Results from the PrimEx-II Experiment at JLab
(Preliminary)

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Outline

- Review of the $\pi^0 \to \gamma\gamma$ decay width (very short)
- Impact of the PrimEx-I experiment
- PrimEx-II experiment, the results (preliminary)
- Summary and outlook

$\pi^0 \to \gamma\gamma$ Decay Width

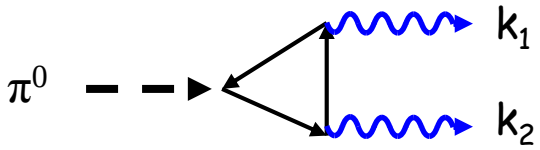
- π^0 is the lightest hadron: (next talk by K. Kampf)
  $m_\pi = 134.9766 \pm 0.0006$ MeV

$$p^0 = (u\bar{u} - d\bar{d})/\sqrt{2}$$

- π^0 is an unstable particle:
  $\pi^0 \to \gamma\gamma$ B.R.($\pi^0 \to \gamma\gamma$)=(98.798 $\pm$ 0.032)%
- The lifetime and decay width:
  τ = B.R.($\pi^0 \to \gamma\gamma$)/ $\Gamma(\pi^0 \to \gamma\gamma) \approx 8.5 \times 10^{-17}$ second

- $\pi^0 \to \gamma\gamma$ decay proceeds primarily via the chiral anomaly in QCD
  the chiral anomaly prediction is exact for massless quarks:

$$\Gamma(\pi^0 \to \gamma\gamma) = \frac{\alpha^2 N_c^2 m_\pi^3}{576\pi^3 F_\pi^2} = 7.725\ eV$$



- a parameter free prediction, precise for the massless quarks limit

$\pi^0 \to \gamma\gamma$ Decay Width (cont.)

- Corrections to the chiral anomaly prediction:

calculations in NLO ChPT:

- ✓ $\Gamma(\pi^0 \to \gamma\gamma) = 8.10\text{eV} \pm 1.0\%$
  (J. Goity, et al. Phys. Rev. D66:076014, 2002)
- ✓ $\Gamma(\pi^0 \to \gamma\gamma) = 8.06\text{eV} \pm 1.0\%$
  (B. Ananthanarayan et al. JHEP 05:052, 2002)

calculations in NNLO SU(2) ChPT:

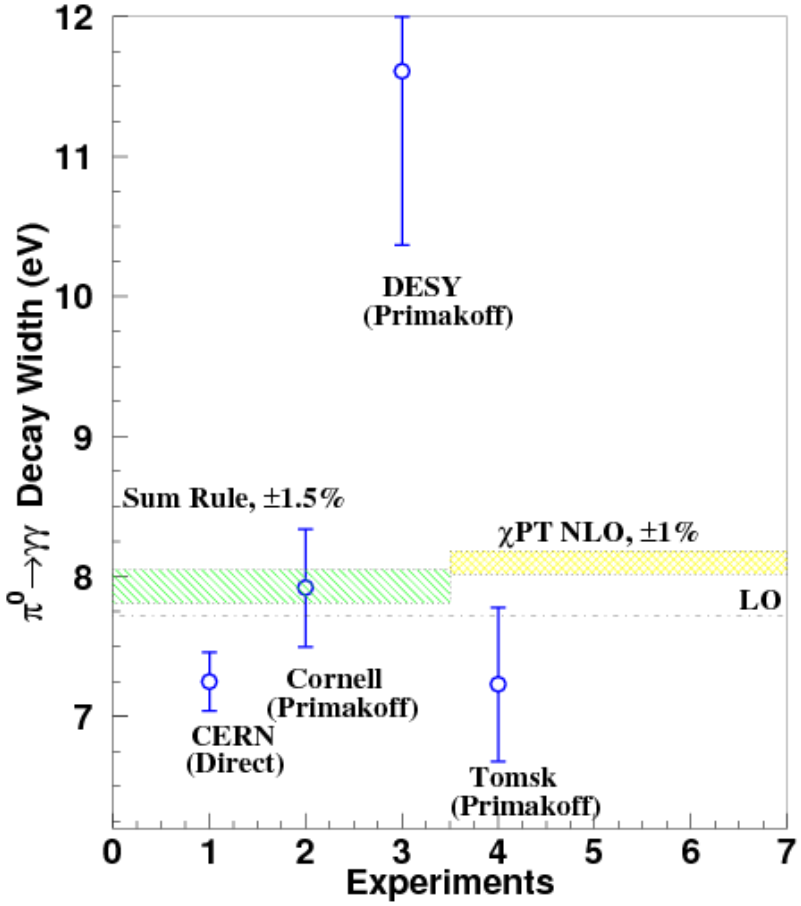
- ✓ $\Gamma(\pi^0 \to \gamma\gamma) = 8.09\text{eV} \pm 1.3\%$
  (K. Kampf et al. Phys. Rev. D79:076005, 2009)

Calculation in QCD sum rule:

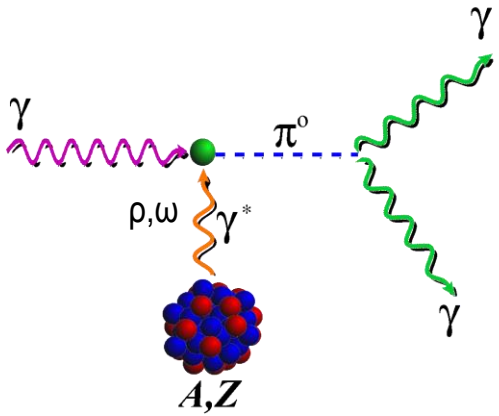
- ✓ $\Gamma(\pi^0 \to \gamma\gamma) = 7.93\text{eV} \pm 1.5\%$
  (B.L. Ioffe, et al. Phys. Lett. B647, p. 389, 2007)

- Precision measurements of $\Gamma(\pi^0 \to \gamma\gamma)$ at the percent level will provide a stringent test of QCD at low energies.

