$J/\psi \rightarrow \mu^+\mu^-$ detection with CLAS12

RICHARD TYSON

CEBAF Large Acceptance Spectrometer

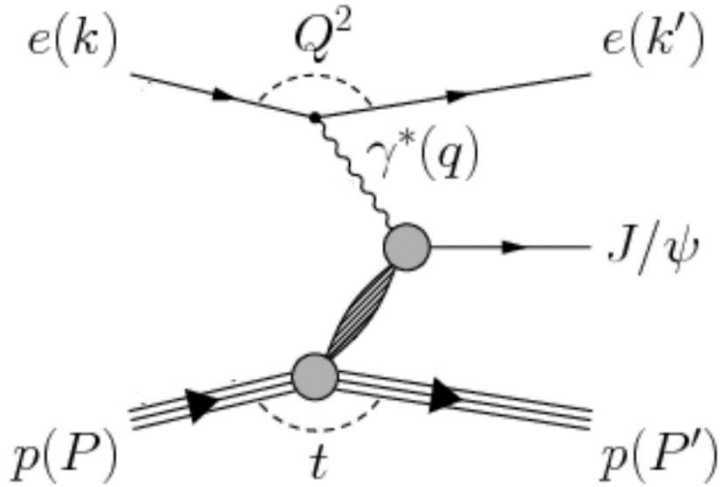
VIA VERITAS VITA

University of Glasgow

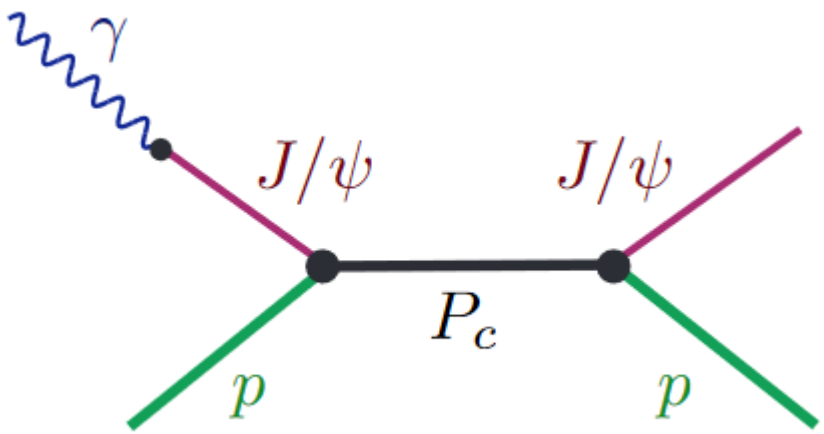
Experiment Overview

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

- The electron beam produced by CEBAF scatters with a liquid hydrogen (proton) target through the exchange of a quasi-real photon $Q^2 \sim 0$
- The proton and $\mu^+\mu^-$ pair produced in J/ψ decay are detected in the FD.
- Experiment 12-12-001 was approved for 120 days of beamtime with CLAS12 at a luminosity of $10^{35} cm^{-2} s^{-1}$

