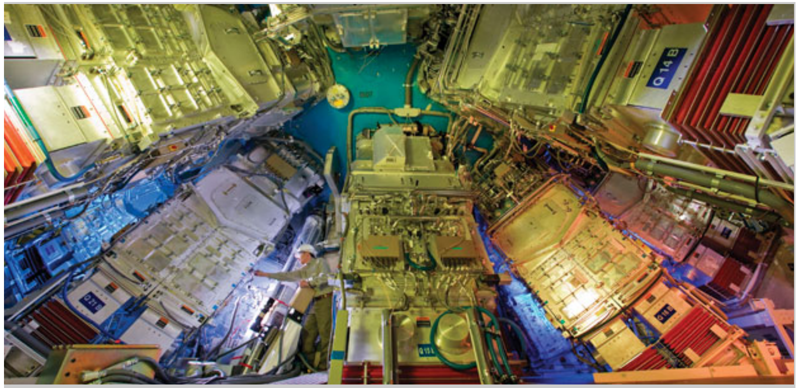
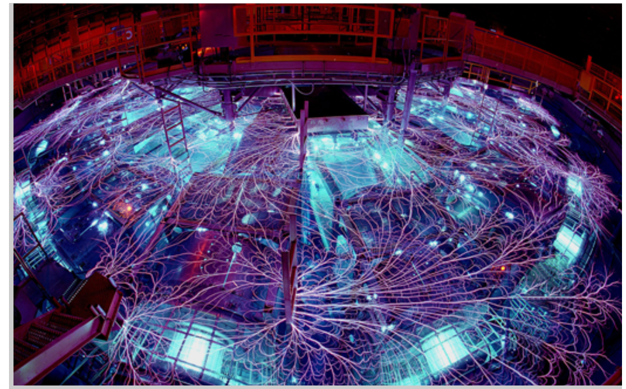




The National Diagnostic Plan

Created by ~ 100 scientists and engineers across the ICF/HEDP complex

Joe Kilkenny, Greg Rochau, Craig Sangster, Steve Batha,…..

10-6-15, LANL, 10th National Diagnostic Working Group Meeting

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.

Outline

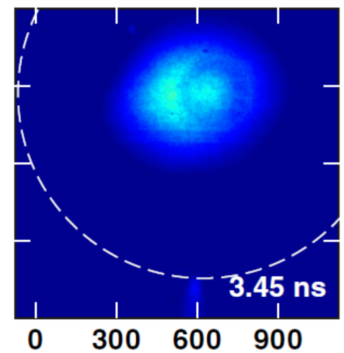
- National diagnostic plan. Reviewed by expert group Jan 2015- laudatory.
- Status & challenges of transformative diagnostic
- Expectations for this workshop

These are the best of times for HED experimental science with the most potential to impact NNSA's SSP mission

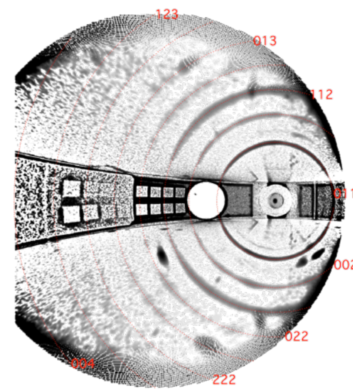
- Three unique, world leading, state of the the art HED facilities are fully operational. LMJ has started.

- Major investments in simulations have resulted in high fidelity models with fewer approximations. 3-D simulations and are becoming increasingly available and investment is continuing.

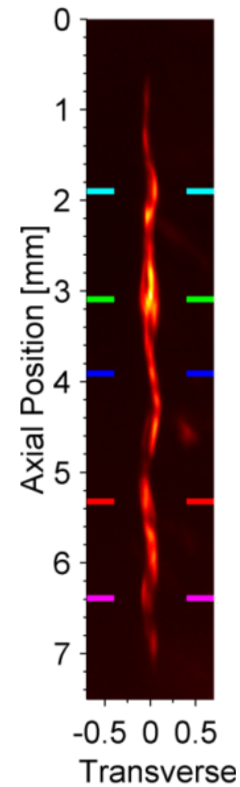
Ω, Cryo DT Radiograph



NIF X-ray Diffraction



Z MagLIF Image



With better drivers and codes we need more precise diagnostics to provide more stringent test of models.

A first ever National Diagnostics Plan (NDP) stewards a new generation of HED diagnostics at all the facilities

2012
- **National Diagnostic Working Group formed following the end of the National Ignition Campaign**
  - **Representation from each NNSA laboratory, LLE, NRL,GA ,CEA,AWE and academia**

2013
- **A series of workshops held since 2009 on ICF diagnostics broadened to include all facilities and additional HED needs.**

2014
- **The Senate Energy and Water Development Subcommittee requests a national diagnostics plan to ensure we capitalize on the potential for HED science**

2015
- **The National Diagnostics Plan is formed, reviewed by an advisory panel, and put into action.**
  - **A multi-million dollar effort that will steward the development of advanced diagnostics and coordinate resources across the NNSA complex**

18 major diagnostic efforts were discussed at the National Diagnostic Working Group meeting Sept. 9-11, 2014

- 117 participants from 13 institutions
- 69 presentations in 3 parallel sessions
- 10 plenary talks summarizing present efforts and needs at NIF, Z, and OMEGA

X-ray Imaging
Single LOS gating
‘small dν’ imaging
High energy imaging

X-ray Spectroscopy
High resolution
High energy (20-80 keV)
Diffraction

Calibration
Neutron sources
Pulsed x-ray sources
High energy x-ray cals

Neutron & Gamma
Gamma spectroscopy
3-D neutron imaging
Alpha heating diag.
Furlong
Radchem

Optical
Thomson Scattering
PDV

Other
Radiation Hardening
Magnetic Fields on NIF

NDP management group, with input from the SSP and HED programs, binned activities into three categories: Transformational, Broad, and Local

Transformational: Major national efforts with the potential to transform experimental capability for the most critical science needs across the complex

Broad: Significant national efforts that will enable new or more precise measurements across the complex

Local: Important efforts involving implementation of known technology for a local need

Transformational	Broad	Local
16-frame high time-res gating	Neutron Temporal Diagnostic	KB microscope
UV Thomson Scattering	Precision nToF	High energy spectroscopy
Fusion Gamma(t,hν)	B-fields on NIF	Various NIF/Omega snouts
3-D fusion burn imaging	Pulsed x-ray cal source	Crystal imaging & backlighting
Fusion Neutron(t,hν)	Photon Doppler Velocimetry	Radchem
X-ray(t,hν) $\lambda/\delta\lambda$ ~ 10000	High-res x-ray streak cameras	…many more…
20-50keV image,10 ps, <10μm	High energy detectors	
Diffraction(t)	Radiation hardening	

NNSA set up a review of our National Diagnostic Plan

January, 13-14, 2015 at LLNL

R. Paul Drake ,Robert D. Fulton, Allan Hauer, J. Pace VanDevender Jeffrey Quintenz, Alan Wootton, Kirk Levedahl

“Overall the comments from the individual reviewers were highly positive on the feasibility, practicability and transformative nature of each of the eight diagnostics proposed. Each was considered highly worthy of continued development with the potential to improve experimental measurements vital to and tied to key mission requirements. The reviewers were impressed at the breadth of discussions across the community that had revitalized the area and by bringing to bear several new capabilities. The efforts highlight the value of the Federally Funded Research and Development Center (FFRDC) construct.”

Outline

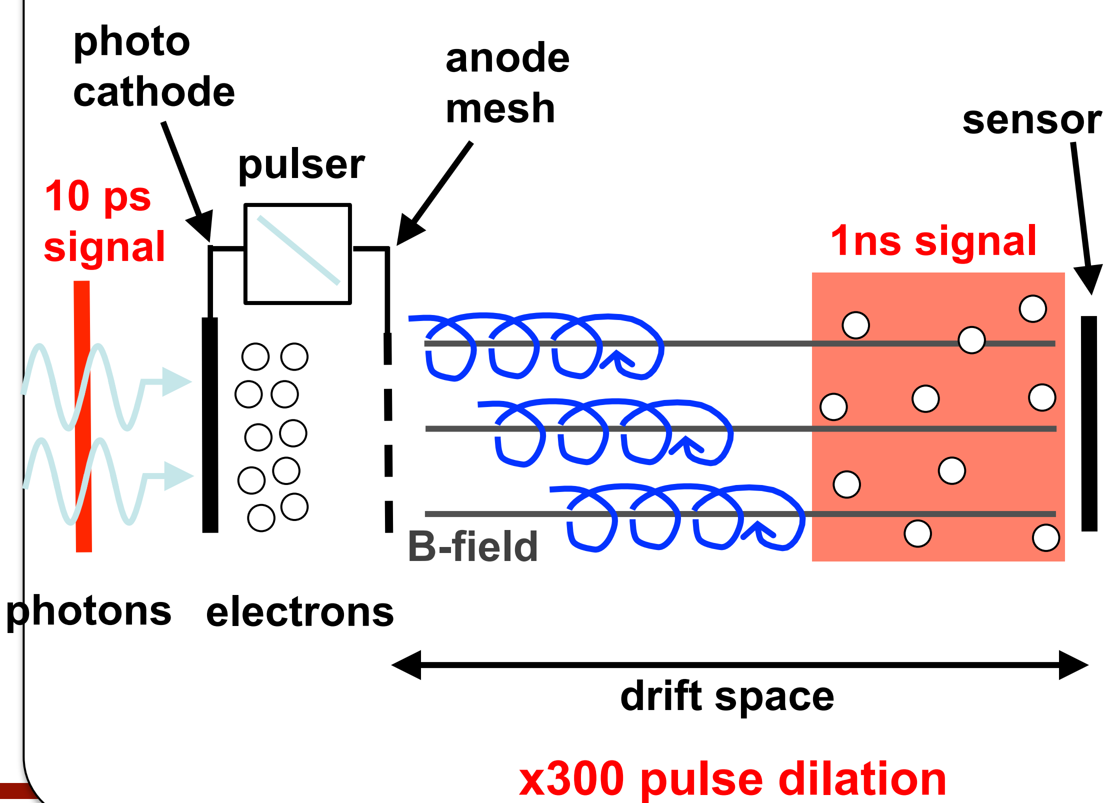
- Plans for eight transformative diagnostics. Reviewed expert group Jan 2015- laudatory.
- Status & challenges of transformative diagnostic
- Expectations for this workshop

8

A marriage made in heaven: Single Line of Sight multi-frame imaging is enhanced by integrating two cutting-edge technologies

Pulse-dilation technology

Manipulate images in time/space (10ps → 1ns)

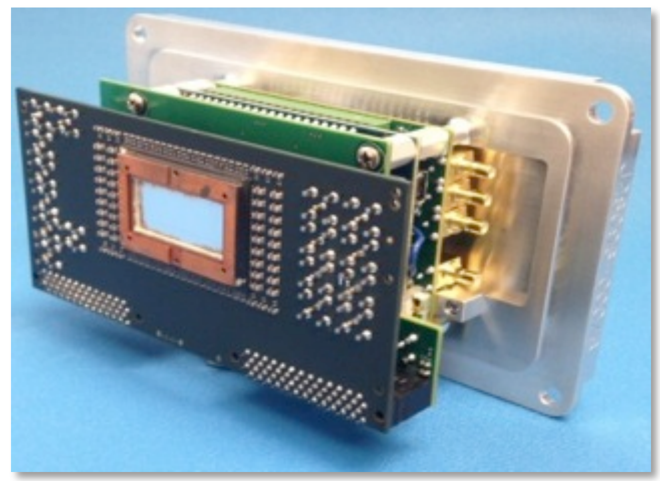


Hybrid-CMOS sensors

Multi-frame fast-gated pixels

Hybrid CMOS (2015)

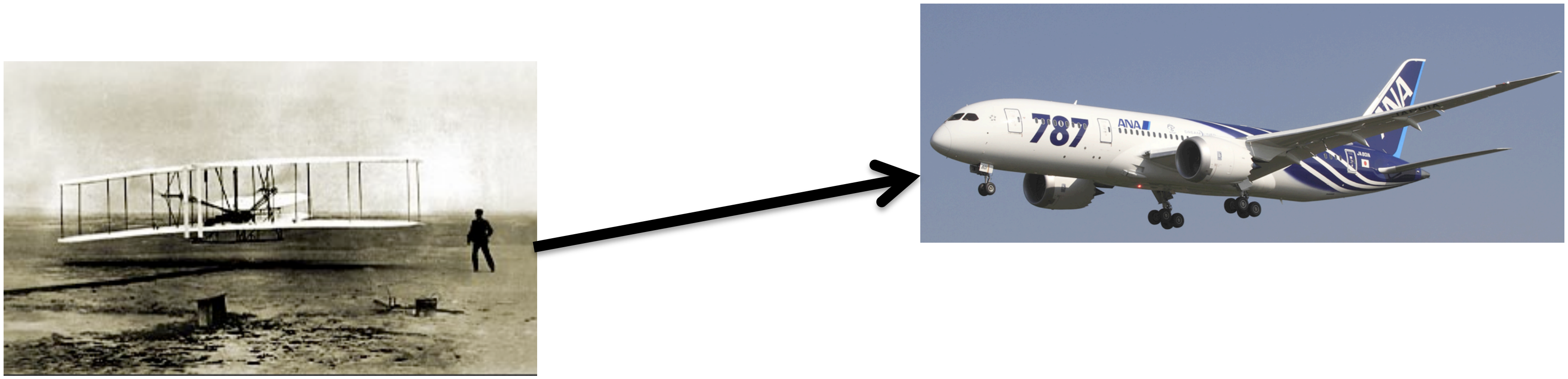
0.5 megapixels
2 frames
1.5ns per frame



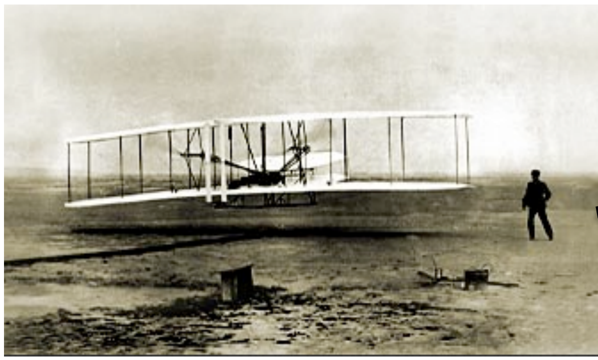
Future sensor (2016)

