Search for New and Unusual Strangeonia States Using $\gamma p \rightarrow p\varphi\eta$ with GlueX at Thomas Jefferson National Accelerator Facility

Prospectus of Dissertation

Bradford E. Cannon
Department of Physics, Florida State University

Overview

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2. Motivation
3. Proposed Analysis
4. Overview of the GlueX Experiment at Jlab
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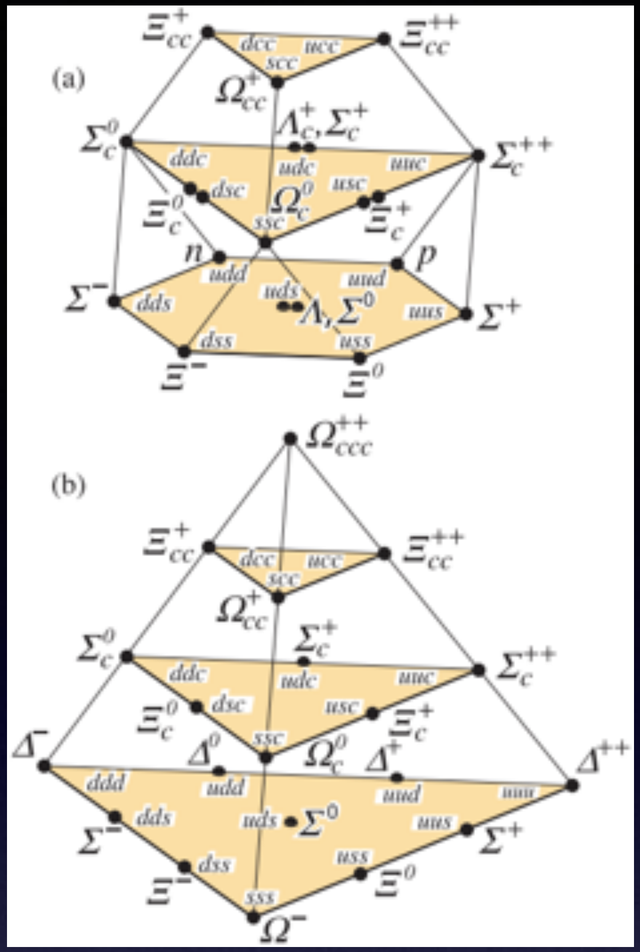
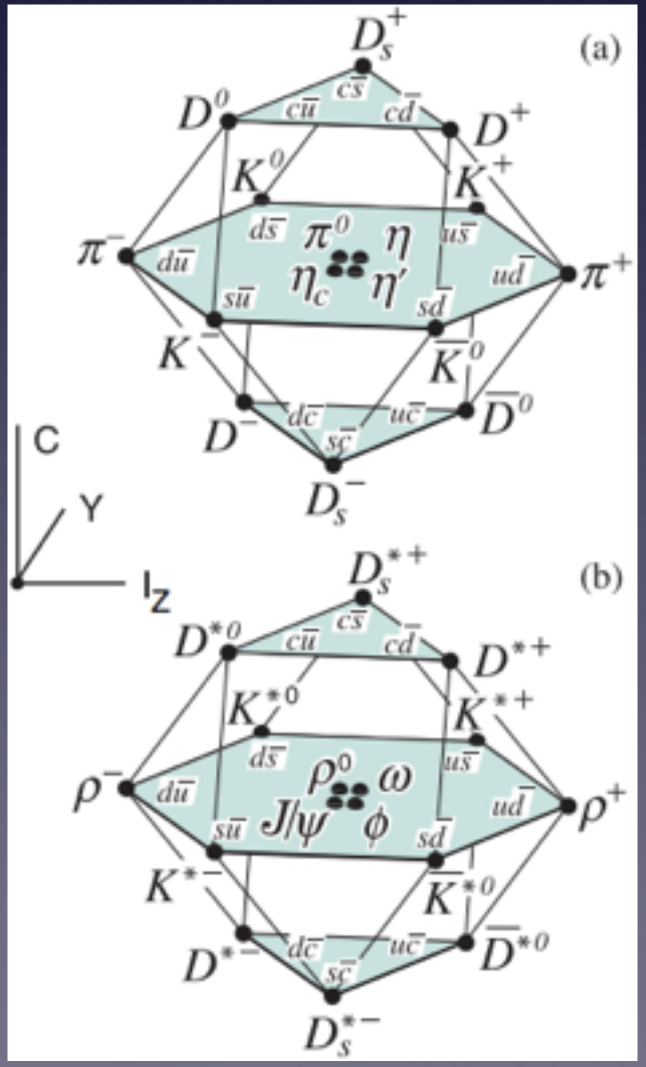
Introduction to Hadrons

- Hadrons are composite particles made of quarks that are held together by the strong nuclear force.
- There are currently two ways quarks can combine in a bound state to make a hadron: <u>mesons</u> or <u>baryons</u>.
- A <u>meson</u> is a bound state comprised of a quark-antiquark pair, and a <u>baryon</u> is comprised of three quarks or three antiquarks.
- Hadrons are organized into groups of identical J^{PC} quantum states. These groups are referred to as 'multiplets' due to the large amount of states for a given J^{PC}.





Introduction to Hadrons

- Given that quarks are spin half fermions, it is easy to derive the allowed quantum numbers for mesons
- Constraints: $|\boldsymbol{\ell}-\mathbf{s}| \leq \mathbf{J} \leq |\boldsymbol{\ell}+\mathbf{s}|$, $P=(-1)^{\ell+1}$, $C=(-1)^{\ell+s}$
- Table of allowed J^{PC} meson states:

s	$\ell=0$	$\ell=1$	$\ell=2$
s=0	0^{-+}	1^{+-}	2^{-+}
s=1	1^{--}	$0^{++},1^{++},2^{++}$	$1^{--},2^{--},3^{--}$

- Looking closely at the table, it is clear that the following quantum numbers are forbidden for mesons: 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, … We refer to these states as “exotic meson states”.

Motivation

- The ultimate goal of the GlueX experiment is to unambiguously map all light quark exotic meson states.

- There are only 7 probable $s\bar{s}$ resonances out of the 22 expected to exist below 2.2 GeV. Furthermore, 3/7 resonances are considered pure $s\bar{s}$: $\varphi(1020)$, $f_2'(1525)$, $\varphi_3(1386)$ [1]

- If we consider the quantum states of $\varphi(1^{--})$ and $\eta(0^{-+})$, we can derive the allowed parent J^{PC} states:

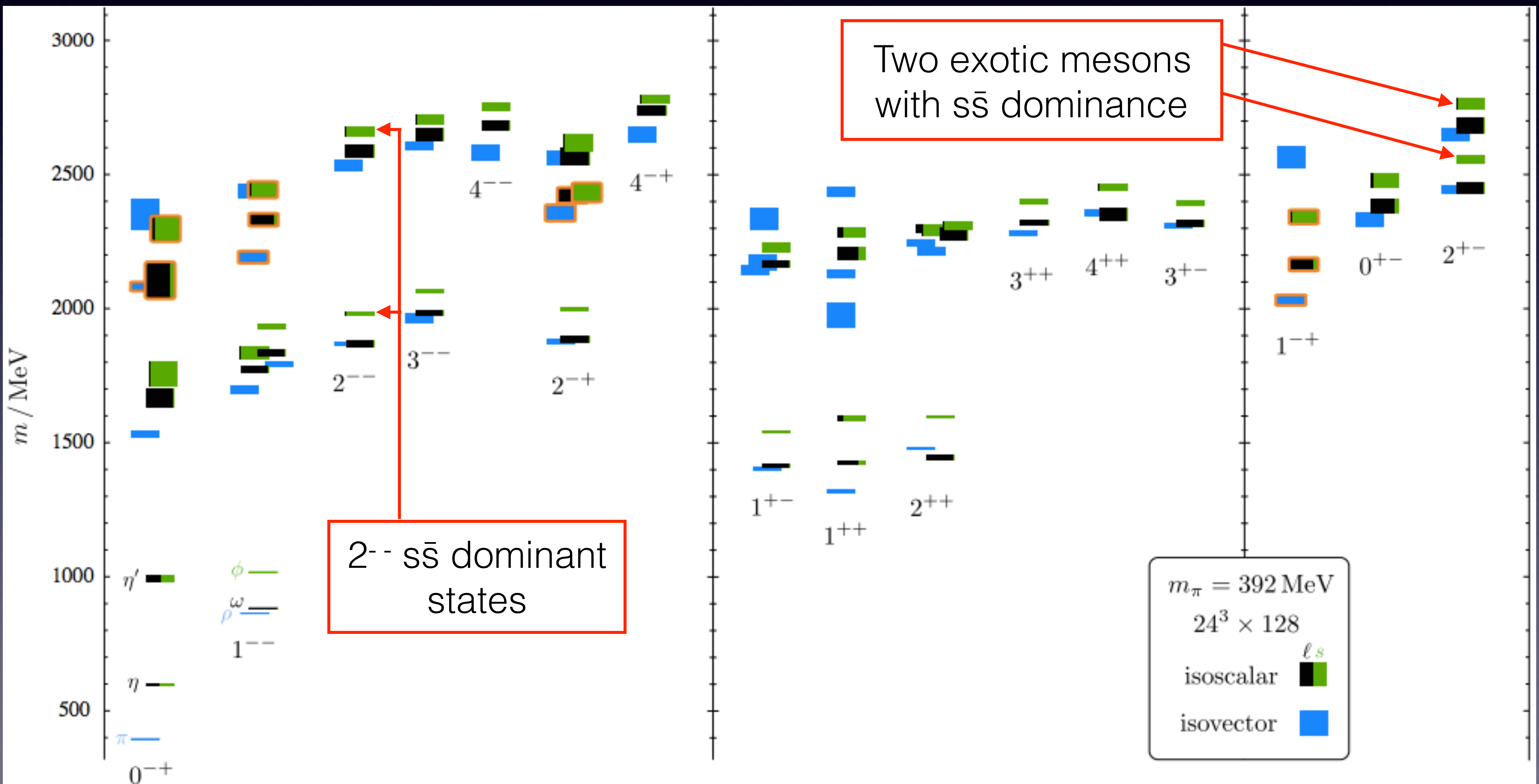
ℓ	J^{PC}
$\ell=0$	1^{+-}
$\ell=1$	$0^{--}, 1^{--}, 2^{--}$
$\ell=2$	$1^{+-}, 2^{+-}, 3^{+-}$

- The states in red are of particular interest because they are either not well understood (2^{--}), or they are exotic (0^{--}, 2^{+-})

$n\,^{2s+1}\ell_J$	J^{PC}	I = 1 $u\bar{d},\ \bar{u}d,\ \frac{1}{\sqrt{2}}(d\bar{d}-u\bar{u})$	I = $\frac{1}{2}$ $u\bar{s},\ d\bar{s};\ \bar{d}s,\ -\bar{u}s$	I = 0 f'	I = 0 f	θ_{quad} [°]	θ_{lin} [°]
$1\,^1S_0$	0^{-+}	π	K	η	$\eta'(958)$	-11.4	-24.5
$1\,^3S_1$	1^{--}	$\rho(770)$	$K^*(892)$	$\phi(1020)$	$\omega(782)$	39.1	36.4
$1\,^1P_1$	1^{+-}	$b_1(1235)$	K_{1B} †	$h_1(1380)$	$h_1(1170)$		
$1\,^3P_0$	0^{++}	$a_0(1450)$	$K_0^*(1430)$	$f_0(1710)$	$f_0(1370)$		
$1\,^3P_1$	1^{++}	$a_1(1260)$	K_{1A} †	$f_1(1420)$	$f_1(1285)$		
$1\,^3P_2$	2^{++}	$a_2(1320)$	$K_2^*(1430)$	$f_2'(1525)$	$f_2(1270)$	32.1	30.5
$1\,^1D_2$	2^{-+}	$\pi_2(1670)$	$K_2(1770)$ †	$\eta_2(1870)$	$\eta_2(1645)$		
$1\,^3D_1$	1^{--}	$\rho(1700)$	$K^*(1680)$		$\omega(1650)$		
$1\,^3D_2$	$\boxed{2^{--}}$		$K_2(1820)$	?	?	?	
$1\,^3D_3$	3^{--}	$\rho_3(1690)$	$K_3^*(1780)$	$\phi_3(1850)$	$\omega_3(1670)$	31.8	30.8
$1\,^3F_4$	4^{++}	$a_4(2040)$	$K_4^*(2045)$		$f_4(2050)$		
$1\,^3G_5$	5^{--}	$\rho_5(2350)$	$K_5^*(2380)$				
$1\,^3H_6$	6^{++}	$a_6(2450)$			$f_6(2510)$		
$2\,^1S_0$	0^{-+}	$\pi(1300)$	$K(1460)$	$\eta(1475)$	$\eta(1295)$		
$2\,^3S_1$	1^{--}	$\rho(1450)$	$K^*(1410)$	$\phi(1680)$	$\omega(1420)$		

† The $1^{+\pm}$ and $2^{-\pm}$ isospin $\frac{1}{2}$ states mix. In particular, the K_{1A} and K_{1B} are nearly equal (45°) mixtures of the $K_1(1270)$ and $K_1(1400)$. The physical vector mesons listed under 1^3D_1 and 2^3S_1 may be mixtures of 1^3D_1 and 2^3S_1.

- J.J. Dudek et al. [Hadron Spectrum Collab.], Phys. Rev. D88, 094505 (2013)[arXiv:1309.2608]



Motivation

- Other states of interest are the $\varphi(1680)$, X(1750), and Y(2175).

- $\underline{\varphi(1680)}$: observed in $e^+e^- \rightarrow K^*K$ cross section enhancement. Interpreted to be the radially excited version of $\varphi(1020)$. Not observed in photoproduction[4].

- <u>X(1750)</u>: observed in $\gamma p \rightarrow pK^+K^-$ invariant mass distribution. Not clear if this is a unique state or simply a shifted peak due to a ρ tail. Not observed in e^+e^- annihilation [5].

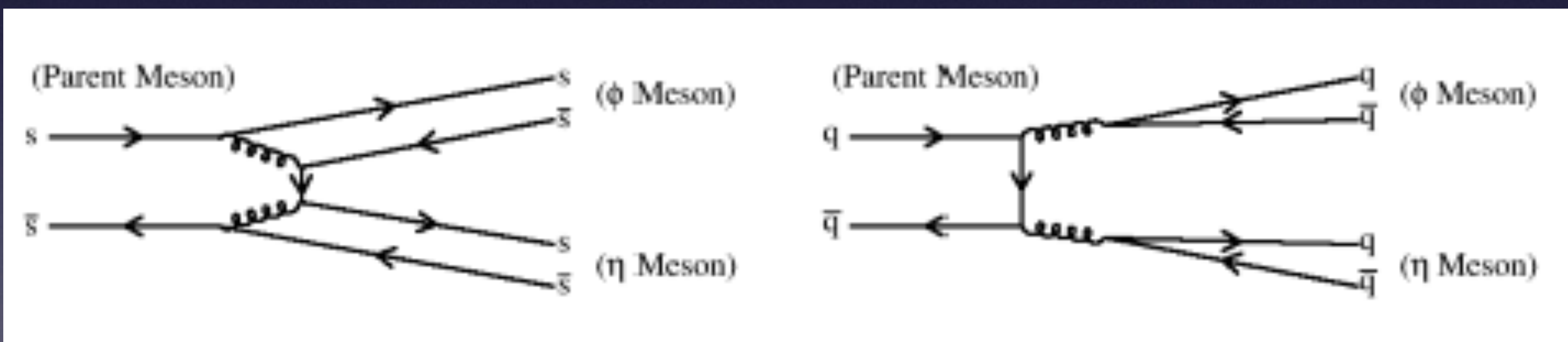
- <u>Y(2175)</u>: observed in $e^+e^- \rightarrow \varphi f_0(980) \rightarrow K^+K^-\pi\pi$ invariant mass distribution [6]. It has been suggested that this is a four quark hybrid strangeonia state [7].

