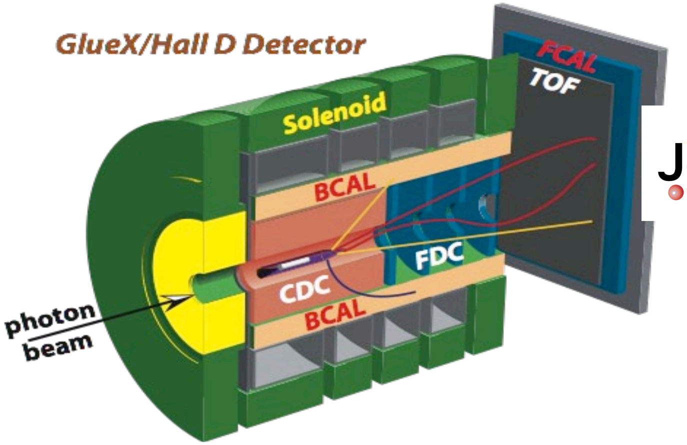


GlueX Capabilities for Nuclear Photoproduction

A. Somov, Jefferson Lab

Nuclear Photoproduction with GlueX
April 28 – 29, 2016

Physics Topics with Nuclear Targets Considered for GlueX

- **Photoproduction of vector mesons off nuclei**
- **Study in-medium modification effects**
- **Color transparency**
- **Primakoff production**
- **Heavy meson photoproduction (open charm, J/ψ)**

. . . . . .

Photon Flux and Run Conditions

Main factors limiting luminosity:

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

➢ GlueX beam requirements for runs with the LH2 target

- $5 \cdot 10^7$ γ/sec on target in the energy range 8.4 GeV < E < 9.1 GeV
- coincidental rate in the tagger:15 % in a 2 ns time window (500 MH RF)
- collimator diameter: 3.4 mm (transmission factor ~1/6 for $E_{min} < E < 12$ GeV)
- LH2 target thickness ~3.4 % R.L.

Photon Flux and Run Conditions

- Nuclear targets (no beam polarization)

  - Some physics topics require measurements in a larger beam energy range

  - Increase size of the collimator to ≥5 mm (transmission factor ~1/3)

  - Increase target thickness to 7 – 10 % R.L.

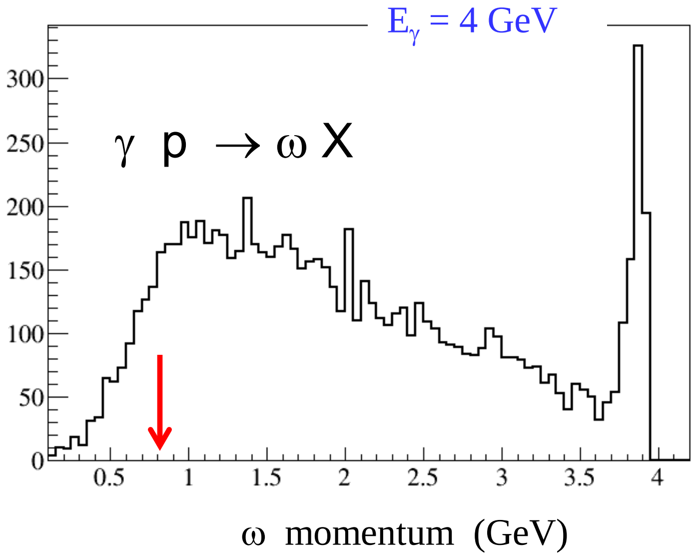
  - Reduce electron beam current by a factor of 9

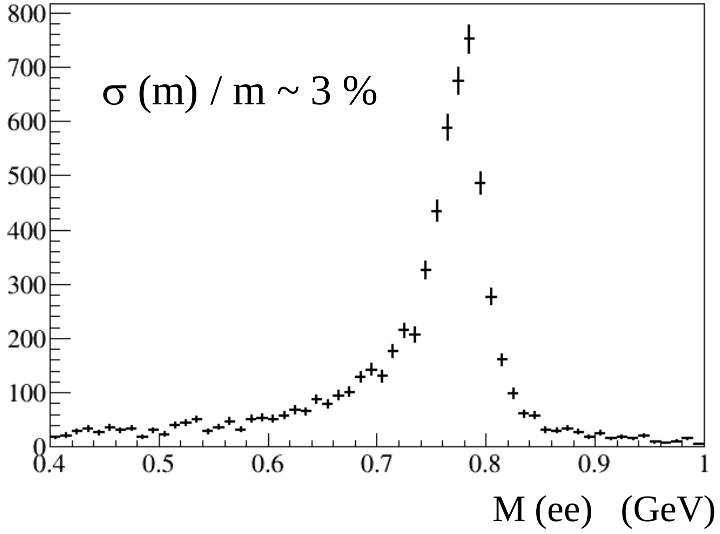
  - Flux of collimated and tagged photons:
    2.1×10^7 γ/sec (6.5 GeV $< E_\gamma <$ 12 GeV)

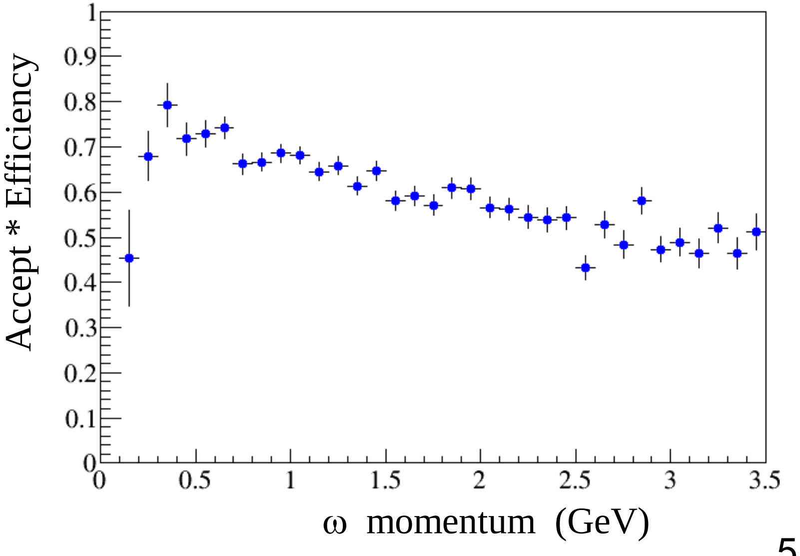
  - Coincidental rate in tagger ~ 17 %

Reconstruction of $\omega \to e^+ e^-$

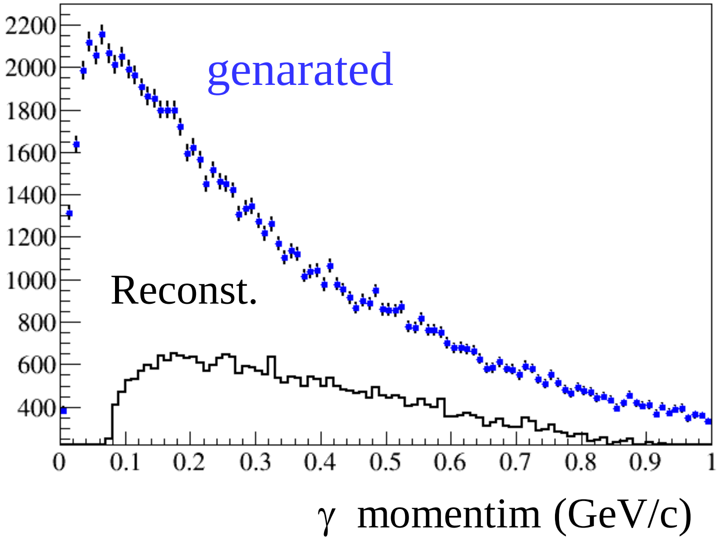
- Study reconstruction efficiency of ω-mesons γ p interactions (Pythia)
- Relatively good reconstruction efficiency over large ω momentum range
- Difficult to measure:
  - Small branching fraction ~10^{-4},
  - e/pi separation is critical
- Small cross section: $\sigma\ (\omega\ X)_{p\ <\ 0.8\ \mathrm{Gev/c}}\ \sim 1.8$ nb



