Cascade Workshop, Newport News, Dec. 1-3 2005

The GlueX Experiment

Searching for gluonic excitations in the light meson spectrum using photoproduction

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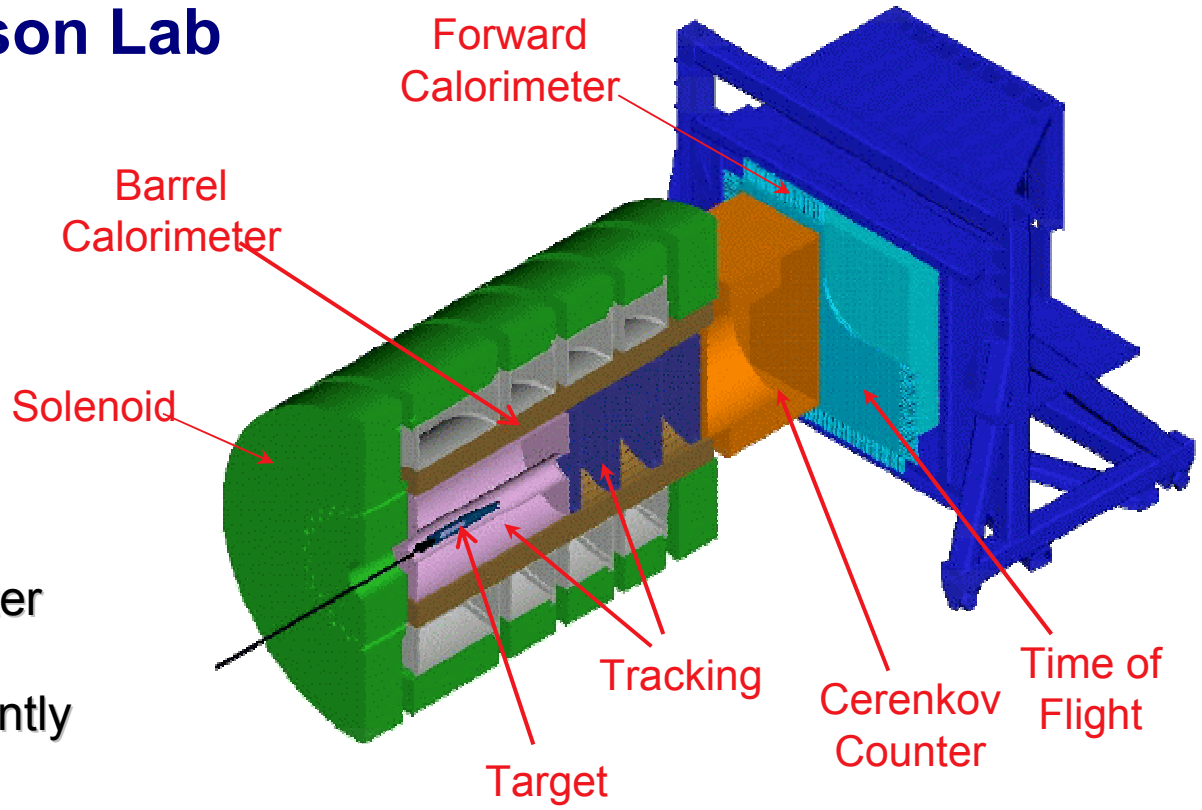
Outline

- Motivation
  - gluonic excitations in QCD
  - hybrid mesons
  - photoproduction
- Experimental design
  - photon beam
  - detector
- Analysis and sensitivity
  - PWA
- Baryon spectroscopy with GlueX?

What is GlueX?

A new meson spectroscopy experiment at Jefferson Lab which requires:

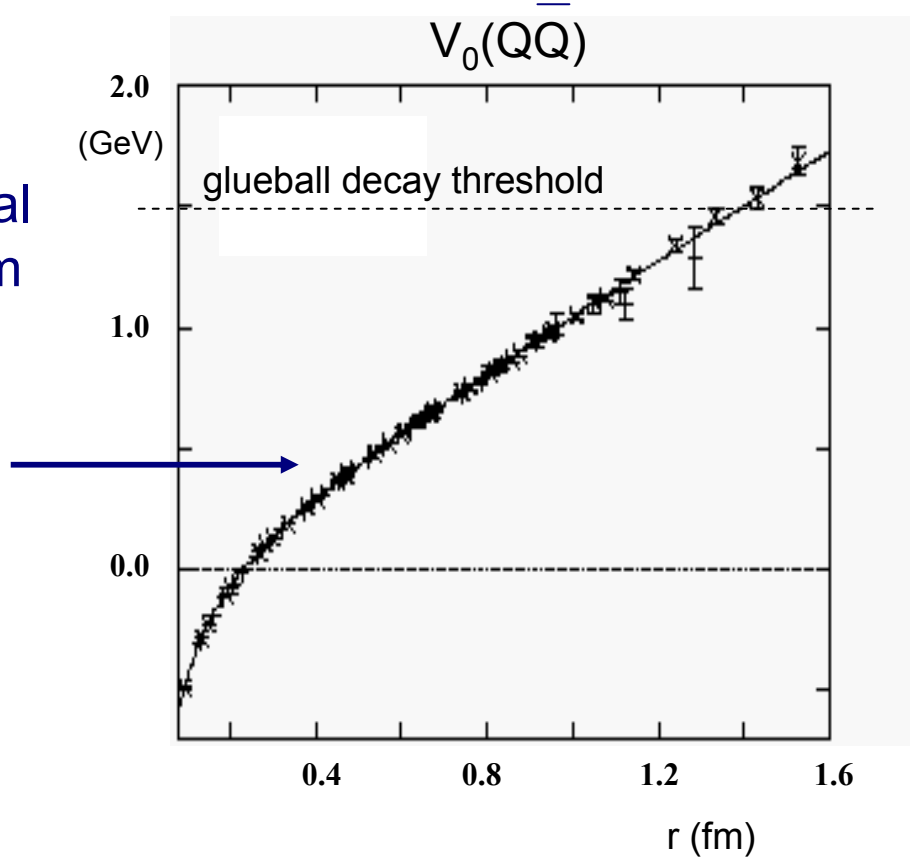
- the 12 GeV upgrade
- a new experimental hall
- a polarized photon beam
- a multi-particle spectrometer
- a new collaboration, presently
  - ~80 physicists
  - ~30 institutions



Motivation: gluonic excitations

Consider QCD with only heavy quarks:

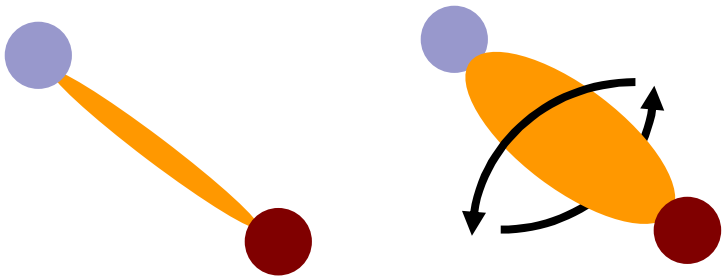
- the light mesons are glueballs
- $\bar{q}q$ mesons have the conventional positronium low-energy spectrum
- spectrum is distorted at higher excitations by a linear potential
- for r >> 0.5 fm a tube of gluonic flux forms between $\bar{q}$ and q



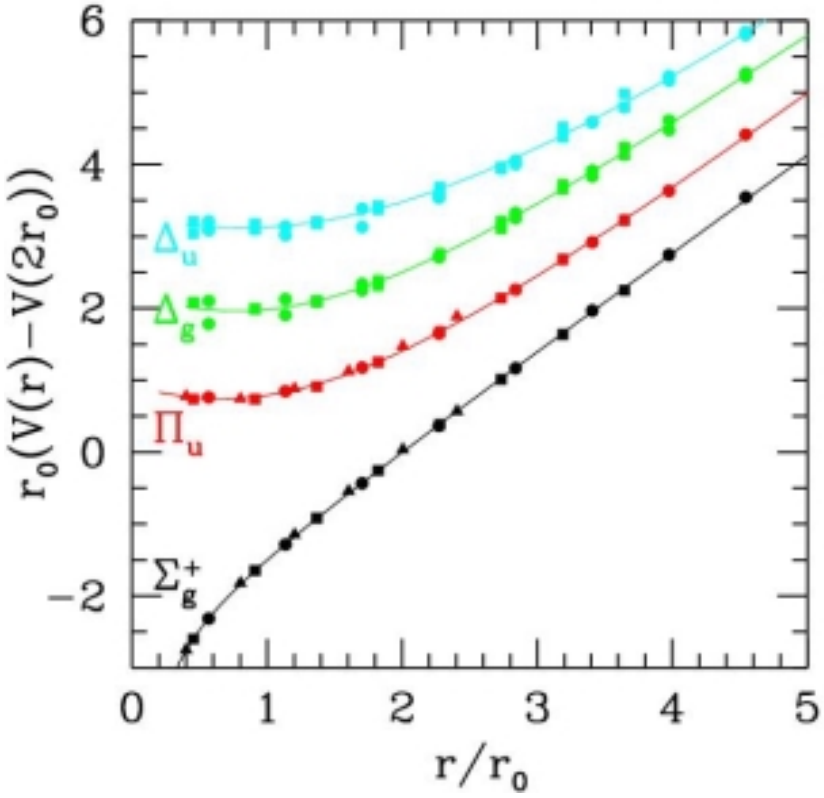
Motivation: gluonic excitations

Consider QCD with only heavy quarks:

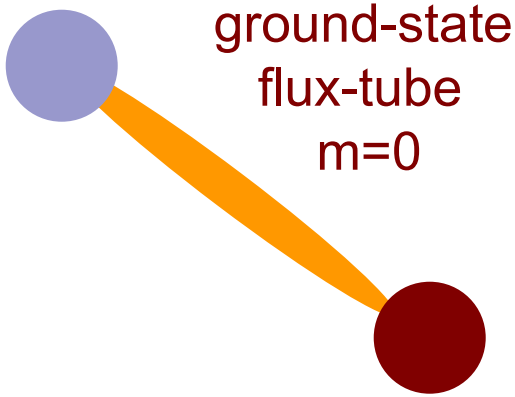
- gluonic excitations give rise to new potential surfaces
- for r >> r_0 gluonic excitations behave like flux tube oscillations



- inspires the **flux tube model**



Motivation: normal *vs* hybrid mesons



normal mesons

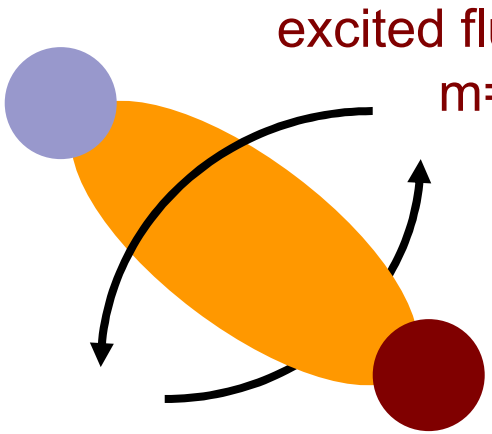
$CP = (-1)^{L+S}\ (-1)^{L+1}$

$= (-1)^{S+1}$

Flux-tube Model

m=0 $CP=(-1)^{S+1}$

m=1 $CP=(-1)^{S}$



1^{-+} or 1^{+-}

S=0, L=0

J=1 CP=+

$J^{PC}=1^{++},1^{--}$

(not exotic)

S=1, L=0

J=1 CP=-

$J^{PC} = 0^{-+},0^{+-}$

$1^{-+},1^{+-}$

exotic $2^{-+},2^{+-}$

Motivation: hybrid masses

Flux-tube model: 8 degenerate nonets

$1^{++}, 1^{--}$ $0^{-+}, 0^{+-}, 1^{-+}, 1^{+-}, 2^{-+}, 2^{+-}$ **~1.9 GeV/c²**

S=0 S=1

Lattice calculations --- 1^{-+} nonet is the lightest

UKQCD (97)	1.87 ± 0.20
MILC (97)	1.97 ± 0.30
MILC (99)	2.11 ± 0.10
Lacock (99)	1.90 ± 0.20
Mei(03)	2.01 ± 0.10
Bernard (04)	1.79 ± 0.14

