Development of a compact, high resolution neutron spectrometer for high-EMP environments

S. Volkmer, J. A. Frenje, F. H. Séguin, C. K. Li, J. R. Rygg, R. D. Petrasso

Massachusetts Institute of Technology

T. C. Sangster, V.Yu. Glebov, D. D. Meyerhofer, C. Stoeckl

University of Rochester – Laboratory for Laser Energetics

Abstract

Neutrons from ICF implosions are routinely measured with neutron time of flight (nTOF) spectrometers, which are sensitive to electromagnetic noise. For charged particles, solid state nuclear track detectors such as CR-39 provide low-priced, compact, EMP insensitive means of measuring their yields and spectra. The neutron Wedge Range Filter (nWRF) spectrometer presented here exploits these favorable features of CR-39 for neutron spectrometry by measuring recoil protons which are induced by 14.1 MeV DT neutrons in a thin CH foil.

We describe the basic experimental setup and instrument characteristics of the nWRF and explain data processing and the method of inferring a neutron spectrum from the corresponding proton spectrum. Also, we show an example of our first experimental data, taken at OMEGA with preliminary hardware, and compare the deduced ion temperature to the corresponding nTOF measurement. Finally, we discuss possible improvements of neutron spectrometry with the nWRF.

Outline

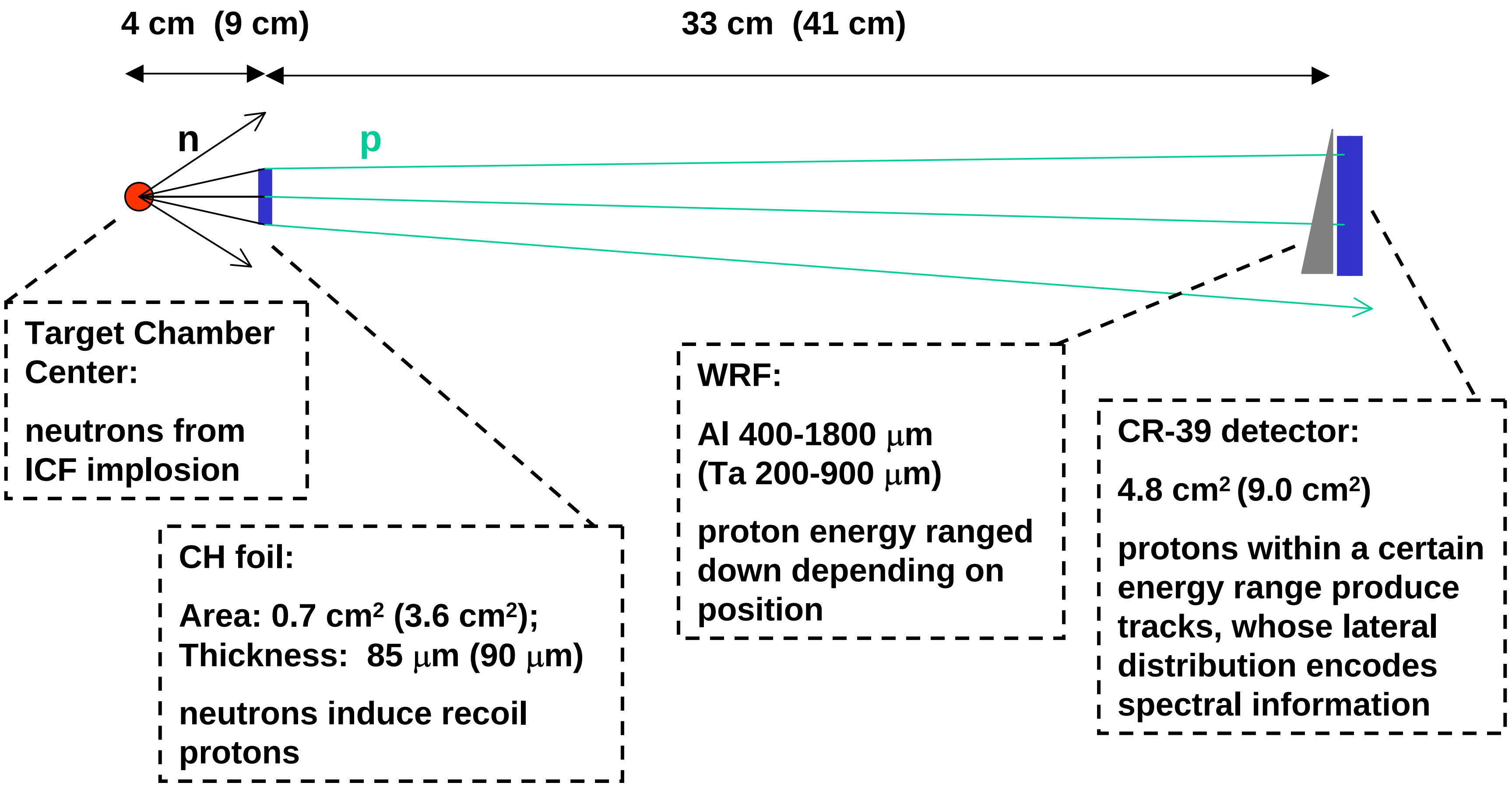
- Motivation
- The principle of the neutron Wedge Range Filter (nWRF) spectrometer
  a) Detection efficiency
  b) Resolution
- The nWRF spectrometer in the OMEGA target chamber
- Deduction of the neutron spectrum from the measured proton spectrum
- Analysis of the first nWRF proton spectrometry data
- First ion temperature measurement with the nWRF
- Improved n-background rejection by coincidence counting
- Conclusion and Outlook