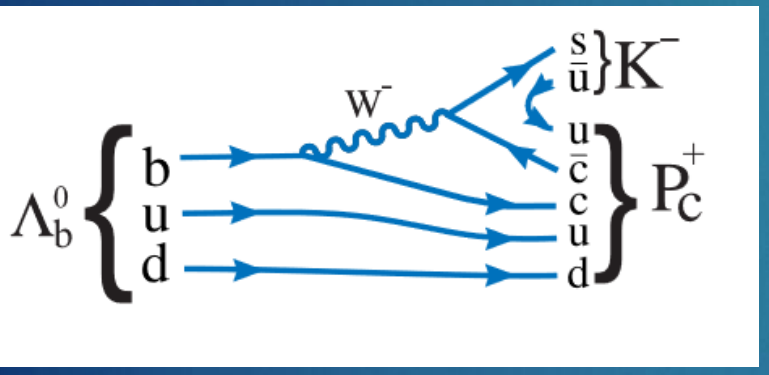


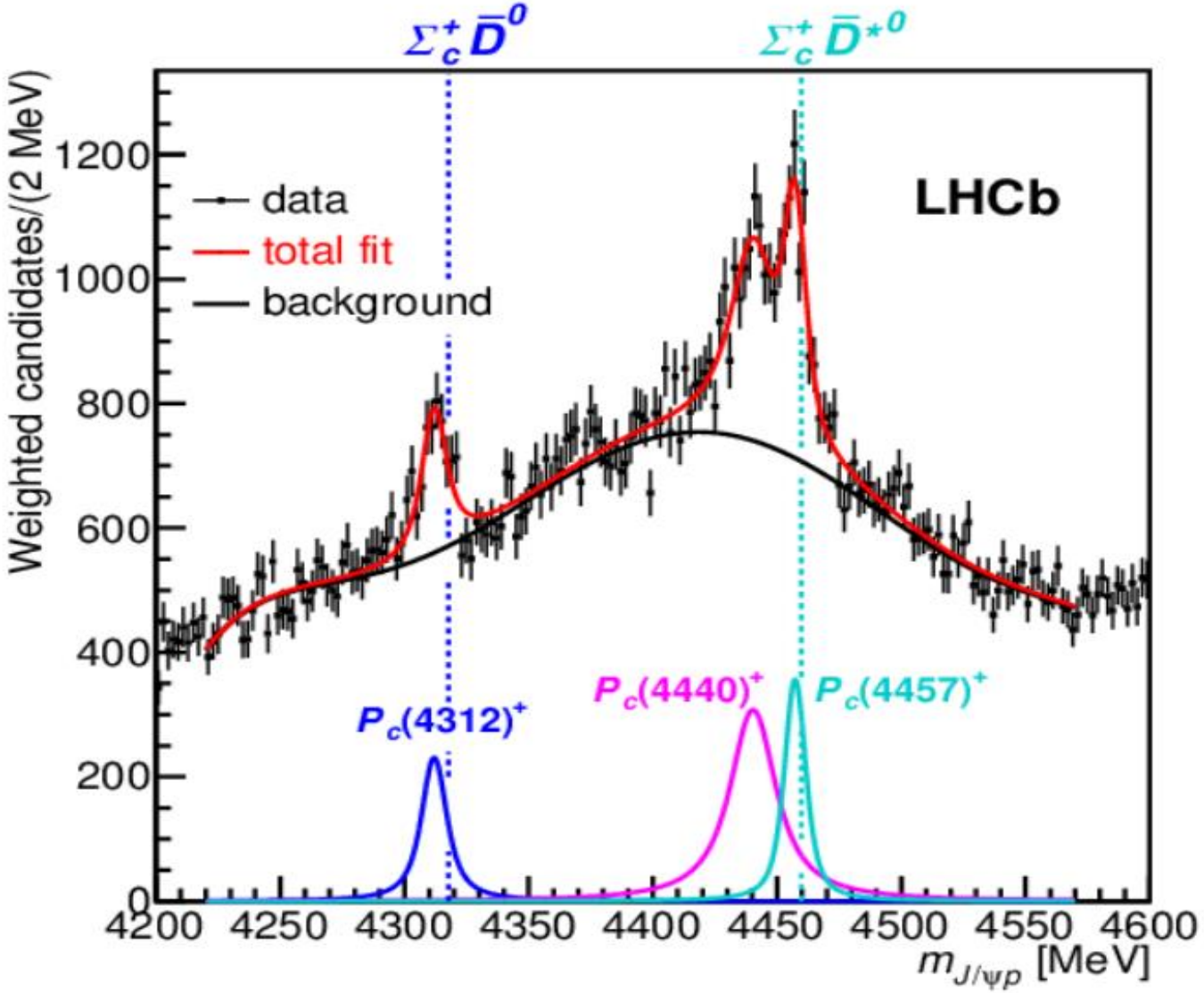
J/ψ quasi-real photoproduction



Feynmann diagram of P_c^+ pentaquark photoproduction.

P_c^+ resonances at the LHCb (2019)

