Electromagnetic processes in strong crystalline fields

Status Report

Ulrik I. Uggerhøj
LPM in pair production
(b) The relative contribution of the LPM effect in the spectral distribution of created electron (see Eq.(14)) $\Delta_p(\omega, y)$ (per cent). The curves 1, 2, 3 are correspondingly for photon energies $\omega = 55, 75, 95$ GeV.
Trident production in strong fields
**Abstract**

The so-called *Klein paradox*—unimpeded penetration of relativistic particles through high and wide potential barriers—is one of the most exotic and counterintuitive consequences of quantum electrodynamics. The phenomenon is discussed in many contexts in particle, nuclear and astro-physics but direct tests of the Klein paradox using elementary particles have so far proved impossible....
Trident production

\[ \chi = \gamma \mathcal{E} / \mathcal{E}_0 \]

\[ \mathcal{E}_0 = mc^2 / e \lambda_c = 1.32 \cdot 10^{16} \text{ V/cm} \]

\[ 10^{11} - 10^{12} \text{ V/cm} \]
Trident (Klein-like)

Trident production:

Background (no target) in nearly complete agreement with GEANT simulation (= no big surprises)

Contributes about 20%

Enhancement when crystal aligned around factor 3 – clearly visible!

Setup optimized for detection of 1-10 GeV pairs from 200 GeV electrons
Simulations measurements

Only non-aligned case can be simulated in Geant4

Fair agreement with data

Enhancement, 400 um Ge <110>, 180 GeV: \( \approx \frac{1.7-0.3}{0.8-0.3} = 2.8 \)
Trident production in Ge crystals

Theory, Baier and Katkov

Preliminary
Sandwich foils (structured targets)
Formation length ($l_f$)

- Separation of electron and photon by a (reduced) wavelength (or the pair by a Compton wavelength):

\[
l_f(1/v-1/c) = \frac{\lambda}{2\pi c} = \frac{1}{\omega}
\]

Can it be detected directly at a few hundred GeV ($l_f =$ microns)?
Sandwich target

- Sandwich target
- 20 layers:
  \[ Z_{Ta}^2/Z_{Al}^2 = 32 \]
- Resonances within formation length

\[ F(k,T,x) \]

Blankenbecler: 2 foils, 25 GeV
Single target

- Shul’ga-Fomin: Reduced multiple scattering – no suppression from LPM effect

JETP Lett. 63, 873 (1996)
Measurements 2007

206 GeV, 20x(Ta5Al6)
- Blankenbecler, 1 foil
- Blankenbecler, 2 foils
- Blankenbecler, 20 foils
- Shul’ga - Fomin

Enhancement, Ta5Al6/Ta100 vs. Photon energy [GeV]
Crystalline undulator
Undulator Radiation from Positron Channeling in a Single Crystal

A. Solov’yov, A. Korol, W. Greiner et al.
Laser-ablated crystals

10 microns, laser

200 microns, diamond-blade (previously ‘state-of-the-art’)

FIG. 2. Surface fragment of one of the manufactured crystal undulators seen by a microscope.
Synthetic (HPHT) Diamonds

Extracted plate

(100) face
(110) sides

Visible light image

Cathodo luminescence image

Seed

(113)
(111)
(110)
(100)
Undulating diamonds

• Bent diamonds a likely solution for 'smart collimator' at LHC (W. Scandale)

Femto-second laser-ablation of 10 micron tracks, spaced 100 microns apart

Successful bending if applied on one side

Alignment tried, but not successful
Tests of crystals done at ESRF

• Phase-contrast imaging with 1-70 keV photons, in a very parallel beam

May have significance for 'bent crystal' collimation and/or extraction schemes, curvature radius 1 m easily achieved by 20 micron deep grooves (confirmed by surface scans)
Publications and plans for 2008
Publications

