Nuclear Diagnostics at the National Ignition Facility

Presentation to

Third Workshop on Nuclear Level Density and Gamma Strength
Univeristy of Oslo, May 23, 2011

Darren Bleuel

(*et.* a lot of *al.*)

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

NIF is the culmination of a long line of glass laser systems developed at LLNL

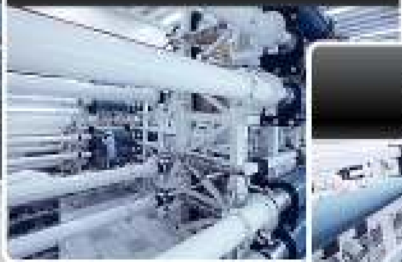
Janus, 1973

100J IR

Argus, 1976

1kJ IR

Shiva, 1977



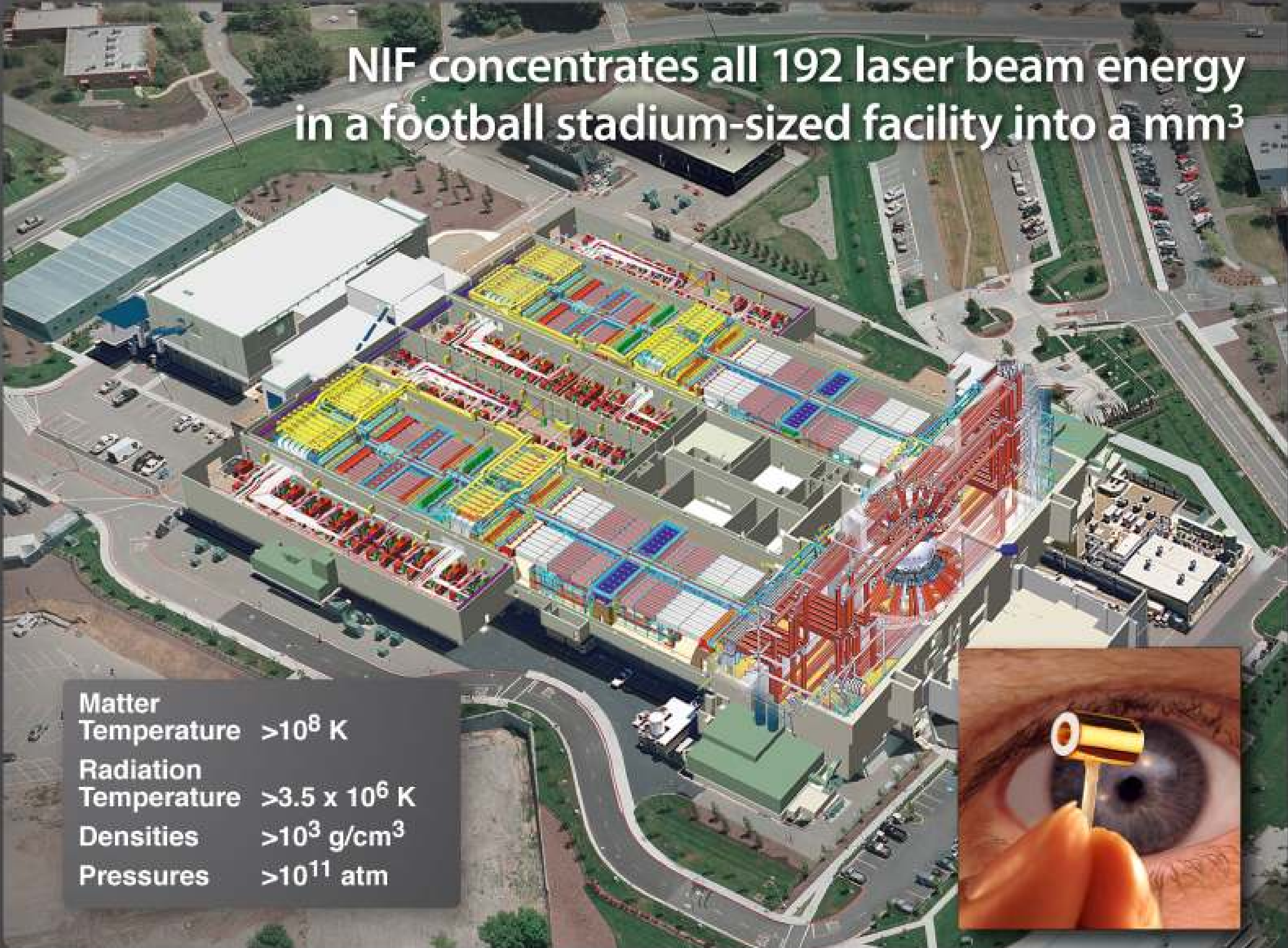
10kJ IR

Nova, 1984

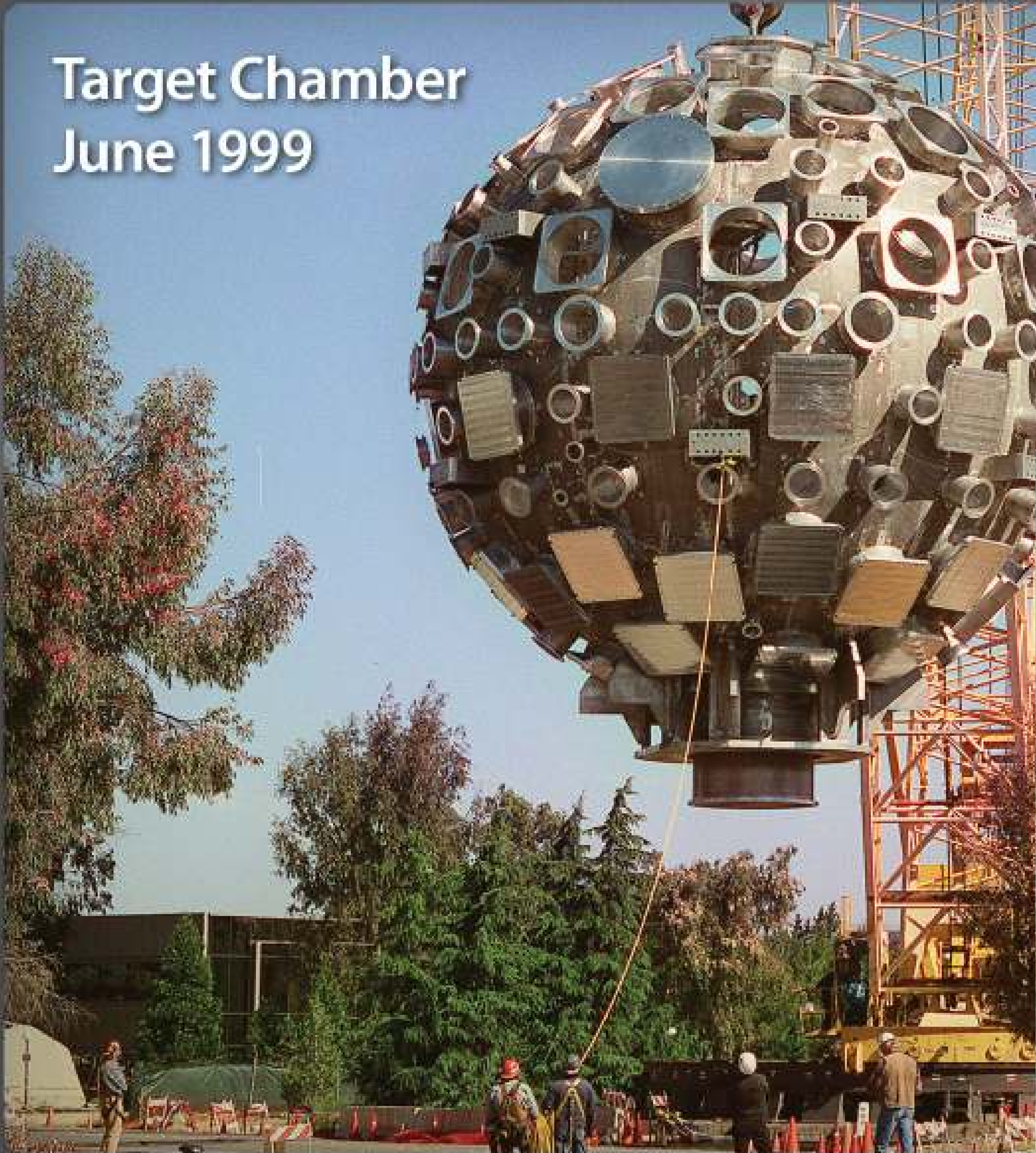
30kJ UV

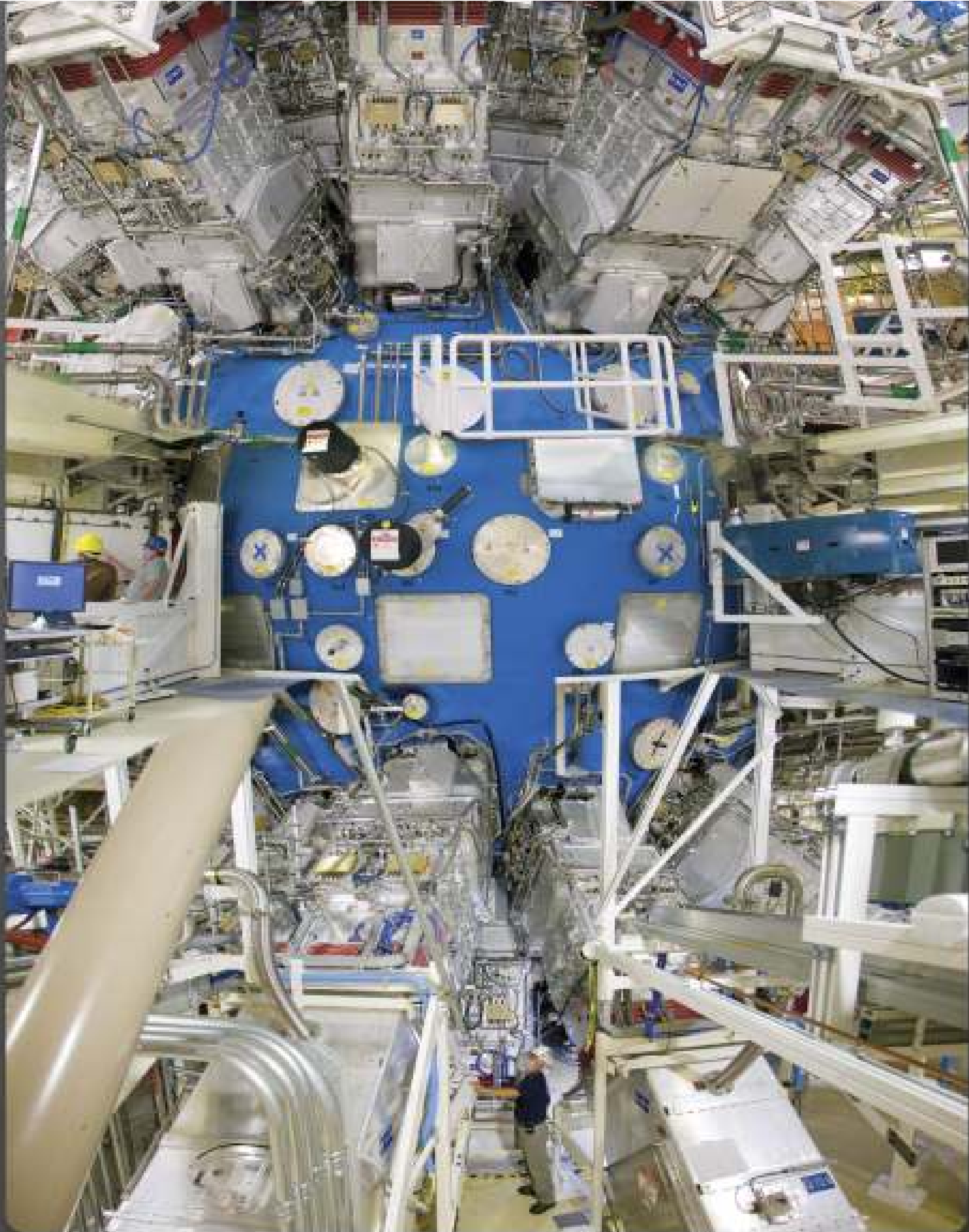
NIF, 2009

1.8MJ UV

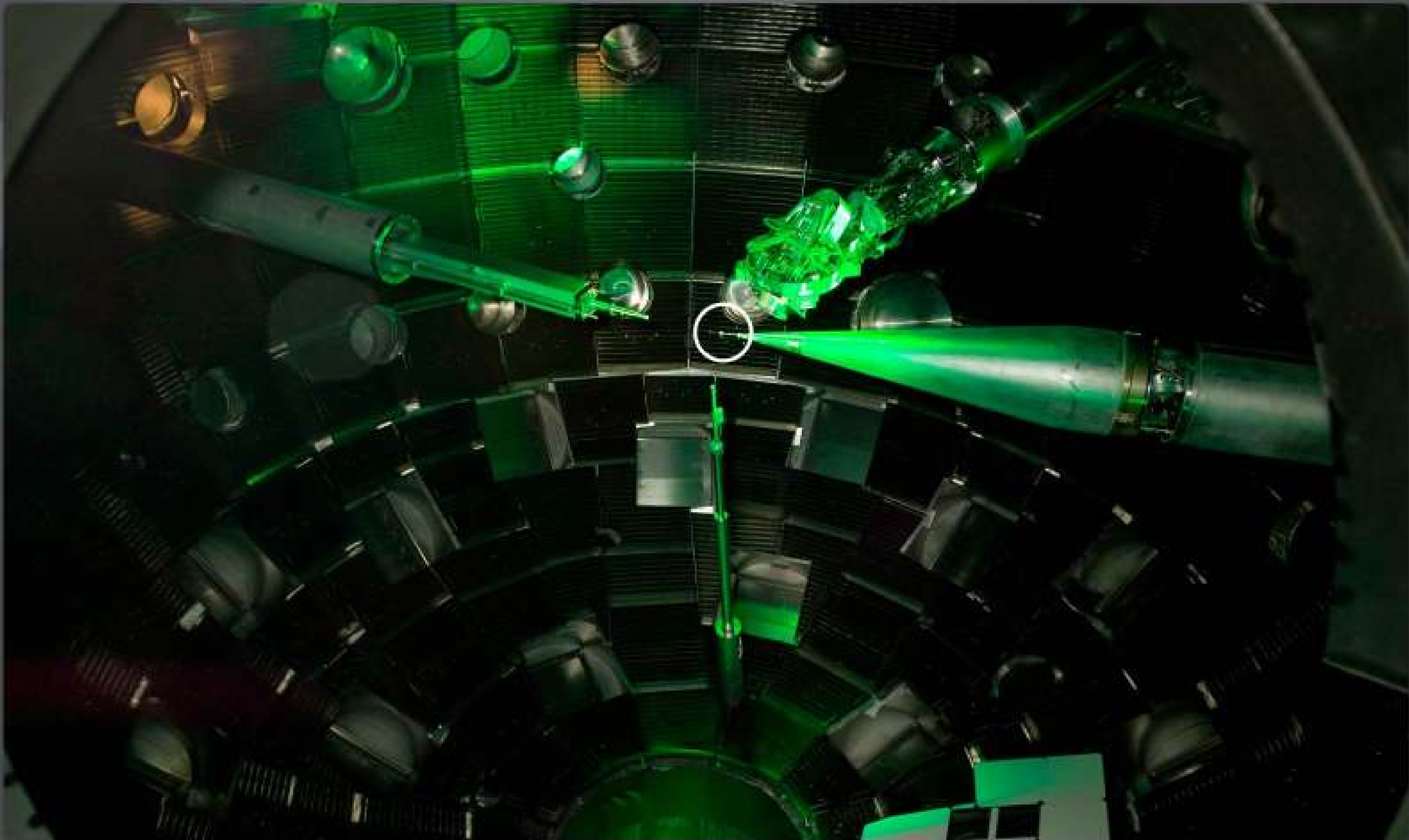

NIF concentrates all 192 laser beam energy in a football stadium-sized facility into a mm^3
Matter Temperature >10^8 K
Radiation Temperature >3.5×10^6 K
Densities >10^3 g/cm^3
