Progress Report on the π^0 Lifetime Experiment (PrimEx) at JLab

Dustin E. McNulty
MIT/JLab
PrimEx Collaboration
mcnulty@jlab.org

November 1, 2006

Progress Report on the π^0 Lifetime Experiment (PrimEx) at JLab

Outline

- Physics Motivation
- π^0 Photoproduction Cross Section
- Experimental Overview
- Preliminary Compton Results
- π^0 Analysis Status
- Summary and Outlook

PrimEx Collaboration

Institutions

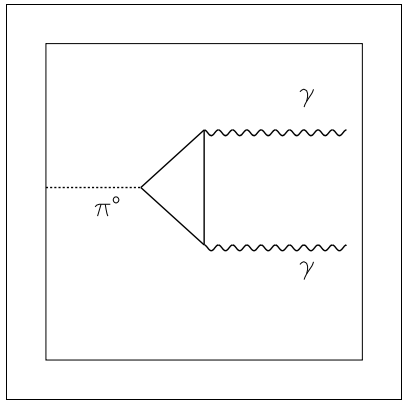
[a] Arizona State University, Tempe, AZ
[b] Catholic University of America, Washington, DC
[c] Chinese Institute of Atomic Energy, Beijing, China
[d] Eastern Kentucky University, Richmond, KY
[e] George Washington University, Washington, DC
[f] Hampton University, Hampton, VA
[g] Institute for High Energy Physics, Chinese Academy of Sciences, Beijing, China
[h] Institute for High Energy Physics, Protvino, Moscow region, Russia
[i] Institute for Theoretical and Experimental Physics, Moscow, Russia
[j] Kharkov Institute of Physics and Technology, Kharkov, Ukraine
[k] Massachusetts Institute of Technology, Cambridge, MA
[l] Norfolk State University, Norfolk, VA
[m] North Carolina A&T State University, Greensboro, NC
[n] North Carolina Central University, Durham, NC
[o] Southern University at New Orleans, New Orleans, LA
[p] Thomas Jefferson National Accelerator Facility, Newport News, VA
[q] Tomsk Polytechnical University, Tomsk, Russia
[r] University of Illinois, Urbana, IL
[s] University of Kentucky, Lexington, KY
[t] University of Massachusetts, Amherst, MA
[u] University of North Carolina at Wilmington, Wilmington, NC
[v] University of Texas at El Paso, El Paso, TX
[w] University of Virginia, Charlottesville, VA
[x] Yerevan Physics Institute, Yerevan, Armenia

Physics Motivation

- π^0 decay rate is a fundamental prediction of confinement scale QCD.

Chiral Anomaly

Presence of closed loop triangle diagram results in nonconserved axial vector current, even in the limit of vanishing quark masses.



→In the leading order (chiral limit), the anomaly leads to the decay amplitude:

$$A_{\pi^0\to\gamma\gamma} = \frac{\alpha_{em}}{4\pi F_\pi}\varepsilon_{\mu\nu\rho\sigma}k^\mu k'^\nu \varepsilon^{*\rho}\varepsilon^{*\sigma}, \quad (1)$$

or the reduced amplitude,

$$A_{\gamma\gamma} = \frac{\alpha_{em}}{4\pi F_\pi} = 0.02513\ \text{GeV}^{-1} \quad (2)$$

where $F_\pi = 92.42 \pm 0.25$ MeV is the pion decay constant.

Physics Motivation

- The $\pi^0 \to \gamma\gamma$ decay width predicted by this amplitude is

$$\Gamma_{\pi^0\to\gamma\gamma} = m_\pi^3 \frac{|A_{\gamma\gamma}|^2}{64\pi} = 7.725 \pm 0.044 \text{ eV} \quad (3)$$

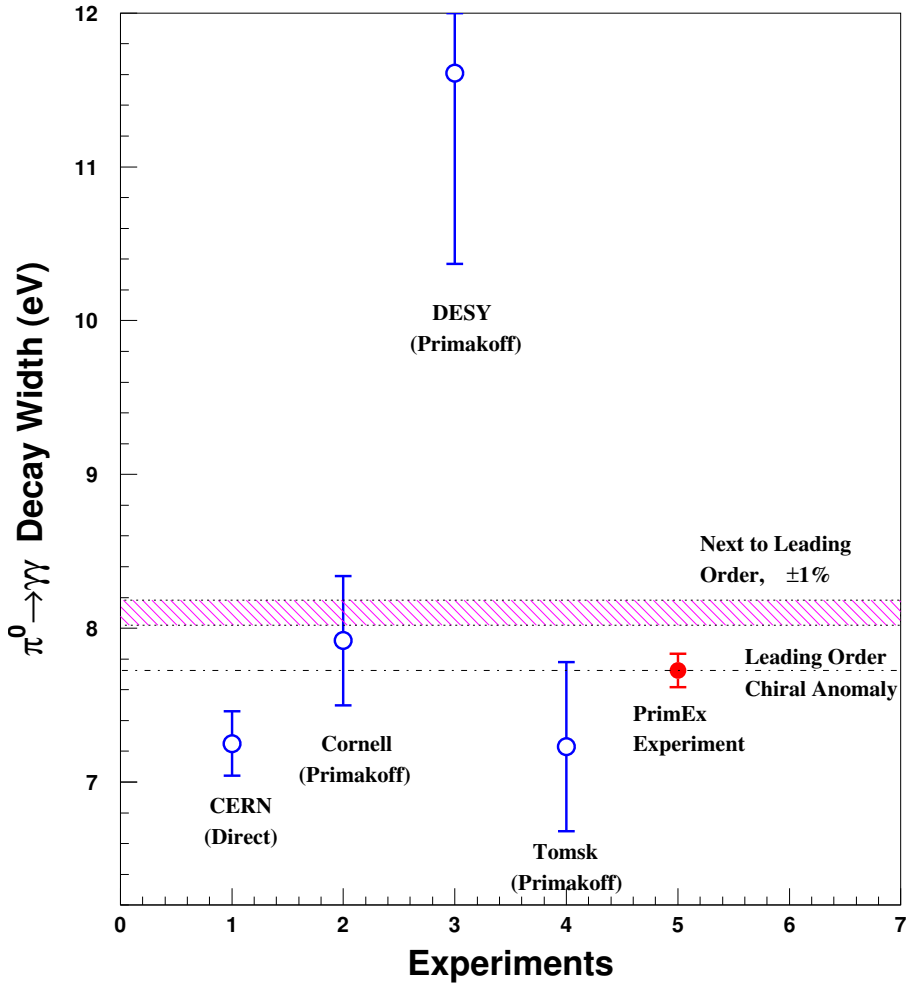
  $\to$ Current Particle Data Book value is 7.84 ± 0.56 eV

- The above result for the decay amplitude is exact in the chiral limit, however for non-vanishing quark masses there are corrections:
  $\to$ Due to isospin sym-breaking ($m_u \neq m_d$), π^0, η and $\eta\prime$ mixing induced.
  $\to$ Further corrections induced by terms in the Chiral Lagrangian.

- Next to Leading Order prediction for the decay width is 8.10 eV $\pm 1\%$
  $\to$ Calc. using Chiral Perturbation Theory and $1/N_c$ expansion.
  J.L.Goity et al, Phys. Rev. D66, 076014 (2002); B.Moussallam, Phys. Rev. D51, 4939 (1995)
  $\to$ This is 4% higher than current experimental value!
  ◦ A precision measurement of the π^0 decay width is needed.

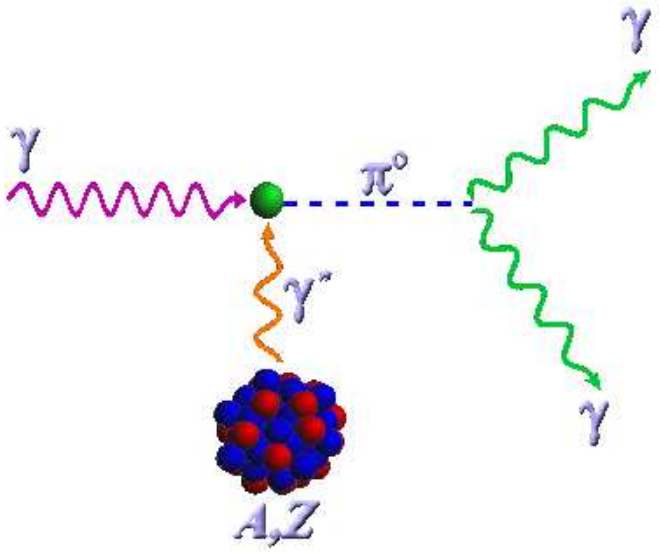
Physics Goal

- Use the Primakoff effect to measure $\Gamma_{\pi^0\to\gamma\gamma}$ to within 1.5% uncertainty



The Primakoff Effect

- π^0 photoproduction from Coulomb field of nucleus.
- Equivalent production ($\gamma\gamma^* \rightarrow \pi^0$) and decay ($\pi^0 \rightarrow \gamma\gamma$) mechanism implies Primakoff cross section proportional to π^0 lifetime.
- Primakoff π^0 produced at very forward angles.

