GlueX a search for gluonic degrees of freedom in mesons.

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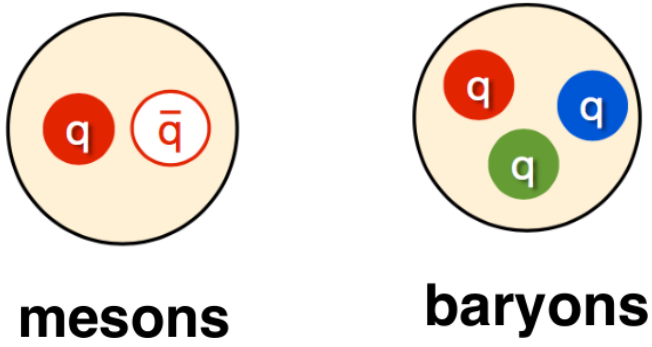
TJNAF

July 21, 2017

QCD and Hadron Spectroscopy

- Visible universe: Mostly Hadrons
- Quark model: mesons, baryons
  $q\bar{q}$, qqq



QCD and Hadron Spectroscopy

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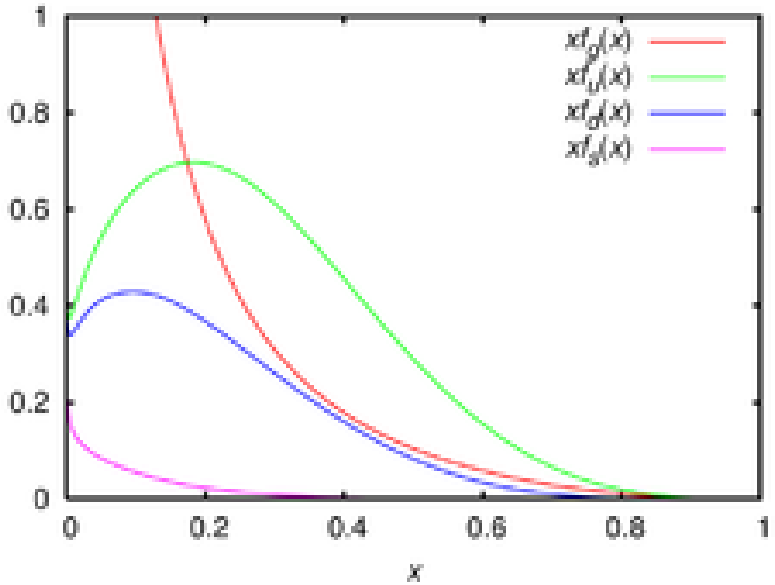
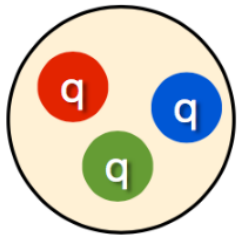
- Hadron mass is mostly dynamic
- QCD, underlying theory of quark interactions



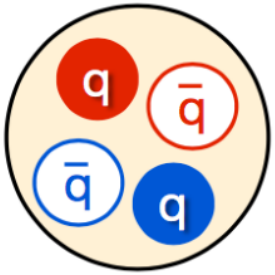
QCD and Hadron Spectroscopy

- Visible universe: Mostly Hadrons
- Quark model: mesons, baryons
  $q\bar{q}$, qqq
- Hadron mass is mostly dynamic
- QCD, underlying theory of quark interactions
- QCD allows other configurations:

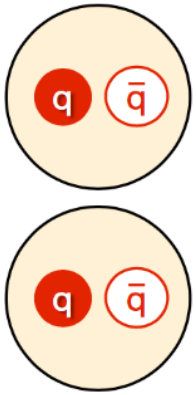
mesons



baryons

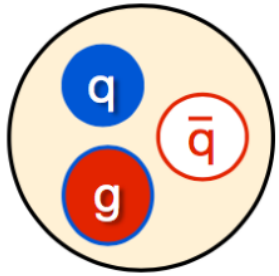


tetraquark



hadronic molecule

pentaquark



“hybrid” meson

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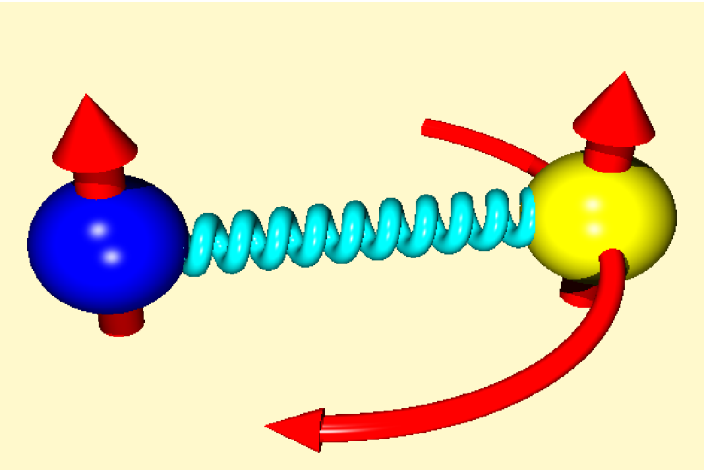
GLUEX

Light Meson Spectroscopy

2-fermion system: $q\bar{q}$

Spectroscopy: $^{(2S+1)}L_J$



S=Spin, 0 or 1

L=Orbital Momentum, 0,1,2,...

J=Total Orbital Momentum, 0,1,2,...

J^{--} and J^{++} $C = P =>$ $S = 1$

J^{PC} Quantum Numbers

- Parity = $(-1)^{L+1}$
- Charge Conjugation = $(-1)^{L+S}$
- Spin = $J = |L - S|, L, L + S$
- Vacuum = $^3P_0 \hat{=} 0^{++}$

Quark Degrees of Freedom **ONLY**

	0^{++}	0^{-+}	
1^{--}	1^{++}		1^{+-}
2^{--}	2^{++}	2^{-+}	
3^{--}	3^{++}		3^{+-}
4^{--}	4^{++}	4^{-+}	
5^{--}	5^{++}		5^{+-}

Experimental observation!!

Jefferson Lab

GlueX

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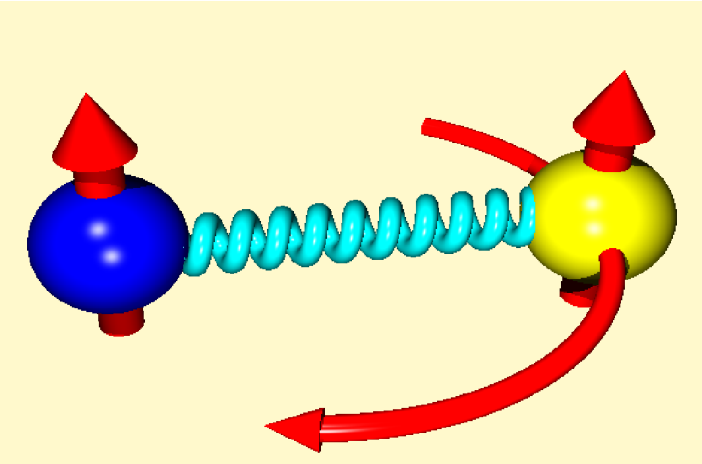

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3^{--}	3^{++}	3^{-+}	3^{+-}
4^{--}	4^{++}	4^{-+}	4^{+-}
5^{--}	5^{++}	5^{-+}	5^{+-}

J^{PC} Exotic quantum numbers

Mesons with exotic quantum numbers?

HYBRID-Meson $q\bar{q}$ with constituent gluon($J^{PC} = 1^{+-}, 1^{--}$):

S = 0, L = 0, m = 1

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

non exotic states

exotic states require S or $L \neq 0$

S = 1, L = 0, m = 1

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

J^{PC} Exotic quantum numbers are

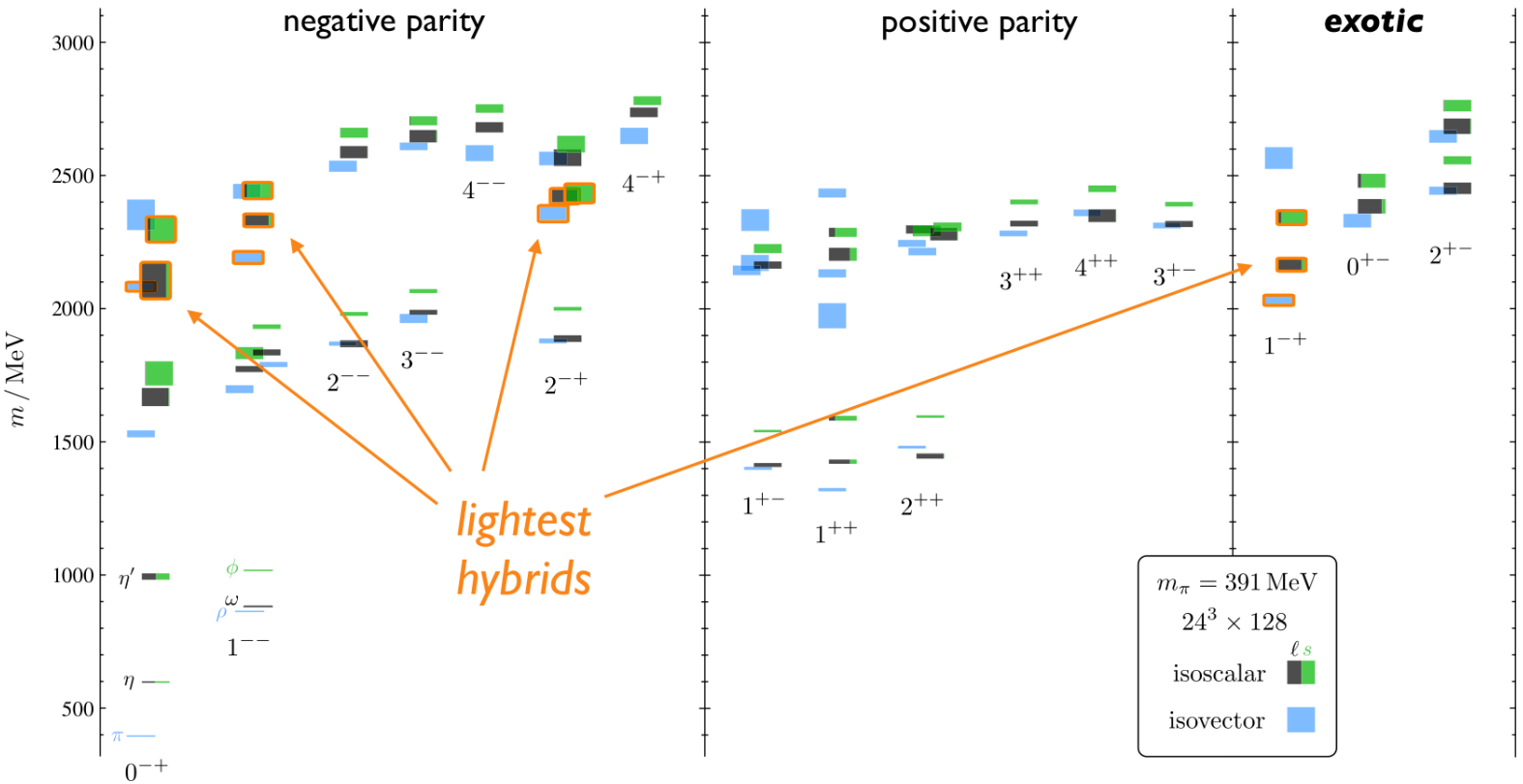
a signature for exotic mesons such as
Glueball, $q\bar{q}$-$q\bar{q}$ Molecule or Hybrid Mesons

GlueX: Search for hybrid mesons with exotic quantum numbers

Hybrid Meson Mass Estimates

Lattice calculations predict exotic J^{PC} states

Dudek, Edwards, Guo, and Thomas, PRD 88, 094505 (2013)



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Hybrid Masses and Decays

Masses (lattice QCD)

- $1^{-+} \sim 2.0 - 2.4$ GeV
- $0^{+-} \sim 2.3 - 2.5$ GeV
- $2^{+-} \sim 2.4 - 2.6$ GeV

Decay widths (from Models)

- $\Gamma \sim 0.1 - 0.5$ GeV

1^{-+} $\pi_1 \rightarrow \rho\pi,\ b_1\pi,\ f_1\pi,\ \eta'\pi,\ a_1\eta$
$\eta_1 \rightarrow f_2\pi,\ a_2\pi,\ f_1\eta,\ \eta'\eta,\ \pi(1300)\pi,\ a_1\pi$
$\eta_1' \rightarrow K^*\overline{K},\ K_1(1270)\overline{K},\ K^*(1410)\overline{K},\ \eta'\eta$

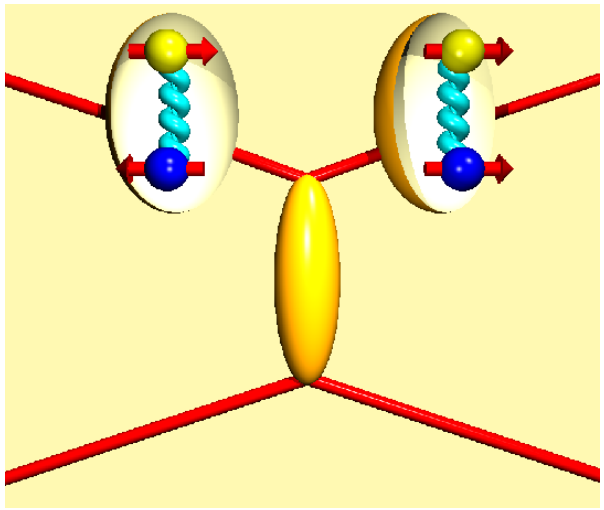
2^{+-} $b_2 \rightarrow \omega\pi,\ a_2\pi,\ \rho\eta,\ f_1\rho,\ a_1\pi$
$h_2 \rightarrow \rho\pi,\ b_1\pi,\ \omega\eta,\ f_1\omega$
$h_2' \rightarrow K_1(1270)\overline{K},\ K^*(1410)\overline{K},\ K_2\overline{K},\ \phi\eta$

0^{+-} $b_o \rightarrow \pi(1300)\pi,\ h_1\pi,\ f_1\rho,\ b_1\eta$
$h_o \rightarrow b_1\pi,\ h_1\eta$
$h_o' \rightarrow K_1(1270)\overline{K},\ K^*(1410)\overline{K},\ h_1\eta$

- Complex Final States!
- Neutrals and Charged!

