J/ψ Near-Threshold Photoproduction off the Proton and Neutron with CLAS12

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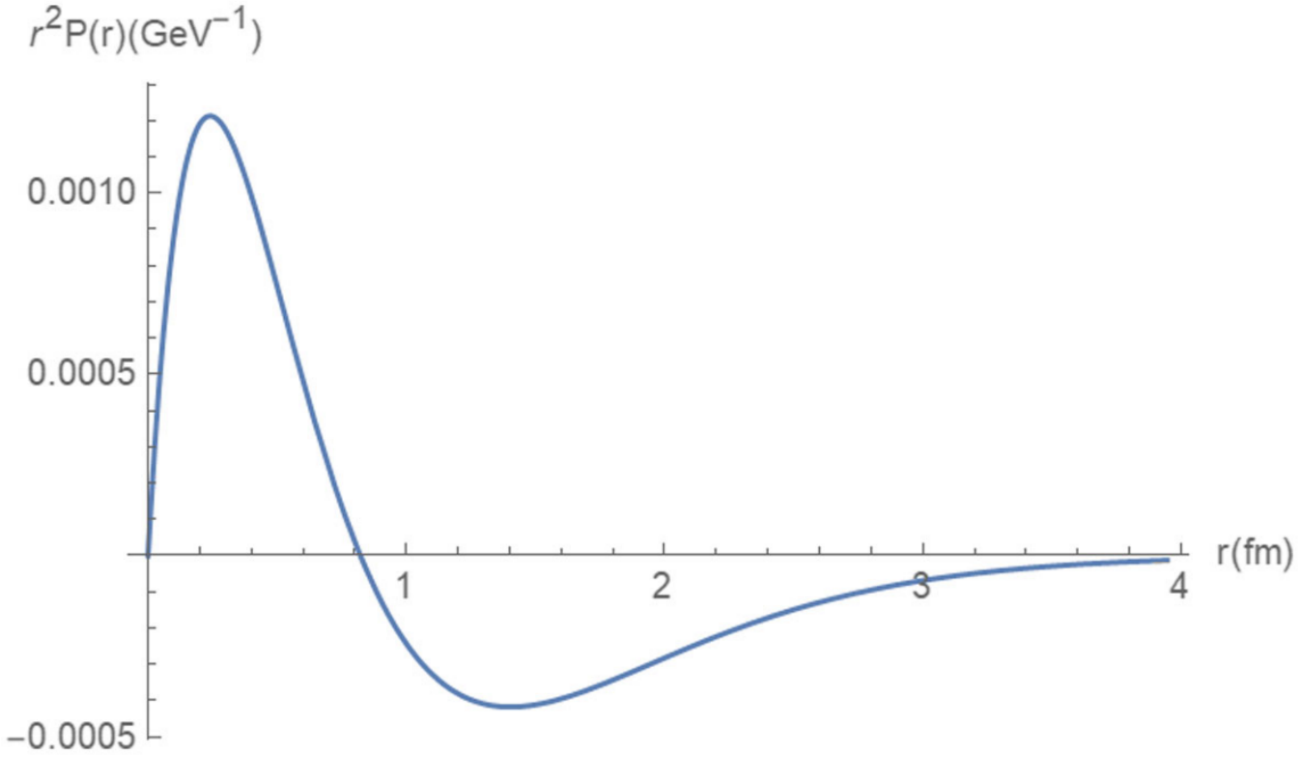
CEBAF Large Acceptance Spectrometer

J/ψ Near-Threshold Photoproduction

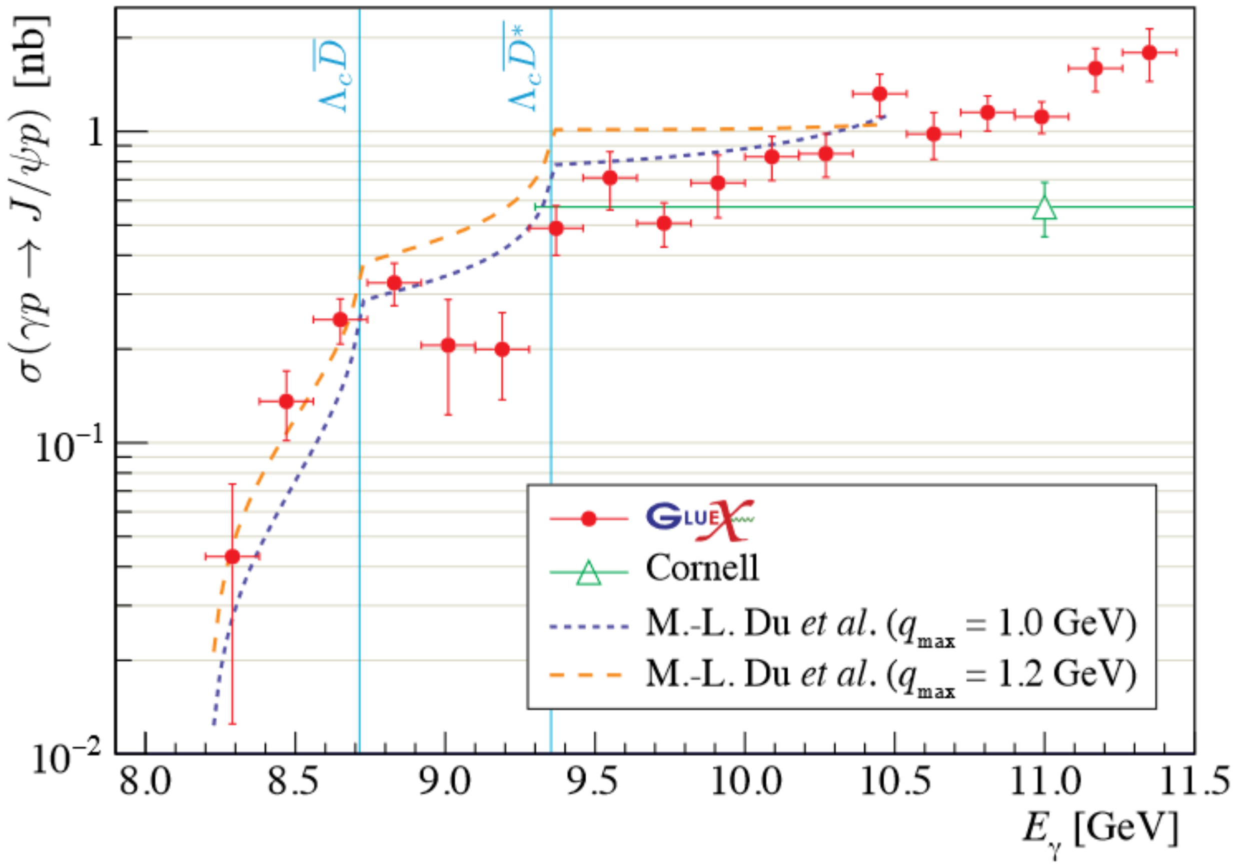
- A (assumed) two-gluon exchange forms a spin-2 coupling between J/ψ and the nucleon.
- Allows access to the Energy Momentum Tensor and gluon Gravitational Form Factors (gGFFs) of the nucleon.
- Lots of theoretical interest:
  - VMD based two-gluon exchange models.
  - Holographic QCD models based on a tensor graviton like exchange (2^{++}).
  - First moments of gluon GPDs used to extract gGFFs.
  - Disagreements on the validity of relating the gGFFs to J/ψ photoproduction.



The gluon contribution to the pressure distribution inside the proton from a GPD based model fit to lattice and J/ψ photoproduction data.

J/ψ in RG-B

- First measurement on the bound neutron.
- Test the isospin invariance of the production mechanism.
- Estimate strength of final state interactions to the cross section.
- Measuring photoproduction on both proton and neutron brings new constraints on open-charm contributions to the cross section.



Predictions for the total cross section due to the open charm production of J/ψ p, which is consistent with the GlueX measurements in red.

Experiment Overview

- CLAS12 took data with both a proton and a deuterium target:

$$e\,p \rightarrow \mathrm{e'}\,\mathrm{J}/\psi\,\mathrm{p} \rightarrow (\mathrm{e'})l^{+}l^{-}\mathrm{p} \qquad \text{(RG-A)}$$

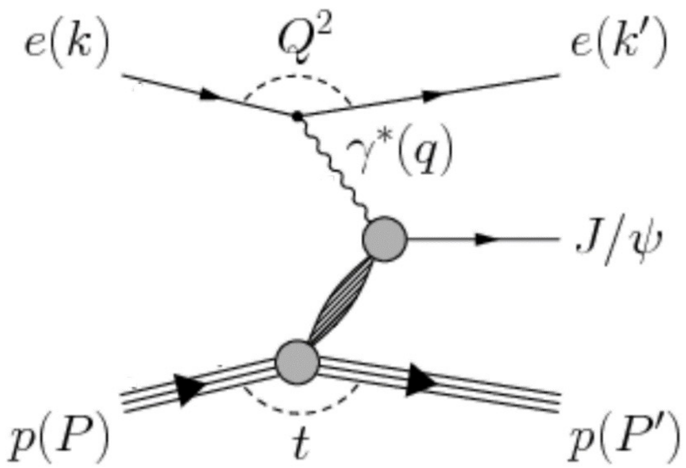
$$e\,p_{bound} \rightarrow \mathrm{e'}\,\mathrm{J}/\psi\,\mathrm{p} \rightarrow (\mathrm{e'})l^{+}l^{-}\mathrm{p} \qquad \text{(RG-B)}$$

$$e\,n_{bound} \rightarrow \mathrm{e'}\,\mathrm{J}/\psi\,\mathrm{n} \rightarrow (\mathrm{e'})l^{+}l^{-}\mathrm{n} \qquad \text{(RG-B)}$$

- J/ψ simulations were produced using elSpectro event generator and OSG. Bethe Heitler simulations produced with TCSGen.

- Data processed with chanser. Fits done with brufit.

- Used same proportion as accumulated charge for data simulated at different energies, beam currents and configurations.

