J/ψ Photoproduction Near Threshold With CLAS12

Joseph Newton
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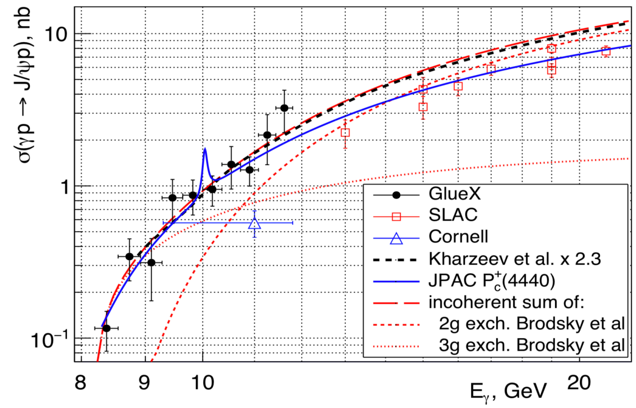
Old Dominion University

Experiment Overview

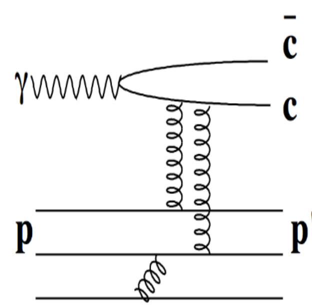
Description

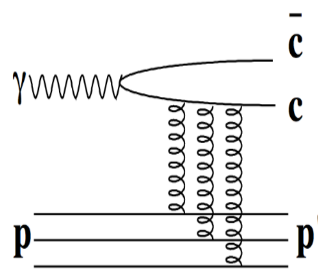
- Electrons accelerated by CEBAF scatter off a liquid Hydrogen target at low scattering angles through the exchange of a quasi-real photon at $Q^2 \sim 0$
- Detect the recoil proton and the e^+e^- from the decay of J/ψ
- Experiment 12-12-001 was approved for 120 days of beamtime on CLAS12 at a luminosity of 10^{35} cm^{-2} s^{-1}



Physics Goals

- Probe the distribution of color charge in the nucleon
  - Measure the t-dependence of the differential cross section of J/ψ photoproduction
- Study the production mechanism of J/ψ near threshold
  - Measure the total cross section as a function of photon energy



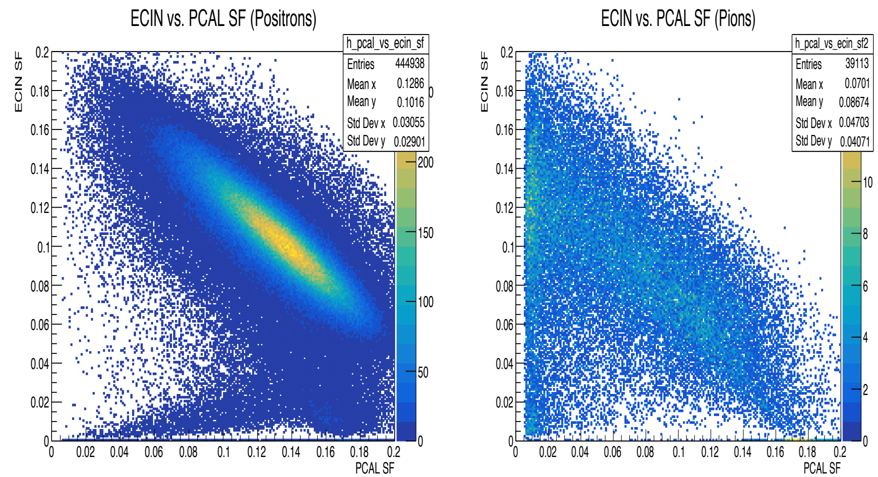


$$\frac{d\sigma}{dt} = N_{2g}\frac{(1-x)^2}{R^2M^2}F_{2g}^2(t)(s-m_p^2)^2$$

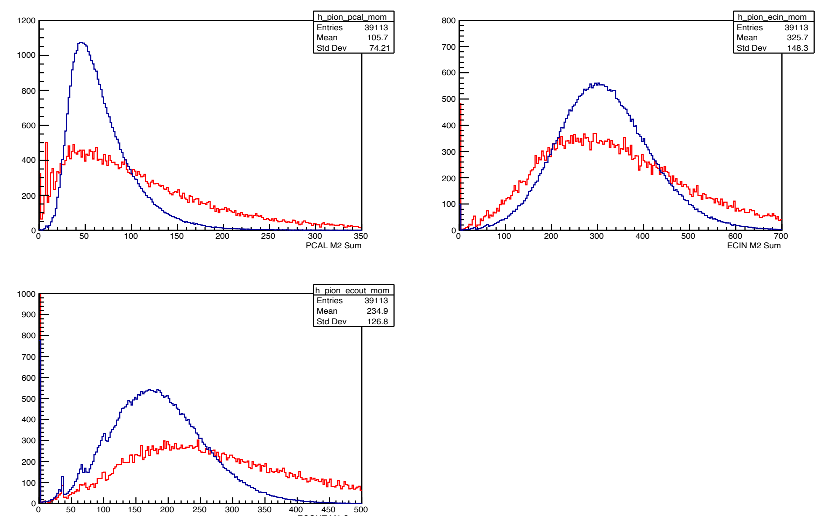
$$\frac{d\sigma}{dt} = N_{3g}\frac{(1-x)^0}{R^4M^4}F_{3g}^2(t)(s-m_p^2)^2$$

Particle Identification

- For e^+e^- detection with (p < 5 GeV)….
  - Accept electrons & positrons that pass the **5σ** sampling fraction cut
  - Keep the same HTCC photoelectrons (**2**) cut & PCAL minimum energy cut (**60 MeV**) from the CLAS12 event builder
- For proton detection…
  - Restrict to forward detector for J/ψ
  - Accept protons that pass the vertex timing cut from FTOF timing
- For e^+ detection with (p > 5 GeV)…
  - For positrons, utilize the Boosted Decision Tree output value cut (**-0.01**) from ROOT's multi-variate analysis package. The following variables are used: PCAL E/p, ECIN E/p, ECOUT E/p, PCAL 2nd Moment, ECIN 2nd Moment, ECOUT 2nd Moment
- Fiducial Cuts For e+e-
  - PCAL LV > 14 cm
  - PCAL LW > 14 cm
- Momentum Corrections
  - Radiated Photon Corrections To e+e-
  - MC-Based Proton Corrections



MC distributions for the PCAL and ECIN sampling fractions for real positrons and mis-identified pions



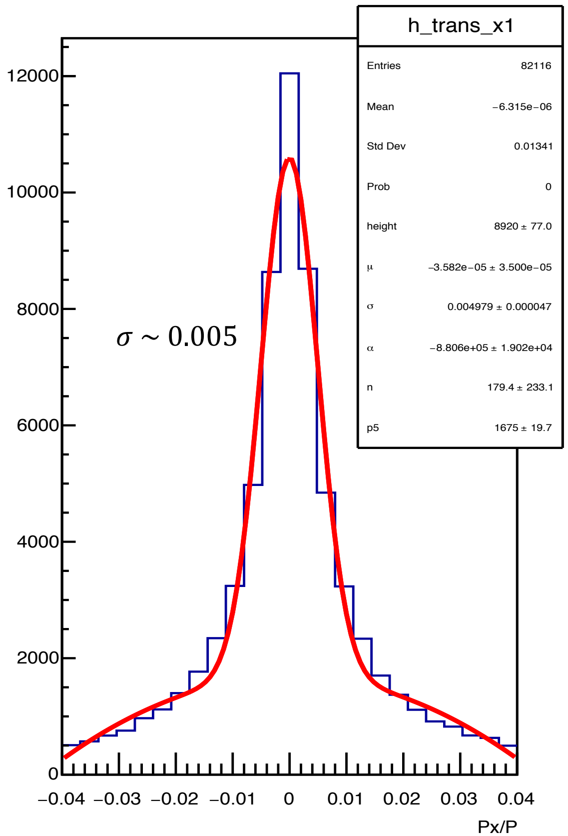
MC distributions for the PCAL and ECIN 2nd moments for real positrons and mis-identified pions

Event Selection For Quasi-Real Photoproduction

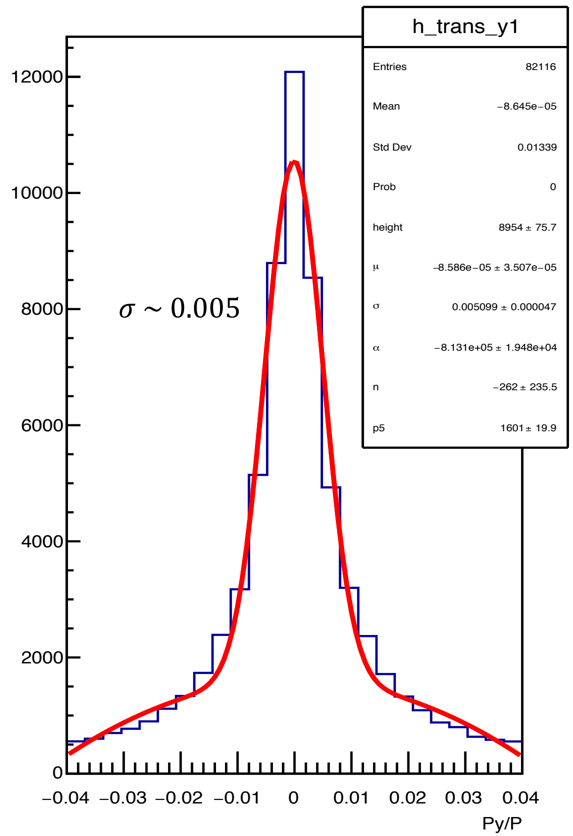
Establishing criteria for event selection is done to understand the measurement of the undetected, forward-scattered,($Q^2 \sim 0$) electron after the exchange of a quasi-real photon

