J/ψ Electroproduction analysis in RGA

Mariana Tenorio Pita

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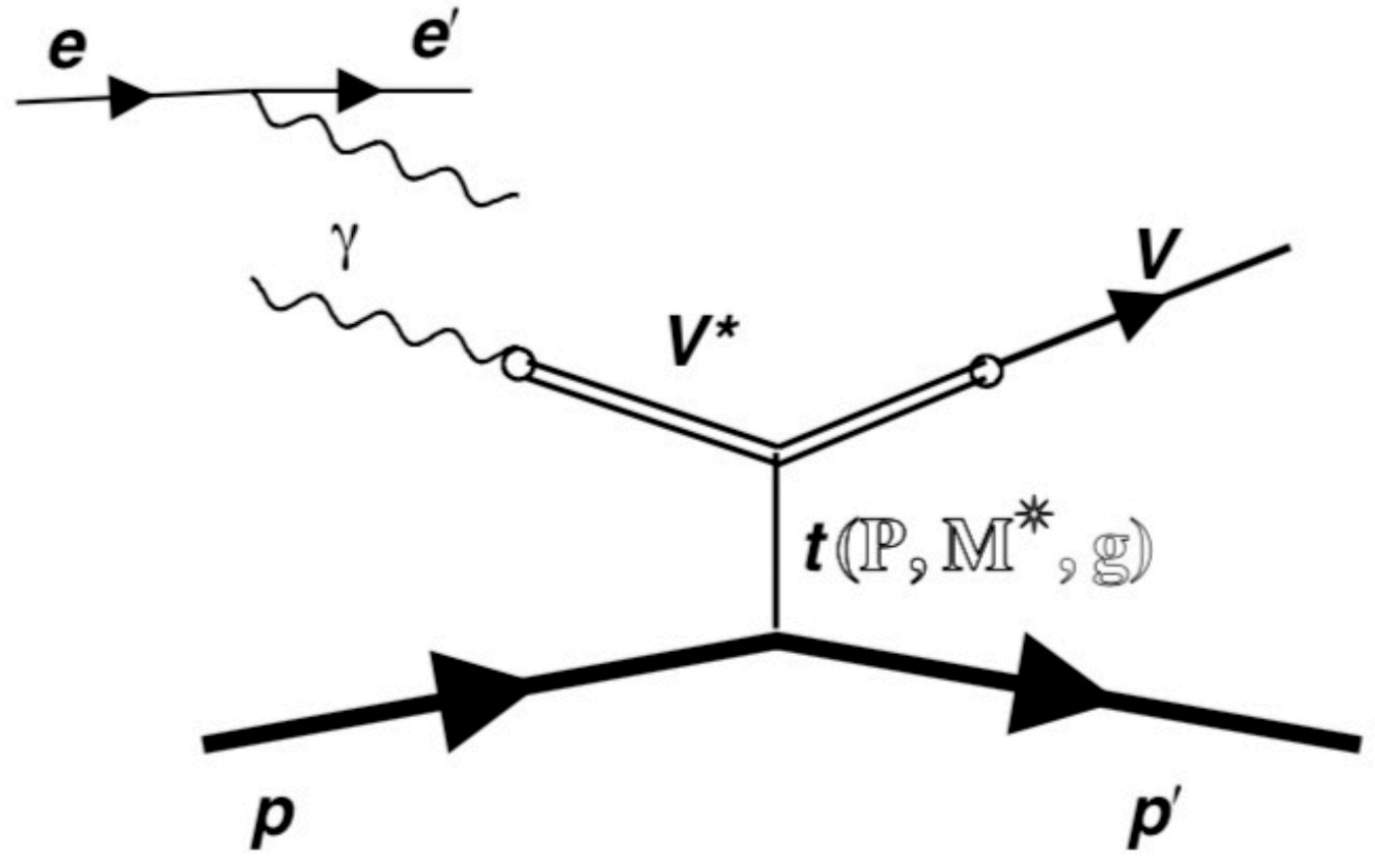
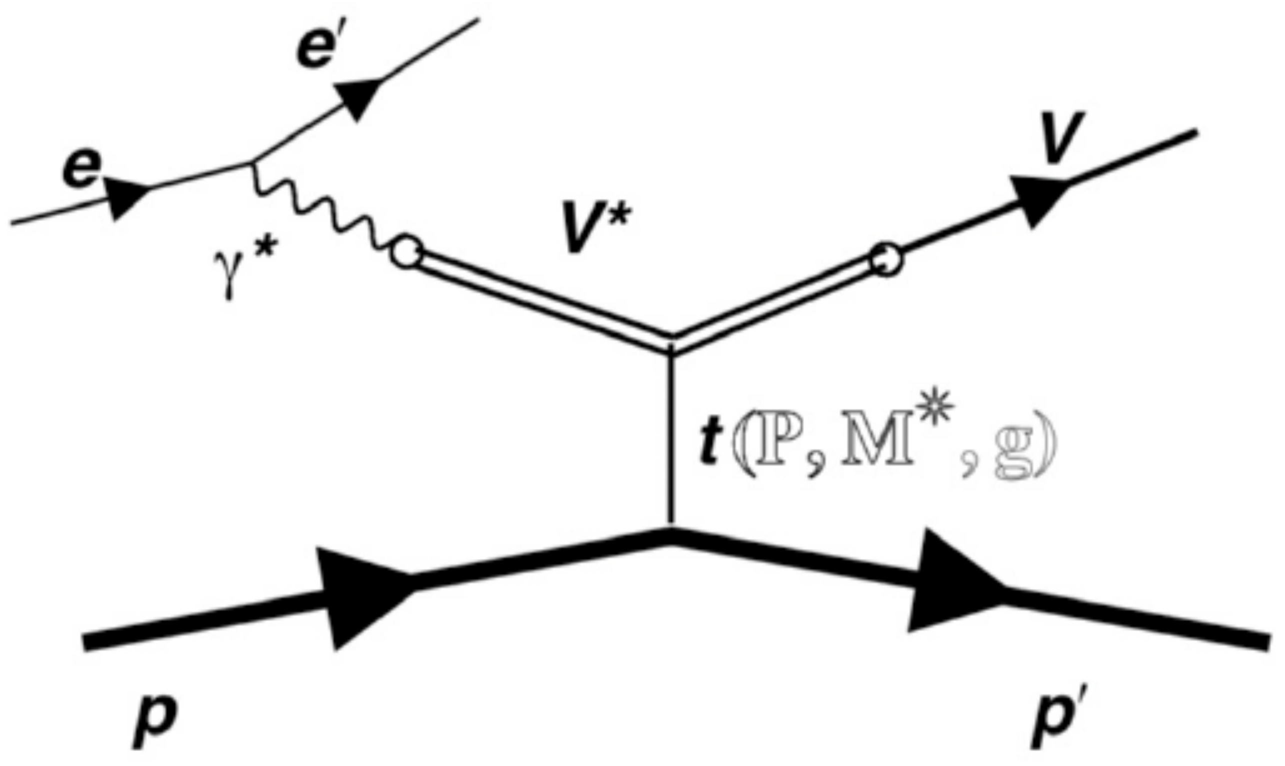
Motivation

- The production process of the J/ψ meson serves as a unique probe of the structure of the nucleon.

- The production of a vector meson such as the J/ψ in an scattered electron experiment can be described as $ep \to e'J/\psi p'$.

- For the measurement of J/ψ production near threshold, two mechanisms contribute to the process: pure photoproduction and electroproduction.





Motivation

- The electroproduction cross-section depends on the total center of mass energy, W, the exchange photon virtuality Q^2 and the transfered momentum squared, t

$$\frac{d\sigma_{ep}}{dWdQ^2dt} = \frac{N_{J/\psi}(W, Q^2, t)}{L \cdot Br \cdot \eta} \frac{1}{\Delta W \Delta Q^2 \Delta t}$$

- In terms of W, we can describe the differential electroproduction cross-section as:

$$\frac{d\sigma_{ep}}{dW} = \frac{\mathcal{Y}}{L \cdot Br} \frac{1}{\Delta W}$$

- The integrated electroproduction cross-section is:

$$\sigma_{ep} = \frac{\mathcal{Y}}{L \cdot Br}$$

Motivation

- The photoproduction cross-section can be obtained from the electroproduction cross-section using:

$$\sigma_\gamma = \frac{1}{\Phi_\gamma}\sigma_{ep}$$

where Φ_γ is the integrated photon flux given by the expression:

$$\Phi_\gamma = \int_{\Delta Q^2}\int_{\Delta W}\Gamma(W, Q^2)\, dW\, dQ^2 = \sum_{i,j}\Gamma_T(W_i, Q_j^2)\Delta W \Delta Q^2$$

- Hence, we can write the integrated photoproduction cross-section as:

$$\sigma_\gamma = \frac{\mathscr{Y}}{\Phi_\gamma \cdot L \cdot Br}$$

Analysis Framework

- For this analysis the RG-A Fall 2018 and Spring 2019 Pass2 data is presented.
  - Fall 2018 Inbending , 10.6, Q=34.6353mC
  - Fall 2018Outbending, 10.6 GeV, Q=32.3415mC
  - Spring 2019: Inbending configuration, 10.2 GeV, Q=44.1839mC

- The reaction to study is $ep \to e'J/\psi\ p' \to e'e^+e^-X$ where e^+ and e^- are measured in the Forward Detector, e' is measured in the Forward Tagger and X corresponds to the recoil proton and will be identified in the missing momentum analysis.

- In addition, we have other topologies that are exploring:
  - $ep \to e'p'e^+e^-$
  - $ep \to e'p'e^+X$

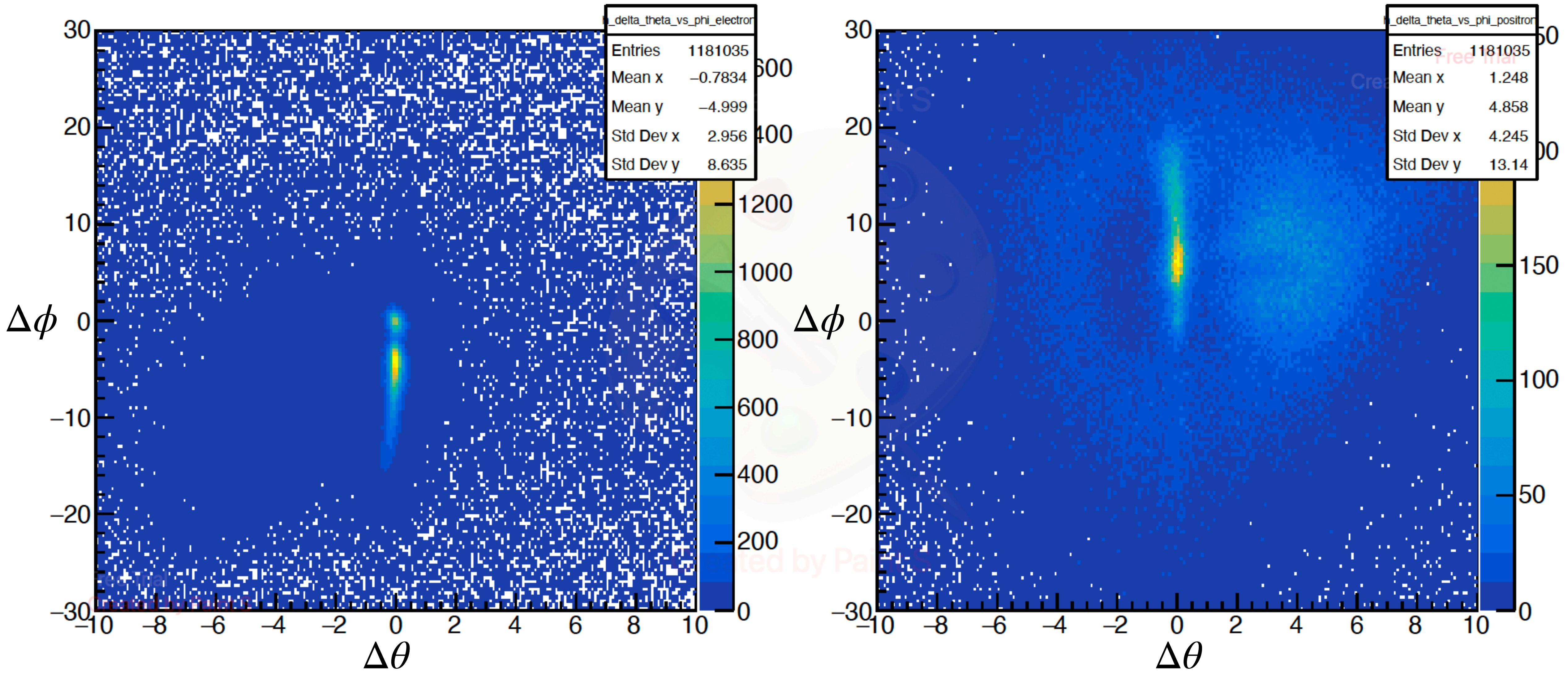
Event Selection

- First, a selection of events is done using the CLAS12 QADB tool.

