CLAS Collaboration Meeting
March 2021

DVCS on proton and neutron from RGB data

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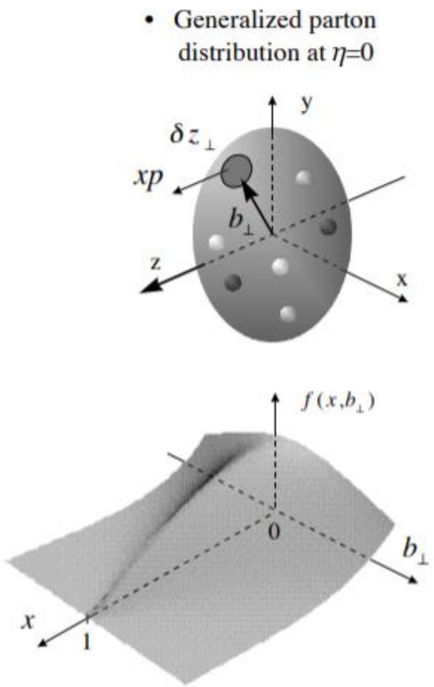
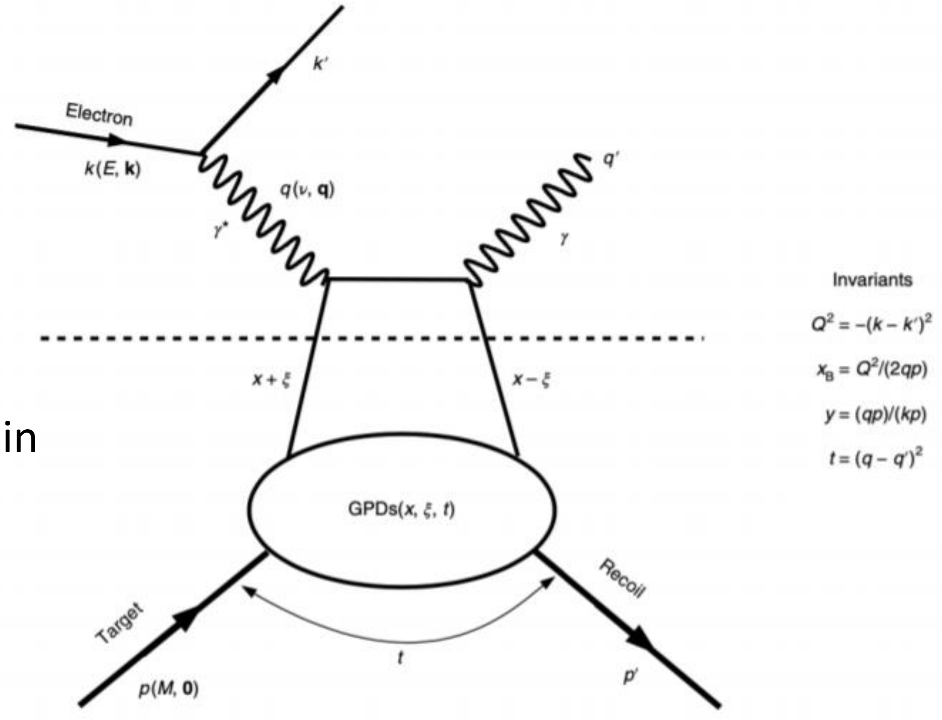
Motivations



Generalised Parton Distributions (GPDs): Correlation of position 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 GPDs
- Measurement of several observable: separation of GPDs
- Measure GPDs on both nucleons: flavour separation of GPD

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

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

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

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

  - Scattering off proton (pDVCS): GPD H
    - Quantify medium effects
      - Essential for the extraction of BSA of a “free” neutron (de-convoluting medium effect)

BSA → **Shape estimated with** → **At first order** → **CFF accessed throught 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

DVCS in RGB with CLAS12

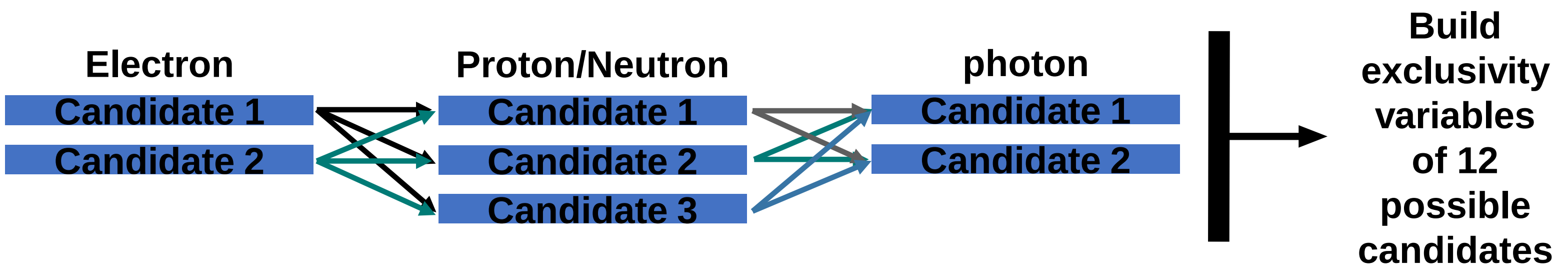
- Experimental configuration:
  - Highly polarized electron beam (~86% polarization) measured with 9 Moeller runs
  - Unpolarized liquid deuterium target
  - Beam energies of 10.6 GeV and 10.2 GeV for the spring2019 inbending run
  - Beam energy of 10.4 GeV for the fall 2019 outbending run

- Run Dates considered in this talk for analysis:
  - Spring 2019 period : ~50% of all collected data. Magnet inbending
  - Fall 2019 period: ~25% of all collected data. Magnet outbending

- Selected runs:
  - the analysis of QA timelines after the pass-1 cooking

Channel selection

- Construct all the possible combinations of final state particles: ed->e’Nγ(Nspec)
  - Final states reconstructed using CLAS12 PID + a dedicated charged particle veto for neutron selection optimisation
  - Best candidate in event is slected based on best exclusivity criteria (a multi-dimension 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, neutron CVT dead zones

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
    - Difference in θ between measured and reconstructed photon

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

Q2>1 GeV2 W>2 GeV2

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

On Fiducial cuts: taken from RGA studies

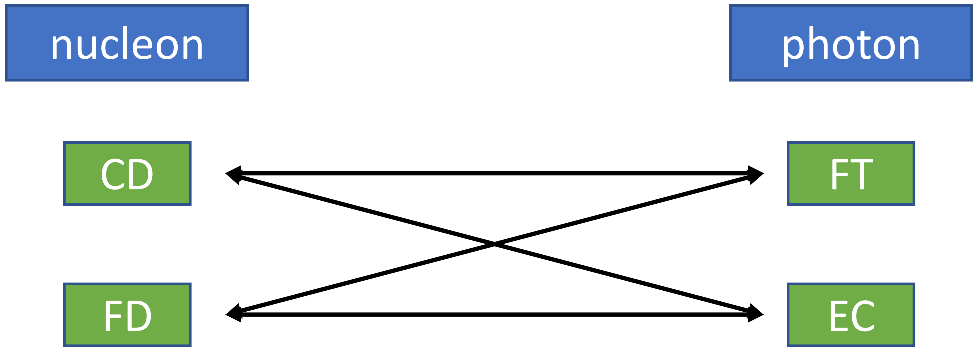
Credits: S.Diehl et al

[Run Group A - HallBWiki (jlab.org)]

- 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 CVT: traking efficiency drops to 0 making proton contamination in neutron sample too high; effect can be seen on exclusivity variables

