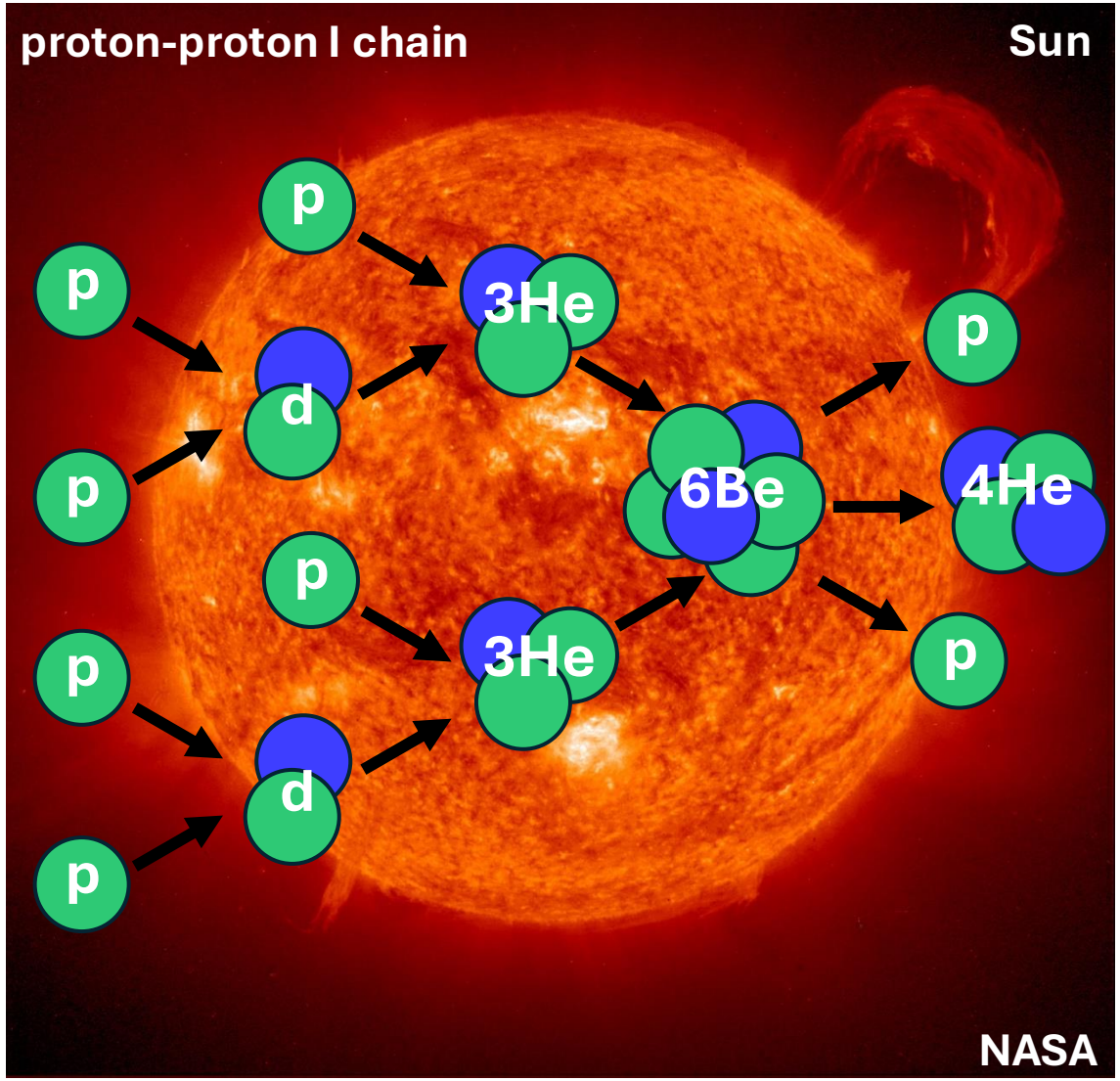
Studying the 3He-3He Reaction for Stellar Nucleosynthesis in HED Plasmas at the NIF



NIF User Group Meeting
Livermore, CA
February 10-12, 2026

A.T. Lanzrath
Plasma Science & Fusion Center

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The high laser energies available at the NIF create the opportunity to study the ^{3}He-^{3}He reaction in a plasma environment at solar-relevant ion temperatures

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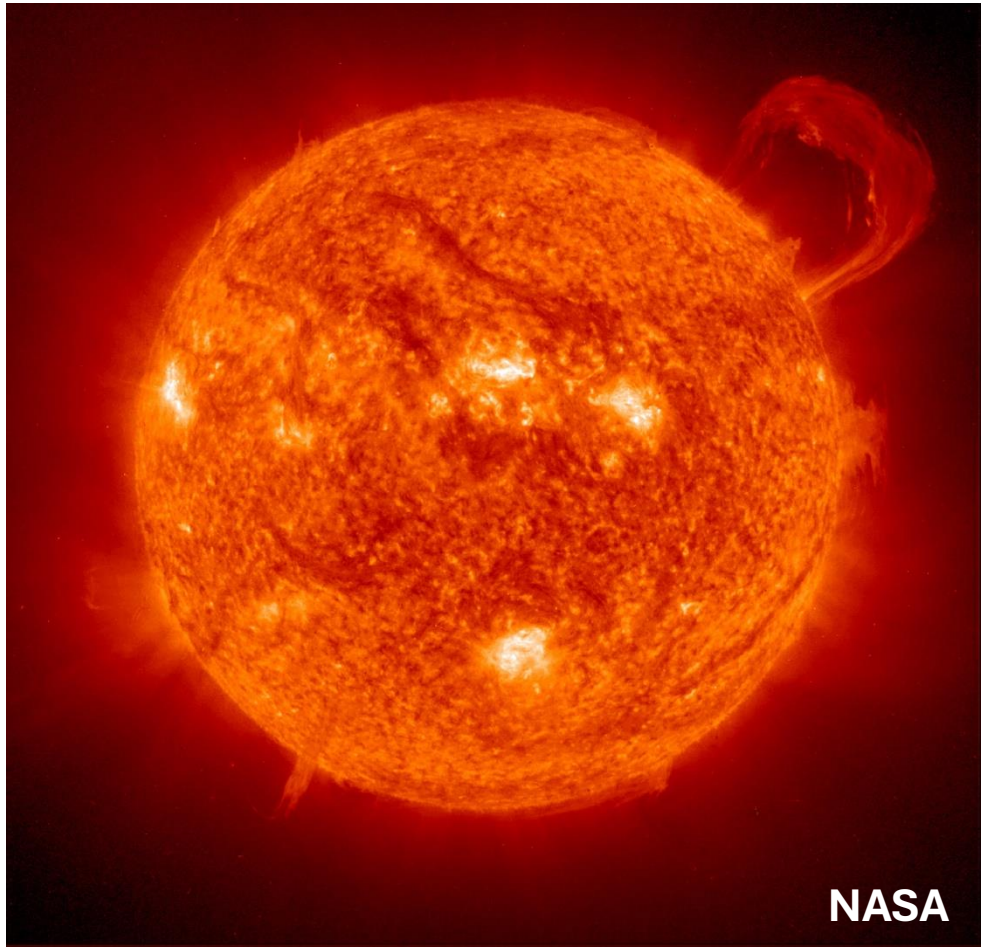
- Measurements of the reaction products in HED plasmas are needed to address uncertainties from bound electron screening, spectral shape, and low statistics in the S-factor data from accelerator experiments
- Experiments are enabled by MagSpec, a newly commissioned charged particle spectrometer able to measure the complete ^{3}He-^{3}He proton spectrum between 1-10 MeV
- Path forward includes development of simulations to account for proton energy loss in the assembled fuel and new implosion designs with larger capsules to access lower ion temperatures

The ^{3}He-^{3}He reaction plays a critical role in stellar nucleosynthesis for the sun and other low-mass stars through the proton-proton chain