~2.0 GeV/c²

1^{-+}
0^{+-} } Splitting ≈ 0.20
2^{+-}

In the charmonium sector:

1^{-+}	4.39 ±0.08
0^{+-}	4.61 ±0.11

Splitting = 0.20

Experiment: hybrid searches

Most of what is presently known about the hybrid spectrum has come from one experiment: **BNL E852**

$\pi^- p \rightarrow X n$ at 18 GeV

- $\pi_1(1400)$ – seen in $\eta\pi$
- $\pi_1(1600)$ – seen in $\rho\pi$, $f_1\pi$, $b_1\pi$, $\eta'\pi$
- $\pi_1(2000)$ – seen in $f_1\pi$, $b_1\pi$

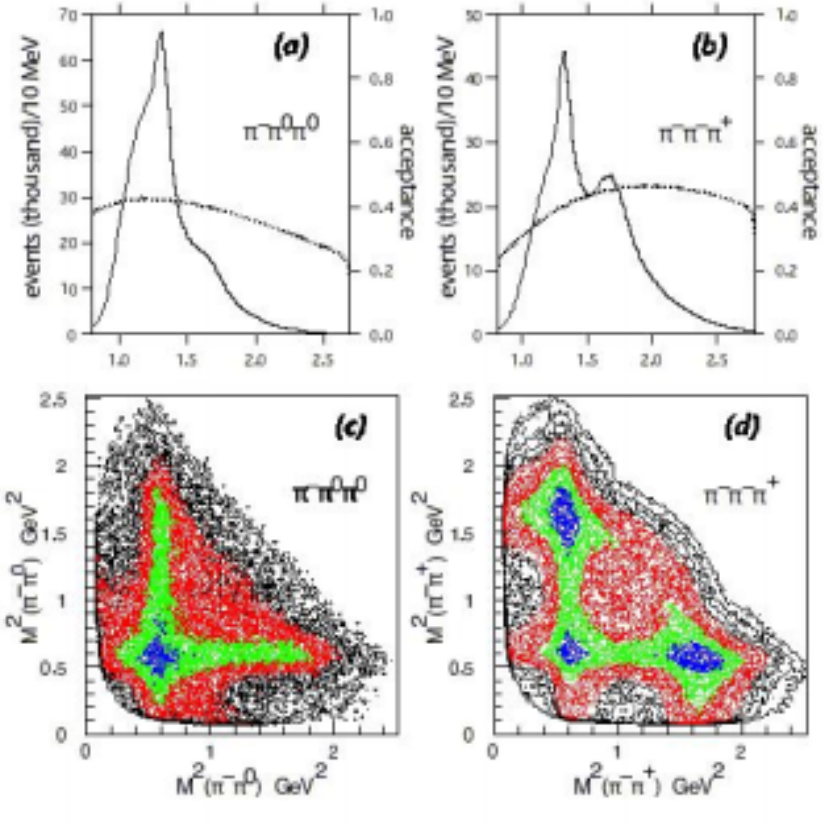
General observations regarding these analyses

- exotic intensities are typically 1/10 dominant ones
- requires large samples (~10^6 in exclusive channels)
- requires good acceptance (uniform and well-understood)
- requires access to high-multiplicity final states

Experiment: hybrid photoproduction

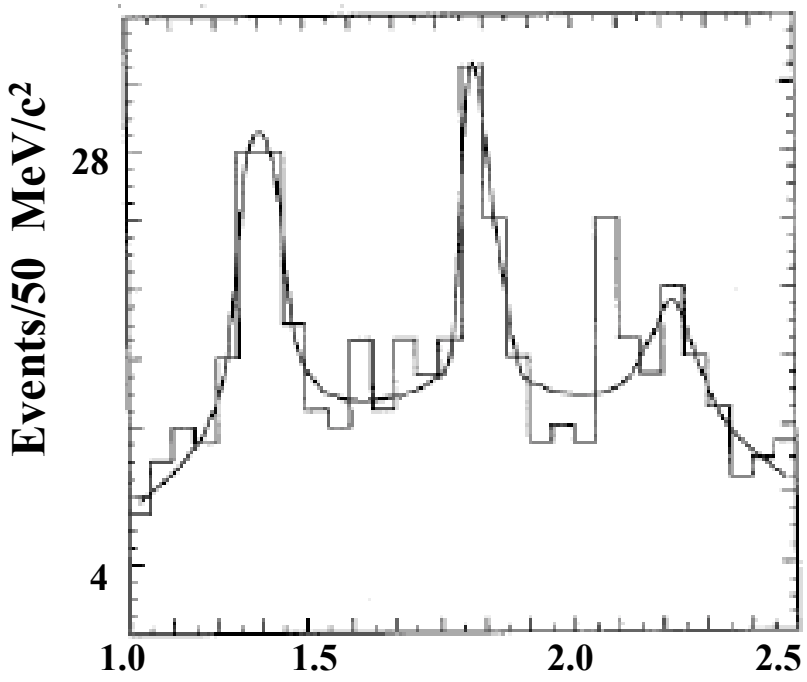
Unexplored territory with unique advantages for hybrid search

$\pi^- p \to \pi^+ \pi^- \pi^- p$



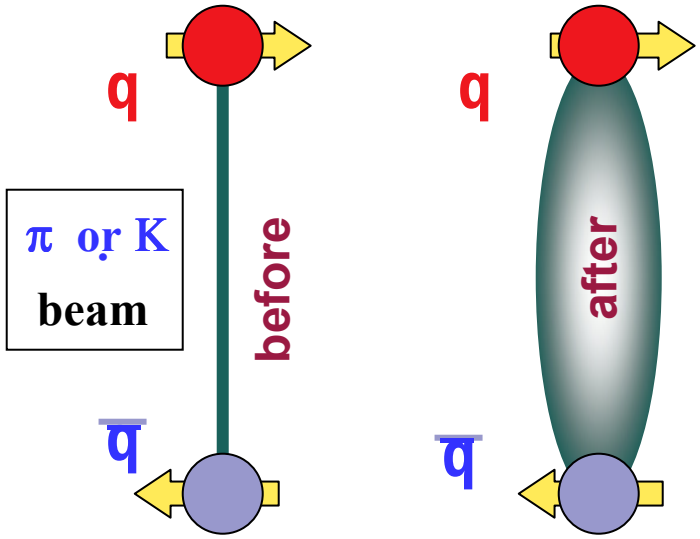
BNL ca. 1998 @ 18 GeV

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



SLAC ca. 1993 @ 19 GeV

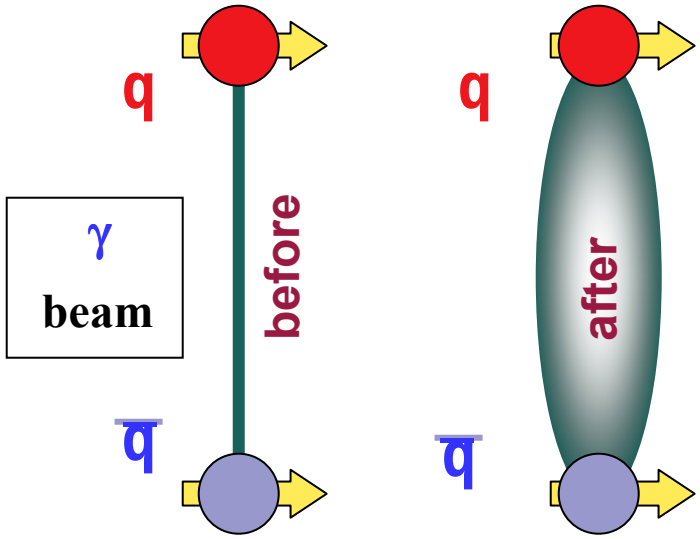
Experiment: hybrid photoproduction



Quark spins anti-aligned

A pion or kaon beam,
when scattering occurs,
can have its flux tube excited

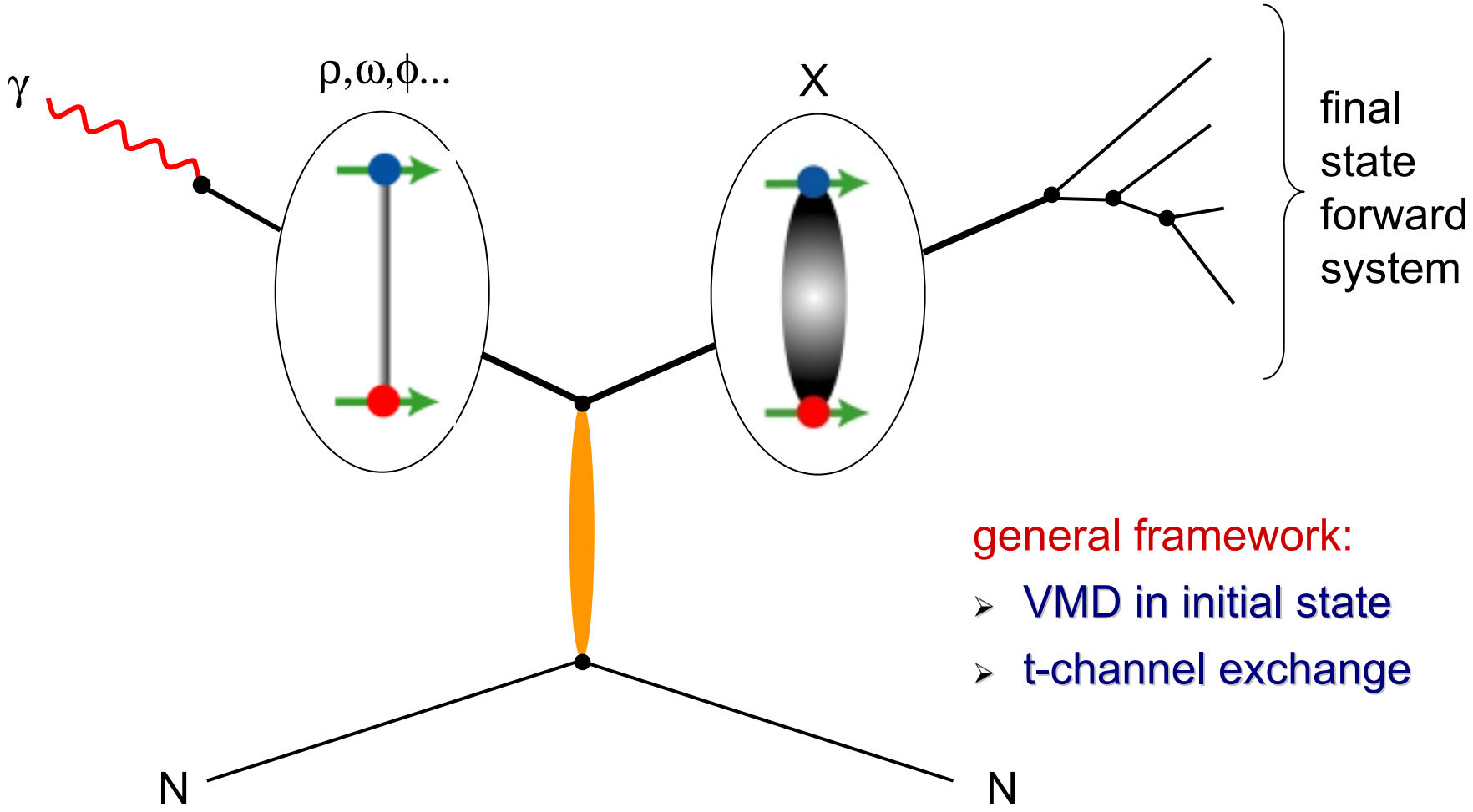
Data from these reactions show
evidence for gluonic excitations
(small part of cross section)



Quark spins aligned

Almost no data is available
in the mass region
where we expect to find exotic hybrids
when flux tube is excited

