NIF Target Diagnostic Automated Analysis Recent Accomplishments – Turning Raw Data Into Performance Metrics

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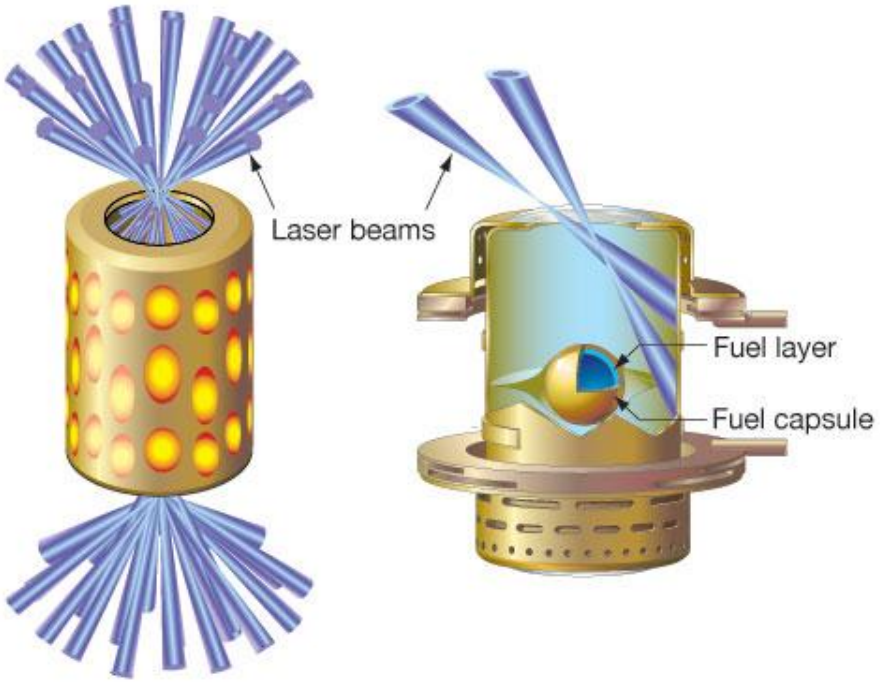
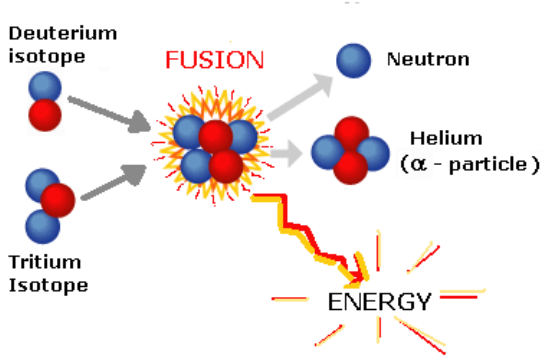
The National Ignition Facility is the world's largest laser-based inertial confinement fusion research platform

NIF is currently in the midst of the National Ignition Campaign where the goal is to achieve a sustained fusion reaction with high energy gain



- 192 laser beams heat gold hohlraum which re-emits the energy as X-rays
- Fuel capsule contains hydrogen isotopes deuterium and tritium inside an ablator shell
- X-rays heat capsule's ablator surface causing it to explode and creating a shock wave
- Target fuel layers are driven inwards and compressed into a small hot spot of extremely high density

