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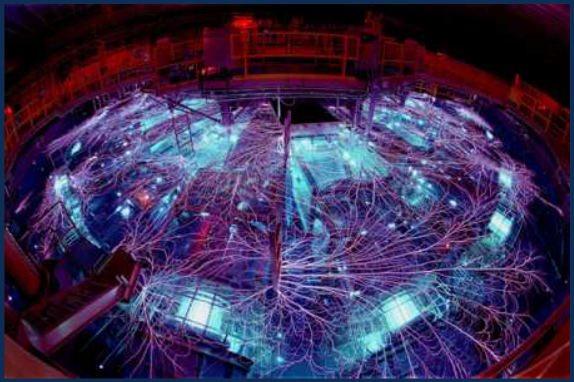

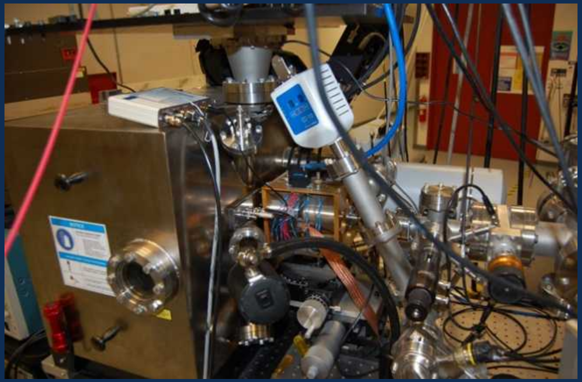

MagLIF Experimental Results

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Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

The first fully-integrated MagLIF experiments successfully demonstrated the promise of the concept.

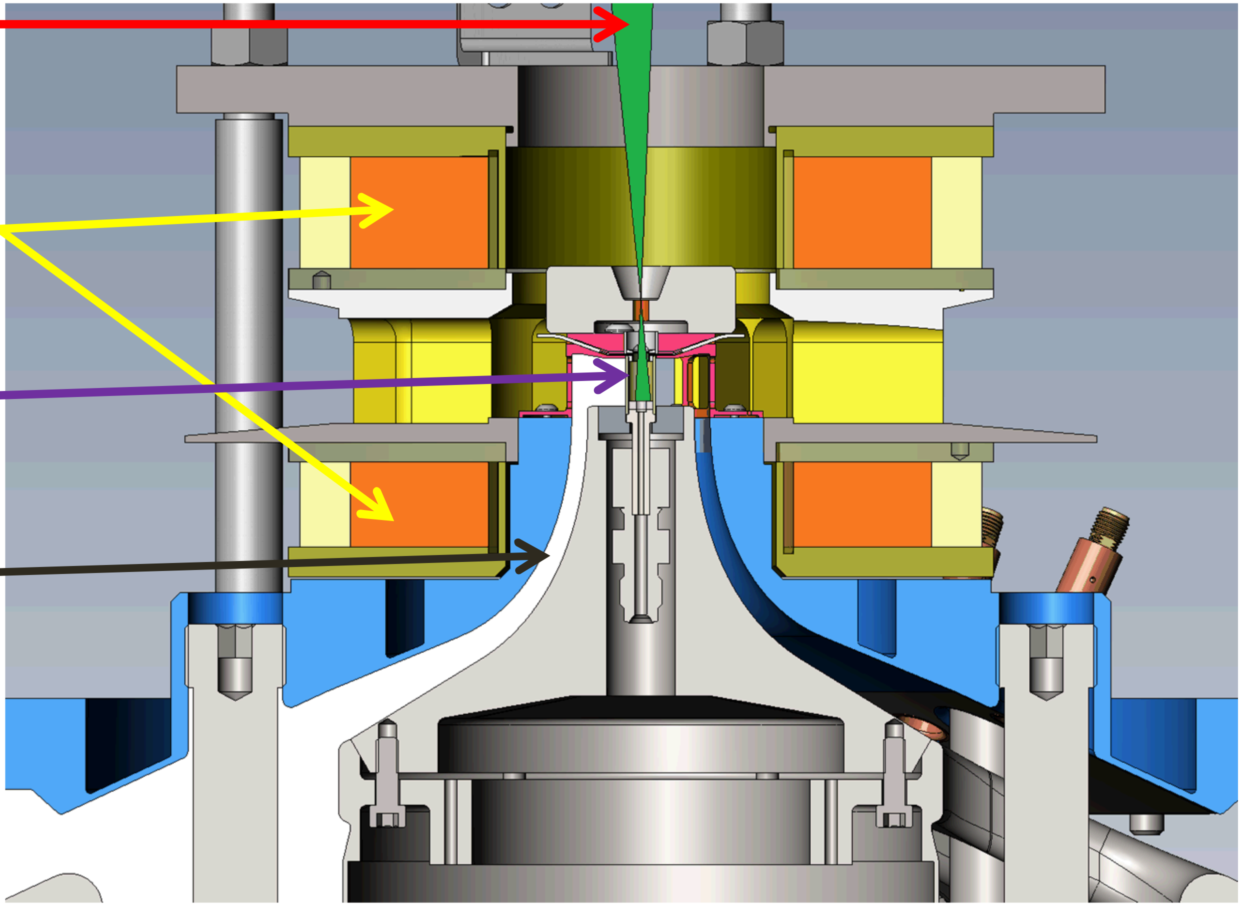
- Thermonuclear neutron generation
  - 0.5-2e12 primary DD neutrons (0.08-0.3 kJ DT equivalent)
- Fusion-relevant stagnation temperatures
  - $T_{ion} \approx$ 2-2.5 keV $T_{electron} \approx$ 2.9-3.5 keV
- Stable pinch with narrow emission column at stagnation
  - Width of emission ≈ 60-120 microns, height of emission ≈ 4-6 mm
- Successful flux compression
  - B*r ≈ 40-110 T-cm

