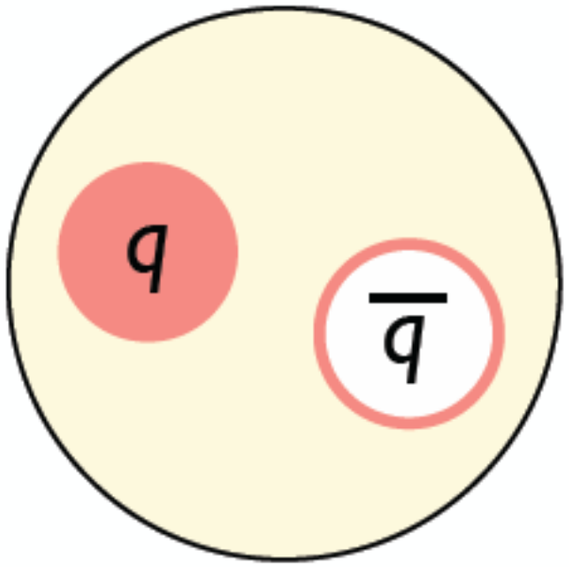
Gluonic Excitations and Jefferson Lab Hall D

Justin Stevens (GlueX Collaboration)

DIS 2014

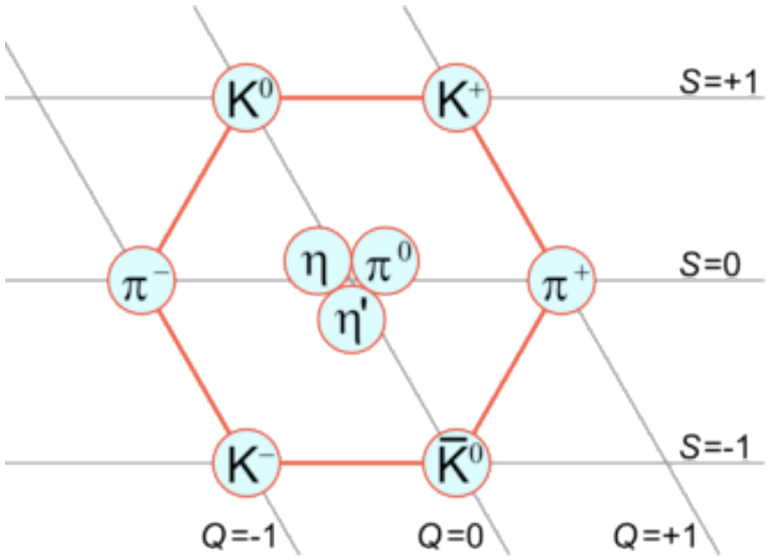
Mesons in the quark model



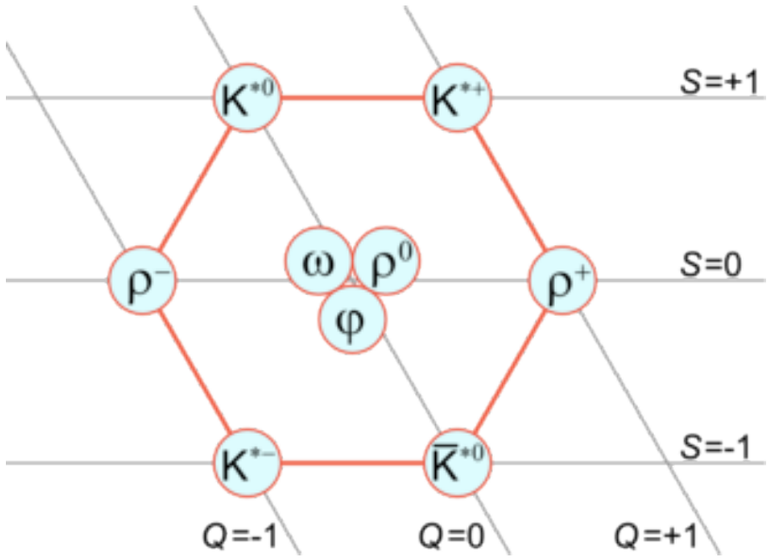
Conventional Meson

- Quark model provides a description of the observed spectrum of light quark mesons
- Mesons are grouped in nonets of given spin with different light quark flavor content
- Allowed quantum numbers for $q\bar{q}$:

$$J^{PC} = 0^{-+}, 1^{--}, 1^{+-}, 0^{++}, 2^{++} ...$$



pseudoscalar mesons



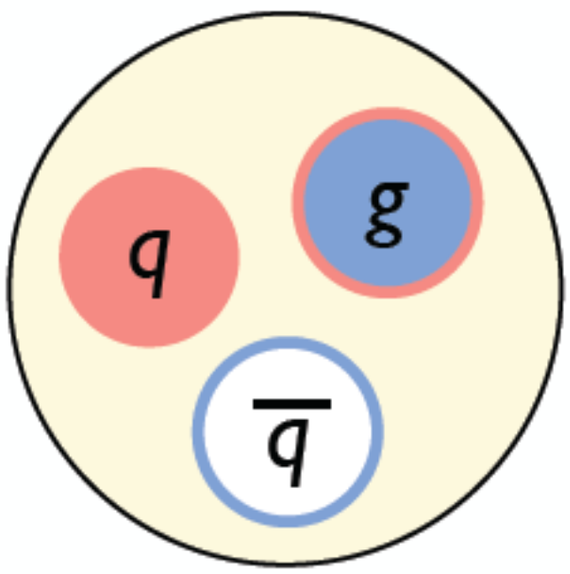
vector mesons

$$\vec{J} = \vec{L} + \vec{S}$$
$$P = (-1)^{L+1}$$
$$C = (-1)^{L+S}$$

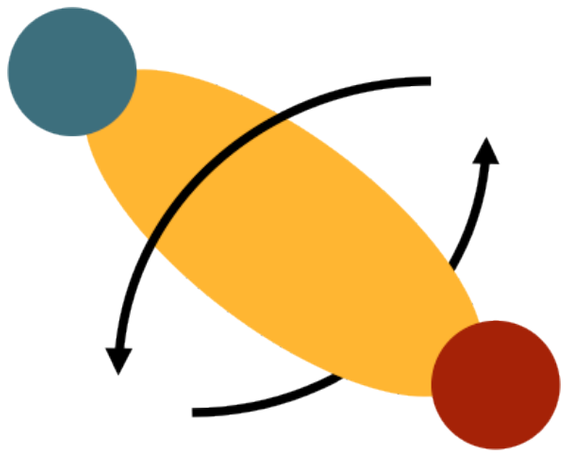
Hybrid mesons and gluonic excitations

- Excited gluonic field coupled to $q\bar{q}$ pair
- Rich spectrum of hybrid mesons predicted by Lattice QCD
- "Constituent gluon" with $J^{PC} = 1^{+-}$ and mass = 1-1.5 GeV
- Some have "exotic" J^{PC} which cannot be formed by $q\bar{q}$:

$$J^{PC} = 0^{+-}, 1^{-+}, 2^{+-} \ldots$$



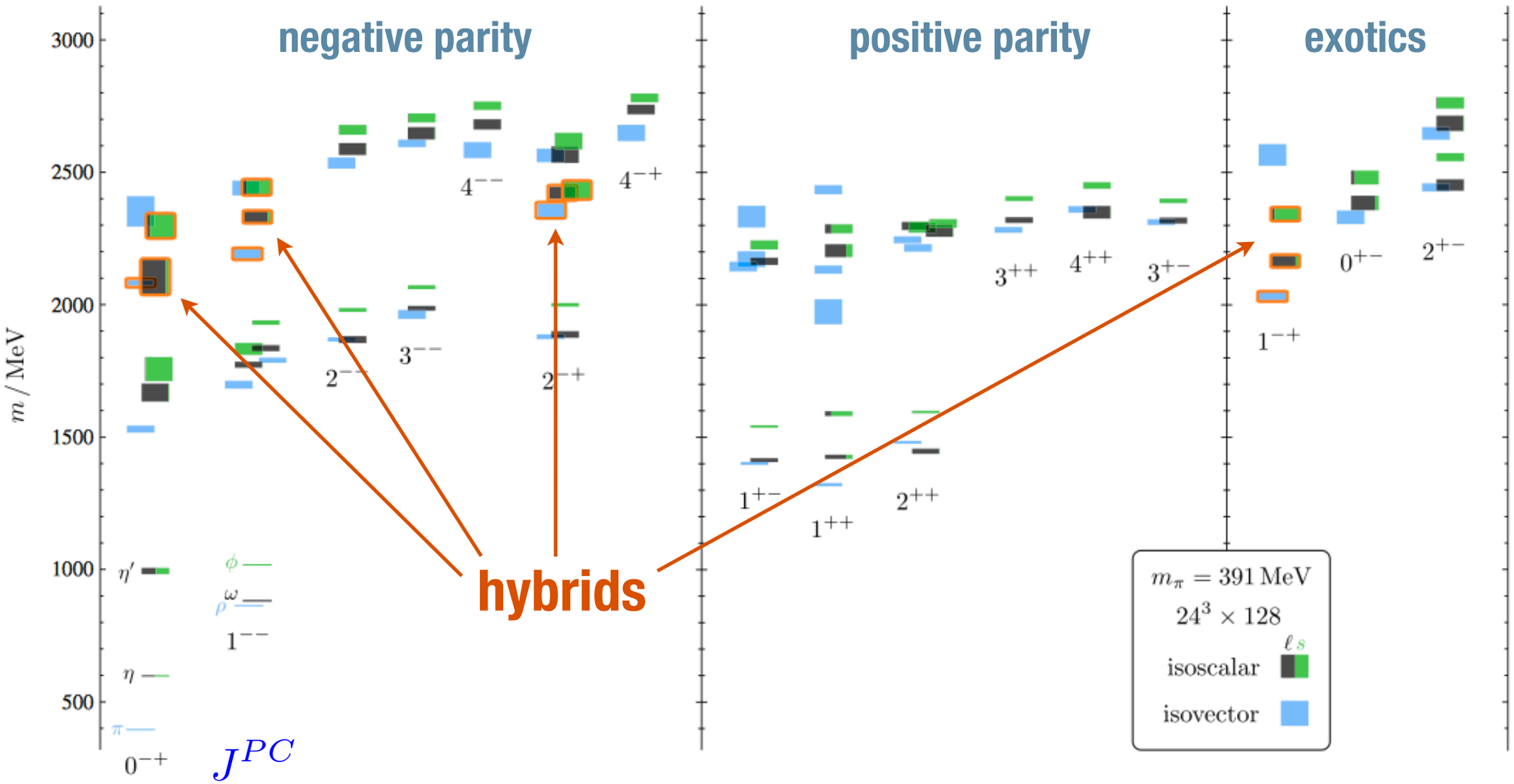
Hybrid Meson



$$\vec{J} = \vec{L} + \vec{S}$$
$$P = (-1)^{L+1}$$
$$C = (-1)^{L+S}$$

Lattice QCD predictions

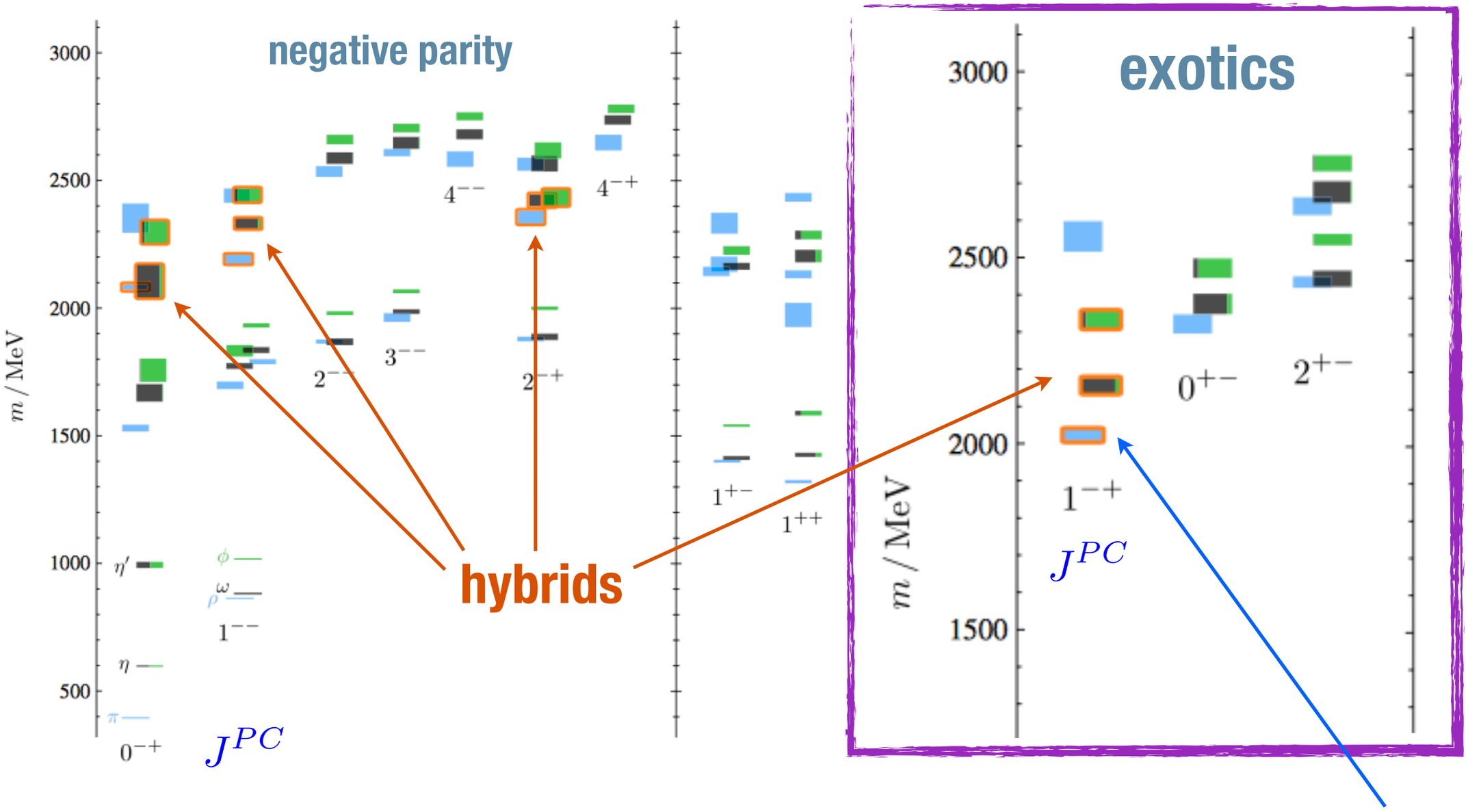
Dudek et al. PRD 88 (2013) 094505



- Most experimental searches for hybrids limited to the **π_1 state**
- Primary goal of the GlueX experiment is to search for and ultimately map out the spectrum of light quark hybrid mesons

Lattice QCD predictions

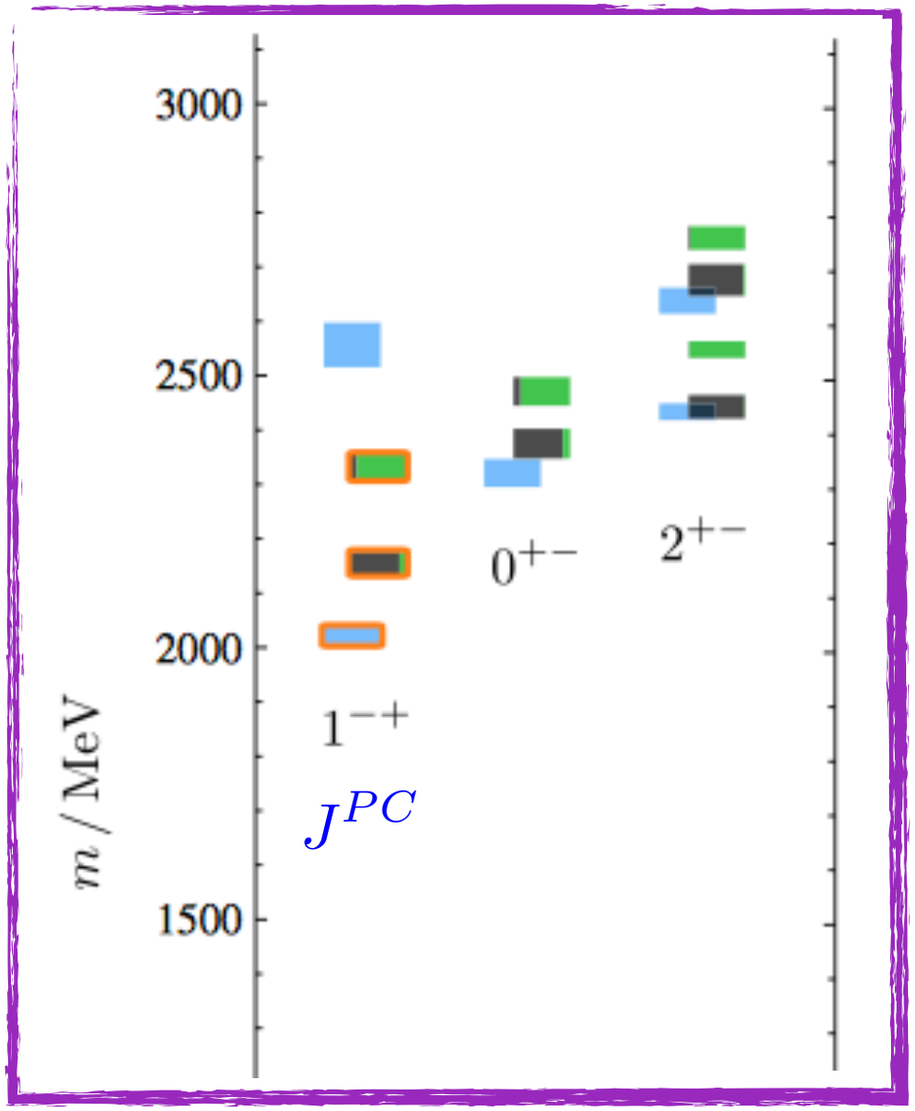
Dudek et al. PRD 88 (2013) 094505



- Most experimental searches for hybrids limited to the **π_1 state**
- Primary goal of the GlueX experiment is to search for and ultimately map out the spectrum of light quark hybrid mesons

Exotic decays

	Approximate Mass (MeV)	J^{PC}	Total Width (MeV) PSS	IKP
π_1	1900	1^{-+}	$80-170$	120
η_1	2100	1^{-+}	$60-160$	110
η_1'	2300	1^{-+}	$100-220$	170
b_0	2400	0^{+-}	$250-430$	670
h_0	2400	0^{+-}	$60-260$	90
h_0'	2500	0^{+-}	$260-490$	430
b_2	2500	2^{+-}	10	250
h_2	2500	2^{+-}	10	170
h_2'	2600	2^{+-}	$10-20$	80



- Predictions for the spectrum of hybrids from lattice, but decay predictions are model dependent

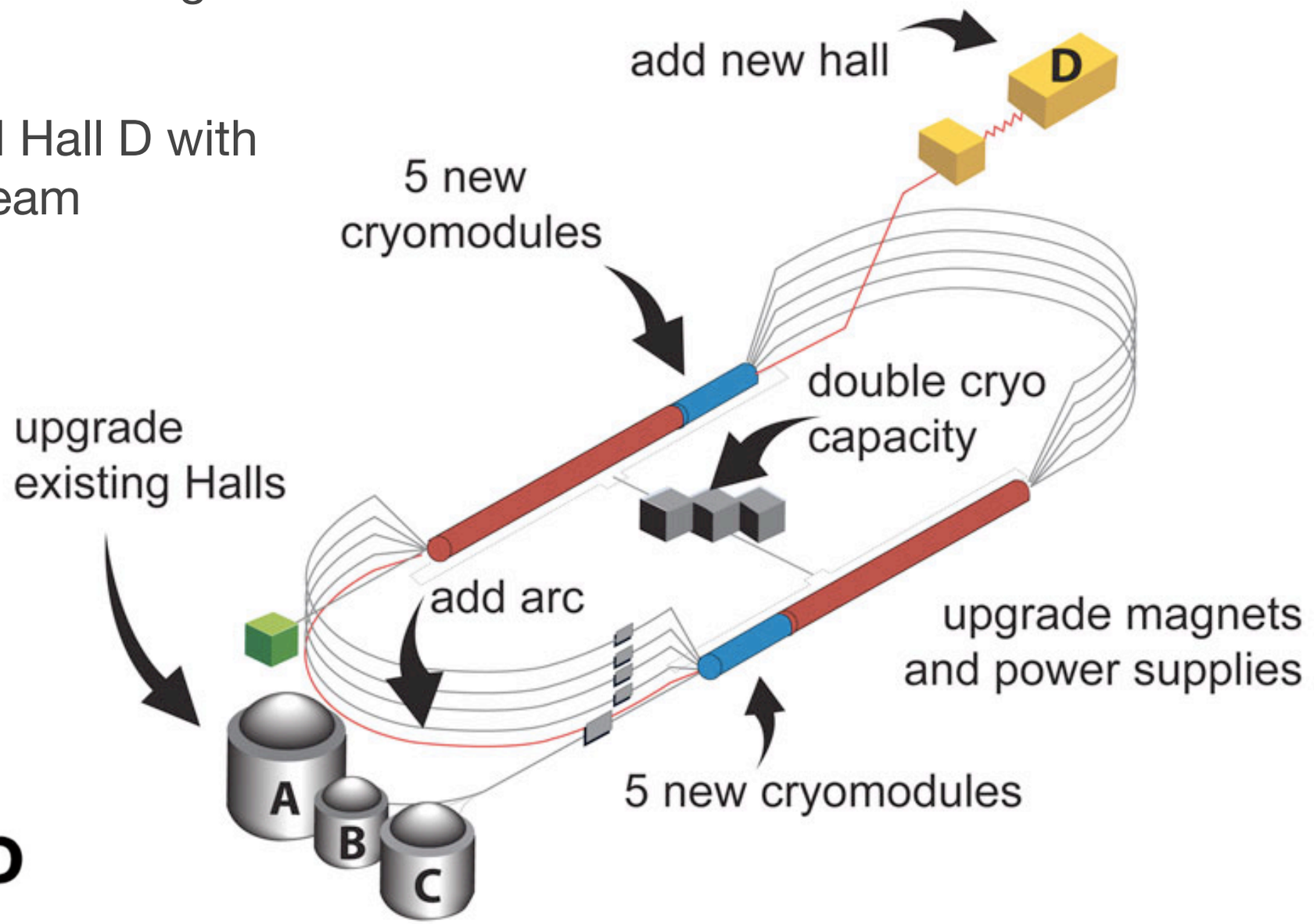
Exotic decays

	Approximate Mass (MeV)	J^{PC}	Total Width (MeV) PSS	IKP	Relevant Decays	Final States
π_1	1900	1^{-+}	$80-170$	120	$b_1\pi^\dagger$, $\rho\pi^\dagger$, $f_1\pi^\dagger$, $a_1\eta$, $\eta'\pi^\dagger$	$\omega\pi\pi^\dagger$, $3\pi^\dagger$, 5π, $\eta 3\pi^\dagger$, $\eta'\pi^\dagger$
η_1	2100	1^{-+}	$60-160$	110	$a_1\pi$, $f_1\eta^\dagger$, $\pi(1300)\pi$	4π, $\eta 4\pi$, $\eta\eta\pi\pi^\dagger$
η_1'	2300	1^{-+}	$100-220$	170	$K_1(1400)K^\dagger$, $K_1(1270)K^\dagger$, $K^*K^\dagger$	$KK\pi\pi^\dagger$, $KK\pi^\dagger$, $KK\omega^\dagger$
b_0	2400	0^{+-}	$250-430$	670	$\pi(1300)\pi$, $h_1\pi$	4π
h_0	2400	0^{+-}	$60-260$	90	$b_1\pi^\dagger$, $h_1\eta$, $K(1460)K$	$\omega\pi\pi^\dagger$, $\eta 3\pi$, $KK\pi\pi$
h_0'	2500	0^{+-}	$260-490$	430	$K(1460)K$, $K_1(1270)K^\dagger$, $h_1\eta$	$KK\pi\pi^\dagger$, $\eta 3\pi$
b_2	2500	2^{+-}	10	250	$a_2\pi^\dagger$, $a_1\pi$, $h_1\pi$	4π, $\eta\pi\pi^\dagger$
h_2	2500	2^{+-}	10	170	$b_1\pi^\dagger$, $\rho\pi^\dagger$	$\omega\pi\pi^\dagger$, $3\pi^\dagger$
h_2'	2600	2^{+-}	$10-20$	80	$K_1(1400)K^\dagger$, $K_1(1270)K^\dagger$, $K_2^*K^\dagger$	$KK\pi\pi^\dagger$, $KK\pi^\dagger$

- Predictions for the spectrum of hybrids from lattice, but decay predictions are model dependent
- Candidates for **π_1 state** observed at multiple experiments (COMPASS, E852, etc.) Recent review by Meyer and Van Haarlem (arXiv:1004:5516)
- Mapping the hybrid spectrum requires: large statistics samples of many particle final states in strange and non-strange decay modes

