PANIC 2021 Conference
QCD, spin physics and chiral dynamics
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Deeply Virtual Compton Scattering off the Neutron and Proton from deuterium with CLAS12 at Jefferson Lab

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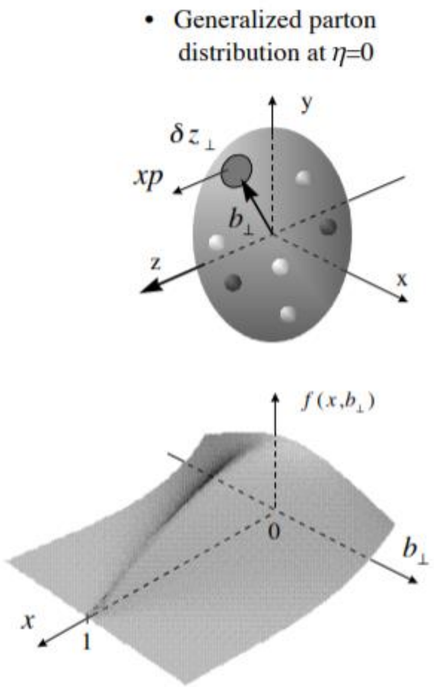
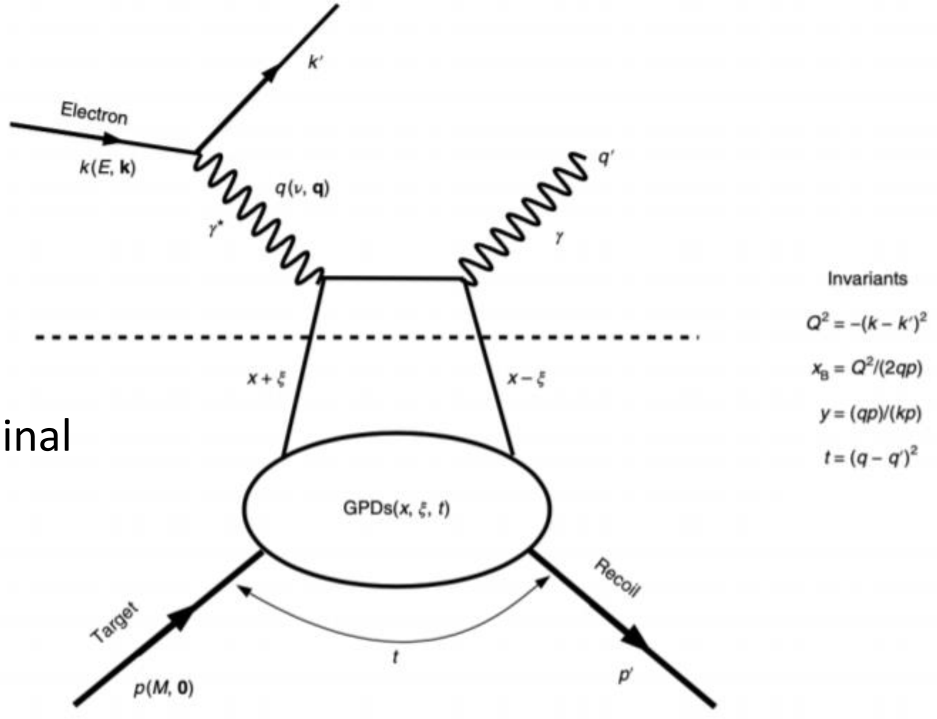
Motivations



Generalised Parton Distributions (GPDs): Correlation of transverse position and longitudinal momentum of partons in nucleon & the spin structure



- Nucleon internal structure: DVCS gives access to 4 complex GPDs-related quantities: Compton Form Factors CFF

$$\mathbf{H},\ \mathbf{E},\ \widetilde{\mathbf{H}},\ \widetilde{\mathbf{E}}\ (\mathbf{x},\xi,\mathbf{t})$$

- 1 measured observable: a certain combination of CFFs
- Measurement of several observables: separation of CFFs
- Measure GPDs on both nucleons: flavour separation of GPD

$$(H,E)_u(x,\xi,t) = {}^{9}\!/_{15}\left[4(H,E)_p(x,\xi,t) - (H,E)_n(x,\xi,t)\right]$$
$$(H,E)_d(x,\xi,t) = {}^{9}\!/_{15}\left[4(H,E)_n(x,\xi,t) - (H,E)_p(x,\xi,t)\right]$$

Motivations

- Physics observable: Beam Spin Asymmetry BSA
  - Scattering off neutron (nDVCS): GPD E
    - Determination of Ji sum rule
      - Contribution of orbital angular moment of quarks to the nucleon spin

$$J^q = \frac{1}{2}\int_{-1}^{1} x dx \left[H^q(x,\xi,0) + E^q(x,\xi,0) \right]$$

  - Scattering off proton (pDVCS): GPD H
    - Quantify medium effects
      - Essential for the extraction of BSA of a “free” neutron (de-convoluting medium effect via comparison with DVCS on hydrogen target)

BSA → **Shape estimated with** → **At first order** → **CFF accessed through BH-DVCS interference terms**

$$A_{LU}(\Phi) = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$

$$f(\Phi; a, b) = \frac{a\, sin(\Phi)}{1 + b\, cos(\Phi)}$$

$$a \propto \frac{s_1^I}{kC_0^{BH} + C_0^I}$$

$$b \propto \frac{kC_1^{BH} + C_1^I}{kC_0^{BH} + C_0^I}$$

$$C_0^I, C_1^I, S_1^I$$

ϕ: angle between the lepton plane and the photon-proton plane

nDVCS with CLAS12

- Experimental configuration:
  - Baseline CLAS12 configuration + Central Neutron Detector
  - Highly polarized electron beam (~86% polarization) measured with 9 Moeller runs
  - Unpolarized liquid deuterium target (5 cm long)

- Run Dates considered in this talk for analysis:
  - Data taken during 3 periods in 2019 and early 2020: ~40% of the approved beamtime
  - Magnet inbending at 10.6 and 10.2 GeV beam energy (50% of all collected data)
  - Magnet outbending at 10.4 GeV beam energy (20% of all collected data)
  - Magnet inbending at 10.4 GeV beam energy (30% of all collected data)

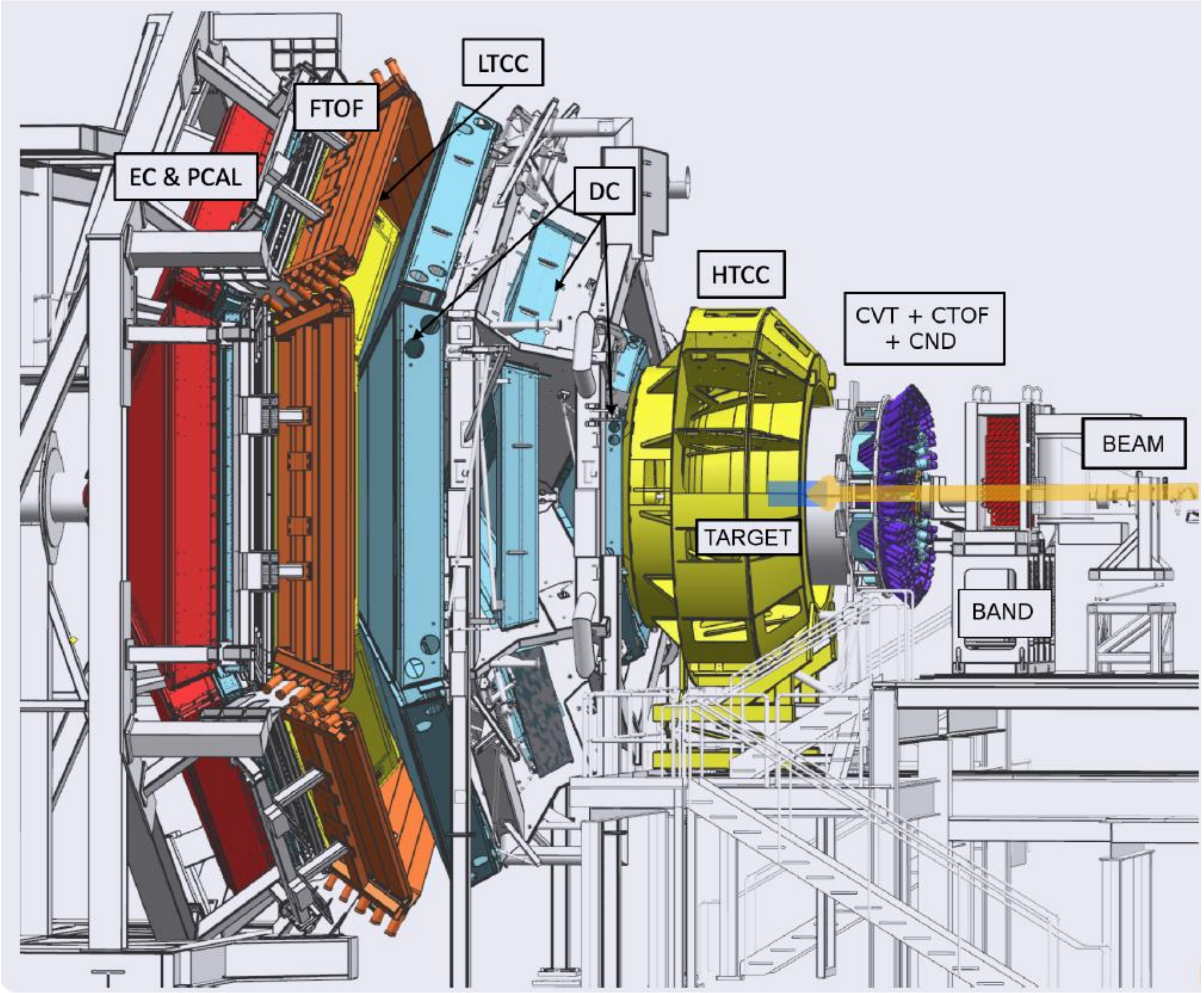
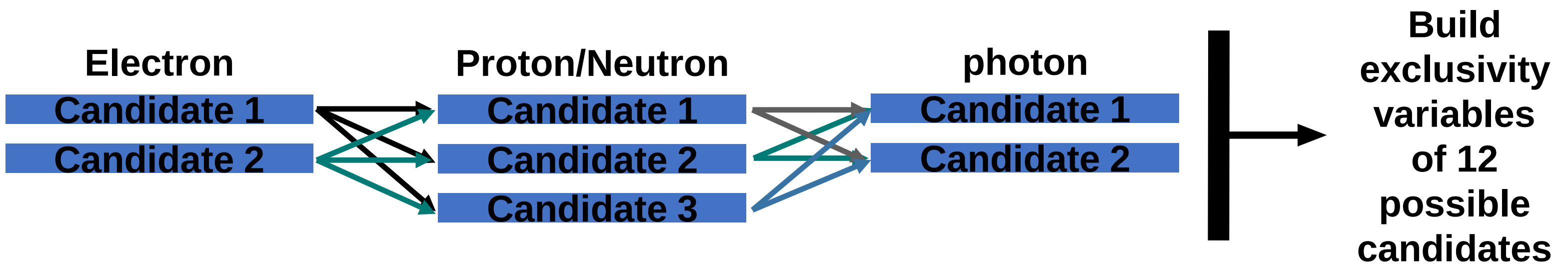


