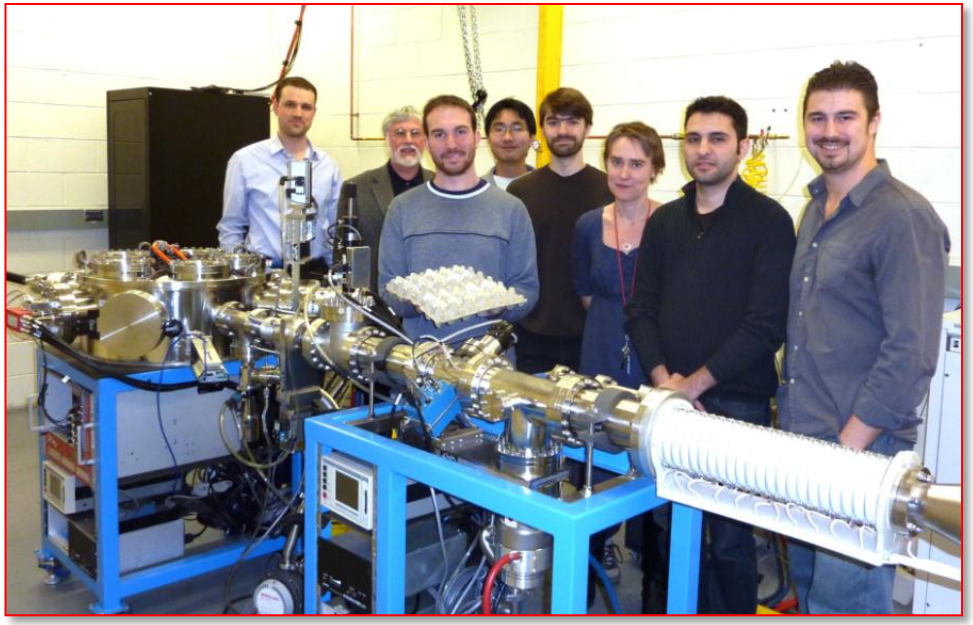
Academic Participation and PhD Thesis Research at the NIF: A Case Study with Advanced Diagnostics



Dr. Daniel Casey's PhD thesis is the first one based on NIF data:

"Diagnosing Inertial Confinement Fusion Implosions on OMEGA and the NIF using Novel Neutron Spectrometry"

Richard Petrasso
MIT

Nemo working his magic in Boston this weekend

Collaborators

MIT

LLNL

UR - LLE

GA

LANL

SNL

Indiana University

All MIT Students obtaining NIF data for PhD Theses have LLNL Scientists as Co Advisors

LLNL Scientist		MIT Student
Rip Collins	-	Alex Zylstra
Joe Kilkenny	-	Hans Rinderknecht
Nino Landen	-	Hong Sio
Andy Mackinnon	-	Mike Rosenberg

We thank Ed Moses who has been a strong advocate of this Program.

Dr. Daniel Casey, currently at LLNL, finished his MIT PhD in 2012.

Summary

Opportunities for academic participation in programmatic work at the NIF have allowed MIT to

- **Work with collaborators on the development of several nuclear diagnostics and platforms for the NIF**
- **Share in the excitement of scientific discovery and the grand challenge of ignition at the NIF**
- **Give PhD students extraordinary experience along with data for their theses**

The final NIC report states that a primary goal is the enhancement of diagnostic measurements.

Outline of diagnostics and platforms with MIT involvement

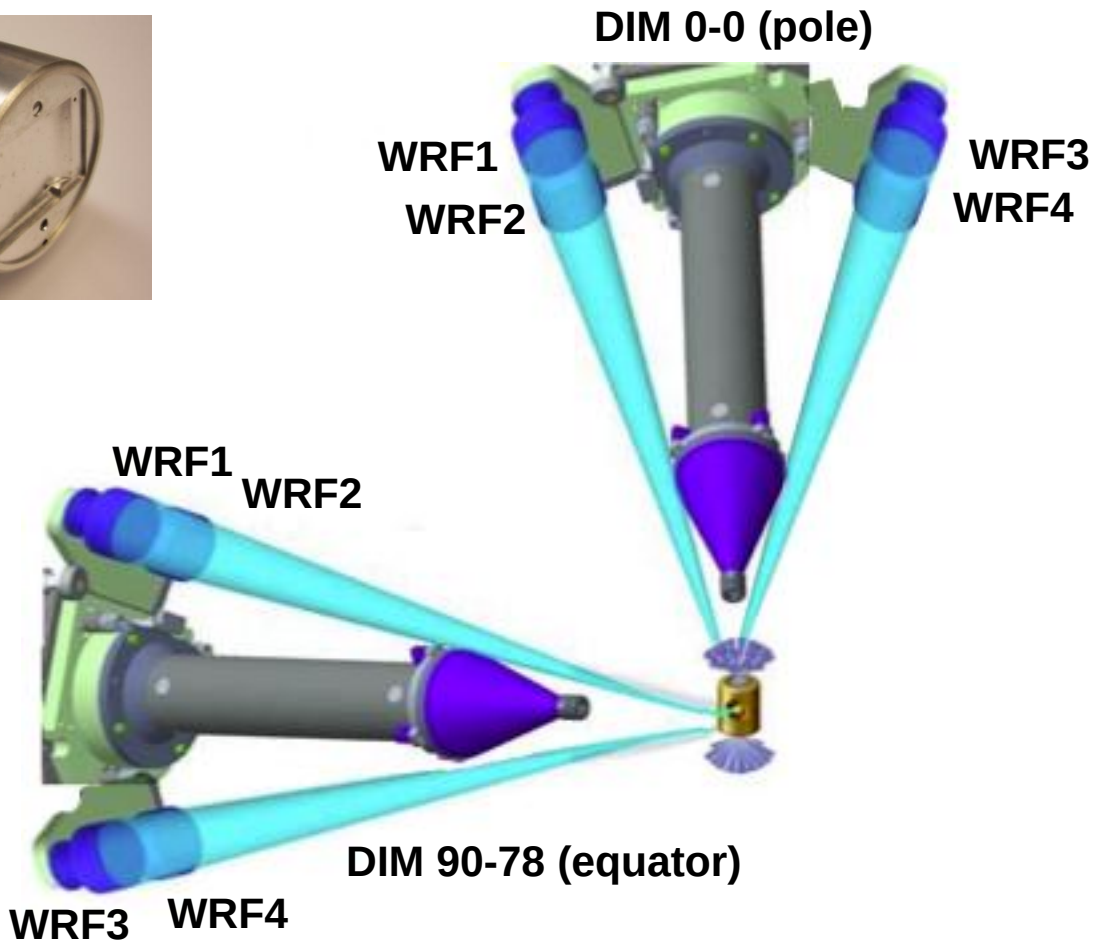
- **Wedge-Range-Filter (WRF) proton spectrometers**
- **Particle Time-Of-Flight (PTOF) detector**
- **Magnetic Recoil Neutron Spectrometer (MRS)**
- **MIT accelerator facility – diagnostics development**
- **Developing new platforms and 2nd-generation diagnostics**

Outline of diagnostics and platforms with MIT involvement

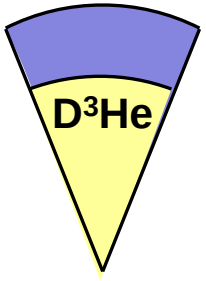
- **Wedge-Range-Filter (WRF) proton spectrometers**
  - Studies of ρR and ρR asymmetry at shock burn (student: Alex Zylstra)
  - Studies of shock-driven exploding pushers (student: Mike Rosenberg)
  - Studying fuel ρR, T_e, & mix with secondaries (student: Hans Rinderknecht)
  - Measuring megagauss B fields in hohlraums (student: Alex Zylstra)
- **Particle Time of Flight Detector**
- **Magnetic Recoil Neutron Spectrometer (MRS)**
- **MIT accelerator facility – diagnostics development**
- **Developing new platforms and 2nd-generation diagnostics**

Wedge-Range-Filter (WRF) proton spectrometers are used for all implosions with D^3He or D_2 fuel at the NIF

