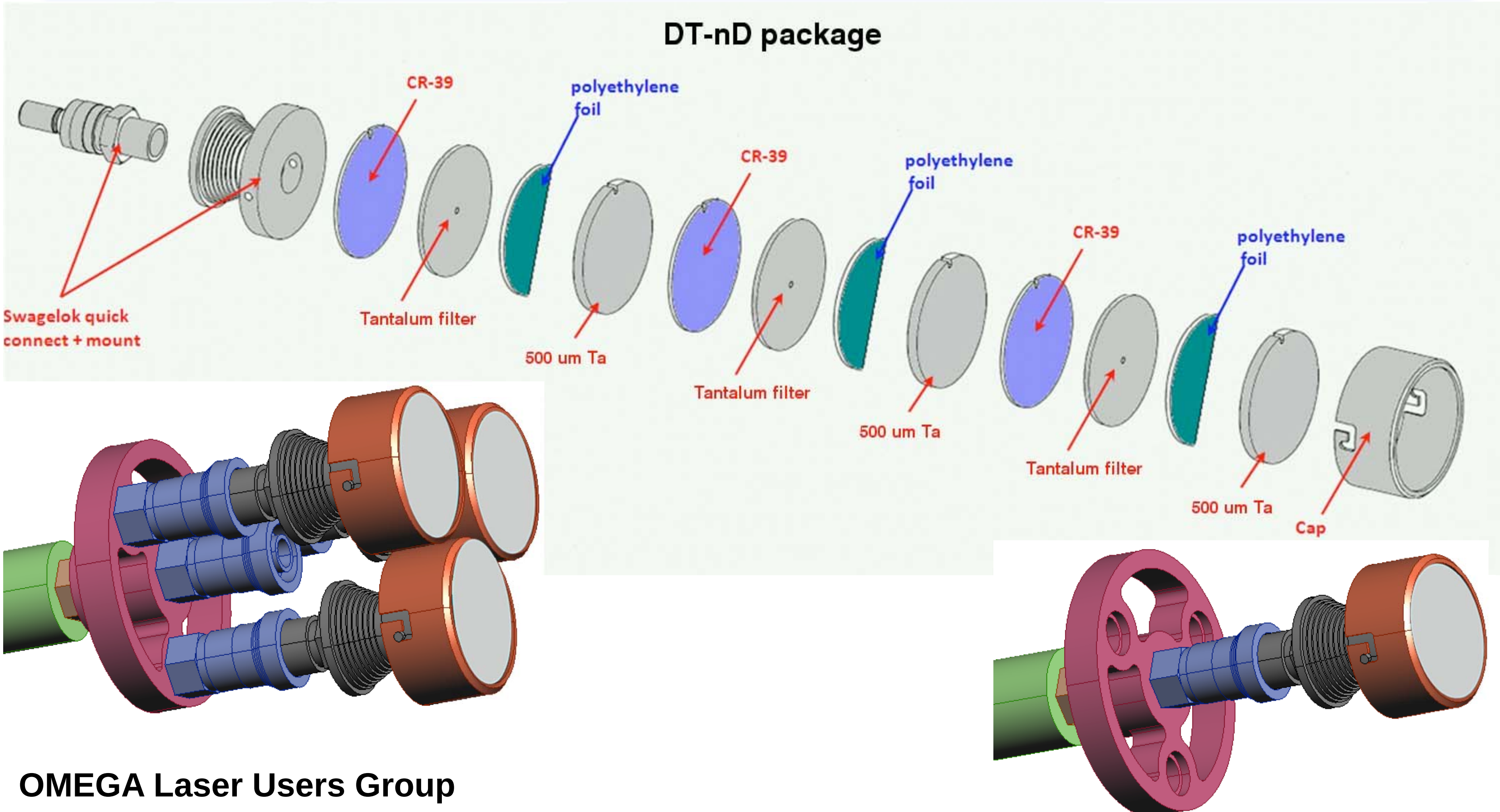
Introduction & Motivation

DRAFT

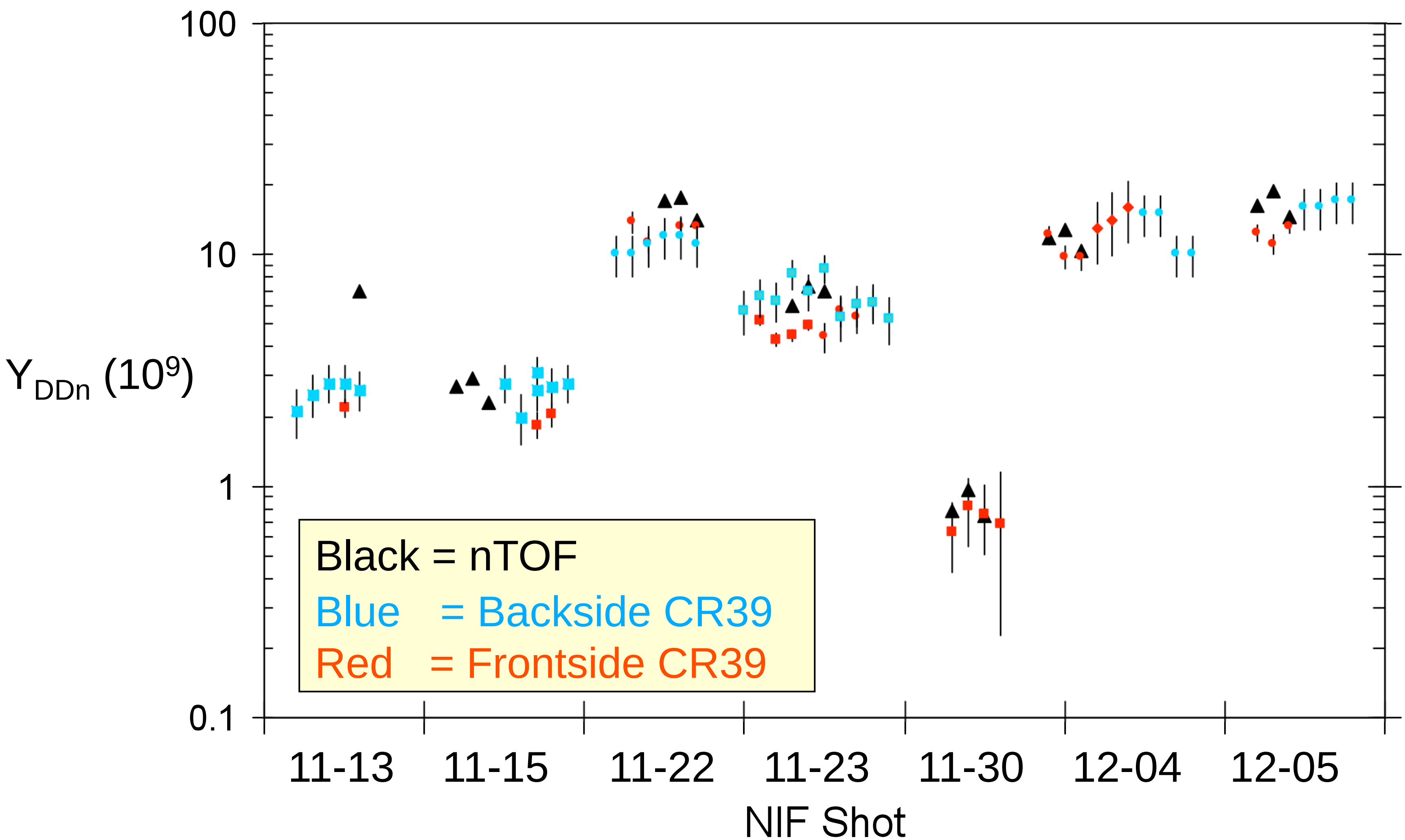
4/26/10

A Compact, CR-39-based DT-neutron Detector for OMEGA and the NIF



OMEGA Laser Users Group
Rochester, NY
April 28th – 30th, 2010

Compact CR-39-based DD-neutron Detectors Have Already Been Fielded on the NIF



Plot courtesy of Fredrick Séguin

Precise Measurements of Fusion DT-neutrons May be Used to Assess the Quality of an ICF Implosion