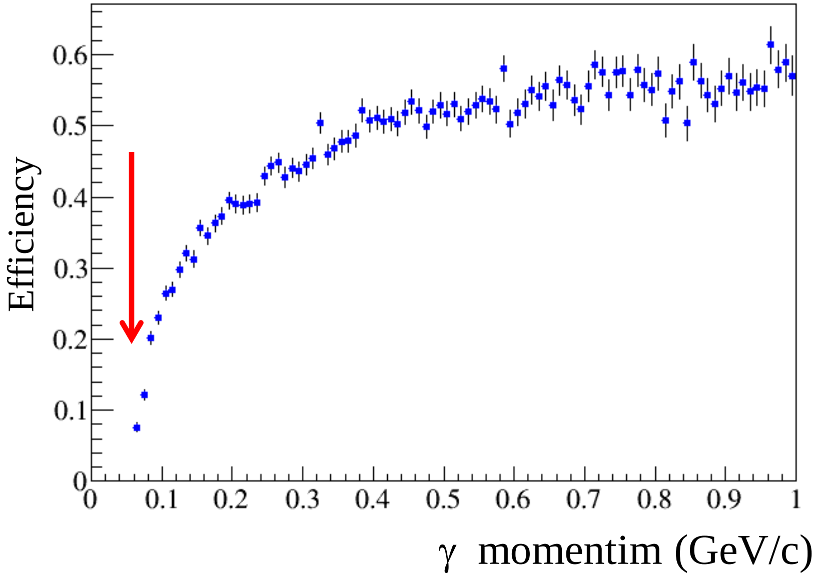


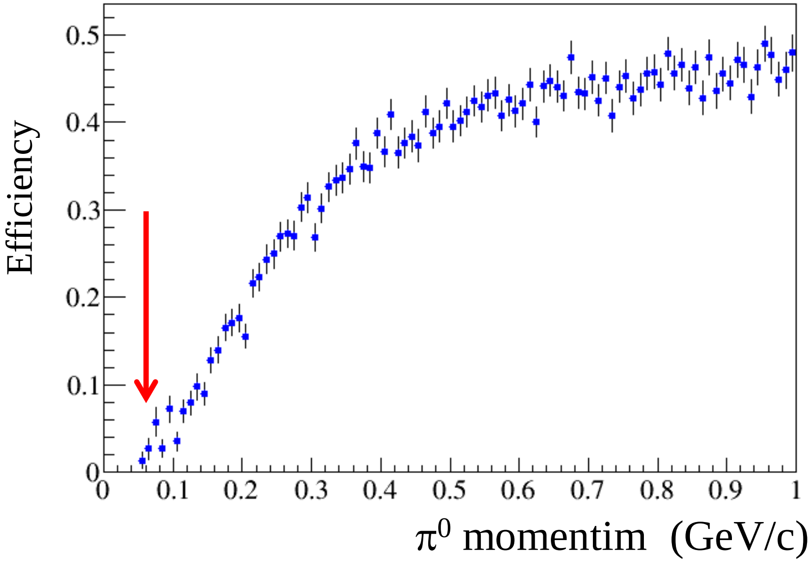


Reconstruction of $\omega \rightarrow \pi \gamma$

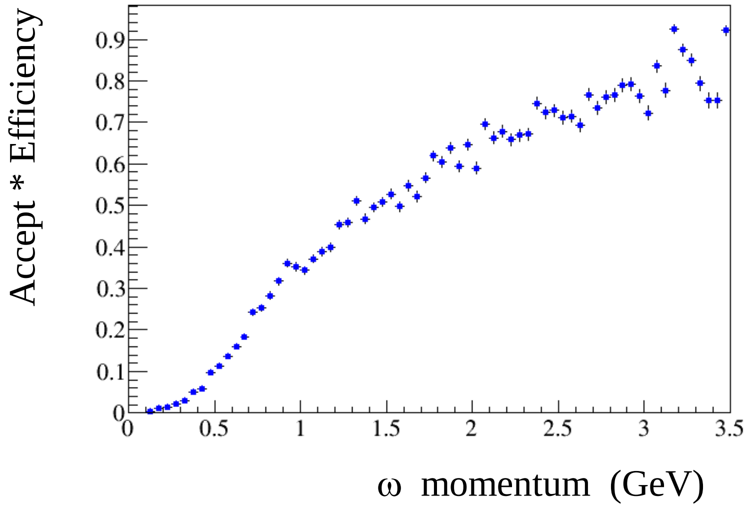


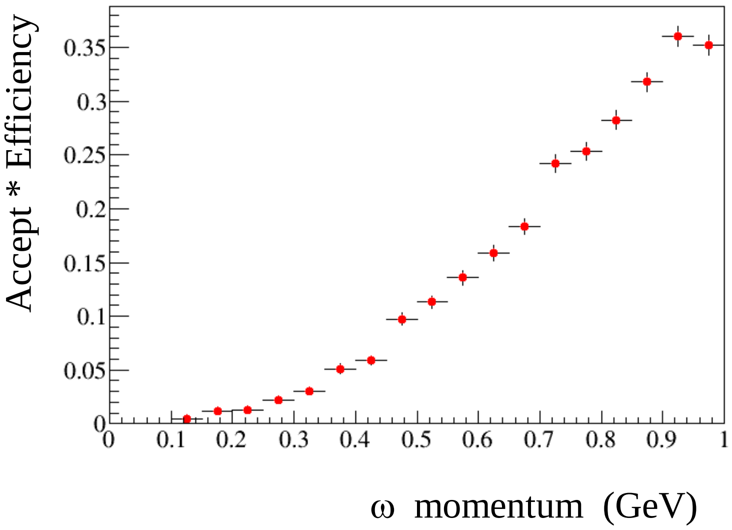
- Production at E_γ = 4 GeV





Reconstruction of $\omega \rightarrow \pi\,\gamma$





- Good detection efficiency of $\omega \rightarrow \pi\,\gamma$ decays at ‘large’ momentum
- Difficult to do line-shape analyses; relatively poor mass resolution $\sigma(m)/m > 3\%$
- **Good capability to study nuclear transparency (see Volker M. talk)**

Photoproduction of Vector Mesons off Nuclei

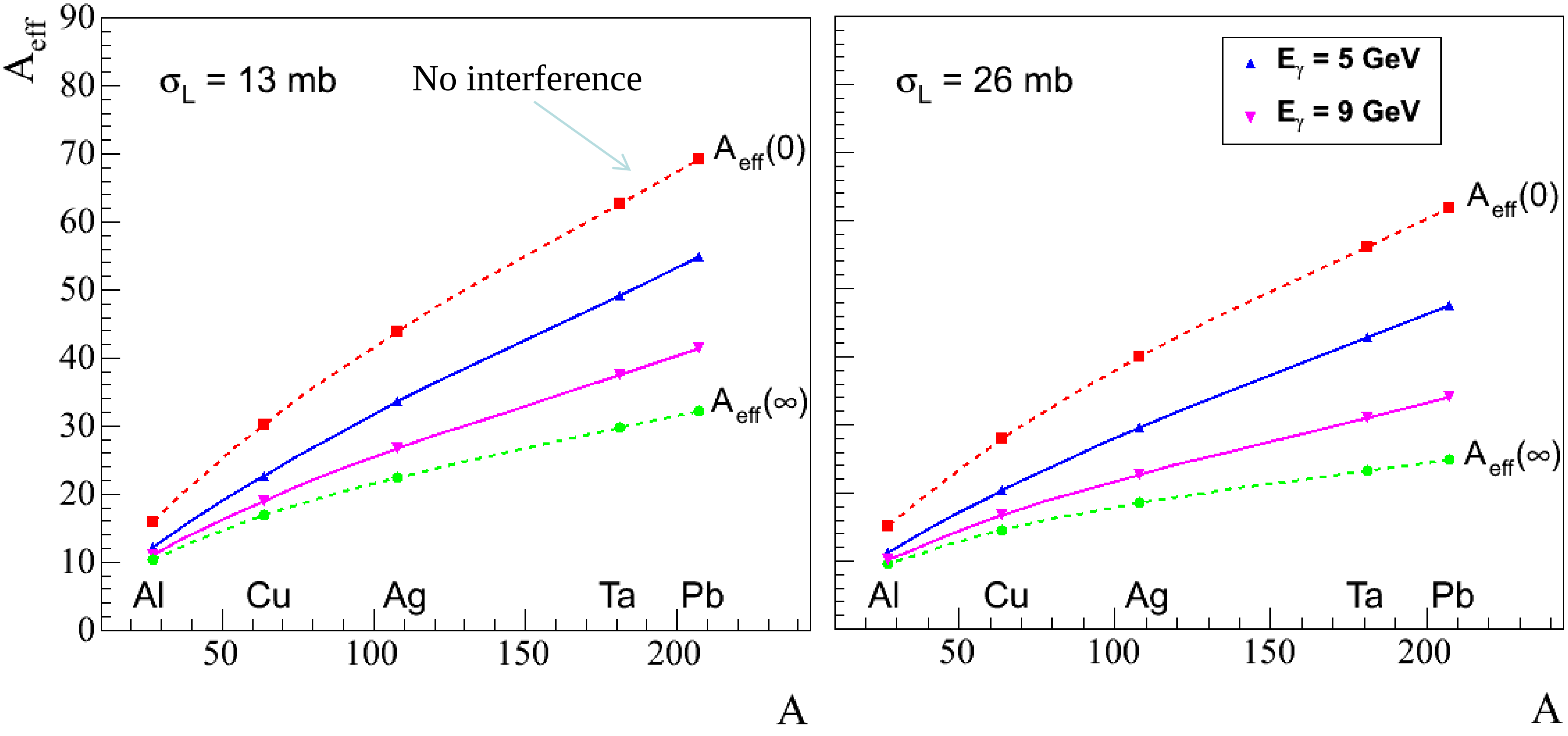
- **Study interactions of transversely and longitudinally polarized vector mesons with nucleons (Sergey G. talk)**

- 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

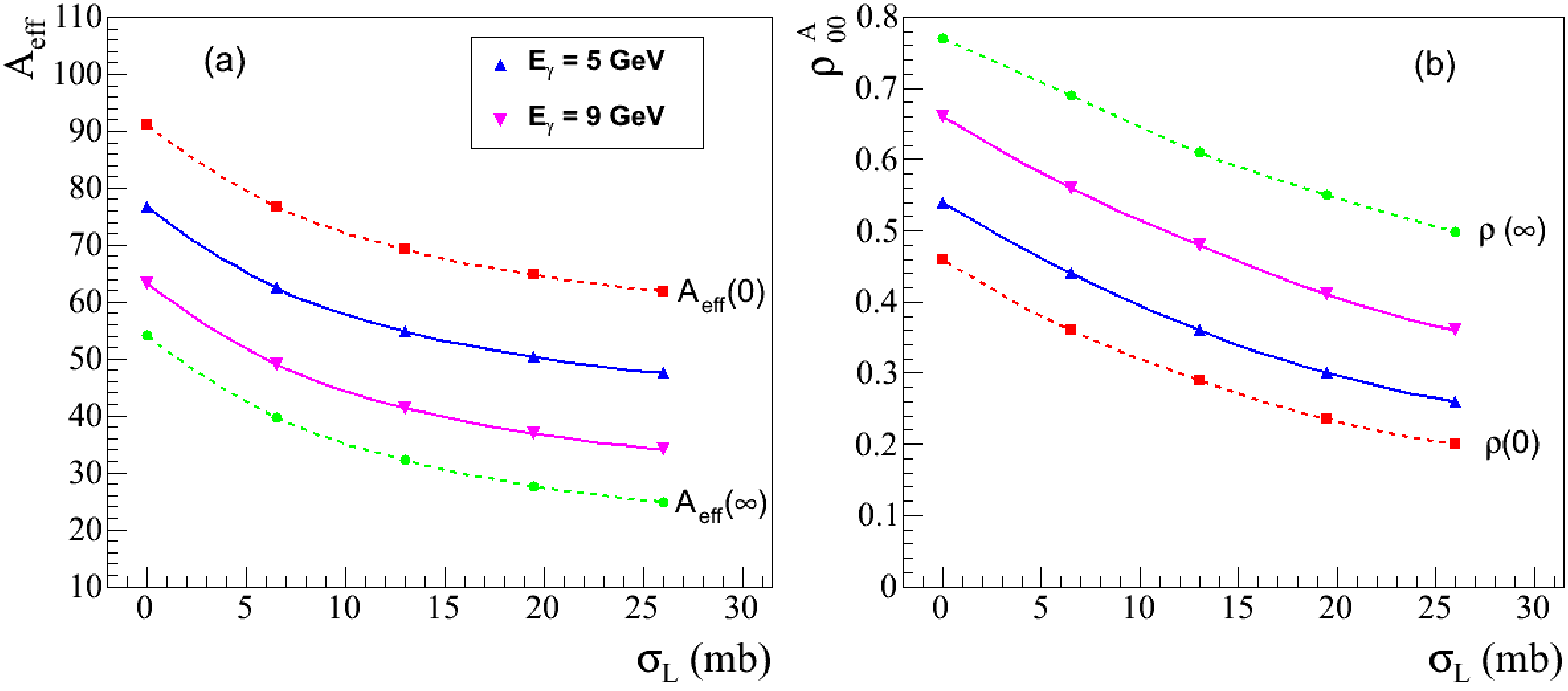
Nuclear Transparency

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

Input values: σ_T = 26 mb
ρ_{00} = 0.2 (mesured by SLAC in photoproduction on nucleon)



