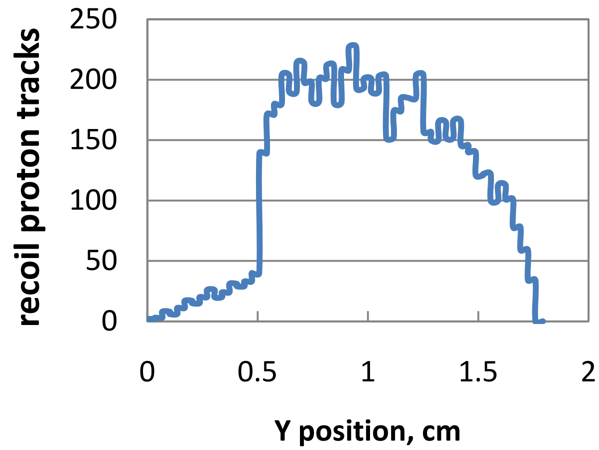
Introduction & Motivation

The Optimization of an EMP/X-Ray Immune CR-39 based detector for Sensitive Measurements of Neutron Yields at Omega & the NIF



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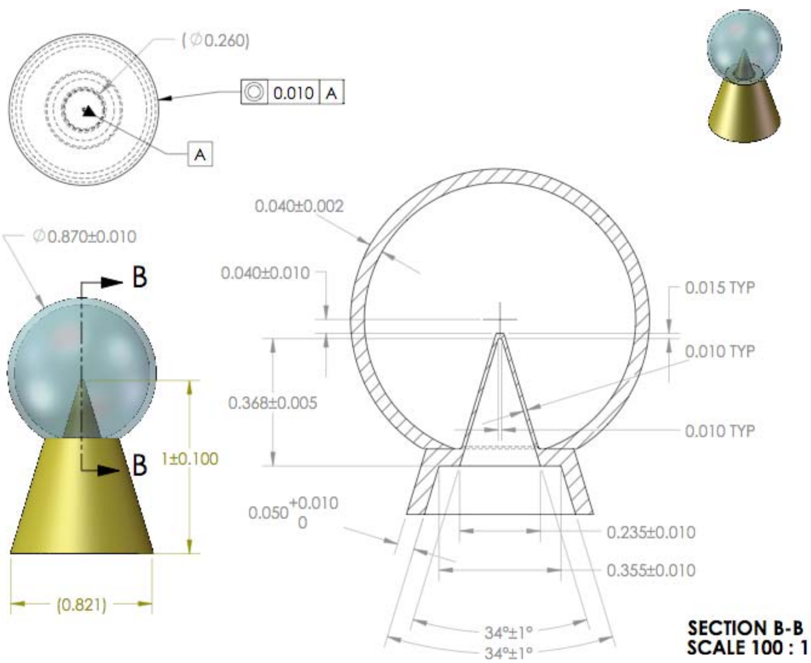
Omega Laser Users Group
1st Annual Workshop
April 29th – May 1st, 2009

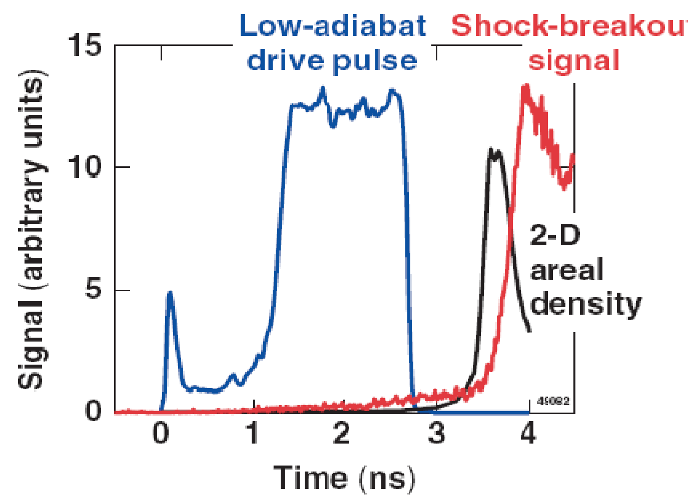
Summary

- A sensitive, CR-39 based neutron detector[1] that is EMP / X-ray immune is being optimized at MIT
- Calibration experiments have been carried out on the MIT fusion products generator[2]
- Preliminary experiments have demonstrated a detection efficiency of 4×10^{-4}
- The neutron detector will be used to measure neutron yields as low as 5×10^{7} (or better if diagnostic is fielded closer to TCC) in support of the May 6th Joint Omega/Omega-EP Fast Ignition Campaign

