Shots, shot and more shots on OMEGA allows diagnostics and targets development, opening new areas of science

Presentation to

OMEGA Laser User Group

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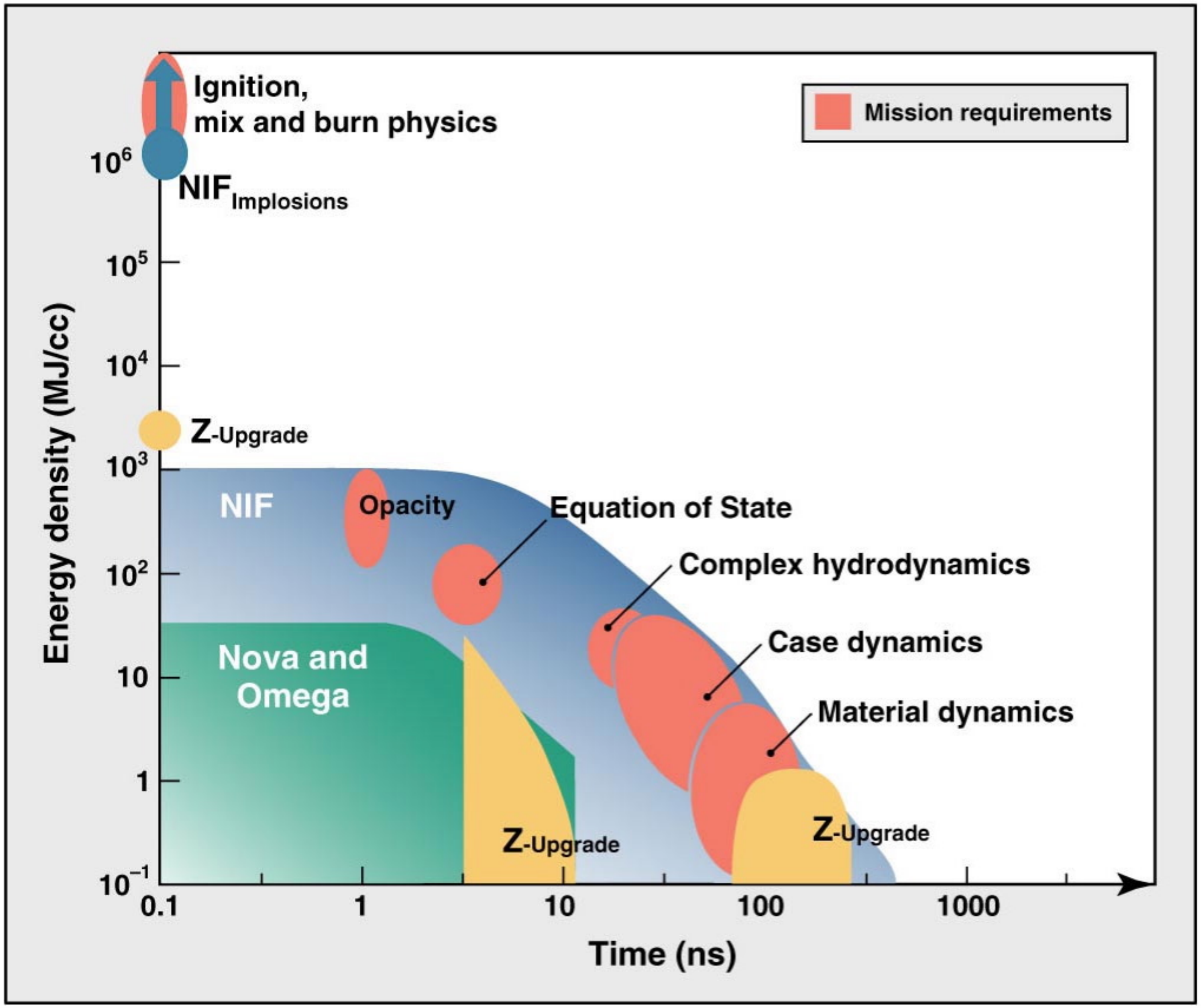
NIF Diagnostic Leader &

General Atomics V. P.

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

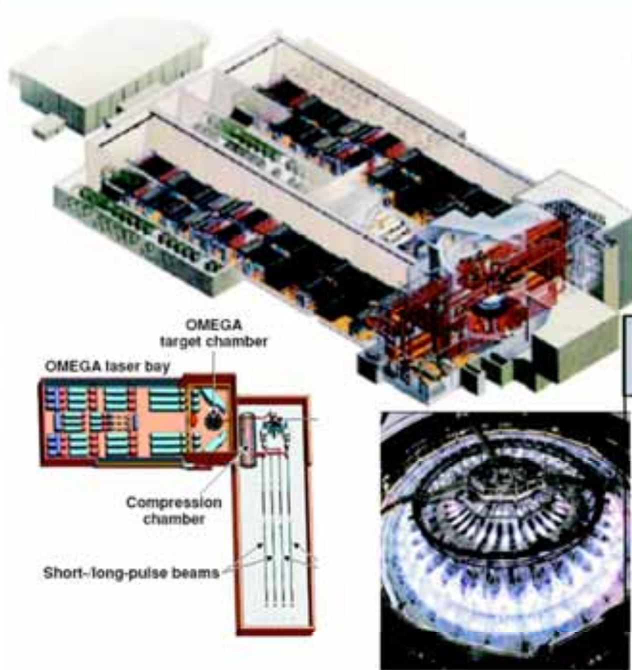
This is an exciting time to be doing High Energy Density Physics: US has 3 forefront facilities



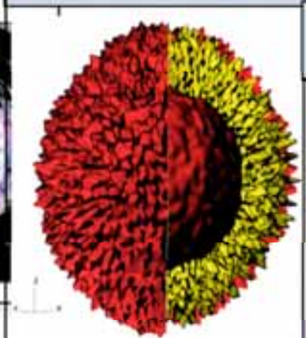
As well an important role for OMEGA is to develop techniques / diagnostics for NIF

Advances in High Energy Density Physics Require:

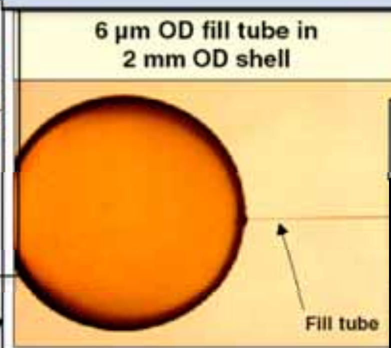
Drivers



Theory



Targets

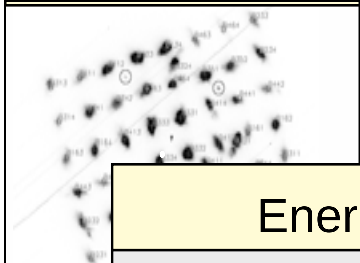


Diagnostics

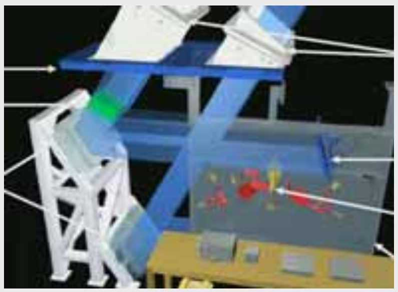
Given a driver, innovation in targets and diagnostics drive new science

Most of the > 40 NIF diagnostics were developed on Nova, OMEGA or NTS

Laser



Energetics



FABS31
on NIF

Energetics diagnostics. Full Aperture Backscatter

Capsule

Gated
X-ray
Detect

Capsule diagnostics, developed on OMEGA,

Ignition

UGT experience, development on OMEGA with neutrons

NIF, OMEGA and Z are generational machines
-diagnostics will continuously evolve

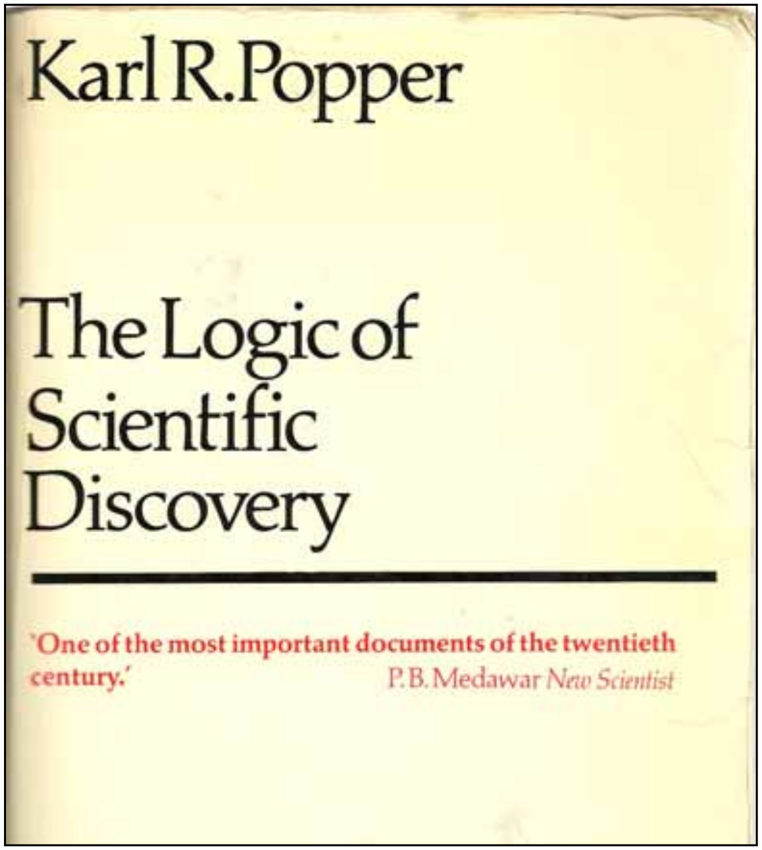
NIF's ignition diagnostics measuring: Yield, Areal density (ρR), Ion Temperature (T_{ion}), Bang time, burn duration and Shape developed on OMEGA