Pressures >10^{11} atm

Target Chamber June 1999

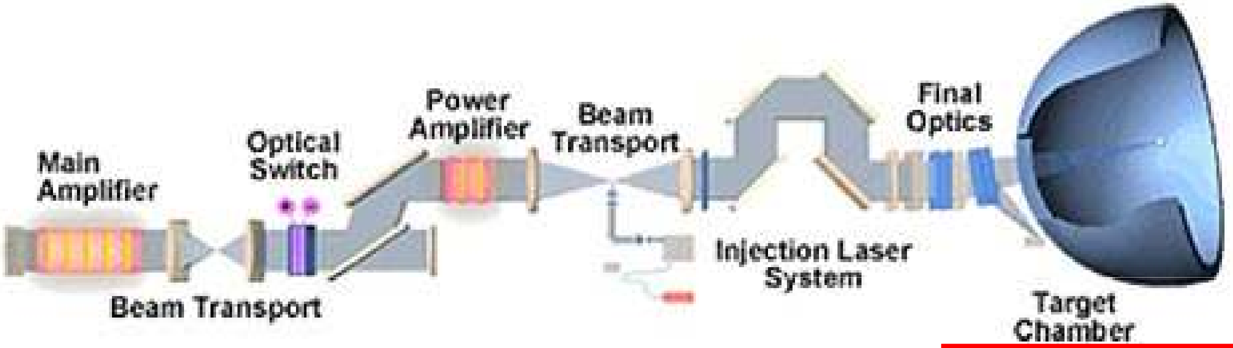


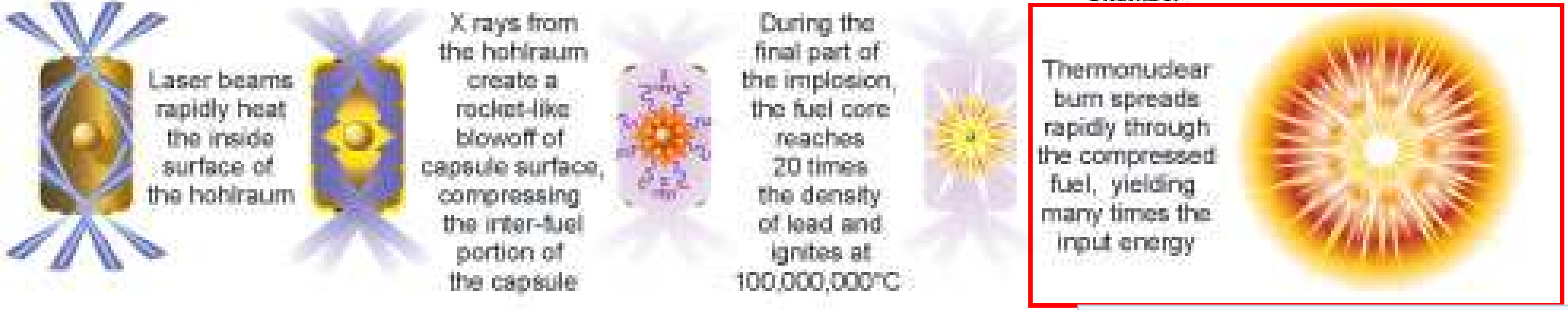


...In the target chamber

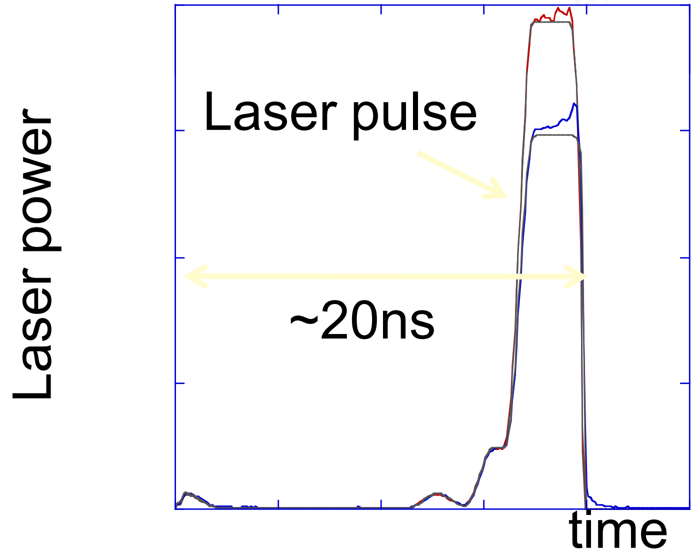


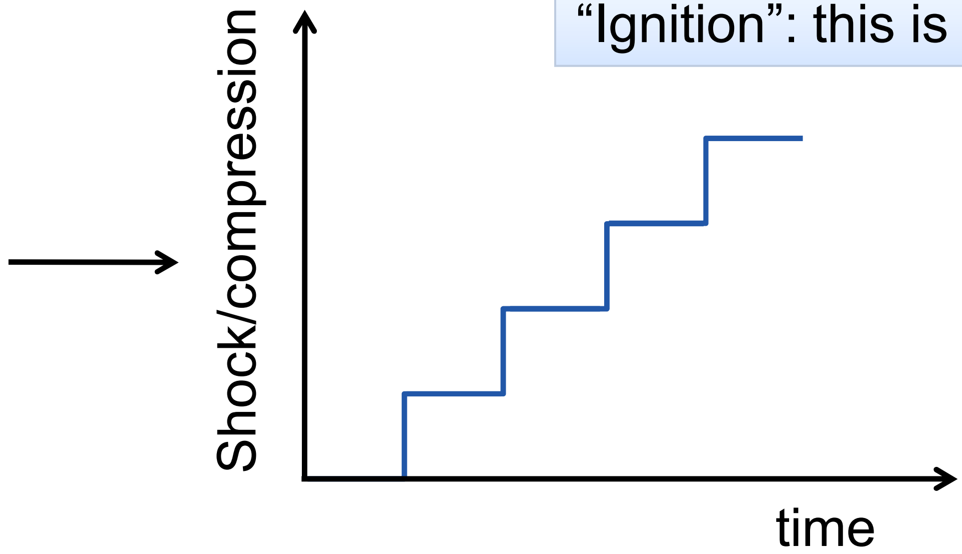
How NIF/ICF Works





"Ignition": this is the goal

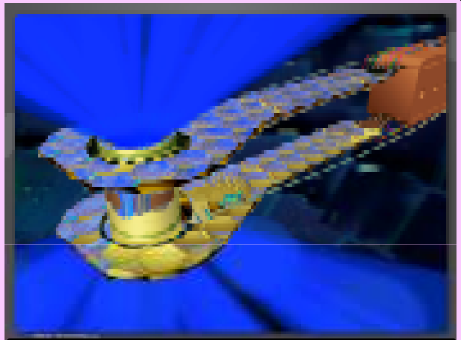




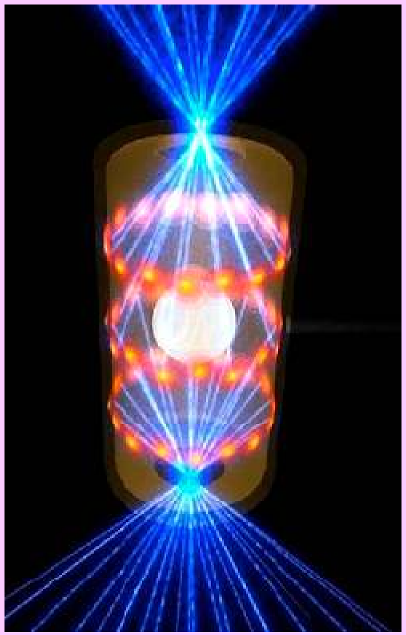
"Layered-cryo" w/ hohlraum (indirect drive) vs. "Exploding pusher" (direct drive)

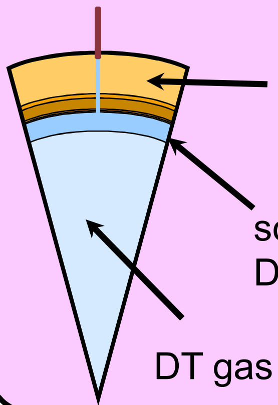
"Layered-Cryo"

- Laser energy produces ~300 eV x-rays in hohlraum "can," heating CH or Be capsule wall
- Cryogenic DT "layered" fuel shell with gas interior
- "Hot spot" ignites high ρR layer burn
- Yield up to 10^{19} n



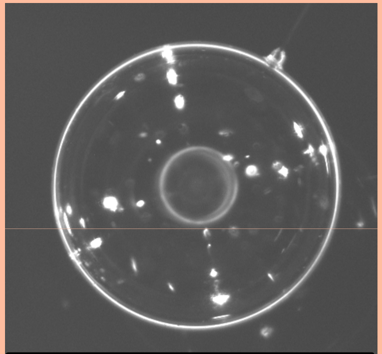
Cryogenic, x-ray driven, layered targets