- Electron e^-
  - Forward Detector
  - $p > 1.95$ GeV/c
  - $E_{PCAL} > 0.07$ GeV
  - $V_{PCAL} > 9$ cm
  - $W_{PCAL} > 9$ cm
  - $-8 < V_z < 4$ cm

- Positron e^+
  - Forward Detector
  - $p > 1.95$ GeV/c
  - $E_{PCAL} > 0.07$ GeV
  - $V_{PCAL} > 9$ cm
  - $W_{PCAL} > 9$ cm
  - $|\chi^2_{PID}| < 5$
  - $SF_{EC} \geq (0.195 - SF_{PCAL})$

- Radiative photons detected at ECAL with θ coincidence $|\Delta\theta| < 0.7$ are detected for energy loss correction.

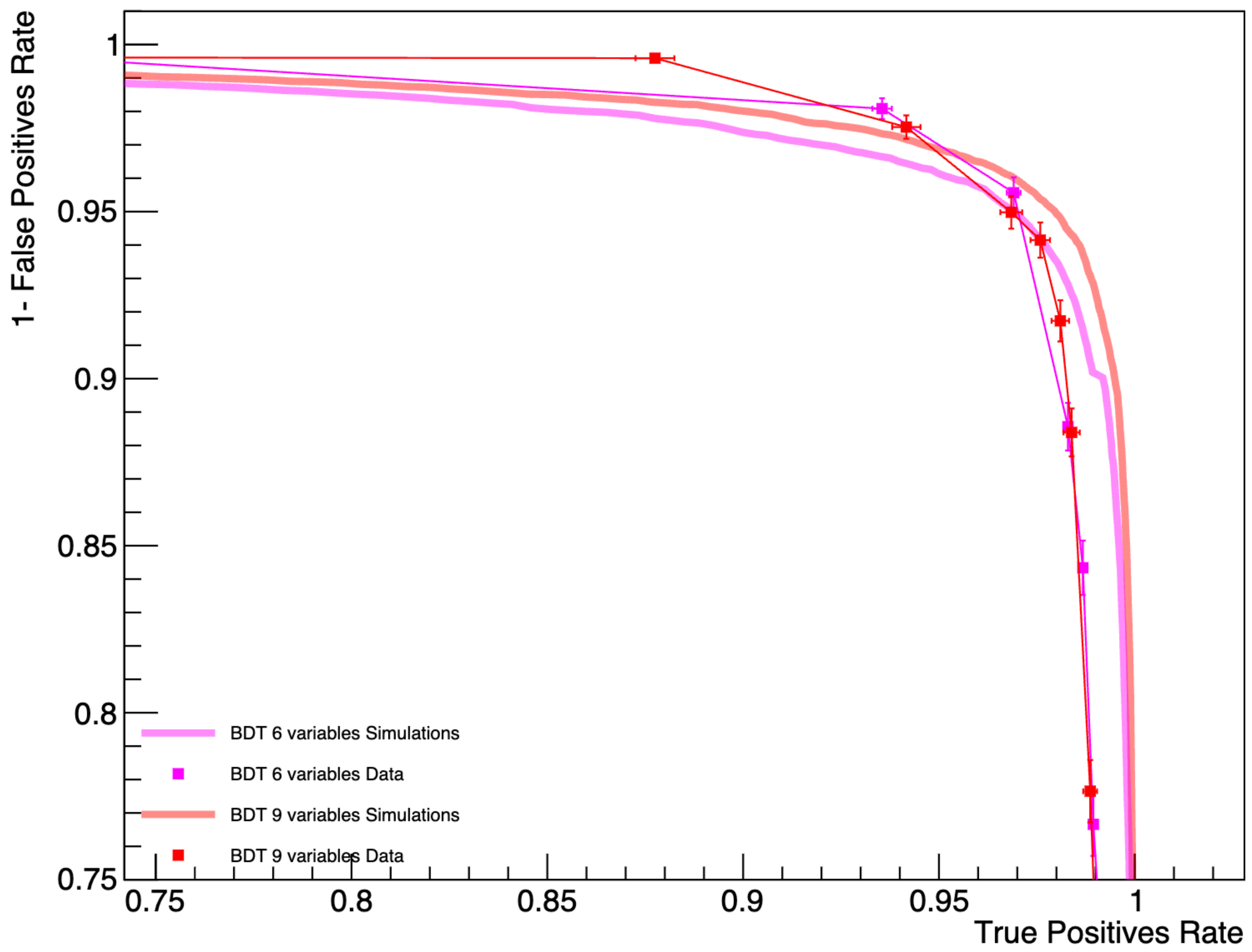


$\Delta\phi$ vs $\Delta\theta$ distributions for electrons (left) and positrons (right). Spring 2019 Pass2 data set

Lepton ID at high momenta

- We apply BDT to identify leptons at high momenta, $p > 4.5$ GeV.
- We have 6 classifiers: e^+ and e^- identification on each Pass2 RGA configuration.
- We use as variables $e^{\pm}(P, \theta, \phi)$ and SF and m2 of PCAL, ECIN and ECOUT
- All models were trained using MC, and validated on data and simulations.

CLAS12 Note 2024-005



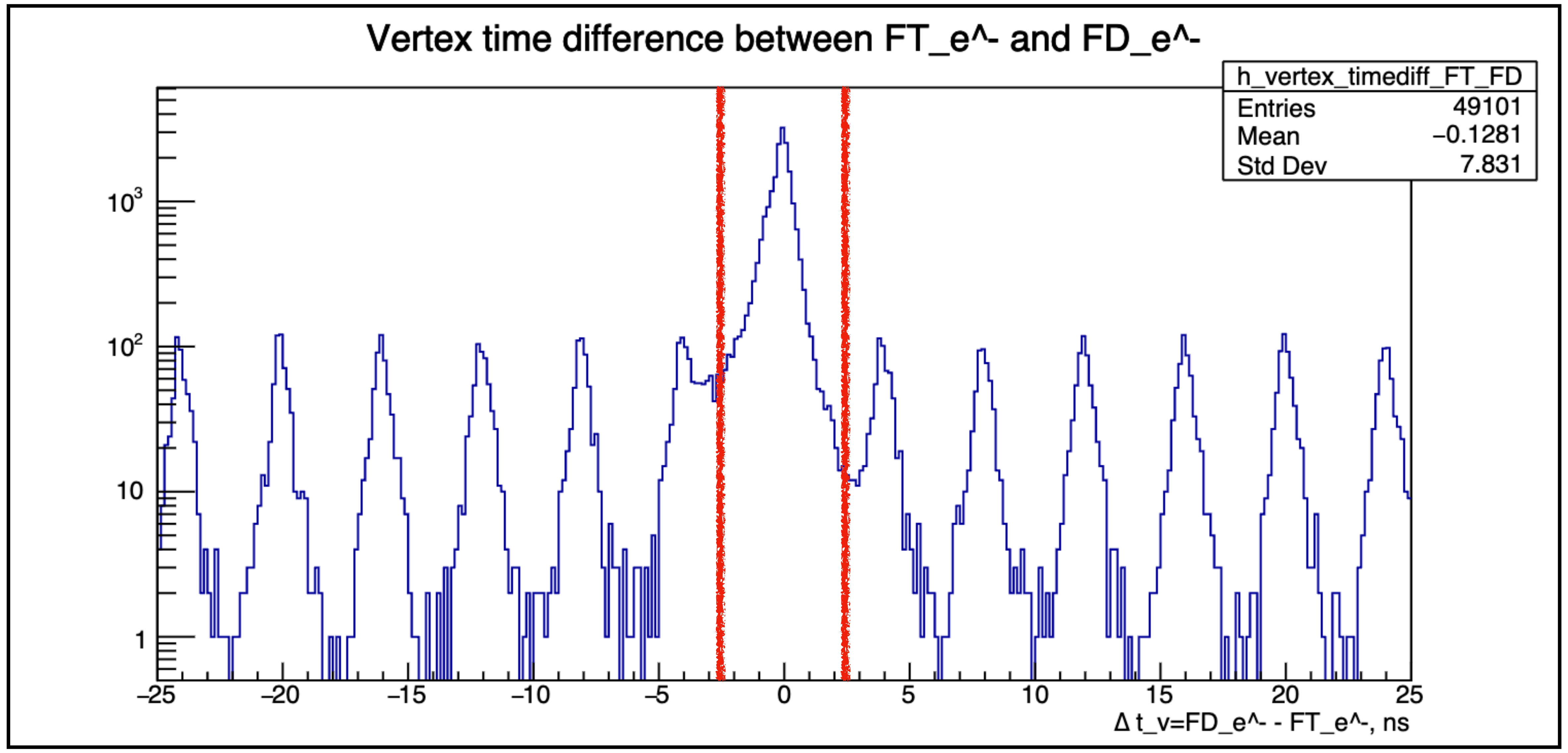
ROC curve for 6 and 9 variable models for F18inbending

Event Selection

- We select one electron in the Forward Tagger. We apply an energy correction for this electron.

  - Electron e^-

    - Forward Tagger
    - $|v_{t_{e-}} - v_{t_{e+}}| \leq 2ns$
    - $\theta_{e'} > 2^\circ$
    - $E_{e'} < 6$ GeV

