IJCLab - Orsay

Measurement of DVCS observables with eγ detection

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CLAS collaboration meeting

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INTRODUCTION

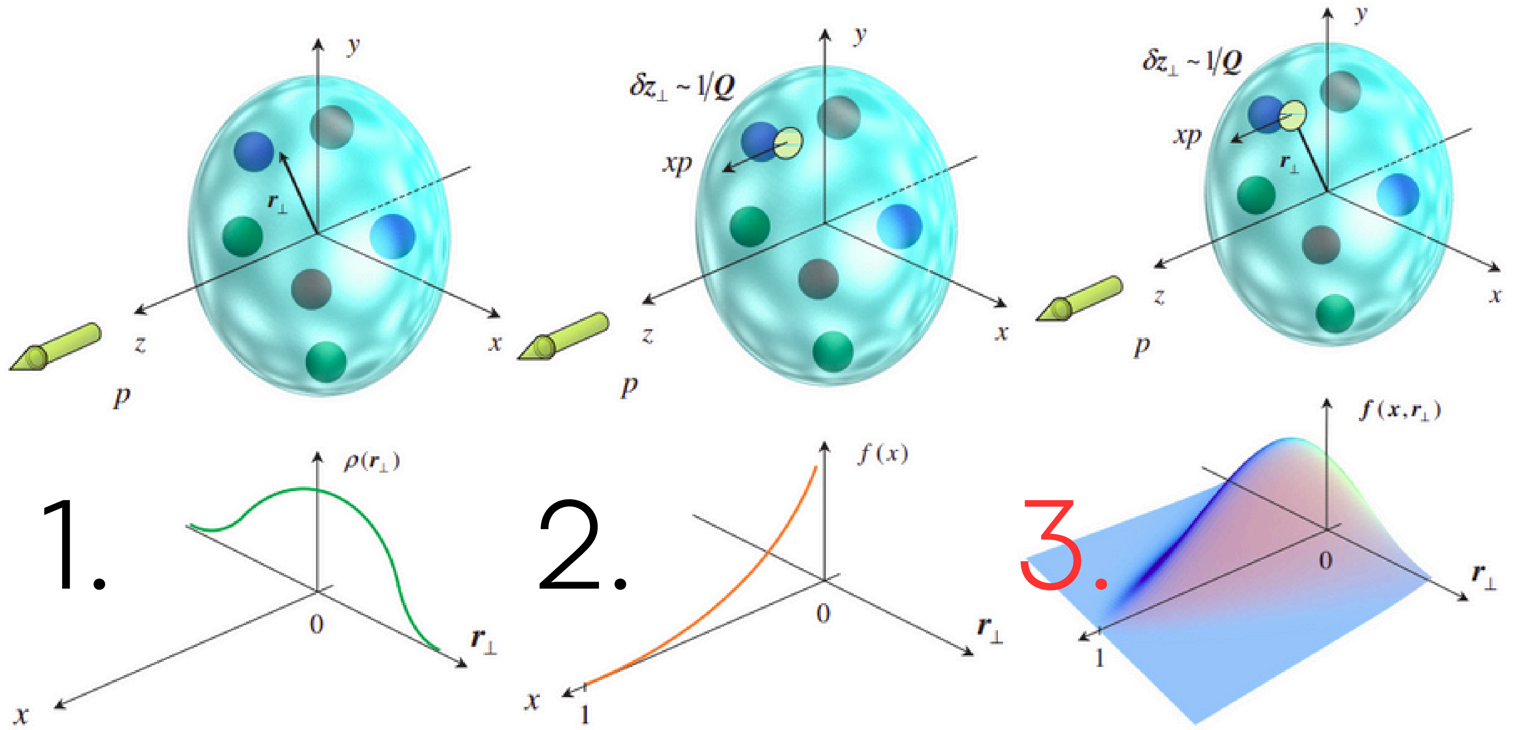
Generalized Parton Distributions

Motivation

1. INTRODUCTION

At low energy QCD, we describe the nucleon structure in terms of structure functions including:

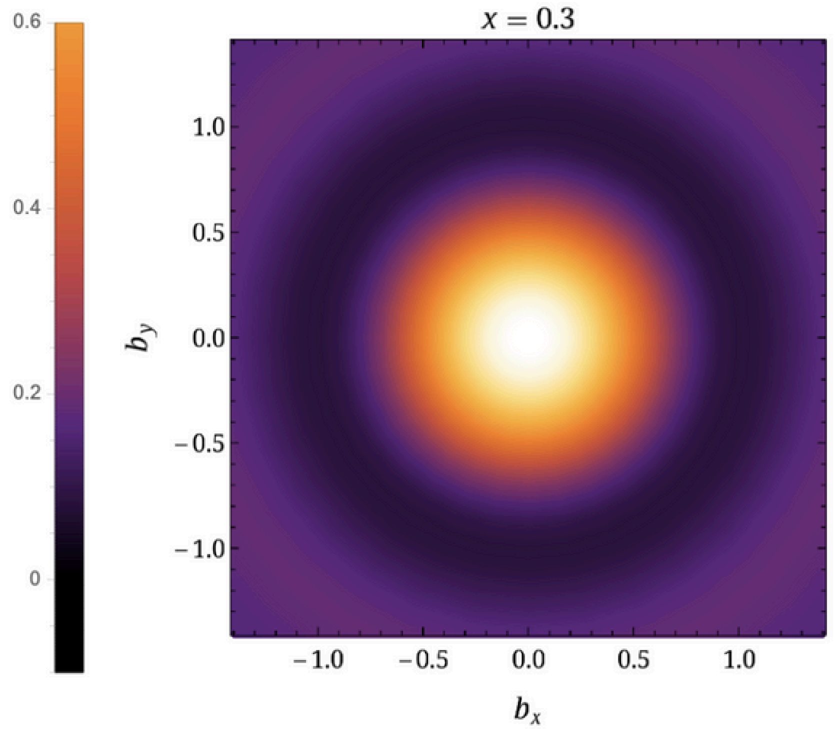
1. Form Factors describe transverse position of partons
2. Parton Distribution Functions describe longitudinal momentum distributions
3. Generalized Parton Distributions (GPDs) correlates transverse position and longitudinal momentum distributions



GPDs encode information of the nucleon structure such as:

Nucleon Tomography

H.W. Lin, Phys. Rev. Lett. 127 (2021) 182001.



Contributions to the nucleon total spin.

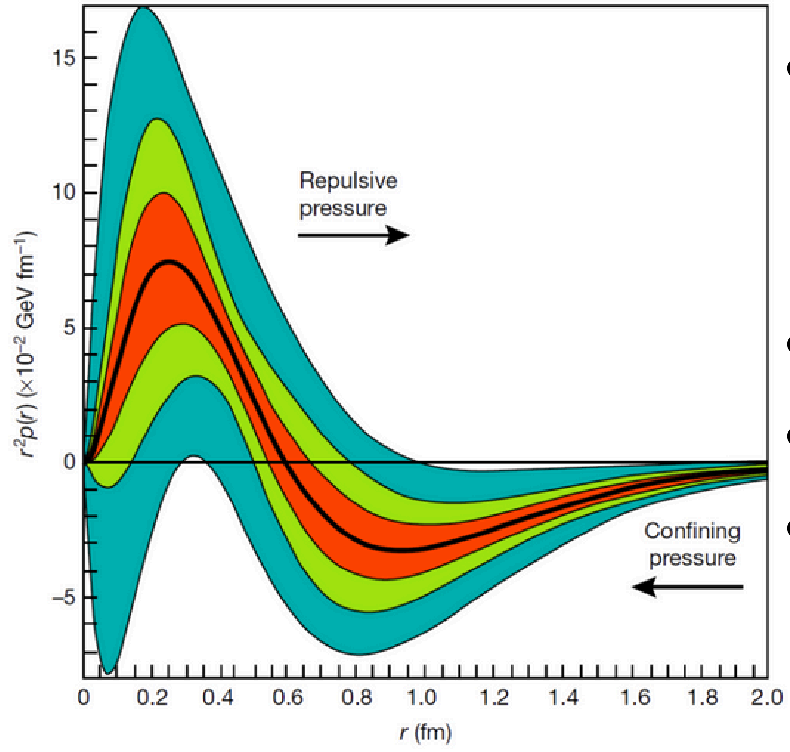
X. Ji, Phy.Rev.Lett.78,610(1997)

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta L + \Delta G$$

- Quark contribution is not the main contribution →Spin Crisis
- Quark's orbital angular momentum is accessed through GPDs
- Gluon contribution

Access to Gravitational Form Factors.

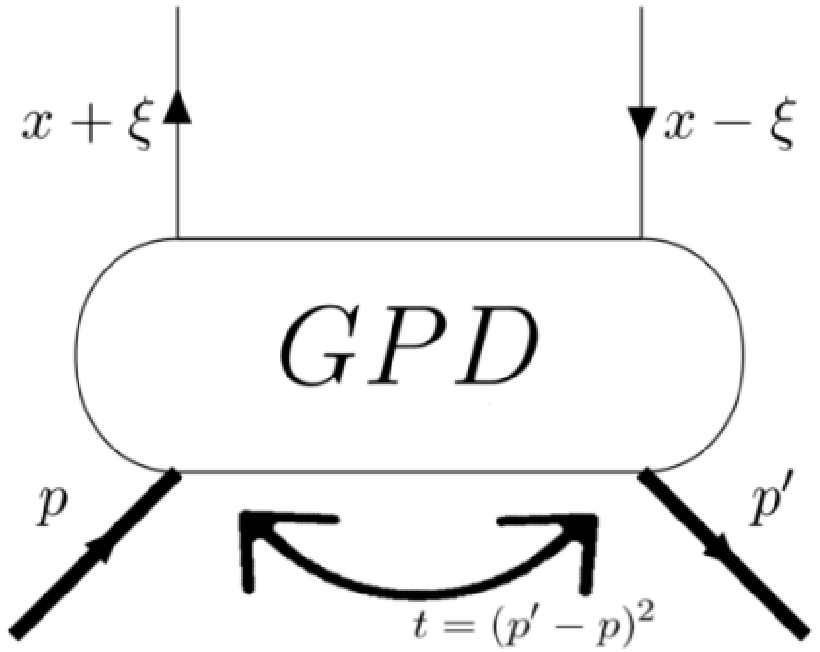
V. D. Burkert *et al*. Nature 557.7705 (2018): 396

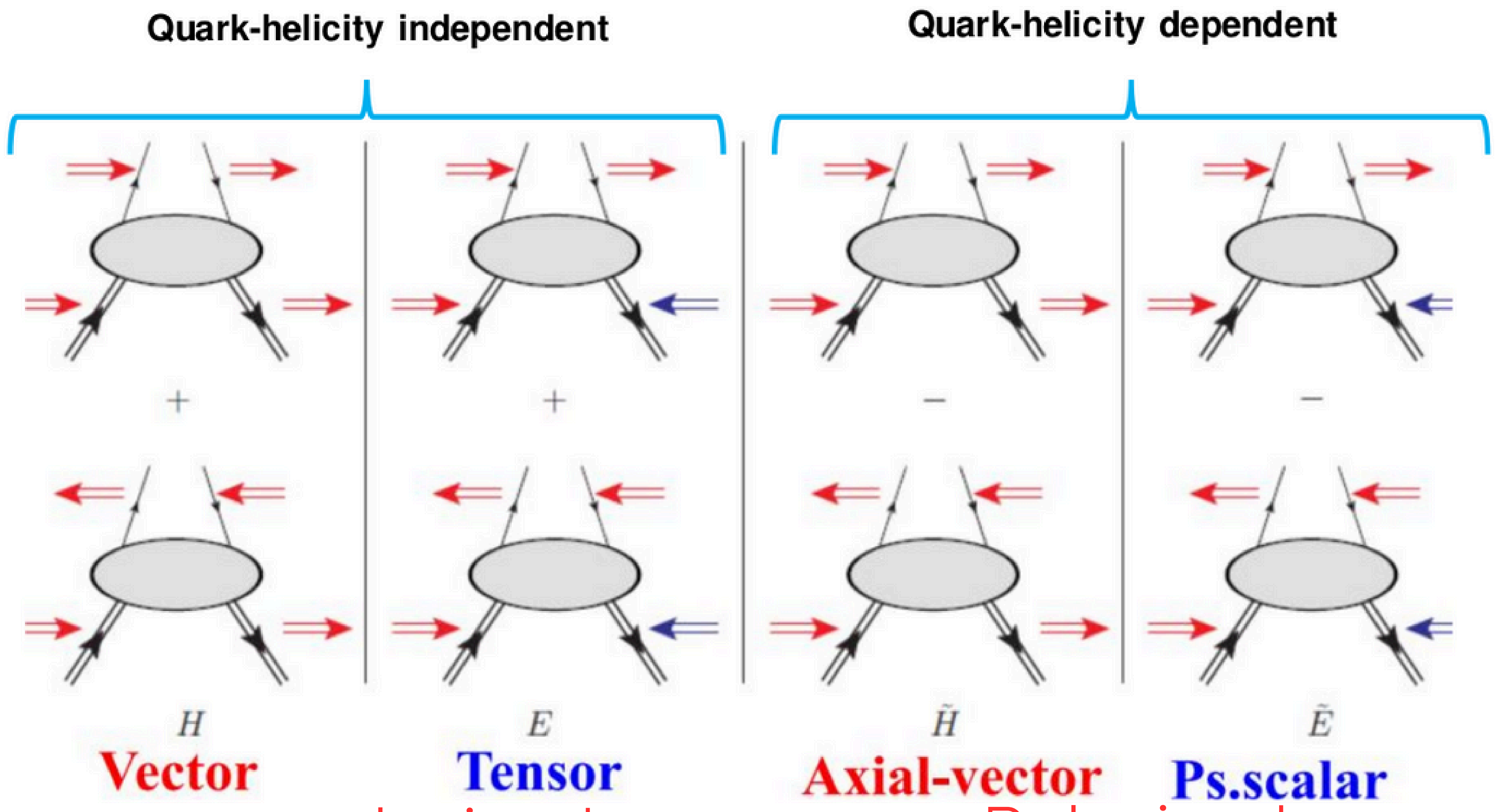


- Mass/Energy distribution inside the nucleon
- Forces distribution.
- Nucleon radius
- Shear forces and pressure distribution

1. INTRODUCTION

GPDs depend on x, ξ and t = (p′ − p) 2





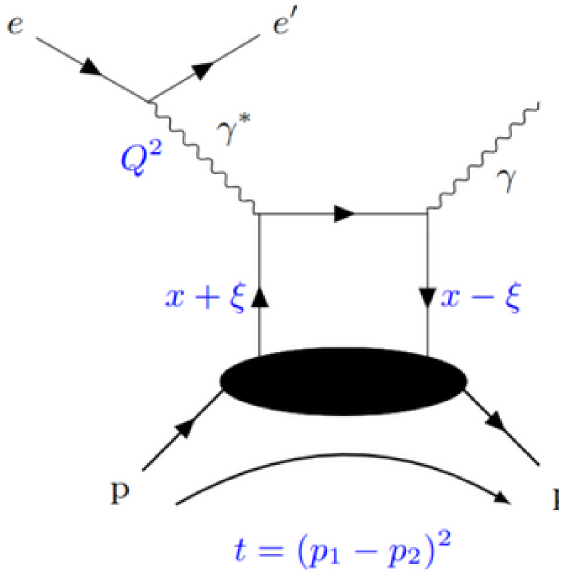
unpolarized

Polarized

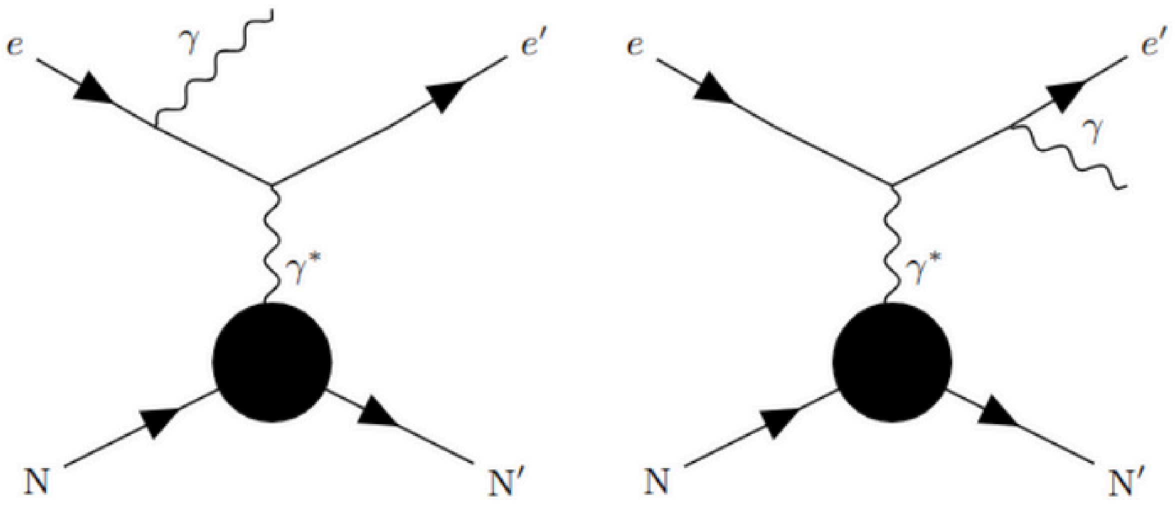
For a spin $\frac{1}{2}$ particle, there are four chiral-even GPDs

$$F = H, E, \tilde{H}, \tilde{E}$$

The proton chiral-even GPDs can be accessed via electro-production of a real photon.



