Search for Gluonic Excitations with GlueX at Jefferson Lab

Volker Credé

Florida State University
Tallahassee, FL

The Structure and Dynamics of Hadrons

Hirschegg, 01/19/2007

Outline

Outline

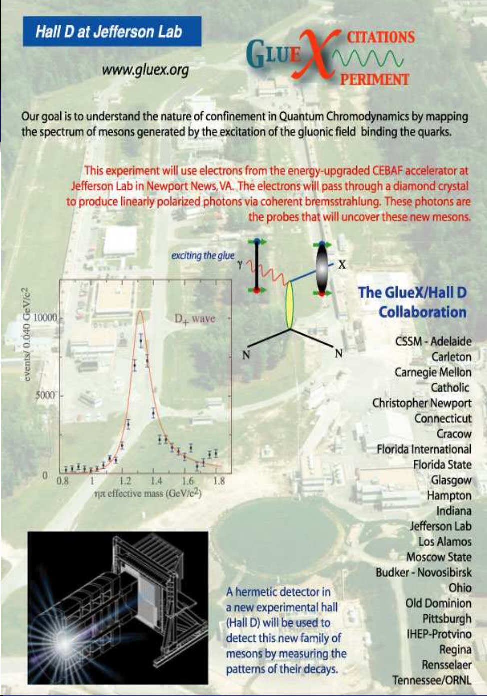
1. Introduction
2. Scientific Goals
   - The Search for Gluonic Excitations
3. The Experimental Setup: GlueX at JLab
   - Experimental Requirements
   - Detector Research & Development
4. Summary and Outlook

The GlueX Collaboration

- $\approx$ 100 Physicists
- Members from 7 countries
  - Australia
  - Canada, Mexico, USA
  - Greece, Russia, Scotland
- Active group since 1998

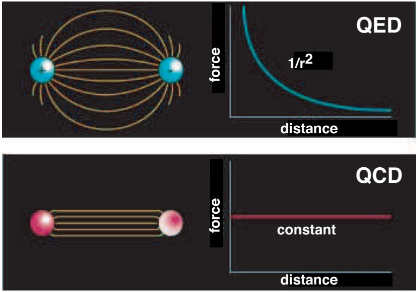
➜ http://www.gluex.org

New members are welcome!

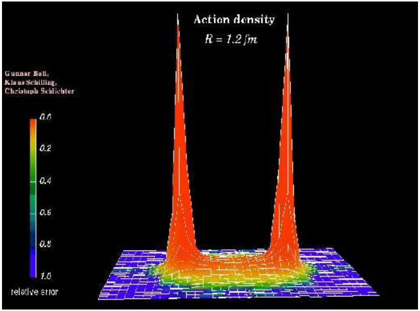


Outline

Flux Tubes



Confinement arises from flux tubes and their excitation leads to a new spectrum of mesons.



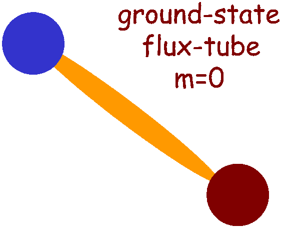
G. Bali *et al.*, *Phys. Rev.* **D62**, (2000) 054503

Color Fields: Because of self interaction between gluons, confining flux tubes form between static color charges.

Ordinary Mesons

$J^{PC} \equiv {}^{2S+1}L_J$

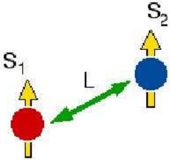
- Parity $P = (-1)^{L+1}$
- Charge conjugation (defined for neutral mesons) $C = (-1)^{L+S}$
- G parity $G = C(-1)^I$



Ordinary Mesons

$J^{PC} \equiv {}^{2S+1}L_J$

- Parity $P = (-1)^{L+1}$
- Charge conjugation (defined for neutral mesons) $C = (-1)^{L+S}$
- G parity $G = C(-1)^I$

