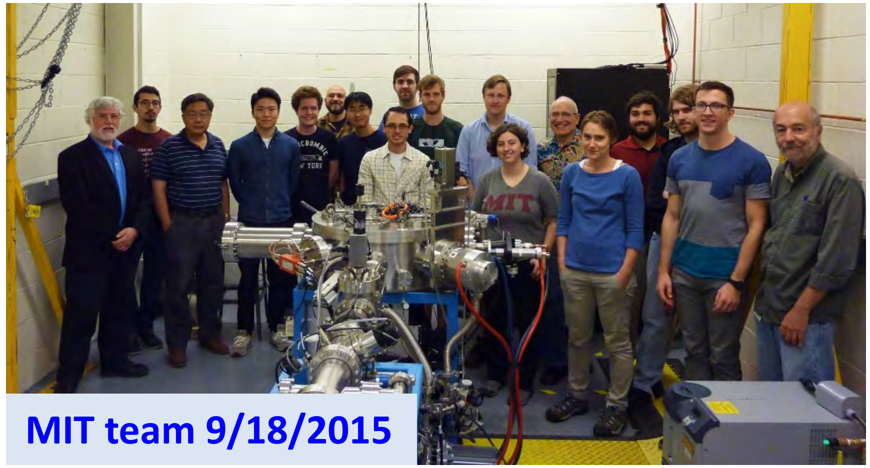
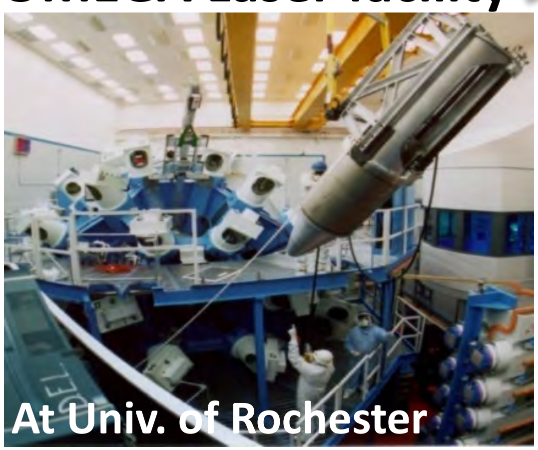
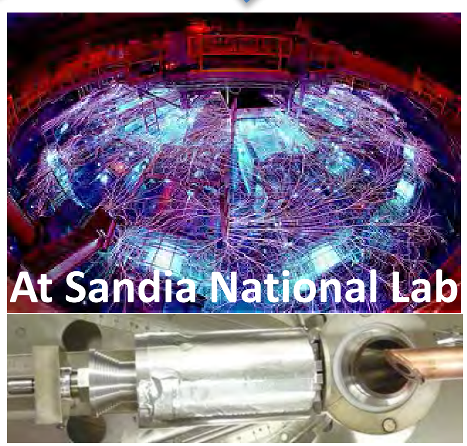
The MIT HED Accelerator Facility for Diagnostic Development for OMEGA, NIF, Z, and for Discovery Science



OMEGA Laser facility



Z



National Ignition Facility (NIF)

Collaborators

M. Gatu Johnson, E. Armstrong, A. Birkel, W. Han, N. Kabadi, B. Lahmann, L. Milanese, D. Orozco, J. Rojas-Herrera, H. Sio, G. Sutcliffe, C. Wink, D.T. Casey[a], M. Manuel[b], H. Rinderknecht[a], M. Rosenberg[c], N. Sinenian[d], C. Waugh[e], A. Zylstra[f], J.A. Frenje, C.K. Li, F.S. Séguin, R.D. Petrasso

Plasma Science and Fusion Center, MIT

T.C. Sangster

Laboratory for Laser Energetics

C. L. Ruiz

Sandia National Laboratories

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[d]Now at Exponent
[e]Now at Lockheed Martin
[f]Now at LANL

Summary

The MIT HED Accelerator Facility is a foundational tool for diagnostic development for OMEGA, NIF, Z, and Discovery Science

- **The facility is used to test and develop nuclear diagnostics using the same particles/background that will then be measured on OMEGA, NIF and Z:**

  ✓ **A linear ion accelerator generates DD, D^3He and DT fusion products**
    - **Absolute yields are determined using the associated particle method**

  ✓ **Three x-ray sources generate K,L-lines and/or continua with energies up to 225 kV**

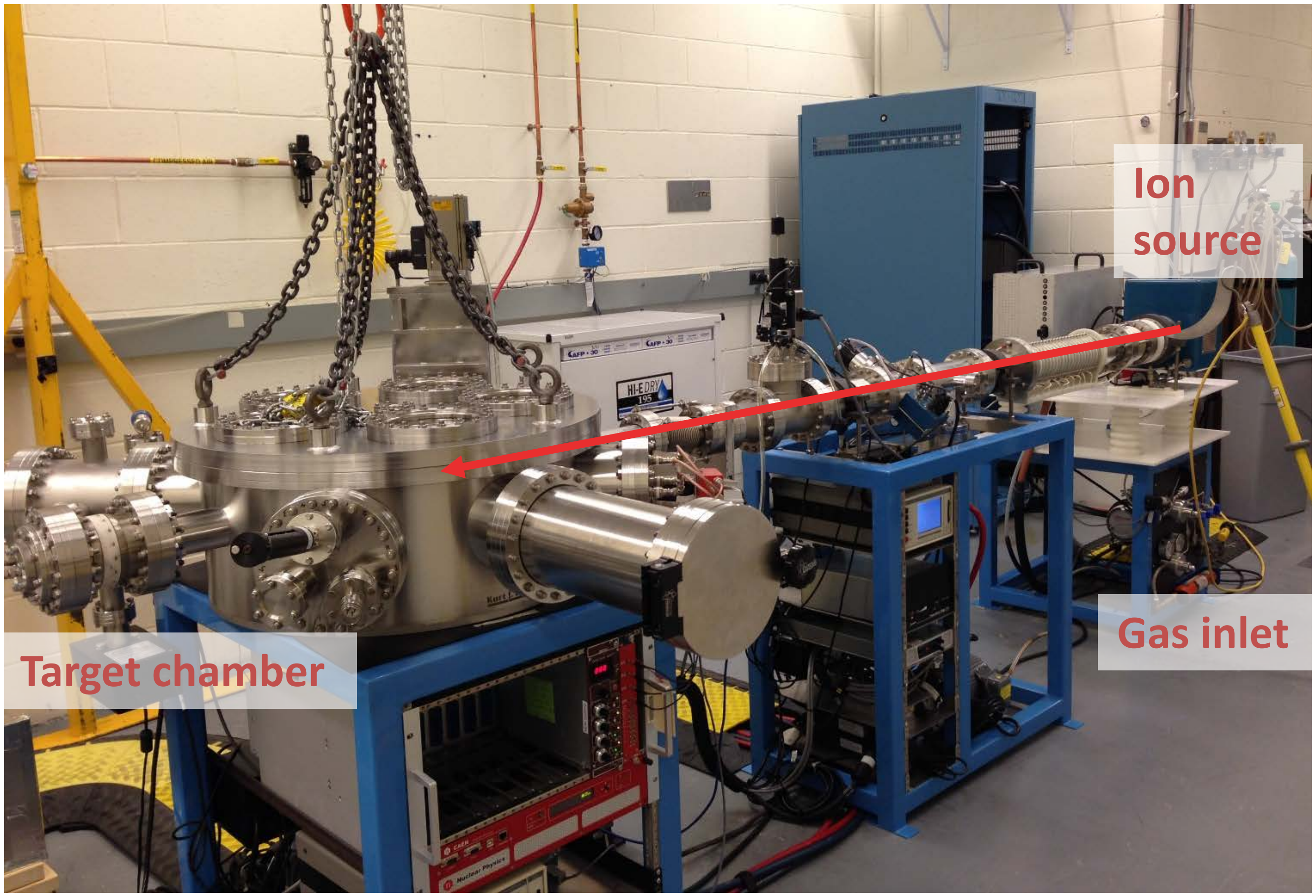
  ✓ **A pulsed DT neutron source produces up to 6e8 n/s**
    - **DD capability (1e7 n/s) is being added**

- **An etch/scan lab allows for precision on-site CR-39 processing**

- **The lab has been crucial for the successful deployment of diagnostics such as MRS, CPS, WRF, (Mag)PTOF, DD-n spectrometry etc.**

This continuously evolving development platform also plays a vital role in student training and has resulted in many student papers based on lab data

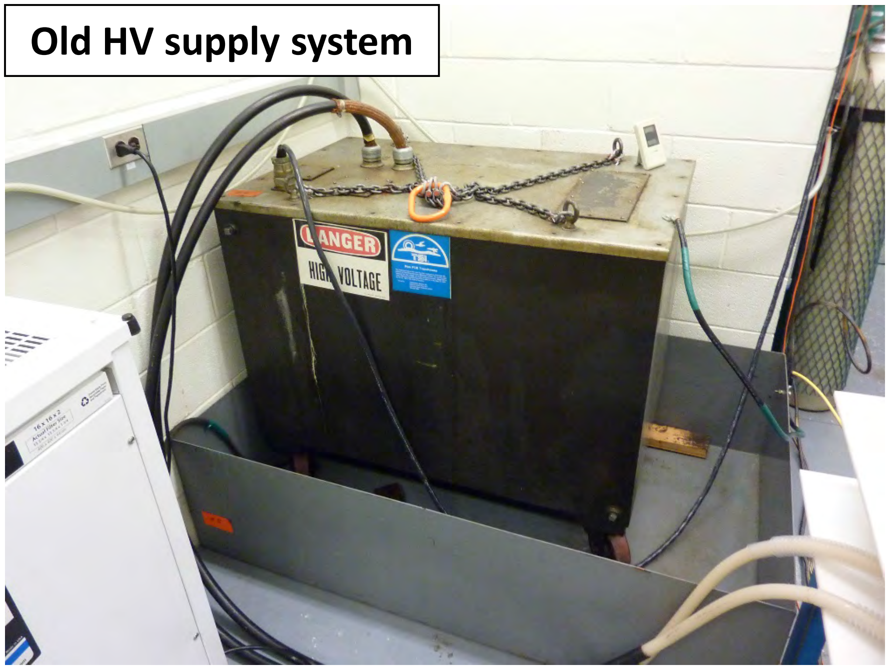
The 135-keV linear ion accelerator runs with D^+ or $^3He^+$ ion beams, generated with a new ion source



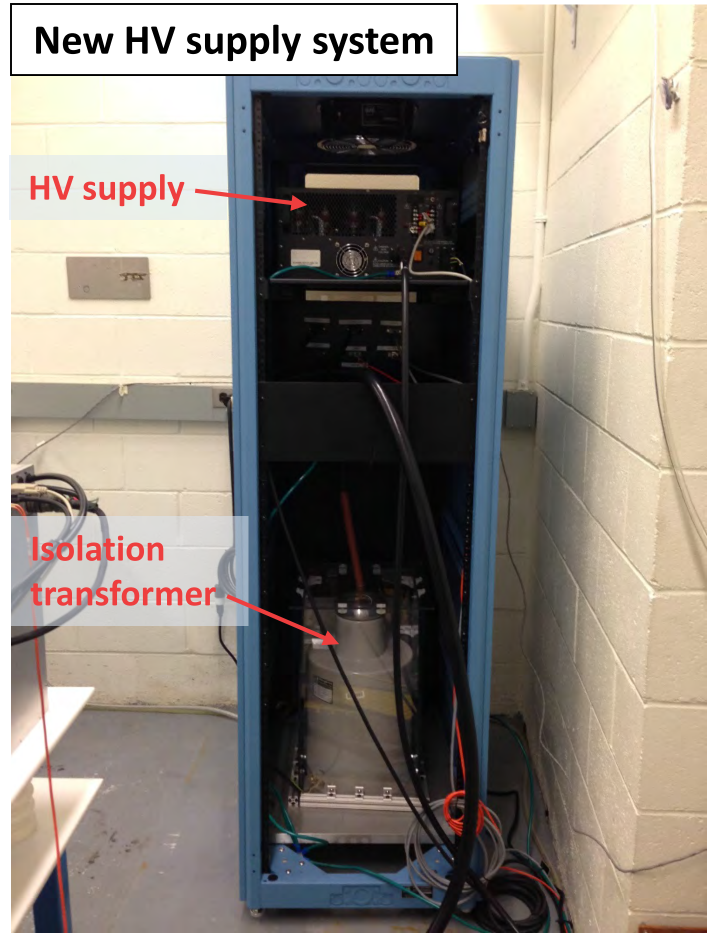
Beam currents around 10 μA are routinely achieved