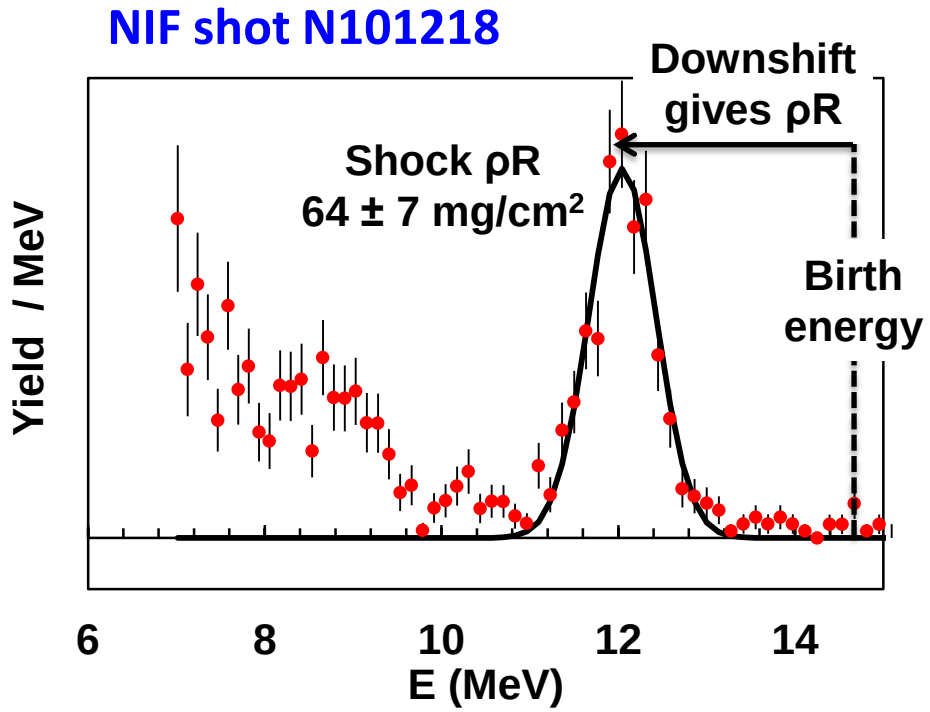
WRFs are fielded on the pole and equator for diagnosing ρR at shock-bang time and for probing fields around the LEH



The WRF spectrometers measure D^3He-proton spectra, from which yields, ρR and ρR asymmetries are inferred

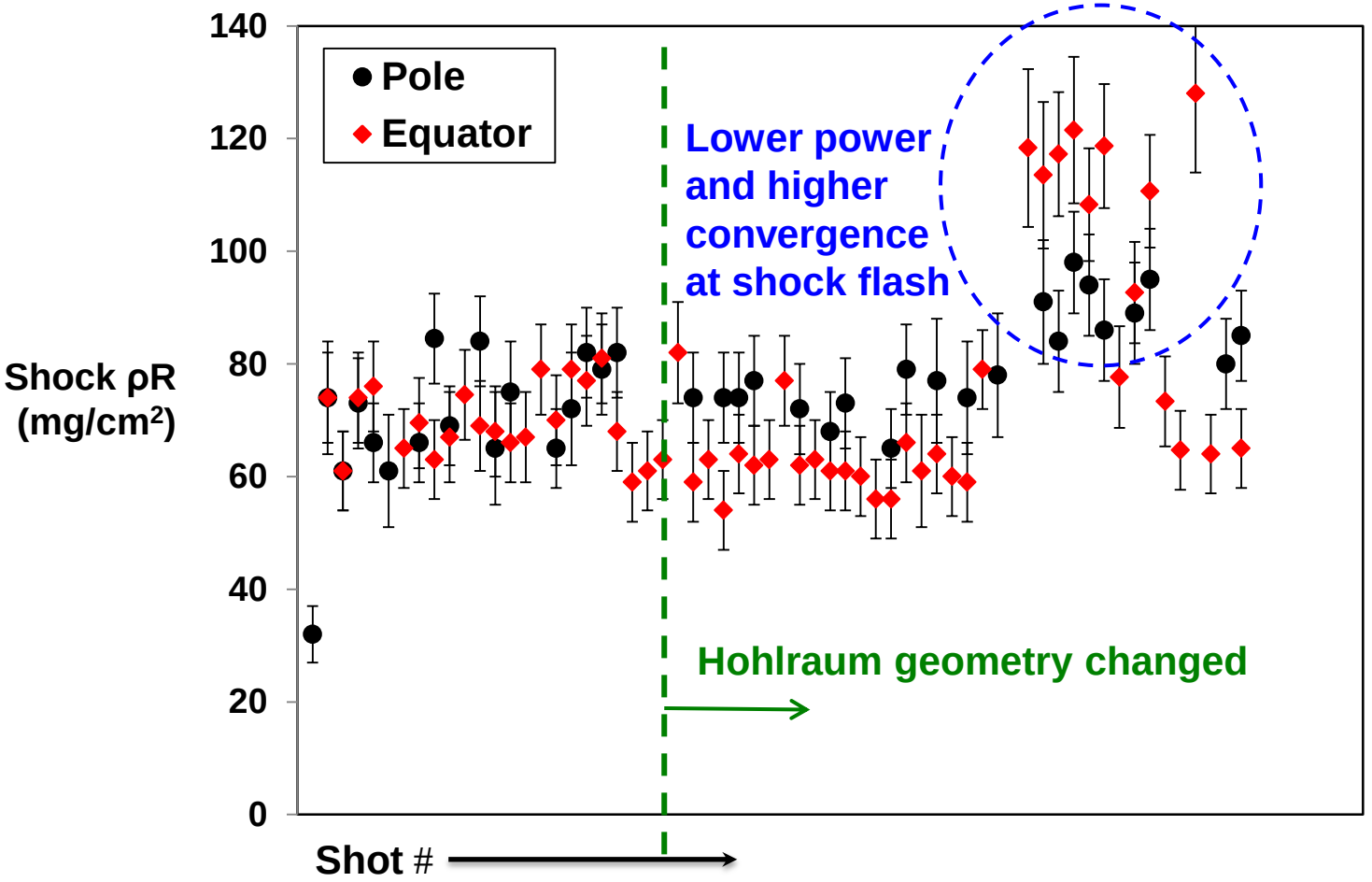


$D + {}^3He \rightarrow {}^4He + p\ (14.7\ MeV)$



See A. Zylstra's poster

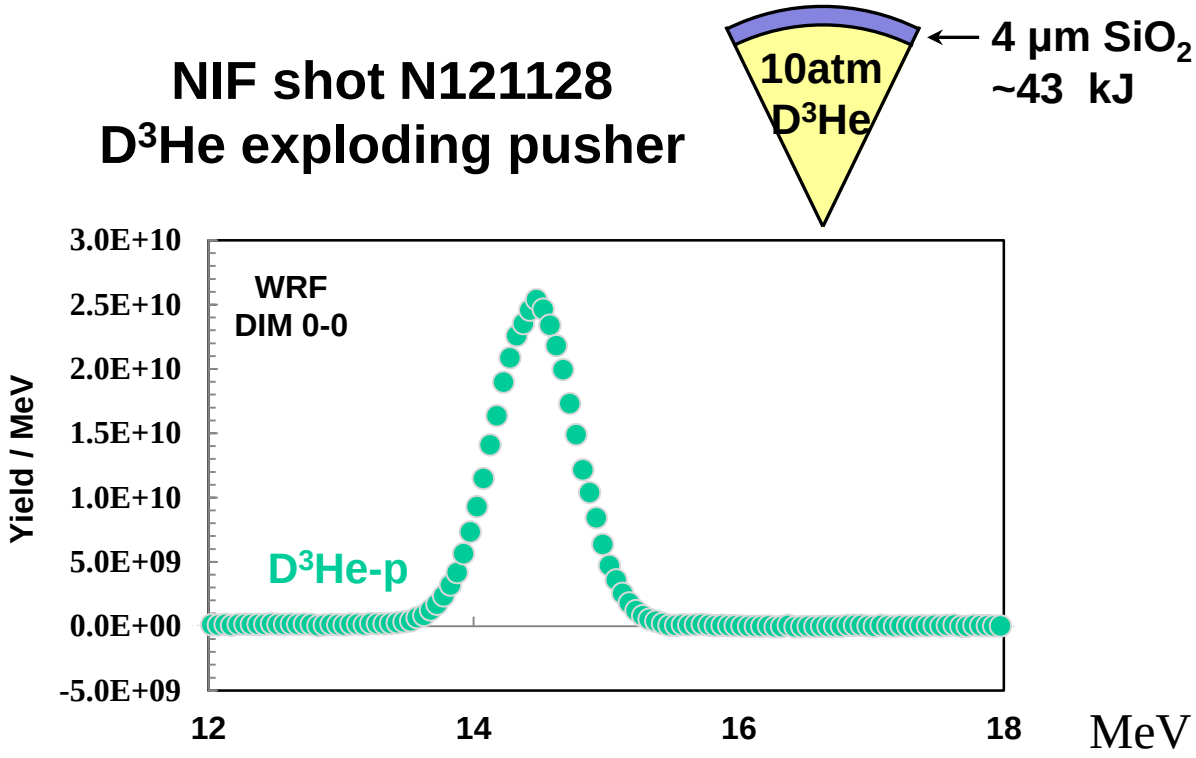
A systematic study of ρR asymmetry at shock burn (~800ps before stagnation) uncovered interesting trends



- Changing hohlraum geometry changed implosion symmetry.
- Lower drive power resulted in higher convergence at shock flash and an implosion symmetry change.