- Precision measurements of DT-neutrons from different lines of sight may be used to diagnose implosion asymmetries.

- A small, compact, passive design may allow fielding of many detectors during a single shot.

- If the down scattered neutron yield is high (ignition type targets), a multiple step filter may be used to measure the down scattered fraction and therefore infer an areal density along that line of sight.

Abstract and References

A compact, CR-39-based DT-neutron detector is being developed at the Laboratory for Laser Energetics (LLE) for use on OMEGA and the NIF. The detector stack consists (from TCC outward) of a polyethylene neutron-to-proton converter and a tantalum filter preceding the CR-39. The polyethylene covers half of the detector surface to 'convert' incoming 14.1-MeV neutrons to protons through elastic scattering, while the other half is used for background subtraction. The tantalum filter ranges down the elastically scattered protons to be efficiently counted on the CR-39. Experiments have been performed at LLE using various thicknesses of tantalum; preliminary results from warm- and cryo-DT experiments are shown.

1. J.A. Frenje *et al.*, RSI 73 (2002)
2. F. Séguin *et al.*, RSI 74, (2003)

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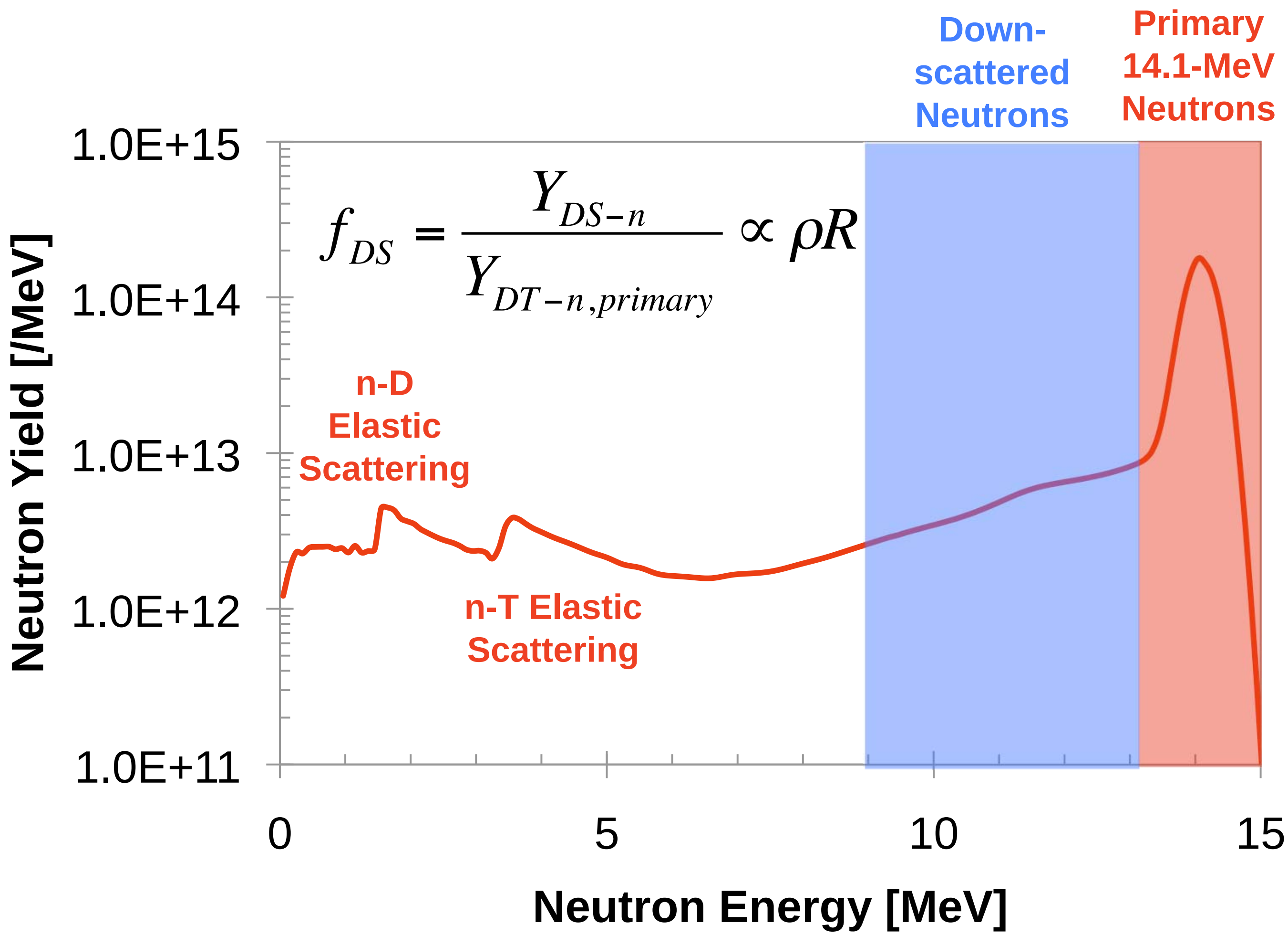
Conceptual Design

Fusion DT-neutrons are Scattered in the Fuel Producing a Spectrum of Neutron Energies