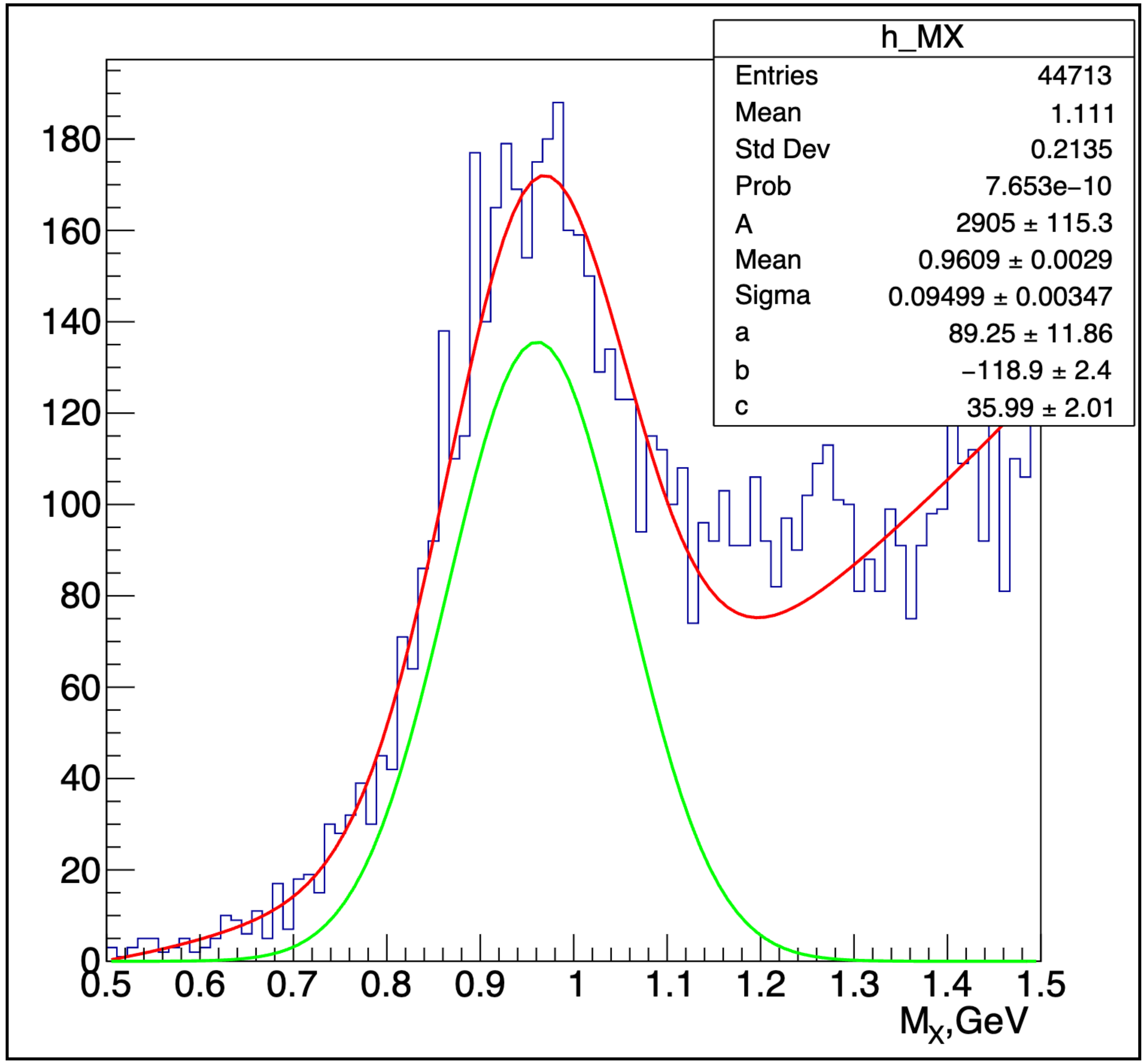


Vertex time difference between the electron in the FD and the electron in the FT

- The central peak shows well-matched events where both particles come from the same interaction vertex, while events outside this area are accidental coincidences. The 4ns spacing between peaks is due to the timing structure of the beam.

$ep \rightarrow e'p'J/\psi \rightarrow e'e^+e^-(p')$

- For the reaction $ep \rightarrow e'e^+e^-(p')$
- The missing four-momentum is defined as $p_X = p_e + p_p - p_{e^-} - p_{e^+} - p_{e'}$
- The peak on the distribution should be around the mass of the missing proton.
- We keep events with $E_\gamma > 8.1$GeV where $E_\gamma = E_{beam} - E_{e'}$
- Invariant mass $M^2(e^-e^+) = (p_{e^-} + p_{e^+})^2$ should be in the 2.0 GeV to 3.5 GeV region
- We also apply a cut in the missing mass as $|M_X = 0.9609| < 3\sigma$



Missing mass distribution for the final state $e'e^+e^-$. The peak correspond to the missing mass of the proton.

$ep \to e'p'J/\psi \to e'e^+e^-(p')$

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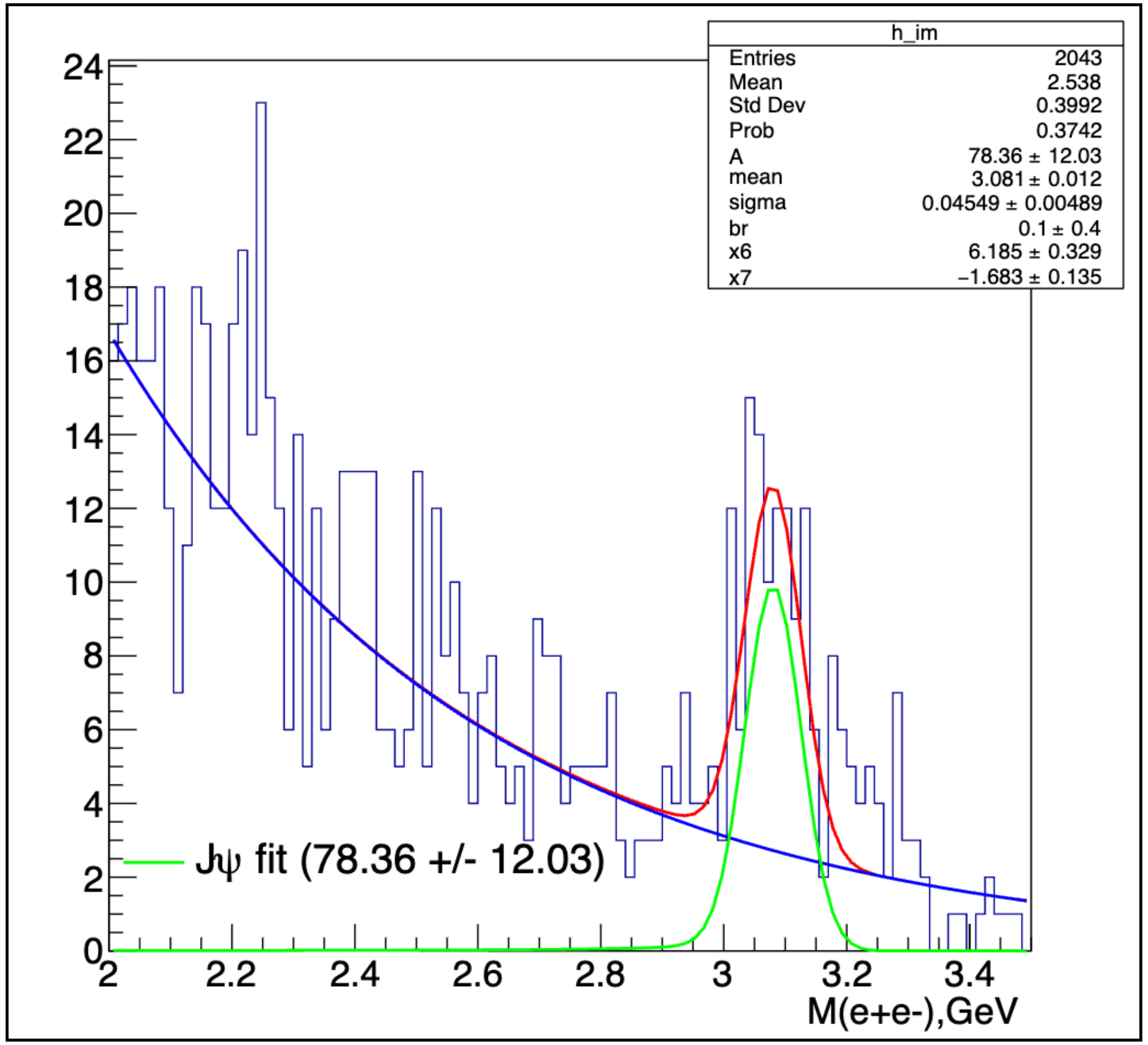
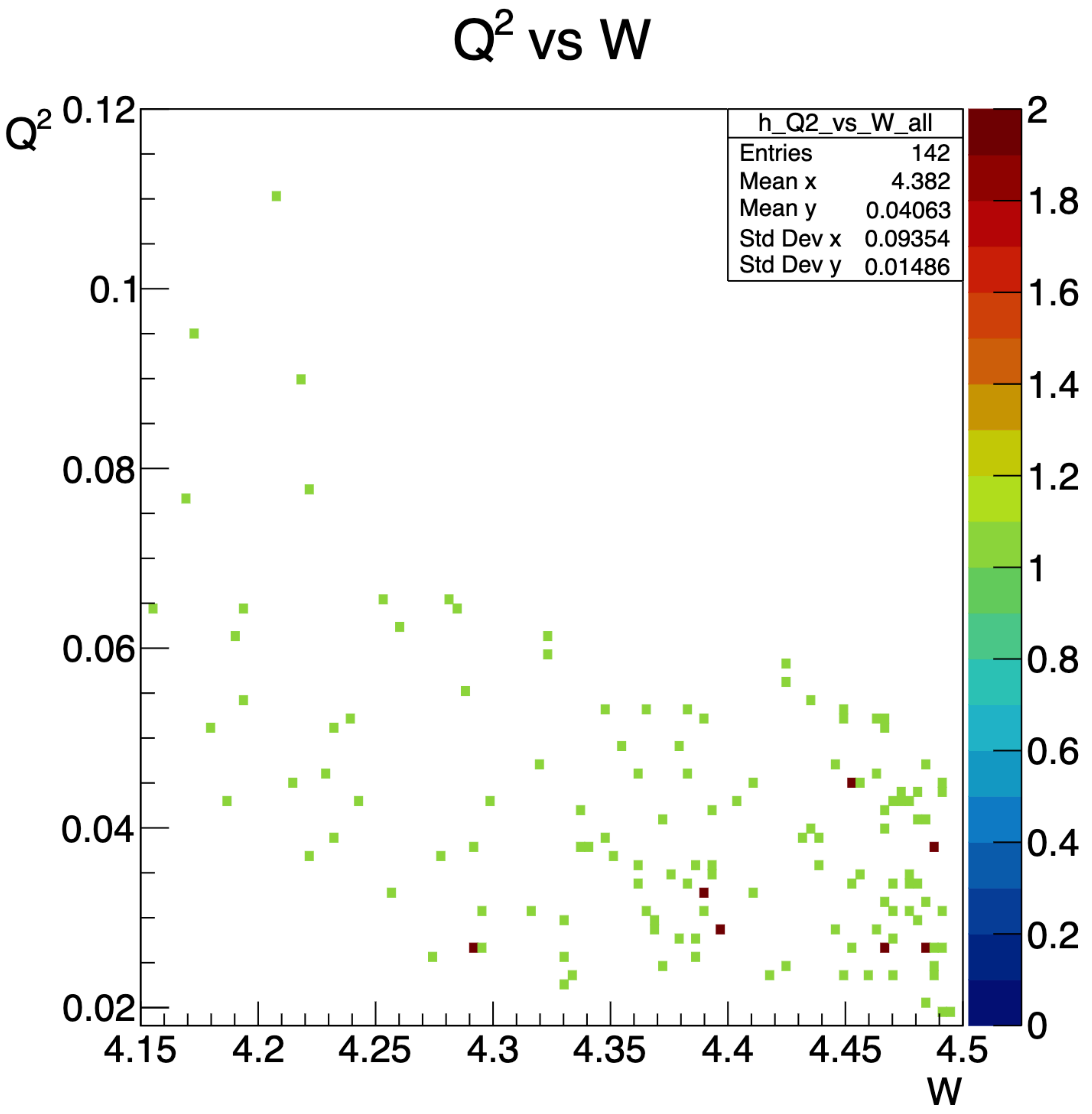
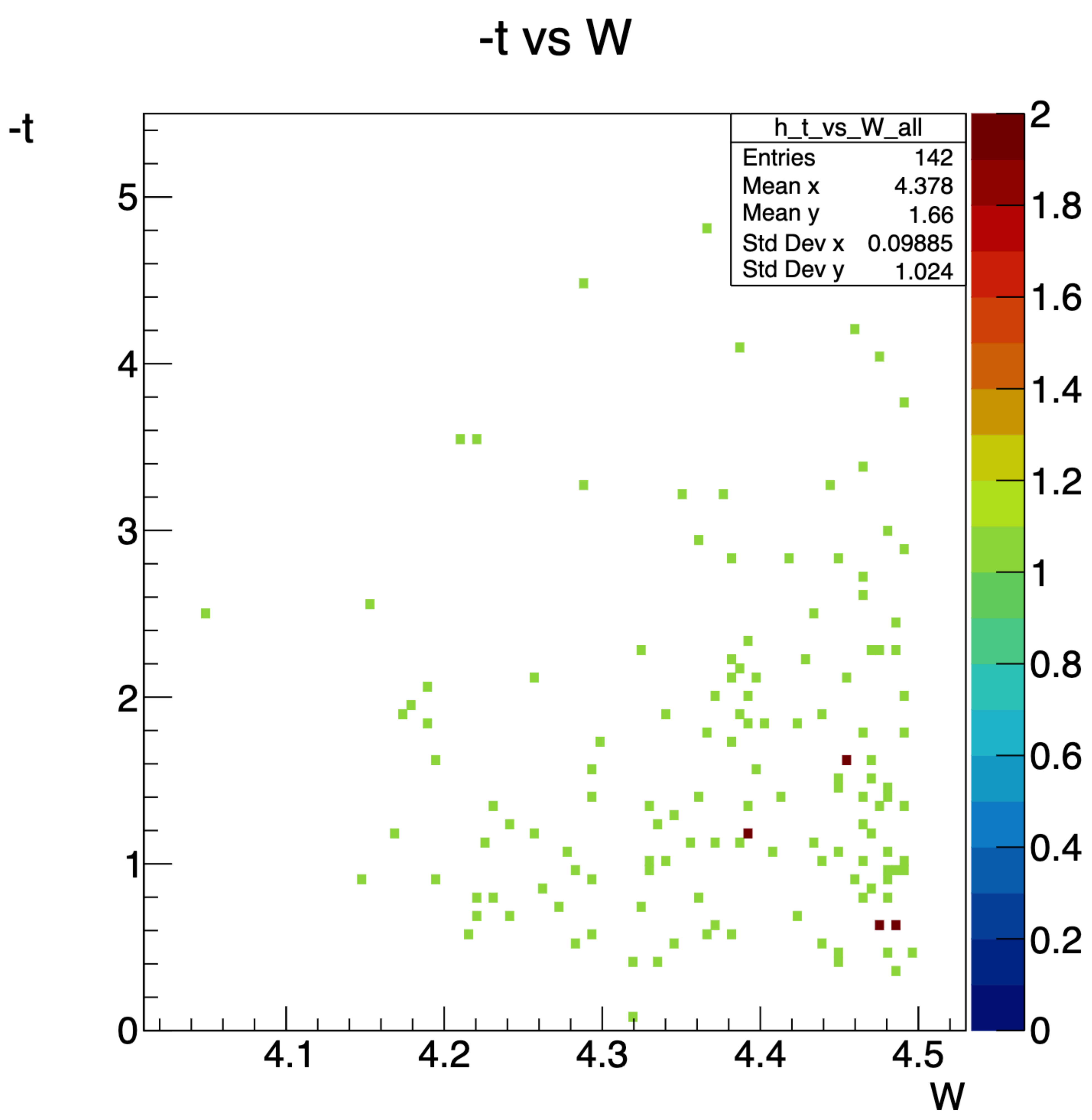


