NIF Diagnostics: mission responsive, user community building and program enabling

NIF User Group Meeting
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Lawrence Livermore National Laboratory • National Ignition Facility & Photon Science

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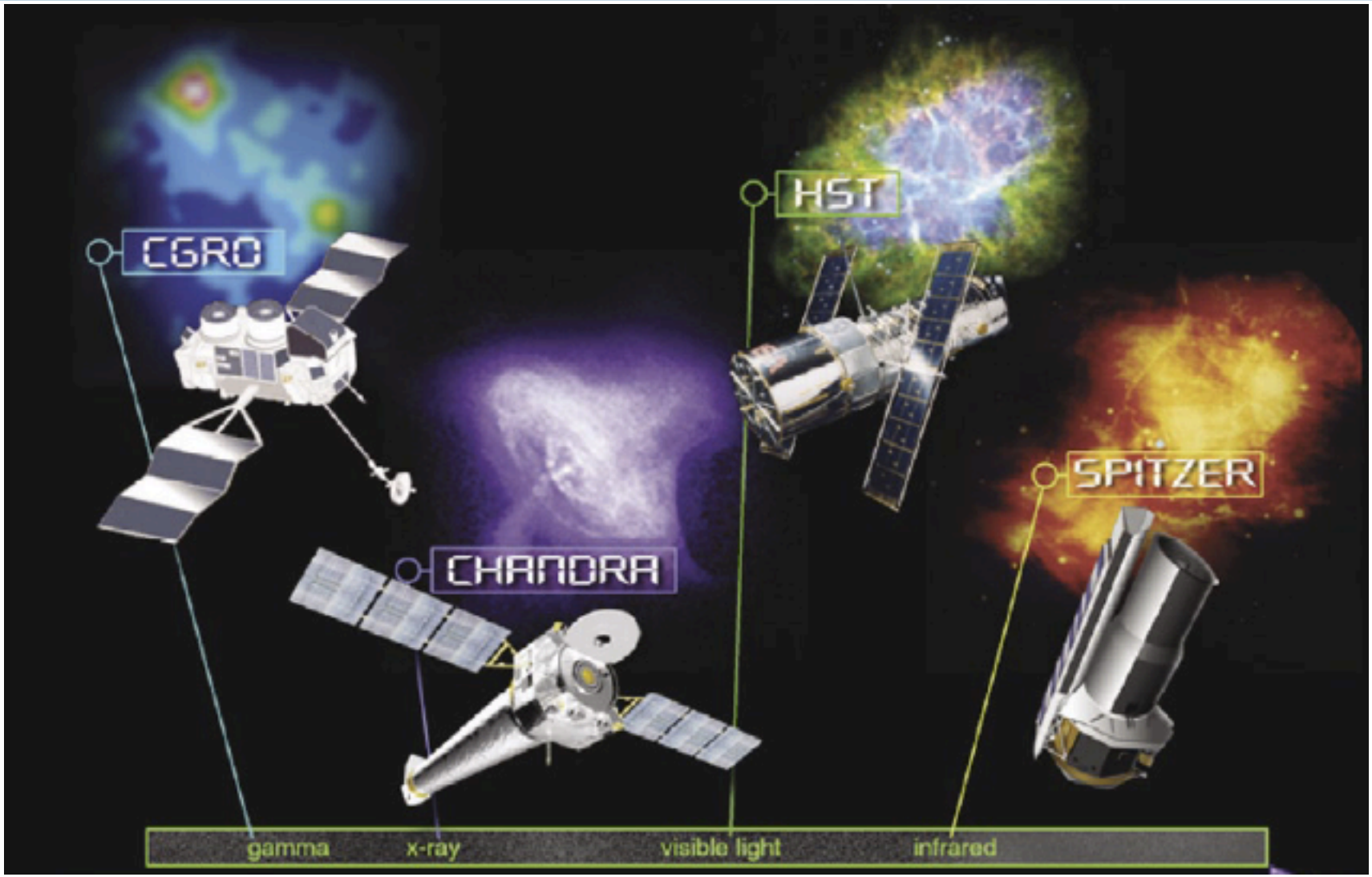
Much of what we know about the universe comes from telescopes

- Telescopes evolved slowly over several centuries
- Our atmosphere restricted studies of the universe to the visible
- Our atmosphere gets in the way even in the visible

Space flight changed all that

Shuttle(& δ) enabled NASA's Great Observatories covering the spectrum from γ s to the infrared and opened our eyes on the Universe



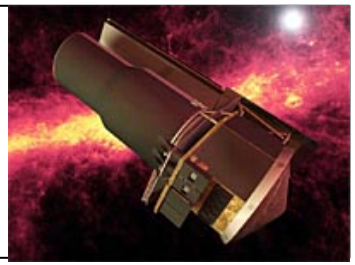
NASA's Great Observatories, are four space-borne observatories measuring in four different bands: visible, gamma rays, x-ray, and infrared)

Chandra x-ray observatory : X-ray telescopes. Detailed studies of black holes, supernovas, and dark matter.

The Compton Gamma Ray Observatory: violent physical processes in the Universe, emitting γ 's

Hubble Space Telescope: 2.4 m optical: star birth, star death, and galaxy evolution, and has helped move black holes from scientific theory to fact.

The Spitzer Space Telescope: infrared



A new set of foundational diagnostics will explore the physics of the Universe on NIF

X-rays – NIF has > 10 μm pinhole cameras, single frame dt ~ 100 psec and low resolution spectroscopy
- NIF needs dx ~ 2 μm, dt ~10 psec with real framing, $\lambda/\delta\lambda \sim 10{,}000$

Gammas- NIF has several MeV resolution, dt ~ 10s psec
- NIF needs 0.1 MeV resolution, dt ~ 10 psec. Imaging?

Optical - NIF has a limited interferometry (f/3.3, 600 nm VISAR)
-NIF needs Thomson, interferometry/Faraday into u.v.

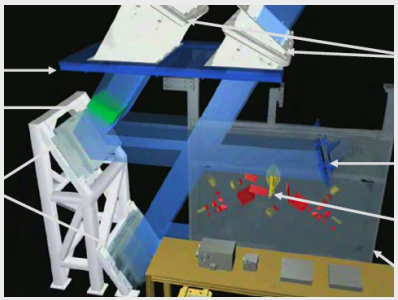
Neutrons- NIF has medium energy spectrometers, 20 μm static imaging
- NIF needs good sub-MeV resolution, versatile imaging

,

Foundational diagnostics need technology basis, consensus, phasing(Ω, Z) and long term commitment

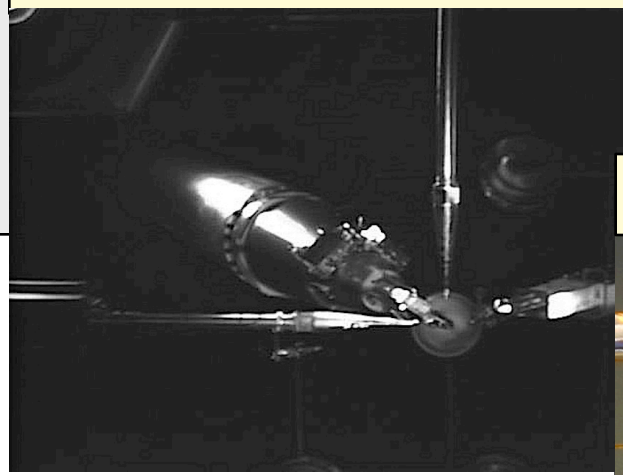
Fifty diagnostics on NIF for Ignition, High Energy Density Science, Basic Science- see posters

Hohlraum diagnostics

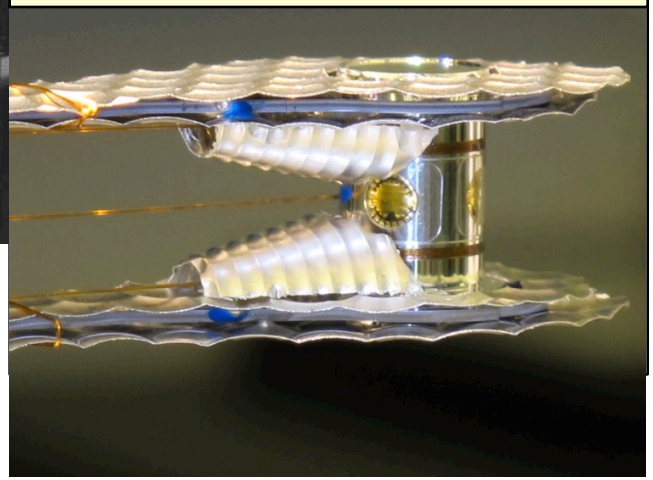


FABS31 on NIF

Capsule diagnostics



Ignition diagnostics



The diagnostics so far have been developed over several decades

NIF supports ~50 sophisticated diagnostics for users (through ~ 2012)- see posters

- Optical ~7 : Backscatter, into and close to lenses, VISAR and Streaked Optical Pyrometer, 4ω fiducials
- X-ray ~25: Gated and streaked imaging and spectroscopy, absolute time resolved x-ray band spectrometers
- Nuclear ~15: Neutron yield, spectroscopy and imaging, radio-chemistry, proton temporal and spectral, time resolved gamma band spectroscopy
- Diagnostic operations: facility operations and data acquisition

Most of the existing diagnostics have been prototyped at NTS or Nova or OMEGA or Z over decades