A stable, modern High-Voltage power supply was implemented in the last year

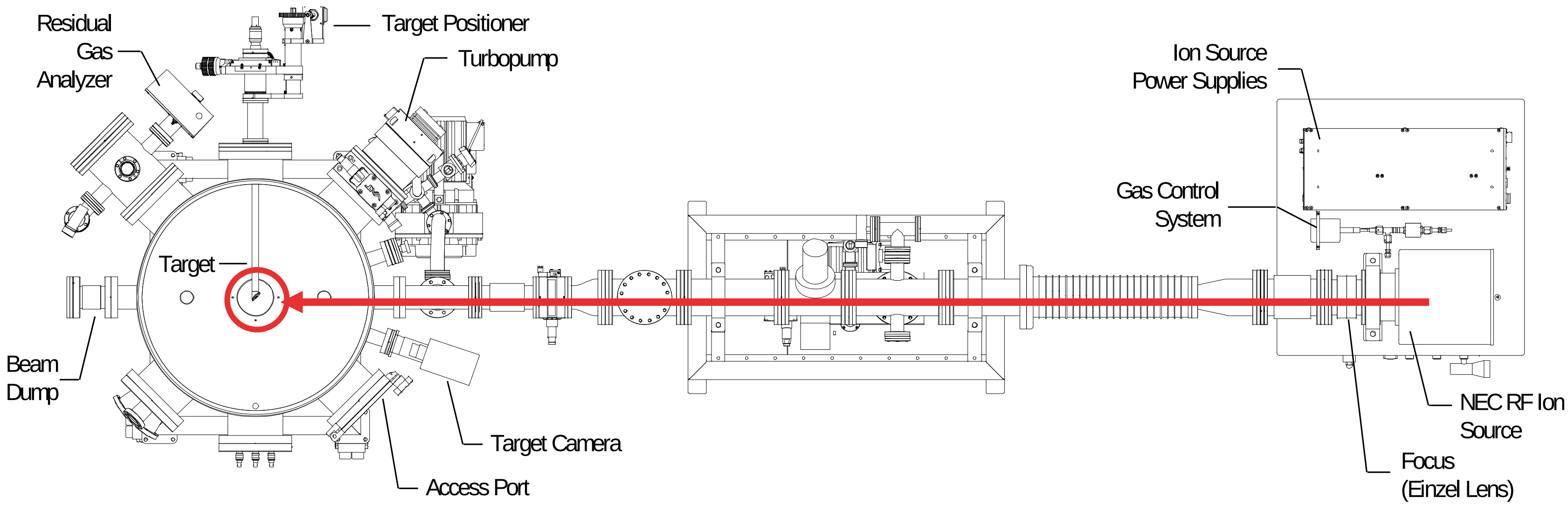
Old HV supply system



New HV supply system



Beam ions strike ErD_2 or ErT_2 targets, provided by Sandia



ErD_2 targets are frequently doped with ^3He to allow for generation of D^3He fusion products

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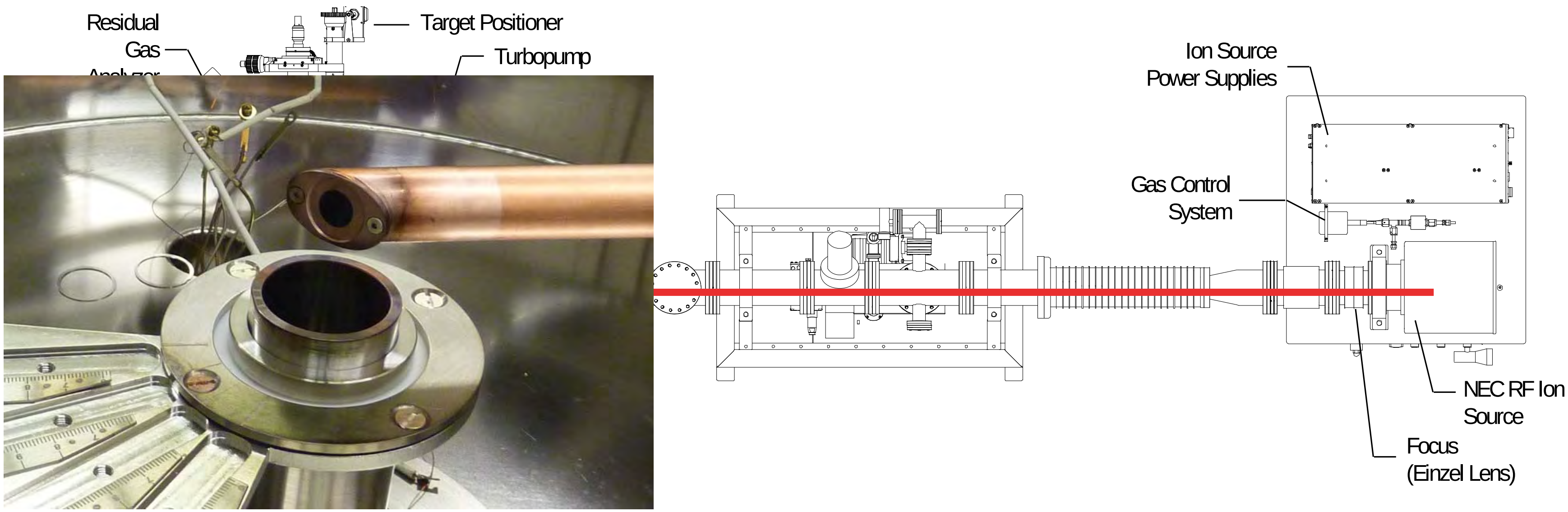

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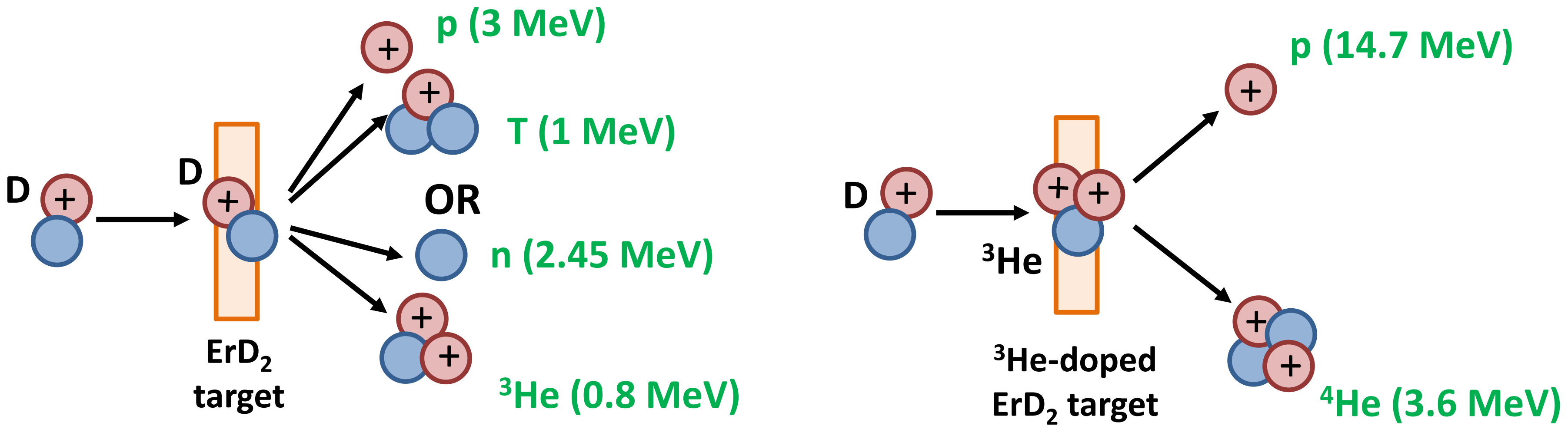
Accelerator

DD, D^{3}He, DT and T^{3}He fusion products are generated when D$^+$ or ^{3}He$^+$ ions strike the target



These same fusion products are used to probe ICF implosions at OMEGA, NIF and Z

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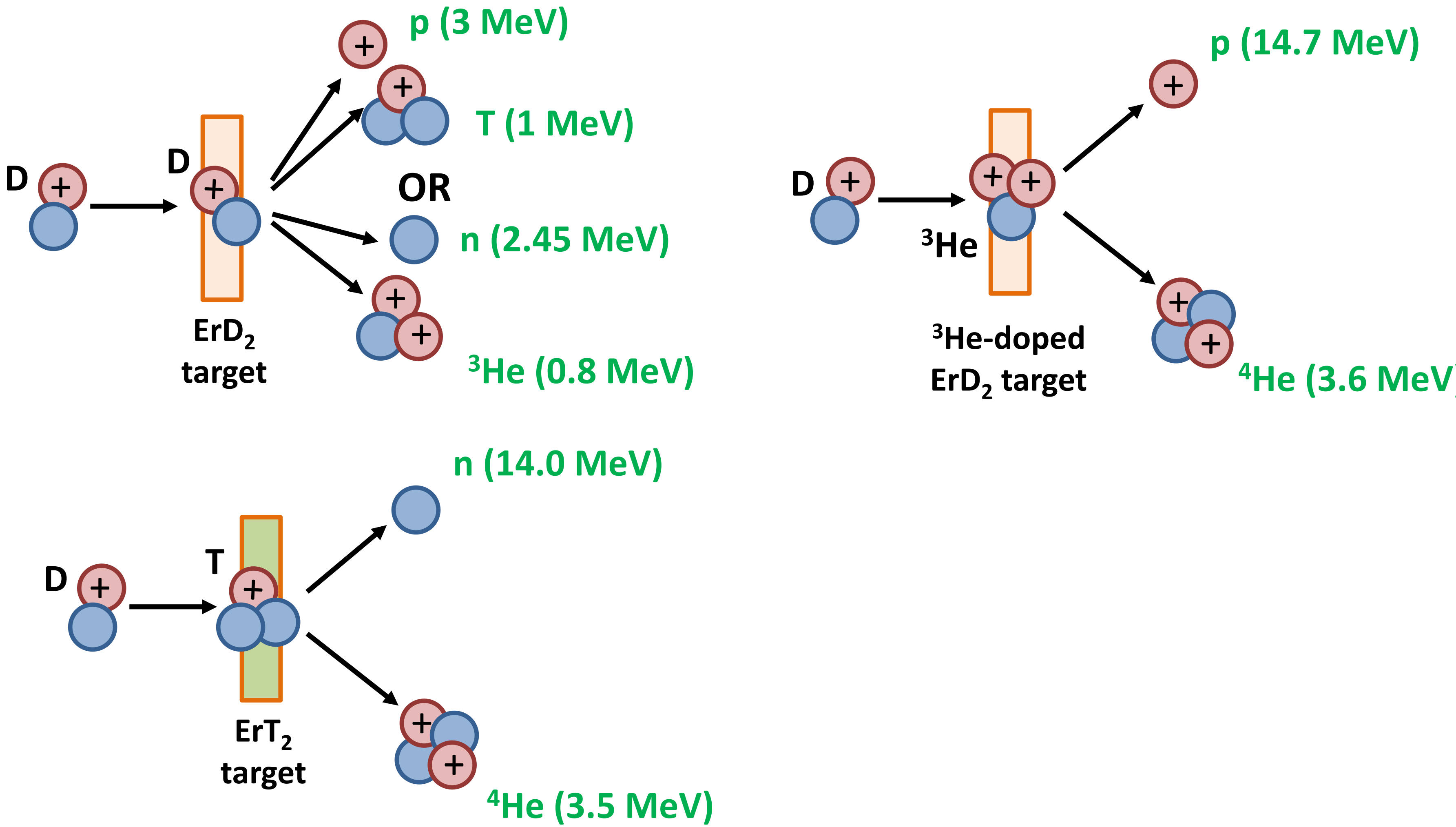

