Title
A CERENKOV DETECTOR FOR HEAVY ION VELOCITY MEASUREMENTS

Author
Olson, D.L.

Publication Date
1984-08-01

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

To be presented at the Conference on
Instrumentation for Heavy-Ion Nuclear
Research, Oak Ridge, TN, September 22-24, 1984

A CERENKOV DETECTOR FOR HEAVY ION VELOCITY MEASUREMENTS

D.L. Olson, M. Baumgartner, J.P. Dufour,
J.G. Girard, D.E. Greiner, P.J. Lindstrom,
T.J.M. Symons, and H.J. Crawford

August 1984

NUCLEAR SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DISCLAIMER

LBL-18259

A CERENKOV DETECTOR FOR HEAVY ION VELOCITY MEASUREMENTS

D.L. Olson, M. Baumgartner, J.P. Dufour, J.G. Girard,
D.E. Greiner, P.J. Lindstrom, and T.J.M. Symons
Nuclear Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

H.J. Crawford
Space Sciences Laboratory
University of California
Berkeley, California 94720

August 1984

This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

A Cerenkov Detector for Heavy Ion Velocity Measurements

D. L. Olson, M. Baumgartner, J. P. Dufour[*], J. G. Girard[**],
D. E. Greiner, P. J. Lindstrom, T. J. M. Symons
Nuclear Science Division, Lawrence Berkeley Laboratory
Berkeley, CA 94720

H. J. Crawford
Space Sciences Laboratory, University of California
Berkeley, CA 94720

We have developed a highly sensitive velocity measuring detector using total-internal-reflection Cerenkov counters of a type mentioned by Jelly[1] in 1958. If the velocity of the particle is above the threshold for total-internal-reflection these counters have a charge resolution of $\sigma = 0.18e$ for a 3mm thick glass radiator. For the velocity measurement we use a fused silica radiator so that the velocity of the particles are near the threshold for total-internal reflection. For momentum-analyzed projectile fragments of 1.6 GeV/nucleon ^{40}Ar, we have measured a mass resolution of $\sigma = 0.1u$ for isotope identification.

Principle of the Detector

Cerenkov light is produced at an angle $\theta_c = \cos^{-1}(1/\beta n)$ relative to the direction of a particle with velocity β passing through a material of index of refraction n. When the particle is traveling through a medium for which all the surfaces are either perpendicular or parallel to the direction of the particle the Cerenkov light is trapped within the medium if the angle $\theta_c > \sin^{-1} 1/n = \varphi_{crit}$, the critical angle for total internal reflection. By placing a photomultiplier in optical contact with a radiator of this type and offset from the position of the particle track one gets a threshold counter where the velocity threshold depends upon the material used. Since real materials are dispersive ($n = n(\lambda)$) the light is produced over a range of angles and this threshold is not a step function but has some width in β. The result is that this type of counter is sensitive to velocity in the threshold region of $\theta_c \sim \varphi_{crit}$.

The theoretical response of this type of detector is given simply by considering the paths of all of the light rays and whether or not they are transmitted or reflected at the surfaces of the radiator. The geometry is a little involved but the various factors affecting the response are shown in the integral below. The number of photoelectrons produced in the photomultiplier tube for a particle with velocity β and charge z passing through a material of index-of-refraction n with incident angle α is

$$N_{pe} = \int\int \varepsilon_{pc}(\lambda)[\partial^2 I/\partial\lambda\partial t(n(\lambda),\lambda,\beta(t))]\, f(\alpha,\lambda,n(\lambda),\beta(t))\, d\lambda\, dt$$

where λ is the wavelength of the light, $\varepsilon_{pc}(\lambda)$ is the wavelength dependent photocathode quantum efficiency, $\partial^2 I/\partial\lambda\partial t(n,\lambda,\beta)$ is the number of photons produced per unit wavelength interval per unit thickness of radiating material, and $f(\alpha,\lambda,\beta,n)$ is the fraction of the Cerenkov light which is trapped in the radiator by total internal reflection and is the term with all of the geometrical dependence folded into it. The integral over t results from energy loss in the radiator which contributes a small but significant effect. Depending upon the choice of material for the radiators, one can select different velocity ranges for which the device is sensitive.