DVCS



BH

GPDs enters the DVCS-BH interference term through **Compton Form Factors**

$$\mathcal{F}(\xi,t) = \sum_q e_q^2 \left\{ \mathcal{P}\int_{-1}^{1} dx\, F^q(x,\xi,t) \left[\frac{1}{x-\xi} + \frac{1}{x+\xi}\right] - i\pi \left[F^q(\xi,\xi,t) - F^q(-\xi,\xi,t)\right] \right\}$$

which are measured in the Beam Spin Asymmetry

$$\mathbf{BSA} = \frac{1}{P_{\text{beam}}} \frac{d^4\sigma^+ - d^4\sigma^-}{d^4\sigma^+ + d^4\sigma^-}$$

$$\propto \Im\mathfrak{m} \left\{ F_1 \mathcal{H} + \xi'(F_1+F_2)\widetilde{\mathcal{H}} - \frac{t}{4M_N^2} F_2 \mathcal{E} \right\},$$

1. INTRODUCTION

1. Detecting the proton is ideal, but by not detecting it:

- There is access to the small $-t=(p-p')^2$ region
- Larger statistics can be achieved, as the proton is not constrained by detector acceptance
- It is complementary to the existing measurements and studies:
  - pass1 BSA RG-A results [Christiaens, G., et al. Phys. Rev. Lett. 130.21 (2023): 211902.]
  - pass1 cross-section measurements (Sangbaek)
  - pass2 BSA with proton detection (Timothy)

2. However,

- There are background contributions from the whole SIDIS spectra.
- There are reduced options for cuts. Missing proton mass is the only exclusivity variable available

3. Therefore,

- We move to a ML approach for channel selection.
- It is first validated by including the proton information. Then applied to the no-proton case

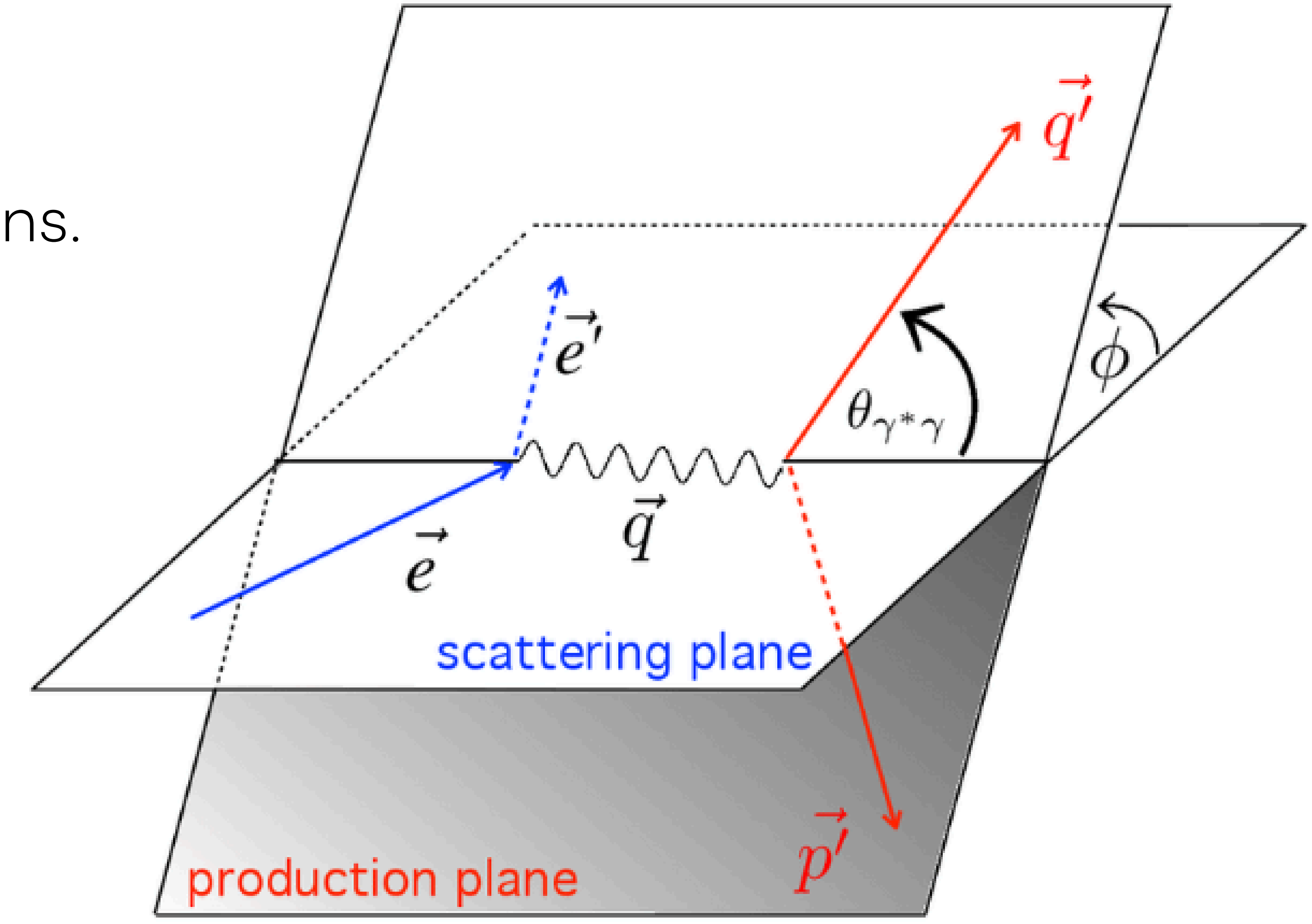
2

DATA SELECTION

2. DATA SELECTION

Data from the fall-2018 RG-A dataset.

- Inbending and outbending torus configurations.
- Pass-2 reconstruction



KINEMATICS

- W>2 GeV
- Q^2>1 GeV^2
- q′ >2 GeV
- e′>1 GeV
- (p′ > 0.3 GeV)

EXCLUSIVITY CUTS (if proton detected)

- $\Delta\phi=|\phi(p')-\phi(\gamma)|<2°$
- $\Delta t=|t(p')-t(\gamma)|<2$ GeV^2
- Pmiss<1 GeV

$\phi(p')$ uses γ^* and p′

$\phi(\gamma)$ uses γ^* and γ

$t(p') = (p-p')^2$

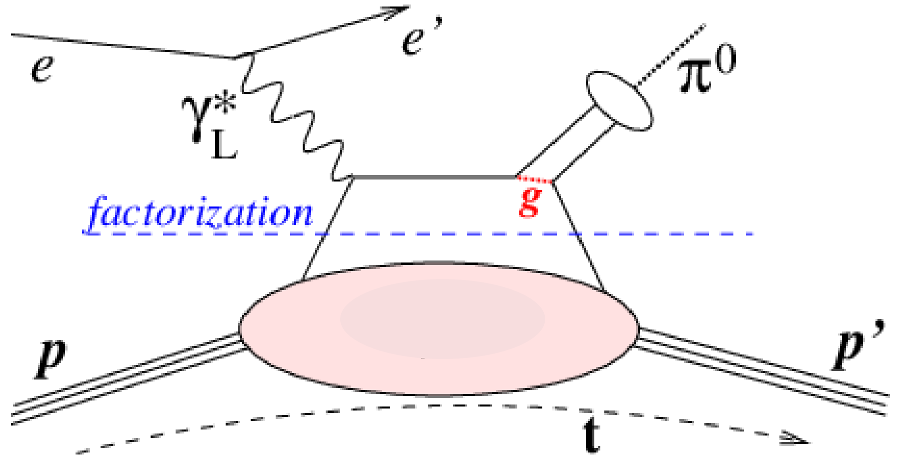
$$t(\gamma) = \frac{Q^2 M_p + 2\nu M_p \left(\nu - \sqrt{\nu^2 + Q^2}\cos\theta_{\gamma^*\gamma}\right)}{\sqrt{\nu^2 + Q^2}\cos\theta_{\gamma^*\gamma} - \nu - M_p}$$

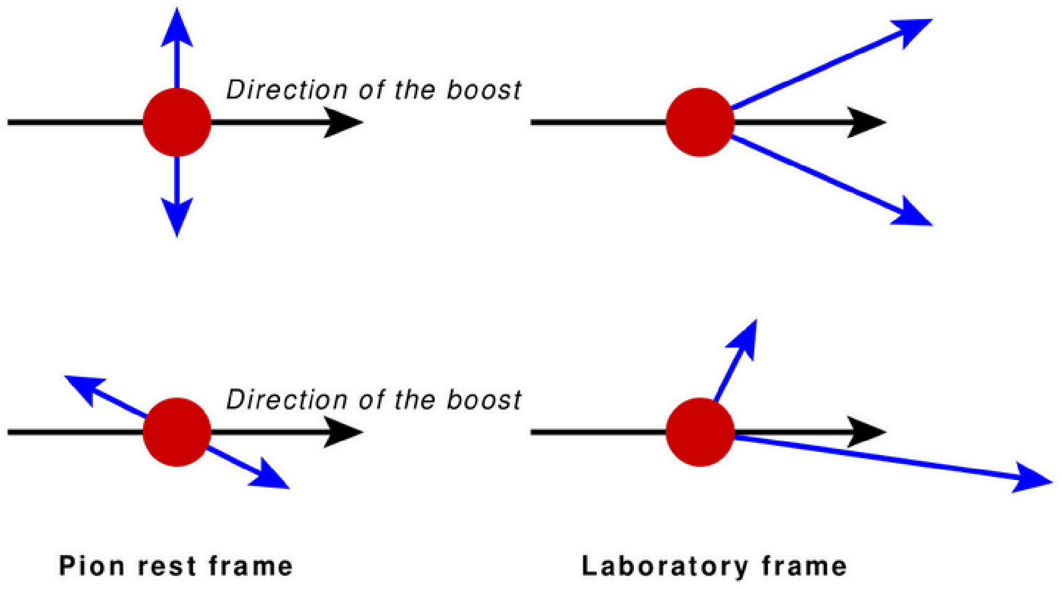
The event is built with the (e,γ,p) set with minimum missing ep → eγp missing mass

