J/ψ Photoproduction Near Threshold With CLAS12

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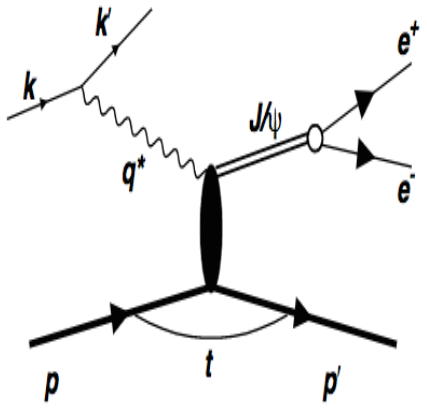
Experiment Overview

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

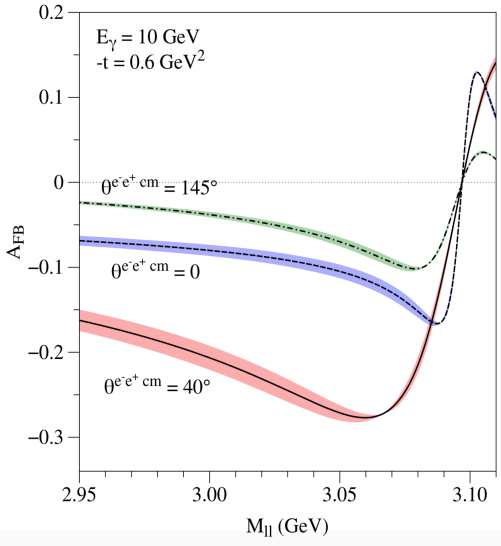
- Experiment 12-12-001 was approved for 120 days of beamtime on CLAS12 at a luminosity of 10^{35} cm^{-2} s^{-1}

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

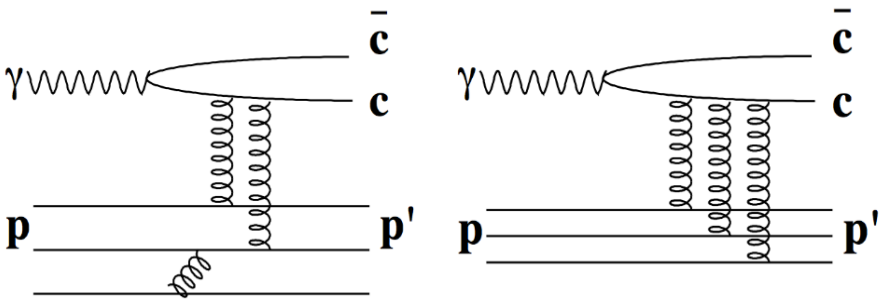
- Study the forward-backward asymmetry to access the real part of the Compton scattering amplitude



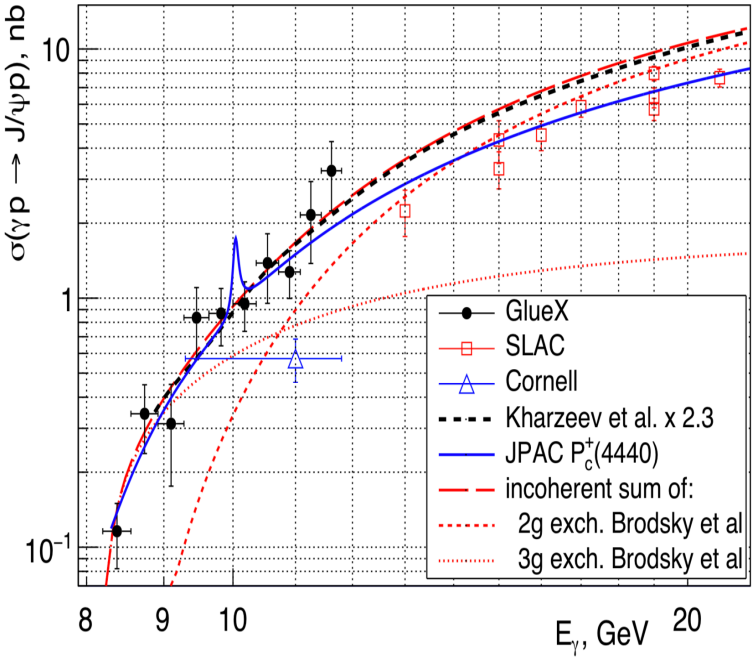
*O. Gryniuk, and M. Vanderhaeghen. Phys. Rev. Lett. (2016)

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



Available Experimental Results



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

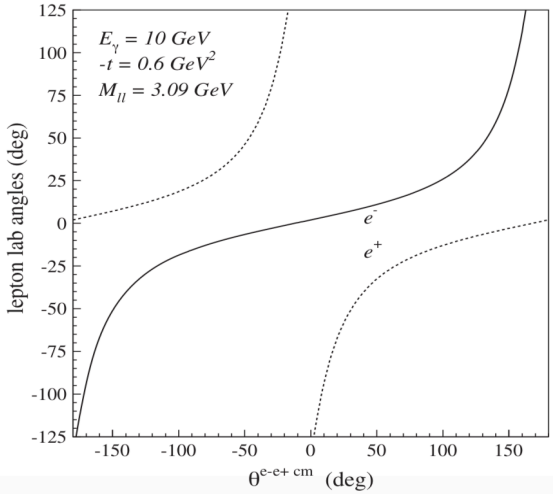
$$\frac{d\sigma}{dt} = N_{3g}\frac{(1-x)^0}{R^4M^4}F_{3g}^2(t)(s-m_p^2)^2$$

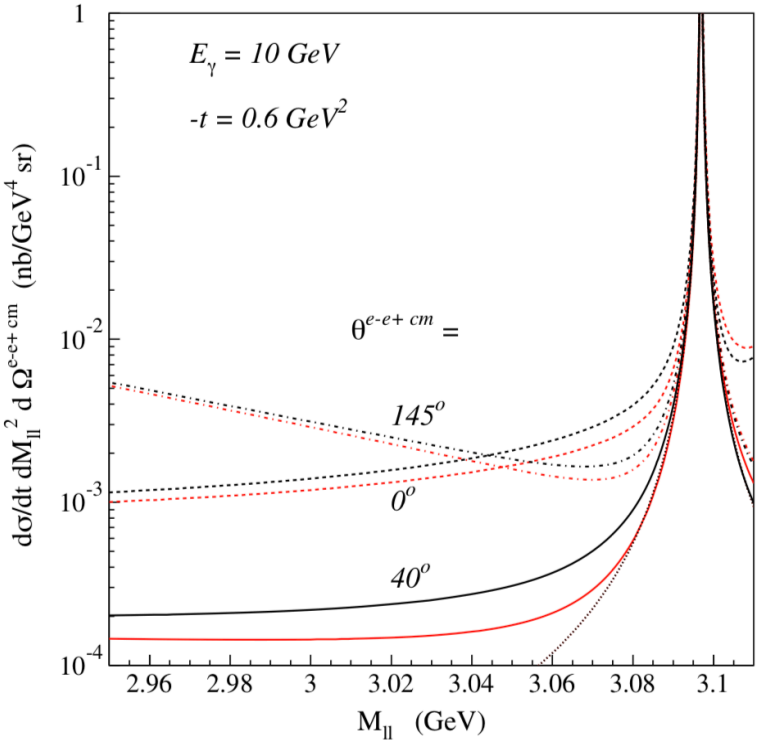
*S.J. Brodsky, E. Chudakov, P. Hoyer, and J.M. Laget. Phys. Rev. Lett. (2008)
*A Ali. et al (GlueX Collaboration). Phys. Rev. Lett. (2019)
*CLAS12 Collaboration, "Timelike Compton Scattering and J/ψ Photoproduction on the Proton in e+e- Pair Production with CLAS12 at 11 GeV", Thomas Jefferson National Accelerator Facility PAC 39 Proposal, (May 2012).

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

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

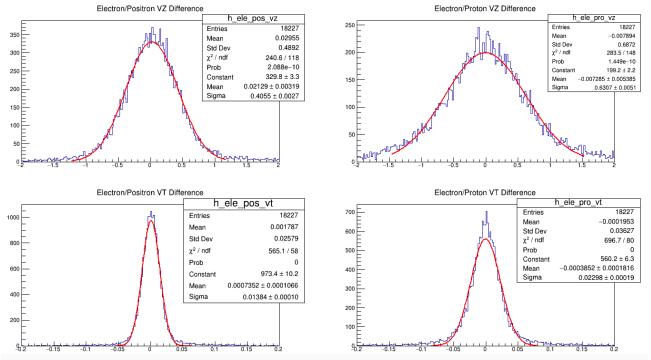




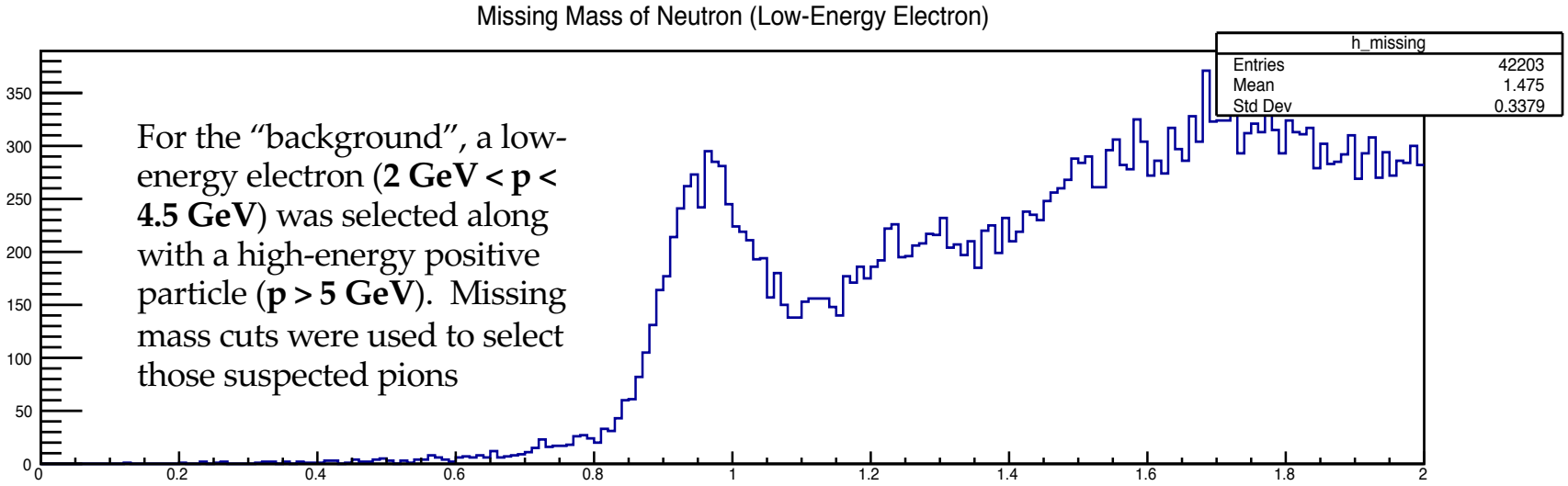
*O. Gryniuk, and M. Vanderhaeghen. Phys. Rev. Lett. (2016)