Jefferson Laboratory: 12 GeV Upgrade

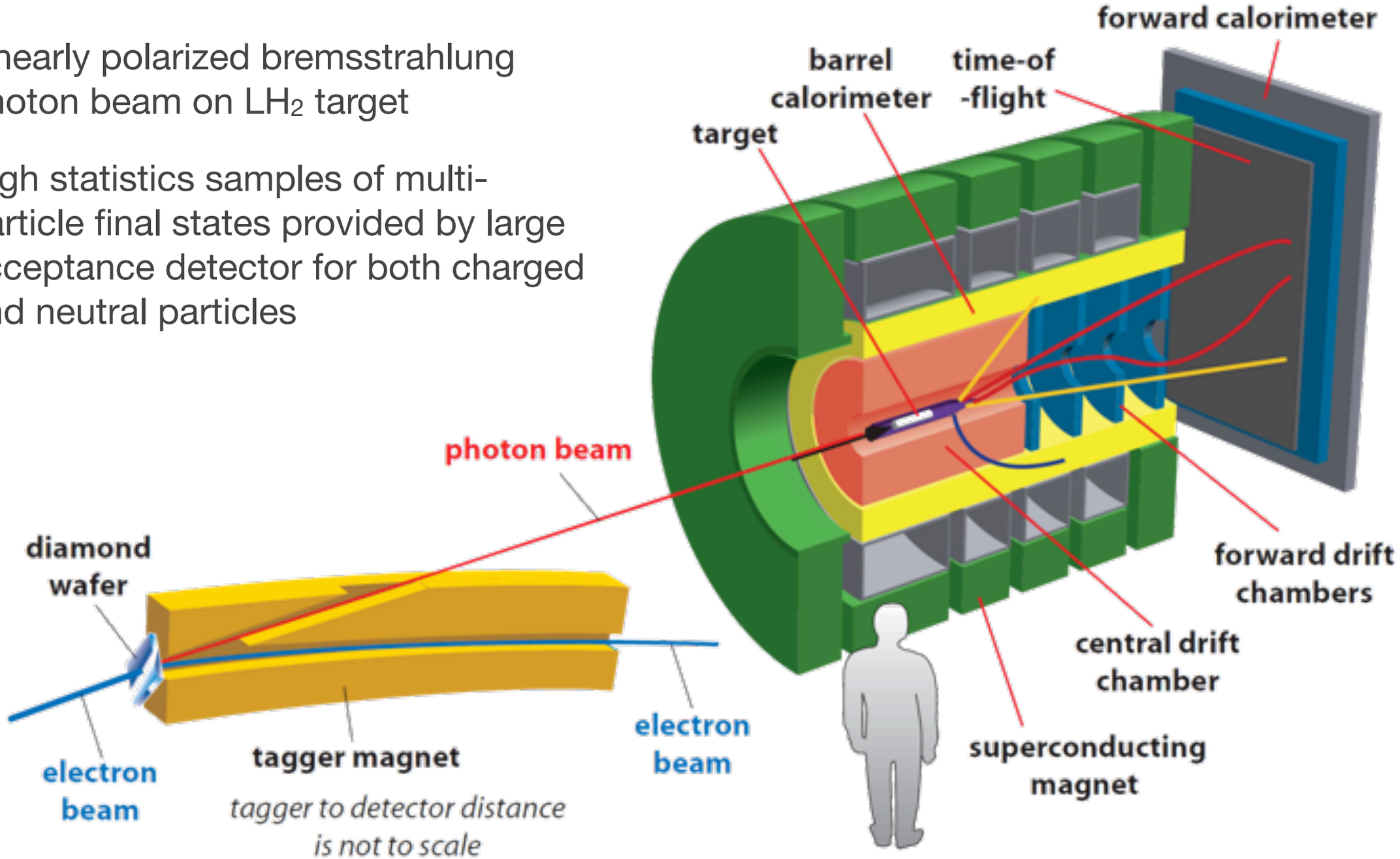
- Upgrade maximum electron beam energy from 6 to 12 GeV: provides access to higher mass states
- Significant upgrades to existing Halls A, B, and C
- Add new experimental Hall D with a dedicated photon beam



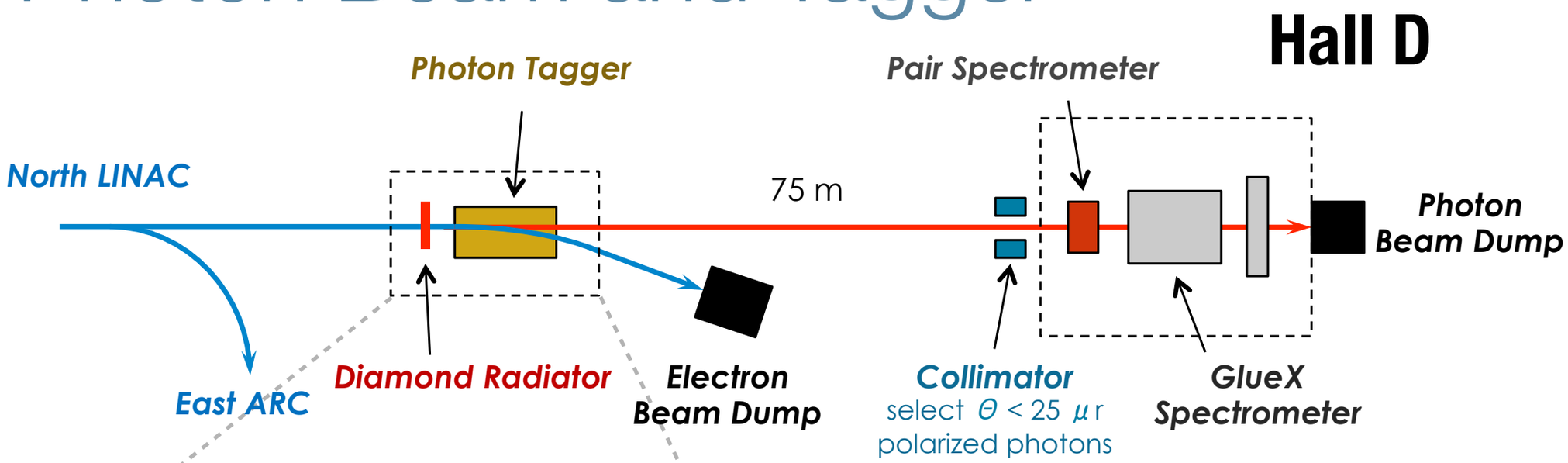
Jefferson Lab

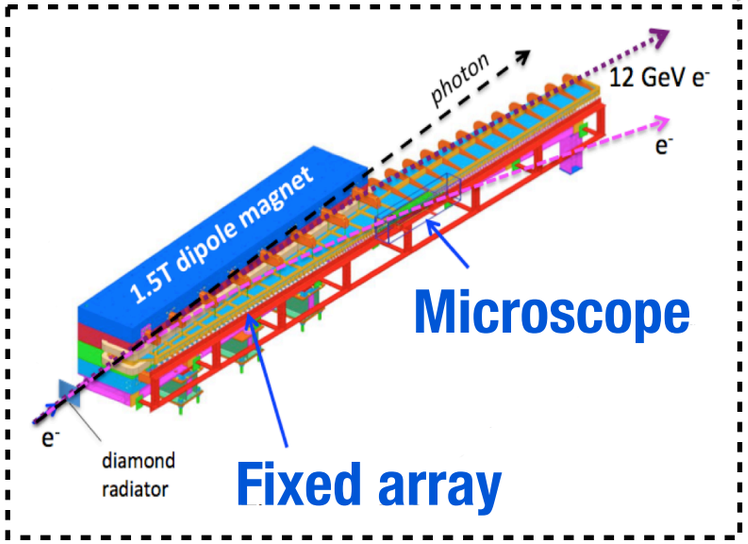
GlueX Experiment in JLab Hall D

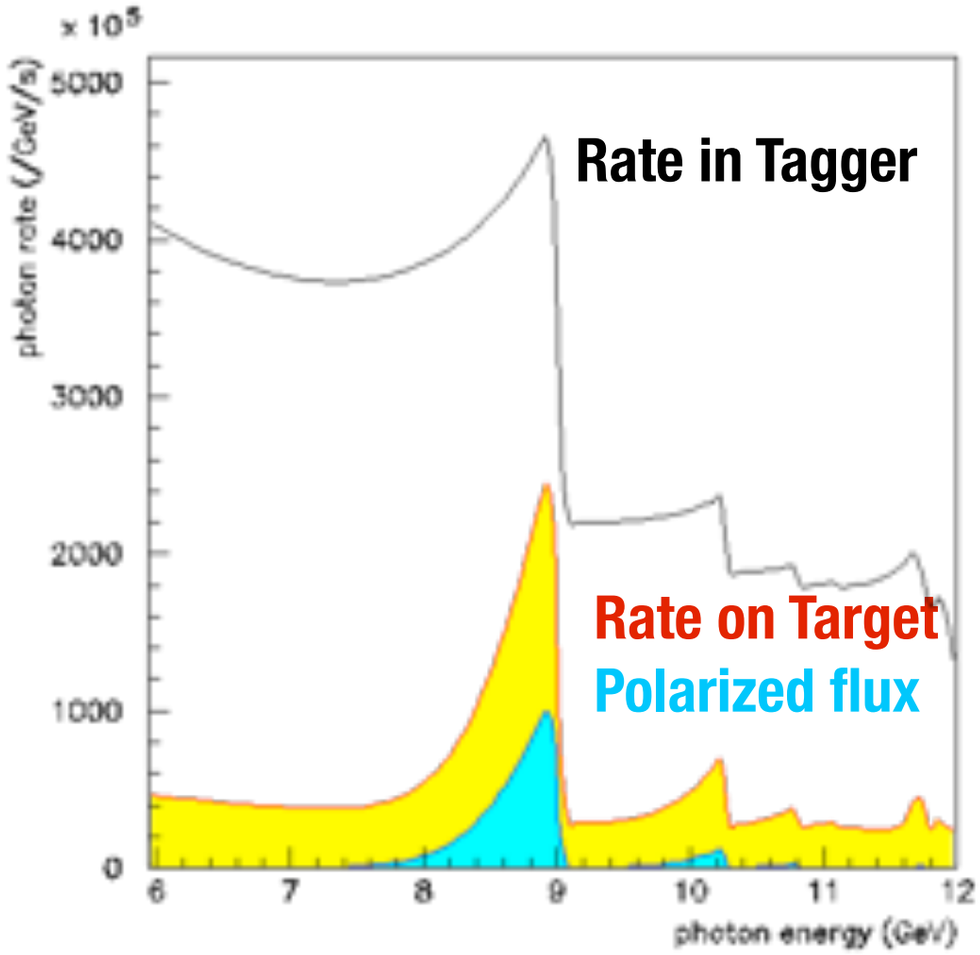
- Designed for light quark hybrid meson spectroscopy
- Linearly polarized bremsstrahlung photon beam on LH_2 target
- High statistics samples of multi-particle final states provided by large acceptance detector for both charged and neutral particles



