The π^0 Lifetime: Experimental Probe of the QCD Chiral Anomaly

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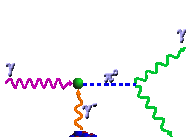
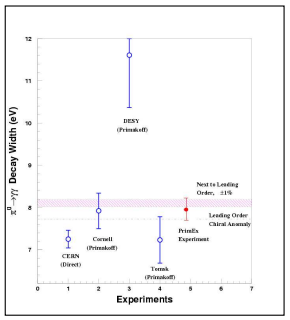
for the PrimEx Collaboration



Motivation

- The $\pi^0 \to \gamma\gamma$ decay rate is a fundamental prediction of QCD which gives insight into one of its most profound symmetry issues--namely, the Axial or Chiral Anomaly. It is this anomalous symmetry-breaking mechanism by which the $\pi^0 \to \gamma\gamma$ decay channel primarily proceeds, and thus a measure of its rate or partial width, $\Gamma_{\gamma\gamma}$, represents a direct probe of the anomaly plus Chiral corrections.



- The transition amplitude is exact in the Chiral Limit and gives the leading order prediction:

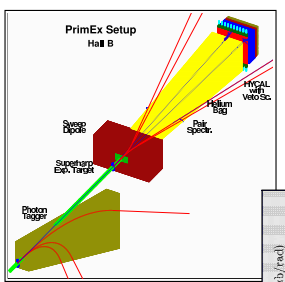
$$\Gamma_{\gamma\gamma}(\text{L.O.}) = \frac{\alpha^2 m_\pi^3}{64\pi^3 F_\pi^2} = 7.725 \text{ +/- } 0.56 \text{ eV}$$

- However, for $m_q \not\to 0$ there are corrections:
  --Due to isospin sym-breaking π^0, η and η' mixing induced
- NLO prediction* for decay width is 8.10 eV +/- 1%
  --Calc using χ_{PT} and $1/N_c$ expansion

* J.L.Goity et al, Phys. Rev. D66, 076014 (2002); B.Moussallam, Phys. Rev. D51, 4939 (1995)

Experiment and Theory Overview

- The PrimEx Collaboration at Jefferson Lab has extracted $\Gamma_{\gamma\gamma}$ from precision measurements of π^0 photo-production cross sections using their Primakoff components.
- Measurements made using 5% X_0 nuclear targets of ^{12}C and ^{208}Pb with incident photons between 4.9 and 5.5 GeV tagged by the hall B tagger facility.



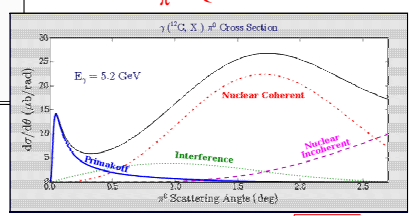
- π^0 decay photons detected by PrimEx high resolution hybrid calorimeter (HyCal).

- The Primakoff Effect:

--Coulomb field scattering
--Very forward π^0 production
--Equiv. production and decay

Primakoff component:

$$\frac{d\sigma_P}{d\Omega} = \Gamma_{\gamma\gamma}\frac{8\alpha Z^2}{m_\pi^3}\frac{\beta^3 E^4}{Q^4}\left|\tilde{F}_{em}(Q)\right|^2 \sin^2\theta_\pi$$



$$\frac{d\sigma_\pi}{d\Omega} = \frac{d\sigma_P}{d\Omega} + \frac{d\sigma_{nc}}{d\Omega} + \frac{d\sigma_{ni}}{d\Omega} + 2\sqrt{\frac{d\sigma_P}{d\Omega}\frac{d\sigma_{nc}}{d\Omega}}\cos(\phi)$$

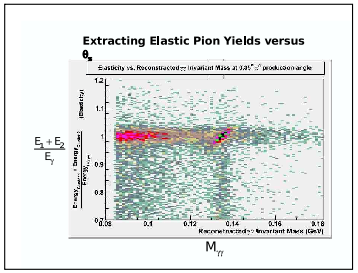
Total | Primakoff | Nuclear Coherent | Nuclear Incoherent | Interference

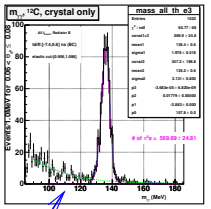
Analysis

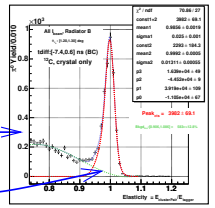
Experimental π^0 Yield Extraction

- Event Cuts:

		Resolution
Timing	(Tagger – HyCal) coincidence	~ +/- 1ns
Invariant Mass ($m_{\gamma\gamma}$)	$\sqrt{2(P^\mu_{\gamma 1} \bullet P_{\gamma 2\mu})}$	~ 2 – 3MeV
Elasticity	$E_{\pi^0}/E^{tagged}_{\gamma}$	~ 1 – 2%

