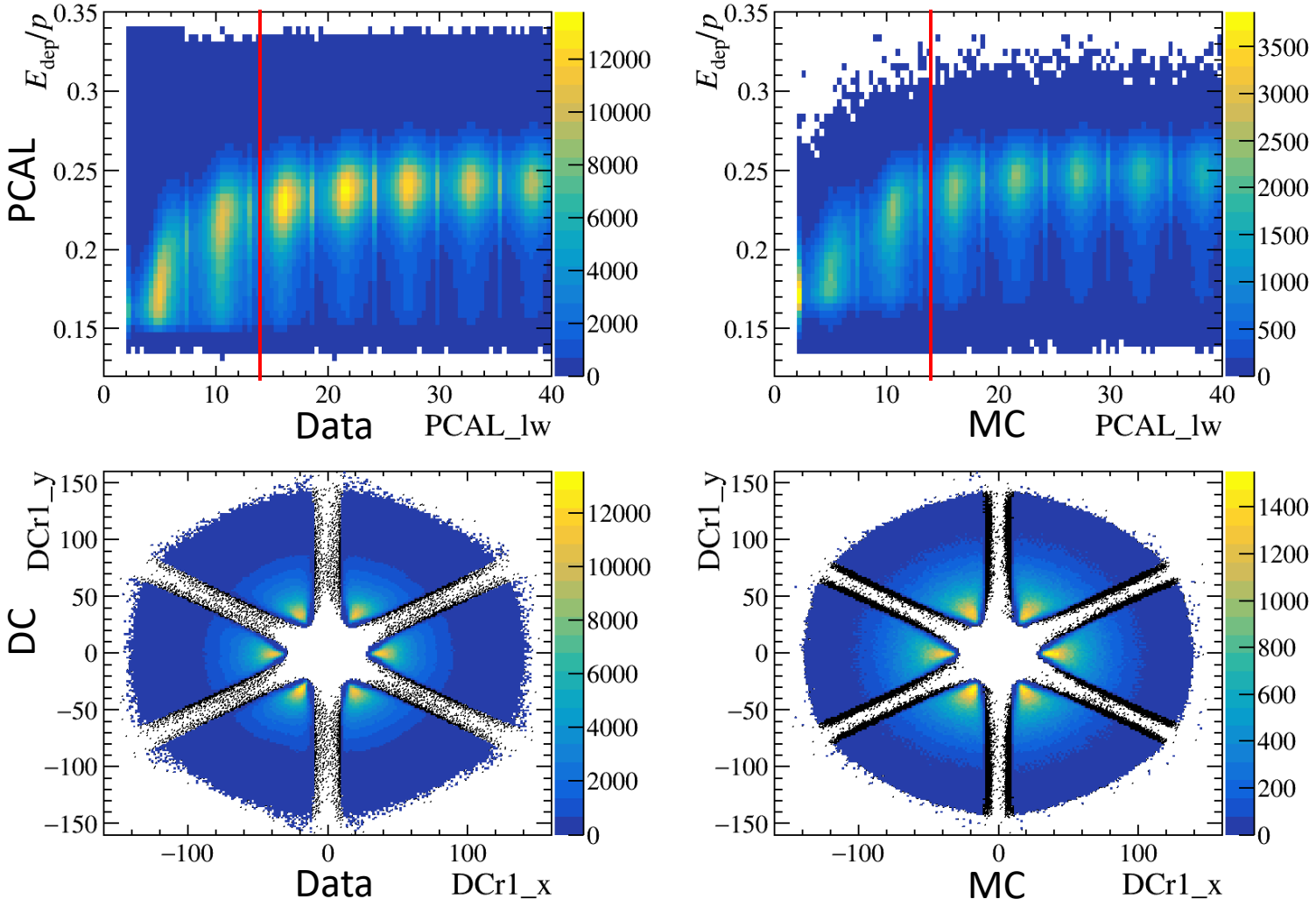
- Study of other topologies (FD&FT, FD&FD) for DVCS
- Tune the selection criteria for π^0 production
- Subtract π^0 production background
- Determine the acceptance
- Extract the integrated luminosity
- Estimate the systematic uncertainties

Thank you!

Backup slides

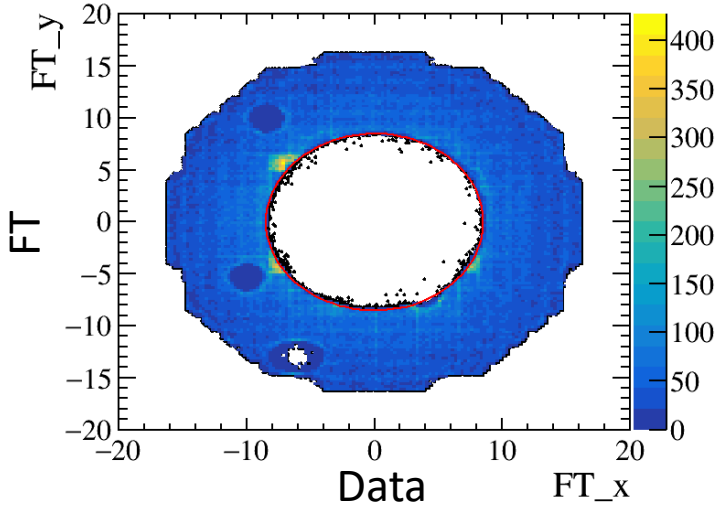
Electron selection

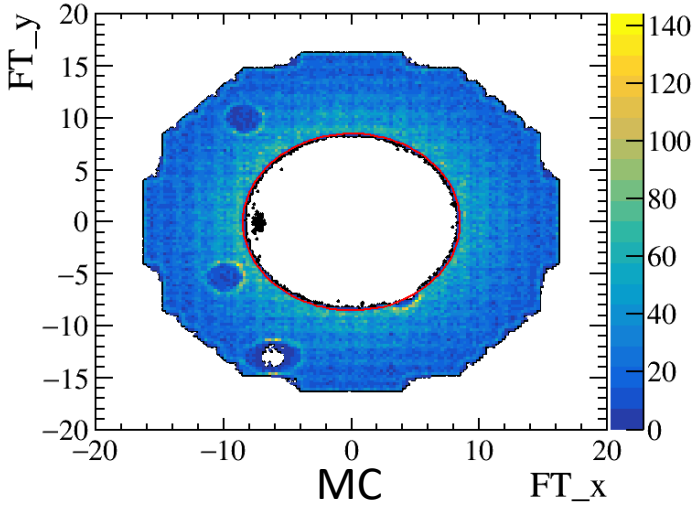
- $q = -1$
- $\mathrm{pid} = 11$
- $p_e > 1\ \mathrm{GeV}$
- Reconstructed in FD
- Fiducial cut
  - PCAL:
    $\mathrm{lv} > 14 \text{ and } \mathrm{lw} > 14$
  - DC: region 1-3
    $\mathrm{edge} > 6$

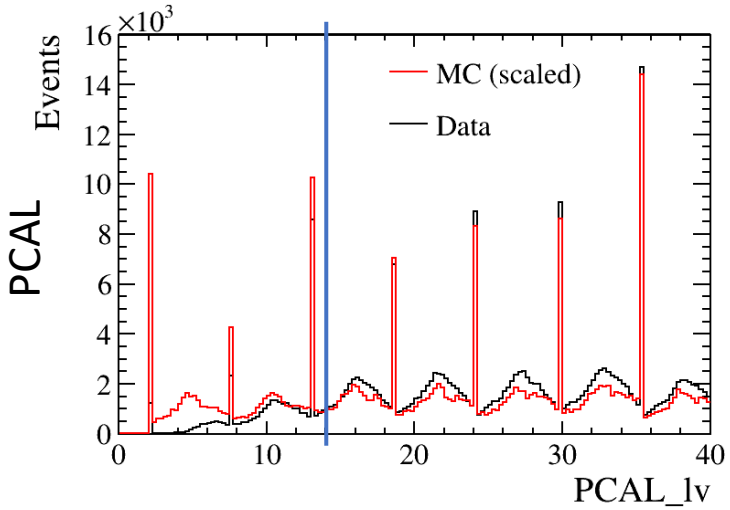


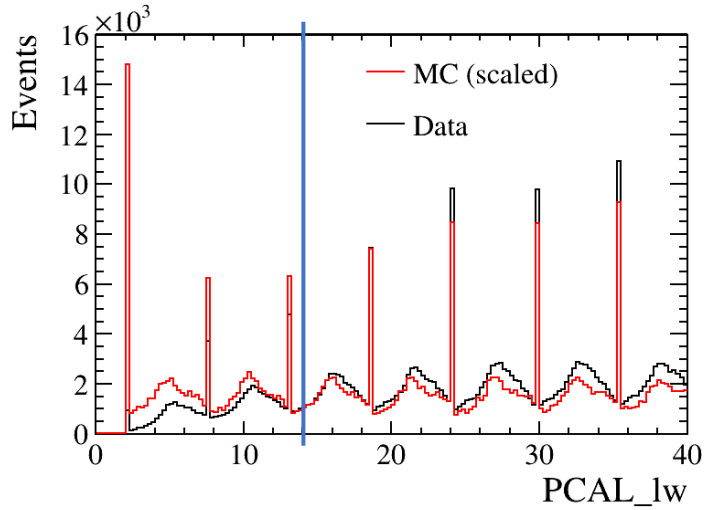
Photon selection

- $q = 0$
- $\mathrm{pid} = 22$
- $p_\gamma > 2\ \mathrm{GeV}$
- Reconstructed in FT
  - Fiducial cut
    $x^2 + y^2 > 72$
- Reconstructed in FD
  - Fiducial cut (PCAL)
    $\mathrm{lv} > 14 \text{ and } \mathrm{lw} > 14$









Neutron selection

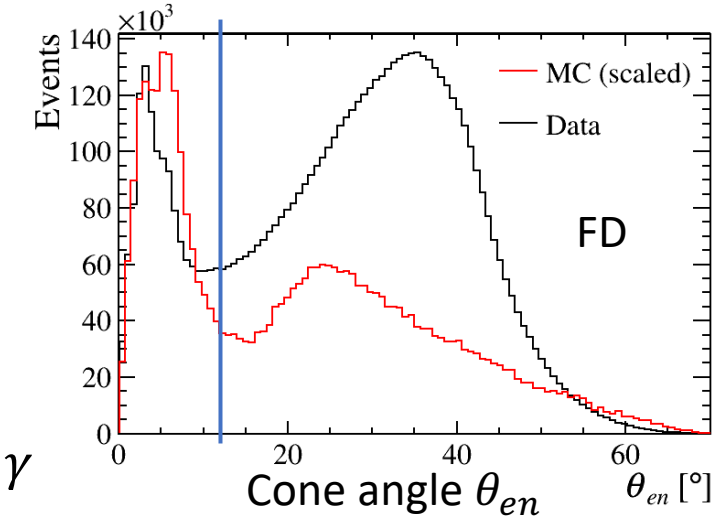
- $q = 0$
- $\mathrm{pid} = 2112$
- $p_n > 0.3$ GeV
- Reconstructed in FD
  - Remove misidentified e^-, γ

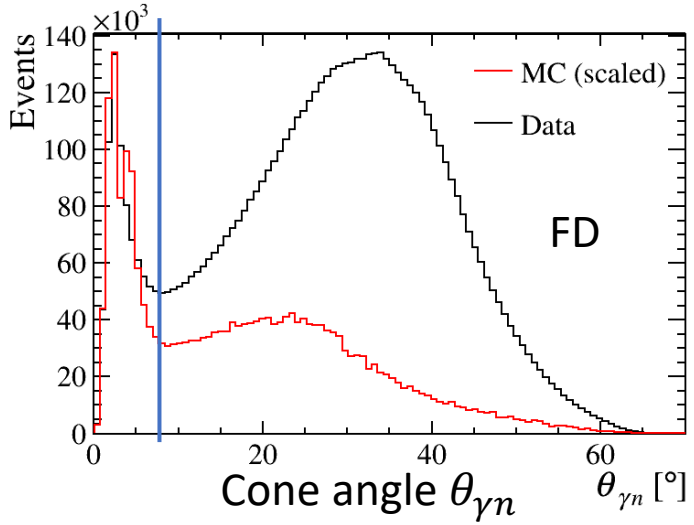
    $\theta_{en} > 12°$ and $\theta_{\gamma n} > 7°$
  - Fiducial cut

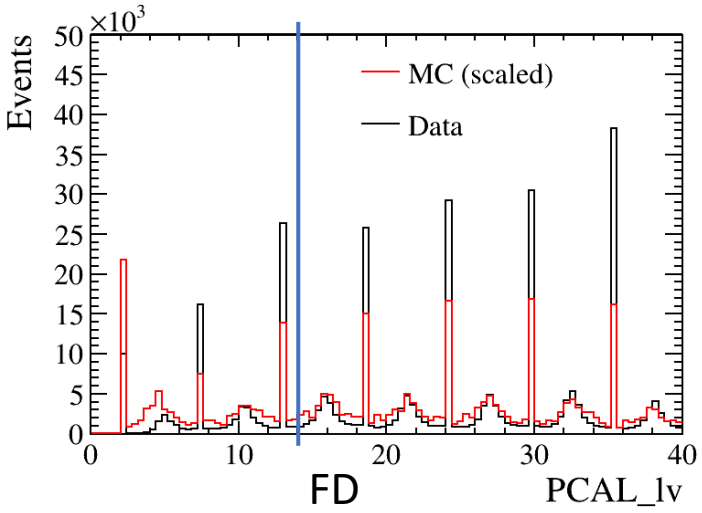
    $\mathrm{lv} > 14$ and $\mathrm{lw} > 14$

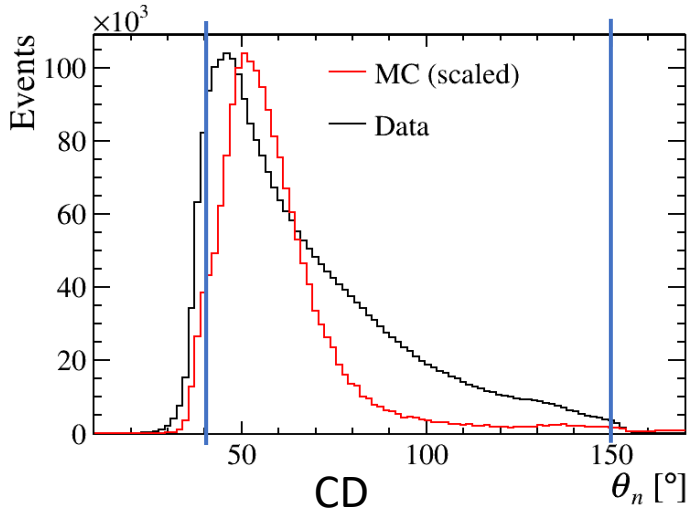
    for PCAL or ECin or ECout
- Reconstructed in CD
  - Fiducial cut