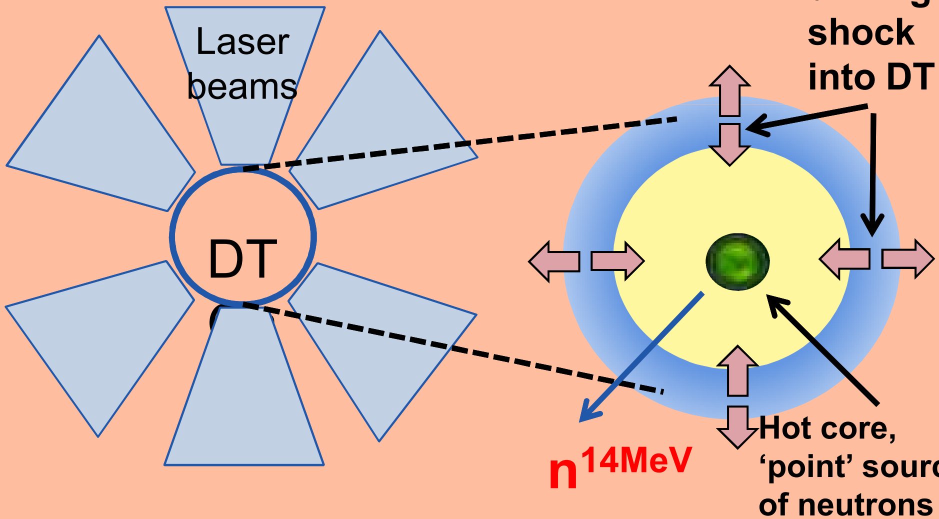


"Exploding Pusher"

- Laser energy produces ~ 10 keV electrons: heats thin Si capsule wall
- Low ρR (no n scatter)
- Isotropic
- Yield up to 5×10^{15} n

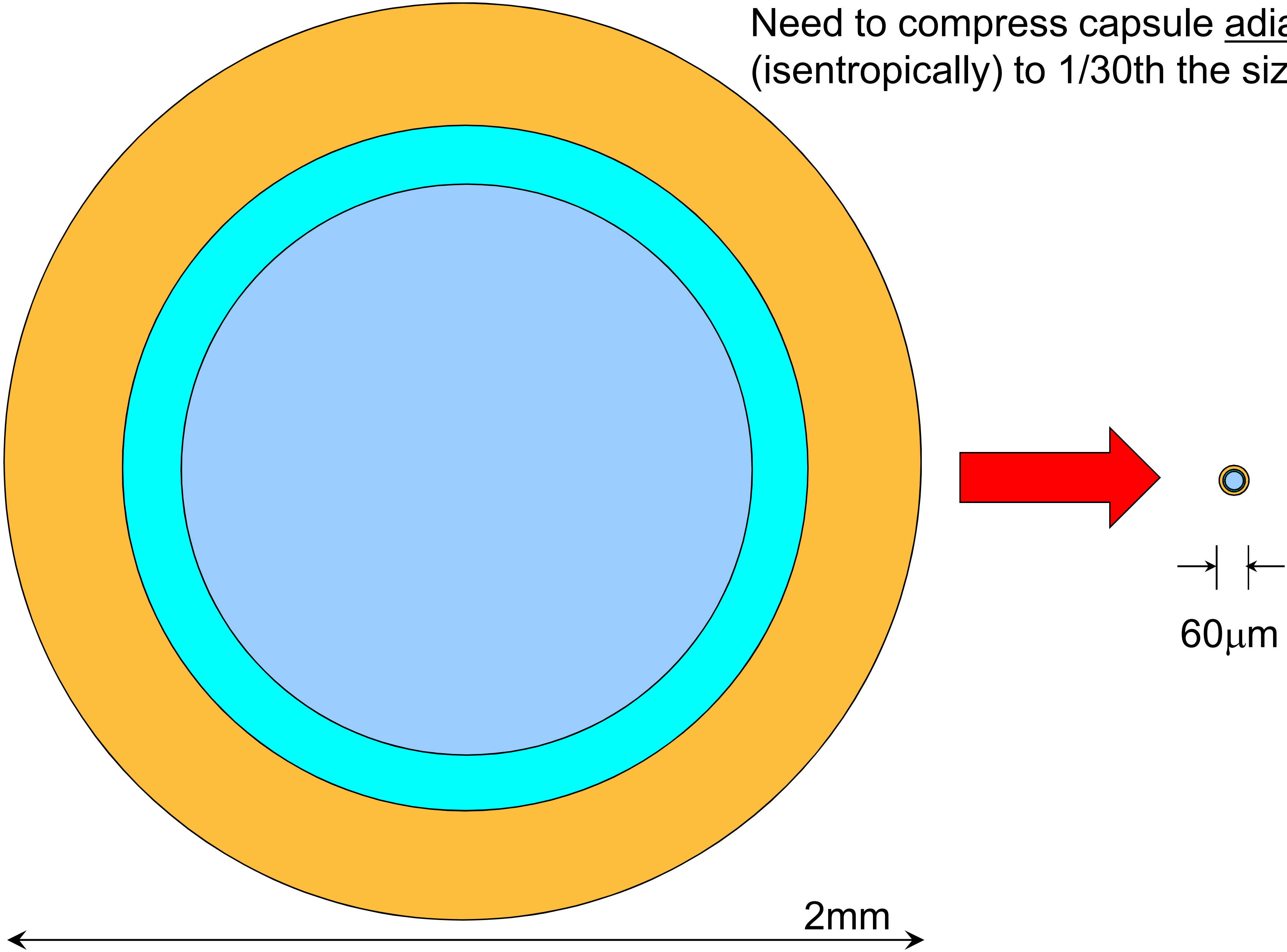


Simple direct drive targets



Lofty goal of the National Ignition Campaign (NIC): "Ignition"

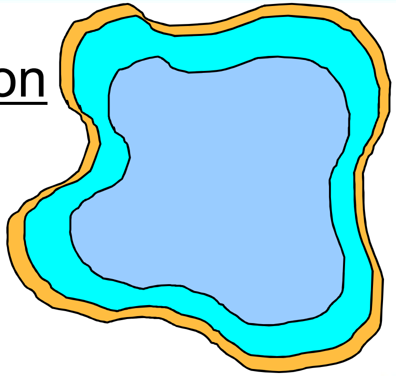
Need to compress capsule <u>adiabatically</u> (isentropically) to 1/30th the size (ρ x1000)

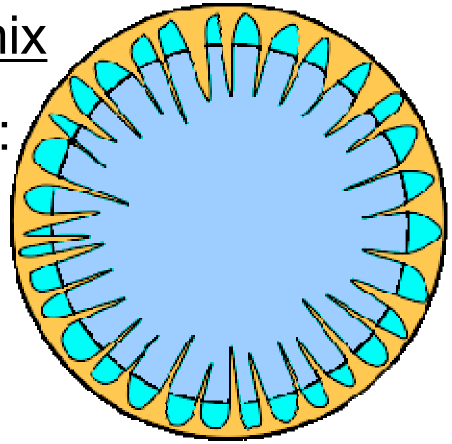


Pitfalls to achieving ignition

<u>Asymmetric implosion</u>

Diagnose with:
Yield, ρR,
temperature,
imaging (n, x-ray)

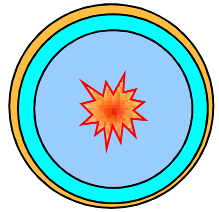




<u>Ablator/Fuel mix</u>

Diagnose with:
radchem?

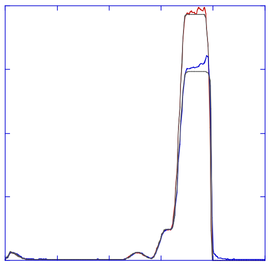
Goal!

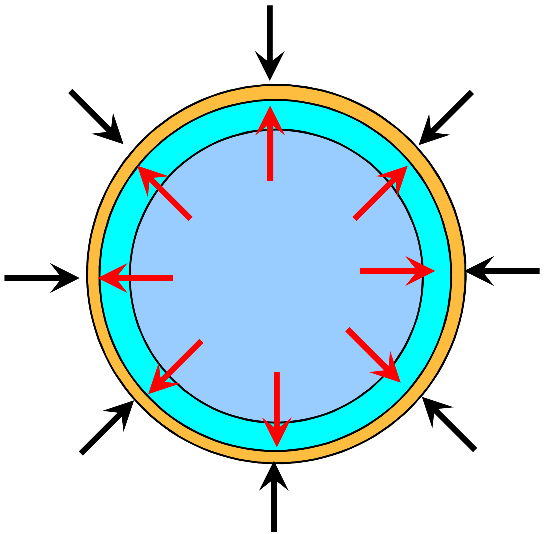


Ignition: Hotspot initiates outward "burn" into dense outer layer

<u>Shock Timing</u>

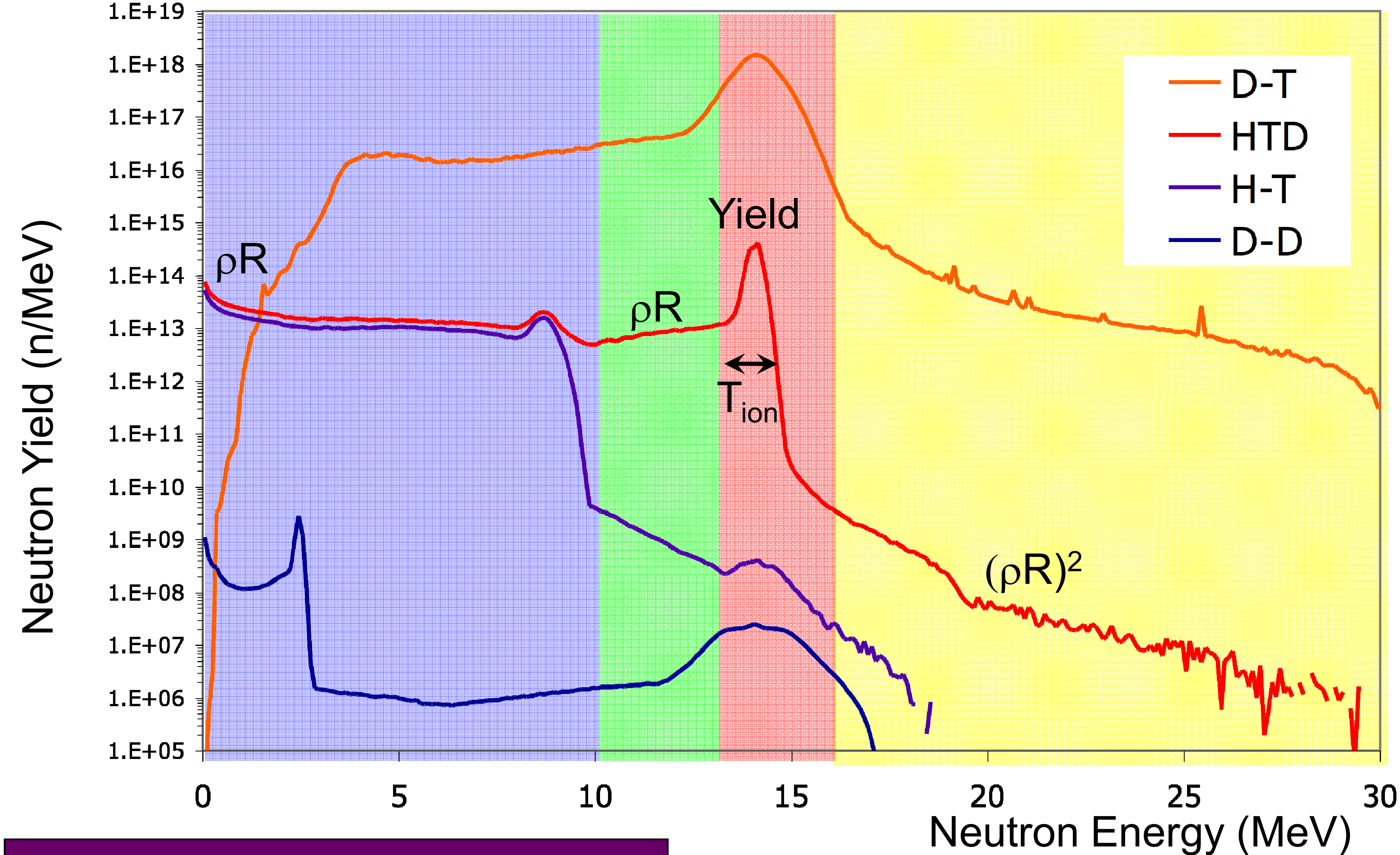
Diagnose with:
γ-ray reaction history





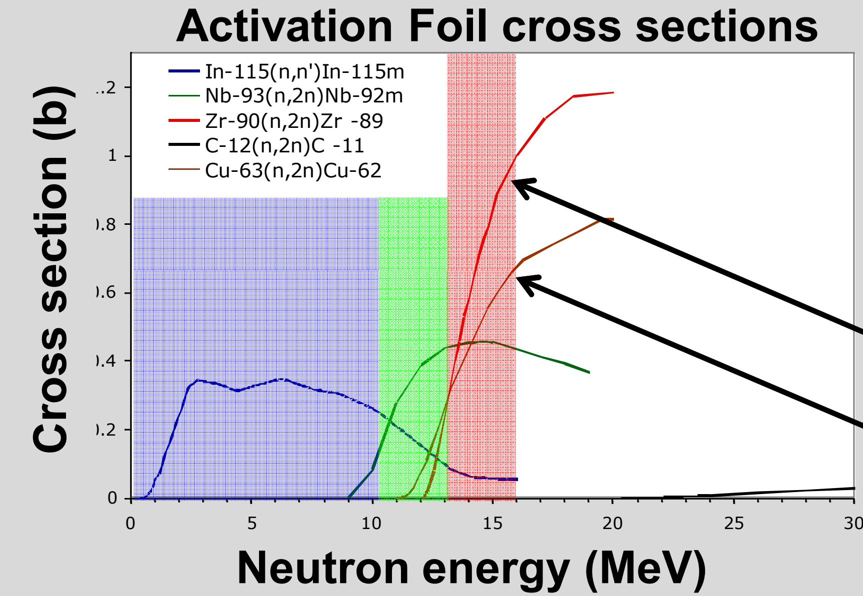
<u>(Etc…)</u>

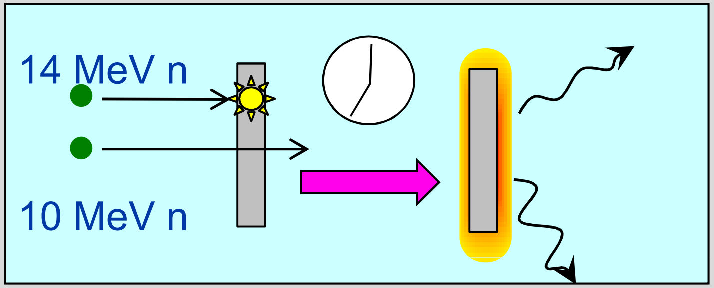
Neutron Spectra
Diagnostics must span 9 orders of magnitude



Atypical measurement challenge:
All neutrons born within <100 ps.