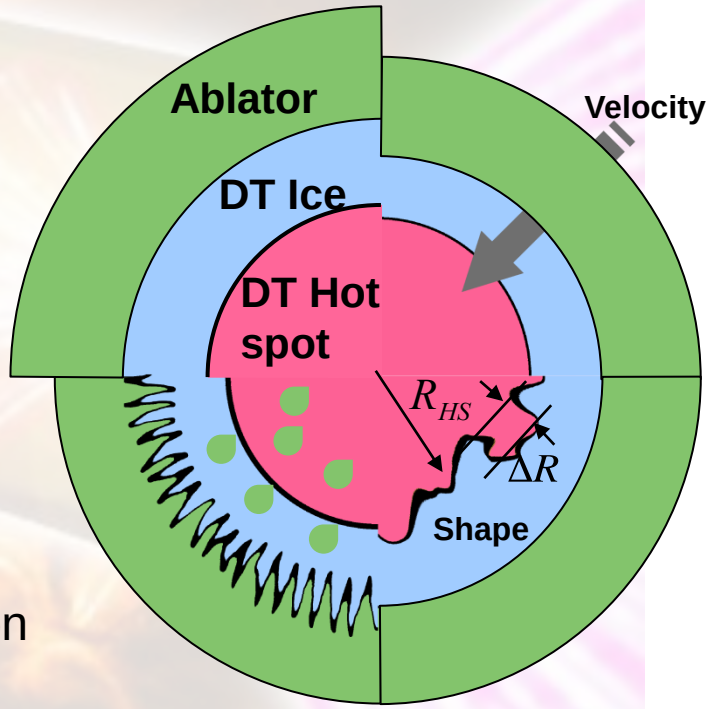
- When temperature and density of the hot spot are high enough, fusion reactions occur
- High energy particles such as neutrons, gamma rays and alpha particles are released



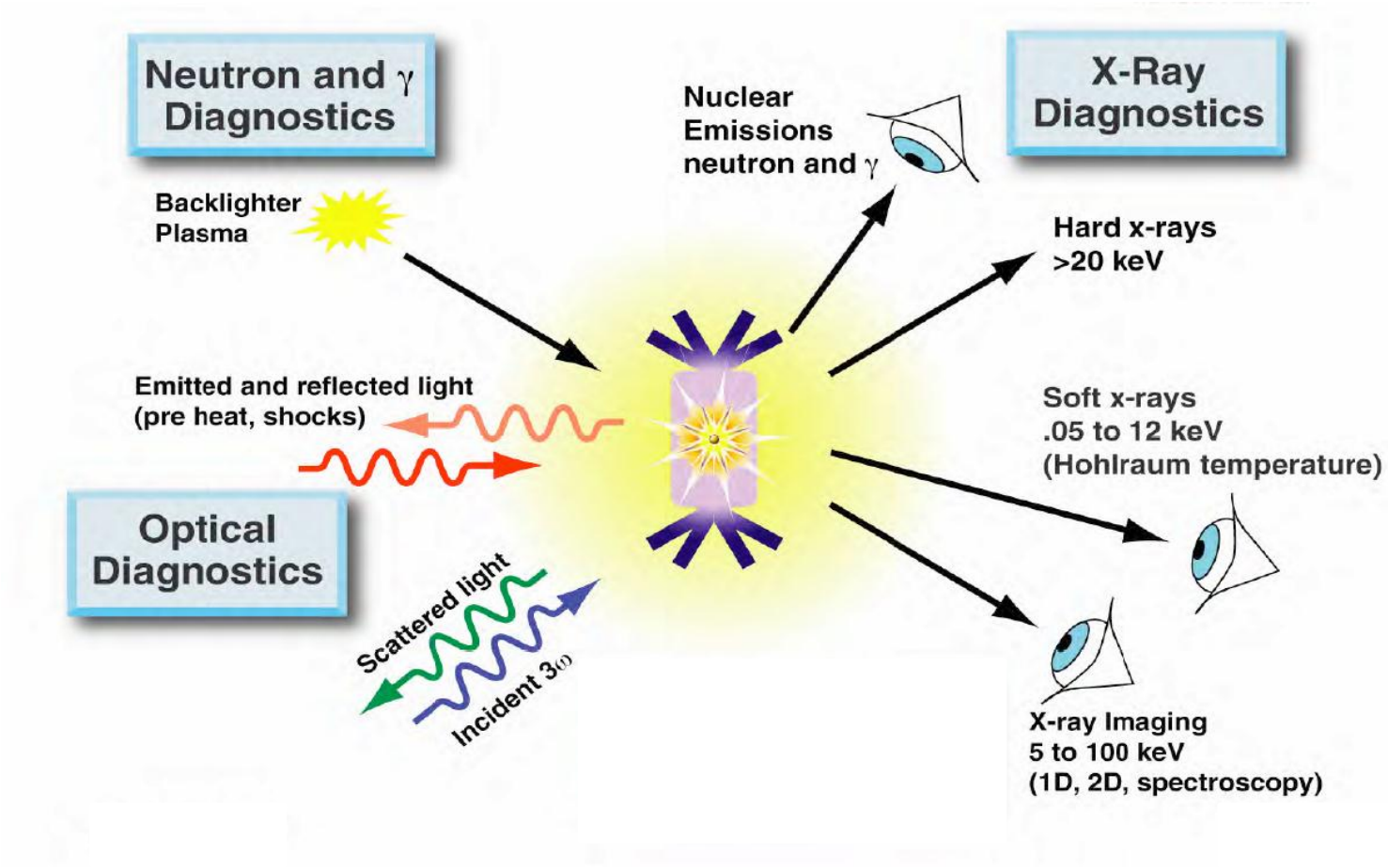
What key information about the target is needed to optimize NIF performance?

