A DETECTION SYSTEM FOR HIGHLY CHARGED IONS WHICH HAVE UNDERGONE CHARGE EXCHANGE IN THE CRYRING ELECTRON COOLER

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Abstract

A detector system has been built for detection of ions that have undergone charge exchange in the CRYRING electron cooler. The charged particle detector is a YAP scintillator equipped with a mirror and lens system that directs the scintillation light towards a photomultiplier outside vacuum. The detector system can be used for experiments where electron-ion recombination processes are studied, $\Delta q = -1$, as well as for detection of stripped ions where $\Delta q = +1$.

1 INTRODUCTION

This paper describes the construction of a device for detection and intensity measurements of the beam of recharged ions, created by recombination reactions in the CRYRING electron cooler.

The environment in the ring makes the use of semiconductor detectors inappropriate and the idea has been to use a scintillator crystal mounted in the path of the recombined beam. A photomultiplier tube, PMT, mounted outside the vacuum chamber registers the scintillating light. Some distance will thus separate the scintillator and the PMT and a thorough analysis of the optical phenomena involved has been made, in order to enhance the transportation of light from inside the scintillator to the entrance window of the PMT.

2 THE YAP:CE SCINTILLATOR

The YAP:Ce (Yttrium Aluminium Perovskite, $YAlO_3$) scintillator[1] has got a number of favourable properties:

- It is chemically and mechanically stable, hence satisfying the extreme vacuum demands of CRYRING.
- It has a high scintillation light output.
- The decay time is short.
- The characteristic wavelength is ideal for operation with most photomultipliers.

The main disadvantage is the fairly high refractive index, the implication of which urges for specific design of the detector device.

3 COLLECTION OF LIGHT

Usually in a scintillation detector, the scintillator crystal and its photomultiplier are directly coupled or connected optically with a light-guide. Optical grease is used to avoid abrupt changes of refractive indices. In the set-up described the crystal will be placed in the path of the recombined beam and the PMT will monitor its light through a viewport from outside vacuum and thus the use of a light-guide is not possible.

3.1 Problems

Light created inside a scintillator is emitted isotropically within the crystal. The fraction of light emitted in a cone with a certain opening angle is plotted in Fig. 1.

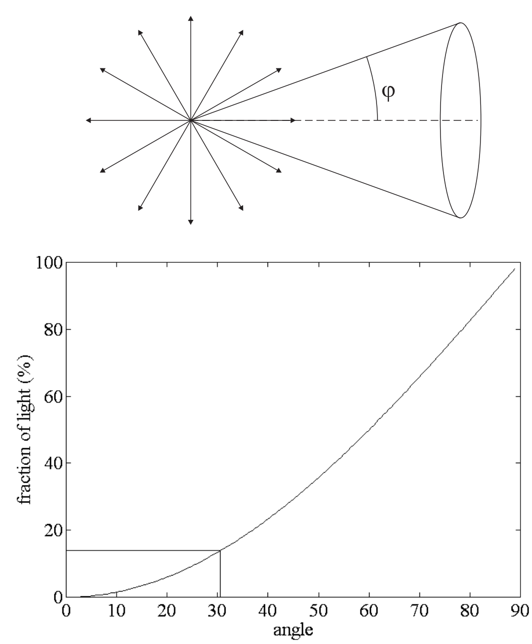

Figure 1: Fraction of light in cone with opening angle φ

Consider now a plane surface between a YAP:Ce scintillator crystal and the surrounding vacuum. Using Snell's law we find that the critical angle for total reflection is approximately 30°. The fraction of light that has an angle of incidence smaller than that is only 0.14, as indicated in Fig. 1. Thus about 86% of the light is lost in a plane surface due to total reflection[2].

In addition to the loss due to total reflection, part of the light with an incident angle lower than 30° is reflected back into the scintillator. We find that the reflectance is about 10% for angles smaller than 30°, resulting in an intensity of the transmitted light of around 12% of the intensity of the light incident to the surface.

If we combine the transmittance and the refraction of the transmitted light with the angular distribution of the light, we obtain the angular distribution as seen from outside the crystal, relative to the amount of light created from the radiation. This relation is shown in Fig. 2.

