

A Measurement of the Neutral Pion Lifetime

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for the PrimEx Collaboration
Users' Group Meeting
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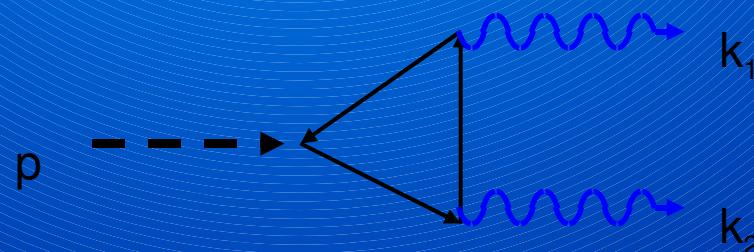
Outline

- History
- PrimEx Experiment
- Luminosity measurement
- Absolute cross section measurements
- π^0 analysis
- Results (preliminary)
- Future

History

Theory

- Partial conservation of axial current (PCAC) predicts $A_{\pi \rightarrow \gamma\gamma} \propto m_{\text{quark}} \rightarrow 0$ in the chiral limit
 - Sutherland, Veltman, 1967
- Discovery of the axial anomaly solves problem
 - Classical symmetry of a field theory broken by quantum fluctuations of quark fields
 - Amplitude does not vanish in the chiral limit
 - Adler, Bell and Jackiw, Bardeen, 1969



Chiral Perturbation Theory (χ PT)

- Effective theory of QCD at low energies
- Coupling of π^0 to axial current only possible because π^0 is a Goldstone boson
- π^0 decay a direct consequence of spontaneous symmetry breaking and the axial anomaly

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

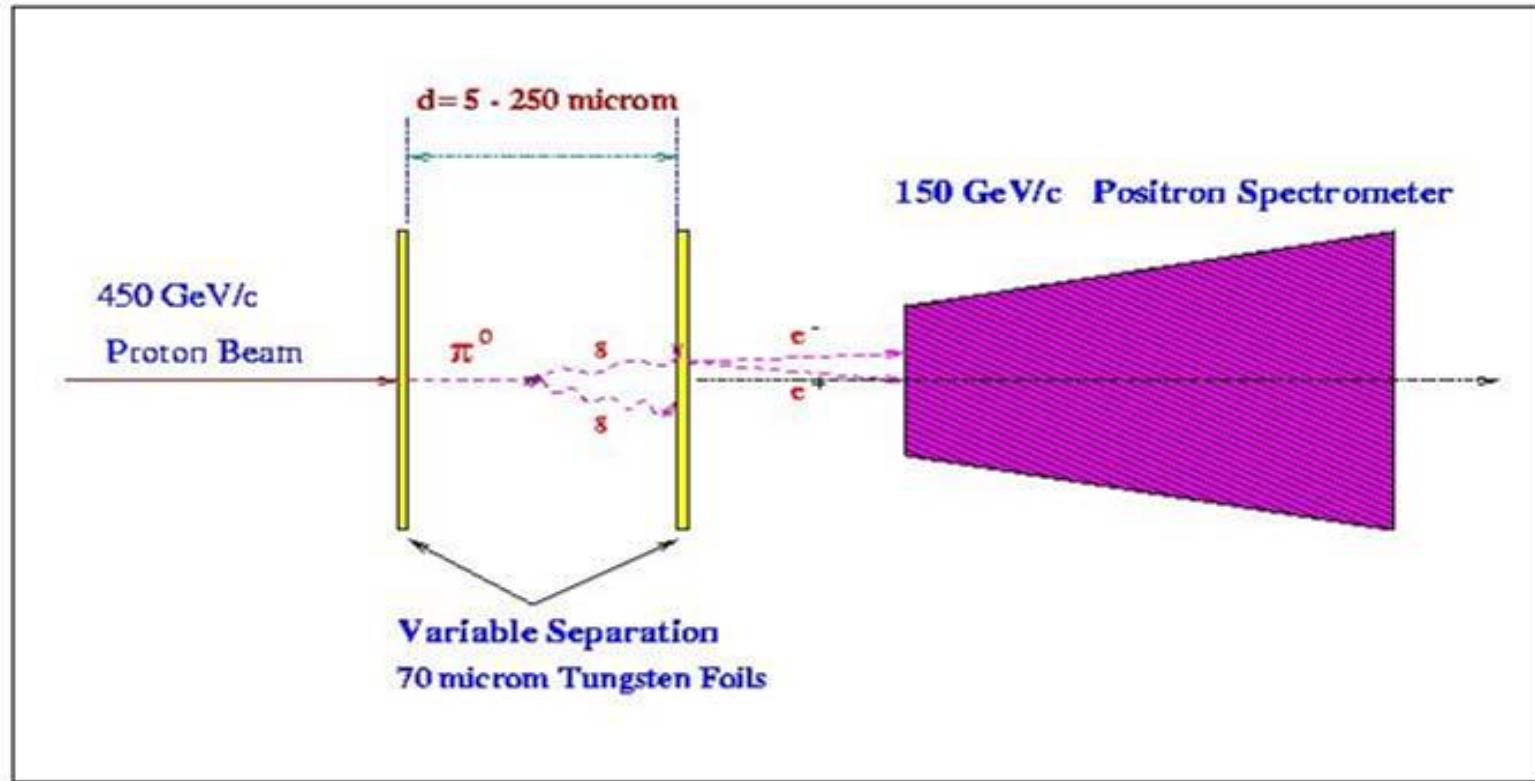
Quark Mass Effects (NLO χ PT)

- If $m_u = m_d$, π^0 pure isospin state
- If $m_u \neq m_d$, π^0 mixes with η and η'
- Anomalies from η and η' must be considered in $\pi^0 \rightarrow \gamma\gamma$
- Rate increases by about 4.5%
 - Moussallam, 1995
 - Goity, Bernstein and Holstein, 2002
- Makes measurement of Primakoff production of η and η' interesting
- QCD sum rules, π^0 - η mixing: 2.7% increase
 - Ioffe and Oganesian, 2007

Experimental Methods (1)

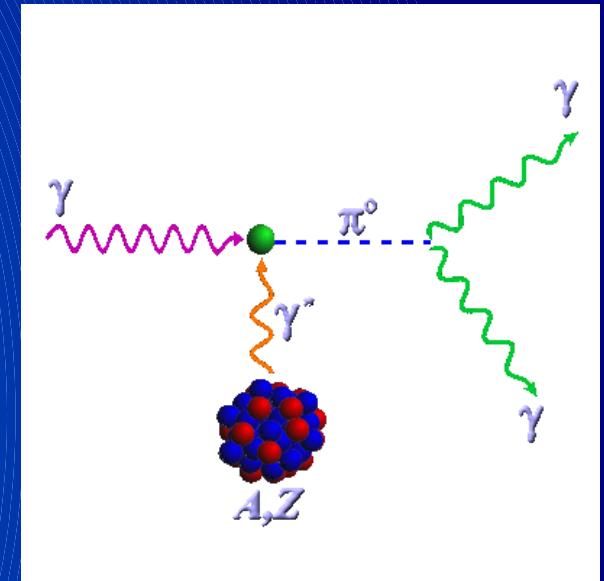
- Direct
 - Emulsion
 - Counters: positron appearance from converter
- Two-photon collisions
 - Measure cross section for π^0 production in $\gamma\gamma \rightarrow \pi^0$
 - Produce photons at an e^+e^- collider

Direct method, counters



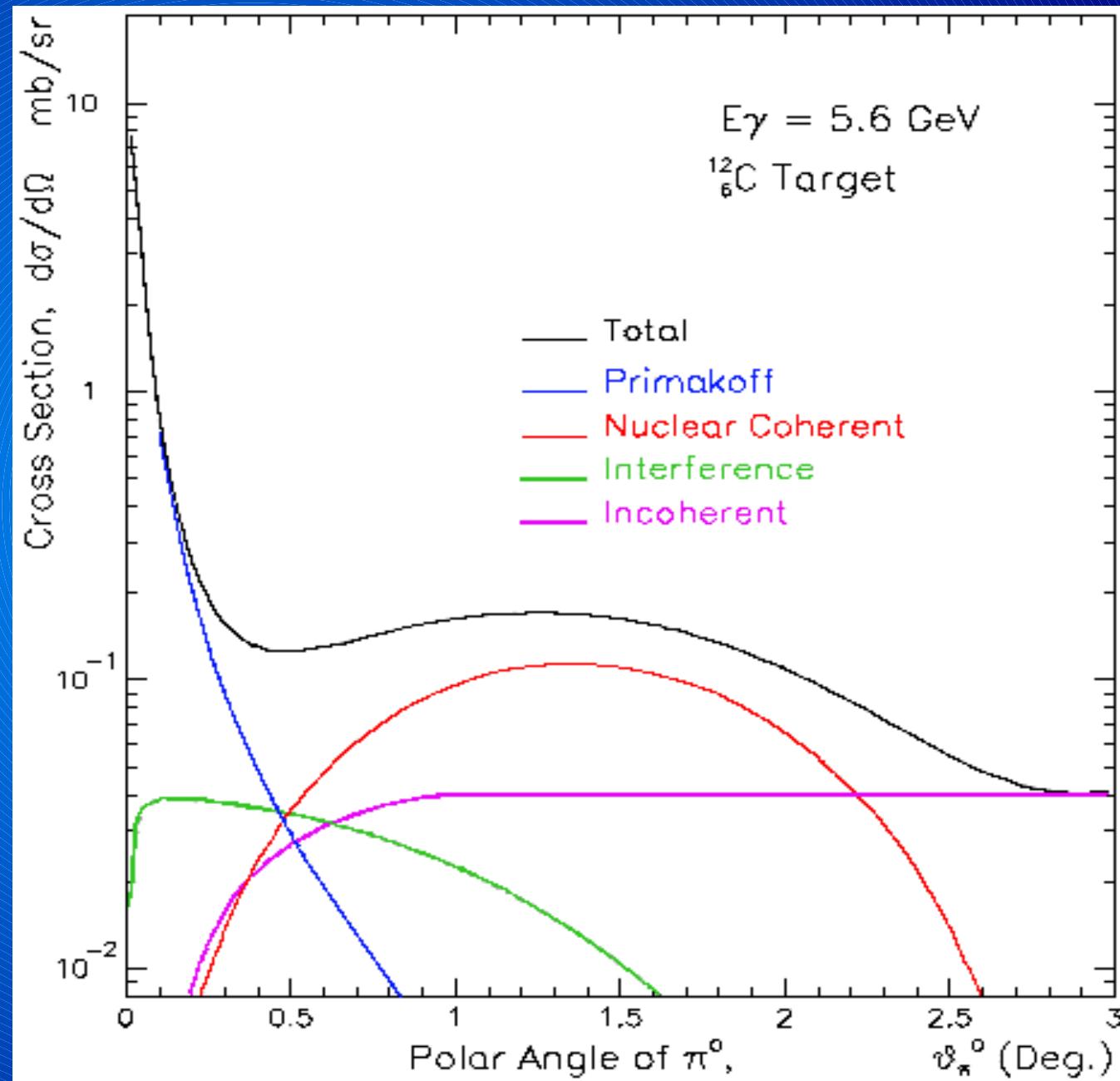
Experimental Methods (2)

