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

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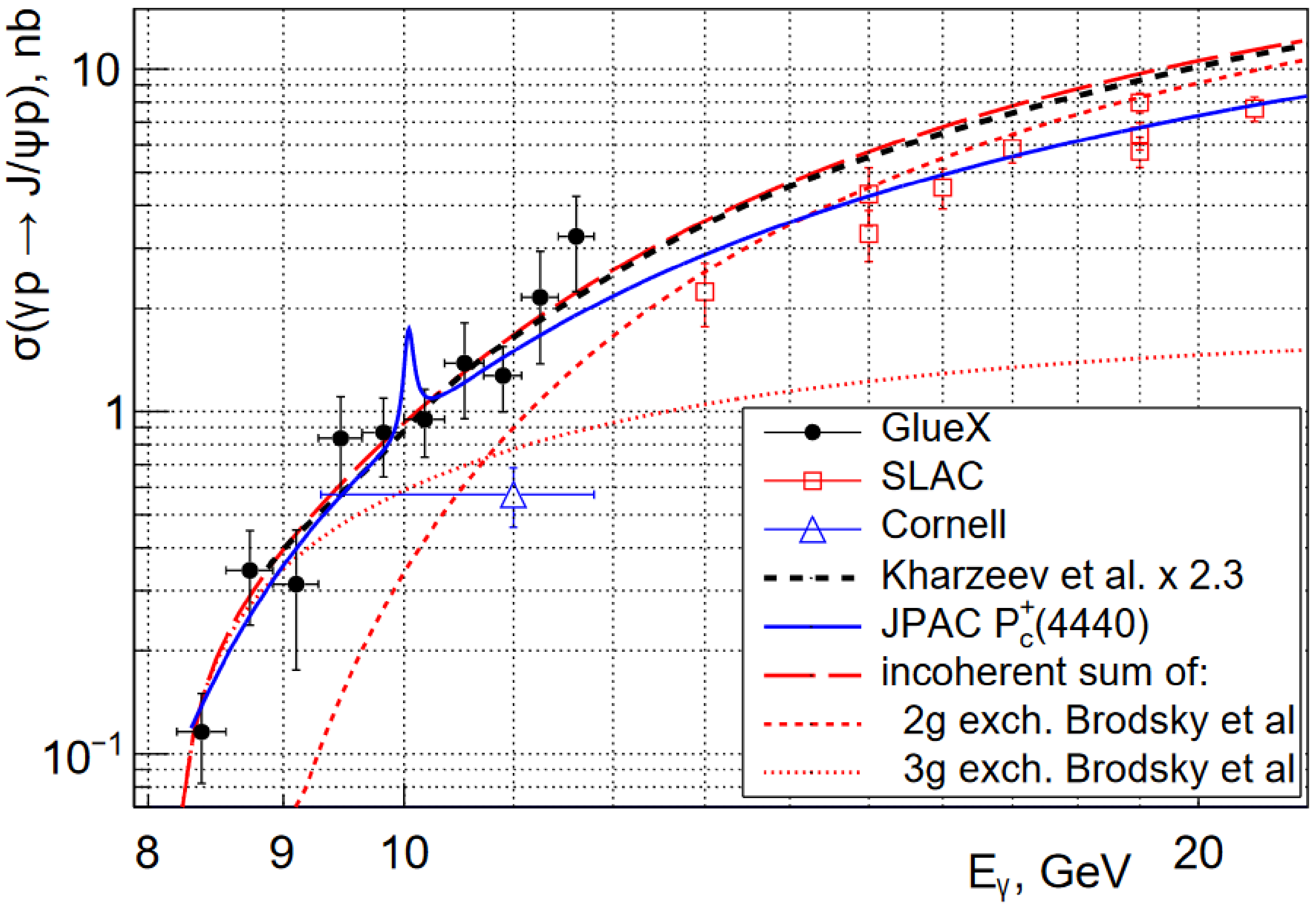
VIA VERITAS VITA

J/ψ Near Threshold Photoproduction

- CLAS12 operates close to the 8.2 GeV J/ψ ($c\bar{c}$ meson) photoproduction threshold.
- Near threshold, all the valence quarks of the nucleon are predicted to participate in the reaction compared to one or two at higher energies [2].
- [3] relates the nucleon gluonic form-factor to the *t* dependency of the differential cross section.
- CLAS12 will make a first measurement of J/ψ near-threshold photoproduction on the neutron.



Measurements of the J/ψ total cross section as a function of the photon beam energy and theoretical predictions scaled to GlueX data [1].

[1] A. Ali, *et. al.* (GlueX Collaboration), *Phys. Rev. Lett.* **123,** 072001 (2019).
[2] S. Brodsky, E. Chudakov, P. Hoyer, J. Laget, *Phys. Lett. B.* **498**, 23 (2001).
[3] L. Frankfurt, M. Strikman, Phys. Rev. D. 66, 031502 (2002).