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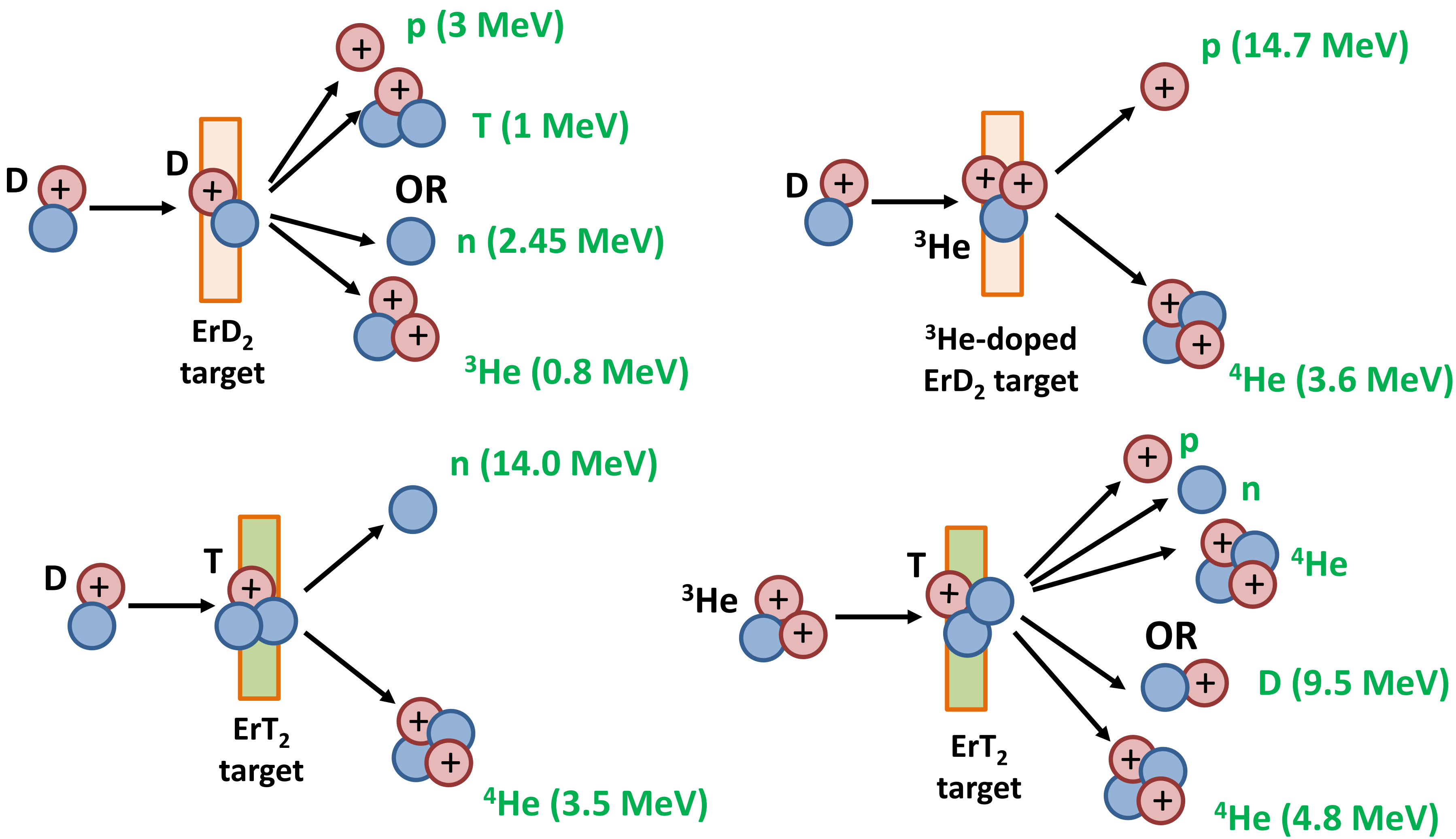
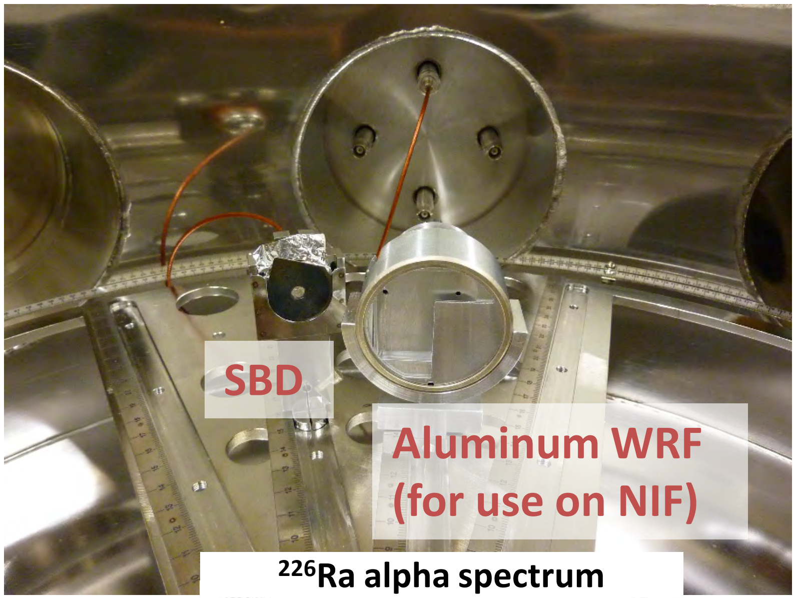
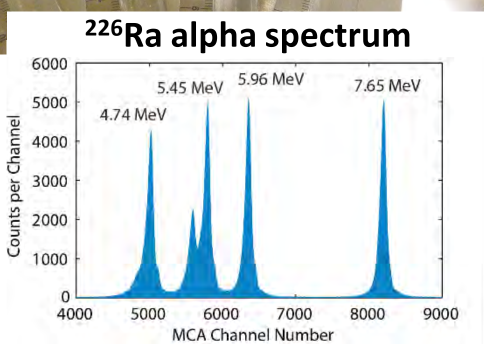
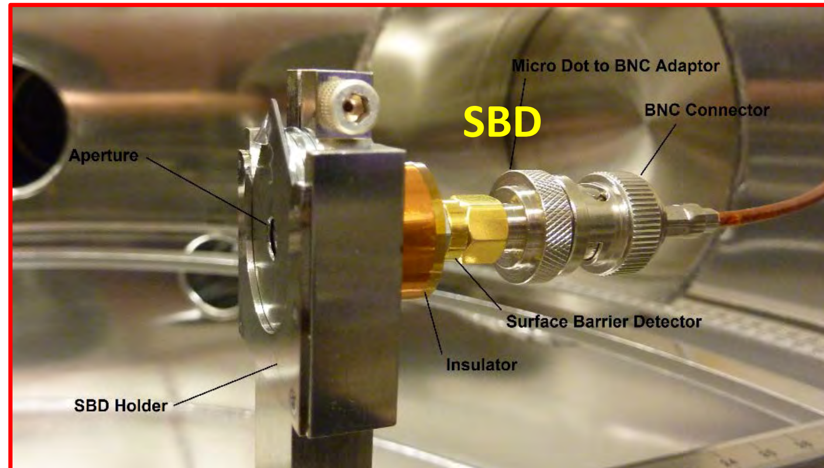


These same fusion products are used to probe ICF implosions at OMEGA, NIF and Z

SBDs and an MCA provide real-time monitoring of fusion rates, and fusion product energies

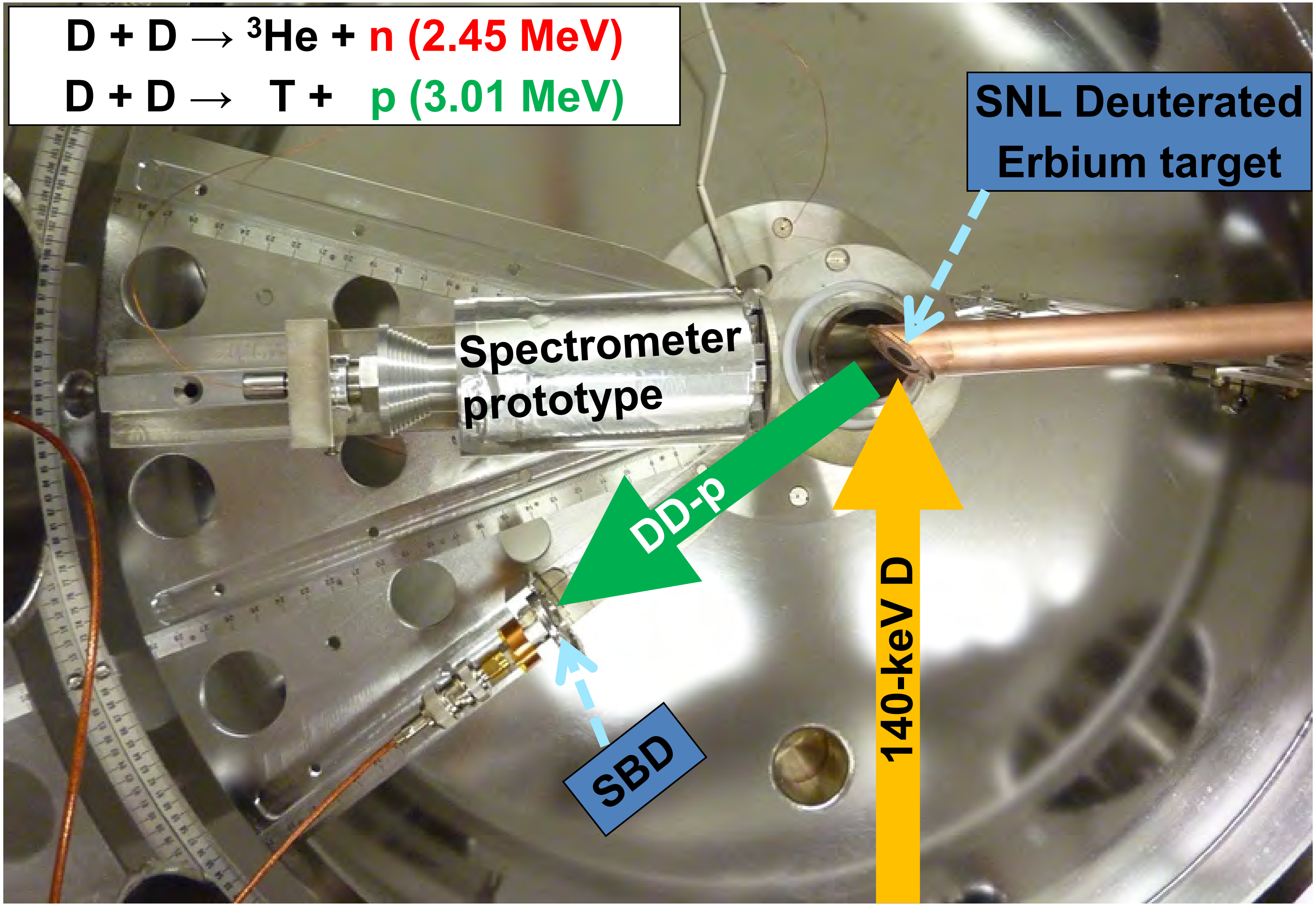






^{226}Ra alphas are used to calibrate the system to within ± 50 keV. Precise calibration is important for charged-particle diagnostics development

Using the SBD and the associated particle method, we control how many particles a detector is exposed to



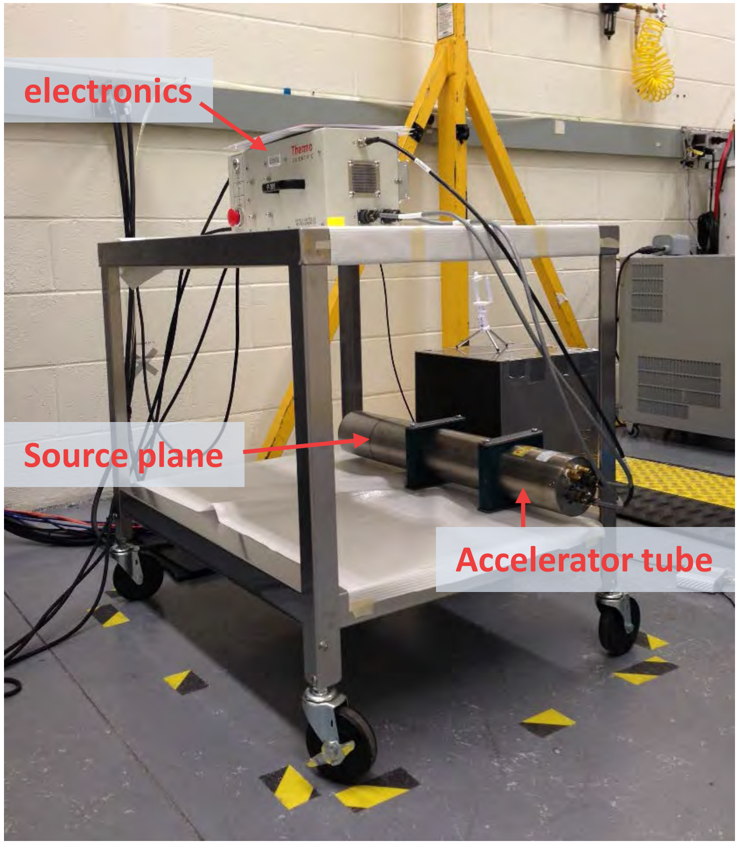
Three x-ray sources are used to determine diagnostic x-ray response and sensitivity