Hybrid Meson Production

Pion Beam on Hydrogen



- π with **S=0, L=0** and Δm=1
  $1^{++}, 1^{--}$
- Require spin flip

- E852, GAMS, KEK, VES, COMPASS

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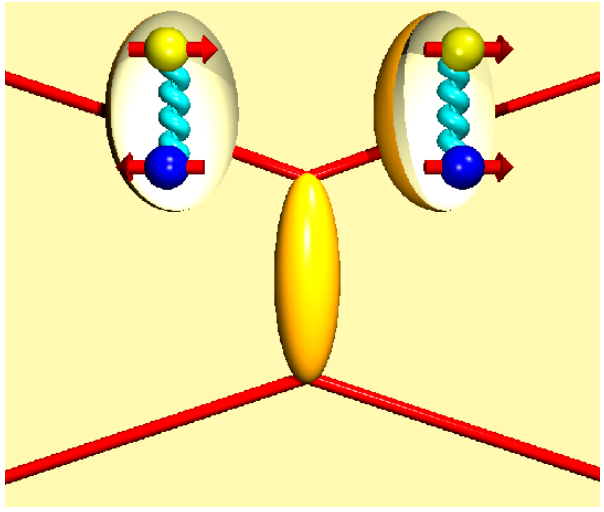
Hybrid Meson Production

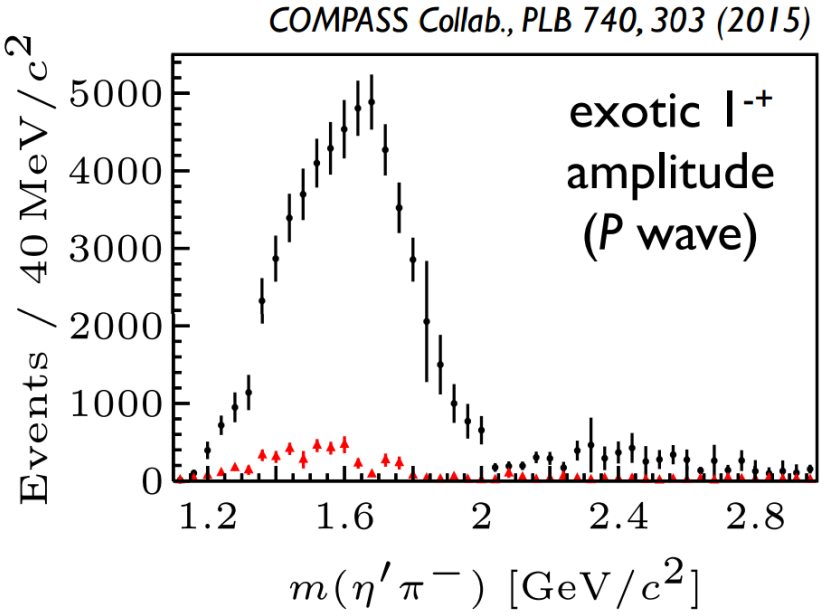
Pion Beam on Hydrogen



- π with **S=0, L=0** and Δm=1 $1^{++}, 1^{--}$
- Require spin flip

- E852, GAMS, KEK, VES, COMPASS

Compass result on $\eta'\pi^-$ final state:



Hybrid Meson Production

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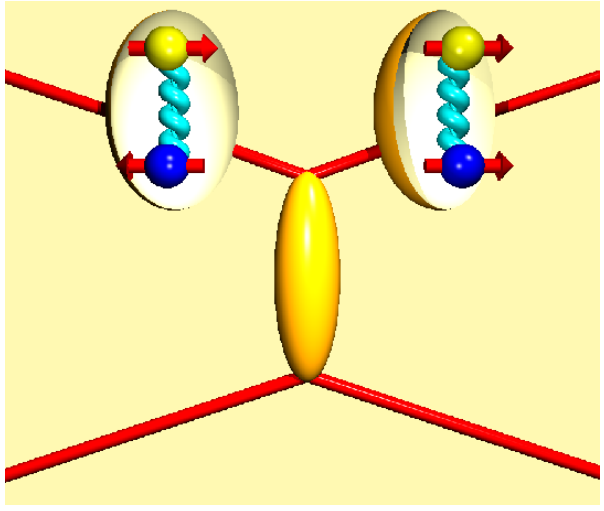
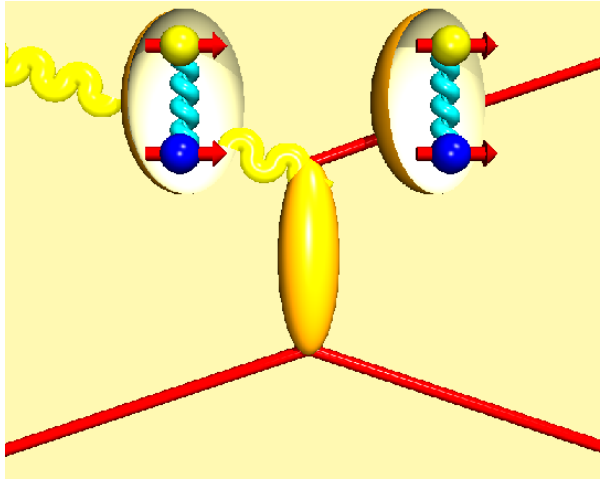


- π with **S=0, L=0** and Δm=1
  $1^{++}, 1^{--}$
- Require spin flip

- E852, GAMS, KEK, VES, COMPASS

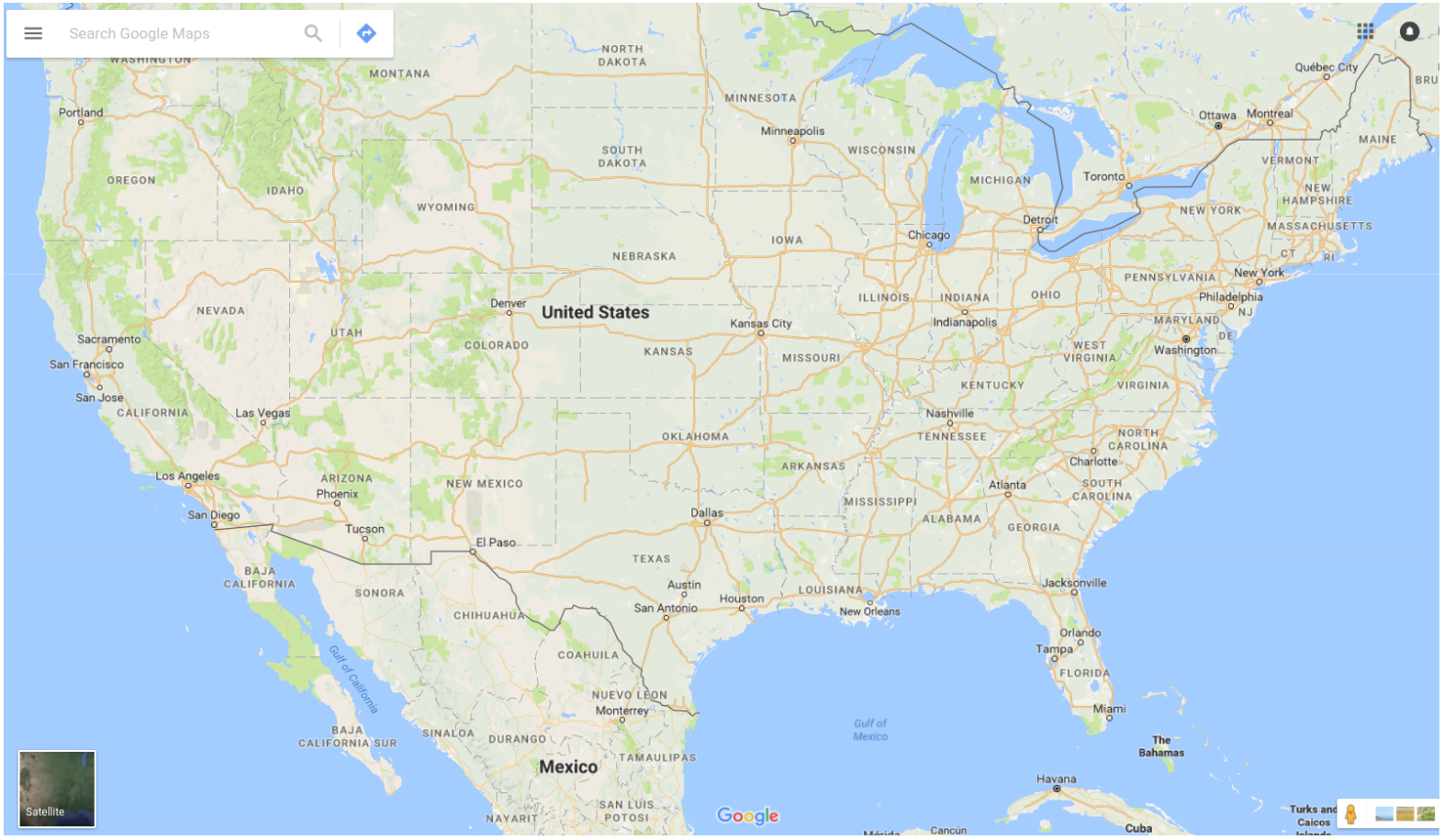
Photon Beam on Hydrogen



- γ with **S=1, L=0** and Δm=1
  $0^{-+}, 0^{+-}, 1^{-+}, 1^{+-}, 2^{-+}, 2^{+-}$
- No spin flip required
- photon linearly polarized
- CLAS, Omega-Photon Coll.
- **GlueX**

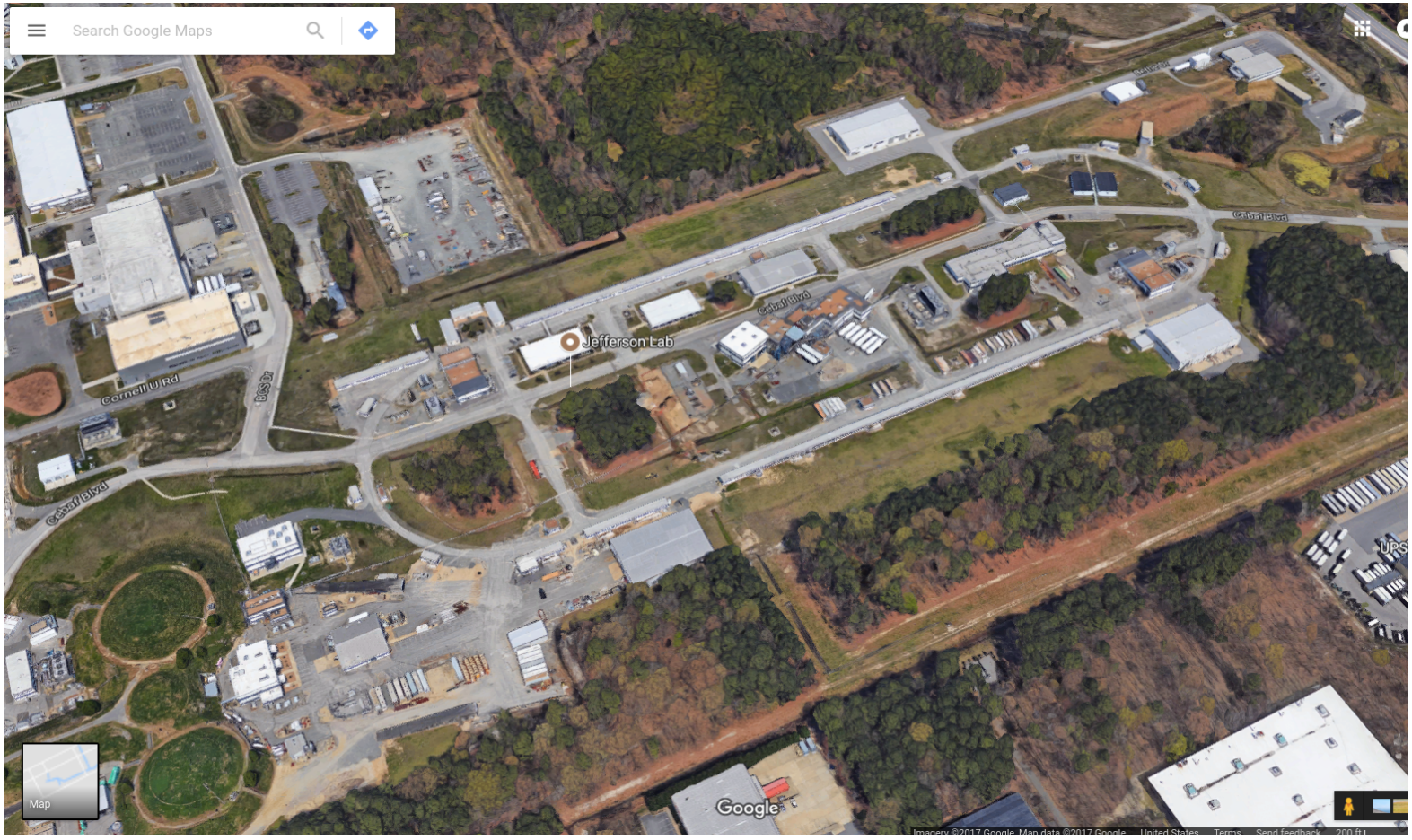
GlueX Hall D

Where is Thomas Jefferson Lab and CEBAF?



