J/ψ Photoproduction Near Threshold With CLAS12

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Topics

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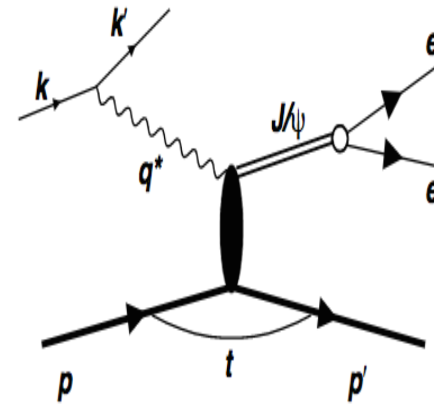
Experiment Overview

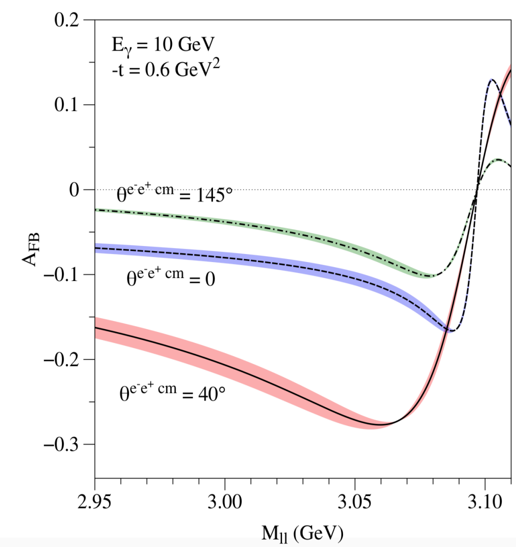
Description

- Electrons accelerated by CEBAF scatter off a liquid Hydroger 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}



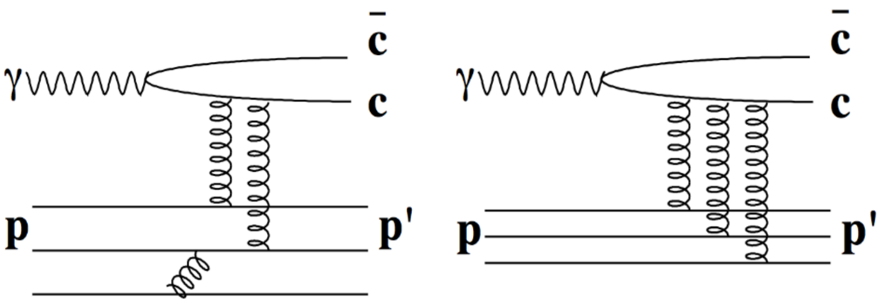
Physics Goals

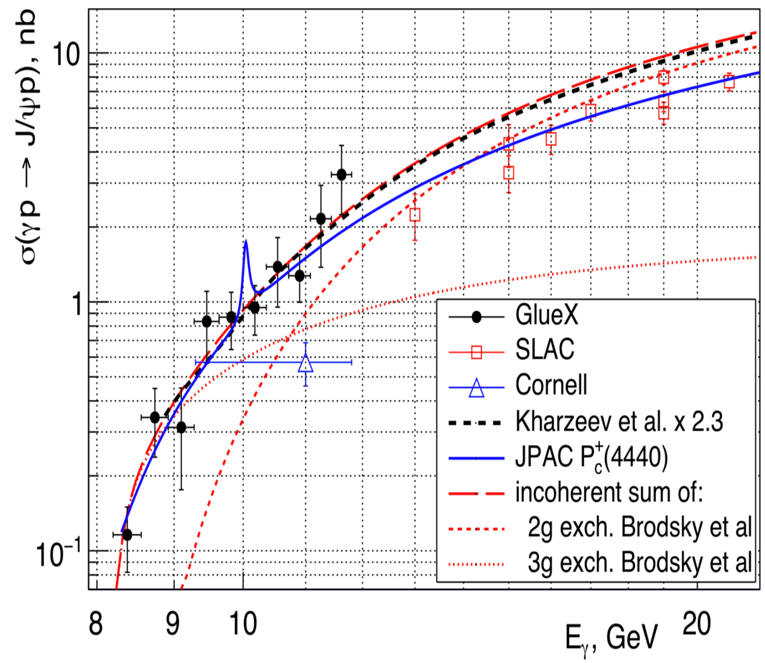
- Probe the distribution of color charge in the nucleon
  - Measure the t-dependence of the differential cross section of J/ψ photoproduction
- Study the production mechanism of J/ψ near threshold
  - Measure the total cross section as a function of photon energy
- Study the forward-backward asymmetry to access the real part of the Compton scattering amplitude



Proposed Models For J/ψ Photoproduction

- The incoming photon couples to the gluon field through an intermediate virtual charm-anti-charm pair
- Near threshold, momentum transfer becomes large and all three valence quarks must exchange energy in the form of gluons for the elastic production of J/ψ. This will allow the study of gluonic form factors of the proton





*S.J. Brodsky, E. Chudakov, P. Hoyer, and J.M. Laget. Phys. Rev. Lett. (2008)
*CLAS12 Collaboration, "Timelike Compton Scattering and J/ψ Photoproduction on the Proton in e+e- Pair Production with CLAS12 at 11 GeV", Thomas Jefferson National Accelerator Facility PAC 39 Proposal, (May 2012).

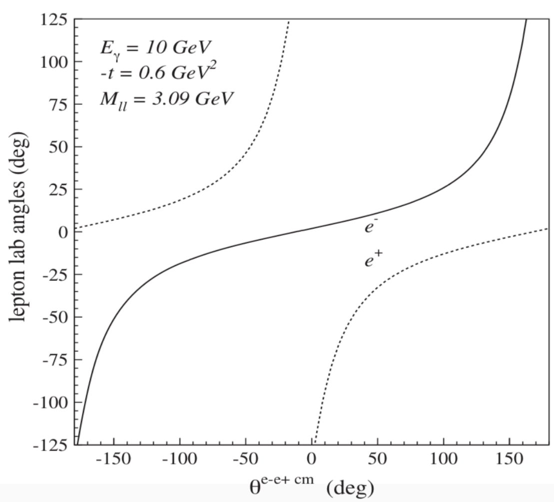
$$\frac{d\sigma}{dt} = N_{2g}\frac{(1-x)^2}{R^2M^2}F_{2g}^2(t)(s-m_p^2)^2$$

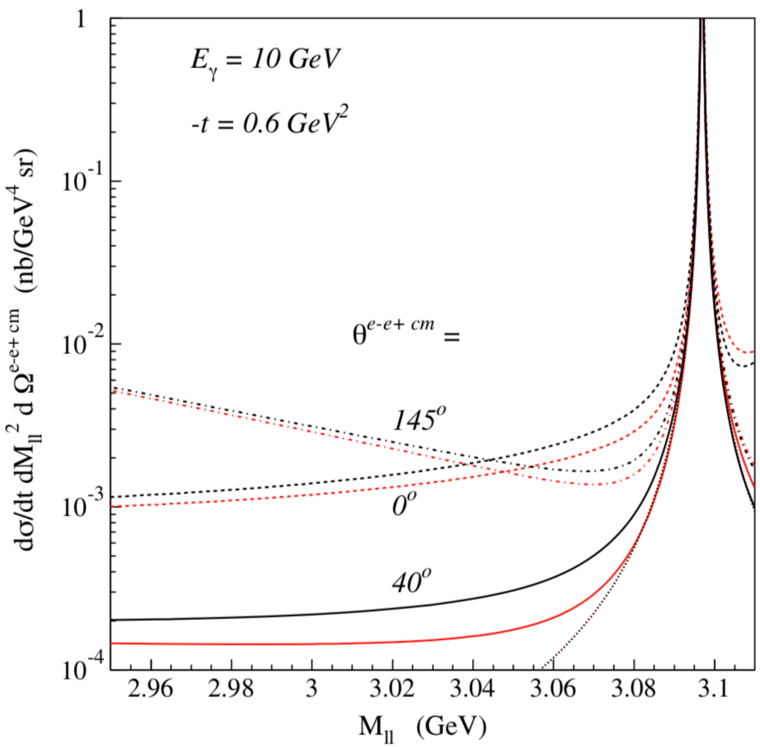
$$\frac{d\sigma}{dt} = N_{3g}\frac{(1-x)^0}{R^4M^4}F_{3g}^2(t)(s-m_p^2)^2$$

Forward-Backward Asymmetry

- The real part of the forward J/ψ-p scattering amplitude can be accessed
- The forward-backward asymmetry results from the interchanging of leptons in the interference between the J/ψ and Bethe-Heitler mechanisms
- The asymmetry depends linearly on the J/ψ-p s-wave scattering length

$$A_{FB} \equiv \frac{d\sigma(\theta^{e^-e^+\mathrm{cm}}) - d\sigma(\theta^{e^-e^+\mathrm{cm}} - 180^\circ)}{d\sigma(\theta^{e^-e^+\mathrm{cm}}) + d\sigma(\theta^{e^-e^+\mathrm{cm}} - 180^\circ)}$$

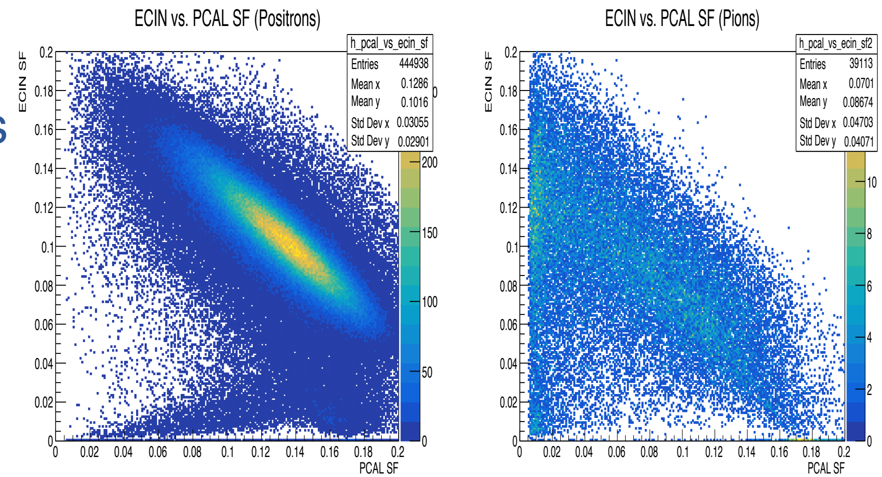




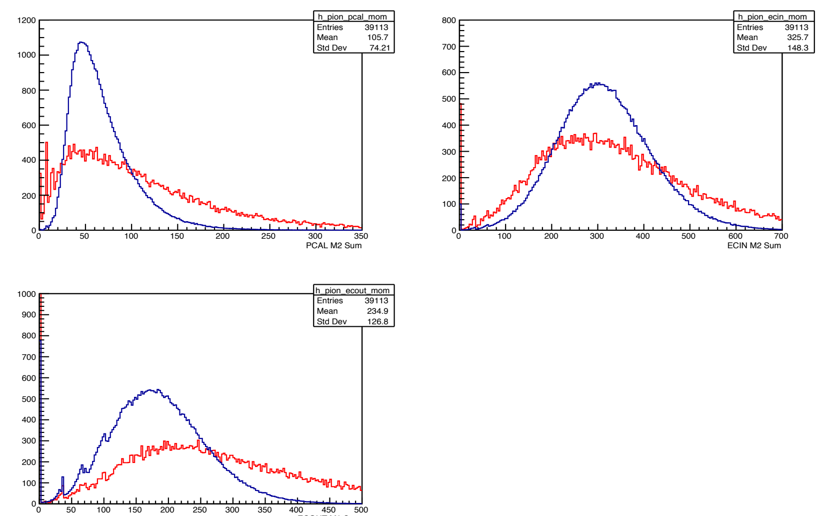
*O. Gryniuk, and M. Vanderhaeghen. Phys. Rev. Lett. (2016)

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



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



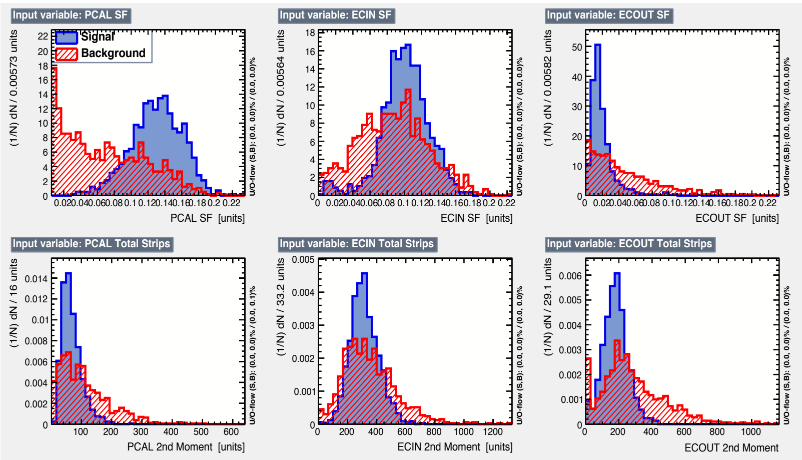
MC distributions for the PCAL and ECIN 2nd moments for real positrons and mis-identified pions

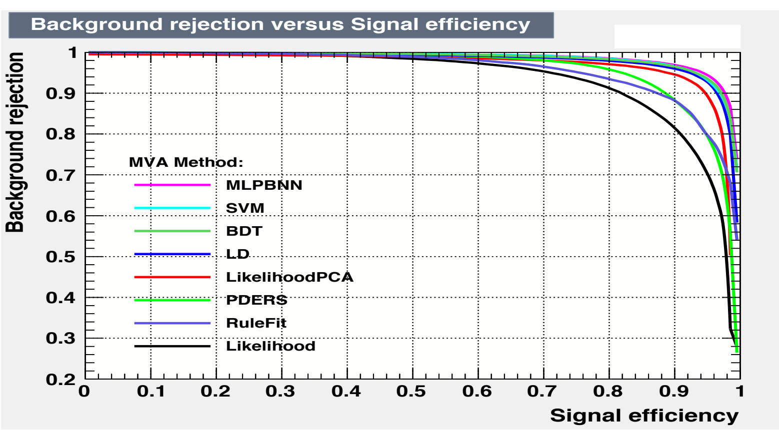
Distinguishing Signal vs. Background For e+e- Particle ID At (p > 5 GeV) With ROOT TMVA

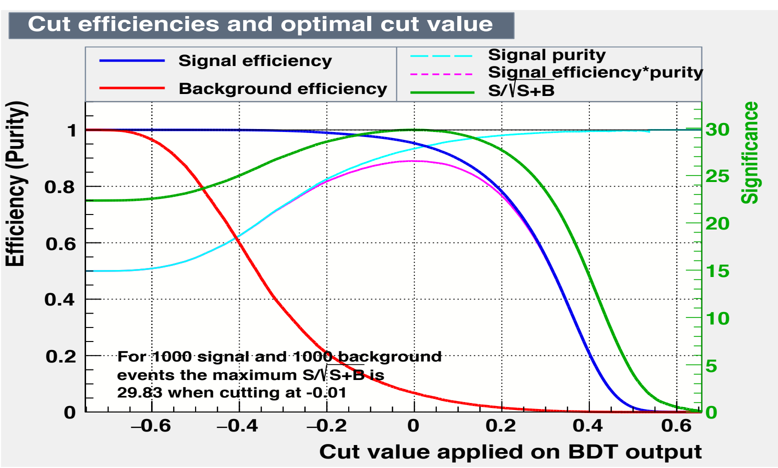
*For positrons with p > 5 GeV, ROOT TMVA (multi-variate analysis) can be implemented to distinguish pions and positrons.