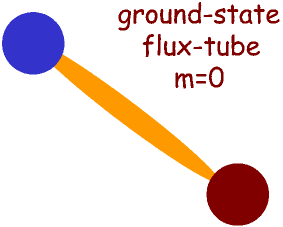


$\underline{L = 0,\ S = 1:}$

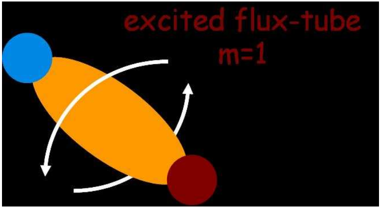
$\rho,\ \omega,\ \phi\ (J^{PC} = 1^{--})$

$\underline{L = 0,\ S = 0:}$

e.g. $\pi\ (J^{PC} = 0^{-+})$

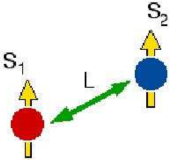


Hybrid Mesons



flux tube $J^{PC} = 1^{+-}$ or 1^{-+}

(from lattice QCD and flux-tube models)



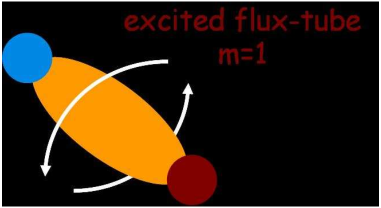
$L = 0,\ S = 1:$

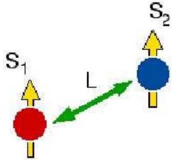
$\rho,\ \omega,\ \phi\ (J^{PC} = 1^{--})$

$L = 0,\ S = 0:$

e.g. $\pi\ (J^{PC} = 0^{-+})$

Hybrid Mesons





$\underline{L = 0,\ S = 1:}$

$\rho,\ \omega,\ \phi\ (J^{PC} = 1^{--})$

$\underline{L = 0,\ S = 0:}$

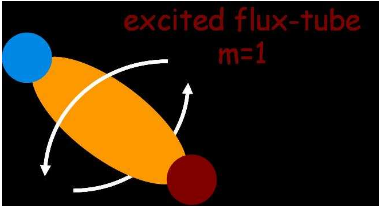
e.g. $\pi\ (J^{PC} = 0^{-+})$

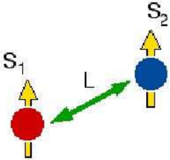
$_{\text{flux tube}}J^{PC} = 1^{+-}$ or 1^{-+}

Pseudoscalar Mesons: $_{\text{quarks}}J^{PC} \otimes {}_{\text{flux tube}}J^{PC} = 1^{--},\ 1^{++}$

Vector Mesons: $_{\text{quarks}}J^{PC} \otimes {}_{\text{flux tube}}J^{PC} = 0^{-+},\ \boxed{1^{-+}},\ 2^{-+}$
$\boxed{0^{+-}},\ 1^{+-},\ \boxed{2^{+-}}$

Hybrid-Meson Production





$\underline{L = 0,\ S = 1:}$

$\rho,\ \omega,\ \phi\ (J^{PC} = 1^{--})$

$\underline{L = 0,\ S = 0:}$

e.g. $\pi\ (J^{PC} = 0^{-+})$

$_{\text{flux tube}}J^{PC} = 1^{+-}$ or 1^{-+}

Pseudoscalar Probe: $_{\text{quarks}}J^{PC} \otimes {_{\text{flux tube}}J^{PC}} = 1^{--},\ 1^{++}$

Vector Probe: $_{\text{quarks}}J^{PC} \otimes {_{\text{flux tube}}J^{PC}} = 0^{-+},\ \boxed{1^{-+}},\ 2^{-+}$
$\boxed{0^{+-}},\ 1^{+-},\ \boxed{2^{+-}}$

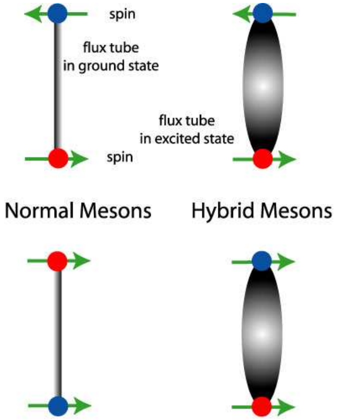
Hybrid-Meson Production

One result of the scattering process of an incoming probe off the target particle can be the excitation of the flux tube:

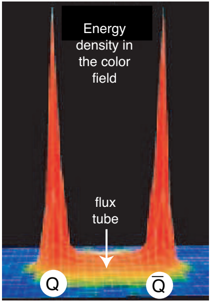
- Not favored for $q\bar{q}$ probe in $L = 0$ and $S = 0$

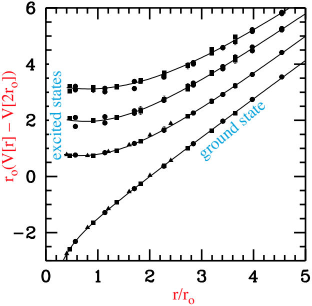
- Favored for incoming vector probes with $L = 0$ and $S = 1$

➜ Photoproduction



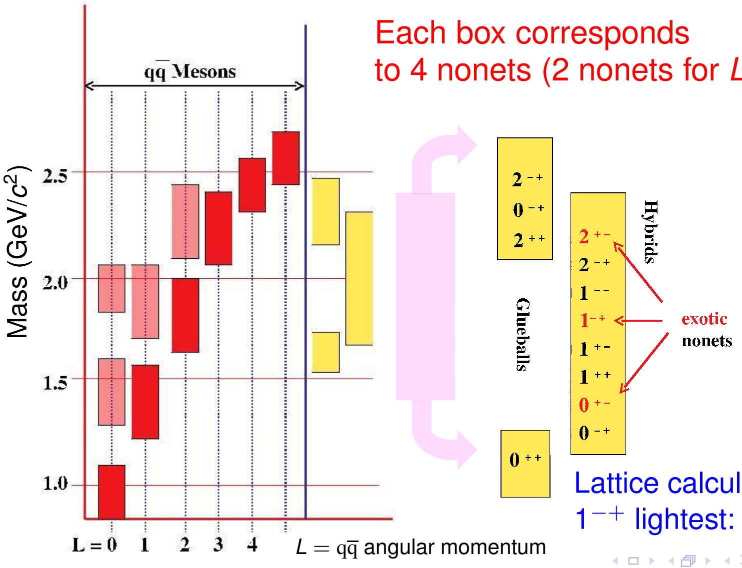
QCD Potential





The observation of exotic quantum numbers are the best experimental signal of gluonic excitations.

➜ Gluonic excitations provide an experimental measurement of the excited QCD potential.



Each box corresponds to 4 nonets (2 nonets for $L = 0$)

Lattice calculations:
1^{-+} lightest: ≈ 1.9 GeV/c^2

Decays of Hybrids

Decay calculations are model dependent, but the $^3P_0$ model does a good job of describing normal meson decays.

The angular momentum in the flux tube stays in one of the daughter mesons (($L = 1$) and ($L = 0$)):

$$\left.\begin{array}{ll} L = 0 & \pi,\ \rho,\ \eta,\ \omega,\ \ldots \\ L = 1 & \mathrm{a},\ \mathrm{b},\ \mathrm{h},\ \mathrm{f},\ \ldots \end{array}\right\} \quad \eta\pi,\ \rho\pi,\ \ldots \quad \text{not preferred decays}$$

Experimental Evidence for Exotic 1^{-+} Signals

- $\pi_1(1400)$: Width $\approx$ 0.3 GeV, Decays: only $\pi\eta$

  Weak signal in πp production (scattering??) and strong signal in antiproton-deuterium annihilation

  Controversy

  - In Crystal-Barrel data, the $\eta\pi^0$ channel is not conclusive.
  - Recent analysis by A. Szczepaniak shows that the exotic wave is not resonant – a rescattering effect.
  - The signal is far too light to be a hybrid by any model.