CLAS12 Forward Detector Particle ID Strategy

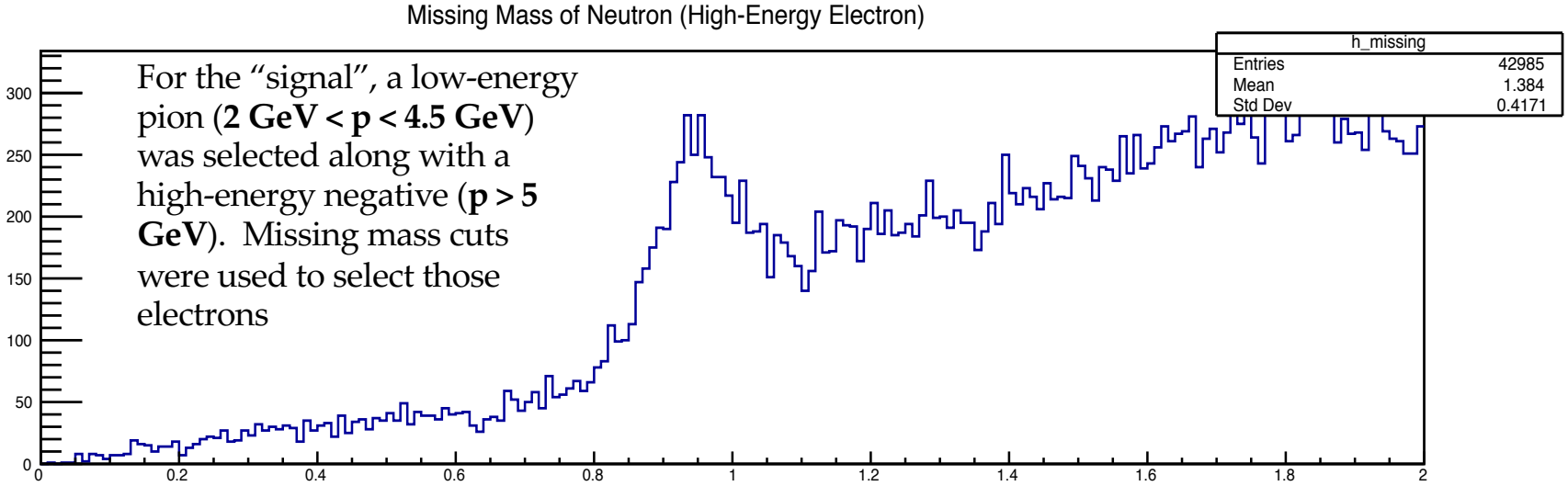
- For e^+e^- detection with p < 5 GeV….
  - Use REC::Particle.chi2pid to constrain sampling fraction's deviation to expected mean value
  - Keep the same HTCC photoelectrons (**2**) cut & PCAL minimum energy cut (**60 MeV**) from the CLAS12 event builder
- For proton detection…
  - Restrict to forward detector for J/ψ
  - Use REC::Particle.chi2pid to constrain the proton's deviation from the expected vertex time for a given FTOF timing resolution
- For e^+e^- detection with p > 5 GeV…
  - For positrons, utilize the Boosted Decision Tree output value cut (**-0.02**) from ROOT's multi-variate analysis package. The following variables are used: PCAL E/p, ECIN E/p, PCAL # of Strips, ECIN # of Strips, ECOUT # of Strips, Number of HTCC Photoelectrons from missing neutron events
  - For electrons, utilize a cut-based approach…
    - ECIN SF vs. PCAL SF diagonal cut, PCAL Strips < (**16**), ECIN Strips < **(20)**, ECOUT Strips < (**13**), PCAL M2U/DU < (**44**), ECIN M2UVW/DUVW < (**165**), ECOUT M2UVW/DUVW < **(130)**, NPHE >= (**3**)
- For e^+e^-p vertex constraints…
  - Electron-Positron VZ MC Resolution ($\boldsymbol{\sigma = 0.41\ cm}$)
  - Electron-Proton VZ MC Resolution ($\boldsymbol{\sigma = 0.63\ cm}$)
  - Electron-Positron VT MC Resolution ($\boldsymbol{\sigma = 0.0138\ ns}$)
  - Electron-Proton VT MC Resolution ($\boldsymbol{\sigma = 0.0227\ ns}$)



Developing Training Samples For Positron MVA Analysis

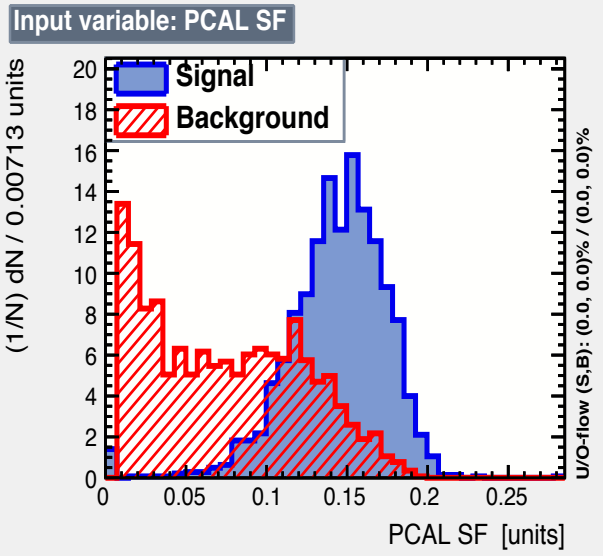


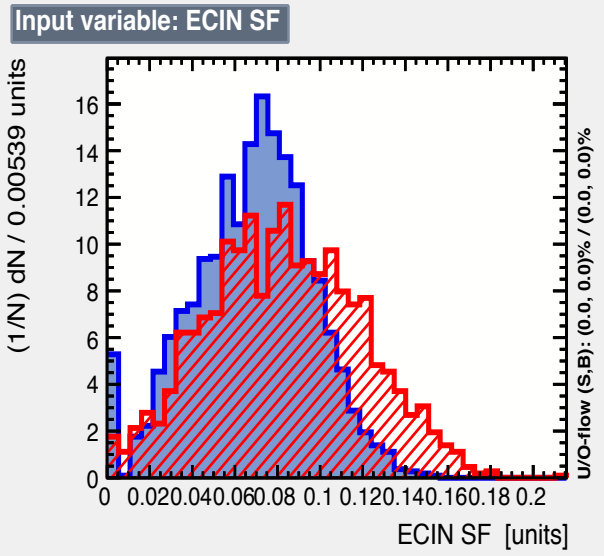
For the "background", a low-energy electron (**2 GeV < p < 4.5 GeV**) was selected along with a high-energy positive particle (**p > 5 GeV**). Missing mass cuts were used to select those suspected pions

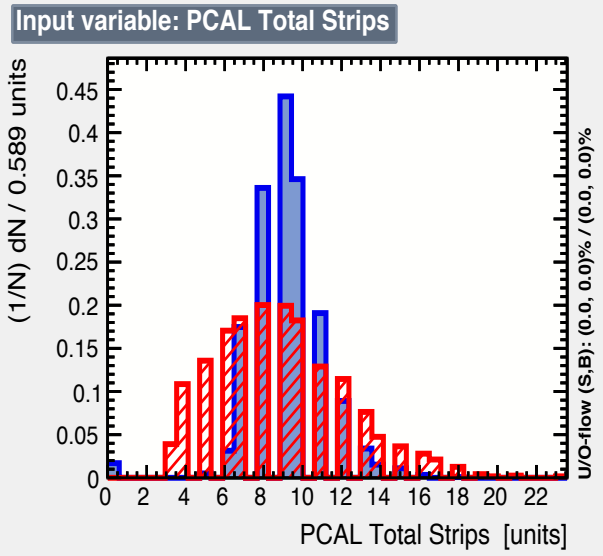


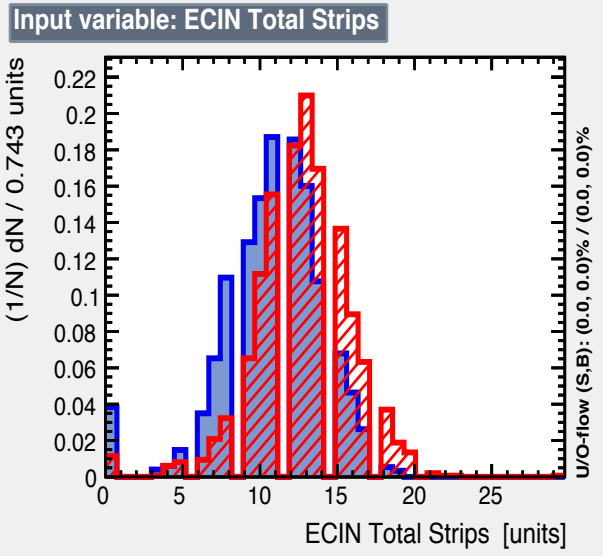
For the "signal", a low-energy pion (**2 GeV < p < 4.5 GeV**) was selected along with a high-energy negative (**p > 5 GeV**). Missing mass cuts were used to select those electrons

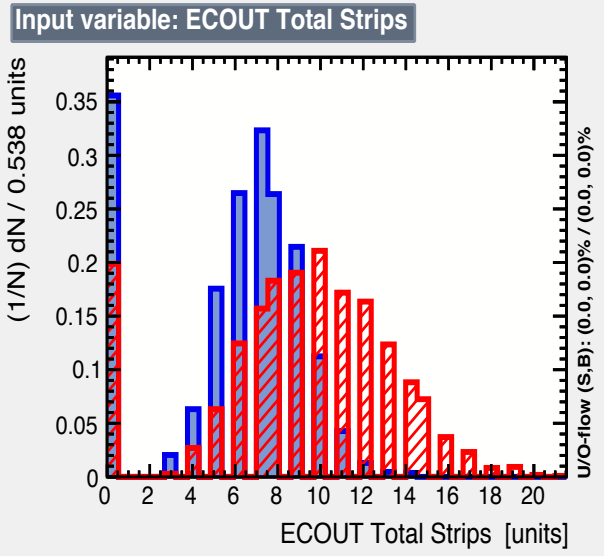
Distinguishing Signal vs. Background For Particle ID At High Momenta With A.I.