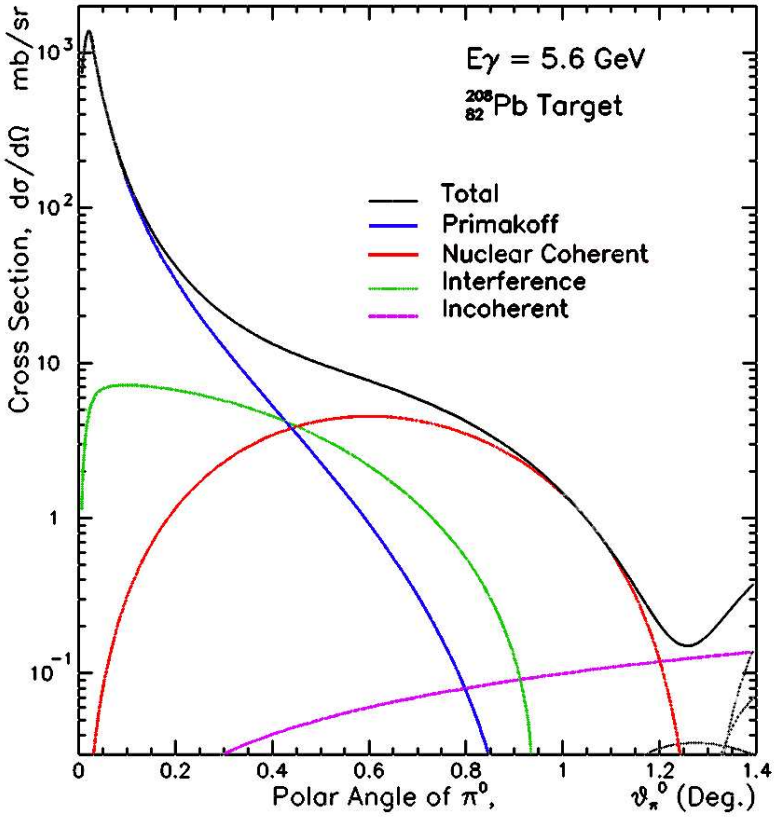


$$\frac{d\sigma_P}{d\Omega} = \Gamma_{(\pi^0 \rightarrow \gamma\gamma)} \frac{8\alpha_{em} Z^2}{m^3} \frac{\beta^3 E^4}{Q^4} |\tilde{F}_{em}(Q)|^2 sin^2\theta_\pi \qquad (4)$$

Full Cross Section Components

$$\frac{d\sigma_{\pi^0}}{d\Omega} = \frac{d\sigma_P}{d\Omega} + \frac{d\sigma_C}{d\Omega} + \frac{d\sigma_I}{d\Omega} + 2\cdot\sqrt{\frac{d\sigma_P}{d\Omega}\cdot\frac{d\sigma_C}{d\Omega}}\cos(\phi) \qquad (5)$$

Primakoff Nucl.Coherent Incoherent Interference



Primakoff:

Proportional to Z^2,

peaked at $\theta_{\pi^0} = m^2_{\pi^0}/2E^2_\gamma$

Nuclear Coherent:

$$\frac{d\sigma_C}{d\Omega} = C\cdot A^2|F_N(Q)|^2 sin^2\theta_\pi \qquad (6)$$

Nuclear Incoherent:

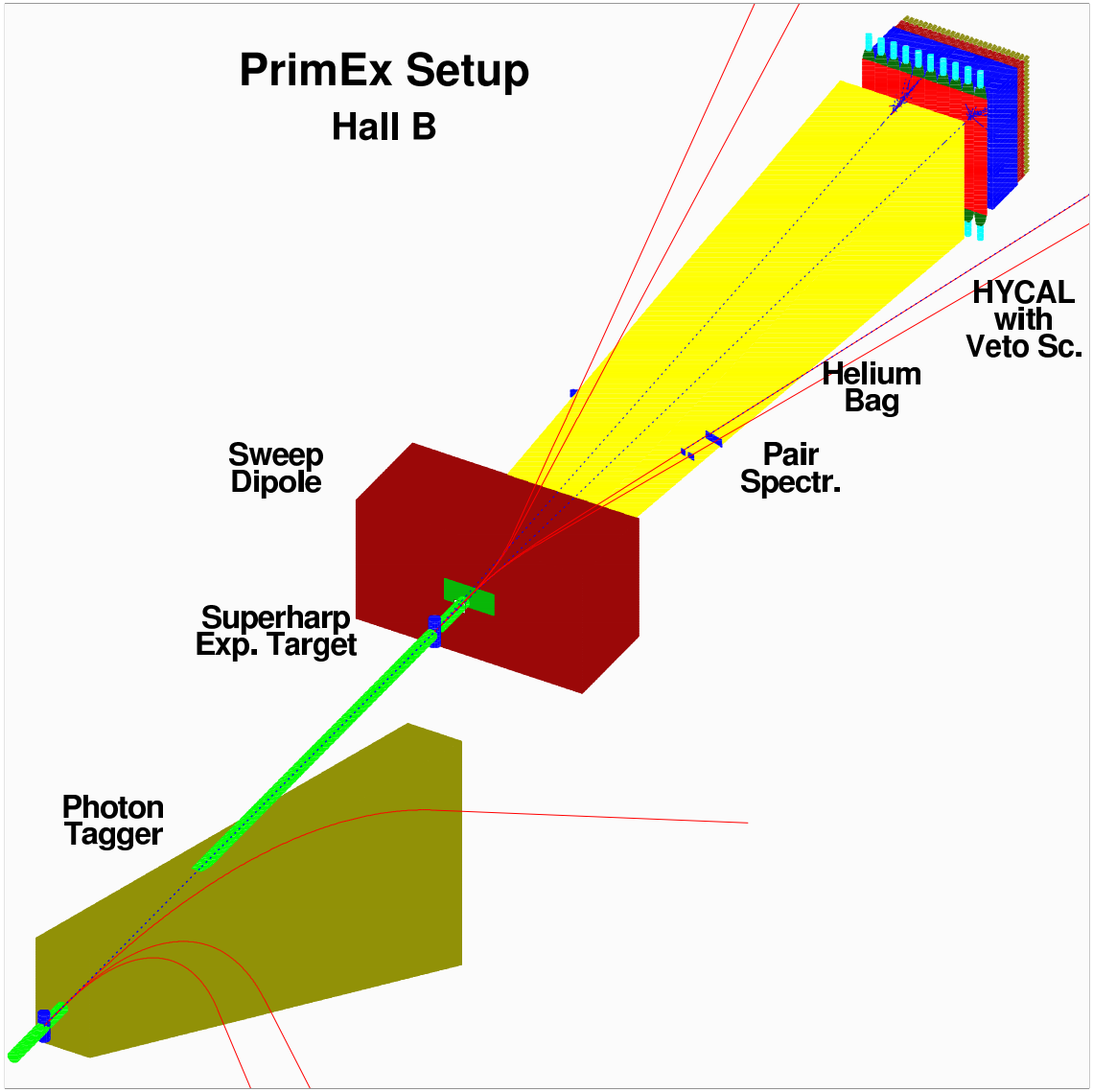
$$\frac{d\sigma_I}{d\Omega} = \xi A(1-G(Q))\frac{d\sigma_H}{d\Omega} \qquad (7)$$

Interference:

Experiment Overview

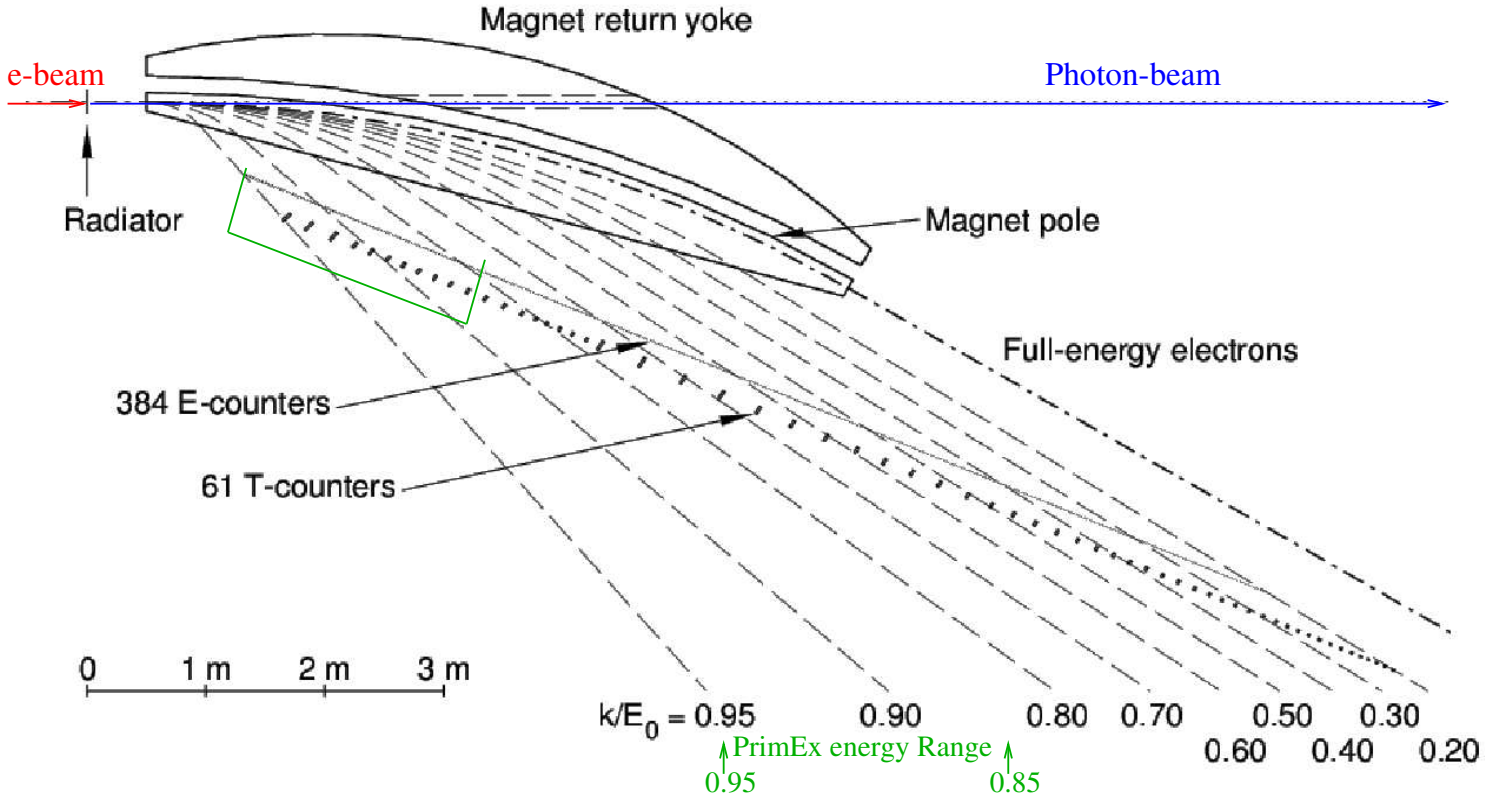
- Conducted at Jefferson Lab, Fall 2004
- Used 5.75 GeV continuous e^- beam and Hall B γ-tagging facility
- Tagged photons incident on $5\%X_0$ targets: ^{12}C and ^{208}Pb
- New PrimEx/Hall B calorimeter (HyCal), upstream of CLAS, designed to detect π^0 decay γ's
- Measured 3 physical processes (absolute cross sections): Primary - π^0 production, Secondary - Compton and e^+e^- pair production
- Improvements over previous experiments: Precision tagged γ flux and incident γ energy info, enhanced π^0 angular and mass resolution, and identification and subtraction of background event contamination