Motivation

- **The nWRF spectrometer is a *compact* and *EMP insensitive* spectrometer.**
- **It will function in high EMP environments as occur at Z, OMEGA-EP, and the NIF.**
- **Several nWRF spectrometers can be simultaneously fielded, potentially allowing for studies of anisotropies in non-thermal plasmas.**
- **The nWRF spectrometer measures the *absolute yield* and *actual spectral shape* of the primary neutrons and thus provides more detailed information than other neutron diagnostics currently operating at OMEGA.**
- **For measuring ion temperatures, the nWRF provides an alternative to nTOF measurements and the yield ratio method, whose results have previously been showing a discrepancy of 1 KeV for temperatures below 5 KeV[†] .**

[†] **C. K. Li et al., Phys. Plasmas 7, 2578 (2000).**

The principle of the neutron Wedge Range Filter (nWRF) spectrometer



Target Chamber Center:

neutrons from ICF implosion

CH foil:

Area: 0.7 cm^2 (3.6 cm^2);
Thickness: 85 μm (90 μm)

neutrons induce recoil protons

WRF:

Al 400-1800 μm
(Ta 200-900 μm)

proton energy ranged down depending on position

CR-39 detector:

4.8 cm^2 (9.0 cm^2)

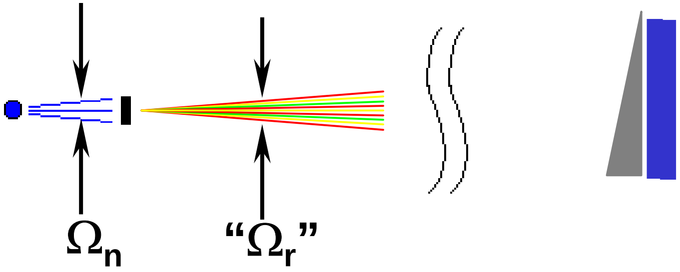
protons within a certain energy range produce tracks, whose lateral distribution encodes spectral information

---

System specifications are given for the first quick and dirty proof of principle experiments, as well as for the optimized setup (in parentheses).

a) Detection efficiency (ε_{nWRF})

$$\varepsilon_{nWRF} = \frac{\Omega_n}{4\pi} \cdot n_i \cdot t \cdot \int^{"\Omega_r"} \frac{d\sigma(E_n)}{d\Omega_{lab}} d\Omega \cdot f_{WRF}$$



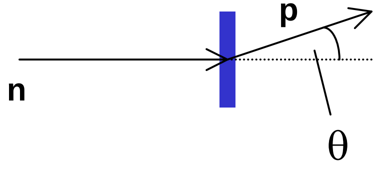
- Absolute yields can be measured since Ω_n, Ω_r, proton density n_i in foil, foil thickness t, and WRF efficiency f_{WRF} are known.
- Maximum differential cross section at forward scattering angles contributes to high resolution and efficiency.

b) Resolution (ΔE_{nWRF})