See M. Rosenberg's poster

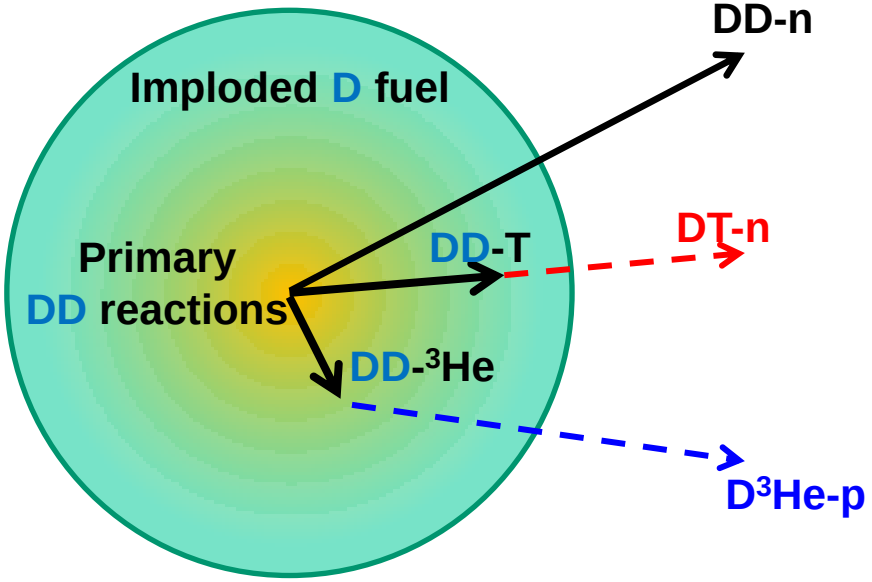
High-accuracy D^3He proton spectra, used for diagnostic calibration, are also being used to study kinetic plasma effects and mix, and shock driven implosions.

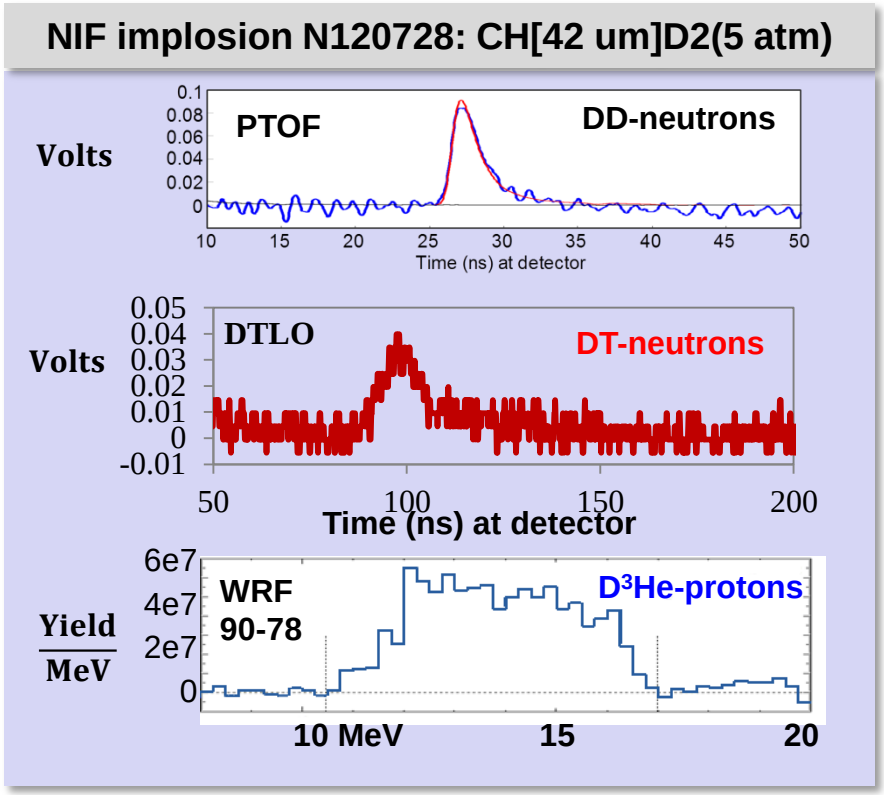


The high-quality of these D^3He data bode very well for the fundamental science proton backlighting platform.

See H. Rinderknecht's poster

Fuel ρR, mix, and kinetic effects in D_2 implosions are assessed with combined information on D^3He and DT secondary yields





Primary reactions:

D + D → p (3.02 MeV) + **T (1.01 MeV)**

D + D → **n (2.45 MeV)** + **³He (0.82 MeV)**

Secondary Reactions:

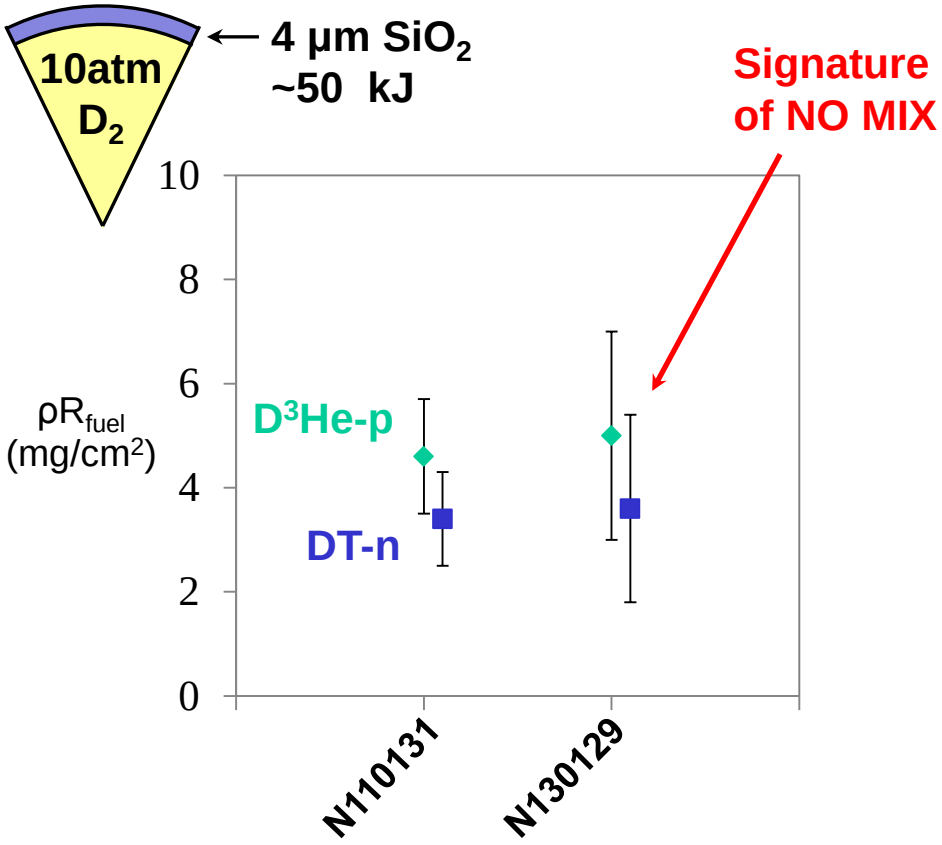
T (< 1.01 MeV) + D → α (6.7-1.4 MeV) + **n (11.9 – 17.2 MeV)**