GlueX Hall D

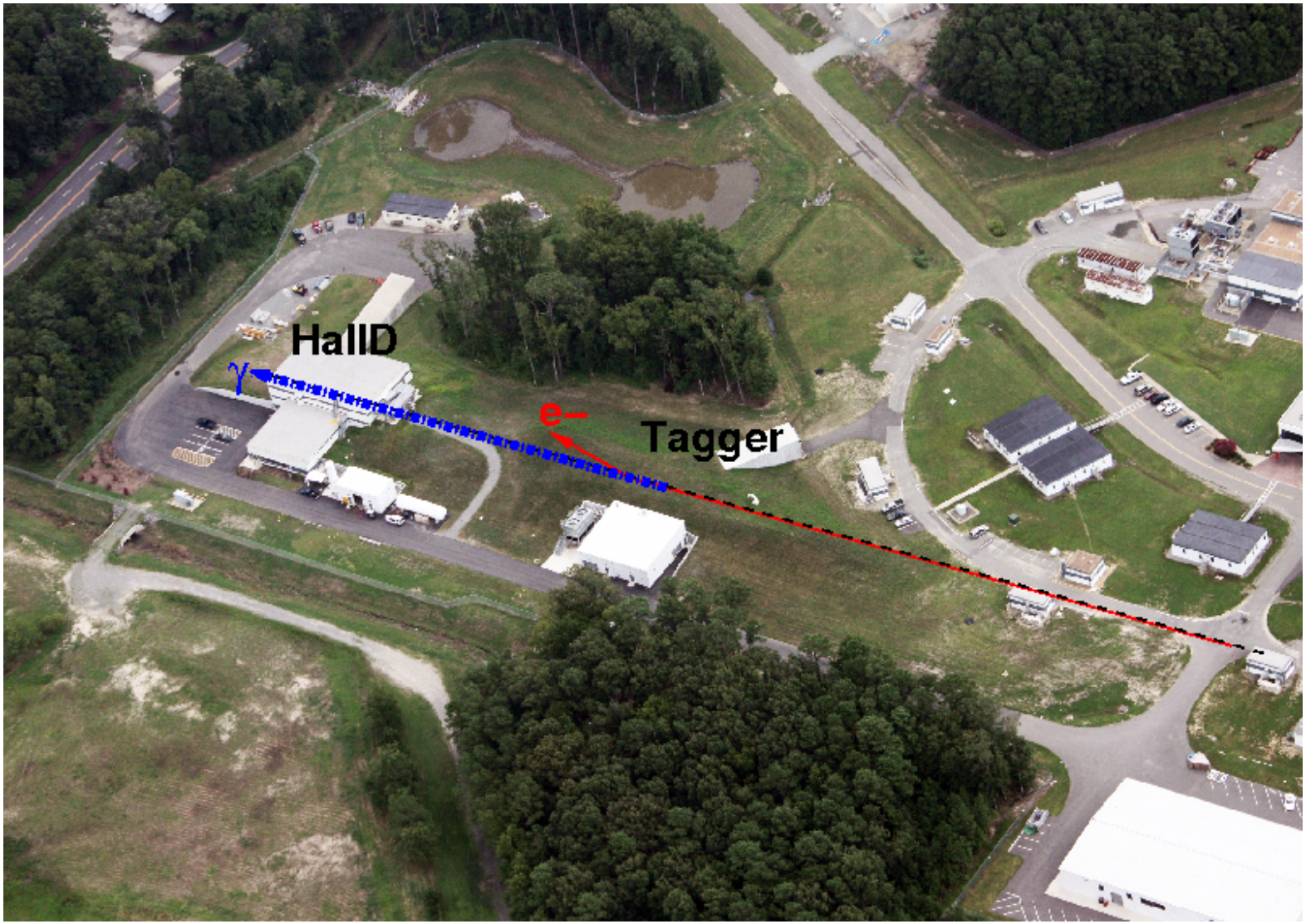
CEBAF Accelerator site:



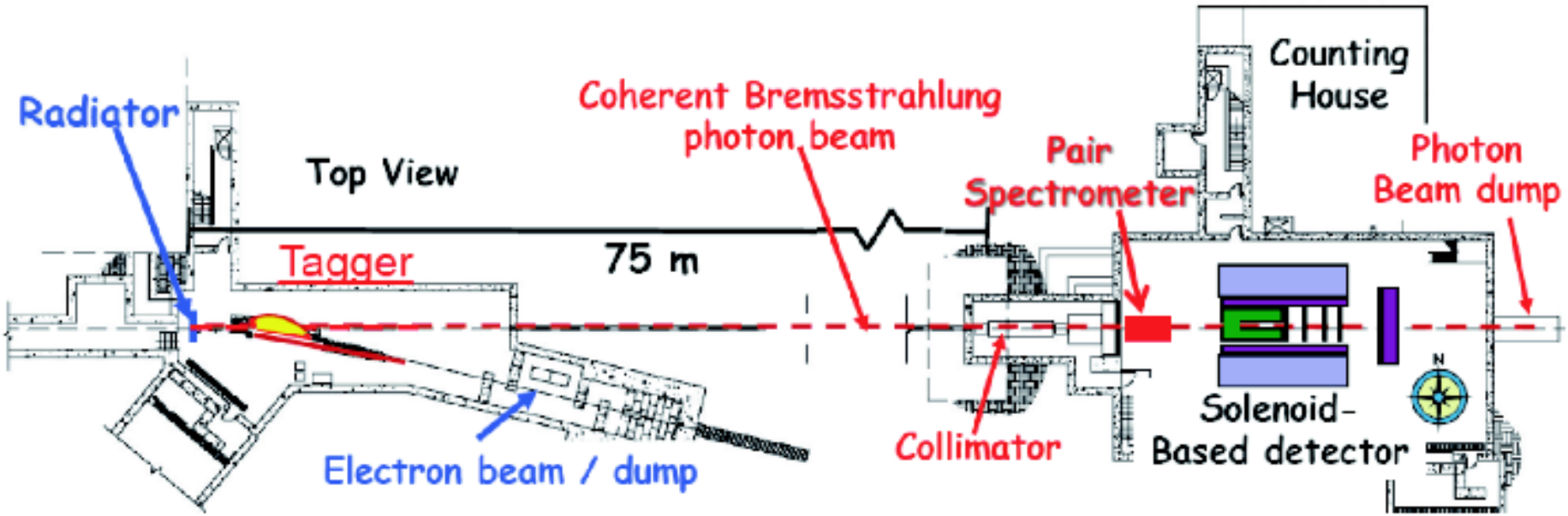
Jefferson Lab

GlueX

GlueX Hall D

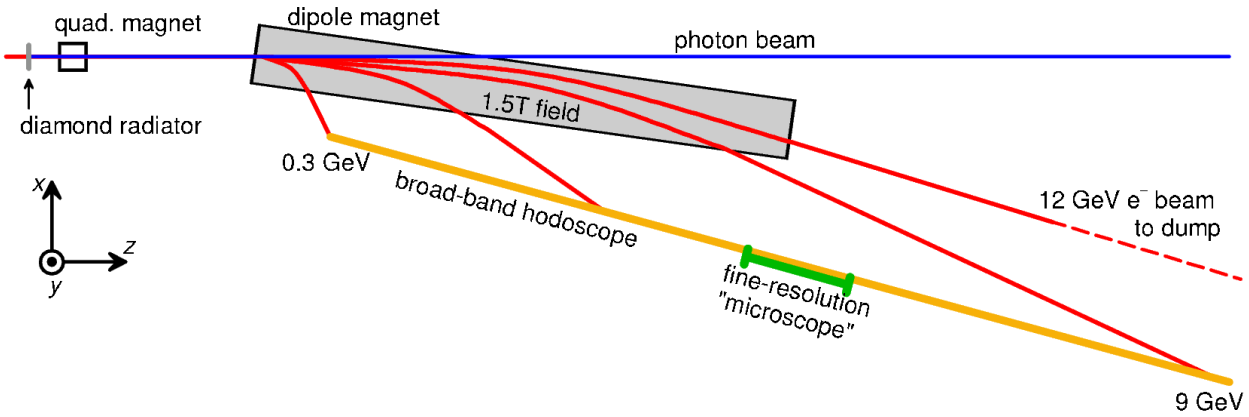


The Hall-D Beam Line

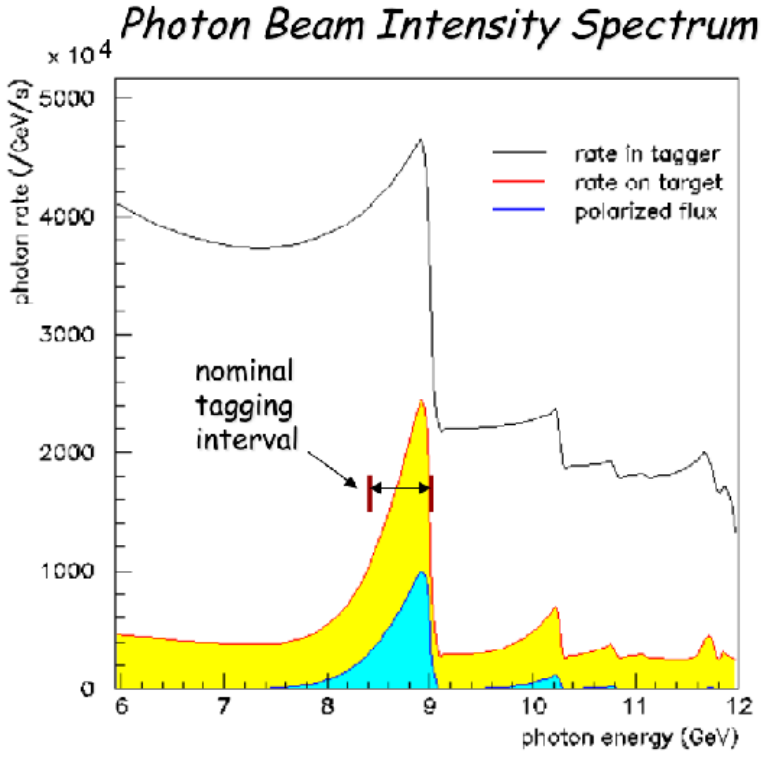


- e^-(12GeV/c) beam
- 20μm thick diamond radiator
- Coherent Bremsstrahlung
- 76m Photon beam line for collimation.
- 40% polarization at 9 GeV
- Hall-D beam dump for photons only!

Photon Beam Tagger



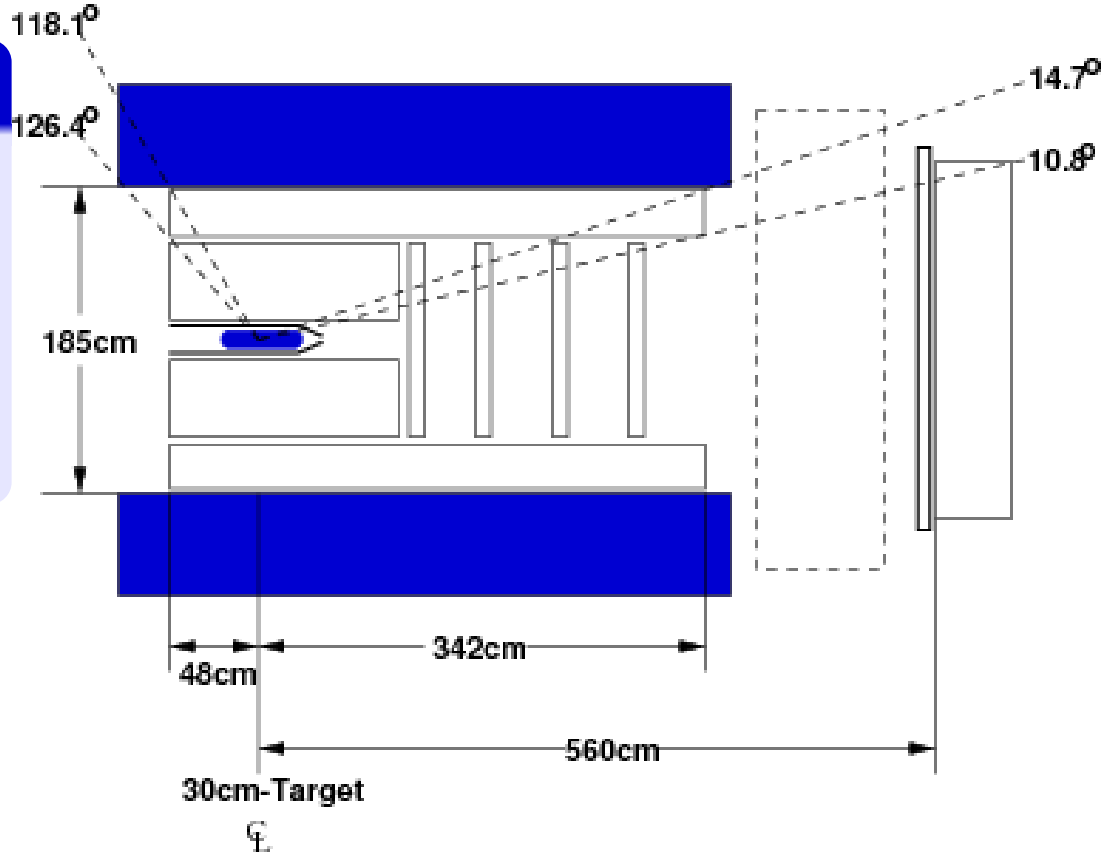
- 20μm thick diamond radiator
- 76 m flight path to collimator
- 40% polarization at peak (9GeV)
- $10^8 \gamma/s$ at 8.4-9.0 GeV
- Fixed Array Hodoscope
  3-11.7 GeV
- Microscope 800 MeV coverage



