Nuclear Inst. and Methods in Physics Research, A 1027 (2022) 166362

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Extending the Lorentz factor range and sensitivity of transition radiation with compound radiators

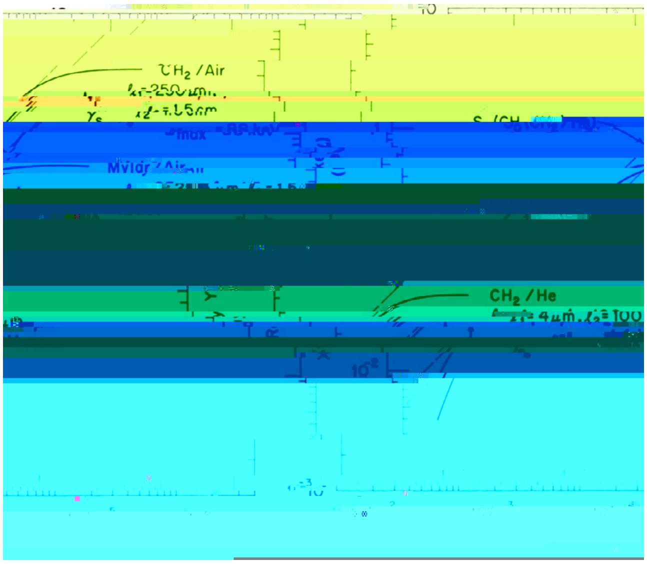

Fig. 1. Total emitted intensity radiated per interface for a single CH $_2$/He interface (dashed line) and three multi-foil radiator configurations, demonstrating ability to tune radiator parameters [15].

(in order to maximize the ratio of detected X-ray signal to dE_dx) and/or the number of foils must be large (although not so large as to produce interactions, delta rays, or bremsstrahlung background). Designing a TRD for an application therefore involves matching the radiator materials, foil thickness, and spacing to the desired range of Lorentz factors, and matching the frequency spectrum to the detector efficiency and radiator transmission.

In Fig. 1, the number of X-ray photons produced in a typical radiator of 100 foils is very roughly the yield in keV/interface times 200 interfaces divided by ‘ !$_{max}$. It can be seen from Fig. 1 that the range in Lorentz factor over which the emitted radiation increases from approximately a single emitted X-ray to saturation is typically no more than a factor í 5. There are currently new experiments being proposed that will require a wider operating range than this. As examples: (1) The Forward Multiparticle Spectrometer (FMS) project [19,20] currently being discussed at CERN may require a TRD to identify 0.5–3 TeV pions, kaons, and protons; and (2) the Advanced Particle-astrophysics Telescope (APT) [21] is a mission concept for a future space-based gamma-ray telescope that may also have the capability to measure the spectrum of cosmic-ray Boron and Carbon at 500 GeV/nucleon up to Iron at 20 TeV/nucleon. In both cases, an appropriate TRD must operate over the range from í 500 to at least 2 10^{4}.

Current TRDs are not able to operate over such a wide range of values. One possibility is to employ multiple TRDs in sequence —for terms of the dielectric constants $_i = 1 * w_i^2 \_ !^2$ as

$$
\begin{aligned}
n_{12} &= n_{20} + \frac{!}{c} \left(l_2 ø\_ {}_2 \cos + \frac{l_2}{\,} \right) = n_{20} * 2 \frac{l_2}{Z_2}; \\
n_{01} &= n_{20} * 2 \left(\frac{l_1}{Z_1} + \frac{l_2}{Z_2} \right); \\
n_{ij} * 1_{ij} &= *.\ n * 1/ \quad ; \\
&= 2 \left(\frac{l_0}{Z_0} + \frac{l_1}{Z_1} + \frac{l_2}{Z_2} \right) :
\end{aligned}
\tag{8}
$$

To within an overall phase factor, the summed electric field amplitude then becomes

$$
E = \frac{A_{01}}{R} e^{*2\, i.l_1\_Z_1 + l_2\_Z_2/} + \frac{A_{12}}{R} e^{*2\, il_2\_Z_2} + \frac{A_{20}}{R} \frac{\sin N \quad \_2}{\sin \quad \_2} : \tag{9}
$$

The intensity radiated per unit angle and frequency ! can be written in terms of the Poynting vector flux

$$
\frac{d^2 S_N}{d \quad d!} = \frac{c}{4} E H^{<} R^2 = \frac{c}{4} \; {}^2 \frac{\sin^2 N \quad \_2}{\sin^2 \quad \_2} \tag{10}
$$

with

$$
\begin{aligned}
{}^2 = {} & A_{01}^2 + A_{12}^2 + A_{20}^2 \\
& + 2 A_{01} A_{12} \cos .2 l_1 \_ Z_2 \_
\end{aligned}
$$

the X-ray absorption. Since APT's prime science goal is to measure the cosmic gamma-ray signal, the total thickness of the radiators must be small enough to have only a small effect on the * ray transmission. Finally, the total radiator thickness must be small enough to produce only a small nuclear interaction probability and -ray background.

As an initial example of a ''low energy - high energy'' radiator combination based on periodically spaced foils, we consider (Configuration a) a regular ''high energy'' (HE) radiator followed by a regular ''low energy'' (LE) radiator. The HE radiator is composed of 11 CH_2 foils each 50 m thick with a vacuum gap between successive foils of thickness 4 mm. This saturates at $_s$ í 2 :8 10^4, with a peak in the TR spectrum at $!_{max}$ í 18 keV. The total thickness of this radiator is 4.05 cm. The HE radiator is followed by an LE module consisting of 30 CH_2 foils each 25 m thick with a vacuum gap between foils of thickness 0.2 mm. This saturates at $_s$ í 4500, with a peak in the TR spectrum at $!_{max}$ í 9 keV. The total thickness of this radiator is 0.675 cm. It is followed by two layers of 2 mm thick Xe straw tubes to detect the TR signals. The crossed Xe layers replace the current scintillating fiber tracker layers. The total thickness of this composite radiator combination is 5.1 cm, comparable to the thickness of the foam plus scintillating fibers in the current APT design. The total detector consists of 20 layers, each layer consisting of 5 mm of CsI plus a CH_2-vacuum (or CH_2

Acknowledgments

This work has been supported by NASA, USA award 80NSSC 19K0625. We appreciate valuable conversations with members of the FMS and APT experiment teams and the ATLAS Transition Radiation group.

References

[1] V.L. Ginzburg, I.M. Frank, Radiation from a uniformly moving electron passing