On cut optimisation

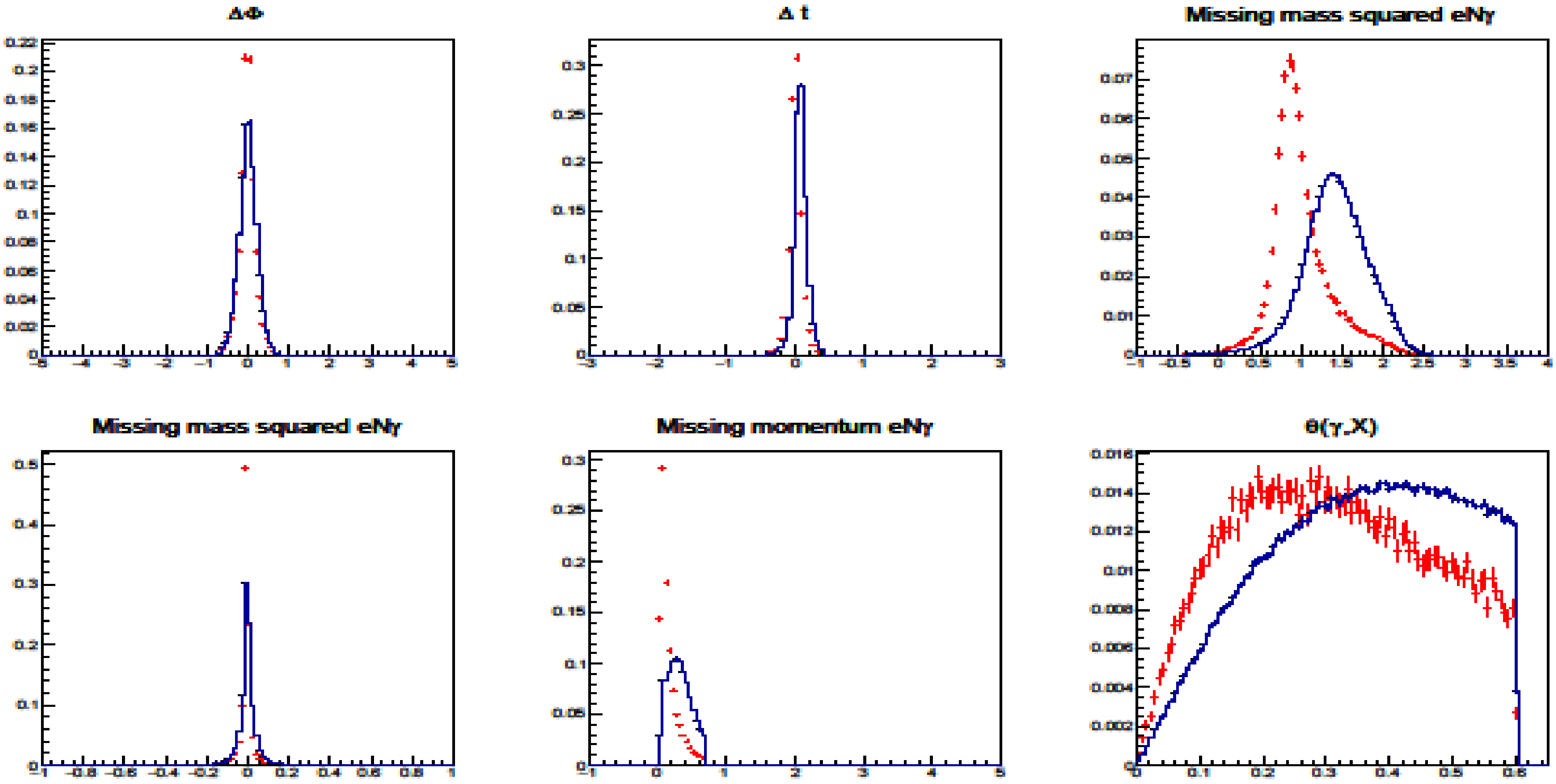
- A long process of optimising exclusivity selection per detection topology: different detectors require different cut values
- Compare DVCS and pi0 simulation (with background merging and reconstructed as DVCS) looking at the « DVCS » exclusivity variables
  - cut in order to minimize pi0 and not lose too much DVCS



- In what follows, I will mainly show plots of distributions integrated over all topologies
- If you are interested to see plots for all combinations of detection topologies please check:
  - https://ipnshare.in2p3.fr/owncloud/index.php/s/Mb5hrkDWRVdMq3J

Exclusivity variables: pDVCS

Red is MC with background merging
Blue is data with pi0 background



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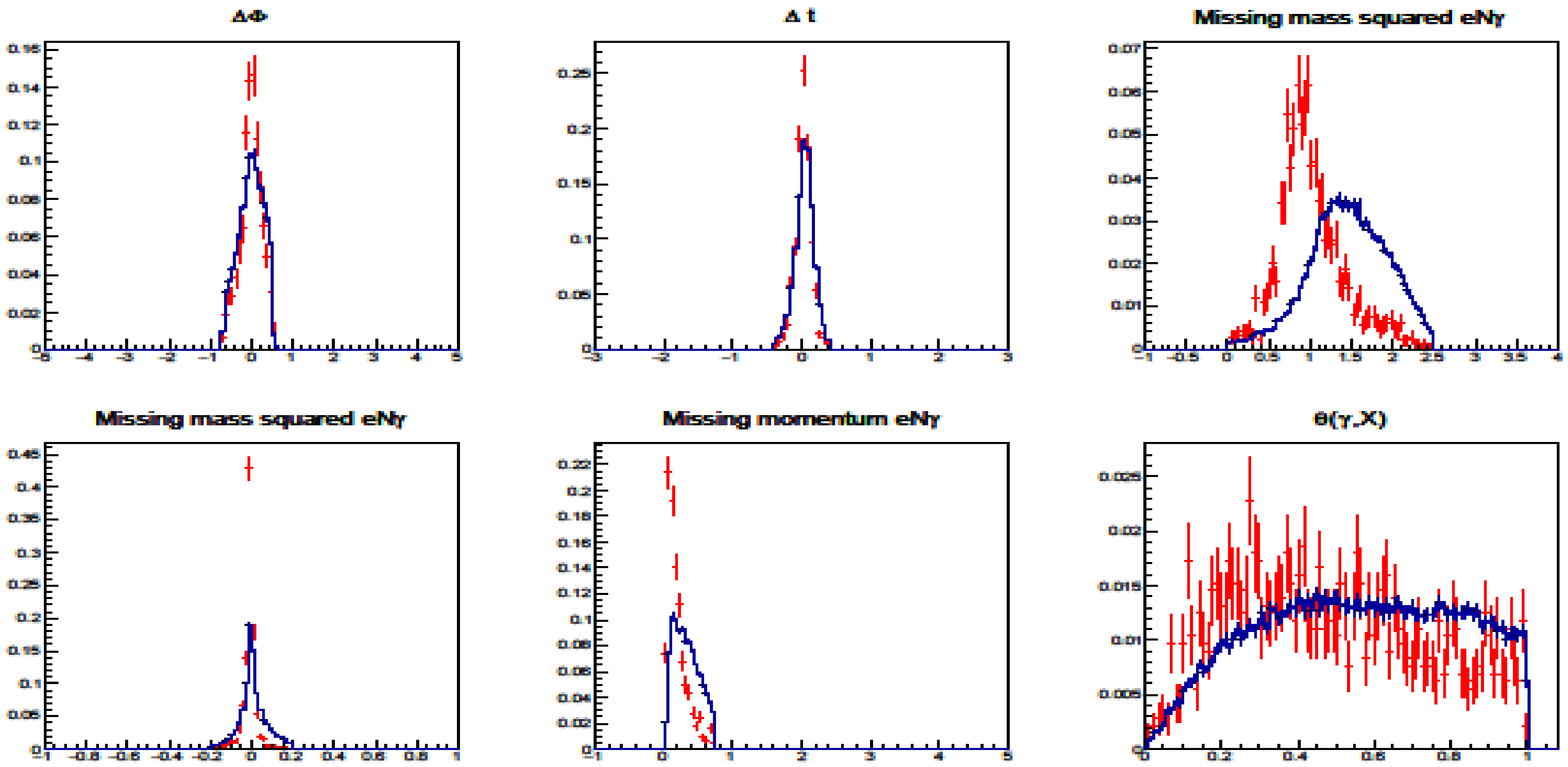
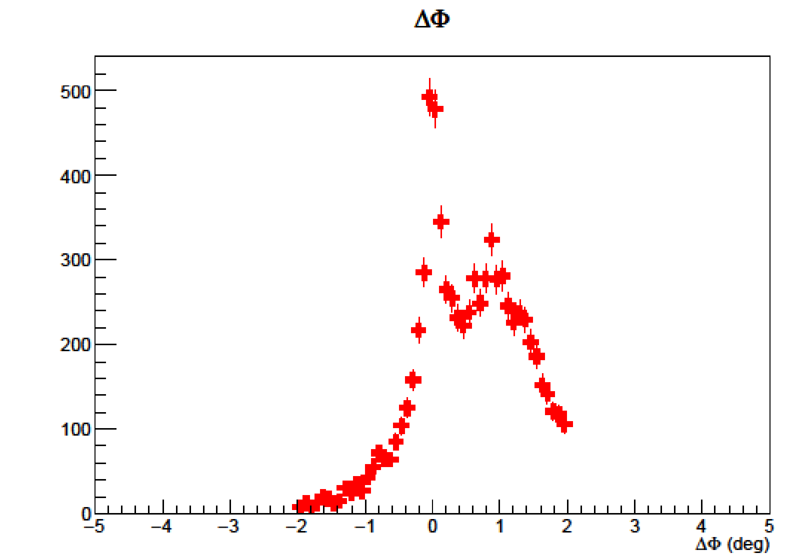


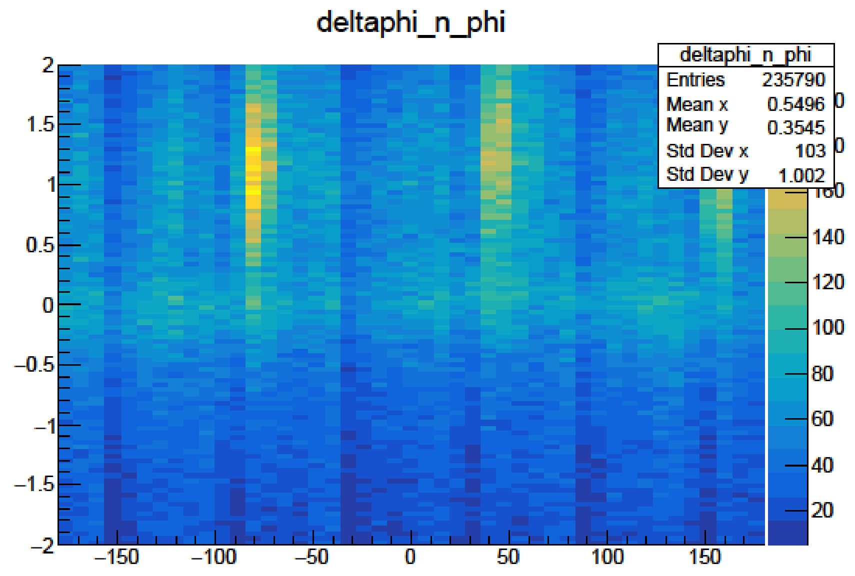
On proton contamination in neutron sample

- Could be clearly observed in the distribution of Delta Phi (both in MC & data)
- Phi is wrongly evaluated when the neutron is actually a proton
- A second bump in the distribution of delta Phi appears
- This is extensively under investigation by Paul Naidoo