- Peak energy: 35 keV
- Max dose rate: ~ 0.5 Gy/min

- Peak energy: 225 keV
- Max dose rate: > 12 Gy/min

The third system is going to be delivered shortly

A pulsed DT source generating 6×10^8 neutrons/s in ~5 μs pulses has been recently added to the lab



A compatible accelerator tube for DD neutron generation has been ordered (10^7 neutrons/s)

Sources will be used to:

- **Characterize CR-39 DT- and DD-neutron background**
- **Test CVD diamond neutron sensitivity**
- **Test components for the MRS-t neutron spectrometer**

Our DD and DT neutron sources can easily generate neutron fluences replicating conditions at 1e7-1e15 yield applicable to OMEGA, Z and NIF

The CR-39 etch/scan lab has served as model for similar facilities at OMEGA and NIF

Research Specialist Ernie Doeg scanning WRF CR-39

Many nuclear diagnostics at OMEGA, NIF and Z have been developed at the MIT HED accelerator facility

Ongoing work:

- MRS DT neutron background studies to ensure data quality at E_n<10 MeV
- Extension of the Coincidence Counting Technique (CCT) for DD neutron spectrometer applications for Z, NIF and OMEGA
- CVD diamond sensitivity tests for improved understanding of NIF pTOF response
- Development of techniques for recovering CR-39 data in the presence of ablator ions
- Development of an orange spectrometer for low-yield, low-energy proton and alpha spectrum measurements, essential for e.g. plasma nuclear and stopping power experiments at OMEGA and NIF

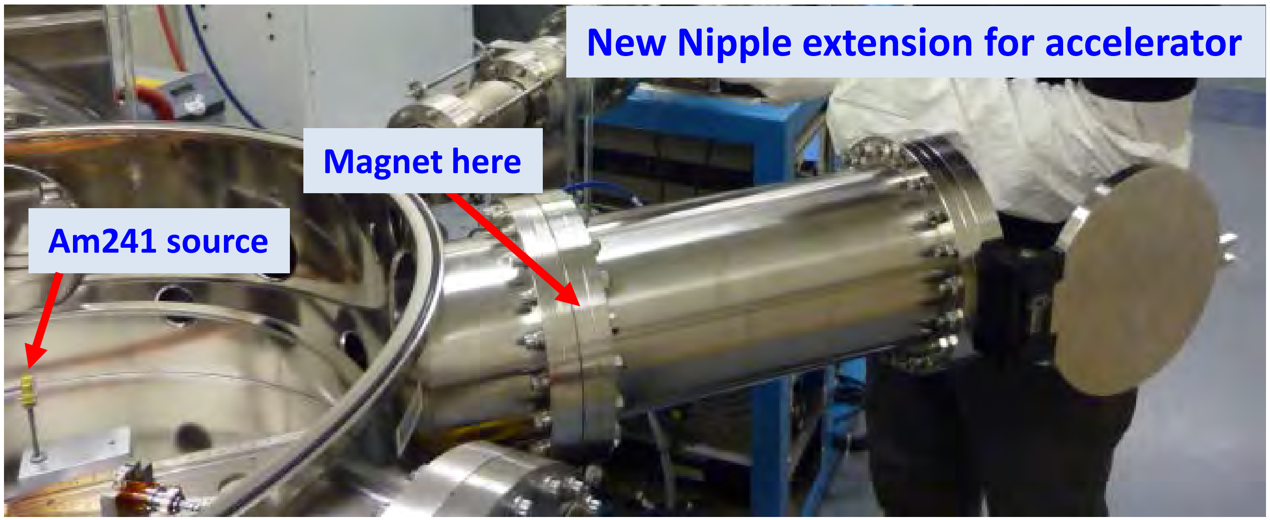
Recent work:

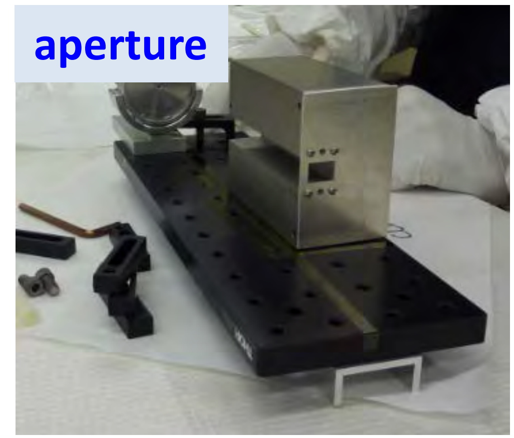
- Calibration of the magnet for the new NIF MagPTOF shock- and compression-bang-time detector
- Calibration (and re-calibration) of WRF proton spectrometers for OMEGA and NIF
- Testing of CR-39 sensitivity to x-rays, relevant for Z and NIF applications
- Assembly and testing of CVD diamond detectors for pTOF on NIF and OMEGA
- Development of a Step-Range-Filter for DD proton spectrum measurements at NIF
- Indium calibration (Sandia)

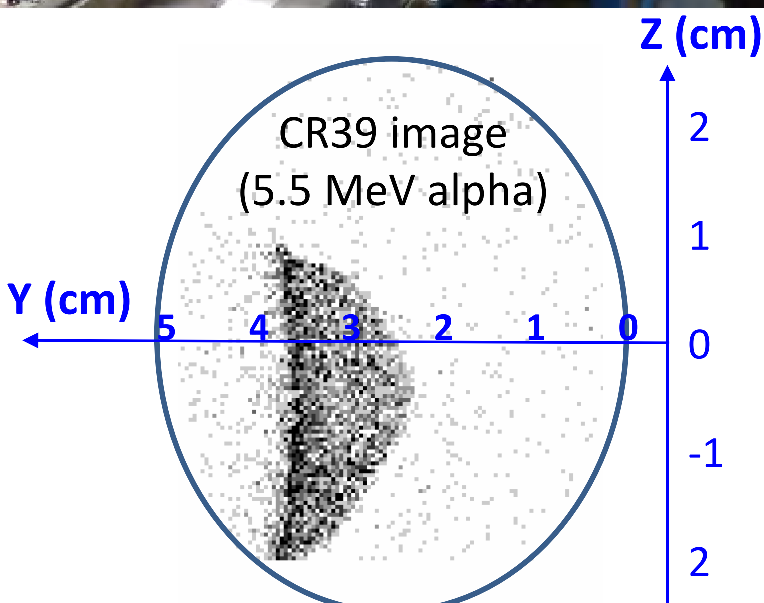
MagPTOF calibration

The magnet ion optics for the NIF MagPTOF* bang-time detector were tested on the MIT accelerator

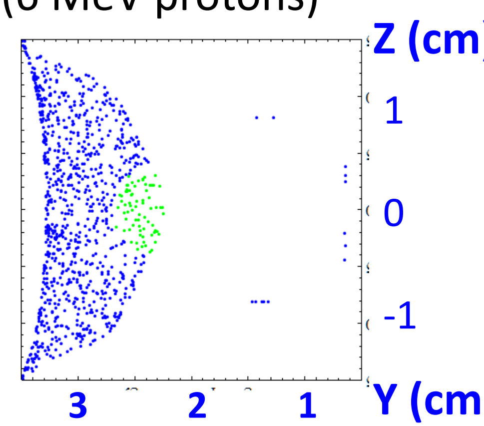
Graduate project: Hong Sio







Dexter simulation
(6 MeV protons)

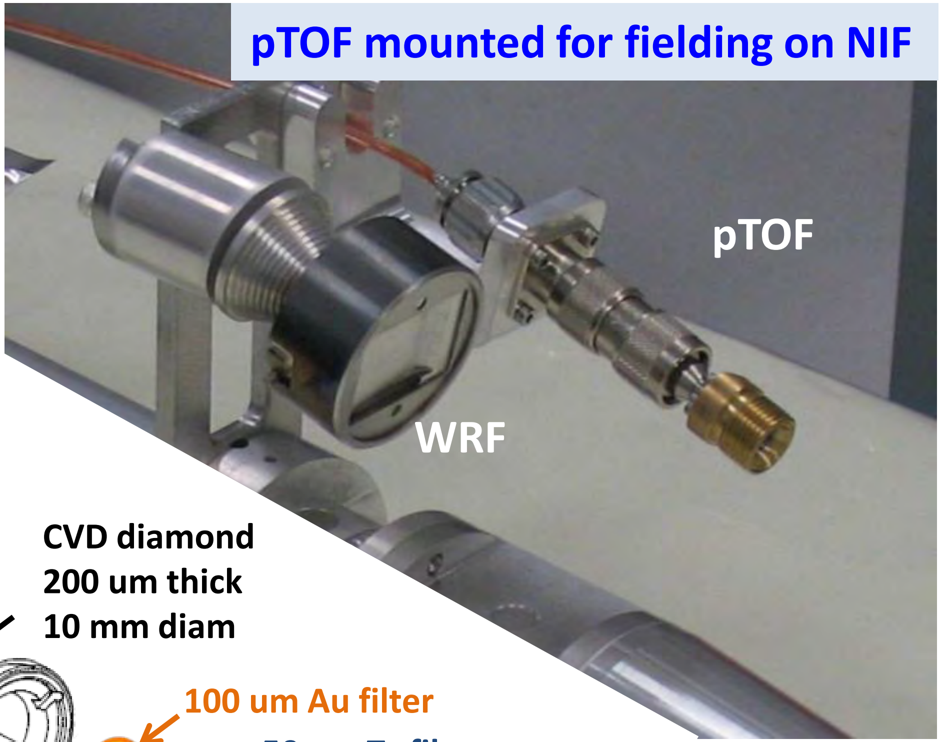


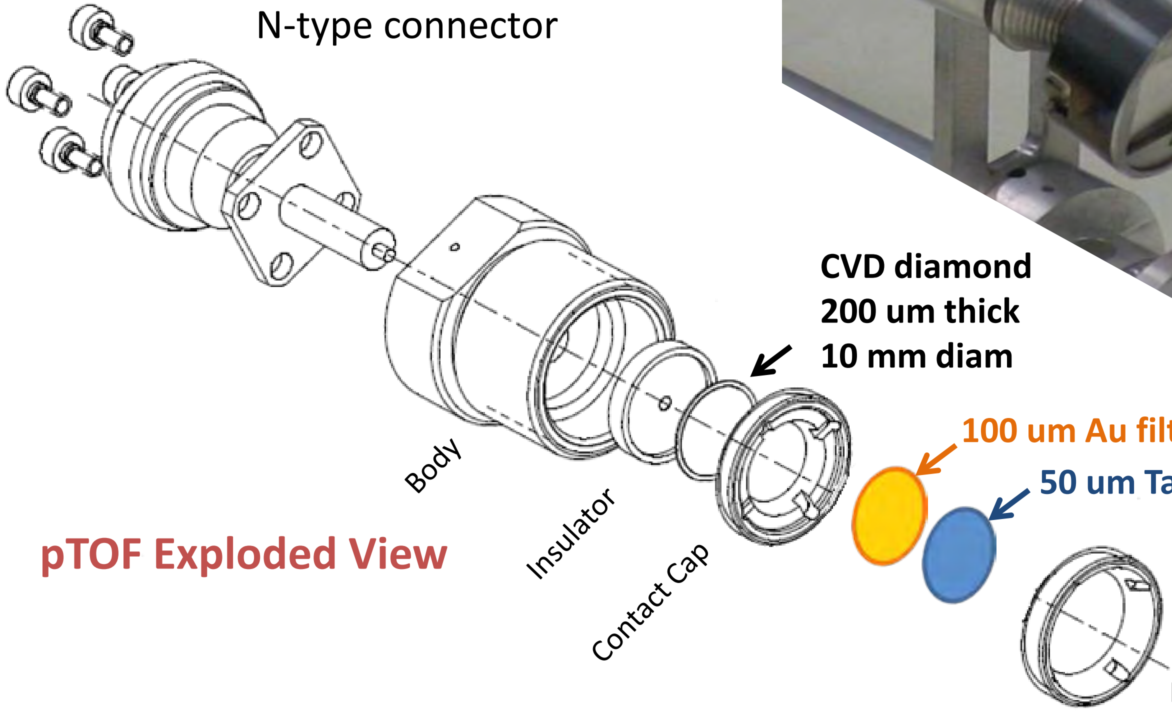
*H.G. Rinderknecht et al., Rev. Sci. Instrum. 85, 11D901 (2014) pTOF testing

pTOF* detector x-ray and neutron sensitivity is being tested on the x-ray and neutron sources

