J/ψ near threshold photoproduction at CLAS12

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VIA VERITAS VITA

The CLAS12 Detector

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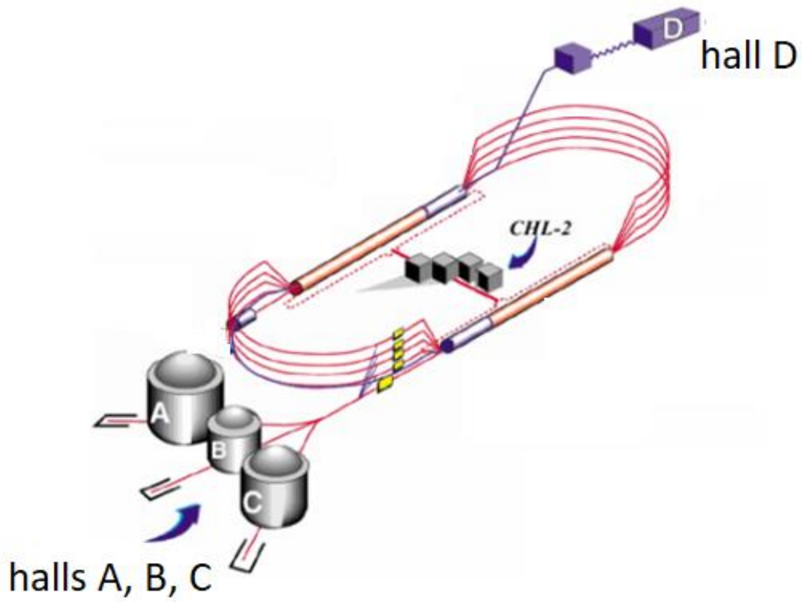
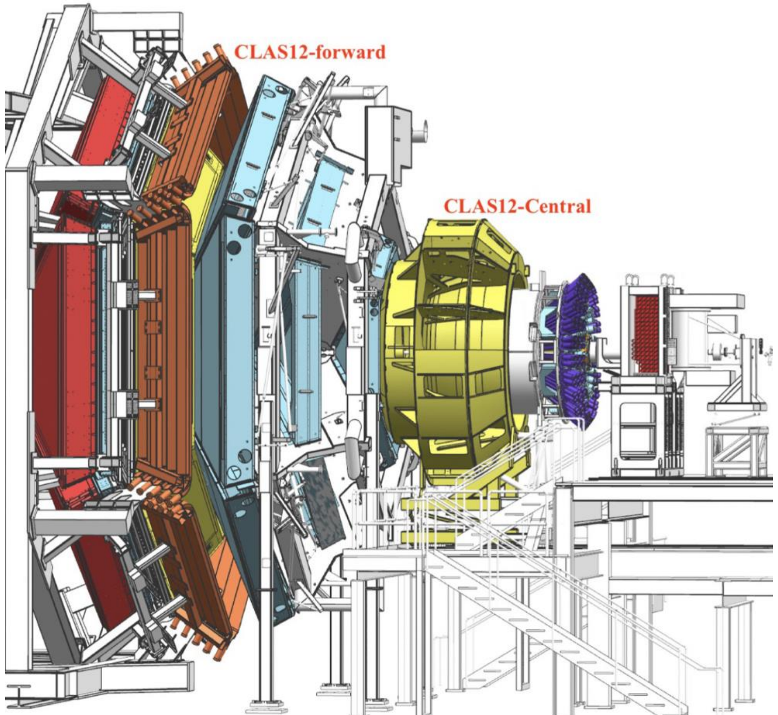
- The recently upgraded CEBAF accelerator facility produces a 12 GeV electron beam, with beam energies up to 11 GeV delivered to Hall B.
- The Forward Detector has polar angle coverage of 5 to 35 degrees.
- The Central Detector has polar angle coverage of 35 to 125 degrees.





Experiment Overview

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

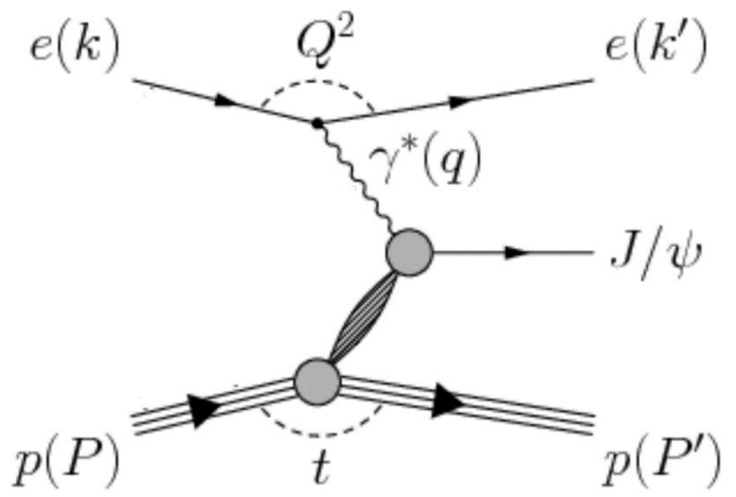
- CLAS12 took data with both a proton and a deuterium target offering several potential final states:

