π^0 Lifetime Measurement via the Primakoff Effect in Jefferson Lab

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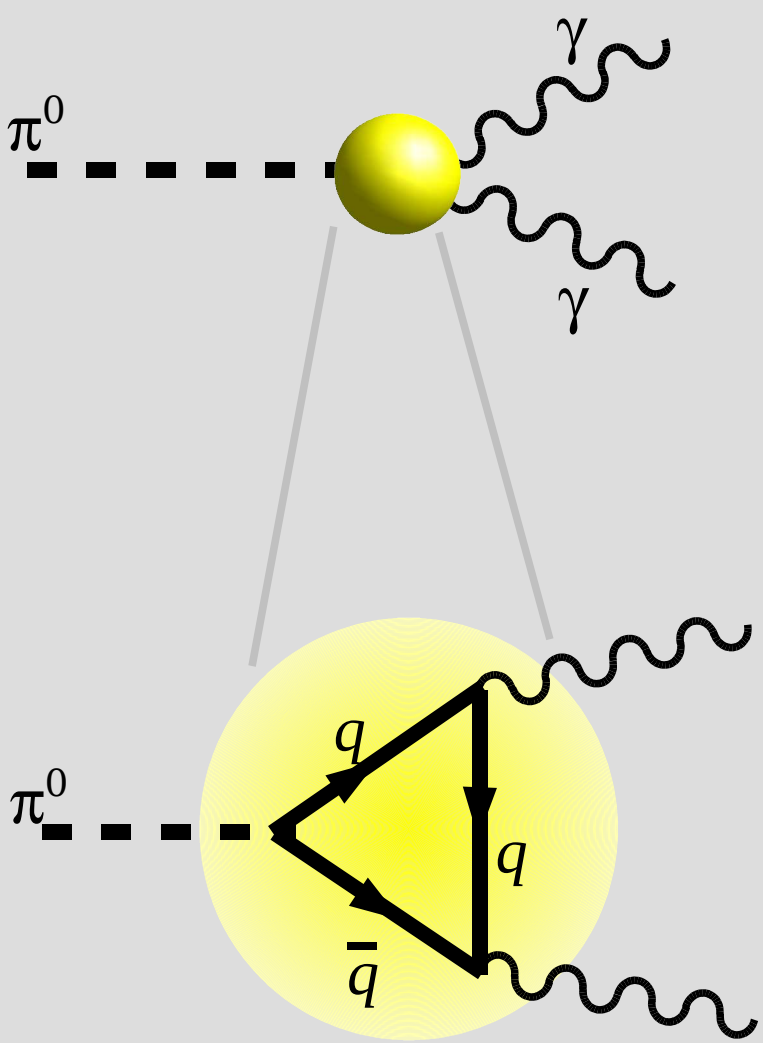
for

The PrimEx Collaboration

π^0 Lifetime



- $\pi^0 \rightarrow \gamma\gamma$ (~99%)
- Pseudoscaler (0^-) Nature
  - Axial Current Dominates
- Quantum fluctuation of quark and gluon field

Axial Current is not Conserved

Axial Anomaly

- Classical QCD Lagrangian :

$$SU_R(3) \times SU_L(3) \times U_A(1)$$

- Axial Current isn't Conserved -> $U_A(1)$ Broken

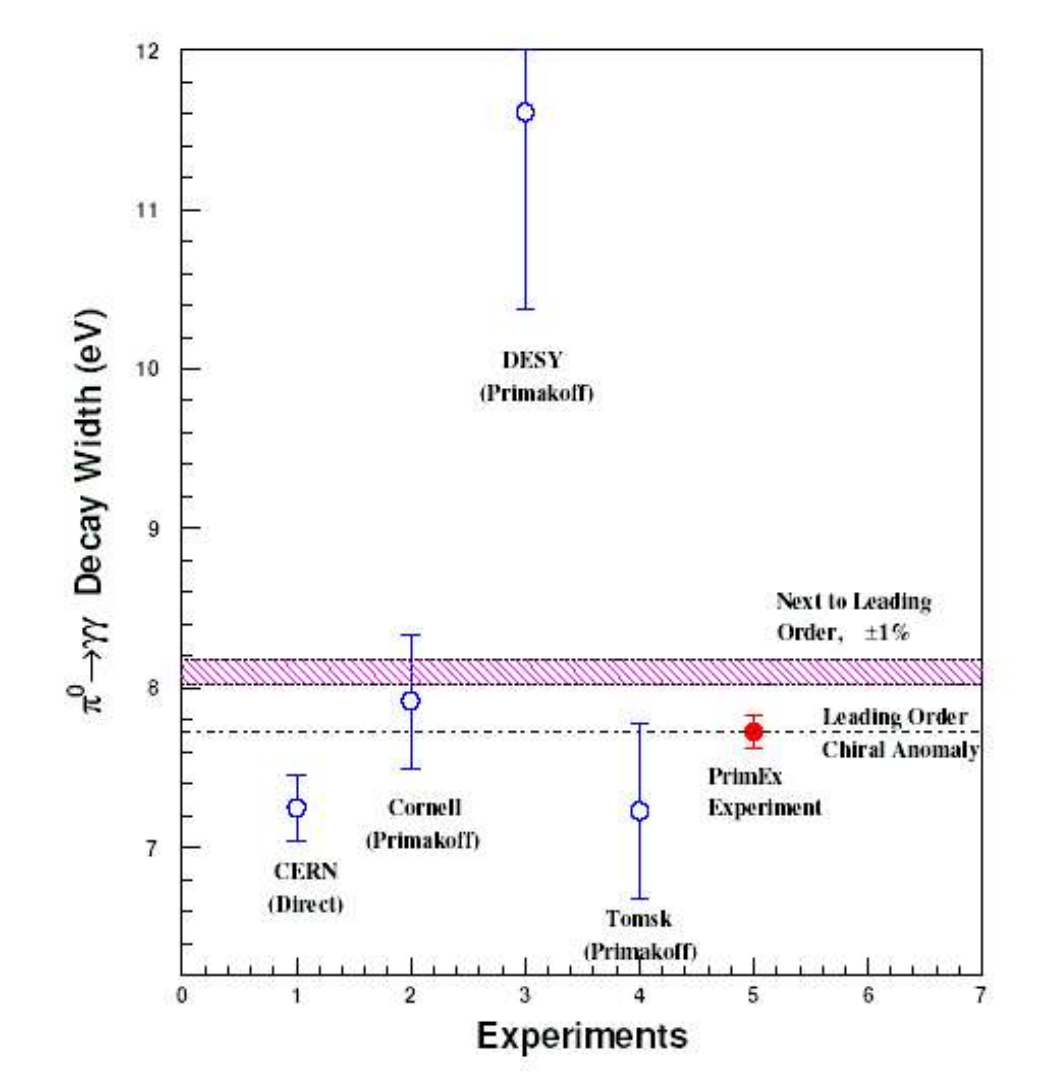
Profound Example of Symmetry Breaking

- Exactly calculated in Chiral limit (m_q -> 0)