Graduate project:
Neel Kabadi

pTOF mounted for fielding on NIF



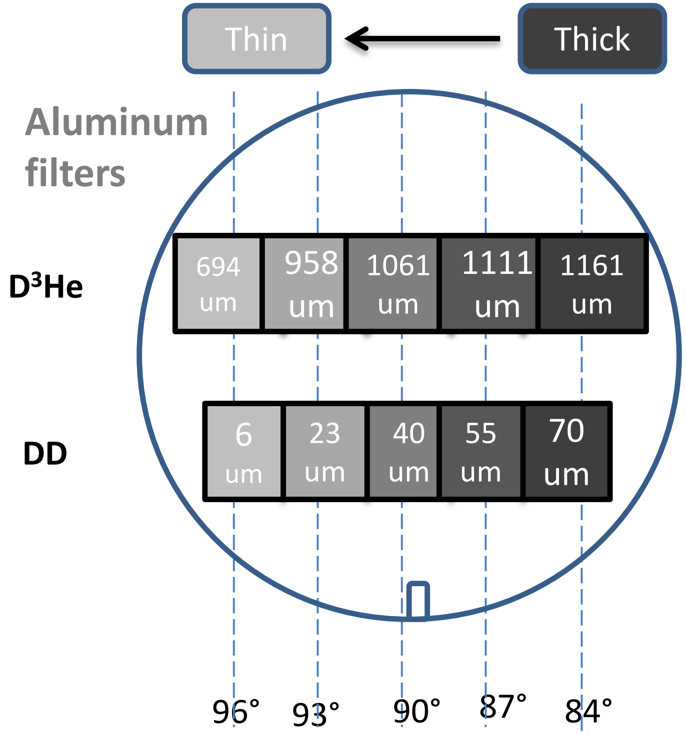


pTOF Exploded View

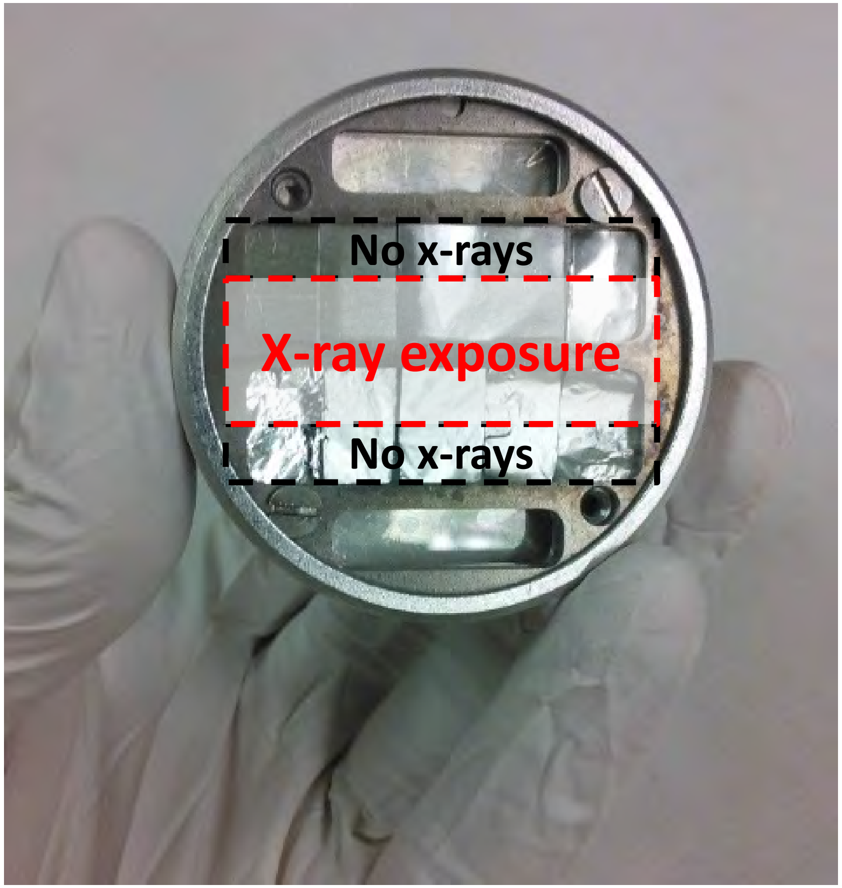
*H.G. Rinderknecht et al., Rev. Sci. Instrum. 83, 10D902 (2012)

Recent experiments address CR-39 sensitivity to x-rays, important for NIF and Sandia applications

Undergraduate project: Jimmy Rojas-Herrera



Each filter results in a different proton energy

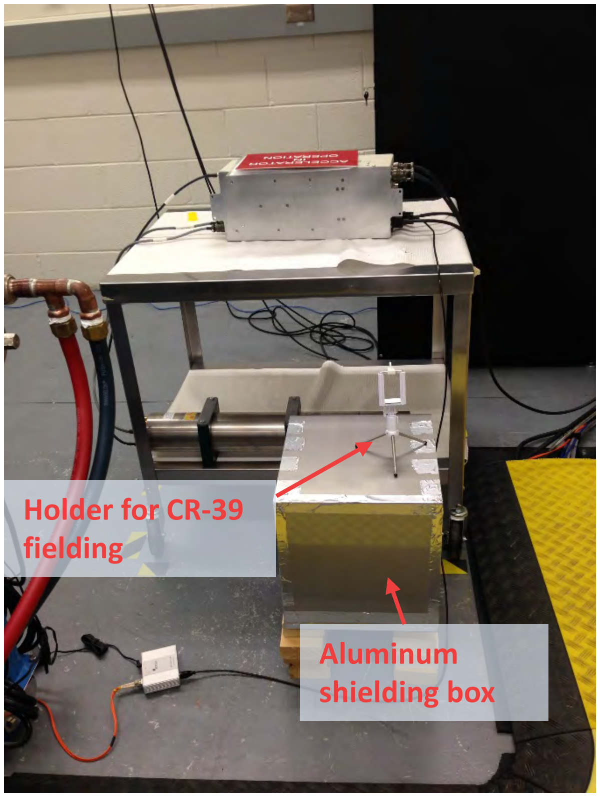


J. Rojas-Herrera et al., Rev. Sci. Instrum. 86, 033501 (2015)
H.G. Rinderknecht et al., submitted to Rev. Sci. Instrum. (2015)

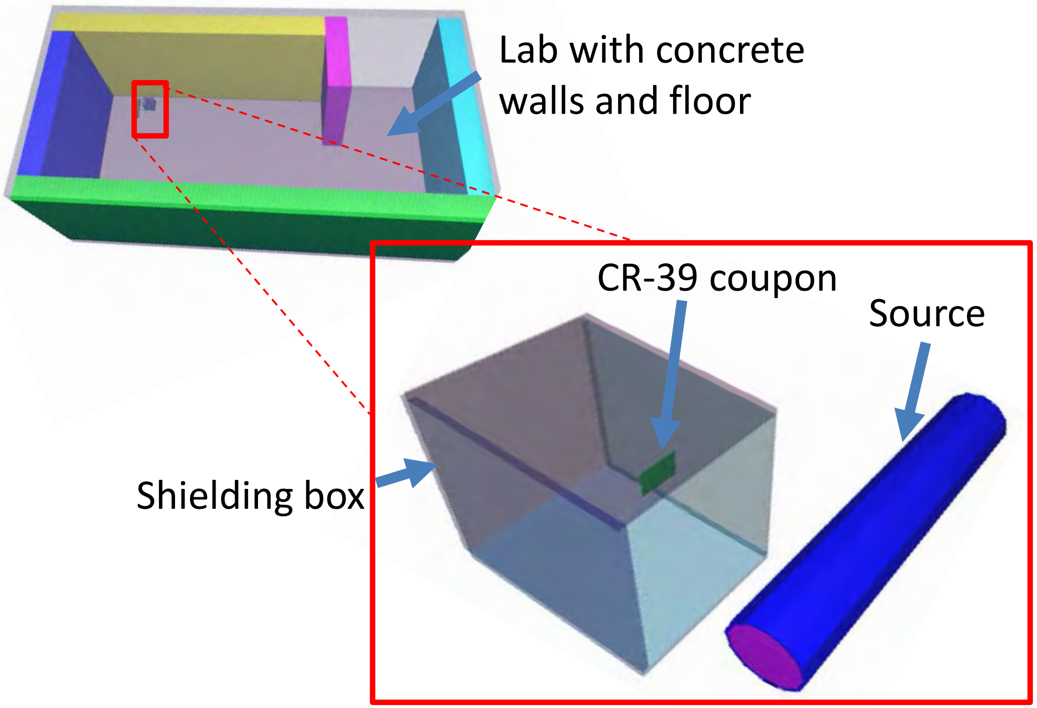
MRS testing

The DT neutron source is used to test the impact of DT neutron background in the MRS shielding

Undergraduate project: Lucio Milanese



Results are compared to MCNP simulations of the setup to aid in interpretation:

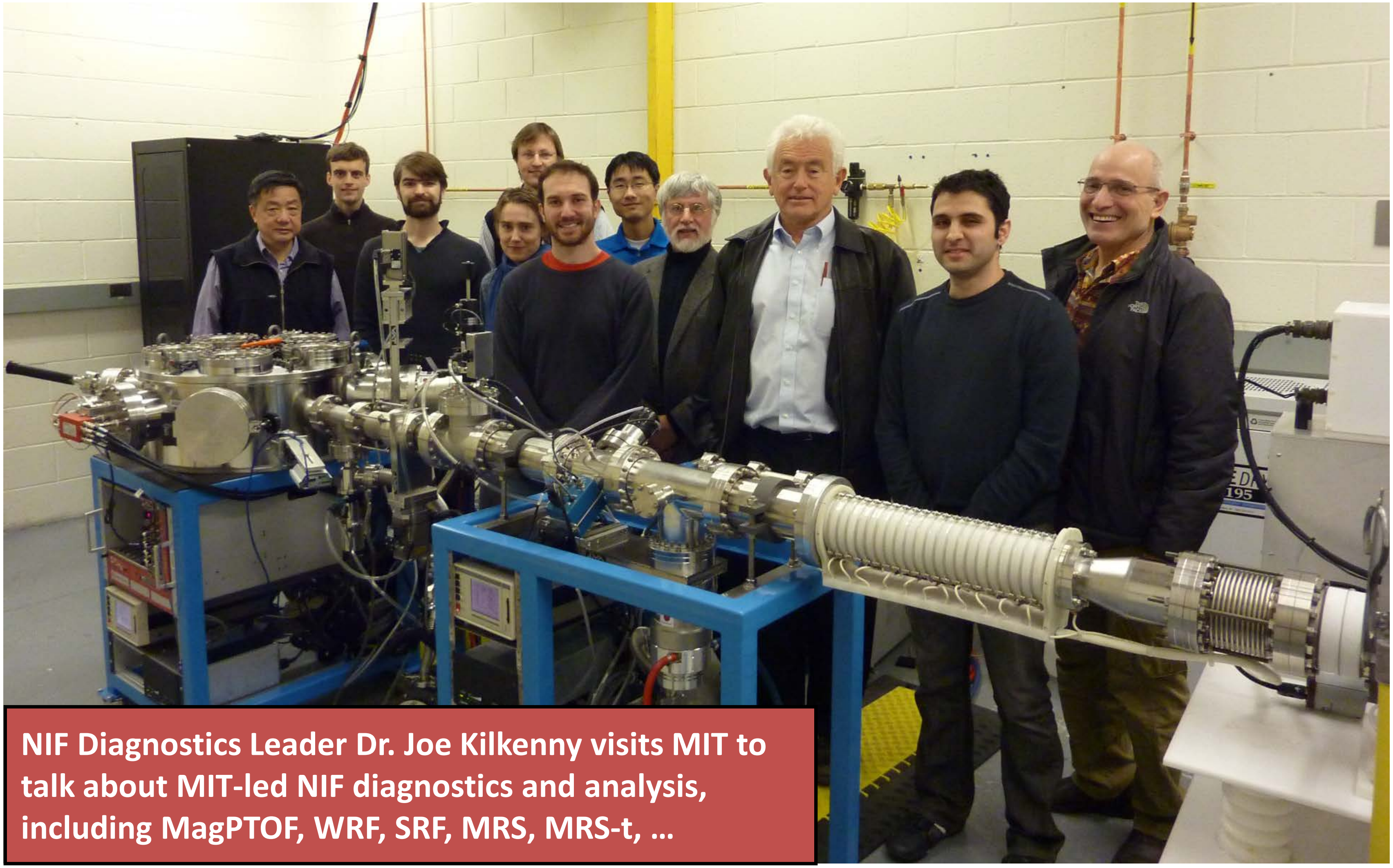


This work will improve our understanding of OMEGA and NIF MRS measurements at neutron energies <10 MeV

