RG-B: J/Ψ in e+ e- p channel

RICHARD TYSON

CEBAF Large Acceptance Spectrometer

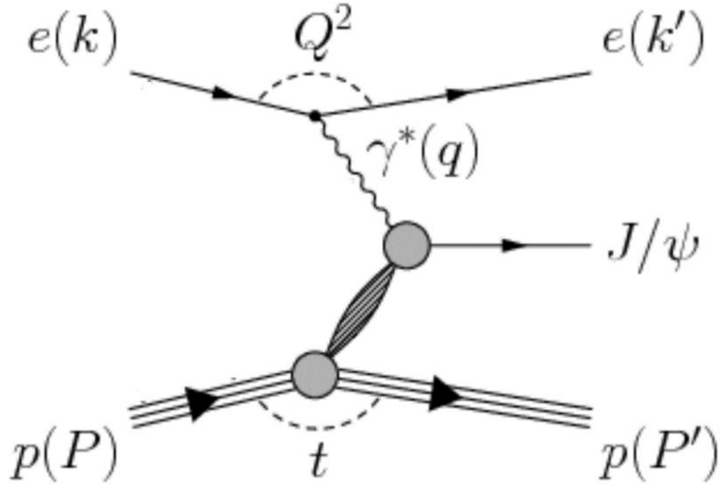
University of Glasgow

VIA VERITAS VITA

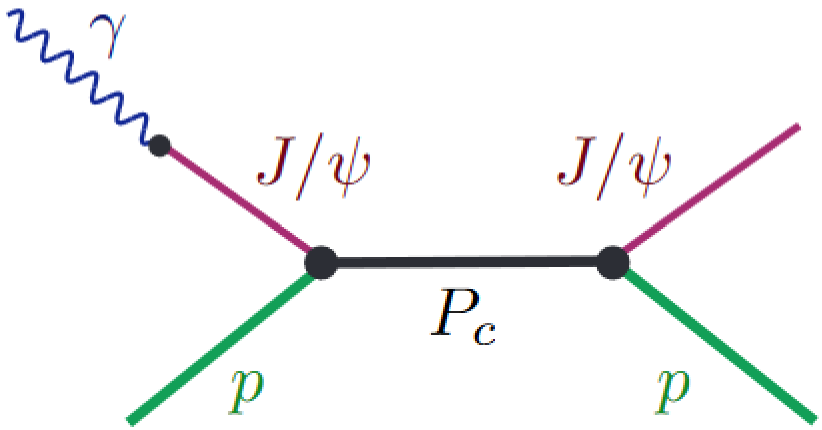
Experiment Overview

$$e\ p_{bound} \rightarrow (\mathrm{e}')e^{+}e^{-}\mathrm{p}$$

- The electron beam produced by CEBAF scatters with a deuterium target through the exchange of a quasi-real photon $Q^2{\sim}0$.
- In the $e^{+}\ e^{-}$ p channel the electron beam interacts with the proton inside the deuteron.
- The proton and $e^{+}e^{-}$ pair produced in J/ψ decay are detected in the FD.



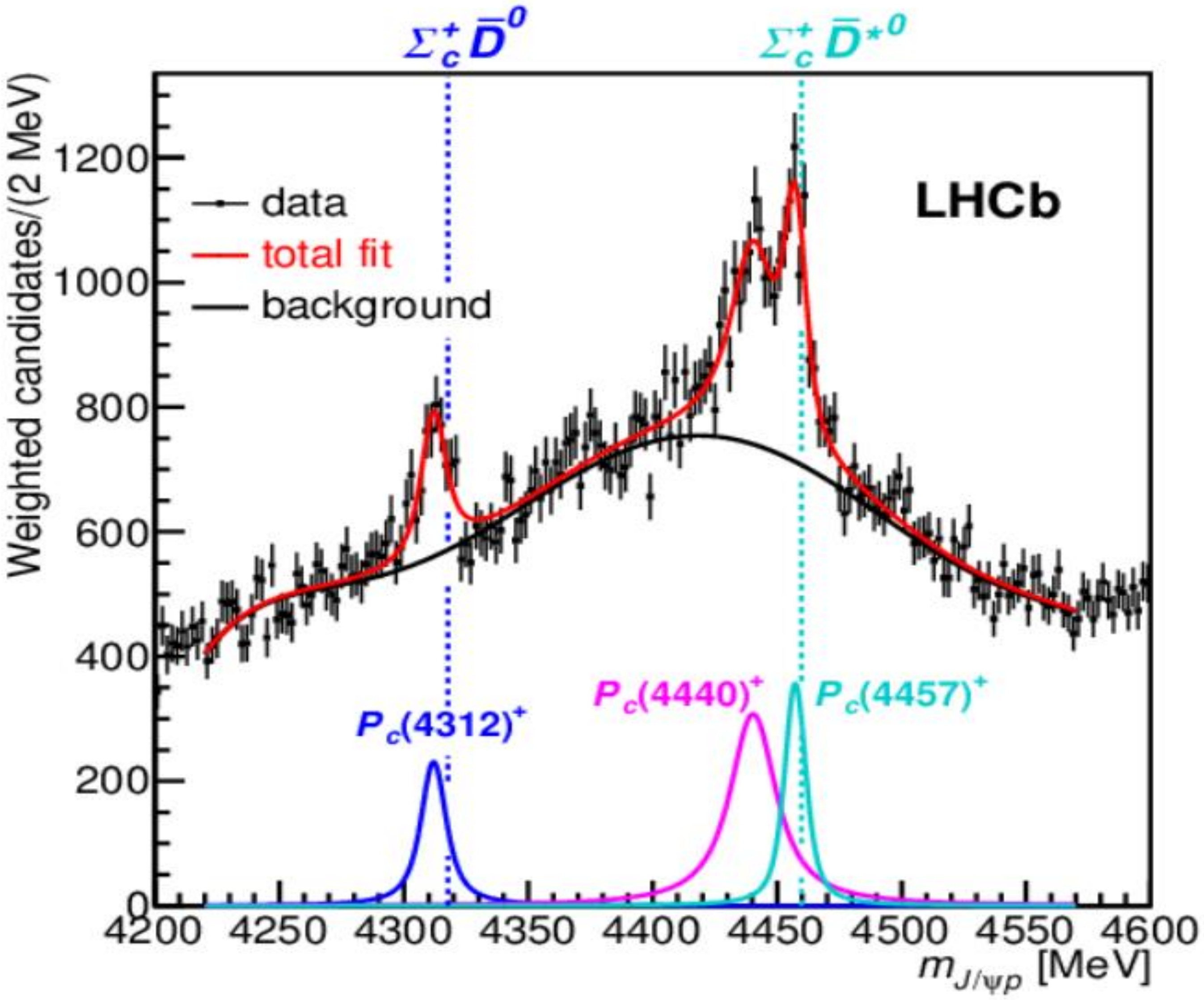
J/ψ quasi-real photoproduction



Feynmann diagram of P_C^+ pentaquark photoproduction.

P_C^+ resonances at the LHCb (2019)

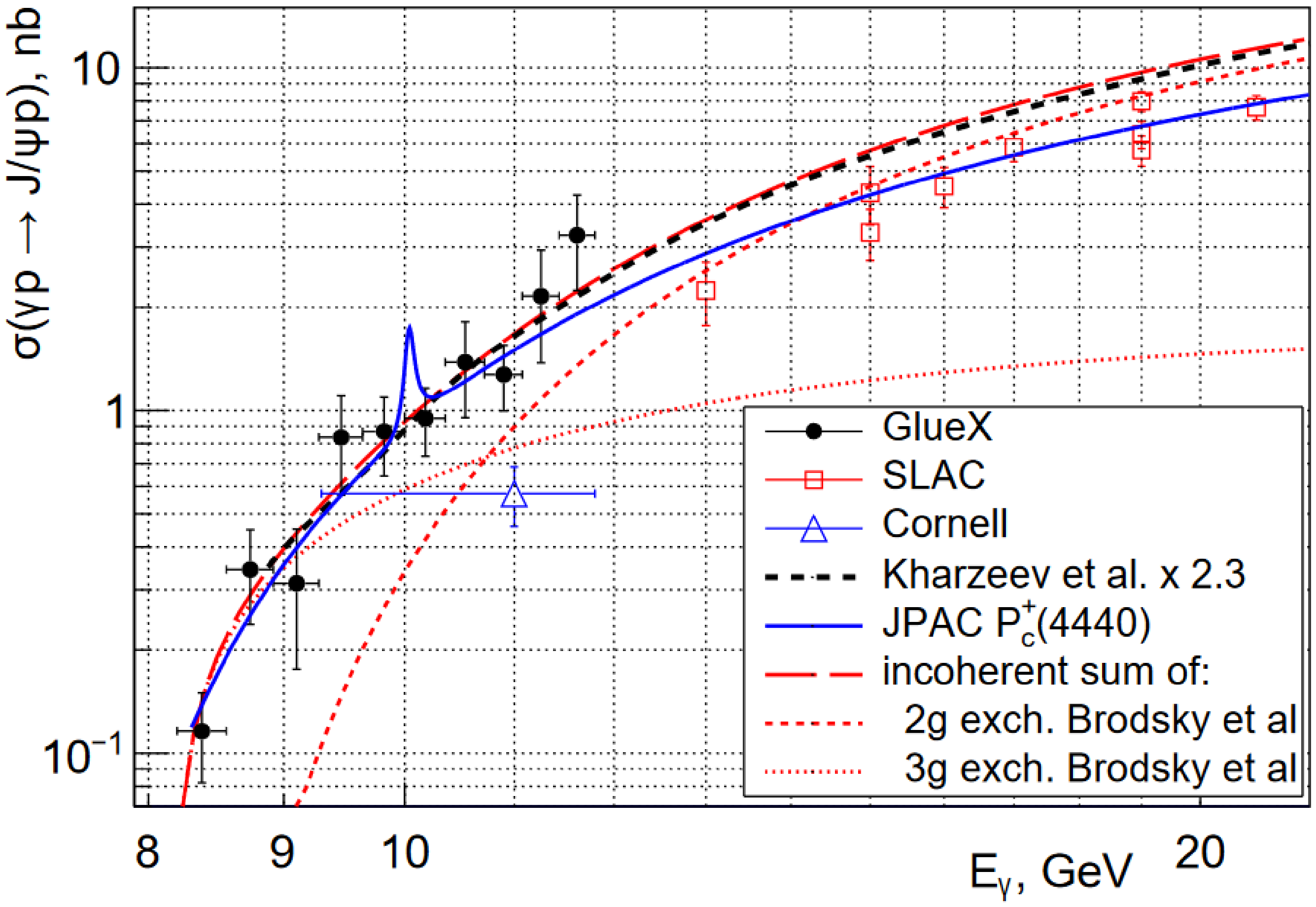
- The e^+e^-n final state further offers the possibility of looking for the isospin partners of the P_c^+ Pentaquarks.



The J/ψ p invariant mass distribution [1].