1.0 megapixels
8 frames
1ns per frame

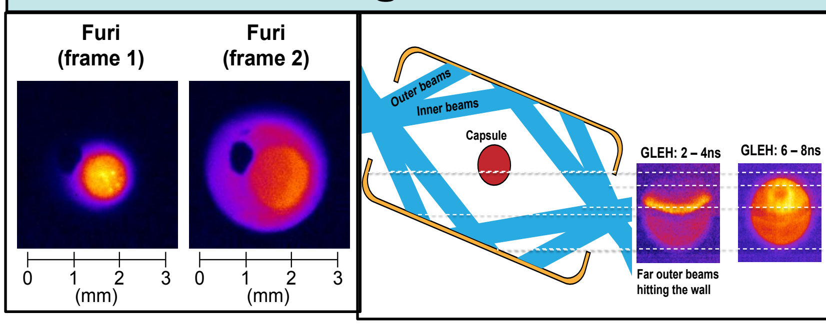
Gated h-CMOS/SLOS devices have taken off



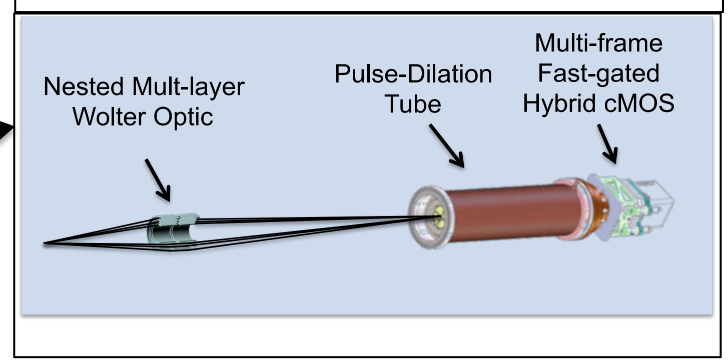
Gated h-CMOS/SLOS devices have taken off



Gated images on Z & NIF



Nested Wolter + 8 frame SLOS



Diagnostic challenges for h-CMOS and SLOS

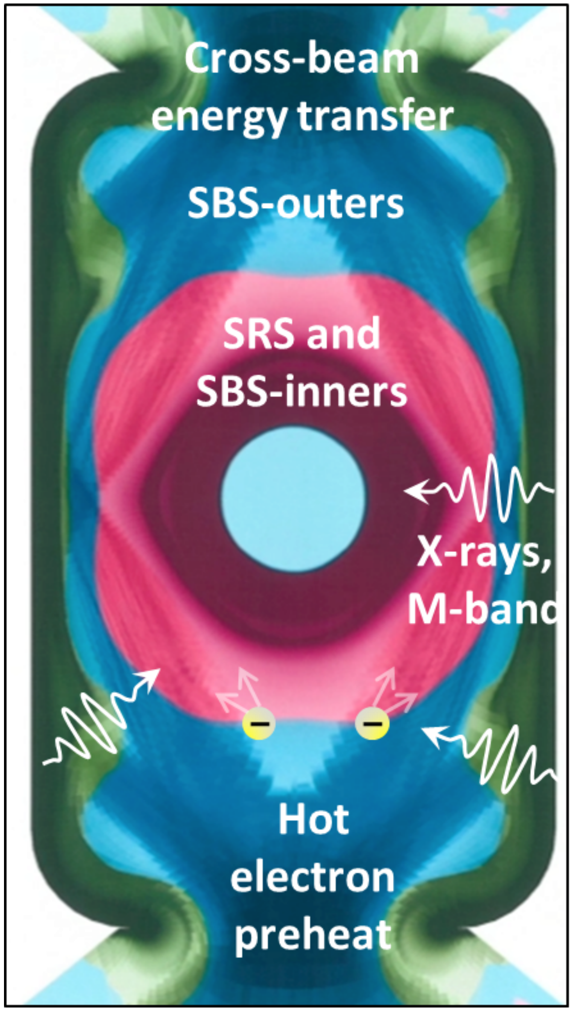
- Manufacture /characterization of devices
- 20-50 keV imaging on to SLOS

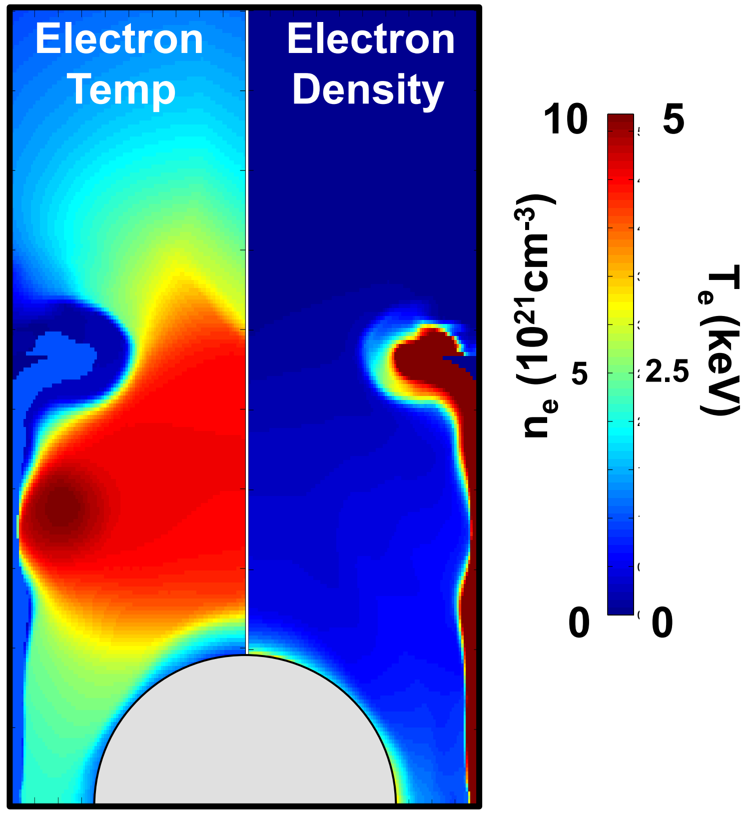
  – scintillator but noise floor too high?

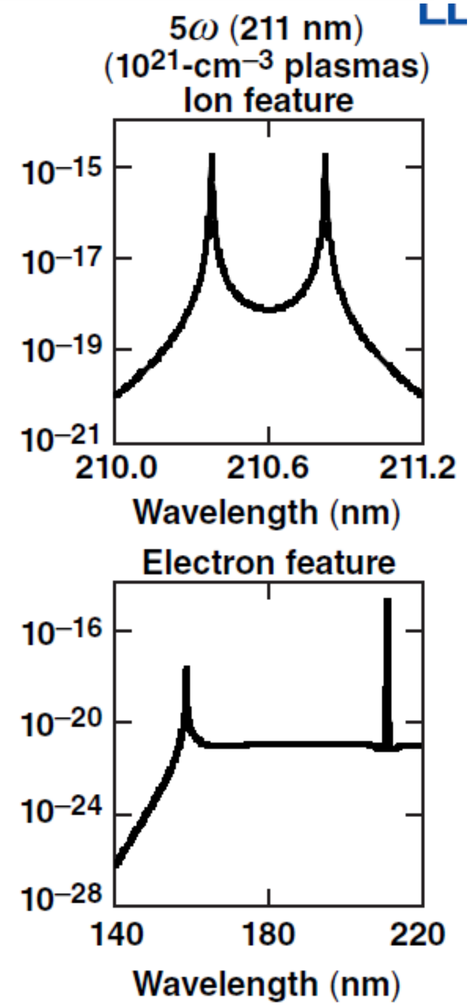
  or

  -- larger storage capacitors
- Hard x-ray photocathode for time dilator

NIF hohlraums have a complex plasma evolution that effects the beam propagation and system energetics

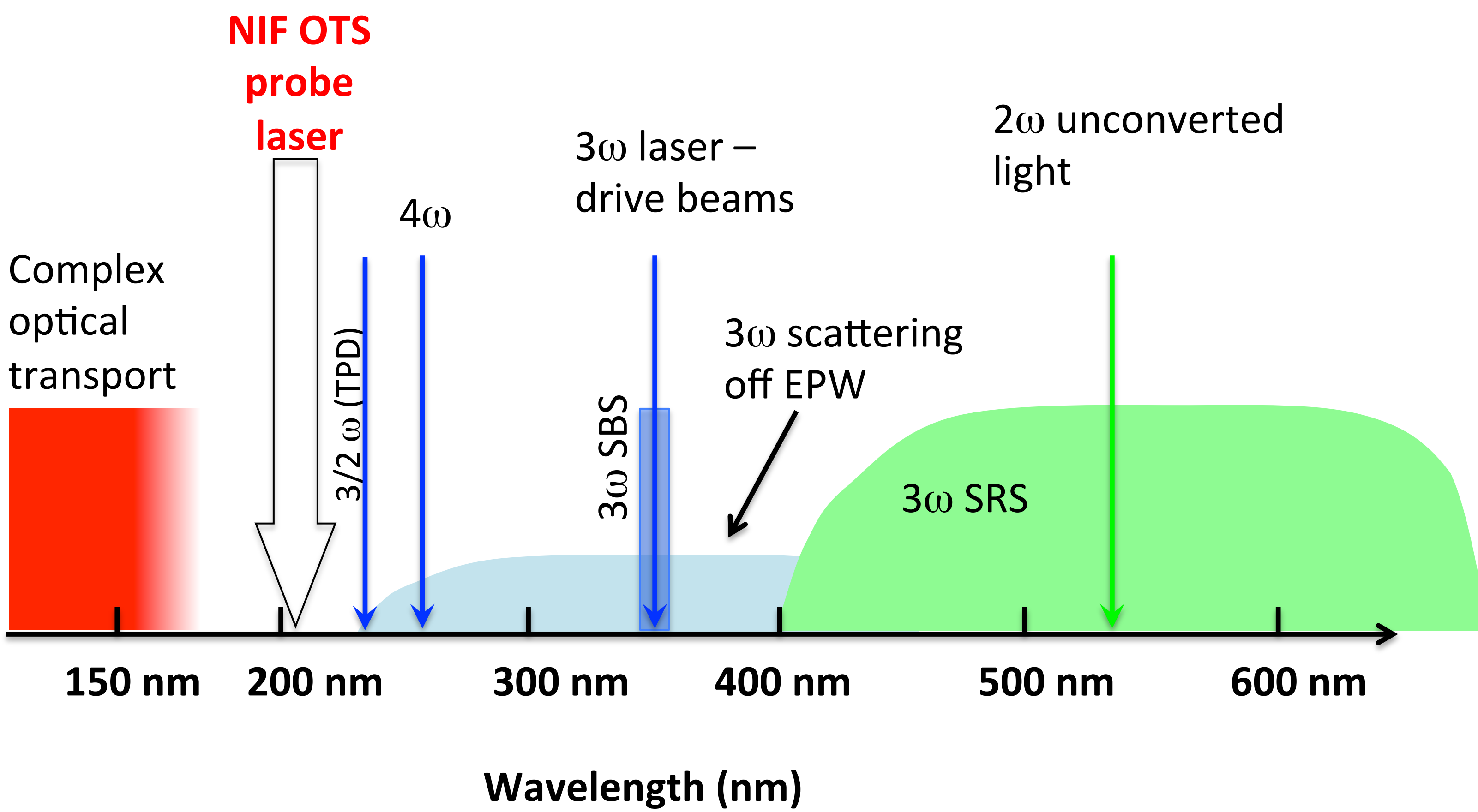






Thomson scattering provides first principle, local, time-resolved measurements of under-dense plasma conditions (T_e, T_i, Z, N_e)

The harsh optical environment of a NIF hohlraum requires Optical Thomson Scattering in the deep-UV



Realizing a high power 5ω laser requires new technology advancement in large crystals for frequency conversion

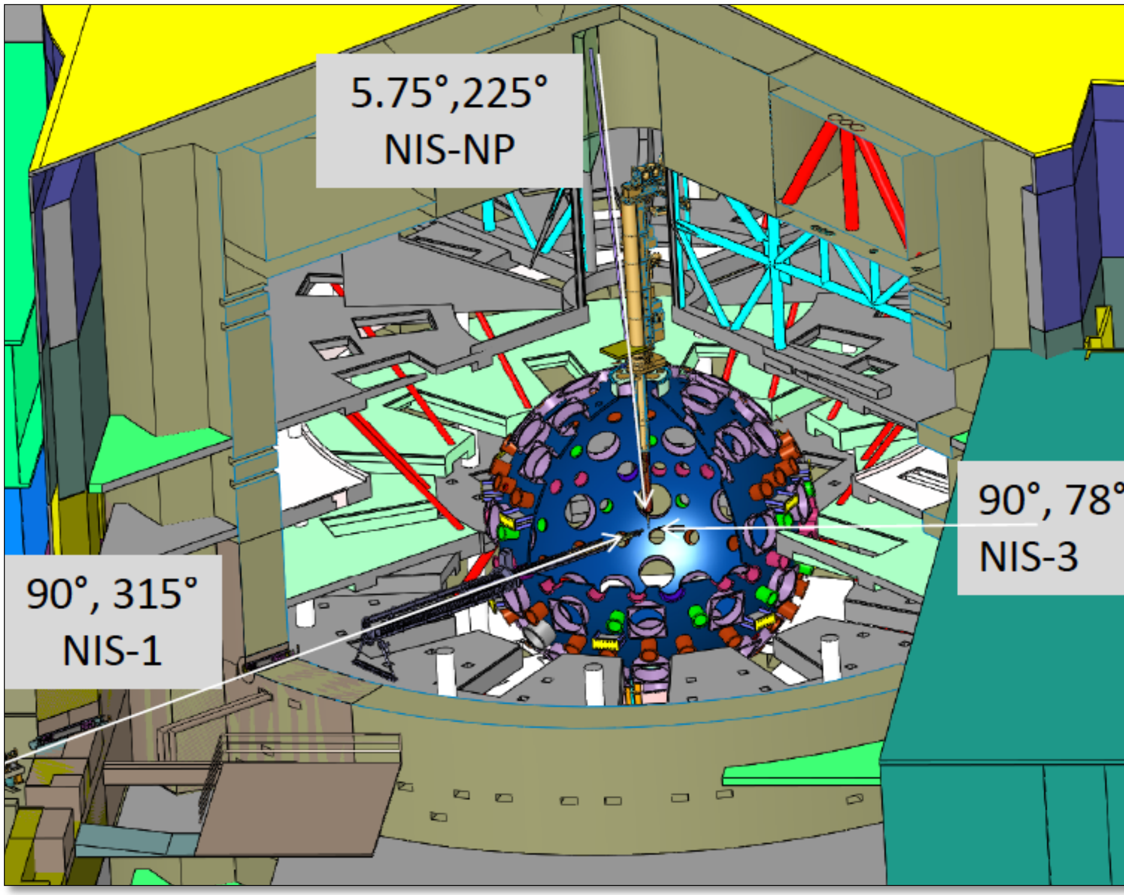
- **LLE is developing a compact laser driver suitable for delivering 200 GW of IR to be frequency converted for Thomson scattering**
- **A large aperture 5ω crystal testbed at LLE is developing the necessary technologies for efficient frequency conversion**
  - **ADP/KDP crystals require temperature tuning and stability around 230 K**
  - **CLBO crystals require heating to prevent structural failure**
- **5ω Thomson scattering probe will**
  - **Provide access to higher densities**
  - **Reduce refraction**
  - **Avoid LPI generated background from 351 nm drive beams**
  - **Allow standard large aperture optics to be used**