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

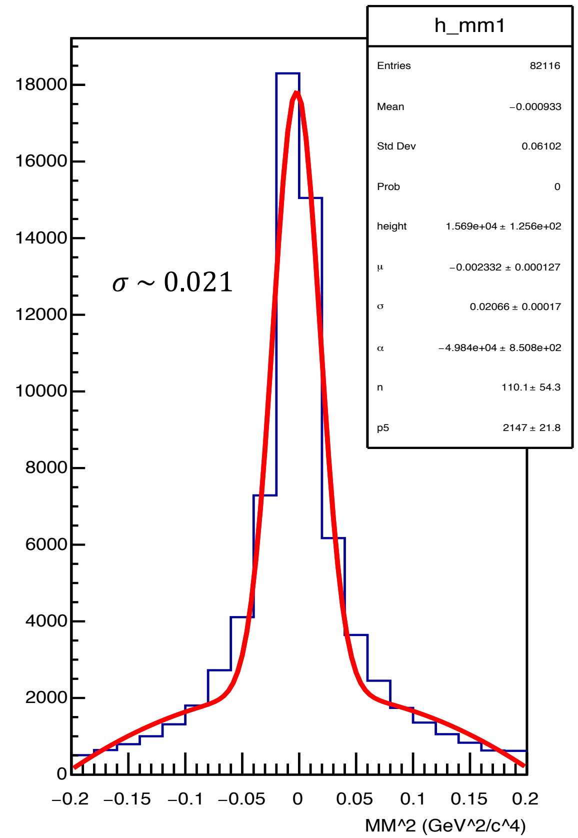
Transverse Missing Momentum X For Un-Detected Scattered Electron



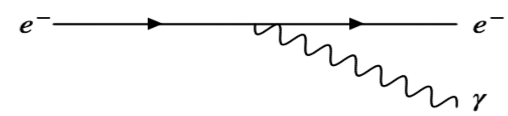
Transverse Missing Momentum Y For Un-Detected Scattered Electron



Square of the Missing Mass For Un-Detected Scattered Electron



Using Radiative Photons For J/psi Reconstruction



*Electrons and positrons from the decay of J/psi lose energy, which can result in radiative photons depositing energy into ECAL.

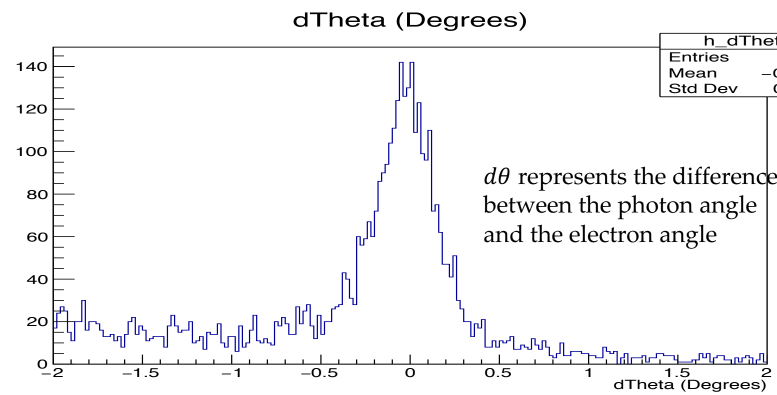
*Photons are selected by applying a 0.5^0 cut on $d\theta$

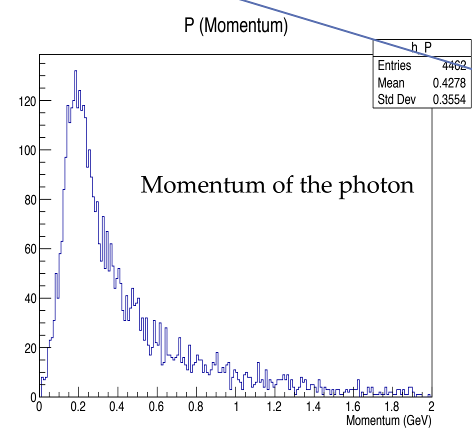
*Application of this technique results in a stronger J/Psi mass signal as well as cleaner quasi-real photoproduction distributions

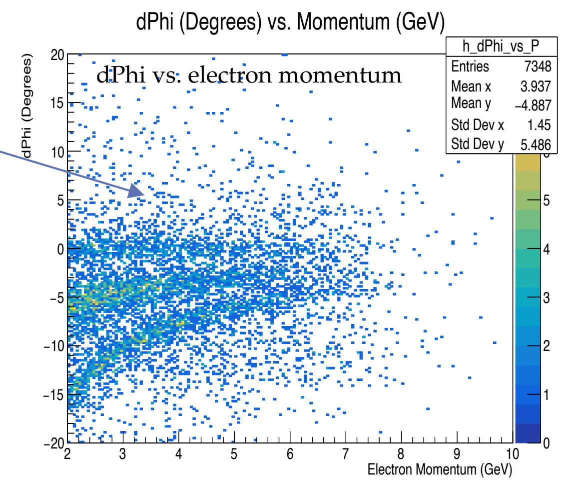
*There are several sources of radiation seen in the dPhi vs. electron momentum plot that is expected due to the Solenoid field

*Work is on-going to understand MC vs. data difference

*More photons from this effect can be found by looking for neutrals with PID==2112 (neutrons) due to misidentification from ECAL timing association

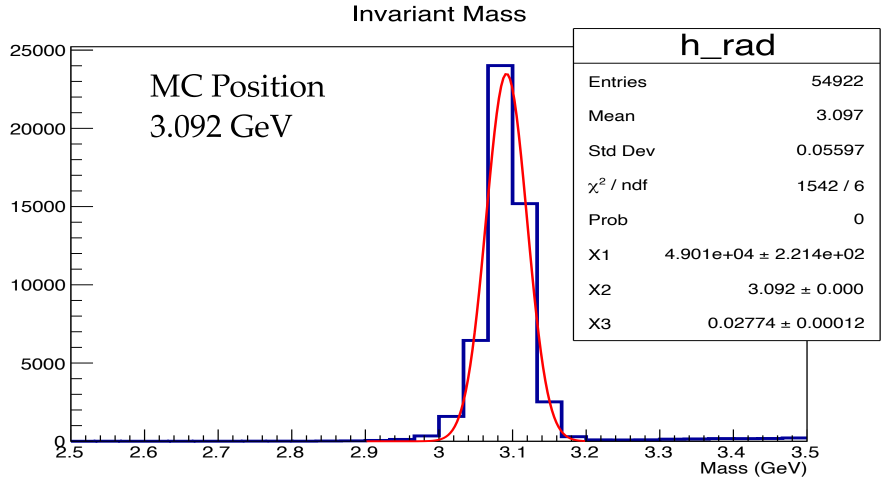


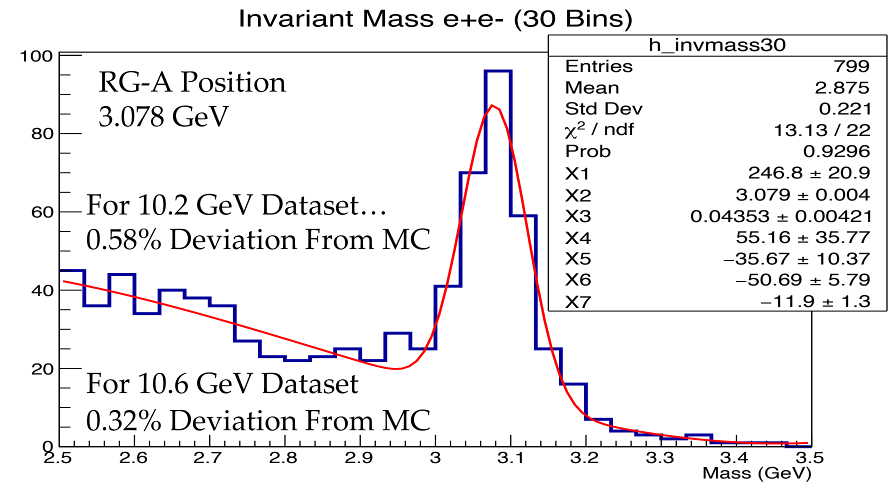




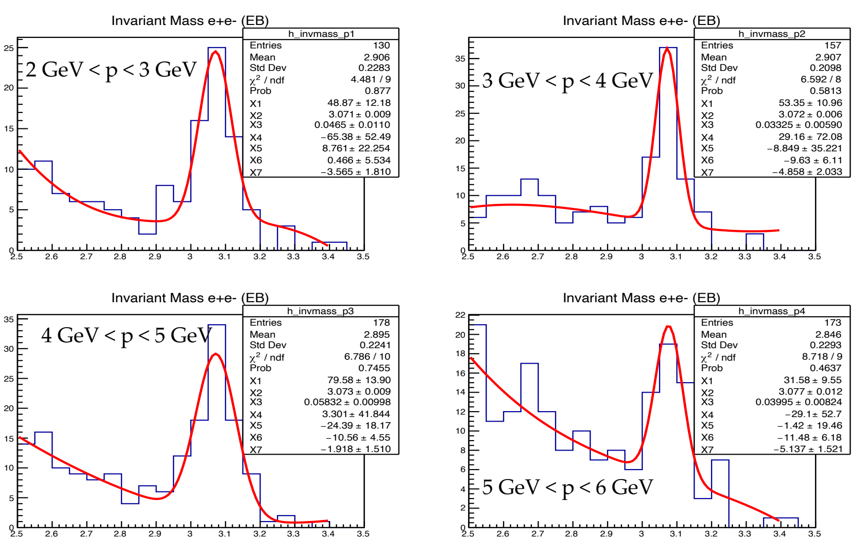
Momentum Corrections Studies Using Exclusive Reactions