    $40° < \theta_n < 150°$





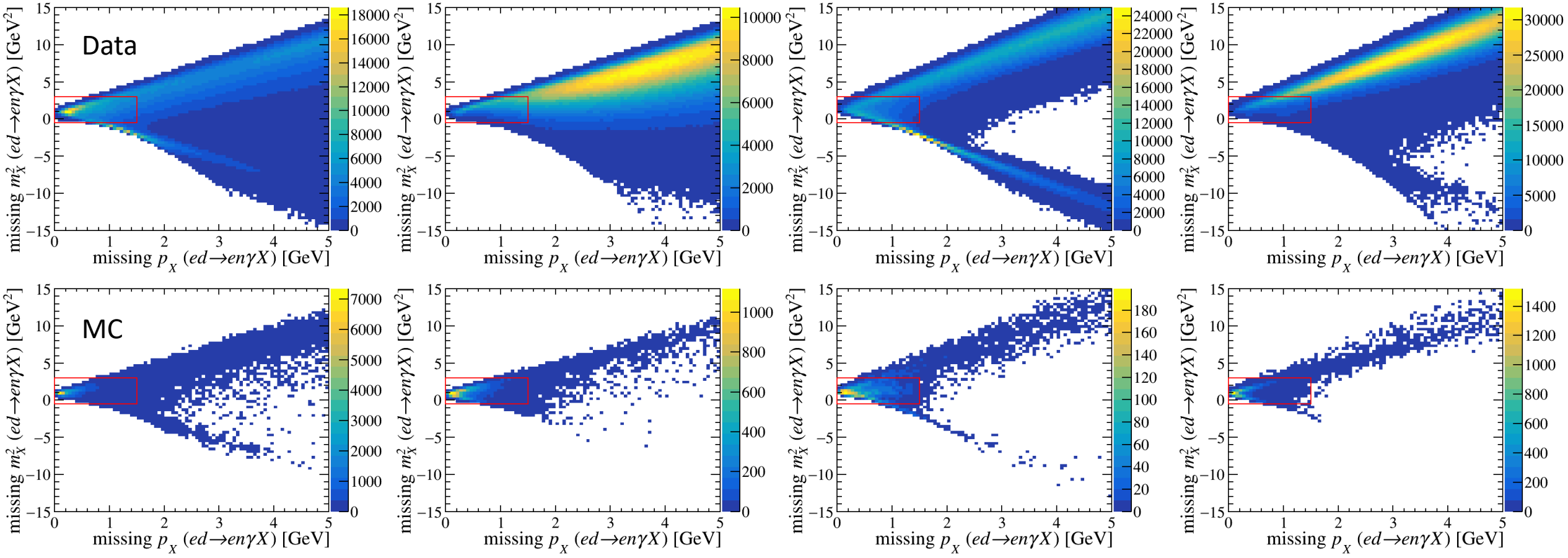




The data and MC distributions are different because MC is nDVCS while data contains lots of channels at this stage.

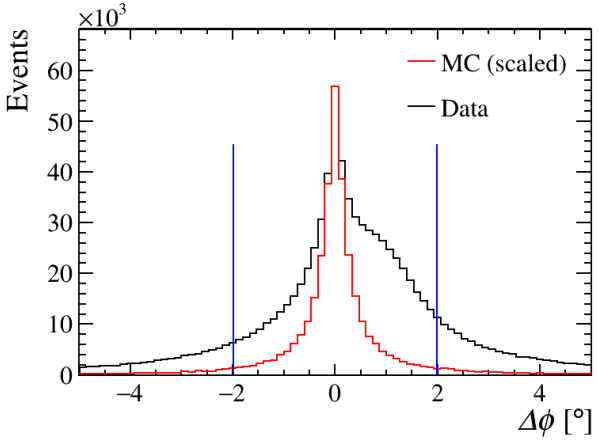
Pre-selection on missing m_X^2 and p_X of $ed \rightarrow en\gamma X$