Goals

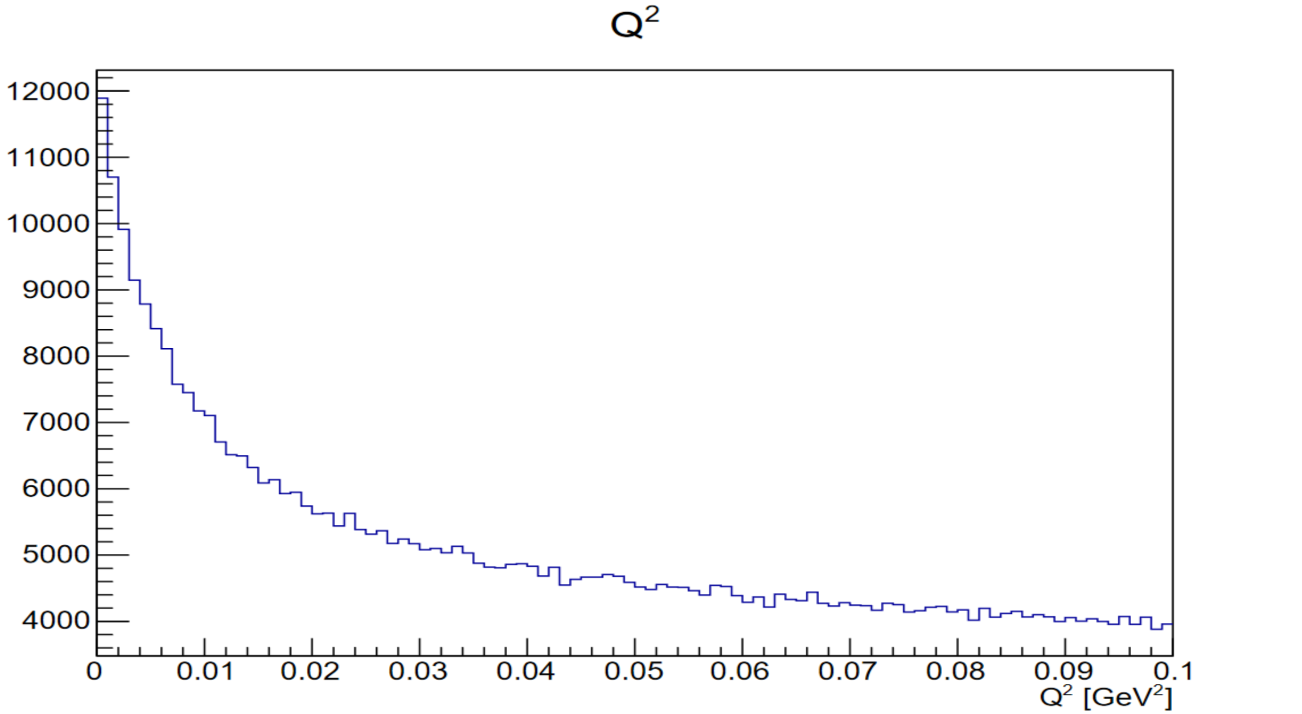
- Verify the LHCb results and look for isospin partners of the P_c^+ Pentaquarks.
- Study the production mechanism of J/ψ near threshold by measuring the total cross section as a function of beam energy.
- Study the distribution of color charge in the nucleon by measuring the t-dependency of the differential cross section of J/ψ photoproduction.

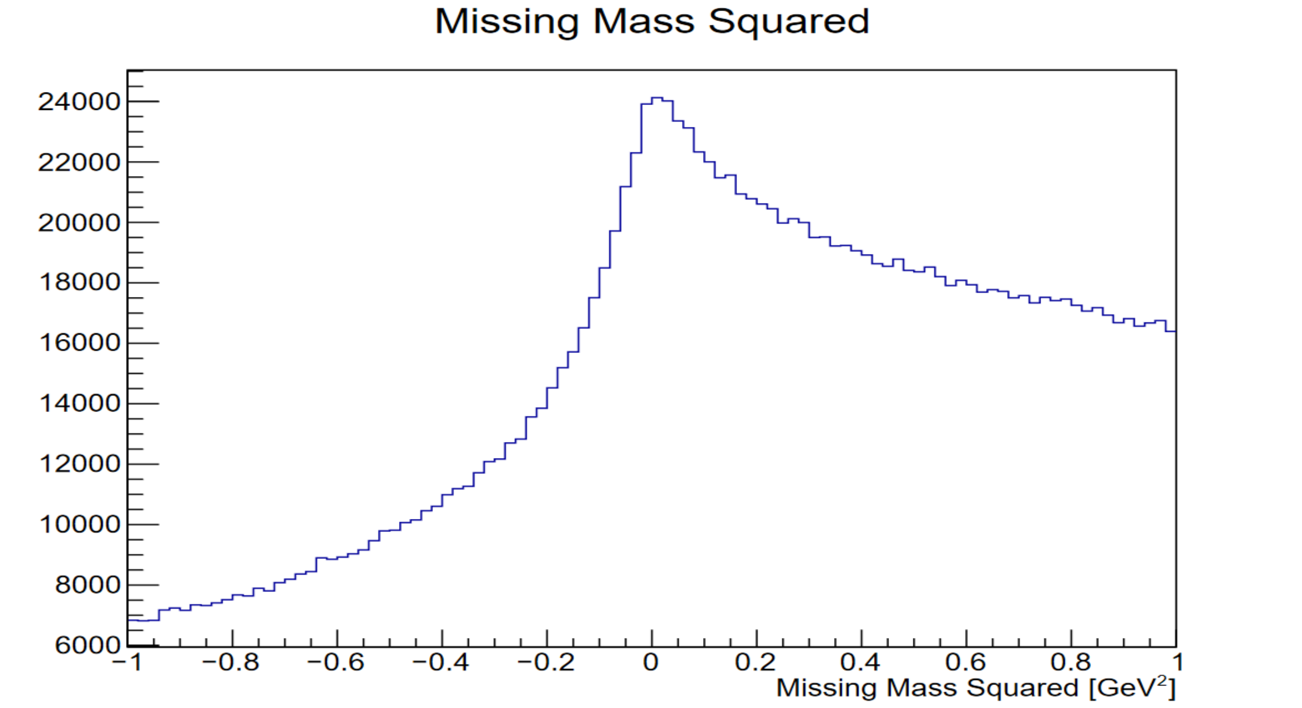


The J/ψ total cross section as a function of beam energy, scaled to GlueX data [2].