[1] J.A. Frenje et al., Rev. Sci. Instrum. 73 (2002).
[2] See poster "The MIT Nuclear Products Generator for development of ICF diagnostics at Omega / Omega EP and the NIF" OLUG Workshop, April 29-May1st, 2009

Fast-ignition experiments are underway at OMEGA/OMEGA-EP to reproduce a previously measured enhancement[1] in neutron yield





A neutron yield enhancement by several orders of magnitude is expected over standard spherical D_2 targets

[1] R. Kodama et al., Nature 412 (2001).

Concept for the Neutron Detector

The detector relies on n-p scattering (for 2.45MeV DD-n) in polyethylene and CR-39 to convert neutrons to protons which are detected using CR-39

Theoretical Maximum Efficiency

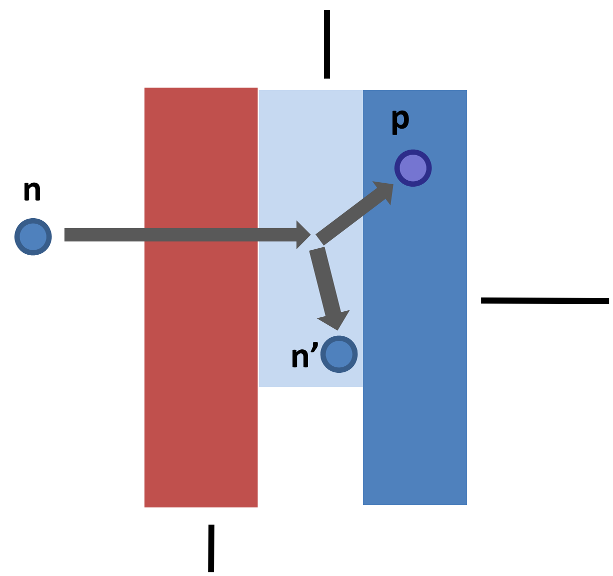
t = CH_2 thickness

$$\lambda = \frac{1}{\sigma n} \qquad \sigma = p(n, \text{elastic}) = 2.45 \text{ barns}$$

$$\text{Efficiency} = 1 - \text{Exp}[-t/\lambda]$$

$$= 2 \times 10^{-3} \text{ for } 100\text{um } CH_2$$

CH_2 stepped radiator
Used as a radiator material for
Converting neutrons to protons



CR-39 Detector
(1mm thick)
Detects proton tracks
Detector area 2.85cm^2

Ta (1mm thick)
Tantalum blocks
high energy protons
induced by laser-plasma
interactions

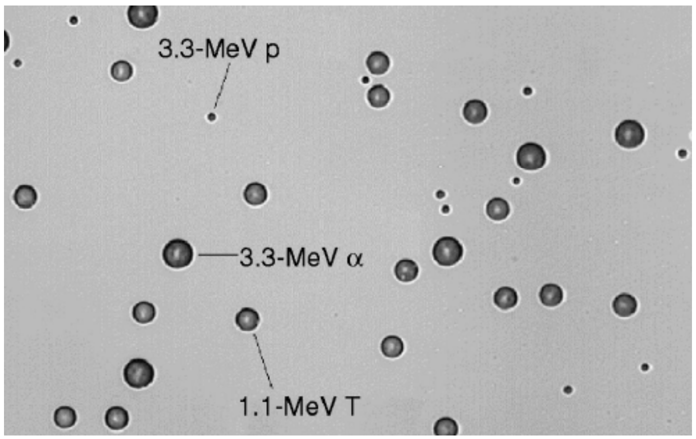
Recoil protons at 2.45MeV have a range of 100um in CH_2.

Therefore, CH foil thickness greater than will have no effect on efficiency.