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

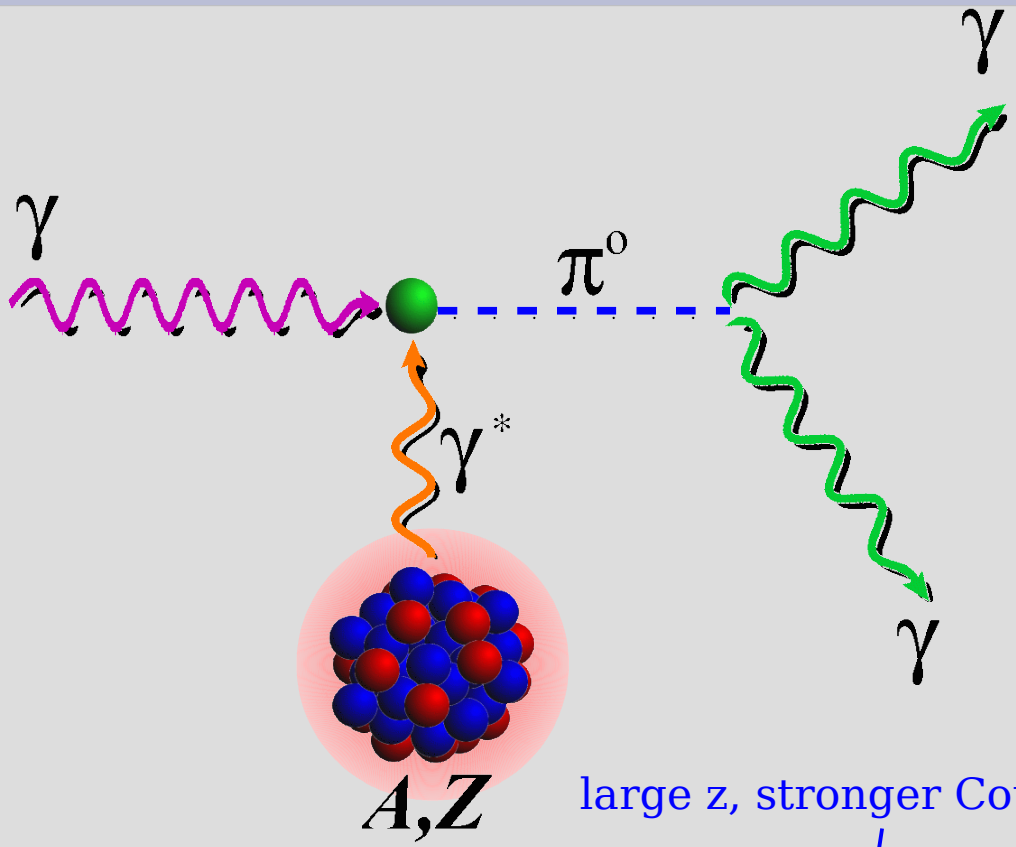
$(N_c = 3)$

Existing Data

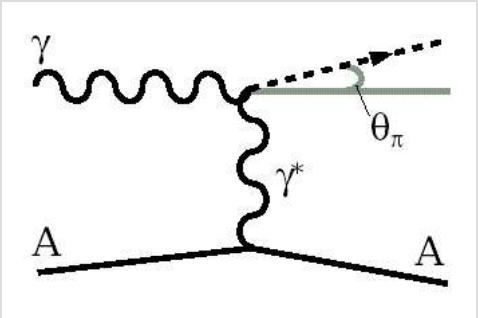


- Presently known only to 10%
- Experimental challenge to measure ~ 1.4%
- Test axial anomaly and next to leading order ChPT

Primakoff π^0 Production



- Virtual photon pickup in the nuclear Coulomb field
- Very forward angle $\theta_\pi < 0.2^o$ @ $E_\gamma \sim 5$GeV



large z, stronger Coulomb field

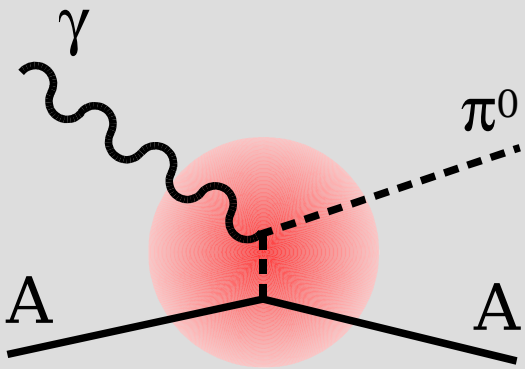
$$\frac{d^3\sigma_{\text{Prmkff}}}{d\Omega} = \Gamma_{\gamma\gamma}\frac{8\alpha Z^2}{m^3}\frac{\beta^3 E^4}{Q^4}|F_{\text{e.m.}}(Q)|^2 \sin^2\theta_\pi$$

