# $J/\psi$ Photoproduction Near Threshold With CLAS12

Joseph Newton
Old Dominion University

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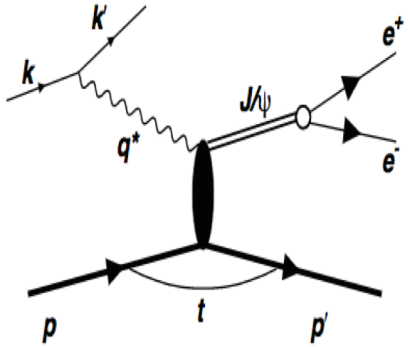
# Experiment Overview

**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/$\psi$

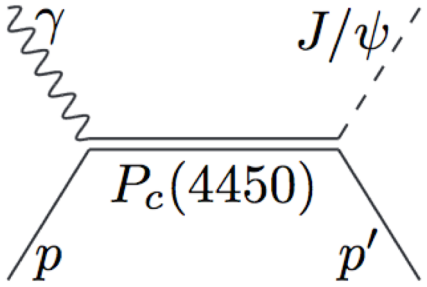
- Experiment 12-12-001 was approved for 120 days of beamtime on CLAS12 at a luminosity of $10^{35}$ cm$^{-2}$ s$^{-1}$




**Physics Goals**

- Probe the distribution of color charge in the nucleon
  - Measure the t-dependence of the differential cross section of J/$\psi$ photoproduction

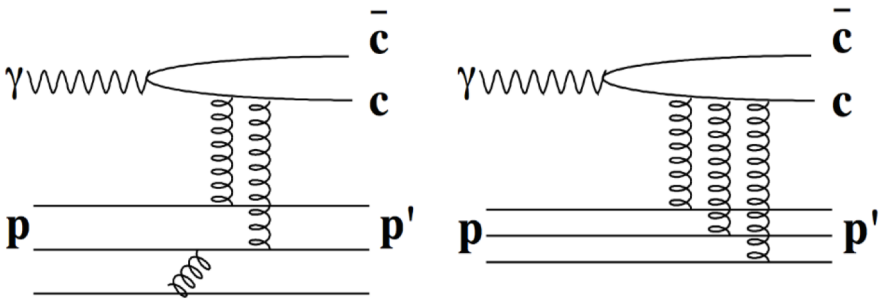
- Study the production mechanism of J/$\psi$ near threshold
  - Measure the total cross section as a function of photon energy



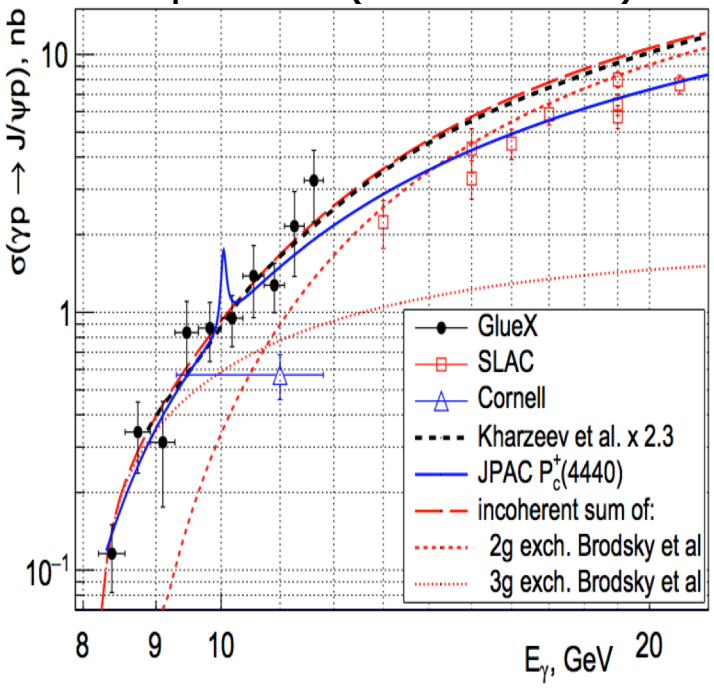

- Verify the existence of LHCb pentaquark through s-channel J/$\psi$ production

# Proposed Models For J/$\psi$ 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/$\psi$. This will allow the study of gluonic form factors of the proton