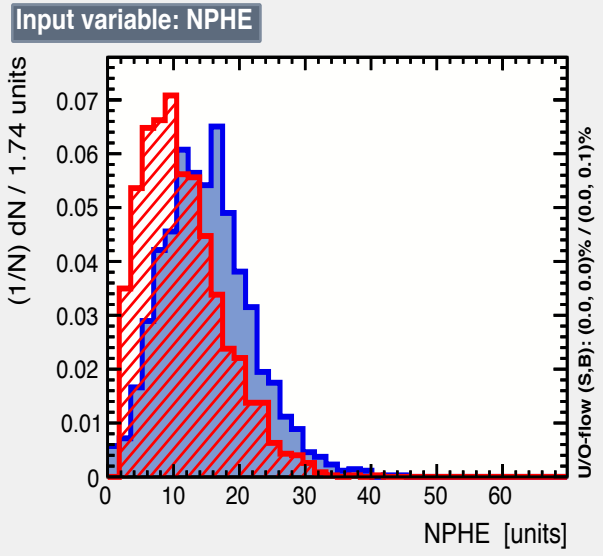




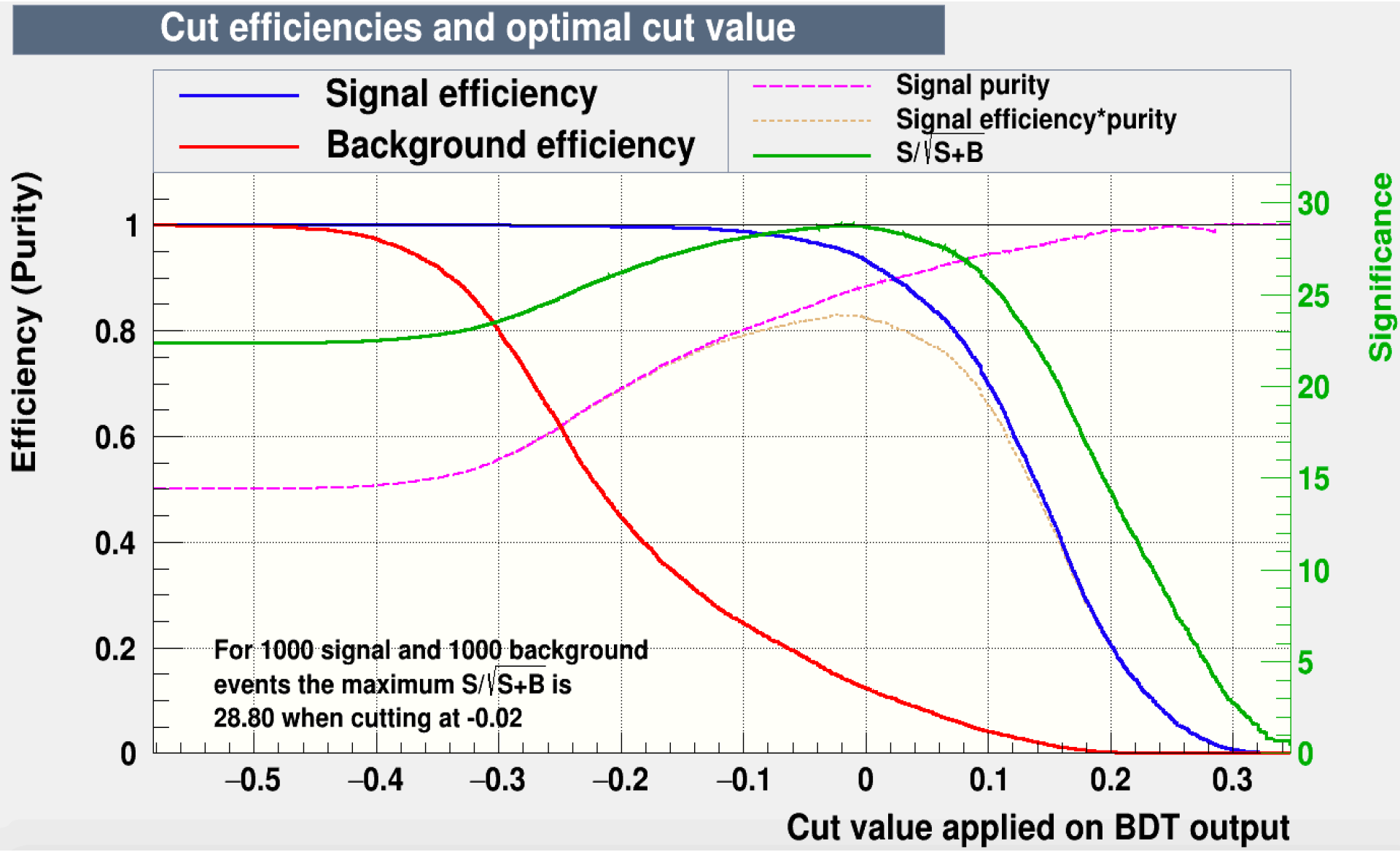




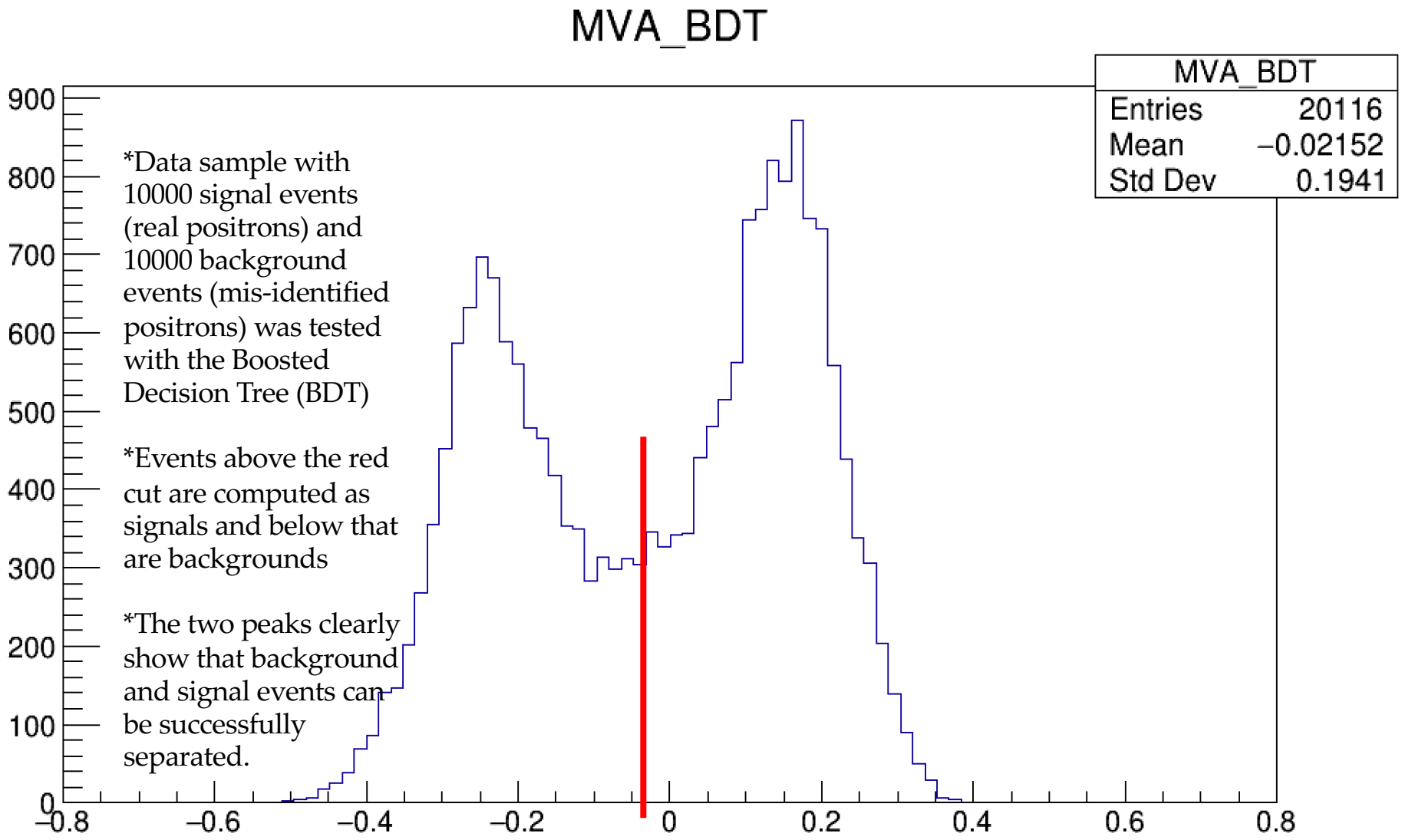




Optimal Cut Value Using The Boosted Decision Tree Machine Learning Method

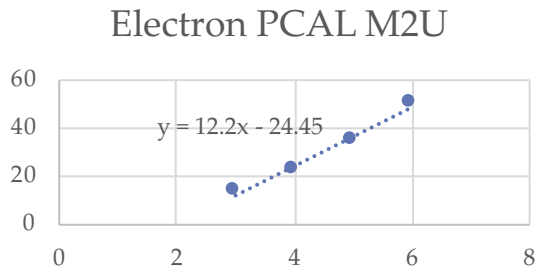


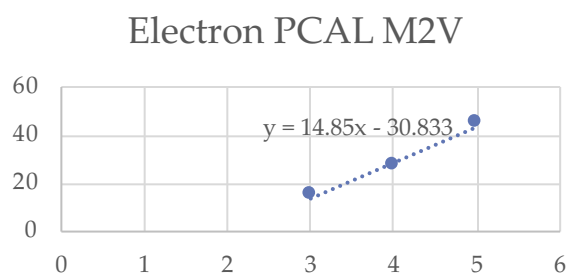
Testing the Boosted Decision Tree (BDT)

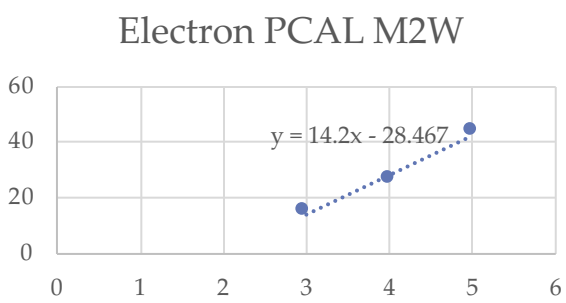


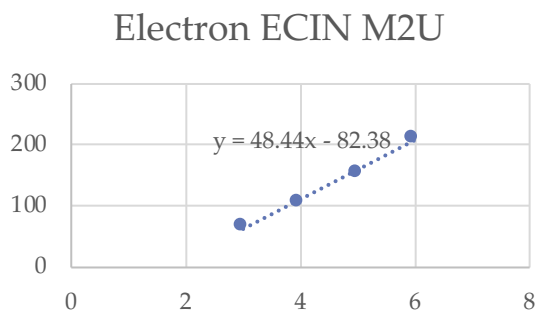
Parametrization of Electron 2nd Moments vs. Strips

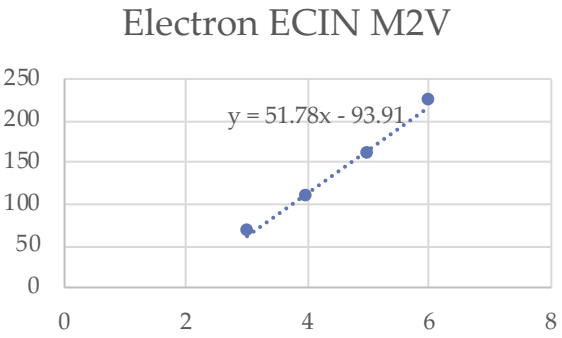
Additional cuts can be applied separately to reduce electron-pion contamination such as 2nd moments. These were not included in the MVA analysis since they are highly correlated with the # of strips and MVA becomes less effective with more input variables.

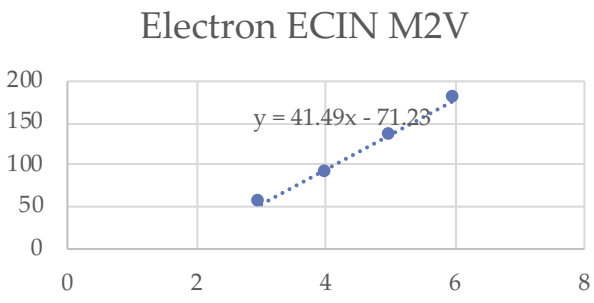


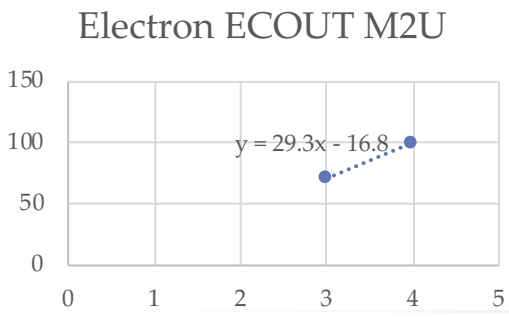


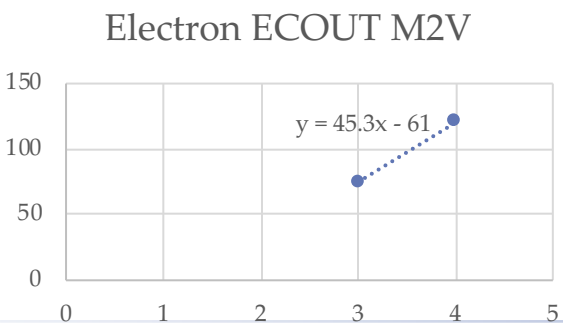


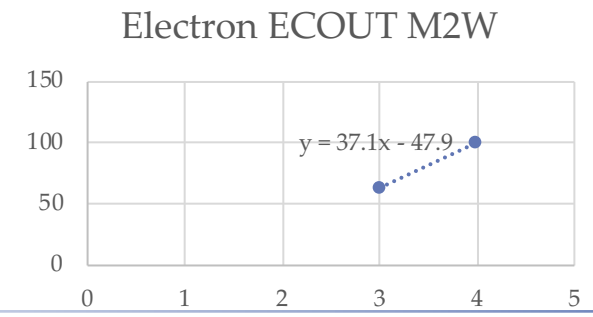




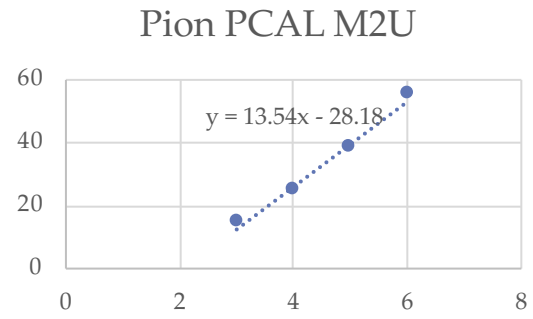


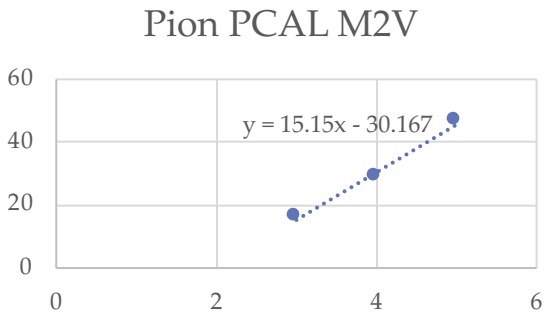


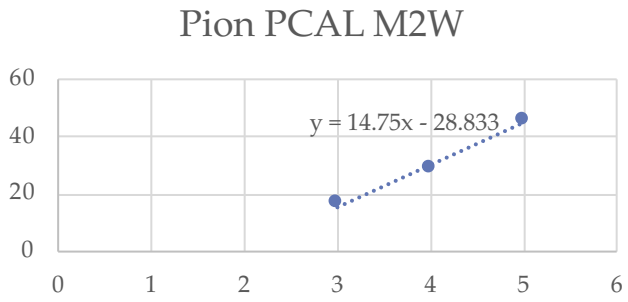


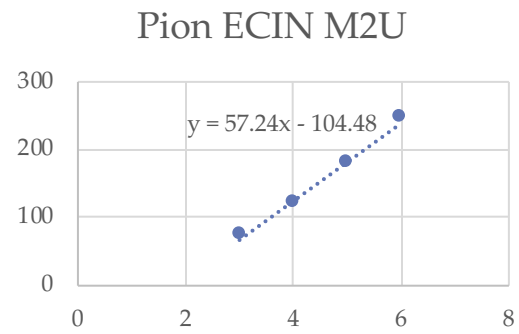


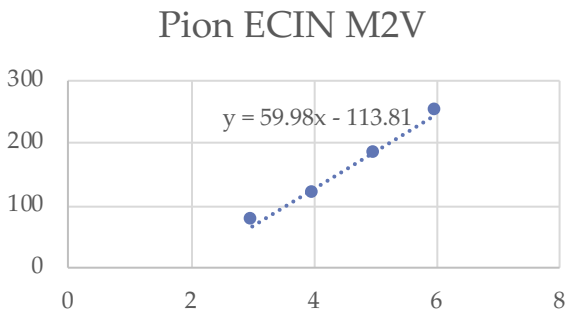
Parametrization of Pion 2nd Moments vs. Strips