$\pi^0 \to \gamma\gamma$ decay width

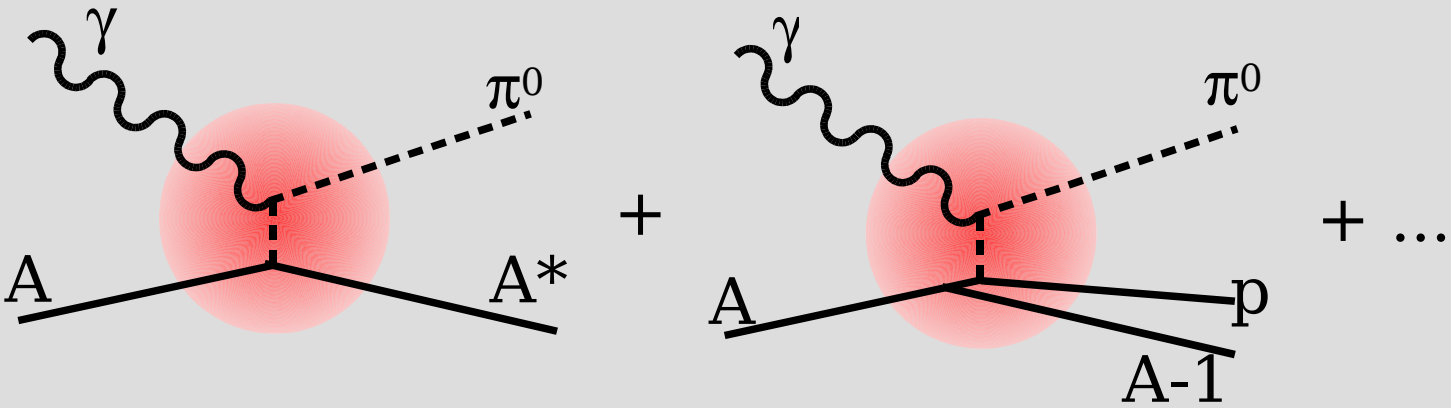
small recoil

Nuclear Coherent / Incoherent Background Processes

Coherent Process

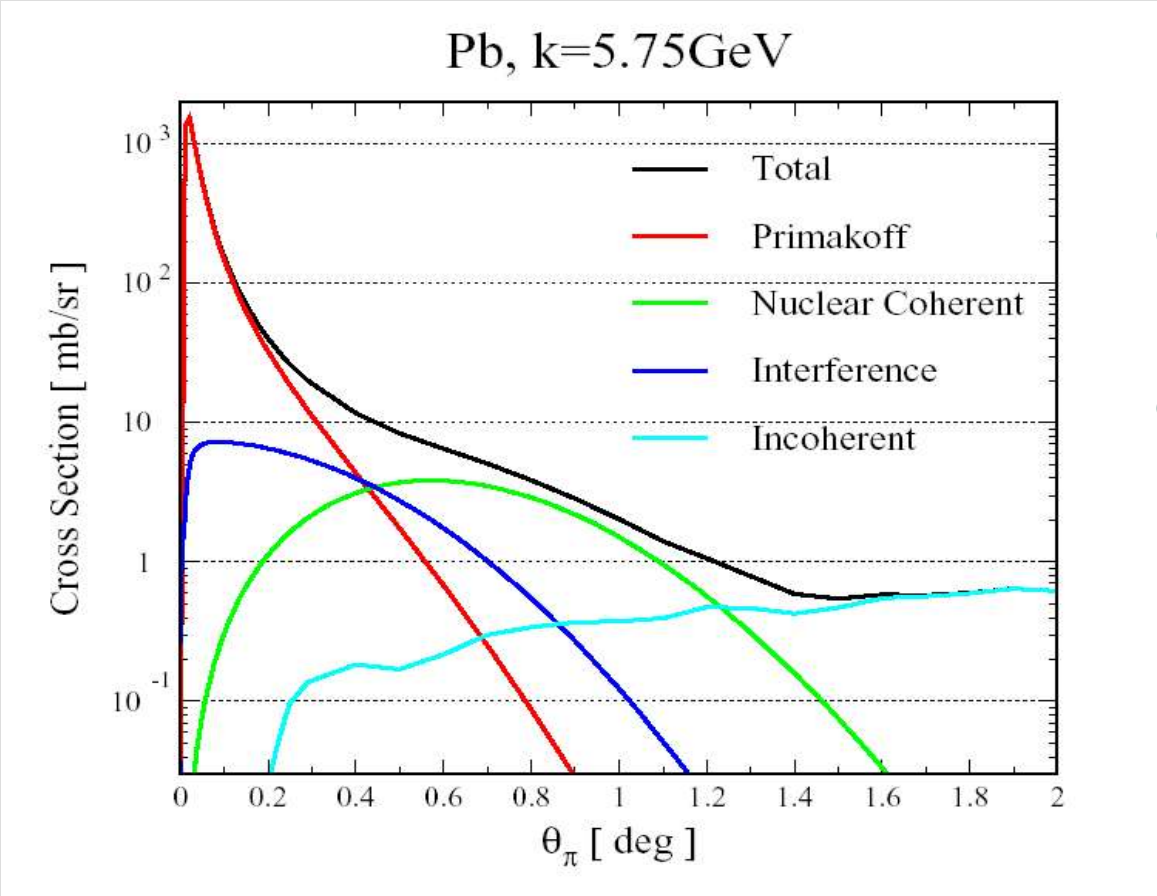


Incoherent Process



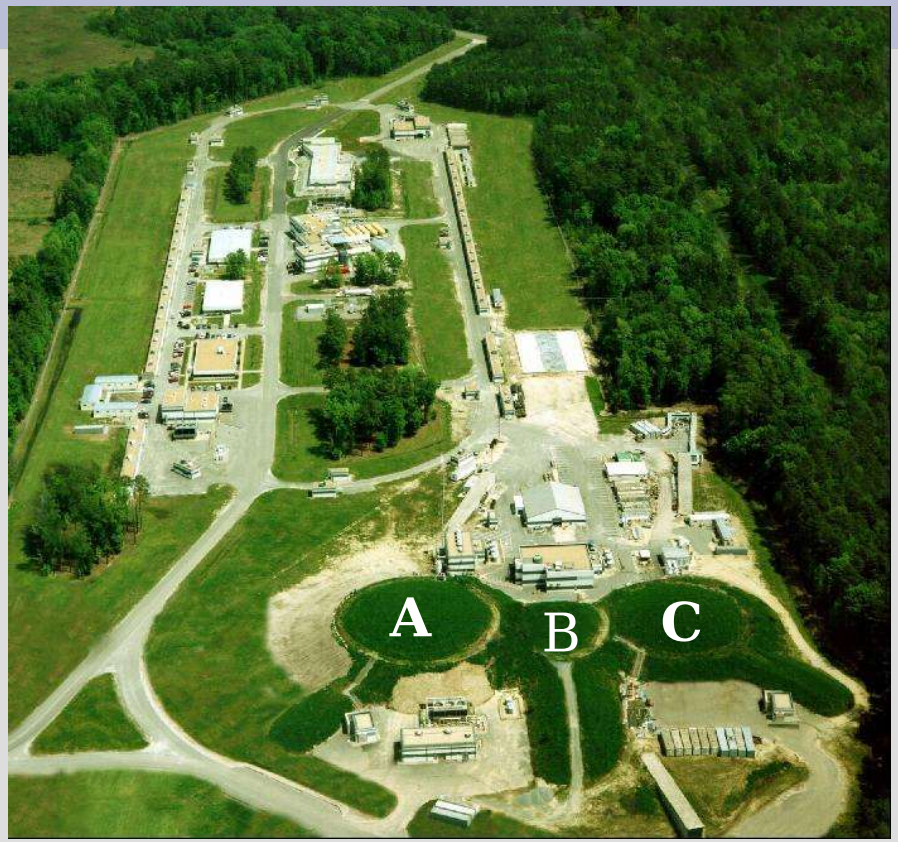
Cross Section

$$\frac{d\sigma}{d\Omega} = \underbrace{\frac{d\sigma_P}{d\Omega} + 2\sqrt{\frac{d\sigma_P}{d\Omega}\cdot\frac{d\sigma_C}{d\Omega}}\cos\phi + \frac{d\sigma_C}{d\Omega}}_{|<\pi^0\psi_A|H_P+H_C|\psi_A>|^2} + \underbrace{\frac{d\sigma_I}{d\Omega}}_{|<\pi^0\psi_{A'}|H_I|\psi_A>|^2}$$

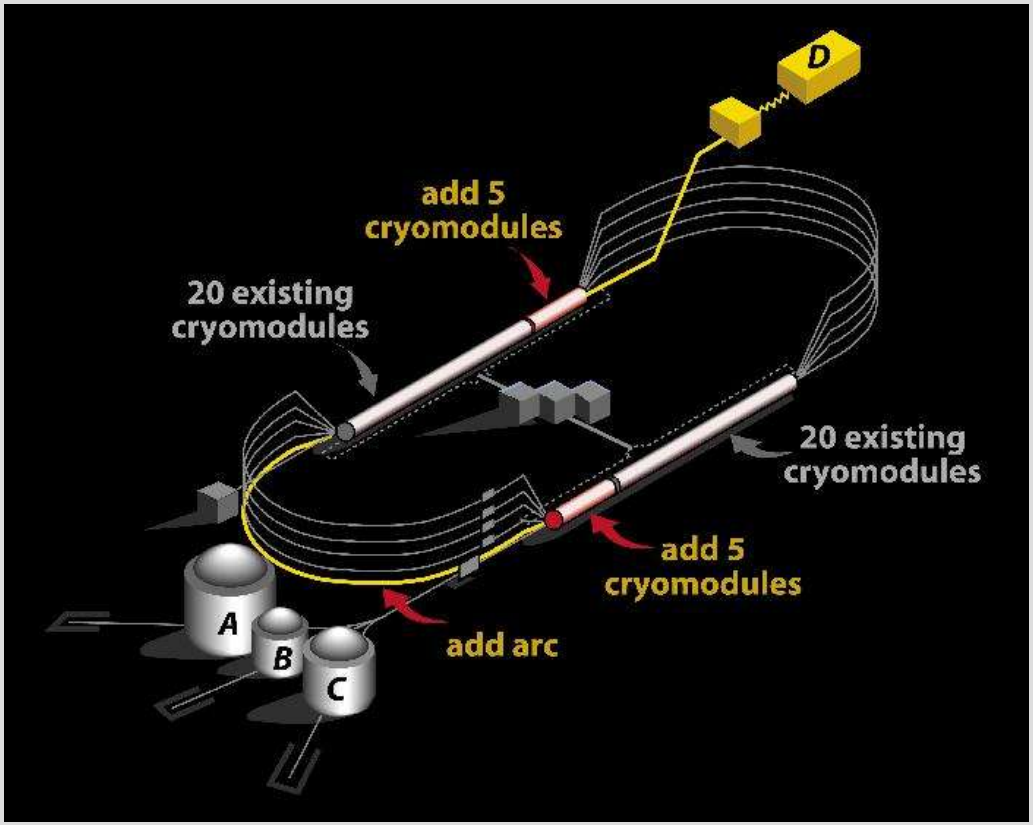


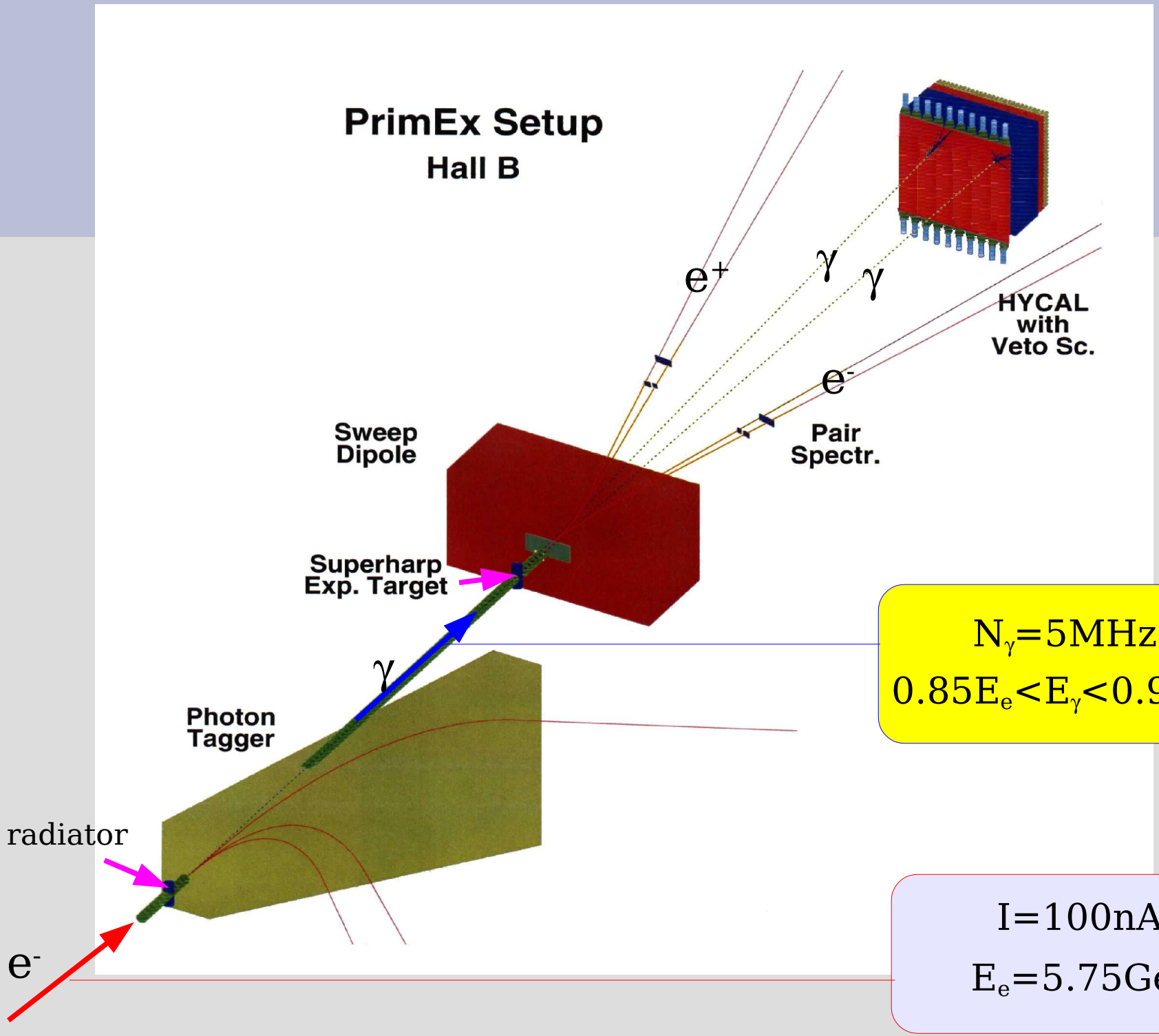
- Primakoff : $\theta_\pi < 0.2^o$
- Background ~ 1%