- **It is unclear what the quark composition of these states are since <u>kaon production does not guarantee a parent $s\bar{s}$ state.</u>**

Proposed Analysis

- $\gamma p \rightarrow p\varphi\eta$ is an important channel to study since it is dominated by an $s\bar{s}$ parent state.

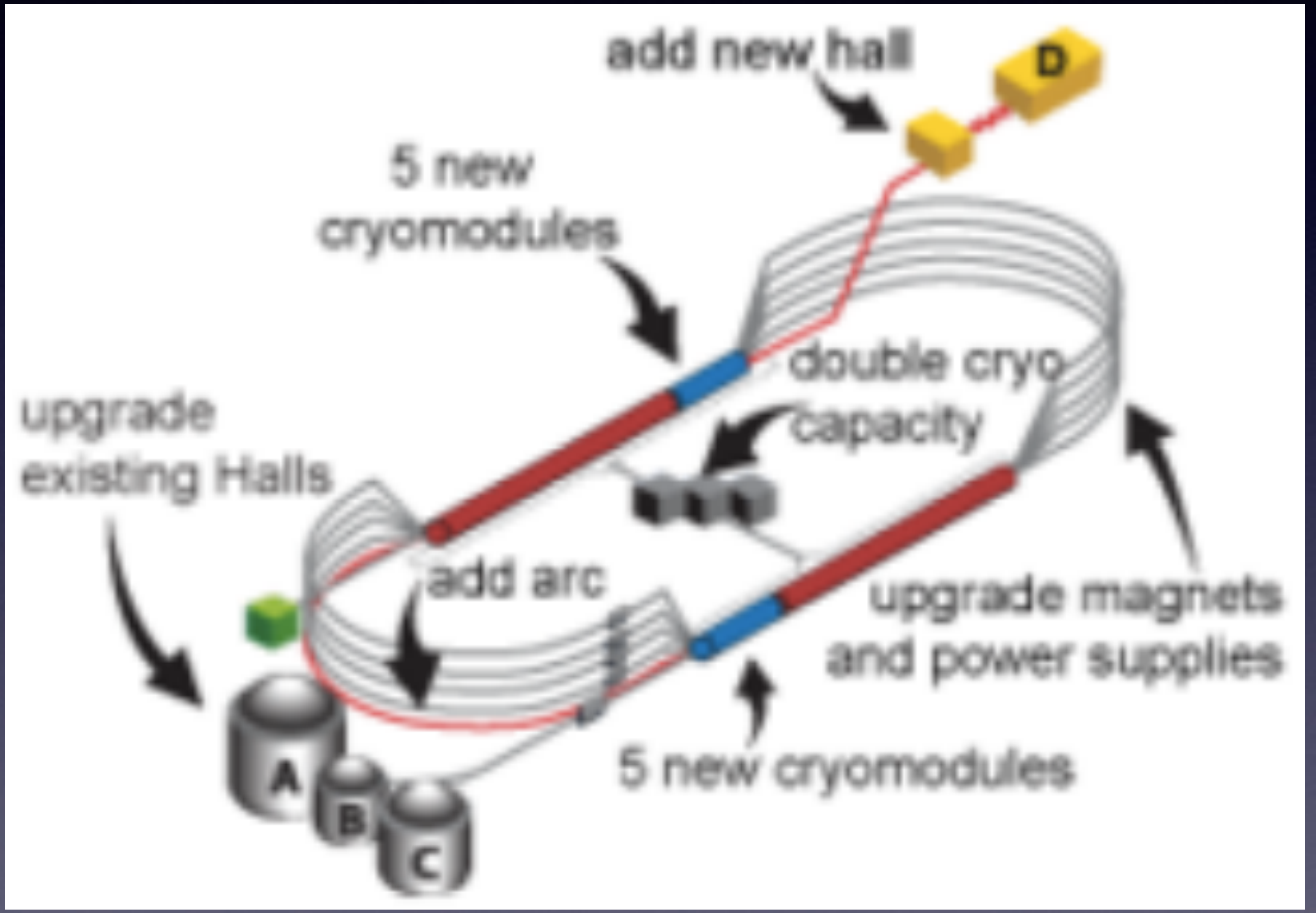
- This comes about because of OZI suppression and because of the fact that the φ meson is dominated by $s\bar{s}$, and that the η meson has some $s\bar{s}$ content.



- A state that had a significant bracing fraction to $\varphi\eta$ will unambiguously be $s\bar{s}$. Conversely, any state that is missing from $\varphi\eta$ will have little to no $s\bar{s}$ content.

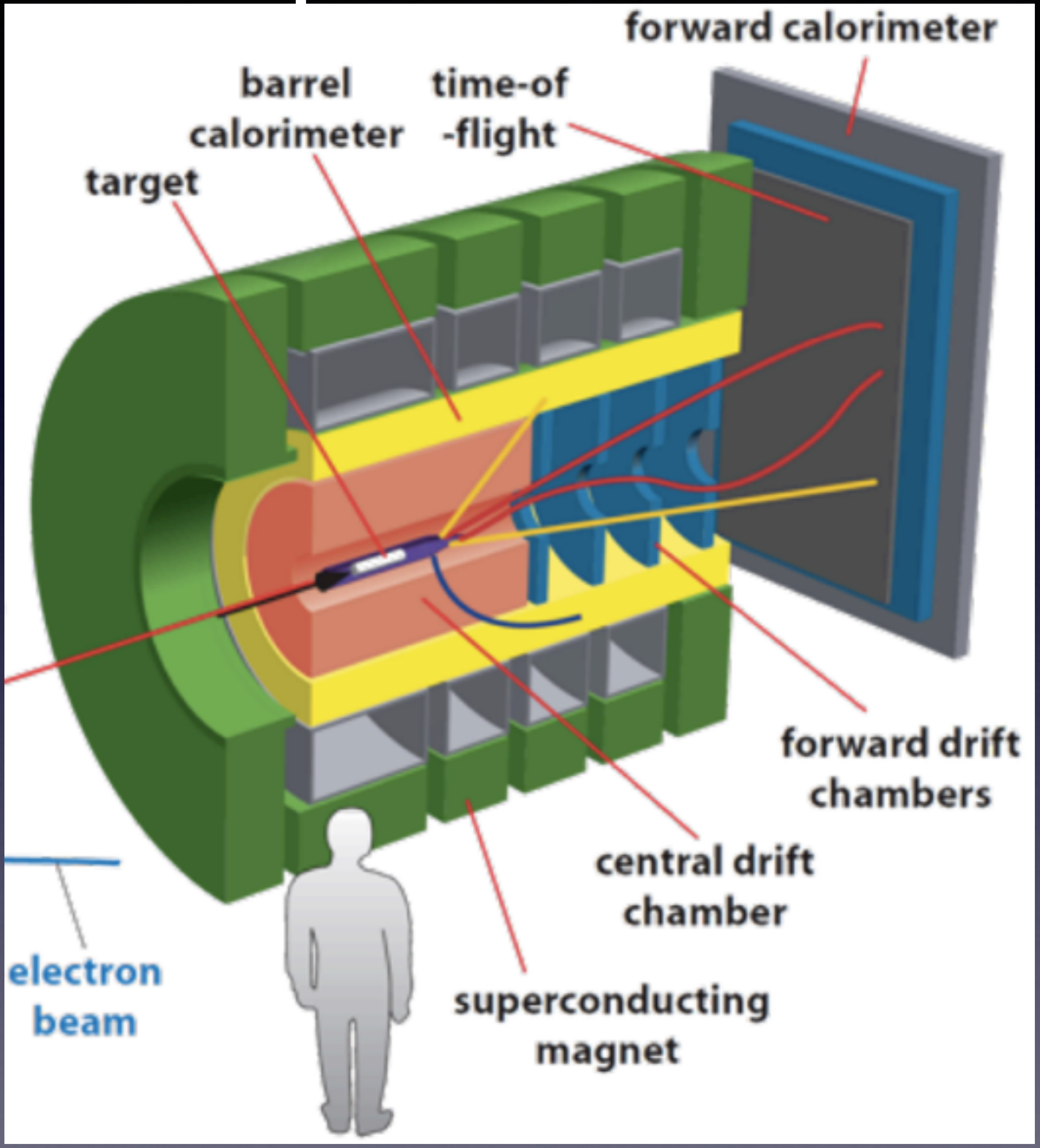
Overview of the GlueX Experiment at Jlab