2. DATA SELECTION

The main contamination channel is exclusive π^0 production

$ep \rightarrow ep\pi^0 \rightarrow ep\ \gamma(\gamma)$

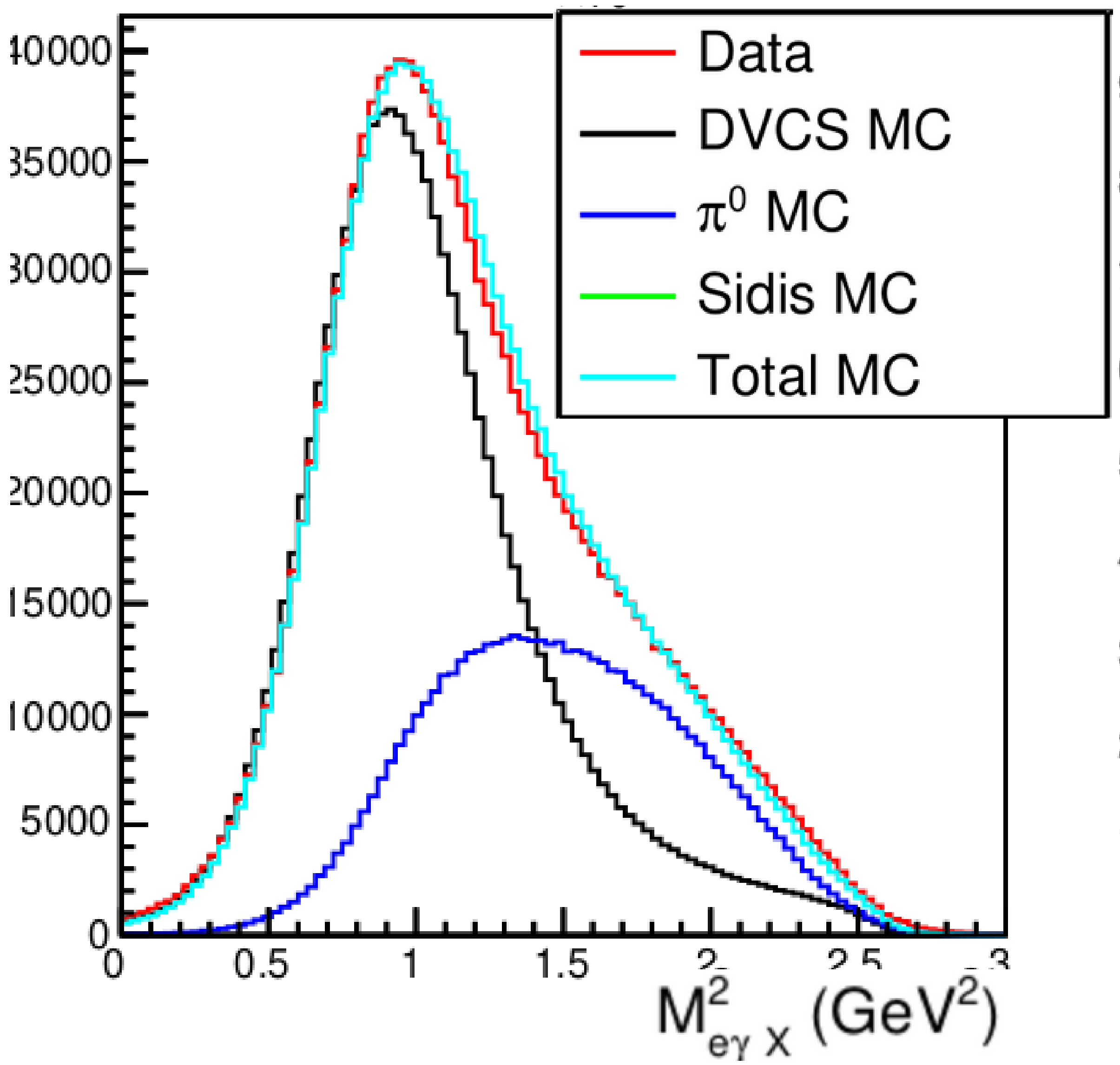


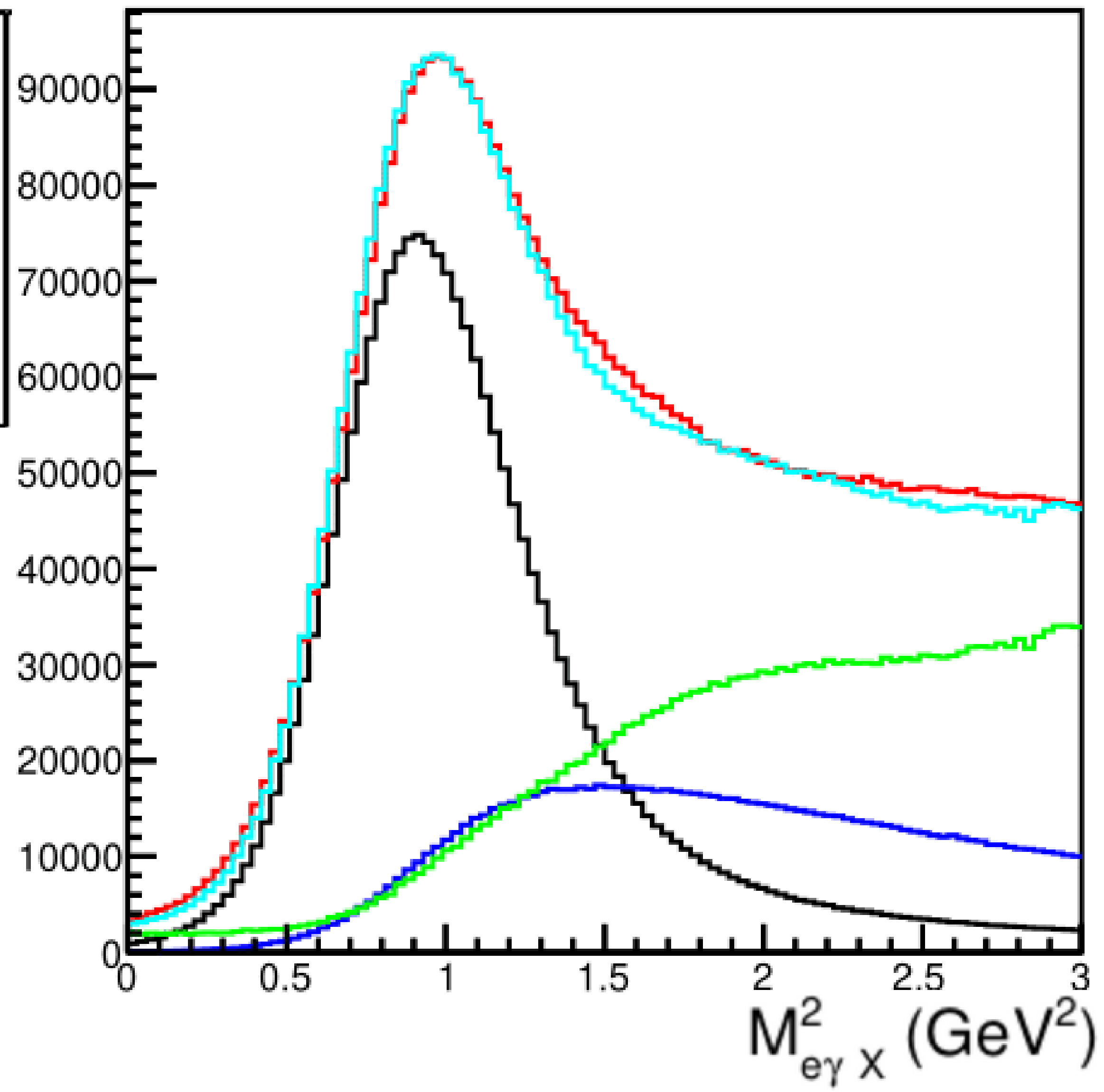


Missing proton mass distribution

$$M_{e\gamma X}^2 = (e + p - e' - \gamma)^2$$

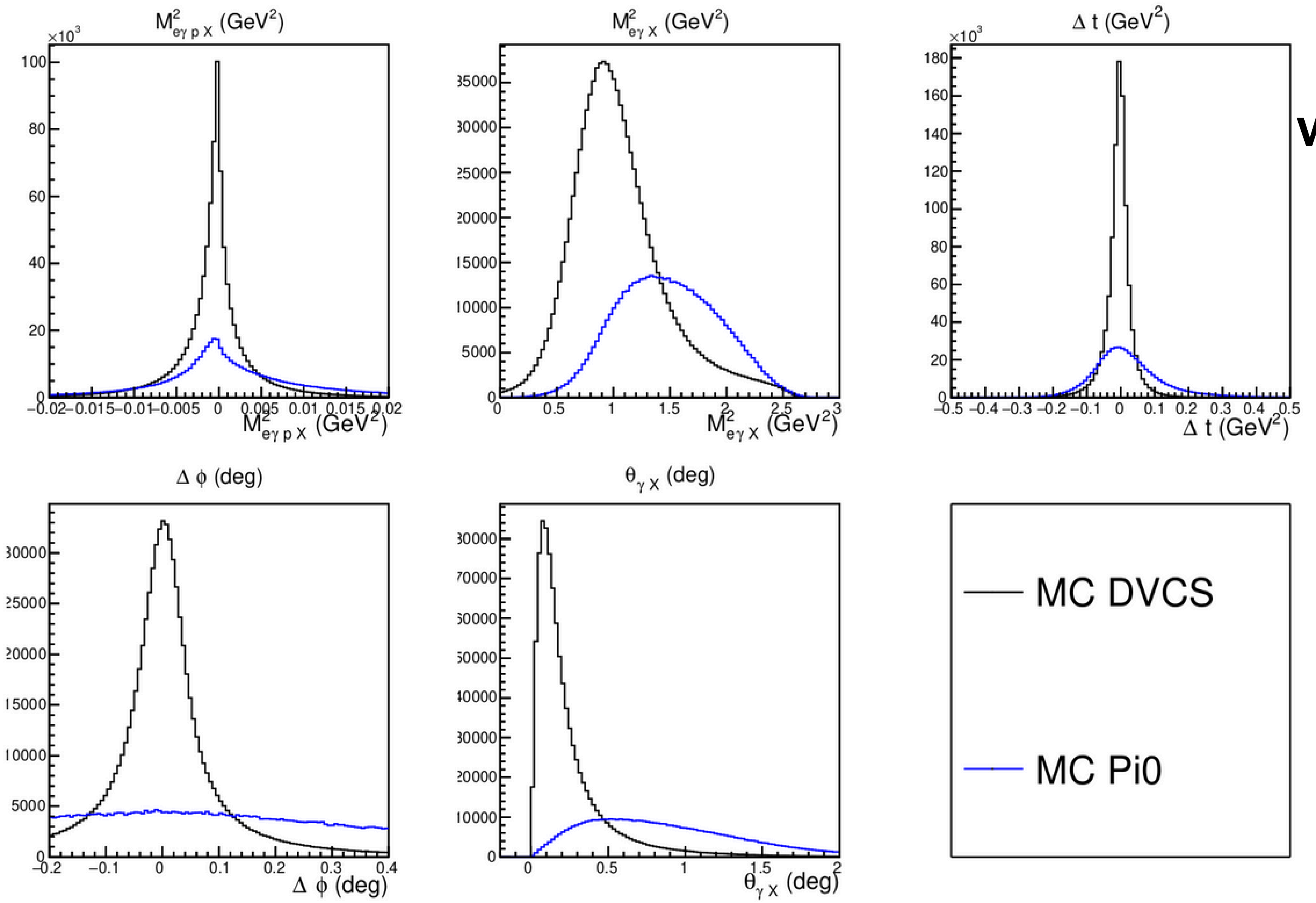
With proton **Without proton**

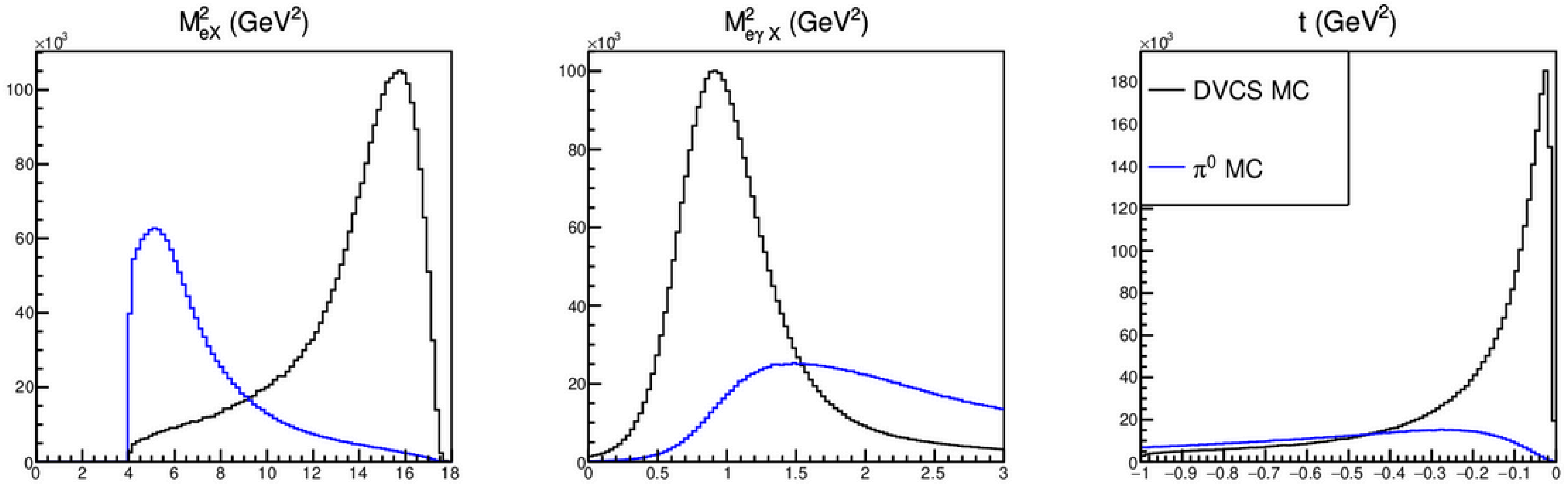




In the case of no proton detection, there is contamination from **inclusive** π^0 production in SIDIS

2. CHANNEL SELECTION

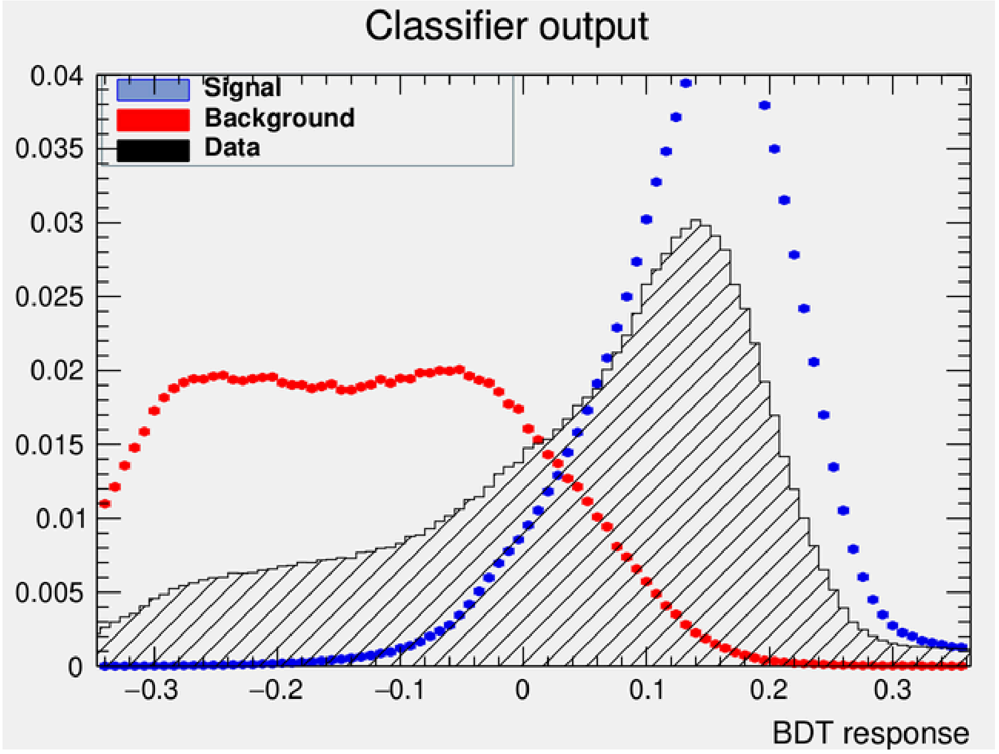




Instead of straight cuts on exclusivity variables,

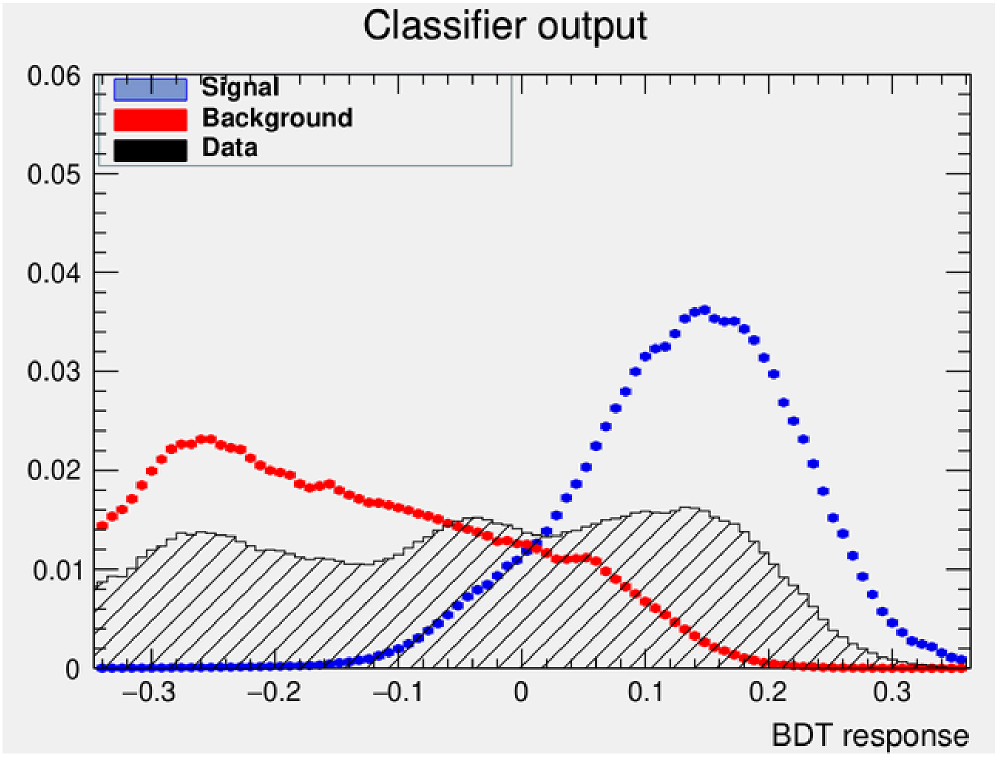
we optimize data selection with Boosted Decision Trees.

With proton



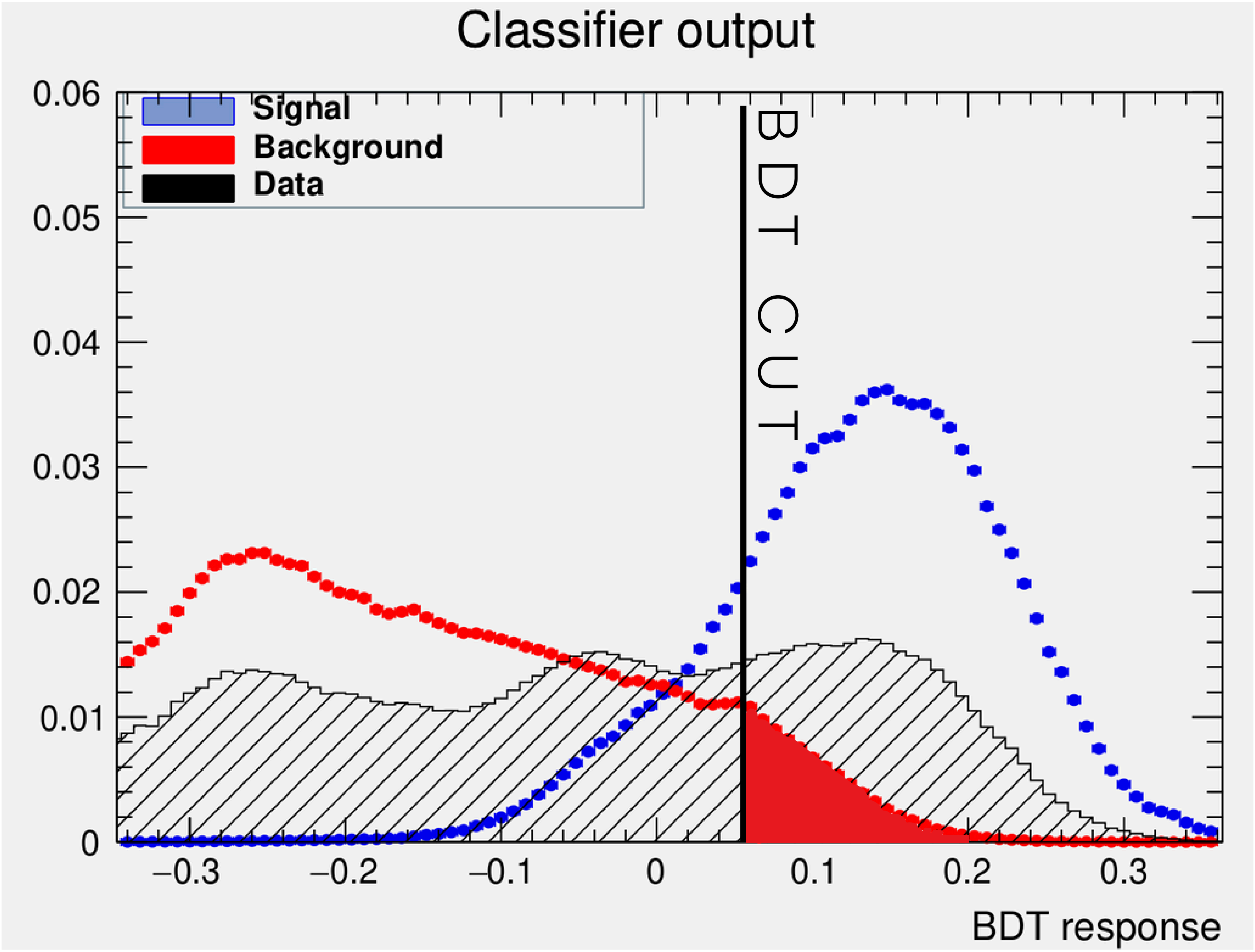
The following variables are used to train a BDT due to its DVCS/DVMP separation power.

W/out proton



After BDT classification, residual background is removed with well known methods

BDT classification leave a leftover contamination



The entirety of the background cannot be removed with a BDT

To estimate and remove the residual background, we estimate the **1γ/2γ - phase space ratio** using two methods

$$\frac{(N^{MC}_{DVMP})_{ep\to ep\gamma}}{(N^{MC}_{DVMP})_{ep\to ep\gamma\gamma}} = \frac{(N^{Data}_{DVMP})_{ep\to ep\gamma}}{(N^{Data}_{DVMP})_{ep\to ep\gamma\gamma}}$$

Method 1:

Let us define:

- $n^{1\gamma}_{MC/Data}$ = Number of simulated π^0 events that pass the DVCS analysis.
- $n^{2\gamma}_{MC/Data}$ = Number of simulated π^0 events that are reconstructed.

The contamination is then:

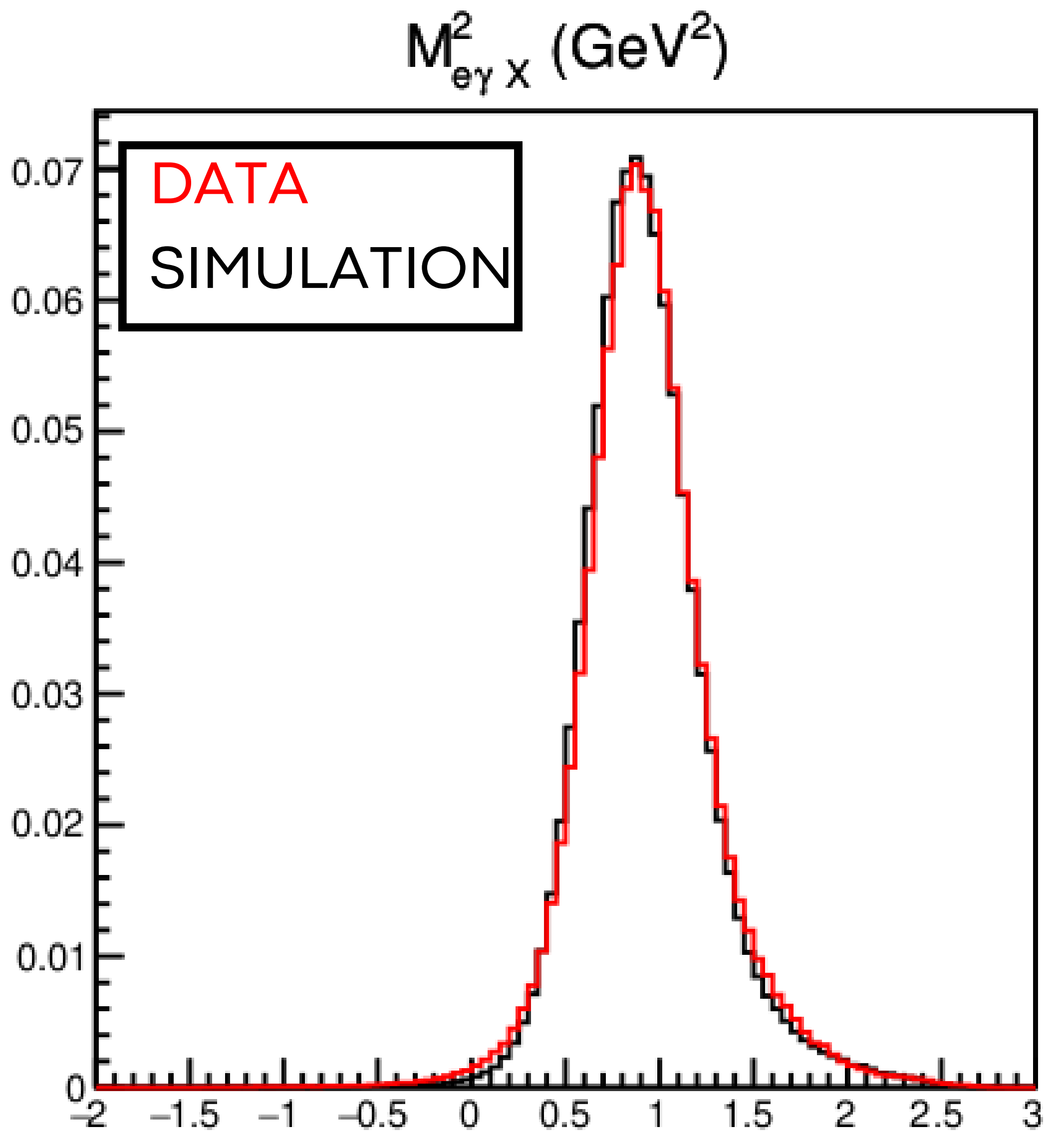
$$n^{1\gamma}_{Data} = \left(\frac{n^{1\gamma}_{MC}}{n^{2\gamma}_{MC}}\right) n^{2\gamma}_{Data}.$$

Method 2:

1. Reconstruct π^0 events.
2. For each π^0, generate 1500 decays.
3. If the event pass the DVCS analysis with any photon, fill histograms.
4. If the event pass the DVMP analysis, increment $n^{2\gamma}_{MC}$ by the reconstruction efficiency.
5. At the end of the decays, DVCS events are normalized by $1/n^{2\gamma}_{MC}$.