Outline

- Summary of experimental results
- Experimental setup
- Details of integrated MagLIF experimental results
  - Fusion yield and ion and electron temperature measurements
  - Stagnation measurements
    - Bang time (x-ray and neutron)
    - X-ray imaging
  - Evidence of magnetic flux compression
    - DT/DD yield ratio
- Conclusions

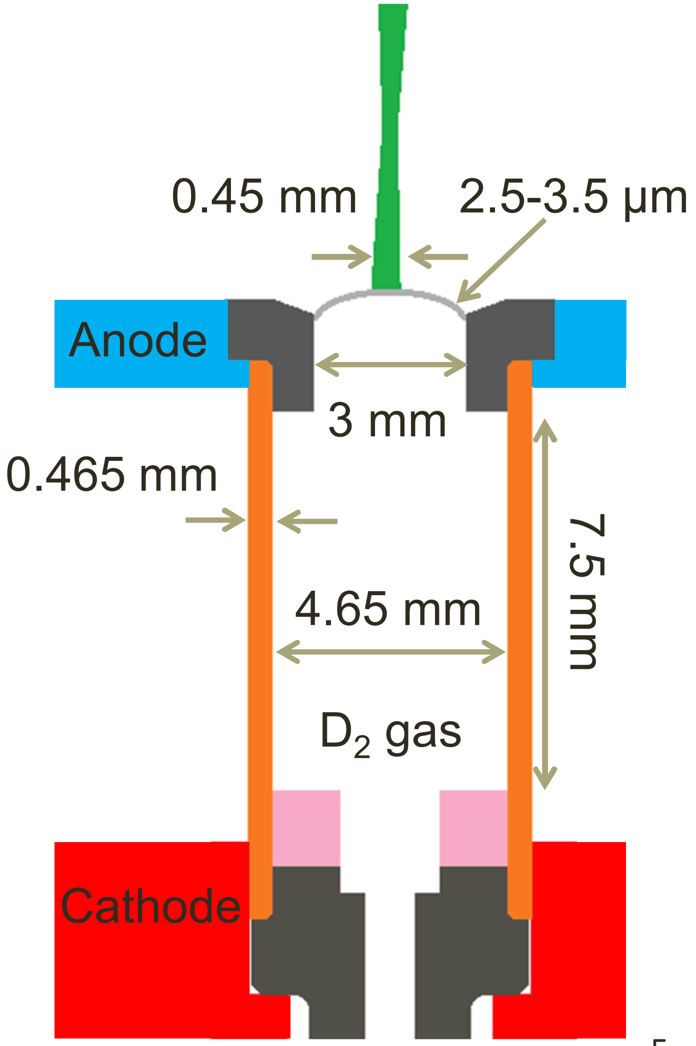
Prior to the integrated experiments, a series of focused experiments were conducted to test all of the critical components of MagLIF

- Laser preheat
  - >20 laser-only experiments
- Applied magnetic field
  - >10 experiments
- Liner Stability
  - >30 experiments
- Modified power flow
  - Geometry scan to minimize losses
  - >20 experiments
- Fully integrated shots
  - 5 Z + ZBL shots



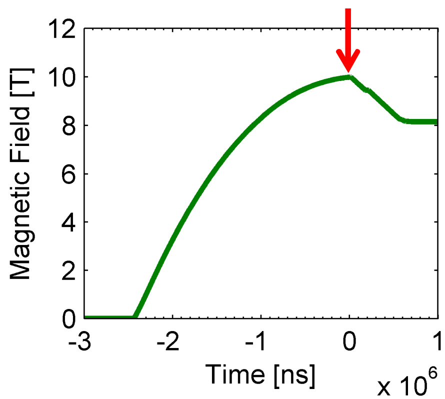
The target design for these initial experiments incorporates the knowledge gained from focused experiments and extensive simulations

- **Beryllium liner with aspect ratio 6**
  - **Thick liner is more robust to instabilities**
  - **Still allows diagnostic access > 5 keV**
- **Top and bottom implosion cushions**
  - **Mitigates wall instability**
- **Standoff between LEH and imploding region**
  - **Avoid window material mixing with fuel**
- **Exit hole at bottom of target**
  - **Avoid interaction with bottom of target**



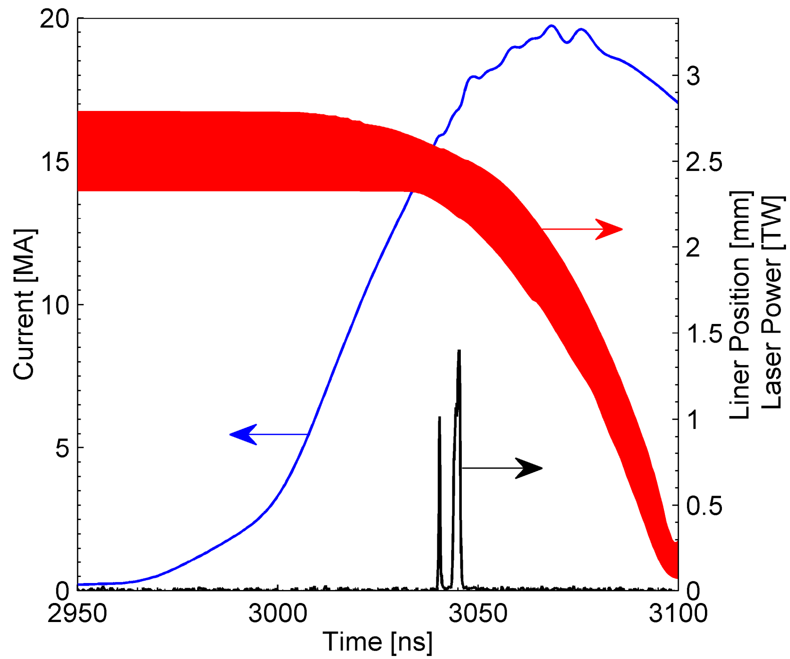
Initial experiments were conducted at I = 20 MA, B = 10 T, and Laser = 2.5 kJ

