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Electromagnetic Properties of Pseudoscalar Mesons via the Primakoff Effect at 11 GeV

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(for the PrimEx Collaboration)

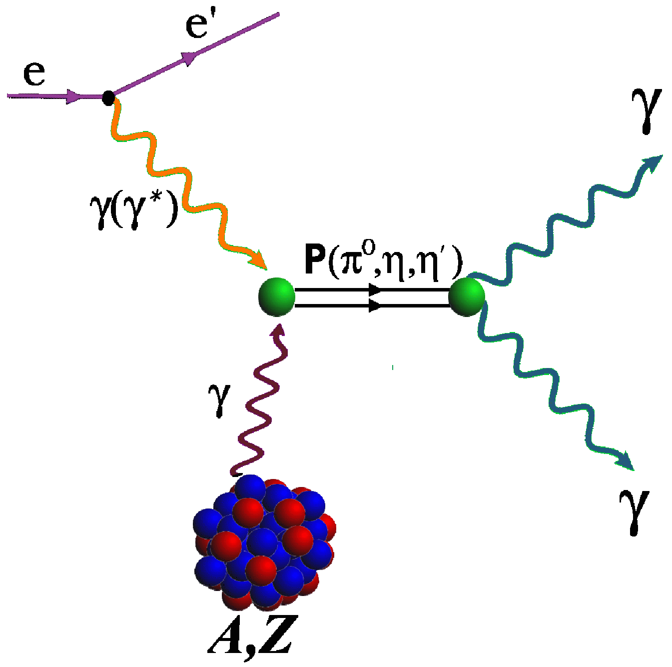
Contents

The Experimental Program

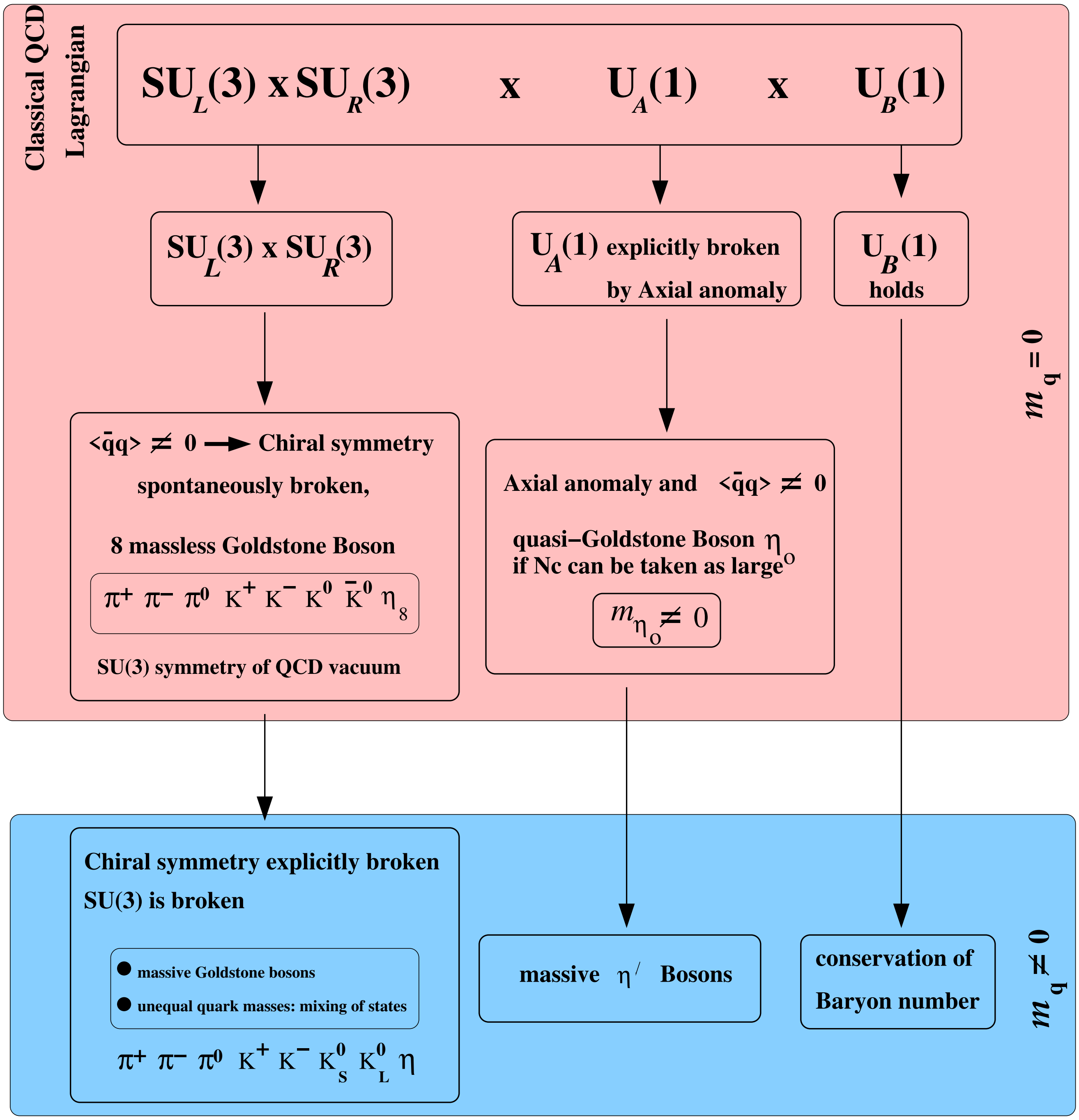
We propose to measure:

- **Two-Photon Decay Widths:** $\Gamma(\pi^0 \to \gamma\gamma)$, $\Gamma(\eta \to \gamma\gamma)$, $\Gamma(\eta' \to \gamma\gamma)$
- **Transition Form Factor** $F_{\gamma\gamma^* P}$ **of** π^0, η, η' **at low** Q^2 **(0.001–0.5 GeV^2)**

via the *Primakoff effect*.



Physics Motivation



Two-Photon Decay Widths

- $m_q = 0$ limit: Chiral Anomaly predicts

$$A(\pi^0 \to \gamma\gamma) = -i\frac{\alpha}{4\pi F_\pi}\epsilon^{\mu\nu\rho\sigma}\epsilon_\mu\epsilon'_\nu k_\rho k'_\sigma$$

$$A(\eta_8 \to \gamma\gamma) = -i\frac{\alpha}{4\sqrt{3}\pi F_\pi}\epsilon^{\mu\nu\rho\sigma}\epsilon_\mu\epsilon'_\nu k_\rho k'_\sigma$$

$$A(\eta_0 \to \gamma\gamma) = -i\frac{\alpha\sqrt{8}}{4\sqrt{3}\pi F_{\eta_0}}\epsilon^{\mu\nu\rho\sigma}\epsilon_\mu\epsilon'_\nu k_\rho k'_\sigma$$

- $(m_q \neq 0)$ limit: corrections to amplitudes.
  - $*$ Mixing corrections: $\pi^0 - \eta - \eta'$ mixing.

$$\eta = \eta_8 \cos\theta - \eta_0 \sin\theta$$

$$\eta' = \eta_8 \sin\theta + \eta_0 \cos\theta$$

  - $*$ Decay constant corrections:

$$F_\eta^8 = F_8 \cos\theta_8, \qquad F_\eta^0 = -F_0 \sin\theta_0$$

$$F_\eta^{\prime 8} = F_8 \sin\theta_8, \qquad F_\eta^{\prime 0} = F_0 \cos\theta_0$$

$\Longrightarrow$ $\Gamma(P \to \gamma\gamma)$ widths are crucial inputs for obtaining fundamental mixing parameters.

- Quark Mass Ratio:
  - $\Gamma_{\eta\to 3\pi}$: best observable for determining $(m_d - m_u)/m_s$.
  - $\Gamma_{\eta\to 3\pi}$ obtained from $\Gamma_{\eta\to\gamma\gamma}$ and known branching ratios.

  $\Longrightarrow$ Precision measurement of $\Gamma_{\eta\to\gamma\gamma}$ necessary.

Transition Form Factors at Low Q^2

- **Direct measurement of slopes**
  - **Interaction radii:**

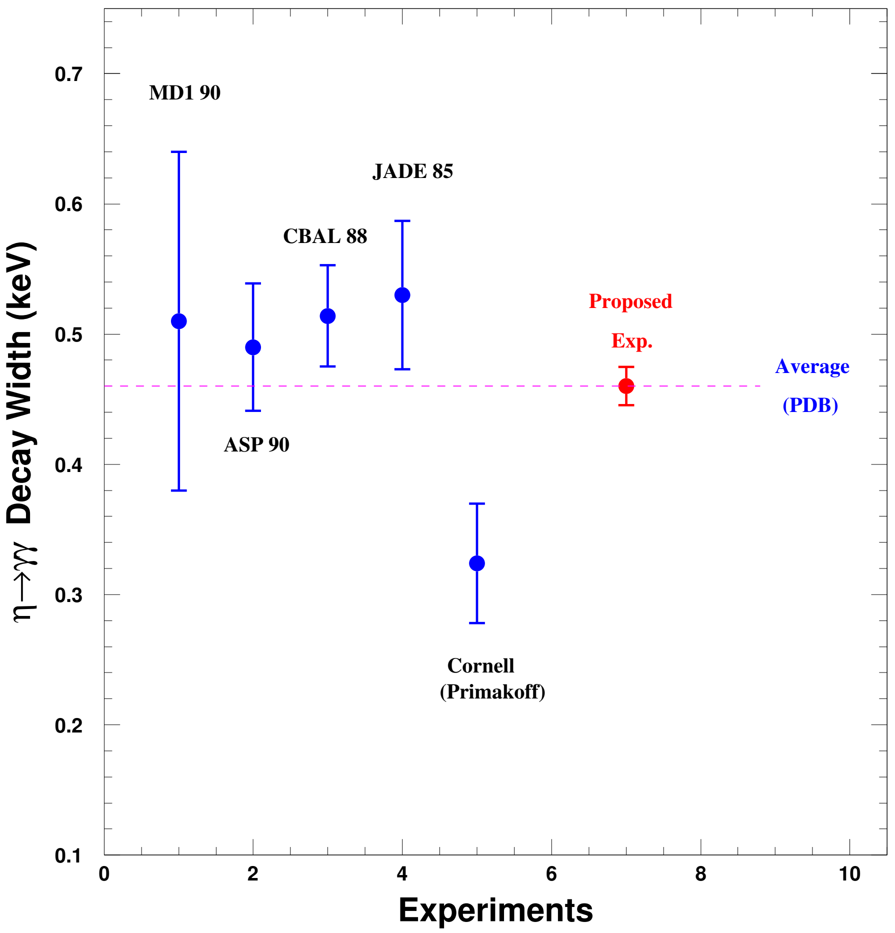
$$F_{\gamma\gamma^* P}(Q^2) \sim 1 - \frac{1}{6} < r^2 >_P Q^2$$