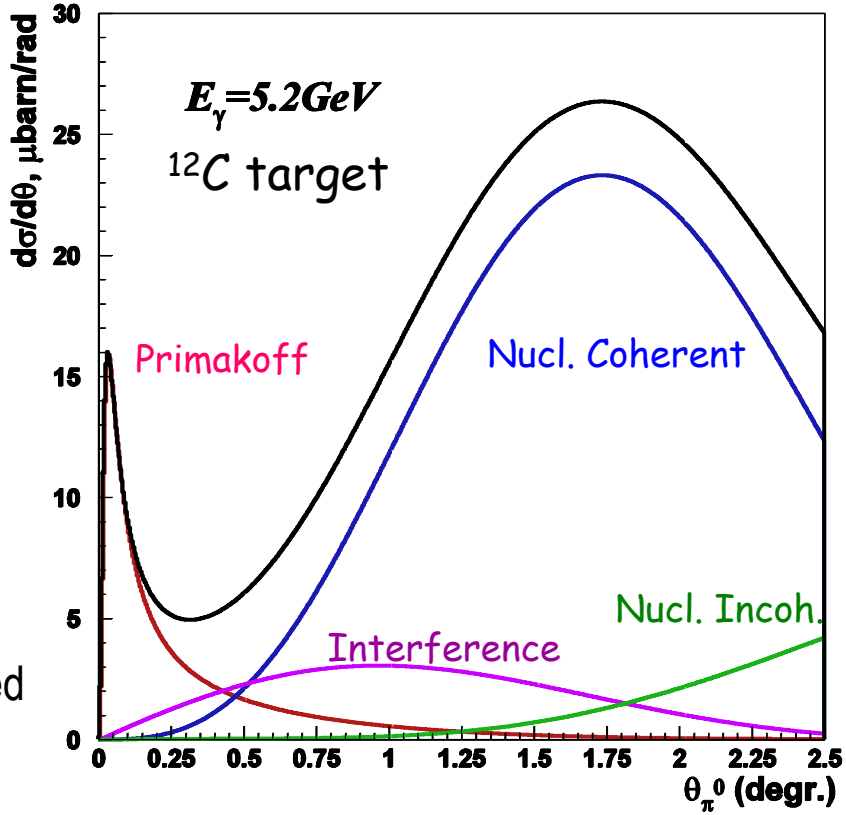
PDG before 2014



Primakoff Method



$$\frac{d^3\sigma_{\mathrm{Pr}}}{d\Omega} = \Gamma_{\gamma\gamma}\frac{8\alpha Z^2}{m_\pi^3}\frac{\beta^3 E^4}{Q^4}\left|F_{e.m.}(Q)\right|^2 \sin^2\theta_\pi$$



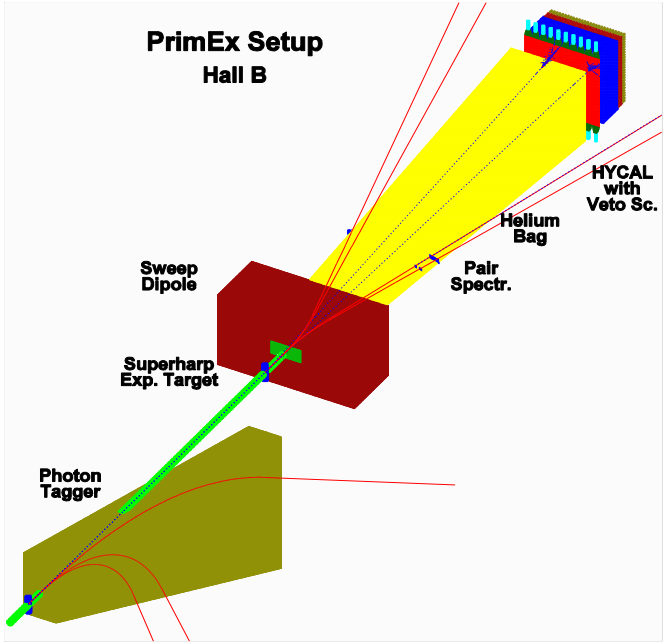
- Primakoff coherent cross section measurement required

$$\langle\theta_{\mathrm{Pr}}\rangle_{peak} \propto \frac{m^2}{2E^2} \qquad \theta_{NC} \propto \frac{2}{E \bullet A^{1/3}}$$

