Experimental report

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Title: Digital Sub-Bragg-Peak Spectroscopy at Lohengrin

Research area: Physics

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Samples:

Instrument	Requested days	Allocated days	From	To
PN1	12	10	04/11/2016	14/11/2016

Abstract:

We propose an experiment that combines the Lohengrin spectrometer with an additional focal-plane detection system consisting of a digital Bragg Spectrometer and short time-of-flight section. The data obtained will be used to characterize the velocity dependence of the specific energy loss in the fill gas at energies below the Bragg peak. An investigation will be made as to the efficacy of an additional TOF filter as a means to reject contamination for yield measurements at Lohengrin.

1 Introduction and Motivation

Stopping of ions in matter is a complicated process, which has been extensively investigated in the past [1][2]. The stopping in matter of fast ions traveling at velocities $v \gg v_0$, where v_0 is the Bohr velocity equal to 2.19×10^6 m/s, is relatively well-understood. The differential energy loss of such ions in gaseous media, such as in a Bragg detector (BD), can be described with the Bethe-Bloch formula, which gives the stopping power $S(E)$ based on ion velocity and charge. Ion velocities below or around the Bohr velocity may be insufficient to fully ionize the atom [1], resulting in electronic screening of the nuclear charge and possible electron exchange with the gas. Subsequent variation of the effective charge of the ion prevents a Bragg peak from forming in the energy loss profile, which is the case for fission fragments (FF).

The nuclear charge yields of FF are required to understand the fission process and for a multitude of applications. Since fission is a result of competition between electrostatic and nuclear force, the information on the charge distribution is critical in understanding fission dynamics by informing fission models [3]. Charge yields have significant implications for nuclear energy applications, where they have direct application to nuclear waste composition [4], reactor heating [5], as well as providing input towards addressing the reactor antineutrino anomaly [6]. Large detector assemblies, such as the SpecTrometer for Exotic Fission Fragments (STEFF) [7], use BDs to provide FF information. Developing a methodology for extracting proton number information from the BD signals would greatly benefit the potential of such spectrometers and the data provided for fission models. In order to develop such a methodology, a BD-based spectrometer called Fission Fragment Identification (FiFI) arm was constructed at the University of Manchester and used in an experimental campaign measuring FF from thermal neutron induced fission on ^{235}U at ILL, using the constant velocity FF beam provided by the Lohengrin facility. BD digitized waveforms for various Lohengrin settings were stored and analyzed in an effort to construct a functional form that can be used for calibrating BDs and extracting the FF Z using differential energy loss and range.

2 Fission Fragment Identification Arm

FiFI is composed of two sections: a time-of-flight (ToF) section and a BD. A diagram of the setup is presented in Fig. 1. The ToF section, located between volumes B and C, relies on two timing detectors separated by a 1-metre flightpath. The START and STOP timing detectors, positioned in volumes B and C, are identical microchannel plate (MCP) assemblies. The assemblies feature thin foils marked D, an electrostatic mirror, marked E, and a MCP denoted with F. The foils are made of ≈0.3 μm formvar, coated in 370 Å aluminium. The BD is filled with 100 mbar of isobutane gas and is isolated from the vacuum of the ToF section using a 0.5 μm Mylar window covered with a steel collimator (4 × 0.8 cm rectangular slit), denoted with letter G in Fig. 1. The BD on FiFI is a cylindrical volume containing 12 field-shaping rings, a Frisch grid and an anode (position H).

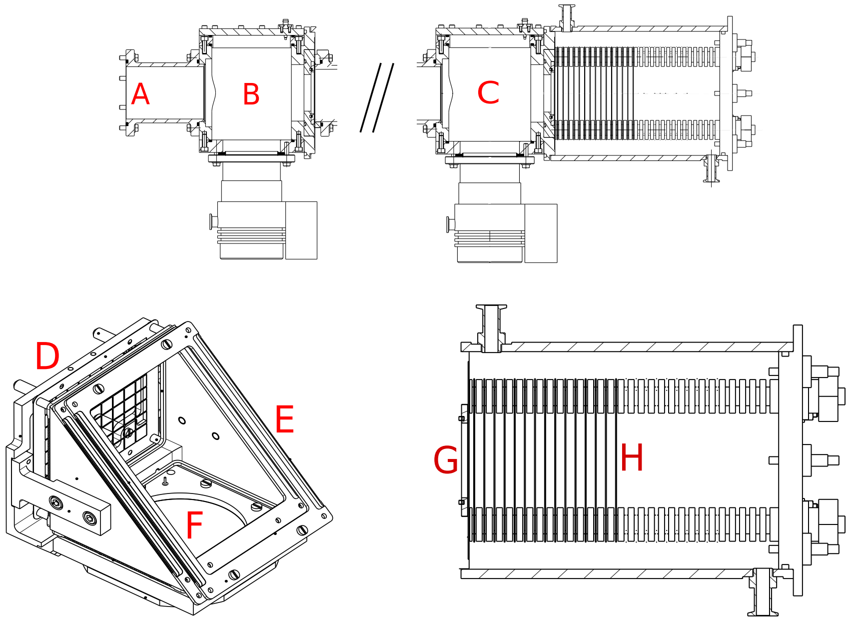

Figure 1: A schematic diagram of the Fission Fragment Identification arm.

