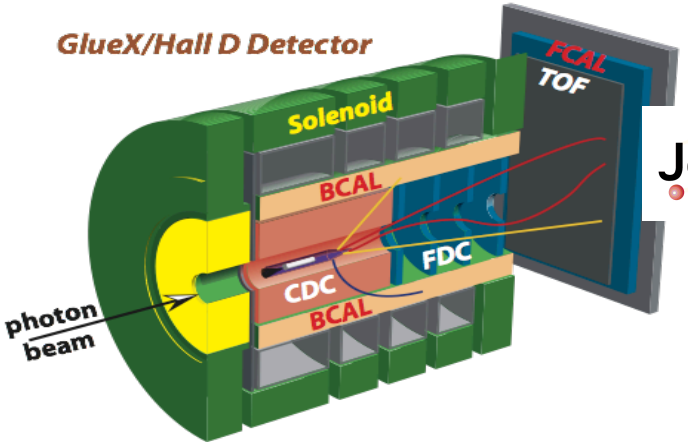


Jefferson Lab

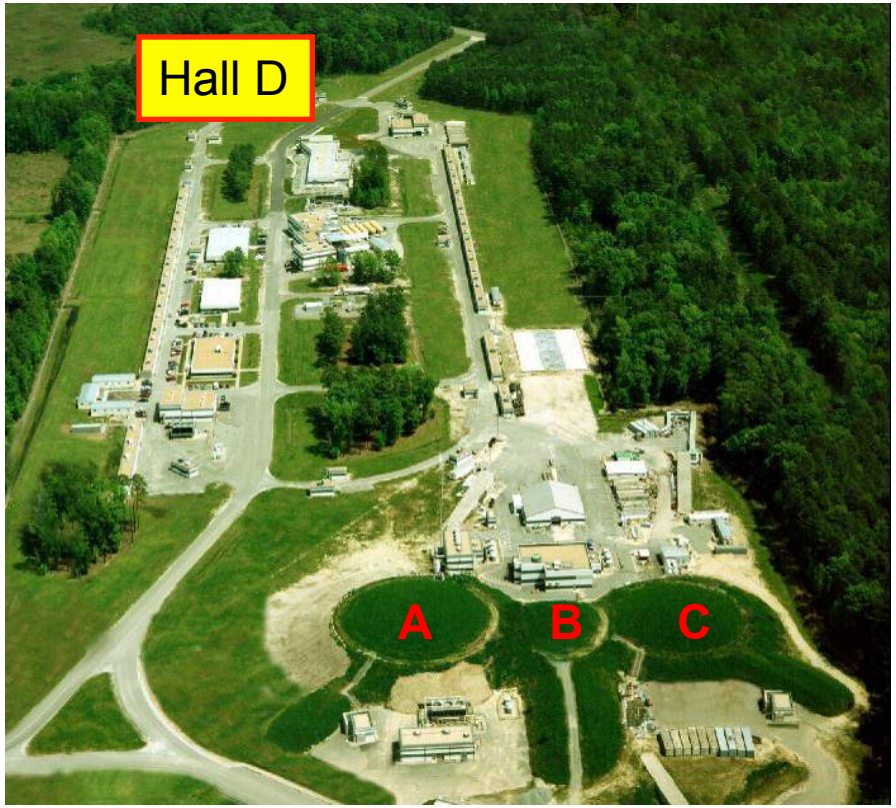
12 GeV Upgrade
Future Science at Jefferson Lab

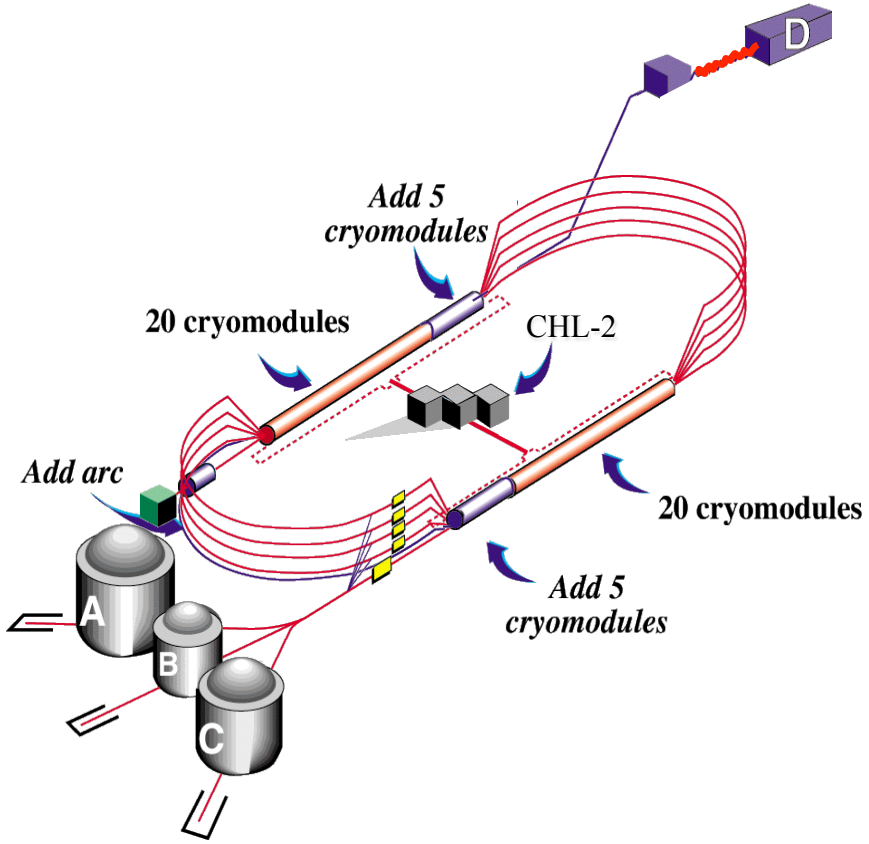
Nuclear photoproduction with GlueX

A. Somov, Jefferson Lab
with E. Chudakov (Jefferson Lab) and S. Gevorkyan (JINR)

Next generation nuclear physics with JLab12 and EIC
Florida International University, 10 – 13 February, 2016

12 GeV CEBAF Energy Upgrade





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

Hall D Physics Program

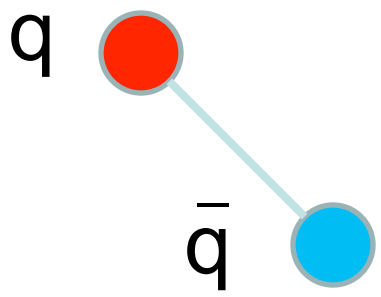
Experiment Proposal	Name	Days	Status	Cond.	Target
E12-06-102	Mapping the Spectrum of Light Quark Mesons and Gluonic Excitations with Linearly Polarized Photons	120	A		LH_2
E12-12-002 E12-13-003	A study of meson and baryon decays to strange final states with GlueX in HallD	220	A	L3 trigger PID	LH_2
E12-10-011	A Precision Measurement of the Radiative Decay Width via the Primakoff Effect	79	A-		LHe_4
E12-13-003	Measuring the Charged Pion Polarizability in the $\gamma\gamma \rightarrow \pi^+\pi^-$ Reaction	25	A-		Sn
C12-14-004	Eta Decays with Emphasis on Rare Neutral Modes: The JLab Eta Factory Experiment (JEF)	(130)	C	Upgrade forward calorim.	LH_2
LOI12-15-001	Physics with secondary K_L beam				LH_2, A
LOI12-15-006	Production ω mesons off nuclei				A

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**

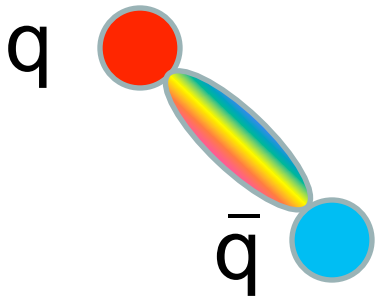
Exotic Mesons

Conventional Mesons



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

Hybrid Mesons



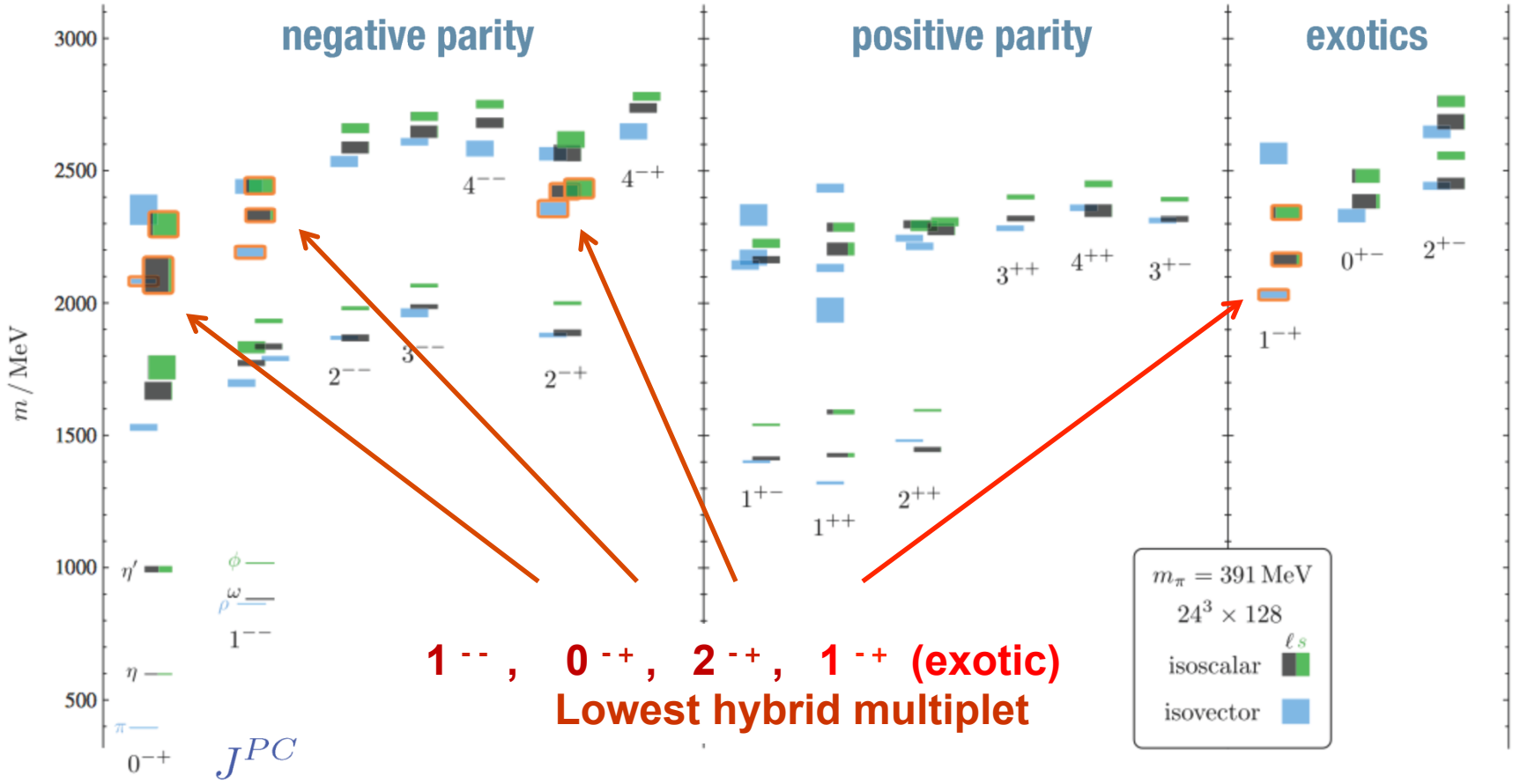
- Gluonic exitations result in hybrid mesons with **exotic J^{PC}**
- Predicted by flux tube model (1970) and lattice QCD
  - constituent gluon with $J^{PC} = 1^{+-}$ and mass 1 – 1.5 GeV

