Smith-Purcell Effect Emission Determination (SPEED)

Team SPEEDers

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1. Introduction

The Smith-Purcell effect occurs when charged particles move closely parallel to a periodic diffraction grating, radiating light known as Smith-Purcell (SP) radiation [1]. Importantly, this type of radiation does not physically interact with the grating, which means it can fulfill a key role in accelerator development as a non-invasive beamline diagnostic tool (e.g. [2][3][4]). However, the wavelength of the SP-radiation is proportional to the periodic length of the grating, impacting the angular distribution of radiated power and the polarization states. Thus, to establish SP-radiation as a diagnostic tool for DESY, we aim to compare and analyze the SP-radiation emitted by DESY's electron and positron beams for different periodic lengths and particle momenta.

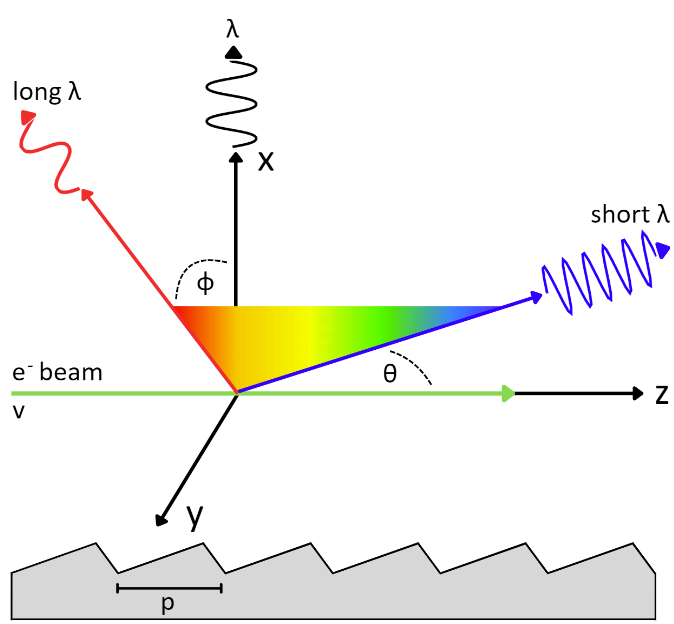

Figure 1: Illustrative diagram demonstrating the Smith-Purcell radiative process.

2. Why we want to go to DESY

As members of the Andover High School physics club, we were excited to discover a competition where we could learn more about physics outside of the classroom. Despite not having a lot of experience with particle physics, in developing our proposal, we were able to learn many new advanced topics. However, hands-on experience is the best teacher, and as aspiring physicists we aim to grow our knowledge by conducting our experiment under the guidance of some of the world's best physicists at DESY.

3. Experiment and methodology

3.1 Experimental design

The main objective of this experiment is to characterize the SP-radiation emitted by the electron and positron beams at DESY passing blazed diffraction gratings of different periodic lengths. Blazed gratings are ideal because they maximize the diffraction efficiency for a given diffraction order [5]. We aim to first compare the angular distribution of radiated power for each grating. To collect data of SP-radiation across a variety of periodic lengths, our goal is to test 4 different aluminum blazed gratings, which could be either manufactured or purchased (we have compiled some options here). We would then repeat our experiment for each grating using different beam momenta (1-6 GeV/c) and beam particles (e^- or e^+). After we identify the angular distribution, we will analyze the polarization states by reconducting the experiment with polarizing filters.

The Smith-Purcell radiation wavelength λ and particle velocity v are related by

$$\lambda = \frac{p}{|m|}\left(\frac{c}{v} - cos\theta\right) \tag{1}$$

where p is the period length of the diffraction grating, m is the diffraction order, and θ is the angle between the moving particle and radiation wave. For highly relativistic particles, the emitted wavelength perpendicular to the beam is equal to the periodic length ($\lambda = p$) if the diffraction order is 1 [2]. However, when measuring the angular distribution,the radiation detected will span a range of wavelengths because the wavelength also depends on the emission angle and diffraction order. Since the bunch length (30 ps) of DESY [6] is much longer than the wavelengths of radiation we will be measuring, the radiation will be dominated by the incoherent emission [2].