Photon Beam and Tagger

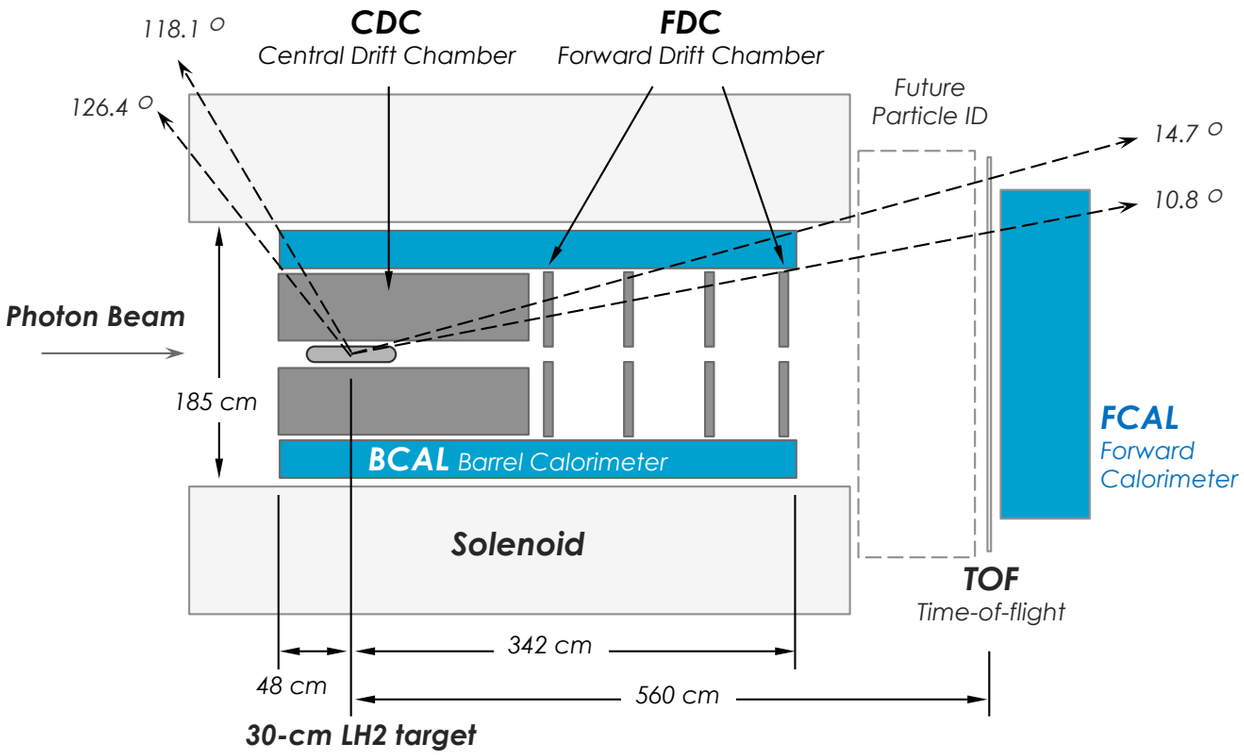






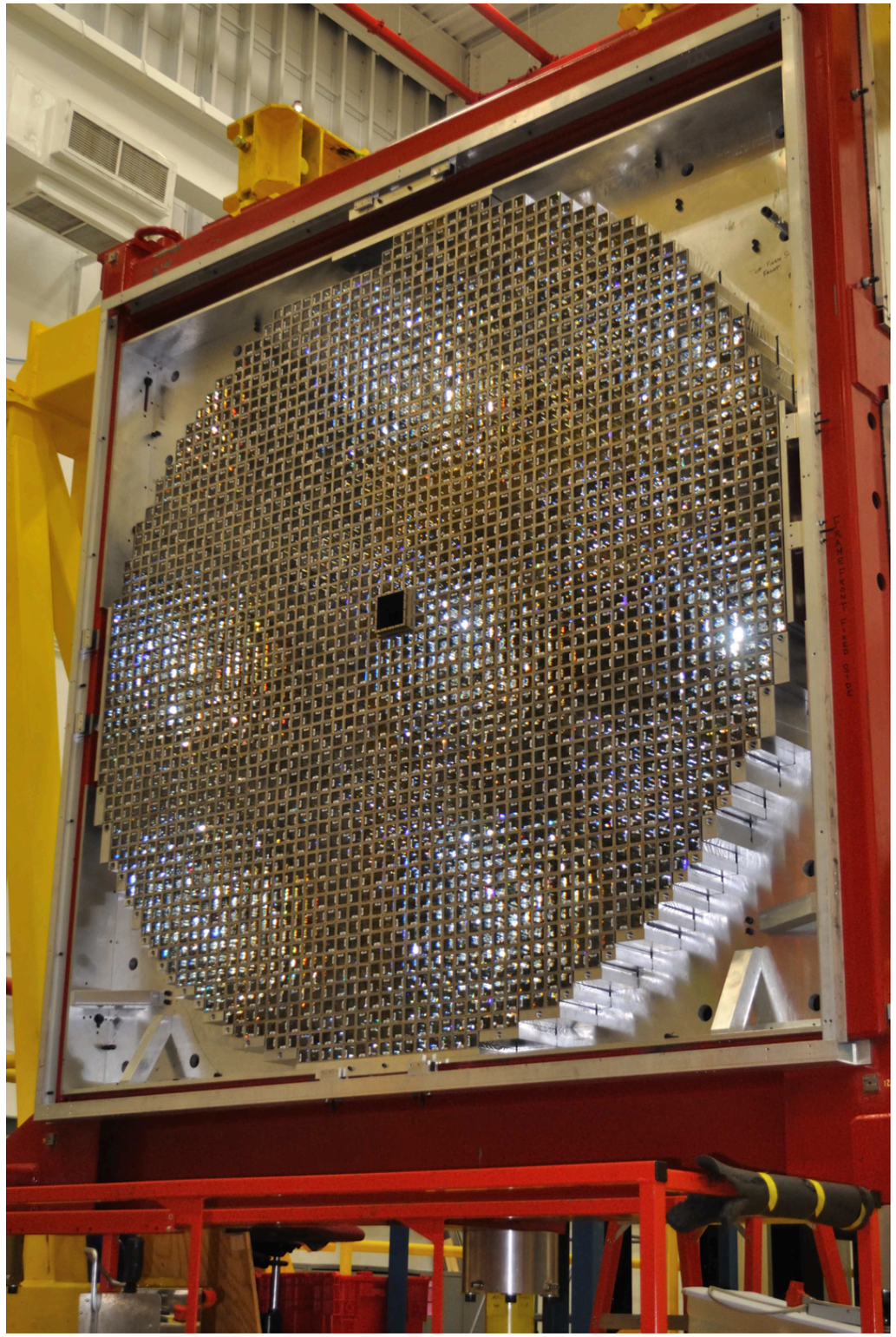
- Linearly polarized (~40%) photons via coherent bremsstrahlung from diamond radiator
- Design intensity of 10^8 γ/s in coherent peak

Calorimetry

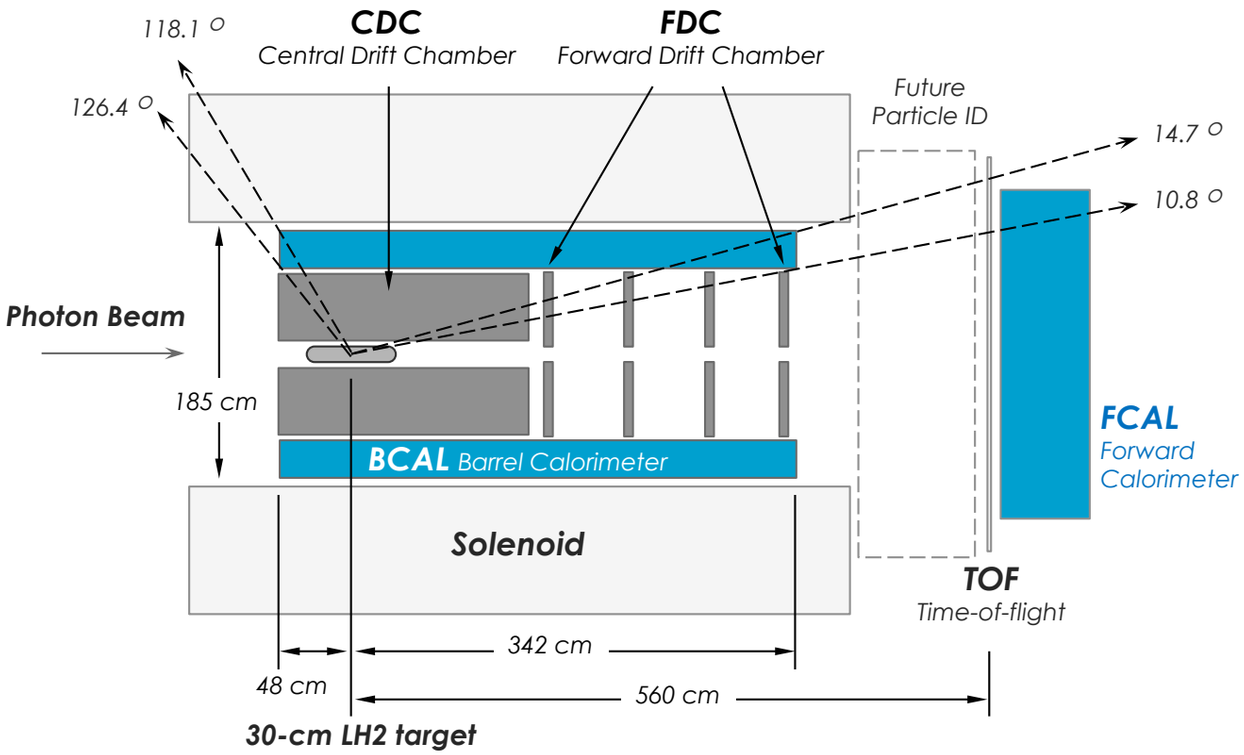


- FCAL: Installed and **first cosmic signals!**
  - 2800 Pb-glass blocks
- BCAL: Built and Installed
  - Pb/Scintillating-fiber calorimeter

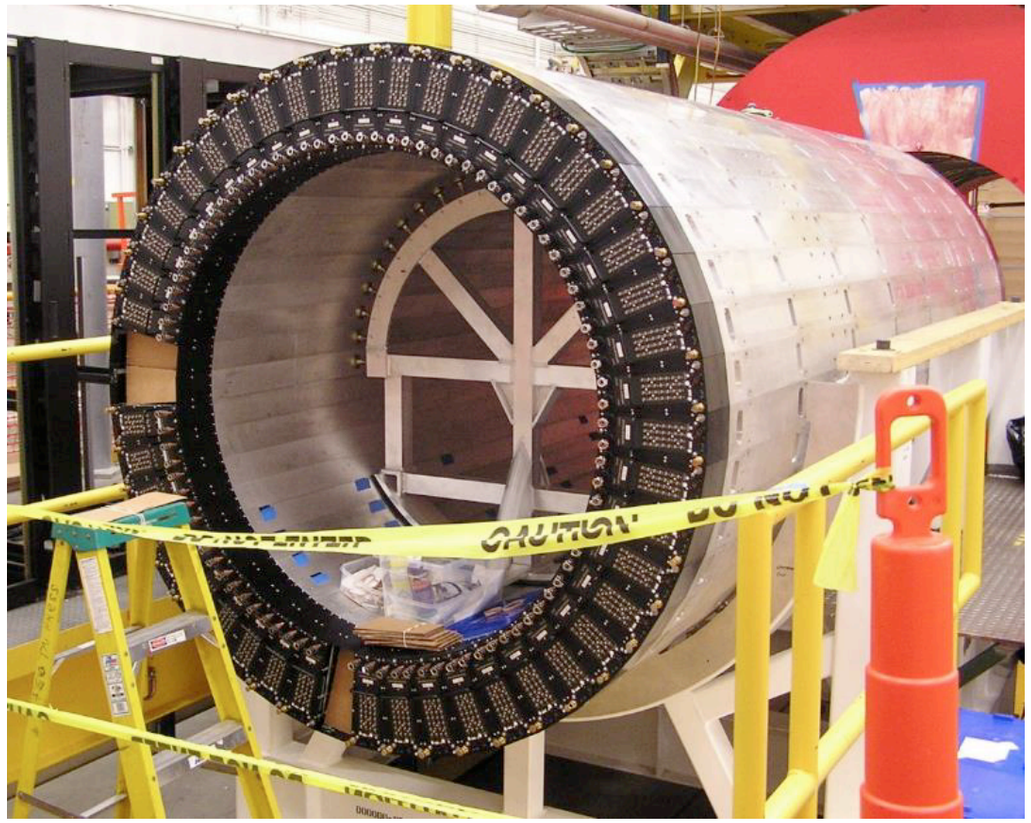
Forward Calorimeter (FCAL)



Calorimetry



Barrel Calorimeter (BCAL)