J^{PC}:

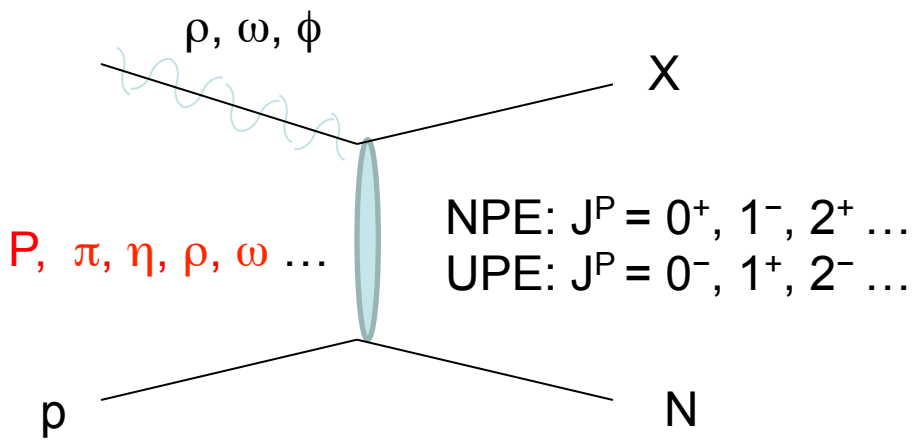
0^{--}	0^{-+}	0^{+-}	0^{++}
1^{--}	1^{-+}	1^{+-}	1^{++}
2^{--}	2^{-+}	2^{+-}	2^{++}

Lattice QCD Predictions

Dudek et al. PRD 88 (2013) 094505

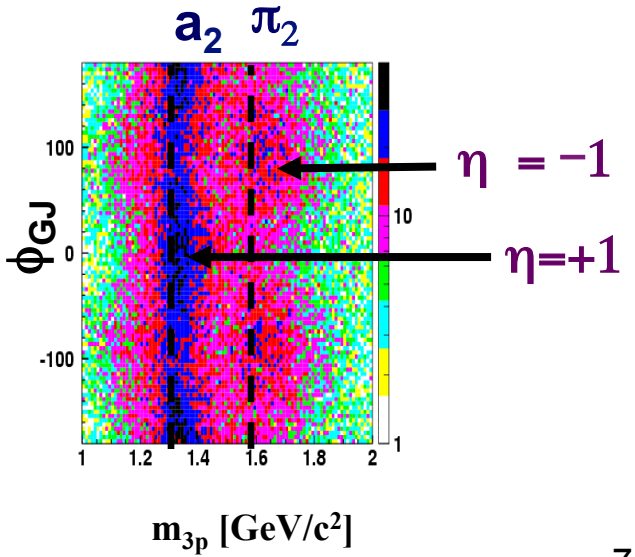


Photoproduction of Exotic Mesons



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'

- Polarized photon beam helps to determine production mechanism (naturality)



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^{+-}	$b_0(2400)$	$\pi(1300)\,\pi$, $h_1\pi$, $f_1\rho$, $b_1\eta$
	$h_0(2400)$	$b_1\pi$, $h_1\eta$
	$h_0'(2500)$	$K_1(1270)\,K$, $K_1(1460)\,K$, $h_1\eta$

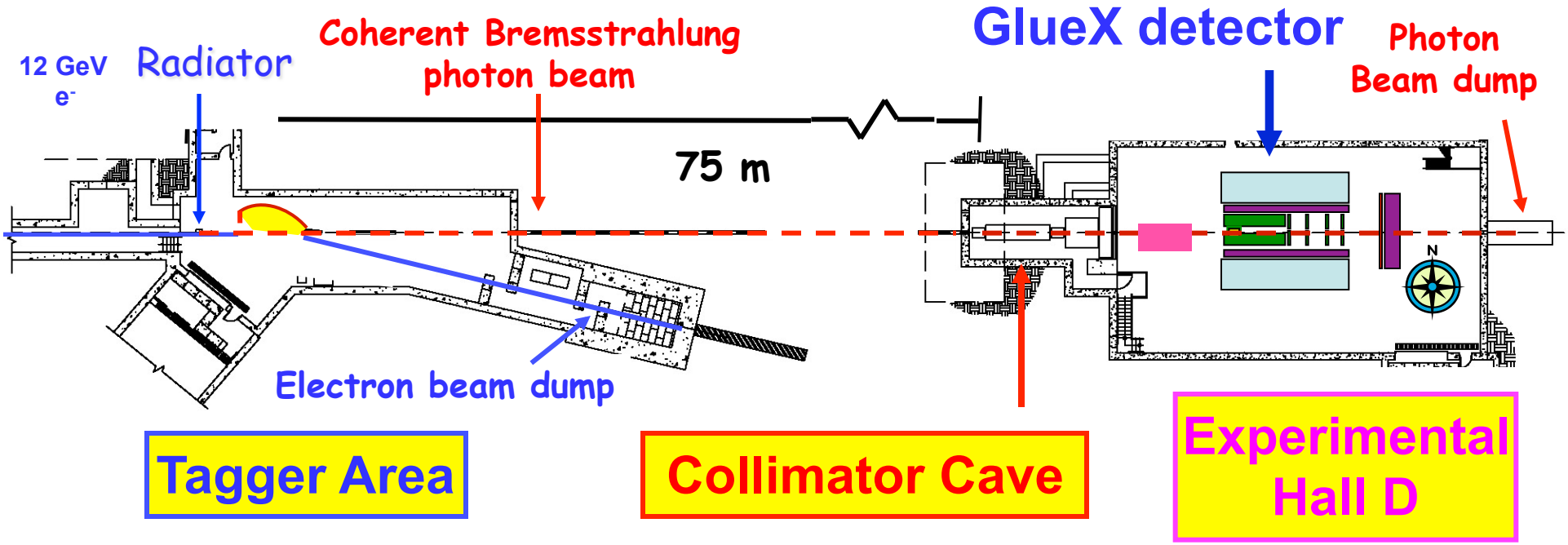
Multiparticle final states:

- (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

➢ **Detector Requirements:**

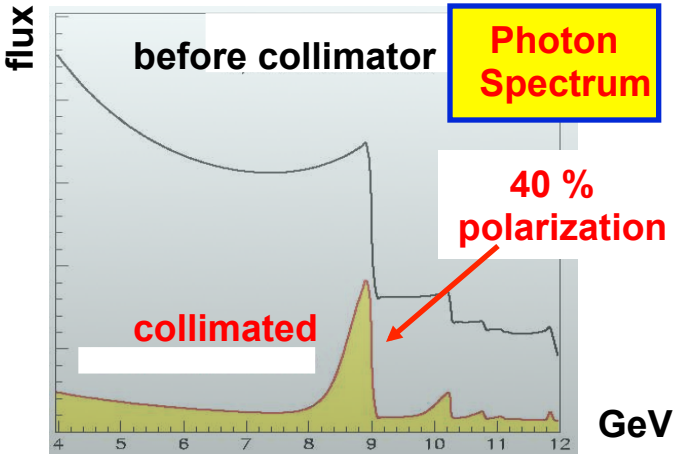
- Hermetic detector
- Large/uniform acceptances
- Good energy and momentum resolution

Polarized Photon Beam



- Beam photons are produced by 12 GeV electrons (I < 2.2 μA) on a thick diamond crystal (20 μm)
- Photon energy: detect bremsstrahlung electrons $\Delta E / E < 0.005$

- Pass beam photons through the collimator
  - increase the fraction of linearly polarized photons
  - beam intensity: 10^8 γ/sec for $8.4 < E_\gamma < 9.1$ GeV



GlueX Detector

Tracking:

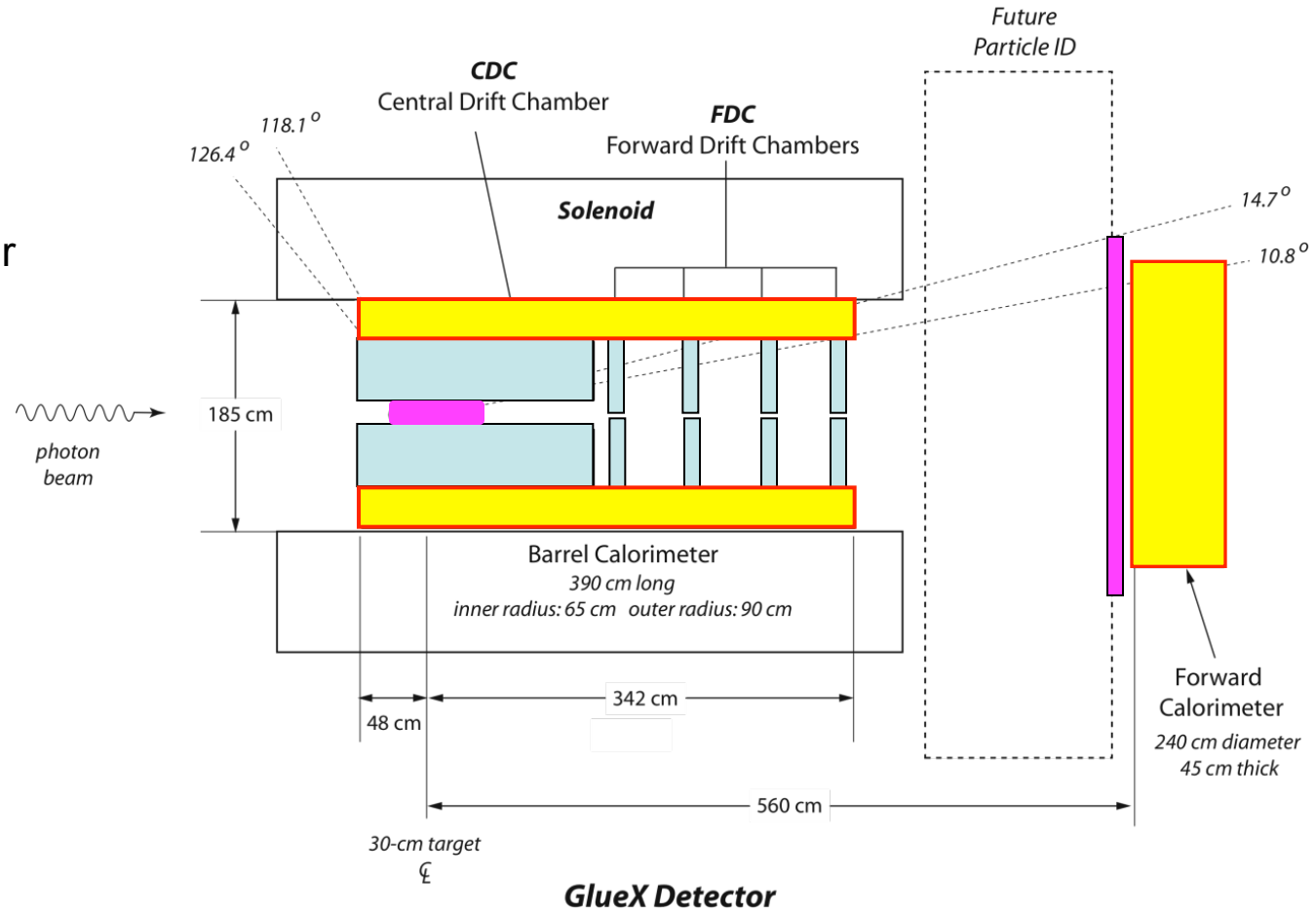
- Central Drift Chamber
- Forward Drift Chamber

Calorimetry:

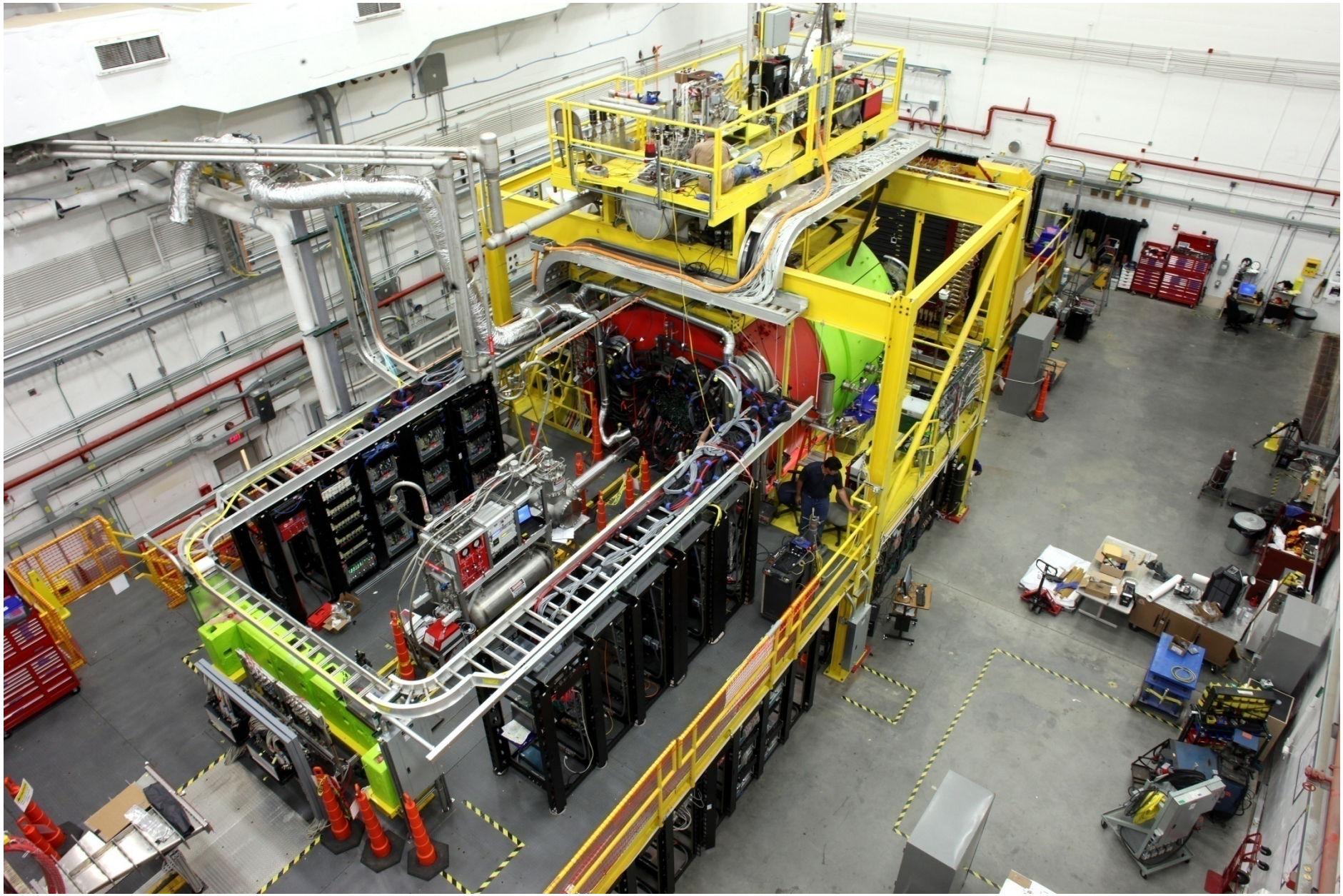
- Barrel Calorimeter
- Forward Calorimeter

PID:

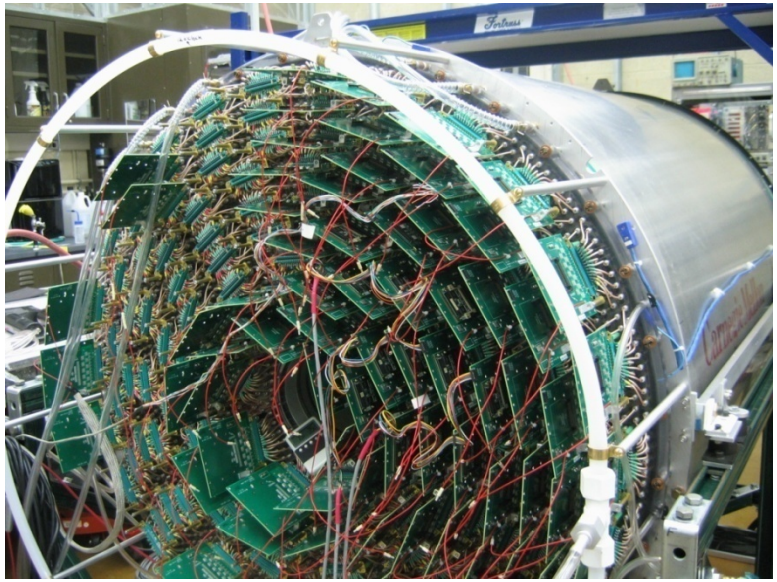
- Time of Flight wall
- Start Counter
- Barrel Calorimeter



GlueX Detector

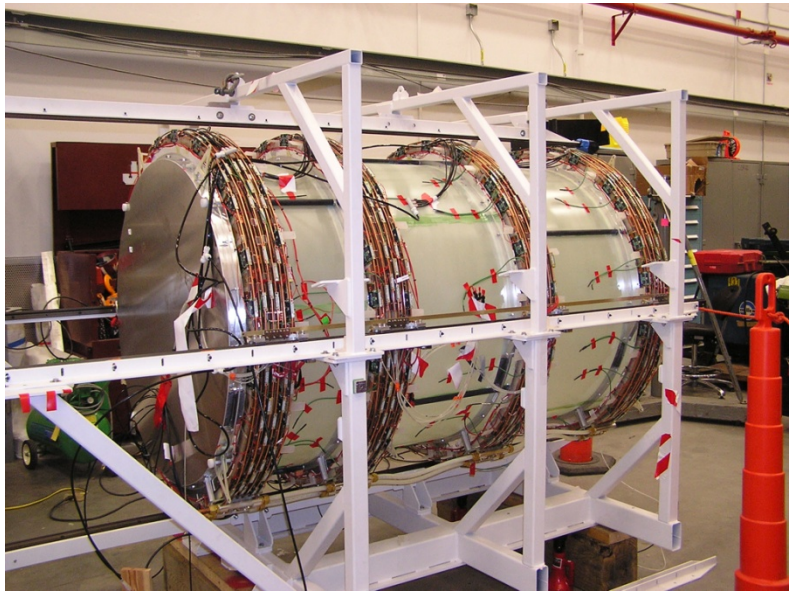


Tracking



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

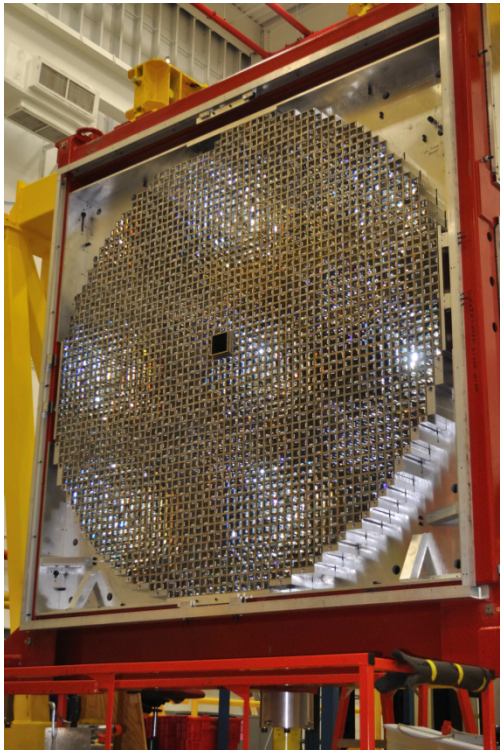


Forward Drift Chamber

- 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: $\sigma_p / p \sim 1 – 3\ \%$

