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Abstract

A model-independent method to determine fuel $\langle \rho R \rangle$ is to measure the energy spectrum and yield of elastically scattered primary neutrons in deuterium–tritium (DT) plasmas. As is the case for complementary methods to measure fuel $\langle \rho R \rangle$ (in particular from knock-on deuterons and tritons), minimizing the background is critical for successful implementation. To achieve this objective, a novel spectrometer for measuring neutrons in the 10- to 18-MeV energy range is proposed. From scattered neutrons (10 to 13 MeV), the DT fuel $\langle \rho R \rangle$ will be measured; from primary neutrons (~14 MeV), the ion temperature and neutron yield will be determined; and from secondary neutrons, in the 12- to 18-MeV energy range, the fuel $\langle \rho R \rangle$ in deuterium plasmas will be inferred at the National Ignition Facility. The instrument is based on a magnetic spectrometer with a neutron-to-deuteron (nd) conversion foil for producing deuteron recoils at nearly forward scattered angles. In its initial phase of implementation, CR-39 track detectors will be used in the focal plane to detect the recoil deuterons with extremely high spatial resolution. Besides simplicity, CR-39 track detectors will facilitate a highly accurate energy calibration. In a later implementation of spectrometer design, however, the recoils will also be detected by an array of fast scintillation counters functioning in current mode. In either detection scheme, the detection efficiency is about 10^{-9} for measuring 14-MeV neutrons with an energy resolution of about 2%. Because of its large dynamic range, its relatively high efficiency, and a compliant design that allows for significant background rejection, this spectrometer can be effectively used, with very high resolution, at both OMEGA and the National Ignition Facility.

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The neutron spectrometer has been designed for various measurements

- Scattered neutrons (10 to 13 MeV) $\Rightarrow$ DT-fuel $\langle\rho R\rangle$
  - Complement to the knock-on studies (ρR_{fuel} ~ 10 mg/cm^2)

- Secondary neutrons (12 to 18 MeV) $\Rightarrow$ D_2-fuel $\langle\rho R\rangle$

- Primary neutrons (~ 14 MeV) $\Rightarrow$ T_i and Y_n

Instrument requirements

- The highest possible detection efficiency for a given resolution
- A large dynamic range
- An insensitivity to different types of background
- Simple to implement
- A reasonble straightforward mechanical interface