Proton-Proton (pp) Chain

$^1H + ^1H \rightarrow ^2H + e^+ + \nu$

$^2H + ^1H \rightarrow ^3He + \gamma$

$^3He + ^3He \rightarrow ^4He + 2\,^1H$ — ppI

$^3He + ^4He \rightarrow ^7Be + \gamma$

$^7Be + e^- \rightarrow ^7Li + \nu$

$^7Li + ^1H \rightarrow ^4He + ^4He$ — ppII

$^7Be + ^1H \rightarrow ^8B + \gamma$

$^8B \rightarrow ^8Be + e^+ + \nu$

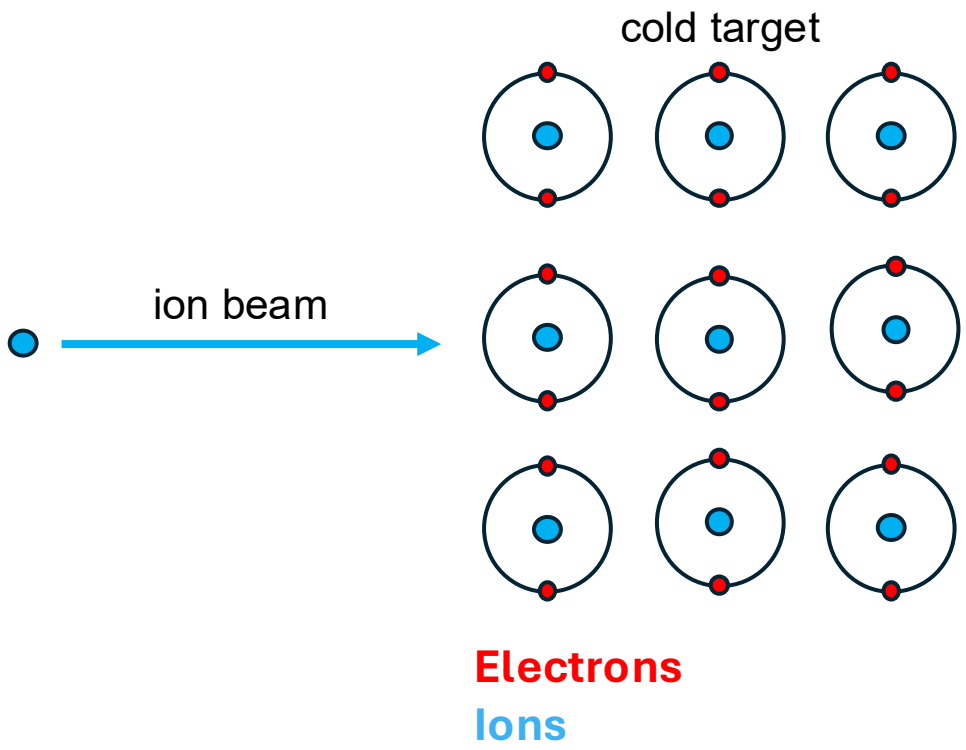
$^8Be \rightarrow ^4He + ^4He$ — ppIII

The ^{3}He-^{3}He S-factor can affect the solar neutrino flux calculated in solar models since it determines the branching ratio between the pp-I and pp-II/pp-III

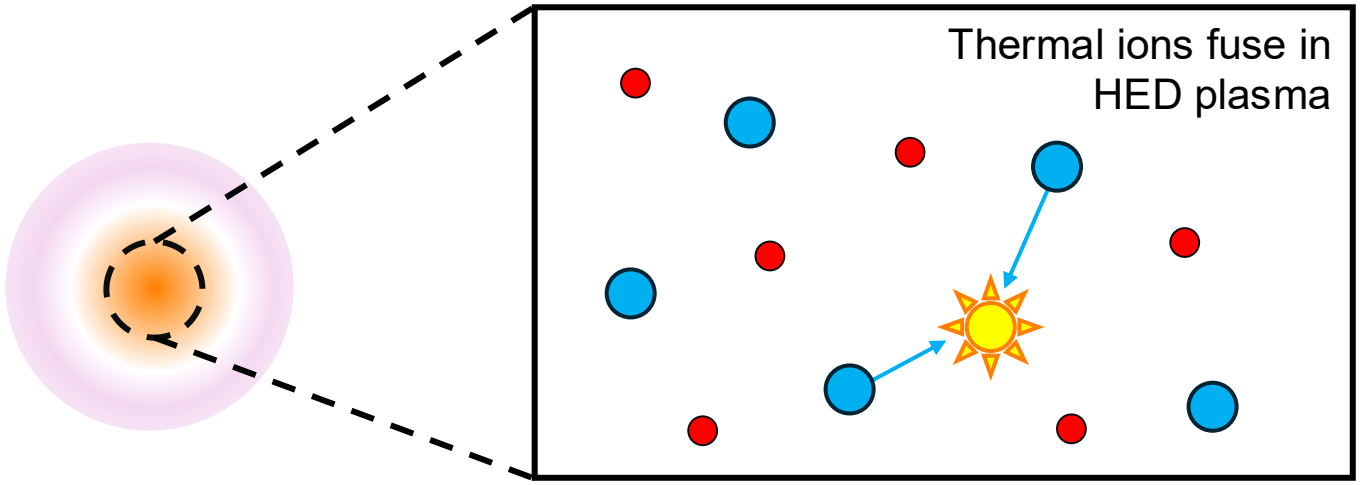
Archaya *Rev. Mod. Phys.* 2025
Vinyoles *Ap. J.* 2017

Accelerator experiments with a monoenergetic beam impinging on a cold target are not physically comparable to the high energy density plasma environment of a stellar core

