Monte Carlo simulation of Transition Radiation for High Energy Experiments

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Transition Radiation Detectors (TRD) have been used successfully in high energy physics experiments at the last ten years. They have become a more widely used for identification particles with different Lorentz factor over a wide range and show great promise for use as a part of identification systems in future heavy quark experiments. Monte Carlo simulation of Transition Radiation generation and detection have been studied in order to make more observable and usable for practical purposes.

1 Introduction

The phenomenon of transition radiation, that is the generation of photons when the relativistic charge particle passes through interface between two media with different dielectric properties. The transition radiation has been predicted in 1944 by V.Ginzburg and I.Frank [1]. Theoretical calculation of G.Garibian [2] predicted that for highly relativistic particles the most appealing feature of transition radiation are the dependence on the Lorentz factor γ and radiation emission in the X-ray region.
The spectral dependence and the total intensity of transition radiation emitted by a charge particle upon perpendicular traversal through a single interface between two media [3]:

$$\frac{d^2W}{d\omega d\theta} = \frac{2\alpha\hbar\theta^3}{\pi}\left(\frac{1}{1/\gamma^2+\theta^2+\omega_1^2/\omega^2} - \frac{1}{1/\gamma^2+\theta^2+\omega_2^2/\omega^2}\right)^2; \qquad (1)$$

$$W = \int\int\left(\frac{d^2W}{d\omega d\theta}\right) d\omega d\theta = \frac{\alpha\hbar}{\pi}\frac{(\omega_1-\omega_2)^2}{\omega_1+\omega_2}\gamma; \qquad (2)$$

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where $\omega_{1,2}$ are the plasma frequencies of the two media.
ω is photon energy.
θ is emission angle with respect to the particle trajectory.

The general structure of TRD is used in high energy experiments is multilayer periodic structure of TR radiator and sensitive area which defined the performance of TRD and analysis methods for particle identification.
Transition radiation is a small effect, the energy radiated at each surface is proportional to the fine structure constant $\alpha = 1/137$. But by staking many layers of material separated by gaps possible to get positive interference between emitted radiation and to enhance the effect enough to build a practical detector. Structure of TR radiator are required optimization.
Structure of sensitive (detecting) area are defined by features of two process: effective transition radiation yield from radiator and ionization loss of primary particle. The transition radiation pattern becomes sharply peaked at the polar angle of $1/\gamma$ relative to incident particle direction and detection of transition radiation is performed on background of ionization loss of primary charged particles. Optimization for sensitive area is that of allowing the particle to pass through the X-ray flax deposits considerable more energy than the direct ionization loss of primary charged particle.

2 MC simulation of Transition Radiation and Ionization loss

The differential spectrum of transition radiation X-ray for the periodic radiator of N layers with thickness $l1$ and spacing $l2$ and including the effect of self absorption in radiator is :

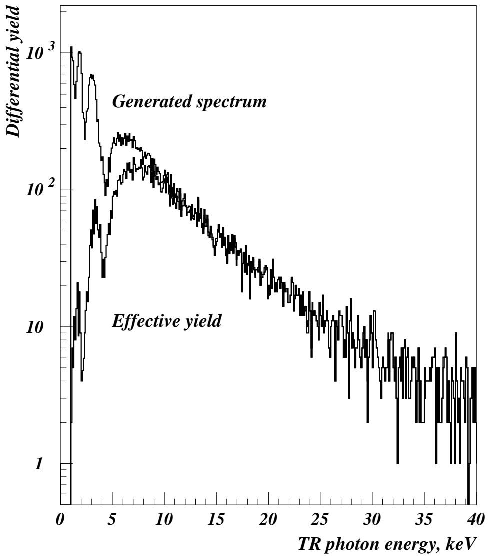
$$\frac{d^2W_N}{d\theta d\omega} = \frac{d^2W}{d\theta d\omega} \times 4sin^2\left(\frac{l_1}{Z_1}\right) \times \left|\frac{1-C^N}{1-C}\right|^2 \tag{3}$$

$$Z_{1,2} = \frac{4c}{\omega}\left(\frac{1}{\gamma^2} + \theta^2 + \frac{\omega_{1,2}^2}{\omega^2}\right)^{-1} \tag{4}$$

$$C = exp(il_1/Z_1 + il_2/Z_2 - l_1\sigma_1 - l_2\sigma_2) \tag{5}$$

where Z_1 and Z_2 are the formation zones for the two media.
σ_2, σ_2 are the absorption cross sections of foil and gap.

