MEASURING LINEAR POLARIZATION USING HIGH-MASS BETHE-HEITLER PAIRS

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- Bethe-Heitler formula for linearly polarized photons
- Searching phase space for a signal
- Can we use this as a way to measure linear polarization?
Bethe-Heitler Pair Production

\[
\frac{d\sigma}{dE_+d\Omega_+d\Omega_-} = \frac{Z^2}{137} \frac{\epsilon^4}{4\pi^2} \frac{p_+ p_-}{k^3 q^4 \rho^3} \left\{ \frac{(\hat{\epsilon} \cdot p_+)^2 (q^2 - 4E_+^2)}{(E_+ - p_+\cos\theta_+)^2} \right. \\
+ \left. \frac{(\hat{\epsilon} \cdot p_-)^2 (q^2 - 4E_-^2)}{(E_- - p_-\cos\theta_-)^2} \right. \\
+ \frac{2(\hat{\epsilon} \cdot p_+) (\hat{\epsilon} \cdot p_-) (q^2 + 4E_+E_-)}{(E_+ - p_+\cos\theta_+)(E_- - p_-\cos\theta_-)} \\
+ \frac{k^2 [p_+^2 \sin^2\theta_+ + p_-^2 \sin^2\theta_- + 2p_+p_- \sin\theta_+ \sin\theta_- \cos(\phi_+ - \phi_-)]}{(E_+ - p_+\cos\theta_+)(E_- - p_-\cos\theta_-)} \right\}
\]


- Variables: \( \hat{\epsilon} \), unit vector along incident linear polarization; \( q \), 3-momentum transfer; \( k \), incident photon momentum; \( E_\pm, p_\pm, \theta_\pm, \phi_\pm \), energy, momentum, and lab angles of the leptons.

- No form factors (i.e. point nucleus with charge \( Z \)).
Method

- Throw dice:
  - Assume $k = 25$ GeV.
  - Pick $0 < p_\pm < 25$ GeV at random
  - Pick $0^\circ < \theta_\pm < 25^\circ$ at random
  - Pick $0^\circ < \phi_\pm < 360^\circ$ at random

- Calculate the cross section for these momenta and angles assuming scattering from the proton.

- Save the event if:
  - the cross section is above a threshold ($\approx 1 - 5\%$ of maximum cross section)
    - muons are within the detector acceptance
    - energy is conserved (selection process can go into forbidden kinematical territory)

- Form cross-section-weighted averages for the events that survive.
• Cut on mass of pairs $M > 1.5$ GeV

• Events are predominantly asymmetric

• Cutoff at low and high momenta comes from detector acceptance.
Polar Angles of BH Events

- Top: Polar angle of $\mathbf{p}_+ + \mathbf{p}_-$
- Bottom: $\theta_+$ vs. $\theta_-$
Azimuthal Angles of BH Events

- Top: Azimuthal angle of $p_+ + p_-$
- Bottom: $\phi_+ - \phi_-$ distribution
Phi Distributions of the Faster BH Muon

- Top: Linear polarization is 100% in the $x$-direction. Curve is $0.1 + 0.13 \sin^2 \phi_{\text{fast}}$.
- Bottom: Unpolarized photons
Bethe-Heitler Pair Production

- Rates of high-mass Bethe-Heitler pairs (> 1.5 GeV) are comparable to $J/\psi$ rates in the detectors.
- BH azimuthal asymmetries must be known to make background subtraction for the $J/\psi$.
- We will have sufficient statistics for each target and energy to determine the linear polarization ($\approx 10k$–30k events).
- As yet unknown systematic errors (detector acceptance, form factors, etc.) will dominate.
Conclusions

- Bethe-Heitler pairs with mass $> 1.5$ GeV are predominantly asymmetric with one $\mu$ having a large fraction of the photon beam energy and being emitted at small angles.

- The azimuthal distribution for the pair momenta $p_++p_-$ is nearly flat.

- The azimuthal distribution of the fast $\mu$ shows a marked $\sin 2\phi$ dependence arising from the linear polarization.

- Using high-mass Bethe-Heitler pairs looks promising as a way of measuring the linear polarization of the photon beam.

- More studies are required which more accurately simulate the process:
  - Use a more reasonable formalism with correct form factors
  - Perform a realistic Monte Carlo simulation of the process