Accelerator



HED Plasma



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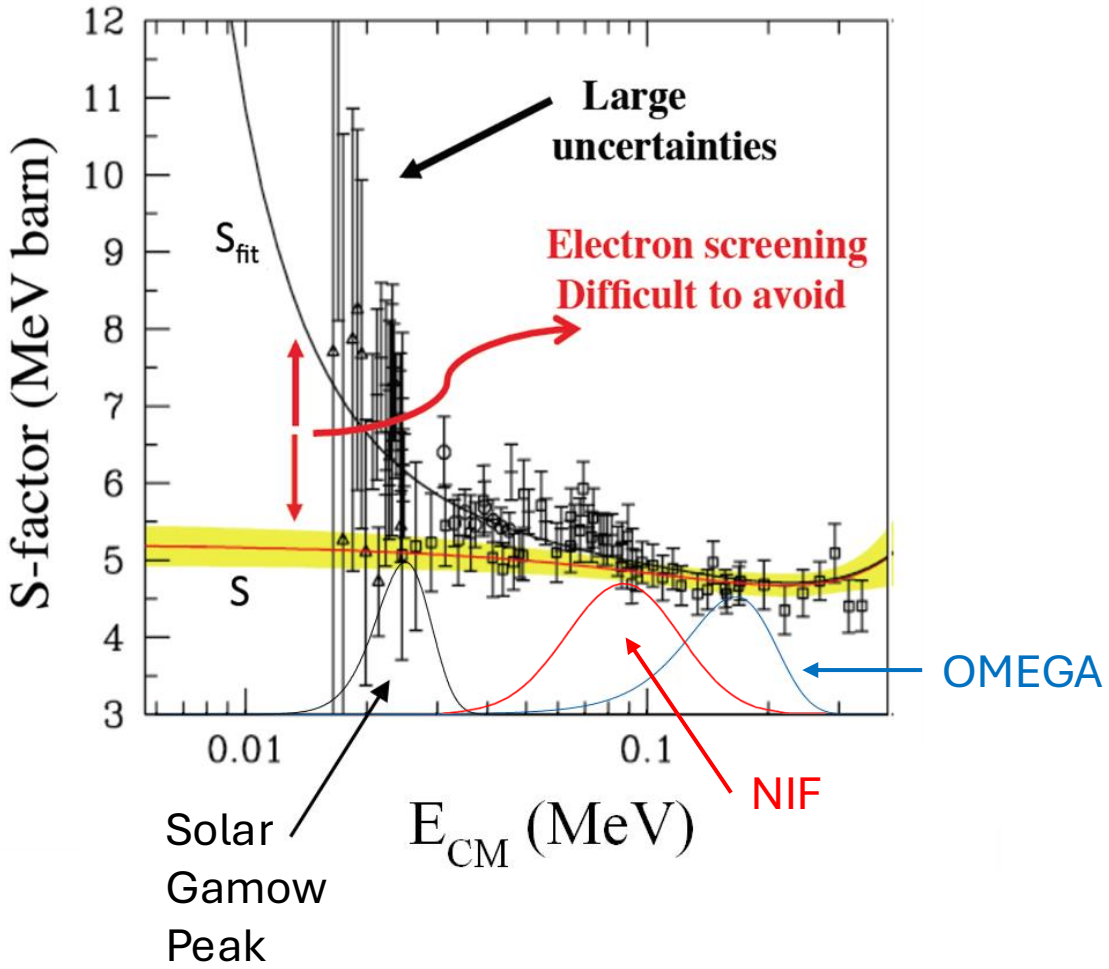
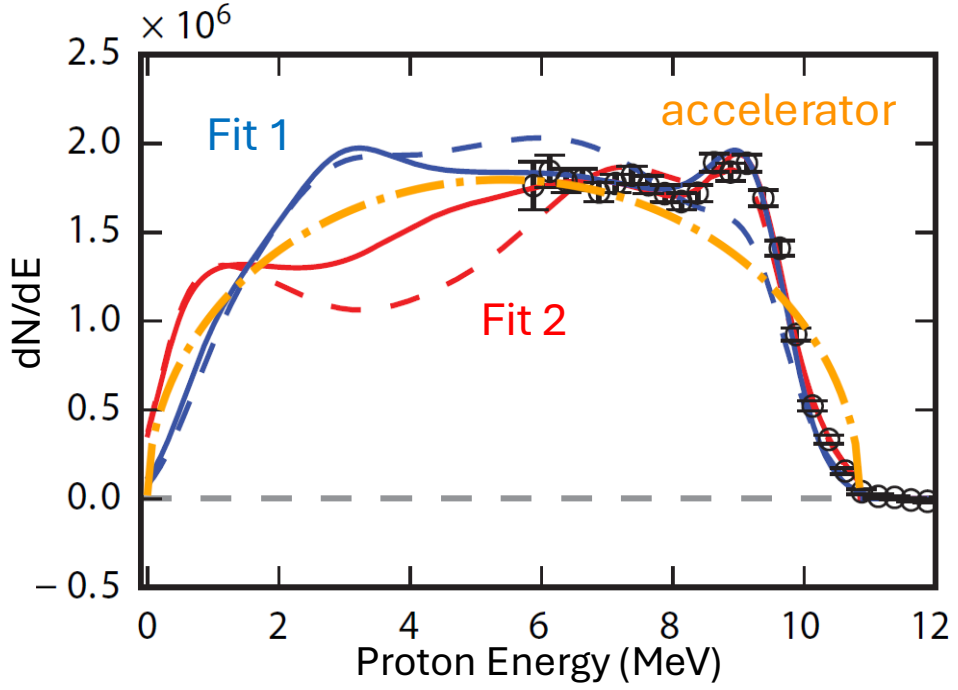
Low statistics, bound electron screening, and assumptions of the proton spectrum shape cast doubt on S-factor data from accelerator experiments

Accelerator ^{3}He-^{3}He Data



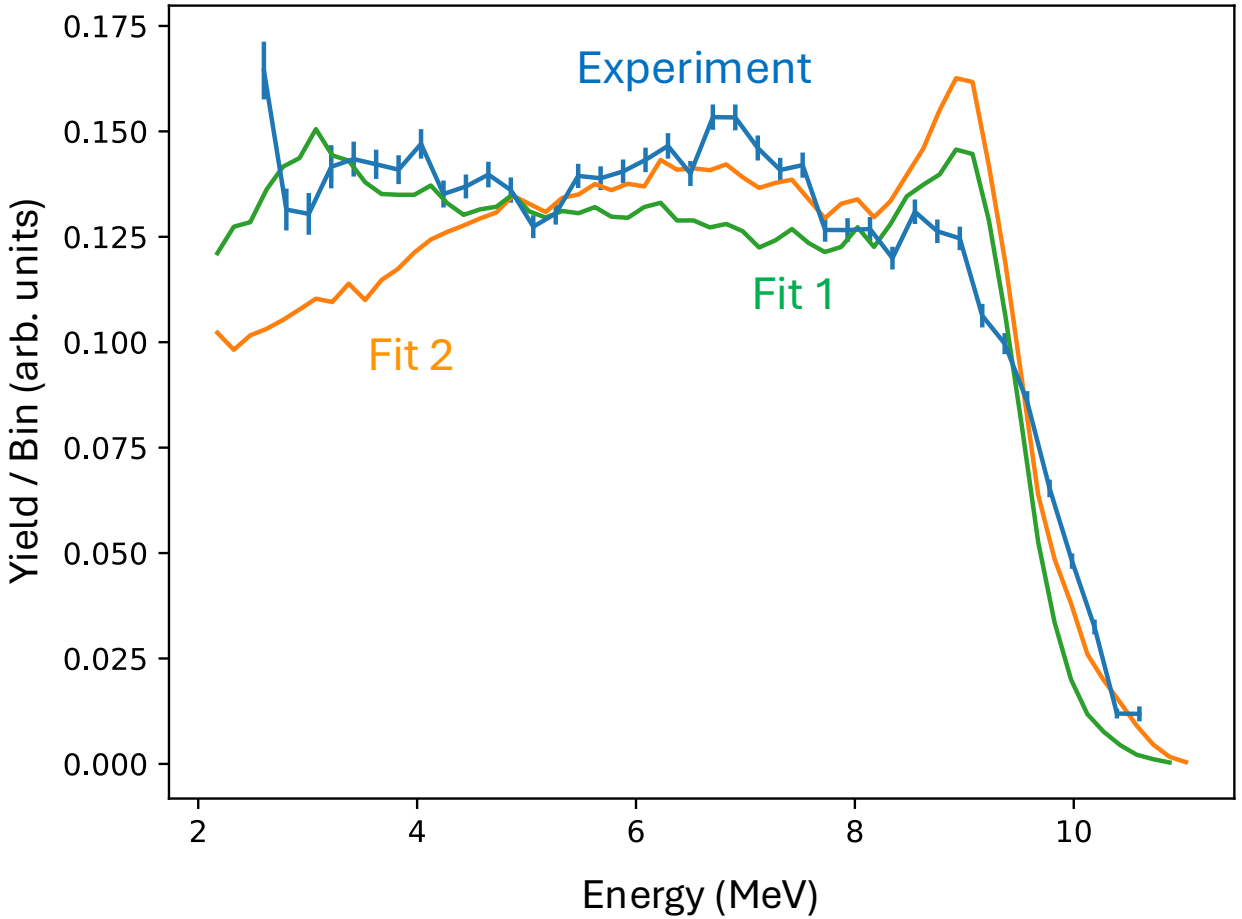
OMEGA ^{3}He+^{3}He Proton Spectrum



Zylstra PRL 2017

Adelberger *Rev. Mod. Phys.* 2011

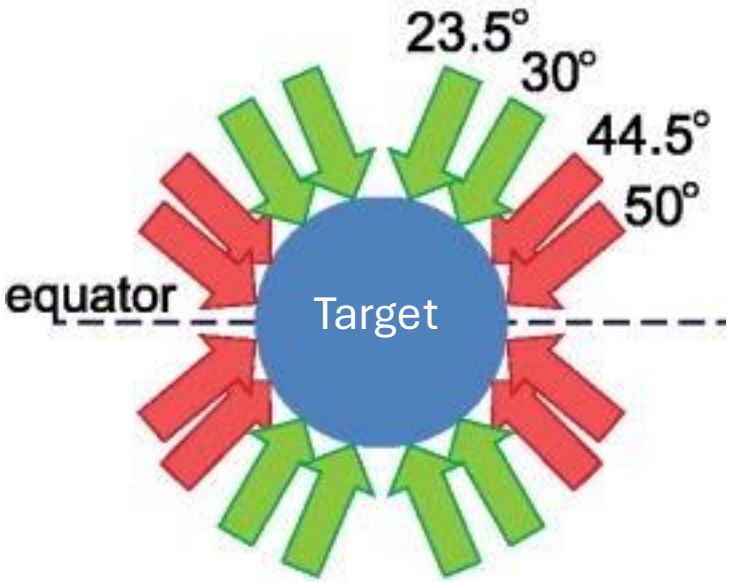
The ^{3}He-^{3}He reaction is also being studied at OMEGA, but the NIF is required to reach solar-relevant conditions



