CLAS Collaboration Meeting
November 2020

Deeply Virtual Compton Scattering off the Neutron

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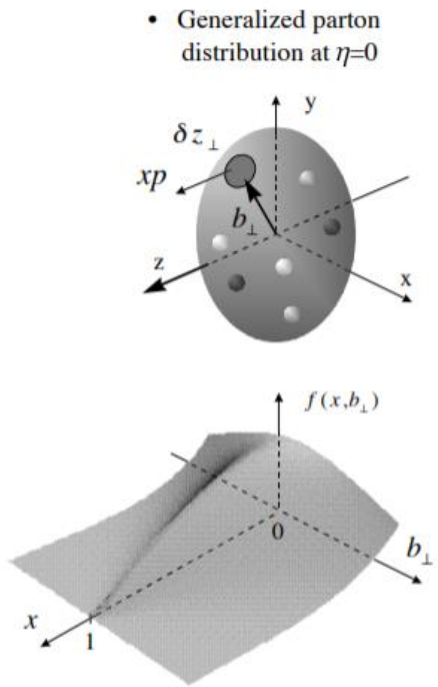
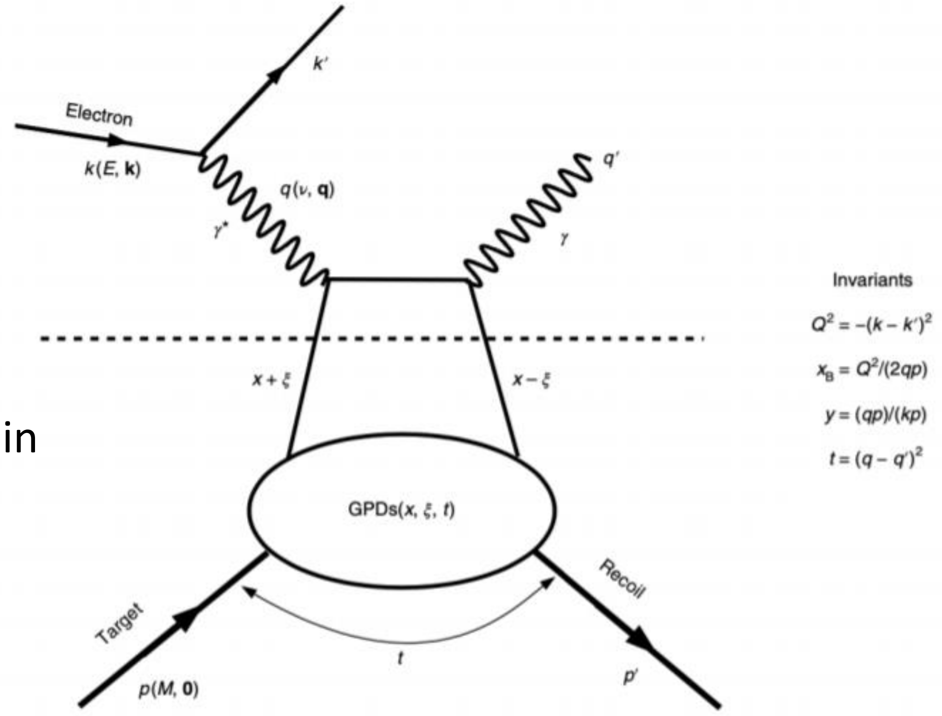
Motivations



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

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

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

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

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

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
  - Beam energies of 10.6 GeV and 10.2 GeV
- Run Date:
  - Spring 2019 period : ~50% of all collected data by CLAS12 so far for this measurement
- Selected runs:
  - the analysis of QA timelines after the pass-1 cooking

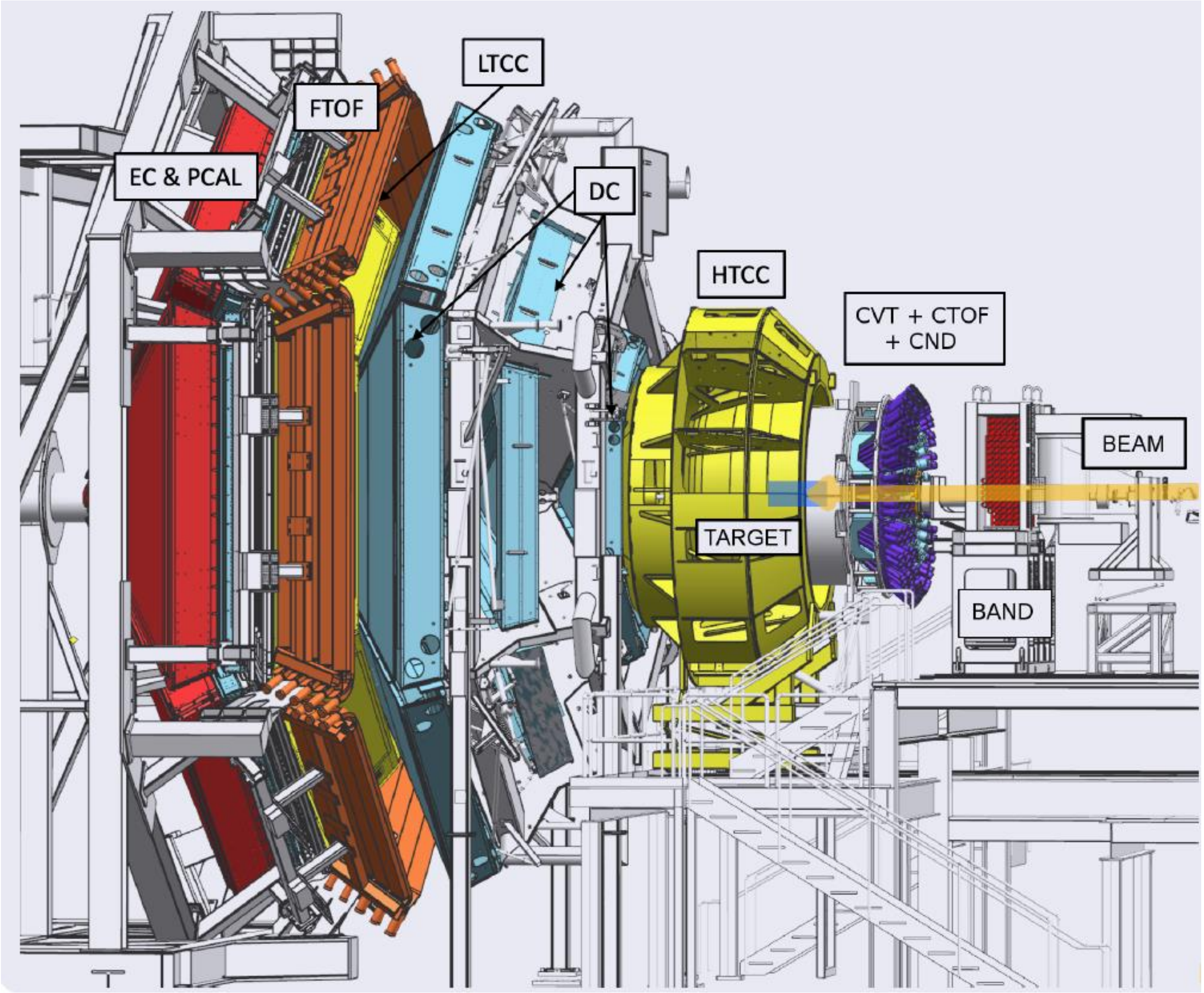
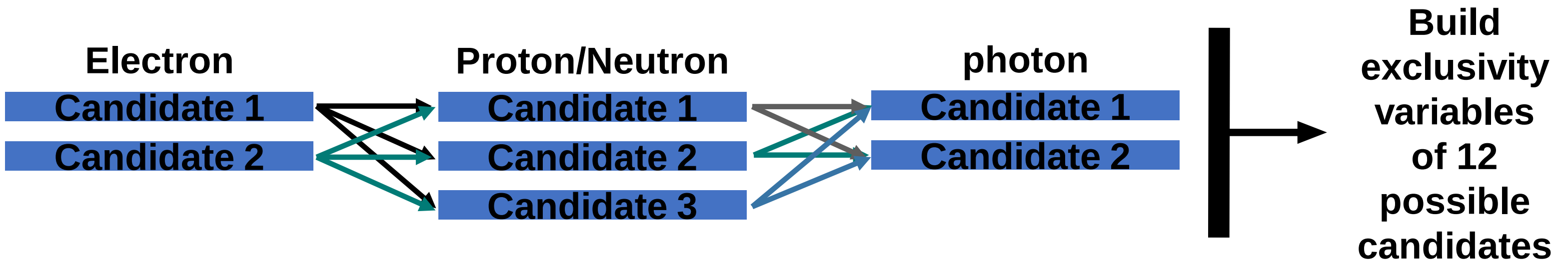


Figure in V. Burkert et al., Nucl.Instrum.Meth.A 959 (2020) 163419

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



Channel selection

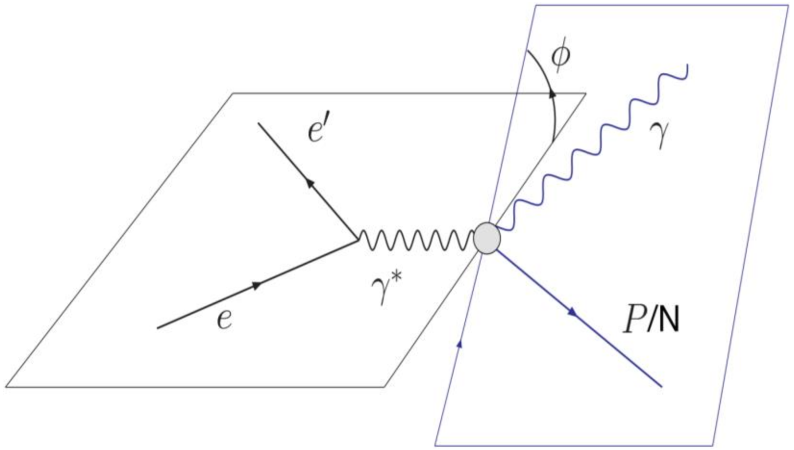
- The nDVCS (pDVCS) final state is selected with the following exclusivity criteria:
  - Missing mass
    - e d → e n γ X
    - e n → e n γ X
  - Missing momentum
    - e d → e n γ X
- ΔΦ, Δt, θ(γ,X)
  - Difference between two ways of calculating Φ and t
  - Difference in θ between measured and reconstructed photon
- Cuts informed by Monte Carlo simulations:
  - GPD based generator
  - DVCS amplitude calculated according to the BKM formalism
  - Fermi-motion distribution evaluated according to Paris potential
- Preliminary fiducial cuts for nDVCS:
  - to remove charged-particles contamination coming from the dead zones of the SVT: the events with $-90^\circ < \phi N < -70^\circ$ or $25^\circ < \phi N < 50^\circ$ or $150^\circ < \phi N < 170^\circ$

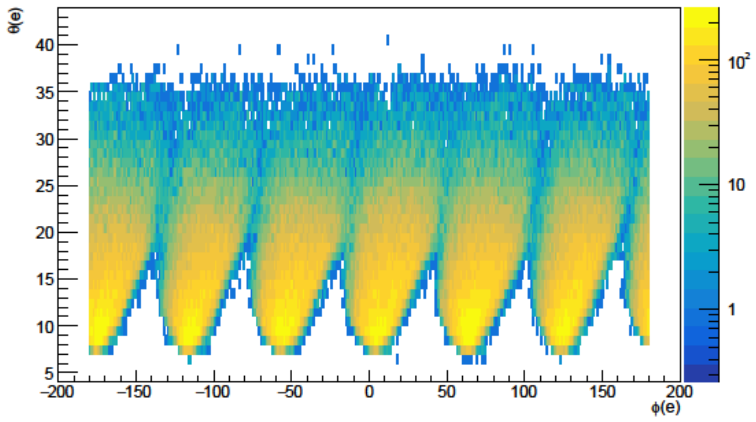
	Proton	Electron	Photon	Neutron
Momentum (GeV)	0.3	1	2	0.35

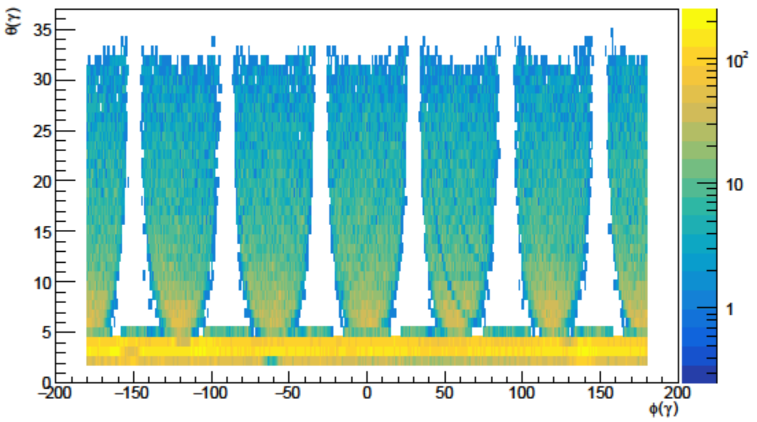
Q2>1 GeV2 W>2 GeV2

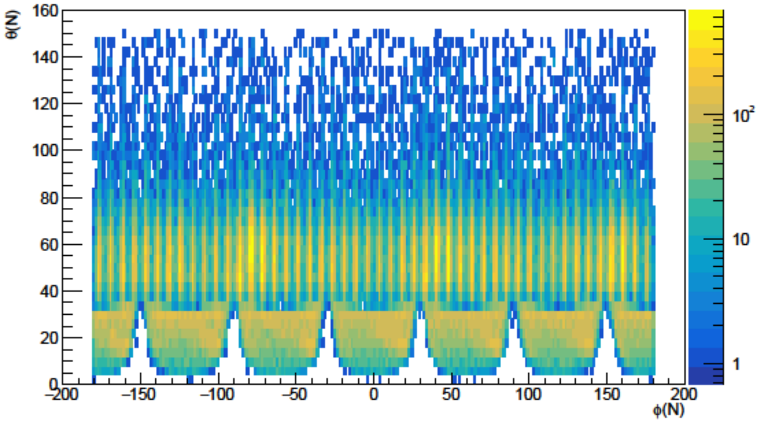
$\theta(e,\gamma) > 5^\circ$ Remove radiative photons

