Observability of Gamma-Ray Triplets and Polarimetry

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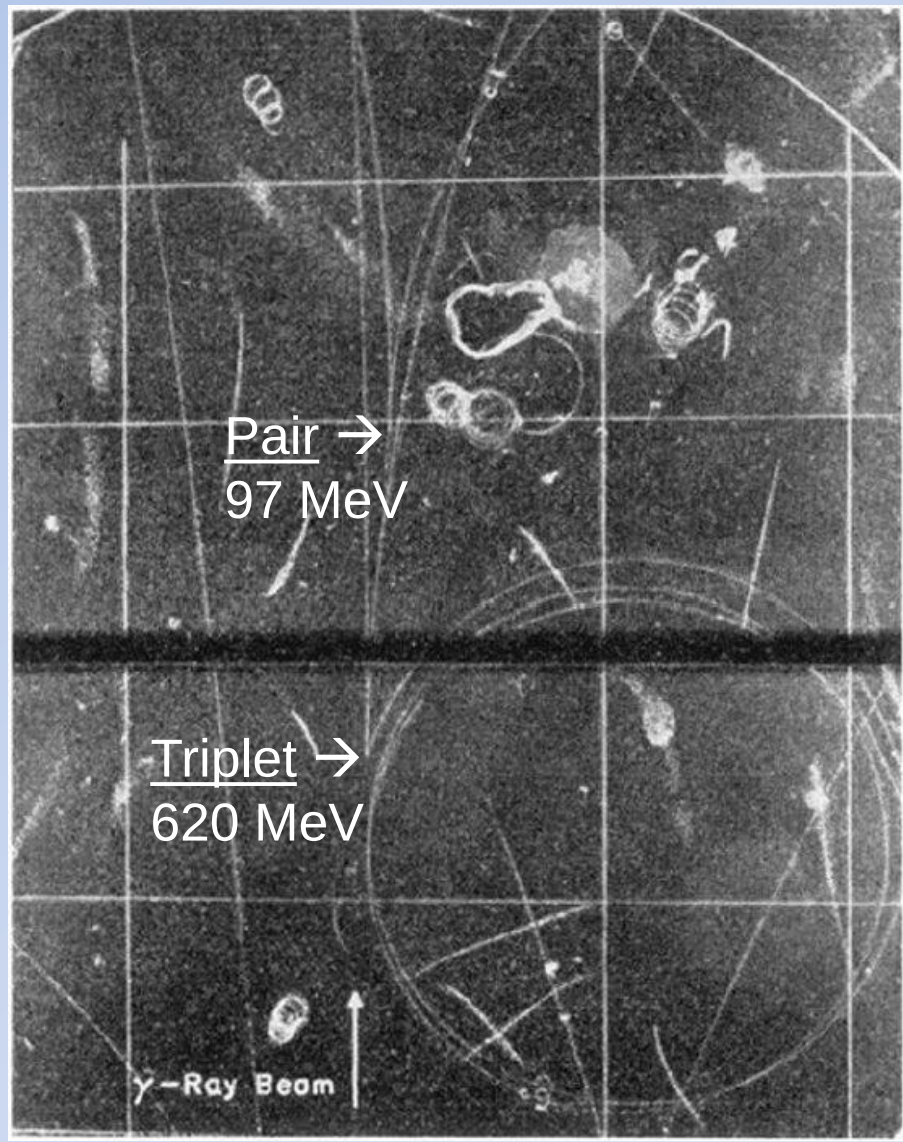
Triplet Production