$$ep \longrightarrow (e')l^+l^-p$$

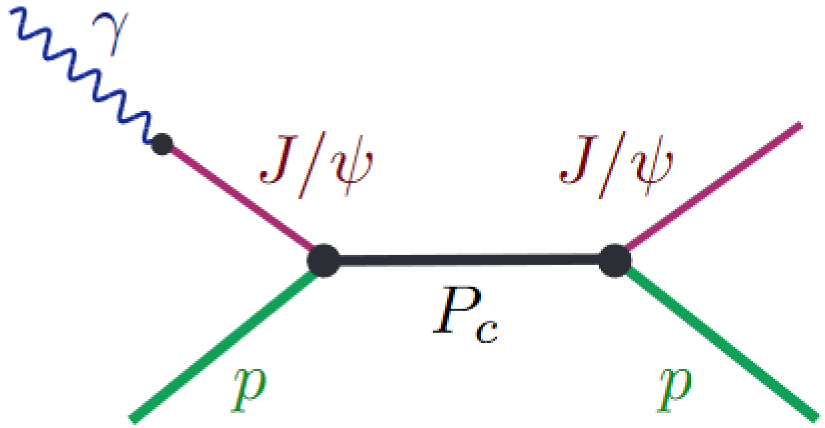
$$ed \longrightarrow (e')l^+l^-d$$

$$e\,p_{bound} \longrightarrow (e')l^+l^-p$$

$$e\,n_{bound} \longrightarrow (e')l^+l^-n$$



J/ψ quasi-real photoproduction on a proton target

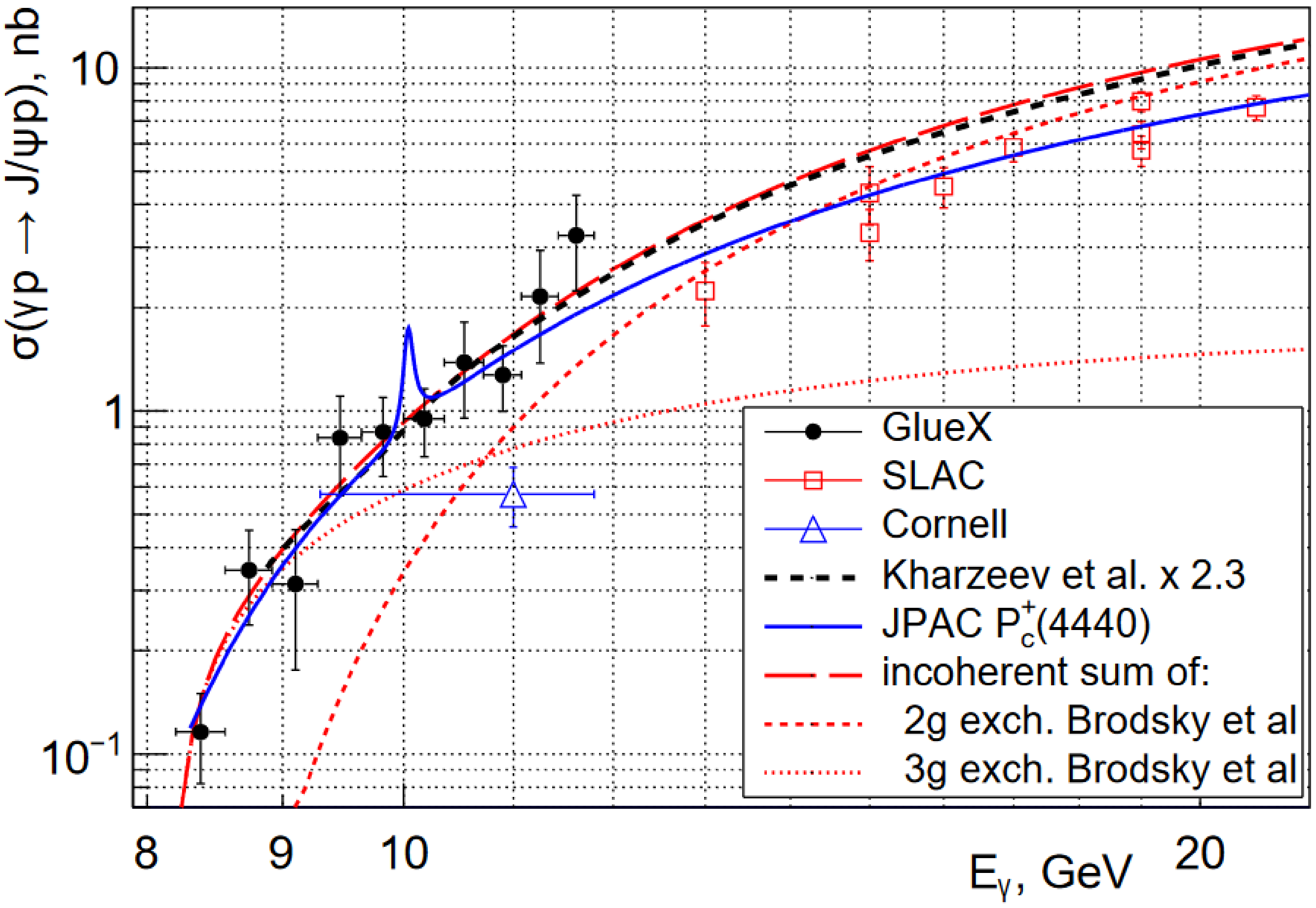


Feynmann diagram of P_c^+ pentaquark photoproduction with a proton target.

J/ψ Near Threshold Photoproduction

- CLAS12 operates close to the J/ψ photoproduction threshold.
- Near threshold, all the valence quarks of the nucleon are predicted to participate in J/ψ photoproduction while at higher energies it is predicted that one or two hard gluons can be involved [3]. This is studied by measuring the total cross section as a function of beam energy.
- [4] predicts that the t dependency of the differential cross section is defined by the proton gluonic form-factor, for which a dipole form is assumed with $m_g^2 \approx 1\ GeV^2$ as:

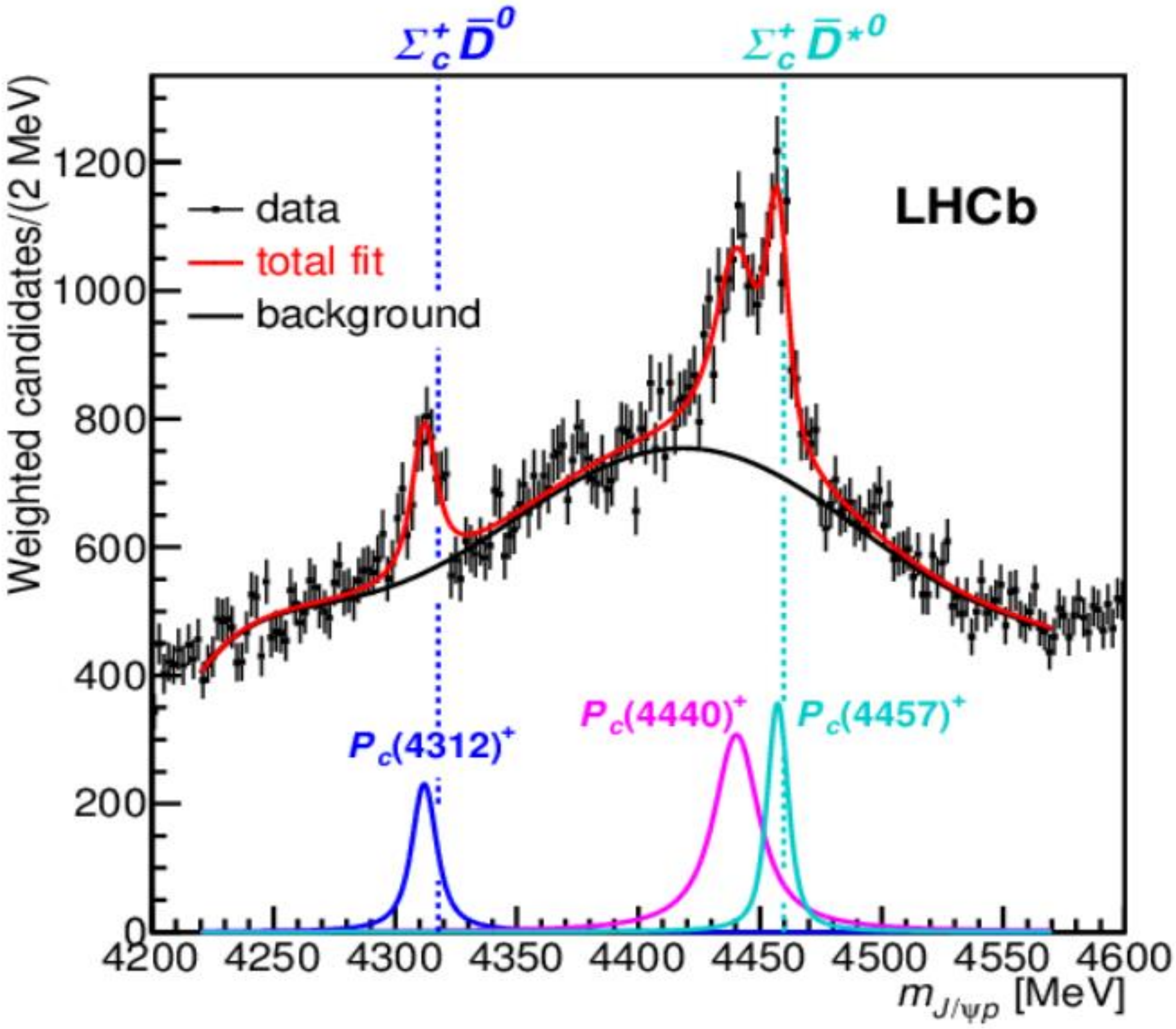
$$F(t) \propto (1 - t/m_g^2)^{-2}$$



Measurements of the J/ψ total cross section as a function of the photon beam energy and theoretical predictions scaled to GlueX data [2].

P_C^+ resonances at the LHCb (2019)

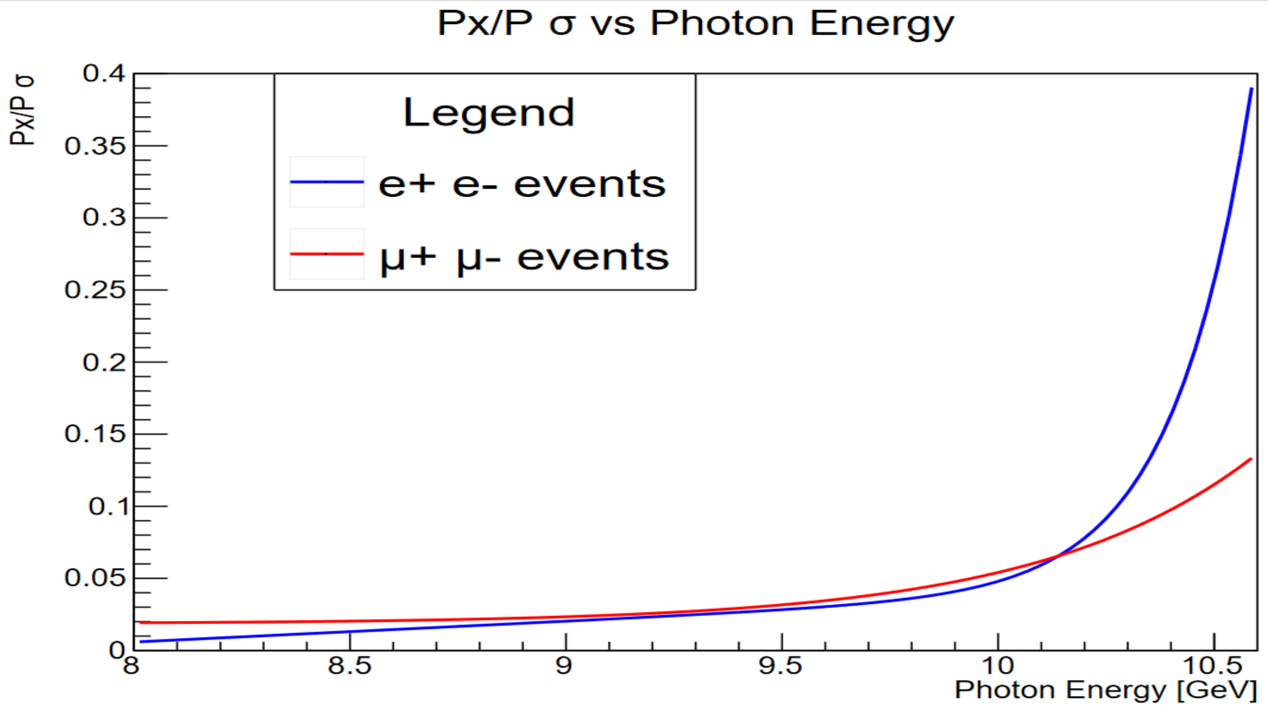
- We should be able to place upper limits on the branching fraction $\mathrm{B}(P_C^+ \rightarrow J/\psi\ p)$ from CLAS12 data.
- J/ψ photoproduction on the neutron further offers the possibility of looking for the isospin partners of the P_c^+ Pentaquarks.