**PHYSICAL REVIEW LETTERS**

*Direct Measurement of the Chudakov Effect*

T. Virkus,¹ H. D. Thomsen,¹ E. Uggerhøj,¹ U. I. Uggerhøj,¹ S. Ballestrero,² P. Sona,² A. Mangiarotti,³ T. J. Ketel,⁴ A. Dizdar,⁵ S. Kartal,⁵ and C. Pagliarone⁶

(CERN NA63 Collaboration)

*On the macroscopic formation length for GeV photons*


(CERN NA63)

*Addressing the Klein paradox by trident production in strong crystalline fields*


(CERN NA63)

From 'preparatory phase' of NA63: testrun in 2004
PRL 02 May issue

NA63: run in 2007
Submitted to Phys. Lett. B

NA63: run in 2007,
In preparation
Plans 2008

- BGO detector
- Extension of photon energy range
- Resonance within reach

![Graph showing enhancement, Ta5Al6/Ta100 vs photon energy in GeV](image)
Pair spectrometer zone

Mounted on 'green table' – exchange with BGO
Ogle effect

Ionization Energy Loss of Relativistic Electrons in Thin Silicon Detectors

W. Ogle, P. Goldstone, C. Gruhn, and C. Maggiore
University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico 87545
(Received 31 January 1978)

We have measured the ionization loss of electrons with Lorentz factors \( \gamma = 2.91 \) and \( 1.6 \times 10^4 \leq \gamma \leq 10^5 \) passing through a \( (100.71 \pm 0.15) \mu \text{m} \) silicon detector. Our results are in agreement with accepted theory for \( \gamma = 2.91 \) and \( \gamma = 1.6 \times 10^4 \); however, for \( \gamma \geq 3 \times 10^4 \) our results are systematically \( (7 \pm 2)\% \) below the theoretical value. We suggest an explanation in terms of the finite detector thickness and a relativistic effect.

\[
q_{\parallel \min} = \bar{\mathbf{q}} \cdot \hat{\mathbf{p}} \approx (\hbar \omega / \beta c) (1 - \beta \sqrt{\epsilon}) \equiv \hbar / l_{\text{coh}}
\]

\[\epsilon = 1 - \omega_0^2 / \omega^2\]

Minimum for:
\[\omega = \gamma \omega_0\]

Coherence length:
\[l_{\text{coh}} = \gamma^2 c / \omega_0\]

Realistic range for tagged e- beam:
\[\text{gamma: } [1 \cdot 10^3; 4 \cdot 10^5]\]
Perhaps rather: disappearance of density effect?

Realistic: 50 energy points (each takes 15-30 minutes), then move solid-state detector across tagged electron beam

\[ \gamma_c = a \omega_0 / 2c \]

Effect beyond \( a = \text{det. thickn.} \): Corresponding to 4 GeV in a 100 micron thick detector

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investigate the significance of the discrepancies. Finally, the confirmation of the results by Ogle et al. [39] awaits energy loss measurements on foils thinner than 100 \( \mu \text{m} \) for \( \gamma \)-values larger than \( 10^4 \).
Each position of SSD corresponds to a certain interval of electron energies – tagged by the energy seen in the LG. One-to-one correspondence between SSD-position and electron energy can be extrapolated to very low electron energies.
Summary

NA63 performed 4 measurements in Oct. 2007:

• LPM in pair production in Ge <110>, 1-100 GeV photons (successful (awaits further analysis))

• Trident production (Klein-like strong field) in Ge <110> @ 125, 180 and 210 GeV, enhancement around 3 (successful (analysis almost completed, paper in preparation))

• Sandwich-foil enhancements (successful (submitted to Phys. Lett. B))

• Undulator-like radiation from diamond (not successful (but successful at MAMI))

<table>
<thead>
<tr>
<th>Activity</th>
<th>Request</th>
<th>Risk</th>
<th>Potential</th>
<th>Beam</th>
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<td>-</td>
<td>-</td>
<td>10-300 GeV e, e⁺</td>
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<td>Basic QED</td>
<td>150-250 GeV e</td>
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<td>Low</td>
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<td>3 days</td>
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