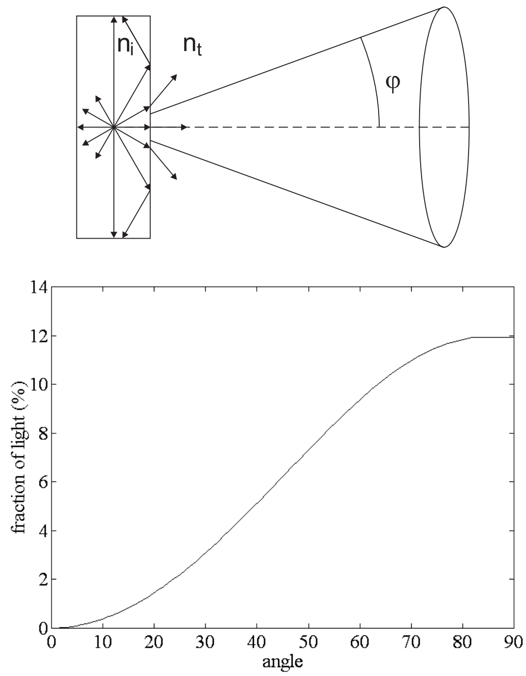

Figure 2: Angular distribution as seen from outside YAP:Ce to vacuum surface.

We note that even at short distances the intensity from a plane surface is low.

3.2 Solutions

In the previous section was shown that a plane surface of crystal is disadvantageous in a detector with the scintillator and PMT separated. By using a scintillator crystal of half-spherical shape, we can avoid refraction and thus the problem of total reflection. If light is created in the centre of the sphere it crosses the surface perpendicularly. The only remaining obstacle, and unavoidable, is the 10% reflectance.

With a crystal of this shape, 90% of the light escapes the crystal; a great improvement compared to the plane surface. At larger distances however, the intensity is still low and only a tiny fraction of the light falls onto the small area of the entrance window of the PMT.

If light is created in the focus of a parabola and reflected on its inner walls, a parallel bundle of light is obtained. By surrounding a half-spherical scintillator crystal with a parabolic reflector, the scintillation light can thus be directed onto the PMT. Such a set-up is shown in Fig. 3.

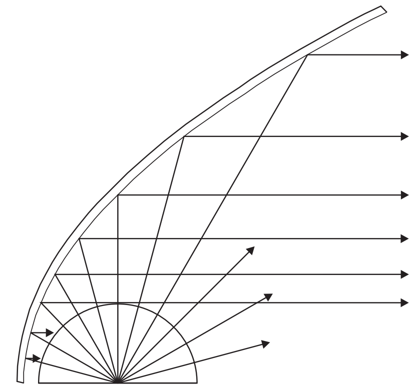

Figure 3: Light is created in the centre of a sphere and reflected on a parabolic mirror, creating a parallel beam of light.

4 DETECTOR DESIGN

The detector is designed to operate on two horizontal ports perpendicular to the beam facing each other. On one side of the beamline the PMT is attached and on the other, the device holding and manoeuvring the reflector package is placed.

4.1 The reflector system

A 10 mm diameter half-spherical YAP:Ce crystal with all surfaces polished and the flat surface coated with silver, delivered by Preciosa Crytur s.r.o., Czech republic, is mounted in the focus of a silver reflector with the shape of a parabola ($y = \pm\sqrt{26x}$, $x \in [0,25]$ mm).

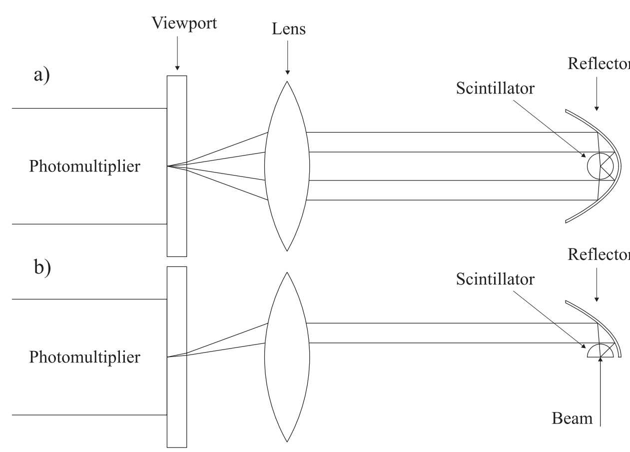

Figure 4: Set-up of reflector system. a) View from the side. b) View from above.

