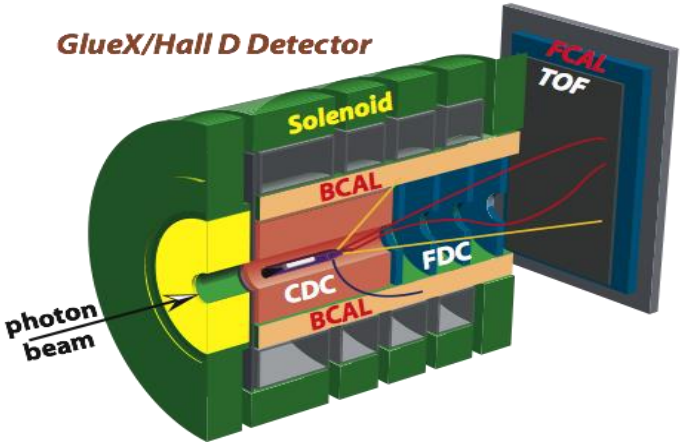


Jefferson Lab

Hall D / GlueX Physics Program

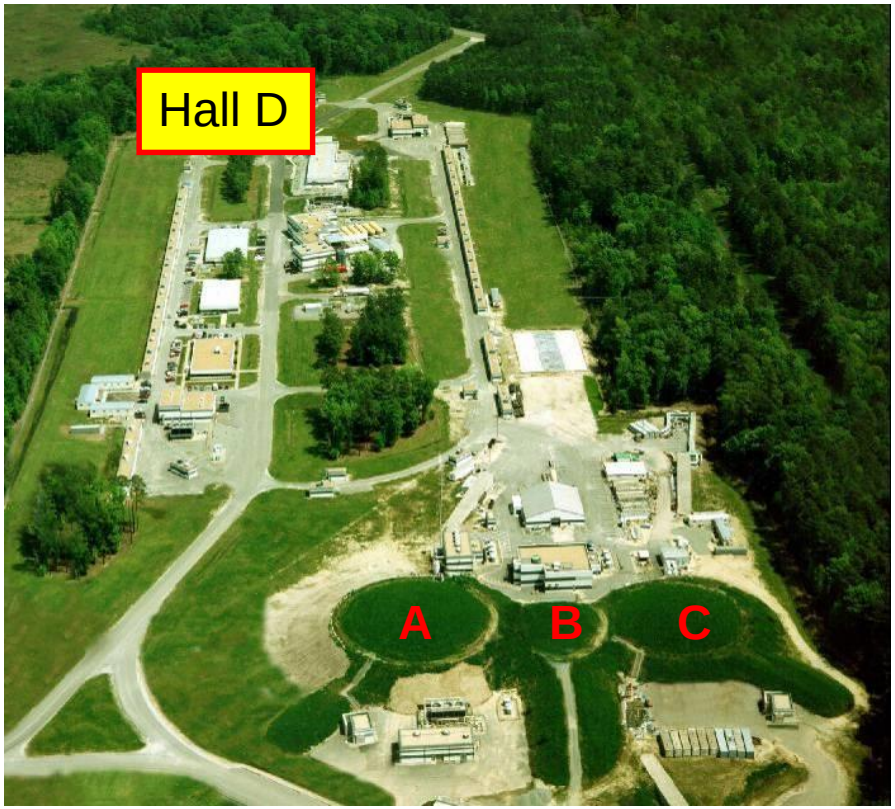
A. Somov, Jefferson Lab
for the GlueX collaboration

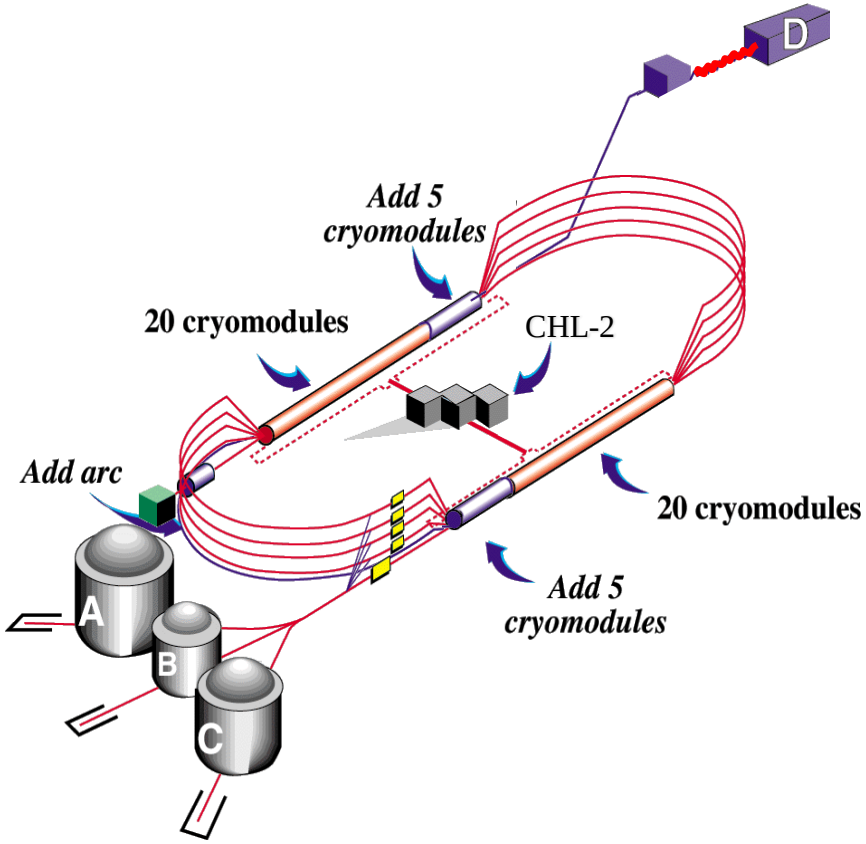
The 8th Workshop on Hadron Physics in China and Opportunities Worldwide, Wuhan, China, 8 – 11 August 2016

Outline

- GlueX detector in the experimental Hall D at Jefferson Lab
- Main physics goal of the GlueX experiment
- Detector overview
- Detector performance during commissioning in 2016
- Other experiments with the GlueX detector

CEBAF Upgrade to 12 GeV





- Upgrade CEBAF energy from 6 GeV to 12 GeV.
- New experimental Hall D with GlueX detector
  - photon beam (linear polarization)

Hall D Physics Program: Approved Experiments

Experiment	Name	Days	Condition	Target
E12-06-102	Mapping the spectrum of light quark mesons and gluonic excitations with Linearly polarized photons	120		LH_2
E12-12-002 E12-13-003	A study of meson and baryon decays to strange final states with GlueX in Hall D	220 (200)	L3 trigger PID	LH_2
E12-10-011	A precision measurement of the η radiative decay width via the Primakoff effect	79		LH_2 LHe_4
E12-13-008	Measuring the charged pion polarizability in the $\gamma\gamma \rightarrow \pi^+\pi^-$ reaction	25		Sn
C12-14-004 (conditionally approved)	Eta decays with emphasis on rare neutral modes: The JLab Eta Factory experiment (JEF)	(130)	Upgrade Forward calorim.	LH_2

Hall D Physics Program

LOI	Name	Days	Condition	Target
LOI12-15-001	Physics with secondary K_L beam			LH_2, A
LOI12-15-006	Production ω mesons off nuclei			A
LOI12-16-001	An experimental test of lepton universality through Bethe-Heitler production of lepton pairs			Active H_2
LOI12-16-002	Probing short-range nuclear structure and dynamics with real photons and nuclear targets at GlueX			LH_2, A
LOI12-16-002	Target helicity correlations in GlueX			C_4H_9OH

Workshops on GlueX Physics Program

K_L Workshop, Jefferson Lab, Feb 1 – 3, 2016
Nuclear production with GlueX, Jefferson Lab, April 28-29, 2016

GlueX Collaboration in Hall D

- Arizona State
- Athens
- Carnegie Mellon
- Catholic University
- University of Connecticut
- Florida International
- Florida State
- George Washington
- Glasgow
- GSI
- Indiana University
- ITEP
- Jefferson Lab
- University Mass Amherst
- MIT
- MEPhI
- Norfolk State
- North Carolina A&T
- University North Carolina Wilmington
- Northwestern
- University of Regina
- Santa Maria
- Tomsk
- Yerevan Physics Institute
- College of William and Mary
- Wuhan University

International collaboration from 24 institutions

Two more groups are currently joining

Hall D Timeline

✓ First commissioning data in Fall 2014 / Spring 2015

- Beamline / detector commissioning
- Beam energy below 6 GeV
- Some liner polarization

✓ Commissioning run in Fall 2015 / Spring 2016

- 12-GeV electron beam
- Linearly polarized photon beam
- Low luminosity (5 times smaller)
- GlueX commissioning completed

➢ Physics running: Fall 2016 - Spring 2018

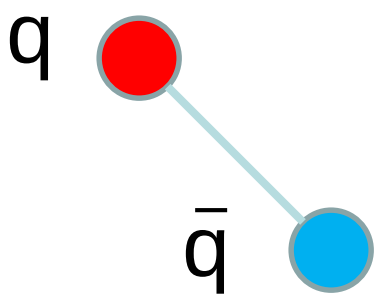
➢ PrimEx D Experiment: Fall 2018 (Plan)

➢ High intensity GlueX running: Starting in spring 2019 (Plan)

- Upgrade kaon identification in 2018

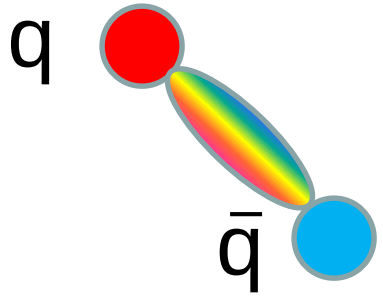
Exotic Mesons

Conventional Mesons



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

Hybrid Mesons



- Excited gluonic field coupled to a $q\bar{q}$ pair can result in hybrid mesons with **exotic J^{PC}**

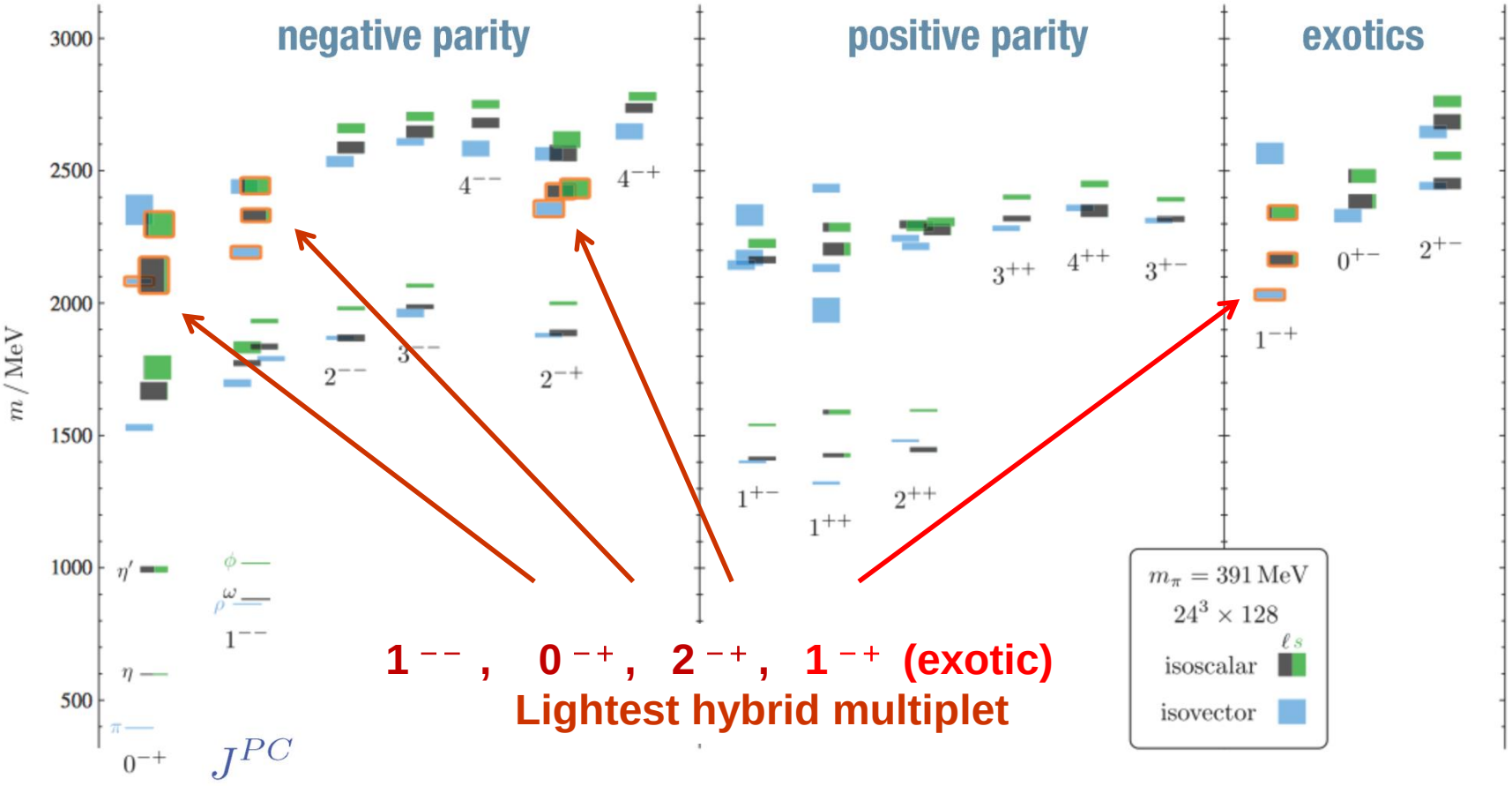
- Predicted by several models. Recent calculations using lattice QCD - constituent gluon with $J^{PC} = 1^{+-}$ and mass 1 – 1.5 GeV

J^{PC}:

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

Lattice QCD Predictions

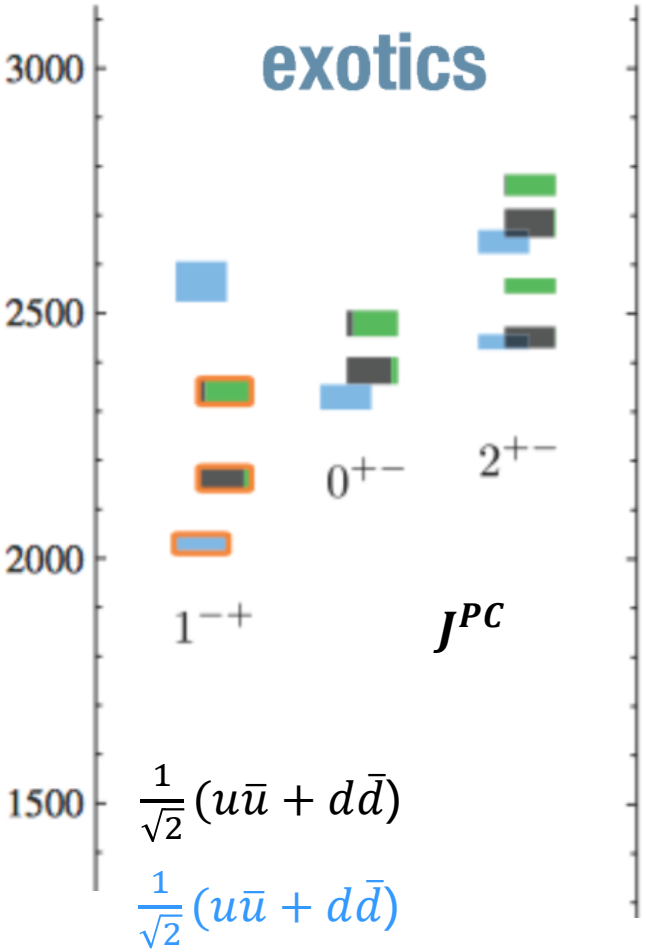
Dudek et al. PRD 88 (2013) 094505



1^{--}, 0^{-+}, 2^{-+}, 1^{-+} (exotic)

Lightest hybrid multiplet

Lattice QCD Predictions



Mass predictions:

	1^{-+}	2.0 – 2.4 GeV/c^2
J^{PC}	0^{+-}	2.3 – 2.5 GeV/c^2
	2^{+-}	2.4 – 2.8 GeV/c^2

- Lattice calculations predict light-quark hybrid mesons and with strange quark content
  - good identification of kaons required (GlueX PID upgrade)
- Search for mesons in many final states

Search Modes of Exotic Decays

J^{PC}	Exotic Meson	Possible Decays
1^{-+}	$\pi_1(1900)$	$\pi\rho$, πb_1, πf_1, $\pi\eta'$, ηa_1
	$\eta_1(2100)$	ηf_2, $a_2\pi$, ηf_1, $\eta\eta'$, $\pi(1300)\,\pi$
	$\eta_1'(2300)$	K^*K, $K_1(1270)\,K$, $K_1(1410)\,K$, $\eta\eta'$
2^{+-}	$b_2(2500)$	$\omega\pi$, $a_2\pi$, $\rho\eta$, $f_1\rho$, $a_1\pi$, $h_1\pi$, $b_1\eta$
	$h_2(2500)$	$\rho\pi$, $b_1\pi$, $\omega\eta$, $f_1\omega$
	$h_2'(2600)$	$K_1(1270)\,K$, $K_1(1410)\,K$, $K_2^*\,K$, $\phi\eta$
0^{+-}	$b_0(2400)$	$\pi(1300)\,\pi$, $h_1\pi$, $f_1\rho$, $b_1\eta$
	$h_0(2400)$	$b_1\pi$, $h_1\eta$
	$h_0'(2500)$	$K_1(1270)\,K$, $K_1(1460)\,K$, $h_1\eta$

Multiparticle final states:

- **(p,n) + 3π, 4π, $3\pi\eta$, $4\pi\eta$ …**
- **70% of decays involve at least one π^0**
- **50% more than two π^0**

Experimental Status

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

$\pi_1(1400) \to \eta\pi$

Seen by several experiments. Interpretation unclear: dynamic origin, 4-quark state. Not a hybrid (?)