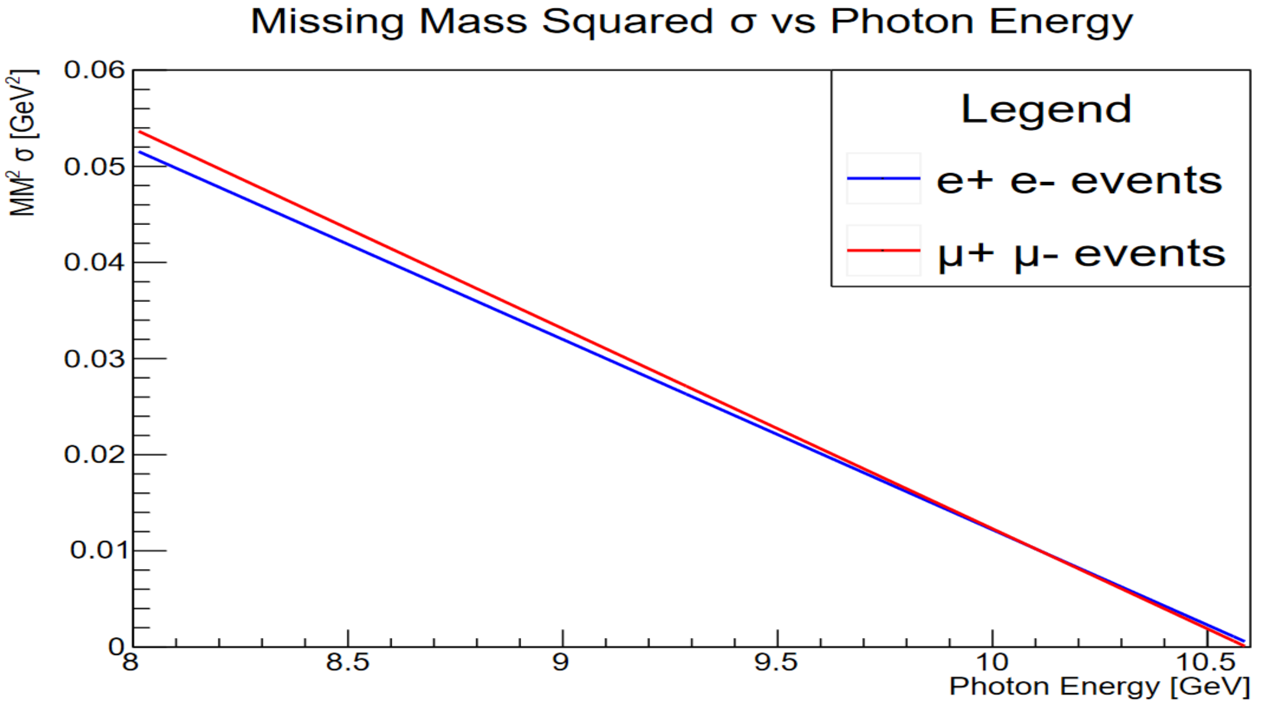


The J/ψ p invariant mass distribution [1].

Initial Event Selection

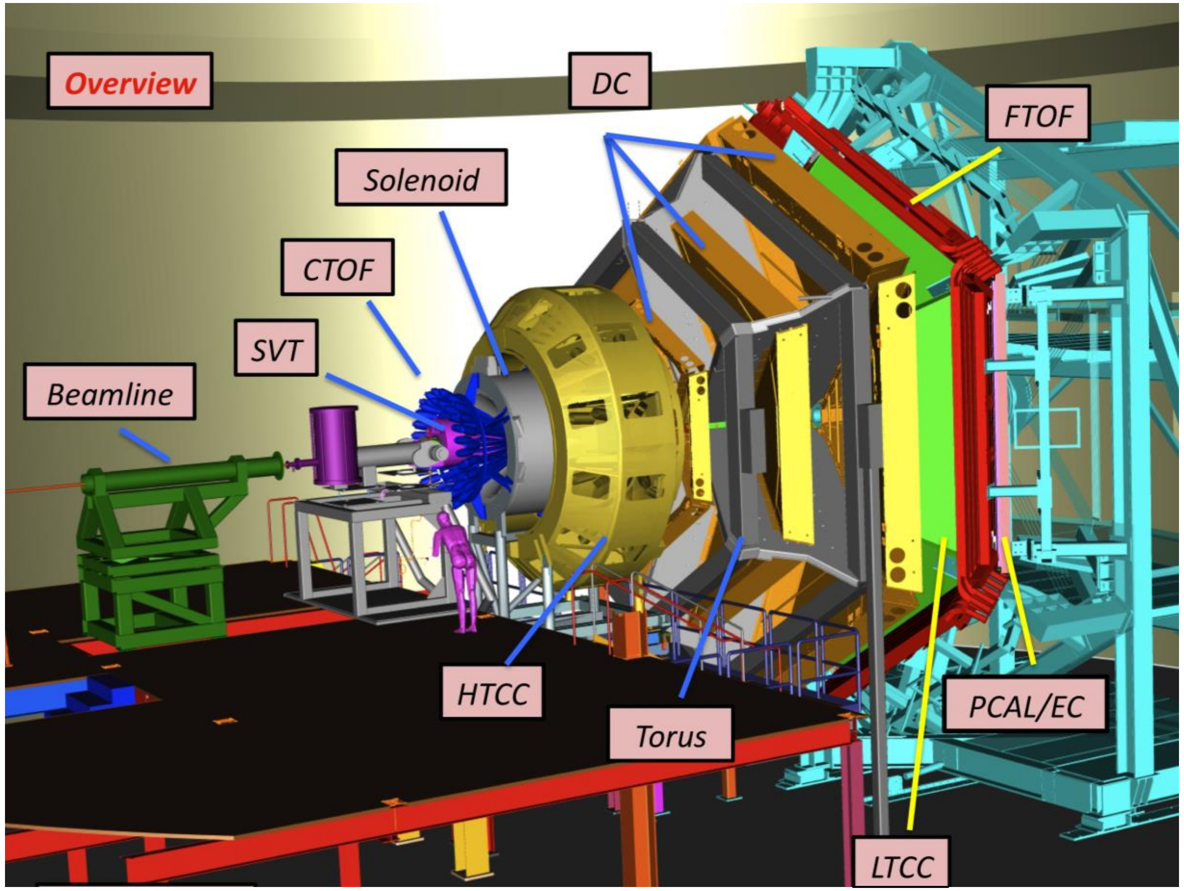
- To select only quasi-real photoproduction events regime we can minimize:
  - The difference between the beam and scattered electron momentum, Q^2
  - The transverse momentum fractions in the x and y components, $|\frac{Px}{P}|$ and $|\frac{Py}{P}|$.
- Similarly, we want the missing mass close to the mass of the scattered electron (which is effectively 0).
- The widths of these distributions can be parametrised as a function of the photon beam energy.





