Compact DD-n spectrometer for Yield, $T_i$, $\rho_R$ & symmetry at Z, OMEGA, NIF, and for Discovery Science

$D + D \rightarrow ^3{\text{He}} + n \ (2.45 \text{ MeV})$

Simulated NIF DD-n spectrum

Predicted measurement

Neutron Yield

Neutron Yields / MeV (arb. Units)

Neutron Energy (MeV)
Compact DD-n spectrometers enable multiple views of an implosion for symmetry studies of yield, $\rho R$, ... 

- Small
- Passive

Prototype spectrometer size
~ 5 cm x 7 cm
Collaborators

**MIT**
- W. Han*
- L. Milanese*,¹
- F. Seguin
- B. Lahmann*
- M. Gatu Johnson
- C. Waugh
- H. Sio*
- N. Kabadi*
- C. Wink*
- G. Sutcliffe*
- J. Rojas-Herrera*
- A. Birkel
- J. Frenje
- C.K. Li
- R. Petrassso

**SNL**
- K. Hahn
- B. Jones
- G. Rochau

**LLNL**
- R. Bionta
- D. Casey
- C. Yeamans

**U of R – LLE**
- V.Yu. Glebov
- J. Knauer
- T.C. Sangster
- C. Stoeckl

*Students
¹Currently at Imperial College, London
Motivation for absolute spectral DD neutron measurements

Method: n-p recoil with CR-39 detectors and “coincidence” noise reduction

Initial tests of concept elements:

a. Measured spectrum of accelerator-generated neutrons without using “coincidence” noise reduction


c. On-going tests of coincidence counting at MIT Accelerator Facility:
   (i) Signal only tests
   (ii) Signal and 2.5 MeV neutron noise background together
   (iii) Monte-Carlo simulations of signal and background
   (iv) Determination of spectrometer sensitivity, characteristics
   (v) Fully integrated test of all spectrometer elements

Future: Field at Z, Omega, and the NIF.
A DD-n recoil spectrometer can be made using a passive CR-39 nuclear track detector

CR-39 records recoil protons from $n,p$ interactions in a CH$_2$ foil
A DD-n recoil spectrometer can be made using a passive CR-39 nuclear track detector

**CR-39 records recoil protons from $n,p$ interactions in a CH$_2$ foil**

Etching the CR-39 reveals proton tracks on the surface

Proton energy will be determined based on track size on the CR-39

Neutron background will be reduced with coincidence counting
Using this geometry, an estimated response to monoenergetic 2.45-MeV neutrons is calculated.

Simulated spectrum of protons on the CR-39

Inferred neutron spectrum

Response FWHM ~ 0.5 MeV

2.45 MeV
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A proof-of-principle test of a prototype was carried out on the MIT accelerator without using coincidence noise reduction.*

Tests utilized DD-n from fusion reactions in the accelerator target

\[ \text{D + D} \rightarrow ^3\text{He} + \text{n} \ (2.45 \text{ MeV}) \]
\[ \text{D + D} \rightarrow ^3\text{T} + \text{p} \ (3.01 \text{ MeV}) \]

The power of the associated particle method
The measured spectrum shape agrees well with expectations

Accelerator-generated DD-n spectrum

*Simulated with MCNP by D. Casey
The measured detection efficiency provides a well-defined quantitative sensitivity.

- Mean = $3.73 \times 10^{-5}$ protons/neutron
- Expected signal level at 20 cm on Z:
  - Yield: $1 \times 10^9$ → Signal: ~100
  - Yield: $1 \times 10^{12}$ → Signal: ~100,000
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• **Future**: Field at Z, Omega, and the NIF.
Test data with simple CR-39 packages were acquired on 14-18 September 2015 during MagLIF shots 2849-52 (DD-n yields ~ $3\times10^{10} - 2\times10^{12}$)

Data about to be analyzed
Test data with simple CR-39 packages were acquired on 14-18 September 2015 during MagLIF shots 2849-52 (DD-n yields $\sim 3\times10^{10} - 2\times10^{12}$).
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The Coincidence Counting Technique (CCT)* is used to eliminate neutron-induced noise (and “intrinsic” noise) in CR-39 track data.

* D. T. Casey et al., RSI (2011)
The Coincidence Counting Technique (CCT)* is used to eliminate neutron-induced noise (and “intrinsic” noise) in CR-39 track data.

These tracks are coincident in position, and are accepted as data.

These tracks are NOT coincident in position, and are rejected as noise.

* D. T. Casey et al., RSI (2011)
Tests of coincidence counting are being conducted at the MIT Accelerator Facility

(i) Signal only tests using DD protons from MIT accelerator

First track etch before bulk etch:

Accelerator shot A2015091702
Tests of coincidence counting are being conducted at the MIT Accelerator Facility

(i) Signal only tests using DD protons from MIT accelerator

First track etch before bulk etch:

Second track etch after 52 \( \mu \text{m} \) bulk etch:

Standard front-side analysis:
8533 protons counted

CCT analysis:
8540 protons counted

Standard front-side analysis:
8536 protons counted
Next steps include noise rejection tests using neutrons from our DD neutron generator

(ii) Signal and 2.5 MeV neutron noise together (noise from DD-n generator)

(iii) Monte-Carlo simulations of signal and background

(iv) Determination of spectrometer sensitivity, characteristics

(v) Fully integrated test of all spectrometer elements

Our DD and DT neutron sources can easily generate neutron fluences replicating conditions at 1e7-1e15 yield applicable to OMEGA, Z and NIF
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Future: Field at Z, Omega, and the NIF
For programmatic and Discovery Science, DD-n spectrometers will be fielded at:

- Z
- OMEGA
- NIF

This will offer a great opportunity for MIT PhD students -- Harry Han, Lucio Milanese, Graeme Sutcliffe, … -- to be directly involved with science on these premier HED facilities.
END
The Coincidence Counting Technique (CCT)* for eliminating noise in CR-39 track detectors

The CCT is used to:
- discriminate between proton-induced and neutron-induced tracks
- reduce the intrinsic and neutron-induced noise by a factor of 100

Bulk etch: up to 200 µm removed

*D. T. Casey et al., RSI (2011)
We can scale the prototype test results to estimate performance with a plausible NIF implosion.

**Assumed parameters at bang time**

- CH shell: \( \rho R \sim 600 \text{ mg/cm}^2 \)
- D fuel: \( \rho R \sim 150 \text{ mg/cm}^2 \)
- Ion temperature: \( T_i \sim 3 \text{ keV} \)

*Simulated by M. Gatu Johnson using MCNP*
A neutron generator will be used to expose CR-39 to the same level of neutron fluence of the Z experiments at SNL.

The signal noise coming from the neutrons will be significantly reduced by employing the coincidence counting technique.