Key performance metrics

- **Temperature**:
  - Hot spot temperature
  - Hohlraum radiation temperature
- **Density** – areal density of hot spot
- **Yield** of fusion reaction– total production of neutrons or gammas
- **Velocity** – measure of capsule radius over time
- **Shape** – symmetry of the implosion
- **Timing**
  - Shock timing
  - Bang time – time of peak fusion reaction
- **Preheat** of the ablator



Specialized target diagnostics record optical, nuclear, and x-ray raw data that is used to estimate key performance metrics



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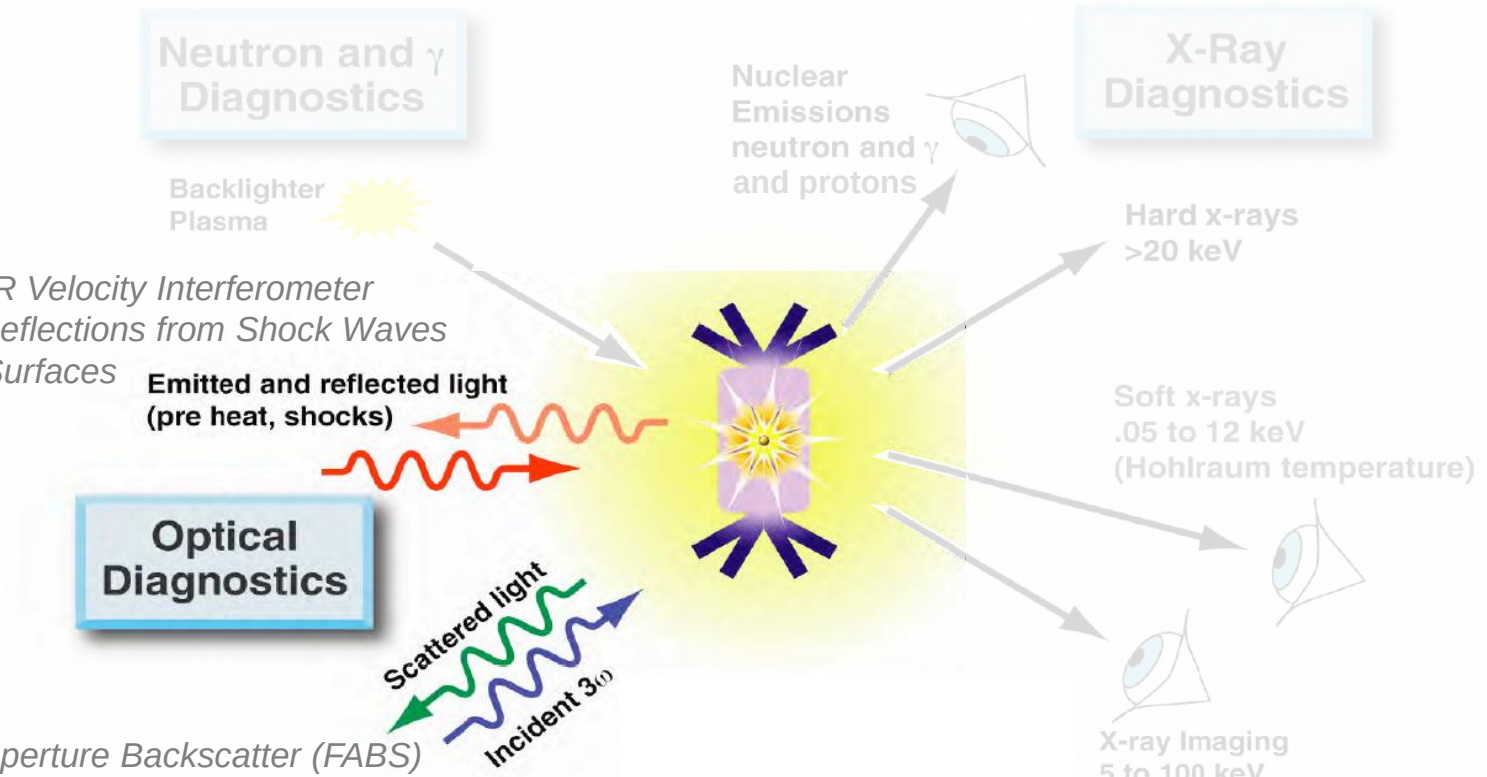