*Development of training samples with background and signal variables can feed into a Boosted Decision Tree (BDT) to train the AI.

*The BDT algorithm can be included in analysis code to make selection cuts on an event-by-event basis

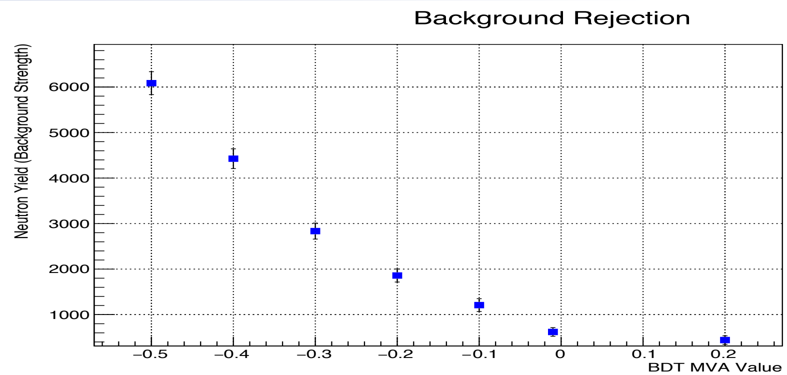


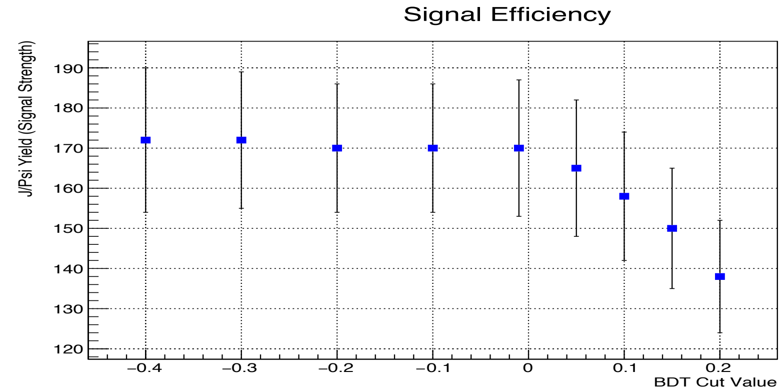


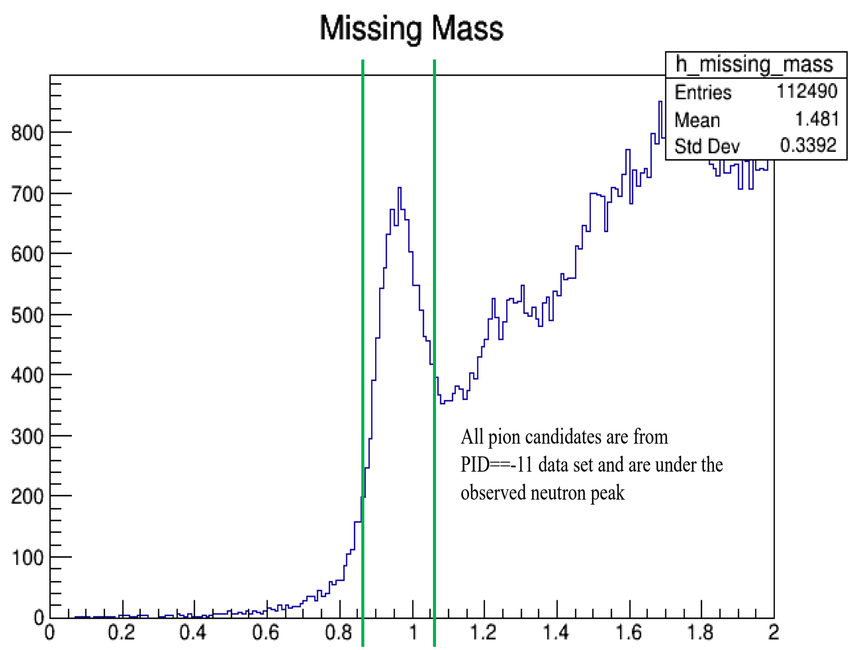


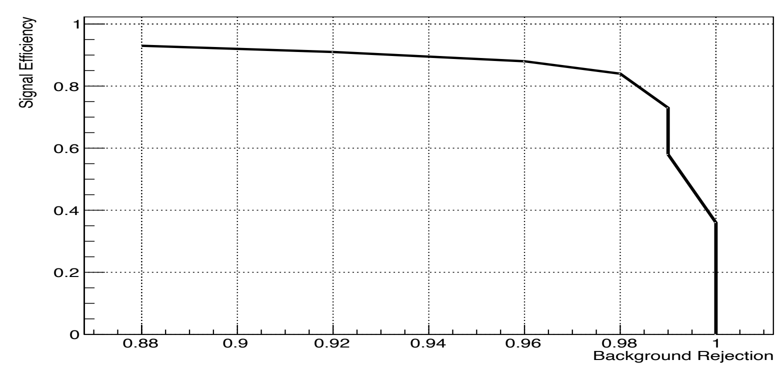
Particle ID Systematic Effects

To understand the systematic effects of the BDT MVA cut value, the J/Psi yield was studied as a measure for the signal efficiency and the number of neutrons in the missing mass distribution was studied as a measure for the background rejection









Effects of Radiative Photons On J/Psi Reconstruction

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

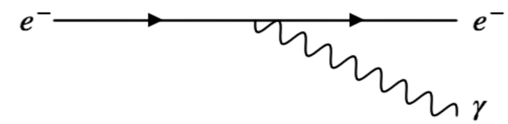
*Photons are selected by applying a 0.5^{0} cut on $d\theta$

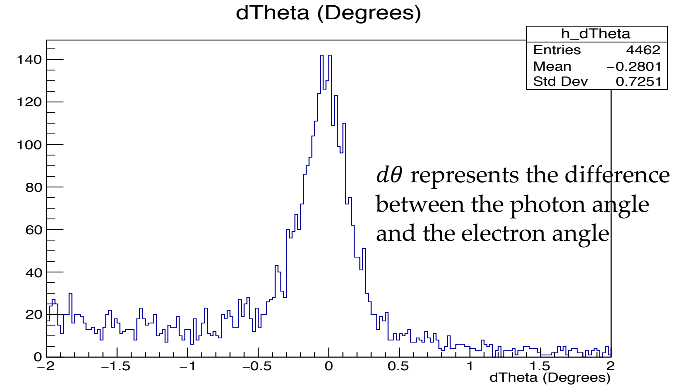
*Application of this technique results in a stronger J/Psi mass signal as well as cleaner quasi-real photoproduction distributions

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

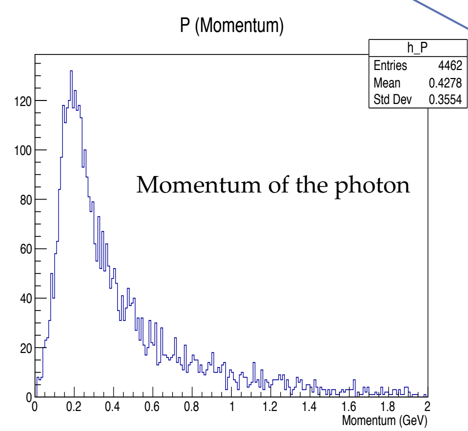
*Work is on-going to understand MC vs. data difference

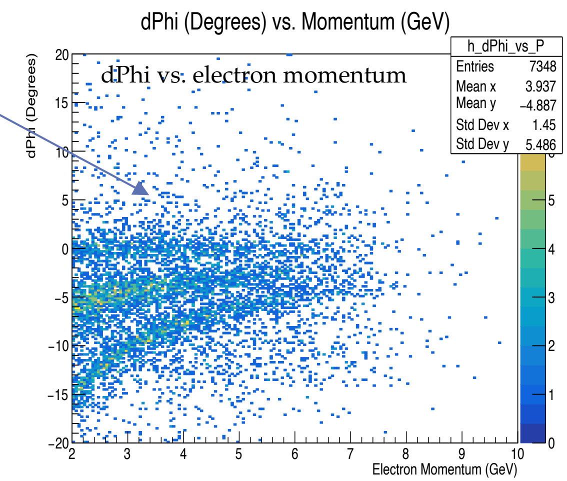
*More photons from this effect can be found by looking for neutrals with PID==2112 (neutrons) due to misidentification from ECAL timing association





% of Events (w/ PID==22)	RG-A Events
Originate From Electron	12%
Originate From Positron	13%
Neither	75%

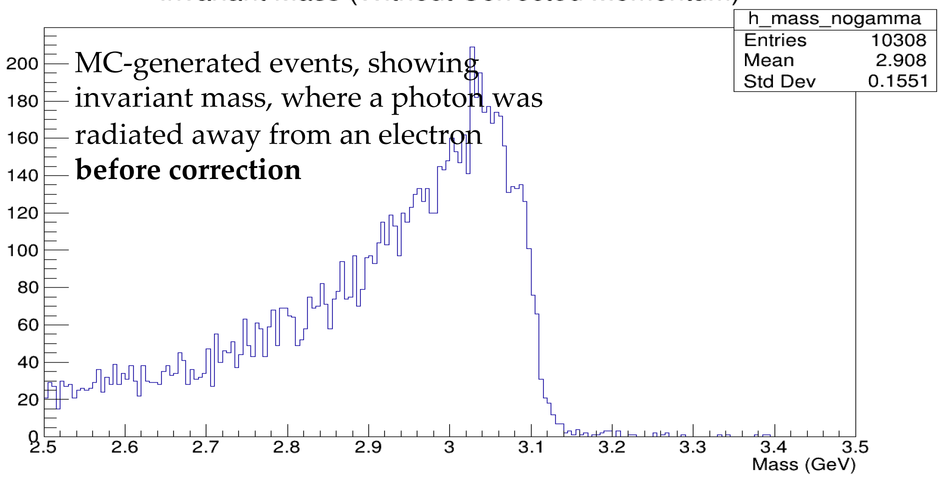




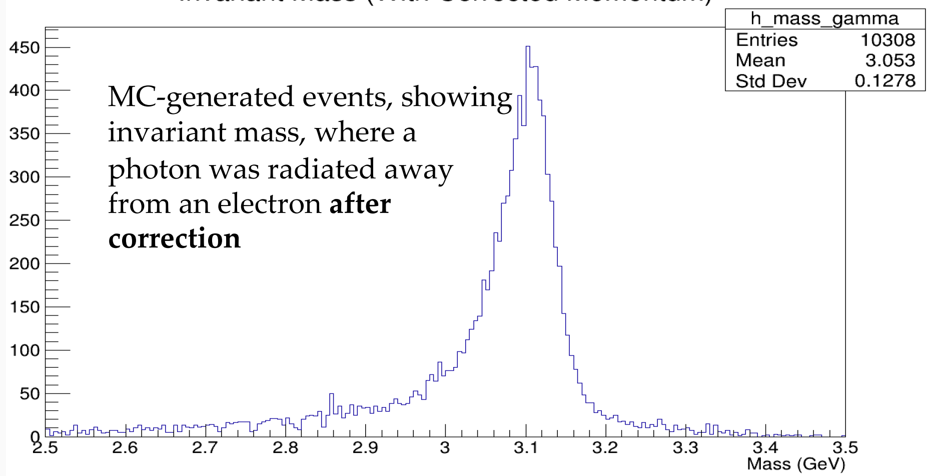
Effects of Radiative Photons On J/Psi Reconstruction (continued)

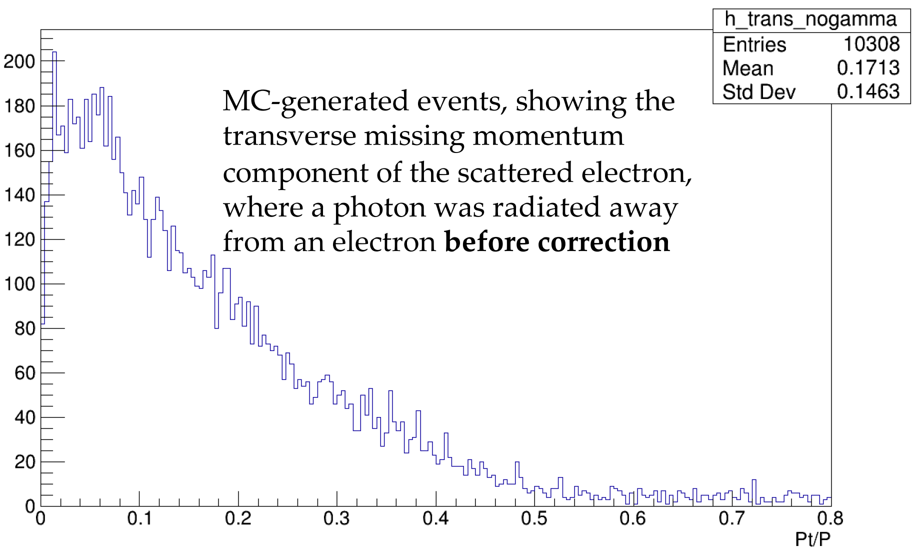
Events with a photon associated with the energy loss of an electron show a clear difference before and after correcting for the momentum. The invariant mass's quality is improved. The transverse missing momentum fraction, a property of quasi-real photoproduction, has a sharper distribution.