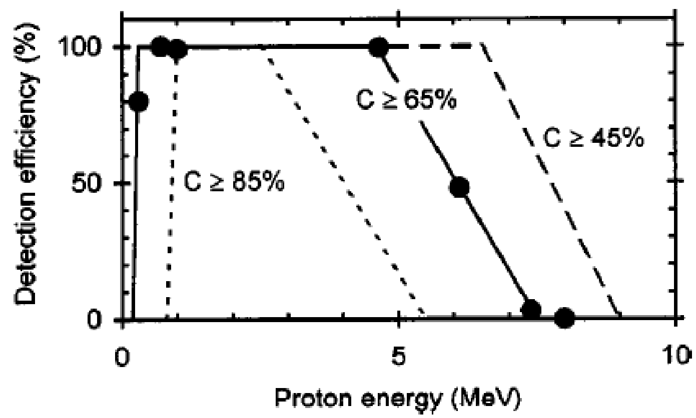
[1] J.A. Frenje et al., Rev. Sci. Instrum. 73 (2002).

CR-39 is a clear, plastic, charged particle and neutron detector which is immune to X rays and EMP

CR-39 Nuclear Track Detector [1]



CR-39 detection efficiency of protons [1]

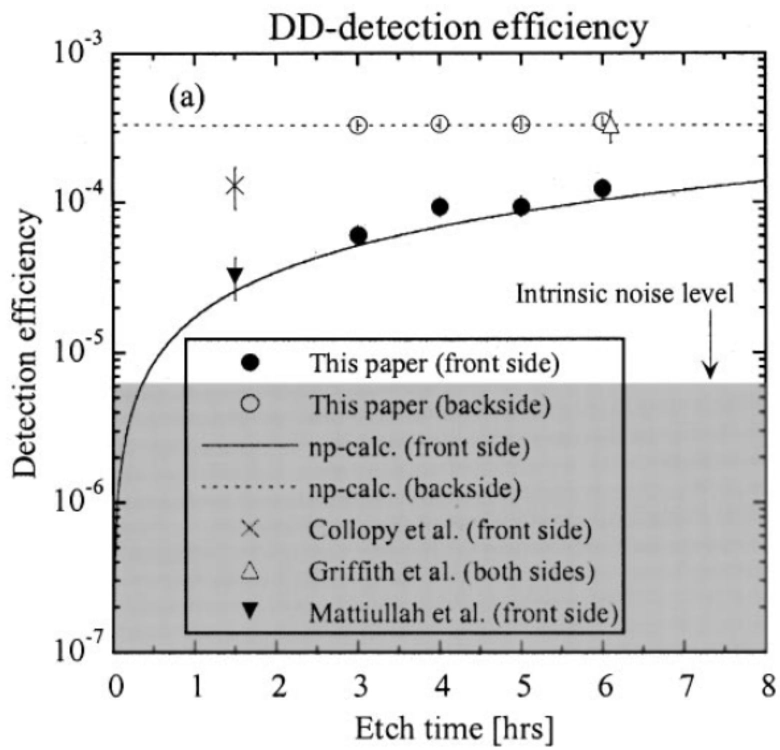


CR-39 is etched after exposure to reveal charged particle tracks. Track size is proportional to the stopping power of charged particles, dE/dx as well as the etch time

CR-39 has a 100% detection efficiency for protons up to 5MeV at normal incidence. Contrast limits on track diameters may be imposed during analysis; efficiency for several user selected contrast values are shown

[1] F.H. Séguin *et al.*, Rev. Sci. Instrum. 74, 975 (2003).

The DD-n detection efficiency of CR-39 has been previously studied theoretically and experimentally on OMEGA[1]