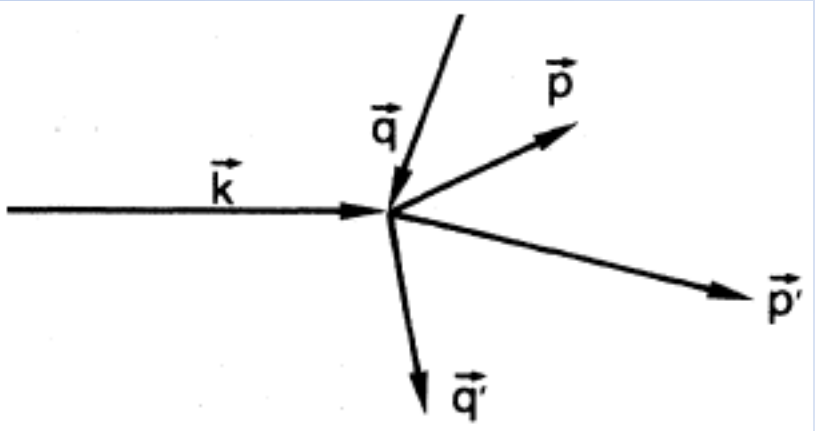
- Pair production in the field of an electron
- Three tracks originating from a vertex
  - two electrons and a positron
  - positron distinguishable in magnetic field
- Electron recoil $q \approx$ ~1 MeV/c
  - Comparable to nuclear recoil momentum, but, electron typically has detectable energy
- Potential background events
  - Nearly coincident Compton scatter followed by nuclear pair production
  - Production of δ-ray near nuclear pair vertex



Hart, et al. Z. Naturforsch. 30 a, 1099-1113 [1975]

Pair production in the field of an electron

- A photon, with four-momenta, $\mathbf{k}=(k, \boldsymbol{k})$
- Collides with an electron, with $\mathbf{p}=(\varepsilon, \boldsymbol{p})$
- Creating and electron-positron pair,
  $\mathbf{p}''=(\varepsilon'' \boldsymbol{p}'')$ and $\mathbf{p}_+=(\varepsilon_+, \boldsymbol{p}_+)$
  and (undistinguishable) recoil electron
  $\mathbf{p}'=(\varepsilon', \boldsymbol{p}')$



- Energy-momentum conservation
  $\mathbf{k} + \mathbf{p} = \mathbf{p}_+ + \mathbf{p}' + \mathbf{p}''$

4-vector metric: $(\mathbf{a}\ \mathbf{b})=a_0b_0 - (\boldsymbol{a}\cdot\boldsymbol{b})$

Differential Cross-Section

- Differential CS for triplet production
  - calculated to lowest order of perturbation theory
  - in terms of invariant products $\chi=(pk)$, $\chi'=(p'k)$, and $\tau=(pp')$
- Haug, Z. Naturforsch. 40a, 1182-1188 (1985)

$$\sigma(\varepsilon',\theta') \equiv \frac{\mathrm{d}^2\sigma}{\mathrm{d}\varepsilon'\,\mathrm{d}\cos(\theta')} = \alpha r_0^2 \frac{p'}{k} \frac{\sqrt{\rho^2-4}}{\rho} \frac{1}{\pi} \int A_t \, d\Omega_{p_+}$$

