DVCS on neutron and proton from RGB data

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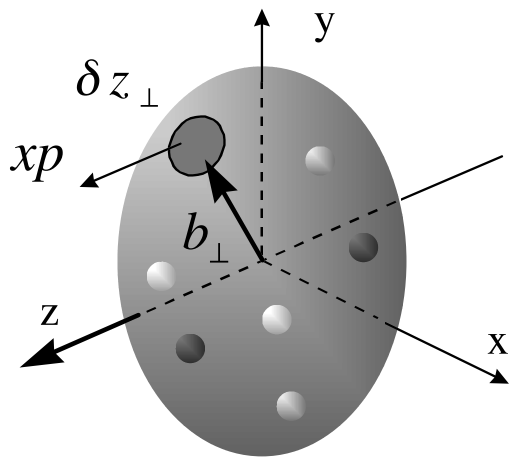
CLAS Collaboration Meeting July 2020

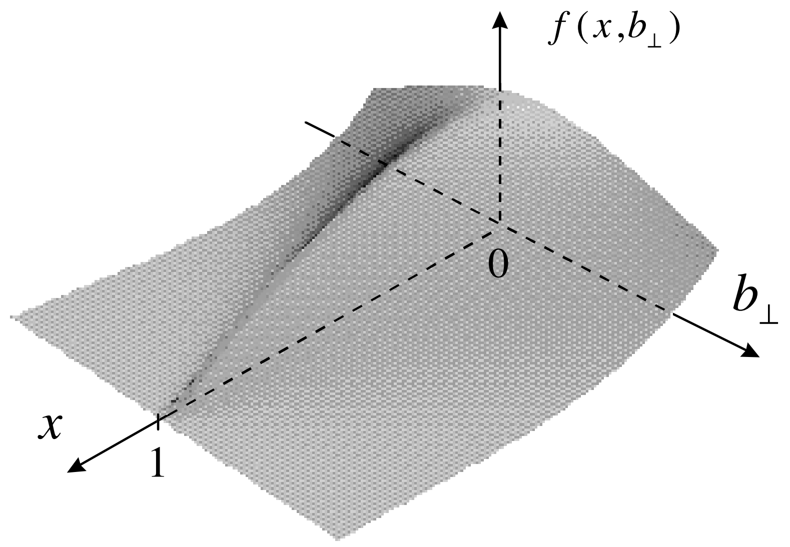
Outline

- Motivations
- Event selection
  - Charged particle veto for nDVCS sample selection optimisation
- Raw BSA plots
- Pi0 analysis: ep->ep pi0 (gamma gamma)
- Summary

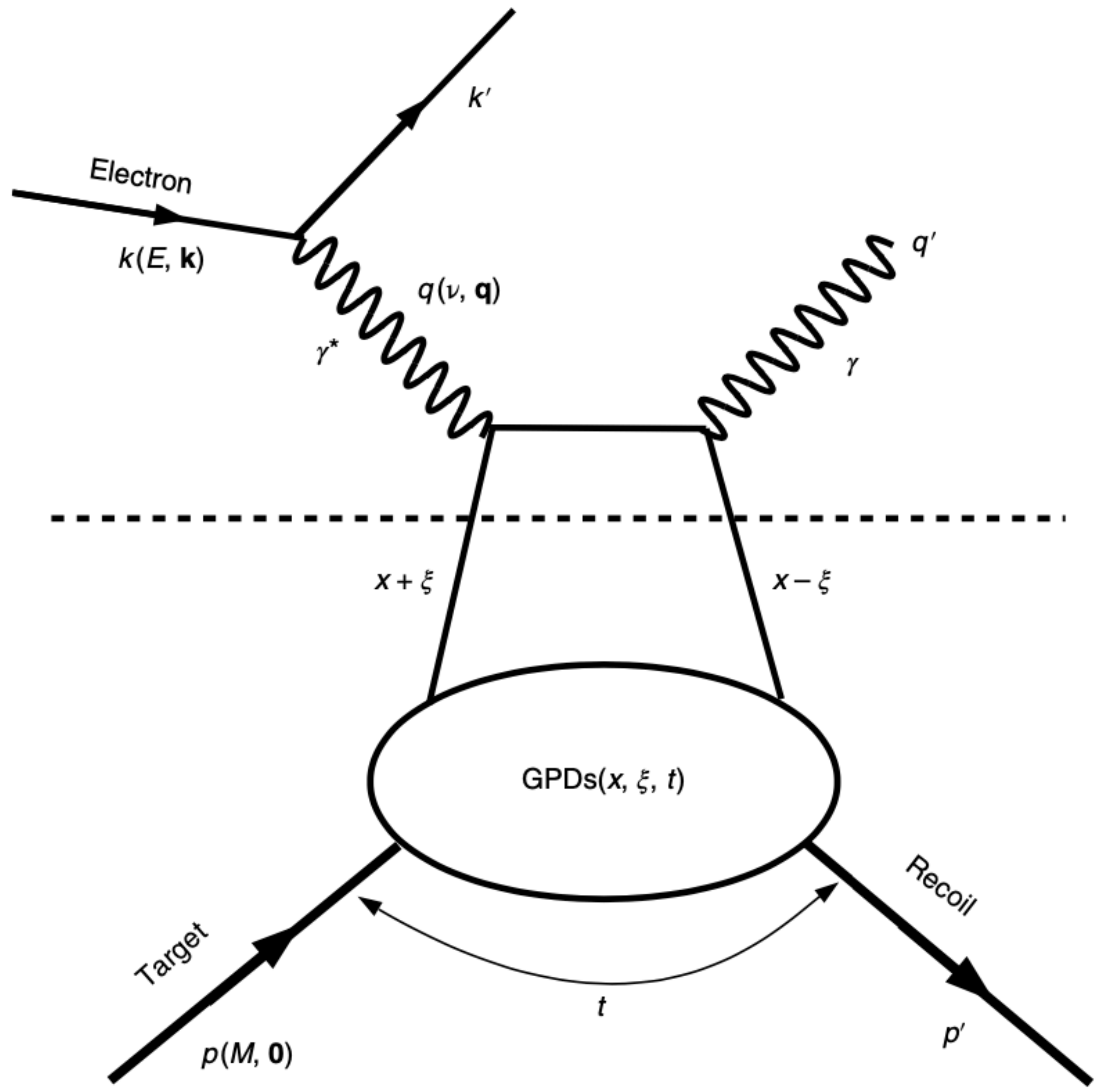
Motivations

- Generalized parton distribution at η=0





Generalised Parton Distributions-GPDs → Correlation of position-momentum of partons in nucleon & the spin structure



Invariants

$Q^2 = -(k - k')^2$

$x_B = Q^2/(2qp)$

$y = (qp)/(kp)$

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

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

$H, E, \widetilde{H}, \widetilde{E}$ (x,ξ,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

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

ed→enγ(p)

  - Scattering off proton (pDVCS): GPD H
    - Quantify medium effects

ed→epγ(n)

→ essential for the extraction of BSA of a "free" neutron (de-convoluting medium effect)

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

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

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

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

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

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

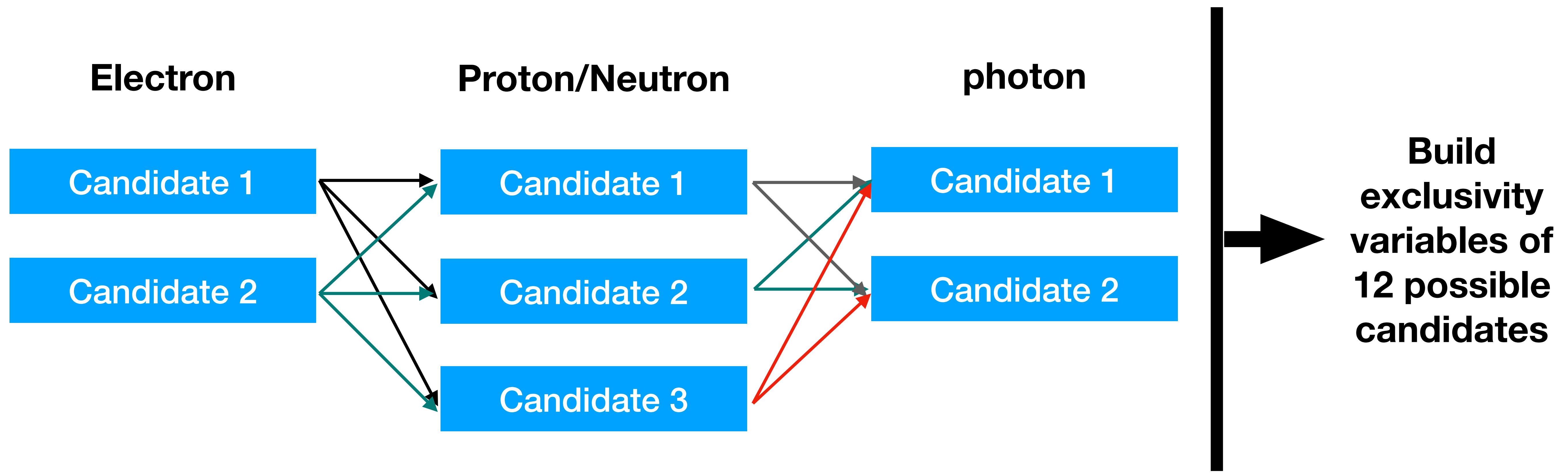
Available used data

- Pass 1 cooking (ongoing) of spring 2019 run period (44% of the spring runs are presented)
- Beam energy 10.6 GeV and 10.2 GeV (starting run 6420)
- The average beam polarisation was 0.8566
- COATJAVA 6.5.8 with important feature for DVCS on neutron: charged particle veto to improve selection

Decay tree stripping

- Construct all the possible combinations of final state particles: ed -> e' N photon (ex: 1 e 1 p 3 photons -> 3 possible pDVCS candidates)

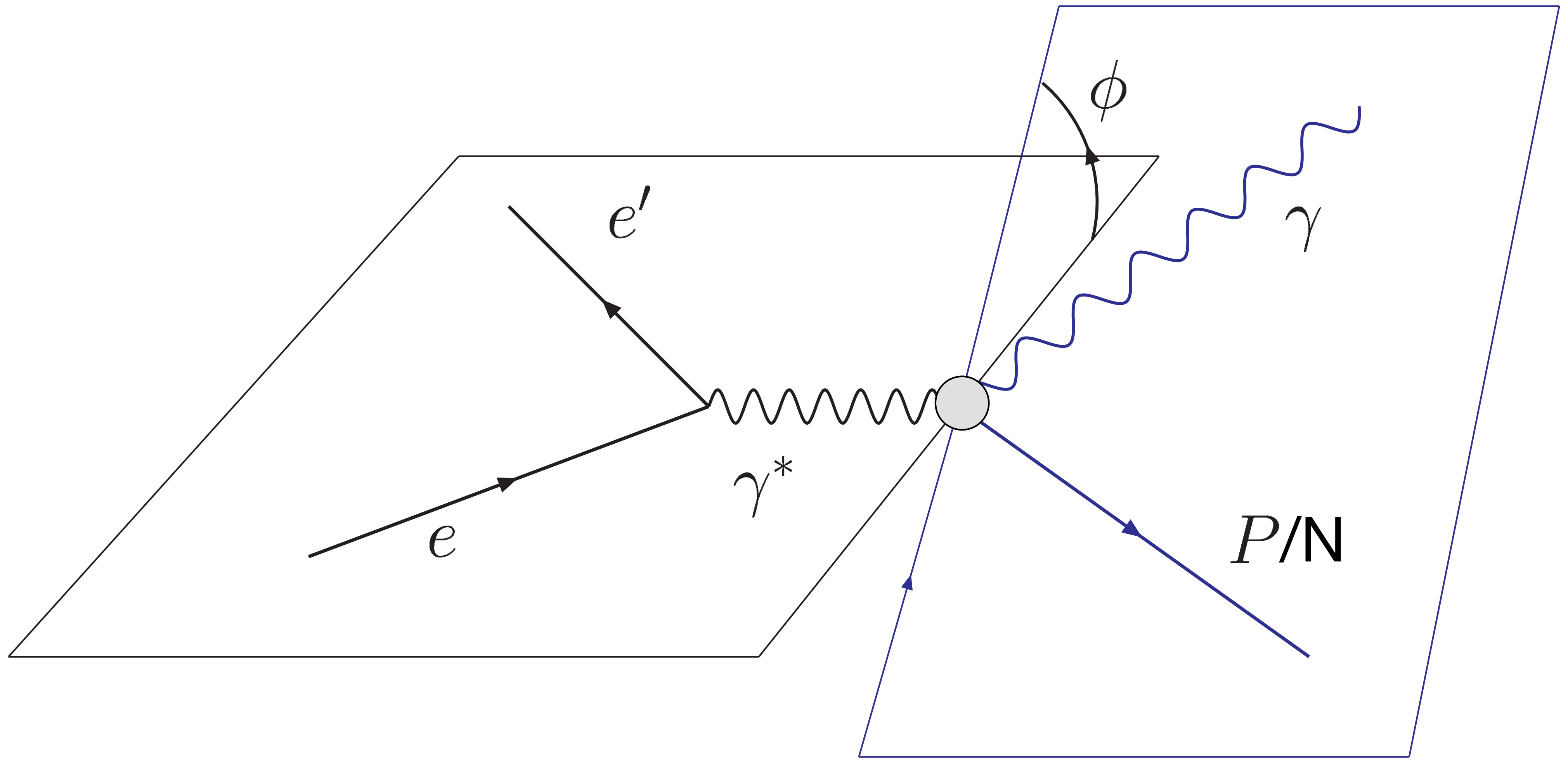
- Build exclusivity variables for pDVCS candidates