Exclusivity cuts $|\Delta\Phi| < 2^\circ$ $|\Delta t| < 2\,GeV^2$ Missing energy<0.7 GeV



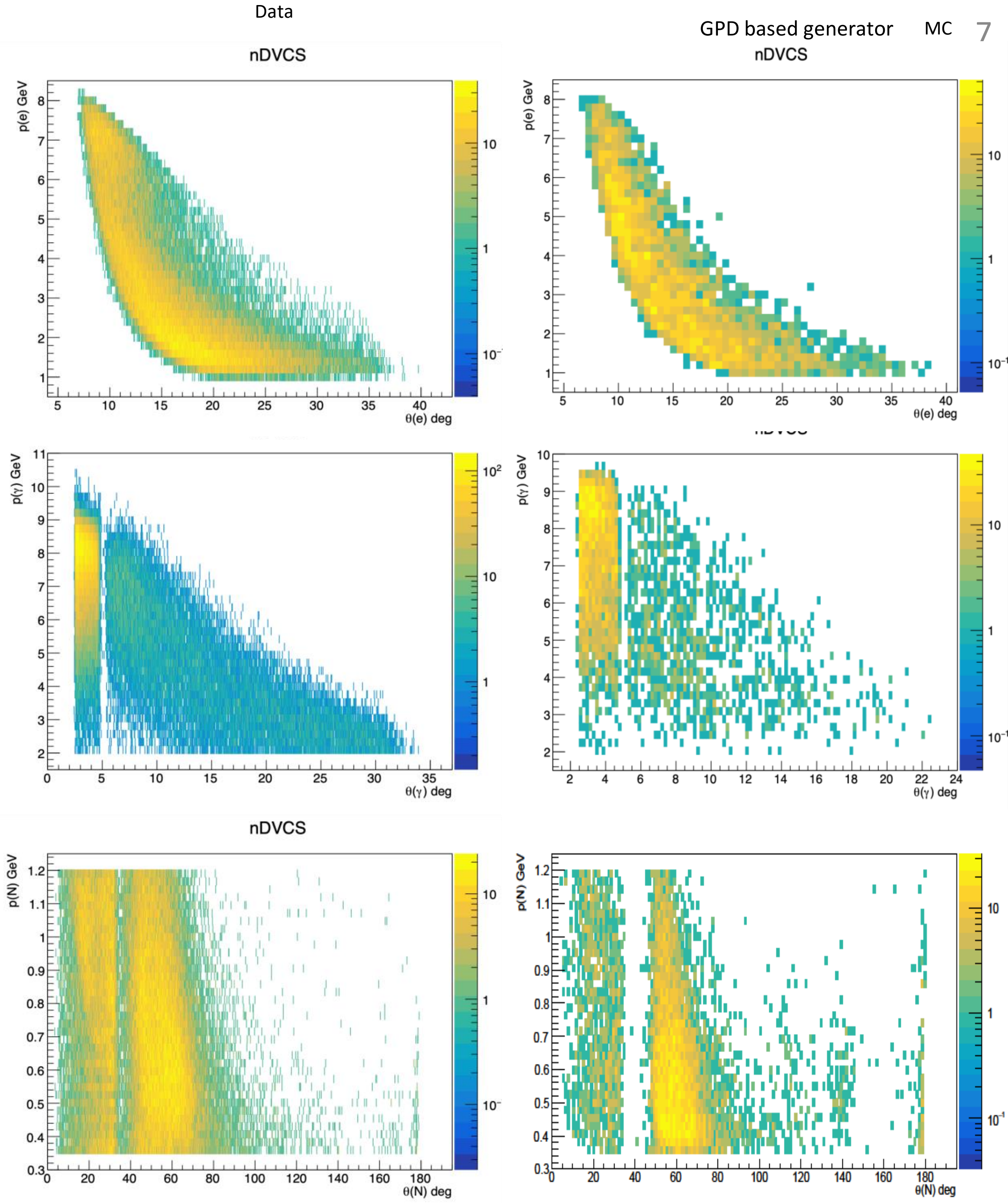






Final state particle kinematics

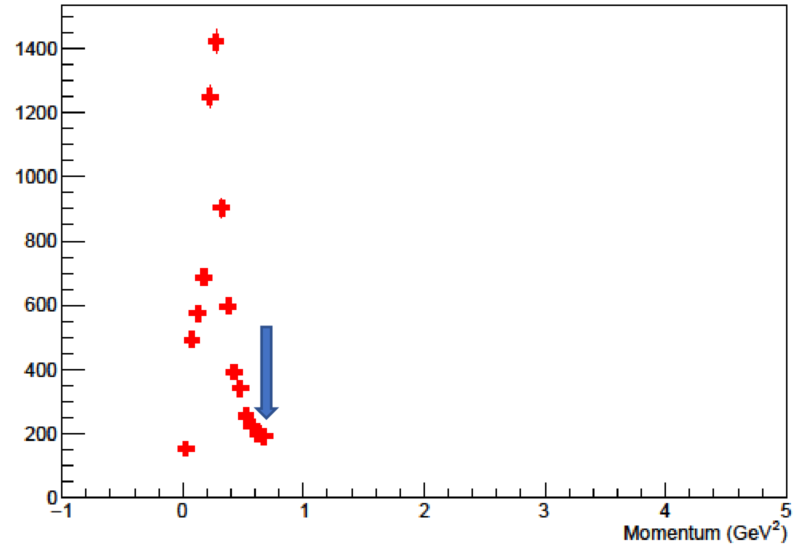
- From simulation:
  - nDVCS photons are mainly at low θ (FT)
  - nDVCS neutrons are mainly in high θ (CD)
- The privileged topology for nDVCS final state particles is for neutron in CD and photons in FT