Experiment Overview



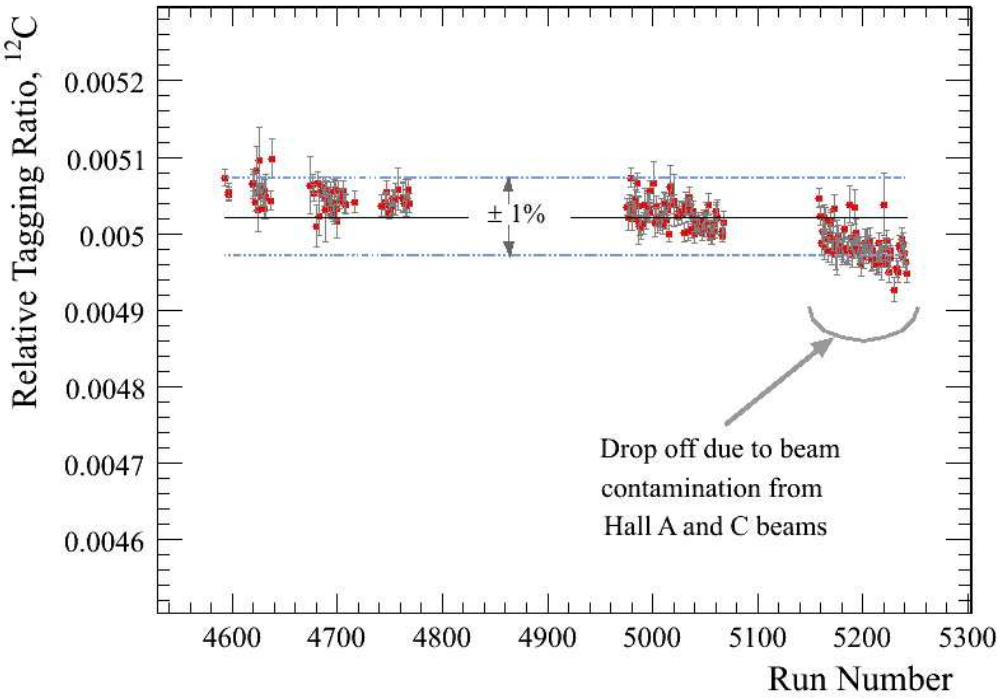
Hall B Photon Tagger

- Single dipole magnet combined with a hodoscope containing two planar arrays of plastic scintillators to detect energy-degraded electrons from a thin bremsstrahlung radiator.
- Tagger has 0.1% energy resolution and is capable of 50 MHz rates.

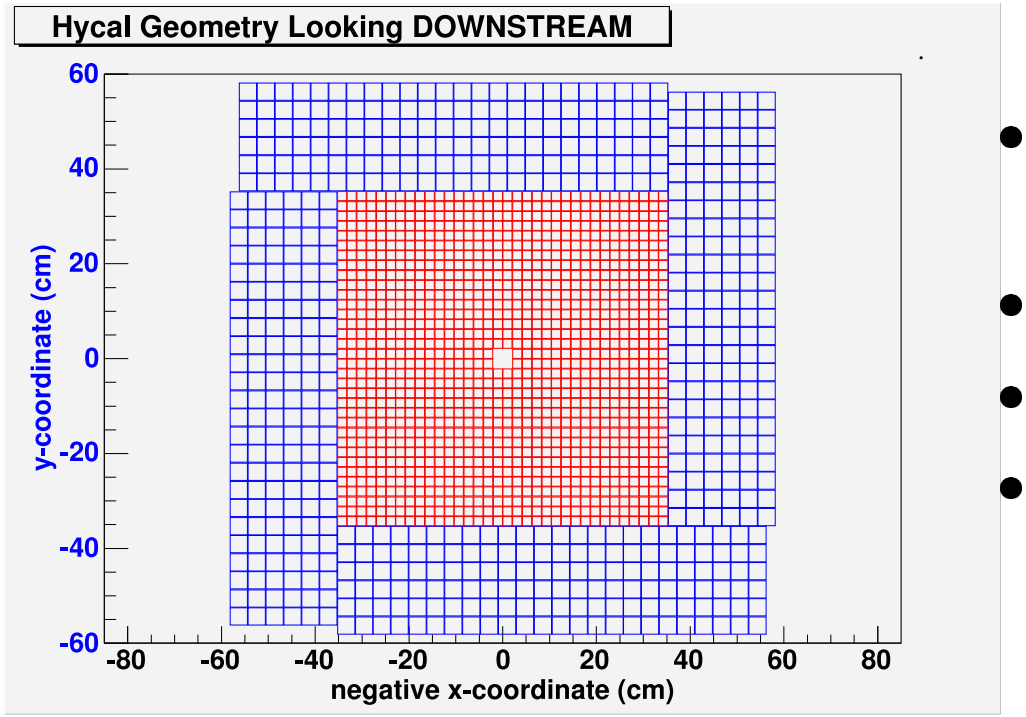


Photon Flux Control

- PrimEx goal: Total uncertainty in photon flux $\leq 1.0\%$.
- Number of tagged photons on target (N_γ) calibrated periodically using a Total Absorption Counter (TAC).
- Any drifts in the tagging ratio, occuring between calibration points, are monitored online with the e^+e^- pair spectrometer.



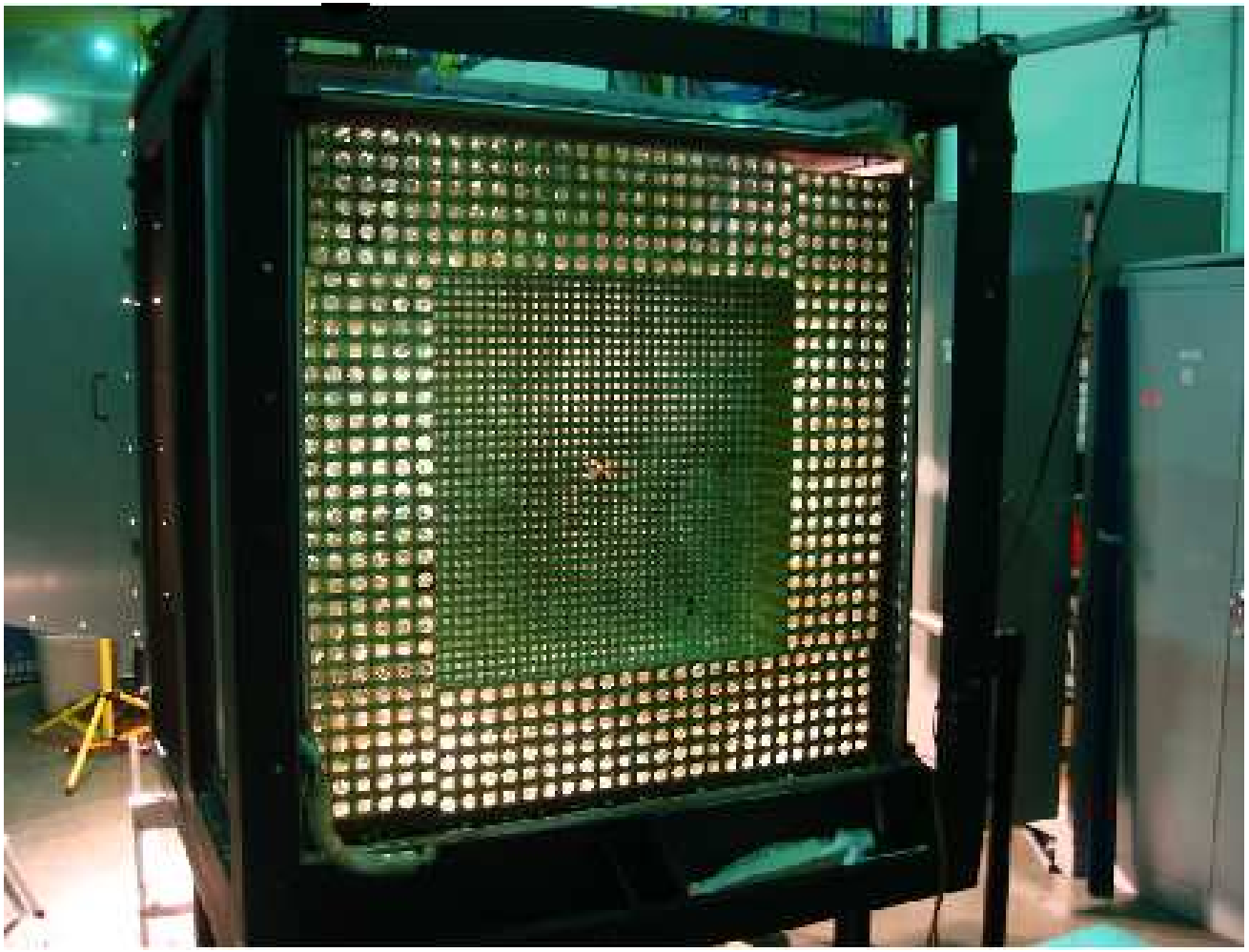
Hybrid Calorimeter – "HyCal"



- Optimal performance/cost design
- 1.2 m ×1.2 m, 1728 channels
- 576 Lead-glass (outer layers)
- 1152 Lead-Tungstenate crystal (inner layers)