Resolution is determined by three spectral broadening effects:

$$\Delta E_{nWRF} \approx \sqrt{\Delta E_{kin}^2 + \Delta E_{foil}^2 + \Delta E_{WRF}^2}$$

ΔE_{kin} = Kinematic energy broadening $\propto$ foil and detector sizes



$$E_p = E_n \cos^2 \theta$$

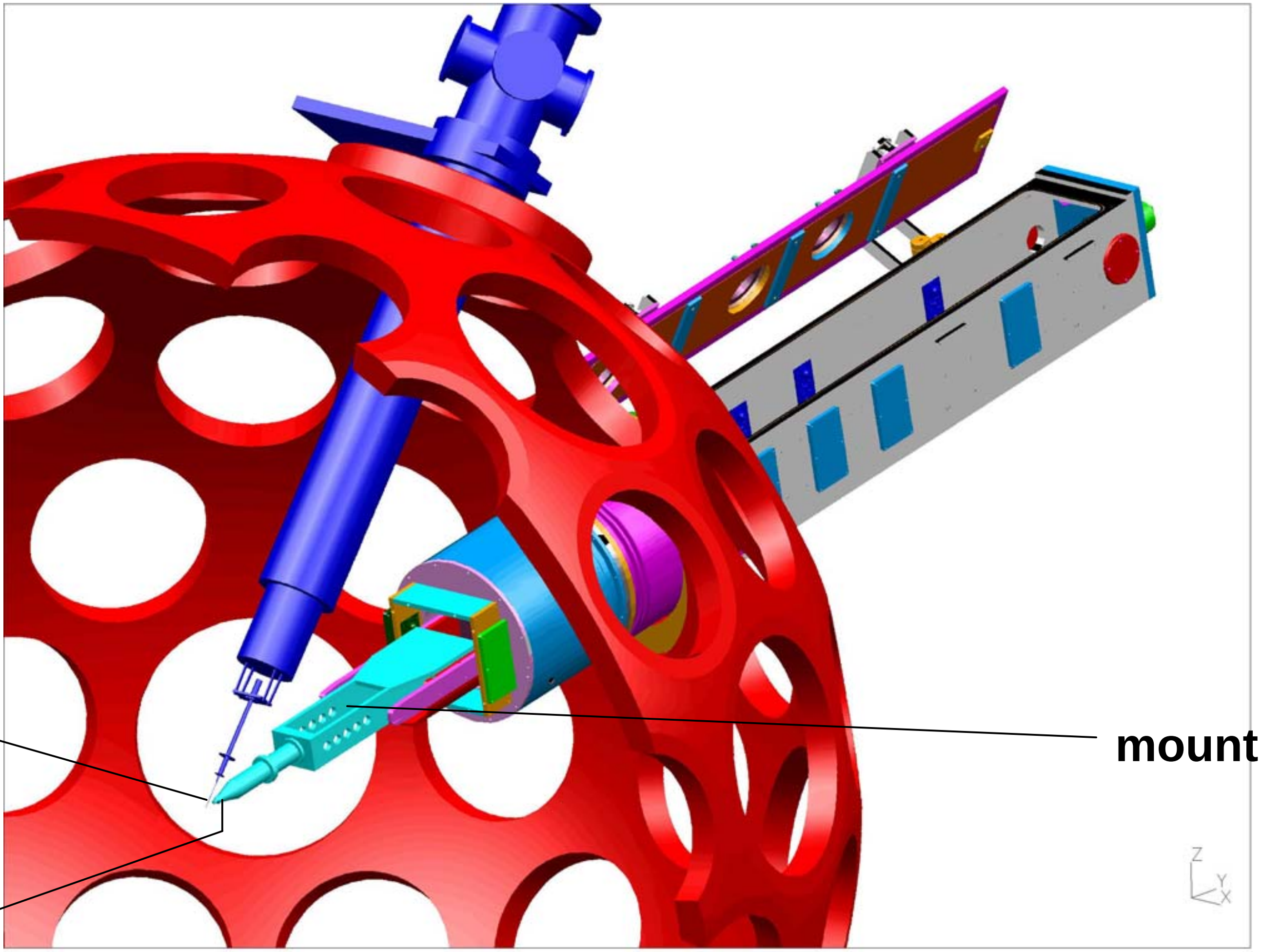
ΔE_{foil} = Energy loss in foil $\propto$ foil thickness