CD&FT CD&FD FD&FT FD&FD

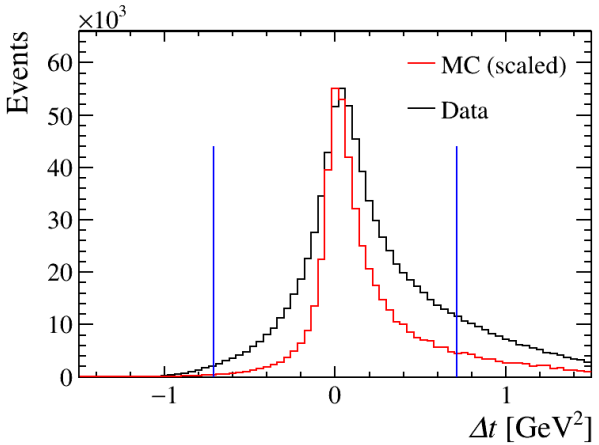


Exclusivity selection

CD&FT

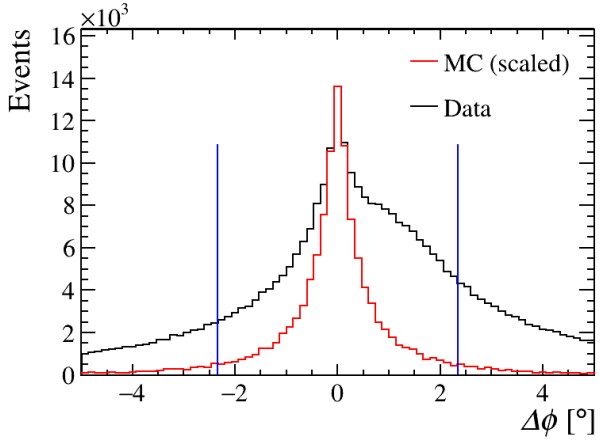


$|\Delta\phi| < 2.0$

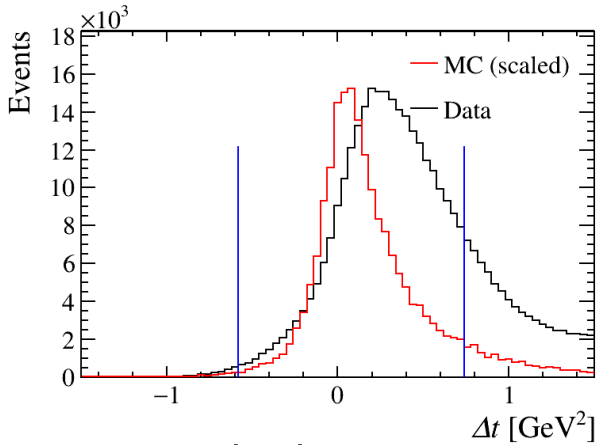


$|\Delta t| < 0.7$

CD&FD

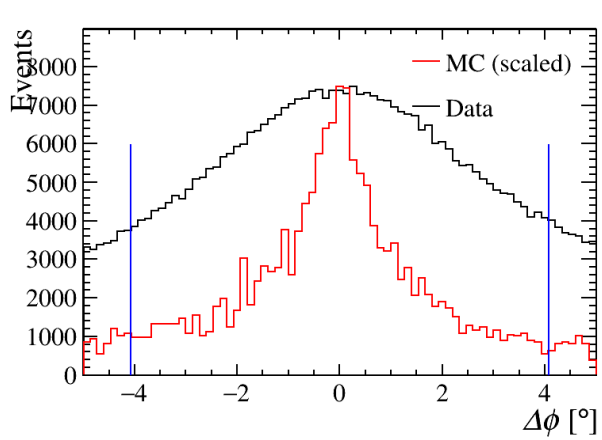


$|\Delta\phi| < 2.3$

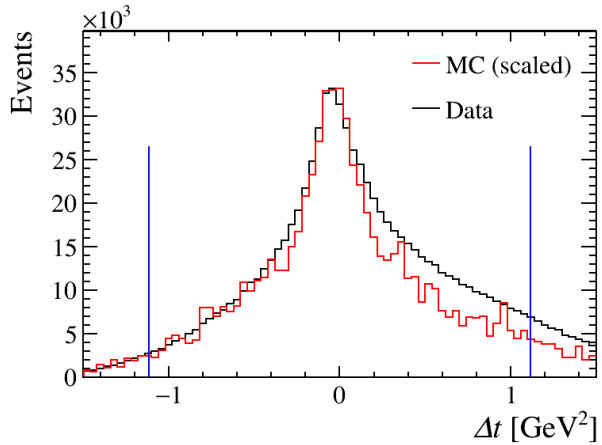


$|\Delta t| < 0.6$

FD&FT

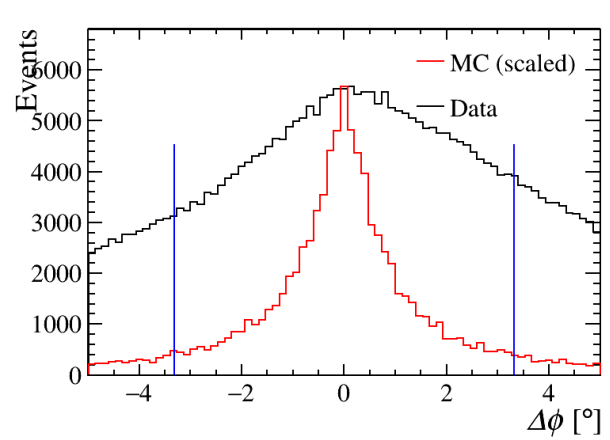


$|\Delta\phi| < 4.1$

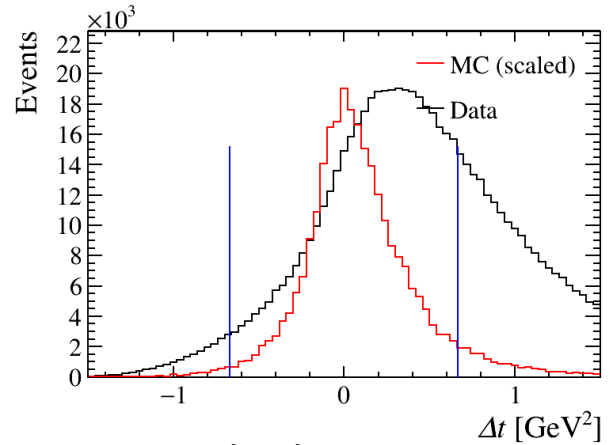


$|\Delta t| < 1.1$

FD&FD



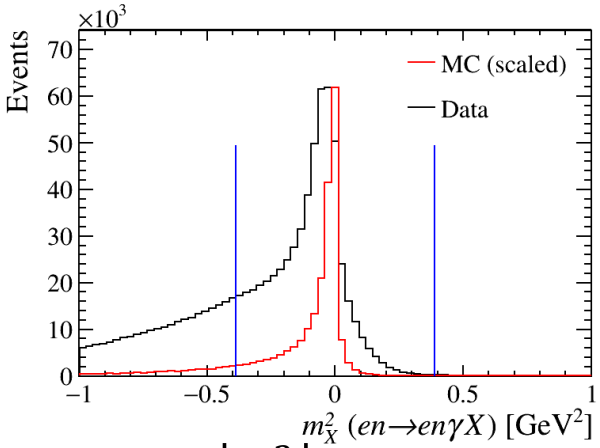
$|\Delta\phi| < 3.3$



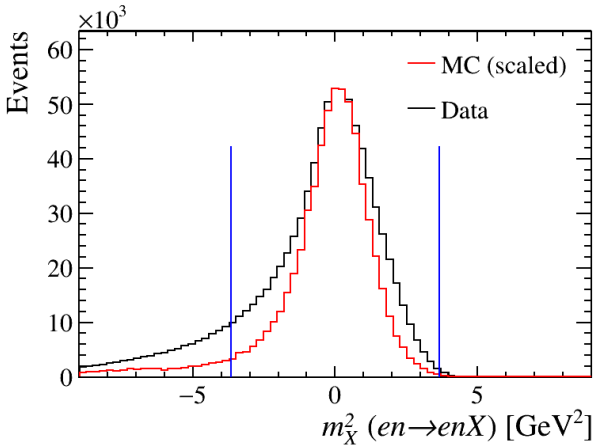
$|\Delta t| < 0.7$

Exclusivity selection

CD&FT

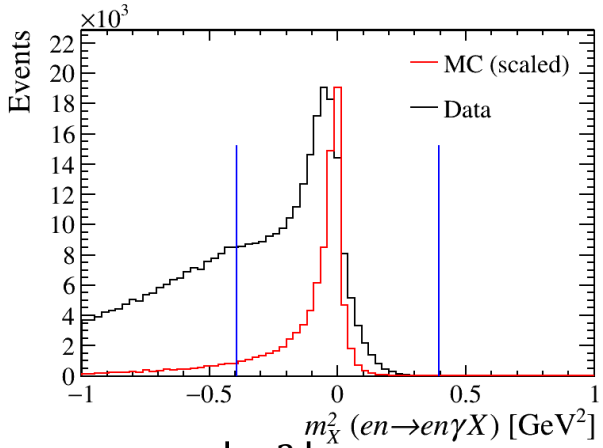


$|m_X^2| < 0.4$

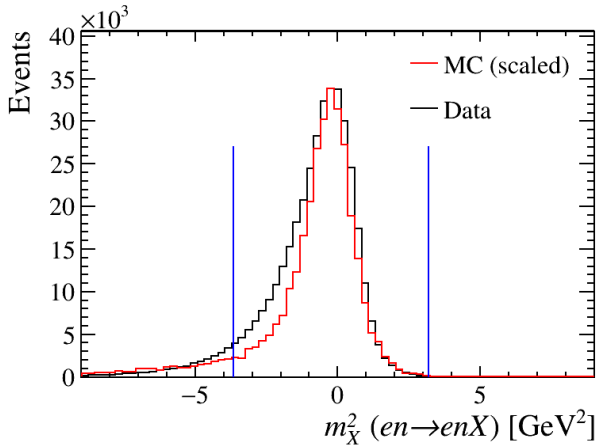


$|m_X^2| < 3.7$

CD&FD

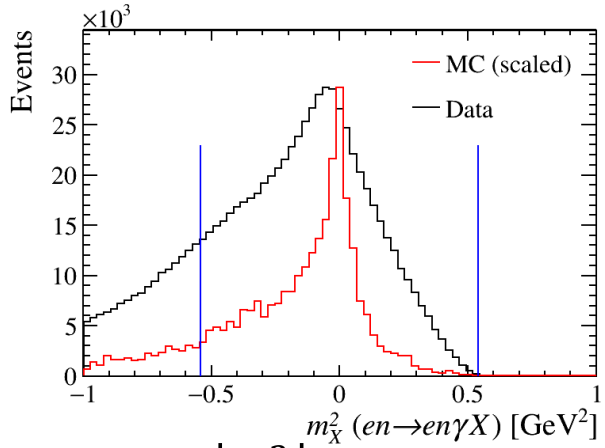


$|m_X^2| < 0.4$

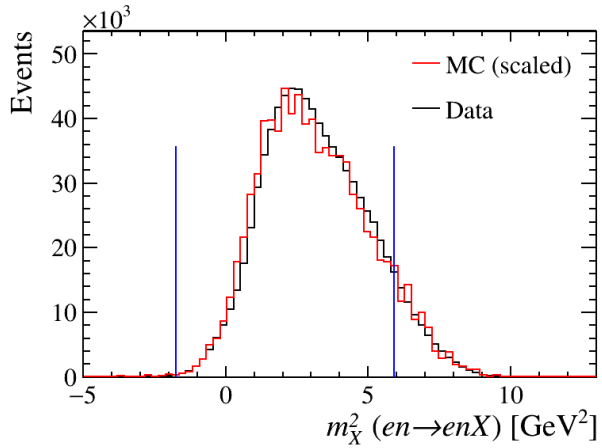


$-3.7 < m_X^2 < 3.2$

FD&FT

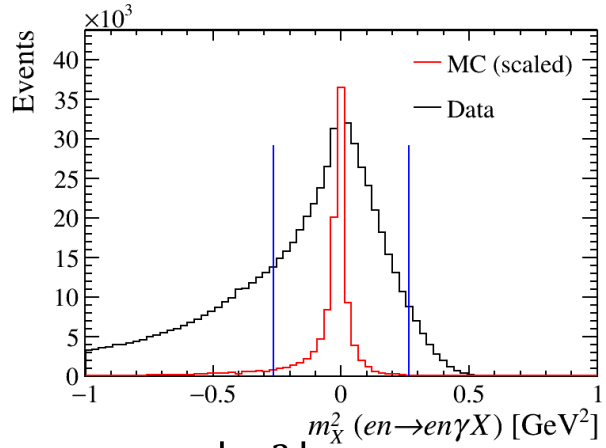


$|m_X^2| < 0.5$

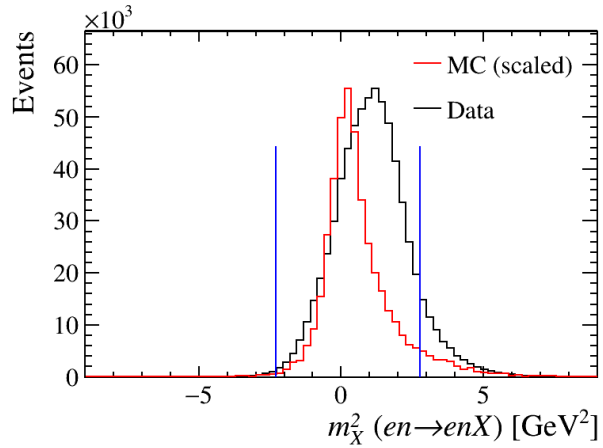


$-1.7 < m_X^2 < 5.9$

FD&FD



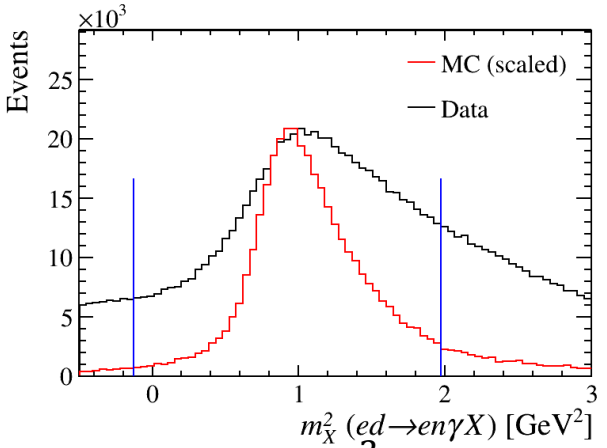
$|m_X^2| < 0.3$



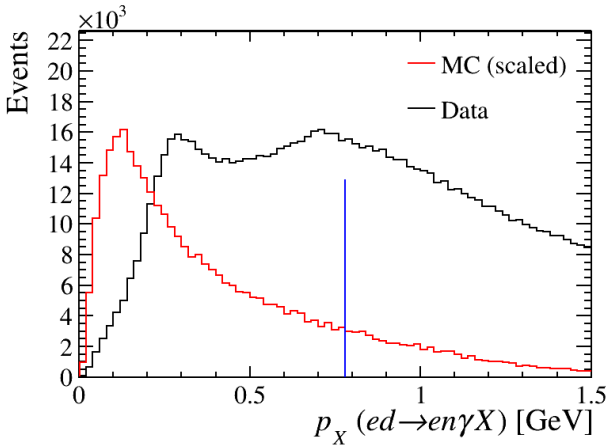
$-2.3 < m_X^2 < 2.8$

Exclusivity selection

CD&FT

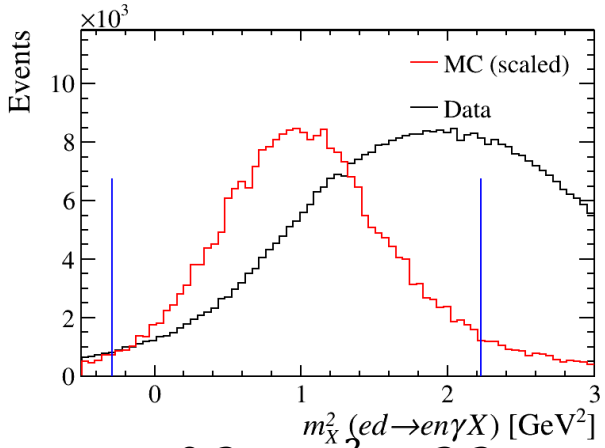


$-0.1 < m_X^2 < 2.0$