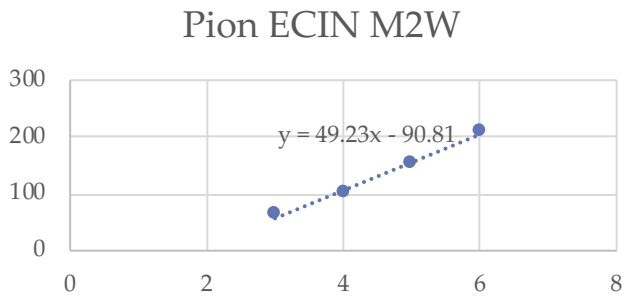


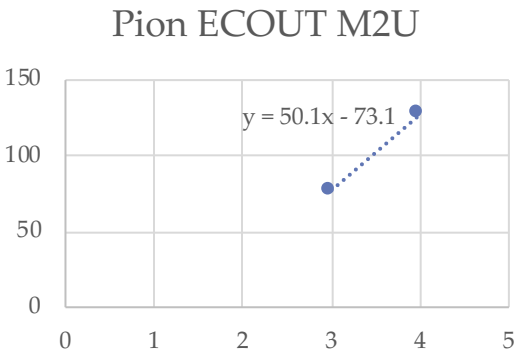


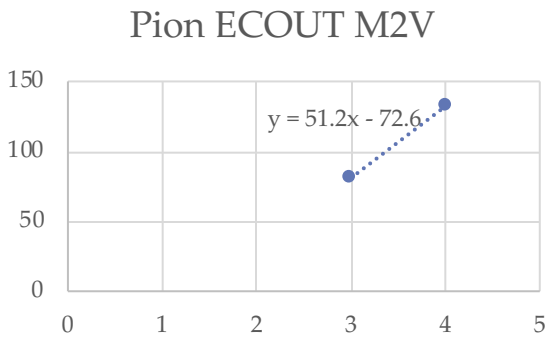


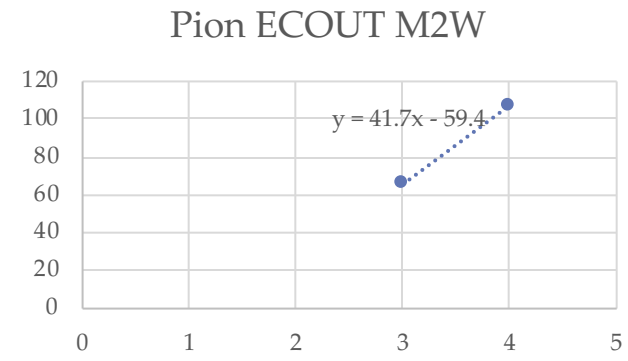






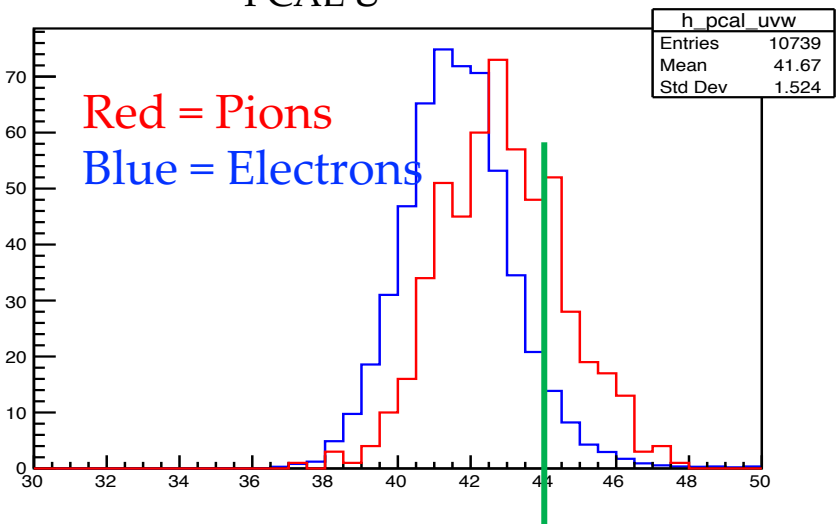




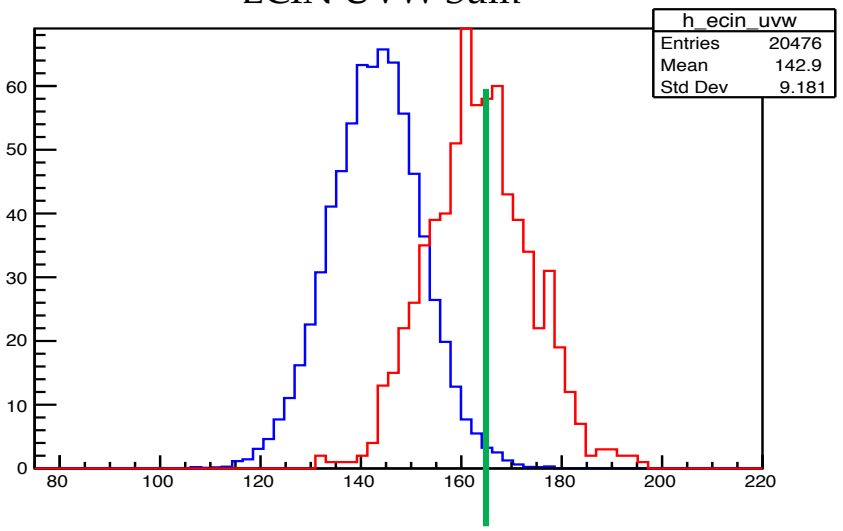


2nd Moment/Strip Ratios For Electrons and Pions

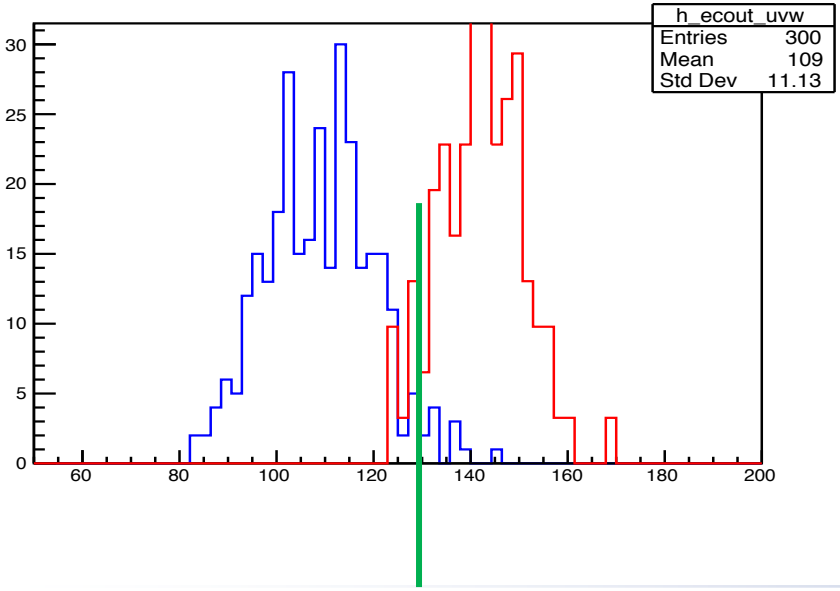
PCAL U



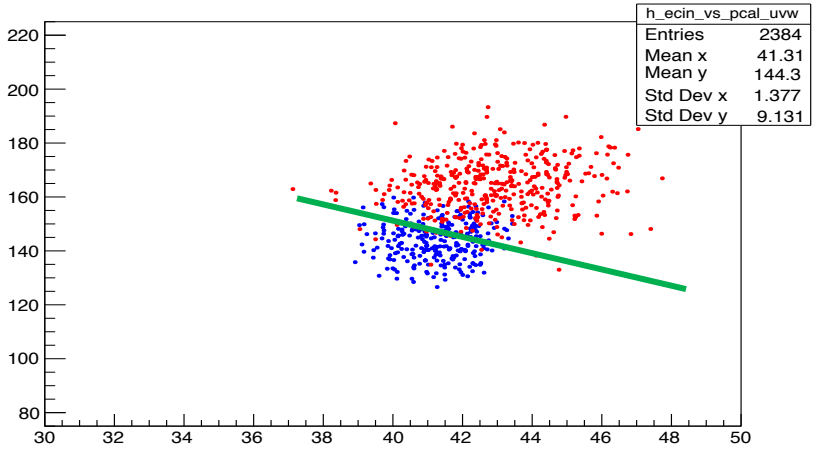
ECIN UVW Sum



ECOUT UVW Sum



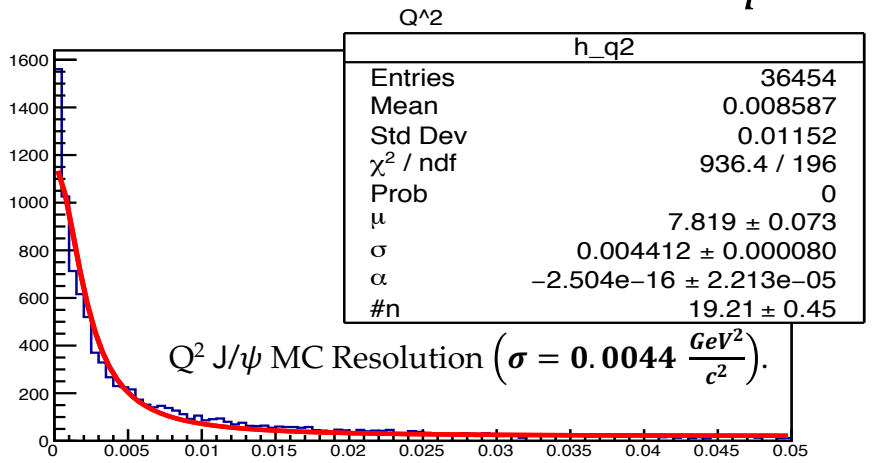
ECIN vs. PCAL Sum

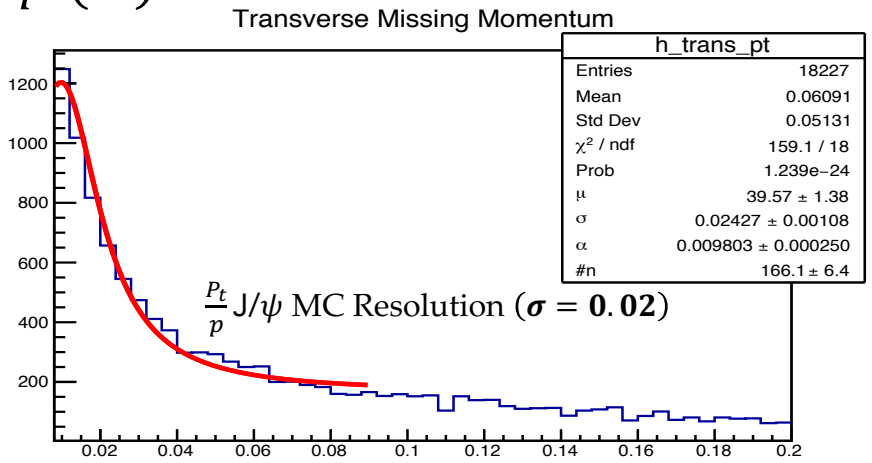


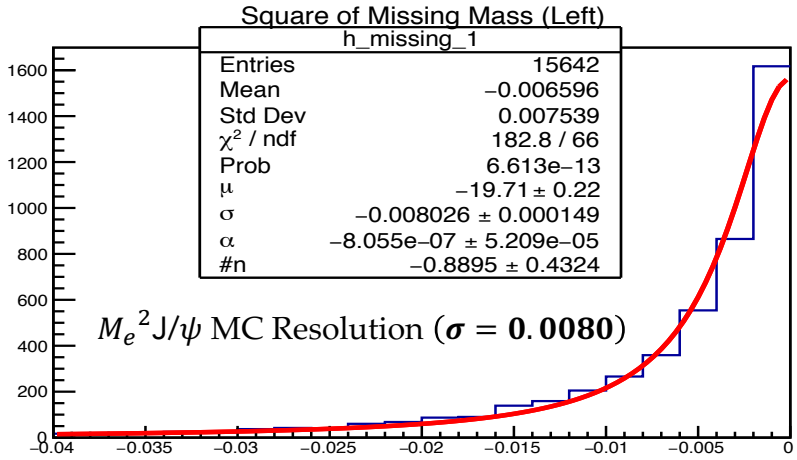
Development Of Event Selection Criteria Using Simulations

