A Precision Measurement of the Neutral Pion Lifetime via the Primakoff Effect

Jefferson Lab Experiment E99-014
PrimEx Collaboration

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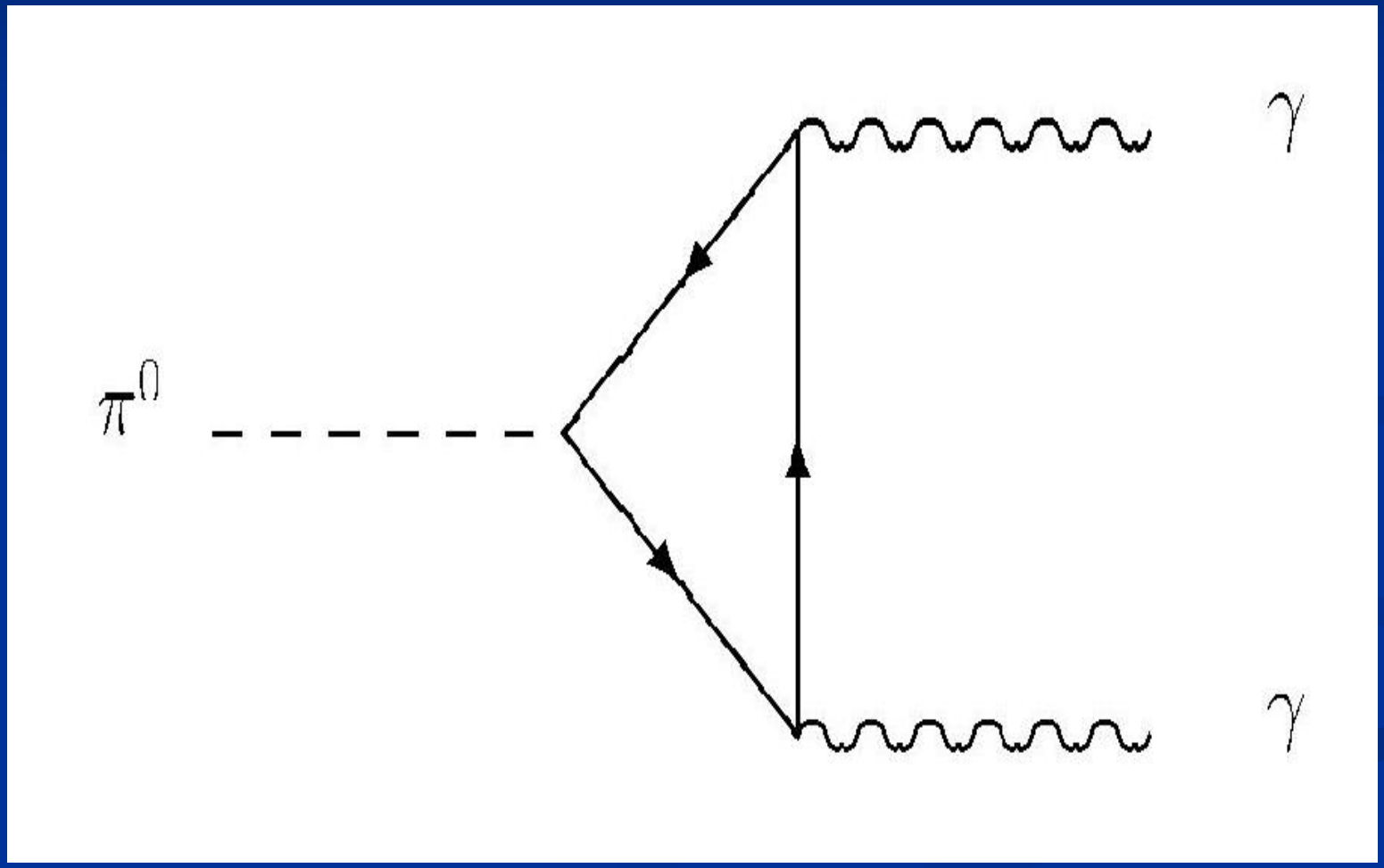
The goal of the PrimEx Collaboration

- Make a high precision measurement of the π_o to $\gamma\gamma$ decay rate dominated by the axial anomaly.
- This will be done using the Primakoff Effect, photopion production in the Coulomb field of the nucleus.
- Using the tagged photon facility in Hall B, a state of the art Hybrid Calorimeter, and well understood nuclear targets, the collaboration hopes to measure the Primakoff cross section to 1.5% or better.

The Chiral Anomaly



What is the physics motivation?

- In the Chiral limit where the u and d quark masses vanish, we can exactly compute the decay amplitude.

$$A_{\gamma\gamma} = \alpha N_c / (3\pi f_\pi)$$

- And we know the decay width of the π_o to $\gamma\gamma$.

$$\Gamma_{CL} = m_\pi^3 |A_{\gamma\gamma}|^2 / (64\pi) = 7.725 \text{ +- } 0.044\text{eV}$$

More physics motivation

- Real world quark masses are not 0 MeV
  - Mass of u,d quarks on order of 5-7 MeV.
- Adler and Bardeen
  - Non-renormalization theorem gives quark mass correction.
  - The π^o mixing with η and η' -- 2-3% increase in the decay width.
- Smaller corrections (~ 0.001)
  - Saturation of the chiral anomaly by heavier mesons.
- Thus, $\Gamma(\pi^o \text{ to } \gamma\gamma)$ is the most accurate prediction in QCD, depending only on the number of colors.

Recent Theory Developments

- Joity, Bernstein, Donoghue, and Holstein
  - Calculated NLO corrections to π^0 width.