Diagnostics have helped build the user community

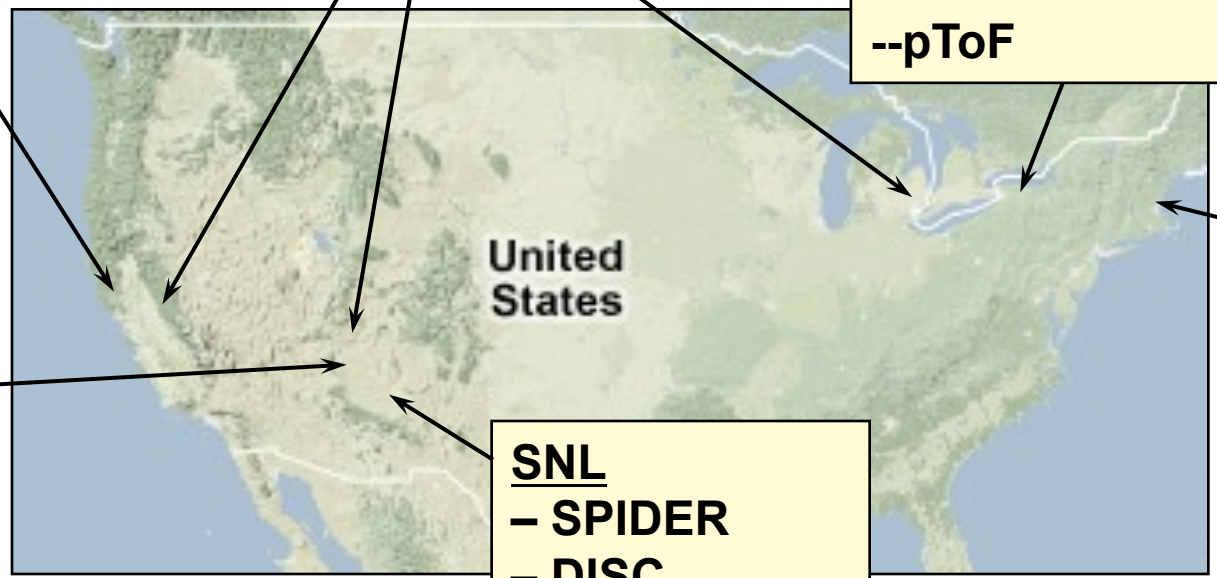
LLNL
- FABS, NBI
- Dante I & II
- VISAR
- DISC
- RAGS
- hGXI
- ARIANE
- DIXI
- NAD
- -- MRS

NSTec
- Calibration

U of M.
- HEMPI

LLE
- NToFs
- 4ω fidu system
- MRS, NADS
- SPBT
- HEXRS
- --pToF

AWE
- FFLEX



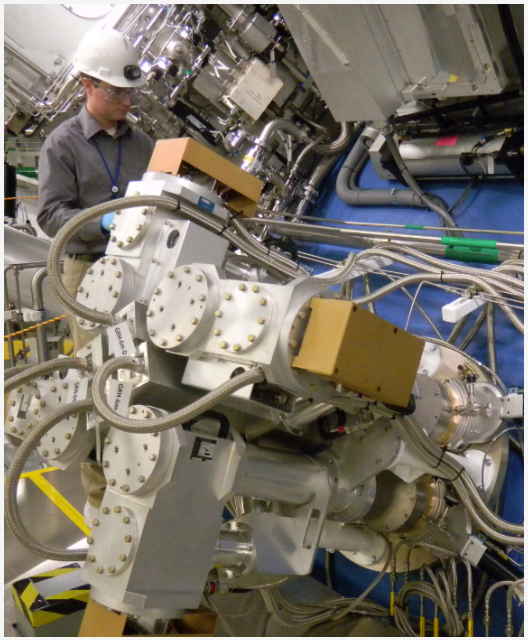
MIT
- MRS
- WRF
- PToF

LANL
- GXD
- γ burn
- n imaging

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

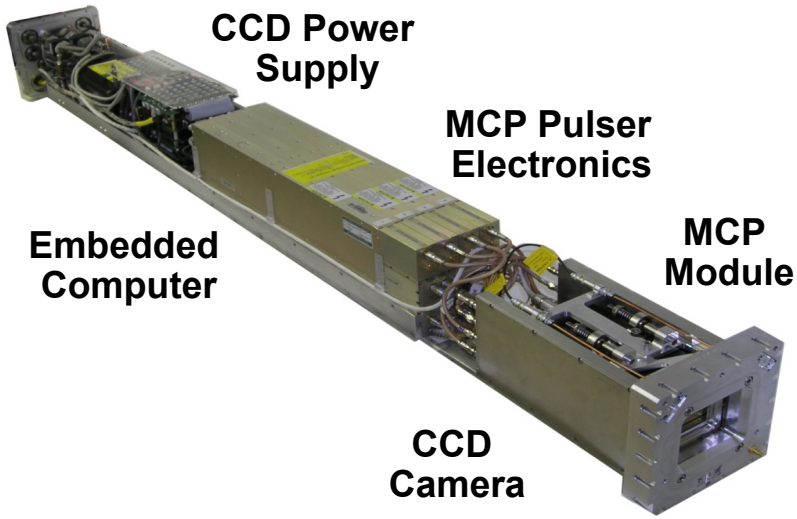
Some of the existing diagnostics are foundational

GRH Installed at NIF



4 Gas Cells mounted on chamber (6m from TCC)

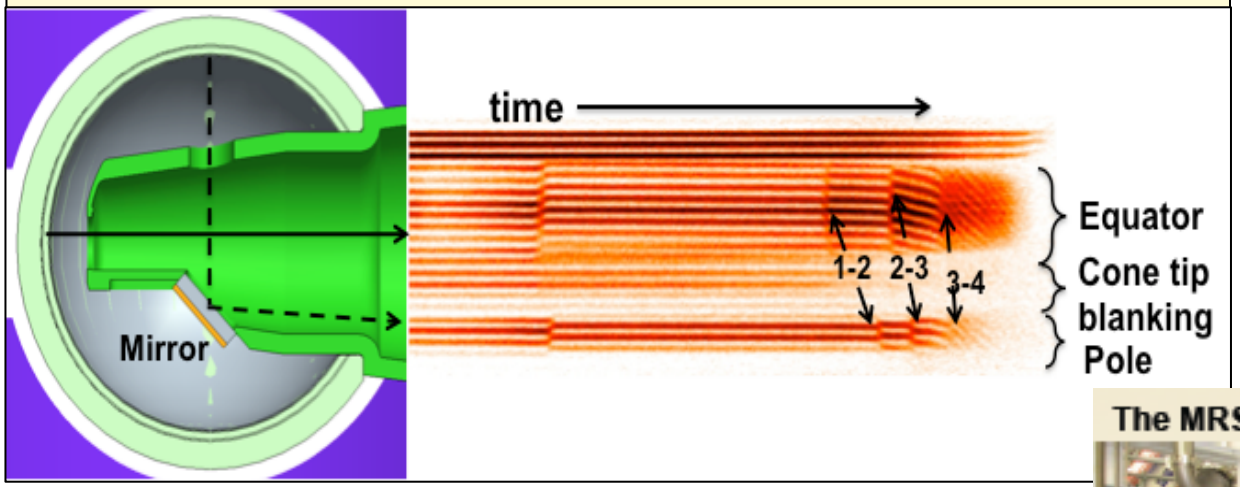
Gated x-ray cameras widely used



Although widely used at the moment they are middle aged

Some of the existing diagnostics are foundational

VISAR used for ignition, WCI and Basic Science

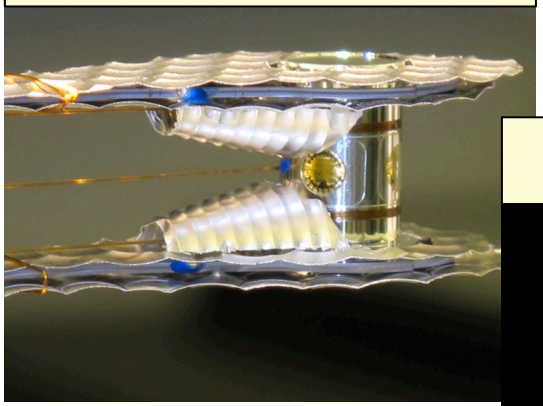


The MRS fully installed on the NIF chamber

Although widely used at the moment they are middle aged

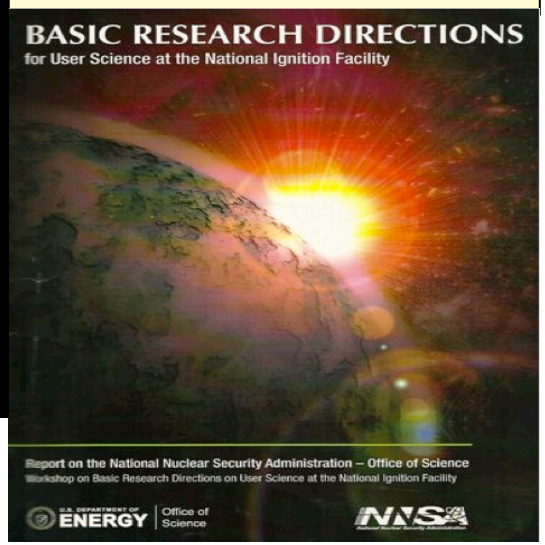
The next set of diagnostics will be chosen to satisfy NIF's missions in the second decade

MTF 10.1



MTF 10.2

Science Use



The 6th NIF diagnostic workshop 5/5–6/11 started process for diagnostic plan beyond 2012

New diagnostics proposed	#
Neutron spectroscopy	7
Neutron/gamma imaging	2
Radio-chemistry	2
Gamma spectroscopy	5
Optical: interferometry, Faraday,Thomson	3
X-ray spectroscopy	9
X-ray imaging	8
Manipulators	2

Work is needed to provide sufficient information to a make an engineering plan

After the workshop NIC and NNSA agreed to do pre-conceptual designs on about 20 of the diagnostics

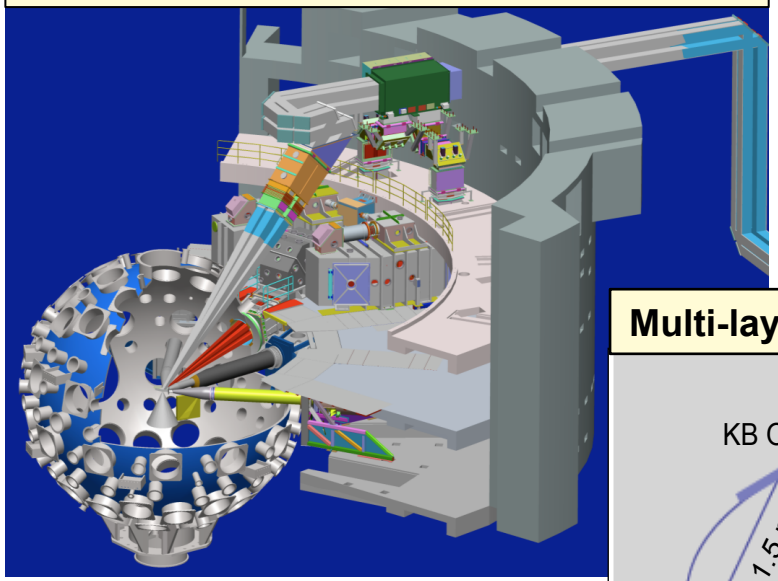
Foundational			
LANL/GA	Design of Gamma Compton Spectrometer	Hilsabeck	10.1
LANL	Gamma Compton Spectrometer/Monochromator	Herrman	10.1
LANL	Hardened GRH-15	Herrman	10.1
LLNL	Optical Interferometer/Faraday	Hye Sook Pa	Science
LLNL	~20 keV x-ray optic imager	Pivaroff	10.1,10.2
LLNL	Furlong Nuclear Diagnostic Station/Test Bench	Schneider	10.1,science
LLNL	High resolution x-ray spectroscopy l/dl >2000	Koch/Stewar	10.1
LLNL	4w Thomson Scattering	Glenzer/Ross	Science
LLNL/GA	Hardened, < 10 ps,multi-mono LOS x-ray camera	Hilsabeck	10.2