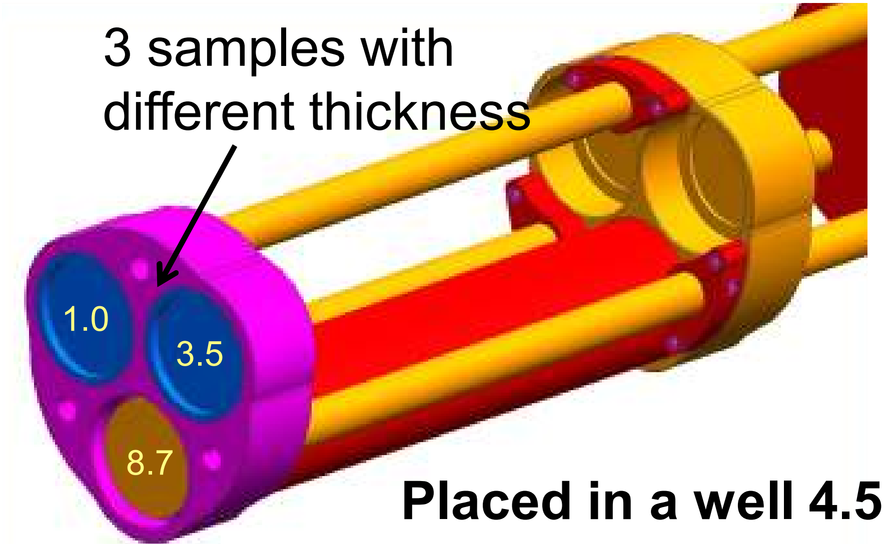
Activation: Zr Neutron activation (NAD) measures yield for DT shots to absolute accuracy of ± 7%





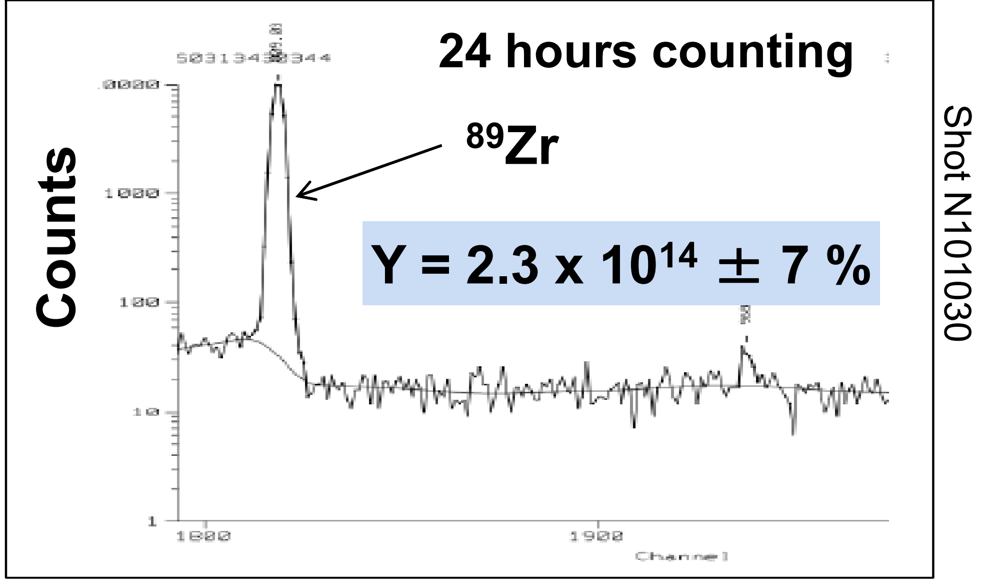
$^{90}Zr(n,2n) \Rightarrow {}^{89}Zr$ ($t_{1/2}$=3.3 d)

$^{63}Cu(n,2n) \Rightarrow {}^{62}Cu$ ($t_{1/2}$=9.74 m)

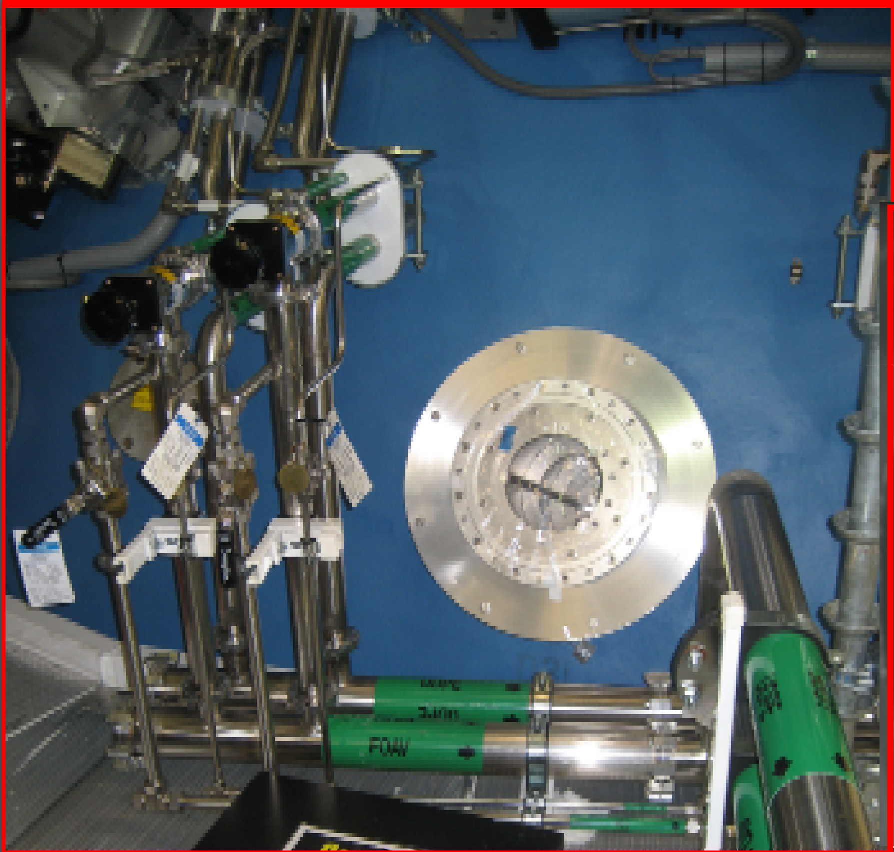


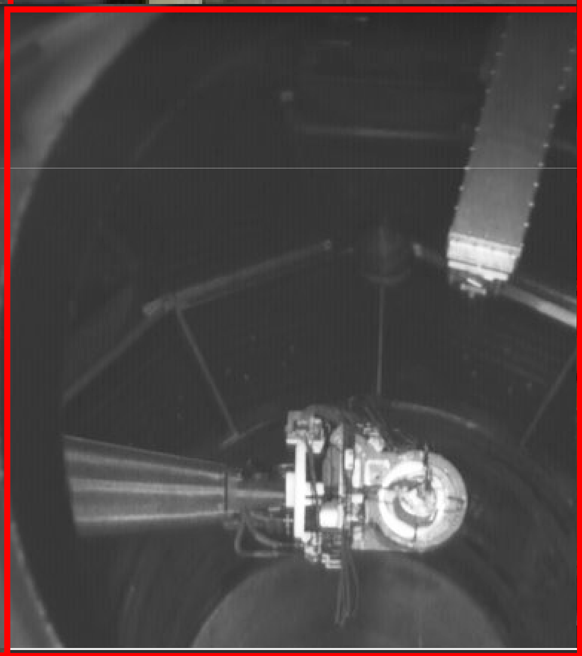
Placed in a well 4.5m from TCC

Exp.Pusher: Raw Data, 8.7mm sample



Neutron Activation Detectors

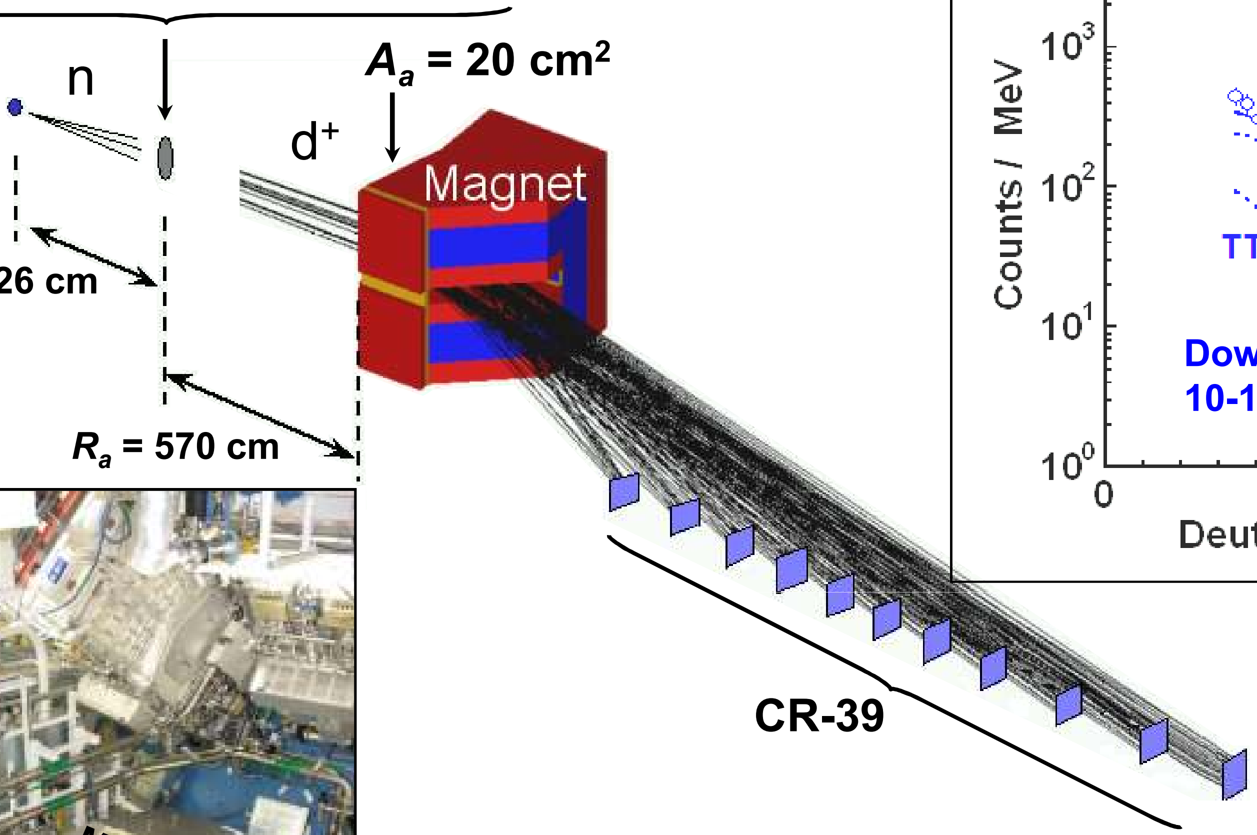




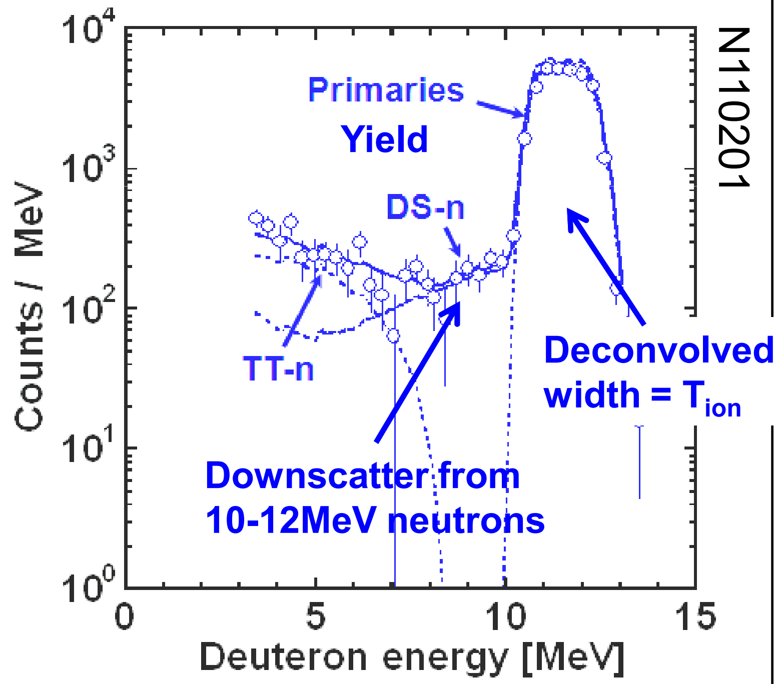
MRS: The MRS has been designed and implemented for simultaneous measurements of ρR, Y_{1n} and T_{ion}