- Result: $\Gamma_{NLO} = 8.10 \pm 0.081$ eV

  $\Gamma_{CL} = 7.725$ +- 0.044eV

  $\Gamma_{PDG} = 7.84 \pm 0.556$eV

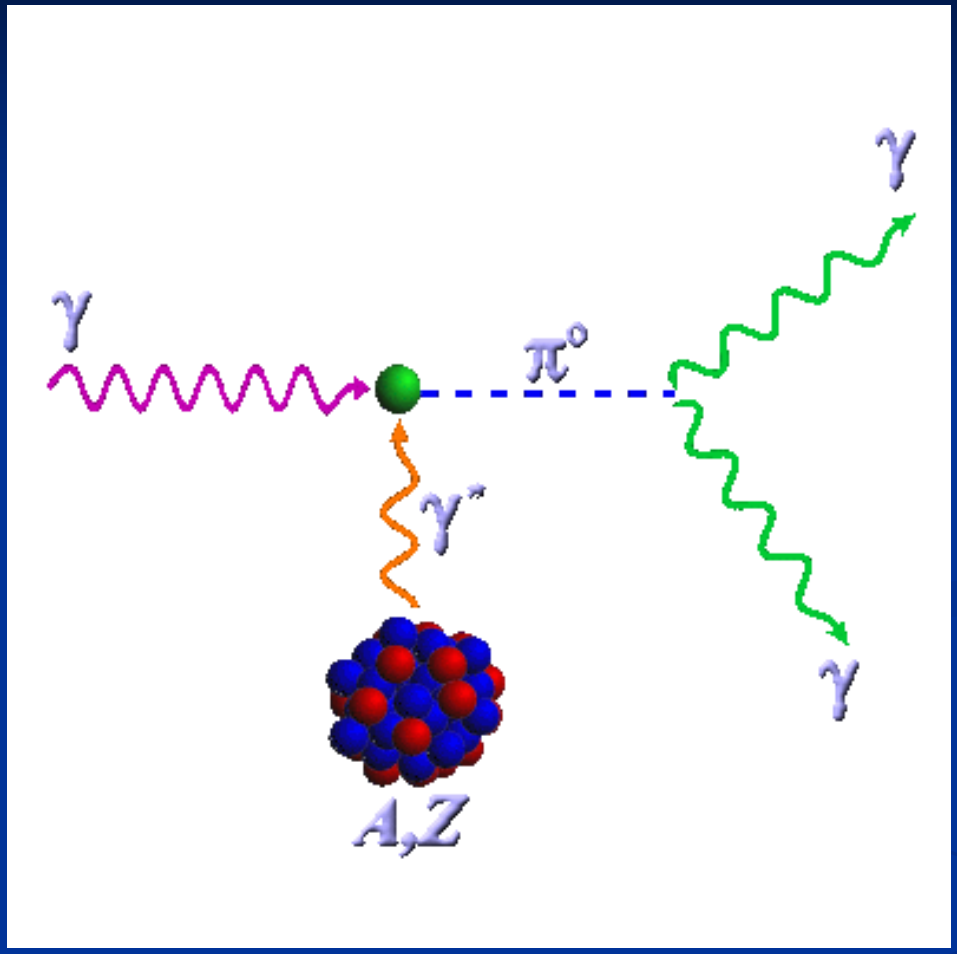
- Mousaallam et. al. have a very similar result.

Other measurements of the π_o decay.

-There are three reactions that allow us to conveniently measure the π^o decay width.

- "Direct measurement" through time of flight data
- $\gamma\gamma$ collisions
- The Primakoff Effect.