The GlueX Detector

Magnet, Target

- Solenoid (hermiticity)
- Super-conducting
- 2 Tesla
- LH_2 target



The GlueX Detector

Tracking Chambers

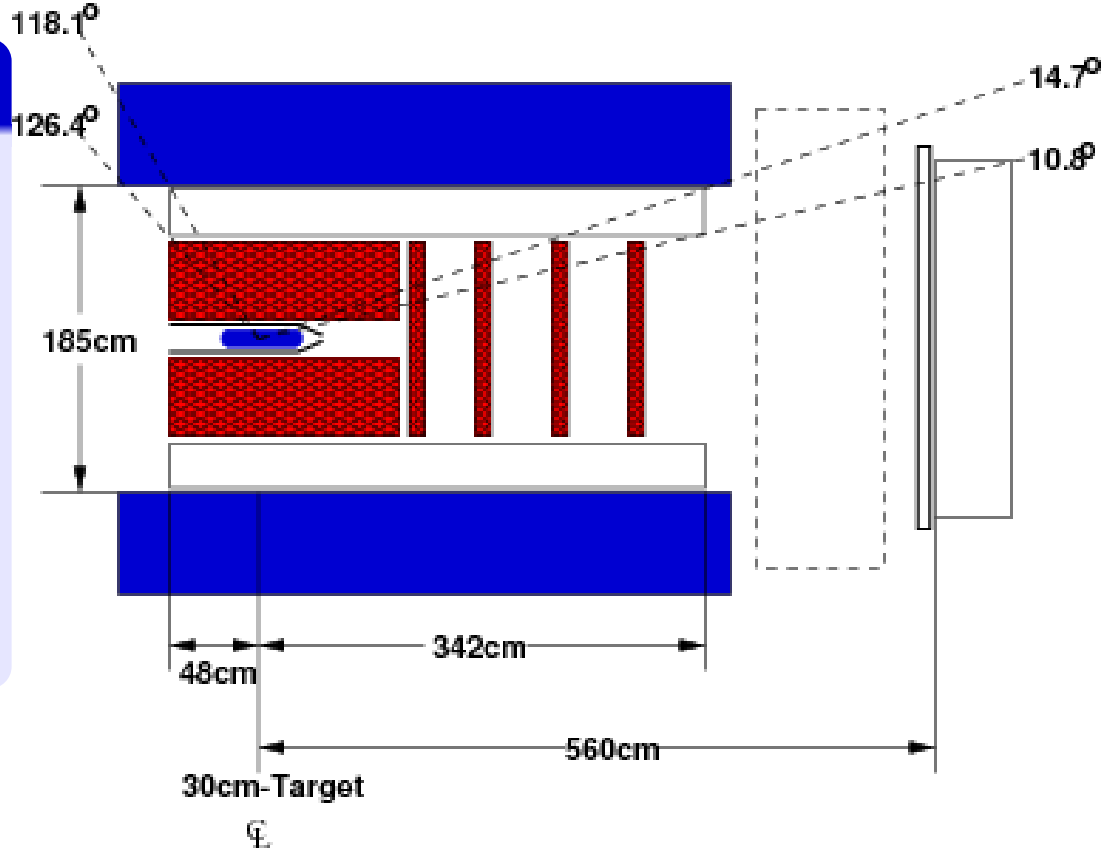
CDC

- Straw tube chamber
- dE/dx for PID

FDC

- Cathode strips

$\delta p/p \sim$1-2%



The GlueX Detector

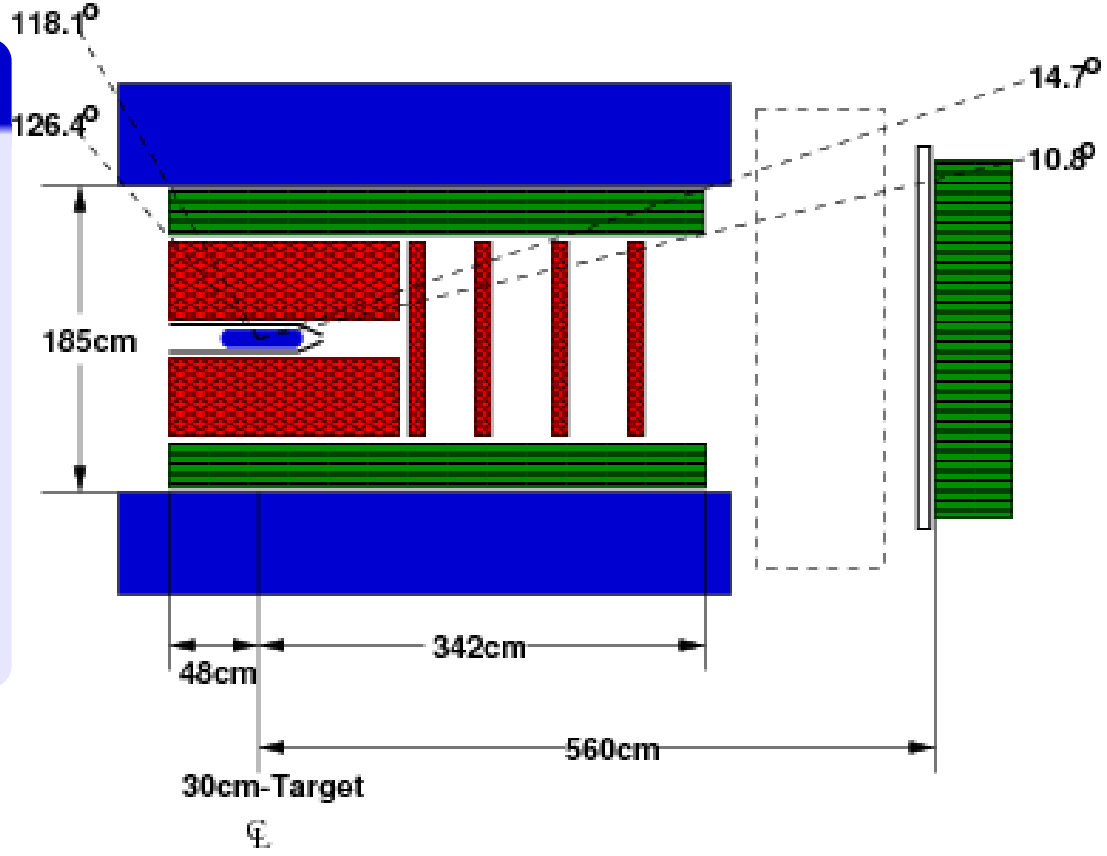
Calorimetry

Barrel Calorimeter

- Scin. fiber/lead
- $\delta E/E = 5.4/\sqrt{E} \oplus 2.3\%$

Forward Calorimeter

- Lead glass
- $\delta E/E = 5.7/\sqrt{E} \oplus 2.0\%$



The GlueX Detector

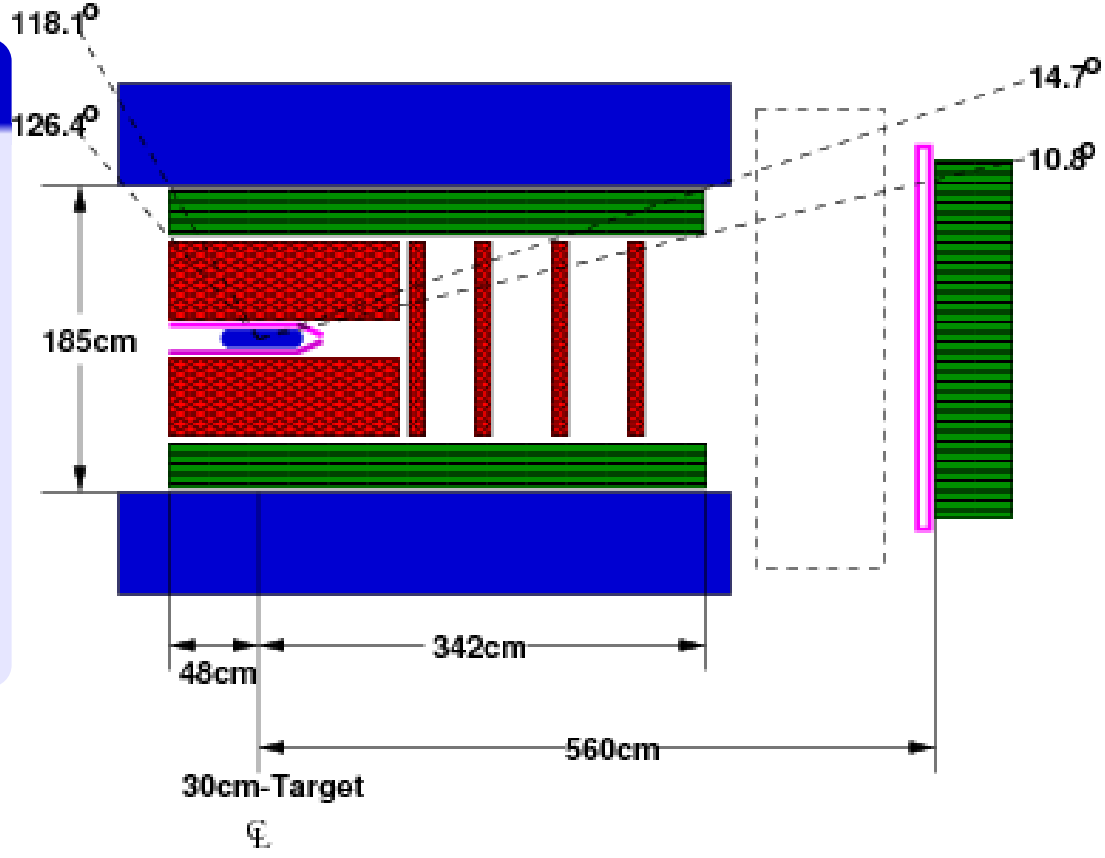
Timing

Start Counter

- Scintillators
- $\delta t/t = 280$ps

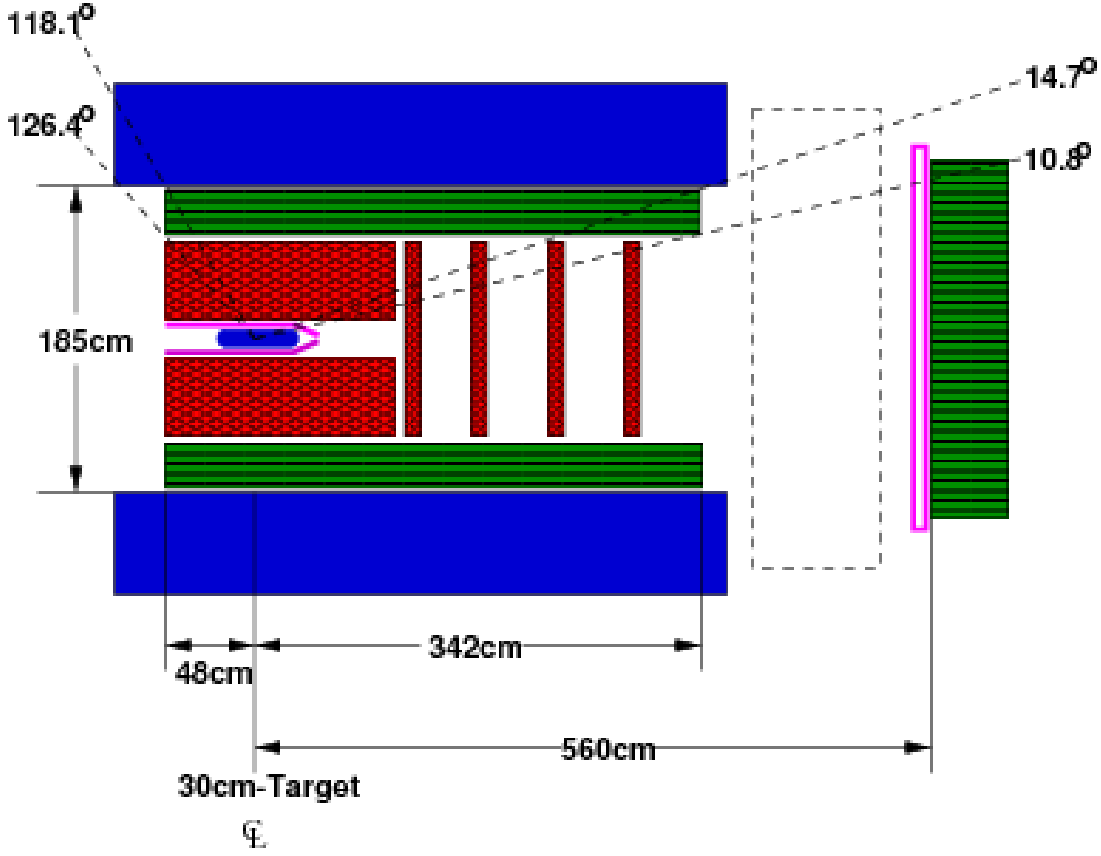
Time of Flight

- Scintillators
- $\delta t/t = 100$ps



The GlueX Detector

- Solenoid, Target
- Tracking
- Calorimetry
- Timing
- **Future PID**
  → **DIRC**



Jefferson Lab

GlueX

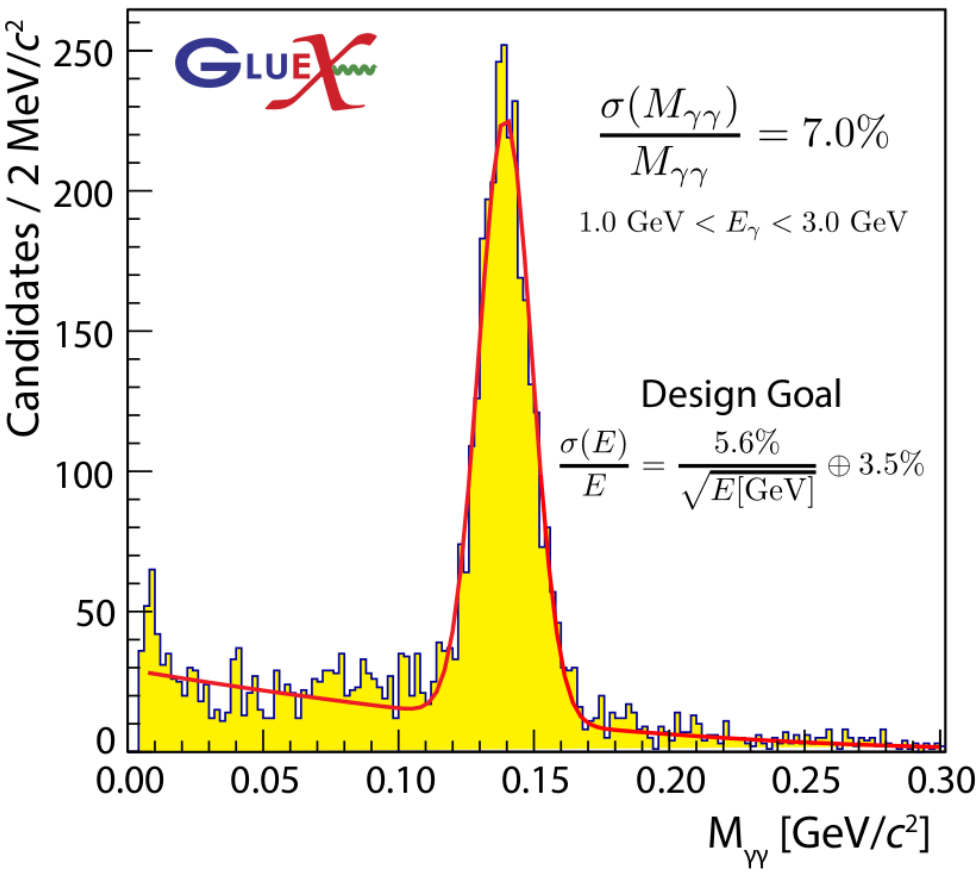
Running periods

- Spring 2016: 12 GeV Engineering run
  - Electron Beam Energy: 12.05 GeV
  - Commissioning complete: Detector, Beamline, DAQ
  - Data taken for early physics results:
    $\sim$26 billion events, $\sim$7 billion with good quality
- Spring 2017: GlueX Phase-I, first part
  - Electron Beam Energy: 11.64 GeV
  - 58μm diamond radiator
  - DAQ trigger rate 30-50 kHz
  - Exceeded nominal luminosity
  - Accumulated $\sim$50 billion events (20%)
- October 2017: Continue GlueX Phase-I