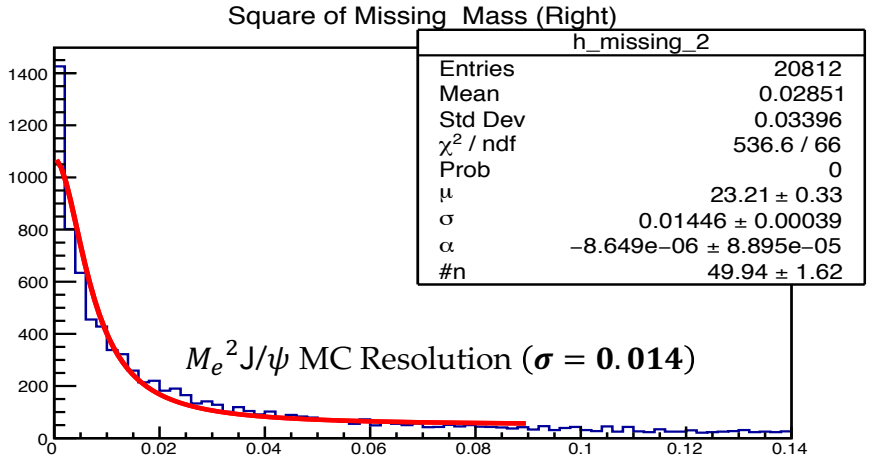
Establishing criteria for event selection is done to understand the measurement of the un-detected forward scattered ($\theta \sim 0$) electron after the exchange of a quasi-real photon. The transverse missing momentum, Q^2, and missing mass were analyzed to develop selection cuts

$$ep \rightarrow e^+e^-p'(\boldsymbol{e'})$$

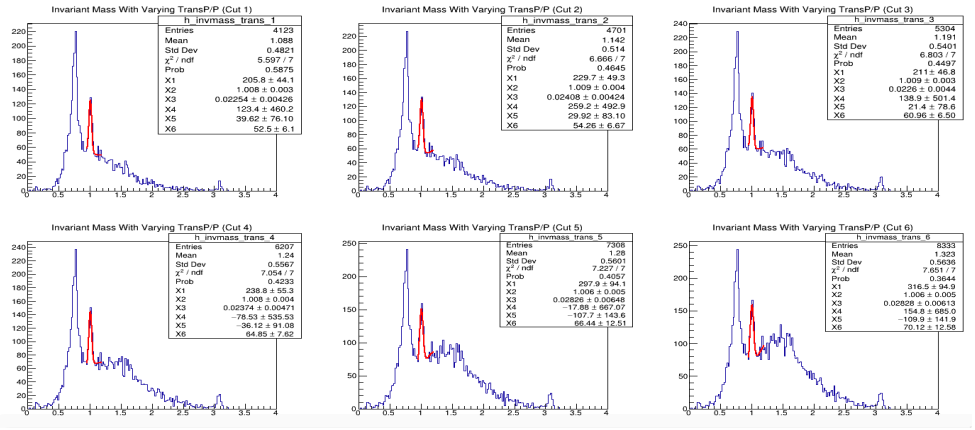


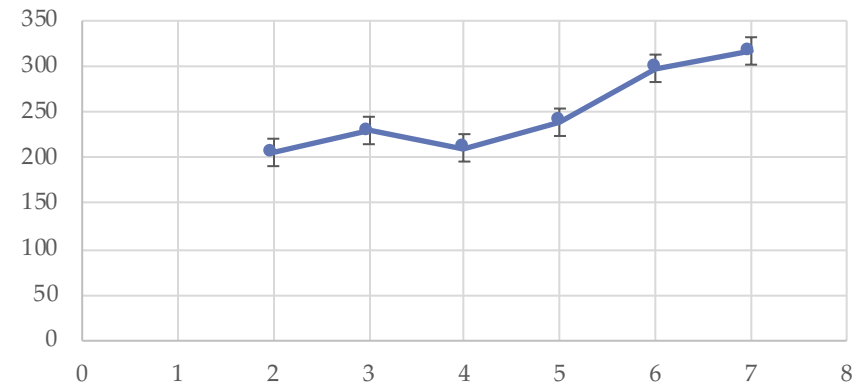


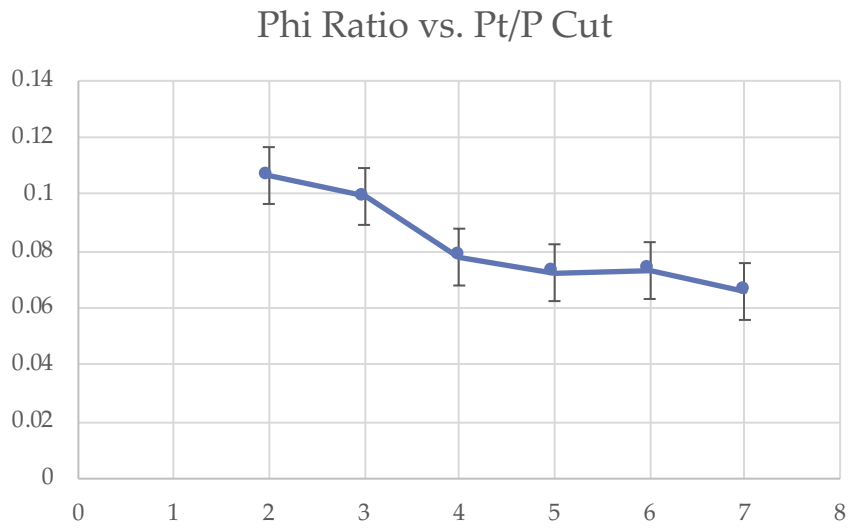


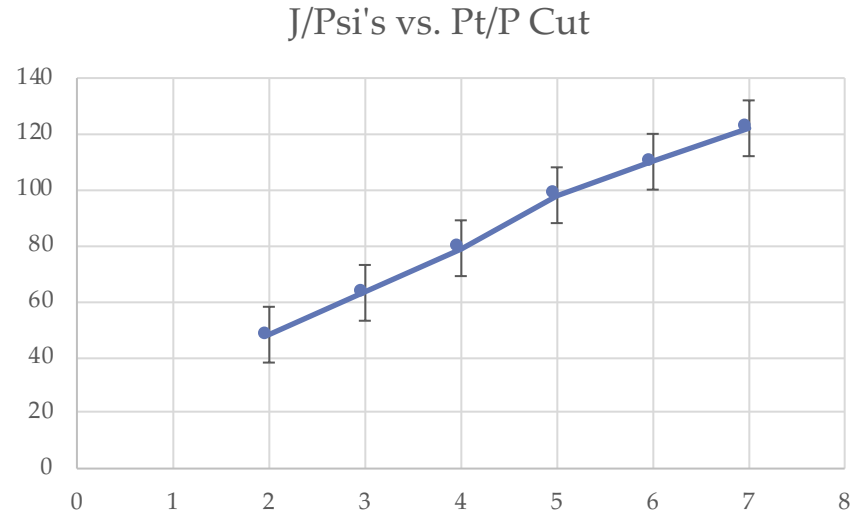


Event Selection Optimization (Pt/P)







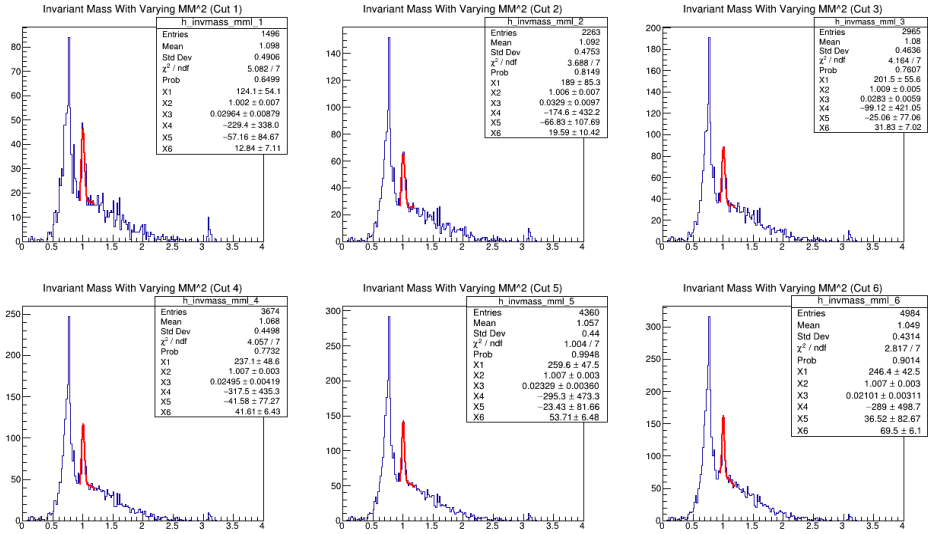


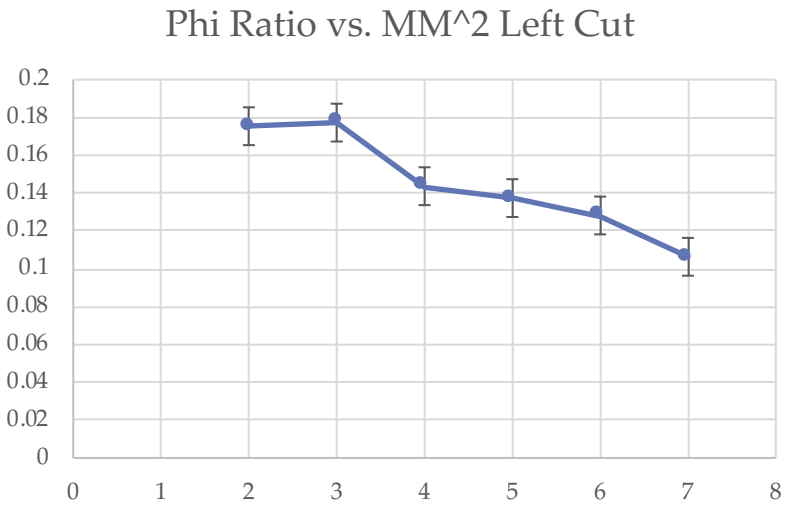
*The number of J/Psi's increases when Pt/P approaches 7 sigma. However, many of these J/Psi events are not real and are due to background.

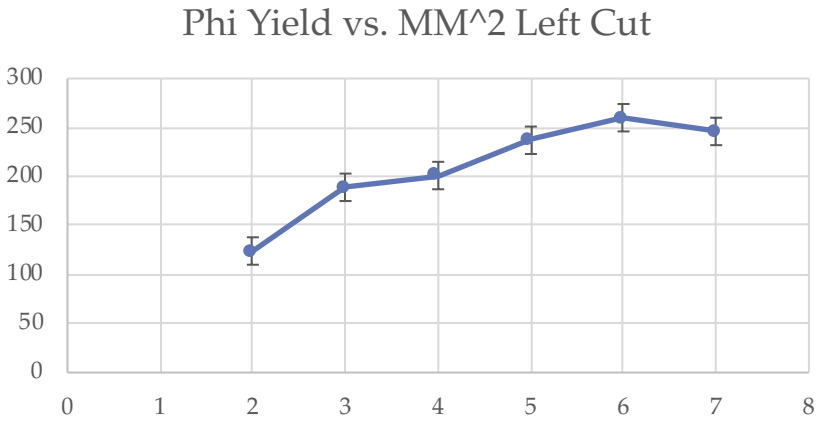
*The reduction in the phi signal ratio indicates the increase in background events as Pt/P approaches 7 sigma

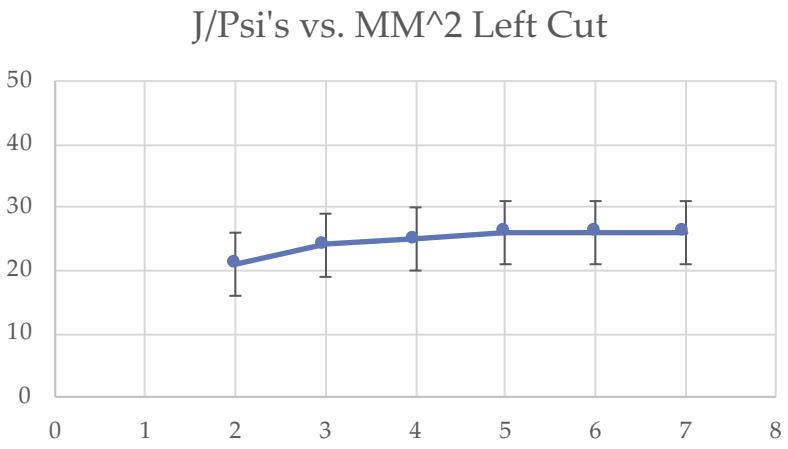
*Correlations between variables need to be studied