3 Lohengrin Campaign and Analysis

Lohengrin separator is ideal for investigating the response of a BD to FF atomic number, since Lohengrin FF beams arrive at a known velocity and with very-well defined masses and energies. FiFI was installed at the focal plane of Lohengrin and operated over the course of 12 days investigating over 200 various Lohengrin settings. During the campaign thickness of the timing foils was found to be excessive for the purposes of the atomic number investigation, as FF straggling in the foils degraded the energy resolution of the apparatus. The foils were removed from FiFI, thus disabling the ToF section and precluding investigation of charge-changing collisions inside Lohengrin, which was a planned application of FiFI during the campaign. Only the waveforms that were measured in the last two days of the campaign following timing foil removal were used in the analysis, limiting the dataset to approximately 40 Lohengrin settings. The collected waveforms were processed into a database and a series of digital filters were applied with the aim of extracting energy loss-like and range-like parameters gated on known FF masses and velocities. The chosen parameters were tau, which corresponds to the waveform risetime from 10% to 90% divided by FF mass A, and $A(\frac{v}{c})^2\epsilon$, which is energy loss divided by the total deposited energy (collectively denoted ϵ), and scaled by FF kinetic energy Av^2. Each mass peak comprised several isobars, and dominant isobars were identified using JEFF 3.1 database [8] to assign average FF atomic number $\bar{Z}$ for each mass.

4 Results and Outlook

The parameters extracted from the waveforms were investigated for each $\bar{Z}$, and a plot of the results is shown in Fig. 2.

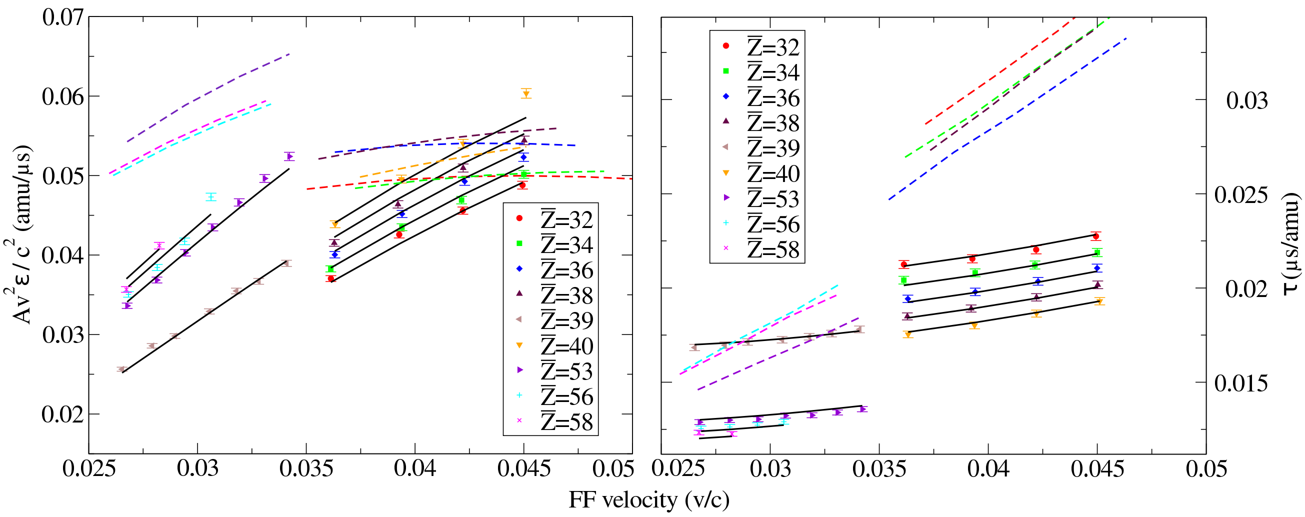

Figure 2: Plots of energy loss-like parameter against FF velocity on the left and τ against velocity on the right. Lines corresponding to separate values of FF $\bar{Z}$ are easily distinguishable in both plots. There are two clusters present: one for heavy and one for light fragments. Functional fits to the parameters are in solid lines and results of a SRIM-2013 simulation for the same fragments are in dashed lines.

The results were fitted with power law-based functions to produce an atomic number calibration for the BD and compared to SRIM-2013 toolkit [9] to examine the correspondence of the measured FF stopping to the commonly-used software. The calibration and the investigation of SRIM-2013, along with further details of the analysis have been compiled into a manuscript [10] currently under review by Nuclear Instruments and Methods A. The identified excess thickness of the timing foils has motivated an improvement in the manufacturing of the foils, resulting in new timing foils which are <100 nm thick, compared to 200-300 nm thickness of the foils used in the campaign. The new foils have been tested with a ^{252}Cf source, and their performance is being investigated. The improvements in the ToF section and interest in investigating different fill gases have motivated plans for a further campaign of measurements at Lohengrin.

References

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