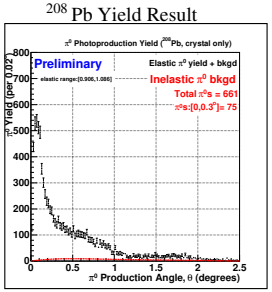




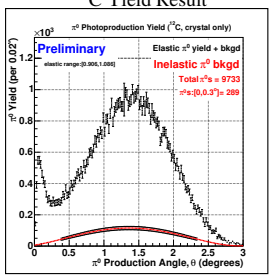


- For each θ_{π^0} bin, apply elastic cut and form $m_{\gamma\gamma}$ distributions; perform fit, extract peak counts = uncorrected yield.
- Correct for inelastic bkgd by evaluating π^0 elasticity distribution explicity for each θ_{π^0}; evaluate inelastic bkgd under elastic peak using fit and subtract from uncorrected yield.

^{208}Pb Yield Result



^{12}C Yield Result



$\Gamma_{\pi^0 \to \gamma\gamma}$ Determination

- Convert Yield to Cross Section: Apply luminosity and experimental acceptances.

$$\frac{d\sigma_{exp}}{d\theta_{\pi^0}} = \frac{N_{\pi^0}^{yield}(\theta_{\pi^0})}{N_\gamma * N_t * \varepsilon_{\pi^0}(\theta_{\pi^0}) * \Delta\theta_{\pi^0}}$$

	Uncertainty
$-N_\gamma$ = # of γ's on target	~ 1.0 %
$-N_t$ = target atoms/cm	~ 0.1 %
$-\varepsilon_{\pi^0}$ = efficiency & accept.	~ 0.6 %

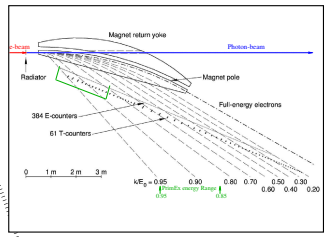
- Fit experimental data with (4 parameter) parameterization:

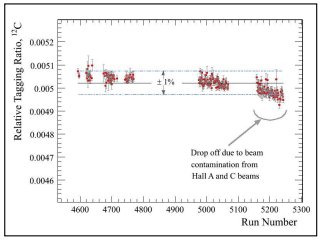
$$\frac{d\sigma_{exp}}{d\theta_{\pi^0}} = b_p \frac{d\sigma_P^{sh}}{d\theta_{\pi^0}} + b_{nc}\frac{d\sigma_{nc}}{d\theta_{\pi^0}} + b_{ni}\frac{d\sigma_{ni}}{d\theta_{\pi^0}} + \cos(\phi)\, 2\sqrt{b_p \frac{d\sigma_P^{sh}}{d\theta_{\pi^0}} b_{nc}\frac{d\sigma_{nc}}{d\theta_{\pi^0}}}$$

--4 theory shapes smeared according to exp. resolutions

--and the parameter $b_p = \Gamma_{\gamma\gamma}$

Photon Flux and Calibration Reactions

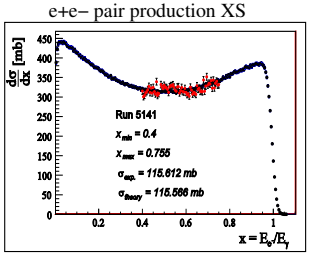




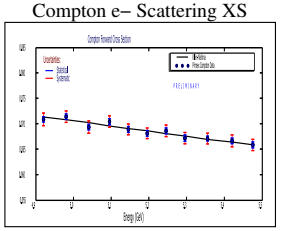
- Tagger has 0.1% energy res. and capable of 50MHz rates
- N_γ calibrated periodically using Total Absorption Counter
- Any drifts in tagging ratio monitored online with e+e- pair spectrometer

Calibration Reaction Preliminary Results

e+e- pair production XS



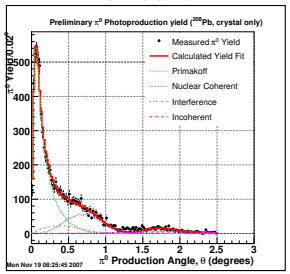
Compton e- Scattering XS



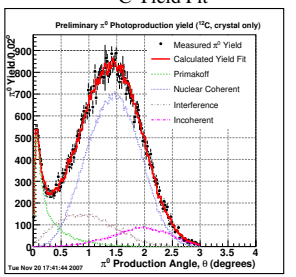
- Calibration reaction results in agreement with theory at ~2% level

Preliminary Results

^{208}Pb Yield Fit



^{12}C Yield Fit



$$\Gamma_{\pi^0 \to \gamma\gamma} = 7.93\text{eV} \pm 1.8\%(\text{stat}) \pm 2.3\%(\text{syst})$$

- The mean lifetime is $(8.20 \pm 0.24) * 10^{-17}$ s
- Results from both targets in excellent agreement
- Three ~independent analysis groups achieved very consistent results

PrimEx conducted at Jefferson Lab Hall B, supported in part by NSF MRI PHY 0079840 grant. Send inquiries to mcnulty@jlab.org