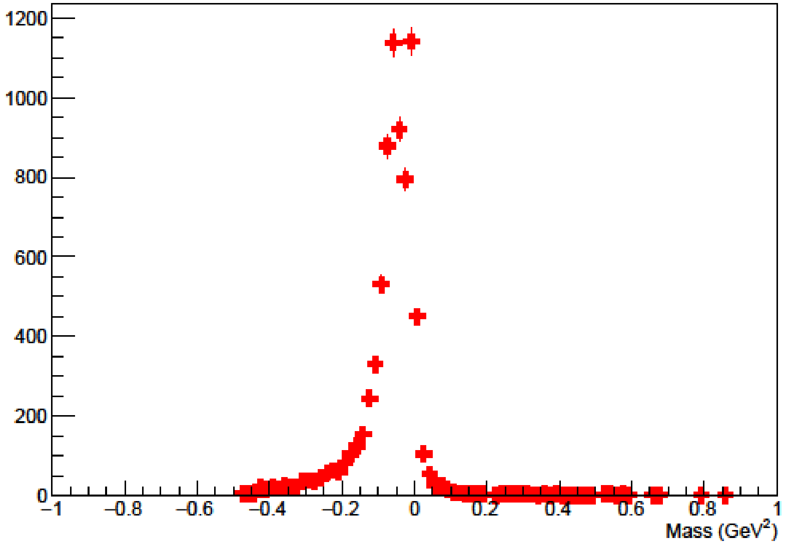
Exclusivity variables: MC-nDVCS

: Cut position

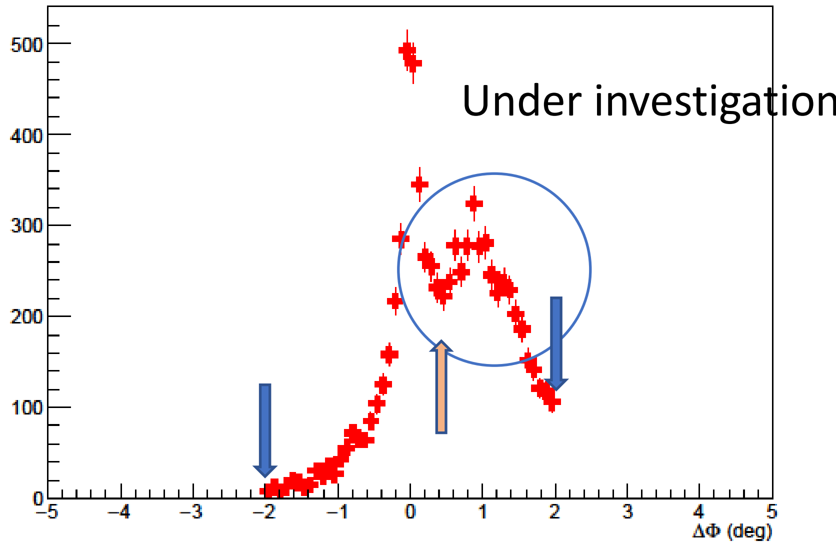
Missing momentum ed → enγ X



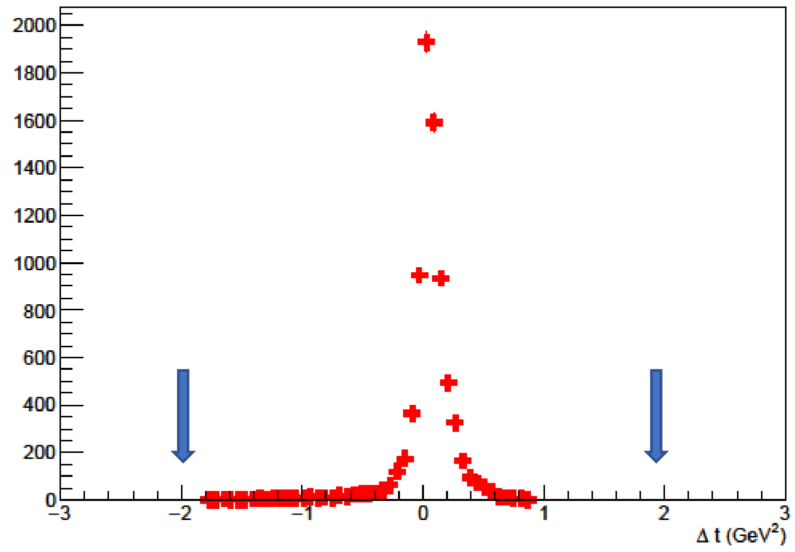
Missing mass squared en → enγ X



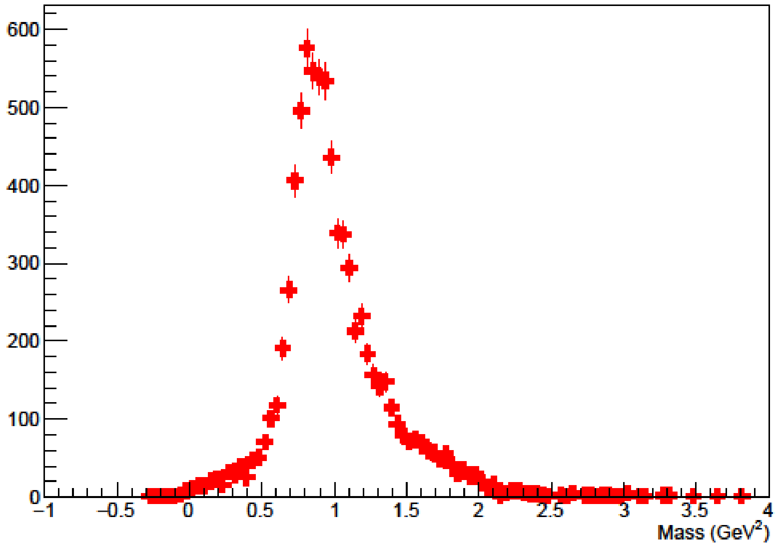
ΔΦ



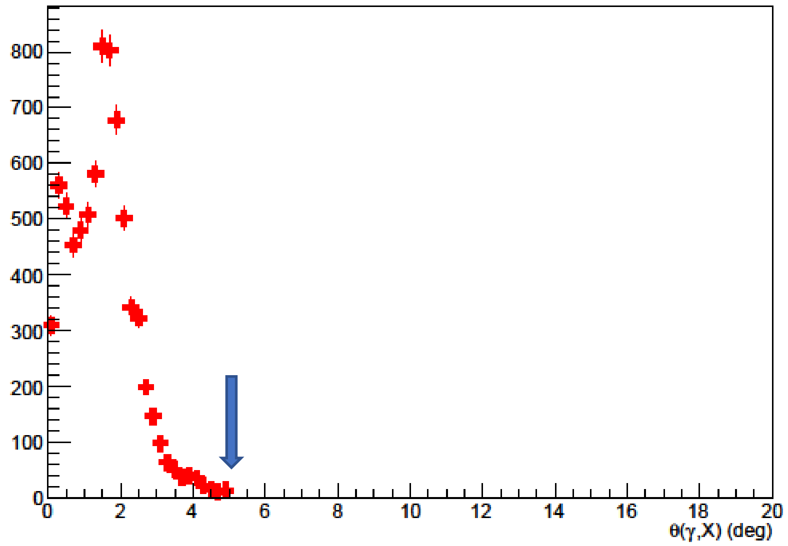
Δ t



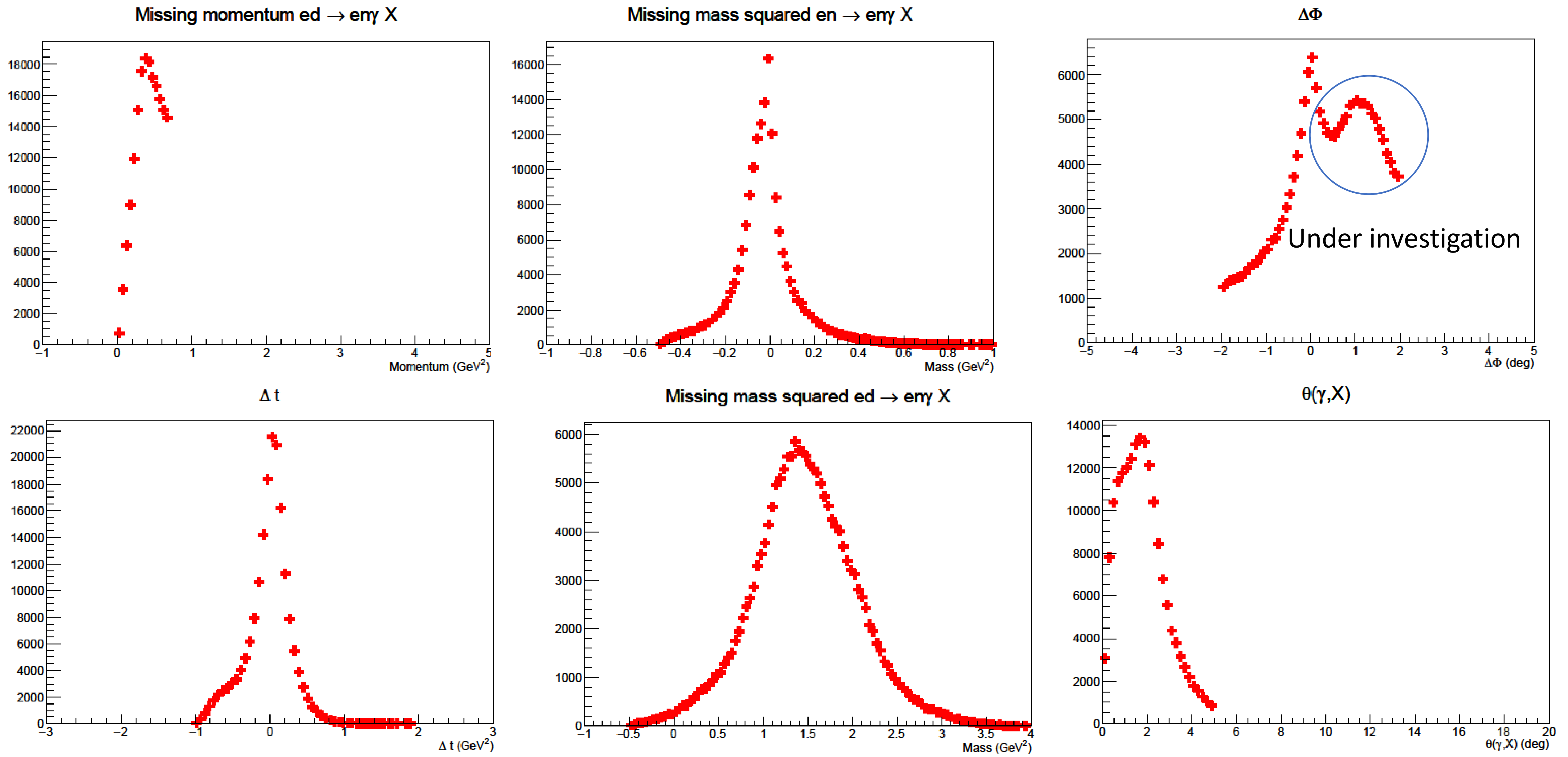
Missing mass squared ed → enγ X



θ(γ,X)

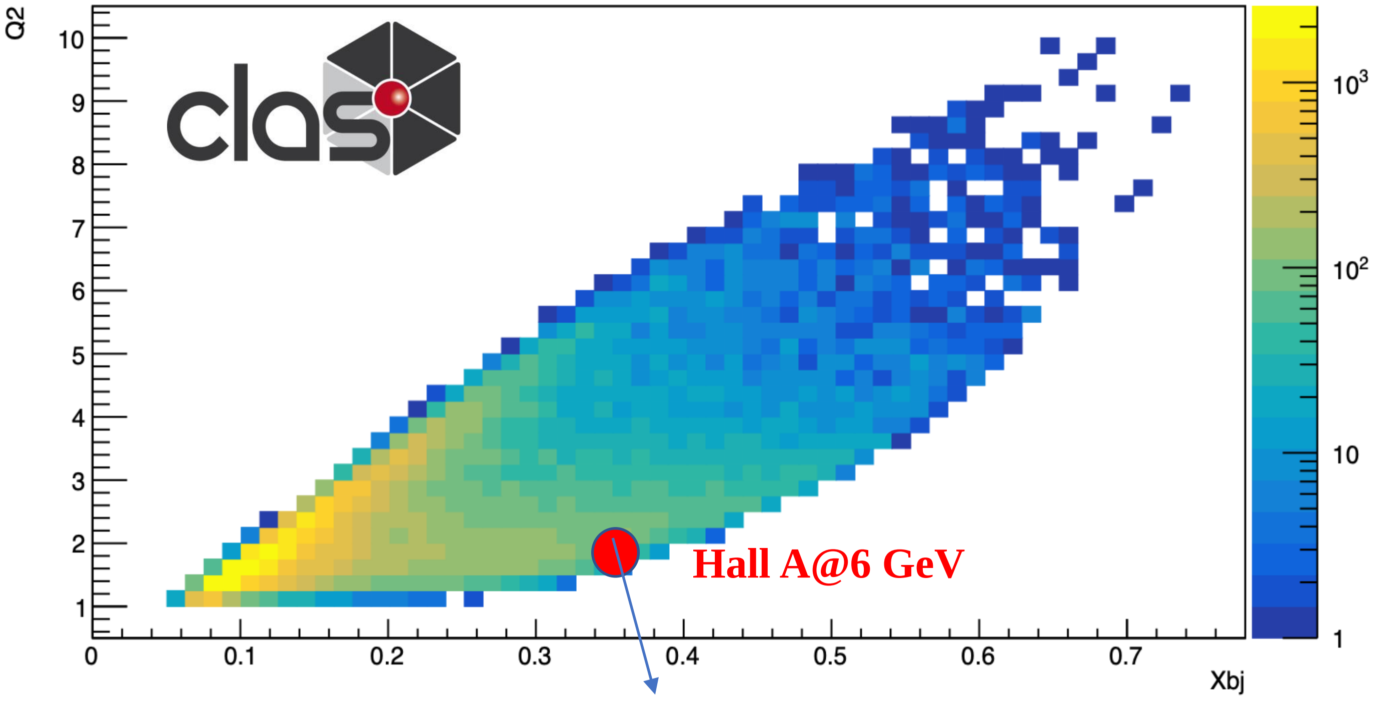


Exclusivity variables: all data with exclusive selection-nDVCS



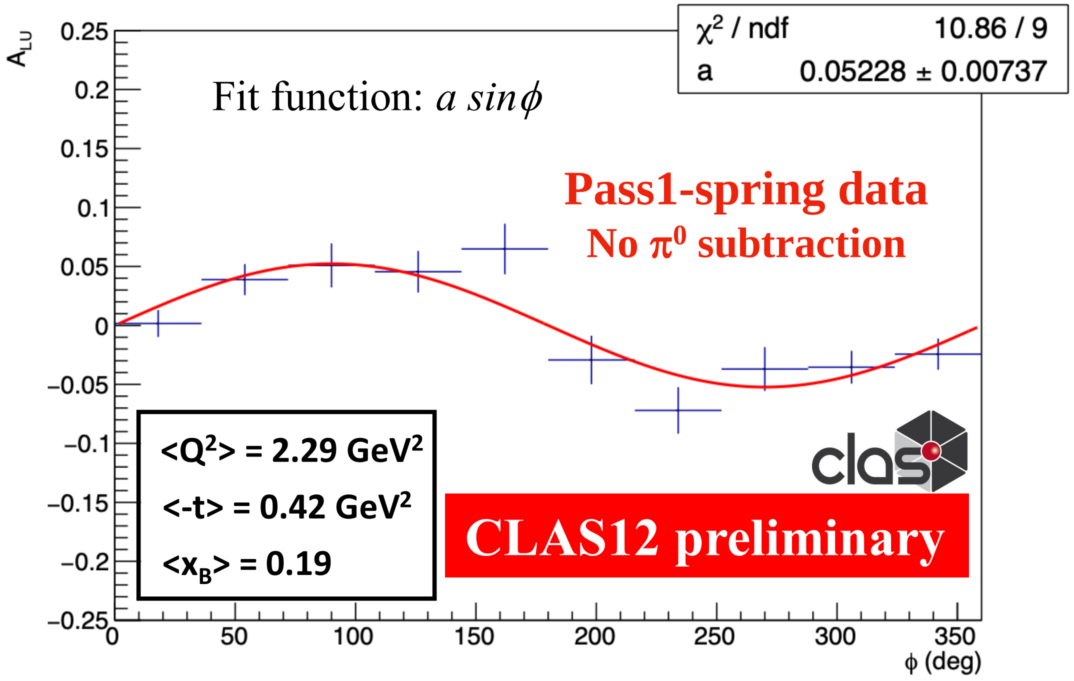
nDVCS with RGB data

First-time measurement of BSA for nDVCS with tagged neutron



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

ed→enγ(p)

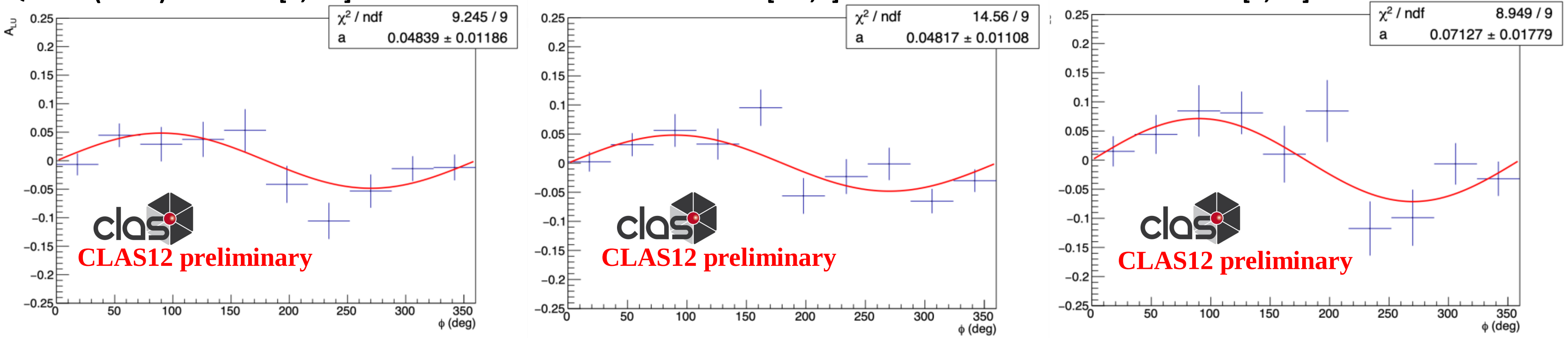


- 55188 nDVCS event candidates
- Raw BSA integrated over all kinematics and topologies
- **10.6 GeV and 10.2 data combined**
- Work ongoing on π^0 subtraction, fiducial cuts, etc…
- Work ongoing on improved neutron identification (neural networks trained on real data).

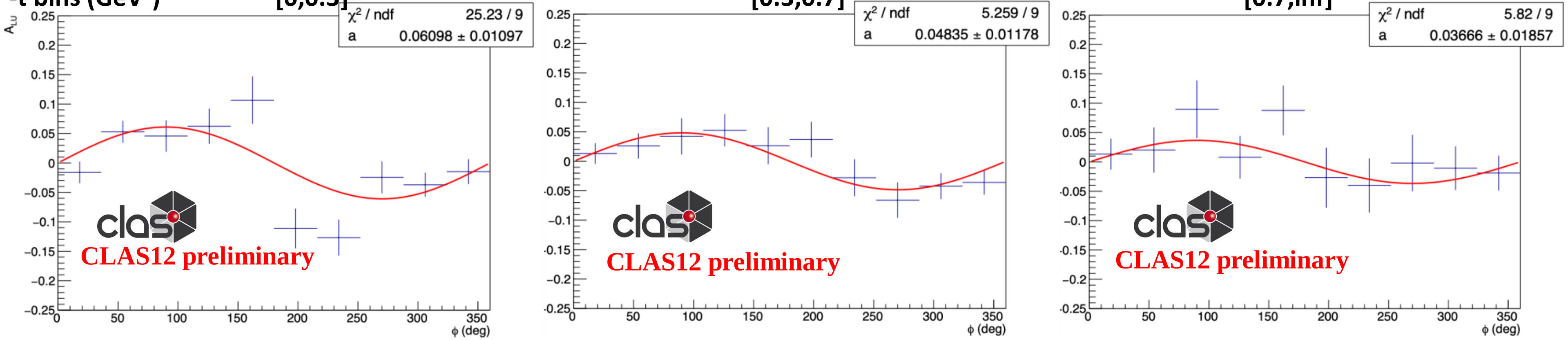
nDVCS raw BSA vs ϕ in 1-dim. bins

~50% of the collected data

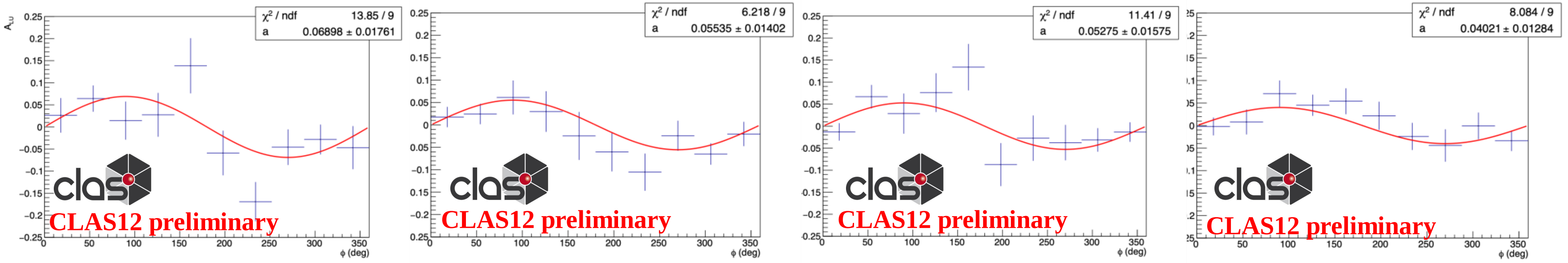
Q^2 bins (GeV^2) [1,1.8] [1.8,3] [3,inf]