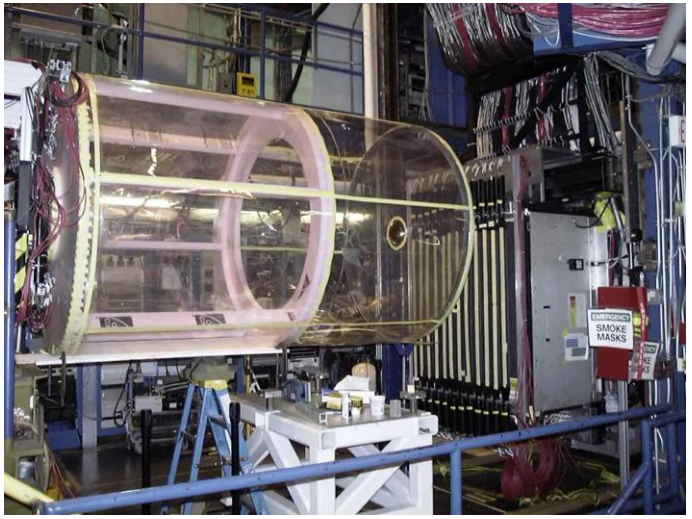
- Challenge of the method:
  - measure the cross section at forward angles with high precision
  - extract the Primakoff amplitude from diff. cross sections vs. angle

PrimEx Experiments in Hall B at JLab

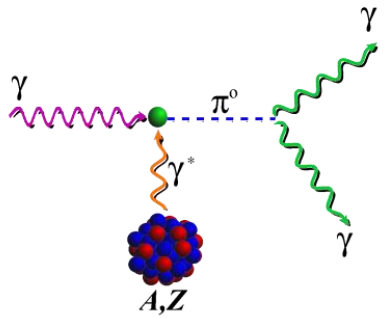
- Requirements of setup:
  - ➢ high angular resolution (~0.3 mrad)
    - ✓ high resolutions in calorimeter
    - ✓ small beam spot size (‹1mm)
  - ➢ Background:
    - ✓ tagging system needed
  - ➢ Particle ID (for γ vs. charged part.)
    - ✓ veto detectors needed



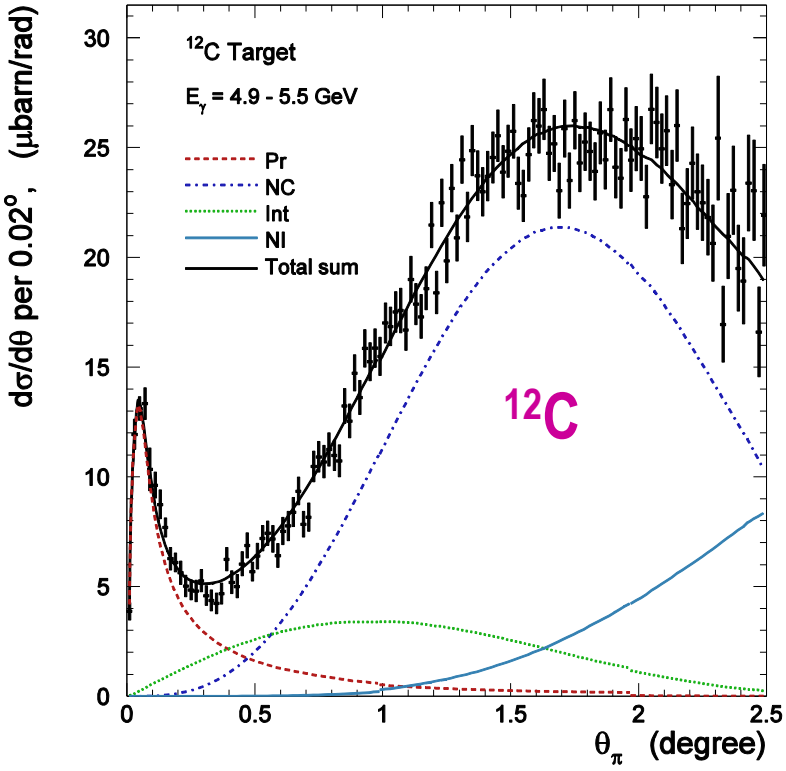
- Performed in Hall B at JLab:
  - ✓ high resolution, high intensity Hall B photon tagging facility
  - ✓ new high resolution hybrid multi-channel EM calorimeter (HyCal)
  - ✓ new pair spectrometer for photon flux at high intensities

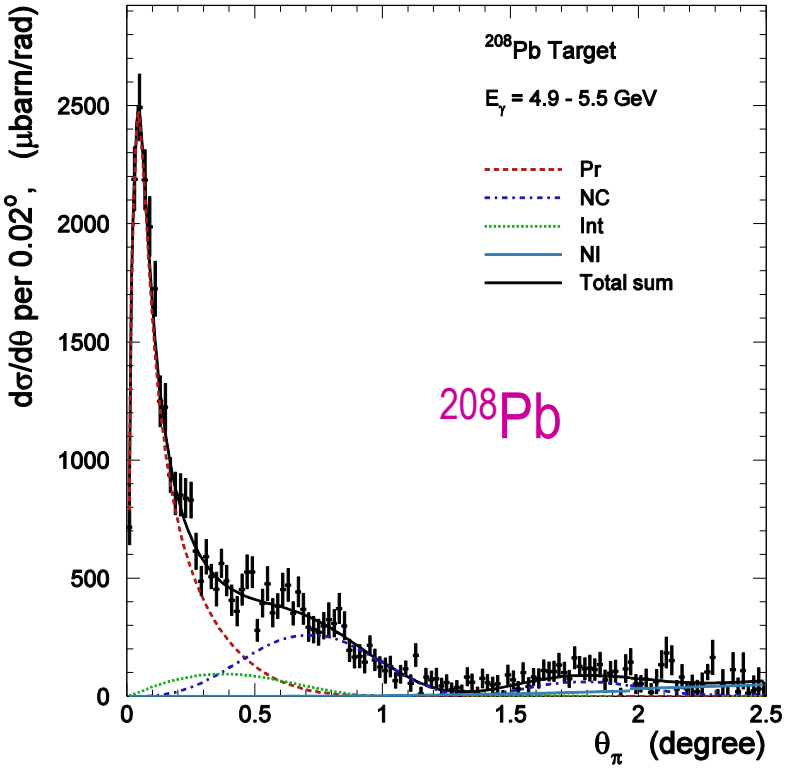


Results from the PrimEx-I Experiment



- Nuclear targets: ^{12}C and ^{208}Pb
- 6 GeV Hall B tagged beam
- experiment performed in 2004