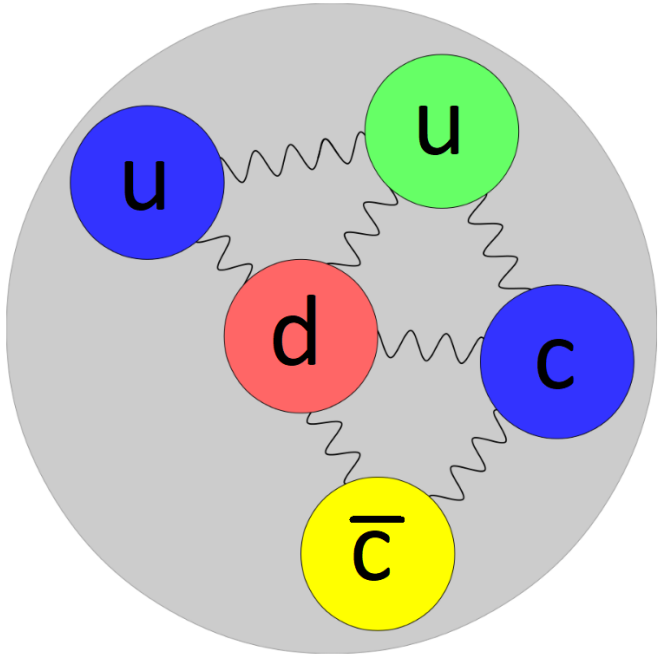


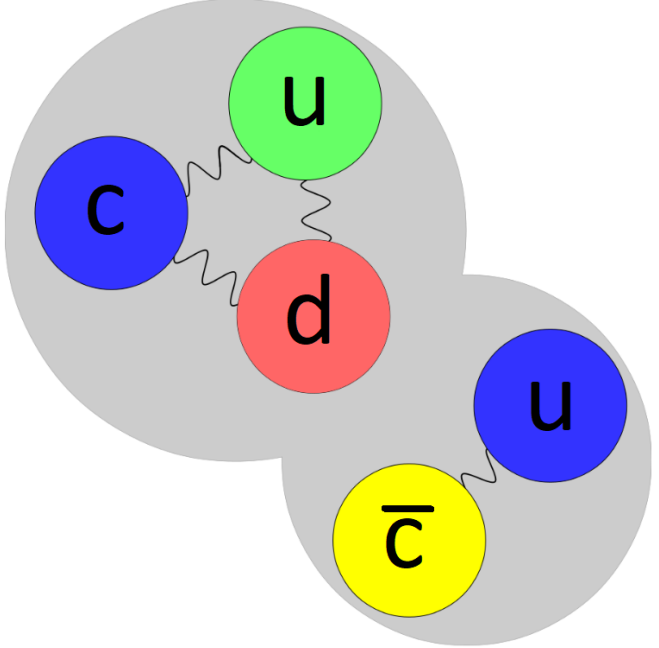


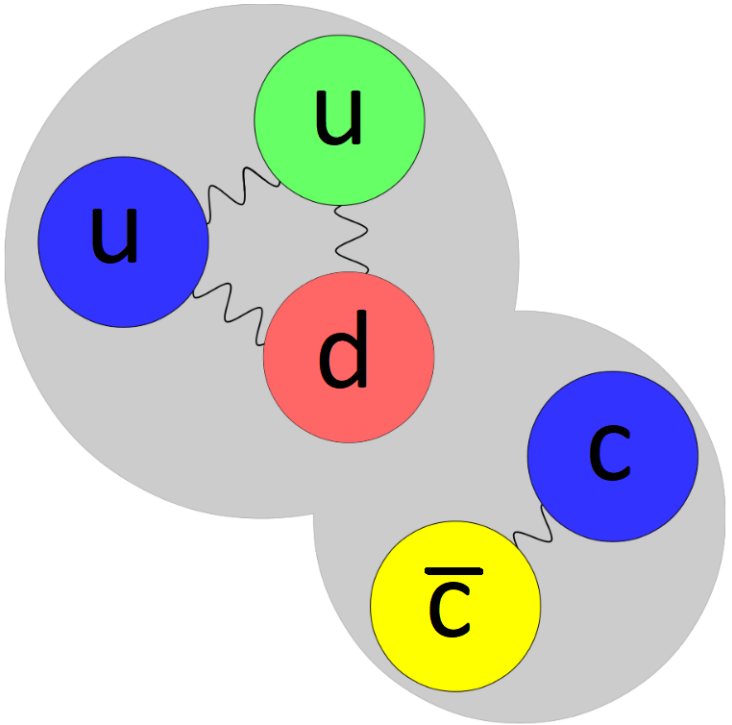
The J/ψ p invariant mass distribution [1].

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.

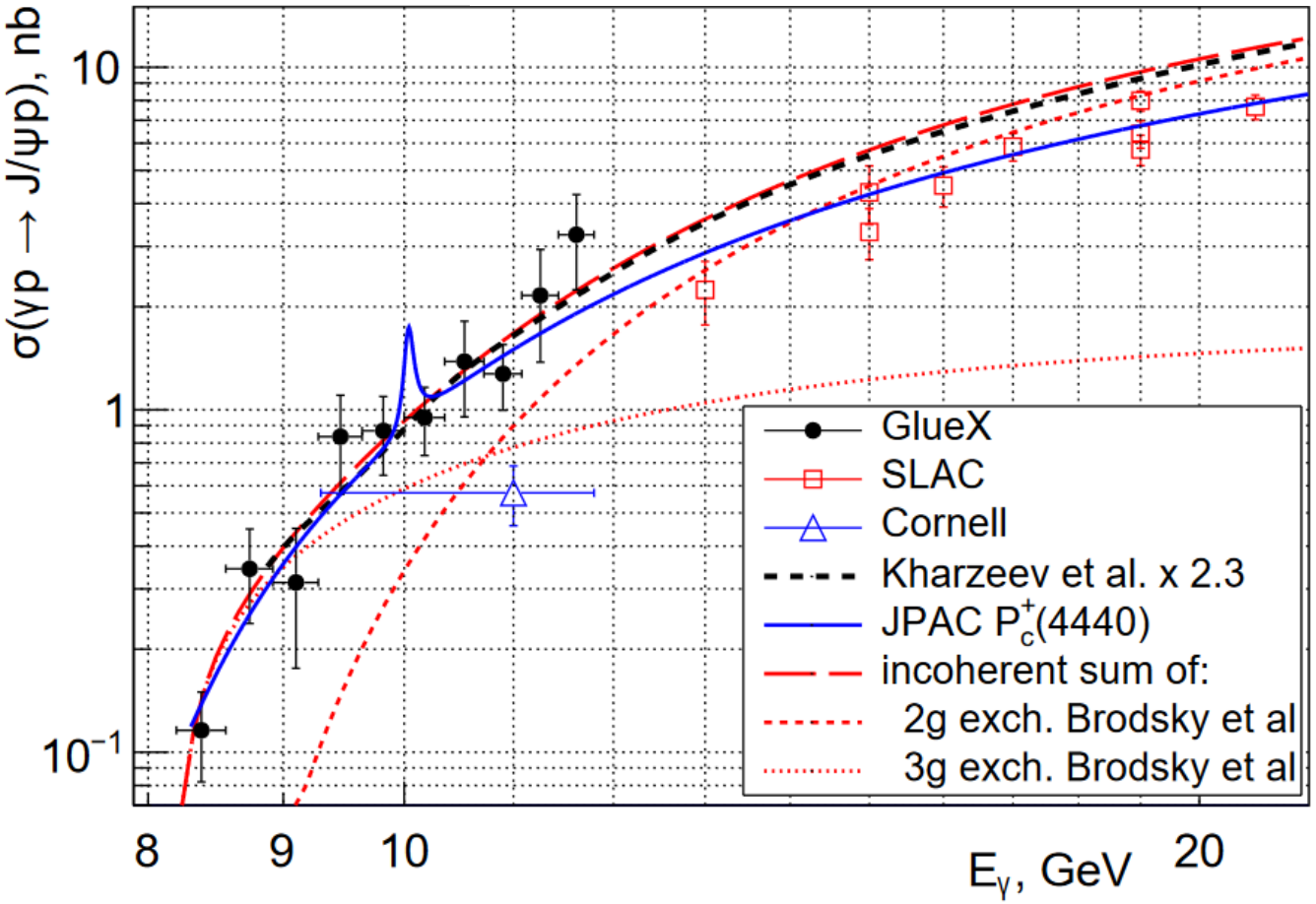






Goals

- Confirm the LHCb results and distinguish between several models for the structure 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].