Experimental Evidence for Exotic 1^{-+} Signals

- $\pi_1(1400)$: Width $\approx$ 0.3 GeV, Decays: only $\pi\eta$

  Weak signal in πp production (scattering??) and strong signal in antiproton-deuterium annihilation

  ➜ Probably not a hybrid

Experimental Evidence for Exotic 1^{-+} Signals

- $\pi_1(1400)$: Width $\approx$ 0.3 GeV, Decays: only $\pi\eta$

  Weak signal in πp production (scattering??) and strong signal in antiproton-deuterium annihilation

  ➜ Probably not a hybrid

- $\pi_1(1600)$: Width $\approx$ 0.16 GeV, Decays: $\rho\pi,\ \eta'\pi,\ (b_1\pi)$

  Only seen in πp production (E852, VES)

  E852 Results

3π	$m = 1593$	$\Gamma = 168$	
$\eta'\pi$	$m = 1597$	$\Gamma = 340$	(A. Szczepaniak: background rescattering)
$f_1\pi$	$m = 1709$	$\Gamma = 403$	
$b_1\pi$	$m = 1687$	$\Gamma = 206$	

Experimental Evidence for Exotic 1^{-+} Signals

- $\pi_1(1400)$: Width $\approx$ 0.3 GeV, Decays: only $\pi\eta$

  Weak signal in πp production (scattering??) and strong signal in antiproton-deuterium annihilation

  ➜ Probably not a hybrid

- $\pi_1(1600)$: Width $\approx$ 0.16 GeV, Decays: $\rho\pi,\ \eta'\pi,\ (\mathrm{b}_1\pi)$

  Only seen in πp production (E852, VES)

  ➜ Still room for a narrower exotic state

Experimental Evidence for Exotic 1^{-+} Signals

- $\pi_1(1400)$: Width $\approx$ 0.3 GeV, Decays: only $\pi\eta$

  Weak signal in πp production (scattering??) and strong signal in antiproton-deuterium annihilation

  ➜ Probably not a hybrid

- $\pi_1(1600)$: Width $\approx$ 0.16 GeV, Decays: $\rho\pi,\ \eta'\pi,\ (b_1\pi)$

  Only seen in πp production (E852, VES)

  ➜ Does it exist? No evidence in Dzierba *et al.*, PRD 73 (2006)

Experimental Evidence for Exotic 1^{-+} Signals

- π_1(1400): Width $\approx$ 0.3 GeV, Decays: only $\pi\eta$

  Weak signal in πp production (scattering??) and strong signal in antiproton-deuterium annihilation

  ➜ Probably not a hybrid

- π_1(1600): Width $\approx$ 0.16 GeV, Decays: $\rho\pi,\ \eta'\pi,\ (b_1\pi)$

  Only seen in πp production (E852, VES)

  ➜ Does it exist? No evidence in Dzierba *et al.*, PRD 73 (2006)

- π_1(2000): Weak evidence in preferred hybrid modes $f_1\pi$ and $b_1\pi$

  ➜ Right place, needs confirmation

Exotics and QCD

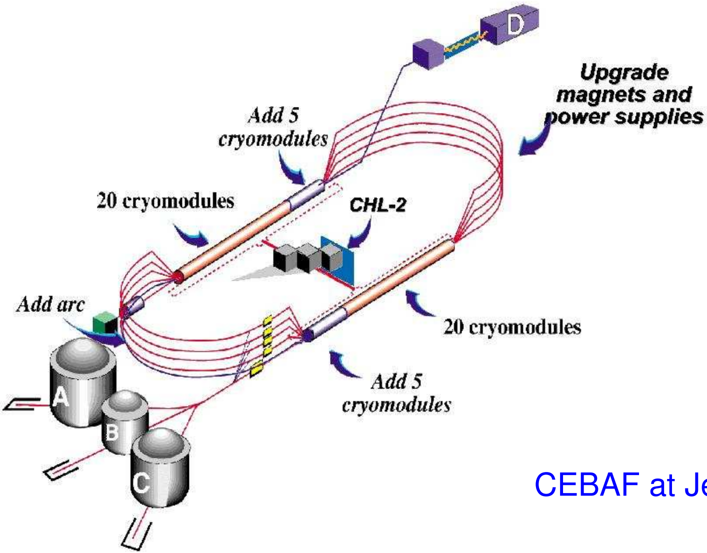
To establish the existence of gluonic excitations, the existence and nonet nature of the 1^{-+} state needs to be established.

