MEASURING LINEAR POLARIZATION USING HIGH-MASS BETHE-HEITLER PAIRS

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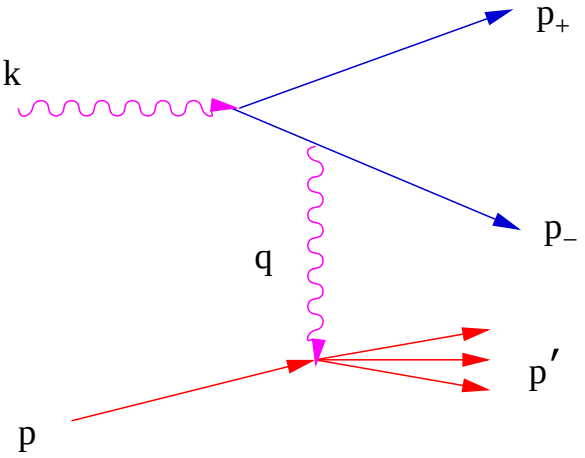
- Bethe-Heitler formula for linearly polarized photons
- Searching phase space for a signal
- Can we use this as a way to measure linear polarization?

Bethe-Heitler Pair Production



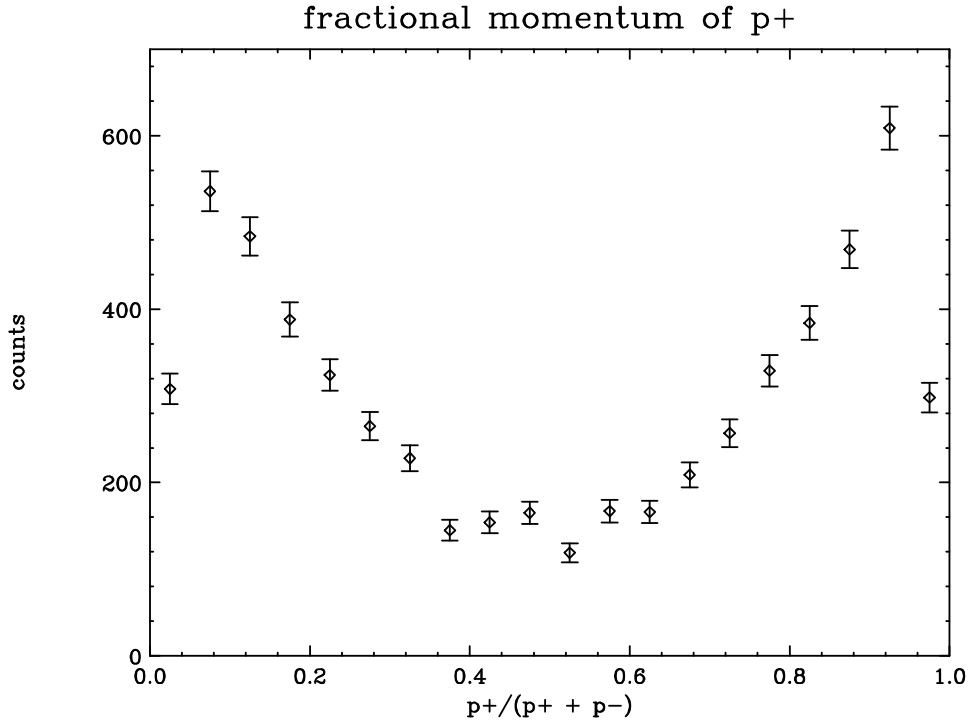
$$\frac{d\sigma}{dE_+ d\Omega_+ d\Omega_-} = \frac{Z^2}{137}\frac{e^4}{4\pi^2}\frac{p_+ p_-}{k^3 q^4}\left\{\frac{(\hat{\epsilon}\cdot\mathbf{p}_+)^2(q^2-4E_-^2)}{(E_+ - p_+\cos\theta_+)^2}\right.$$
$$+\ \frac{(\hat{\epsilon}\cdot\mathbf{p}_-)^2(q^2-4E_+^2)}{(E_- - p_-\cos\theta_-)^2} - \frac{2(\hat{\epsilon}\cdot\mathbf{p}_+)(\hat{\epsilon}\cdot\mathbf{p}_-)(q^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