A_{EFF} and ρ_{00} versus σ_L



Yield of ω Mesons

- Thickness of nuclei targets – 7 % X_0
- Production rate of omega mesons in incoherent process on a Al target:

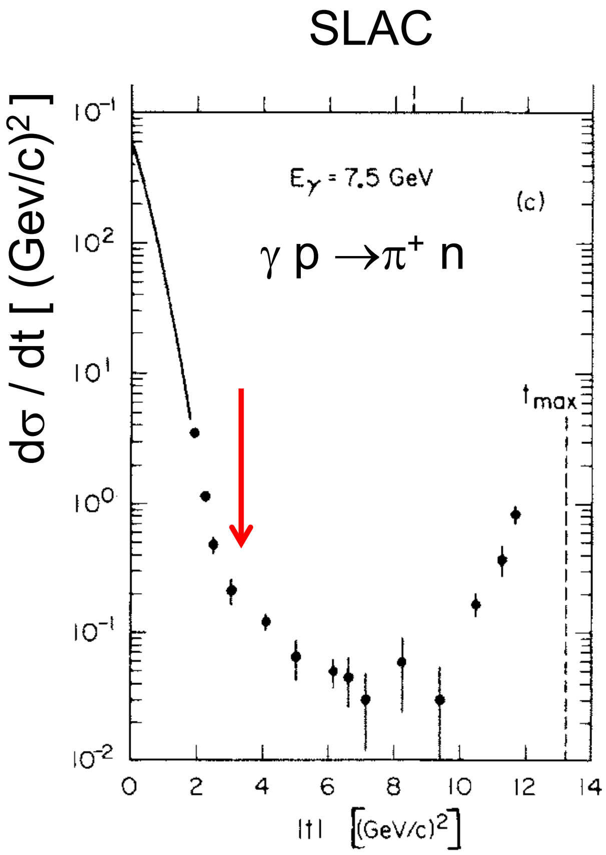
R = 1.8 ω/sec 6.5 GeV $< E_\gamma <$ 7.5 GeV 0.07 reconstructed ω /sec

Target	**σ_{INCOH} (μb)**		**Reconstructed $\omega \to \pi^0 \gamma$ per day**	
	6 GeV	9 GeV	6.5 – 7.5 GeV	8 - 9 GeV
Al	31	19	5672	6336

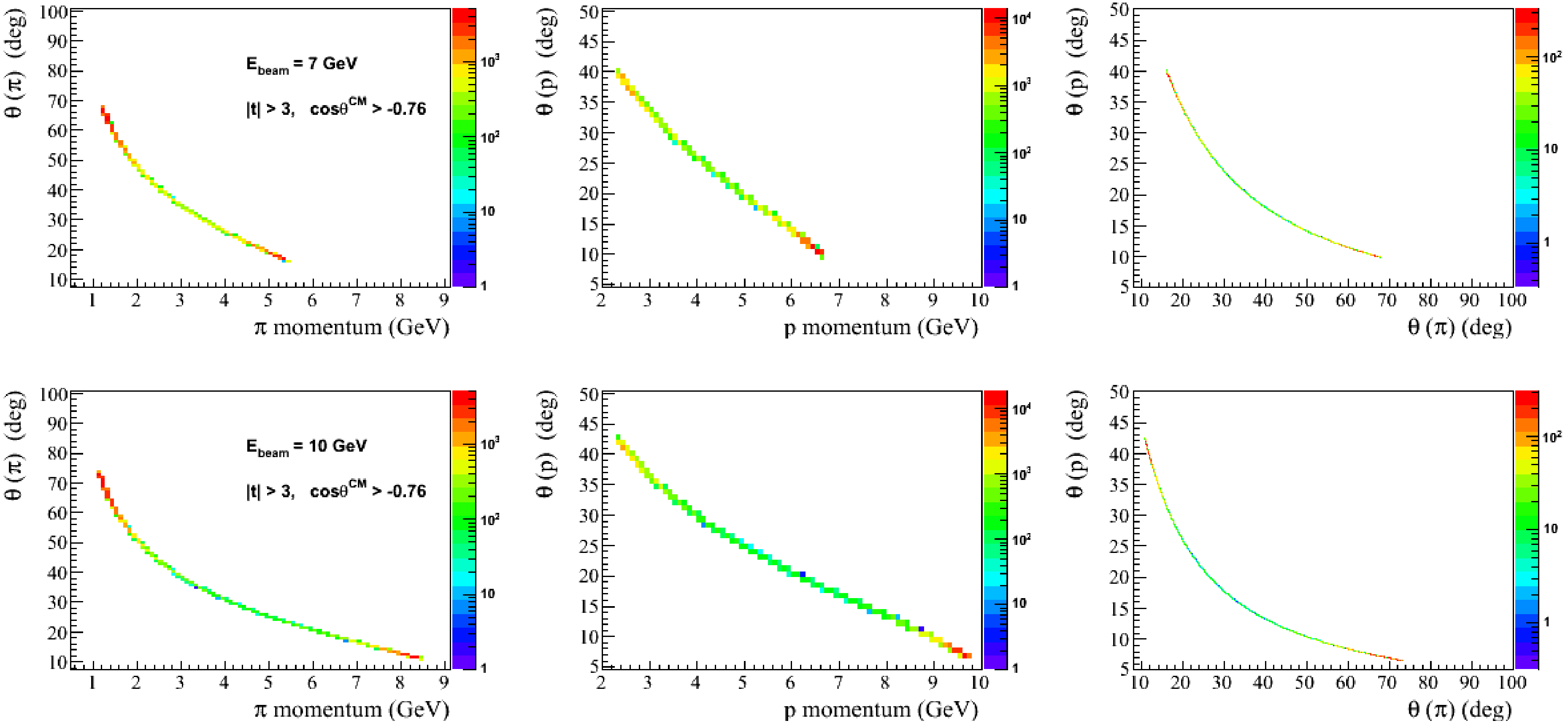
Meson Production with Large Momentum Transfer

Meson Photoproduction with Large Momentum Transfer

- Sensitive to color transparency effects
- Study production A (γ, π^- p) and A (γ, π^+ n)
  $|t| > 3$ GeV ^{2}, cos (θ) $_{C.M.}$ > -0.75
- Realatively small cross sections but still may be possible to study with GlueX
- Consider production of other mesons (ρ, …) at high-momentum transfer



Kinematics: $\gamma\ n \rightarrow \pi^-\ p$



Reconstruction with GlueX

- Process signal events through the GlueX Geant simulation
  - Reconstruction efficiency ~ 75 %

- Trigger: select events with back-to-back hits

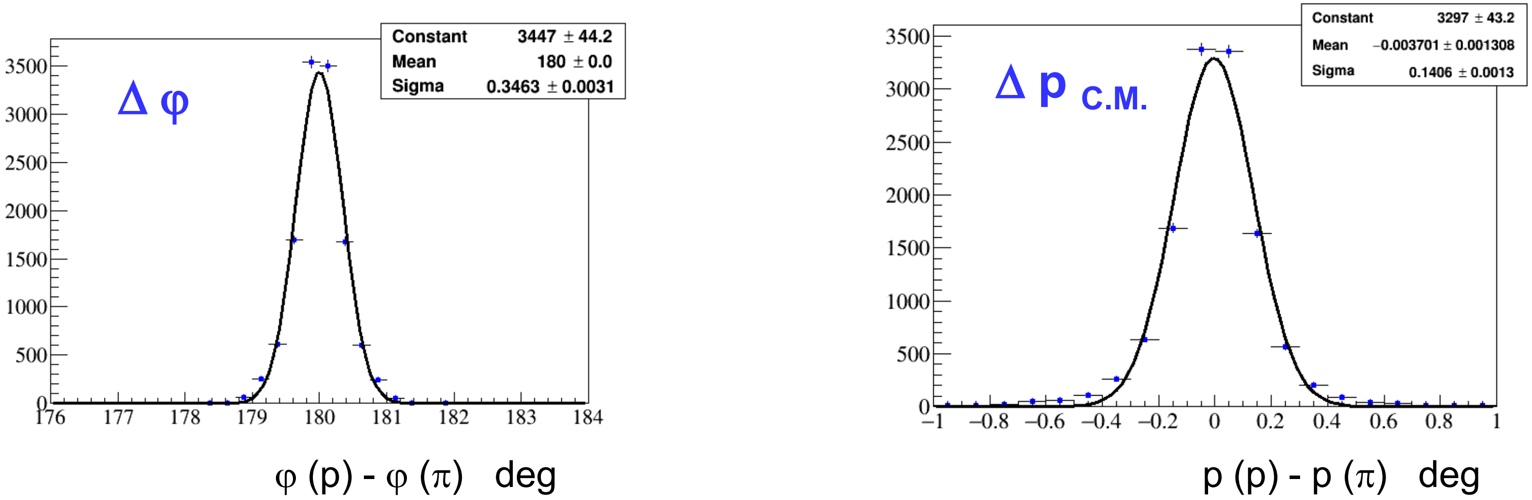
- Expected yield: 100 p π^- reconstructed events per day

	Energy range (GeV)				
	6.5 – 7.5	**7.5 – 8.5**	**8.5 - 9.5**	**9.5 - 10.5**	**10.5 - 12**
$\sigma_{\gamma\,\mathrm{Au}}$ (nb)	10.7.1	59.2	36.0	23.5	14.5
N_γ (10^6)	2.2	3.4	5.6	4.5	6.0
$N_{p\pi}$ per day	(29.7)	25.8	23.1	13.7	11.2

Reconstruction with GlueX

- Started studying background in γ n interactions using Pythia

  - expected background is small (work in progress):
  binary reaction, two back-to-back tracks



- Study background using γ A event generator

- $\gamma p \rightarrow \pi^+ n$ is more difficult to measure (see Or and Werner talks) :
  need to trigger on high-p_T pion
  can use time-of-flight wall for the trigger