➜ Also, 0^{+-} and 2^{+-} nonets need to be established.

Decay pattern are crucial:

Have provided the most sensitive information in the scalar glueball sector

Outline



CEBAF at Jefferson Lab

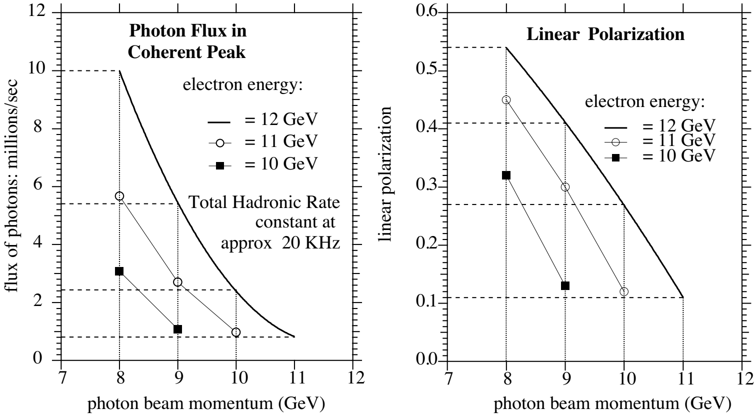
Detector Requirements

A partial-wave amplitude analysis is required in order to identify exotic hybrid, non-exotic hybrid, and conventional meson nonets.
This puts demands on the experiment:

- Hermiticity (4π detector)
  ➜ Uniform detector acceptance in the variables appropriate for PWA
- Energy and momentum resolution
- Particle identification (sensitivity to decay modes)
- High statistics (photon flux and rate capability)
- Appropriate beam energy (reach masses/good acceptance)
- Identification of production mechanism (linear polarization)

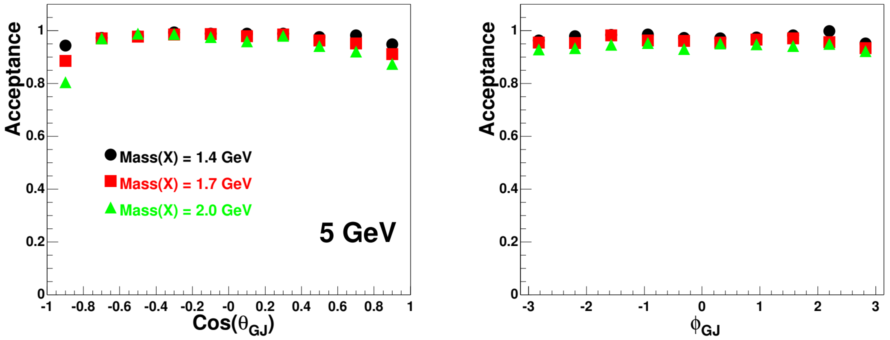
Finding the Optimal Energy ...

Detector optimized for 8-9 GeV photons:



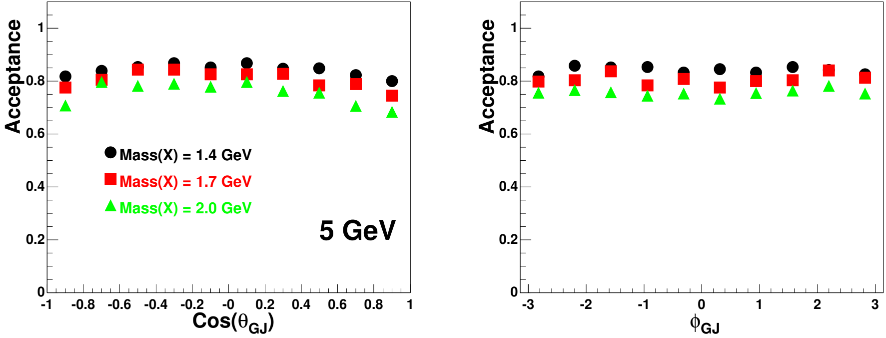
Acceptance for Different Effective Masses