**GlueX Published Cross Sections of J/$\psi$ Photoproduction (arXiv:1905.10811)**

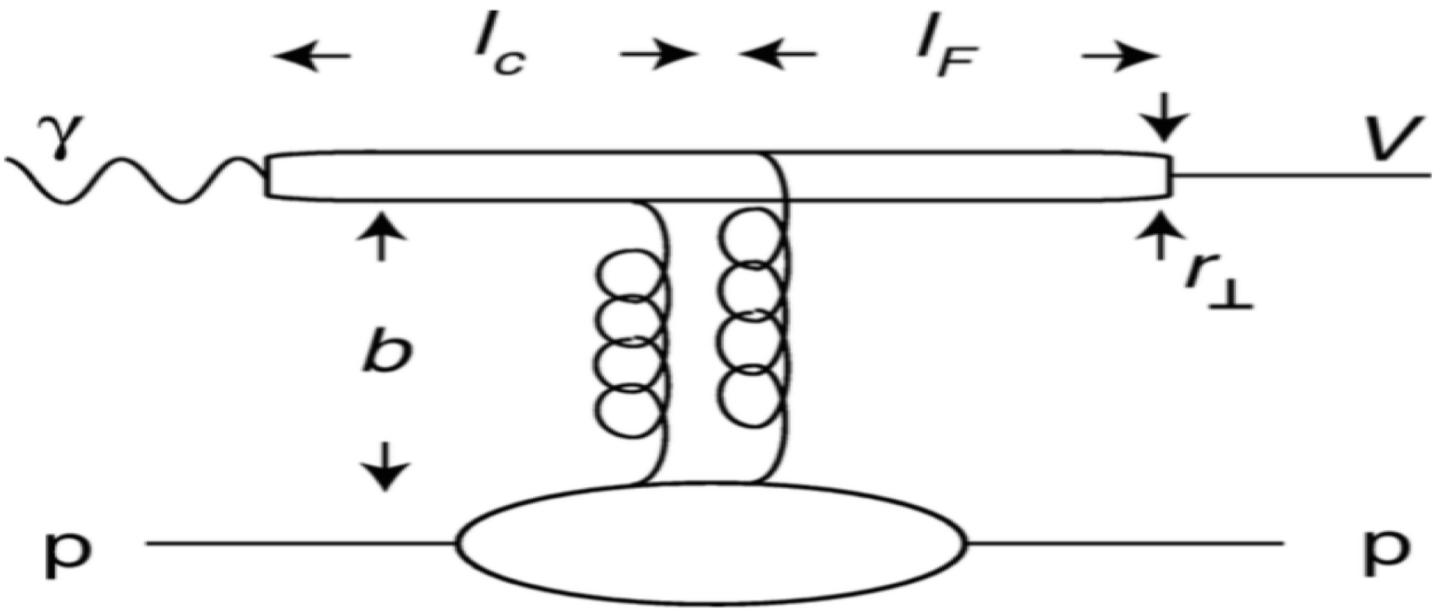



$$\frac{d\sigma}{dt} = N_{2g}\frac{(1-x)^2}{R^2M^2}F_{2g}^2(t)(s-m_p^2)^2$$

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


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

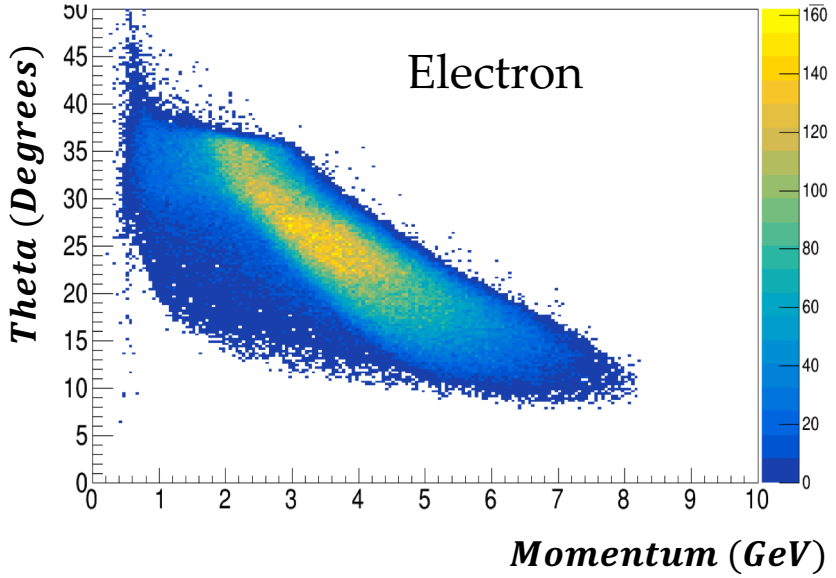
# Vector Meson Dominance Model

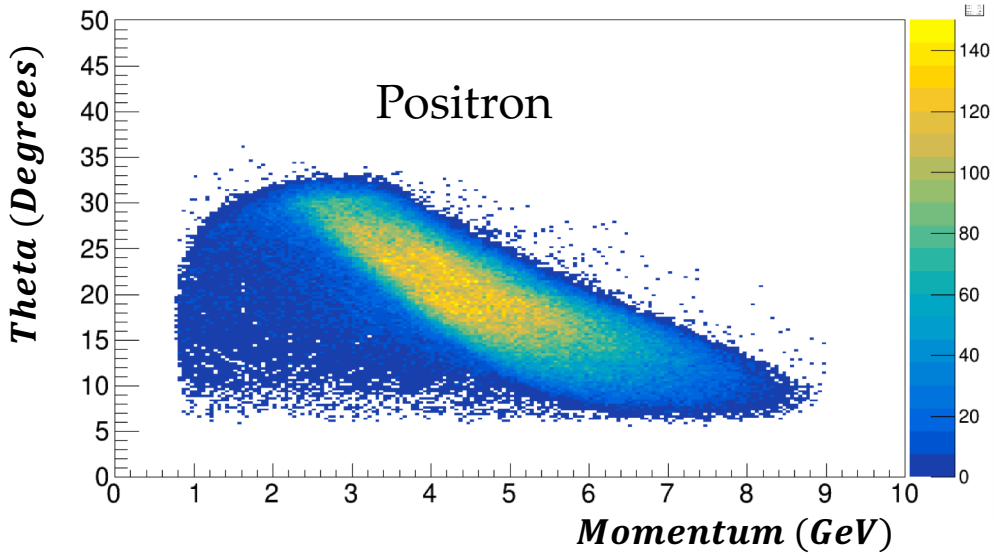


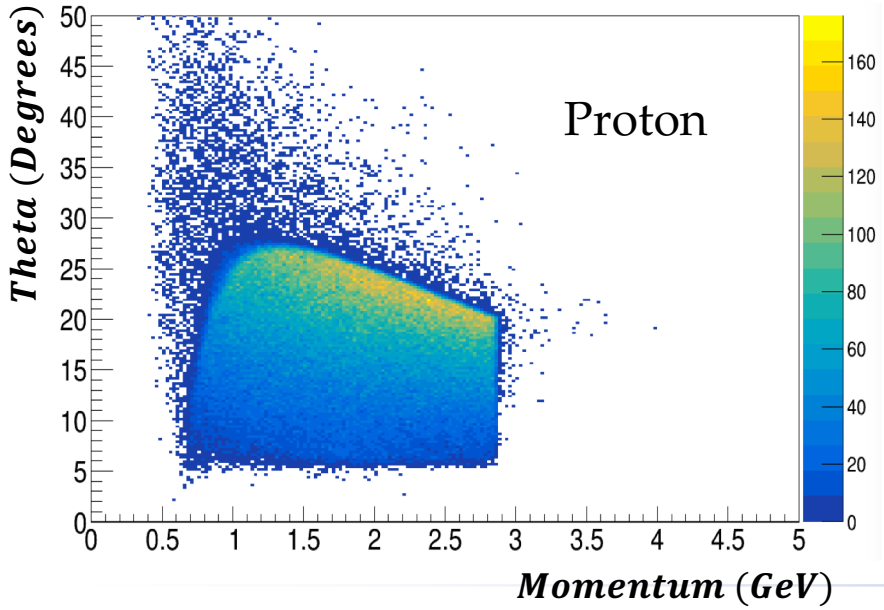

S.J. Brodsky, E. Chudakov, P. Hoyer, and J.M. Laget. Phys. Rev. Lett. (2008)

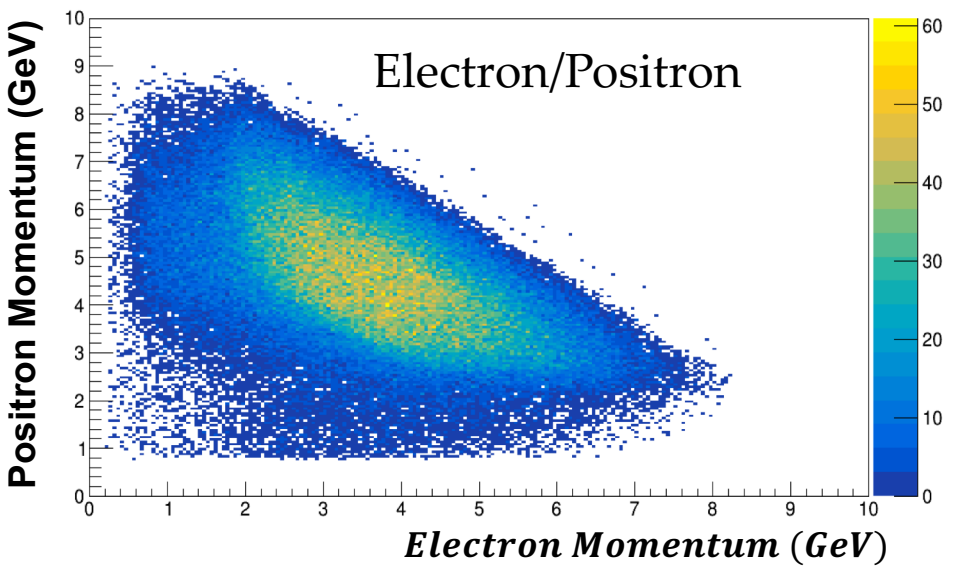
The impact parameter is $b \sim 0.2\ fm$
The transverse size is $r_\perp \sim 0.13\ fm$
The longitudinal coherence length is $l_c \sim 0.36\ fm$