Diagnostic		Primary purpose	Acronym
Zirconium Nuclear Activation		Yield	Well NADS
Copper Nuclear Activation		Yield	NAD 20
Magnetic Recoil Spectrometer		Yield, ρR, T_{ion}	MRS
Gamma Reaction History		N bang time, burn duration	GRH
Neutron Time of Flight	20m – Equator	T_{ion} , ρR	NTOF_20E
	20m - Alcove	T_{ion} , ρR	NTOF_20A
	Neutron Bangtime	N bang time	NTOF_BT
	DT – high yield	Yield > 5e13	NTOF4_DTHI
	DT – Low yield	Yield < 5e13	NTOF4_DTLO
Hardened Gated X-ray Imager (hGXI)		X-ray Shape, X-ray bang time	hGXI
Neutron Imaging (NIS)		Neutron shape	NIS

Why measure attributes different ways?

Complementary redundant diagnostics are essential for the scientific method

- Karl Popper, Hutchinson Press, 1959: "cannot prove a theory (measurement) is right, can prove it is wrong"- by test (comparison with other diagnostics



Falsifiability and Testability

: "Hypotheses are nets: only he who casts will catch"

- Down Scatter Fraction (DSF): measure by NToF and Magnetic Recoil Spectrometer
- ρR: measure with NToF, MRS, Radchem and by ARC
- Hot spot T measured by x-rays and neutron emission

To make a contribution to NIF diagnostics you don’t have to work at a large national Laboratory

LLNL
- FABS,NBI
- Dante I & II
- VISAR
- DISC
- RAGS
- hGXI
- ARIANE
- DIXI
- NAD

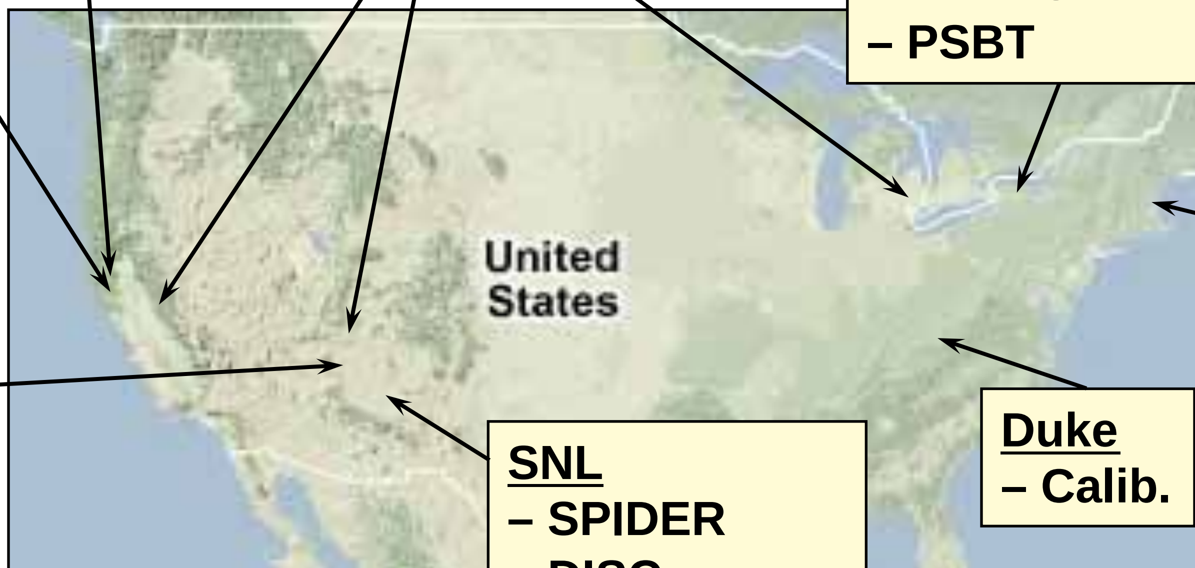
LBNL
- Calibration
- Rad. Chem.

NSTec
- Calibration
- NToF

U of M.
- HEMPI

LLE
- NToF
- 4ω fidu system
- MRS, NADS
- SPBT
- HEXRS
- PSBT

AWE
- FFLEX



MIT
- MRS
- WRF
- PTOF

LANL
- GXD
- γ burn
- Rad. Chem. II
- n imaging

SNL
- SPIDER
- DISC
- NAD (Cu)
- NToF
- RAGS

Duke
- Calib.

CEA
- N imaging

Universities develop valuable niches: MIT- CR39, U of M targets, Imperial College- high speed electronics.

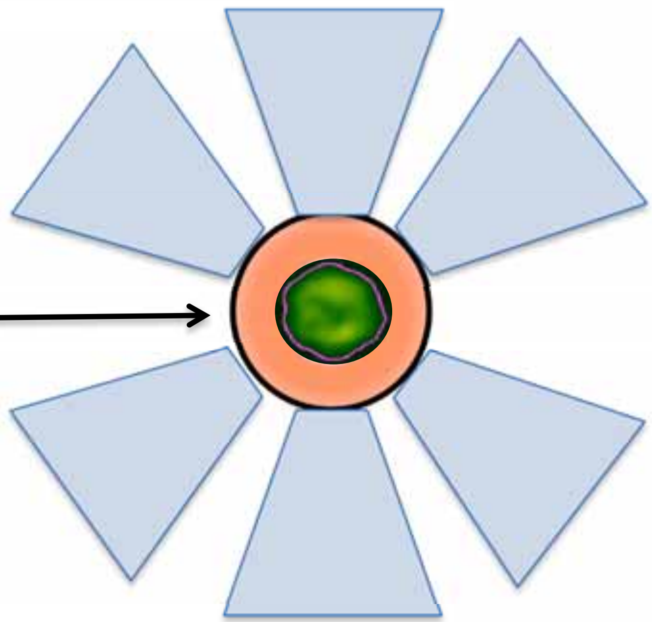
Pat McKenty's polar direct drive exploding pushers verify the performance of the ignition diagnostics

Yn: Neutron Activation (NAD, Zr)

NIF-02211-21072s2.ppt

Exploding pushers:
Direct drive – 125kJ
Isotropic Yield ~ 2e14
Low ρR < 20mg/cm^2

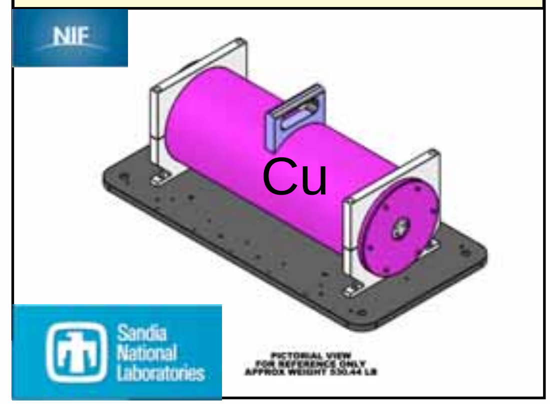
1.5mm diam.
Capsule w/ 10 atm
50:50 DT fill



Polar direct drive platform designed, developed at LLE

Low ρR provides ideal, low background for yield and downscatter diagnostics

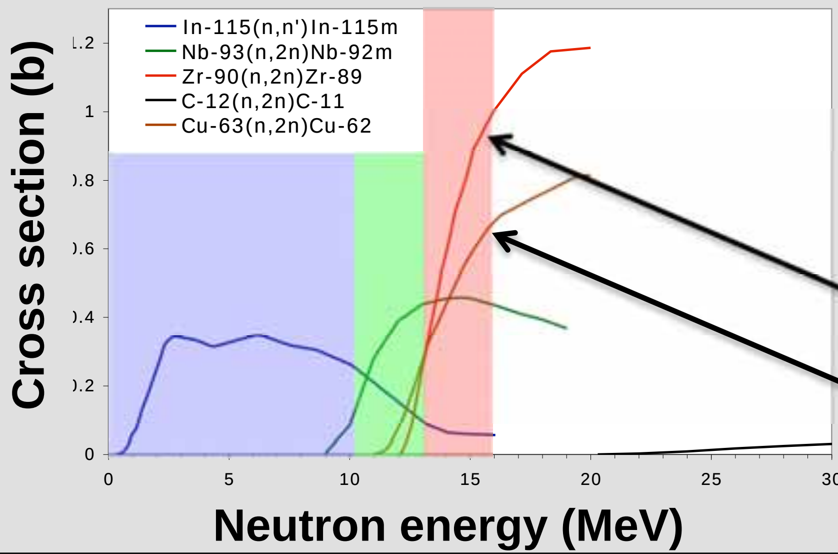
Yn: Neutron Activation (NAD, Cu)