Experiment: photoproduction phenomemology



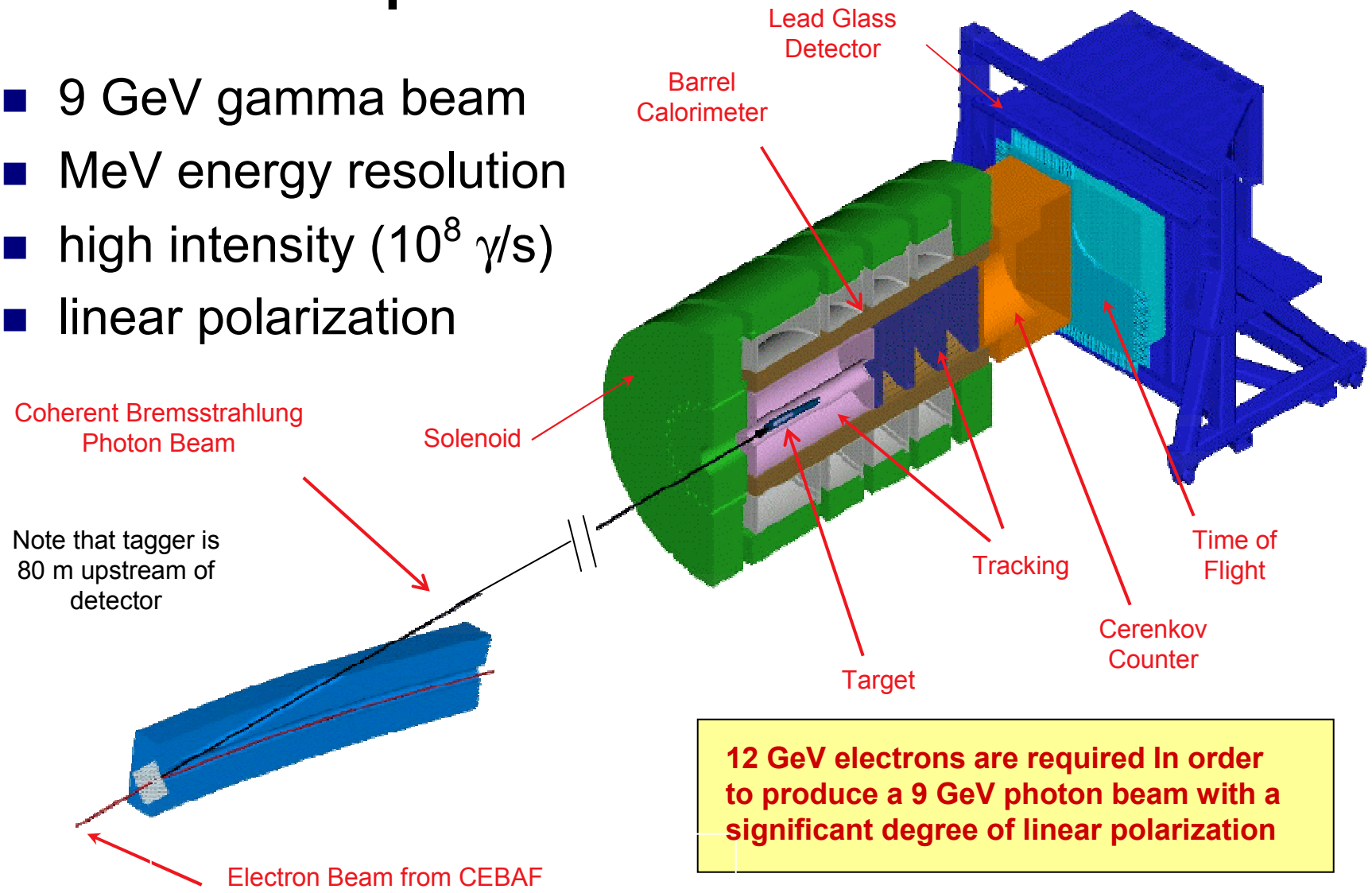
general framework:

- VMD in initial state
- t-channel exchange

GlueX Experiment

www.gluex.org

- 9 GeV gamma beam
- MeV energy resolution
- high intensity (10^8 γ/s)
- linear polarization



12 GeV electrons are required In order to produce a 9 GeV photon beam with a significant degree of linear polarization

GlueX Experiment: beam polarization

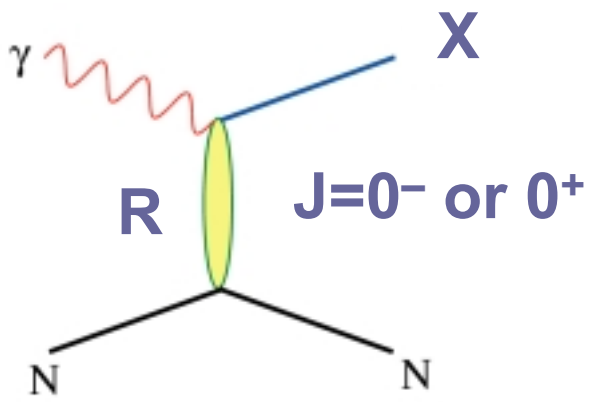
Gottfried-Jackson frame

for R with J = 0

photon **exchange particle**

$$L = 0,\ 1,\ \text{or}\ \ 2$$

$$P_V = P_\gamma \cdot P_X \cdot (-1)^L$$



Suppose we want to distinguish the exchange: O^+ from 0^- (A^N from A^U)

For circular polarization:

photon **V = vector**

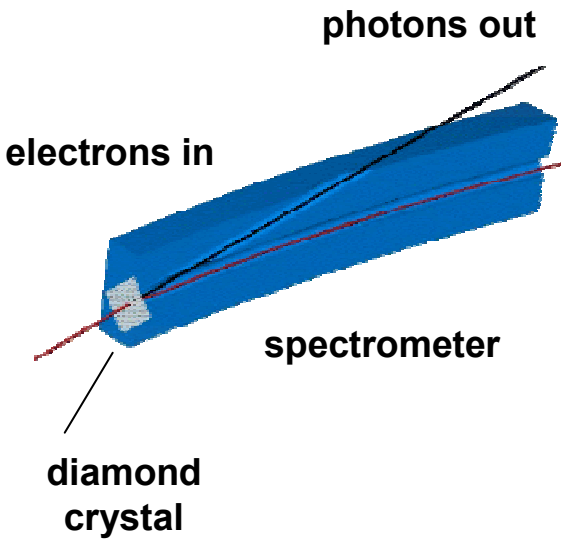
$|R\rangle$ → **m = 1** → $A^N + A^U$

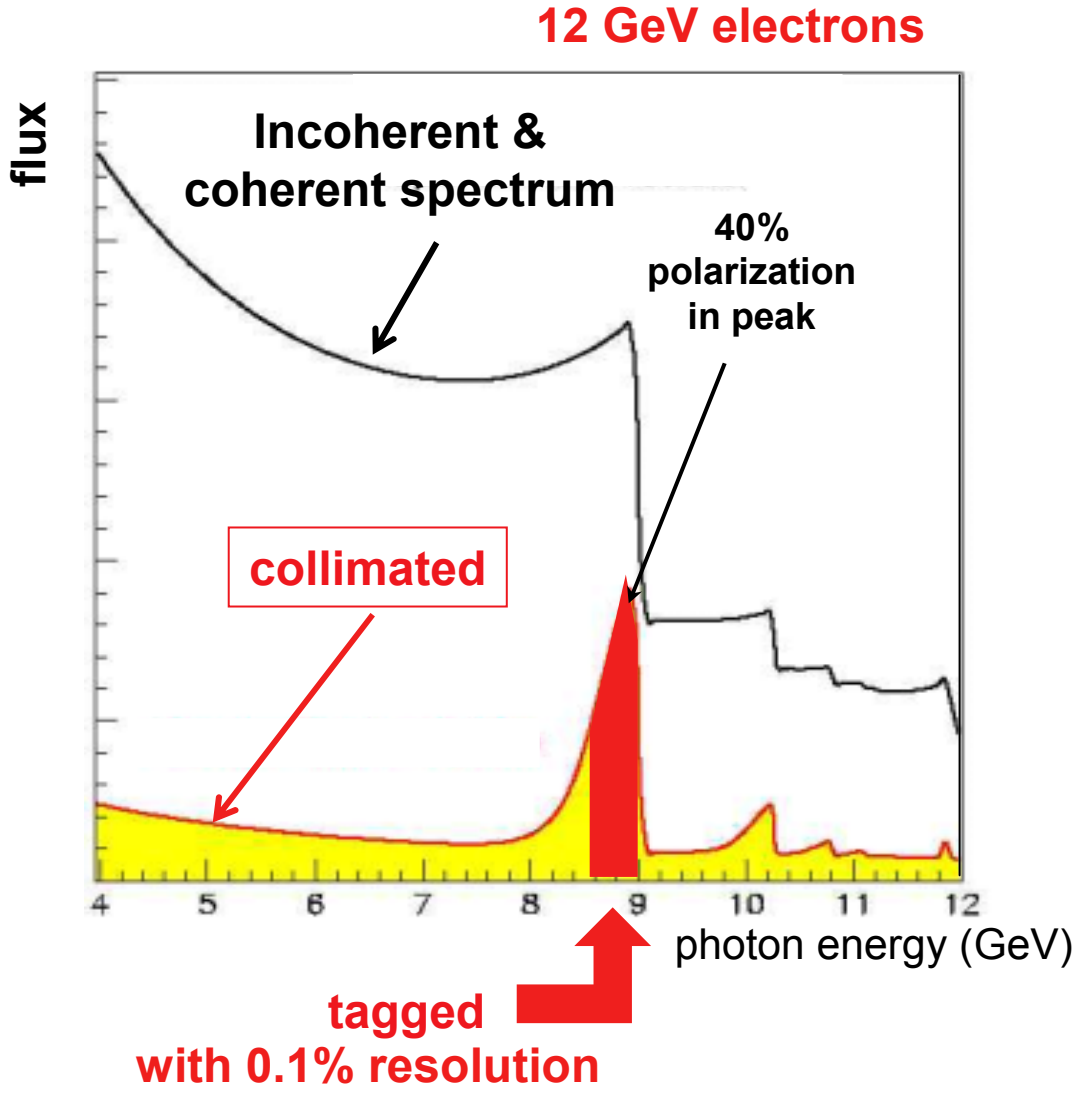
$|L\rangle$ → **m = -1** → $A^N - A^U$

- With linear polarization we can isolate A^N from A^U
- Circular polarization gives access to their interference

GlueX Experiment: photon beam

The coherent bremsstrahlung technique provides requisite energy, flux and polarization



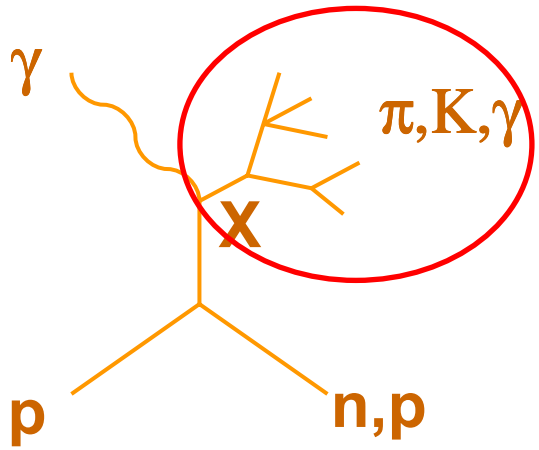


GlueX Experiment: detector design

The GlueX detector design has been driven by the need to carry out amplitude analysis.