# Simulation and Reconstruction of $ep \rightarrow J/\psi\, p\,(e') \rightarrow e^+e^-p(e')$

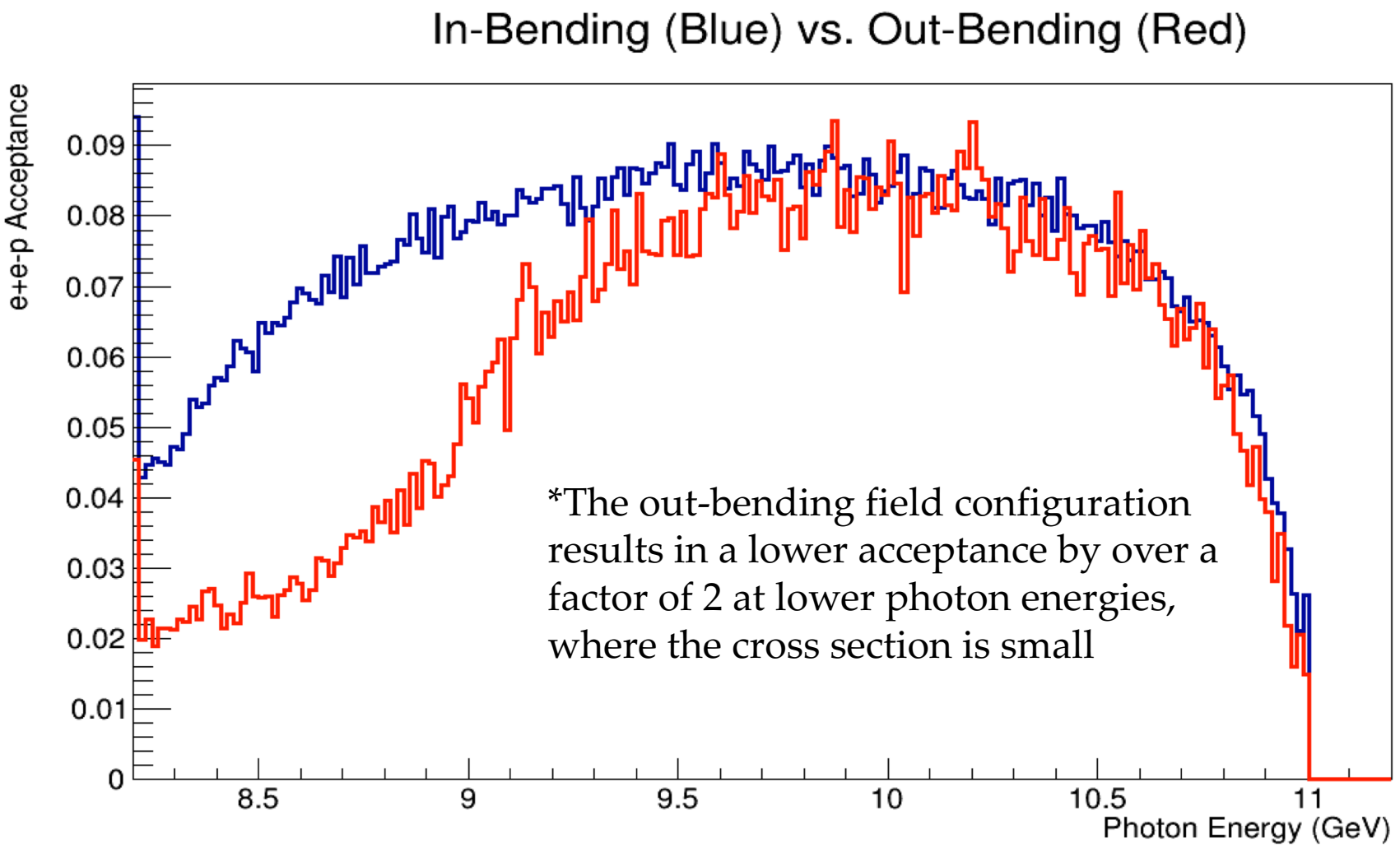


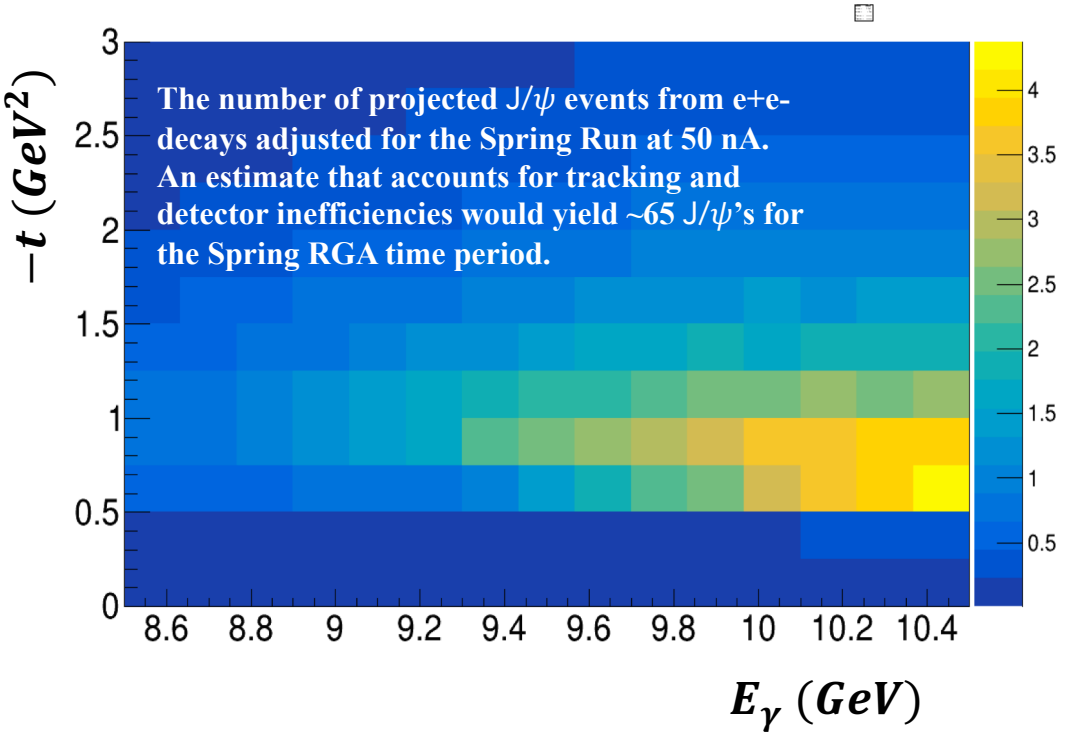
# Geometrical Acceptances Using GEMC



# Calculation of Detection Rate

With a large event sample, it is possible to predict J/$\psi$ detection rates and geometrical acceptances in various areas of phase space. The normalization terms are the integrated luminosity for the spring run as well as a conservative cross section estimate, photon flux, and the branching ratio, the detection rate can be calculated.

$$N_{events} = \frac{L_{T15} * \frac{d\sigma}{dt} * psf * \gamma * N(rec) * 0.06}{N(gen)}$$