- The GlueX experiment receives beam via the CEBAF (Continuous Electron Beam Accelerator Facility) at JLab
- The electron beam comes in bunches every four nano seconds and can now reach a maximum energy of 12 GeV
- The beam will eventually collide with a diamond radiator which will produce coherent Bremsstrahlung radiation to be used in the experiment.



Overview of the GlueX Experiment at Jlab

- Target
- Start Counter (SC)
- Central Drift Chamber (CDC)
- Barrel Calorimeter (BCal)
- Superconducting Magnet
- Forward Drift Chamber (FDC)
- Time of Flight (TOF)
- Forward Calorimeter (FCal)



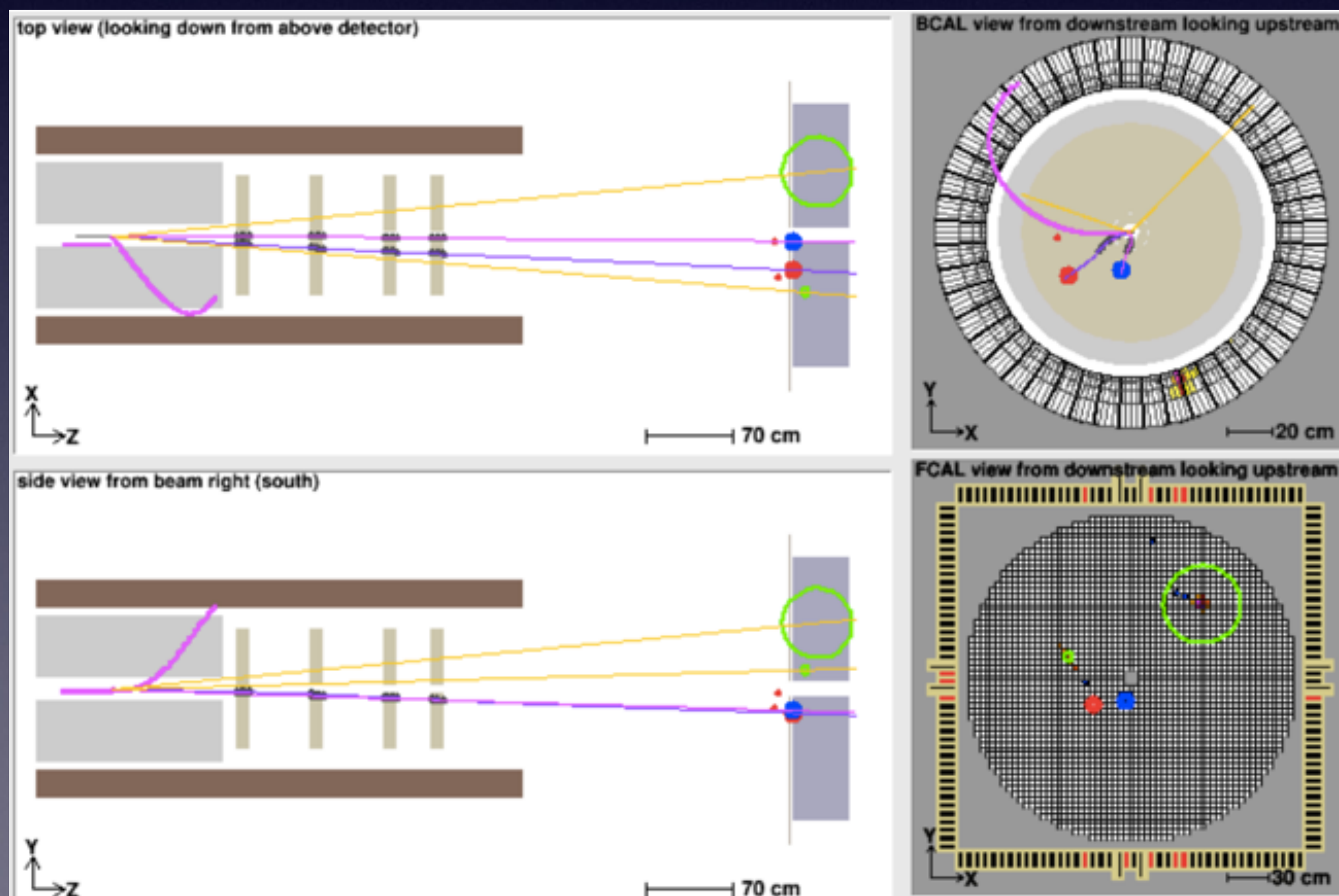
- DIRC (Detection of Internally Reflected Cherenkov light). To put in 2018

Generating Monte Carlo (MC)

- MC is divided into two sets: $\gamma p \rightarrow p\varphi\eta$ and $\gamma p \rightarrow [p]\varphi\eta$. The purpose of this is to study how acceptance changes as a function of proton detection inside GlueX.

- 100k $\gamma p \rightarrow p\varphi\eta$ MC events were generated with:

1. An incident photon beam of 9 GeV
2. A target proton at rest
3. A final state proton
4. $X \rightarrow \varphi\eta$
5. $\varphi \rightarrow K^+K^-$
6. $\eta \rightarrow 2\gamma$