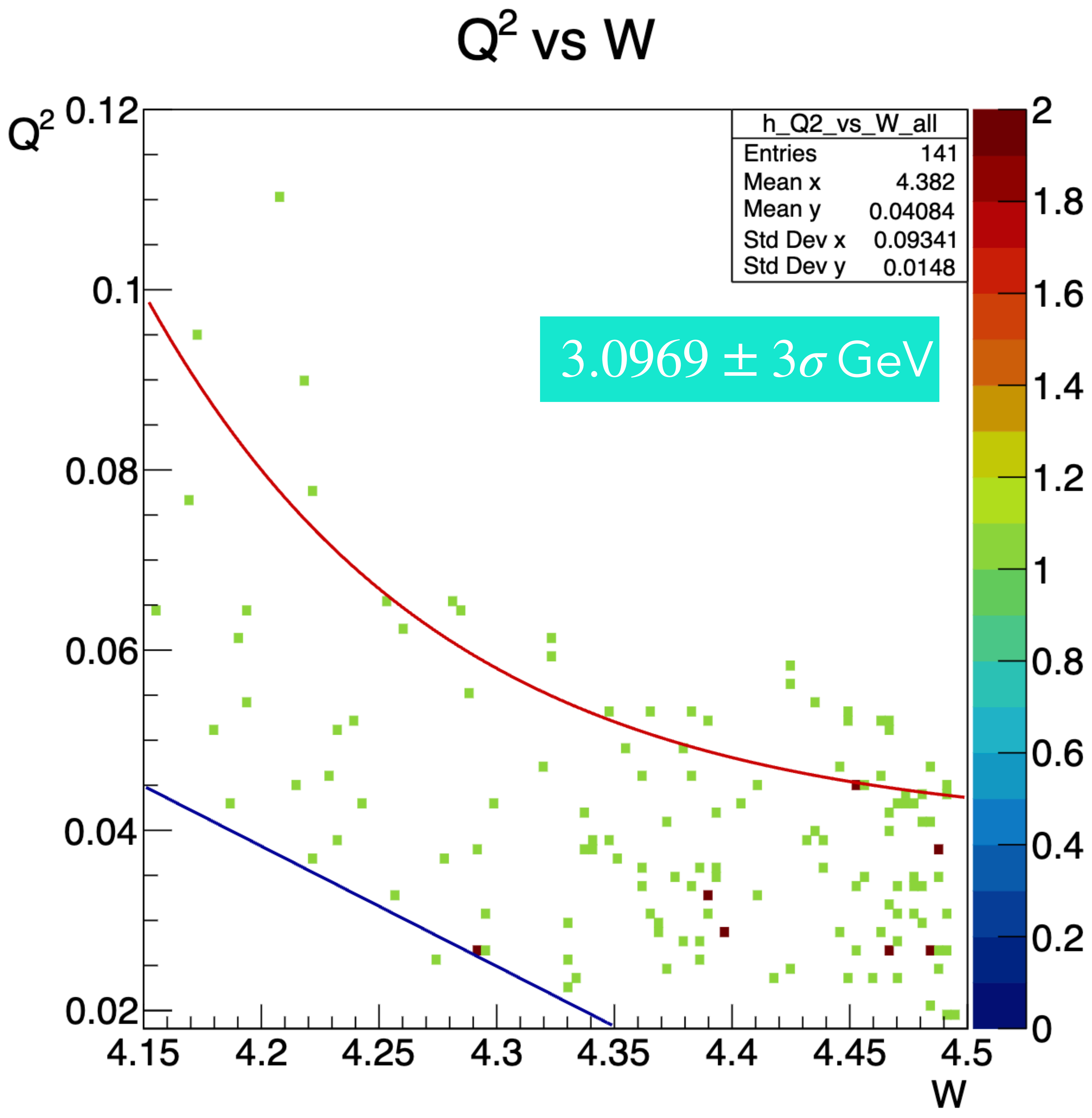
Invariant Mass

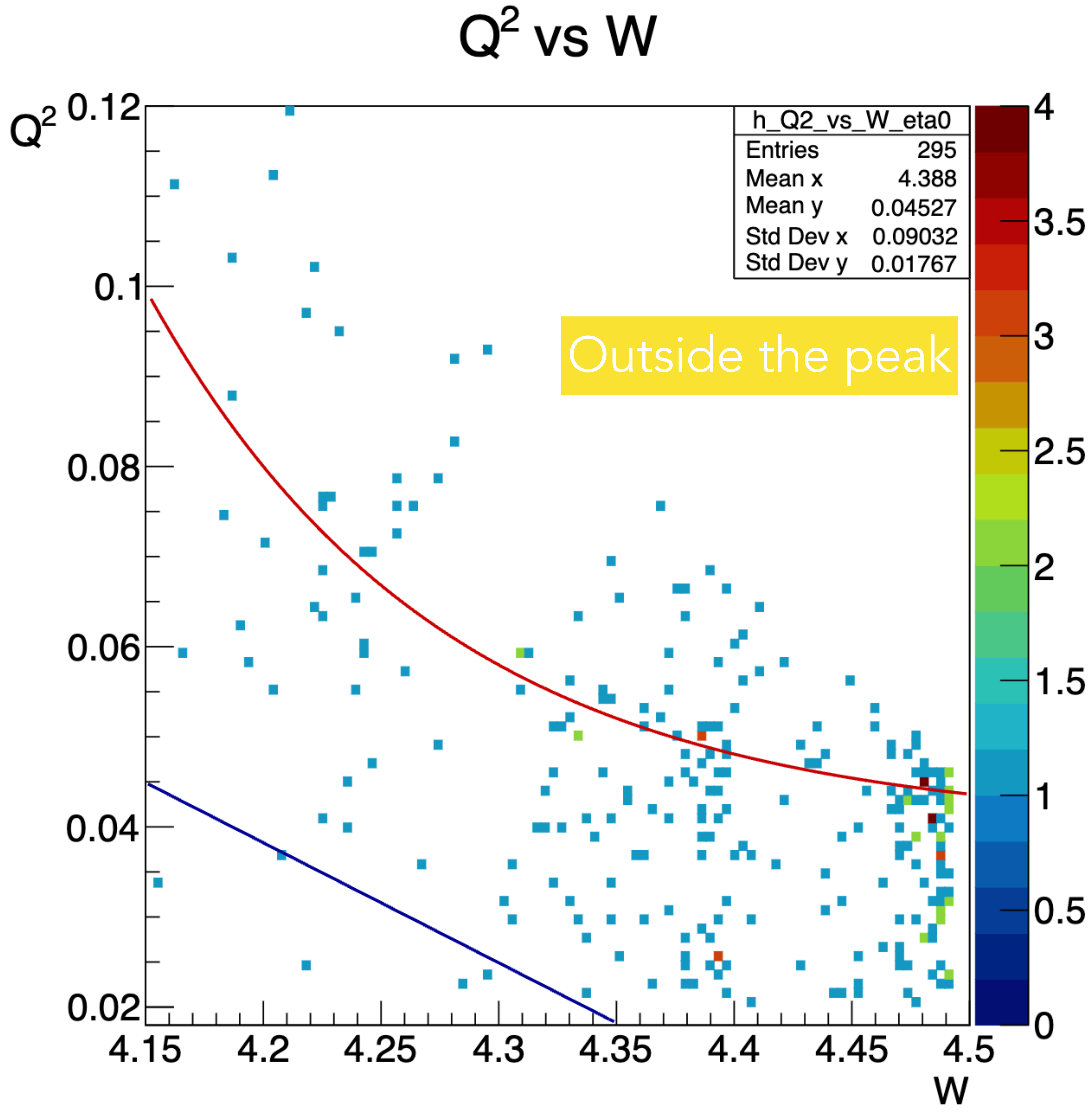
- We examine the distributions within the peak region, defined as $3.0969 \pm 3\sigma$ GeV. Based on this we define our binning in W.