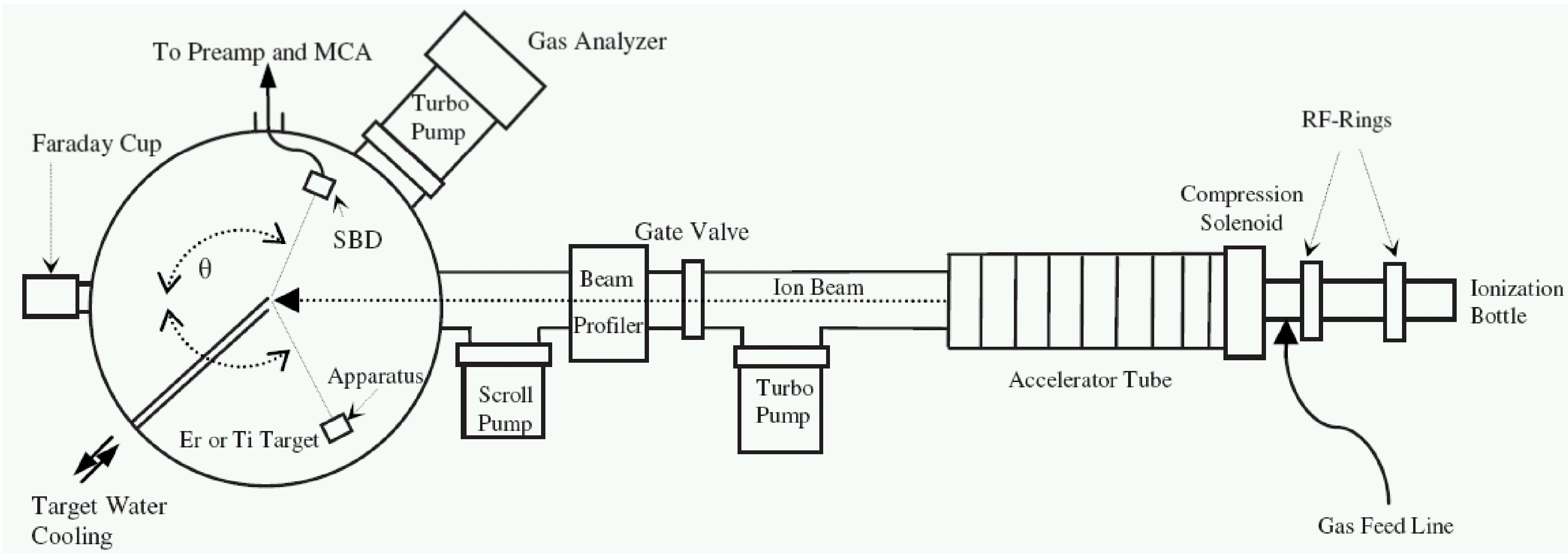
The total efficiency must take into account the neutron detection efficiency of CR-39 as well as the proton detection efficiency at various angles of incidence.

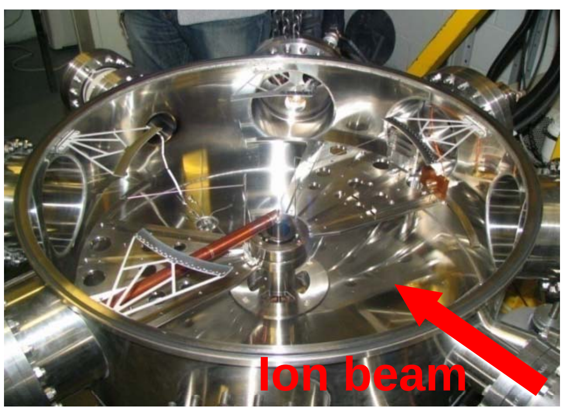
All of these effects may be accounted for with a simple experiment…

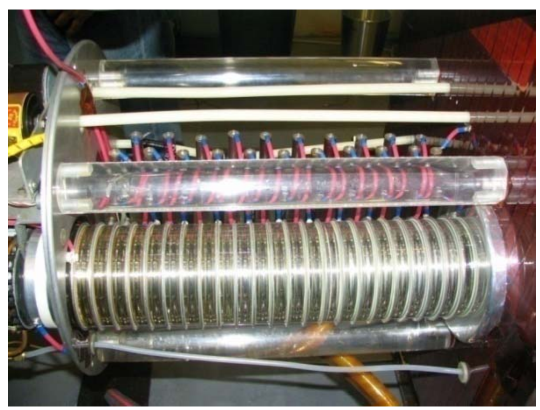
[1] J.A. Frenje et al., Rev. Sci. Instrum. 73 (2002).

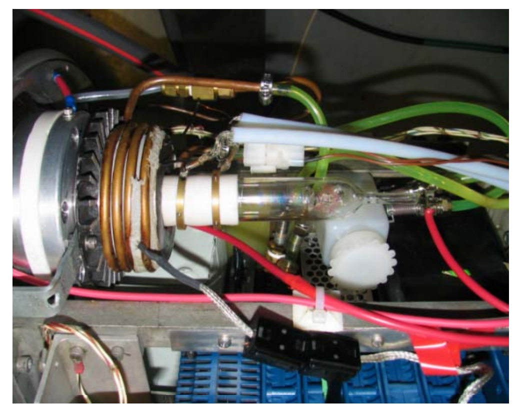
Experimental Testing and Calibration

The MIT nuclear products generator is being used to characterize and optimize the detection efficiency