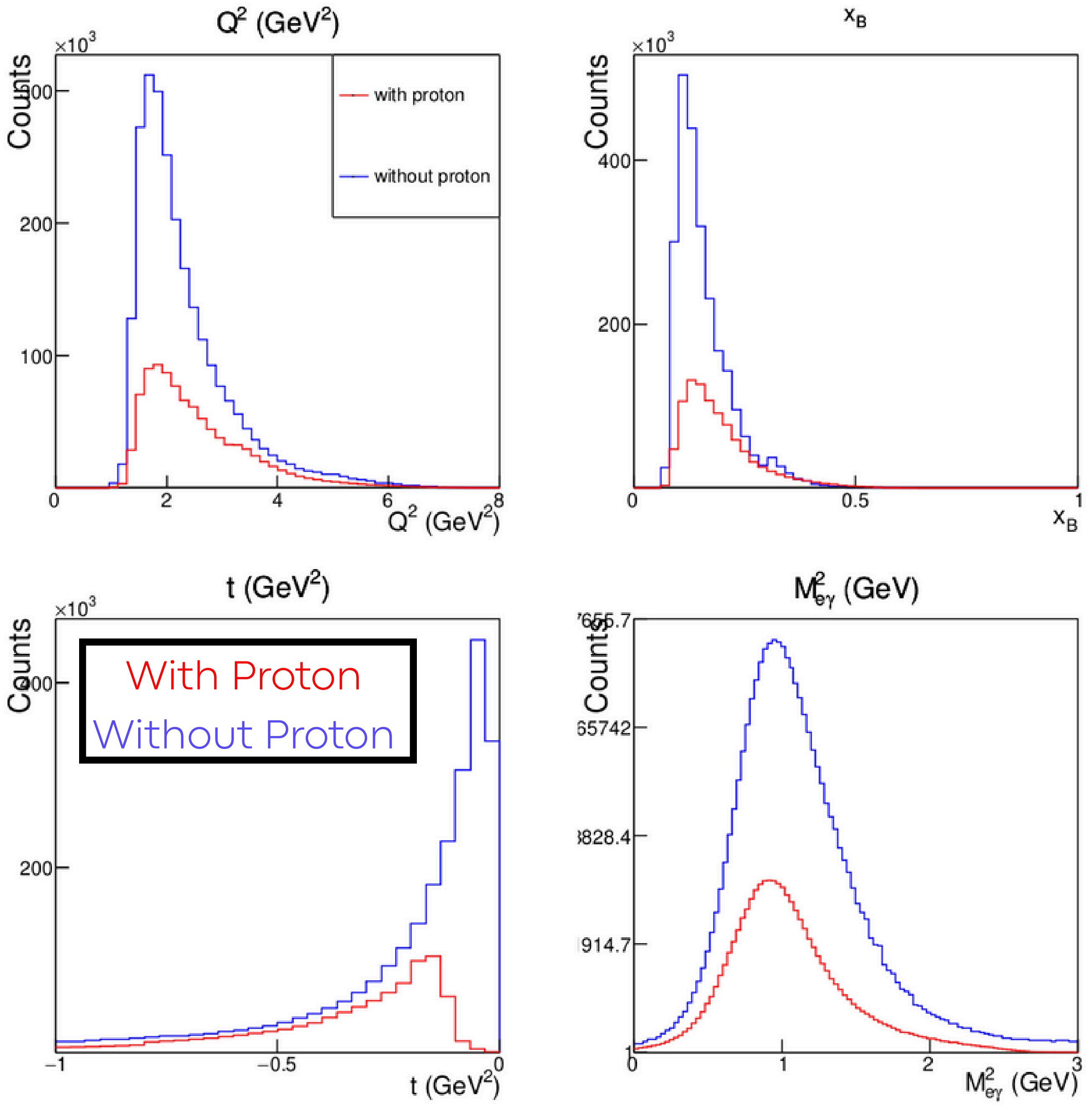
2. CHANNEL SELECTION

With proton



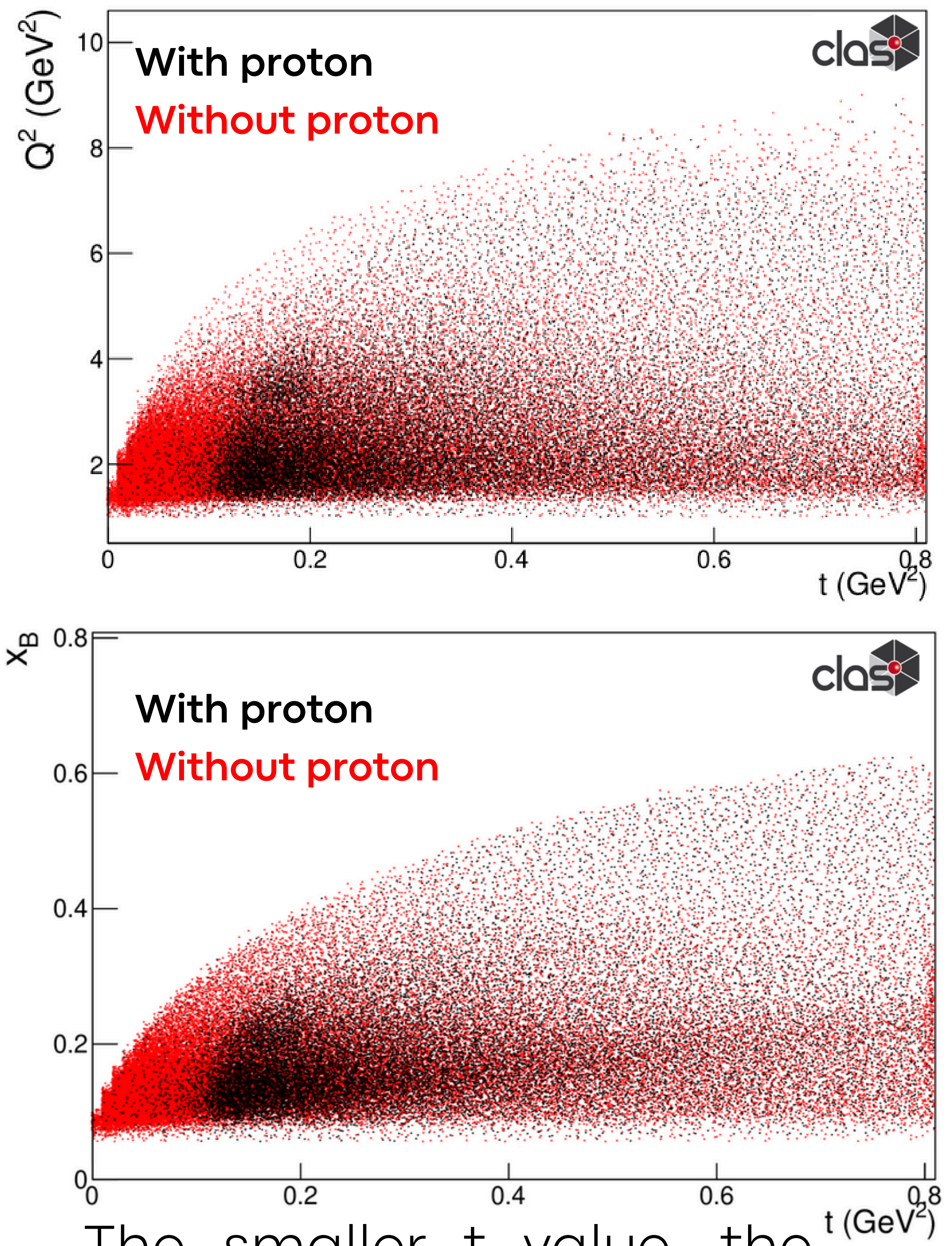
Most of the background was removed, leading to a good agreement between simulation and data.

Without proton



When not requiring a proton:

- Increased statistics
- Access to smaller -t values



The smaller t value, the better interpretation of DVCS in terms of GPDs!

