Transition Radiation in Multi-Layered Dielectric–Metallic Targets for Soft X-Ray Generation and Beam Diagnostics

Team XTReme

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1 Introduction

Transition Radiation (TR) is an electromagnetic phenomenon that occurs at times when charged particles, such as high-energy electrons, cross the boundary between two media with different dielectric constants [1]. While studied extensively in certain domains (optical and UV), TR in the soft X-ray regime (100 eV - 10 keV) remains underexplored, especially when considering engineered multilayer targets [5]. In multilayer systems, this leads to complex interference patterns that either enhance or suppress spectral components [6]. These effects, in turn, are described by relativistic electrodynamics and governed by material properties (eg. permittivity & layer thickness)[7].

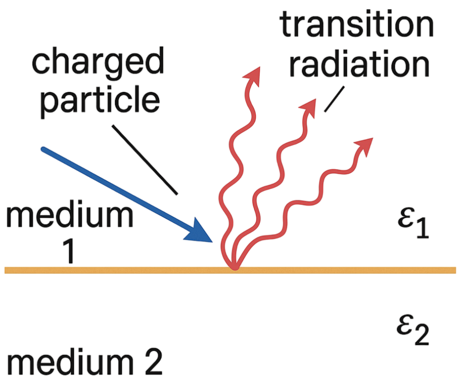

Figure 1: Illustrative diagram of the process of Transition Radiation

Our experiment proposes an investigation of transition radiation (TR) generation using composite dielectric–metallic targets with the tunable electron beam at DESY (1–6 GeV). Through this approach, we aim to map how TR yield, angular spread, and spectral distribution vary as a function of beam energy and target structure, thereby deepening our understanding of radiation generation at specific relativistic energies and contributing to the development of soft X-ray sources and non-invasive beam diagnostics.

2 Motivation to go to DESY

Our motivation for studying dielectric targets and transition radiation at DESY is to gain hands-on experience in our field of study while contributing to a new understanding of a blooming concept with novel applications, specifically in non-invasive beam diagnostics [2]. The equipment, experience, and atmosphere at DESY will be crucial in helping us achieve findings and conclusions that not only benefit us and our own understanding of the topic, but hopefully provide new knowledge to the field as a whole [4].

3 Objectives

1. Our team aims to quantify TR yield and angular distribution for multilayer targets, which are composed of varying dielectric and metallic materials.

2. Our team aims to investigate how TR output scales with electron beam energy variations (1-6 GeV) and layer thickness.

3. We plan to determine the spectral content of emitted TR, which we will do by using optical/X-ray filters and detectors.

4. We plan to validate our predictions using Geant4 simulations and compare them with experimental data [3].

4 Experiment and Methodology

4.1 Beam Usage and Setup

Our team proposes to utilize the high-quality electron beam available at DESY, which offers the desired energy tunability (1-6 GeV range) and excellent collimation as well. A purely electronic beam will ensure that there is minimal background from certain hadronic interactions, which simplifies TR isolation.

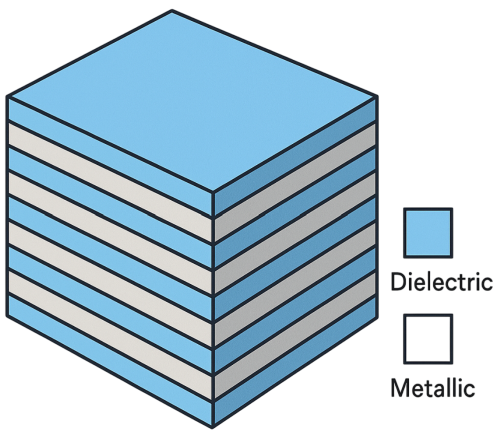

Figure 2: Targets of alternating dielectric and metallic layers

The beam will be directed perpendicularly at thin, engineered targets composed of alternating dielectric and metallic layers. The specific beam parameters (flux, energy, spill structure) match well with expected TR photon production rates ($\sim 10^{-3}$ photons/electron), making DESY an optimal facility for our investigation.

