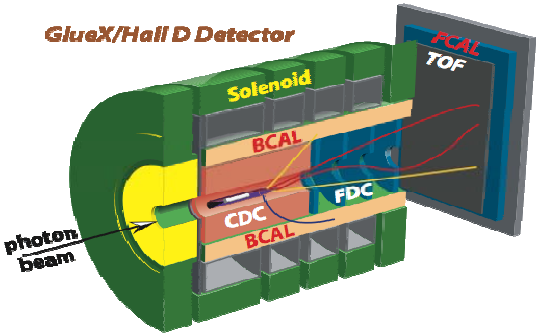


Jefferson Lab

Physics Prospects with GlueX

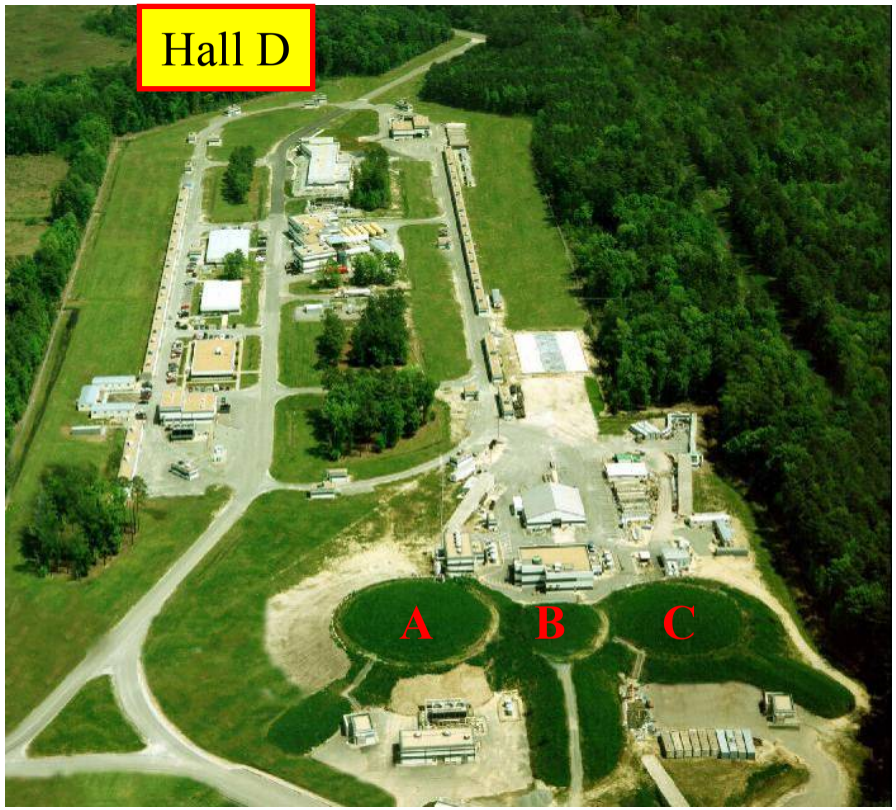
A.Somov Jefferson Lab

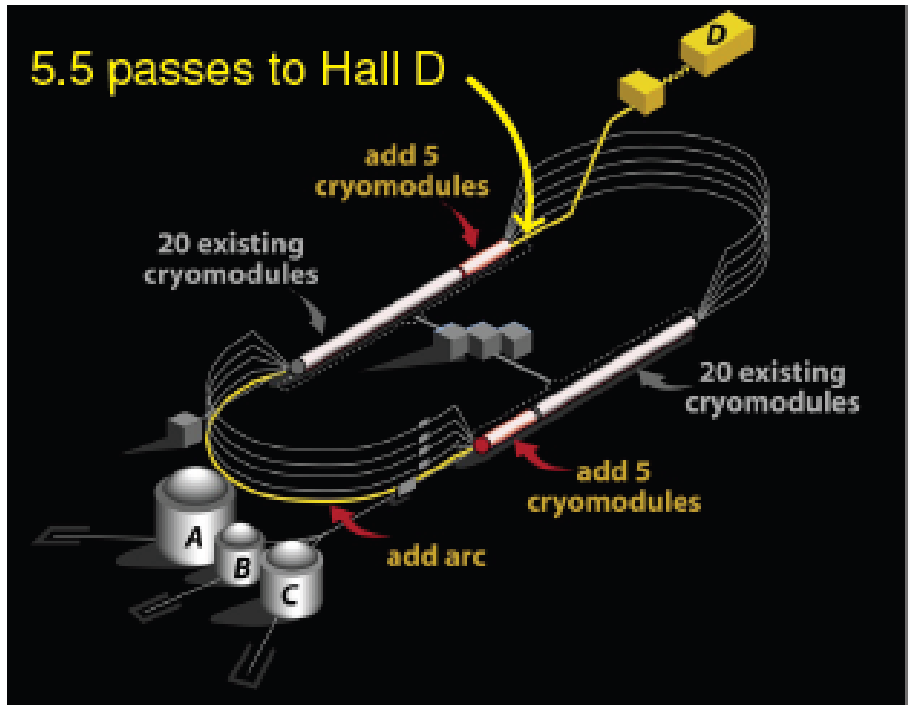
Meson-Nucleon Physics and the Structure of the Nucleon (MENU 2010)

College of William and Mary, Williamsburg, Virginia

May 31, 2010

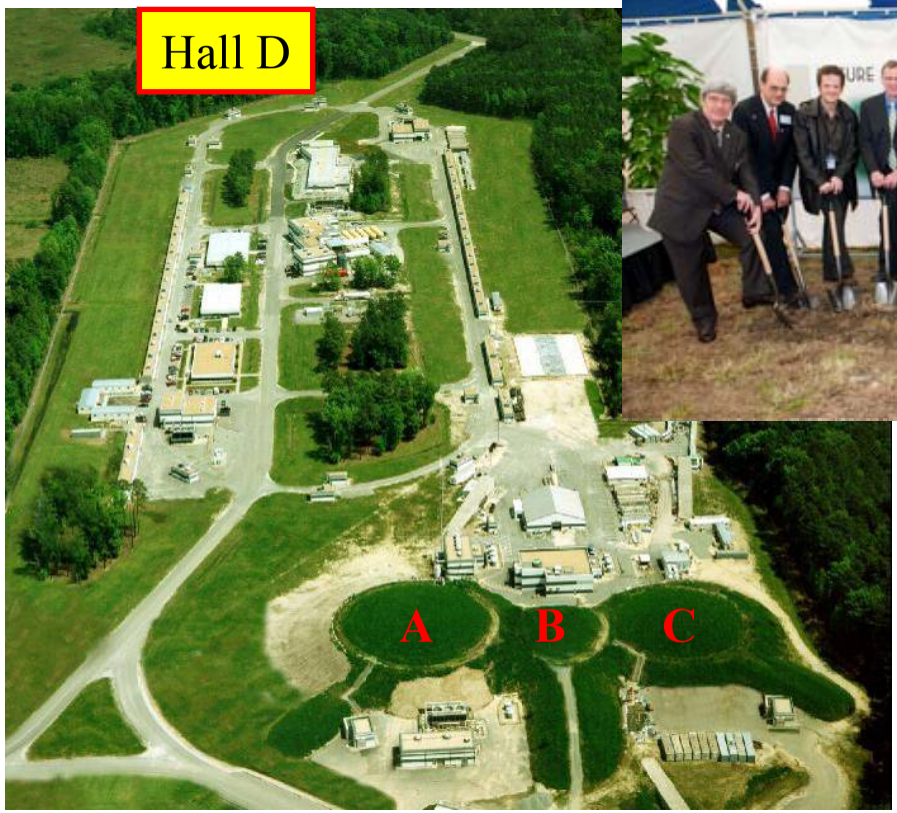
12 GeV CEBAF Energy Upgrade





- Upgrade CEBAF energy from 6 GeV to 12 GeV.
- New experimental Hall D
  - photon beam (linear polarization at 9 GeV)
- New experiment, **GlueX**

12 GeV CEBAF Energy Upgrade



Hall D ground breaking
April 2009

April 2010

- Upgrade CEBAF energy from 6 GeV to 12 GeV.
- New experimental Hall D
  - photon beam (linear polarization at 9 GeV)
- New experiment, **GlueX**

GlueX Physics Program

- GlueX main physics goal is to **search for gluonic excitations in the spectra of light mesons**
  - Detector design is optimized for detecting multi-particle final states and performing Partial Wave Analysis
- Detector is well suited to study many other physics topics using high-intensity photon beam:

  ✓ A precision measurement of the $\eta \rightarrow \gamma\gamma$ decay width via the Primakoff effect (experiment is approved by Jefferson Lab Program Advisory Committee in 2010)

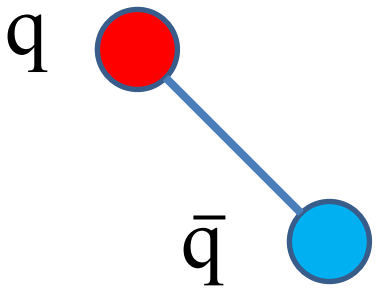
  - Charm production near threshold
  - Photoproduction with nuclear targets
  - Inverse DVCS
  - Exclusive reactions at high-momentum transfer

  . . .