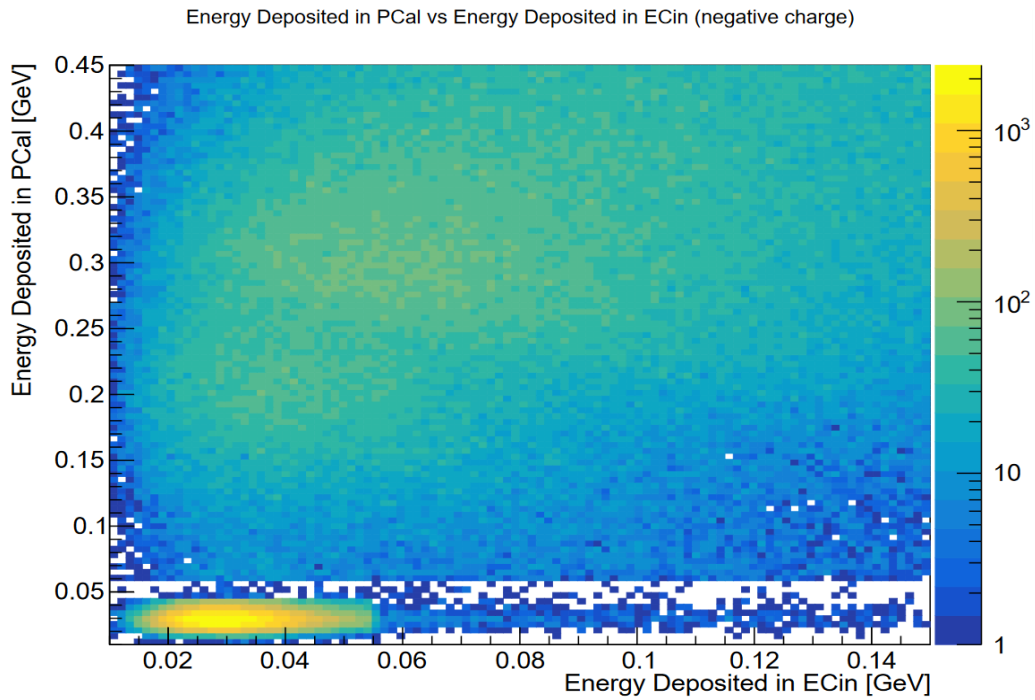
Initial particle selection

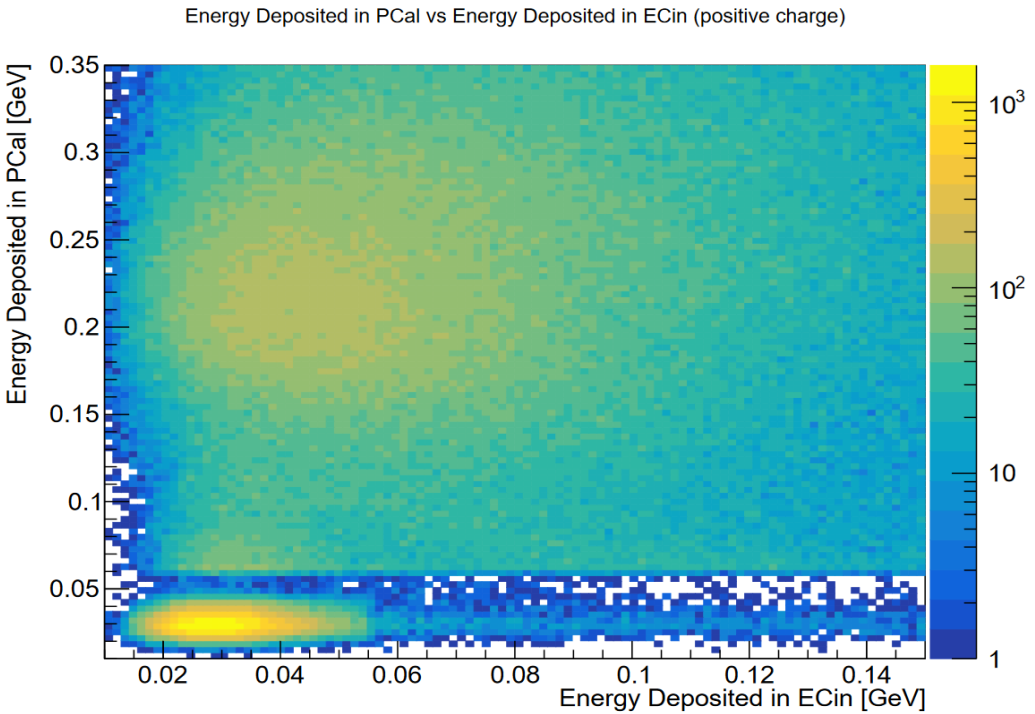
- Take a proton in FD, use event builder PID.
- Take two additional oppositely charged tracks in FD.
- Require for these mip-like energy deposition in the calorimeters (upper bounds from skim1 requirements):