A lens is mounted in front of the PMT, the purpose of which is to focus the incoming light on to the centre of the entrance window of the PMT.

4.2 The detector system

The reflector package is mounted on a device, constructed in such a way that the reflector package can be moved in the plane perpendicular to the beam.

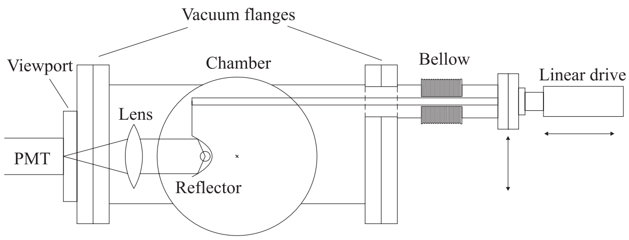

Figure 5: The detector system.

5 EARLY RESULTS

Due to the possibilities of movement in the plane perpendicular to the beam the detector can easily be used to map the profile of the CRYRING charge exchanged beam. In Fig. 6, the result of such a measurement is shown. The cross-section of a beam of non-cooled $^{40}Ar^{13+}$, charge exchanged due to collisions with residual gas molecules in the straight section of the ring before the detector, was measured in one dimension. The full width of half-maximum was estimated to 8-10 mm.

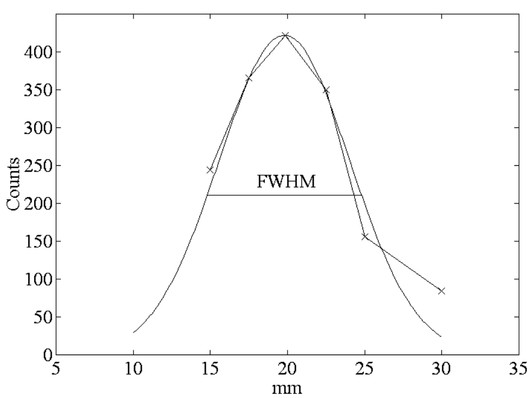

Figure 6: Beam profile in horizontal direction.

Measurements have also been done on cooled beam, in this case 8 MeV/u $^{19}F^{6+}$ ions that had undergone charge exchange in the straight section before the detector. The beam cross-section was 1.2 mm. Fig. 7 shows an energy spectrum of the stripped $^{19}F^{7+}$ beam. The energy spectrum shows a full-energy peak with good resolution and a distribution of signals at about half the energy. The latter is most probably due to light not collected the regular way. This urges for further investigation.

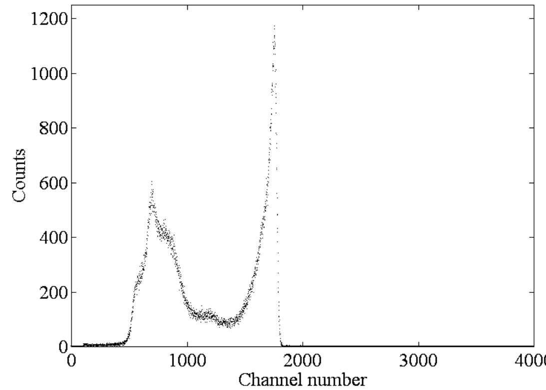

Figure 7: Energy spectrum of 8 MeV/u $^{19}F^{6+}$, stripped by residual gas to $^{19}F^{7+}$.

REFERENCES

[1] M. Moszynski, M. Kapusta, D. Wolski, W. Klamra, B. Cederwall, "Properties of the YAP:Ce scintillator", Nucl. Inst. Meth. A **404** (1998) 157.

[2] S. Westman, "New scintillation crystal for particle detection in CRYRING", Stockholm, 1998