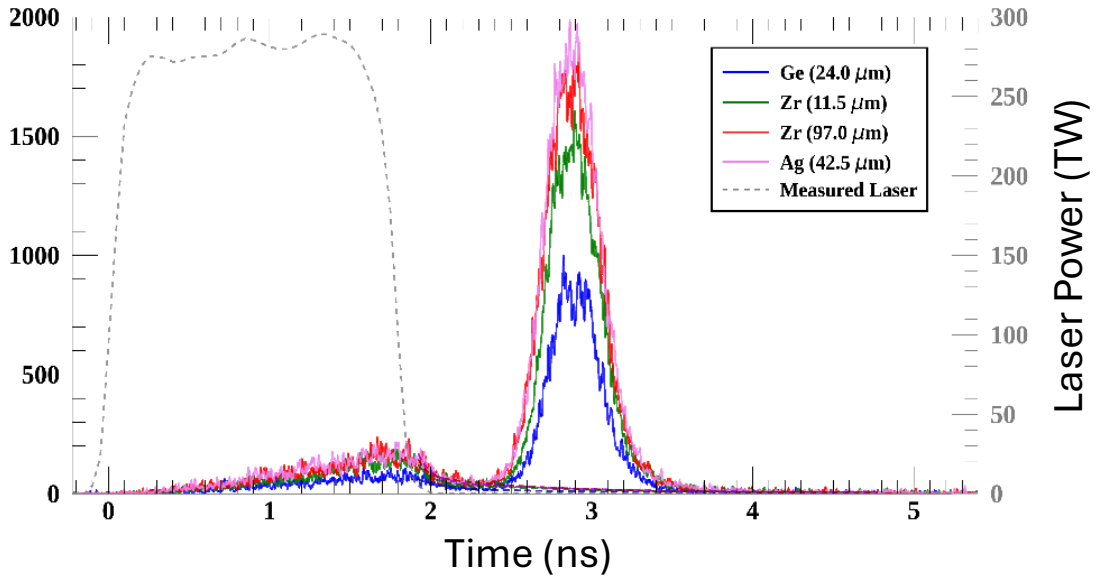
Johnson *Rev. Sci. Instrum.* 2025

A polar direct drive platform has been developed at the NIF to study light ion reactions