(see Workshop on Photon-Hadron Physics, JLab 2008. A new Workshop is planned for 2011)

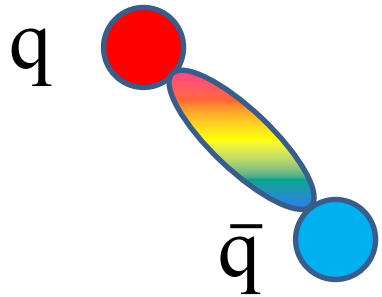
Exotic Mesons

Normal Mesons



flux tube in ground state
m = 0

Hybrid Mesons



flux tube in excited state
m = 1

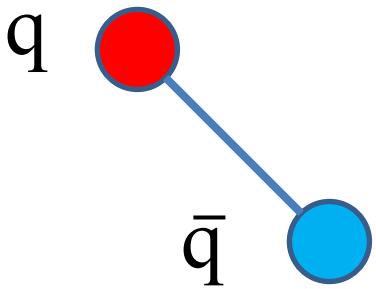
$$\vec{J} = \vec{L} + \vec{S}$$
$$P = (-1)^{L+1}$$
$$C = (-1)^{L+S}$$

Quantum Numbers of the exited flux tube ($J^{PC} = 1^{+-}$ and 1^{-+}) is combined with that of quarks resulting in **conventional** and **exotic** J^{PC}

		0^{-+}		0^{++}
J^{PC}:	1^{--}		1^{+-}	1^{++}
	2^{--}	2^{-+}		2^{++}

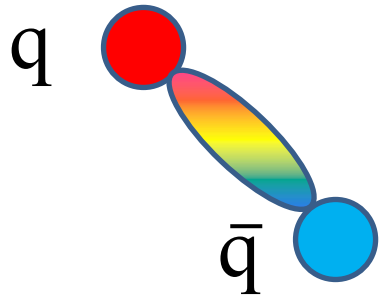
Exotic Mesons

Normal Mesons



flux tube in ground state
m = 0

Hybrid Mesons



flux tube in excited state
m = 1

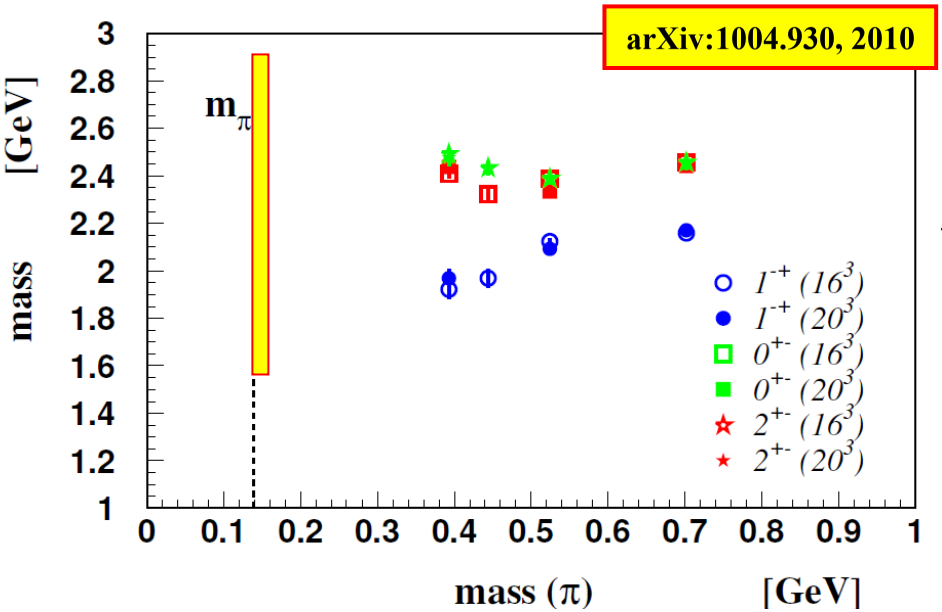
$$\vec{J} = \vec{L} + \vec{S}$$
$$P = (-1)^{L+1}$$
$$C = (-1)^{L+S}$$

Quantum Numbers of the exited flux tube ($J^{PC} = 1^{+-}$ and 1^{-+}) is combined with that of quarks resulting in **conventional** and **exotic** J^{PC}

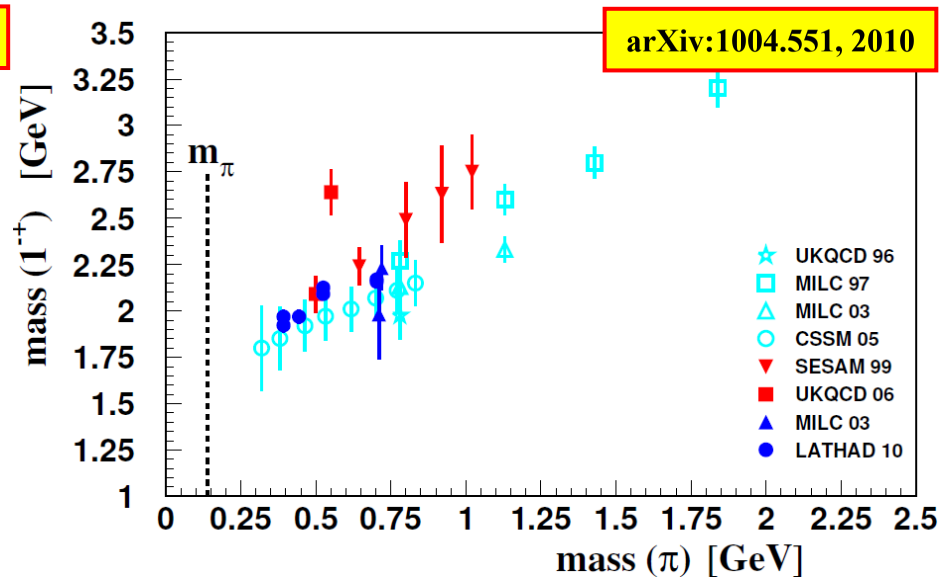
	0^{--}	0^{-+}	0^{+-}	0^{++}
J^{PC}:	1^{--}	1^{-+}	1^{+-}	1^{++}
	2^{--}	2^{-+}	2^{+-}	2^{++}

Mass Predictions of Hybrid Mesons

Mass spectrum of exotic meson predicted by lattice QCD



The mass of $J^{PC} = 1^{-+}$ exotic hybrid predicted by lattice calculations



- Various model calculations for hybrid meson masses
- The lightest hybrid meson nonet predicted by lattice QCD is $J^{PC} = 1^{-+}$ (see Jo Dudek's talk)

Predicted hybrid meson mass region for experimental search: 1.5 GeV – 2.9 GeV

Initial Exotic Hybrid Search Modes

J^{PC}	Exotic Meson	Possible Decays	
0^{+-}	h_0	$b_1\pi^0 \rightarrow (\omega\pi^0)\,\pi^0 \rightarrow \pi^+\pi^-\pi^0\pi^0\pi^0$	many photons
1^{-+}	π_1	$\rho\,\pi \rightarrow \pi\pi\pi$	
		$b_1\pi \rightarrow \pi^+\pi^-\pi^0\pi^0\pi^0$	
		$f_1\,\pi \rightarrow (\eta\pi\pi)\,\pi$	
	η_1	$a_1\pi \rightarrow (\rho^0\pi^+)\,\pi^- \rightarrow \pi^+\pi^-\pi^+\pi^-$	all charged
2^{+-}	b_2	$a_2\pi$	
	h_2	$\rho\pi$	
		$b_1\pi$	

Multiparticle final states:

- (p,n) + $\pi\pi\pi$, $\pi\pi\pi\pi$, $\pi\pi\pi\eta$, $\pi\pi\pi\pi\eta$
- 70% of decays involve at least one π^0
- 50% involve more than one π^0