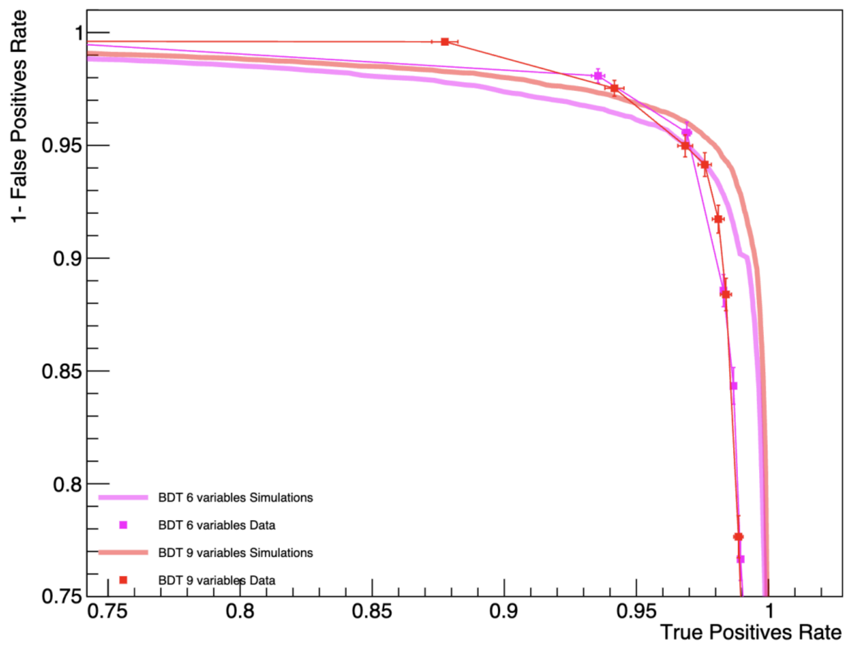


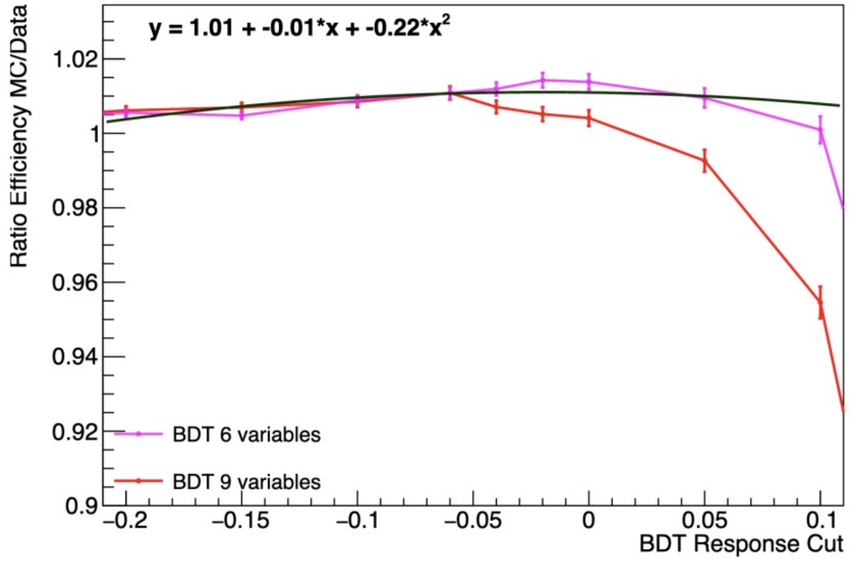
J/ψ quasi-real photoproduction on a proton target

Dataset	Beam Energy	Beam Current	Acc. Charge
Spring 2019	10.6 GeV	35 nA	7.1 mC
Spring 2019	10.6 GeV	50 nA	19.91 mC
Spring 2019	10.2 GeV	50 nA	39.39 mC
Fall 2019 (outbending)	10.4 GeV	40 nA	12.85 mC
Spring 2020	10.4 GeV	50 nA	28.4 mC

Lepton Identification

- Refine the lepton PID by training a machine learning classifier using information from the calorimeters.
- The PID process is then reduced to a cut on the response of the classifier.
- Mariana has studied the difference in efficiency of the ML lepton PID in MC and data.
- Studies from Stepan gave ratio of event builder PID efficiency in MC/Data when applying fiducial cuts.

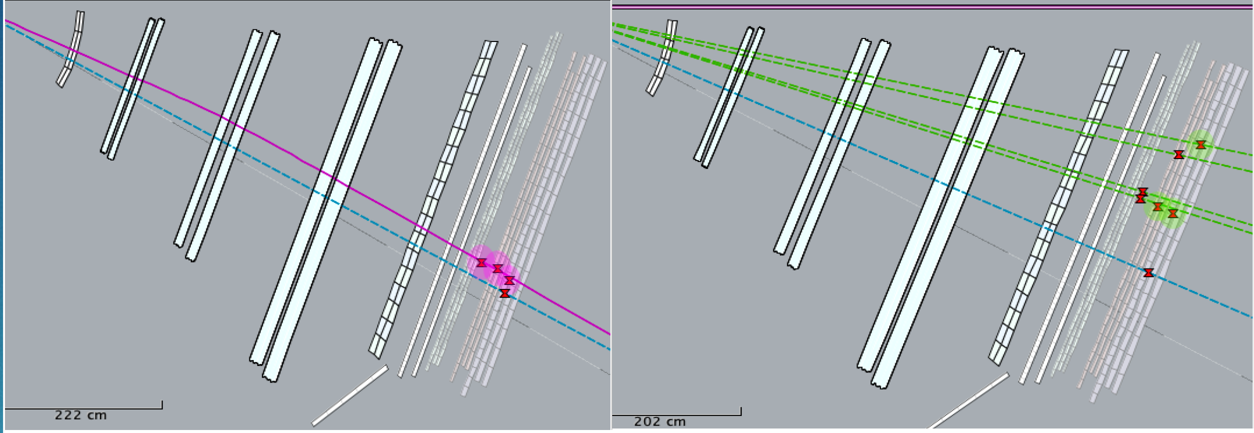




Work by Mariana Tenorio-Pita, see slides at CLAS meeting

Particle Corrections

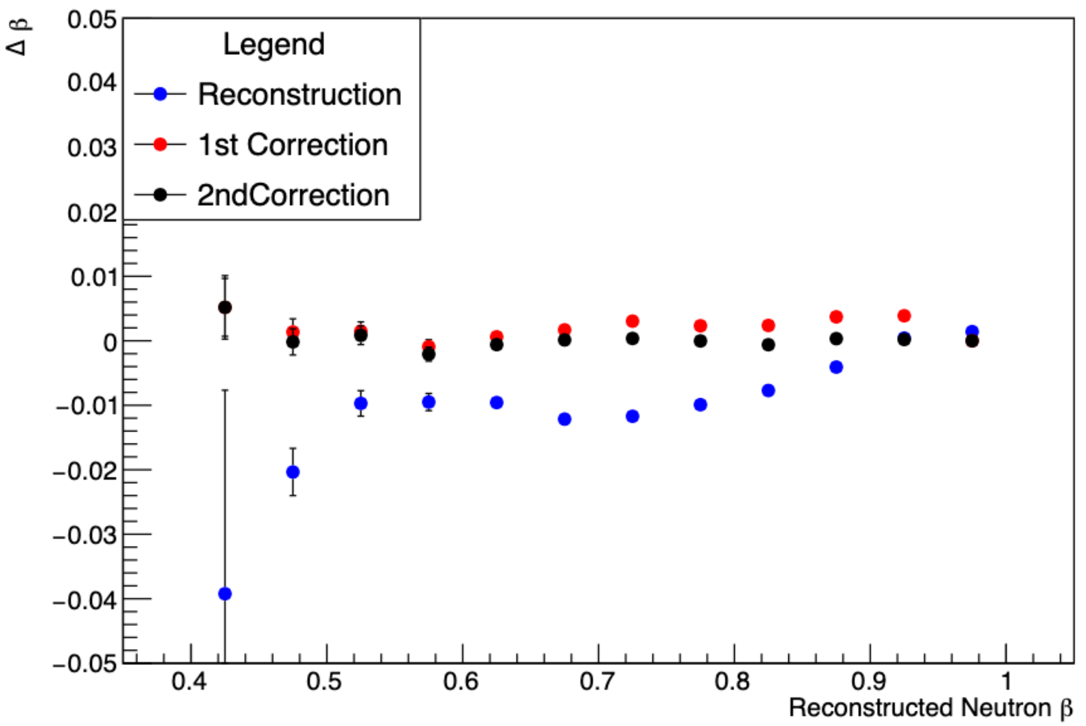
- Radiative corrections for electrons/positrons add the momentum of radiated photons.
- Neutrons also produce secondary clusters. These are removed by taking the earliest neutral in a given sector.
- Apply momentum dependent neutron corrections established from $e\,p \rightarrow e'\pi^+\,n$
- We apply fiducial cuts to remove e+/e- hits close to the edges of the PCAL.
- Working on momentum corrections for e+/e- and p.



J/ψ Simulation in CED

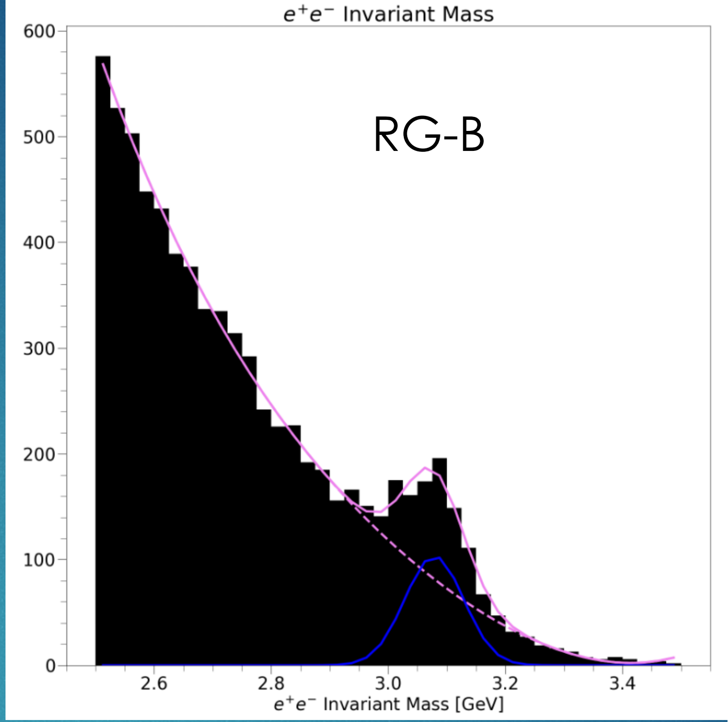
Can see radiated photon and secondary neutrons.