  - **ChPT for large N_c predicts relation between the three slopes. Extraction of $\mathcal{O}(p^6)$ low-energy constant.**

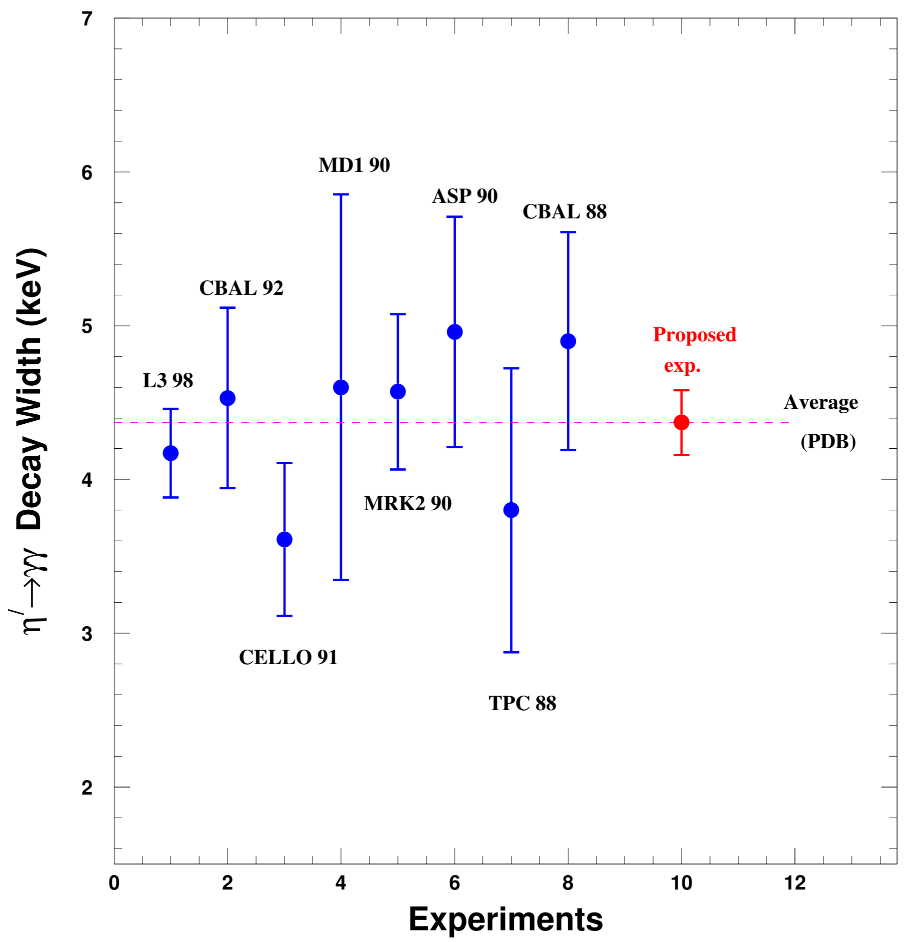
- **Input for light-by-light scattering for muon $(g-2)$ calculation.**