Grating ID#	n (grooves/mm)	p (nm)	λ (nm)
1	1200	833	833
2	1800	556	556
3	2400	417	417
4	3600	278	278

Table 1: Parameters of the proposed blazed gratings used for testing, where n is the line density, p is the periodic length, and λ is the wavelength of the first-order Smith-Purcell radiation at $\theta = 90^{\circ}$.

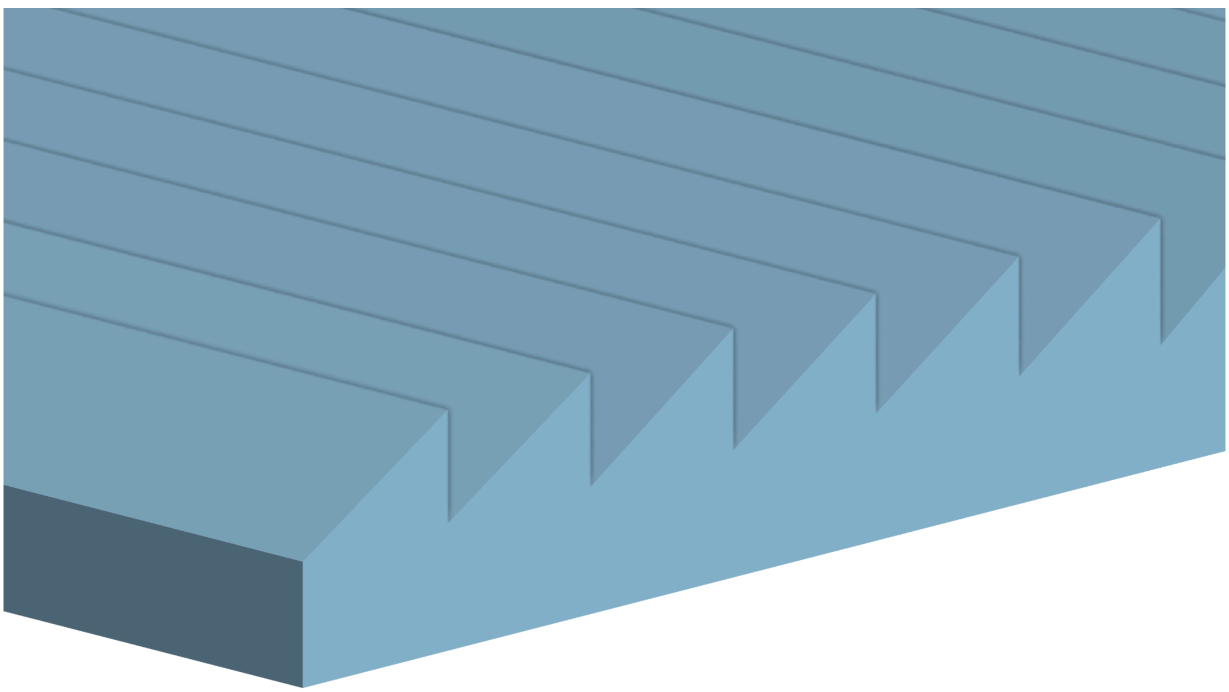

Figure 2: Magnified 3D model of blazed grating with blaze angle 30°.

3.2 Experimental setup

Our experimental setup consists of a halo counter, beam telescopes, blazed grating, photomultiplier tube, and polarizing filters.