Experimental Results

We have performed both detailed tests of this detector measuring its response as a function of β and α. We have also used it for isotope identification in a charge-changing cross section experiment. For the prototype tests we used detectors with 6 mm thick fused silica radiators. We exposed these devices to a 1.9 GeV/nucleon ^{56}Fe beam which we degraded in energy with varying thicknesses of Cu in order to measure the detector response as a function of the velocity of the beam. The result of this measurement is shown in Fig. 1a, where the measured points are shown in comparison with a curve calculated from the theory. By rotating the detector relative to the beam direction we measured the response as a function of incident angle for two beam energies. These results are shown in Fig. 1b, again in comparison to the theory. Note that within a band of about 10 mrad about 0 degrees the response is fairly insensitive to angle and that an angular range of about 10 mrad is larger than that for the production of heavy projectile fragments.

From these results we can estimate that the resolution in velocity corresponds to a mass resolution of $\sigma = 0.07$u for equal rigidity isotopes of Fe. One should note that the predicted mass dependence of this device is proportional to A/Z and so depends only weakly upon the mass of the particle.

The charge-changing reaction experiment was largely a repeat of a previous experiment[2] where we have replaced the lucite radiators with 3mm thick BK7W glass and 2mm thick fused silica radiators. The results we report here are from the running mode in which we fragmented a 1.6 GeV/nucleon ^{40}Ar beam at the input to the LBL 0° spectrometer and looked at fragmentation products with this detector. With a rigidity acceptance of 0.5% we were able to resolve isotopes of Ar with $\sigma = 0.1$ u as seen in Fig. 2, where the velocity measurement is from a single 2mm thick fused silica radiator. Figure 3 is a scatter plot of all of the isotopes observed and combines data from many rigidity settings. Note that our trigger threshold cut out the low mass fragments.

The dynamic range in β for this detector covers 4-5 mass units of equal rigidity Si isotopes. However, we never observed more than two isotopes of Si for any one rigidity setting in this experiment.

Conclusion

Encouraged by these results, we are proceeding with the construction of a 0.3m by 1.0 m hodoscope for use at the LBL HISS facility which should provide excellent charge and velocity measurements for projectile fragments in the 1.45 to 1.75 GeV/nucleon energy region. This hodoscope consists of a layer of BK7W glass radiators for the charge measurement and a layer of fused silica radiators for the velocity measurement. When coupled with momentum analysis from HISS, this device will provide a clear isotope identification signal for heavy projectile fragments that was previously impossible.

This work was supported by the Director, Office of Energy Research, Division of Nuclear Physics of the Office of High Energy and Nuclear Physics of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

References

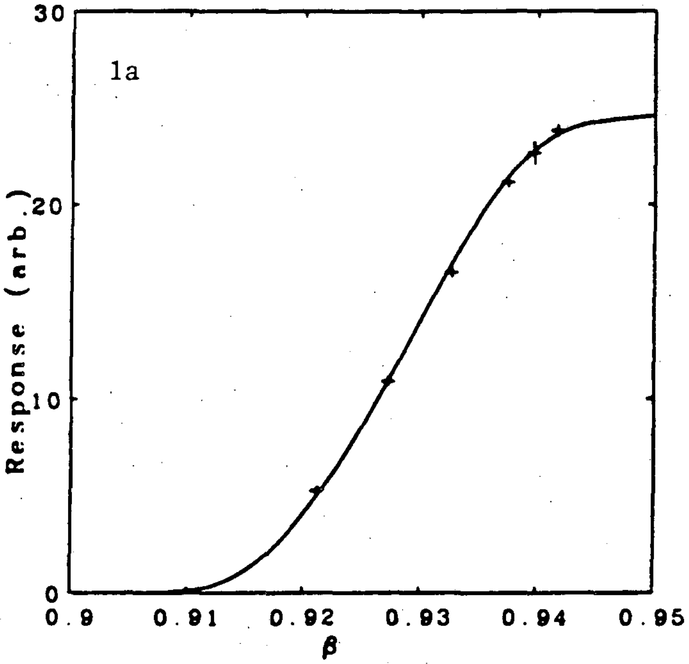
* Present address: Centre d'Etudes Nucleaires de Bordeaux-Gradignan, Le Haut Vigneau, F-33170 Gradignan, France.