Med-Res
t_f = 125 µm

Low-Res
t_f = 275 µm



MRS Spectrum THD-3



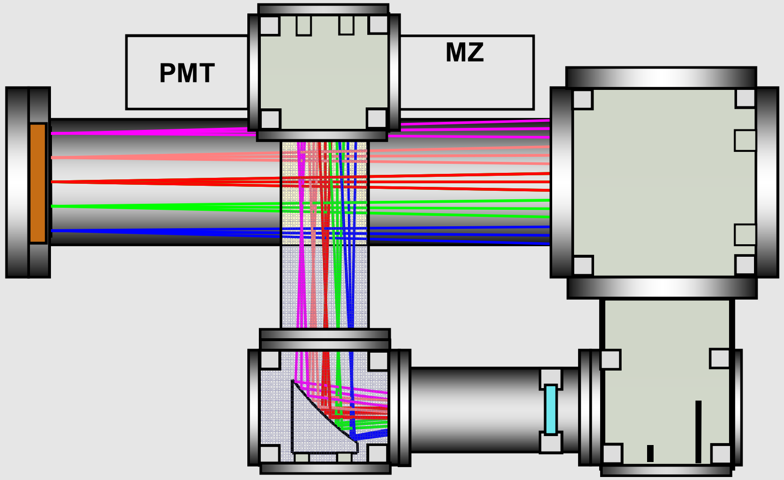
Accuracy requirement for the MRS absolute *yield* measurement < 10% for Y_{1n} > 10^{14}

Magnetic Recoil Spectrometer

Massachusetts Institute of Technology

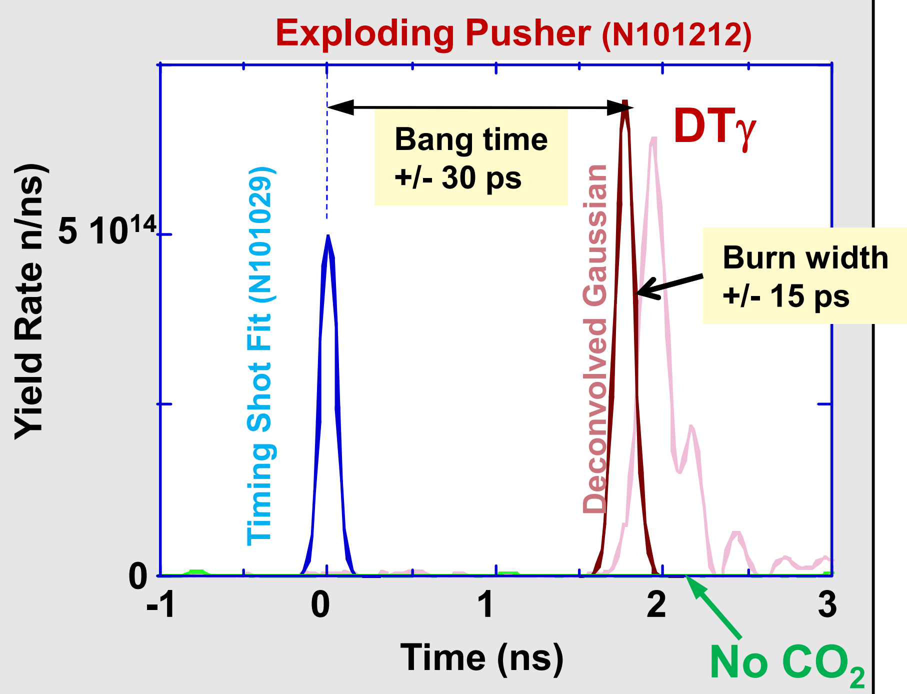
GRH: Gamma Reaction History (GRH) measures Bang Time (w/in 30 ps) and Burn Width (w/in 15 ps) with Gas Cherenkov Detectors

GRH-6m at (64,20)



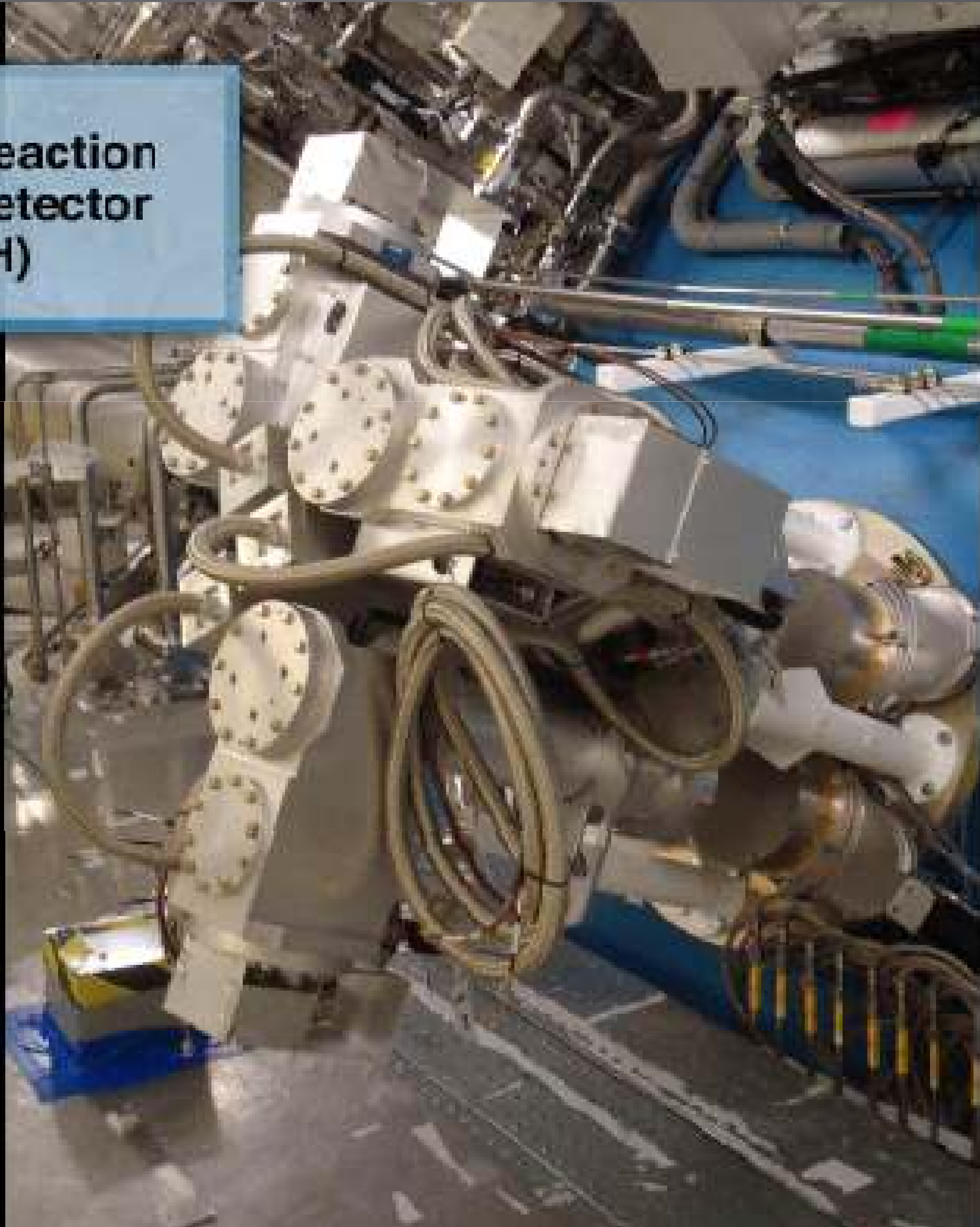
- 4 Gas Cherenkov cells
- Detectors installed with Ultra-fast MCP PMTs and optical Mach Zehnders

DT exploding pusher Data

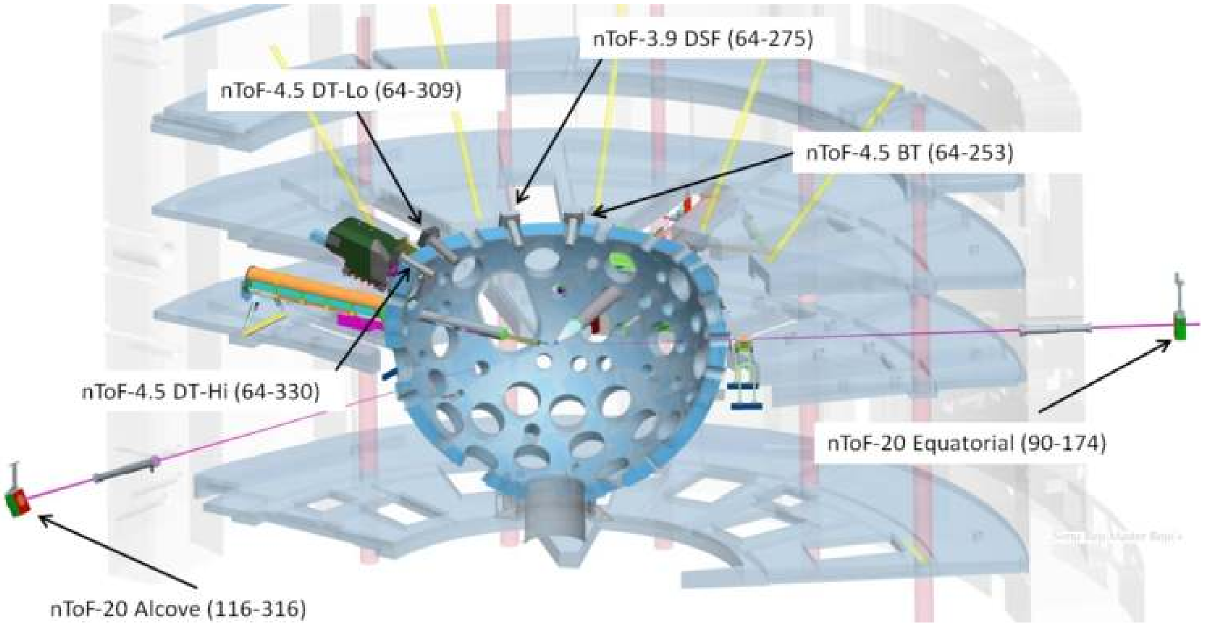


- Bangtime agrees with Ntof_BT data to within 100 ps
- Energy threshold of each cell set by gas pressure /composition
- 3-10MeV GRH will be fielded on DT implosions for yield and 4.4MeV carbon γ (ablator density measurement)

Gamma Reaction History Detector (GRH)

