Generating positrons with femtosecond-laser pulses

Gahn, C; Tsakiris, G. D; Pretzler, G; Witte, K. J; Delfin, C; Wahlström, Claes-Göran; Habs, D

Published in:
Applied Physics Letters

DOI:
10.1063/1.1319526

2000

Link to publication

Citation for published version (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.
Generating positrons with femtosecond-laser pulses

C. Gahn, G. D. Tsakiris, G. Pretzler, and K. J. Witte
Max-Planck-Institut für Quantenoptik, D-85748 Garching, Germany

C. Delfin and C.-G. Wahlström
Department of Physics, Lund Institute of Technology, P.O. Box 118, S-221 00 Lund, Sweden

D. Habs
Sektion Physik, LMU München, Am Coulombwall 1, D-85748 Garching, Germany

(Received 19 June 2000; accepted for publication 29 August 2000)

Utilizing a femtosecond table-top laser system, we have succeeded in converting via electron acceleration in a plasma channel, low-energy photons into antiparticles, namely positrons. The average intensity of this source of positrons is estimated to be equivalent to $2 \times 10^8$ Bq and it exhibits a very favorable scaling for higher laser intensities. The advent of positron production utilizing femtosecond laser pulses may be the forerunner to a table-top positron source appropriate for applications in material science, and fundamental physics research like positronium spectroscopy. © 2000 American Institute of Physics. [S0003-6951(00)00143-1]
electron pair shares the energy of the $\gamma$ photon or primary electron, the positron number per MeV is calculated and shown in Fig. 1.

The experimental setup had to be carefully chosen to suppress the background signal due to stray $\gamma$’s to a minimum on account of the weak positron signal. After some iterations the arrangement depicted in Fig. 2 was deemed satisfactory. The primary electrons were collimated in a plastic block with a 1-cm-diam hole. The low-Z material stops electrons without producing undue bremsstrahlung. The converter was a 2-mm-thick lead disk positioned inside the collimator at a distance of 16 cm from the gas jet where the laser beam was focused. The collimation of the beam results in reducing the number of MeV electrons to $(8 \pm 1.7) \times 10^5$ (from a total of $2 \times 10^{10}$) for performing a clean demonstration experiment. The positrons emanating from the converter have a quasi-isotropic distribution. Those traveling in the laser direction are collimated by another 2 cm in the plastic block. This means that the background signal is produced by $\gamma$’s seeping through the shielding and not by scattered electrons or $\gamma$’s coming via the open positron channel. As can be inferred from Fig. 1, the number of expected positrons in the 0.08 MeV channel is 25 per laser pulse, which means that the positron signal would amount to 50 MeV, i.e., 6% of the background signal. It is apparent that under these circumstances, statistical sampling and precise data analysis are necessary for decidedly extracting the positron signal from the background. Such analysis was actually performed after the signal from $N = 100$ laser pulses and was recorded in two cases. Case I: with the positron path to the detector blocked (see Fig. 2). This measurement yielded the background signal level. Case II: with positron path to the detector open. The signal obtained in this way consists of background plus positron signal. The difference in the average value of the signal in these two cases represents the signal due to positrons that have struck the detector. This is depicted in Fig. 3, where the fraction of laser pulses $P(\varepsilon)$ (out of 100 total) that gave rise to a signal corresponding to a deposited energy less than $\varepsilon$ is plotted as a function of $\varepsilon$. The experimental data have an energy binning of $\Delta \varepsilon = 65$ MeV, which matches the accuracy of the energy reading. This presentation of the experimental data best illustrates the subtle but significant difference between the two cases. In fact, the clearly discernible displacement of the curve in case II with respect to case I along the deposited energy axis is indicative of the positron existence. Using the two sets of experimental

---

**FIG. 1.** Measured energy distribution of the primary electrons (closed-circles, exponential fit as dashed line) used to produce positrons (expected spectrum as solid line). The line-shaded stripe gives the energy range covered by the detector. It encompasses $\sim 5\%$ of the total number of positrons.