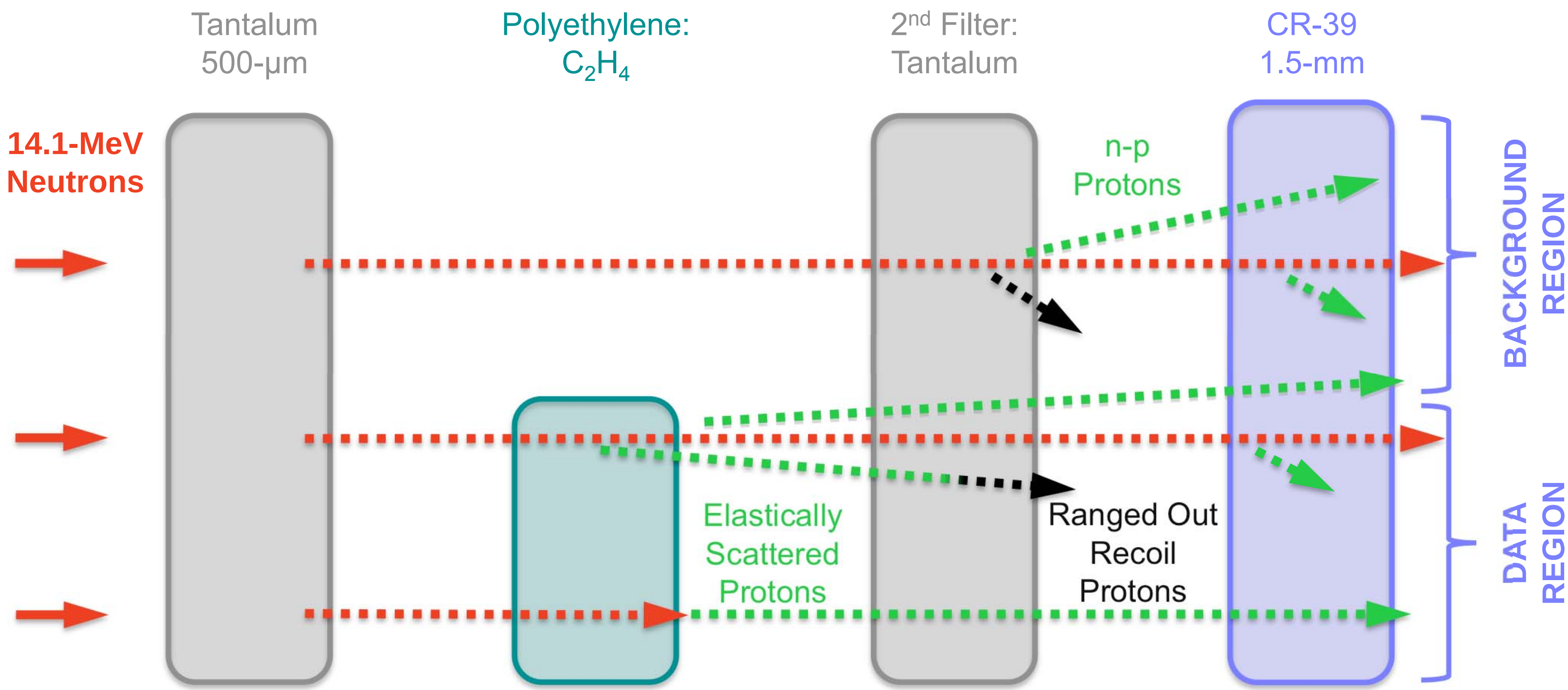
Sample DT-neutron Spectrum (TART) for:

T_{ion} = 10-keV
ρR = 2 g/cm^2
$Y_{DT\text{-}n}$ = $1*10^{14}$



The primary DT-neutrons dominate the fluence at the detector.
A filter configuration which gives consistent results with a large dynamic range may be able to measure the down-scattered fraction f_{DS}.

Various Filtering Schemes Have Been Tested to Precisely Measure DT-neutrons



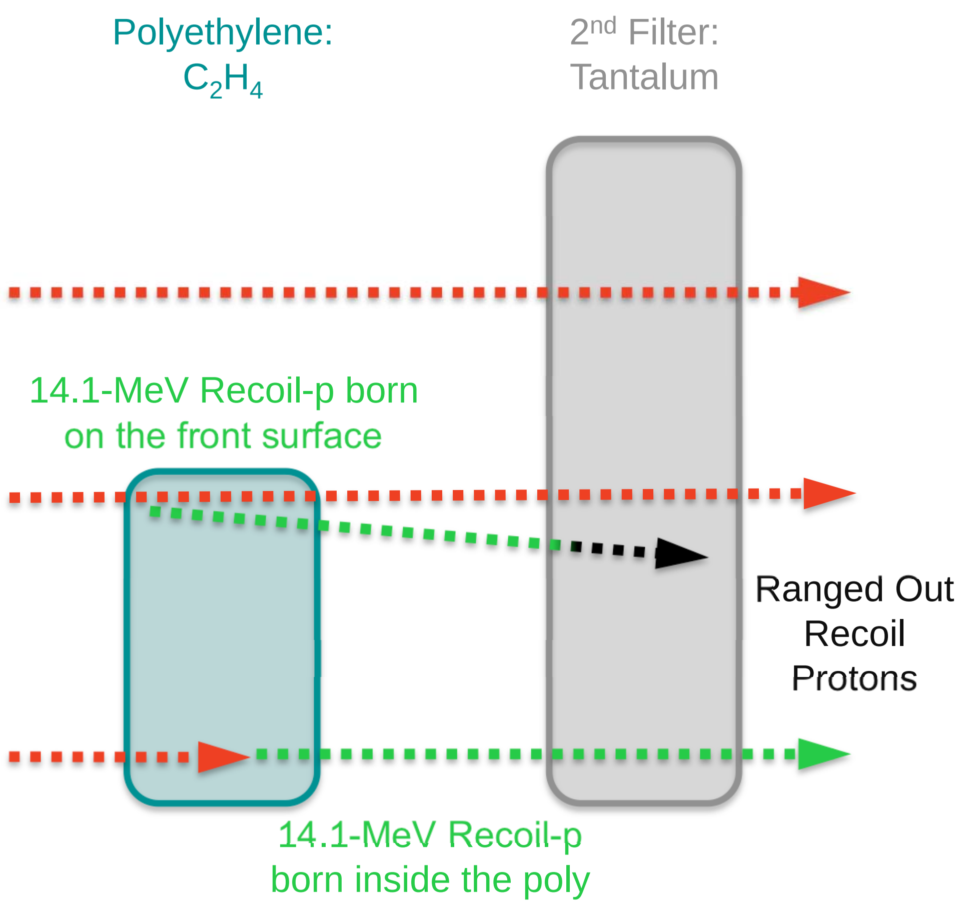
The front filter stops charged particles, while neutrons pass through

Poly is used to convert incoming neutrons to protons on half of the detector area

A secondary filter is used to stop recoil protons below a cutoff

Half of the CR-39 is used for background subtraction

Filter Thicknesses are Chosen to Range Out (n,p)-Protons from the Front Surface of the Polyethylene



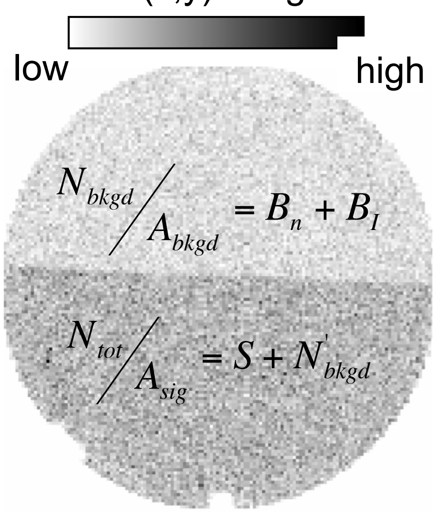
- The highest energy particles born on the front surface of the neutron-to-proton converter are ranged out
- This eliminates the error associated with the poly thickness
- Various sets of Poly and Tantalum thicknesses were fielded on warm- and cryo-DT experiments