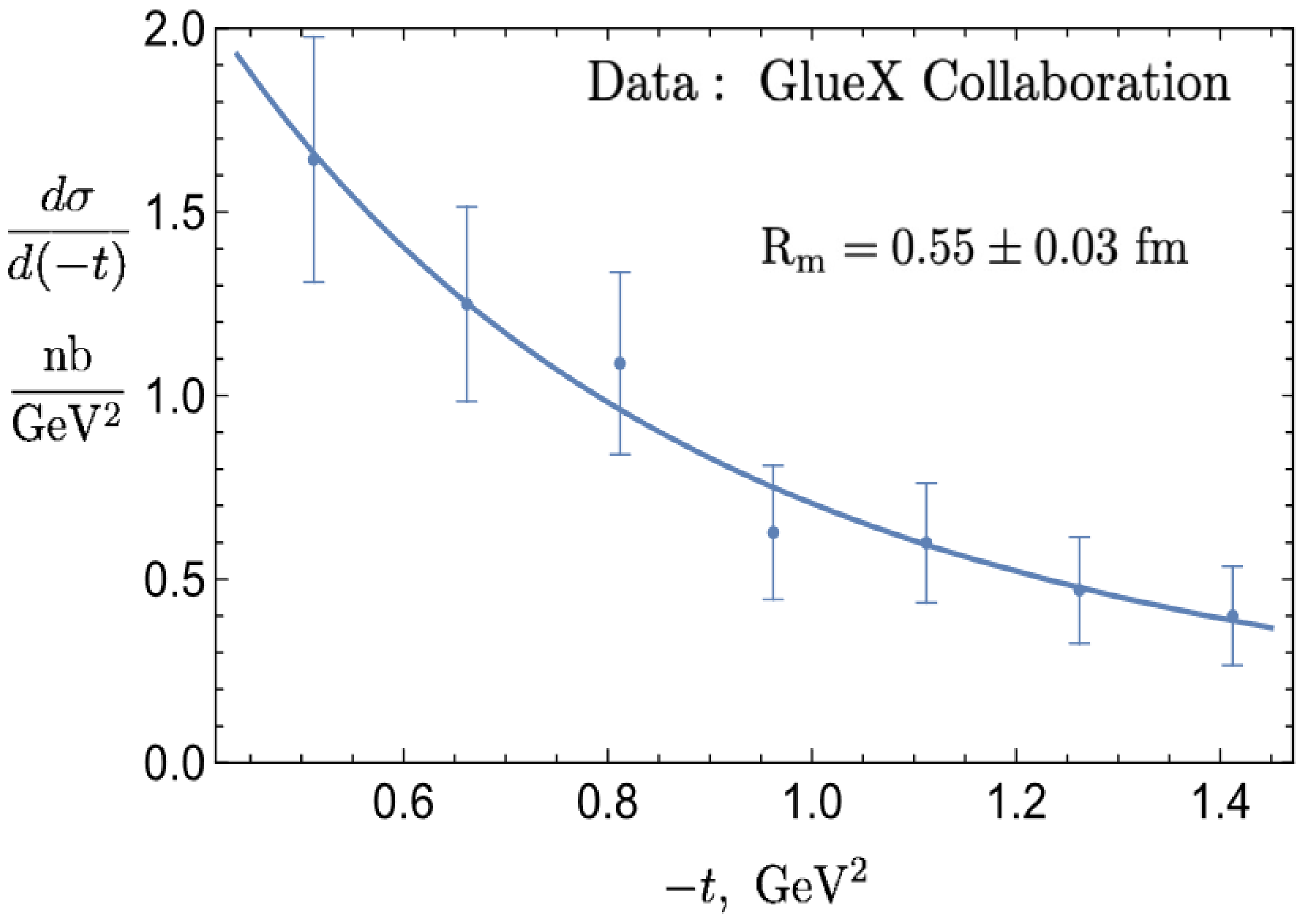
Mass Radius of the Nucleon

- The J/ψ differential cross section as a function of t can be related to the mass radius of the nucleon [4].

- Measurements at Jlab's Hall-C are in good agreement with those from GlueX [5].

- The proton mass radius is significantly different from the charge radius ($R_c = 0.8409 \pm 4 \cdot 10^{-4}$ fm), suggesting that its gluon radius is significantly smaller than its quark radius [5].

- CLAS12 will make the same measurements for the neutron.



J/ψ differential cross section as a function of –t. Data from the GlueX Collaboration [1], plot taken from [4].

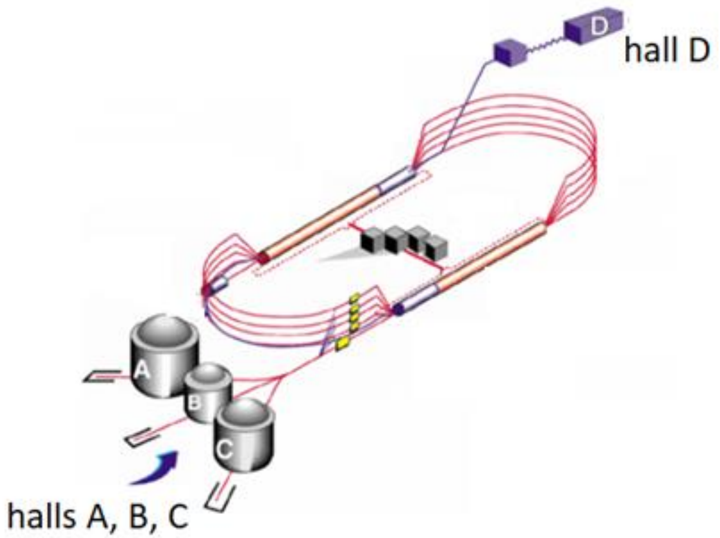
[4] D.E. Kharzeev, *Phys. Rev. D* **104**, 054015 (2021).
[5] B. Duran, et. al. (J/ψ – 007 Collaboration), preprint available at arXiv:2207.05212 (2022).

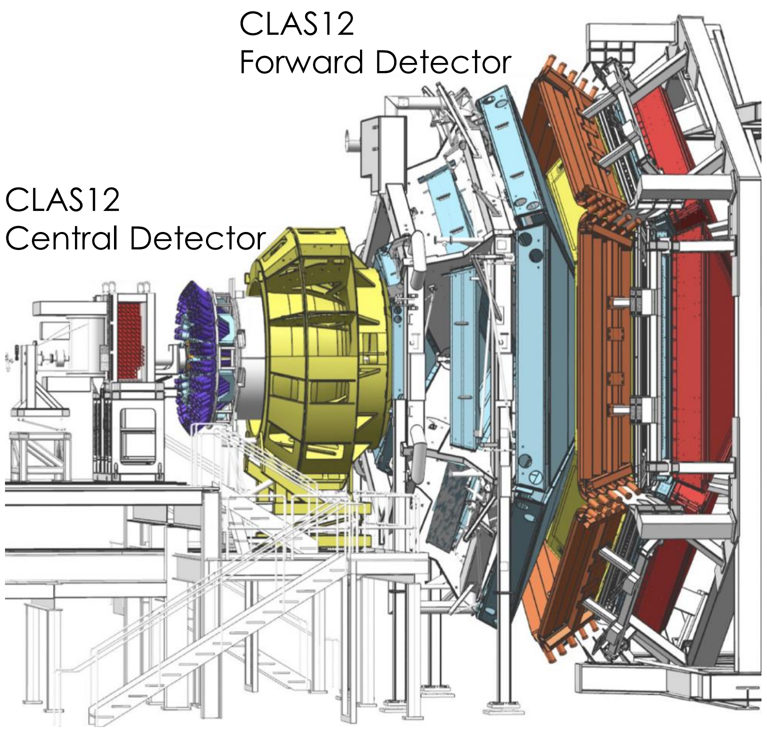
The CLAS12 Detector

- The CLAS12 Detector is located in Jefferson Lab's Hall B, in Newport News, Virginia.
- The GlueX detector is located in Hall D.

The CLAS12 Detector

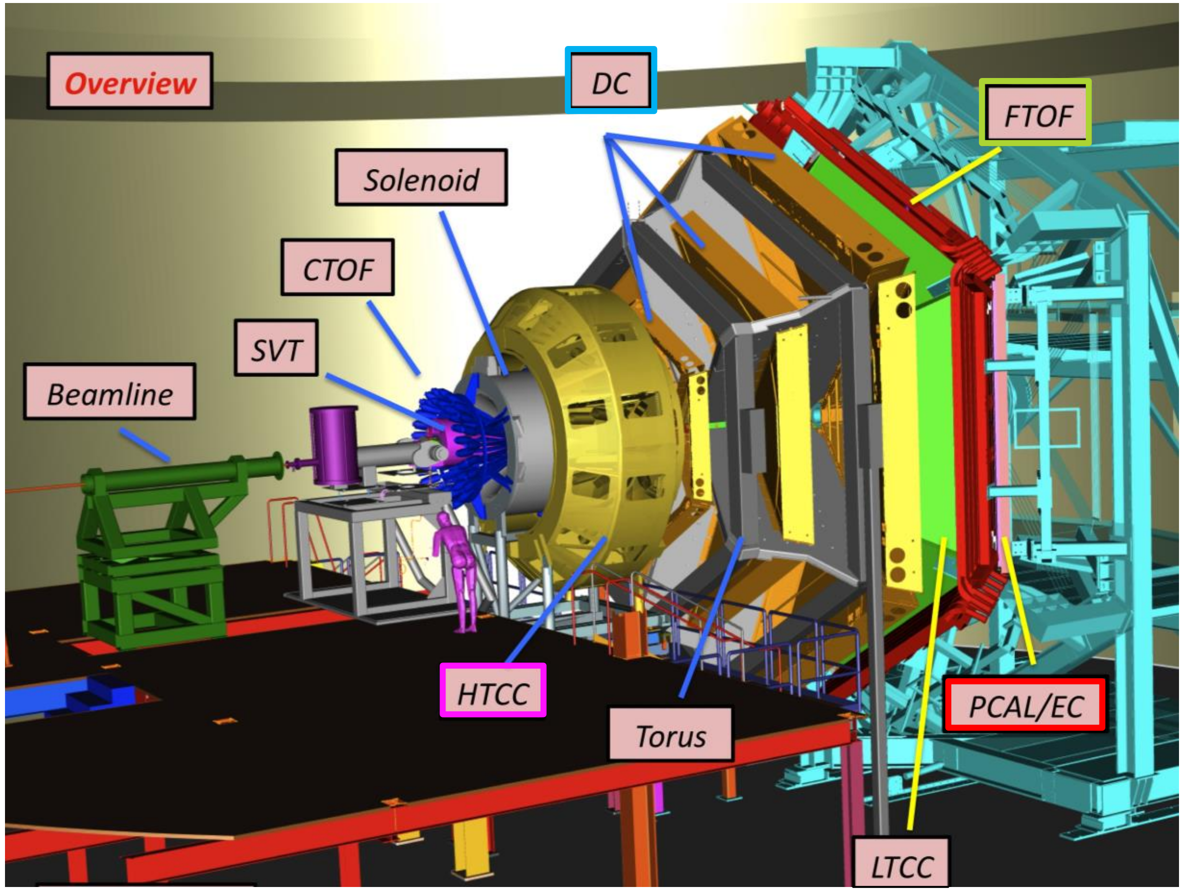
- The CLAS12 Detector is located in Jefferson Lab's Hall B, in Newport News, Virginia.
- The recently upgraded CEBAF accelerator facility produces a 12 GeV electron beam, with beam energies up to 11 GeV delivered to Hall B.
- The Forward Detector has polar angle coverage of 5 to 35 degrees.
- The Central Detector has polar angle coverage of 35 to 125 degrees.