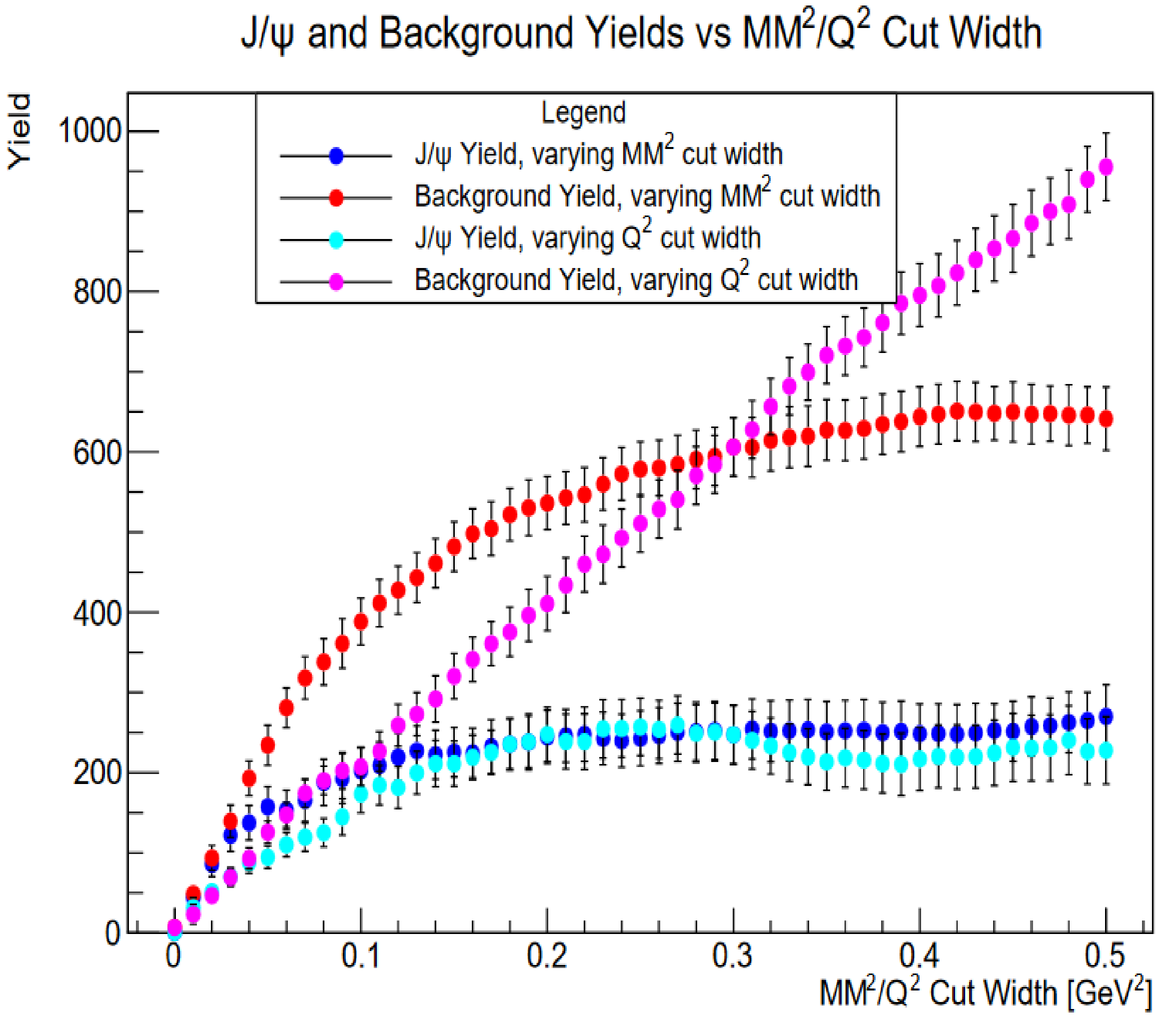
Initial Event Selection

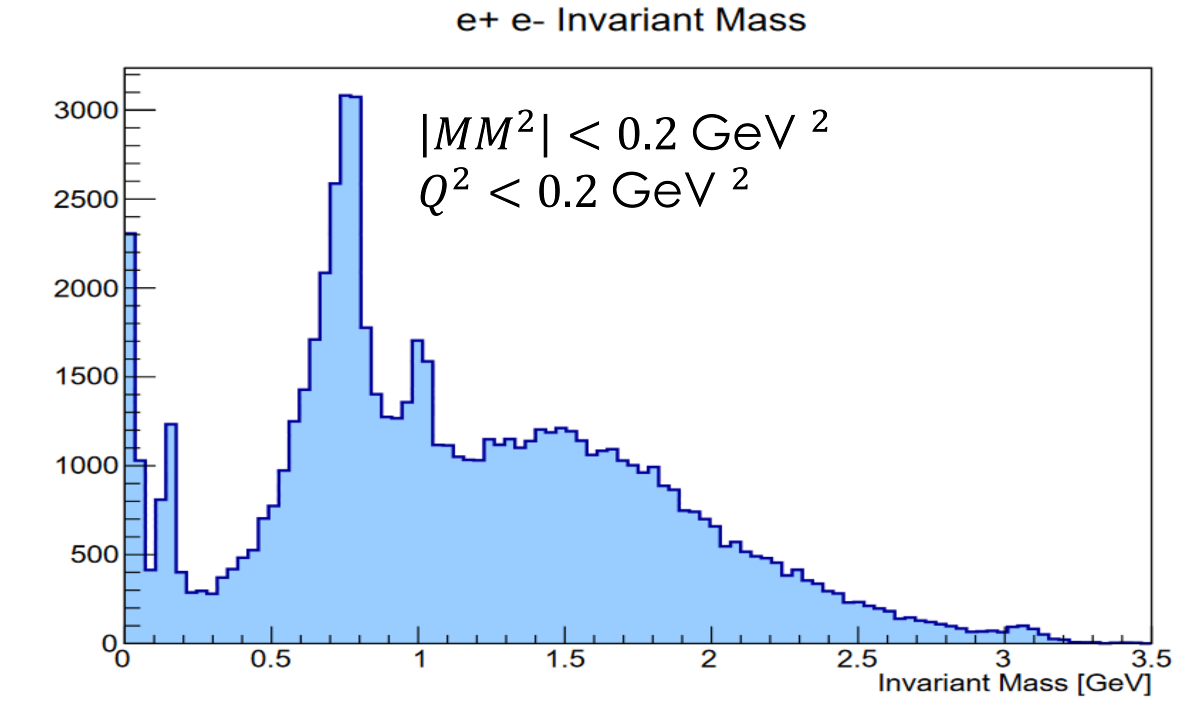
- We start with the Event Builder (EB) PID for our final state particles:
  - For e+/e-, the EB requires 2 photoelectrons produced in the HTCC, 60 MeV energy deposition in PCAL and 5σ cut on the sampling fraction parametrization
  - For protons, the EB cuts on the expected time of flight.
- As we're interested in the quasi-real photoproduction regime we want Q^2 close to 0.
- Similarly, we want the missing mass close to the mass of the scattered electron (which is effectively 0).

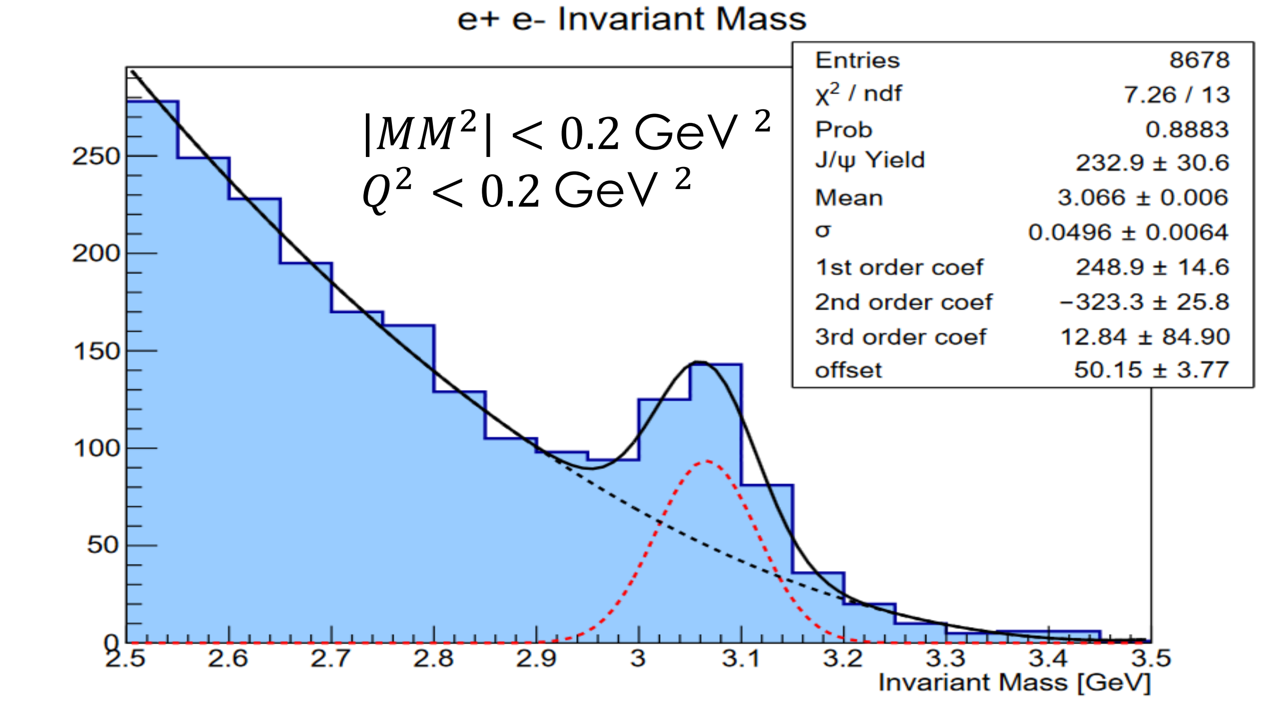




$|MM^2|$ and Q^2 Cuts





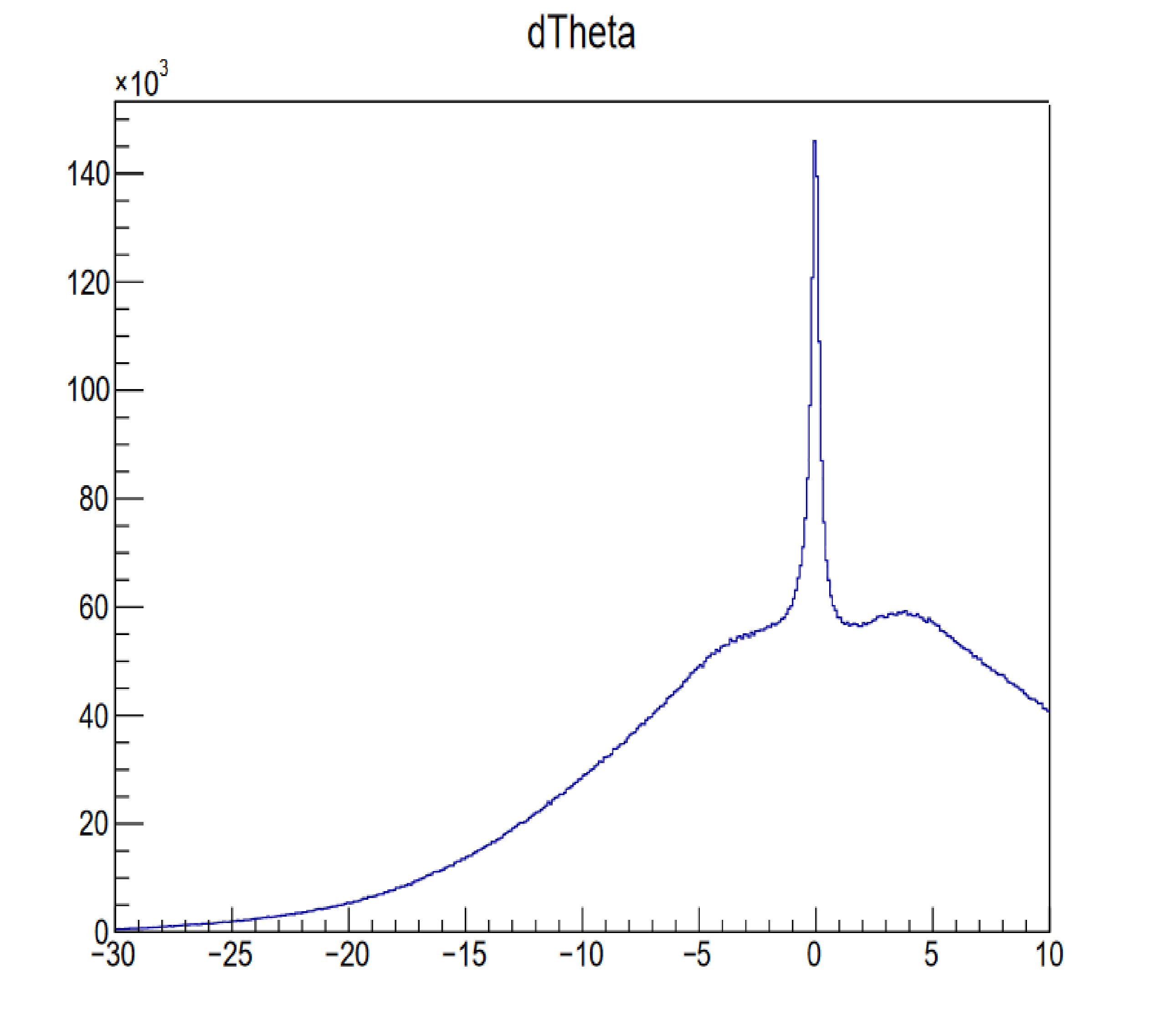


Radiative Corrections

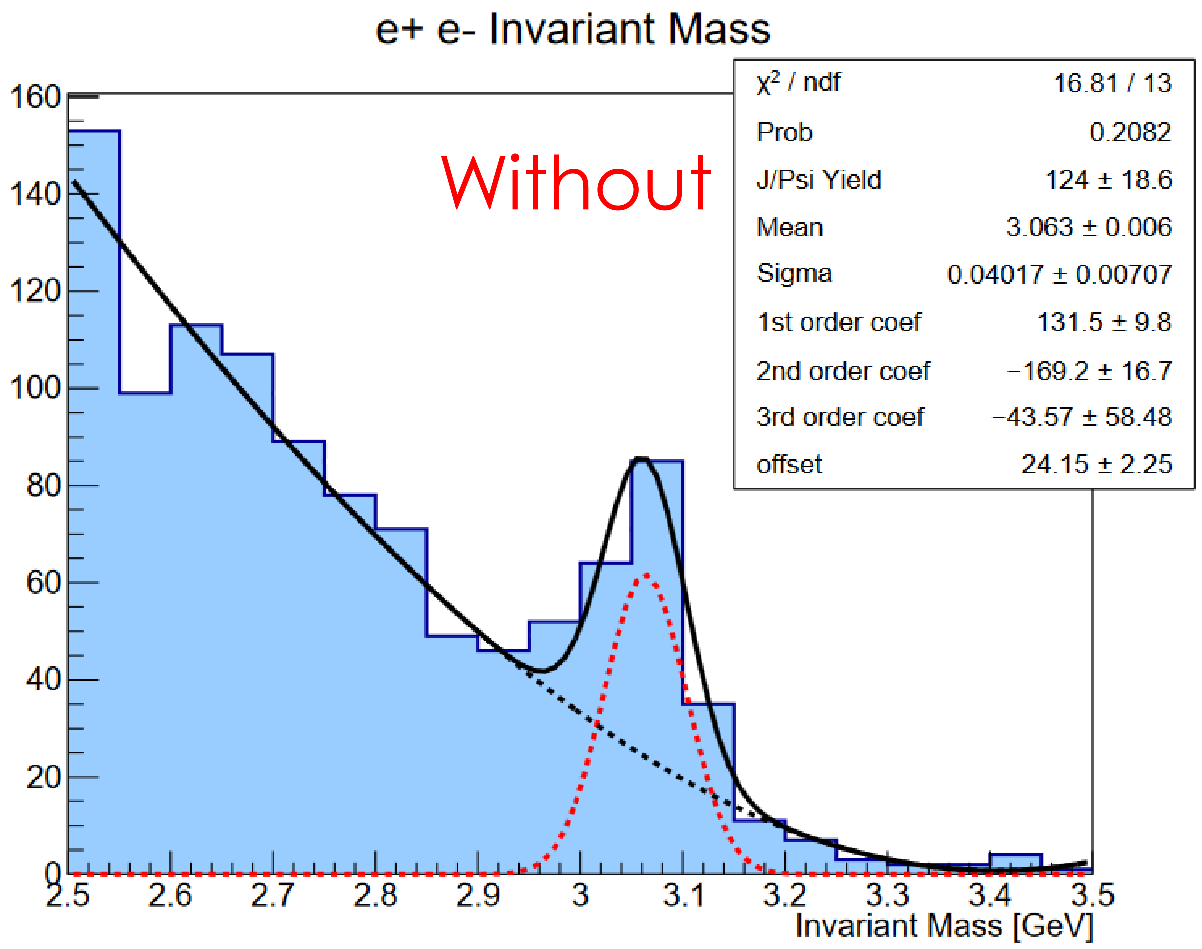
- Radiated photons in ECAL are identified by looking at the difference in theta for the electrons and photons. Here we cut on |dTheta|<0.7 degrees.