- Ongoing work:
- 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

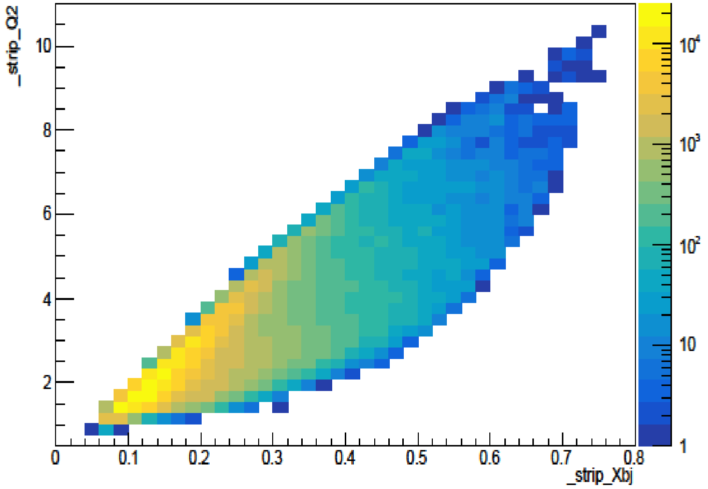
- Use information from central detectors CND and CTOF to perform separation: energy, hit and layer multiplicities



Kinematical reach:pDVCS

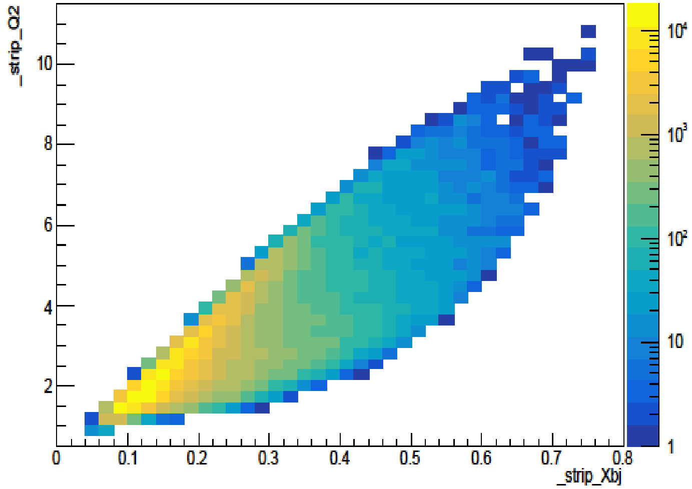
10.2 GeV	10.6 GeV	10.4 GeV
$\langle Q^2 \rangle = 2.48\ GeV^2$ $\langle -t \rangle = 0.49\ GeV^2$ $\langle x_B \rangle = 0.18$	$\langle Q^2 \rangle = 2.58\ GeV^2$ $\langle -t \rangle = 0.50\ GeV^2$ $\langle x_B \rangle = 0.19$	$\langle Q^2 \rangle = 1.84\ GeV^2$ $\langle -t \rangle = 0.44\ GeV^2$ $\langle x_B \rangle = 0.14$