CLAS12 Forward Detector

- The High Threshold Cherenkov Counter (HTCC) was built to identify electrons.
- The tracking system and Drift Chambers (DC) measure the charge and momentum of particles.
- The Forward Time Of Flight (FTOF) counters were designed to resolve charged hadrons.
- The Electromagnetic Calorimeters (PCAL and EC) are used to detect neutrals and identify electrons and muons.



Experiment Overview

- J/ψ decays to a lepton pair, with l^+l^- denoting either e^+e^- or $\mu^+\mu^-$.

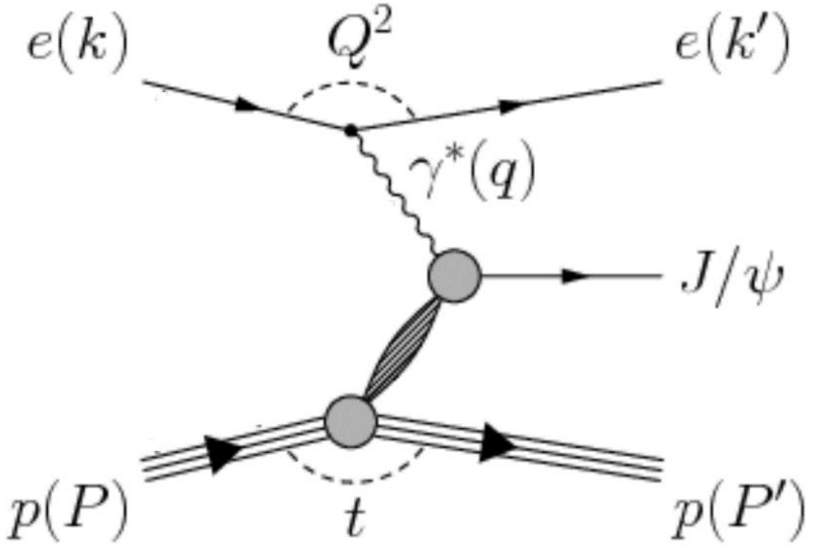
- CLAS12 took data with both a proton and a deuterium target offering several potential final states:

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

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

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

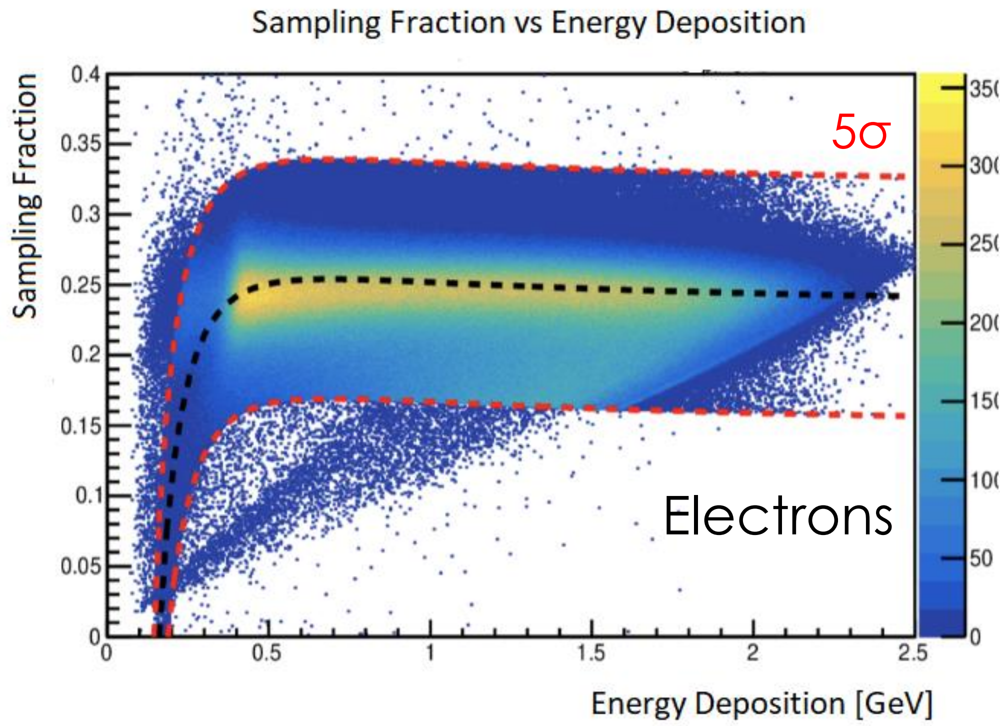
$$ed \rightarrow e' J/\psi\, d \rightarrow (e') l^+ l^- d$$

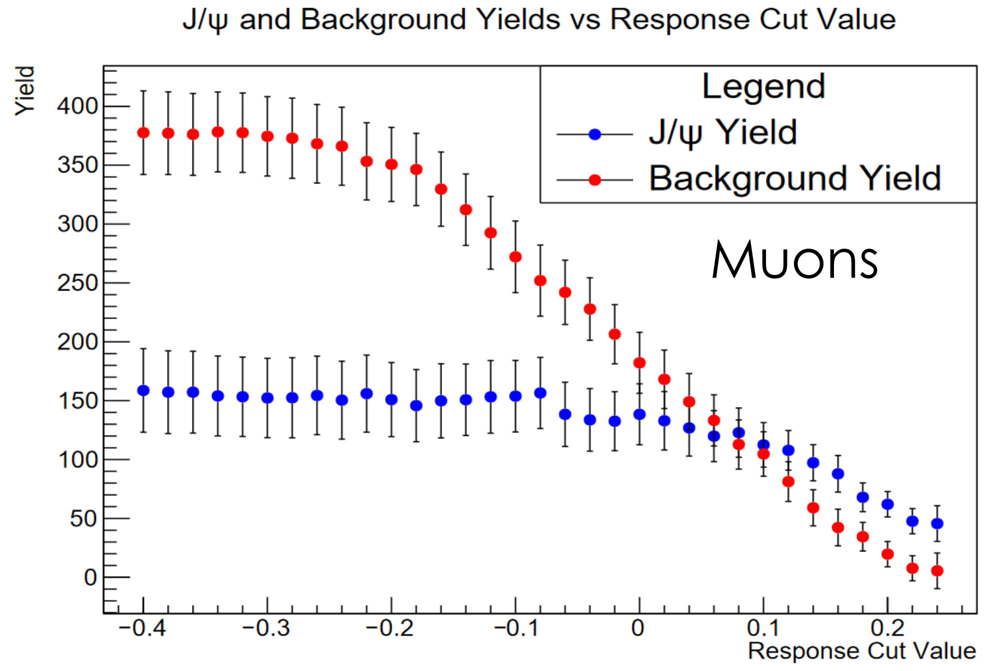


J/ψ quasi-real photoproduction on a proton target

Lepton Identification

- Electrons and positrons are required to produce a signal in the HTCC and high energy deposition in the calorimeter. Their main source of background is due to high momentum pions firing the HTCC.
- Muons are minimum ionising particles which we select with cuts on their energy deposition in the calorimeters. These are susceptible to a significant charged pion contamination.
- We refine leptons PID by training a machine learning classifier on variables from several CLAS12 detector subsystems to remove the pion background.
- The PID process is then reduced to a cut on the response of the classifier.