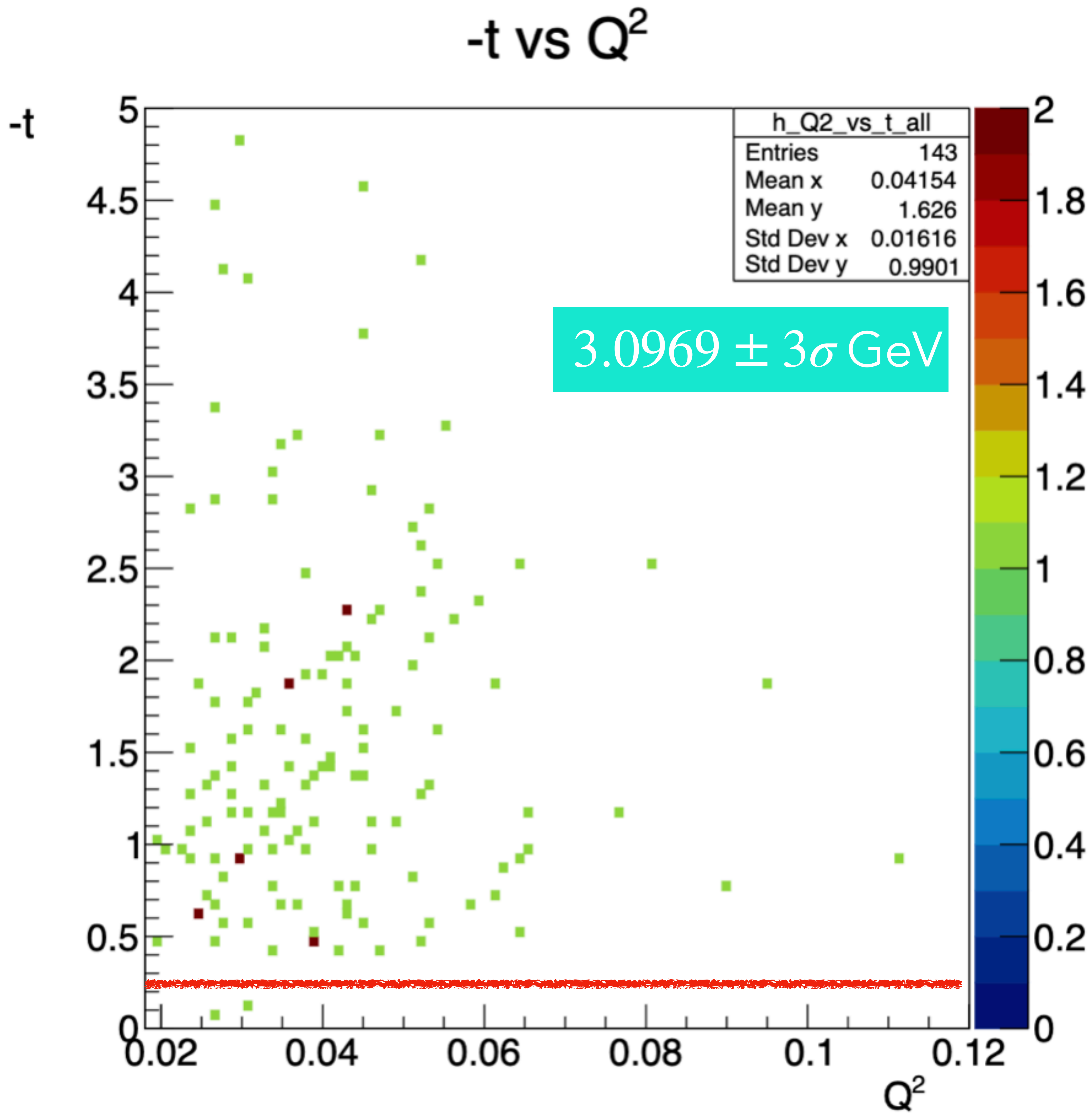


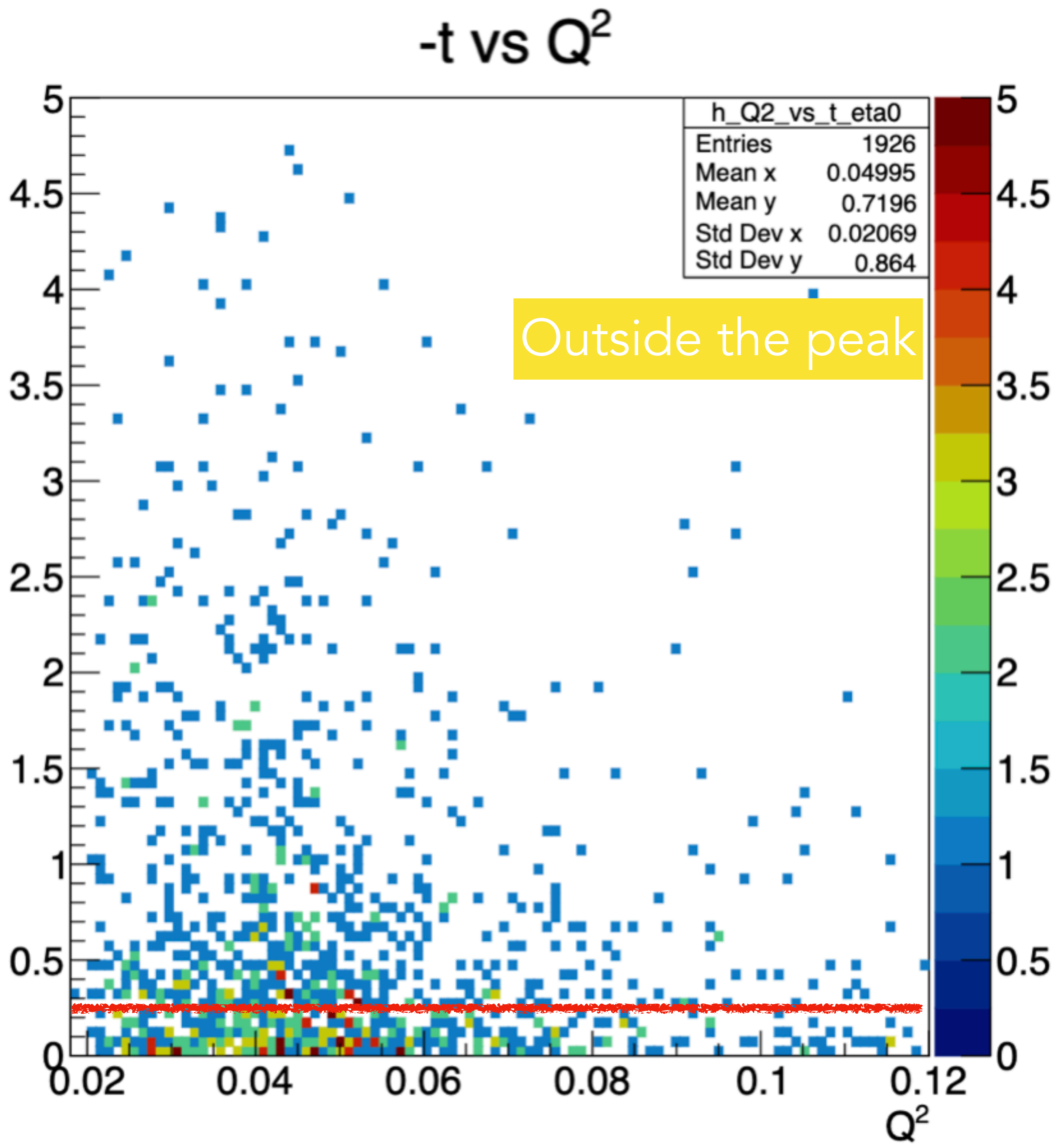
Distributions of Q^2 and -t as a function of W for all selected events.





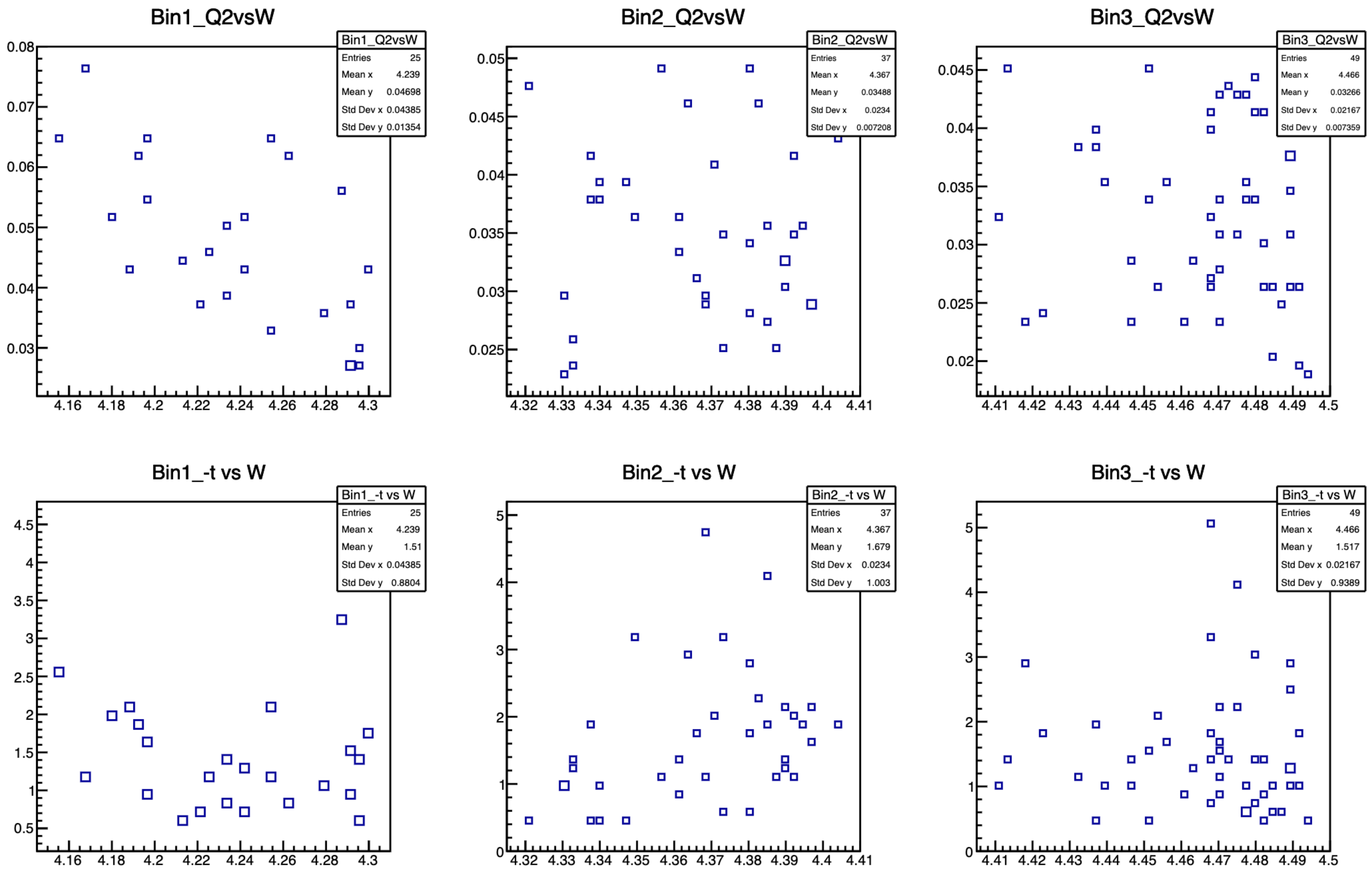
Q2 vs W distribution for events under the peak (left) and below 2.9 Gev (right). The red curve is the new upper cut, and the blue line a new lower cut.





$-t$ vs Q^2 distribution for events under the peak (left) and below 2.9 Gev (right). As we can observe, most of the events under the peak are at -t>0.5