Work is on-going to parametrize electron and positron momentum corrections as a function of momentum using exclusive reactions such as J/psi and missing neutrons

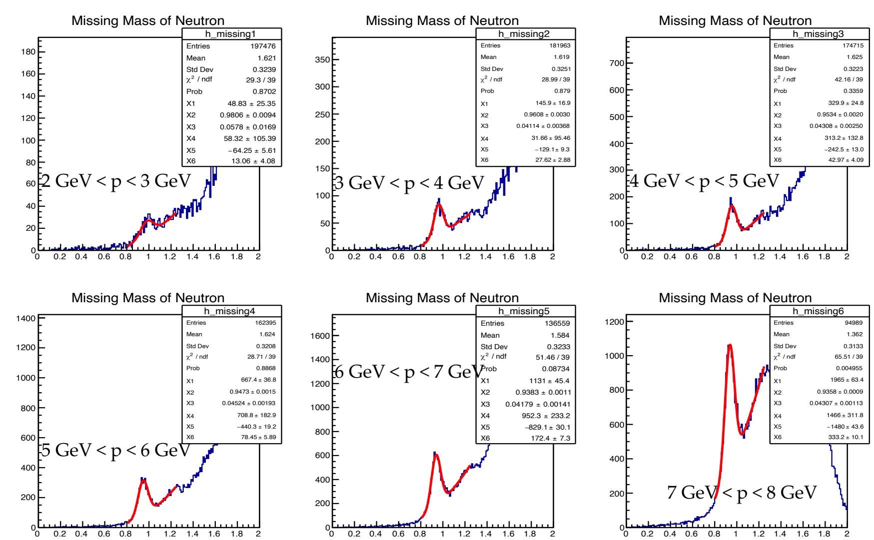




Effect of e- momentum on J/psi peak position

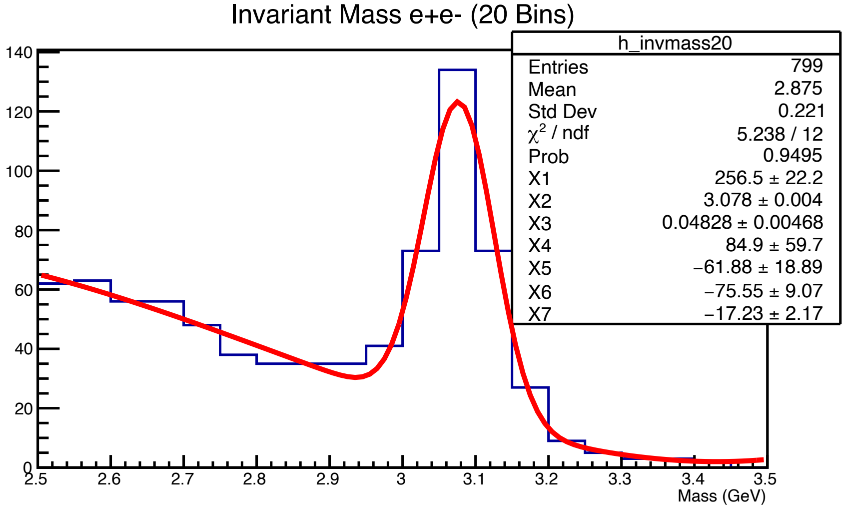


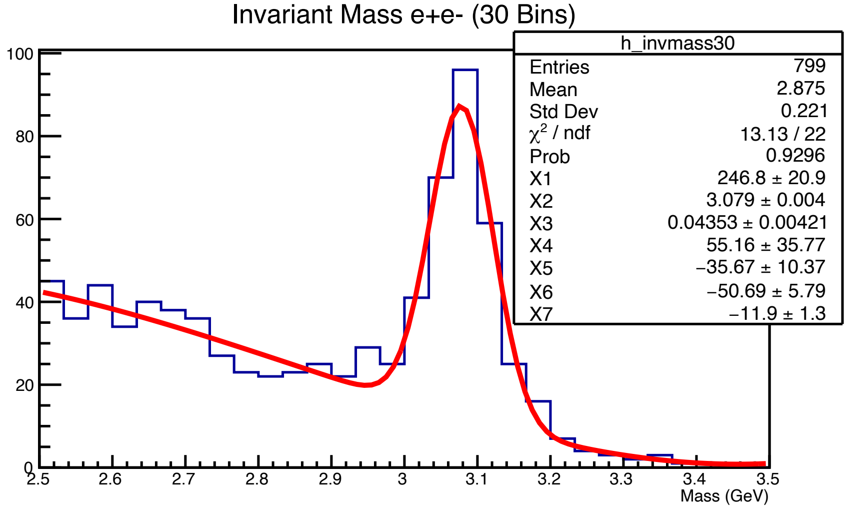
Effect of e- momentum on missing neutron peak position

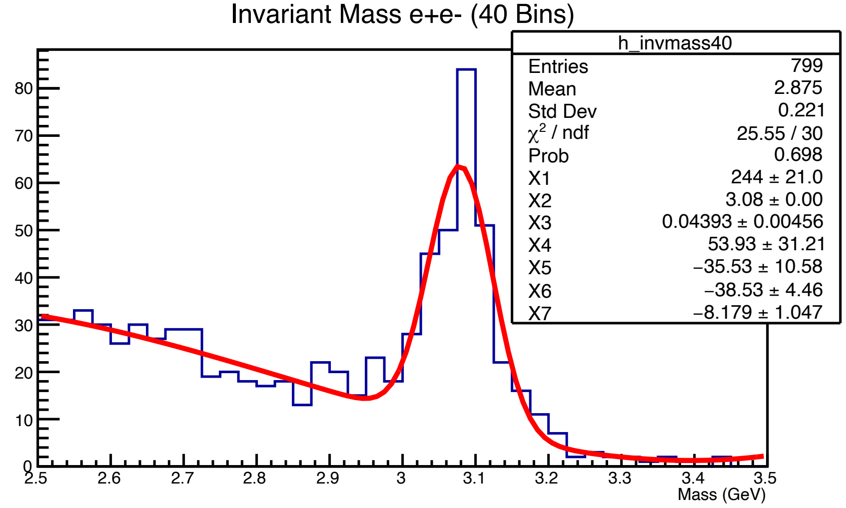


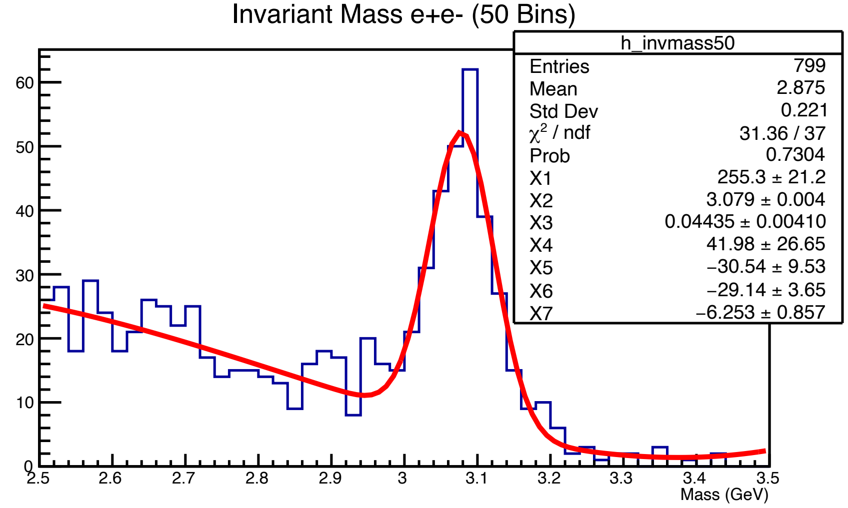
Systematic Effect Of Bin Size For Invariant Mass

The invariant mass was analyzed for varying bin sizes when combining the Fall 2018 and Spring 2019 datasets. This is important for studying the fit of the peak and the background.