VISAR Velocity Interferometer For Reflections from Shock Waves and Surfaces

Full Aperture Backscatter (FABS) Near Backscatter Imager (NBI) For Energy Balance and Laser/Plasma Instabilities

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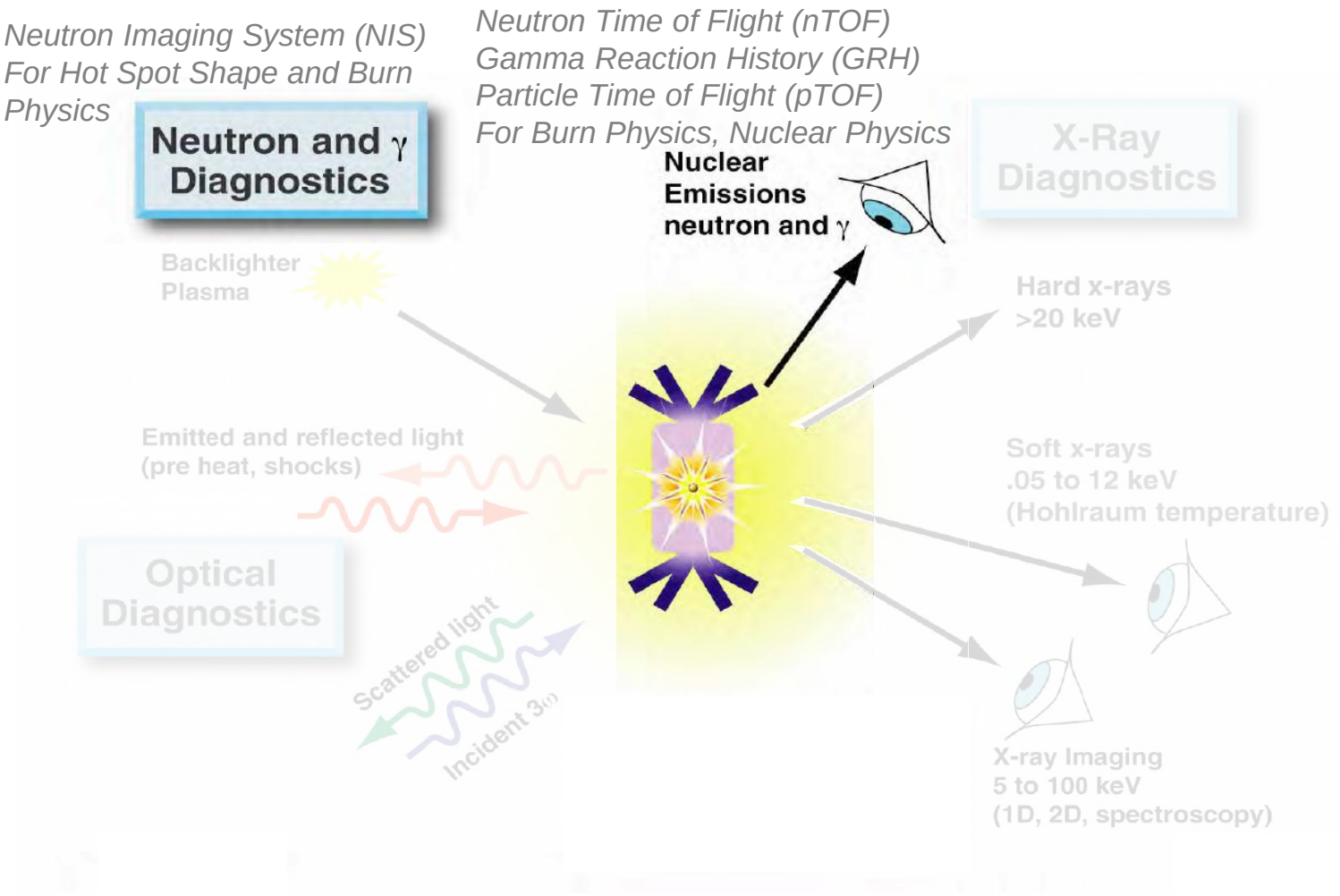