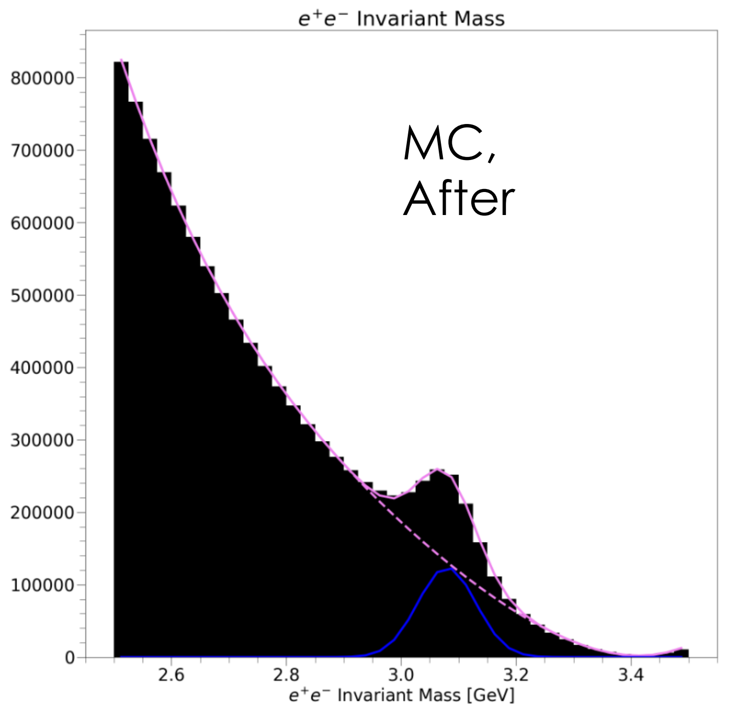
Δ β vs Reconstructed Neutron β

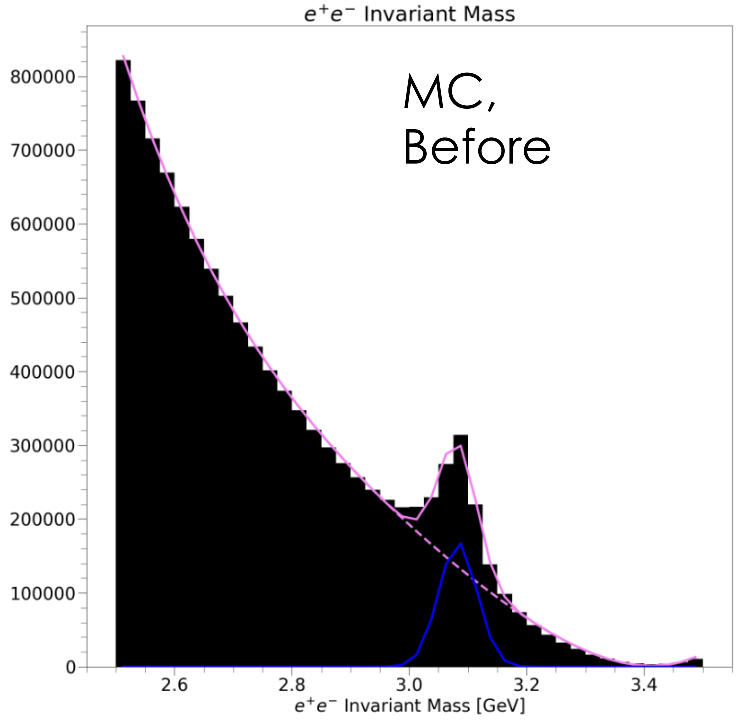


Ad-Hoc Smearing

- To ensure matching between data and MC I apply some ad hoc smearing to the e^+e^- momentum.
- The algorithm aims to minimize the difference between 1 and the ratio of width of gaussian fitted to MC and data.
- Add same background shape as in data to MC.
- $\frac{\Delta P_{e^-}}{P_{e^-}} = 0.012, \frac{\Delta P_{e^+}}{P_{e^+}} = 0.017$, similar scale to (preliminary) momentum corrections.
- In the future, will establish smearing after momentum corrections.



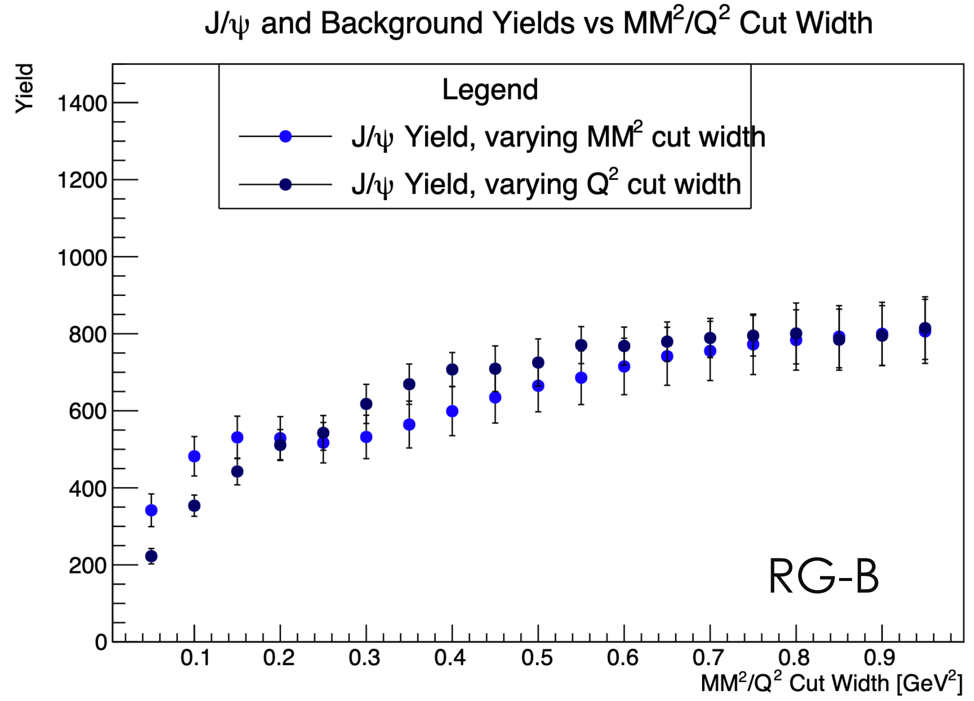


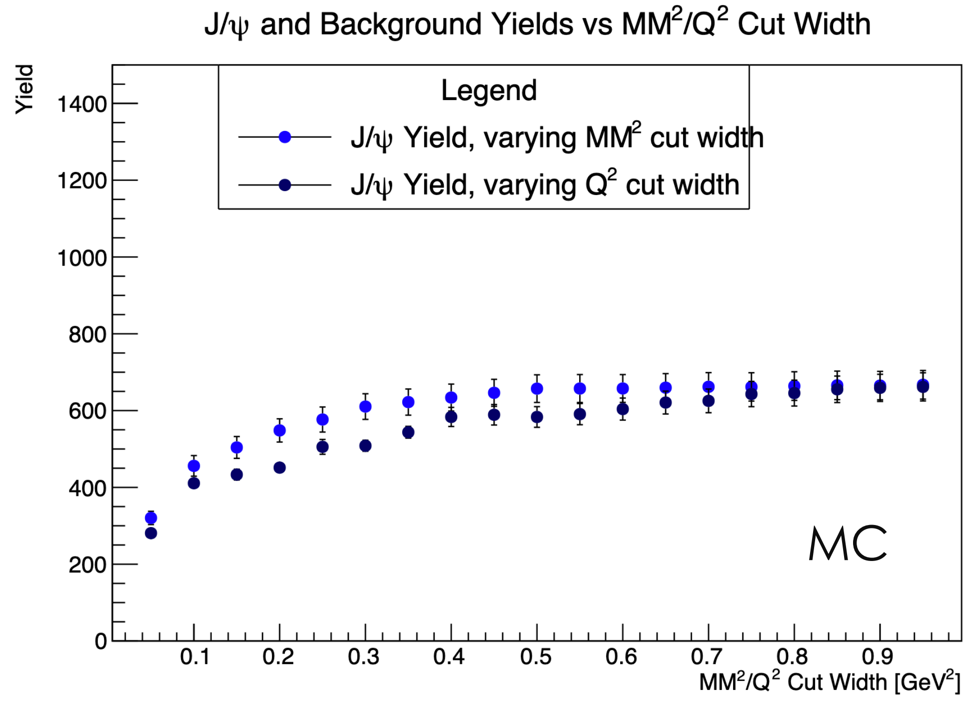


	Ratio σ	Δμ
Before	0.65	4 MeV
After	1.00	0.9 MeV

Event Selection

- We remove high Q^2 events to select only quasi-real photoproduction events.
- We also want the missing mass close to the mass of the scattered electron.
- Can compare in RG-B and MC the impact of cuts on the number of J/ψ.
- **Note**: Add high Q^2 background to MC to negate impact of fit. Add some normalisation to ensure matching between BG and J/ψ ⇒ compare shape not scale.
- Looser cuts (~0.5 GeV^2) seem to be better reproduced in MC.



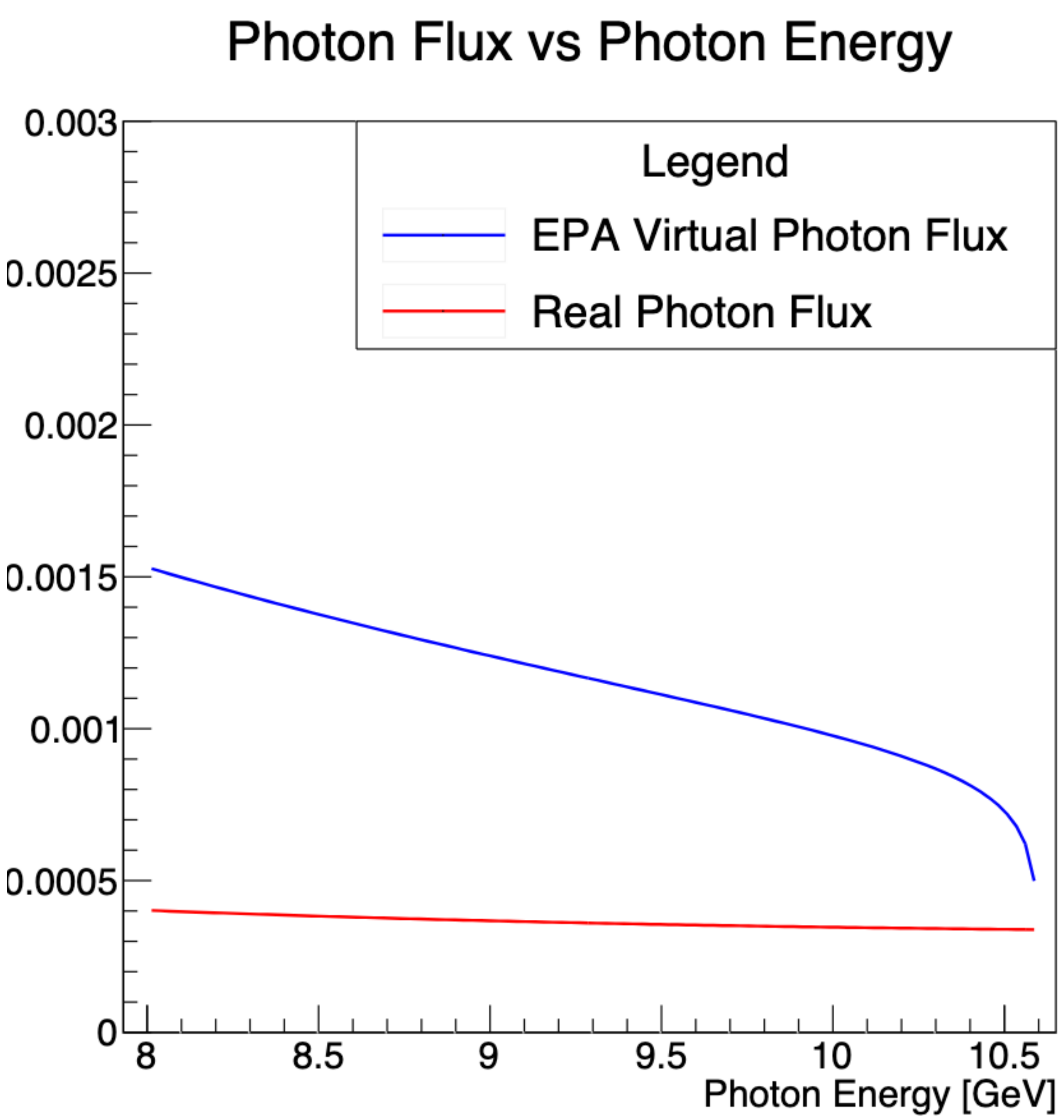


Cross Section Calculation

- We can calculate the total cross section as:

$$\sigma_0(E_\gamma) = \frac{N_{J/\psi}}{N_\gamma \cdot l_T \cdot \rho_T \cdot Br \cdot R_c \cdot \epsilon(E_\gamma) \cdot \omega_c}$$

- Where:
  - $N_{J/\psi}$ is the number of J/ψ in each E_γ bin
  - N_γ is taken from the sum of real and virtual photon flux
  - l_T/ρ_T is the target length and density
  - Br is the branching ratio (~6%)
  - $\epsilon(E_\gamma)$ is the acceptance in each E_γ bin
  - R_c are radiative corrections
  - ω_c is a normalisation factor

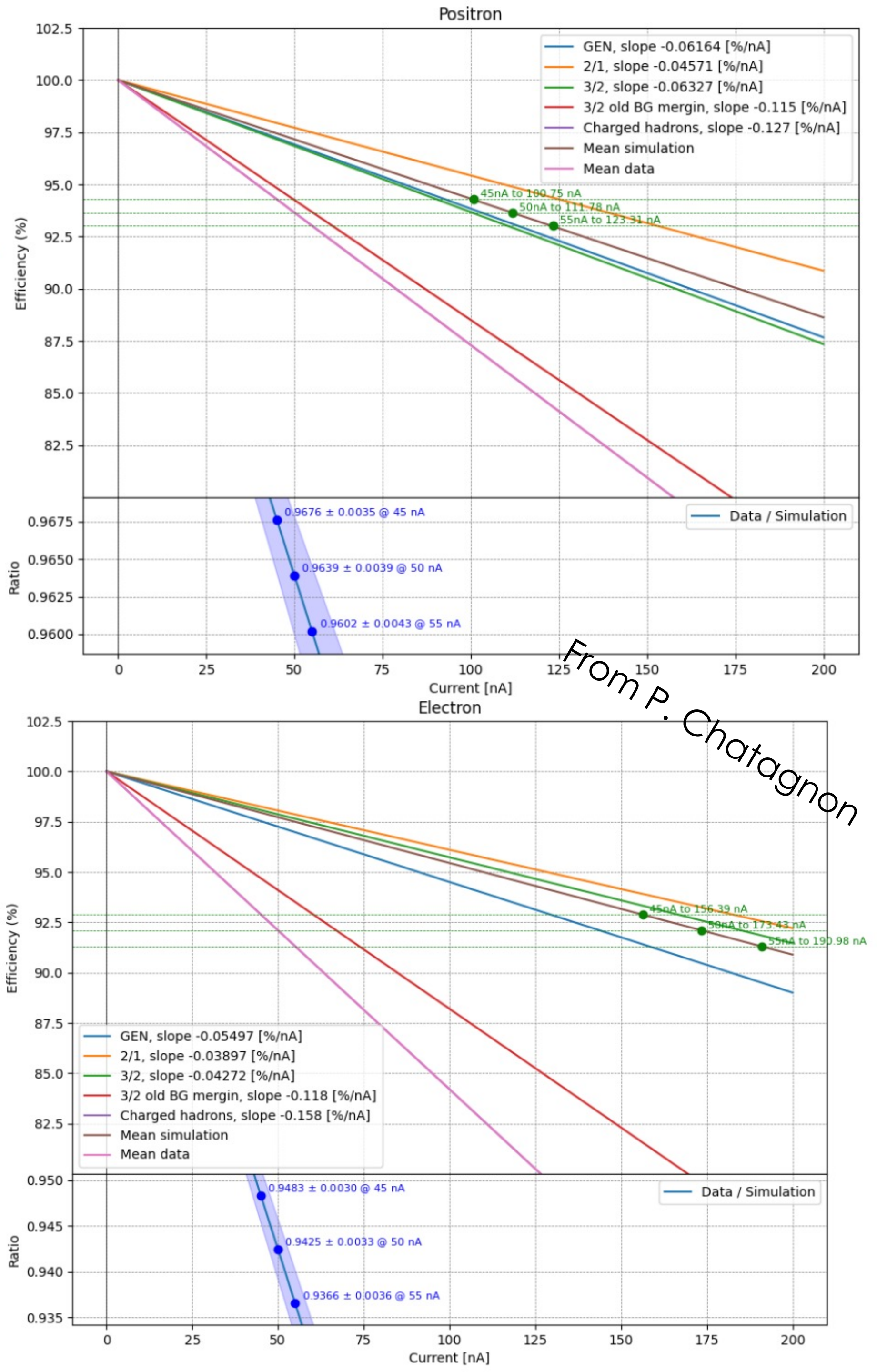


Note: Some systematics involved in the flux calculation

Corrections to MC

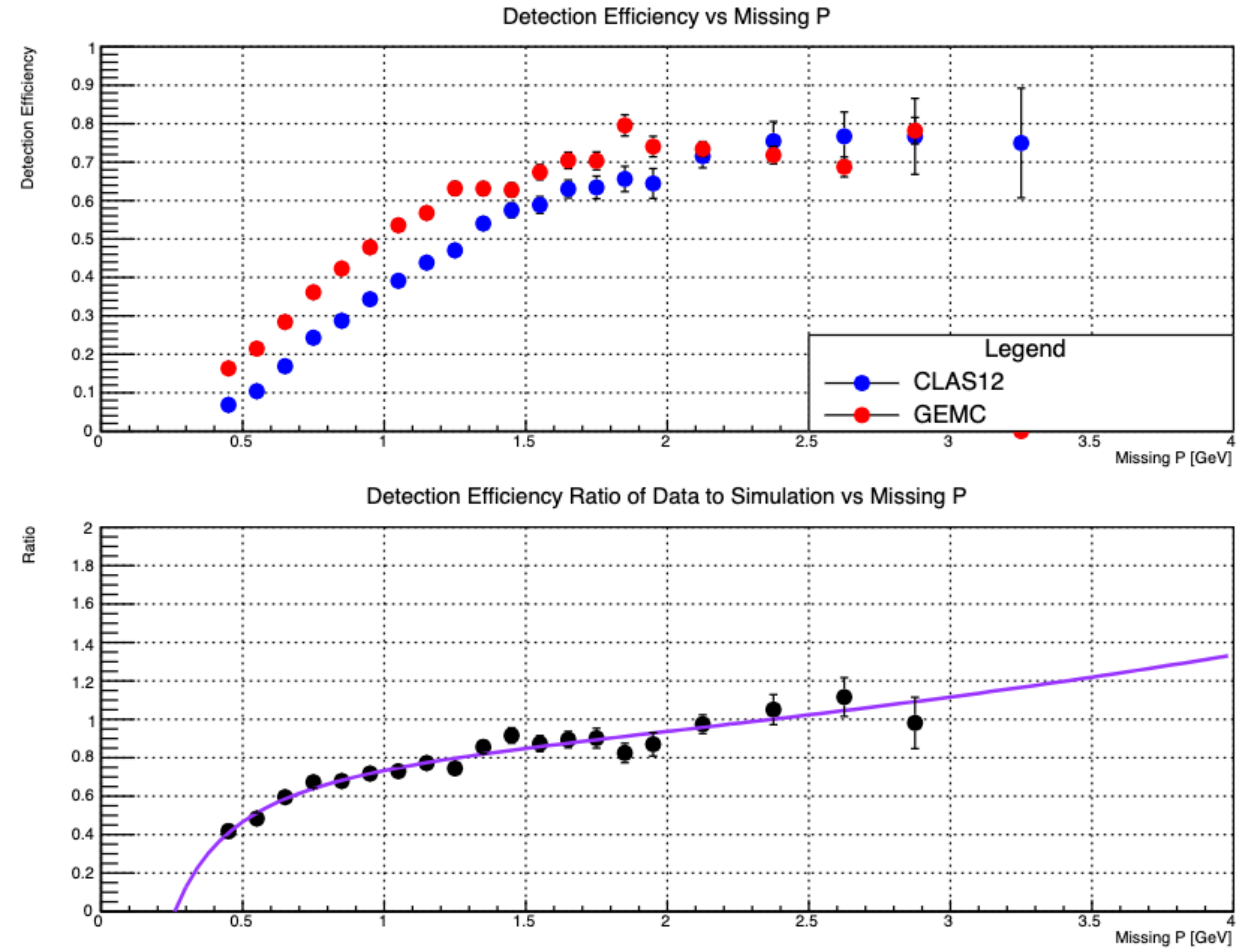
- Several steps are taken to ensure that as realistic as possible efficiency in MC:
  - Neutron detection efficiency.
  - Background merging correction **(should be fixed in GEMC soon)**.
  - Cut out known dead or low efficiency strips in PCAL.
  - Differences in e+/e- PID.

- MC smearing and momentum corrections are meant to decrease impact of different resolution on cuts and fitting.