**FIG. 2.** Experimental setup.

**FIG. 3.** The number of laser pulses $P(\varepsilon)$ that deposited an energy at the detector less than $\varepsilon$ for case I (background only, dark shaded area) and case II (background+$\gamma$-light, shaded area). The experimental data are drawn as integrated histograms. The dashed lines represent the probability integral for the mean value $m$ and standard deviation $\sigma$ calculated from the experimental data for both cases.
data, we have calculated the mean value \( m \) and the corresponding standard deviation \( \sigma \) for both cases. Under the assumption that the data points follow a Gaussian distribution, the probability integral corresponding to a given set of assumption that the data points follow a Gaussian distribution, addition to the exact geometry, GEANT requires as input the shielding, magnet, vacuum chamber wall, and detector. In addition to the exact geometry, GEANT requires as input the electron energy distribution. Individual electrons are released in the direction of the laser axis in such a way as to collide with the converter. Moreover, the direction of motion is randomly assigned so that the whole converter area is uniformly covered. Their energy is likewise randomly chosen as to correspond to a Boltzmann distribution. A total number of \( 10^9 \) electrons ensure sufficient statistical accuracy of the result. The output is the total energy that is deposited at the detector irrespective of origin, hence the simulation result includes not only the actual positron signal, but also the signal due to overall \( \gamma \) background. Finally, the detector response is scaled to the actual number of electrons produced. Both cases were simulated, i.e., case I: with the positron channel blocked and case II: with the positron channel open.

The simulations confirmed the experimental result according to which with open collimator but blocked positron channel the background level is increased by \( \sim 400 \text{ MeV} \) and the funding that stray \( \gamma \)-ray flux is responsible for the observed background signal. Additionally, two systematic variations were undertaken. First, for a fixed electron temperature of \( T_{\text{eff}} = 3 \text{ MeV} \), the converter thickness was varied leading to an optimum \( l_{\text{opt}} = 2 \text{ mm} \). Second, for fixed converter thickness \( l_{\text{opt}} \), the primary electron temperature was varied between \( T_{\text{eff}} = 2 \) and \( 4 \text{ MeV} \). The results are detailed in Fig. 4 where the number of positrons expected within the \( 2 \pm 0.08 \text{ MeV} \) channel is given. The simulations reproduce the experimentally measured number of positrons and the electrons from the gas jet having an effective temperature of \( T_{\text{eff}} = 2.7 \text{ MeV} \).

Scaling the number of positrons detected within the \( 0.16 \) MeV energy range and \( 7.0 \text{ mrad} \) solid angle to full energy spread (see Fig. 1) and solid angle, one obtains a total number of \( 10^6 \) positrons per laser pulse. Using the full uncollimated electron beam gives a positron number of \( \sim 2 \times 10^5 \), which corresponds to an activity of \( 2 \times 10^5 \text{ Bq} \). Given the prodigious technological advances in laser technology, it is almost certain that in the near future there will be laser systems delivering pulsed power of \( 100 \text{ TW} \) or more at high repetition rates. Then, at these higher attainable laser intensities an increase in the \( T_{\text{eff}} \) of the primary electrons would lead to a sharp rise on the output as manifested by Fig. 4. Under these circumstances, it is quite realistic to contemplate a compact, high-flux positron source suitable for a variety of envisaged applications like, e.g., positron-annihilation and Doppler-broadening spectroscopy in material science,\(^16\) but also in diverse fields of fundamental research such as positronium spectroscopy,\(^17\) where a high intensity positron source is a requisite.

The technical assistance of H. Haas, A. Bößwald, and P. Sachsenmeier is greatly appreciated. This research was partially supported by the Commission of the EC within the framework of the Association Euratom–Max-Planck-Institut für Plasmaphysik.

15 Application Software Group, Computing and Networks Division, GEANT—Detector Description and Simulation Tool, CERN Program Library Long Writeup W5013 (1993).