Calorimetry

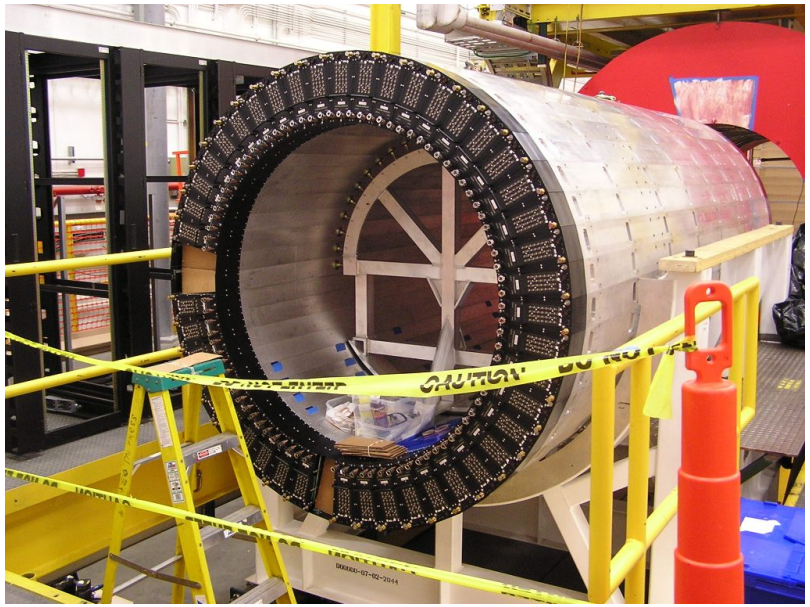


Forward Calorimeter:

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

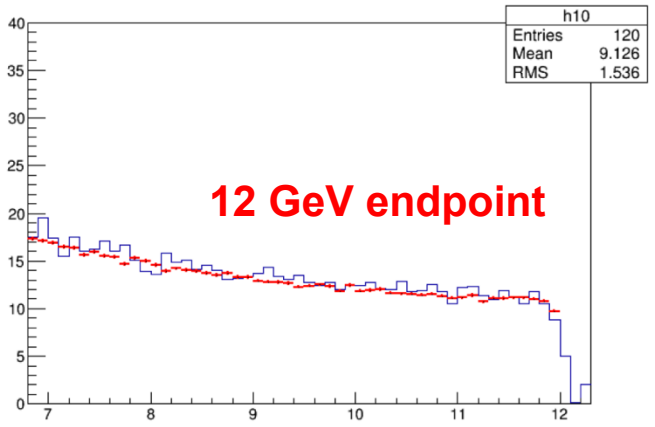
Barrel Calorimeter:

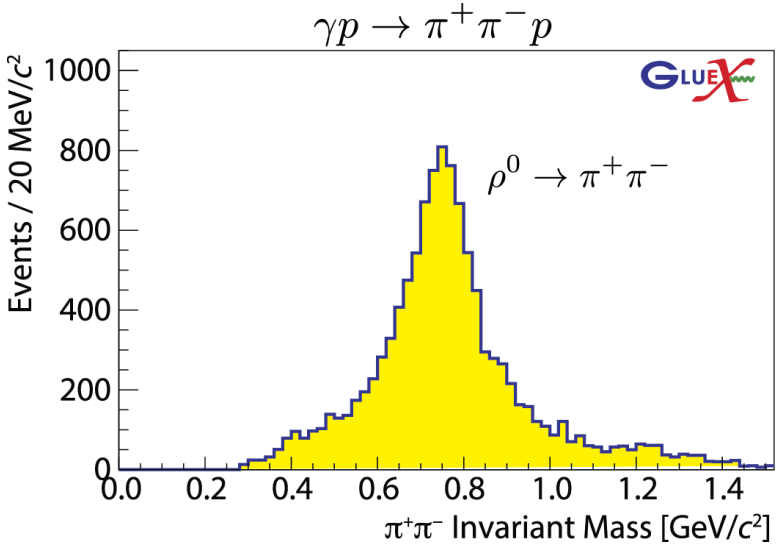
- Angular coverage $11° < \theta < 120°$
- 191 layers Pb:ScFib:Glue (37:49:14%)
- Double side readout (SiPM)
- $\sigma_E / E = 6\ \% / \sqrt{E} \oplus 1.6\ \%$
- $\sigma_Z = 5\ mm / \sqrt{E}$
- $\sigma_t = 74\ ps / \sqrt{E} \oplus 33\ ps$

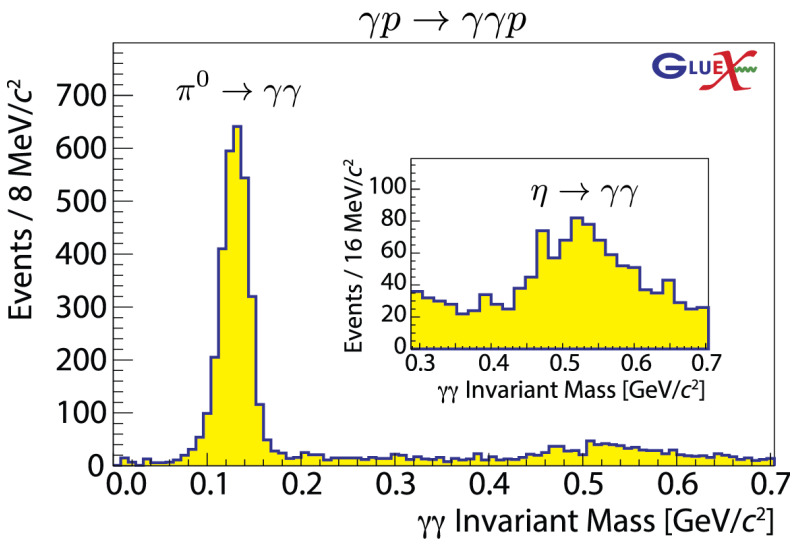


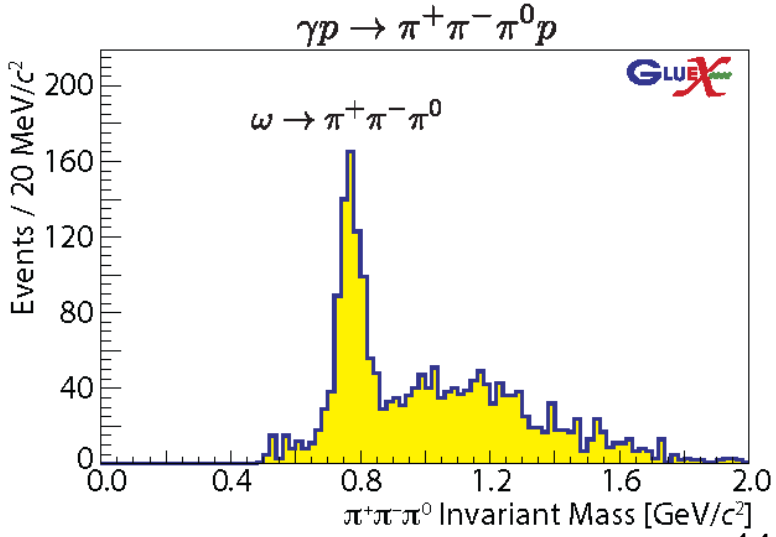
GlueX Commissioning

12 GeV photons delivered to Hall D
in the Fall 2015



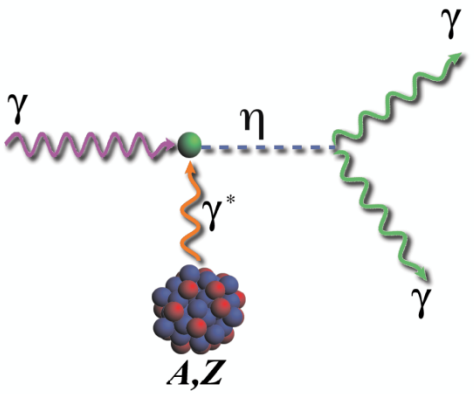






Experiments using Primakoff Production

Measurement of Γ(η→γγ) via Primakoff Effect



Physics:

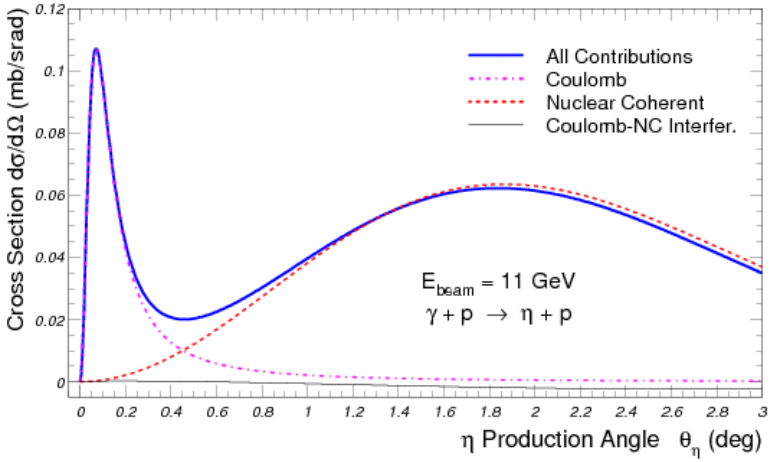
- Light quark mass ratio
- η - η′ mixing angle