PrimEx-I Result and the PDG status Before 2014

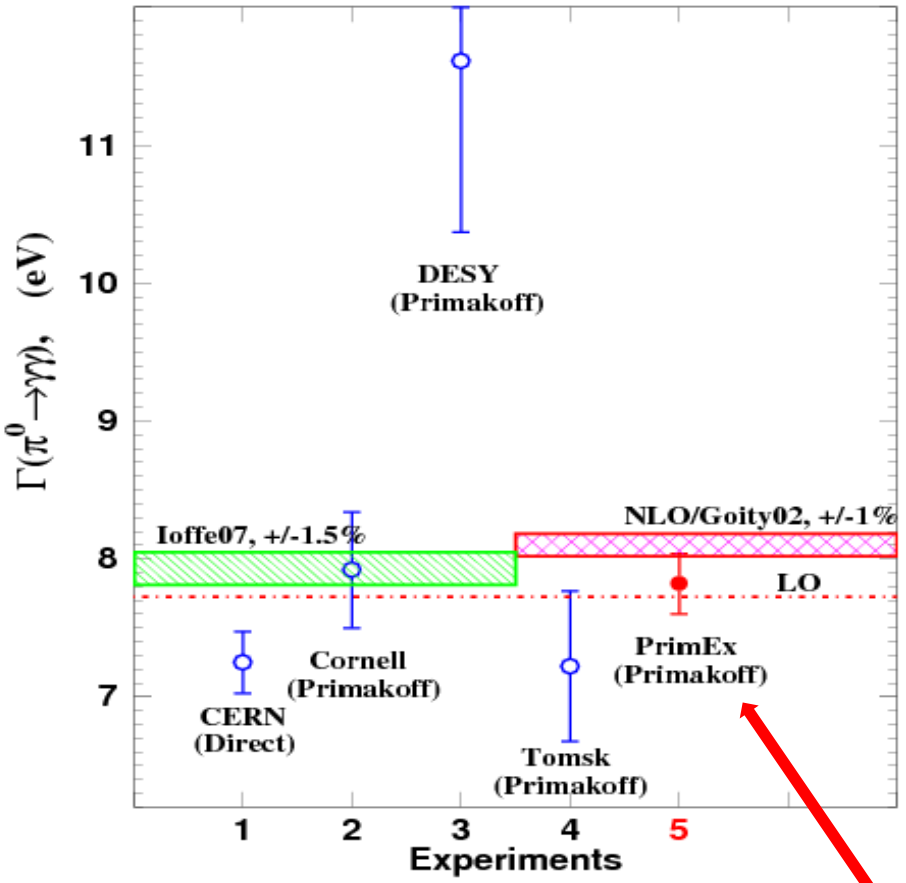
- ✓ **PrimEx-I achieved 2.8% precision (total):**

  $\Gamma(\pi^0 \to \gamma\gamma)$ = 7.82 eV ±1.8% (stat) ±2.1% (syst.)

  (I. Larin, et al. PRL 106, 162303, 2011)

- ➢ **Task for PrimEx-II:**
  to achieve 1.4% precision:

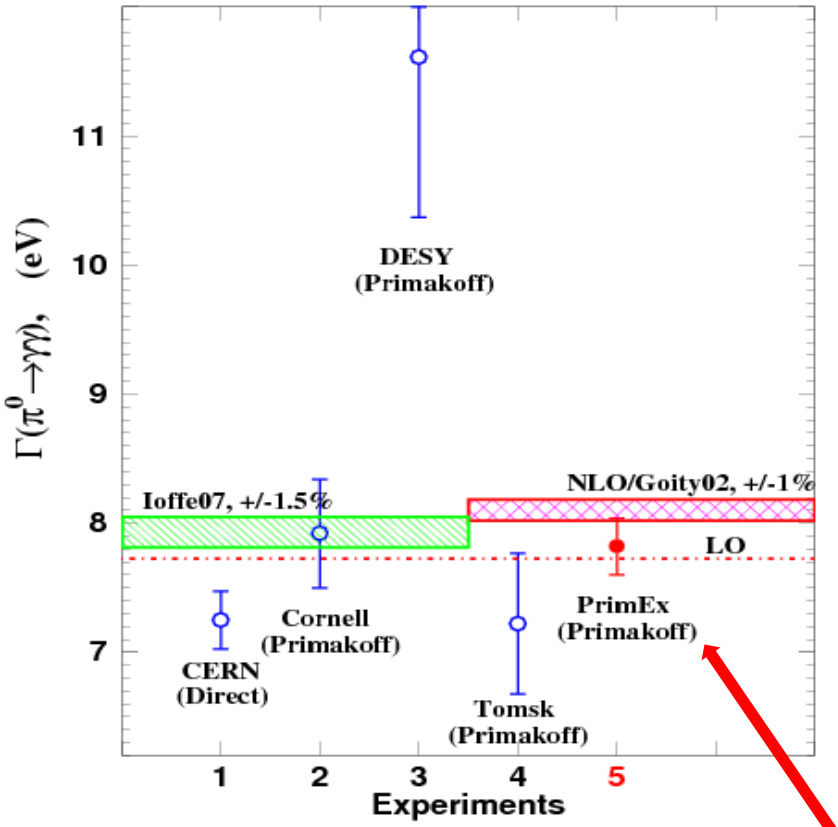
  Projected errors:
  ±0.5% (stat.) ±1.3% (syst.)