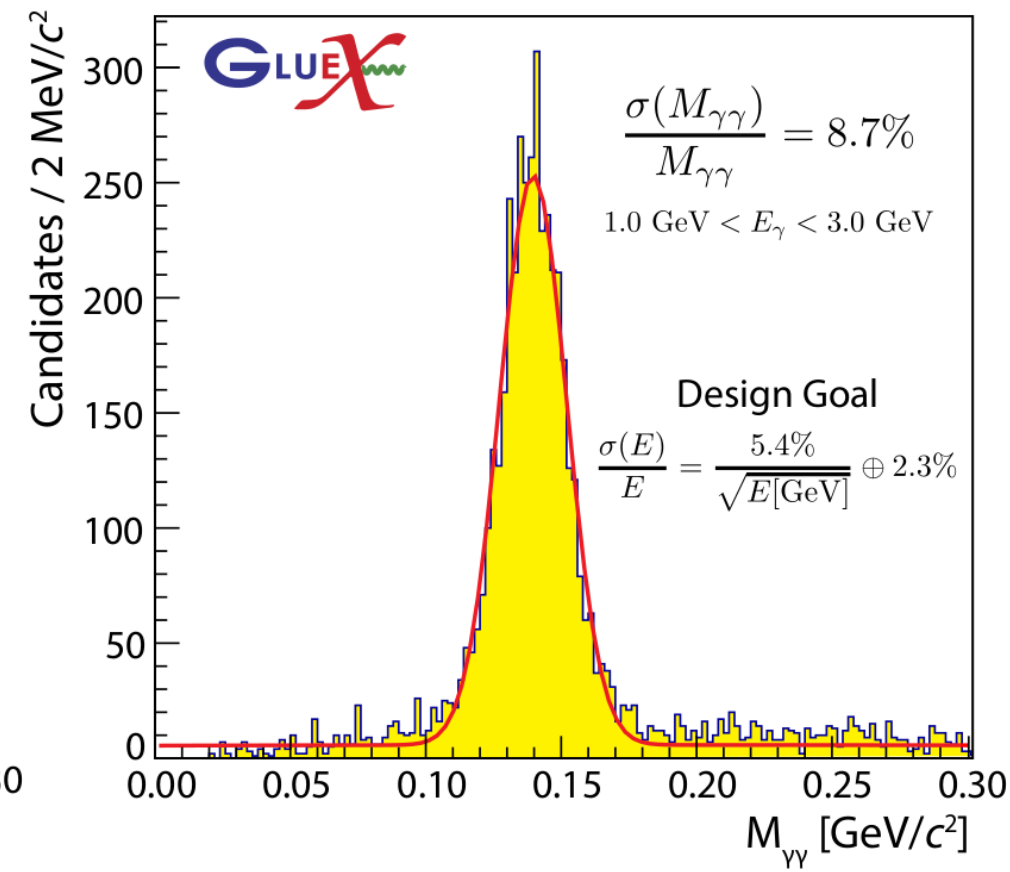
Calorimeter Resolutions

FCAL and BCAL Energy resolution with π^0:

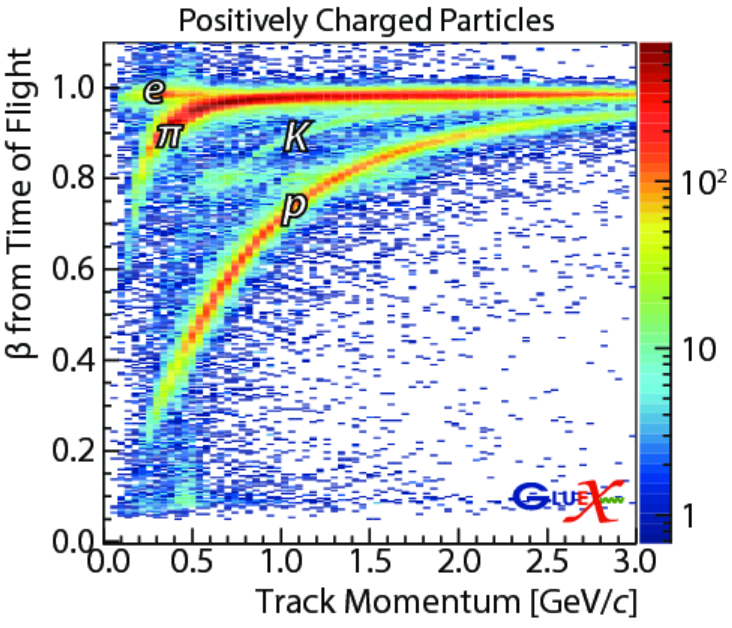
Forward Lead Glass Calorimeter

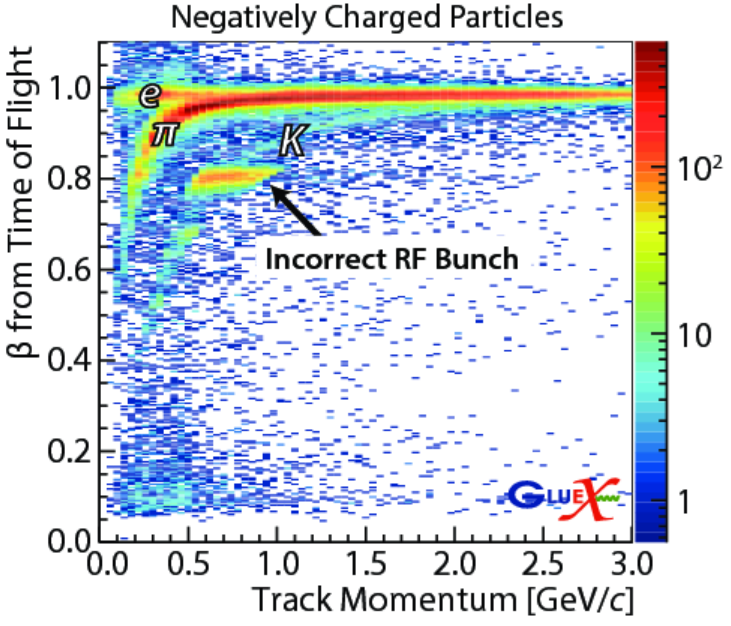


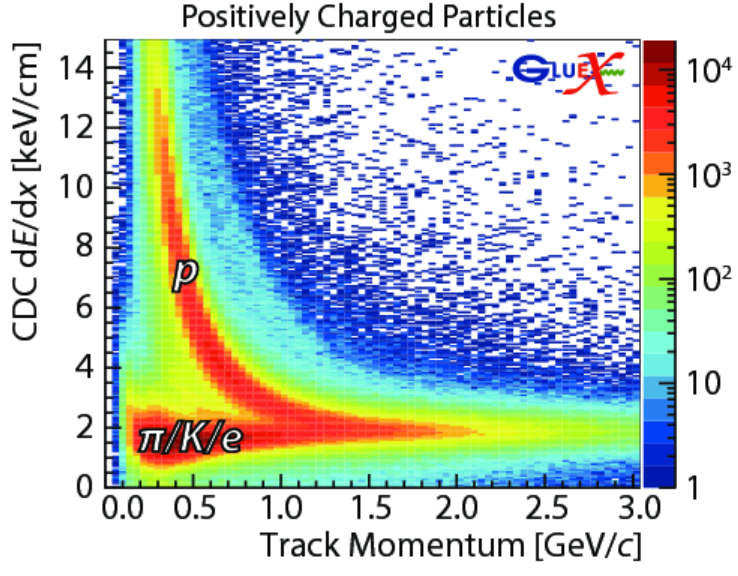
Barrel Lead-Scintillating Fiber Calorimeter

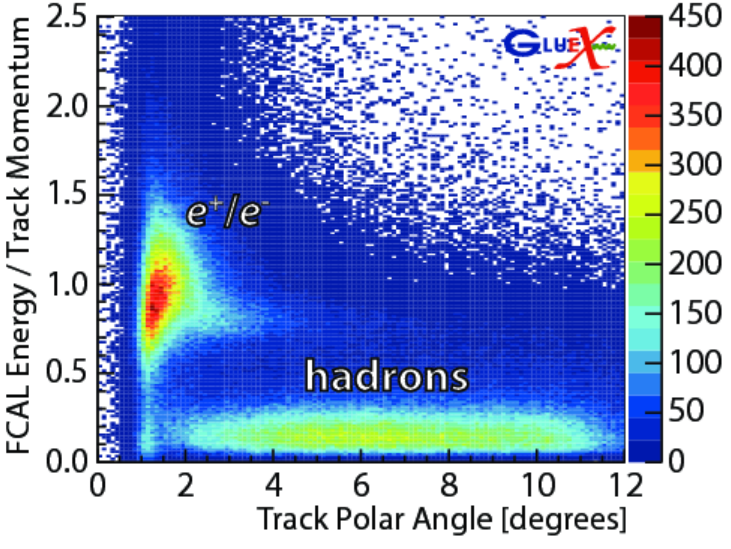


Particle Identification





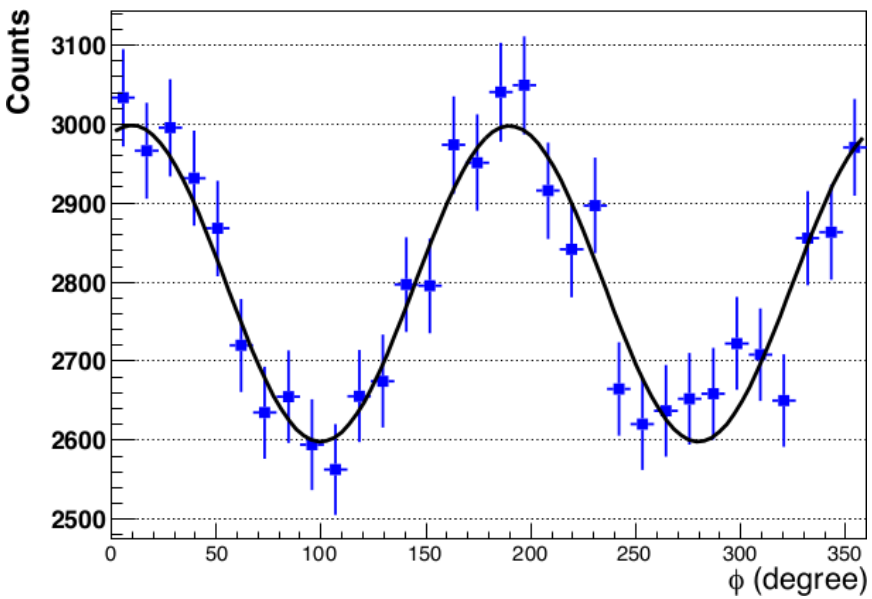




Photon Beam Polarization

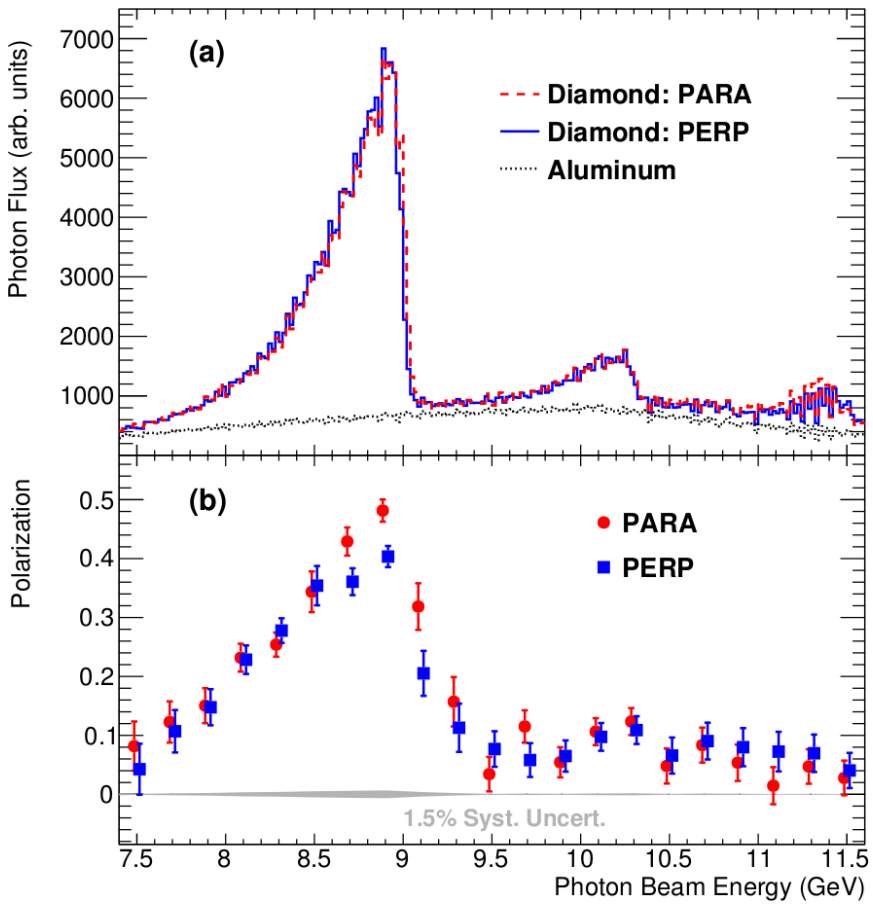
Triplet Polarimeter:

$\gamma e^- \rightarrow e^- e^+ e^-$

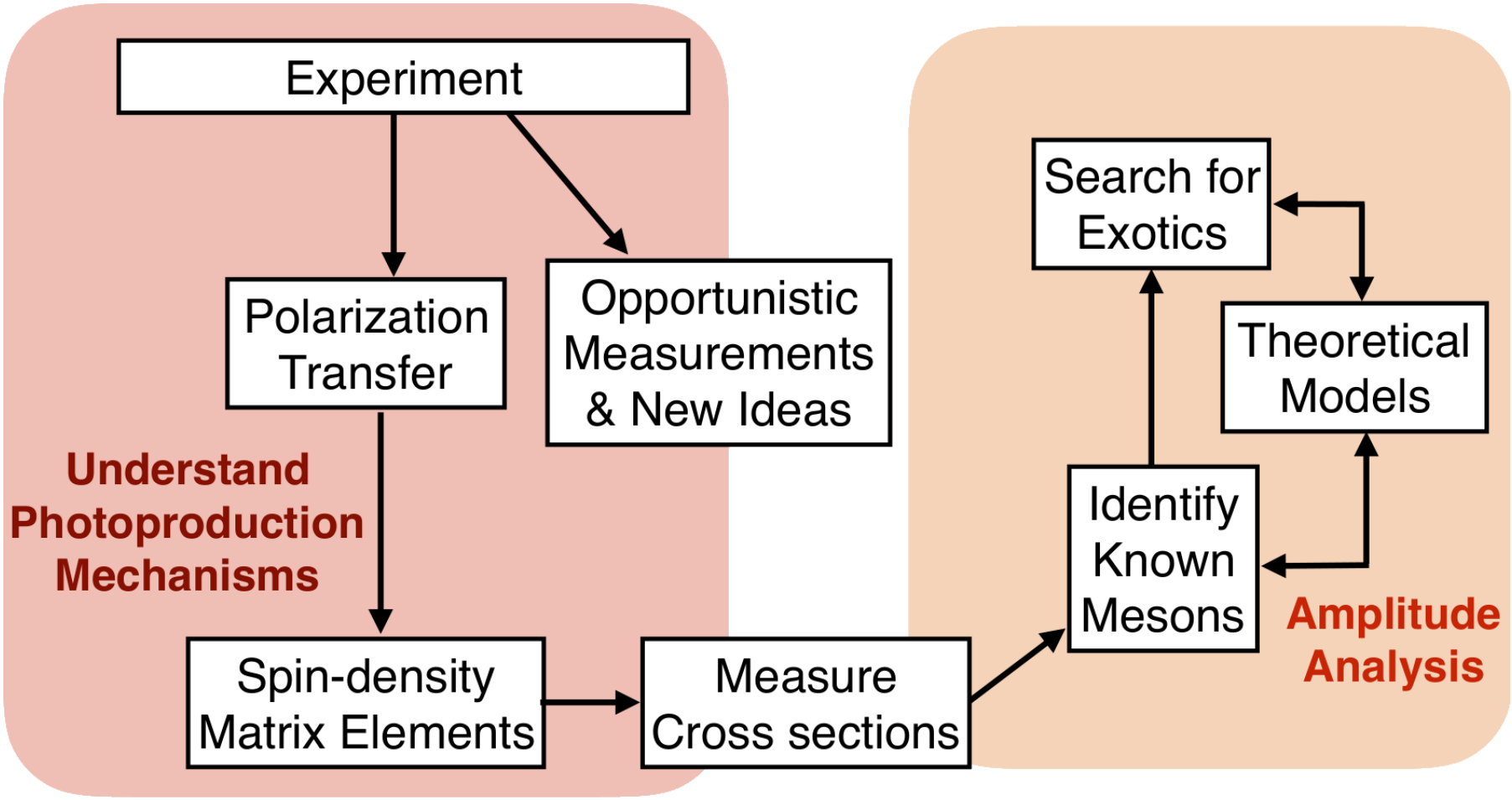


$N_{||} \propto A(\phi)(1 - \mathbf{P}\Sigma\cos(2(\phi - \phi_o)))$

Polarization: $P(E_\gamma)$



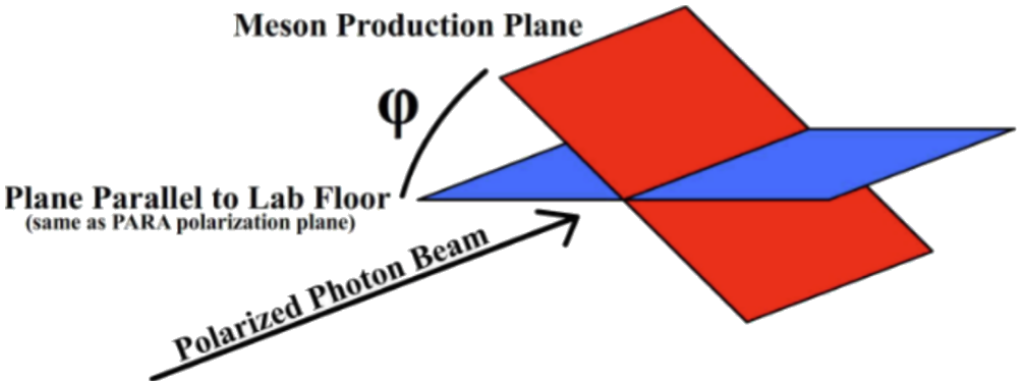
GlueX Data Analysis Strategy

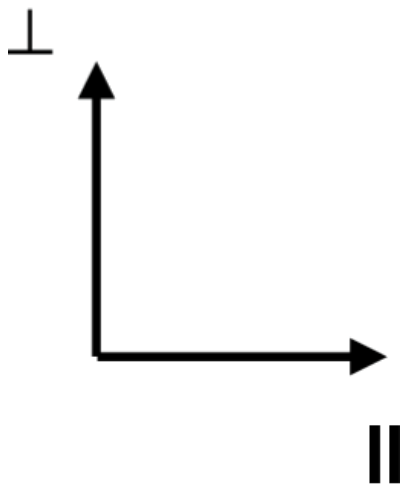


→ A road map to search for exotic mesons in GlueX.

Pseudo-scalar Mesons Beam Asymmetries

Pseudo-scalar mesons: π^0 and η





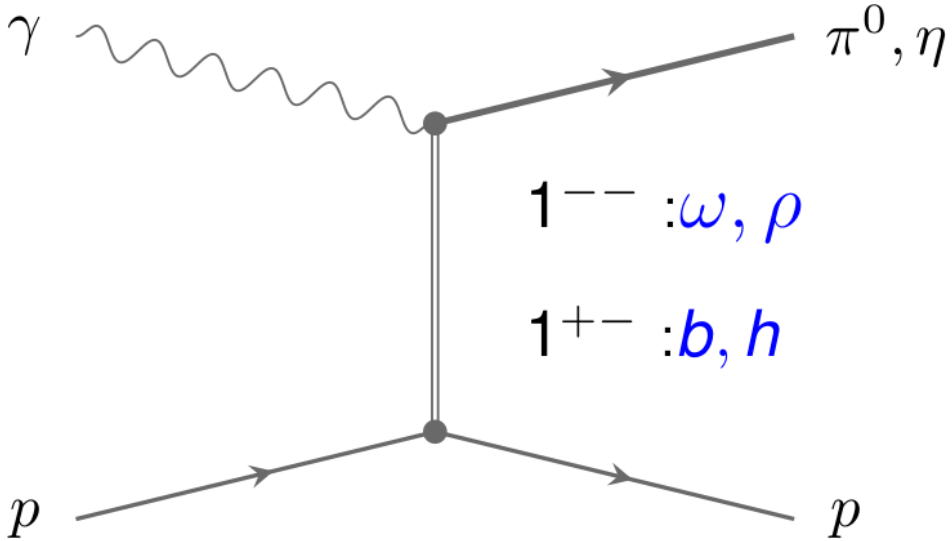
- $P_{||}$: $\frac{d\sigma}{d\phi} \propto (1 - P\Sigma\cos(2\phi))$
- $P_{\perp}$: $\frac{d\sigma}{d\phi} \propto (1 - P\Sigma\cos(2\phi - \pi))$
- Asymmetry: $A(\phi) = \frac{\frac{d\sigma}{d\phi}_{\perp} - \frac{d\sigma}{d\phi}_{||}}{\frac{d\sigma}{d\phi}_{\perp} + \frac{d\sigma}{d\phi}_{||}}$

  $\approx P\Sigma\cos(2\phi)$

Detector efficiency/acceptance CANCEL!

Photo-production of Pseudo-scalar Mesons

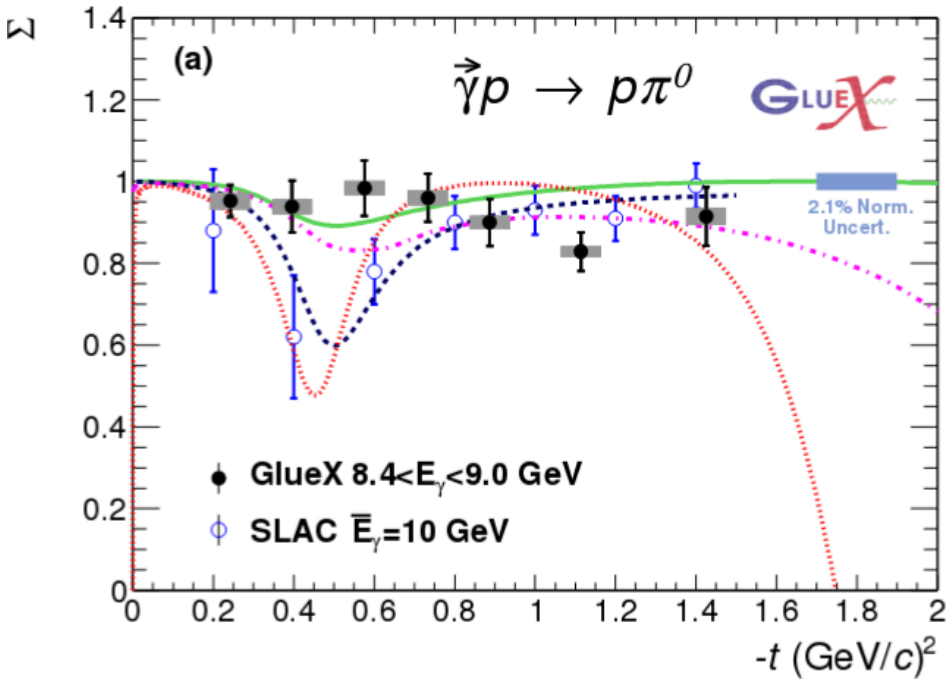
π^0 and η production:

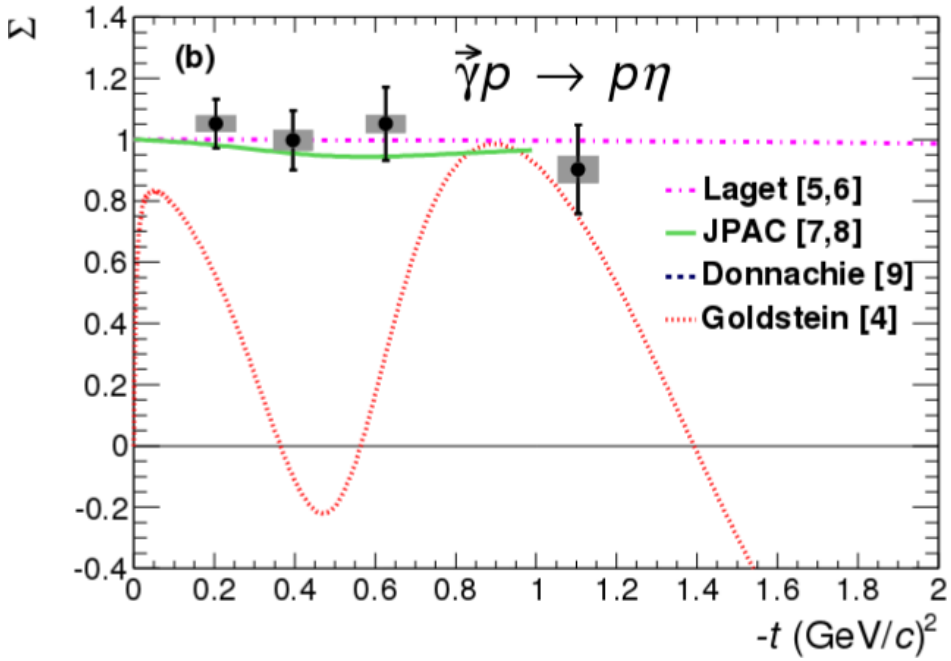


- PRD 92 (2015) 074013
  $\Sigma = \frac{|\omega+\rho|^2 - |b+h|^2}{|\omega+\rho|^2 + |b+h|^2}$
- Beam asymmetry sensitive to nature of exchange particles
- $\Sigma \approx +1 \Rightarrow$ vector meson dominance

First GlueX Physics Result

Azimuthal Beam Asymmetries in π^0 and η production:
Published: H. Al Ghoul, et al., Phys. Rev. C 95, 042201 (2017)

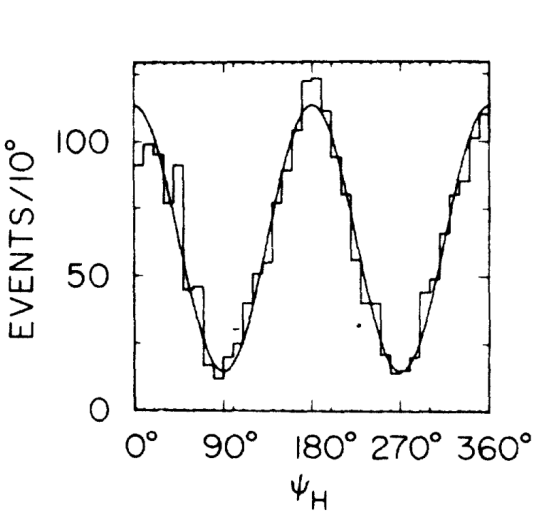


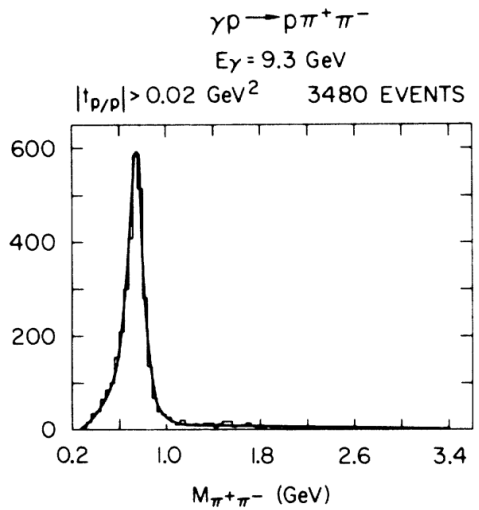


- Both π^0 and η asymmetries close to $+1$
- No dip observed at $t = -0.5$ (GeV/c)^2
- First measurement on η asymmetries
- $\Sigma \approx +1 \Rightarrow$ vector meson exchange dominates

