The GlueX experiment and the search for exotic mesons

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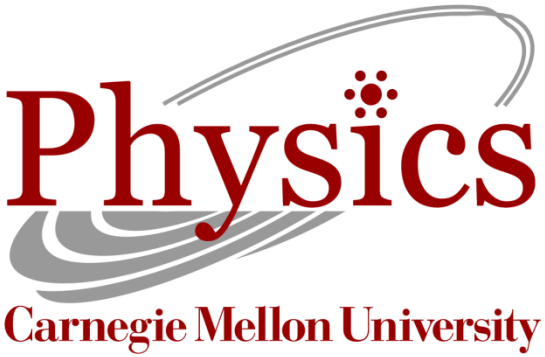
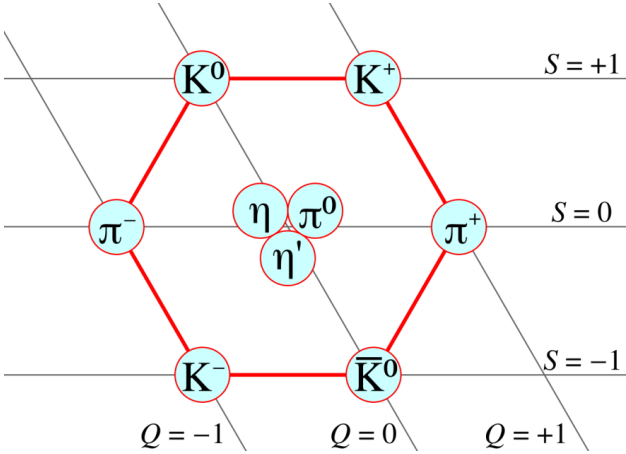


Outline

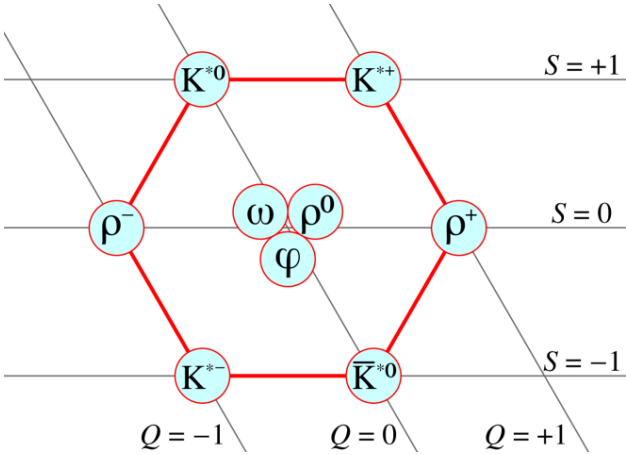
- Meson spectroscopy
  - Conventional and exotic meson quantum numbers
  - Hybrid mesons
  - Amplitude analysis
  - Experimental observation of exotic mesons
- GlueX experiment
  - Detector
  - Current status

Conventional $q\bar{q}$ mesons

- Mesons classified by quantum numbers J^{PC}
- SU(3): For each J^{PC}, nonet of mesons
- J^{PC} of $q\bar{q}$ mesons
  - Total spin of $q\bar{q}$ pair: S=0,1
  - Orbital angular momentum: L=0,1,2,…
  - Total angular momentum: J=|L-S|,…,L+S
  - Parity: $P = (-1)^{L+1}$
  - Charge conjugation: $C = (-1)^{L+S}$
  - Allowed J^{PC}: 0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 1^{++}, 2^{++}, …