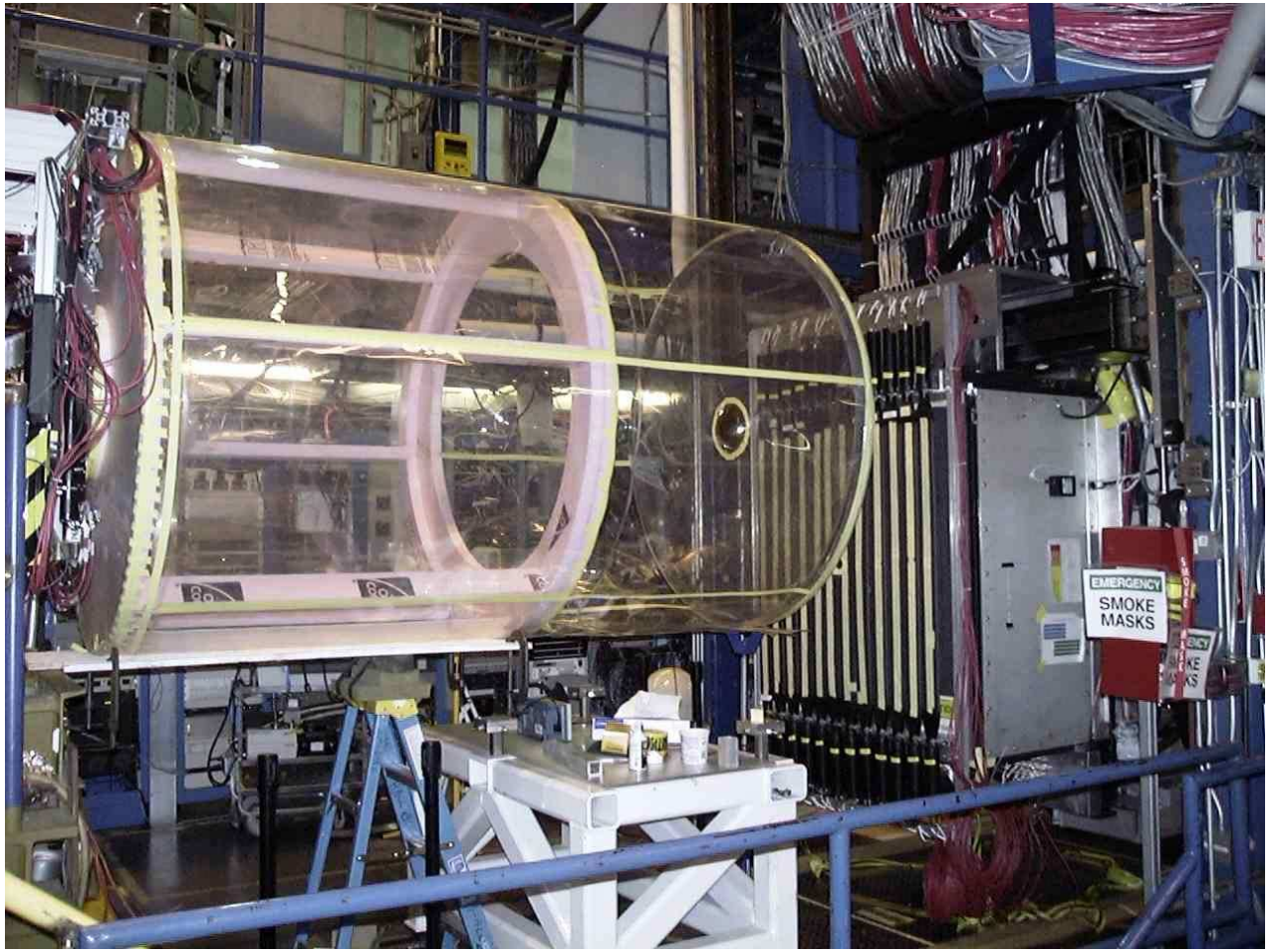
	Lead-glass	$PbWO_4$
Energy Res. ($\Delta E/E$)	3 – 5 %	1 – 2 %
Position Res. ($\Delta x,y$)	~ 5 mm	~ 1.5 mm
Angular Res. ($\Delta\theta_{\pi^0}$)	~ 675 μrad	~ 300 μrad

HyCal

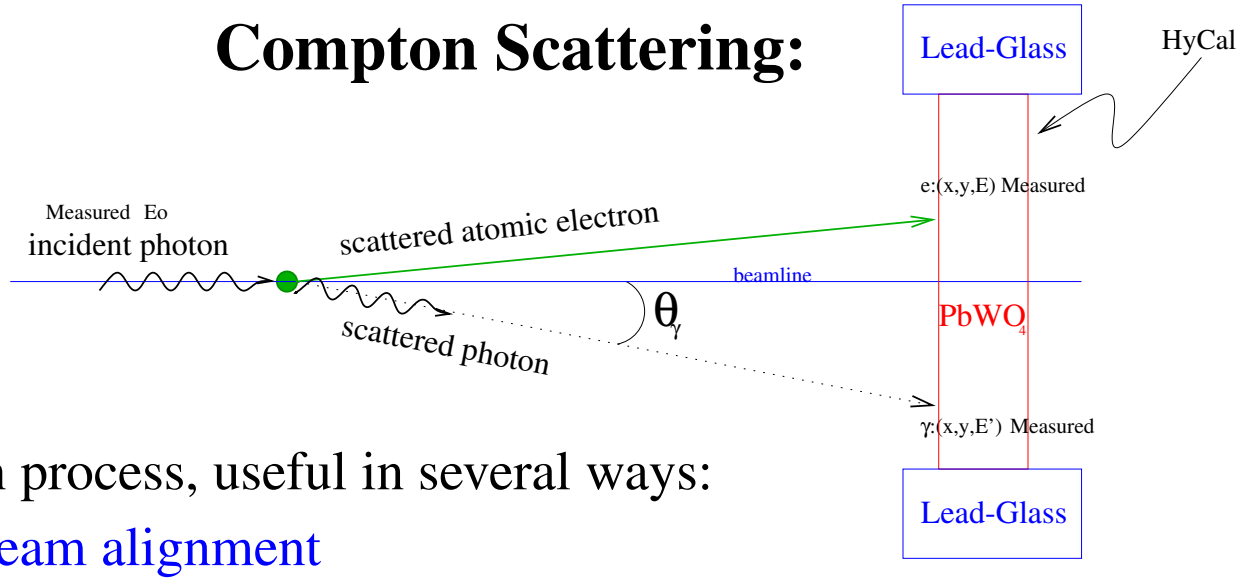


HyCal Calibration

- Full x,y motion allowed each ch. to be scanned through tagged γ beam.
- Performed at both the beginning and end of the experiment.

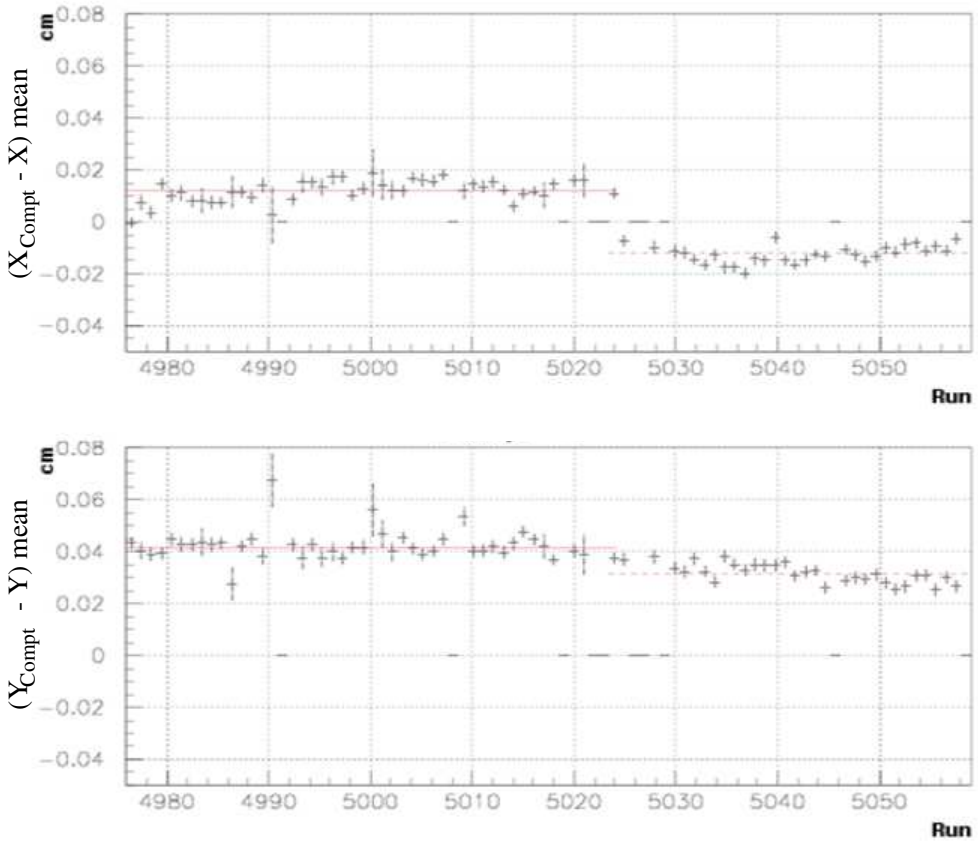


Compton Scattering:



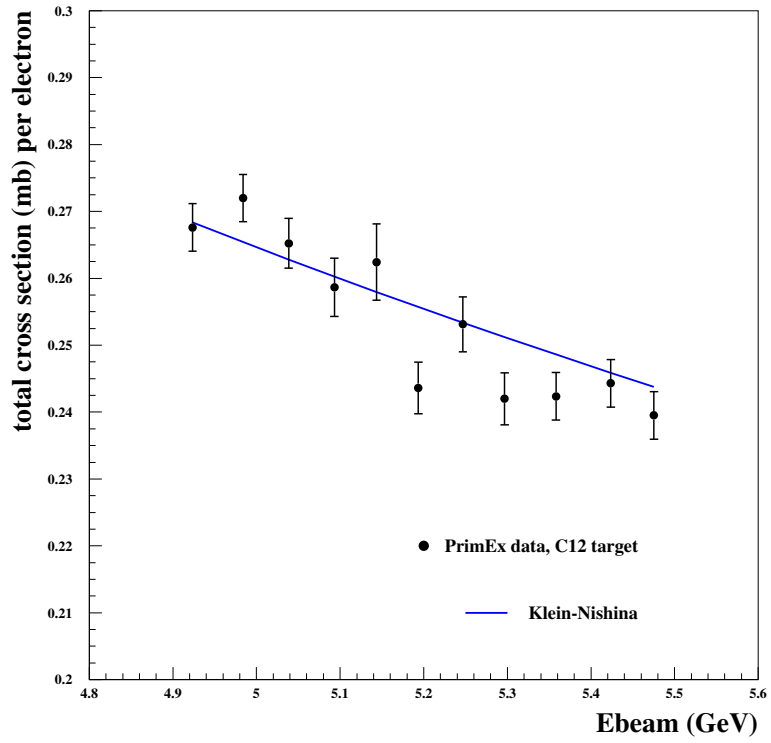
- A well known process, useful in several ways:
  - → Detector/beam alignment
  - → HyCal gain monitoring
  - → Overall check of PrimEx setup to measure absolute cross sections
    - ○ Dedicated "Double-Arm" Compton Runs:
      - → Performed on a weekly basis, $B_{PS} = 0$, $I_{beam} \sim 5 - 10$ nA
      - → Both e^- and scattered photon detected in HyCal
      - → Compton Cross Section Measured: ^{12}C and $0.5\%X_0$ ^4Be
    - ○ "Single-Arm" Compton Data:
      - → Dominant Source of Events in π^0 production dataruns
      - → $B_{PS} \sim 2$ T, $I_{beam} \sim 100$ nA, only scattered photon detected