Error Budget for CR-39-based DT-neutron Detection

$$\sigma_{tot}^2 = \sigma_{position}^2 + \sigma_{flux}^2 + \sigma_{analysis}^2 + \sigma_S^2 + \sigma_{np,CH}^2 + \sigma_{XS}^2$$

$\sigma_{position}$	uncertainty in detector position	(~500-μm ➔ ≤ 0.2 %)
σ_{flux}	uncertainty in R^2 due to flat detector	(≤ 0.75% for R > 25-cm)
σ_S	statistical uncertainty	(≤ 1% - dependent on $\Gamma_{DT\text{-}n}$)
$\sigma_{analysis}$	uncertainty due to analysis parameters	(~4%)
$\sigma_{np,CH}$	uncertainty in proton num. dens.	(≤ 1%)
σ_{XS}	uncertainty in np cross section	(~1.4% - for abs. cal. only)
σ_{tot}	total uncertainty in measurement	(~ 5%)

OMEGA Shot
57231
(725Poly+285Ta)
N(x,y) Image



Theoretical Statistical Uncertainty is Calculated by:

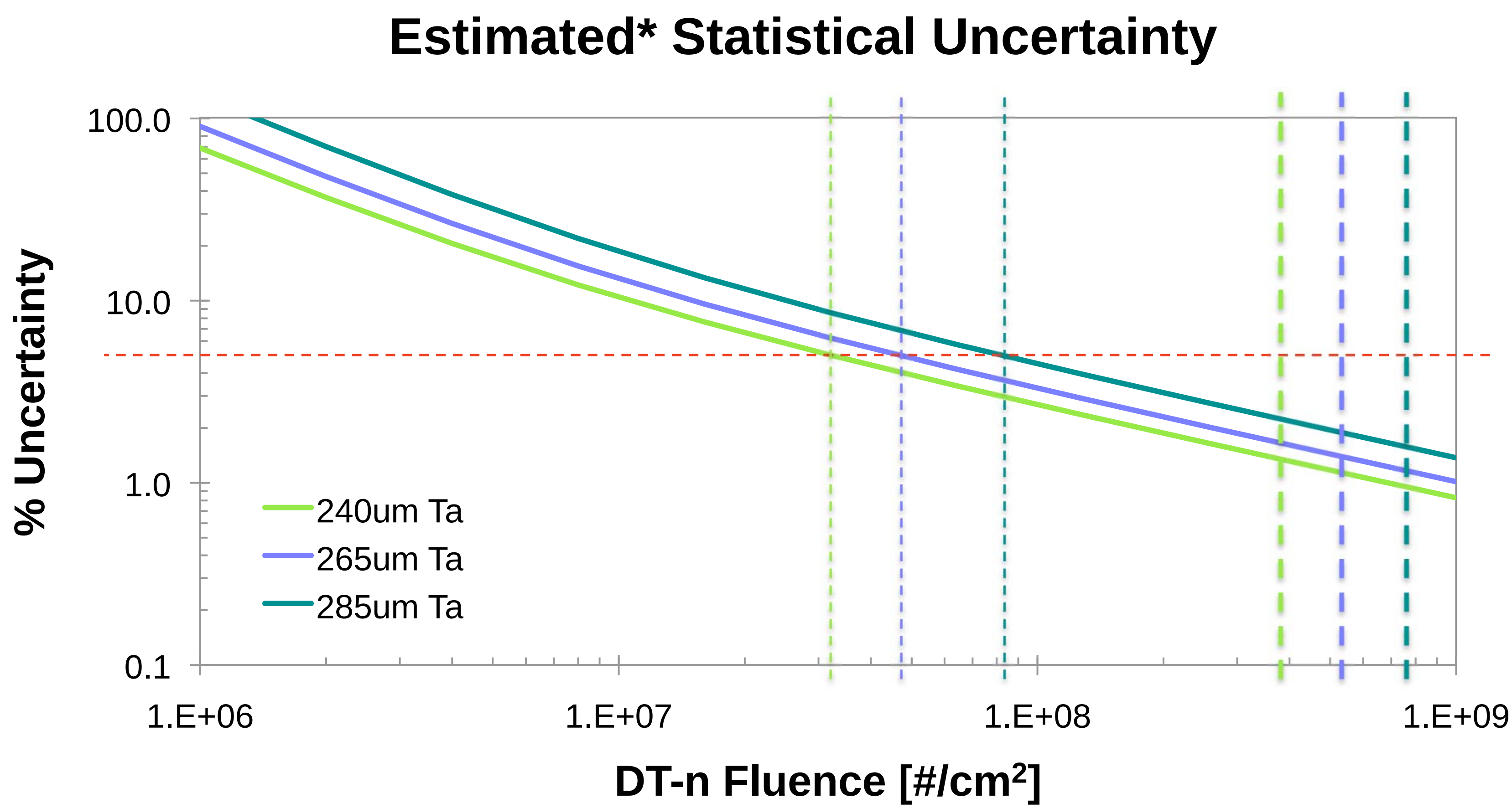
$$B_n = \varepsilon_{CR39,n}\Gamma_n \;\; ; \;\; B_I = \langle \Gamma_{noise} \rangle \;\; ; \;\; S = \varepsilon_{\det}\Gamma_n$$

$$\sigma_S = \sqrt{(S + B_n + B_I)A_{sig} + (B_n + B_I)A_{bkgd}}$$

$$\sigma_S = \sqrt{SA_{sig}}\left[1 + \frac{1}{\varepsilon_{\det}}\left(\varepsilon_{CR39,n} + \frac{\langle \Gamma_{noise} \rangle}{\Gamma_n}\right)\left(1 + \frac{A_{bkgd}}{A_{sig}}\right)\right]^{1/2}$$

There exists a range of neutron fluence that a specified filter pack will perform to the desired level of precision.