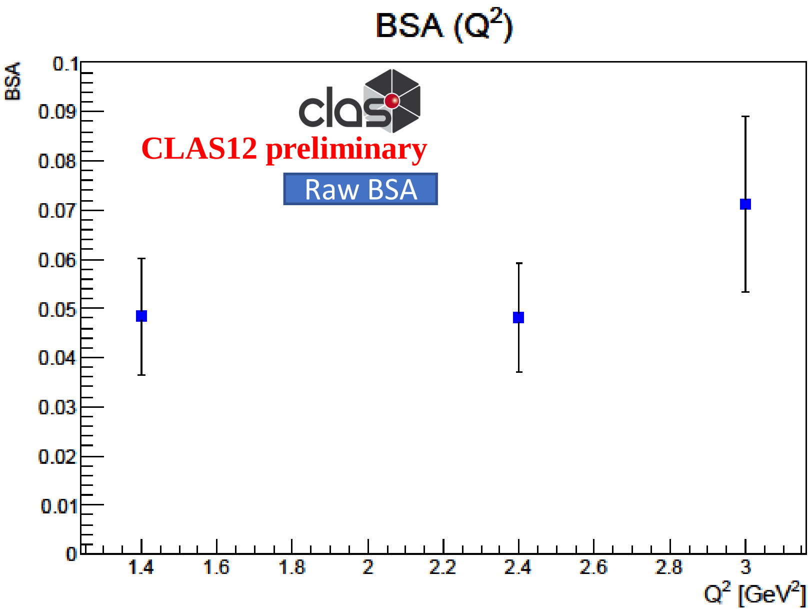
-t bins (GeV^2) [0,0.3] [0.3,0.7] [0.7,inf]

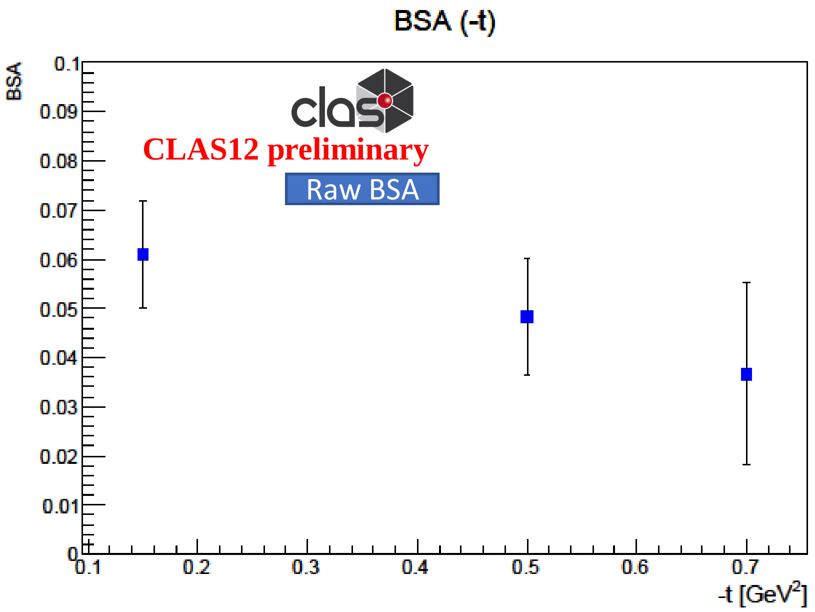


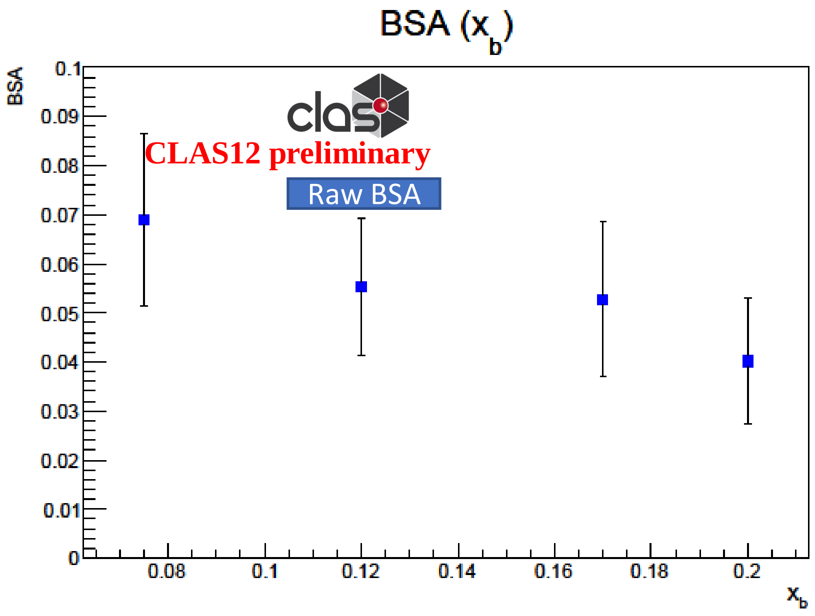
x_B bins [0.05,0.1] [0.1,0.14] [0.14,0.2] [0.2,inf]



Evolution of the sin ϕ amplitude for nDVCS

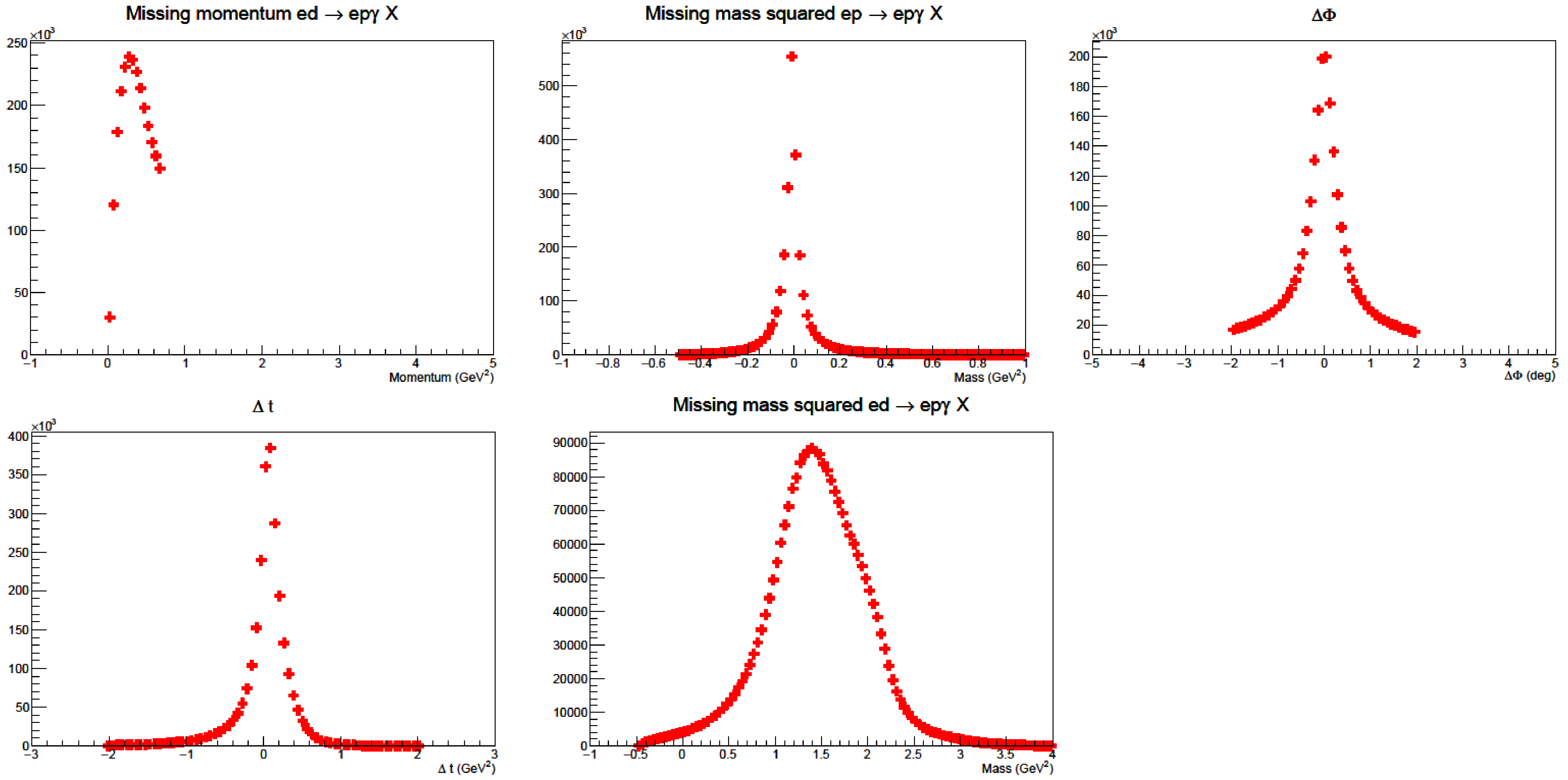






To be compared with models after background subtraction and all corrections are in place and improvements to neutron identification with neural nets

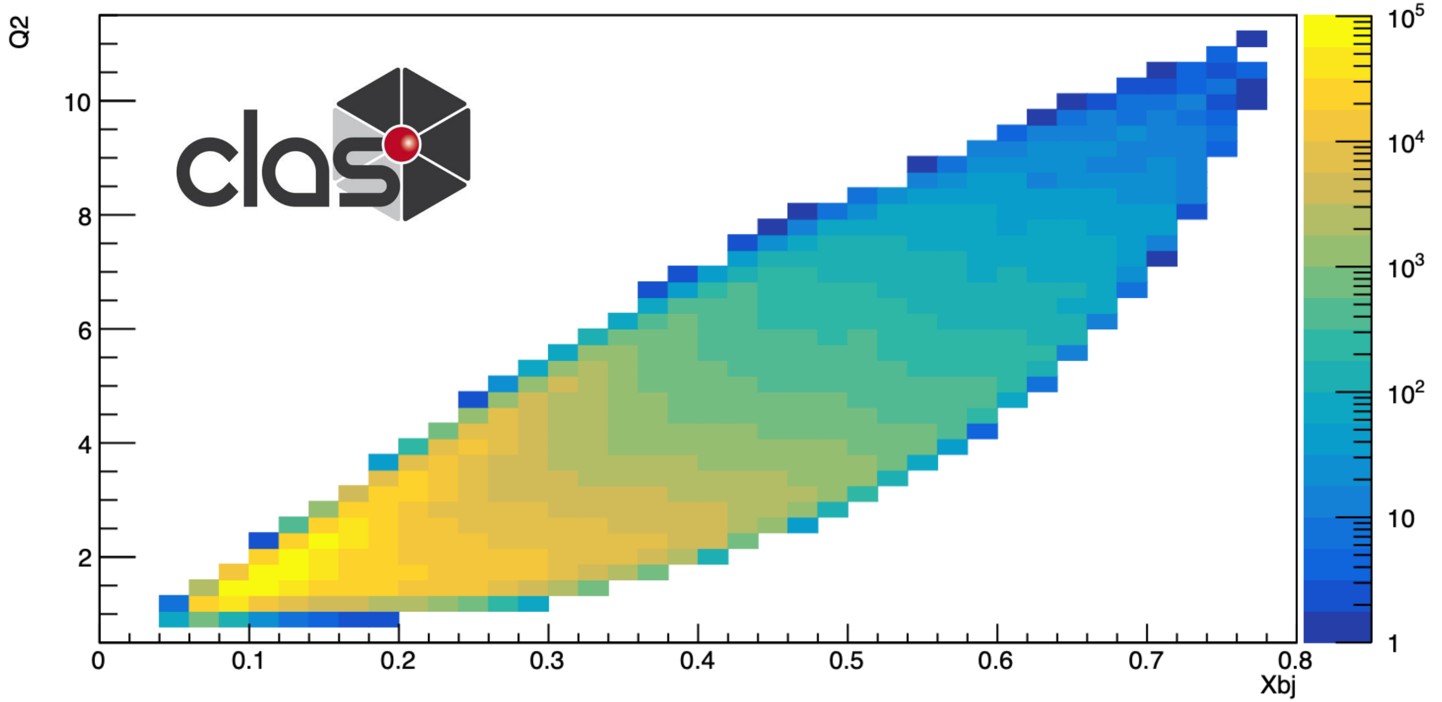
Exclusivity variables: all data with exclusive selection-pDVCS