Time of experiment



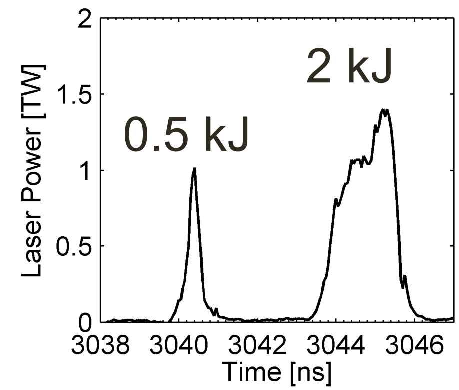
Magnetic field risetime is approximately 2 ms

B is constant over the timescale of the experiment

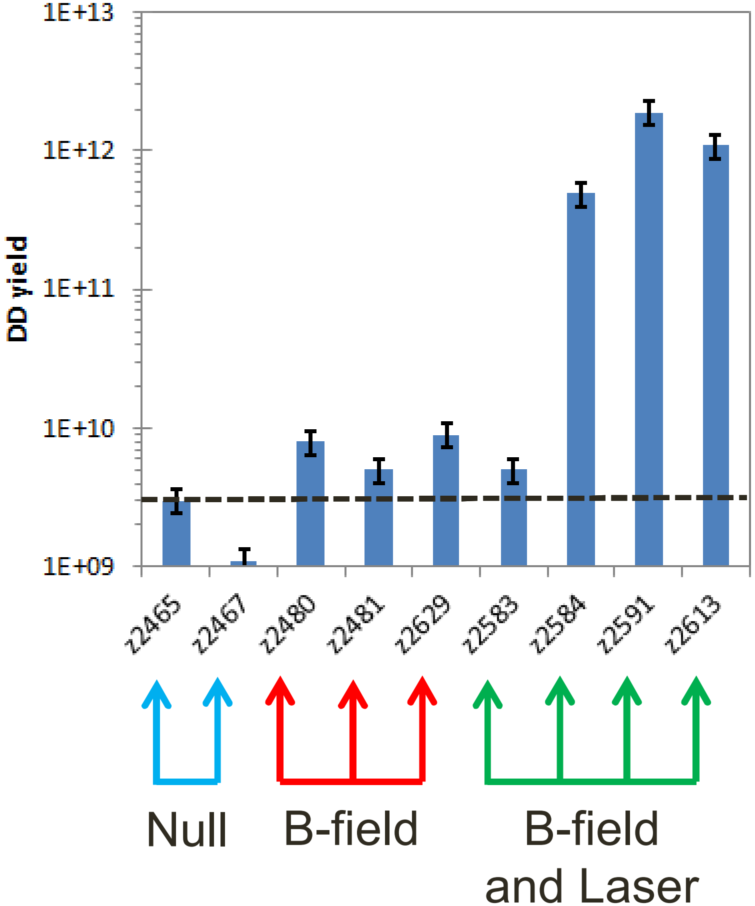


Peak current is 20 MA
Magnetic field is 10 T
Total laser energy is 2.5 kJ

Laser energy is split into 2 pulses:
1st pulse intended to destroy LEH
2nd pulse intended to heat fuel

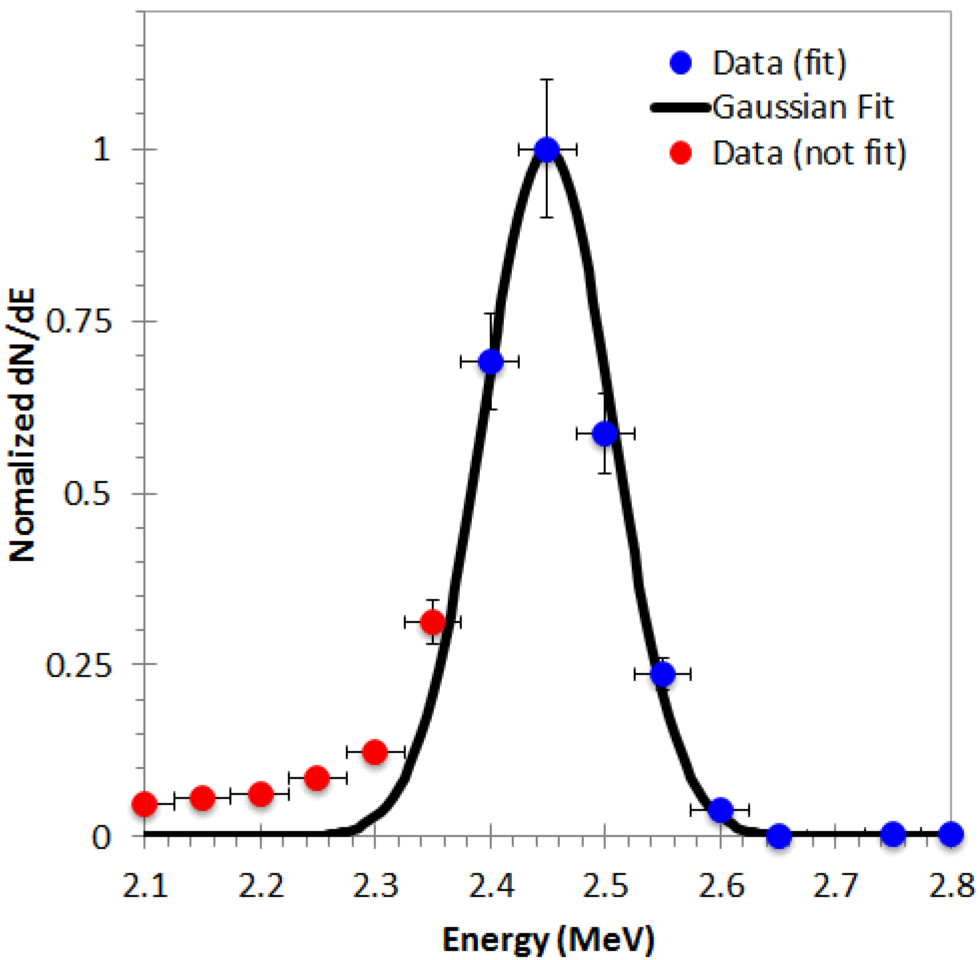


Thermonuclear DD yields in excess of 10^{12} were observed in experiments with laser and B-field