Jefferson Laboratory



- Continues electron beam
- E_e^{max}= 6 GeV





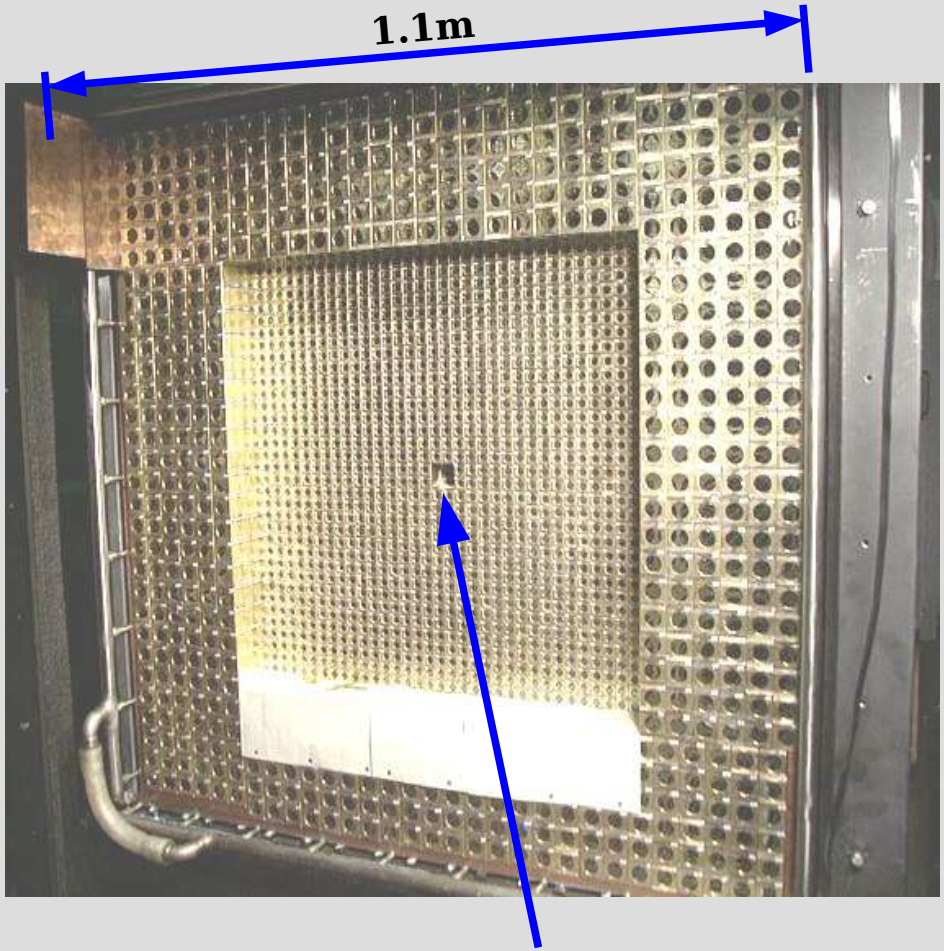
N_γ=5MHz

$0.85E_e<E_\gamma<0.95E_e$

I=100nA

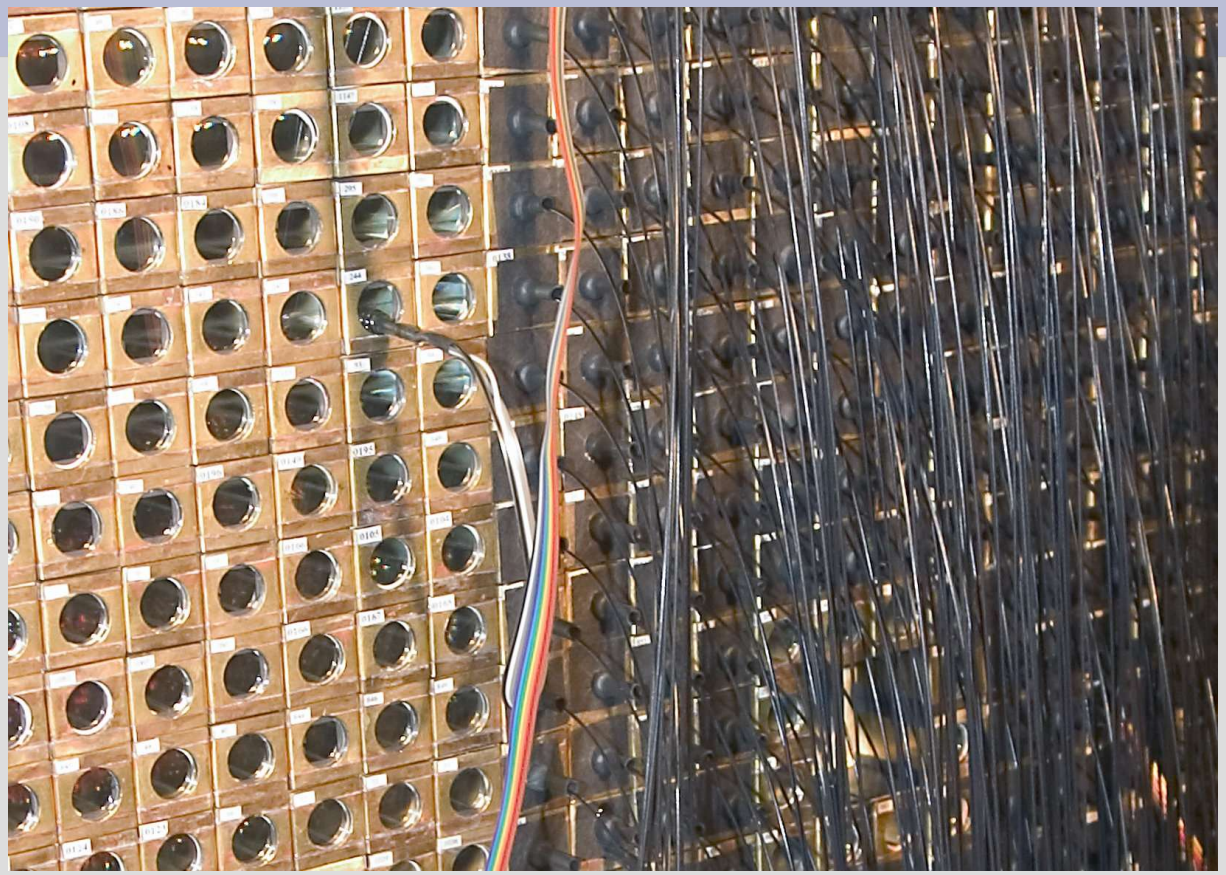
E_e=5.75GeV

Hybrid Calorimeter (HYCAL)



- $PbWO_4$ x 1152ch
  - $\Delta E/E$ ~ 1.2% @ 2.5GeV
  - σ_x ~ 1.5mm -> σ_θ ~ 0.01°
- Lead-Glass x 600ch
  - $\Delta E/E$ ~ 5% @ 2.5GeV