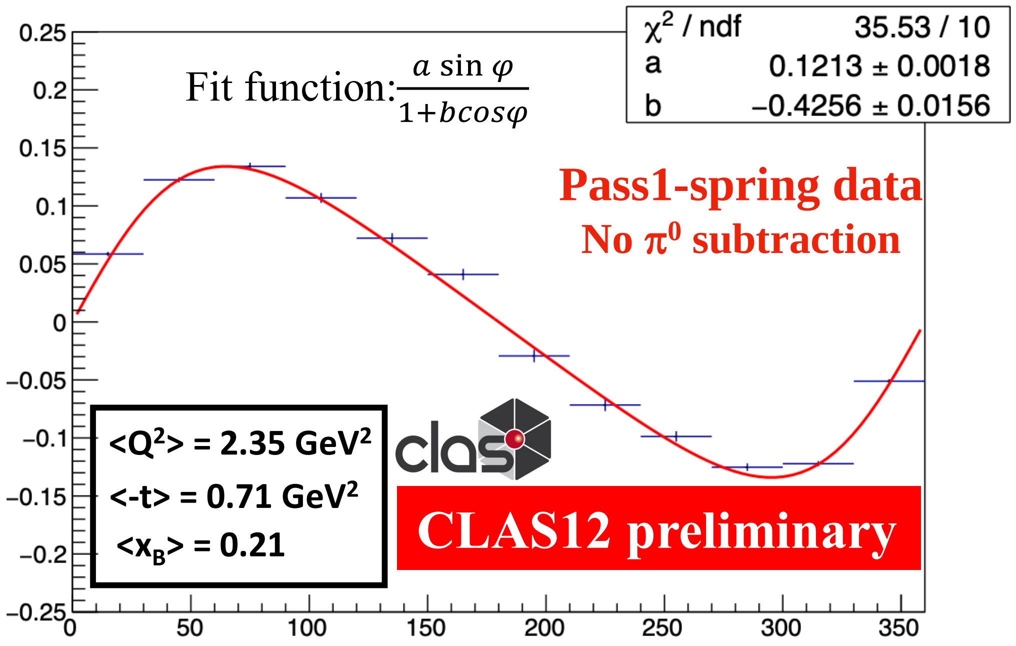


Incoherent pDVCS on deuterium

ed→epγ(n)

First-time measurement of BSA for pDVCS with a deuterium target (proton in a weakly bound state)





- 2020720 identified pDVCS candidates
- Raw BSA integrated over all kinematics and detection topologies
- **Compatible within 2 σ with raw BSA from pDVCS with proton target**
- **nDVCS and pDVCS yields scale as expected: $(CS*eff)_p$~$40(CS*eff)_n$**
- Work ongoing on π^0 subtraction, fiducial cuts, etc…

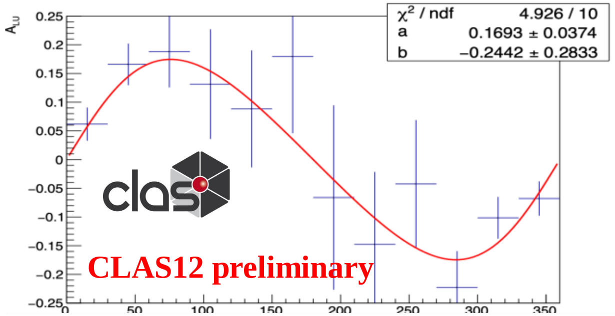
pDVCS raw BSA vs ϕ in 3-dim. bins

Q^2 bins (GeV^2)

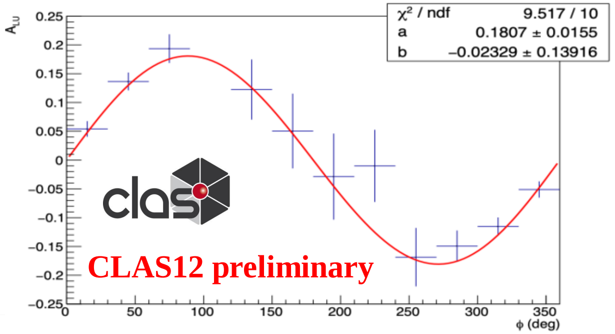
[4,inf]

First-time Measurement on a deuterium target

-t bin [0,0.2] (GeV^2)



[3,4]



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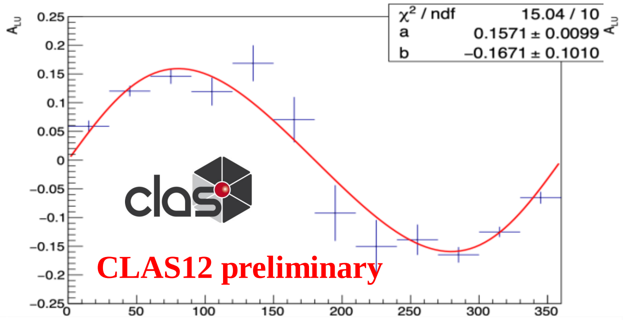

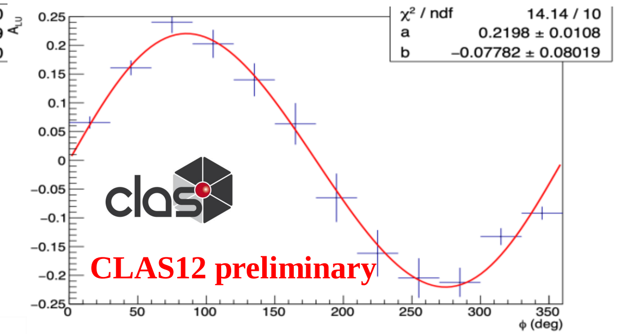

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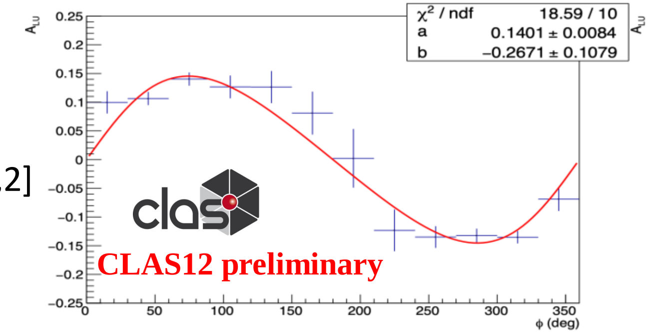
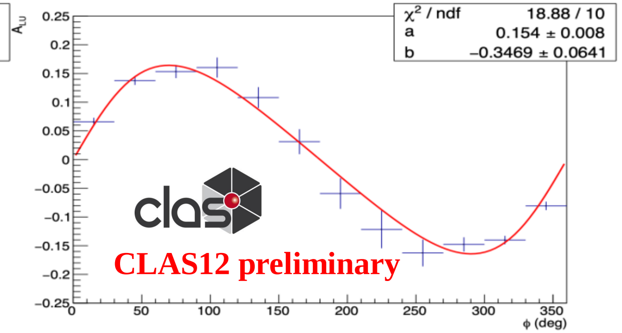
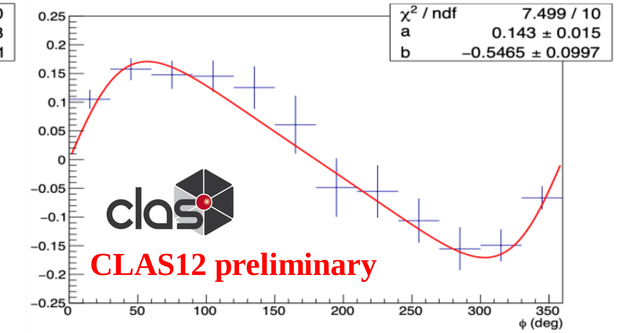






[0.05,0.1] [0.1,0.17] [0.17,inf] **x_B bins**

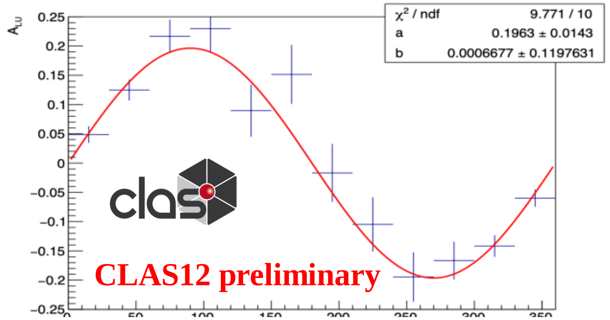
pDVCS raw BSA vs ϕ in 3-dim. bins

Q^2 bins (GeV^2)

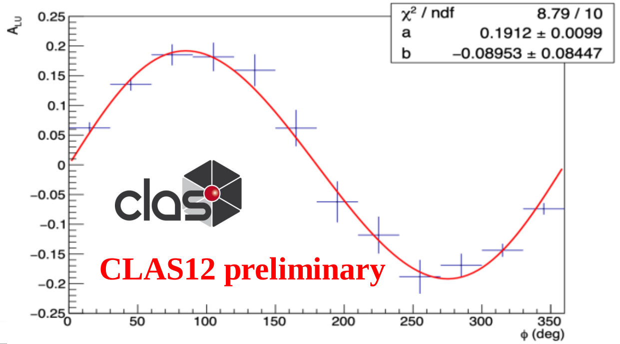
First-time Measurement on a deuterium target

-t bin [0.2,0.4] (GeV^2)

[4,inf]



[3,4]



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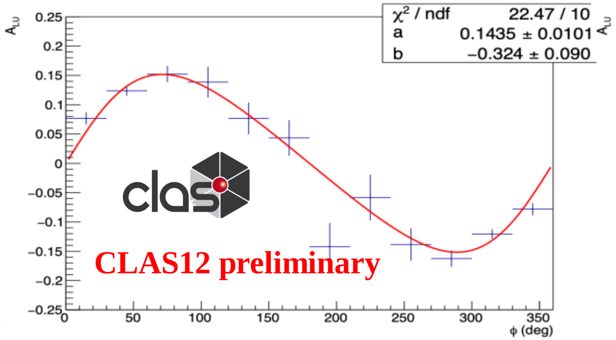

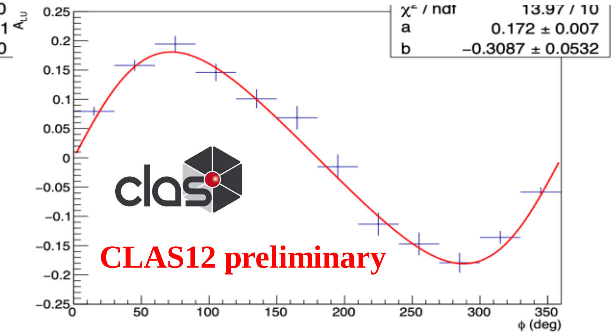

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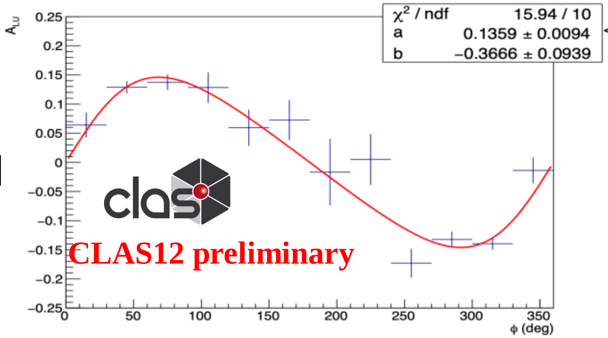
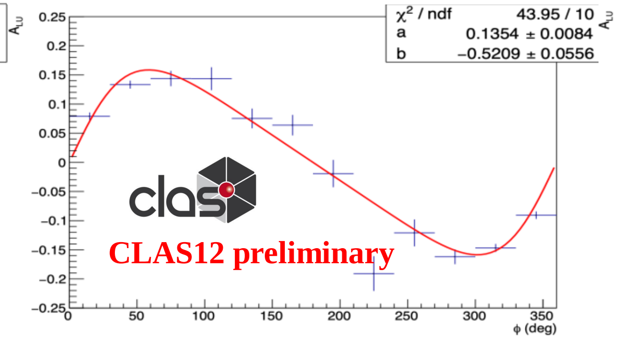
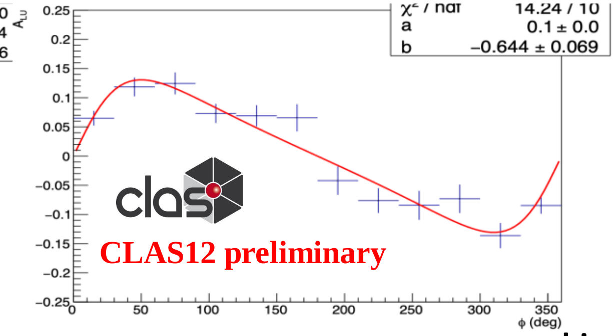






[0.05,0.1] [0.1,0.17] [0.17,inf]

x_B bins

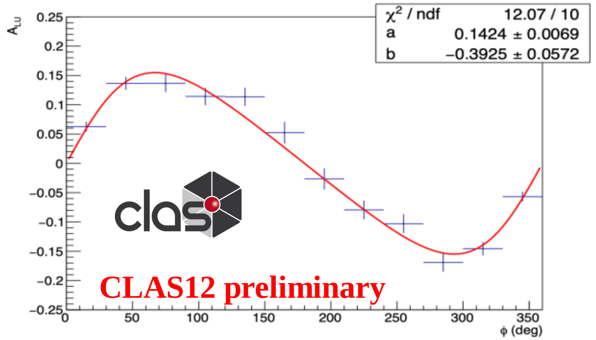
pDVCS raw BSA vs ϕ in 3-dim. bins

First-time Measurement on a deuterium target

Q^2 bins (GeV^2)

-t bin [0.4,inf] (GeV^2)

[4,inf]



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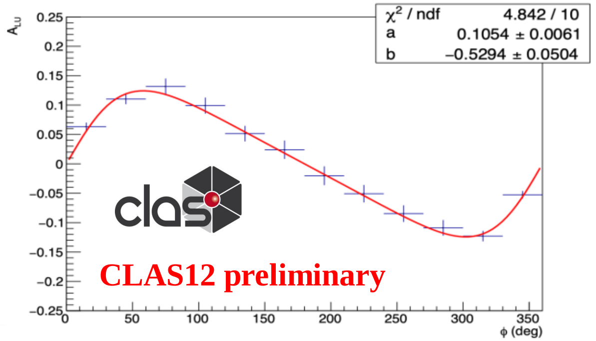