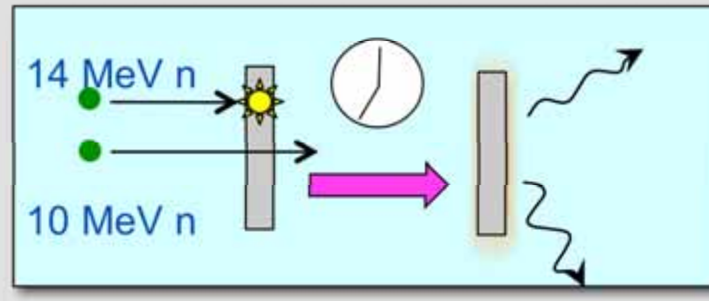


Yn: Magnetic Recoil Spectrometer (MRS)

Yield: Zr Cu and Zr activation measures yield for DT shots to absolute accuracy of ± 7% : BUT how do we know it is right?

Activation Foil cross sections

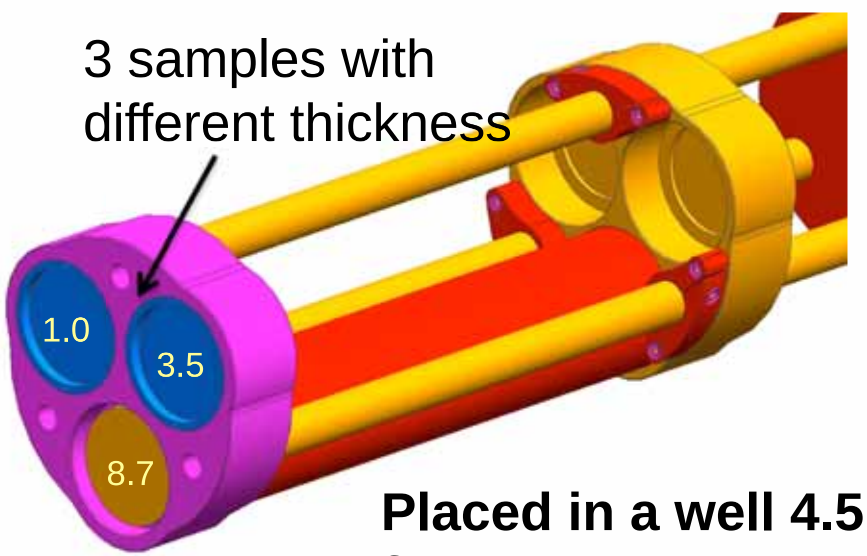




$^{90}Zr(n,2n) \Rightarrow {}^{89}Zr$ ($t_{1/2}$=3.3 d)

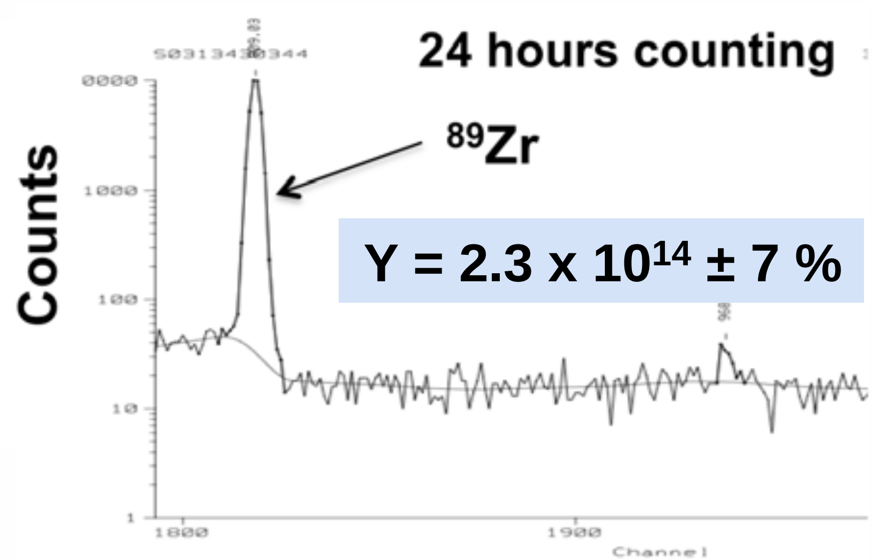
$^{63}Cu(n,2n) \Rightarrow {}^{62}Cu$ ($t_{1/2}$=9.74 m)

3 samples with different thickness



Placed in a well 4.5m from TCC

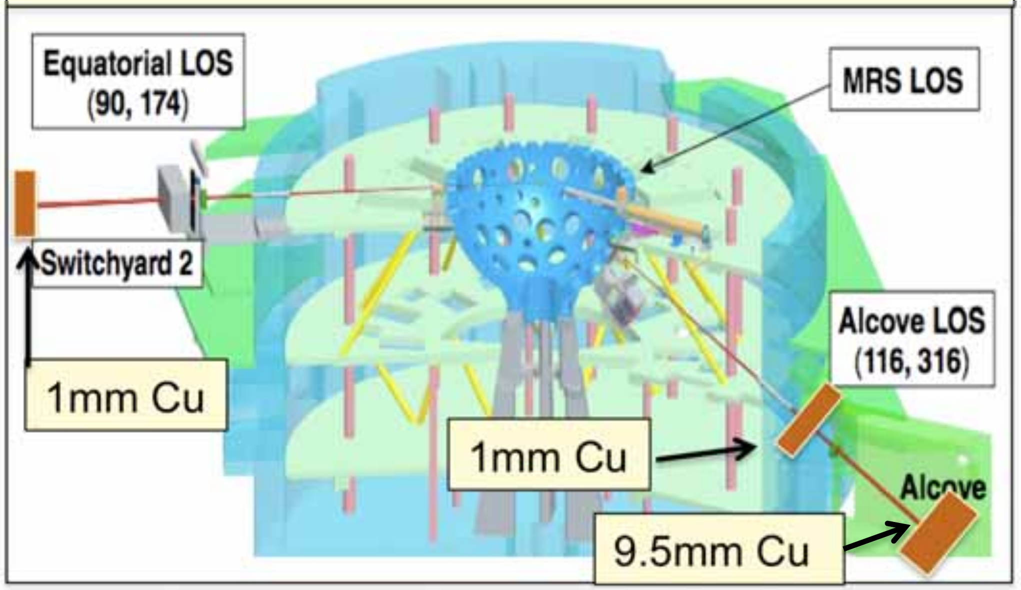
Exp.Pusher: Raw Data, 8.7mm sample



Shot N101030

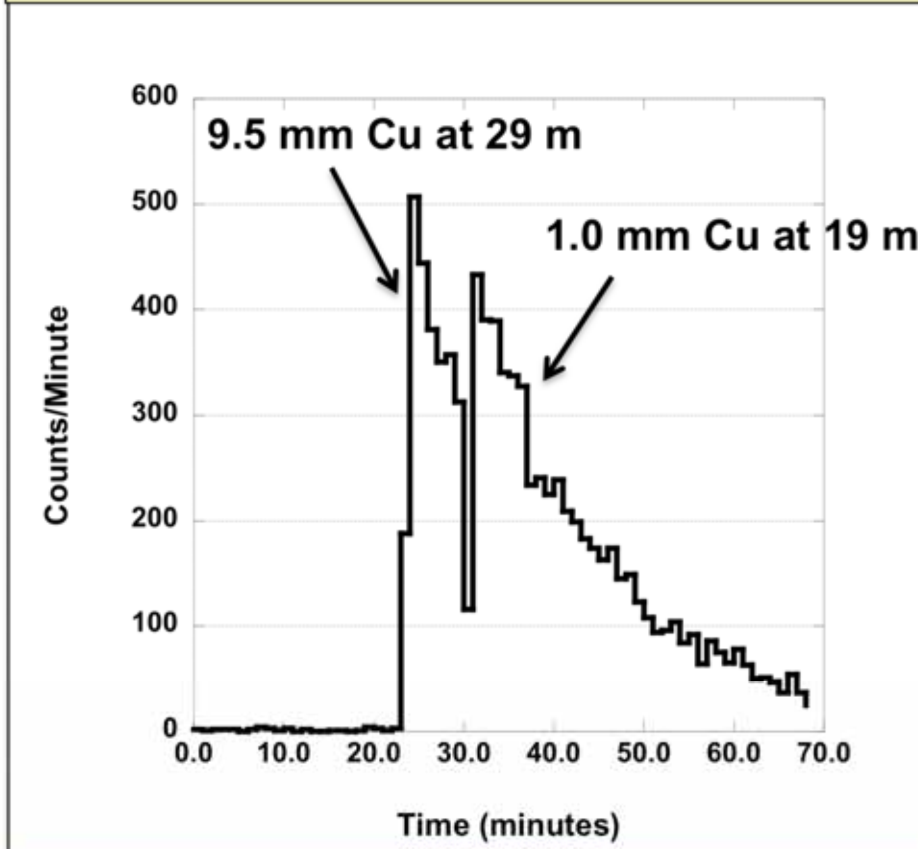
Yield: Copper activation has an absolute accuracy of ±10%- maybe