W-Bin
4.15 - 4.30
4.30 - 4.41
4.41- 4.50



W-Bin
4.15 - 4.30
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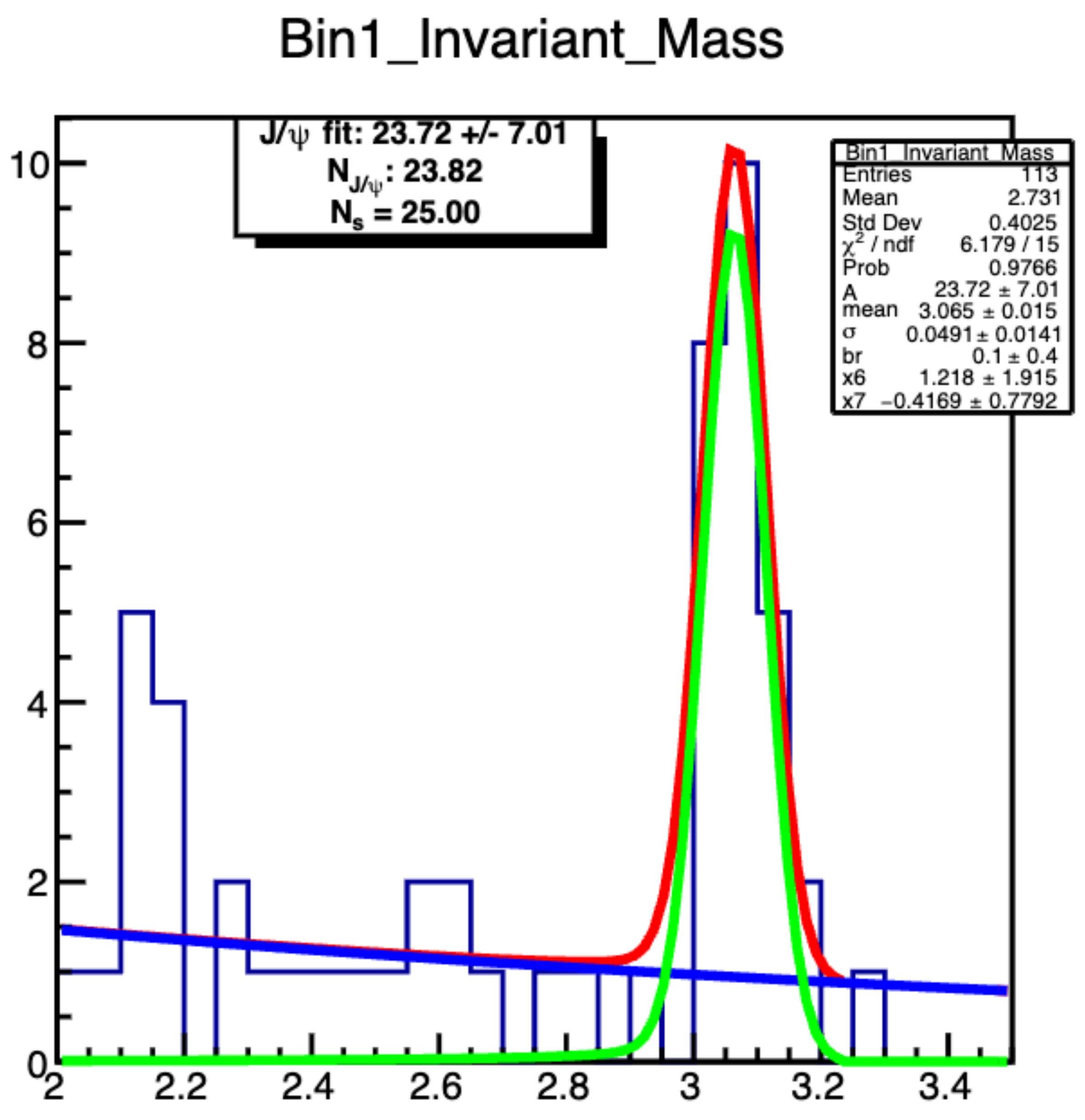
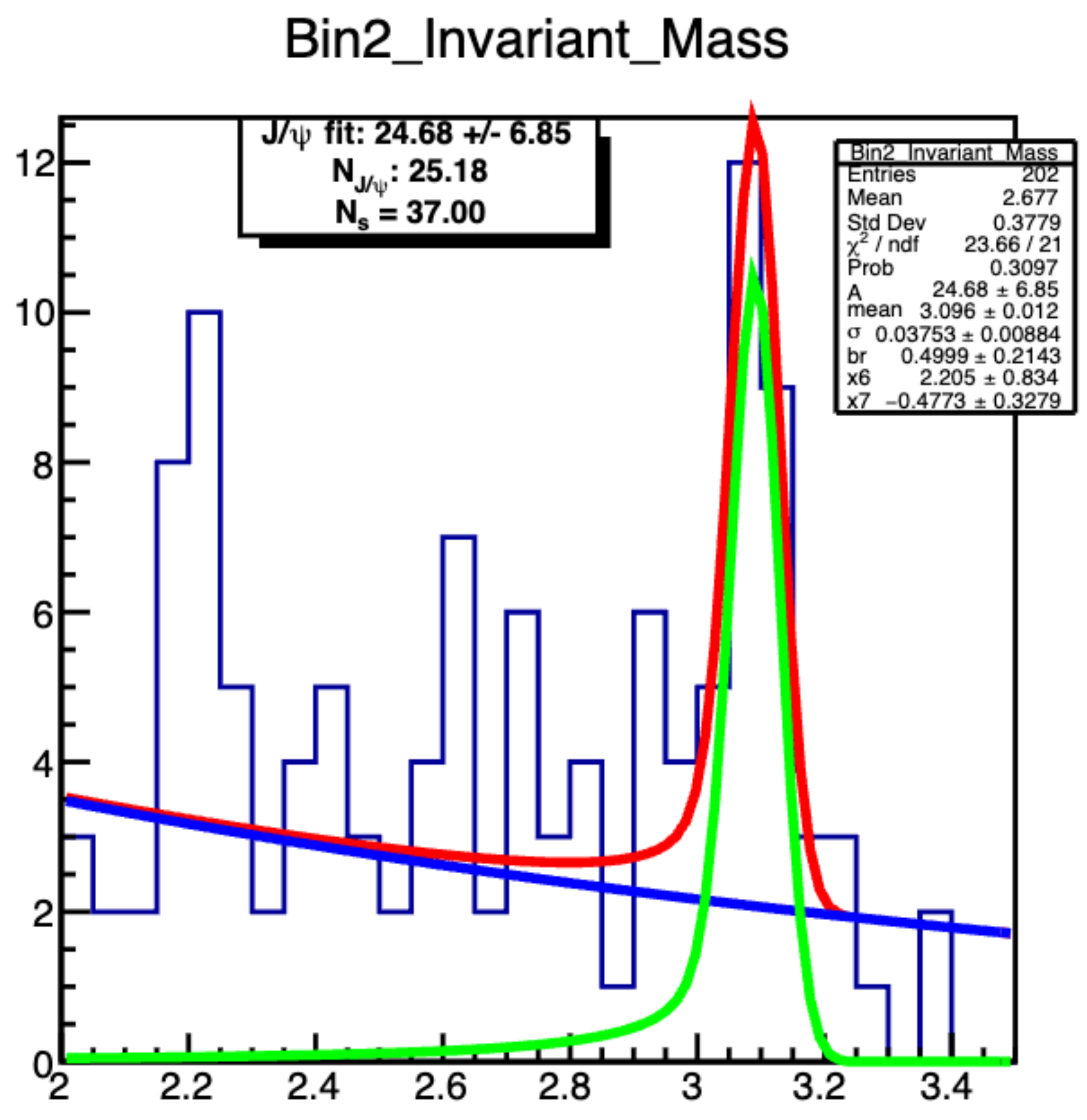
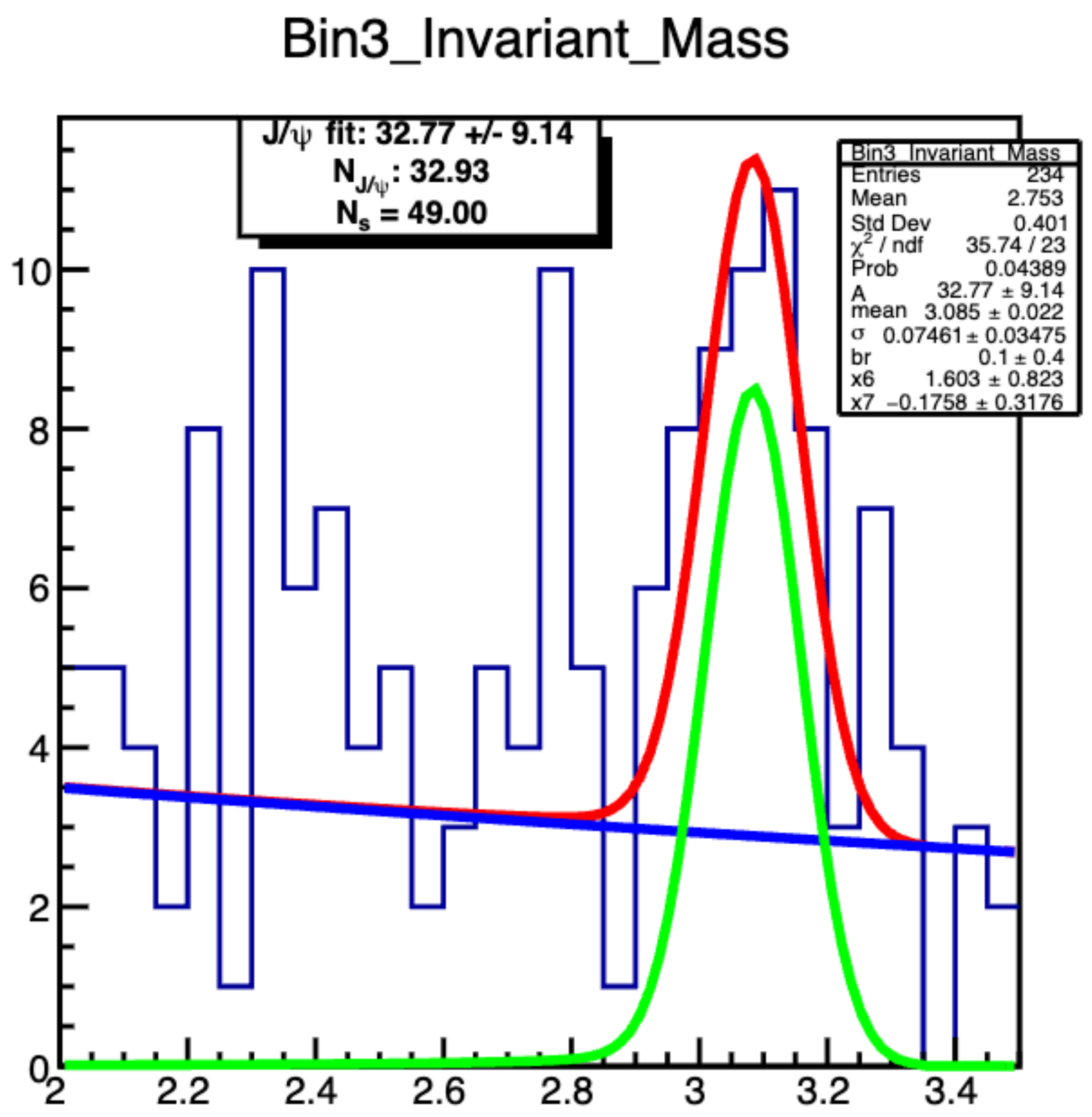






Yield Calculation

- We tested different ways to extract the yield. Our objective was made sure that the yields were equivalent.

- For the next results we are using $\mathscr{Y}_1$ as our yield

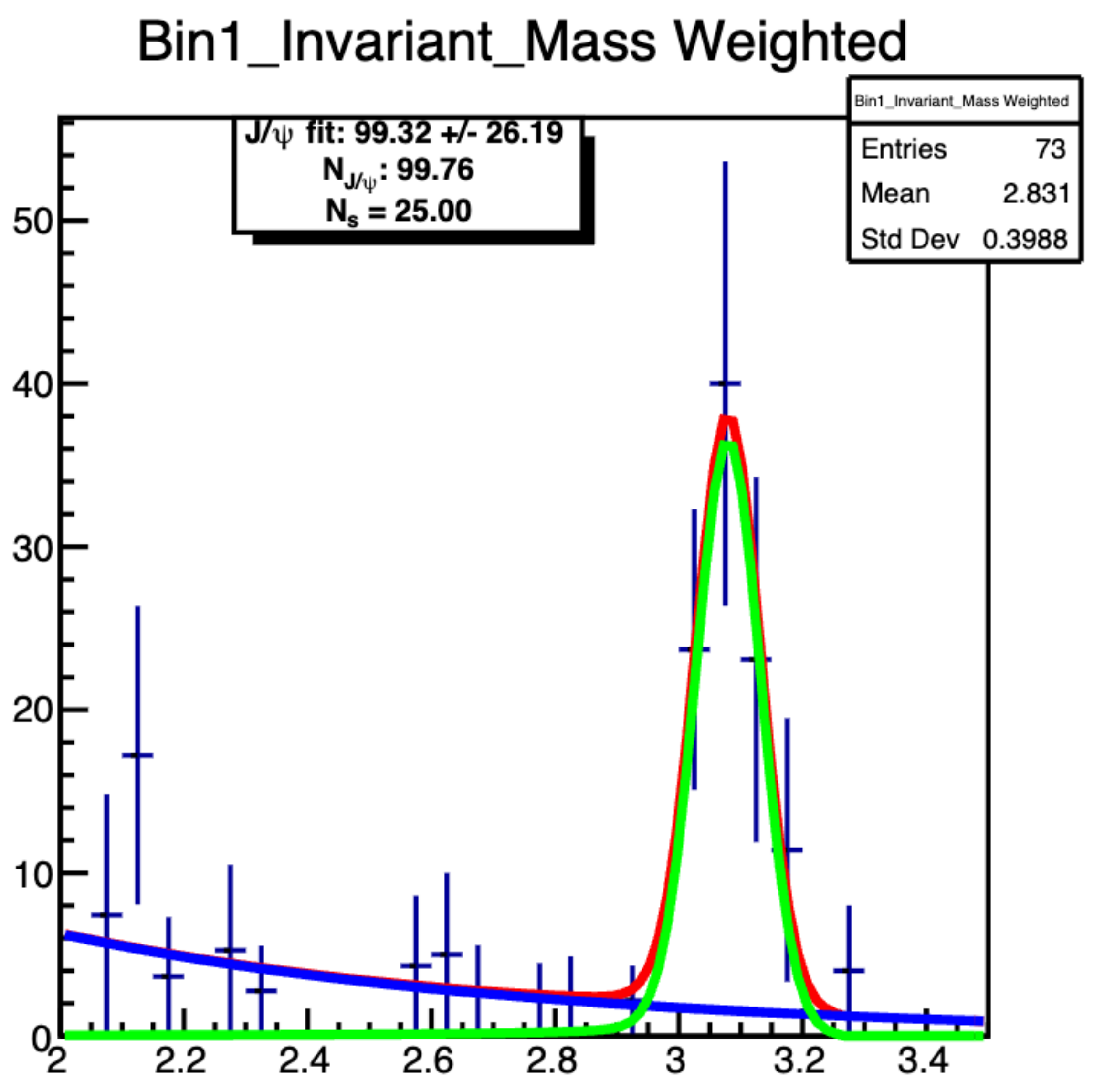
$$\mathscr{Y}_1 = \frac{N_{J/\psi}}{N_s} \times \sum_{i=1}^{N_s} \frac{1}{\eta_i}$$