Figure in V. Burkert et al., Nucl.Instrum.Meth.A 959 (2020) 163419

Channel selection for nDVCS and pDVCS

- Construct all the possible combinations of final state particles: ed->e'Nγ(N_{spec}) (N:nucleon)
  - Final states reconstructed using CLAS12 PID + a dedicated charged particle veto for neutron selection optimisation
  - Best candidate in event is selected based on best exclusivity criteria (a multi-dimensional χ2 with all exclusivity variables)



- When a distribution shows a gaussian behavior, estimate cut with +/- 5 standard deviations
- Fiducial cuts included for: electrons in PCAL and DC, photons in PCAL and protons in DC
- Preliminary fiducial cuts for neutrons to remove charged-particles contamination coming from the dead zones of the SVT

Reconstruction of final states and exclusive selection

- The nDVCS (pDVCS) final state is selected with the following exclusivity criteria: (N:nucleon)
  - Missing mass
    - e d → e N γ X
    - e N → e N γ X
    - e N → e N X
  - Missing momentum
    - e d → e N γ X
  - ΔΦ, Δt, θ(γ,X)
    - Difference between two ways of calculating Φ and t
    - Cone angle between measured and reconstructed photon
- The optimization of the exclusivity cut is performed on the sum of the squares of ΔΦ, Δt, θ(γ,X) and missing mass e N → e N X
- Cuts informed by Monte Carlo simulations:
  - GPD-based event generator for DVCS/pi0 on deuterium
  - DVCS amplitude calculated according to the BKM formalism
  - Fermi-motion distribution evaluated according to Paris potential

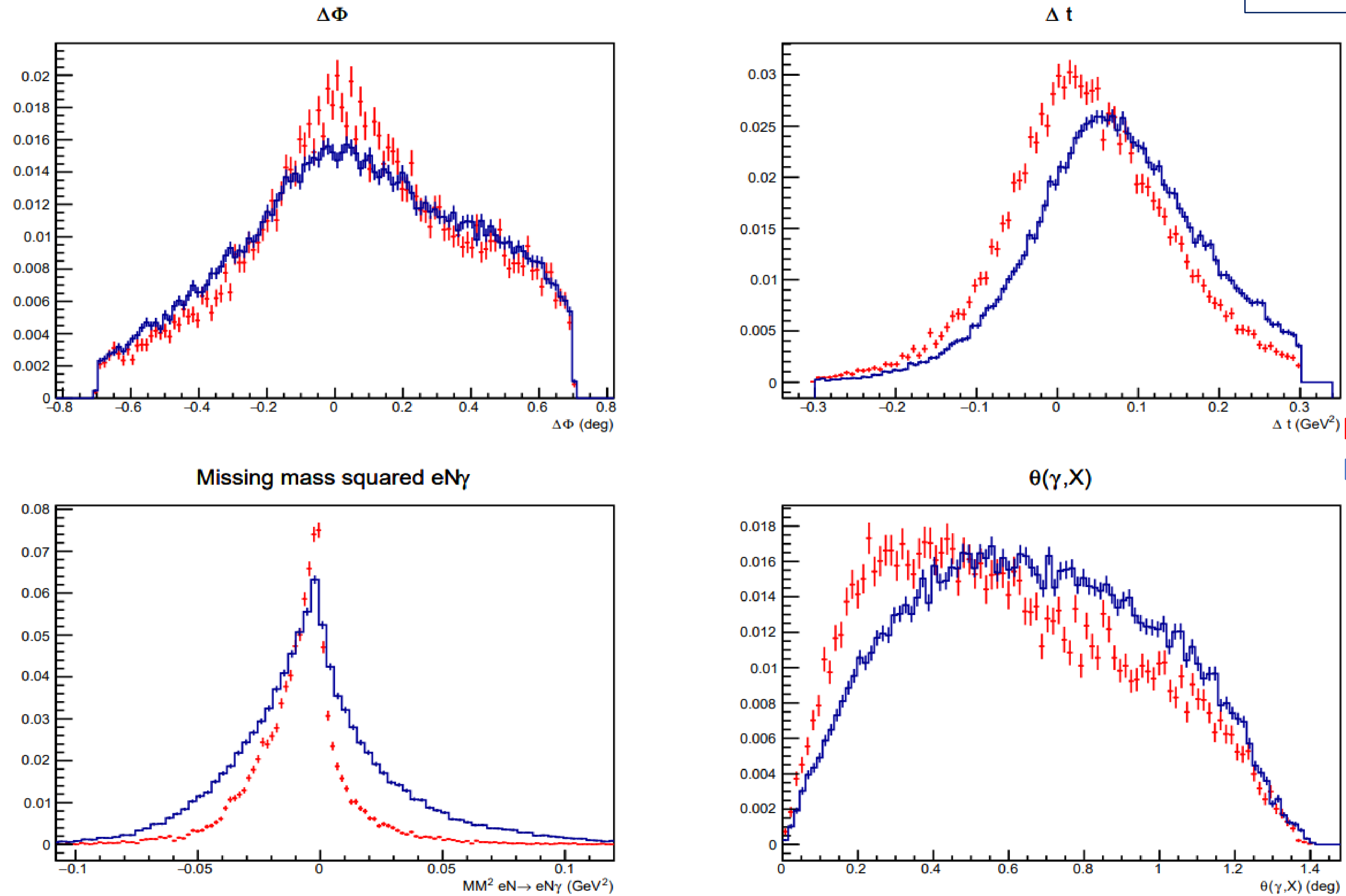
	Proton	Electron	Photon	Neutron
Momentum (GeV)	0.3	1	2	0.35

Q2>1 GeV2 W>2 GeV2

$\theta(e,\gamma) > 5^\circ$ Remove radiative photons

Exclusivity variables: nDVCS

no kinematical corrections of final state particles momenta



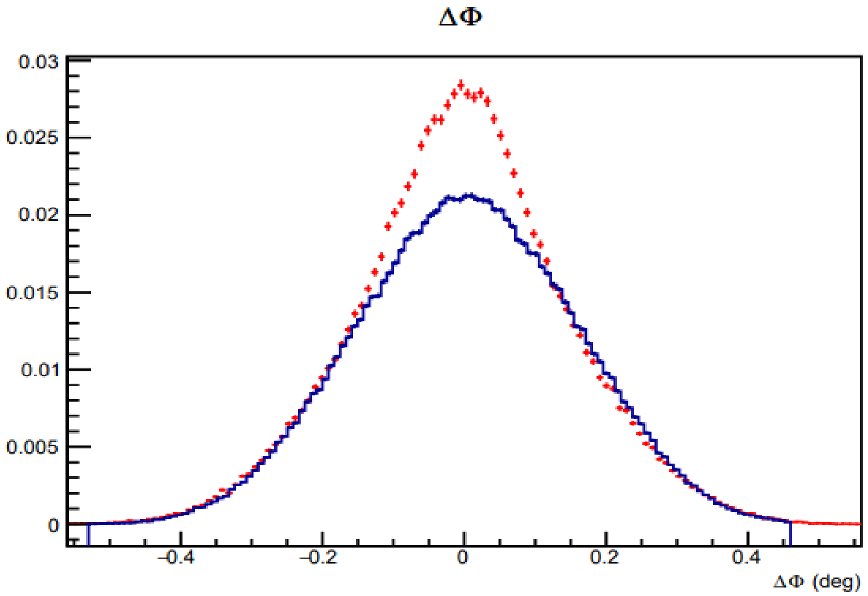
Red:MC (DVCS)