$\pi_1(1600) \to \eta'\pi$
$\pi_1(1600) \to \rho\pi$
$\pi_1(1600) \to b_1\pi$
$\pi_1(1600) \to f_1\pi$

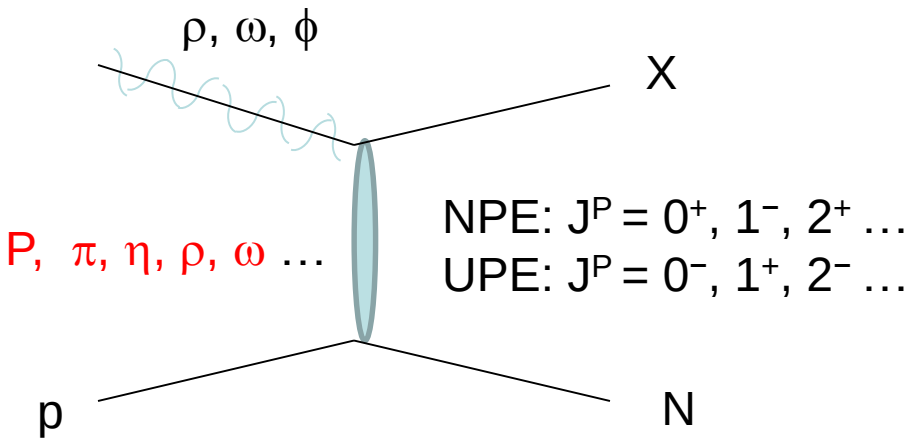
- First seen by VES, E852, COMPASS
- 3π controversial:
  - 3π not seen in photoproduction (CLAS)
- May be a hybrid
- Need more analysis and data

$\pi_1(2000) \to f_1\pi$
$\pi_1(2000) \to b_1\pi$

- Seen by E852 (but not seen by VES)
- Statistics is limited
- May be a hybrid

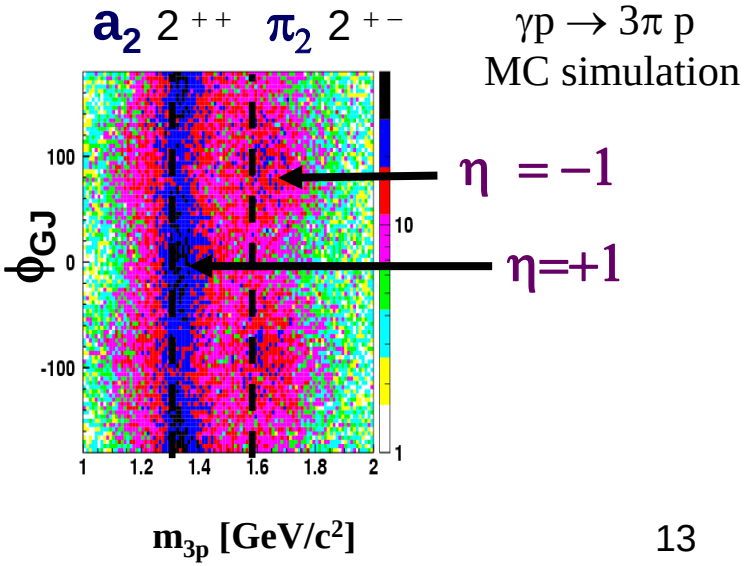
- Exotic meson candidates, but no strong evidence
- Reconstruct exotic mesons in many final state. More data are needed

Photoproduction of Exotic Mesons



Exchange particle		Final States	
P	0^+	$0^{+-}, 2^{+-}$	b^0, h, h′
π^0	0^-	2^{+-}	b_2^0, h_2, h_2'
$\pi^\pm$	0^-	1^{-+}	$\pi_1^\pm$
ω	1^-	1^{-+}	π_1, η_1, η_1'

- t-channel exchange
- couple to photoproduction (via Vector Meson Dominance)
- Polarized photon beam helps to determine production mechanism (naturality)



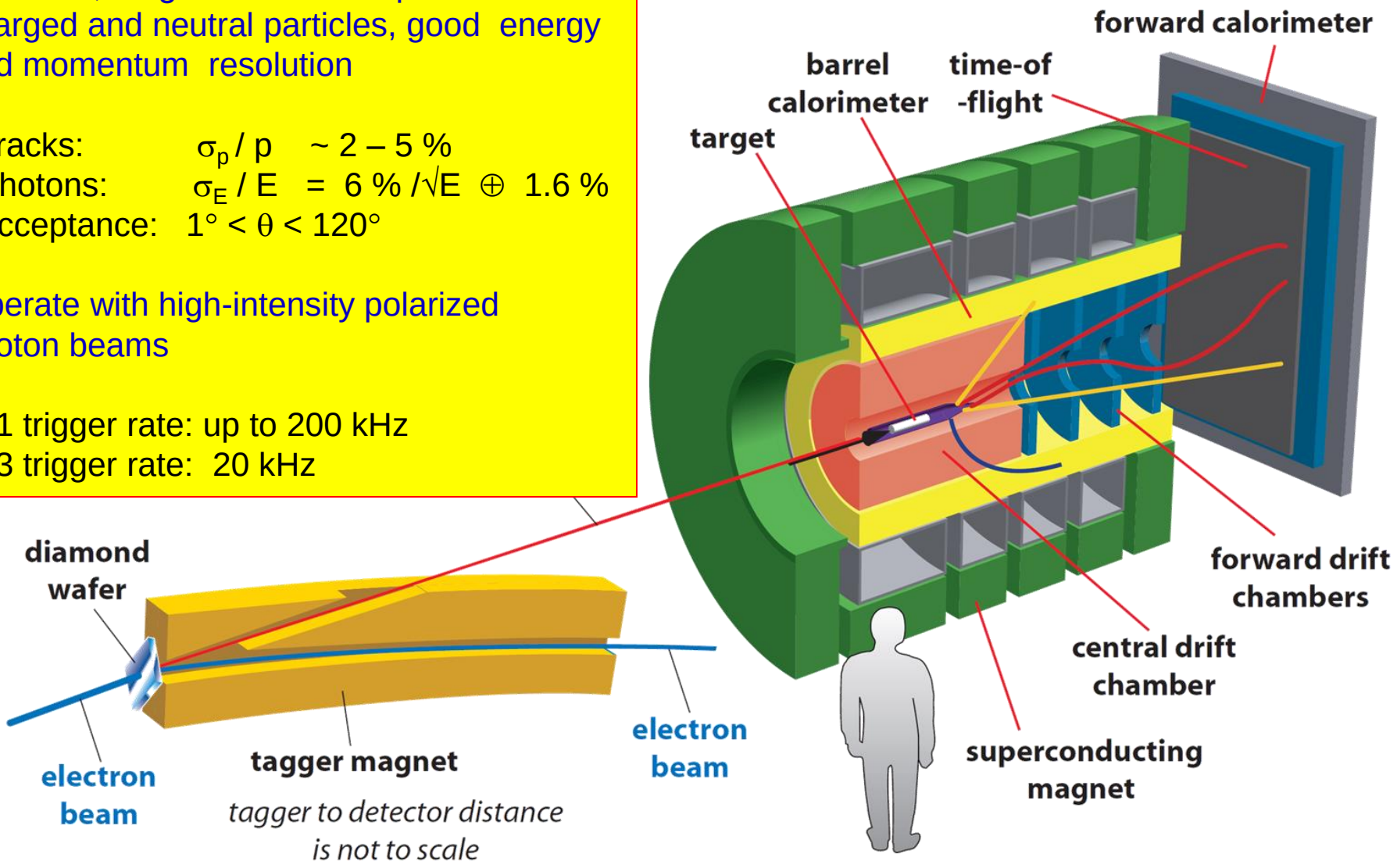
GlueX Spectrometer: Design Requirements

- Optimized to detect multi-particle final states
- Hermetic, large/uniform acceptance for charged and neutral particles, good energy and momentum resolution

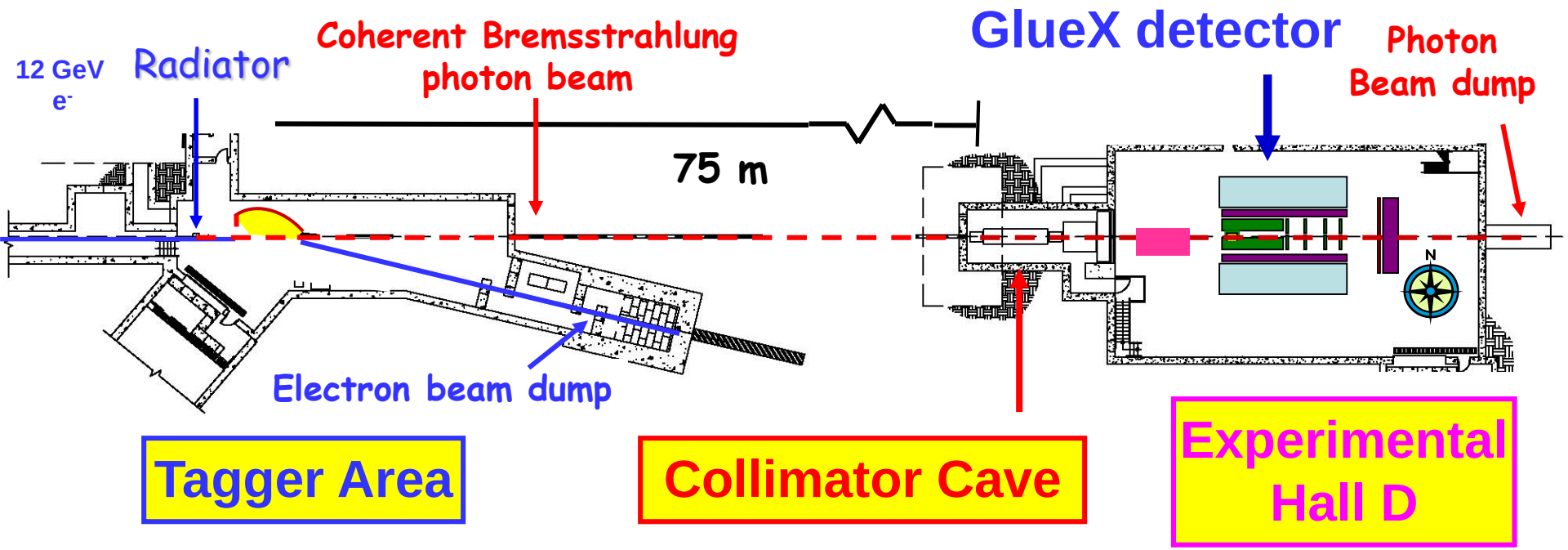
  Tracks: σ_p / p ~ 2 – 5 %
  Photons: $\sigma_E / E = 6\,\% / \sqrt{E} \oplus 1.6\,\%$
  Acceptance: $1^\circ < \theta < 120^\circ$

- Operate with high-intensity polarized photon beams

  L1 trigger rate: up to 200 kHz
  L3 trigger rate: 20 kHz



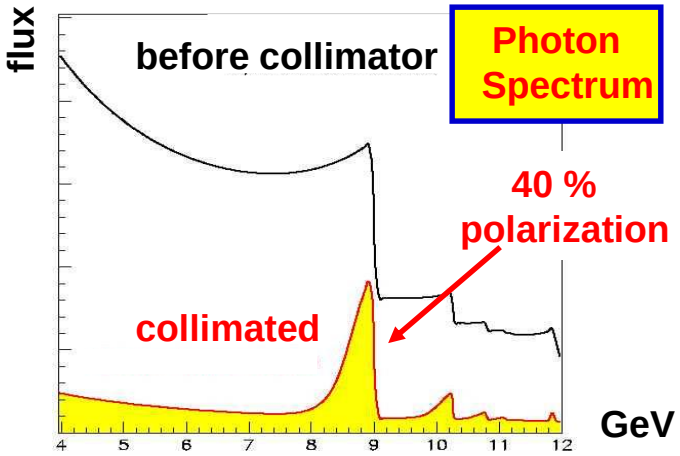
Polarized Photon Beam



- **Beam photons are produced by 12 GeV electrons (I < 1.1 μA) on a thin diamond crystal (20 – 50 μm)**
- **Photon energy: detect bremsstrahlung electrons**

$$\Delta E / E \sim 10^{-3}$$

- **Pass beam photons through the collimator**
  - **increase the fraction of linearly polarized photons**
  - **beam intensity: $5 \cdot 10^7$ γ/sec for 8.4 < E_γ < 9.1 GeV**

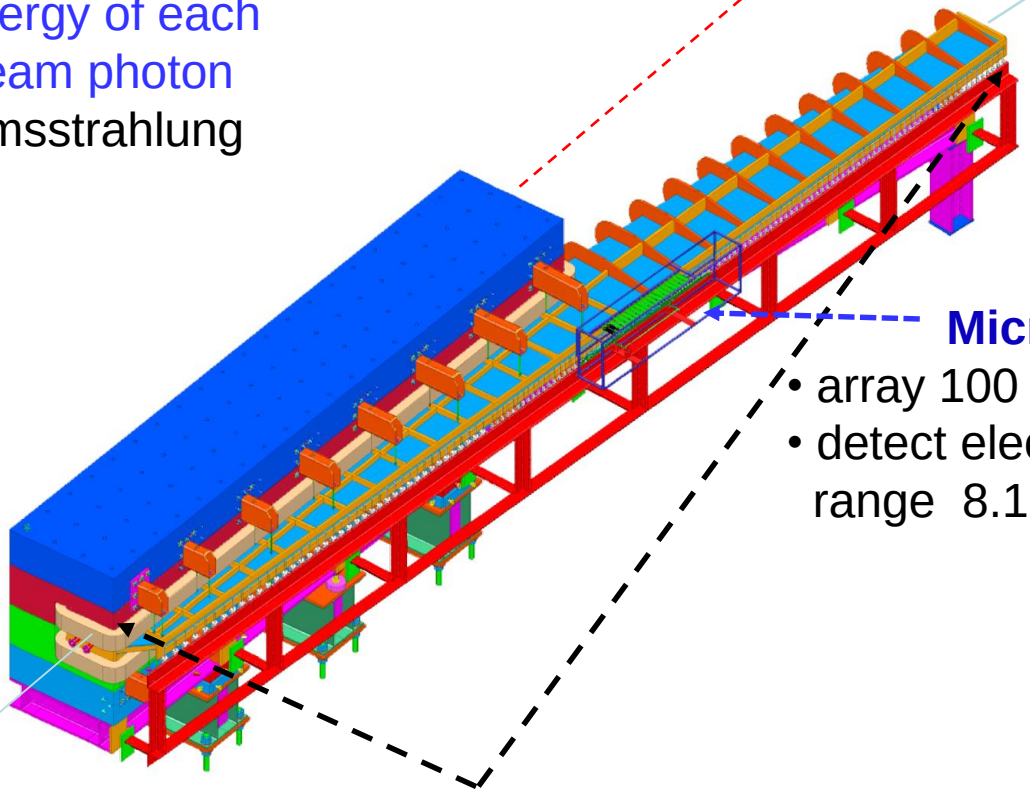


Tagged Photon Beam

Electrons to the beam dump

Photons to Hall D

- Measure energy of each individual beam photon
  - detect bremsstrahlung electron



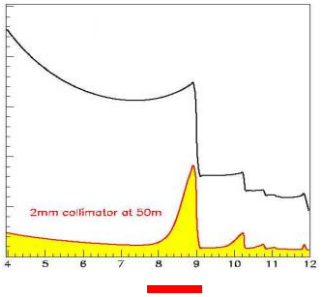
Microscope

- array 100 x 5 of thin scintillators
- detect electrons in the energy range 8.1 GeV < E_γ < 9.2 GeV

12 GeV e beam

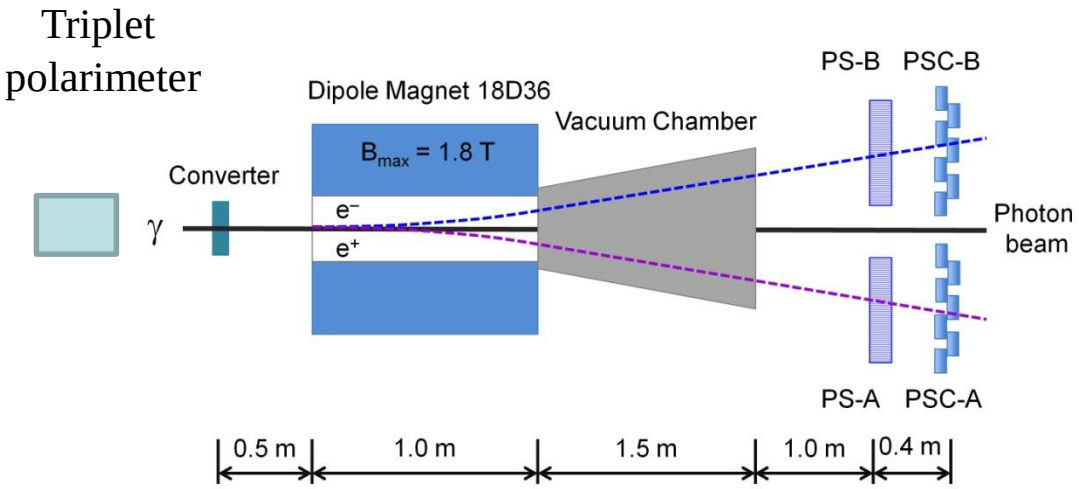
Radiator

Fixed Array Hodoscope



- cover large energy range 3 GeV < E_γ < 11.78 GeV
- 233 counters installed
- detect tagged electrons with E_γ > 9.2 GeV during data runs