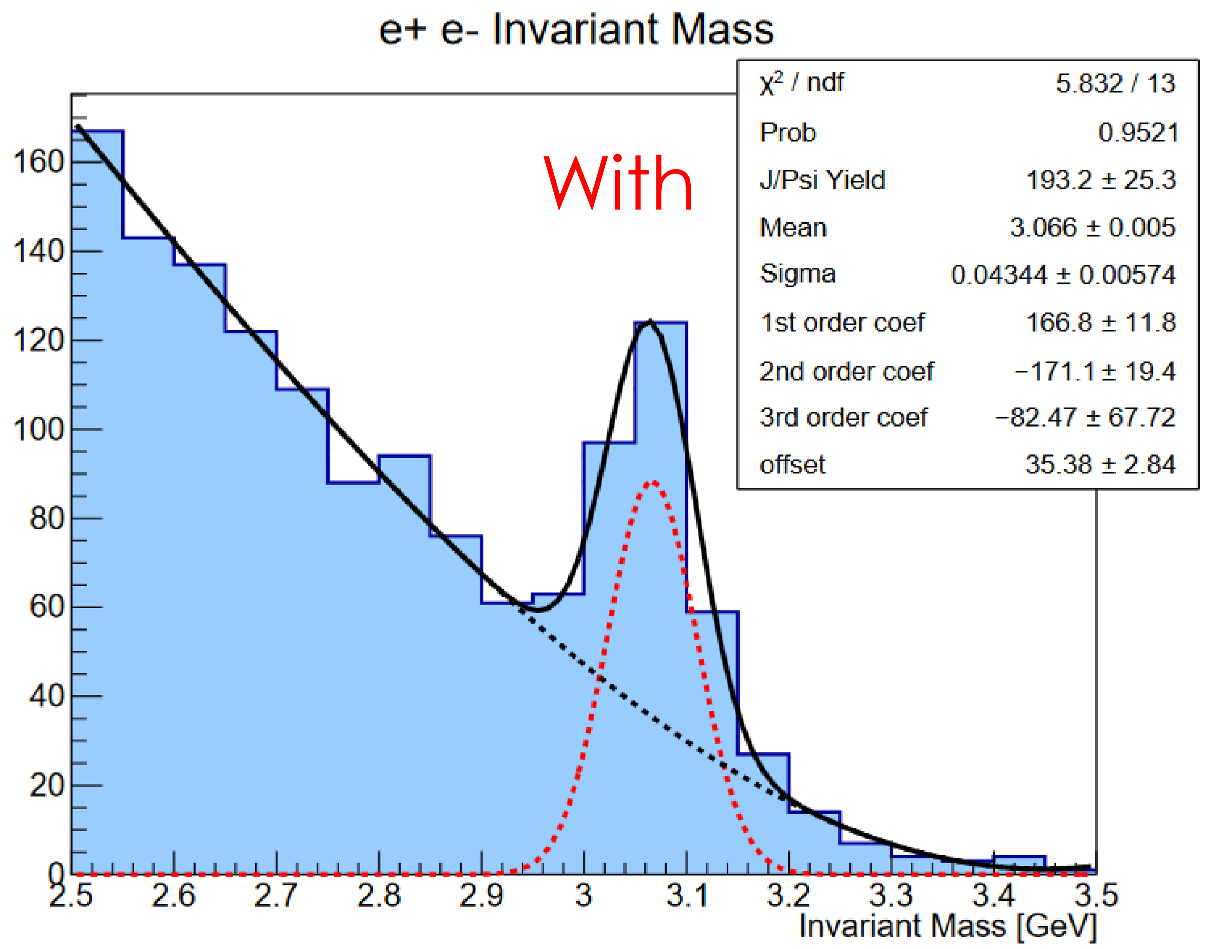
- The electron momentum is recovered by adding the momentum of the radiated photon.

- Some photons are mis-IDed as neutrons by the event builder. Their momentum is recalculated from the photon sampling fraction parametrization then added to the electron momentum.



Radiative corrections

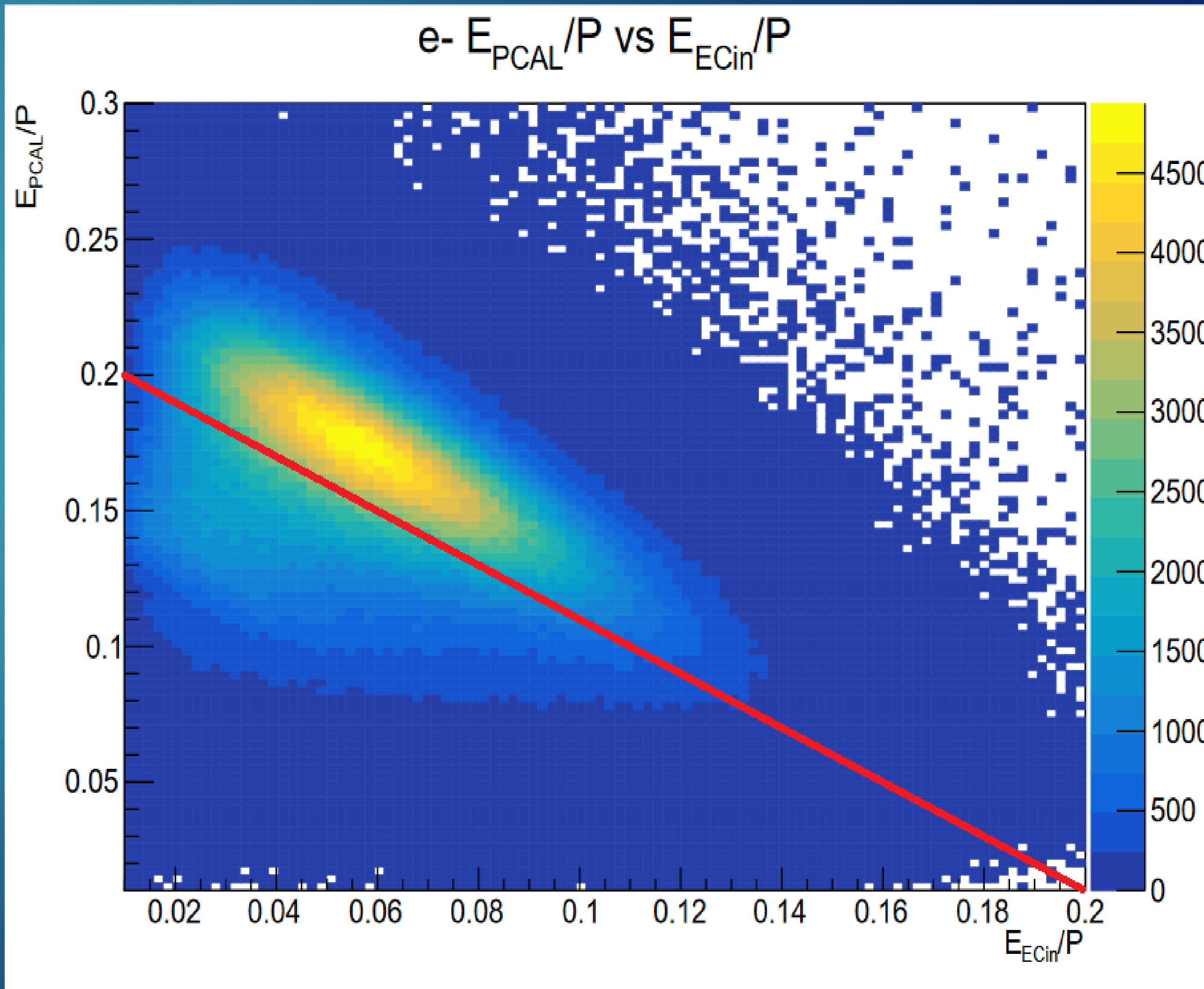




Require $|MM^2| < 0.2$ GeV, $Q^2 < 0.2$ GeV, and some additional PID (cf next few slides).