- Primakoff
 - Proposed by H. Primakoff, 1951
 - Photon beam
 - Virtual photon target: Coulomb field of nucleus



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

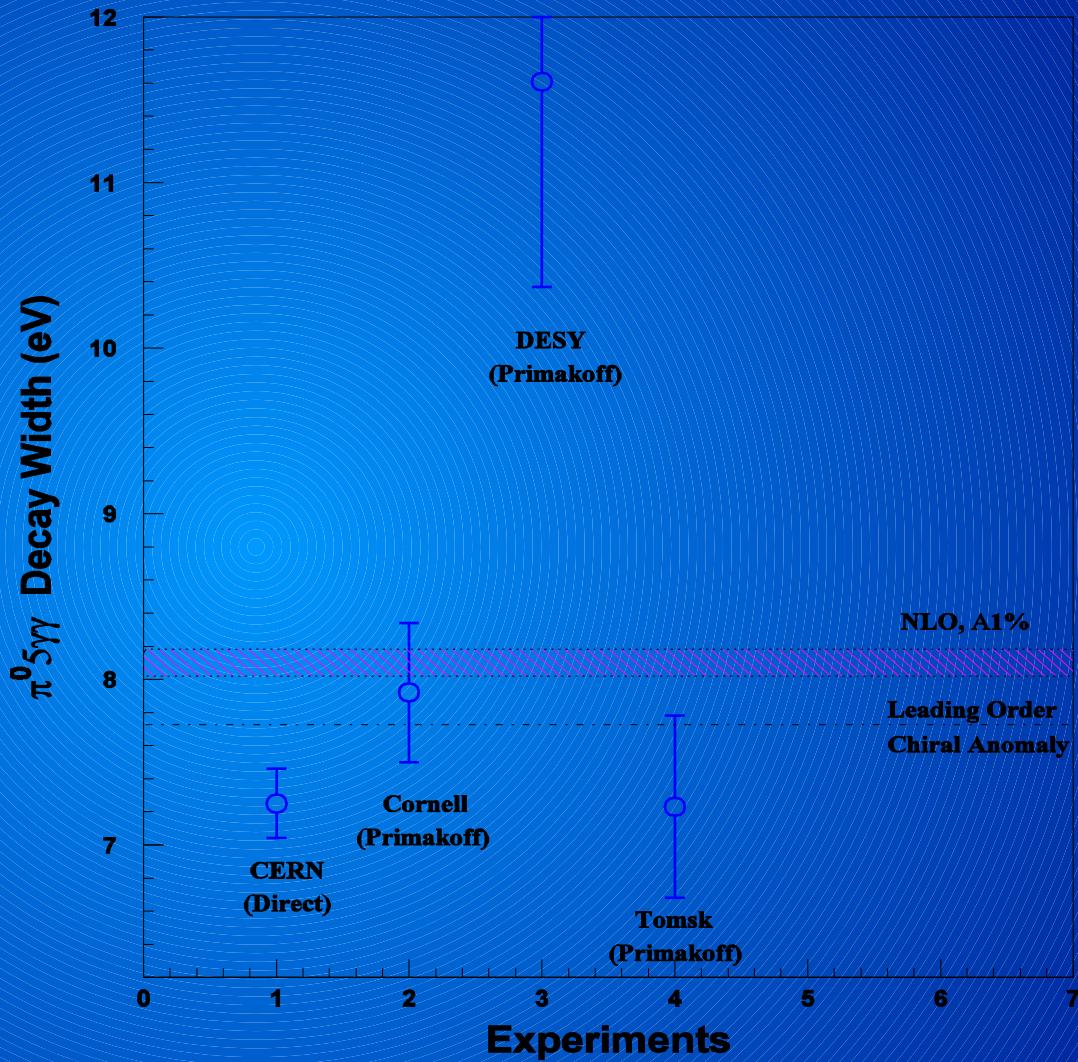
Physics backgrounds



Motivation

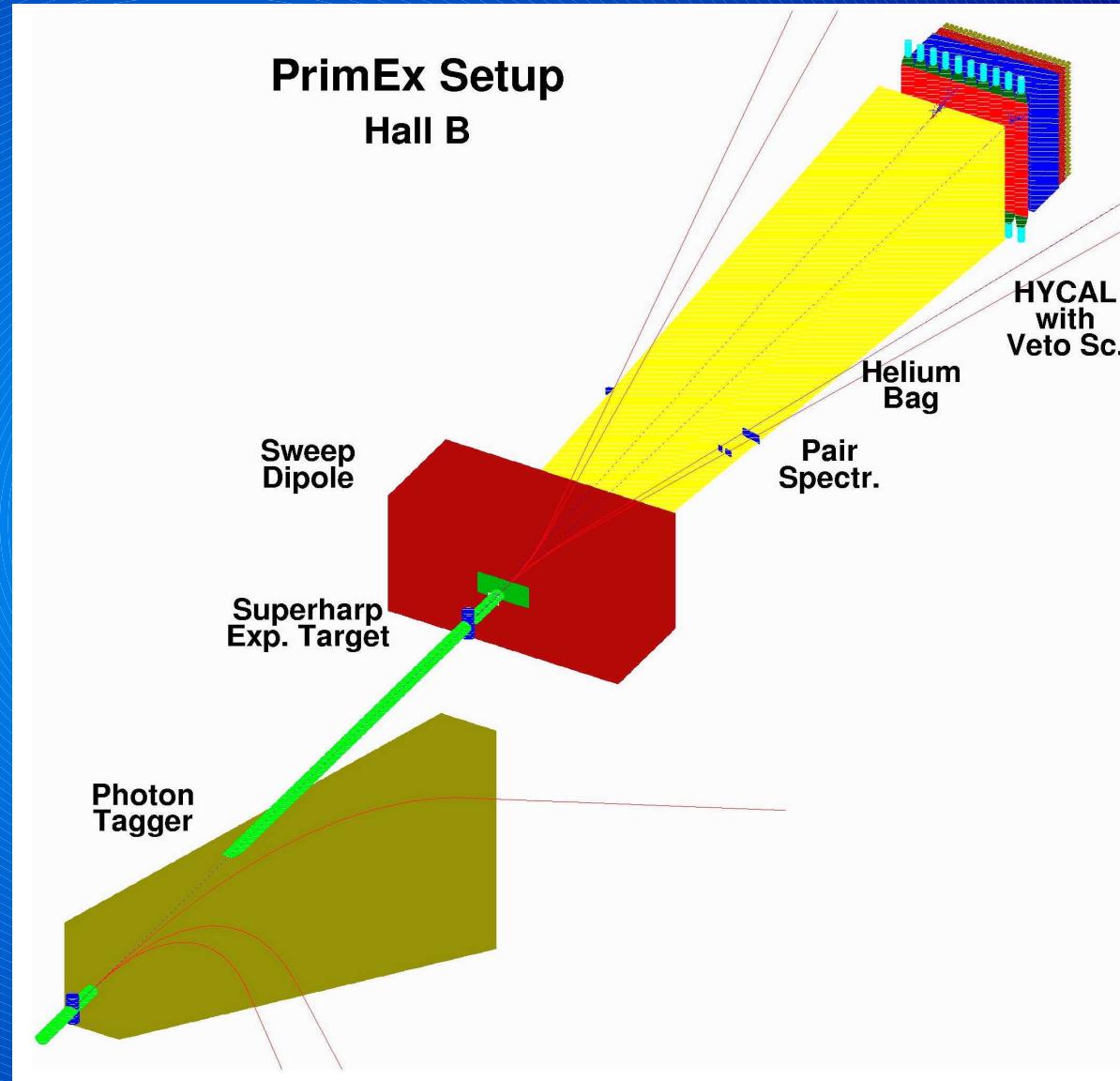
- Theoretical predictions very well-founded, very precise
- New theoretical developments: corrections to lowest order rate at level of a few percent
- Best single measurement uses direct method (CERN, Atherton, 2.9%)
 - Disagrees with lowest order rate
 - Disagrees more with next order χ PT
- Best Primakoff (Cornell bremsstrahlung beam, Browman, 5.2%) marginally disagrees with Atherton
- η Primakoff measurement by Browman disagrees with world average