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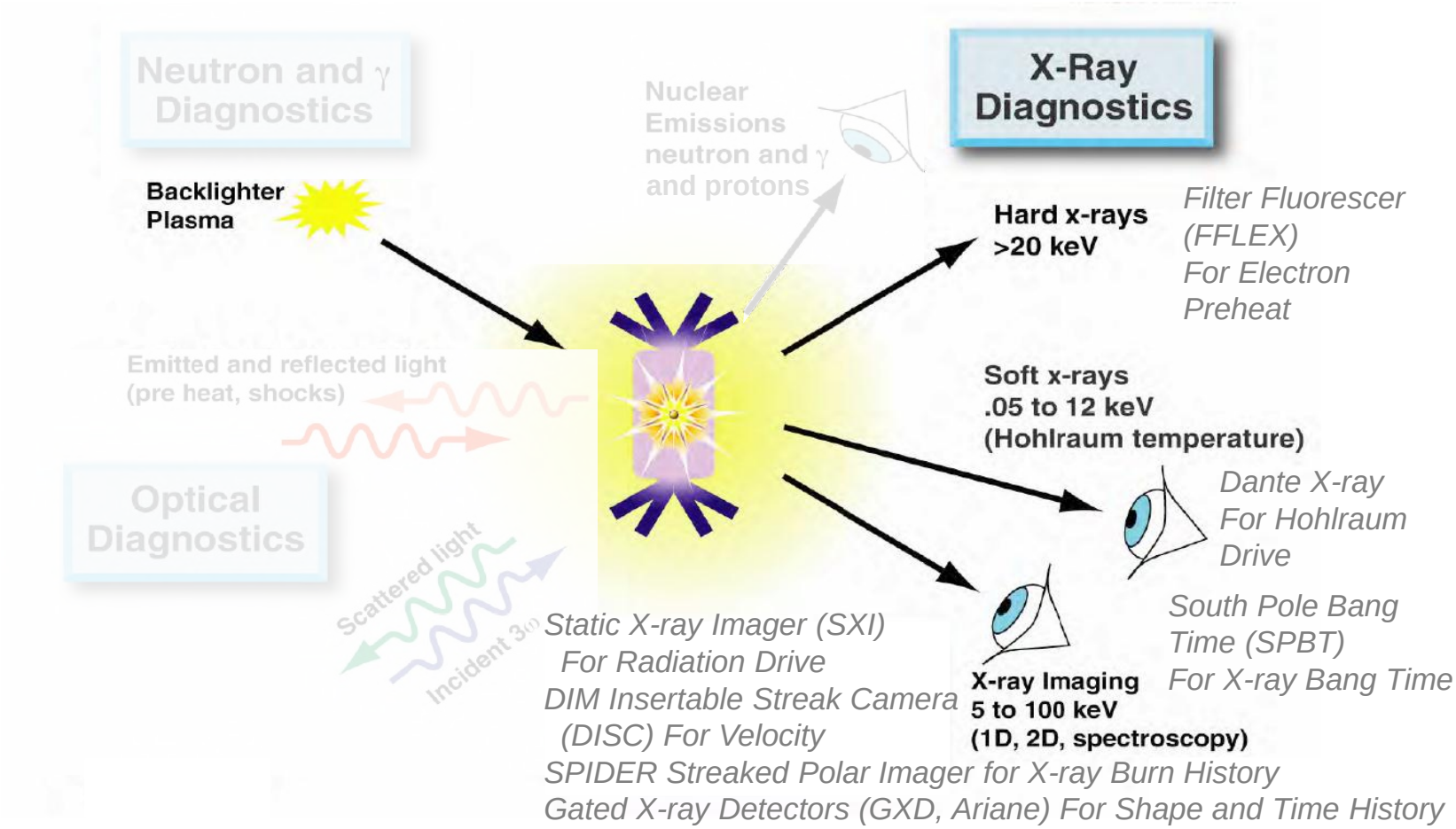
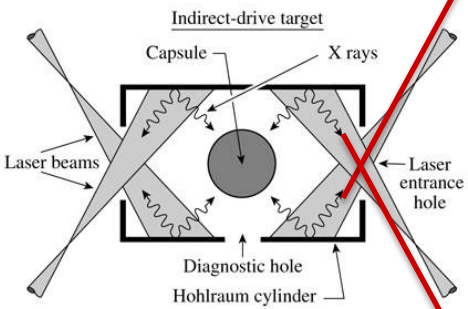