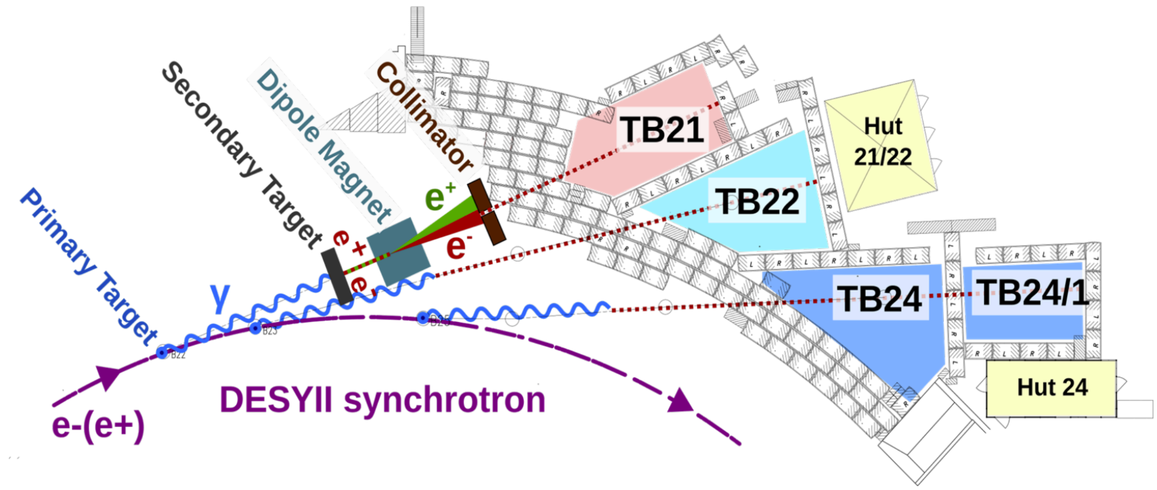

Figure 3: Beamline set up at DESY [6].

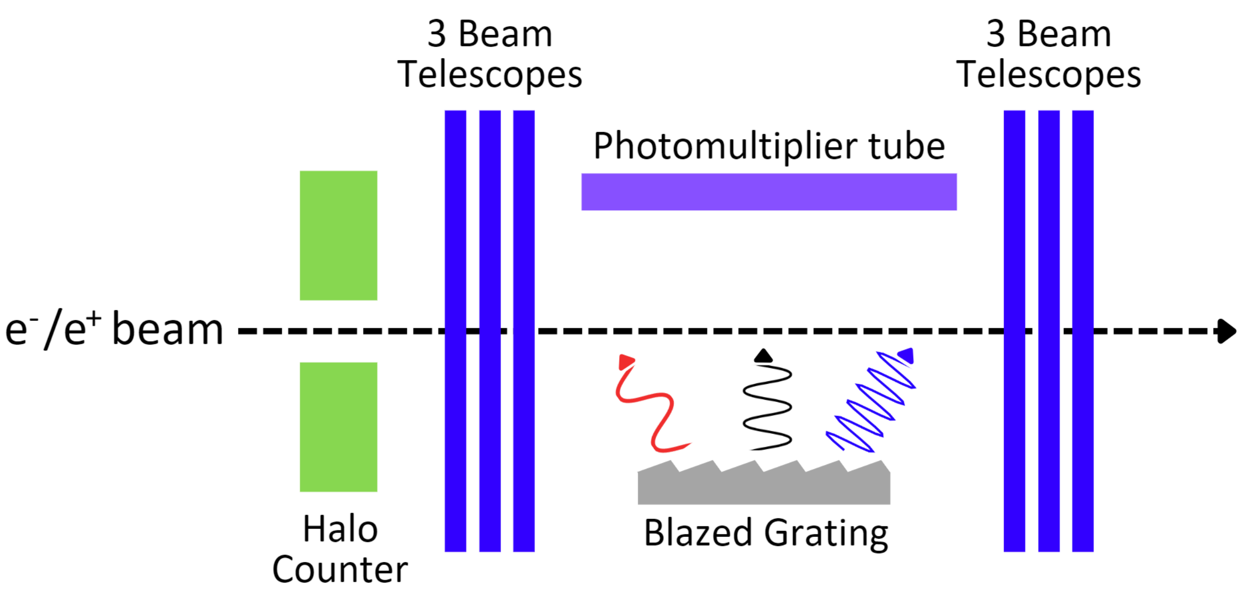

Figure 4: Experimental set up to detect the angular distribution of radiated power of SP-radiation.

We will place the blazed grating 1 mm from the center of the beam to minimize loss of radiated power [7]. Considering the beam has a 2x2 cm area [6], there will be non-negligible transition radiation from collisions between the beam and the grating. Using the halo counter and beam telescopes to determine the path of the charged particles, we can focus only on cases where the particles pass closely parallel to the grating and release SP-radiation. Since the emission lies in the UV to near-IR spectrum and the photomultiplier tube is highly-sensitive to photons between 200-900 nm [8], we will place the photomultiplier tube parallel to the beam, opposite of the grating, to detect photons. Furthermore, to filter out background radiation, the experiment should be conducted in darkness. This experimental setup will be repeated with each blazed grating and particle momenta to compare the angular distribution of the radiated power.