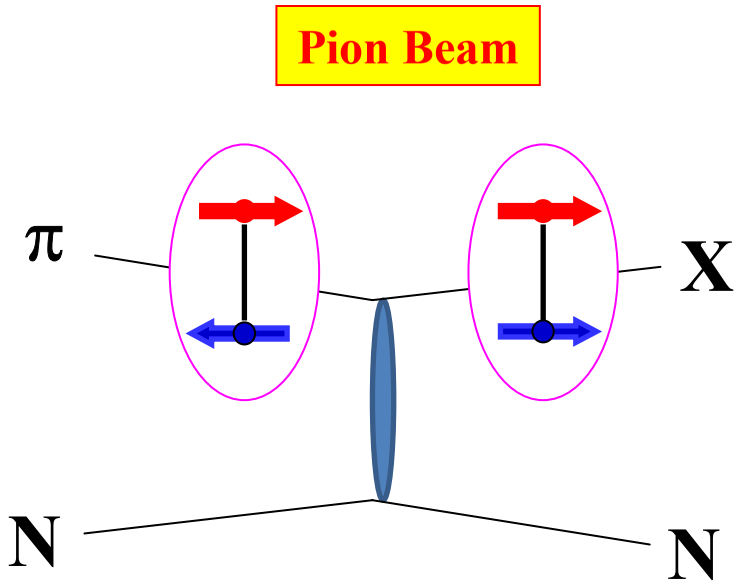
Experimental Status

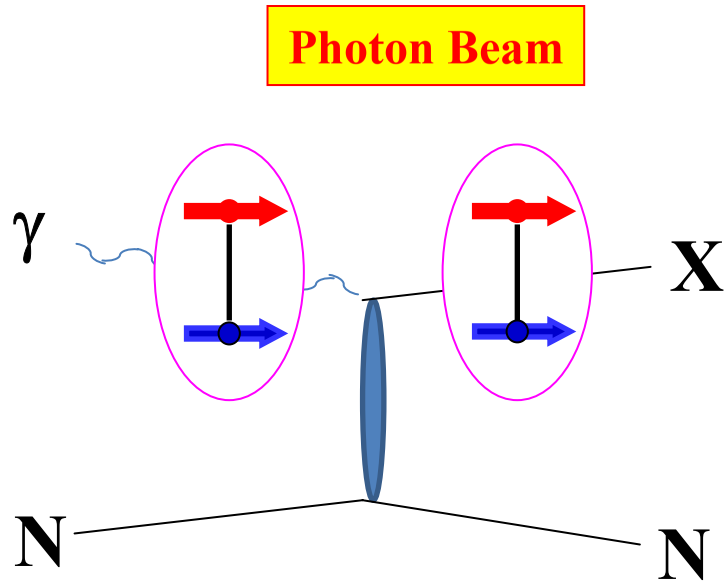
- Exotic mesons have been searched in several experiments: GAMS, VES, CBAR, E852, COMPASS, CLAS
- Exotic Meson Candidates ($J^{PC} = 1^{-+}$)

$\pi_1(1400) \to \eta\pi$	Seen by several experiments. Interpretation unclear: dynamic origin, 4-quark state (?) Not a hybrid.
$\pi_1(1600) \to \eta'\pi$ $\pi_1(1600) \to \rho\pi$ $\pi_1(1600) \to b_1\pi$ $\pi_1(1600) \to f_1\pi$	• First seen by VES, E852, COMPASS • 3π controversial: - signal disappeared in E852 analysis with about10 times larger statistics. Added $J^{PC} = 2^{-+}$ wave in the analysis - still seen by COMPASS (preliminary) - 3π not seen in photoproduction (CLAS) • May be a hybrid
$\pi_1(2000) \to f_1\pi$ $\pi_1(2000) \to b_1\pi$	• Seen by E852 (but not seen by VES) • Statistics is limited • May be a hybrid

More data is needed to study the nature of exotic meson candidates

Meson Photoproduction





Combine exited glue QN with those of quarks

- $L = 0,\ S = 0,\ m = 1$
  $J^{PC} = 1^{--}$ or 1^{++}
- **Spin flip is needed to form exotic quantum numbers**

- $L = 0,\ S = 1,\ m = 1$
  $J^{PC} = 0^{-+}, 0^{+-}, 1^{-+}, 1^{+-}, 2^{-+}, 2^{+-}$
- **No Spin flip needed**

Requirements for Search of Exotic Mesons ?

➢ Photon Beam Requirements:

- **Sufficient beam energy to cover exotic candidate mass energy between 1.5 – 3 GeV**
- **Photon polarization (determine spin/parity of final state)**
- **Luminosity**

➢ Detector Requirements:

- **Hermetic detector**
- **Large/uniform acceptances**
- **Energy and momentum resolution**

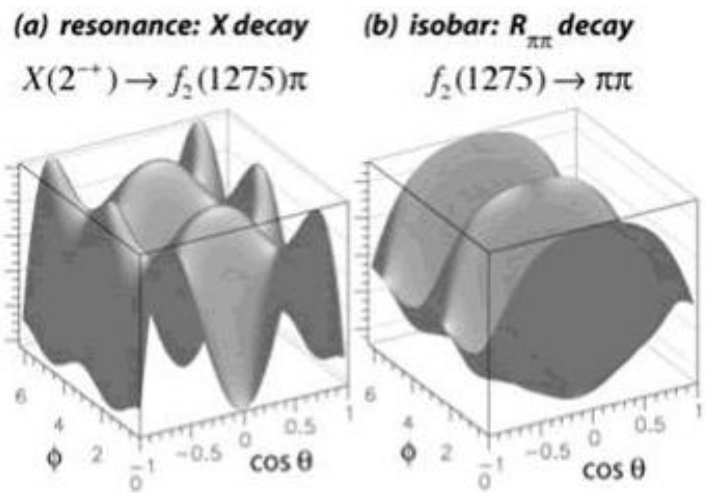
Example of E852 3π analysis

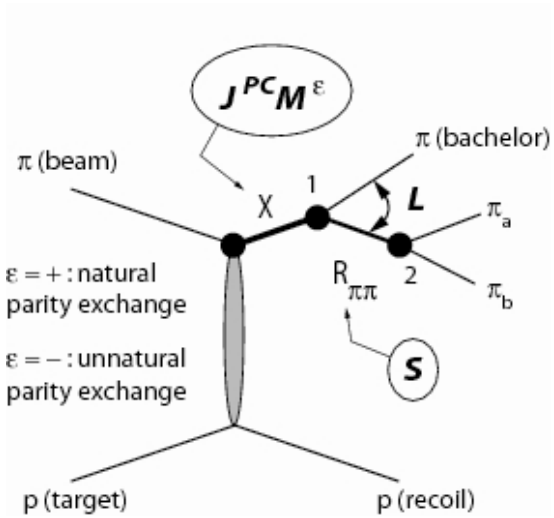
Partial Wave Analysis

➢ Kinematic variables: θ_{GJ} φ_{GJ} θ φ $m_{\pi\pi}$

➢ Bin in 3π mass and fit for the intensity of J^{PC} states

Gottfried-Jackson frame **Helicity frame**





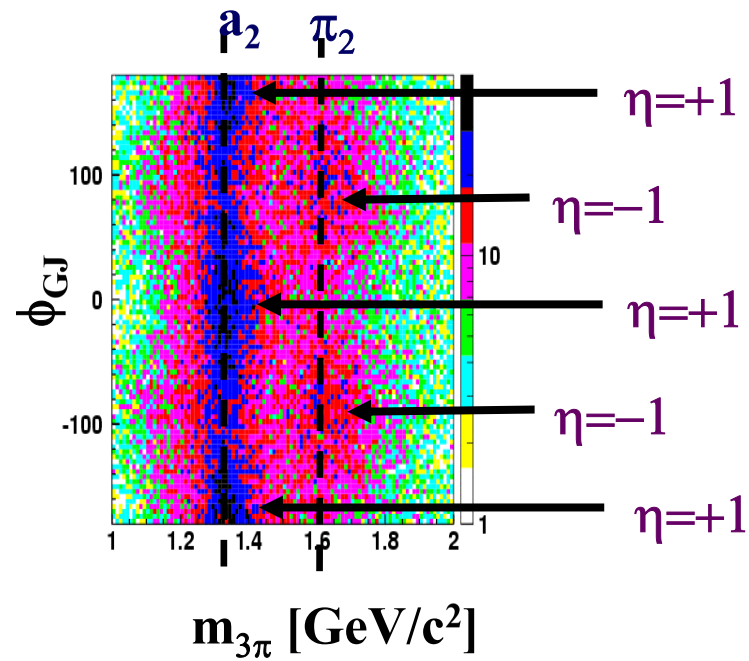
Photon Linear Polarization

- $E_\gamma > 8$ GeV allows to see $M_X \sim 2.8$ GeV
- **Linear polarization of photons provides azimuthal angle dependence of decay products**