- Determine best DVCS candidate in event based on exclusivity criteria
  - Closest-to-nominal missing mass eN->eN gamma X as a criteria to determine best candidate
  - Tests performed with multivariate exclusivity criteria

Selection cuts

- Final states reconstructed using CLAS12 PID
- Intentionally dropped cuts on missing mass distributions:
    1. The best candidate exclusivity criteria already cleans up missing mass eN->eN gamma X distribution
    2. Missing mass ed->eN gamma X to be studied closely for background subtraction
- When a distribution shows a gaussian behaviour, estimate cut with +/- 5 standard deviations



	Proton	Electron	Photon	Neutron
Momentum (GeV)	0.3	1	2	0.35
	Q2>1 GeV2		W>2 GeV2	
$\theta(e,\gamma) > 5^\circ$	Remove electron shadow			
Exclusivity cuts	$\lvert\Delta\Phi\rvert < 2^\circ$	$\lvert\Delta t\rvert < 2\,GeV^2$		Missing energy<0.7 GeV

Selection cuts: charged particle veto

Credits: K. Price

- Neutron sample for nDVCS analysis is contaminated with charged particles (and photons)
- This is due to reduced tracking efficiency of the CVT: all deposits with no associated tracks are considered as neutral particles
- Veto charged particles based on information from central detectors (CND and CTOF)
- Efficiency of ~90% with MC (still to be evaluated on data)
- Veto is implemented in COATJAVA as of v 6.5.8, this required:
  - Improvements of clustering algorithms in CND and CTOF
  - Changes to EventBuilder

Thanks to Raffaella and Nathan

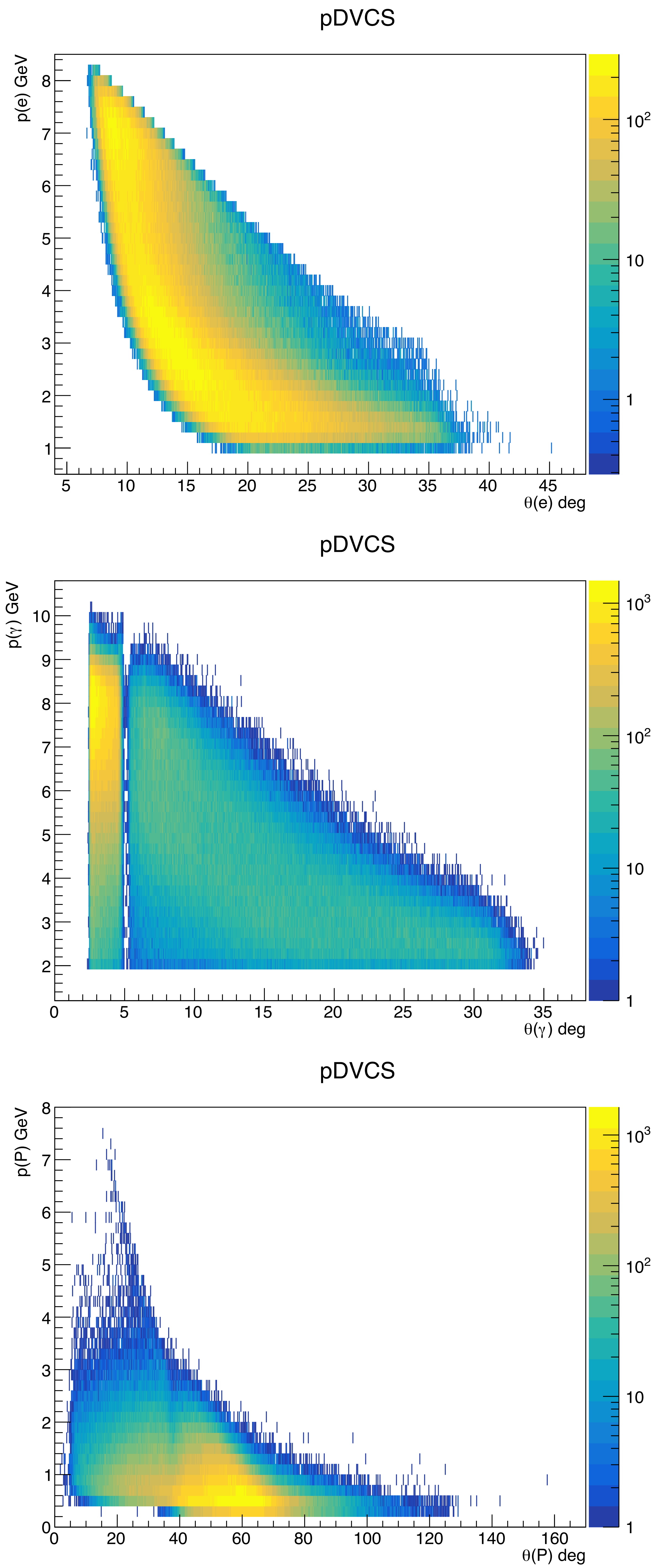
- Neutron ID in RGB Pass1 cooking includes this veto criteria

Detection topologies

- **Photons** are reconstructed in FT and FEC
- **Neutrons/protons** are reconstructed in CND and FEC
- Use simulation to determine optimal detection topology and exclusivity cuts

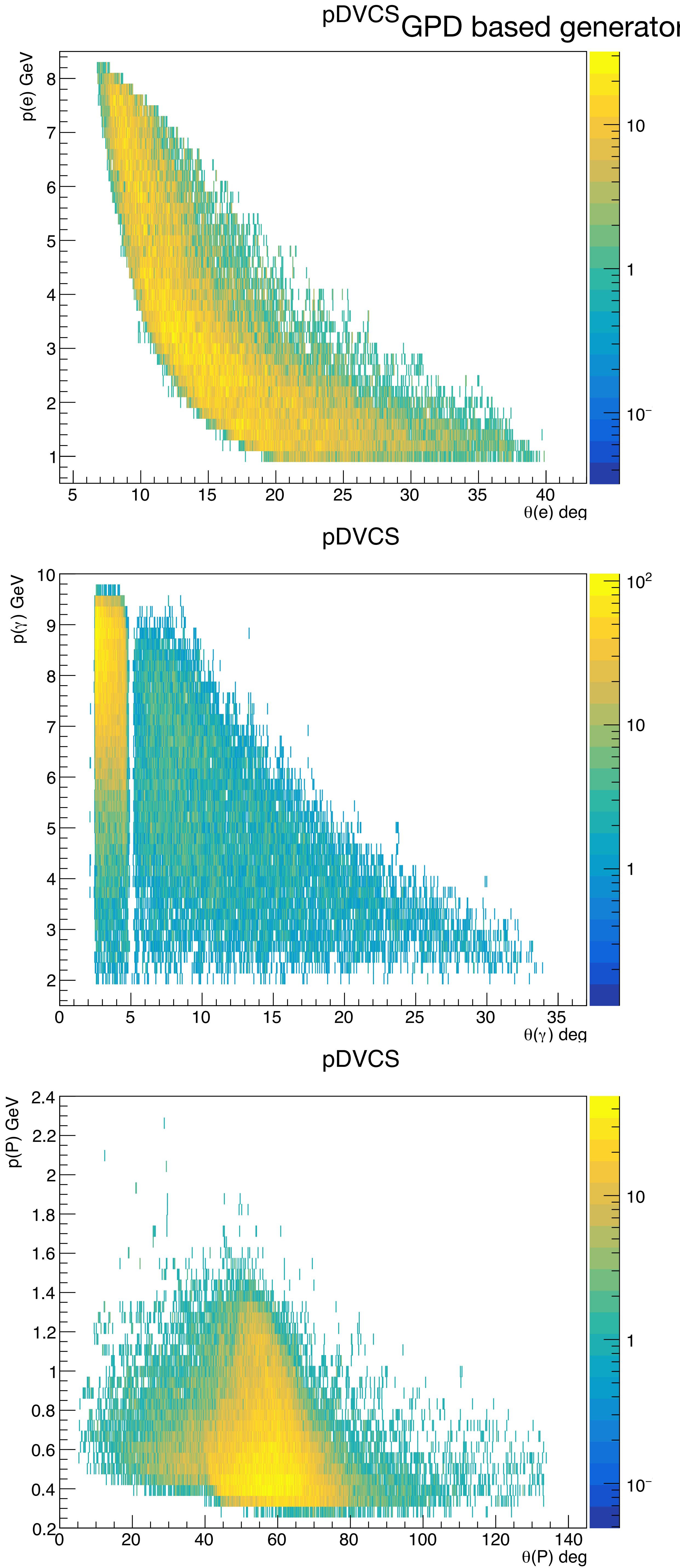
Data

Final state particle kinematics pDVCS



- From simulation:
  - pDVCS photons are mainly in FT
  - pDVCS protons are mainly in CD
- The privileged topology for pDVCS final state particles is for proton in CD and photons in FT