Summary

- The GlueX 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

  - Nuclear production can be studied in the wide photon beam energy range

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

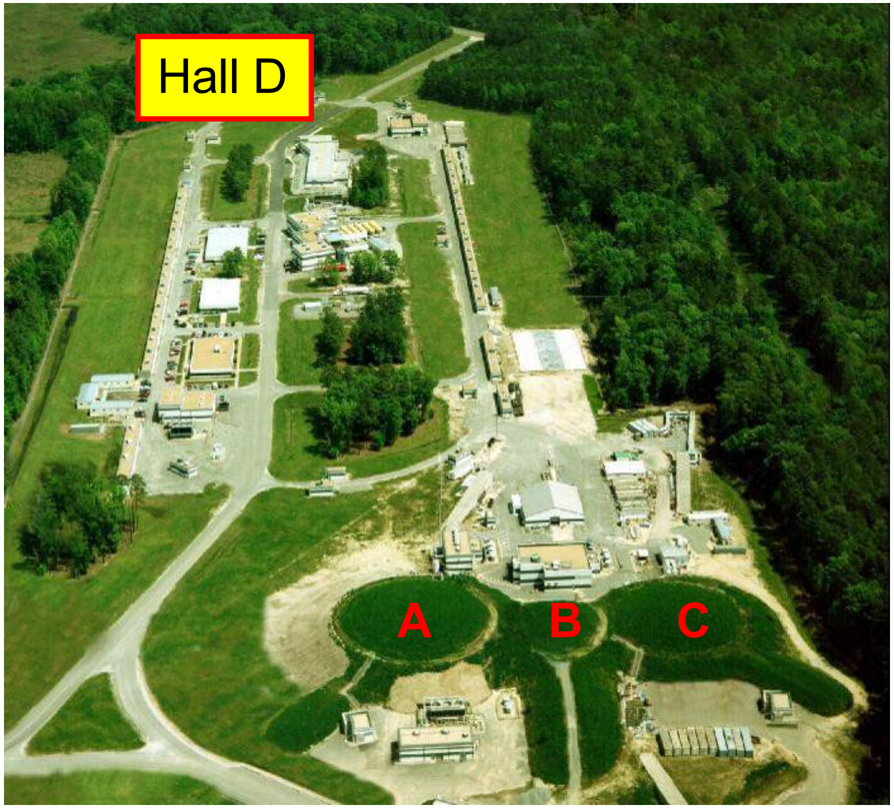
  Photoproduction of vector mesons off nuclei

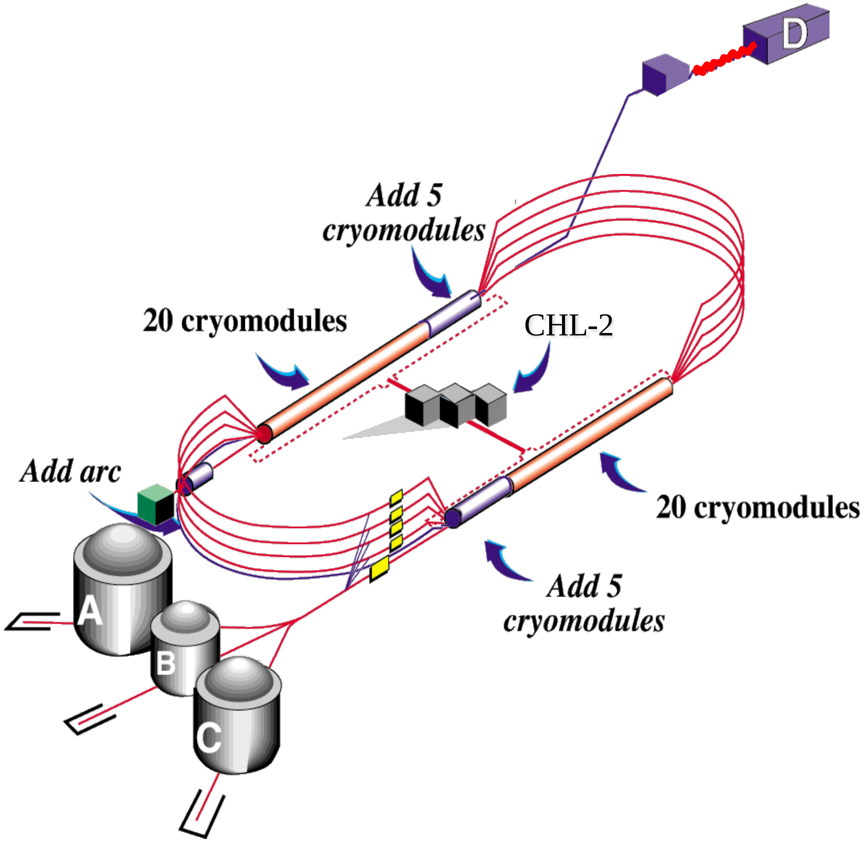
  Study in-medium modification effects

  Color transparency

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

12 GeV CEBAF Energy Upgrade





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

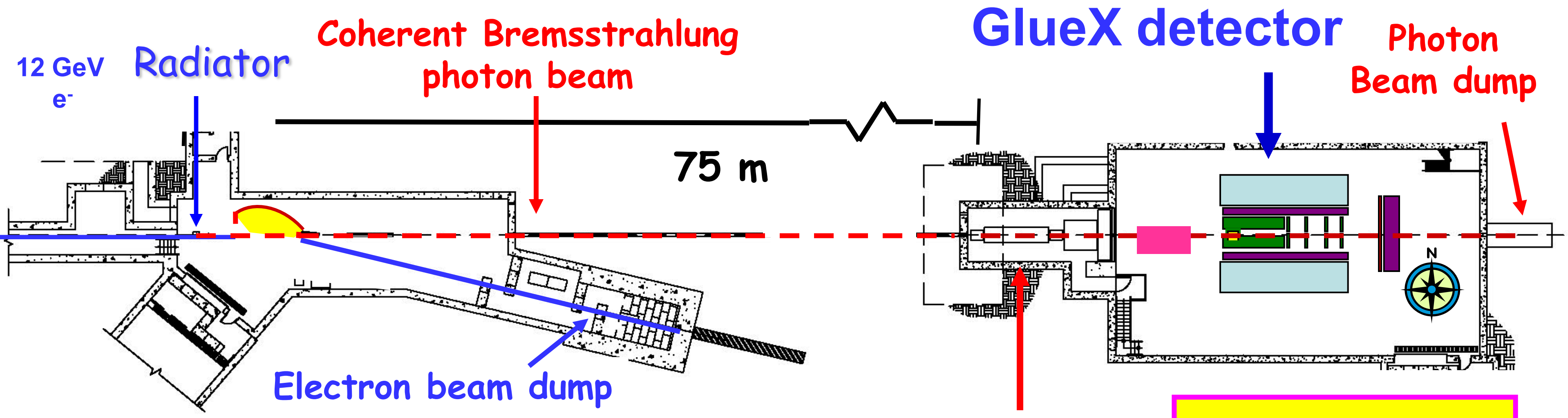
Hall D Physics Program

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**

Polarized Photon Beam



12 GeV e⁻

Radiator

Coherent Bremsstrahlung photon beam

75 m

GlueX detector

Photon Beam dump

Electron beam dump

Tagger Area

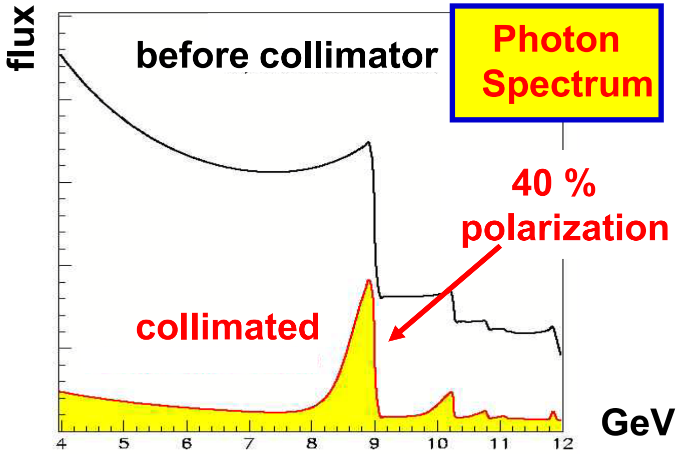
Collimator Cave

Experimental Hall D

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

  Δ 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_γ < 9.1 GeV



GlueX Detector

Tracking:

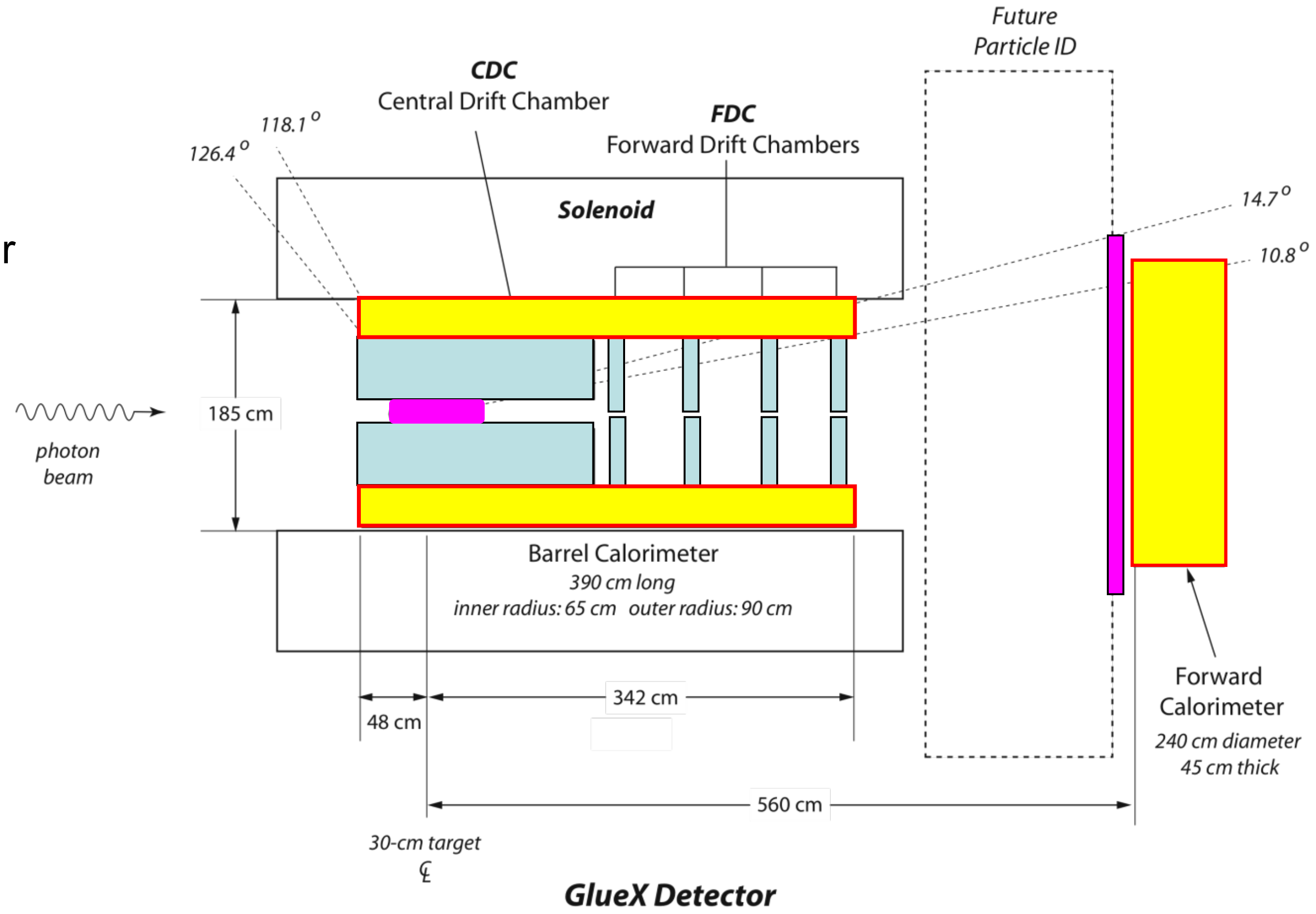
- Central Drift Chamber
- Forward Drift Chamber