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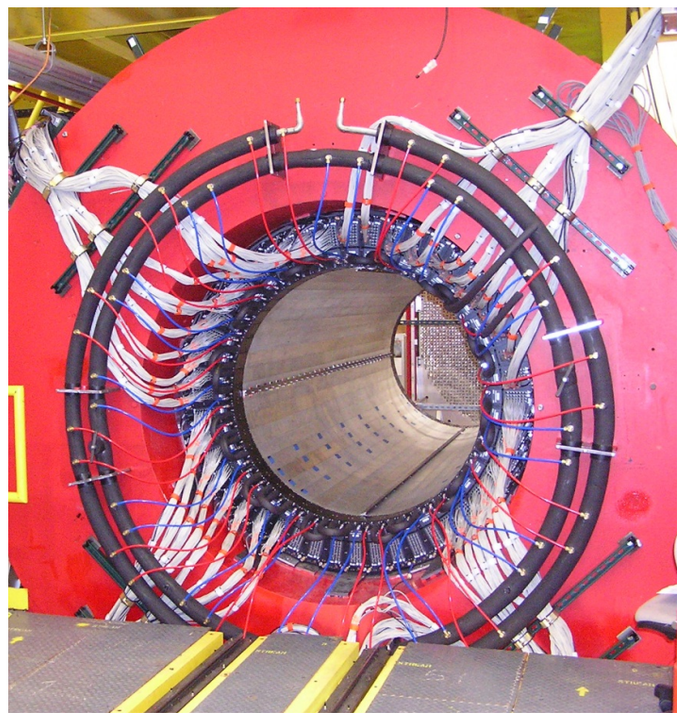
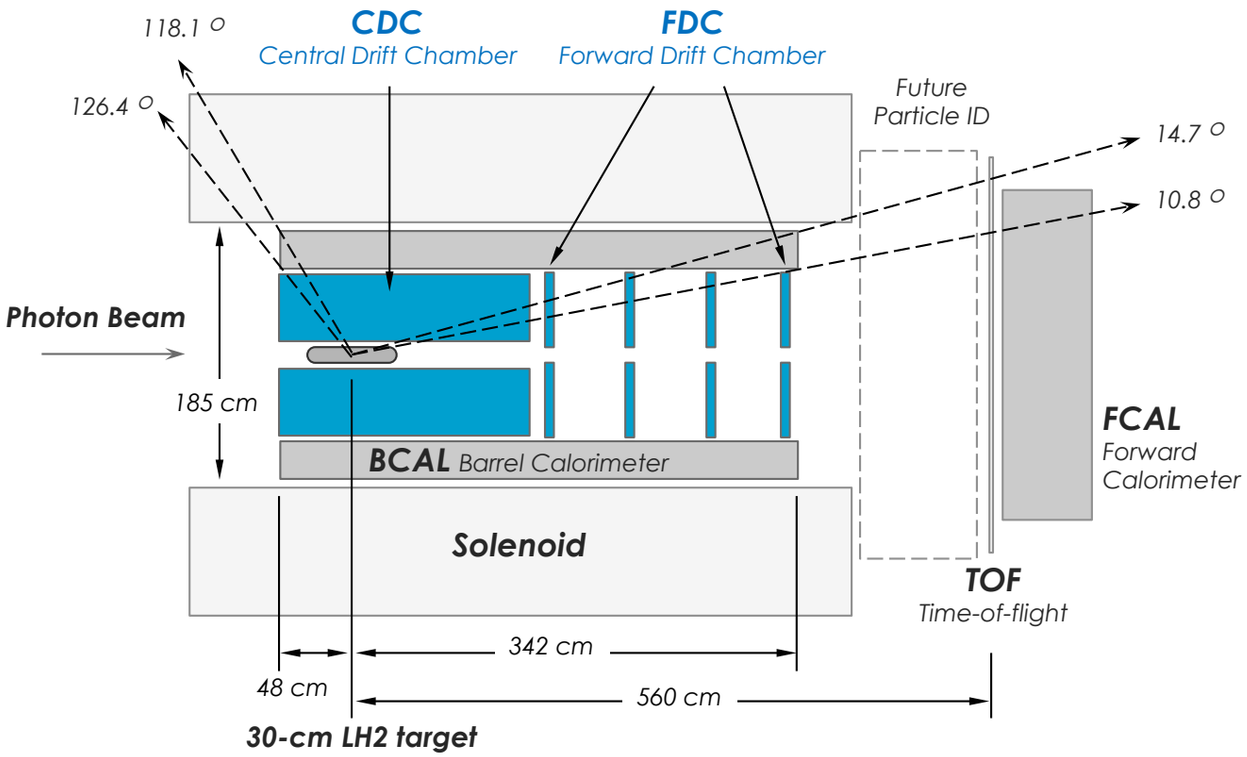
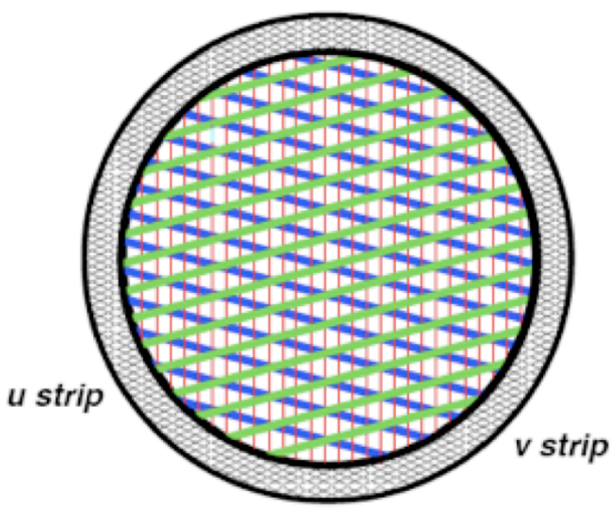


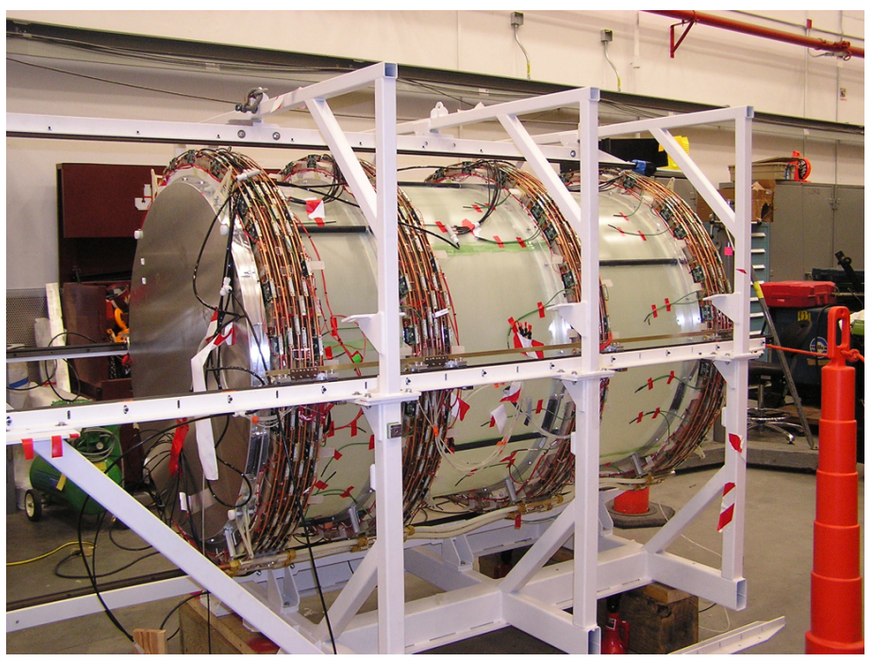
Tracking

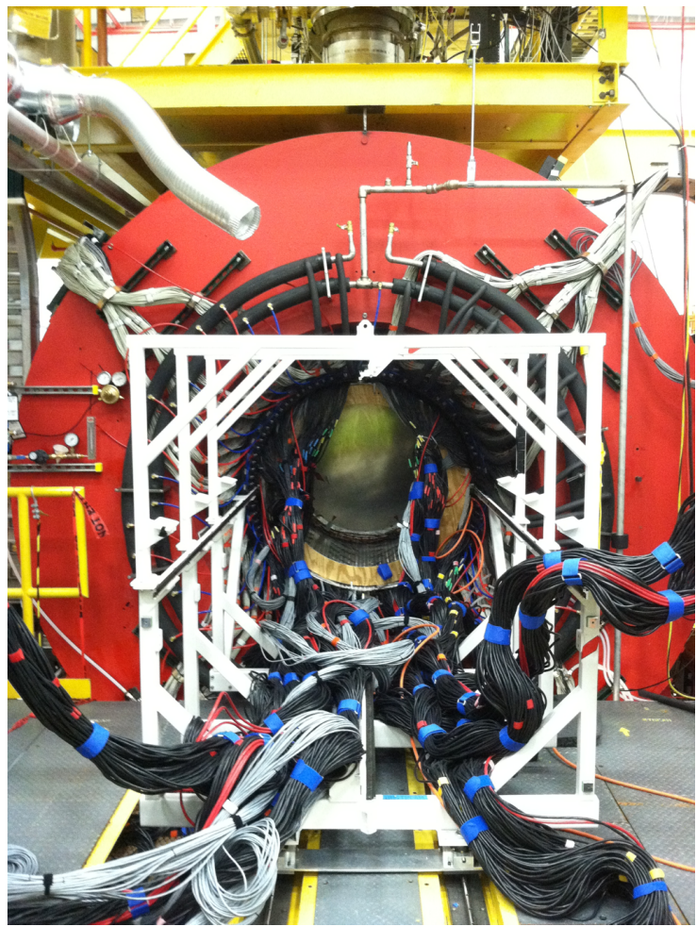


- FDC: Built and Installed
  - u/v cathode strip planes on either side of anode wires
- CDC: Built and Installed
  - 28 straw tube layers

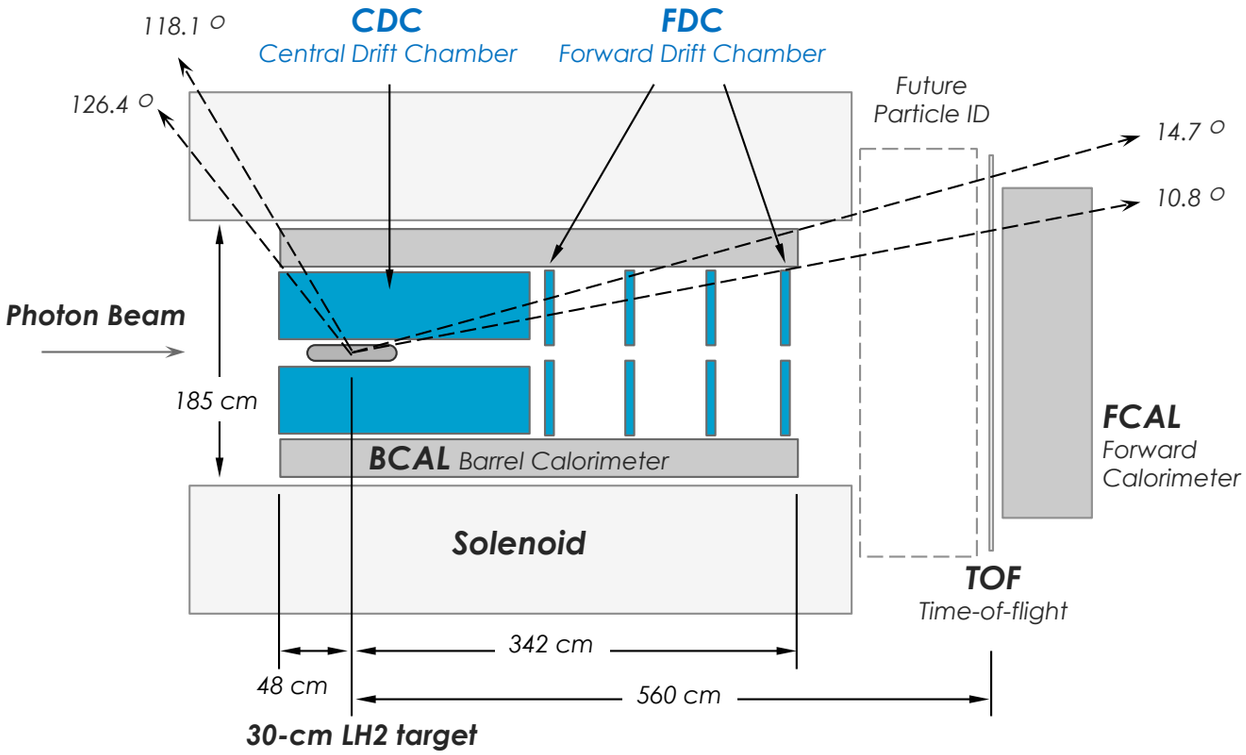
Forward Drift Chamber (FDC)