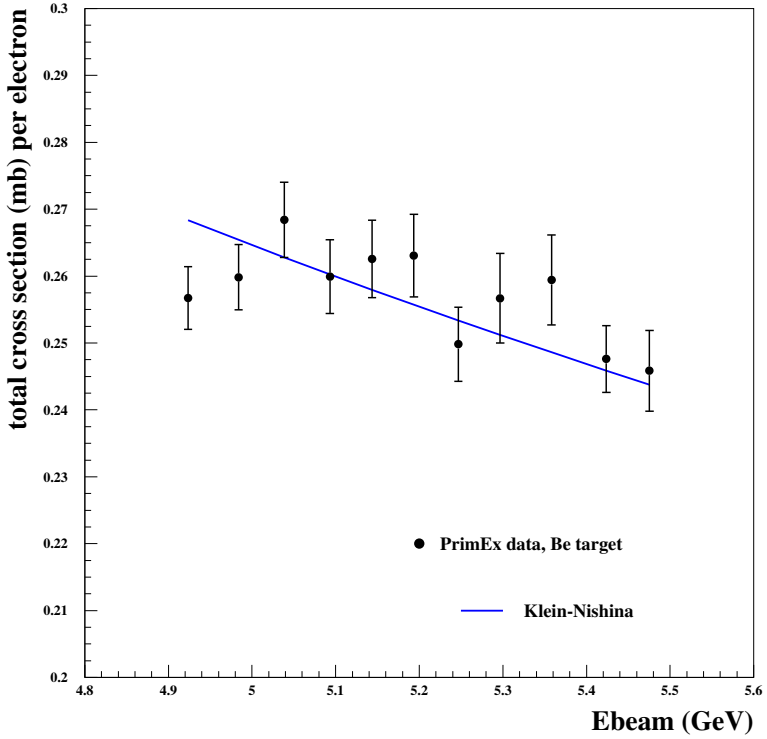
Beam Alignment Monitoring using Single-Arm Compton



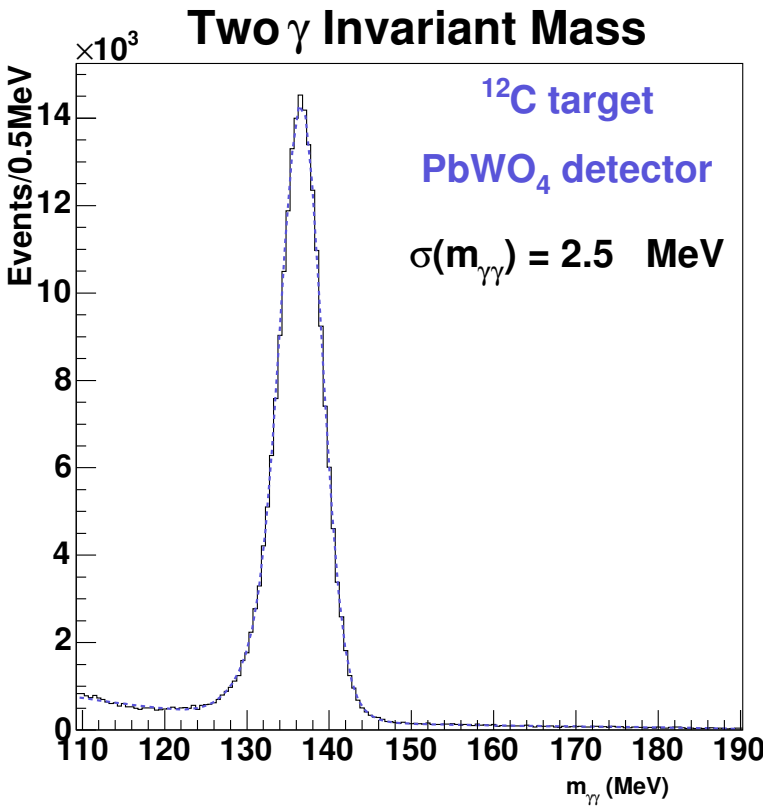
- Only scattered γ measured
- X $\equiv$ reported HyCal coord
- $X_{Compt} \equiv$ calc. (x,y) from Hycal E and Compton kin.
- If beam alignment perfect: $(X_{Compt}-X) = 0$
- Technique tracks alignment at 0.1 mm level
- Jump in X correlated with beamline BPM