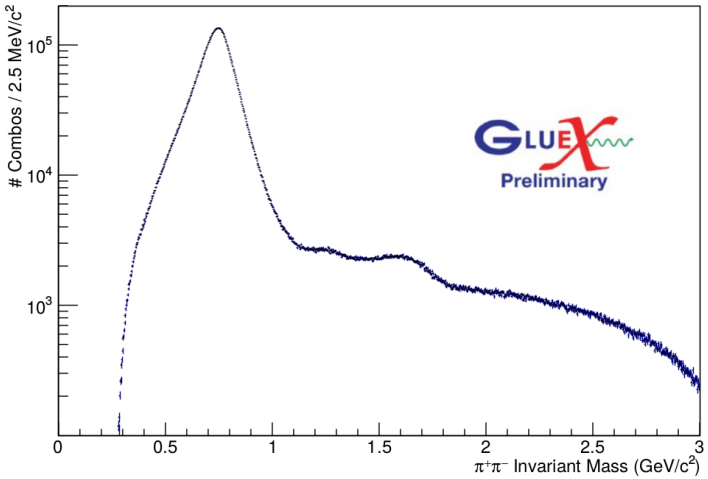
The ρ, Vector meson Beam Asymmetry

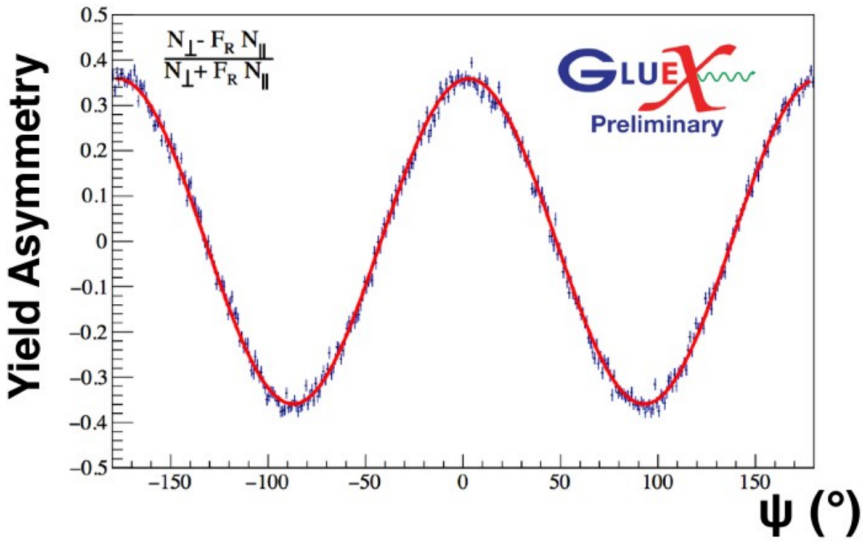
SLAC: PRD7(1973)3150

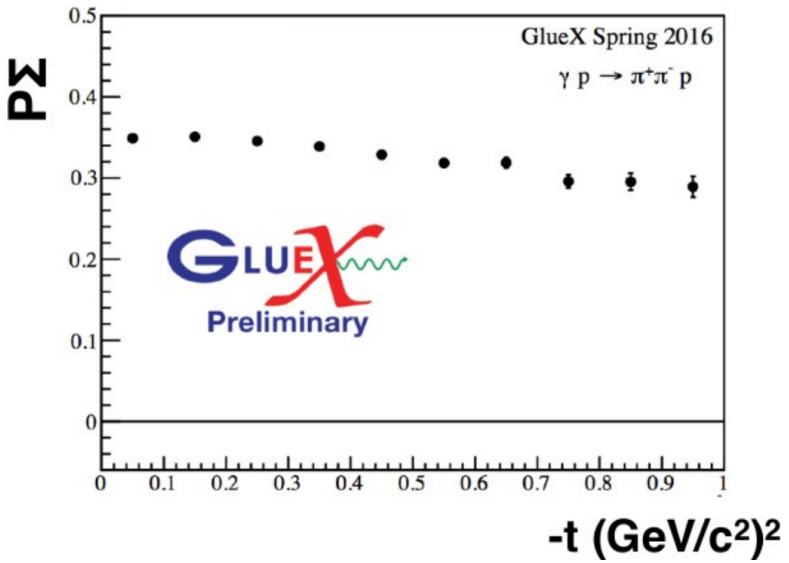




GlueX: large statistics







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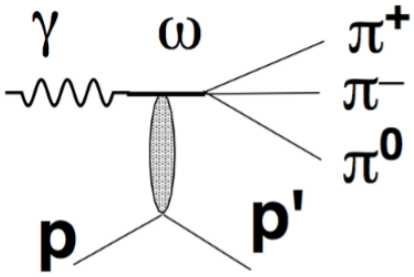
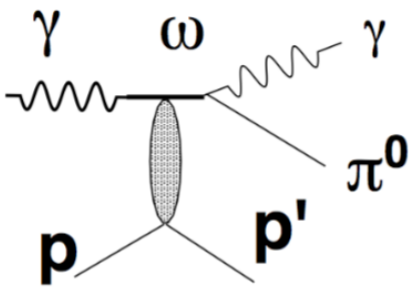
GLUEX

The ω, Beam Asymmetry



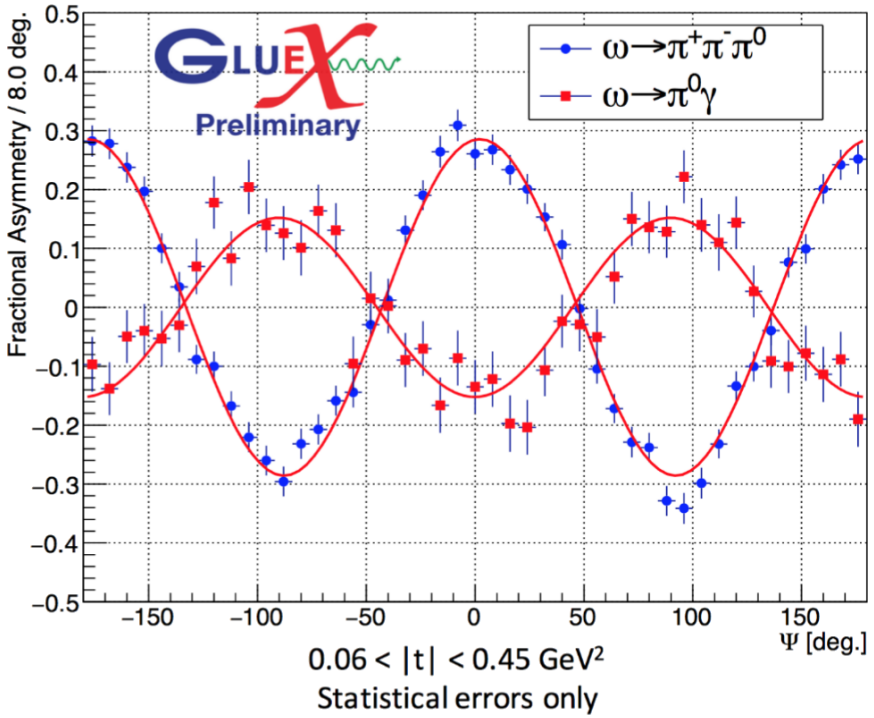
Hadronic ω



Radiative ω

- Radiative/Hadronic ω decay
- $A^{\pi^o\gamma} = -\frac{1}{2} P \cos(2(\Phi - \phi))$
- $A^{3\pi} = P \cos(2(\Phi - \phi))$
- Beam Asymmetry Ratio
  $R = \frac{\Sigma_{3\pi}}{\Sigma_{\pi^o\gamma}}$
- Expect: $R = -2$
  PRC 78 (2008) 038201

The ω, Beam Asymmetry



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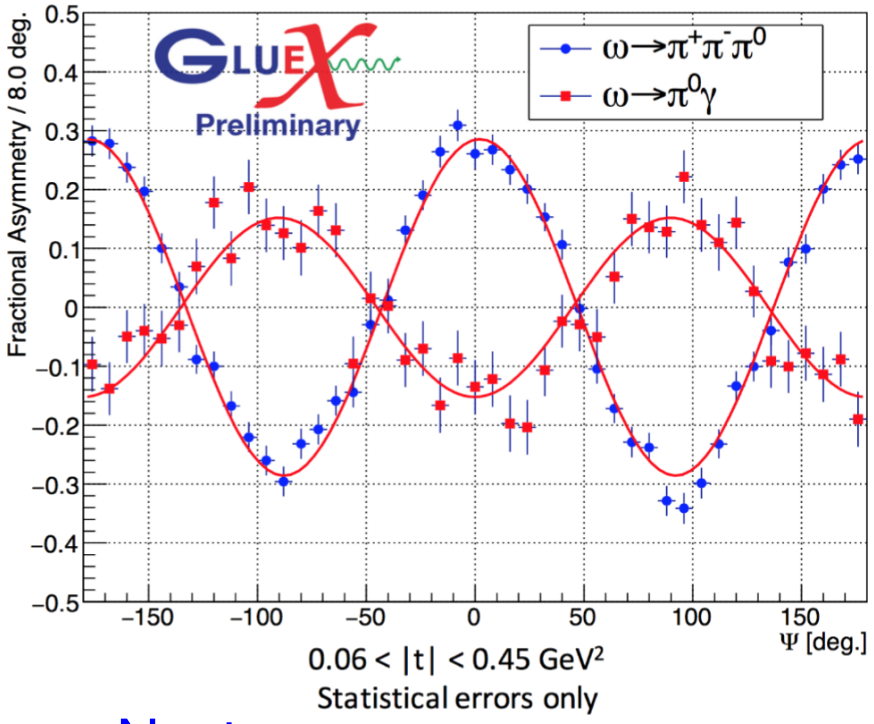
The ω, Beam Asymmetry



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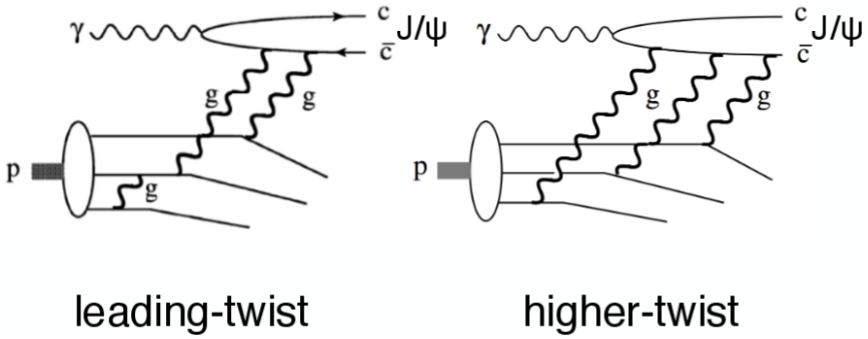
Next:

- Determine Detector Acceptance
- Determine Detector Efficiencies
- Extract Cross Sections, $\frac{d\sigma}{dt}$
- Determine SDMEs for ρ, ω, ϕ

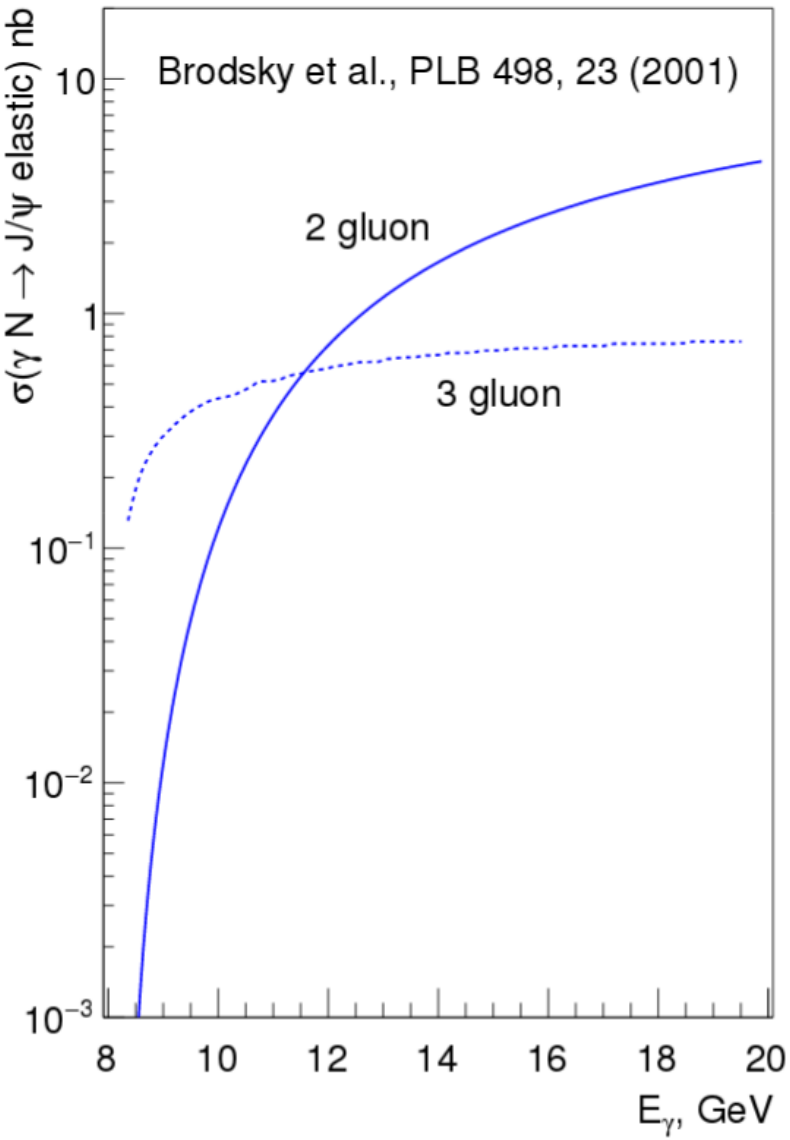
J/ψ Photo Production



leading-twist higher-twist

- Study J/ψ-nucleon interaction
- Probe gluon in the nucleon
- Probe multi-quark correlations