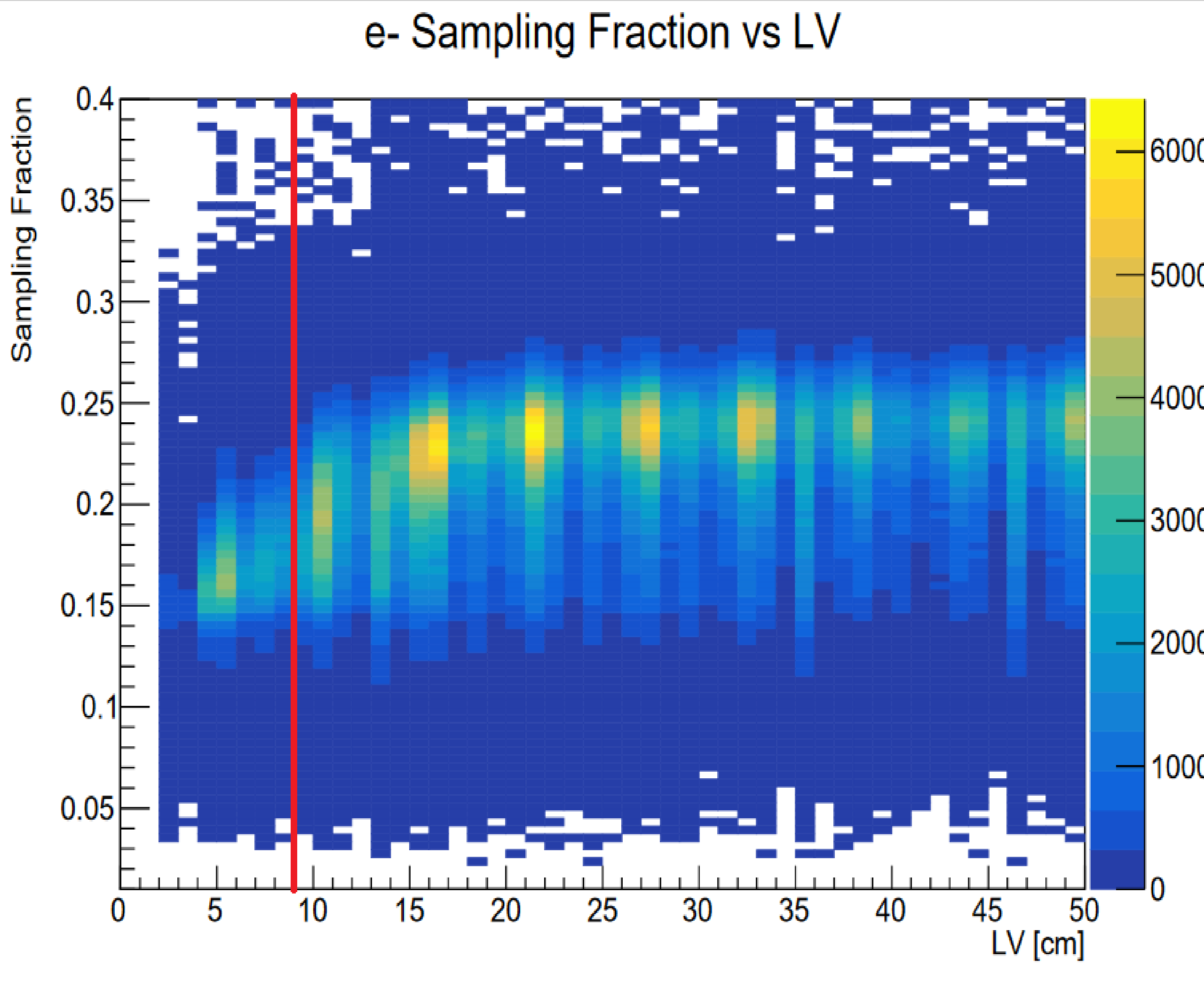
PID Refinement

- The RG-A Analysis Note defined a list of cuts to improve electron, positron and hadron identification:
  - Triangular cut on individual calorimeters sampling fraction (as shown).
  - 3.5σ cut on the sampling fraction parametrization.
  - 0.07 GeV minimum energy deposition in the PCAL cut.
  - Z-Vertex position cut.
  - 3.5σ chi2PID cut for the proton.

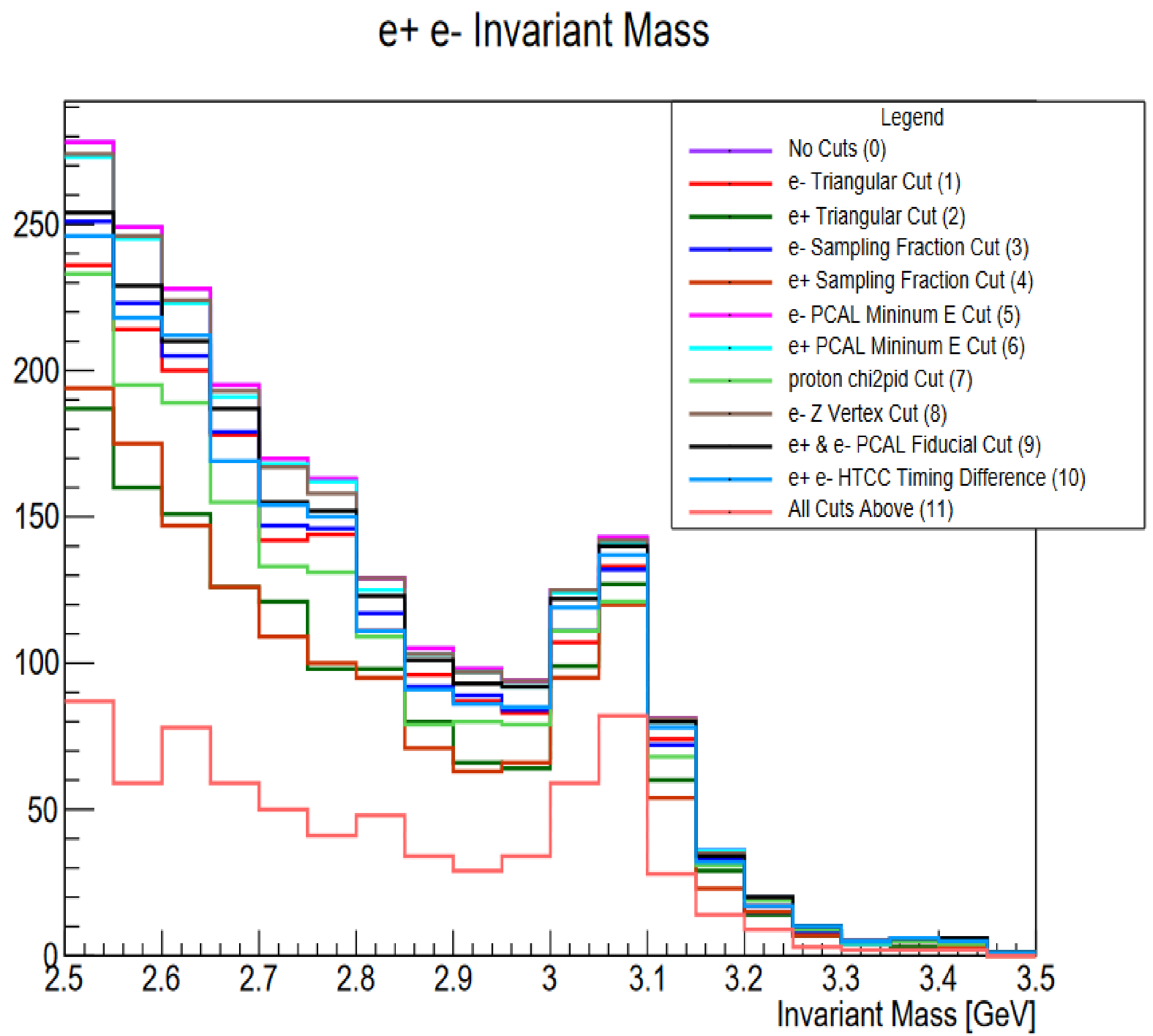


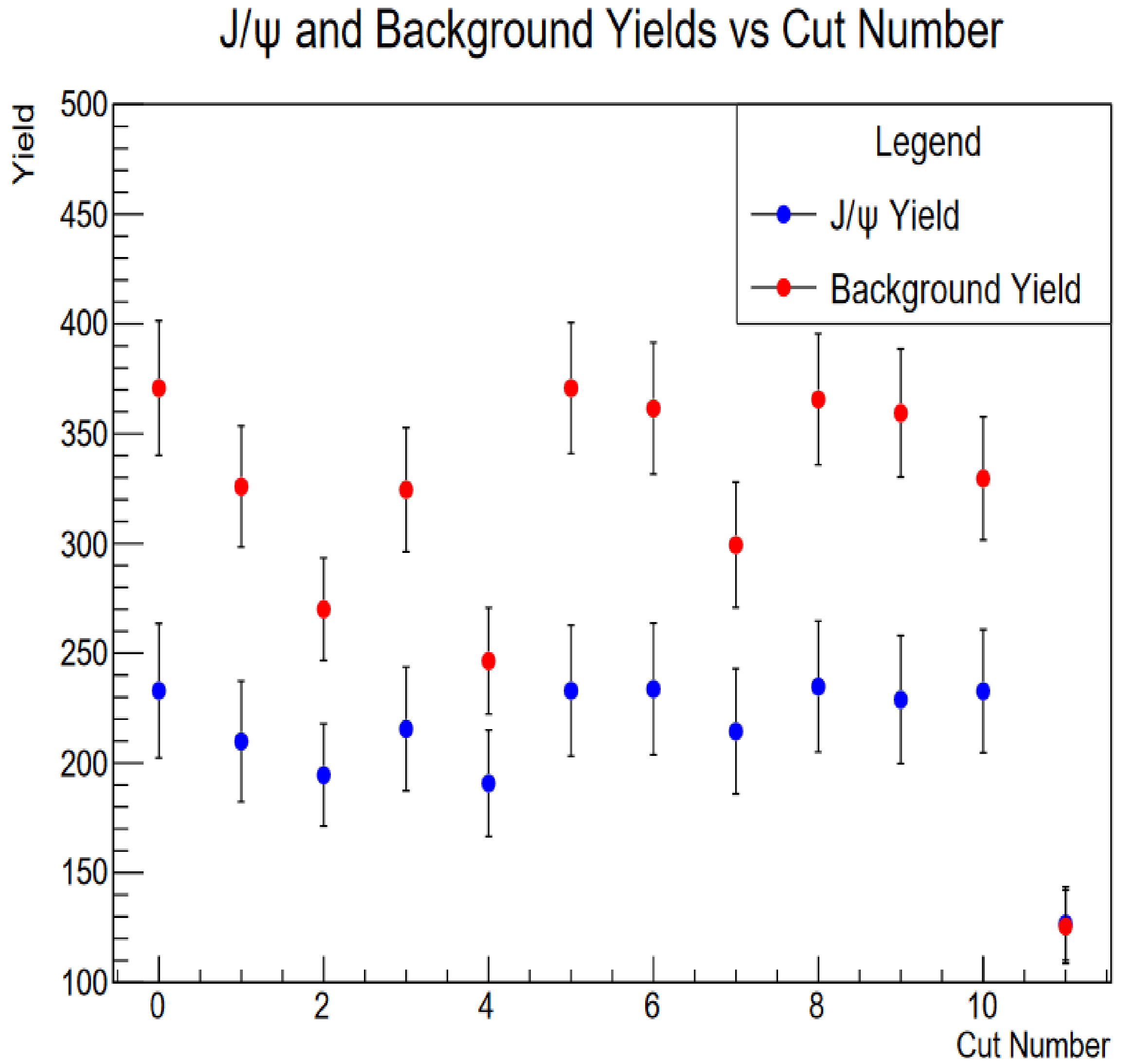
PCAL Fiducial Cuts

- If the electron hits close to the edges of the PCAL, the shower may not be fully contained within the calorimeter volume.
- This can lead to a wrong sampling fraction and reduced identification power for electrons and positrons.
- A proper cluster formation requires at least 1 bar (4.5 cm) distance to the edge so we place our cut at 2 bars (9.0 cm).
- Additional work is being done on electron PID and fiducial cuts for RG-B by Dien Nguyen and Andrew Denniston