0^{-+}: S=0; L=0

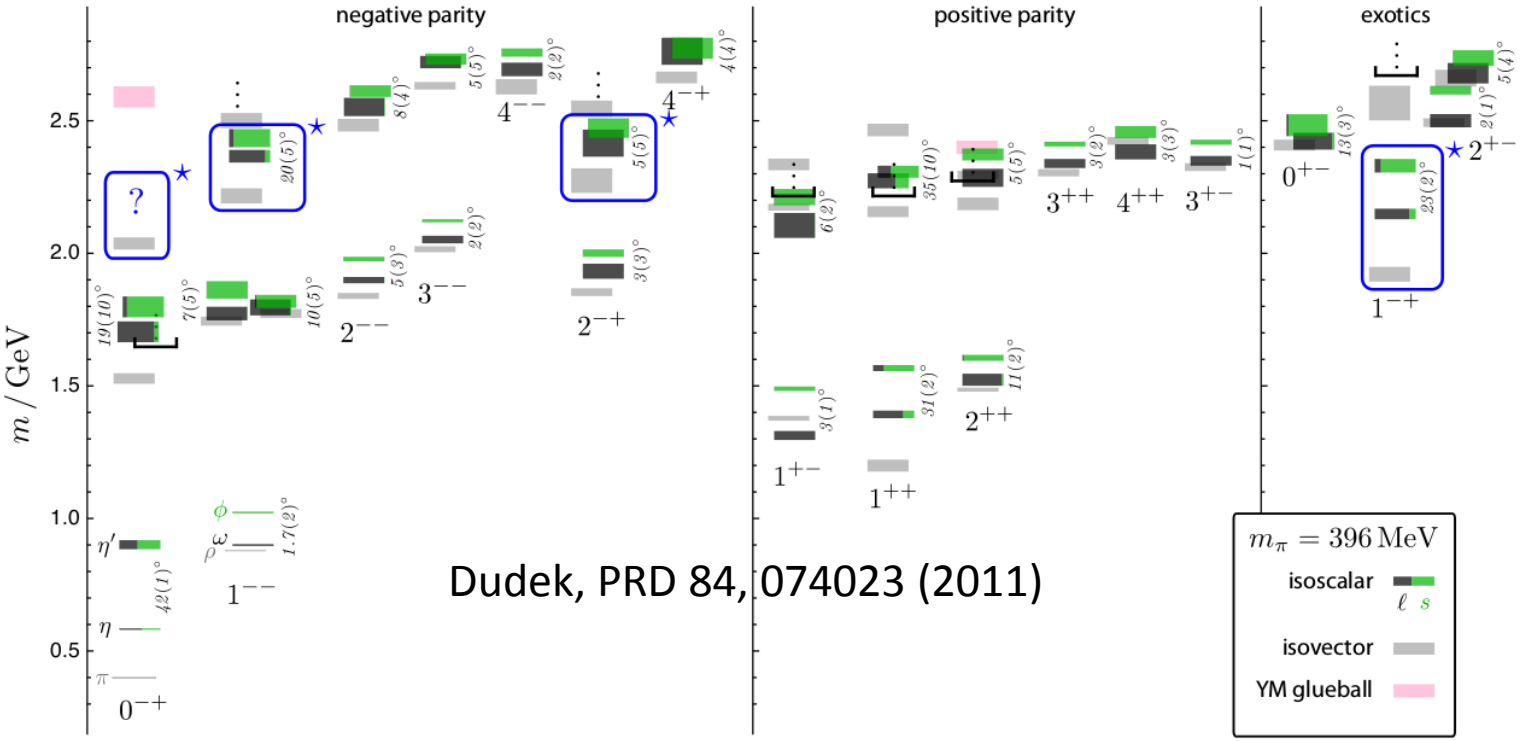


1^{--}: S=1; L=0

Exotic quantum number mesons

- What if gluonic field is excited inside mesons?
  - "Hybrid" meson
  - Hybrids could have exotic quantum numbers (0^{+-}, 0^{--}, 1^{-+}, 2^{+-}, …) not allowed in simple $q\bar{q}$ meson
  - Expect hybrids in nonets
- Lattice QCD predicts mass, J^{PC} of hybrids
- Models predict decay modes of hybrids
- Limited experimental evidence

Lattice QCD



Dudek, PRD 84, 074023 (2011)

- Non-perturbative QCD on lattice
- Identify hybrid-like states by overlap with $q\bar{q}g$-like operators
- Lowest mass hybrid states: 0^{-+}, 1^{--}, 2^{-+}, 1^{-+}
- Higher mass exotics: 0^{+-}, 2^{+-}
- Note m_π = 396 MeV (mass predictions may not be precise)

Hybrid meson decay modes

	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	$K_1(1400)K^\dagger$, $K_1(1270)K^\dagger$, $K_2^*K^\dagger$	$KK\pi\pi^\dagger$, $KK\pi^\dagger$

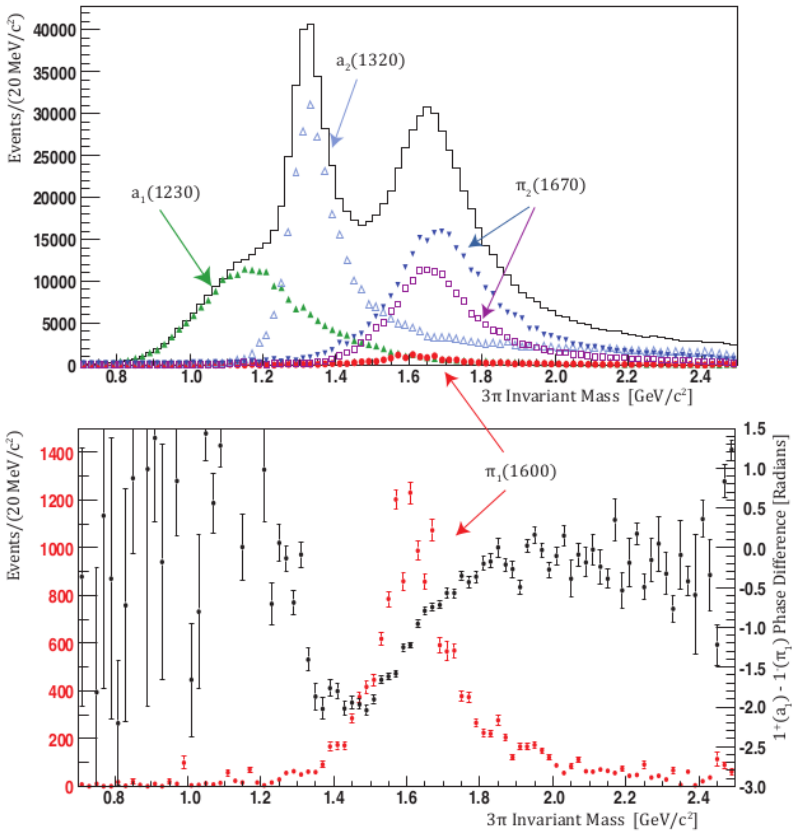
- High multiplicity final states (up to 5π)
- Neutral and charged decay products
- Isoscalar states decay to K's

Amplitude Analysis

- Amplitude analysis (aka partial-wave analysis) uses angular distribution of final-state particles to determine J^{PC}'s of interfering parent resonances
- Phase motion indicates resonance in partial wave

GlueX simulated data:

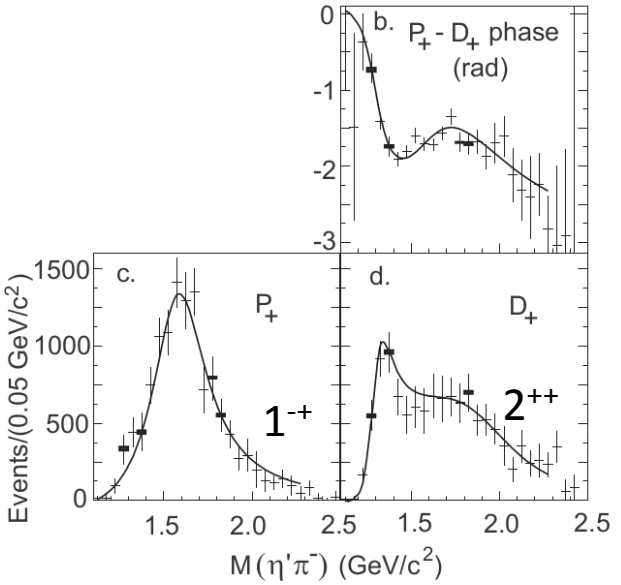
$\gamma p \rightarrow \pi^+\pi^-\pi^+ n$