Copper sampling yield on equator and in neutron alcove



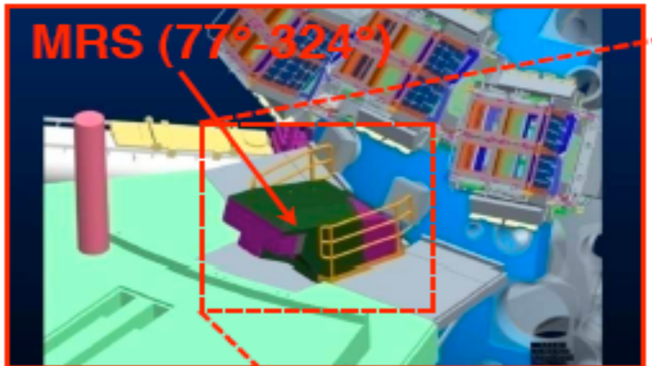
Uncertainty Estimates	Error ±1 σ
Detector efficiency & Gamma-ray self-shielding	8.6 %
Cu cross section uncertainty	1.3 %
Position uncertainty (awaiting measurements)	0.1 %
Scatter/absorption from Al and W attenuators	5.0 %
TOTAL SYSTEMATIC	10.0 %
Statistical	2.5 %

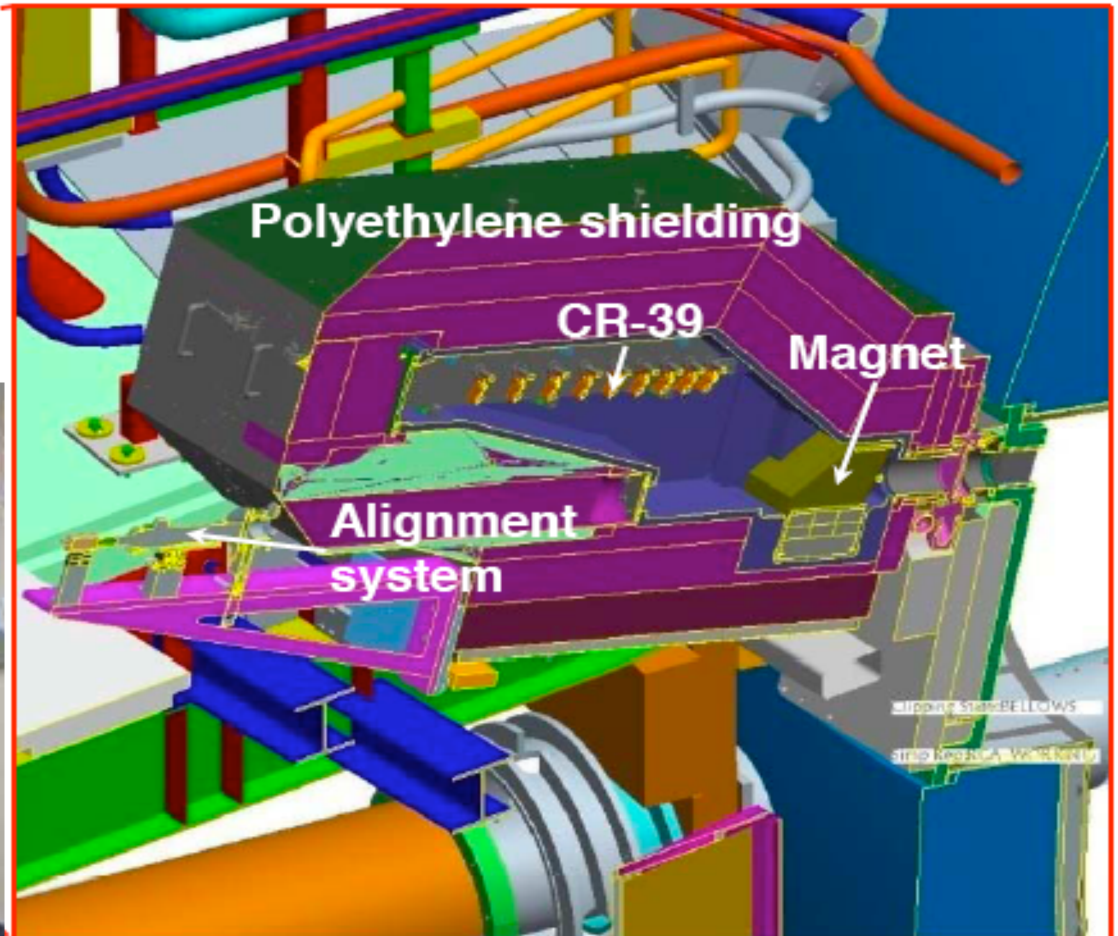
Copper Decay curve N101030 – Exp pusher



$Y = 2.5 \times 10^{14} \pm 10\ \%$

The NIF magnetic recoil spectrometer (MRS) was developed on OMEGA by MIT and LLE

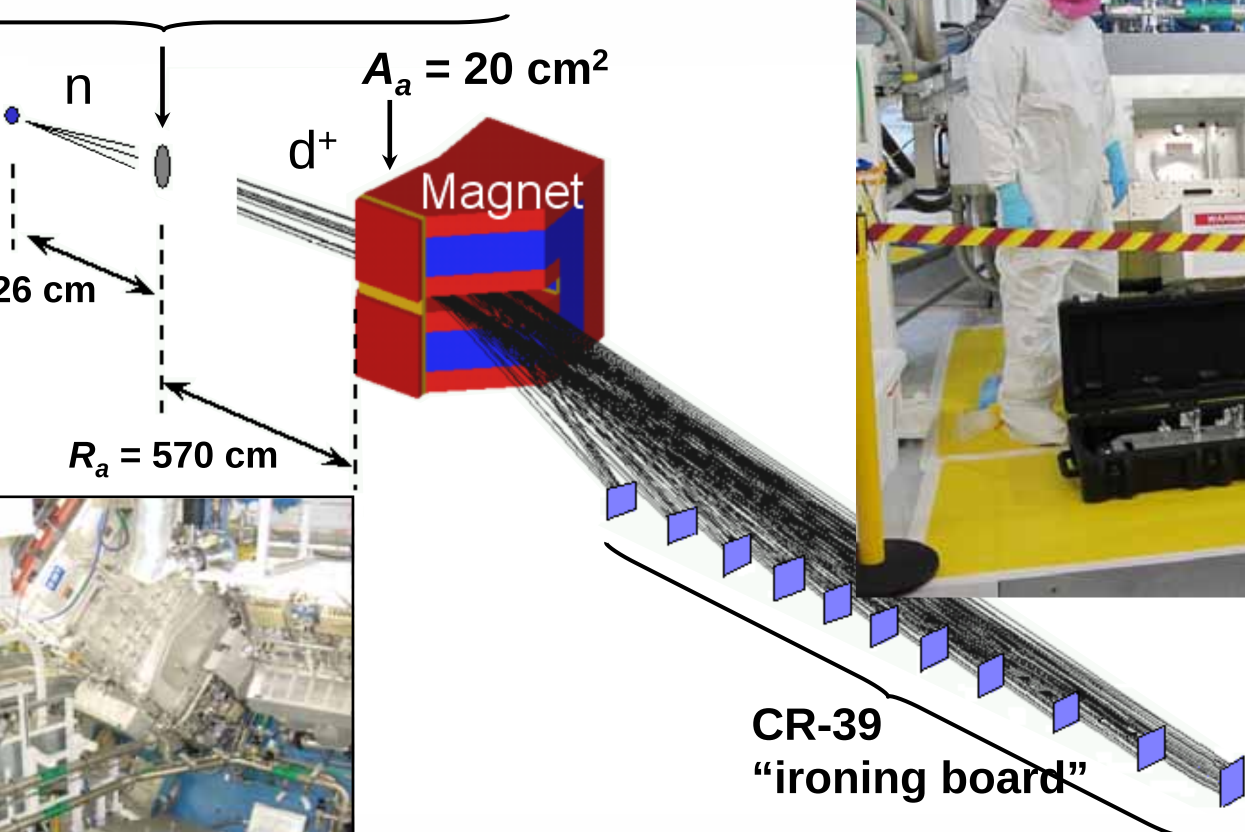




<u>Yield:</u> The MRS has been designed and implemented for simultaneous measurements of ρR, Y_{1n} and T_{ion}