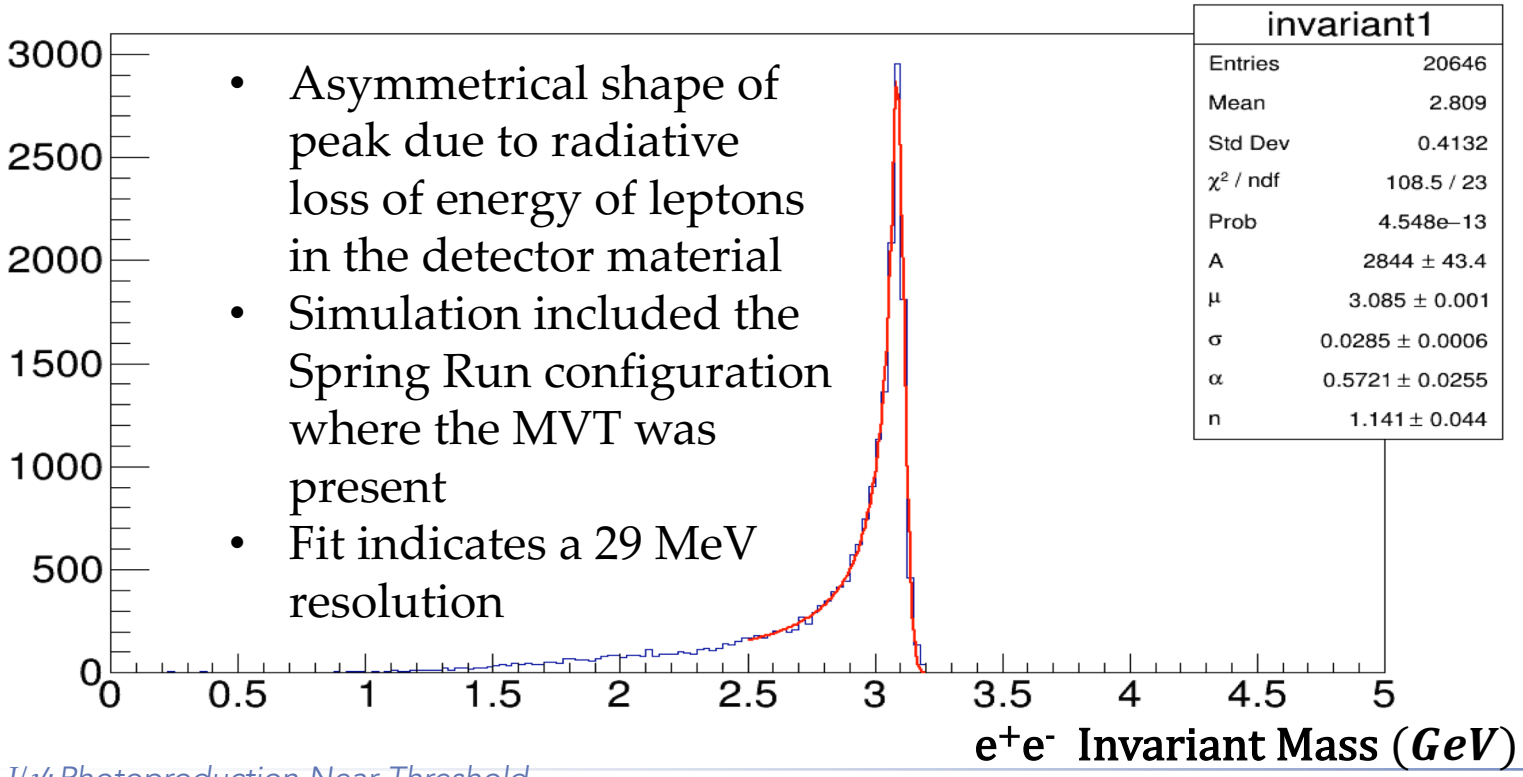

$L_{T15}$ is the integrated luminosity for 15 days at 50 nA
$\frac{d\sigma}{dt}$ is the differential cross section
$psf$ is the phase space factor
$\gamma$ is the photon flux factor
0.06 is the branching ratio

# Invariant Mass Fitting Procedure

Analysis of the J/$\psi$ resonance peak highlights the overall resolution of the final reconstruction quality as well as the quantification of radiative losses of leptons in the CLAS12 detector material.

$$f(x;\alpha,n,\bar{x},\sigma) = N \cdot \begin{cases} \exp\left(-\frac{(x-\bar{x})^2}{2\sigma^2}\right), & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha \\ A \cdot \left(B - \frac{x-\bar{x}}{\sigma}\right)^{-n}, & \text{for } \frac{x-\bar{x}}{\sigma} \leqslant -\alpha \end{cases}$$

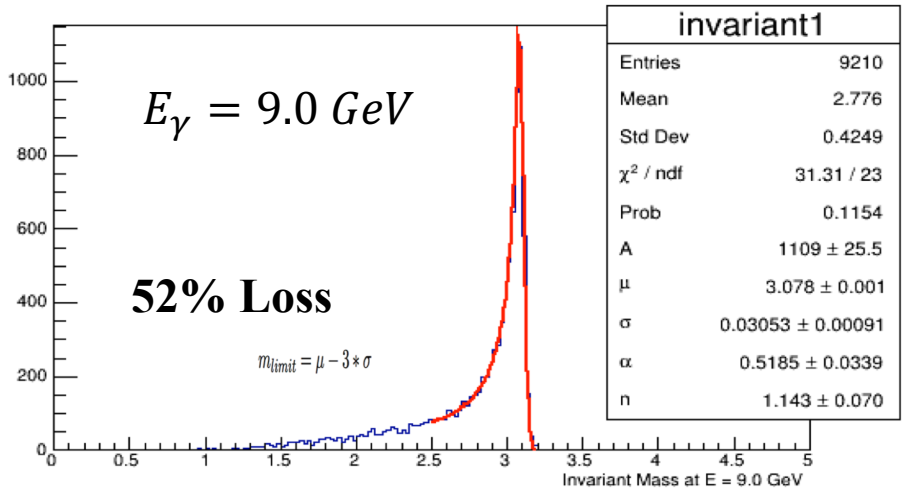
Introduced by the Crystal Ball Collaboration, this functional form is a piece-wise function with a Gaussian on the right, but a power-law function on the left

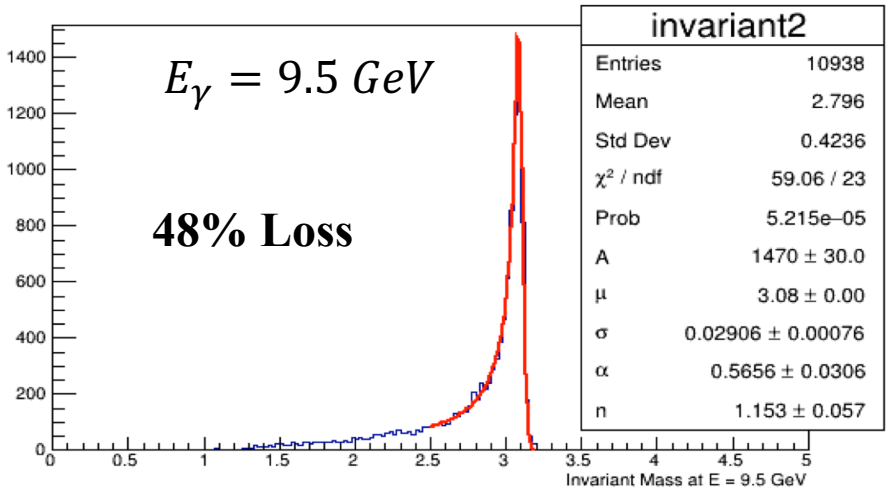


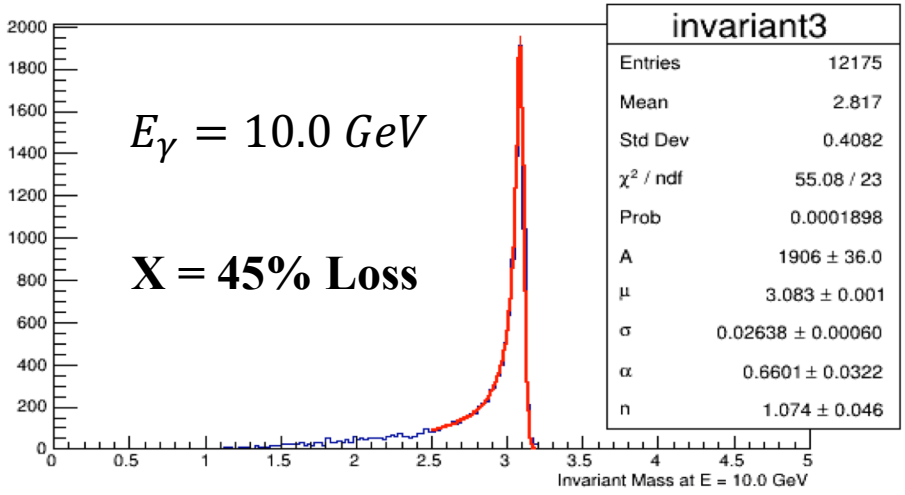

- Asymmetrical shape of peak due to radiative loss of energy of leptons in the detector material
- Simulation included the Spring Run configuration where the MVT was present
- Fit indicates a 29 MeV resolution