Experimental evidence for hybrids

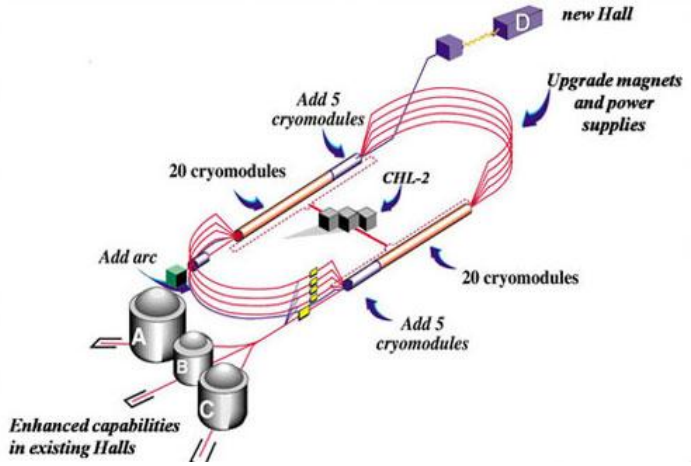
- Previous searches for hybrid mesons
  - Pionproduction (COMPASS, E852, VES)
  - $p\bar{p}$ annihilation (Crystal Barrel)
  - Charmonium decays (CLEO)
  - Photoproduction (CLAS)
- Only π_1 (isovector, 1^{-+}) states claimed
  - $\pi_1(1400)$ – only $\eta\pi$ decay seen, possible non-resonant interpretation
  - $\pi_1(1600)$ – $b_1\pi$, $\eta'\pi$, $f_1\pi$ decays seen by multiple experiments, $\rho\pi$ decay mode disputed
  - $\pi_1(2000)$ – needs further confirmation
  - See review: Meyer and Van Haarlem, PRC 82, 025208 (2010)
- No sightings of isospin 0 states or other exotic J^{PC} (0^{+-}, 2^{+-})
- Exotic sector needs further clarification!
  - Limited data in photoproduction—promising for future searches

$\pi^-p \rightarrow \eta'\pi^-p$
E852, PRL 86, 2977 (2001)



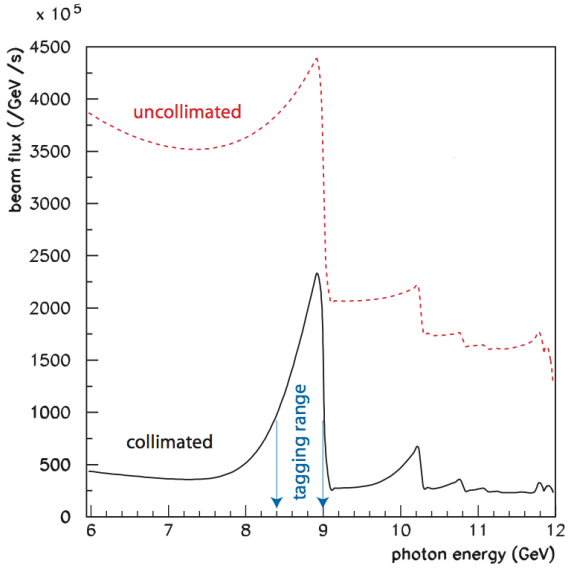
GlueX @ JLab

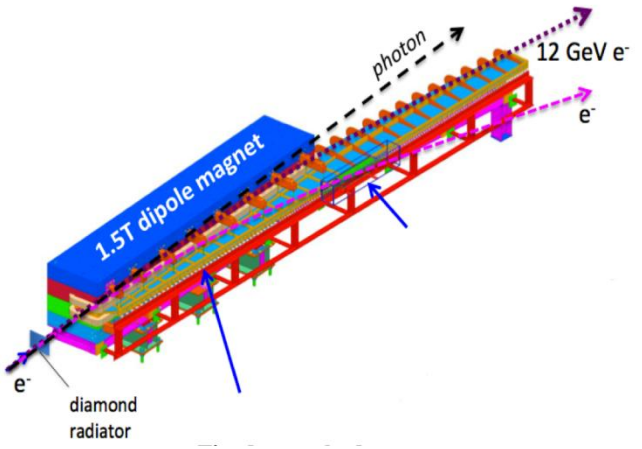
- CEBAF accelerator at Jefferson Lab (Newport News, Virginia)
- 12 GeV electron beam
- GlueX photoproduction experiment located in Hall D at Jlab
- Starts operation in 2015