Evolutionary			
LLNL	HOPG spectrometer for XRTS	Glenzer	Science
LANL	Advanced radiochemistry: beta decay	Grim	10.2
LANL	n image x-ray image registration	Grim	10.1
LANL	Multiple Monochromatic Imager	Kyrala	10.2
LLE	Time-resolved HXRD	Sangster	10.1
LLE	HSXRS for the streak camera	Regan	10.2
LLNL	sub-Mev neutrons using a Fission detector	Bernstein	10.2
LLNL	Strength Diffraction Diagnostic	Smth	10.2
LLNL	Rad Optic Diagnostics with ps Resolution for NIF 2013-2015	Lowry	10.2
LLNL	Bang time and drift velocity	McNaney	10.1
LLNL	Advanced CR with ARC-FIDO	Crane	10.1
LLNL	X-ray Crystal Spectrometer- survey spectrometer	Seeley	10.2

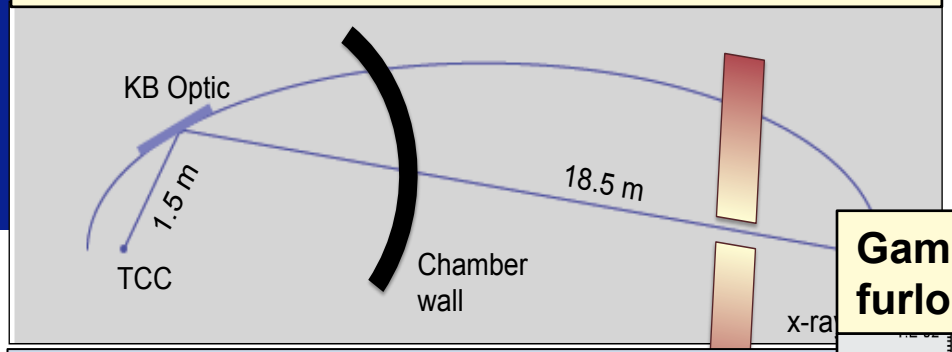
Designs and new ideas discussed at 7th diagnostic workshop May 1-4

Foundational diagnostics will be enabling for NIF in the second decade

ARC :new states of matter and a diagnostic

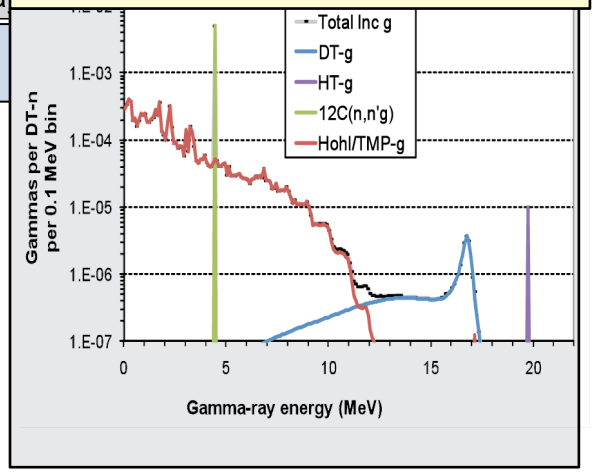


Multi-layer X-ray Imager(MXI): DIXI x-ray framing



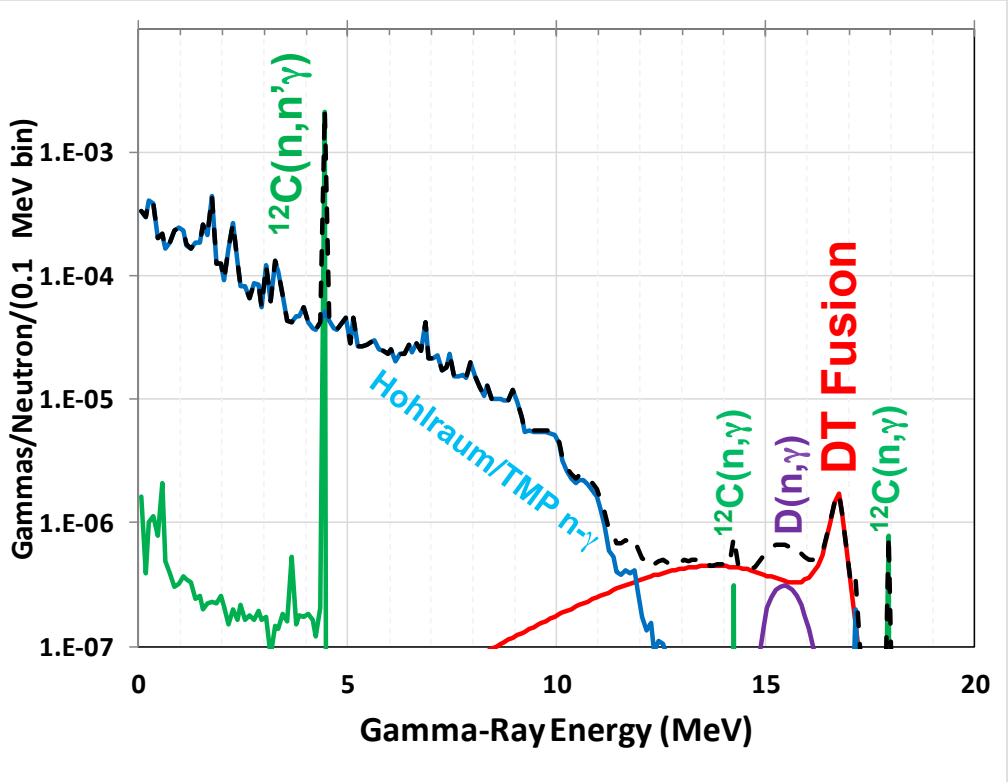
MXI - < 5 μm: DIXI - < 10 ps gating

Gamma ray spectroscopy: furlong detector station



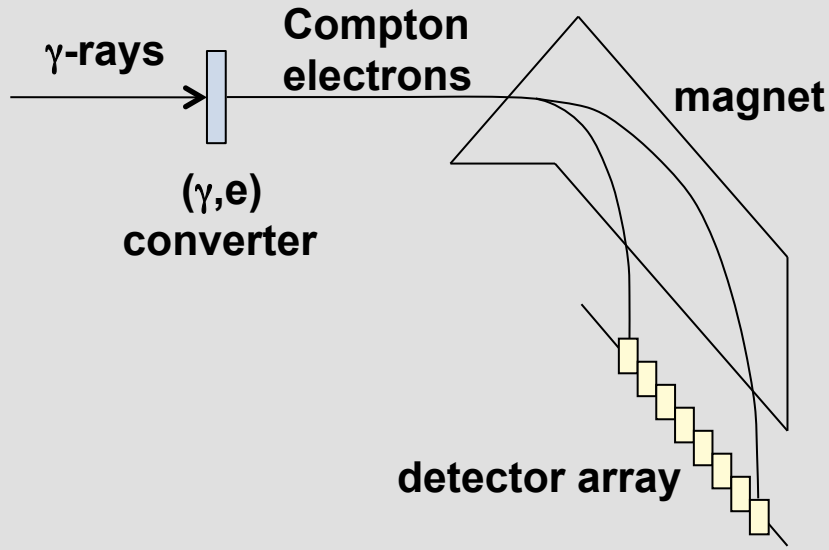
An energy-resolving Gamma Compton Spectrometer (GCS) : LANL, LLNL, GA & NSTec

Calculated DT Gamma-Ray Spectrum



- Spectral uncertainties call for energy resolution
  - GRH is only energy thresholding, not resolving
- Spectral lines may provide:
  - DT yield from 16.75 MeV fusion line
  - Fuel rhoR from D(n,γ) 15.58 MeV line
  - Ablator rhoR from 12C(n,n'γ) 4.44 MeV line
  - Additional nuclear physics outside of NIC campaign