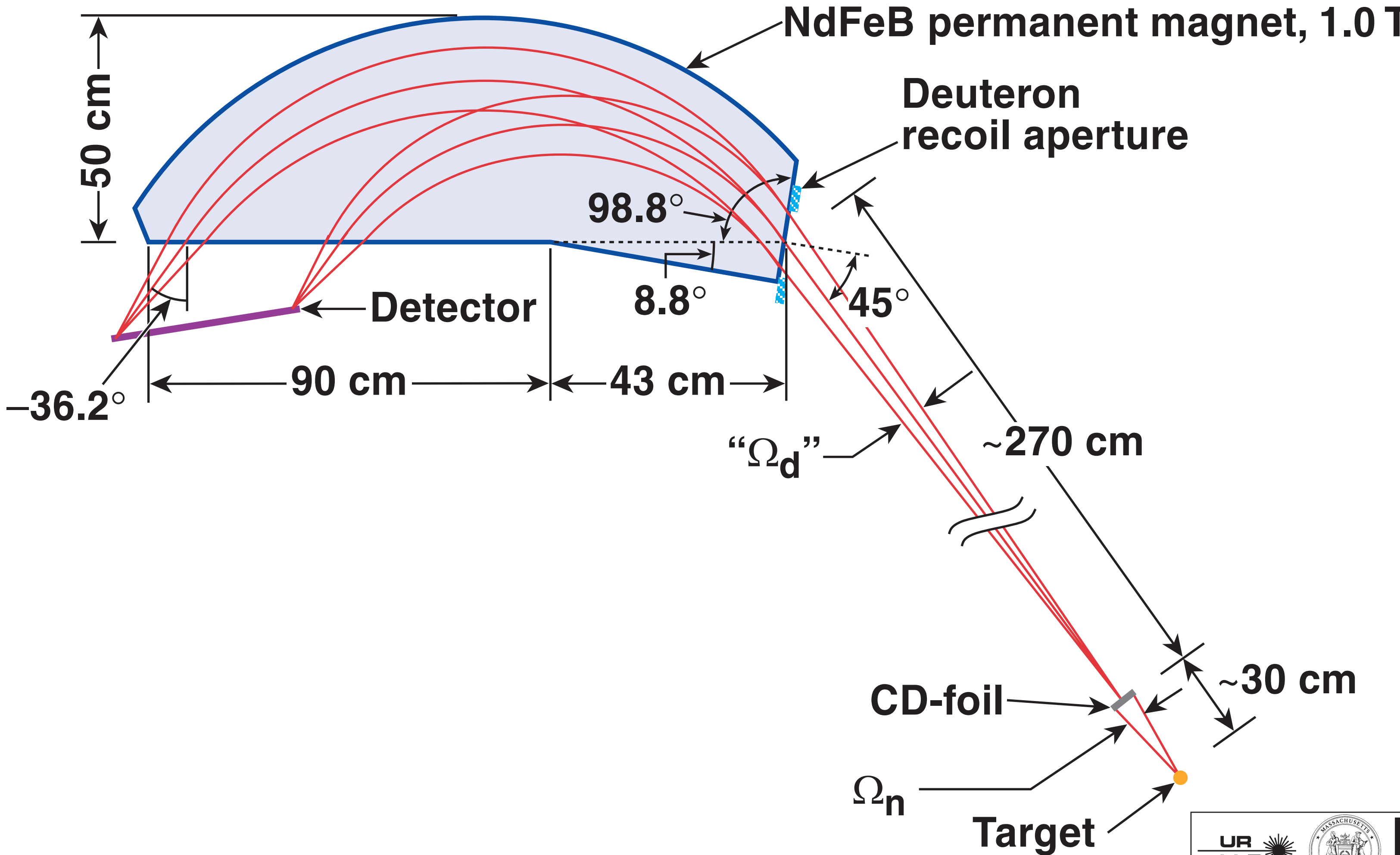
It will be shown that these features are inherent to this design.

The results of the design require the following primary neutron yields (Y_{1n})

Measurement	OMEGA	NIF
Scattered neutrons	$Y_{1n} > 10^{13\dagger}$	$> 10^{14*}$
Primary neutrons	$Y_{1n} > 10^{11*}$	$> 10^{12*}$
Secondary neutrons	$Y_{1n} > 3 \times 10^{12\dagger}$	$> 3 \times 10^{13*}$