³He (< 0.82 MeV) + D → α (6.6-1.7 MeV) + **p (12.6 – 17.5 MeV)**

See H. Rinderknecht's poster

A signature of NO MIX is similar values of ρR_{fuel} inferred from D^3He-p & DT-n yields

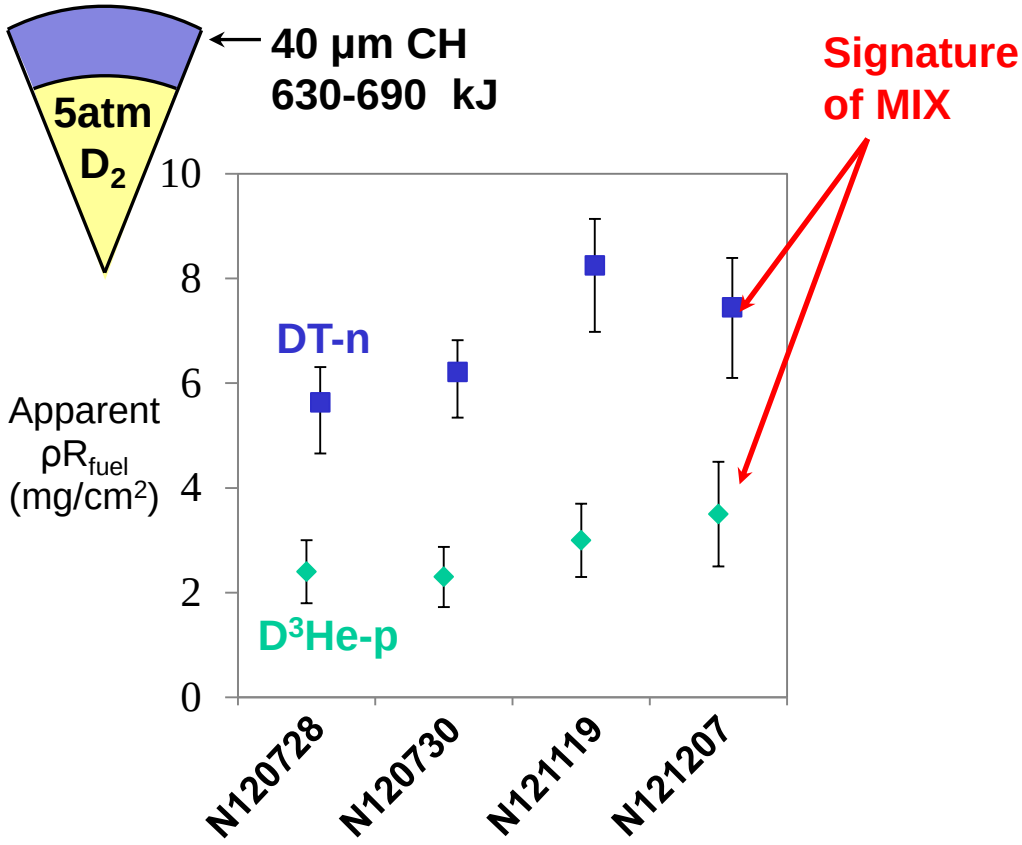
Thin-glass exploding pushers



See H. Rinderknecht's poster

A signature of MIX is different values of ρR_{fuel} inferred from D^3He-p & DT-n yields

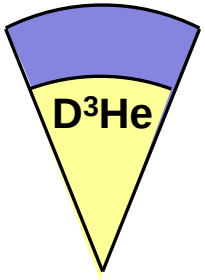
DIME exploding pushers



See also H. Rinderknecht's seminar on Thursday, 11 AM, B481

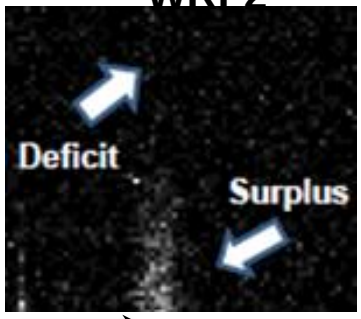
See C.K. Li's poster

Images of proton spectra vs. position obtained from NIF shot N101218 indicate ~MGauss B-fields in the direction of LEH



DIM 0-0 (pole)

WRF2

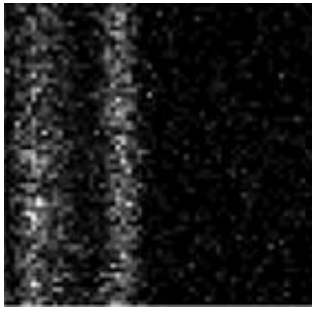


Space

Energy

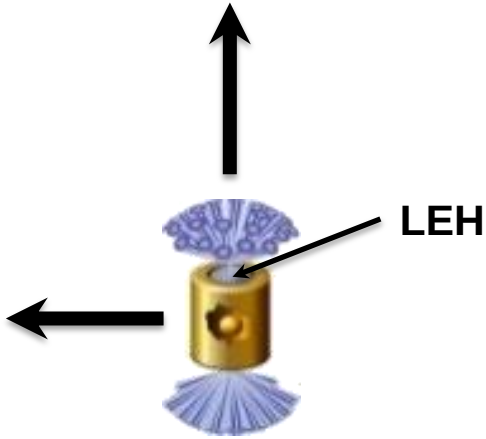
DIM 90-78 (equator)

WRF1



Space

Energy



C.K. Li et al.,
New J. Physics (2013).

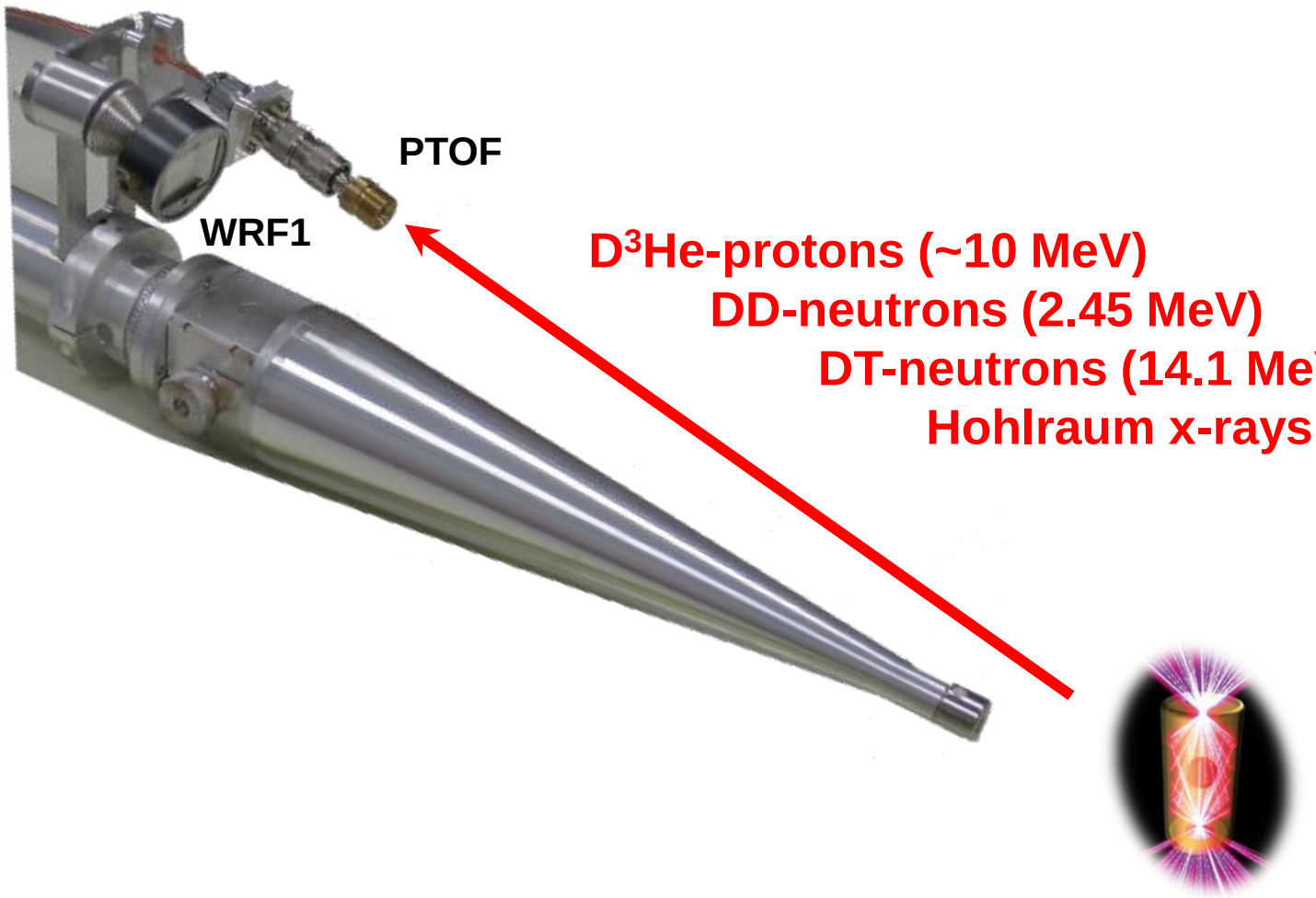
Outline of diagnostics and platforms with MIT involvement