ΔE_{WRF} = WRF energy broadening $\propto$ WRF thickness and slope

---

J. A Frenje et al., Rev. Sci. Instrum 72, 854 (2001).

The nWRF spectrometer in the OMEGA target chamber



target

CH foil

mount for a WRF

Deduction of the neutron spectrum from the measured proton spectrum

Under the simple assumption of Gaussian neutron and proton energy distributions, the parameters of the neutron spectrum can be deduced from the corresponding proton spectrum in the following way:

- **Mean energy of neutron spectrum:**

$$\overline{E_n} \approx \overline{E_p} + 200 KeV$$

(proton energy downshifted due to scattering and energy loss in foil)

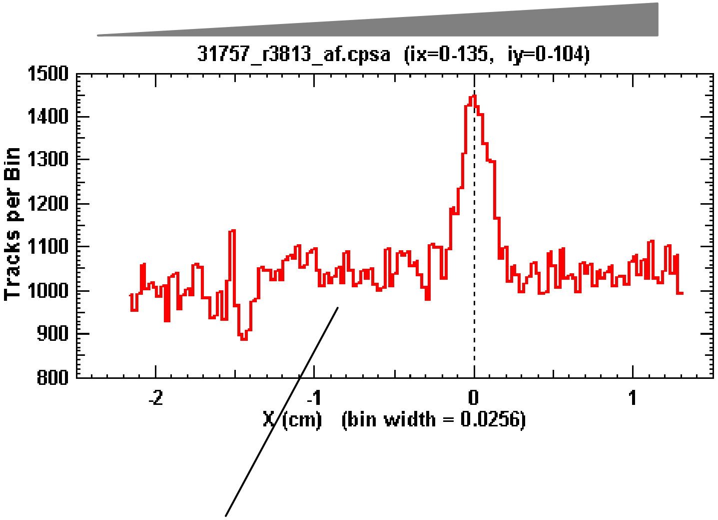
- **Width (standard deviation) of neutron spectrum:**

$$\Delta E_n \approx \sqrt{\Delta E_p^2 - \Delta E_{kin+foil}^2 - \Delta E_{WRF}}$$

with $\Delta E_{kin+foil} \approx 110 KeV$ **and** $\Delta E_{WRF} \approx 140 KeV$

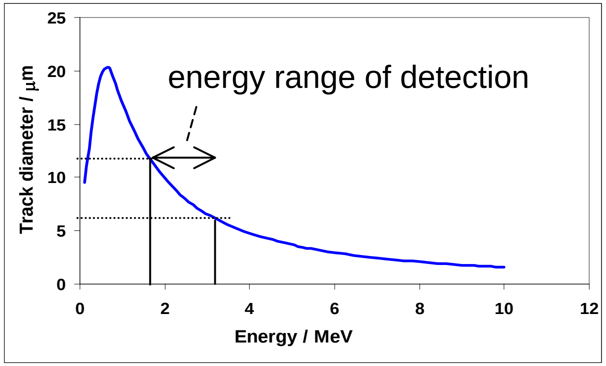
Analysis of the first nWRF proton spectrometry data

lateral track position

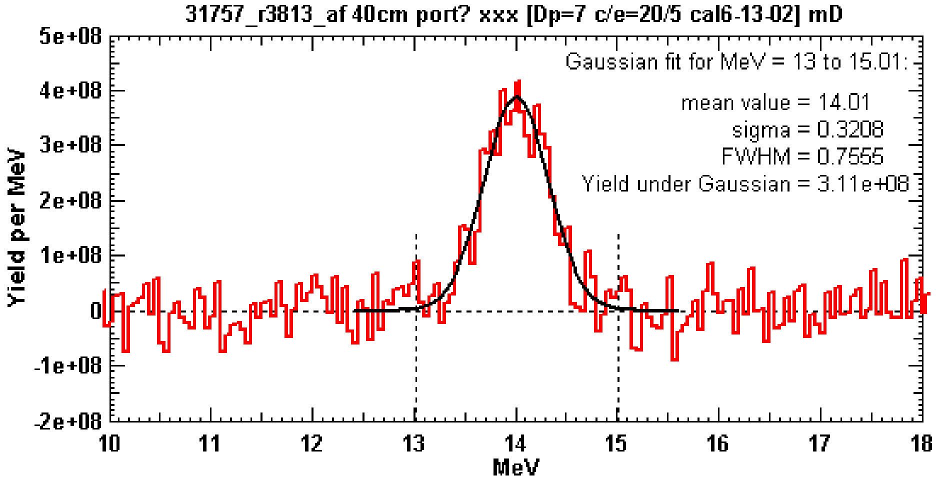


+

track diameter



= proton spectrum



neutron-induced background

Notice:
signal/background only
about 45% !

