Primakoff Production of η'

Outline:

- Primakoff measurements at Jefferson Lab: completed and scheduled experiments
- Physics motivation and previous η' measurements
- η‘ decay modes, GlueX detector acceptance and target choice
- expected rates and beam time
- Estimated η’→γγ decay width errors
- Work in progress: summary

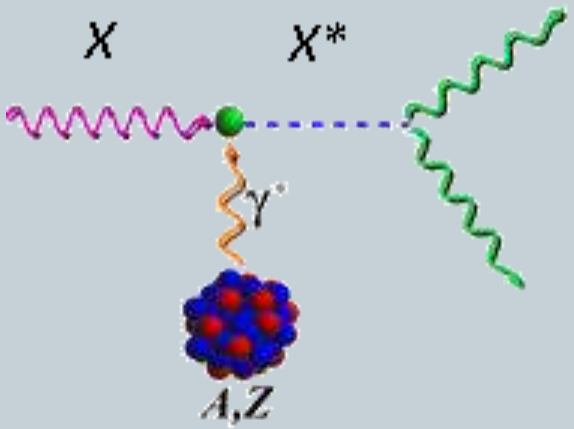
Primakoff measurement of radiative width

- Idea of Primakoff measurement is based on connection between production in Coulomb field and radiative decay:

$$X^* \rightarrow X+\gamma \quad \Longleftrightarrow \quad X+\gamma \rightarrow X^*$$

(H. Primakoff 1950)

$$\frac{d\sigma_P}{d\Omega} = \Gamma_{\gamma\gamma}\frac{8\alpha Z^2}{m^3}\frac{\beta^3 E^4}{Q^4}|F_{e.m.}(Q)|^2 sin^2\theta$$



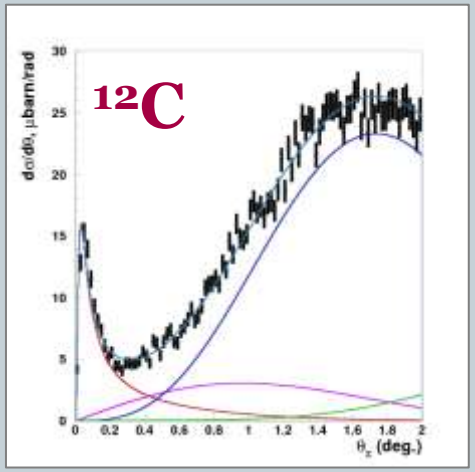
- Total cross section needs to be measured precisely
- Coulomb production part needs to be extracted (models are involved):

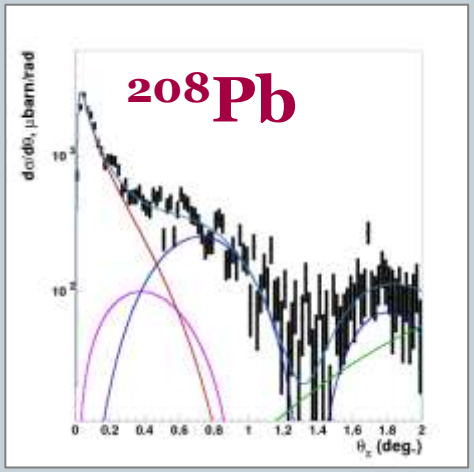
$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_P}{d\Omega} + \frac{d\sigma_C}{d\Omega} + \frac{d\sigma_I}{d\Omega} + 2\cdot\sqrt{\frac{d\sigma_P}{d\Omega}\cdot\frac{d\sigma_C}{d\Omega}}\cos(\phi_1+\phi_2)$$

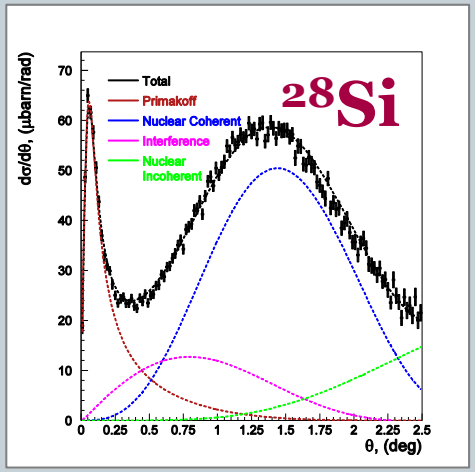
Completed Primakoff experiments at JLab

- PrimEx-I run (π^0Primakoff production) opened Primakoff measurements era at JLab in 2004
- Achieved 2.8% precision (result published in 2010)
- Photon beam flux measurement at 1% level
- Carbon-12 and Lead-208 targets were used in PrimEx-1, Carbon-12 and Silicon-28 in PrimEx-II