π_1 η_1 η'_1 b_2 h_2 h'_2 b_0 h_0 h'_0

1^{-+} 2^{+-} 0^{+-}



$\eta_1 \rightarrow a^+_1\pi^- \rightarrow (\rho^o\pi^+)(\pi^-) \rightarrow \pi^+\pi^-\pi^+\pi^-$

all charged

$h_0 \rightarrow b^o_1\pi^o \rightarrow (\omega\pi^o)\gamma\gamma \rightarrow \pi^+\pi^-\gamma\gamma\gamma\gamma\gamma$

many photons

$h'_2 \rightarrow K^+_1K^- \rightarrow \rho^o K^+ K^- \rightarrow \pi^+\pi^-K^+K^-$

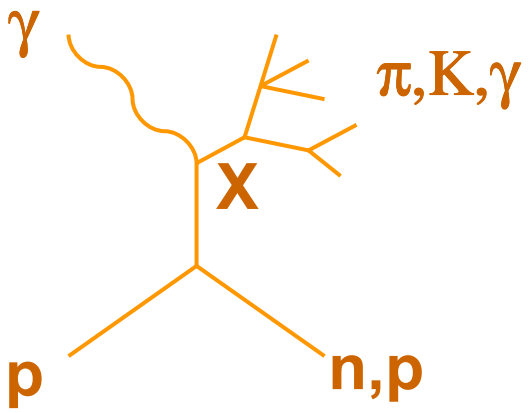
strange particles

Final state particles: $\pi^\pm$ $K^\pm$ γ p n K_L

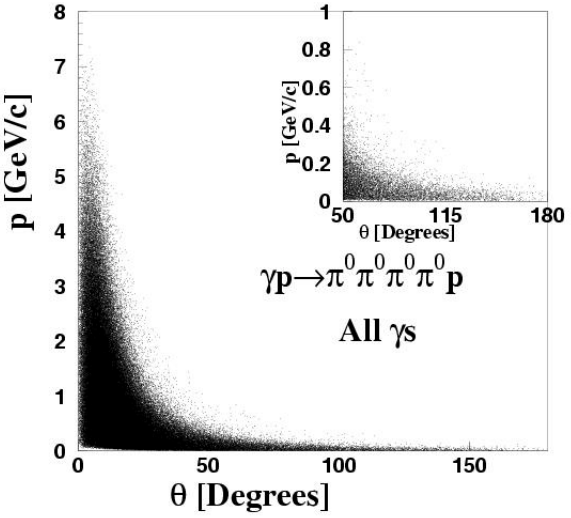
GlueX Experiment: topologies

t-channel meson photoproduction

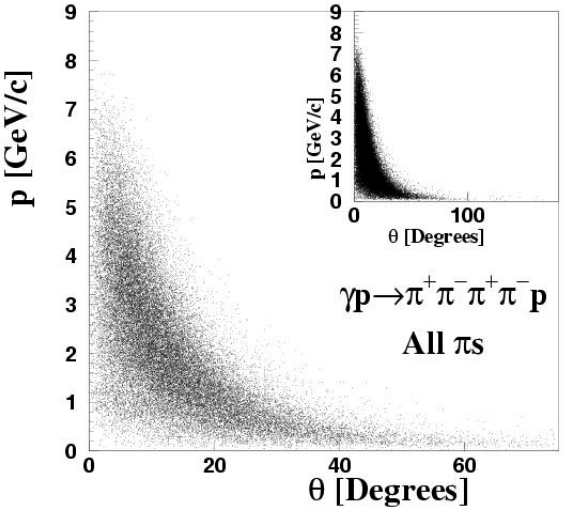
$\sigma(t) \sim e^{-\alpha t}$



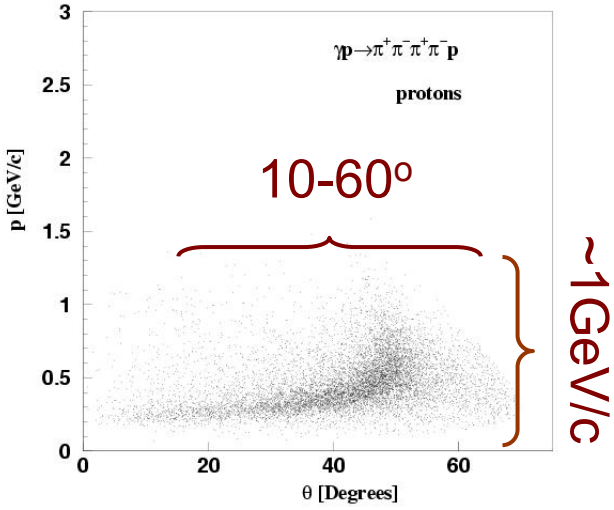
photons



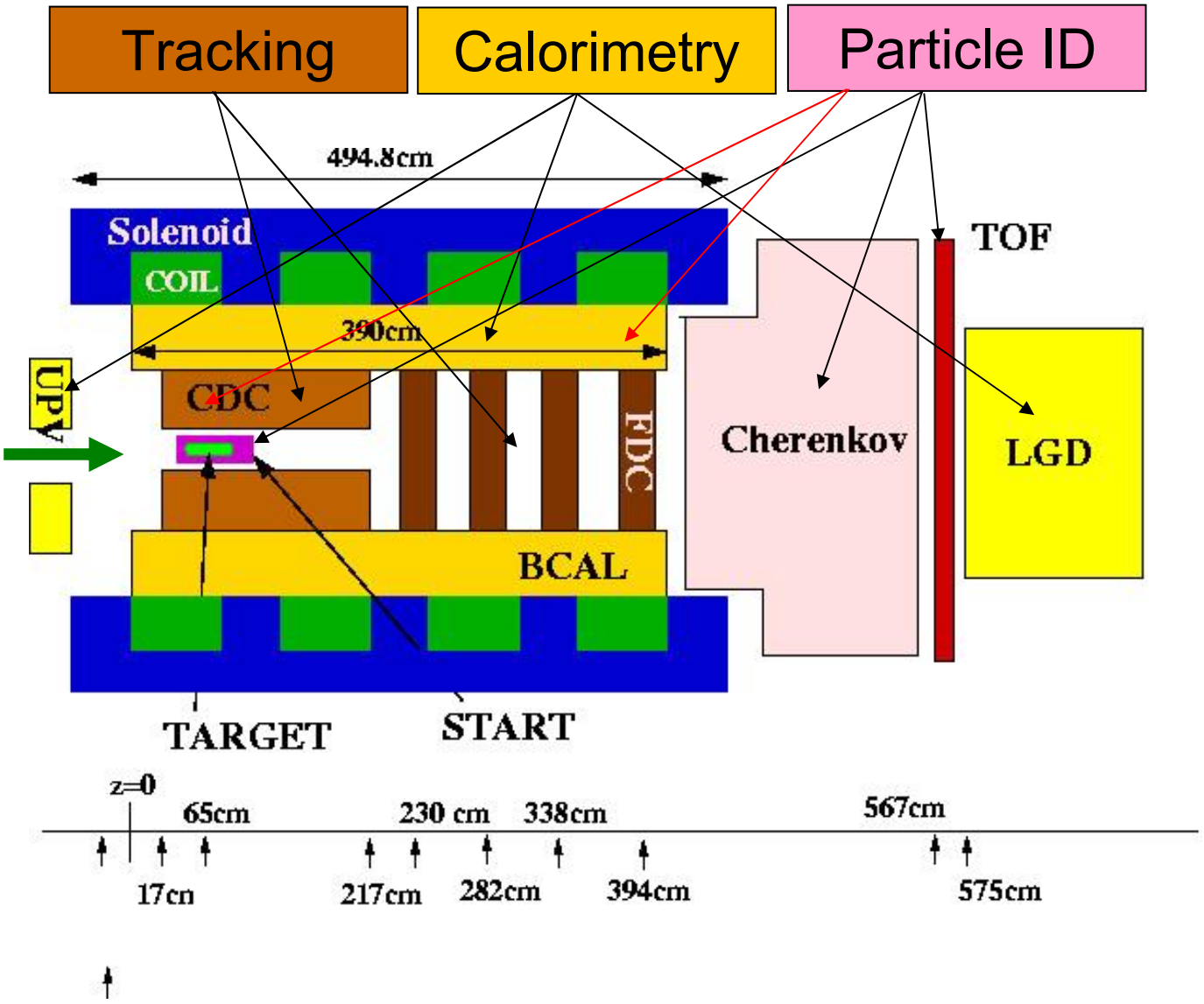
pions



protons

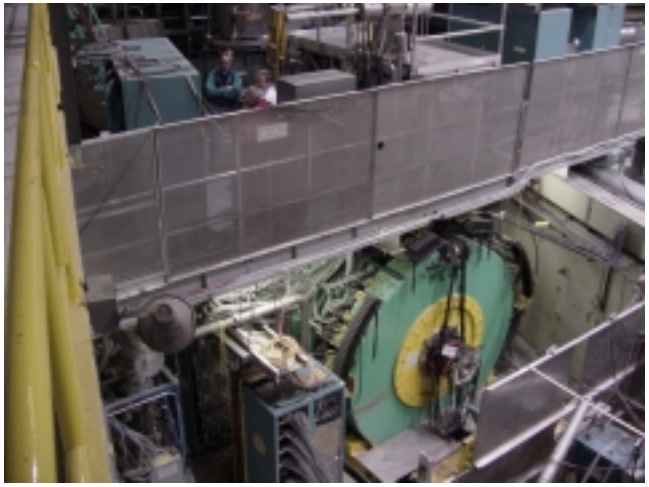


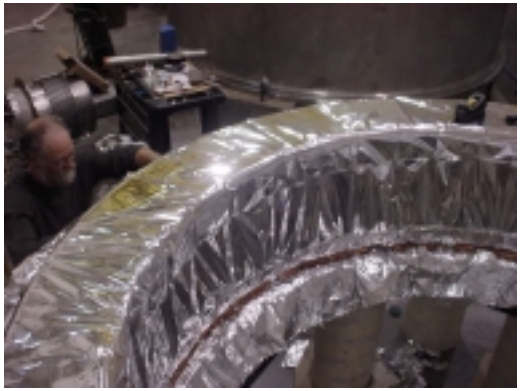
GlueX Experiment: components



GlueX Experiment: superconducting solenoid

LASS Solenoid
Superconducting 2.24T
Used in Los Alamos MEGA Experiment.
Moved to IUCF for refurbishing Oct. 2003.

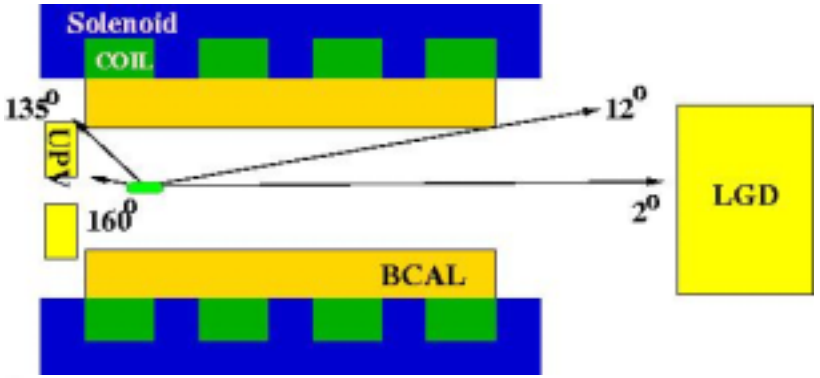




GlueX Experiment: calorimetry

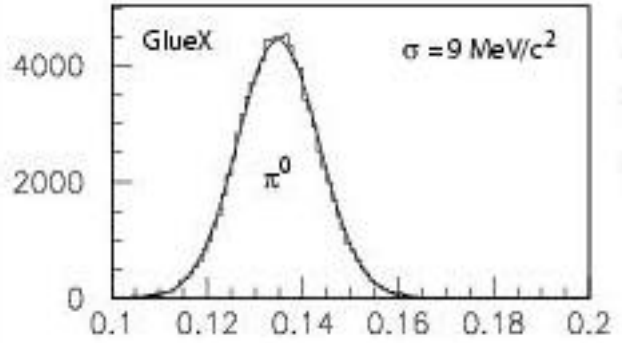
Forward Calorimeter LGD

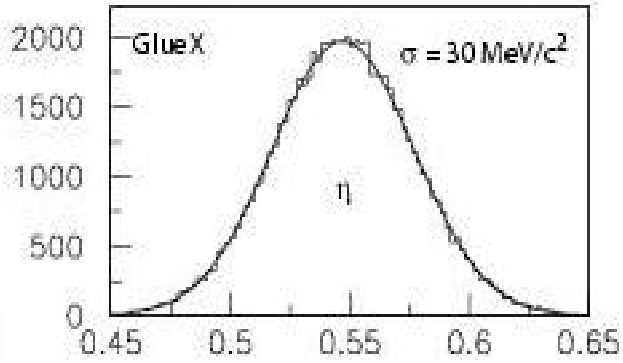
- Existing lead glass detector
- 2500 blocks
- $\sigma_E/E \cdot 0.036+0.073/E^{1/2}$
- 100 MeV < $E\gamma$ < 8 GeV