Selecting φ and η Invariant Mass

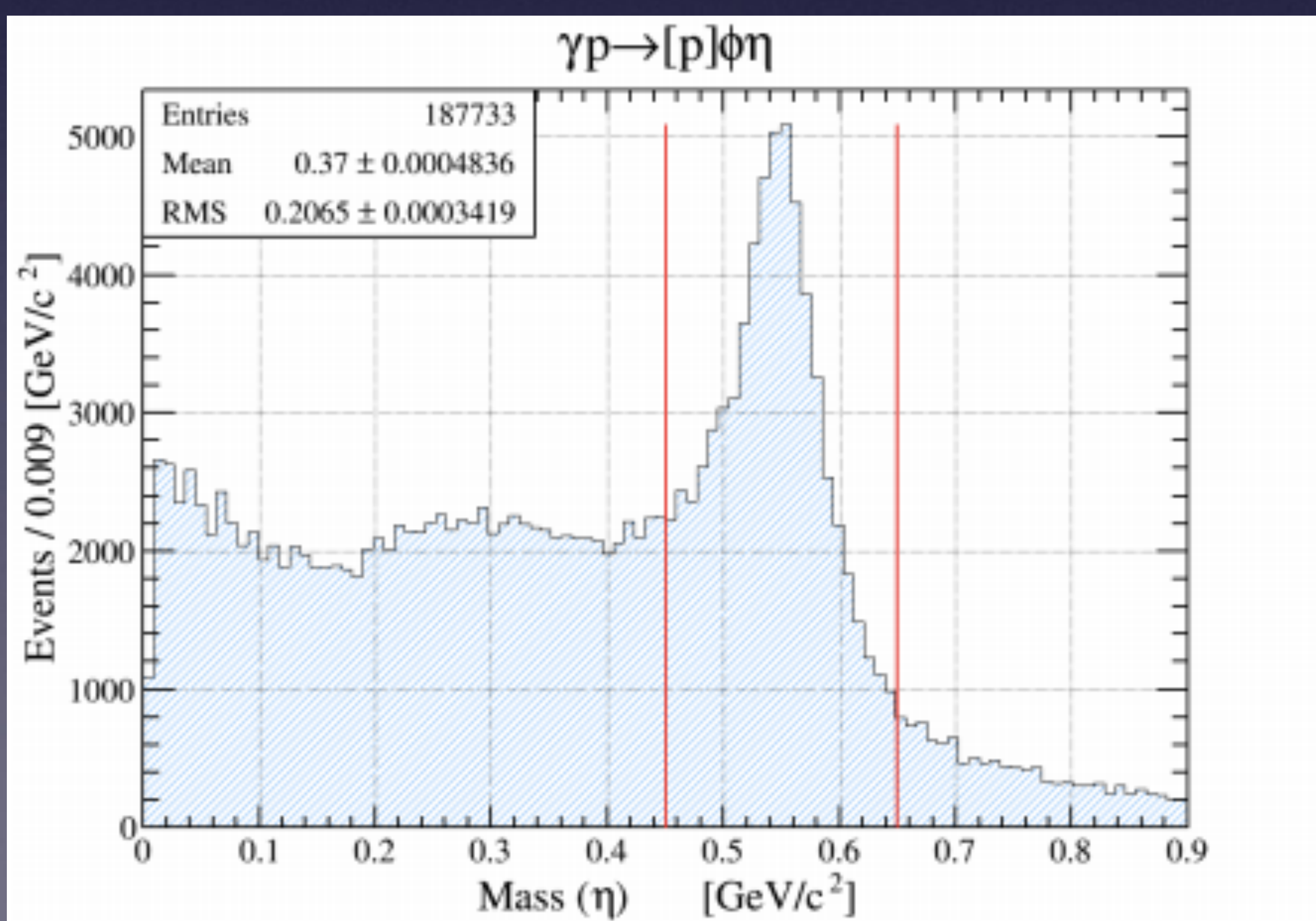
- After generating 100k events, the events are then:

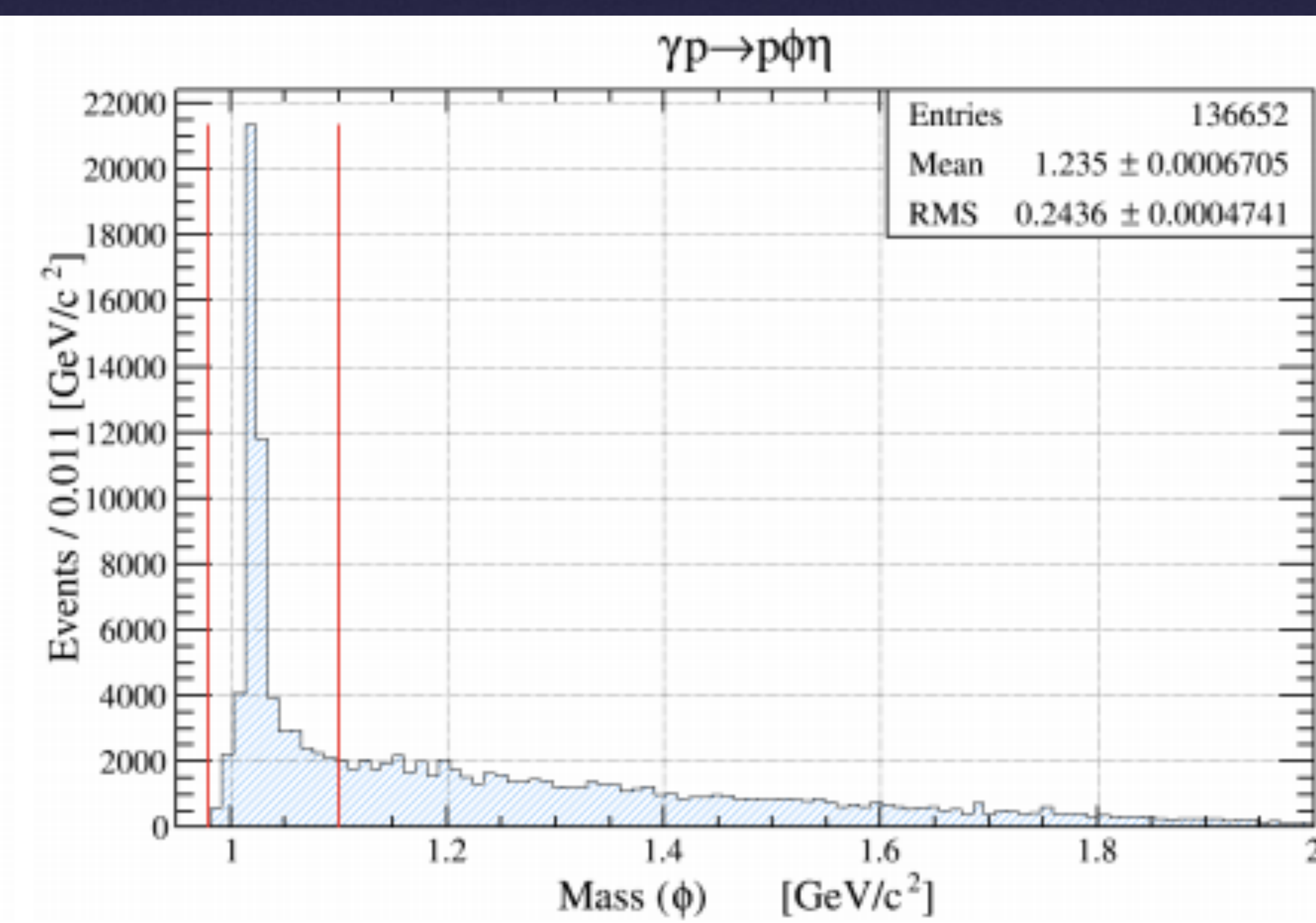
  1. Converted into a data file which converts the 4 vectors into physical sub detector hits

  2. That file is then ‘smeared’ in order to represent the acceptance of each sub detector, creating the final event file

  3. This file is then passes into event reconstruction software which outputs several measurements in order to perform a physics analysis

- The first step in analyzing the Monte Carlo data is to select the φ from $K^+ K^-$ and η from $\gamma_1\gamma_2$