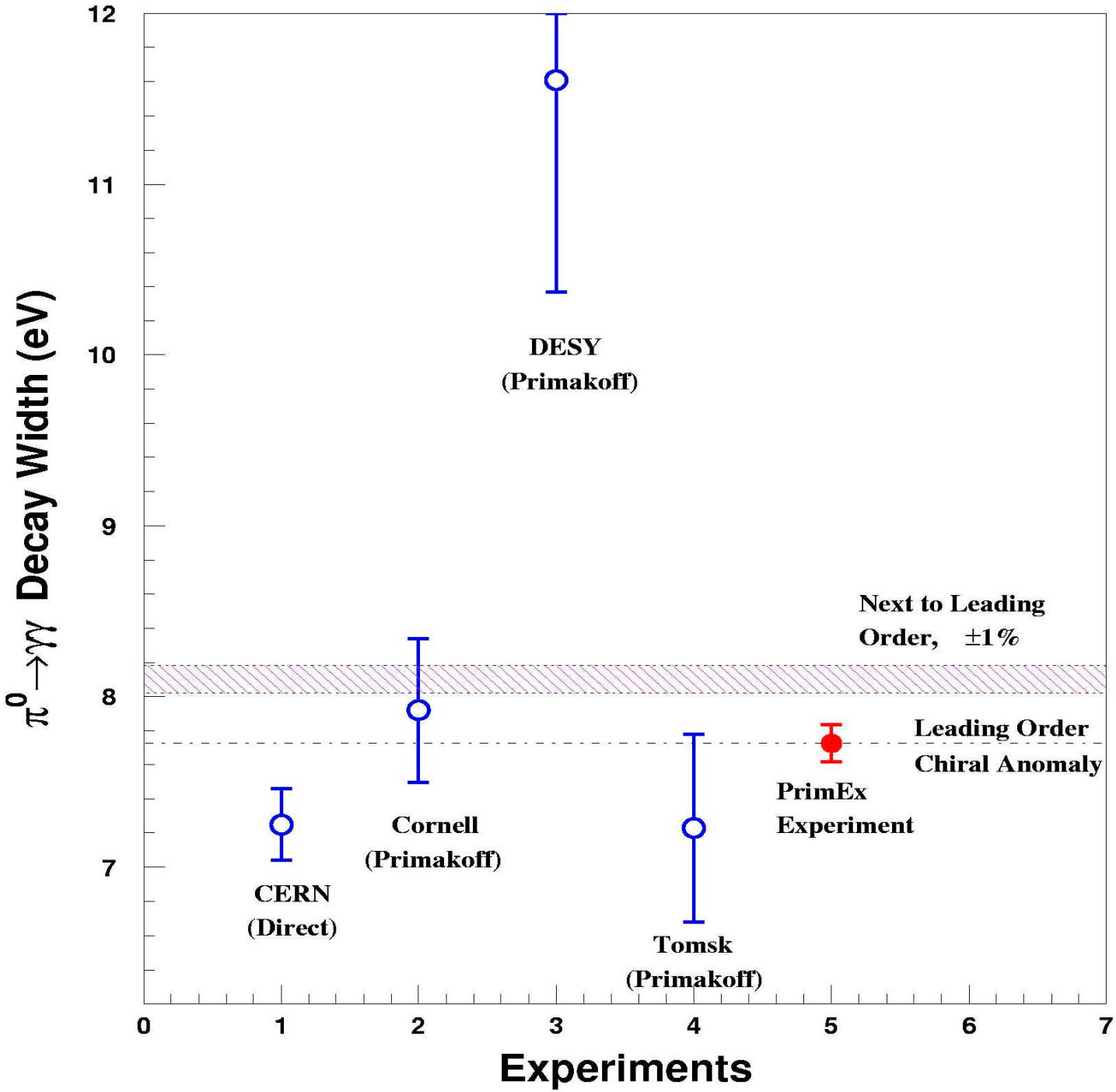
The Primakoff Effect



- The Primakoff Effect is photopion production in the Coulomb field of a high Z nucleus.

Previous Primakoff Experiments

- Browman et al.
  - $\Gamma = 8.02 \pm 0.42$eV
    - (no luminousity or detector efficiency uncertainties included).
  - η decay widths measured using a similar set-up and analysis yielded questionable results.
- DESY
  - 1.0 GeV beam---- $\Gamma = 9.02 \pm .95$ eV
  - 1.5-2.0 GeV beam----$\Gamma = 11.7 \pm 1.2$ eV.
- Tomsk
  - 1.1 GeV beam---- $\Gamma = 7.32 \pm 0.5$ eV.


12
11
10
9
8
7
$\pi^0 \rightarrow \gamma\gamma$ Decay Width (eV)
DESY
(Primakoff)
Next to Leading
Order, ±1%
Leading Order
Chiral Anomaly
PrimEx
Experiment
Cornell
(Primakoff)
CERN
(Direct)
Tomsk
(Primakoff)
0
1
2
3
4
5
6
7
Experiments

PrimEx at Jefferson Lab

- Tagged Photon Facility at JLab
  - Increase precision and get cleaner kinematics.
- The invariant pion mass will be deduced by detecting the neutral pion decay γ's.
- Good neutral pion detector
  - Identify nuclear coherent and multi-photon background contributions
  - Provide good energy and angular resolution.