Technical challenges for Optical Thomson Scattering

- What is the background emission level?
- Preventing the collecting optics from blanking from the hohlraum x-ray emission
- Best scattering angle for phase 1
- 5w generation and transport

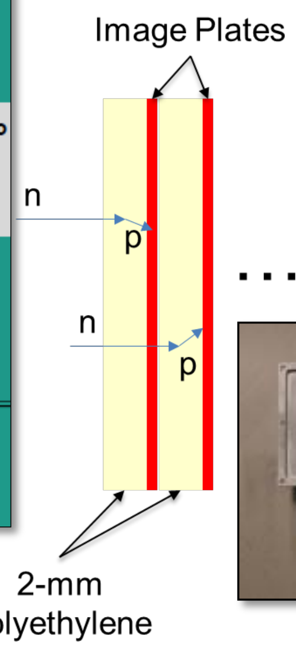
16

Two new neutron imagers will be added to the NIF to enable ~3-D reconstructions of ICF implosion cores



Design Goals:

Yield	>1E15
Resolution	<10 μm
Reconstructed Field-of-view	>200 μm



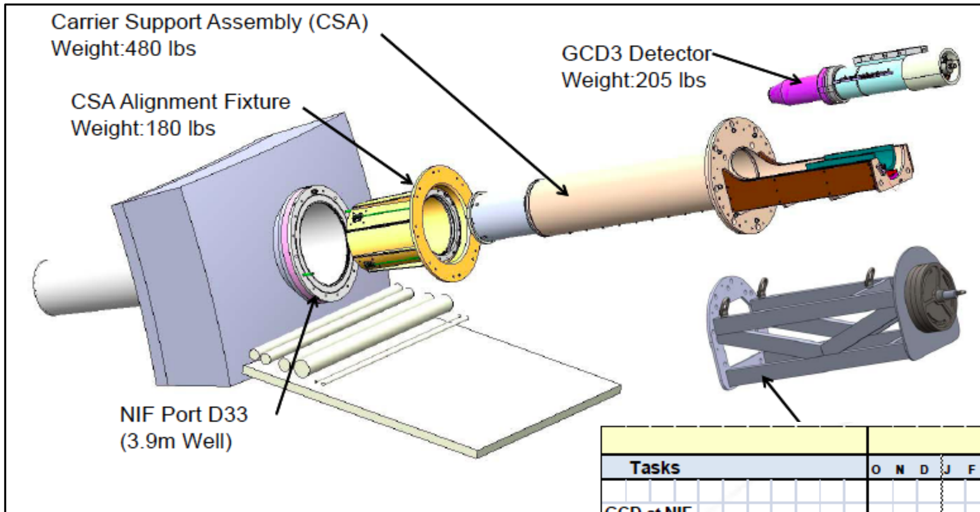
Diagnostic challenges for neutron imaging

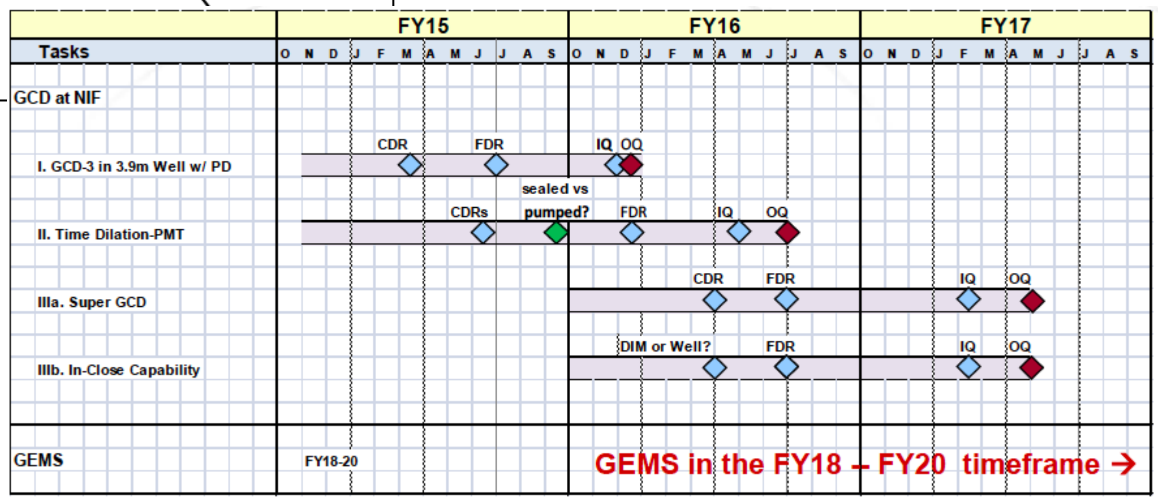
- Alignment tolerances for pre-aligned polar view on NIF-phase 1a
- Major engineering costs for phases 1b and Phase 2
- Can we spatially resolve T_{ion}
- Gamma imaging- need? –time resolution?

18

Gamma Spectroscopy: NIF- GCD3 in NIF 3.9 m well : phase1- Photek, phase 2 new dilation PMT

PMT

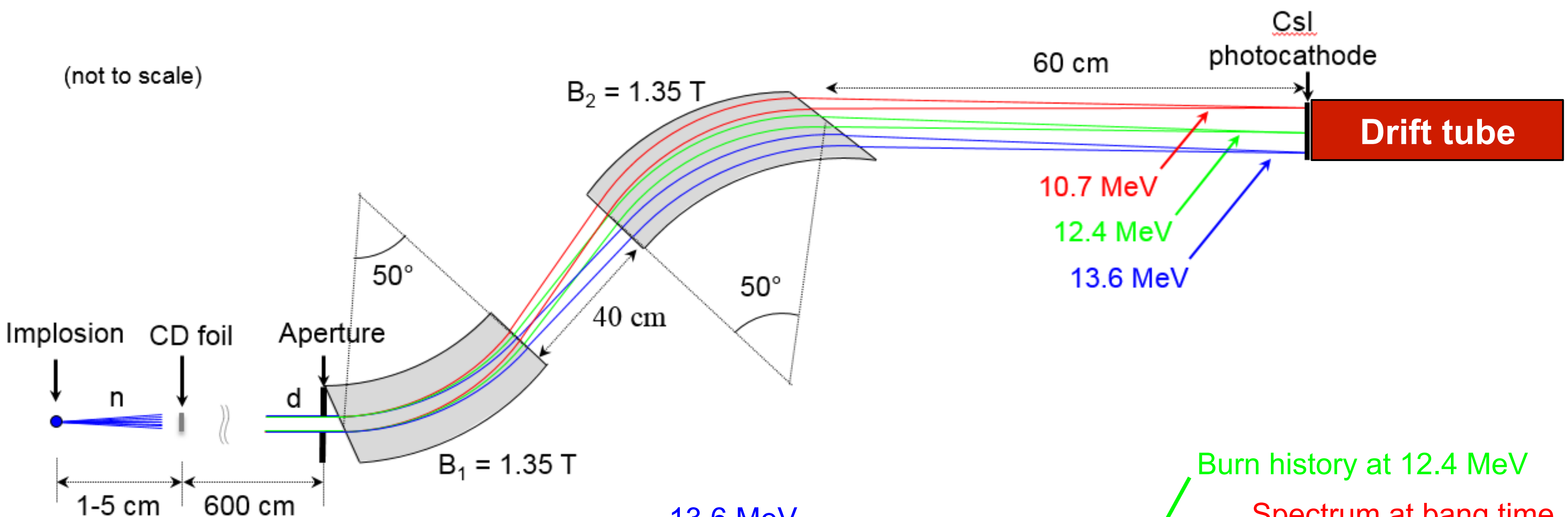


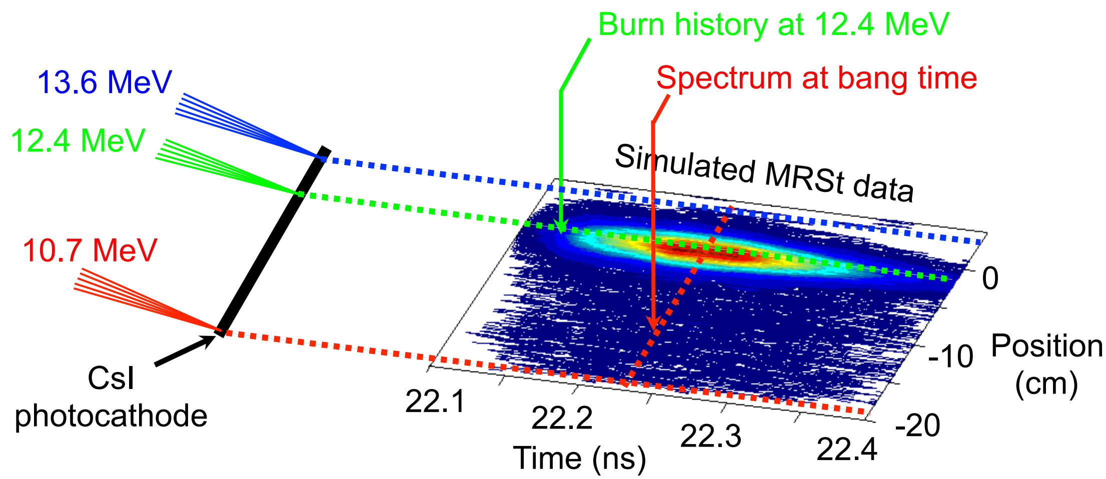


Challenges : Engineering, gamma background, build, test dilation PMT, procrurement

The MRSt will combine the MRS principle with a second magnet and a novel pulse-dilation drift-tube

<u>Design goals</u>: $\Delta t < 20$ ps and $\Delta E < 200$ keV for Yn> 10^{16}





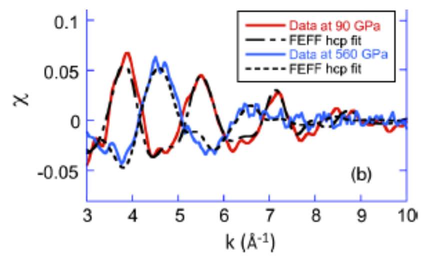
The path-length difference must be close to zero for deuterons with same energy

Challenges for MRS-time

- The time spread of ions across the dilation detector adds a lot of complication, can be mitigated – but needs testing
- How accurately does the core n spectrum need to be measured- see “Precision nToF” discussion Wednesday afternoon.

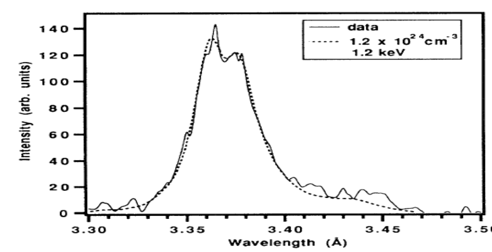
Plasma temperature and density can be measured with a high resolution (HiRes) spectrometer

- Measure temperature of cold, compressed materials using EXAFS



Y. Ping, F. Coppari et al. Phys Rev Lett 111,065501 (2013)

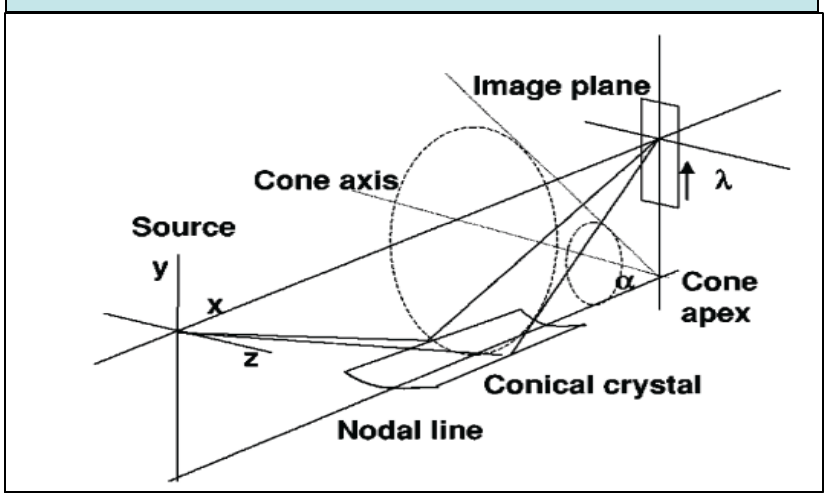
- Measure electron density (**ne**) in “hot spot” of surrogate ignition capsule (symcap) using Stark Broadening.