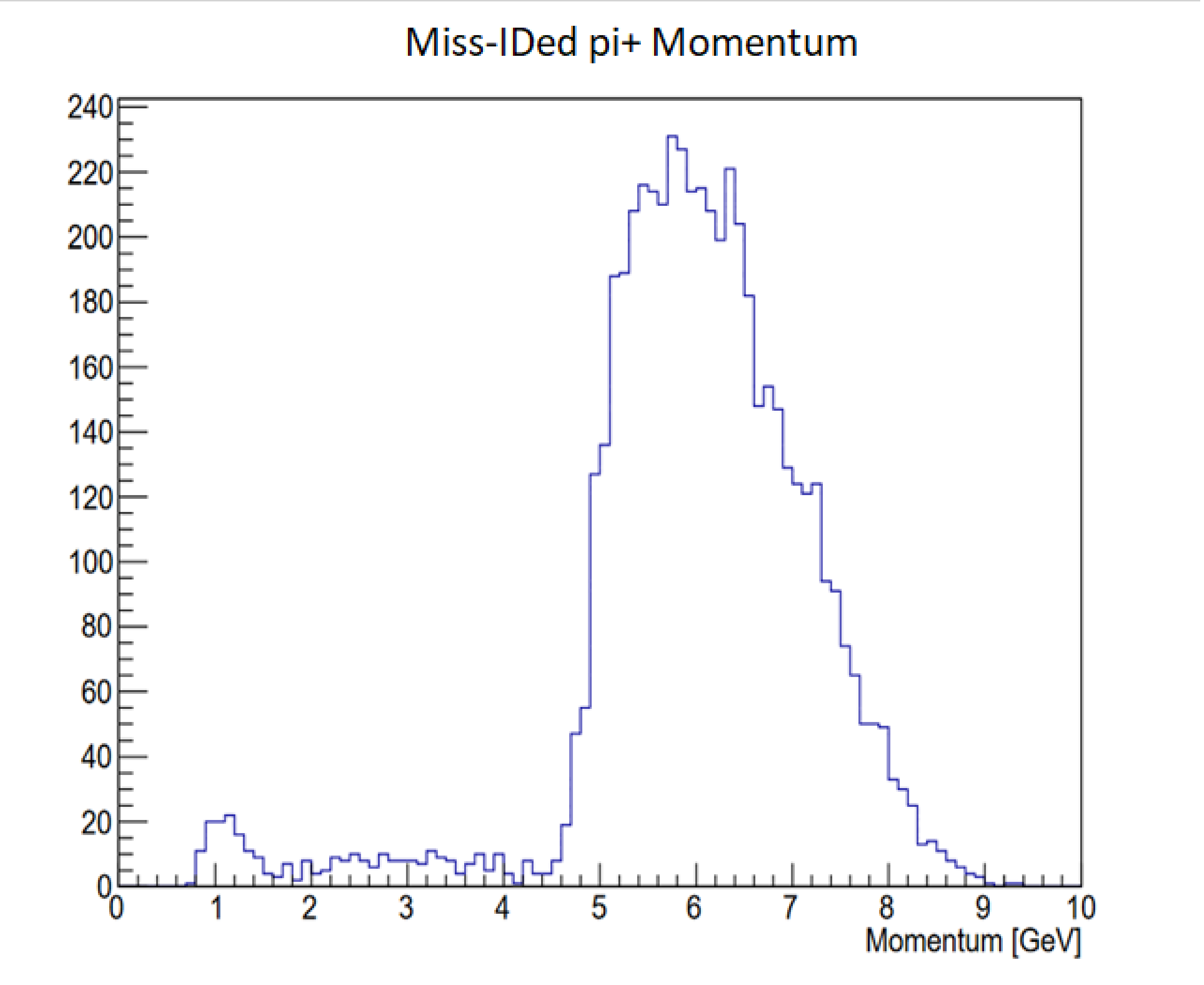
Effect of PID and Fiducial Cuts





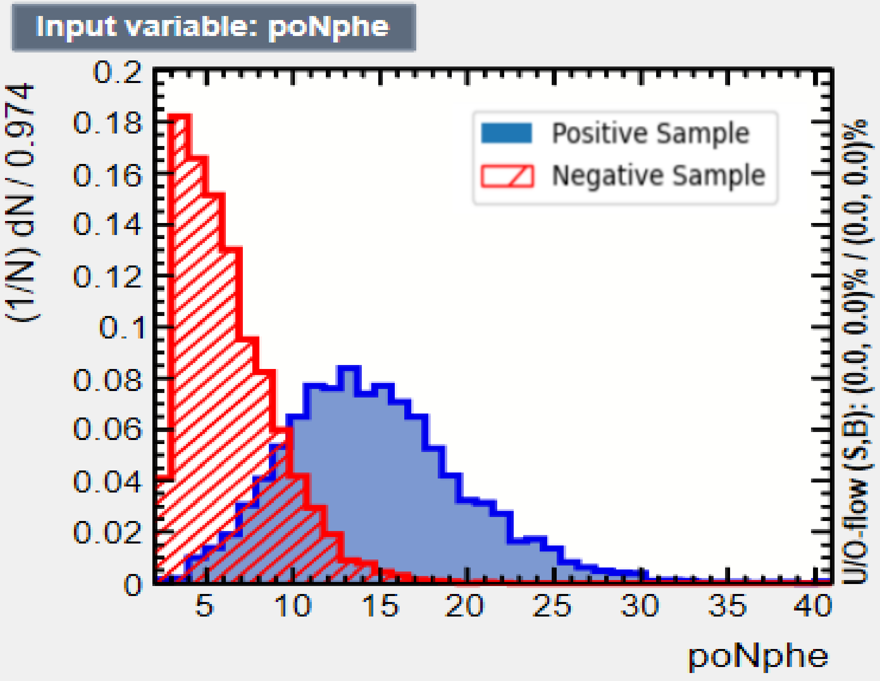
Positron ID Refinement

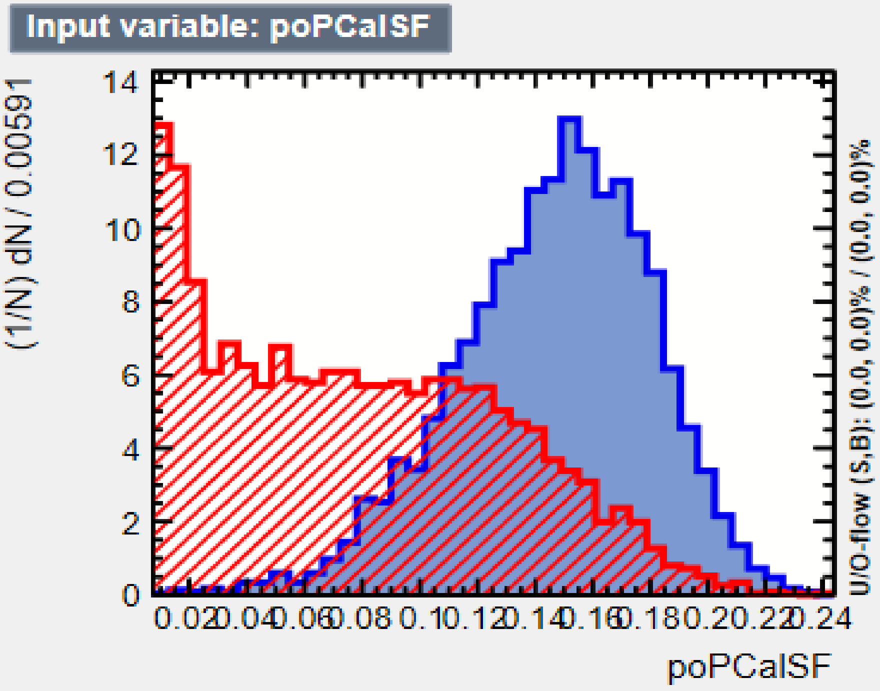
- From MC we see pions being miss-IDed as positrons above 4.5 GeV, due to the HTCC firing for high momentum pions.
- Train a multivariate classifier on MC data. The training is done with the ROOT TMVA software package.
- Our positive and negative training samples are then:
  - MC positron as signal training sample.
  - MC pion IDed as positron as background training sample.



Variables used for AI

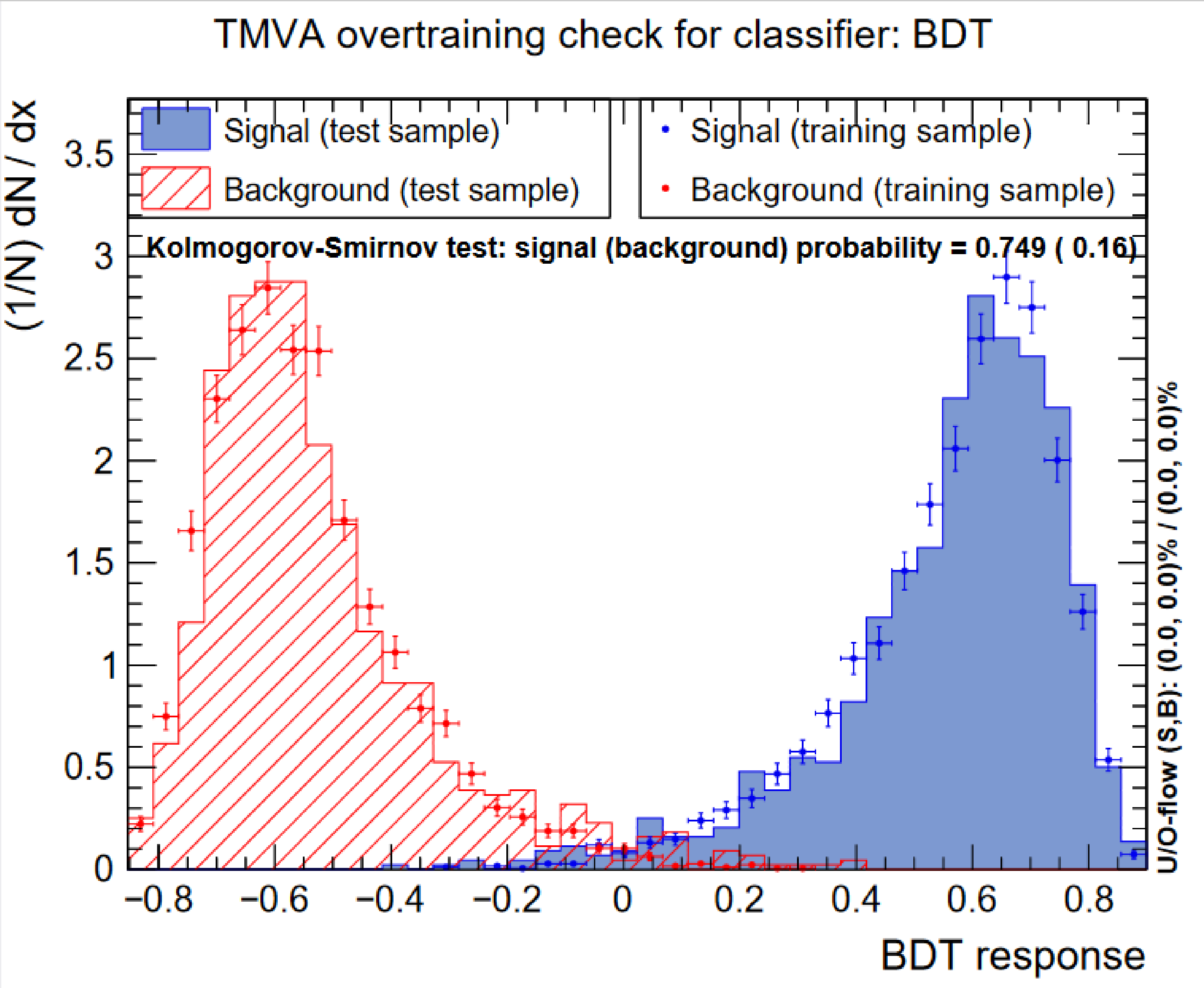
- High momentum pions are mis-identified as positrons as they produce photoelectrons in the HTCC.
- However, the distributions in, for example, the number of photoelectrons in the HTCC, or the PCAL sampling fraction, show notable differences.
- Our classifier will learn to recognise the distributions characteristic of pions and positrons in each of the following:
  - PCAL LU/LV/LW and M2U/M2V/M2W.
  - PCAL/ECIN/ECOUT energy depositions and individual calorimeter sampling fractions.
  - HTCC photoelectrons.