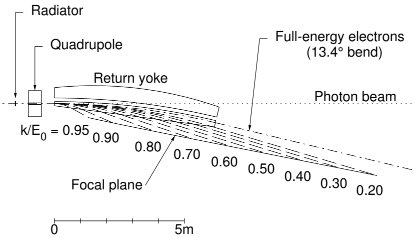
$\gamma p \to n\, \pi^+ \pi^+ \pi^-$



Acceptance for Different Effective Masses

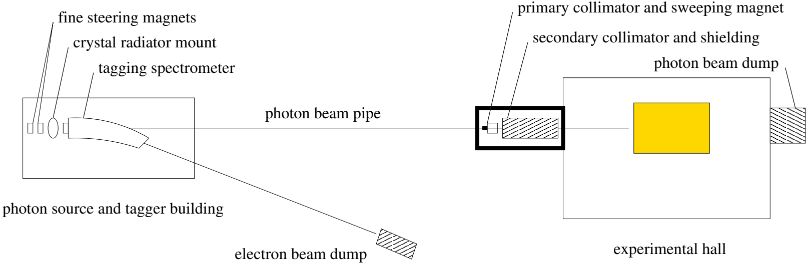
$\gamma p \to n\, \omega\, \pi^0\, \pi^+$



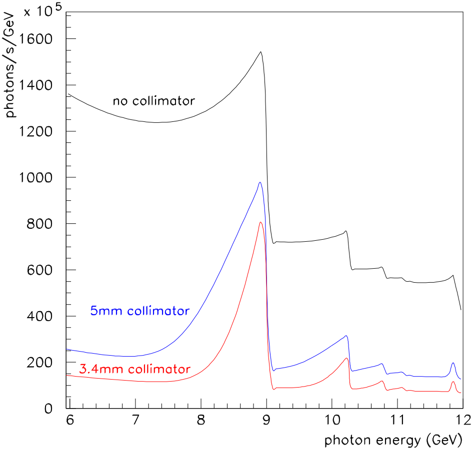


Coherent Bremsstrahlung

- 15 micron diamond radiator
- 1 μA 12 GeV electron beam



Linear Polarization



Coherent Bremsstrahlung

- 15 micron diamond radiator
- 1 μA 12 GeV electron beam

Linear Polarization is

- helpful in extracting decay amplitudes.

Linear Polarization and Decay Angular Distributions

Possible Example: $\rho \to \pi\pi$ or $\phi \to \mathrm{K}\overline{\mathrm{K}}$

In the rest frame of the vector, the two-pseudoscalar w.f. is:

$$Y_1^m(\theta,\phi) \propto \sin\theta \cdot \mathrm{e}^{im\phi} \quad \text{(s-channel helicity conservation)}$$

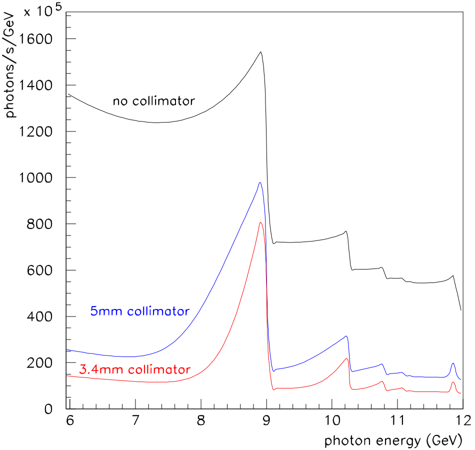
➜ For circularly-polarized photons (either $m = 1$ or $m = -1$), the square of amplitude carries no ϕ information.

However, for linearly-polarized photons:

$$\text{e. g.} \quad |x> = \frac{|R> + |L>}{\sqrt{2}} \propto \sin\theta \cdot \cos\phi$$

➜ For in-plane photons, there is a $\cos^2\phi$ dependence.

Linear Polarization



Coherent Bremsstrahlung

- 15 micron diamond radiator
- 1 μA 12 GeV electron beam

Linear Polarization is

- helpful in extracting decay amplitudes.
- essential in identifying the production mechanism.
- a filter for exotics.