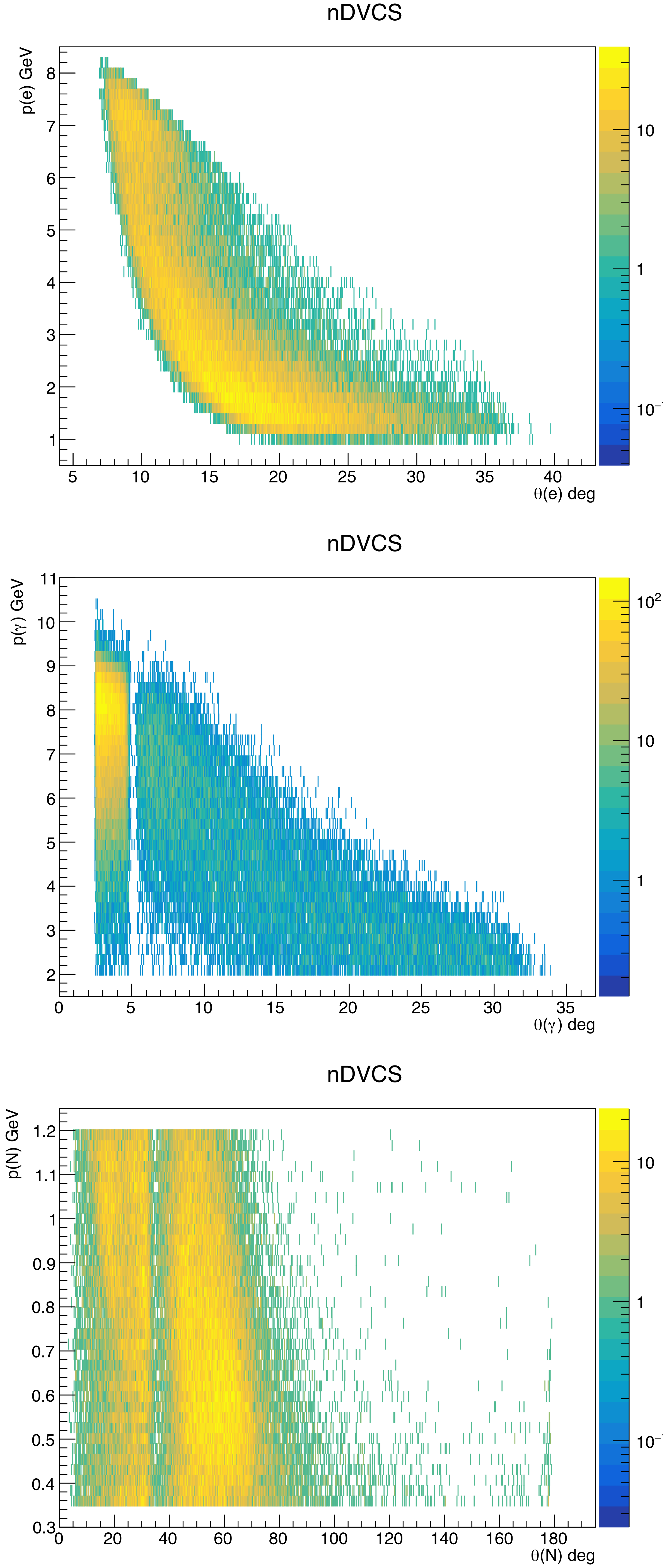
GPD based generator **MC**



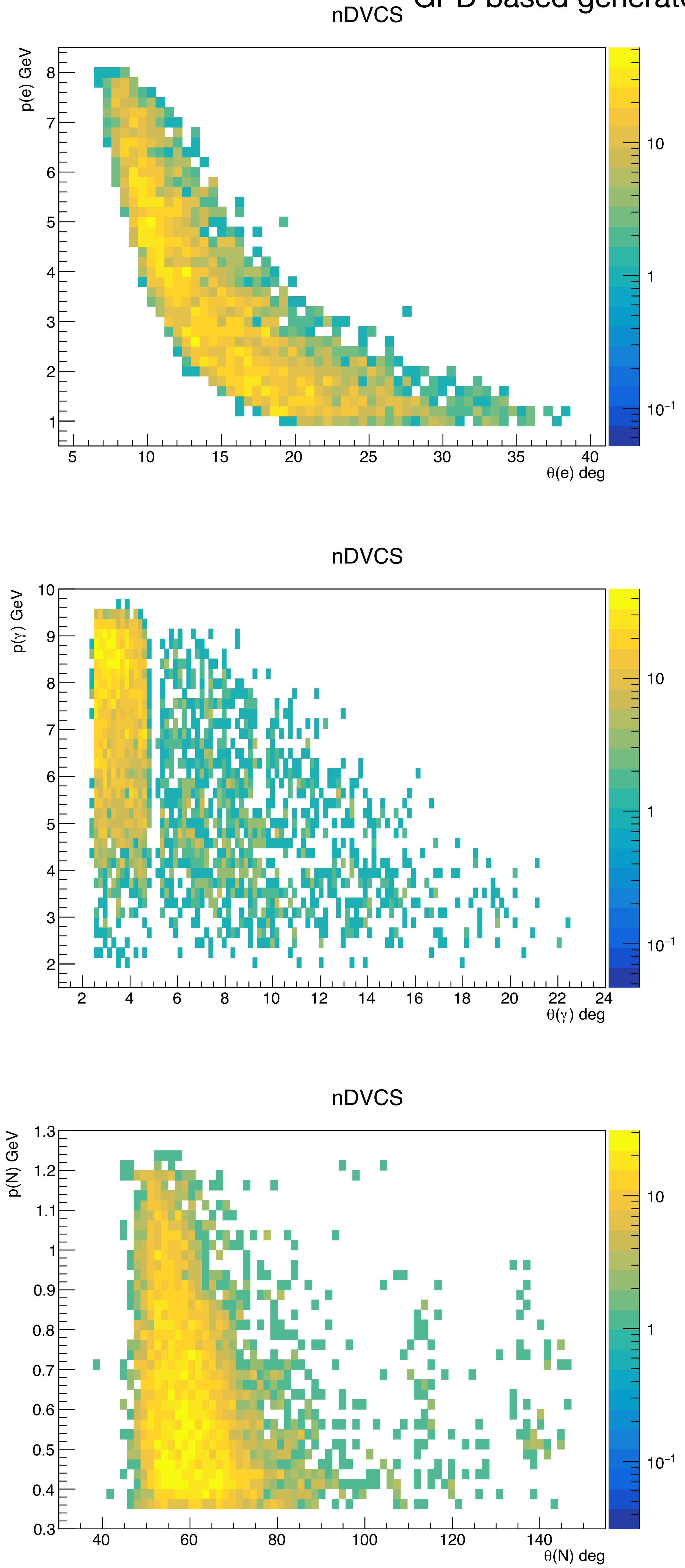
Data

Final state particle kinematics nDVCS

GPD based generator **MC**

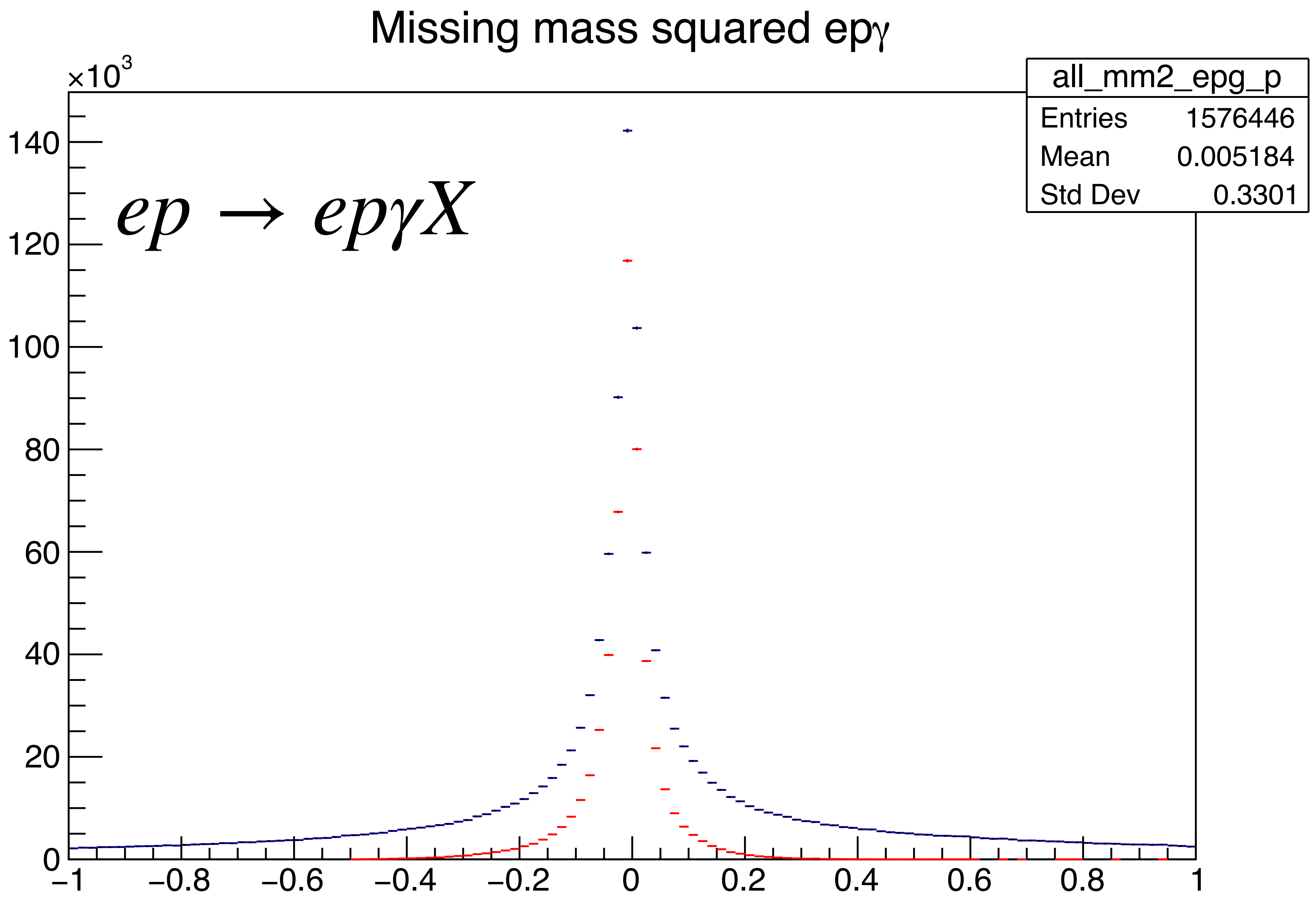


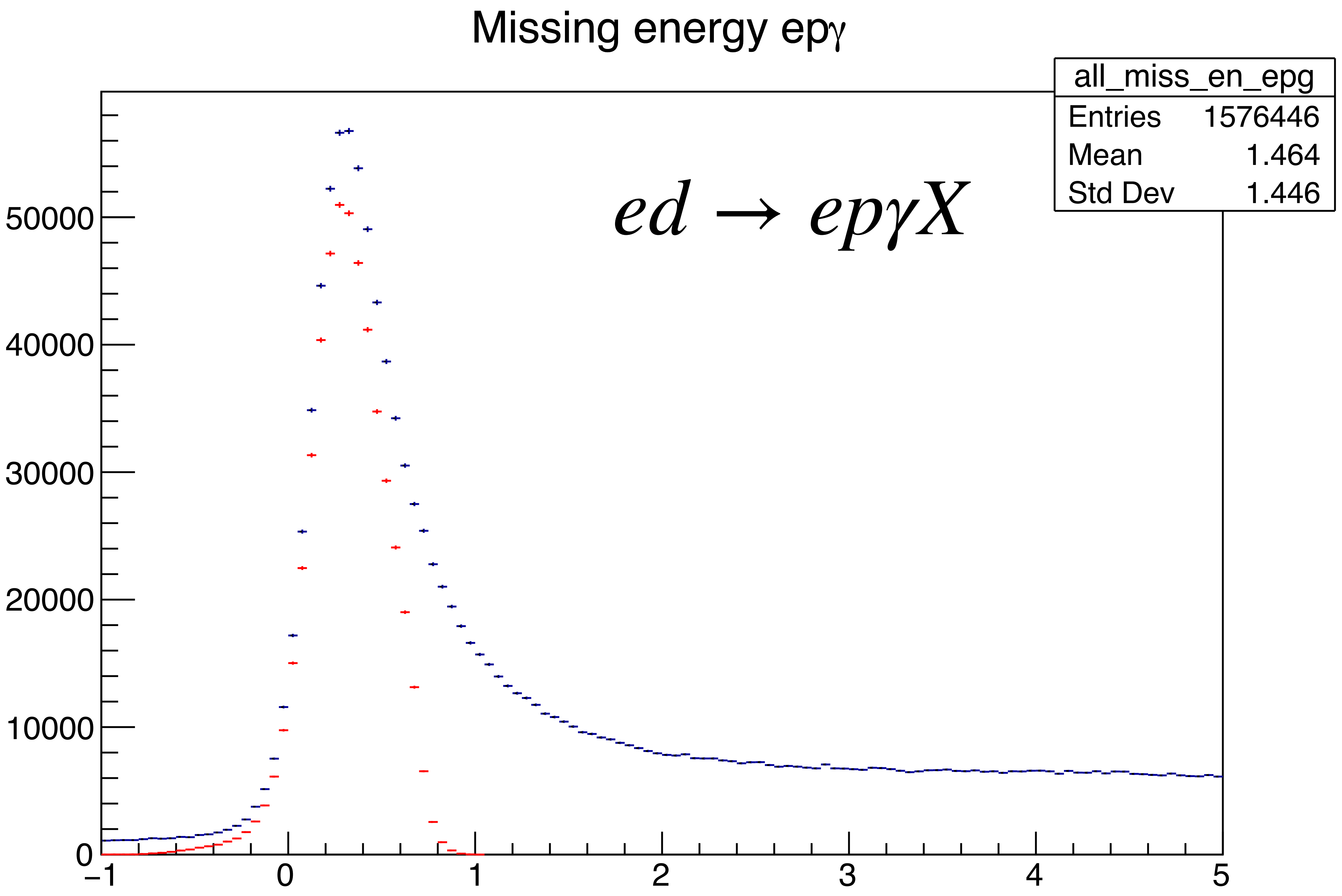
- From simulation:
  - nDVCS photons are mainly in FT
  - nDVCS neutrons are mainly in CD
- The privileged topology for nDVCS final state particles is for neutron in CD and photons in FT