- **Test of future lattice calculations.**

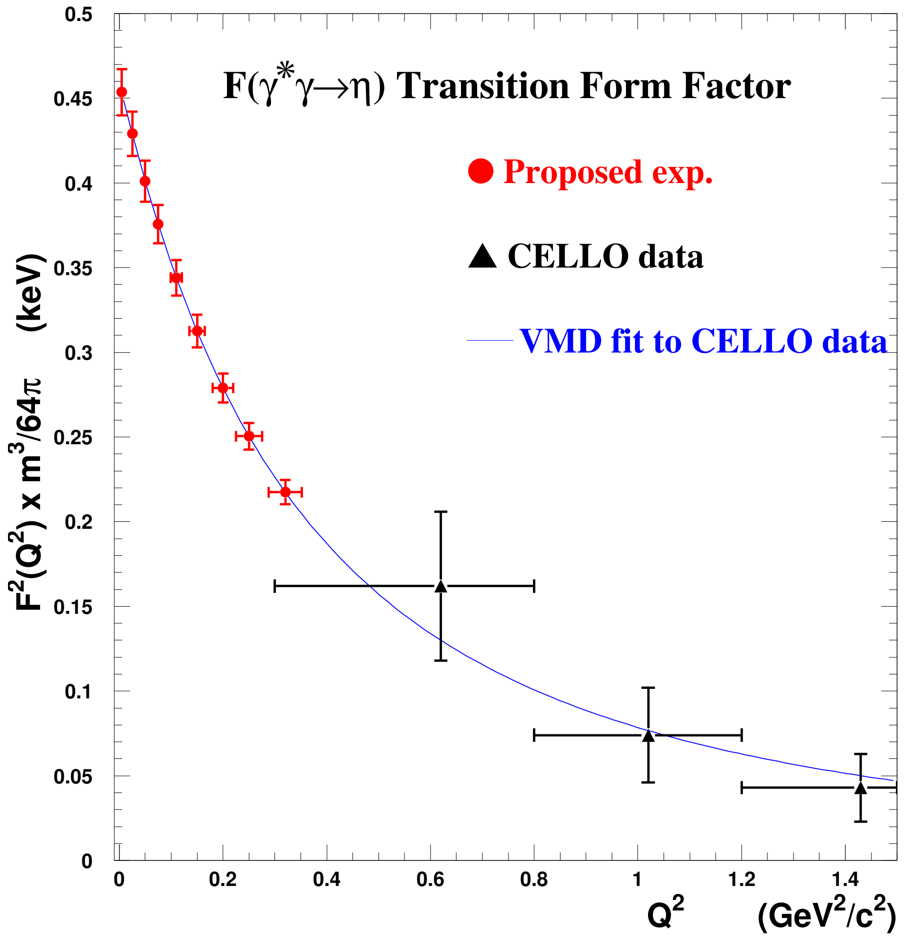
Experimental Data for $\Gamma(\eta \rightarrow \gamma\gamma)$



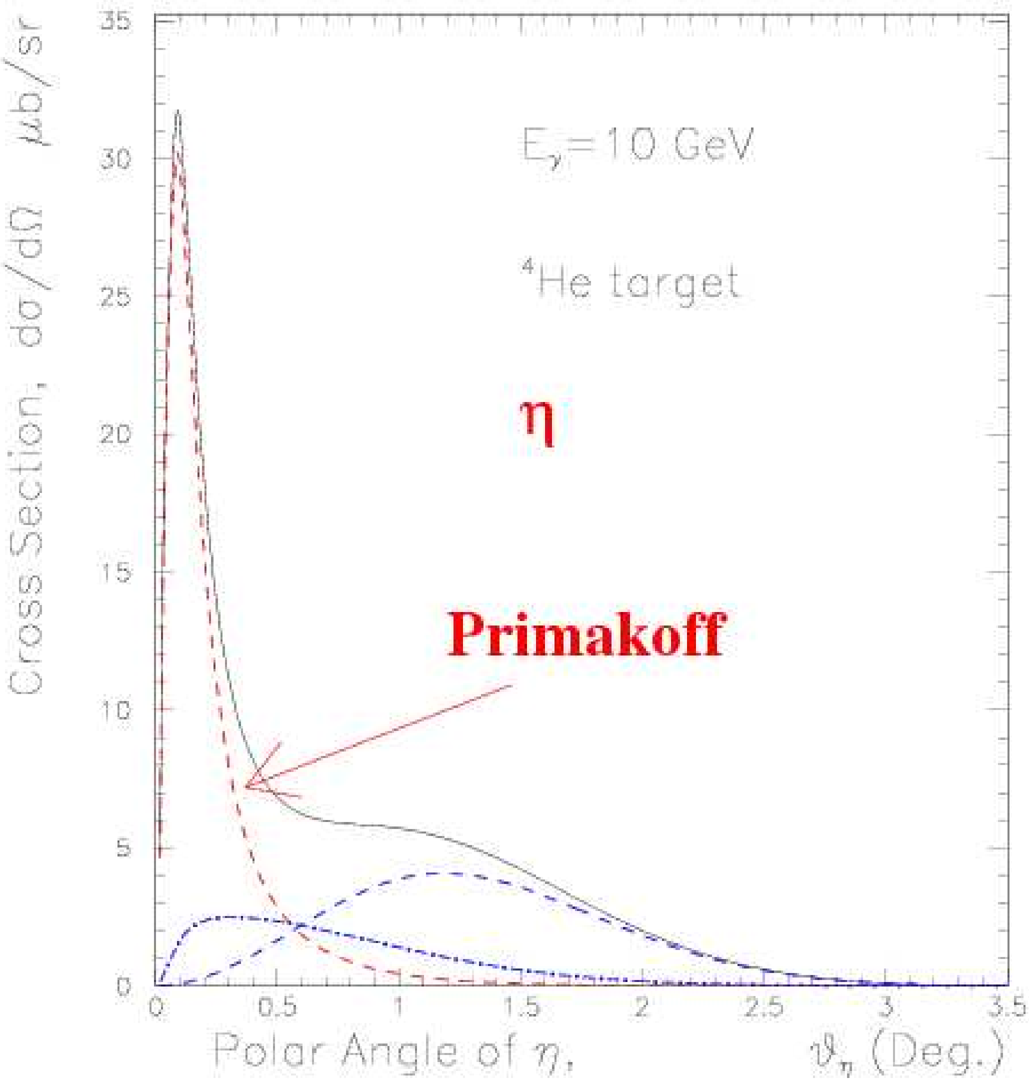
Experimental Data for $\Gamma(\eta' \to \gamma\gamma)$