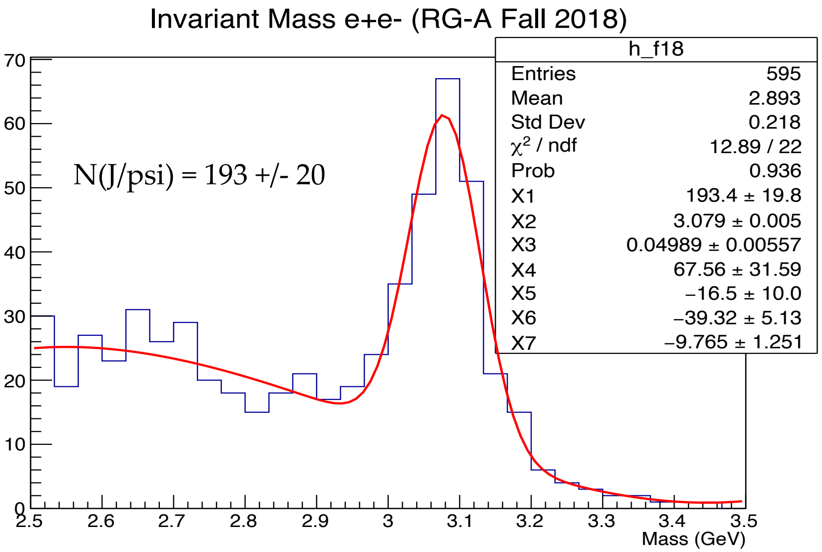


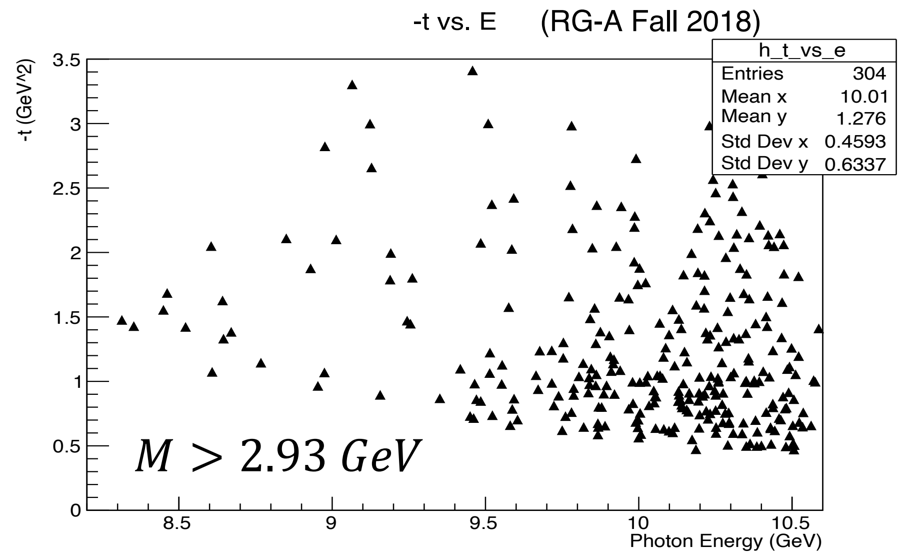


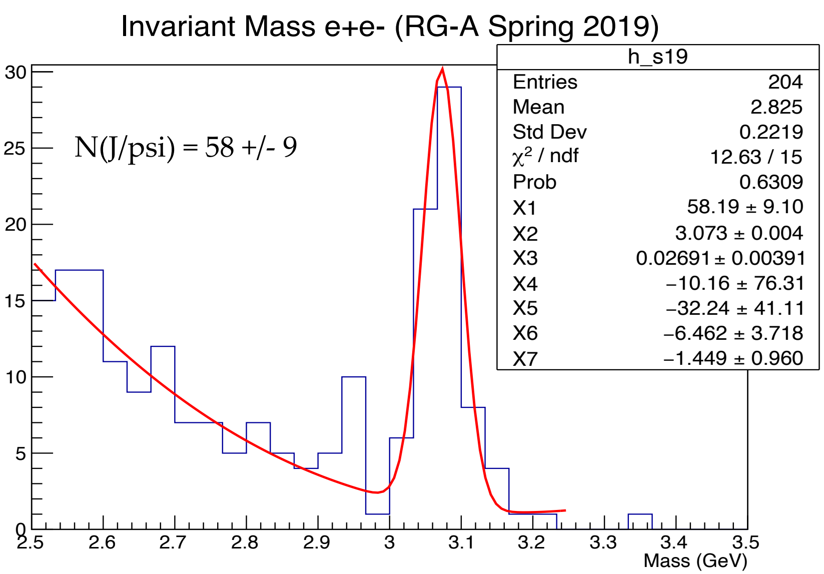


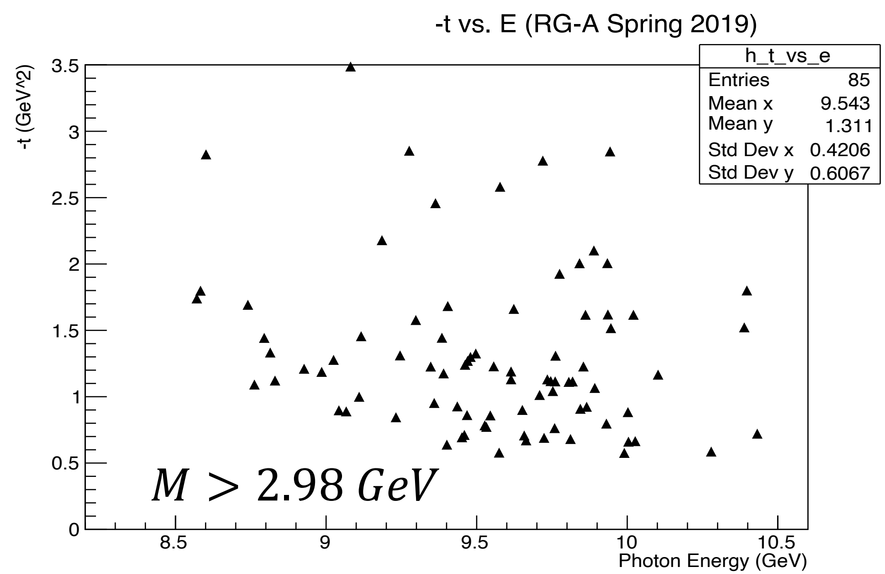


J/psi Photoproduction For RG-A Fall & Spring Datasets







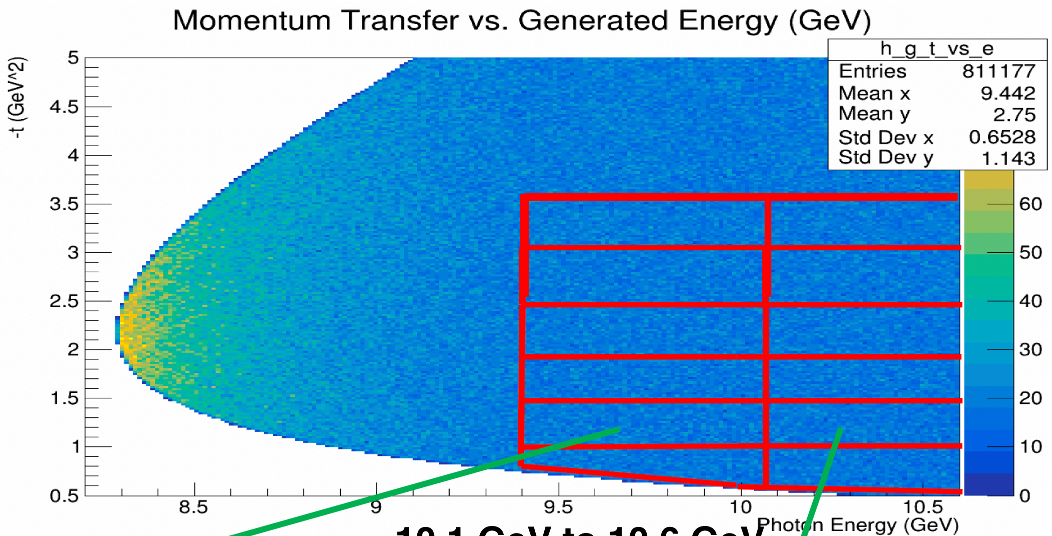


Procedure for Differential Cross Section Calculations

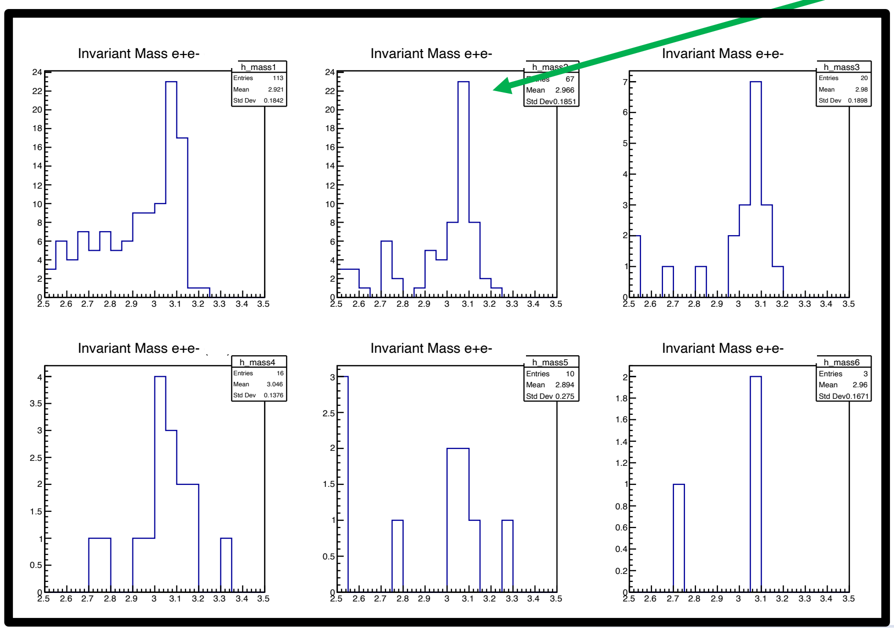
- Define the binning for the photon energy and momentum transfer
- Study the $(E_\gamma, |t - t_{min}|)$ distributions to determine the average $|\boldsymbol{t} - \boldsymbol{t_{min}}|$ & E_γ for the individual $(E_\gamma, -t)$ bin
- Use MC to study the reconstruction efficiency using fine binning for $(E_\gamma, -t)$
- Calculate the sum of the real and virtual **photon flux**
- Extract the # **of J/psi** events in each $(E_\gamma, -t)$ bin
- Calculate the efficiency for each J/Psi event and use the average value as the **efficiency** for that $(E_\gamma, -t)$ bin or weight each event and take the sum as the yield
- Quantify the integrated luminosity based on the accumulated charge for the analyzed data