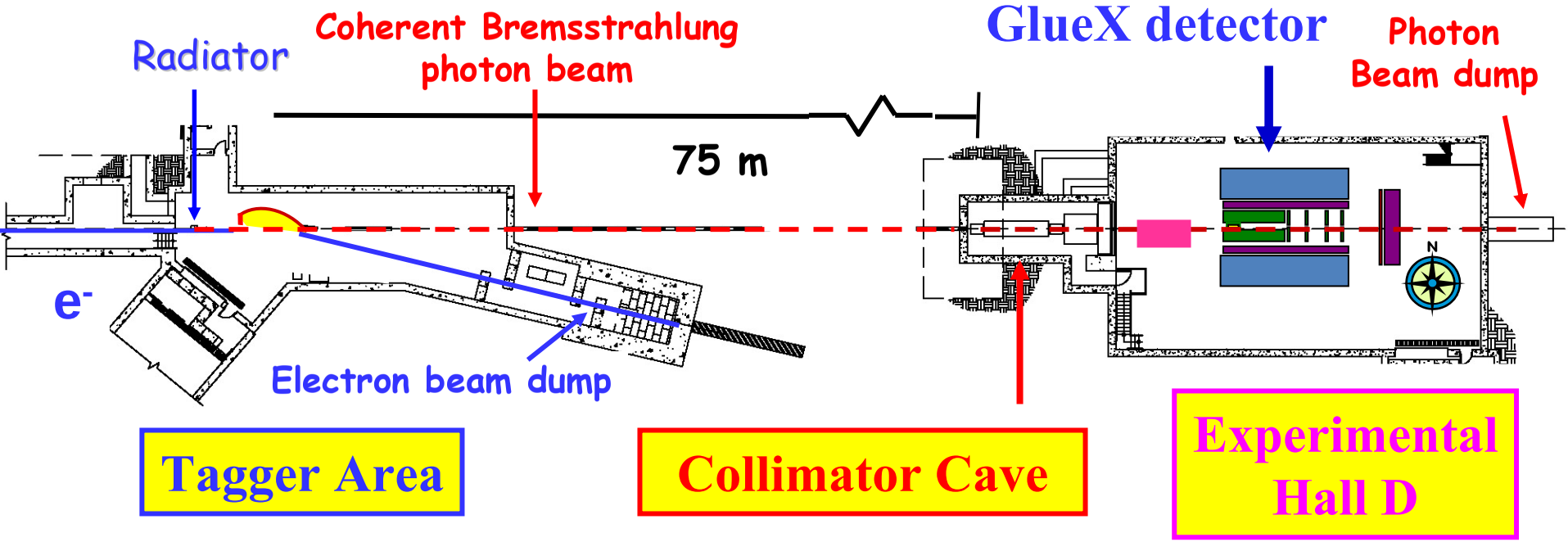
  - allows one to distinguish parity of the exchange particle

- **Linearly polarized photon beam**
  - electrons incident on the diamond radiator
  - coherent bremsstrahlung
  - use collimator to increase the polarization fraction

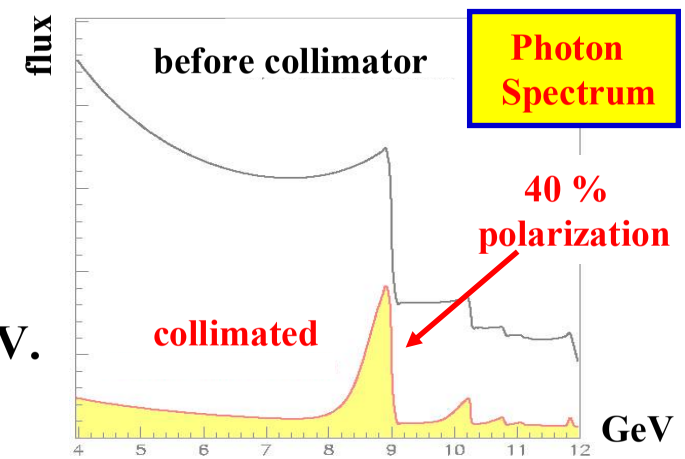
$\gamma\, p \rightarrow n\, \pi^+\pi^-\pi^+$



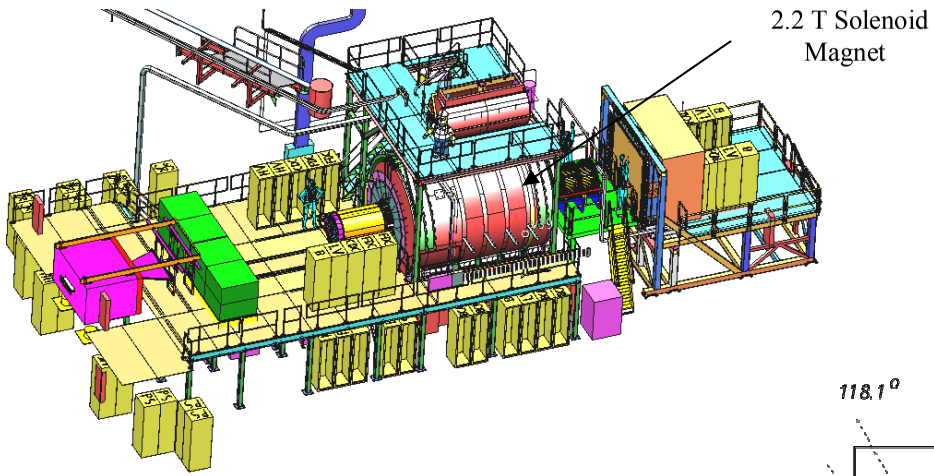
Photon Beam for Hall-D



- Bremsstrahlung beam photons are produced by a 12 GeV electron beam incident on a 20 μm thick diamond crystal (Tagger Area)
- Pass bremsstrahlung photons through the collimator
  - increase the fraction of linearly polarized photons
  - main coherent bremsstrahlung peak is $8.4<E_\gamma<9.0$ GeV. Photon flux 10^8 γ/sec in the peak (Collimator CAVE)



The Challenge: GlueX Detector



Beam photons incident of LiH_2 target
- 10^8 γ/sec in the energy range 8.4 – 9.0 GeV

Tracking:

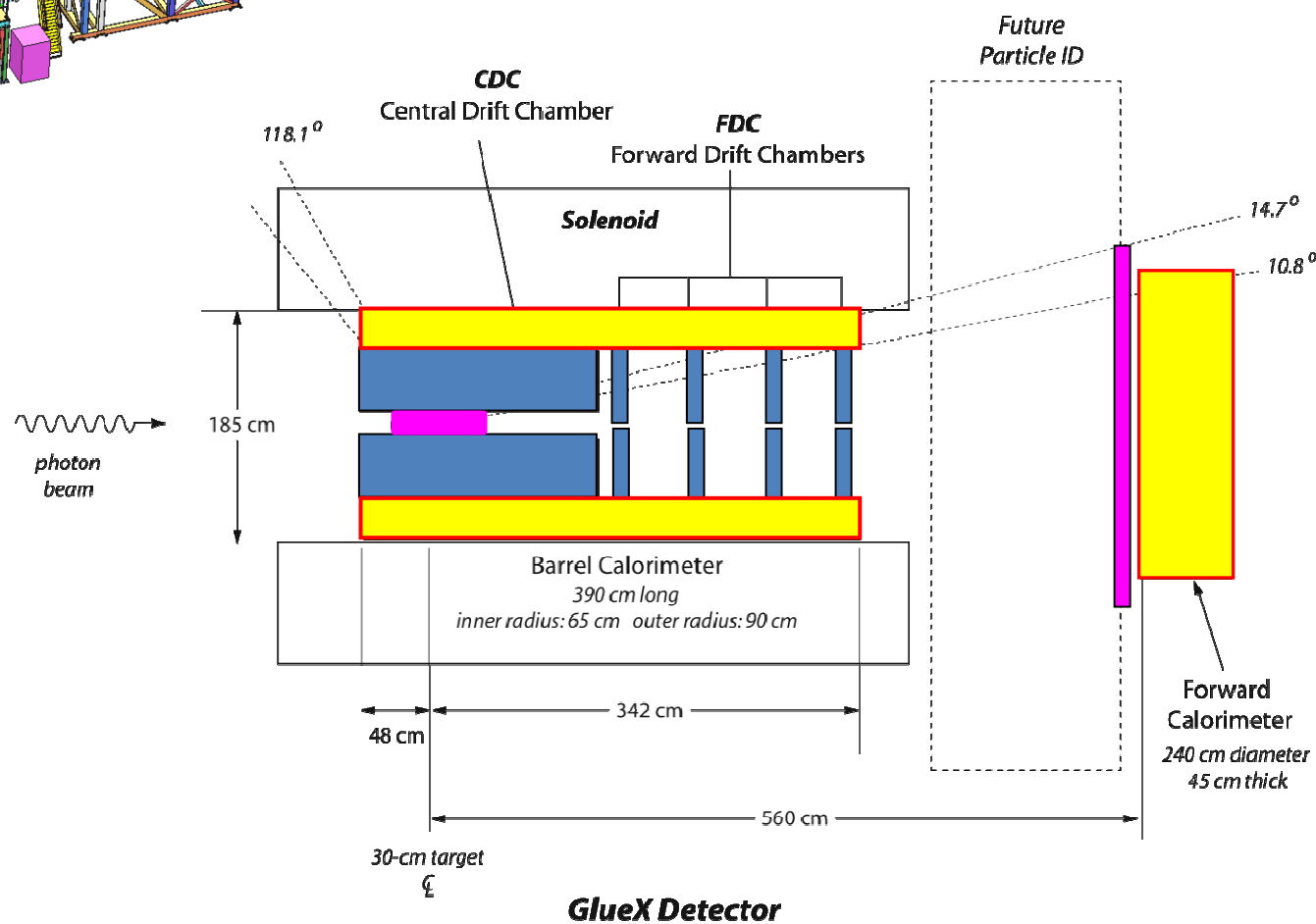
- Central Drift Chamber
- Forward Drift Chamber