Previous Measurements



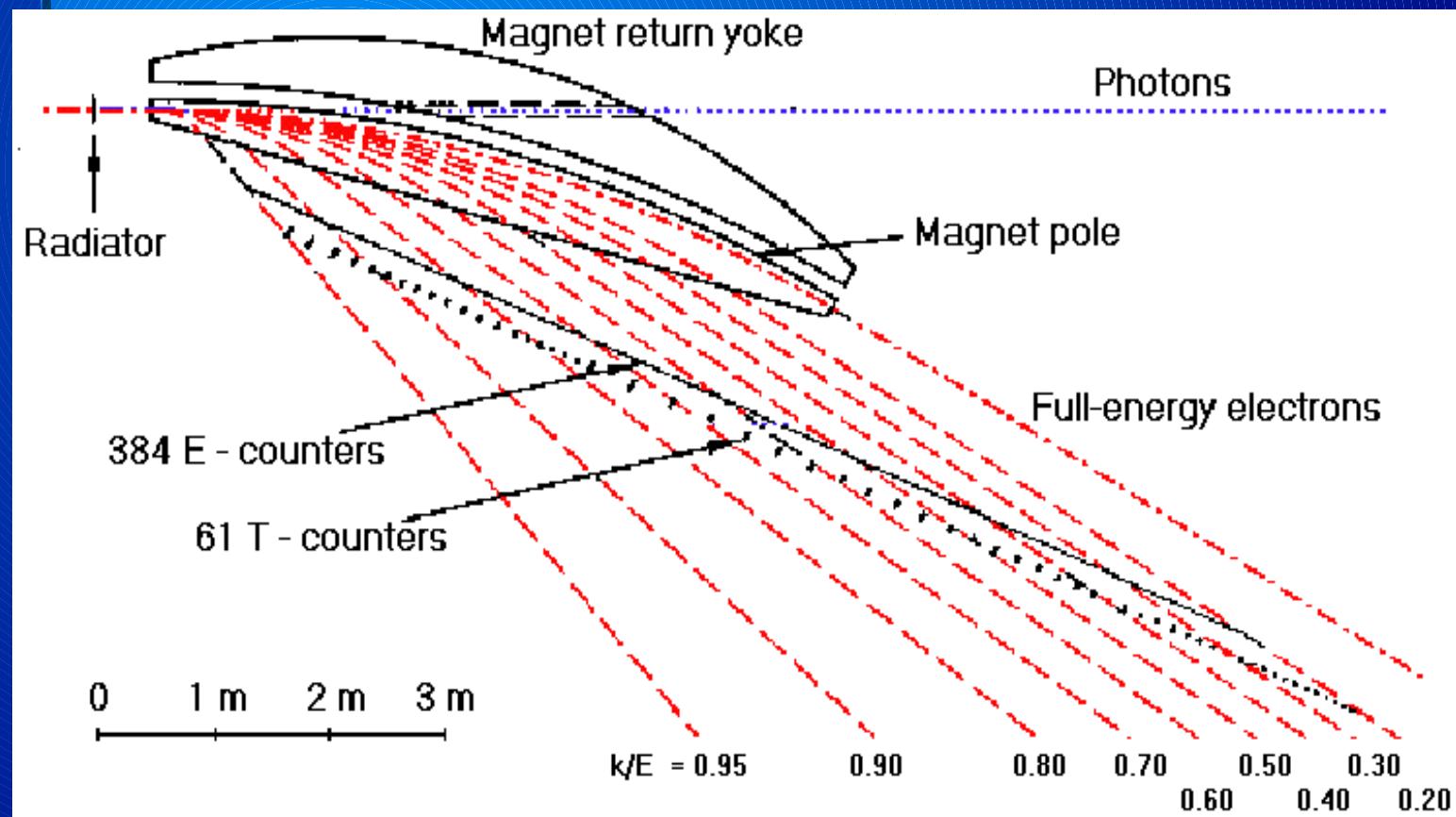
- Measurement at 1-2% level called for

PrimEx Experiment



Hall B tagged photon beam

- 61 T-counters (thick, timing)
- 384 E-counters (energy)
- Highest γ energies, 11 T-counters: 4.9-5.6 GeV
- Flux $O(10^7)$ photons/second



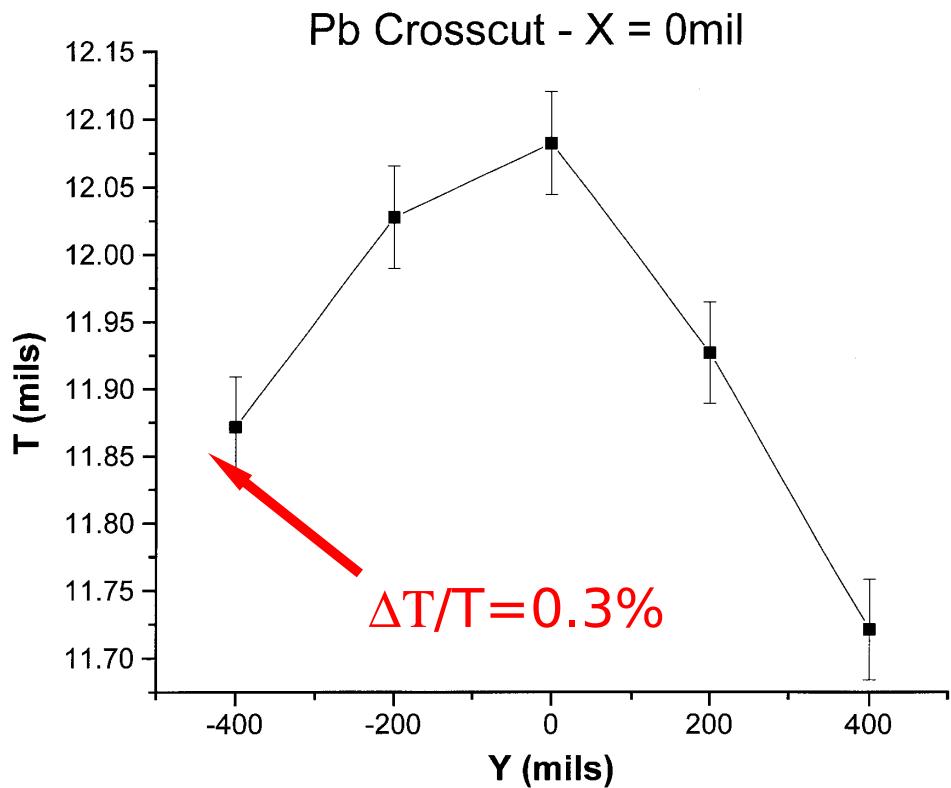
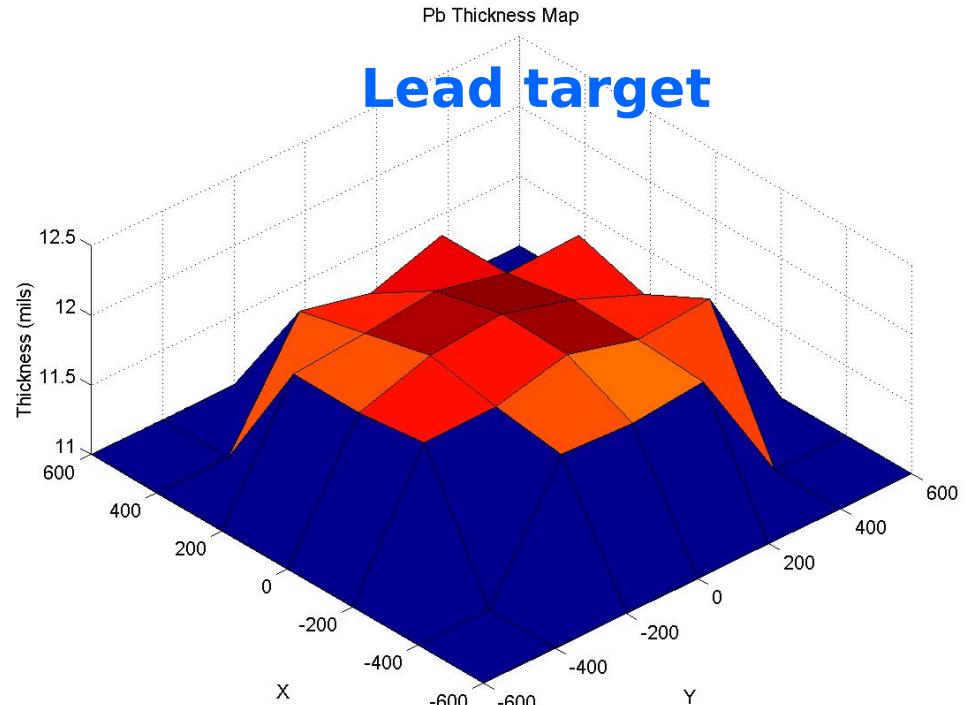
Detector Systems (1)

- Targets
 - 5% radiation length
 - Carbon, lead
- Pair Spectrometer
 - 18D36 dipole magnet, 15 kG
 - Scintillator hodoscope
- Helium bag
- Charged particle veto: scintillator hodoscope

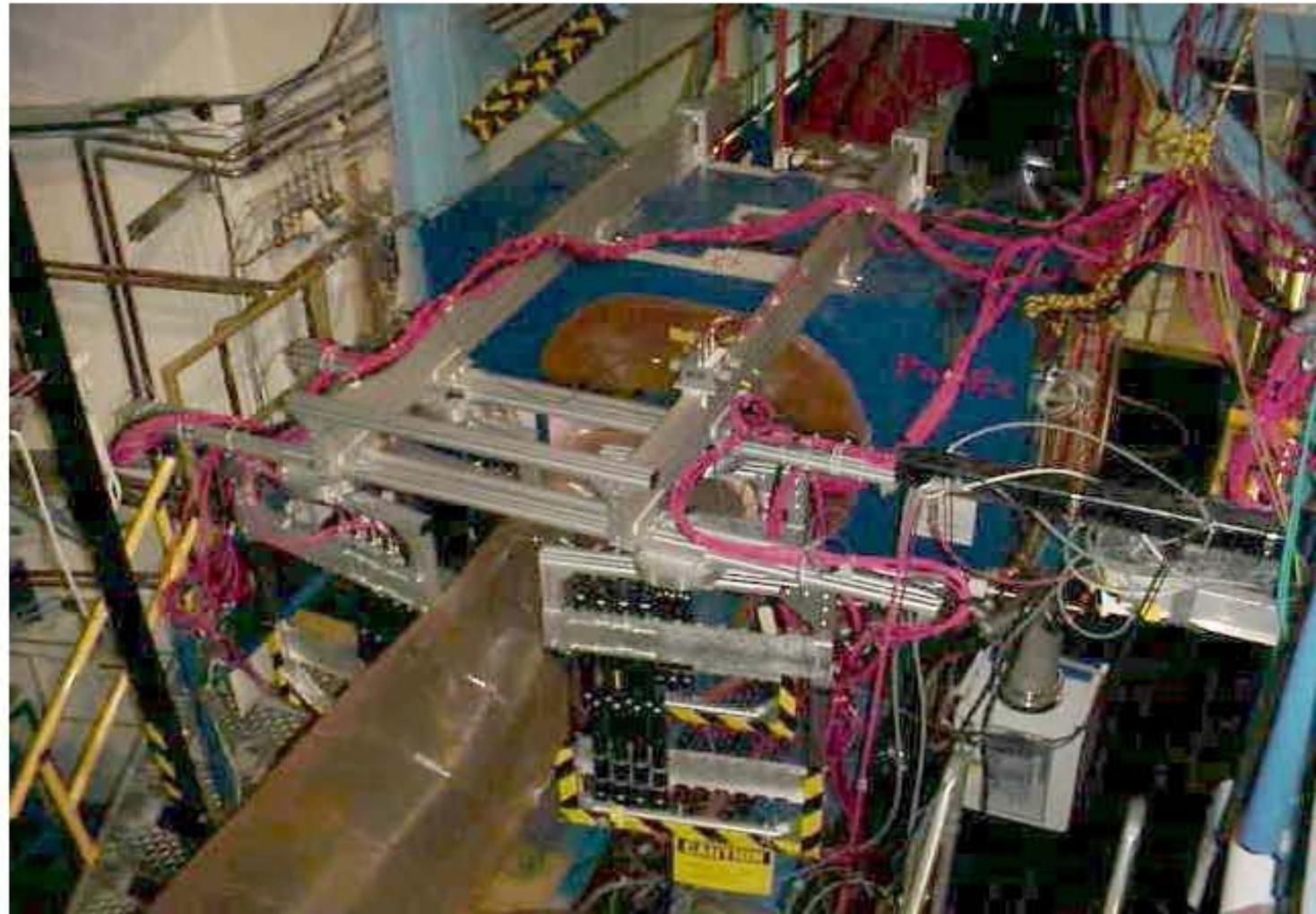
PRIMEX Targets



The effective number of carbon atoms/cm² in the carbon target is known to precision of $\pm 0.05\%$