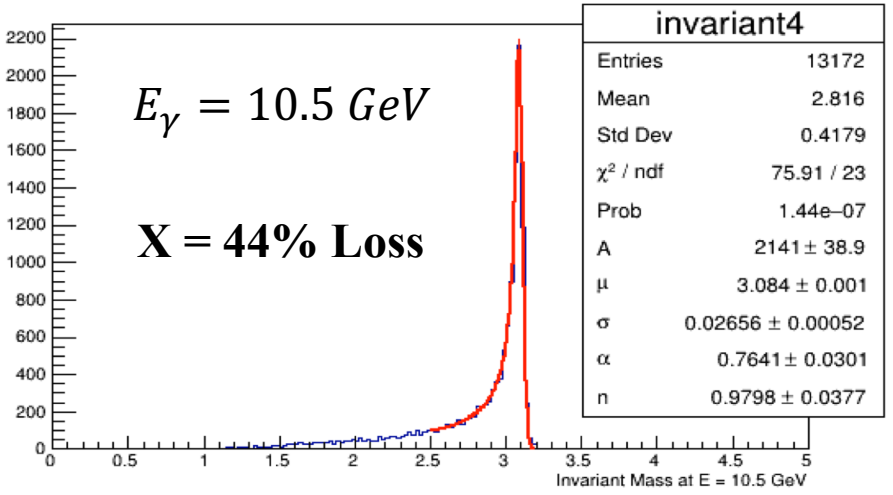
# Quantifying J/ψ Radiation Loss

The asymmetric resonance is due to the loss energy of electrons due to radiative effects due to the presence of the FMT. To quantify that loss, cuts were imposed on the energy at 3 sigmas less than the fitted invariant mass mean



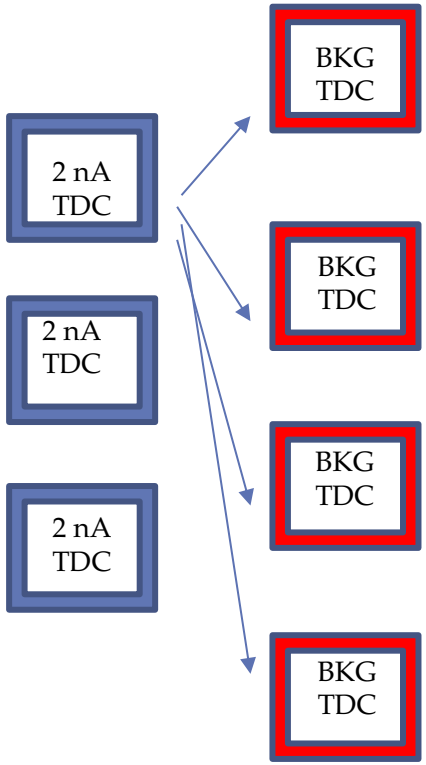



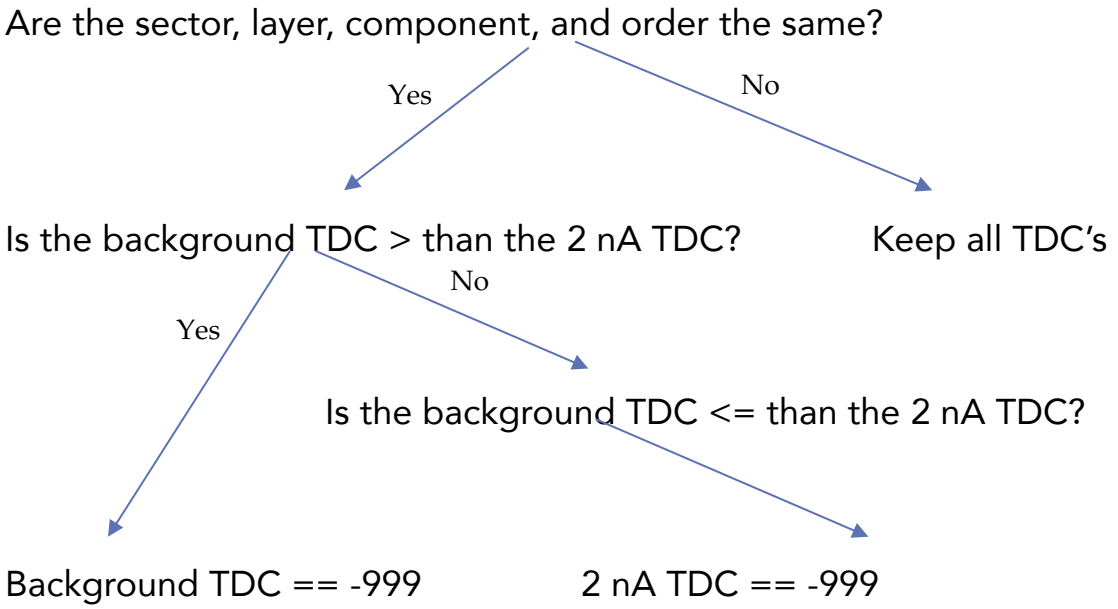



# Validation of Background Merging

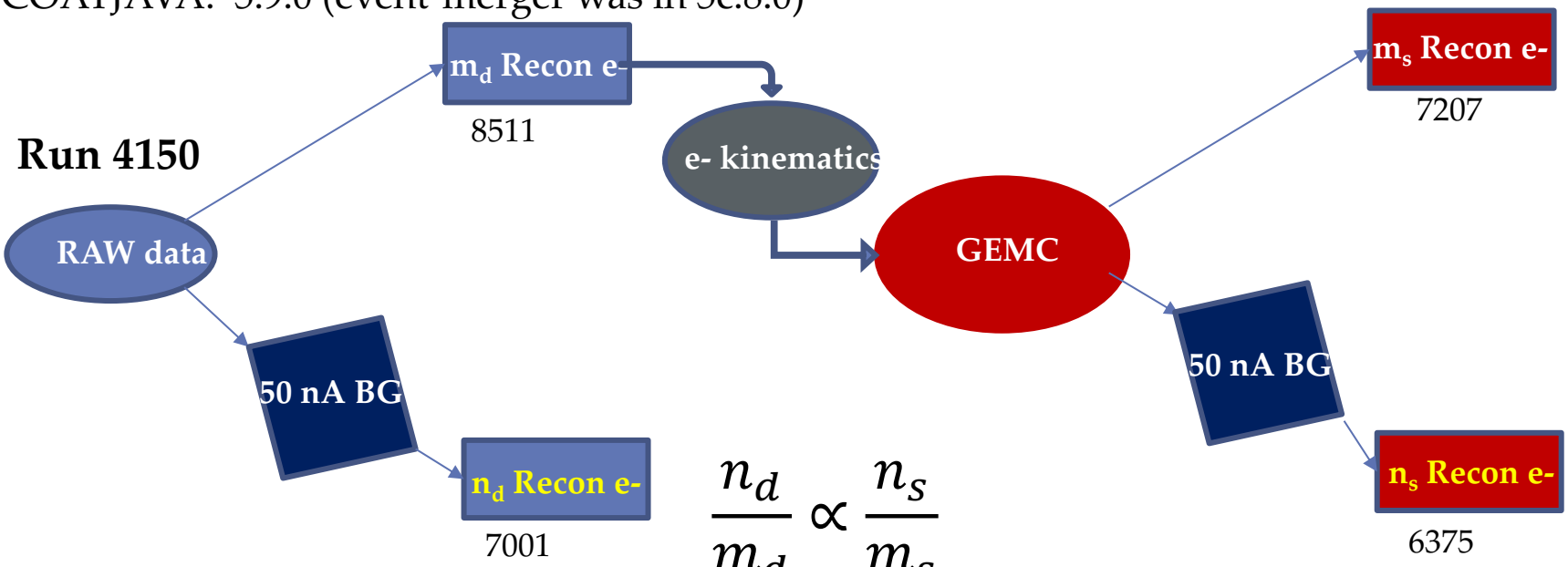
- For cross section measurements, the reconstruction efficiency of the CLAS12 forward detector has to be studied in great detail. Previous calculations of the acceptance were done in absence of background and this process must be validated.