π^0 photoproduction cross sections at forward angles on different nuclei (PrimEx experiment, $E\gamma \sim 5$GeV)







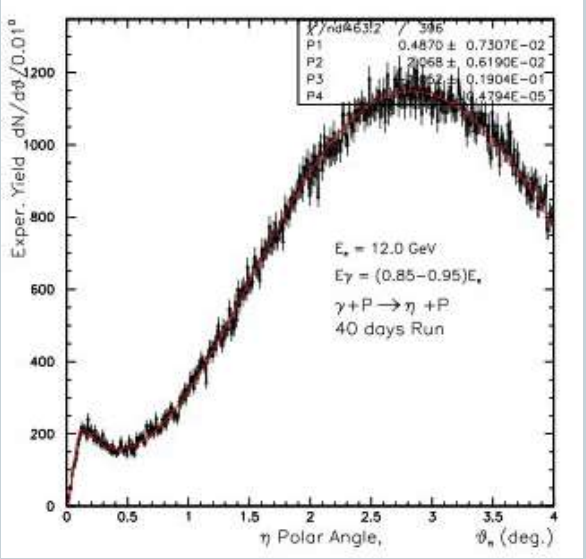
Scheduled Primakoff Experiments at JLab

- "Precision Measurement of the eta Radiative Decay Width via the Primakoff Effect" (E12-06-102) is scheduled to run in Hall-D at JLab in 2018
- Proposed precision 3.2%, photon beam flux measurement precision 1%
- Liquid H and He4 targets will be used
- $\eta \rightarrow \gamma\gamma$ FCAL acceptance ~70%

Estimated total error contributions for Primakoff eta

photon flux	1.0%
beam energy	0.2%
acceptance, misalignment	0.5%
model dependence	0.3%
target thickness	0.5%
branching ratio	0.66% (PDG)
events selection	1.7%
detection efficiency	0.5%
background subtraction	2.0%
statistical	1.0%
Total	3.2%

Expected η yield for 40 days running with LH2 target



η': physics motivation

- $\eta \to \gamma\gamma$ and $\eta' \to \gamma\gamma$ decays are associated with chiral anomaly and must be analyzed together, calculations involve ChPT
- Relations involve mixing angle and decay constants
- Triangle anomaly calculations (see for example *Adler, Phys. Rev 177 2426 (1969)*):

$$\Gamma^{\eta}_{\gamma\gamma} = \frac{\alpha^2}{64\pi^3}\frac{M_\eta^3}{3}\left[\frac{1}{f_8}\cos\theta_P - \frac{\sqrt{8}}{f_1}\sin\theta_p\right]^2,$$

$$\Gamma^{\eta'}_{\gamma\gamma} = \frac{\alpha^2}{64\pi^3}\frac{M_{\eta'}^3}{3}\left[\frac{1}{f_8}\sin\theta_P + \frac{\sqrt{8}}{f_1}\cos\theta_P\right]^2,$$

where f_1 and f_8 are the singlet and octet decay constants of the SU(3) basis states η_1 and η_8, analagous to the pion decay constant $f_\pi = 93$ MeV.

$$\frac{\Gamma_{\pi^0\to\gamma\gamma}}{m_{\pi^0}^3} : \frac{\Gamma_{\eta\to\gamma\gamma}}{m_\eta^3} : \frac{\Gamma_{\eta'\to\gamma\gamma}}{m_{\eta'}^3} = 3 : (\cos\Theta - \sin\Theta\, 2\sqrt{2})^2 : (\sin\Theta + \cos\theta\, 2\sqrt{2})^2$$

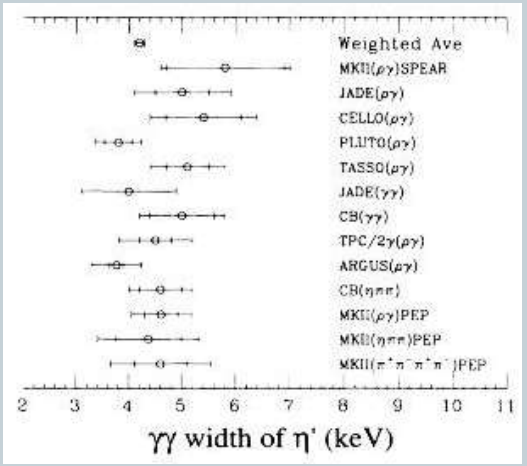
Previous measurements

- Collider experiments:

η' width measured using reaction $e^+e^- \rightarrow e^+e^-\eta'$

from F. Butler review (*PRD Vol 42, 5 (1990)*) :

Experiment	$\Gamma_{\eta'\rightarrow\gamma\gamma}$ (keV)	Mode
Mark II (SPEAR)	5.8±1.1±1.2	$\rho\gamma$
JADE	5.0±0.5±0.9	$\rho\gamma$
CELLO	5.4±1.0±0.7	$\rho\gamma$
PLUTO	3.80±0.26±0.43	$\rho\gamma$
TASSO	5.1±0.4±0.7	$\rho\gamma$
JADE	4.0±0.9	$\gamma\gamma$
Crystal Ball	5.0±0.6±0.8	$\gamma\gamma$
TPC/2γ	4.5±0.3±0.7	$\rho\gamma$
ARGUS	3.76±0.13±0.47	$\rho\gamma$
Crystal Ball	4.6±0.4±0.6	$\eta\pi^0\pi^0$
Mark II (PEP)	4.61±0.32±0.57	$\rho\gamma$
Mark II (PEP)	4.37±0.62+0.96−0.94	$\eta\pi^+\pi^-$
Mark II (PEP)	4.60±0.49+0.65−0.95	$\pi^+\pi^-\pi^+\pi^-$



Disadvantages:

relatively high luminosity error

most of measurement include $\eta' \rightarrow \gamma\gamma$ and $\eta' \rightarrow \pi^+\pi^-\gamma$ BR errors

production angle measurement is problematic

Advantages:

no strong production mechanism to be separated

Previous measurements

- No Primakoff measurement is published so far ?
- This can be done with GlueX detector in Hall-D with better precision and free of systematics of such measurements
- η' has a lot of decay channels to offer, which of them are good for GlueX detector ?

η' decay mode candidates: Branching ratios and GlueX detector acceptance

Decay mode(s)	Nγ	BR	Eγ / Eπ⁰ cut, [GeV]	efficiency @1° (Fcal only)	BR × eff.	BR rel. error
$\eta' \to \gamma\gamma$	2	2.2%	0.5 / 1	57% (40%)	**1.25%**	3.7%
$\eta' \to \pi^+\pi^-\gamma$	1	29%	1.0 / -	50% (50%)	14.5%	2.0%
$\eta' \to \pi^0\pi^0\eta,\ \eta \to \gamma\gamma$	6	8.5%	0.2(0.5) / 1	7% (4.5%)	**0.6%**	3.7%
$\eta' \to \pi^0\pi^0\eta,\ \eta \to \pi^+\pi^-\pi^0$	6	4.9%	0.2 / 1	4.5% (3.5%)	0.2%	3.9%
$\eta' \to \pi^0\pi^0\eta,\ \eta \to \pi^0\pi^0\pi^0$	10	7.0%	0.2 / 1	0.45% (0.2%)	0.03%	3.8%
$\eta' \to \pi^+\pi^-\eta,\ \eta \to \gamma\gamma$	2	17%	0.5 / 1	32% (28%)	5.4%	1.7%
$\eta' \to \pi^+\pi^-\eta,\ \eta \to \pi^+\pi^-\pi^0$	2	9.9%	0.2 / 1	18% (18%)	1.8%	2.0%
$\eta' \to \pi^+\pi^-\eta,\ \eta \to \pi^0\pi^0\pi^0$	6	14%	0.2 / 1	4% (3.5%)	0.56%	1.8%