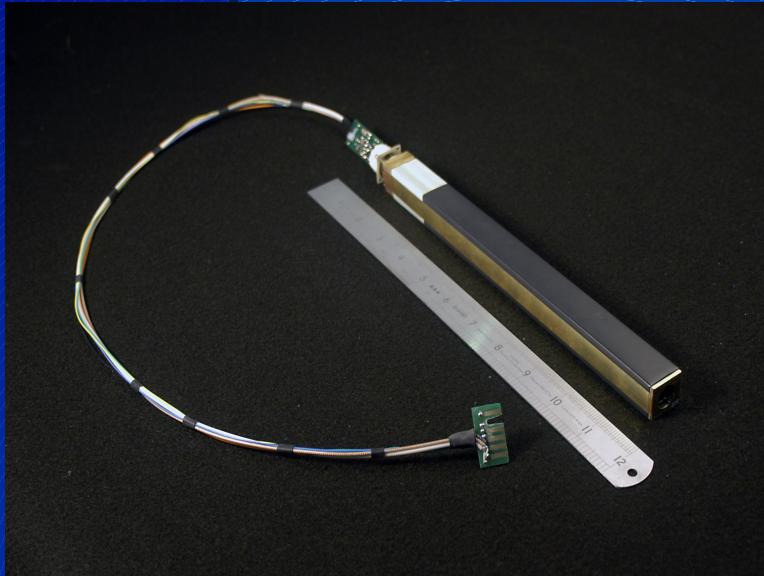
Upstream Devices



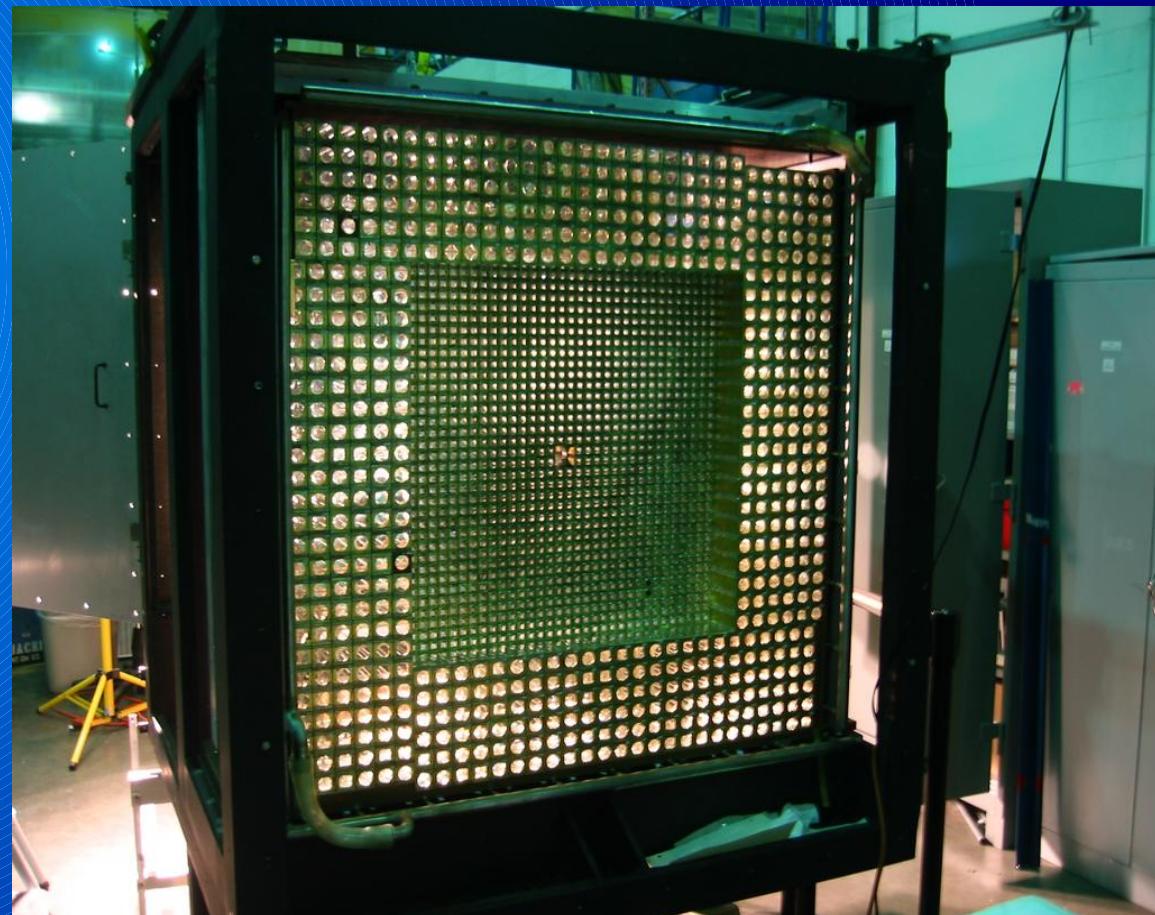
Detector Systems (2)

- Hybrid Calorimeter (HyCal)
 - Lead tungstate scintillating crystals
 - Lead glass
 - Phototube read-out
 - Temperature control
 - LED light monitoring system
 - Movable stage for calibration

HyCal



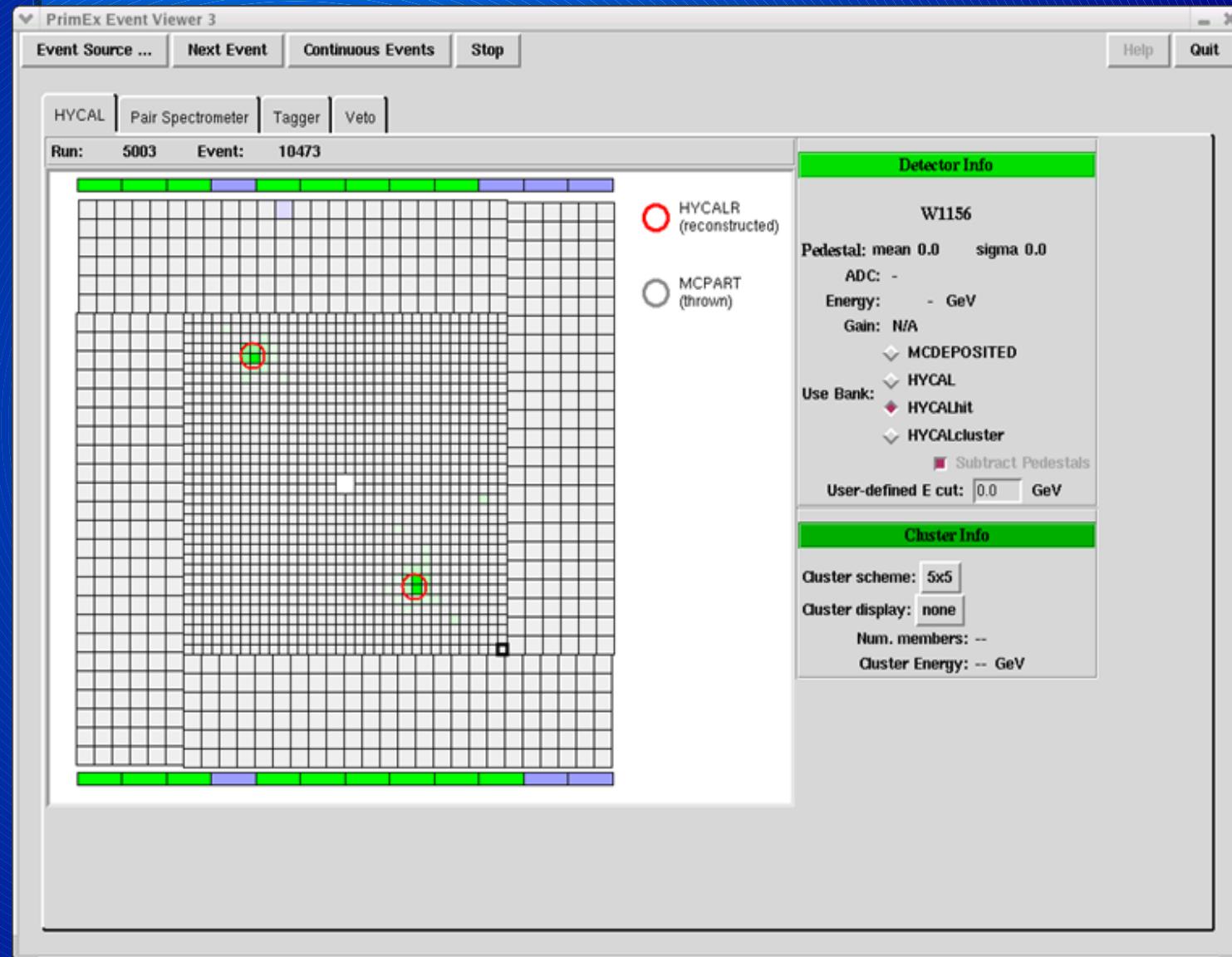
- Energy resolution
 - Lead tungstate: $2.5\%/\sqrt{E}$
 - Lead glass: $5.4\%/\sqrt{E}$
- Position resolution
 - Lead tungstate: $2.6 \text{ mm}/\sqrt{E}$
 - Lead glass: $\sim 6 \text{ mm}/\sqrt{E}$



Detector Systems (3)