$\Gamma(\pi^0 \to \gamma\gamma)$ = 7.82±0.14(stat)±0.17(syst) eV
2.8% total uncertainty

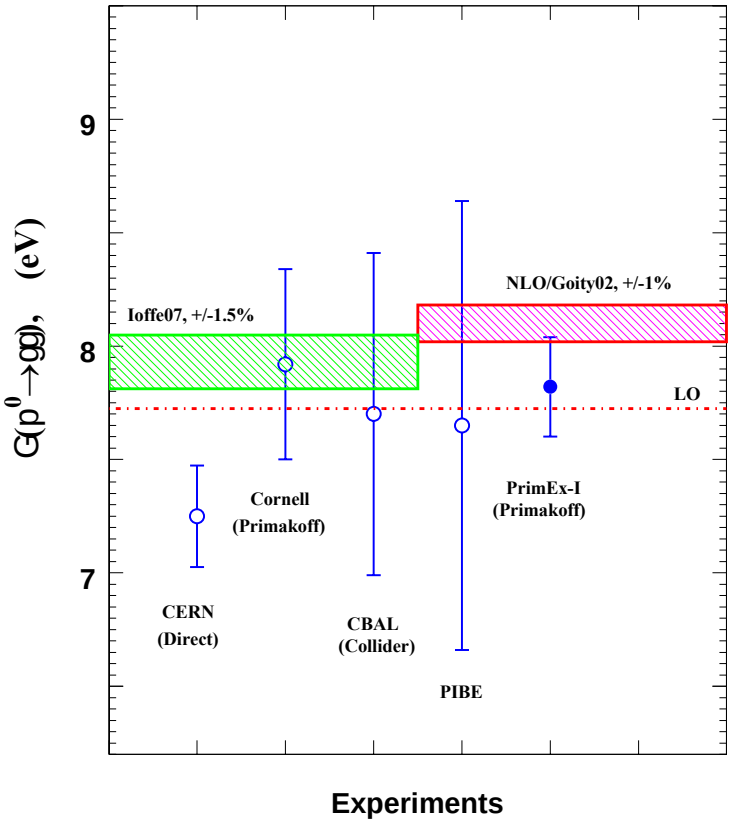
$\Gamma(\pi^0\to\gamma\gamma)$, PDG Status Before and After the PrimEx-I Experiment

PDG before 2014



$\Gamma(\pi^0\to\gamma\gamma)$ = 7.82±0.14(stat)±0.17(syst) eV
2.8% total uncertainty

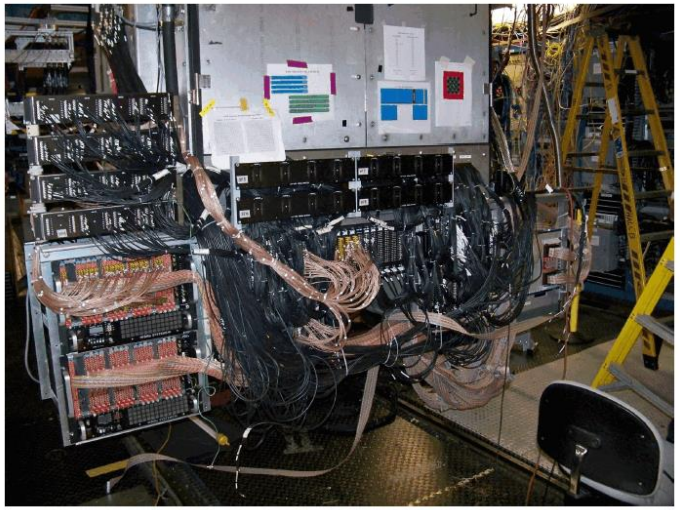
PDG after 2014



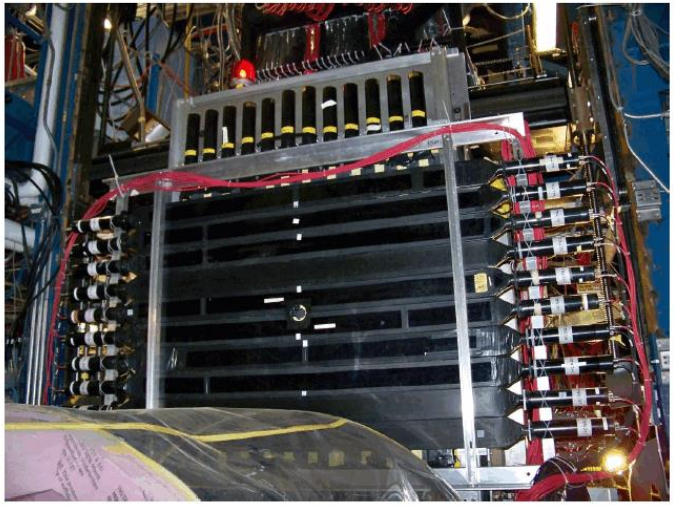
- ✓ PDG average on $\Gamma(\pi^0\to\gamma\gamma)$ improved by factor of 2