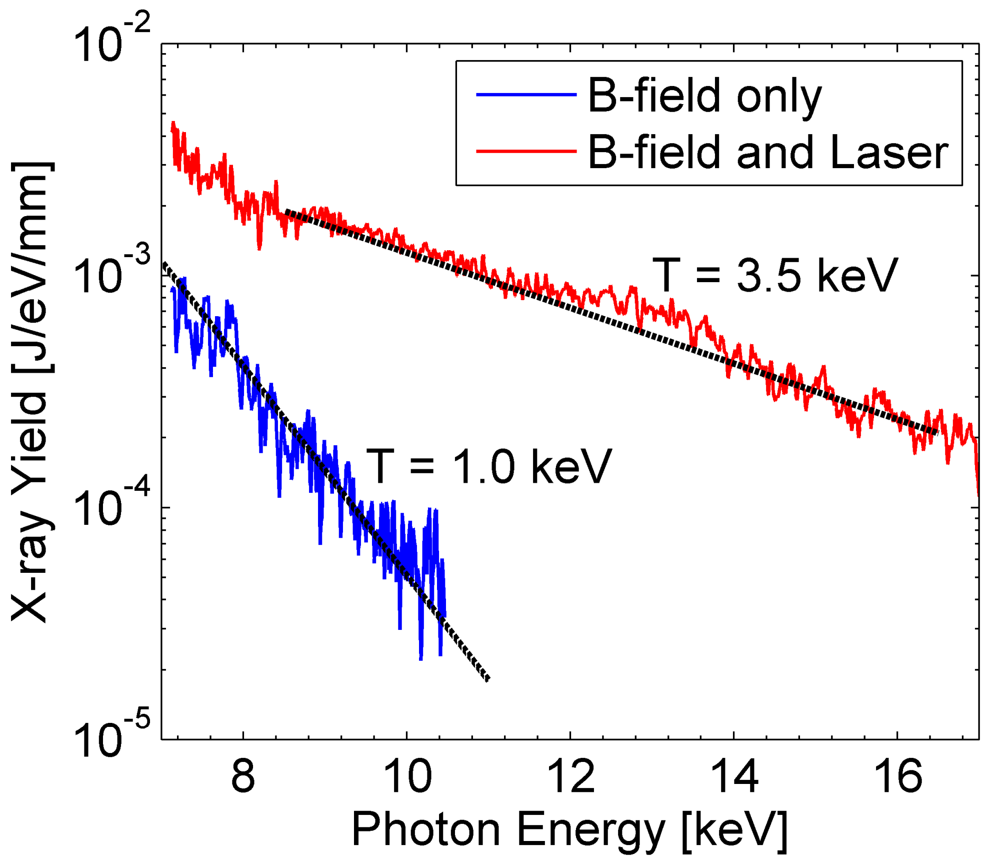
- High yields were only observed on experiments incorporating both applied magnetic field and laser heating
- A series of experiments without laser and/or B-field produced yields at the background level of the measurement
- Result of z2583 is not well understood nor reproduced at this time

Neutron Time of Flight spectra indicate ion temperatures greater than 2 keV at stagnation



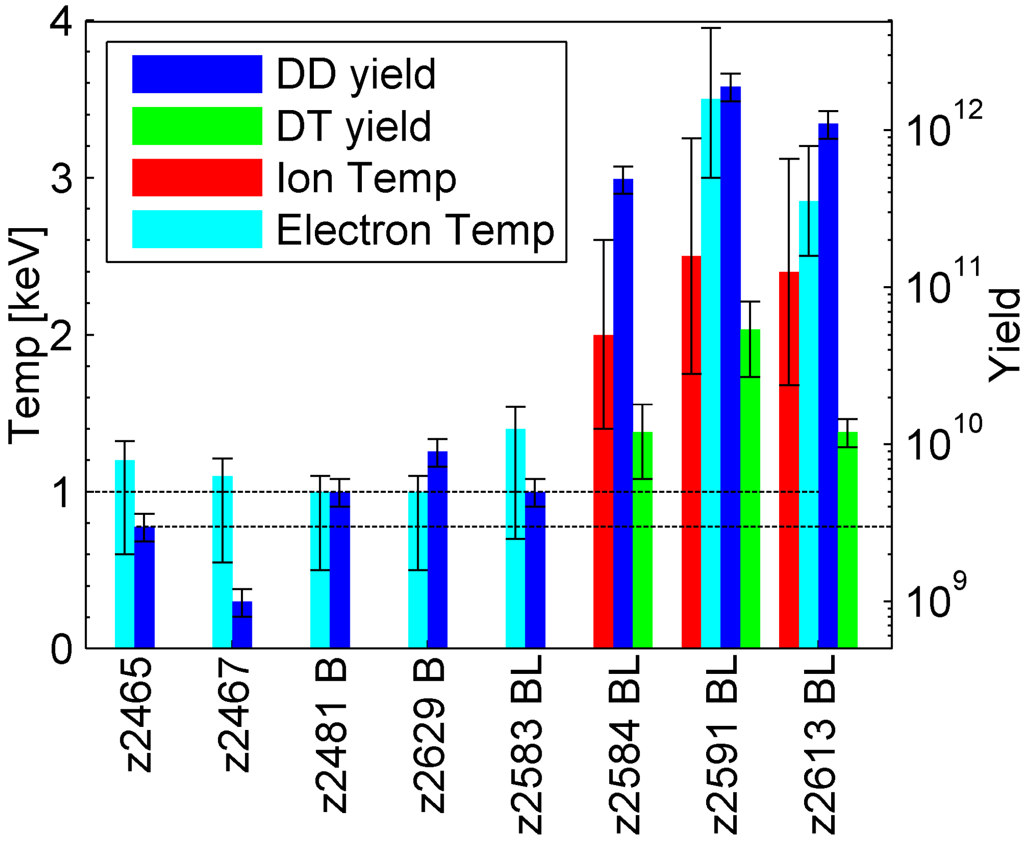
- **DD neutron peak observed in experiments with significant yield (>1e10)**
- **Gaussian profile fit to high energy side of peak to determine ion temp**
- **Ion temperatures were between 2 and 2.5 keV for high yield experiments**