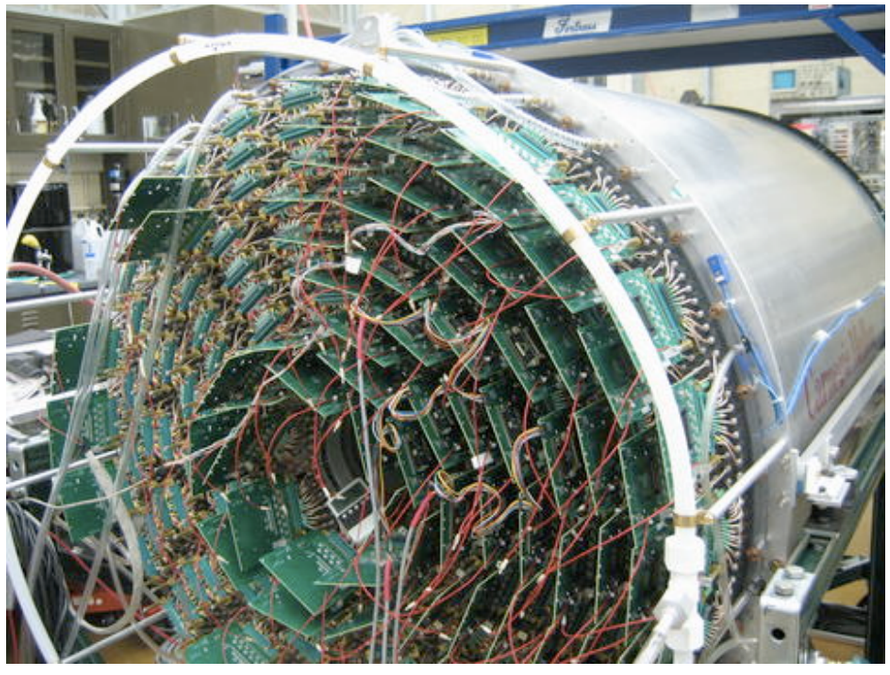
Tracking

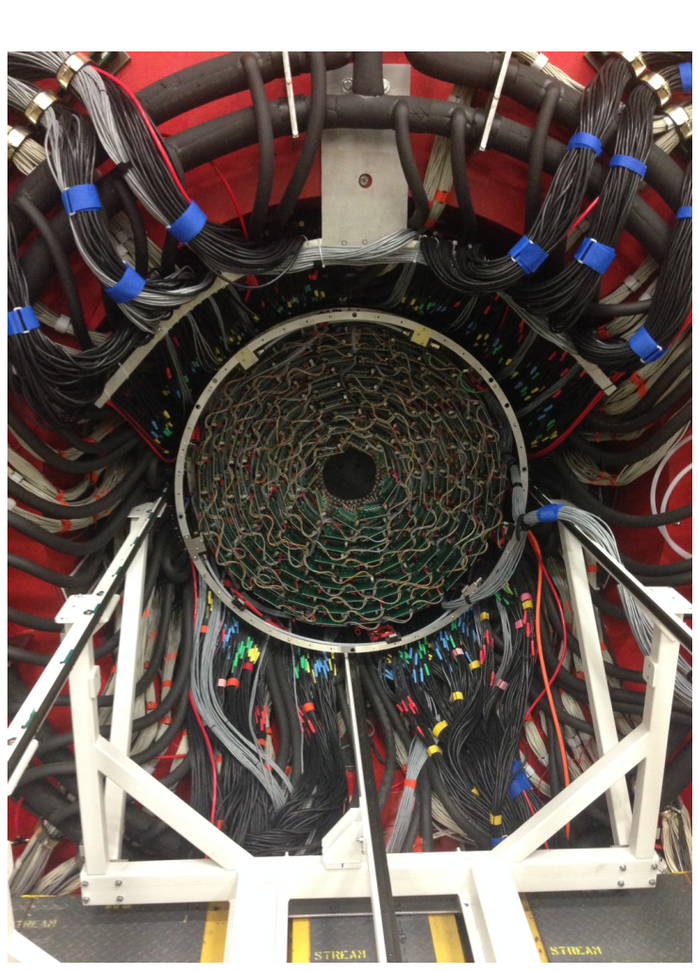


- FDC: Built and Installed
  - u/v cathode strip planes on either side of anode wires
- CDC: Built and Installed
  - 28 straw tube layers

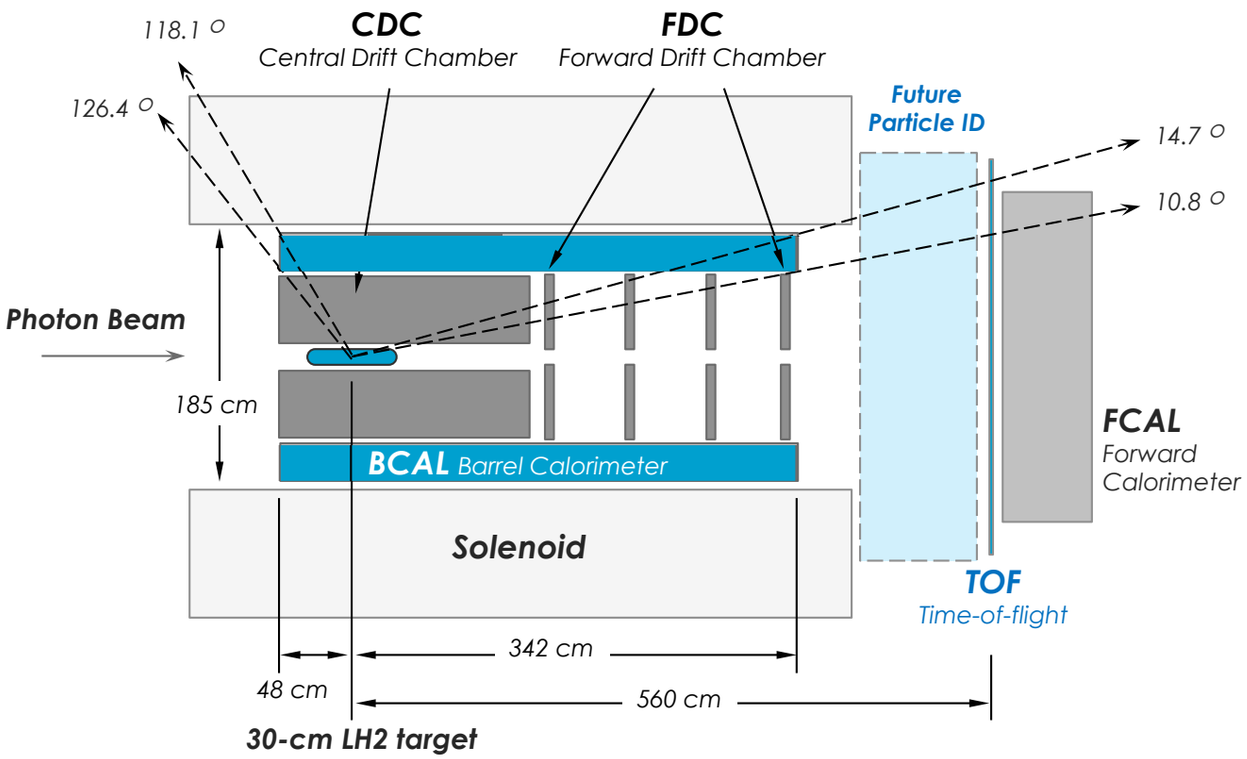

CDC during assembling

Central Drift Chamber (CDC)



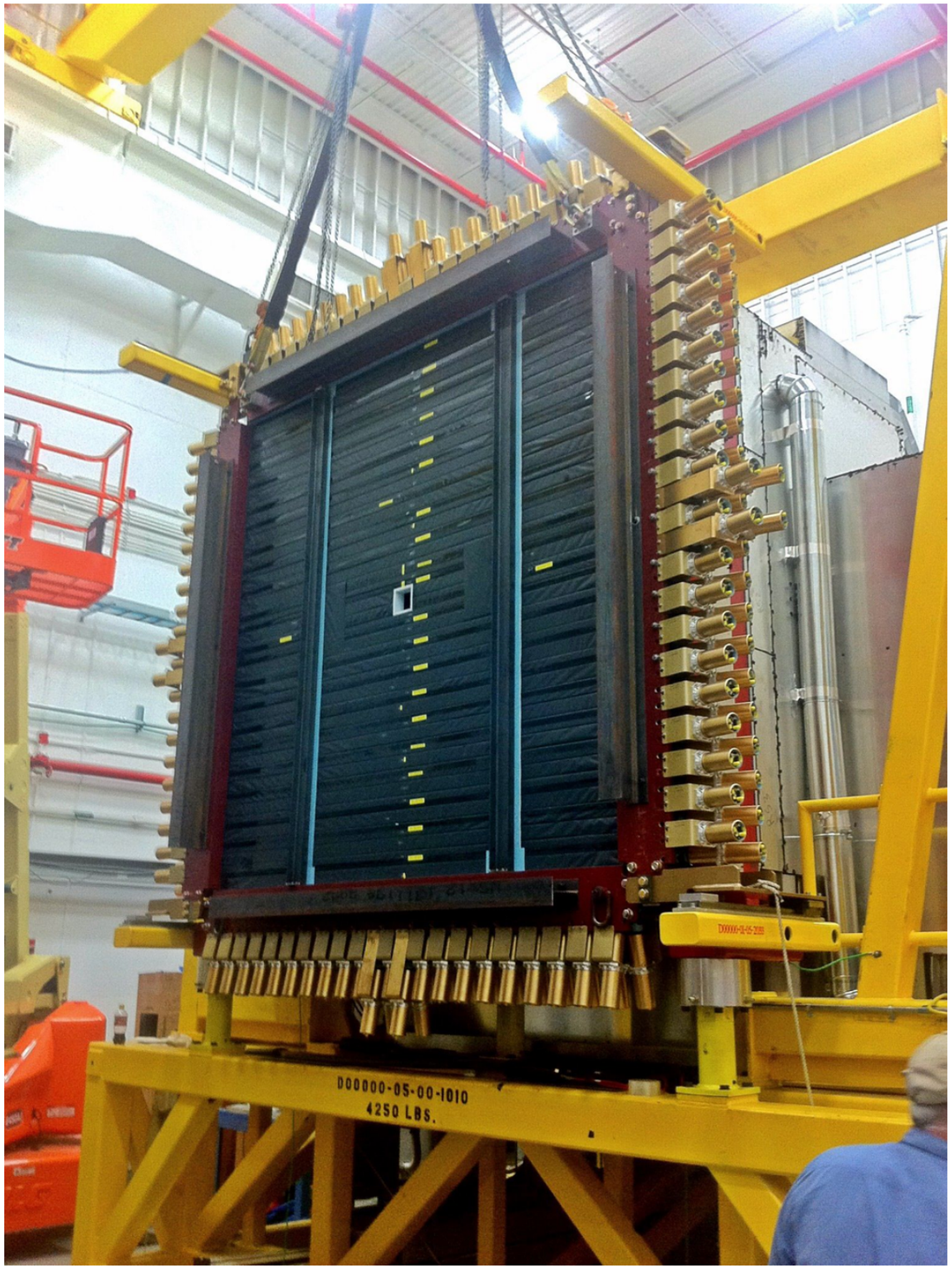


Particle Identification

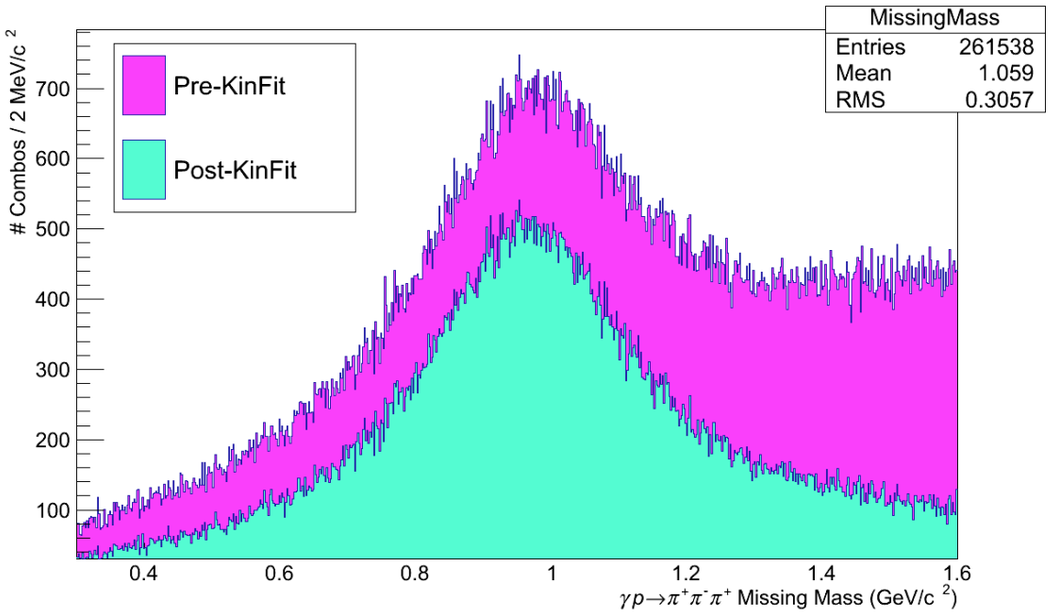


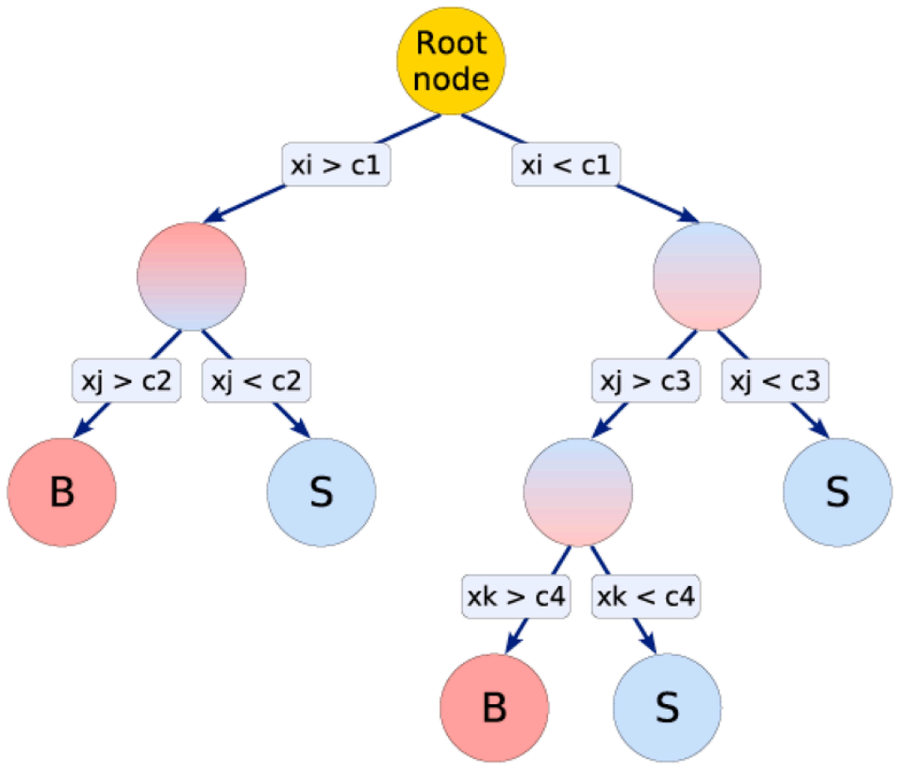
- Start Counter: Under construction
  - Thin scintillator surrounding target
  - ~300 ps resolution
- TOF: Built and Installed
  - 2 scintillator planes
  - 70 ps resolution; provides ~4σ π/K separation up to p ~ 2 GeV/c