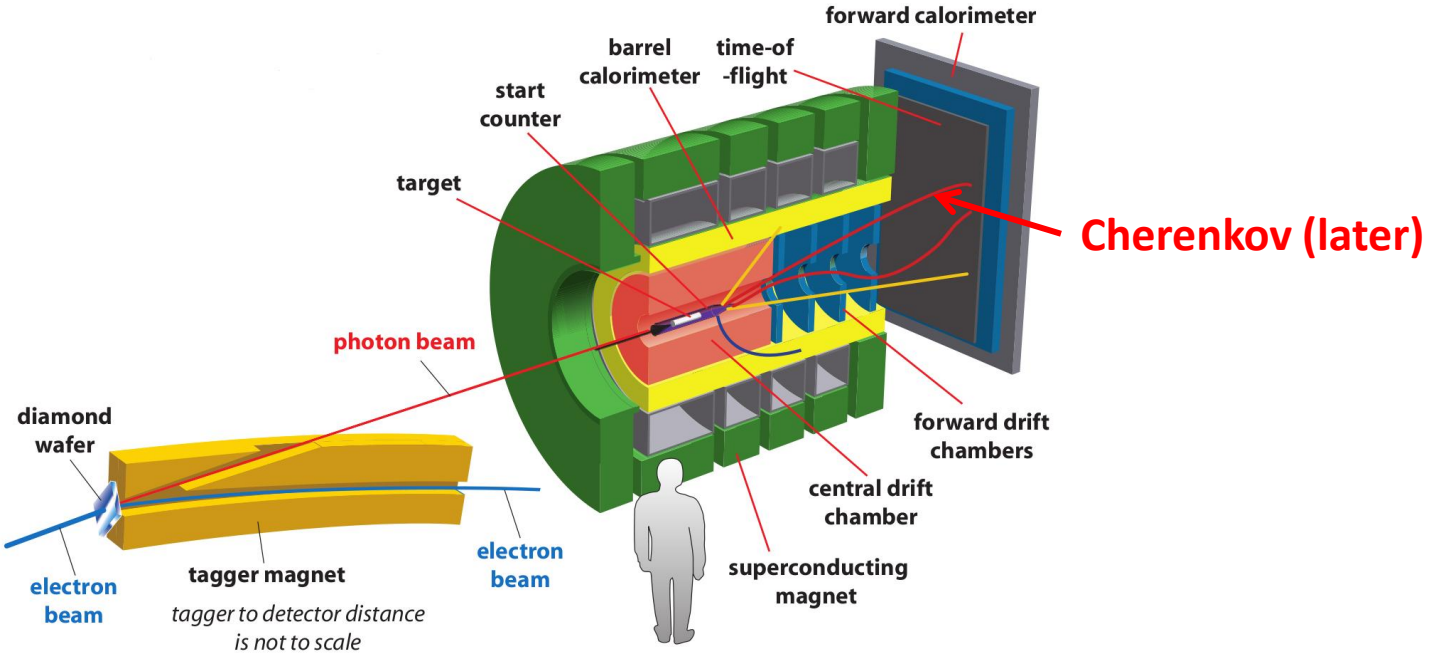
Photon beam

- Photon beam produced by coherent bremsstrahlung of 12 GeV electron beam on 20-μm thin diamond radiator
  - Coherent peak from E_γ= 8.4-9 GeV
  - 40% linear polarization in coherent peak
  - 10^7-10^8 photons/s on target
- Tagger measures energy of beam photons
  - Tagger microscope: E_γ = 8.4-9 GeV, E resolution 0.1%
  - Tagger hodoscope: E_γ = 3-11.6 GeV, E resolution 0.2-0.5%
- Linear polarization
  - Helps in amplitude analysis
  - Distinguish parity of exchange particles