Invariant Mass For Individual (E, -t) Bins

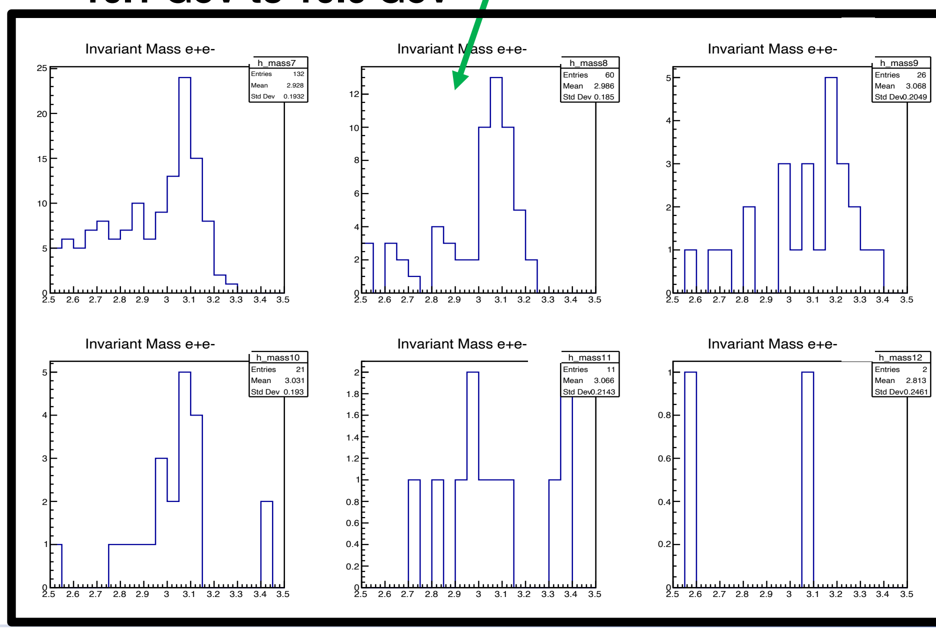
- Binning was developed with relatively wide photon energy bins to allow for the study of the t-dependence for the differential cross sections
- The invariant masses for the respective phase space locations clearly show J/psi events but not enough to do good quality fits



9.4 GeV to 10.1 GeV

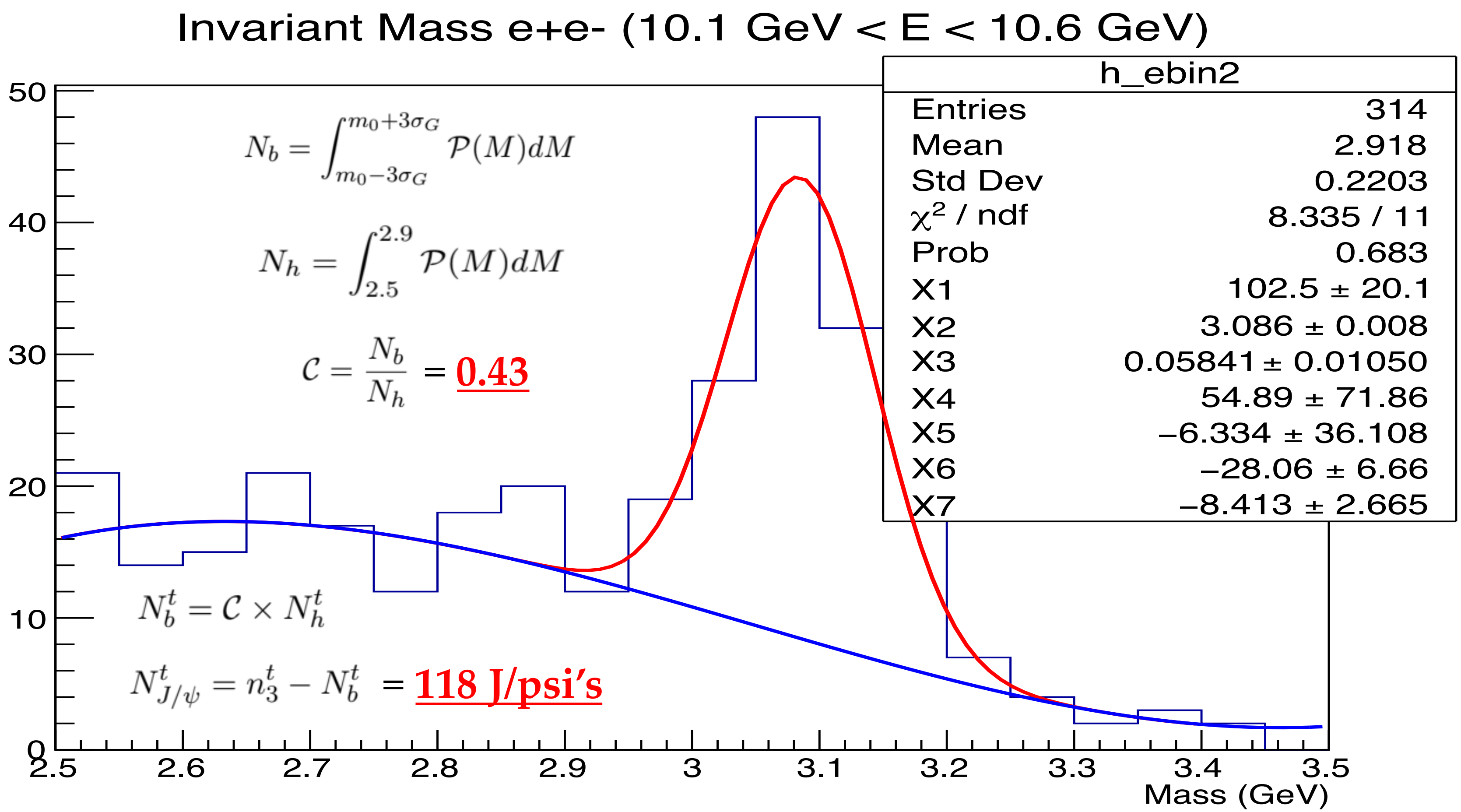


10.1 GeV to 10.6 GeV



N(J/psi) Calculation Strategy For Low-Statistic Bins

- Special considerations need to made for bins with low statistics since a direct fitting of the Gaussian and polynomial is not practical
- One method is to fit the invariant mass for an entire photon energy bin and use the background fitting result to calculate the number of background events. The difference between the total number of events and the background would be the number of J/Psi events