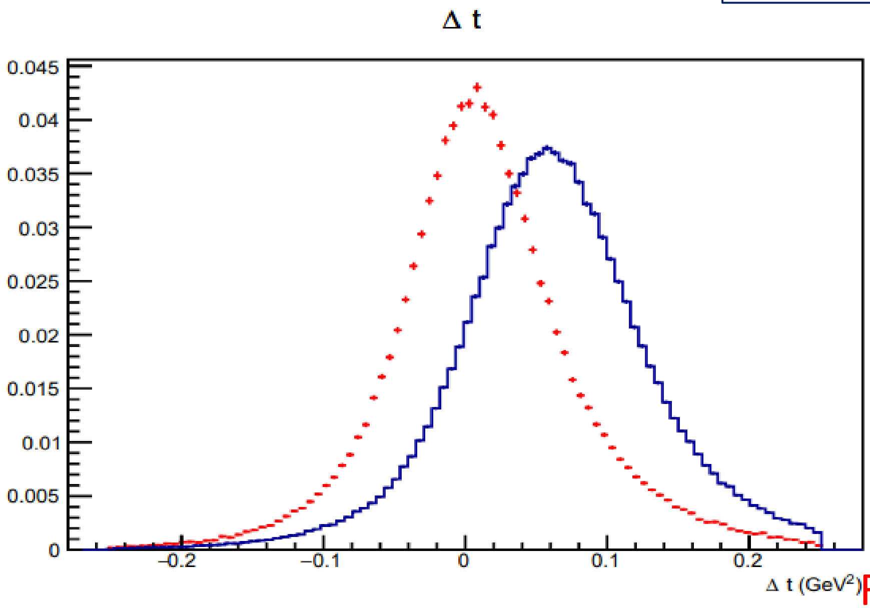
Blue: data (DVCS + π^0 background)

π^0 background:
partially reconstructed
e n → e n π^0 (1γ)

Exclusivity variables: pDVCS

no kinematical corrections of final state particles momenta





Red:MC (DVCS)

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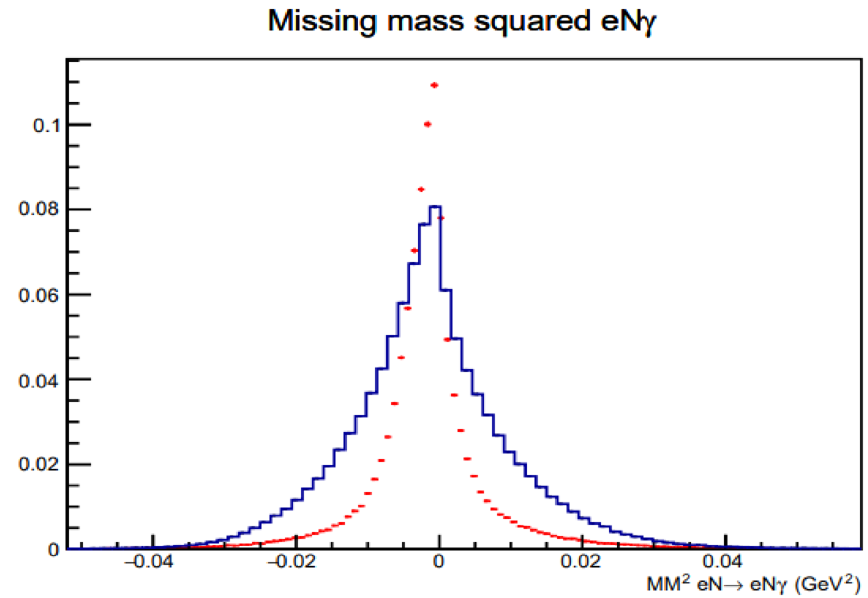
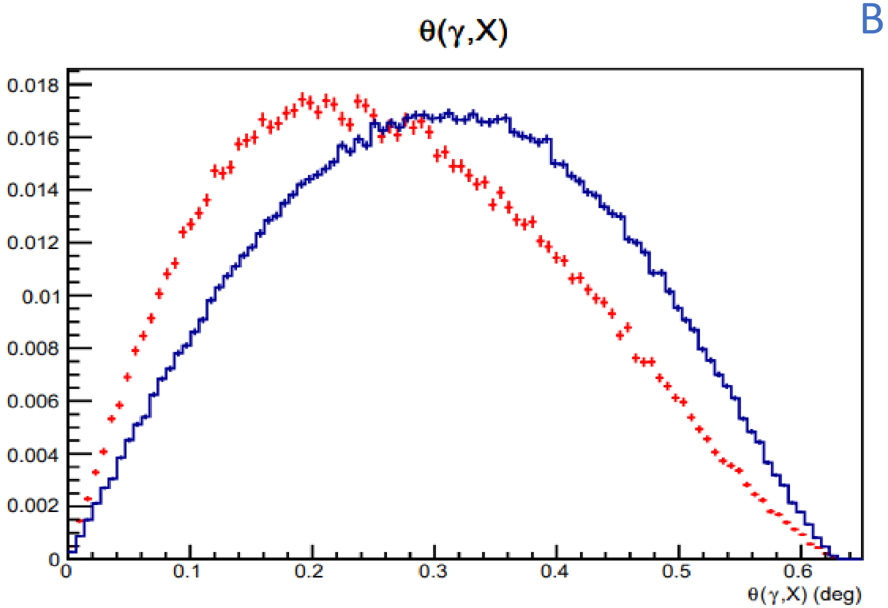




π^0 background: partially reconstructed $e\,p \rightarrow e\,p\,\pi^0\,(1\gamma)$

π^0 background subtraction

- Subtraction using simulations of the background channel
- Description of the method:
  - Estimate the ratio of partially reconstructed eN π^0(1 photon) decay to fully reconstructed eN π^0 decays in MC
  - This is done for each kinematic bin to minimize MC model dependence
  - Multiply this ratio by the number of reconstructed eN π^0 in data to get the number of eN π^0(1 photon) in data
  - Subtract this number from DVCS reconstructed decays in data per each kinematical bin

In MC

$$\mathrm{R} = \mathrm{N}(\mathrm{e}N\pi^0_{1\gamma})/N(eN\pi^0)$$

In data　　In data

$$N\left(eN\pi^0_{1\gamma}\right) = R * N(eN\pi^0)$$

In data　　In data　　In data

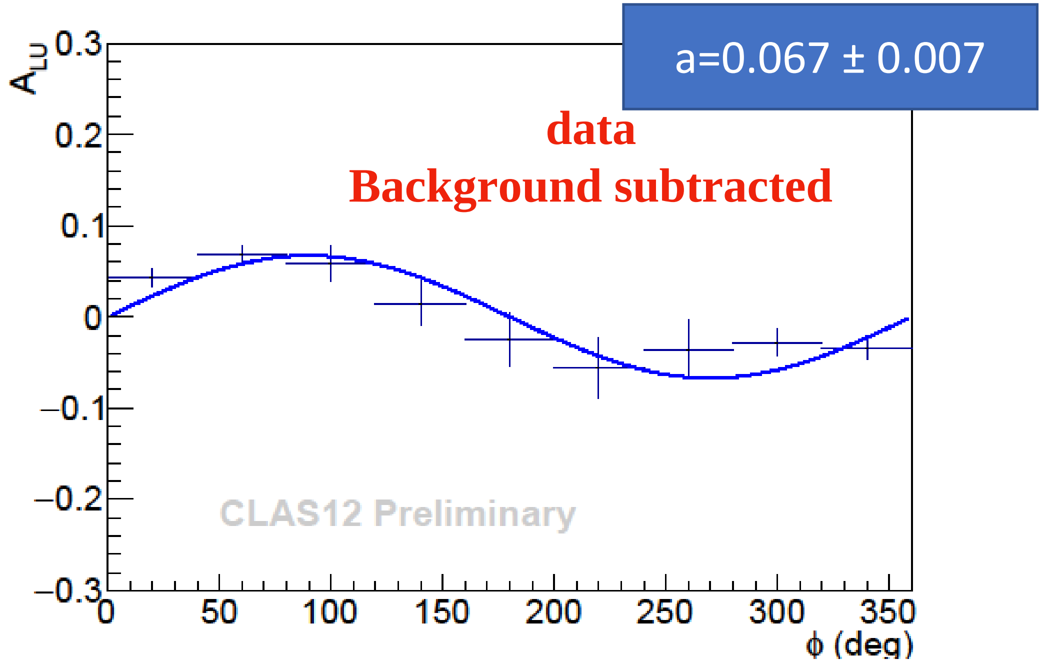
$$N(DVCS) = N(DVCS_{recon}) - N(eN\pi^0_{1\gamma})$$

nDVCS with RGB data

First-time measurement of BSA for nDVCS with exclusive final state selection:

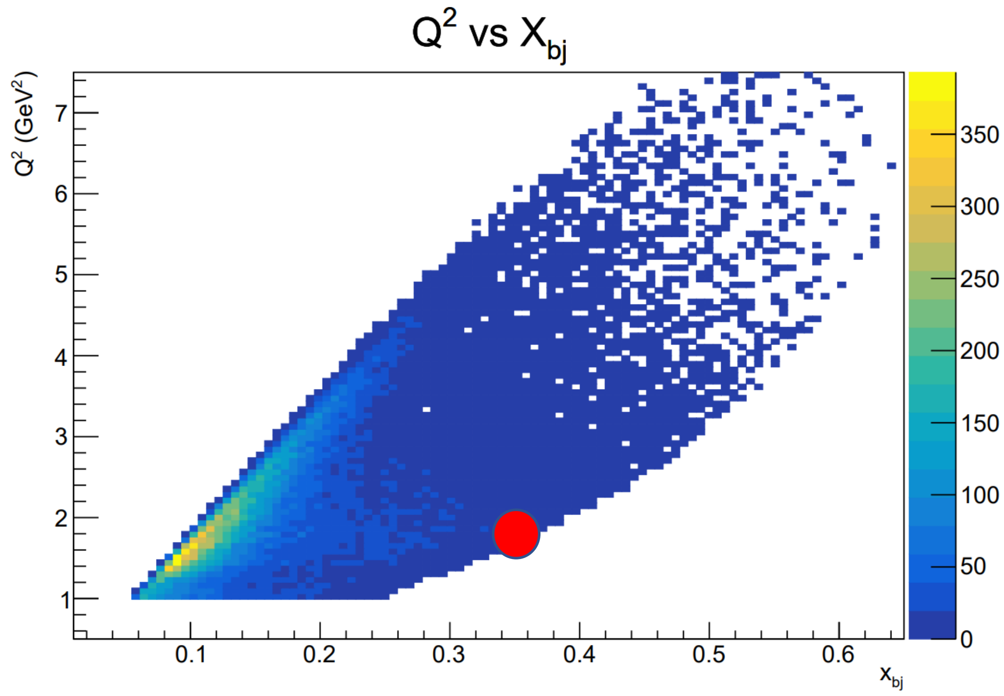
ed→enγ(p)

BSA integrated over all kinematics and detection topologies



Fit function: $a \sin \phi$

$\langle Q^2 \rangle = 2.27\ GeV^2$
$\langle -t \rangle = 0.44\ GeV^2$
$\langle x_B \rangle = 0.19$



Hall A@6 GeV ed→e(n)γ(p)

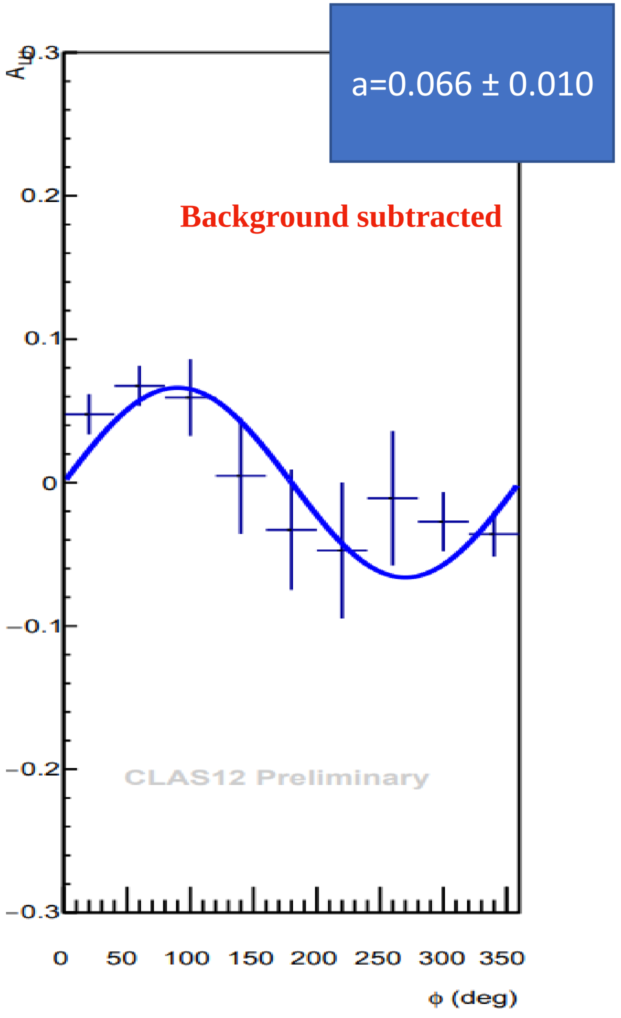
Benali, M., Desnault, C., Mazouz, M. *et al. Nat. Phys.* **16,** 191–198 (2020)

nDVCS BSA vs ϕ in 1-dimensional bins

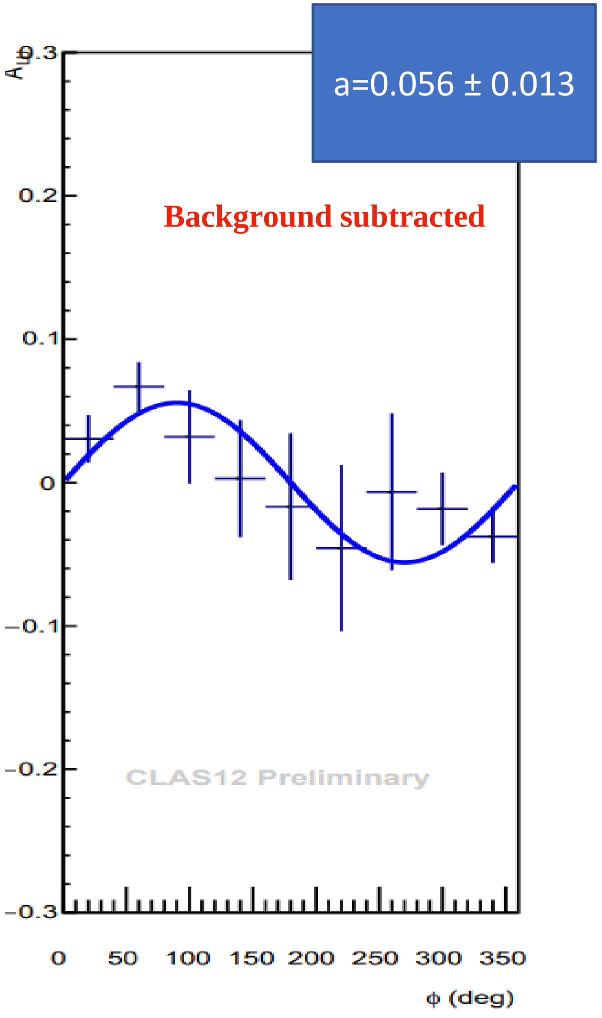
Fit function: $a \sin \phi$

Q^2 **bins (GeV^2)**

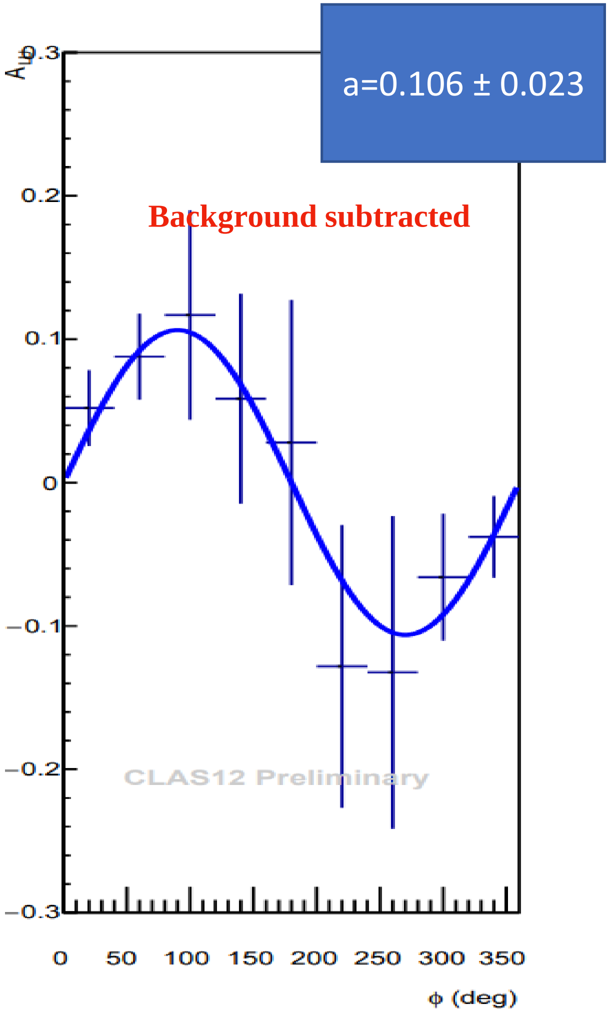
[1,2]