J/ψ Photo Production



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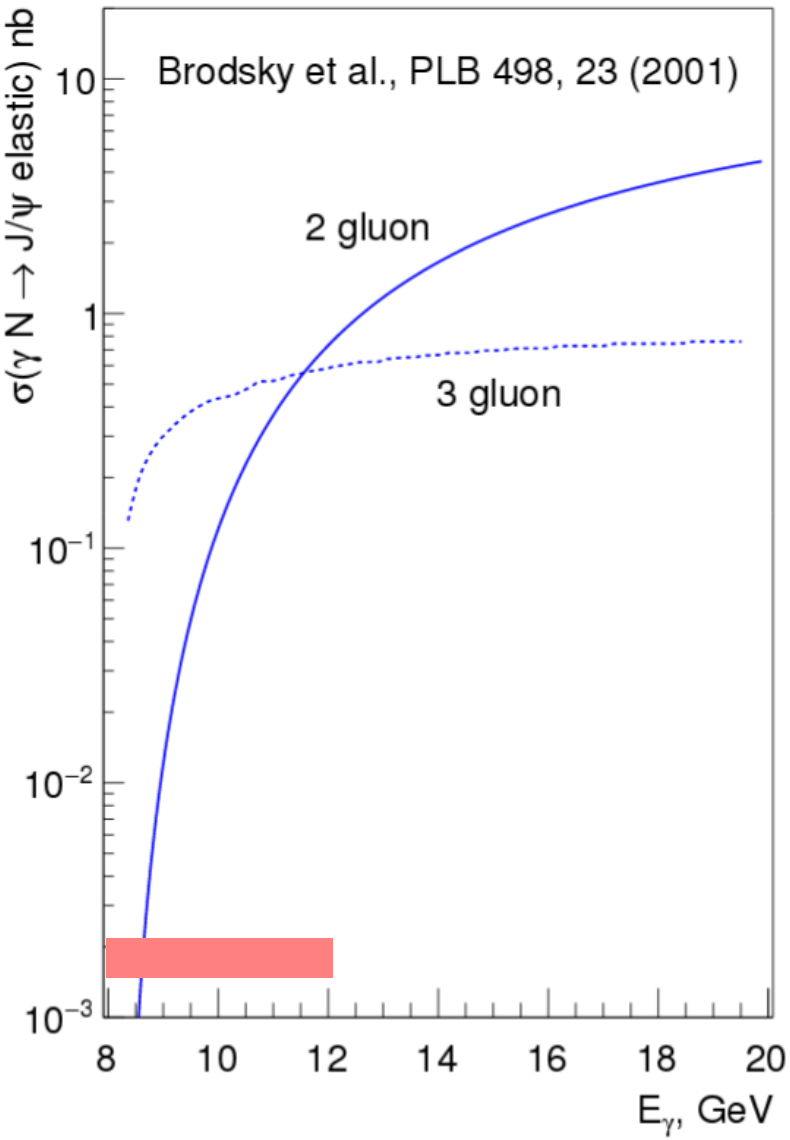
J/ψ Photo Production



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- GlueX Range 12 GeV max

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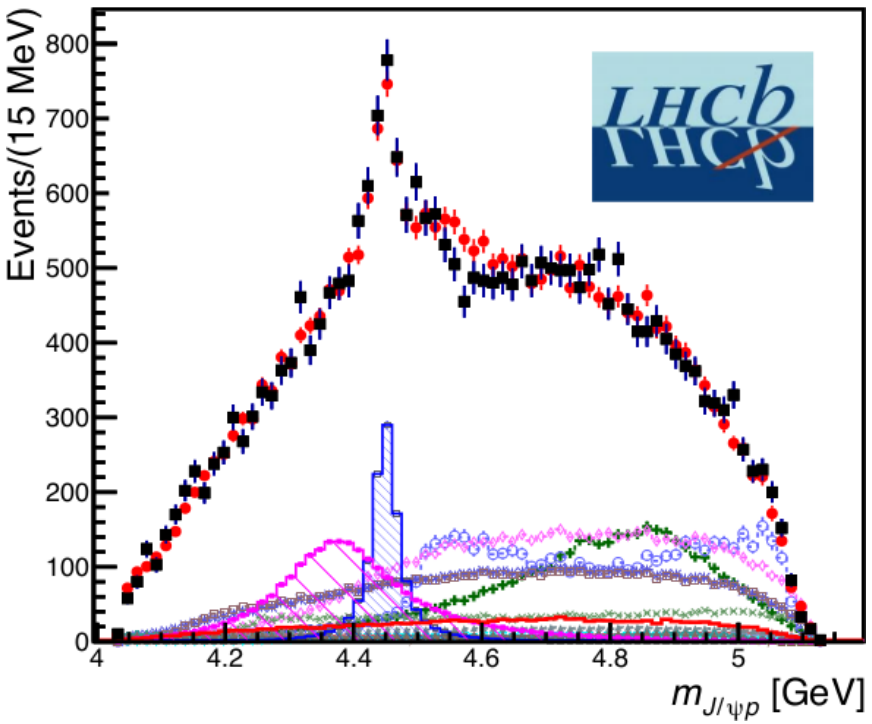
GlueX

J/ψ Photo Production



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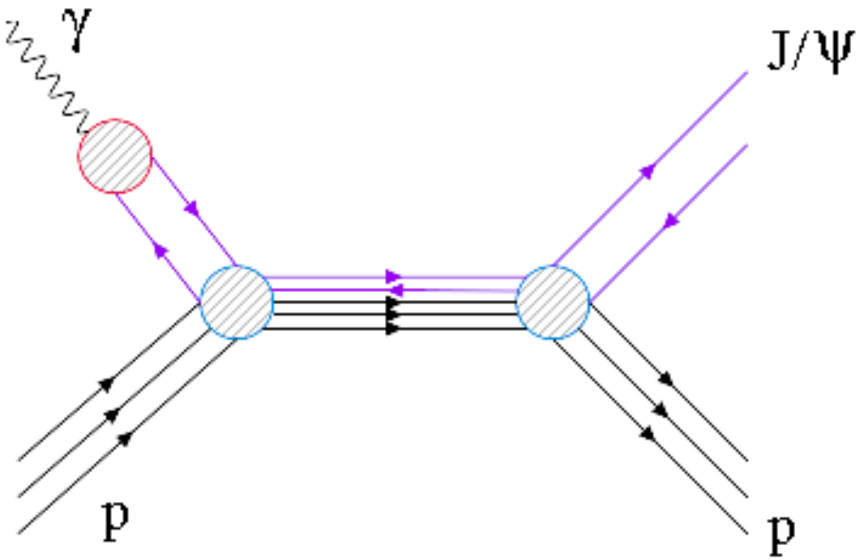
- LHCb reports J/ψp pentaquark candidate
- PRL 115, 072001 (2015)

J/ψ Photo Production

s-channel production in GlueX:



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- GlueX Range 12 GeV max
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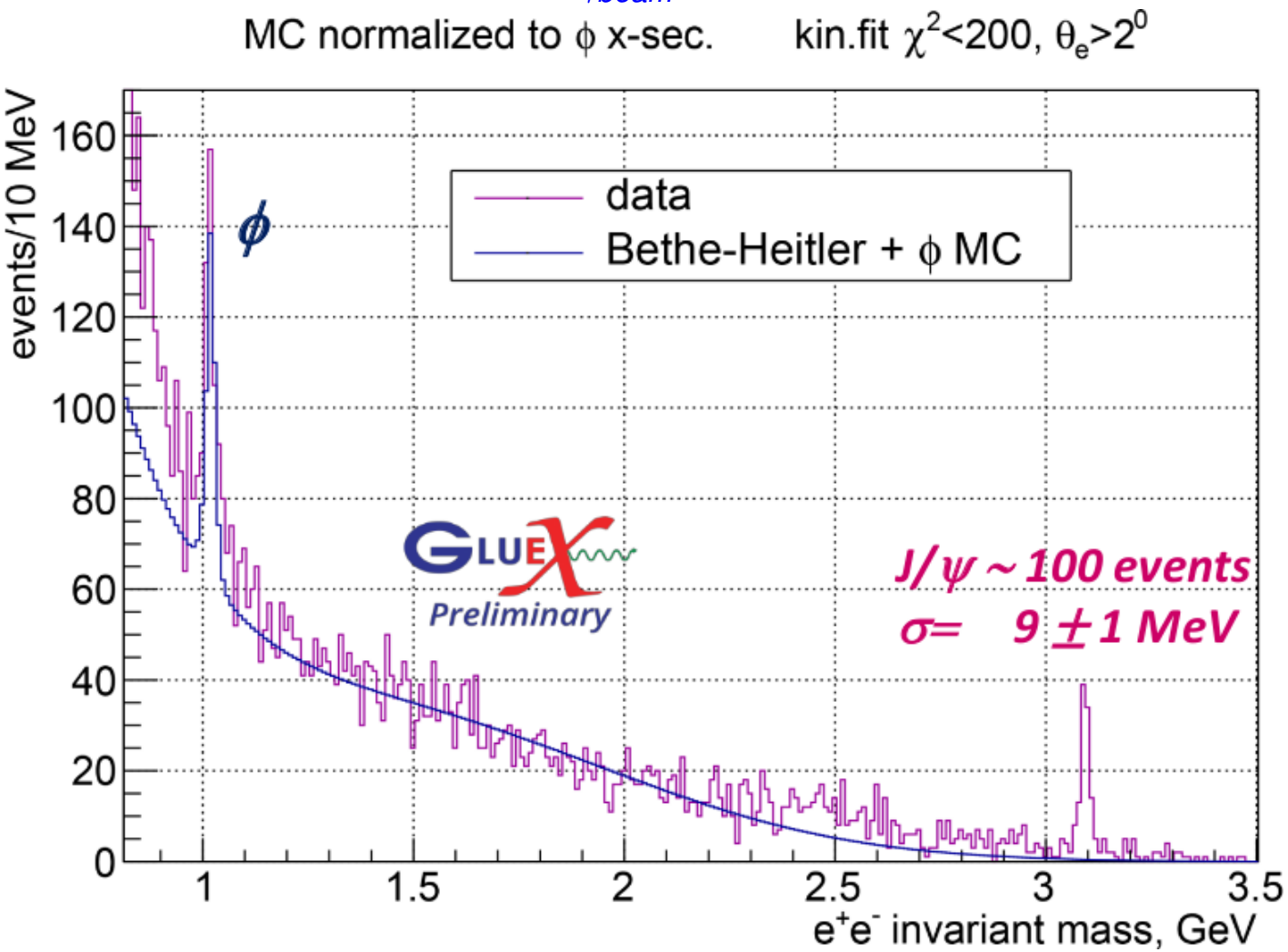
- PRL 115, 072001 (2015)
- P_c at $E_{\gamma beam} \sim 10$ GeV

J/ψ at GlueX a first look

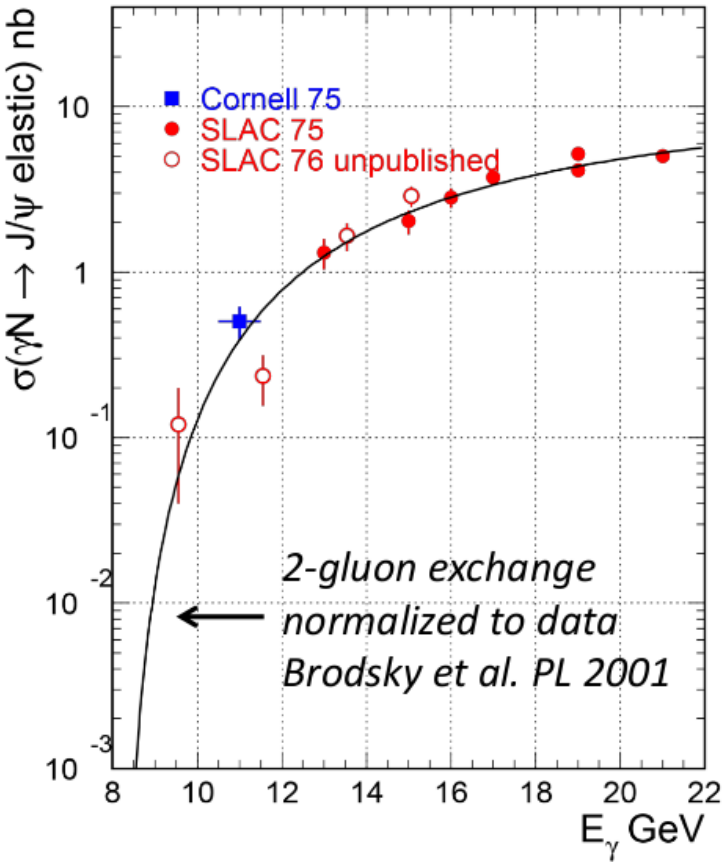
Invariant e^+e^- Mass distribution in GlueX:

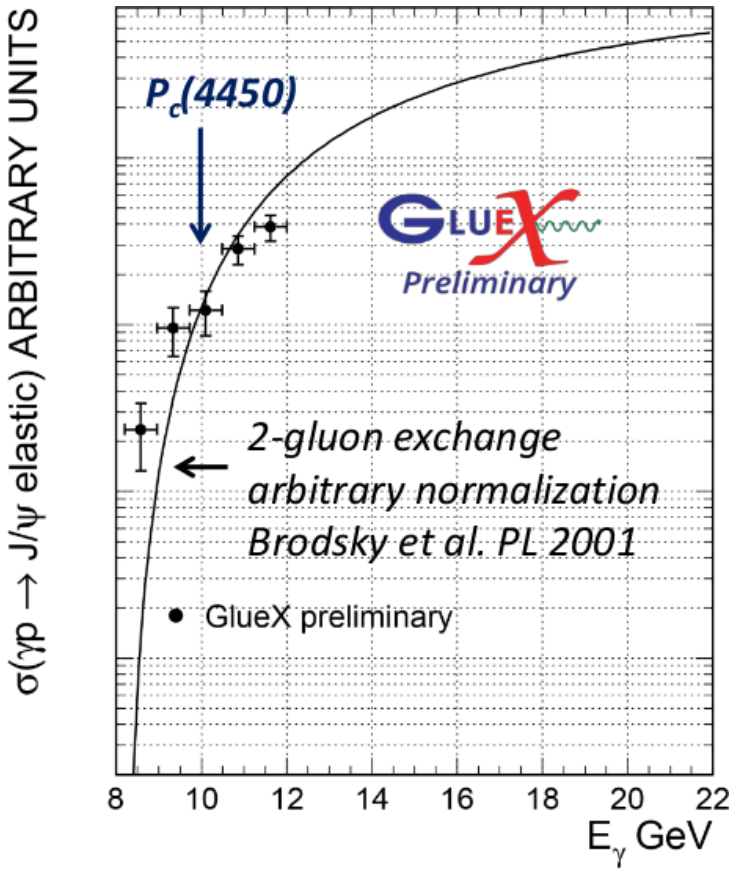
- Lepton ID with E/p in BCAL/FCAL
- Kinematic fit with $E_{\gamma_{beam}}$ and recoil proton



J/ψ at GlueX a first look

J/ψ cross section as function of $E_{\gamma_{beam}}$





Plan: Combine 2016/2017 data sets
$\rightarrow$ upper limit to P_c photo-production

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GlueX

Conclusions

- Successfully commissioned HallD beam line and GlueX detector
- First GlueX publication: Phys. Rev. C 95, 042201 (2017) beam asymmetries for π^0 and η
- GlueX physics program started: 20% complete (Phase-I)
- Data analysis underway to reach cross sections and SDMEs
- Next data taking period Fall 2017
- Other experiments in HallD:
  a) η Radiative Decay Width via the Primakoff Effect
  b) Charged Pion Polarizability in the $\gamma\gamma \to \pi^+\pi^-$ Reaction
  c) Meson and baryon decays to strange final states
  d) Rare η decay channels