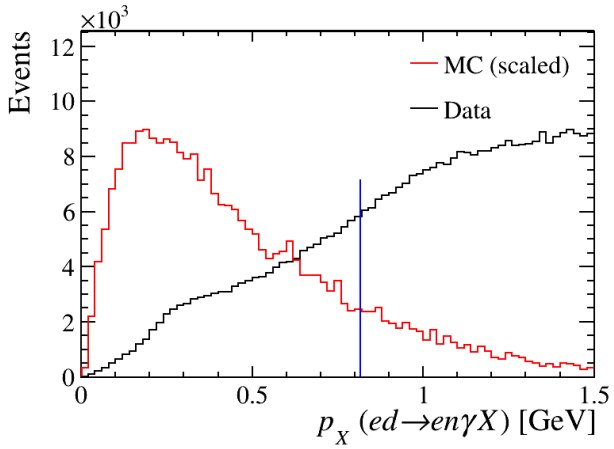


$p_X < 0.8$

CD&FD

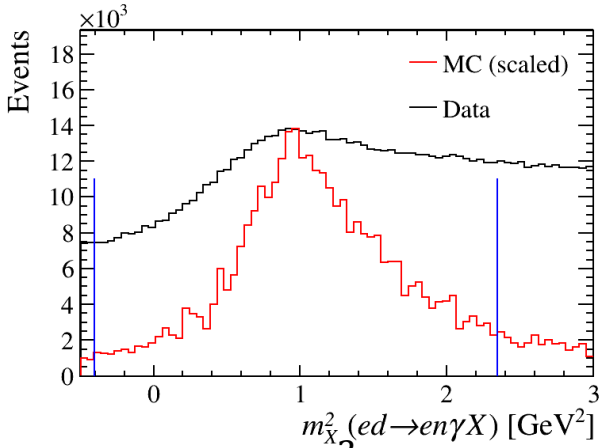


$-0.3 < m_X^2 < 2.2$

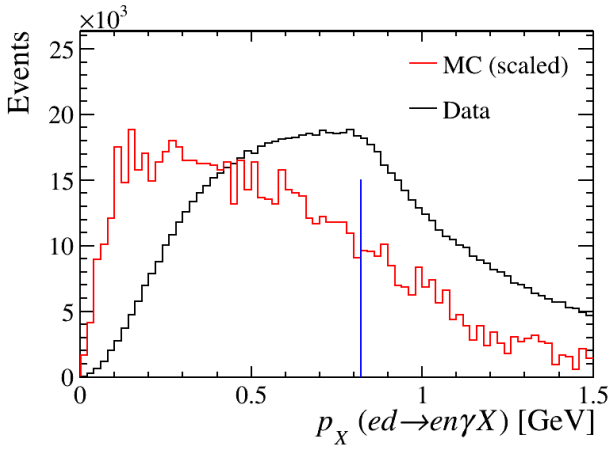


$p_X < 0.8$

FD&FT

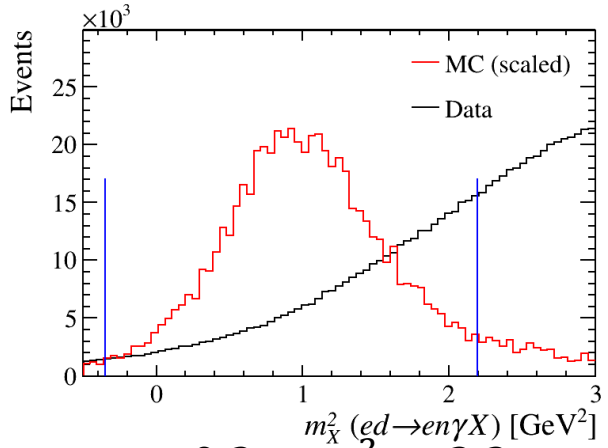


$-0.4 < m_X^2 < 2.3$

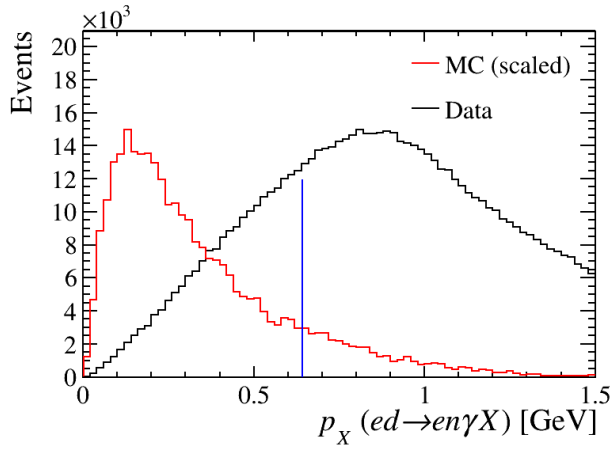


$p_X < 0.8$

FD&FD



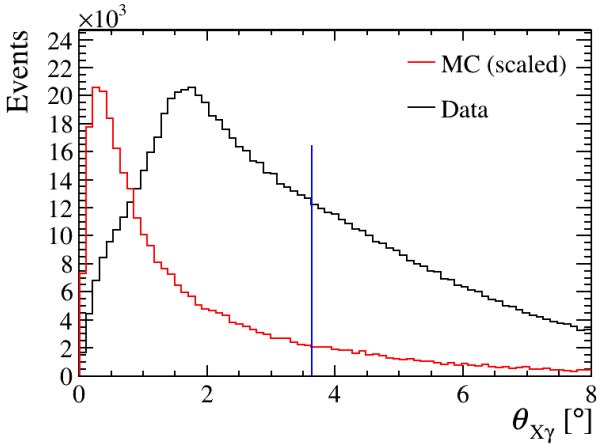
$-0.3 < m_X^2 < 2.2$



$p_X < 0.6$

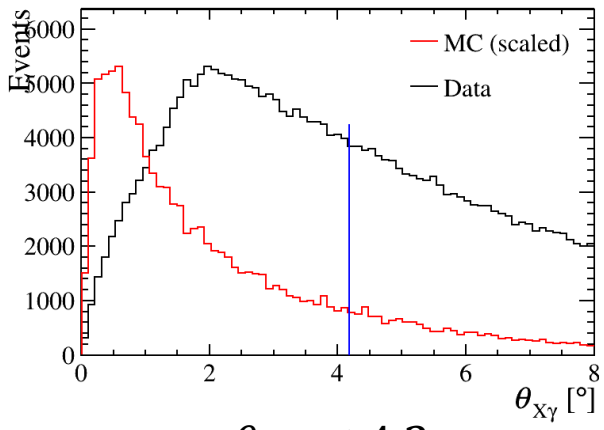
Exclusivity selection

CD&FT



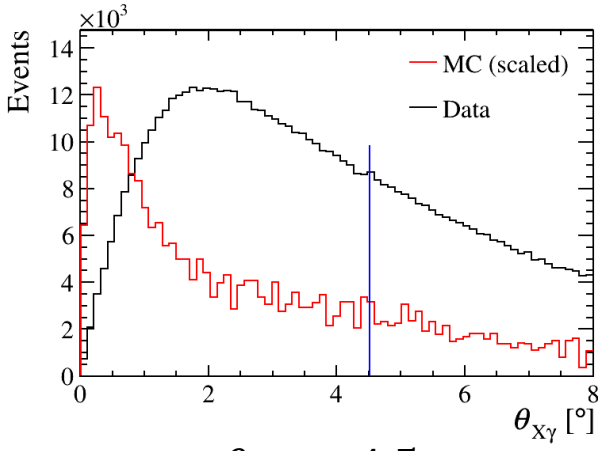
$\theta_{X\gamma} < 3.6$

CD&FD



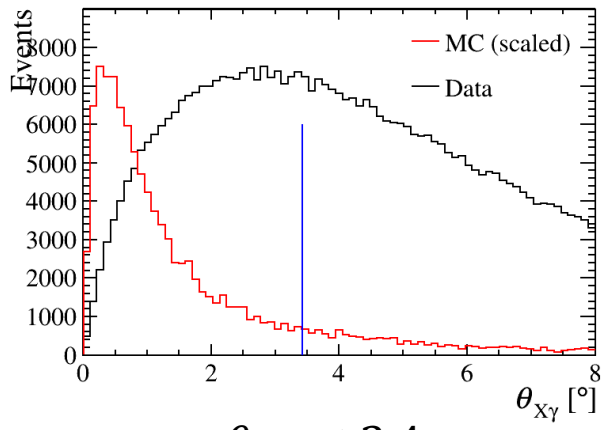
$\theta_{X\gamma} < 4.2$

FD&FT



$\theta_{X\gamma} < 4.5$

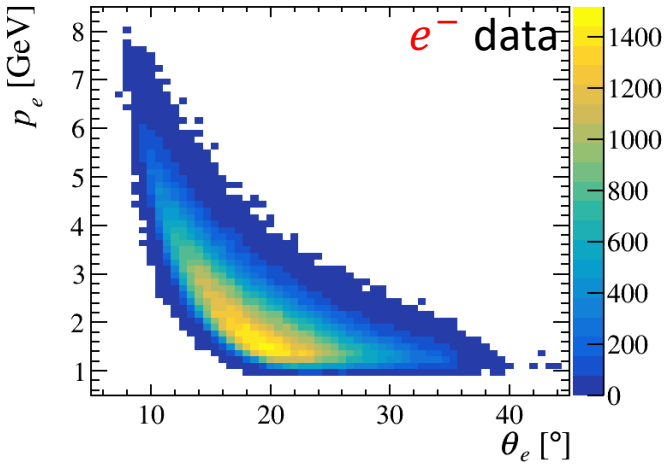
FD&FD

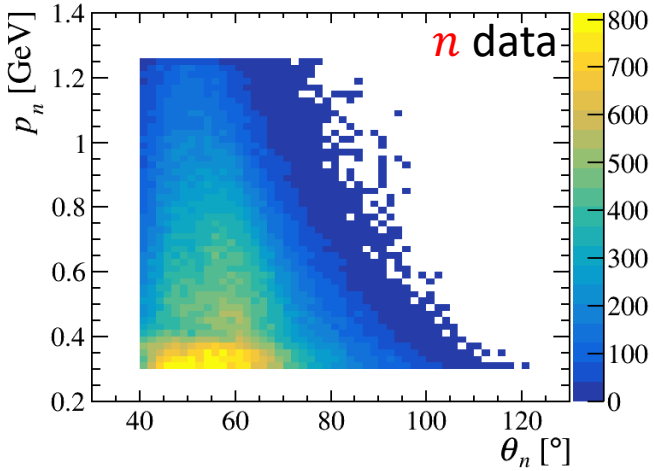


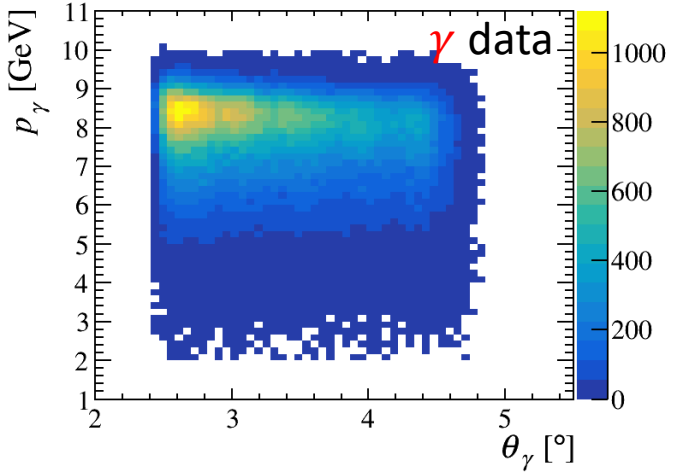
$\theta_{X\gamma} < 3.4$

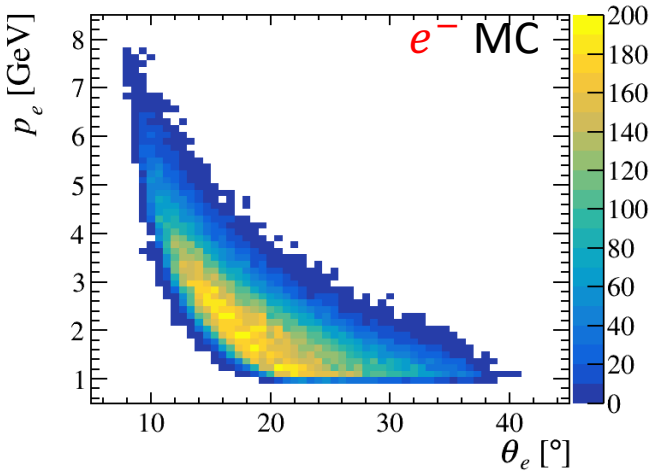
Particle kinematics after the selection

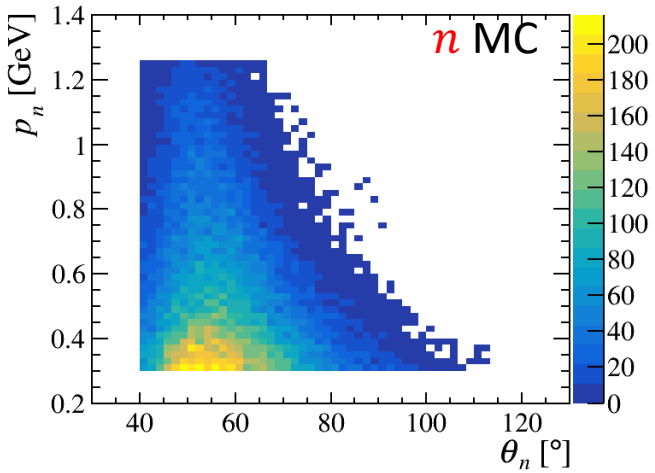
- CD&FT (n in CD & γ in FT)

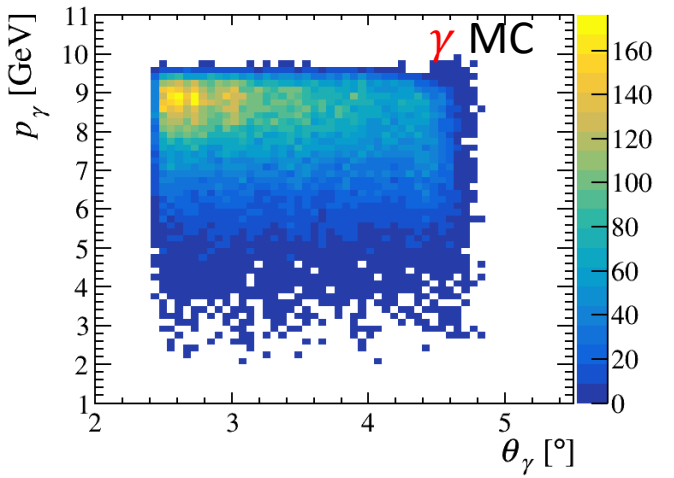






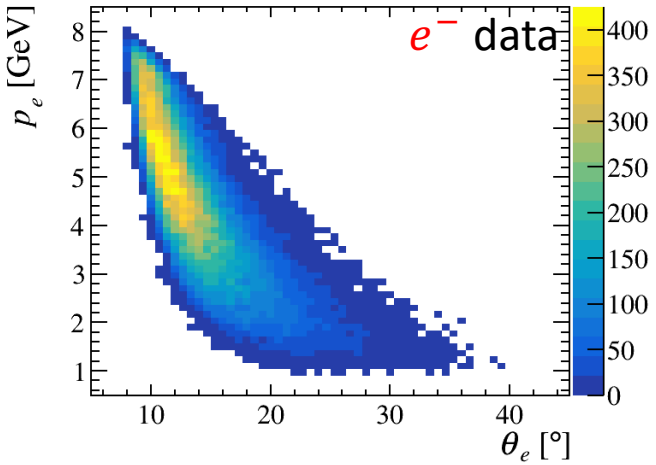


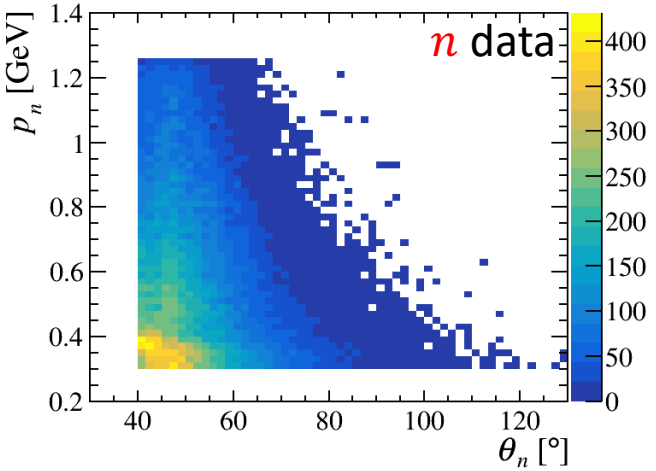


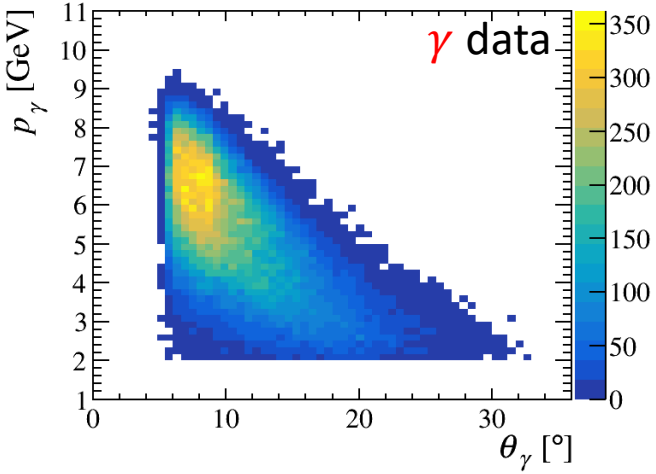


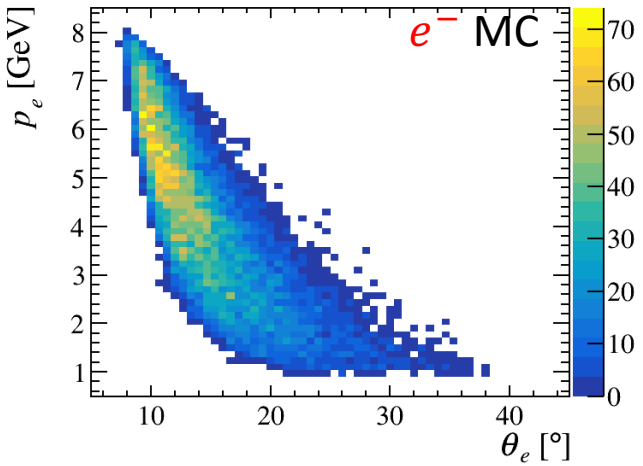
Particle kinematics after the selection

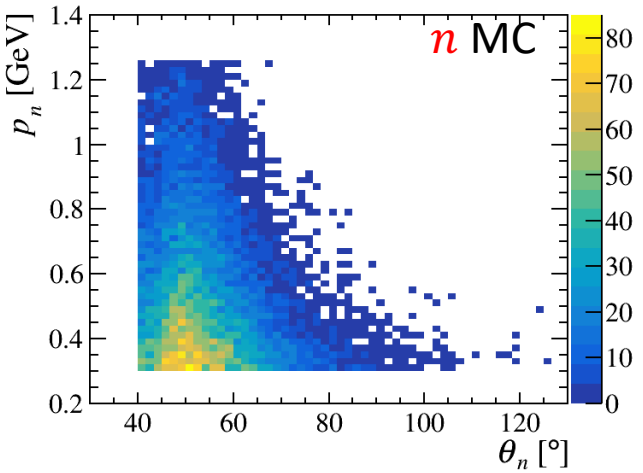
- CD&FD (n in CD & γ in FD)