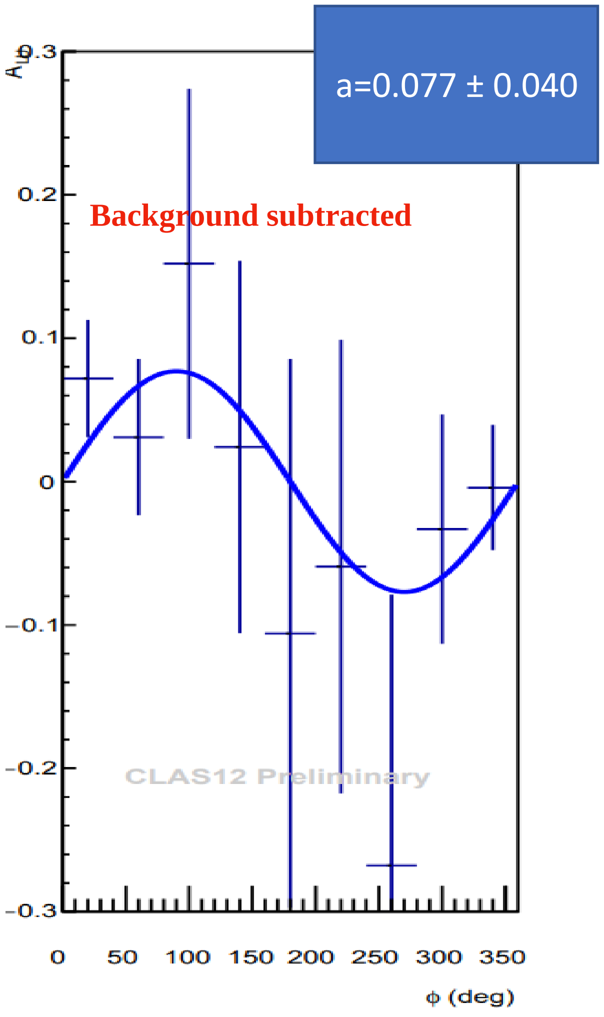
[2,3]



[3,4]



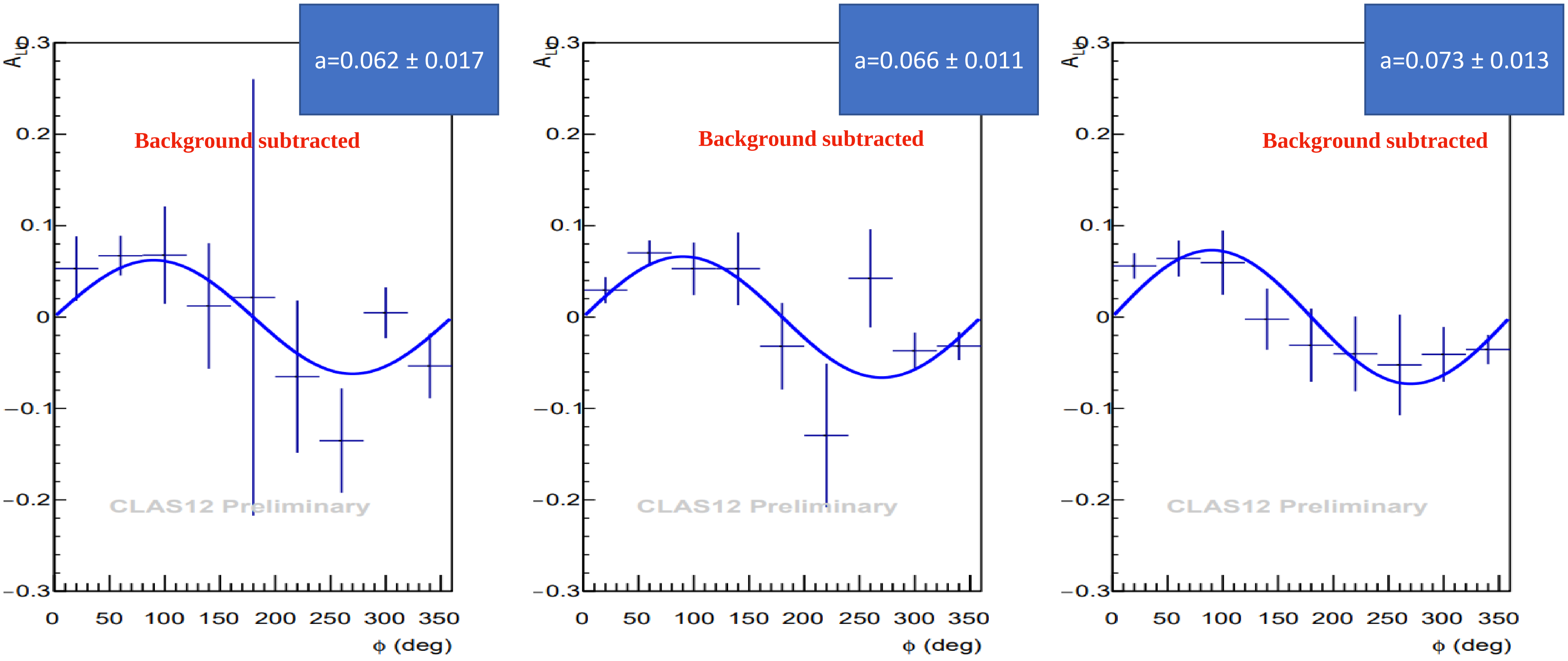
[4,inf]



nDVCS BSA vs ϕ in 1-dimensional bins

Fit function: $a \sin \phi$

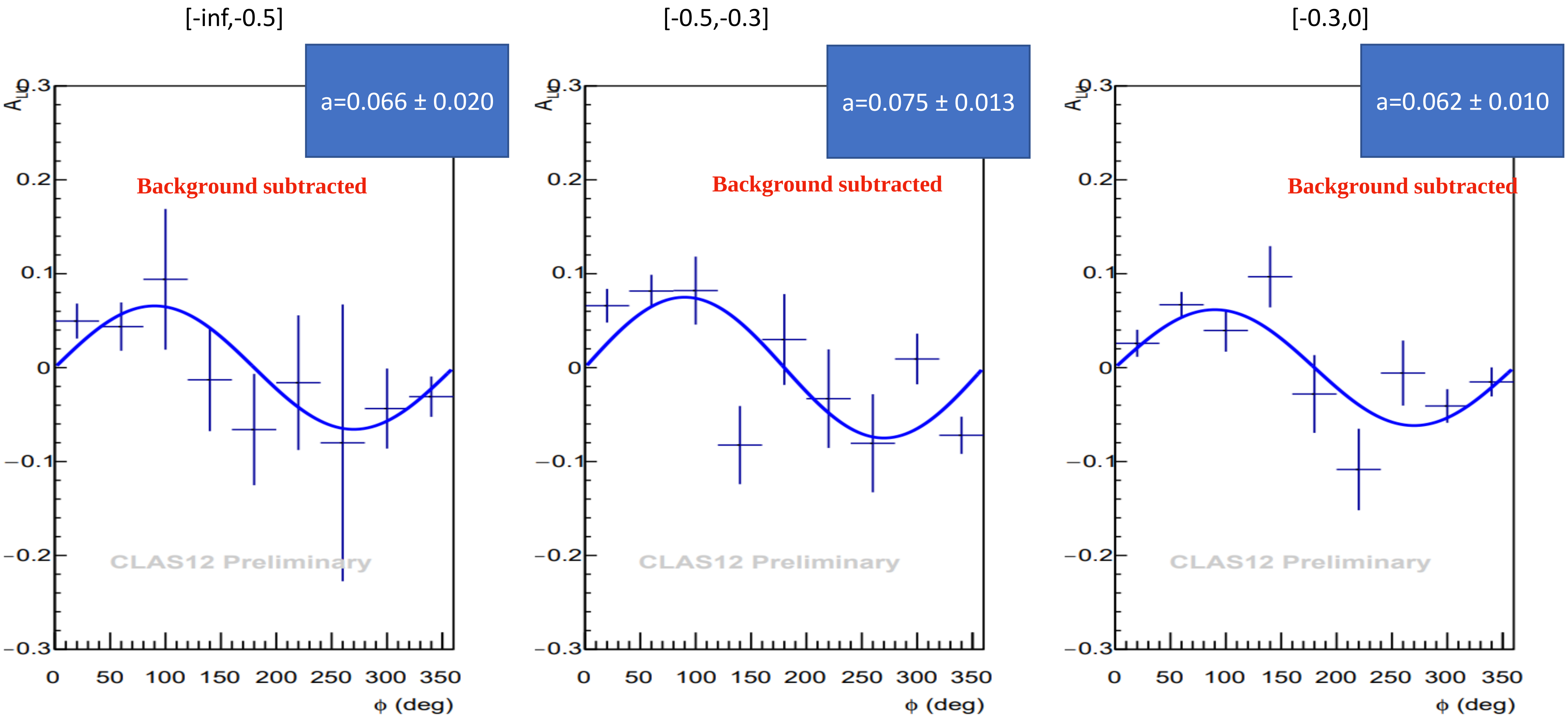
x_B bins [0.05,0.1] [0.1,0.17] [0.17,inf]