  0.01<PCAL<0.045

  0.01<ECin<0.055

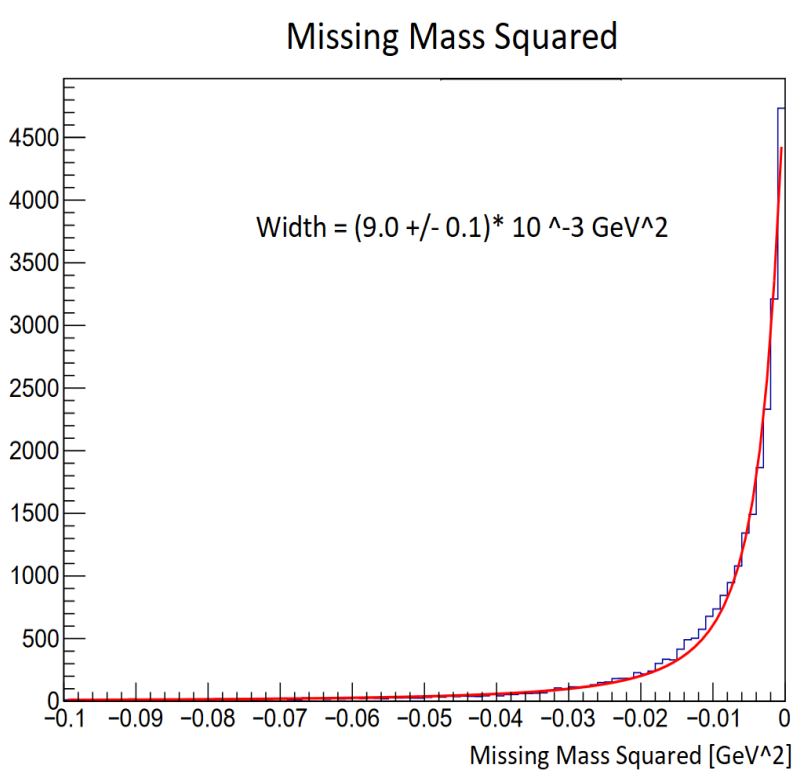
  0.01<ECout<0.85

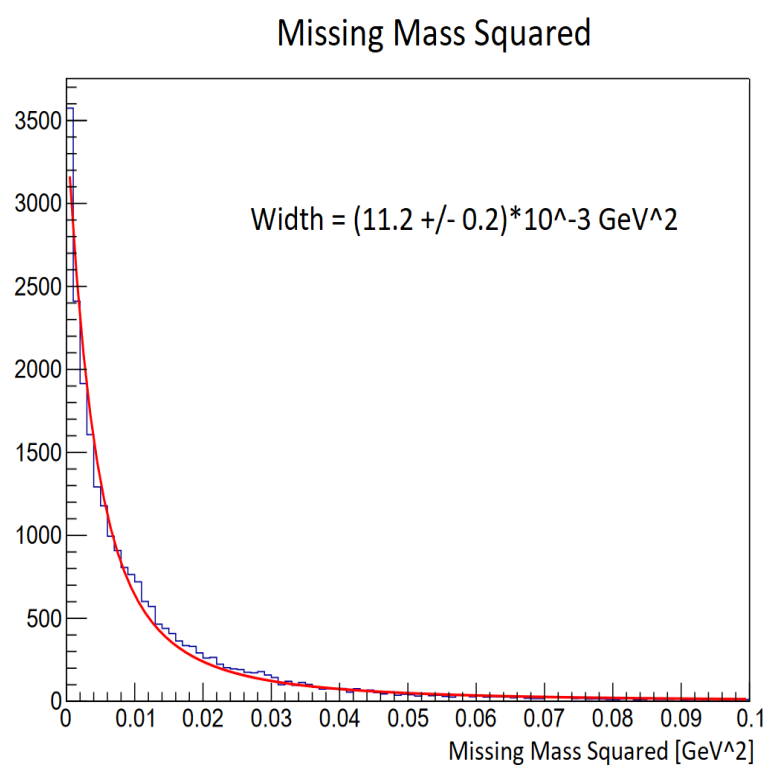


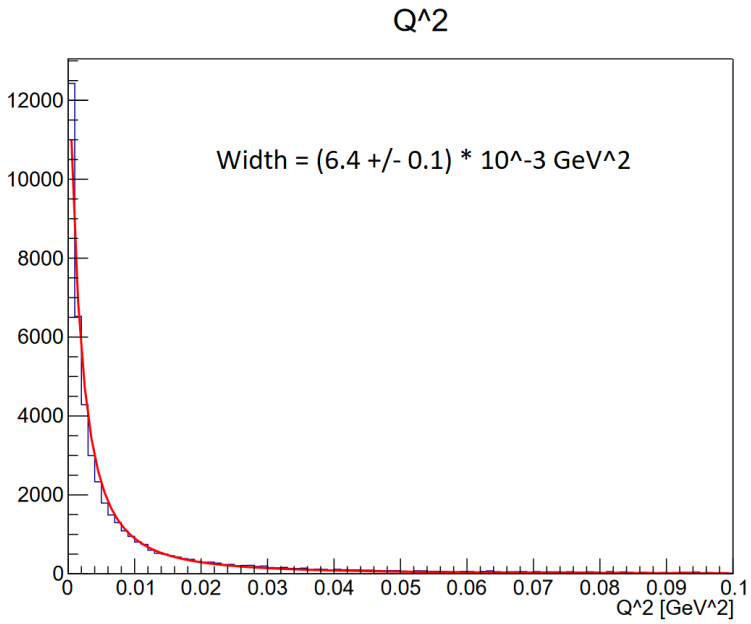


Event Selection Criteria

- Restrict the missing mass squared of the event and virtuality of the photon.
- Studied how the range of these cuts affected our $\mu^+\mu^-$ invariant mass.