Calorimetry:

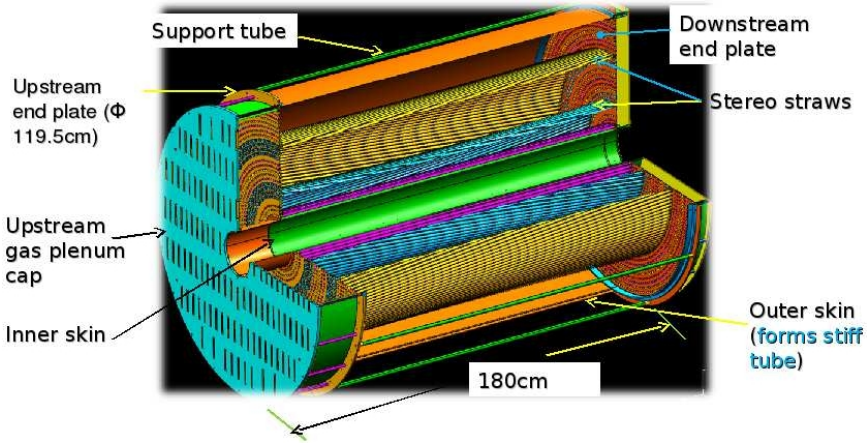
- Barrel Calorimeter
- Forward Calorimeter

PID:

- Time of Flight wall
- Start Counter
- Barrel Calorimeter



Tracking

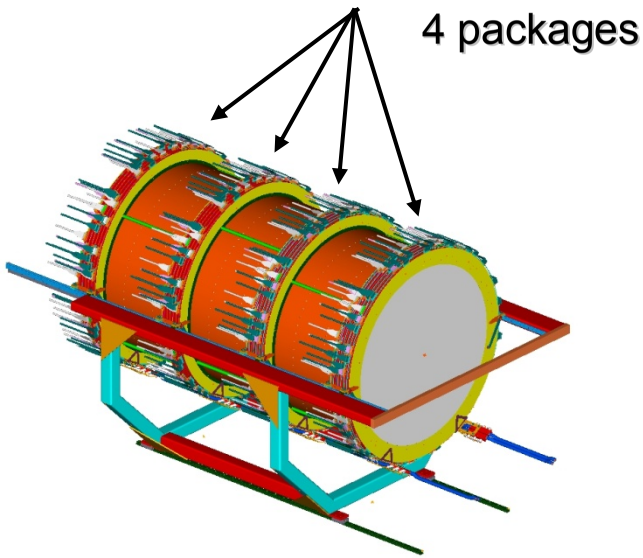


Central Drift Chamber

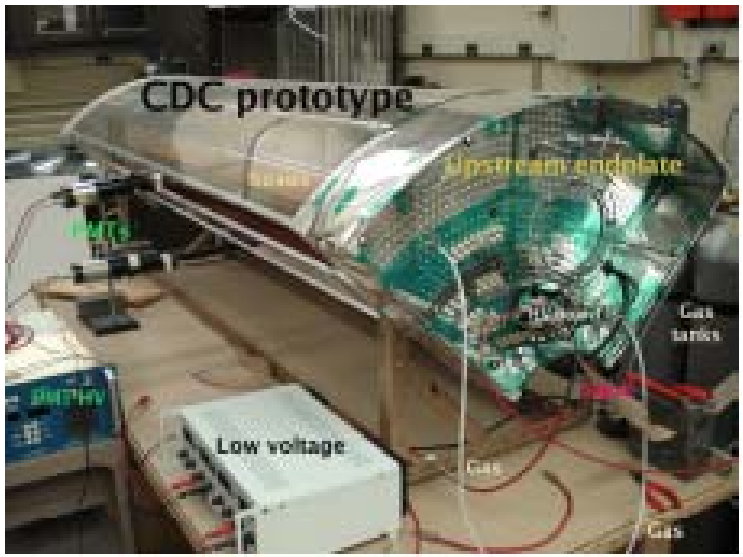
- Angular coverage $6° < \theta < 155°$
- 12 axial layers, 16 stereo layers
  3522 straw tubes (1.6 cm diameter)
- De/dx for p, π identification
- $\sigma_\varphi \sim 150\ \mu m$, $\sigma_z \sim 2$ mm

Forward Drift Chamber

- Angular coverage $1° < \theta < 30°$
- 4 packages, 6 cathode/wire/cathode chambers in each package
- ~12000 channels
- $\sigma_{xy} \sim 200\ \mu m$



Tracking



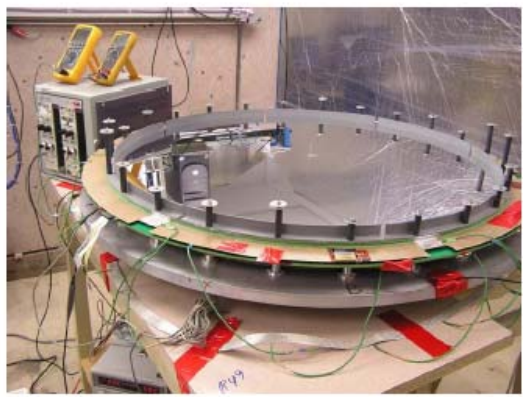
Central Drift Chamber

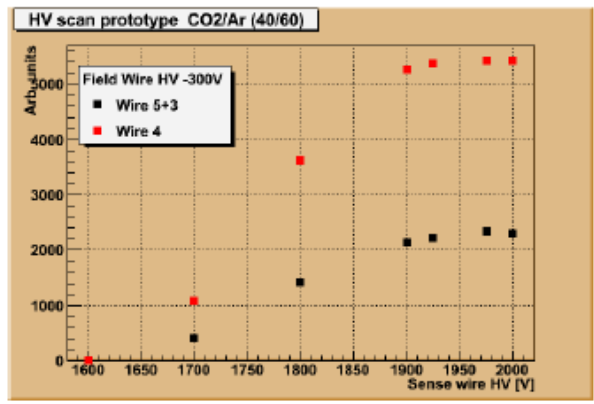
- Angular coverage $6° < \theta < 155°$
- 12 axial layers, 16 stereo layers
  3522 straw tubes (1.6 cm diameter)
- De/dx for p, π identification
- $\sigma_\varphi \sim 150\ \mu m$, $\sigma_z \sim 2$ mm

FDC prototype: 3 planes, good performace !