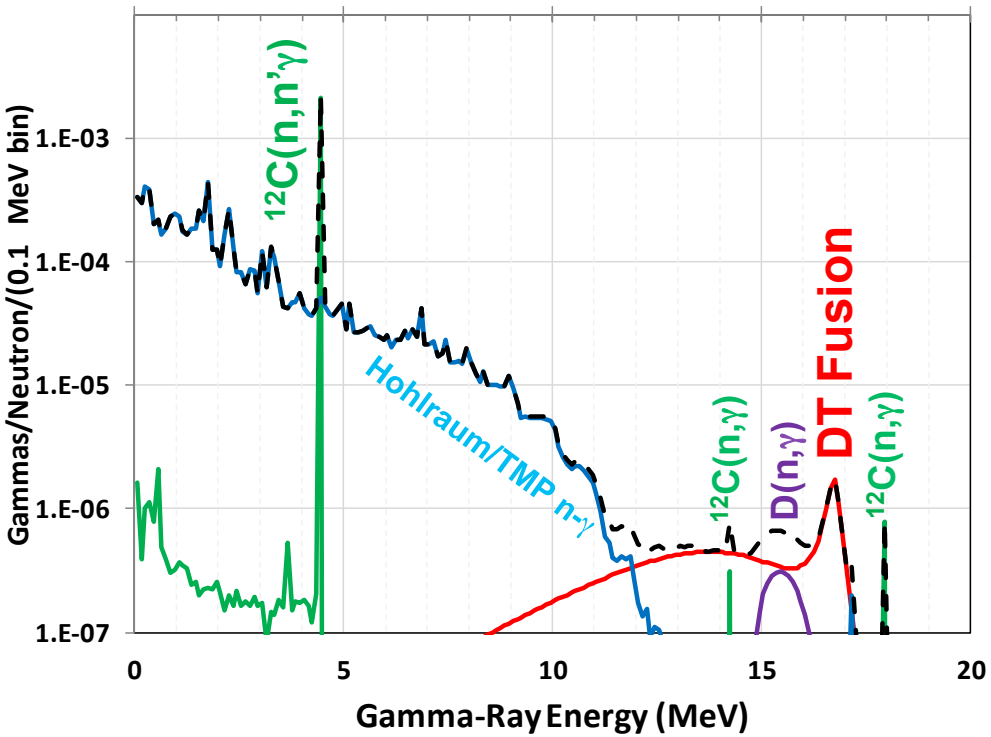
Gamma Compton Spectrometer

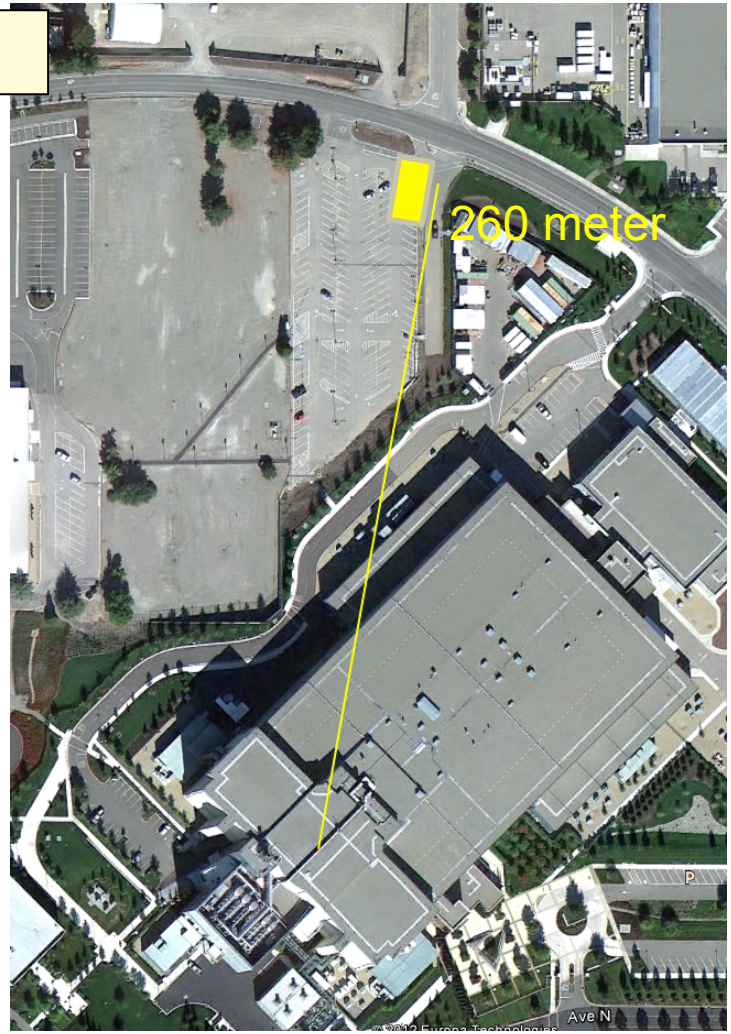


- Requirements
  - Yield >1e16 DTn
  - Energy Resolution ≤ 0.5 MeV
  - <1ns temporal response
  - Tunable energy range (1-20 MeV)

Gamma ray spectroscopy, single hit pixelated detector, conceptualized as a multi-purpose new 260 m detector station

Calculated DT Gamma-Ray Spectrum

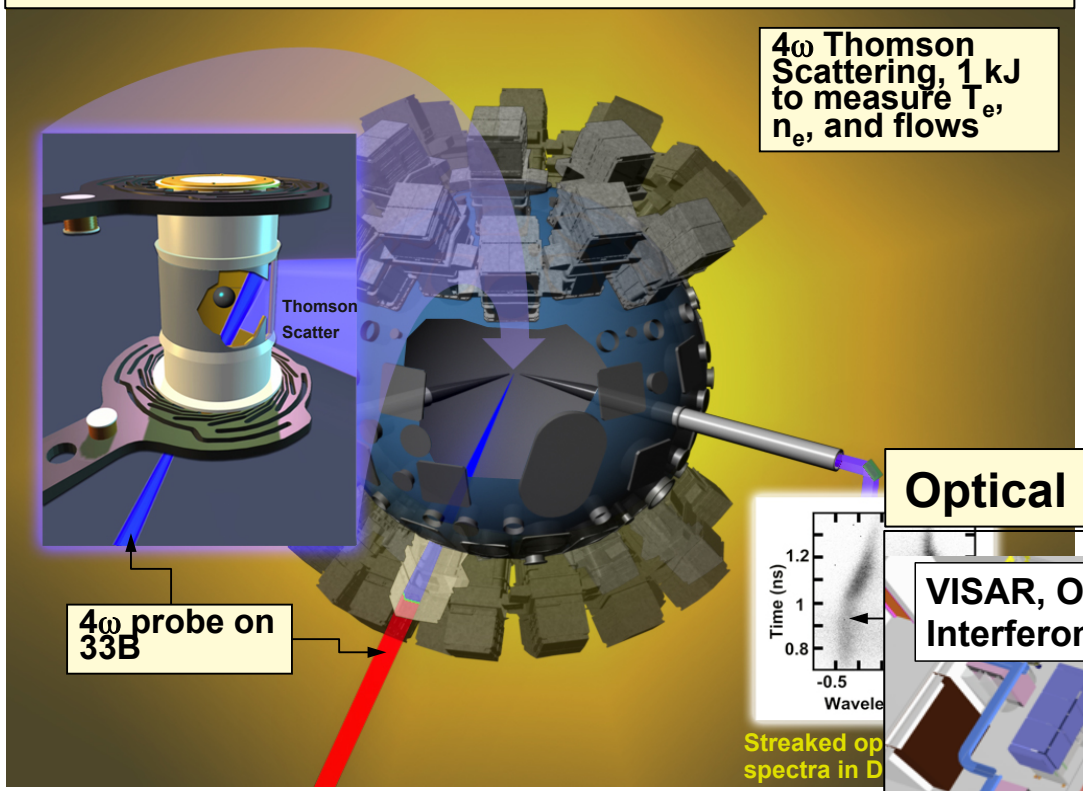




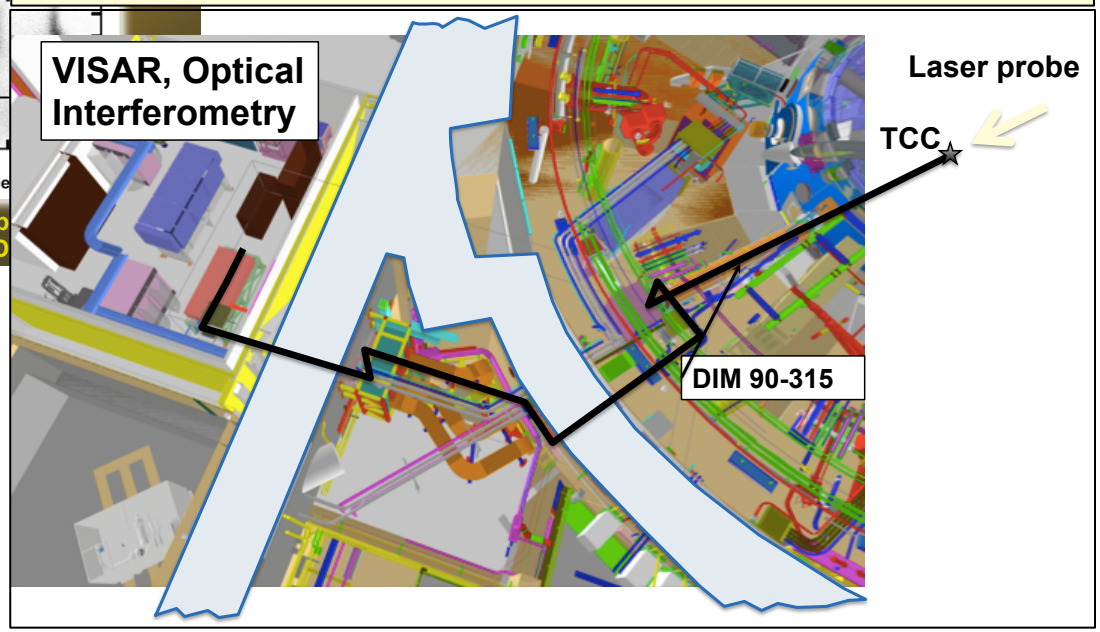
New detector station will be multi-purpose and will require a broad user community support

New optical diagnostics will be foundational for NIF

Thomson scattering used for all missions



Optical probe for interferometry, Faraday



Should we use a soft X-ray laser?