- Wedge-Range-Filter (WRF) proton spectrometers
- **Particle Time-Of-Flight (PTOF) detector**
  - Studies of shock and compression dynamics (student: Hans Rinderknecht)
  - Studies of evolution of ρR and ρR asymmetries (student: Alex Zylstra)
- Magnetic Recoil Neutron Spectrometer (MRS)
- MIT accelerator facility – diagnostics development
- Developing new platforms and 2nd-generation diagnostics

See H. Rinderknecht's poster

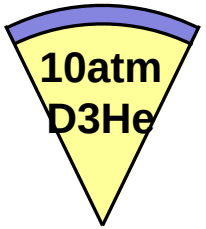
The Particle-Time-Of-Flight (PTOF) diagnostic is used to measure compression and *some* shock bang times at the NIF

DIM 90-78 (equator)

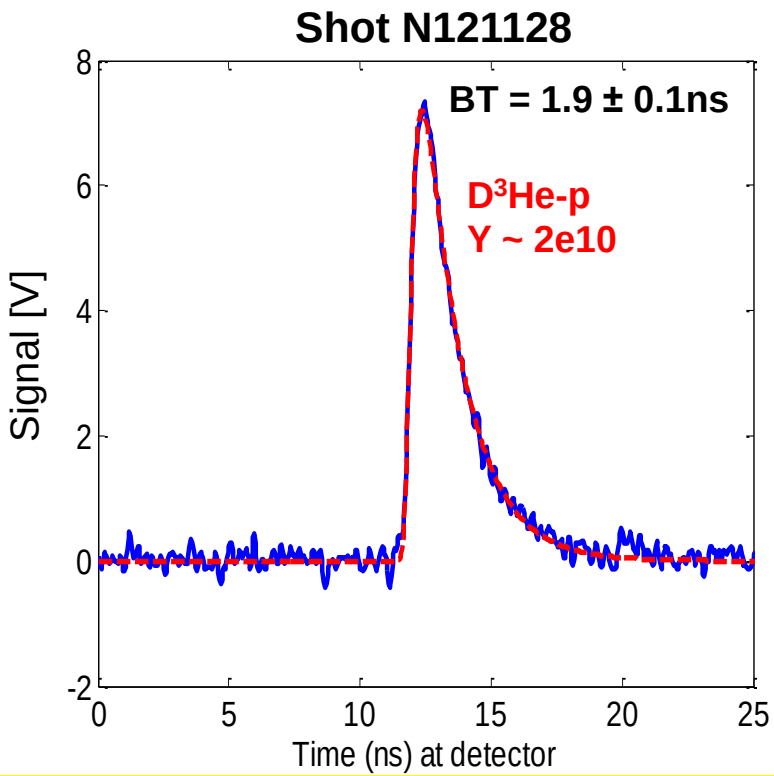


See H. Rinderknecht's poster

Shock bang time is accurately measured for all directly driven implosions, such as this NIF D3He one.



← 4 μm SiO_2
~40 kJ PDD



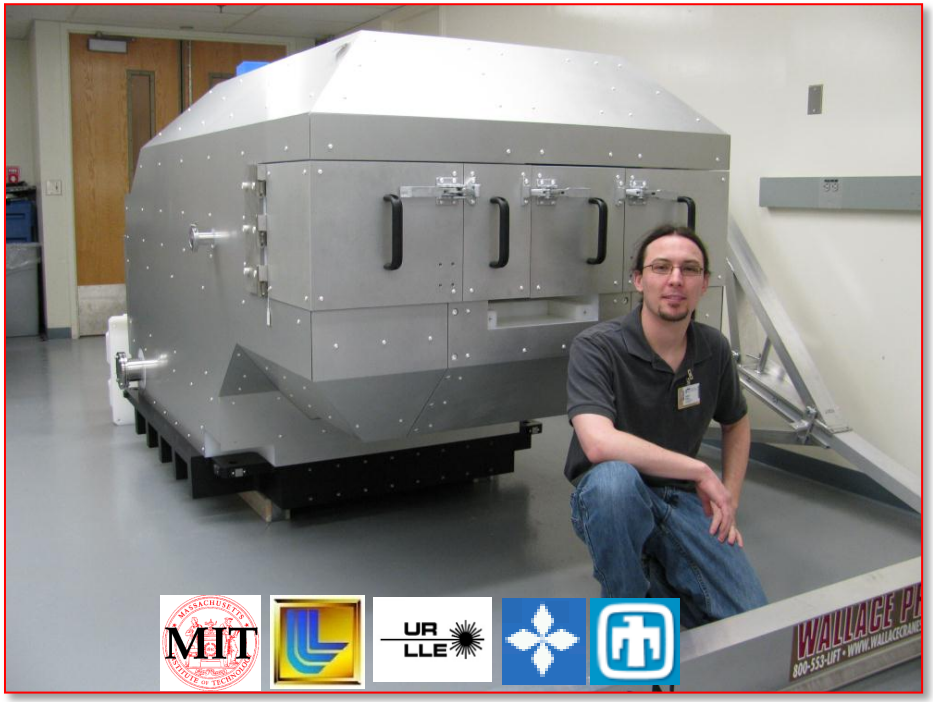
The 2nd-generation version of pTOF will be Magnetic pTOF: needed to circumvent the huge xray background of the hohlraum.

Outline of diagnostics and platforms with MIT involvement

- Wedge-Range-Filter (WRF) proton spectrometers
- Particle Time-Of-Flight (PTOF) detector
- **Magnetic Recoil Neutron Spectrometer (MRS)**
  - NIF ignition experiments (former student: Dan Casey**)
  - Plasma nuclear science experiments (former student: Dan Casey**)
- MIT accelerator facility – diagnostics development
- Developing new platforms and 2nd-generation diagnostics

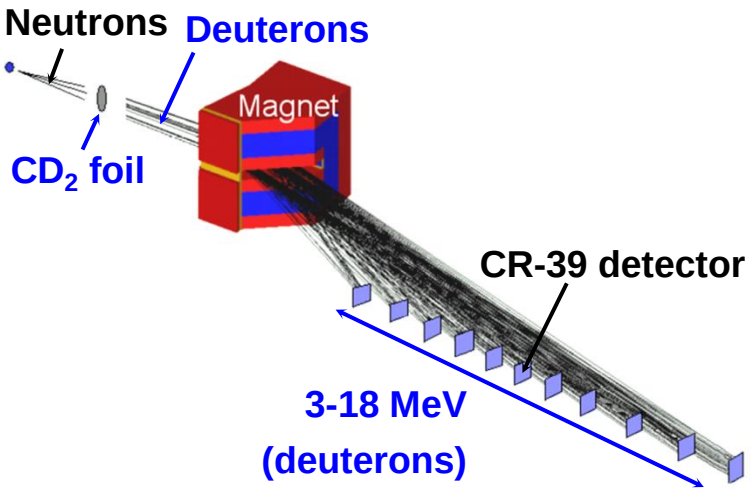
**** 1st PhD thesis based on NIF data.**