10.2 GeV



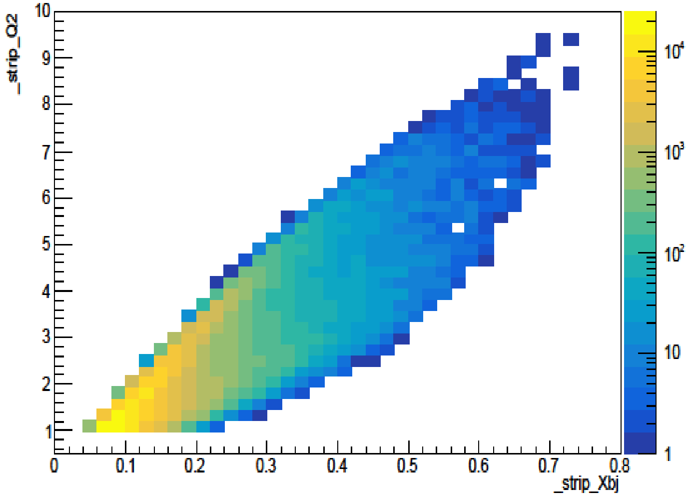
spring2019

10.6 GeV



spring2019

10.4 GeV

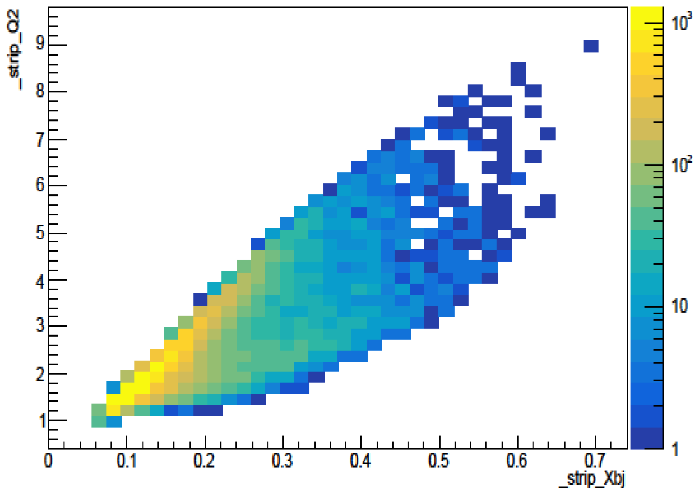


Fall2019 outbending

Kinematical reach:nDVCS

$<Q^2> = 2.40\ GeV^2$
$<-t> = 0.39\ GeV^2$
$<x_B> = 0.18$

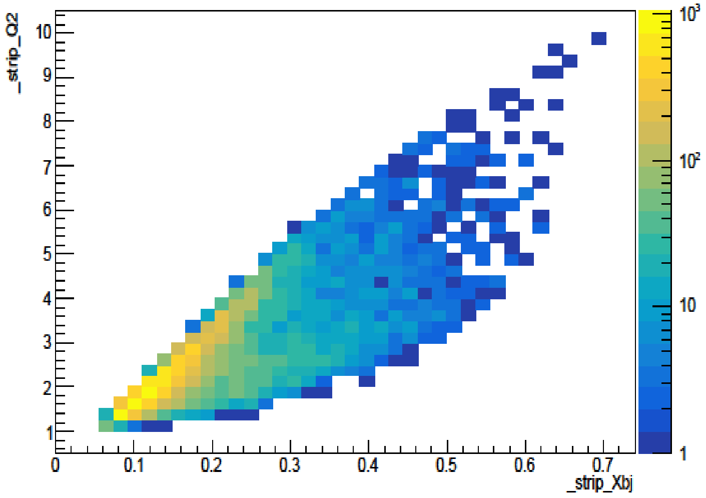
10.2 GeV



spring2019

$<Q^2> = 2.50\ GeV^2$
$<-t> = 0.40\ GeV^2$
$<x_B> = 0.18$

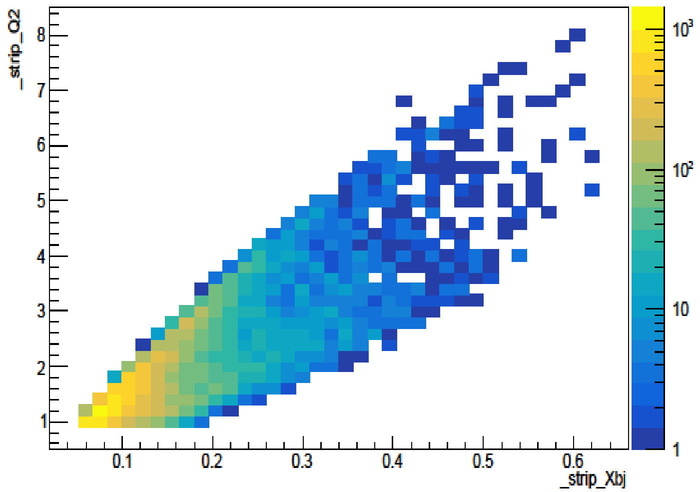
10.6 GeV



spring2019

$<Q^2> = 1.79\ GeV^2$
$<-t> = 0.36\ GeV^2$
$<x_B> = 0.14$

10.4 GeV

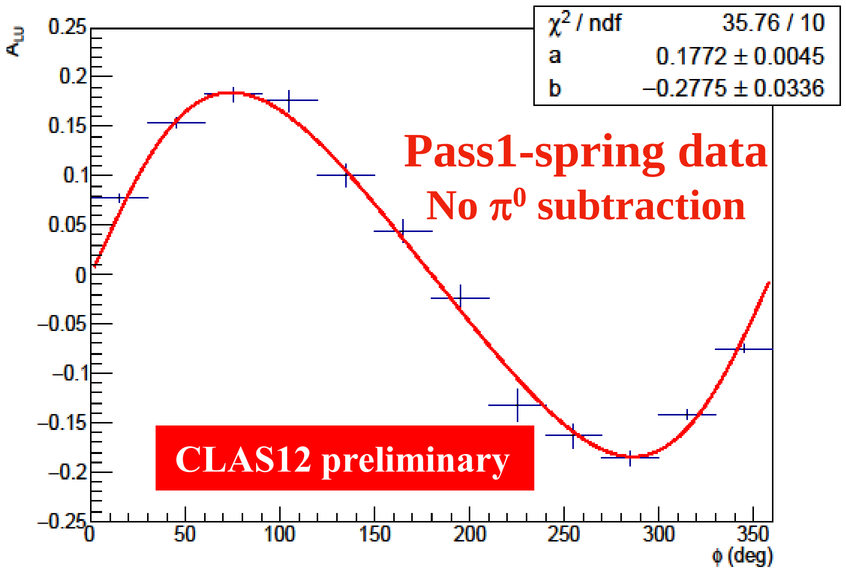


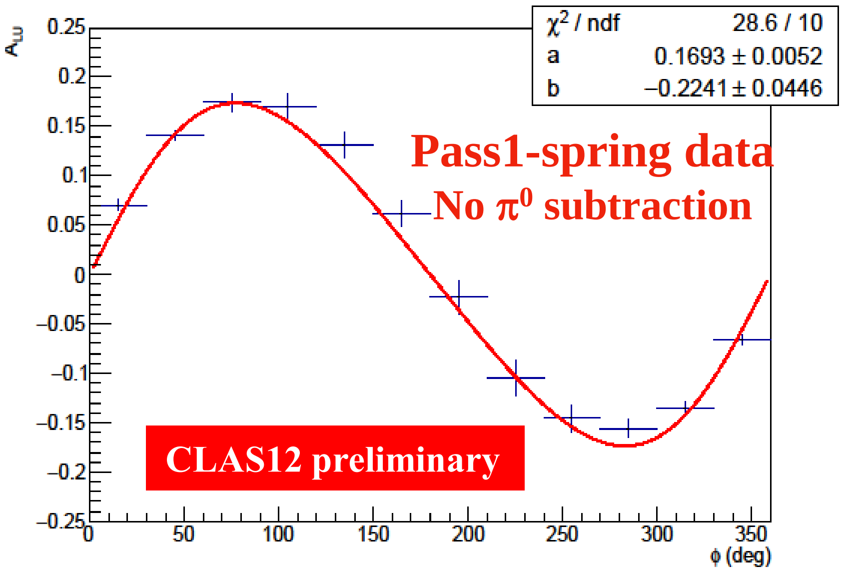
Fall2019
outbending

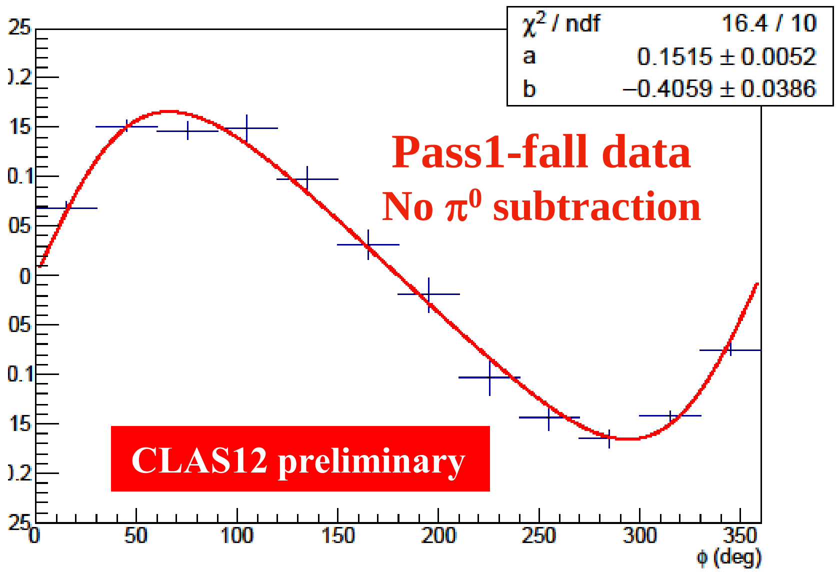
Incoherent pDVCS on deuterium

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

ed→epγ(n)







- Raw BSA integrated over all kinematics and detection topologies
- Beam energy = 10.2 GeV

- Raw BSA integrated over all kinematics and detection topologies
- Beam energy = 10.6 GeV

- Raw BSA integrated over all kinematics and detection topologies
- Beam energy = 10.4 GeV

pDVCS binned BSA 10.2 GeV beam energy

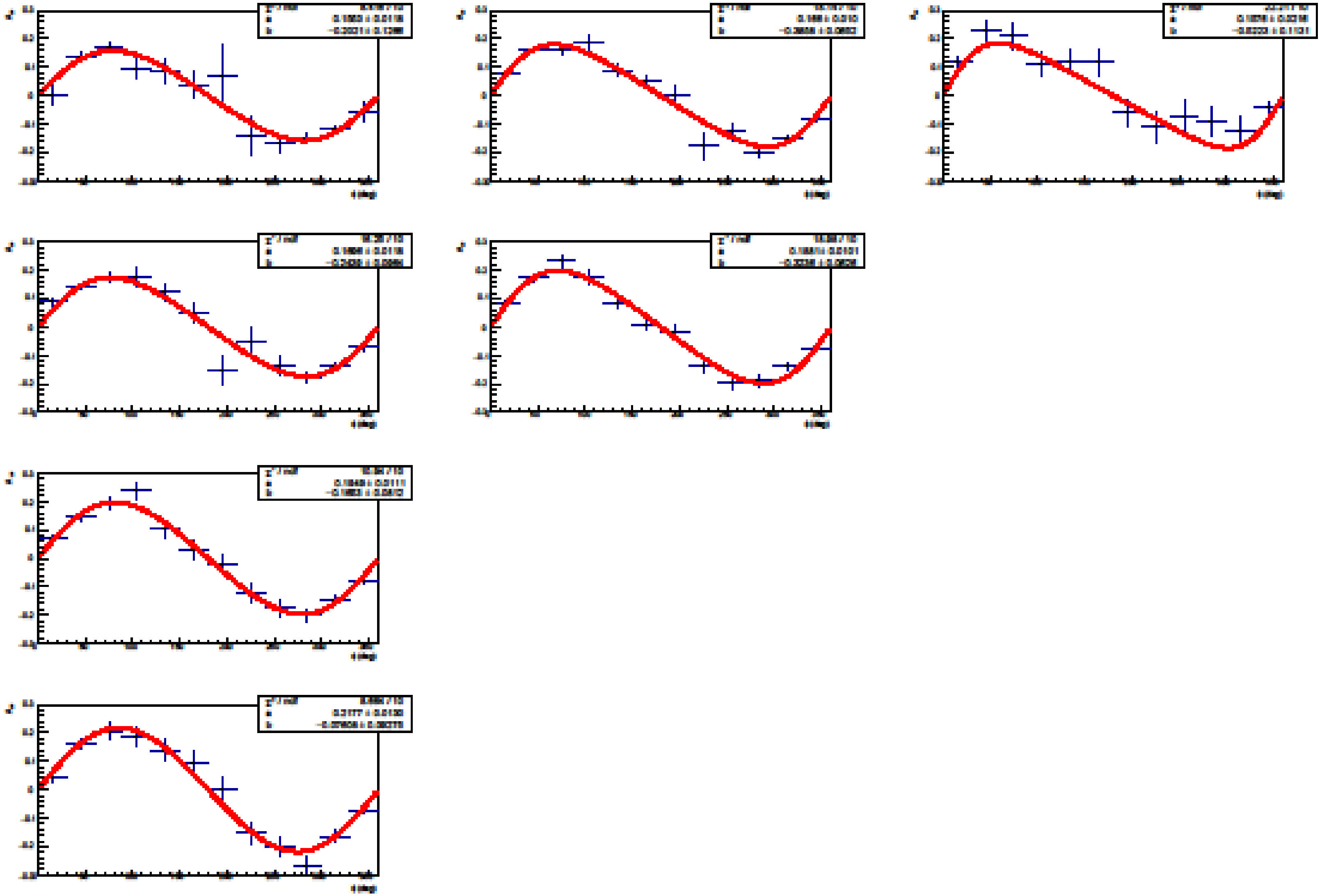
Q^2 bins (GeV^2)

[1,2]

[2,3]

[3,4]

[4,inf]