Invariant Mass (Without Corrected Momentum)

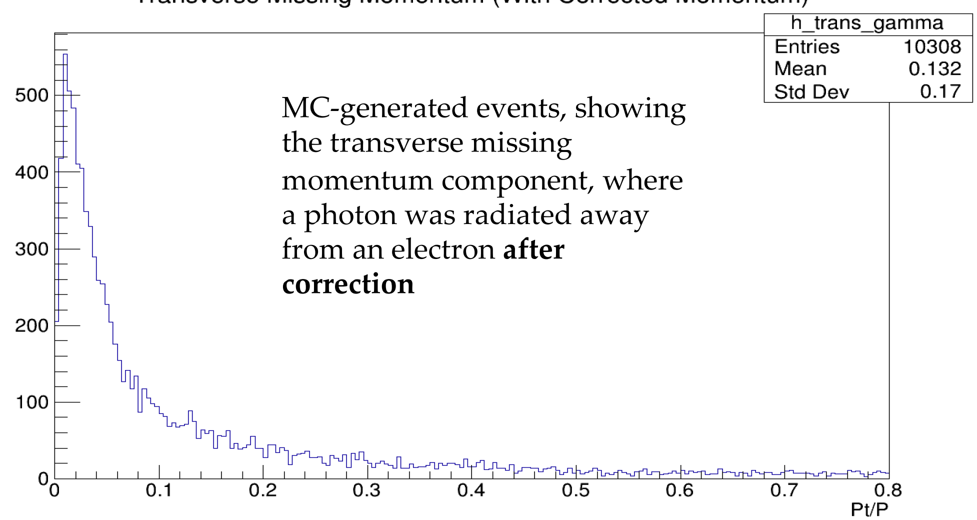


Invariant Mass (With Corrected Momentum)



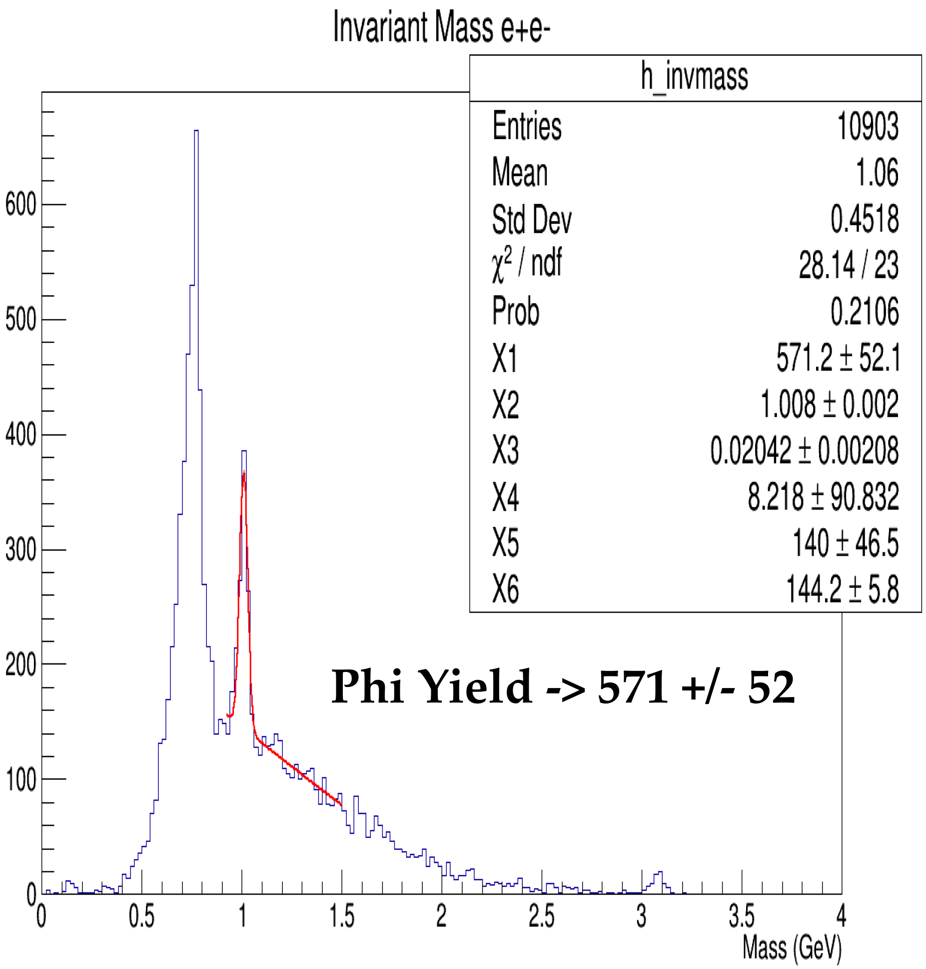


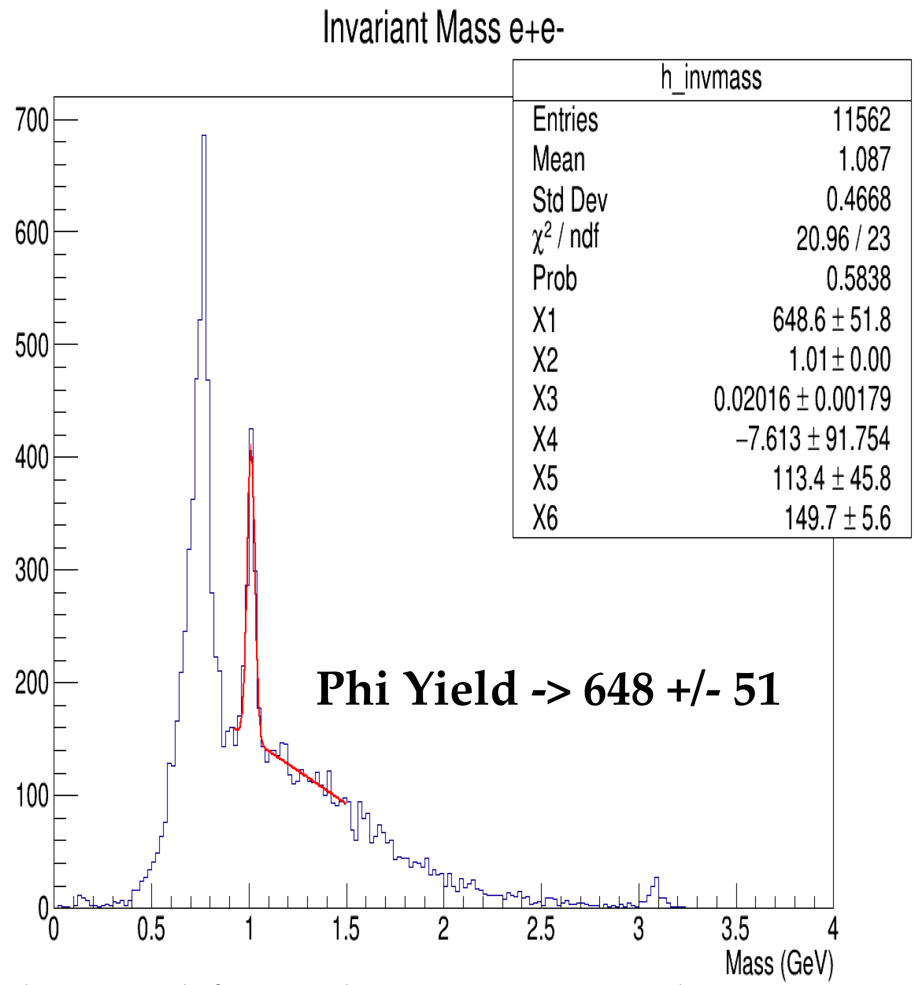
Transverse Missing Momentum (With Corrected Momentum)



Un-Corrected vs. Corrected Radiated Energy Loss (With Same PID & Exclusivity Cuts) For Phi Resonance

To understand the effects of this momentum correction on RG-A data, the phi resonance's peak was analyzed after momentum and exclusivity cuts.





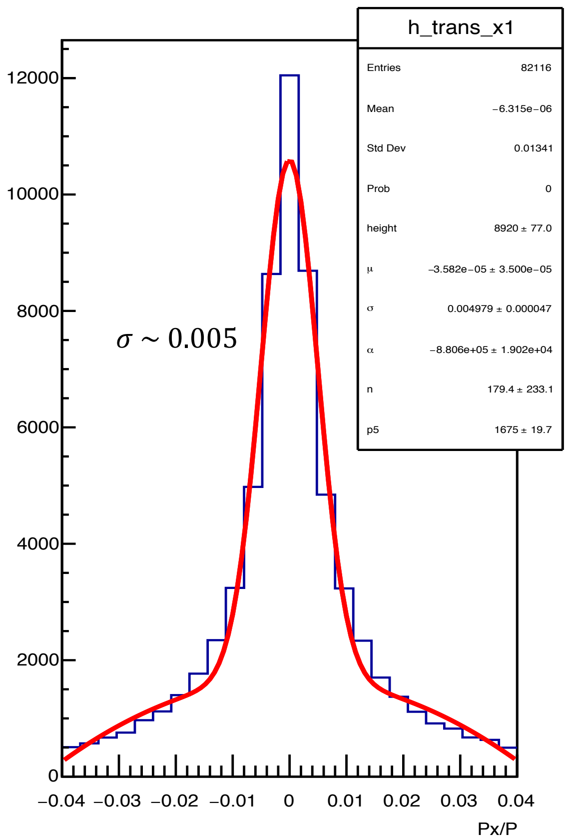
A 13% increase in the number of phi's was observed from this correction alone

MC Quasi-Real Photoproduction

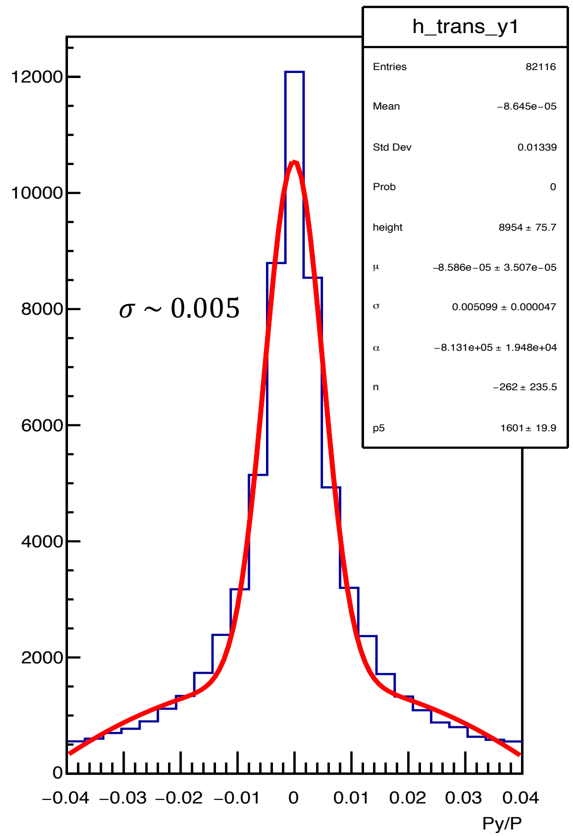
Establishing criteria for event selection is done to understand the measurement of the undetected, forward-scattered,($Q^2 \sim 0$) electron after the exchange of a quasi-real photon

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

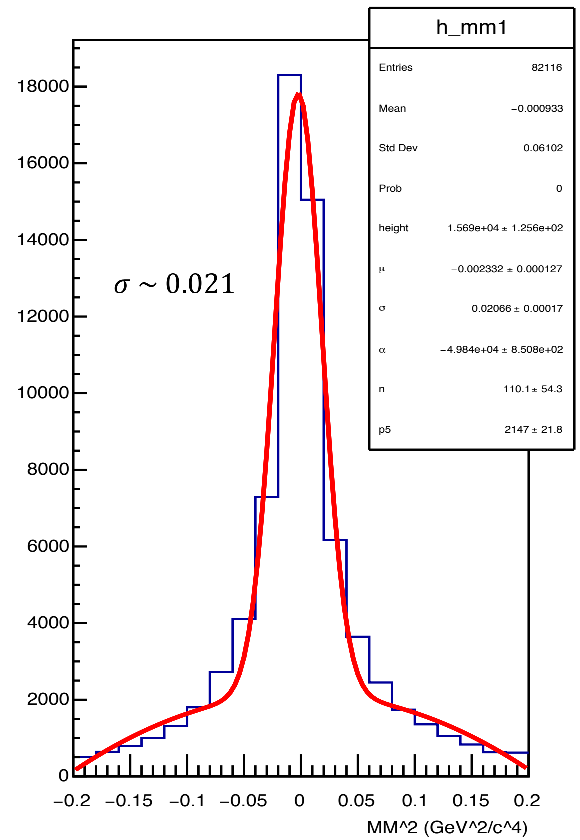
Transverse Missing Momentum X For Un-Detected Scattered Electron