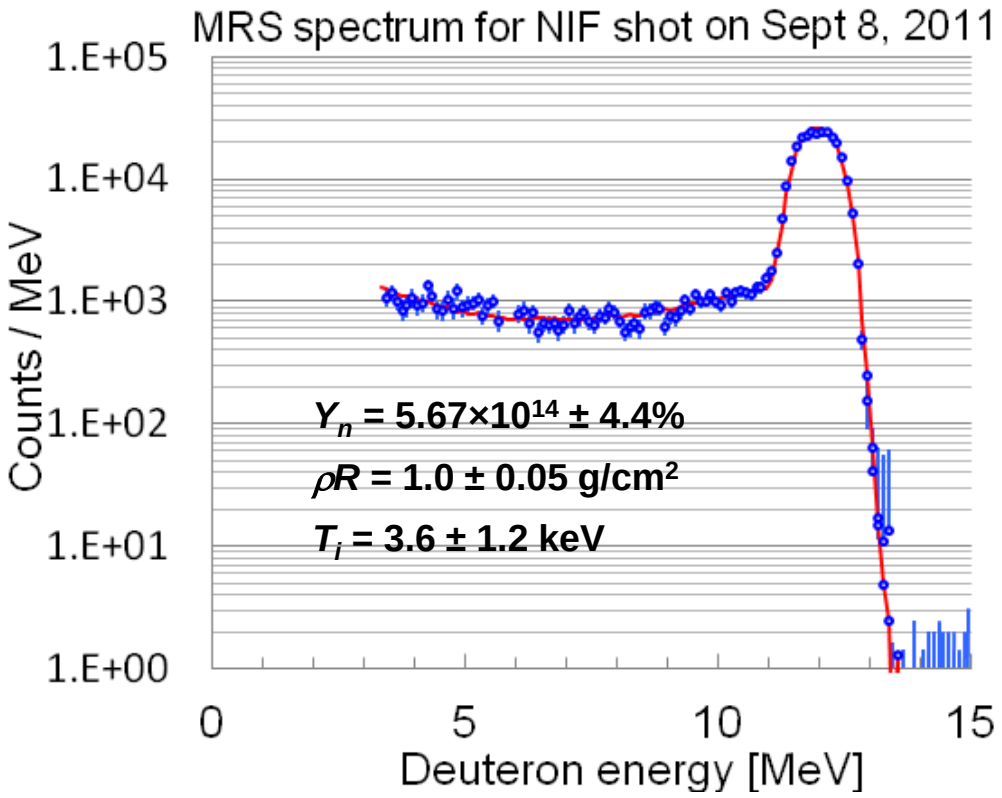
The MRS Neutron Spectrometer is used both for NIF ignition experiments and for plasma nuclear science experiments



See M. Gatu Johnson's poster

The MRS diagnostic, implemented by MIT, LLNL and LLE, has played an important role in ICF experiments at OMEGA and the NIF

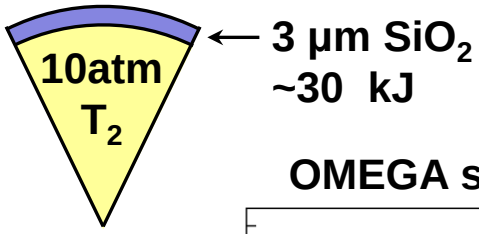




MRS data and neutron time-of-flight (nTOF) data indicate that the implosions performance has improved ~50x since the 1st layered shot in Sept 2010

See M. Gatu Johnson's poster

The MRS concept was first successfully tested on OMEGA for diagnosing ICF implosions and for conducting basic science

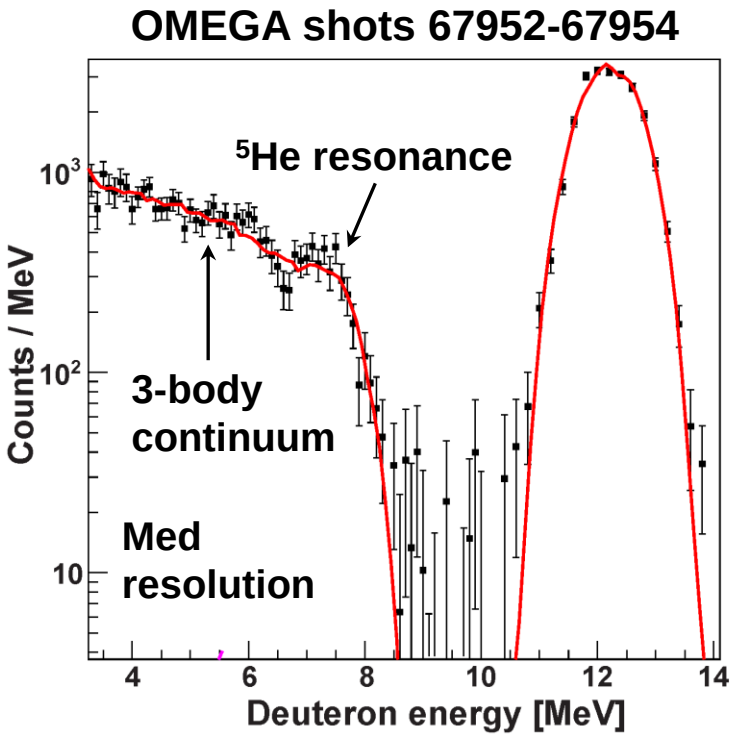


Possible T-T reactions:

T + T → ^{4}He + 2n (0-9.5 MeV)

T + T → ^{5}He + n (8.7 MeV)

T + T → ^{5}He* + n

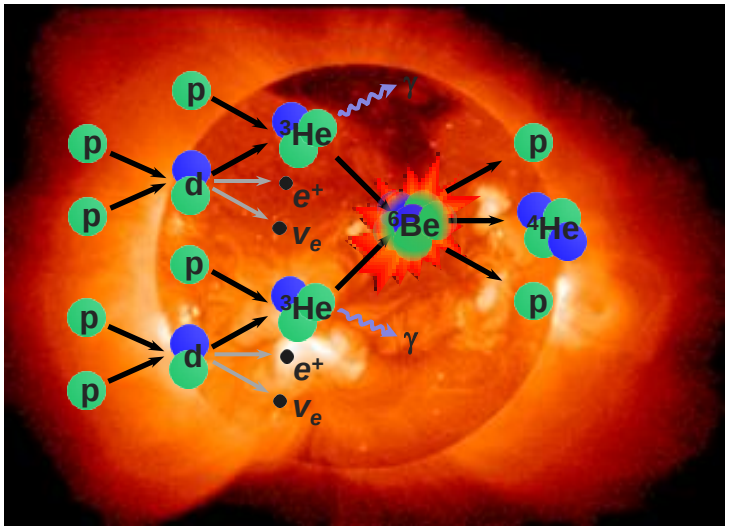


These T-T experiments are being conducted at the NIF to very high accuracy

D.T Casey et al., PRL (2012).

The ^{3}He-^{3}He mirror reaction, important for stellar nucleosynthesis, studied on OMEGA, can be studied with higher accuracy at the NIF

pp1 chain in hydrogen-burning stars



Possible ^{3}He-^{3}He reactions:

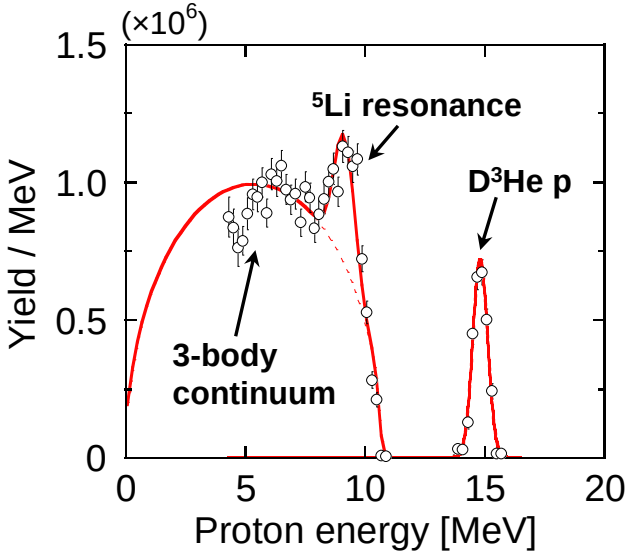
^{3}He + ^{3}He → ^{4}He + 2p (0-10.8 MeV)

^{3}He + ^{3}He → ^{4}He + (pp)

^{3}He + ^{3}He → ^{5}Li + p (9.2 MeV)