Photon Flux and Beam Polarization: Pair Spectrometer



Two layers of scintillator detectors:

High-granularity hodoscope (measure photon energy in the range 6 – 12 GeV)

Low-granularity counters (use in the trigger)

- Reconstruct the energy of a beam photon by detecting the $e^{\pm}$ pair produced by the photon in a thin converter
  - measure the spectrum of the collimated photon beam
  - monitor the photon beam flux
  - calibrate energy of tagger detectors

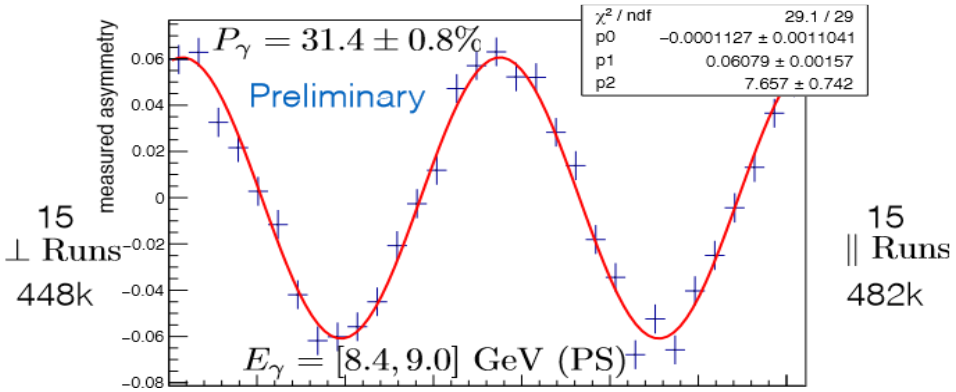
Beam Polarization

- Polarization measurements:
  - triplet production process e $\gamma \rightarrow$ e$^-$ e$^+$ e$^-$ (Triplet Polarimeter)
  - photon beam spectrum (Pair Spectrometer, Tagger Microscope)
  - physics channel like $\gamma p \rightarrow \rho p$
- Two orthogonal orientations of the polarization plane (radiator orientation)
  - horizontal and perpendicular

Polarimeter

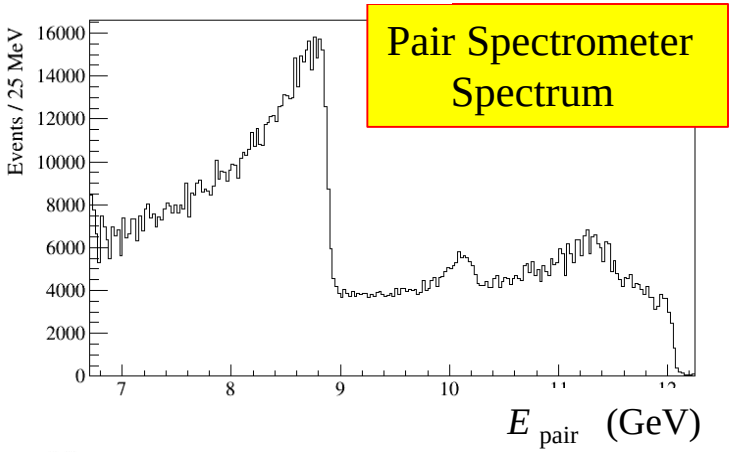
$$d\sigma_{\parallel,\perp} \propto 1 \pm P_{\parallel,\perp} \Sigma \cos 2\phi$$

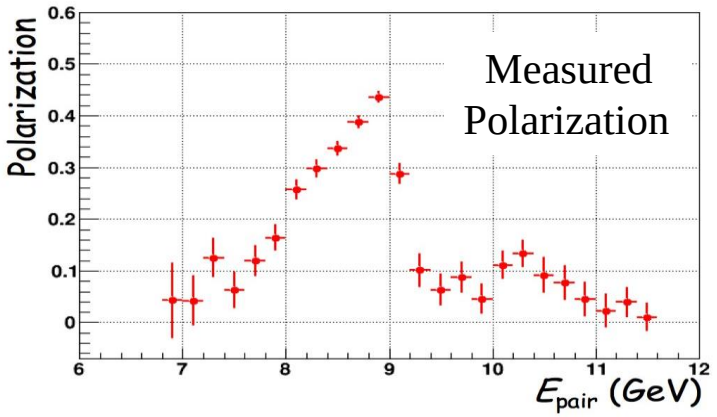
$$\frac{N_\perp - N_\parallel}{N_\perp + N_\parallel} \sim P_\gamma \Sigma \cos 2\phi$$



Triplet azimuthal angle [degrees]

Pair Spectrometer Spectrum





GlueX Detector

Tracking:

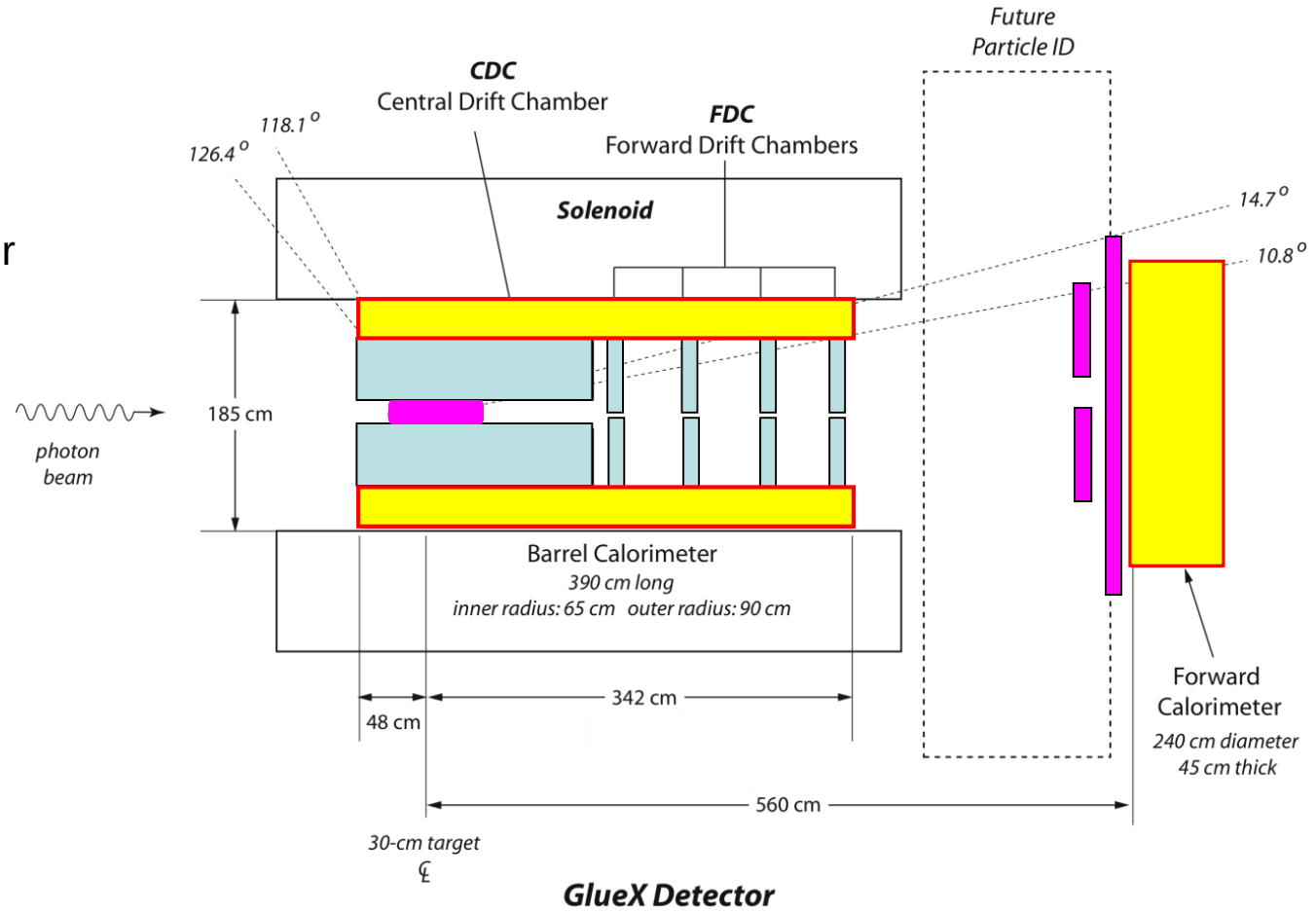
- Central Drift Chamber
- Forward Drift Chamber

Calorimetry:

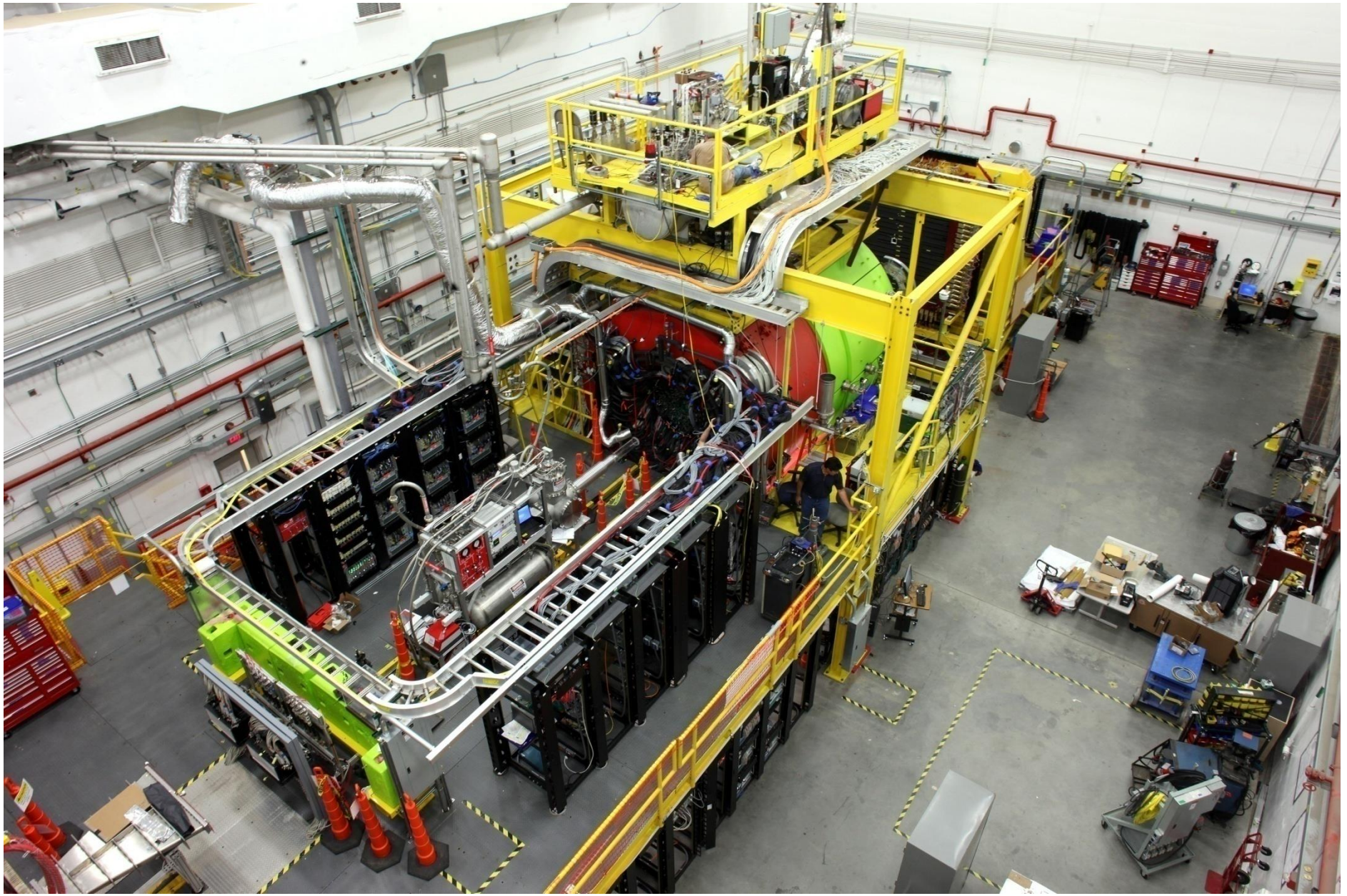
- Barrel Calorimeter
- Forward Calorimeter

PID:

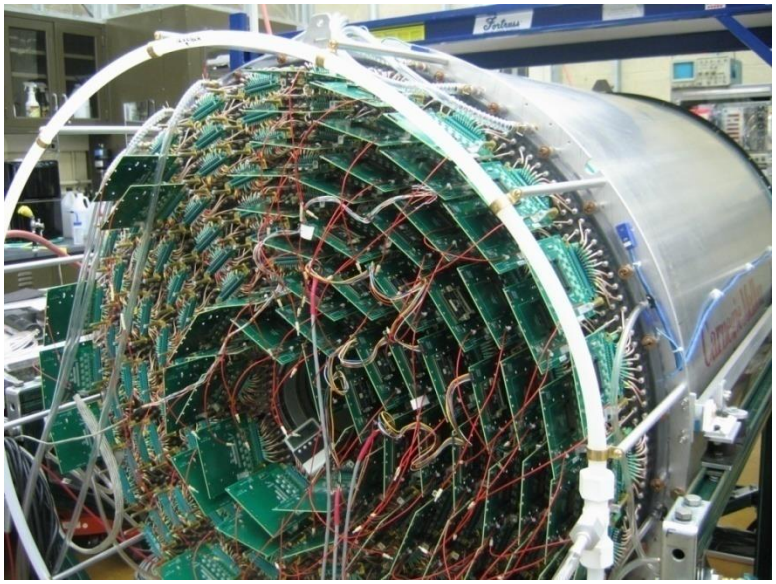
- Time of Flight wall
- Start Counter
- Barrel Calorimeter
- DIRC detector



GlueX Detector

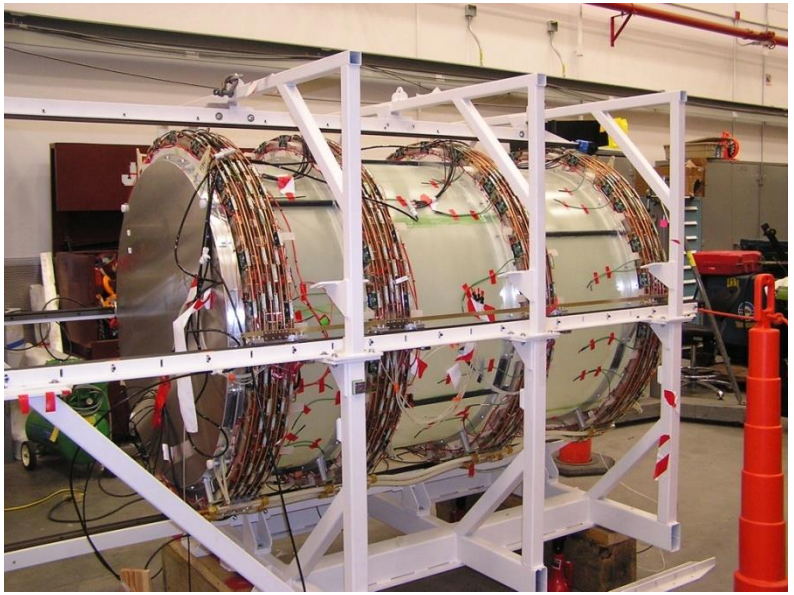


Tracking



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

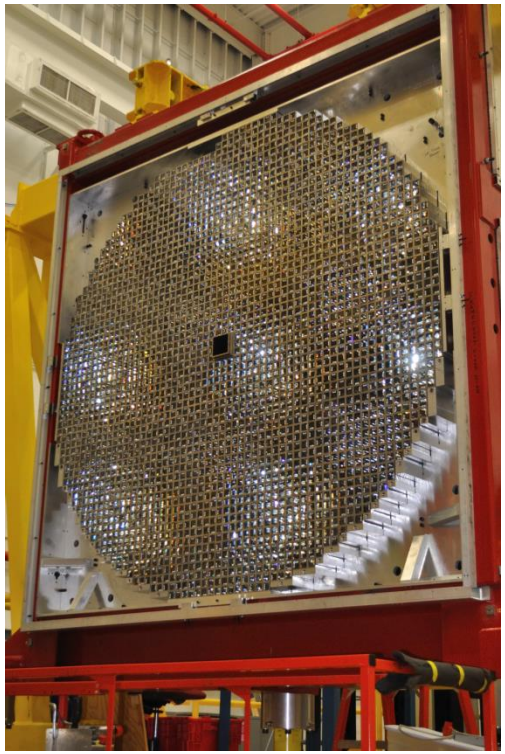


Forward Drift Chamber

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

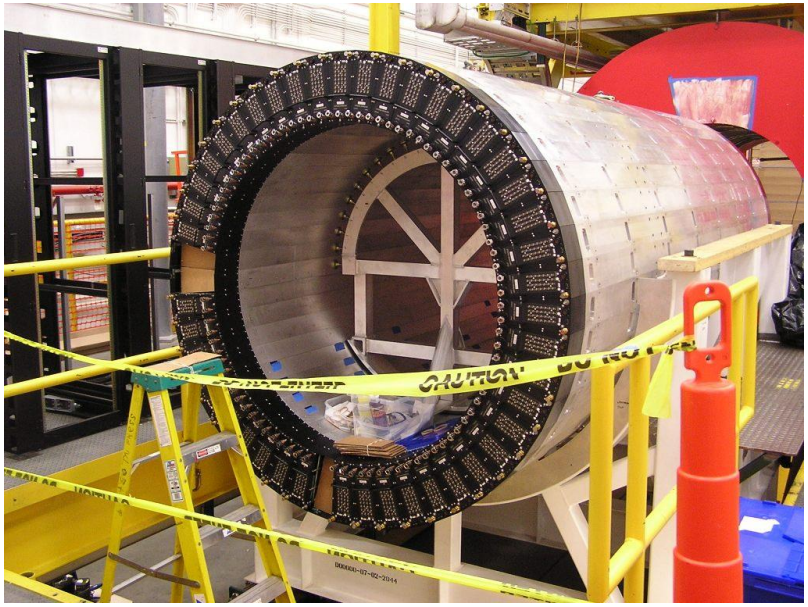
Tracking performance: $\sigma_p / p \sim 2 – 5\ \%$