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

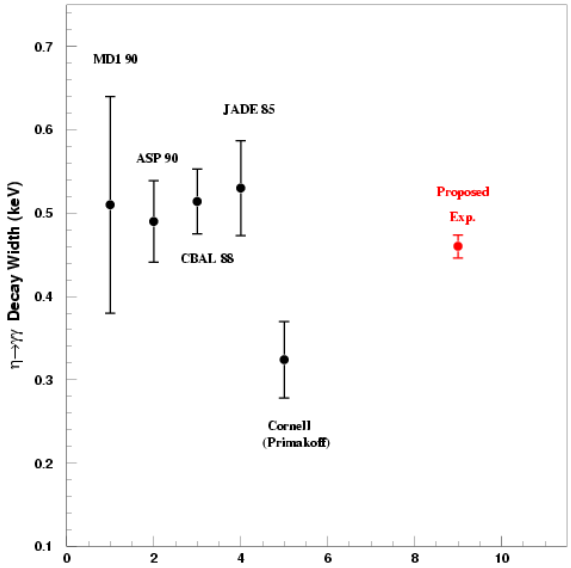
$$Q^2 = \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}, \qquad \text{where } \hat{m} = \frac{1}{2}(m_u + m_d)$$

Measurements:

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



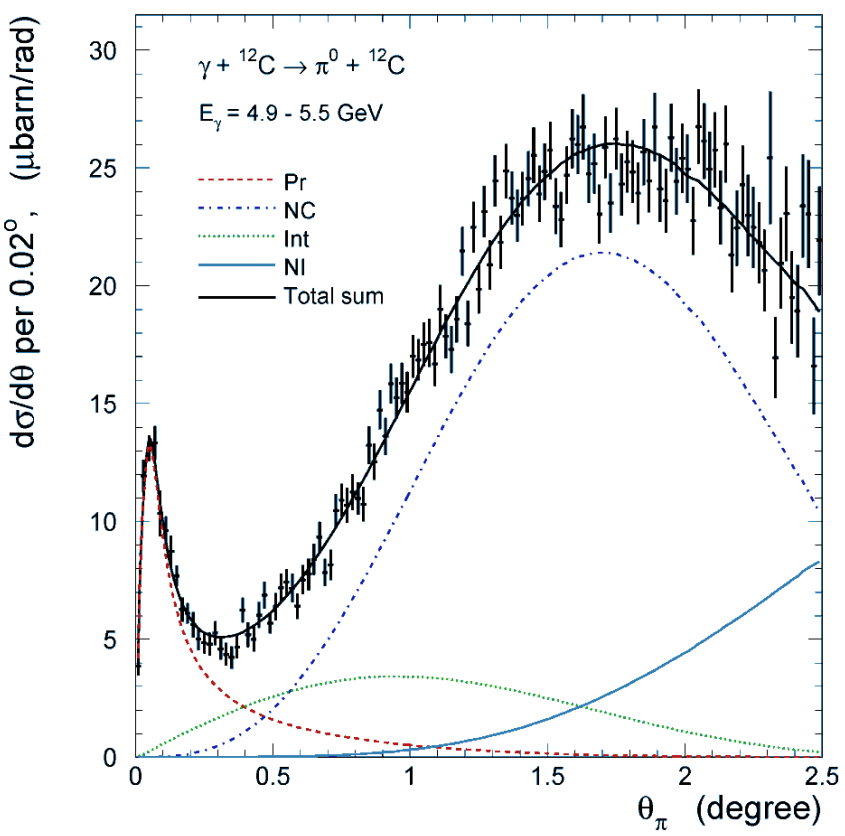
Γ(η→γγ) Hall-D projection

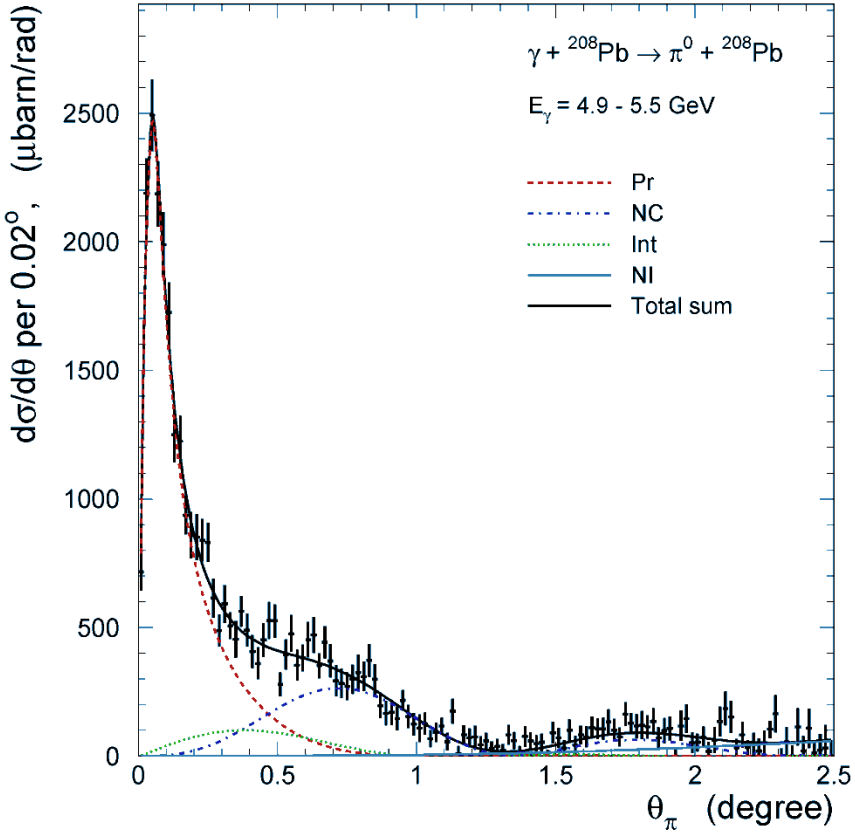


- 11.0 - 11.7 GeV incoherent tagged photons
- 30 cm LH_2 and LHe_4 targets (~3.6% r.l.)
- Forward Calorimeter (FCAL) for η→γγ

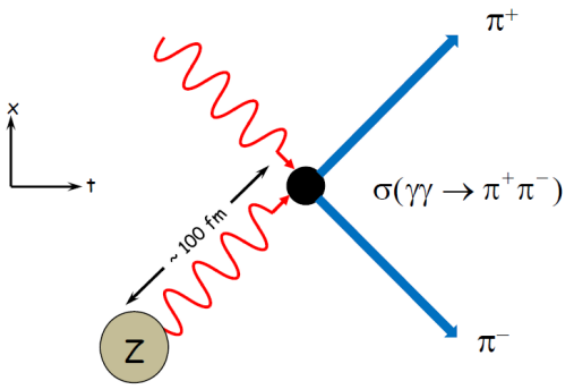
Nuclear Targets in PrimEX I Experimet

- 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

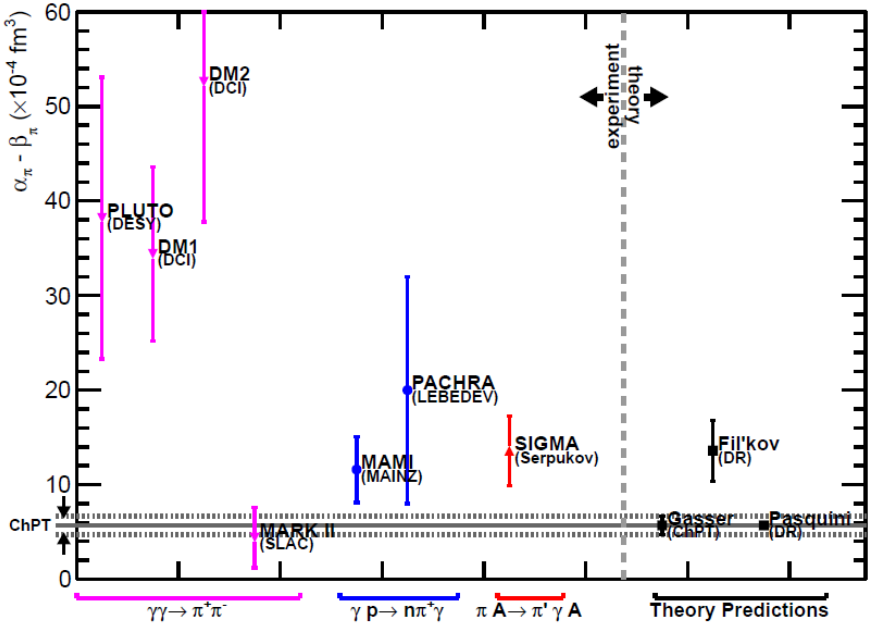


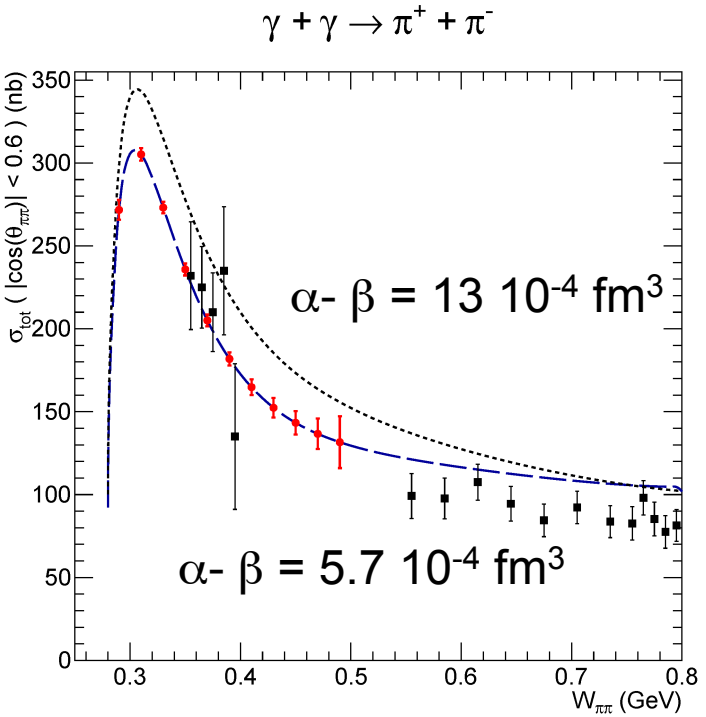


Charged Pion Polarizability



- Use Primakoff production γ A $\rightarrow$ π^+ π^- A to extract pion polarizability - *test χPT predictions*
- Photon energy of interest 5.5 – 6 GeV, polarization 76 %
- Major background from rho decays and $\mu^+\mu^-$
- Requires new muon detector





Physics Topics with Nuclear Targets Considered for GlueX

- **Photoproduction of vector mesons off nuclei**
  Phys. Rev. C 93, 015203 (2016)

- **Study in-medium modification effects**

- **Color transparency**
  (initial calculations by Mark Strikman and A. Larionov)

- (Production of J/ψ)

. . . . . .