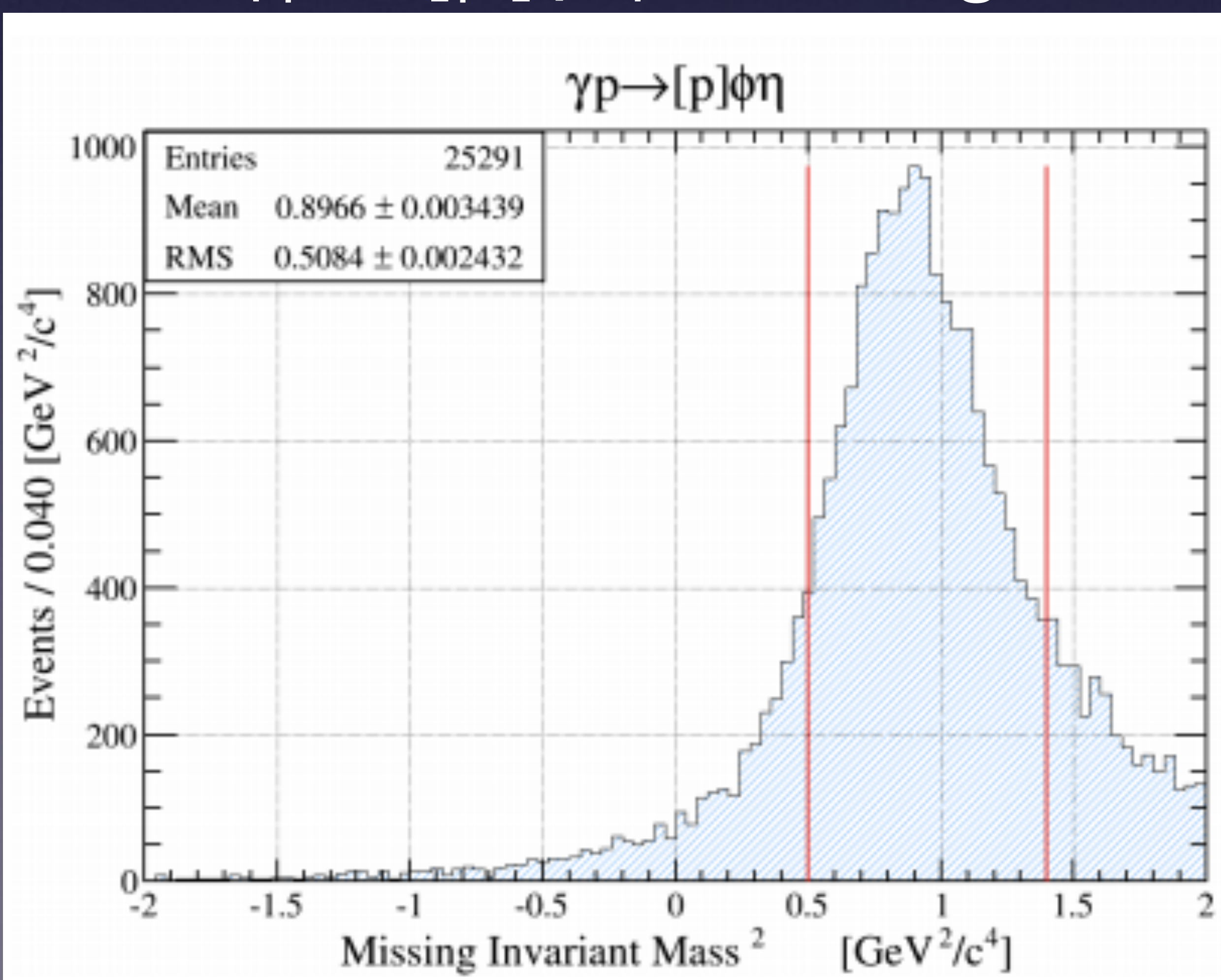


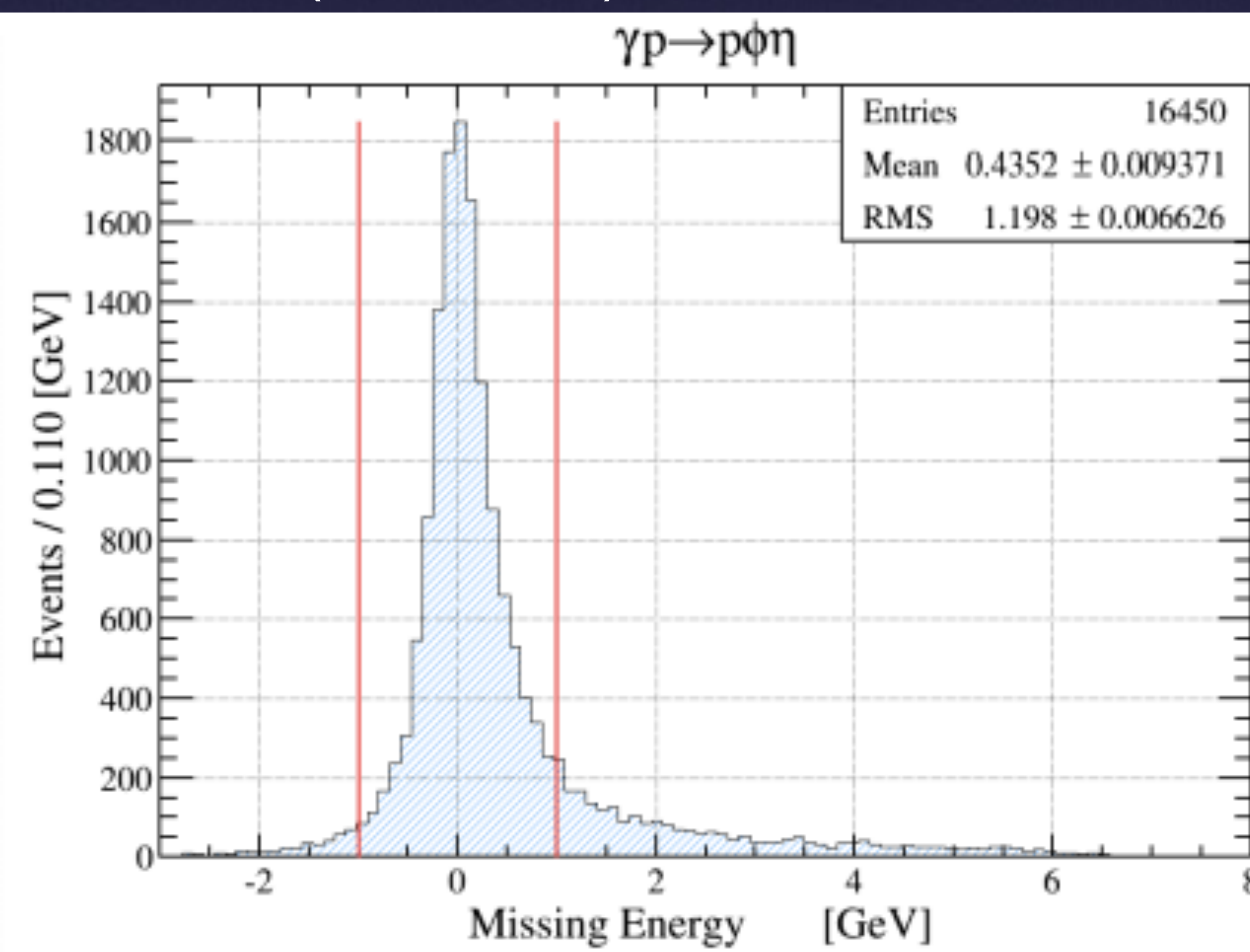
Missing Mass / Energy Cut

- For the missing proton analysis, a cut must be made on the missing invariant mass. Whereas, for the detected proton analysis a cut is made on the missing energy.