$$\rho^2 = 2\left[\chi - \chi' - \tau + 1\right] \geq 4$$

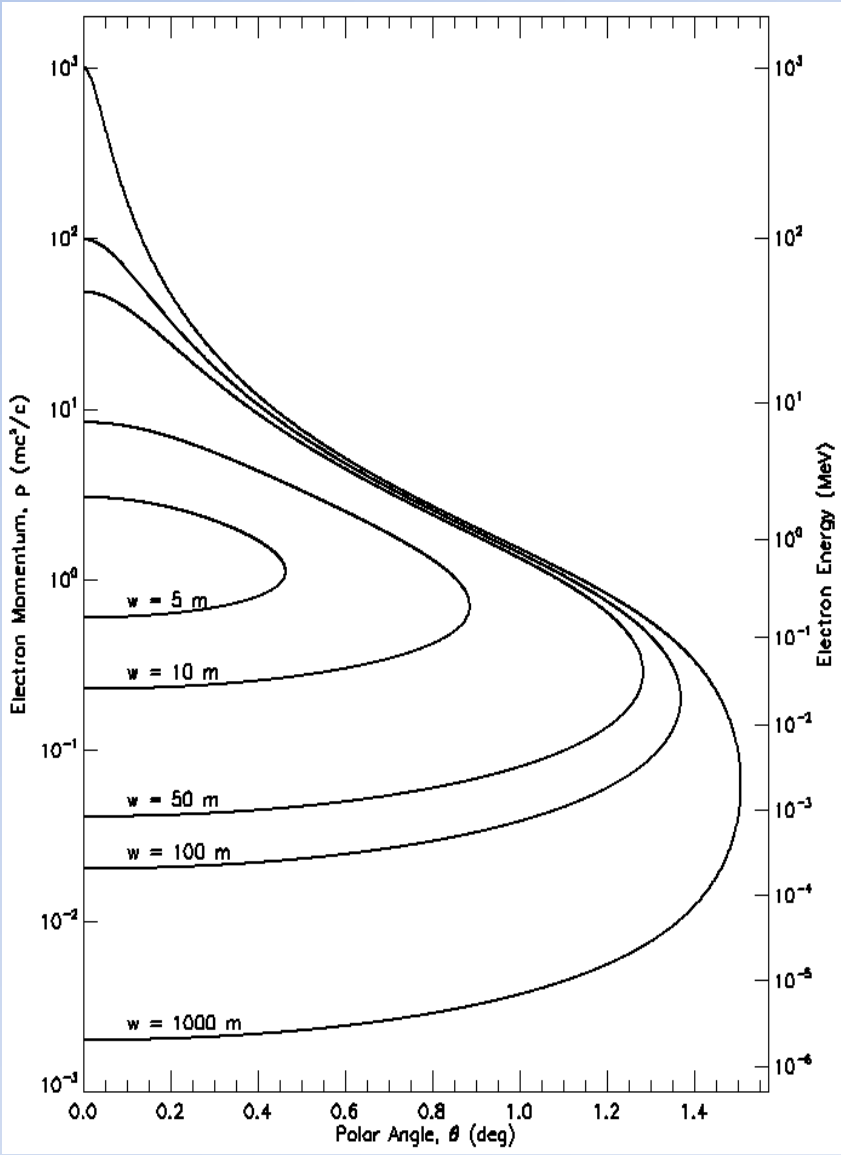
- $\frac{1}{\pi}\int A_t \,\mathrm{d}\Omega_{p_+}$ is given by

Haug, Phys. Rev. D 31, 2120-2128 (1984)

Polar Angle Distribution

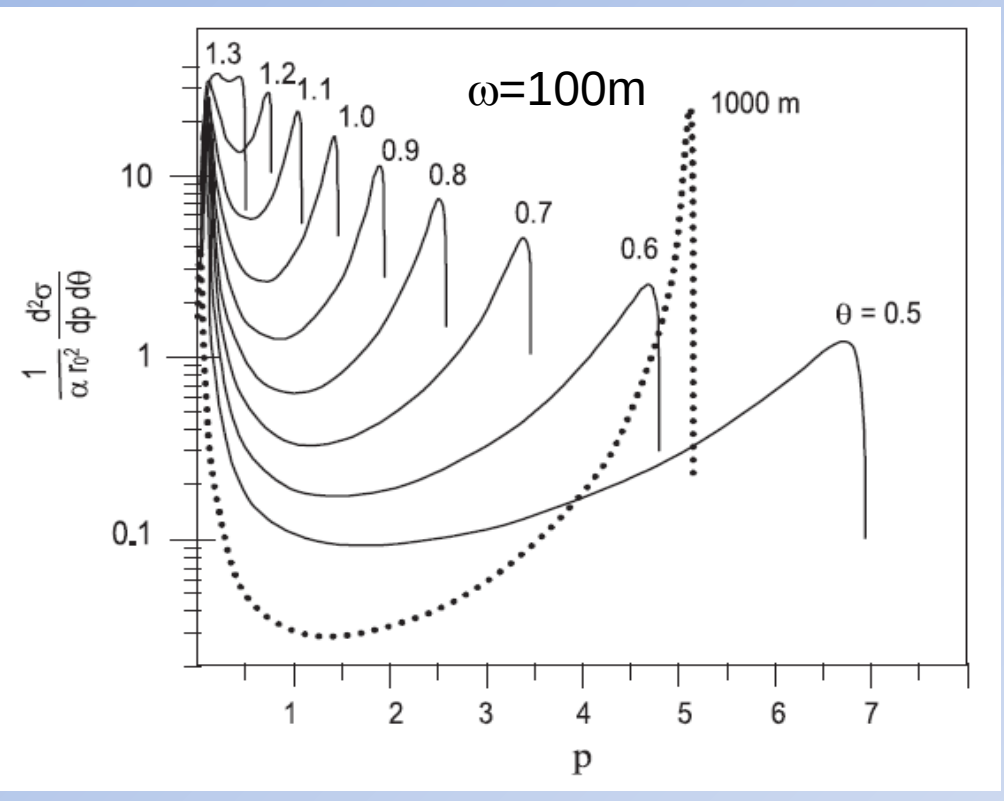
- Polar angle range – $2/\sqrt{k} \leq \cos\theta \leq 1$
- Energetic "pair" electron and positron are forward scattered
- Low-energy "recoil" electron is emitted at large, ~90°, polar angle with azimuth angle preferentially aligned with electric field of photon