High energy x-ray spectra indicate electron temperatures = 2.9-3.5 keV in experiments with laser and B-field



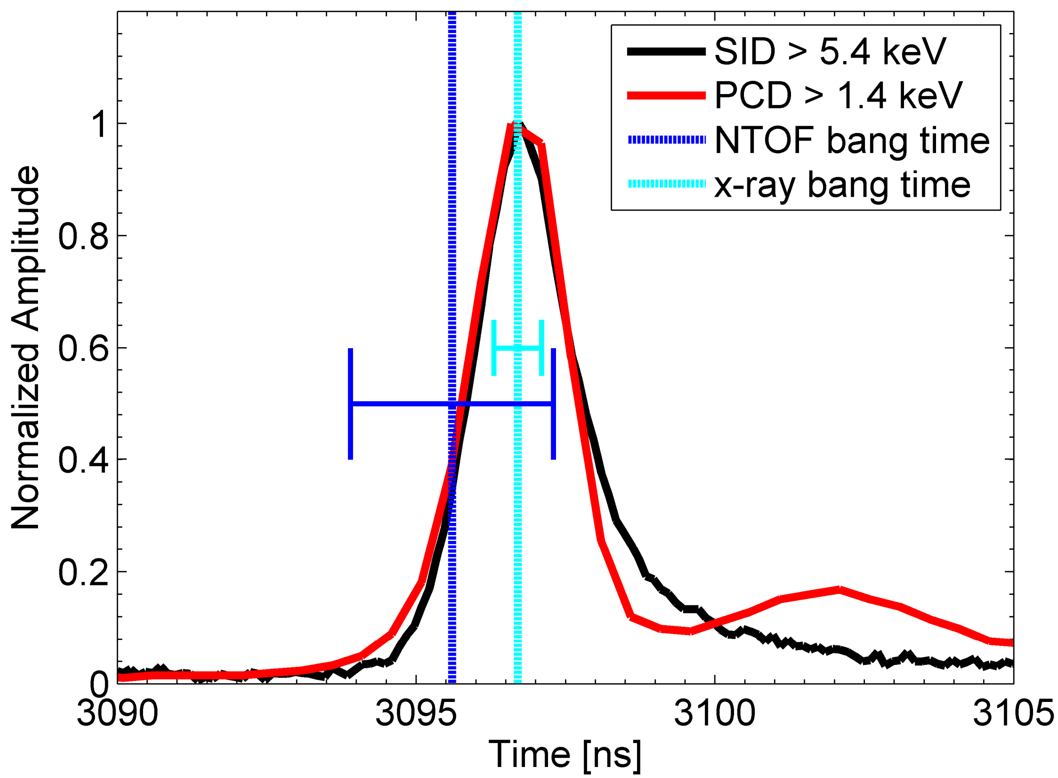
- Electron temperatures inferred from continuum emission
- > 2 keV observed on shots with yield
- Approximately 1 keV observed on shots without yield
- Lower bound on measurement capability is around 1 keV

Neutron yield, ion temperature, and electron temperature all trend as expected



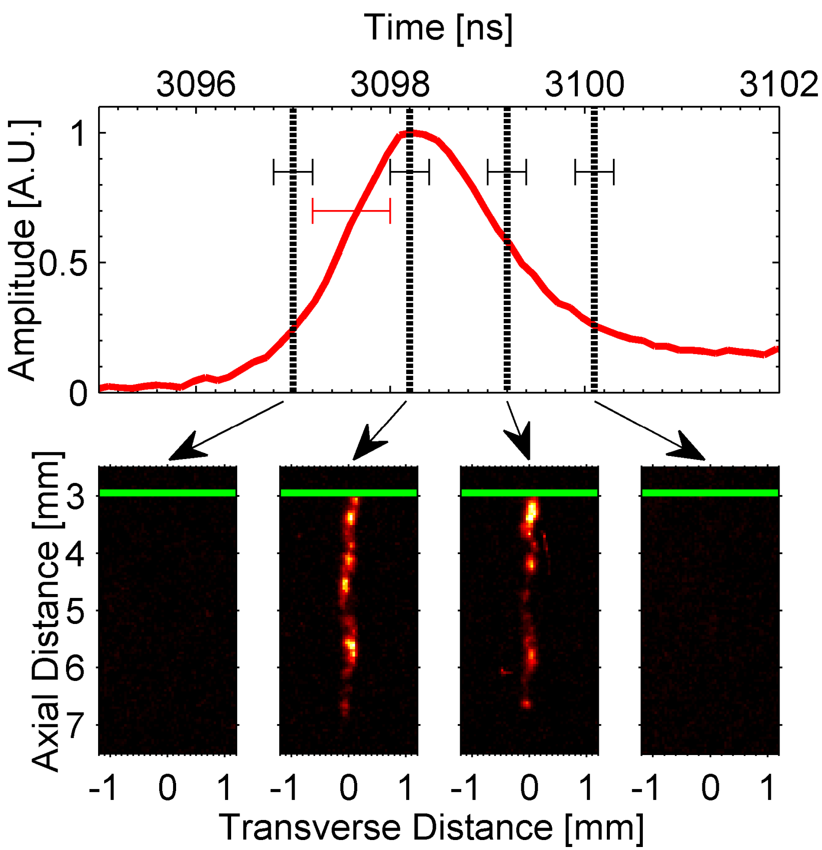
- **Experiments with $T_{electron} \approx 1$ keV have negligible DD yield**
- **For $T_i \approx T_e > 2$ keV, significant yield is observed**
- **Measurable DT yield is observed on experiments with high DD yield (more on this later)**