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

pDVCS binned BSA 10.6 GeV beam energy

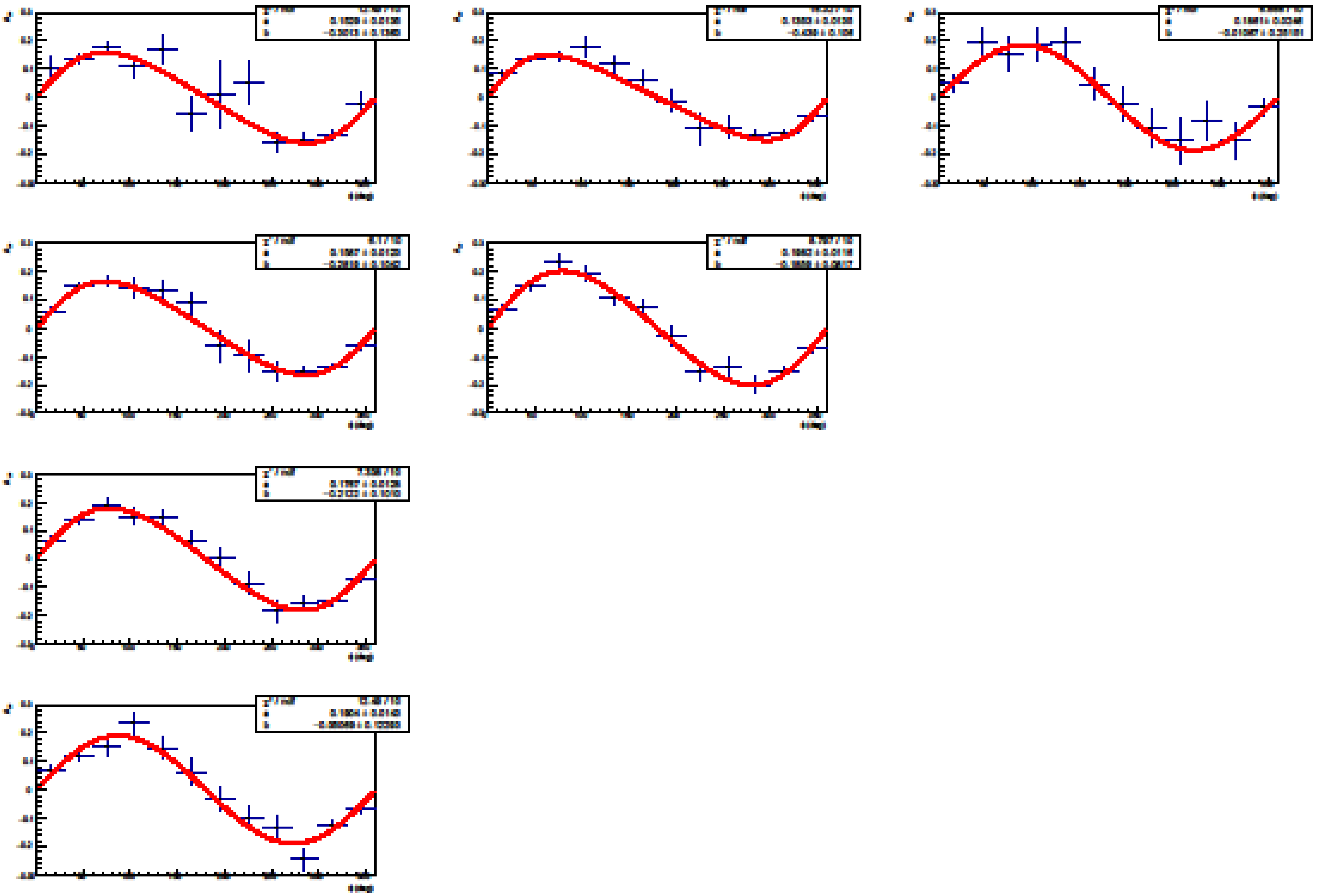
Q^2 bins (GeV^2)

[1,2]

[2,3]

[3,4]

[4,inf]



[0.05,0.1] [0.1,0.17] [0.17,inf]

x_B bins

pDVCS binned BSA 10.4 GeV beam energy

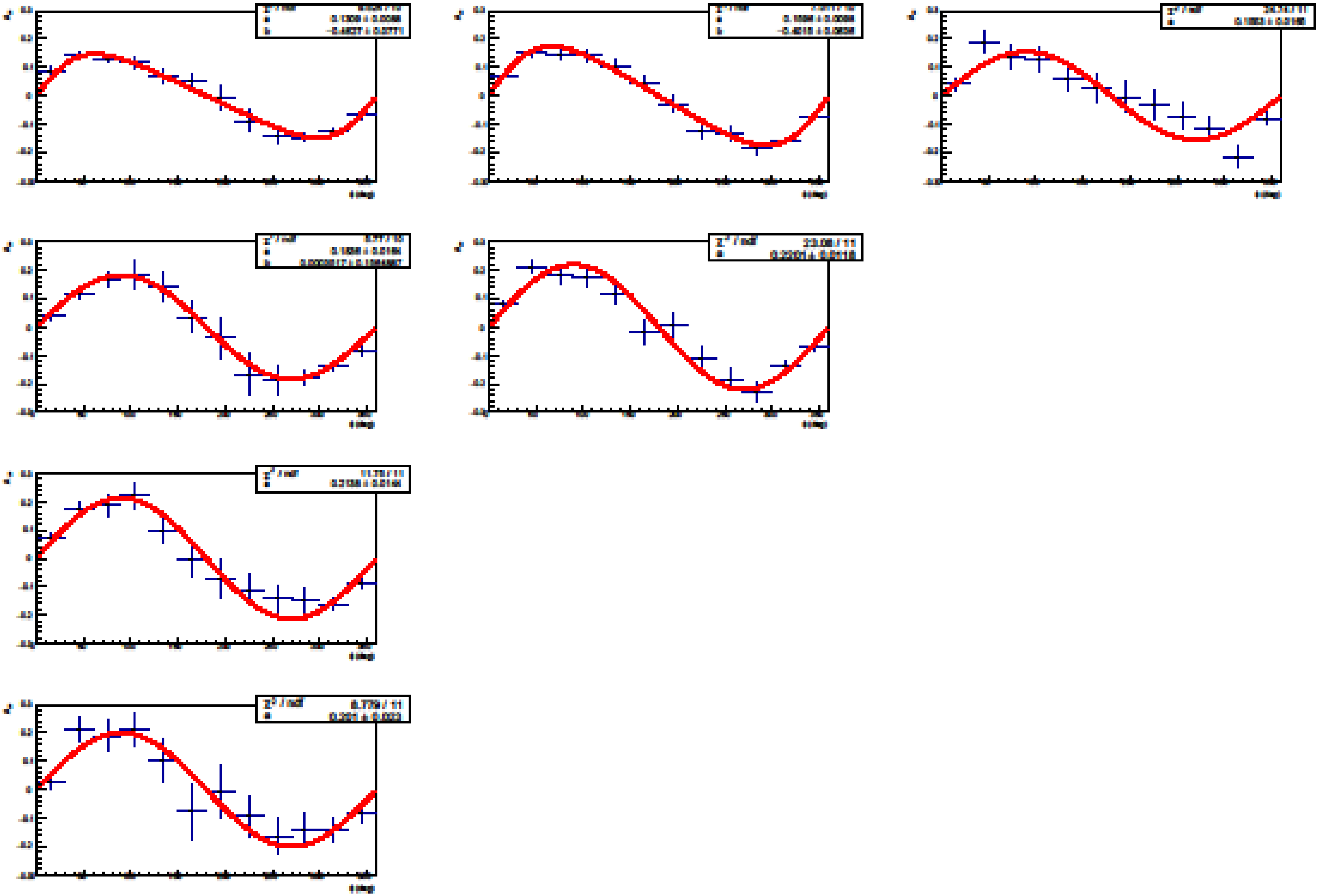
Q^2 bins (GeV^2)

[1,2]

[2,3]

[3,4]

[4,inf]



[0.05,0.1] [0.1,0.17] [0.17,inf]

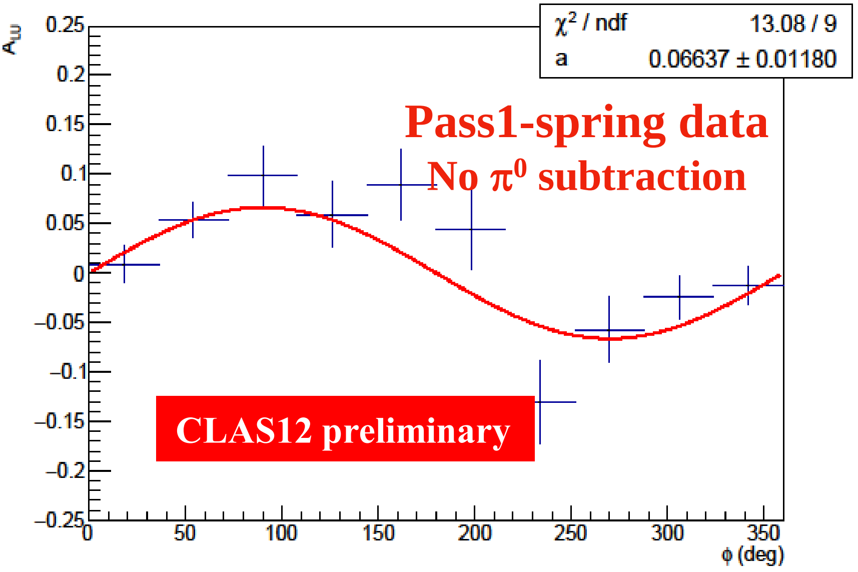
x_B bins

nDVCS with RGB data

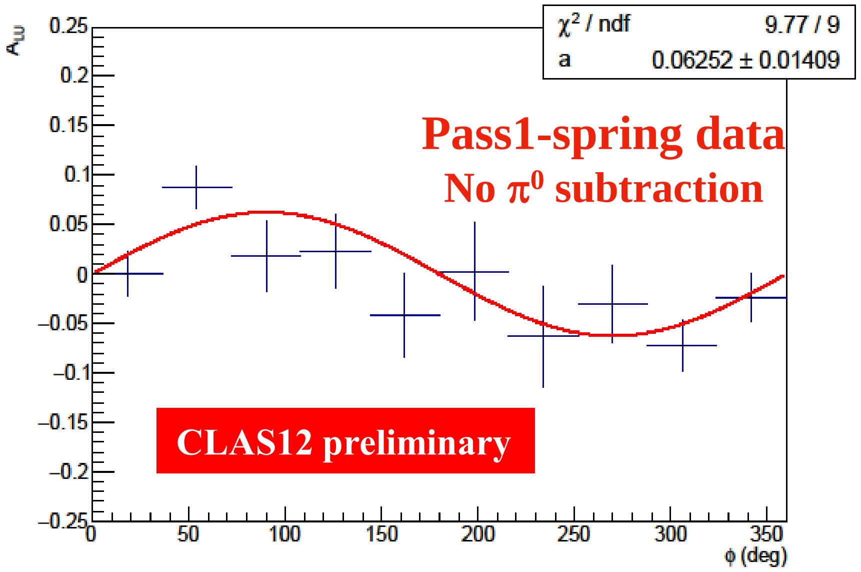
Fit function: $a \sin \phi$

ed→epγ(n)