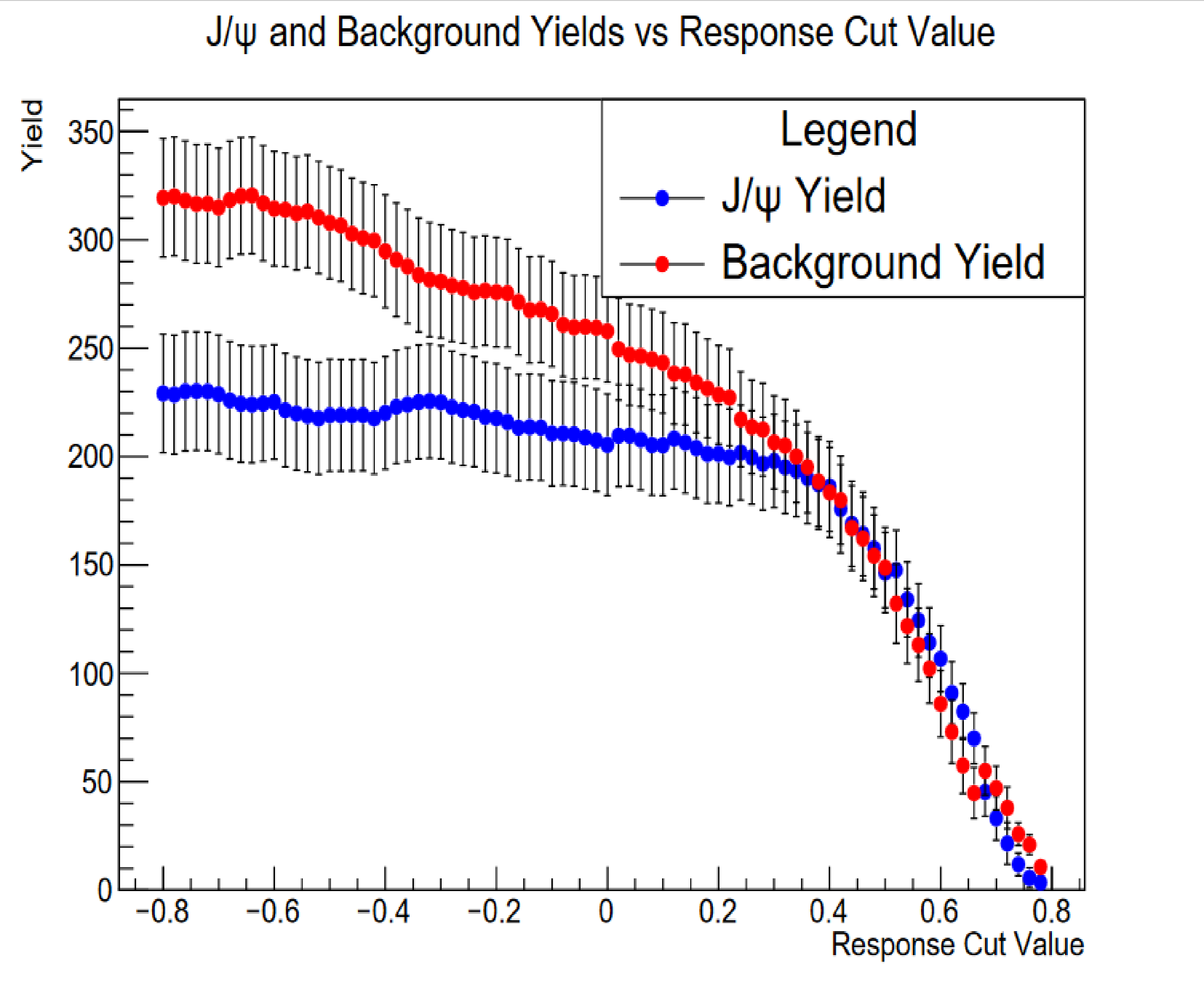
Response

- The classifier output is given as a probability of being a signal event. We call this probability the response.
- A perfect classifier would assign a response of 1 to all signal events and a response of 0 to all background events.
- The classifier effectively reduces the PID process down to a cut on the response.



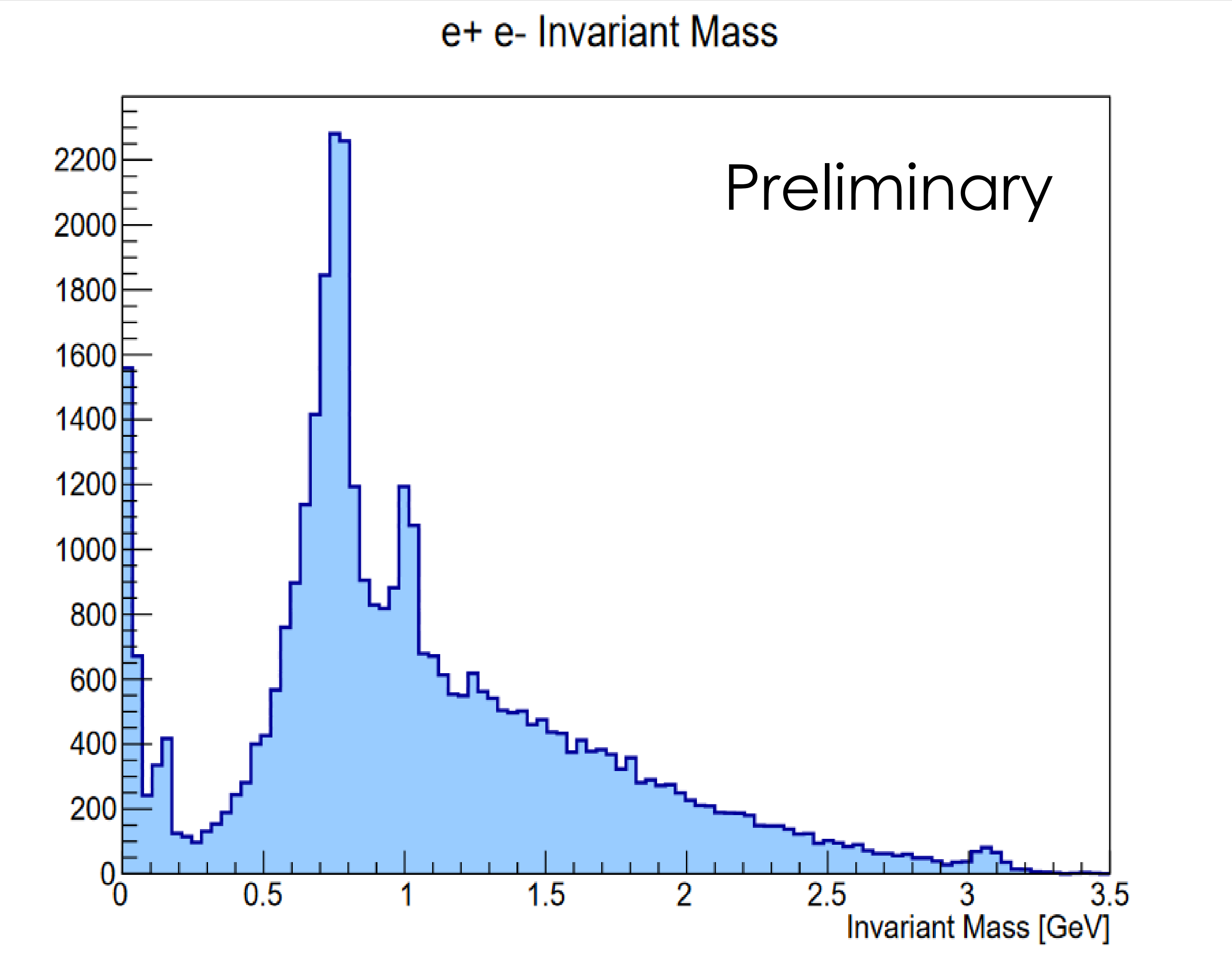
Cutting on the Response

- As we vary the cut on the response, we start to reject signal and background events.
- We can use this to evaluate the systematic error introduced by our cut.
- Here we chose to place this cut at 0.3.



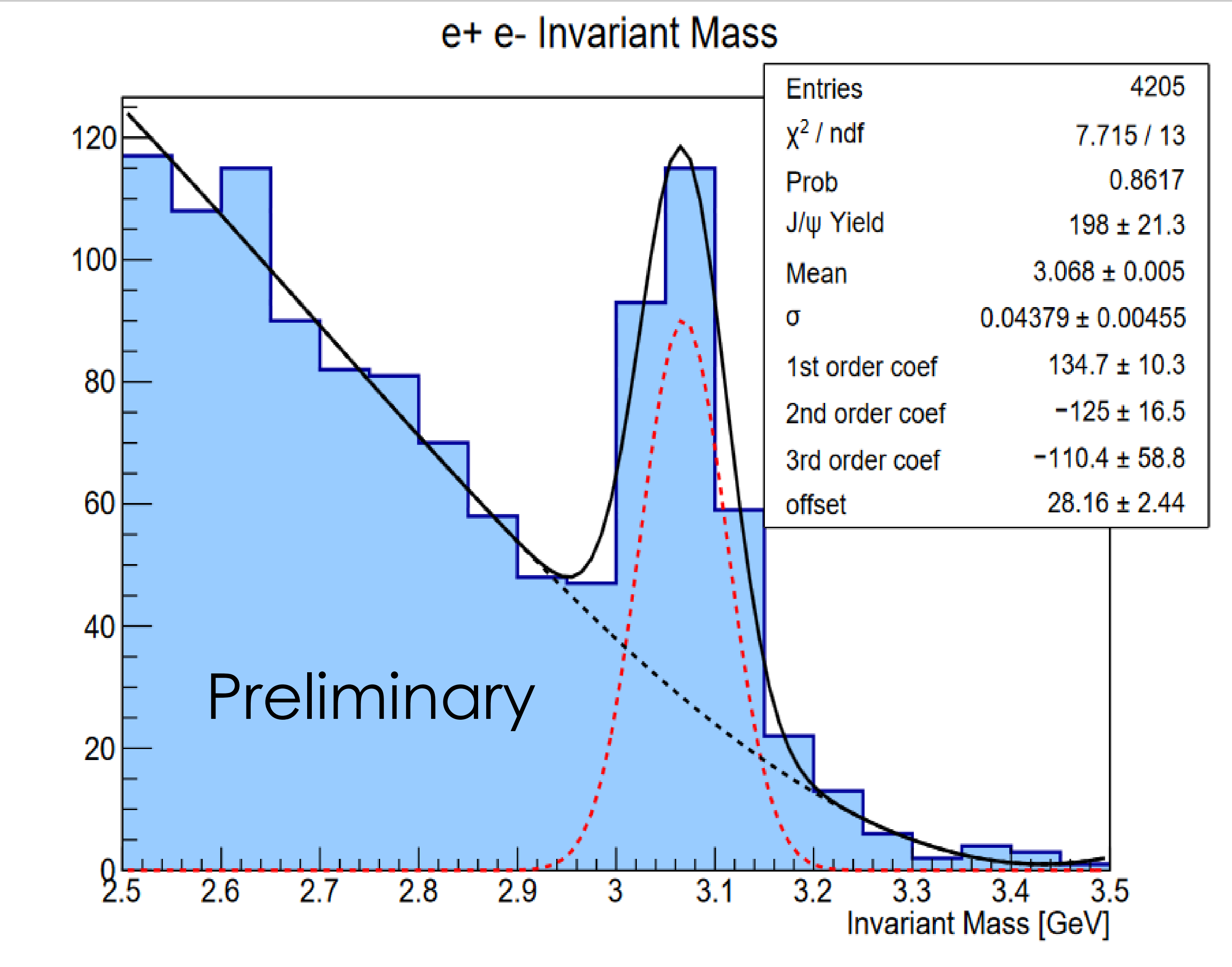
e+ e- Invariant Mass

- $|MM^2| < 0.2$ GeV ^{2}
- $Q^2 < 0.2$GeV ^{2}
- e+ PID response>0.3
- e+/e- PCAL Fiducial Cuts
- Proton and electron EB PID only