nDVCS BSA vs ϕ in 1-dimensional bins

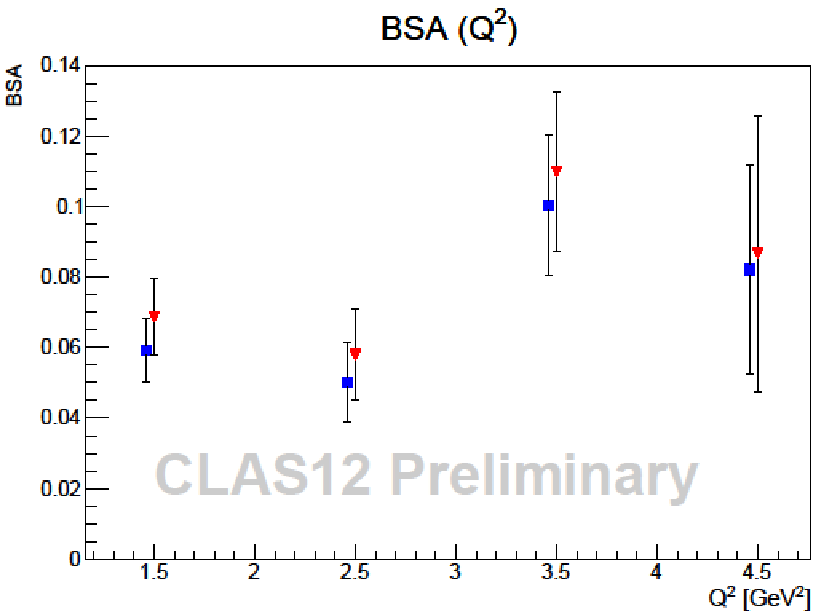
Fit function: $a \sin \phi$

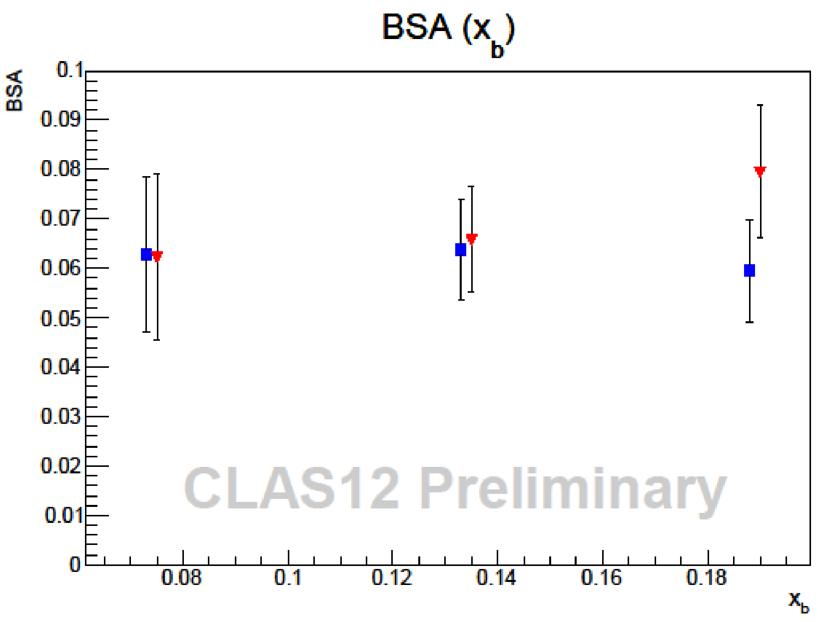
t bins

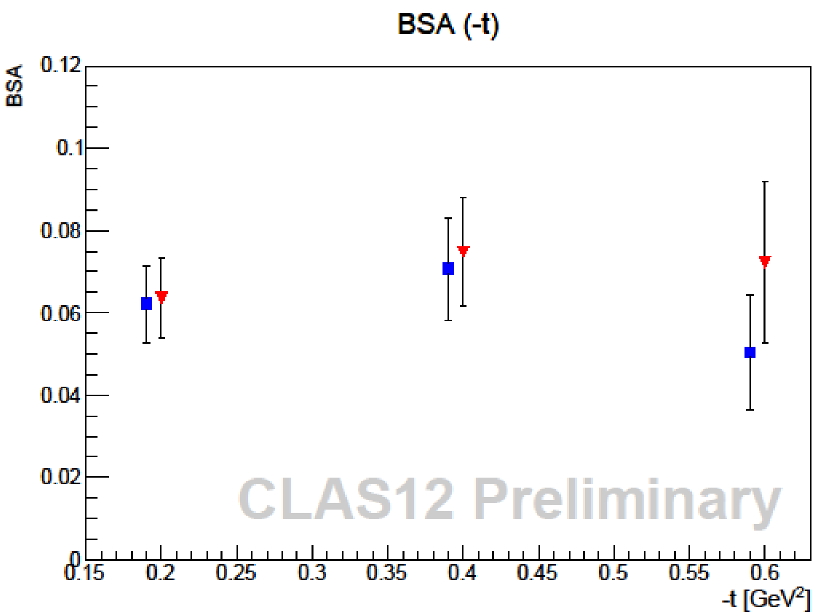


Dependence of the sin ϕ amplitude for nDVCS

Red: background subtracted
Blue: with pi0 background







π^0 background corresponds to 10-45 % depending on the bin in consideration

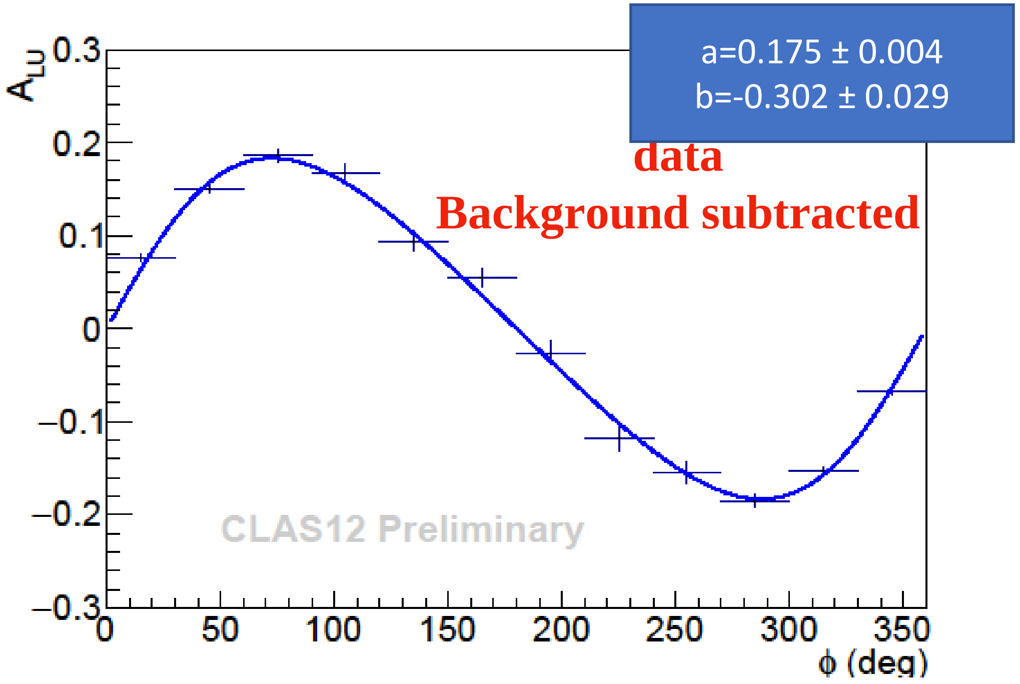
Incoherent pDVCS on deuterium

First-time measurement of BSA for pDVCS with a deuterium target

- **proton in a weakly bound state**

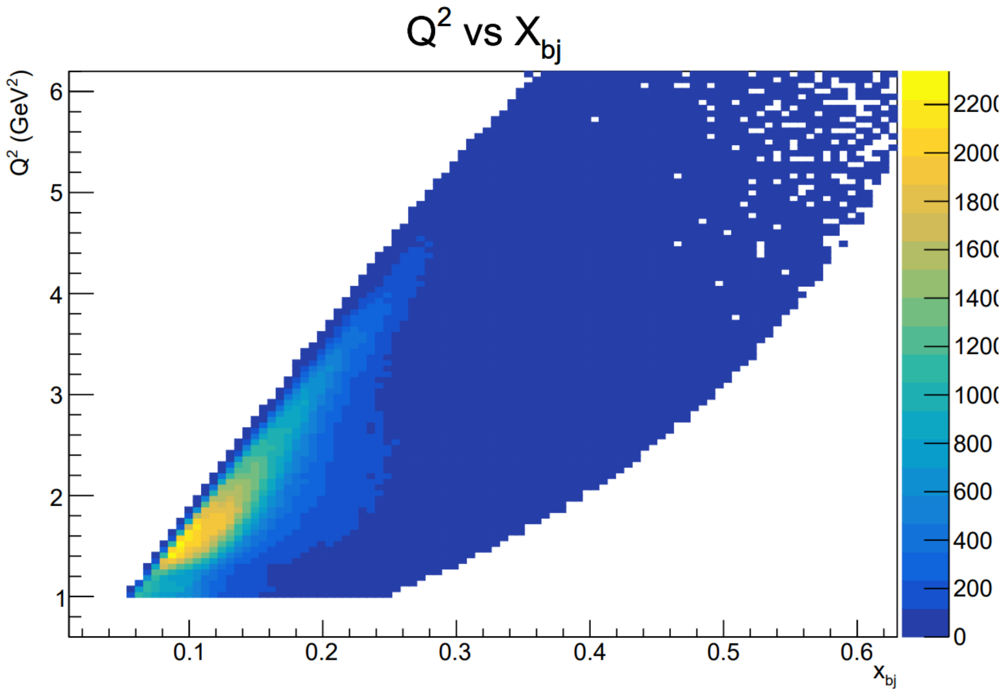
BSA integrated over all kinematics and detection topologies