Time of Flight (TOF)



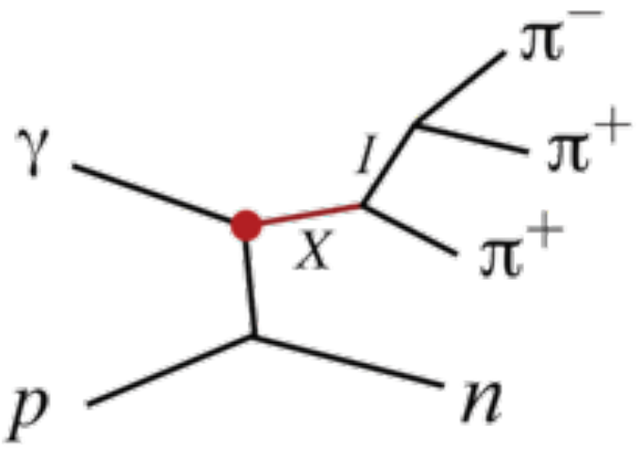
$\gamma p \to (n)\pi^+\pi^-\pi^+$: Event selection



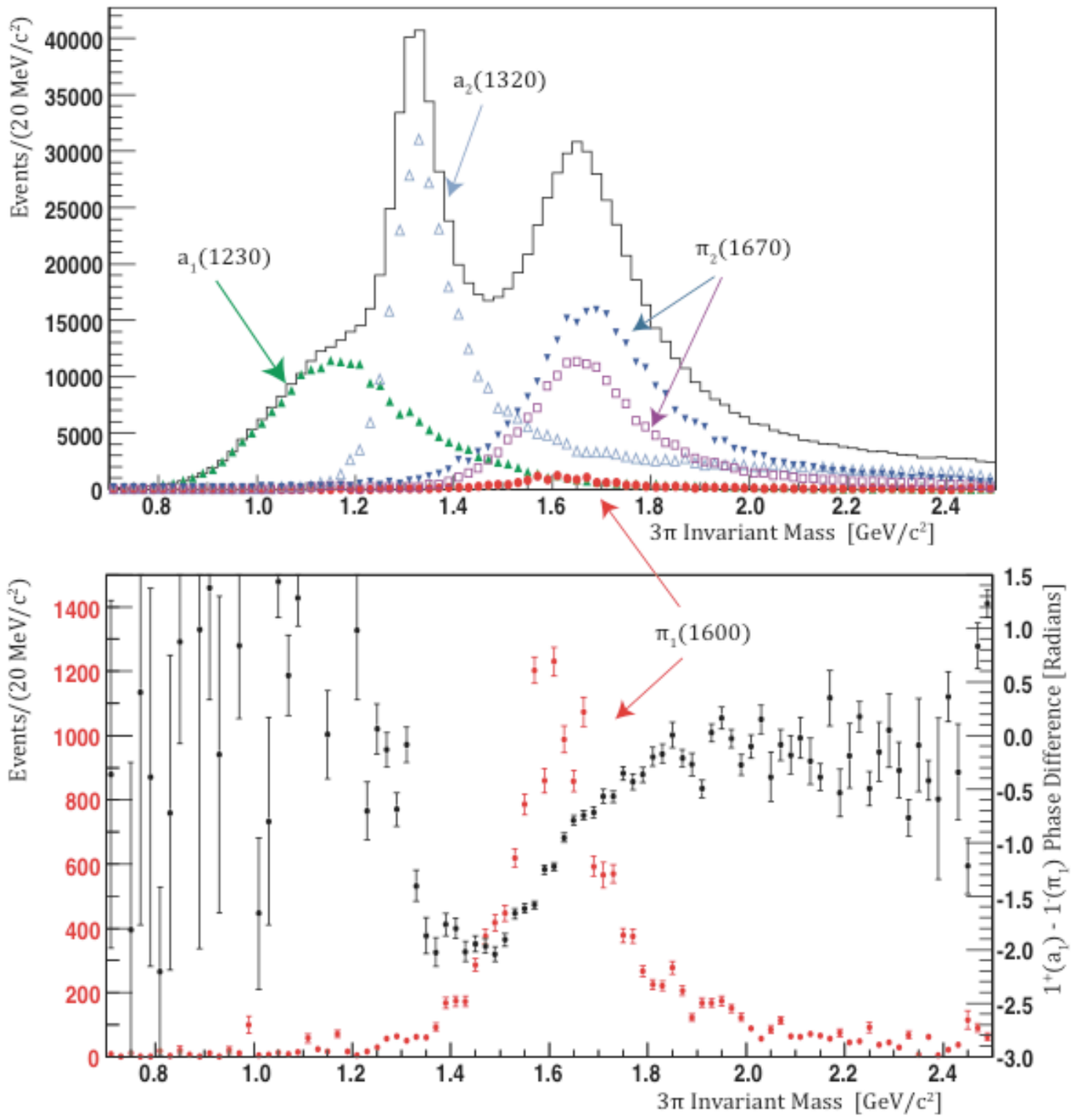


- Simulate inclusive photoproduction with PYTHIA-based generator
  - Large MC datasets (~10 billion events) produced in “data challenges” for background studies
- Many “handles” available to select the channel of interest: kinematic fit, particle ID, missing mass, etc.
- Can combine all variables into single classifier using multivariate analysis (eg. Boosted Decision Trees, Neural Networks, etc.)
- Simulated performance: $\gamma p \to (n)\pi^+\pi^-\pi^+$
  - Purity of 95%, with ~20% efficiency
- Many other topologies currently being studied, including strange final states for high intensity running

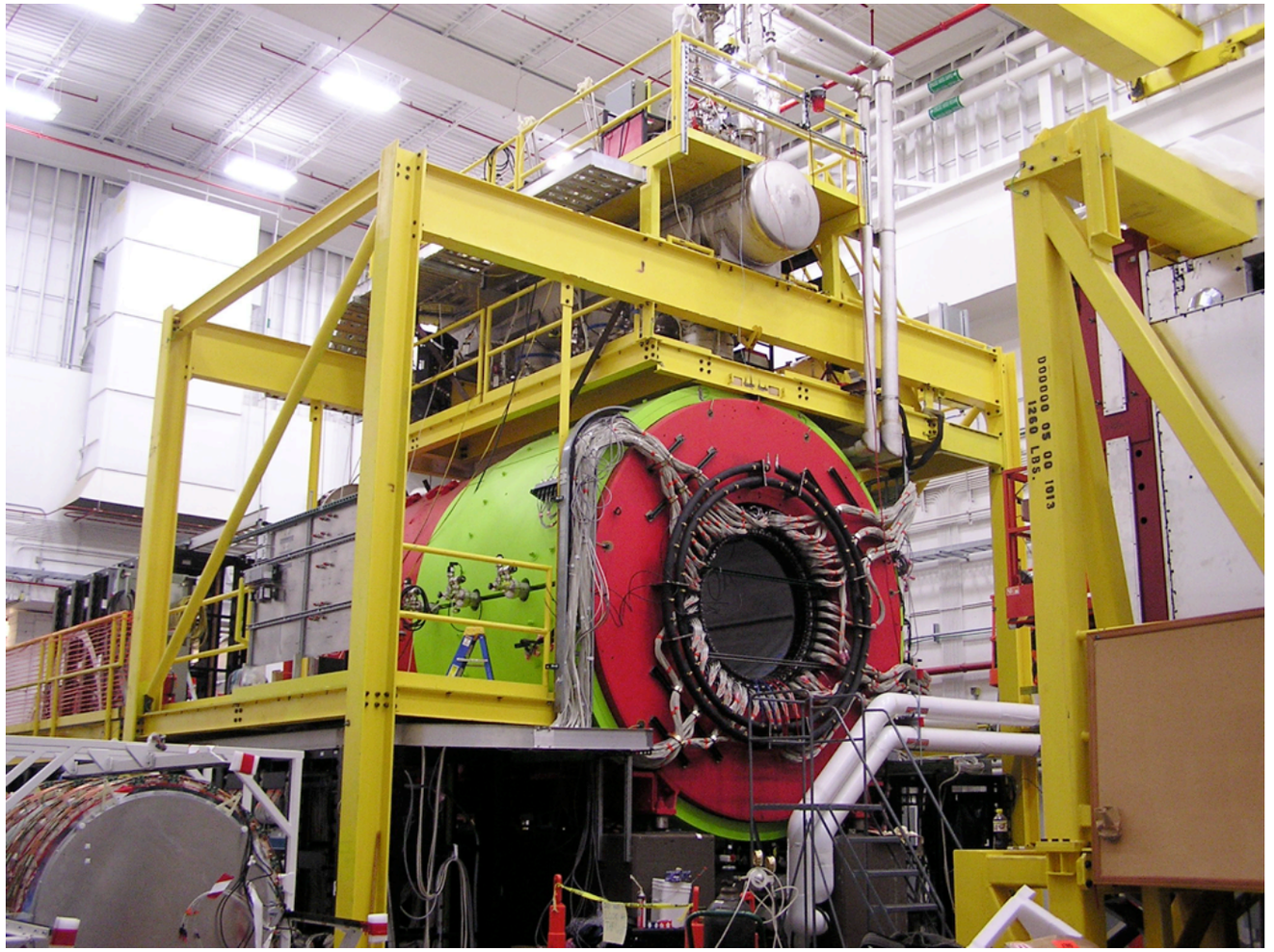
$\gamma p \to (n)\pi^+\pi^-\pi^+$: Partial Wave Analysis



- Exclusive (n)$\pi^+\pi^-\pi^+$ is ~2% of the total hadronic cross section
- Simulate production of known resonances and **exotic hybrid (1^{-+}) signal** with 1.6% relative strength
- Yields correspond to **~3.5 hours** of GlueX data taking
- Benchmark test of GlueX sensitivity to small amplitudes using detector full simulation and reconstruction