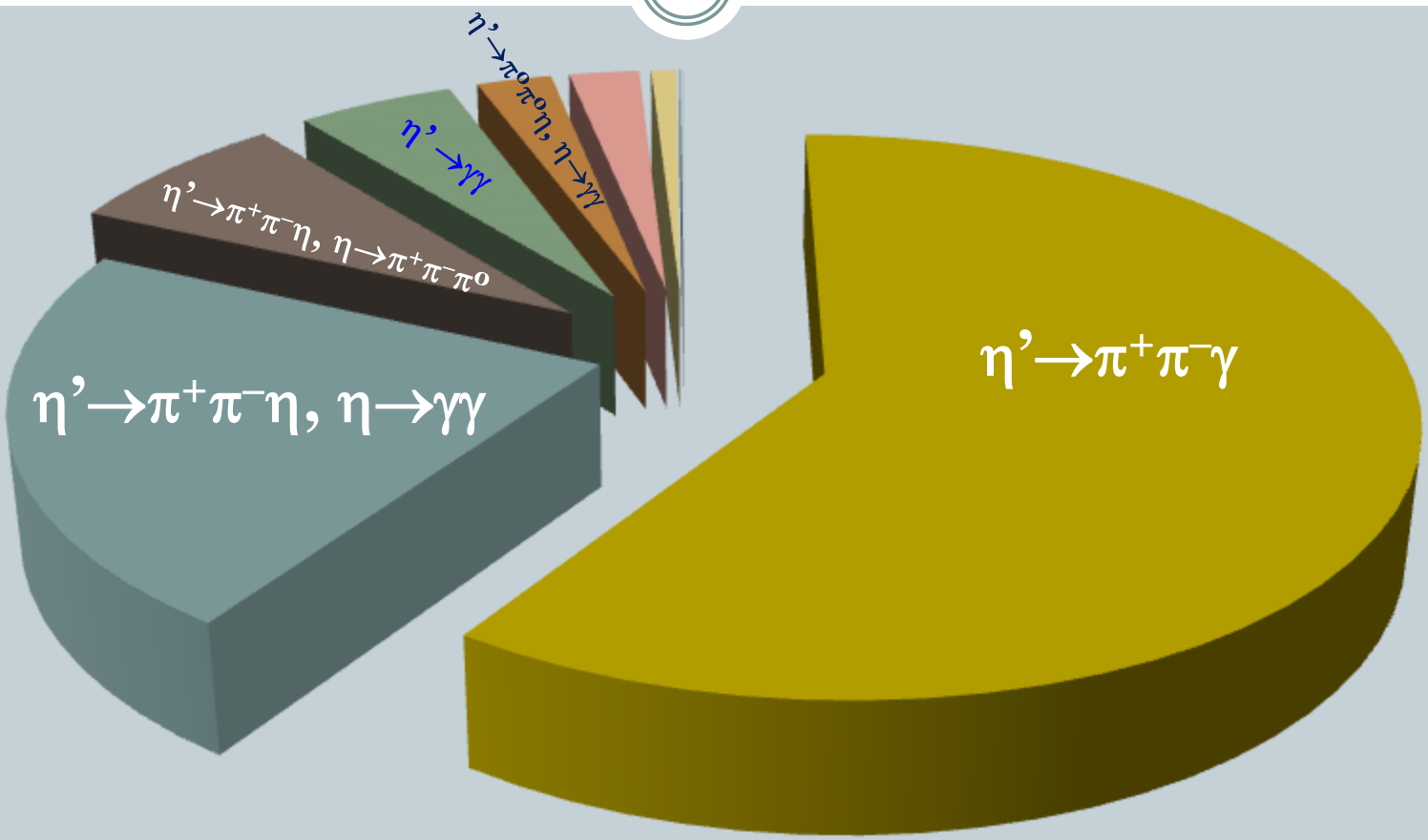
* Given are values for 9 GeV γ-beam energy

η' decay mode candidates: GlueX detector resolutions

Decay mode(s)	BR × eff.	Mass resol., [MeV] / with constr.	Fcal only Mass resol., [MeV] / with constr.	Angular resolution, [°] / with constr.	Total energy resolution, [GeV]
$\eta' \to \gamma\gamma$	**1.25%**	35 / 18	30 / 15	0.1 / 0.06	0.35
$\eta' \to \pi^+\pi^-\gamma$	14.5%	45 / 42	45 / 42	0.4 / 0.4	0.2
$\eta' \to \pi^0\pi^0\eta$, $\eta \to \gamma\gamma$	**0.6%**	35 / 20	30 / 15	0.12 / 0.07	0.4
$\eta' \to \pi^0\pi^0\eta$, $\eta \to \pi^+\pi^-\pi^0$	0.2%	32 / 22	30 / 20	0.2 / 0.2	0.35
$\eta' \to \pi^0\pi^0\eta$, $\eta \to \pi^0\pi^0\pi^0$	0.03%	35 / 20	30 / 15	0.14 / 0.08	0.45
$\eta' \to \pi^+\pi^-\eta$, $\eta \to \gamma\gamma$	5.4%	32 / 22	30 / 20	0.24 / 0.22	0.3
$\eta' \to \pi^+\pi^-\eta$, $\eta \to \pi^+\pi^-\pi^0$	1.8%	30 / 25	30 / 25	0.32 / 0.3	0.22
$\eta' \to \pi^+\pi^-\eta$, $\eta \to \pi^0\pi^0\pi^0$	0.56%	32 / 22	30 / 20	0.22 / 0.2	0.35