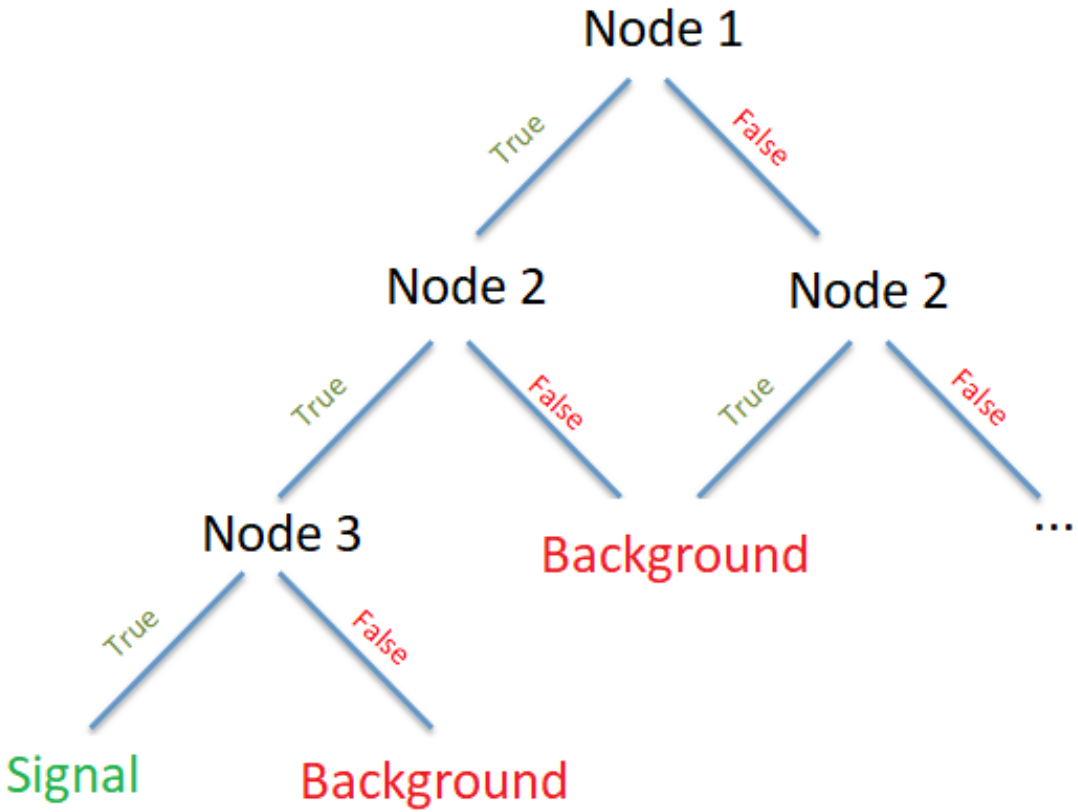






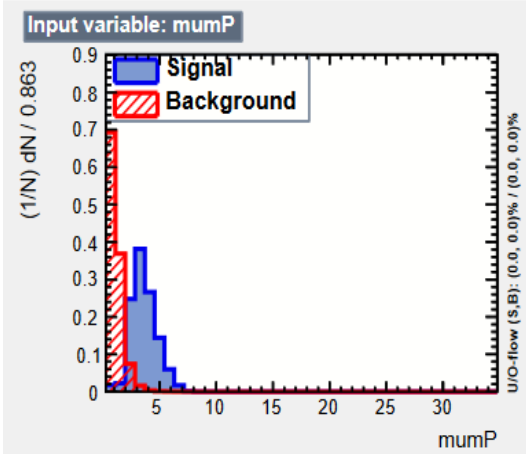
Boosted Decision Trees (BDTs)

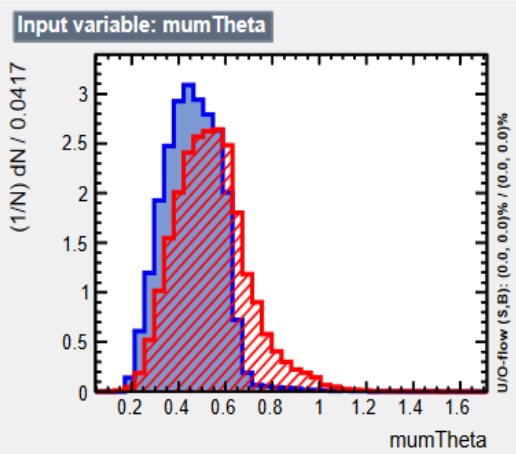
- Multivariate classifier available with ROOT TMVA.
- A boosted decision tree picks trees at random in a forest to refine the weights.
- Requires a training sample to learn how to differentiate the "signal" and "background" distributions.

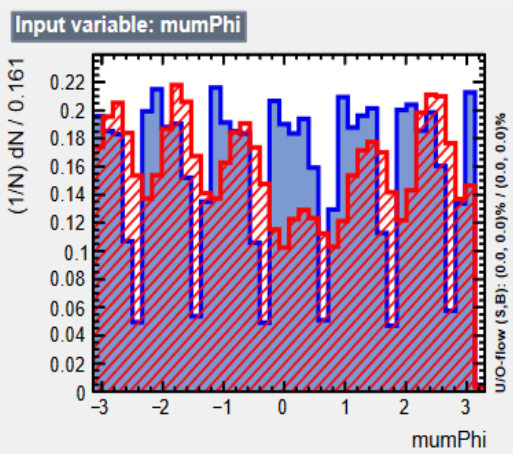


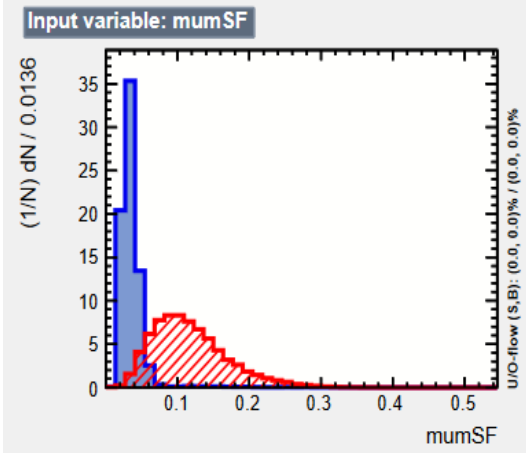
Variables and training

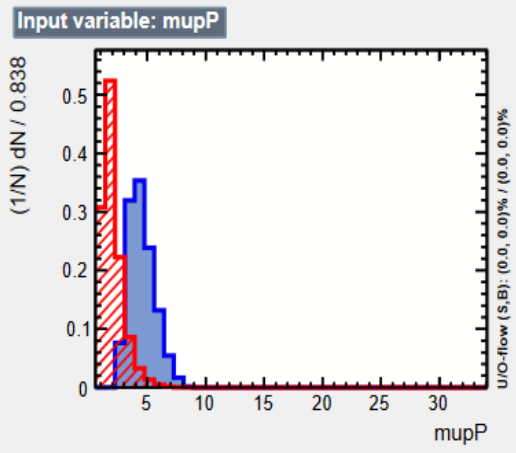
- Also included the missing mass squared of the event, Q^2 and the opening angle between the two muons in our discriminating variables.
- Simulated events with J/ψ decaying to two muons are used as signal for training.
- Events with the scattered electron in the FT and a proton and two mip candidates in FD are used as background for training.