Exclusivity variables

- pDVCS; detection topology: proton in CD and photon in FT



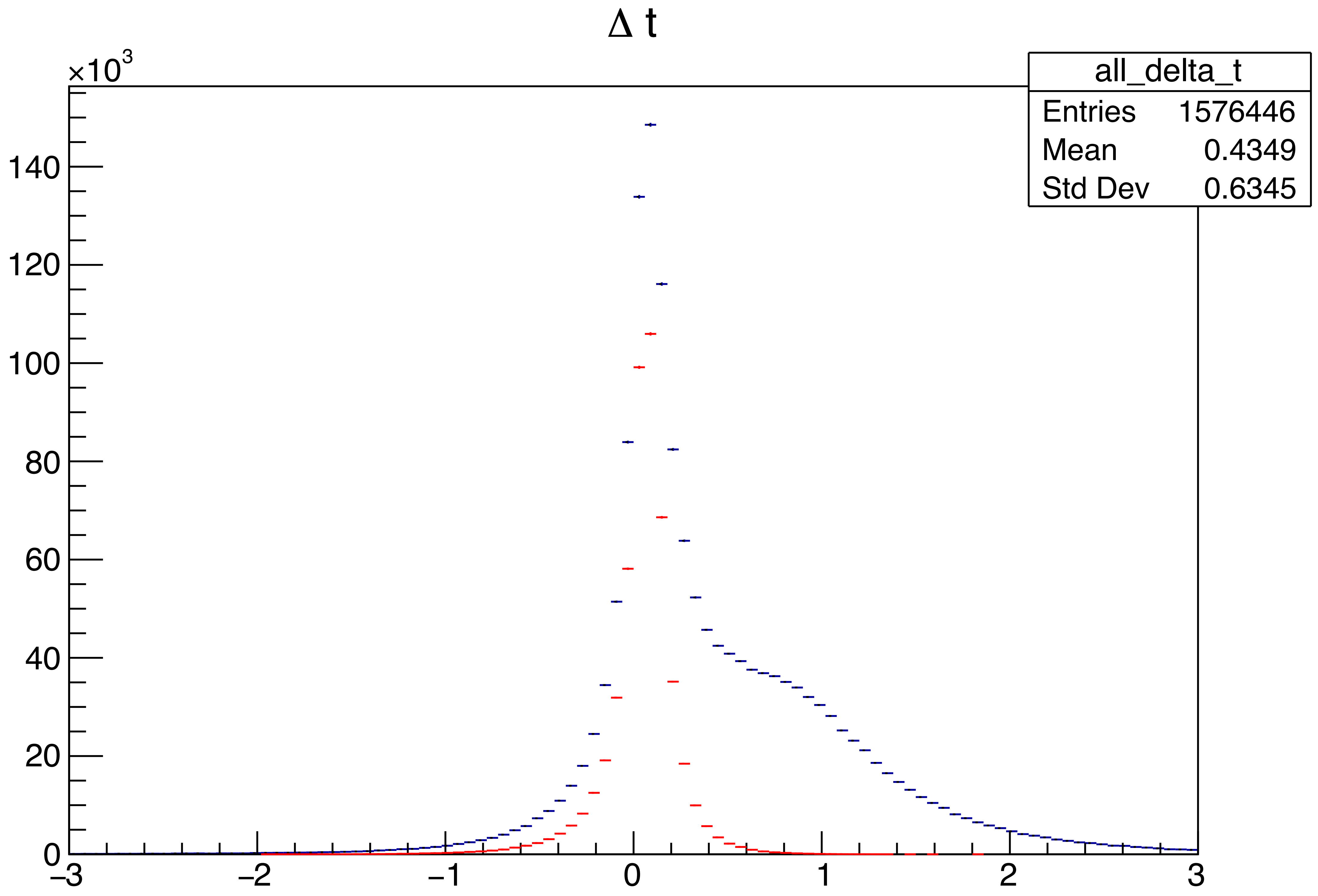


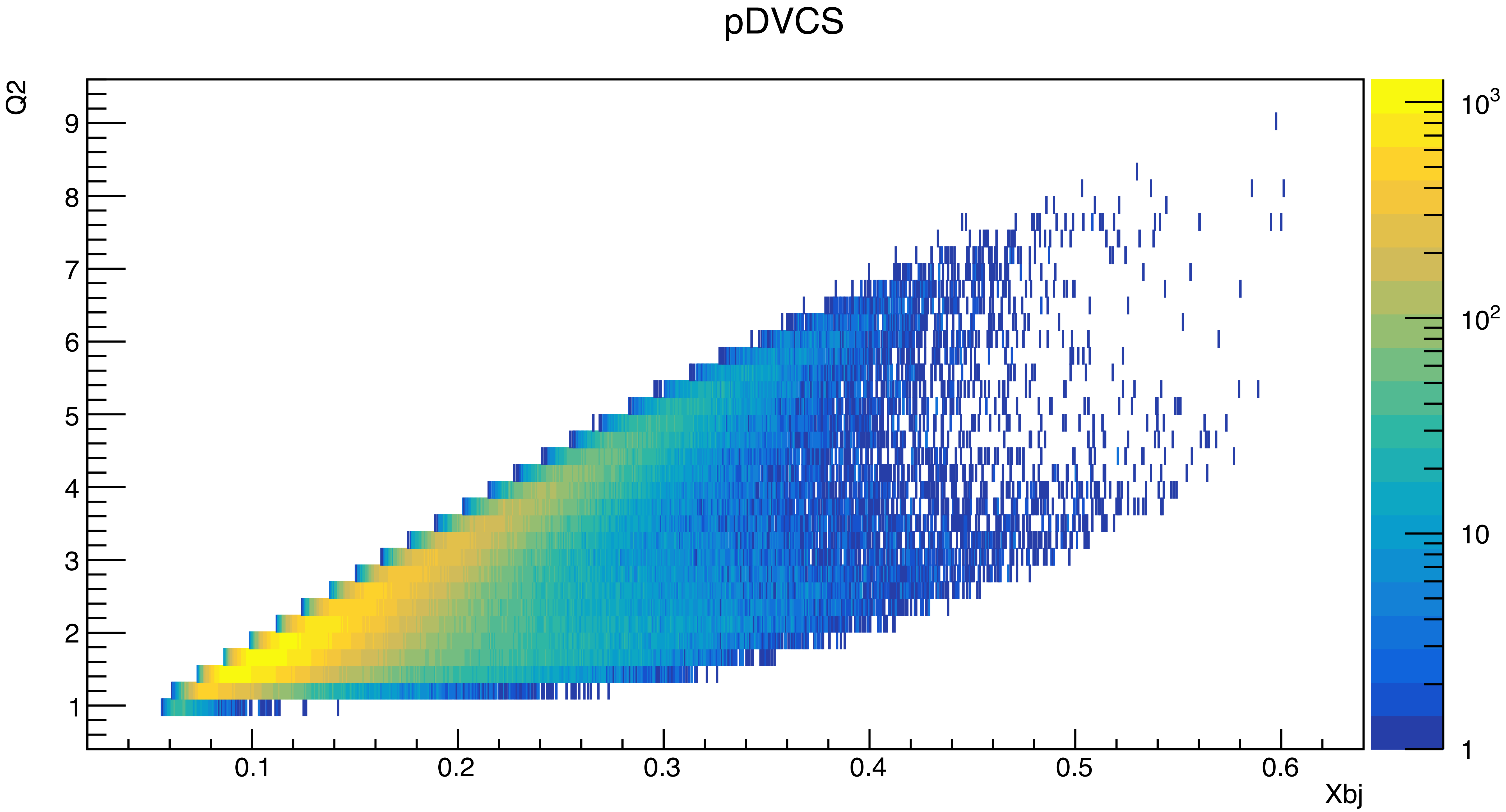
Blue: before Exclusivity selection

Red: after Exclusivity selection

Exclusivity variables

- pDVCS; detection topology: proton in CD and photon in FT





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Exclusivity variables

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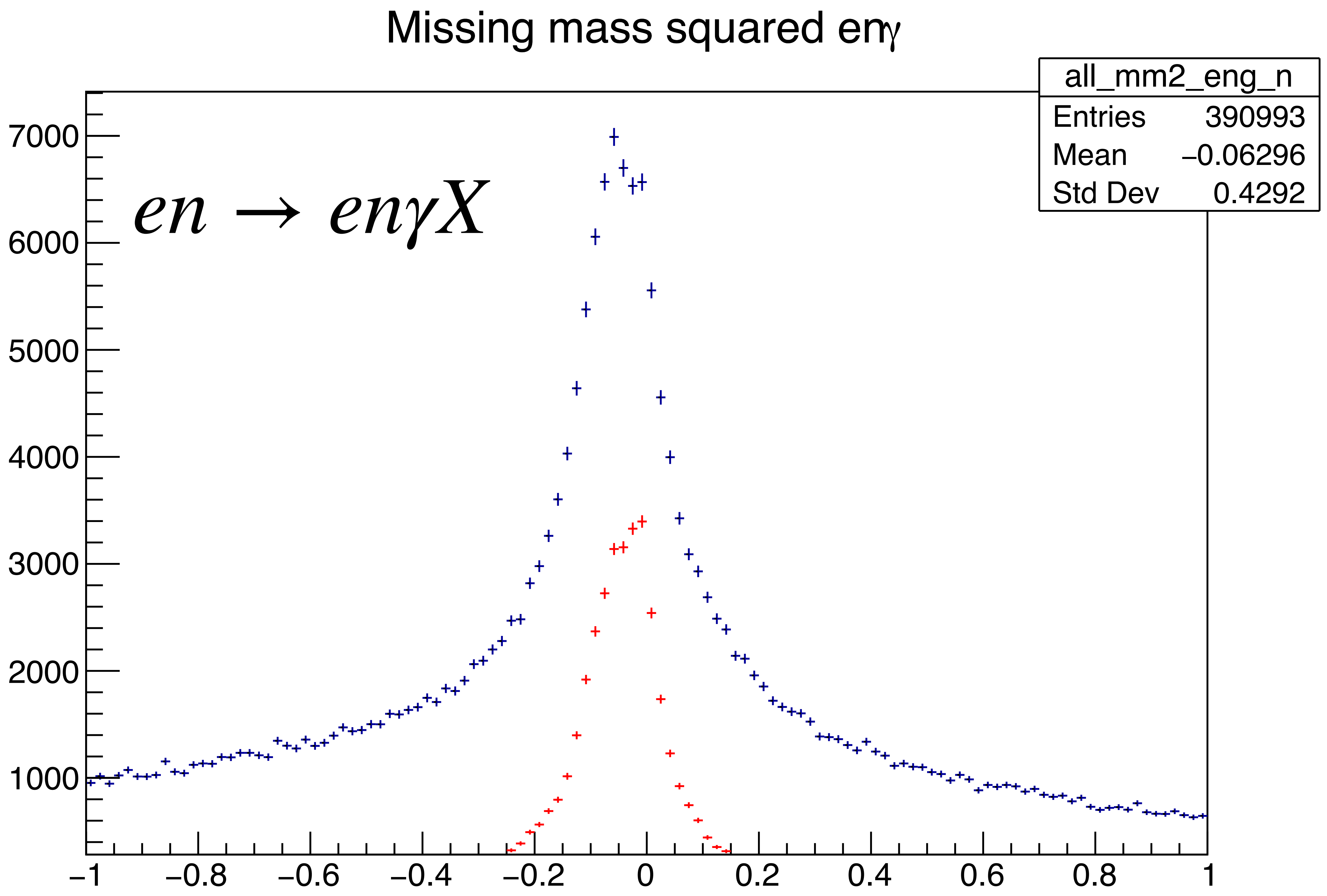