Improvements for the PrimEx-II Experiment (2010, Hall B at JLab)

- Statistics:
  - ✓ double the target thickness (10% R.L.)
  - ✓ Increase DAQ speed to 5 kHz (factor of 5 gain)
  - ✓ accept twice more tagged photon energy interval

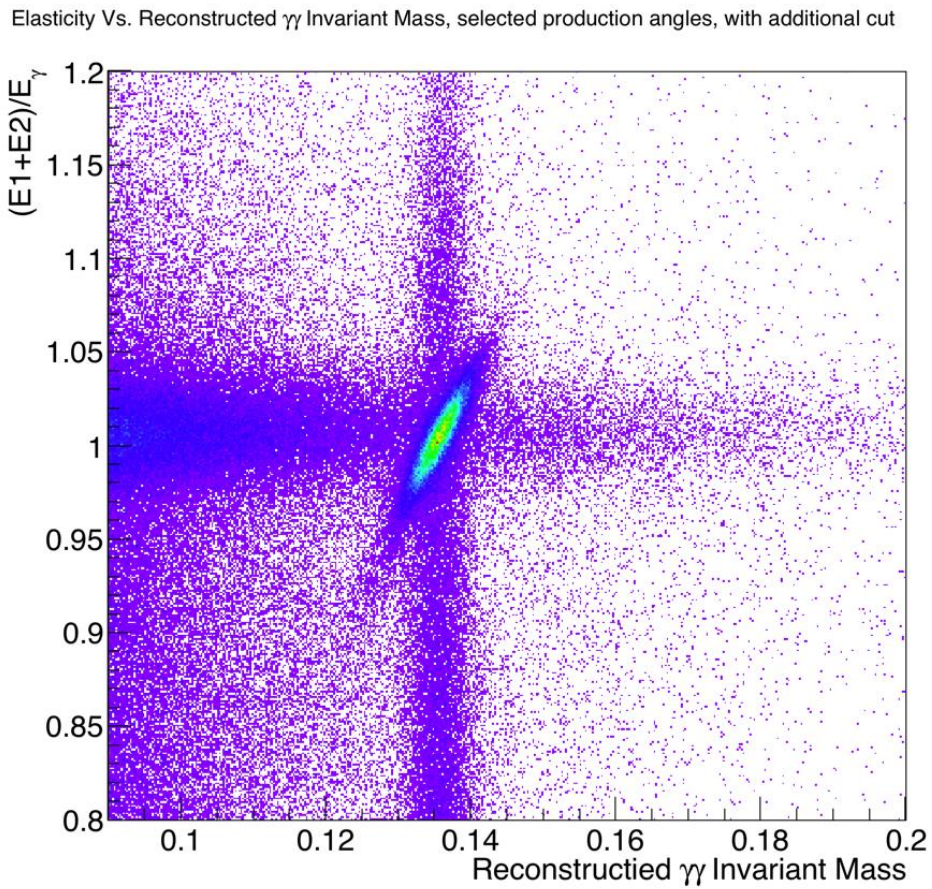


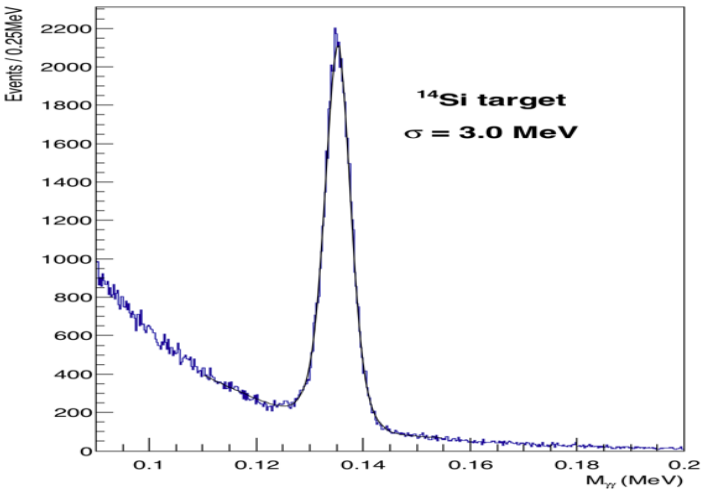
- Systematics:
  - ✓ Add more timing information in HyCal (~500 TDC channels)
  - ✓ Improve PID (add horizontal veto counters)
  - ✓ Improve photon beam line
  - ✓ Take more “empty target” data
  - ✓ Measure HyCal detection efficiency
  - ✓ take data for new ^{28}Si target.