A Precision Measurement of DT-neutron Fluence Is Dependent on DT-neutron Fluence

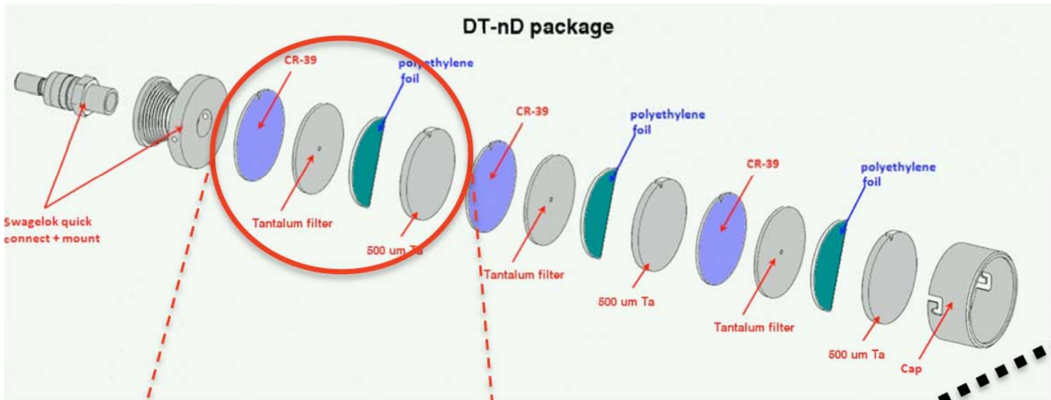


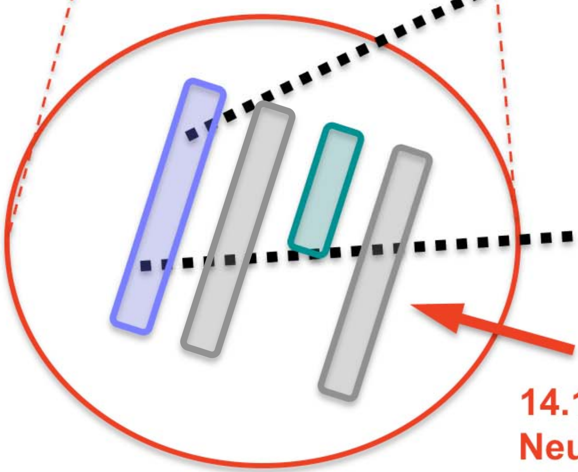
The lower limits are shown at 5% and upper limits are calculated for track saturation at ~40 tracks/frame for each of the filter pack detection efficiencies.

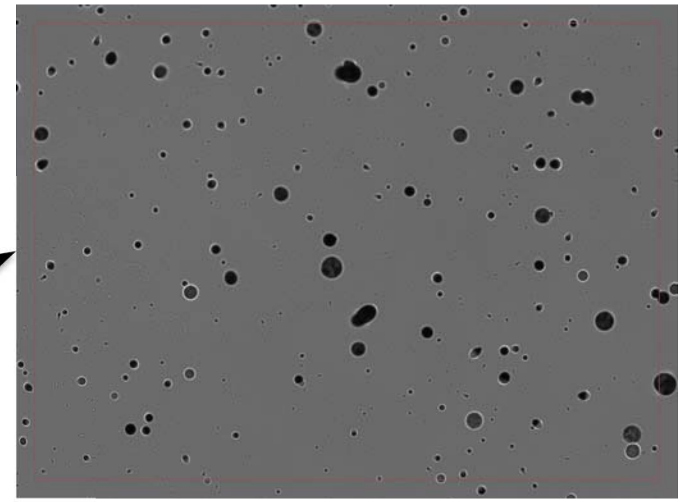
*Estimated Values for this Plot:
ε_{det} = 8.5e-5 (240), 6.4e-5 (265), 4.3e-5 (285); $\varepsilon_{CR39,n}$ = 3e-5; $\langle\Gamma_{noise}\rangle$ = 452 [#/cm^2]; A_{sig} = 3.5 [cm^2]; A_{bkgd} = 3.0 [cm^2]

Data Analysis

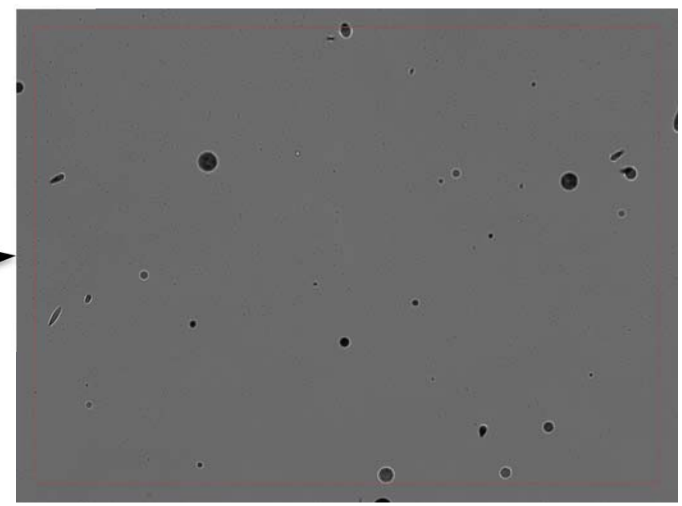
DT-Neutrons are Converted to a Continuous Proton Spectrum Producing a Variety of Track Diameters on CR-39







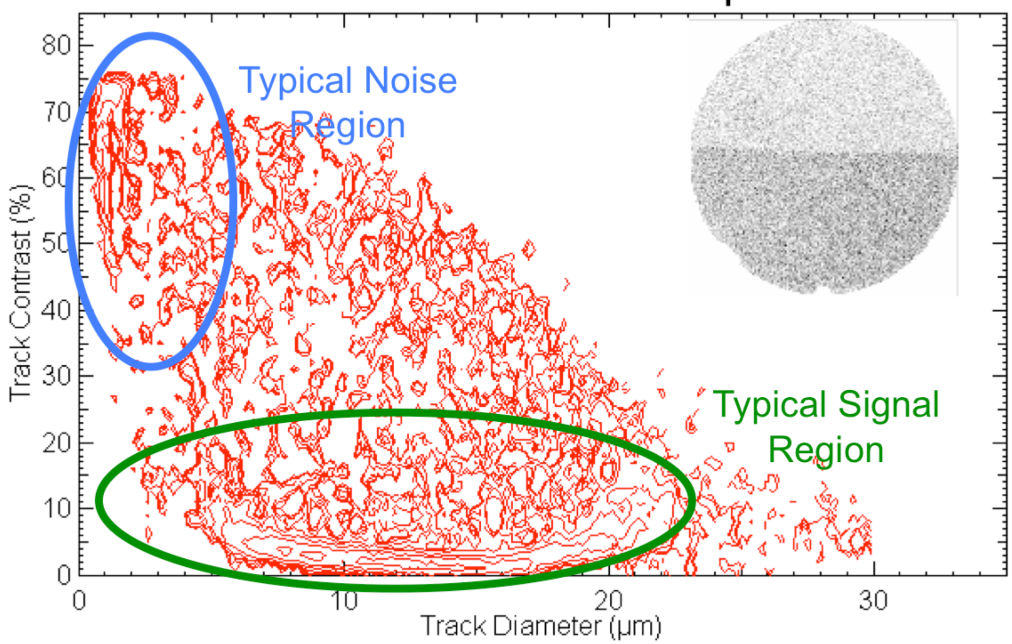
Microscope image of CR-39 in the signal region



Microscope image of CR-39 in the background region

Track Eccentricity, Contrast, and Diameter are Used to Differentiate Signal from Noise