$$\mathscr{Y}_{2a} = \frac{N_{J/\psi}}{\bar{\eta}_a}$$

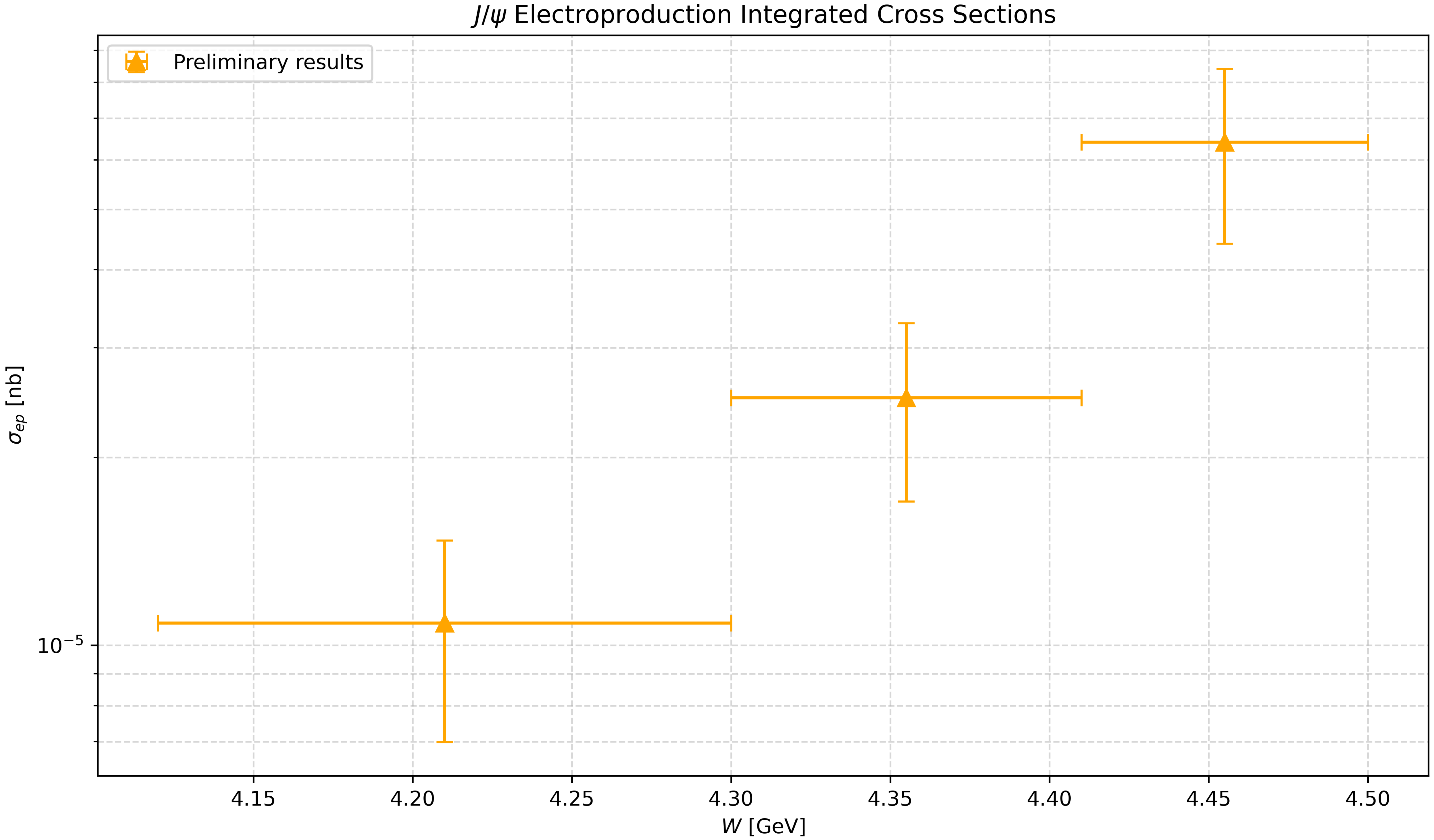
$$\bar{\eta}_a = \frac{N^R}{N^G}$$

$$\mathscr{Y}_{2b} = \frac{N_{J/\psi}}{\bar{\eta}_b}$$

$$\bar{\eta}_b = \frac{1}{n_{bins}} \sum_{1}^{nbins} \eta_i$$



Electroproduction integrated cross-section



$$\sigma_{ep} = \frac{\mathscr{Y}}{L \cdot Br}$$

$Br = 0.06$

$L = N_p * N_e$=1.3052×10^{42} cm−2 $\times Q$

Integrated Photon Flux $\sigma_\gamma = \frac{\mathcal{Y}}{\Phi_\gamma \cdot L \cdot Br}$

$$\Phi_\gamma = \int_{\Delta Q^2} \int_{\Delta W} \Gamma(W, Q^2)\, dW\, dQ^2 = \sum_{i,j} \Gamma(W_i, Q_j^2) \Delta W \Delta Q^2$$

Where Γ is given as:

$$\Gamma = \frac{\alpha}{4\pi} \cdot \frac{W^2 - M_p^2}{M_p^2 E^2} \cdot \frac{W}{Q^2(1-\varepsilon)}$$

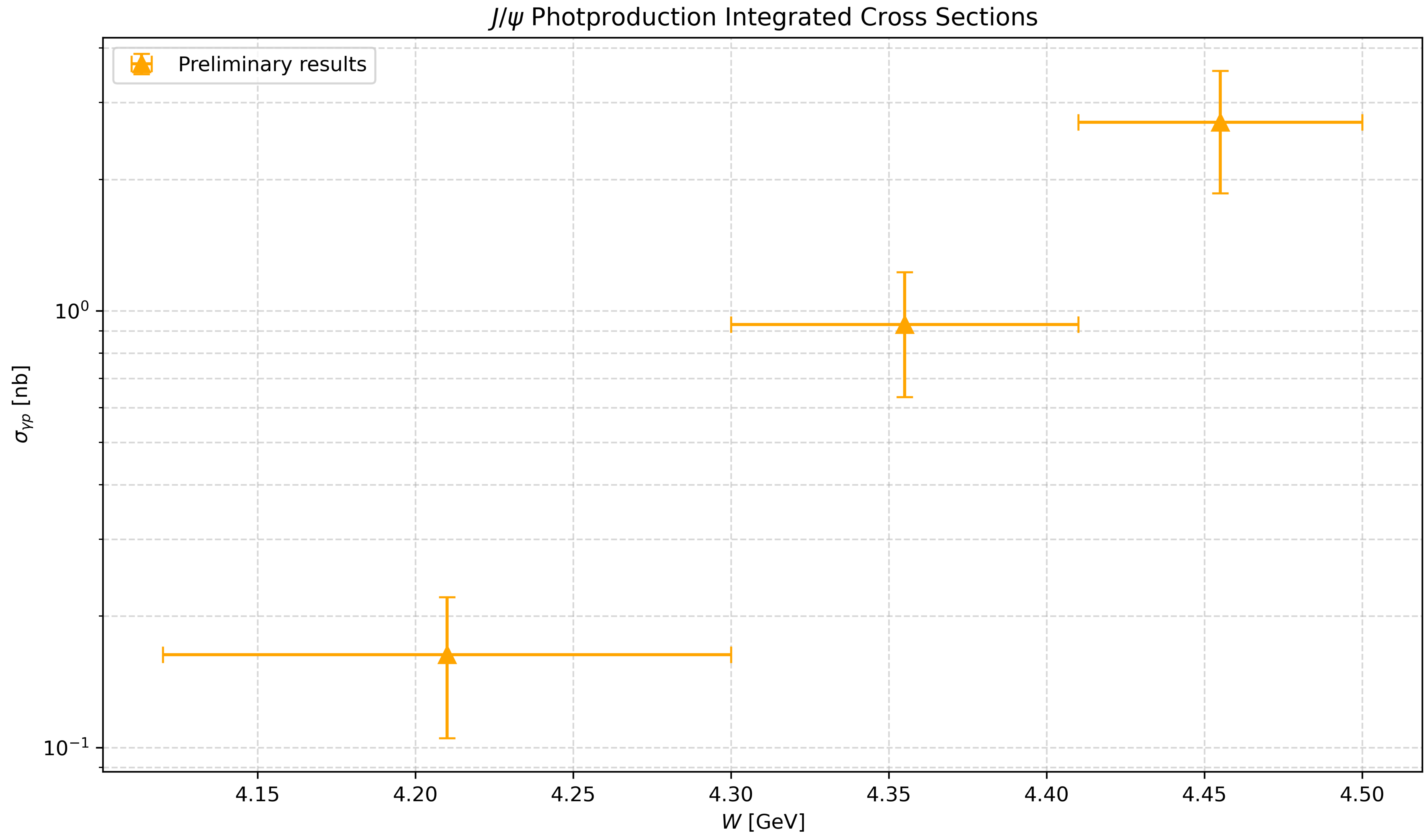
$\alpha = \frac{1}{137}$ is the fine-structure constant,

$M_p = 0.938\,\mathrm{GeV}$ is the proton mass,

E is the incoming electron energy, and E' the scattered energy,

ε is the transverse polarization of the virtual photon, given by: $\varepsilon = \frac{1}{1 + \frac{2(Q^2+\nu^2)}{4EE' - Q^2}}$

Photoproduction integrated cross-section



$$\sigma_\gamma = \frac{\mathscr{Y}}{\Phi_\gamma \cdot L \cdot Br}$$

Conclusion and Next Steps

- We presented preliminary measurements of the integrated photoproduction cross section of the J/ψ off a liquid hydrogen target, as a function of W.

- This are preliminary results for only one topology, we still have two more topologies:
    - $ep \rightarrow e'p'e^+e^-$
    - $ep \rightarrow e'p'e^+X$

- We are still doing adjustments, looking into the applied cuts, include MC background for the efficiency, etc..