- Berlin and Madansky, Phys. Rev. **78** (1950) 623.
- 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

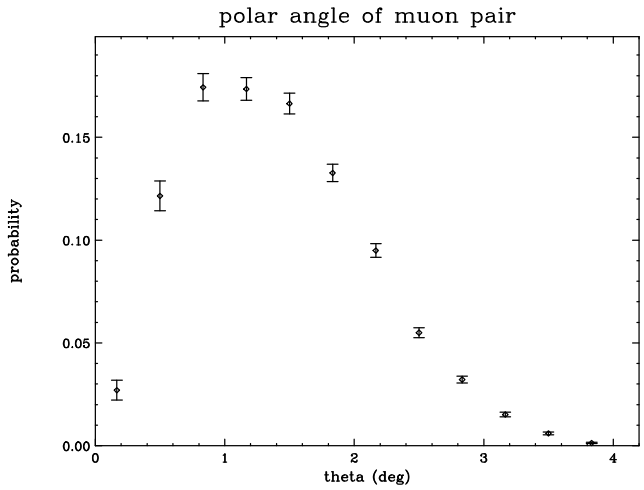
- Throw dice:
  - Assume $k = 25$ GeV.
  - Pick $0 < p_{\pm} < 25$ GeV at random
  - Pick $0^{\circ} < \theta_{\pm} < 25^{\circ}$ at random
  - Pick $0^{\circ} < \phi_{\pm} < 360^{\circ}$ at random
- Calculate the cross section for these momenta and angles assuming scattering from the proton.
- Save 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.

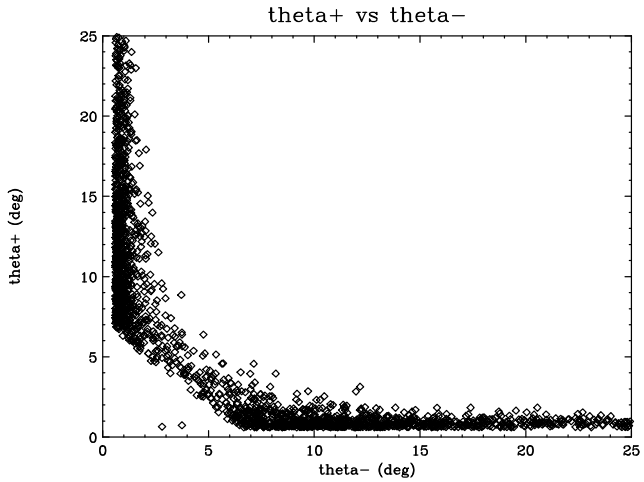
Distribution of BH momenta



- Cut on mass of pairs $M > 1.5$ GeV
- Events are predominantly asymmetric
- Cutoff at low and high momenta comes from detector acceptance.