Event Selection Optimization (Square of Missing Mass)



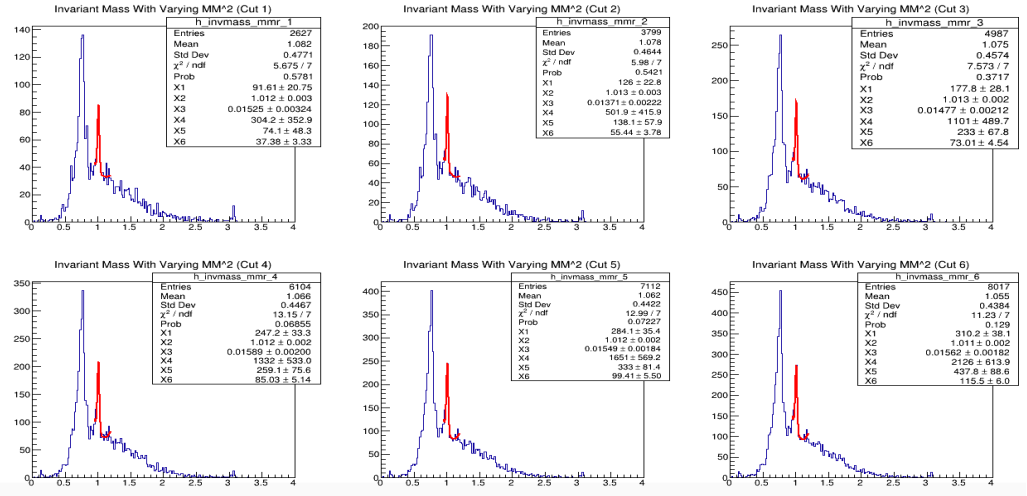


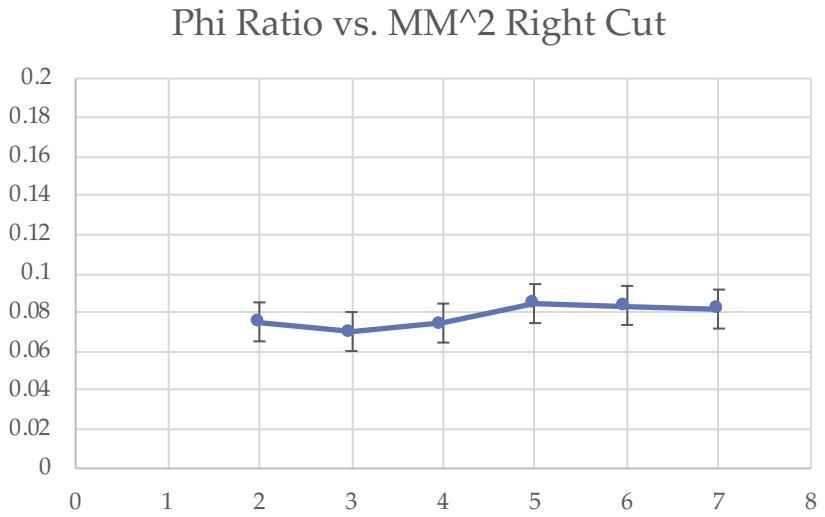


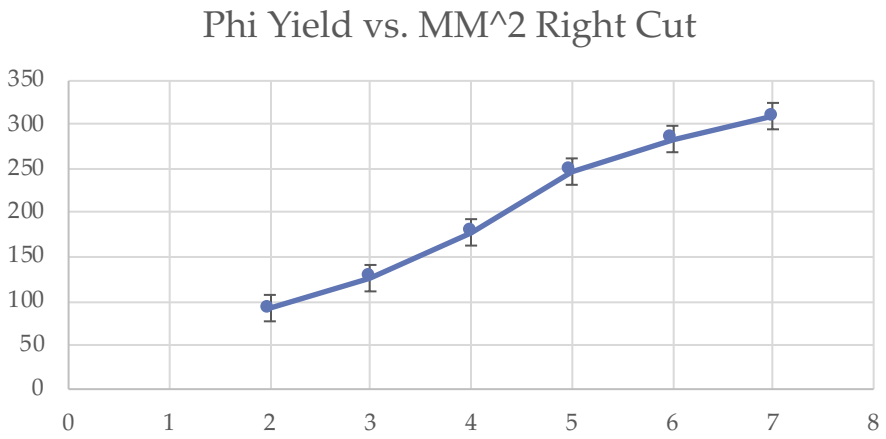


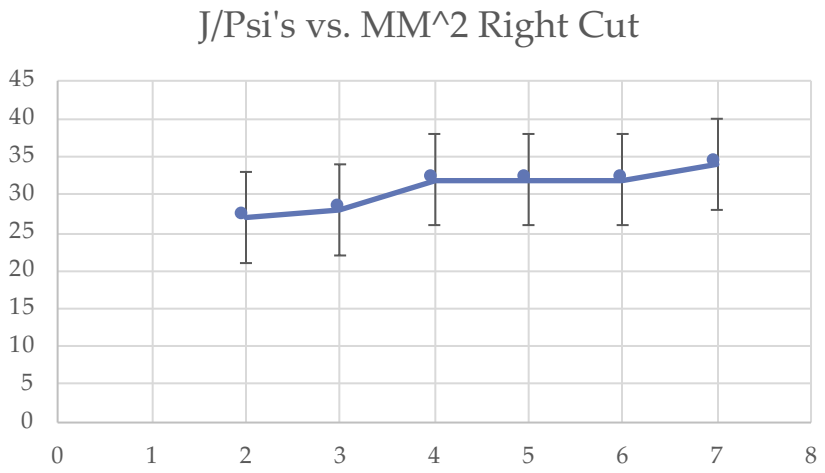
*The reduction in the phi signal ratio indicates that the negative side of the square of the missing mass should have a tighter cut.

Event Selection Optimization (Square of Missing Mass)









*The phi signal ratio is consistent, so loosening the cut on the right side of the square of the missing mass will not contaminate the data sample.

Fiducial Volume Strategy

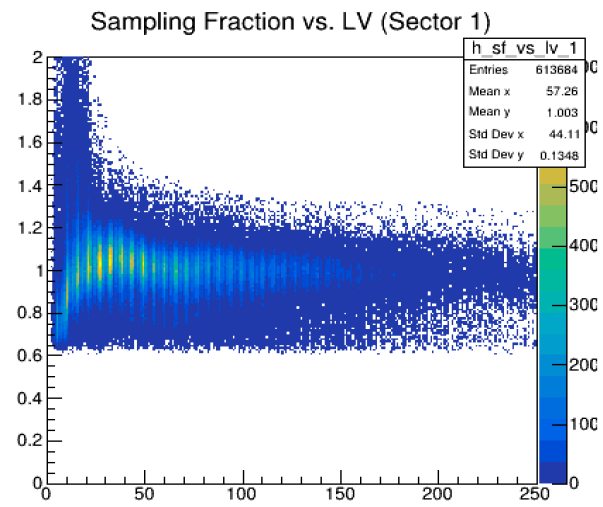
Procedure...

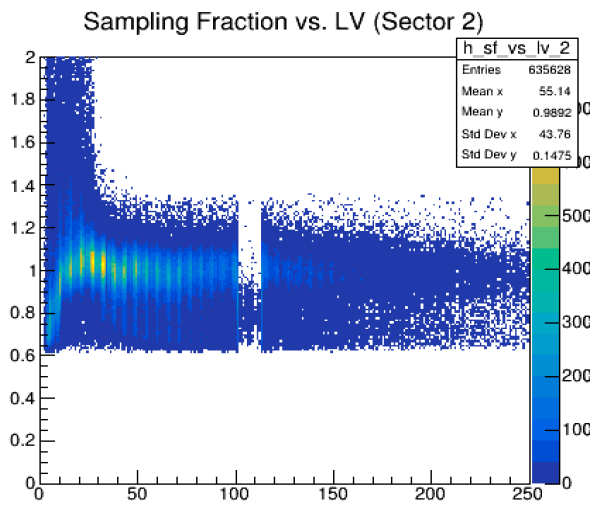
- Study sector-dependent electron sampling fraction as a function (called f(p)) of momentum (p > 2 GeV) while constraining PCAL LU, LV, and LW in order to isolate independent variables

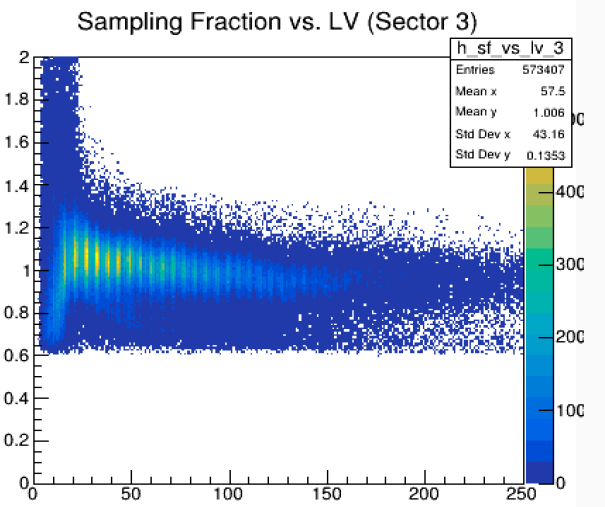
- With the momentum-dependent electron sampling fraction parametrization, study the sector-dependent electron sampling fraction as a function of PCAL LU called g(LU).

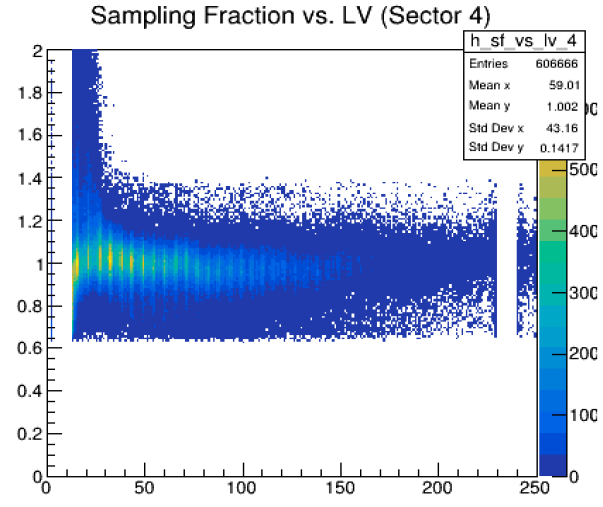
- With the PCAL LU-dependent electron sampling fraction parametrization, study the sector-dependent electron sampling fraction as a function of PCAL LV and PCAL LW