Light Monitoring System

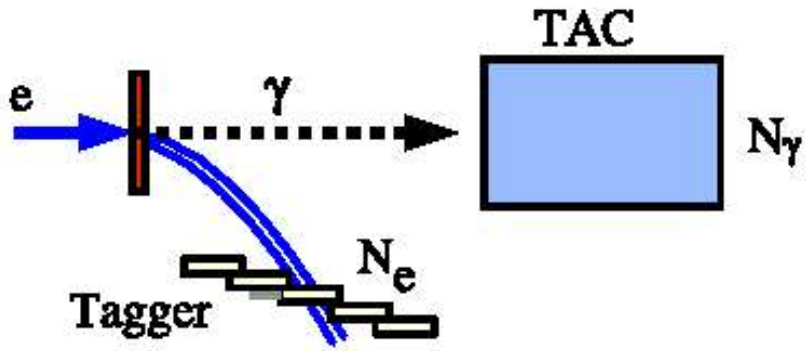


- 470 nm blue LED
- 10 ~ 20 Hz continues sampling of PMTs gain

Error Budget

Statistical	0.4 %
Target Thickness	0.7 %
Photon Flux	**1.0 %**
π^0 Detector Acceptance & Misalignment	0.4 %
Backgound Subtraction	0.2 %
Beam Energy	0.2 %
Distorted Form Factor Calculation Errors	0.4 %
Total	1.4 %

Tagging Technique



$$N_\gamma^{tag} = N_e^{tag} \cdot \epsilon_{tag}$$

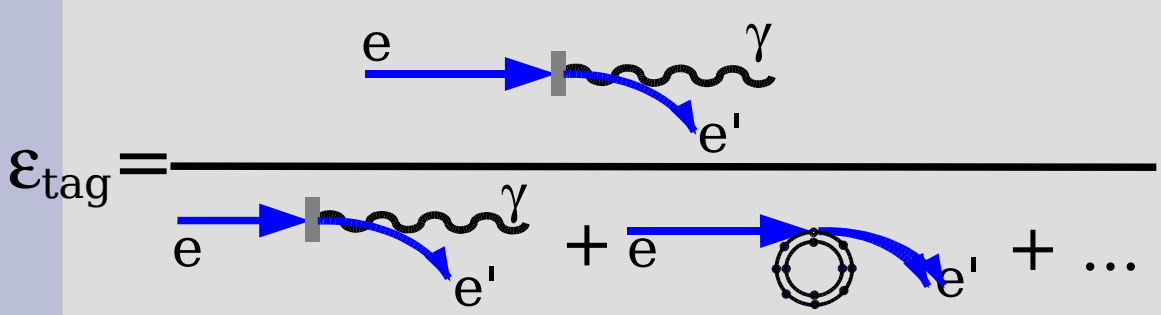
N_γ^{tag} : Number of Tagged Photon

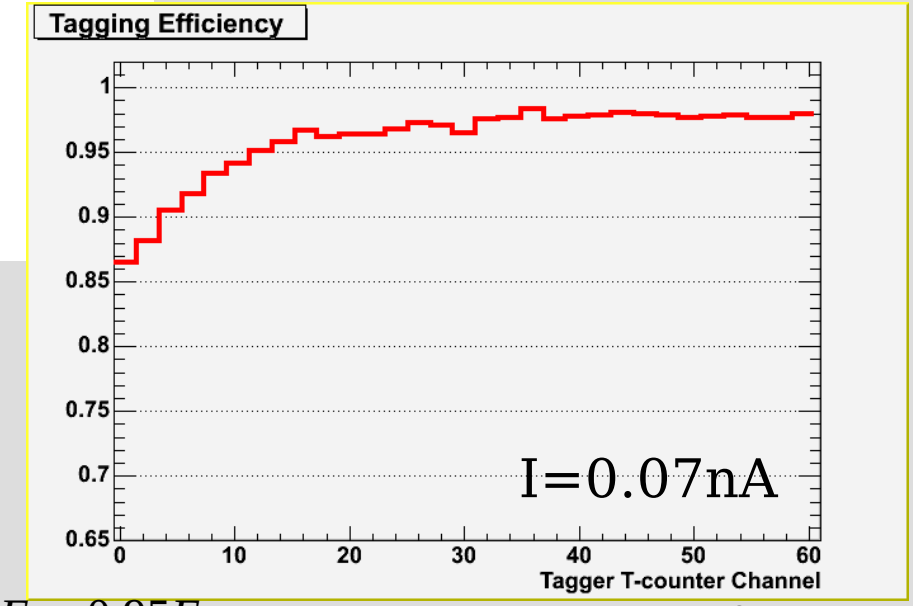
N_e^{tag} : Number of Tagged Electron

ϵ^{tag} : Tagging Efficiency

- $N_\gamma = N_{e'} * \varepsilon_{tag}$
- $E_\gamma = E_e - E_{e'}$

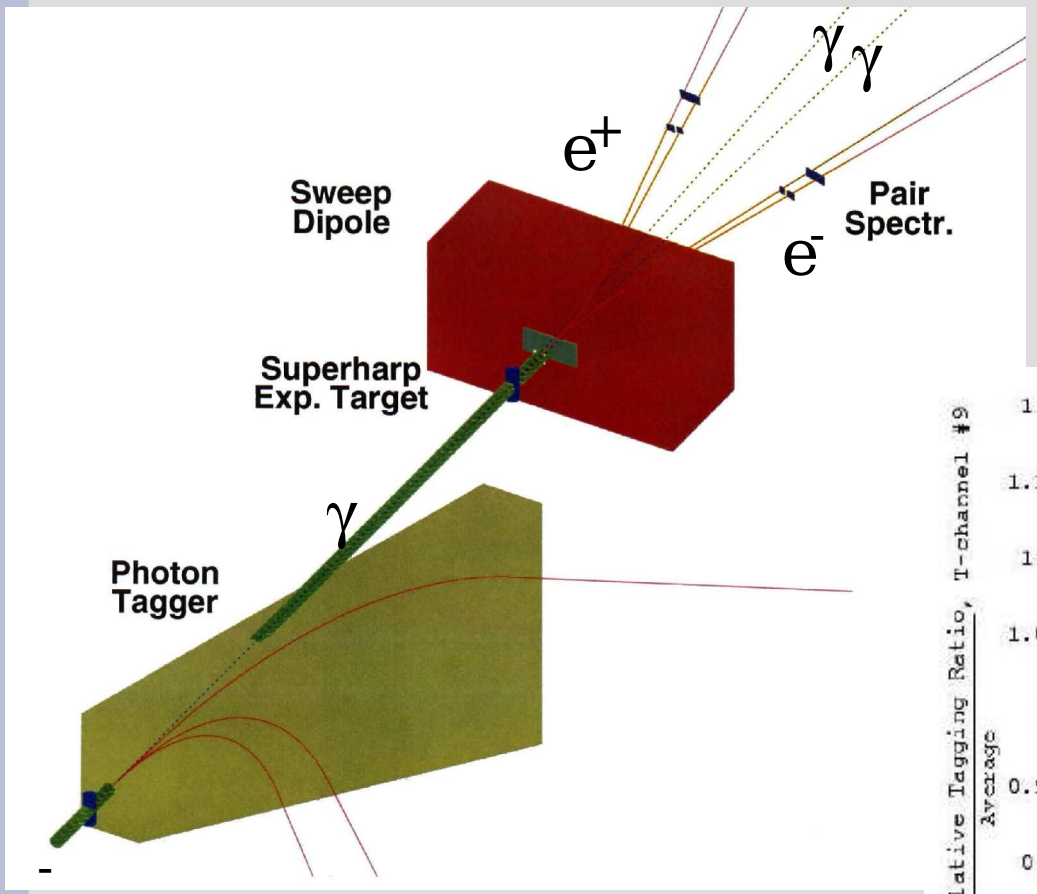
  $(\Delta E_\gamma / E_\gamma \sim 10^{-3})$