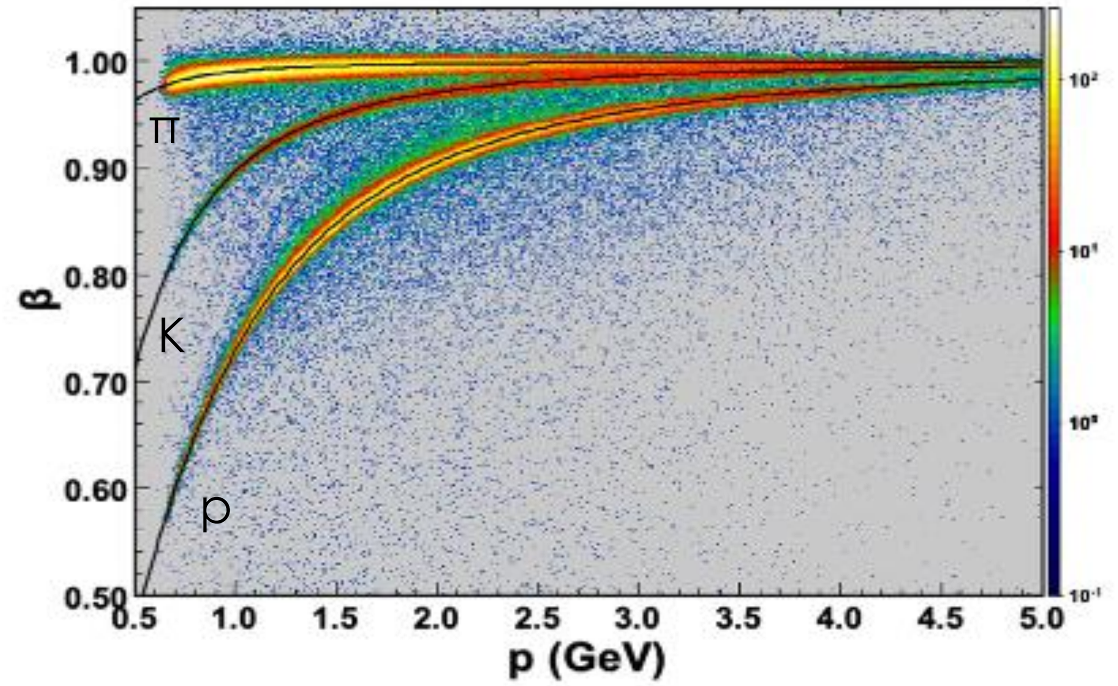




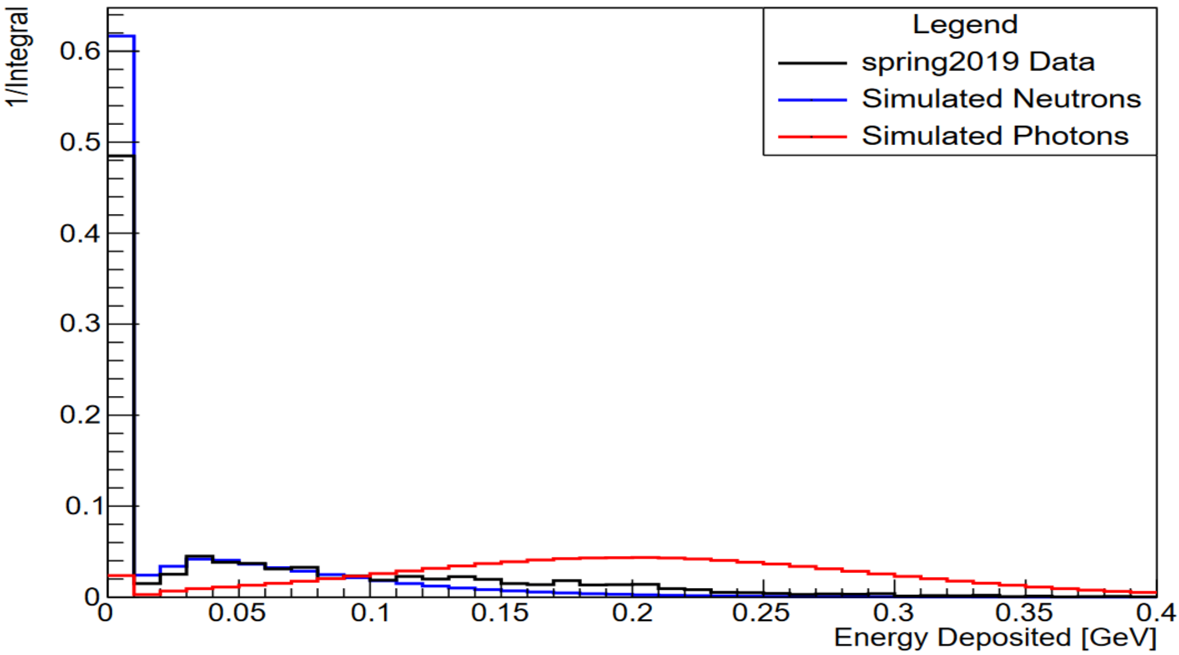
Hadron Identification

- 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.