Foundational Diagnostics focus groups- reporting out in May

- X-ray : Bradley, Bell, Pivovaroff
- Gamma: Herrmann, Stoeffl, Yon Ho Ki, Zacharias
- Optical : Bower, Park, Ross
- Neutron: Bernstein, Frenje

Capability gaps-from Sarrao

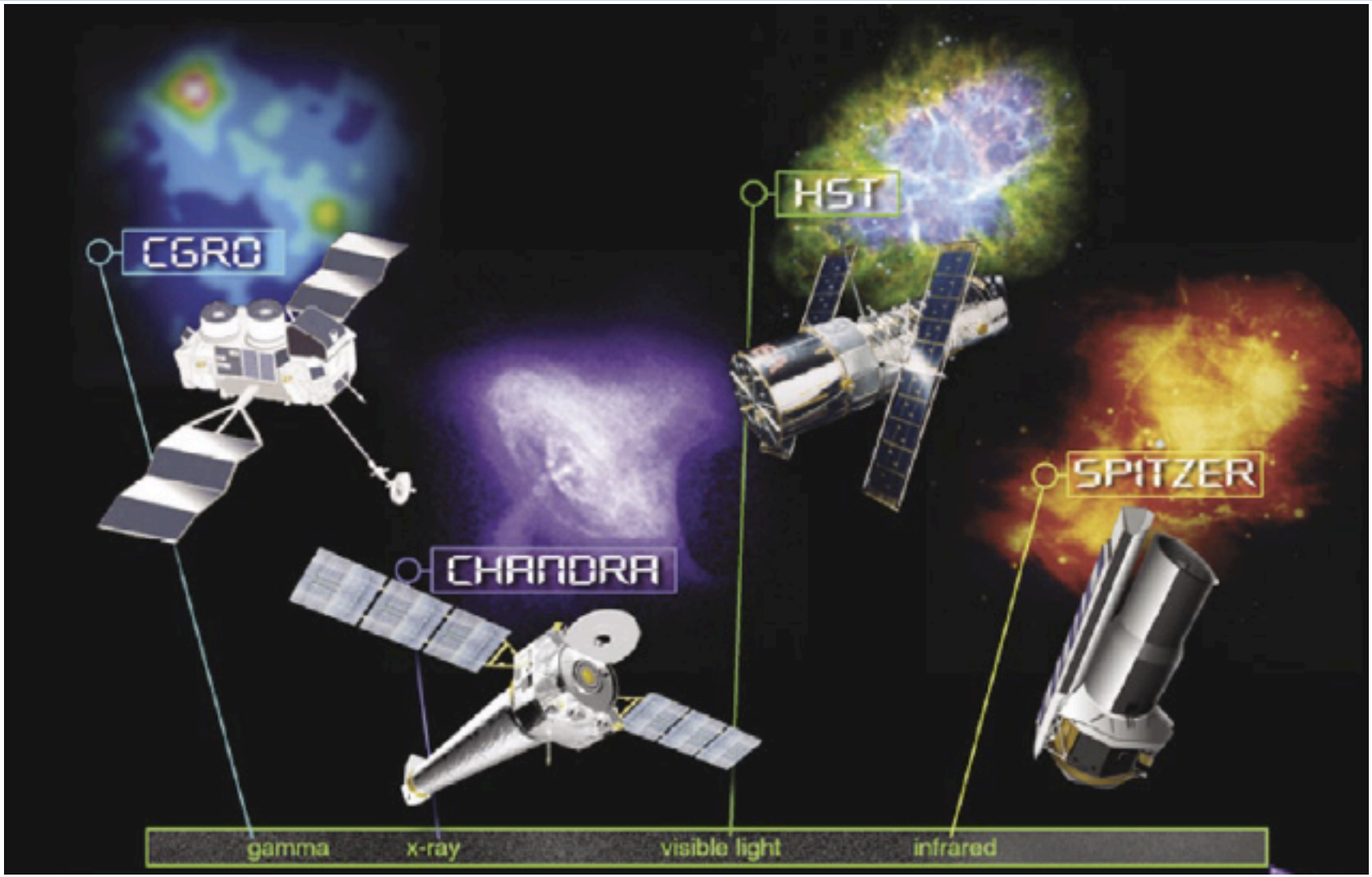
Lab-Astro Panel

- **Facility capabilities**
  - Beam delays up to 10 μs
  - Far off axis (10 cm) laser pointing
  - Induction coils
- **X-ray diagnostics**
  - Large FOV (~cm), ~ μm resolution gated imaging
  - Large aperture, high res spectral x-ray imager
  - Versatile x-ray scattering
  - Diverse x-ray spectroscopy
- "**Optical" diagnostics**
  - Optical interferometry
  - Faraday rotation
  - UV Thomson scattering

Nuclear Physics Panel

- High resolution charged-particle, neutron and gamma spectrometry techniques at low energies
- Capsule designs tailored to mimic thermonuclear reaction plasma environments in stellar and big bang nucleosynthesis
- Capsule designs tailored to mimic neutron spectra in Asymptotic Giant Branch and massive stars that drive s process nucleosynthesis
- Capabilities to load radioactive elements in capsules
- Radiochemical diagnostic capabilities (debris collection) and in-situ counting

Shuttle(& δ) enabled NASA's Great Observatories covering the spectrum from γ's to the infrared and opened our eyes on the Universe



NIF and a new generation of diagnostics will allow us to explore the physics of the Universe in the Laboratory

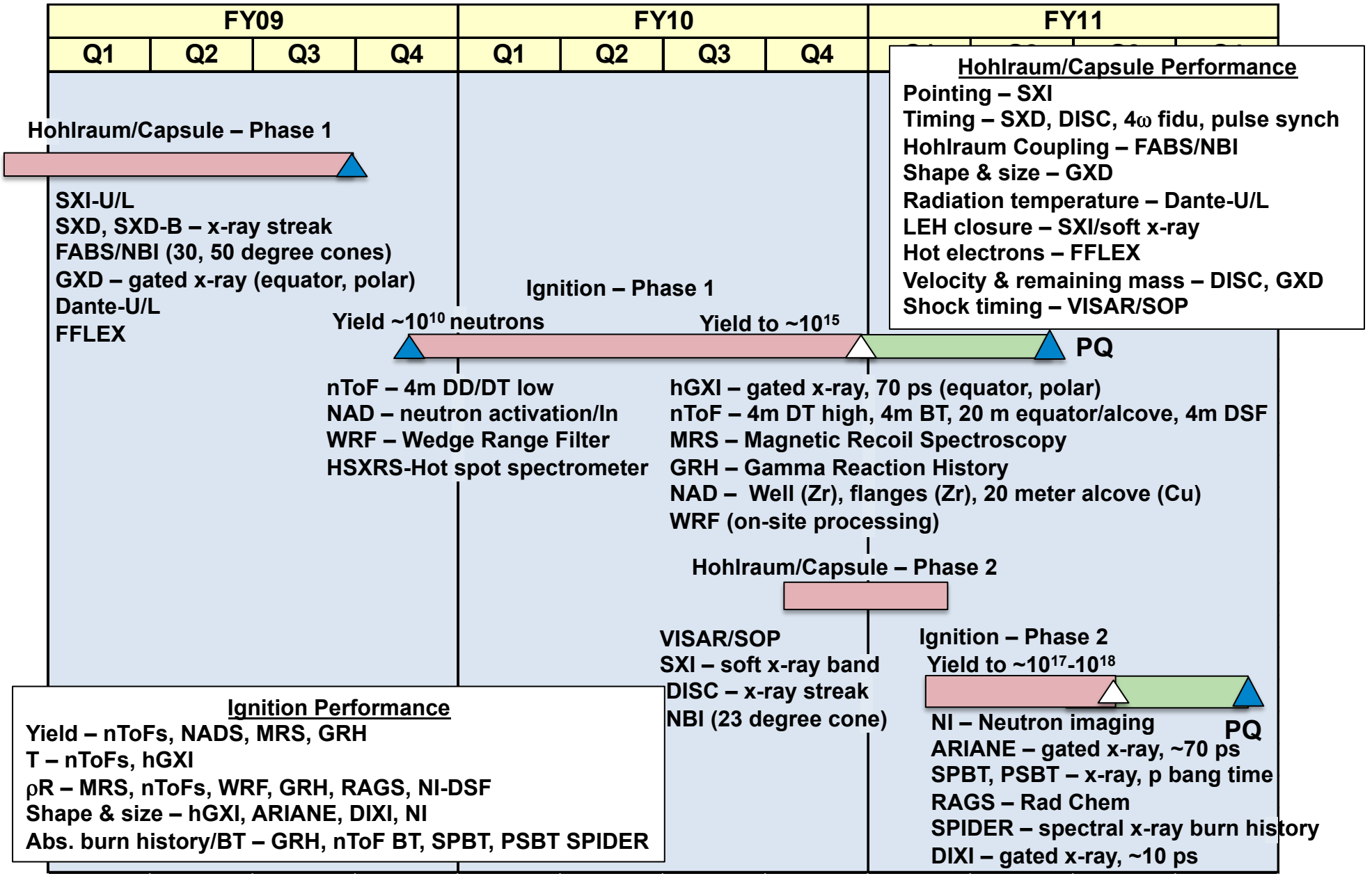

NIF

Implementing diagnostics on the NIF engages the user community, but needs major effort by LLNL

- About 50 diagnostics systems have been implemented over the last 5 years. Proposed by community. Scope driven by ICF and SSP programs, reviewed by community

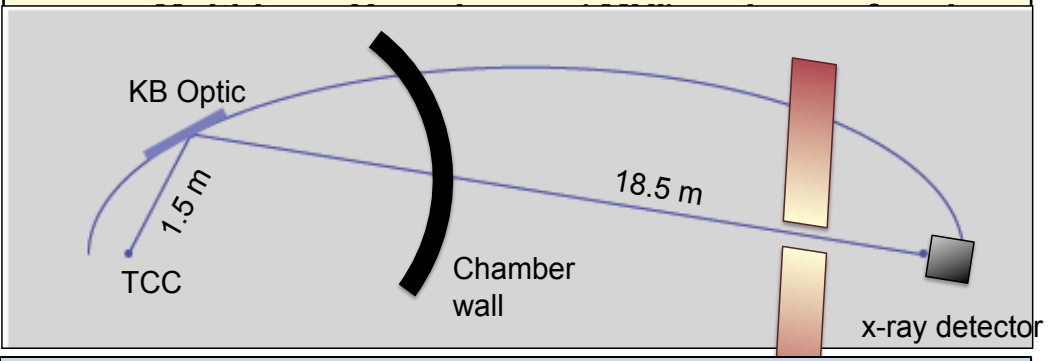
- Diagnostics on NIF require major resource efforts: user requirements, design, facility interfacing, IQ, OQ, PQ, operations, data analysis
  - There are no simple diagnostics on NIF: IBR review CDR, FDR, IQ, OQ , PQ, WAP processes, data archiving and analysis

NIF target diagnostic implementation: Phase I and II up to 2012



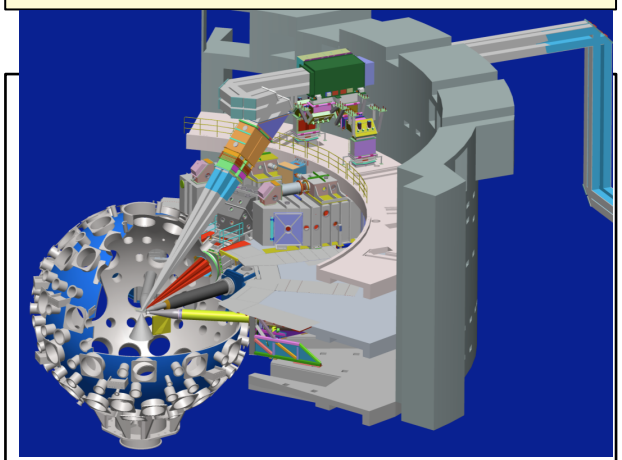
Foundational diagnostics will be enabling for NIF in the second decade