- γp→p𝜑η: Missing Energy (-1,1) GeV

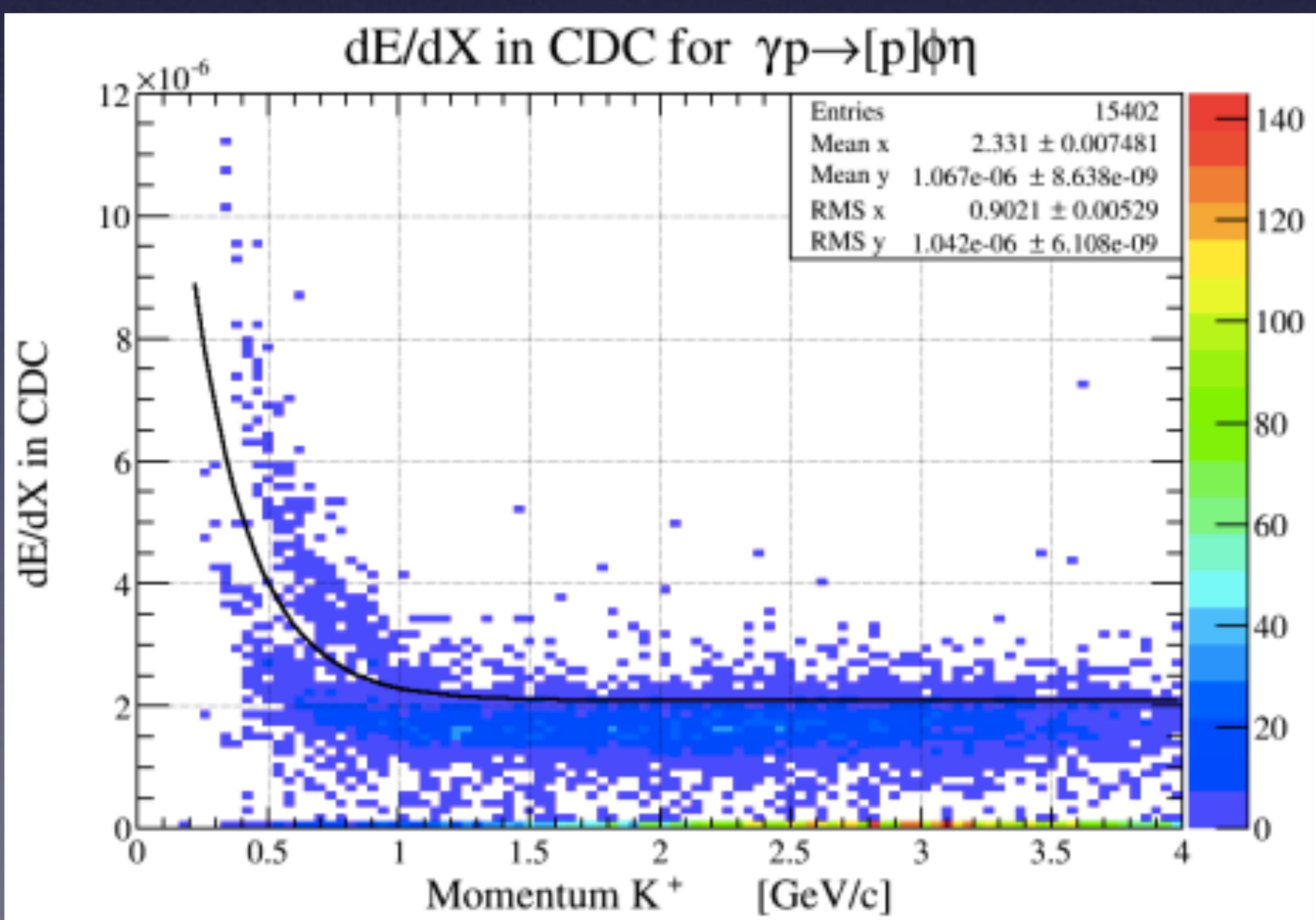
- γp→[p]𝜑η: Missing Invariant Mass (0.5-1.4) GeV