Experimental Data for $F(\gamma^*\gamma \to \eta)$



Cross Sections



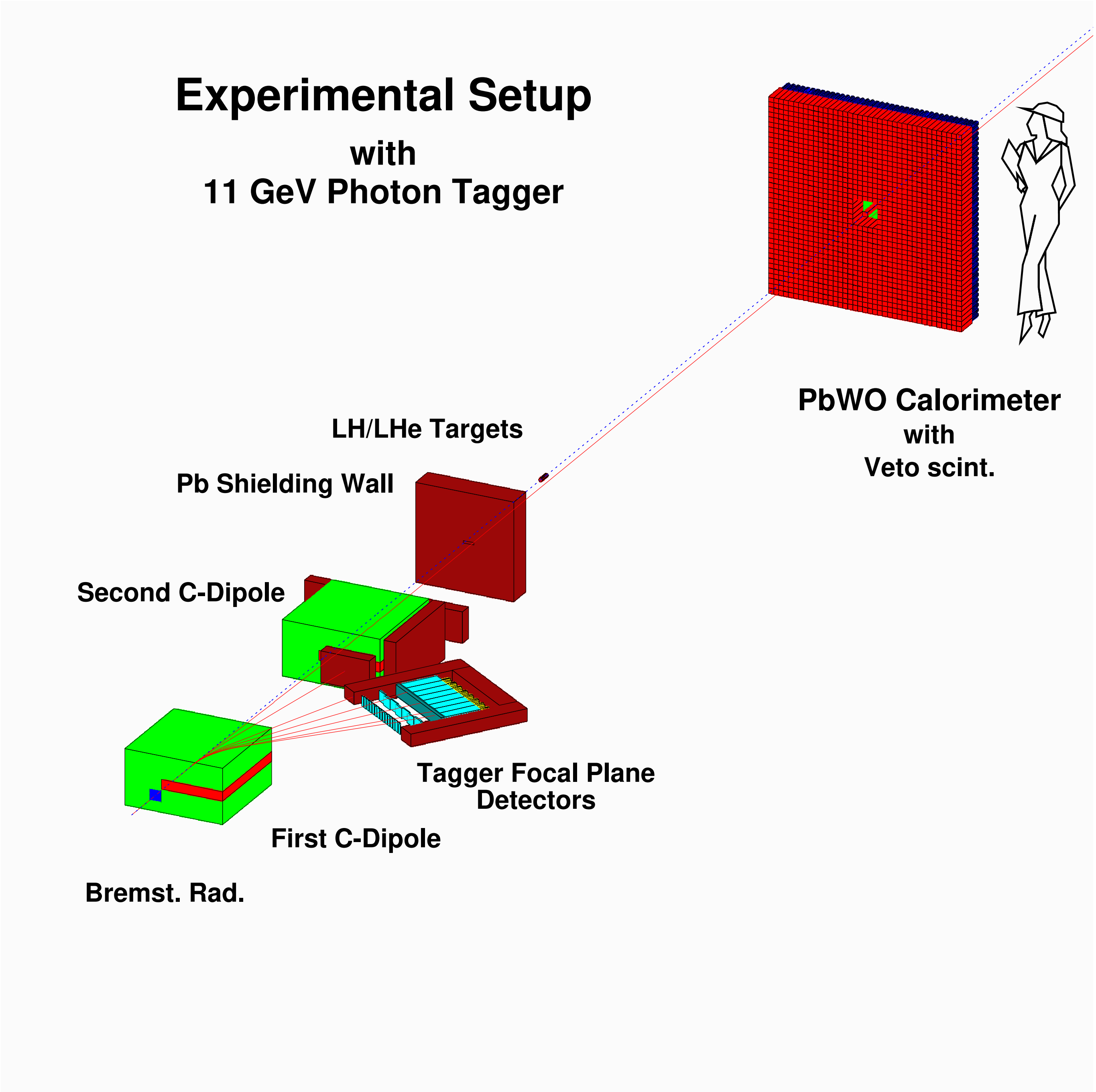
Production cross section:

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}|_{Pr} + \frac{d\sigma}{d\Omega}|_{NC} + 2\sqrt{\frac{d\sigma}{d\Omega}|_{Pr} \cdot \frac{d\sigma}{d\Omega}|_{NC}} \cdot \cos\phi + \frac{d\sigma}{d\Omega}|_{I}$$

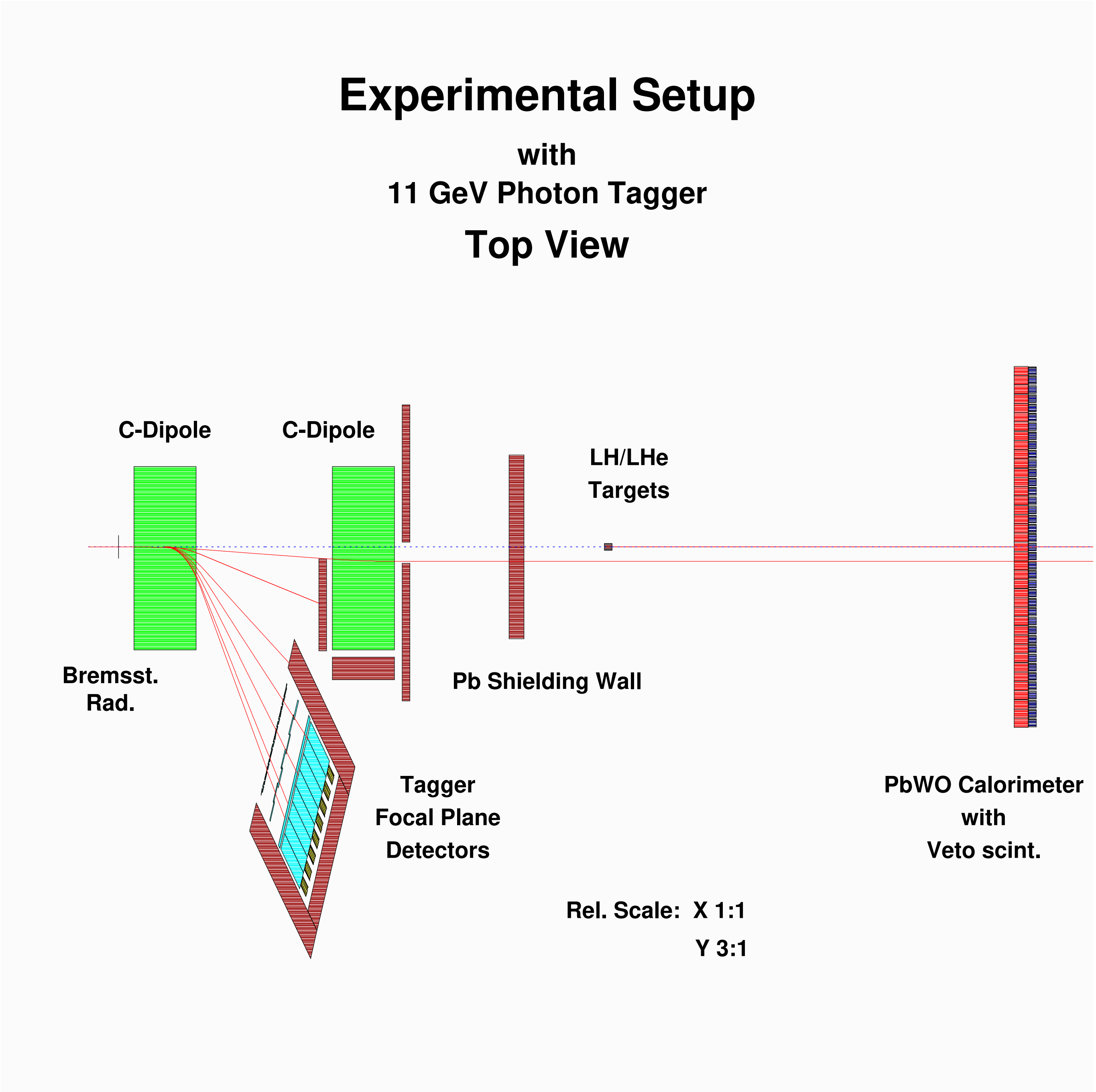
Primakoff cross section:

$$\frac{d\sigma}{d\Omega}|_{Pr} = \Gamma_{\gamma\gamma}\frac{8\alpha Z^2}{m^3}\frac{\beta^3 E^4}{Q^4}|F_{em}(Q^2)|^2 \sin^2\theta$$