B.Hammel et al, Phys Rev Lett 70, 1263 (1993)

R. Mancini et al., HEDP 9 731 (2013)

Conical Von-Hamos snout for DISC



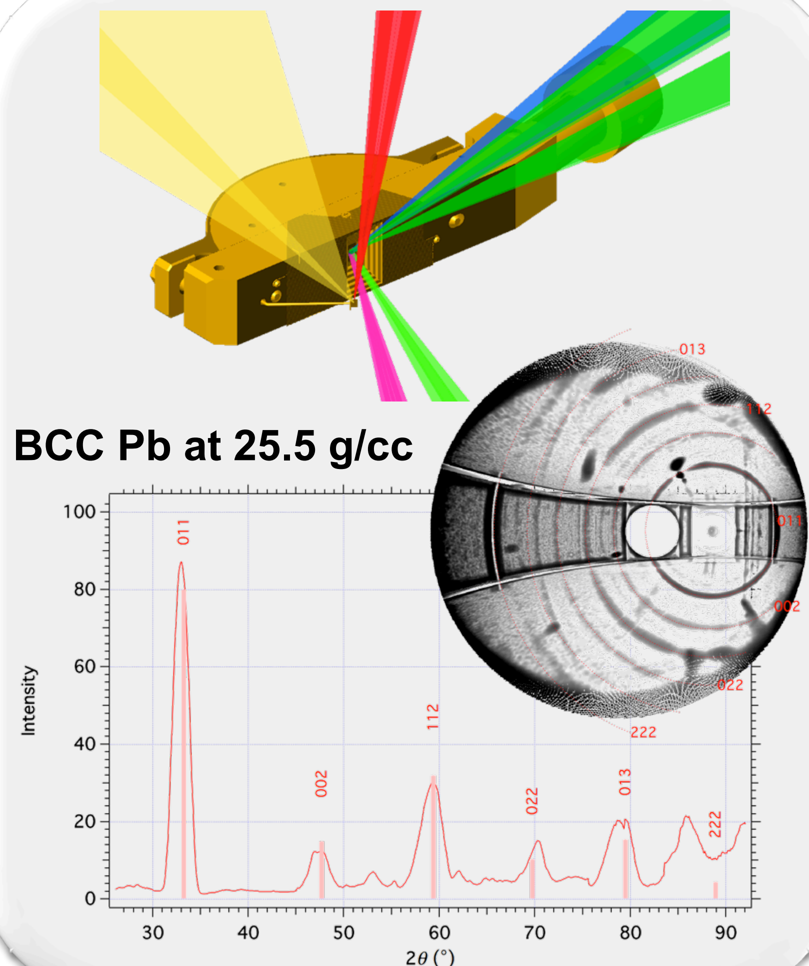
Challenges:

1 Fabricate elliptical conical crystal

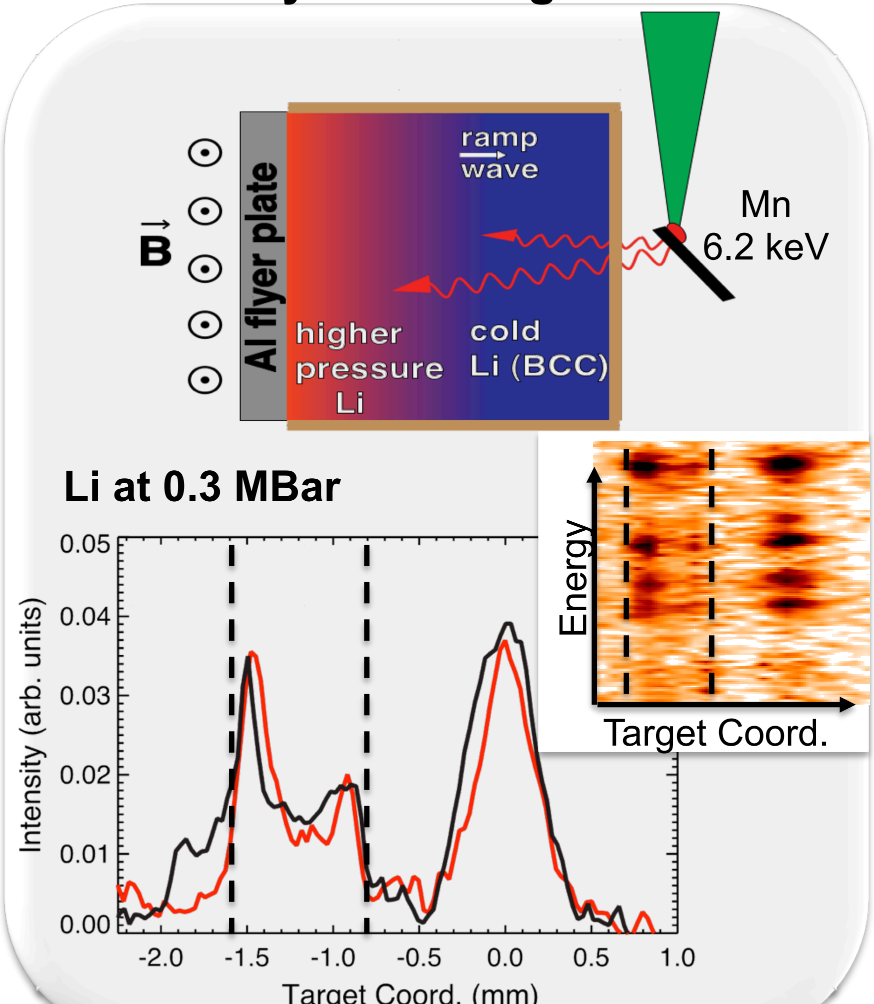
2 Implement fix to DISC- requested by Sean R

Implementation of advanced diagnostics for materials science is opening the window to new understanding.

Dynamic Diffraction on NIF*



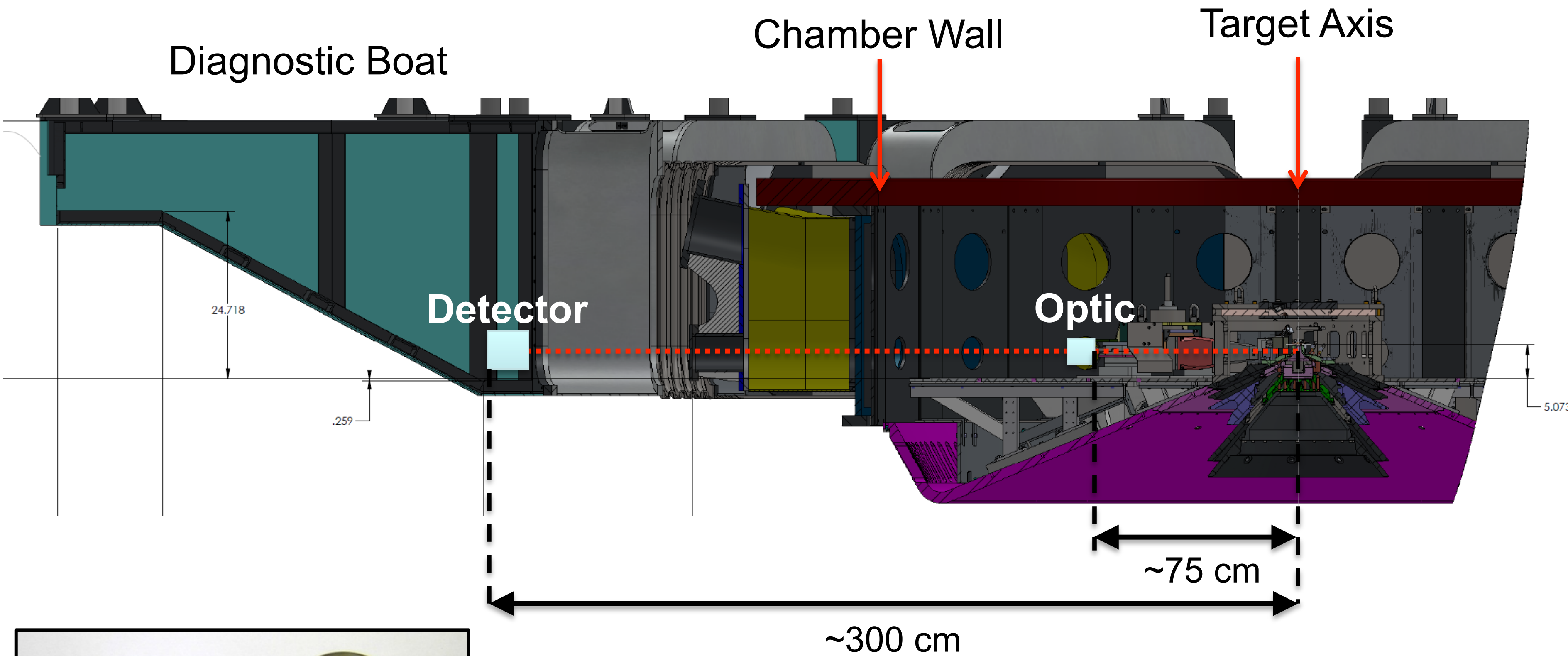
X-ray Scattering on Z**

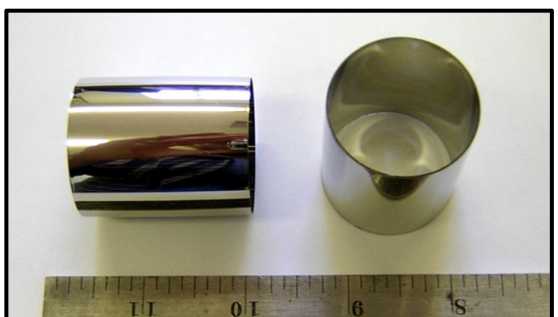


*Eggert (LLNL) et al.

**Harding (SNL) et al.

A mag = 3 Wolter microscope would go along a 0-degree port on the Z target chamber with the optic ~75 cm from the source





This is a geometry very similar to what has been previously demonstrated with Wolters

Goals and objectives of this workshop

- Our job is to make recommendations to NNSA and its facility managers
- Are the facilities on the right diagnostic development path for NNSA ?
- Are there new ideas and new diagnostic efforts we should start ?
- Are there ongoing diagnostic development efforts which should be stopped ?

Today's agenda

Tuesday, Oct. 6

8:00 AM	---------------------Badging--------------------------------	
	Plenary 1 (Rosen Auditorium)	
9:30 AM	Meyerhoffer	Welcome and opening remarks
9:45 AM	Daryl Jones	Security Brief
9:50 AM	Kilkenny	Developments since last workshop-challenges
10:15 AM	----------------------Break-------------------------------	
10:30 AM	Hilsabeck	SLOS progress and plans
11:10 AM	Ross	UV Thomson Scattering:hohlraum measmnt/probe
11:50 AM	Herrmann	Super GCD/GEMS
12:15 PM	----------------------Lunch-------------------------------	

Rooms	Presentations
Rosen seats 159	LLNL 13
A234 seats 30	SNL 12
D105 seats 25	LANL 9
A218 seats 10	LLE 8
	MIT 7
	Other 9
	TOTAL = 58

	X-ray Imaging 1 (A234)		**Neutron/Gamma 1 (Rosen Auditorium)**		**Optical (D105)**	
1:30 PM	Porter	First use of hCMOS cameras on Z ar	P. Schmit	Diagnosing magnetization with secondary	Swadling	Background and blanking limits for OTS
2:00 PM	Looker	Low-energy diodes for hCMOS sens	Seguin	Compact DD neutron spectrometer	Datte	DIM Detector for OTS
2:20 PM	Pickworth	KB on NIF	Gatu-Johnson	The MIT HEDP Accelerator Facility	Bliss	OTS on MagLIF
2:40 PM	Harding	Spherical crystal imaging/spectra o	B. Jones	Diagnostic Value of Tritium on Z	Zweiback	DCS Laser development status
3:00 PM	Benjamin	Coded Aperture Imaging	Gooden	Thulium and Bismuth as RIF diagnostics an	Sorce	EP SOP
3:20 PM	----------------------Break-------------------------------		----------------------Break-------------------------------		----------------------Break-------------------------------	
	X-ray Imaging 2 (A234)		**Neutron/Gamma 2 (Rosen Auditorium)**		**X-ray Spectroscopy 1 (D105)**	
3:50 AM	Vogel	Wolter on NIF	Kim	GEMS update	Nilson	High Res on OMEGA
4:10 PM	Bourdon	Wolter on Z	Wilde	Gamma Imaging	Aglitsky	High Res He-like Fe for ICF
4:30 PM	Koch	XDV	Stoeckl	P11 nTD	Ross	Opacity Spectrometer
4:50 PM	Tregillis	A Suite of Synthetic X-ray Diagnosti	Lahmann	NIF nTD	Hill	Kr Stark broadening on NIF with DISC
5:20 PM			Sio	Mag pTOF	Nagayama	Synthetic tests of Te/ne from spectra
5:40 PM	----------------------End-------------------------------		----------------------End-------------------------------		----------------------End-------------------------------	

Tomorrow's Agenda

Wednesday, Oct. 7

	Plenary 2 (Rosen Auditorium)				
8:00 AM	Holtkamp	Advanced Diagnostics at U1A			
8:40 AM	Merrill	Multi-LOS neutron imaging-Tion(r)			
9:20 AM	Schneider	Outbrief from the Spectroscopy workshop			
10:00 AM	Barnes	Diagnostic Needs for Marie			
10:40 AM	----------------------Break--------------------------------				
	X-ray Spectroscopy 2 (A234)		**Neutron/Gamma 3 (Rosen Auditorium)**		
11:00 AM	Schollmeier/Ao	Diffraction on Z	Frenje	MRS(t)	
11:30 AM	McPherson	Te(t) from continuum on Z	Hilsabeck	MRS(t) pulse-dilation detector	
11:50 AM	Khan	Te from SPIDER & DISC	Hares	10 ps PMTs	
12:10 PM	Mancini	Time- and space-resolved diagnosis	Li	NIF Proton Backlighter	
12:30 PM	----------------------Group Photo----------------------------		----------------------Group Photo-------------------------------		
12:40 PM	----------------------Lunch--------------------------------		----------------------Lunch--------------------------------		----------------------Lunch--------------------------------
	X-ray Detection (A234)		**Neutron/Gamma 4 (Rosen Auditorium)**		
2:00 PM	Robertson	Direct detection of >15 keV on hCM	Spears/Kilkenı	Antipodal nToFs- why and how-moments	
2:30 PM	MacPhee	Scintillators for high energy x-ray de	Grimm	"Precision" nTOF	
3:00 PM	Izumi	AXIS	Beeman/Moo	High DR electrical recording	
3:20 AM	Opachich	High Energy Photocathodes	Rinderknecht	Diag. Signatures of Kinetic Effects	
3:40 AM	----------------------Break--------------------------------		----------------------Break--------------------------------		----------------------Break--------------------------------
4:00 PM	MacPhee	Improving x-ray streak cameras on	Murphy	DD/DT Ion Temperatures	
4:20 PM	Loisel	Crystal calibration methods	Knauer	nTOFs on NIF and OMEGA	
4:50 PM	Marshall	Framed KB			
5:10 PM	----------------------End--------------------------------		----------------------End--------------------------------		----------------------End--------------------------------