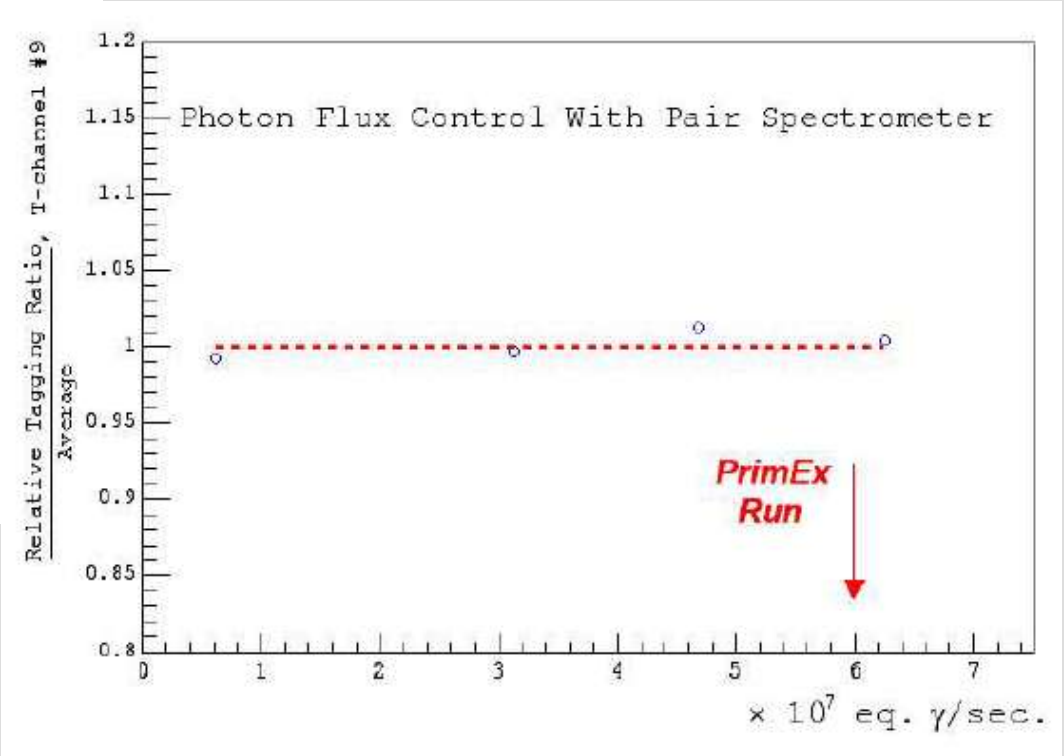


$E_\gamma = 0.95E_e$ → $0.55E_e$

Luminosity Control

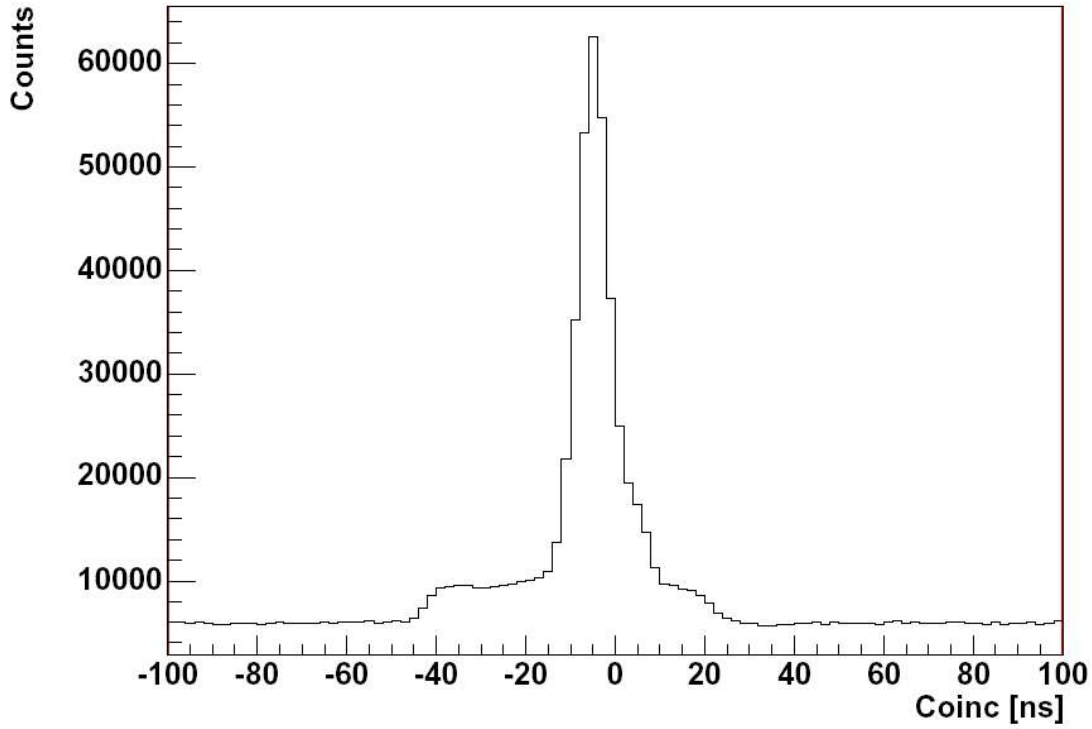


- Monitor e^+/e^- pairs which are proportional to photon flux.