Narrow (<2 ns FWHM) peak on PCD and Si Diode signals is consistent with NTOF bang time estimate



- **Narrow x-ray signature only observed on experiments with significant neutron yield**
- **X-ray burst has high energy components**
- **X-ray bang time and NTOF bang time agree within the uncertainty of the measurements**

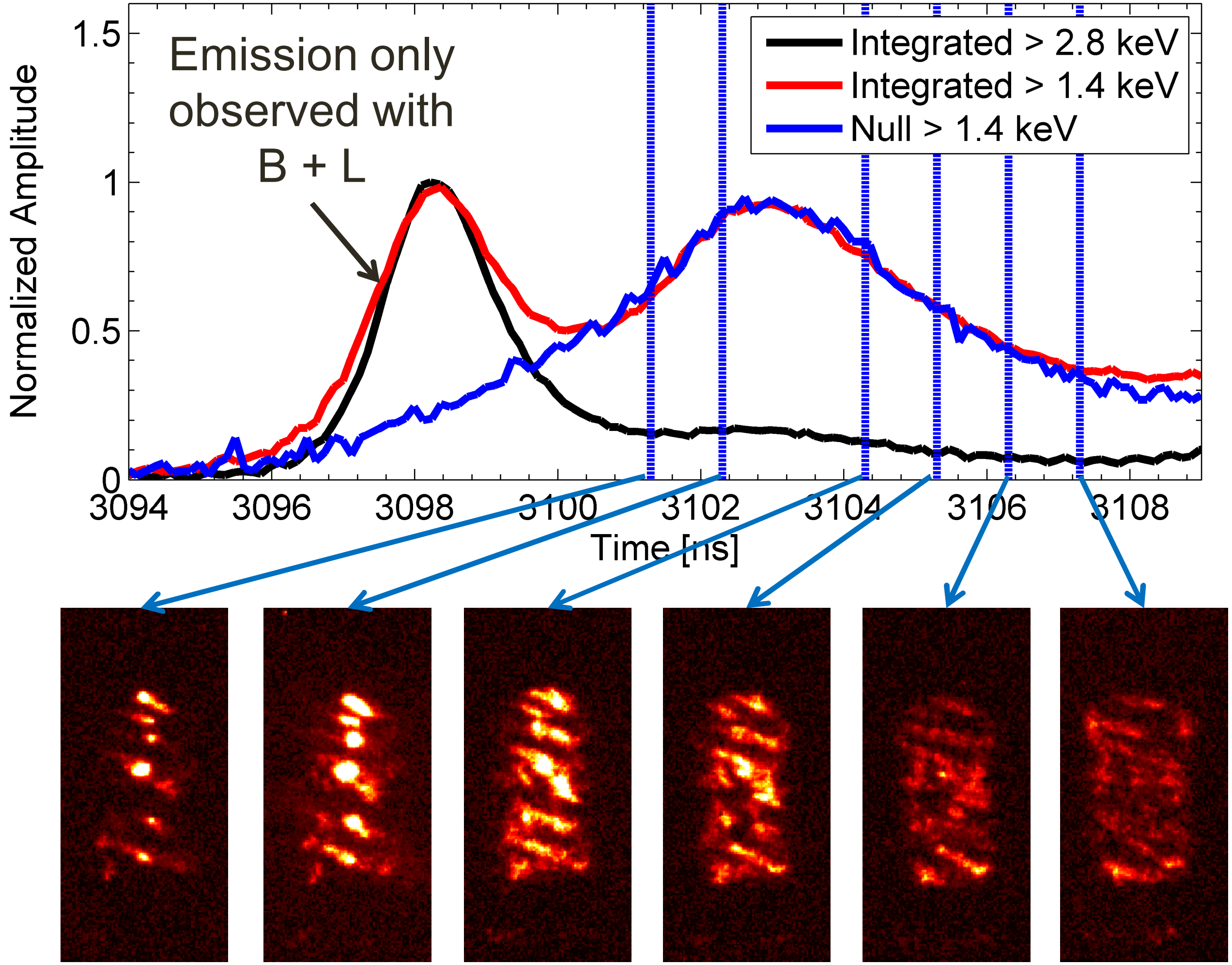
Time-resolved x-ray pinhole imaging (hν > 2.8 keV) shows a narrow emission column during peak in X-ray signal