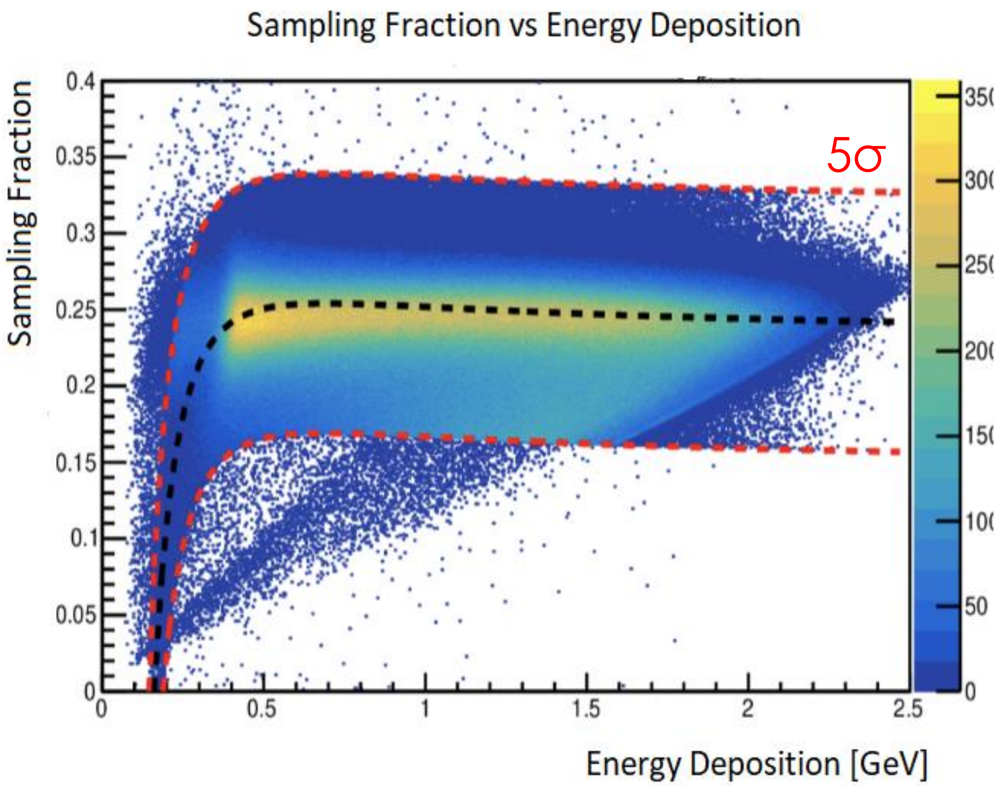
CLAS12 Forward Detector

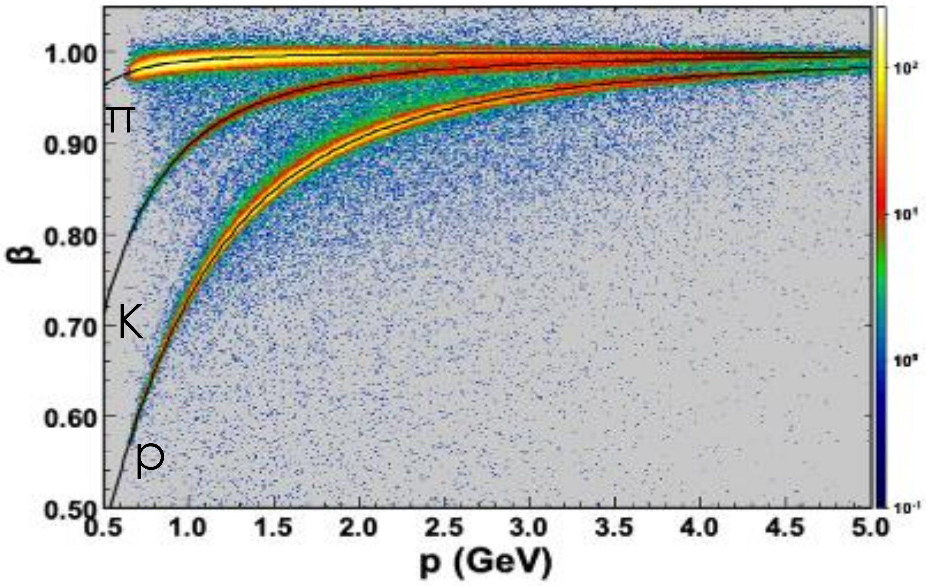
- All final state particles are detected with the Forward Detector.
- The High Threshold Cherenkov Counter (HTCC) was built to identify electrons as other particle types generally won't fire the HTCC.
- The tracking system and Drift Chambers (DC) measure the charge and momentum of particles.
- The Forward Time Of Flight (FTOF) counters were designed to resolve pions, kaons, protons and deuterons.
- The Electromagnetic Calorimeters (PCAL and EC) are used to detect photons and identify electrons as they should deposit more energy than other particle types.



Initial Particle Identification

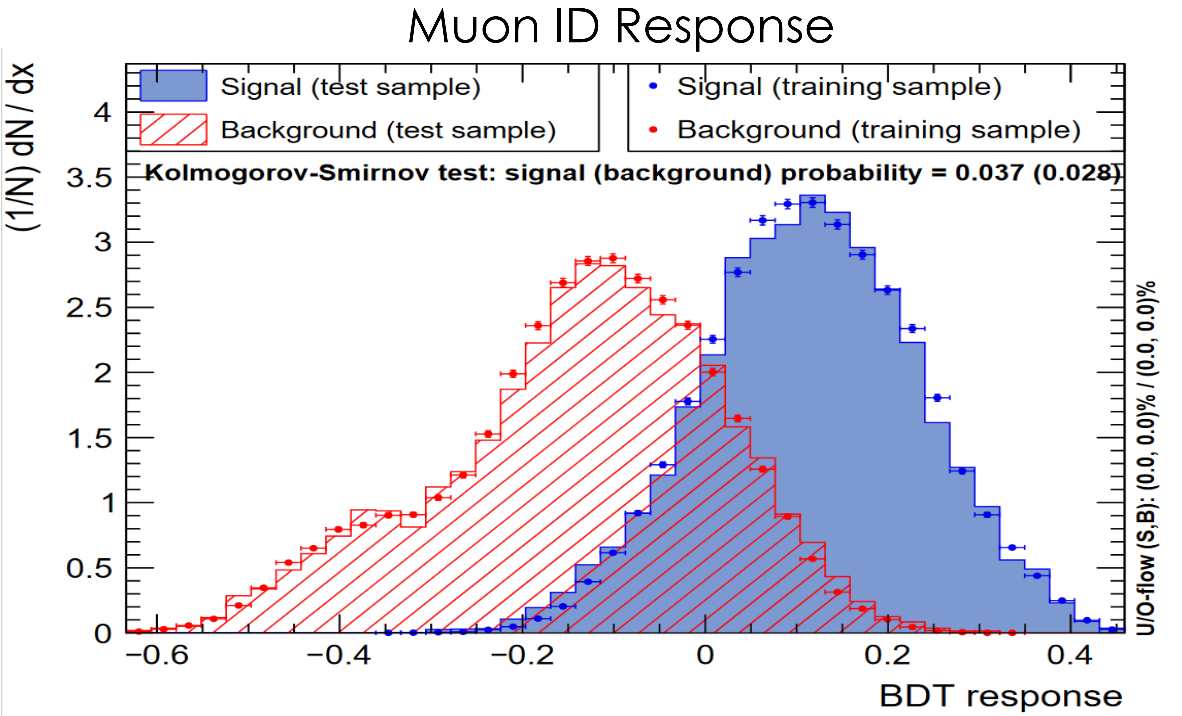
- Electrons and positrons are required to produce a signal in the HTCC and high energy deposition in the calorimeter. Their main source of background is due to high momentum pions firing the HTCC.
- Muons are required to have mip like energy deposition in the calorimeters. However, this is also susceptible to high pion contamination.
- For protons (and charged hadrons) a cut is made on the Beta versus Momentum parametrization.
- For neutrons, the initial requirement is simply Beta<0.9. Their main source of background comes from photons reconstructed with low Beta.