# Validation of Background Merging (continued)

- GEMC: 4.3.0
- COATJAVA: 5.9.0 (event-merger was in 5c.8.0)

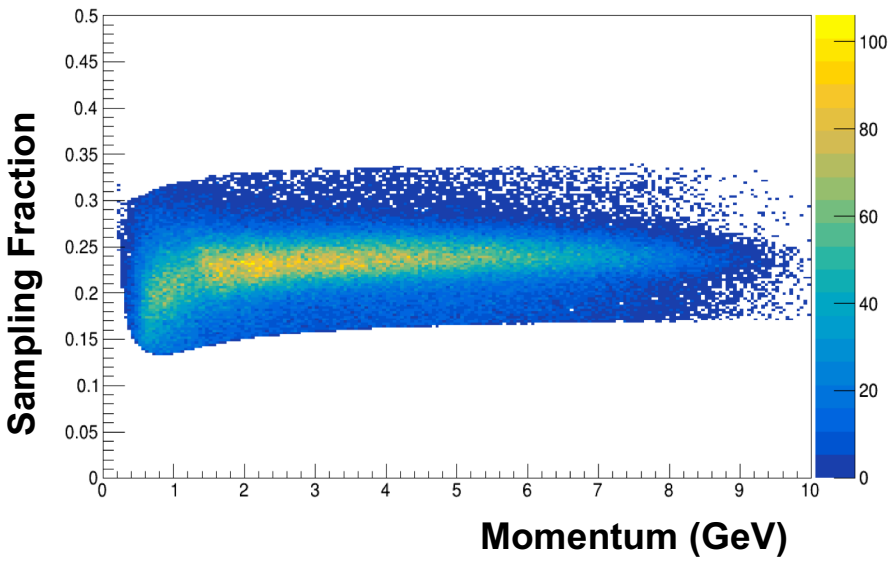


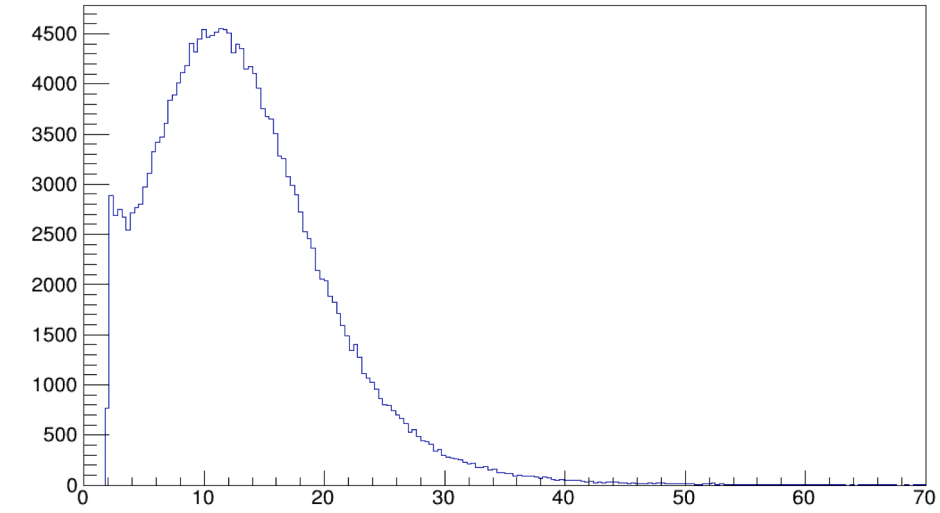

$$\frac{n_d}{m_d} \propto \frac{n_s}{m_s}$$

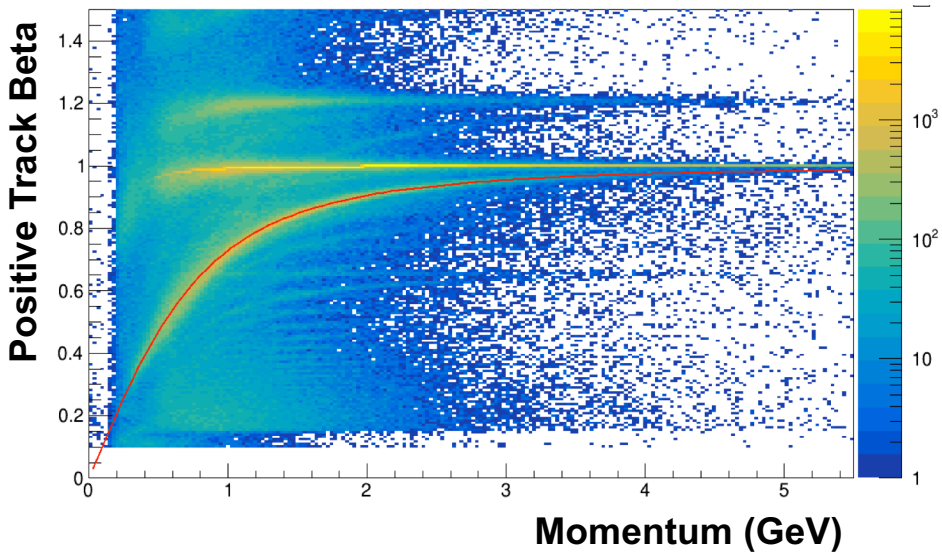
$$\frac{n_{d,e-}}{m_{d,e-}} = 0.82 \qquad \frac{n_{s,e-}}{m_{s,e-}} = 0.88 \qquad \frac{n_{s,-}}{m_{s,-}} = 0.90$$

*Simulations without background merging will include tracking reconstruction inefficiency. Background merging with simulations must be used to calculate detector efficiencies correctly and this merging process must be validated.