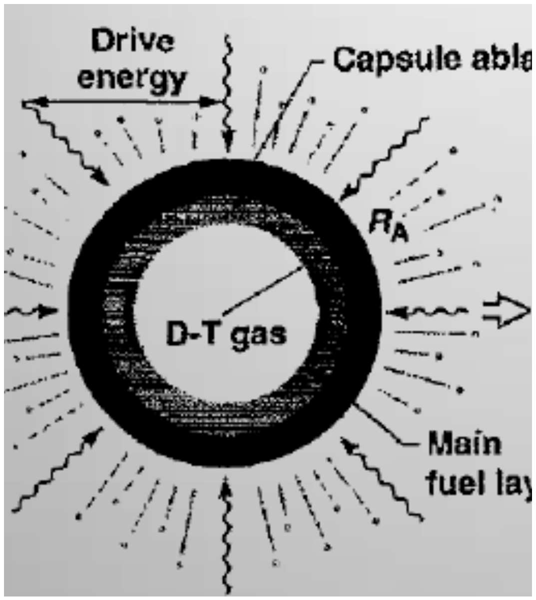
Thursday morning is for summarizing

Thursday, Oct. 8

	Plenary 3 (Rosen Auditorium)	
8:30 AM	X-ray Imaging 1	C. Bourdon
9:30 AM	X-ray Imaging 2	D. Bradley
10:30 AM	Optical Outbrief	D. Froula

END

We designed ignition diagnostics around Nino's methodology of tuning a hot spot



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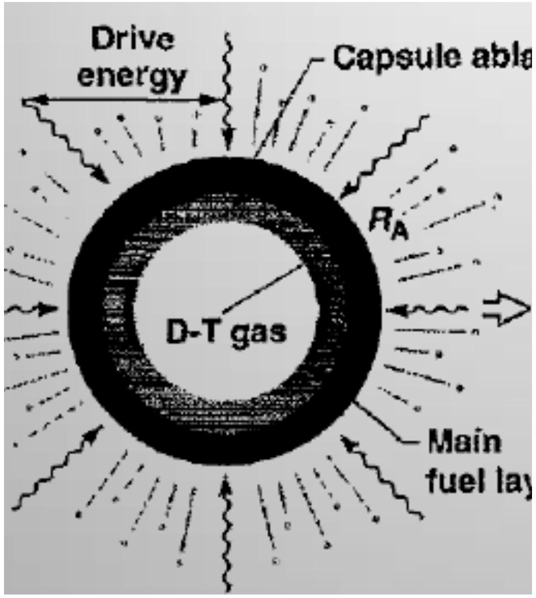
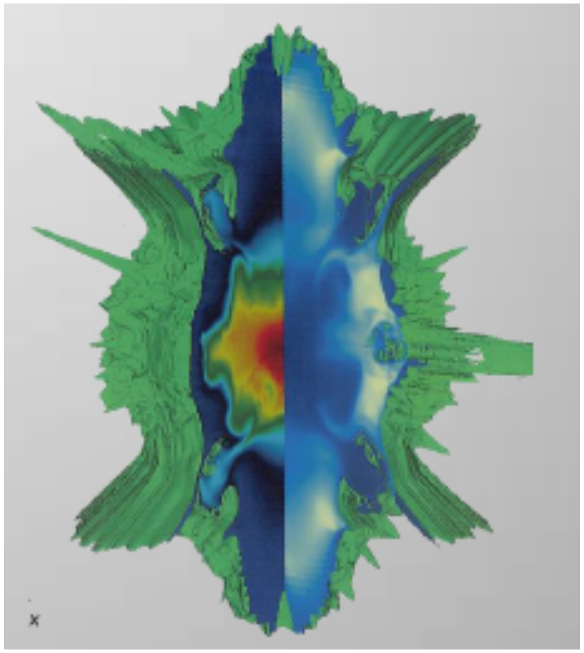


But core is more like a roadkill badger



I should have known better !

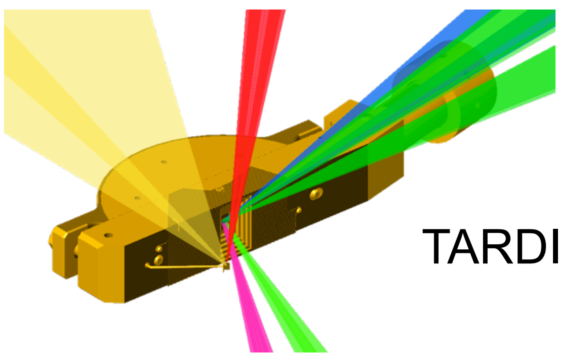
Transformative diagnostics will allow time-dependent phase change measurements in materials at high pressure.

Science Drivers

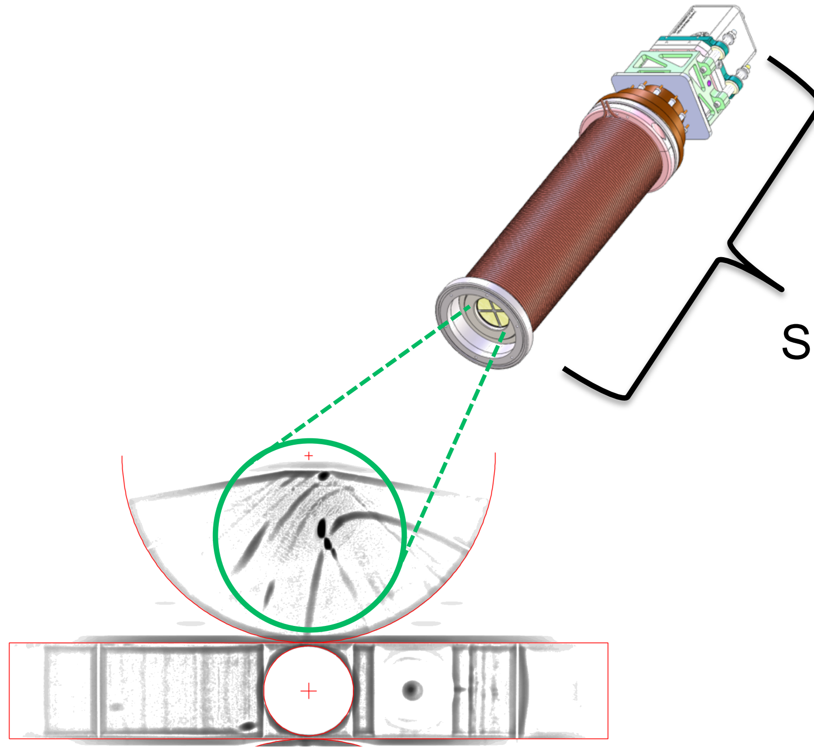
- Phase determination at high pressure
- Lattice deformation at high stress

Transformational Diagnostic Approach

- Time-gated x-ray diffraction



TARDIS

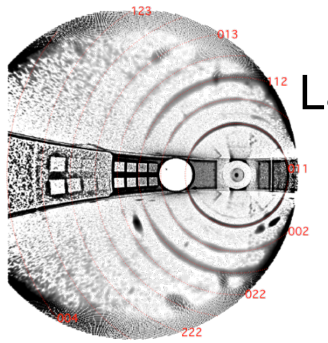


SLOS

Diagnostic	**Facility Implementation**	**Collaborating Institutions**
Fast Phosphors	Z	**SNL, NSTec**
TARDIS + SLOS	NIF	**LLNL**, GA, SNL

Coupling hCMOS sensors to pulse-dilation provides ultra-fast gating and flexible detection area

High Pressure Materials



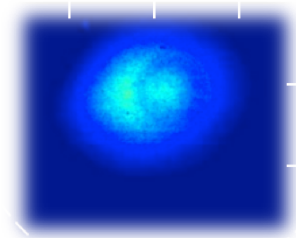
Diffraction

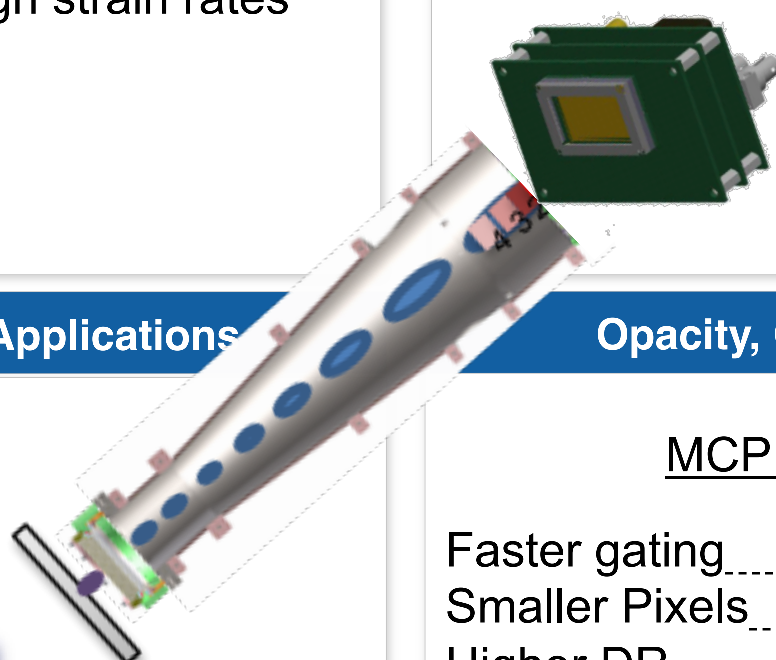
Large angular coverage

High strain rates

Complex Hydrodynamics

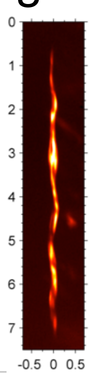
High Speed Radiography



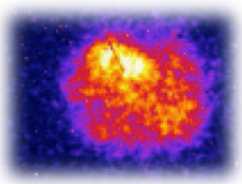


Thermonuclear Applications

Z-Pinch Stagnation



Hot-Spot Imaging



3-D

$T_e\ (r,\theta,\phi,t)$

Opacity, Outputs & Effects

MCP replacement

Faster gating........<10 ps up to 1 ns

Smaller Pixels.....25 μm

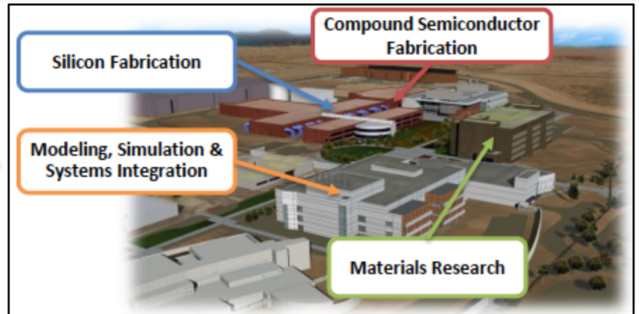
Higher DR...........~1000

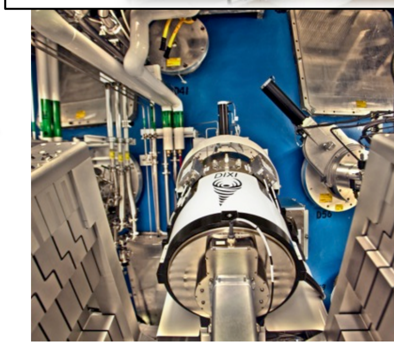
Single LOS..........Better optics

Calibrated...........no V^12 dependence

The National Diagnostic Plan builds on exciting transformative technologies

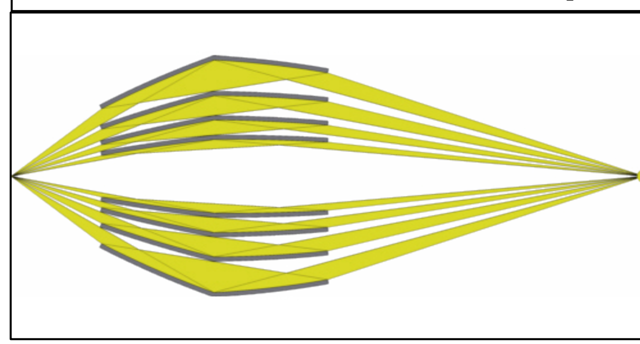
- The hybrid CMOS
  >four, ~1 ns x-ray gates,
  512 x 512 array of 25 μm pixels
- Manipulate images in time or space
- 10 psec Photo-multipliers
- X-ray imaging up to 50 keV
- Stand alone 10 J deep u.v. laser

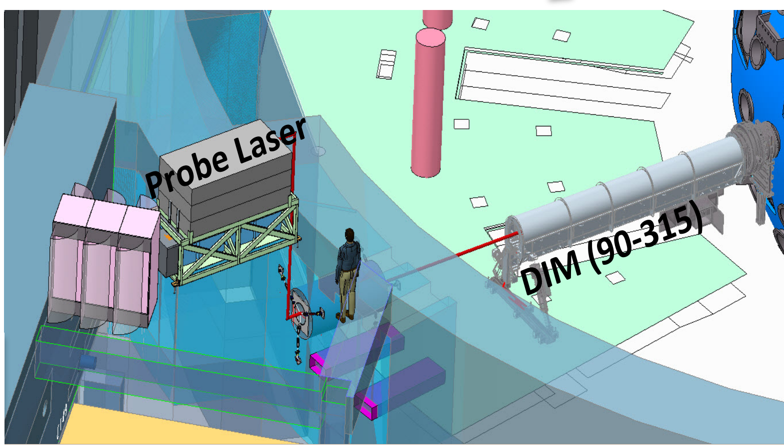




DIXI: magnifies time, demagnifies space

Nested coated Wolter optics





100J,1ω
10J, 5ω
probe
laser
(DCS)

NDP management group identified eight transformative diagnostics to meet SSP mission need and increase the utility of the major facilities over next 3-5 years

Transformative diagnostic	Institutions	New capability-program
Single LOS imaging (h-CMOS, dilation)	SNL,GA, LLNL,LLE, AWE	Many measurements on one shot for all missions. Short gating capability for implosions measure shape change during the stagnation process
Optical Thomson Scattering (OTS)	LLE, LLNL, LANL, NRL	Hohlraum ne, Te, Ti, Z-All: Radiation channel flow: discovery science
3D n/gamma imaging (NIS)	LANL, LLNL	3D shape of burn
Gamma spectroscopy (GCD)	LANL, AWE, GA,LLNL	Burn duration, mix
Time resolved n spectrum (MRS-t)	MIT LLNL, GA, LLE	Alpha heating diagnostic - burn
Hi Res. X-ray spect. (HiRes)	LLNL,LLE,PPL, NSTec, SNL	T warm compressed hi Z-strength: density of burning plasmas
Hard x-ray imaging (Wolter)	SNL, LLNL	Higher areal density backlighting for strength, complex hydro. Time & space resolved T of burning plasmas
Time resolved diffraction TARDIS-t	SNL, LLNL	Material phase change versus time for strength & discovery science

National Diagnostic Plan will be an ongoing effort for HEDP and SSP

Goals and objectives of this workshop

- Are we on the right diagnostic development path for NNSA ?