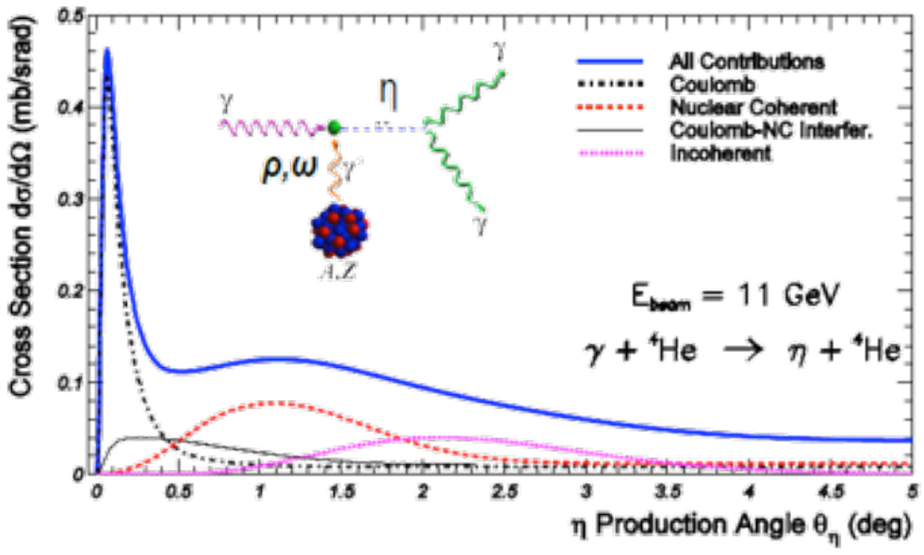
GlueX timeline

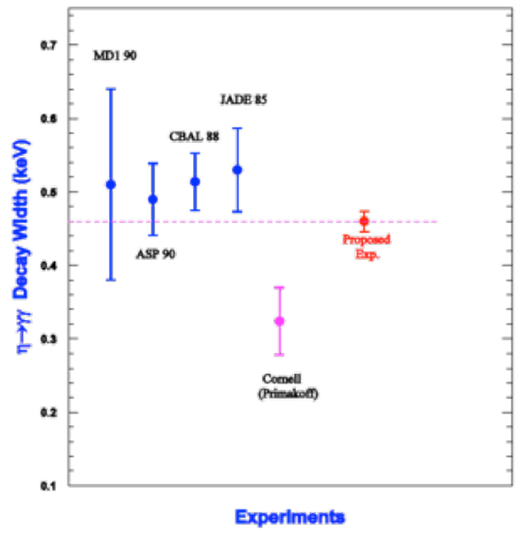


- Spring/Summer 2014: complete installation
- Fall 2014: expect first commissioning beam in Hall D!
- 2015-2016: initial “low intensity” physics running
- 2017: begin high intensity running and possible PID upgrades

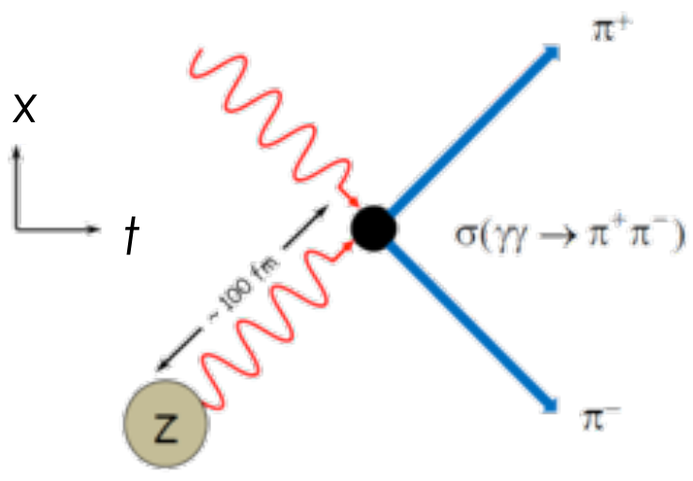
Approved experiments in Hall D

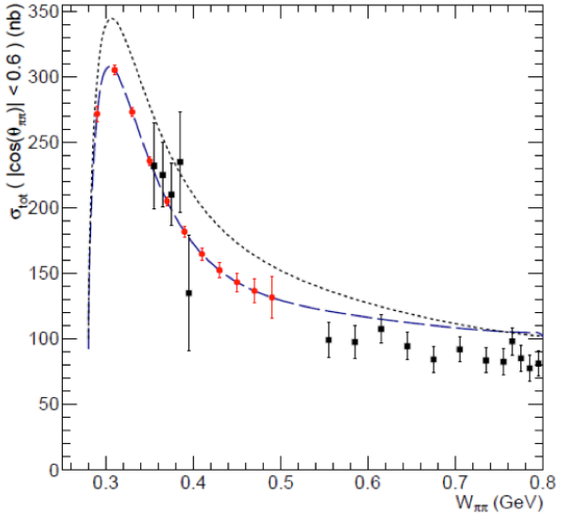
- GlueX: meson and baryon spectroscopy
- PrimeX: precision η→γγ decay width





- Charged Pion Polarizability





Summary

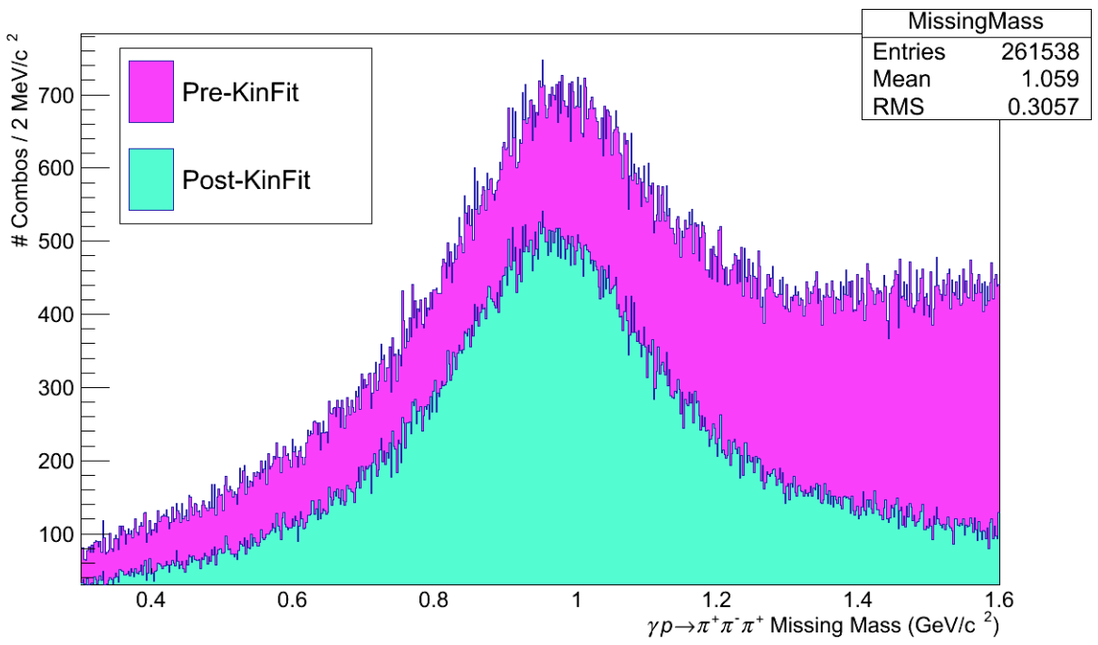
- The GlueX experiment in Hall D at JLab is designed to search for and study hybrid mesons for which a rich spectrum is predicted by Lattice QCD
- Detector construction and installation is nearing completion: first beam to Hall D this fall!
- Expect first physics data in 2015 and full intensity running in 2017
- Additional Hall D approved experiments provide important low energy tests of QCD

Backup

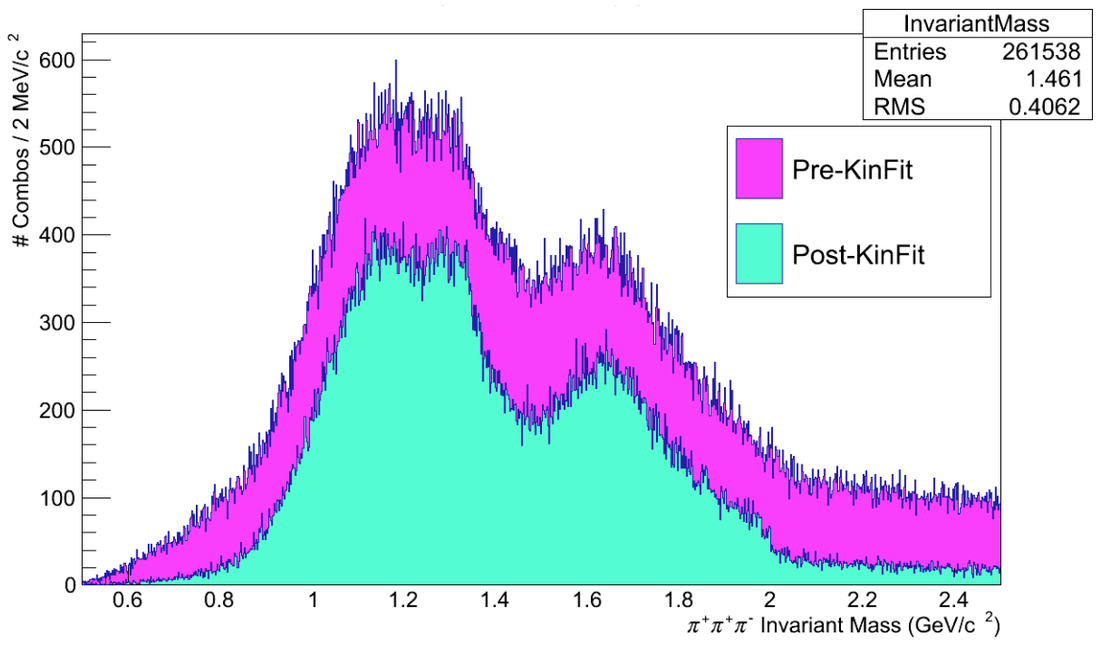
Kinematic Fitting: $\gamma p \to (n)\pi^+\pi^-\pi^+$

- Kinematics over-constrained by measured incident photon energy
- Constraints from four momentum conservation, invariant masses, and primary/secondary vertices
- For example, in this case have 10 conserved quantities and 6 unknowns (missing neutron $\vec{p}$ and vertex position)

Missing Mass



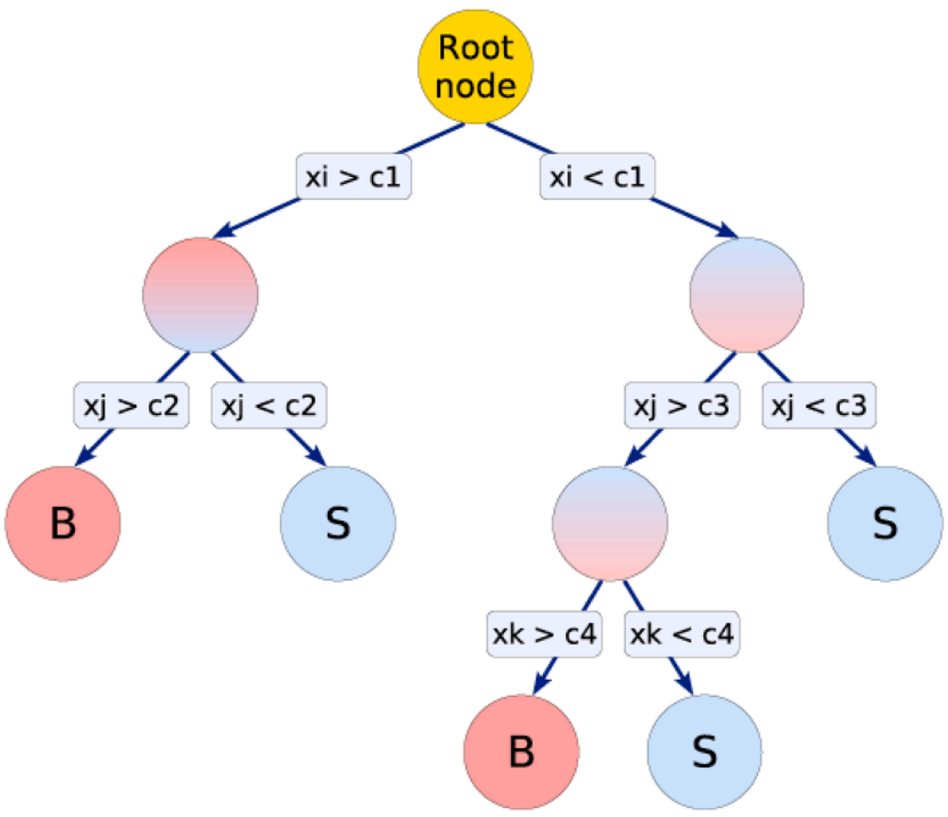
$\pi^+\pi^-\pi^+$ Mass



Measured quantities pre- and post-Kinematic Fit

Multivariate Analysis

- Common in HEP analyses to search for rare signals in high background environments
- Include all variables possibly relevant to separating signal and background in a way that incorporates correlations between variables to obtain a single classifier variable
- So far used mainly Boosted Decision Tree (BDT), but others available
- Conveniently packaged in ROOT via (*TMVA*): http://tmva.sourceforge.net



- To train a classifier we need a sample of known signal (AmpTools) and background (bggen) events
- Build a single Decision Tree (DT) by splitting the data multiple times to produce highly pure signal or background “leaves”, and classify them based on signal fraction above some threshold
- Single DTs are sensitive to fluctuations in the training data, but we can “boost” them by increasing the weights of incorrectly classified events in the previous DT
- Build many DTs with these modified weights, and combine them to form a single BDT classifier

BDT: Event Selection Procedure

- Includes many variables, such as charged track particle ID (TOF and dE/dx), kinematic fit confidence level, and excess calorimeter energies
- Combine into a single “classifier” response to select events for an amplitude analysis