- Gamma profiler: scintillating fiber arrays, x and y views
- Total absorption counter: lead glass block
- Trigger: total energy sum in HyCal \times tagger
- Data acquisition system
 - CODA
 - Fastbus/VME

Event Display



Luminosity Measurement (1)

- Target thickness
- Absolute tagging ratios
 - Probability of photon in beam line given electron in tagger
 - Use total absorption counter as 100% efficient device for 5 GeV photons
 - Measure at very low rate (10^{-4} of normal flux)

Luminosity Measurement (2)

- Relative tagging ratios
 - Use pair spectrometer L-R coincidence
 - Measure stability of tagging ratios
 - Check for systematics in extrapolation of absolute measurement to normal running rates

Luminosity Measurement (3)

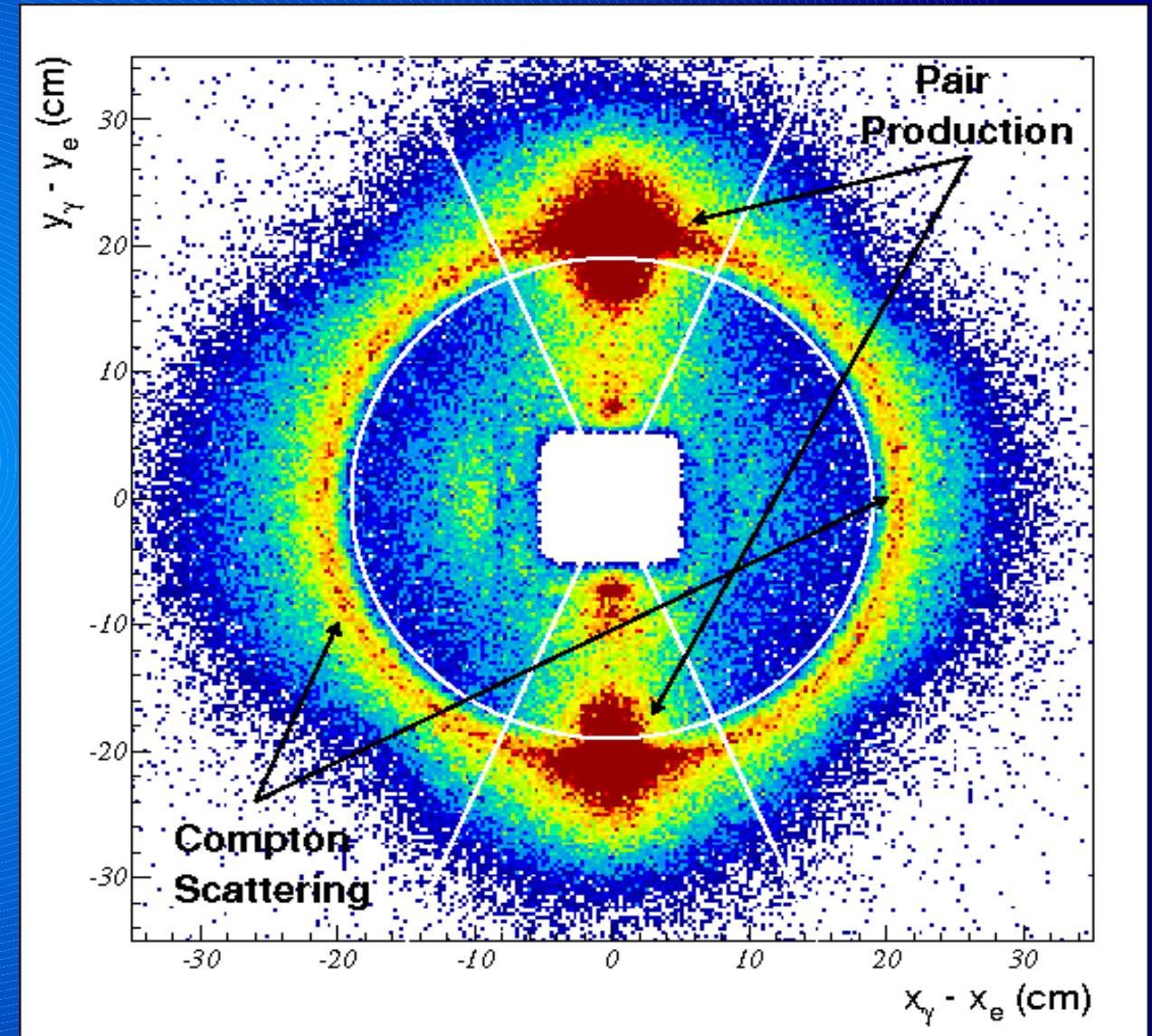
- Flux measurement
 - Clock triggers mixed in with π^0 triggers
 - Measure rate (counts per unit time) in tagger counters using pipeline TDC's
 - Measure live time with scalers

Absolute Cross Section Measurements

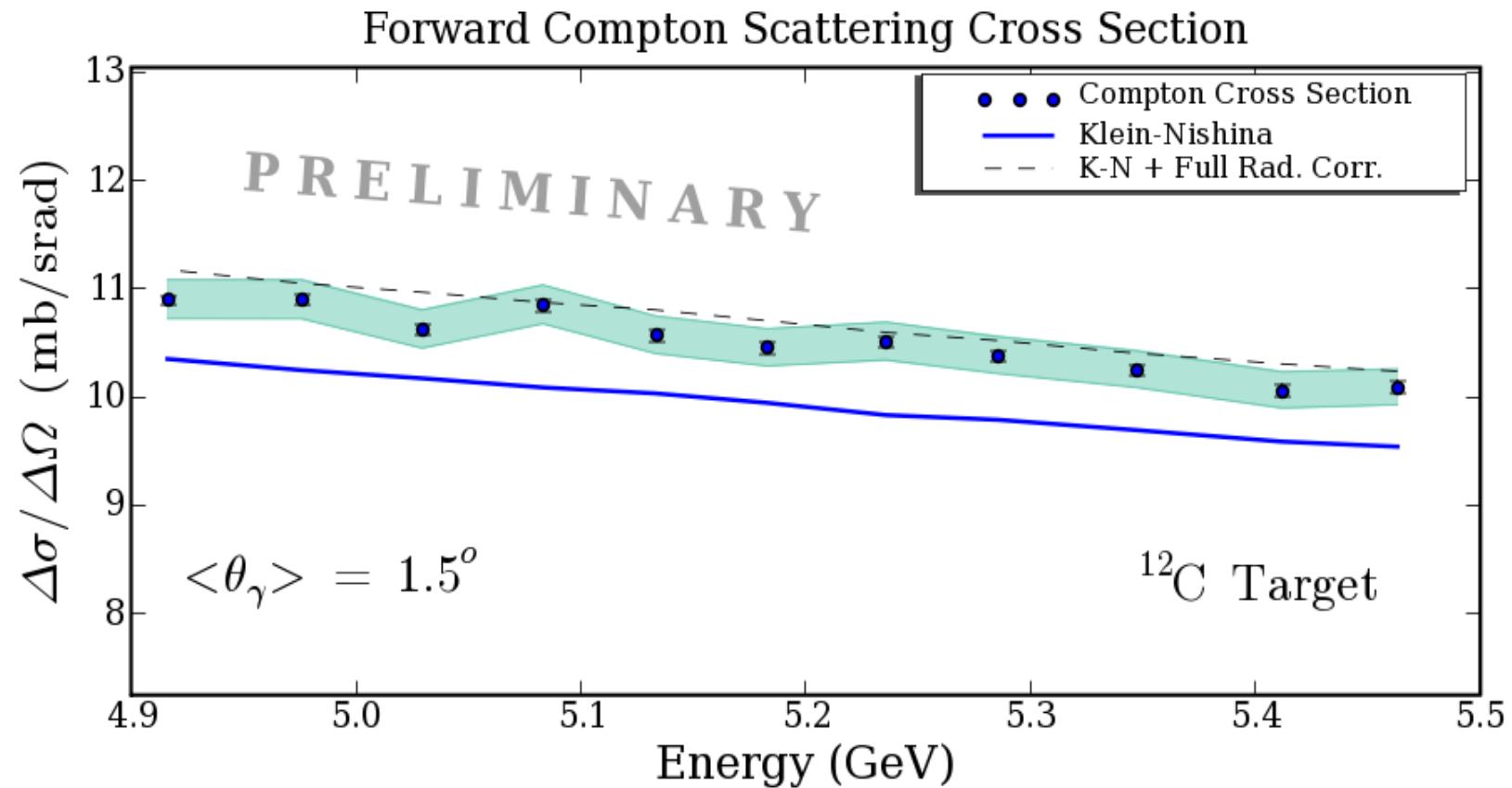
- Try to use PrimEx to measure a cross section where the answer is known
 - Compton scattering from atomic electrons ($\gamma e^- \rightarrow \gamma e^-$)
 - Pair production ($\gamma\gamma^* \rightarrow e^+e^-$)
- Check of
 - Luminosity
 - Geometric acceptance
 - Efficiency