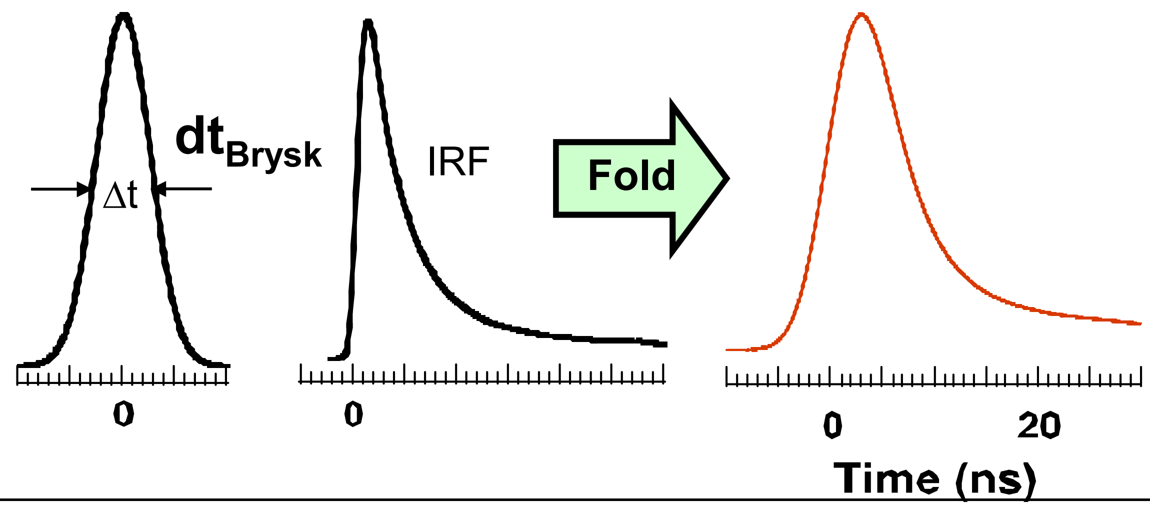


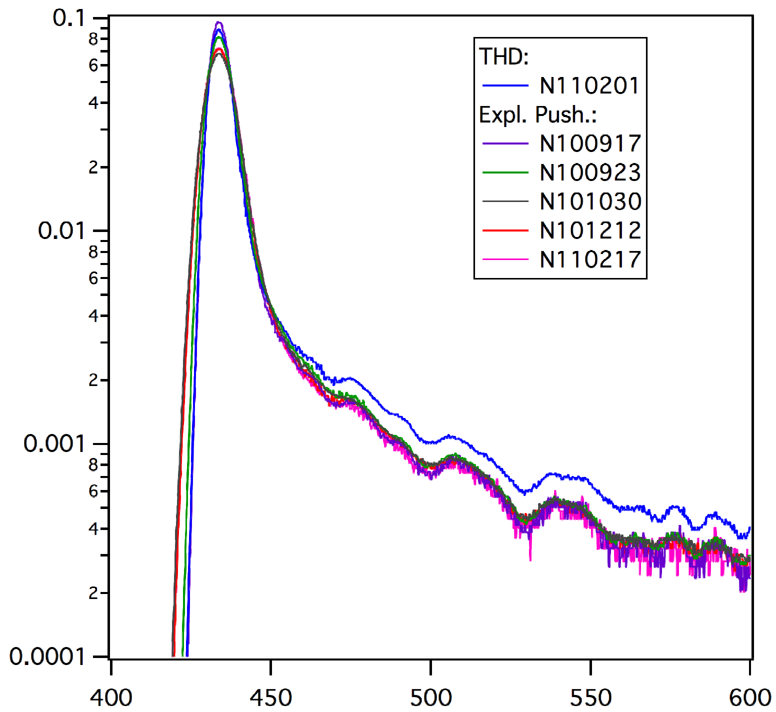
nToF: Ion temperatures, yields, and ρR from ~6 nToF detectors are calculated by an iterative process



- Neutron energy determined by time to reach detector
- To measure downscattered neutrons after 100x primary 14MeV signal, must choose detector with fast recovery time (p-xylene, CVD diamond…)

Convolve Brysk dt_{Brysk}= c x distance x $T^{1/2}$ with IRF



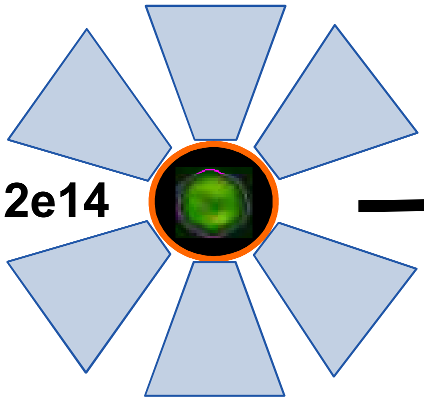



Neutron Time of Flight (NToF)

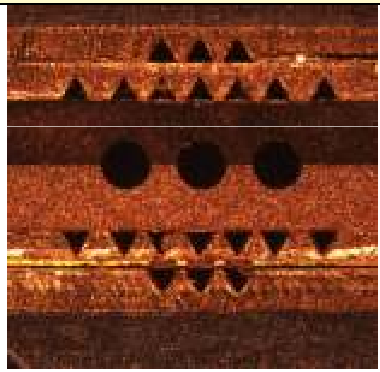
Neutron Imaging system has begun performance qualification process using exploding pusher shots