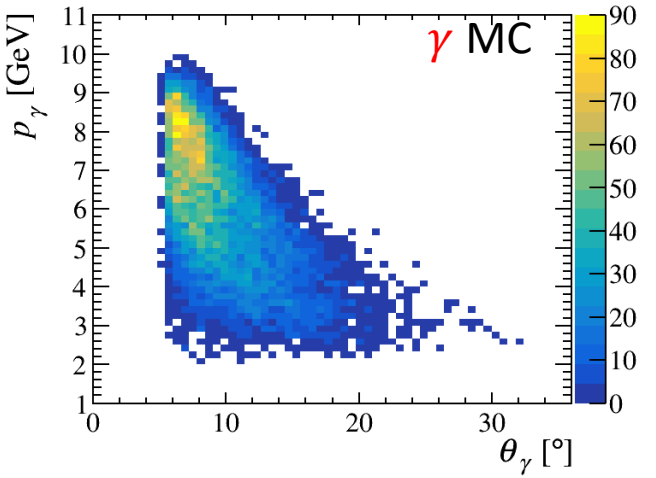












Distributions of nDVCS variables for CD&FT

- Remain backgrounds:
  - Proton misidentified as neutron
    - Mostly reduced by BDT
  - π^0 production contamination
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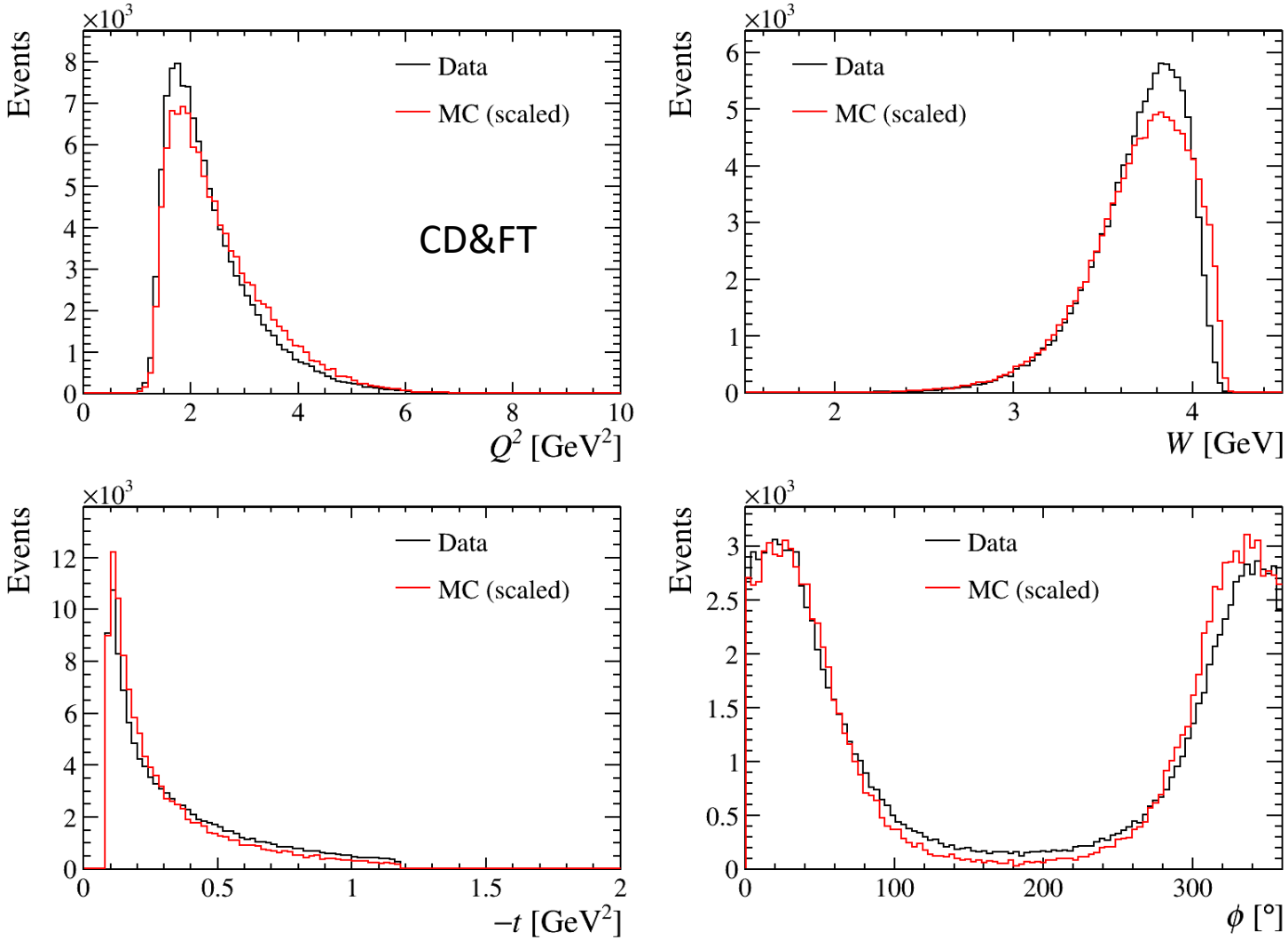
    - Mainly for γ in FD



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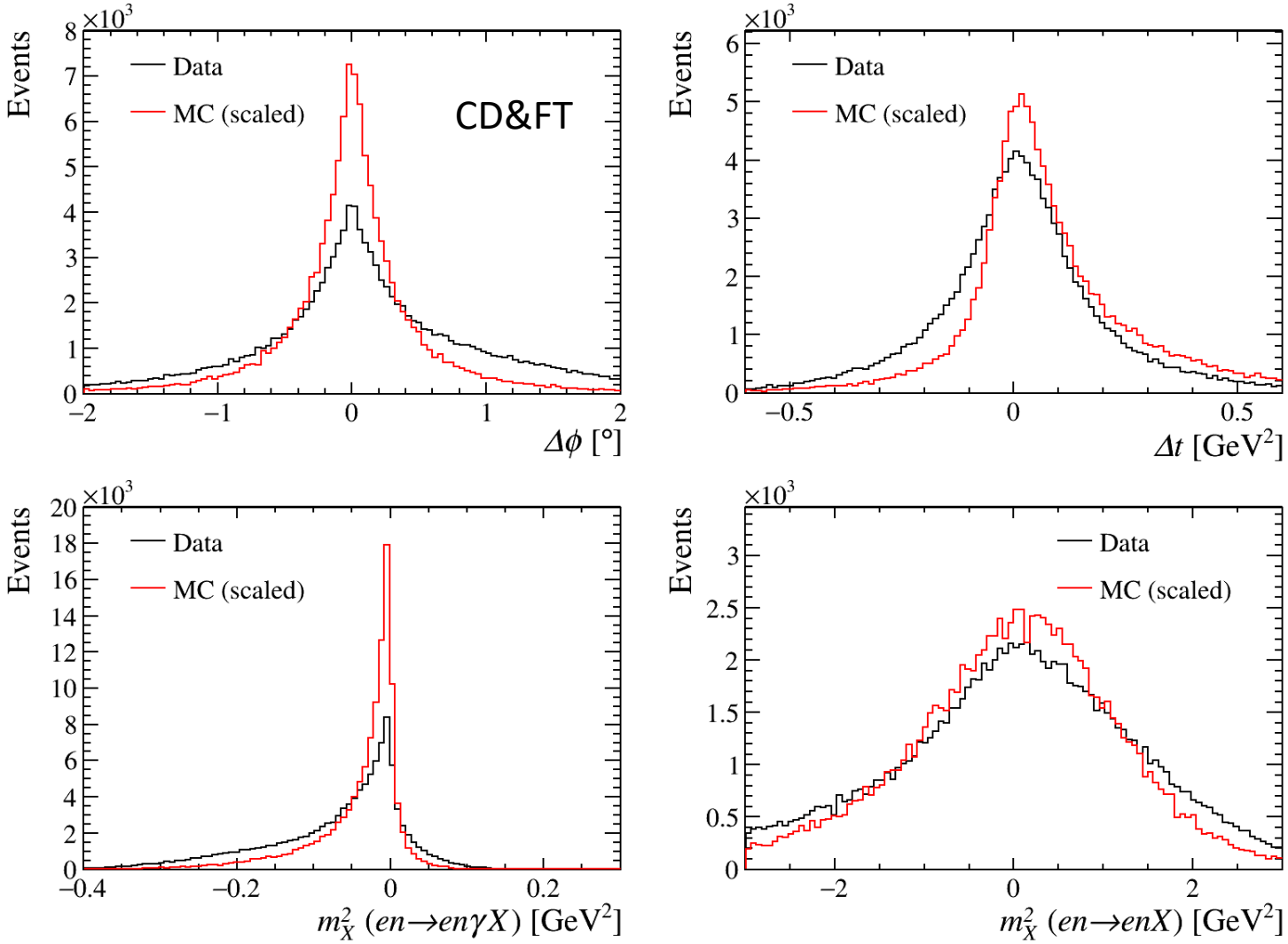

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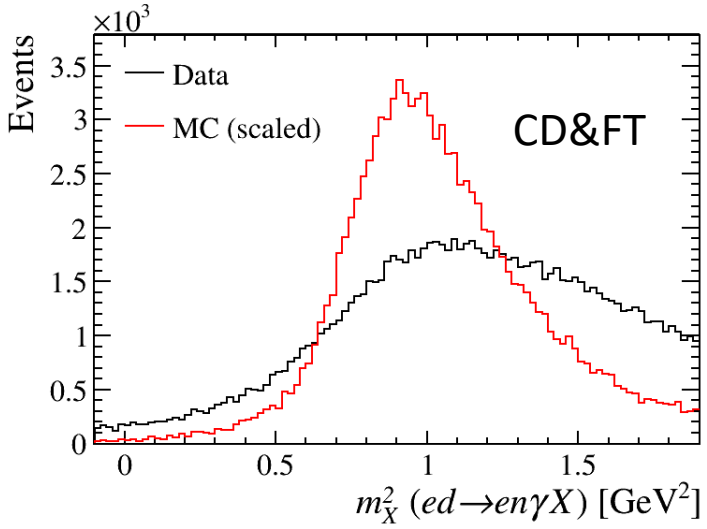

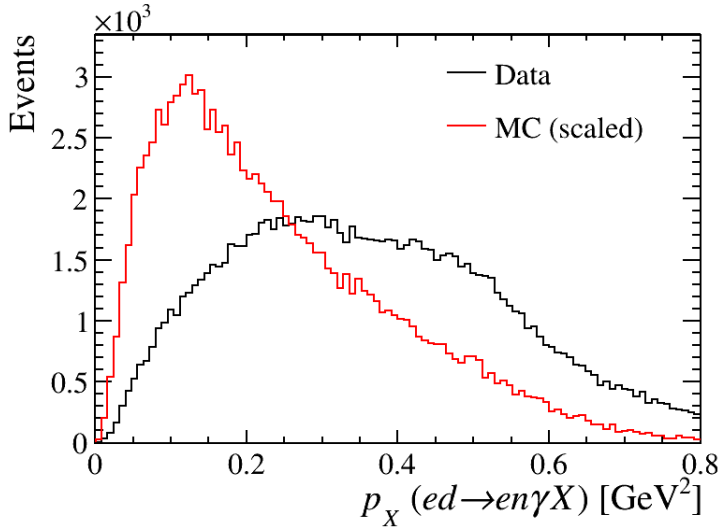

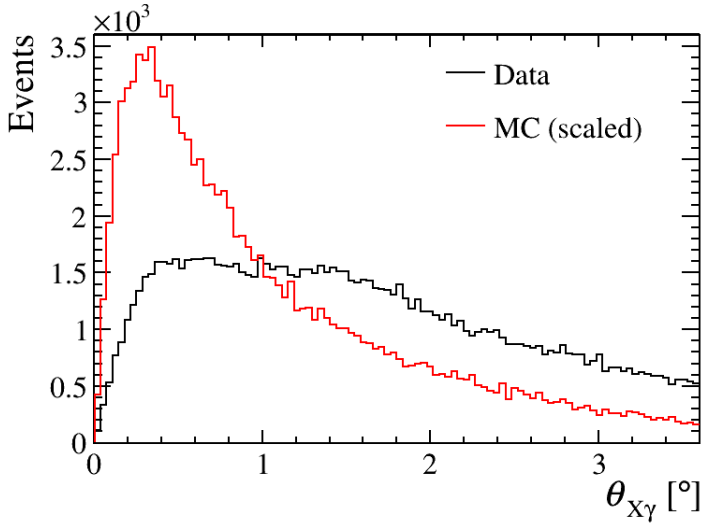

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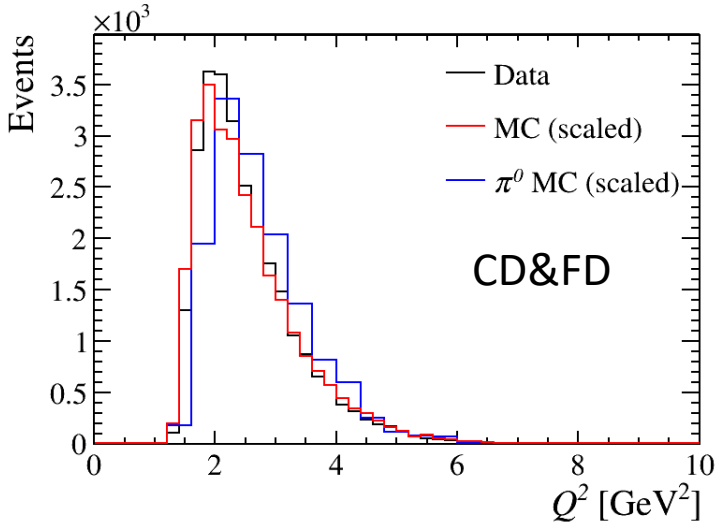