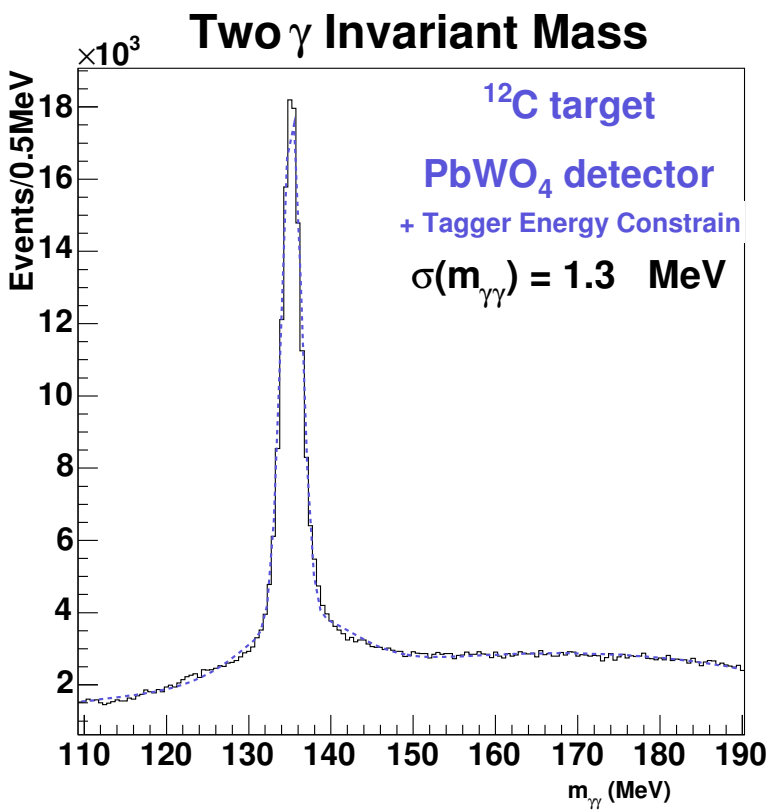
Very Preliminary Compton Cross Section



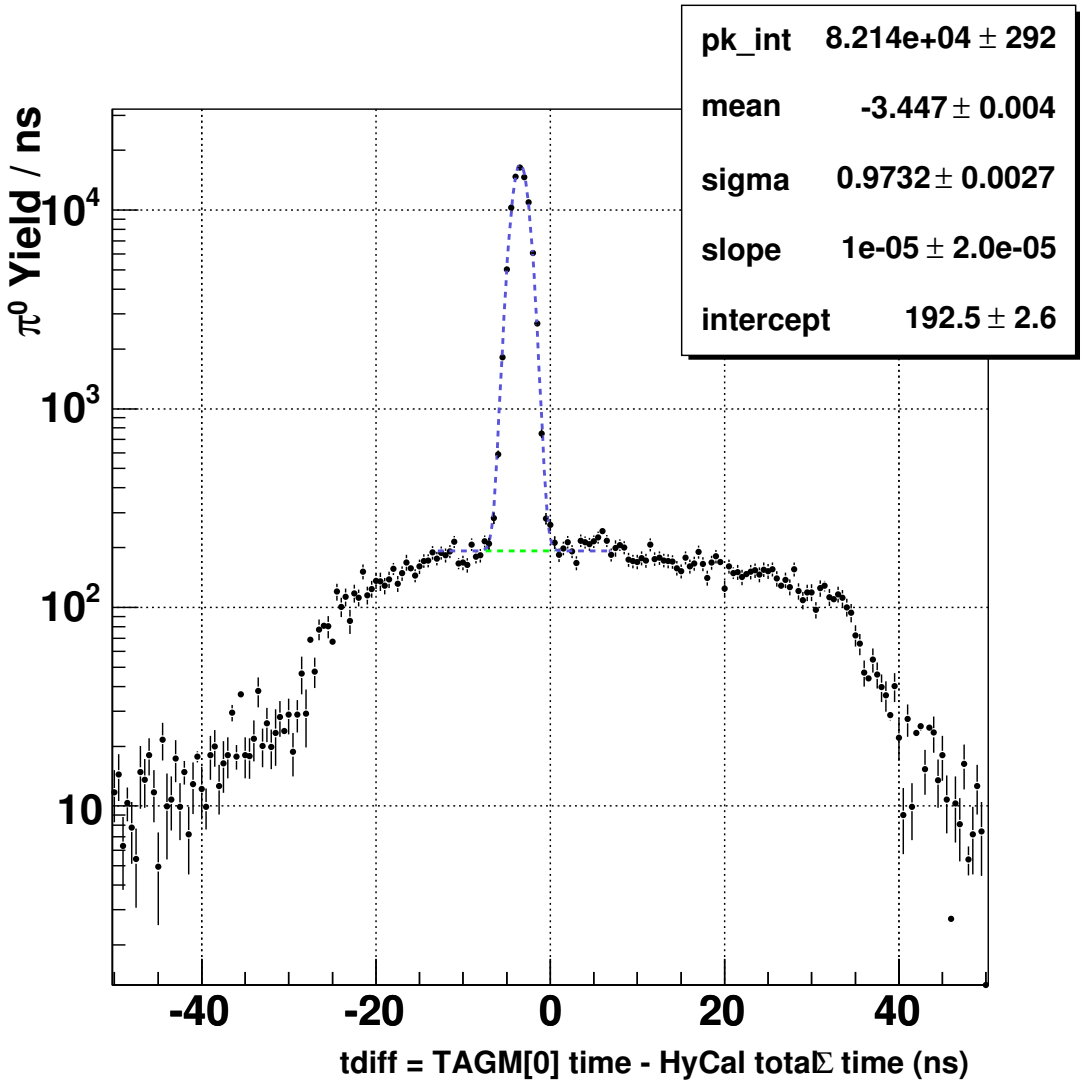


π^0 Analysis Status: $\gamma\gamma$ Invariant Mass

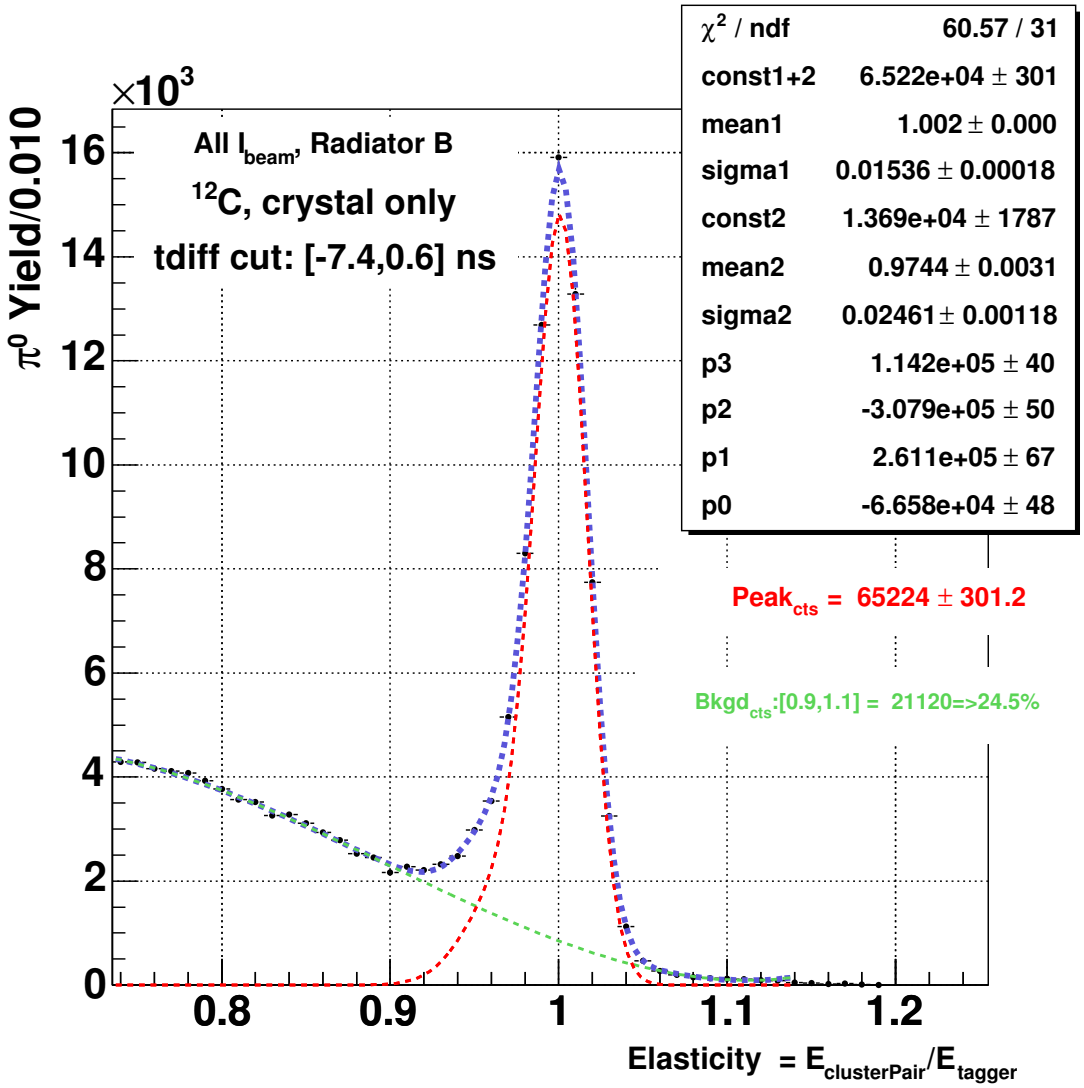




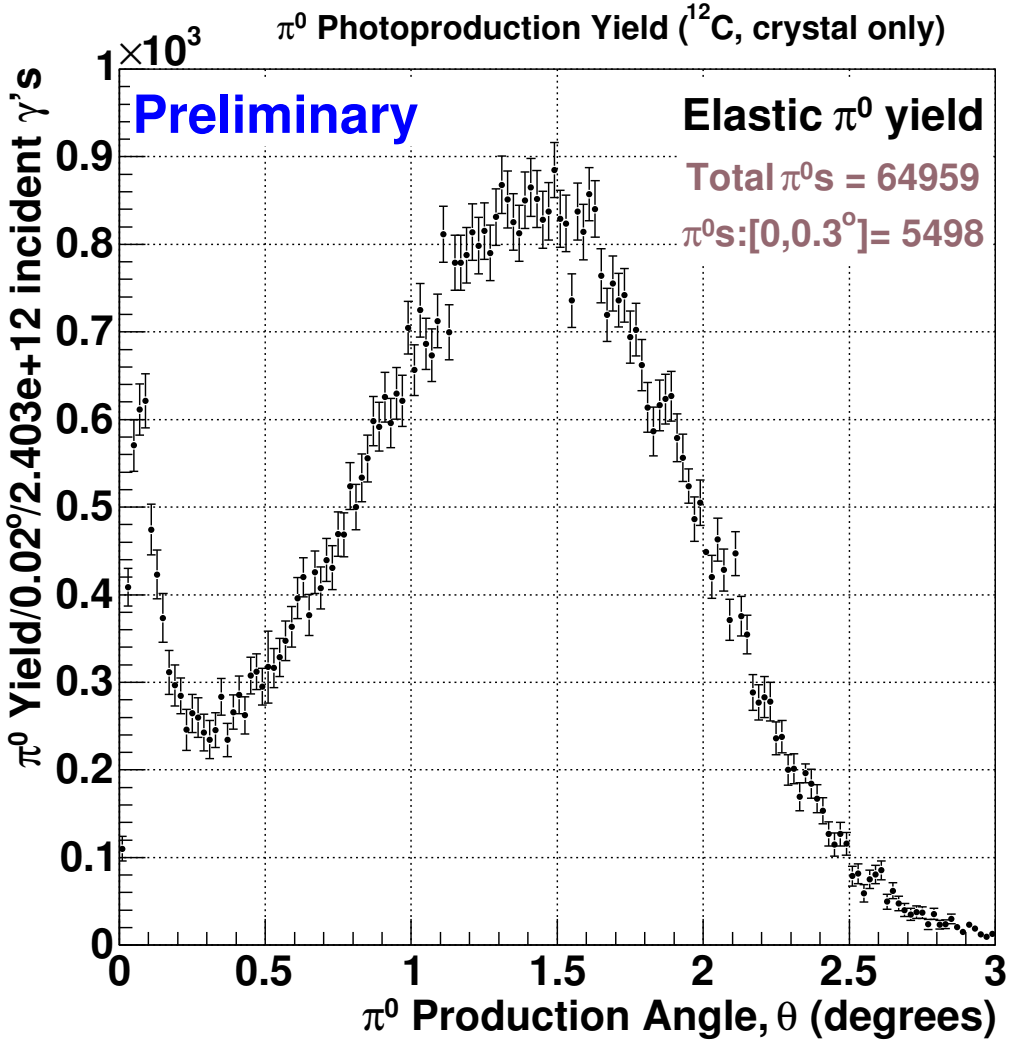
π^0 Analysis: Event Timing



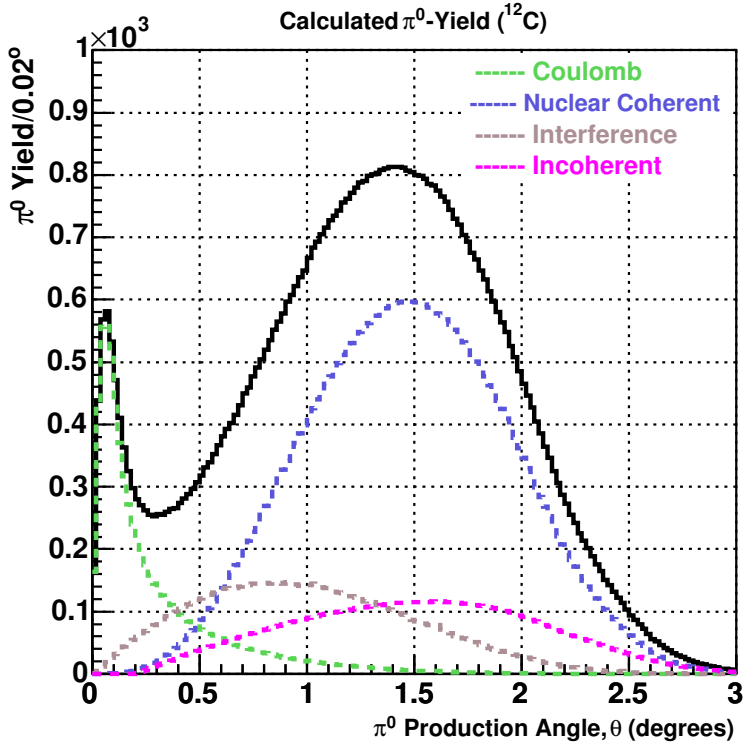
π^0 Analysis: Event Elasticity

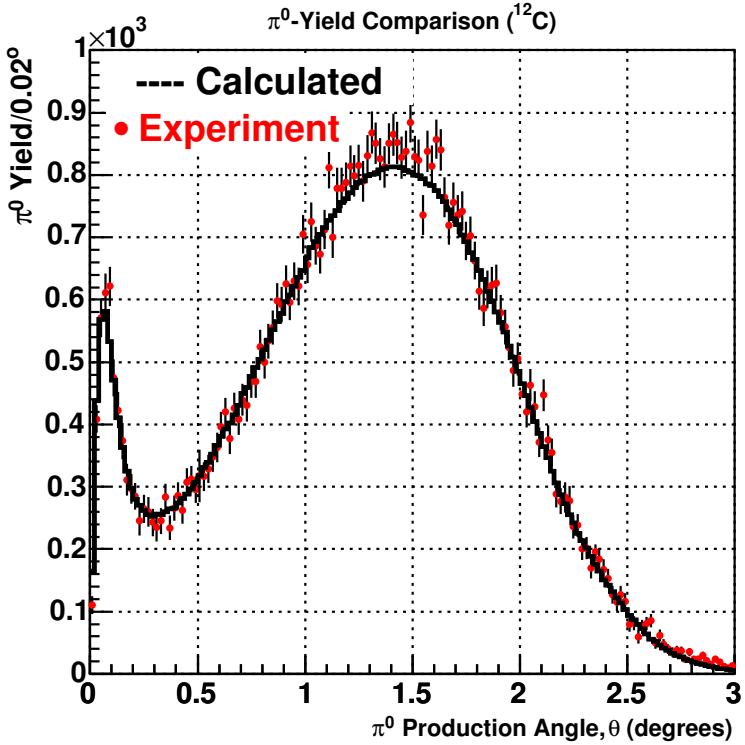


π^0 Experimental Yield: ^{12}C



π^0 Experimental Yield Comparison: ^{12}C





π^0 Lifetime Extraction

- Convert Yield to Cross Section.

$$\frac{d\sigma_{exp}}{d\theta_{\pi^0}} = \frac{N_{\pi^0}^{yield}(\theta_{\pi^0})}{N_\gamma \times N_t \times \varepsilon_{\pi^0}(\theta_{\pi^0}) \times \Delta\theta_{\pi^0}} \tag{8}$$

  → where $N_\gamma \equiv$ # of γ's on target (preliminary uncertainty $\leq 1\%$).