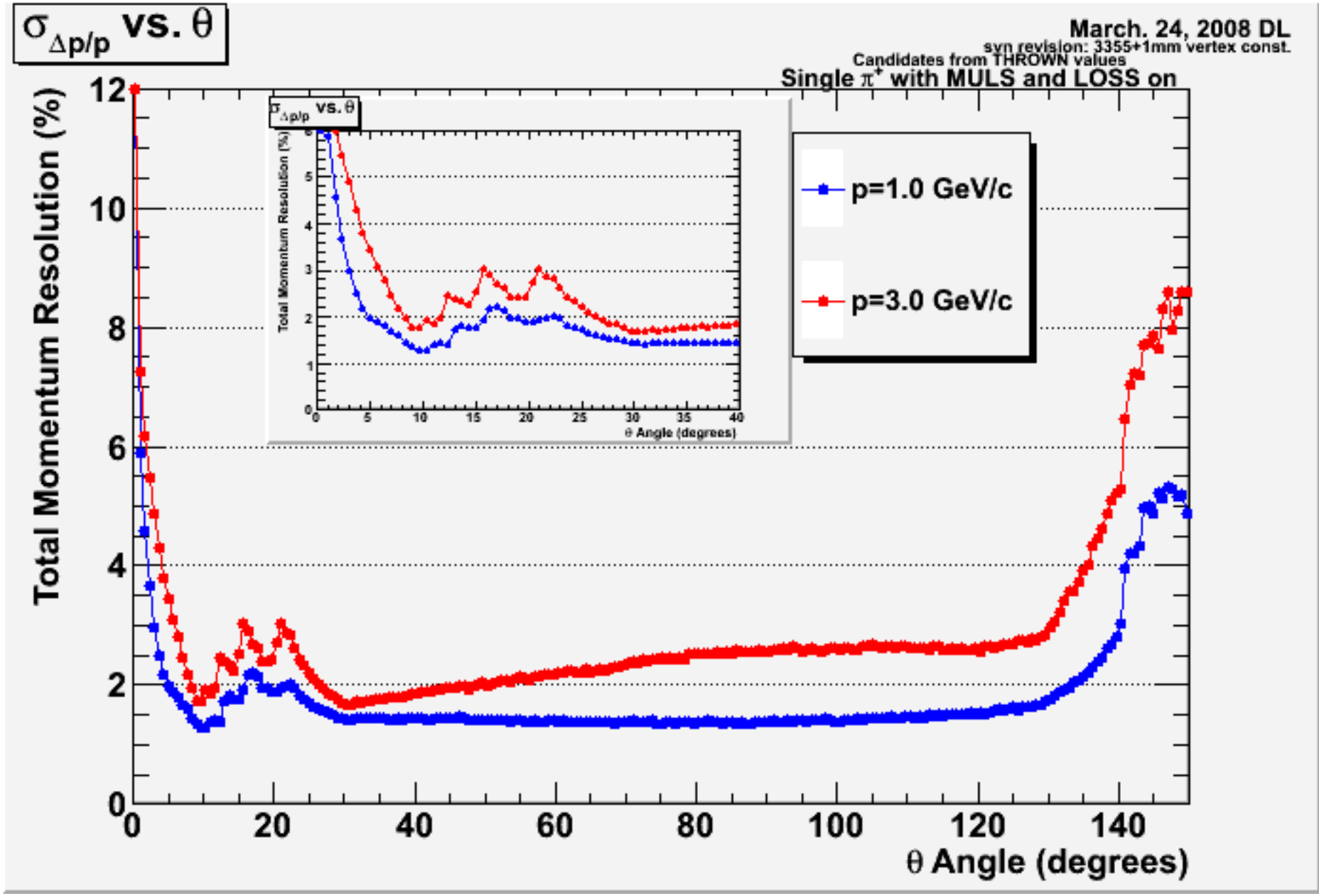
Forward Drift Chamber

- Angular coverage $1° < \theta < 30°$
- 4 packages, 6 cathode/wire/cathode chambers in each package
- ~12000 channels
- $\sigma_{xy} \sim 200\ \mu m$

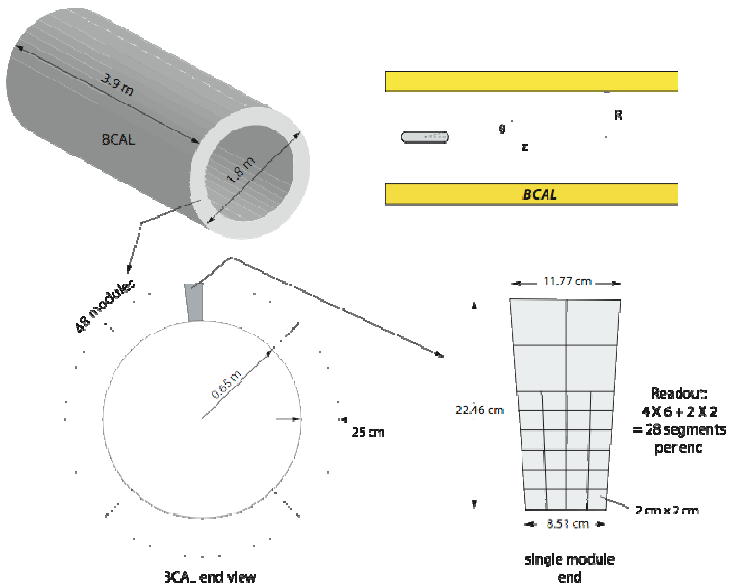




Tracking


σΔp/p vs. θ
March. 24, 2008 DL
svn revision: 3355+1mm vertex const.
Candidates from THROWN values
Single π+ with MULS and LOSS on
Total Momentum Resolution (%)
θ Angle (degrees)
p=1.0 GeV/c
p=3.0 GeV/c

Calorimetry

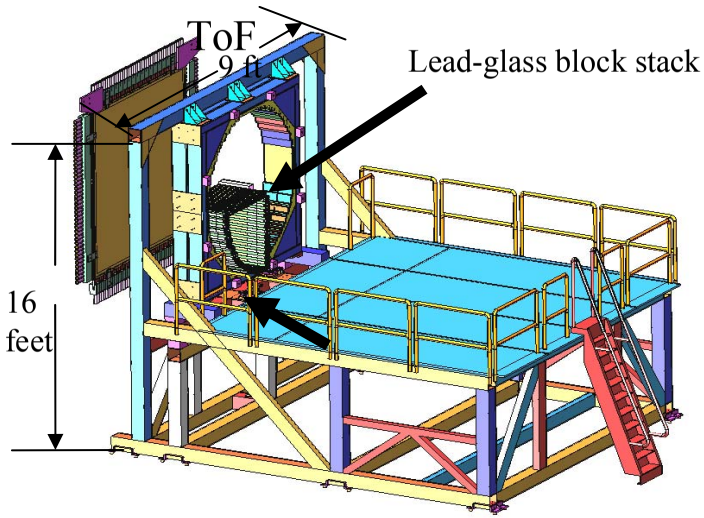


Barrel Calorimeter:

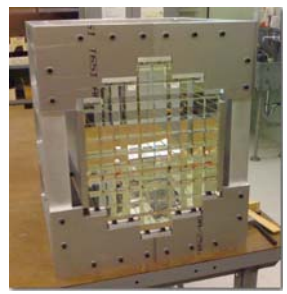
- Angular coverage $11° < \theta < 120°$
- 191 layers Pb:ScFib:Glue (37:49:14%)
- Double side readout (SiPM)
- $\sigma_E / E\ (\%) = 5.5/\sqrt{E} \oplus 1.6$
- $\sigma_Z = 5\ \text{mm} / \sqrt{E}$
- $\sigma_t = 74\ \text{ps} / \sqrt{E} \oplus 33\ \text{ps}$

Forward Calorimeter:

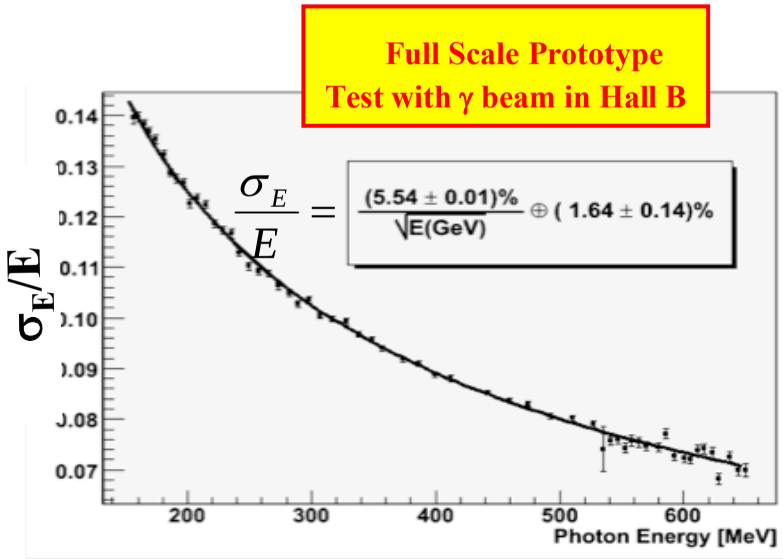
- Angular coverage $2° < \theta < 11°$
- 2800 Pb-glass blocks: 4cm x 4 cm x 45 cm
- $\sigma_E / E\ (\%) = 5.7/\sqrt{E} \oplus 2.0$
- $\sigma_{xy} = 6.4\ \text{mm} / \sqrt{E}$



