ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-MOPRI006

POSSIBLE USES OF GAMMA-RAYS AT FUTURE INTENSE POSITRON SOURCES*

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Abstract

The baseline design of the ILC (International Linear Collider) positron source requires the production of an intense flux of gamma rays. In this paper we present an investigation of using the gamma ray beam of the ILC for additional applications, including nuclear physics. As a result of changing the collimator shape, as well as the parameters of the undulator magnets, we obtained spectra from numerical simulations using the HUSR/GSR software package. We present results from simulations and a discussion of possible future investigations in this paper.

INTRODUCTION

Dedicated gamma-ray sources play an important role in nuclear physics and low-energy particle physics experiments. The baseline design of the ILC (International Linear Collider) positron source requires the production of an intense flux of gamma rays, but only 7% or less of these gamma rays will be used to produce the positrons, and 93% or more of the gamma ray beam will pass to the dump. Simulations for an idealised undulator show that the beam could exceed the current flux produced from HIGS (Duke University) [1, 2] by several orders of magnitude reaching 10^{13} photon/second with a bandwidth of 5%.

HUSR/GSR software packages [3, 4] were originally developed to calculate the synchrotron output from a helical undulator as included in the ILC baseline design [5]. The code tracks particles' trajectories inside the undulator system using Lie maps. This allows us to track inside any magnet system with high accuracy.

We will present the output spectra from three different kind of magnet system maps: firstly an ideal helical map, secondly a measured field map of the prototype of the ILC undulator, and finally, a simulated realistic field map. The latter will be described later in this paper. Moreover, we present an initial investigation of the optimized collimator shape to give a spectrum suitable for nuclear spectroscopy.

IDEAL AND MEASURED SPECTRUM

There were two field maps measured from the ILC prototype undulator models using a Hall probe on-axis. We used these two field maps in the HUSR/GSR software to investigate the output spectra. Figure 1 shows the output of the energy spectrum from an ideal undulator system [3, 4] and the measured undulator system. The parameters of the magnet system we used to evaluate the spectra are shown in Table 1. These parameters were used in our calculations for the analytical model as well.

Table 1: Magnet System Parameters

On-Axis magnetic field strength	0.88 T
Energy of the Electron Beam	150 GeV
Period Length	0.0115 m
Number of Periods	155 periods

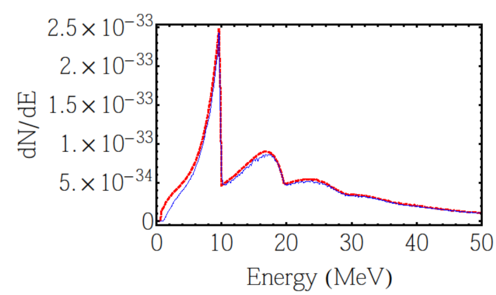

Figure 1: Calculated energy spectrum from tracking a single electron through a 1.7825 m long undulator with circular aperture radius of 0.0045 m at a distance of 500 m. The red dashed line shows the result from an ideal map, and the blue solid line shows the result from the measured map.

SPECTRUMS FROM ANALYTICAL FIELD MAPS

We used the measured field maps mentioned earlier and calculated the size, shape, and locations of the errors, and used them in our calculations to produce simulated field maps.

Calculation Method

In our calculation we introduced two types of error in to the simulated field map. We introduced error in the magnetic field strength as well as in the period size over the length of the undulator along the z direction. Such errors represent imperfections in the magnet winding or deformation of the

* This research was funded in part by the STFC Cockcroft Institute Core grant no. ST/G008248/1.
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magnet 'former'. Equations 1 and 2 describe the magnetic field inside an ideal helical undulator,

$$B_x = B_0 \sin \frac{2\pi z}{\lambda_u} \quad (1)$$

$$B_y = B_0 \cos \frac{2\pi z}{\lambda_u} \quad (2)$$

where B_0 is the field strength, z is the distance along the primary axis of the undulator, and λ_u is the period size.