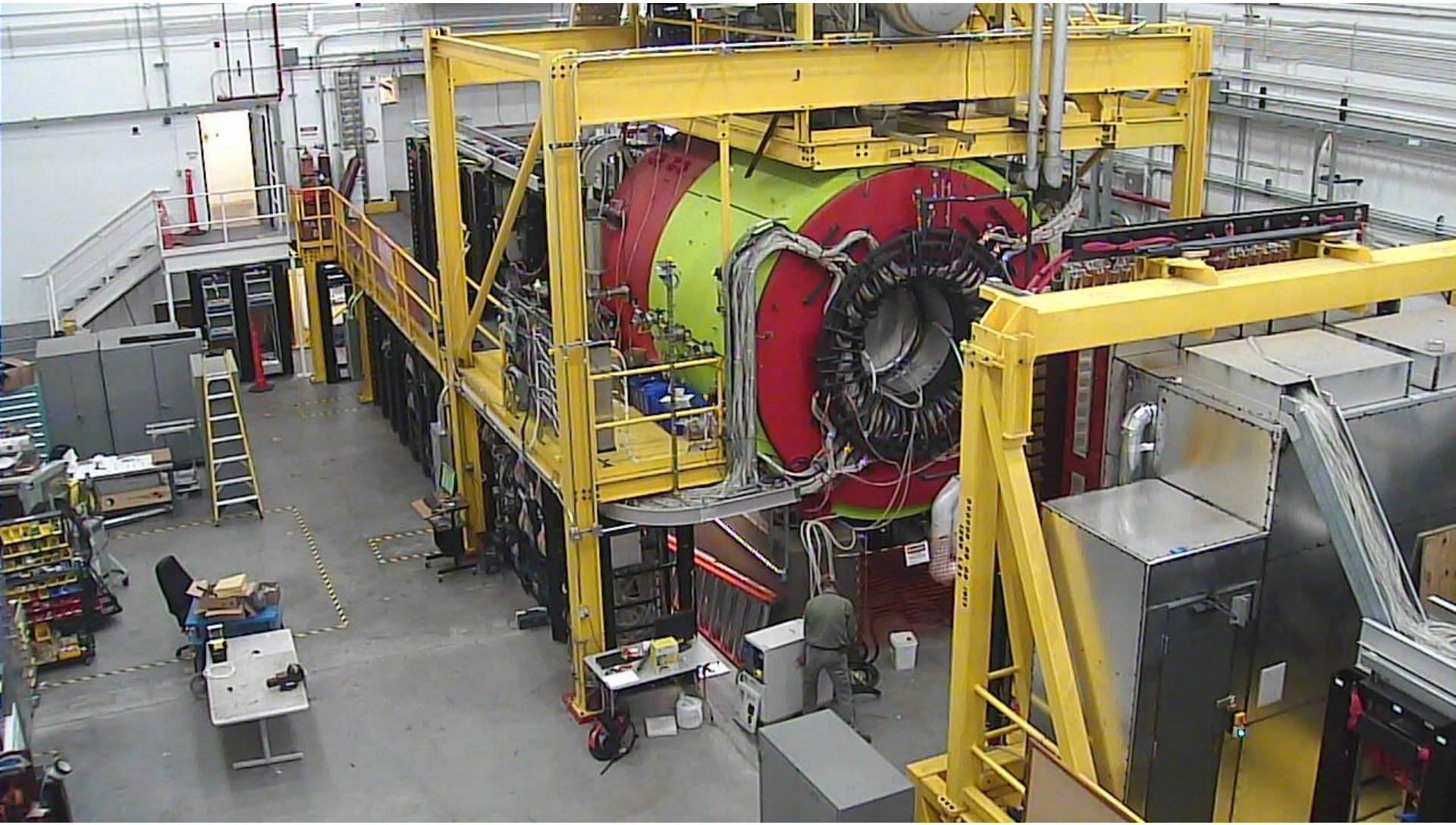


GlueX detector



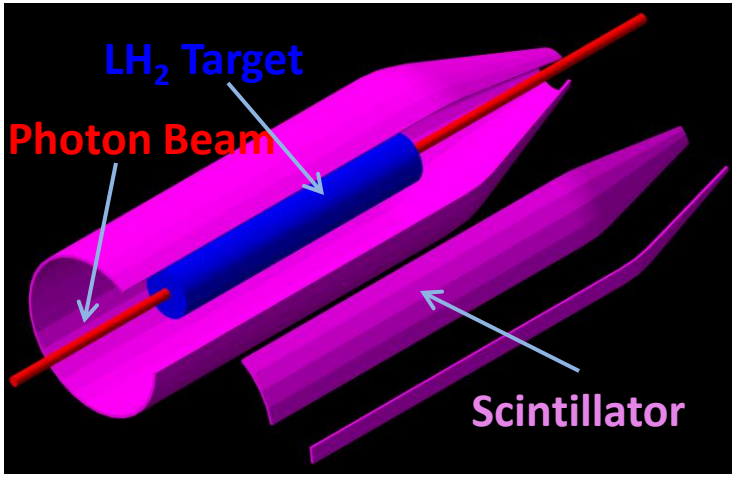
- Need exclusive reconstruction of high-multiplicity final states
  - Large acceptance
  - Tracking and Calorimetry
  - K/π separation

GlueX in Hall D



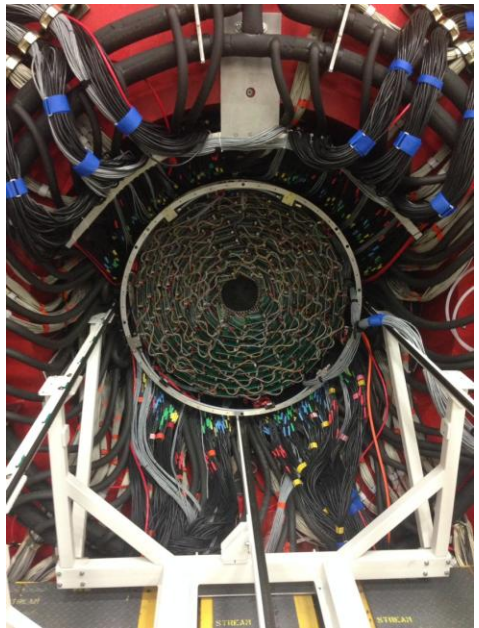
GlueX detector

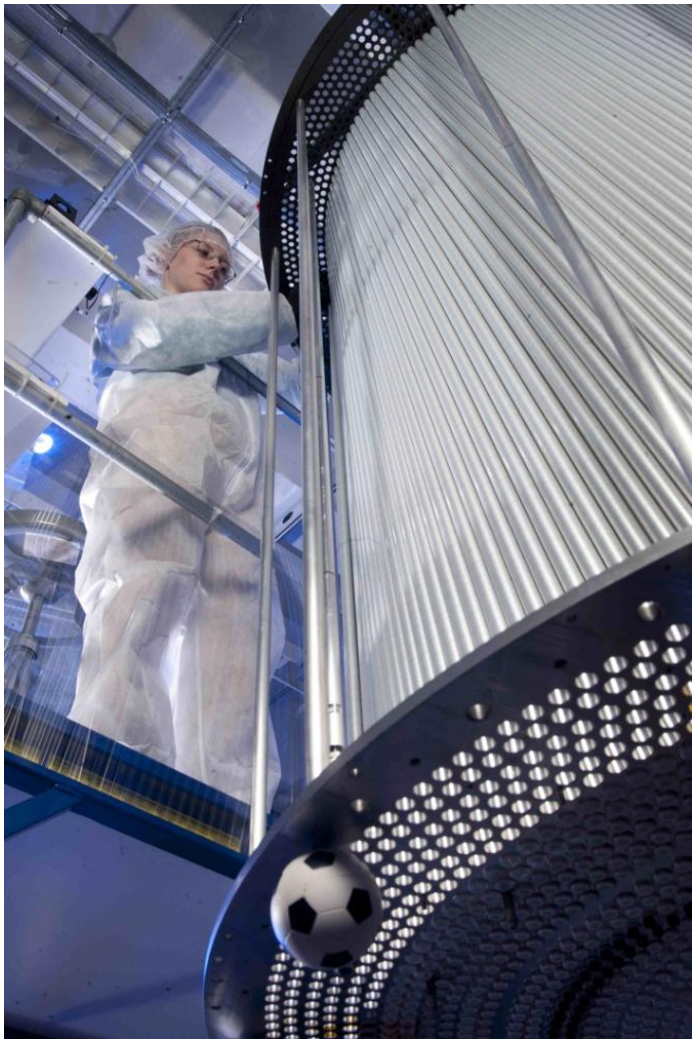
- Solenoid
  - 1350A, 2T
  - Previously at LASS, MEGA, refurbished for GlueX
- Liquid H_2 target
- Start counter
  - 30 thin scintillators surrounding target
  - ~350 ps resolution