What Signal & Image Processing is needed to turn raw diagnostic data into the key performance metrics?



Performance Metric:
Radiation
Temperature History

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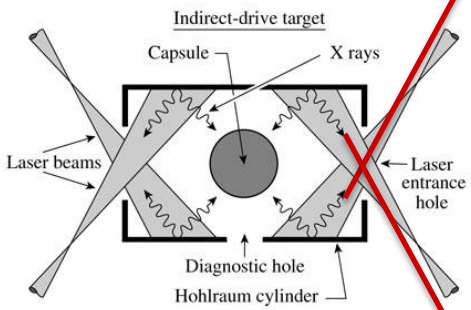

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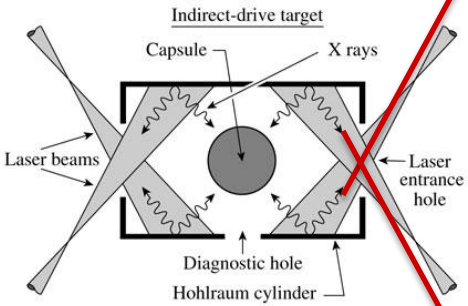
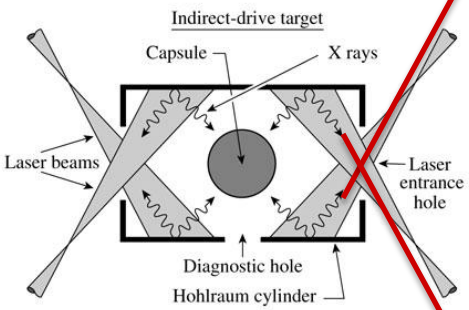
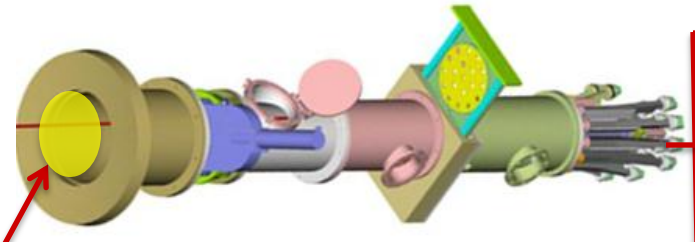
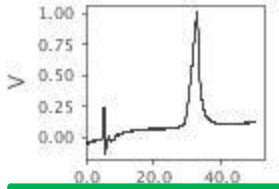