†Detection efficiency 10^{-8} at resolution 10%
*Detection efficiency 10^{-9} at resolution 2%

The instrument is based on a magnetic spectrometer with a neutron-to-deuteron (nd) conversion foil



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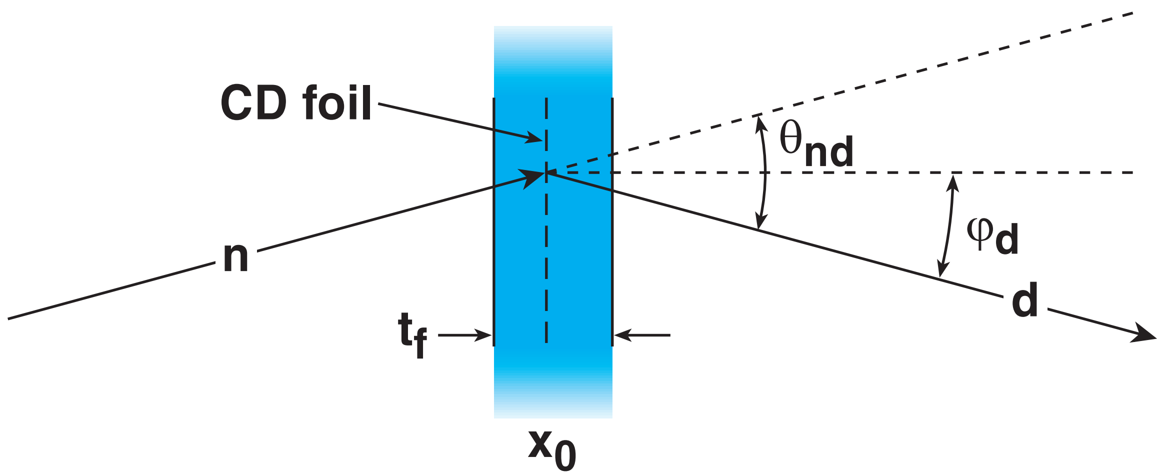
Optimization of the detection efficiency