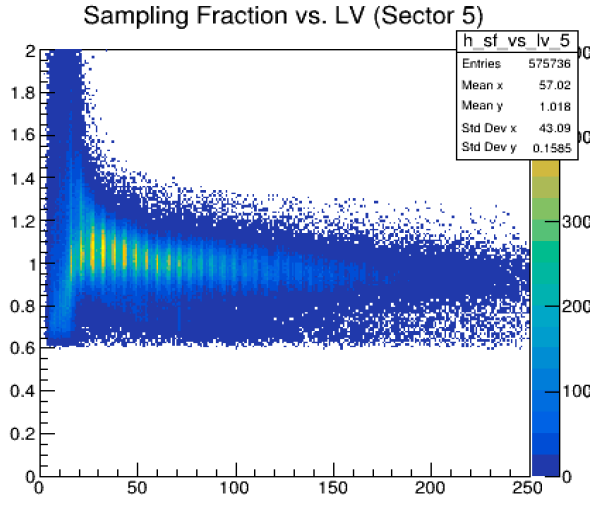
PCAL LV Dependence

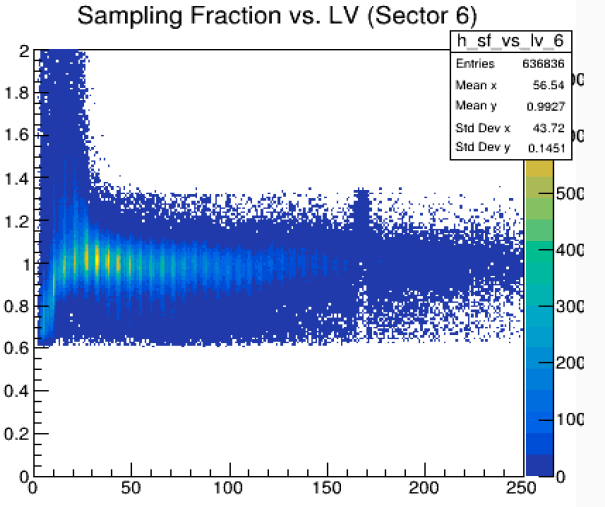






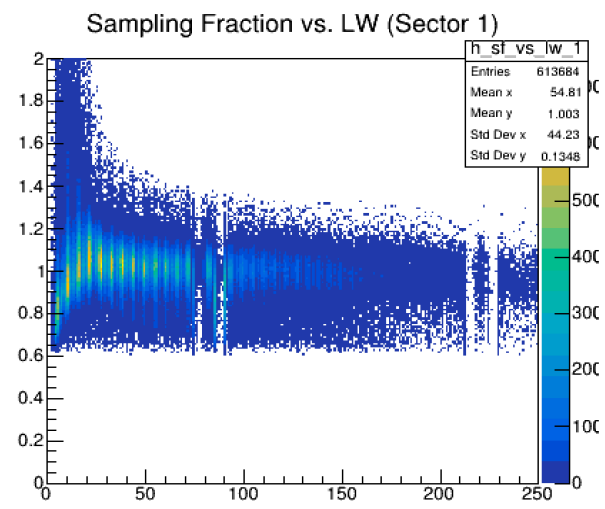


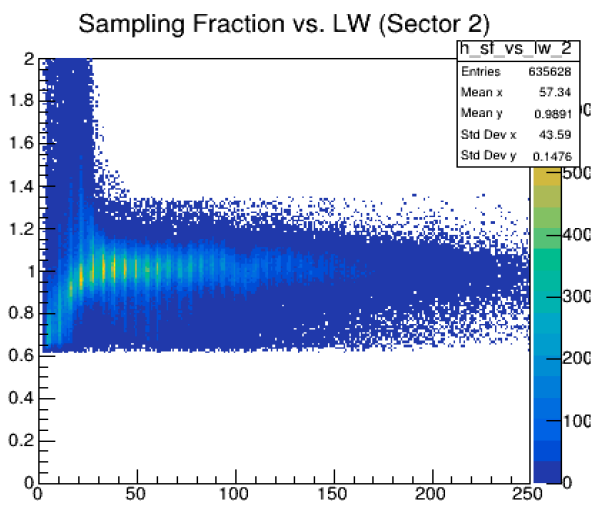


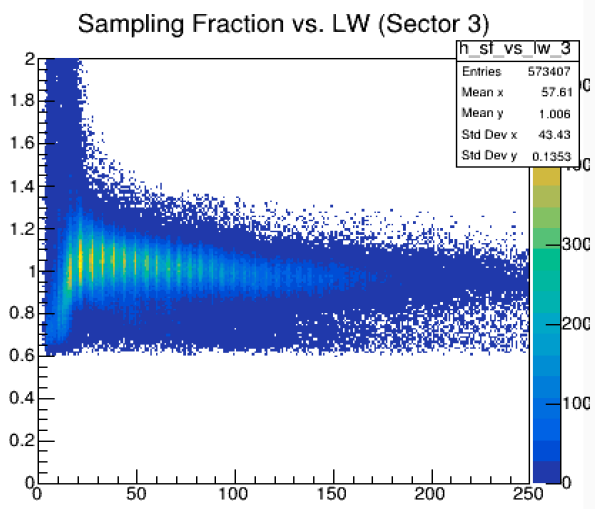


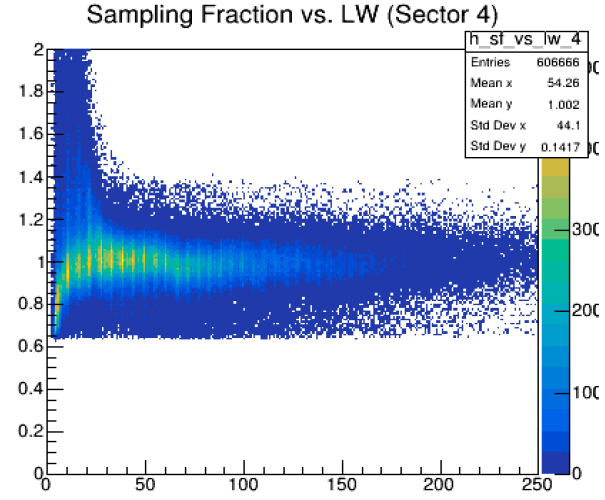
*Applying 15 cm cuts on LV would be reasonable for removing electron candidates with shower leakage

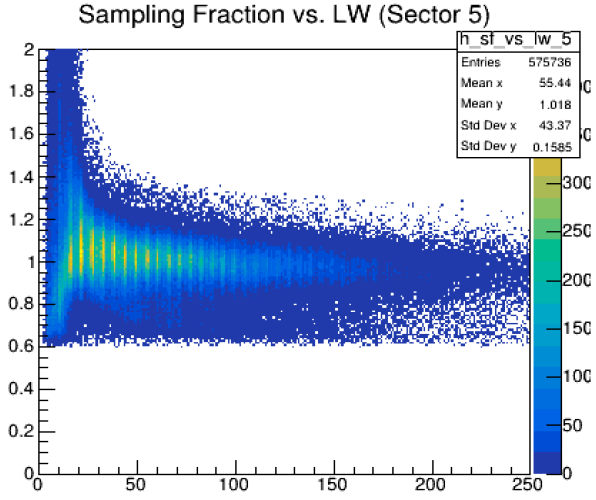
PCAL LW Dependence

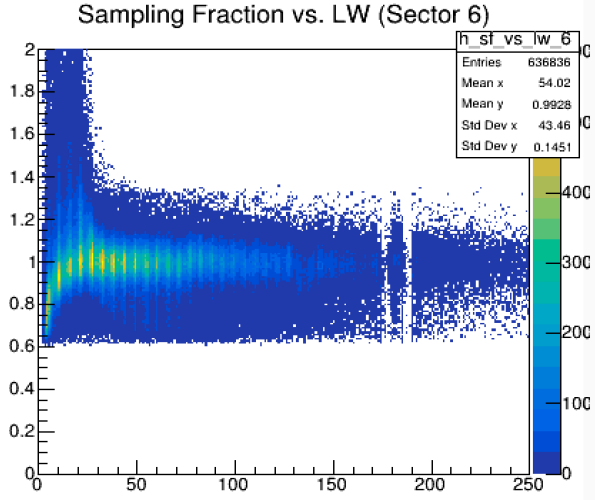








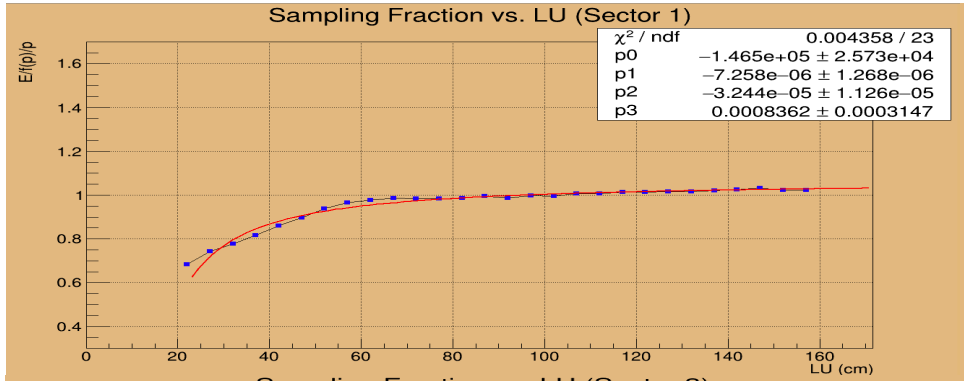


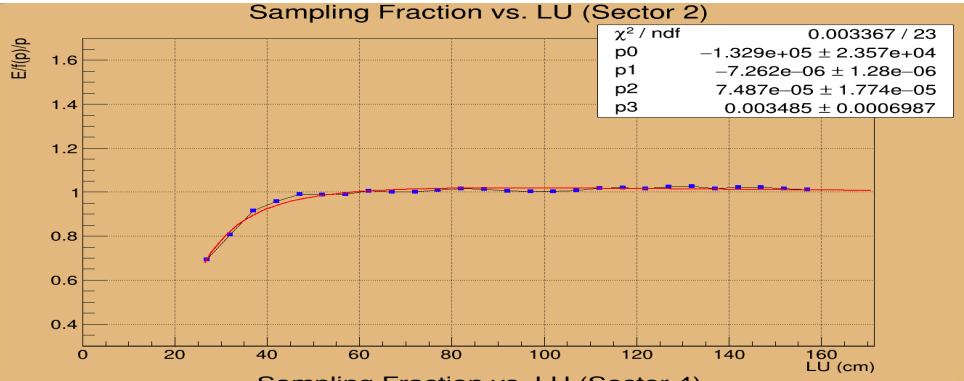


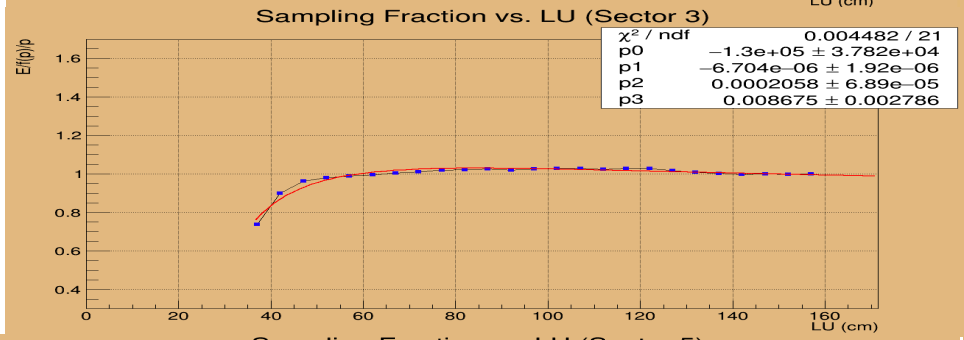
*Applying 15 cm cuts on LW would be reasonable for removing electron candidates with shower leakage

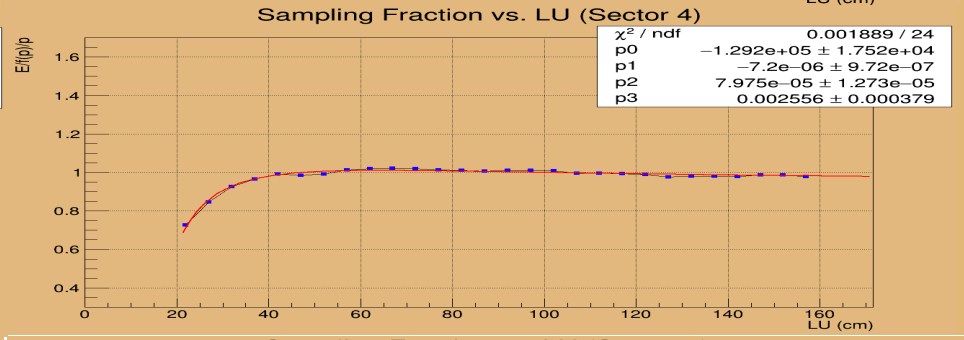
Sampling Fraction vs. PCAL LU Position

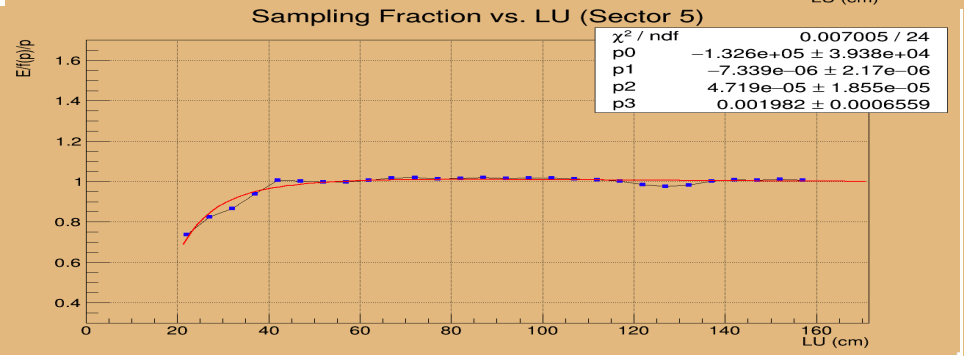
The sampling fraction was studied for each sector for its dependence on LU, which is the distance between the shower peaks and the edge of the PCAL