In this case we added the errors shown in equations 3 and 4 to the value of the field strength as well as to the period size.

$$\sigma_\lambda = \sum_{i=1}^{n} A_i \cos \frac{2\pi i z}{L} + \sum_{i=1}^{n} A_i \sin \frac{2\pi i z}{L} \quad (3)$$

$$\sigma_B = \sum_{i=1}^{n} A_i \cos \frac{2\pi i z}{L} + \sum_{i=1}^{n} A_i \sin \frac{2\pi i z}{L} \quad (4)$$

where A_i are pseudo random numbers with maximum values determined from the measured map. We used the $\lambda_u + \sigma_\lambda$ and $B_0 + \sigma_B$ in equations 1 and 2 instead of λ_u and B_0. By using equations 1 and 2 after introducing the error, we can control the error size, and typical length scales of the errors. The model ensures the simulated map will not have a discontinuity.

We compared the Discrete Fourier Transform of the x-projection of the magnetic field within the undulator for the measured data and simulated data to tune the model in the following section.

Results

Figure 2 shows a comparison between the Discrete Fourier Transform of the x-projection of the measured field map and the simulated field map. Figure 3 shows the photon energy spectra from the first model and the energy spectra from our analytical field map.

As we can see there is a very good agreement between the two spectra. This allows us to simulate many 'realistic' undulator models based on the prototype.

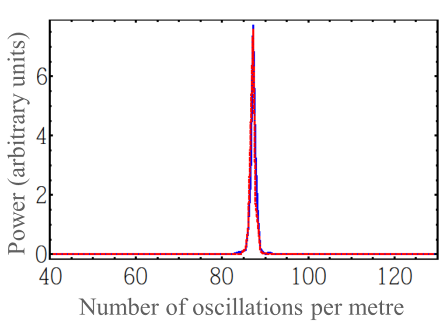

Figure 2: Discrete Fourier transform of the x-projection of the magnetic field in the undulator. The measured map is shown by red dashed line, and the analytical field map is shown by blue solid line.

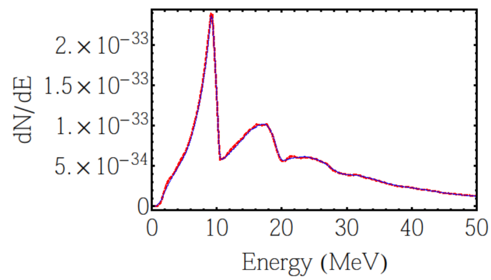

Figure 3: Energy spectrum calculated from the magnet field map. Energy spectrum from the analytical map is shown by red dashed line, and the energy spectrum from the measured field map is showing by blue solid line.

OPTIMIZATION OF THE COLLIMATOR SHAPE FOR NARROW BAND SPECTRA

As mentioned earlier, only 7% or less of these gamma rays beam for the ILC positron source will be used to produce the positrons. Therefore, we could consider introducing a small secondary facility in the region of the photon beam dump of the current baseline design for the ILC positron source [5] to utilise the otherwise wasted photons for additional applications, e.g nuclear physics.

After tracking the electron(s), we set observation points at the end of the undulator. HUSR/GSR calculates the retarded potential from the electron(s). Then, from the retarded potential it calculates the electric field at each observation point as a function of time. Finally, the frequency spectrum of the observed radiation is obtained by Fourier transforming the field.

We adapted the HUSR/GSR software to automatically detect the positions of the observation points which give spectra in accordance with the users requirements. For example, in nuclear physics a narrow-band spectrum around 10 MeV is useful for some areas of research such as Giant Dipole Resonance (GDR) [6]. The adapted HUSR/GSR software produces the location, shape, and size of the collimator which will give spectra 'close to' the required spectra. We can produce the required spectra from any field map.

Result to Obtain a Narrow Bandwidth Spectra

Here we present results from the HUSR/GSR collimator algorithm. We used the measured field map in our calculations to find a narrow bandwidth spectrum. We designed the required spectra and we select those observation points which have a spectra which lies fully underneath the designed spectra. Figure 4 shows the energy spectra from the measured map and the collimated narrow bandwidth spectra which we specified. Figure 5 shows the collimated energy spectra bandwidth size in clear view.