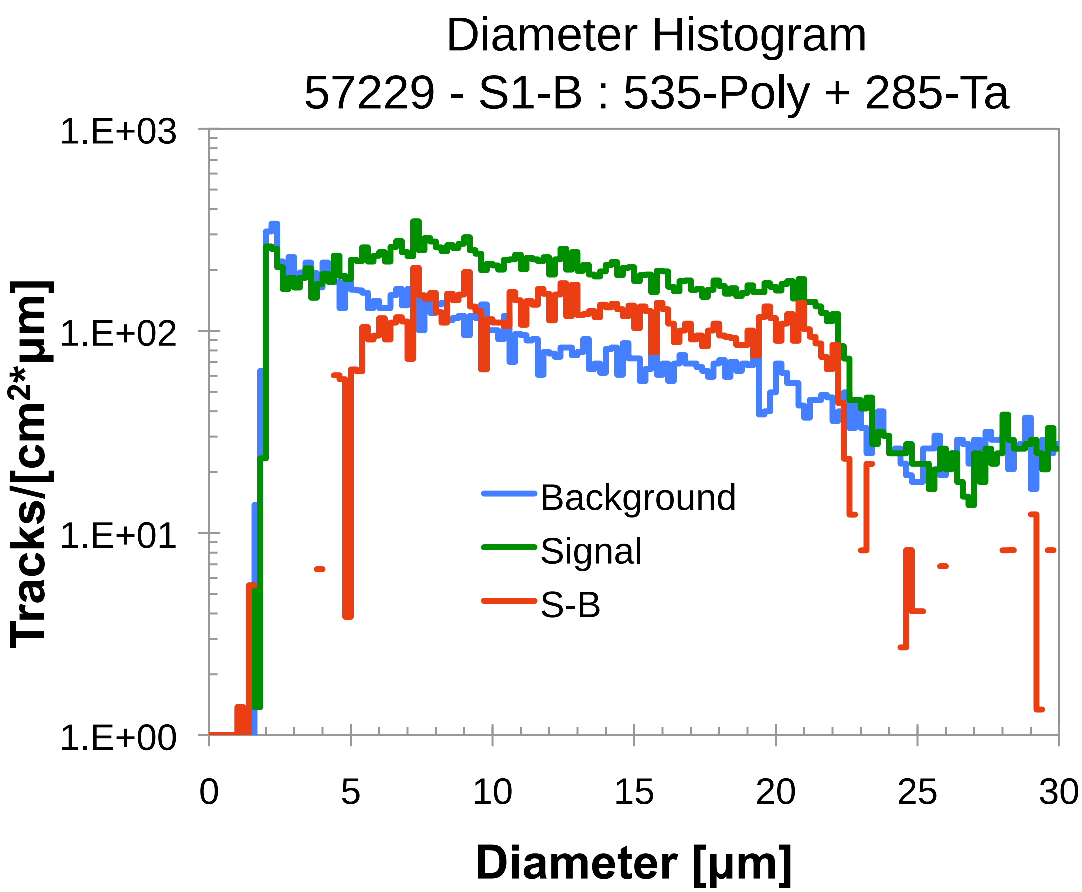
Background-subtracted log-contour plot in Contrast-Diameter space



57229 - S1-B : 535-Poly + 285-Ta

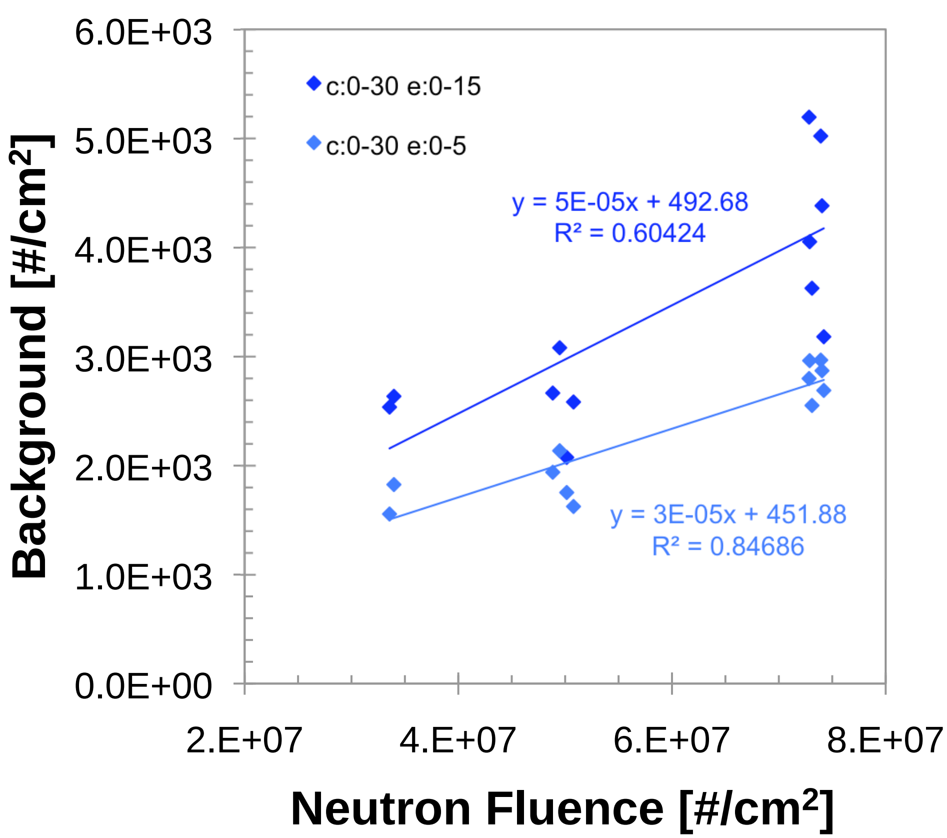
- The eccentricity, contrast, and diameter are recorded for each track.
- CR-39 has 100% detection efficiency when proper contrast limits are set [2].
- Constant eccentricity and contrast limits are set for analysis of DT-n data.
- Stringent eccentricity limits are set to eliminate larger diameter noise tracks.

Clear Diameter Limits Are Observed After Background Subtraction



- Obvious upper and lower diameter limits are seen after background subtraction.
- Piece-to-piece CR-39 response variation is accounted for by choosing diameter limits independently for each piece