Transverse Missing Momentum Y For Un-Detected Scattered Electron

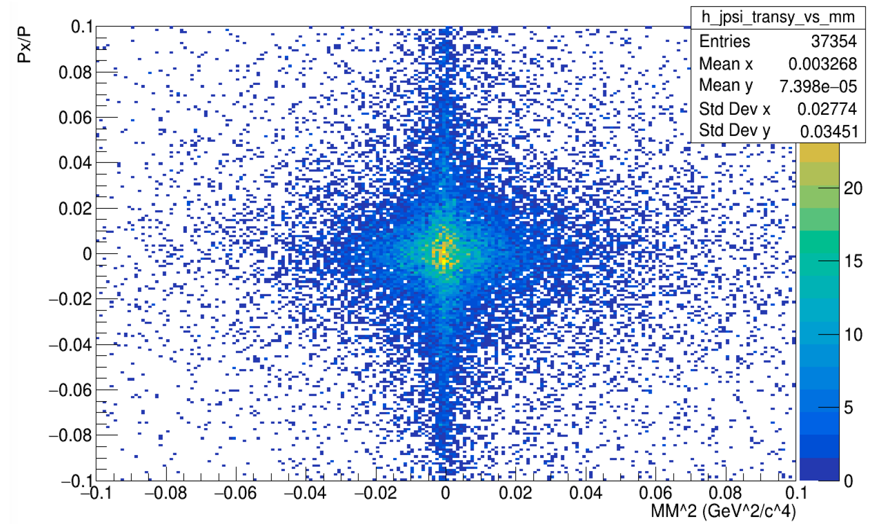


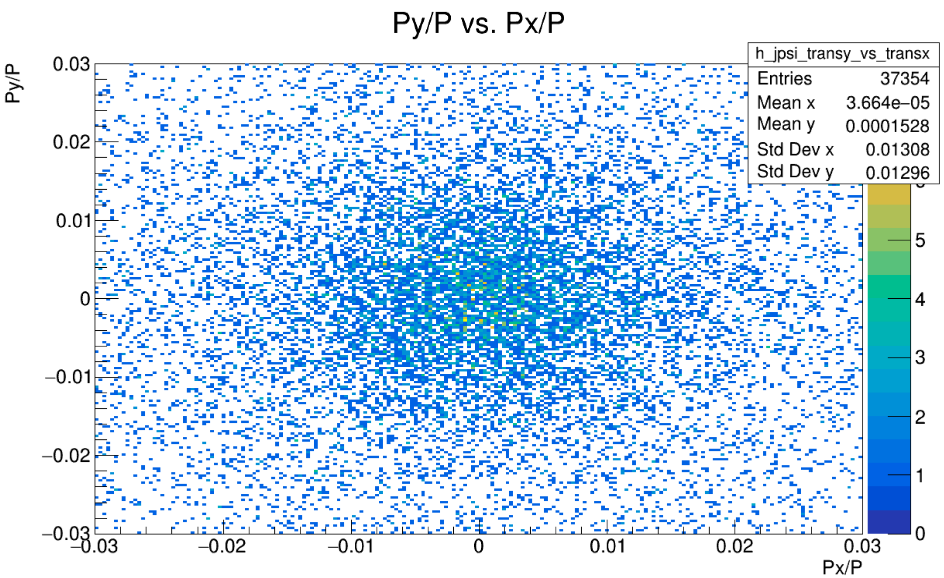
Square of the Missing Mass For Un-Detected Scattered Electron

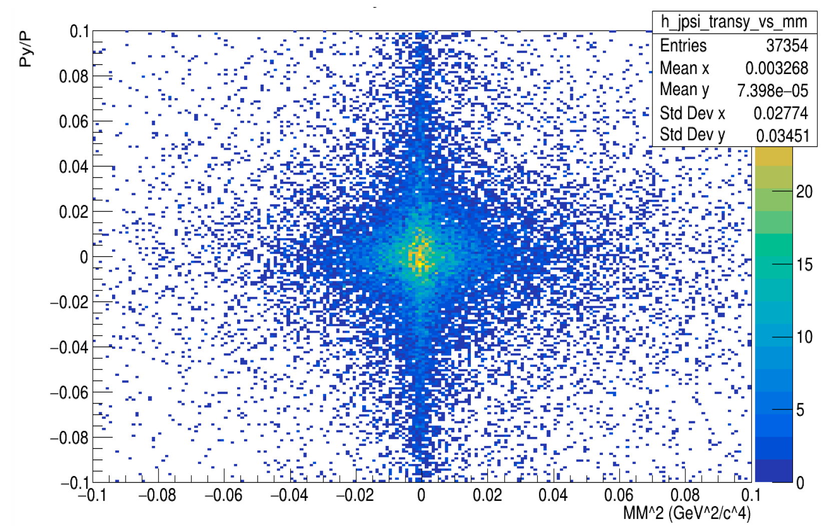


Exclusivity Variable Correlations

These 2D profiles of combinations of the exclusive variables indicate minimal correlation, showing that they can be independently used to constrain quasi-real photoproduction events

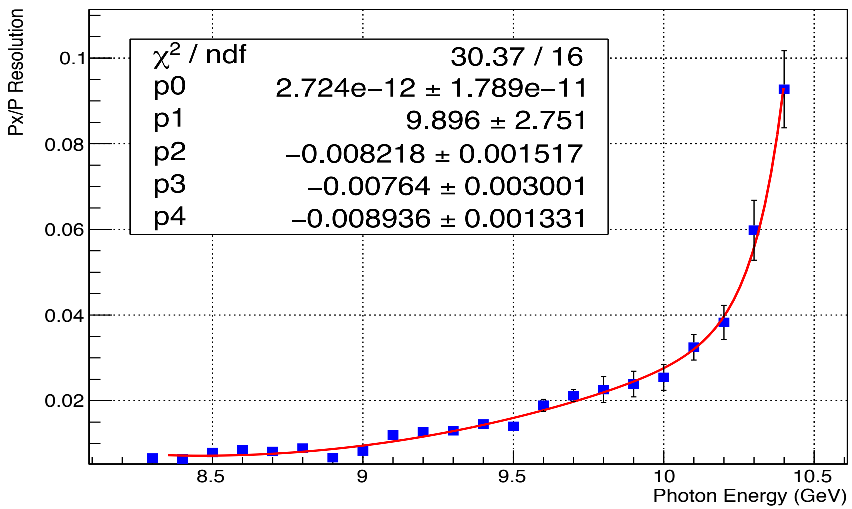


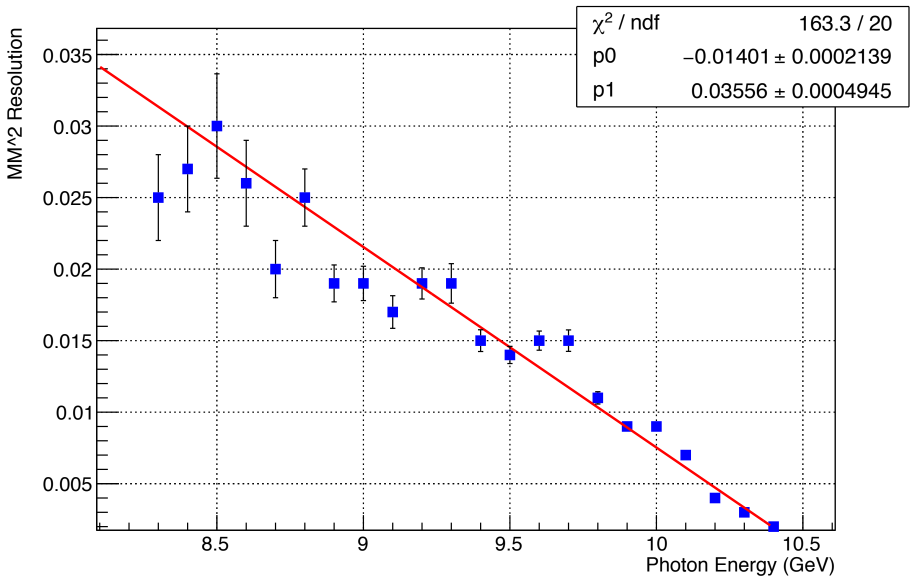


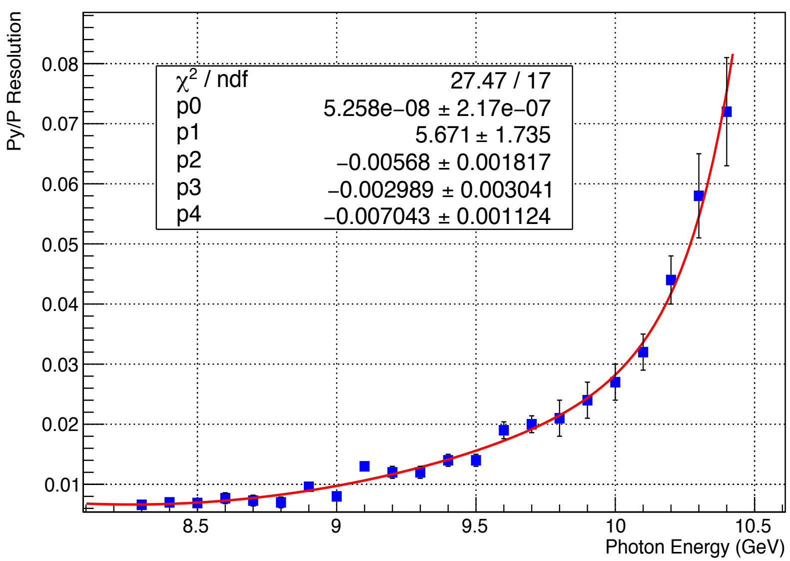


Exclusivity Variable Parametrizations

Using MC, the widths of the exclusive variable distributions were studied in bins of photon energy. Such parametrizations can help reduce background by keeping the cuts tight at lower photon energies & higher photon energies depending on which variable is being analyzed.

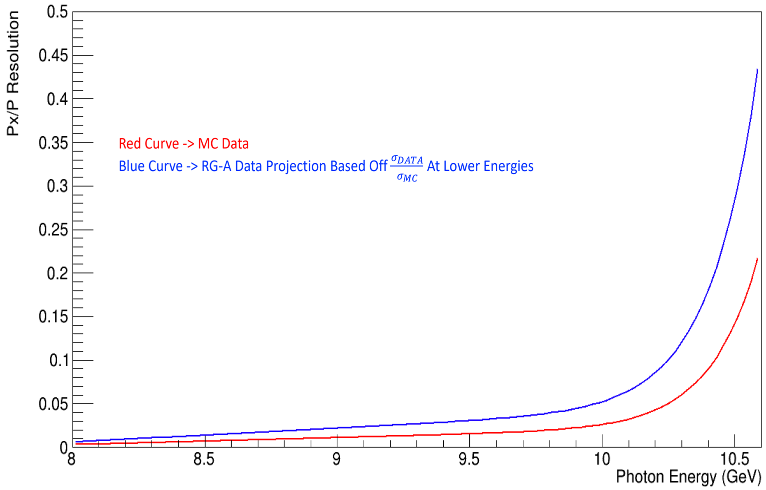


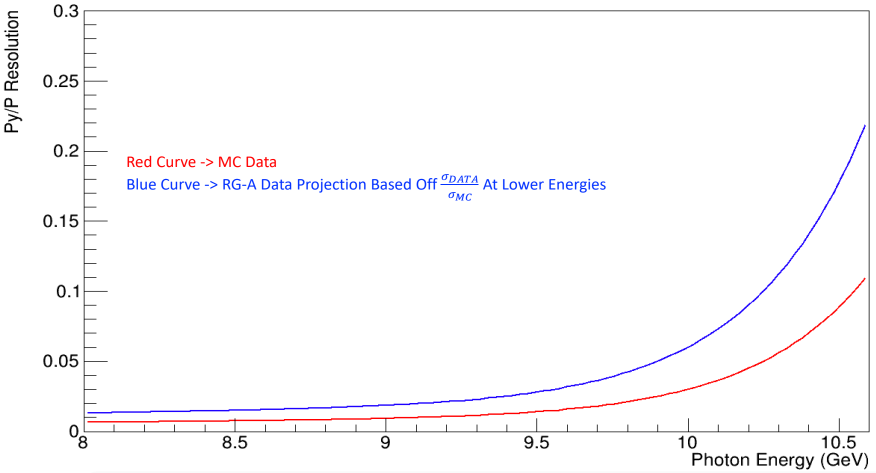


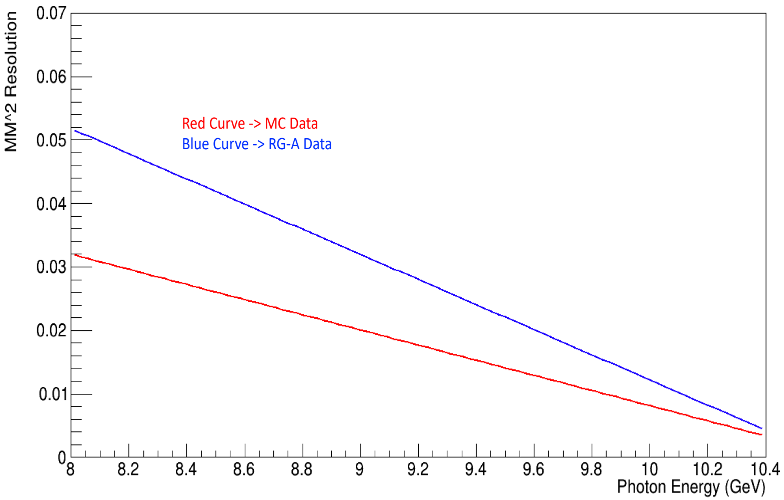


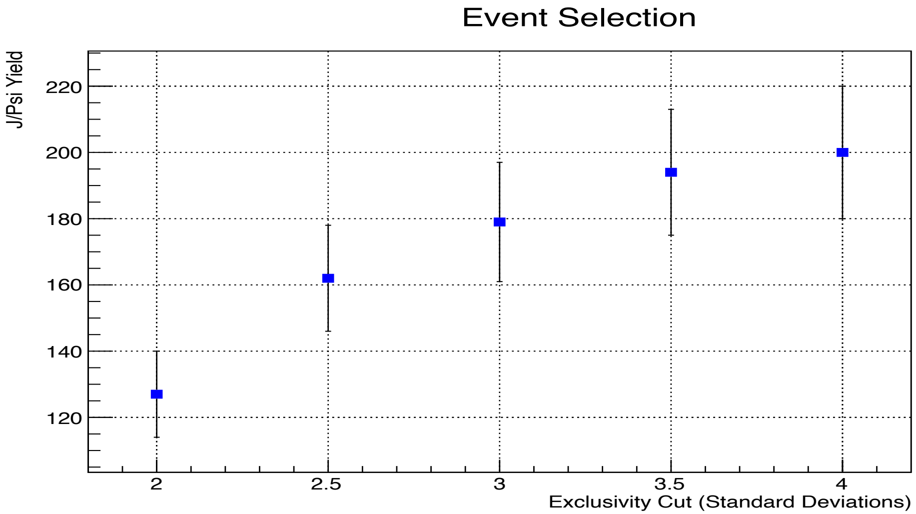
Event Selection Observations In RG-A Data