F. H. Seguin et al., Rev. Sci. Instrum 74, 975 (2003).

First ion temperature measurement with the nWRF

From the above proton spectrum of shot 31757 with

$$\overline{E_p} = (14.01 \pm 0.04)\, MeV$$

$$\Delta E_p = (320 \pm 50) KeV$$

the following neutron mean energy and FWHM are deduced:

$$\overline{E_n} = (14.21 \pm 0.04)\, MeV$$

$$\Delta E_n = (265 \pm 60) KeV$$

For DT reaction products, the ion temperature and the spectral width are related by:

$$T_i \,/\, KeV = \left(\Delta E_n \,/\, KeV\right)^2 / 5630$$

Thus, the ion temperature measured with the nWRF is:

$$T_{i(nWRF)} = (12.5 \pm 6) KeV$$

The corresponding nTOF measurement yields:

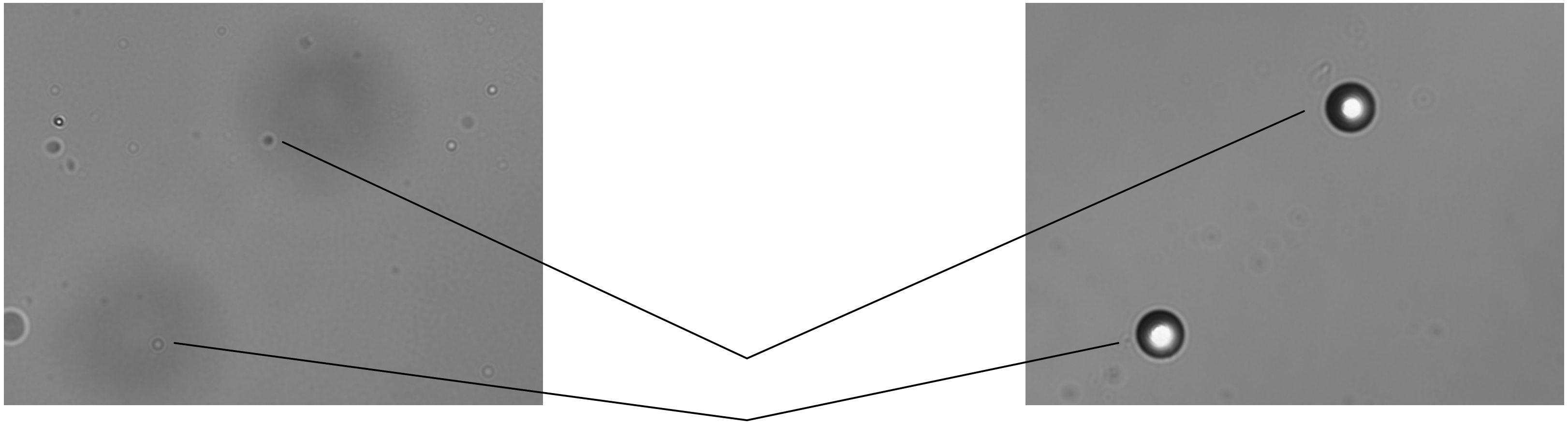
$$T_{i(nTOF)} = (10.9 \pm 0.5) KeV$$

Improved neutron background rejection by coincidence counting

Protons of sufficient energy can penetrate thin CR-39 pieces, thus leaving coincident tracks on the front and back side. Neutron induced CR39 tracks, on the other hand, generally produce a track on only either side and can therefore be discarded.

front side image

back side image



possible coincidences

Conclusion and Outlook

- The first quick and dirty proof-of-principle experiments indicate the feasibility of the nWRF for neutron spectrometry.
- A new, optimized hardware design will provide better efficiency and resolution in future experiments.
- Coincidence counting on the front and back side of thin CR-39 detectors is currently being developed for the purpose of improved neutron background rejection.
- The flexibility of the fitting procedure will be increased by allowing for non-Gaussian neutron spectra.