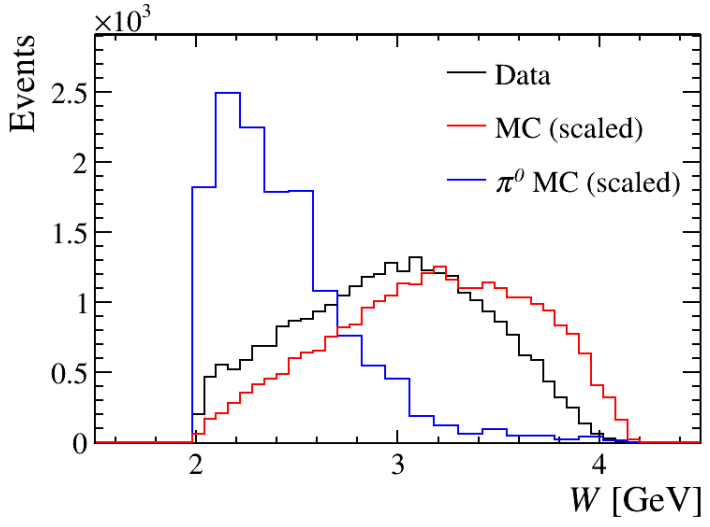

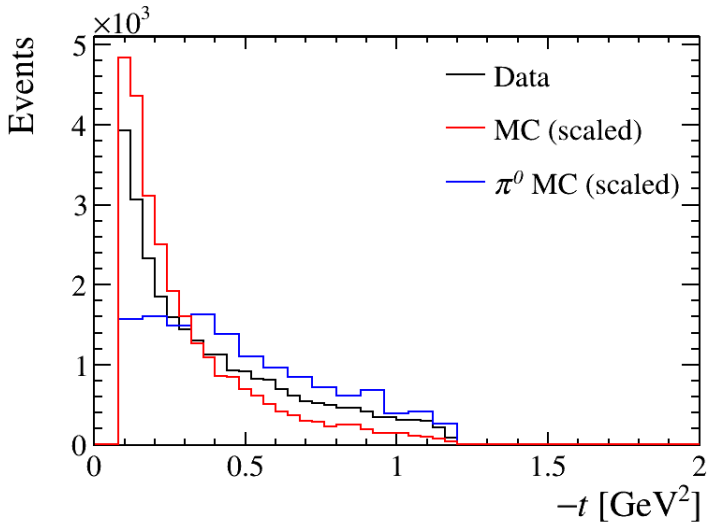

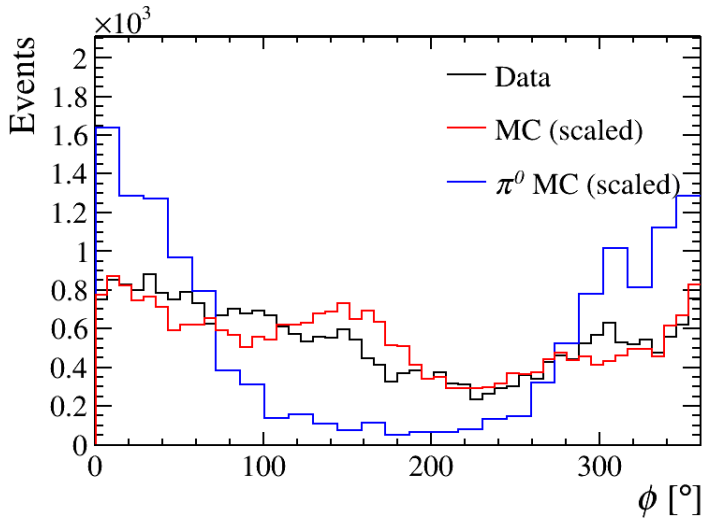

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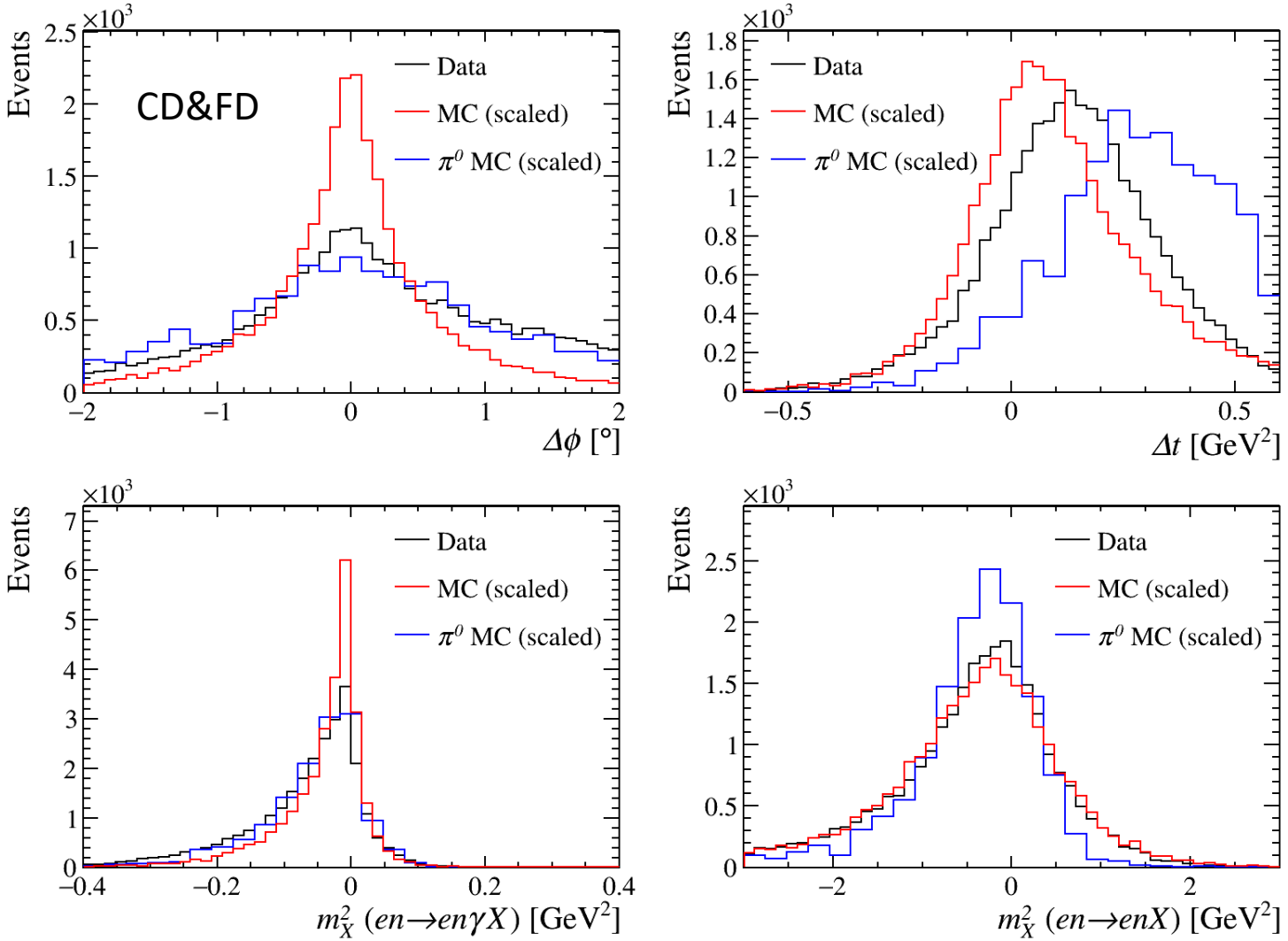

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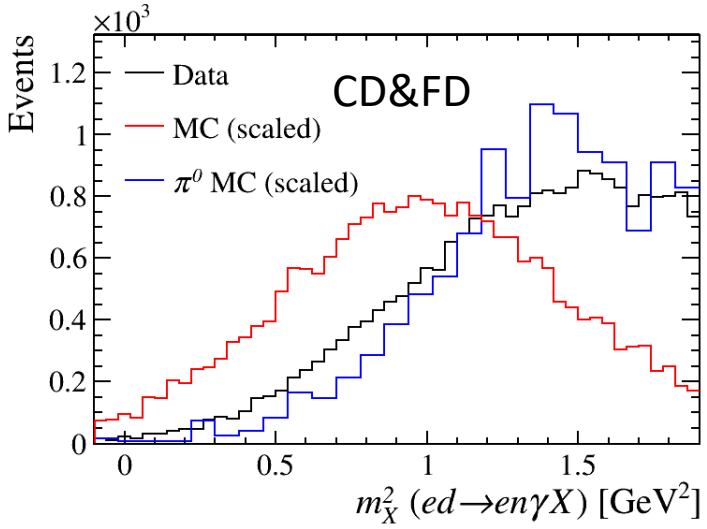
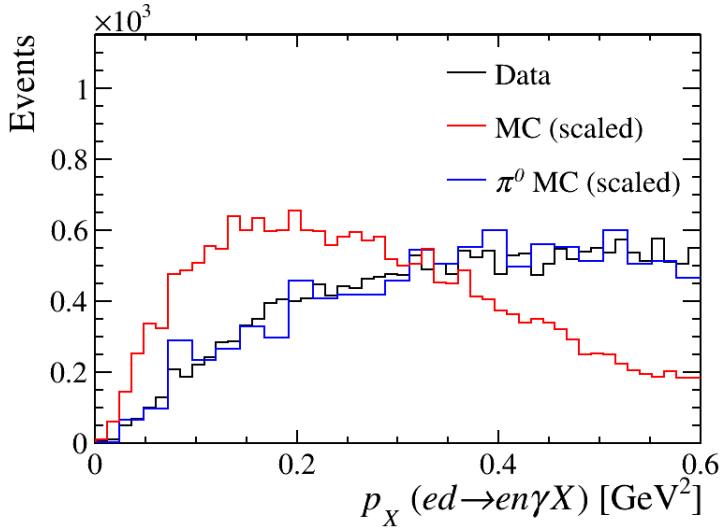
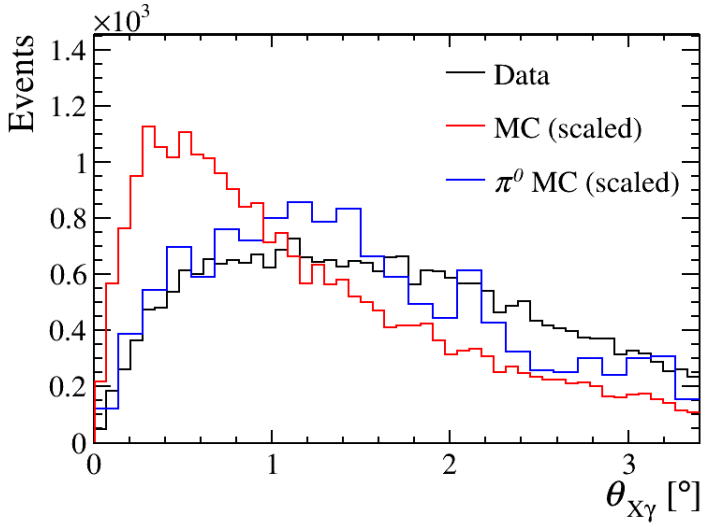
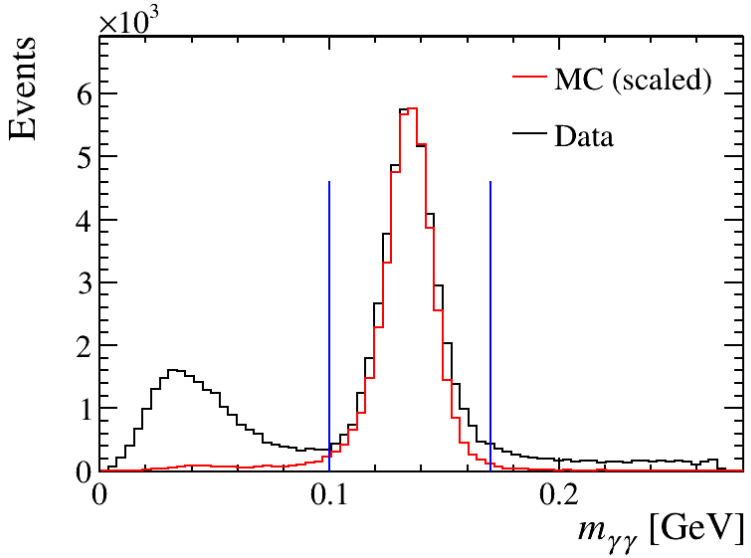




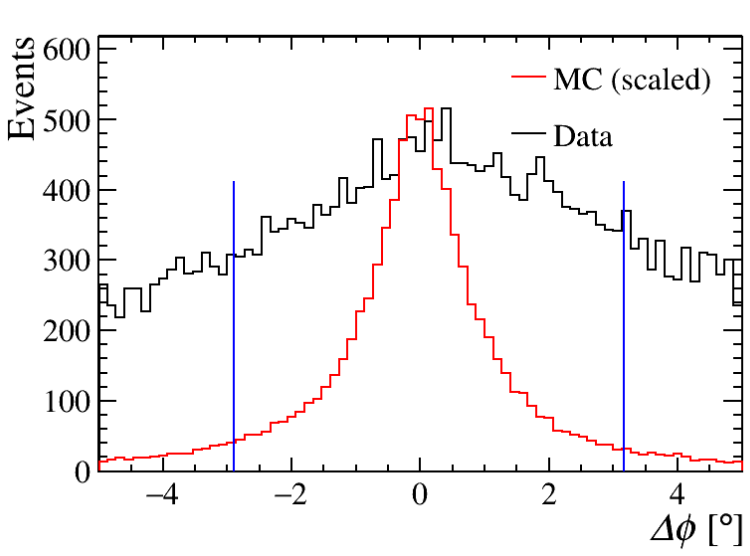


Exclusivity selection for FD&2FD

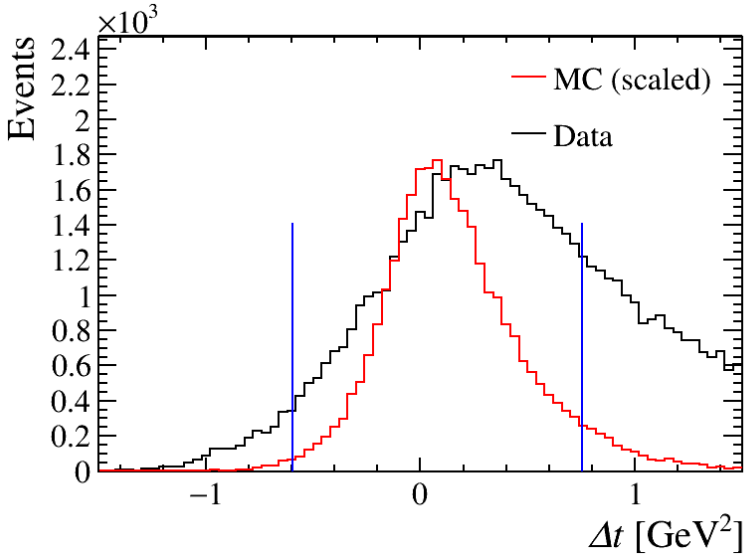
- Criteria determined by comparing data and MC
  - $\sim 2\sigma$ of the MC distribution
- π^0 production MC
  - 45M events, but not enough to get the distribution for all topologies
  - Need more MC to tune the selection criteria