$ed \to ep\gamma(n)$

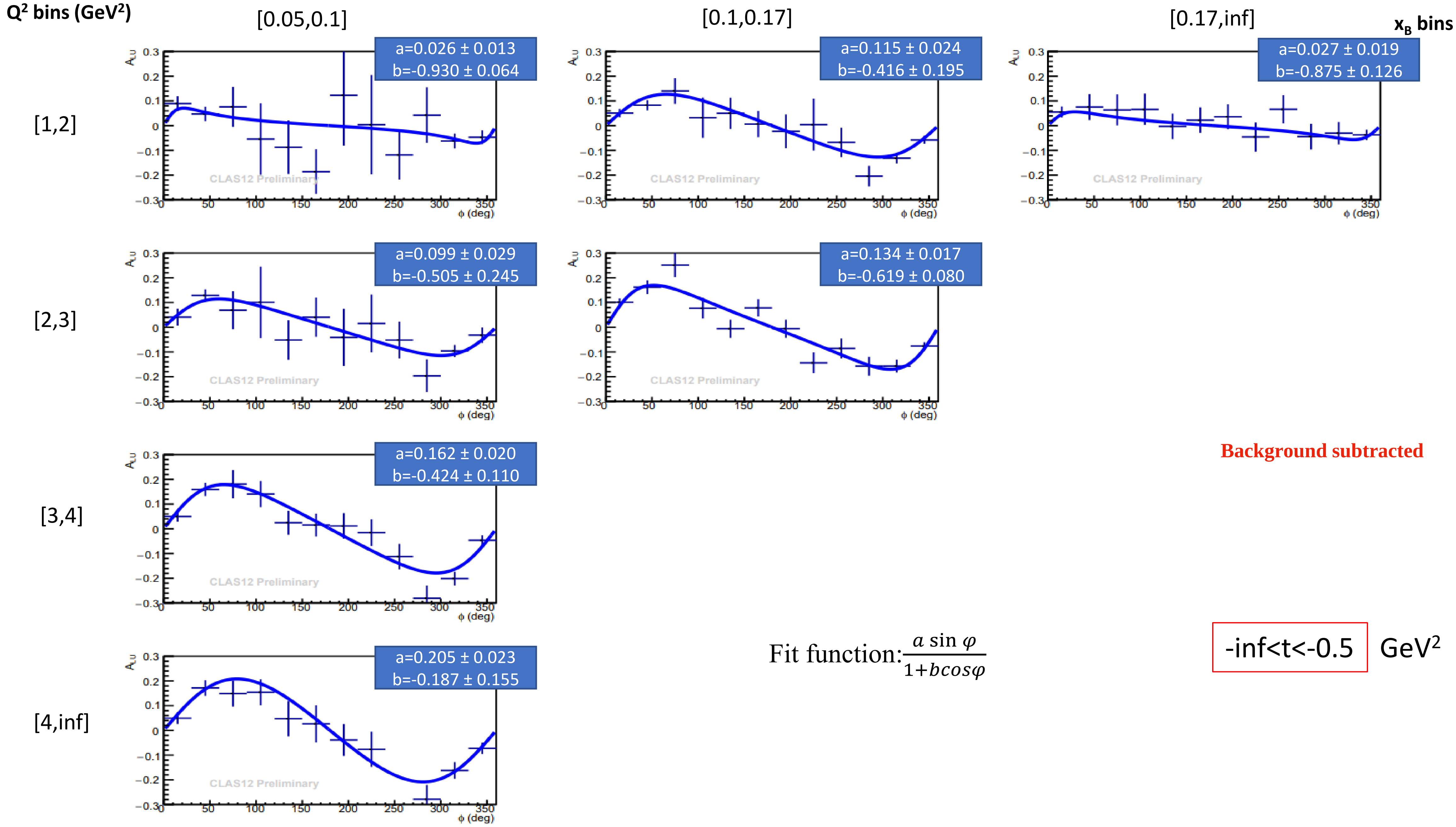


Fit function: $\frac{a \sin\varphi}{1+b\cos\varphi}$

$<Q^2>$ = 2.25 GeV^2
$<-t>$ = 0.45 GeV^2
$<x_B>$ = 0.18



pDVCS binned BSA



Background subtracted

Fit function: $\frac{a \sin \varphi}{1+b\cos\varphi}$

-inf<t<-0.5 GeV²

pDVCS binned BSA

Q^2 bins (GeV^2)

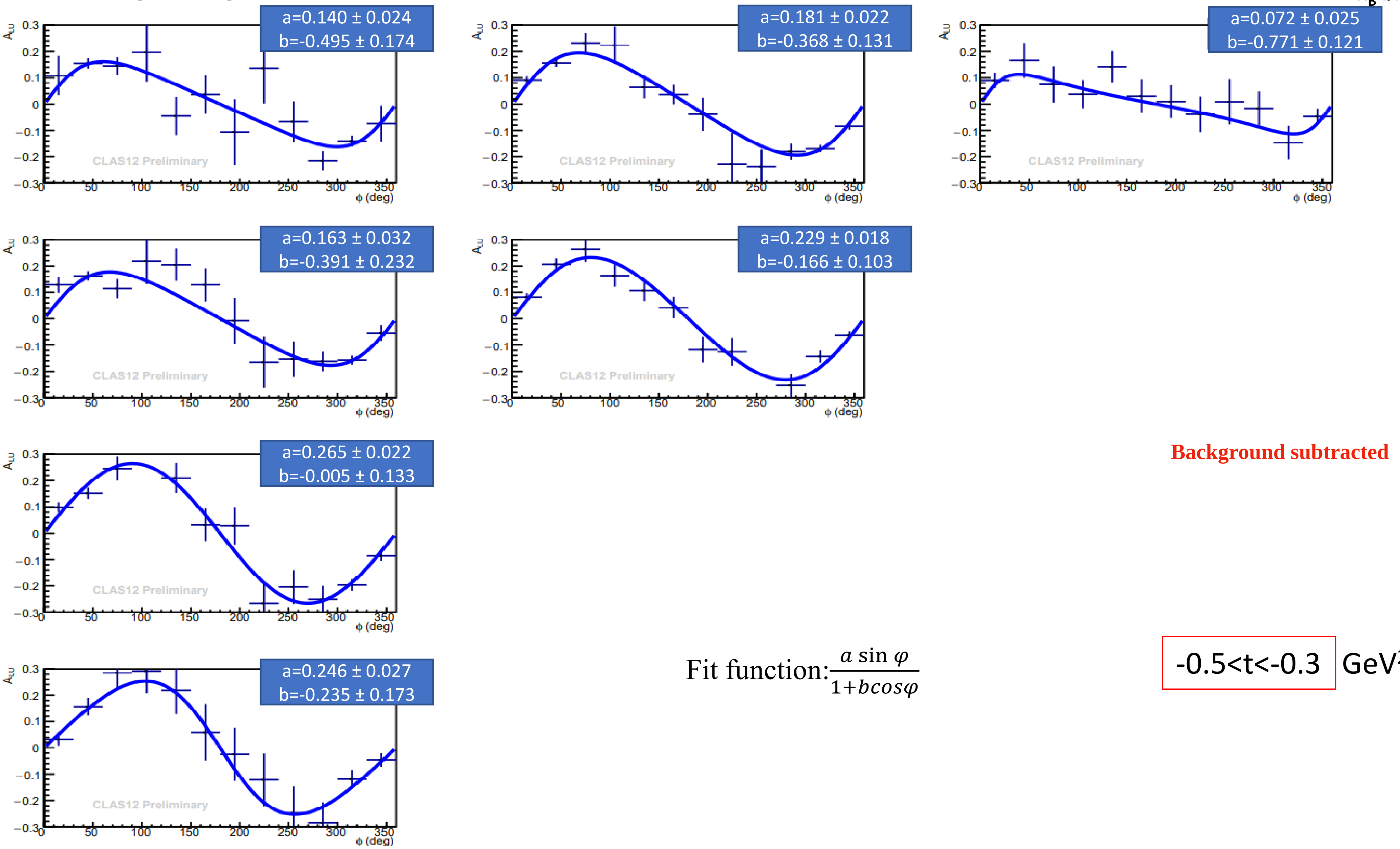
[0.05,0.1] | [0.1,0.17] | [0.17,inf] | **x_B bins**

[1,2]

[2,3]

[3,4]

[4,inf]