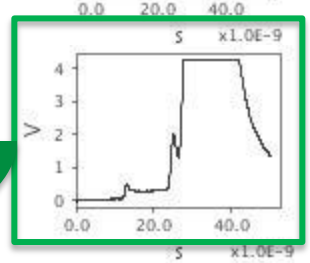
Diagnostic analysis usually involves a series of nonlinear & ill-posed inverse problems as well as timing analysis and unique processing.

What Signal & Image Processing is needed to turn raw diagnostic data into the key performance metrics?



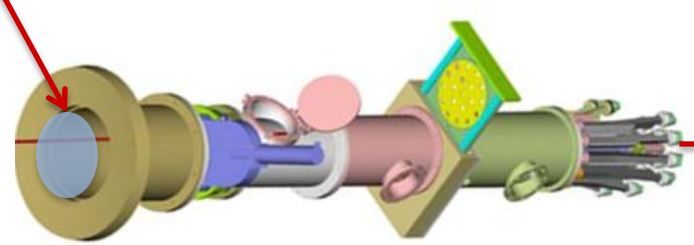


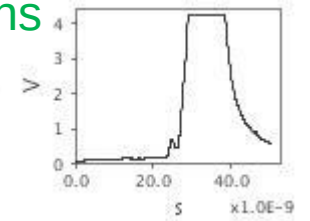


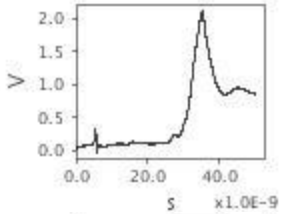


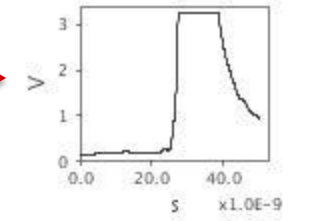
Correct for recording device distortions

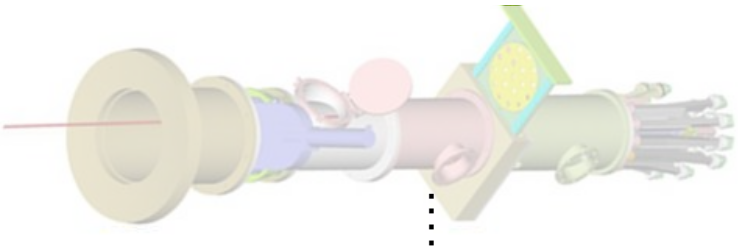
Examples: non-linear time base of oscilloscope, warping of CCD images











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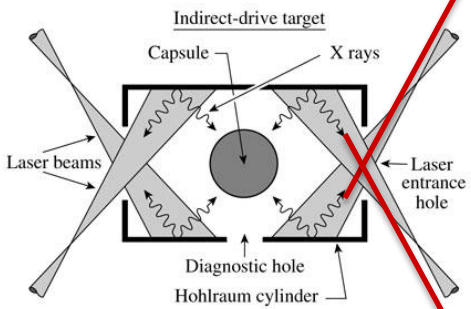
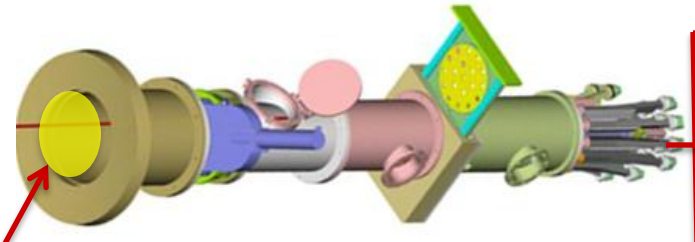
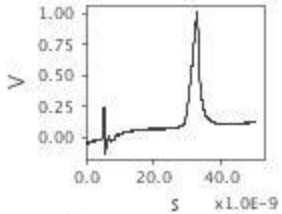
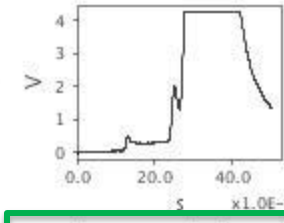