- The detection efficiency can be expressed as

$$\frac{N_d^{det}}{Y_n} \approx n_d t_f \frac{\Omega_n}{2} \int^{\Omega_d} \sin\theta \frac{d\sigma(\theta)}{d\Omega_{lab}} d\theta$$

- Cross section for nd-elastic scattering has a maximum for $\theta_{nd} = 0°$.
- Detection efficiency is maximized when selecting forward-scattered deuteron recoils.

Optimization of the energy resolution



- The energy relationship between neutron and deuterons is given by

$$E_d \approx \frac{8}{9} E_n \cos^2 \theta_{nd} - \frac{1}{\cos \varphi_d} \int_{x_0}^{t_f} \frac{dE(E_d)}{dx} dx$$

- Energy loss is minimized when selecting forward-scattered recoils.

Definition of spectrometer resolution

- The energy resolution (ΔE_I) of the spectrometer is defined as the deuteron energy distribution at the focal plane when viewing a fluence of mono-energetic neutrons. The broadening can be written as

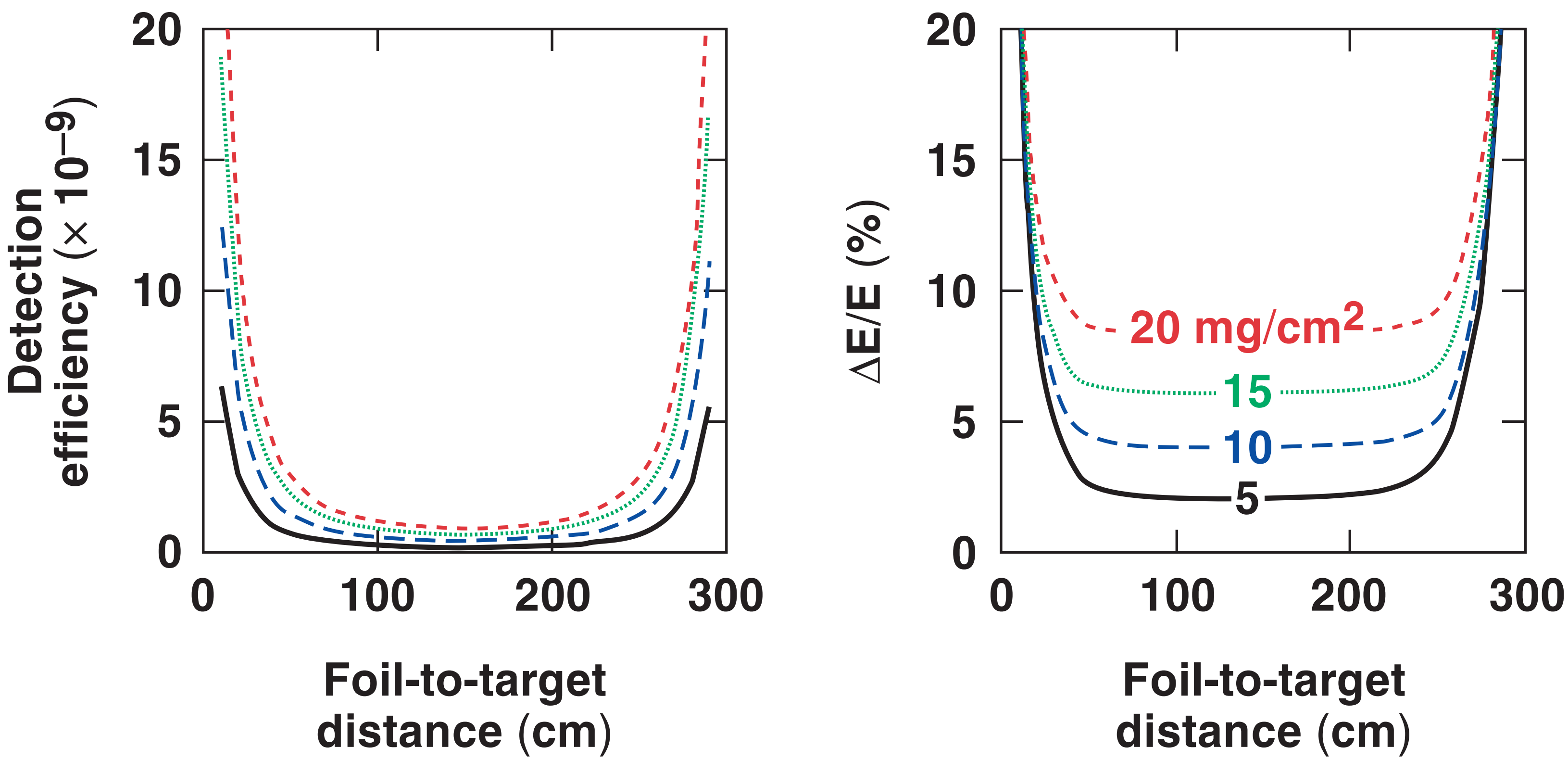
$$\Delta E_I \approx \underbrace{\sqrt{\Delta E_f^2 + \Delta E_k^2}}_{\Delta E} + \Delta E_s^2\ .$$

ΔE_f = energy loss in CD-foil $\propto$ t_f

ΔE_k = kinematic energy broadening $\propto$ Ω_n, Ω_d, and foil area

ΔE_s = ion optical energy broadening $\propto$ Ω_d and foil area

Monte-Carlo calculations were performed to determine the optimal combination of Ω_n, Ω_d and t_f



Foil area = 128 cm^2
Deuteron recoil aperture = 48 cm^2 (300 cm from TCC)