Barrel Calorimeter BCAL

- Lead-sci-fiber sandwich
- 4m long cylinder
- $\sigma_E/E \cdot 0.020+0.05/E^{1/2}$
- ~20MeV < E_γ < 3 GeV
- 200ps timing resolution
  - z-position of shower
  - time-of-flight

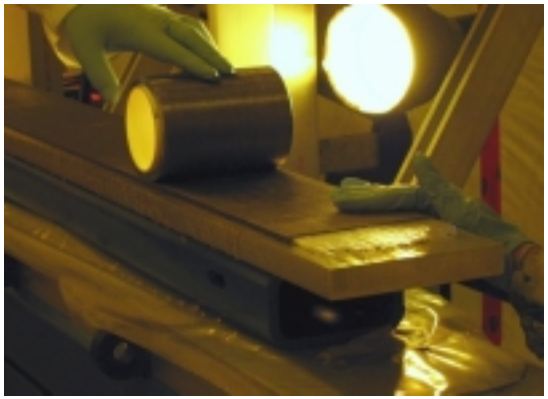


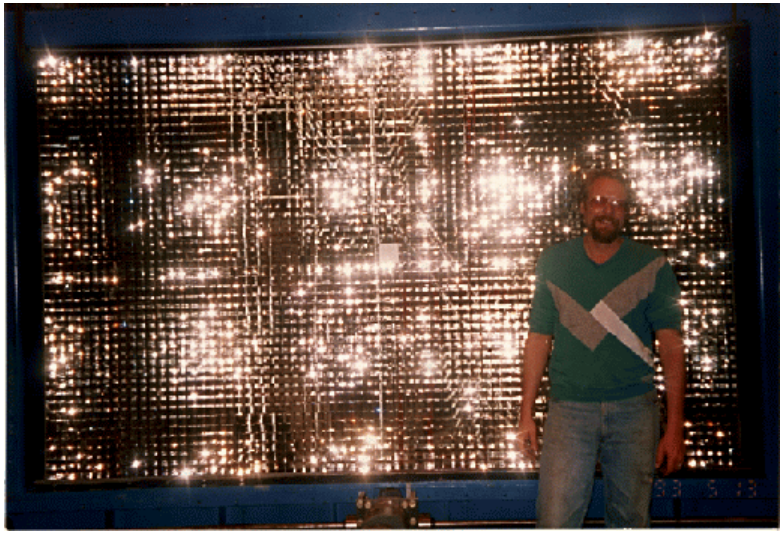


Upstream Photon Veto UPV

- Veto photons
- 20MeV < E_γ < 300 MeV

GlueX Experiment: calorimetry

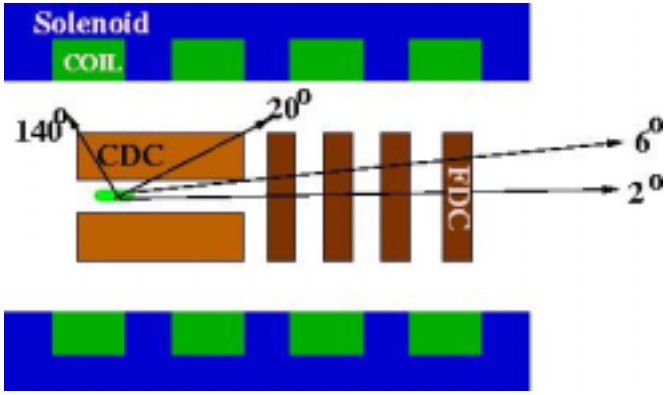




GlueX Experiment: tracking

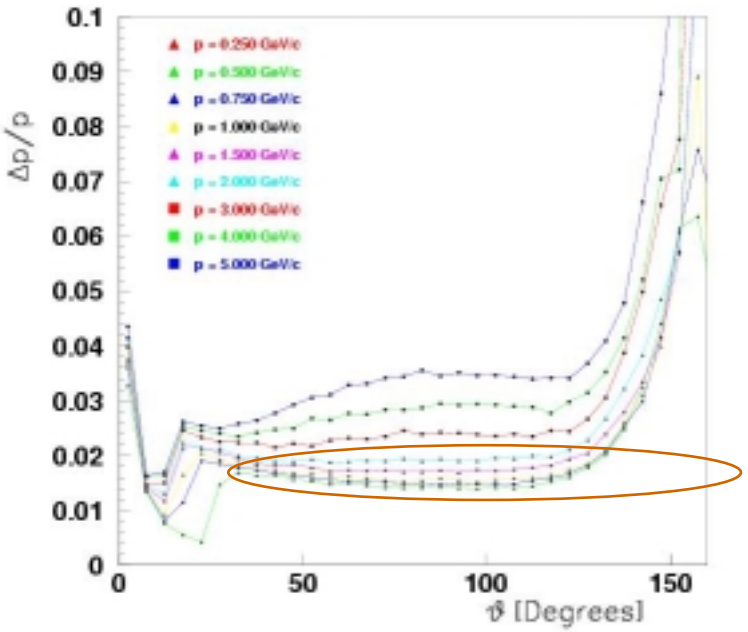
Forward Region FDC

- 4 packages of planar drift chambers
- anode + cathode readout
- six planes per package
- σ_{xy}=150μm
- active close to the beam line.



Central Region CDC

- cylindrical straw-tube chamber
- 23 layers from 14cm to 58cm
- 6° stereo layers
- $\sigma_{r\phi}$=150μm σ_z = 2mm
- minimize downstream endplate
- dE/dx for p<450 MeV/c ← Necessary for protons



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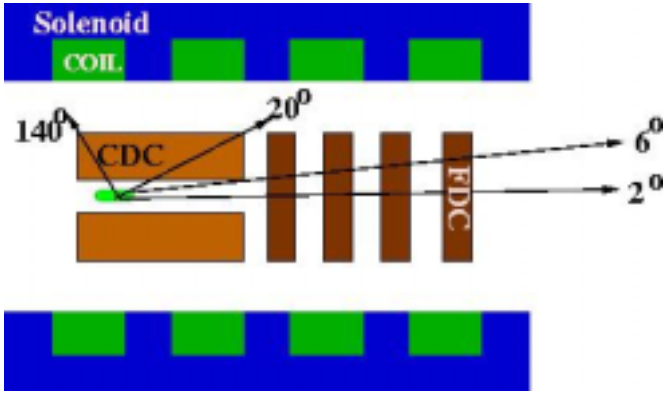

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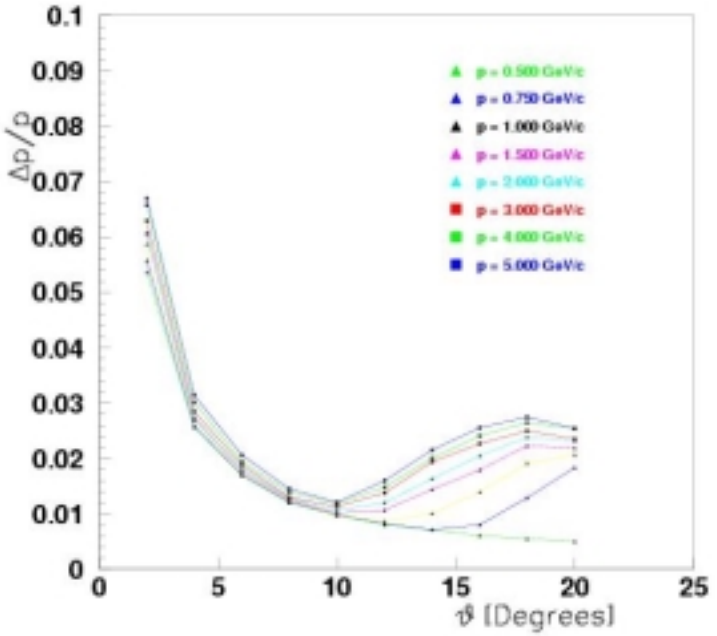
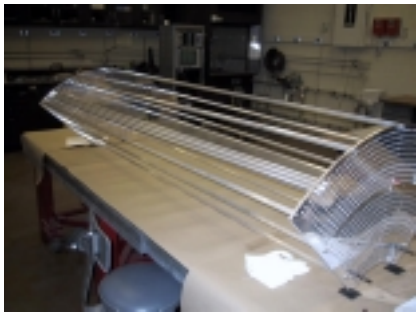
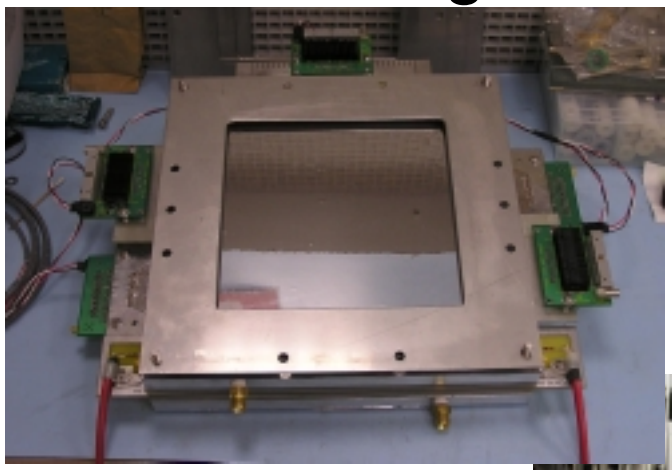
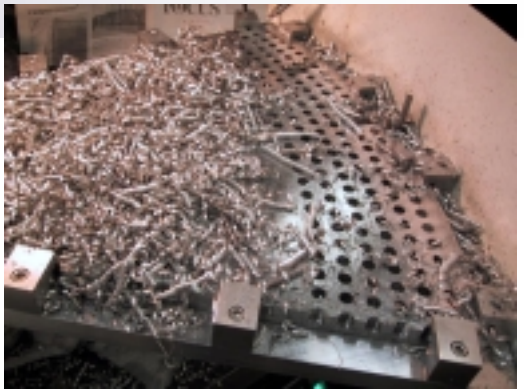
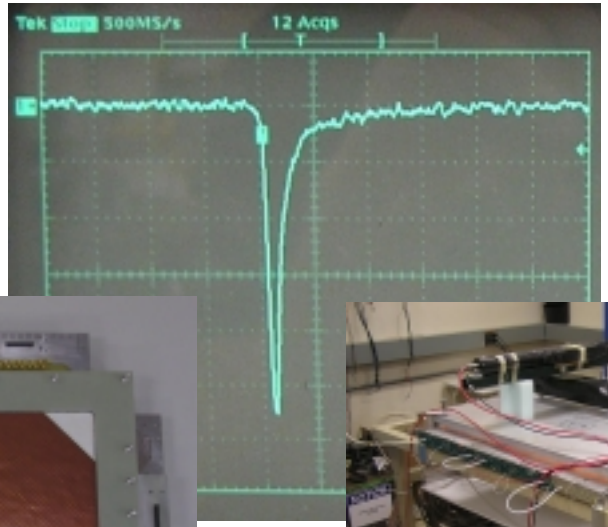