The difference in the exclusive variable width was studied in RG-A events using events which pass the photon energy threshold and by applying cuts to un-correlated exclusive variables. A scale factor to the MC parametrization was applied. MC & RG-A data have their own set of cuts.



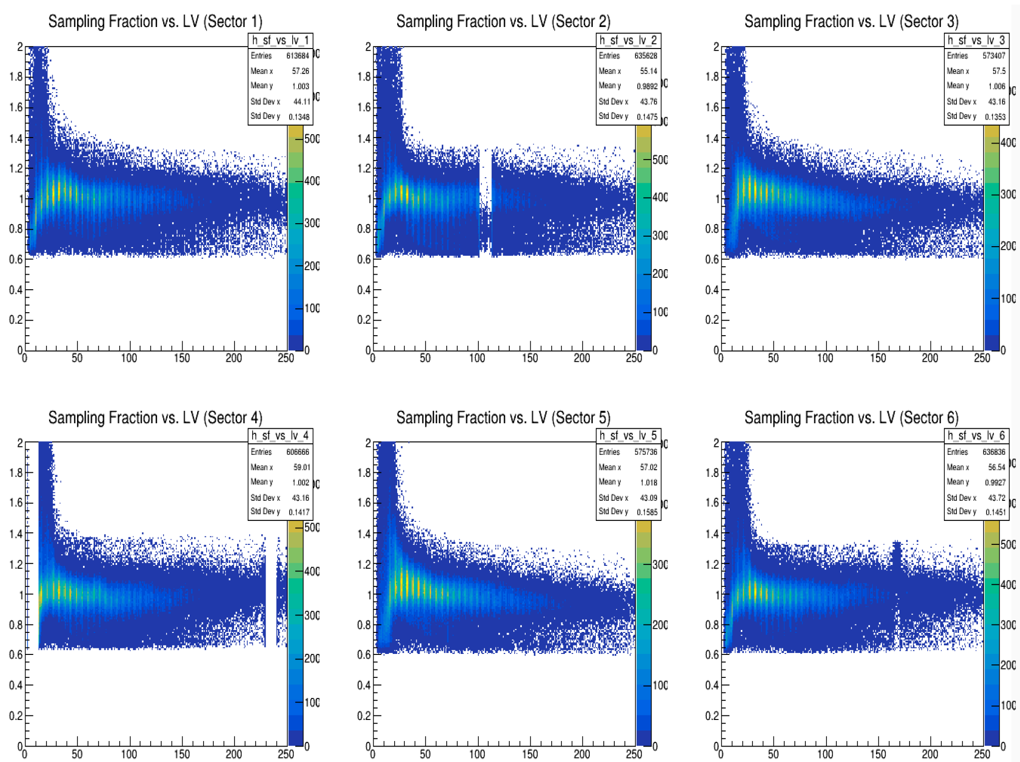


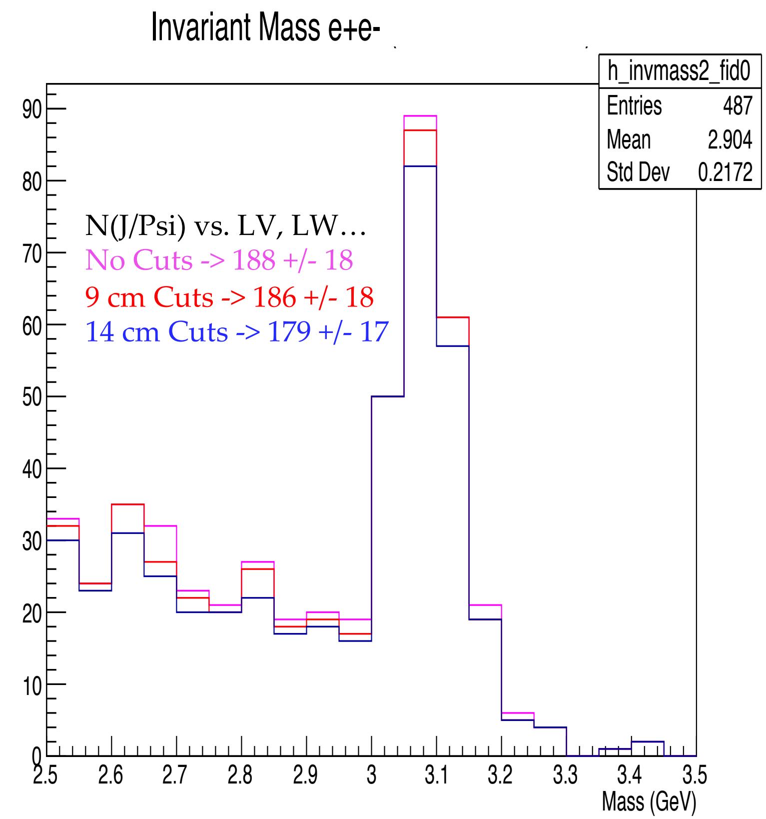




Fiducial Volume Strategy

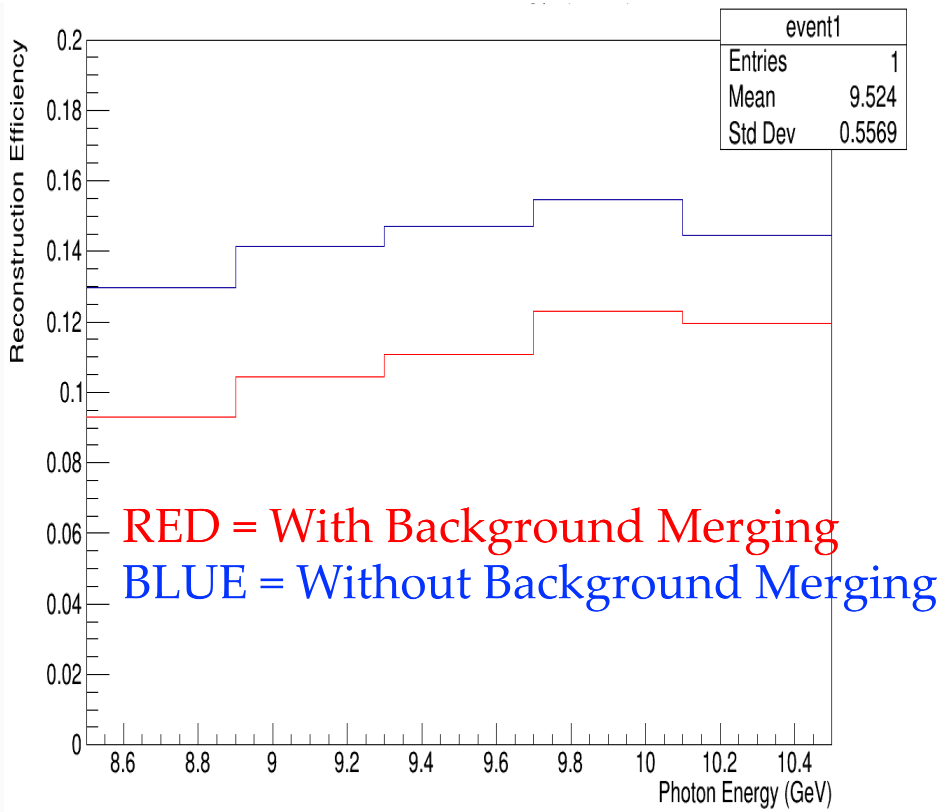
- Fiducial cuts will be applied to regions of PCAL.
- This strategy follows the procedure discussed in the Deep Process Working Group that will be standardized for the RG-A common analyses.
- The cuts used are: PCAL LV > 14 cm & PCAL LW > 14 cm.
- Fiducial cuts may possibly be added to DC for protons; however, systematic studies will be needed to determine effect on J/Psi yield due to proton efficiency

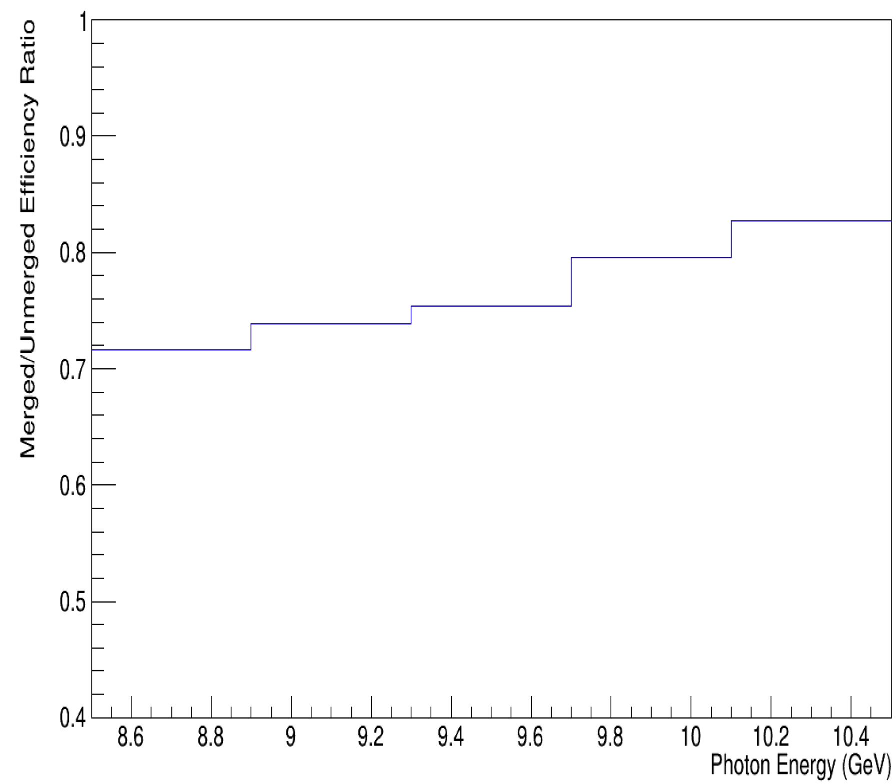




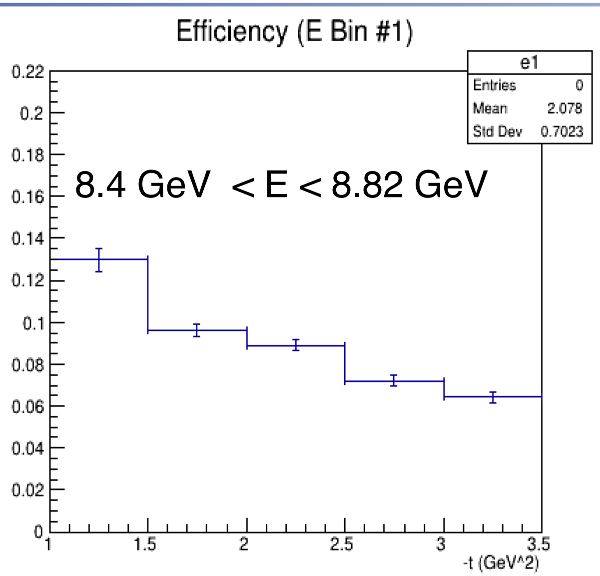
J/Psi Reconstruction Efficiency (Background Merging)

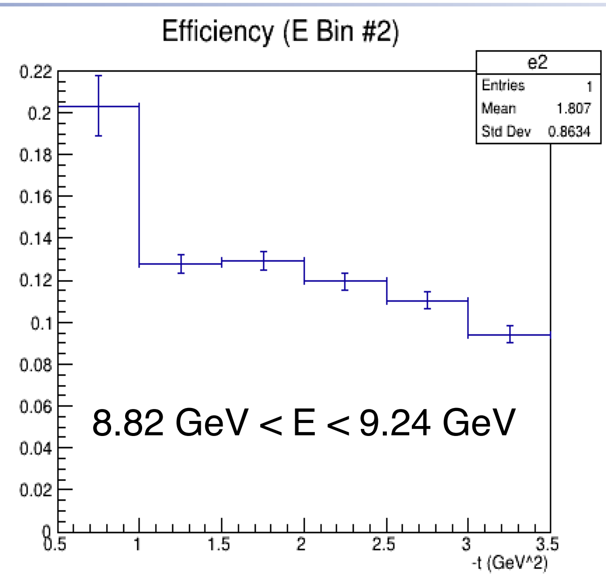
Background merging using the algorithm & GEMC version in the OSG are now utilized for studying the reconstruction efficiency, an important part of calculating cross sections