Sandia Indium activation diagnostics were calibrated using the facility DD-neutron capability

Accelerator before major 2011-2012 upgrade

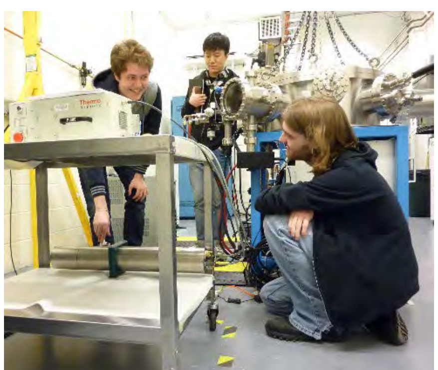
The MIT HED Accelerator Facility is continuously adapting to serve the needs of the ICF community



NIF Diagnostics Leader Dr. Joe Kilkenny visits MIT to talk about MIT-led NIF diagnostics and analysis, including MagPTOF, WRF, SRF, MRS, MRS-t, …

…while simultaneously allowing students to get real hands-on experience…

Lucio, Harry and Brandon setting up for a neutron source run



Harry and Graeme setting up for a Sandia neutron spectrometer test

…and publishing critical instrumentation papers in peer-reviewed journals

H.G. Rinderknecht et al., "Impact of x-ray dose on track formation and data analysis for CR-39-based proton diagnostics", (RSI 2015)

J. Rojas-Herrera et al., "Impact of x-ray dose on the response of CR-39 to 1-5.5 MeV alphas", (RSI 2015)

M. Rosenberg et al., "A compact proton spectrometer for measurement of the absolute DD proton spectrum from which yield and ρR are determined in thin-shell inertial-confinement fusion implosions", (RSI 2014)

H. Sio et al., "A technique for extending by 10^3 the dynamic range of compact proton spectrometers for diagnosing ICF implosions on the National Ignition Facility and OMEGA" (RSI 2014)

M. Rosenberg et al., "Empirical assessment of the detection efficiency of CR-39 at high proton fluence and a compact proton detector for high-fluence applications" (RSI 2014)

A. Zylstra et al., "A new model to account for track overlap in CR-39 data" (Nucl. Instrum. Meth. A 2012)

N. Sinenian et al., "Improvements to the MIT Linear Electrostatic Ion Accelerator for advanced diagnostics development for OMEGA, Z and the NIF" (RSI 2012)

D.T. Casey et al., "The Coincidence Counting Technique for orders of magnitude background reduction in data obtained with the Magnetic Recoil Spectrometer at OMEGA and the NIF" (RSI 2011)

N. Sinenian et al., "The response of CR-39 nuclear track detector to 1-10MeV protons" (RSI 2011)

M. Manuel et al., "Observable change in proton response of CR-39 due to prolonged exposure to high vacuum environments" (RSI 2011)

Zylstra et al., "Increasing the energy dynamic range of solid-state nuclear track detectors using multiple surfaces" (RSI 2011)

S. McDuffee et. al., "An accelerator based fusion-product source for development of inertial confinement fusion nuclear diagnostics" (RSI 2008)

Summary

The MIT HED Accelerator Facility is a foundational tool for diagnostic development for OMEGA, NIF, Z, and Discovery Science

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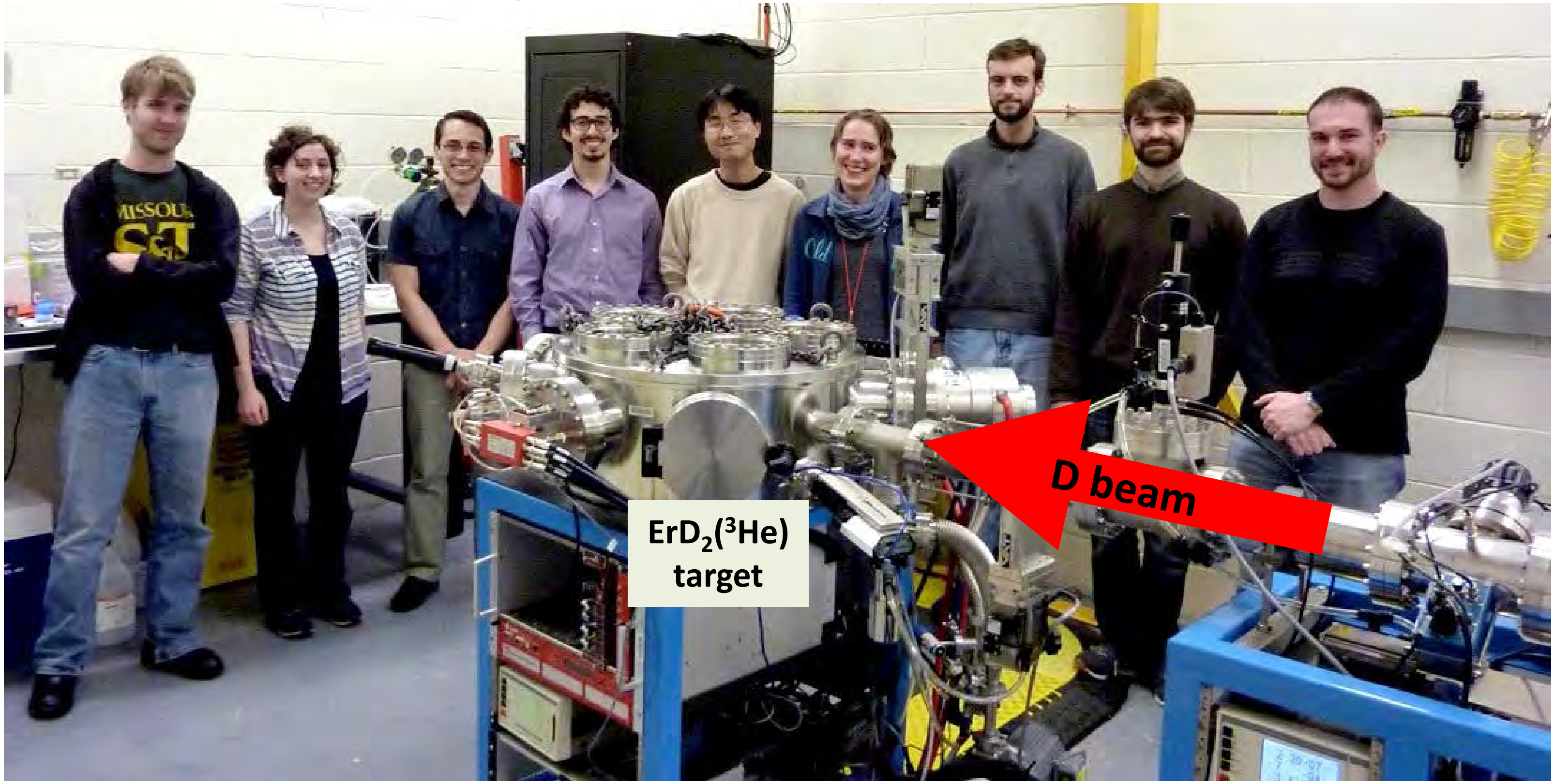
    - DD capability (1e7 n/s) is being added
- An etch/scan lab allows for precision on-site CR-39 processing
- The lab has been crucial for the successful deployment of diagnostics such as MRS, CPS, WRF, (Mag)PTOF, DD-n spectrometry etc.

This continuously evolving development platform also plays a vital role in student training and has resulted in many student papers based on lab data

Appendix

The accelerator is capable of generating D+D and D+^{3}He fusion products for diagnostic development and calibration



$$D + {}^3He \rightarrow p\ (14.7\ MeV) + \alpha\ (3.7\ MeV)$$

$$D + D \rightarrow p\ (3.0\ MeV) + T\ (1.0\ MeV)$$

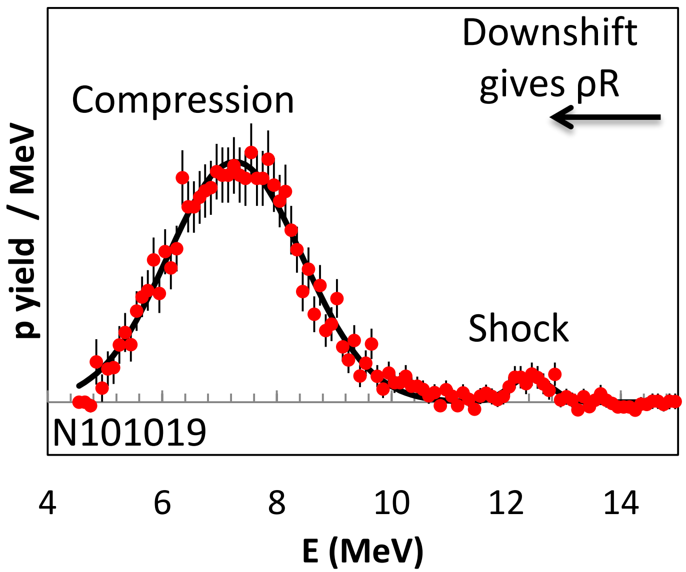
$$\rightarrow n\ (2.5\ MeV) + {}^3He\ (0.8\ MeV)$$

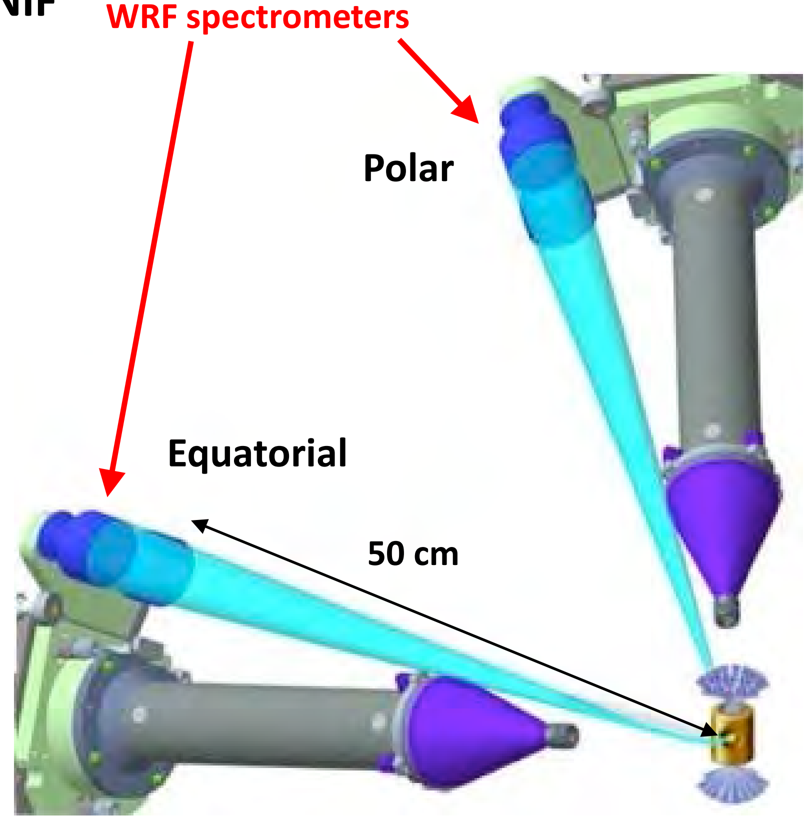
These same reactions/diagnostics are used to probe ICF implosions at NIF and OMEGA.