Calorimetry



Forward Calorimeter:

- Angular coverage $2° < \theta < 11°$
- 2800 Pb-glass blocks: 4cm x 4 cm x 45 cm
- **$\sigma_E / E = 6\% / \sqrt{E} \oplus 2.0\%$**
- **$\sigma_{xy} = 6.4\ mm / \sqrt{E}$**

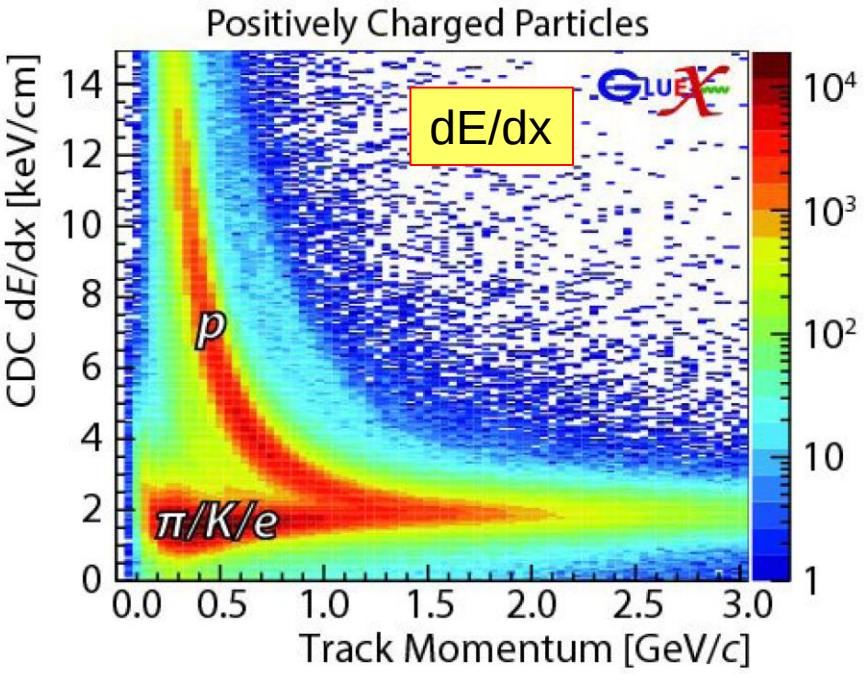


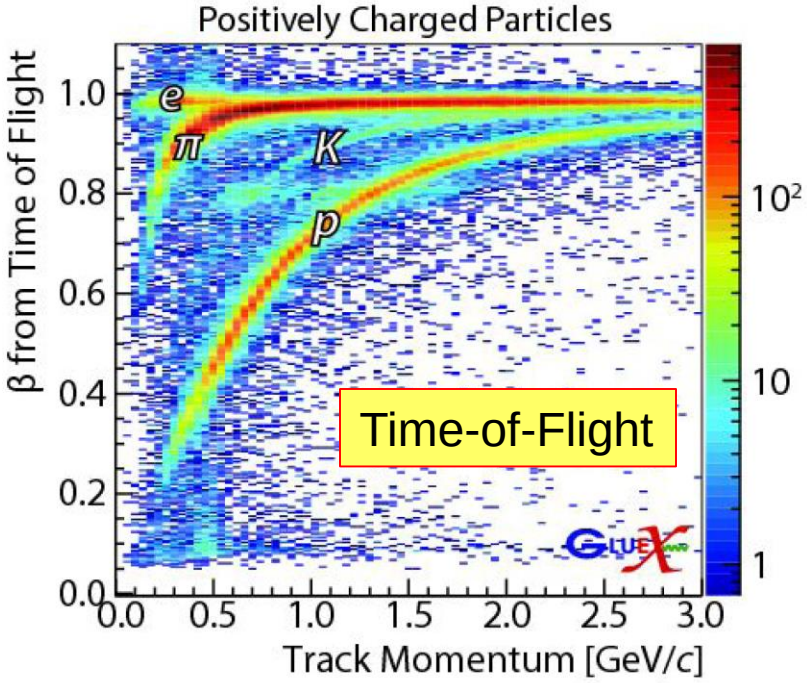
Barrel Calorimeter:

- Angular coverage $11° < \theta < 120°$
- 191 layers Pb:ScFib:Glue (37:49:14%)
- Double side readout (SiPM)
- **$\sigma_E / E = 6\% / \sqrt{E} \oplus 1.6\%$**
- **$\sigma_Z = 5\ mm / \sqrt{E}$**
- **$\sigma_t = 74\ ps / \sqrt{E} \oplus 33\ ps$**

Particle Identification

- dE/dx: p/π separation p < 0.7 GeV/c
- Time-of-Flight wall: K/π separation up to p = 1.3 GeV/c
- kinematical constraints

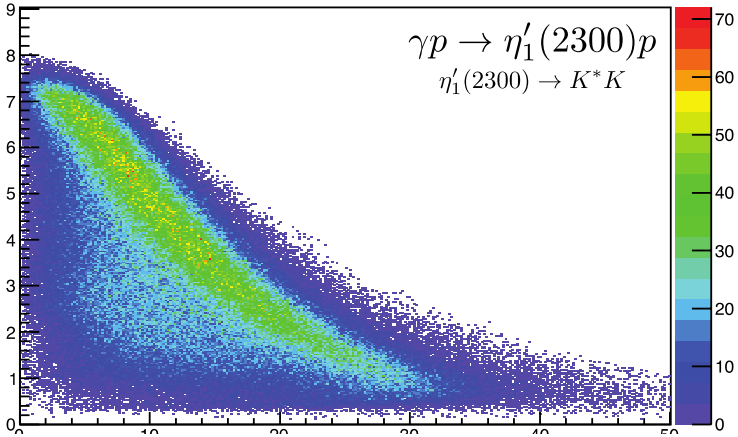




Kaon Identification

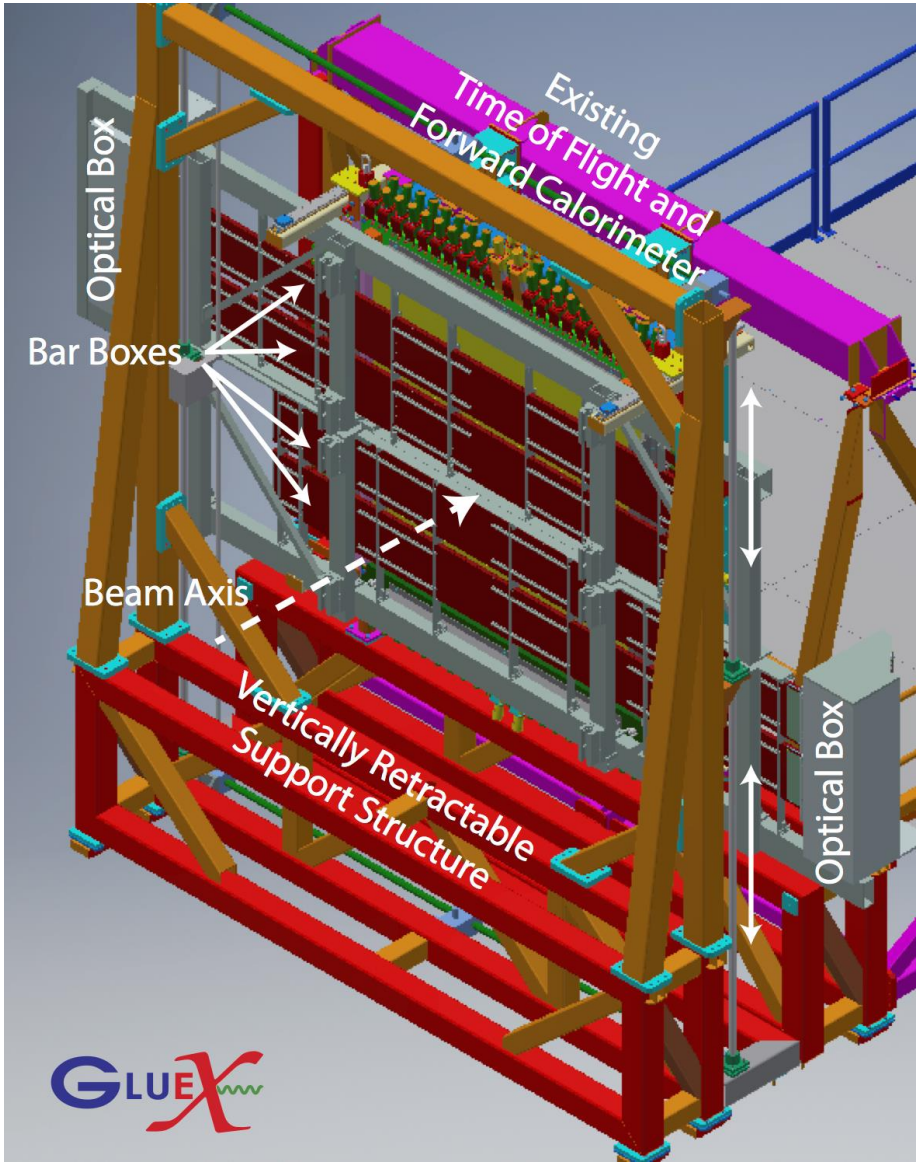
- Install quartz bars
  (used in BaBar DIRC)

- improve K/π separation up to 4.0 GeV/c



Eff = 15 % (no DIRC)
Eff = 33 % (with DIRC) purity 95 %

- installation scheduled for spring 2018

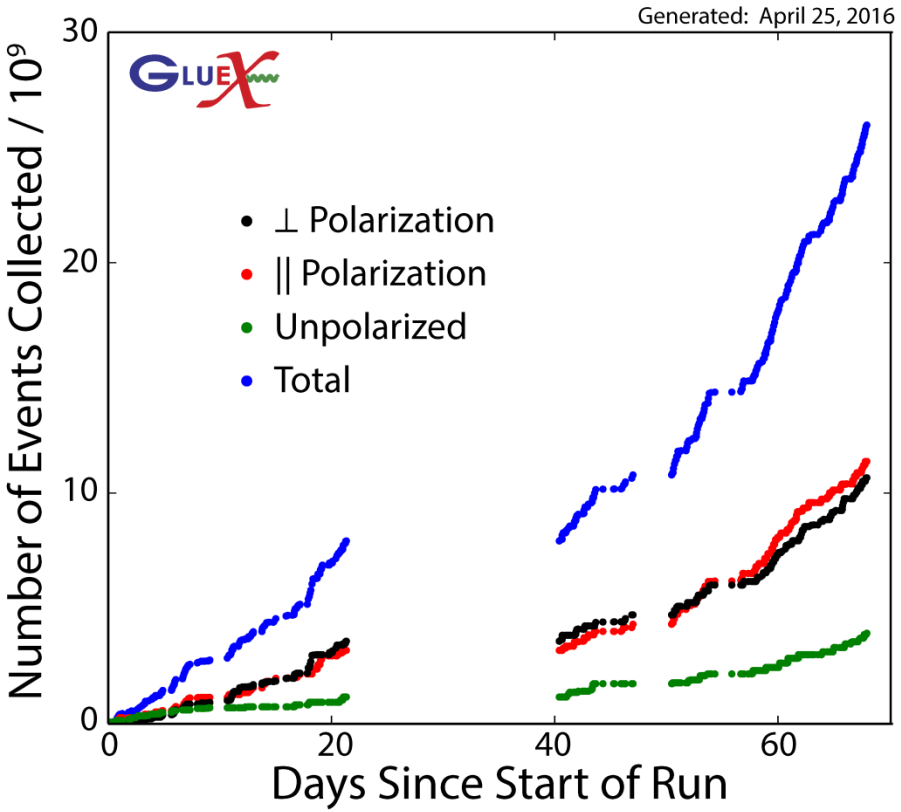


GlueX Commissioning in Spring 2016

- 12 GeV polarized photon beam delivered to Hall D
- Beam studies
- Detector performance studies
- Trigger studies

  - Trigger rate 30 kHz
  - 90 % live time
  - 750 Mbyte/sec data rate

- Acquire data for detector calibration and first physics



GlueX commissioning completed

Plans for Early Physics

- Physics analyses using commissioning data

  - photoproduction of light mesons

    $\gamma\, p \rightarrow (\pi, \eta, \eta', \rho, \omega, \phi)\, p$

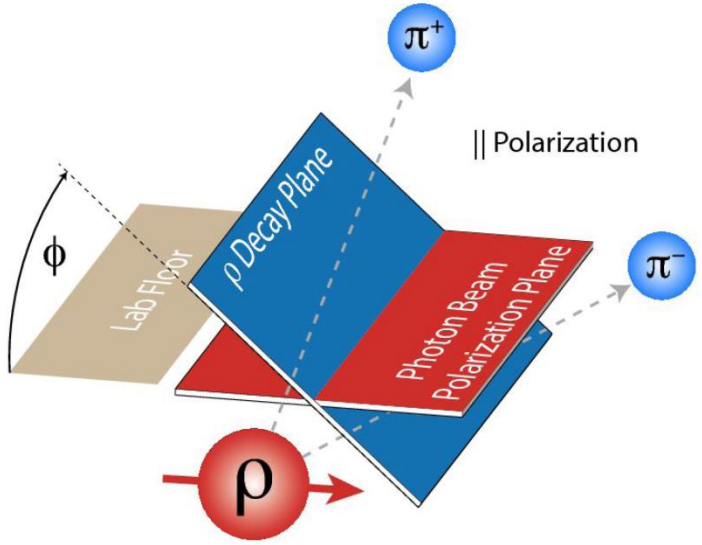
  - measurements of polarization transfer, beam asymmetry
  - cross sections

- Initial searches for exotic hybrid mesons:

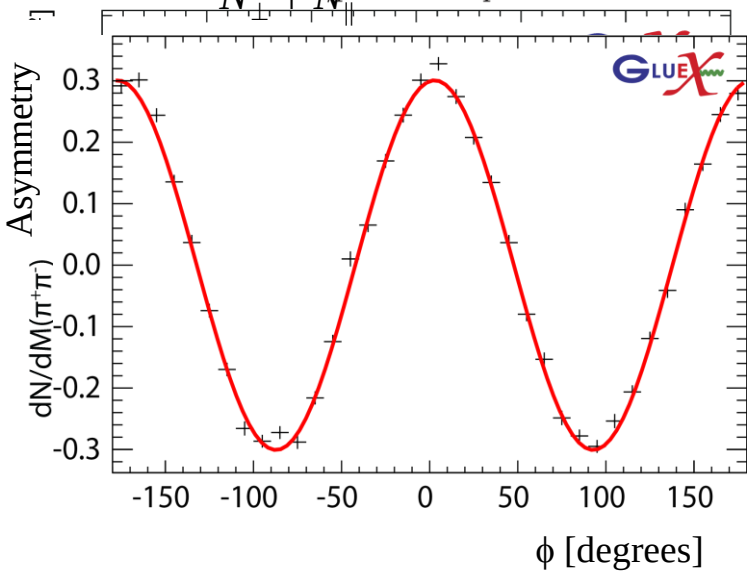
$\gamma\, p \rightarrow \eta\, \pi\, (n, p)$
$\gamma\, p \rightarrow \eta'\, \pi\, (n, p)$
$\gamma\, p \rightarrow \rho\, \pi\, (n, p)$
$\gamma\, p \rightarrow \omega\, \pi\, (n, p)$
$\gamma\, p \rightarrow \omega\, \pi\, \pi\, (n, p)$
$\gamma\, p \rightarrow \eta\, \pi\, \pi\, (n, p)$

Photoproduction of ρ Mesons: $\gamma p \rightarrow \rho^0 p$

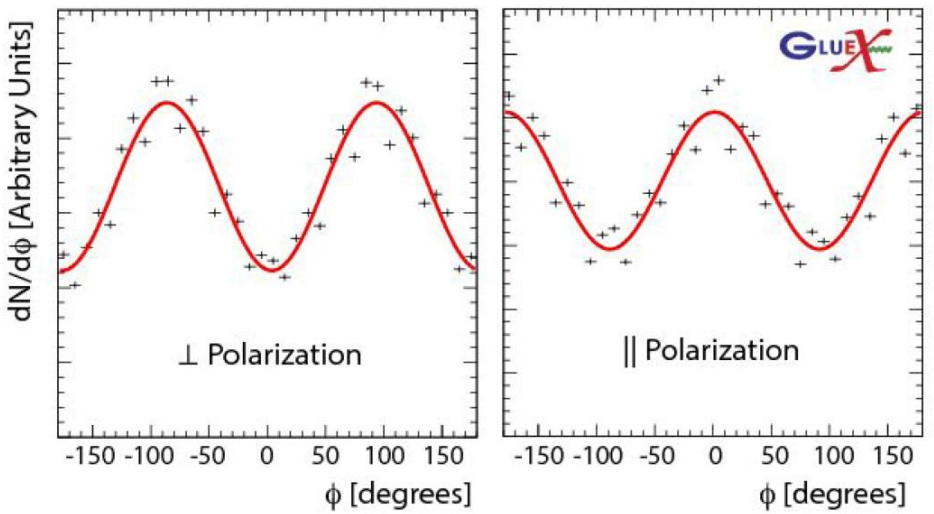
- Large polarization transfer to ρ meson
- Good channel to monitor photon beam polarization
- Data sample acquired: ~4 M reconstructed $\gamma p \rightarrow \rho^0 p$ in $8.4 < E\gamma < 9.0$ GeV
  - about two orders of magnitude larger than world existing data !