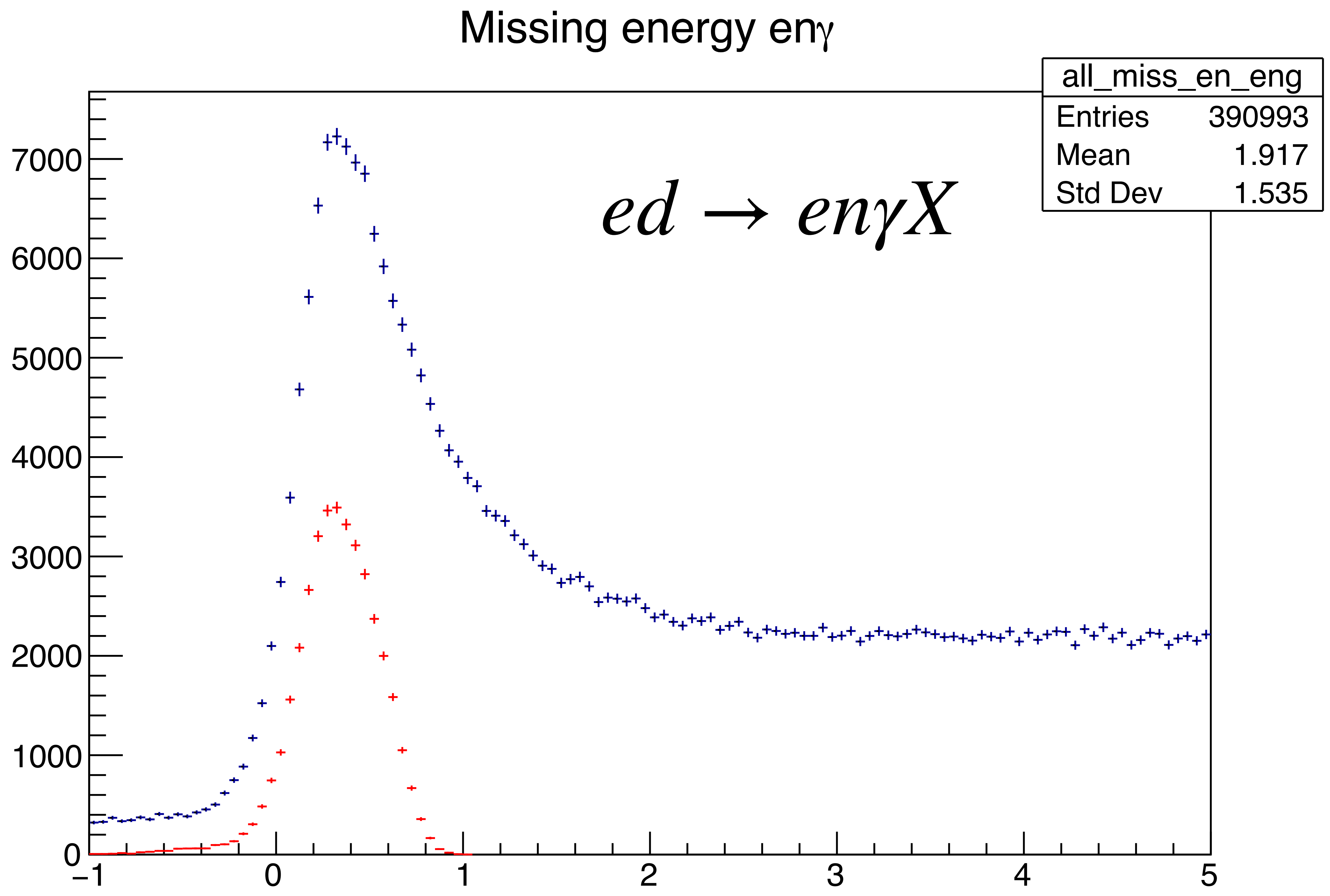

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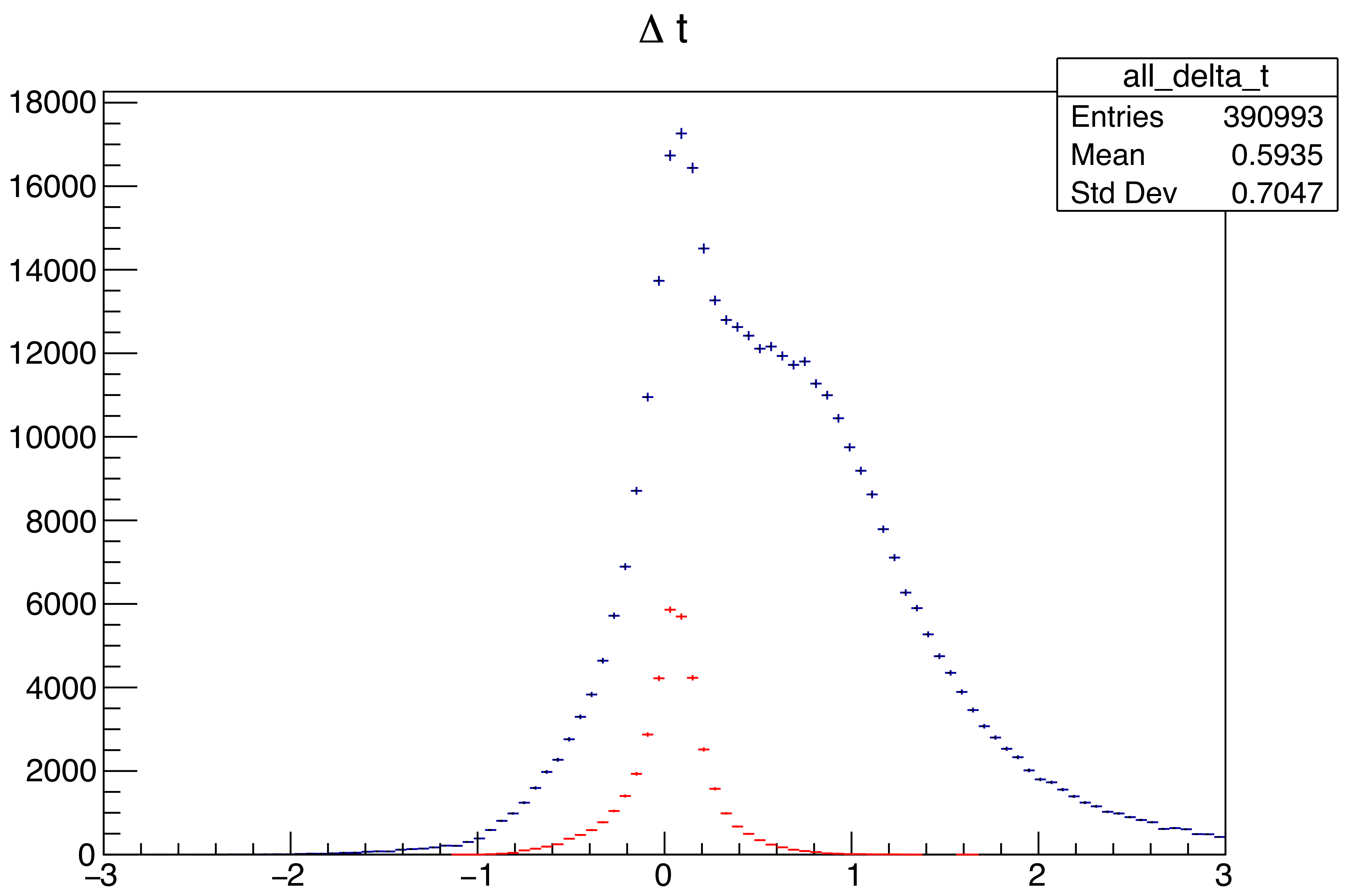
Exclusivity variables

- nDVCS; detection topology: neutron in CD and photon in FT



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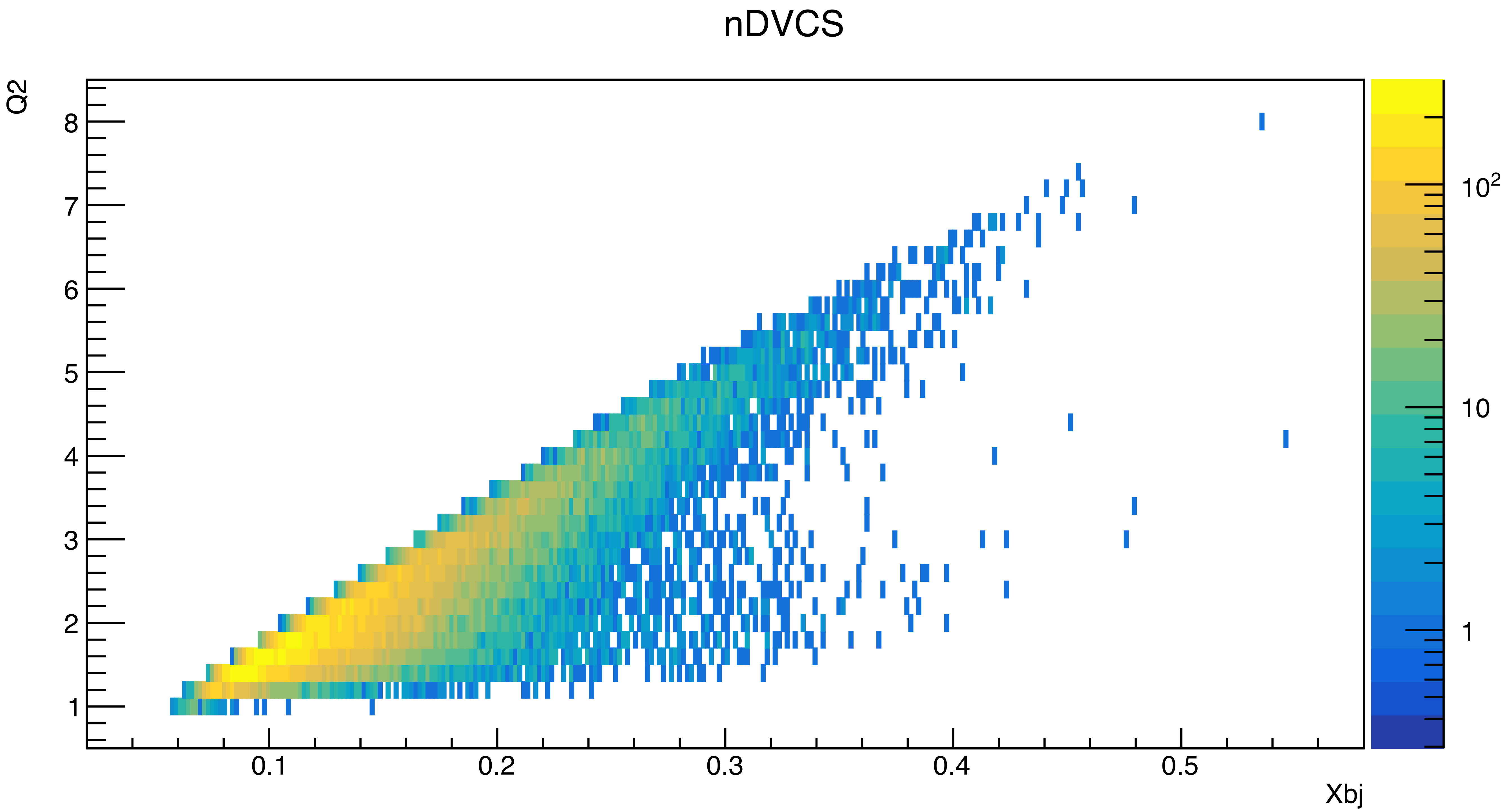
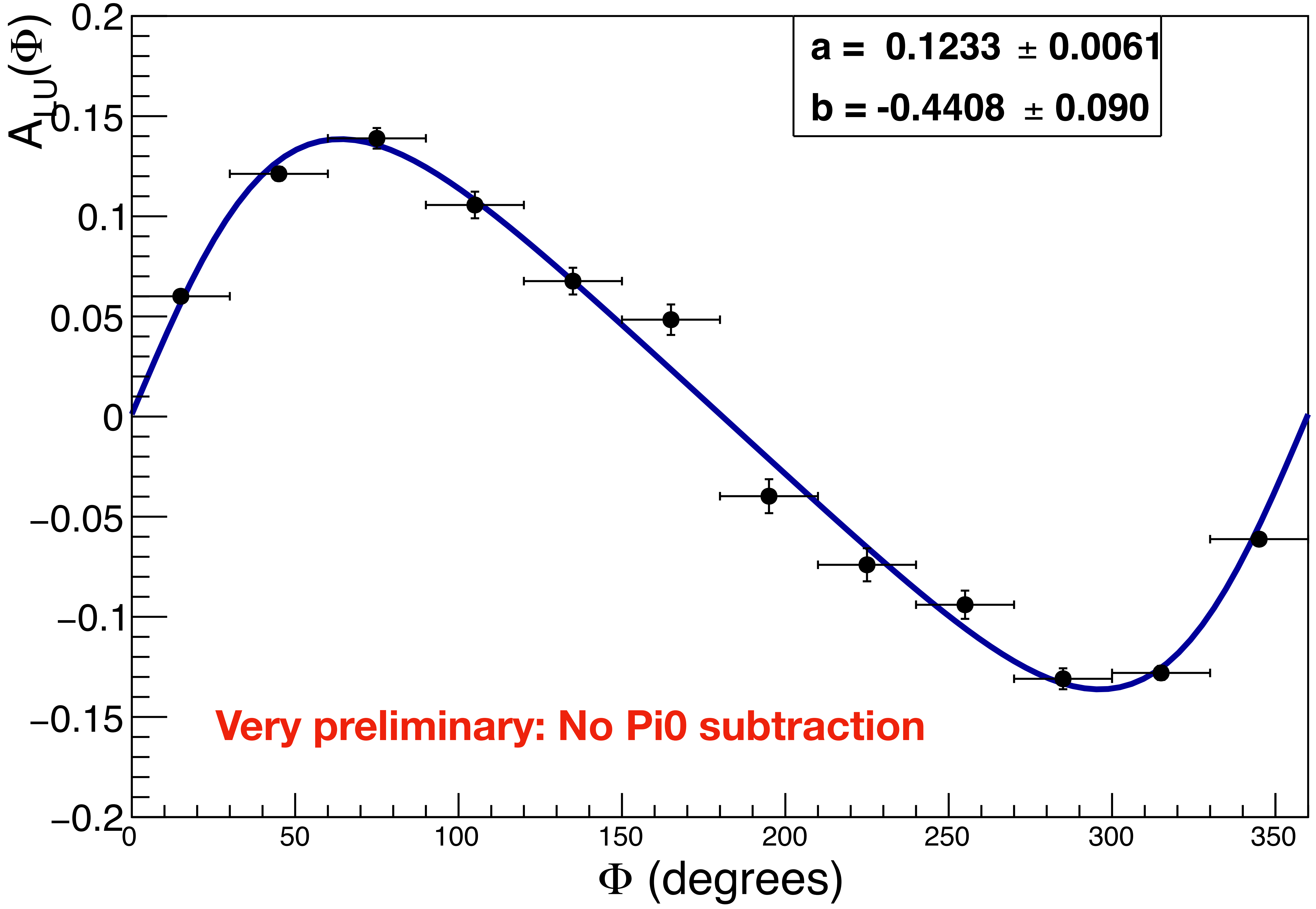