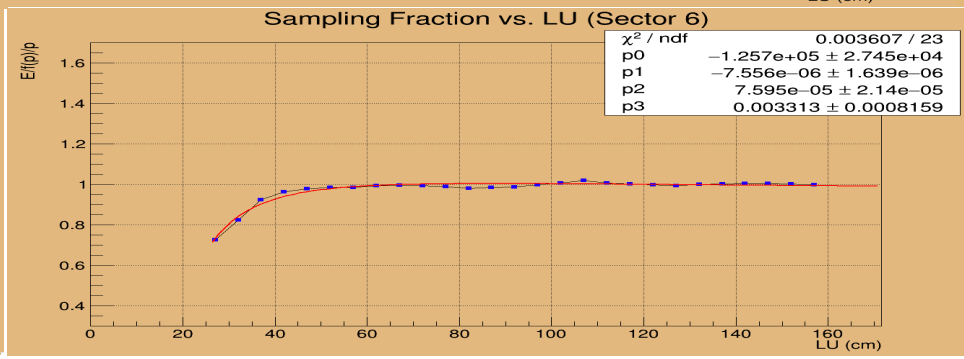












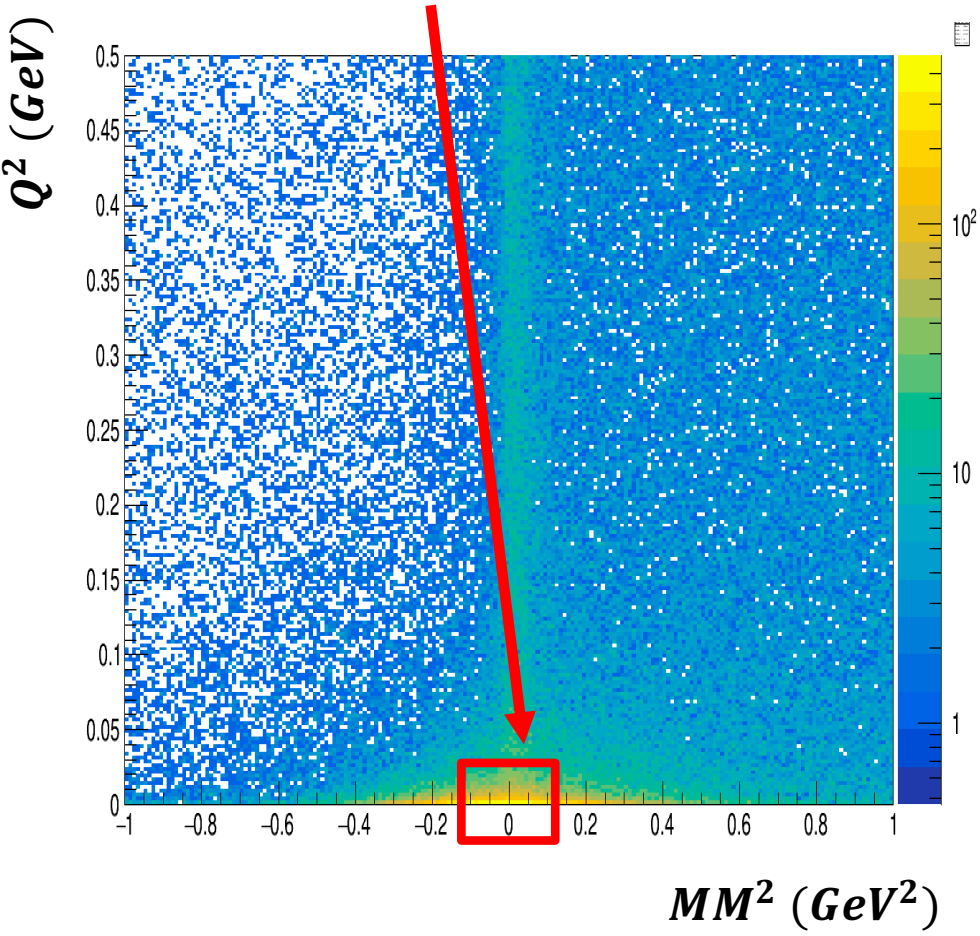
Event Selection For Quasi-Real Photoproduction From Fall 2018 Data

$$ep \rightarrow e^+e^-p'(X)$$

Q^2 and Missing Mass Criteria…..

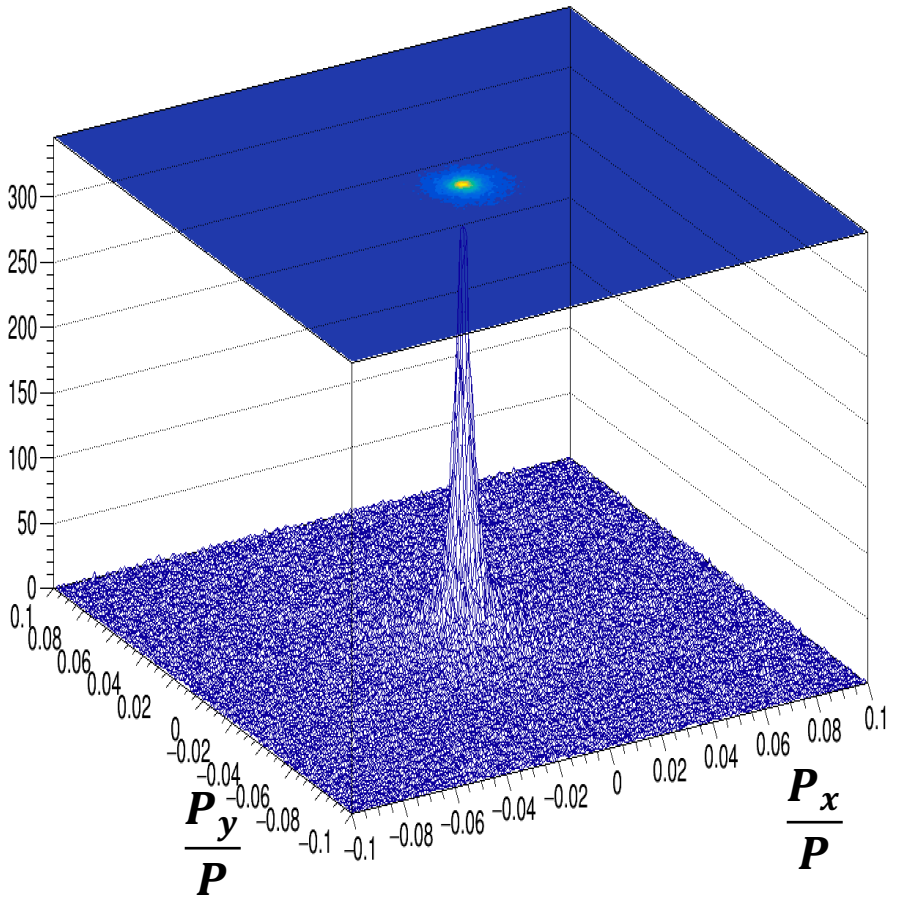
$Q^2 < 0.018$

$-0.032 < MM^2 < 0.11$

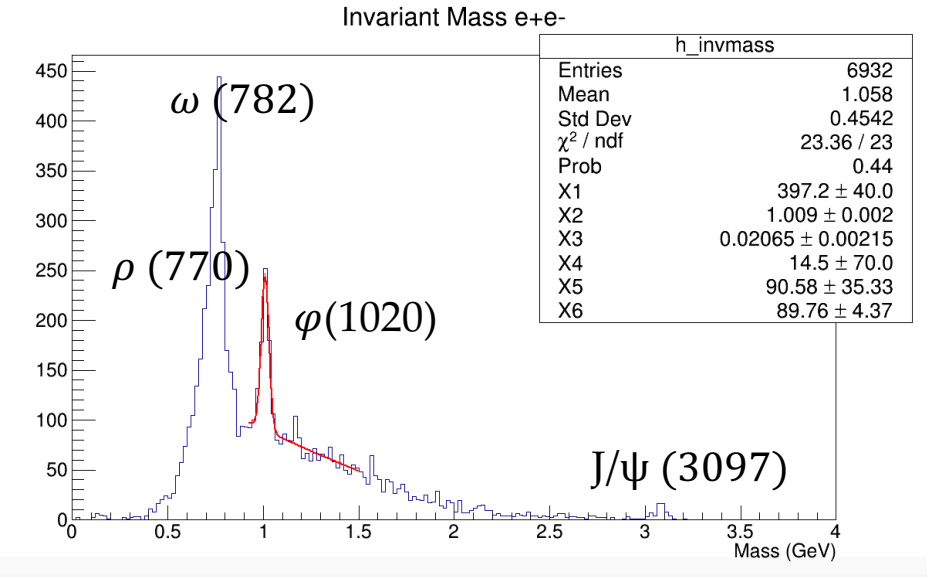


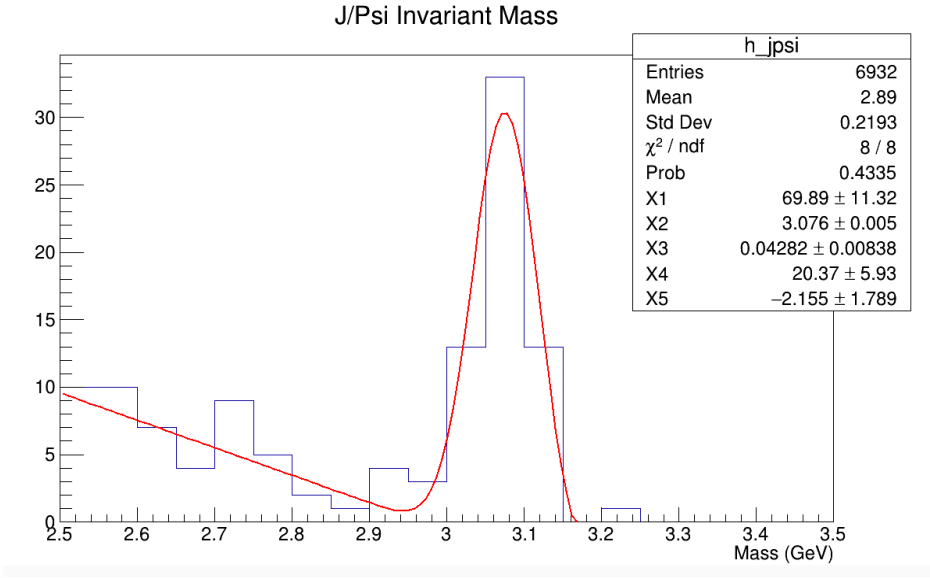
Transverse Missing Momentum Criteria…..

$\frac{Pt}{P} < 0.06$

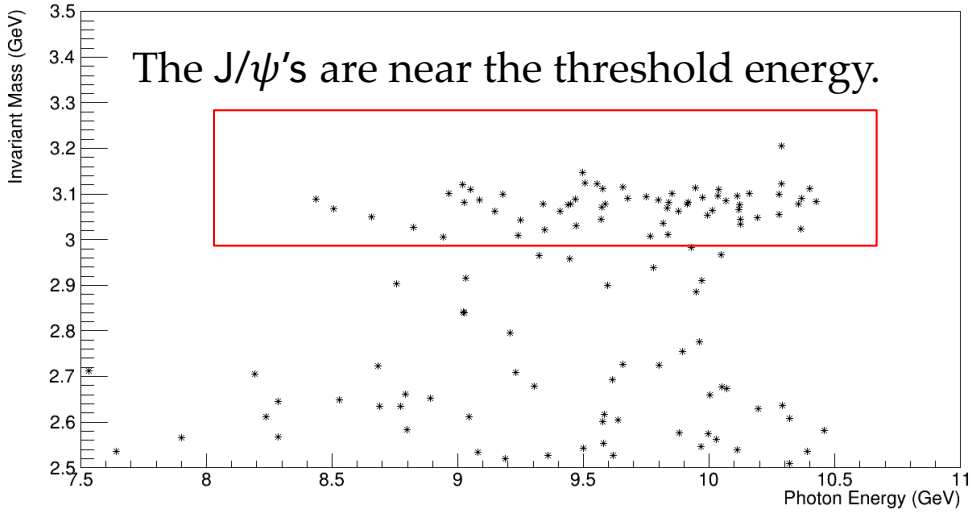


Invariant Mass From Fall 2018 Data





- Using the exclusivity cuts, the invariant mass of the e+e- pair was calculated to show the reconstruction of vector mesons
- With the in-bending runs from Fall 2018 dataset, approximately 70 J/ψ's were extrapolated from the fit



Next Steps

- Analysis framework with particle identification and event selection nearly complete
- High statistics from the completion of the RG-A pass1 data processing will allow for the measurements of cross sections and the forward-backward asymmetry
- Acceptances and normalization using Bethe-Heitler MC simulations will be completed with latest software releases
- Kinematic fitting & momentum corrections to be developed for this reaction.
- Work is being documented for a future analysis note

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Thank you!