# Particle Identification

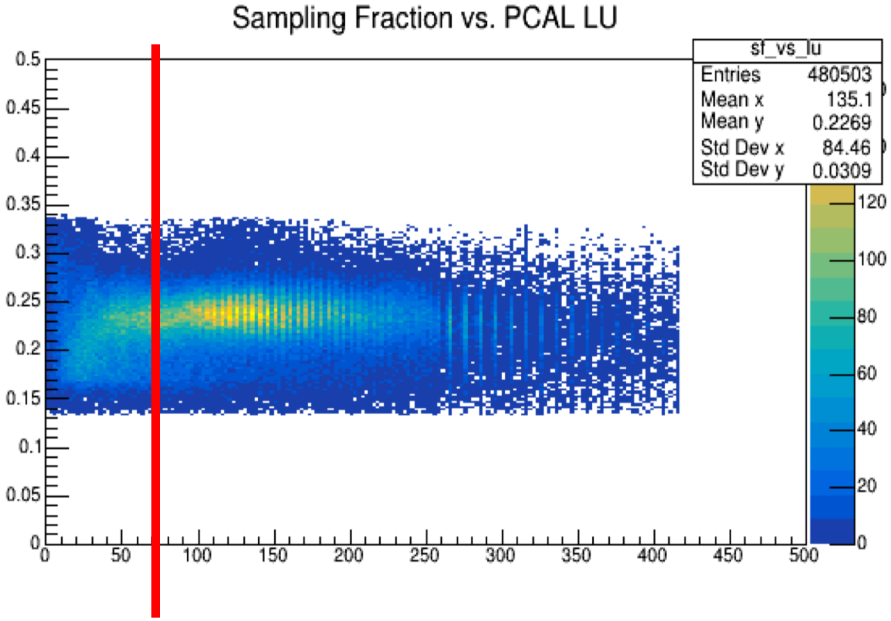


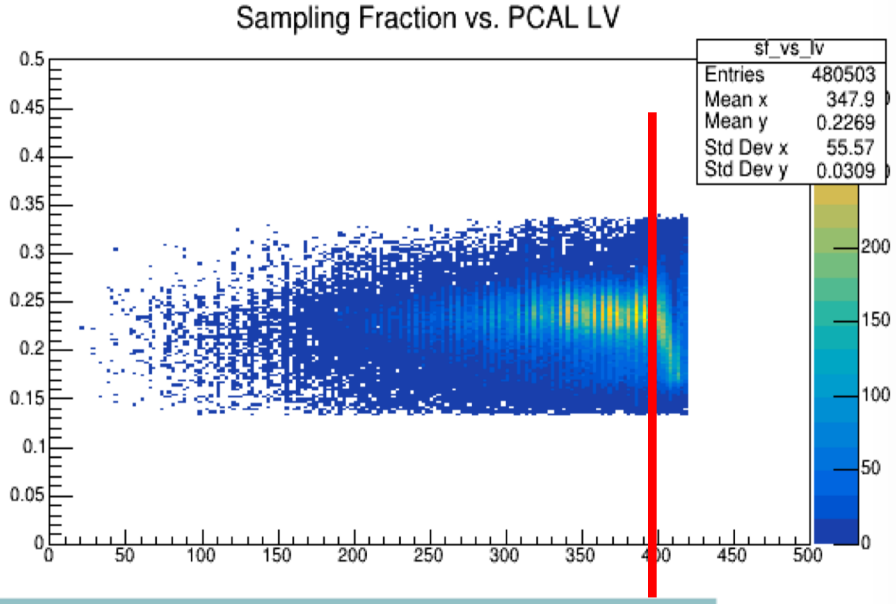



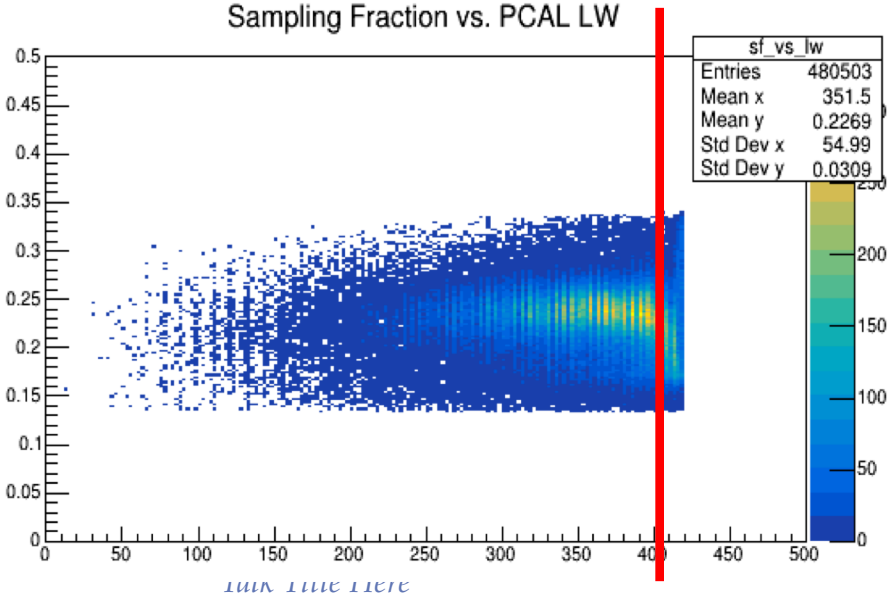



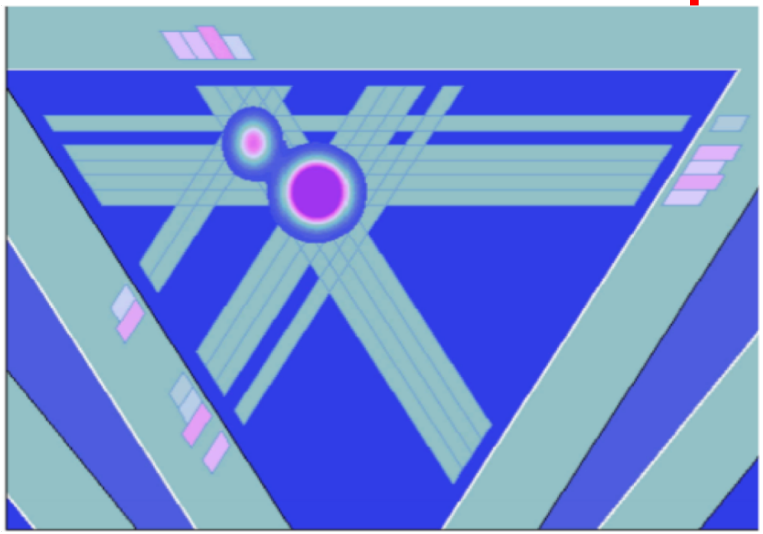

*For p < 4.9 GeV, electrons and positrons are identified using 3-sigma cuts on the sampling fraction parametrization as well as a HTCC cut of 2 photoelectrons.
*For p > 4.9 GeV, electron and positron identification will rely on the shower profile analysis
*Protons are identified by comparing charged particle velocity with expected velocity assuming the mass of the proton

# Developing Fiducial Cuts on the Electromagnetic Calorimeter



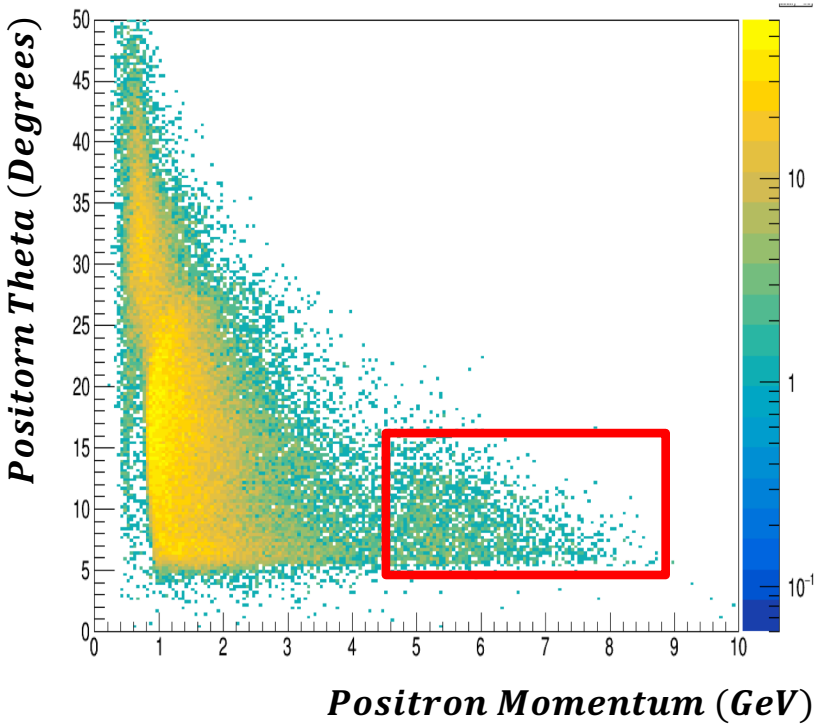



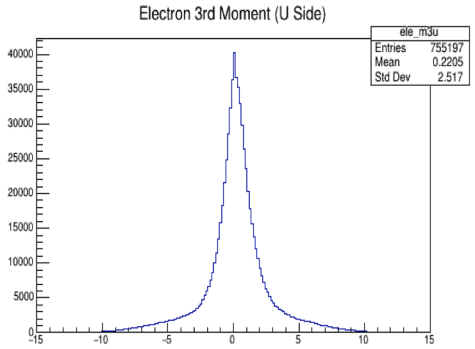



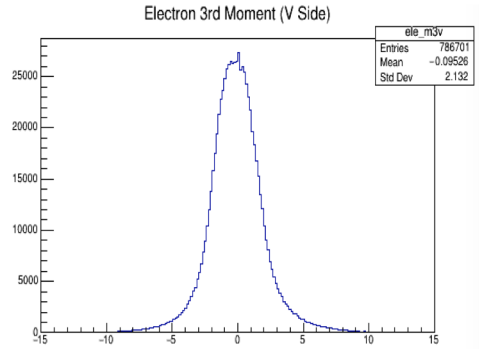
The lu, lv, and lw variables are the distances from the peak positions to the edges

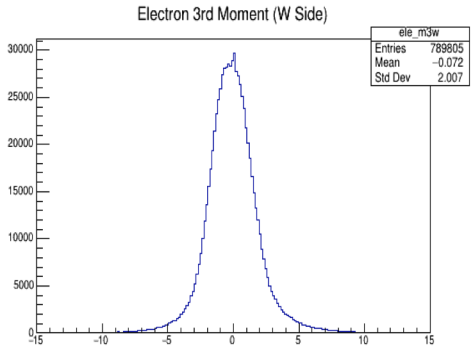
# Key Issue: Pion Contamination In Positron Sample