WRF spectrometers calibrated at MIT are used at OMEGA and the NIF for diagnosing ρR

Graduate project: Alex

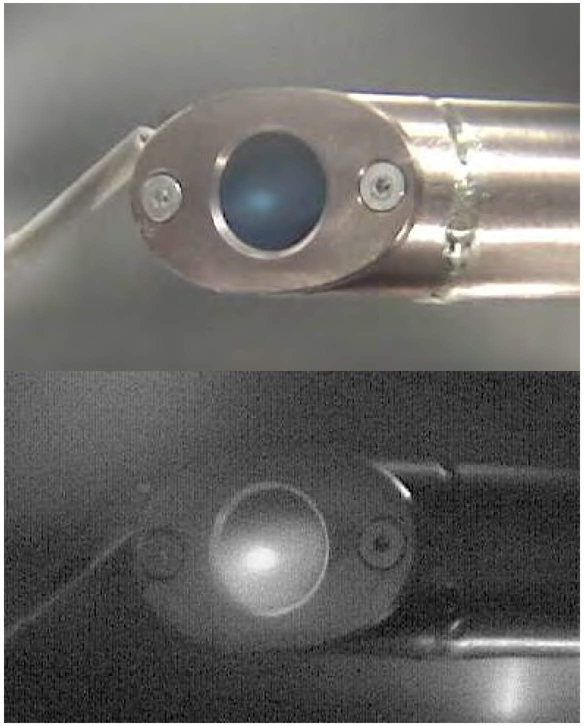
Example: Diagnosing ρR asymmetries on NIF

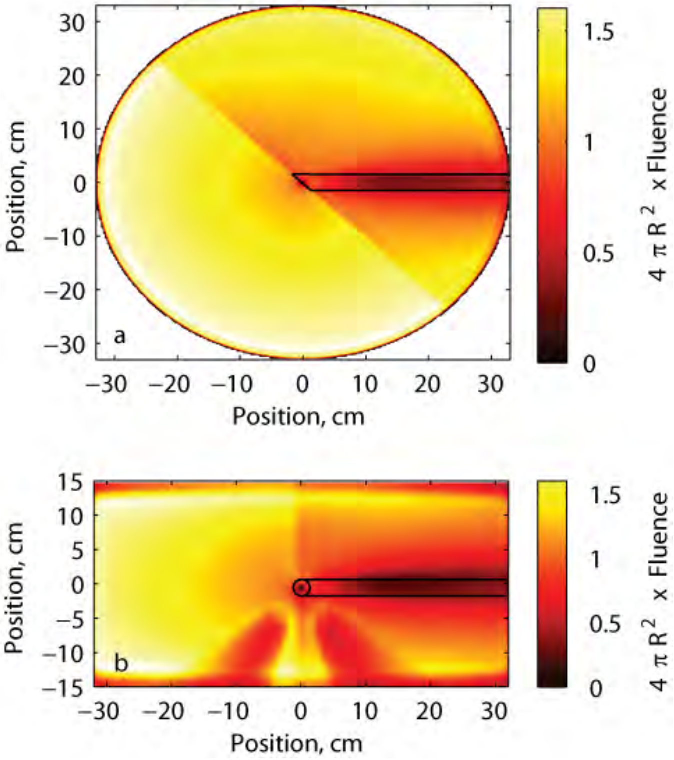




A. Zylstra *et al.*, submitted to Phys. Rev. E and Phys. Plasmas (2014)
F.H. Séguin *et al.*, Rev. Sci Instrum 83, 10D908 (2012)
P.B. Radha *et al.*, Phys. Plasmas 18, 012705 (2011)
H.F. Robey *et al.*, Phys. Plasmas 17, 056313 (2010)

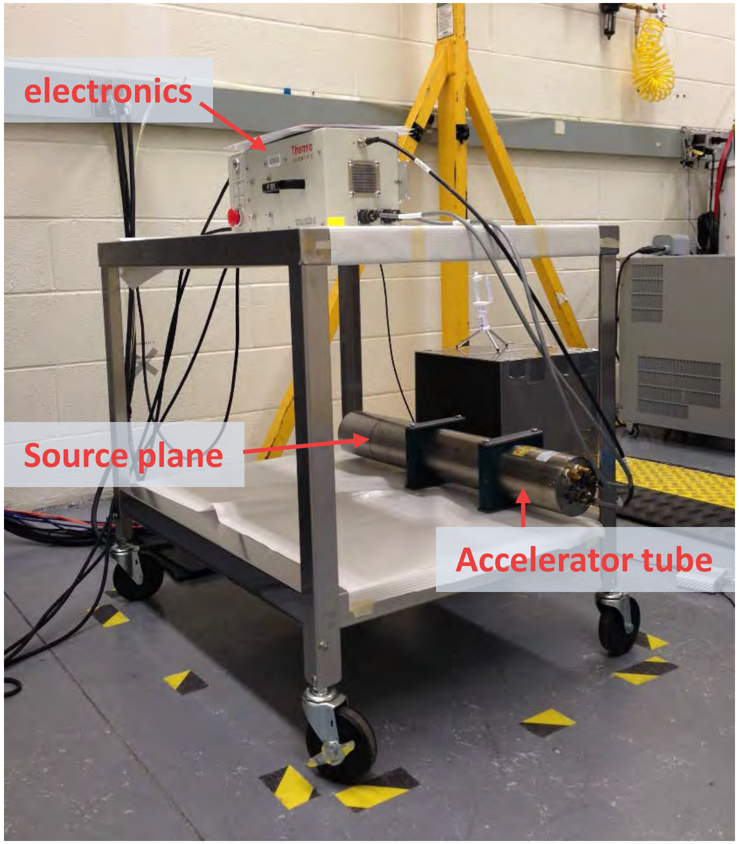
A target viewing system and MCNP simulations are used to characterize the neutron-fluence field in the target chamber





Source size and scattering of neutrons are important for neutron diagnostics development

The neutron source fluences given by the manufacturer will be verified using absolutely calibrated CR-39



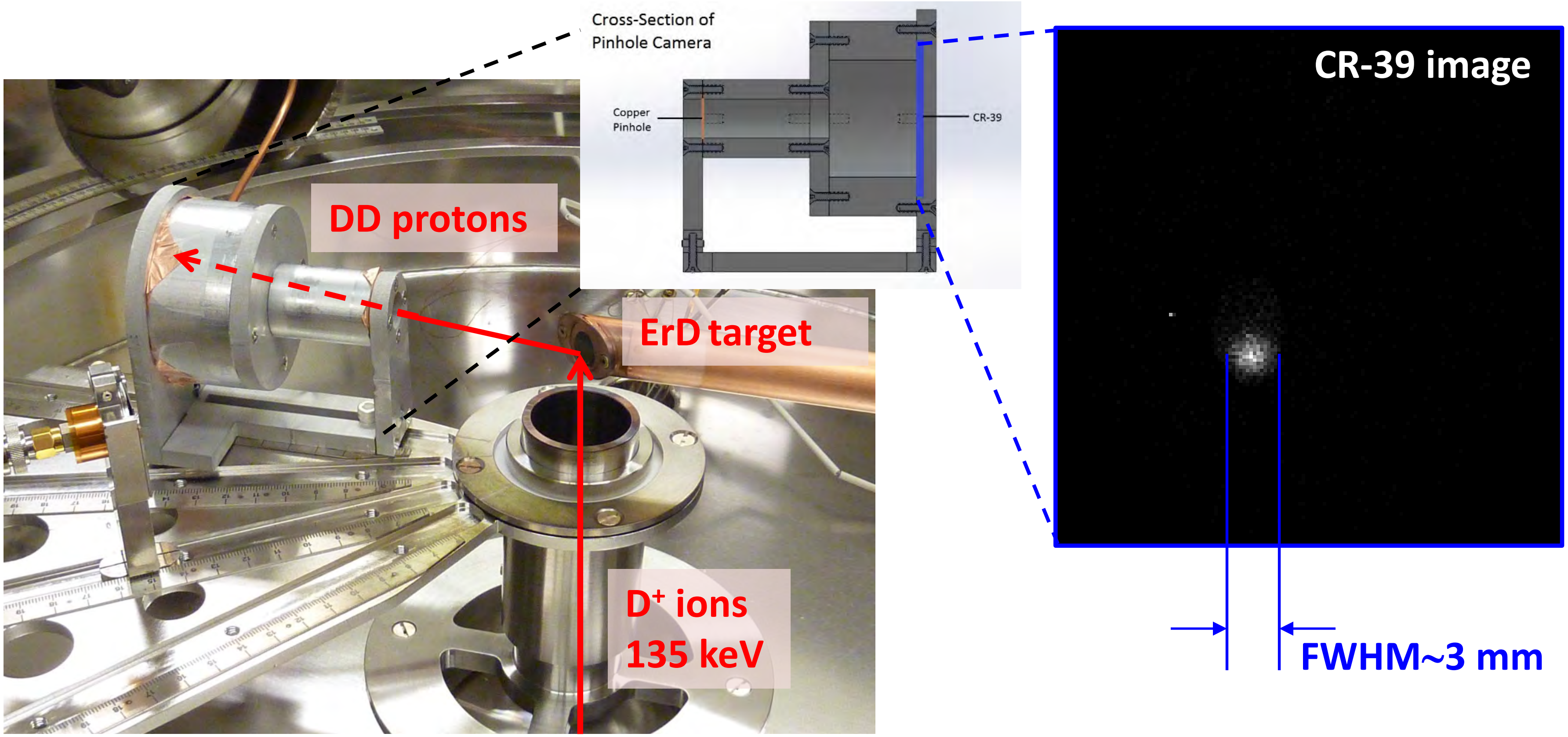
- **CR-39 efficiency for 2.5-MeV and 14-MeV neutron detection will re-established on OMEGA***
- **Reliability of accelerator MCNP models will be verified by fielding CR-39 in the target chamber with the ErT_2 target using the associated particle method**
- **CR-39 can then be used to verify the fluence from the neutron source, using MCNP to correct for scatter**

An independently calibrated neutron fluence monitor will also be used

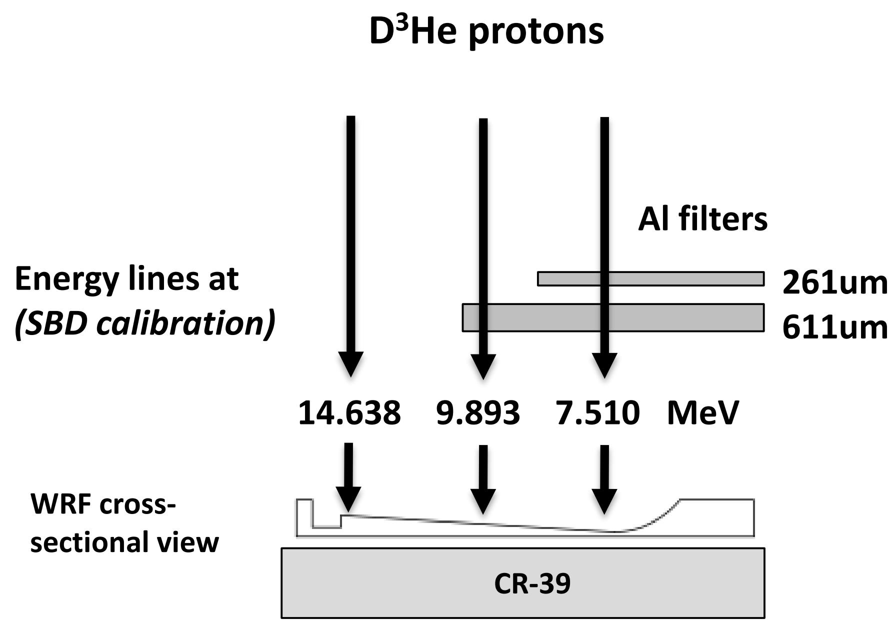
***J. Frenje *et al.*, Rev. Sci Instrum 73, 2597 (2002)**

A pinhole camera is being implemented to further improve the characterization of source size and shape

Undergraduate project: David



WRF spectrometers for measurements of D-^{3}He proton spectra are calibrated and re-calibrated on LEIA