PrimEx, continued

- The Primakoff cross section for unpolarized photons is

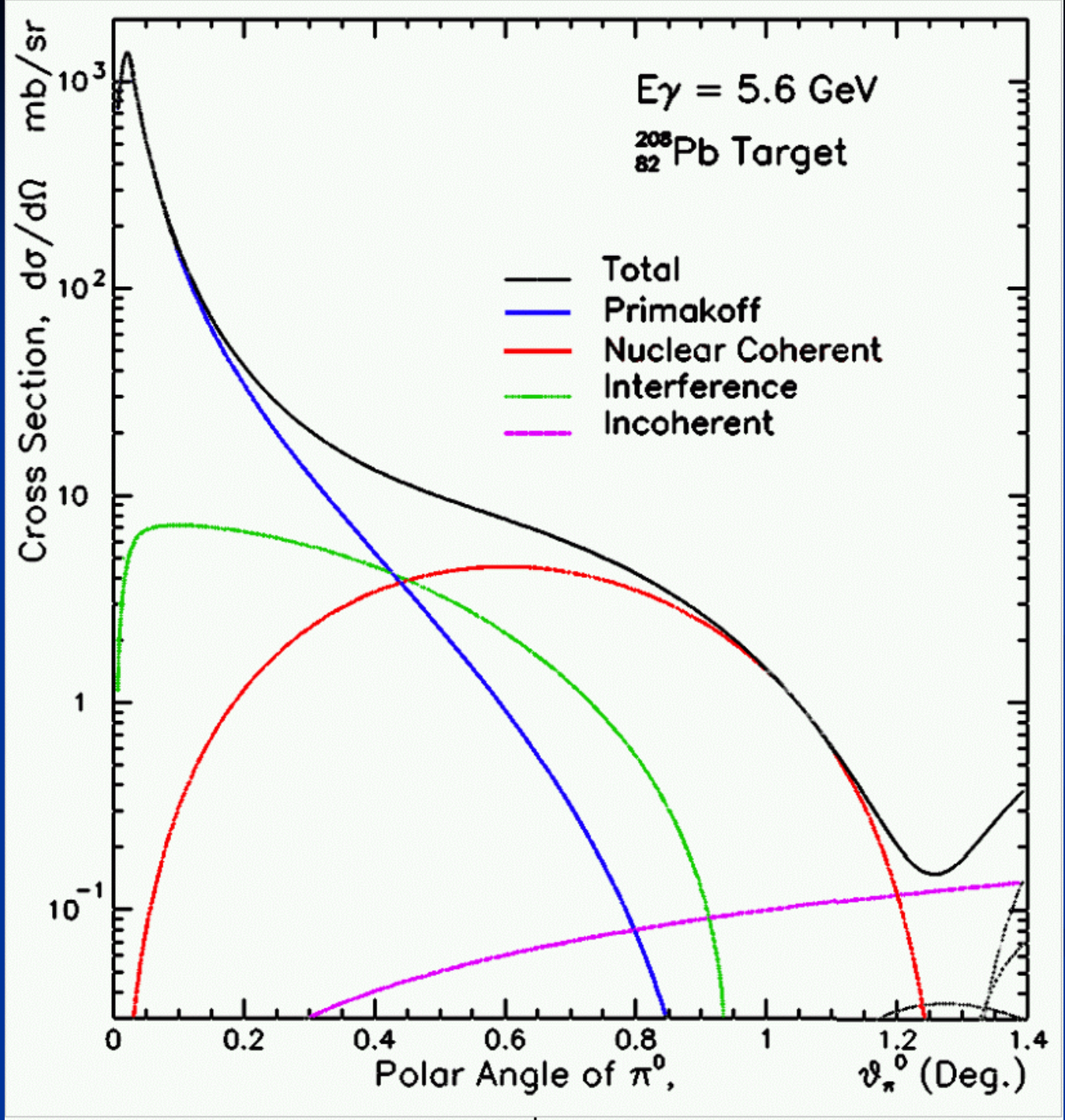
$$d^3\sigma_\pi/d\Omega =$$

$$(\Gamma_{\gamma\gamma} 8\alpha Z^2 \beta^3 E^4 |F_{em}(Q)|^2 / m^3 Q^4) \sin^2\theta_\pi$$

- Strong maximum in the Primakoff CS at

  $\theta \sim m_\pi{}^2 / (2E_\pi{}^2)$

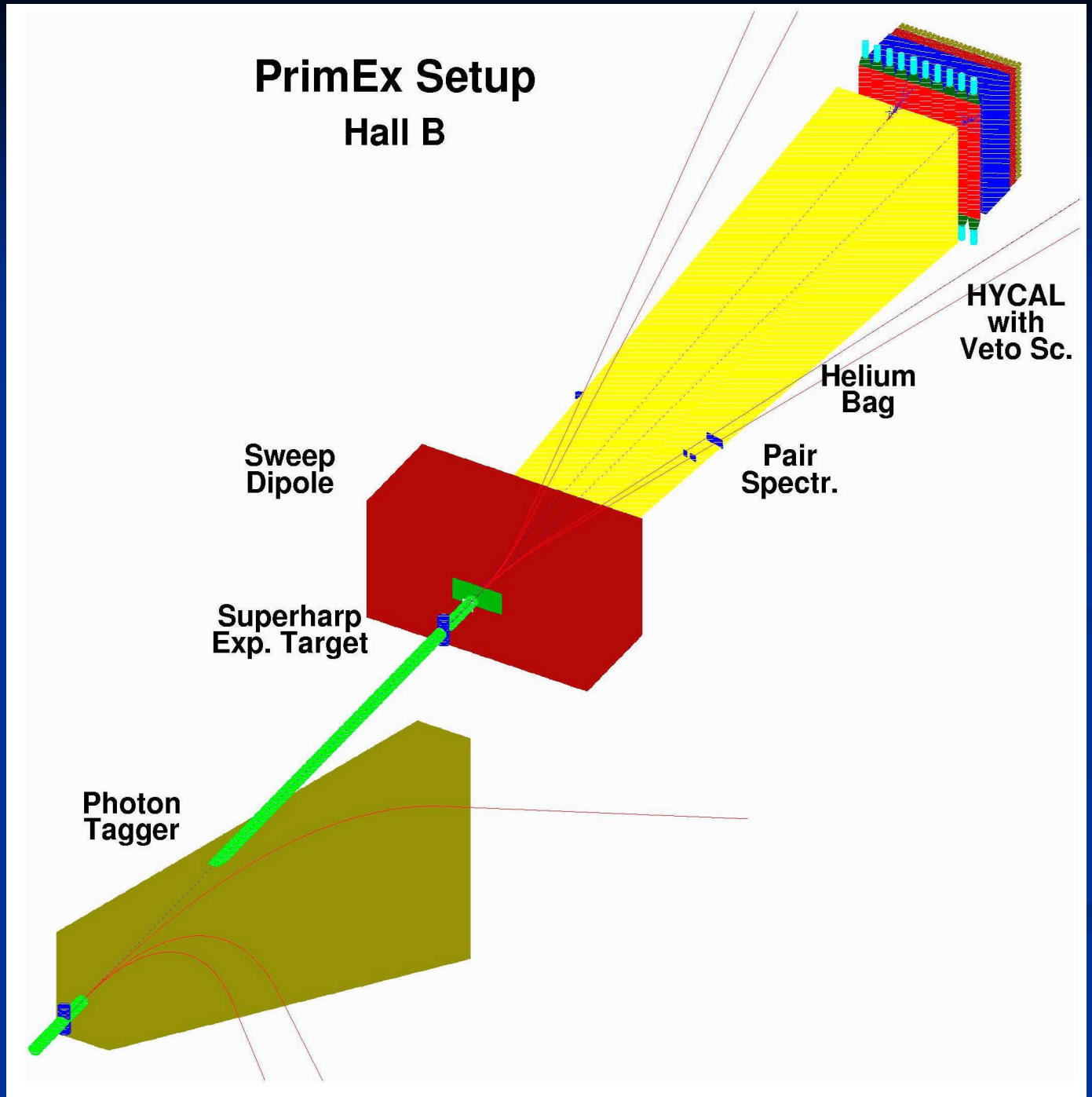
  - Falls off rapidly at higher angles.
- That's not the whole story
  - Nuclear coherent and incoherent processes and a cross term between NC and Primakoff effect contribute to the cross section.


Eγ = 5.6 GeV
208 82 Pb Target
Total
Primakoff
Nuclear Coherent
Interference
Incoherent
Cross Section, dσ/dΩ mb/sr
10^3
10^2
10
1
10^-1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Polar Angle of π^0, ϑ_π^0 (Deg.)