- Depaola & Iparraguirre, NIM A 611, 84-92, 2009

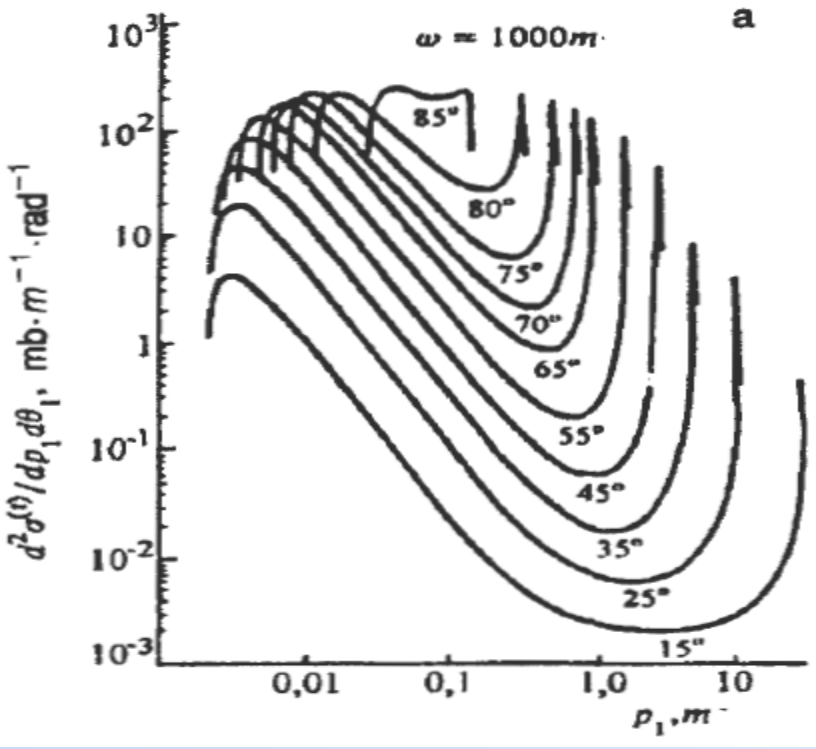


Momentum Probability Density

- Electron or positron ω =100 and various polar angles (radians)
- ω =1000, Probability is concentrated near the min and max momenta



Iparraguirre & Depaola, Eur. Phys. J. C 71, 1778, 2011



Boldyshev, et al. Phys. Part. Nucl. 25, 292, 1994

Triplet Cross Section

- Majority of CS probability corresponds to the case in which:
- a electron-positron "pair" emerges with high energy and minimum deviation with respect to the incoming radiation
- the other "recoil" electron has low energy and relatively large polar angles

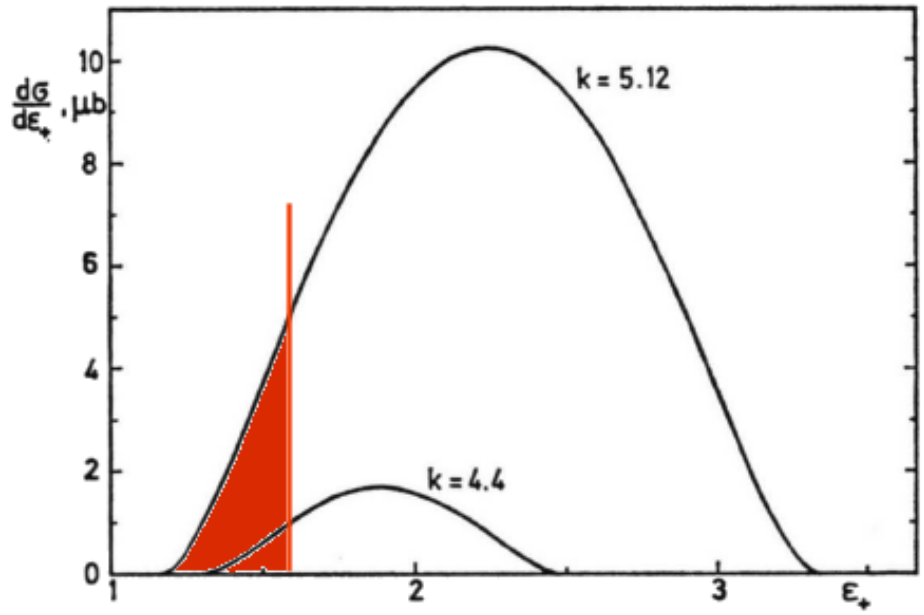
- Detection of the "recoil" electron is necessary to define a triplet