- Are there new ideas and new diagnostic efforts we should start?

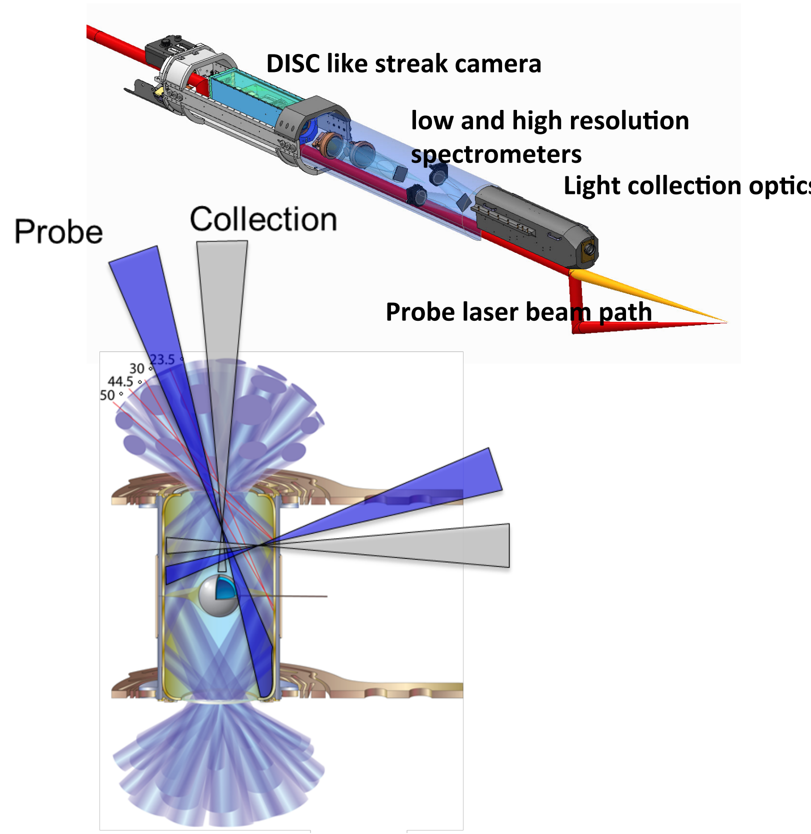
- Are there ongoing diagnostic development efforts which should be stopped?

36

Research Thrust: Local determination of the plasma conditions in low-density plasmas.

Science Drivers

- Hohlraum plasma formation and energetics
- Radiation channel evolution
- MagLIF LEH window interaction and gas heating
- Coronal conditions of direct-drive capsules
- Electron transport
- Independent of spectroscopy



Transformational Diagnostic Approach

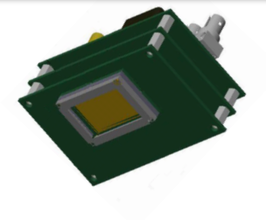
- Time-resolved Optical Thomson Scattering at deep UV for localized probing of electron temperature and density

Diagnostic	**Facility Implementation**	**Collaborating Institutions**
OTS	Omega, NIF	**LLE**, LLNL, LANL, NRL

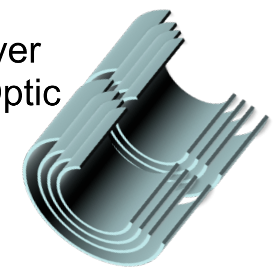
Research Thrust: High energy, high resolution many-frame imaging.

Science Drivers

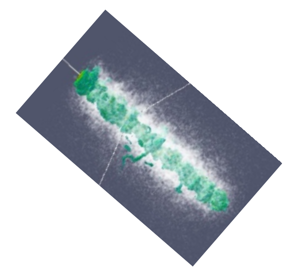
- Non-thermal x-ray production
- Material strength with high-energy radiography
- Complex hydro
- Three-dimensional ICF implosion dynamics
  - Characterize final stages of implosions and propagating burn
  - 3-D through multiple views



Hybrid CMOS



Multi-Layer Wolter Optic



K-alpha z-pinch source

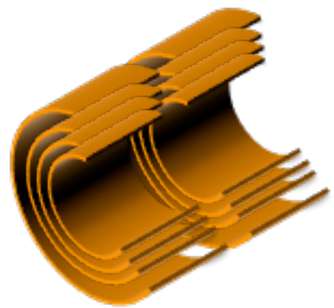
Transformational Diagnostic Approach

- Multi-layer Wolter microscopes for flexible field-of-view and high solid angle with high spatial res
- Coupled to SLOS for time-res

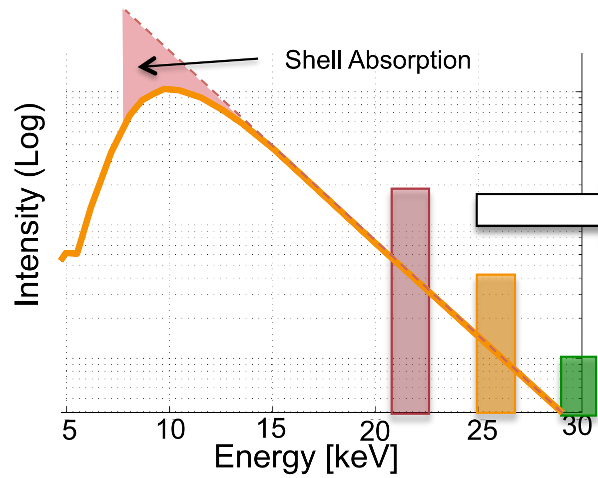
Diagnostic	Facility	Collaborating Institutions
KB + SLOS	NIF	**LLNL**, GA, LLE
Wolter + SLOS	Z, NIF, Omega	**LLNL**, SNL, LLE
Spherical Crystal + SLOS	Z, Omega	**SNL**, GA, LLE

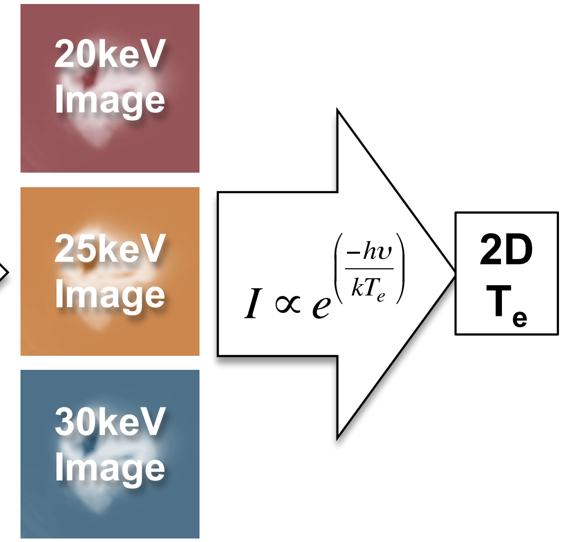
Nested multilayer Wolter optics coupled to a pulse-dilation SLOS will enable space-resolved T_e of capsule

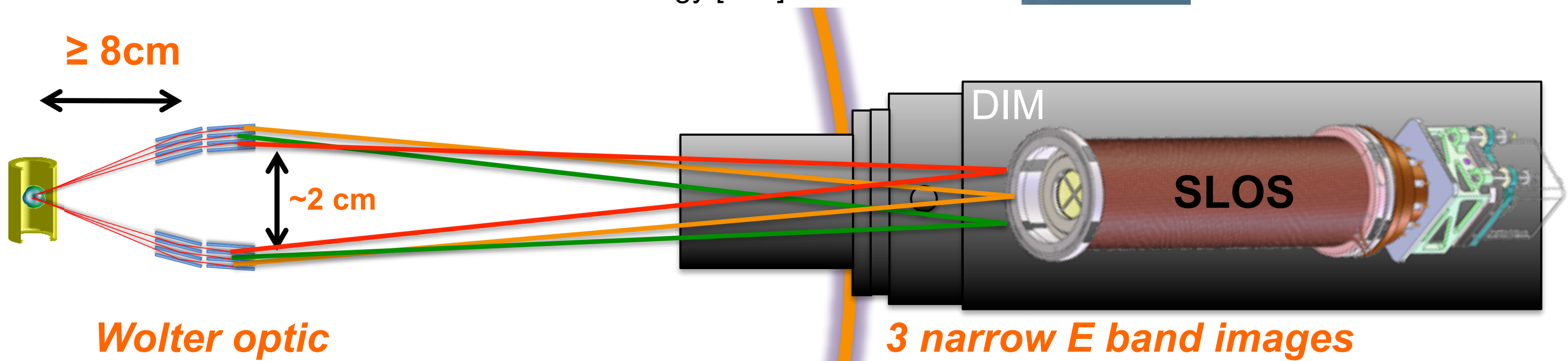
Nested Wolter with 3-different multilayers



Capsule Emission Spectrum





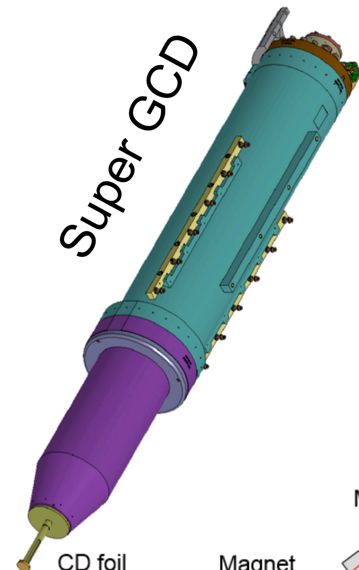


Benefit: enables multi-monochromatic imaging (MMI) in the optically-thin regime

Research Thrust: Detailed determination of fusing plasma evolution and burn propagation.

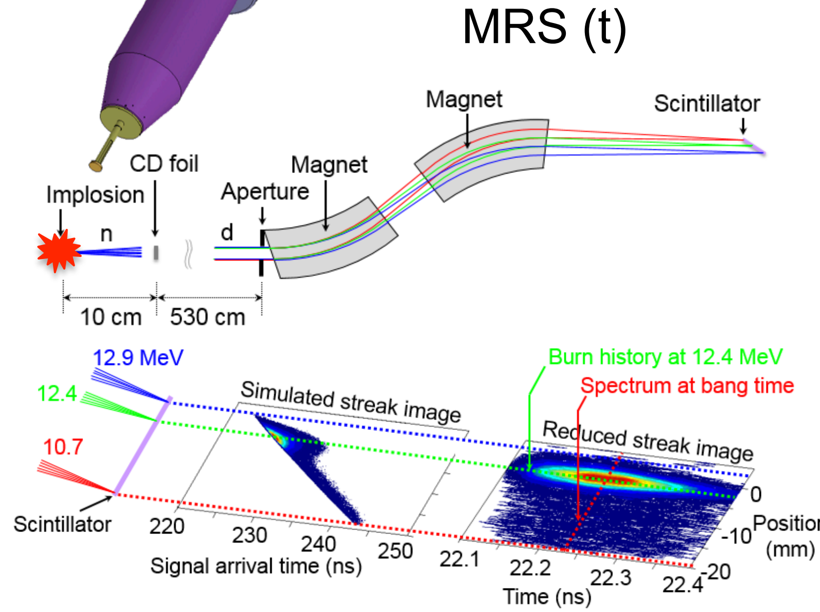
Science Drivers

- Hot spot formation
- Ablator – hot spot mixing
- rho-r evolution
- Fusion propagation
- Ion – electron equilibration
- Nuclear Astrophysics



Transformational Diagnostic Approach

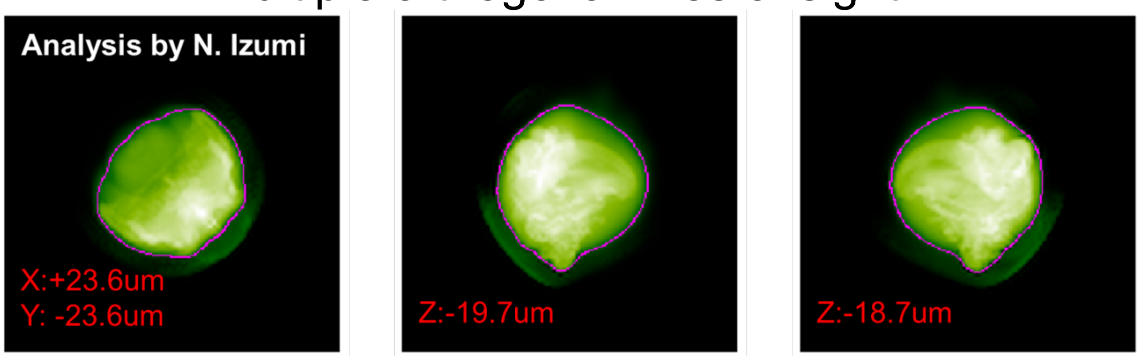
- High sensitivity Gas Chenkov Detectors (GCD) for high resolution fusion gamma spectroscopy
- Magnetic Recoil Spectrometer (MRS) coupled to time-resolved detectors (>1E16 yields)
- Neutron/gamma imaging from multiple orthogonal directions
- High resolution x-ray spectrometer for Ti, Te, ne



Research Thrust: Detailed determination of fusing plasma evolution and burn propagation.