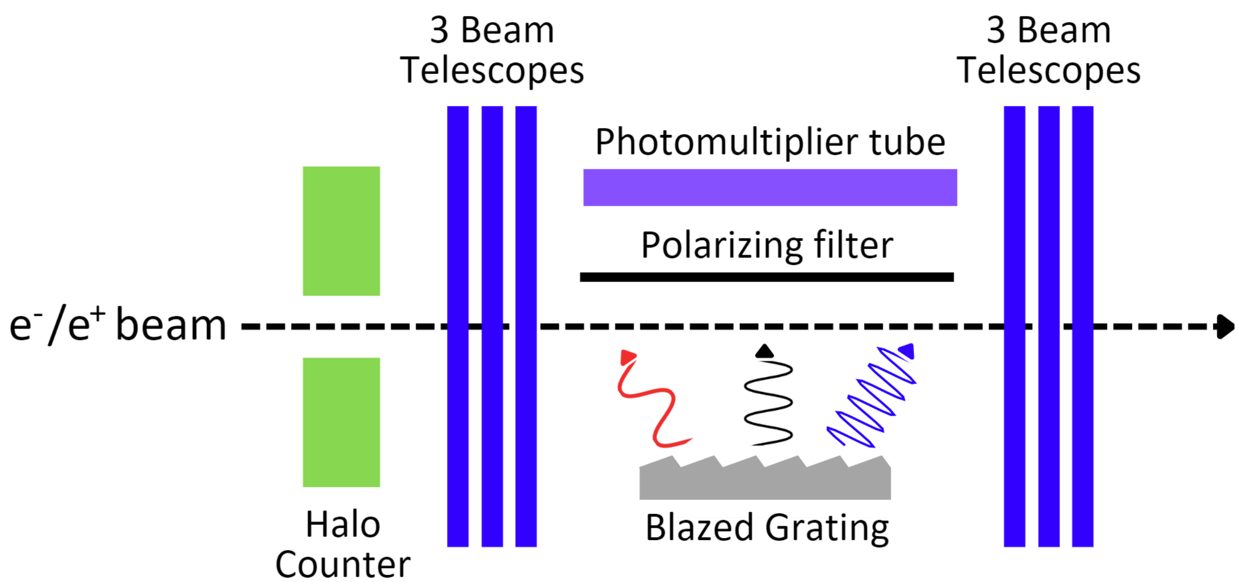

Figure 5: Experimental set up to detect the polarization state of SP-radiation.

To determine the polarization state of the SP-radiation, we will use the same experimental setup as before, but we will add the polarizing filter in front of the photomultiplier tube to unidirectionally filter out the photons.

3.3 Data analysis

To accurately discern SP-radiation, it is critical to eliminate transmission factors as well as background radiation while processing the data. After post-processing, we will make graphs for each blazed grating, particle momenta, beam particle, and polarization state describing:

- Wavelength versus emission angle
- Spectrum of emitted power versus emission angle
- Intensity of photon emission versus impact parameter

These graphs will thereby inform us how changing periodic length, particle momenta, and beam particle affects the angular distribution of radiated power and the polarization states of SP-radiation.

4. What we hope to take away

After one of our members shared with us his experience visiting the National Synchrotron Light Source II, we were inspired to become not just observers, but active contributors to the field of particle physics. We hope that our team can conduct our experiment at DESY to continue this cycle: bringing back what we learn to inspire our friends, school, and town to get more involved with physics. While working on this project has been a rewarding experience in and of itself, making it a reality allows us to take the next steps in becoming real physicists and spreading our passion for physics. This would be an amazing opportunity for not just us, but our entire community to learn more about physics.

5. Acknowledgements

We would like to thank our club mentor Mr. Donovan for his support, as well as the Andover High School library for helping us get open-access to research papers from the American Physical Society.

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