FCAL prototype



Calorimetry

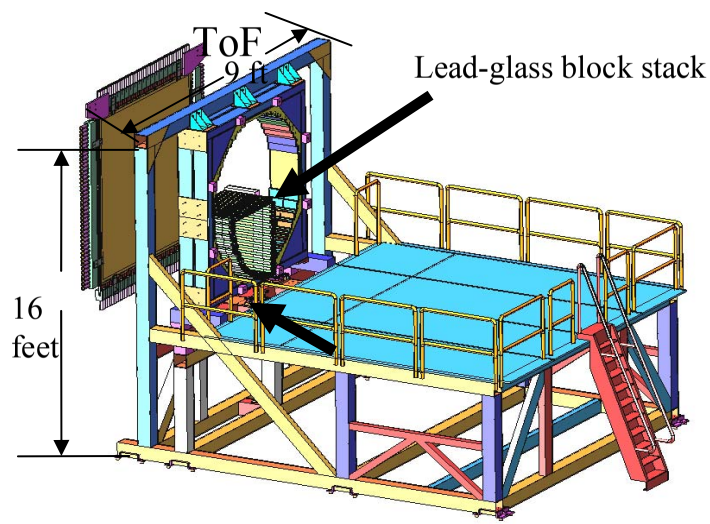


Barrel Calorimeter:

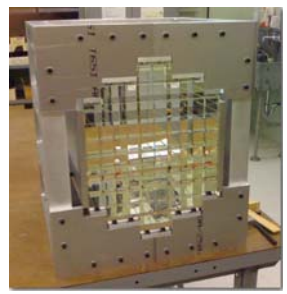
- Angular coverage 11° < θ < 120 °
- 191 layers Pb:ScFib:Glue (37:49:14%)
- Double side readout (SiPM)
- **σ_E / E (%) = 5.5/√E ⊕ 1.6**
- **σ_Z = 5 mm / √E**
- **σ_t = 74 ps / √E ⊕ 33 ps**

Forward Calorimeter:

- Angular coverage 2° < θ < 11 °
- 2800 Pb-glass blocks: 4cm x 4 cm x 45 cm
- **σ_E / E (%) = 5.7/√E ⊕ 2.0**
- **σ_{xy} = 6.4 mm / √E**

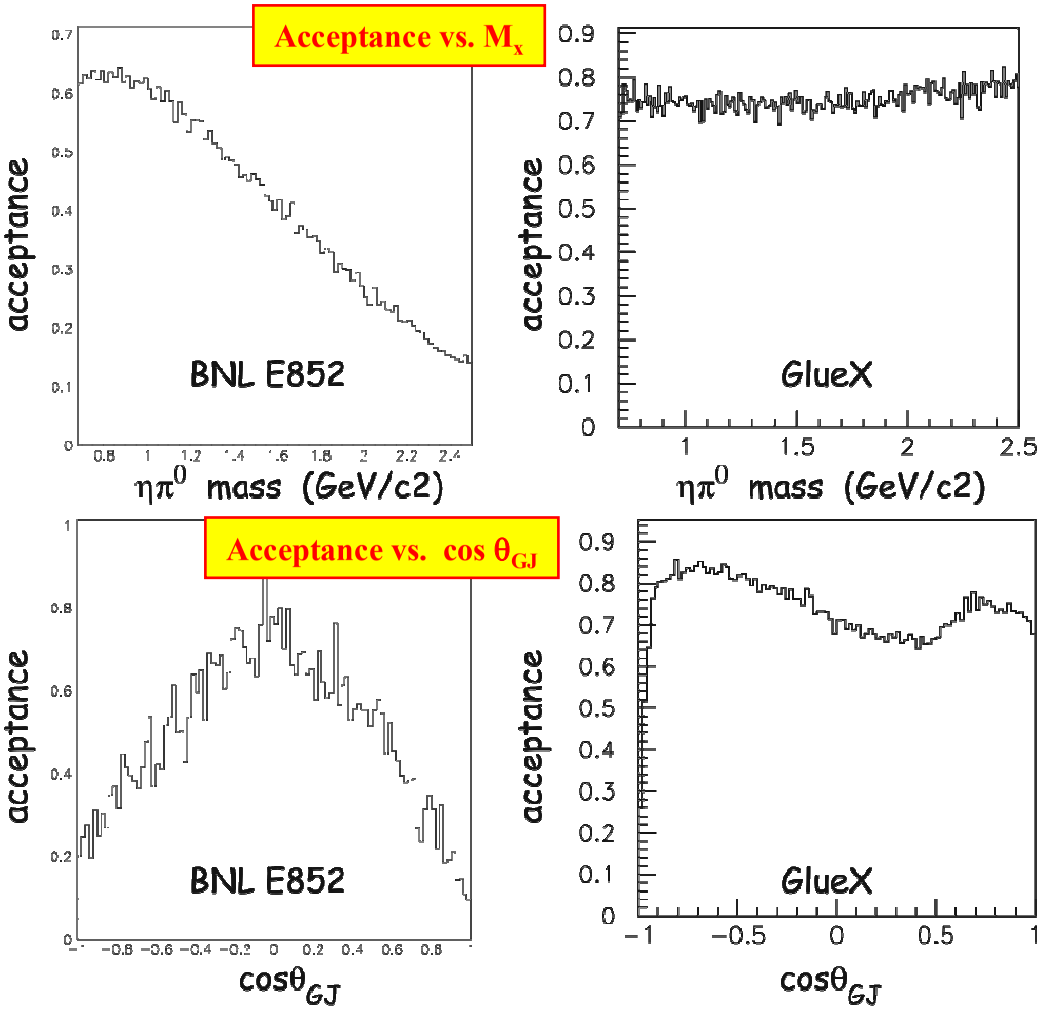


FCAL prototype



Detector Performance

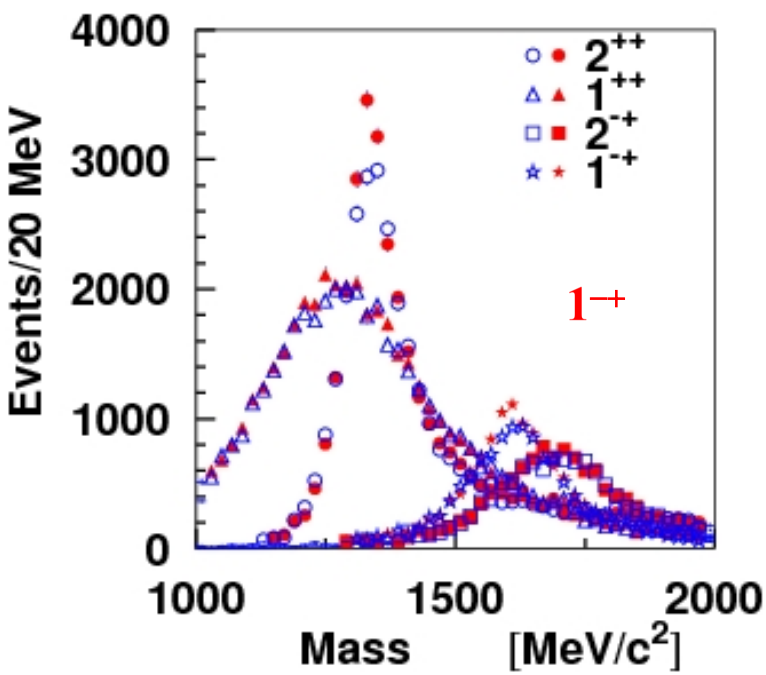
GlueX Acceptance



- E852 experiment contains the largest sample of exotic meson candidates
- GlueX has more uniform acceptance as a function of the exotic meson mass
- GlueX angular acceptance for $\eta\pi$ is expected to be better than that of E852