Backup Slides

Yield Comparison

- ----Bin1-------

Yield (Method 1) = 93.5632

Yield (Method 2a) = 98.0501

Yield (Method 2b) = 87.0551

Yield NJpsi w=99.7573

- ----Bin2-------

Yield (Method 1) = 214.955

Yield (Method 2a) = 126.184

Yield (Method 2b) = 218.731

Yield NJpsi w=170.002

- ----Bin3-------

Yield (Method 1) = 332.708

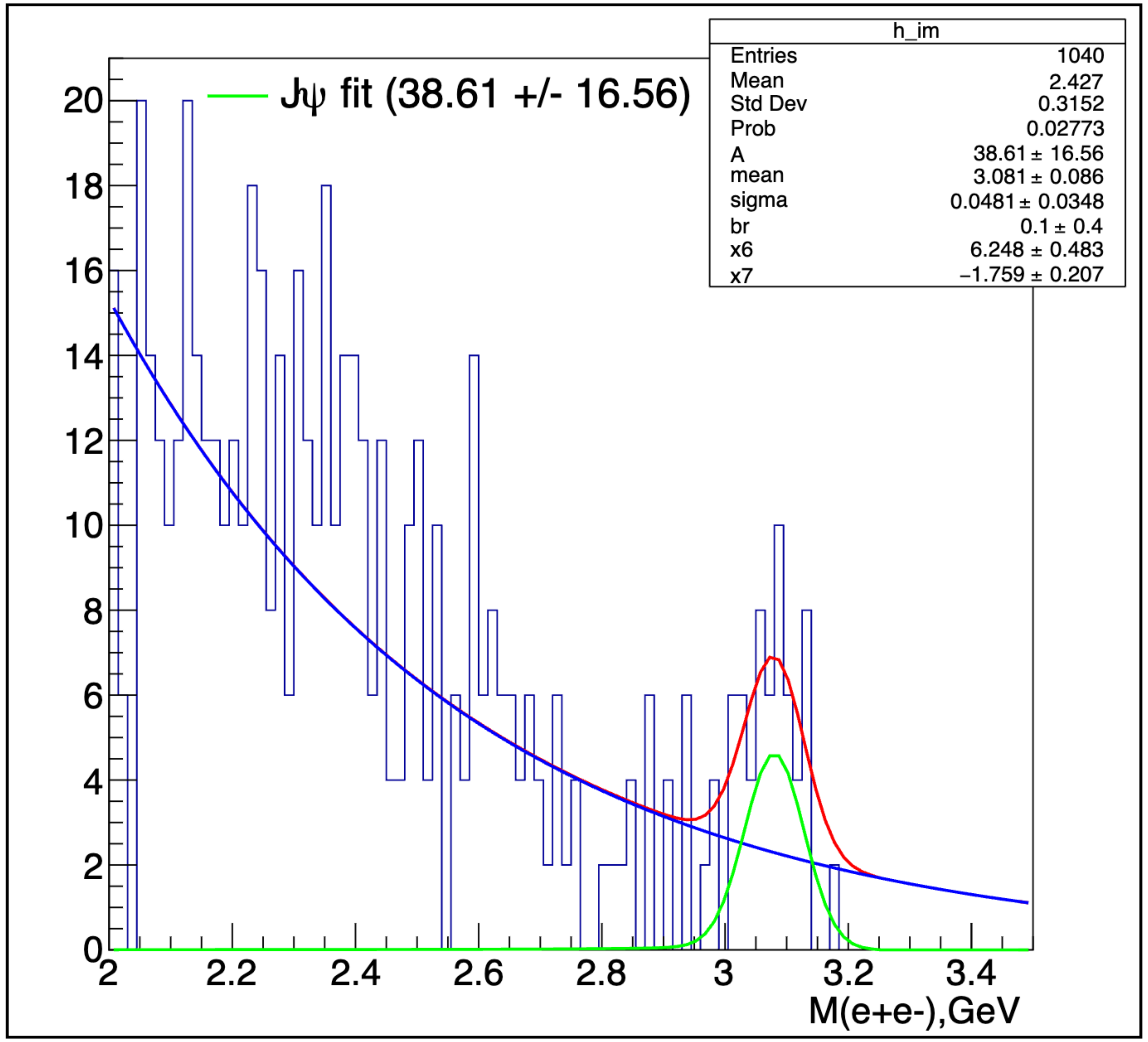
Yield (Method 2a) = 373.532

Yield (Method 2b) = 347.169

Yield NJpsi w=428.612

$ep \to e'p'J/\psi \to e'e^+e^-p'$

- For the reaction $ep \to e'e^+e^-p'$
- The missing four-momentum is defined as $p_X = p_e + p_p - p_{e^-} - p_{e^+} - p_{e'} - p_{p'}$
- We looked at the missing mass of the reaction, expecting it to peak at zero.
- We keep events with $E_\gamma > 8.1$GeV where $E_\gamma = E_{beam} - E_{e'}$
- Invariant mass $M^2(e^-e^+) = (p_{e^-} + p_{e^+})^2$ should be in the 2.0 GeV to 3.5 GeV region
- We also apply a cut in the missing mass as $|M_X| < 0.1$



Invariant Mass

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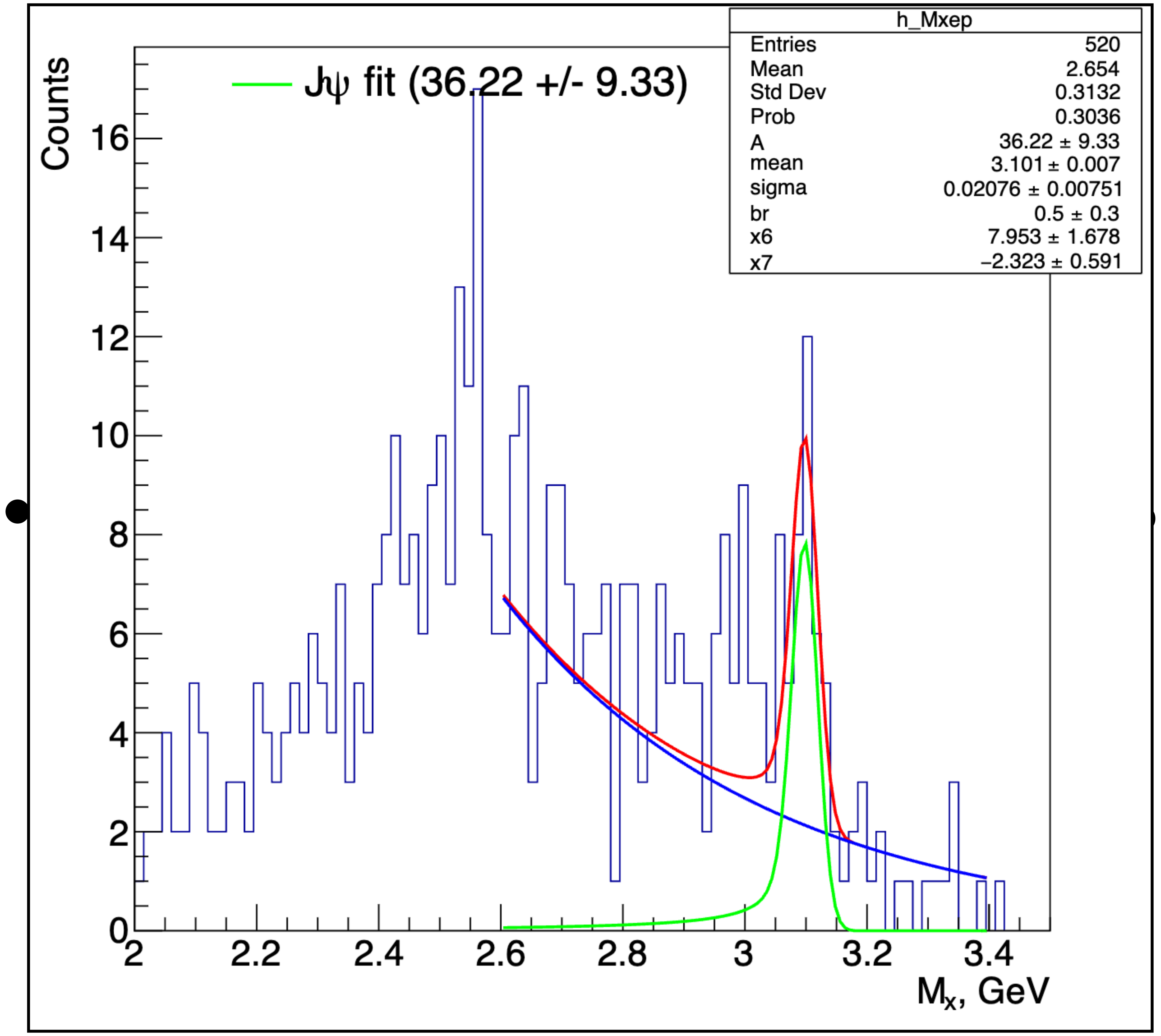
- We keep events with $E_\gamma > 8.1\text{GeV}$ where $E_\gamma = E_{beam} - E_{e'}$
- Invariant mass $M^2(e^-e^+) = (p_{e^-} + p_{e^+})^2$ should be in the > 2.0 GeV region
- We also apply a cut in the missing mass as $|M_X| < 0.1$

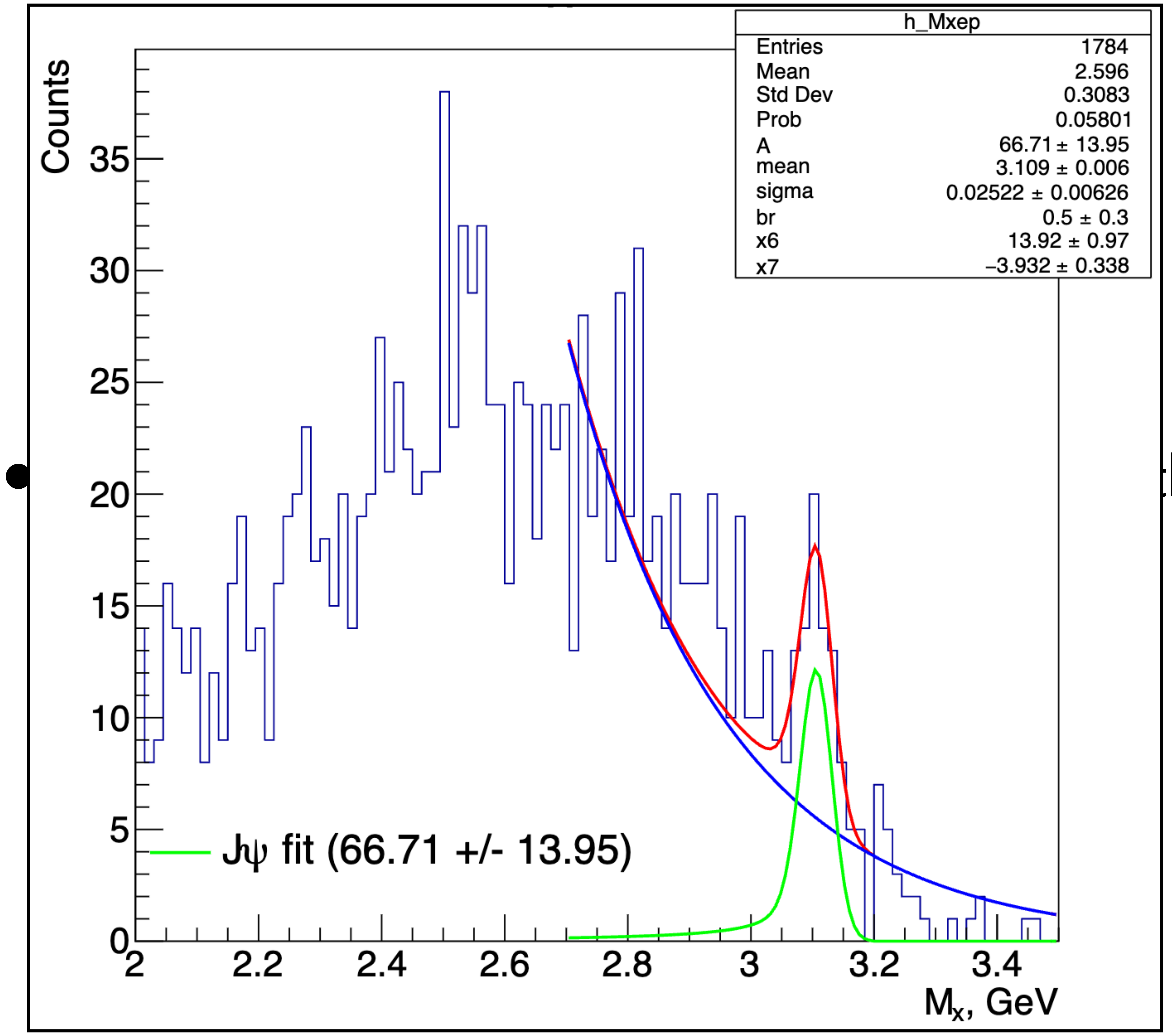


$M_X(e'p')$

- k at

$ep \to e'p'J/\psi \to e'e^+p'(e^-)$

- For the reaction $ep \to e'p'e^+(e^-)$
- We select one electron in FT, one positron in FD and one proton in FD.
- The missing four-momentum is defined as $p_X = p_e + p_p - p_{e^+} - p_{e'} - p_{p'}$
- The peak on the distribution should be around the mass of the missing lepton.
- We keep events with $E_\gamma > 8.1$GeV where $E_\gamma = E_{beam} - E_{e'}$
- We apply a cut in the missing mass as $|M_X| < 0.1$



$M_X(e'p')$