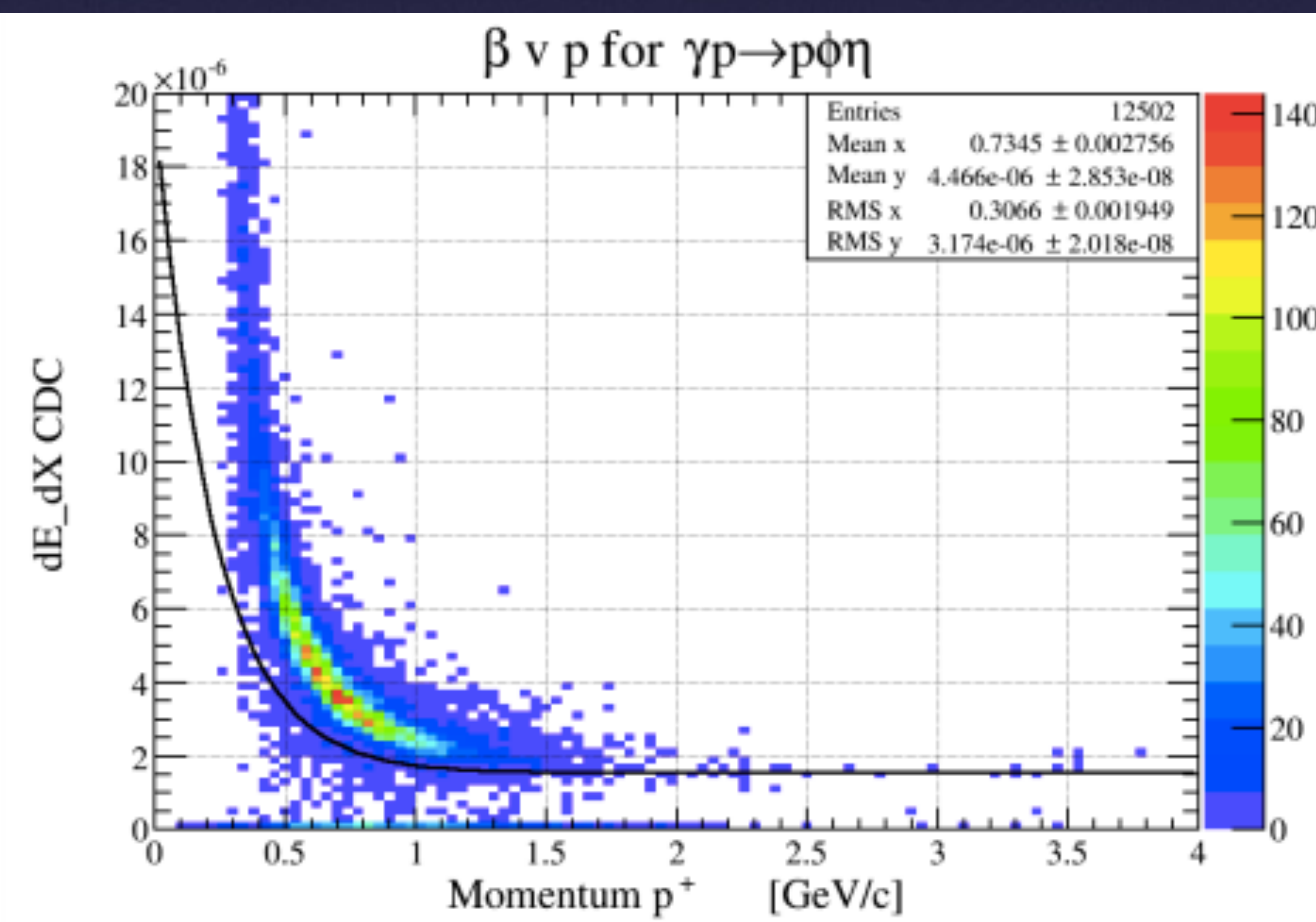




Low q⁺ Momenta Cut

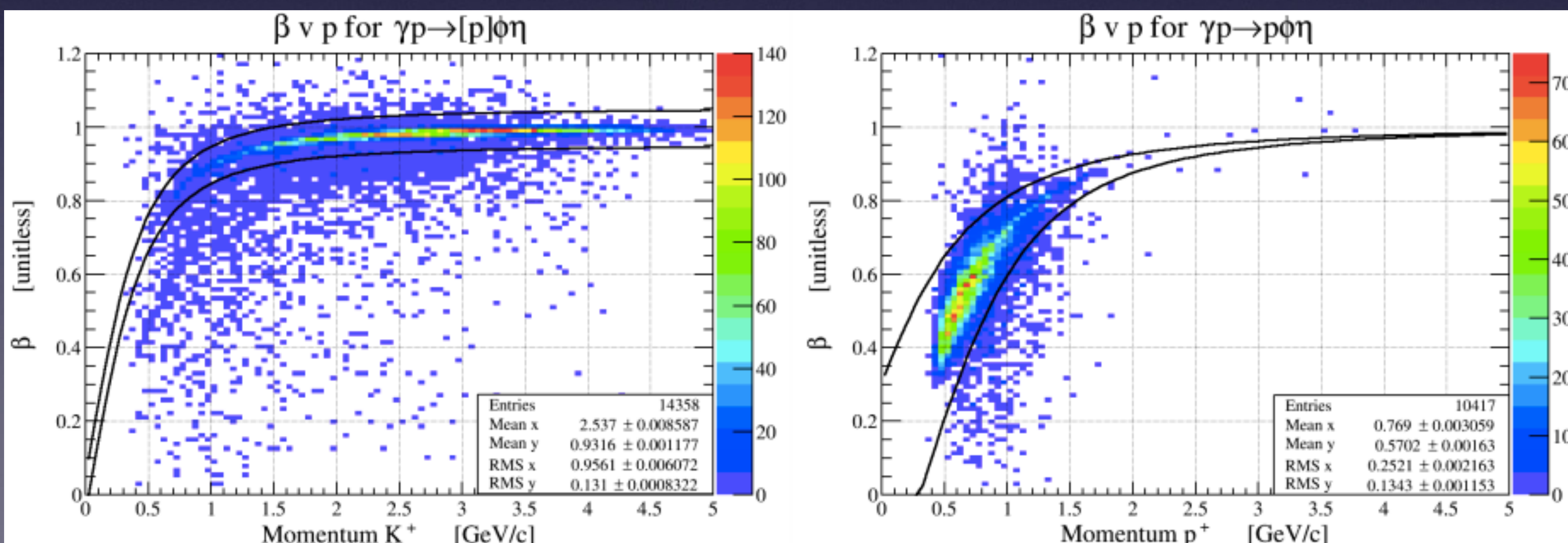
- Since there are two positively charged particles in my final state, it is imperative make PID cuts on charged tracks
- One cut that we use to differentiate between low momenta K^+ and p is the amount of energy lost in the CDC per distance
- Since the proton is much heavier than the K^+, it will lose more of its energy in the CDC, resulting in the behavior depicted below





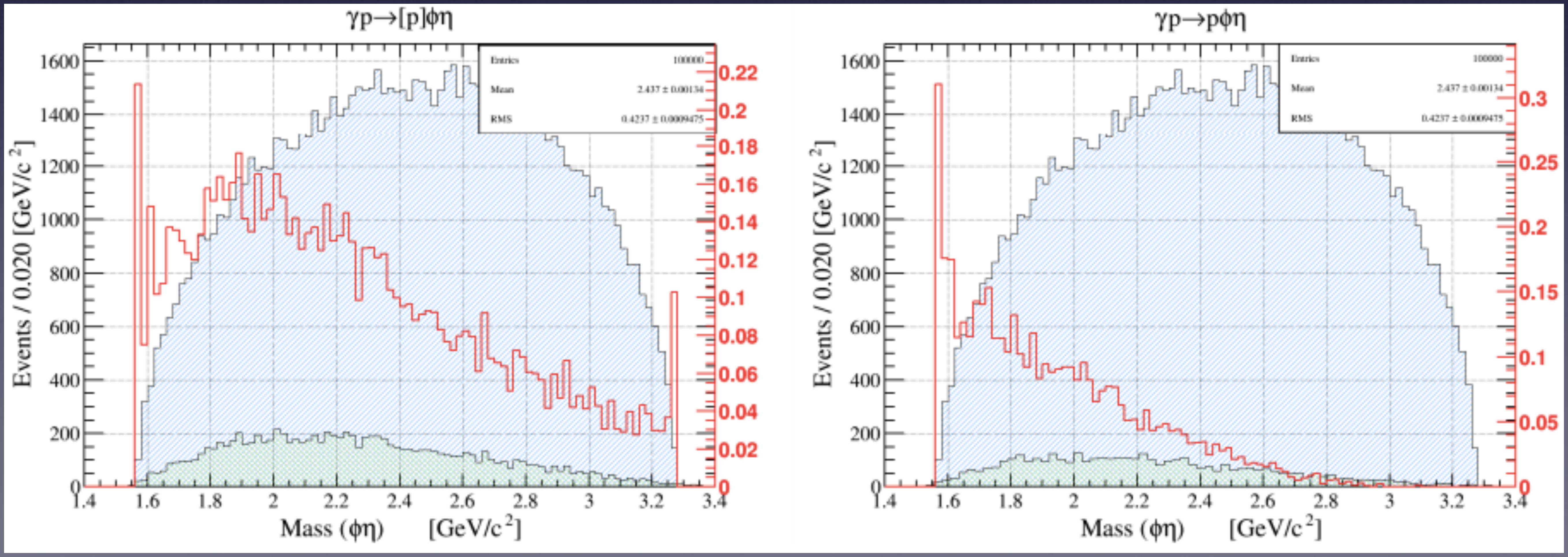
High q⁺ Momenta Cut

- Another charged particle PID technique between K^{+} and p is cutting on β vs. |P|
- At high momenta, it is difficult to differentiate between protons and kaons
- Since K^{+} and p have different masses, imposing a β vs. |P| cut allows separation at higher momenta



Acceptance Results

- After imposing all of the previous cuts, a study of X→$\varphi\eta$ invariant mass is done.
- I have found that a detected proton has an acceptance of ~4.3%, and a missing proton has an acceptance of ~9.8%
- It is important to note that the missing proton acceptance is much more promising in the invariant mass region where we expect to see new $s\bar{s}$ resonances.



Future Analysis

- Investigation of GlueX background (Monte Carlo and Data)
- Analyze actual GlueX data from this Spring 2016 (data being taken right now)
- PWA (Partial Wave Analysis)

References

[1] Barnes, T., N. Black, and P. R. Page. ”Strong decays of strange quarkonia.” Physical Review D 68.5 (2003): 054014.

[2] K.A. Olive et al. (Particle Data Group), Chin. Phys. C, 38, 090001 (2014).

[3] J.J. Dudek et al. [Hadron Spectrum Collab.], Phys. Rev. D88, 094505 (2013)[arXiv:1309.2608]

[4] F. Mané et al. (DM1), Phys. Lett. 99B, 261 (1981).

[5] D. Aston et al. (Omega Photon), Phys. Lett. 104B, 231 (1981).

[6] Aubert, Bernard, et al. ”Structure at 2175 MeV in e^+e^- ! f_0(980) observed via initial-state radiation.” Physical Review D 74.9 (2006): 091103.

[7] A Candidate for 1– strangeonium hybrid - Ding, Gui-Jun et al. Phys.Lett. B650 (2007) 390-400 hep-ph/0611319 USTC-ICTS-06-14

Thanks!