Central Drift Chamber

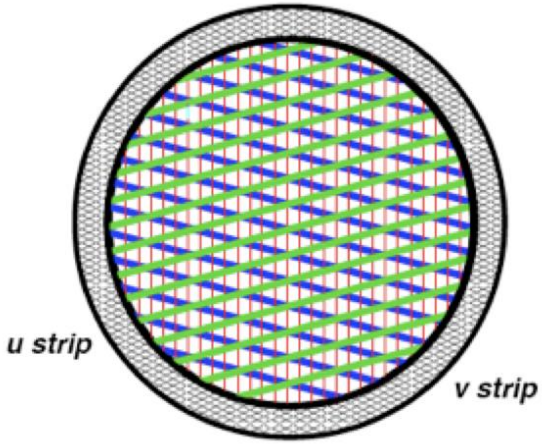
- 28 straw tube layers
  - 12 axial, 16 stereo (±6°)
  - 3522 straws
- $\sigma_{r/\phi}$ = 150 μm, σ_z = 1.5 mm





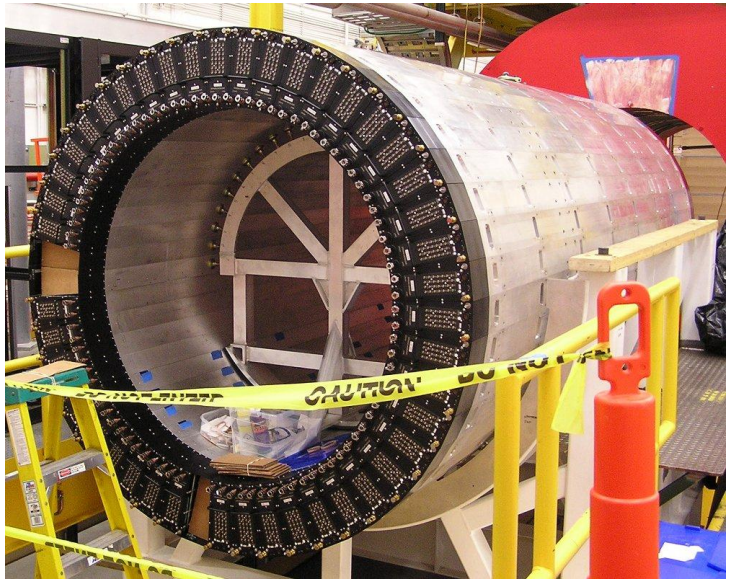
Forward Drift Chamber

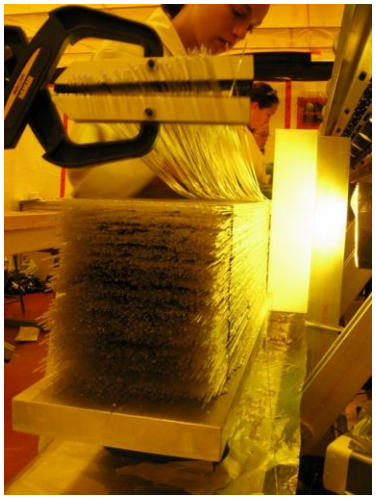
- 4 packages; 6 cells per package
  - Cell = cathode plane – wire plane – cathode plane
  - Each layer at 60° from neighbors
  - Cathode plane at 75° to wires
  - Sense wires alternate with field wires
  - 96 sense wires/plane: 2304 sense wires
  - 216 cathodes strips/plane: 10368 cathode strips
  - Both wires and cathodes read out
- $\sigma_{x/y}$ = 200 μm

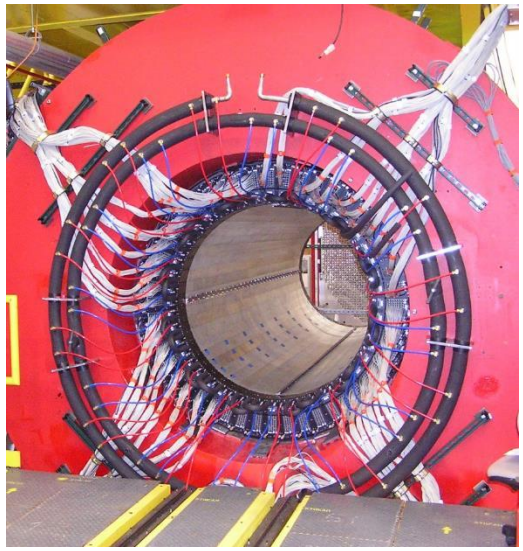


Barrel Calorimeter

- Lead/scintillating fiber matrix
- $\sigma_E/E = 5\%/\sqrt{E} \oplus 1\%$
- Double-ended readout by silicon photomultipliers