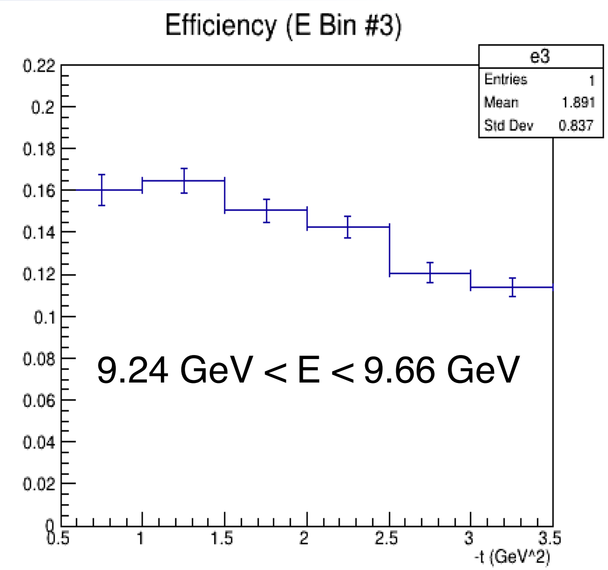


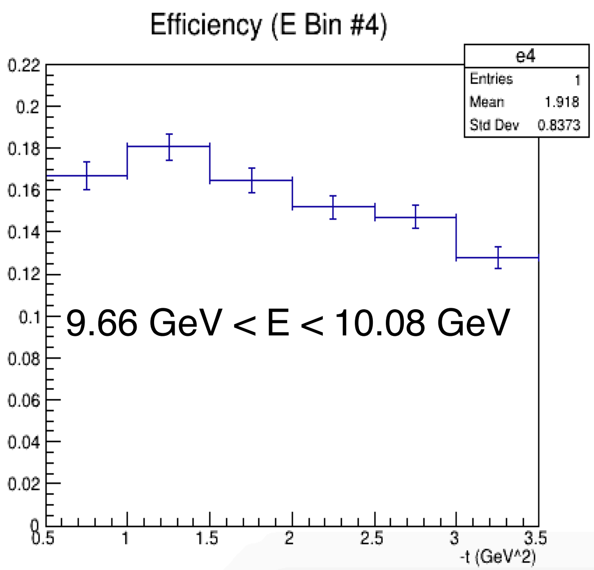


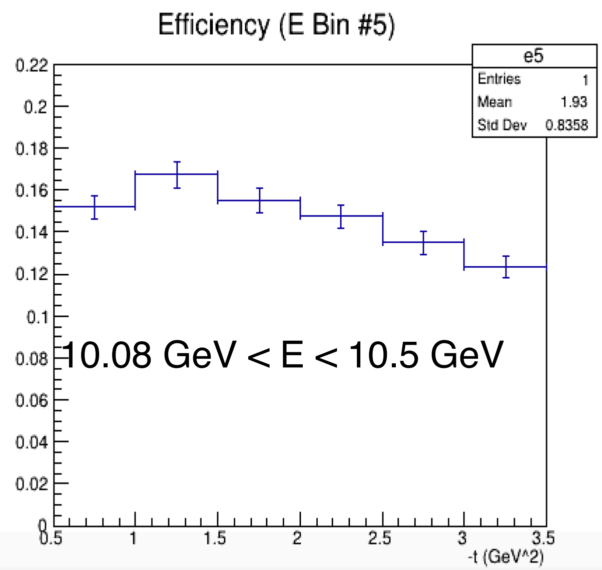
Reconstruction Efficiency (E, -t)







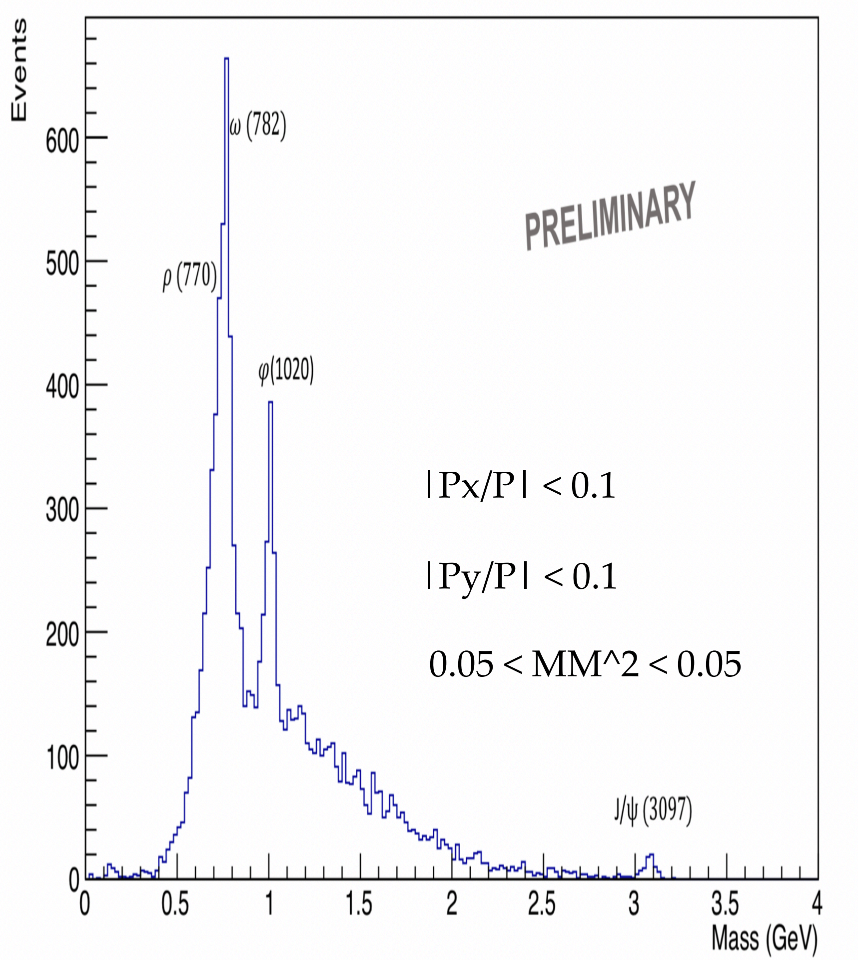


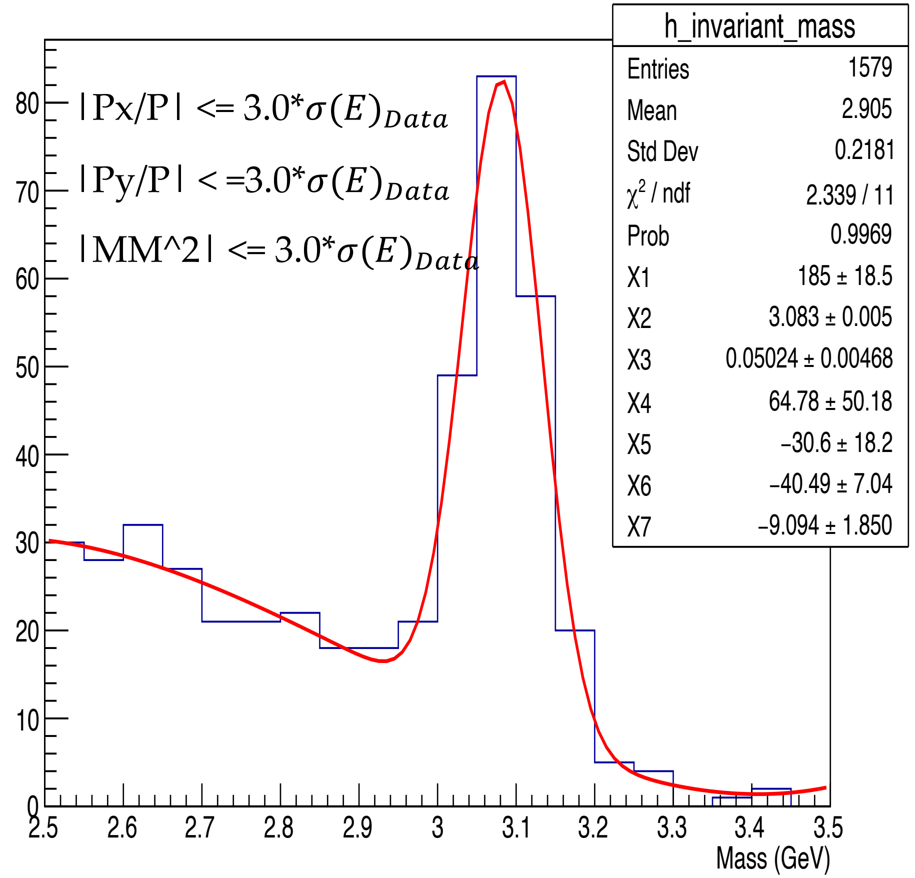


Reconstruction Efficiency (Center-Of-Mass Angle)

Studying the reconstruction efficiency as a function of the center-of-mass angles is an important part of the forward-backward asymmetry measurement

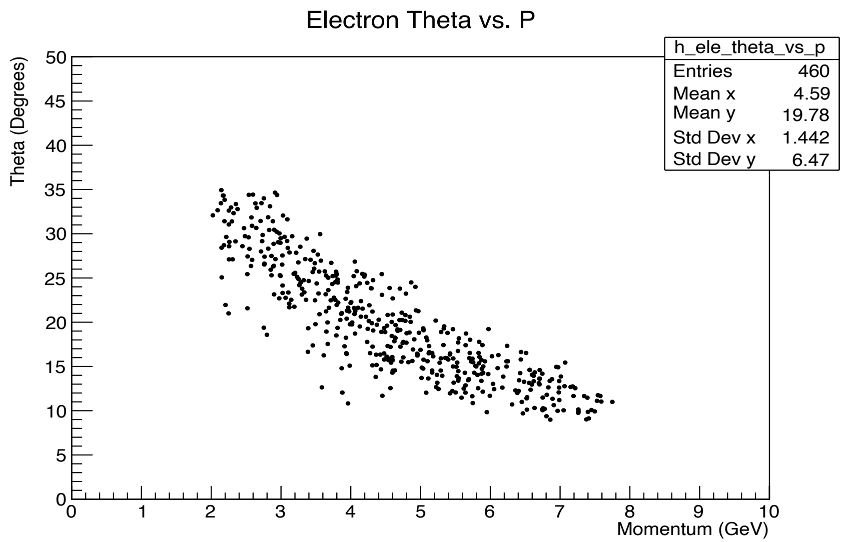
Invariant Mass (Runs 5032-5419)

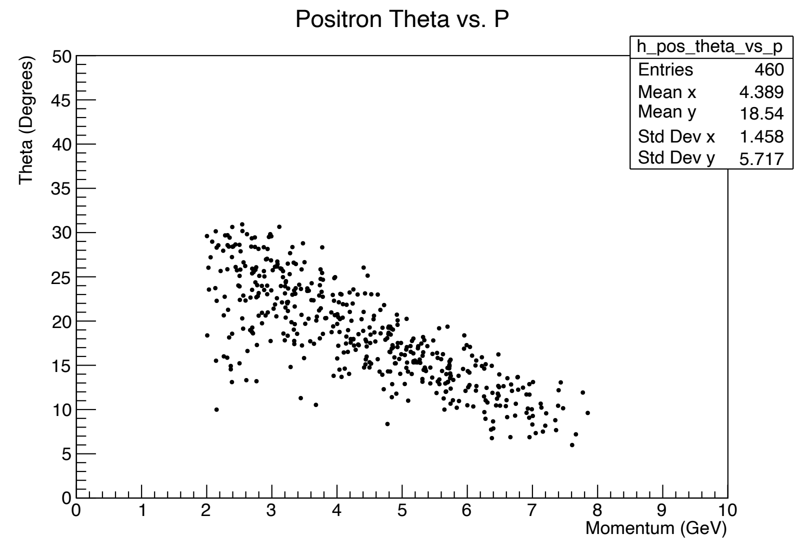


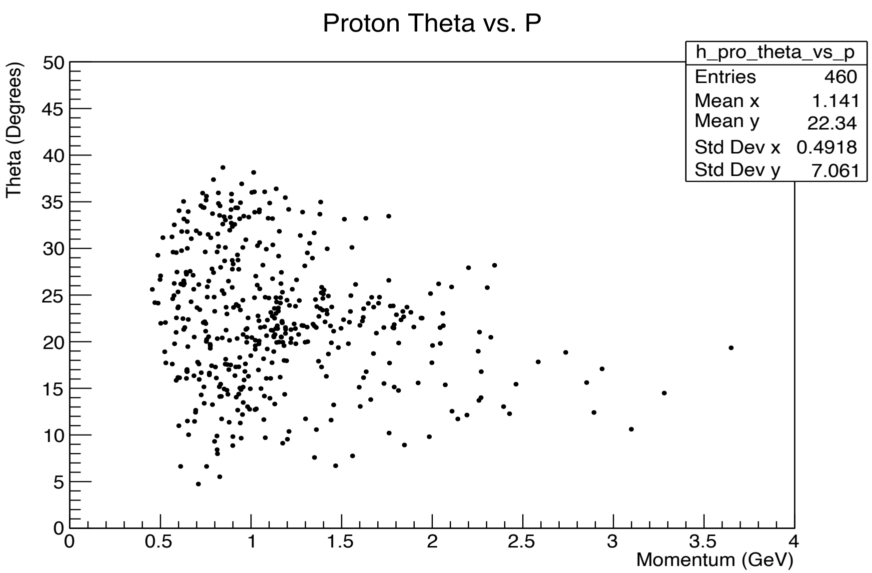


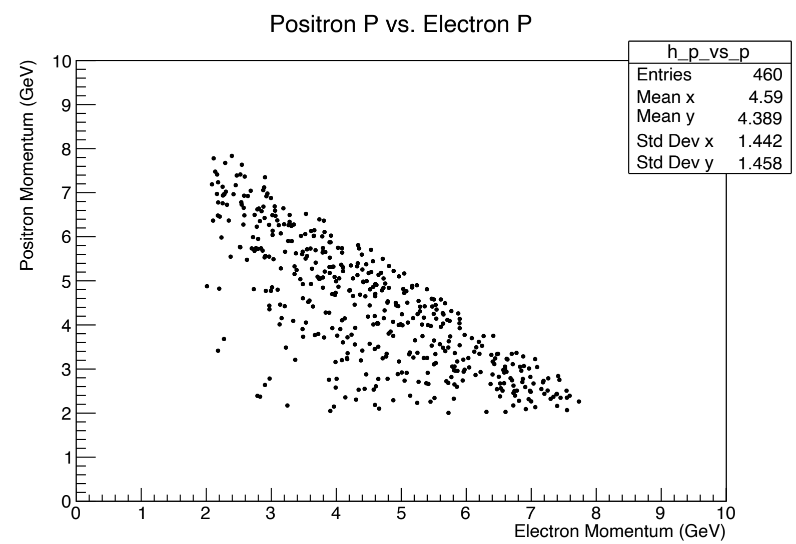
Note: These two distributions do not have the same exclusivity cuts and momentum cuts. The cuts for the full spectrum are tighter just to highlight the lower mass vector mesons.