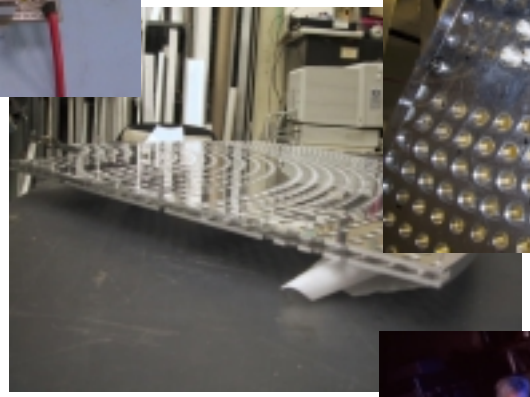
GlueX Experiment: tracking

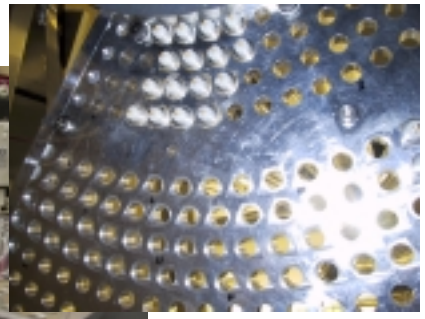


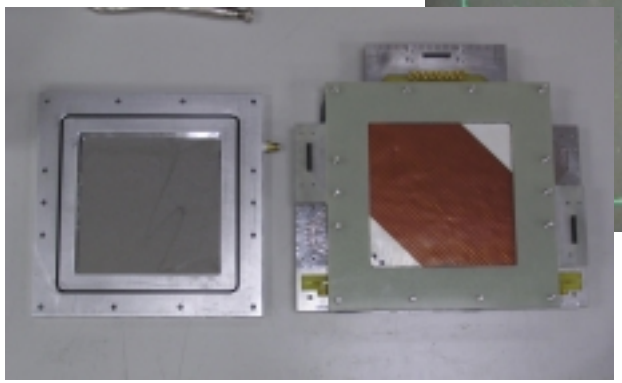


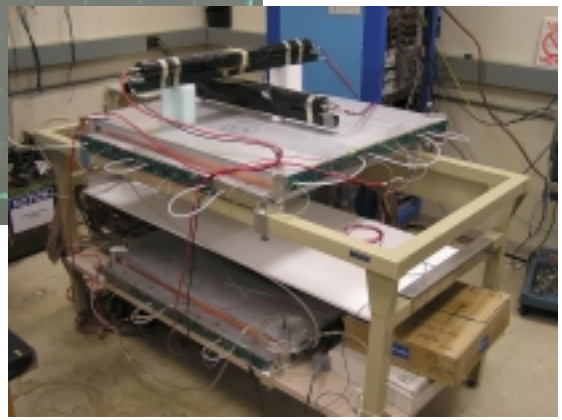








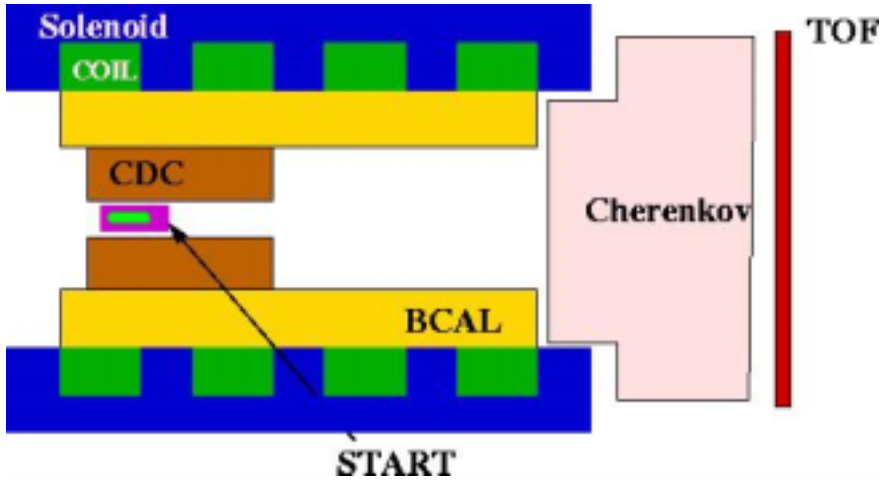




GlueX Experiment: particle identification

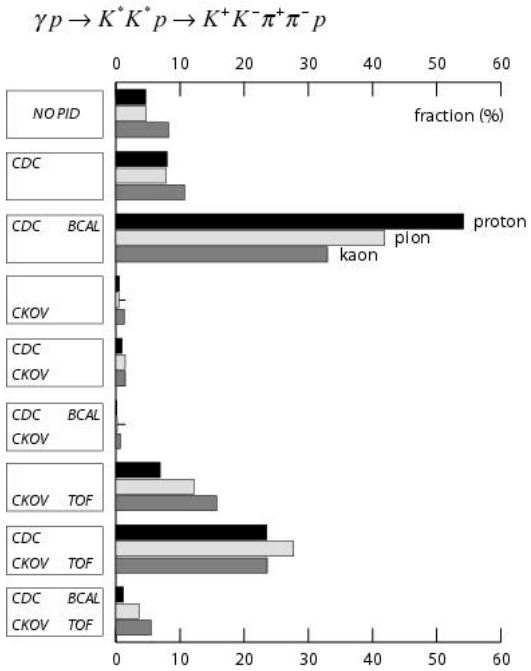
Time-of-flight Systems

- Forward tof ~80ps
- BCAL ~200ps
- Start counter



dE/dx Information

- dE/dx in both FDC and CDC
- p<450 MeV/c

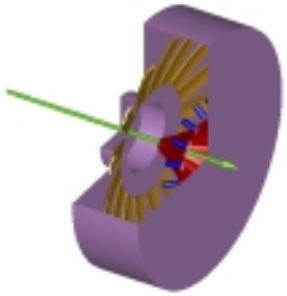


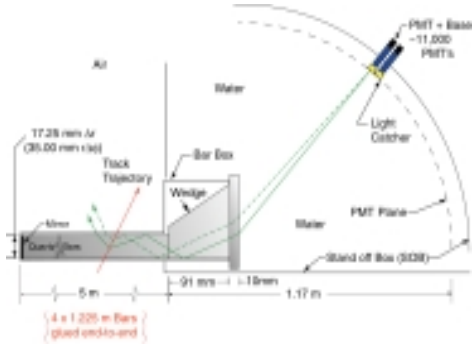
Cherenkov Detector

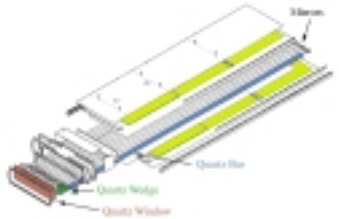
- DIRC π K p separation

GlueX Experiment: particle identification

The documentation discusses both a DIRC design and an atmospheric pressure Gas Cherenkov design
We do not believe that the latter will satisfy the physics requirements of GlueX.



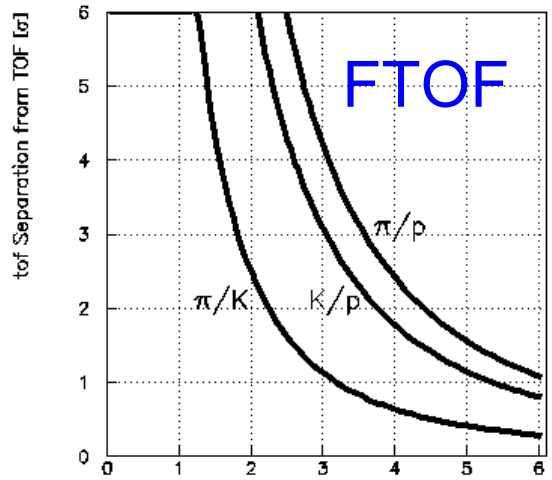


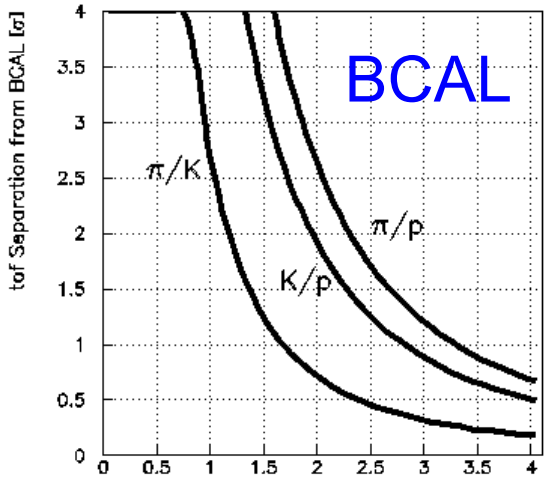


The DIRC design will accomplish the physics goals of the GlueX experiment.

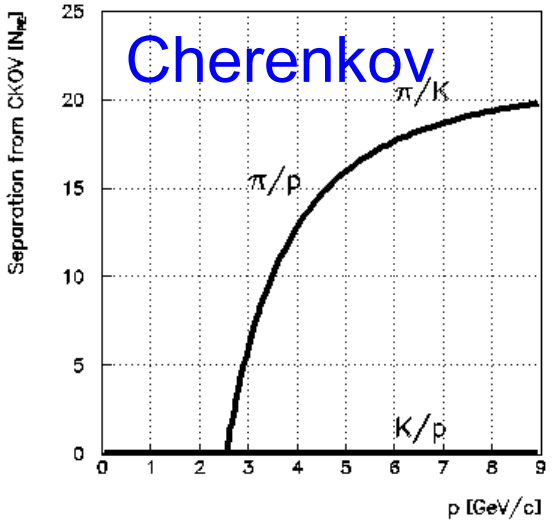
There are collaborators interested in pursuing the DIRC design and construction.

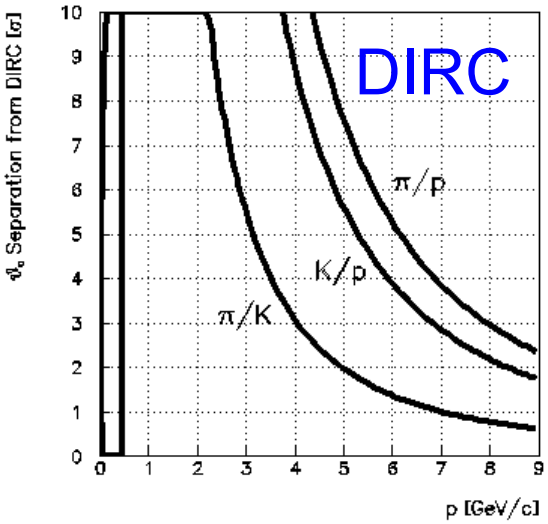
GlueX Experiment: particle identification

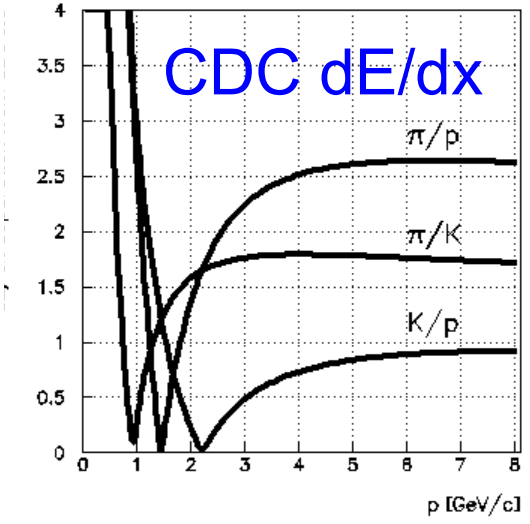




Separation from individual systems







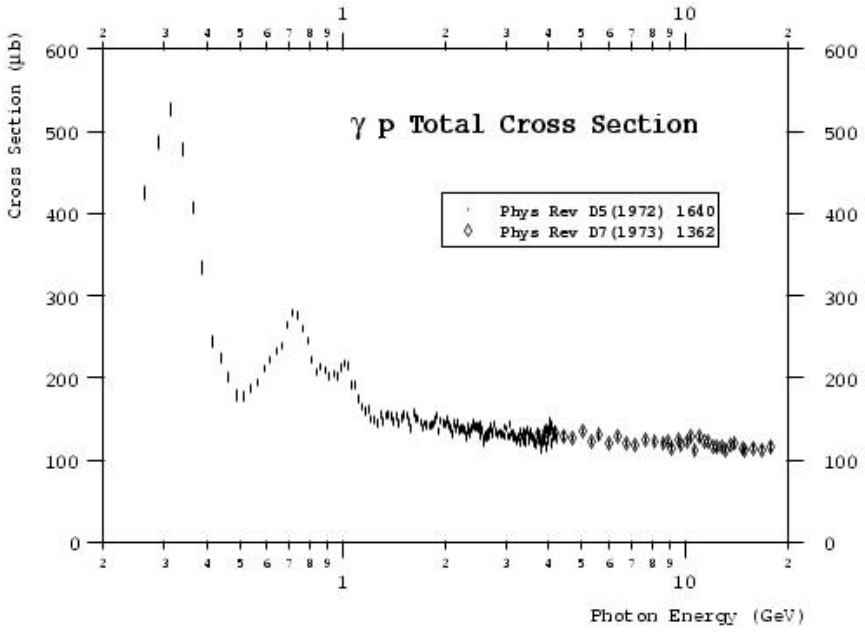
GlueX Experiment: event rates

Initially 10^7 tagged γ/s
Design detector for 10^8

JLab CLAS runs at 10^7 already.