Multi-layer X-ray Imager(MXI) and x-ray framing camera

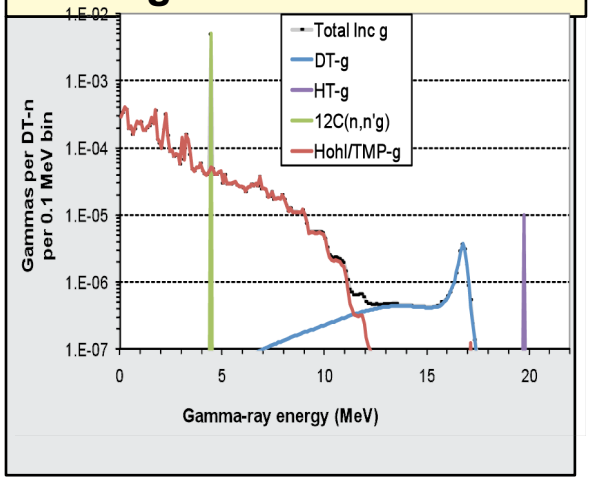


DIXI technology allows gating camera

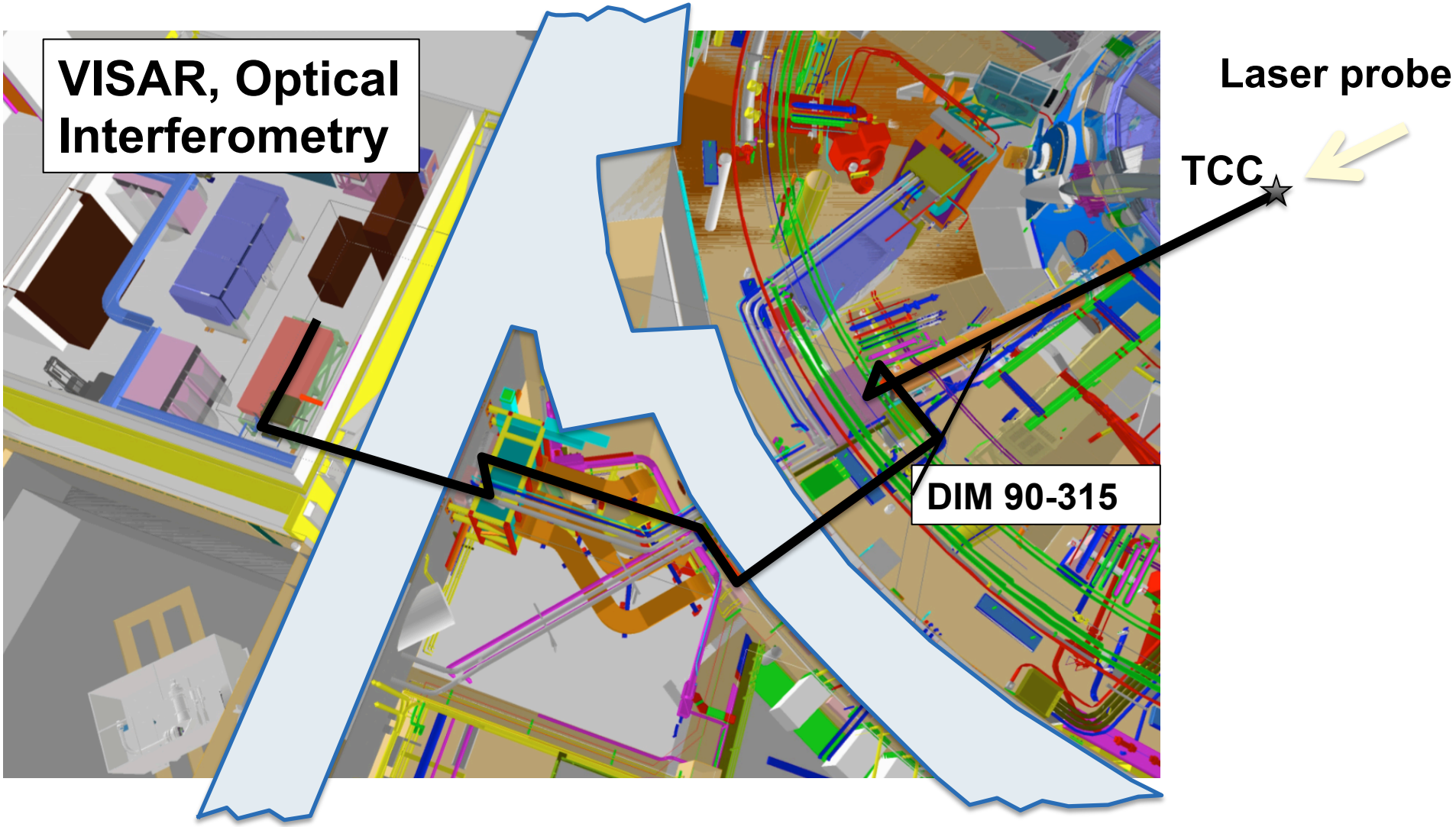
ARC



Gamma ray spectroscopy: furlong detector station

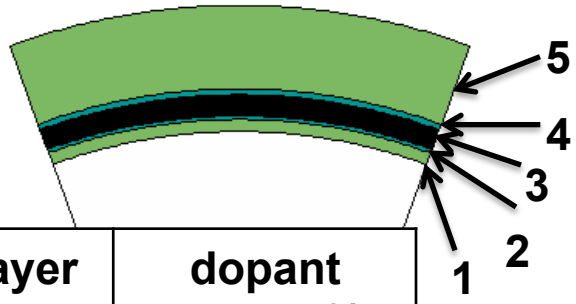


Moving VISAR outside of the Target Bay enables Optical Interferometry in the VISAR lab

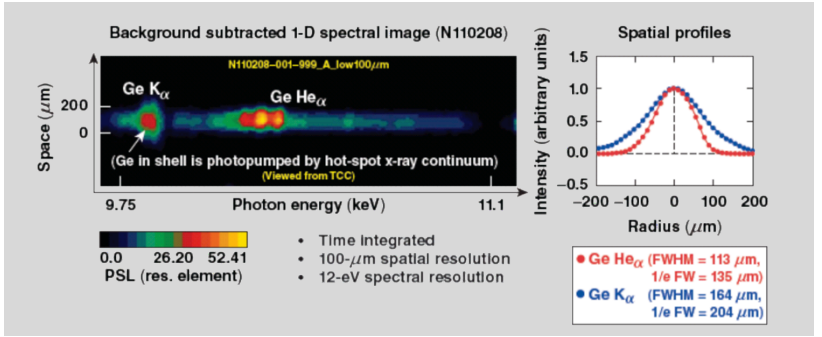


LLE: Special capsules and spectrometer have been designed to trace origin of ablator mix in the hot spot

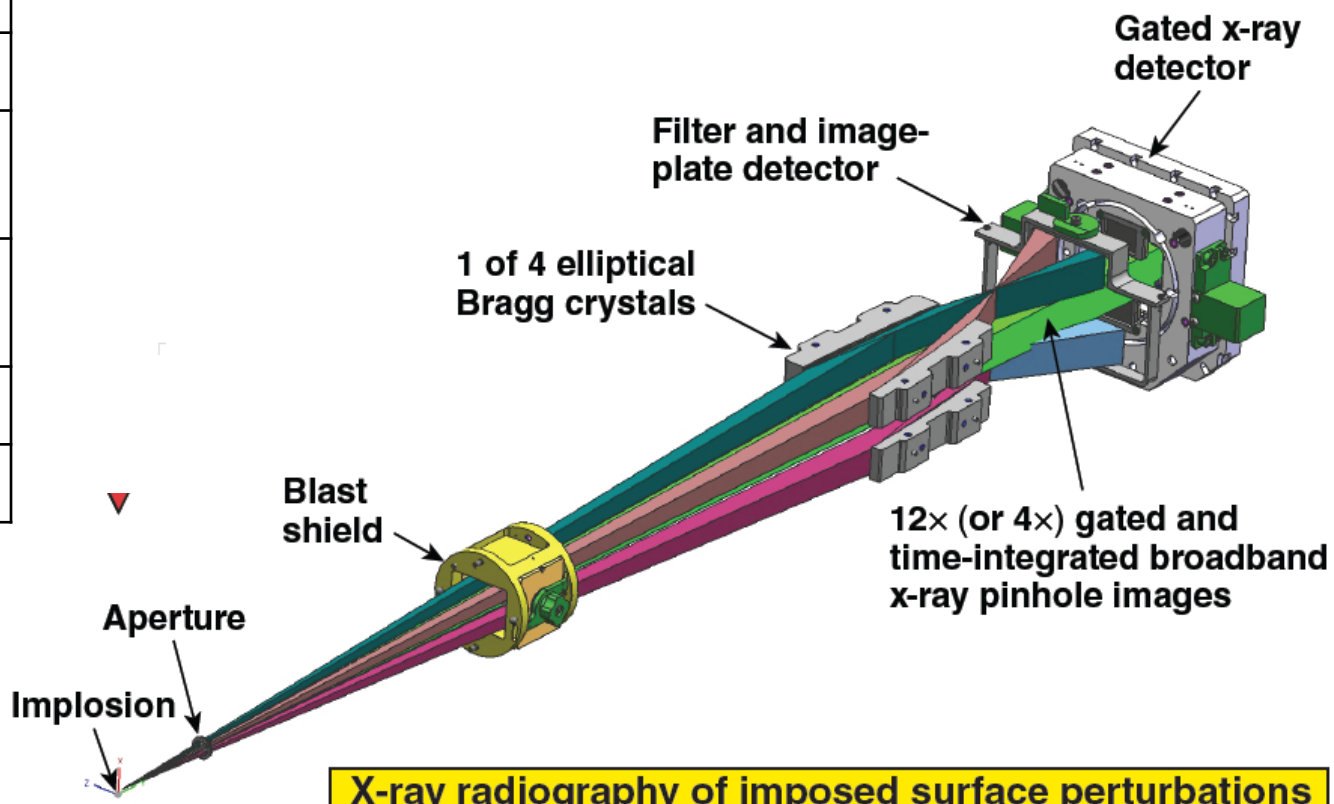
Cu, Ge, Si doped CH ablator



layer	dopant (atomic %)
1	Cu(0.1%)
2	Si(0.7%) Ge(0.15%)
3	Si(1.7%) Ge(0.15%)
4	Si(1%)
5	none