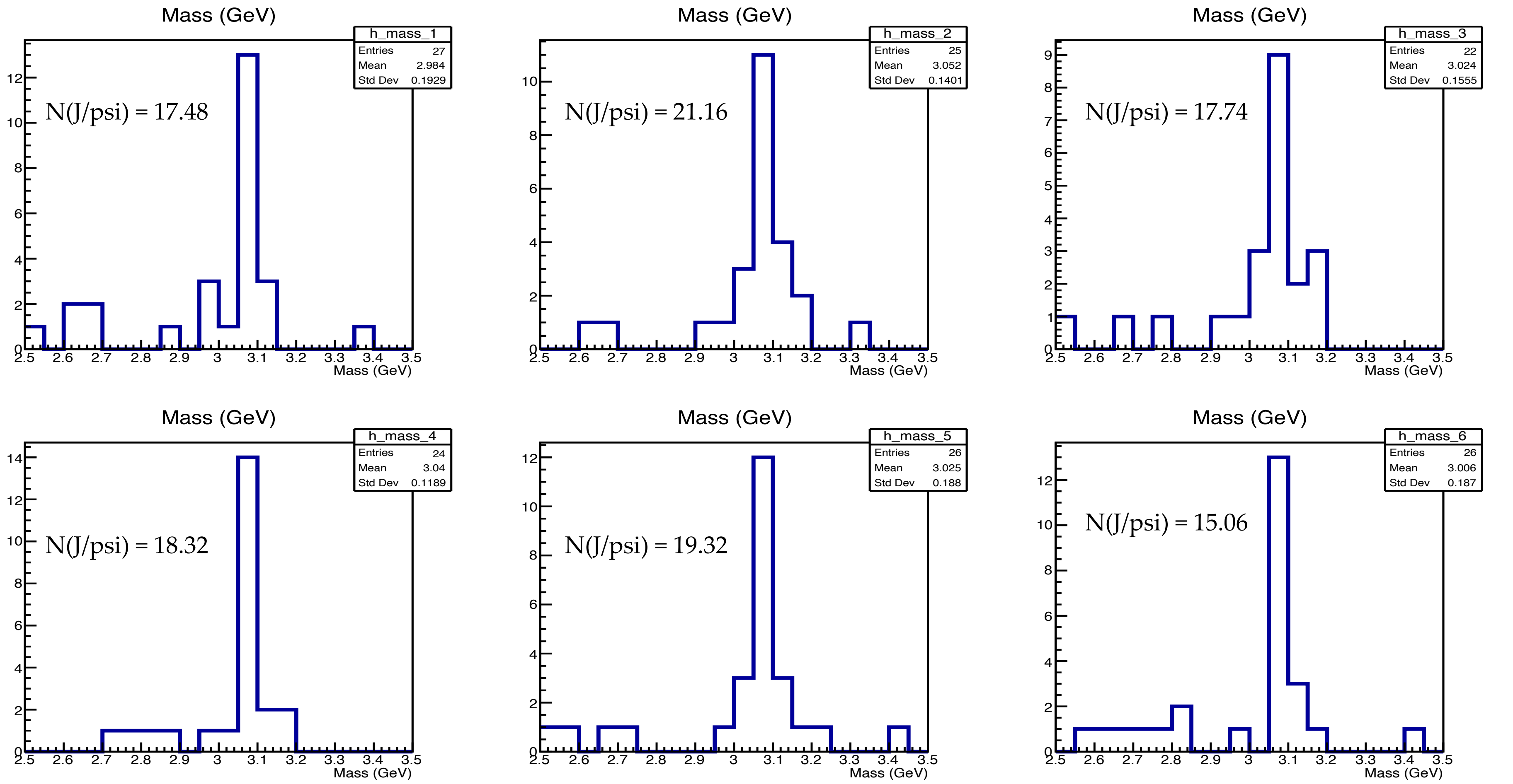


~ 15% Difference Between Fitting & Background Subtraction Method

Quantifying N(J/psi) Systematic Uncertainty With MC

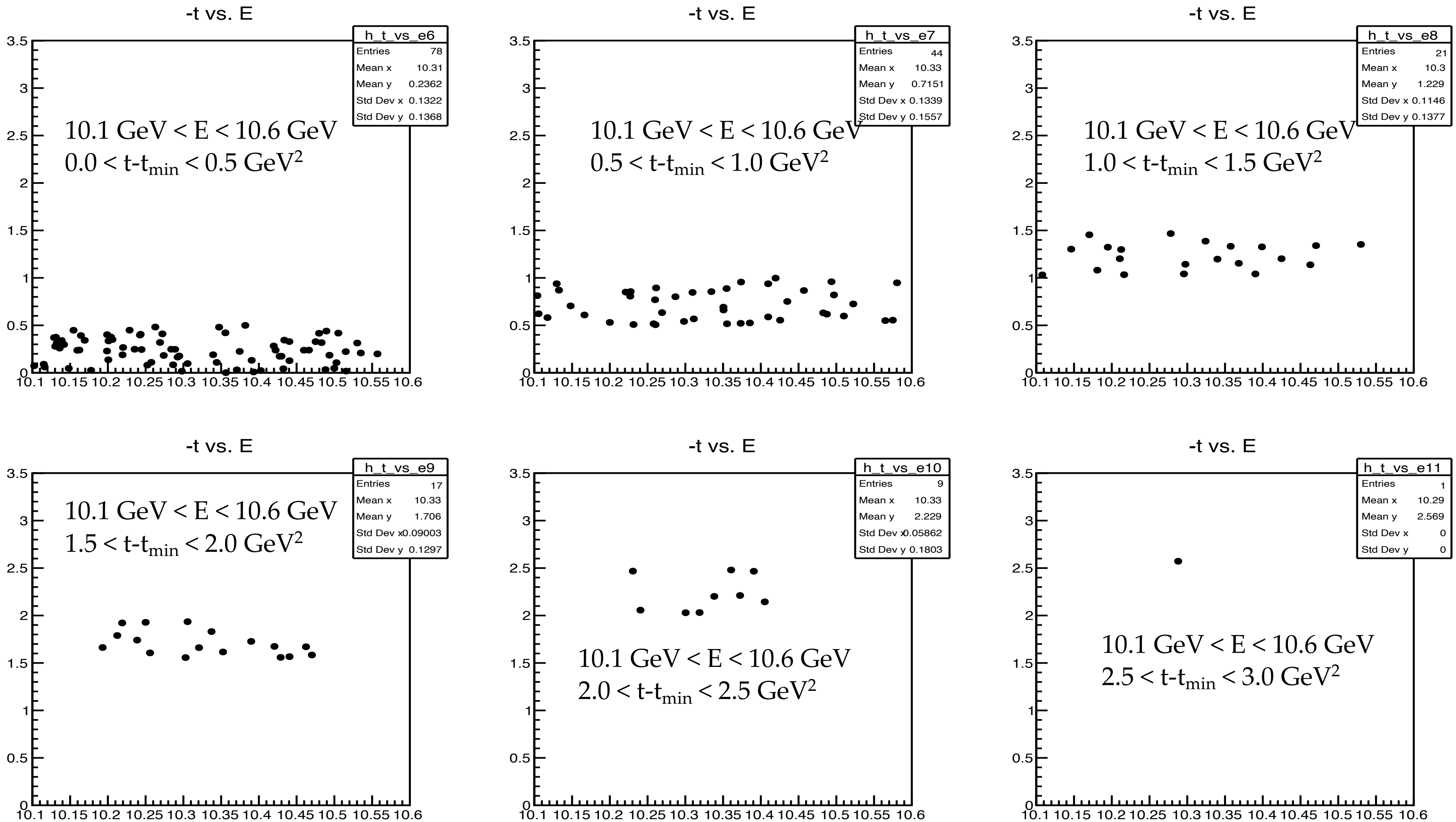
High-statistics MC can be used to study the systematic uncertainty for this method. For example, each histogram contains roughly 26 total MC events with 19 +/- 4 J/psi events & 7 +/- 3 BH events. Each histogram contains completely different MC events in the same photon energy and momentum transfer range. The plan is to produce large quantities of these histograms to quantify the systematic error for this J/psi yield calculation method.

$$\mathcal{N}^t_{J/\psi} = n^t_3 - \mathcal{C} \times N^t_h$$

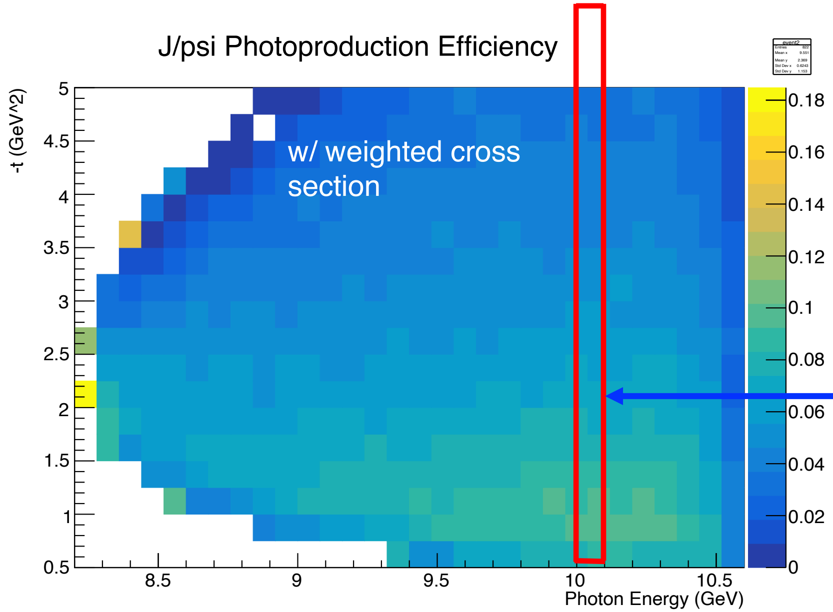


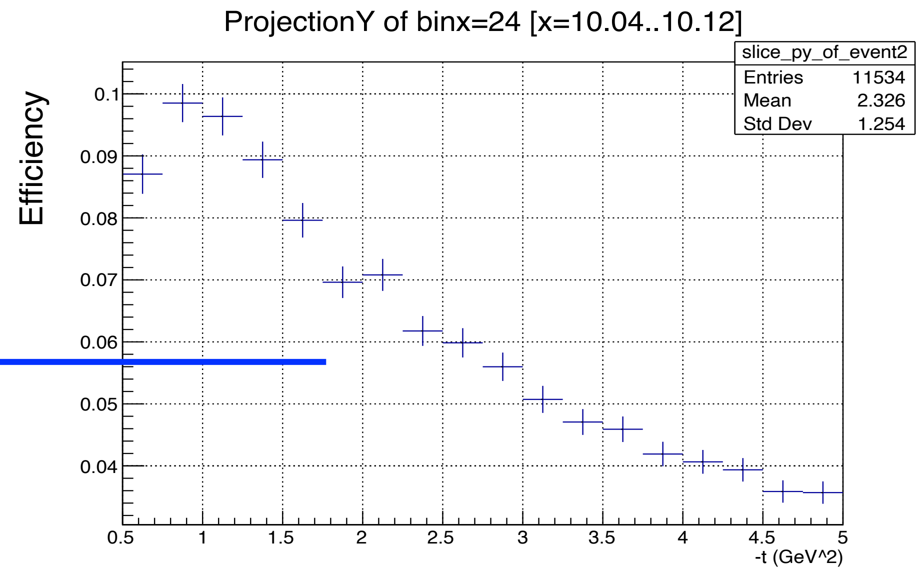
|t - t_min| vs. E Distributions (10.1 GeV to 10.6 GeV)