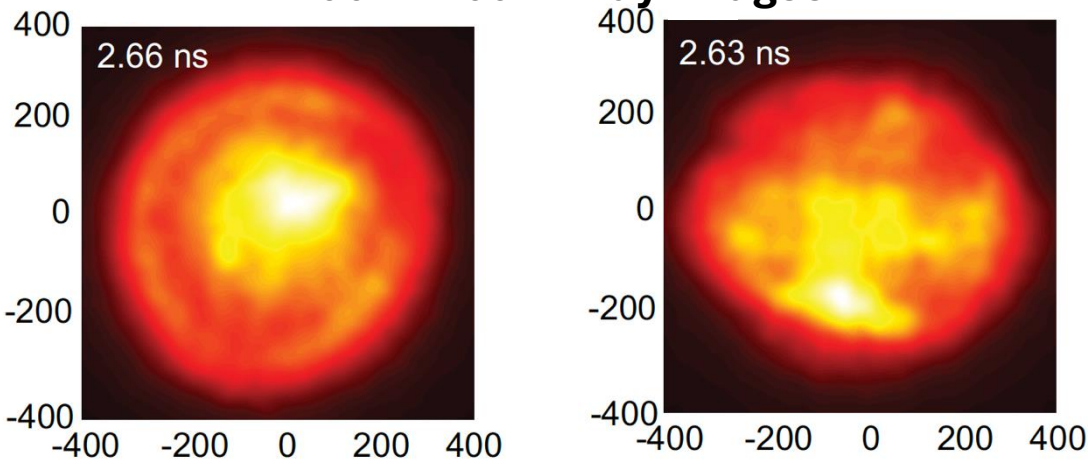
Polar Direct Drive Configuration



N200211-002 SPIDER

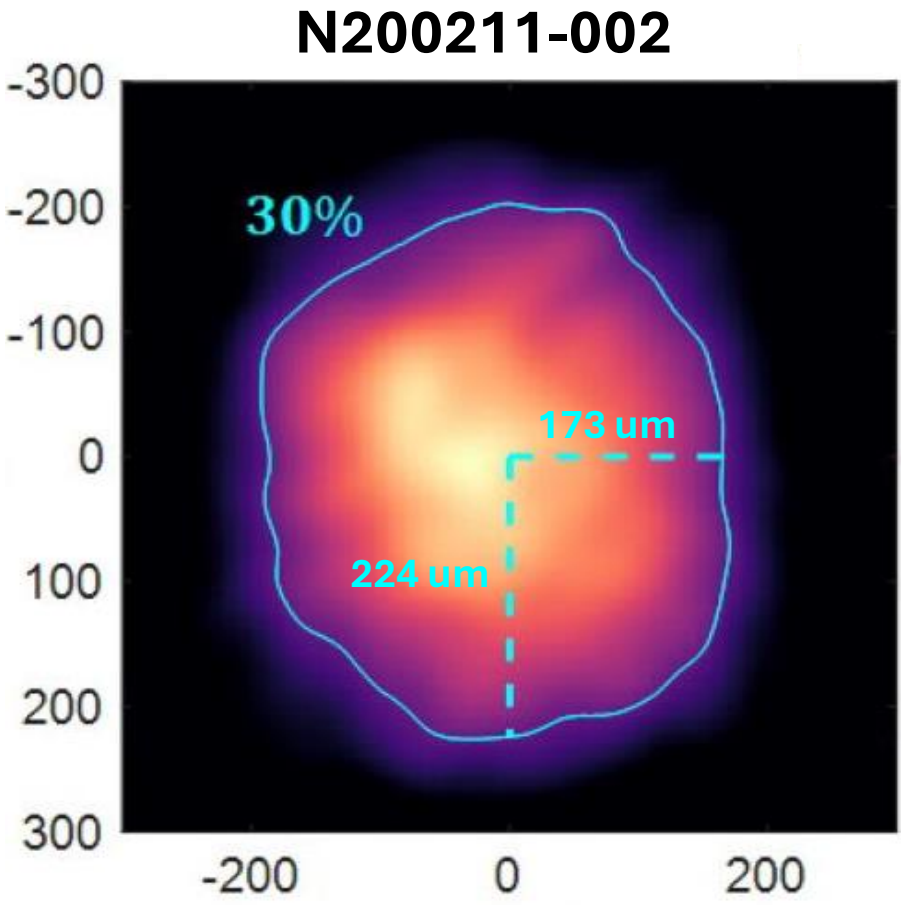


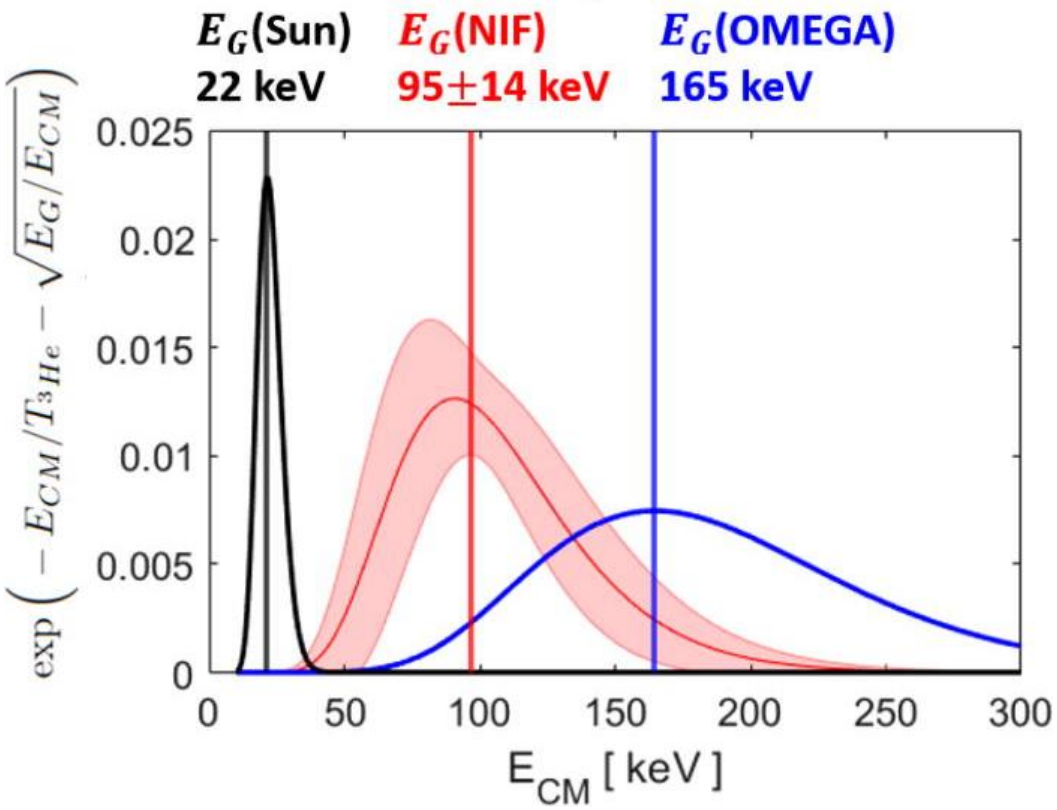
N200211-002 X-ray Images



Gatu Johnson *Phys. Plasmas* 2018

Penumbral x-ray imaging and nuclear data were used to constrain implosion conditions to infer the Gamow peak energy



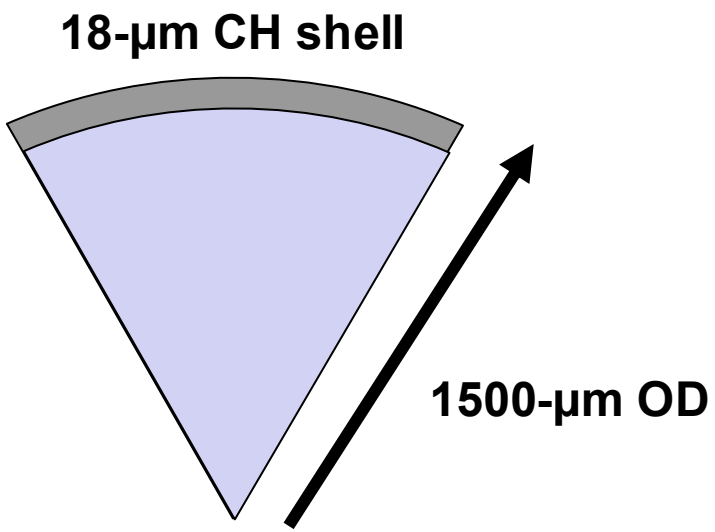


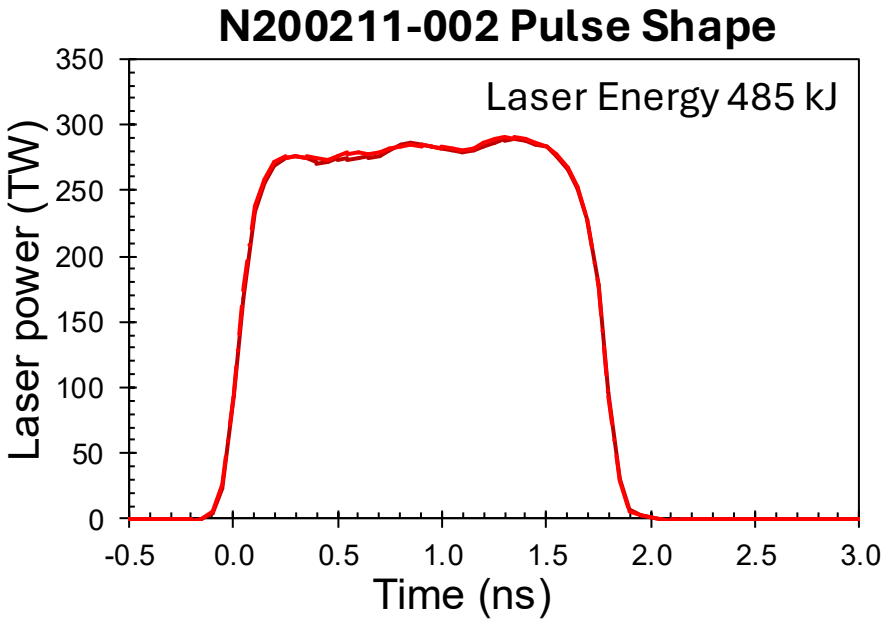
Adrian *Phys. Plasmas* 2025

D-^{3}He ion temperature is determined by using inferred n_e and T_e to calculate ranging of D-^{3}He protons and matching to the measured spectrum

The FY27 Discovery Science campaign will use the platform for light ion reactions to measure reaction products and plasma conditions with established diagnostics

Shot No.	Gas Fill
Shot 1	^{3}He (10 atm)
Shot 2	^{3}He (10 atm)
Shot 3	D_2 (1.2 atm) + ^{3}He (8.4 atm)





Primary Diagnostics:

- Penumbral x-ray imaging (hot spot size)
- SPIDER (x-ray burn history)
- MagSpec (proton spectra)
- pTOF (nuclear burn history)
- WRF (proton spectra)