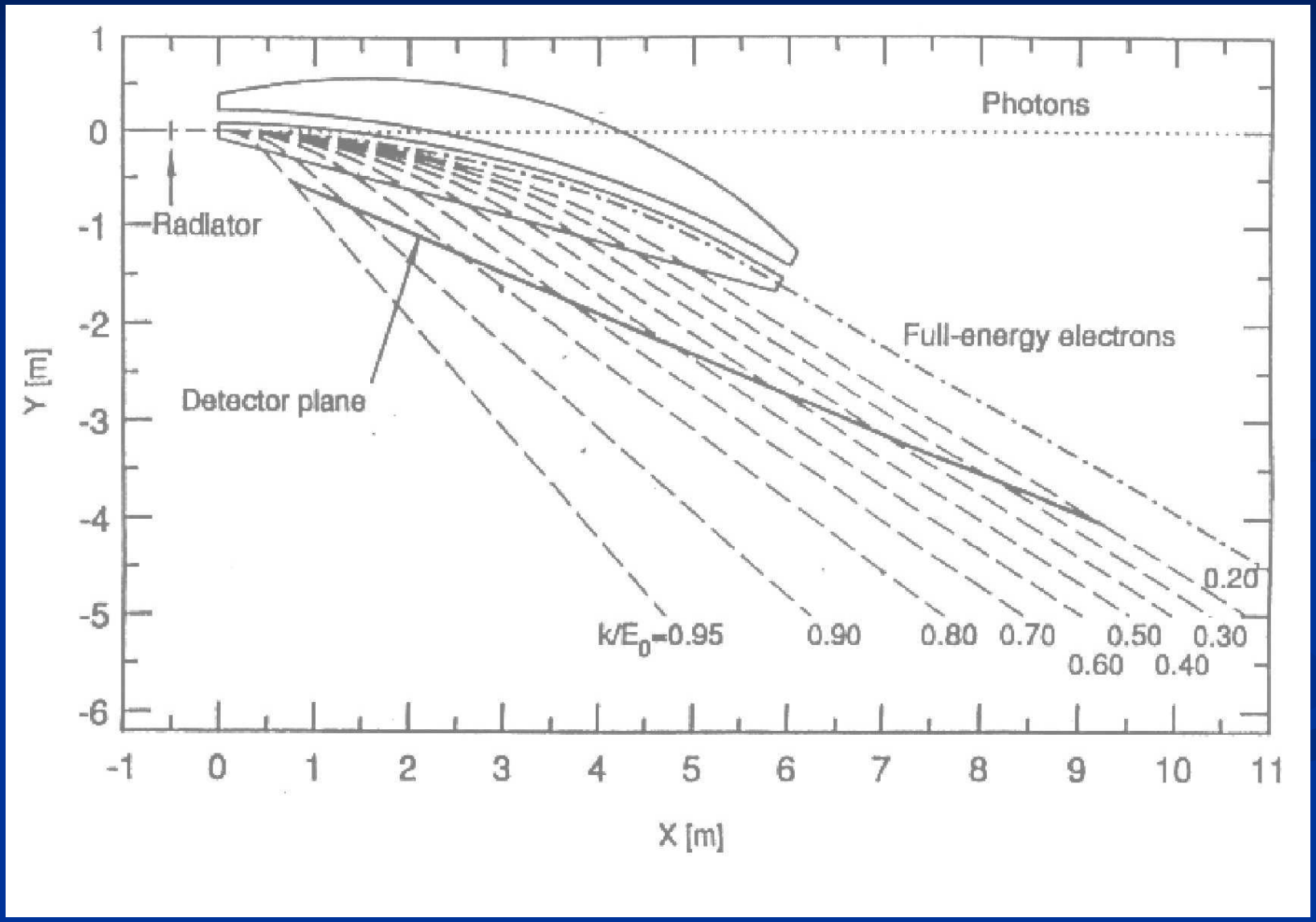
Error budget

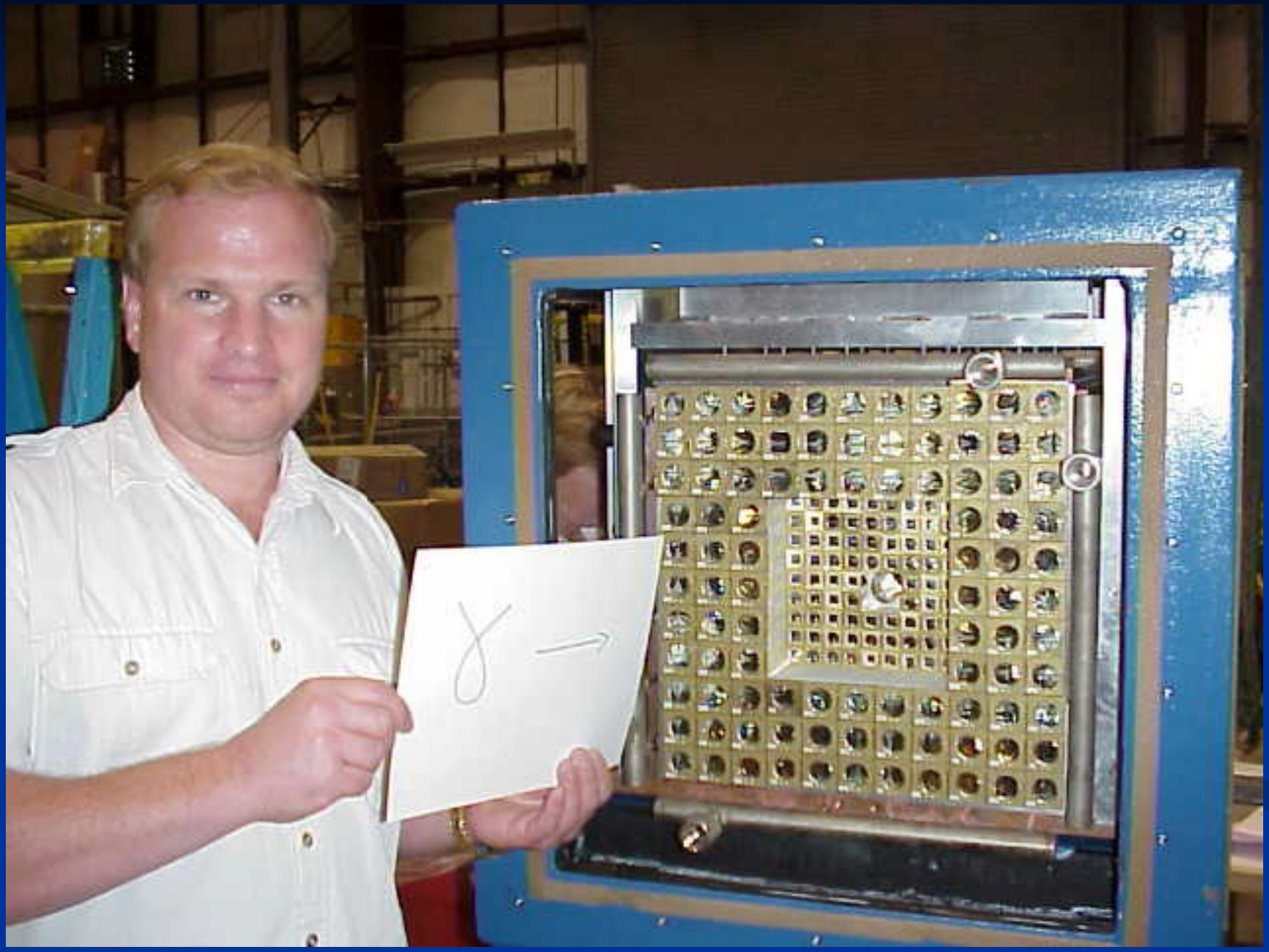
Statistical	0.4%
Target Thickness	0.7%
Photon Flux	1.0%
π^o detector acceptance and misalignment	0.4%
Background subtraction	0.2%
Beam energy	0.2%
Distorted form factor calculation errors	0.3%
Total Error	1.4%