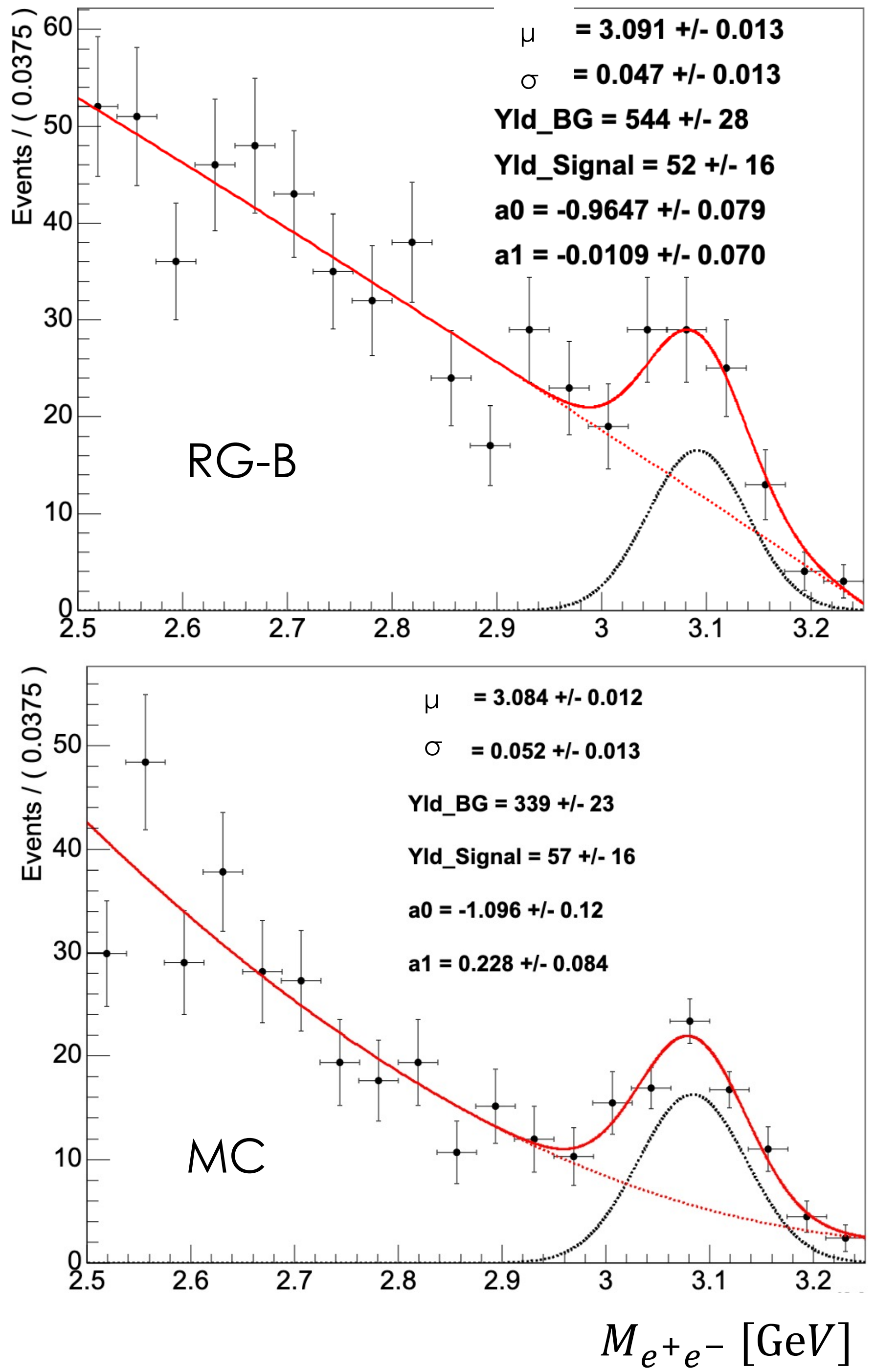
Neutron Detection Efficiency

- Use $ep \rightarrow e'\pi^+n$ channel to study neutron detection efficiency.
- Find good agreement in data with studies for GMn analysis.
- Simulate $ep \rightarrow e'\pi^+n$ channel, take ratio of data to simulation.
- Use this ratio to correct simulation.
- Introduces some systematic uncertainty due to cuts in analysis.



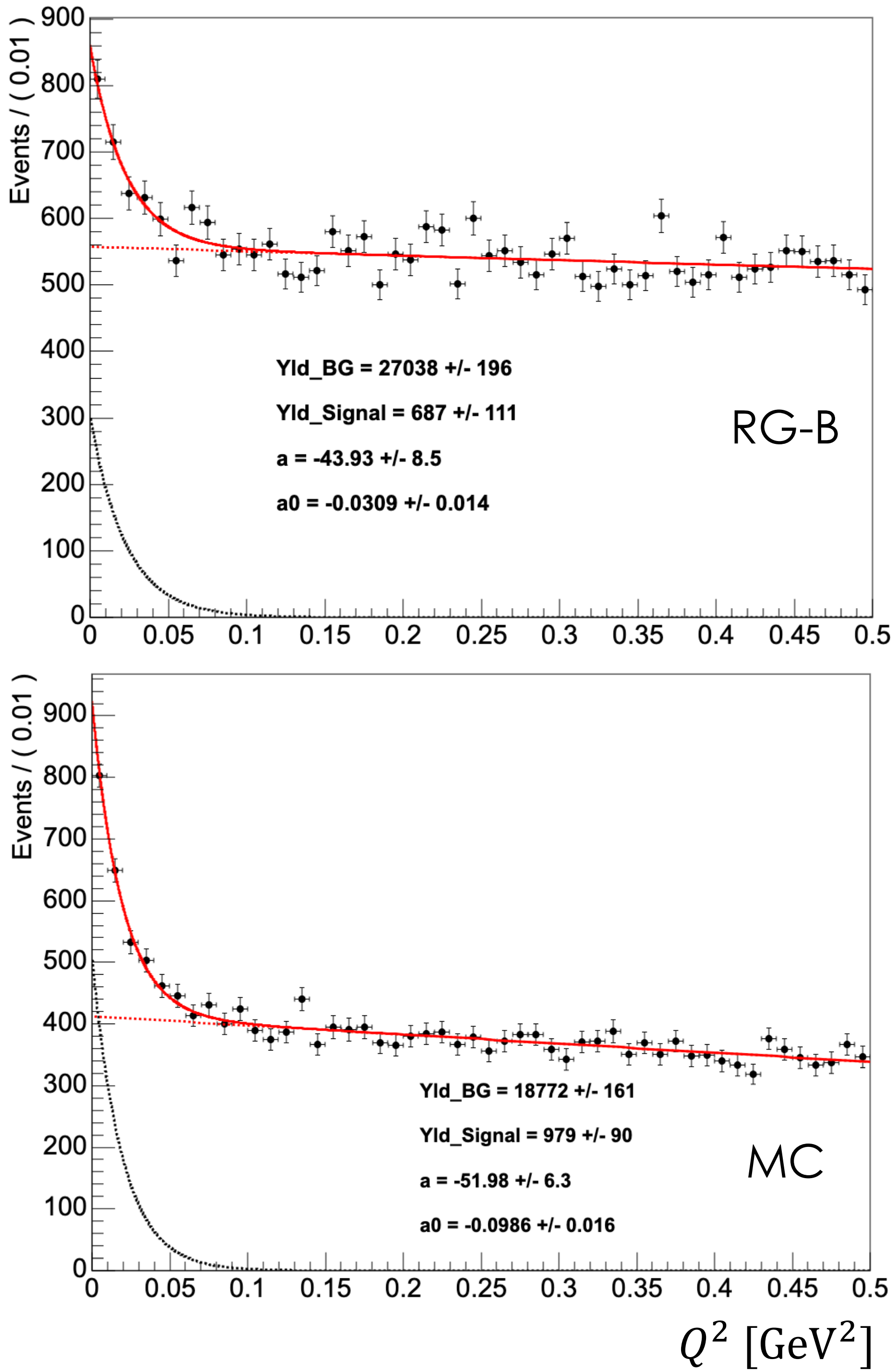
Acceptance

- Calculate acceptance by fitting the simulated data in same bins as those in which the cross section is calculated.
- Add high Q^2 background to simulation and a weight to match it to background.
- Try to use loose cuts to limit impact of MC/Data resolution matching on acceptance.
- Another way to estimate fit systematics would be to generate N samples with similar number of signal/background as data and fit these to estimate deviation in number of J/ψ.



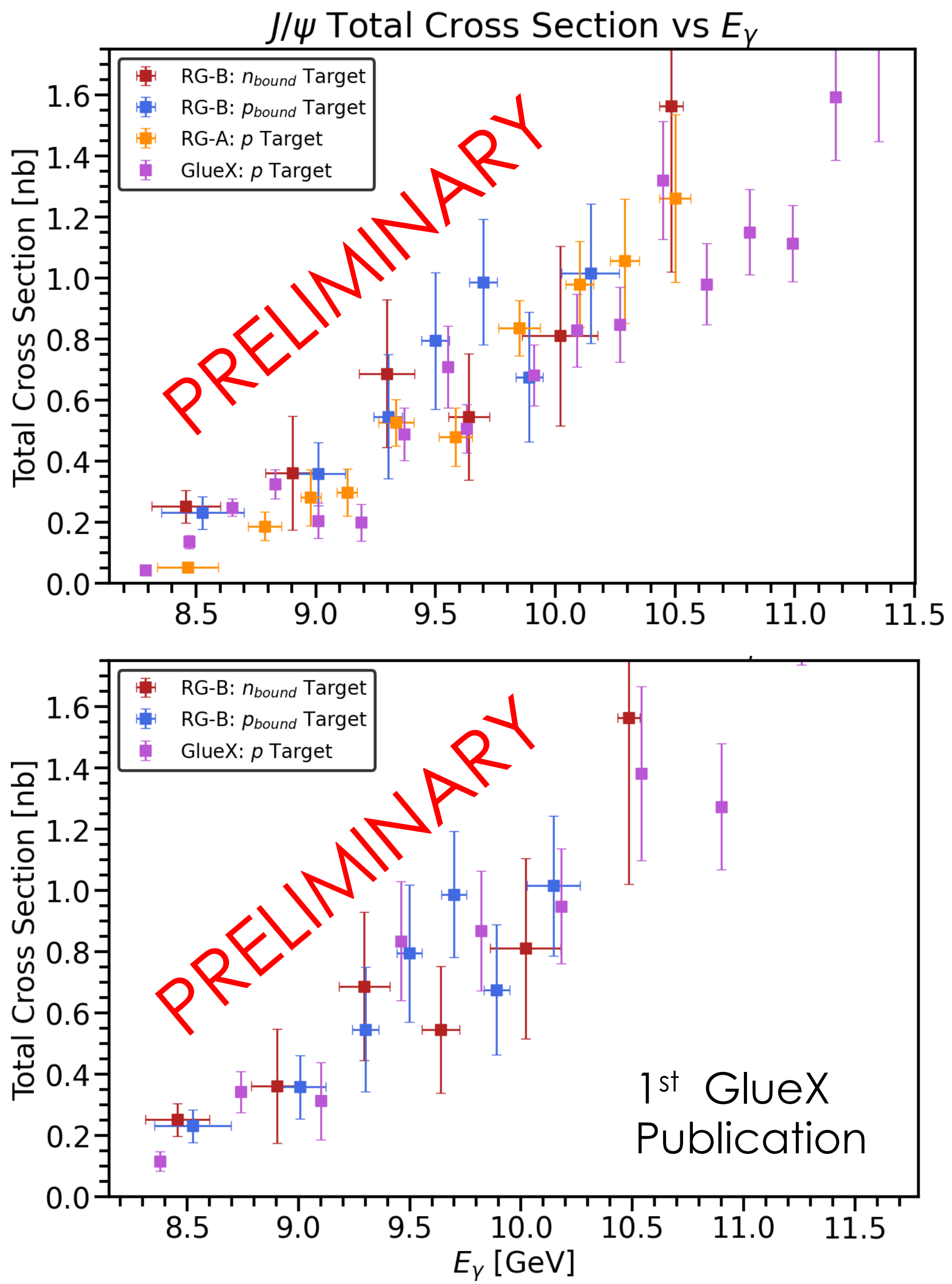
Normalisation

- Fit Q^2 in e^+e^- invariant mass region of 2.0 - 2.9 GeV in data and weighted Bethe Heitler simulation.
- Fit exponential to the signal and straight line to background.
- Add background to simulation.
- The ratio give us the Bethe Heitler normalization factor (here 0.702 ± 0.130).
- Apply same normalization factor to neutron cross section. Apply same exclusivity cuts to neutron analysis.