* Given are values for 9 GeV γ-beam energy

Reconstructed modes ratio

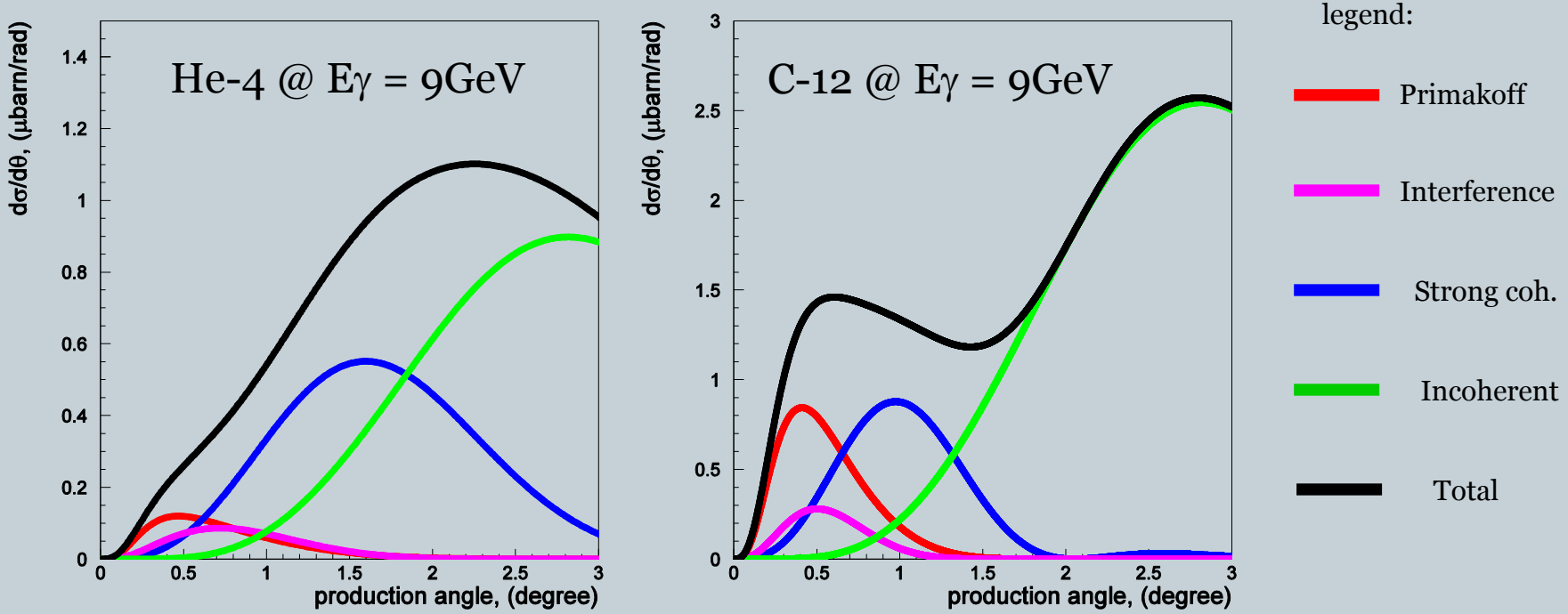


Main decay mode candidates

- $\eta' \to \pi^+\pi^-\eta$, $\eta \to \gamma\gamma$
  BR × eff. = 5.4%, BR uncertainty = 1.7%
- $\eta' \to \pi^+\pi^-\eta$, $\eta \to \pi^+\pi^-\pi^0$
  BR × eff. = 1.8%, BR uncertainty = 2.0%
- These 2 charged modes allow to reconstruct about $\frac{1}{14}$ η's, have angular resolution 0.25…0.3°
- **$\eta' \to \gamma\gamma$**
  BR ×eff. = 1.25%, BR uncertainty = 3.7%
- **$\eta' \to \pi^0\pi^0\eta$, $\eta \to \gamma\gamma$**
  BR ×eff. = 0.6%, BR uncertainty = 3.7%
- These 2 neutral only modes allow to reconstruct about $\frac{1}{50}$ η's, have angular resolution 0.1° or better (with kinematic fit), can run w/o solenoid field, decent energy deposition in FCal

Target choice: Helium-4 and Carbon-12

Differential cross sections $\frac{d\sigma}{d\vartheta}$



Production terms calculations have been made with the same framework as for PrimEx experiment. Based on S. Gevorgyan calculations