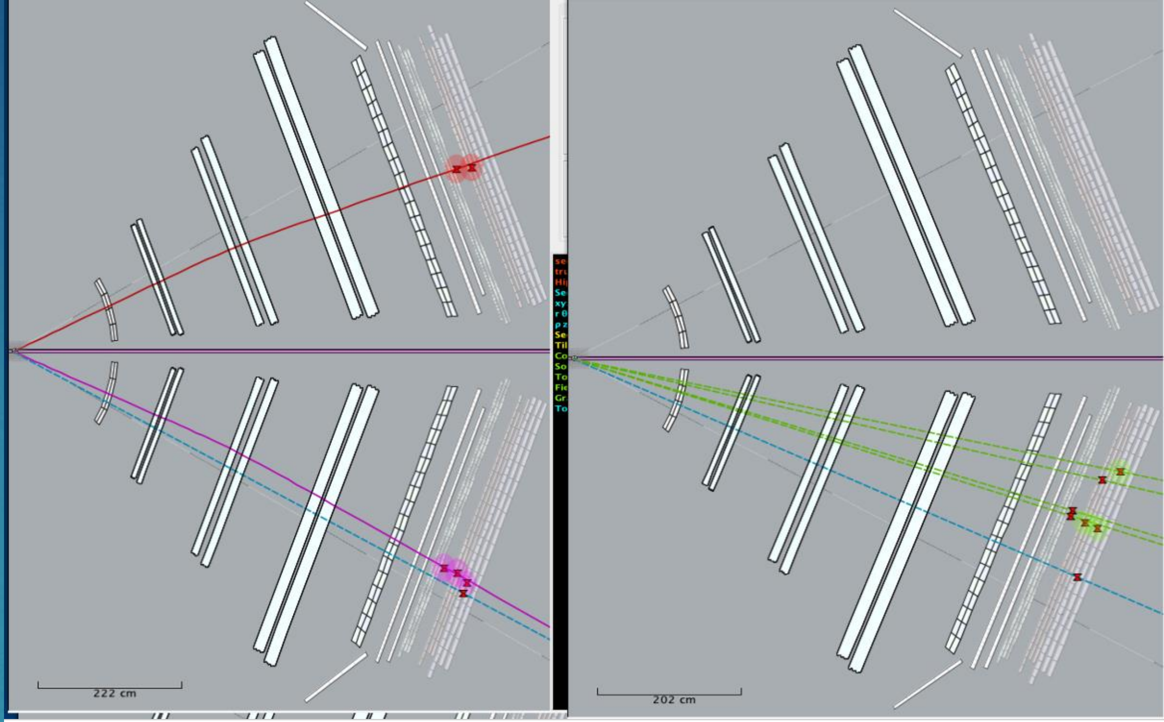


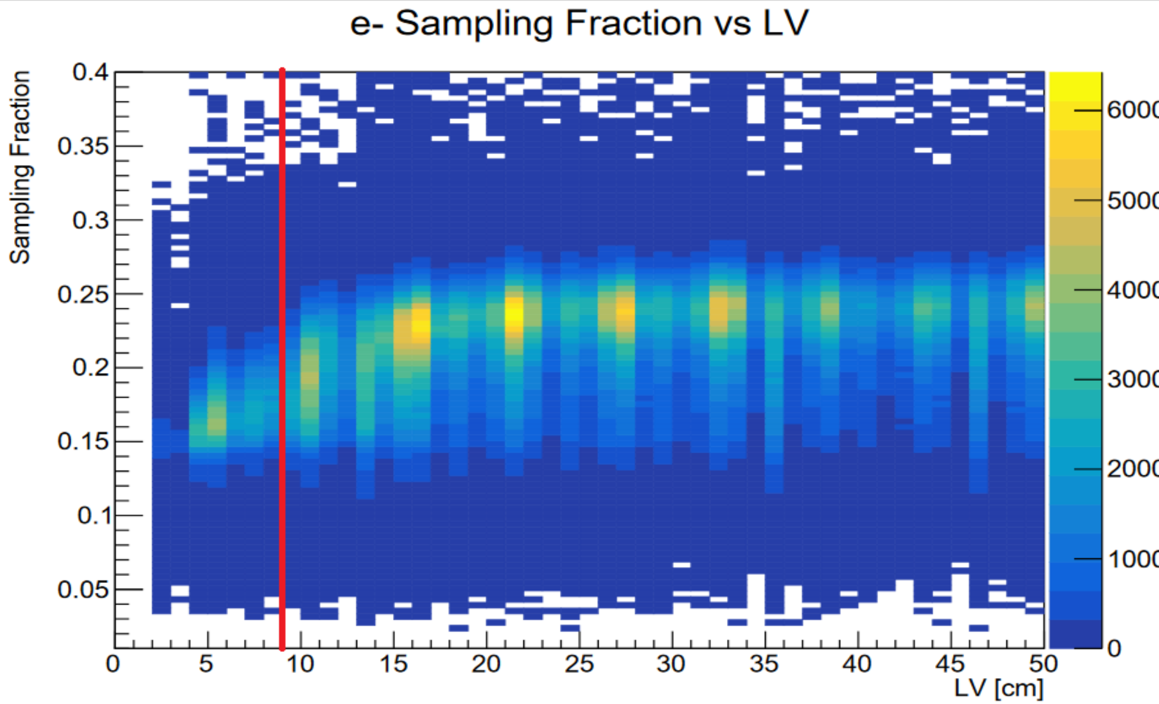
Energy Deposited in PCal



Particle Corrections

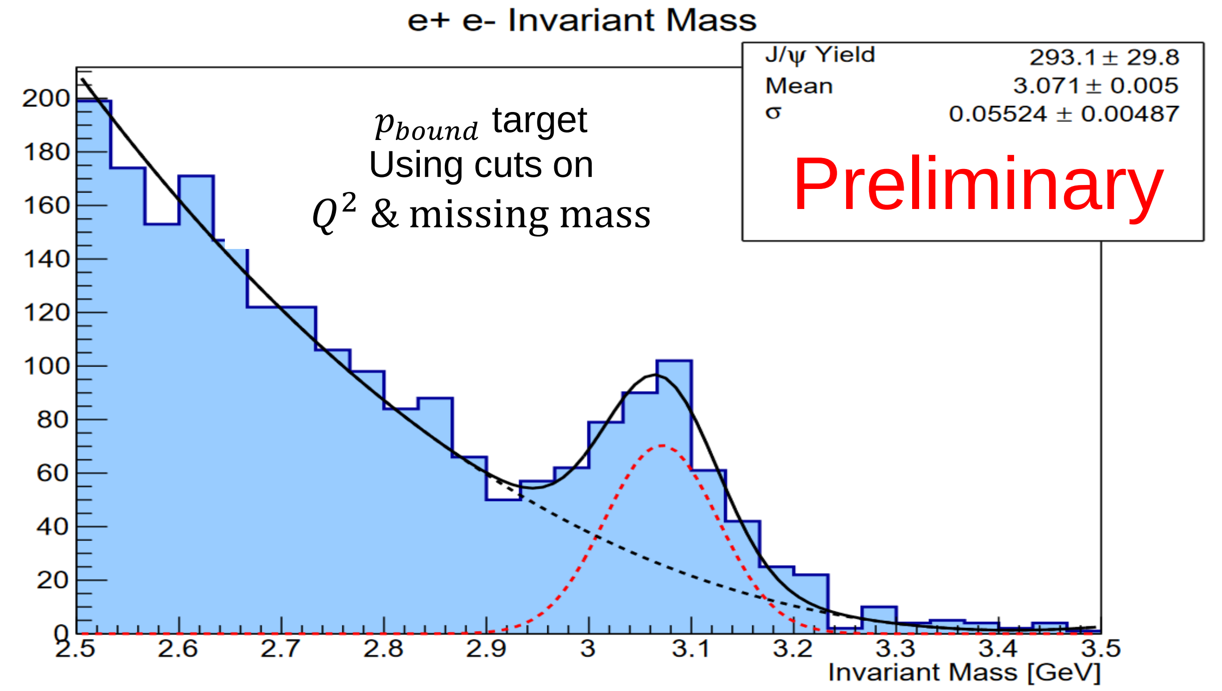
- Radiative corrections for electrons/positrons add the momentum of radiated photons.
- Neutrons also produce secondary clusters. These are removed by taking the earliest neutral in a given sector.
- The reconstructed path length for neutrons is corrected for a more accurate calculation of the momentum.
- We apply fiducial cuts to remove e+/e- hits close to the edges of the PCAL where the shower is not fully contained within the calorimeter.
- Fiducial cuts in the drift chambers are applied to electrons, positrons, protons and muons by removing hits at the edge of the layers.