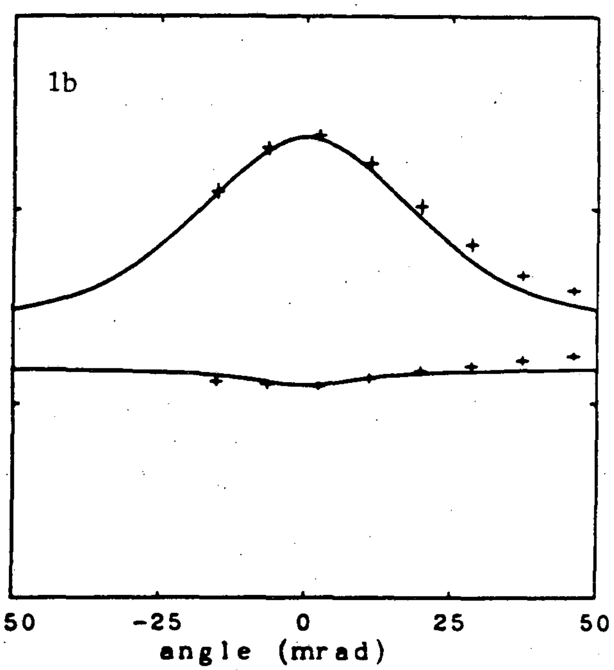
** Present address: Commissariat a l'Energie Atomique de Saclay, F-91191 Gif-sur-Yvette Cedex, France.

1 J. V. Jelly, *Cerenkov Radiation and its applications* (Pergamon Press, London, 1958), p. 138.

2 T. J. M. Symons, M. Baumgartner, J. P. Dufour, J. Girard, D. E. Greiner, P. J. Lindstrom, D. L. Olson, H. J. Crawford, Phys. Rev. Lett. *52*, 982 (1983).

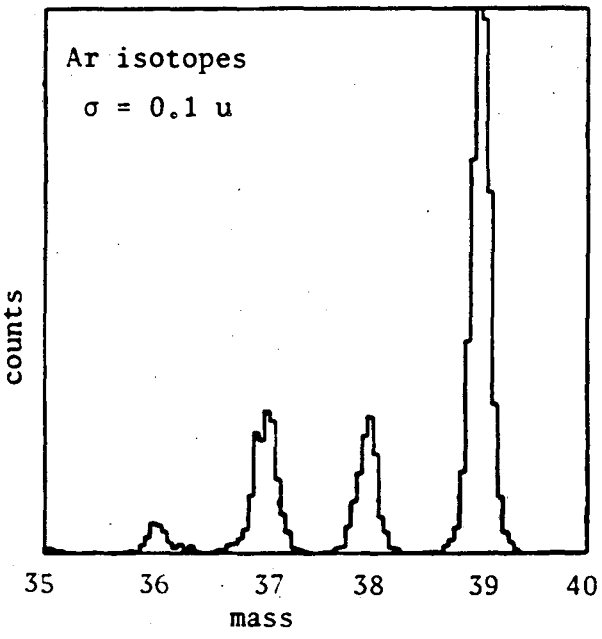
Figures

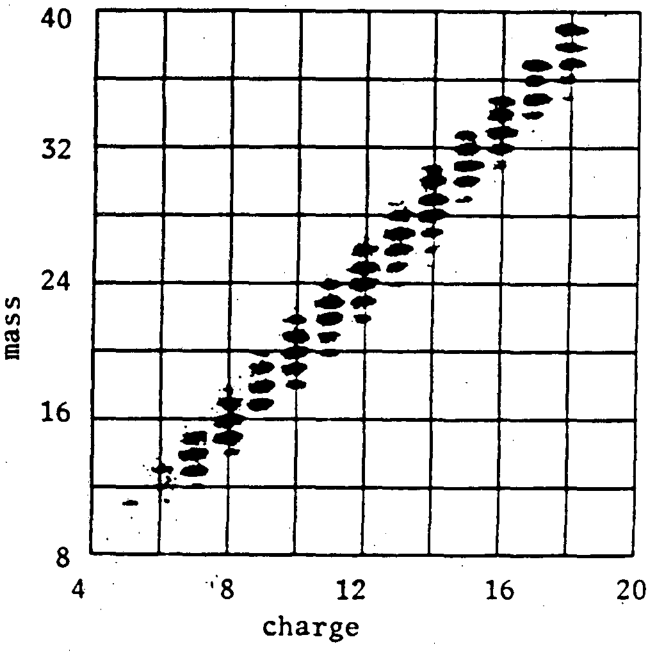

1a
Response (arb.)
0
10
20
30
0.9
0.91
0.92
0.93
0.94
0.95
β


1b
50
-25
0
25
50
angle (mrad)

2

3


Ar isotopes
σ = 0.1 u
counts
35
36
37
38
39
40
mass


40
32
24
16
8
mass
4
8
12
16
20
charge

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720