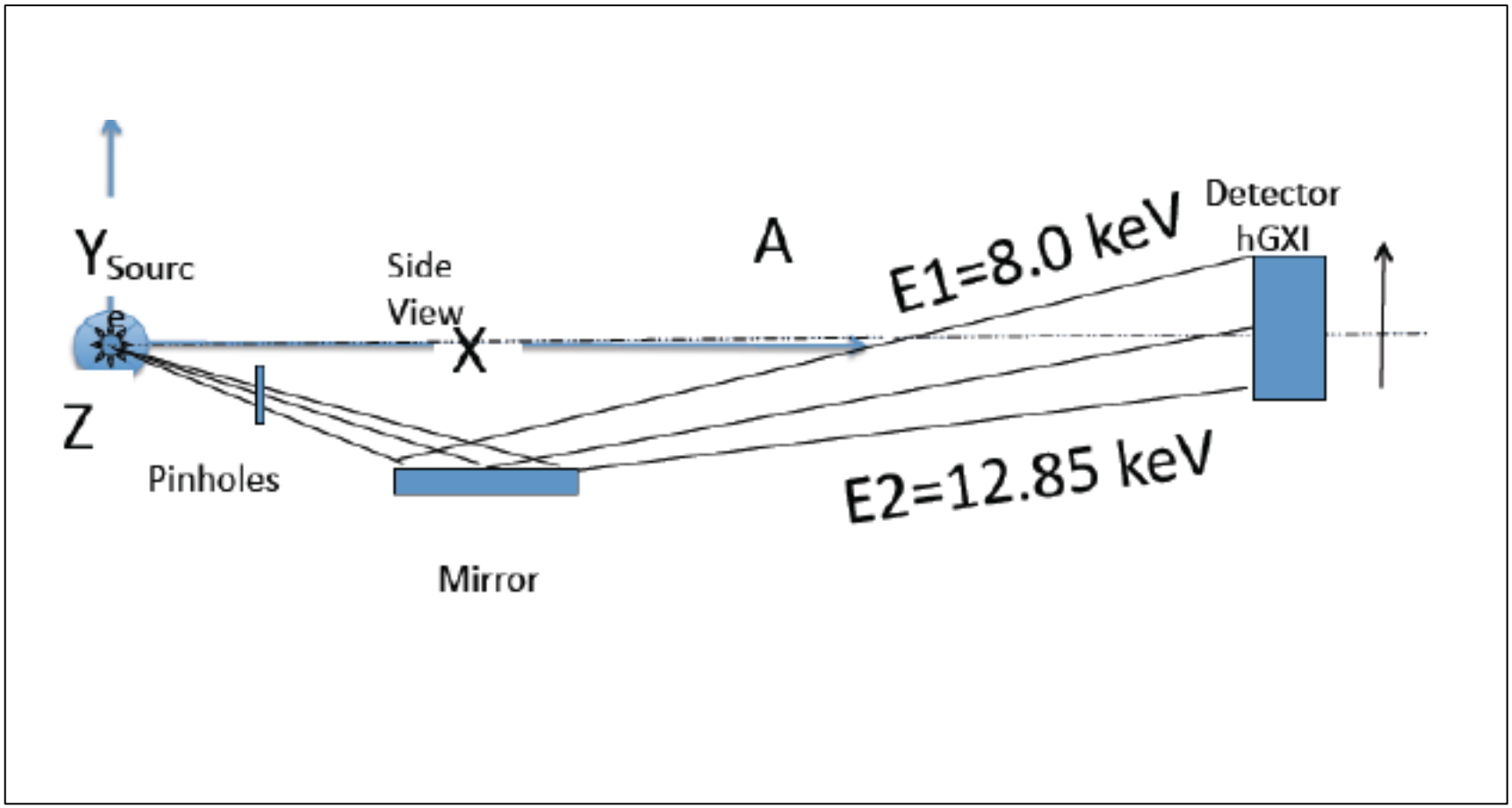


Supersnout II (5.75 to 16.5 keV)



X-ray radiography of imposed surface perturbations will be studied in future experimental campaigns.

Multiple Monochromatic imager



Phase III diagnostic planning

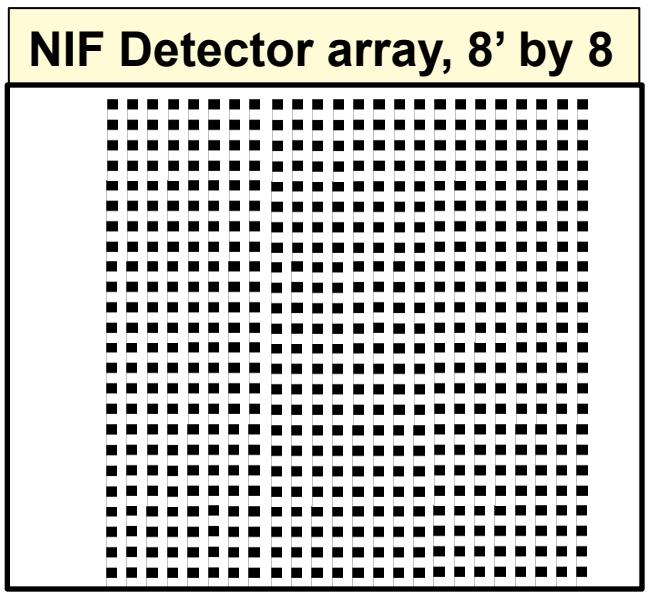
- In April 2012 another diagnostic workshop will evaluate the pre-conceptual designs of the ~20 proposed diagnostics
- The diagnostic management group will work ICF Execs to recommend a second decade diagnostic plan

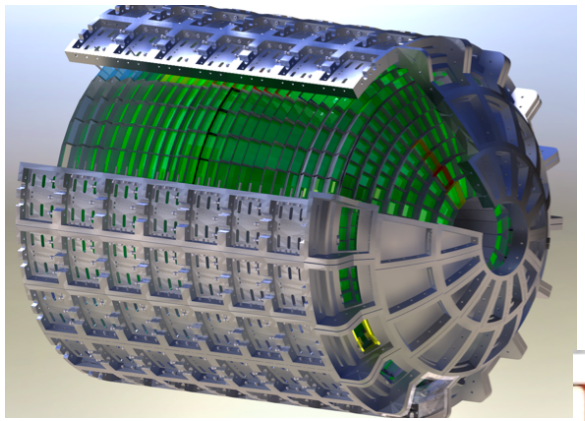
Some of the foundational detectors will be costly and hard to accommodate in 10.3

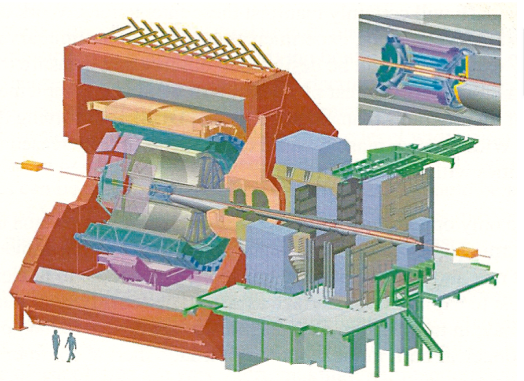
Higher spectral resolution requires many single hit fast detectors about 200 m away

The gamma detectors have to be very fast, to prevent pilup when the NIF neutrons hit the chamber wall.

Some fast scintillators are:
LaBr3 "Brilliance" detectors. The Best…. But VERY expensive.
Need to build factory, share with GSI / FAIR plans







Dedicated heavy-ion detector built by the ALICE collaboration to exploit the unique physics potential of nucleus-nucleus interactions at Large Hadron Collider energies.

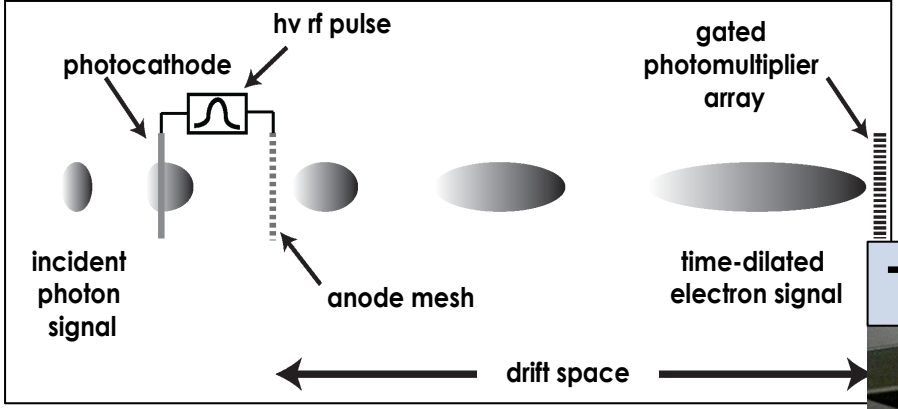
Moving onto Phase III of NIF Diagnostics

- Phase I and II ~fifty diagnostics mostly finished- selected in response to user programs through 2012

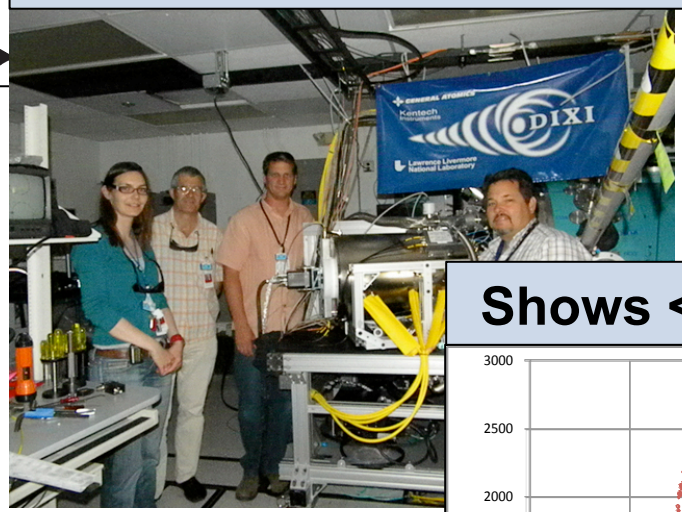
- Phase III Diagnostics for >2012 - mission responsive, foundational-high impact, and user community building