Kinematics Of Final-State Particles (In-Bending Fall 2018 Dataset)

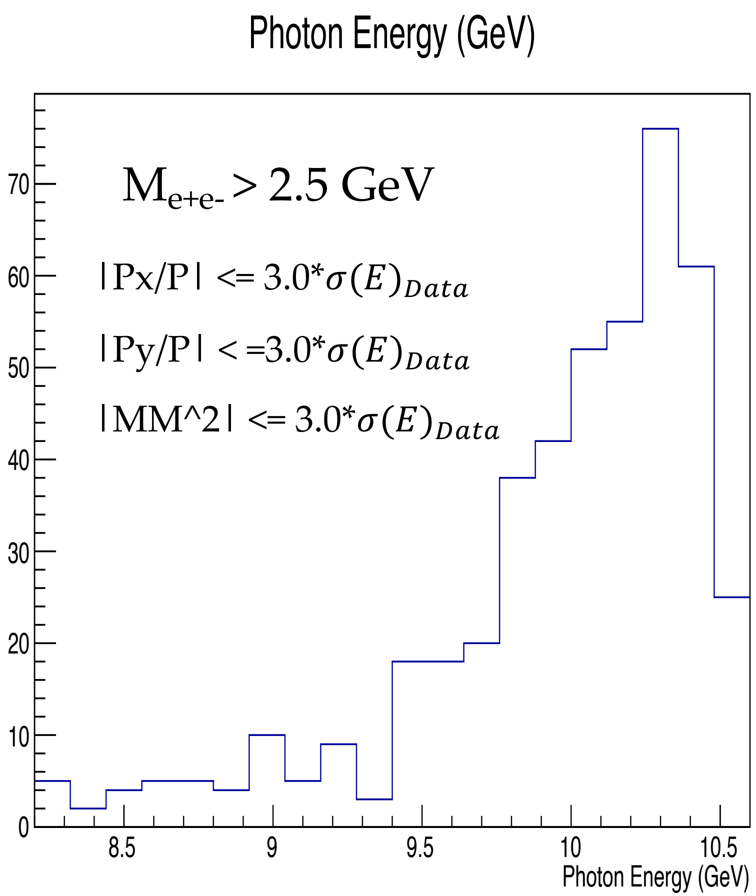


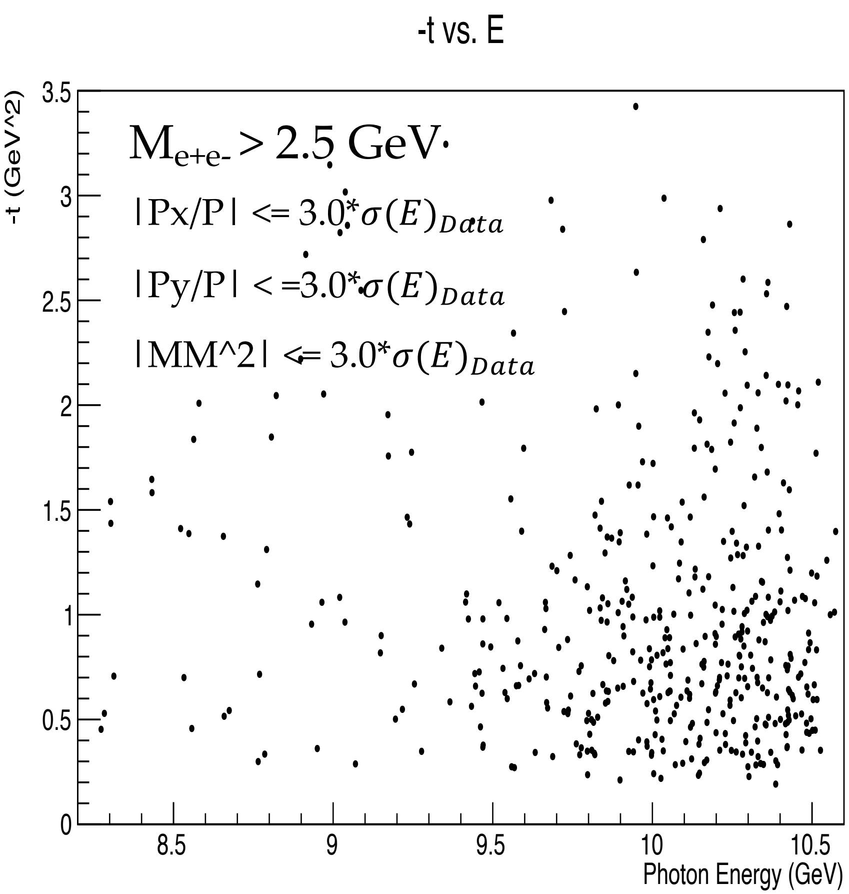






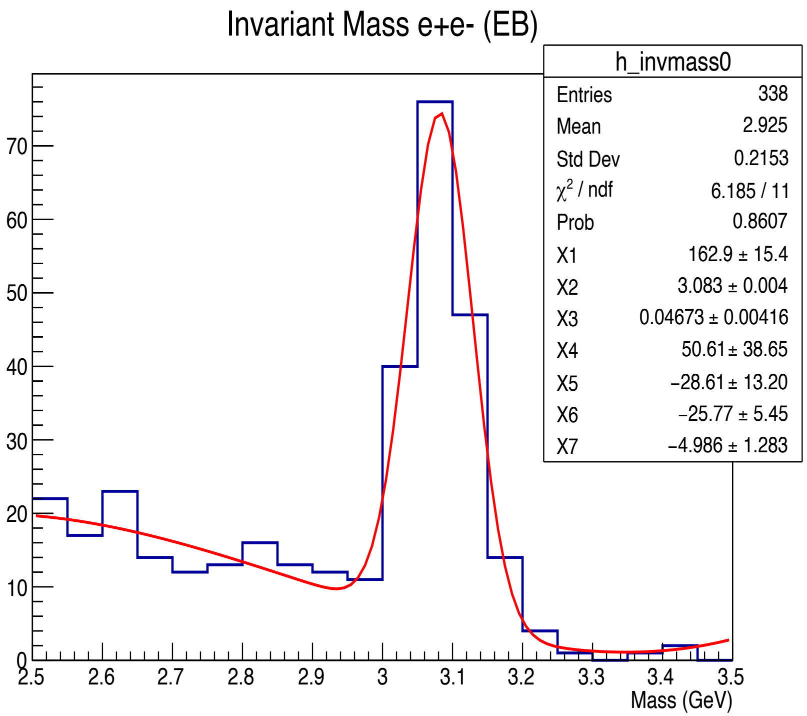
Kinematic Variables (In-Bending Fall 2018 Dataset)

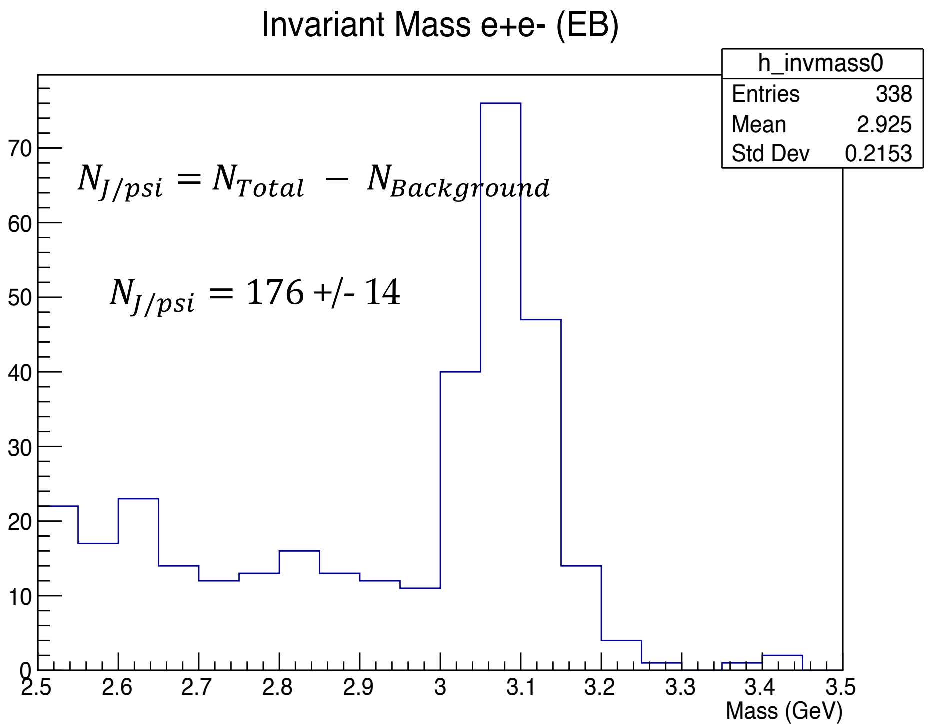




Systematic Effect Of J/Psi Yield Calculation For Individual (E, -t) Bins

Two methods of extracting J/Psi yield were compared. On the left is a simple Gaussian fit above a 3rd order background. On the right, MC Bethe-Heitler was utilized to estimate the number of background events, from 2.5 GeV and 3.2 GeV, based on the number of events between 2.5 GeV and 2.9 GeV. The difference between the total number of events and the number of estimated background events is the presumed number of J/Psi's.

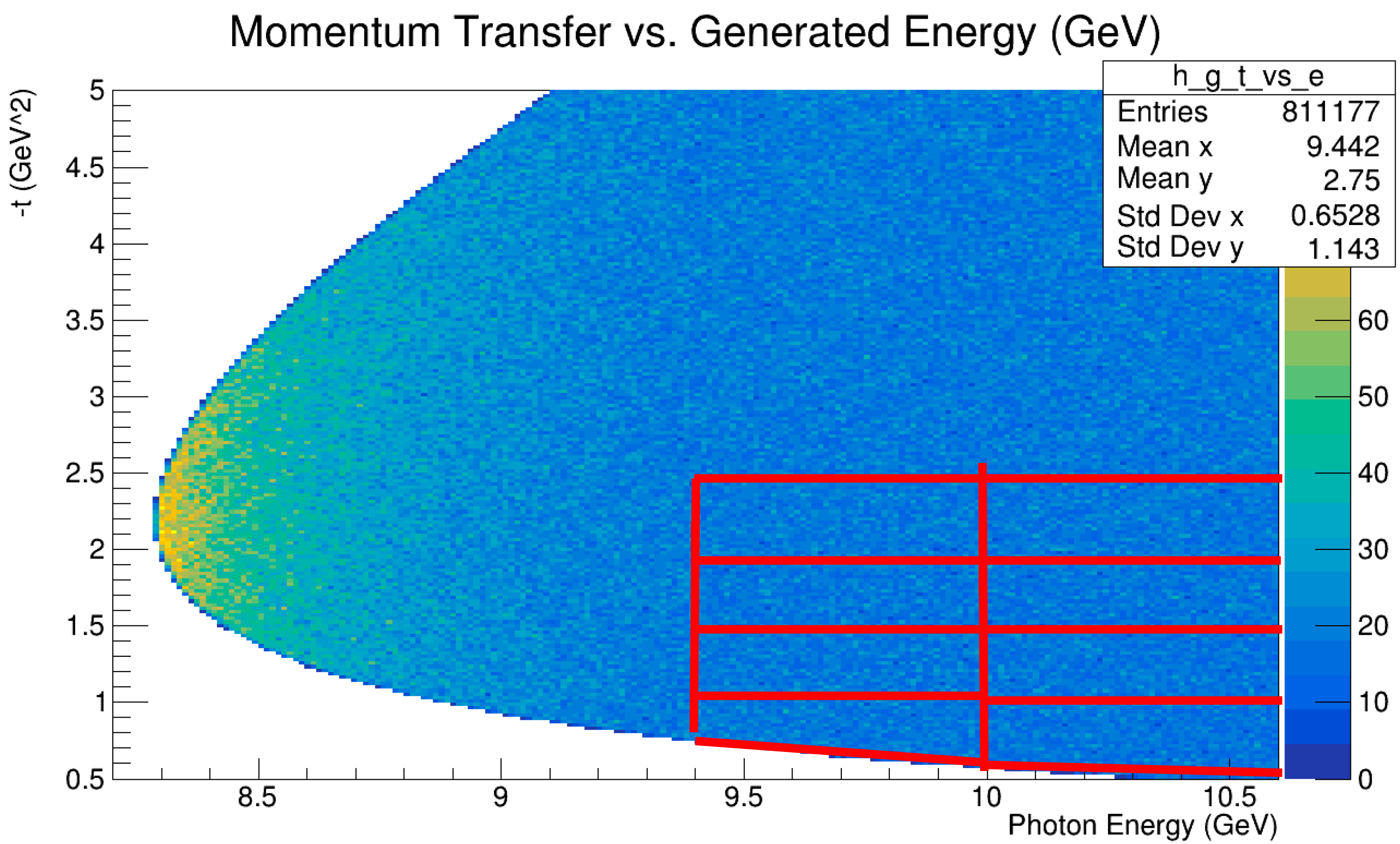




With higher statistics, there is an ~8% difference in the results for the two calculations