- Since the HTCC pion threshold is at 4.9 GeV, procedures must be developed to distinguish electromagnetic and hadronic showers
- 2nd and 3rd moments can be used to separate pions and positrons
- As seen in RG-A data, pions can be viewed in positron kinematic plot without cuts on shower profile analysis




For example, these are PCAL's reported 3rd momenta for electrons

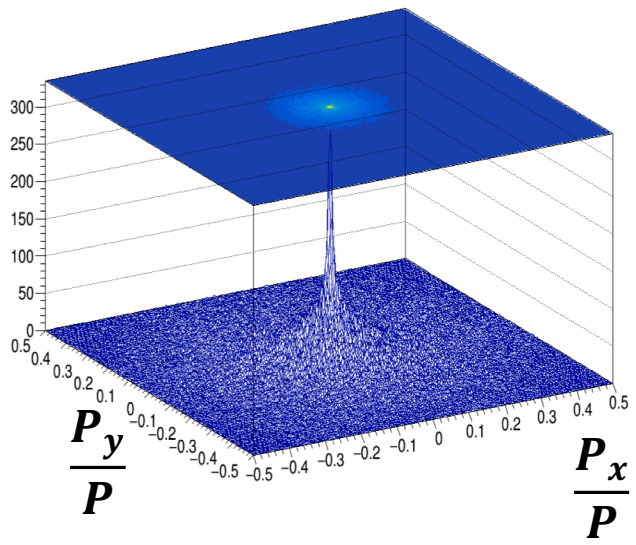
$$\mu^3 = \frac{\sum (x_{ch} - \hat{x})^3 * \omega^3}{\sigma^3}$$

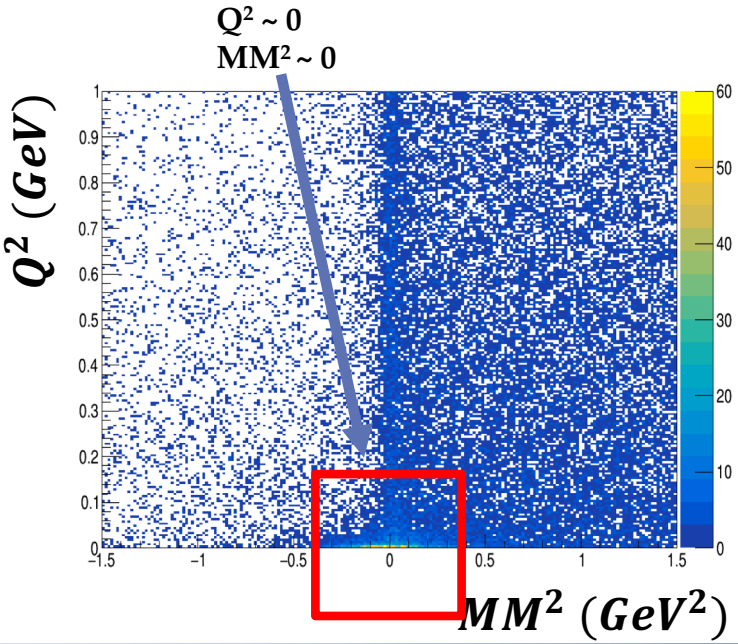
# Event Selection Criteria

- The missing momentum analysis will be done to reconstruct the kinematics of the un-detected scattered electron.
- Cuts on the transverse missing momentum, $Q^2$, and the square of the missing mass will be used to select quasi-real photoproduction events.

$$ep \rightarrow e^+e^-p'X \qquad X = e^-$$

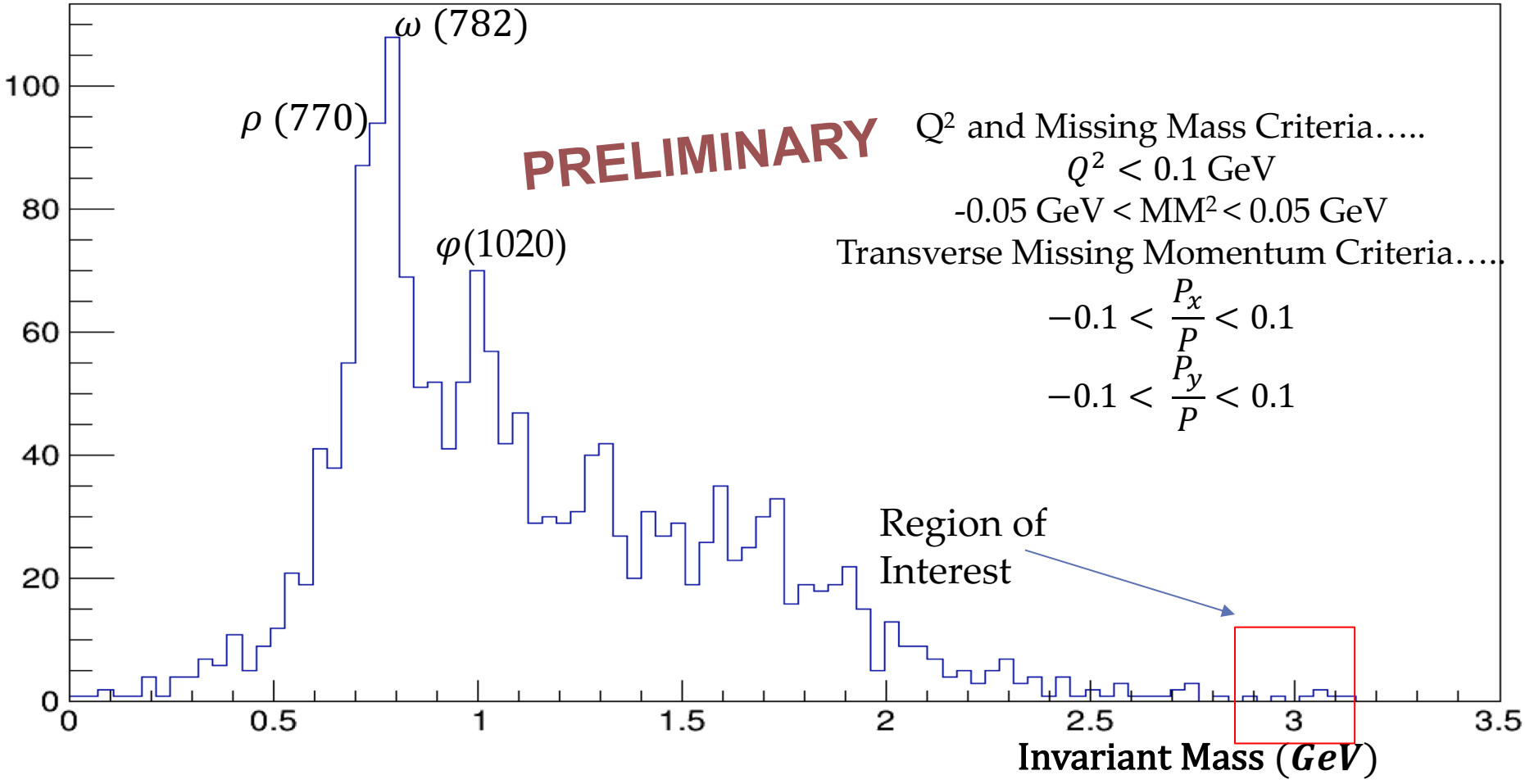
**Small Fractional Momenta of the Scattered Electron**



# Invariant Mass

- Vector mesons are clearly visible in the invariant mass distribution of e+e- pairs after selecting quasi-real photoproduction events.
- The data sample accounts for **~ 1%** accumulated charge as it stands



# The Path Forward

- Improve particle identification, especially for positrons and electrons with p > 4.9 GeV
- Study fiducial cuts and momentum corrections
- Refine event selection criteria
- Study kinematic fitting approach
- Study acceptances and efficiencies using simulated data merged with background
- Develop a fitting procedure to the invariant mass distribution to extract the number of J/Psi events in each kinematic bin
- The goal for the next year is to extract the cross sections from RG-A data