Time dilation x-ray imaging show < 10 ps resolution on LLNL's COMET laser. Shows the way to build an x-ray framing camera

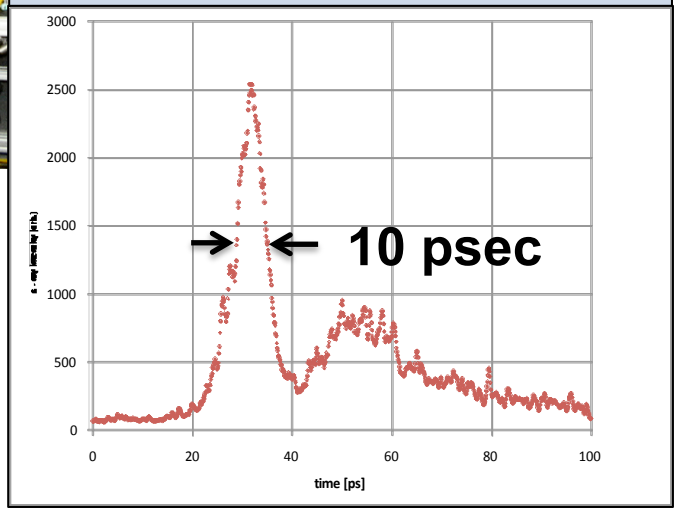
The time dilation tube magnifies time by drifting pho-electron image



Tested on COMET laser



Shows < 10 psec gating



Phase I and II Hohlraum/capsule diagnostics

Phase I Phase 2

Diagnostic	Acronym	Purpose and Function	Works
Static x-ray imager	SXI(upper) SXI (lower)	Provides time integrated images of low energy (3-7 keV) x-ray emission and is used to survey hohlraum experiments and pointing of laser beams	2009
Streaked X-ray Detectors	SXD1 SXD2	Measures with continuous time resolution x-ray emission from the targets and used to synchronize the arrival time of laser beams on targets	2009 2009
Broad-band, time-resolved x-ray spectrometer	DANTE 1 DANTE 2	Measures the soft x-ray flux vs time and primarily used to determine the radiation temperature in the hohlraum	2009
Full Aperture Backscatter Station	FABS 31B-in FABS 36B-out	Light backscattering stations that measure the angular, temporal and spectrally resolved light backscattered into the focus lenses. One quad of beams on the inner cone 31B and one quad. on the outer cone 36B	2009
Near Backscatter Imager	NBI 31B-in NBI 36B-out	Light backscattering stations that measure the angular,temporal andspectrally resolved light backscattered near the focus lenses. One quad of beams on the inner cone 31B and one quad on the outer cone 36B	2009
Filter Fluorescer Diagnostic	FFLEX	Measures hard x-rays bands (10 keV to 400 keV) with time resolution on some channels from which the hot electron fraction can be inferred	2009
Time-Gated X-ray Detectors	GXD1 GXD2	Images x-rays with time resolution of > 70 psec and detector spatial resolution of 60 micron	2009
Velocity Interferometer For Any Reflector	VISAR	Measures the shock velocities, specifically the timing of the first three shocks in the NIC ignition pulse	2010
VISAR/Streaked Optical Pyrometer	VISAR/SOP	Measures the timing of the 4th shock in the NIC ignition pulse	2010
DIM insertable Streak camera	DISC 3 of	Hardened x-ray streak cmaera with u.v. fiducials	2010
4ω fiducial	4ω Fidu	4 w fiducial for x-ray streak cameras	2010
Near backscatter imager	NBI23	Backscatter on 23 degree beam	2011

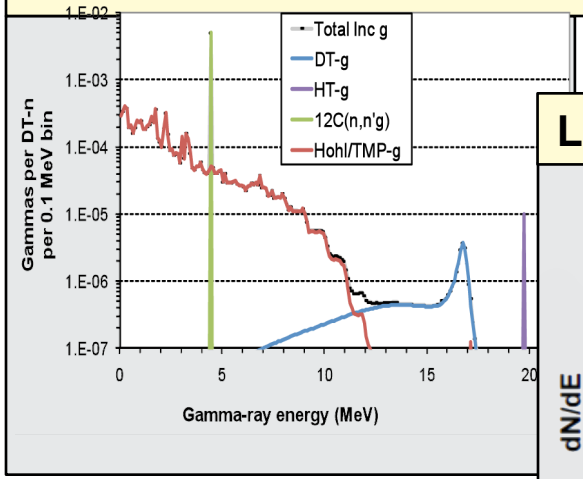
Phase I and II ignition diagnostics (17 + 6)

Phase I Phase 2

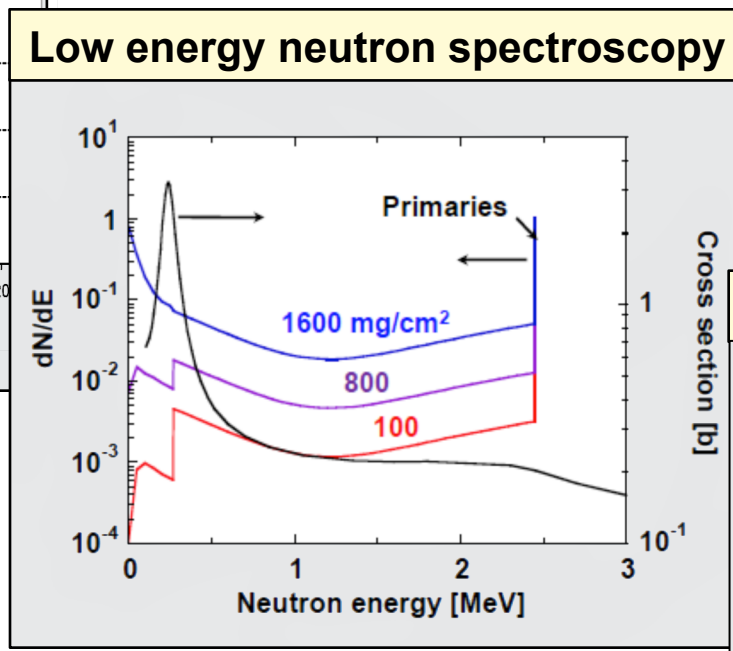
Diagnostic	Acronym	Purpose and Function	peration
Wedge Range Filter	WRF	Measures the energy of charged particle products (protons)	2009
Gamma Reaction History	GRH	Measures γ spectrum and time history. Used for bang time, burn history, yield	2010
Gated x-ray Imager to 10^{15}	hGXI	Measures spatially and temporally resolved x-ray emission from an implosion core containing THD fuel to determine core temperature and shape	2010
Hot spot x-ray Spectrometer	HSXRS	Measures x-ray emission from ablator dopants mixing into the hot core.	2009
X-ray Pinhole Camera	xPHC	Measures static x-ray images of implosions	2010
Neutron Time-Of-Flight	NTOF4.5- 4of	Four NTOFs located 4.5 m from TCC used to measure neutron yield, ion temperature, neutron bang time, γ history	2009
Neutron Time-Of-Flight	NTOF20- 4 of	Four NTOFs located 20 m from TCC used to measure neutron yield, ion temperature, and areal density (ρr).	2010
Magnetic Recoil Spectometer	MRS	Measures the absolute neutron spectrum between 6 and 30 MeV from which ion temperature, areal density (ρr), and neutron yield can be directly inferred	2010
Neutron Activation Detector	NAD 4 of	Absolute yield measurement by activation (In, Zr, Cu)	2010
Neutron Time-Of-Flight	NTOF3.8	NTOFs located 3.8 m from TCC used to measure neutron yield, ion temperature, neutron bang time, γ history	2011
Neutron Imaging	NI	Measures neutron images of primary (14 MeV) and downscattered neutrons to assess hot spot size and fuel asymmetry and the cold fuel areal density (ρr_{shell}).	2011
South Pole Bang Time	SPBT	Measures time history of x-ray emission of capsule through lower LEH	2011
X-ray imager for Y < 10^{17}	ARIANE	30 psec x-ray images for Y< 10^{17}	2011
Radiochemical Diagnostic	RAGS	Uses radiochemical separations and nuclear counting methods to measure neutron activation products produced from tracers embedded in the ablator shell of the target with gas sample collection	2011
X-ray burn history	SPIDER	Time and spectrally resolved x-ray emission through upper LEH	2011
Dilation x-ray imager	DIXI	10 psec x-ray imager	2011

High impact diagnostics will be enabling for new HED science on the NIF in the out-years

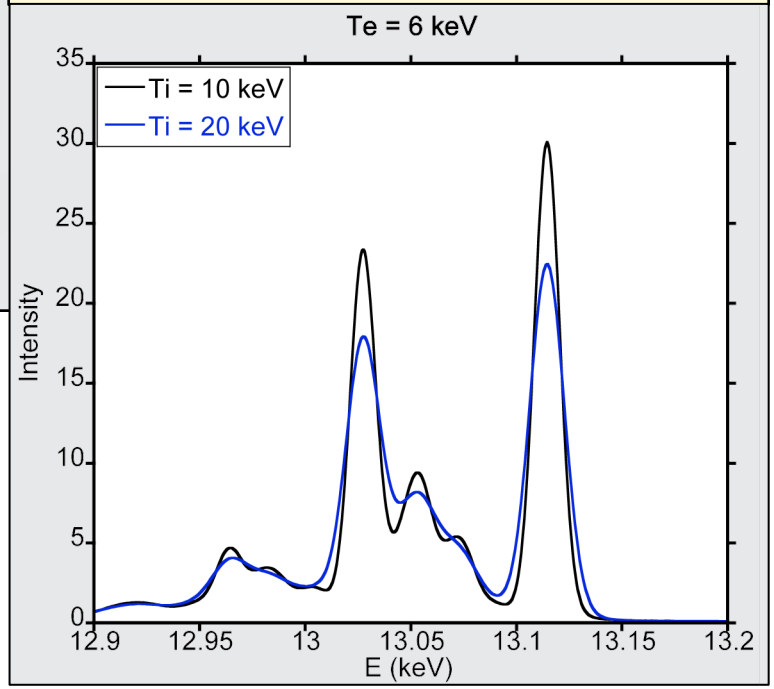
Gamma ray spectroscopy: 200 m detector station



Low energy neutron spectroscopy



High resolution x-ray spectroscopy



Diagnostic plans for the out-years currently being developed by and for the community