3

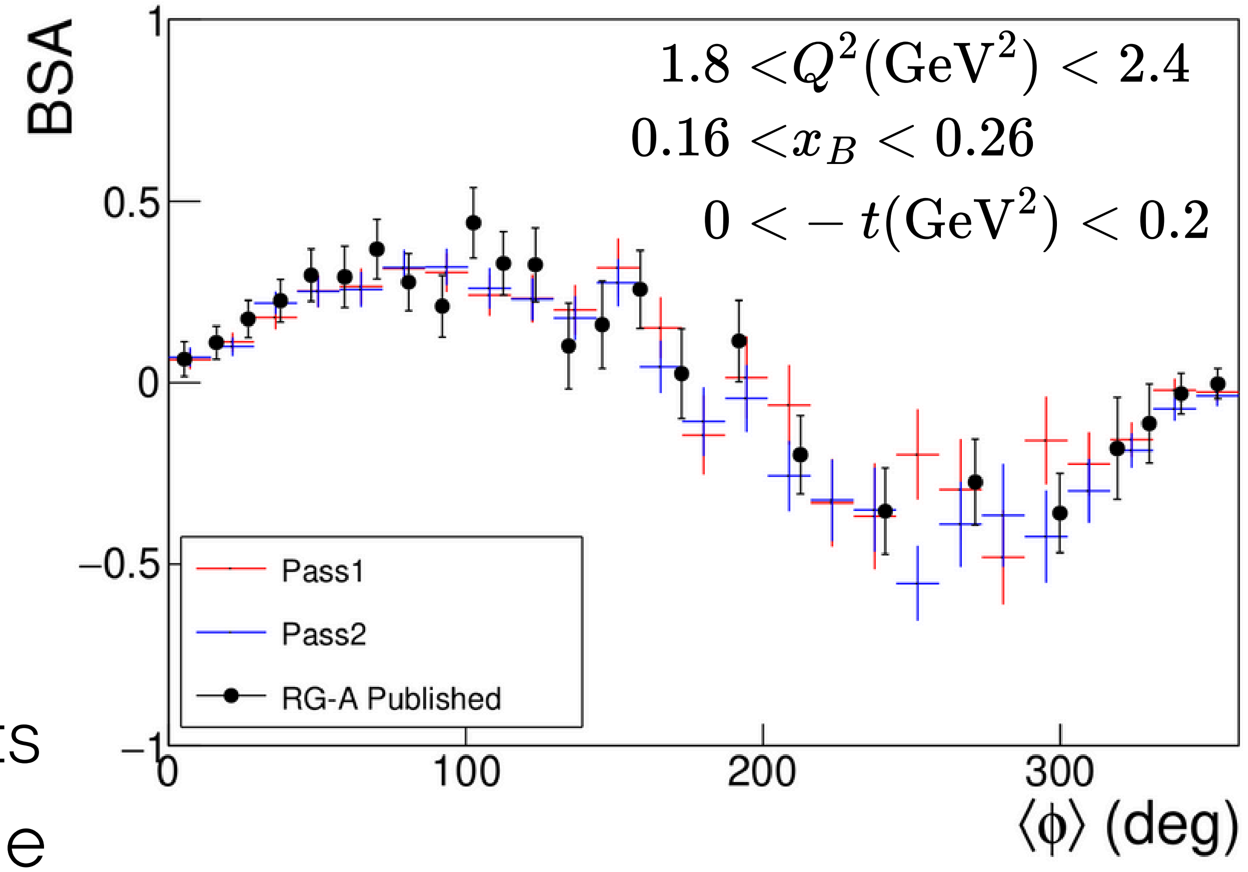
DVCS MEASUREMENTS

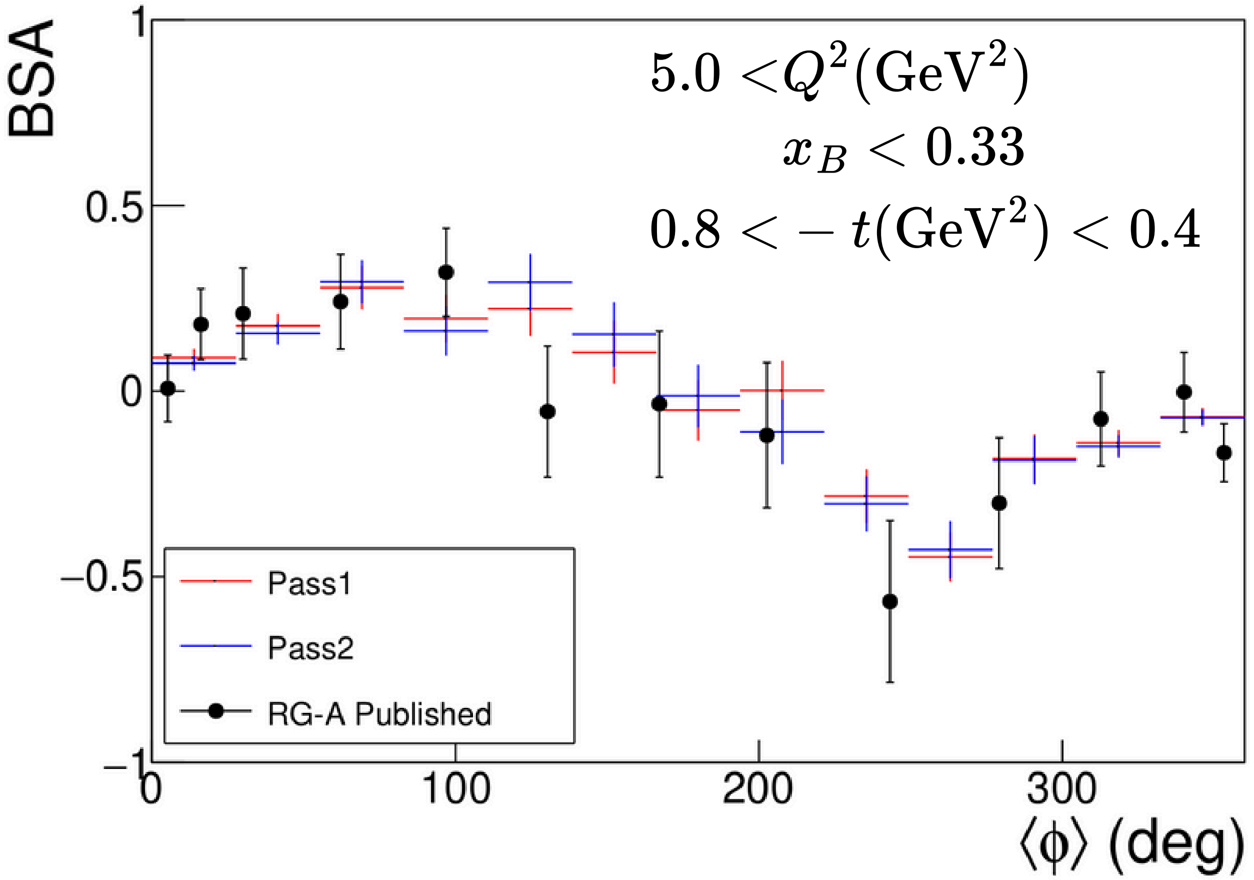
Beam Spin Asymmetry

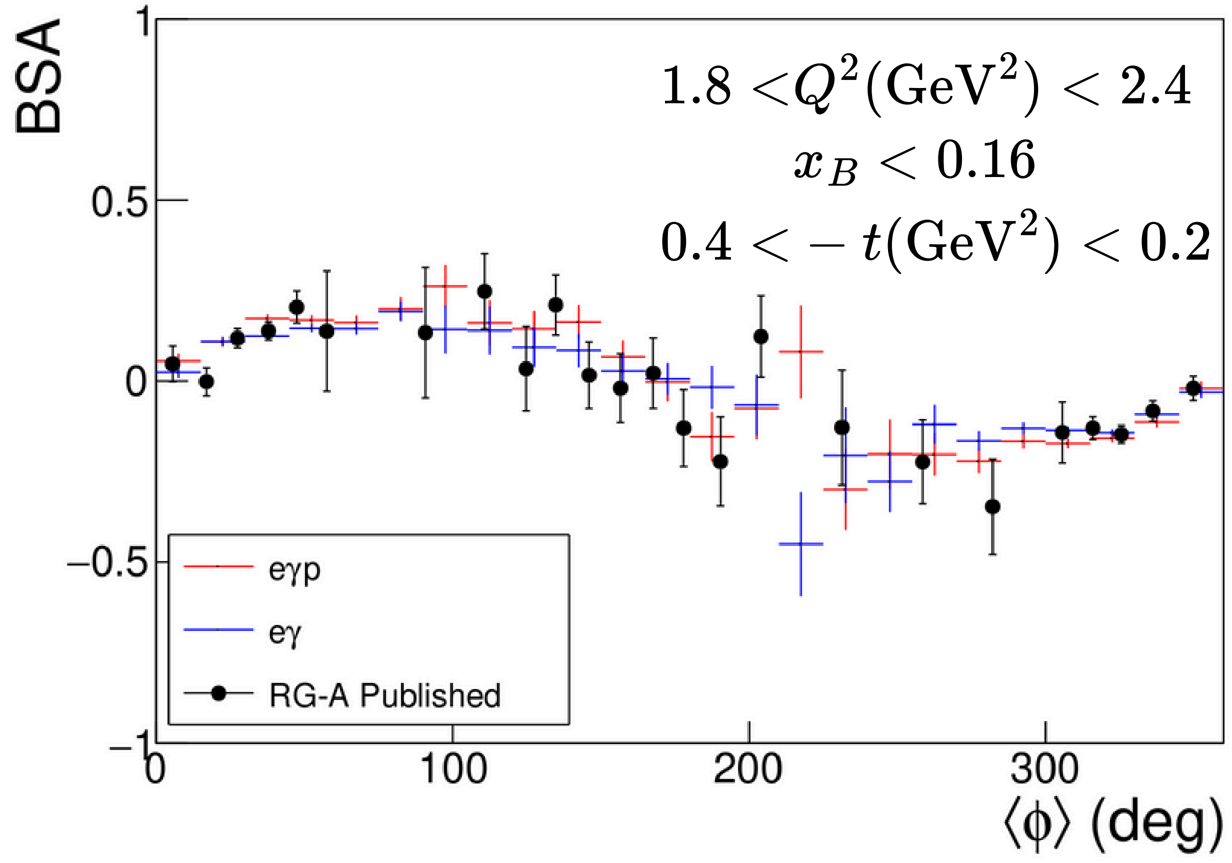
Cross-section

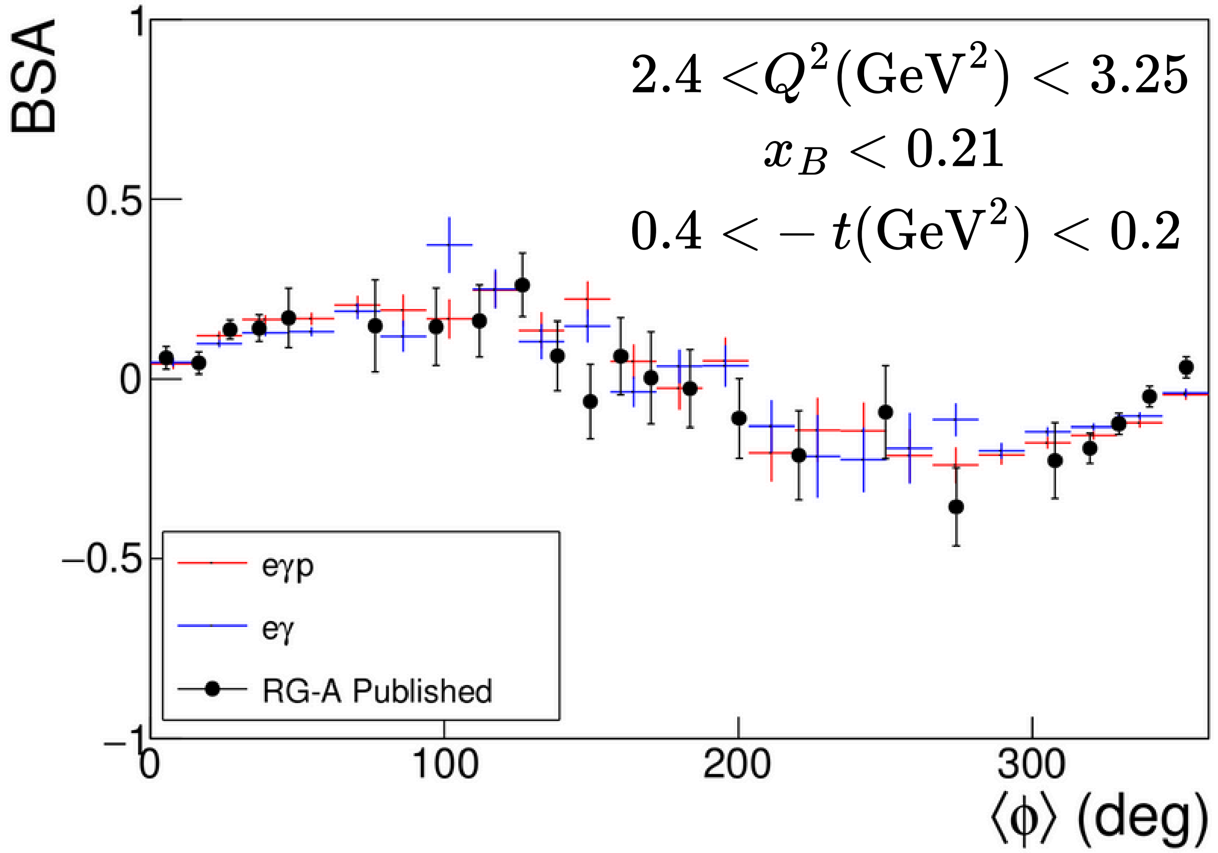
3. DVCS BSA

Pass-1 and pass-2 eγp measurements are compatible





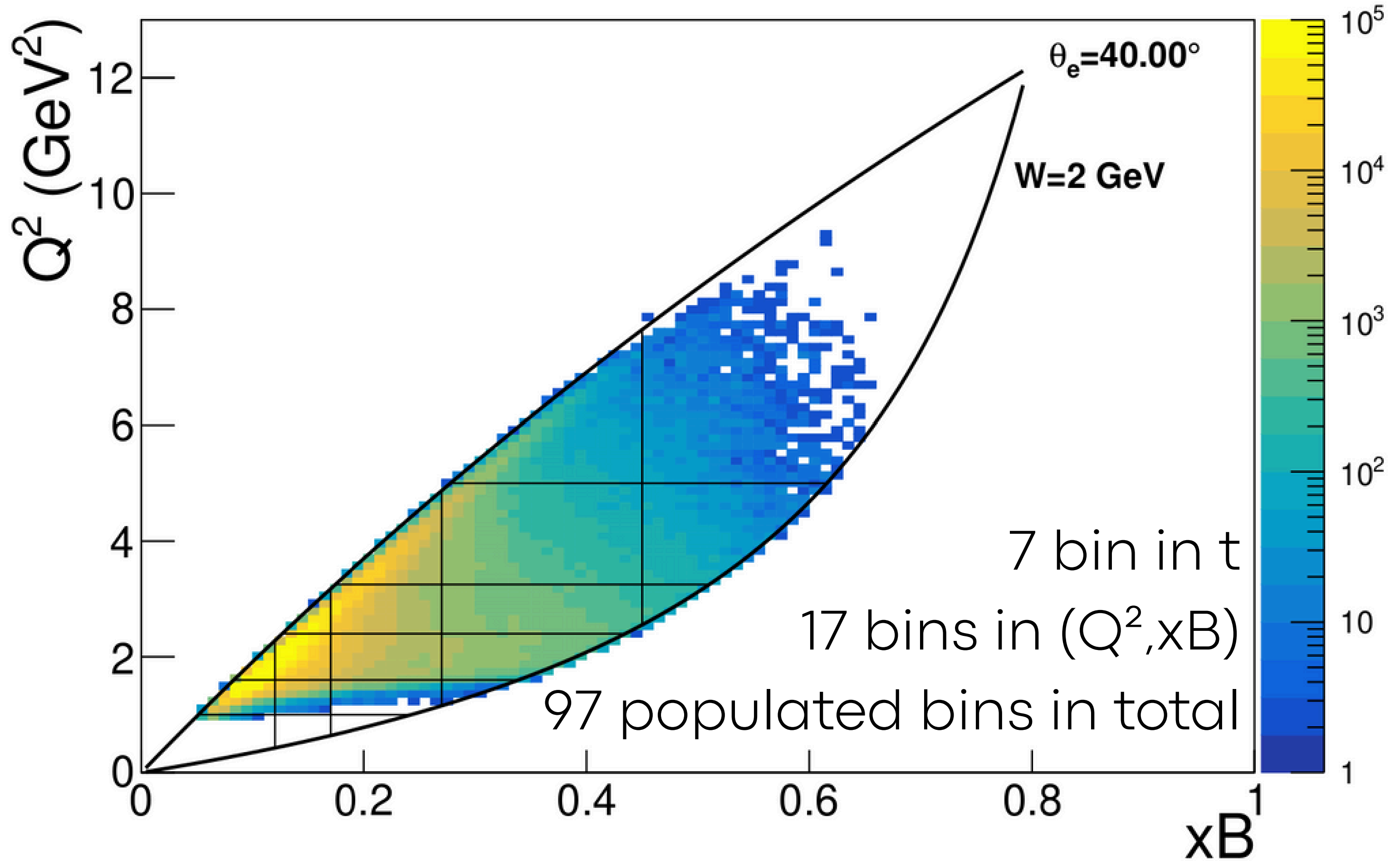


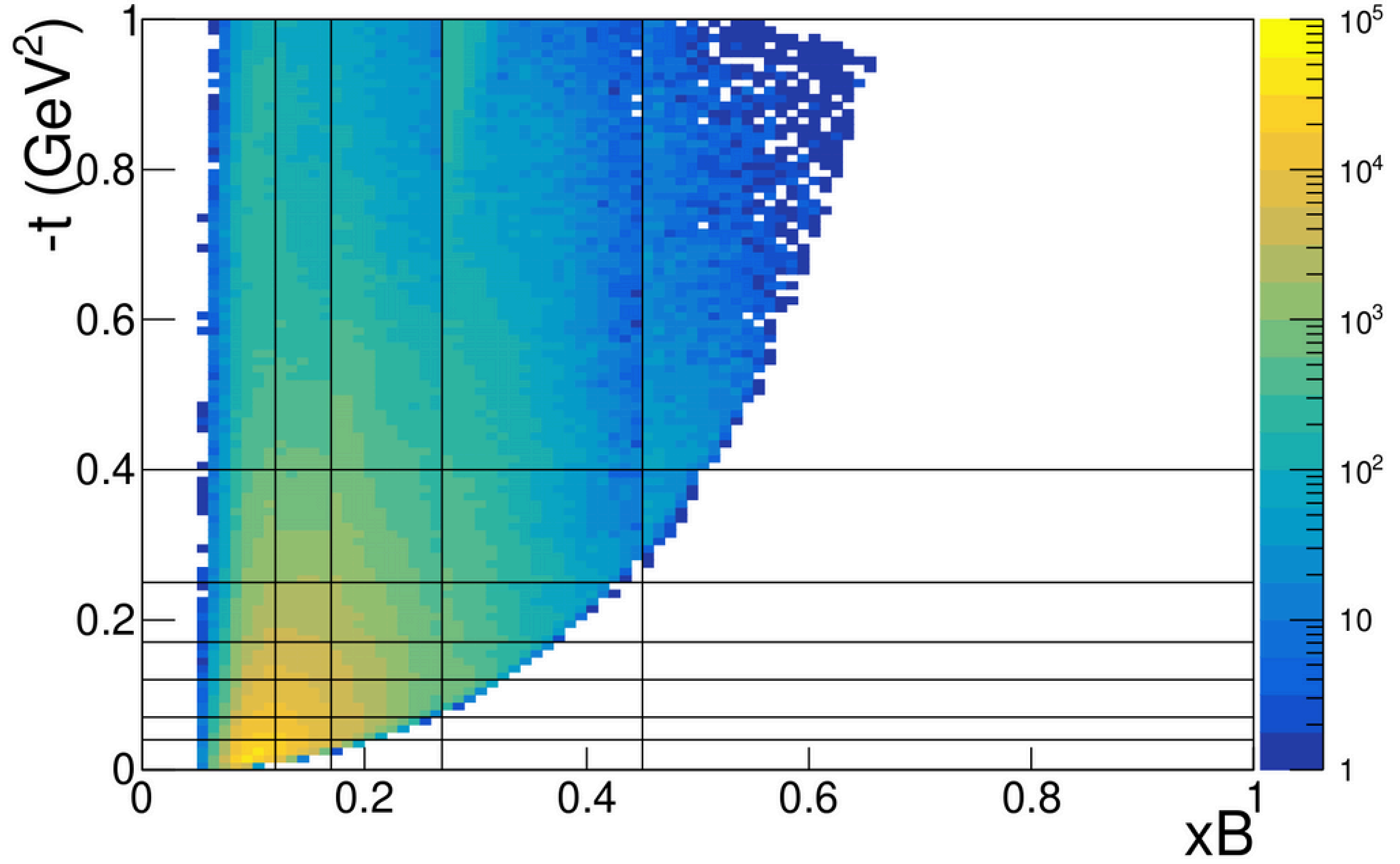


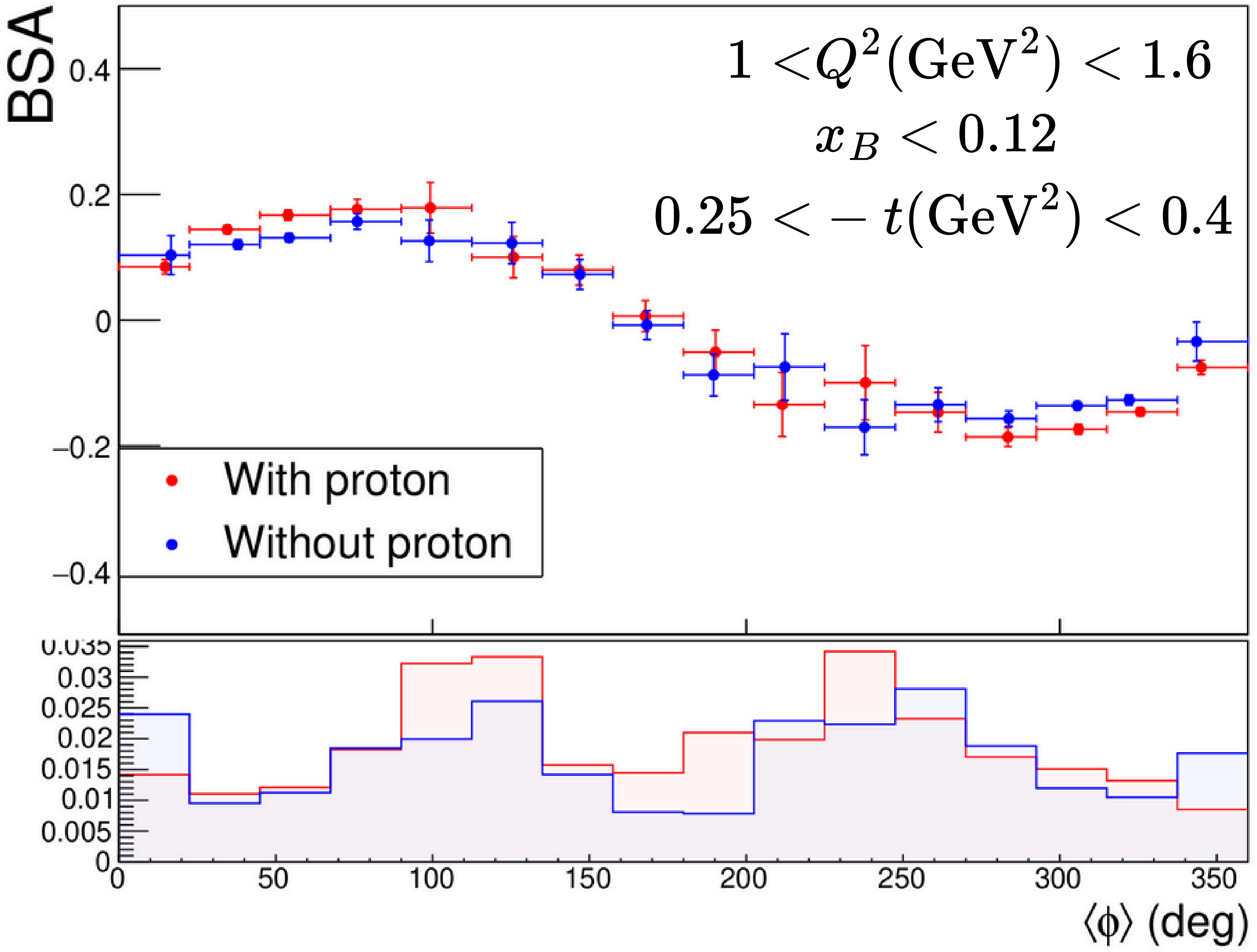
Pass-2 eγ, eγp and RG-A measurements are compatible

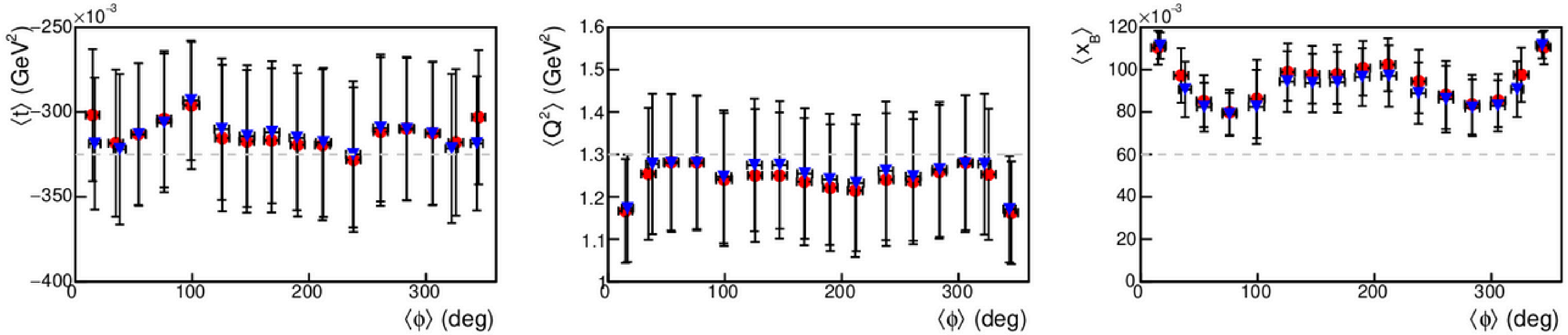
Results compatible with the published pass1 RG-A results