Exploding pusher

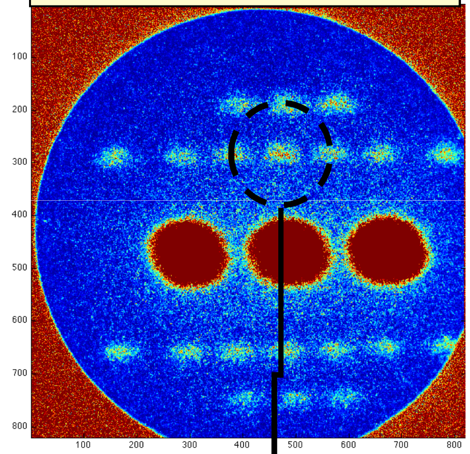
Yield = 2e14



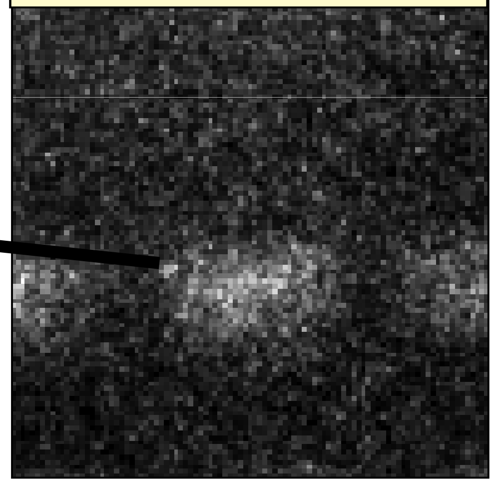
NIS Pinhole array



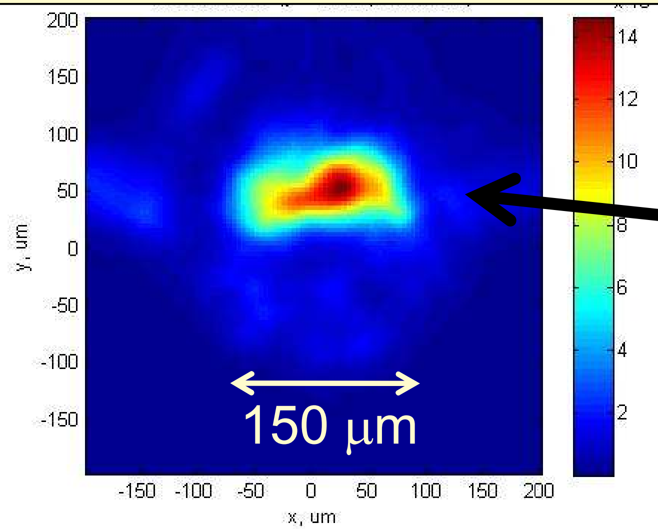
DATA



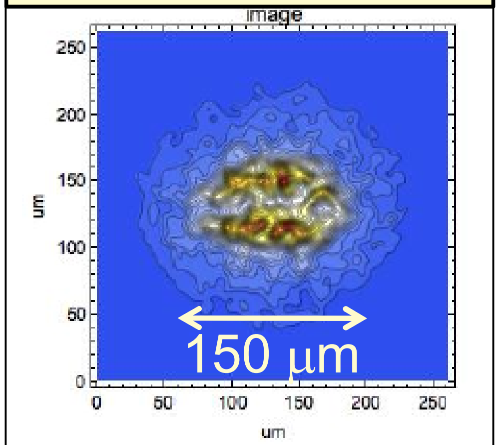
Raw Image



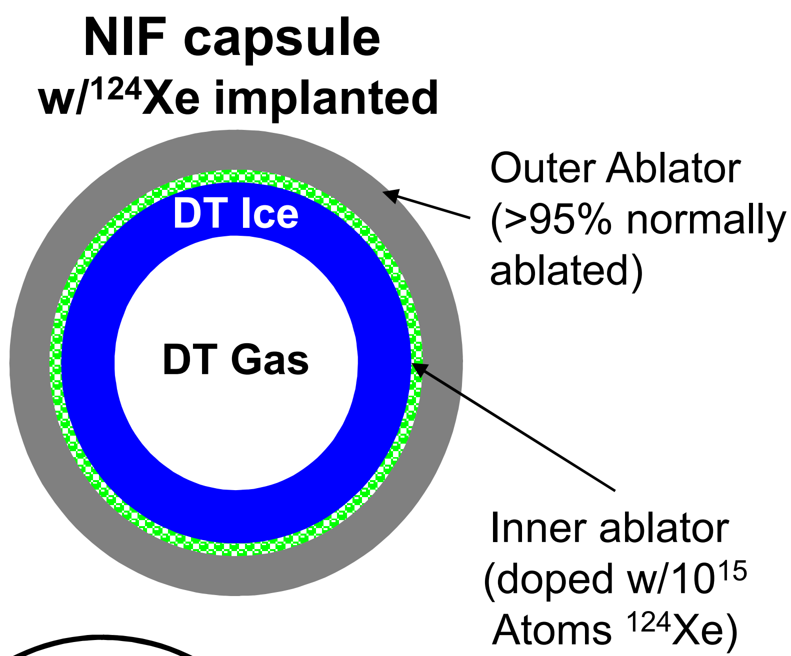
Reconstructed Neutron Image

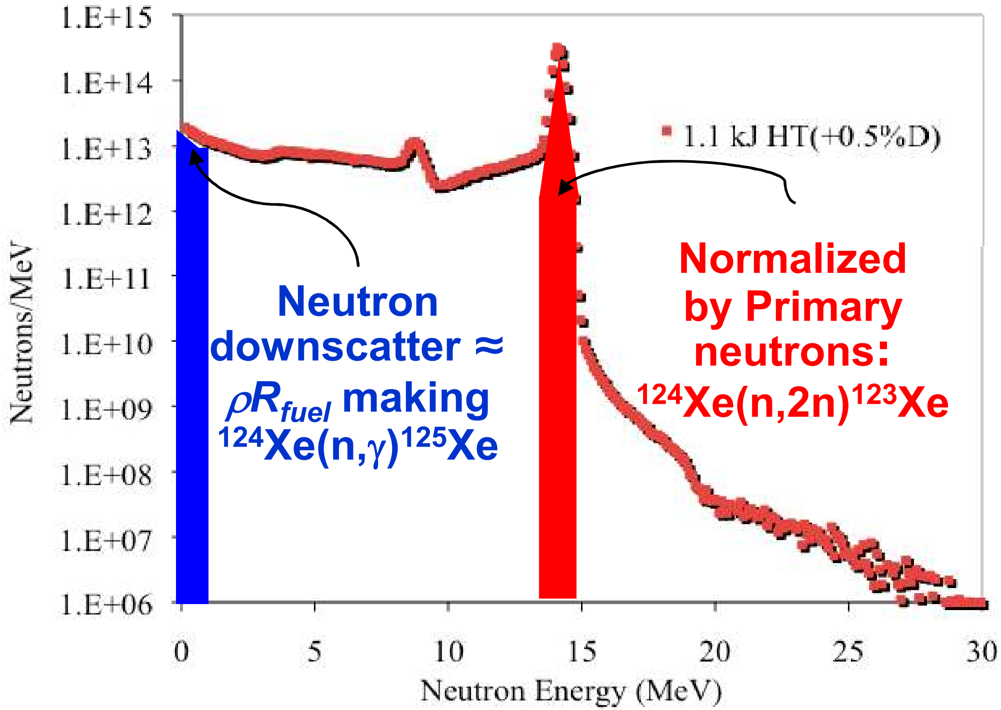


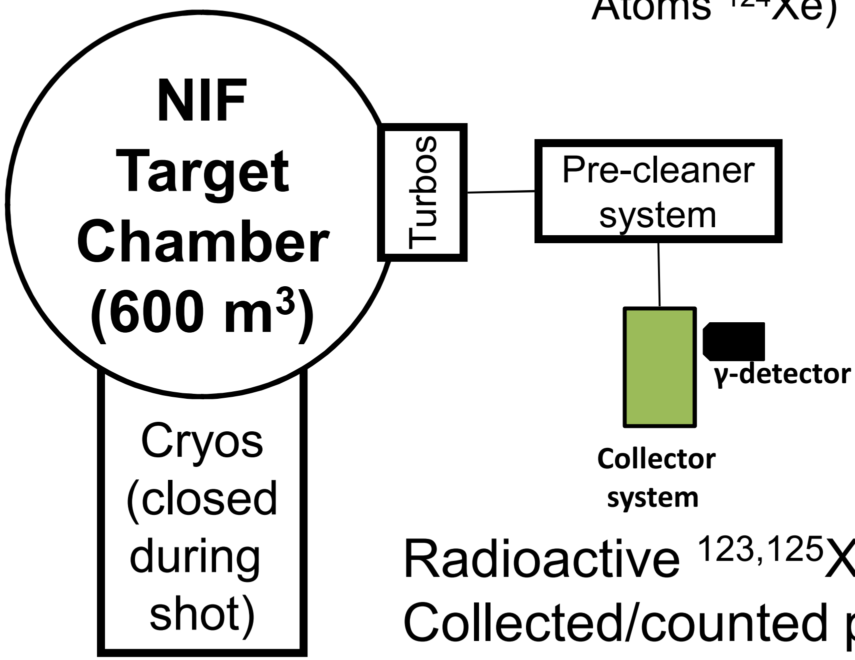
Compare to gated x-ray Image



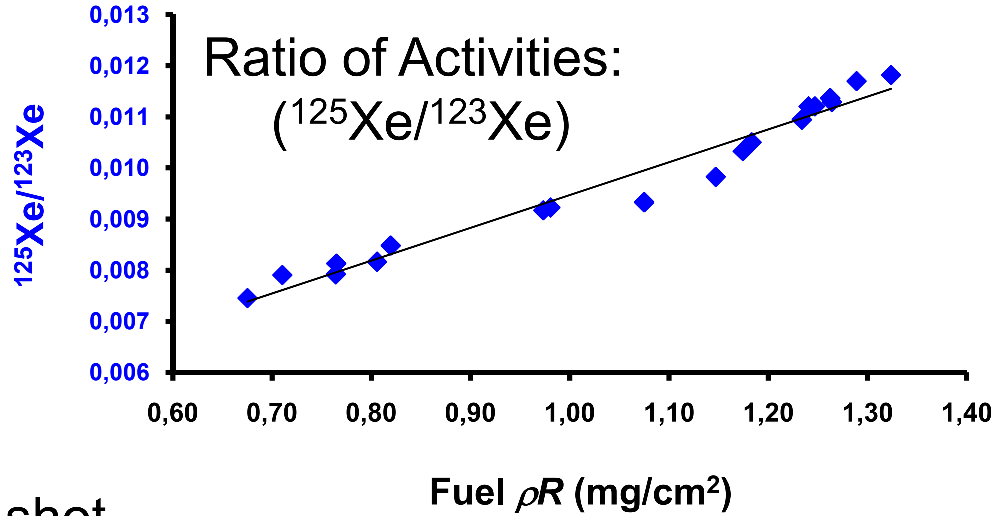
First radiochemistry (RAGS) diagnostic utilizes ^{124}Xe(n,γ) and ^{124}Xe(n,2n) to measure average ρR

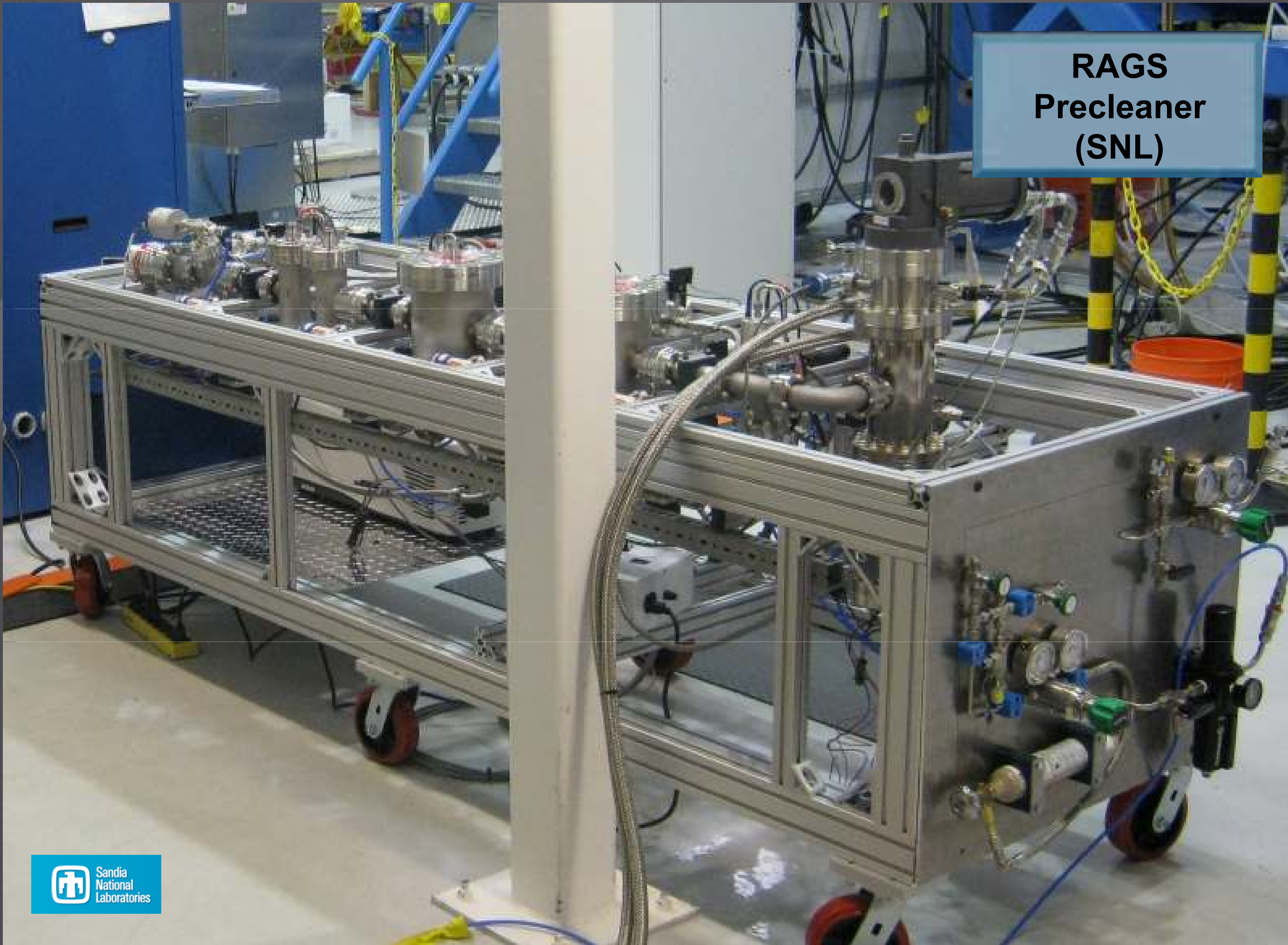






Radioactive ^{123,125}Xe
Collected/counted post-shot




RAGS
Precleaner
(SNL)

Where we are now and where we're going

- Primary purpose of these first two diagnostics phases are to achieve ignition
- We are now (≈3 weeks ago) beginning to think about science-enabling diagnostics, including:
  1. Solid-debris collection (fast and slow)
  2. Energy resolving γ-ray detectors (bent crystal)
  3. Fission-based low-energy neutron spectrometers

  (Supplements what Lee talked about)

…

Coming up with an idea for a new diagnostic is a great way to get involved

~~Nuclear Physics AT NIF~~ (thanks Lee!) Nuclear Physics FOR NIF

- D-T fusion 16.7 MeV γ-ray branching ratio

- T-T neutron spectrum (^{6}He breakup)
  - Sequential, di-neutron, or two-body?

- Nuclear-plasma interactions/rates/thermal population
  - NEEC, NEET, etc.

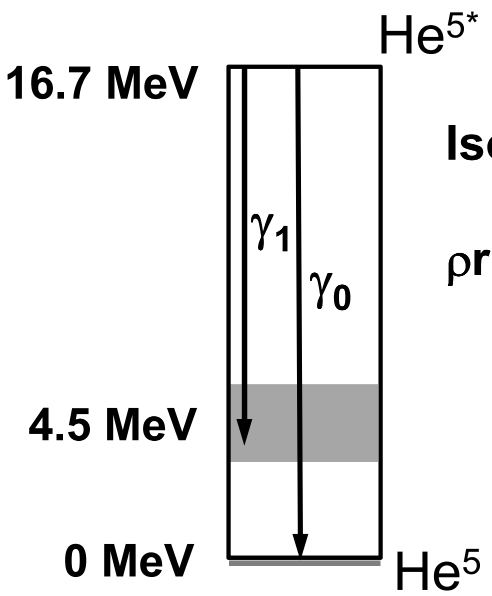
- Reactions on highly-excited states

- Cross sections: (n,x) for radchem

NIF is providing opportunities to explore new areas of nuclear physics

DT produces n and fusion γ

$$D+T \rightarrow {}^5He^* \xrightarrow{\sim 1} n\,(14.1\ MeV) + \alpha\,(3.5\ MeV)$$

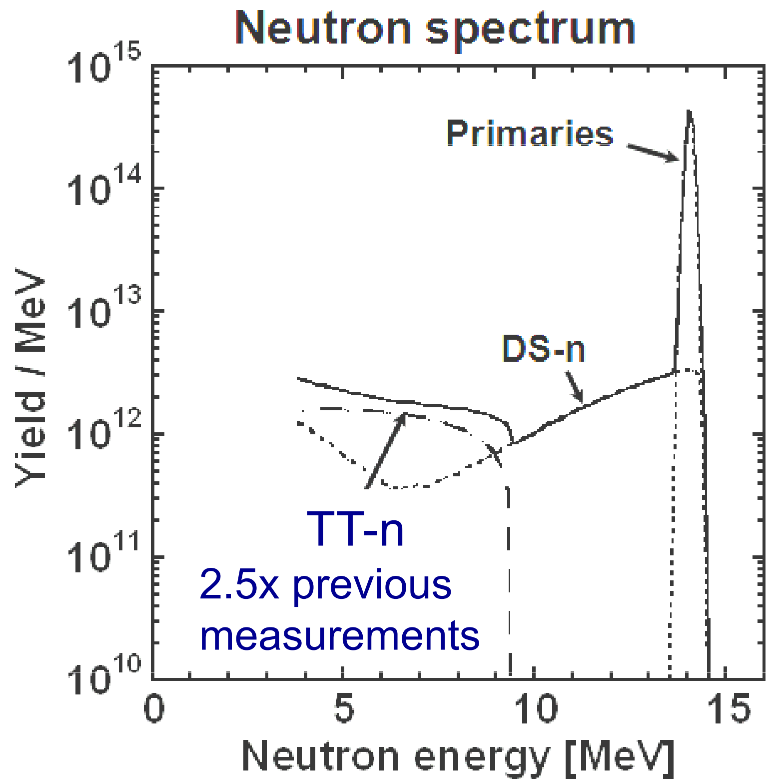


Isotropic

ρr insensitive

<u>OMEGA</u> measure γ_1/γ_0 1.35 ± 0.35 THD suggest HTγ about 5x weaker than estimates –> more accurate average yield measurement from GRH

Neutron spectrum inferred from MRS



Confirms recent OMEGA data in TT cross section region
– This information helps reduce uncertainties for RAGS

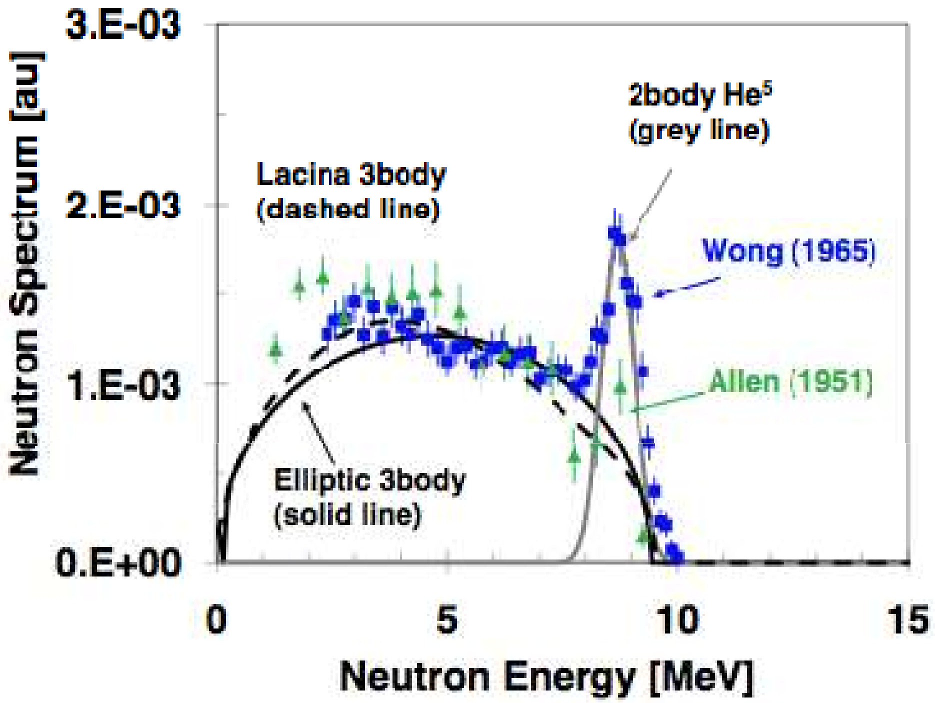
Nuclear physics needs
T-T neutron spectrum at NIF-relevant energies (~10keV)