Linear Polarization and Production Mechanism

Example:

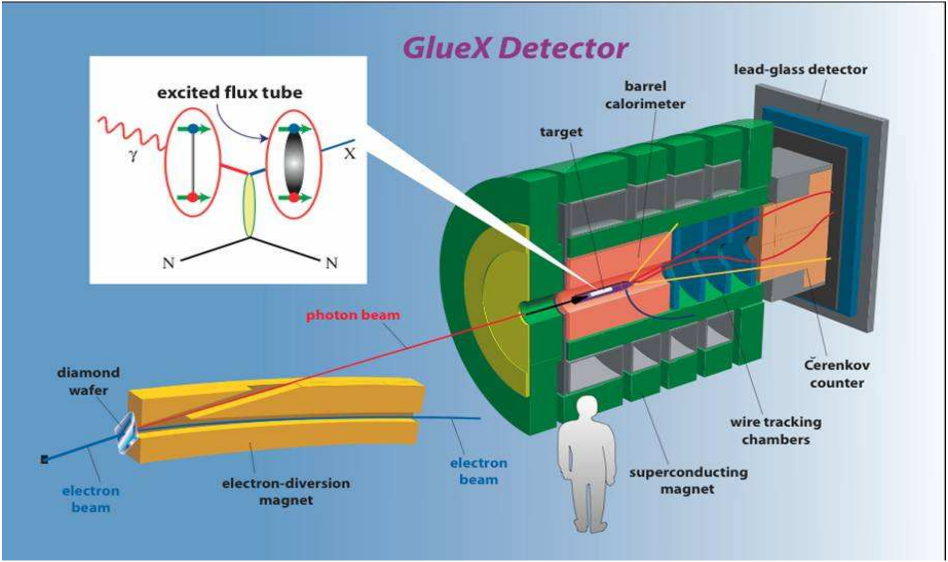
Separating Natural-Parity (0^+) from Unnatural-Parity (0^-) Exchange

For circularly-polarized photons:

$$|R> (m = 1) \;\rightarrow\; A^N + A^U$$
$$|L> (m = -1) \;\rightarrow\; A^N - A^U$$

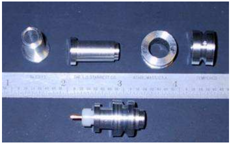
For linearly-polarized photons:

$$|x> = \frac{|R> + |L>}{\sqrt{2}} \propto A^N \qquad |y> = -i\,\frac{|R> - |L>}{\sqrt{2}} \propto A^U$$

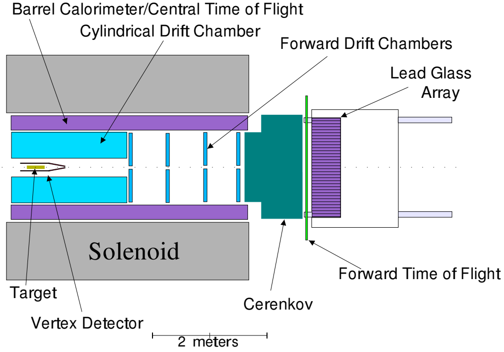

GlueX Detector
excited flux tube
γ
X
N
N
lead-glass detector
barrel
calorimeter
target
photon beam
diamond
wafer
electron
beam
electron-diversion
magnet
electron
beam
superconducting
magnet
wire tracking
chambers
Čerenkov
counter