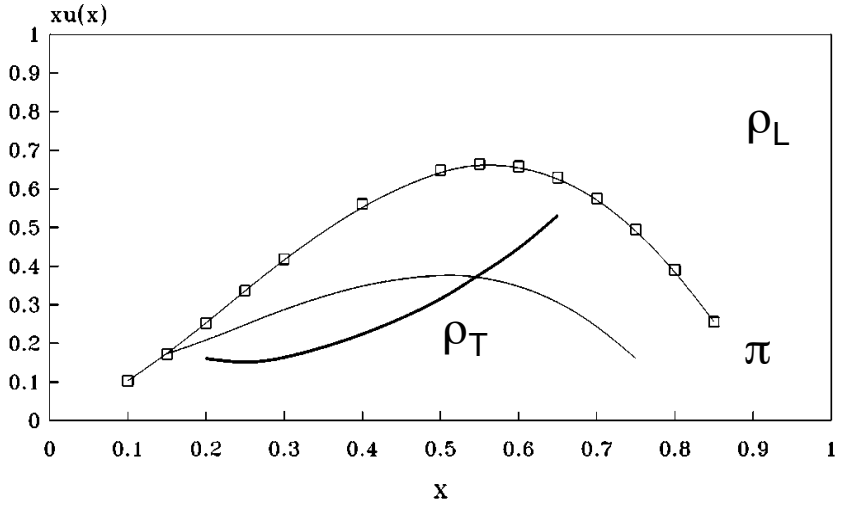
Photoproduction of Vector Mesons off Nuclei

- Develop physics motivation for the study of photoproduction of vector mesons (ω, ρ, ϕ) on nuclear target with the GlueX detector

- Measure differential cross section of the vector meson photoproduction in the energy range between 5 GeV and 12 GeV and the momentum transfer range $|t| < 0.5$ GeV^2

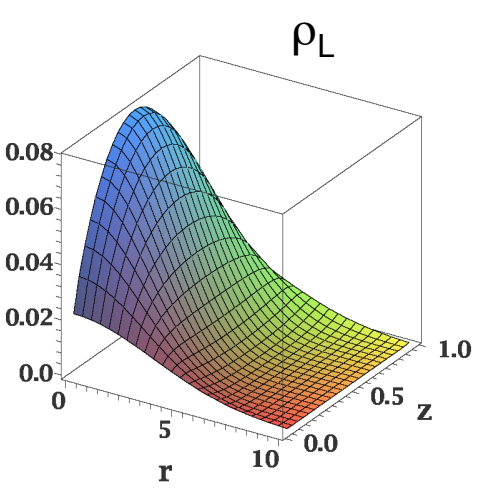
- **Study interactions of transversely and longitudinally polarized vector mesons with nucleons**

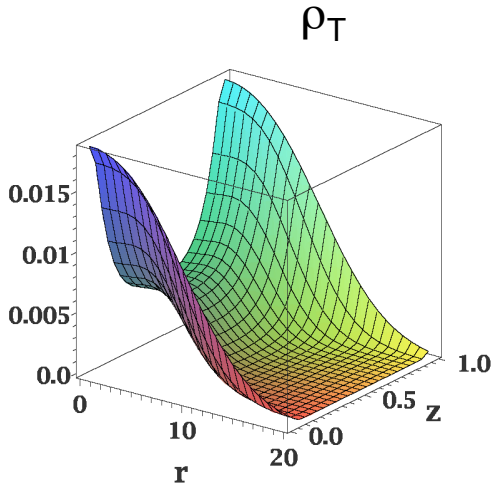
Quark Distributions in Polarized Mesons



Distribution of valence quarks

B.Ioffe and A.Oganesian Phys. Rev. D63, 09606, 2001





Light cone wave function for ρ mesons
J.Forshaw and R.Sandapen
Phys.Rev. Lett. 109,081601,2012

Dipole model of strong interaction

Different distributions of quarks in the transversely and longitudinally polarized mesons

Photoproduction of ω-mesons off Nuclei

Coherent photoproduction $\gamma + A \rightarrow \omega + A$

- obtain the total cross section of transversely polarized ω meson with nucleons σ_T (ω N)
- measure the ω - photon coupling constant

Incoherent photoproduction $\gamma + A \rightarrow \omega + A'$

- extract the total cross section of longitudinally polarized ω meson with nucleons σ_L (ω N) **which has not yet been measured**
- measure nuclear transparency and the spin density matrix elements for different nuclei

Coherent Production of ω-mesons

- Exchange of particle with isotopic spin one (pion exchange) has different signs in photoproduction on proton and neutron
  - the contribution of pion exchane cancels out when amplitudes are summed
- S - channel helicity conservation in production at small angles
  - transversely polarized ω mesons

$$\frac{d\sigma_A(q)}{dt} = |F_A(q_\perp, q_L, \sigma_T)|^2 \left.\frac{d\sigma_N}{dt}\right|_{t=0}$$

Obtain ω - photon coupling constant

$$\left.\frac{d\sigma_N}{dt}\right|_{t=0} = \frac{4\pi}{\gamma_\omega^2}\frac{\alpha}{64\pi}\sigma_\omega^2(1+\alpha_\omega^2)$$

Measure coupling constant in photoproduction on nucleons using linearly polarized photons (distinguish contributions from the natural and unnatural parity exchange)

- measure photoproduction cross section on both nuclei and nucleons
- help to sort out some contradictions in the measurements of the ω - photon coupling constant

Incoherent production of ω mesons

Nuclear transparency

$$\frac{d\sigma_A(q)}{dt} = \frac{d\sigma_0(q)}{dt} \cdot (\rho_{00} N(\sigma_L) + (1-\rho_{00}) N(\sigma_T))$$

$$N(\sigma) = \int \frac{1-\exp(-\sigma \int \rho(b,z)dz)}{\sigma} d^2b$$

$$A_{EFF} \equiv \frac{d\sigma_A(q)}{dt} \Big/ \frac{d\sigma_0(q)}{dt}$$

Spin density matrix elements

$$\rho_{00}^A = \frac{N(\sigma_L)}{\rho_{00} N(\sigma_L) + (1-\rho_{00}) N(\sigma_T)} \rho_{00}$$

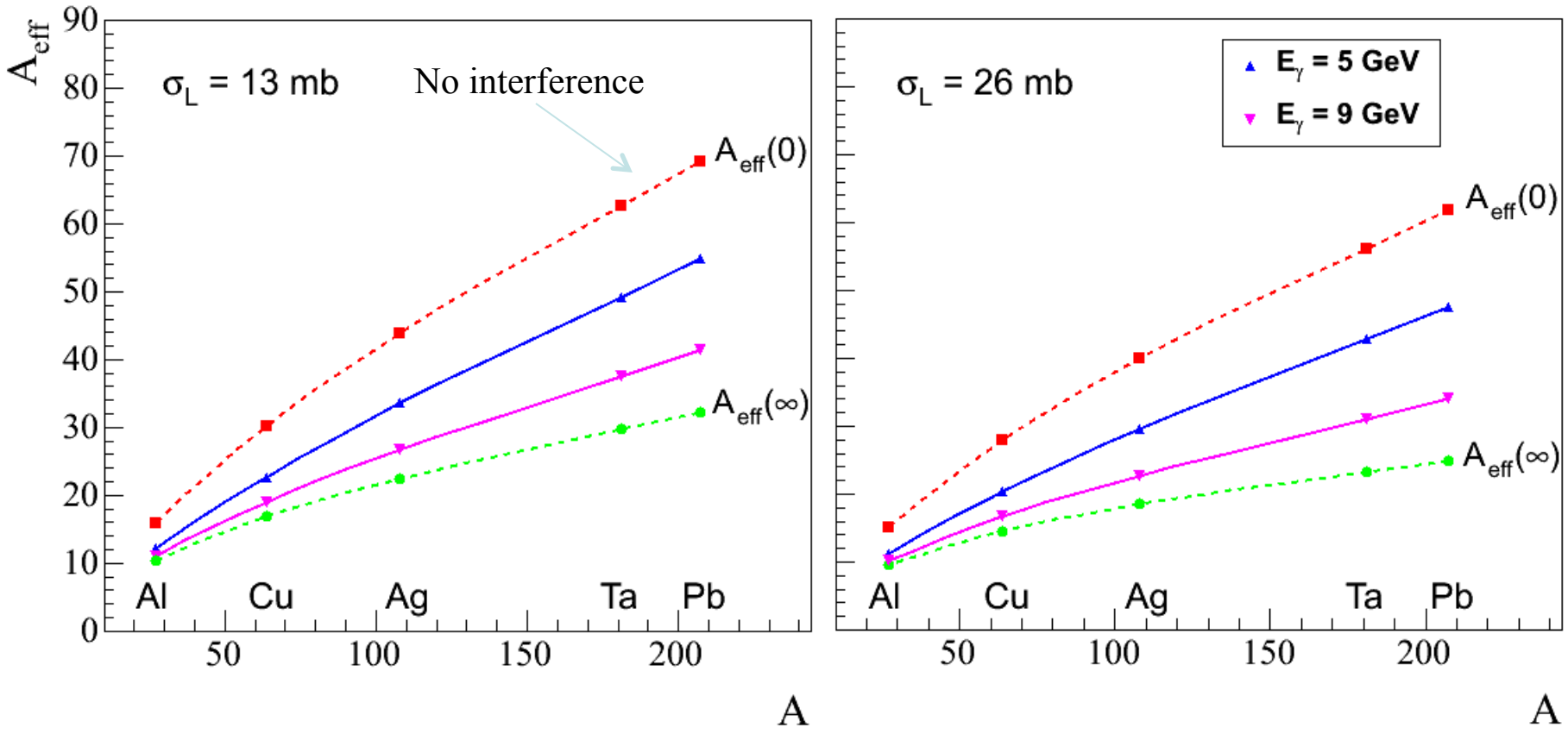
Extend the model by taking into account interference of production amplitudes

- required to describe electroproduction of vector mesons
- energy dependent transparency: $N(\sigma_T) \rightarrow W(\mathbf{q_L}, \sigma_T)$, where $q_L = m^2 / 2E$