$0.10 < m_{\gamma\gamma} < 0.17$ GeV



$|\Delta\phi| < 3.0°$



$|\Delta t| < 0.7$ GeV^2

Exclusivity selection for FD&2FD

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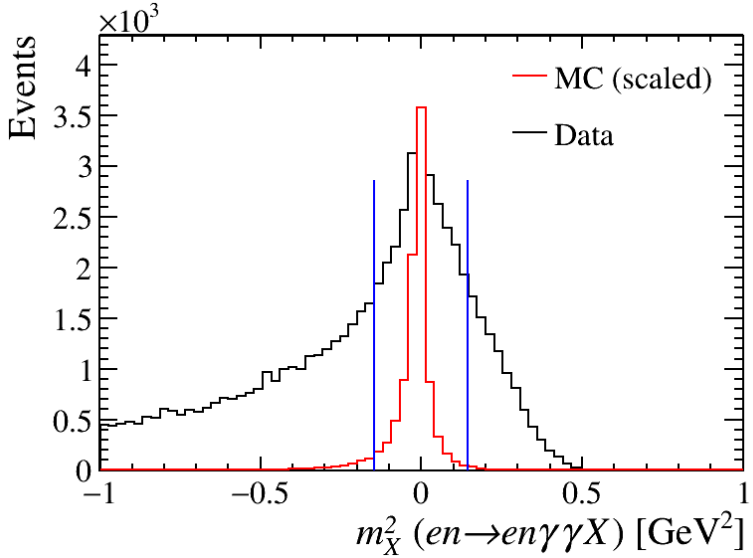
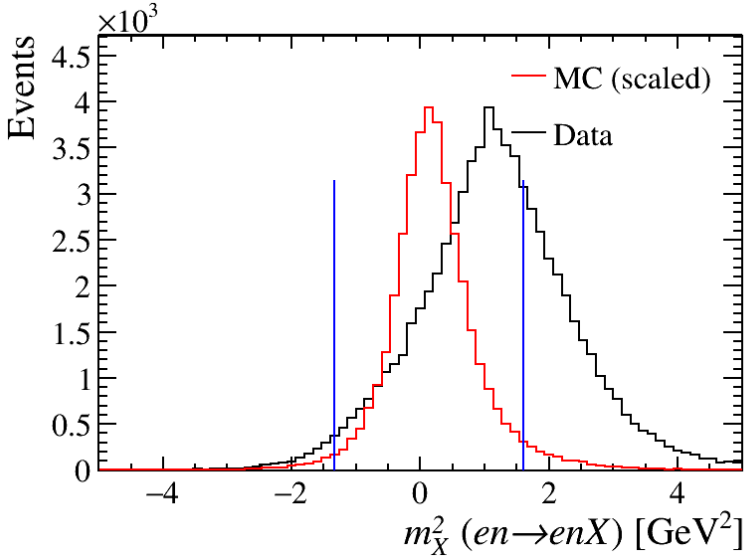
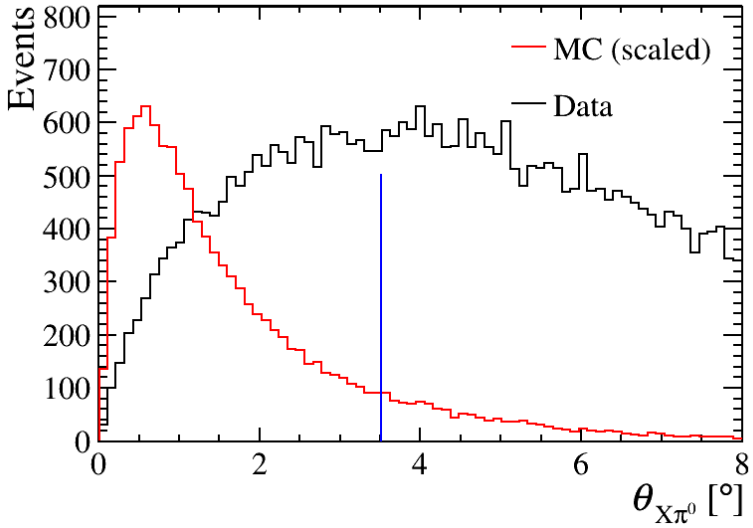
  - $\sim 2\sigma$ of the MC distribution
- π^0 production MC
  - 45M events, but not enough to get the distribution for all topologies
  - Need more MC to tune the selection criteria



$|m_X^2| < 0.15\ \mathrm{GeV}^2$



$|m_X^2| < 1.5\ \mathrm{GeV}^2$



$\theta_{X\pi^0} < 3.5°$

Exclusivity selection for FD&2FD

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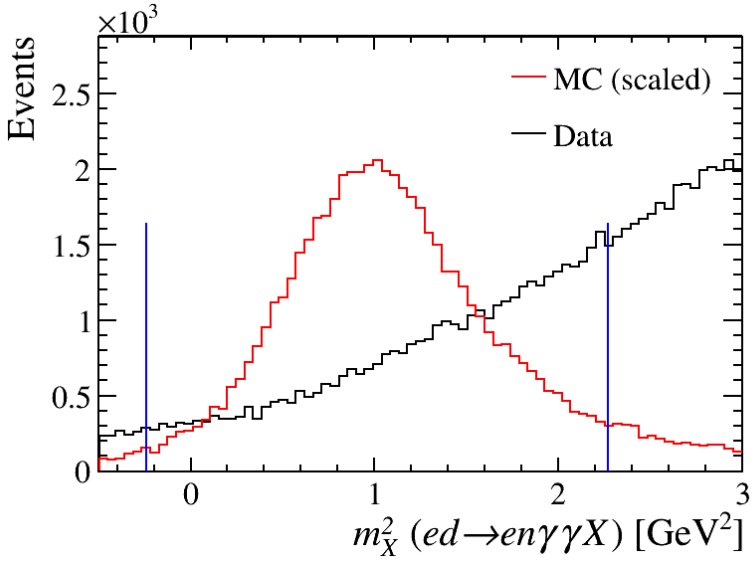
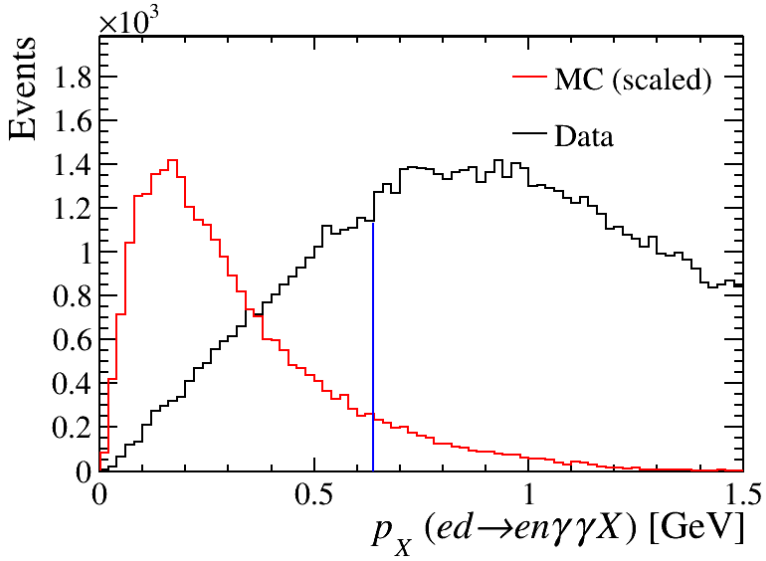
  - $\sim 2\sigma$ of the MC distribution
- π^0 production MC
  - 45M events, but not enough to get the distribution for all topologies
  - Need more MC to tune the selection criteria

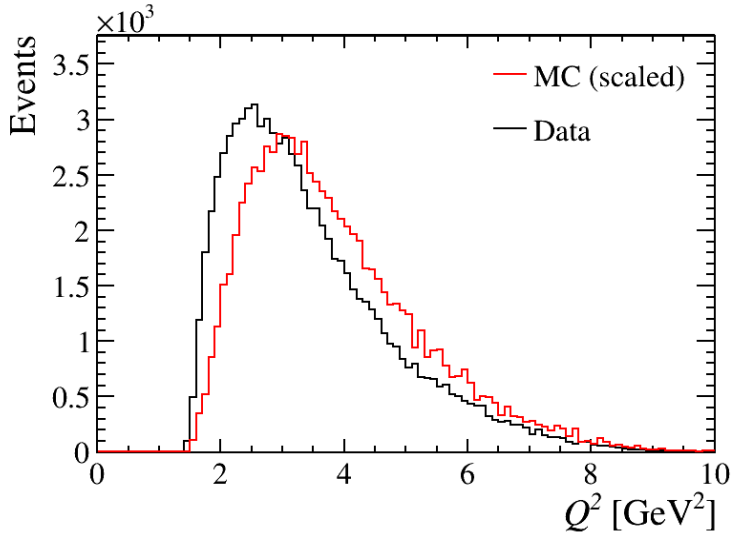


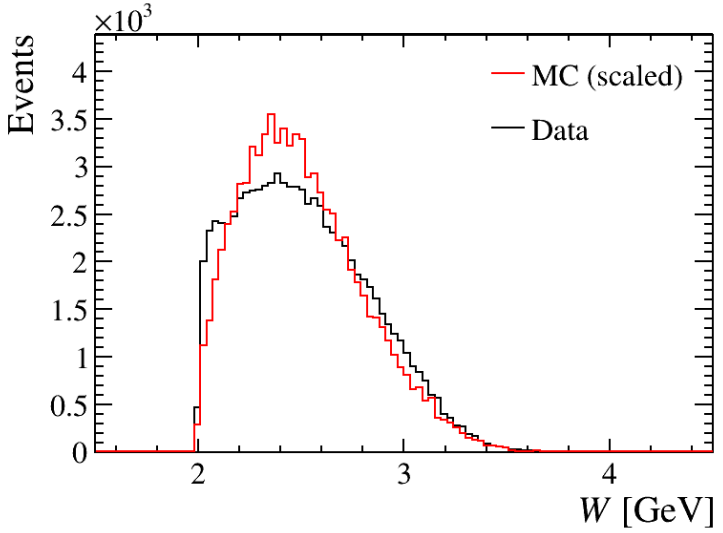
$-0.2 < m_X^2 < 2.3\ \mathrm{GeV}^2$

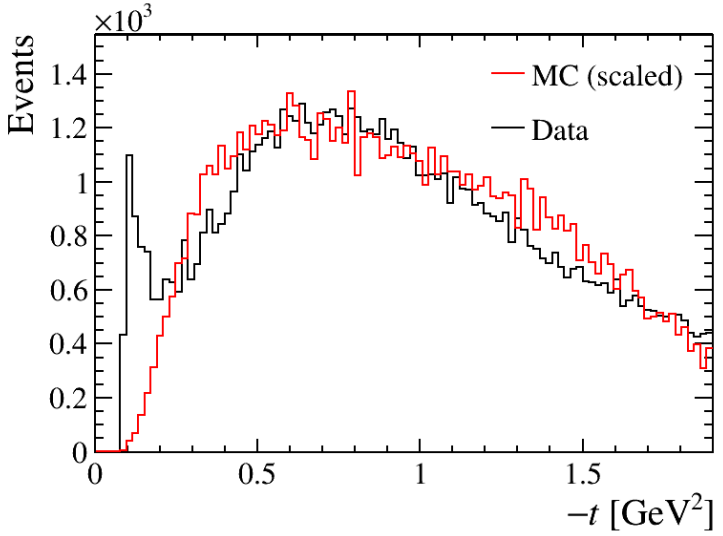


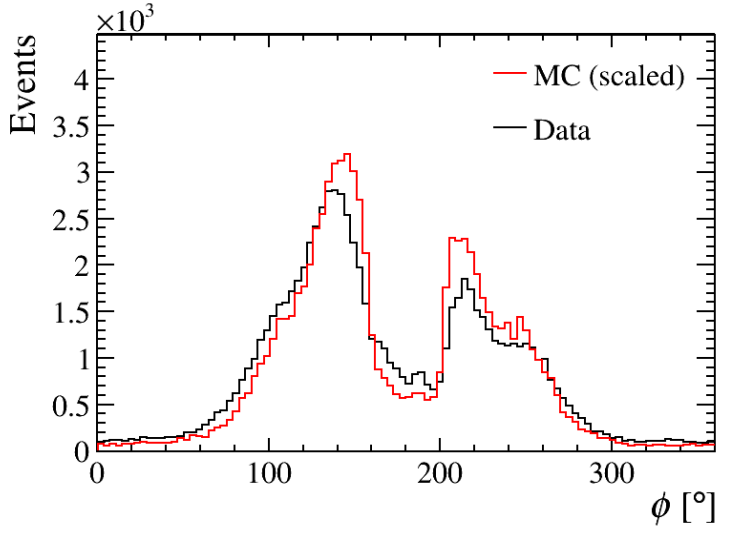
$p_X < 0.6\ \mathrm{GeV}$

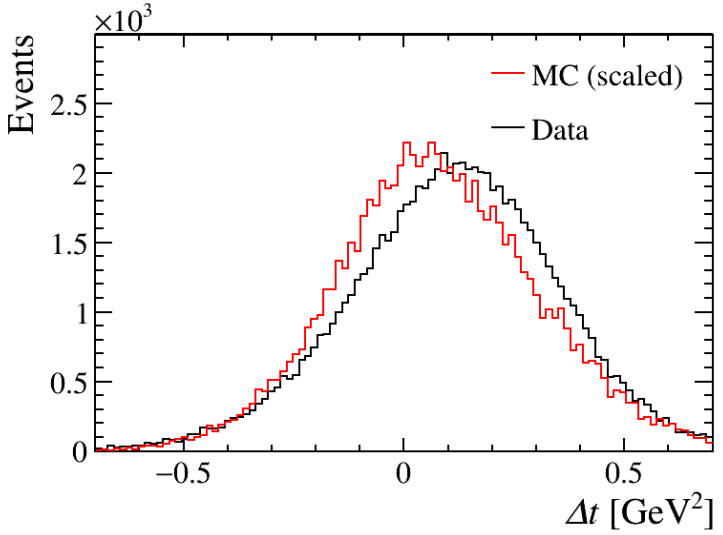
Distributions of π^0 production for FD&2FD