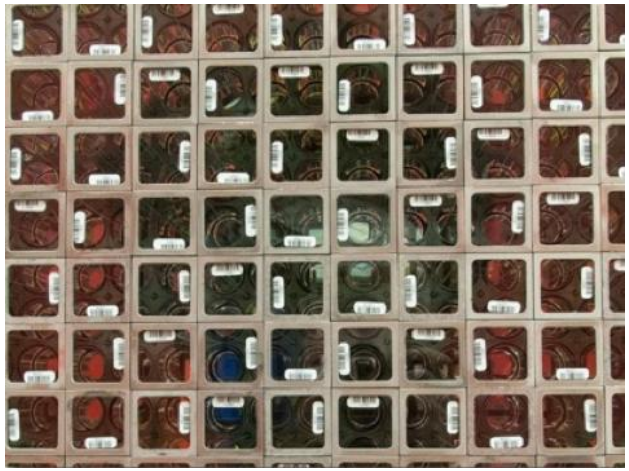


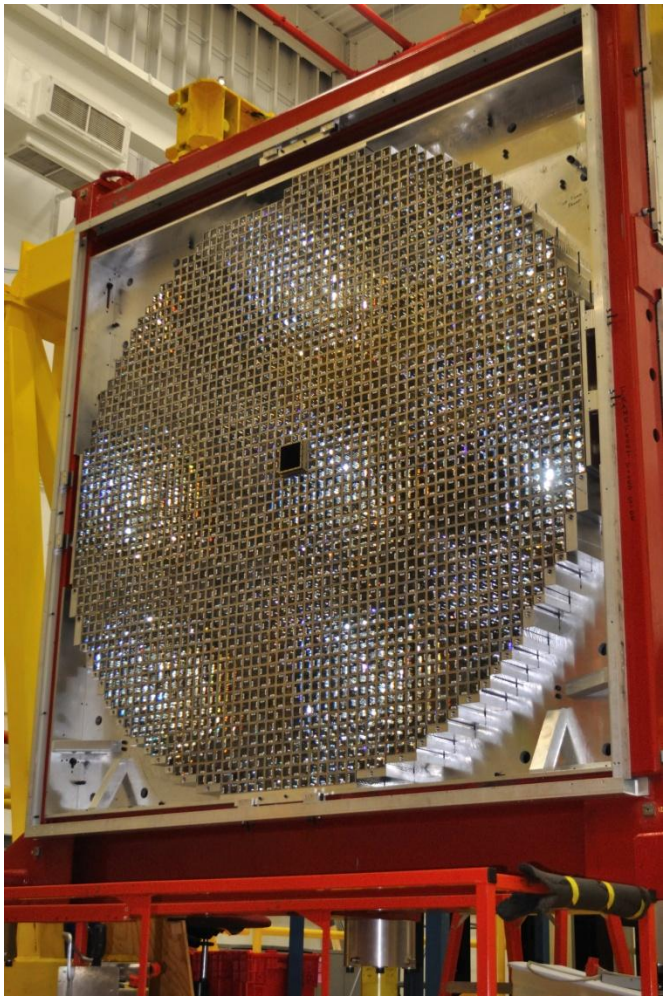




Forward Calorimeter

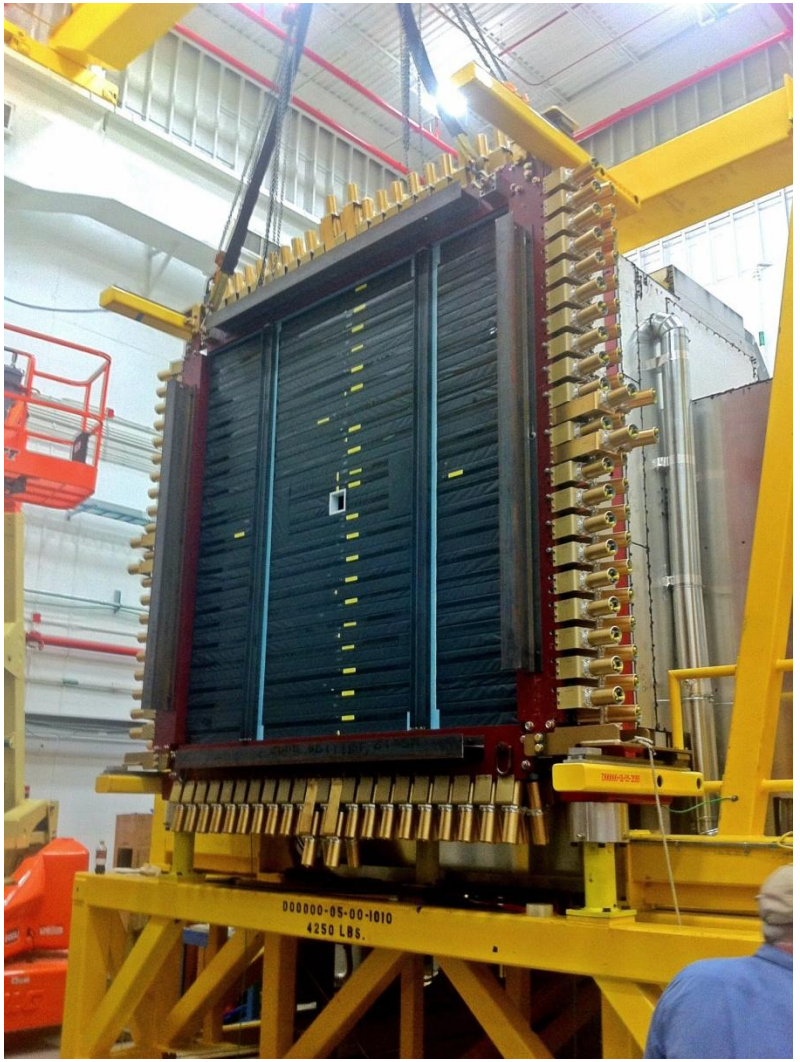
- 2800 lead glass blocks
- $\sigma_E/E = 6\%/\sqrt{E} \oplus 2\%$