J/ψ Total Cross Section

- Shown here is the total cross section produced on proton and neutron in RG-B and compared to world data.
- Points are located at the mean of the E_γ distributions in a bin, with the error representing the standard deviation in E_γ .
- Only report statistical uncertainty.
- Agreement with RG-A shows we don't have the statistical precision to estimate final state interaction contribution to cross section.
- Good agreement between cross section on proton and neutron suggests isospin invariant production mechanism. (Or isospin breaking less than statistical uncertainty).



J/ψ Differential Cross Section

- Shown here is the differential cross section produced on proton and neutron in RG-B.
- A scalar gravitational form factor $G(t)$ gives access to the mass radius of the nucleon:

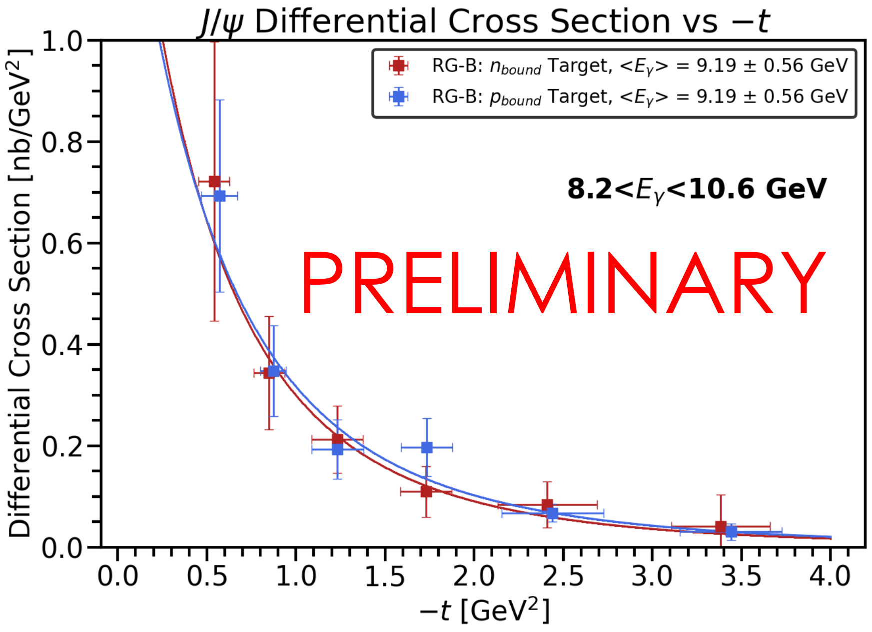
$$\frac{d\sigma}{dt} = G(t)^2$$

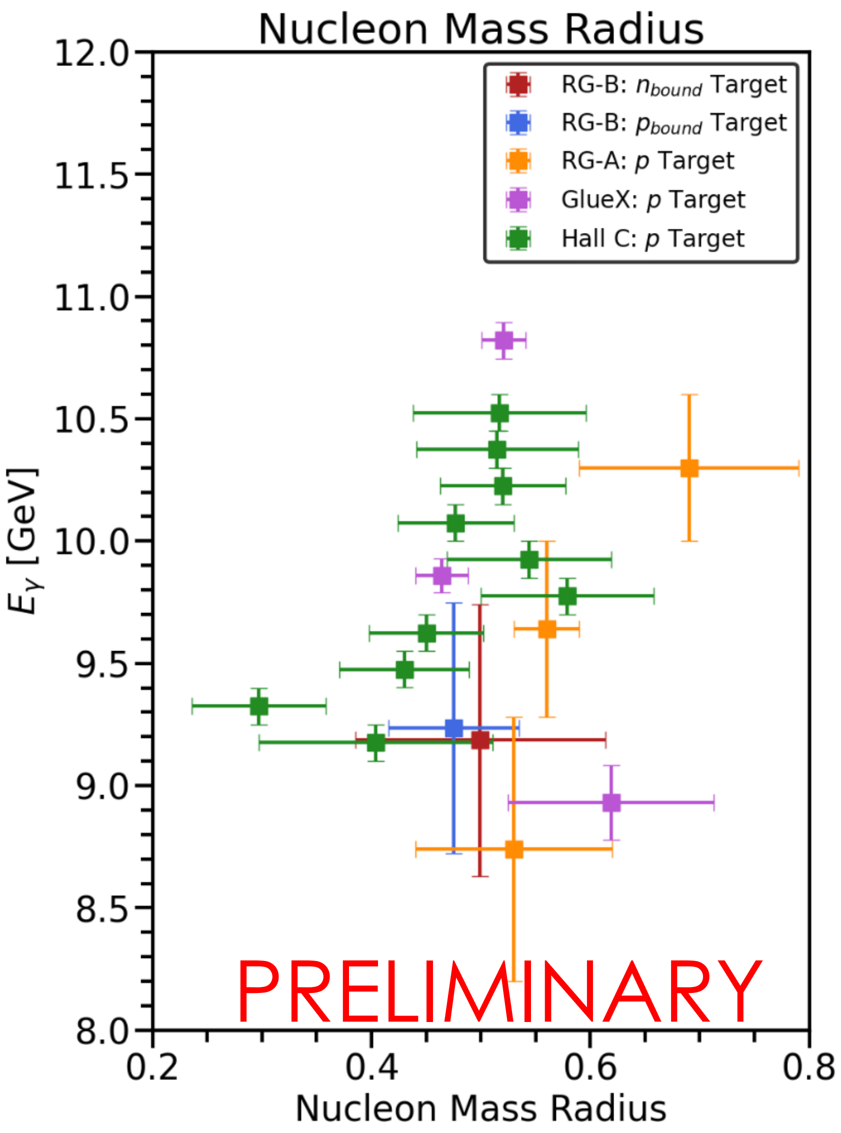
- Assuming a dipole form for $G(t)$:

$$G(t) = \left(\frac{M_p}{(1-\frac{t}{m_s^2})^2}\right)^2$$

- The mass radius r_m is calculated from the free parameter m_s:

$$r_m = \frac{\sqrt{12}\hbar c}{m_s}$$





Conclusion

- Aim for first measurement of near-threshold J/ψ photoproduction on the neutron using RG-B data.

- Good progress on the J/ψ analysis in RG-B:
  - Normalisation is under control.
  - Sources of systematic uncertainty are better understood.
  - Preliminary total and differential cross sections.

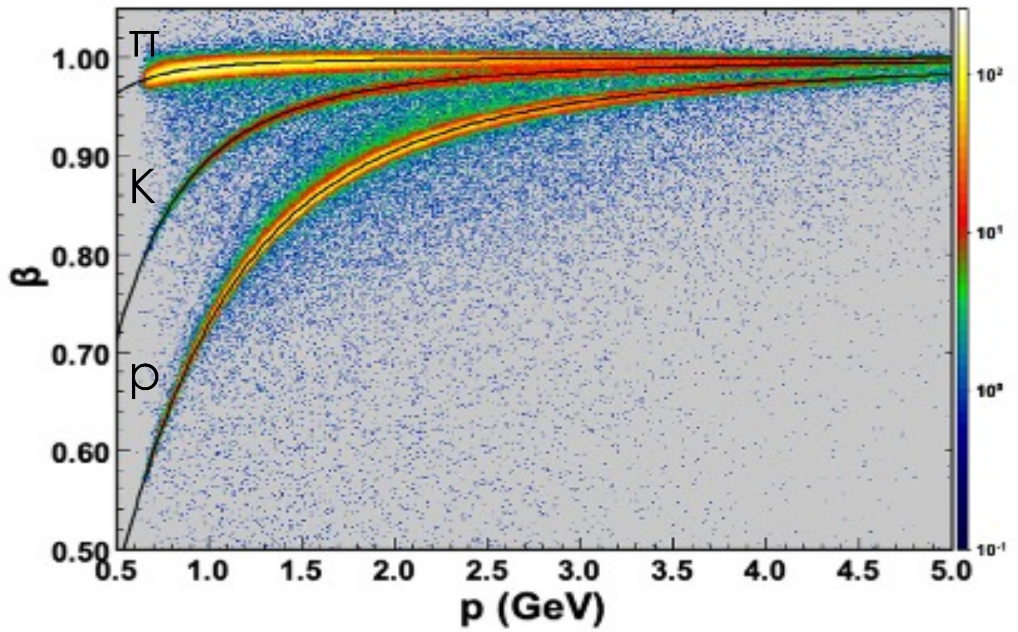
- To do:
  - Momentum corrections (already done for neutron).
  - Re-run simulations with updated background merging
  - QADB is being updated for pass 2.
  - Systematic uncertainty quantification.
  - Analysis note.