Compton scattering

- Pair spectrometer magnet off
- Standard target
- Lowered luminosity

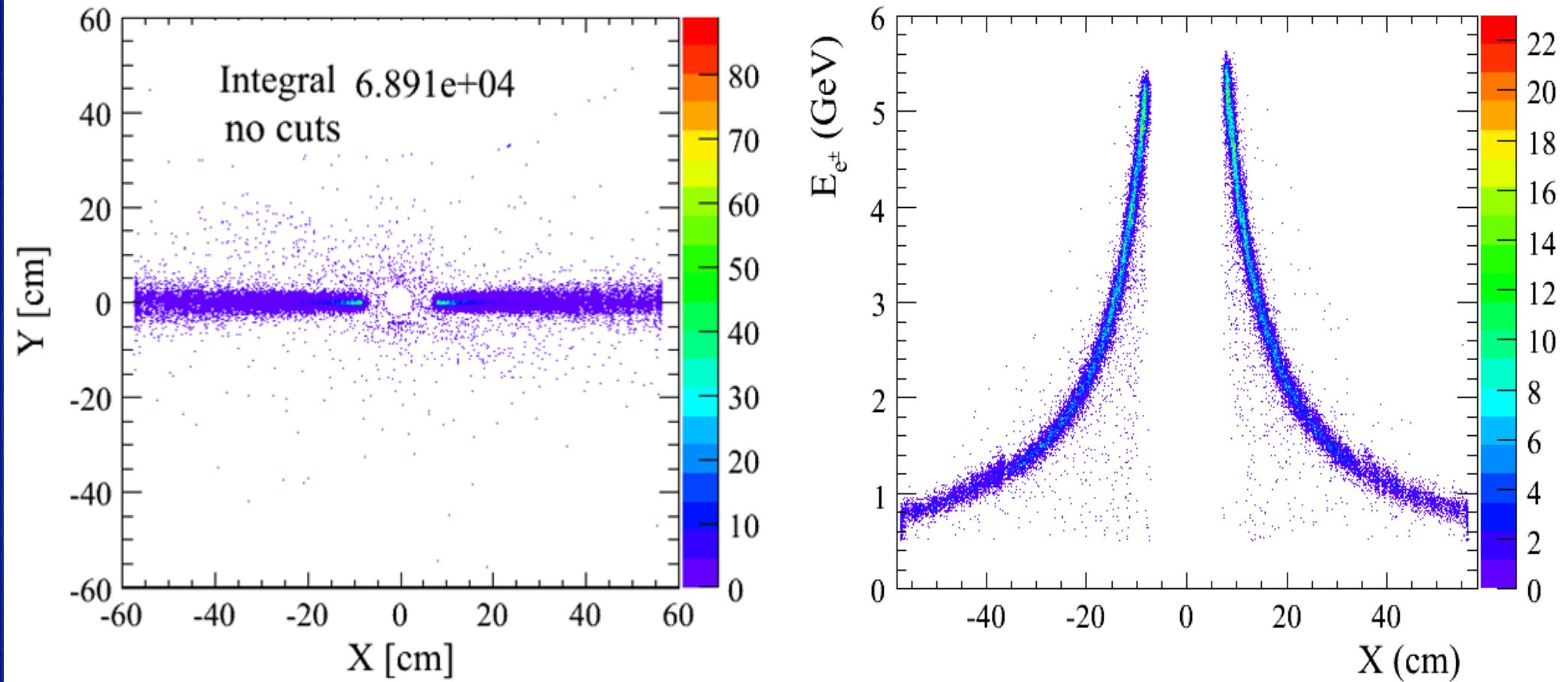


Compton Cross Section



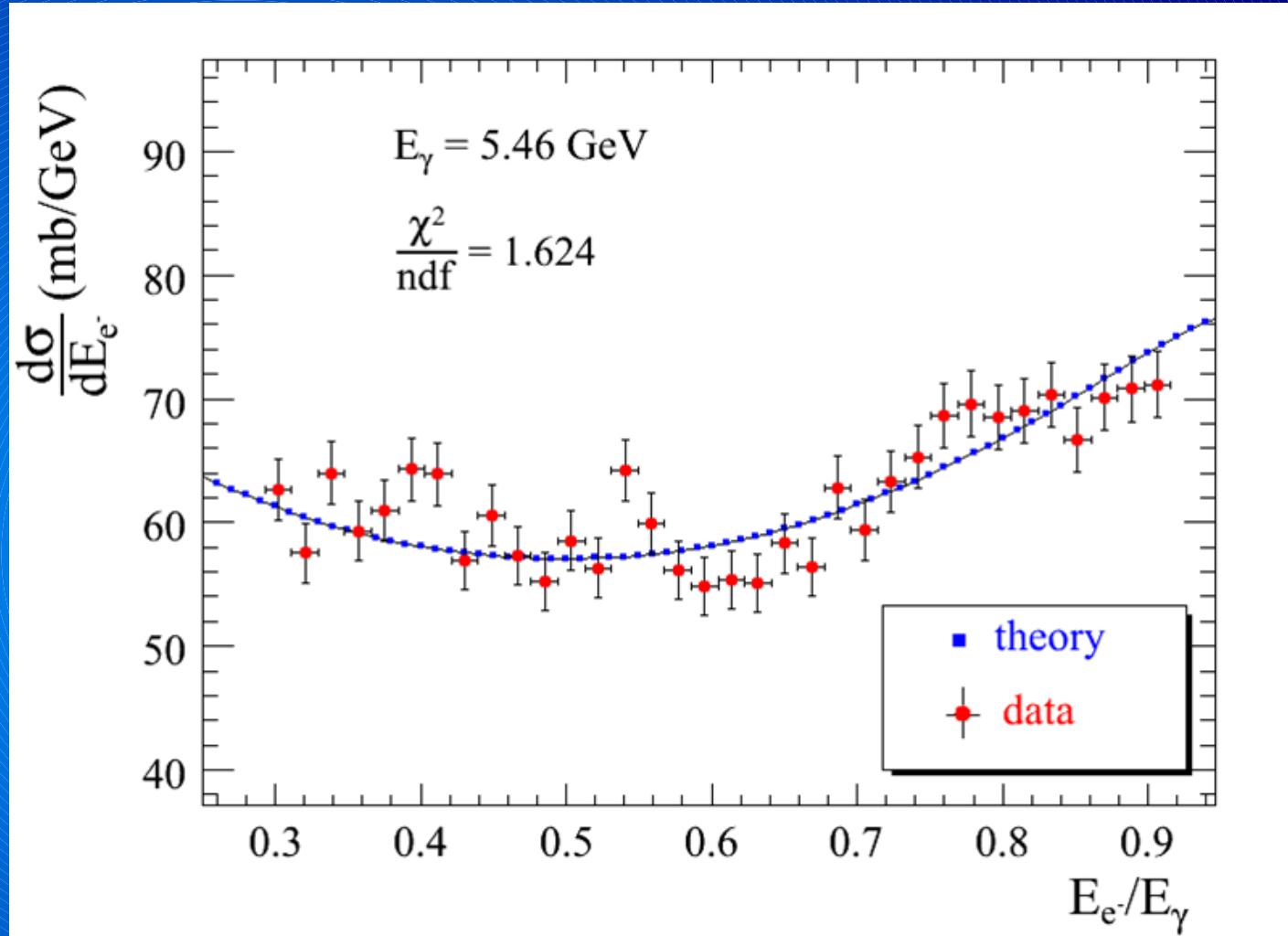
- Total estimated error: 3.5%
- Work in progress to reduce systematic error to 1-2%

Pair production



- Pair spectrometer magnet lowered
- Lowered luminosity

Pair Production Cross Section



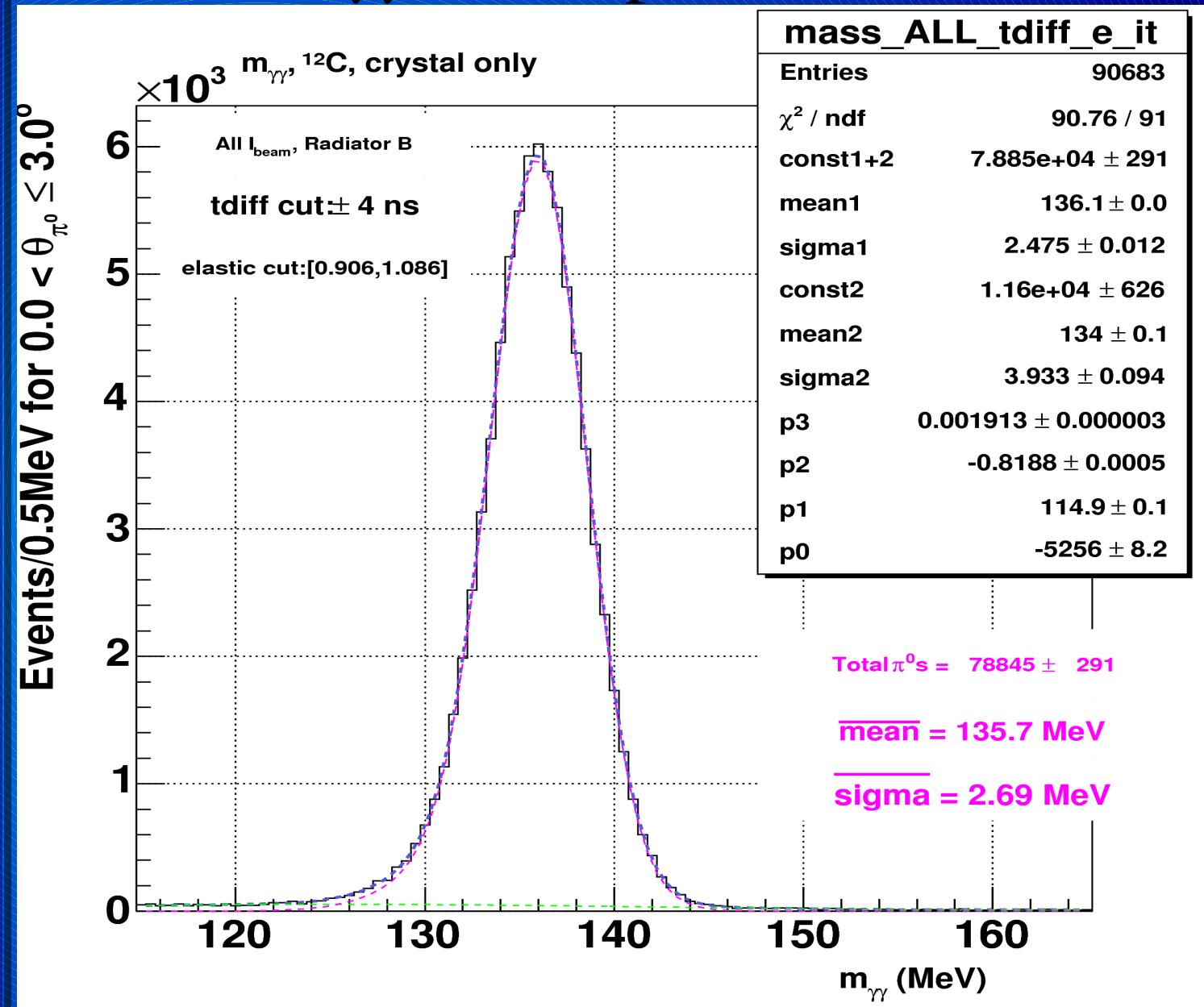
- Agreement with theory within 2.5%
- Work in progress to reduce systematic errors to 1-2% level