Med-Res
t_f = 125 μm

Low-Res
t_f = 275 μm

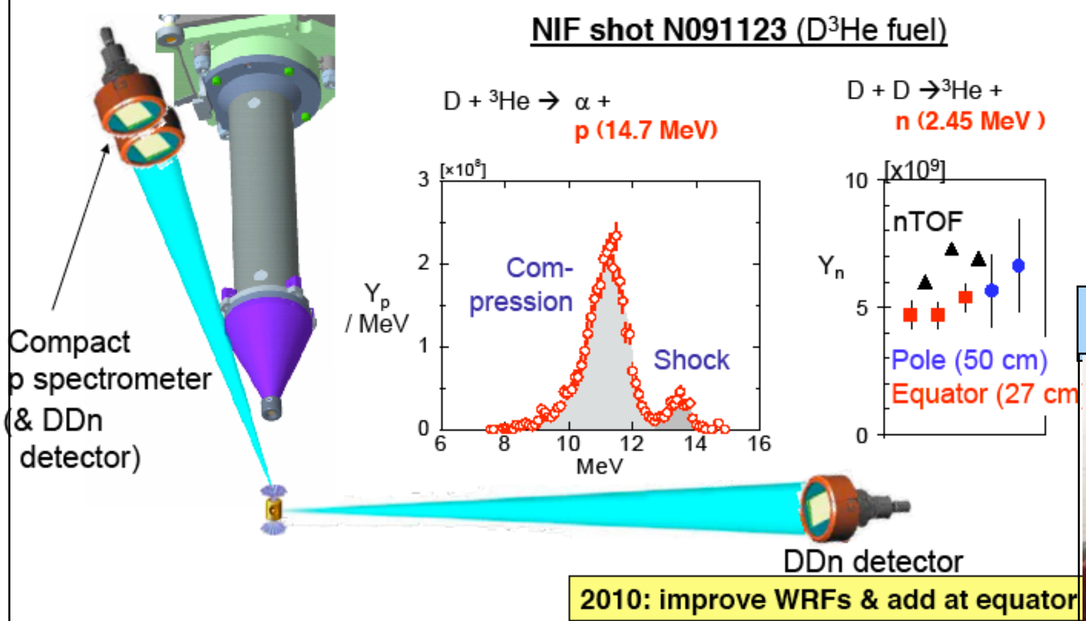


Is the CR-39 "ironing board" radioactive?

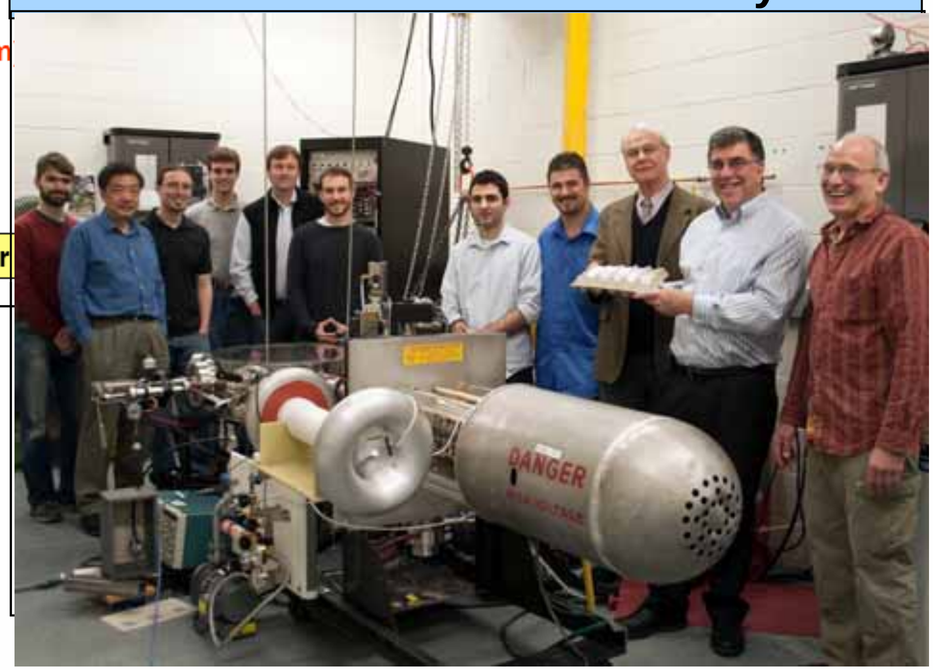
Accuracy requirement for the MRS absolute *yield* measurement < 10% for Y_{1n} > 10^{14}

CR39 used in Wedge Range Filter (WRF) after major OMEGA/MIT development on MIT accelerator

NIF WRF proton spectrometer used in 2009, improvements for 2010

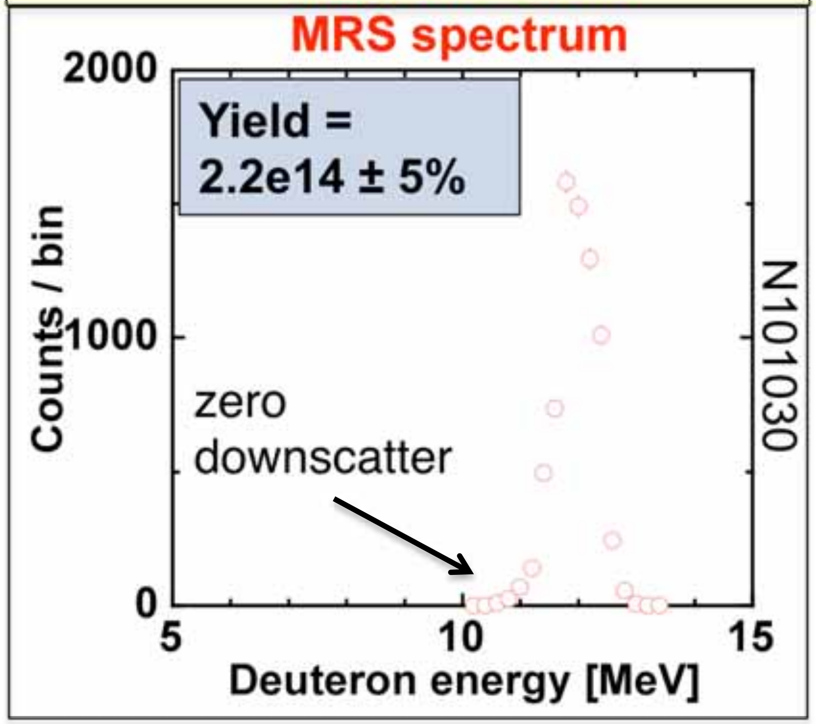


East /West summit on Good Friday 2011



Yield: MRS provides absolute primary yield to ± 5% accuracy: nd cross section and foil area uncertainty are largest components

MRS Spectrum for Pusher shot



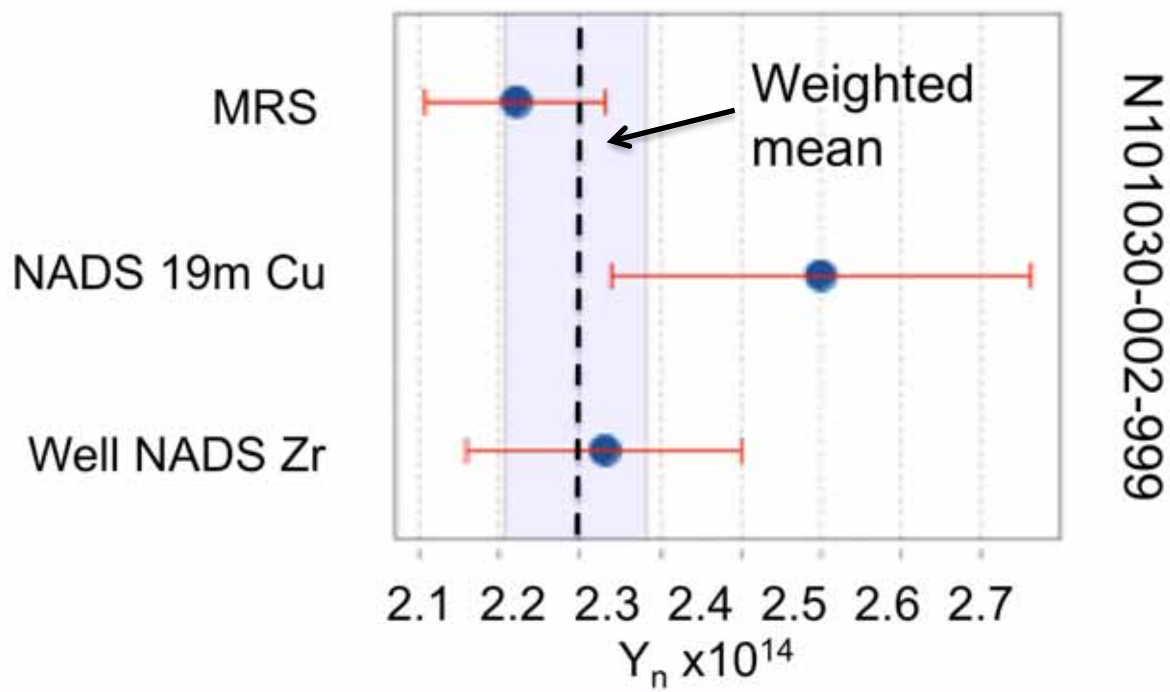
Yield Error Budget

MRS setting CD-Med Res	Param	Abs. unc	% unc
Foil distance to TCC [cm]	26	± 0.3	± 1.2
Foil area [cm^2]	12.8	± 0.3	± 2.3
CD-foil thickness [μm]	125	± 2.0	± 1.6
Magnet aperture area [cm^2]	20	± 0.2	± 1.0
Magnet distance to foil [cm]	570	± 0.2	± 0.04
d-number density [cm^{-3}]	7.7×10^{22}	± 10^{21}	± 1.3
n-d cross section (at 0°) [mb/sr]	501	± 12	± 2.3
Systematic uncertainty for Y_n			± 4.5
Statistical uncertainty at 2×10^{14}			± 1.5
Total uncertainty			± 4.7