^{3}He + ^{3}He → ^{5}Li* + p

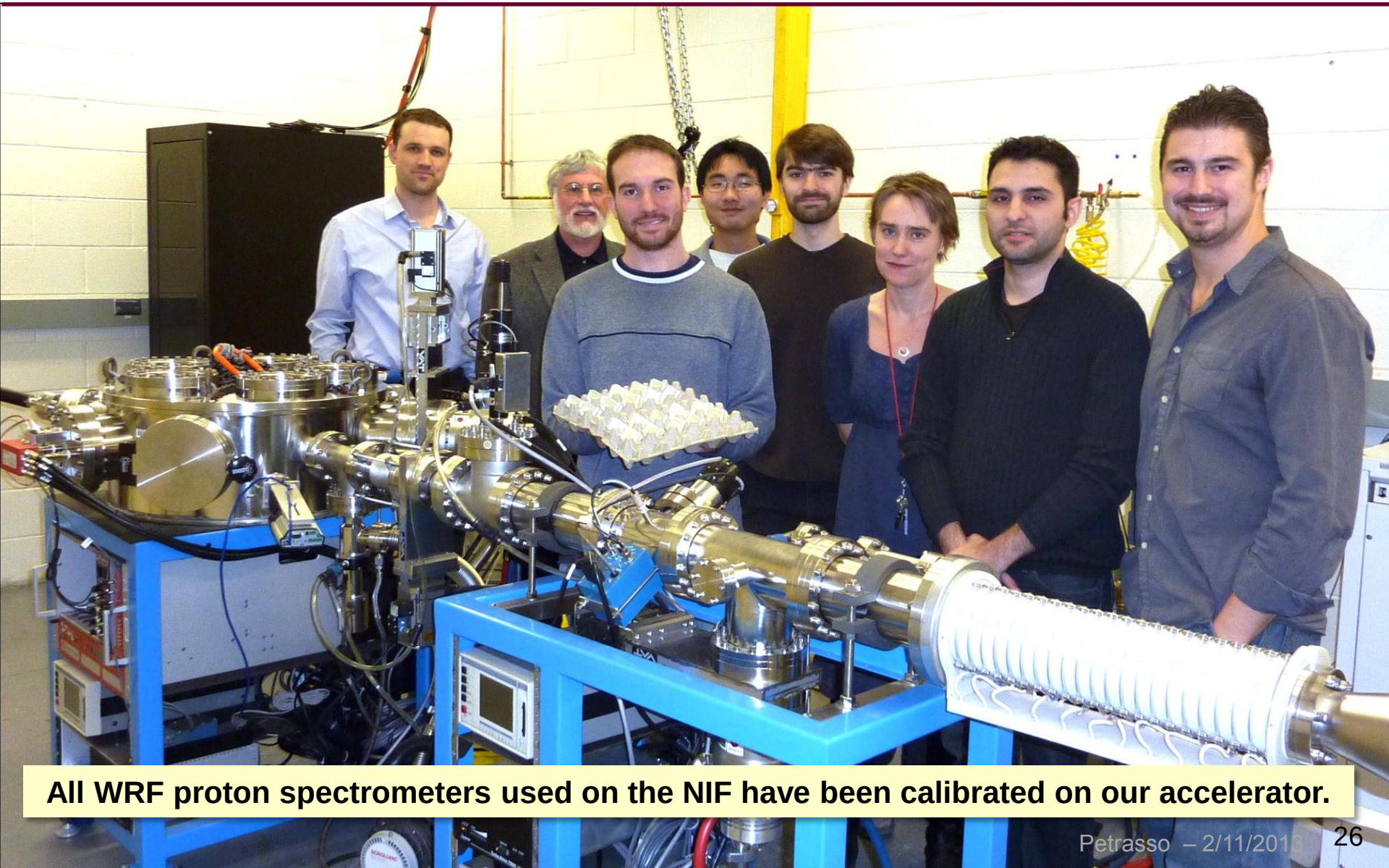
^{3}He-^{3}He proton spectrum from OMEGA shots 61251-61252



Outline of diagnostics and platforms with MIT involvement

- Wedge-Range-Filter (WRF) proton spectrometers
- Particle Time-Of-Flight (PTOF) detector
- Magnetic Recoil Neutron Spectrometer (MRS)
- **MIT accelerator facility – diagnostics development**
  - Developing diagnostics and experimental platforms for the NIF
  - Providing students with real hands-on experience
- Developing new platforms and 2nd-generation diagnostics

The MIT accelerator facility for developing and calibrating diagnostic platforms for the NIF



All WRF proton spectrometers used on the NIF have been calibrated on our accelerator.

Outline of diagnostics and platforms with MIT involvement

- Wedge-Range-Filter (WRF) proton spectrometers
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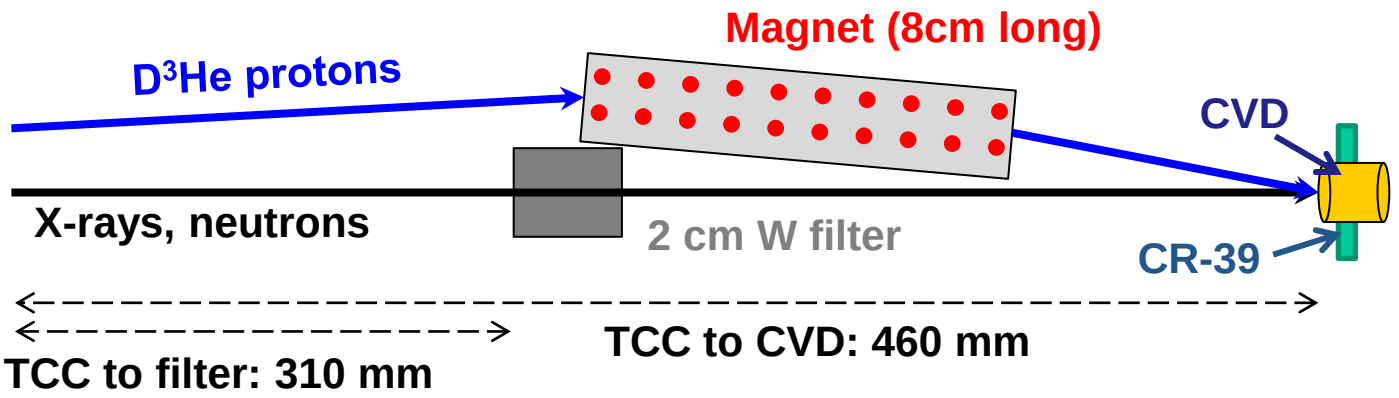
- MIT accelerator facility – diagnostics development
- **Developing new platforms and 2nd-generation diagnostics**
  - PTOF → MagPTOF (student: Hans Rinderknecht)
  - Proton Core Imaging System (student: Alex Zylstra)
  - Proton radiography (student: Mike Rosenberg)
  - WRF → Step-WRF / pinhole-scattering WRF (student: Mike Rosenberg)
  - WRF → Neutron-WRF (student: Alex Zylstra)
  - MRS → Time resolved MRS (student: New student)