3. DVCS BSA





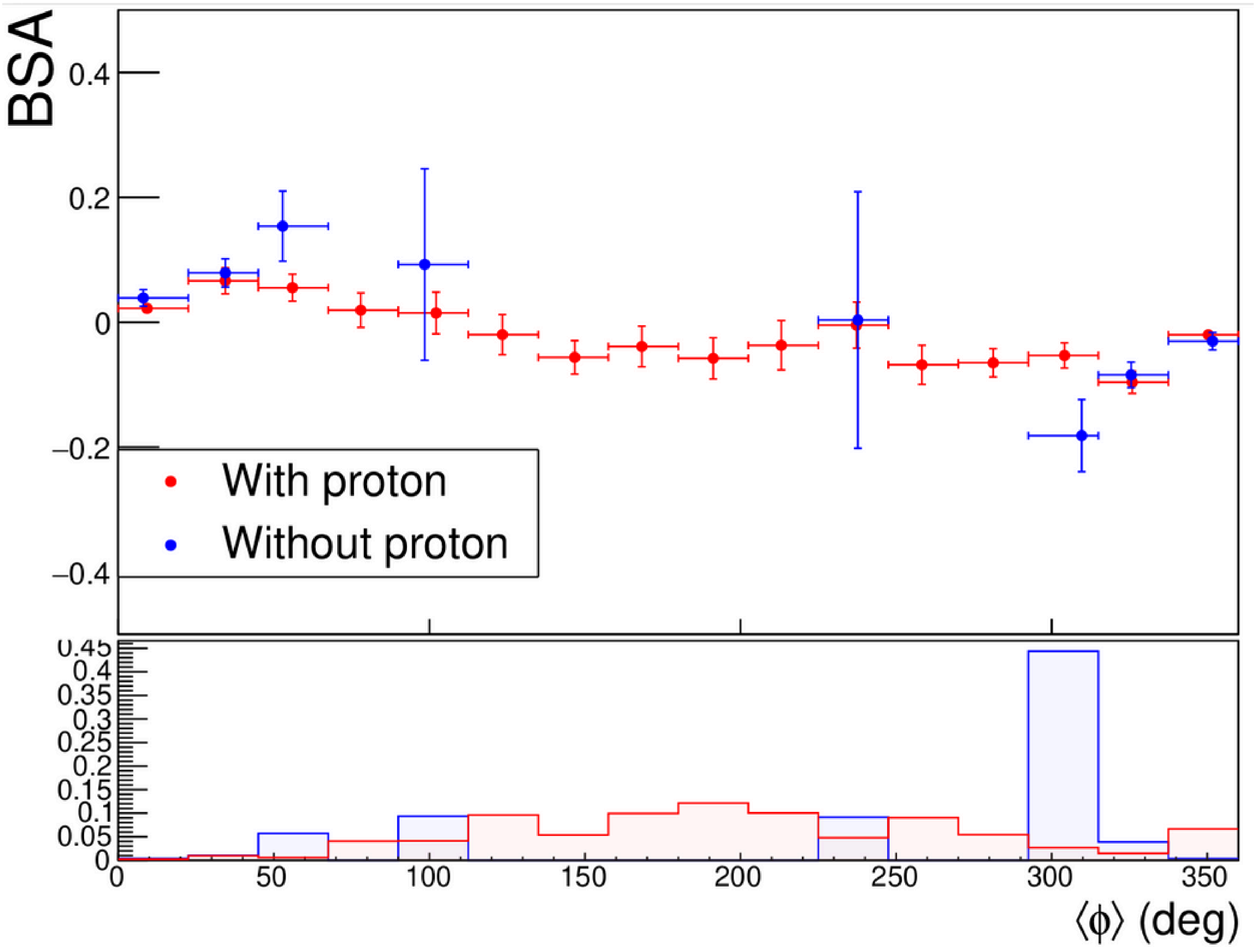




We can obtain compatible measurements in the common region of the eγ and eγp detection topologies

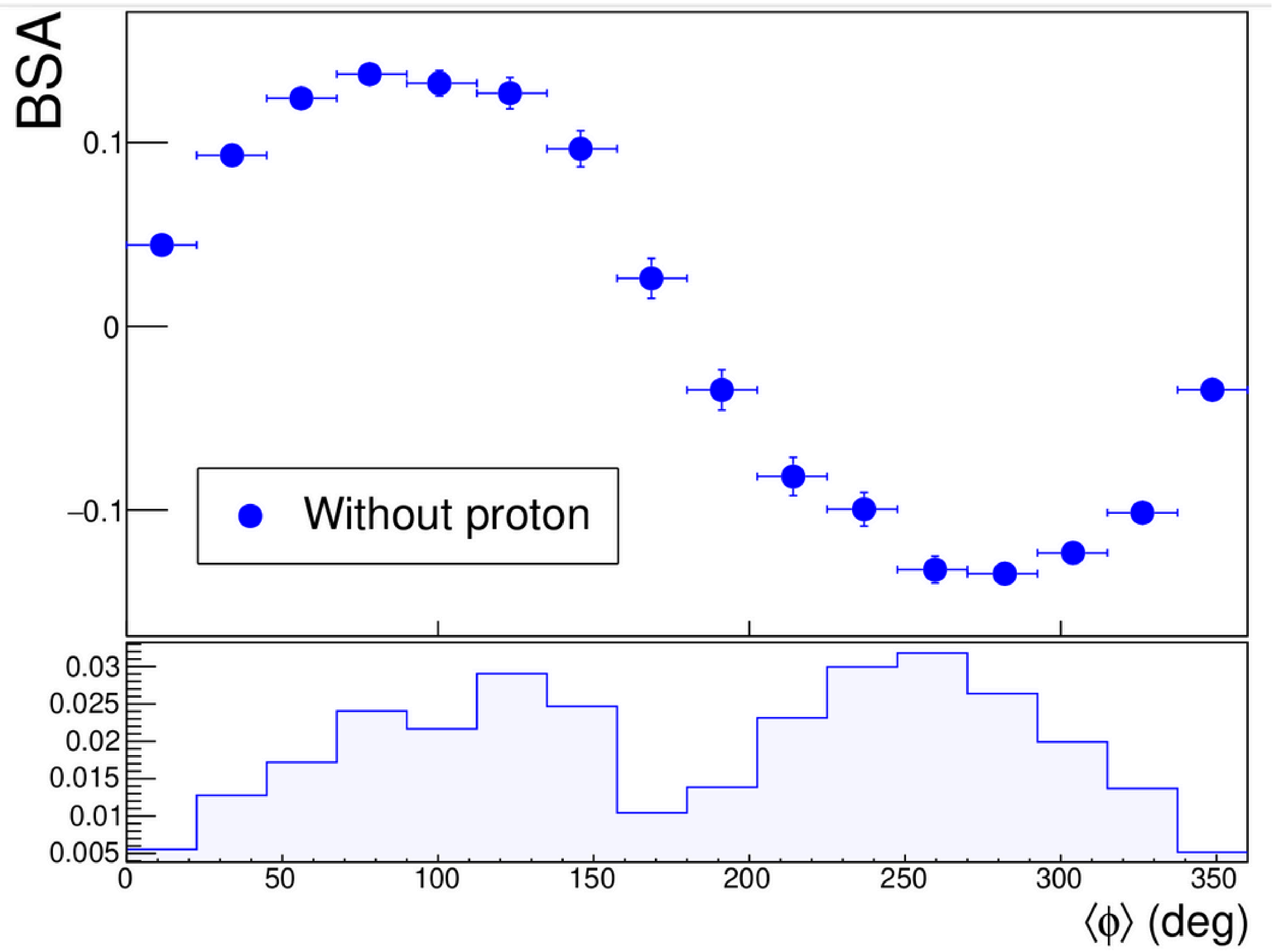
3. DVCS BSA

$$1 < Q^2(\mathrm{GeV}^2) < 1.6$$
$$0.17 < x_B < 0.27$$
$$0.25 < -t(\mathrm{GeV}^2) < 0.4$$



The eγp selection favors large -t measurements

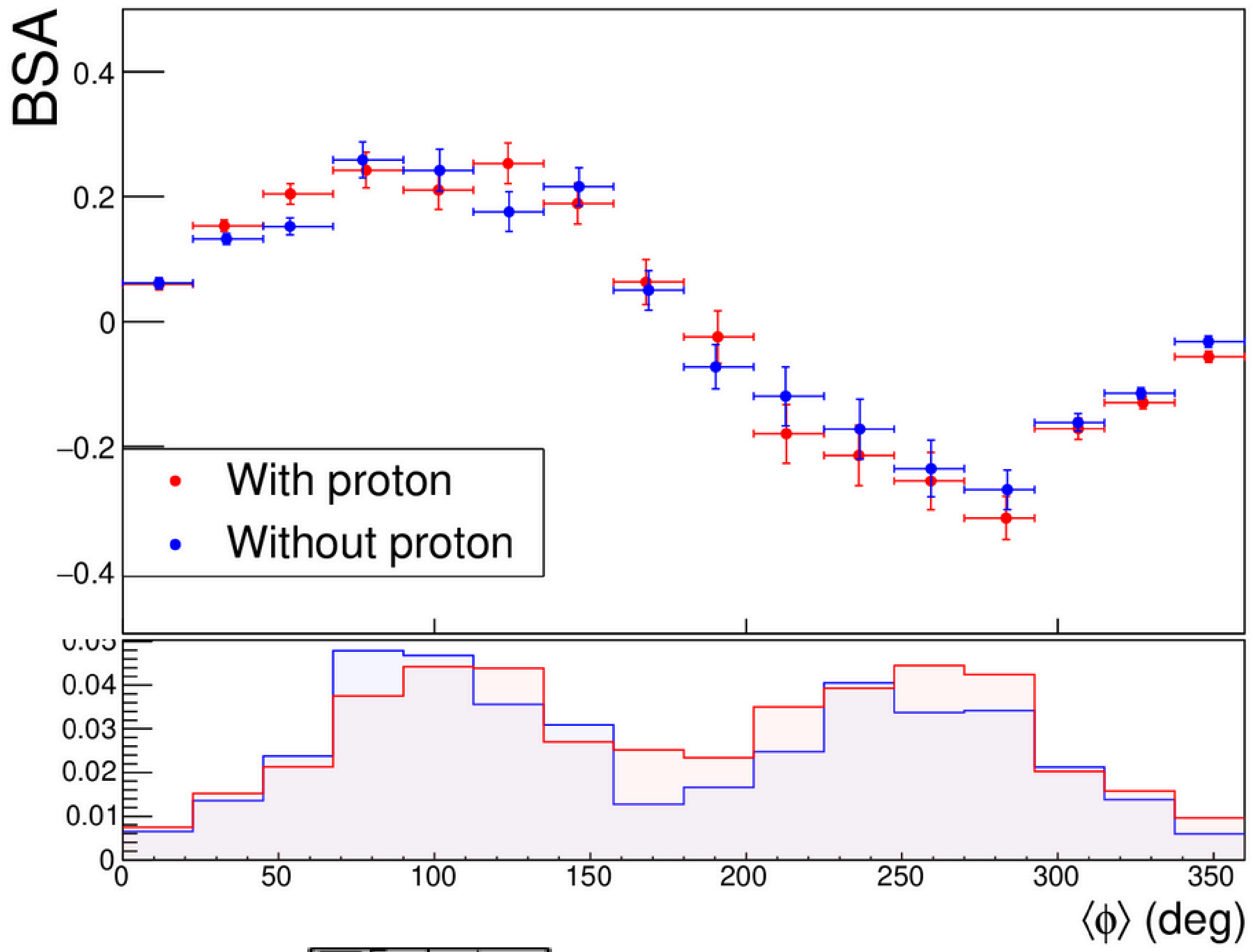
$$1 < Q^2(\mathrm{GeV}^2) < 1.6$$
$$0.17 < x_B < 0.27$$
$$0.25 < -t(\mathrm{GeV}^2) < 0.4$$



The eγ gives unique access to the small -t region

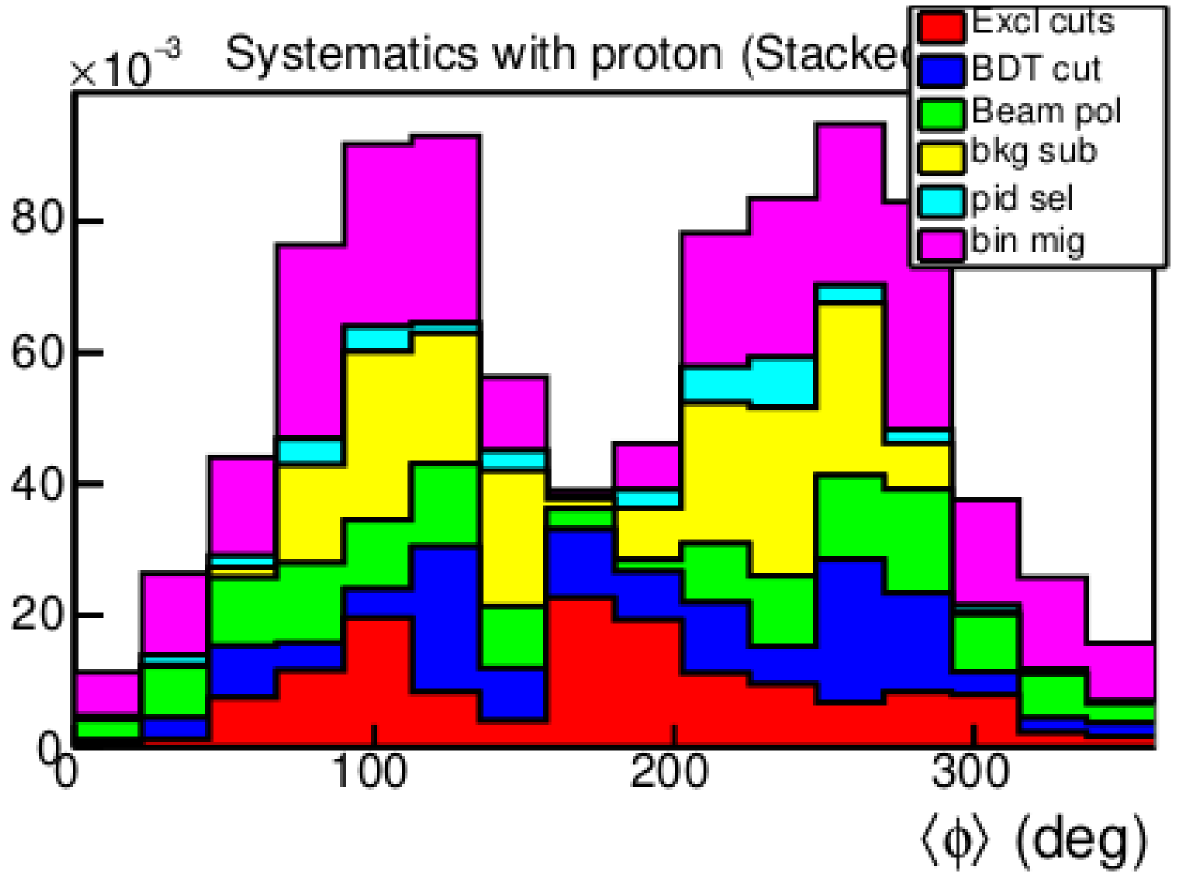
3. DVCS BSA

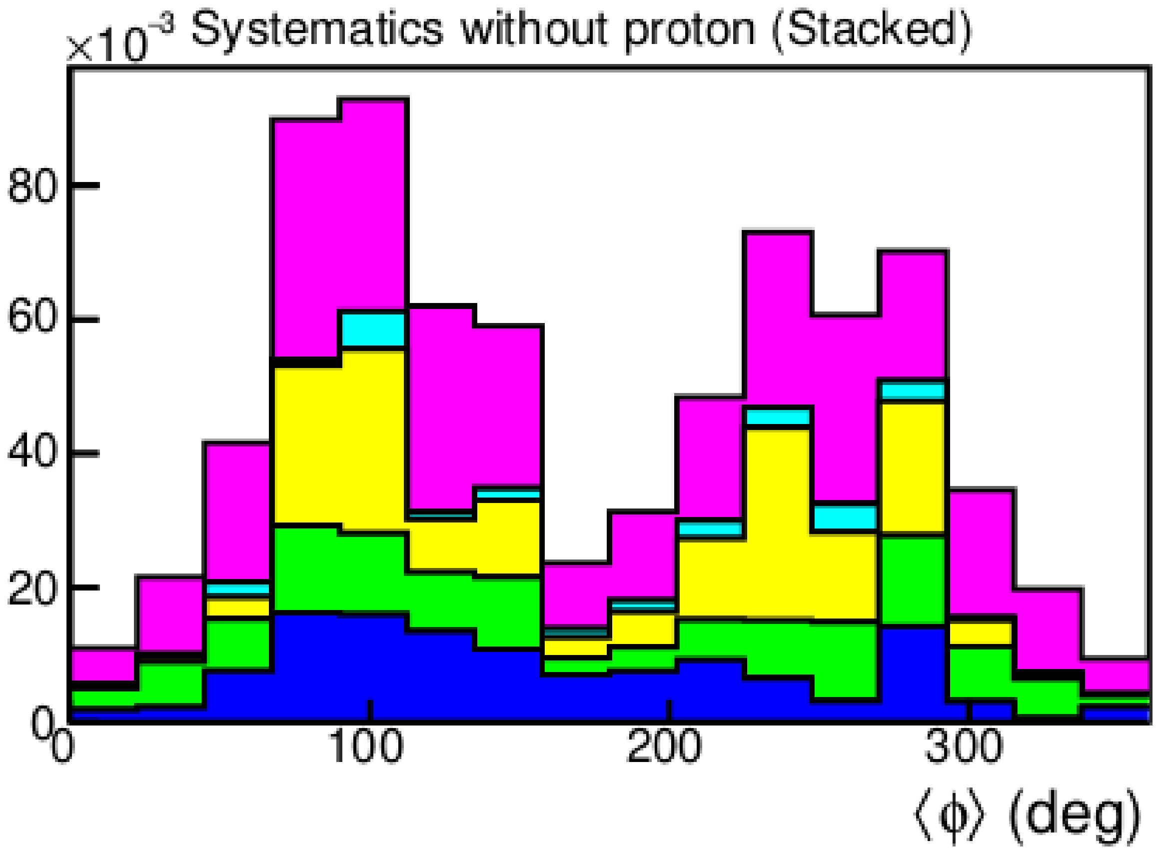
$$2.4 < Q^2(\mathrm{GeV}^2) < 3.25$$
$$0.17 < x_B < 0.27$$
$$0.25 < -t(\mathrm{GeV}^2) < 0.4$$