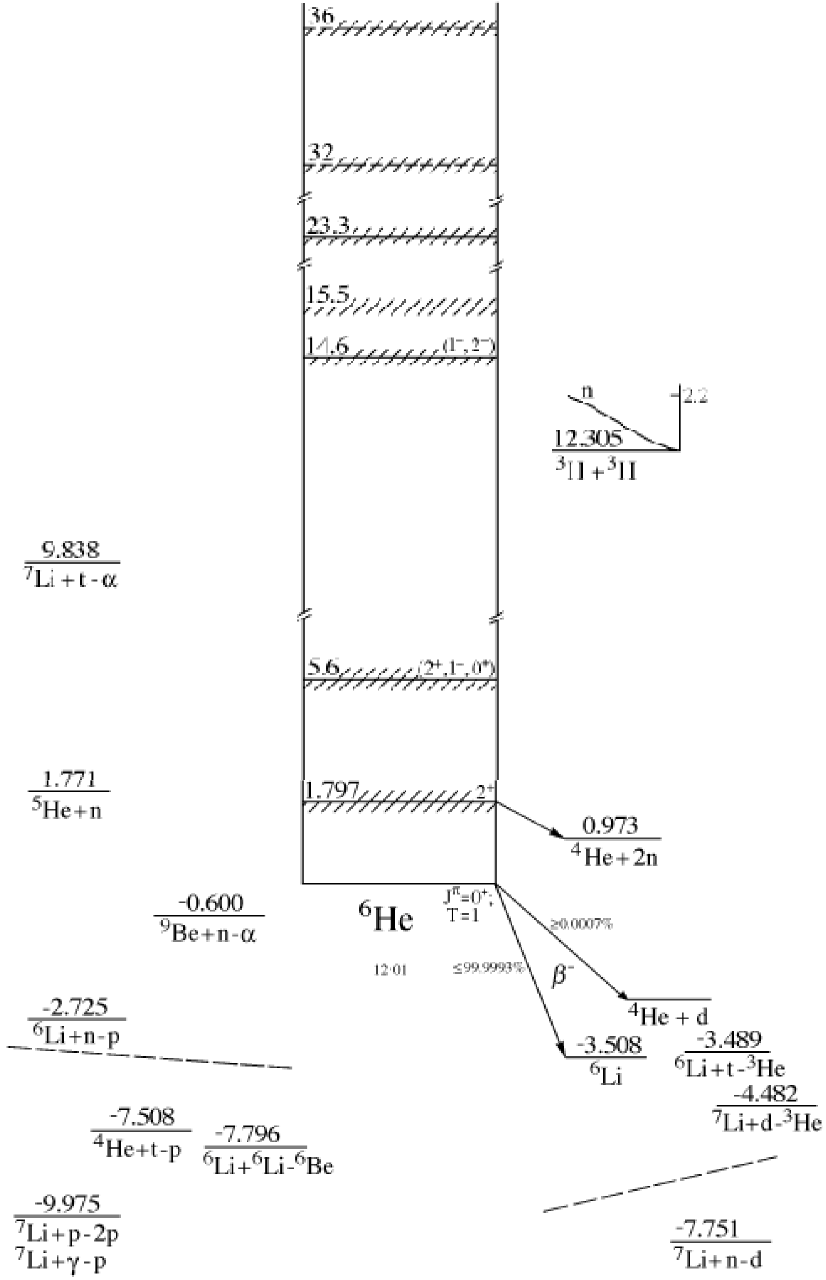
3 body reaction

T+T □α+n + n (0-9.5 MeV)

2 body reaction

T+T □^{5}He+ n (8.7 MeV) □ α+n





Could investigate by creating ^{6}He at relevant energies via ^{6}Li(d,^{3}He), tag on ^{3}He,α coincidences

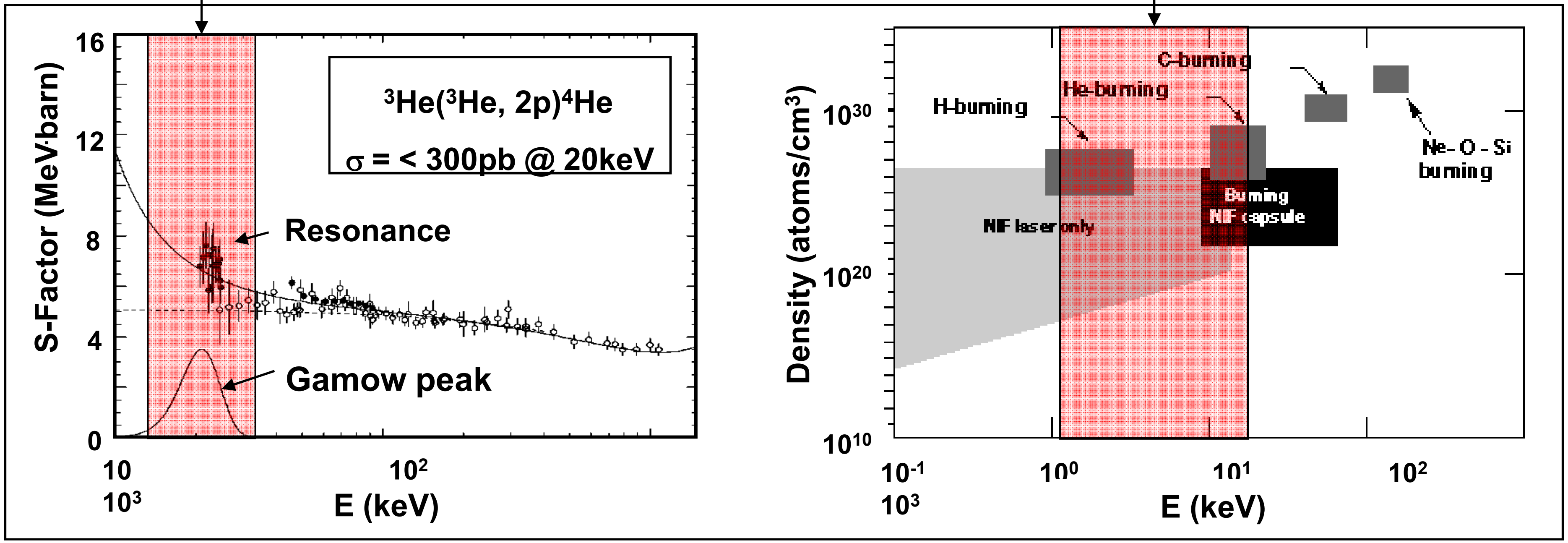
Thanks…

- Lee Bernstein (LLNL)
- Jac Caggiano (LLNL)
- Dan Casey (MIT)
- Johan Frenje (MIT)
- Stephan Friedrich (LLNL)
- Vladimir Glebov (LLE)
- Hans Hermann (LANL)
- Joe Kilkenny (General Atomics)
- Andy MacKinnon (LLNL)
- Craig Sangster (LLE)
- Dieter Schneider (LLNL)
- Dawn Shaughnessy (LLNL)
- Wolfgang Stoeffl (LLNL)

- lots and lots of others…

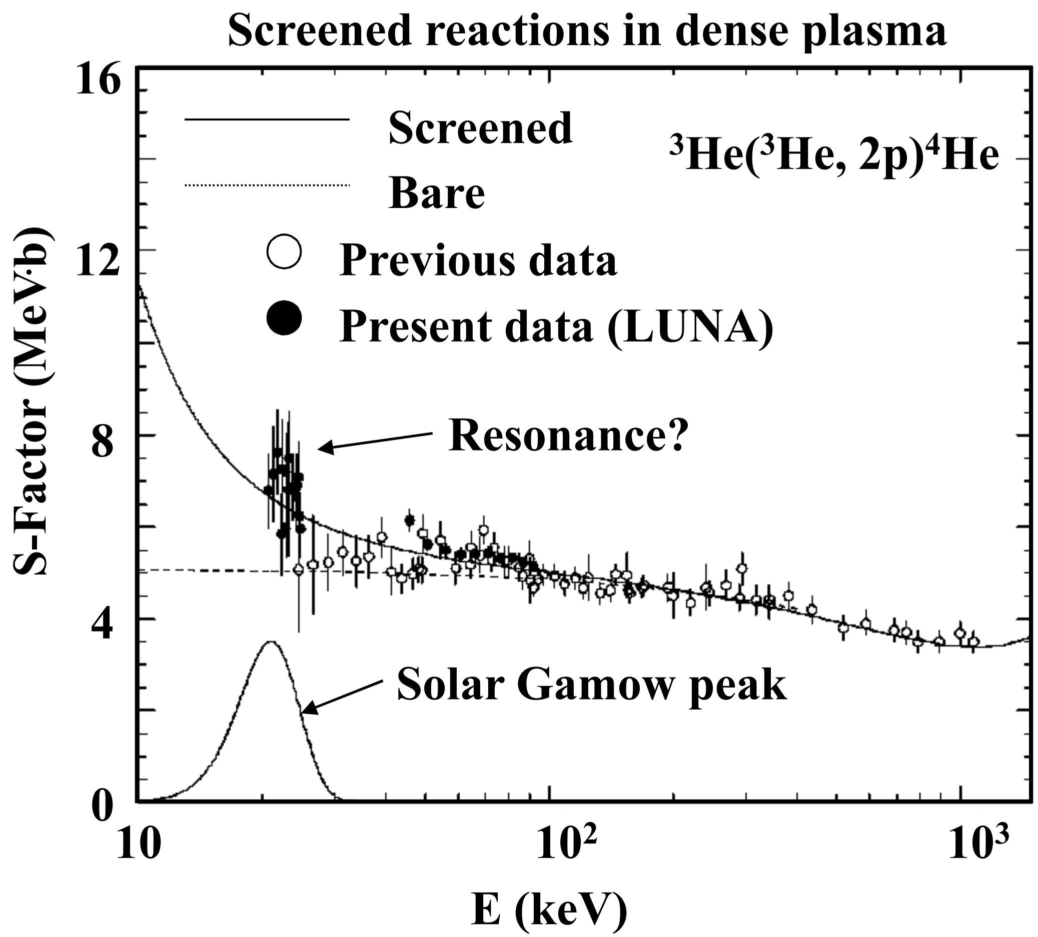
Nuclear Cross Sections for Charged Particles at Energies Relevant to Astrophysics are Difficult to Measure

$$Rate = \langle \sigma v \rangle \propto \frac{S(E)}{E} e^{-2\pi\xi}$$



By measuring reaction products at NIF the relevant cross sections are inferred

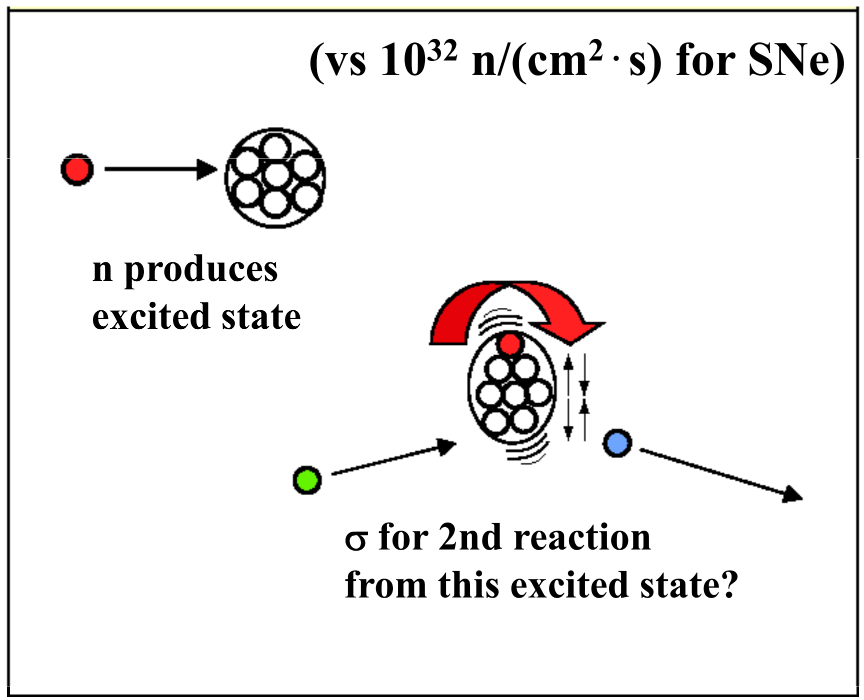
The achievement of ignition will provide unique research opportunities in astrophysics, stewardship physics, and inertial fusion energy studies



M. Junker et al., PRC 57, 2700 (1998)

- Strongly screened reactions are relevant to stellar evolution

Multi-hit reactions from 10^{33} n/(cm$^2 \cdot$ s) flux



- First hit gives excited nuclear state
- Reactions from excited states, relevant to r-process nucleosynthesis of heavy elements
- Second hit reaction cross section uncertain

S. Libby, IFSA proceedings (2004)