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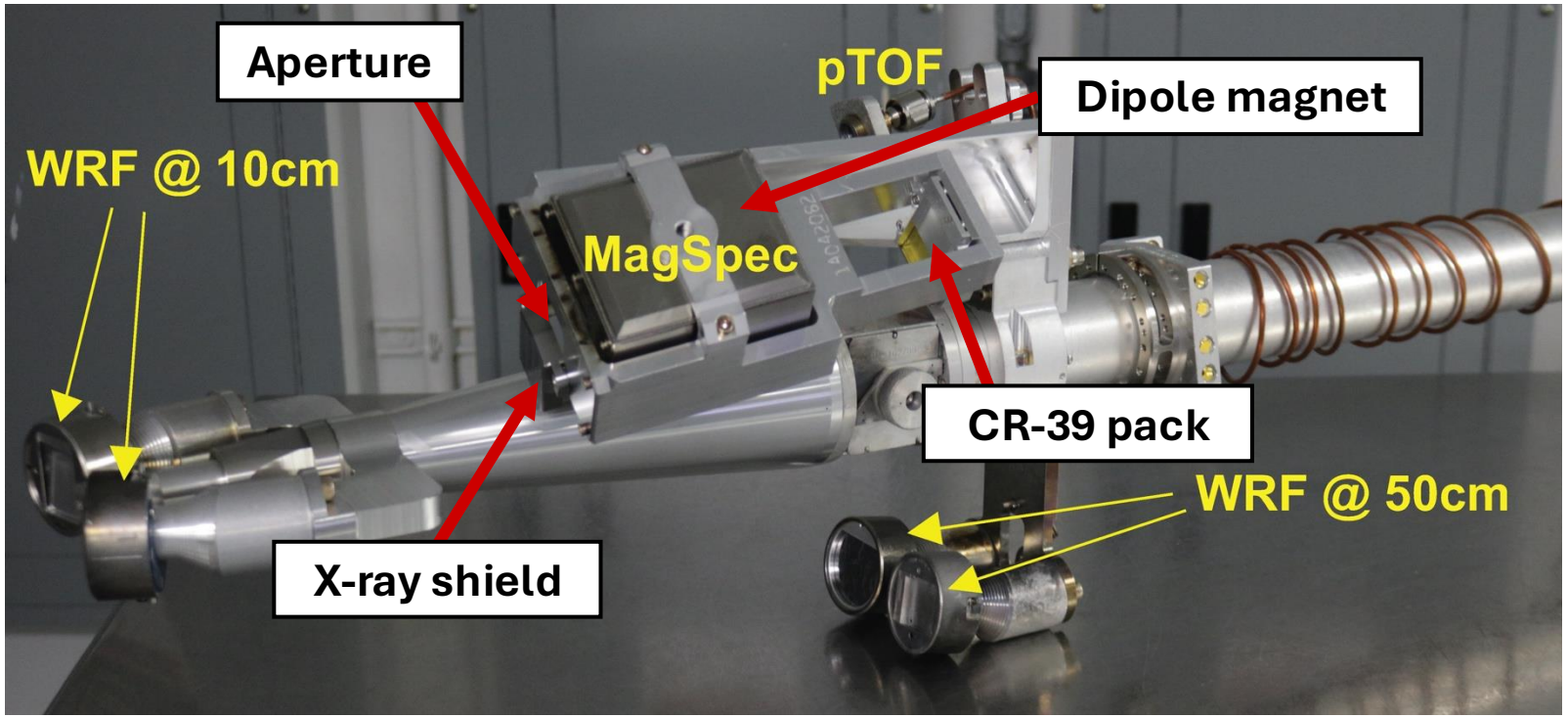
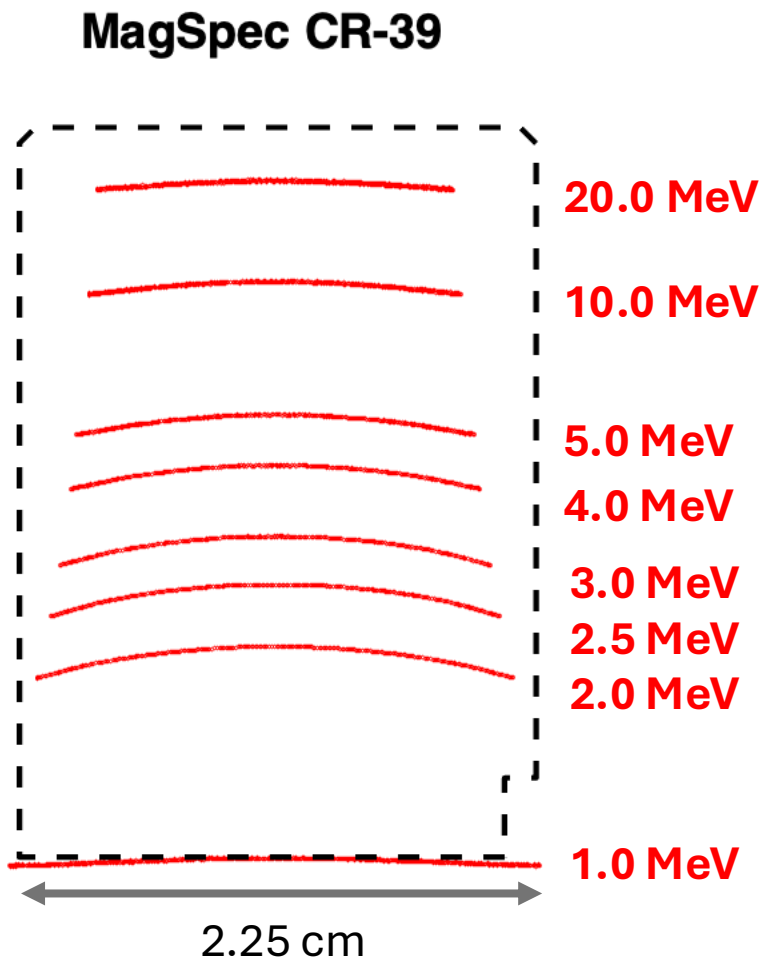
MagSpec is a newly commissioned charged particle spectrometer that enables the measurement of the complete ^{3}He-^{3}He proton spectrum between 1-10 MeV