Conceptual PrimEx set-up



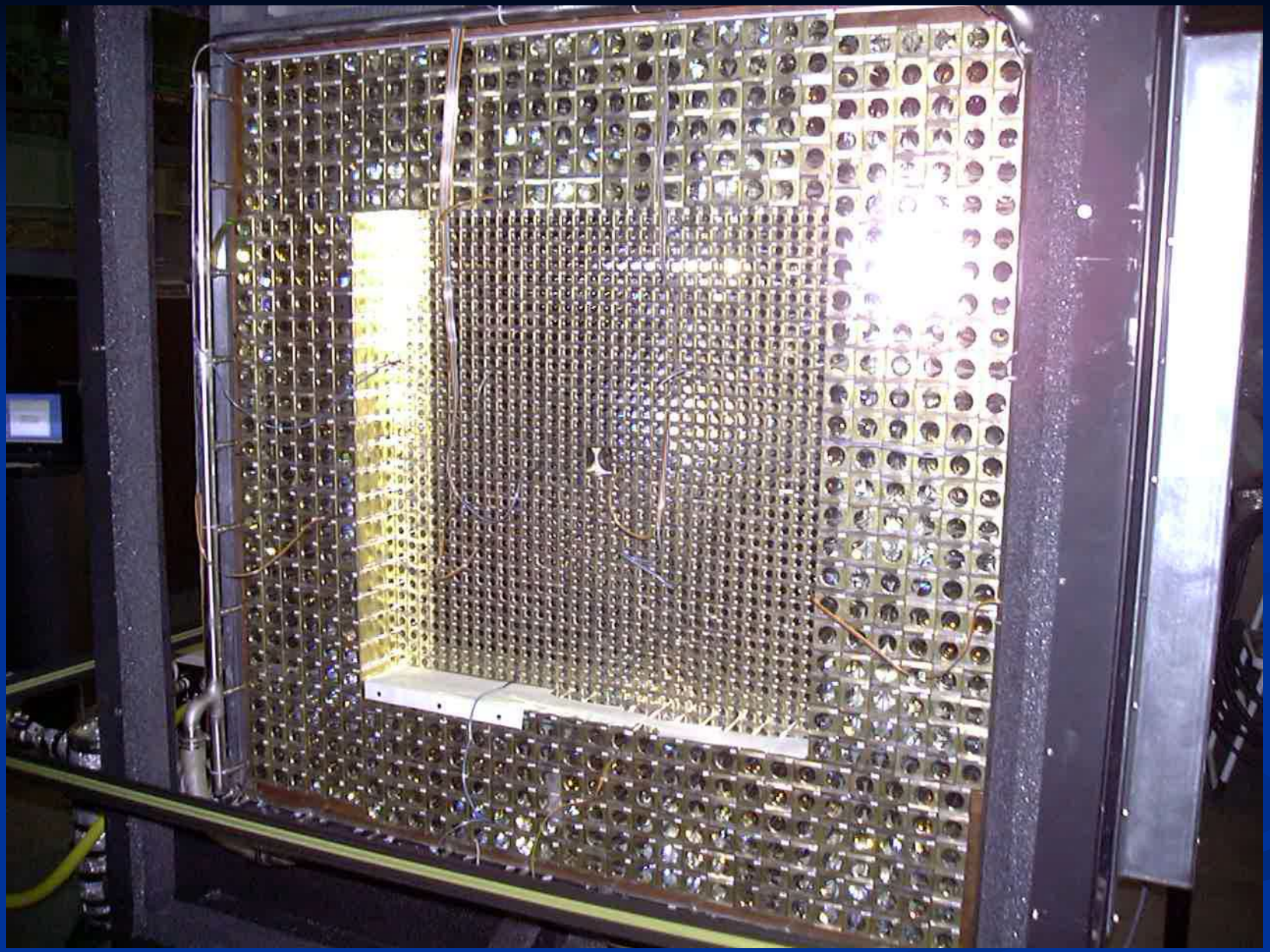
Photon Tagger

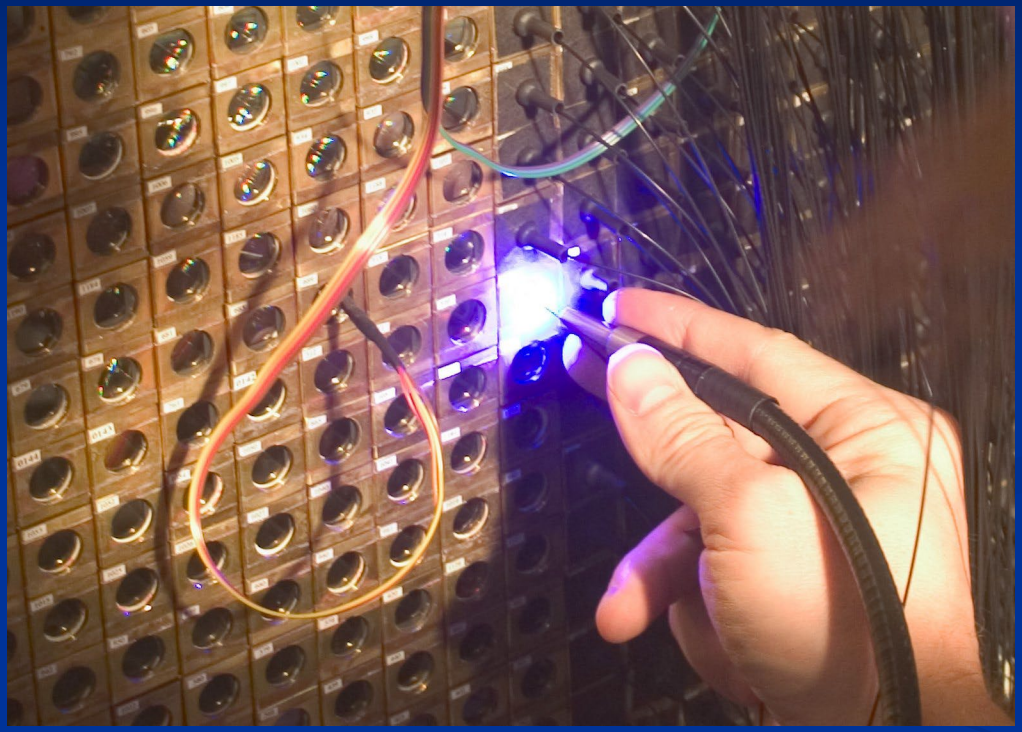


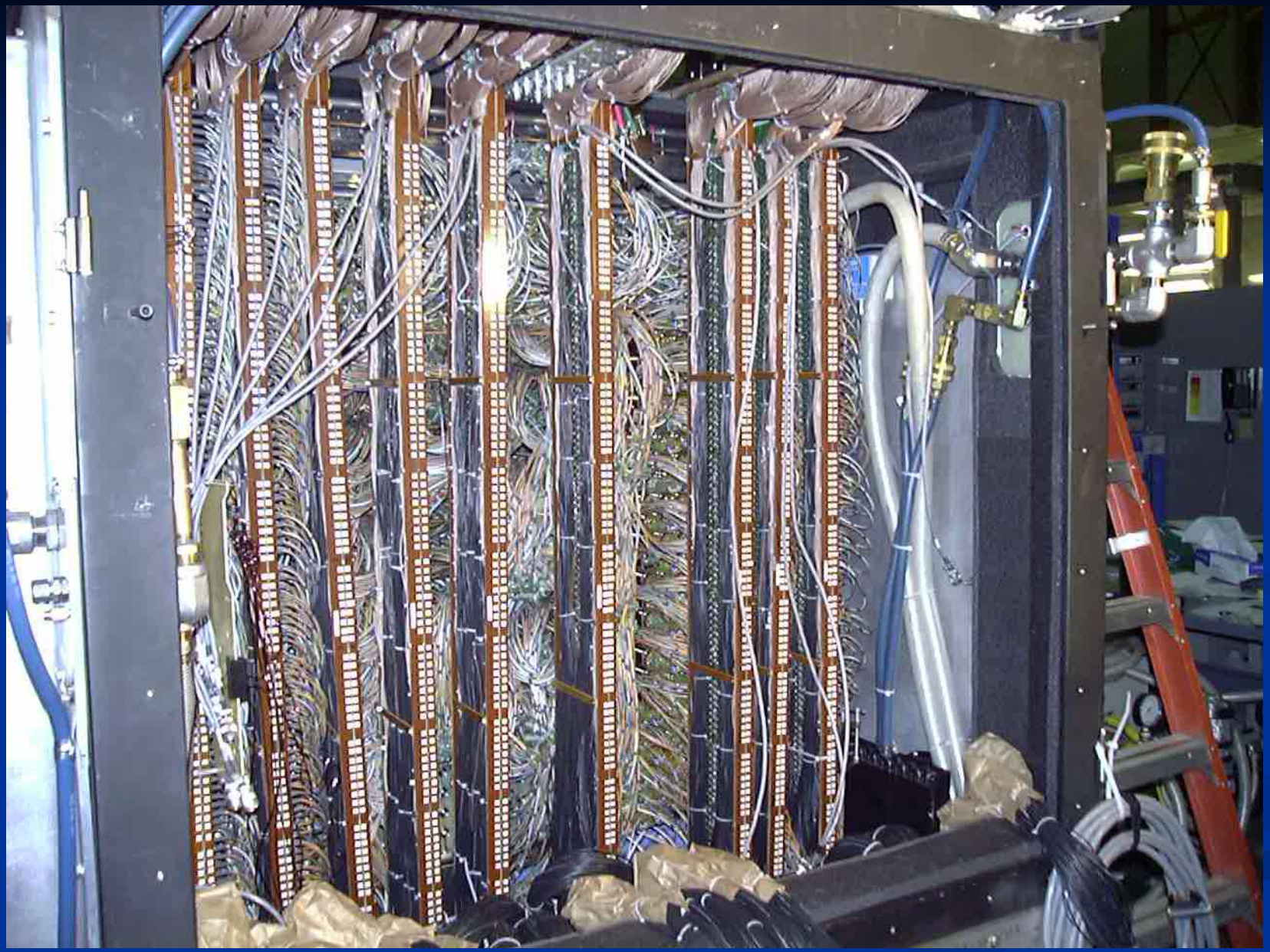


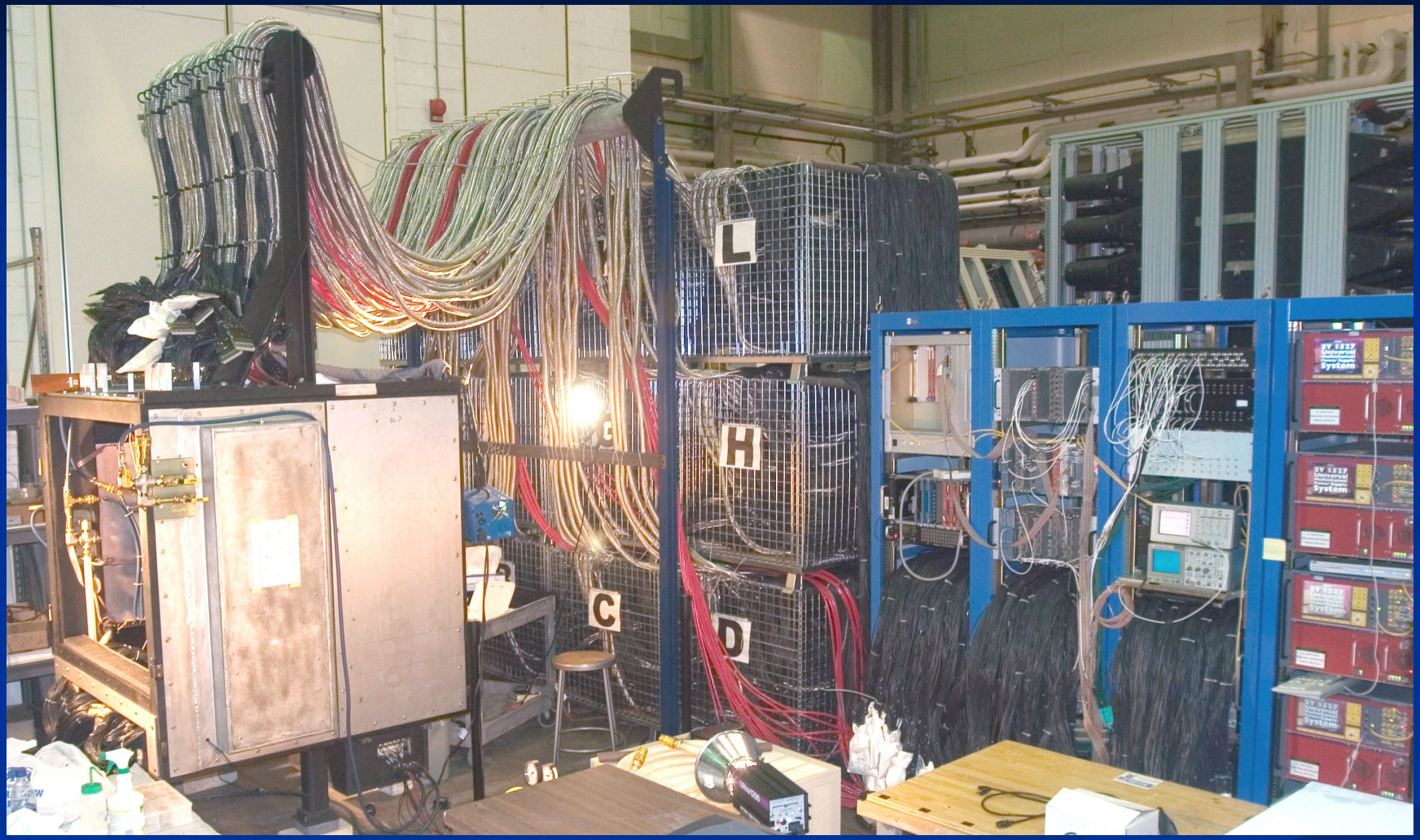
The Hybrid Calorimeter

- HyCal is a highly segmented array of lead tungstate and lead glass crystals
  - 7.5 meters downstream of the targets.
  - The interior array of crystals
    - 1152 lead tungstate modules, each 2.05x2.05.18 cm^3, 20 Xo, and 2.0 cm Moliere radius.
  - The outer array
    - 576 lead glass modules, each 3.84x3.84.45 cm^3 and 17 Xo.
  - The small size of the interior detectors means very fine angular resolution (better than 0.02^o) and energy resolution (~3.5 Mev).








L
H
C
D

Final Thoughts

- The PrimEx took date from September 2004 to November 2004.
  - We see lots of pi-zeros.
    - Good statistics on Carbon, fair statistics on Lead.
  - Preliminary analysis, calibration, and book-keeping stage.
- Then, about 1.5 years from now, I graduate.
    - I'm crossing my fingers…