4.2 Layout and Components

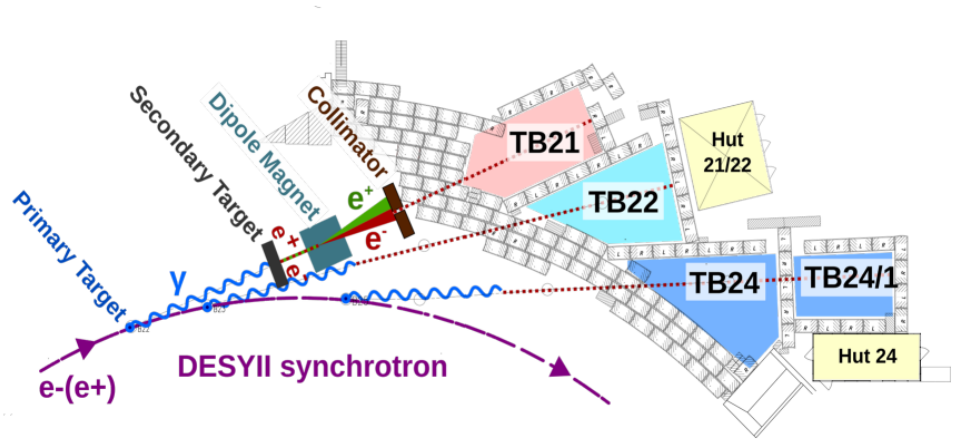

Figure 3: Beam line production at DESY[10]

Our experiment will be housed in a standard beamline test setup, incorporating the following components:

1. Scintillator 1 (Beam Trigger): Provides the initial beam detection as well as triggering the data acquisition system.

2. Delay Wire Chamber (DWC): Captures the spatial position and the incoming trajectory of electrons.

3. Rotatable Target Mount: Holds and adjusts the multilayer TR target. Mounted on a precision rotation stage to vary the incident angle (if needed).

4. Target Materials: We plan to test three main configurations:

   T1: 10 alternating layers of Aluminum/Polycarbonate (100 μm per layer)

   T2: 20 alternating layers of TiO_2/SiO_2 (50 μm per layer)

   T3: Graded-index "chirped" stack of Al_2O_3/Kapton (50-200 μm per layer)

5. X-ray Detector: A lead glass calorimeter or Si-based soft X-ray camera placed off-axis to capture the emitted TR photons.

6. Scintillator 2 (Exit Coincidence): Detects outgoing electrons for signal-background discrimination.

7. Beam Telescope: Measures any deviations in outgoing trajectory indicative of beam-target interaction.

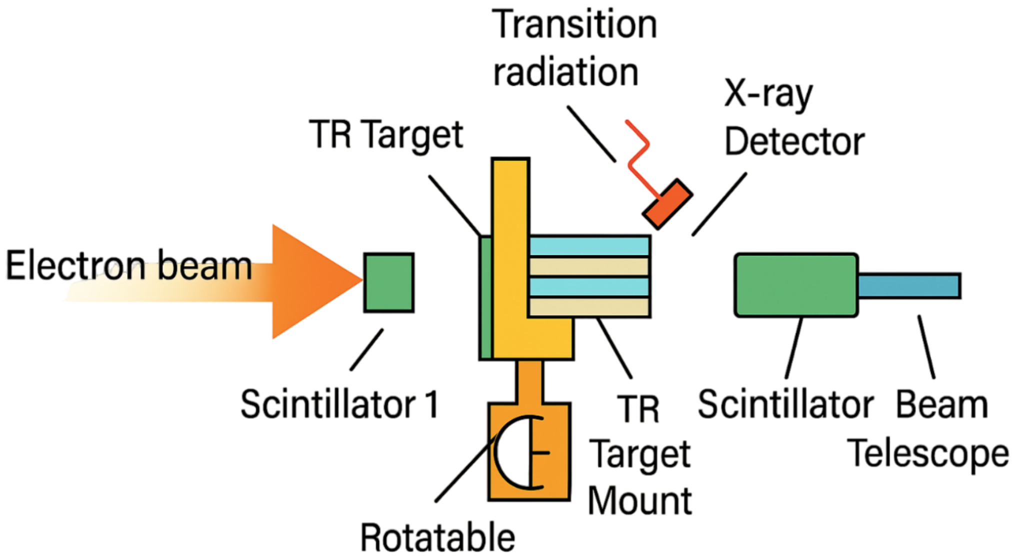

Figure 4: Experimental set up to measure the transition radiation emitted by different types of multilayer targets