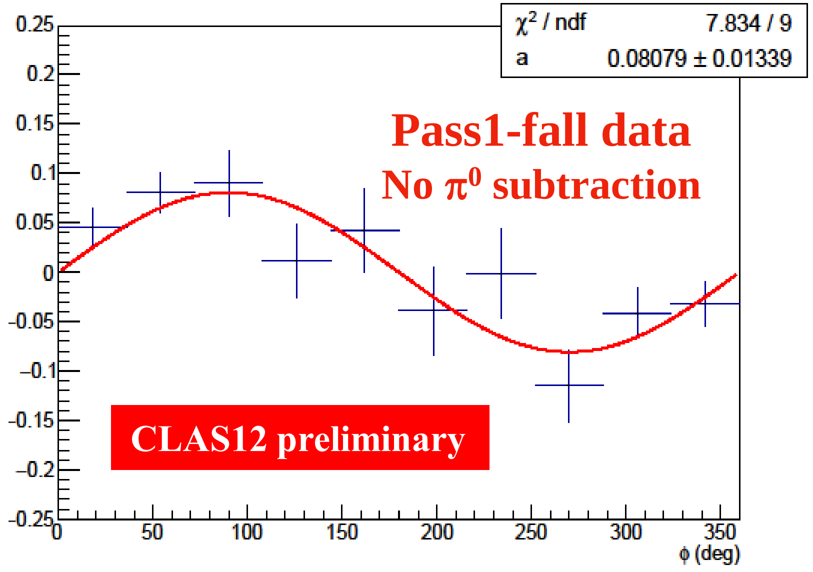
First-time measurement of BSA for nDVCS with exclusive final state selection:



- Raw BSA integrated over all kinematics and detection topologies
- Beam energy = 10.2 GeV

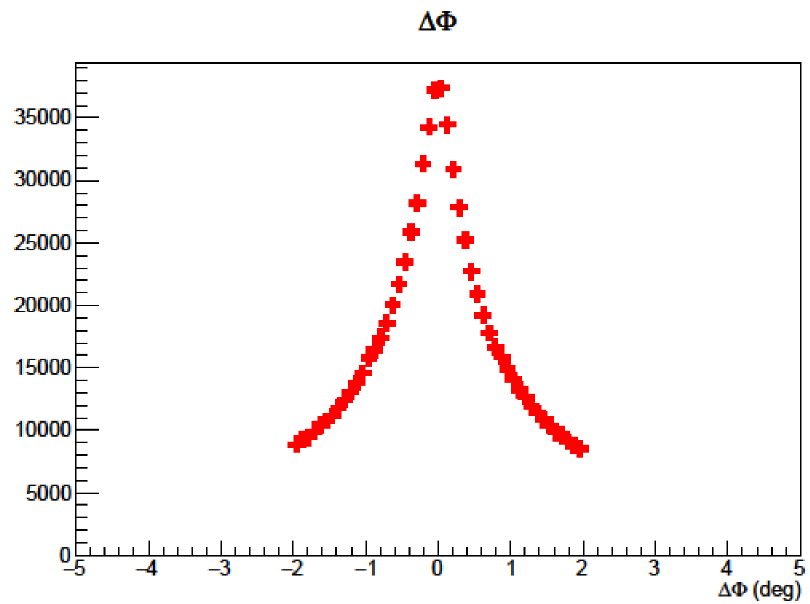


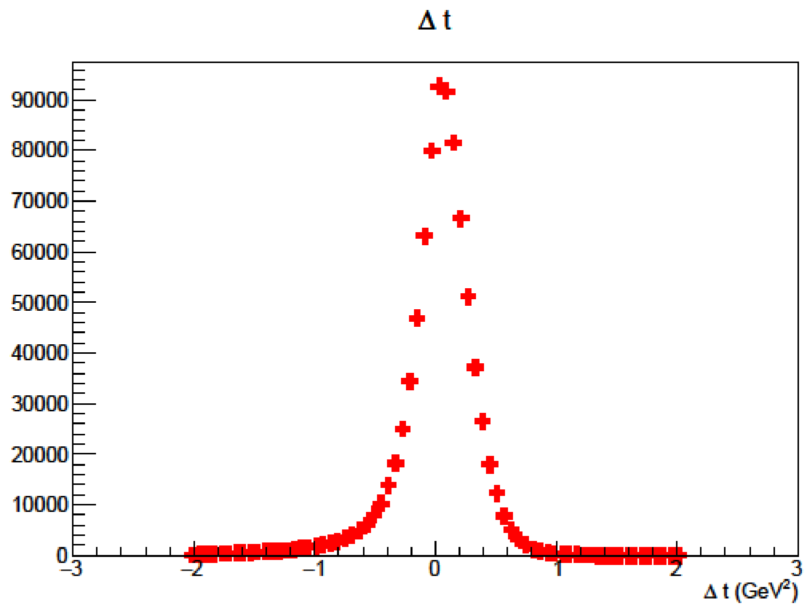
- Raw BSA integrated over all kinematics and detection topologies
- Beam energy = 10.6 GeV

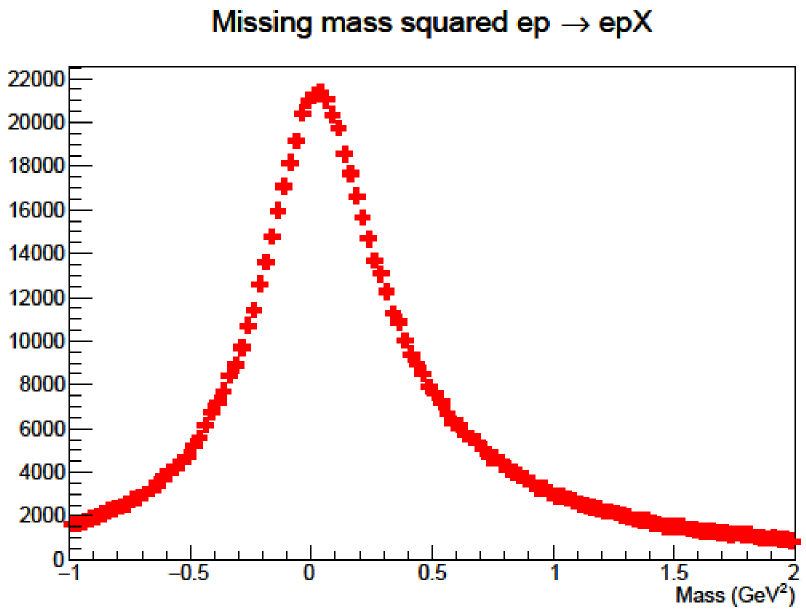


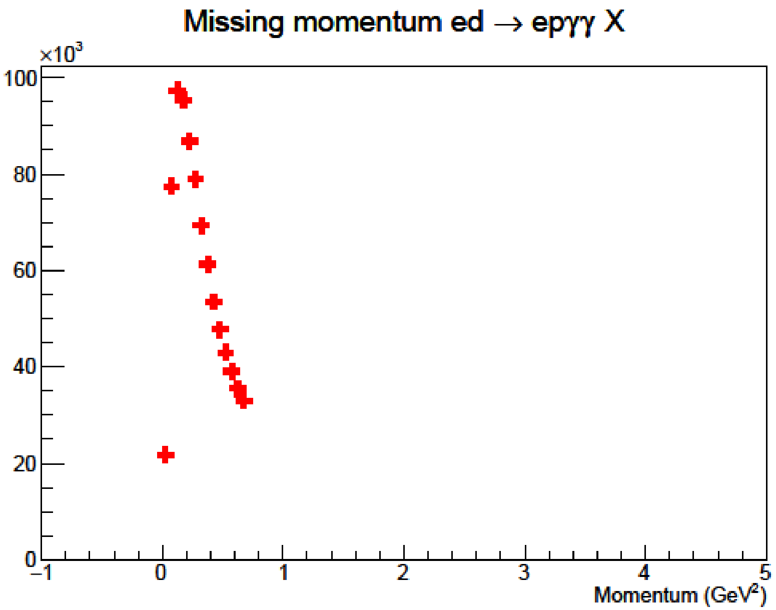
- Raw BSA integrated over all kinematics and detection topologies
- Beam energy = 10.4 GeV

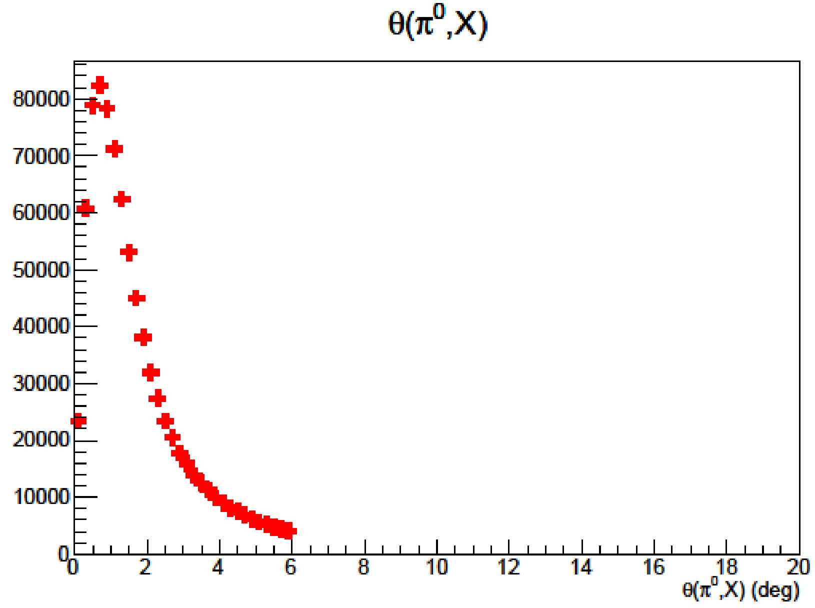
epPi0 Exclusivity Variables: all detection topologies