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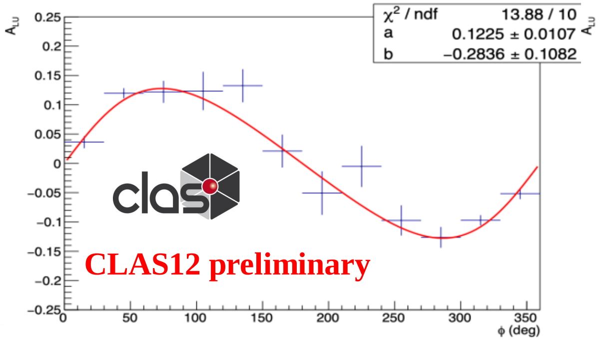

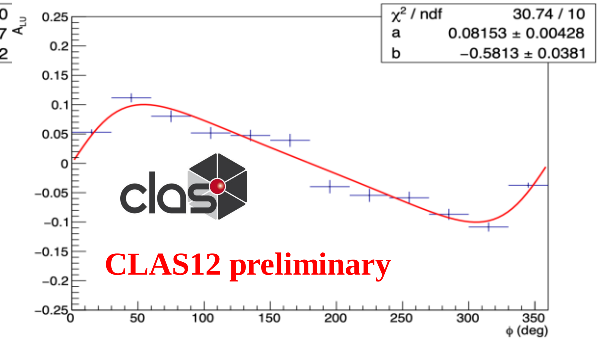

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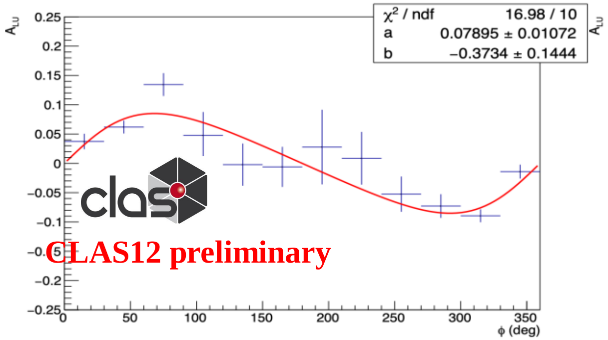
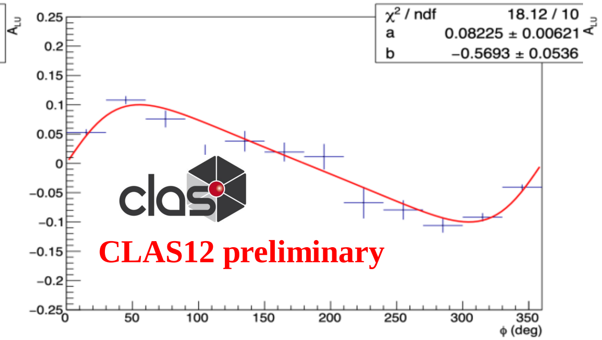
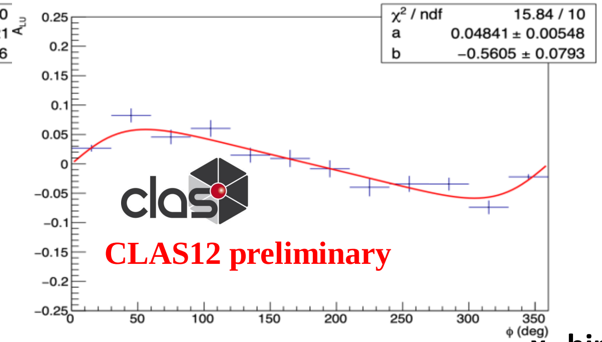






[0.05,0.1] [0.1,0.17] [0.17,inf]

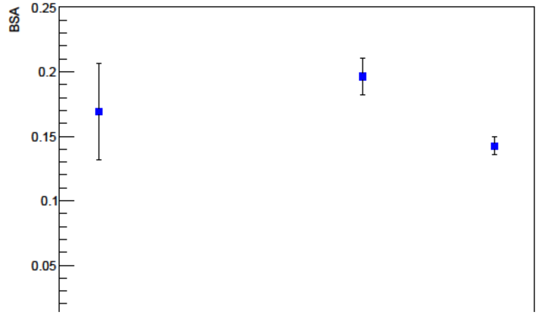
x_B bins

Evolution of the sin ϕ amplitude for nDVCS

Q^2 bins (GeV^2)

[4,inf]

First-time Measurement on a deuterium target



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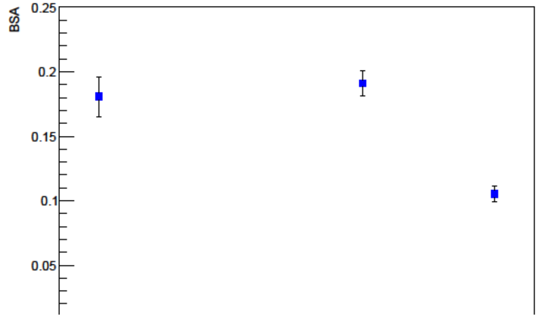

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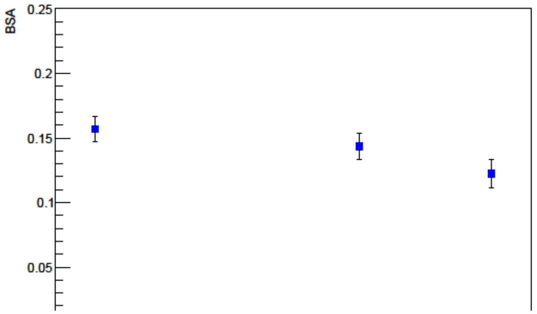

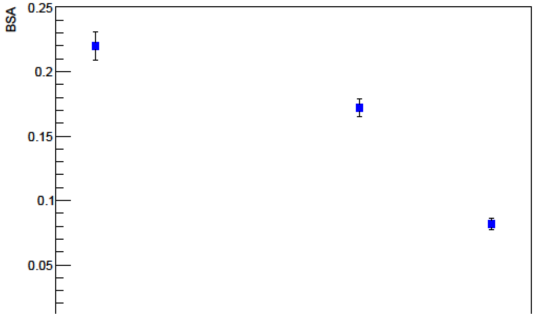

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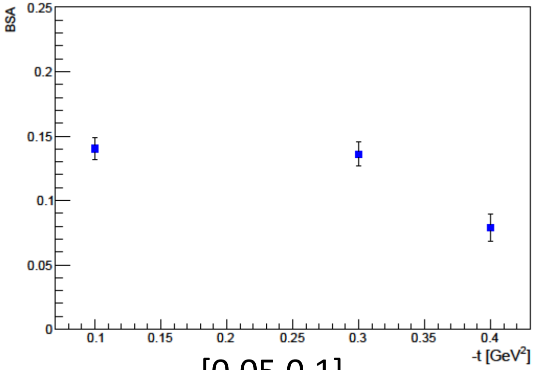
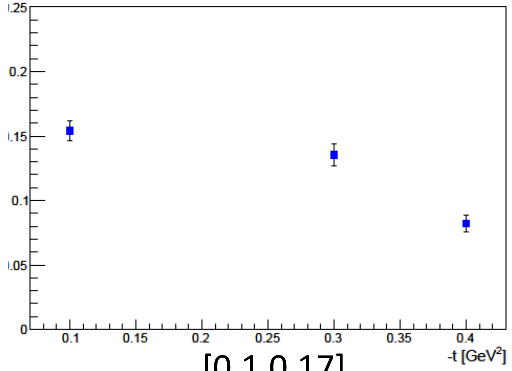
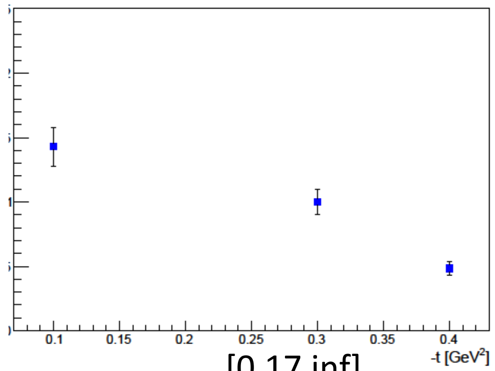






[0.05,0.1] [0.1,0.17] [0.17,inf]

x_B bins

π0 subtraction: preliminary attempt

- Reconstruction: final state ep gamma gamma
- Pi0 selection:

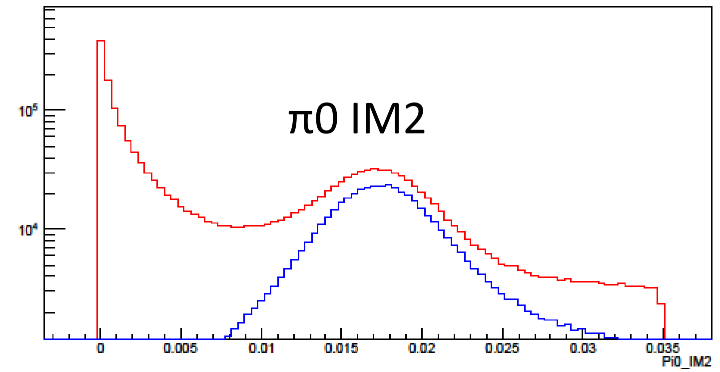
```
Pi0_IM2>0.0        Pi0_IM2<0.03
```

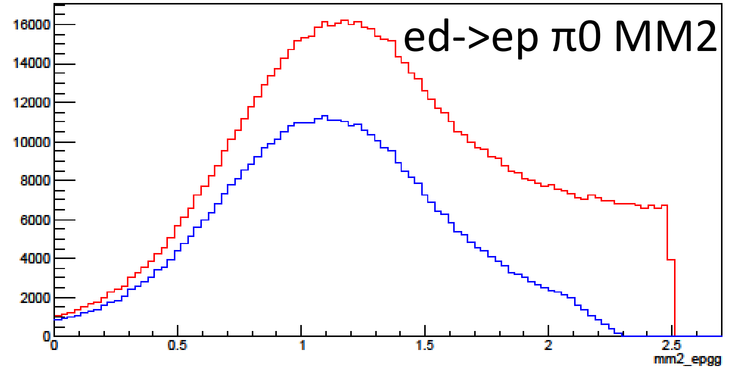
- Kinematical cuts on final state particles

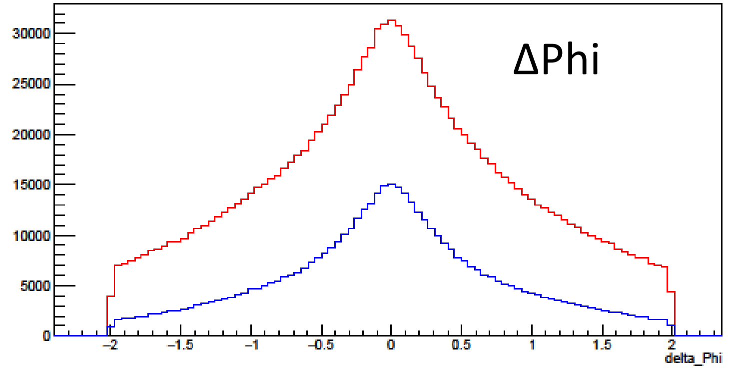
```
strip_Q2>1.0      strip_W>1.6      strip_Pr_P>0.3      strip_El_P>1.0
strip_Ph1_E>0.3   strip_Ph2_E>0.3
```

- ep gamma gamma exclusivity cuts

```
abs(mm2_epgg_p)<0.05   theta_pi0_X<5       abs(deltamm2_pi0_X)<0.7
abs(delta_Phi)<5       abs(delta_t)<0.5
```







Partial cuts

Total cuts

Modelling the missing mass for statistical background subtraction

- Procedure: model different contributions to data distribution on a variable which is not correlated (or weakly correlated) to physical observable to be measured
  - Missing Mass (MM) distribution