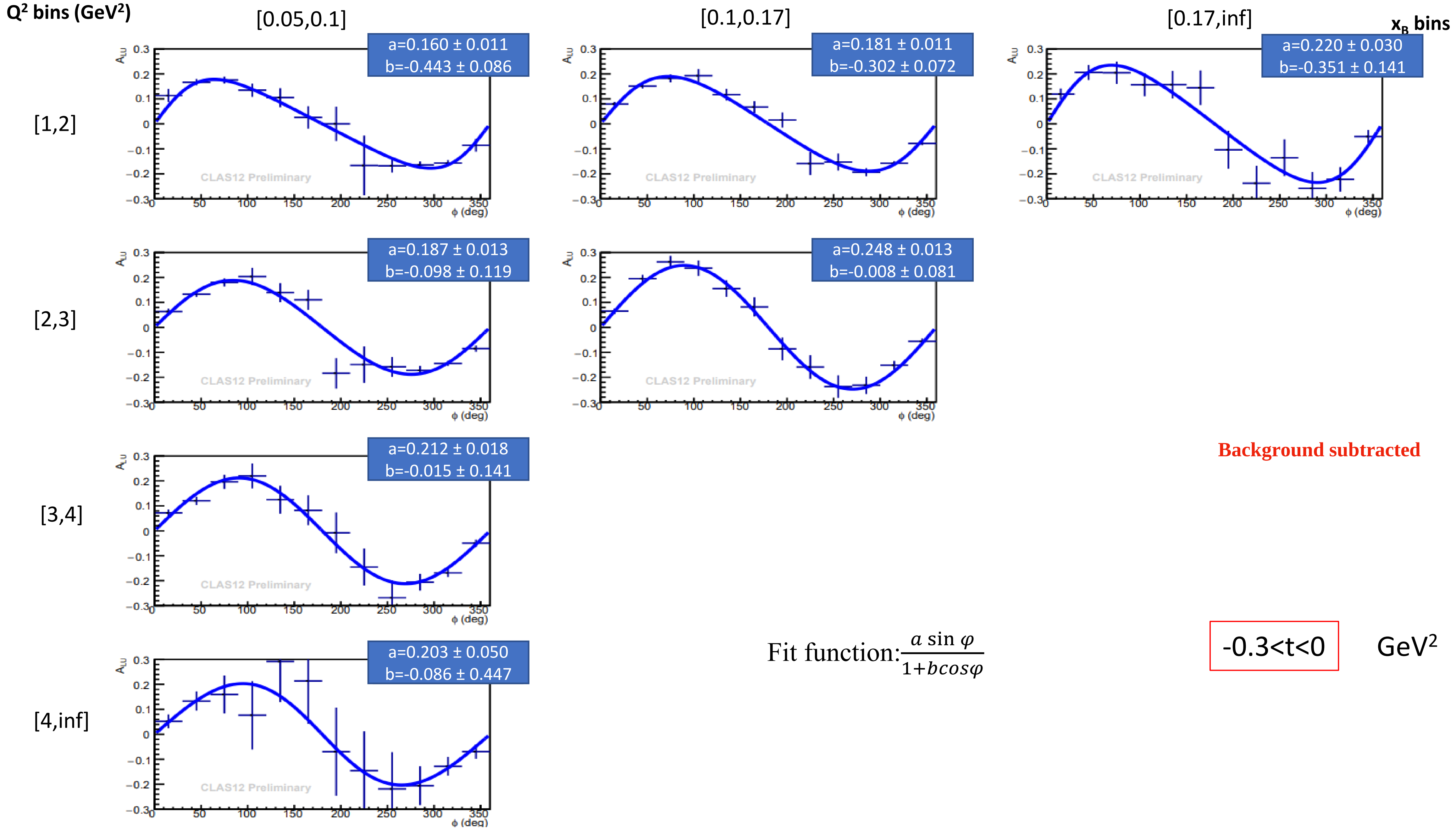


Background subtracted

Fit function: $\frac{a \sin\varphi}{1+b\cos\varphi}$

-0.5<t<-0.3 GeV^2

pDVCS binned BSA

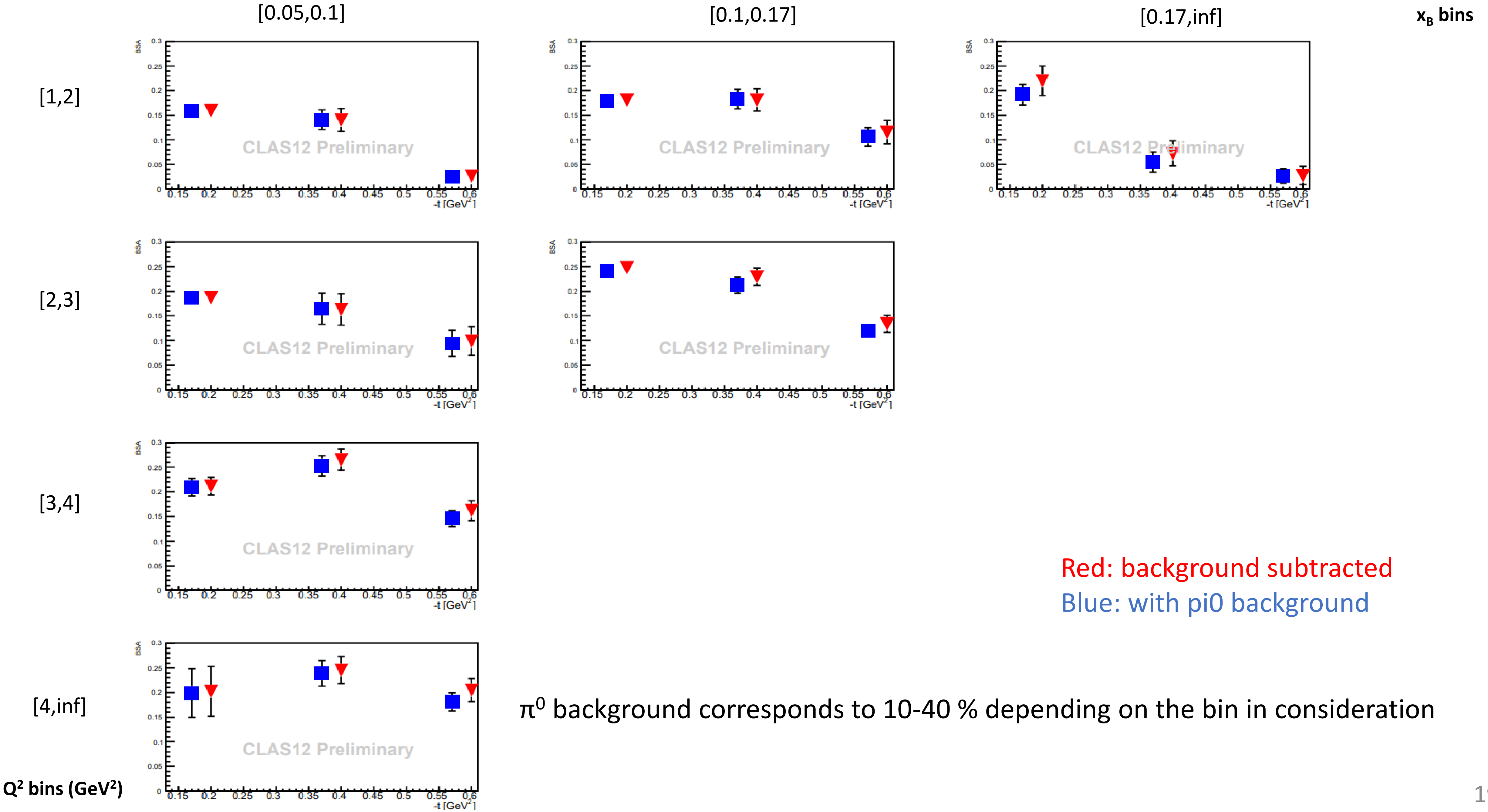


Background subtracted

Fit function: $\frac{a \sin \varphi}{1+b\cos\varphi}$

-0.3<t<0 GeV²

Dependence of the sin ϕ amplitude for pDVCS



π^0 background corresponds to 10-40 % depending on the bin in consideration

Summary

- Promising results from incoherent DVCS on deuteron (n and p channels) from CLAS12 data
- First BSA measurement from neutron-DVCS with tagged neutron
- First measurement of BSA for proton-DVCS with deuterium target
  - To be compared to free-proton dvcs bsa measured by CLAS12
- Corrections to final state particles momenta and improvements to the neutron ID are ongoing

backup

On Fiducial cuts

- For electrons:
  - homogenous cut on the natural v and w coordinates of the PCAL to ensure enough distance between the cluster center and the edges
  - Ensure a homogenous response of DC: Reject not well reconstructed tracks from the sides; cut based on the position dependence of the χ^2/NDF distribution
- For photons:
  - cut based on the position dependence of the sampling fraction in the PCAL
- For Protons:
  - Ensure a homogenous response of DC: Reject not well reconstructed tracks from the sides; cut based on the position dependence of the χ^2/NDF distribution
- For neutrons (preliminary)
  - A direct cut on neutron phi distribution to remove dead regions of SVT: traking efficiency drops to 0 making proton contamination in neutron sample too high; effect can be seen on exclusivity variables

Offline Neutron ID with neural nets: a concept under investigation

- Train neural nets directly on data:
  - Use clean neutron sample from RGK 7.5 GeV data: ep->enpi+ (true neutron are identified based on missing mass criteria) as signal
  - Use clean proton sample from RGB data: ed->eppi0 as background

- Use information from central detectors CND and CTOF to perform separation: energy, hit and layer multiplicities