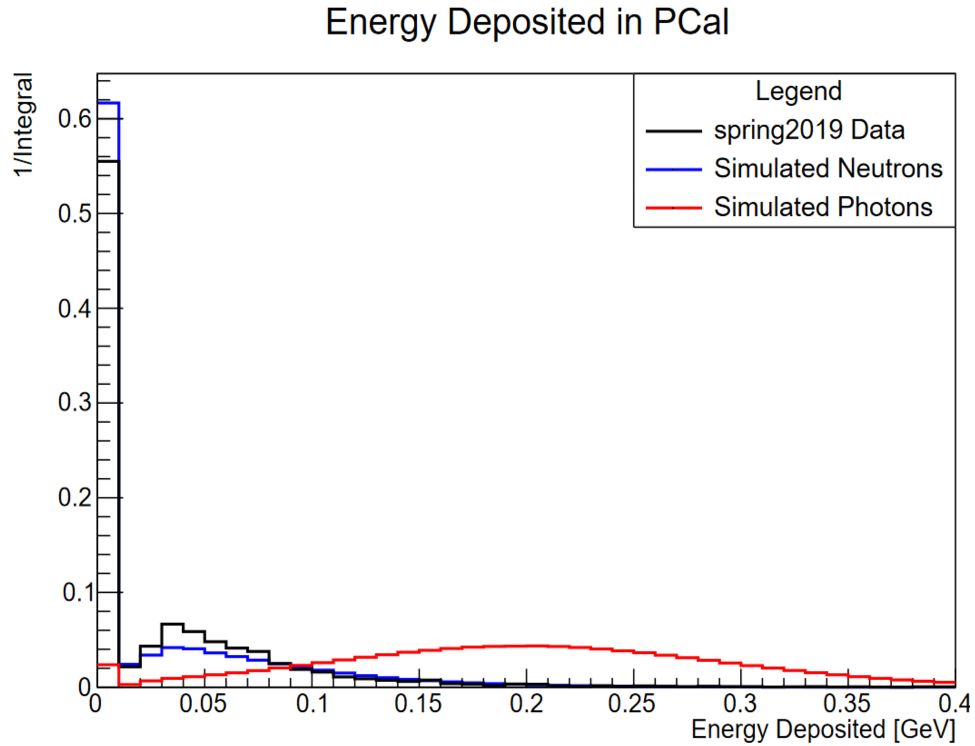
Back-up Slides

Hadron Identification

- For protons (and charged hadrons in general) a cut is made on the Beta versus Momentum parametrization.

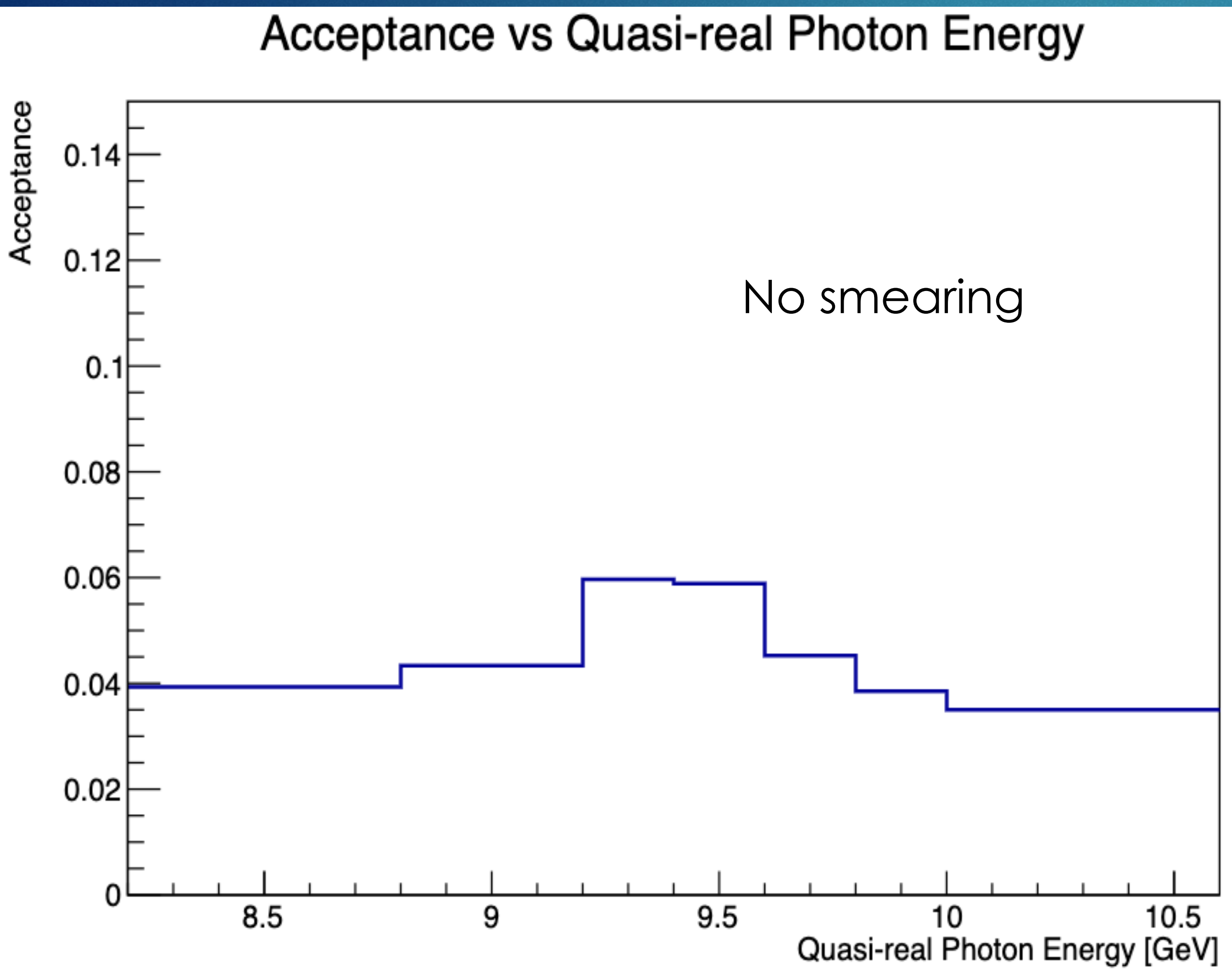
- For neutrons we require a neutral charge. No further cuts were applied as there isn't any strong evidence of photon contamination.

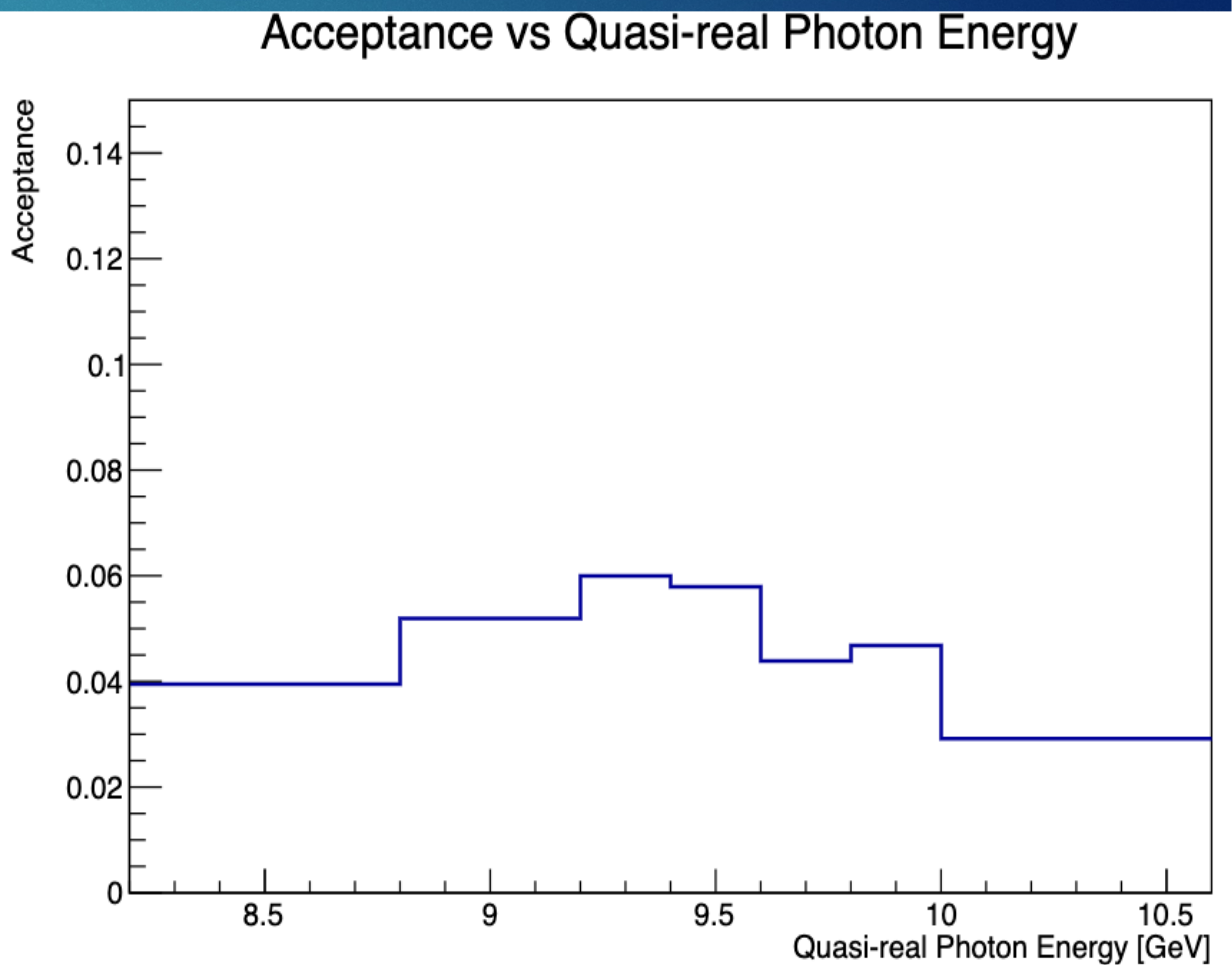




Acceptance & Smearing

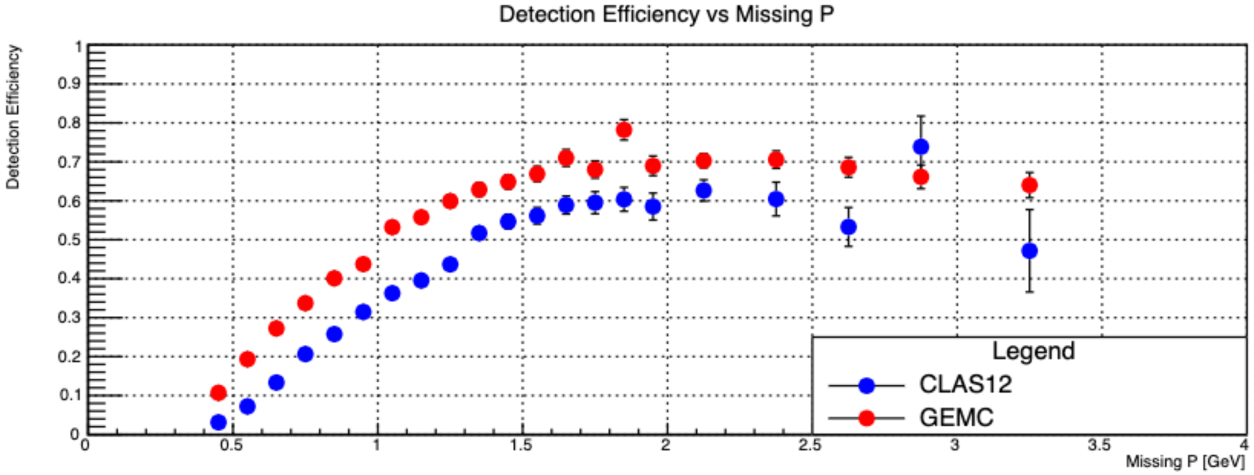
Includes ~10% of outbending data. Various factors to correct efficiency.