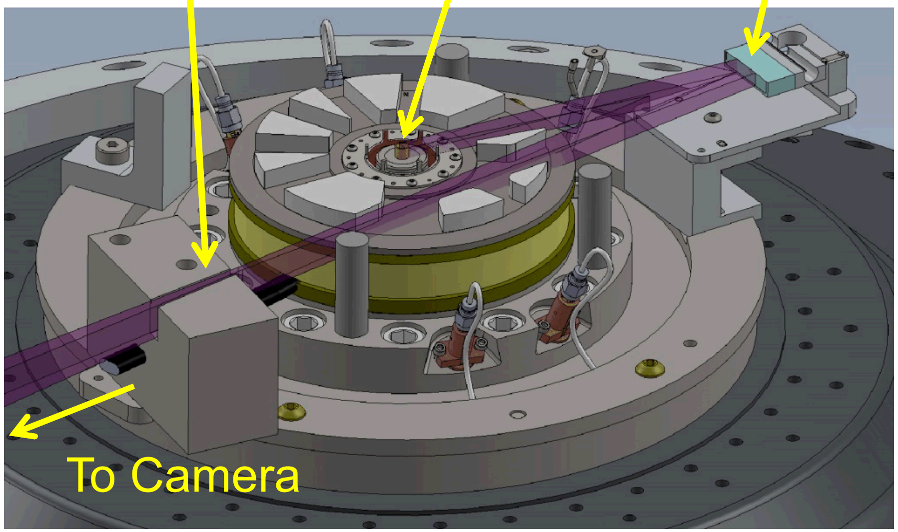
- Emission column is observed only during the peak in the x-ray signal
- Emission column is only observed on experiments with high neutron yield
- Stagnation column width is at the resolution limit of the instrument (~150 microns)

High energy x-ray signal and narrow emission region are absent in null experiments

- Liner emission is observed in all experiments
- Liner emission is at a lower photon energy (< 2.8 keV)
- Liner emission is getting larger at late times



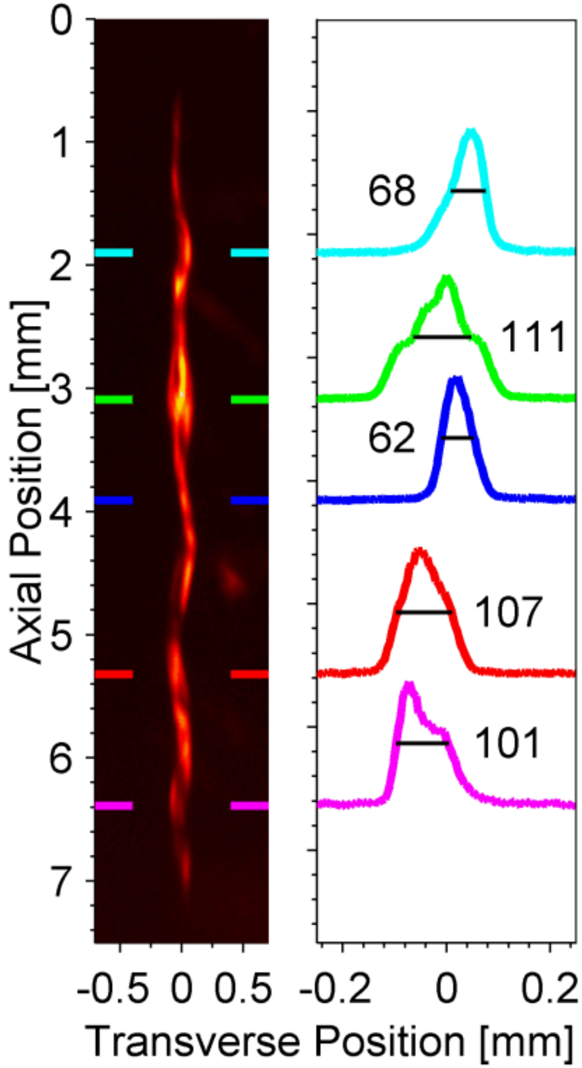
A new self-emission diagnostic was developed, which helps diagnose the stagnation column with high resolution



- **Bent crystal imager, similar to backlighter system, but in self emission with a Ge 220 crystal**
- **Imaging continuum emission from stagnation column**
- **Given the instrument response and the liner opacity, the signal should primarily consist of 6 and 9 keV photons**

High resolution images of the x-ray emission from the hottest part of the fuel show a relatively stable stagnation column

- Lineouts of stagnation column vary from 60 to 120 µm FWHM (resolution is about 60 microns)
- Emission is observed from about 6 mm of the 7.5 mm axial extent
- Emission region does not define the fuel-liner boundary, but defines the hottest region of the fuel
- Stagnation column is weakly helical with 1.3 mm wavelength and 0.05 mm offset



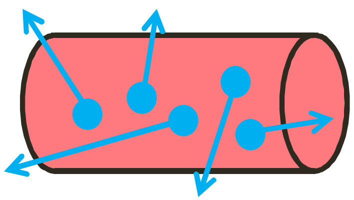
Measured and inferred stagnation parameters are consistent with the measured DD yield

- Hot fuel: r = 40-50 µm, h = 4-6 mm
  - $V \approx 2.0\text{-}4.7 \times 10^{-5}$ cm^3
- $\tau \approx$ 1-2 ns
- Stagnation density = 0.15-0.39 g/cm^3
  - $n \approx 0.5\text{-}1.3 \times 10^{23}/cm^3$
- Stagnation temperature = 2-3.5 keV
  - $\langle\sigma v\rangle \approx 0.5\text{-}4.4 \times 10^{-20}$
- $f = 0.5n^2\langle\sigma v\rangle \approx 0.6\text{-}37 \times 10^{25}/cm^3s$
- Calculated Yield = $\tau V f \approx 0.1\text{-}35 \times 10^{12}$ DD neutrons
- Measured yield = $0.5\text{-}2 \times 10^{12}$ DD neutrons

$Yield_{DT}/Yield_{DD}$ and NTOF spectra indicate significant magnetic flux compression