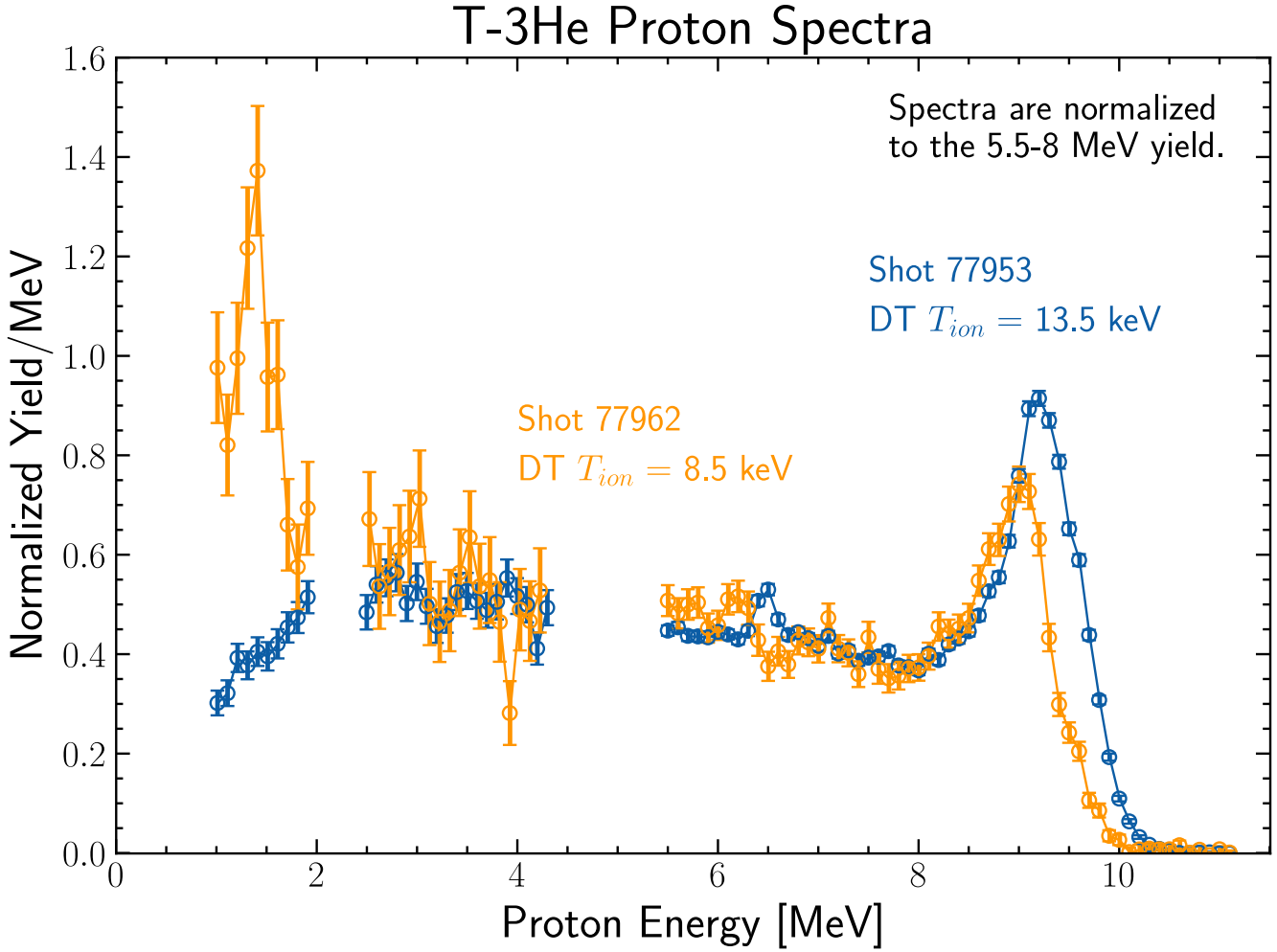


Pearcy *Rev. Sci. Instrum.* 2024

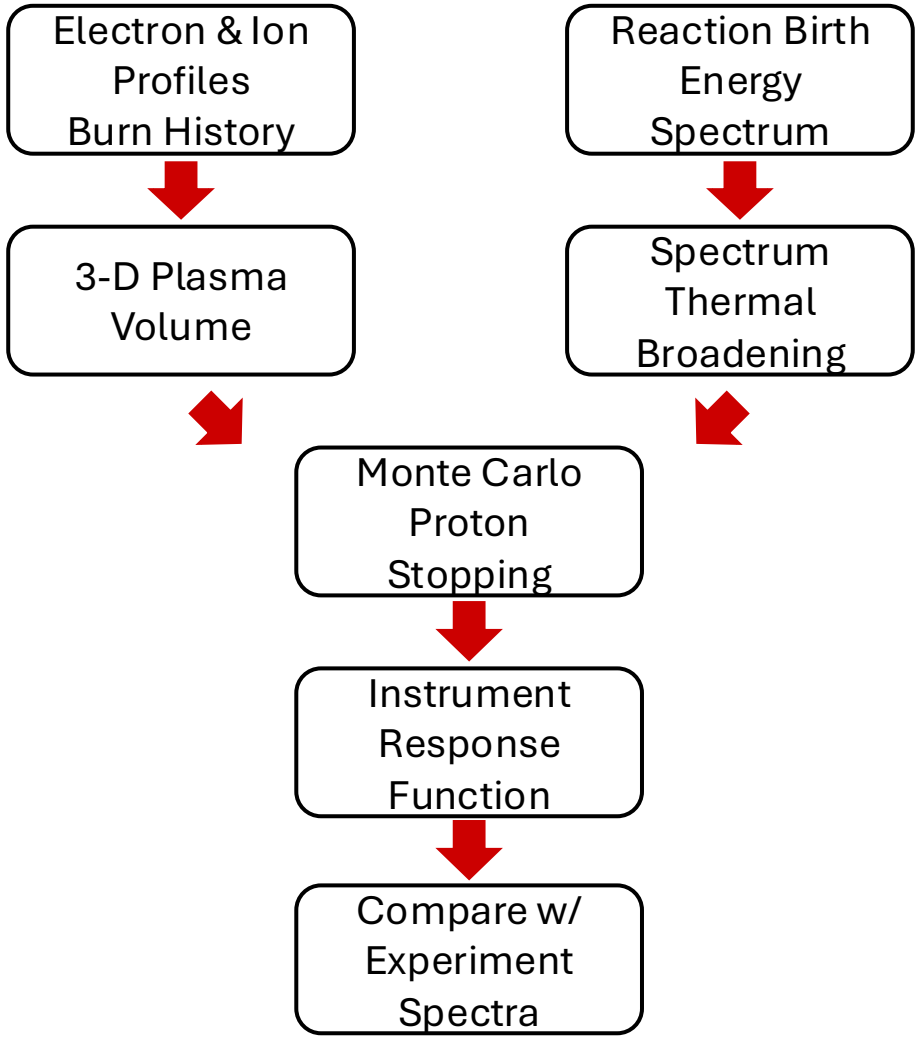
OMEGA shots at different E_{cm} display evidence of nuclear and plasma effects on the T-^{3}He proton spectrum with similar effects expected for ^{3}He-^{3}He spectra

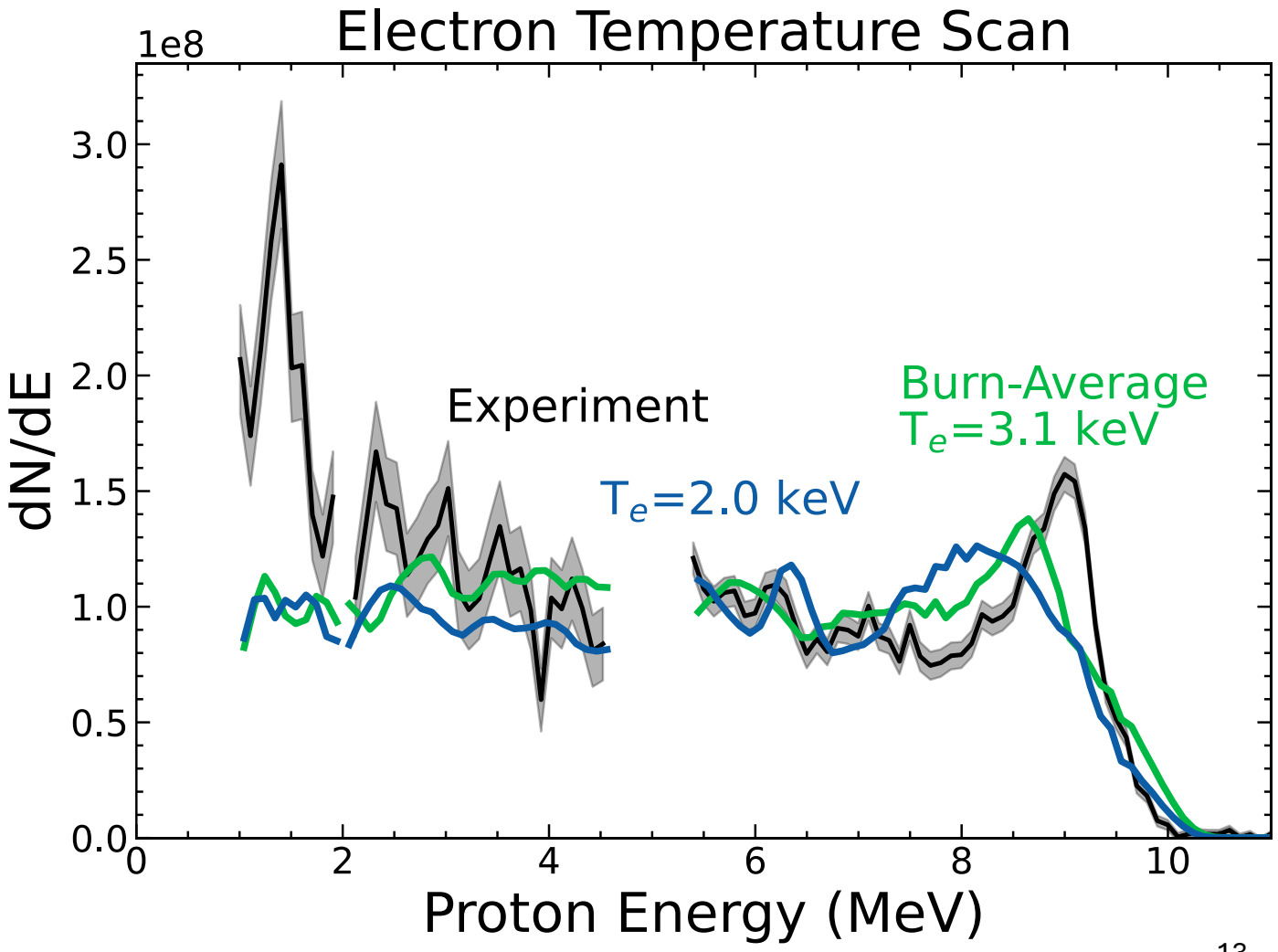
$$^3\mathrm{He} + {}^3\mathrm{He} \rightarrow {}^4\mathrm{He} + \mathrm{p} + \mathrm{p}\ (\mathrm{Q} = 12.9\ \mathrm{MeV})$$

$$\mathrm{t} + {}^3\mathrm{He} \rightarrow {}^4\mathrm{He} + \mathrm{n} + \mathrm{p}\ (\mathrm{Q} = 12.1\ \mathrm{MeV})$$