At 10^7, the total hadronic rate is 37kHz
the tagged hadronic rate is 1.4kHz
At 10^8, the total hadronic rate is 370kHz
the tagged hadronic rate is 14kHz

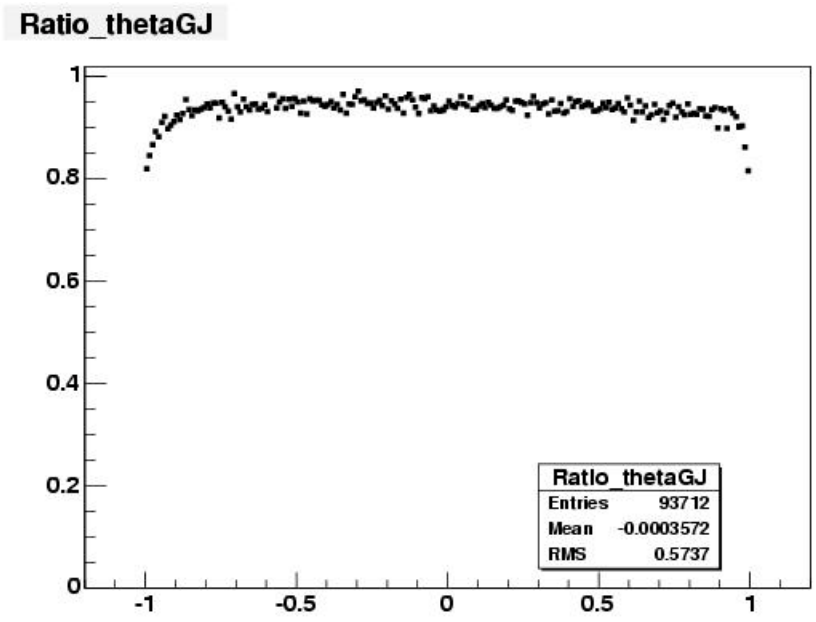
Running at 10^7 for 1 year will exceed current photoproduction data by several orders of magnitude and will exceed current π data.



GlueX Experiment: acceptance

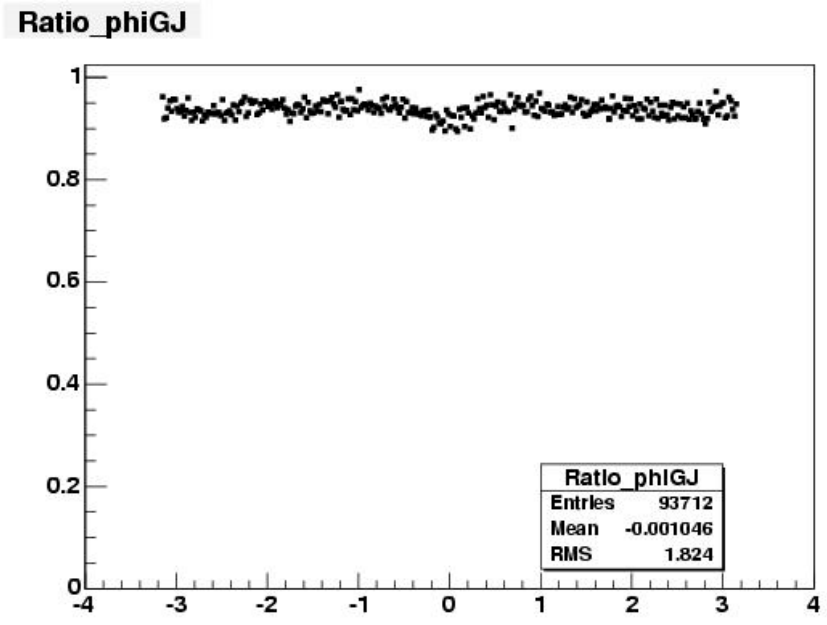
Very uniform over PWA angles $\begin{cases} \varepsilon_\pi \sim 0.99 \\ \varepsilon_\gamma \sim 0.98 \end{cases}$

$$\gamma p \rightarrow \eta_1 p \rightarrow \pi^+\pi^- 4\gamma p$$



$\cos\theta_{GJ}$

Acceptance

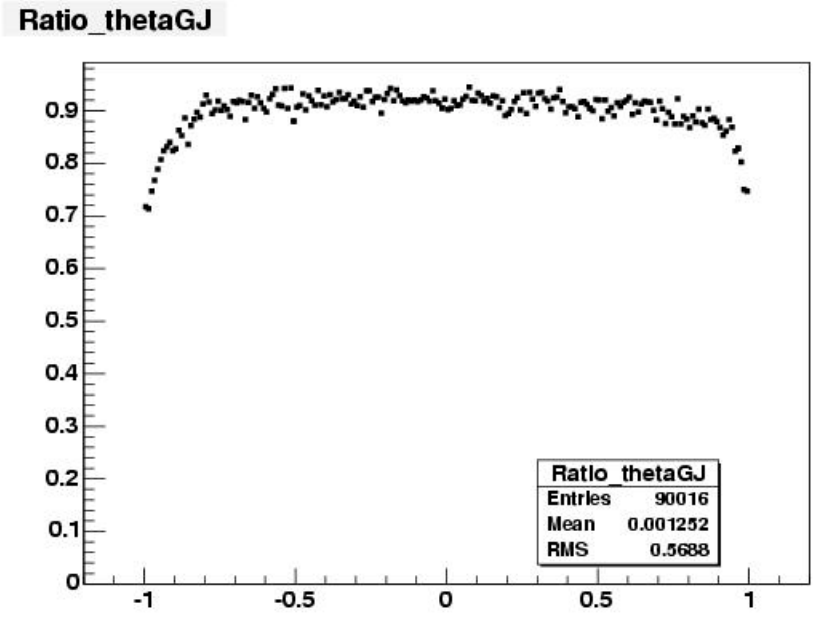


ϕ_{GJ}

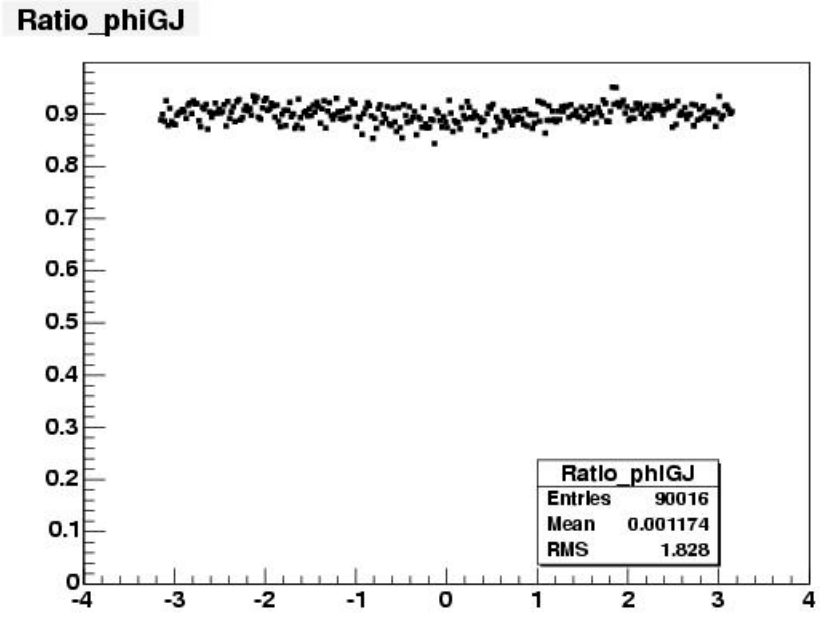
GlueX Experiment: acceptance

Very uniform over PWA angles $\begin{cases} \varepsilon_\pi \sim 0.99 \\ \varepsilon_\gamma \sim 0.98 \end{cases}$