B*r = 0

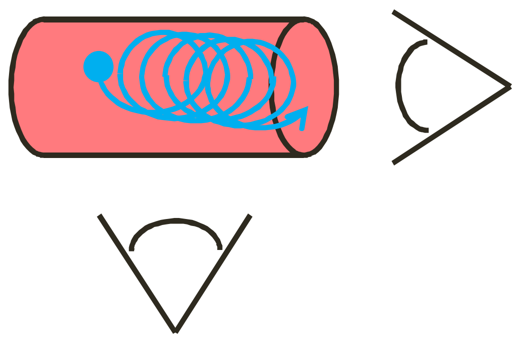
$Y_{DT}/Y_{DD} \sim 10^{-4}$

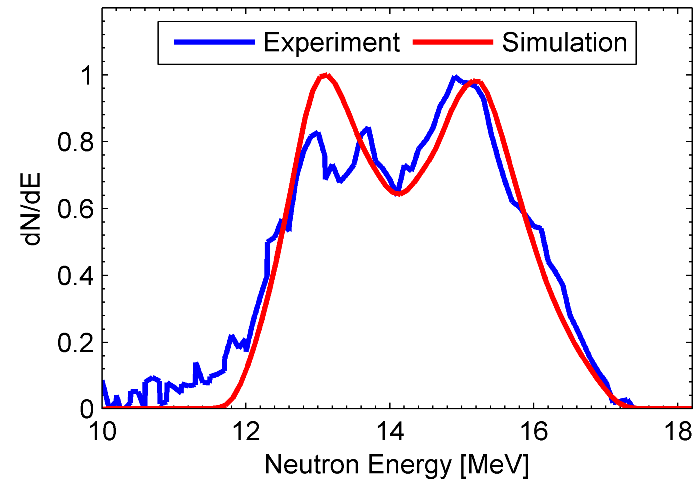


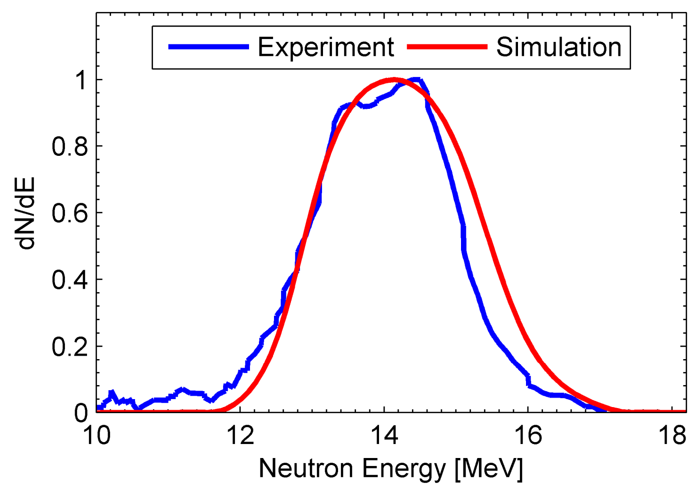
Relatively low estimated ρr for these experiments (2.5 mg/cm²)

B*r > 40 T-cm

$Y_{DT}/Y_{DD} \sim 10^{-2}$





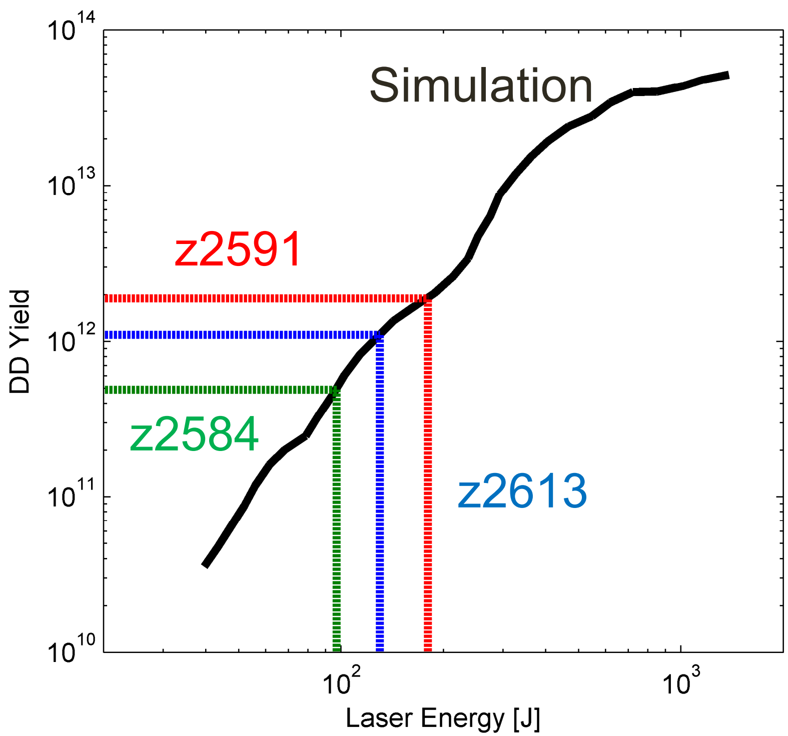


$Y_{DT}/Y_{DD} = 1.3\text{-}4.3 \times 10^{-2}$ is consistent with **B*r = 40-110 T-cm**

NTOF spectra are consistent with **B*r ≈ 45 T-cm**

Simulations indicate that the efficiency of laser-energy coupling in these targets is a critical factor

- **Fantastic results obtained in these experiments could get even better**
- **Measured yields are consistent with 100-200 J of laser energy coupled into the fuel according to HYDRA simulations**
- **Laser transmission experiments indicate less than 400 J transmitted through foil similar to LEH due to poor beam quality**



Recent laser transmission experiments with smoothed beam show significantly improved foil transmission

The first fully-integrated MagLIF experiments successfully demonstrated the promise of the concept.

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Back up slides

Hypothesis about integrated experiment that failed to produce significant yield

- **The main difference between z2583 and the other integrated experiments was the initial fill pressure**
  - **1.4 mg/cc on z2583 vs 0.65 mg/cc on others**
  - **Radiation loss scales as n^2 so 4x losses**
  - **If initial fuel temperature is already marginal, extra losses could push past a cliff**
- **Result has not been duplicated**
- **Experiments will be conducted in June with higher initial fill pressure and better laser coupling**