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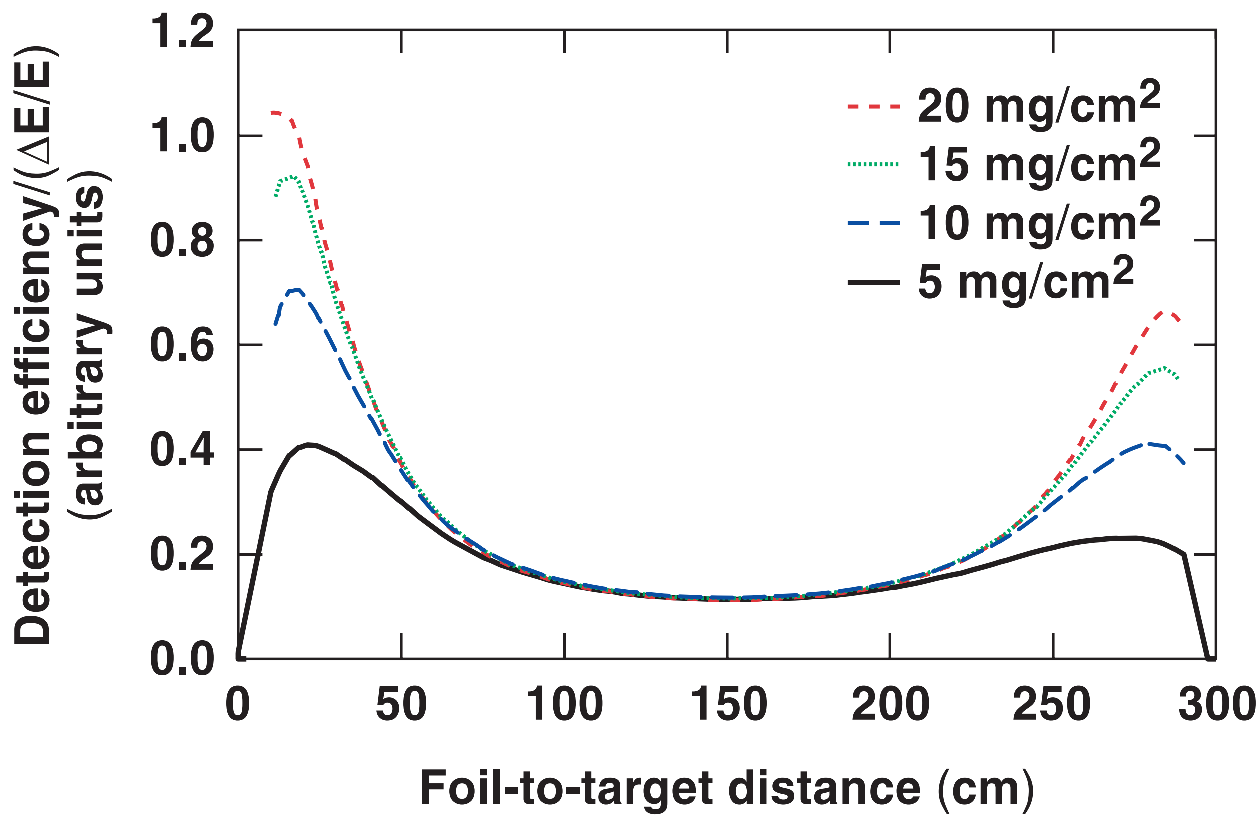
The ratio between detection efficiency and resolution provides information of the optimum foil position



Foil area = 128 cm^2
Deuteron recoil aperture = 48 cm^2 (300 cm from TCC)