See H. Rinderknecht's poster

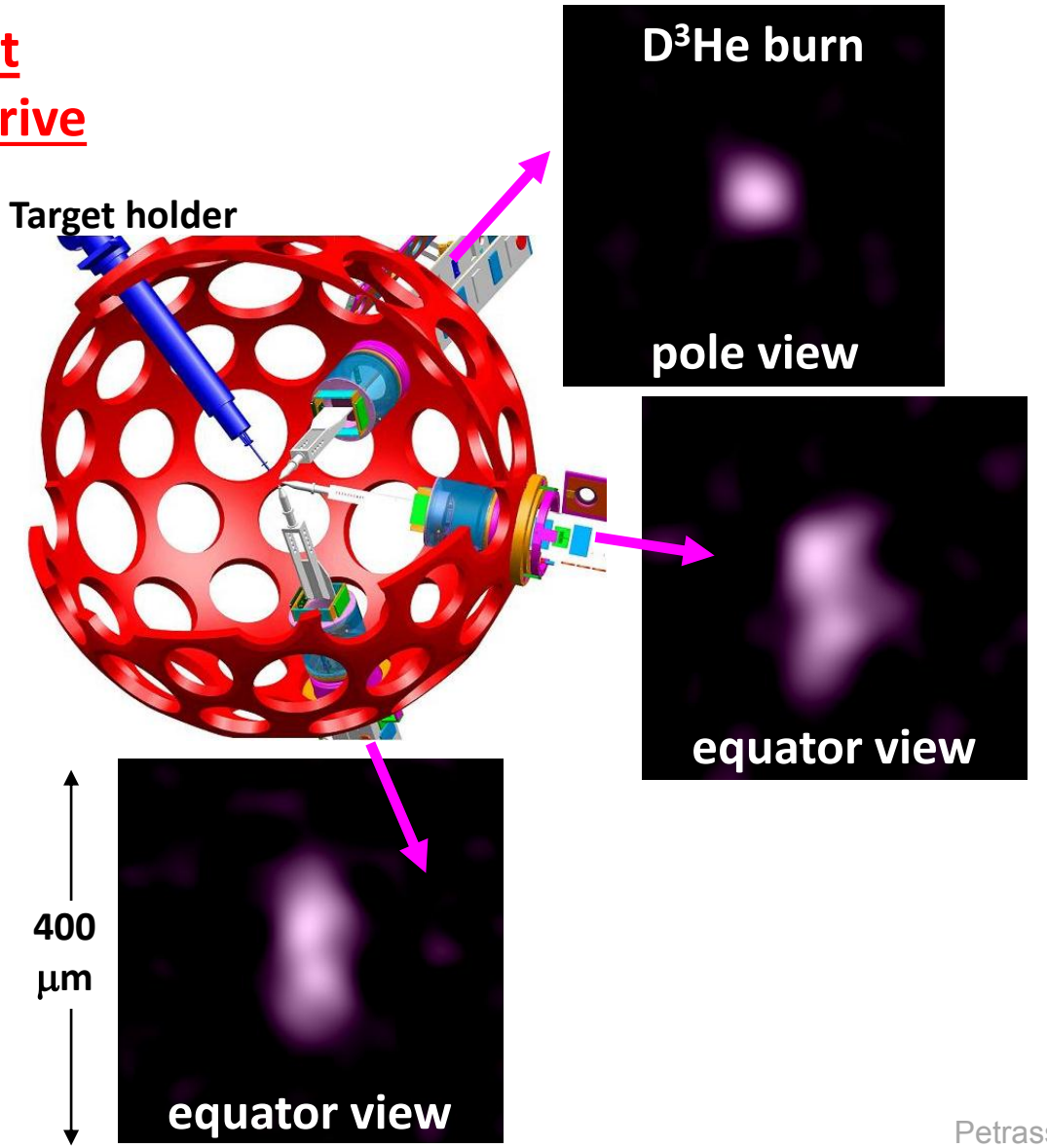
A 2nd-generation, magnet-based PTOF will be implemented for measuring both shock and compression bang times on the NIF for indirectly driven D3He implosions.



See H. Rinderknecht's poster and talk

To enhance mix studies, a method of imaging and measuring D^3He burn regions at OMEGA* is being ported to the NIF

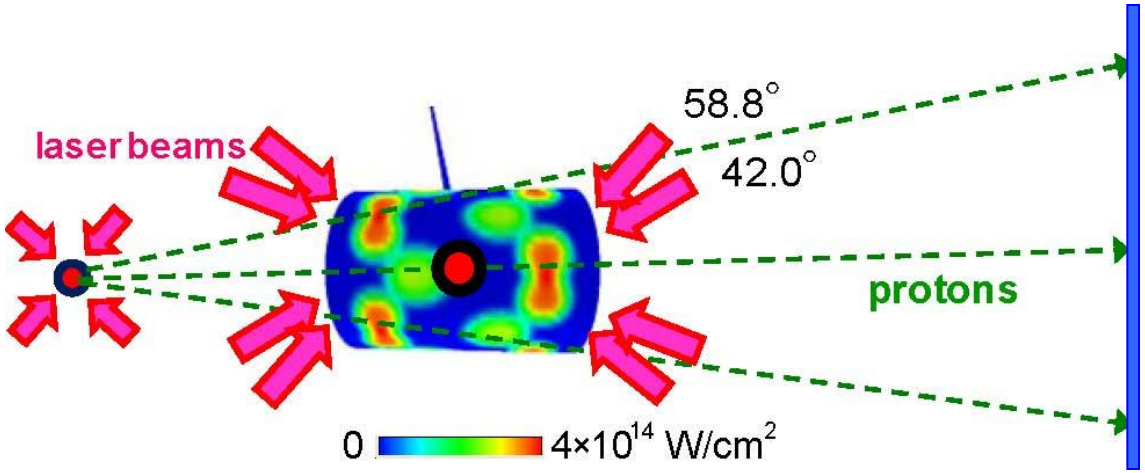
OMEGA experiment
With asymmetric drive



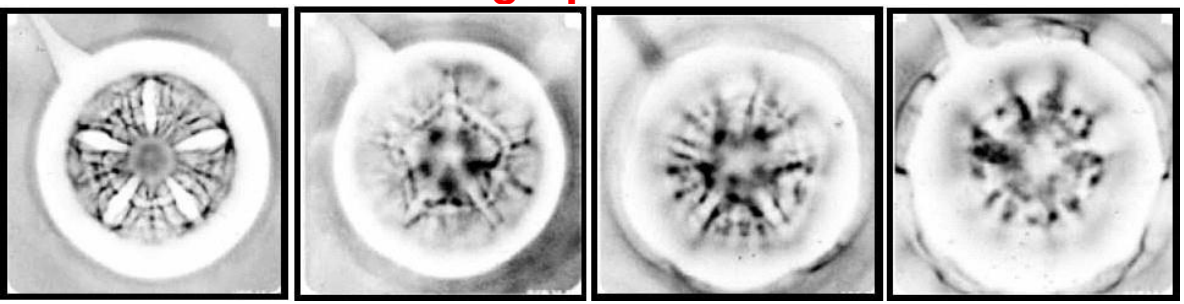
*F.H. Séguin *et al.*, RSI (2004), PoP (2006), and to be submitted

See C.K. Li's poster

A monoenergetic-proton-radiography technique used on OMEGA is being ported to the NIF: 1st experiments in March



15-MeV-Proton radiographs of OMEGA hohlraum



0.9 ns **1.6 ns** **2.2 ns** **2.8 ns**

C.K Li *et al.*,
Science (2010)

NIF Applications

- **Electromagnetic fields and plasma flows in hohlraums**
- **Fields effects in NIF VIEW-FACTOR experiments**
- **Backlighting of direct-drive ICF implosions**
- **Scaled astrophysical jets**
- **Magnetic reconnection**
- **Collisionless shock**
- **Charged-particle stopping power**
- **Rayleigh-Taylor and other hydrodynamical instabilities**
- **……**

Summary

Opportunities for academic participation in programmatic work at the NIF have allowed MIT to

- **Work with collaborators on the development of several nuclear diagnostics and platforms for the NIF**
- **Share in the excitement of scientific discovery and the grand challenge of ignition at the NIF**
- **Give PhD students extraordinary experience along with data for their theses**

The final NIC report states that a primary goal is the enhancement of diagnostic measurements.

MIT posters about development of diagnostics and platforms

Monday:

- **Chikang Li** *et al.*, **Observation of strong fields around LEHs of ignition-scale holhraum in ICF experiments at the NIF**

Tuesday:

- **Mike Rosenberg** *et al.*, **Studies of Shock-Driven Exploding Pusher Implosions on the NIF and OMEGA**
- **Johan Frenje** *et al.*, **Next-generation neutron spectrometry for probing ICF implosions and for conducting basic-science experiments at OMEGA and NIF**
- **Maria Gatu Johnson** *et al.*, **Novel nuclear science experiments on the NIF and OMEGA relevant to stellar nucleosynthesis**
- **Hans Rinderknecht** *et al.*, **Quantitative assessment of fuel ρR, mix, and kinetic effects using combined D^3He and DT secondary yields from D_2 implosions**
- **H. Sio, N. Sinenian** *et al.*, **Upgrade of the MIT Accelerator (LEIA) for development of nuclear diagnostics for Omega, Z and the NIF**
- **Alex Zylstra** *et al.*, **Charged-particle measurements of ρR asymmetry at shock-bang time in NIF implosions**

See also H. Rinderknecht's seminar on Thursday 11 in B481