Systematic uncertainties come from

- Selection cuts
- BDT classification
- Background subtraction
- Bin migration

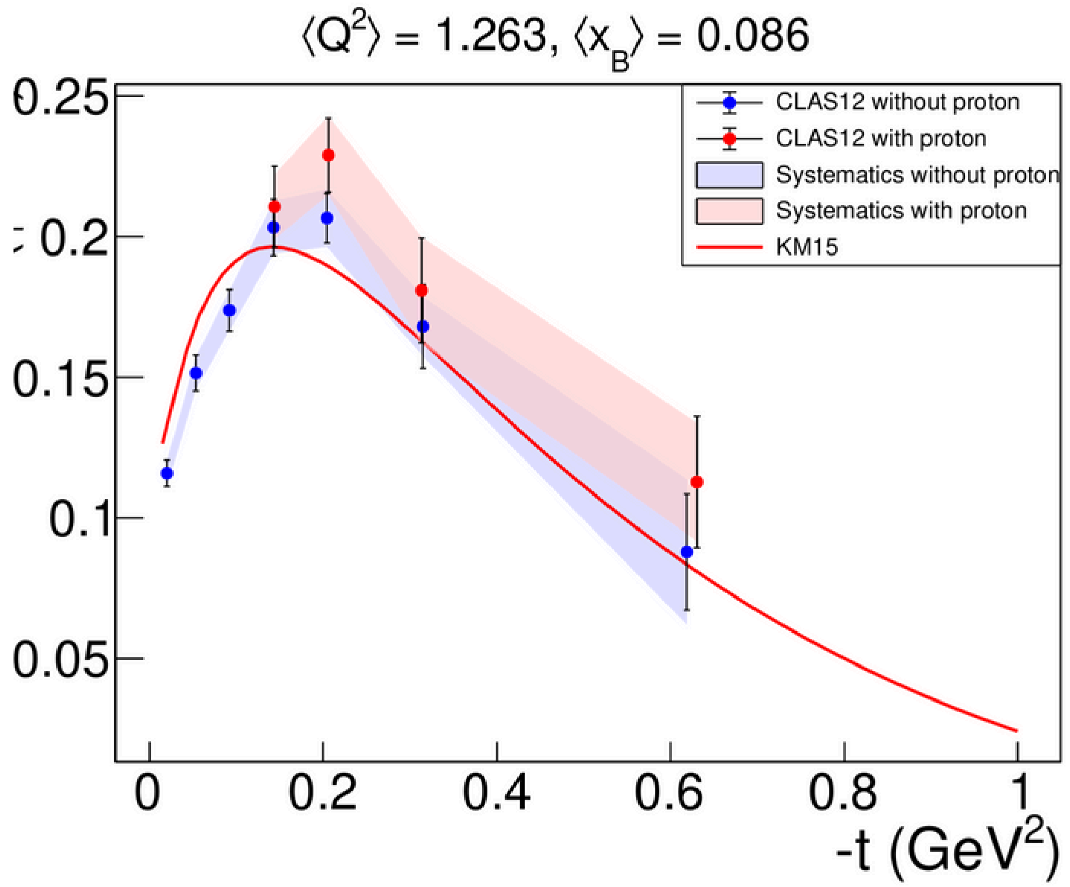


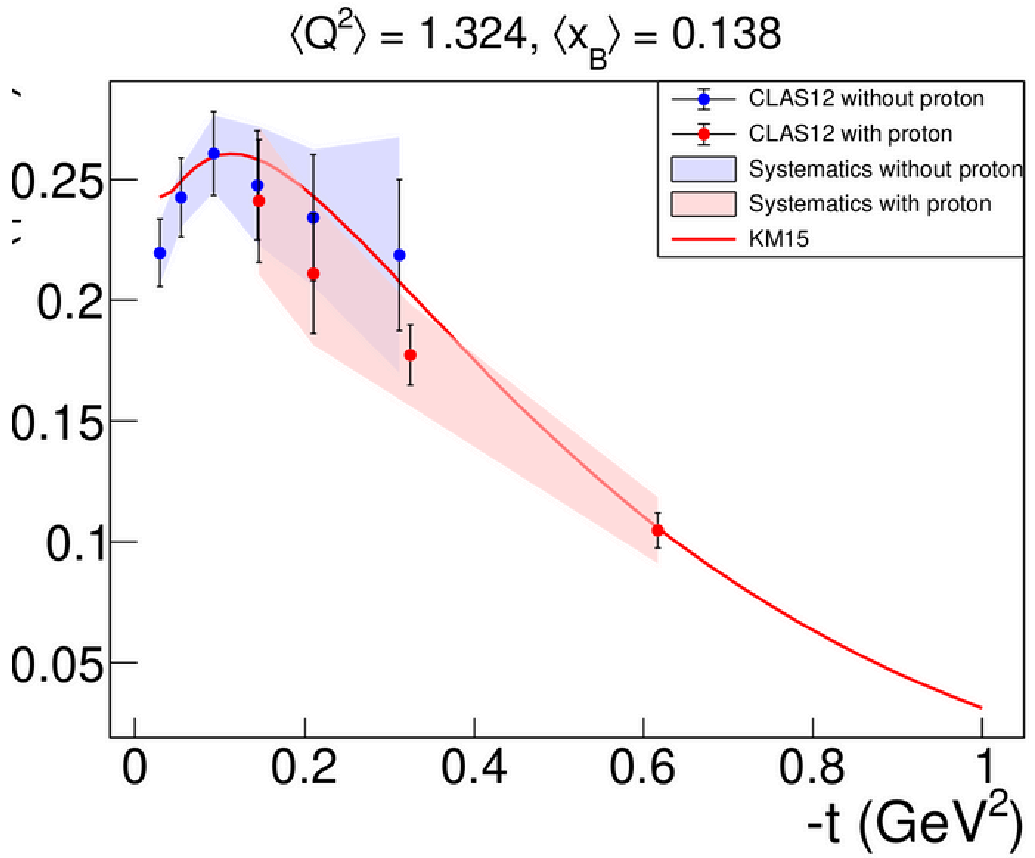


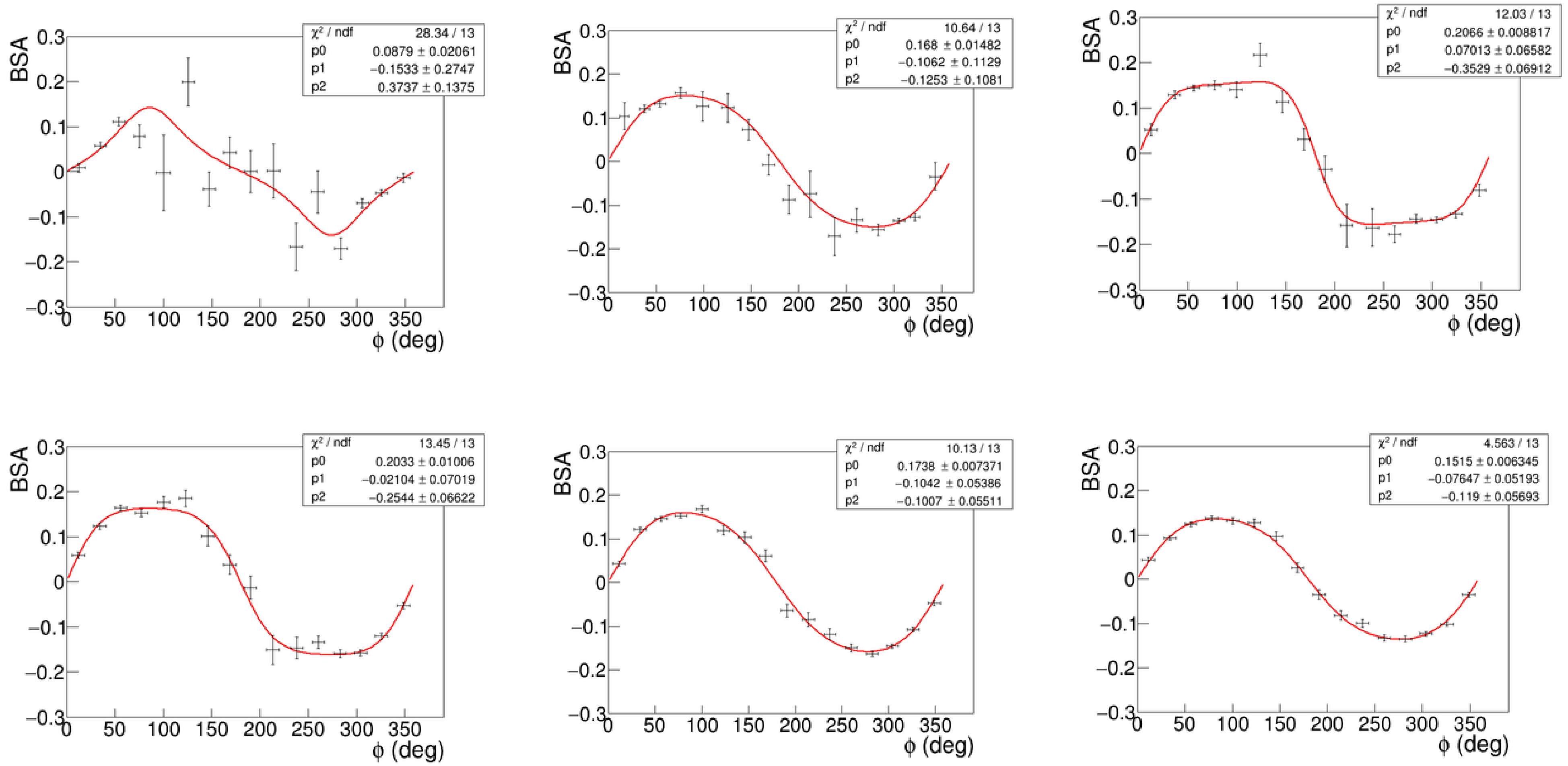
Statistical and systematic errors can be at the same level for for approaches

3. DVCS BSA

BSA amplitude as a function of -t



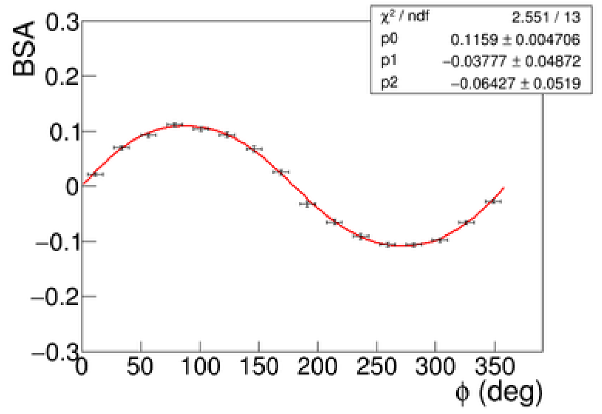




$$1.0 < Q^2(\mathrm{GeV}^2) < 1.6$$
$$0 < x_B < 0.12$$

and 7 bins in t

$$BSA = \frac{a\sin(\phi)}{1 + b\cos(\phi) + c\cos(2\phi)}$$

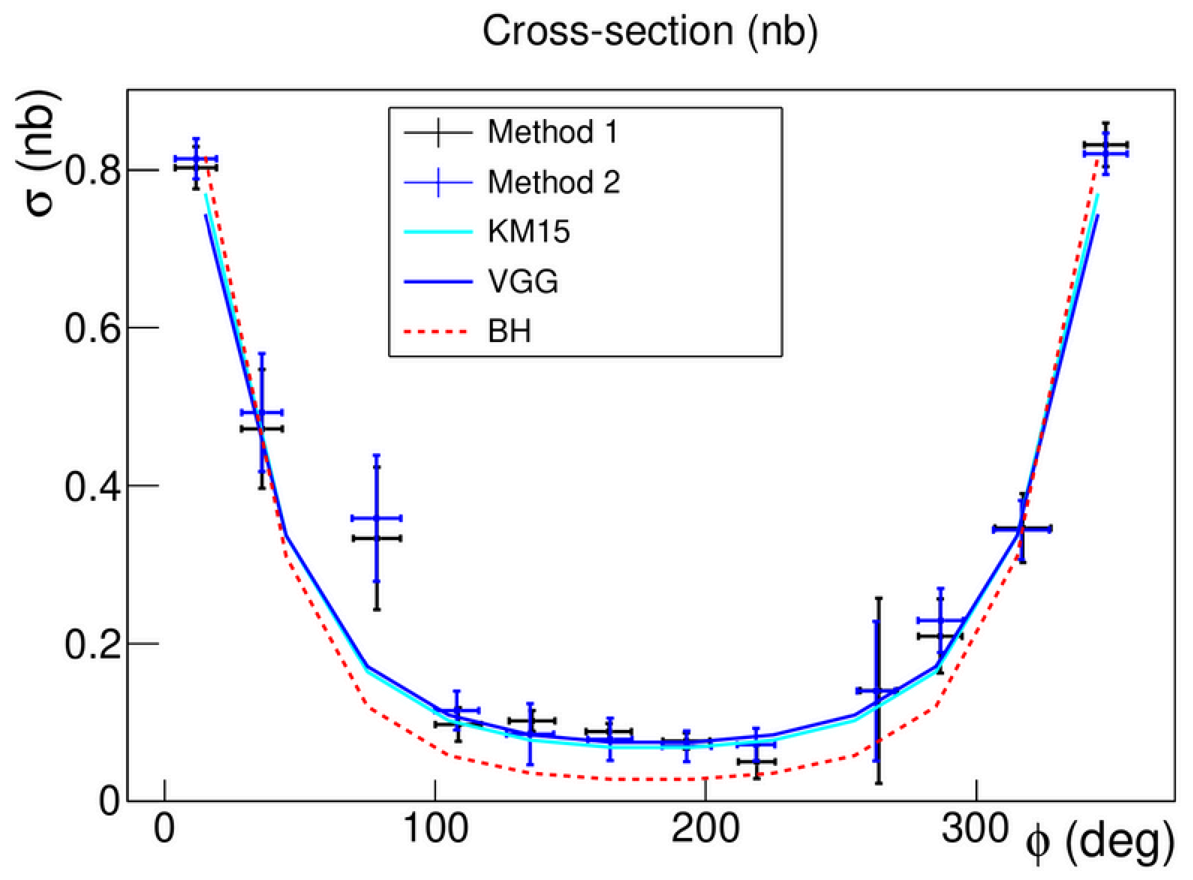


- The eγ selection gives access to the small -t region
- Results compatible with the KM15 model prediction

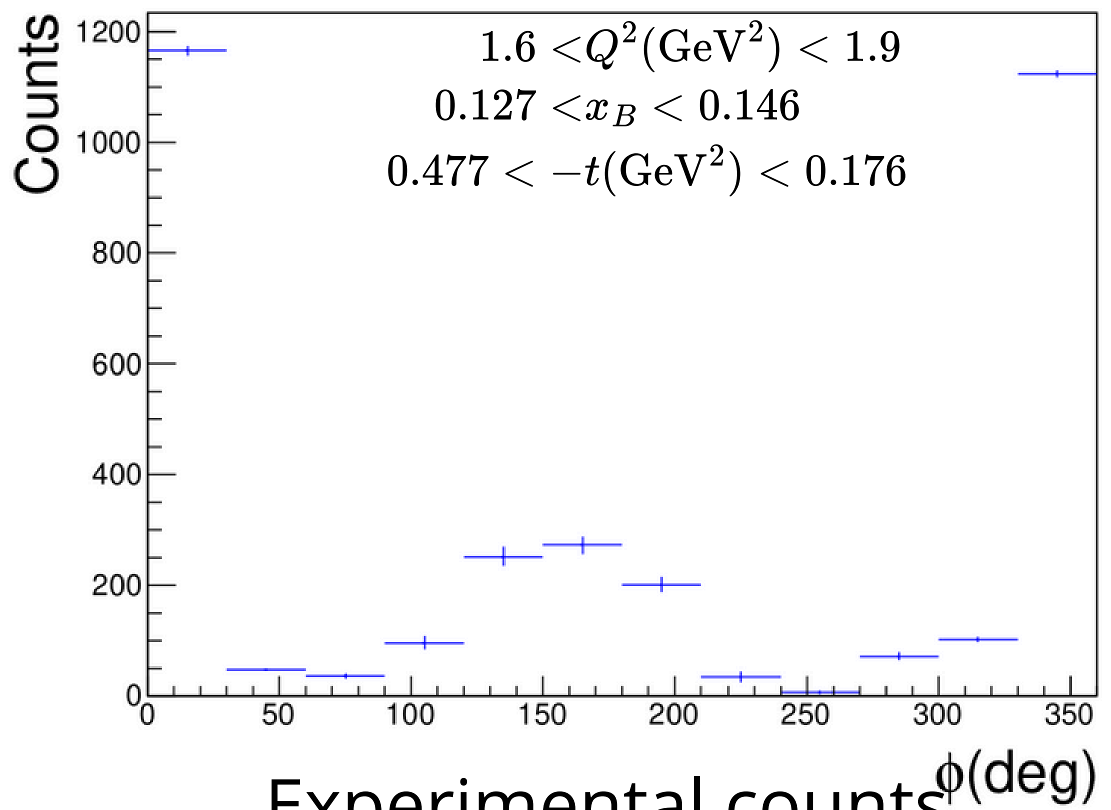
4. DVCS MEASUREMENTS: BEYOND BSA

We foresee cross section measurements for a separate work.

$$\boxed{\frac{d^4\sigma}{dx_B dQ^2 dt d\phi}} = \frac{1}{F_{eff}} \times \left\{ \frac{1}{F_{Bin}} \times \frac{1}{F_{RC}} \times \frac{1}{\mathcal{L}\Delta\Omega} \times \left[\frac{N(e', p', \gamma)_{\text{bin mig}}}{F_{Acc}} \right] \right\}$$



Normalized to match BH at the endpoints



Experimental counts

Final normalization should account for electron and photon detection efficiency.
Yet, preliminary results are in a good track

bin36

4. SUMMARY

- GPDs are crucial for understanding the nucleon structure as they encode a variety of properties.
- DVCS is a golden channel for GPD studies due to its direct access to GPDs.
- While detecting the DVCS recoil proton is ideal, by not detecting it
  - There is a boost in statistics
  - There is access to a larger phase space
- Most recent BSA measurements were presented.
  - the $e\gamma$ and $e\gamma p$ selection are complementary to each other
  - BSA measurements are compatible with the KM15 model predictions at low ($e\gamma$) and high ($e\gamma p$) -t values.
  - Systematic errors were estimated
  - Analysis note is currently is ready for a 3rd third round of comments.
- Cross-section measurements with $e\gamma$ selection are foreseen for a separate work.