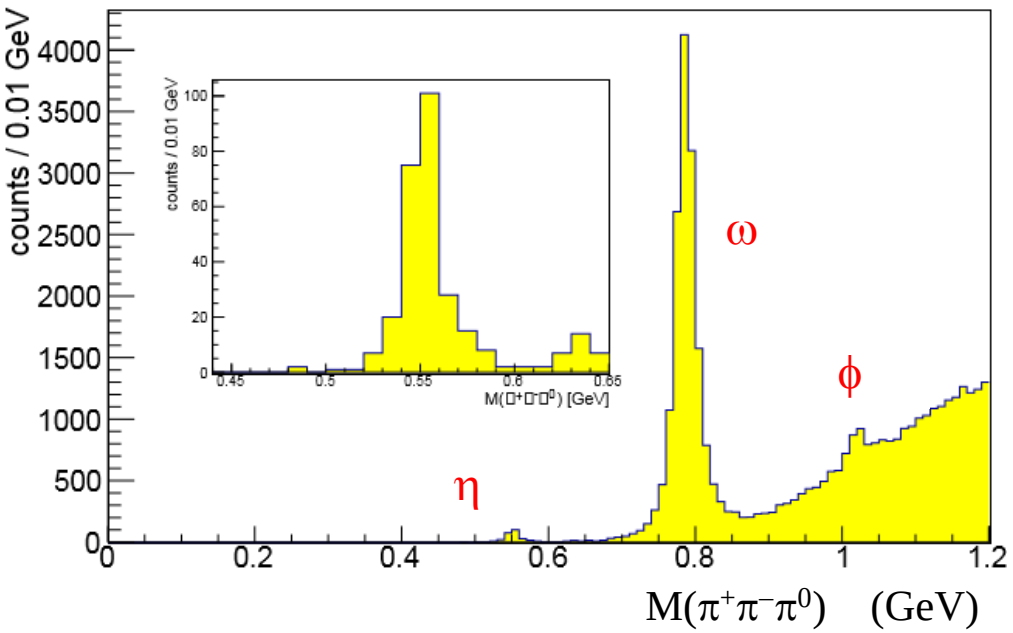
$$\frac{N_\perp - N_\parallel}{N_\perp + N_\parallel} \sim P_\gamma \Sigma \cos 2\phi \qquad p\gamma \rightarrow \pi^+\pi^- p$$



$$d\sigma_{\parallel,\perp} \propto 1 \pm P_{\parallel,\perp} \Sigma \cos 2\phi$$



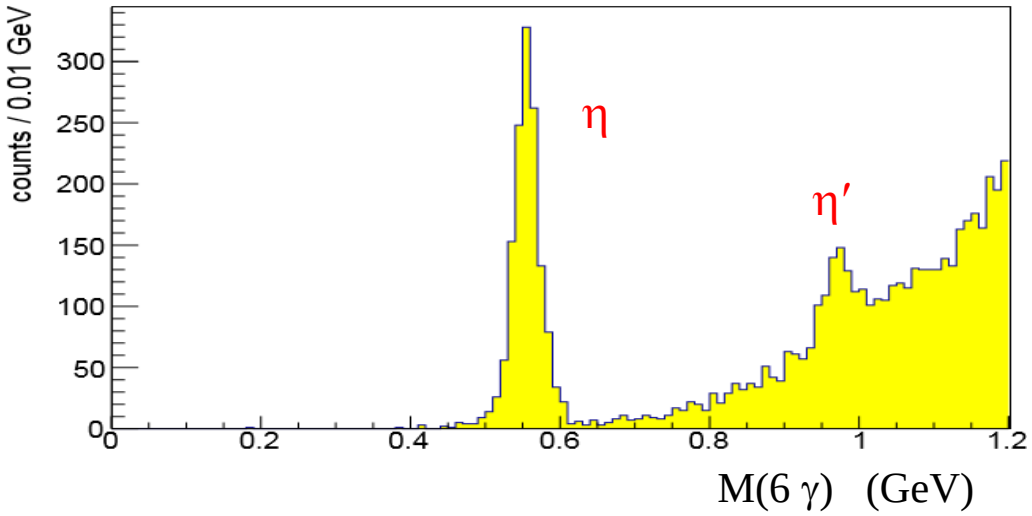
Mesons Reconstructed with GlueX



Exclusive reactions

$$\gamma + p \rightarrow X + p$$

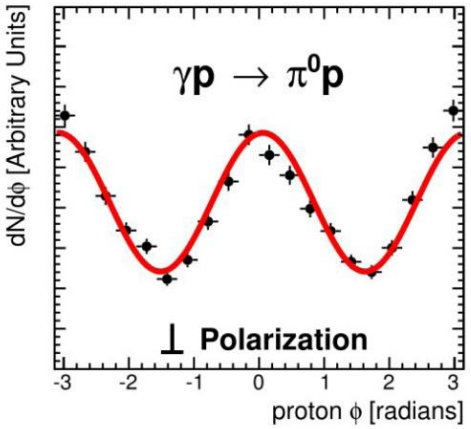
$\pi^+\pi^-\pi^0$ invariant mas

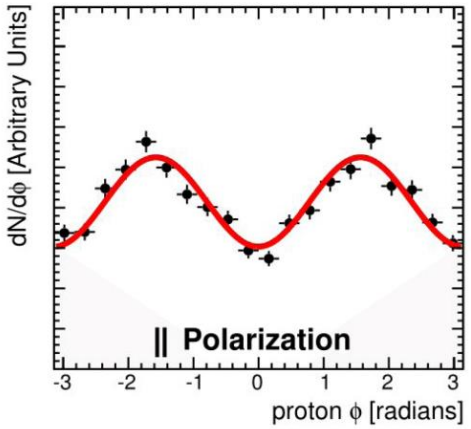


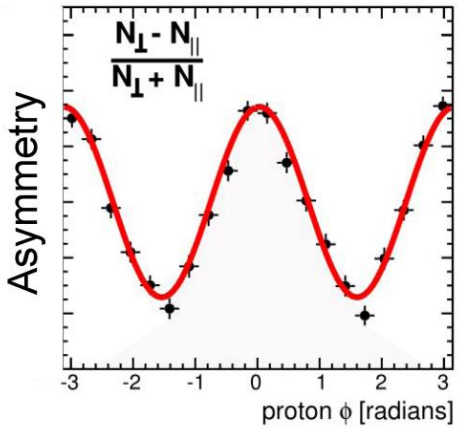
6 γ invariant mas

Beam Asymmetries for Pseudoscalar Mesons

$\gamma\, p \rightarrow \pi^0\, p$



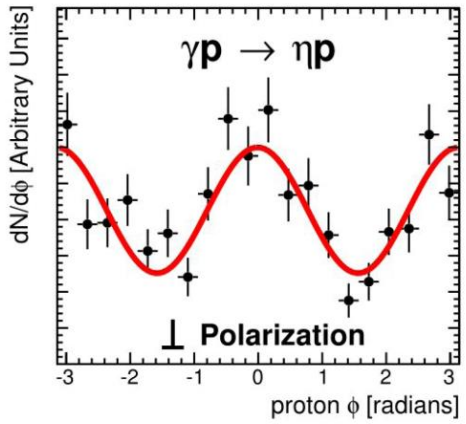


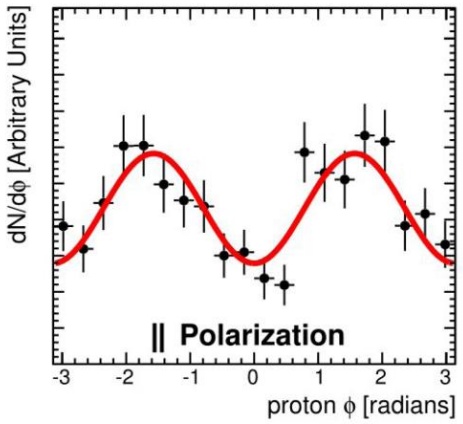


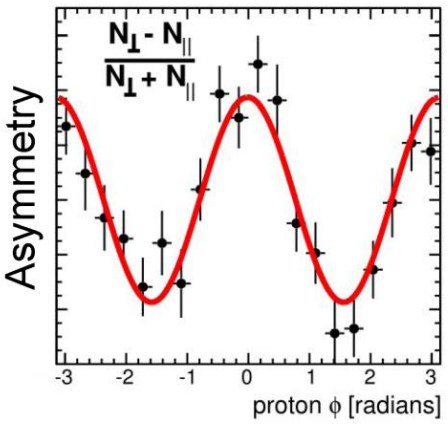
$$\frac{N_\perp - N_\parallel}{N_\perp + N_\parallel} \sim P_\gamma \Sigma \cos 2\phi$$

$\gamma\, p \rightarrow \eta\, p$

E_γ = 8.4 - 9.0 GeV



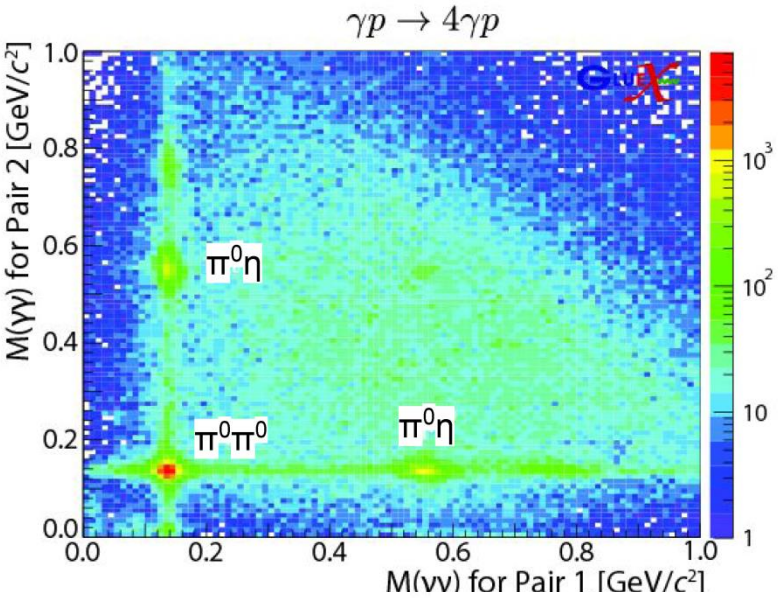


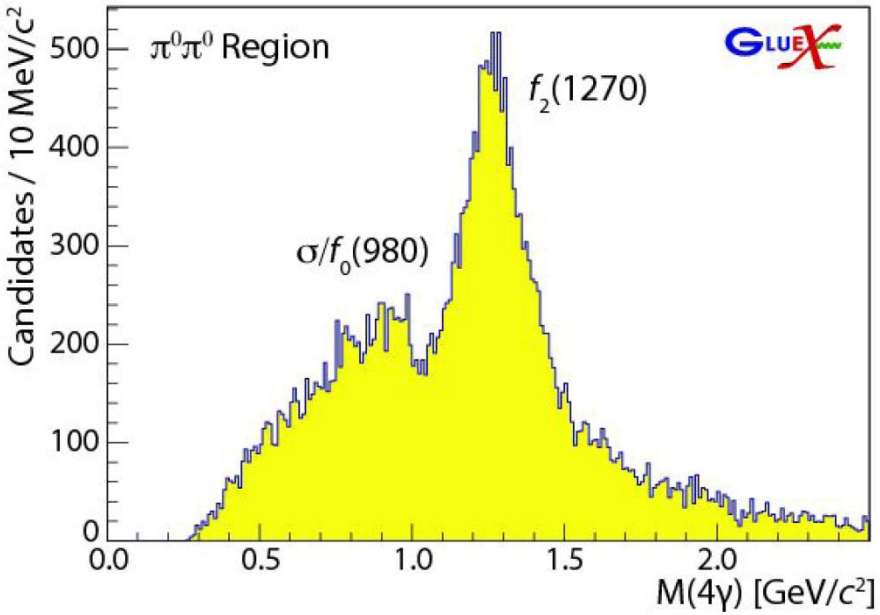


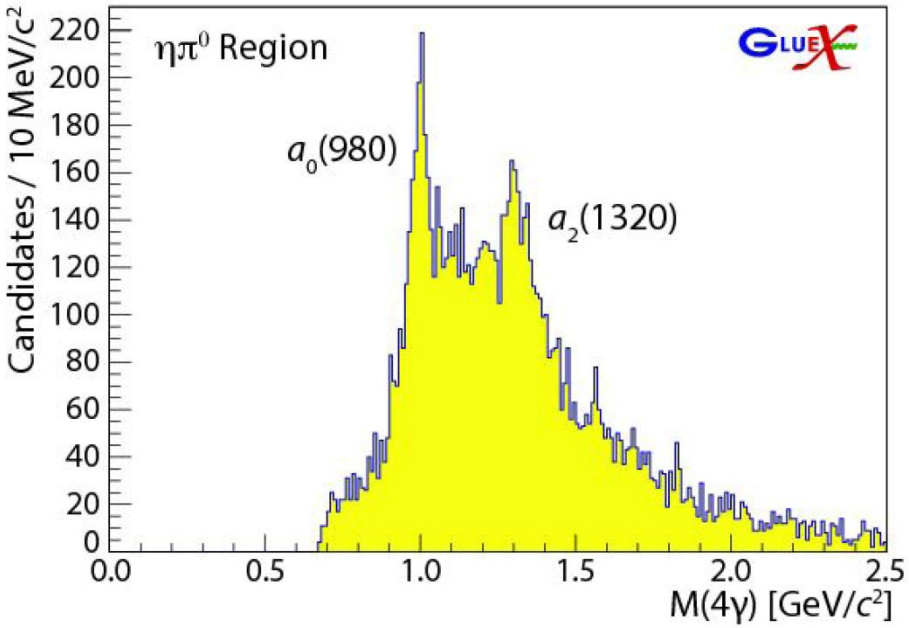
First asymmetry measurements for $\gamma\, p \rightarrow \eta\, p$

Multiphoton Final States

- $\gamma\, p \rightarrow p\, 4\gamma$
- reconstruct $a_0(980)/\sigma$, $f_2(1270)$, $a_2(1320)$

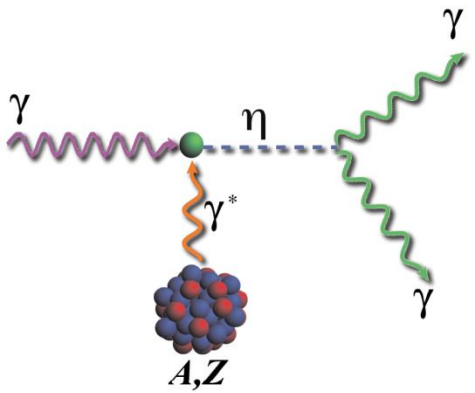






Experiments using Primakoff Production

Measurement of Γ(η→γγ) via Primakoff Effect



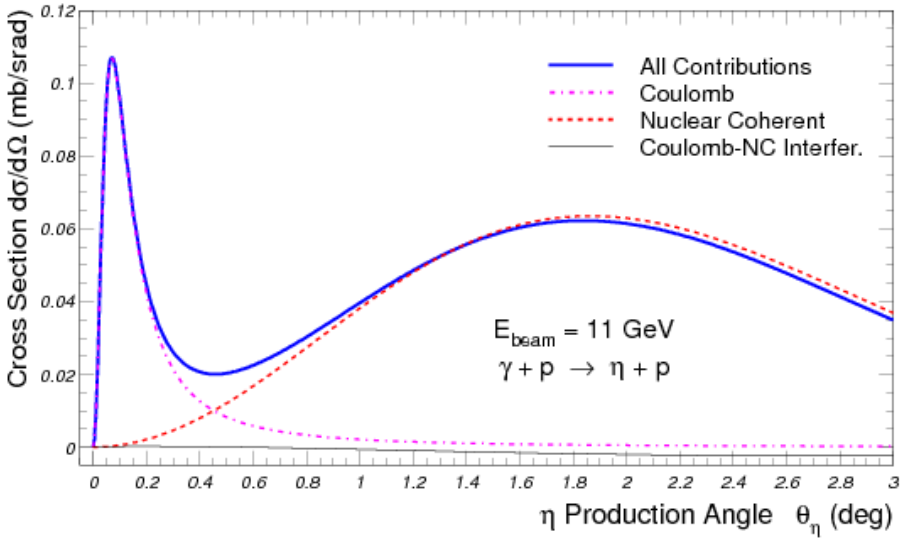
Physics:

- Light quark mass ratio $\Gamma(\eta\to 3\pi) \propto |A|^2 \propto Q^{-4}$
- η - η′ mixing angle $Q^2 = \dfrac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}$, where $\hat{m} = \dfrac{1}{2}(m_u + m_d)$

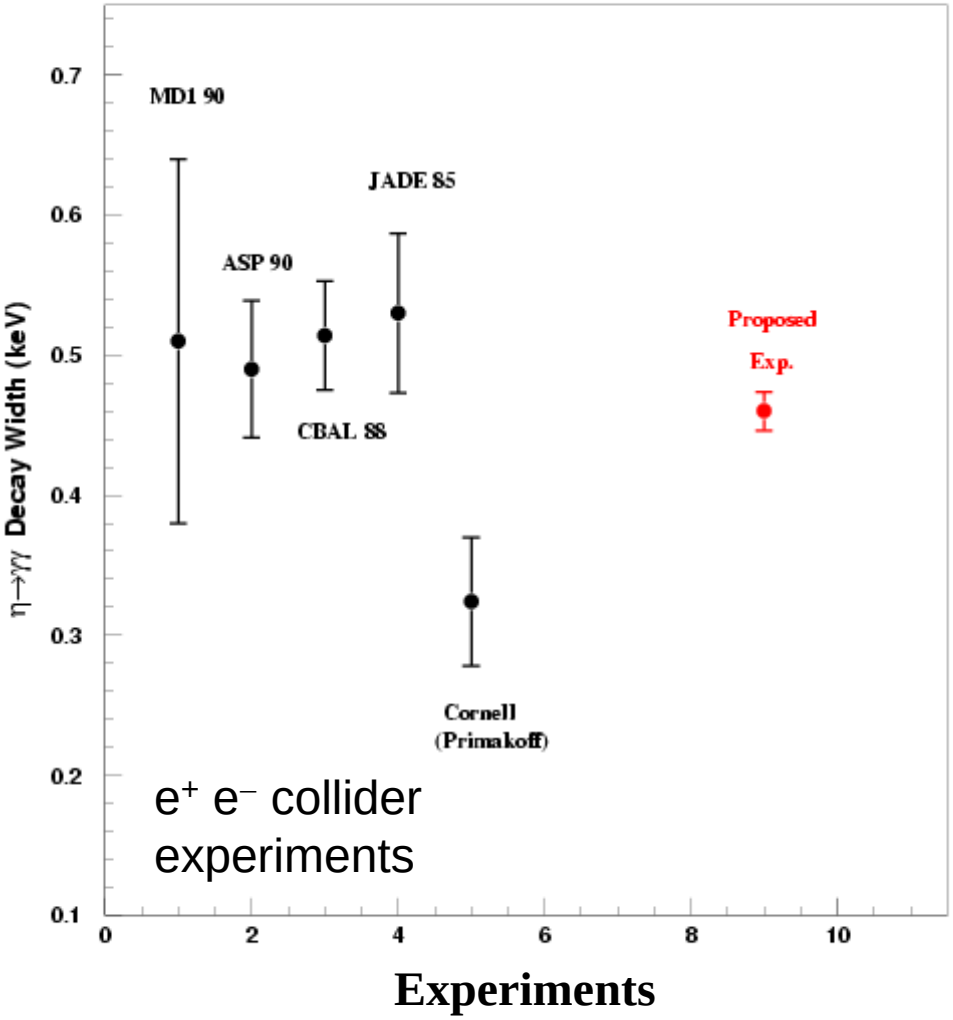
Measurements:

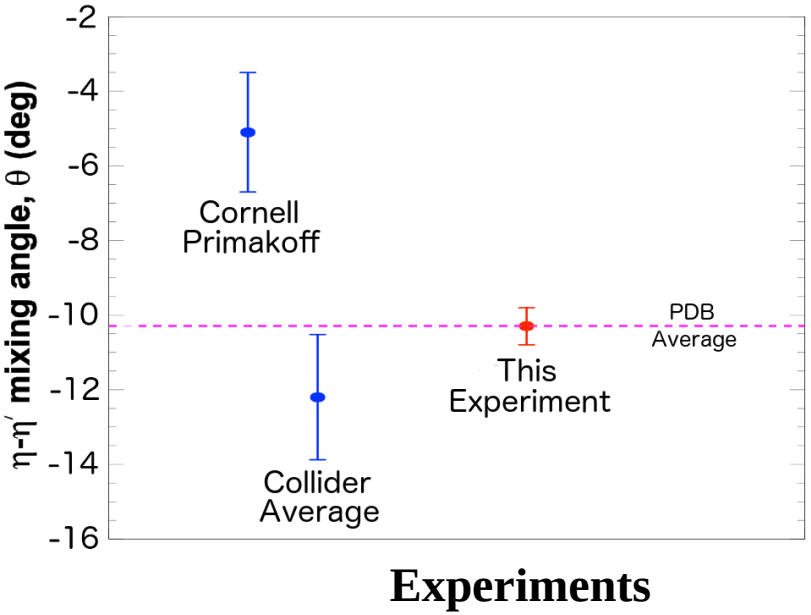
$$\frac{d\sigma}{d\Omega} = \Gamma_{\gamma\gamma}\frac{8\alpha Z^2 E^4}{m^3 q^4}\cdot\left|F_{E.M.}(q)\right|^2\cdot\sin^2\theta$$

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



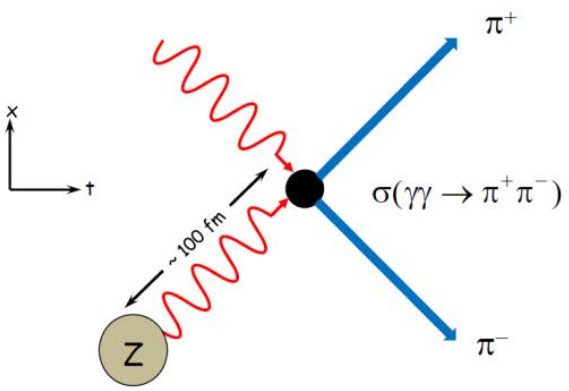
$\Gamma(\eta \to \gamma\gamma)$ Hall D Projection

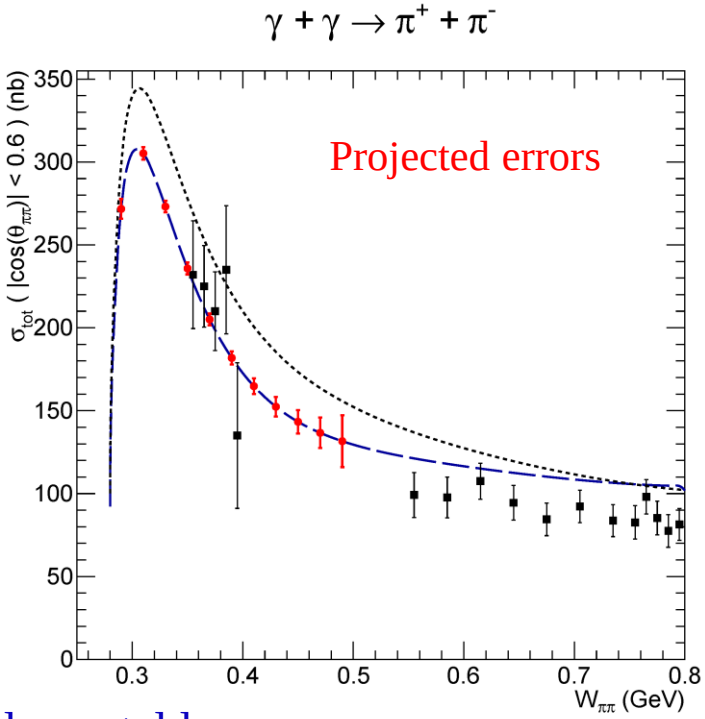




- GlueX measurements should help to resolve discrepancies between $e^+ e^-$ and Primakoff results

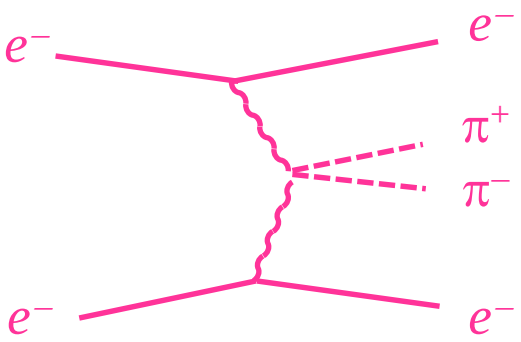
Charged Pion Polarizability

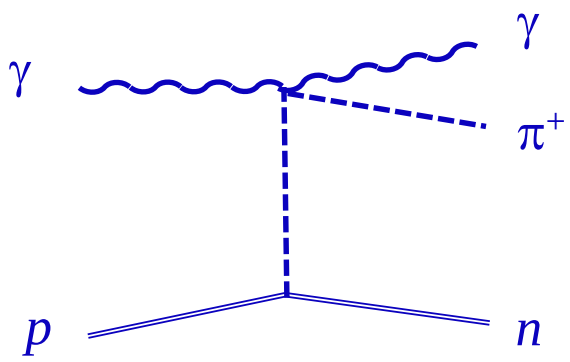


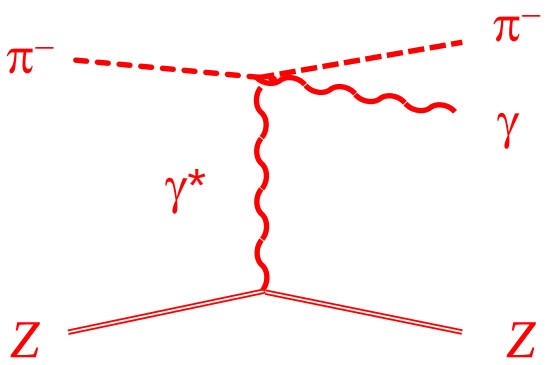


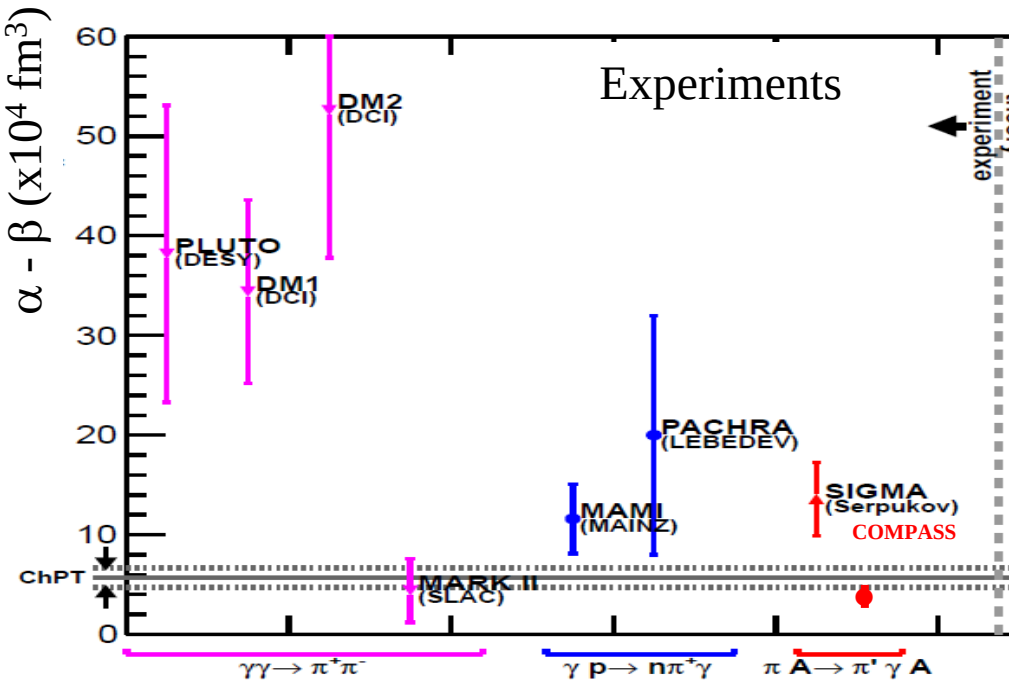
- Electric and magnetic dipole polarizabilities are fundamental low-energy properties of strong interactions
- Use Primakoff production γ A $\rightarrow$ π^+ π^- A to extract pion polarizability
  - *test χ_{PT} predictions*
- Use polarized photon beam to reduce background from ρ decays and $\mu^+\mu^-$
- Require new muon detector

Charged Pion Polarizability









- ChPT prediction: *Nucl. Phys. B 745 (2006*

$\alpha_\pi - \beta_\pi = (5.7 \pm 1.0) \cdot 10^{-4}$ fm^3

$\alpha_\pi \approx - \beta_\pi$

- Latest measurement of COMPASS

($\pi^- \gamma \rightarrow \pi^- \gamma$) *PRL 114, 062002 (2015)*

$\alpha_\pi = (2.0 \pm 0.6 \pm 0.7) \cdot 10^{-4}$ fm^3

assuming $\alpha_\pi = - \beta_\pi$

- GlueX expectation

$\sigma (\alpha_\pi - \beta_\pi) \sim 0.6 \cdot 10^{-4}$ fm^3

η Decays with Emphasis on Rare Neutral Modes:

The Jefferson Lab η Factory Experiment (JEF)

JEF Project Overview

Mode	Branching Ratio	Physics Highlight	Photons
priority:			
$\pi^0 2\gamma$			4
$\gamma + B$	beyond SM	leptophobic dark boson	4
$3\pi^0$	$(32.6 \pm 0.2)\%$	$m_u - m_d$	6
$\pi^+\pi^-\pi^0$	$(22.7 \pm 0.3)\%$	$m_u - m_d$, CV	2
3γ	$< 1.6 \times 10^{-5}$	CV, CPV	3
ancillary:			
4γ	$< 2.8 \times 10^{-4}$	$< 10^{-11}$[112]	4
$2\pi^0$	$< 3.5 \times 10^{-4}$	CPV, PV	4
$2\pi^0\gamma$	$< 5 \times 10^{-4}$	CV, CPV	5
$3\pi^0\gamma$	$< 6 \times 10^{-5}$	CV, CPV	6
$4\pi^0$	$< 6.9 \times 10^{-7}$	CPV, PV	8
$\pi^0\gamma$	$< 9 \times 10^{-5}$	CV, Ang. Mom. viol.	3
normalization:			
2γ	$(39.3 \pm 0.2)\%$		2

Upgrade the Forward Calorimeter

Main physics goal:

1. Probe interplay of VMD & scalar resonances in ChPT to calculate $O(p^6)$ LEC's in the chiral Lagrangian
2. Search for a dark boson (B)
3. Directly constrain CVPC new physics
4. Constrain the light quark mass ratio

Search for B-boson

See Liping Gan talk

- Dark leptophobic B-boson

$$L = \frac{1}{3} g_B \bar{q} \gamma^\mu q B_\mu + ...$$

- Arises from a new gauge baryon symmetry $U(1)_B$

Early studies by Lee and Yang, Phys.Rev.,98 (1955) 1501; Okun, Yad.Fiz., 10 (1969) 358,

- the $m_B < m_p$ region is strongly constrained by long-range forces search exp. ; the $m_B > 50 GeV$ has been investigated by the collider exp

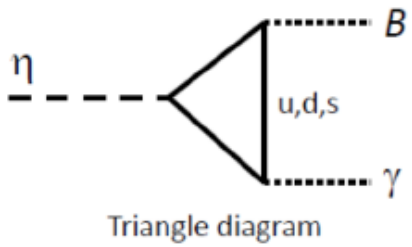
- GeV-scale domain is poorly constrained

discovery opportunity!