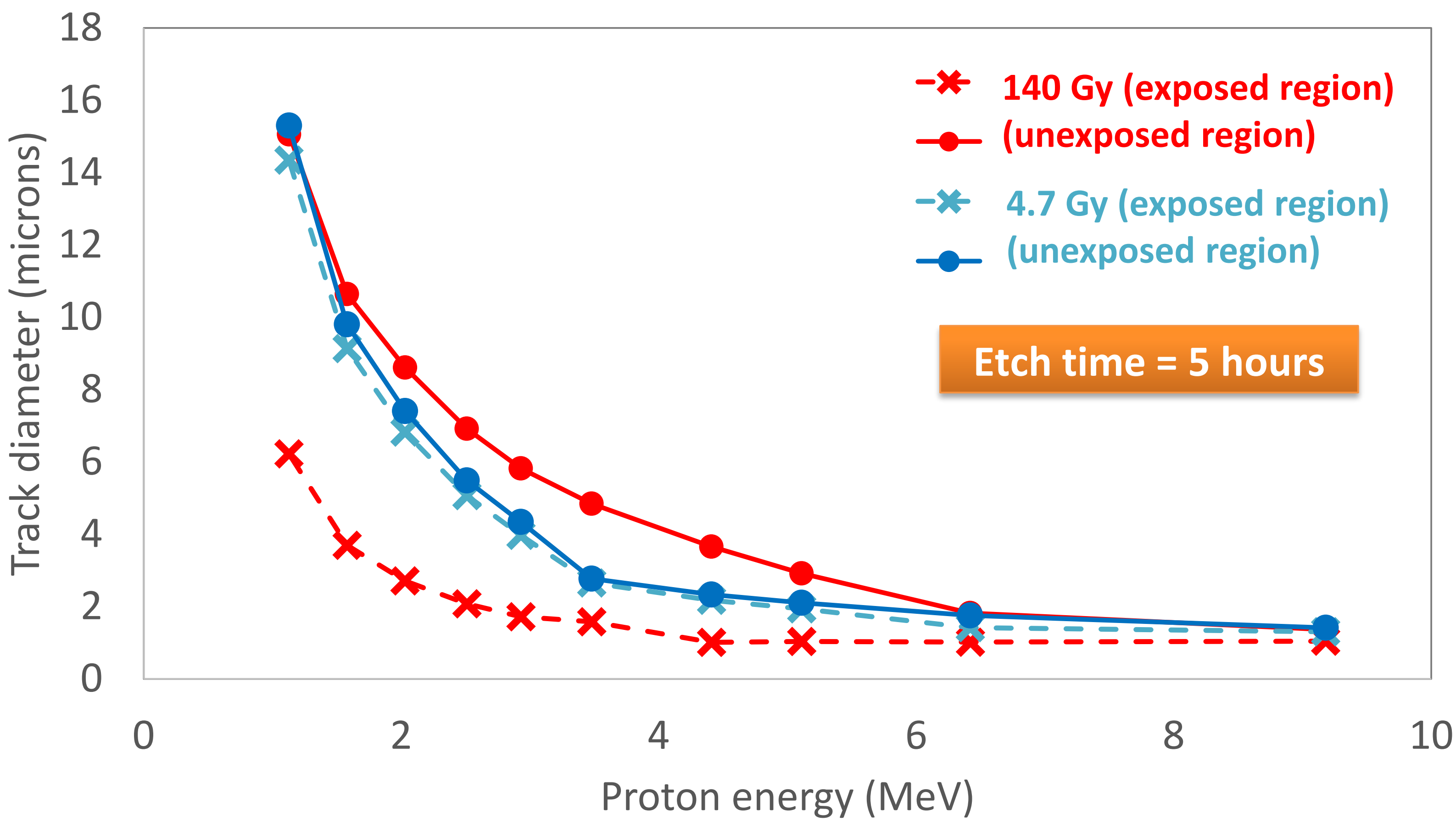


Aluminum WRFs have been used on the recent NIF campaign

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

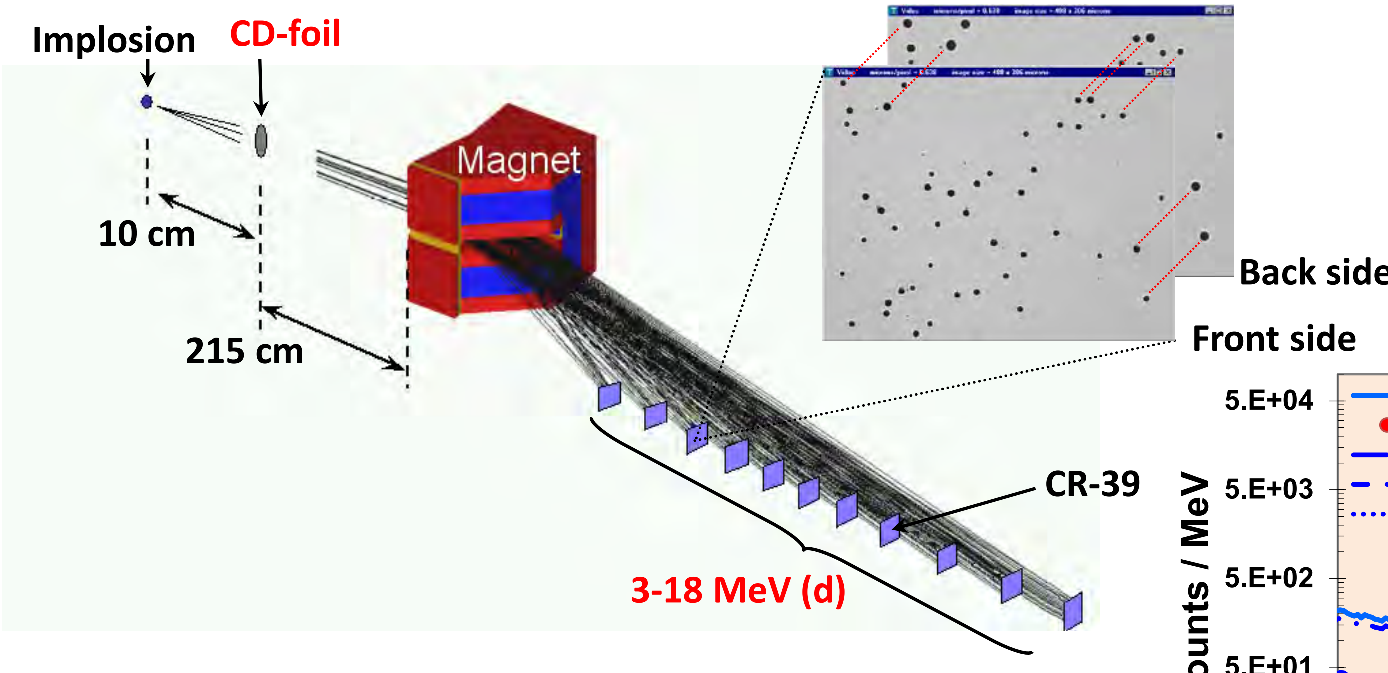
CR-39 testing

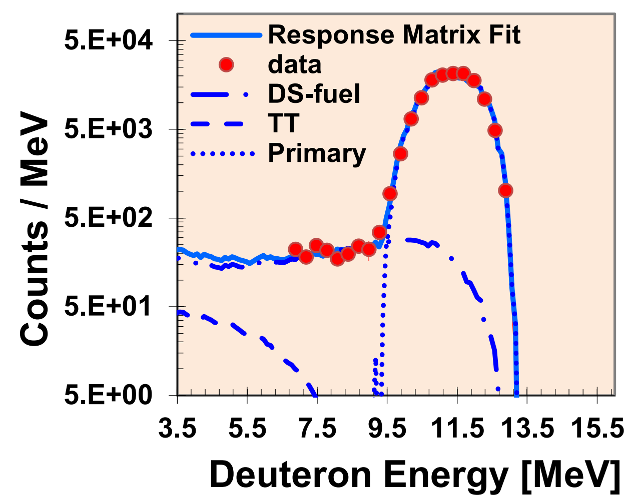
Regions of the CR-39 which were exposed to x-rays show a lower mean track diameter



At NIF, the expected dose on WRF CR-39 is ~6 Gy at 50cm

The MRS' on OMEGA and the NIF use CR-39 for detecting recoil deuterons



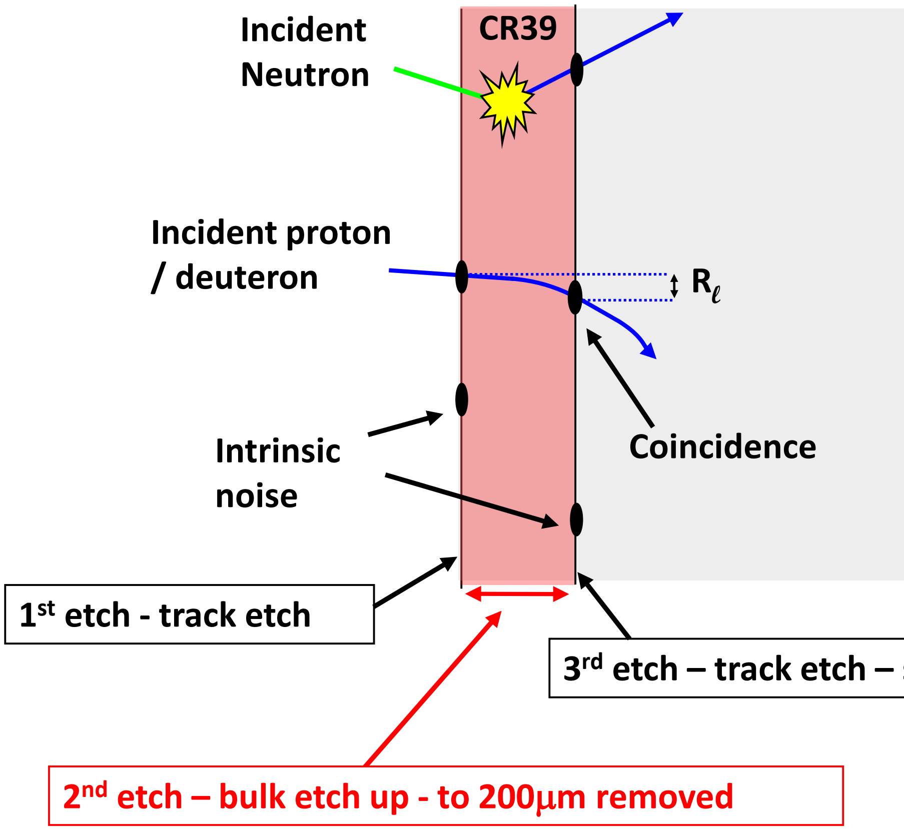


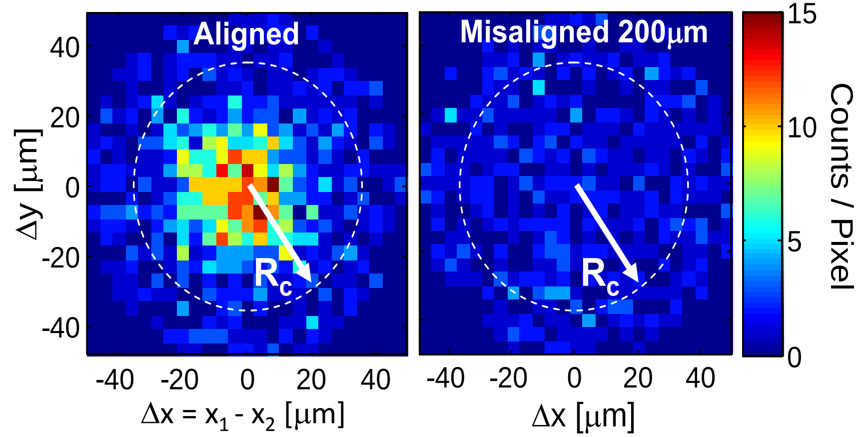
For low-signal applications, special processing is required to enhance S/B

J.A. Frenje *et al.*, Rev. Sci. Instrum. 72, 854 (2001)
J.A. Frenje *et al.*, Rev. Sci. Instrum. (2008)

Analysis techniques

The coincidence counting technique* (CCT) for the MRS was developed and optimized on LEIA





By applying the CCT, *S/B* is enhanced orders of magnitude*

*D.T. Casey *et al.*, Rev. Sci. Instrum. (2011)