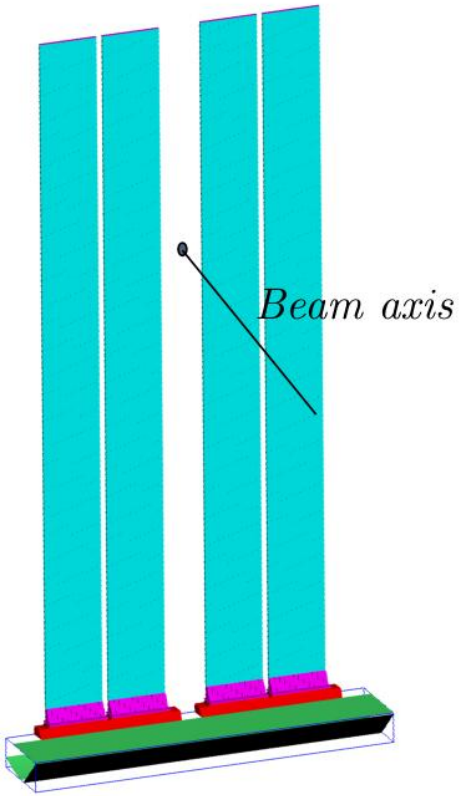
Time of flight

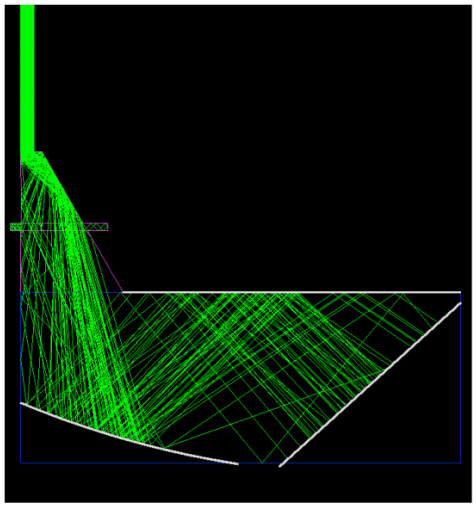
- Horizontal scintillator array + vertical scintillator array
- 70 ps resolution
- 3σ K/π separation up to p=2.5 GeV

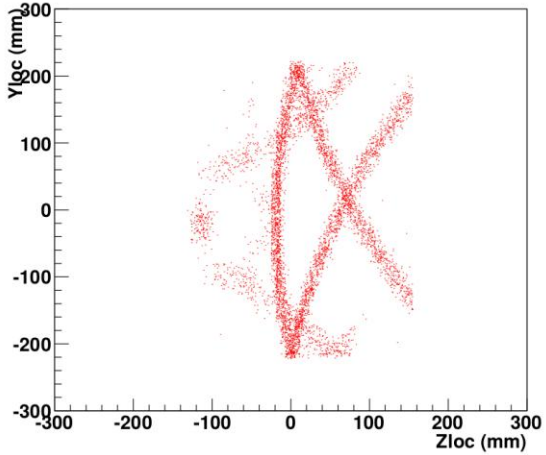


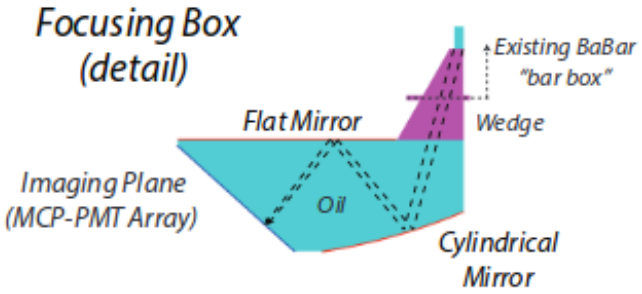
FDIRC

- Focusing Detection of Internally Reflected Cherenkov light
  - Reuse of BaBar DIRC components recently approved
  - 3σ K/π separation up to p=4 GeV
- Enhance ability to study exotic and non-exotic $s\bar{s}$ mesons
  - Installation in 2017-2018





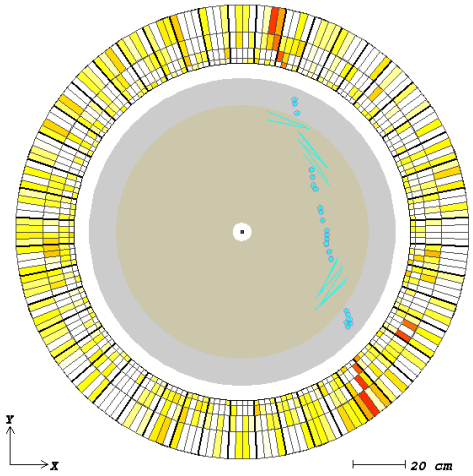




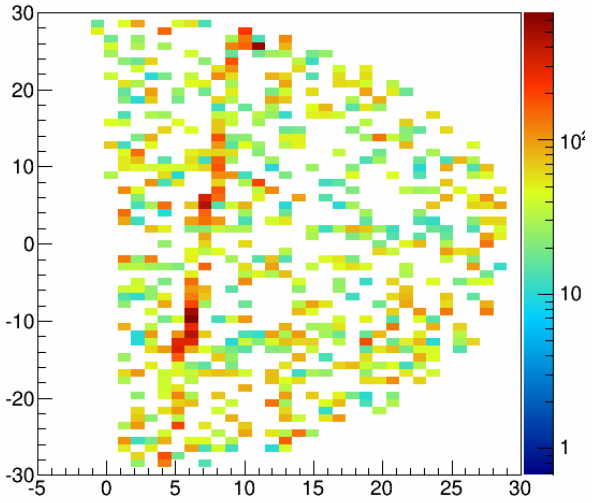
Current status

- Most detector systems installed and operational
- Taking data with cosmics
- Commissioning beam in October
- Physics beam in 2015!

Cosmic in BCAL+CDC



Cosmic in FCAL



Summary

- GlueX to study hybrid/exotic meson spectrum
- Other physics in Hall D
  - Non-exotic meson and baryon (Ξ*) spectroscopy
  - Measure charged pion polarizability
  - Precision $\eta \rightarrow \gamma\gamma$ width
  - Rare η decay studies
- First physics data in 2015
- High-intensity running and new Cherenkov detector starting in 2017