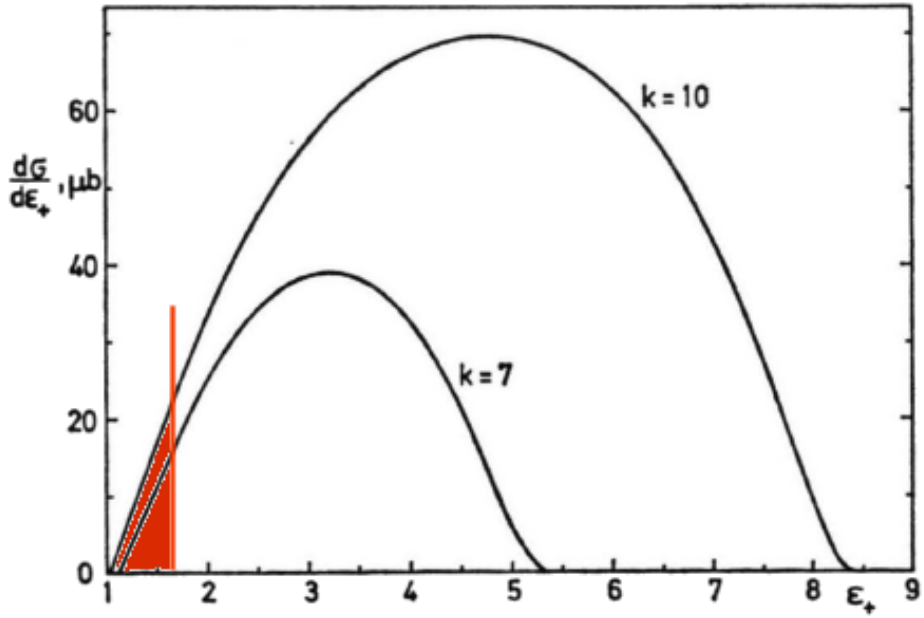
Minimum Detection Momentum

- Gamma converts (on average) in middle of a SiStrip
- Recoil electron must traverse half of first strip
  - All of a second SiStrip
  - And hit third SiStrip layer with minimum detectable energy, ~ 25 keV
- Min detectable particle must have a range in Si of ≥~1-1/2 times the SiStrip thickness
  - Cosine effect
    - "Recoil electron" emitted at larger, ~90 deg, angle to photon
- Min detectable momentum 0.7-1.8 $m_e c$ depending on traversed SiStrip thickness, 100-1000 μm
  - Take $\langle q \rangle = 1.6\ m_e c \rightarrow \langle E \rangle = 1.6\ m_e c^2$

Positron Energy Spectra

- E_+ is quasi-symmetric about k/2
  - More so at higher k
- Small fraction of cross-section lost to minimum detection, decreases as k increases
- Remaining energy divided between pair electron and recoil electron