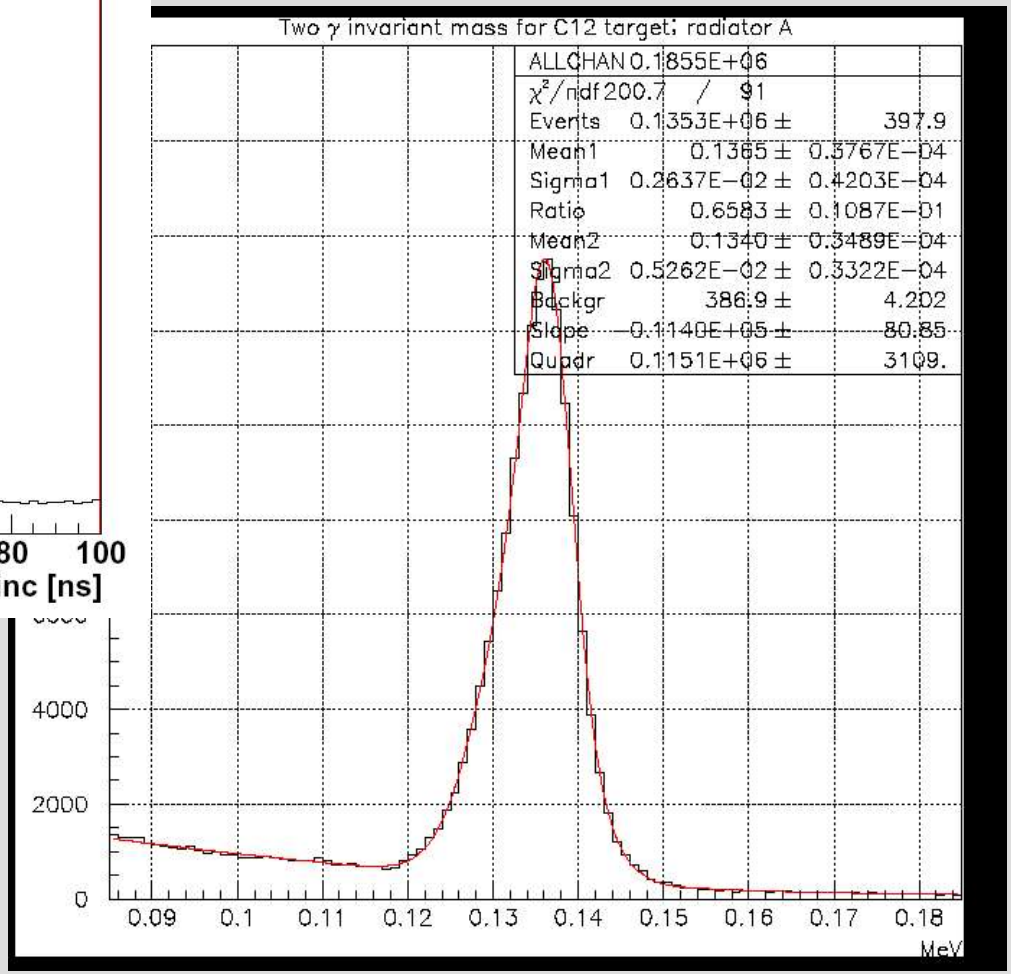


Online Data

Tagged electron – HYCAL coincidence

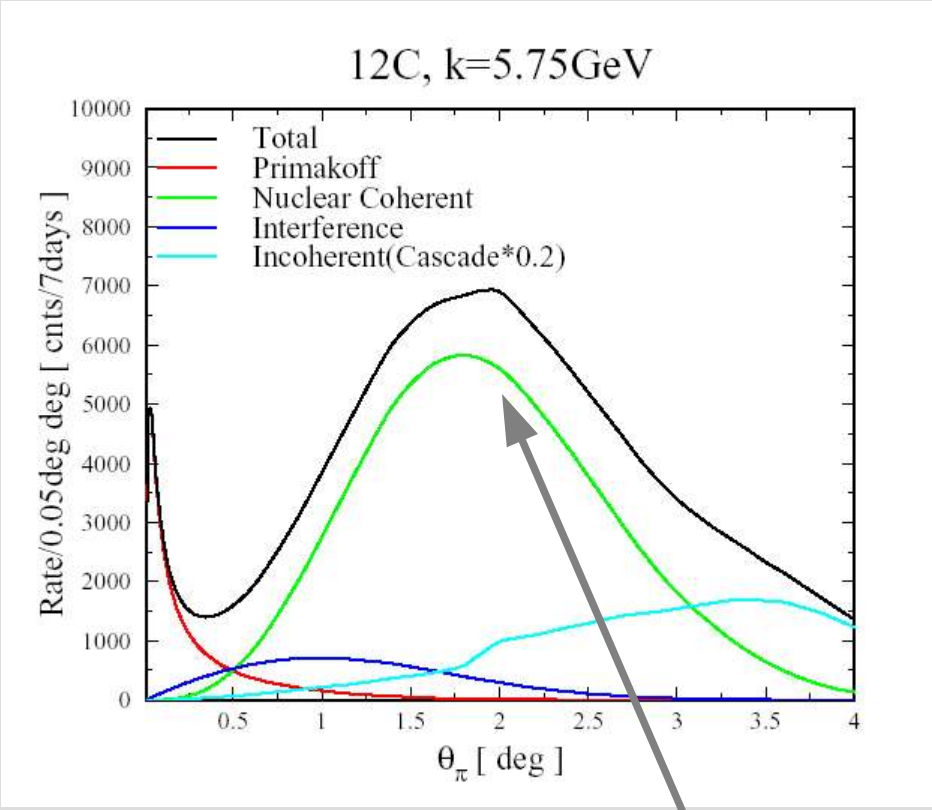


π^0 Invariant mass

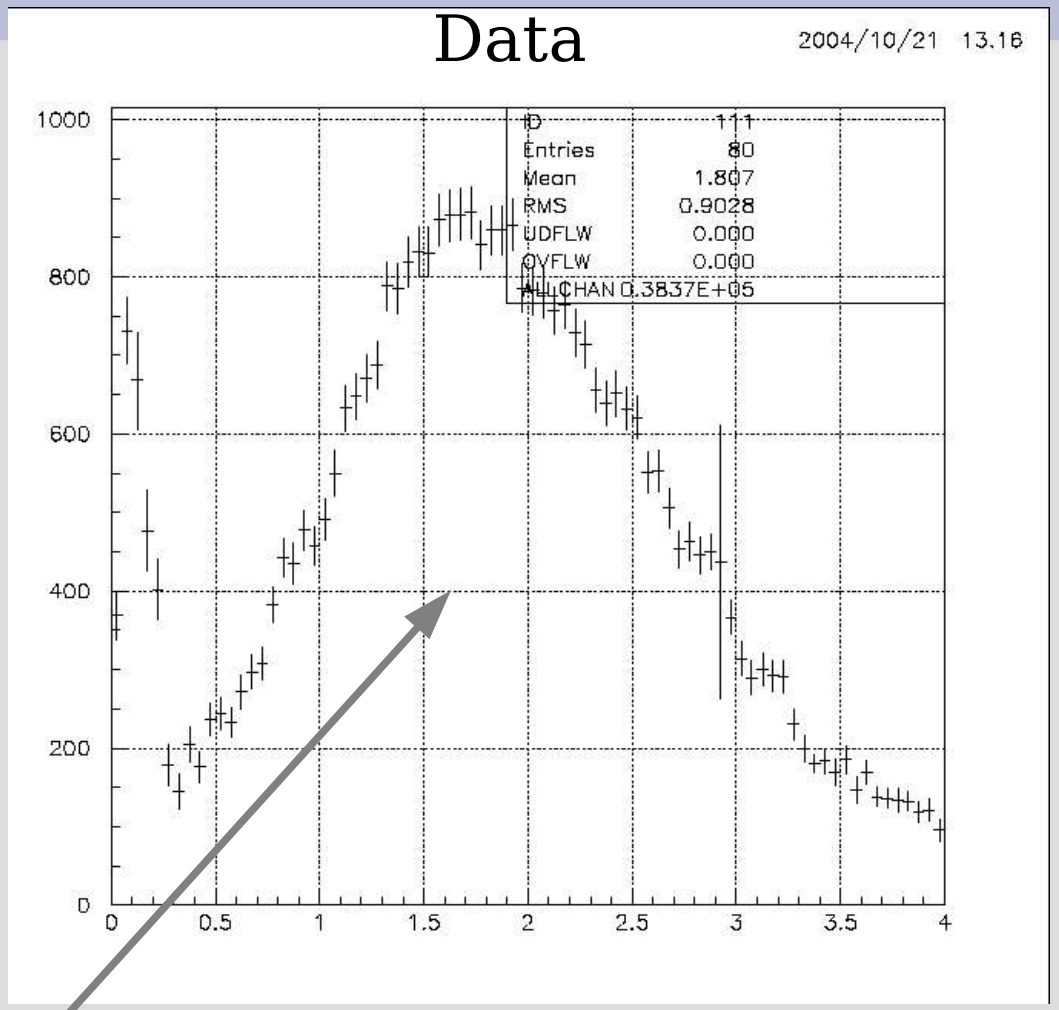


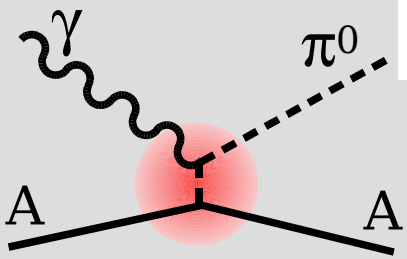
Angular Distribution : ^{12}C

Model Prediction



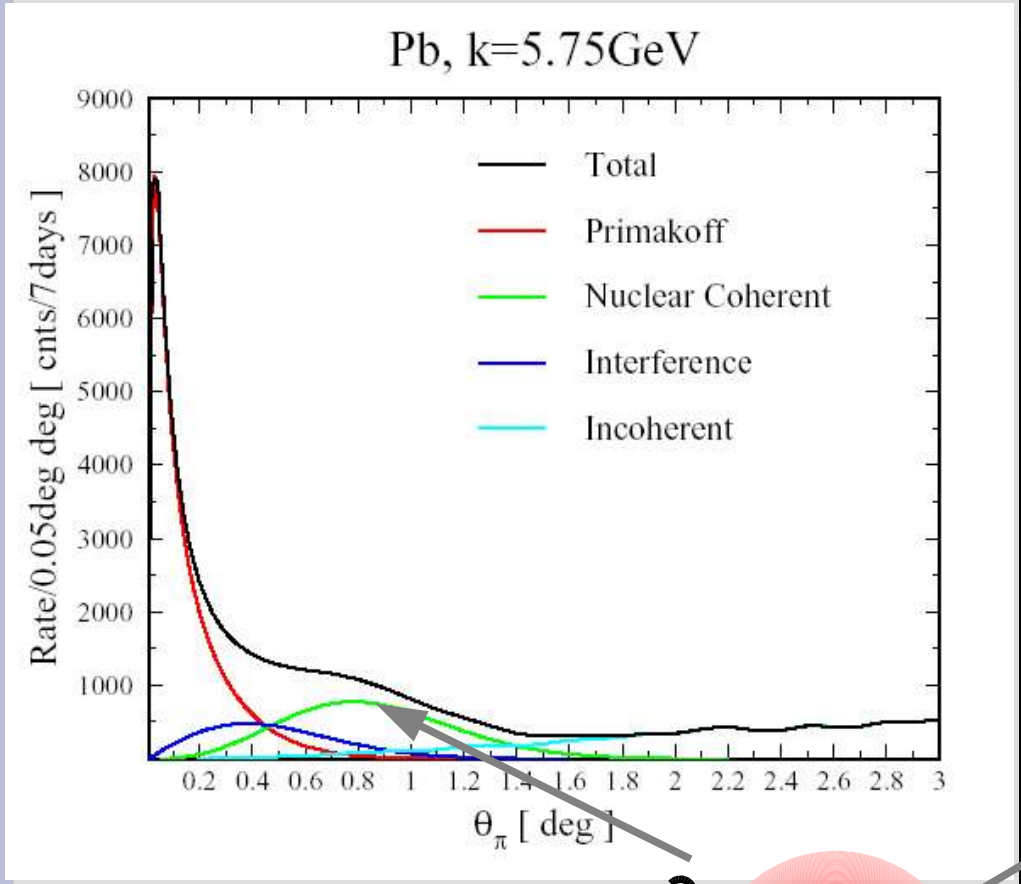
Data



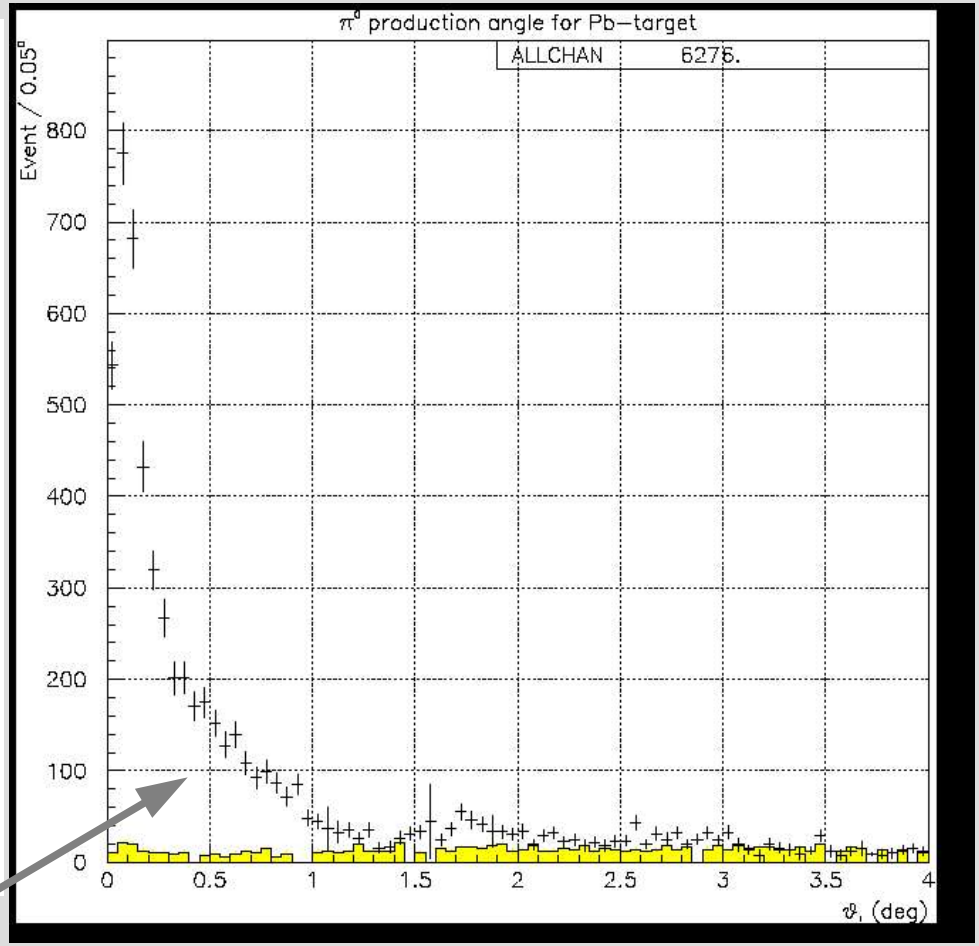


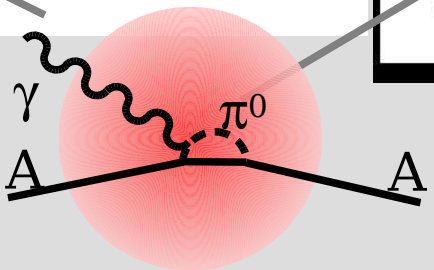