Calorimetry:

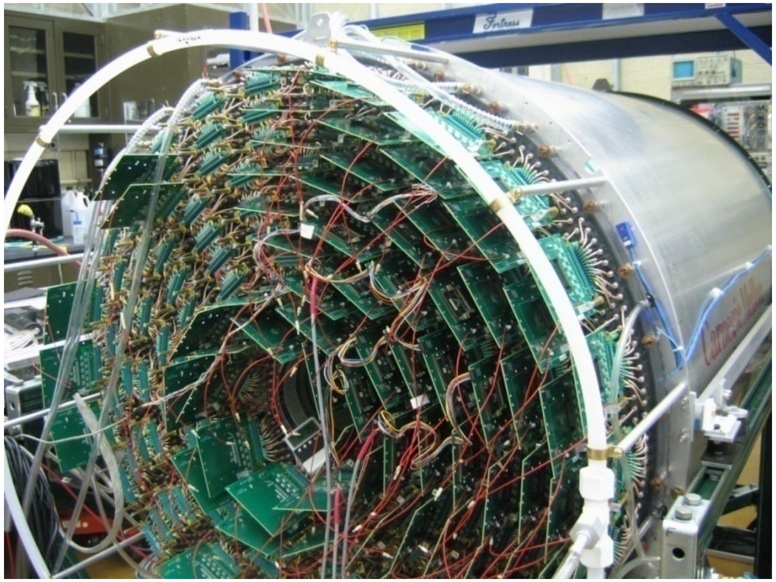
- Barrel Calorimeter
- Forward Calorimeter

PID:

- Time of Flight wall
- Start Counter
- Barrel Calorimeter

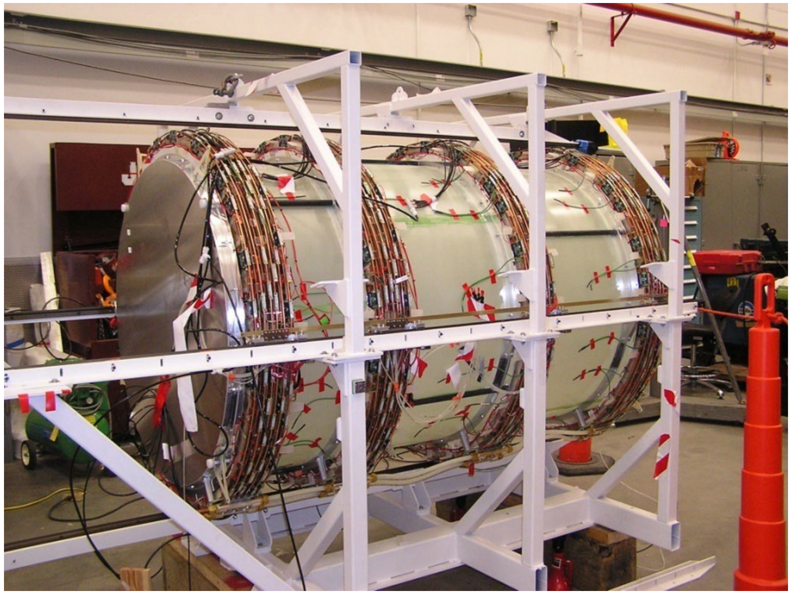


Tracking



Central Drift Chamber

- Angular coverage 6° < θ < 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

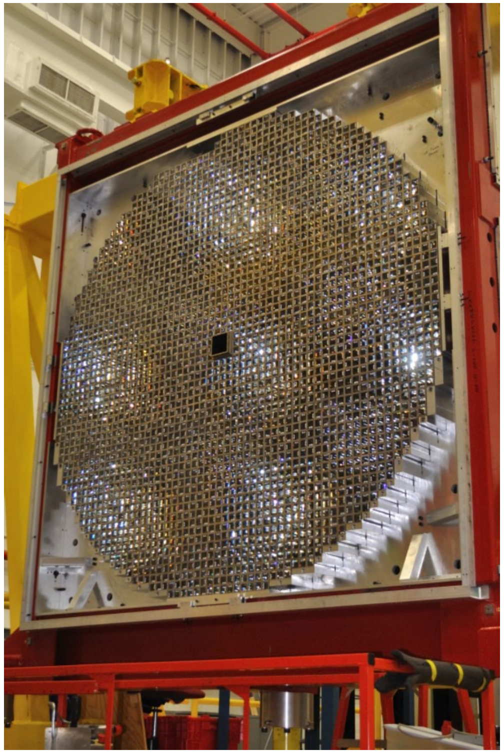


Forward Drift Chamber

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

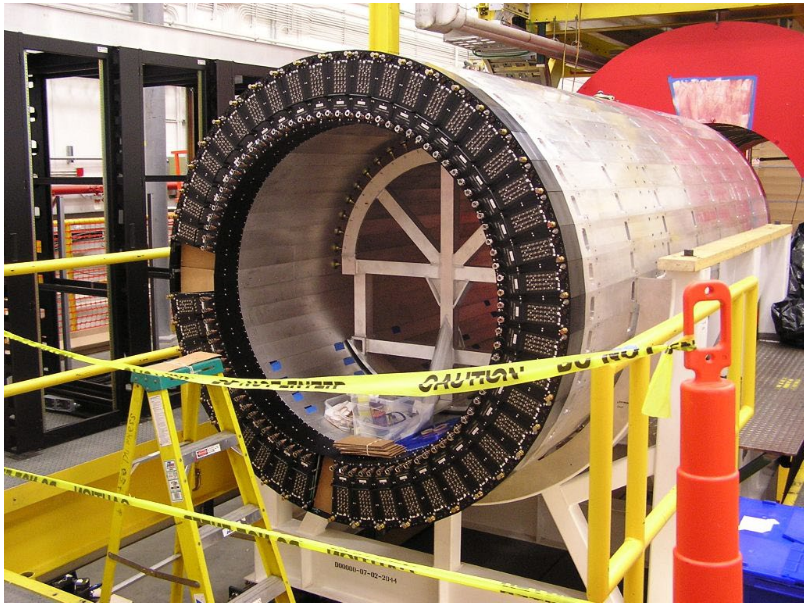
Tracking performance: $\sigma_p / p \sim 1 – 3$ %

Calorimetry



Forward Calorimeter:

- Angular coverage 2° < θ < 11 °
- 2800 Pb-glass blocks: 4cm x 4 cm x 45 cm
- **σ_E / E = 6 % /√E ⊕ 2.0 %**
- **σ_{xy} = 6.4 mm / √E**

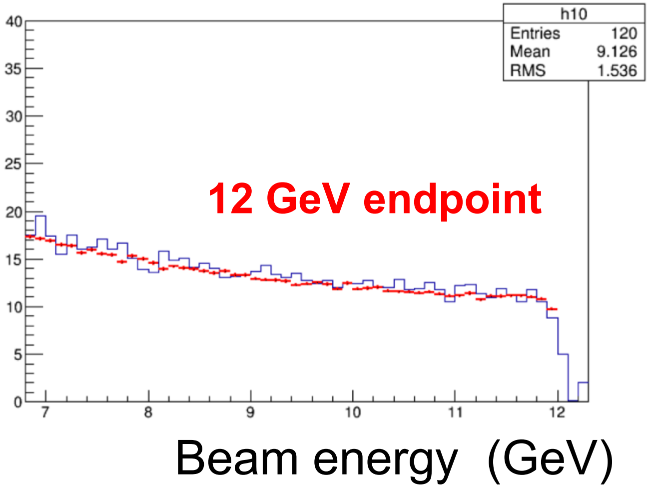


Barrel Calorimeter:

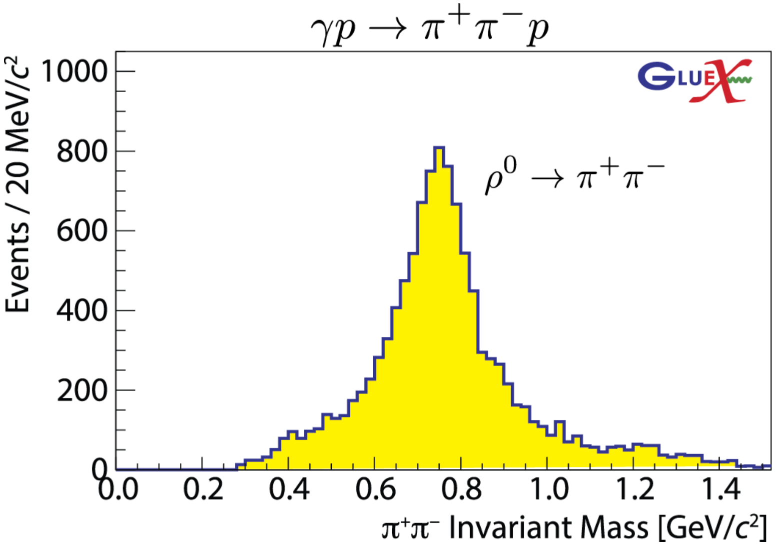
- Angular coverage 11° < θ < 120 °
- 191 layers Pb:ScFib:Glue (37:49:14%)
- Double side readout (SiPM)
- **σ_E / E = 6 % /√E ⊕ 1.6 %**
- **σ_Z = 5 mm / √E**
- **σ_t = 74 ps / √E ⊕ 33 ps**