MRS has different systematic errors from nuclear activation (NAD)

Three independent Y_n diagnostics (Zr, Cu & MRS) gives 4% error in the weighted mean yield

Neutron Yield



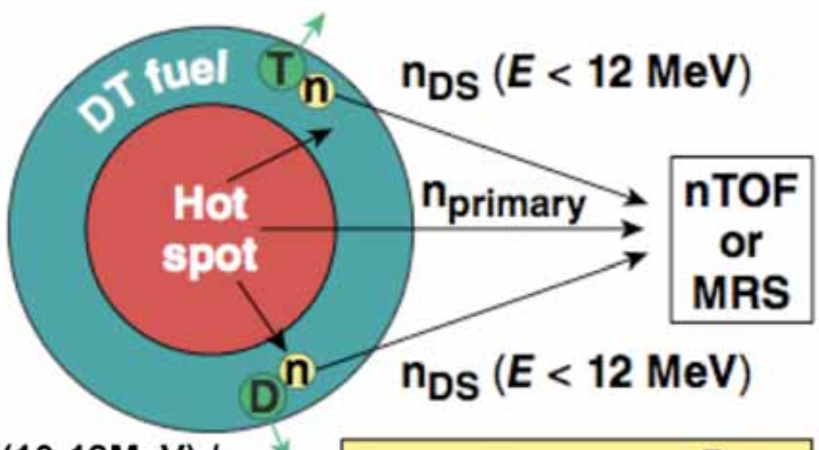
Weighted mean yield = 2.3e14 ± 8.9e12 (± 3.9%)

$X^2/(n\text{-}1) = 0.9$

So what?: surprisingly (at first) we found the OMEGA nTOF calibration did not transfer to NIF

ρR: Neutron downscatter measured from three different directions to minimize sampling errors due to directionality of scattered neutrons

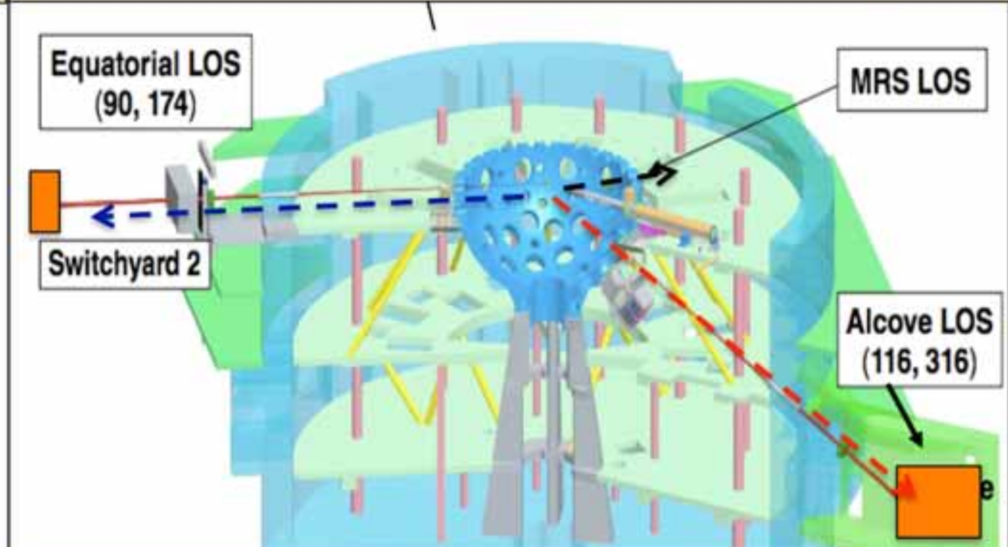
Downscatter ratio (DSR*) technique



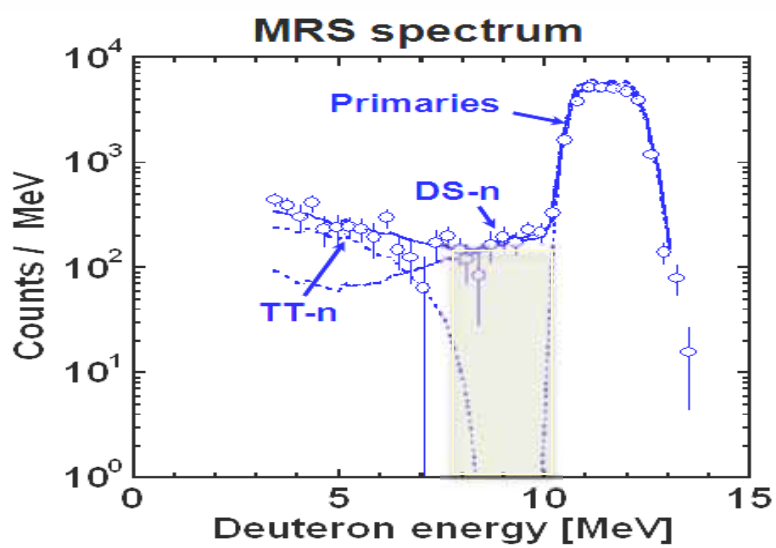
* DSR = (10-12MeV) / (13-15MeV)