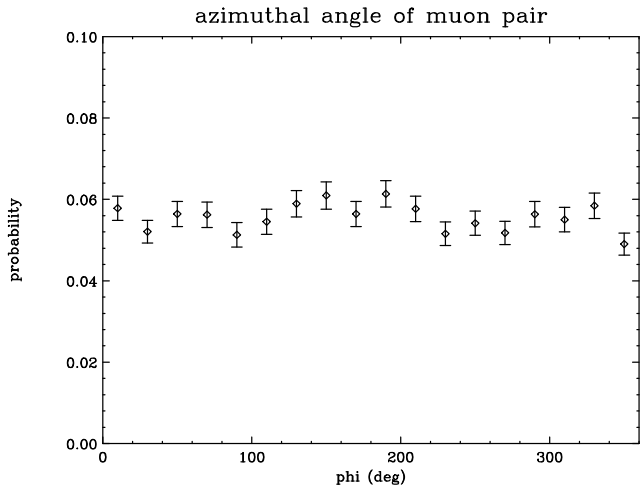
Polar Angles of BH Events

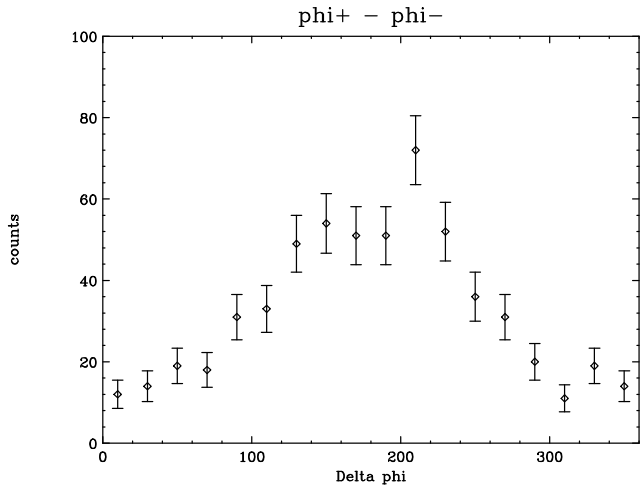




- Top: Polar angle of $\mathbf{p}_+ + \mathbf{p}_-$
- Bottom: θ_+ vs. θ_-

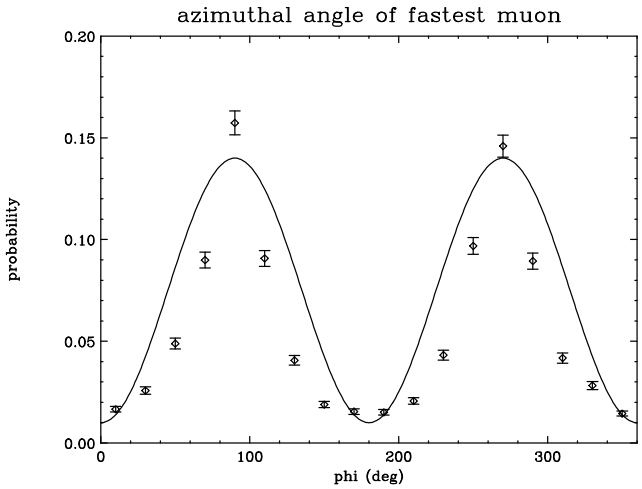
Azimuthal Angles of BH Events

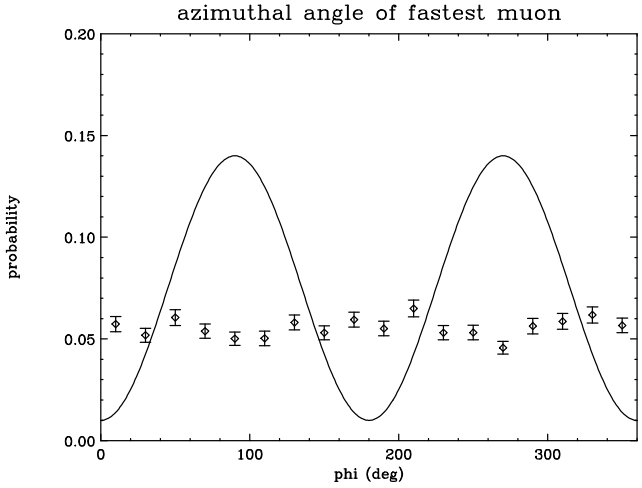




- Top: Azimuthal angle of $\mathbf{p}_+ + \mathbf{p}_-$
- Bottom: $\phi_+ - \phi_-$ distribution

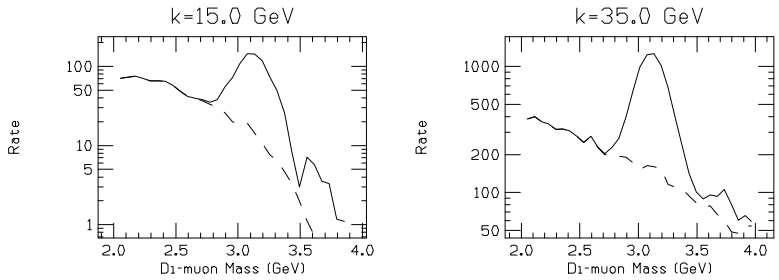
Phi Distributions of the Faster BH Muon





- 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/ψ rates in the detectors.
- BH azimuthal asymmetries must be known to make background subtraction for the J/ψ.
- 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 μ having a large fraction of the photon beam energy and being emitted at small angles.
- The azimuthal distribution for the pair momenta $\mathbf{p}_+ + \mathbf{p}_-$ is nearly flat.
- The azimuthal distribution of the fast μ 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