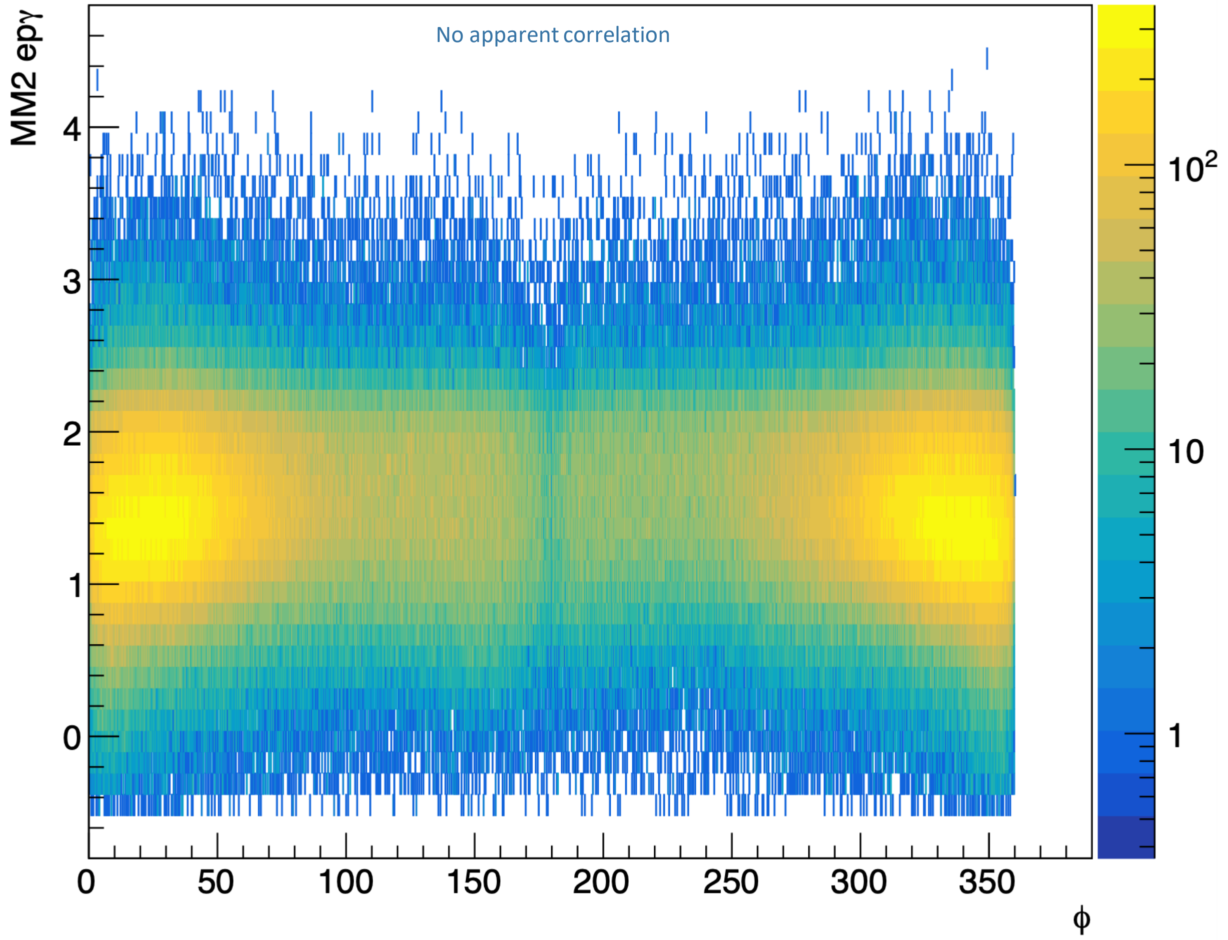
- Statistically unfold contribution based on used model for each species

- Propagate weights to observable of interest and work with background-free distribution of physical observable

Nucl.Instrum.Meth.A 555 (2005) 356-369

arXiv:0905.0724

pDVCS



The method

Estimate different contributions from background sources to distribution A

Evaluate weights to events based on the model chosen for each species

Propagate weights to other uncorrelated distributions

Plot distribution B with weights evaluated on distribution A

If weights chosen are those of signal: the obtained B distribution would be background free

Distribution A

No correlation

Distribution B

- Method largely used in high energy physics as a way of statistically unfolding distributions and subtracting background
- Associated systematics are known and relatively easy to calculate

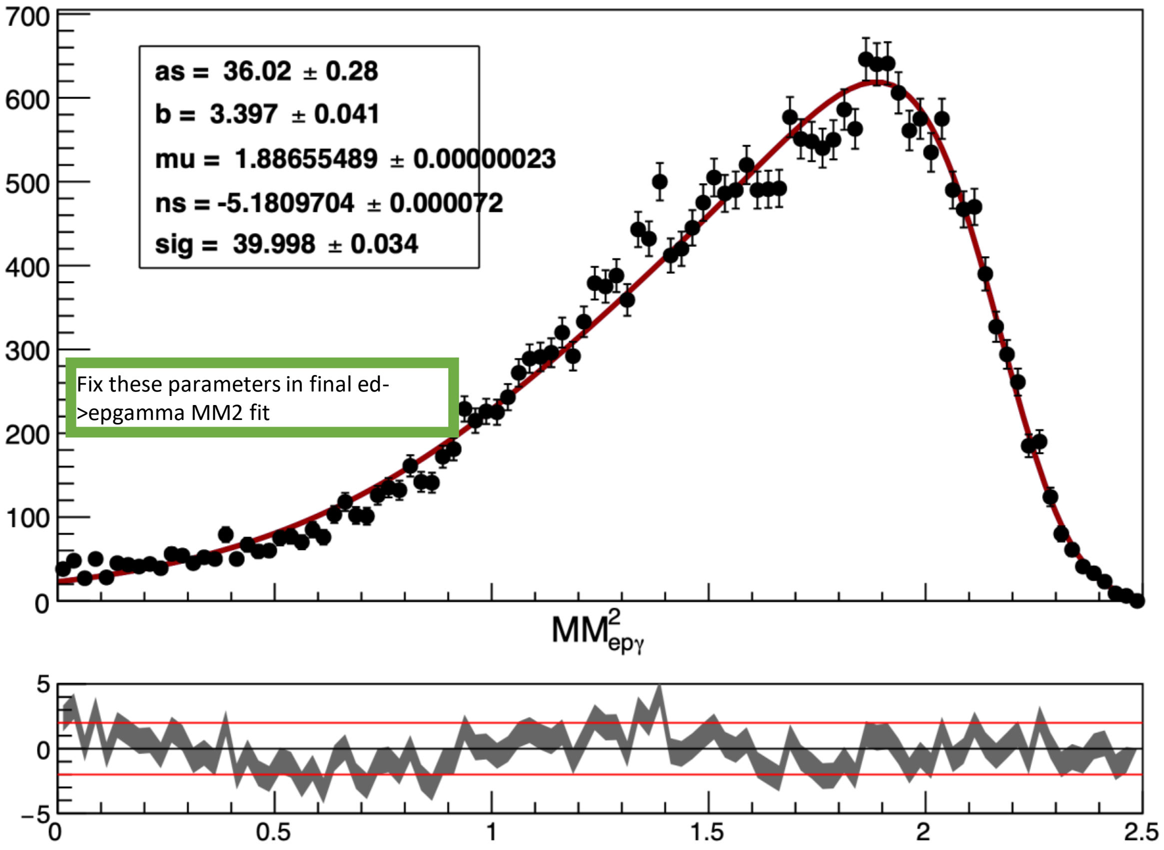
Modelling the missing mass for statistical background subtraction

Need to know all the contributions to the MM spectrum

- Signal: model a priori determined with recurrence to Simulations
- Possible backgrounds:
  - Combinatorial (under test): random association of final state particles mimicking signal decay (modelled with a polynomial)
  - Partially reconstructed ep gamma (gamma): ed->ep pi0 decay where one of the photons is considered in the reconstruction of the ep gamma final state (next slides)

$Partially\ reconstructeded \rightarrow ep\pi^0$
$ed \rightarrow ep\pi^0(1\gamma)$

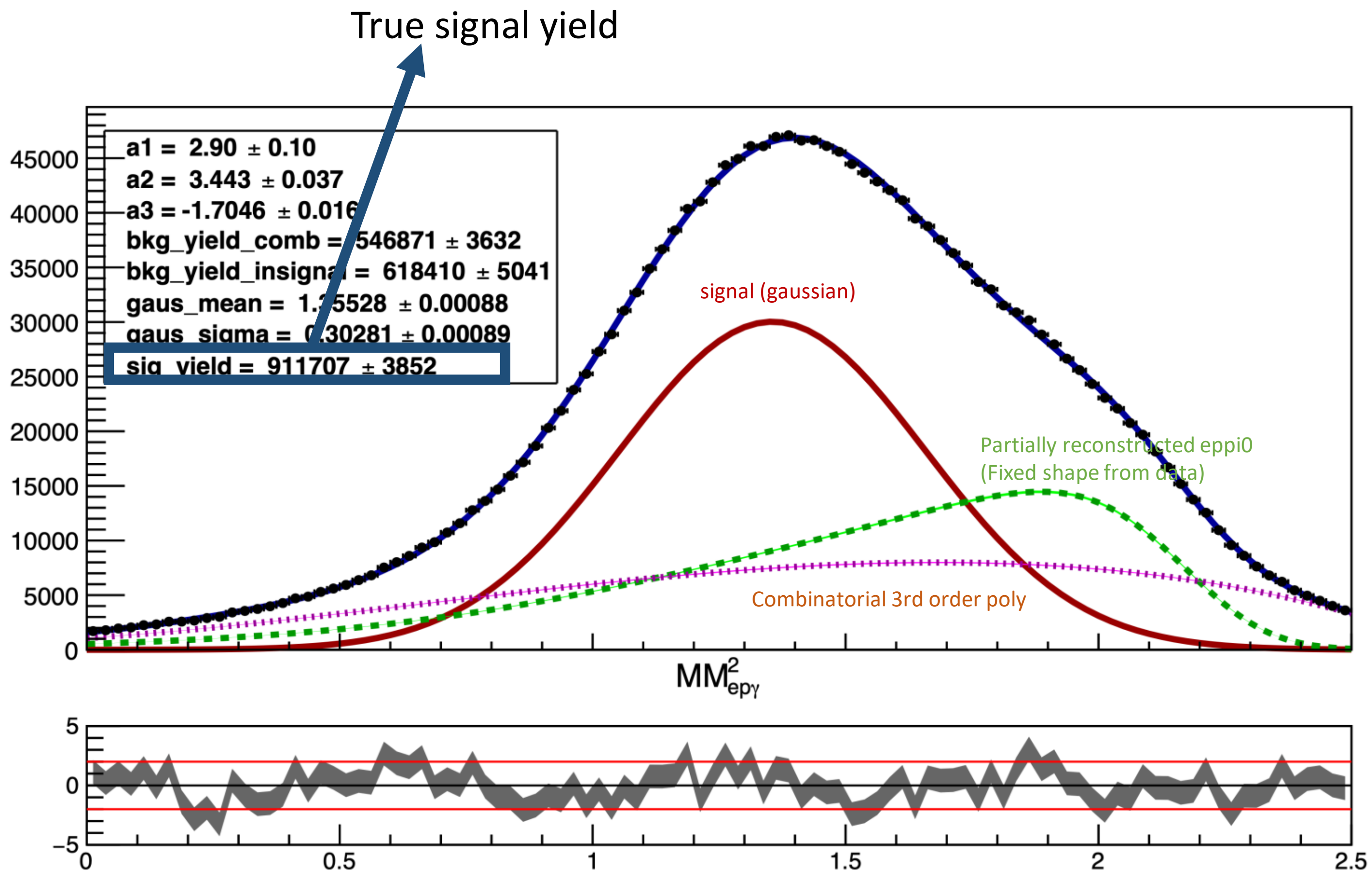
- Reconstruct pi0->gamma gamma in the event with the same cuts as for ep->ep gamma gamma decay
- But: build the decay tree as (ep->ep gamma) by virtually dropping one of the photons from the final state
  - Require that at least one of the photons has energy>2 GeV (to imitate signal pDVCS)
  - Apply pDVCS exclusivity cuts
- Model the partially reconstructed decay with an Apollonios function directly on data
  - Unbinned Maximum Likelihood extended fit
- Region of interest in mass 0<mm2<2.5 (GeV2)



$$\mathcal{A}(t) = e^{-b\sqrt{1+\frac{(t-\mu)^2}{\sigma^2(as,ns,sig)}}}$$

ed->epgamma MM2

- Unbinned Maximum Likelihood extended fit
- Up till now, all estimation are data driven
- Signal shape directly evaluated on data: only one contribution left!
  - Used different models: CB, double CB, bifurcated CB, Bifurcated Gaussian, Apollonios
- Systematic related to this method: the choice of the fitting model



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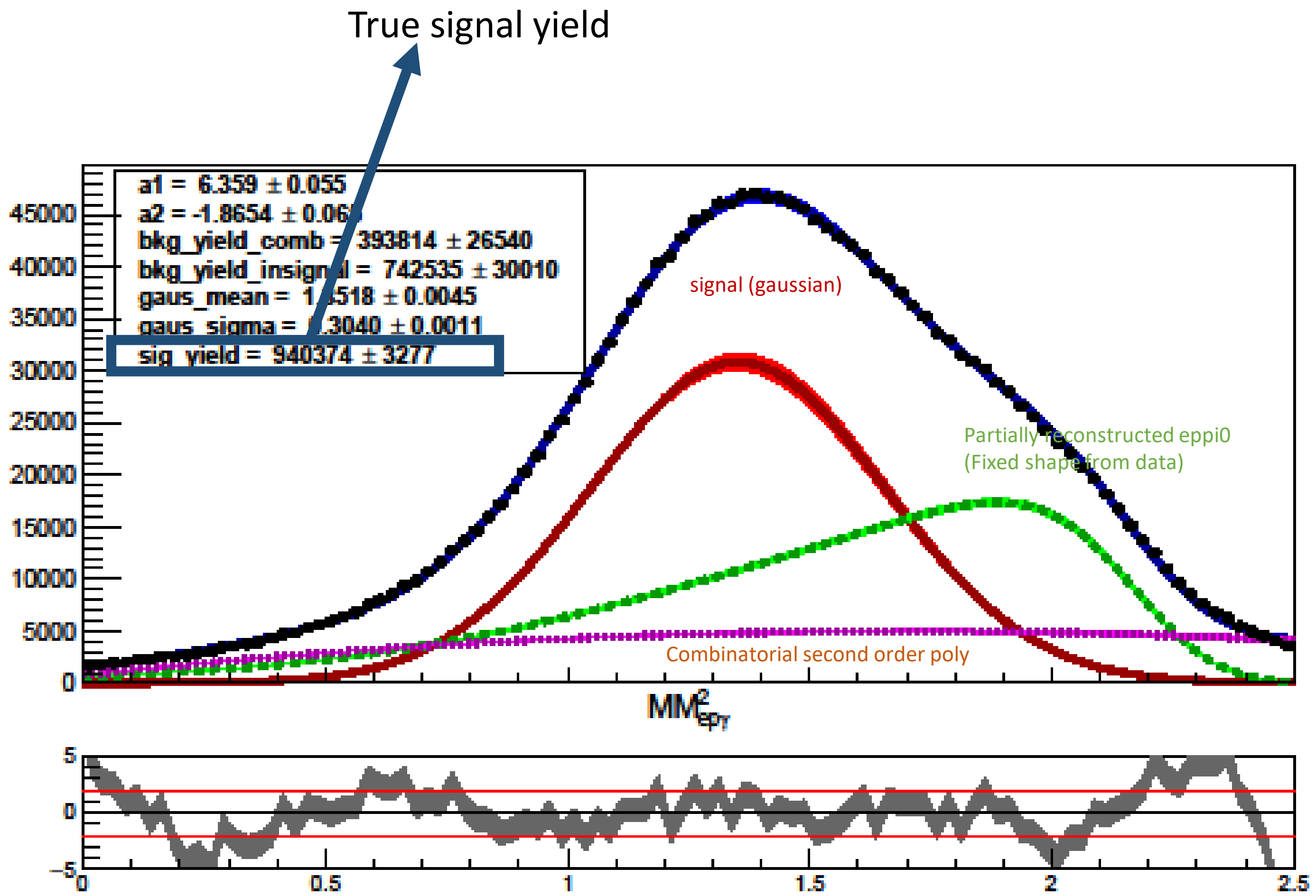