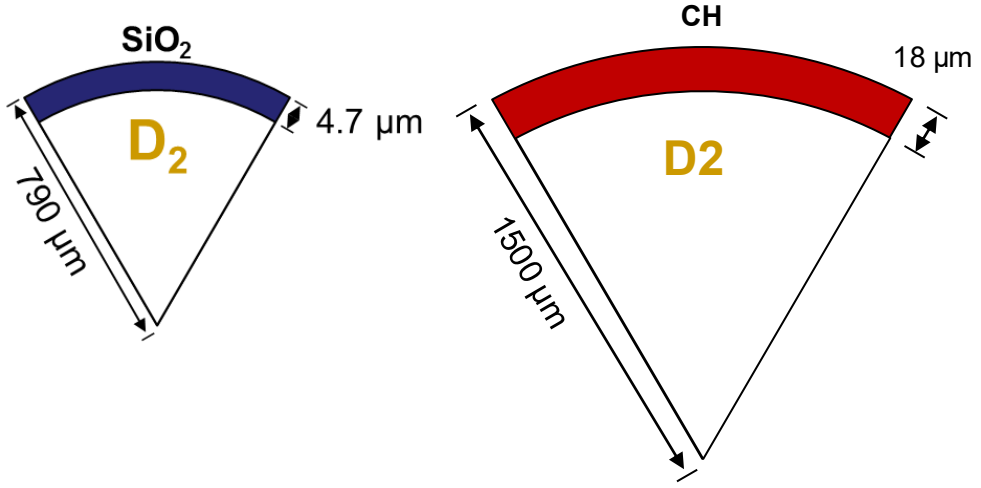


Simulations tools are being developed to correct for proton energy loss in the assembled fuel and are being tested for the T-^{3}He proton spectrum

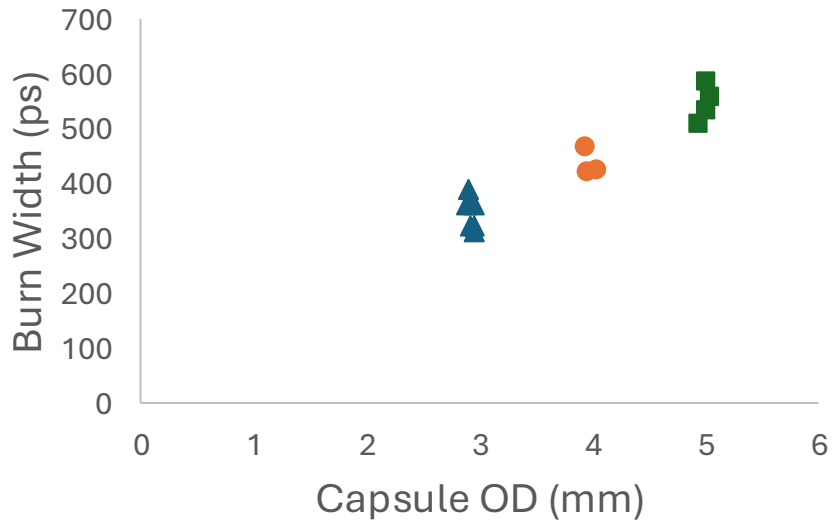


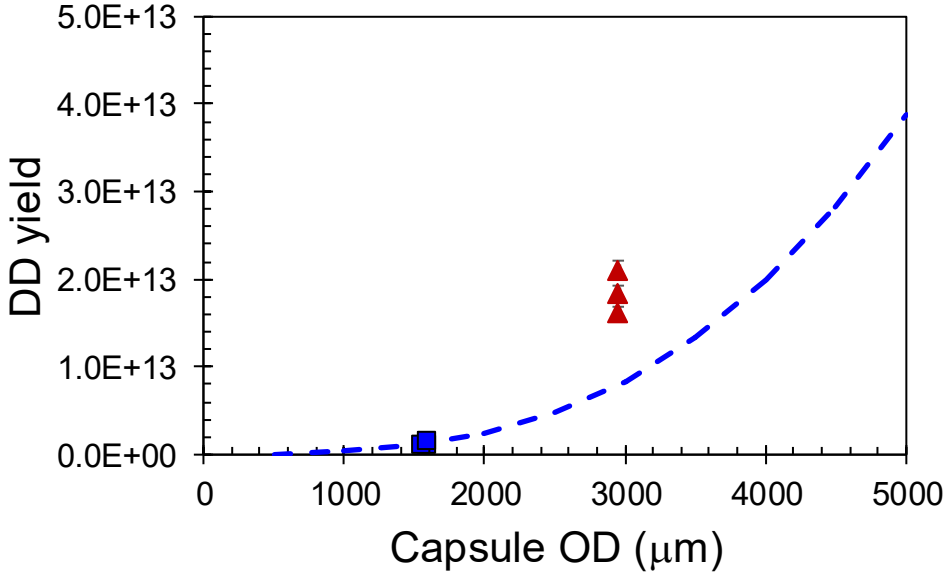


A new implosion design with larger capsules will be needed to achieve ion temperatures closer to those found in the sun



$$Y \sim n_1 \times n_2 \times \langle \sigma v(T_{ion}) \rangle \times V \times \tau_{burn}$$





Gatu Johnson *Phys. Plasmas* 2018

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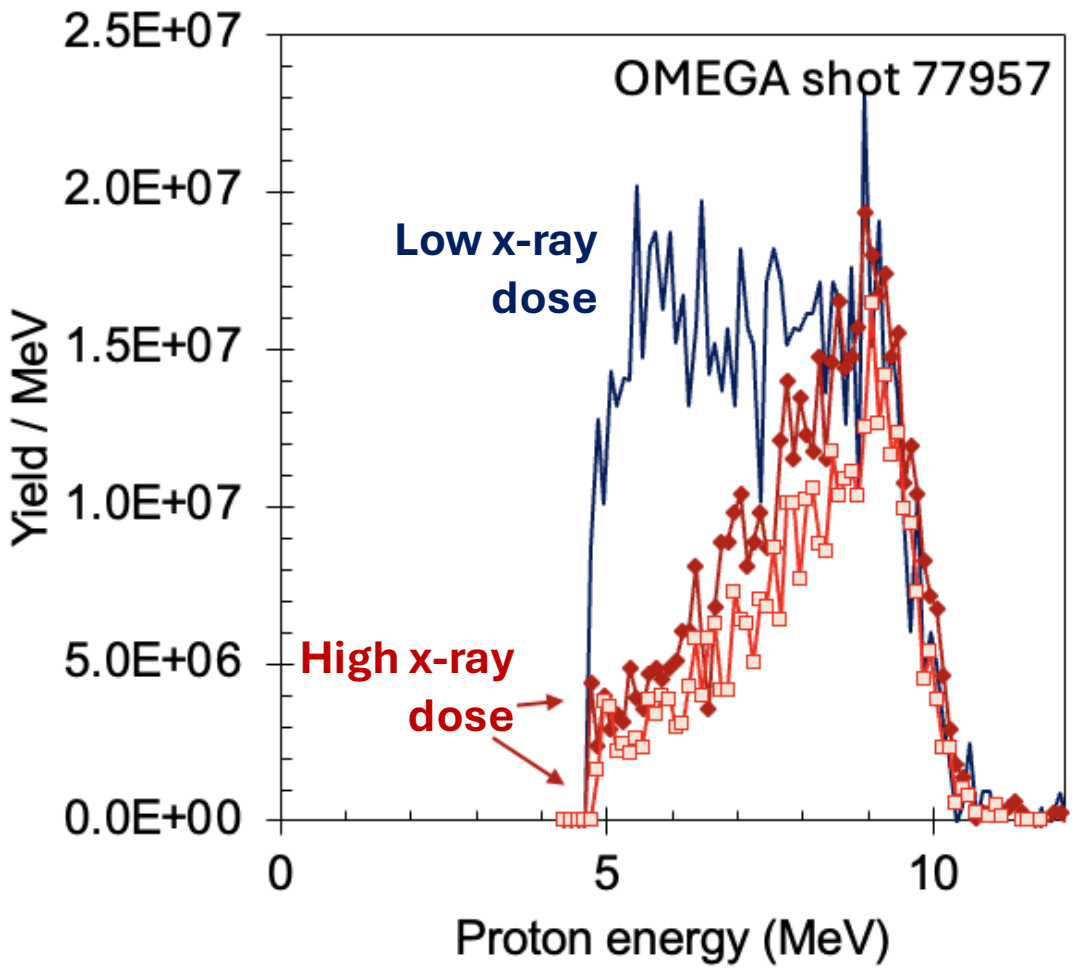
Measurements from the same OMEGA shot at different standoff distances demonstrate the impact of x-ray dose on the ^3He-^3He spectrum