Diagnostic	Facility Implementation	Collaborating Institutions
Super GCD	NIF, Omega	**LANL**, LLNL, AWE, Photek, LLE
3-D n/γ-imaging	NIF	**LANL**, LLNL
HiRes	Omega, NIF, Z	**NSTec**, LLNL,LLE,PPL, Aartep, SNL
MRS-t	NIF, Omega	**MIT**, LLE, LLNL, GA

Multiple orthogonal lines of sight



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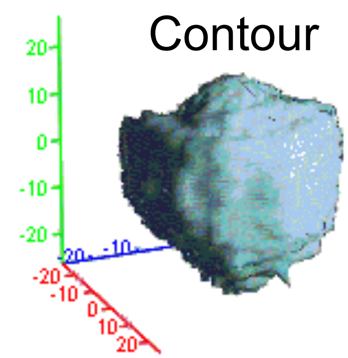
Reconstructed 3-D Contour



Mission Needs

The temperature of cold, compressed matter can be measured with EXAFS

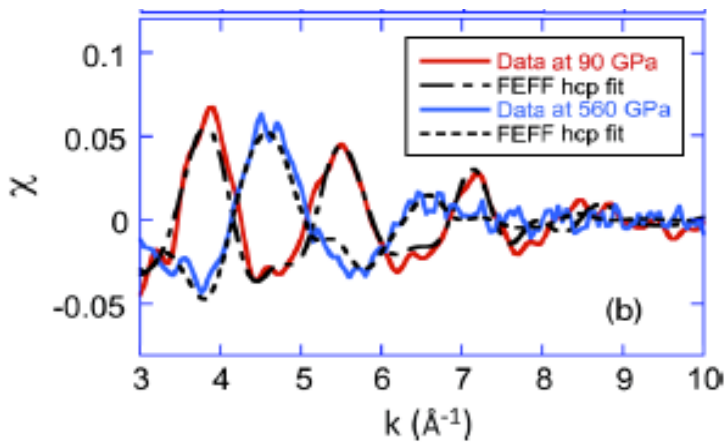
Current NIF Experiment: Ramp-compress sample

- Measure velocity with Visar to deduce STRESS
- Measure DENSITY with Diffraction

NEED to measure **Temperature**

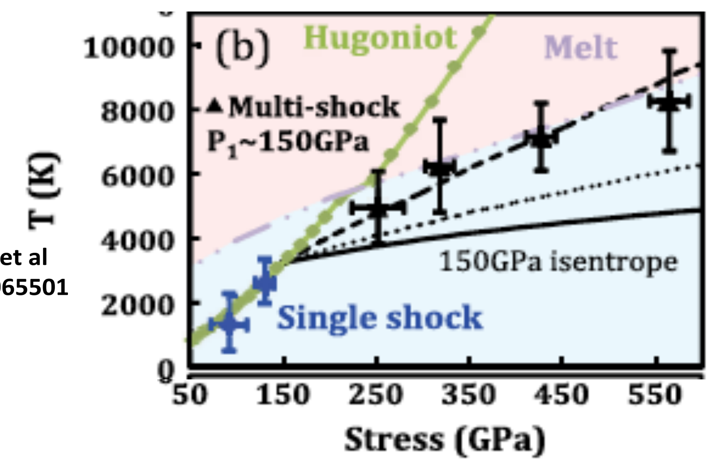
OMEGA experiments used EXAFS to measure Temperature

EXAFS data (ramp compressed Fe)



Y. Ping, F. Coppari, et al Phys Rev Lett 111,065501 (2013)

Temperature vs Stress



Extending these studies of cold, compressed matter to to mid and high Z materials needs NIF

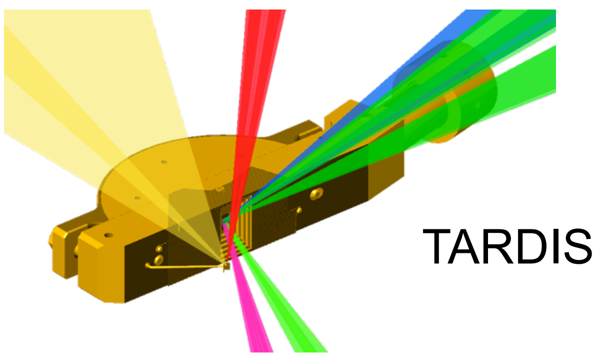
Research Thrust: Time-dependent phase change in materials at high pressure.

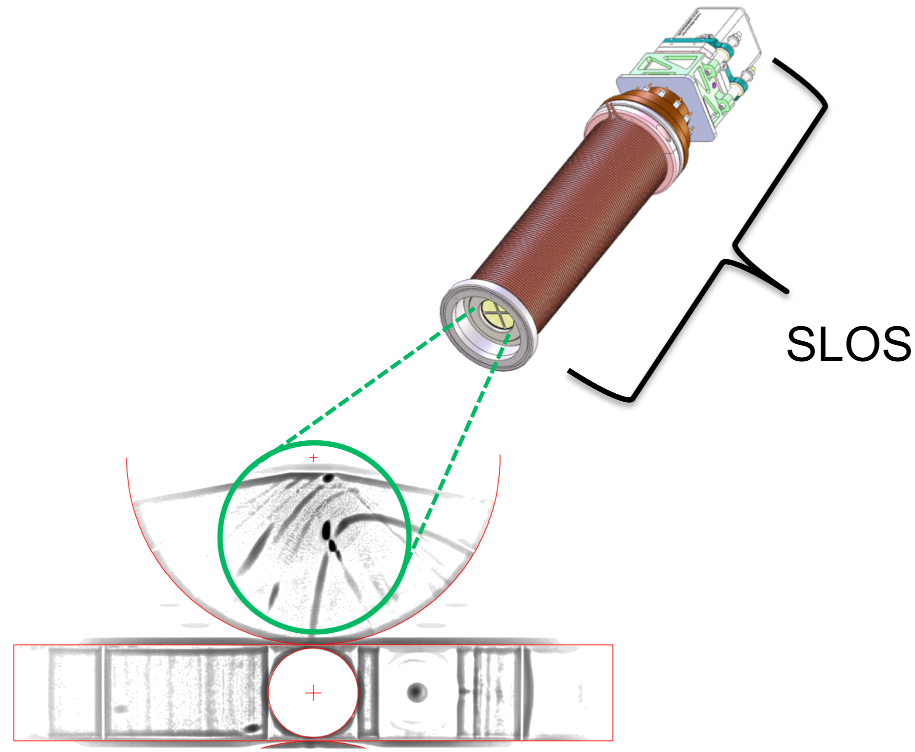
Science Drivers

- Phase determination at high pressure
- Lattice deformation at high stress

Transformational Diagnostic Approach

- Time-gated x-ray diffraction





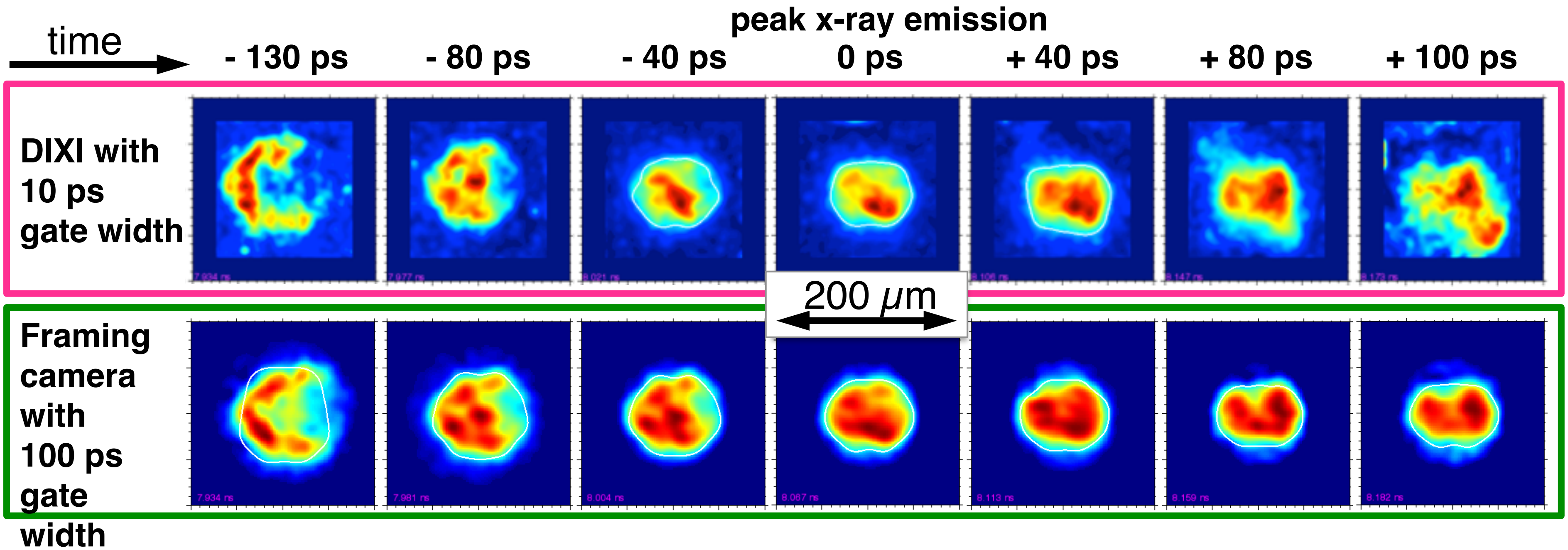
Diagnostic	Facility Implementation	Collaborating Institutions
Fast Phosphors	Z	**SNL, NSTec**
TARDIS + SLOS	NIF	**LLNL**, GA, SNL

Summary

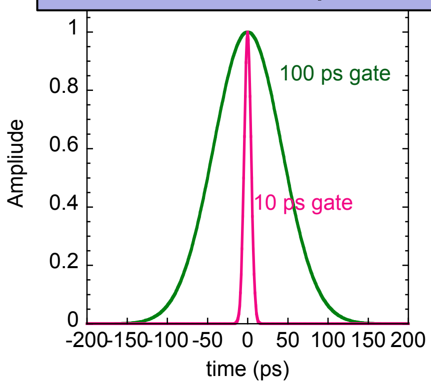
1. **Why a new diagnostics for HED science**
2. **Lots of people involved**
3. **Transformative technology- selection of eight diagnostics will allow new attributes to to measured**

Mission	New Observable	Technique	Acronym
Materials	Strength vs time of compressed matter	> 4 images/costly target	SLOS
	Phase change compressed matter - rates	Time dependent diffraction	TARDIS-time
	T of compressed Pu	Extended x-ray fine structure	Hi Res
Complex Hydro.	3D structure at ~ 50 keV	X-ray bands imager +SLOS	Wolter
Rad. Flow	T_e of Marshak wave	Deep u. v. Thomson scattering	OTS
Burn	Time history of burn	Ultra-fast Cerenkov detector	GCD
	3D T_e and density vs time	Dilation tube + SLOS+Wolter	DIXI-SLOS
	3D burn, 3D mix vs time	3D neutron/γ imaging	NIS
	T_{ion} and areal density vs time	Neutron spectrum vs time	MRS-time
All	Hohlraum- density & T vs space & time	Deep u. v. Thomson scattering	OTS

DIXI takes clearer pictures of the hot spot evolution around peak x-ray emission, due to its faster 'shutter'



Gate width comparison



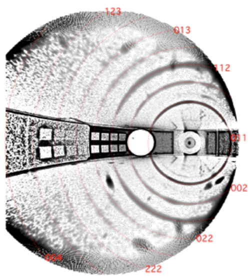
DIXI's 10X higher temporal resolution (reduced temporal blur) reveals details in the evolution of implosions at NIF never before possible, using the slower cameras.

N141116

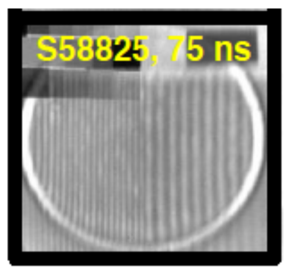
Multi-gated multi-frame hybrid CMOS sensors will transform capability across all HED programs

High Pressure Materials

Diffraction

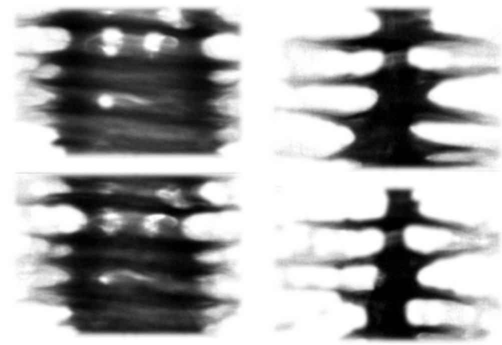


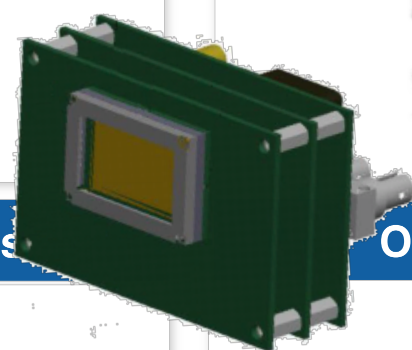
Strength



Complex Hydrodynamics

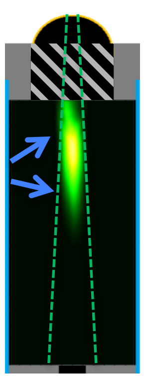
Radiography



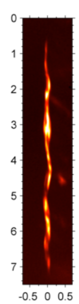


Thermonuclear Applications

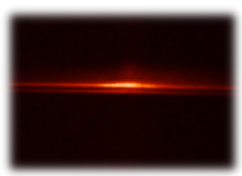
Laser Preheat



Stagnation

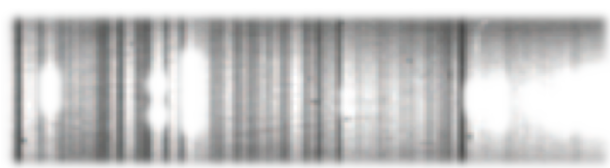


Spectroscopic Mix

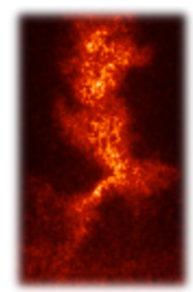


Opacity, Outputs & Effects

Absolute Gated Spectra



High-Z K-α Imaging



Eight major national efforts emerged with the potential to transform experimental capability for the most critical needs

- **Broad enabling capability of multi-frame single line-of-sight (SLOS) time-gating at 10 ps – 1 ns**

- **2- and 3-D visualization of the plasma evolution with very high spatial (<10 micron) and temporal (<10 ps) resolution at a broad range of photon energies (5-50 keV)**

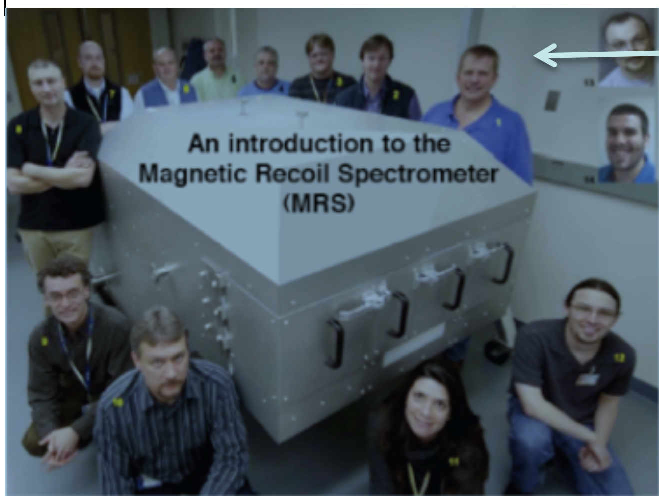
- **Detailed determination of fusing plasma evolution and burn propagation**