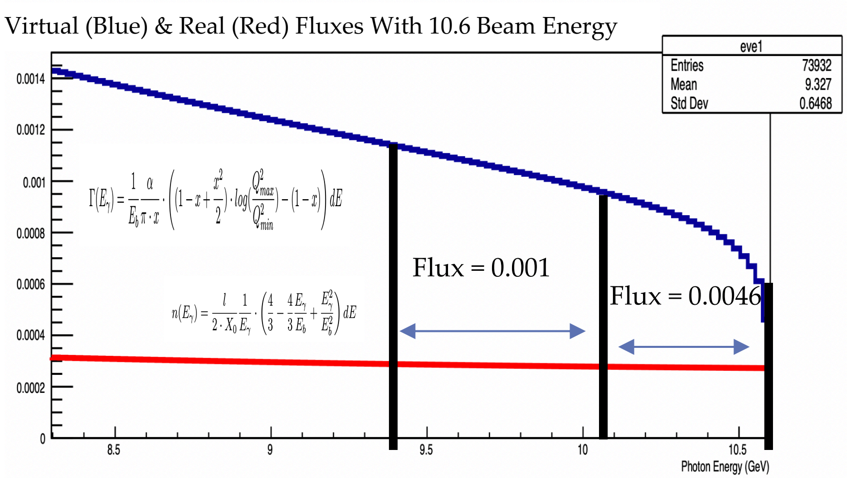
For the differential cross section study, the distribution of –t vs. E is studied to determine the correct position of $|t - t_{min}|$ for each bin. For example, the distributions below correspond to the 10.1 GeV < E < 10.6 GeV energy bin.

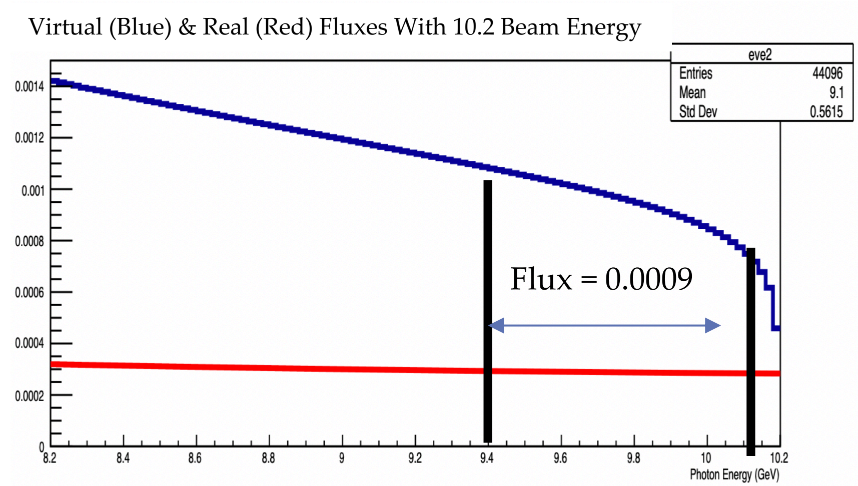


J/psi Reconstruction Efficiency & Photon Flux









Differential Cross Section vs. $|t-t_{min}|$

For 9.4 GeV < E < 10.1 GeV….

$t-t_{min}$ Bin #1 (**0.192 GeV²**): **0.1957 nb/GeV²**
$t-t_{min}$ Bin #2 (**0.578 GeV²**): **0.1066 nb/GeV²**
$t-t_{min}$ Bin #3 (**1.096 GeV²**): **0.03175 nb/GeV²**
$t-t_{min}$ Bin #4 (**1.572 GeV²**): **0.002617 nb/GeV²**
$t-t_{min}$ Bin #5 (**2.133 GeV²**): **0.0014457 nb/GeV²**
$t-t_{min}$ Bin #6 (**2.515 GeV²**): **0.009976 nb/GeV²**

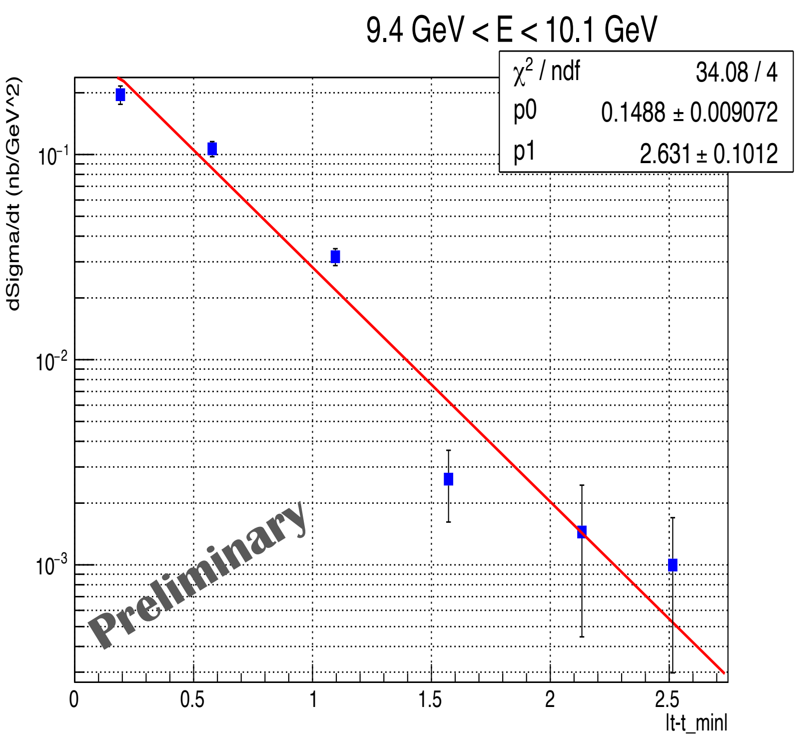
$$\frac{d\sigma}{dt} = \frac{N_{J/Psi}}{L_{int} f(E_\gamma)\eta(E_\gamma, -t) Br_{J/Psi} \Delta t}$$

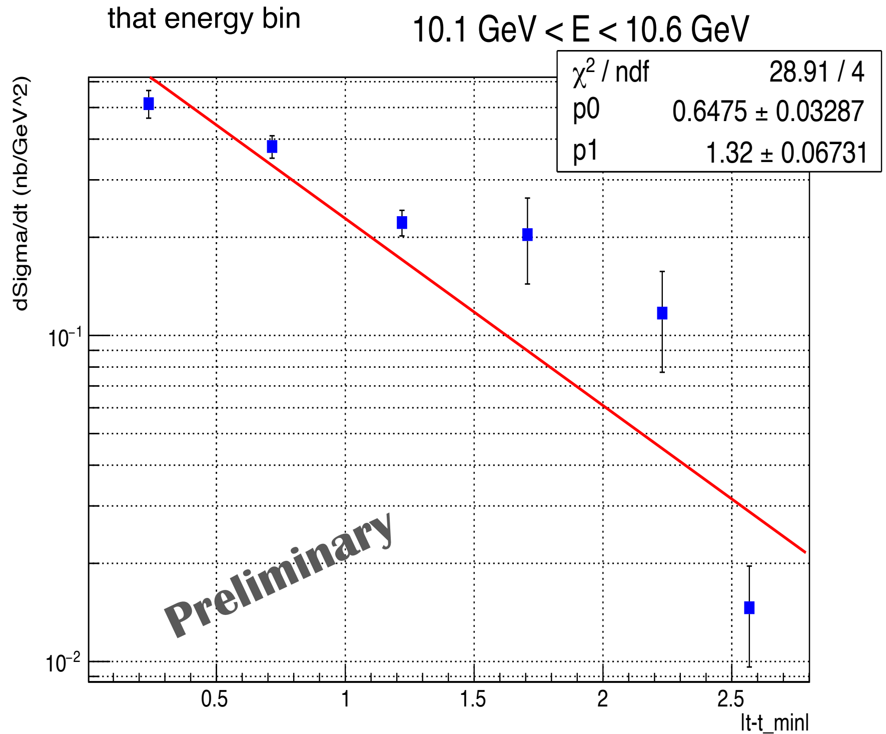
$$\frac{d\sigma}{dx} = \sigma_0 \cdot b e^{-b(x - x_{min})}$$

σ_0 , which is the p0 parameter, is the total cross section for that energy bin

For 10.1 GeV < E < 10.6 GeV….