π^0 Analysis

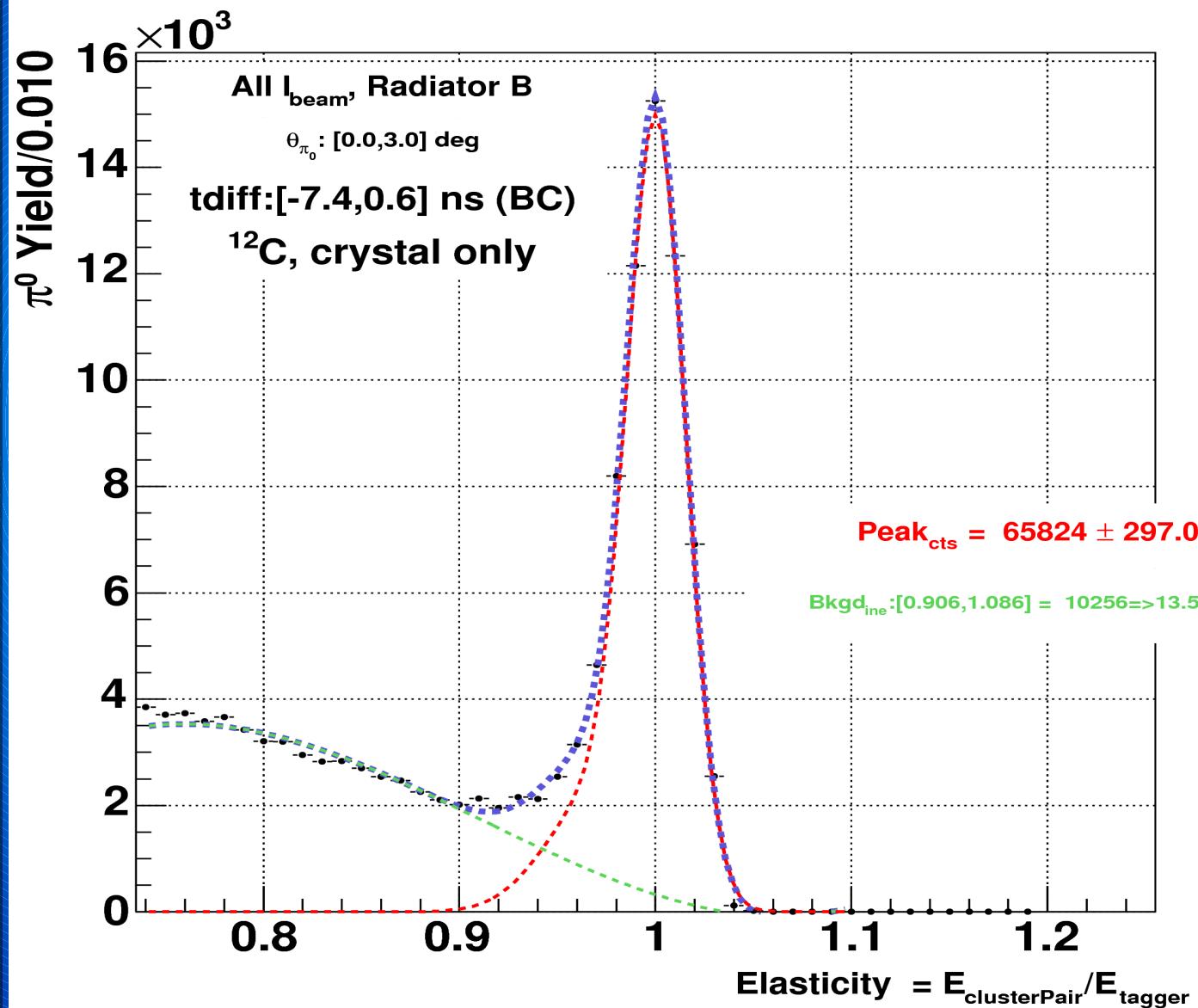
Analysis variables

- $\gamma\gamma$ mass: require π^0 mass
- Elasticity, $x = E_\pi/E_{\text{beam}}$: require full beam photon energy
- Timing: HyCal in time with tagger

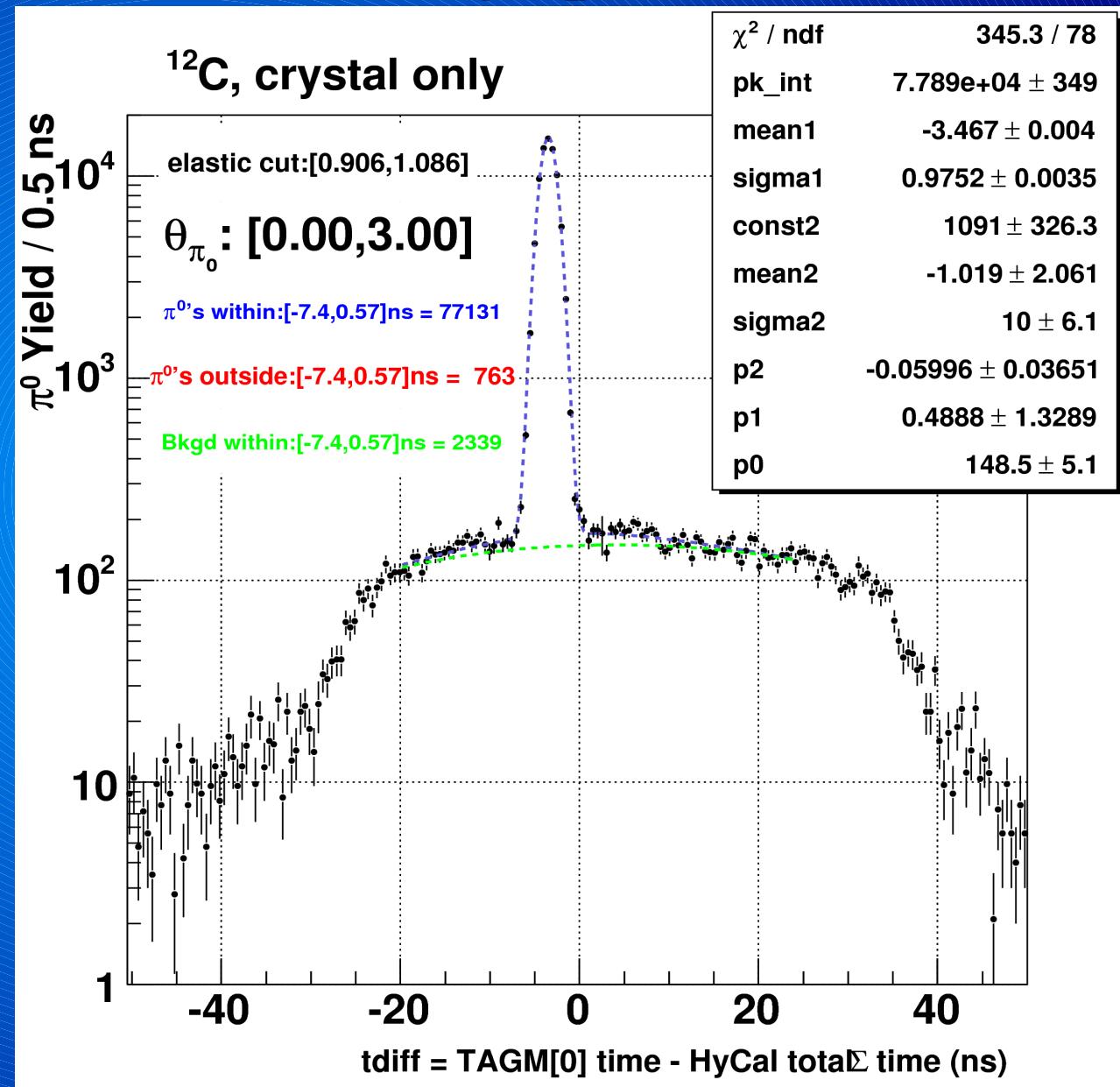
$\gamma\gamma$ mass spectrum



Elasticity spectrum



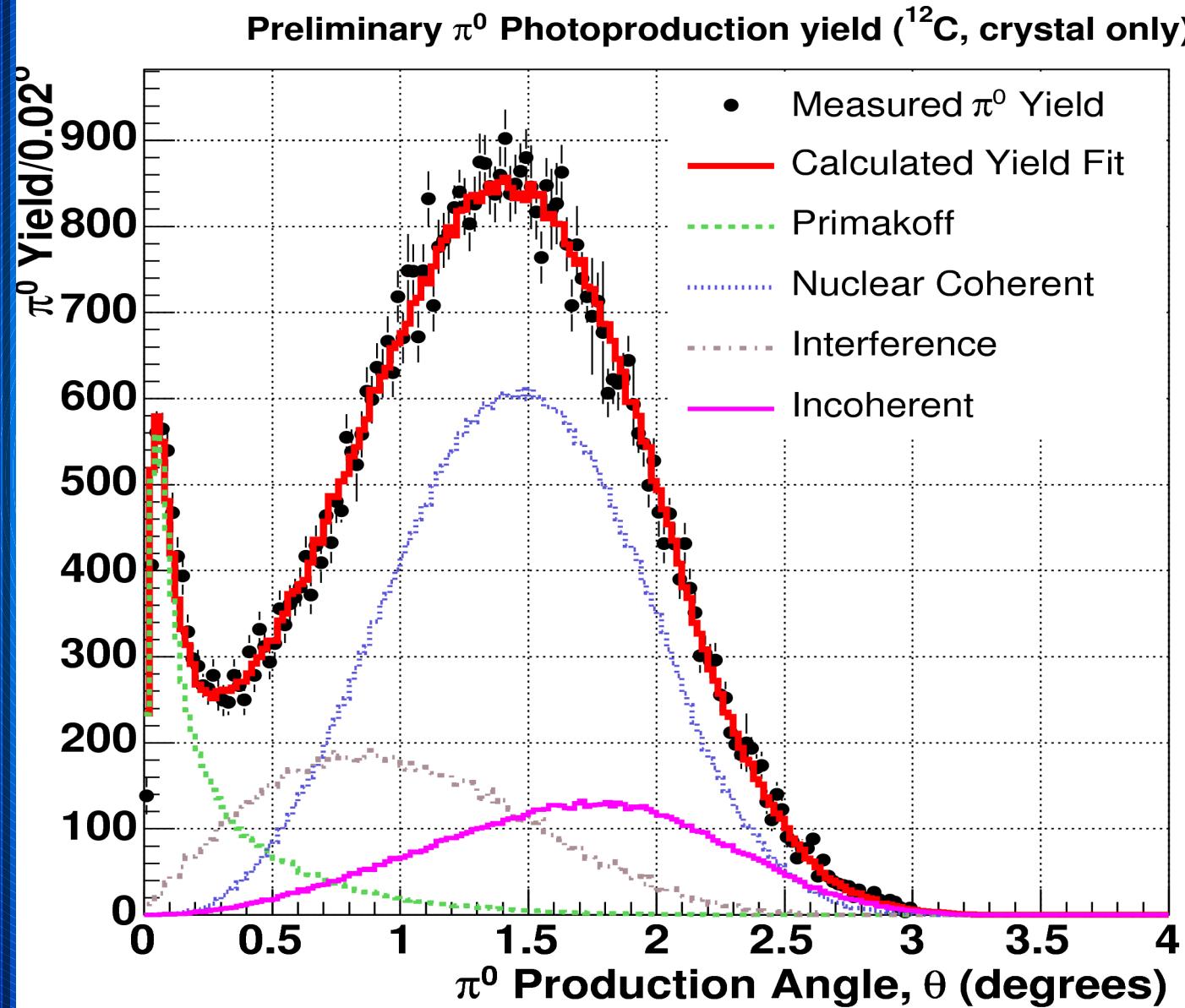
Timing spectrum



Analysis Teams

- Three independent analyses
- Substantially different analysis approaches
- All results consistent with each other