  → where $N_t \equiv$ target atoms/cm^2 (thickness mapped to $\sim .03\%$ uncertainty).

  → where $\varepsilon_{\pi^0} \equiv$ experimental acceptance (uncertainty still being evaluated)

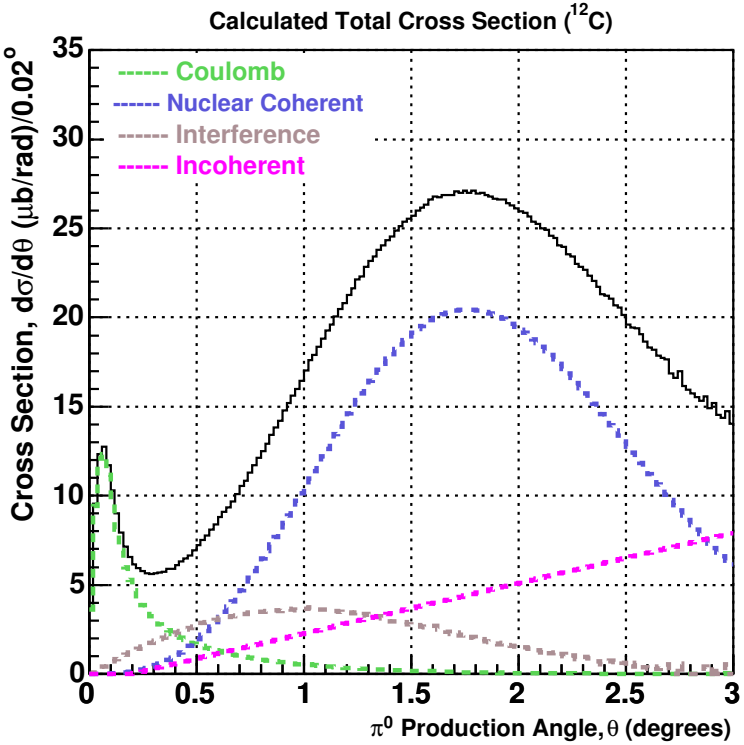
- Fit experimental cross section with parameterization:

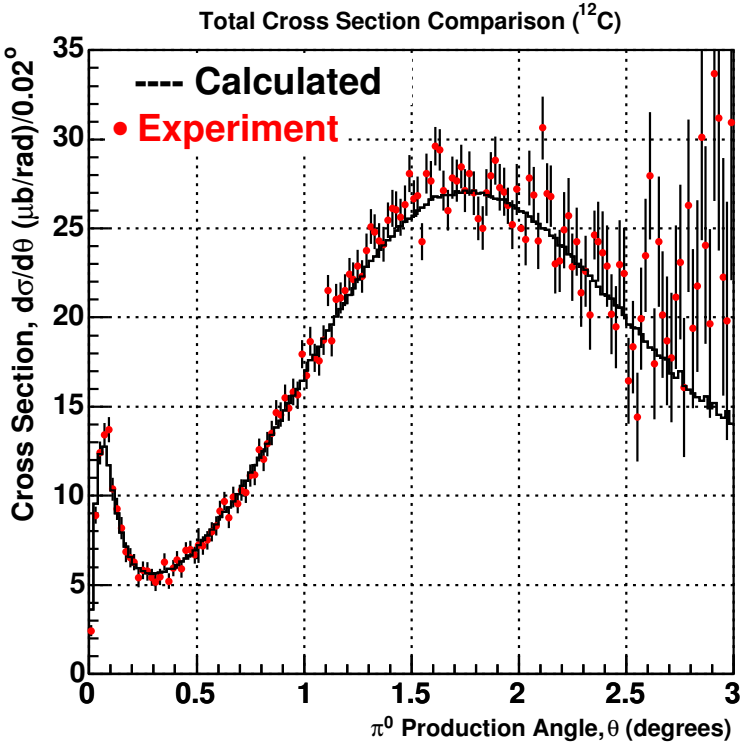
$$\frac{d\sigma_{exp}}{d\theta_{\pi^0}} = b_p T_p^2 + b_c T_c^2 + b_i T_i^2 + 2cos\phi\sqrt{b_p b_c} T_p T_c \tag{9}$$

  → where the parameter $b_p = \Gamma_{\gamma\gamma}$

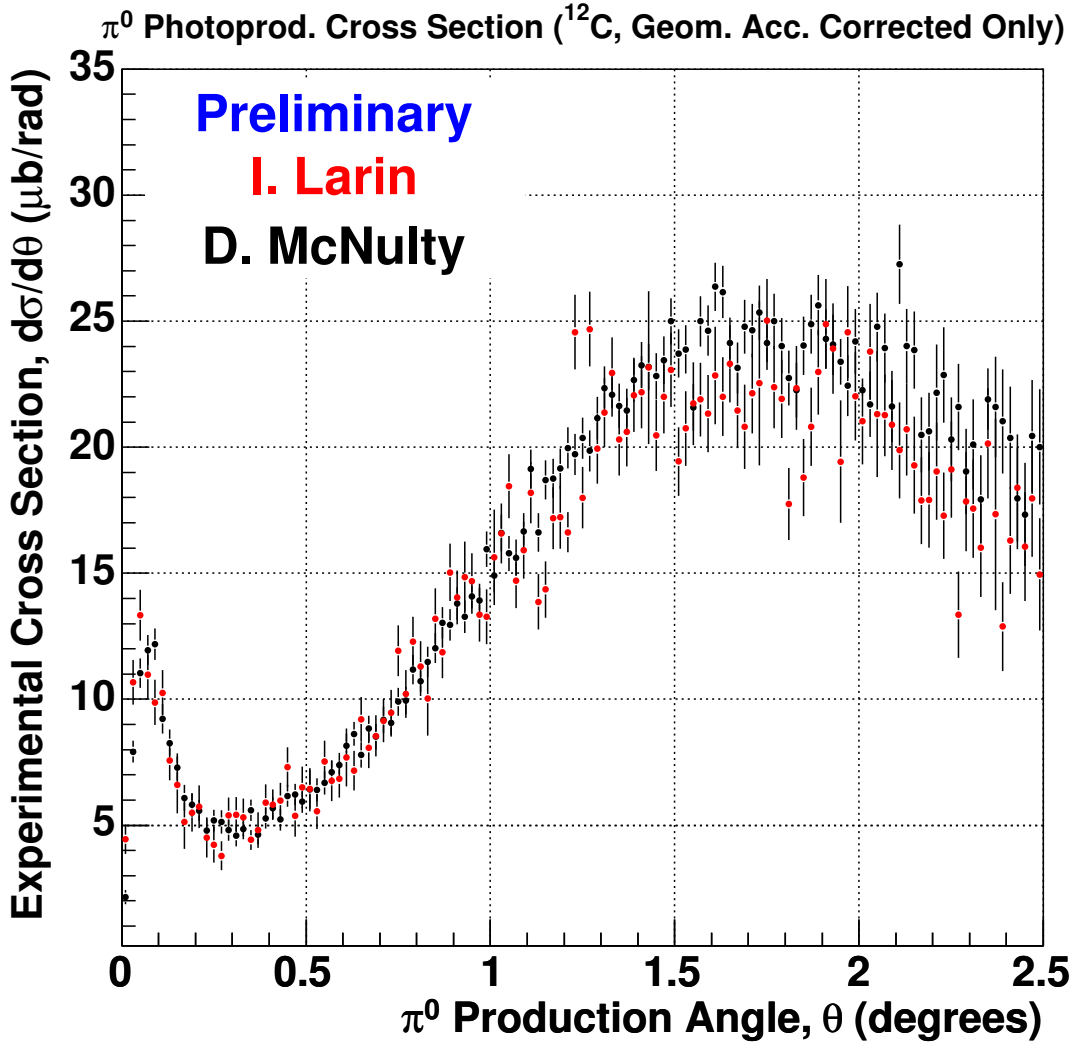
  ○ Vary the four parameters (b_p, b_c, b_i, and ϕ) and minimize χ^2.