Angular Distribution : ^{208}Pb

Model Prediction



Data

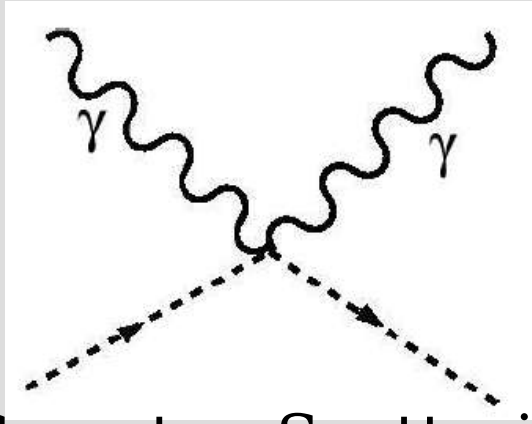
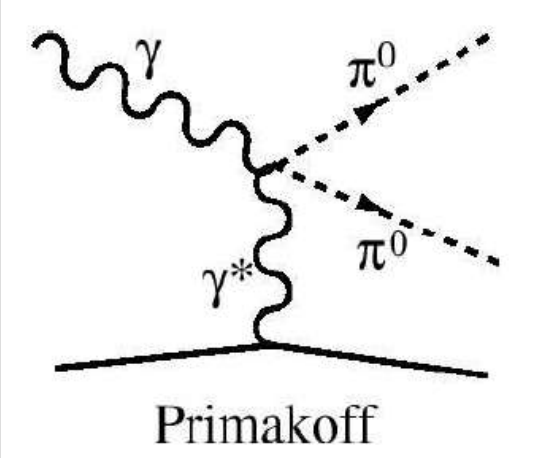
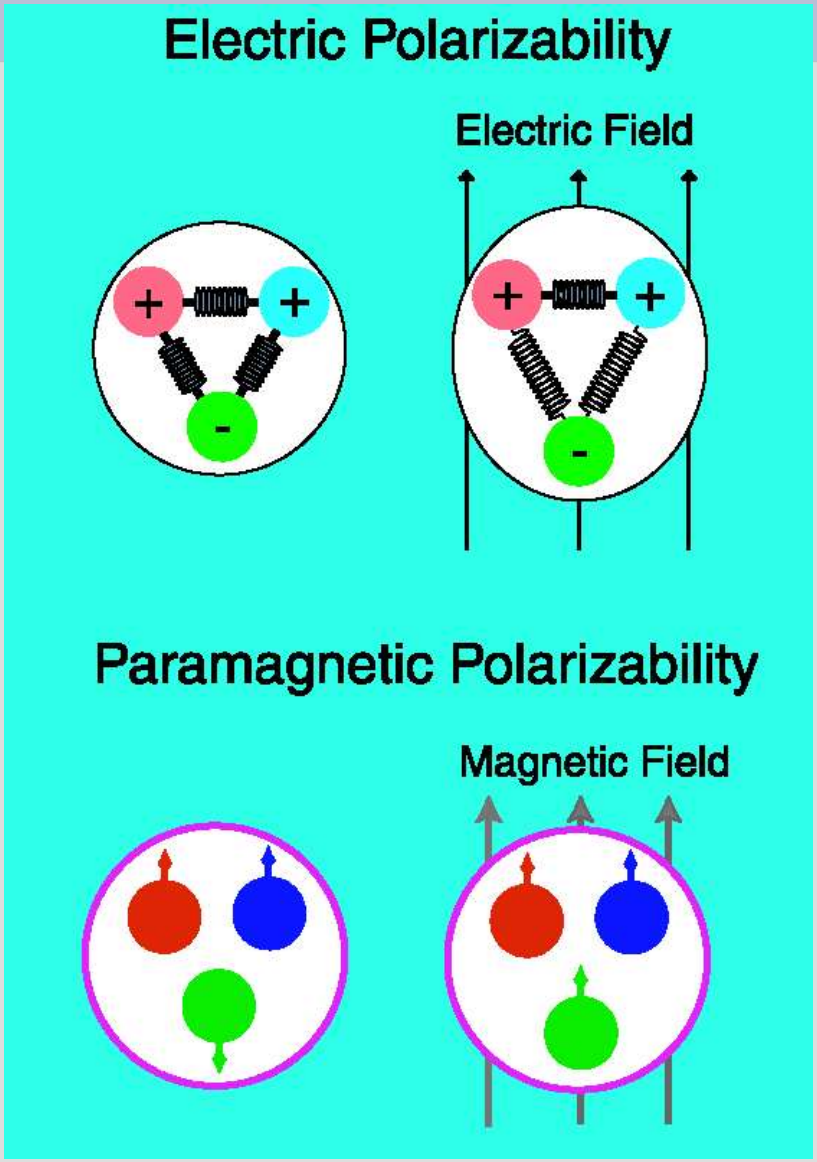




Summary

- Precision Measurement of π^0 Lifetime
- Axial Anomary: Profound Example of Symmetry Breaking
- The High Resolution Calorimeter has been built
- Finished ^{12}C data taking. ^{208}Pb and empty target run till Nov. 24, 2004.

PrimEx++



Compton Scattering