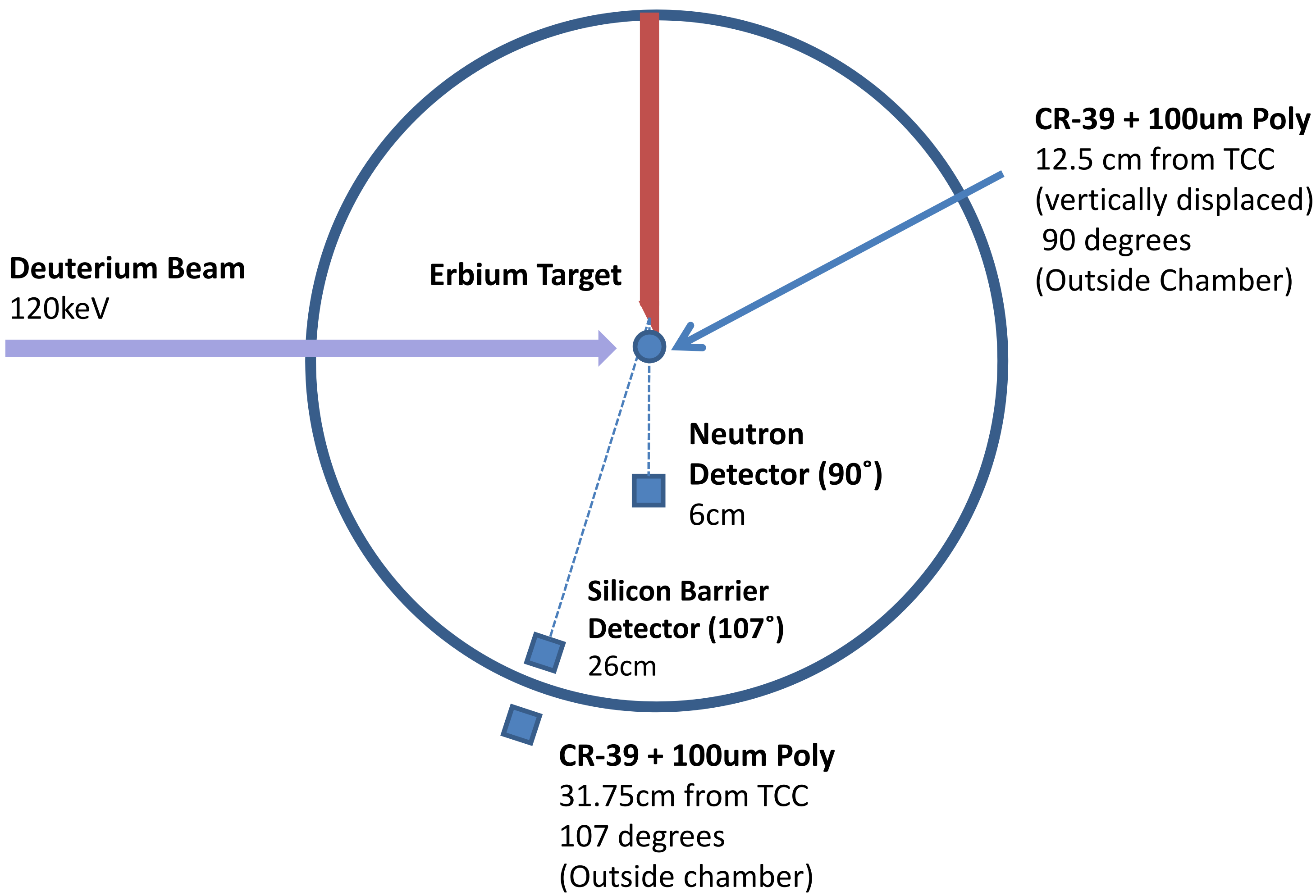




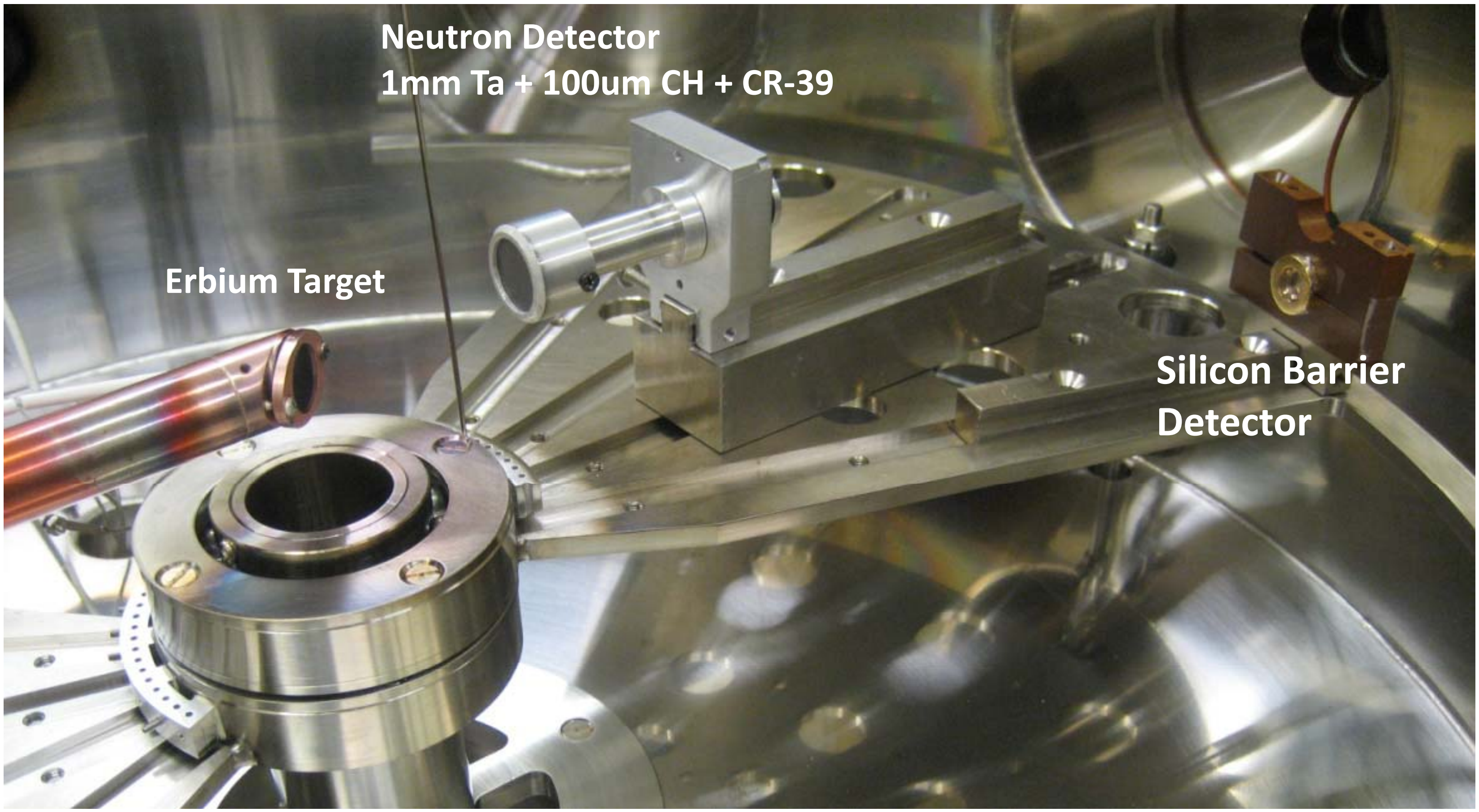


[1] See poster "The MIT Nuclear Products Generator for development of ICF diagnostics at Omega / Omega EP and the NIF" OLUG Workshop, April 29-May1st, 2009

The MIT nuclear products generator was used to calibrate several CH_2- CR-39 track detectors in various configurations



A Silicon Barrier Diode (SBD) is used to cross calibrate the neutron detector

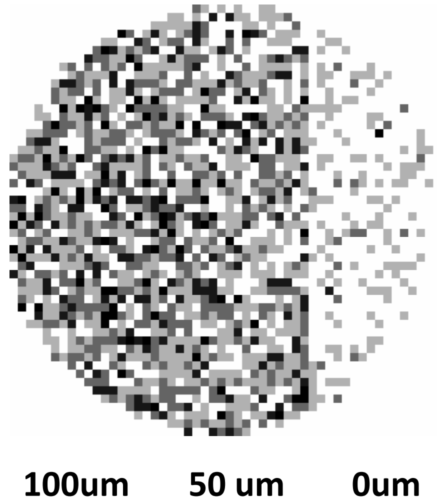


Experiments were conducted with 0um, 50um and 100um of polyethylene; no difference was found between 50 and 100um