Differential spectrum of transition radiation for periodic radiator calculated MC method on base procedures [3] [4] is shown on fig. 1a. Using tabulated X-ray absorption crossection we have computed the effective transition radiation emitted from a given radiator and to be absorbed in detecting area fig. 1b.



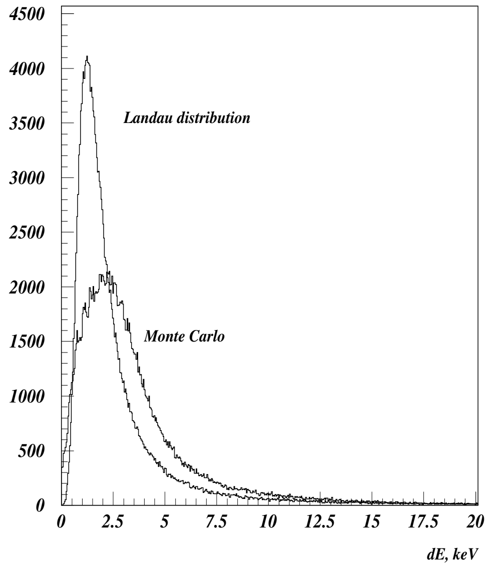


Fig. 1. *a.) Differential and effective yield of transition radiation as a function of photon energy. b) Landau and Monte Carlo calculated ionization loss.*

Reabsorption does strongly suppress the transition radiation from radiator at low X-ray energy. Irregular structure of radiator described as equivalent periodic structure with normalization factor corrected on experimental data.
As mentioned above the transition radiation emitted from radiator propagate essentially along the primary particle track and in sensitive area X-ray are detected on background of ionization loss of primary charged particles. Ionization loss in very thin gas layers cause great interest in connection with detection of transition radiation and identification fast charge particles according to relativistic rise of ionization in Lorentz factor. The analysis in [5] showed that the energy deposited by a charged particle in a sensitive area is well reproduced by Landau theory only if the material thickness is large than $2\beta Z$ cm. The revised version of Landau theory given by Blunk and Leisegang still fails to explain experimental fluctuation curves since it considerable overestimates their width for very thin gas layers. Energy loss distribution in thin gas layers have calculated on the base of Monte Carlo calculation [5]. On fig 1b is shown the comparison of Landau distribution with Monte Carlo distribution this work for very think gas sensitive layer $6mm\ Xe$ gas mixture.

3 Monte Carlo date and comparison with experimental data

Monte Carlo simulation of transition radiation and energy distribution in straw proportional chambers for multilayer detector system of transition radiation detector for HERA-B experiment DESY [6] are shown on fig. 2a.
Fig. 2b shows the experimental total energy distribution are measured by

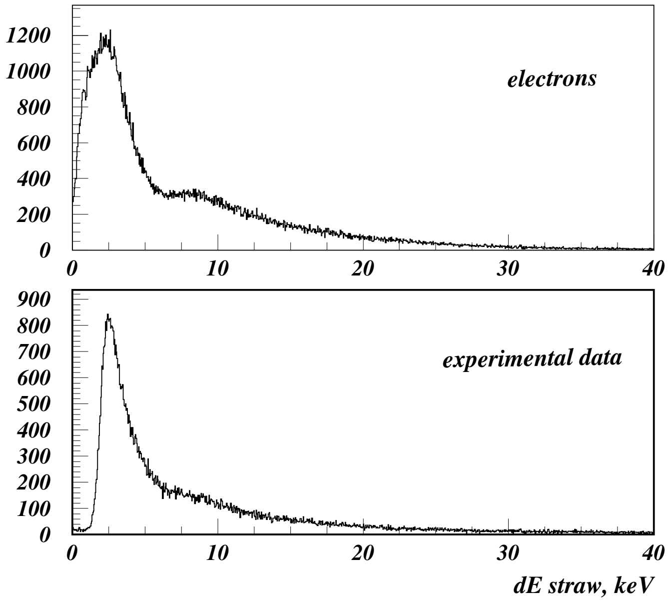


Fig. 2. *Monte Carlo spectrum for electrons and experimental spectrum for HERA proton beam 820 Gev/c with internal target.*

Transition Radiation Detector prototype on HERA proton ring ($820 Gev/c$) with internal target. Contribution of electrons in secondary flux is around 50 rercent.

4 Conclusion

Monte Carlo program are developed for simulation of process transition radiation generation and detection. The experimental spectra are well reproduced by Monte Carlo simulation and confident in applying the theory to predict the performance of transition radiation detectors in High Energy Experiments. Program is full compatible with GEANT simulation tool.

References

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