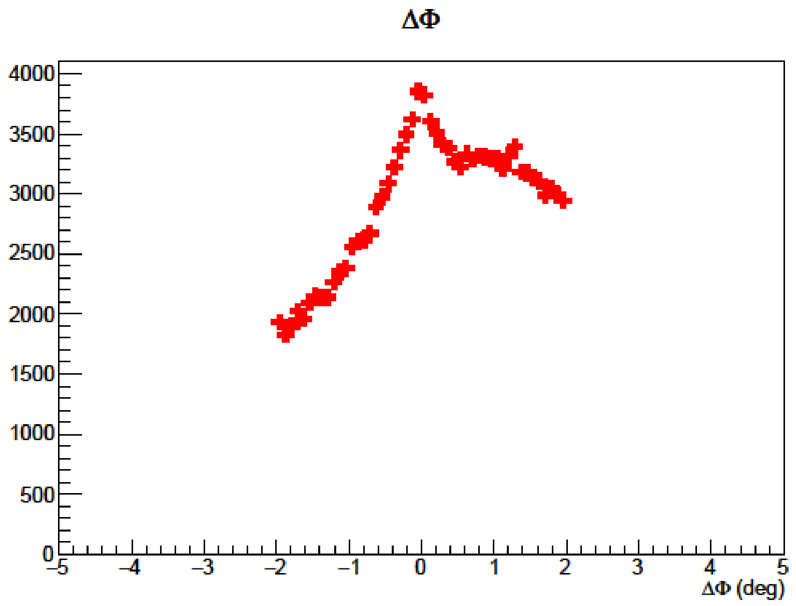


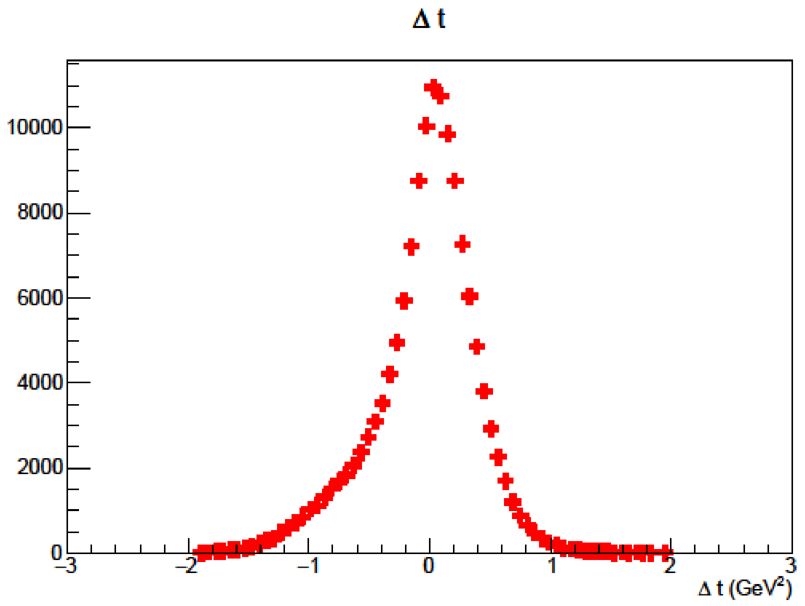


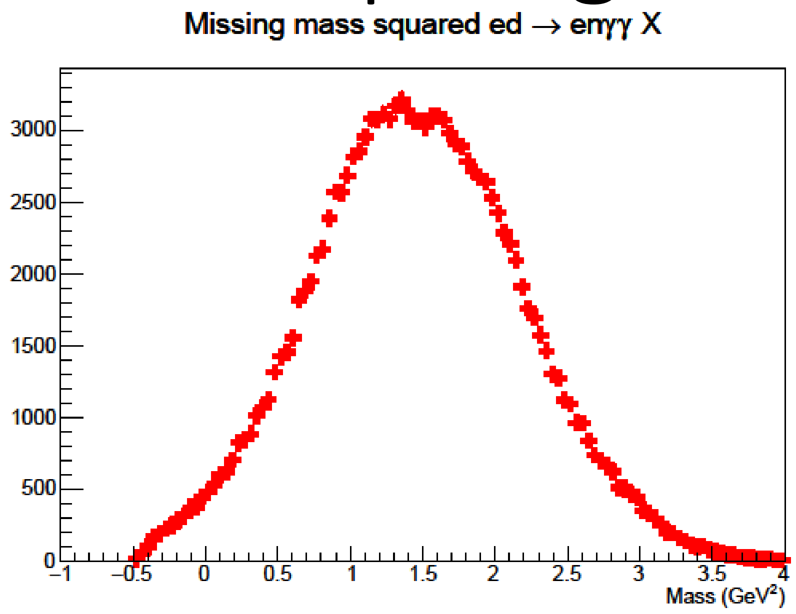


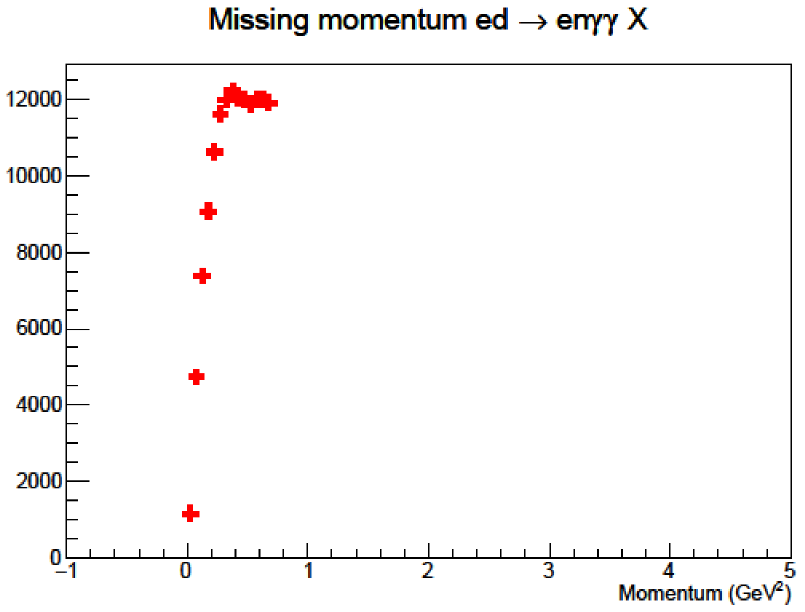


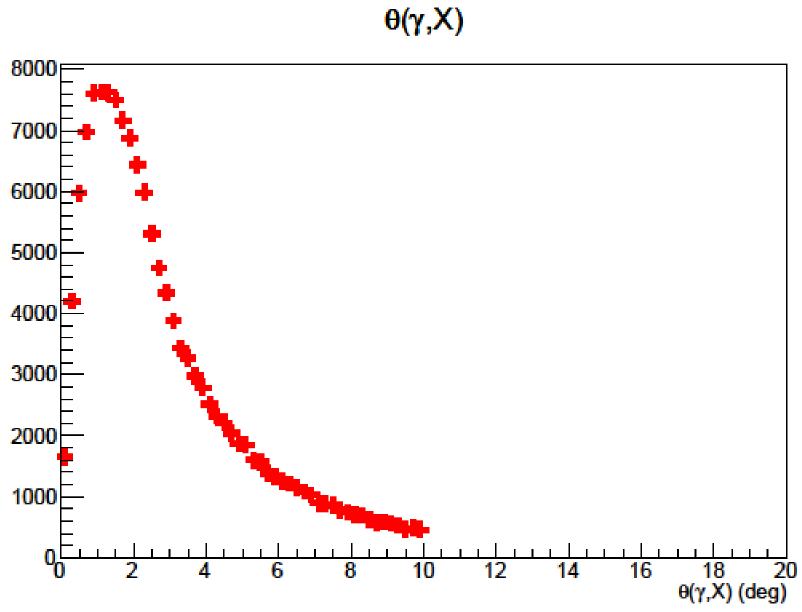
enPi0 Exclusivity Variables: all detection topologies