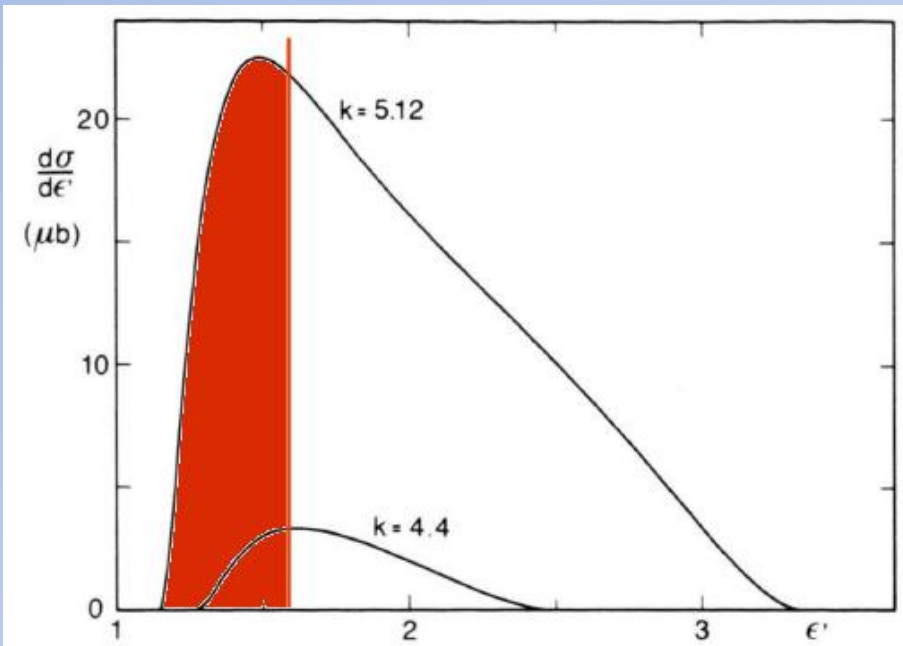


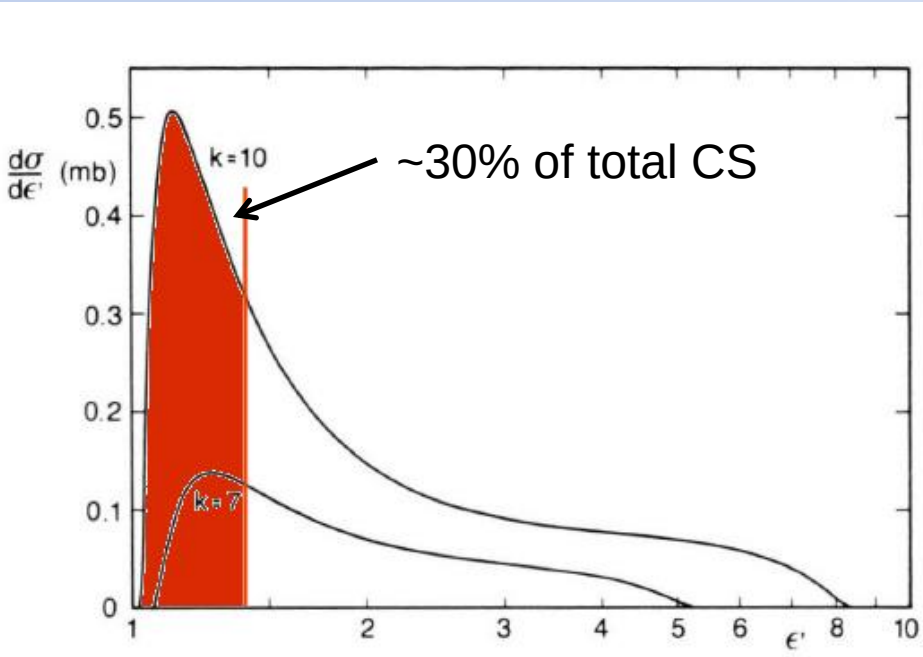


Haug, Z. Naturforsch. 30a 1099 (1975)

Electron Energy Spectra

- E_- cross-section is shifted to lower energies
  - ~30% of cross-section lost for ω =10m
  - Significantly more lost at ω > ~100m
- Moderate probability that a triplet is misidentified as a pair





Haug, Z. Naturforsch. 40a 1182 (1985))

Consequence for Polarization

- Triplet cross-section is 1/Z of nuclear CS, = 1/14 = 7% for Silicon
- As photon energy increases, CS for low-energy fraction also increases, or number of detected recoil electrons is constant (Iparraguirre & Depaola)
- Need to minimize threshold for "recoil" electrons detection
- Reduction from 400 μm SiStrips to 100 μm SiStrips would reduce threshold to ~1 $m_e c$ and increase triplet identification fraction from 0.7 to ~0.9

QUESTIONS?

DISCUSSION?