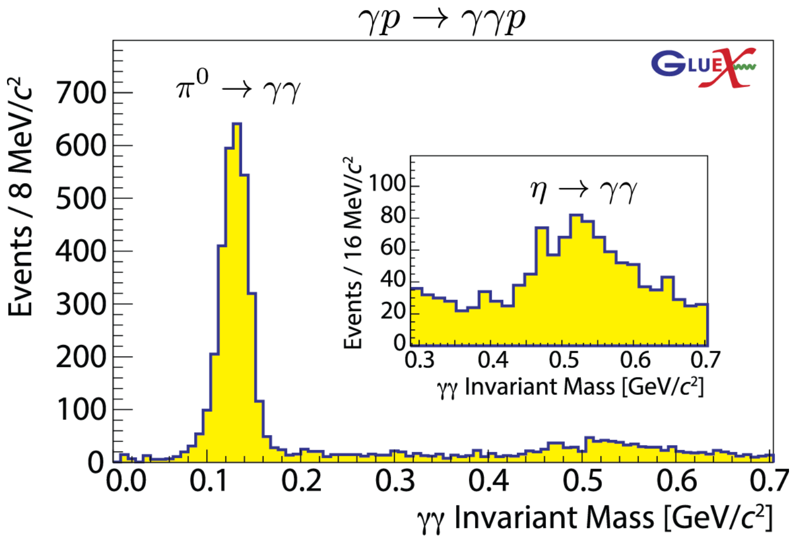
GlueX Commissioning

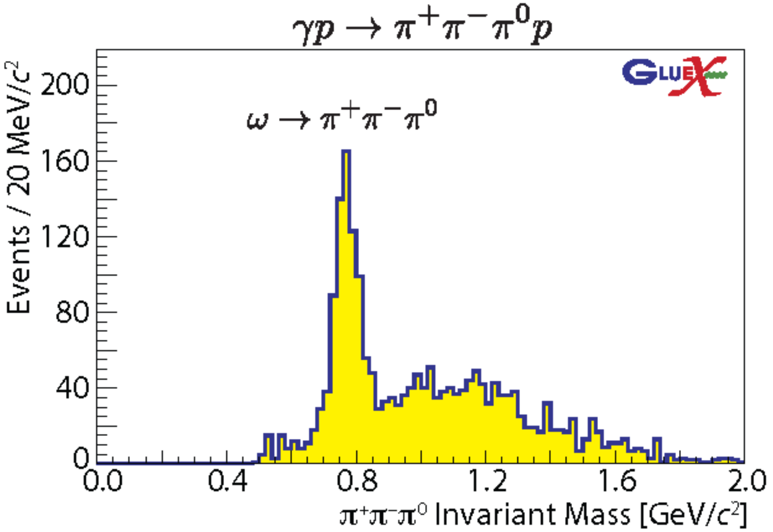
12 GeV photons delivered to Hall D in the Fall 2015



12 GeV endpoint

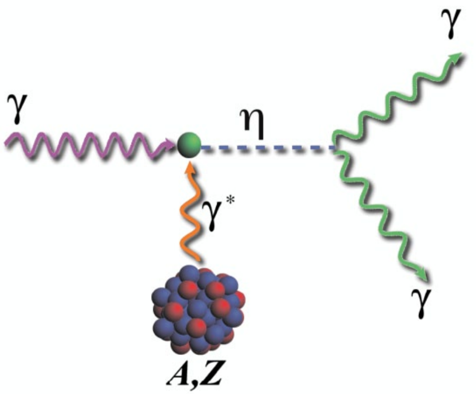






Experiments using Primakoff Production

Measurement of $\Gamma(\eta\to\gamma\gamma)$ via Primakoff Effect



Physics:

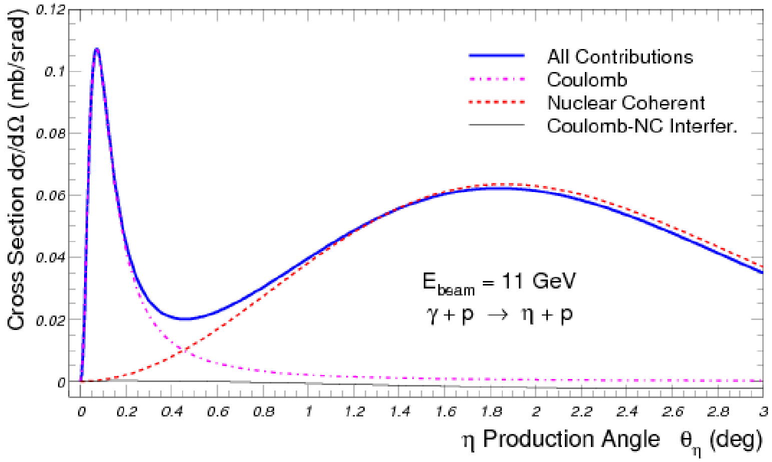
- Light quark mass ratio
- η - η′ mixing angle

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

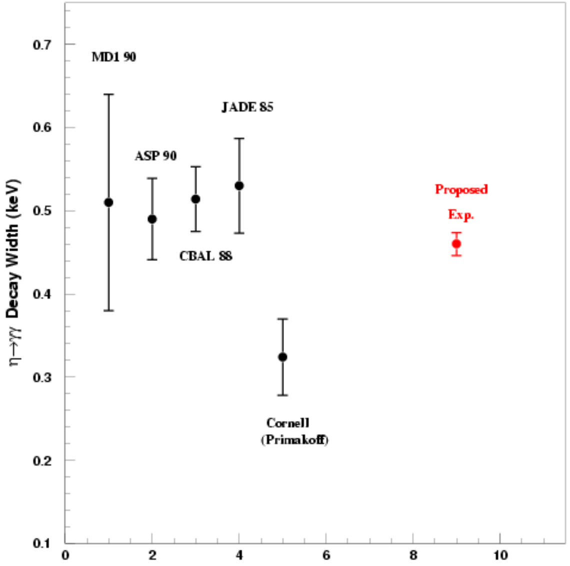
$$Q^2 = \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2}, \qquad \text{where } \hat{m} = \frac{1}{2}(m_u + m_d)$$

Measurements:

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



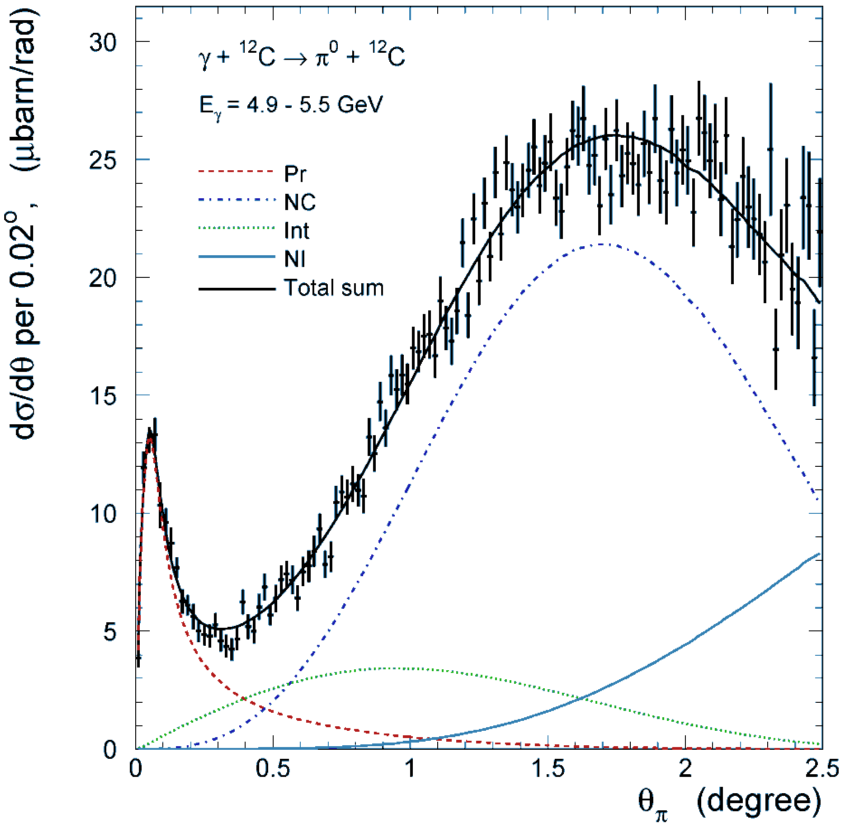
$\Gamma(\eta\to\gamma\gamma)$ Hall-D projection

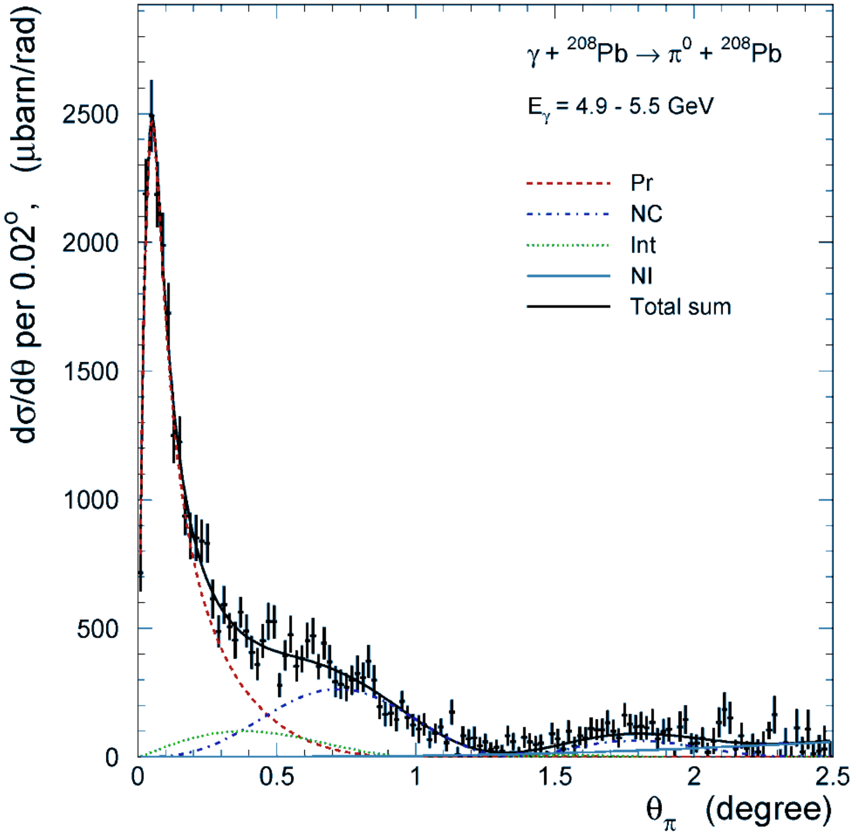


- ➢ 11.0 - 11.7 GeV incoherent tagged photons
- ➢ 30 cm LH_2 and LHe_4 targets (~3.6% r.l.)
- ➢ Forward Calorimeter (FCAL) for $\eta\to\gamma\gamma$