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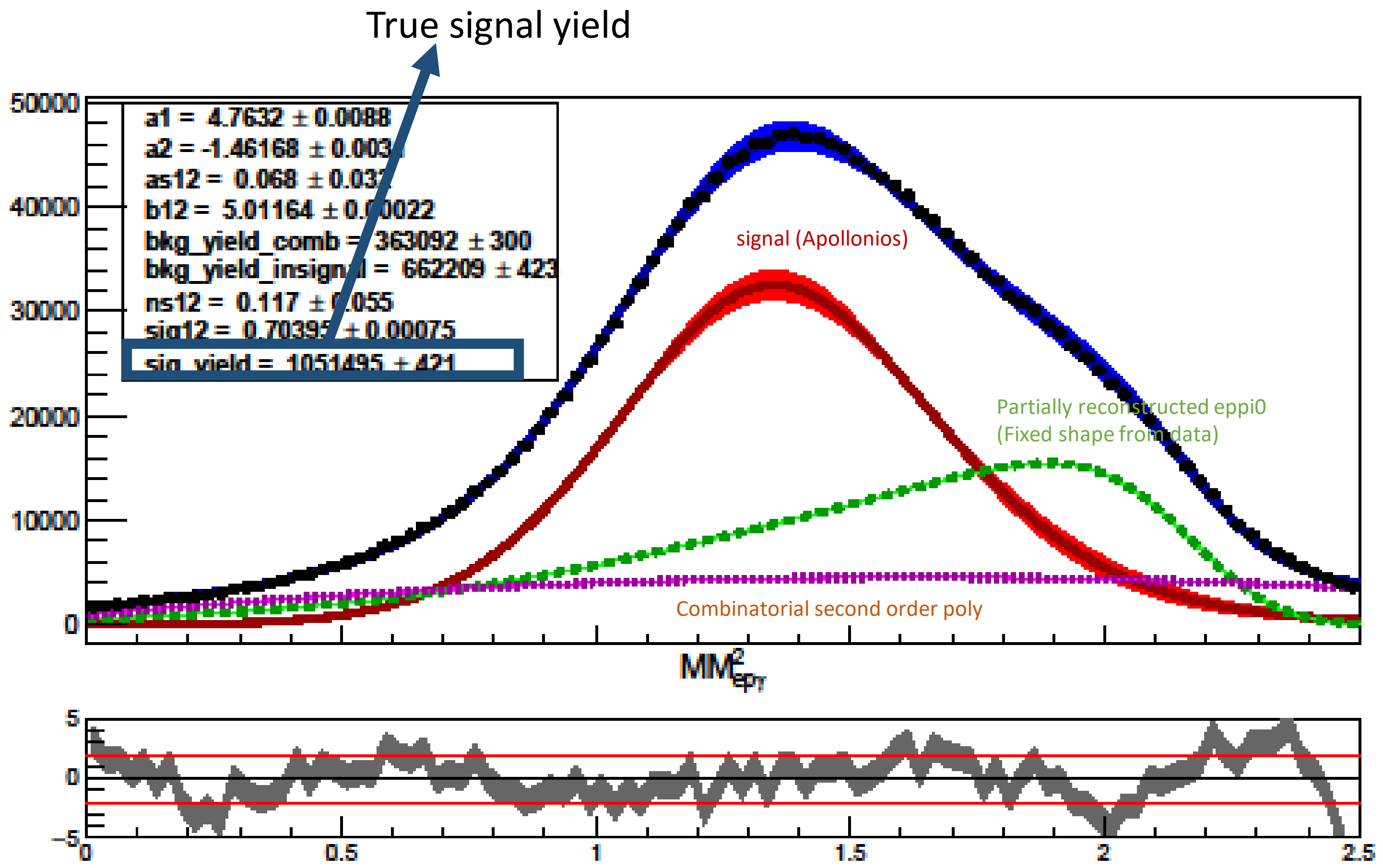

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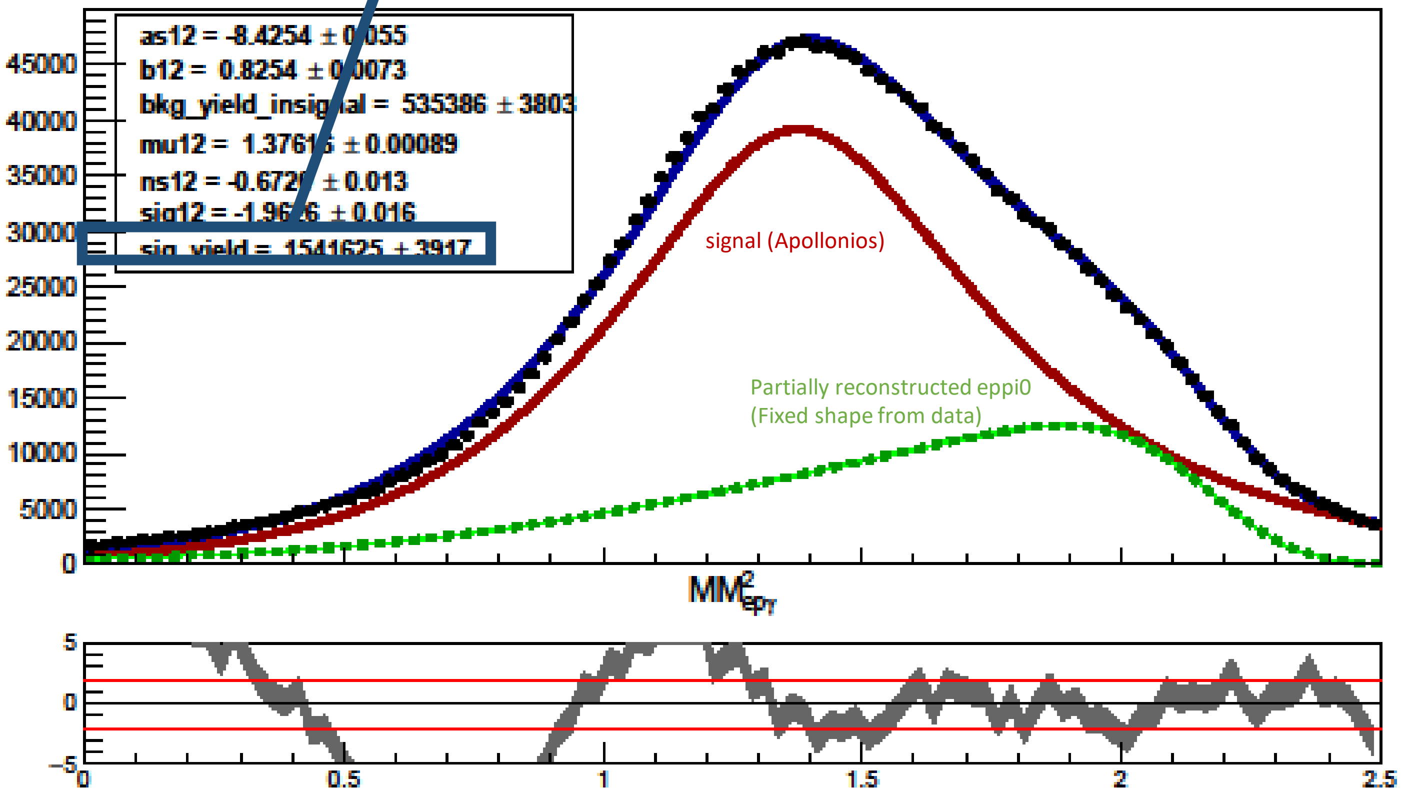
True signal yield

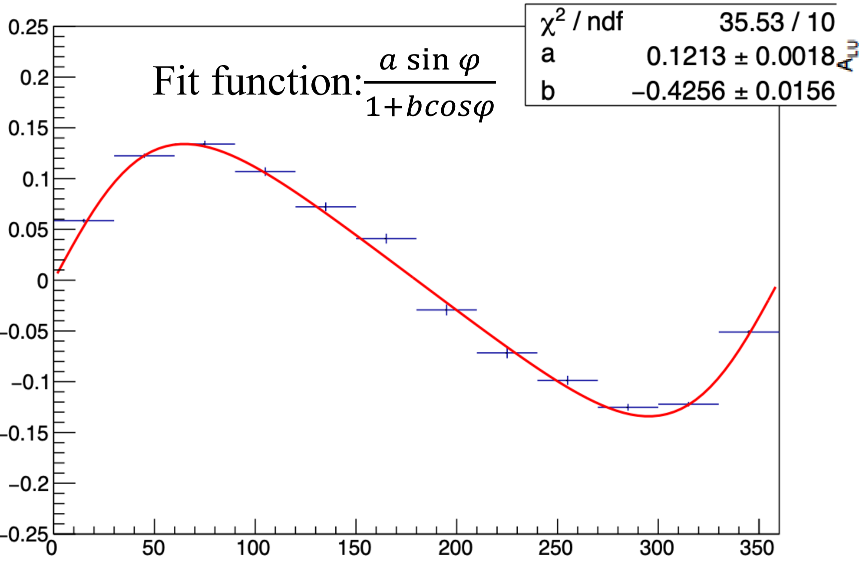


Modellling background is a cross check test of exclusivity selection

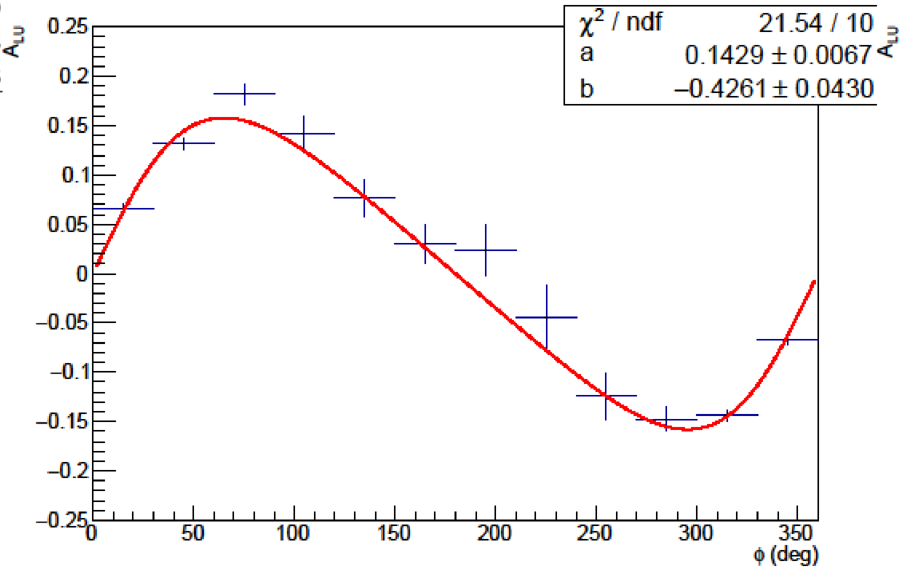
No combinatorial

BSA after background subtraction: all topos integrated

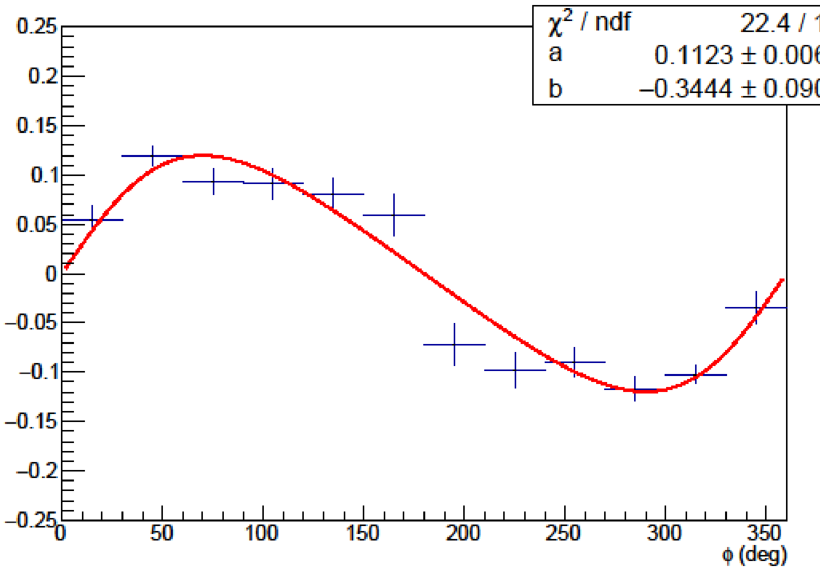
pDVCS before background subtraction



pDVCS after background subtraction



BSA of eppi0(partially reconstructed) sample



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

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
- With the whole collected data treated: a factor ~1.5 improvement in precision

What is missing

- Corrections to final state particles momenta: ongoing work by Paul Naidoo
- Crosscheck of neutral pion background subtraction with traditional method
- For nDVCS, estimate and remove proton contamination in neutron sample: a neural net based method is under study
- Systematics …