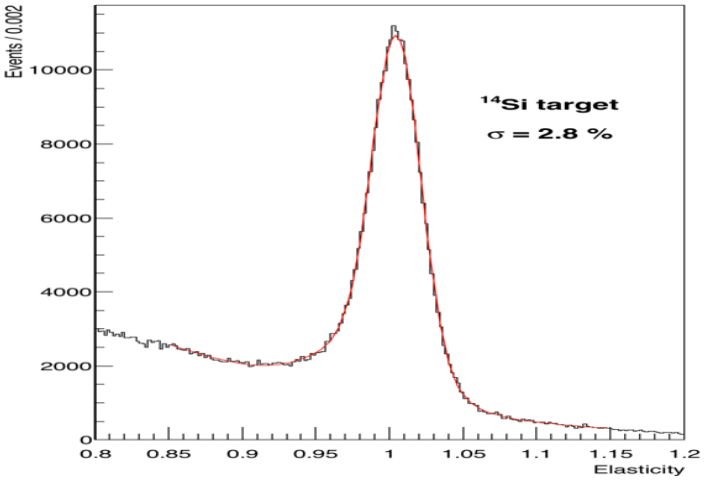


Experimental Data (^{28}Si Target)

- ✓ PrimEx-II was performed in 2010 in Hall B at Jlab
- ✓ Reach data taken for two 10% R.L. targets: ^{12}C and ^{28}Si