Search for B-boson in η decay

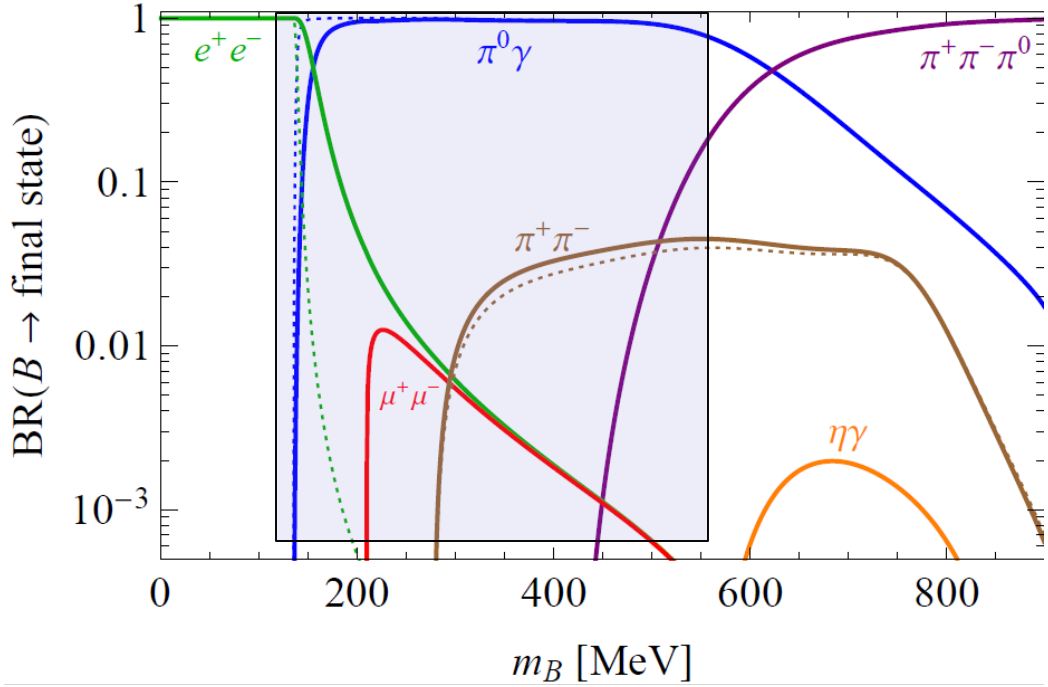
B production: A.E. Nelson, N. Tetradis, Phys. Lett., B221, 80 (1989)

$\eta \rightarrow B\gamma$ decay ($m_B < m_\eta$)



Triangle diagram

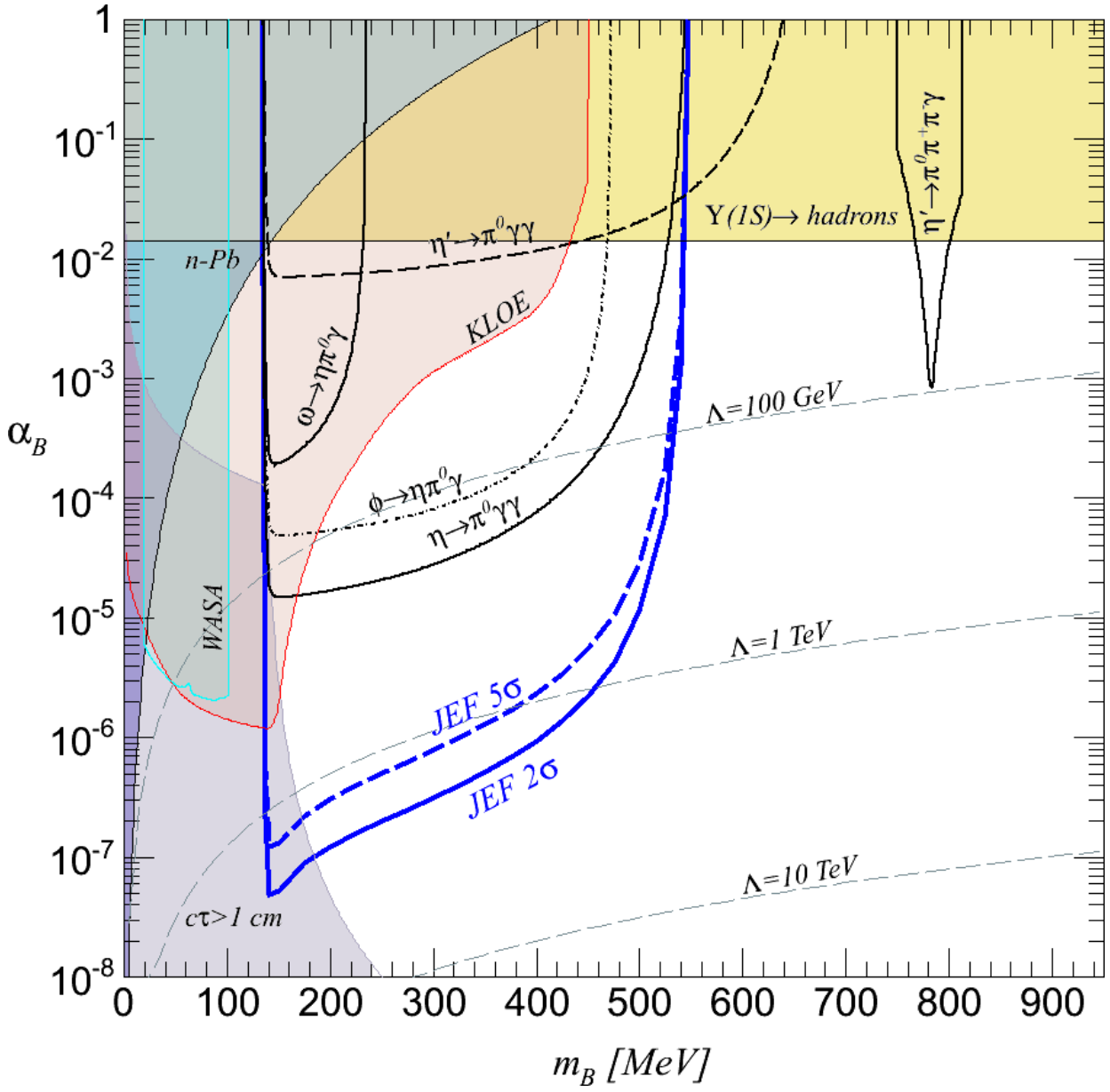
B decays: $B \rightarrow \pi^0\gamma$ in 140-600 MeV mass range



S. Tulin, Phys.Rev.,D89, 14008 (2014)

$\Gamma(\eta \rightarrow \pi^0\gamma\gamma) \sim 0.3eV$ ⇨ suppressed SM background

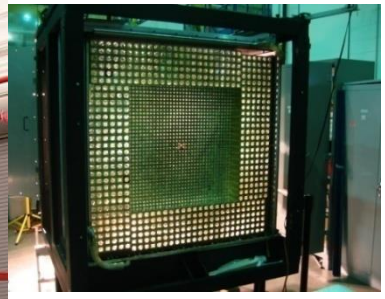
JEF Experimental Reach ($\eta \rightarrow B\gamma \rightarrow \pi^0\gamma\gamma$)



A stringent constraint on the leptophobic B-boson in 140-550 MeV range.

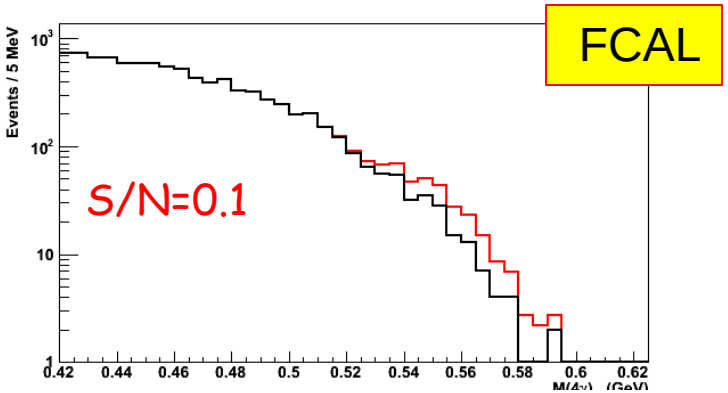
Future η' experiment will extend the experimental reach up to 1 GeV

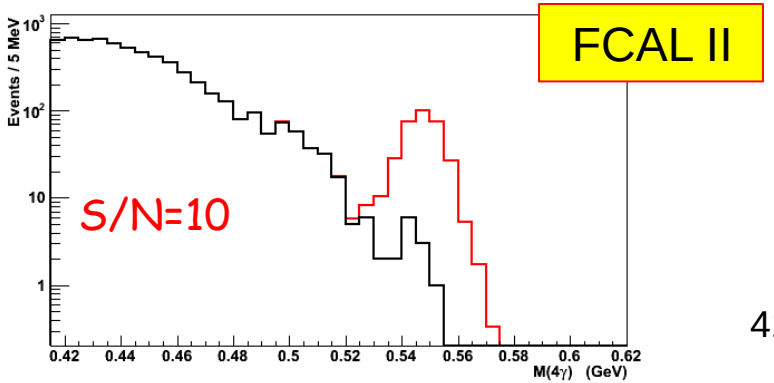
New Calorimeter for GlueX: FCAL-II



- **Replace the inner part of FCAL with the PWO insertion:**
  - 100x100 cm^2 in Size (2496 $PbWO_4$)
  - 2cm x 2cm x 18cm per module

signal: $\eta \to \pi^0\gamma\gamma$ background: $\eta \to 3\pi^0$





FCAL-II ($PbWO_4$) vs. FCAL (Pb glass)

Property	Improvement factor
Energy σ	2
Position σ	2
Granularity	4
Radiation-resistance	10

Summary

- The GlueX detector has been commissioned and is ready to start the main physics program in Fall 2016

  - data sample acquired during the commission run is currently used in first physics analyses

- The GlueX experiment will study the spectrum of light-quark mesons and perform a search of exotic mesons with a polarized photon beam

- Other experiments:

  - Radiative decays of $\eta \rightarrow \gamma\gamma$
  - Charged pion polarizability
  - Study rare η decays (require upgrade of the forward calorimeter)
  - Several other physics topics are being currently discussed

If you are interested in GlueX physics, please join us !

Backup Slides

Impact of $\eta \to \pi^0\gamma\gamma$ measurements on ChPT

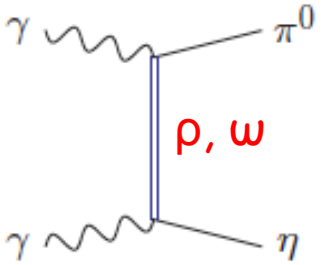
- Unique probe for the high order ChPT: the major contributions to $\eta \to \pi^0\gamma\gamma$ are two $O(p^6)$ counter-terms in the chiral Lagrangian

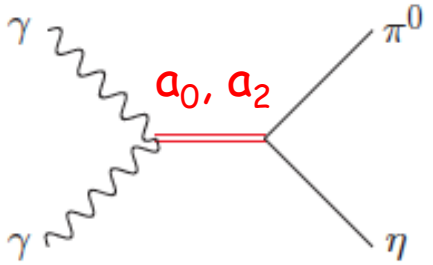
  L. Ametller, J, Bijnens, and F. Cornet, Phys. Lett., B276, 185 (1992)

- Study contribution of scalar resonances in calculation of $O(p^6)$ LECs in the chiral Lagrangian

- Shape of Dalitz distribution is sensitive to the role of scalar resonances

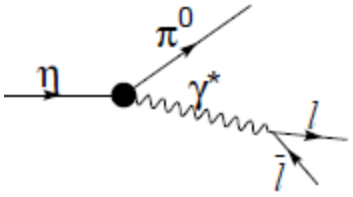
Higher order LEC's are dominated by resonances
Gasser, Leutwyler 84; Ecler, Gasser, Pich, de Rafael1989; Donoghue, Ramirez, Valencia 1989



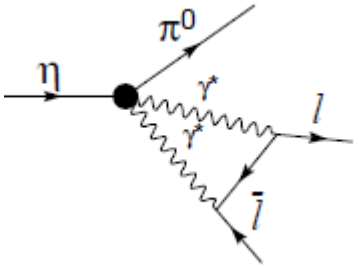


- A cross-check of LEC's with different processes

C and CP violating



C and CP conserving background



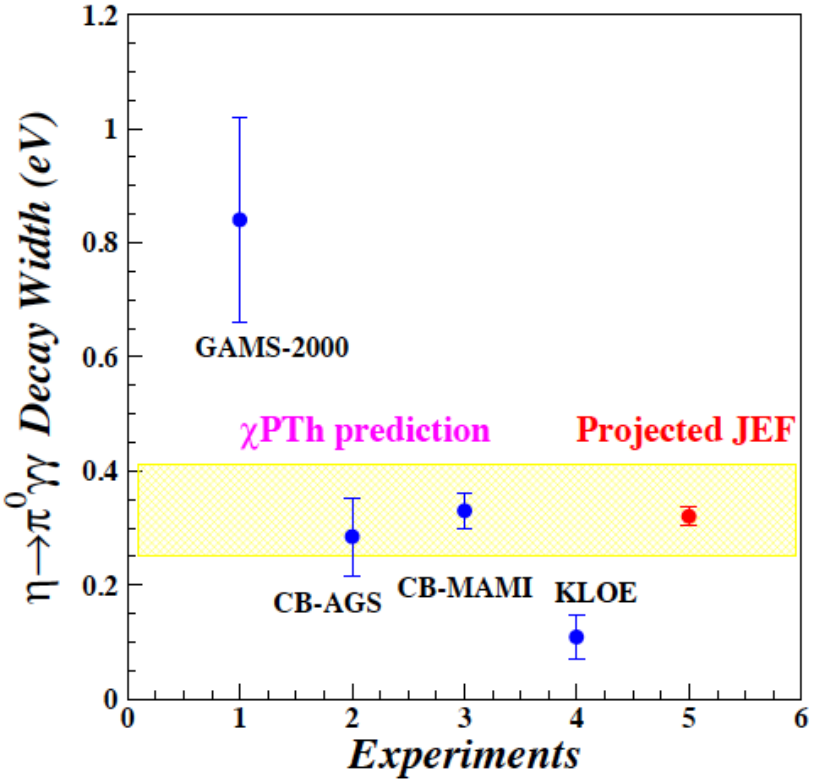
J.N. Ng, et al., Phys. Rev., D46, 5034 (1992)

$\eta \to \pi^0\gamma\gamma$: Partial Decay Width

Theory	$\Gamma(\eta \to \pi^0\gamma\gamma)$ (eV)
χPTh, $\mathcal{O}(p^2)$	0
χPTh, $\cdots + \mathcal{O}(p^4)$	0.004
χPTh, $\cdots + \mathcal{O}(p^6)$	0.42 ± 0.20
χPTh, $\cdots + \mathcal{O}(p^6)$	0.47
χPTh, ENJL, $\cdots + \mathcal{O}(p^6)$	0.58 ± 0.30
χPTh, ENJL, $\cdots + \mathcal{O}(p^6)$	$0.27^{+0.18}_{-0.07}$
VMD	0.30 ± 0.15
Q box	0.70
χPTh, $\cdots + \mathcal{O}(p^6)$	0.44 ± 0.09
unitarized χPTh	0.47 ± 0.10
unitarized χPTh	0.33 ± 0.08

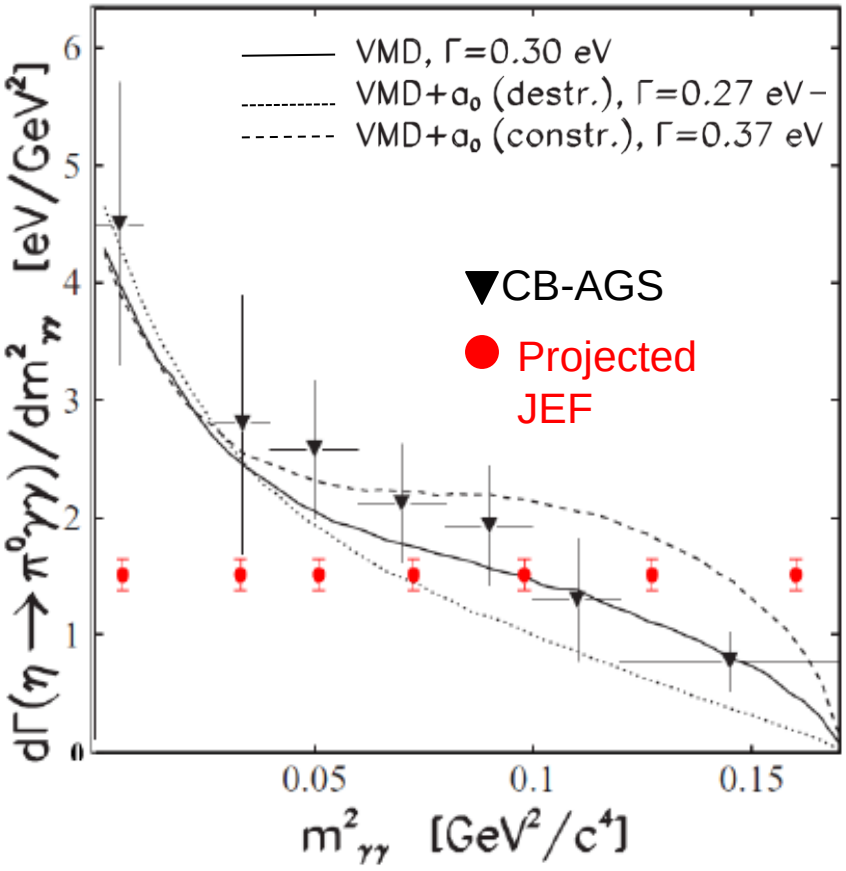
χPTh by Oset et al., Phys. Rev. D77, 07300 (2008)
arXiv:08801 (2013)