THANKS

Systematic error

- PID selection:
  - $-13 < v_z^{electron} < 12$,
  - FD photons and electrons detected in different sectors.
  - $|v_z^{electron} - v_z^{proton}| < 20$ cm for photons as recommended on [10].
  - For electrons with momentum greater than 4.5 GeV:

$$\frac{E_{dep}^{ECIN}}{p_e} > 0.2 - \frac{E_{dep}^{PCAL}}{p_e}$$

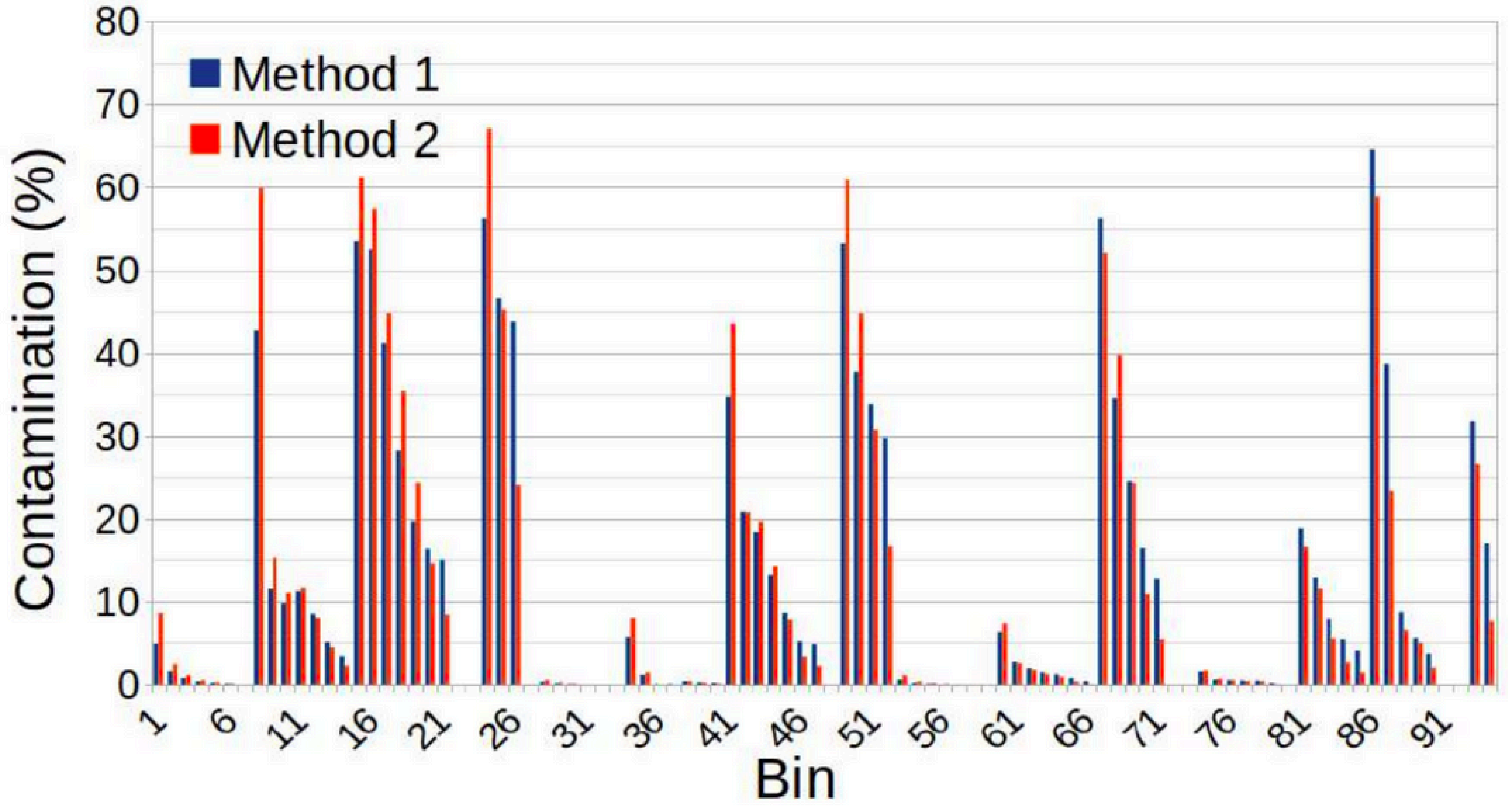
- Exclusivity cuts:
  - $|\Delta t| < 2$ GeV^2 $\rightarrow$ $|\Delta t| < 1.5$ GeV^2
  - $|\Delta\phi| < 2° \rightarrow |\Delta\phi| < 1.5°$
  - $P_{miss} < 1$ GeV$\rightarrow$ $P_{miss} < 0.8$ GeV.
- BDT-Score cut:
  - BDT-Score$> 0.0 \rightarrow$ BDT-Score> 0.04 .

$$\sigma^{bkg} = \frac{A^{raw} - A^{\pi^0}}{(1-f)^2}\delta f$$

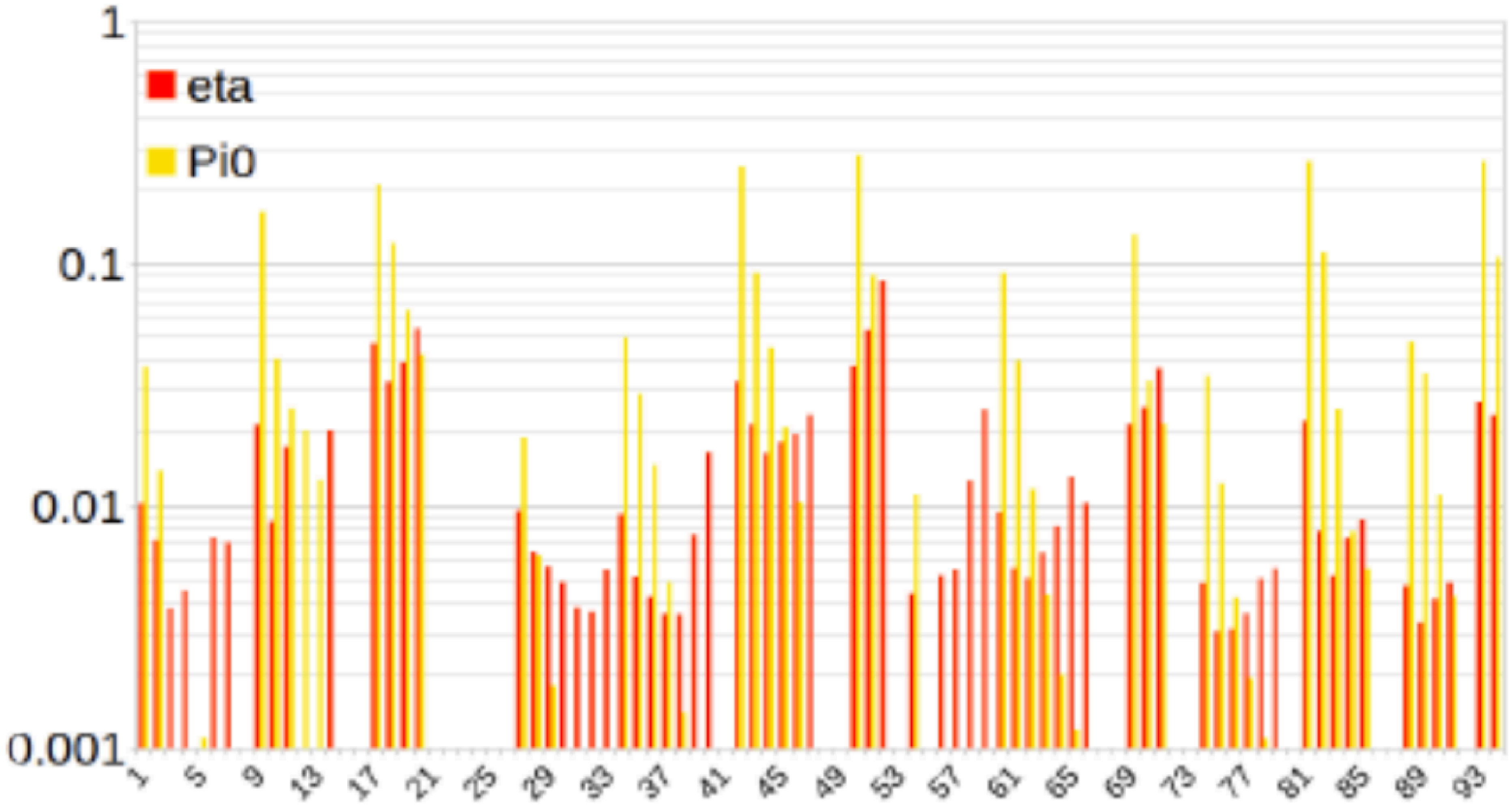
$$\sigma^{cut} = \frac{\frac{A_{cut}}{\sigma(A_{cut})} - \frac{A}{\sigma(A)}}{\frac{1}{\sigma(A_{cut})} + \frac{1}{\sigma(A)}}.$$

$$\sigma^{cut} = \sqrt{\frac{(A_+ - A_0)^2 + (A_- - A_0)^2}{2}}$$

$$A_\pm = \frac{\frac{A_{inb} \pm \sigma_{inb}^{cut}}{\sigma(A_{inb})^2} + \frac{A_{outb} \pm \sigma_{outb}^{cut}}{\sigma(A_{outb})^2}}{\frac{1}{\sigma(A_{inb})^2} + \frac{1}{\sigma(A_{outb})^2}}$$



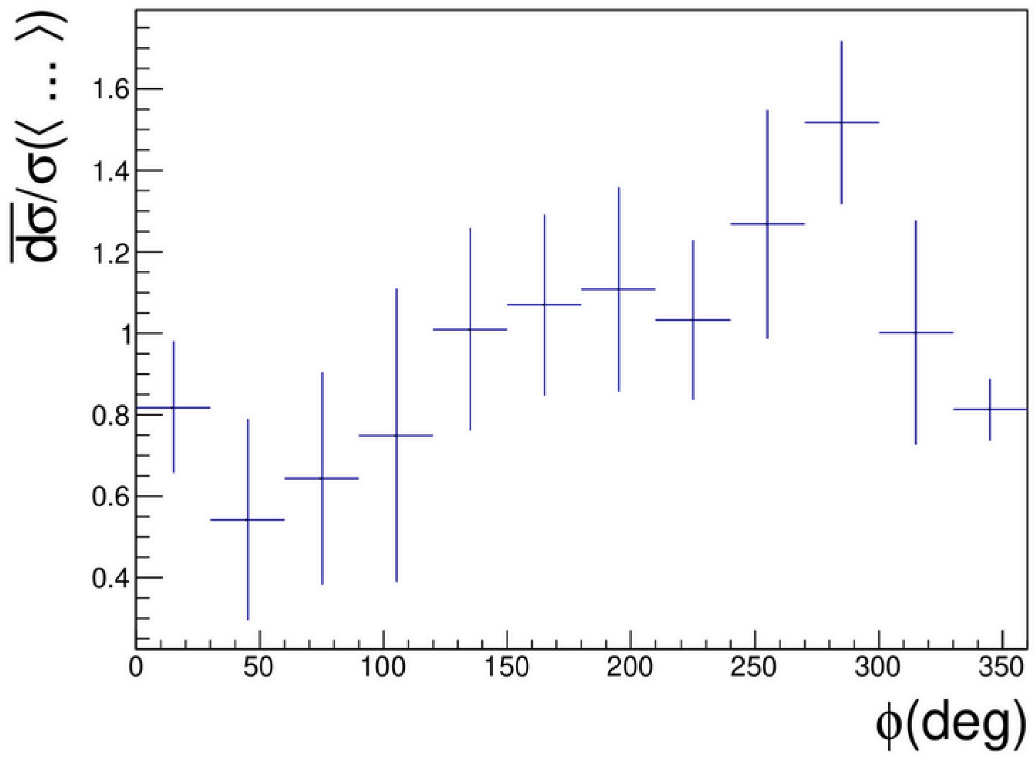
Method 1
Method 2
Contamination (%)
Bin



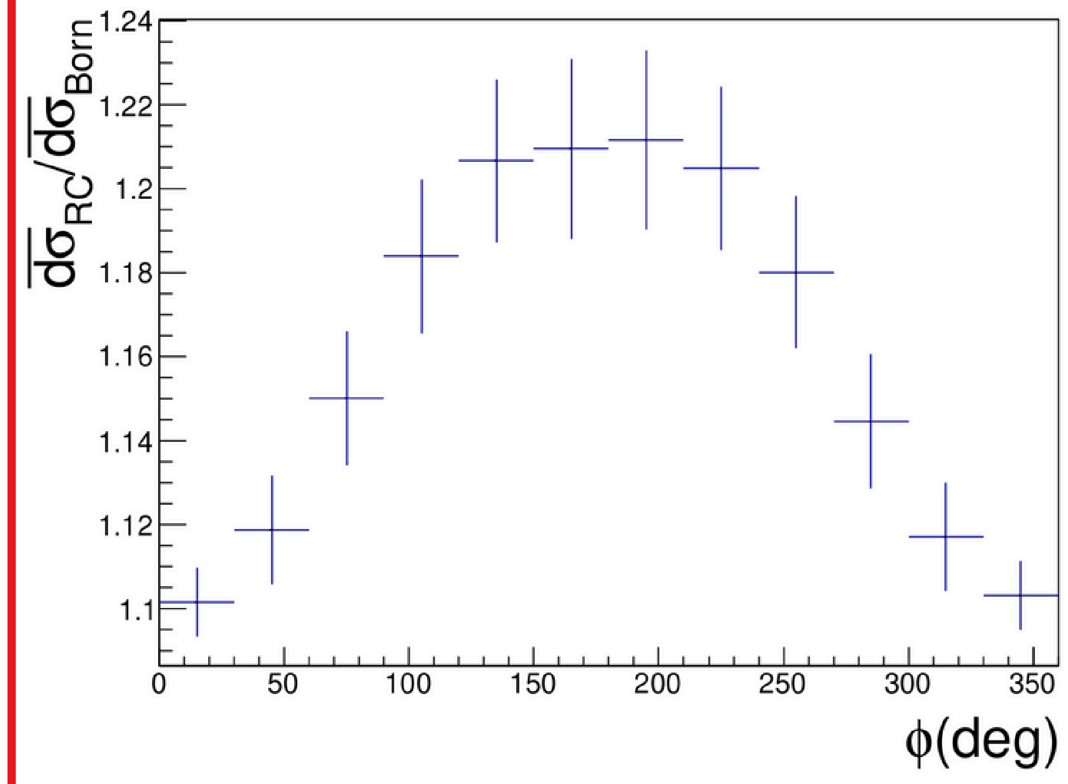
eta
Pi0

If the eg selection allows BSA measurements

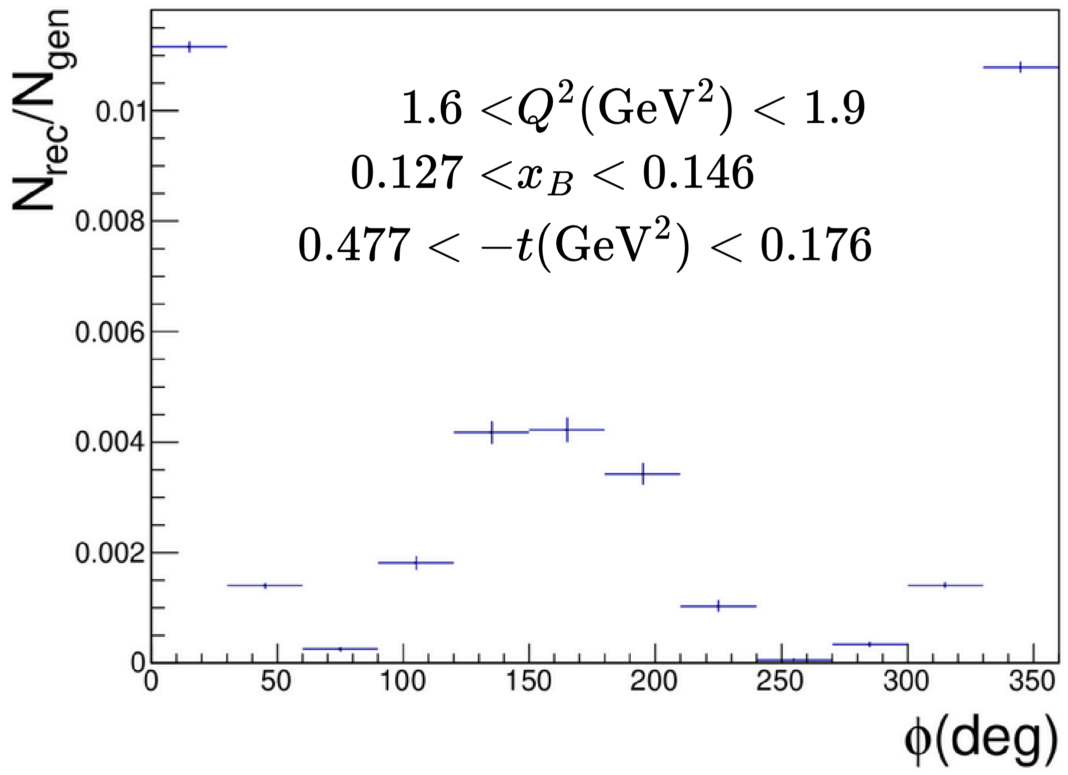
$$\frac{d^4\sigma}{dx_B dQ^2 dt d\phi} = \frac{1}{F_{eff}} \times \left\{ \boxed{\frac{1}{F_{Bin}}} \times \boxed{\frac{1}{F_{RC}}} \times \frac{1}{\mathcal{L}\Delta\Omega} \times \left[\frac{N(e', p', \gamma)_{\text{bin mig}}}{\boxed{F_{Acc}}} \right] \right\}$$



Bin centering correction



Radiative correction



Acceptance correction

Bin centering and RC corrections are significant.