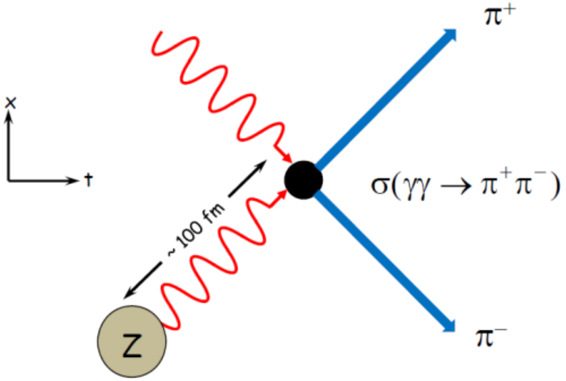
Nuclear Targets in PrimEX I Experimet

- 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

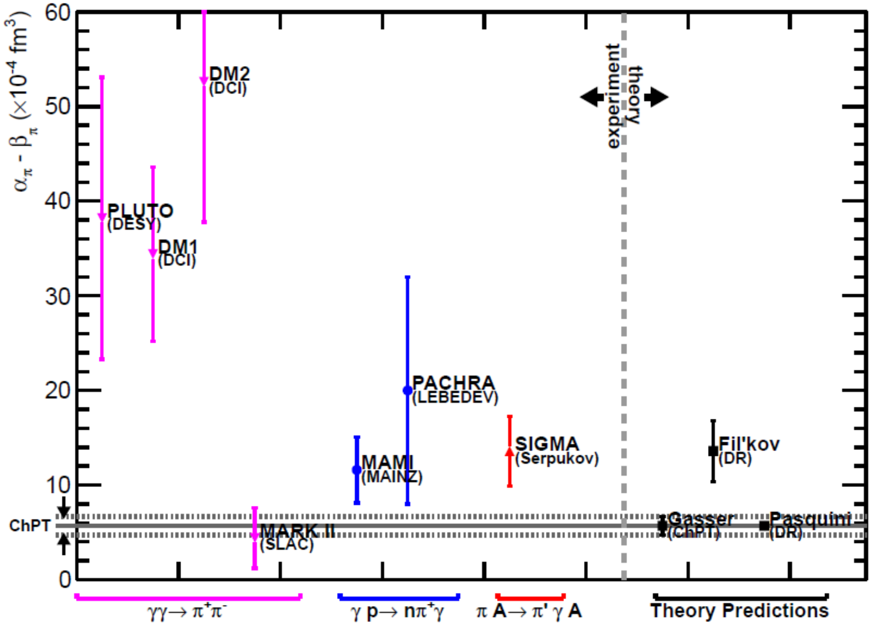




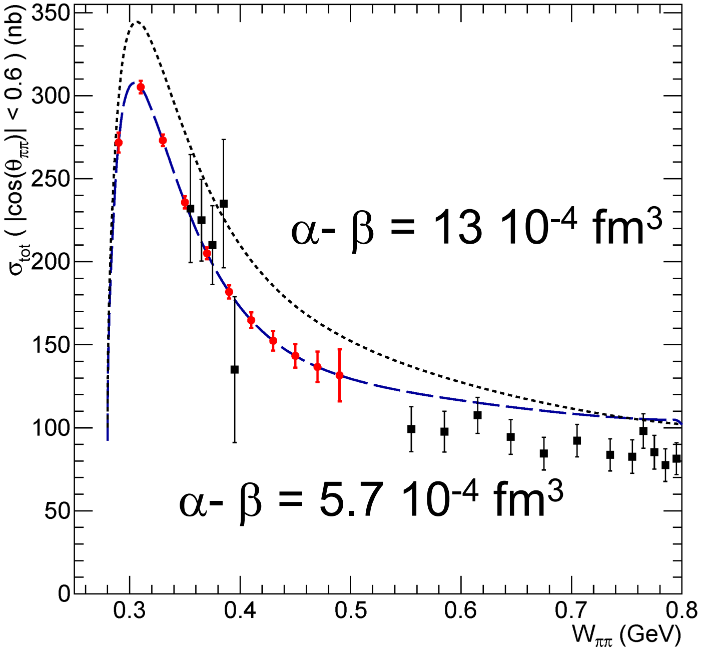
Charged Pion Polarizability



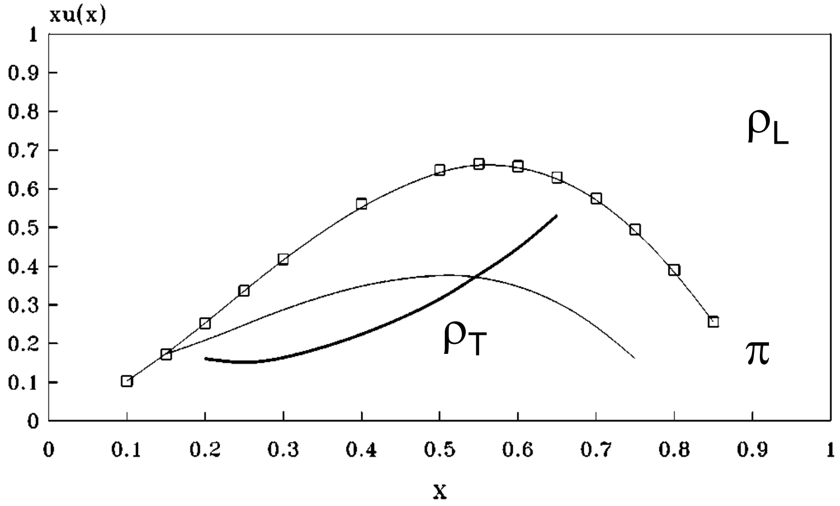
- Use Primakoff production $\gamma\, A \rightarrow \pi^+ \pi^- A$ to extract pion polarizability - *test χ_{PT} predictions*
- Photon energy of interest 5.5 – 6 GeV, polarization 76 %
- Major background from rho decays and $\mu^+\mu^-$
- Requires new muon detector