π^0 Experimental Cross Section Comparison: ^{12}C





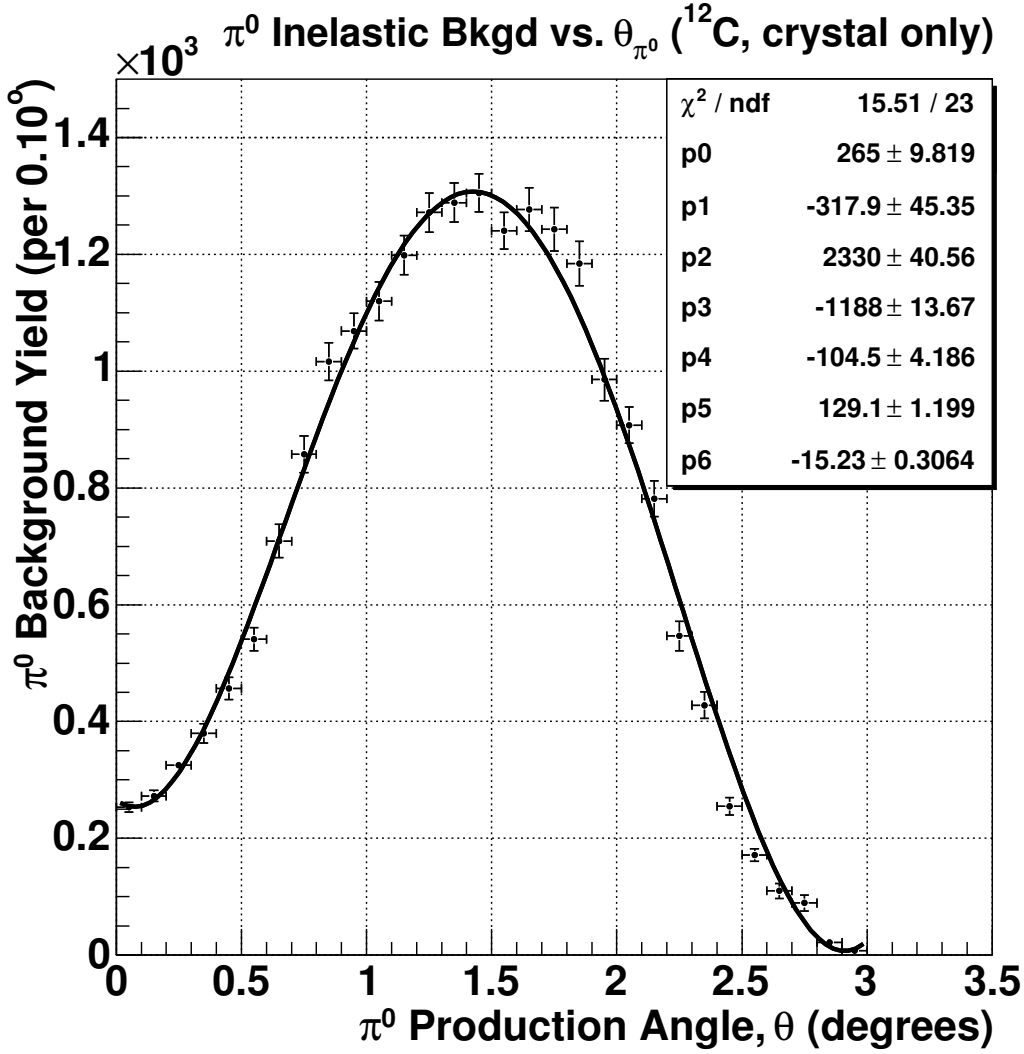
Comparison of ~Independent π^0 Analyses: ^{12}C



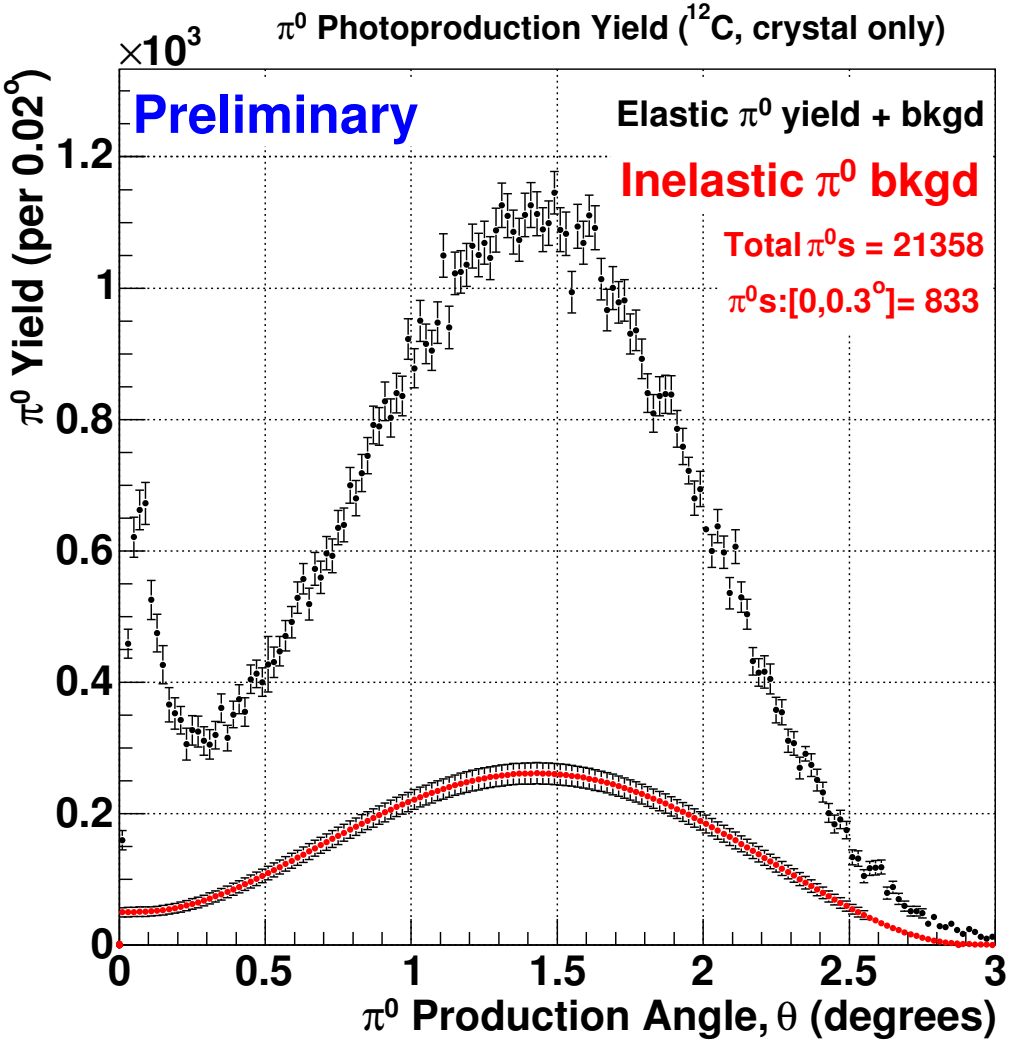
Summary and Outlook

- High Quality precision π^0 photoproduction data on ^{12}C and ^{208}Pb targets using $4.9 \leq E_\gamma^{tagged} \leq 5.5$ GeV has been collected and analyzed by the PrimEx Collaboration.
- State of the art performance by the Hall B tagger and PrimEx calorimeter — delivering precision photon flux statistics combined with stellar energy and coordinate resolutions.
- Three ∼independent π^0 analysis groups; two groups have achieved nice agreement, third group coming with comparison soon.
- Preliminary Compton cross section results in good agreement with theory; final radiative corrections still pending.
- Preliminary π^0 results should be expected early next year–including cross sections and lifetime.

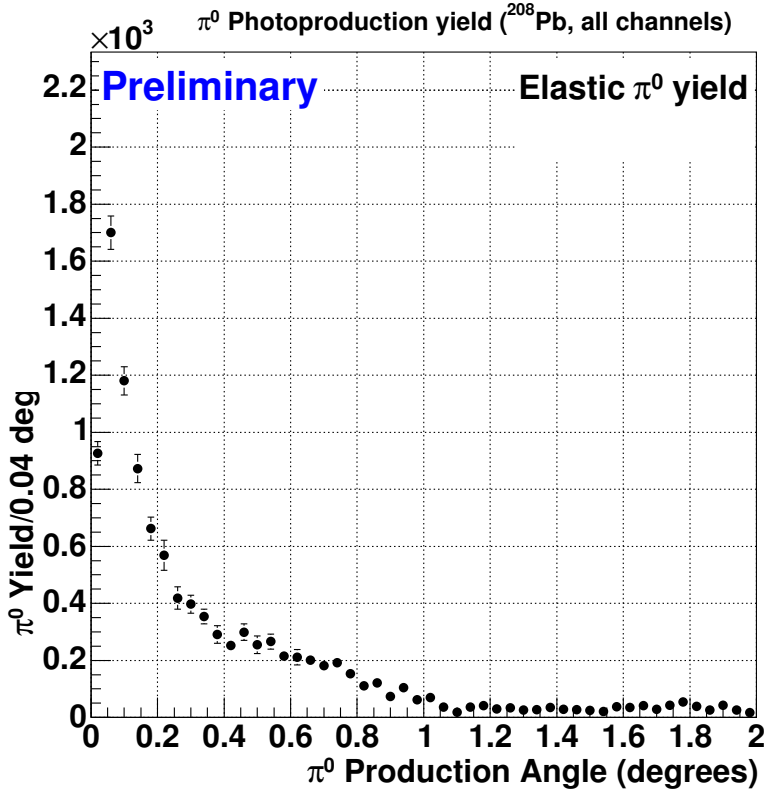
Extra Slide: Inelastic Bkgd Correction

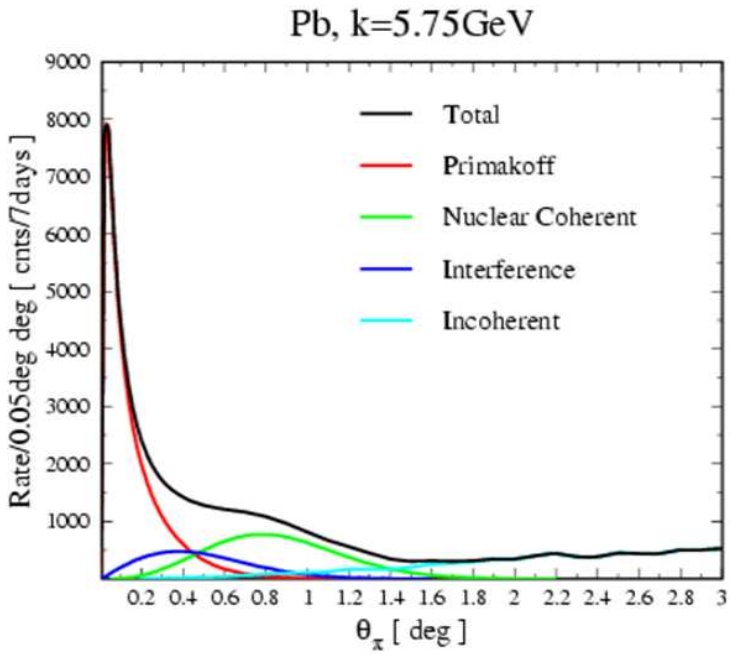


Extra Slide: Inelastic Bkgd Correction



Extra Slide: π^0 Experimental Yield: ^{208}Pb





Extra Slide: π^0 Experimental Yield: ^{12}C