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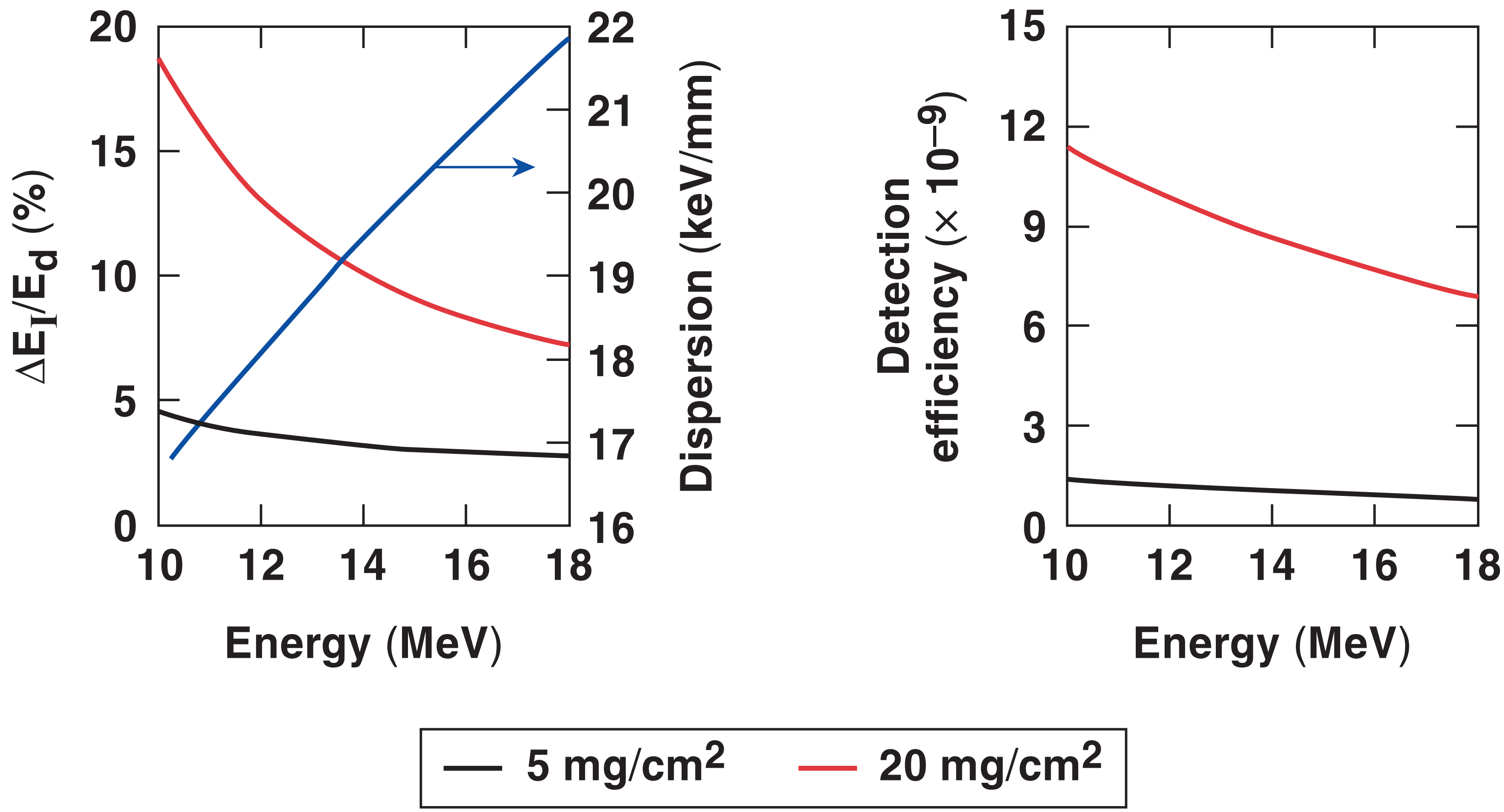
Dispersion, $\Delta E_I/E_d$, and detection efficiency are functions of neutron energy the in range of 10 to 18 MeV



Foil area = 128 cm^2; foil-to-target distance = 30 cm
Recoil aperture = 48 cm^2 (300 cm from TCC)

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Detector system

Initial implementation: ***CR-39 detectors***

- **Accurate energy calibration (~5 keV) due to high spatial resolution**
- **Discrimination between deuteron signal and background due to existing CR-39 curves**
- **Simplistic detection technique**

Final implementation:
Array of fast scintillation counters working in current mode

- **Instant results from the measurements**
- **The large stand-off distance between CD-foil and detectors provides time separation between signal and primary neutron background (40 to 50 ns).**

Signal-to-background (S/B) optimization

CR-39 case:

– Interfering background: neutrons

– Substantial background rejection can be achieved by
  - shielding
  - track size and shape discrimination

Current-mode detection case:

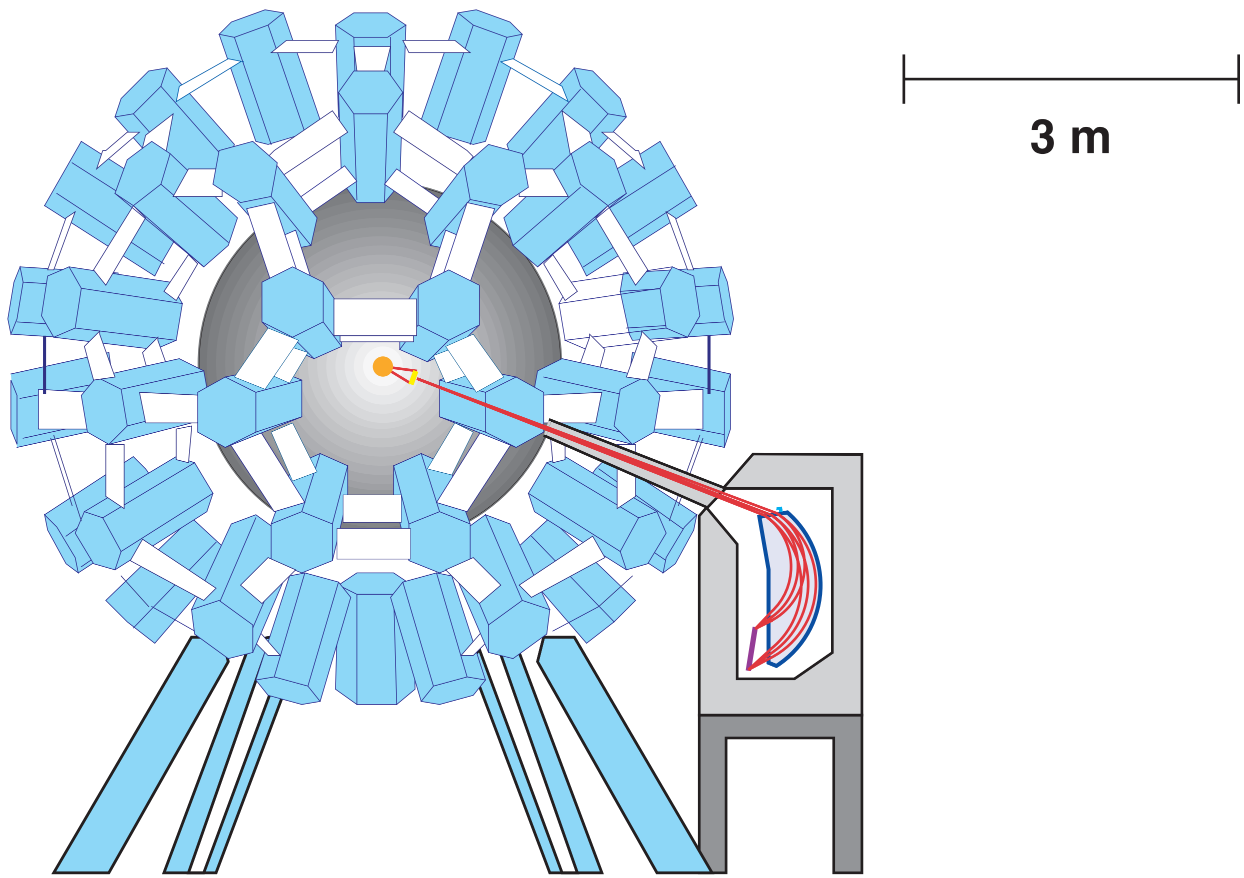
– Interfering background: neutrons, x rays, and γ rays

– Substantial background rejection can be achieved by
  - shielding
  - time discrimination
  - reducing the scintillator volumes

Signal-to-background (S/B) optimization (cont'd)

- **In either detection scheme, the bulk of the remaining detected background can be characterized by moving the CD-foil out of the spectrometer line of sight.**
- **The intensity and spectrum of backscattered neutron background (from target chamber structures) hitting the CD-foil can be determined by using high-yield, low fuel $\langle \rho R \rangle$ implosions.**
- **The transport codes MCNP and TART98 in combination with detector response codes should be useful.**

Envisioned location of the neutron spectrometer in the OMEGA Target Bay area



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Summary

- A neutron spectrometer, covering an energy range of 10 to 18 MeV, has been designed for measurements of primary, scattered, and secondary neutrons.
- The magnet design minimizes the aberrations so that the largest possible solid angle can be utilized.
- The design provides for a detection efficiency of about 10^{-9} at an energy resolution of 2% when measuring 14-MeV neutrons.
- A dynamic range of $>10^6$ will be achieved.

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