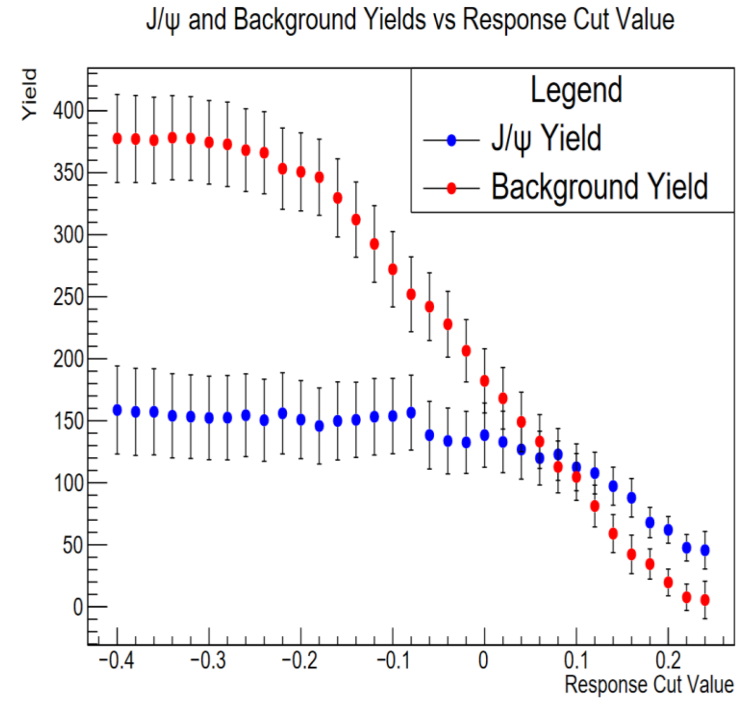




Particle ID Refinement

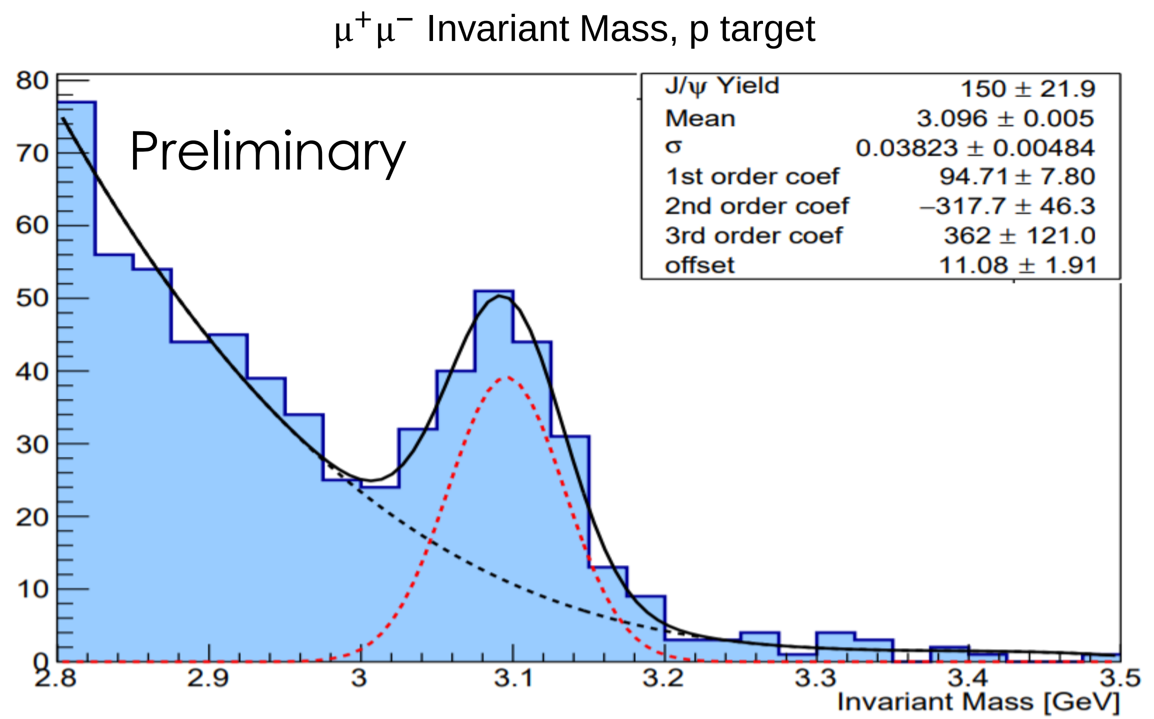
- Machine learning algorithms are well suited to classification tasks such as particle identification.
- We trained two classifiers to distinguish between pions and either muons or positrons. The response of several detector susbystems was simulated to create the training samples.
- The classifier output is given as a probability of being a signal event, called the response, and effectively reduces the PID process down to a cut on the response.
- This cut can be varied to study the systematic effect introduced by the classifiers.
- This was implemented using the ROOT TMVA package [5].