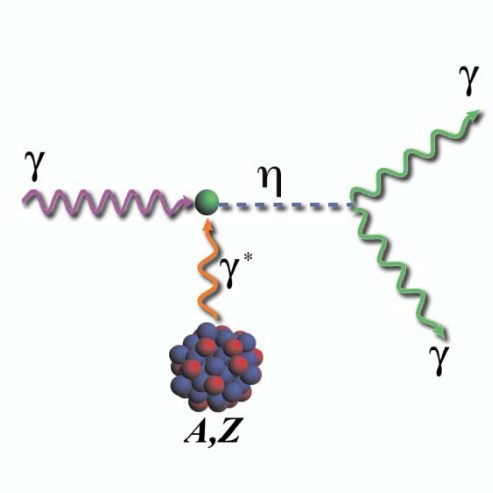
Partial Wave Analysis Study

- Simulation of Partial Wave Analysis for $\gamma p \rightarrow n \pi^+\pi^-\pi^+$
- Input amplitudes for: $a_1(1260)\ 1^{++}$, $a_2(1320)\ 2^{++}$, $\pi_2(1670)\ 2^{-+}$, **$\pi_1(1600)\ 1^{-+}$**
  - **$\pi_1(1600)$** constitutes about 2.5% of the total sample. $\sigma(\pi_1) = 20$ nb.
  - data sample corresponds to about 1% of the reconstructed statistics for 1 year of running at low luminosity



Unbiased shapes of the 3π mass distributions and phase differences obtained from the fit

Measurement of Γ(η→γγ) via Primakoff Effect



Physics:

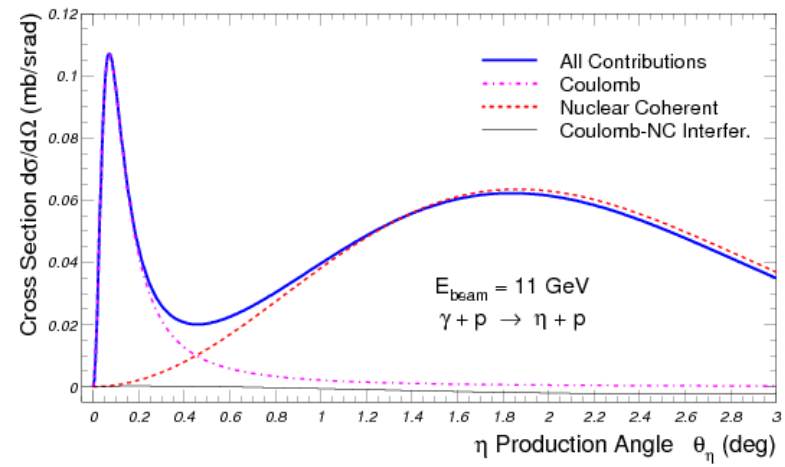
- Light quark mass ratio
- η - η′ mixing angle

$\Gamma(\eta\to 3\pi) \propto |A|^2 \propto Q^{-4}$

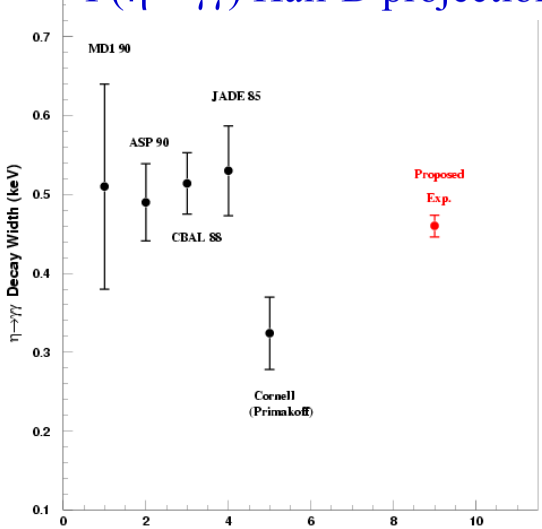
$$Q^2 = \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}, \qquad \text{where } \hat{m} = \frac{1}{2}(m_u + m_d)$$

Measurements:

- Primakoff $\theta < 0.5°$
- Fit to $\frac{d\sigma}{d\Omega}(\theta)$



Γ(η→γγ) Hall-D projection



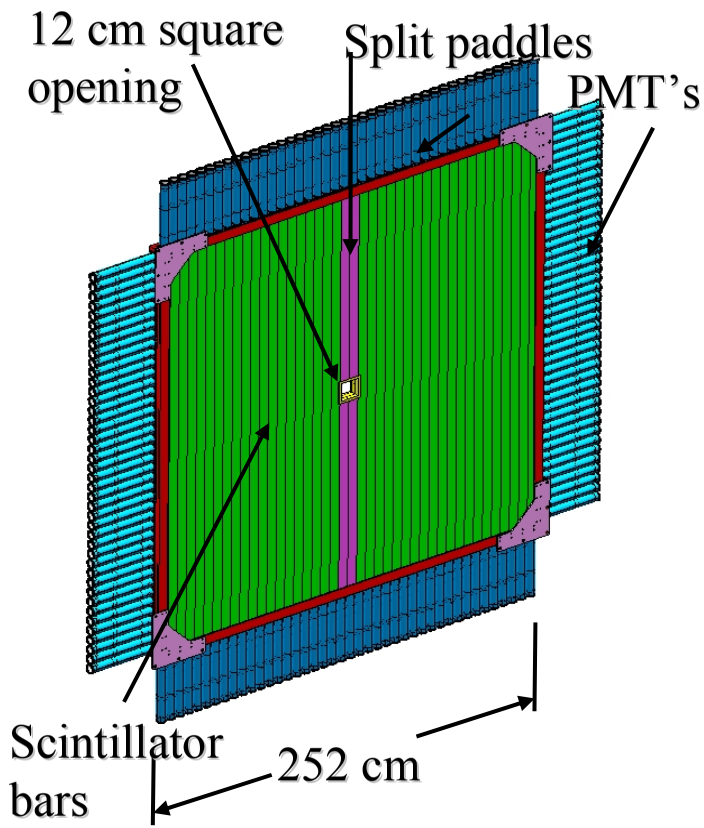
- 11.0-11.7 GeV Incoherent tagged photons
- Pair spectrometer to control photon flux
- Solenoid detectors (for background rejection)
- 30 cm LH2 and LHe4 targets (~3.6% r.l.)
- Forward Calorimeter (FCAL) for η→γγ
- Add CompCal detector for overall control of systematic error

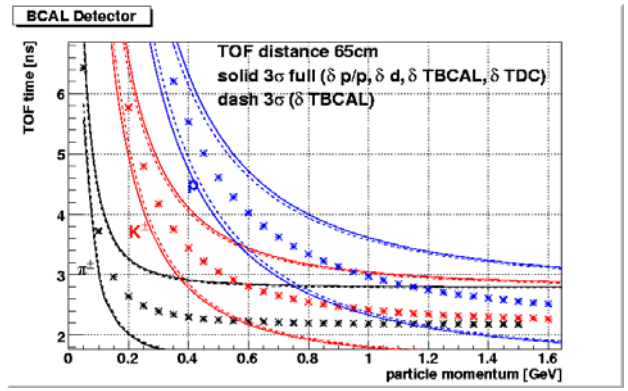
Summary

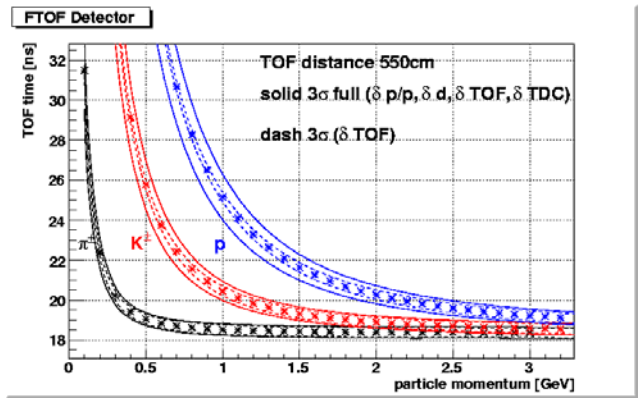
- A new detector, GlueX, is under construction at Jefferson Lab
- The detector design was optimized for search and mapping the spectrum of light exotic mesons using the hight-intensity linearly polarized photon beam
  - The detector is designed to have excellent acceptance for both charged particles and photons in the final state
- During only one year of running, the GlueX experiment will collect a data sample a few order of magnitude larger than all existing photoproduction data
- Being optimized for the search of exotic mesons, the detector is well suited for many other physics topics…

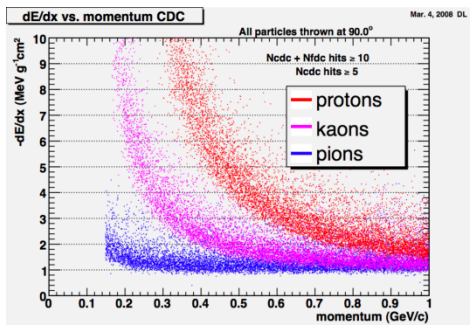
Join us !

TOF & PID









- πp separation <450MeV/c
- πK separation <275MeV/c