Raw BSA pDVCS

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

- Binned maximum likelihood fit
- Raw BSA integrated over all kinematics
- Preliminary work ongoing on Pi0 subtraction and fiducial cuts



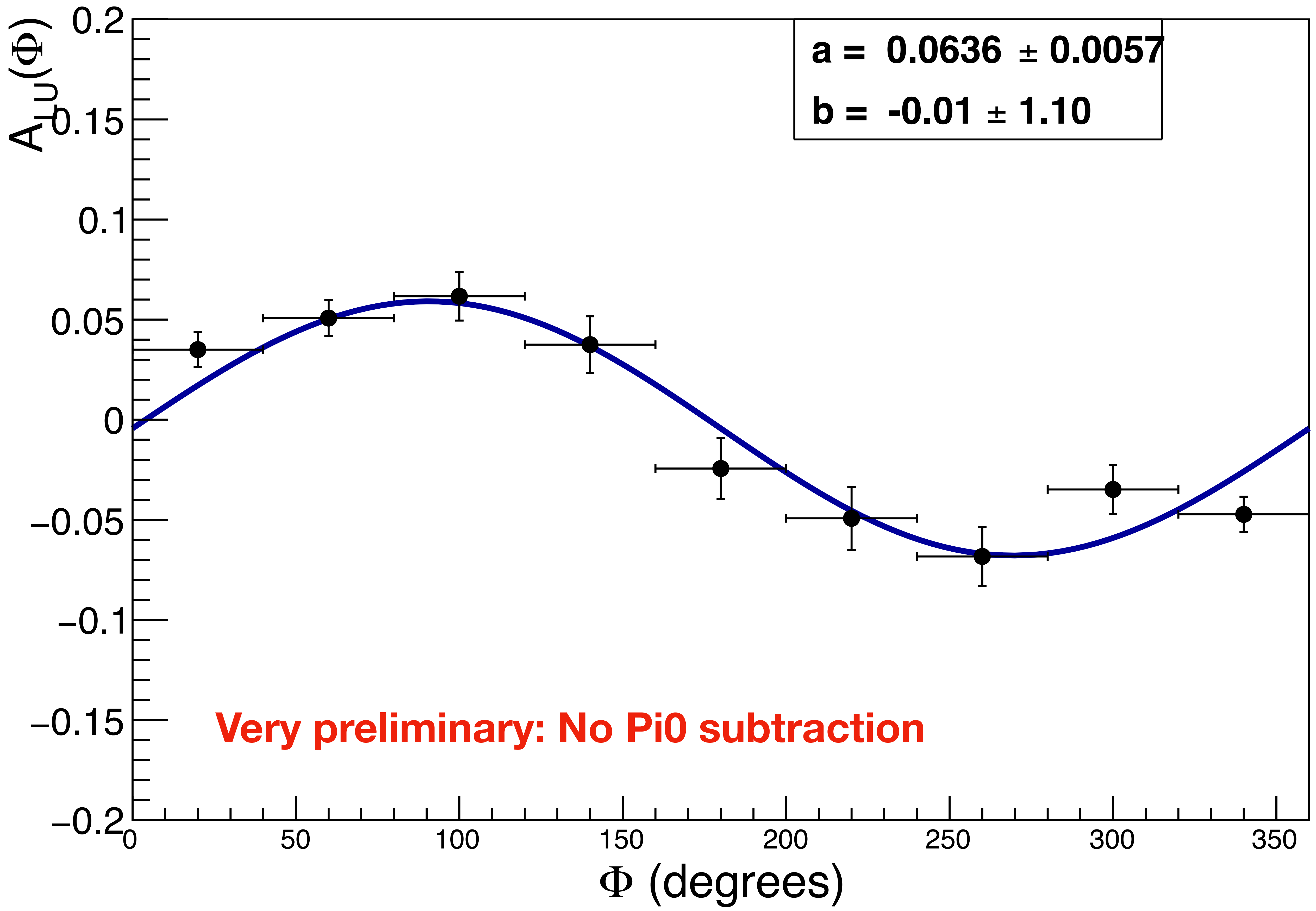
777111 events

<Q2> = 2.36 GeV2
<-t> = 0.91 GeV2
<xb> = 0.24

Raw BSA nDVCS

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

- Binned maximum likelihood fit
- Raw BSA integrated over all kinematics
- Preliminary work ongoing on Pi0 subtraction and fiducial cuts



28298 events

<Q2> = 2.27 GeV2
<-t> = 0.49 GeV2
<xb> = 0.18

$$ed \to ep\pi^0$$

ep->ep gamma gamma channel

- Reconstruction: final state ep gamma gamma (credits: K. Price)
- Pi0 selection:

```
Pi0_IM2>0.0          Pi0_IM2<0.03          pi0_2DChi2<0.15          best2DChi2Flag
```

- 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

```
Exclpi0_2DChi2<0.5    abs(mm2_epgg_p)<0.05    theta_pi0_X<5          abs(deltamm2_pi0_X)<0.7
bestExclPi0Flag       abs(delta_Phi)<5        abs(delta_t)<0.5
```

pi0 (gamma gamma) selection

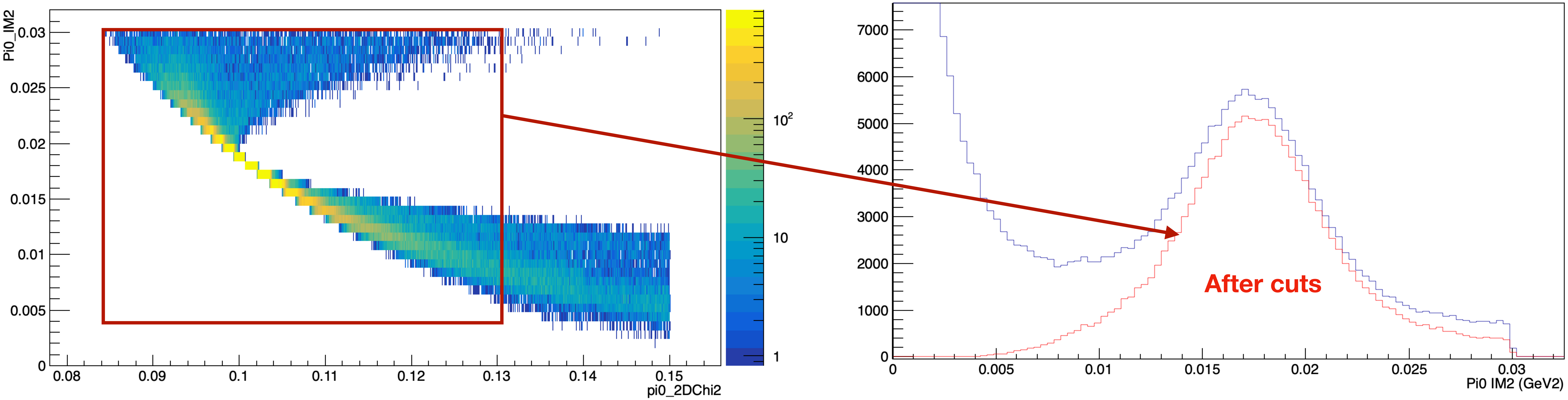
- Pi0 selection:

```
Pi0_IM2>0.0          Pi0_IM2<0.03          pi0_2DChi2<0.15       best2DChi2Flag
```

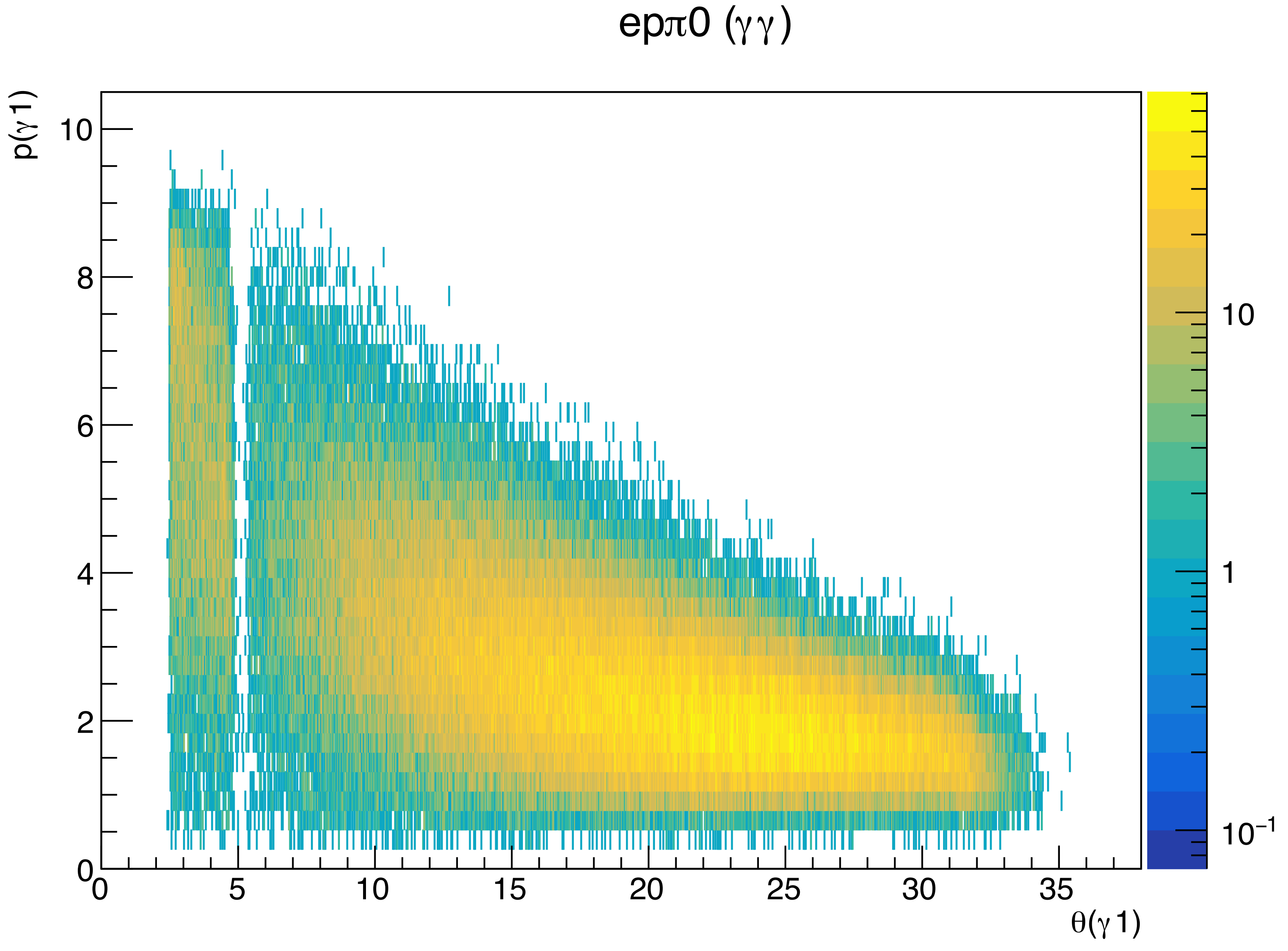
$$2D\chi^2 = \frac{(M_{measured} - M_{expected})^2}{M_{expected}} + \frac{(\theta^{\gamma^1\gamma^2}_{measured} - \theta^{\gamma^1\gamma^2}_{expected})^2}{\theta^{\gamma^1\gamma^2}_{expected}}$$