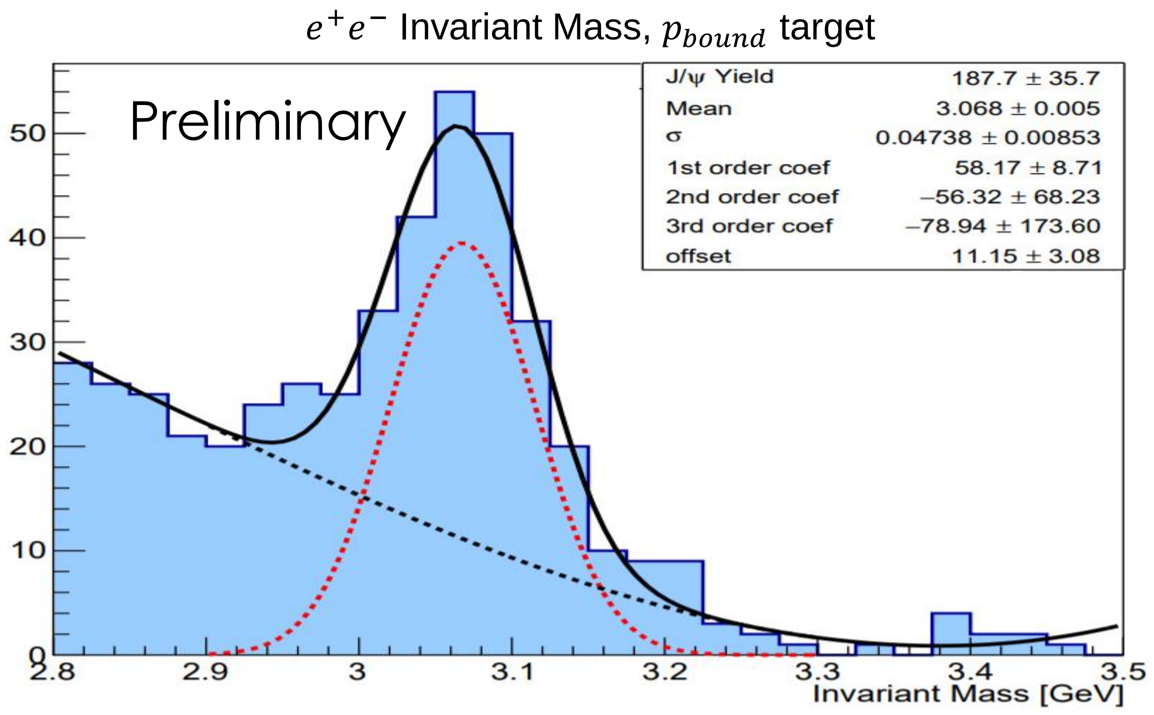




Di-lepton Invariant Mass

- Plotted here are the invariant mass distributions of:
  - $\mu^+\mu^-$ produced on a proton target
  - e^+e^- produced on a bound proton in the deuteron target.
- Electron radiation in the detector shifts the e^+e^- J/ψ mass peak to away from the J/ψ mass (3.097 GeV) as the reconstructed momentum is post-radiation.
- These are preliminary and produced with only a subset of all available data.





Conclusion

- The total and differential J/ψ photoproduction cross sections are predicted to provide unique insight about the nucleon gluonic form factor and the J/ψ near-threshold production mechanism.
- Several CLAS12 analyses aiming for these measurements are ongoing and well-advanced, as they have well defined event and particle identification techniques.
- Next, we aim to calculate the total and differential cross sections for the proton and deuterium targets.
- This is a collaborative effort, involving the whole of the CLAS12 collaboration, and in particular Joseph Newton's work on J/ψ photoproduction in the $ep \rightarrow (e')e^{+}e^{-}\mathrm{p}$ channel and Pierre Chatagnon's work on Timelike Compton Scattering in the same channel.

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).

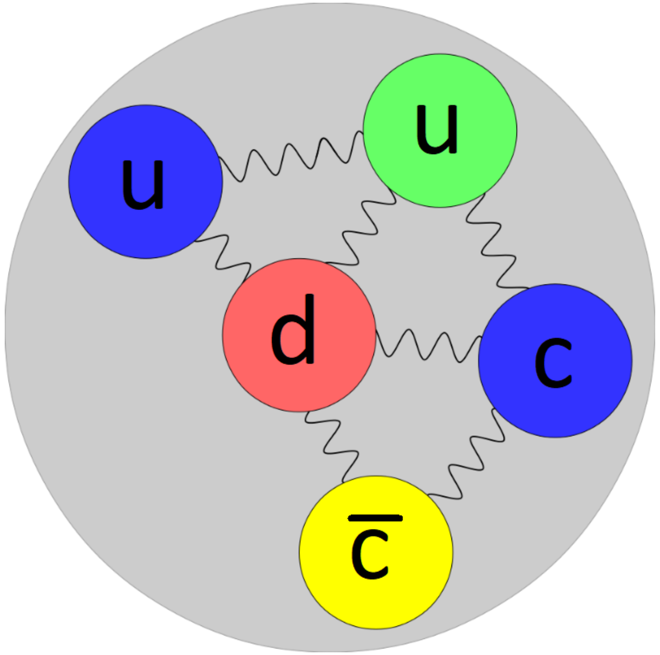
[3] S. Brodsky, E. Chudakov, P. Hoyer, J. Laget, Photoproduction of charm near threshold, *Phys. Lett. B.* **498**, 23 (2001).

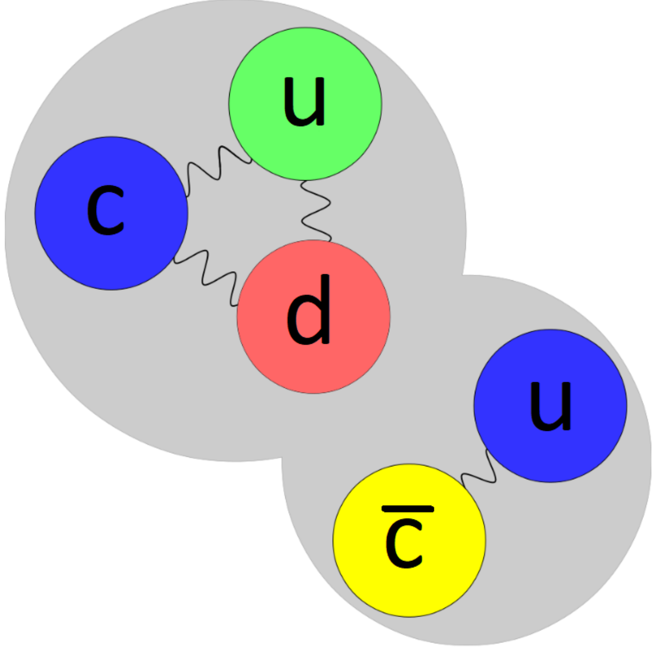
[4] L. Frankfurt, M. Strikman, Two-gluon form factor of the nucleon and J/ψ photoproduction, *Phys. Rev. D.* **66**, 031502 (2002)