Fit to Extract Primakoff Signal



Systematic Errors

Photon flux	1.1%
Target thickness (+impurity)	0.4%
Background subtraction	1.0%
Incoherent backgr. (shape)	1.0%
Analysis cuts	0.5%
HyCal Response function	0.5%
Beam energy (+parameters)	0.4%
Acceptance	0.3%
Total	2.0%

Results (preliminary)

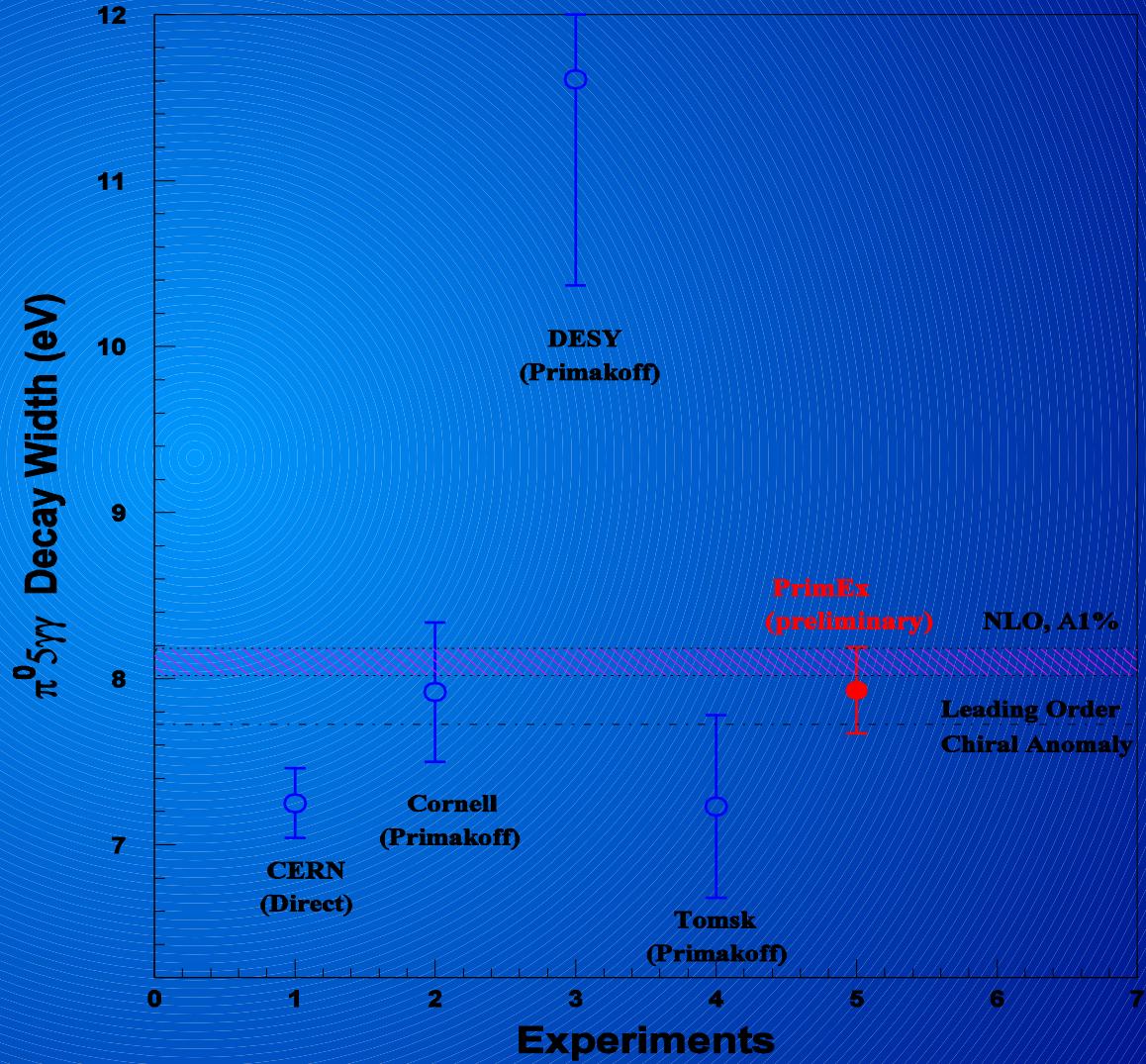
- Combined result, crystal only:

$$\Gamma_{\gamma} = 7.93 \pm 0.17 \pm 0.16 \text{ eV}$$

(2.1%) (2.0%)

- Consistent with lowest order and NLO
- Higher than CERN direct

Preliminary Result



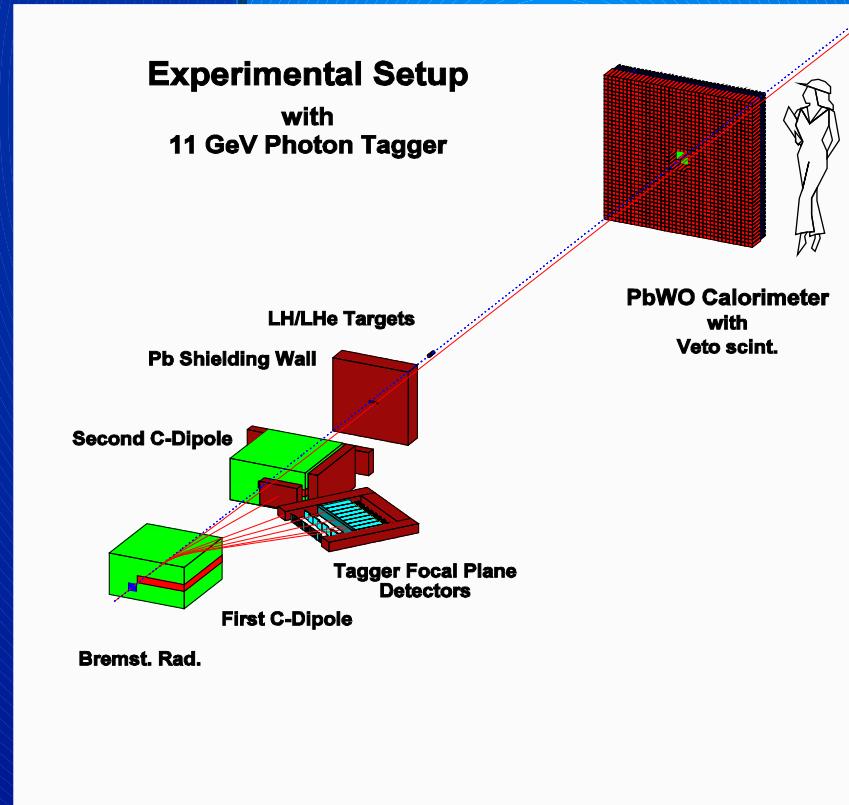
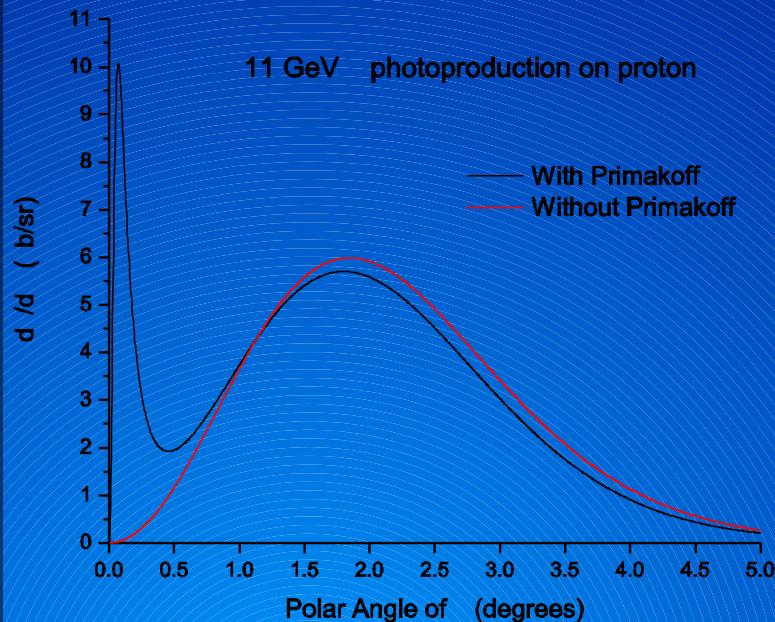
Improvements for Final Result

- Add lead glass region of HyCal
- Finish analysis of lead target
- Add in full statistics for carbon
- Better model incoherent nuclear background (theory)
- Better control of systematic errors

Future

- More running at 6 GeV
 - Run more efficiently
 - Get proposed statistics
- Rich program at 12 GeV

PrimEx at 12 GeV



- Primakoff cross section for π^0, η, η'
- Transition form factors for $\gamma\gamma^* \rightarrow \pi^0, \eta, \eta'$

Summary

- Preliminary result for π^0 lifetime from PrimEx
- Consistent with χ PT
- Improvements in works for final result
- More running at 6 GeV desired
- 12 GeV program being planned

Analysis A

- Fit 2-photon mass in angular bins to get π^0 yield
- Fit resulting π^0 yields to get elastic yield
- Dustin McNulty

Analysis B

- Use energy kinematic constraint when fitting 2-photon mass
- Use π^0 mass kinematic constraint when fitting for elastic yield
- Ilya Larin

Analysis C

- Transform to coordinate system with no covariance between π^0 mass and elasticity
- Fit resulting 1-dimensional yield
- Eric Clinton