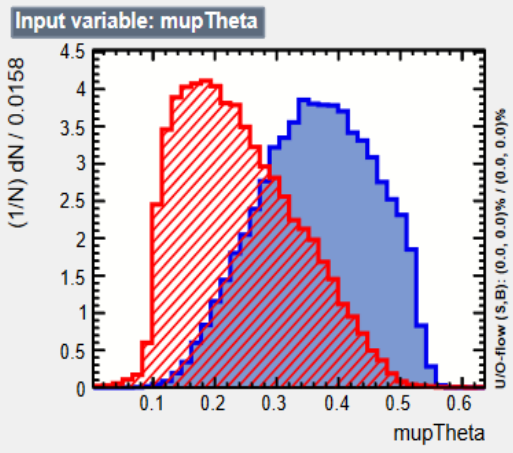


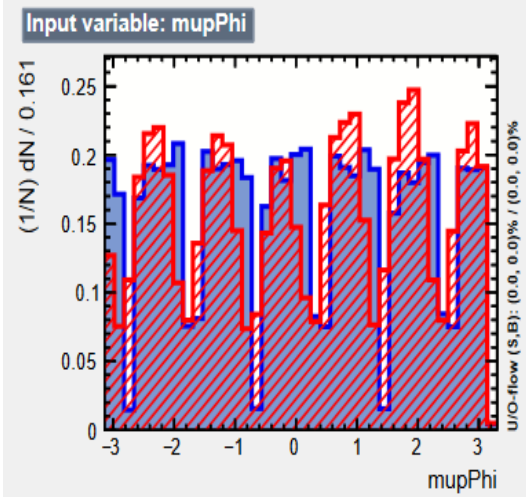


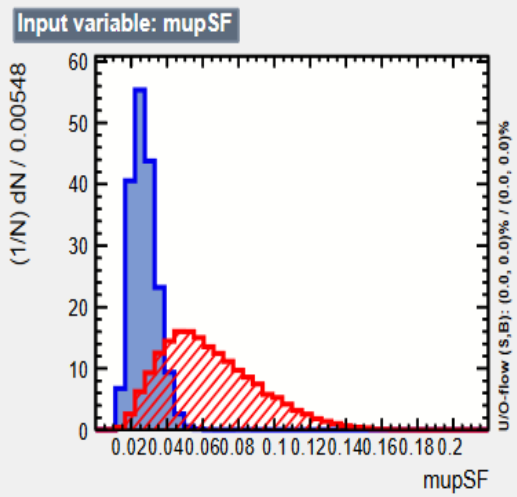












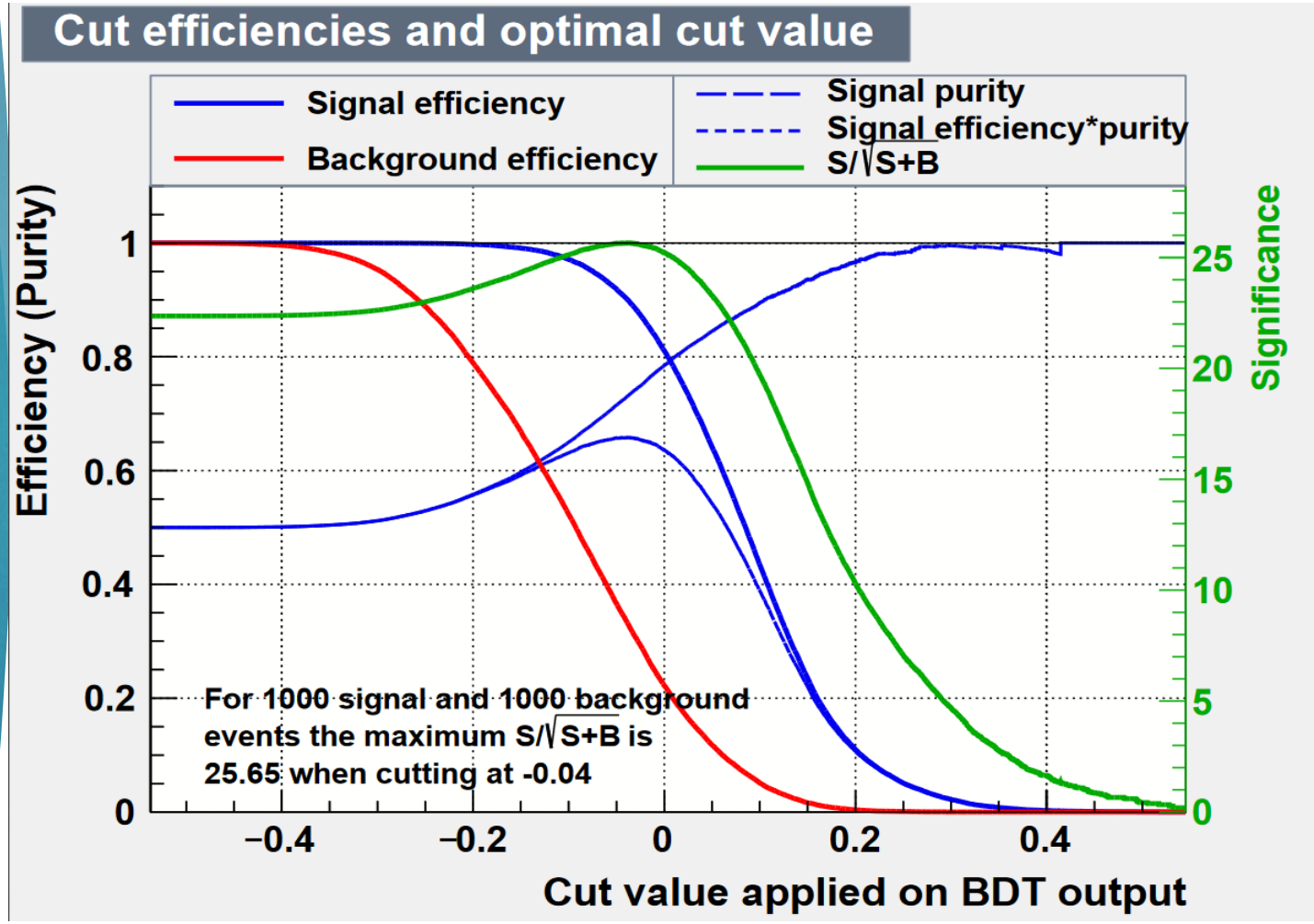
Choosing the best response

$$Efficiency = \frac{signal}{signal + missed} = \frac{TP}{TP + FN}$$

- Signal efficiency gives an indication of how effective my signal selection is.