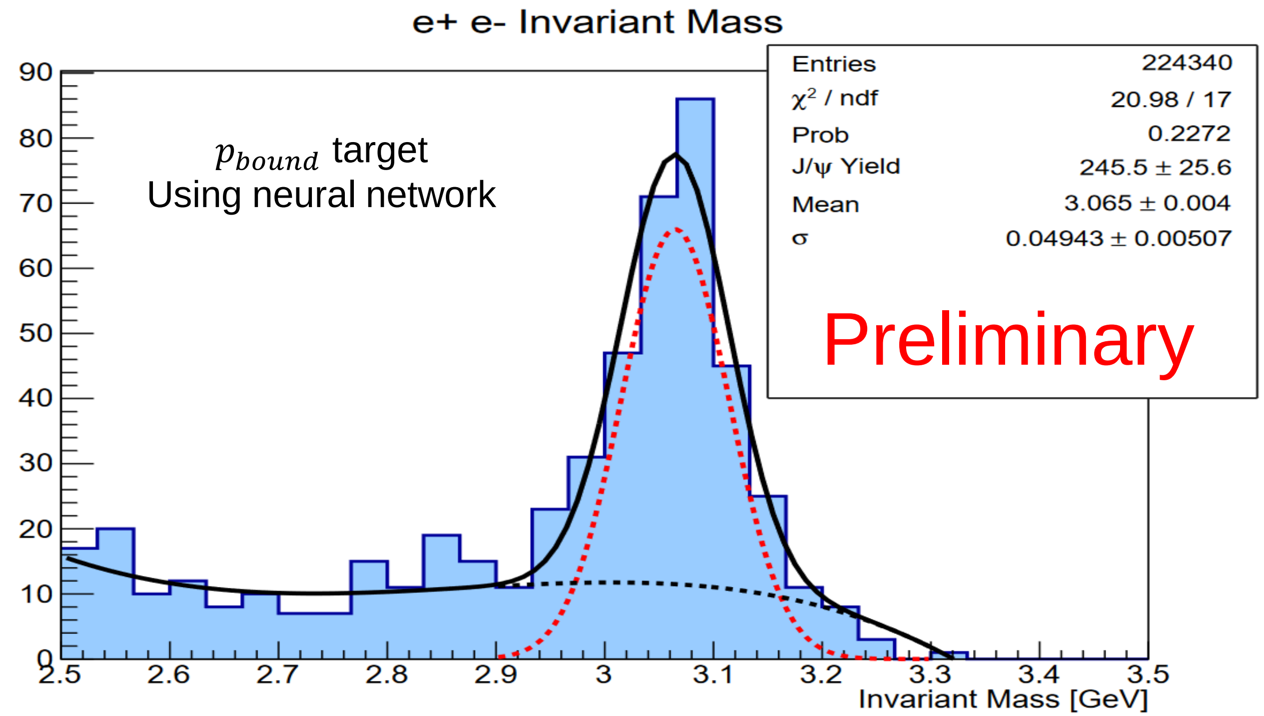




Event Selection

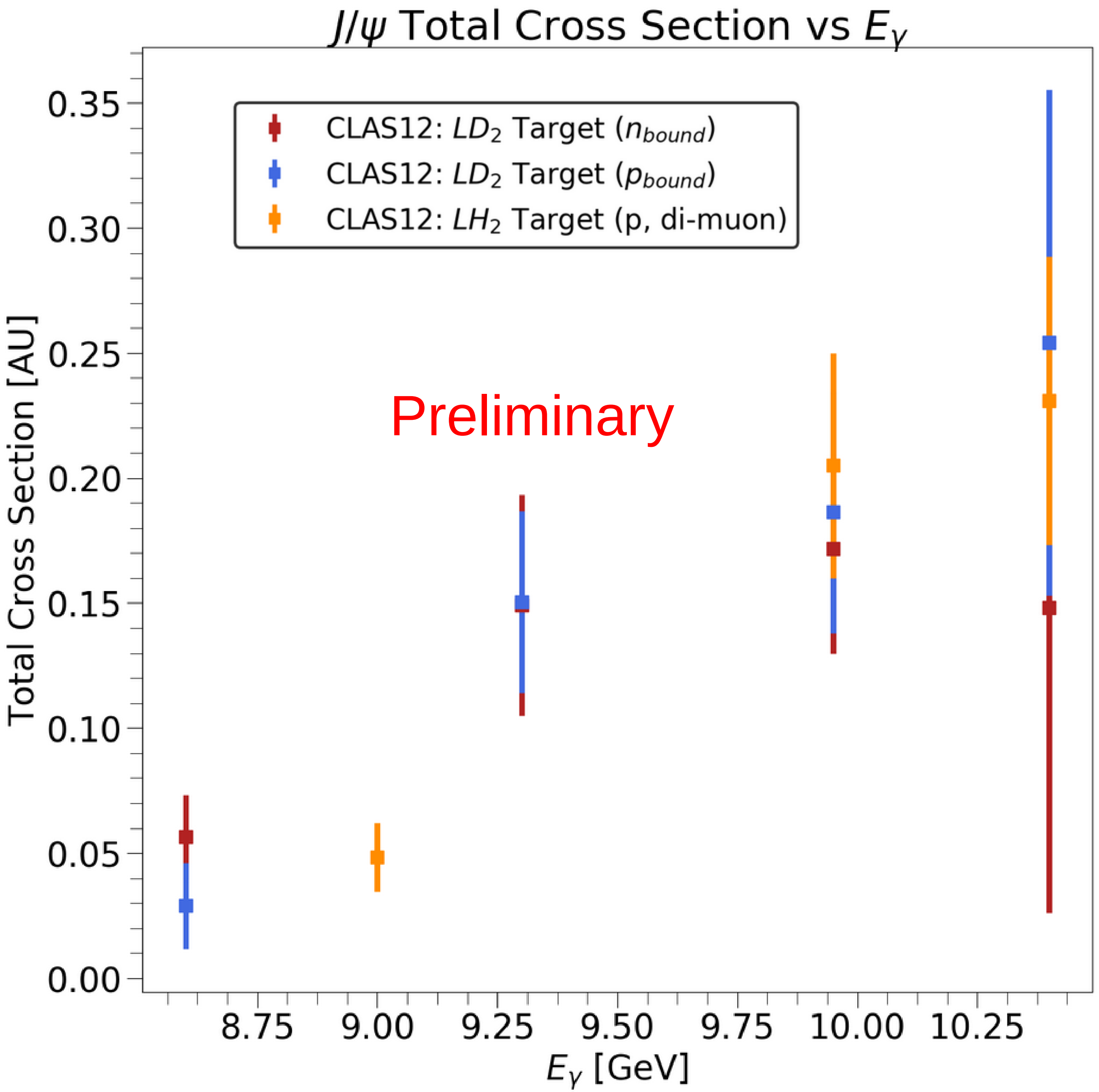
- We minimize Q^2 to select only quasi-real photoproduction events. We also want the missing mass close to the mass of the scattered electron.
- The widths of these distributions can be parametrised as a function of the photon energy.
- Alternatively, we can train a neural network to distinguish between:
  - J/ψ simulation.
  - Mismatched particles from different events of the above.





Total Cross Section

- Shown here are the cross sections measured in:
  - $ep \to (e')\mu^+\mu^- p$
  - $e\, p_{bound} \to (e')e^+e^- p$
  - $e\, n_{bound} \to (e')e^+e^- n$
- We are still working on the absolute normalization, ω_c. This is here set to 1.



Outlook

- CLAS12 is working on upgrading the luminosity by a factor of two. Assuming this goes on as planned we can expect about 5 times more data to collected.

- AI based improvements in the tracking reconstruction at CLAS12 show an average 30% increase in the efficiency for 3 charged particles. The data already taken at CLAS12 is about to be reprocessed with the new tracking improvements.

- In total, we can expect a factor of 6 increase in available statistics from already approved CLAS12 experiments.