Target choice: other targets

Primakoff production of π^0, η and η' in the Coulomb field of a nucleus

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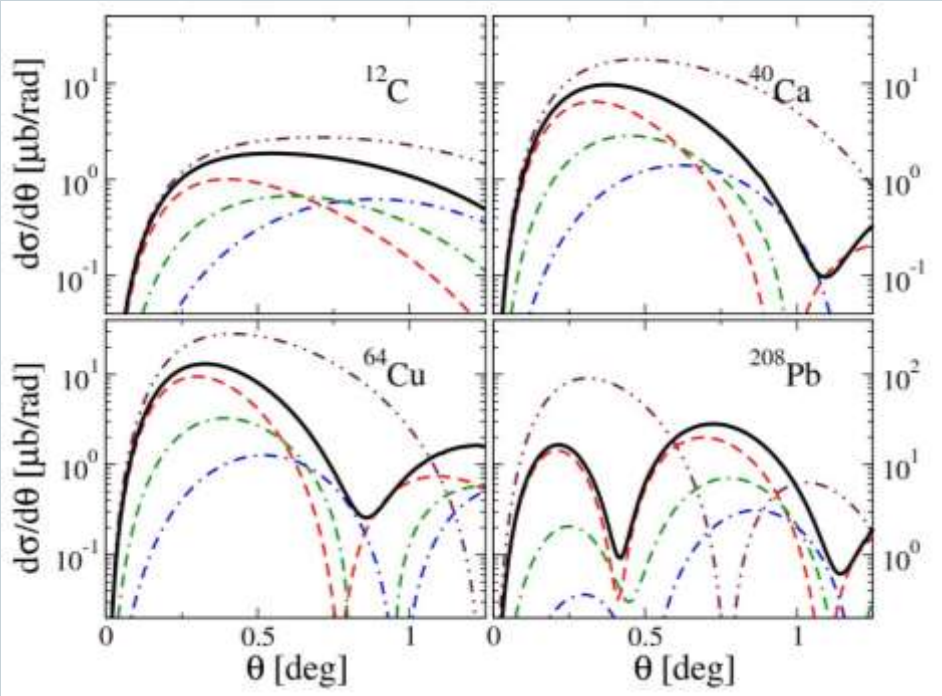
Institut für Theoretische Physik, Universität Giessen, D-35392 Giessen, Germany
(Dated: December 23, 2011)



$E\gamma = 9GeV$

Beam time and luminosity

- η' integrated Primakoff cross section ~10nb, total coherent cross section ~30nb for Carbon
- For γ-beam energy range 8…11GeV, intensity 2×10^7 photons/sec, 10% rad. length carbon target:

  3.3k Primakoff η' /day and 10k total coherent η' /day for Carbon
- Heavy target like Pb will give increased Primakoff number of events but suppressed coherent yield
- 10 days running on 10%r.l. Carbon will give 33k Primakoff η', that means 660 events in neutral modes (~5% stat. error) or 2.3k events in 2 main charged modes, excluding $\pi^+\pi^-\gamma$ mode (~3% stat. error) and 4.5k $\pi^+\pi^-\gamma$ (~2% stat. error)
- Combining statistics from 3 different targets (10 days each) will allow to achieve 1.5%-3.0% stat. error in different decay channels

Error contributions

Source of error	Contribution [%]
Photon beam flux	1
Branching Ratios	1.7 / 3.7 (neutral modes)
Background separation	work in progress
Model dependence	work in progress
All others (estimated using Primakoff η)	2
Statistical	2 / 3 (neutral modes)
Total	? Expected within 6…8 ?

Summary

- η' radiative width measurement would complete series of Primakoff experiments at Jefferson lab
- It will be first publishable result for η' Primakoff production cross section and will verify group of collider results for η' radiative decay width in terms of systematics
- η' neutral decay modes have ~4 times less yield, ~3 times better angular resolution, don't require magnetic field and have high energy deposition in FCAL
- Intermediate atomic number targets (carbon, silicon) are more preferable: have significant Primakoff part, in the same time light targets like helium have well separated nuclear coherent peak (less model dependent). Measurement on one high-Z target (lead etc.) can be also included in the run
- Background study for different modes and model dependence of Primakoff part extraction are in progress. They will allow to estimate the total error of such a measurement and come up with a proposal to PAC.
- Expected precision of this measurement has 6%-8% level for ~40 days of running