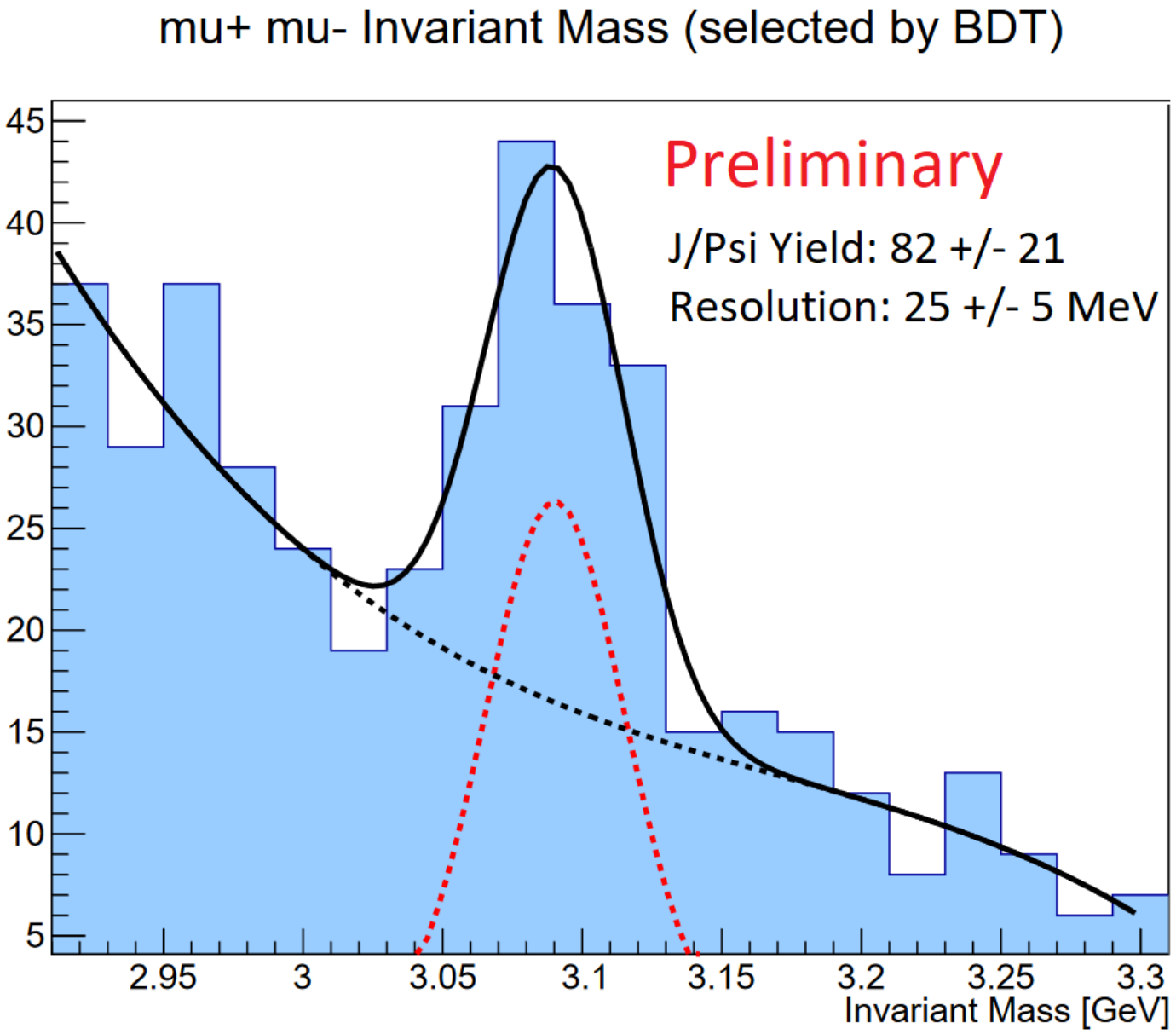
$$Purity = \frac{signal}{signal + background} = \frac{TP}{TP + FP}$$

- Signal purity gives an indication of how clean my sample is.



$\mu^+\mu^-$ Invariant Mass

The $\mu^+\mu^-$ invariant mass obtained with <10% of the total expected inbending data.



Future Work

- Additional work on muon/pion discrimination.
- Acceptance and normalization studies.
- Kinematic fitting.
- From there we'll look at selecting events with P_c^+ decaying to a proton and J/ψ and measuring the J/ψ cross section.

Collaborators

- Dr. Stepan Stepanyan (Jefferson Lab)
- Dr. Rafayel Paremuzyan (University Of New Hampshire)
- Dr. Nathan Baltzell (Jefferson Lab)
- Dr. Valery Kubarovsky (Jefferson Lab)
- Dr. Pawel Nadel-Turonski (Old Dominion University)
- Dr. Silvia Niccolai (Institut de Physique Nucléaire d'Orsay)
- Dr. Bryan McKinnon (University of Glasgow)
- Pierre Chatagnon (Institut de Physique Nucléaire d'Orsay)
- Jiwan Poudel (Old Dominion University)
- Joseph Newton (Old Dominion University)

Questions?

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).