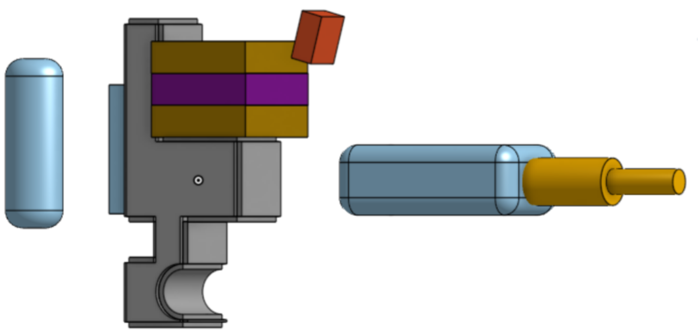

Figure 5: CAD model of the rotatable TR target

4.3 Theoretical Framework

The spectral-angular distribution of TR [8] from a single interface is given by

$$\frac{d^2W}{d\omega d\Omega} = \frac{e^2}{\pi^2 c} \cdot \frac{\beta^2 sin^2\theta}{(1-\beta^2 cos^2\theta)^2} \cdot \left|\frac{\epsilon_2 - \epsilon_1}{\epsilon_2 + \epsilon_1}\right|^2$$

where θ is the emission angle, ω is the photon frequency, β is the velocity ratio $\frac{v}{c}$, and ϵ_1, ϵ_2 are the dielectric constants of the adjacent media. In this equation, $\frac{d^2W}{d\omega\, d\Omega}$ represents the differential energy emitted as transition radiation per unit angular frequency ω and per unit solid angle Ω.

In multilayer systems with N layers of thickness d [9], constructive interference leads to

$$W_{total} \propto N \cdot \left(1 + cos\left(\frac{2\pi d}{\lambda}\right)\right)$$

This formula highlights the sensitivity of TR yield to layer thickness and photon wavelength, motivating our choice to explore graded chirped stacks. W_{total} represents the total transition radiation energy emitted, and λ represents the emitted photon wavelength.

4.4 Data Collection Plan

The experiment will span five operational days, scheduled as follows:

Day	Activity
1	System setup, alignment, and calibration
2	T1 data collection across all energies
3	T2 data collection across all energies
4	T3 data collection across all energies
5	Background runs, dark runs, cross-checks

At each beam energy (1, 3, and 6 GeV), data will be collected with and without filters to isolate spectral components. Background subtraction using dark and no-target runs will isolate the true TR signal.

4.5 Analysis

The collected data will be analyzed using ROOT and Geant4 simulations. We will extract:

- TR intensity vs. beam energy and target type,
- Angular distribution histograms of emitted photons,

- Filtered spectra to estimate photon energy distributions,
- Comparison with Monte Carlo TR models.

All of our datasets will be calibrated using known source tests and cross-validated using beam telescope tracking. Any deviation in angular profiles will then be used to infer the structural response of TR to multilayer configuration.

4.6 Feasibility and safety

All chosen target materials (e.g., Kapton, SiO_2, Al, TiO_2) are non-toxic, thermally stable, and commonly used in accelerator environments. No cryogenic, radioactive, or chemically reactive substances are involved. In addition, all detectors used are standard BL4S components, meaning power, cooling, and data acquisition needs are minimal. Mirrors are extremely effective sources of PXR, and highlight the role of multilayer structures in tailoring X-ray emission.

5 What we hope to take away

While the members of our group have completed numerous different levels of physics material, classes, and competitions, we hope that our experience at DESY will allow us to do more in actively participating in and contributing to the field that we have all come to know and love. Beyond just gaining knowledge about a topic that sparks our interest, our time at DESY would let us discover what it truly means to work in the field. While we could always read more papers, watch more lectures, and take more notes on the subject, we strongly believe that the hands-on participation we will receive at DESY is invaluable to our enrichment as both physicists and academics.

6 Outreach Activity

As active members of the physics community at our high school, we will organize a live demonstration of our TR experiment using simple materials. These materials will include a laser pointer and some other basic materials to successfully analogize our experiment. As our experiment is otherwise invisible, we would be able to use this analogy in order to make it visible in order to teach those who are interested about it. In addition, we plan to perform this same demonstration at our local middle and elementary schools in order to get more students engaged in the world of physics, particularly particle physics.

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