Background Tracks are Generated by Intrinsic Noise in CR-39 and (n,p)-protons



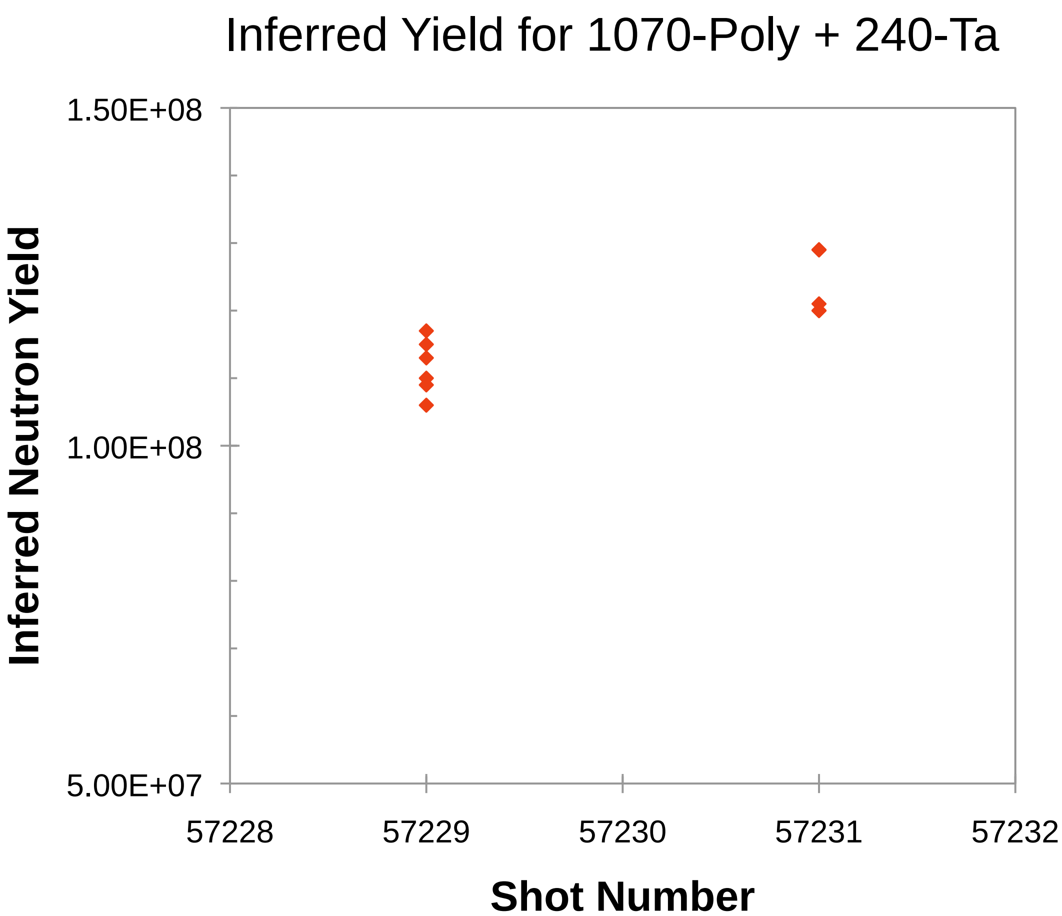
- (n,p)-protons come from the first few microns of the CR-39 [1] and the secondary Tantalum filter.
- Imperfections in CR-39 are picked up as tracks during analysis.
- Neutron-induced and intrinsic background tracks are uniform across a piece.
- Using different analysis parameters changes the character of the background tracks observed.

The tighter set of analysis parameters (c:0-30, e:0-5) are used through the rest of the analysis because of the reduction in background tracks and the consistency of the data.

$$\varepsilon_{CR39,n} = 3 * 10^{-5}$$

$$\langle \Gamma_{noise} \rangle = 452 \ \left[{}^{\#}\!/_{cm^2} \right]$$

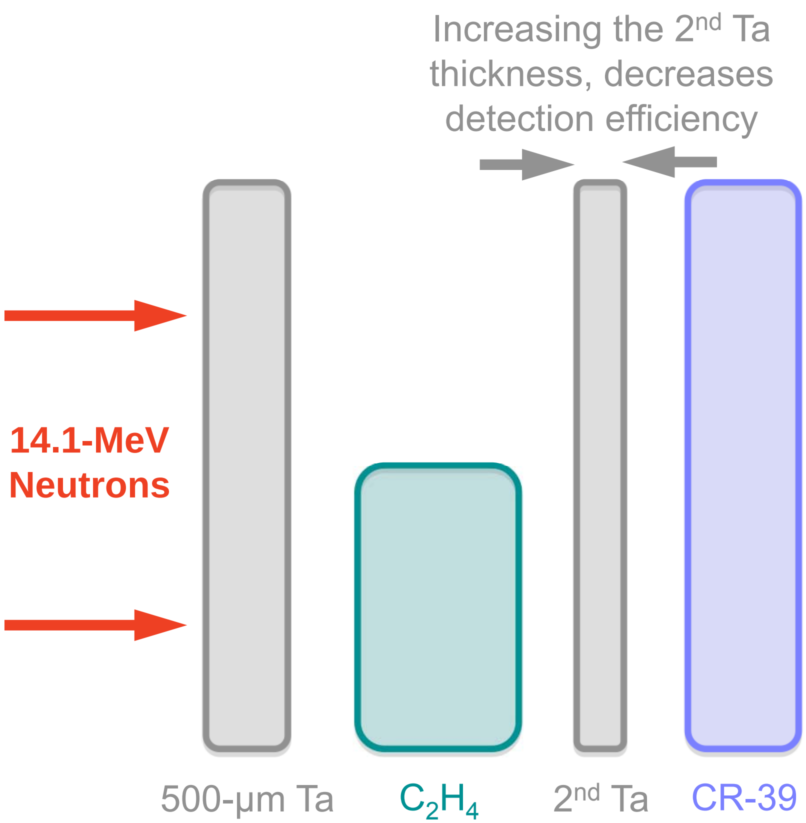
Variability in Diameter Limits Results in <2% Deviation in Measured Track Fluence

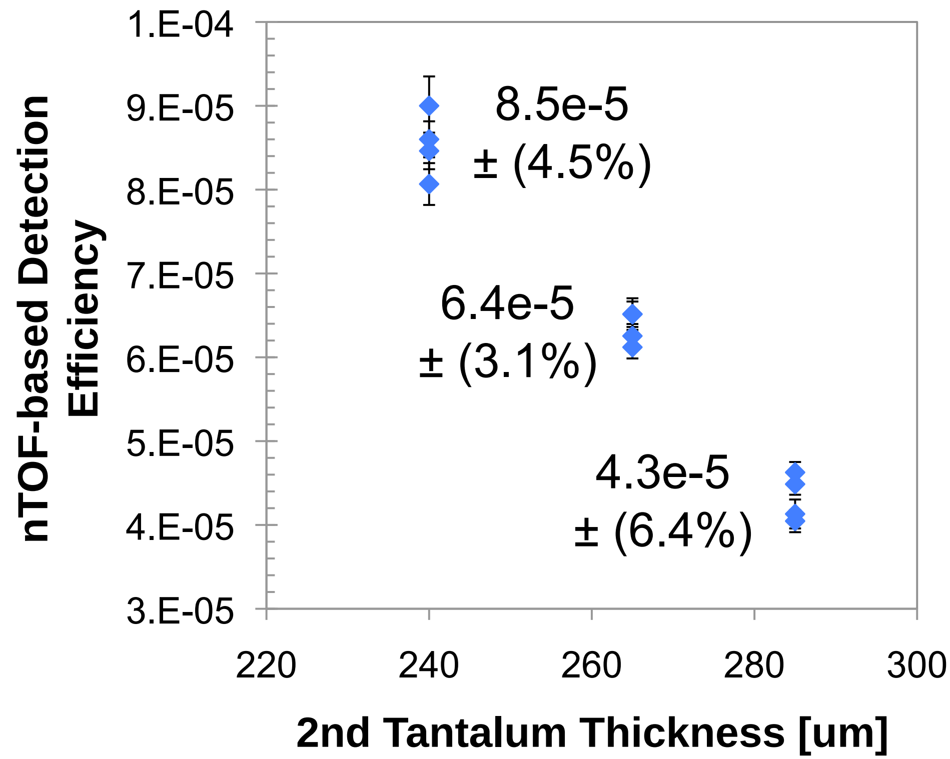


- Two nominally identical filter packs were used on each shot.
- Small, large, and 'best guess' diameter limits were chosen for each filter pack.
- The inferred yield does not account for detection efficiency.
- 'best guess' limits were used in the following analyses.
- The average %-variation over both shots is <2%.