Experimental Setup

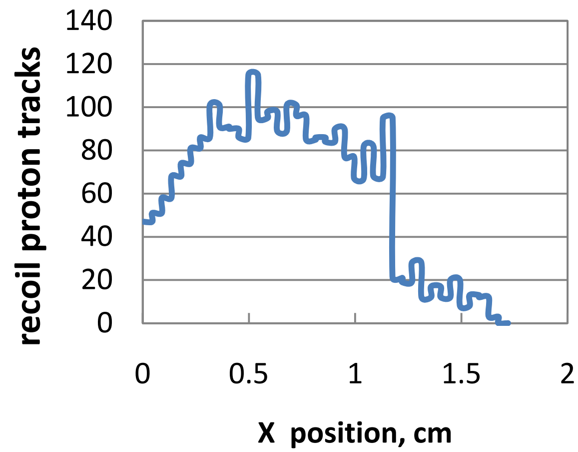
CR-39, on top of CH_2 (layered from left to right: 100, 50um, 0um) on top of 1mm of tantalum

Scanned image of CR-39



Darker regions indicate higher recoil proton fluence. Clear step between 50um and 0um CH_2 is visible

Number of tracks vs. position



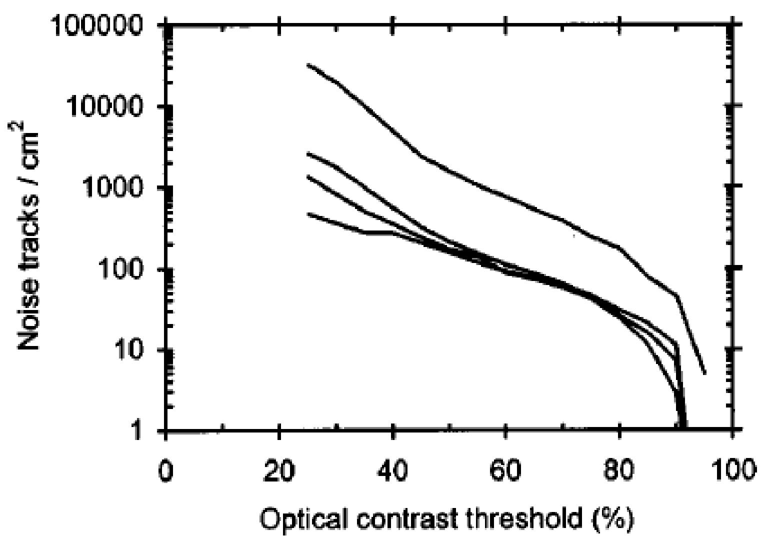
Analysis of scanned detector piece, again showing the corresponding step in number of detected tracks going from 50um to 0um of CH_2

Preliminary experiments have shown an efficiency of 4×10^{-4}

Future Work

We'd like to improve the lower limit of neutron yield measurements, which is limited by the intrinsic noise in CR-39

Intrinsic noise track density for various samples of CR-39 [1]

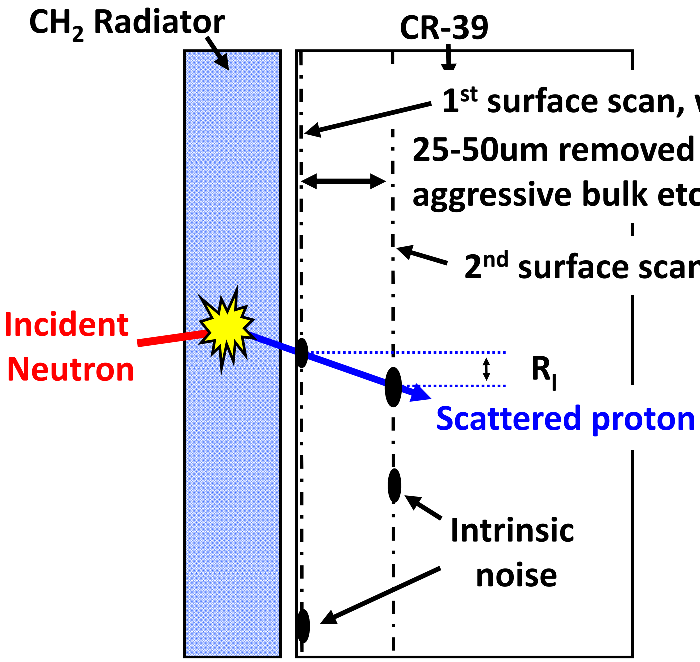


The lower limit of neutron yield detection occurs when the intrinsic noise and the neutron track densities are of the same order

At a distance of 6cm from target chamber center, the intrinsic noise becomes significant for neutron yields below 1×10^8

[1] F.H. Séguin *et al.*, Rev. Sci. Instrum. 74, 975 (2003).