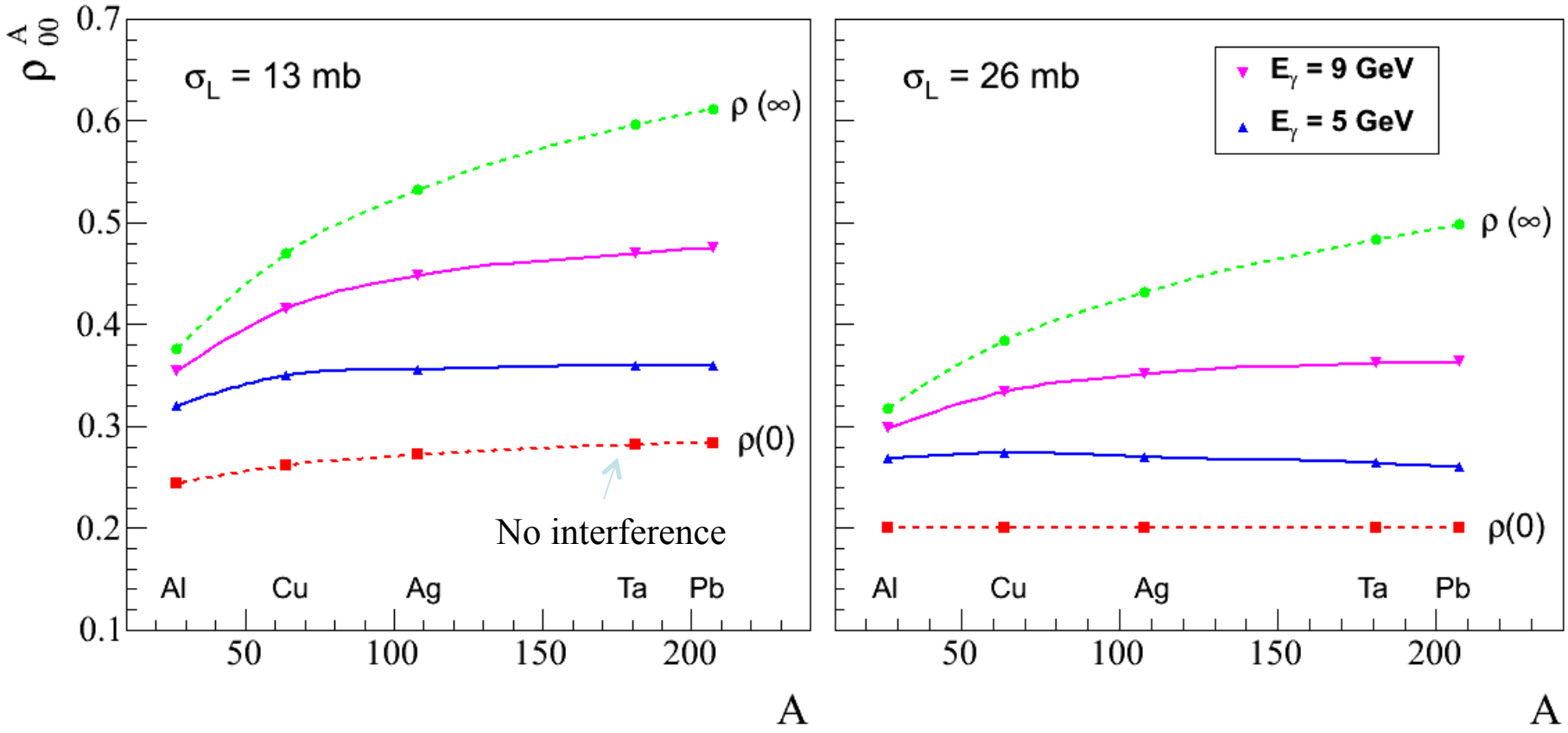
Nuclear Transparency

E. Chudakov, S, Gevargyan, A, Somov
Phys. Rev. C 93, 015203 (2016)

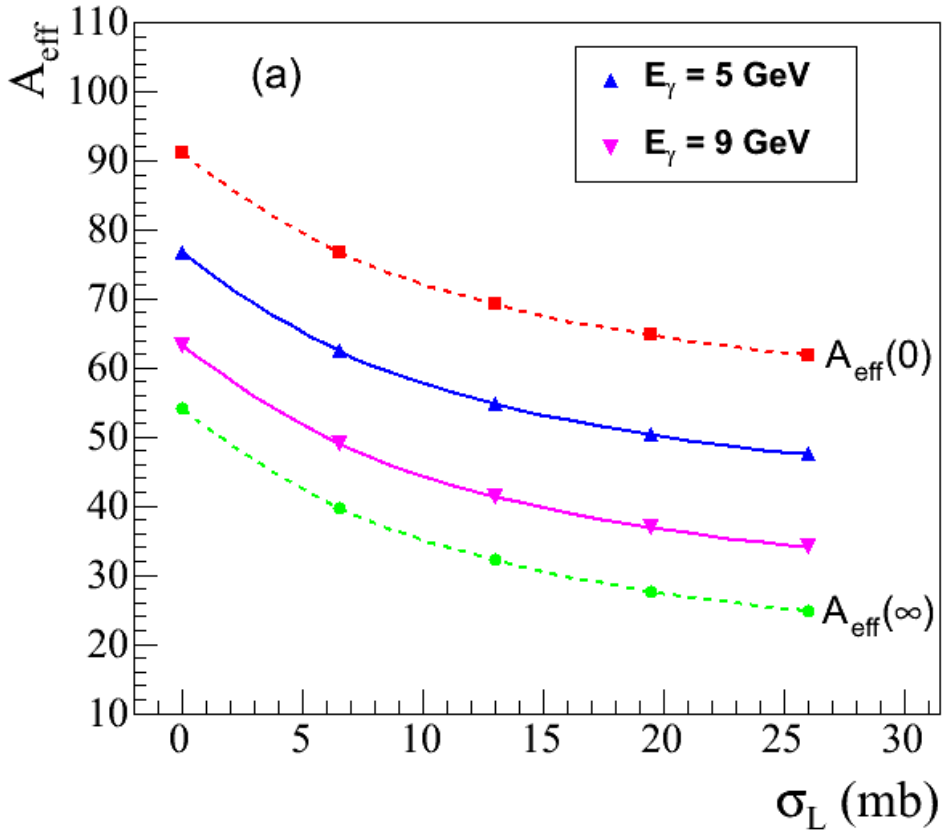
Input values: $\sigma_T = 26$ mb
$\rho_{00} = 0.2$ (mesured by SLAC in photoproduction on nucleon)

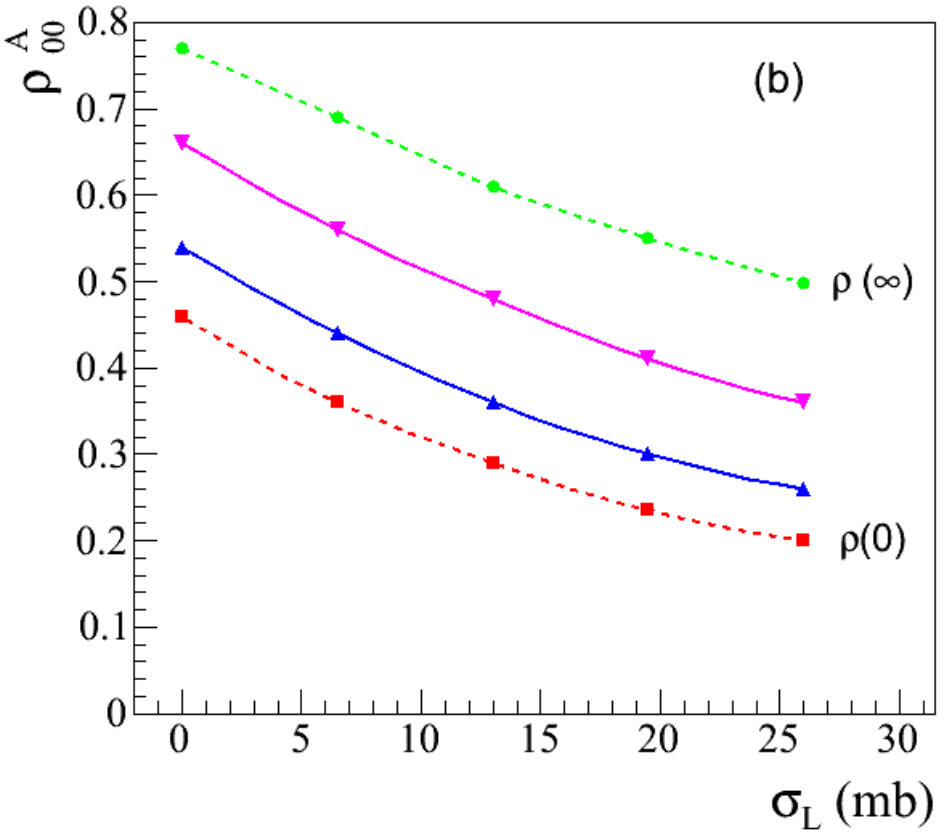


Spin Density Matrix Elements



A_{EFF} and ρ_{00} versus σ_L





Experimental Requirements

Main factors limiting luminosity:

- **rate of coincidential hits in tagger (for small beam energies)**
- **background (neutrons) in the experimental Hall-D**

- Reduce beam current 10 nA (about 220 times smaller that the nominal GlueX current of 2.2 μA)
- Coincidential rate in the tagger in the energy range 4.5 – 6.5 GeV is about 3 %
- Flux of collimated and tagged photons:

2.3×10^5 γ/sec (5 GeV < E_γ < 6 GeV can be increased by moving high granularity tagging detectors

4.1×10^5 γ/sec (8 GeV < E_γ < 9 GeV)

Yield of ω Mesons

- Thickness of nuclei targets – 7 % X_0 (400 μm Pb)
- Production rate of omega mesons in incoherent process on a Pb target:

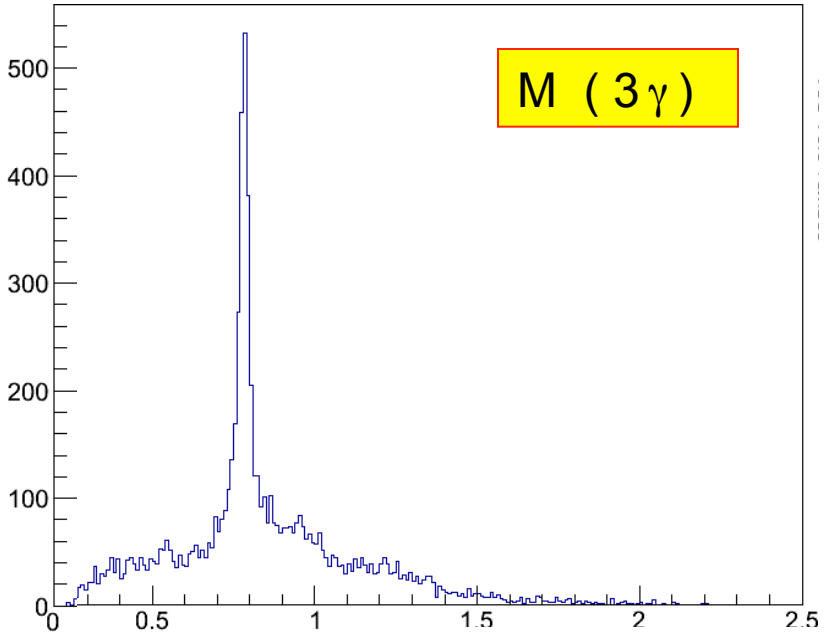
R = 7.8 ω/sec 5 GeV < E_γ < 6 GeV 0.28 reconstructed ω /sec

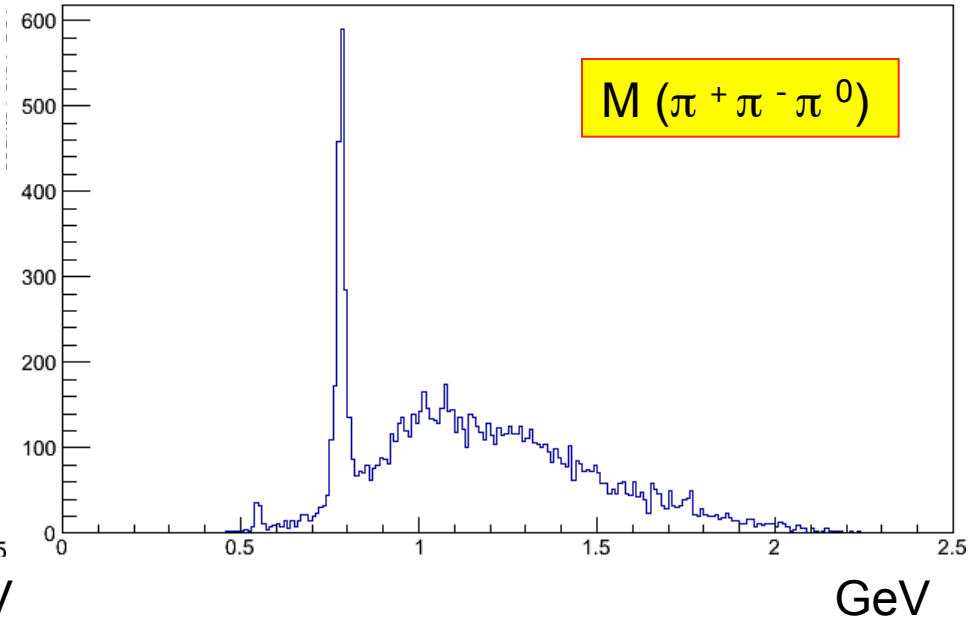
R = 7.3 ω/sec 8 GeV < E_γ < 9 GeV

Target	σ_{INCOH} (μb)		Reconstructed $\omega \rightarrow \pi^0 \gamma$ per day	
	5 GeV	9 GeV	5 GeV	9 GeV
Al	31	19	15600	17600
Pb	130	64	17300	16500

Reconstruction of ω-mesons with GlueX

- ω - mesons reconstructed with GlueX
- Detector calibration is in progress





Medium Modifications of Mesons

- Study modifications of meson properties by nuclear matter:

  Spectroscopy of hadron line shapes

  Attenuation measurements

- Use vector mesons to study the mass distribution and medium absorption
  ($c\tau$ = 1.3 fm, 23 fm, and 46 fm for ρ, ω, and ϕ)

- In-medium modification measurements have been performed by several experiments

  - Experimental measurements are not completely understood
    (more measurements are required)

Experimental Results on In-medium Modifications

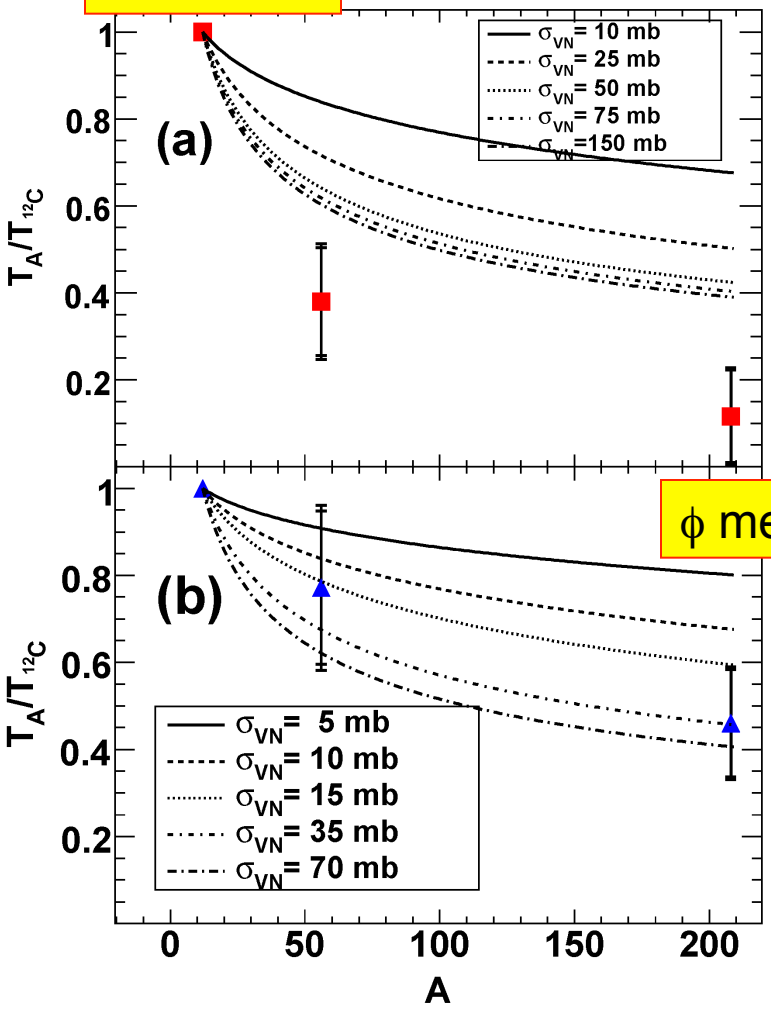
S.Leupold, V. Metag, U. Mosel
Int. J. Mod. Phys. E 19 (2010)

Experimet	Beam GeV	P range GeV/c	ρ	ω	ϕ
Spring 8	γ A 1.5 – 2.4	p > 1 K^+K^- final state			ΔΓ ~ 70 MeV p = 1.8 GeV/c
CBELSA/ TAPS	γ A 0.9 – 2.2	p > 0 $\pi^0\gamma$ final state		ΔΓ ~ 130 MeV p = 1.1 GeV/c	
CLAS E01-112	γ A 0.6 – 3.8	p > 0.8 e^+e^- final state	Δm ~ 0 ΔΓ ~ 70 MeV p = 1.1 GeV/c		
KEK-E325	p A 12	p > 0.6 e^+e^- final state	Δm /m = -9 % ΔΓ ~ 0	Δm /m = -9 % ΔΓ ~ 0	Δm /m = -3.4 % ΔΓ / Γ = 3.6
GlueX	γ A 6 – 12		ππ (e^+e^-)	$\pi^0\gamma$, $\pi^+\pi^-\pi^0$, (e^+e^-)	K^+K^- (e^+e^-)

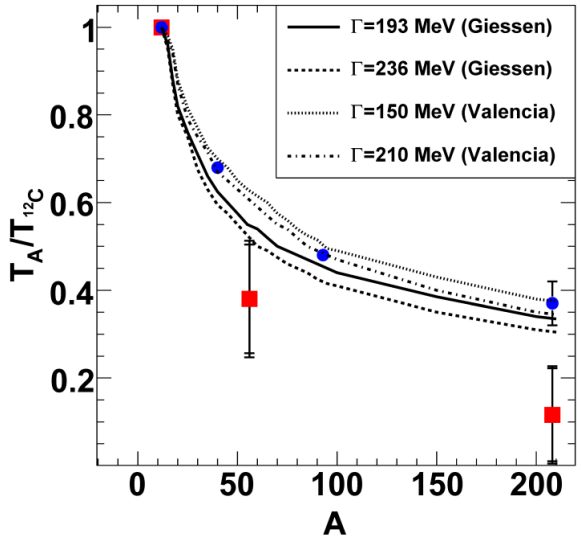
Nuclear Transparency Measured by CLAS E01-112

PRL 105, 112301 (2010)

ω mesons



ϕ mesons



Transparency $T_A = \sigma_A / A\,\sigma_N$

Large absorption observed for ω mesons

not consistent with CBELSA/TAPS results
- Interference between ω and ρ mesons in the e^+e^- decay mode (?)

GlueX Perspectives to Measure In-medium Effects

- Study medium modifications of light mesons ρ, ω, and ϕ
- Reconstruct mesons in different final states
  - study contribution from final state interactions
  - small final state distortion in the dilepton final state
    - small branching fractions of 10^{-4} – 10^{-5}
    - ρ - ω interference
    - have to study GlueX reconstruction capabilities of dileptons
- Study in-medium effects for different beam energies and meson momenta

Summary

- A new detector, GlueX, has been construction at Jefferson Lab

- The detector design was optimized for search and mapping the spectrum of light exotic mesons using the hight-intensity linearly polarized photon beam

  - The detector is designed to have excellent acceptance for both charged particles and photons in the final state

- We have strated developing physics program for the GlueX to study photoproduction on nuclear targets. Some topics we have considered so far:

  Photoproduction of vector mesons off nuclei

  Study in-medium modification effects

  Color transparency

- We want to get interested people involved and build a strong physics motivation for the experiment

Workshop on nuclear photoproduction at GlueX, JLab, April 28 - 29, 2016

Join us !