Results & Conclusion

The nTOF-based Detection Efficiency for All Tested Filter Packs are in Agreement to Better than 10%

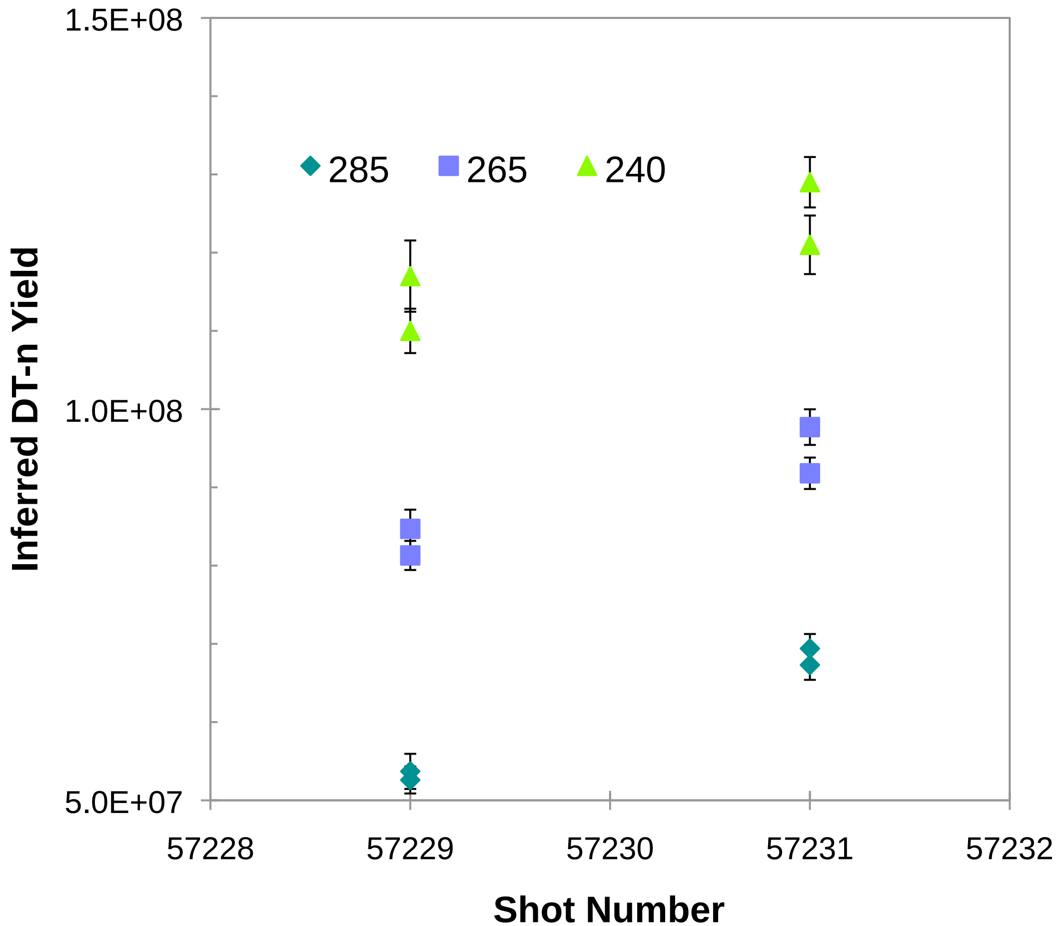




The Poly thickness was chosen to maximize signal based on the thickness of the secondary tantalum.

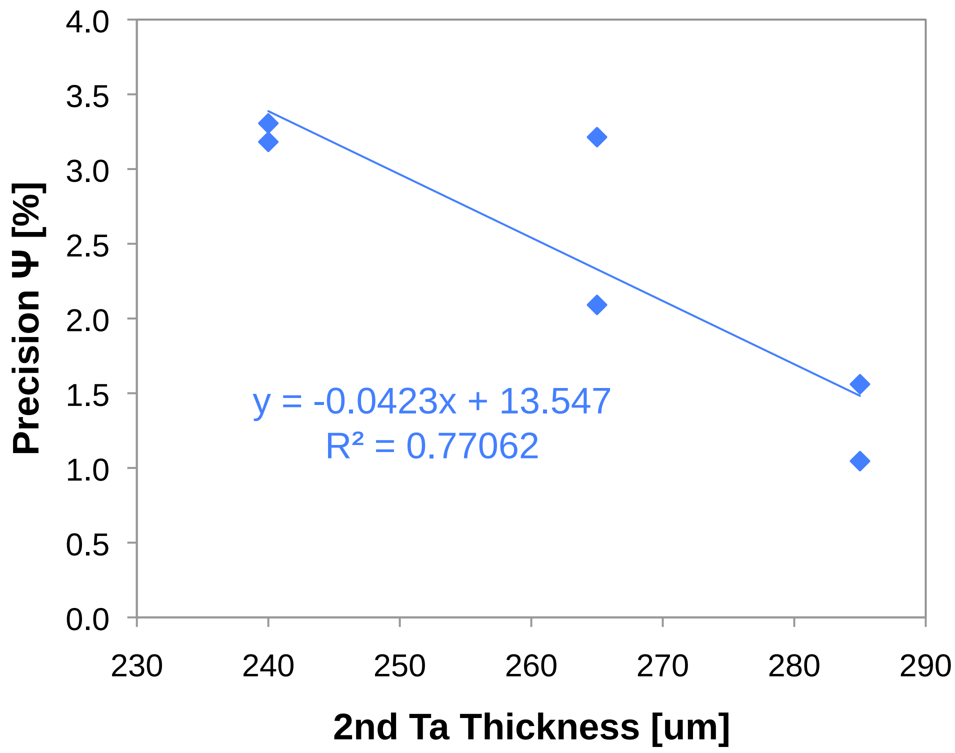
The detection efficiency is linearly dependent on secondary Tantalum thickness.

Filter Packs Fielded in the Same TIM Measured Equal DT-neutron Fluence to Better than 4%



- Each filter pack type was fielded twice per shot and uncertainties for each piece calculated.
- Individual number statistics, geometric uncertainties, and analysis uncertainties were considered.

Precision for All Tested Filter Packs are in Agreement to Better than 5%



- Each filter type was fielded twice per shot and the precision between the two filters was calculated by:

$$\psi = 100 * \left| 1 - \frac{\langle Y_{DT-n} \rangle}{\min(Y_{DT-n})} \right|$$

Summary

- A small, compact, passive DT-neutron detector design has been developed and tested at the OMEGA laser facility.

- Detailed data analysis has demonstrated a precision measurement of DT-neutrons to better than 5%.

- Multiple thicknesses of filtering have been demonstrated, providing a large dynamic range for this type of detector.

Future Work

- Other data will be analyzed using the method described herein and the results compared with the performance parameters described here.

- Simulations of expected proton distribution incident on CR-39 are to be performed using Geant4 and/or MCNPX.

- Since different thicknesses of Tantalum have been shown to make precision measurements, an investigation of a stepped filter will be made with regard to measuring the down-scattered fraction.

- Experiments are to be performed on the NIF to measure the DT-n yield and associated asymmetries greater than ~5%.