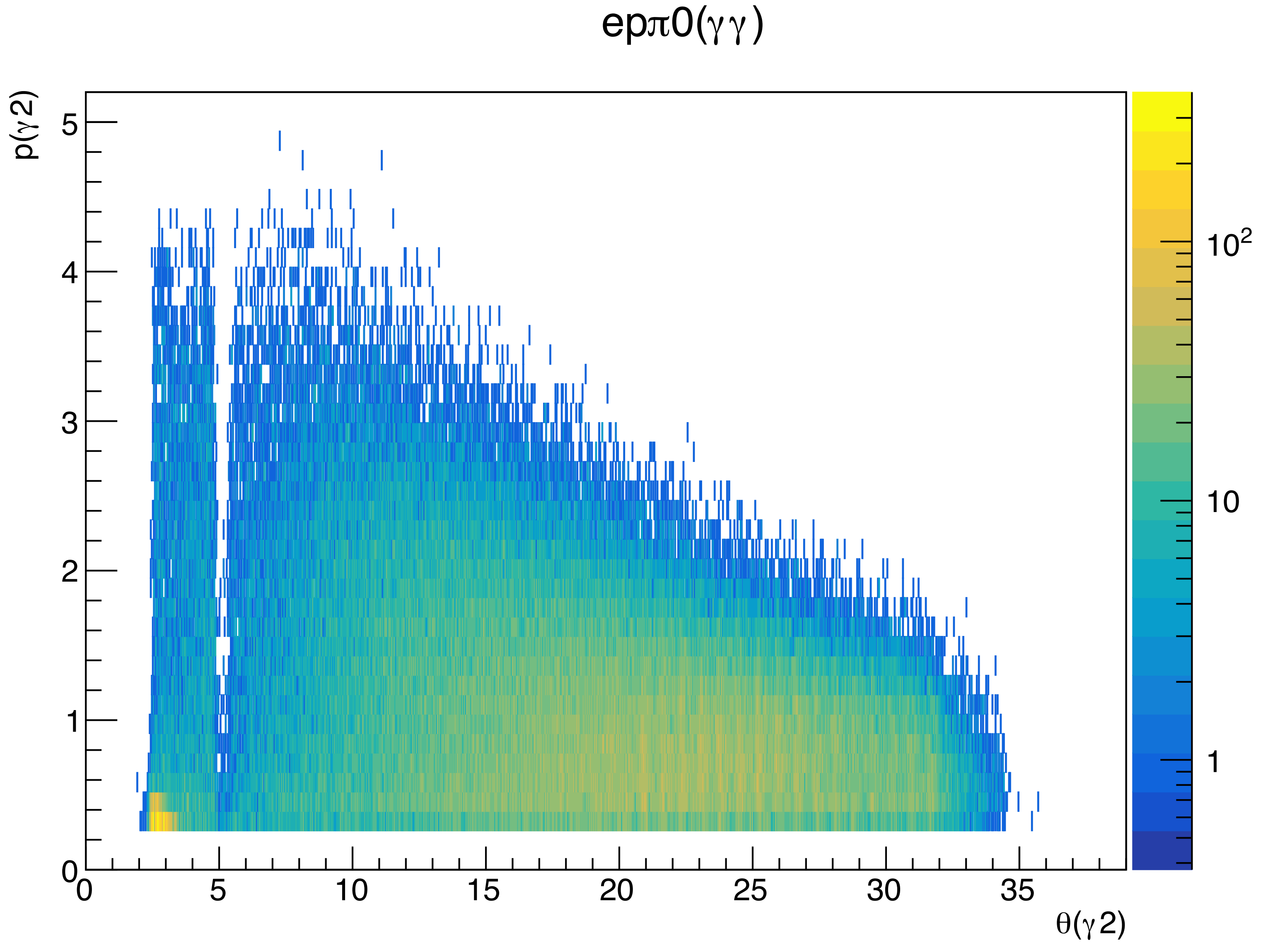
pi0 (gamma gamma) selection

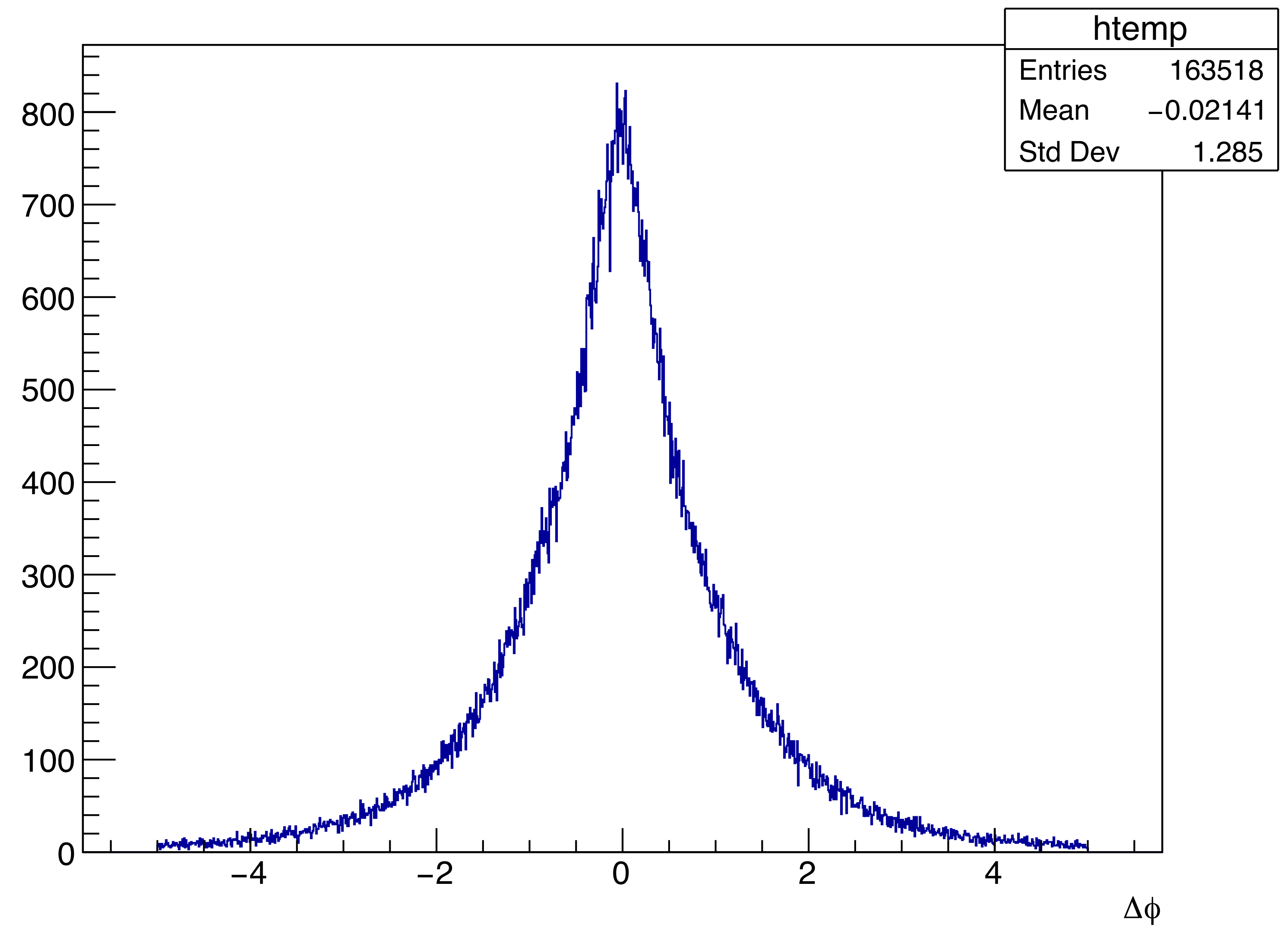
$$2D\chi^2 = \frac{(M_{measured} - M_{expected})^2}{M_{expected}} + \frac{(\theta^{\gamma^1\gamma^2}_{measured} - \theta^{\gamma^1\gamma^2}_{expected})^2}{\theta^{\gamma^1\gamma^2}_{expected}}$$

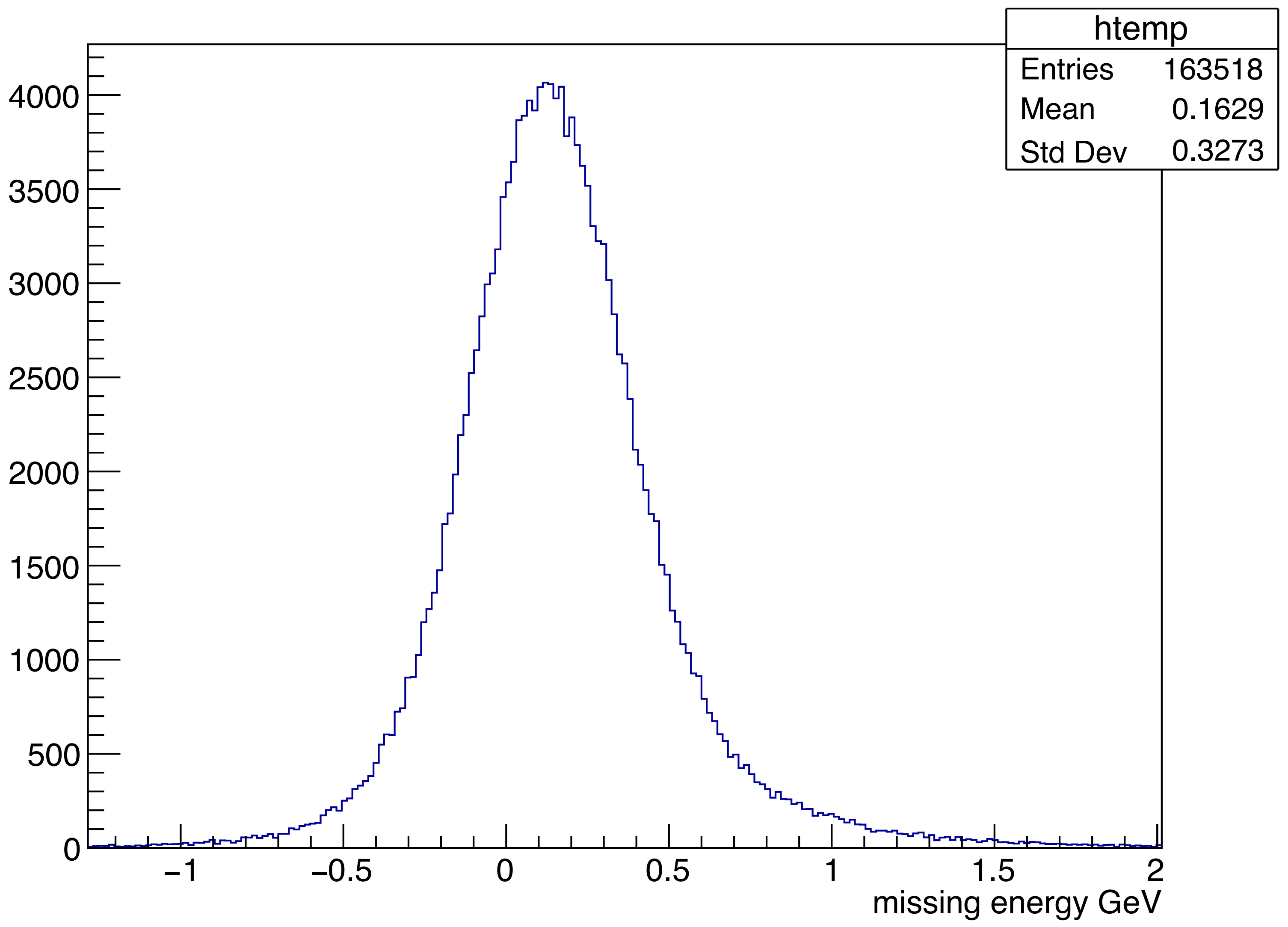


Photons kinematics and exclusivity variables









- A non negligible contamination (to pDVCS) of Pi0 photons in the FT

- A major contamination (to pDVCS) in the EC from Pi0 photons

Summary

- BSA in pDVCS and nDVCS from deuterium are studied
- Analysis steps are partly in place
- Preliminary treatment of data is performed
- Optimisation of selection with fiducial cuts is ongoing
- A neural net based neutron ID is being developed
- Pi0 background subtraction is ongoing using the sPlot technique