$n_{DS} \sim n_{primary}\, \rho R_{fuel}$

MRS+ 2x NTOF20's on 3 lines of sight

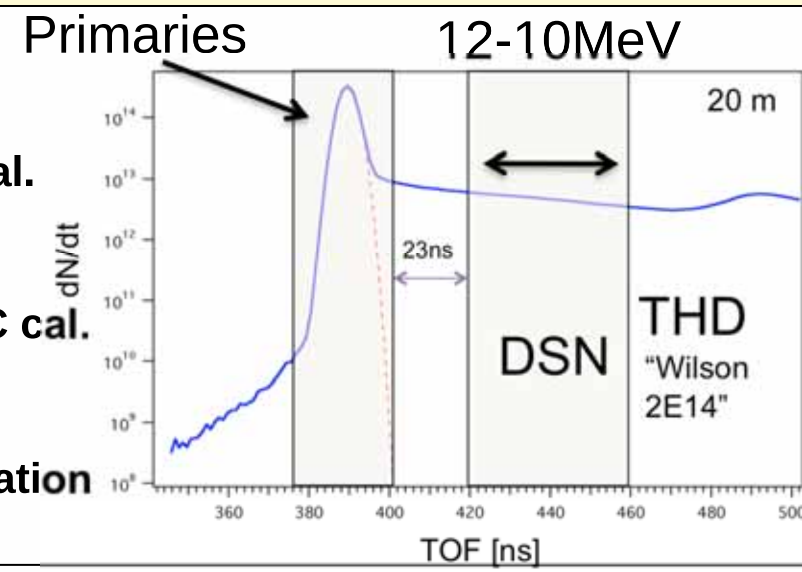


MRS - measure tracks in DSR region



NTOF – scattered neutrons in tail

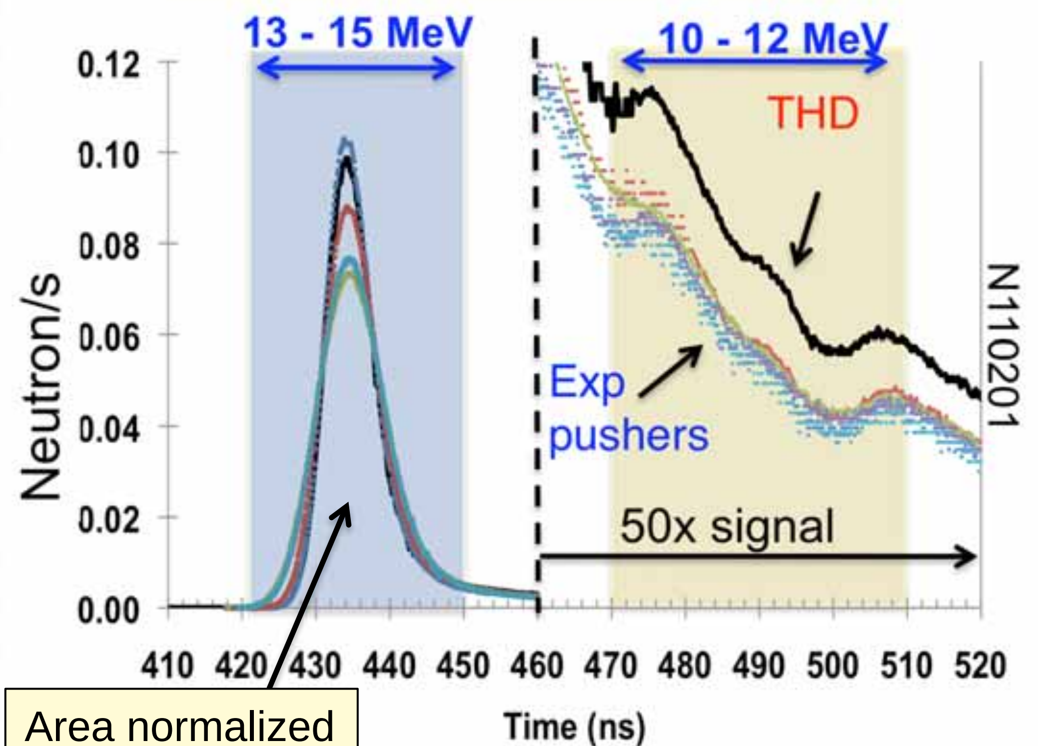
- LLE cal.
- SNL, NsTEC cal.
- LLNL installation



ρR: Down Scatter Ratio (DSR) by MRS and NToF20 are self consistent within the measurement error

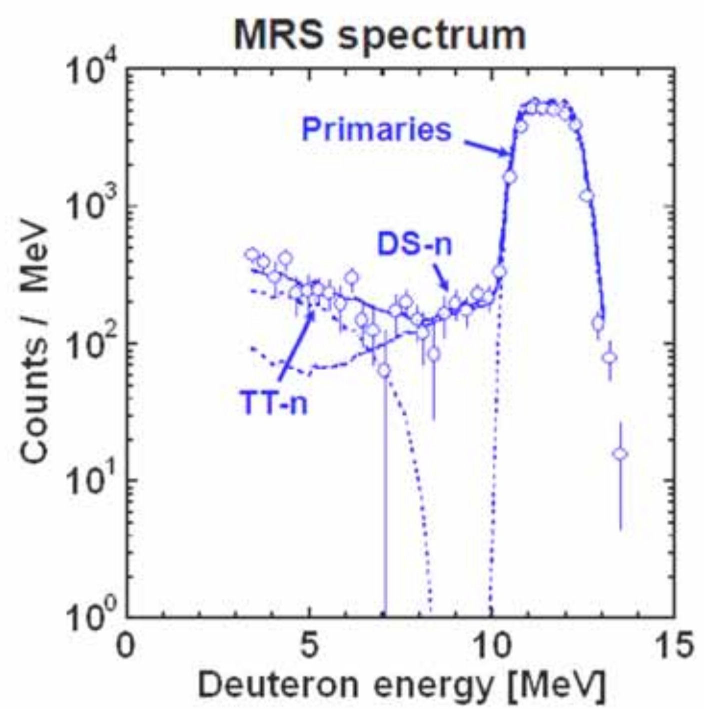
NToF Signal clearly shows down scatter signal on all THD shots

THD-3: DSR = 0.027 ± 0.005



MRS: DSR error < 10% for Yn >1e14 and ρ.R ~ 1g/cm^2

THD-3: DSR = 0.024 ± 0.003



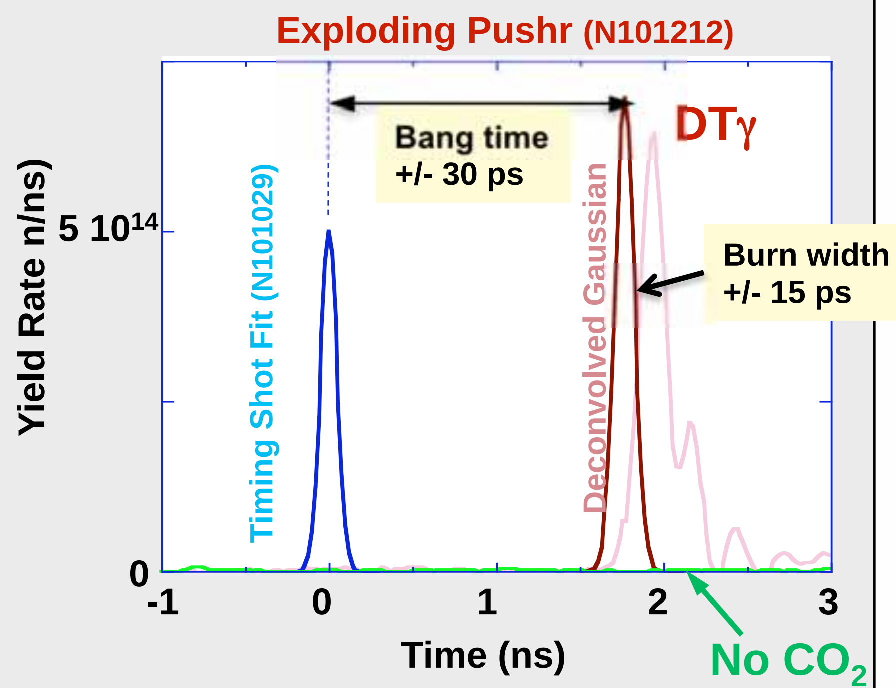
- **Background level from exploding pushers is reproducible**
- **Shorter cables planned for NTOF20 will reduce uncertainty**
  - **Lower cable induced background levels by ~3x**

Bangtime: Gamma Reaction History (GRH) routinely measuring Bang Time (w/in 30 ps) and Burn Width (w/in 15 ps)

GRH-6m at (64,20)

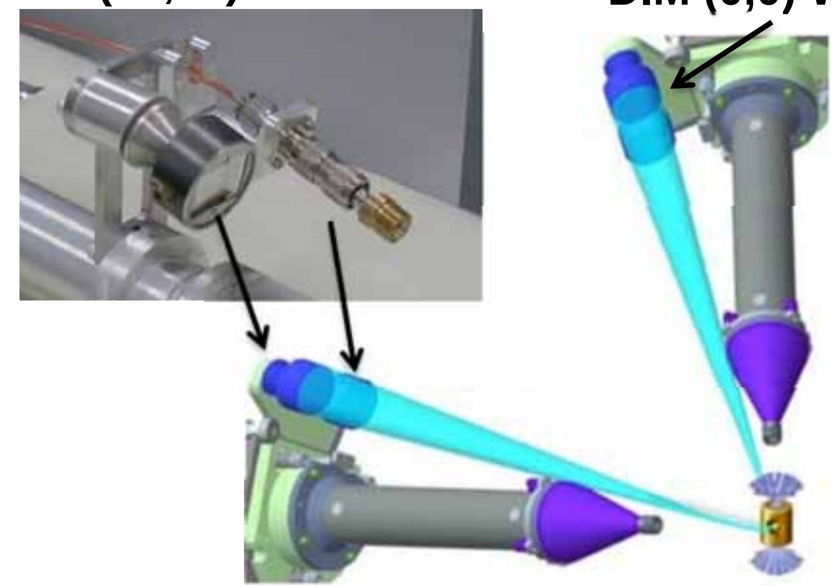
- 4 Gas Cherenkov cells
- Detectors installed with Ultra-fast MCP PMTs and optical Mach Zehnders

DT exploding pusher Data

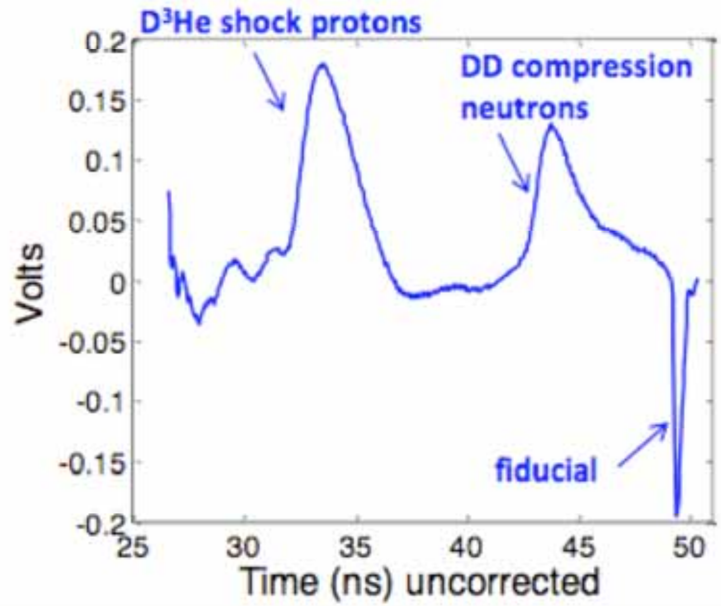


Bangtime agrees with NToFBT data to within 100 ps
3-10MeV GRH will be fielded on DT implosions for yield and 4.4MeV carbon γ (ablator density measurement)