e+ e- Invariant Mass

- RG-A has J/ ψ yields:
  - 200 ± 21 in the fall2018 dataset for an accumulated charge of 60 mC at 10.6 GeV.
  - 58 ± 9 in the spring2019 for an accumulated charge of 54 mC at 10.2 GeV.
- The total accumulated charge of the spring2019 RG-B runs was 80 mC at 10.6 and 10.2 GeV.



Conclusion and Next Steps

- The analysis for J/ψ photoproduction in the $e^+e^-\mathrm{p}$ final state with RG-B data is well advanced. Calculating the total and differential cross sections will provide a healthy cross check to RG-A measurements.
- This analysis needs to be repeated for the $e\, n_{bound} \rightarrow (\mathrm{e}')e^+e^-\mathrm{n}$ channel. The main complications will be due to neutron efficiency and reconstruction.

References

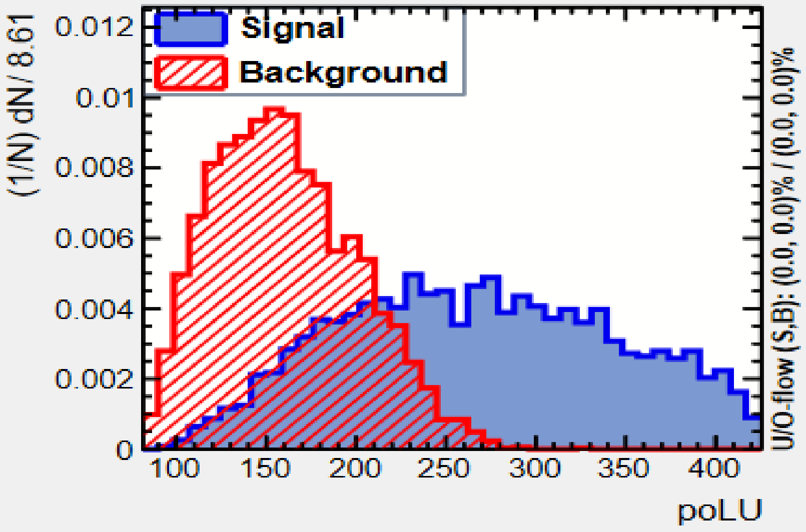
[1] R. Aaij et al. (LHCb Collaboration), Observation of a narrow pentaquark state, $P_c(4312)^+$, and of two-peak structure of the $P_c(4450)^+$, *Phys. Rev. Lett.* **122** 22 (2019).

[2] A. Ali et al (GlueX Collaboration), First measurement of near-threshold J/ψ exclusive photoproduction off the proton, *Phys. Rev. Lett.* **123** 072001 (2019).

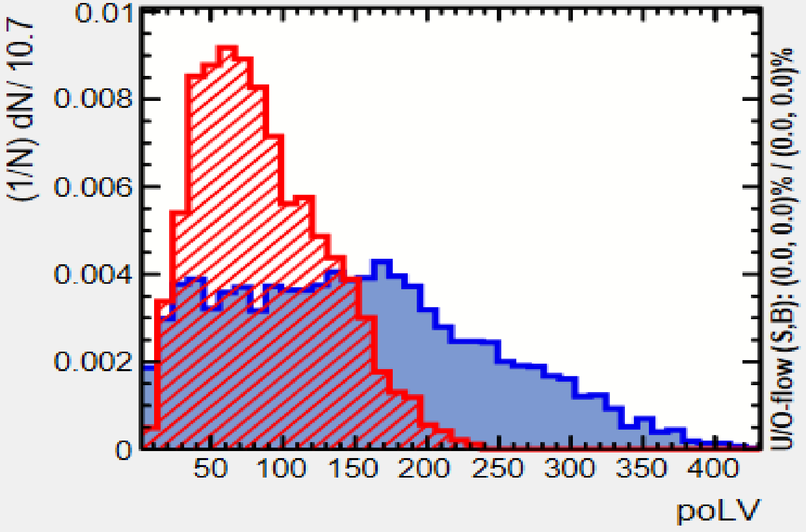
Backup Slides

All training Variables I

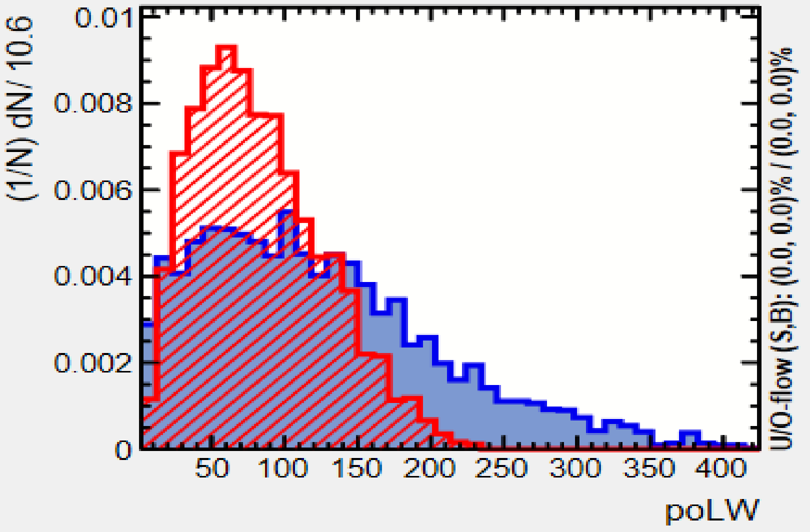
Input variable: poLU



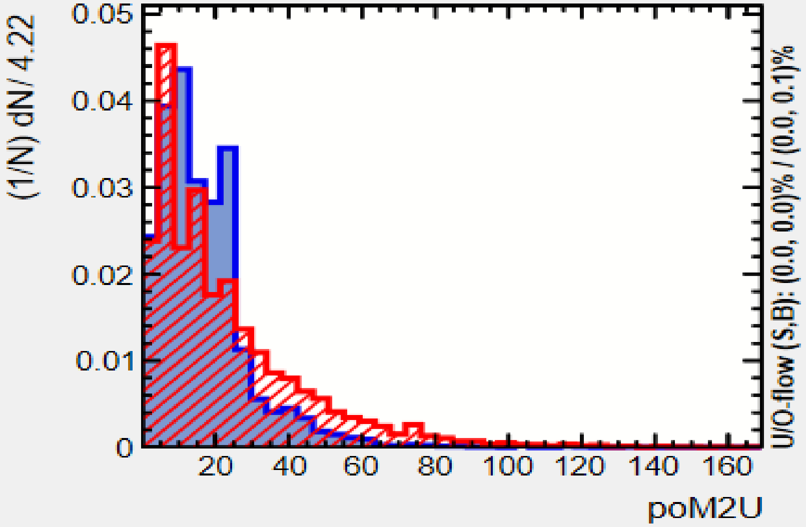
Input variable: poLV



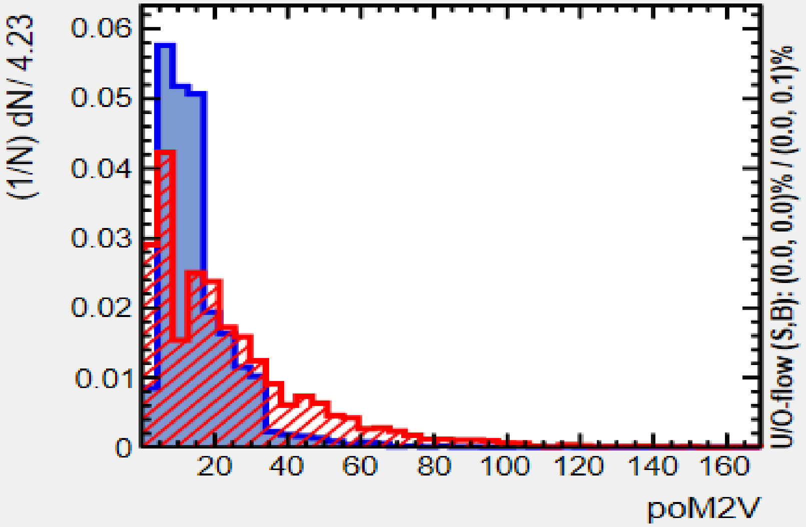
Input variable: poLW



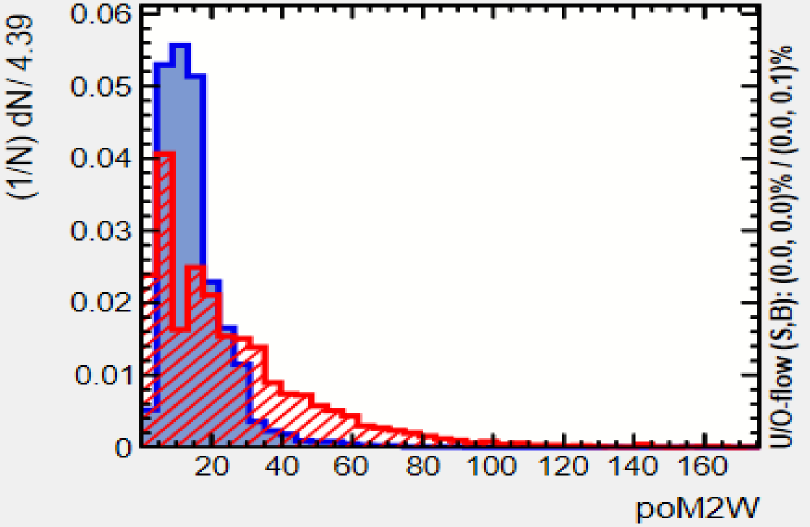
Input variable: poM2U



Input variable: poM2V



Input variable: poM2W



All training Variables II