The Staged Etch Coincidence Counting technique will be used to significantly enhance sensitivity and subtract intrinsic background



Where:
- n_1 = 1st scan track density (per unit area)
- n_2 = 2nd scan track density (per unit area)
- S = Signal
- B = Intrinsic Background
- A = Detection area
- R_c = Search radius ~ 15-50um

$$B_{CCT} = \pi R_c^2 n_1 n_2 A$$

Then assuming $n_1 \sim n_2 = B + S$ and $B >> S$

The search radius must be greater than the straggling

$$B_{CCT} \approx \frac{\pi R_c^2 B^2}{A} \qquad B/B_{CCT} \approx \frac{A}{\pi R_c^2 B} = 1.5 - 14$$

Thus, the background may be reduced by as much as a factor of 10, allowing the measurement of neutron yields of 5 x 10^7

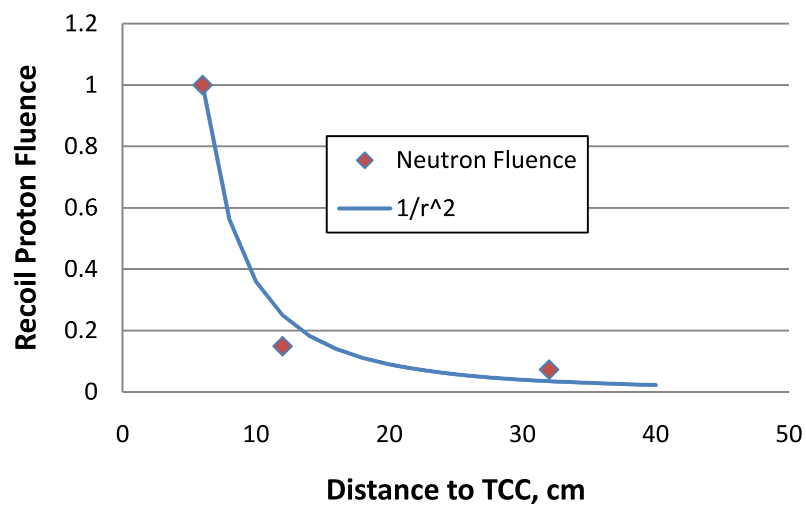
[1] Lengar, I et al. Nuc. Instrum. and Methods in Phys. Research Section B, Vol. 192 (4) p 440-444.

The deviations of recoil proton fluence from the expected $1/r^2$ scaling are due to scattering effects, which will be quantified.

6cm from TCC
3511 Tracks / cm^2

12cm from TCC
523 Tracks / cm^2

32cm from TCC
255 Tracks / cm^2



Three pieces were fielded at 6cm, 12cm, and 32cm, respectively.
The recoil proton density does not scale as R^2, confirming the importance of scattering

Some important references

F. H. Seguin, et al., “Spectrometry of Charged Particles from Inertial Confinement Fusion Plasmas.” Rev. Sci. Instrum. 74, 975 (2003).

J.A. Frenje et al., “Absolute measurements of neutron yields from DD and DT implosions at the OMEGA laser facility using CR-39 track detectors.” Rev. Sci. Instrum. 73 (2002).

Lengar, I et al., “Fast neutron detection with coincidence counting of recoil tracks in CR-39.” Nuclear Instruments and Methods in Physics Research Section B, Vol. 192 (4) p 440-444.

R. Kodama et al., “Fast heating of ultrahigh-density plasma as a step towards laser fusion ignition.” Nature. 412 (2001) p798-802

Other posters in this workshop:

N. Sinenian, et al., “The MIT Nuclear Products Generator for the Development of ICF Diagnostics for Omega / Omega EP and the NIF”

D.T. Casey, et al., “Diagnosing Areal Density using the Magnetic Recoil Spectrometer (MRS) at OMEGA and the NIF “