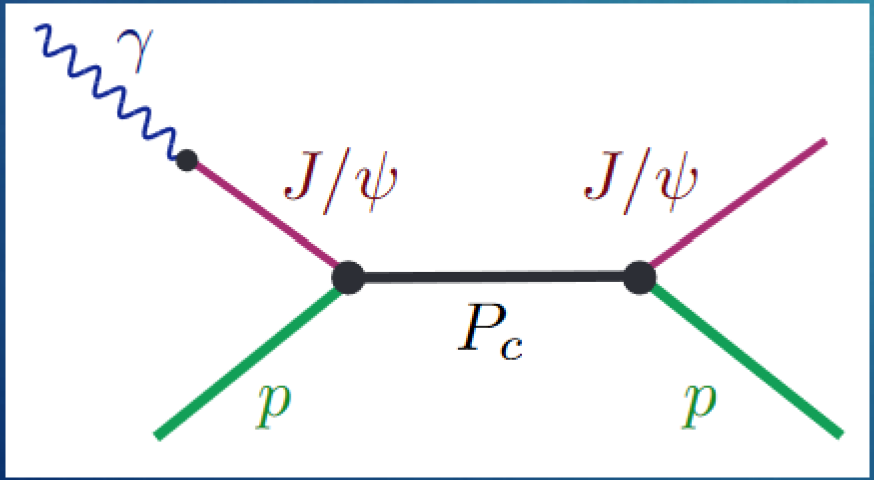
Conclusion

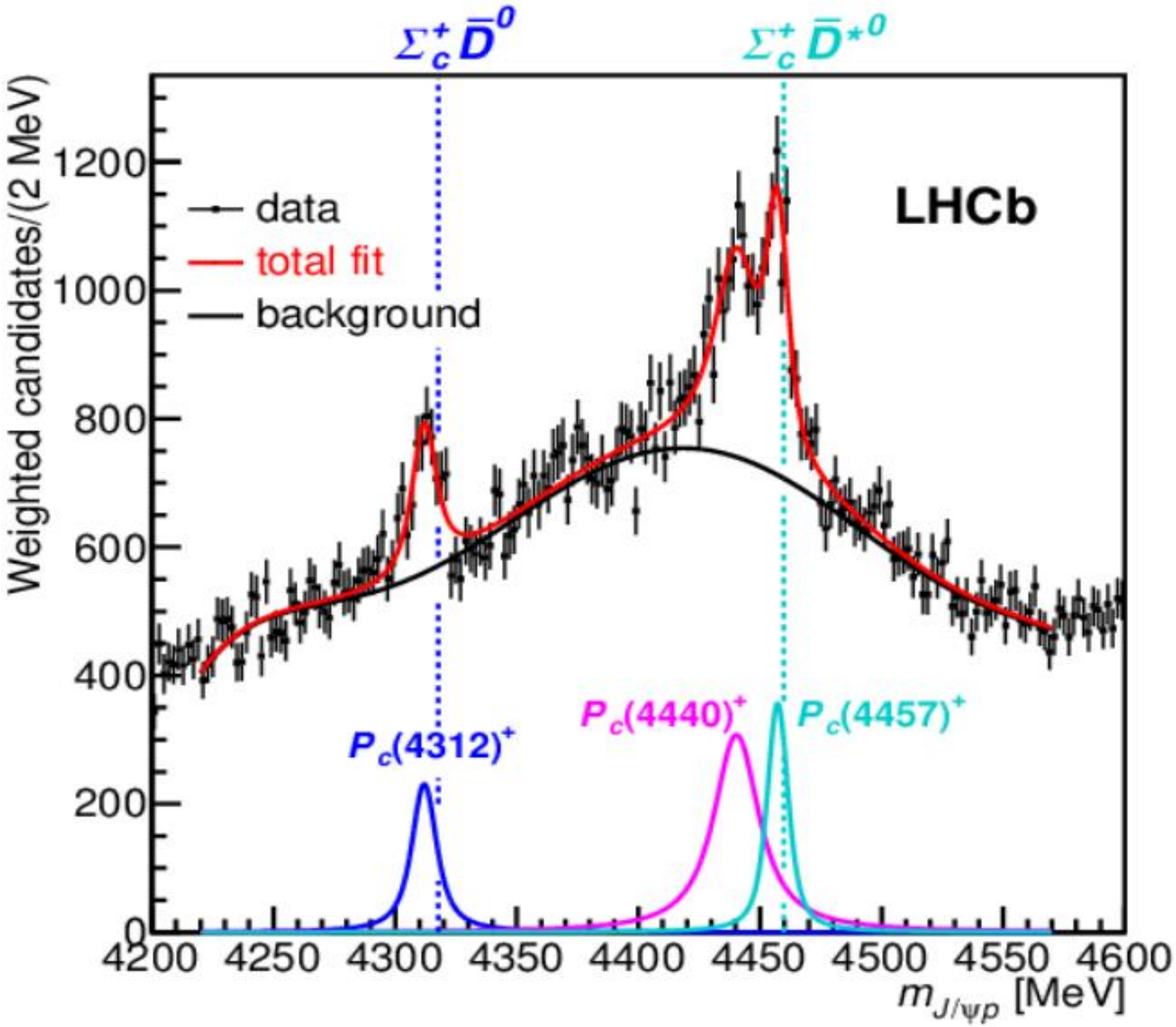
- The near-threshold J/ψ photoproduction cross sections are related to J/ψ production mechanism and the nucleon gluonic form factor.
- This also provides unique insight about the structure of nucleons on which J/ψ is produced, such as their mass radius.
- We're aiming for a first measurement directly comparing the J/ψ photoproduction cross section on proton and neutron.
- The analysis of data at CLAS12 is ongoing and well advanced.

Backup Slides

P_c^+ resonances with CLAS12

- CLAS12 should be able to place upper limits on the branching fraction $B(P_c^+ \to J/\psi\ p)$ and $B(P_c^+ \to J/\psi\ n)$.



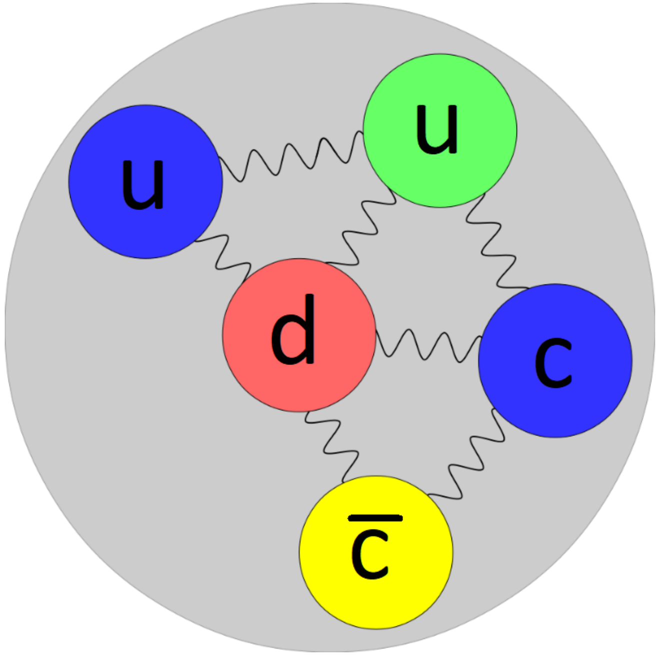


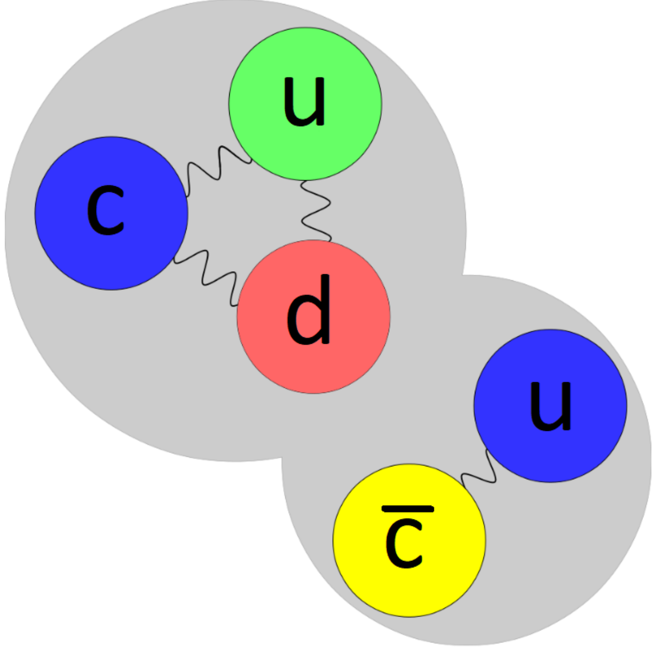
The J/ψ p invariant mass distribution measured at the LHCb. Taken from:

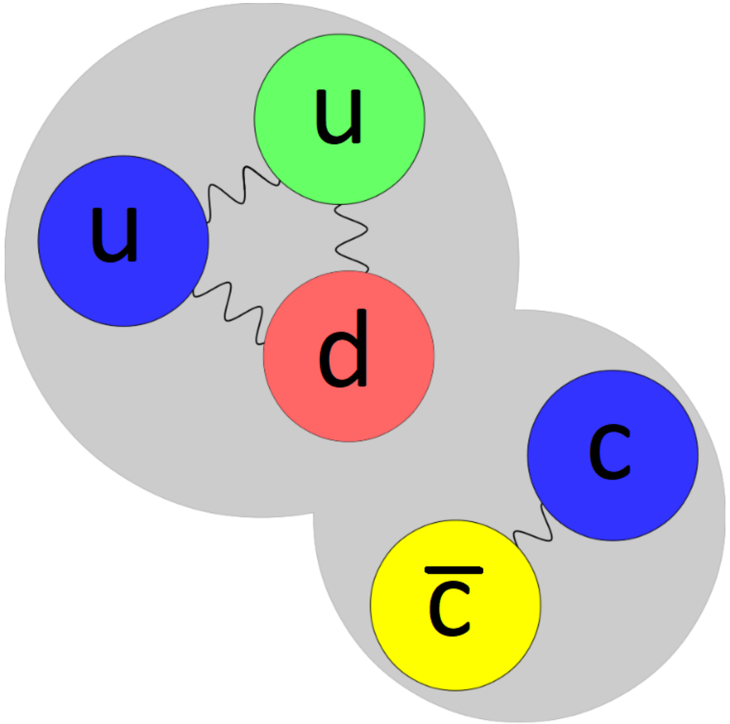
R. Aaij, *et. al.* (LHCb Collaboration), *Phys. Rev. Lett.* **122**, 22 (2019).

P_c^+ Models

- Hadronic molecules: Weekly coupled charmed baryon and charmed meson.
- Hadro-charmonium states: compact bound $\mathbf{c\bar{c}}$ state and light quarks.
- Quarks in a bag: Two tightly correlated di-quarks and an anti-quark.

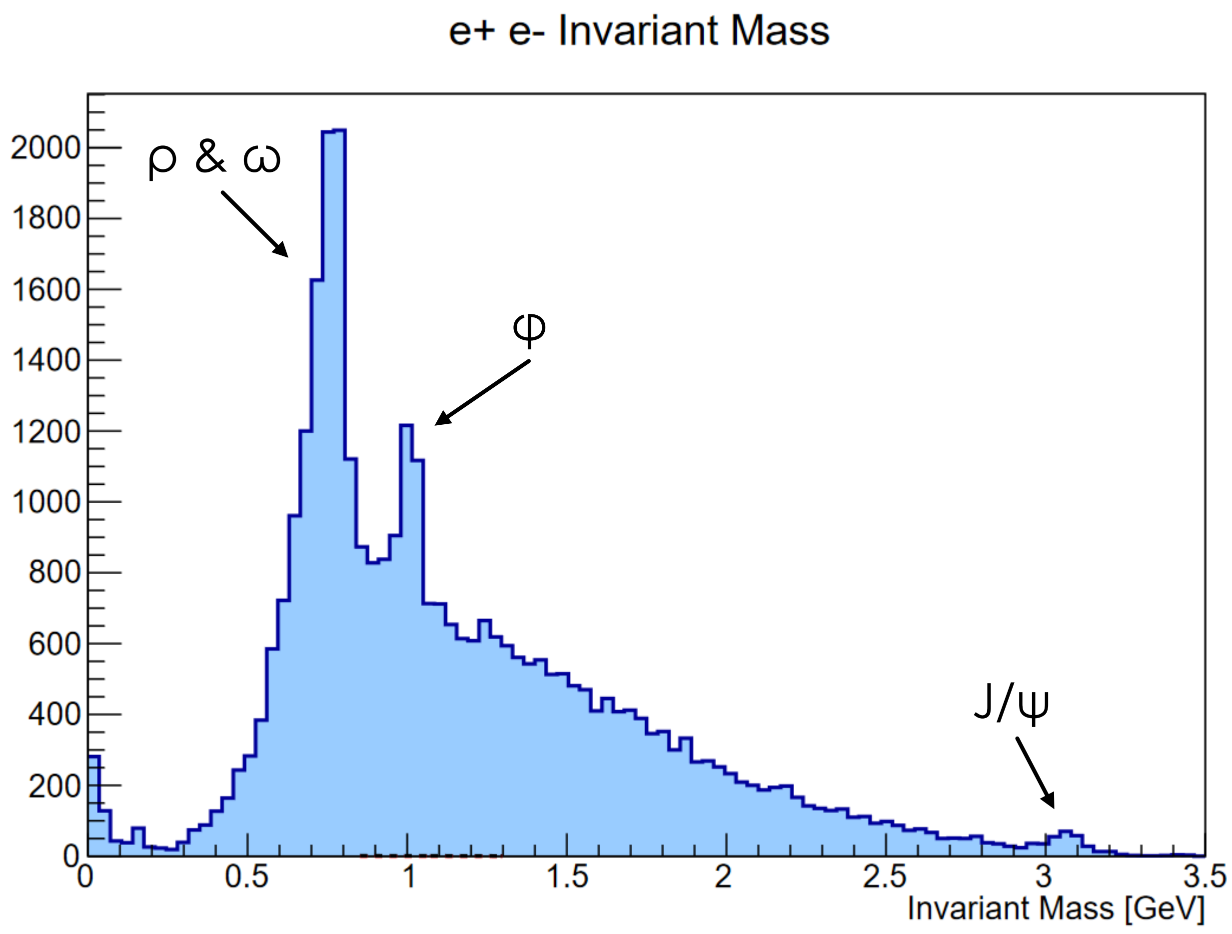






ρ, ω and φ mesons

- Plotted here is the invariant mass of e^+e^- produced on a bound proton in the deuteron target.
- φ mesons are clearly resolved.
- ρ and ω mesons are unresolvable but clearly present.



Cross Section Calculation

- We can calculate the total cross section as:

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

- Where:
  - $N_{J/\psi}$ is the J/ψ yield in each E_γ bin
  - N_γ is the sum of real and virtual photon flux
  - η_T is the integrated luminosity
  - ω_c is the Bethe Heitler normalisation factor
  - Br is the branching ratio (~6%)
  - $\epsilon(E_\gamma)$ is the acceptance in each E_γ bin