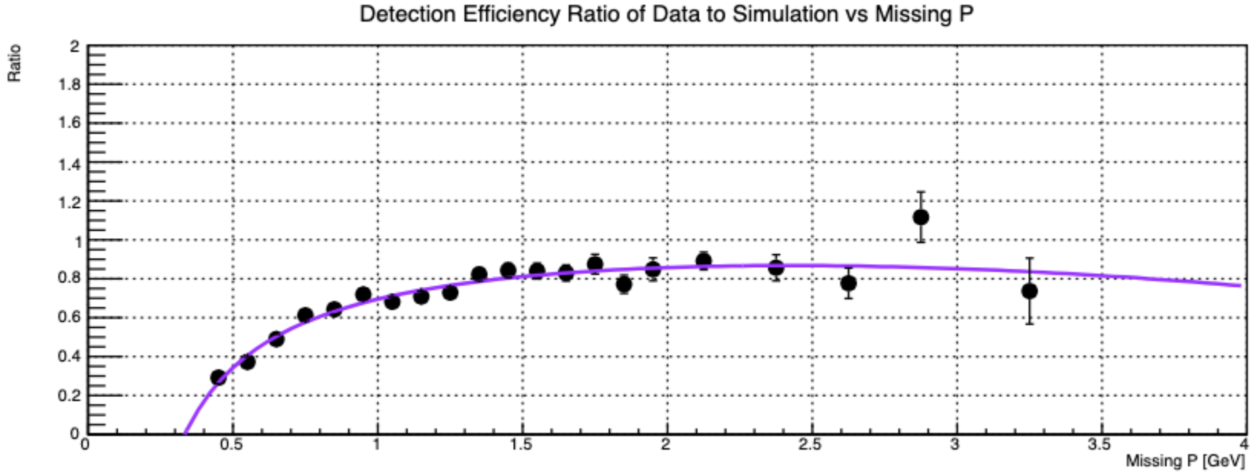




Tighter Cut on MM^2

Cut on Data & Sim > 0.9
Different Sectors for n and e'/ π
$|MM^2| < 0.5\ GeV^2$





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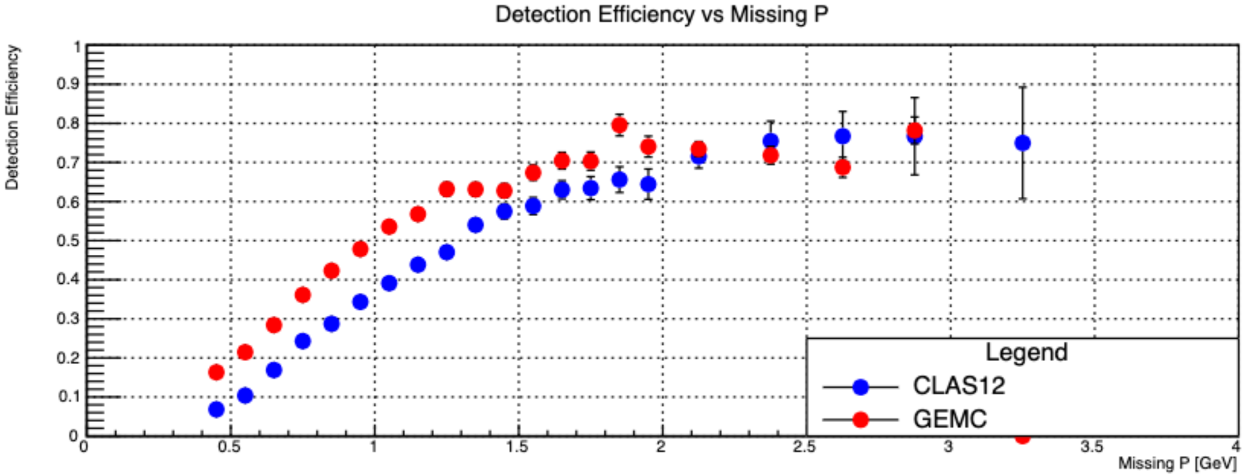
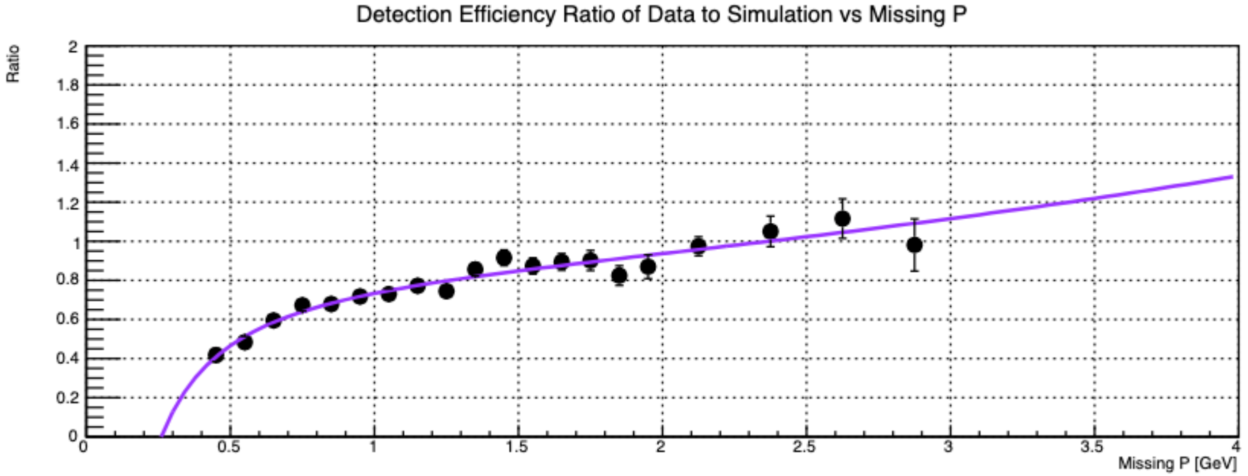
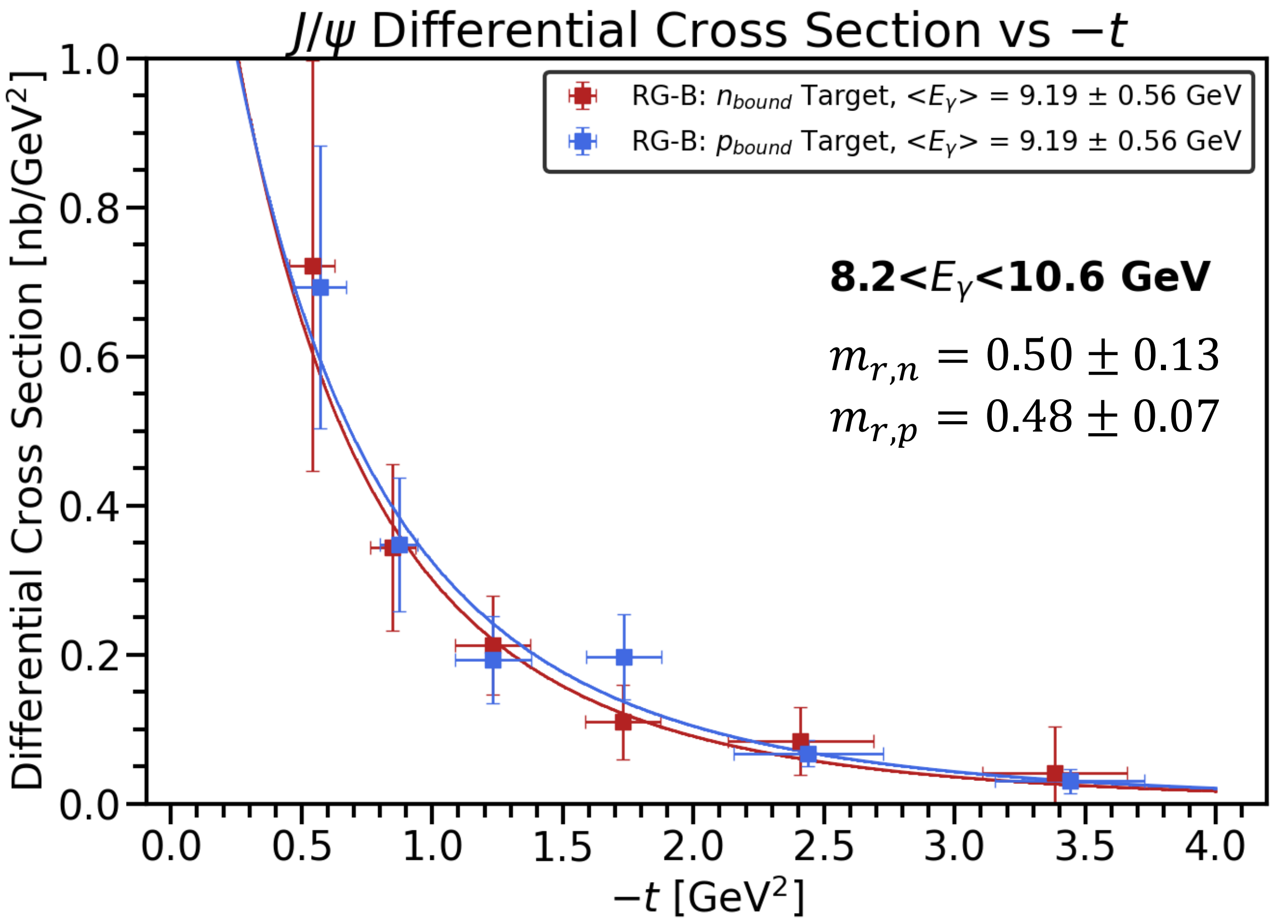




Neutron Efficiency Systematics

Cut on Data & Sim > 0.9
Different Sectors for n and e'/ π
$|MM^2| < 1\ GeV^2$



Cut on Data & Sim > 0.9