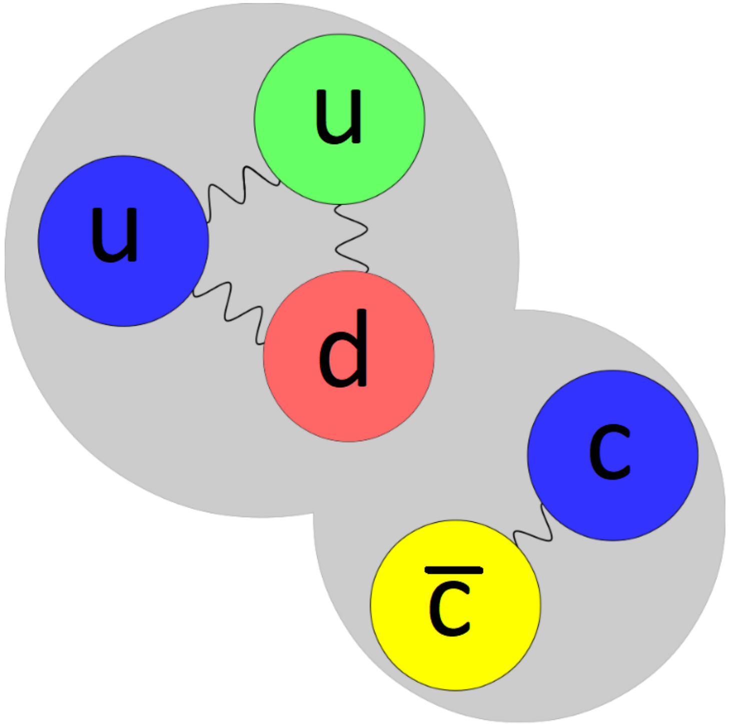
[5] A. Hoecker, *et. al.*, TMVA - Toolkit for Multivariate Data Analysis, available online at arXiv:physics/0703039v5

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.

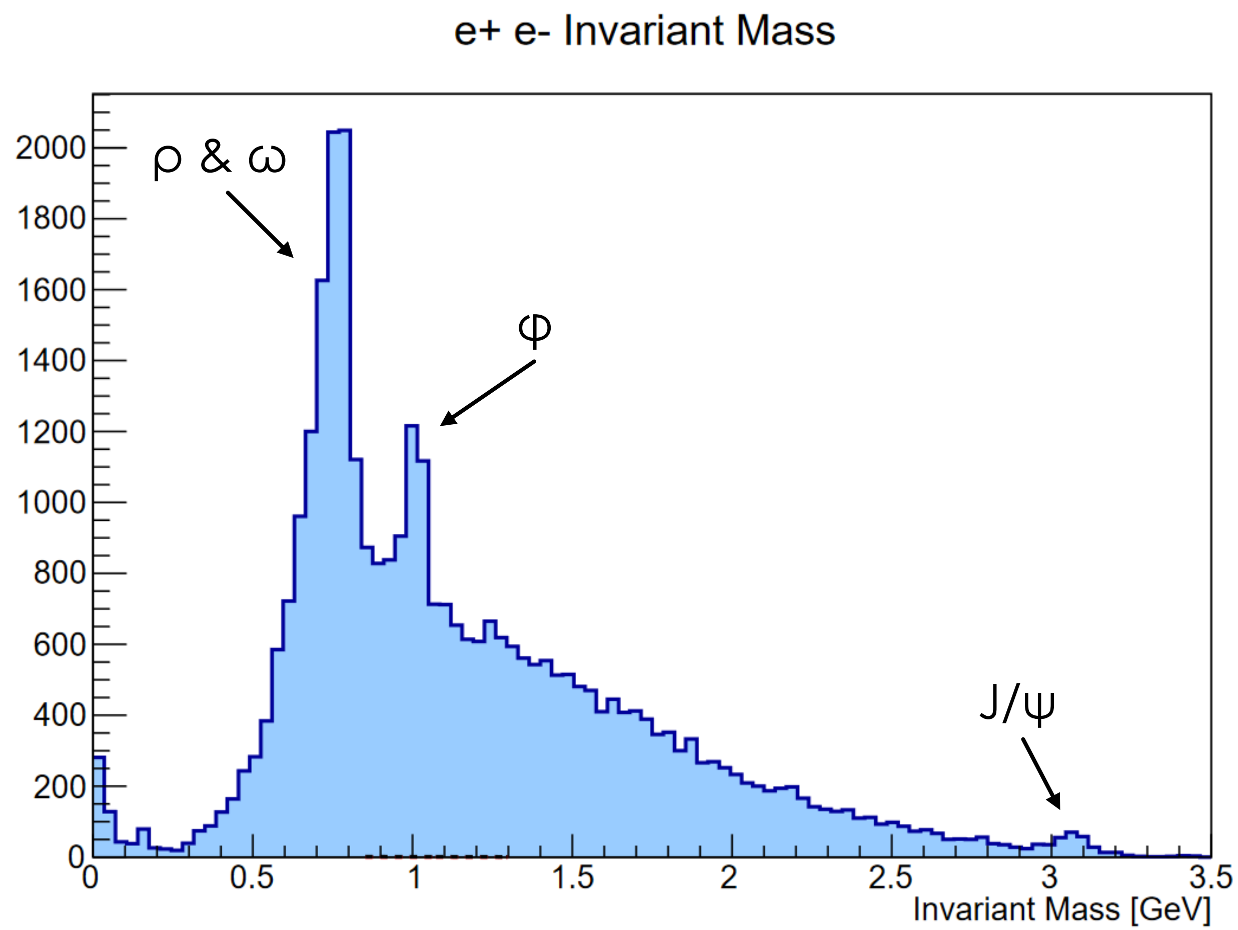






ρ, ω and φ mesons

- 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.



Fiducial Cuts and Momentum Corrections

- If an electron or positron 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.
- Electrons and positrons radiate photons before reaching the forward detector. The reconstructed electron momentum is therefore the post-radiation momentum.
- This is corrected by adding the momentum of the radiated photon, identified by a small angular difference with the electron.