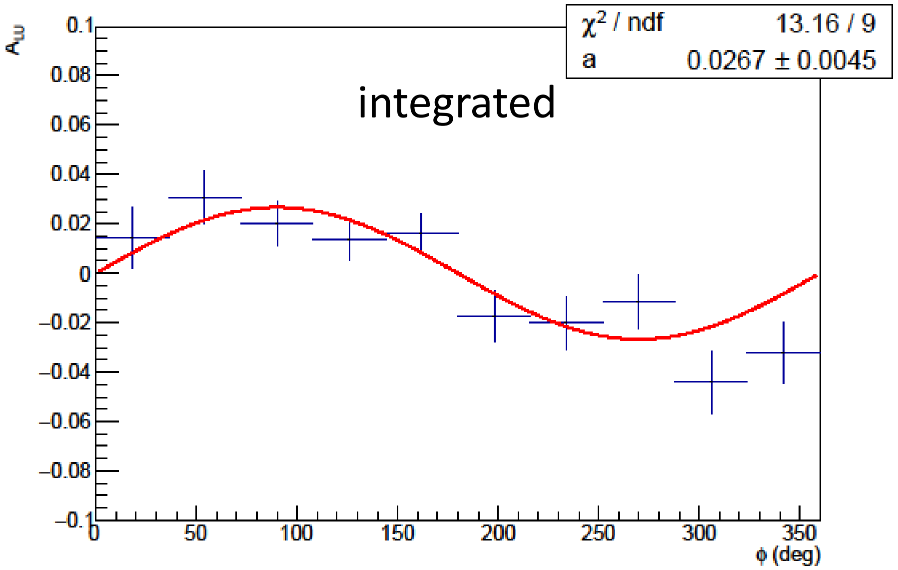




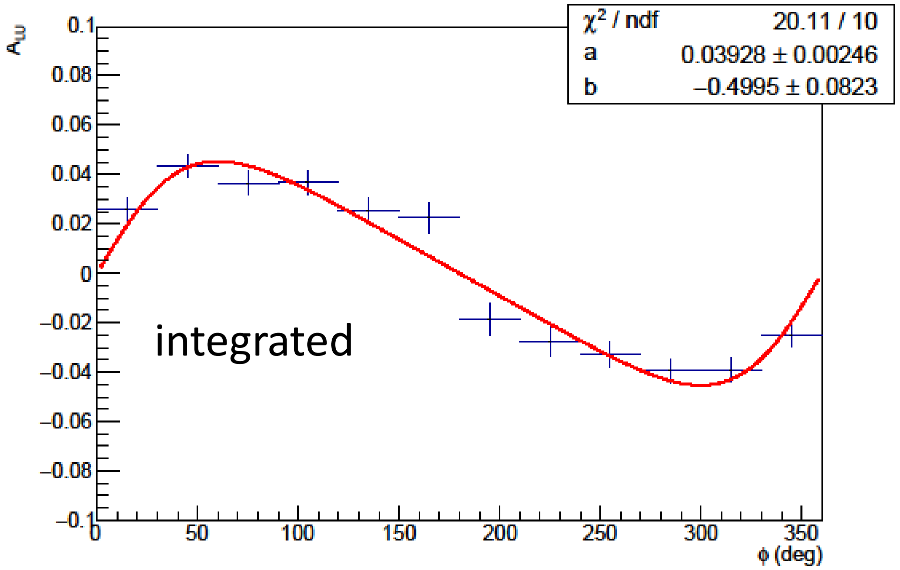




BSA: enPi0



BSA: epPi0



$\pi 0$ subtraction

- Last time: subtraction of pi0 background by statistically unfolding contributions to the missing mass spectrum
- Ongoing work: subtraction using the standard Hall B method using simulations of the background channel
- Description of the method:
  - Estimate the ratio of partially reconstructed epPi0(1 photon) decay to fully reconstructed epPi0 decays in MC
  - this ratio is equal to that in data
  - Do this in each bin: All acceptance differences and MC/data discrepencies cancel in the ratio
  - Multiply this ratio by the number of reconstructed epPi0 in data to get the number of epPi0(1 photon) in data
  - Subtract this number from pDVCS reconstructed decays in data per 4D kinematical bin

In MC	In data	In data	In data	In data	In data

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

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

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

Summary

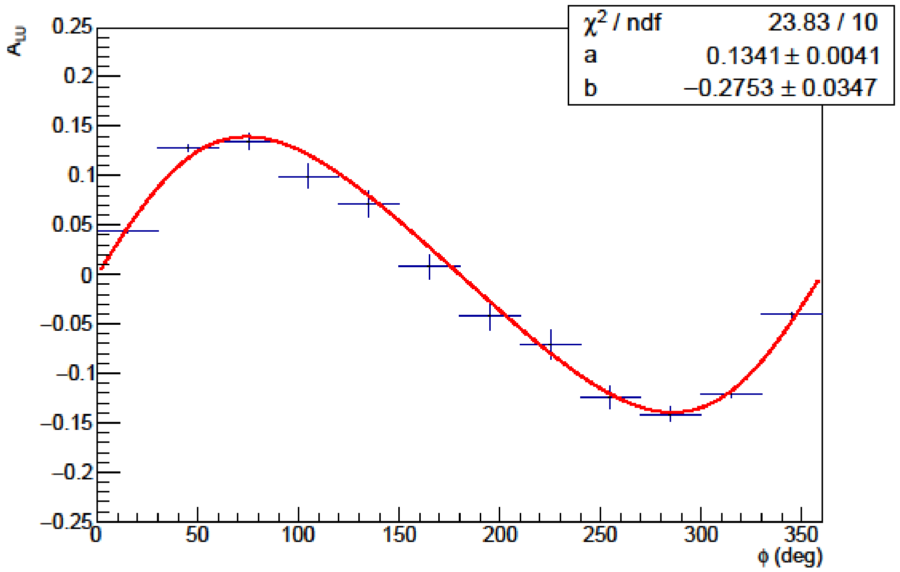
- Promising results from DVCS on proton and neutron from RGB data

- Analysis is progressing, what is missing:
- Evaluate and supress proton contamination in neutron sample: ML based approach is under study
- Corrections to final states momenta
- Cross-check different background subtraction methods to asses possible differences

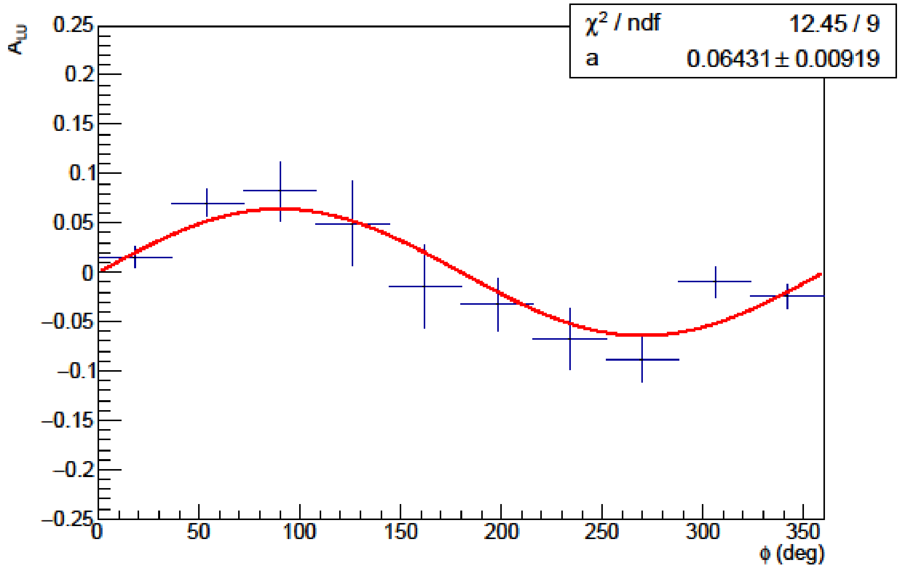
backup

BSA after background subtraction: all topos integrated

pDVCS after background subtraction

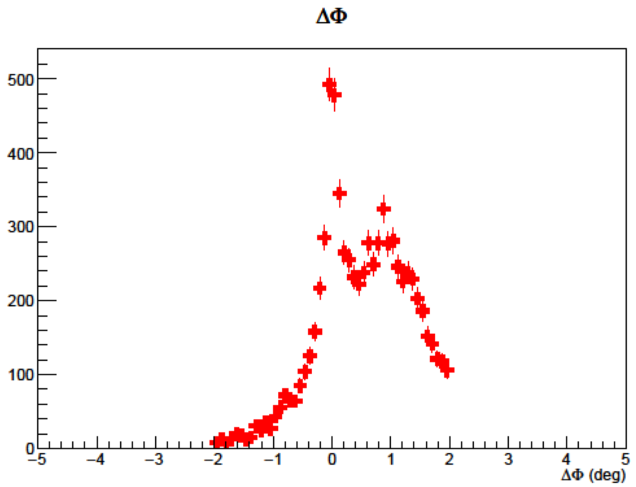


nDVCS after background subtraction

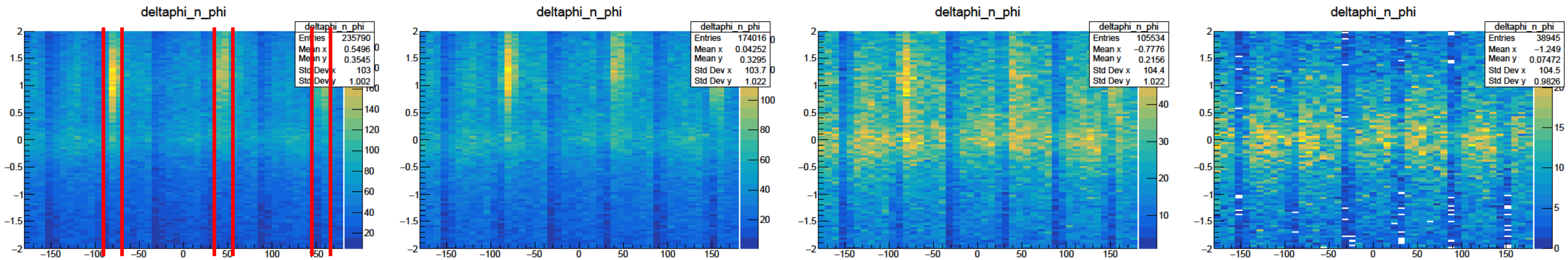


On proton contamination in neutron sample

- Could be clearly observed in the distribution of Delta Phi (both in MC & data)
- Phi is wrongly evaluated when the neutron is actually a proton
- A second bump in the distribution of delta Phi appears
- This is extensively under investigation by Paul Naidoo



Tightening the cut on the cone angle between the reconstructed and missing neutron



2D plot of neutron phi vs delta phi