- **Local probing of plasma conditions and evolution in low-density plasmas**

- **Time-dependent phase change and temperature at high pressure**

The National Diagnostic Group facilitates engineering collaboration to ensure most cost effective design & fabrication

LLE Engineers & MIT built the MRS* for NIF in 2009



Milt Shoup

MRS* on NIF & four MIT Stockpile Stewards

Jon Zeugel

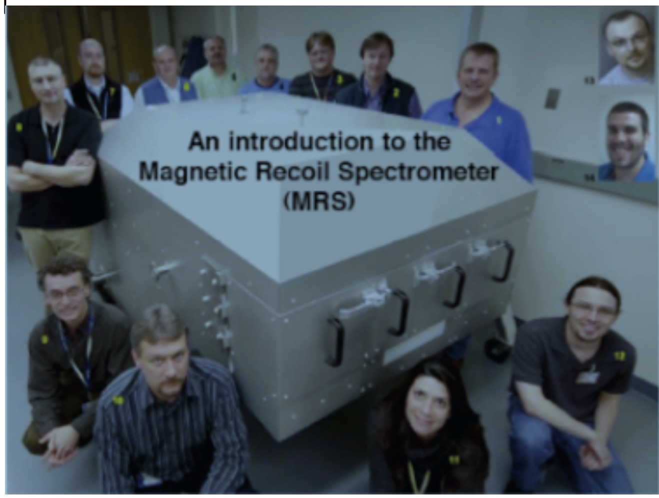
LLE Engineering Leaders 3/5/15

LLE Engineering leaders visited NIF 3/5/15 to discuss further LLE engineering for NIF

* MRS- Magnetic Recoil Spectrometer

The National Diagnostic Group facilitates engineering collaboration to ensure most cost effective design & fabrication

LLE Engineers & MIT built the MRS* for NIF in 2009



MRS* on NIF & four MIT Stockpile Stewards

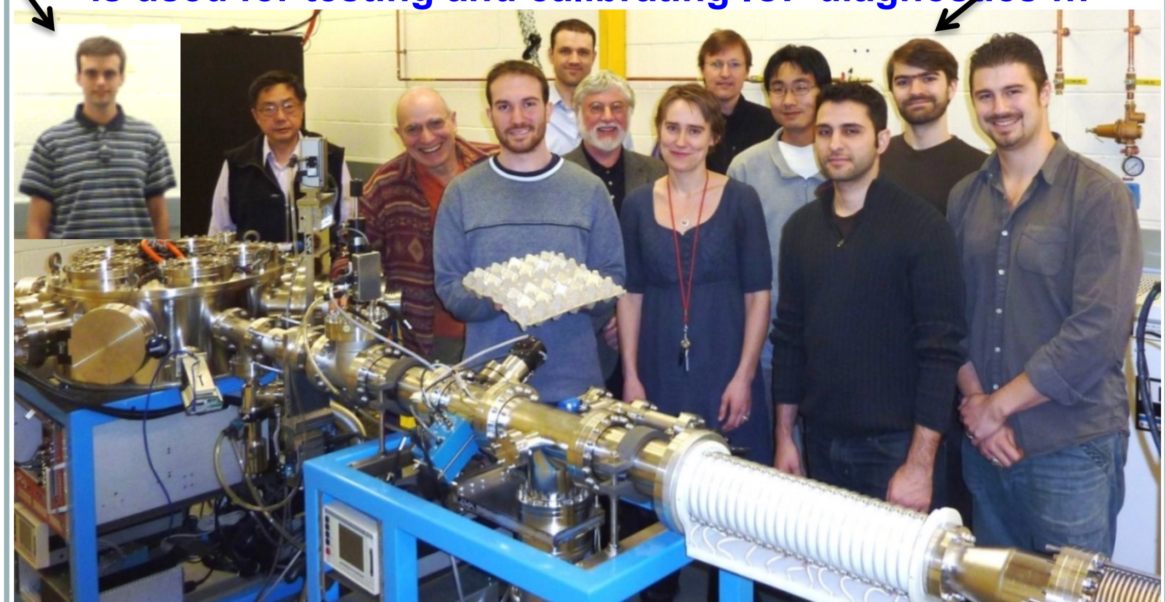
* MRS- Magnetic Recoil Spectrometer

Diagnostic development clearly attracts new Stockpile Stewards (from MIT: 3 to LLNL[1], 1 to LLE[2], 2 pending)

Alex Zylstra
Lawrence Fellowship
Reines Fellowship

Hans Rinderknecht
Lawrence Fellowship
Truman Fellowship

The MIT Accelerator Facility for Diagnostic Development is used for testing and calibrating ICF diagnostics …



1 Damien Hicks, Ryan Rygg, Dan Casey
2 Mike Rosenberg

Transformative diagnostic schedule- largely complete in five years if budget shortfalls can be adressed

Measurement needs		Technology	FY15	FY16	FY17	FY18	FY19	FY20	FY21
Multi-frame single line-of-sight detection	SLOS	Hybrid CMOS sensors & drift tubes	2-frame Z & NIF	4-frame Z/NIF/Ω	SLOS+KB	8-frame	40 keV diodes SLOS+Wolter	16-frame	
Localised low-density plasma ρ & T	OTS	Deep UV Optical Thomson Scattering	Xtal (LLE)	Laser	Emission NIF	Ω, NIF			
Time/space resolved Burn-Boost	Super GCD	Time-resolved γ spectrometer (GCD)		Bkg	20ps ~1 meter	start GEMS			
	NIS/GRI	Three-dimensional n & γ imaging			GRI 90-315		Polar n/g(time)	Eq NIS/GRI	3D n
Time resolved Te, Ti and ρr in burn-boost	HiRES	High-resolution x-ray spectrometer	EP (static)	EP (t), NIF (static)		NIF (t) Ω (t)	NIF Exo-chamber		
	MRS-t	Time-resolved n spectrometer				CD-readout	NIF		
Time resolved phase change	Tardis-t	Time-resolved x-ray diffraction			NIF (GXD)	Z (static)	NIF (SLOS)	Z (t)	
High energy, x-ray imaging/ hi ρr	Wolter	Multi-layer Wolter			Z (static)	NIF (SLOS)	Z (SLOS), NIF (50 keV)		

After feedback CDR level costings will be done this summer for FY17 budget development & FY16 implementation

Meeting mission need: transformative diagnostics measure new observables critical to HED/ICF mission

Mission	New Observable	Technique	Acronym
Materials	Strength vs time of compressed Pu	> 4 images/costly target	SLOS
	Phase-time compressed Pu - Z, NIF	Time dependent diffraction	TARDIS-time
	T of compressed Pu	L_3 Extended x-ray fine structure	Hi Res
Complex Hydro.	3D structure at ~ 50 keV	X-ray band imaging +SLOS	Wolter +SLOS
Rad. Flow & Effects	T_e of Marshak wave	Deep u. v. Thomson scattering	OTS
	Hard spectrum vs space & time	X-ray bands imager +SLOS	Wolter
Burn and boost (thermonuclear physics)	Time history of burn	Ultra-fast Cerenkov detector	GCD
	3D T_e and density vs time	Dilation tube + SLOS+Wolter	DIXI-SLOS
	3D burn, 3D mix vs time	3D neutron/γ imaging	NIS
	T_{ion} and areal density vs time	Neutron spectrum vs time	MRS-time
All	Hohlraum- density & T vs space & time	Deep u. v. Thomson scattering	OTS
	Many measurements on one shot	h-CMOS with dilation if needed	SLOS, dilation

The ND management team is exploring the impact of these diagnostics on other SSP facilities and on the broader DOE scientific community

Preliminary un-scrubbed costing estimates from the sites shows a shortfall ~ $20M per year FY16-FY19" using steady state out year ICF budgets **only- but NDP benefits SSP broadly**

How to address shortfalls

1. Increase ICF   -FY17 and beyond

Within ICF

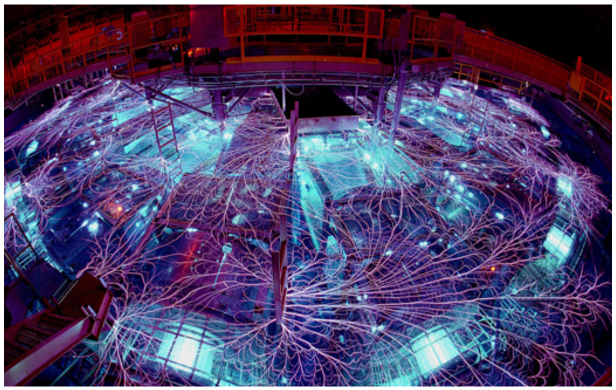
1. Free up funds from completion of other capability projects
   e.g. ARC "dividend" ~$10 M in FY 16
2. HQ advanced diagnostics holdback
3. Rebalance between transformative and other diagnostics or user optics
4. Balance against current operations
   -sacrifice ongoing experiments for facility improvements
   -impact on shot rate and shot rate improvement?

Shared fate with science campaigns

1. Synergies with / leverage against advanced radiography or other science campaigns.

H-CMOS x-ray imager, the top priority diagnostic was developed in collaboration by MESA and Pulsed Power at SNL and will impact both ICF and C3

Z (SNL)



MESA (SNL)

- 2013 C3 imaging workshop highlighted the need for SLOS gated imagers in Radiography and associated science mission
  - Multiple ~50 ns frames improve efficiency on multi-pulse machines)
  - Single ~200 ns gated frame improves radiograph contrast
  - Flexible multi-frame imaging for source and materials science (diffraction)

- Report recommends development of fast CMOS cameras
  - Major challenges for radiographic applications are in achieving low noise floor and in developing large-area detectors

Budget and management for transformative diagnostics

- Working with sites and NNSA estimates of budget shortfalls for FY15 and out-years are being worked
- After initial feedback cost estimate of transformative diagnostics are being reworked
  - Projects with significant costs in FY16/17 need CDR level costing in the summer allowing more accurate costing input to NNSA for FY17 budget development and FY16 implementation
- Propose that a core management team do a detailed examination of the costing of the transformative diagnostics on a rolling basis and make annual recommendations to NNSA/sites on priorities, updated costs and shortfalls.

National Diagnostic Plan summary- next steps

- NNSA review group said: ***"Diagnostics Working Group provides a superb model for a scientific peer community coming together to share issues, ideas and approaches to innovate diagnostics for our HED facilities."***
- After initial feedback NDP group is reworking scope and budget
- To maintain NDP group cohesion, budget and scope discussions with NNSA and all sites need to continue

Budget coordination with diagnostic priorities and leadership will maintain cohesion and inter-lab cooperation ensuring maximum effectiveness/value for the Program

Students who have gotten either PhDs or Masters from MIT HED/ ICF division are :

- Chikang Li………PhD (yah, he was the first!).
- Damien Hicks PhD
- Ryan Rygg……..PhD
- Dan Casey….PHD ………….Awarded LANL Directors Fellowship, but tookfor staff position at LLNL
- Nareg Sinenian PhD
- Mario Manuel PhD Awarded and took Einstein Fellowship, Received 2014 Outstanding Rosenbluth Thesis Award*
- Mike Rosenberg PhD Awarded LANL Directors Fellowship, but took position at LLE
- Hans Rinderknecht PhD Awarded both Lawrence and Truman Fellowships (hasn't yet decided)
- Alex Zylstra ….. PhD on april 15, 2015 (defense). Awarded Lawrence and Reines Fellowships
- *Mario's Rosenbluth award, for first measurements using mono –P radiography of B fields associated with RT, was first ever to a HED PhD student (yep, always before to MFE phd students, and other disciplines, but NOT HED!).
- Current students working towards PhD:
- Hong Sio
- Brandon Lahmann
-
- Masters:
- Joe Deciantis
- Shinya Kurebayashi
- Brook Schwartz

Why do we need Hybrid CMOS Camera Systems?

Currently On NIF, Z, OMEGA ➡ Image Plate & Film

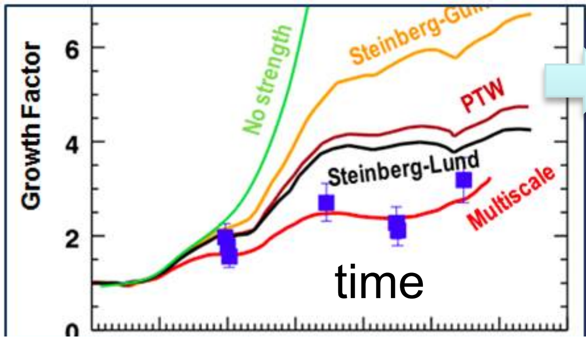


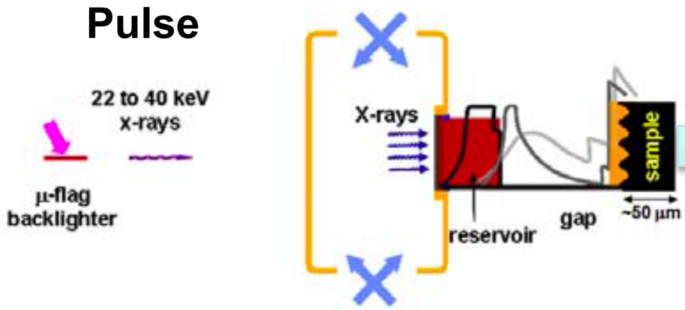
Image Plate Disadvantages

- Multiple Shots Required To Do A Time Scan
- Measurement @Single Time
- Expensive To Process
- Issue of Non-Reproducibility

Image Plate Replacement

Future On All Facilities ➡ Hybrid CMOS (hCMOS) Imager

Picket Fence Pulse



hCMOS Imager
4-8
1ns Frames

Hybrid CMOS Capabilities

- >256x256, Buttable
- 4-8, 1ns Frames
- Several Pixel Sizes/DILATION Tube
- 3D X-ray Diode

A hCMOS image sensor can, with X-ray source development, eliminate the need for multiple shots making multiple measurements at user defined times within one shot.