Figure 6 shows the shape of the aperture which will best match our required energy spectra obtained from measured and simulated field maps. It seems that with this current shape of both of the collimators it is not possible to build

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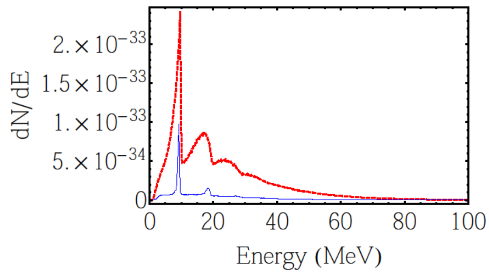

Figure 4: Energy spectra from the measured magnet field map in red, collimated energy spectra in blue.

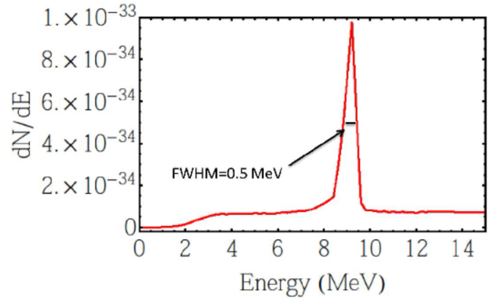

Figure 5: The collimated energy spectra shewing a bandwidth of ~ 5 MeV.

a single collimator that matches both modules. A more sophisticated analysis is planned which averages the collimator shapes obtained from a large number of simulated data sets.

As we can see we have been able to determine the position of idealised collimator shape corresponding to the required spectra. The possibility of designing a similar shape in a real experiment is of course very challenging. The code gives us the ability to choose any required energy bandwidth, but the values chosen in this initial study are comparable with other nuclear/gamma-ray facilities.

CONCLUSION

Carrying out prototype experiments to evaluate the spectrum is very expensive. By evaluating the spectrum using a numerical code with a high accuracy and realistic simulated data we hope to turn this initial study into a rigorous investigation. Based on preliminary results, we believe there is a good chance that the spent ILC gamma-ray beam could be put to good use. Further investigations are ongoing on how the spectrum changes when we evaluate it through several modules of the undulator, as the ILC will be around 84 modules (~ 147 m) long. Moreover, we will build on previous work showing how the spectrum evolves after the target.

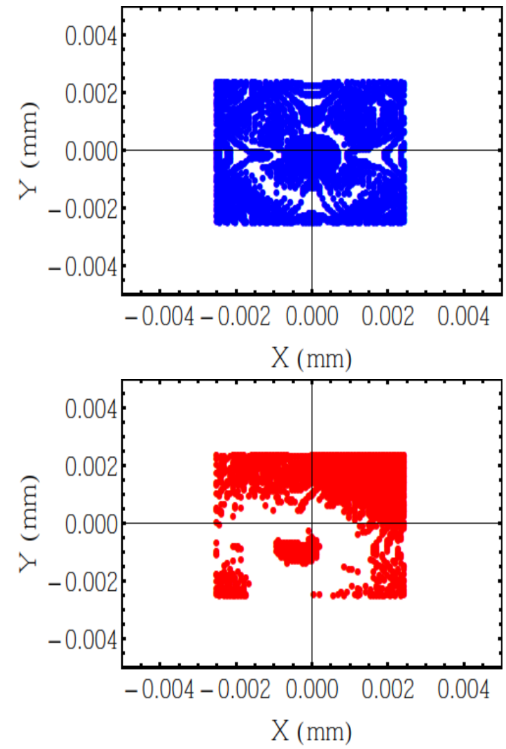

Figure 6: Shape of the square aperture obtained from the collimator algorithm based on an initial square mesh of observation points. Red shows the points where we can have a narrow bandwidth spectra from the measured map. Blue shows the points where we can have a narrow bandwidth spectra from the simulated map.

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