Backup

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

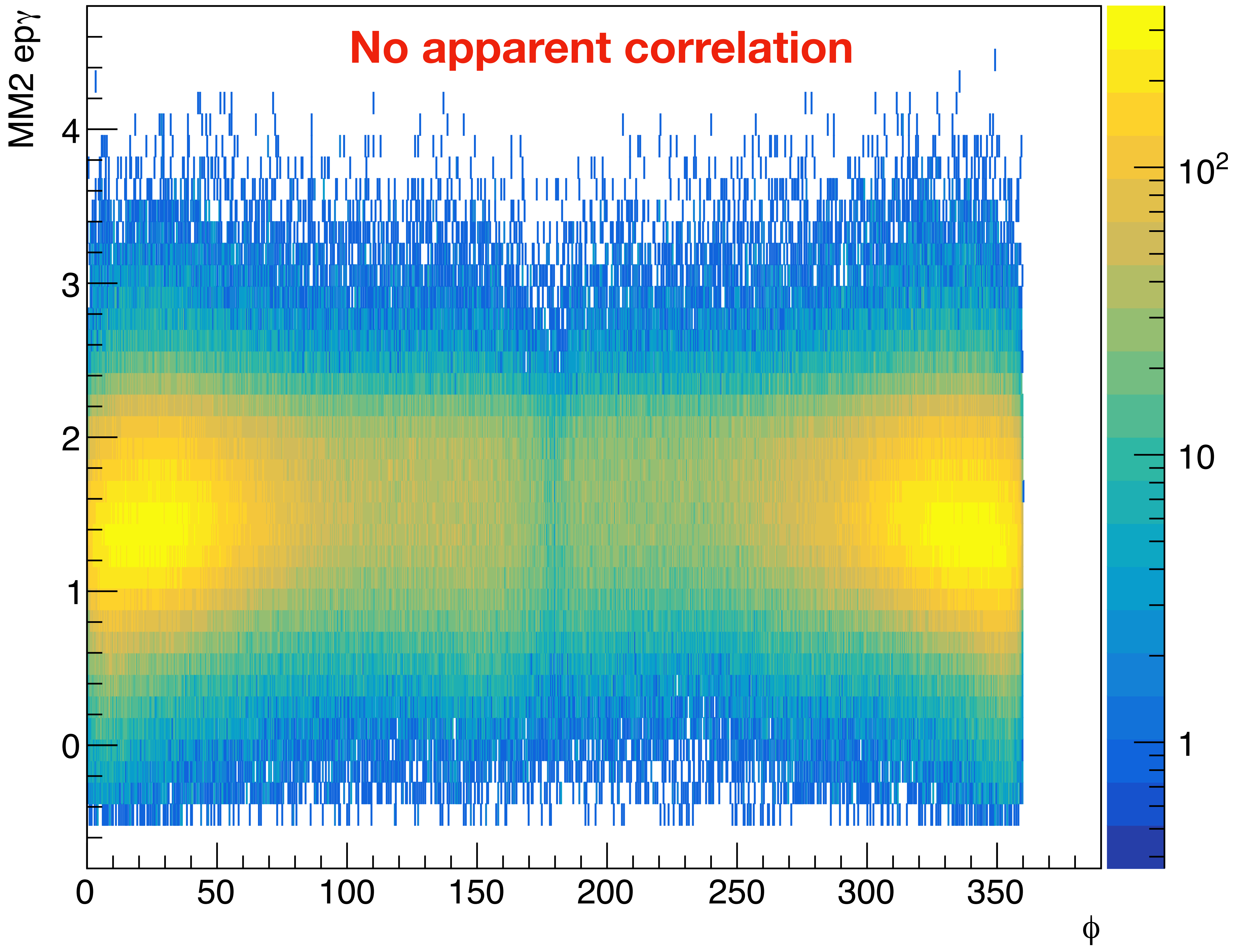
    - Missing Mass (MM) distribution

- 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

- 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: 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)
    - Merged Pi0 background?: high momentum Pi0 decaying into 2 photons forming a single deposit in detector (still not taken into account)
        - Too dangerous as it peaks under signal invariant mass peak: need dedicated identification tools

Partially reconstructed $ed \to ep\pi^0$

$ed \to ep\pi^0(1\,\gamma)$

- 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

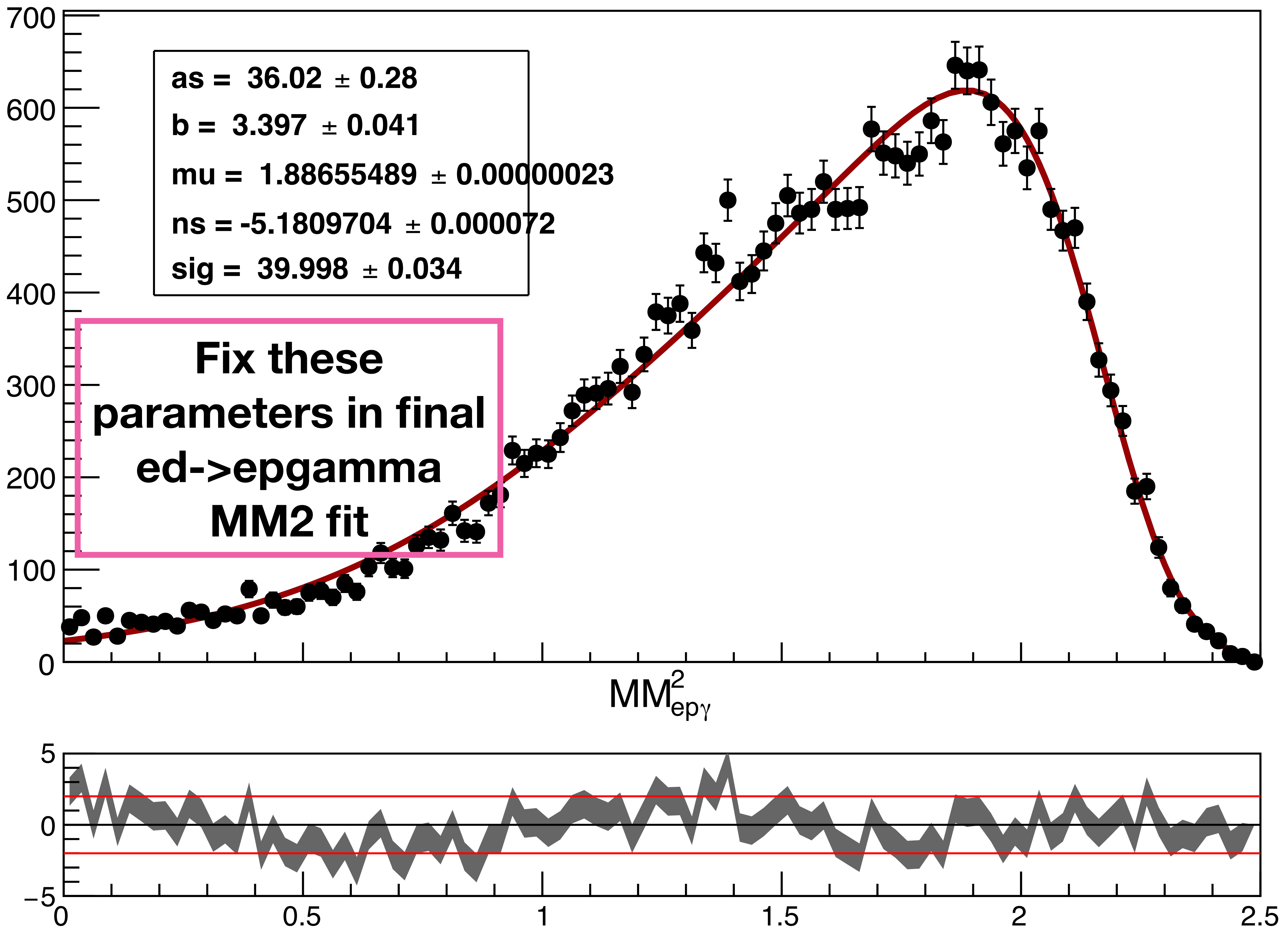
    - Require that at least one of the photons has energy>1 GeV (to imitate signal pDVCS)

    - Apply pDVCS exclusivity cuts

- Model the partially reconstructed decay with an Apollonios function directly on data

    - Unbinned Maximum Likelihood extended fit

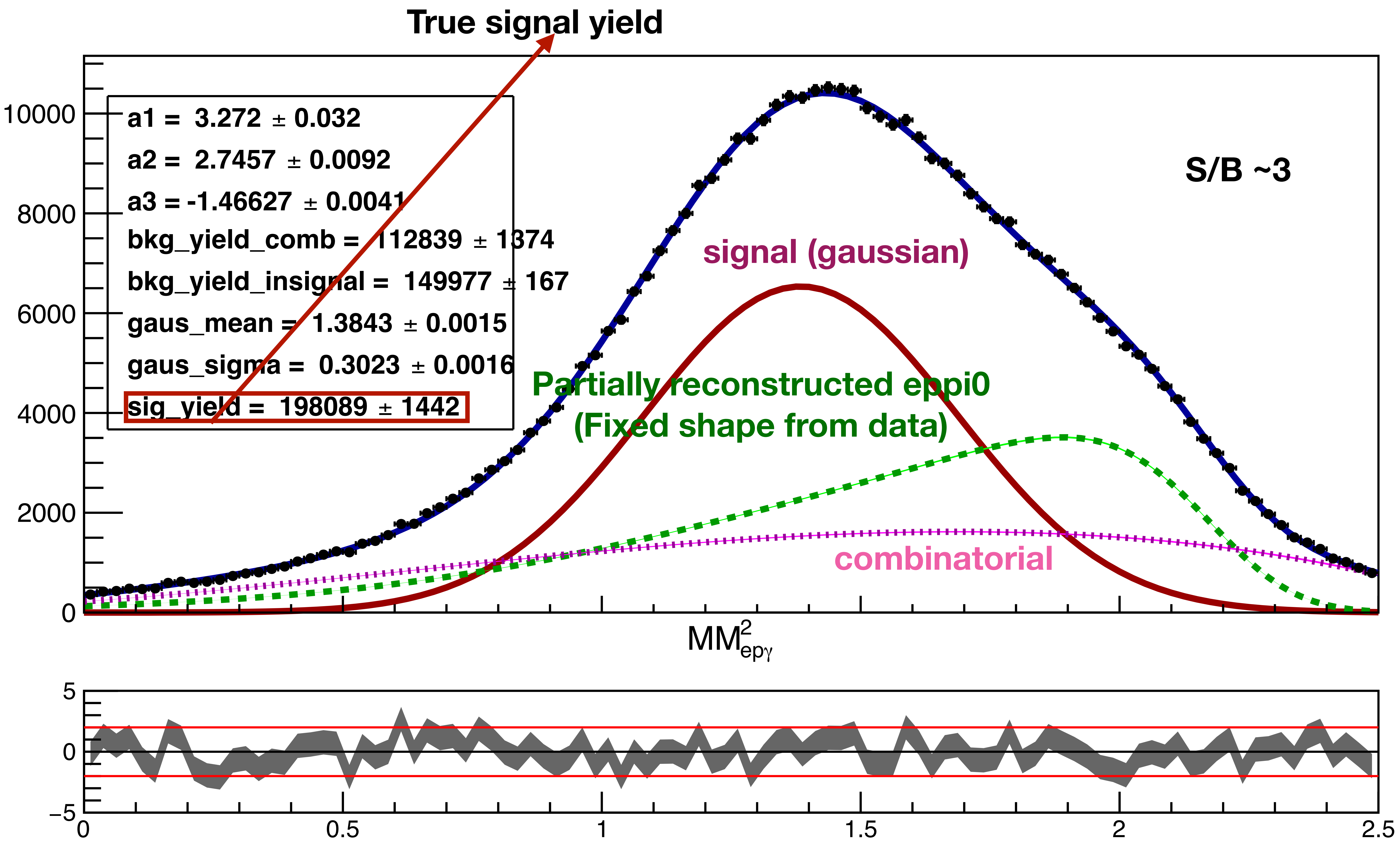
- Region of interest in mass 0<mm2<2.5 (GeV2)



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

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 -> all reduced down to a simple Gaussian
    - Cross check with MC when we have the new better calibrated cooking
- Systematic related to this method: the choice of the fitting model



BSA after background subtraction

pDVCS after background subtraction

a = 0.198 ± 0.038

b = -0.09 ± 1.3

BSA of eppi0(1gamma) sample

a = 0.102 ± 0.058

b = -0.40 ± 1.7