A new Particle Time of flight (pTOF) detector has been implemented for shock-bang and compression-bang time using D^{3}He-protons and DD-neutrons, respectively

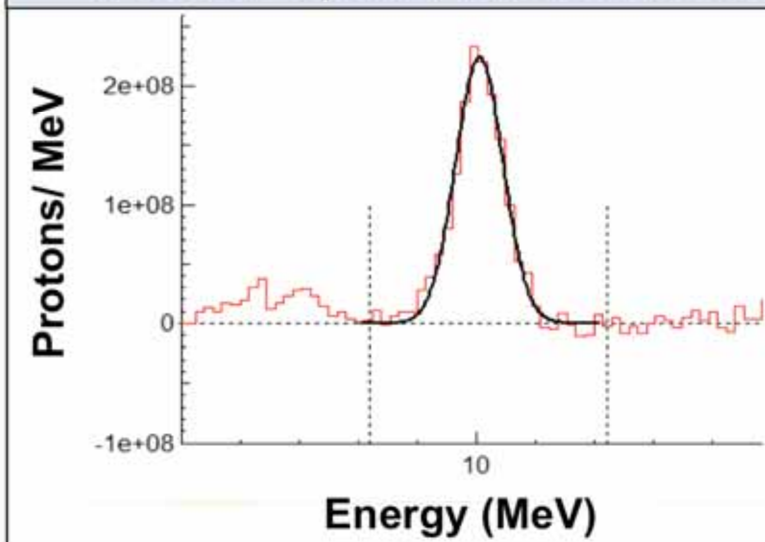


Particle bang time data DHe3 SYMCAP 1208



- Compression BT = 21.2 ± 0.15 ns

Proton Spectrum from WRF

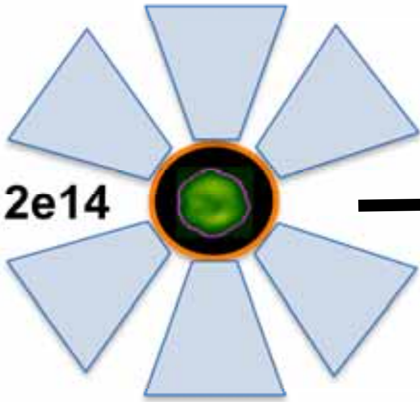


- Relative timing of shock and compression feature is constraint to implosion models
- Project led by MIT
- Requires Exploding pusher to qualify

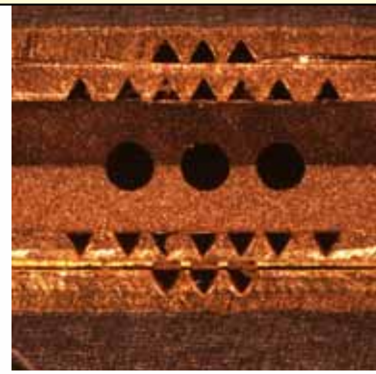
NIF's $20M Neutron Imaging System has begun performance qualification using McKenty's exploding pushers

Exploding pusher

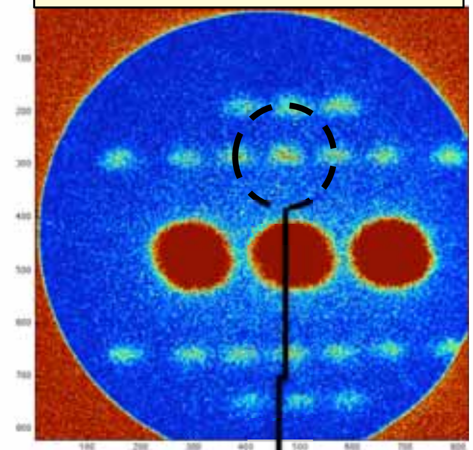
Yield = 2e14



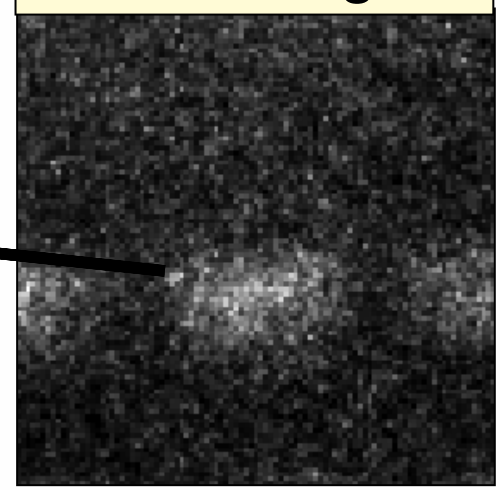
NIS Pinhole array



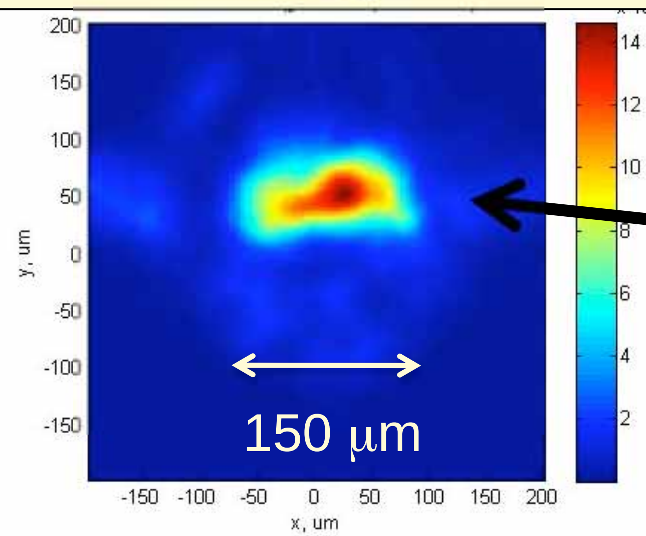
DATA



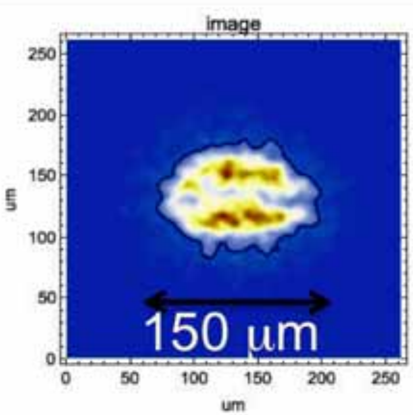
Raw Image



Reconstructed Neutron Image

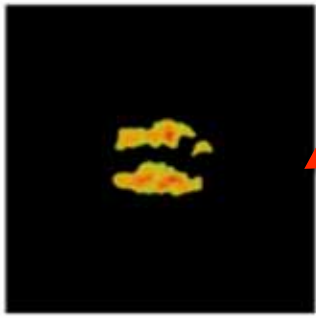


Compare to gated x-ray Image



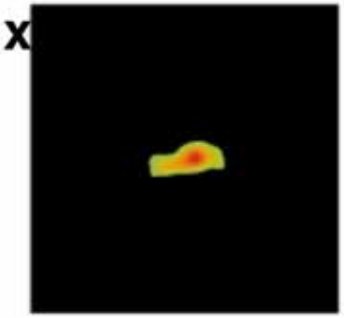
Consistent with neutron hot spot inside x-ray emitting region ?

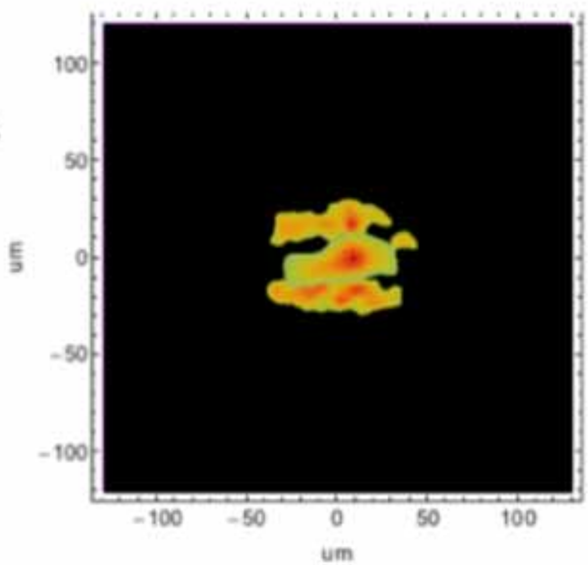
X-ray image



Remnant of Si pusher emits strongly in 6keV x ray region

Neutron image





R. Tommasini

NIF's owl is skeptical without image registration

P. Volegov – NIS analysis
R. Tommasini – hGXI analysis

The best of times in HED!

- Innovative diagnostics allow advances in HED

- New diagnostics require a significant number of development shots

- OMEGA users are playing a major role in development of NIF diagnostics

But what next ?
Decadal innovation in diagnostics by new minds will allow us to fully exploit OMEGA, Z and NIF.
Think clever, think big!


NIC