$t-t_{min}$ Bin #1 (**0.237 GeV²**): **0.5138 nb/GeV²**
$t-t_{min}$ Bin #2 (**0.716 GeV²**): **0.3796 nb/GeV²**
$t-t_{min}$ Bin #3 (**1.22 GeV²**): **0.2219 nb/GeV²**
$t-t_{min}$ Bin #4 (**1.707 GeV²**): **0.2038 nb/GeV²**
$t-t_{min}$ Bin #5 (**2.230 GeV²**): **0.1171 nb/GeV²**
$t-t_{min}$ Bin #6 (**2.568 GeV²**): **0.01462 nb/GeV²**





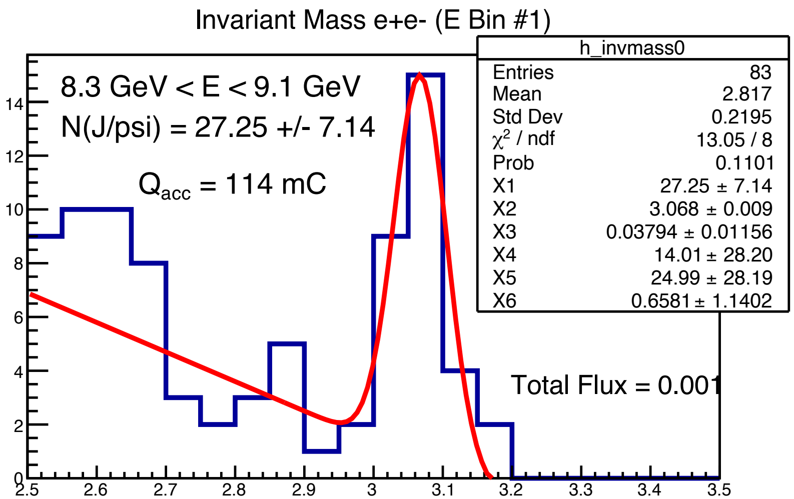
Procedure For Total Cross Sections

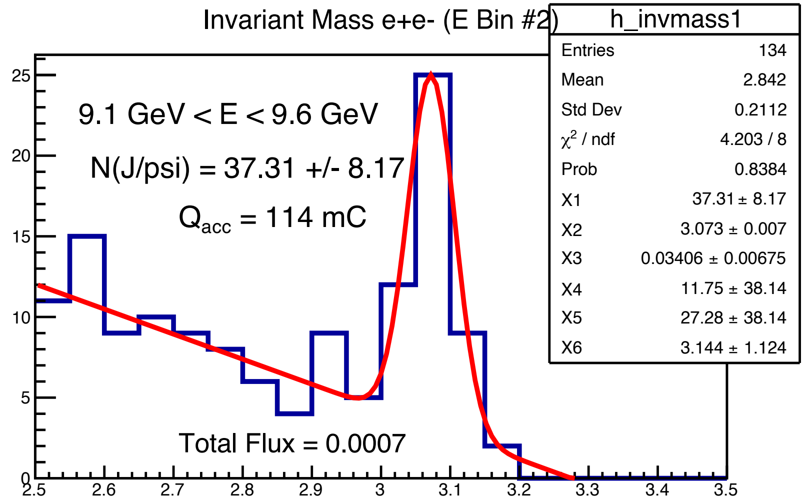
In the previous slide, the total cross section was determined by integrating the t-dependent differential cross section. There is another method that GlueX utilized, which relies on the correct t-dependent modeling for the efficiency.

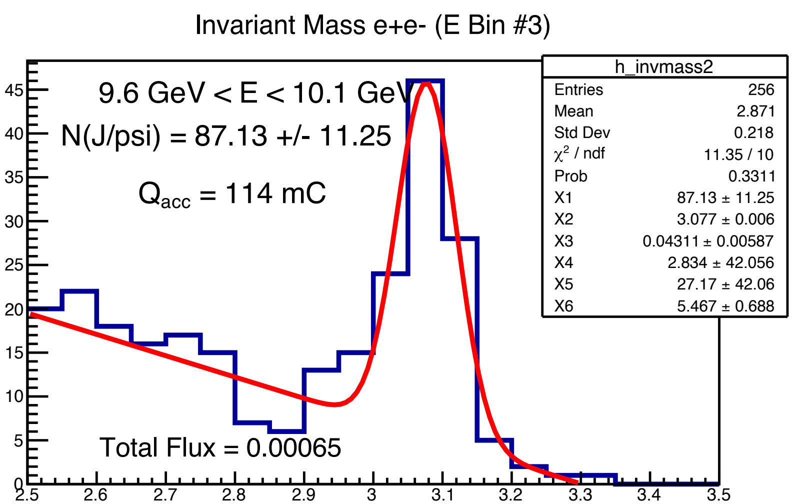
- Step #1: Quantify N(J/psi) for each energy bin
- Step #2: Quantify N(BH) for each energy bin
- Step #3: Calculate the BH efficiency for each energy bin
- Step #4: Calculate the J/psi efficiency for each energy bin
- Step #5: Calculate the BH theoretical total cross section

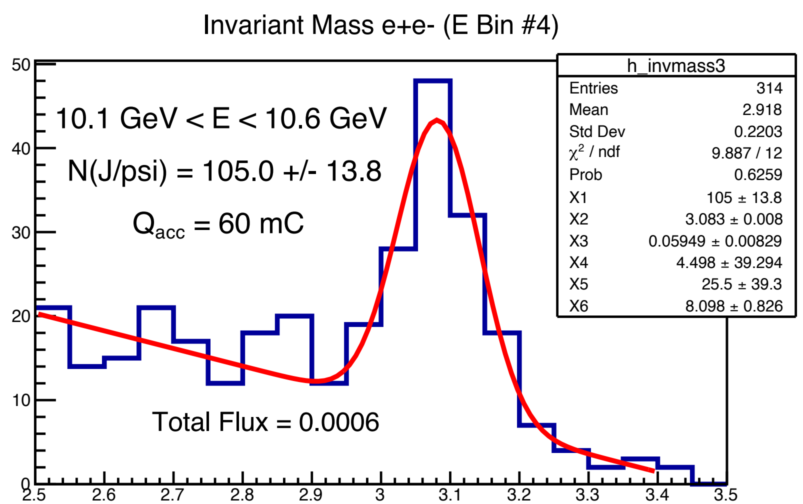
$$\sigma_{J/\psi}(E_\gamma) = \frac{N_{J/\psi}(E_\gamma)}{N_{BH}(E_\gamma)} \frac{\sigma_{BH}(E_\gamma)}{\mathcal{B}_{J/\psi}} \frac{\varepsilon_{BH}(E_\gamma)}{\varepsilon_{J/\psi}(E_\gamma)}.$$

N(J/psi) Yield For Selected Photon Energy Bins









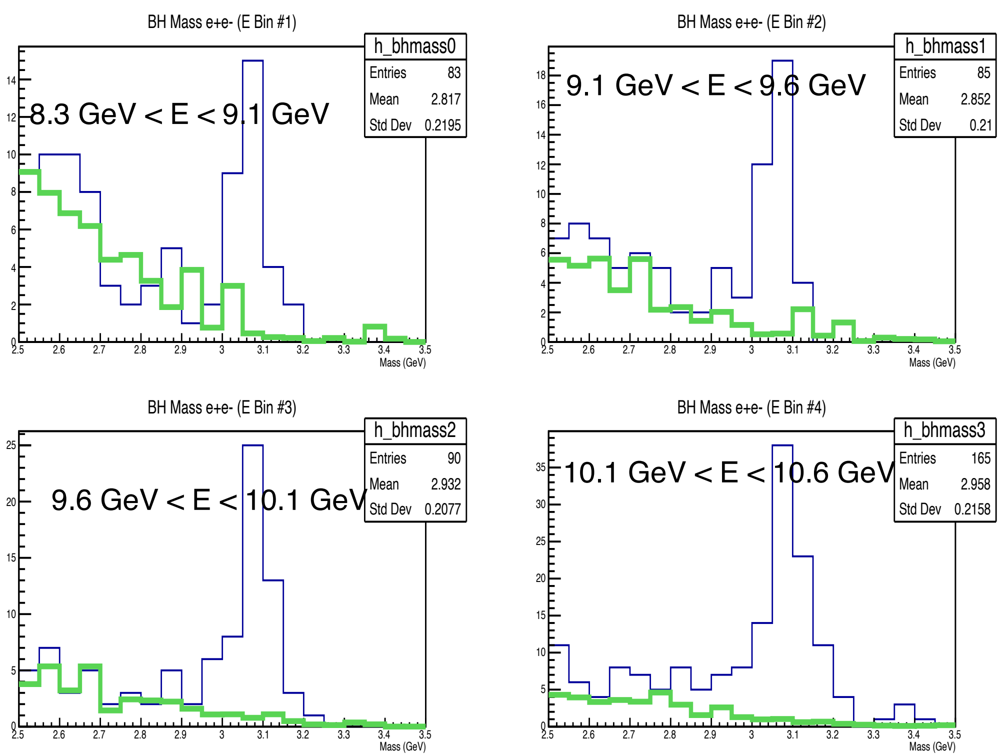
Using Bethe-Heitler To Normalize The Total Cross Sections

- An MC generator, written by Dr. Rafayel Paremuzyan, called TCSGen contains the Bethe-Heitler cross section and is being used to study the expected rates in the same areas of phase space the J/psi events are located
- Work is on-going to optimize the ideal cuts, such as the invariant mass and the exclusivity cuts, in order to effectively normalize the cross section.
- Overall, agreement between RG-A and MC rates is reasonable.

$$\frac{1}{N_{Gen}} \sum_{i=1}^{N_T} \sigma_i \cdot psf_i$$

Energy Bin	BH Theoretical Cross Section
8.3 GeV to 9.1 GeV	0.0038 nb
9.1 GeV to 9.6 GeV	0.0030 nb
9.6 GeV to 10.1 GeV	0.0034 nb
10.1 GeV to 10.6 GeV	0.0038 nb

Agreement between RG-A (blue) & MC expected rates (green)



Summary

- Analysis framework is well-advanced (particle identification, momentum corrections, fiducial cuts, & quasi-real photoproduction selection)
- Procedures and codes for calculating the differential and total cross sections have been developed.
- Systematic uncertainties are being tested and analyzed.
- High-statistics MC is being used with background merging for efficiency & normalization studies
- Analysis note is being written.

Thank you

Questions or comments?