Experiments After 1980

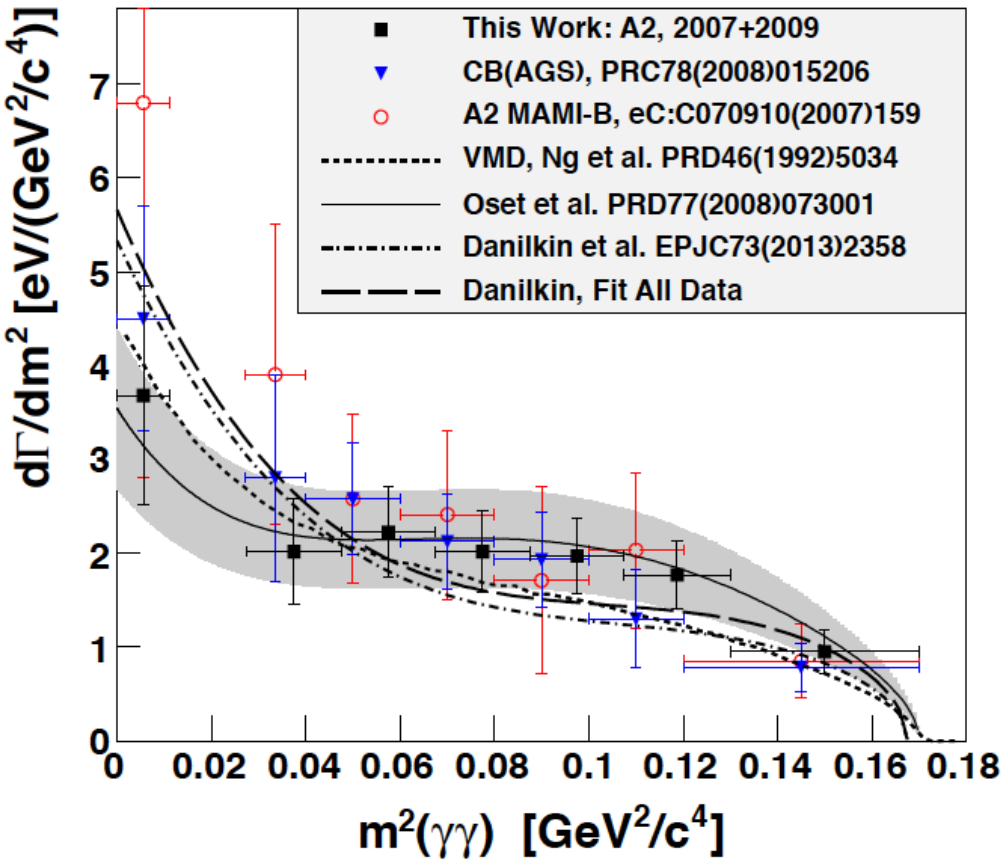


$\eta \to \pi^0\gamma\gamma$: Dalitz Distribution

Prakhov et al., Phys. Rev. C78, 015206 (2008)



A2 at MAMI arXiv:1405.4904, 2014

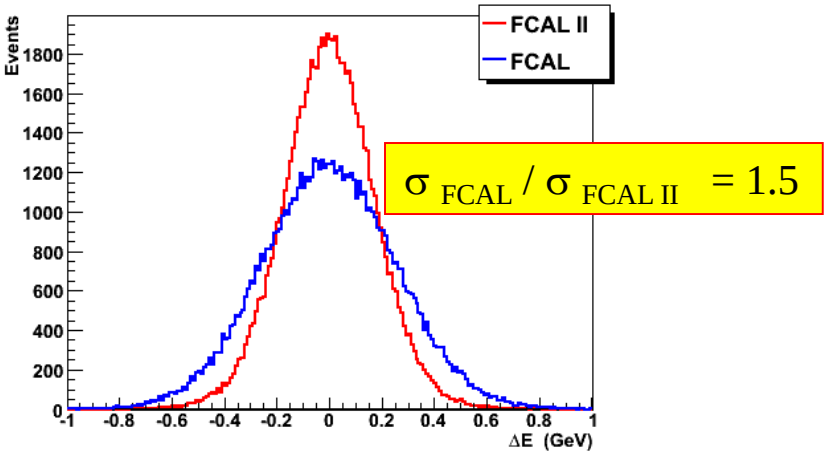


FCAL II Improvements for Other GlueX Channels

- Impact on GlueX Spectroscopy program

$p + \gamma \rightarrow p + X(1400)$

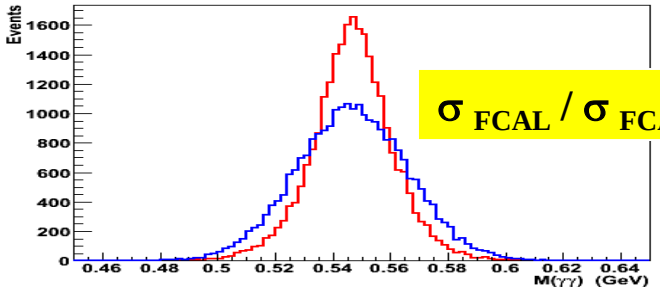
$X(1400) \rightarrow \eta\, \pi^0$



$\sigma_{FCAL} / \sigma_{FCAL\ II} = 1.5$

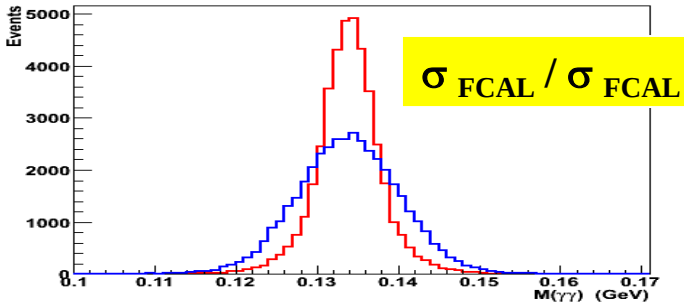
$\Delta E = E_{\eta\pi} + E_p - m_p - E_{beam}$

Invariant Mass: $\eta \rightarrow \gamma\,\gamma$



$\sigma_{FCAL} / \sigma_{FCAL\ II} \sim 1.6$

Invariant Mass: $\pi^0 \rightarrow \gamma\,\gamma$



$\sigma_{FCAL} / \sigma_{FCAL\ II} \sim 1.9$

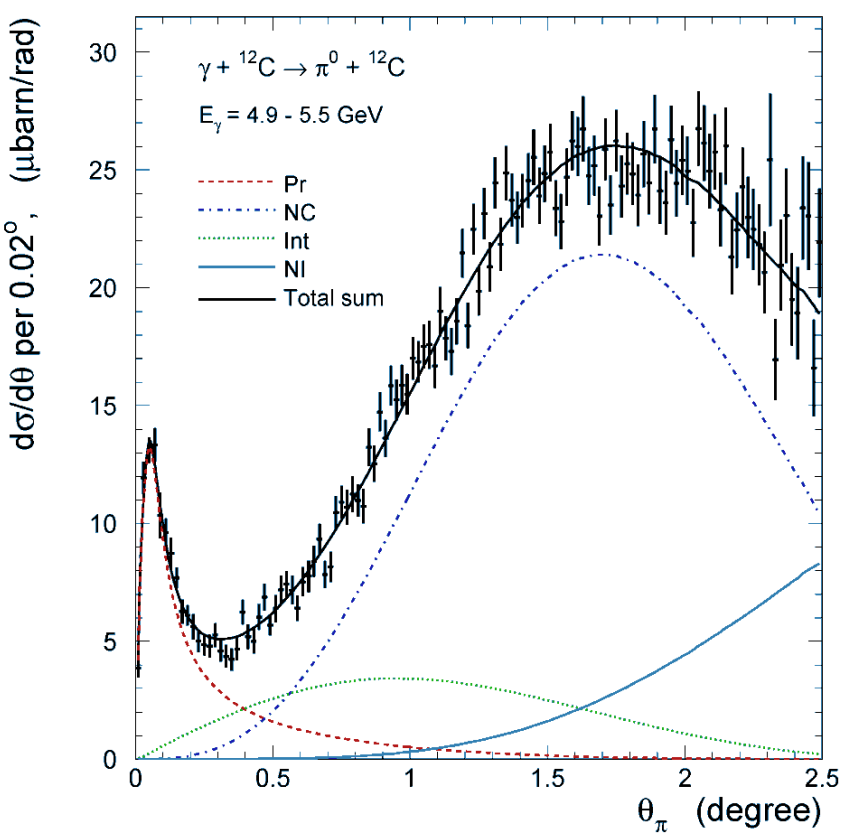
- Improve precision of Primakoff experiment on $\Gamma(\eta \rightarrow \gamma\gamma)$ from 3% to 2%

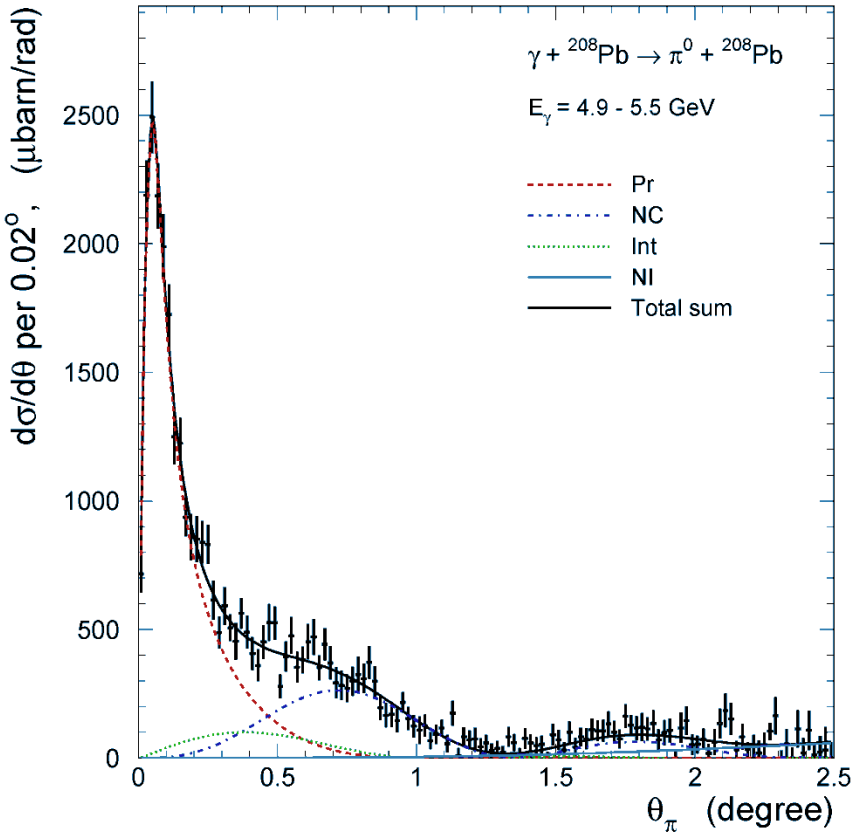
Photon Beam Requirements

Experiment	Photon Energy Range (GeV)	Polarization	Photon Flux γ/ sec
GlueX Search for gluonic excitations in the spectra of light mesons	**8.4 – 9.0**	**44 %**	**$5 \cdot 10^7$**
PrimEx A precision measurement of the $\eta \rightarrow \gamma\gamma$ decay width via the Primakoff effect	**10.5 – 11.7**	**None**	**$7.6 \cdot 10^6$**
Measuring the charged pion polarizability	**5.5 – 6.0**	**76 %**	**10^7**

Nuclear Targets in PrimEX I Experimet

- Experiment performed in Hall-B using a 6 GeV photon beam
- Measure $\Gamma(\pi^0 \rightarrow \gamma\gamma)$ using nuclear targets: ^{12}C and ^{208}Pb





C Invariance

- Maximally violated in the weak force and is well tested
- SM prediction:

  BR(η→3γ) <10^{-19} via P-violating weak interaction.

- Study constraints on CVPC from EDM

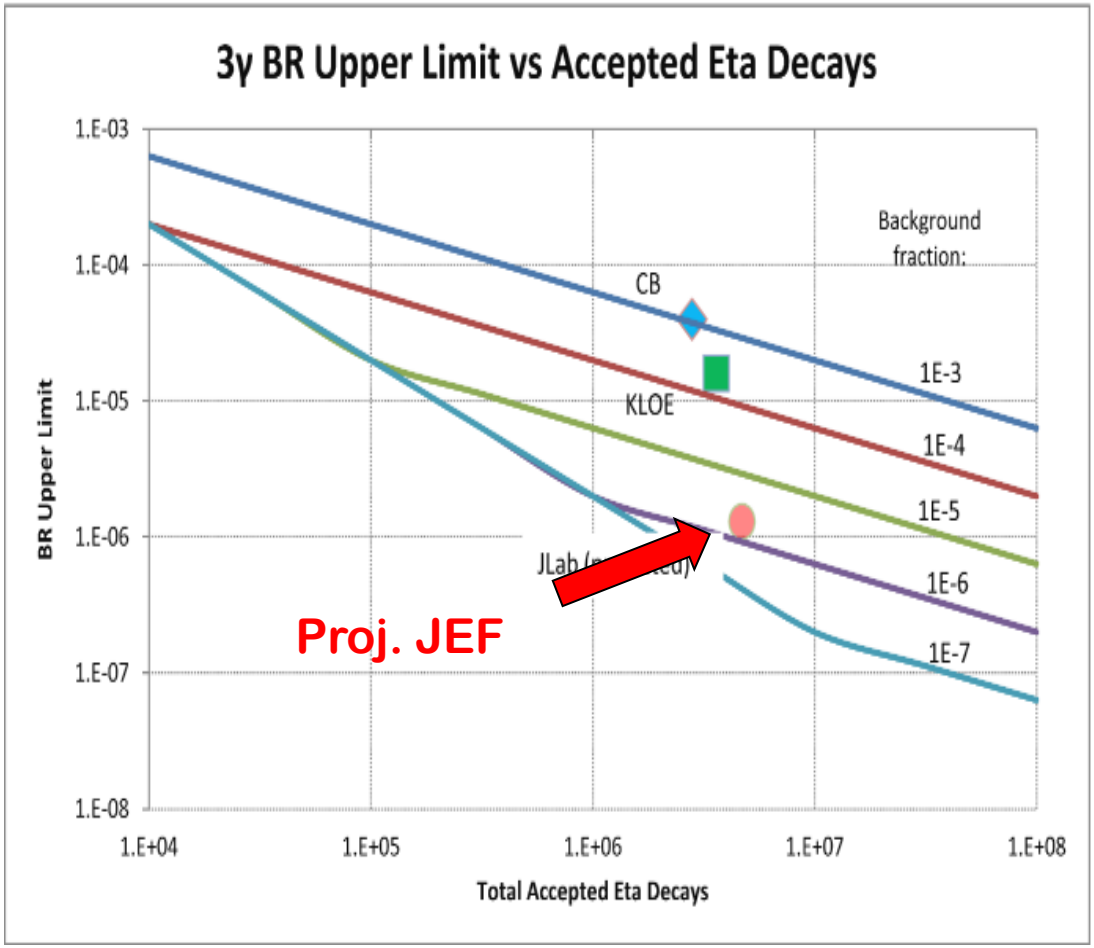
  - no constraints in the presence of a conspiracy or new symmetry; only the direct searches are unambiguous

M. Ramsey-Musolf, phys. Rev., D63 (2001),
talk at the AFCI workshop,
studies are in progress

C Violating η neutral decays

Final State	Branching Ratio (upper limit)	Gammas in Final State
3γ	< $1.6 \cdot 10^{-5}$	3
$\pi^0\gamma$	< $9 \cdot 10^{-5}$	
$2\pi^0\gamma$	< $5 \cdot 10^{-4}$	5
$3\gamma\pi^0$	Nothing published	
$3\pi^0\gamma$	< $6 \cdot 10^{-5}$	7
$3\gamma 2\pi^0$	Nothing published	

Upper Limit on $\eta \rightarrow 3\gamma$

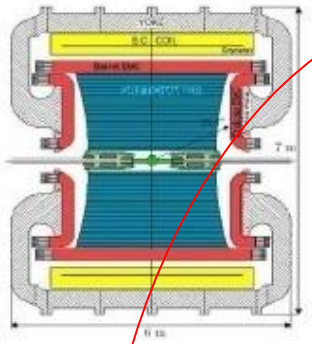


Improve BR upper limit by one order of magnitude

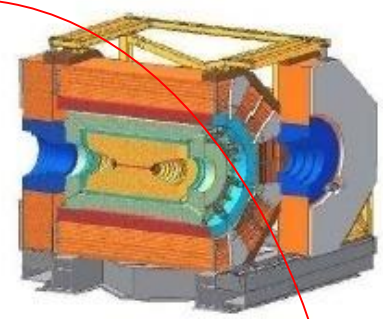
World competition in η decays

e^+e^- Collider

KLOE-2 at DAϕNE



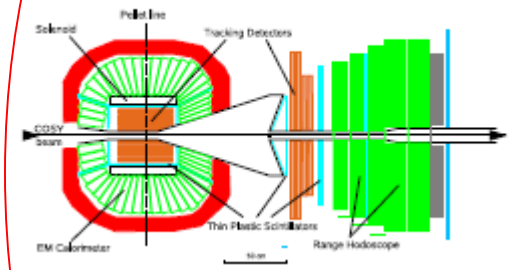
BESIII at BEPCII



Low energy η-facilities

Fixed-target

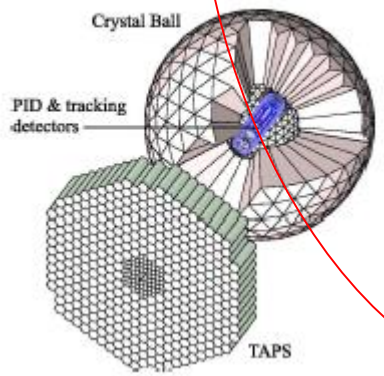
WASA at COSY



hadroproduction

High energy η-facility

Crystall Ball at MAMI



photoproduction