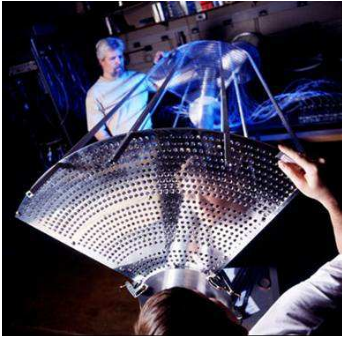
Detector R & D Work: Drift Chambers

Model of straw-tube chamber



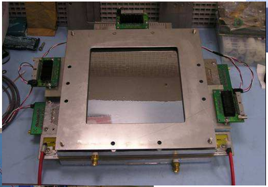
Cylindrical Drift Chamber

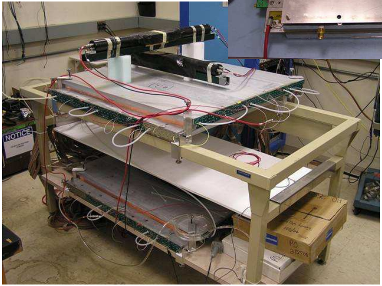


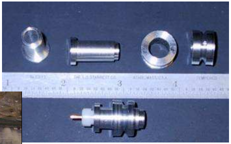


Detector R & D Work: Drift Chambers

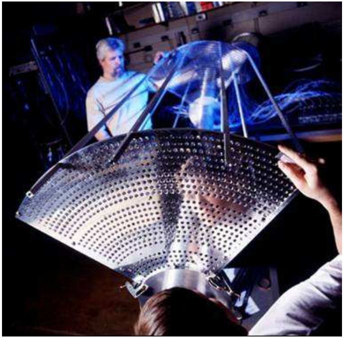
Forward
Drift Chamber







Cylindrical
Drift Chamber

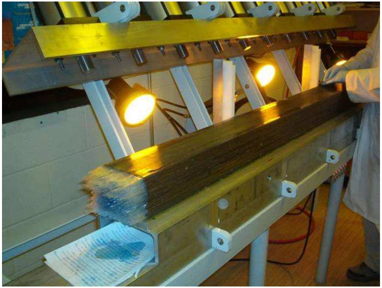


Detector R & D Work: Solenoid Refurbishment

LASS Solenoid

- Superconducting 2.5 T
- Used in Los Alamos MEGA Experiment
- Moved to IUCF for Refurbishing

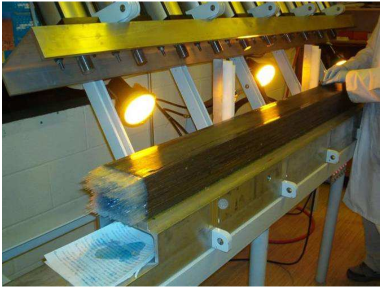
Detector R & D Work: Calorimeters



Barrel Calorimeter Pb-SciFib

- Scintillating fibers (1 mm) embadded in matrix of lead
- Resolution $\sigma/E \approx 6.3\,\%\sqrt{E}$

Detector R & D Work: Calorimeters



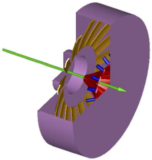
Barrel Calorimeter Pb-SciFib

- Scintillating fibers (1 mm) embadded in matrix of lead
- Resolution $\sigma/E \approx 6.3\,\%\sqrt{E}$

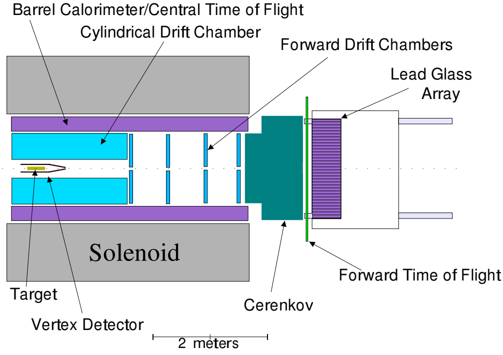
Existing Pb-Glass Forward Detector

Upstream Photon Detector

Detector R & D Work: Particle Identification



1. Time-of-Flight (TOF)
2. Cerenkov detector
3. dE/dx from tracking chambers



TOF Tests
(IHEP)

Outline

Summary and Outlook

- The scale of data from GlueX will be comparable to the LHC experiments
  - Grid technologies will be crucial
  - Tools to parallelize the analysis of 100,000,000 event data sets are being developed
- Theorists need to be closely integrated into the analyses fom the start
  - Partial wave analysis is the tool to find exotic states
    $\Rightarrow$ Theoretical underpinnings of PWA need to be looked at closely
    What are the model assumptions?
    How do they affect the results?

Summary and Outlook

- 12-GeV Upgrade
  CD-0 Signing at Jefferson Lab (April 19, 2004)
- CD 1 for JLab Facilities Upgrade
  Secretary of Energy announces Approval and Funding for Project (February 2006)
- CD 2 in Summer 2007

November 2003