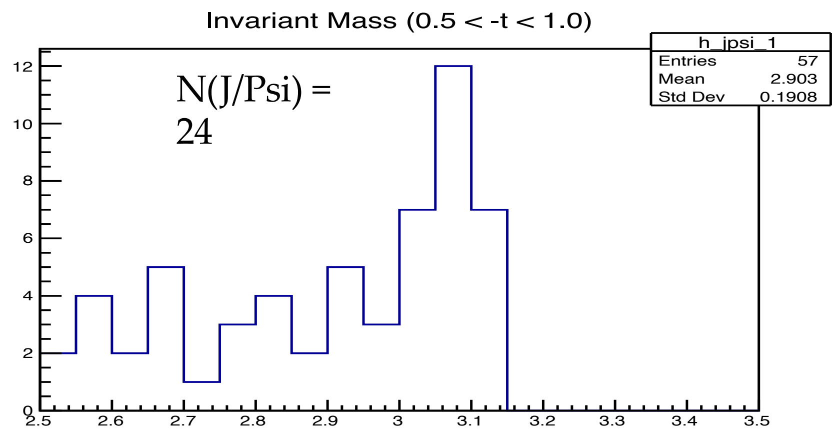
J/Psi Photoproduction Phase Space

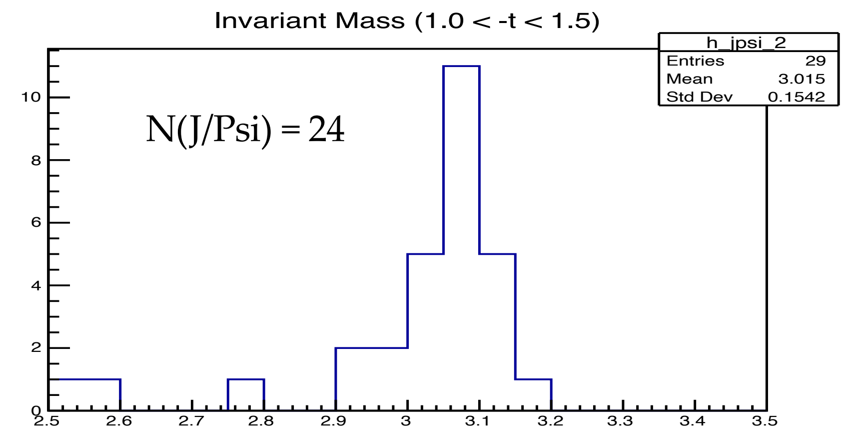
For the study of the method discussed in the previous slide, select bins were focused on. These bins were optimal due to limitations in statistics from this dataset (Runs 5032 – 5419). Notice the boundaries from the minimum –t and the maximum –t as a function of photon energy. With the addition of Spring 2019, the lower energies near threshold will be analyzed.

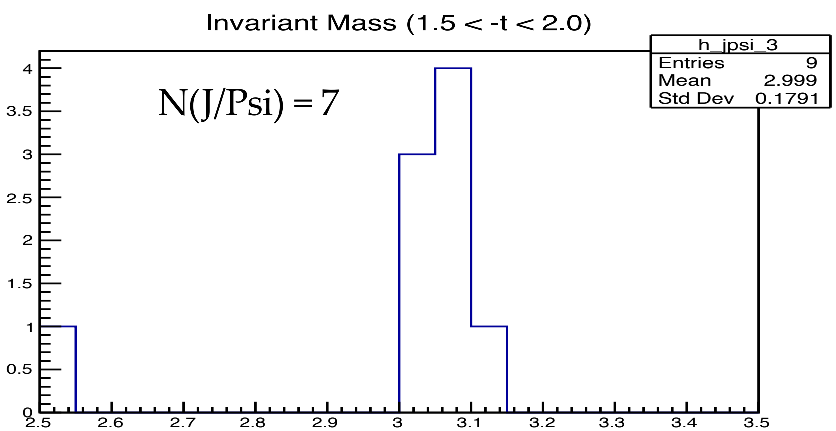


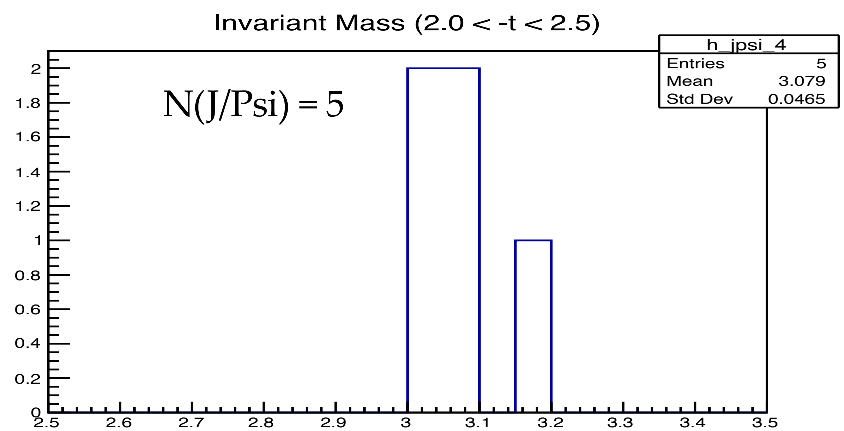
Calculating N(J/Psi) For 9.4 GeV < E < 10.0 GeV

These distributions represent wide (E, -t) bins from Runs 5032 to 5419. This represents a fraction of the in-bending Fall 2018 dataset. Higher statistics are needed for more conclusive results.



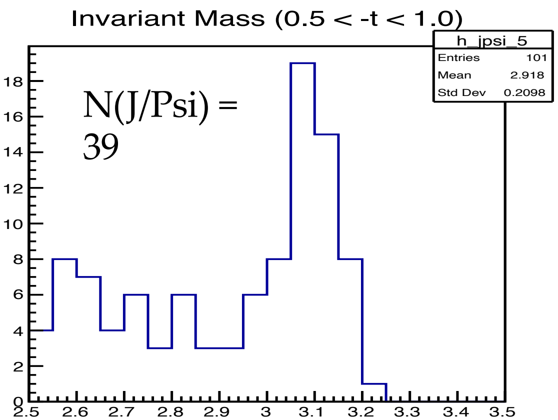


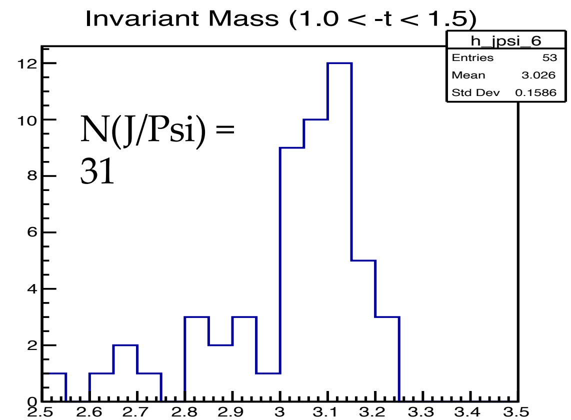


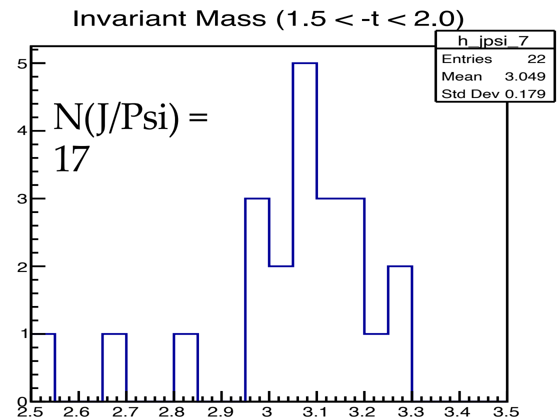


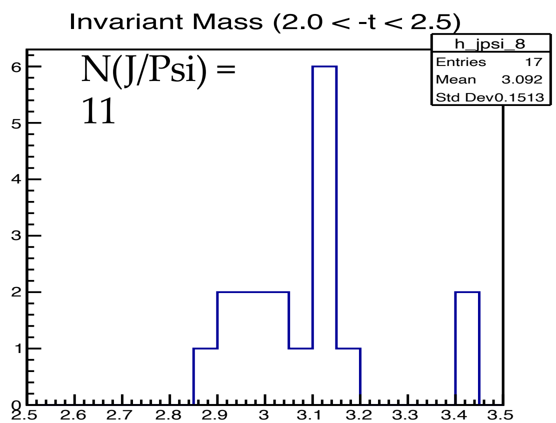
Calculating N(J/Psi) For 10.0 Ge V< E < 10.6 GeV

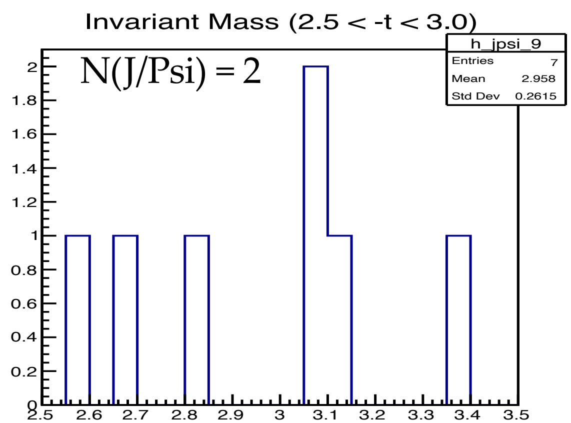
These distributions represent wide (E, -t) bins from Runs 5032 to 5419. This represents a fraction of the in-bending Fall 2018 dataset. Higher statistics are needed for more conclusive results.







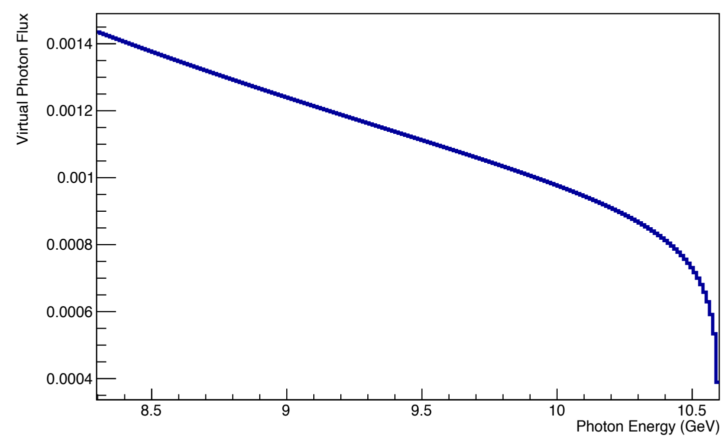




Calculating Differential Cross Section In Data

- Extract # of J/Psi's For Each Bin
- Correct For Efficiency & Photon Flux (Sum of Virtual & Real)
- Multiply Constants: Integrated Luminosity, Branching Ratio, and $\Delta E \Delta t$
- Normalize To Bethe-Heitler (*Work In Progress To Validate MC*)

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



Accumulated Charge = 45 mC
Proton Density in Liquid Hydrogen = 4.27 * 10^{22} Protons/cm^3
Target Length = 5 cm
Elementary Charge = 1.6 * 10^{-19} C

$$L_{INT} = \frac{Q_{Acc}\rho_{H2}l_{target}}{e}$$

CONSTANTS

$$Br_{J/Psi} = 0.06$$

$$\Delta E \Delta t$$

NON-CONSTANTS

$$\Gamma(E_\gamma) = \frac{1}{E_b}\frac{\alpha}{\pi \cdot x} \cdot \left((1 - x + \frac{x^2}{2}) \cdot log(\frac{Q^2_{max}}{Q^2_{min}}) - (1-x)\right) dE$$

Virtual Photon Flux

$$n(E_\gamma) = \frac{l}{2 \cdot X_0}\frac{1}{E_\gamma} \cdot \left(\frac{4}{3} - \frac{4}{3}\frac{E_\gamma}{E_b} + \frac{E_\gamma^2}{E_b^2}\right) dE$$

Real Photon Flux

$\eta(E_\gamma, -t)$ for in-bending and out-bending

Next Steps

- Analysis framework is well-advanced (particle identification, momentum corrections, fiducial cuts, & quasi-real photoproduction selection)
- Validation of Bethe-Heitler MC is important for normalization for the differential cross section calculation
- Background merging is being used for all MC analysis
- Analysis note is being written
- The addition of the Spring 2019 RG-A dataset will give the statistics necessary for preliminary production mechanism cross section & forward-backward asymmetry results
- The $\mu^+\mu^-$ final state is being studied (Richard Tyson)