$\gamma + \gamma \rightarrow \pi^+ + \pi^-$

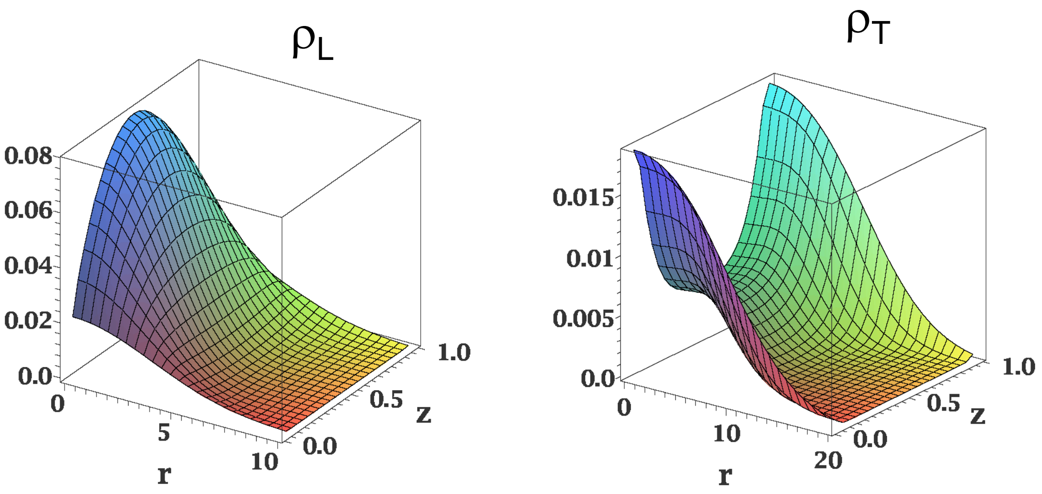


Quark Distributions in Polarized Mesons



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

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

Obtain ω - photon coupling constant

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

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

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

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

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

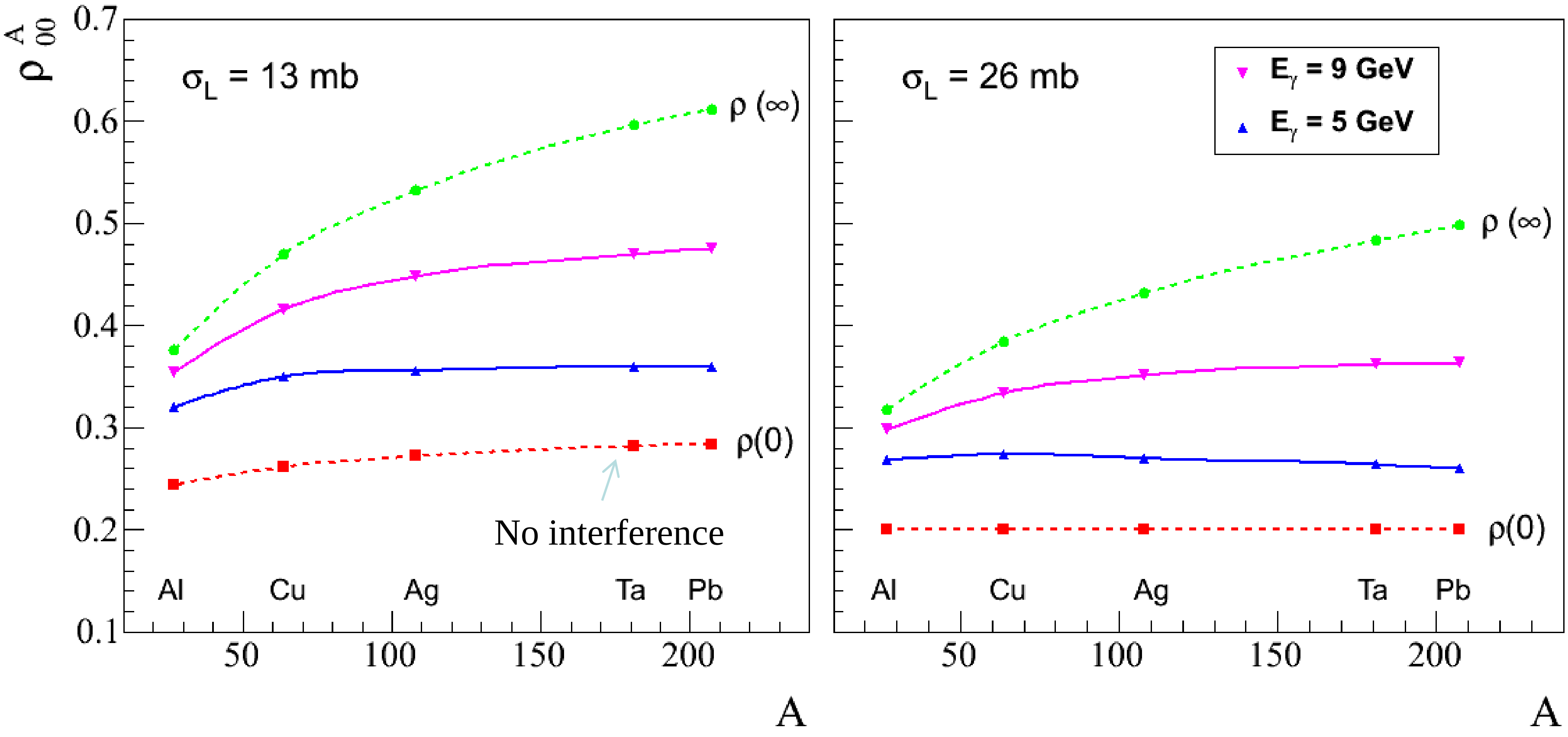
Spin density matrix elements

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

Extend the model by taking into account interference of production amplitudes

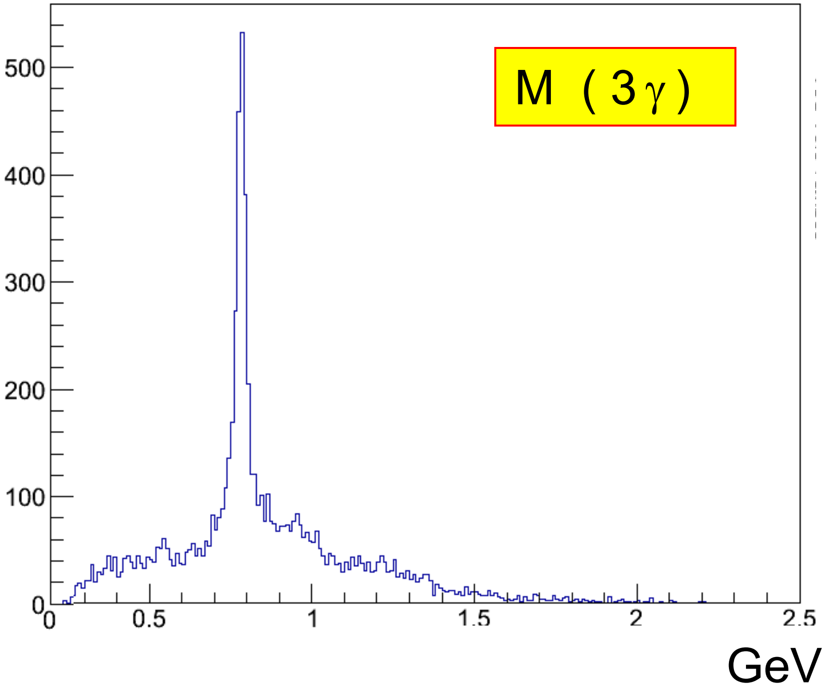
- required to describe electroproduction of vector mesons
- energy dependent transparency: $N(\sigma_T) \rightarrow W(\mathbf{q_L}, \sigma_T)$,
  where $q_L = m^2 / 2E$

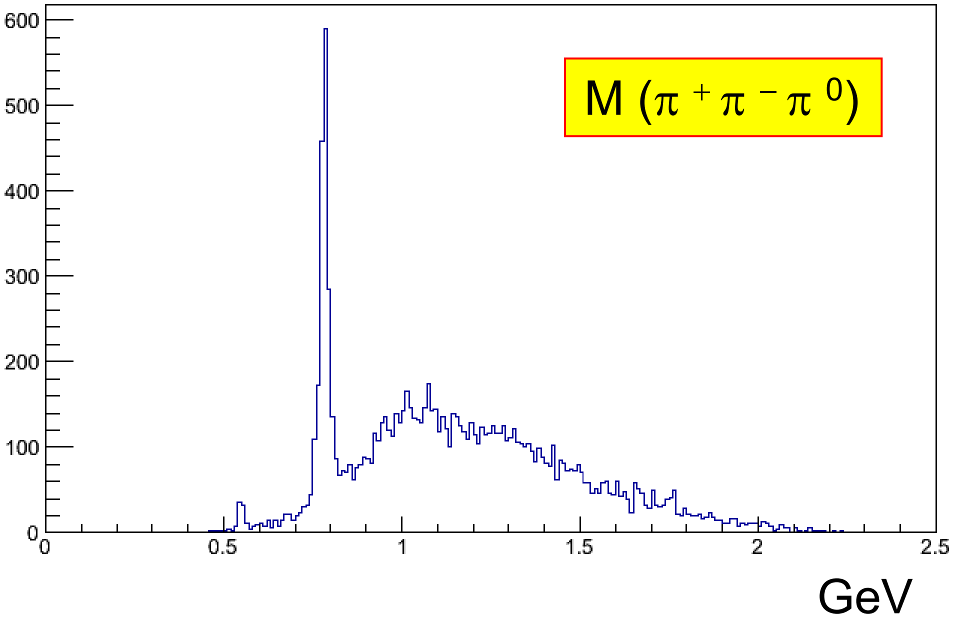
Spin Density Matrix Elements



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)

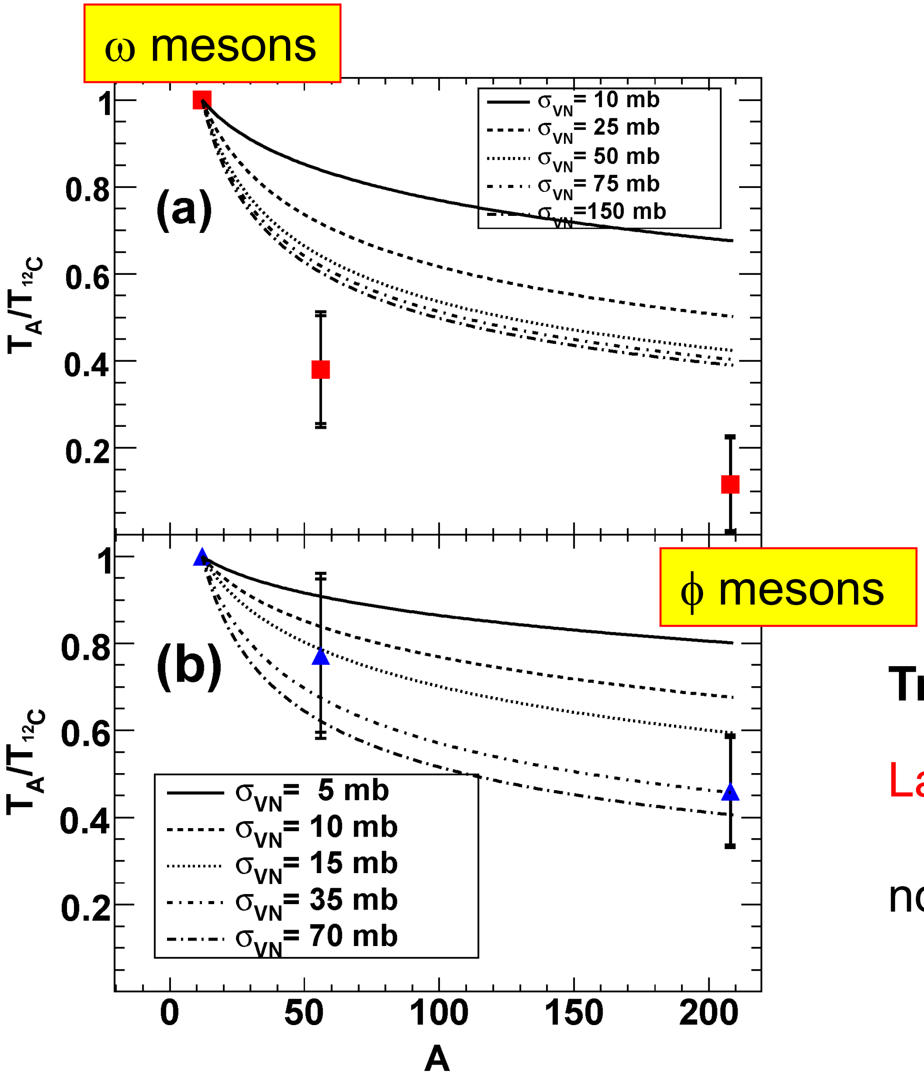
Experimental Results on In-medium Modifications

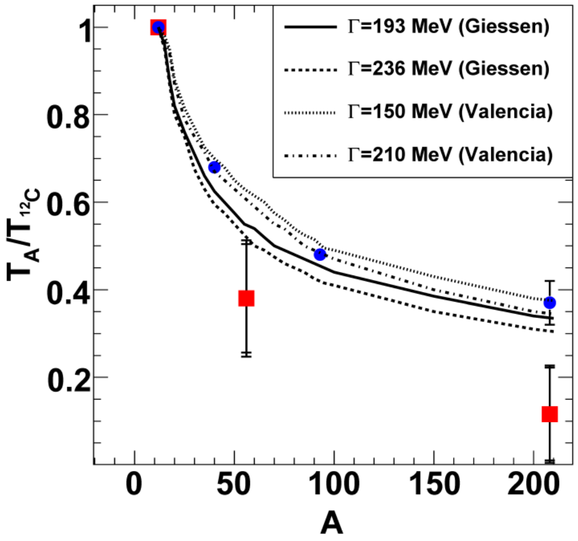
S.Leupold, V. Metag, U. Mosel
Int. J. Mod. Phys. E 19 (2010)

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





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