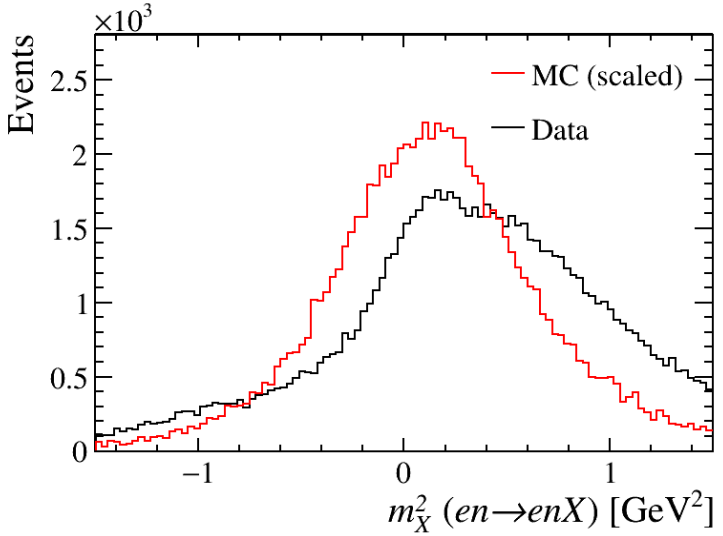




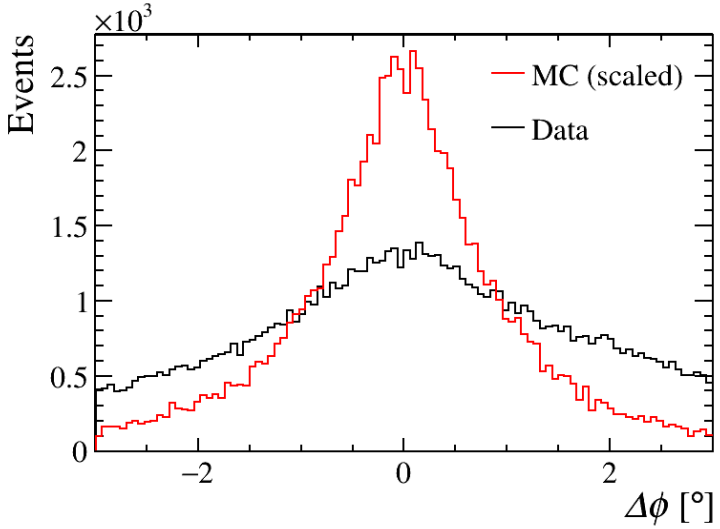


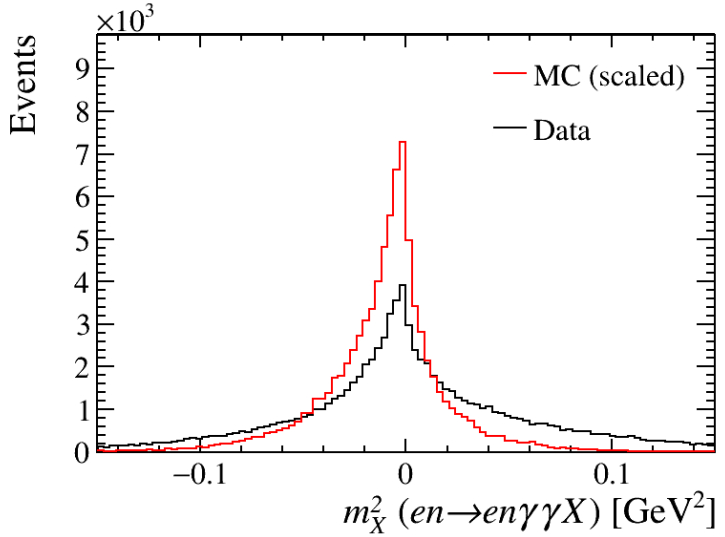


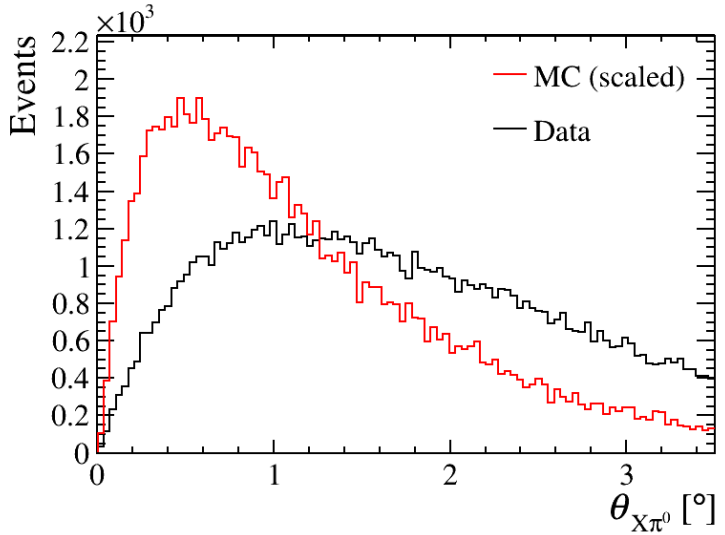


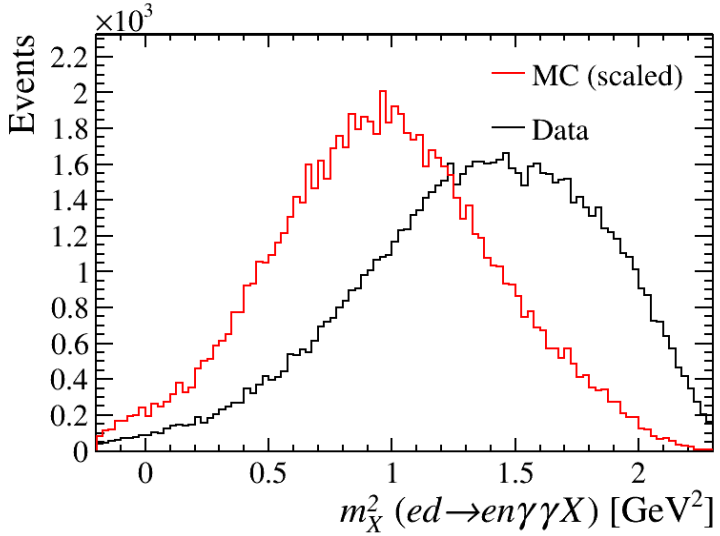


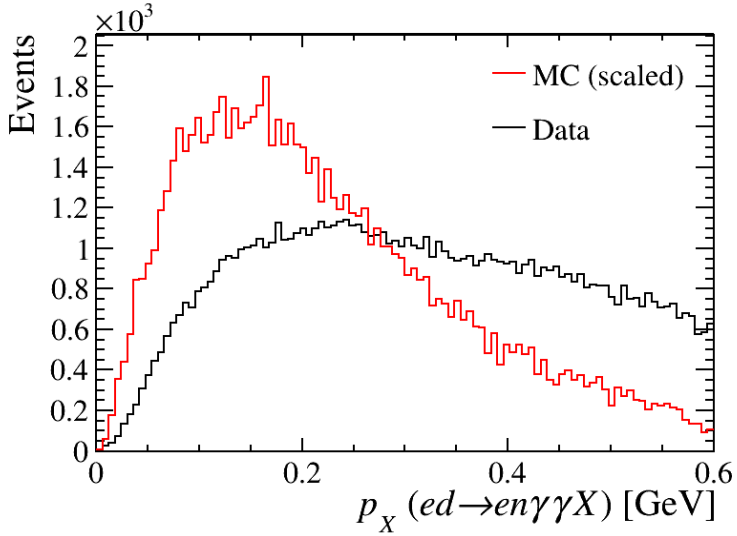
Distributions of π^0 production for FD&2FD



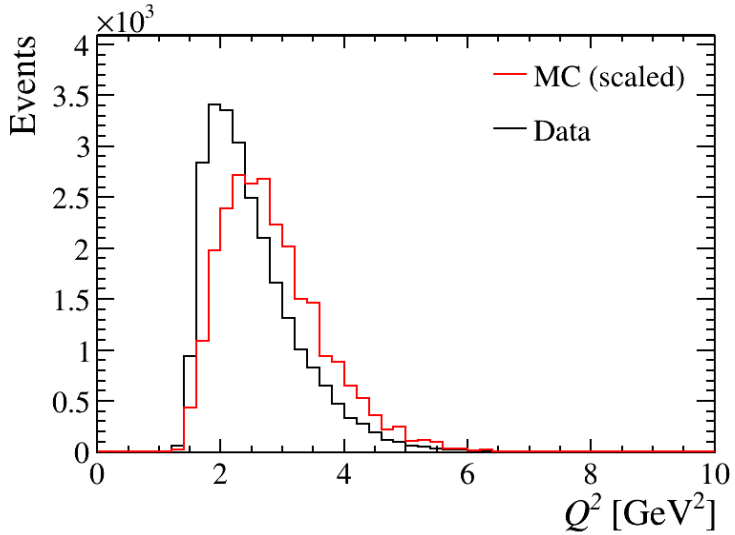


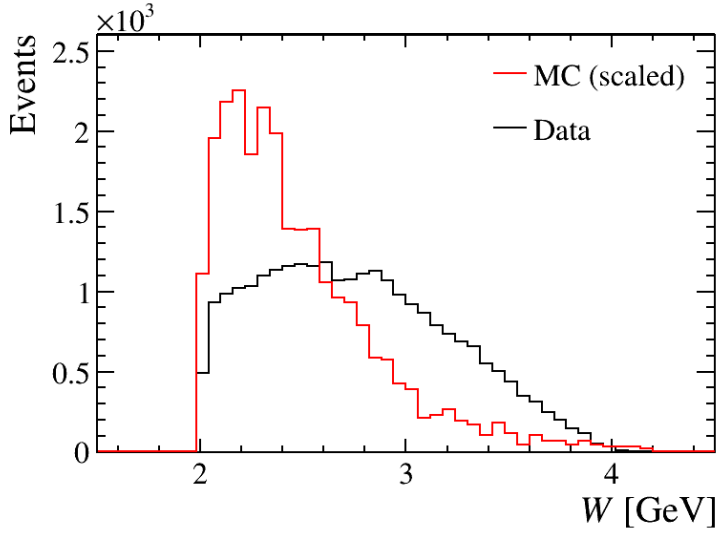


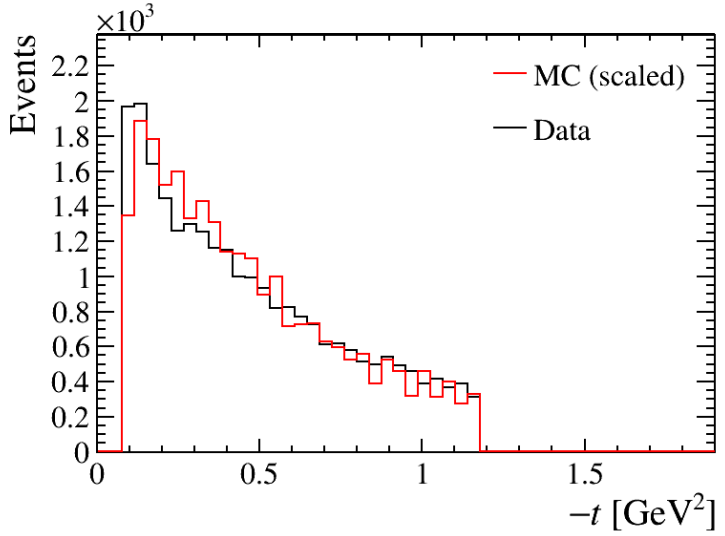


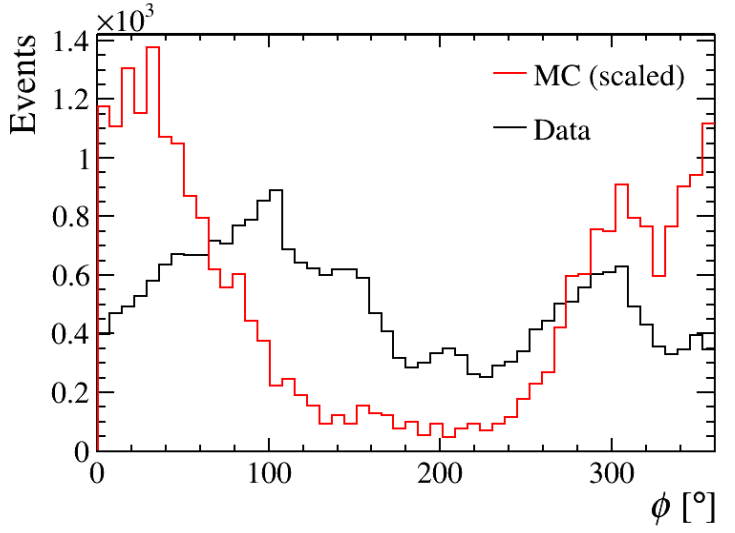


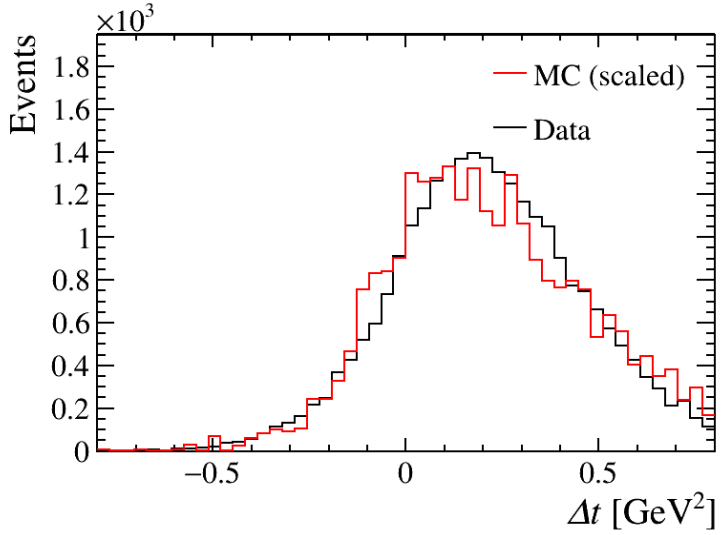
Distributions of π^0 production for CD&2FD

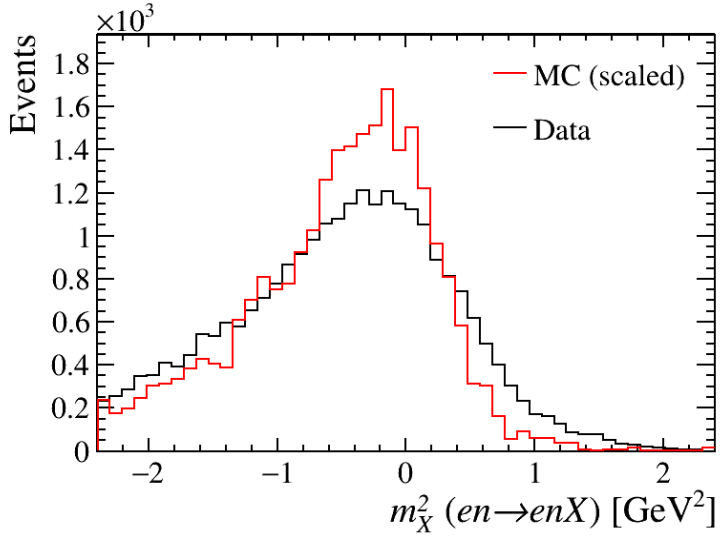












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