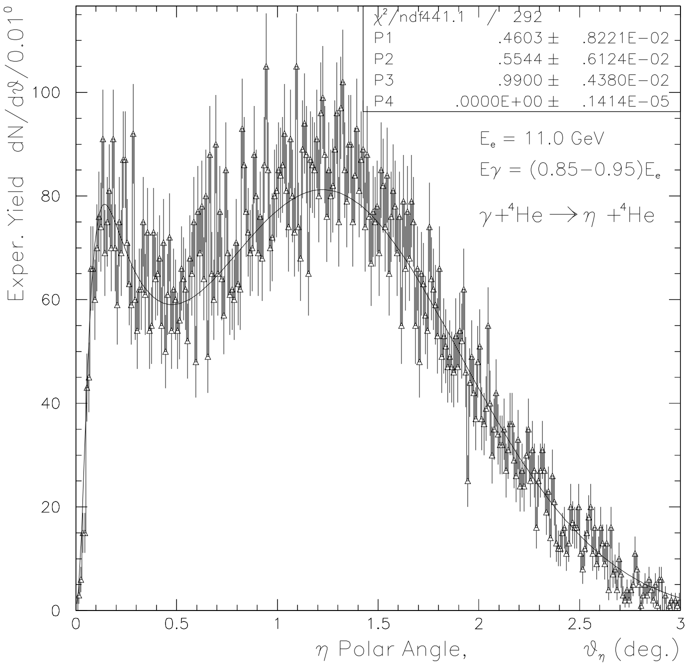
Experimental Setup



Experimental Setup

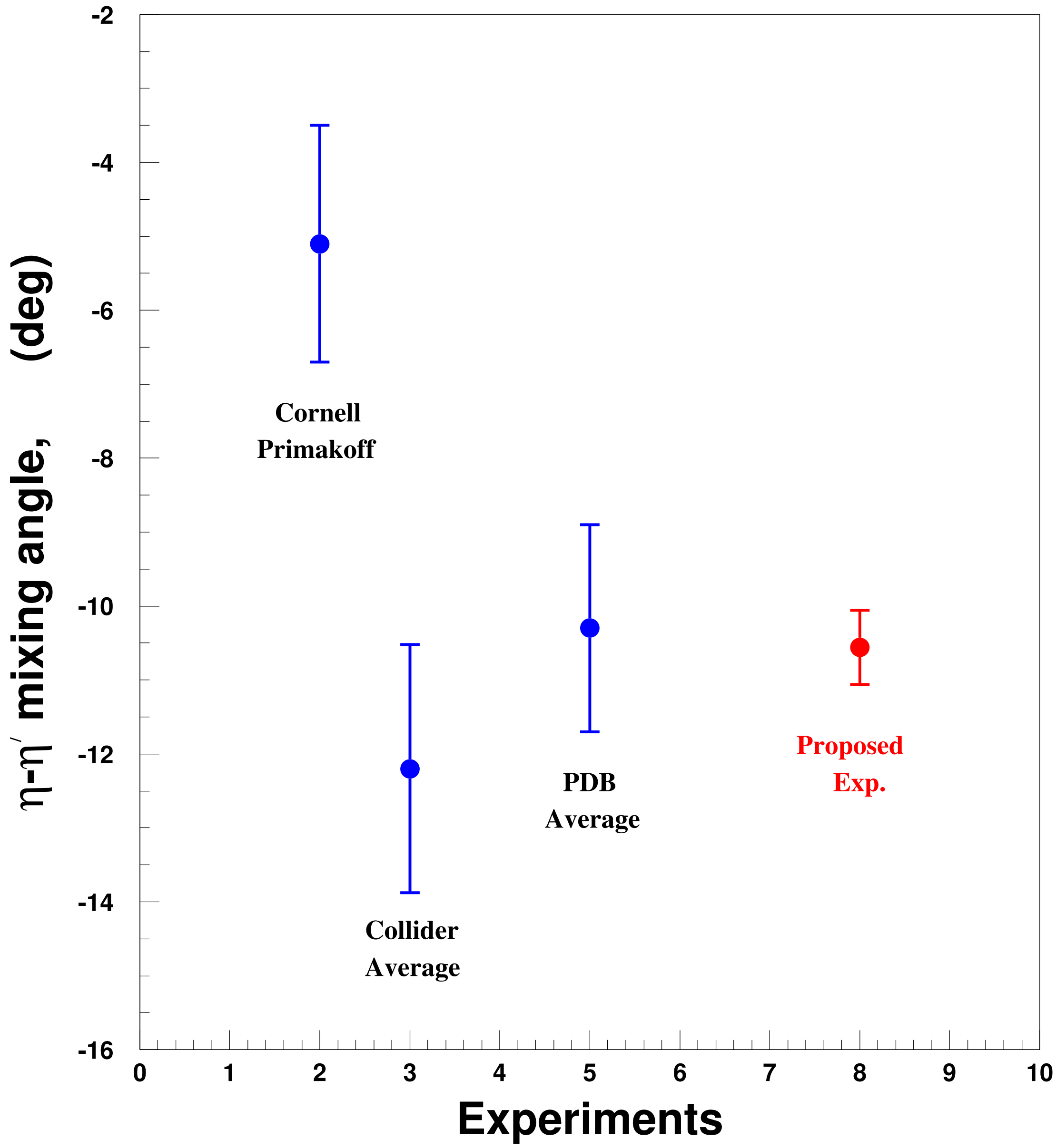


Error Estimation

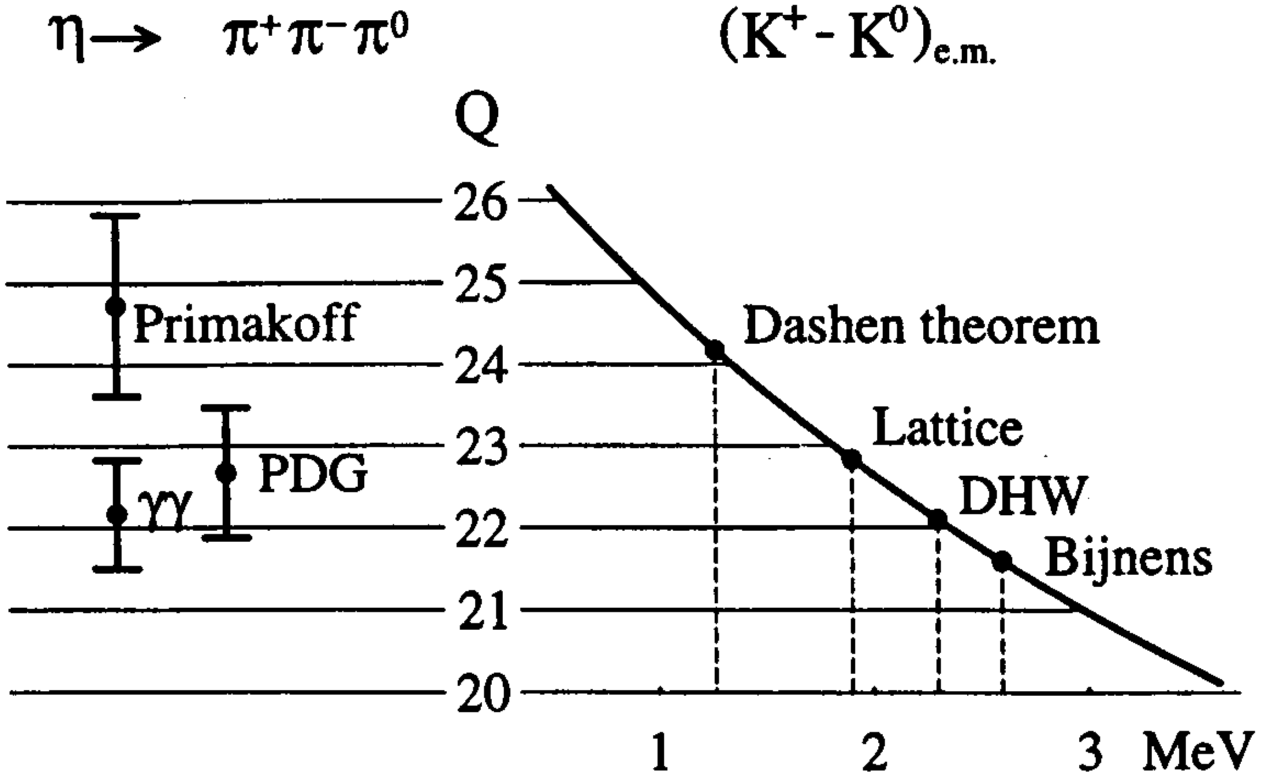


Statistical	1.0% **(60 days)**
photon flux	2.0%
target thickness	1.5%
acceptance, misalignment	0.5%
background subtract	0.4%
beam energy	0.2%
nuclear coherent contr.	1.0%
distorted form factor	0.3%
branching ratio	0.8% **(PDB)**
Total	3.1%

Improvement on η–η' mixing angle



Determination of Quark Mass Ratio



Conclusions

1. **High precision measurements (~ 3–5%):**
   - $\Gamma(\pi^0 \to \gamma\gamma)$, $\Gamma(\eta \to \gamma\gamma)$, $\Gamma(\eta' \to \gamma\gamma)$
   - **Transition form factor of π^0, η, η' at very low Q^2**

2. **Fundamental input to physics:**
   - η–η' **mixing**
   - **Determination of Quark Mass Ratio**
   - **Interaction radius of π^0, η and η'**
   - $\mathcal{O}(p^6)$ **in Chiral Lagrangian**
   - **Crucial input for test of SM via $(g-2)$**
   - **Test QCD based models**