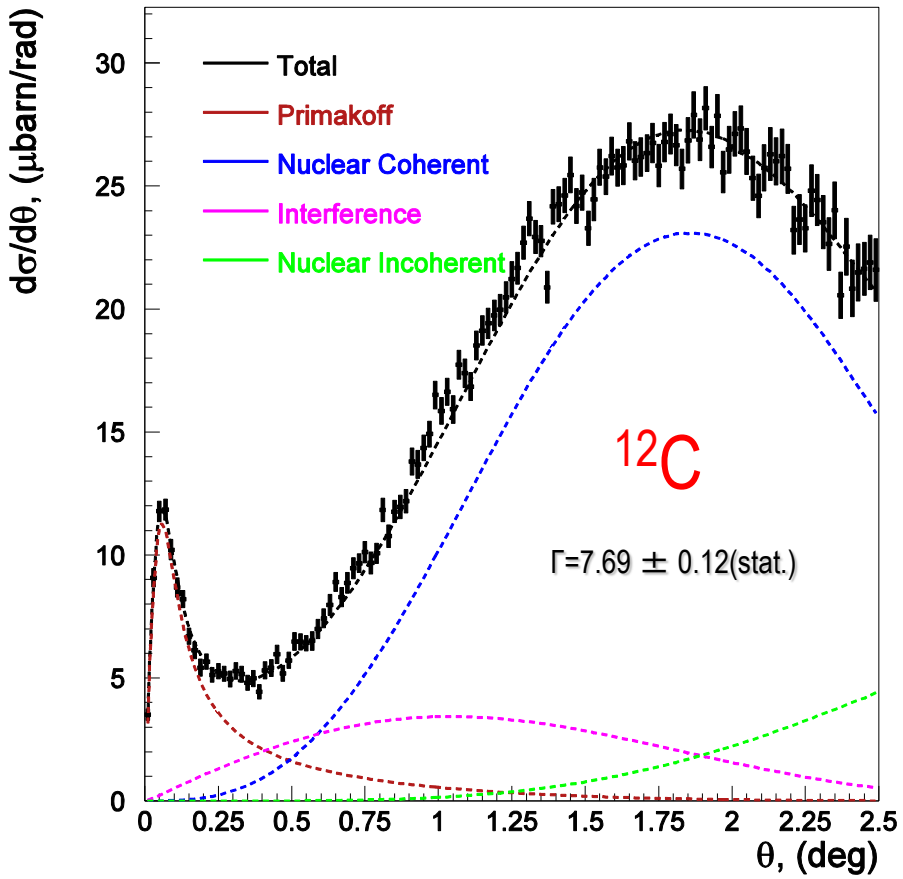


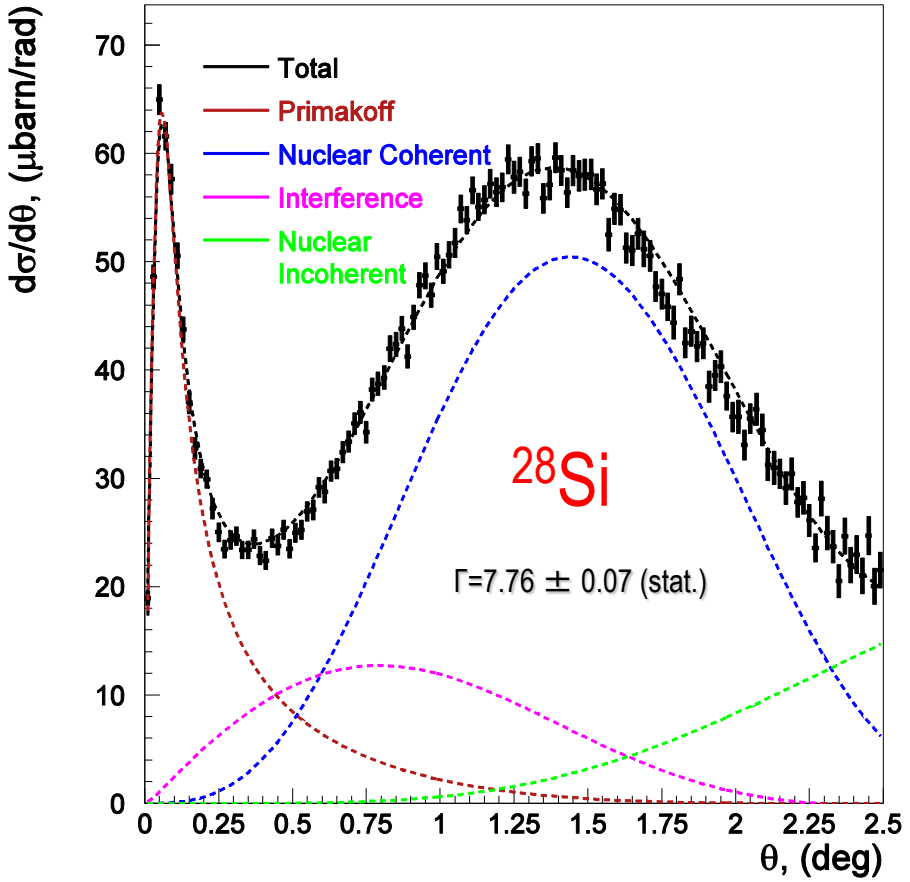




Extracted Differential Cross Sections and Fit Results (Preliminary)

- Results from the first group (ITEP Moscow/China) ($E\gamma$ = 5.0 GeV)





Estimated Systematic Uncertainties (preliminary)

Contributions	Uncertainty (%)
Photon flux	0.7
Beam parameters	0.4
Accidentals	0.1
Target parameters	0.2 ^{12}C; 0.4 ^{28}Si
Yield extraction	1.0
Acceptance	0.3
Trigger efficiency	0.3
Detector resolution	0.28
Model errors (theory)	0.5
Physics background	0.3
Branching ratio (PDG)	0.03
Total	**1.6**

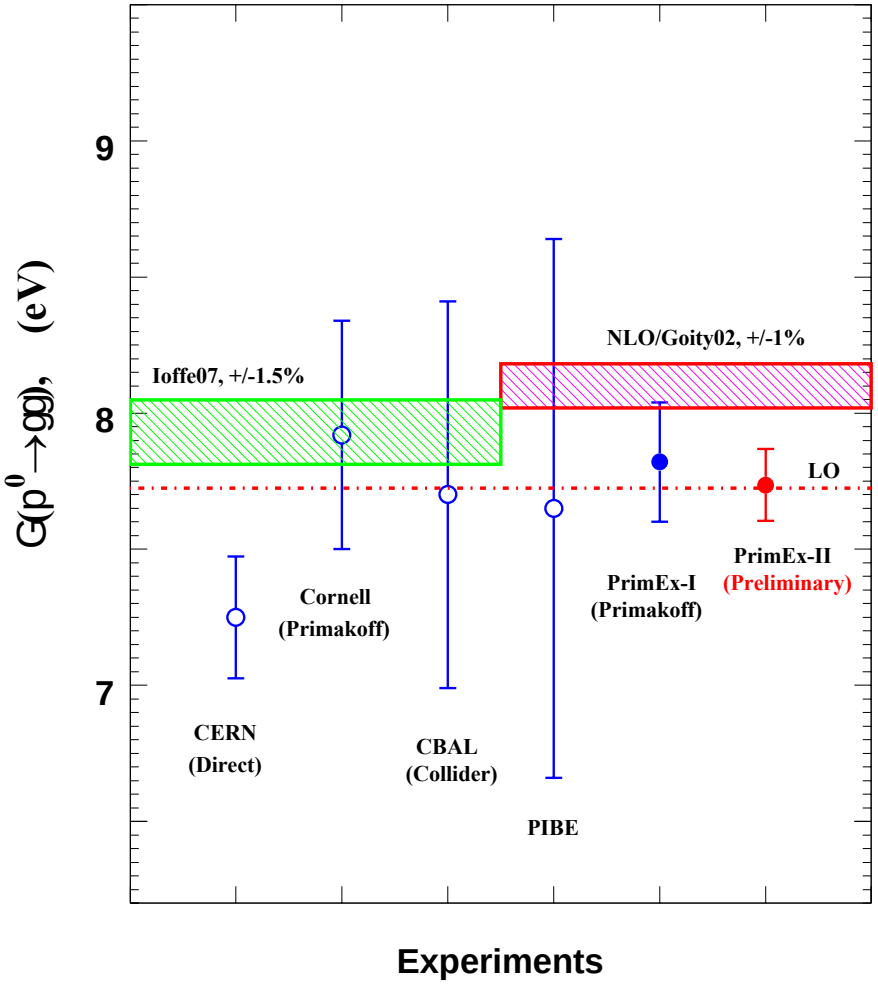
Results from the PrimEx-II Experiment (Preliminary)

- Results from the first group (ITEP Moscow/China) are presented (Preliminary).

$\Gamma(\pi^0 \to \gamma\gamma) = 7.74 \pm 0.06(\text{stat.}) \pm 0.12(\text{syst.})$ eV

1.7% total uncertainty

- Results from the second group (Duke University) are expected soon.



Summary and Outlook

- Percent level measurements of the $\pi^0 \to \gamma\gamma$ decay width are needed to test the fundamental predictions of QCD at the low energy domain.

- The PrimEx collaboration at JLab developed a new high resolution experimental setup and performed two experiments using the Hall B tagging facility to address this quest.

- The PrimEx-I experiment achieved 2.8% total uncertainty in the $\pi^0 \to \gamma\gamma$ decay width:
  - ✓ it significantly changed the "landscape" of PDG for the π^0 sector
  - ✓ improved the decay width average by a factor of $\sim$2

- The PrimEx-II currently reached to 1.7% level of total uncertainty in decay width (Preliminary). The final result is expected soon (possibly this year).

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The PrimEx Collaboration