$$\gamma p \rightarrow \eta_1 p \rightarrow 8\gamma p$$



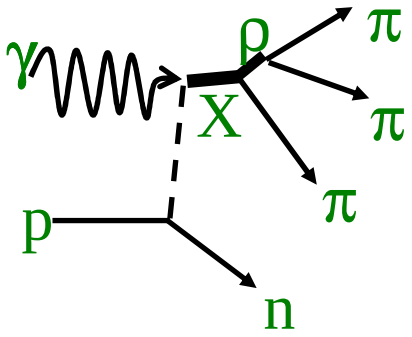
$\cos\Theta_{GJ}$



Φ_{GJ}

GlueX Analysis: test of PWA

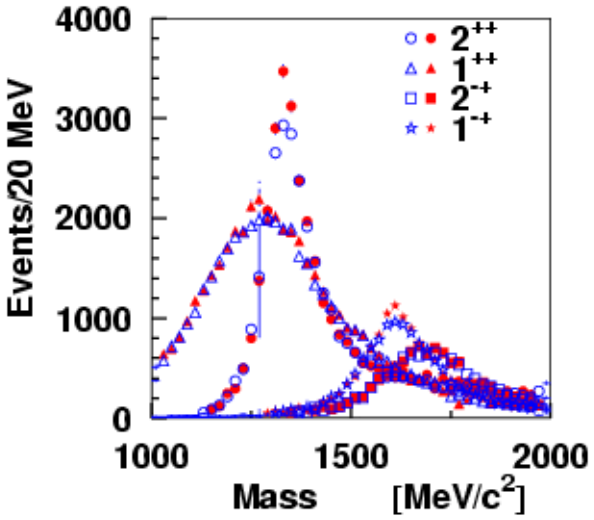
Double-blind study of 3π final states

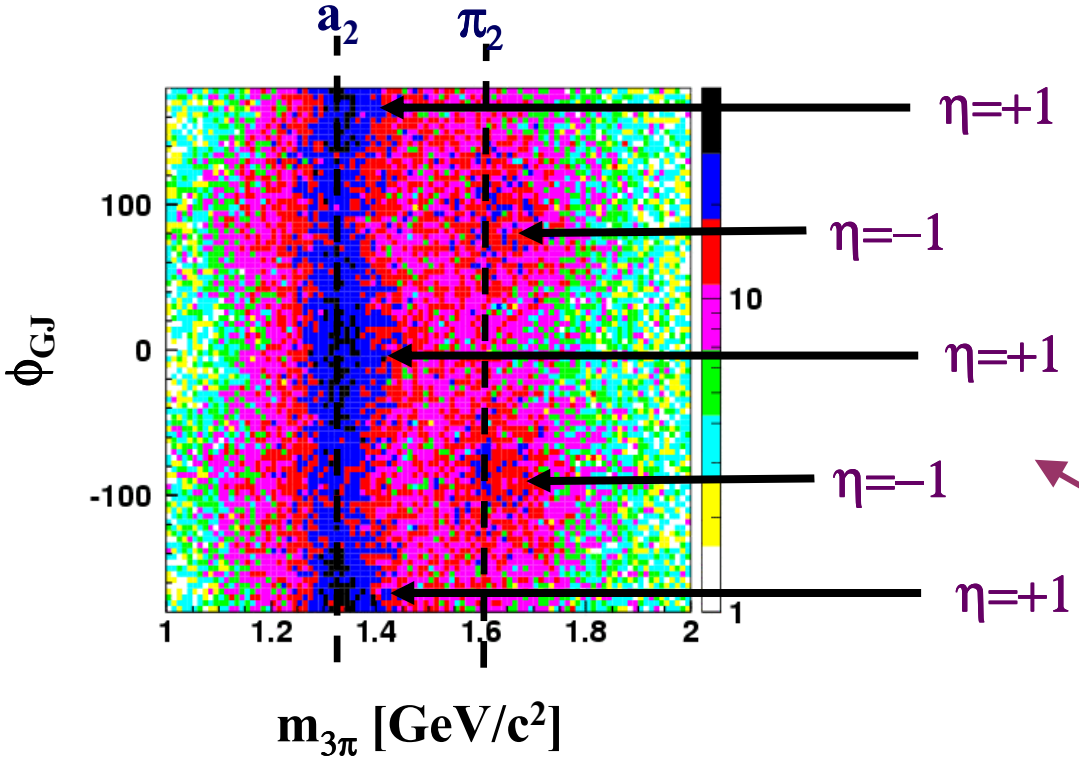


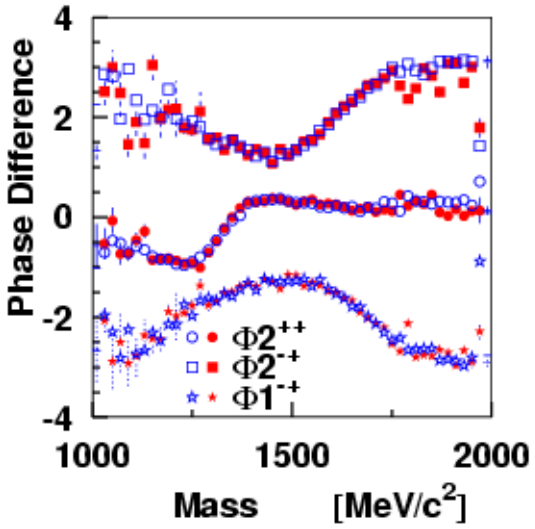
GlueX Monte Carlo

$\gamma p \rightarrow \pi_1^+ n \rightarrow \pi^+\pi^+\pi^- n$

$\rightarrow \pi^+\pi^0\pi^0 n$



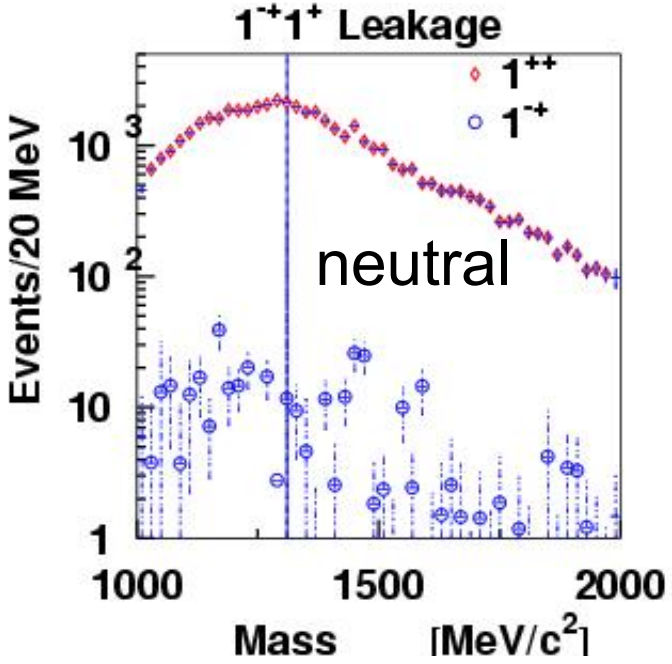




Polarization effects!

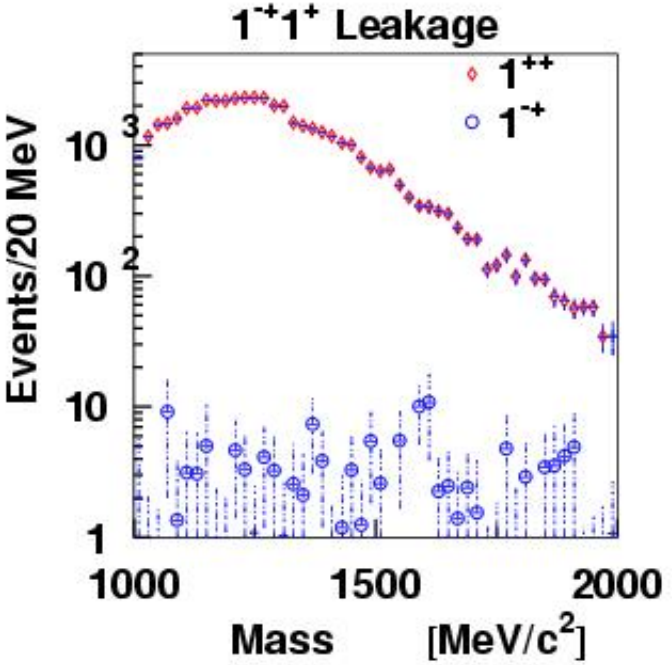
GlueX Analysis: test of PWA

If acceptance is not well understood, the PWA will "leak" one wave into another.



Break the GlueX detector in MC:

- distort B-field
- degrade resolution
- change hole sizes
- distort beam energy



Largest leakage is ~ 1/2% of a strong signal: $a_1(1^{++}) \rightarrow \pi_1(1^{-+})$

GlueX Analysis: summary

- Double-blind test showed capability to pull out signals that are ~1% of a strong signal using PWA.
- It is extremely difficult to produce leakage that is as large as 1%.
- Assuming a good theoretical understanding, if hybrids are present at ~1% of normal mesons strength, this detector will be able to find them.

Baryon spectroscopy with GlueX

From the GlueX statement to the Jefferson Lab PAC27 (Jan. 05)

- GlueX is an "electronic bubble chamber." The interplay between excited meson and baryon resonance production will be studied – with excellent acceptance for both.

- GlueX will also search in the hyperon and **cascade sectors** with the potential to determine spin and parity of these states.

Thus far, the design effort has focused on optimizing the experiment for meson spectroscopy. How would that apparatus function as an excited baryon spectrometer?

Baryon spectroscopy with GlueX

Unique features of cascade decays:

- ✓ large particle multiplicites
- ✓ both neutral and charged
- ✓ need good K/π separation
- ✓ acceptance at low momenta, wide angles
- ✓ good momentum resolution (narrow peaks)
- ★ energy greater than 10 GeV
- ★ detached vertices

Take an example: a medium-difficult final state

$$\gamma p \rightarrow K^0 K^{*+} \Xi^{*0} \rightarrow \pi^0 \pi^0 K^+ \pi^0 \Lambda K^0$$
$$= 5\pi^0 \pi^- K^+ p$$

Baryon spectroscopy with GlueX

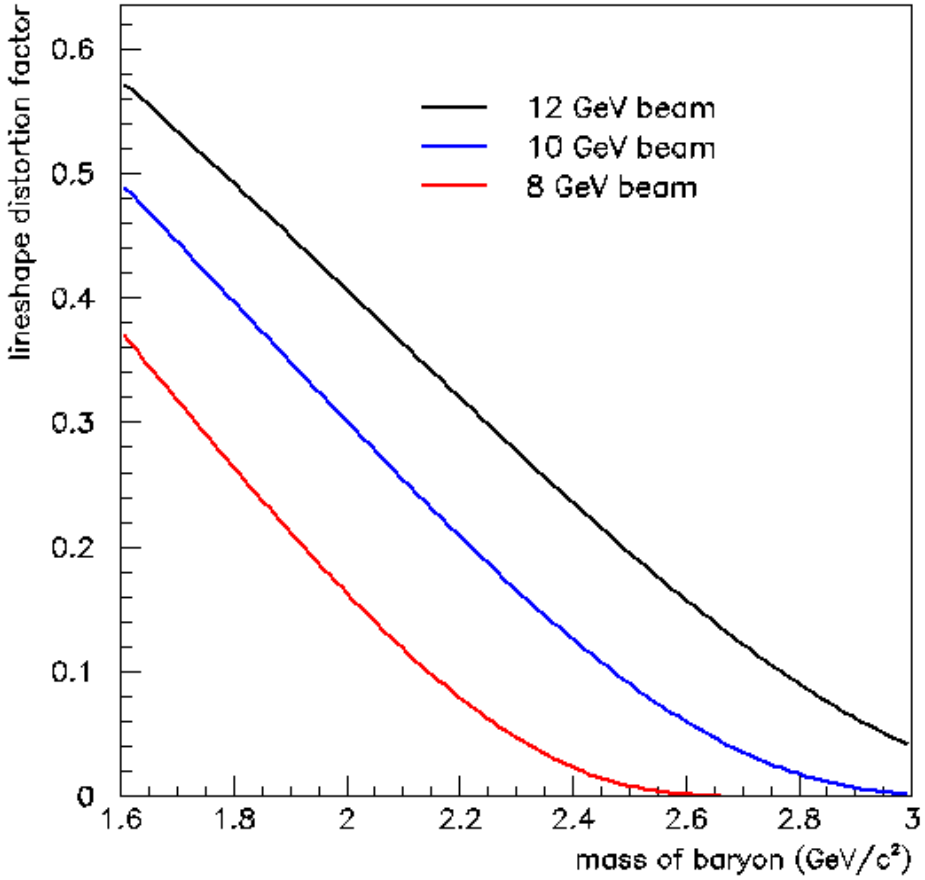
$\gamma p \rightarrow K^0 K^{*+} \Xi^{*0} \rightarrow \pi^0 \pi^0 K^+ \pi^0 \Lambda K^0$

$= 5\pi^0 \pi^- K^+ p$

Vary the mass
Watch production rate
as function of beam energy

GlueX beam energy range
8.4 - 9.0 GeV
driven by need for polarization

Baryon spectroscopy has no use for beam polarization
=> run near the endpoint



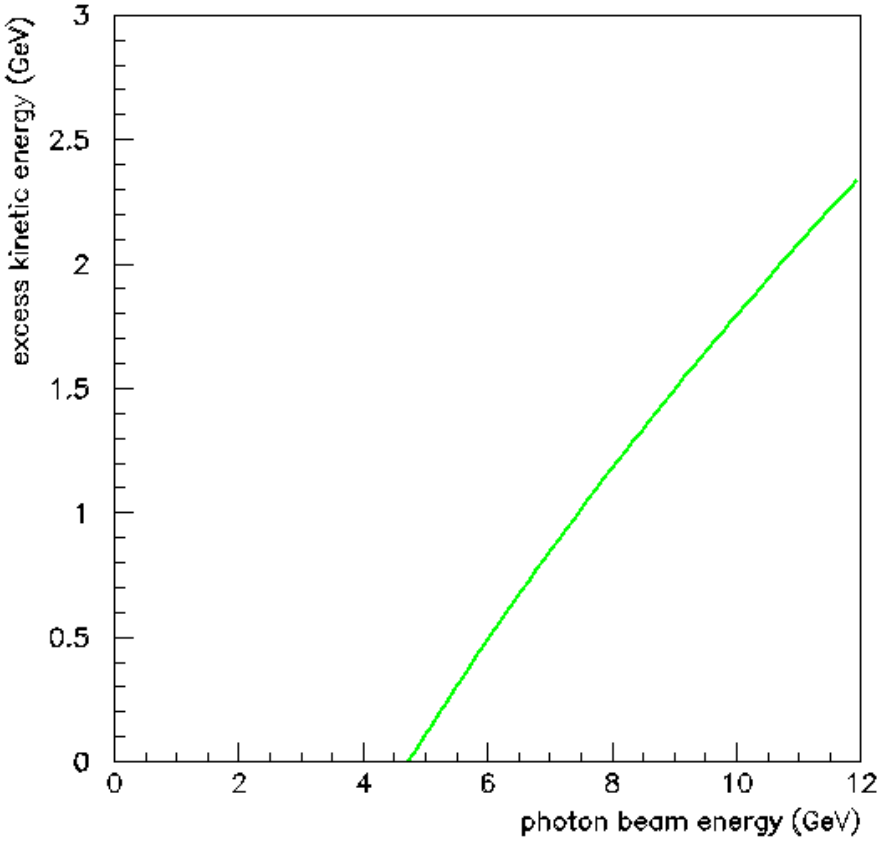
Finding "Cascaderium" with GlueX

$\gamma d \rightarrow 2K^+ 2K^0 [\Xi^0 \Xi^-]$

$\gamma \alpha \rightarrow 2K^+ 2K^0 [\Xi^0 \Xi^-]$ n p

Whatever worries one may have about rates for this process in GlueX…

beam energy is probably not going to be a problem.



Australia

Mexico

Russia

Canada

GlueX Collaboration

100 Physicists
28 Institutions
7 Countries

+ an active theory group

United Kingdom

Greece

USA