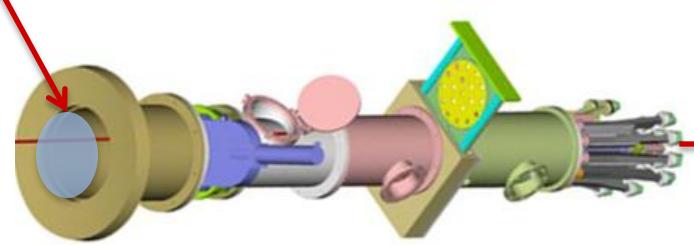


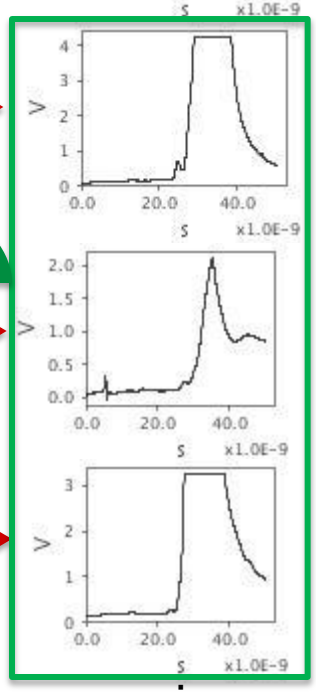


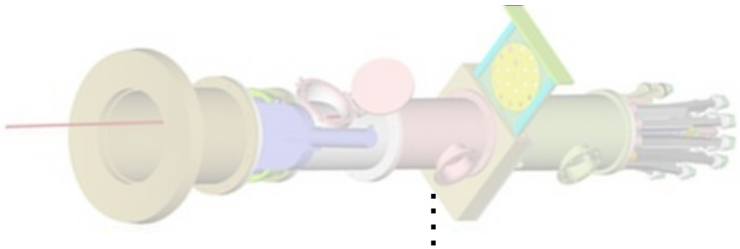


Combine partial datasets

Examples: stitching scope traces, overlaying images







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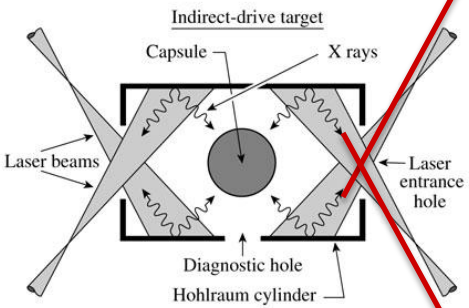
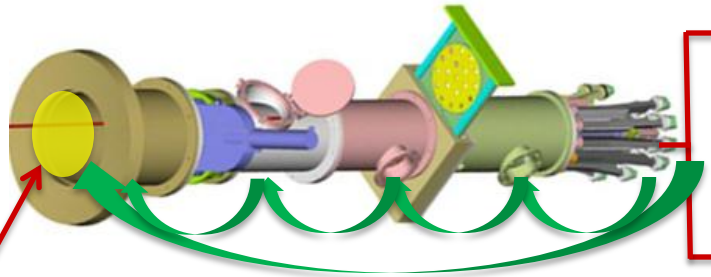
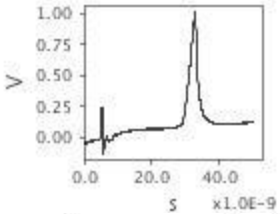
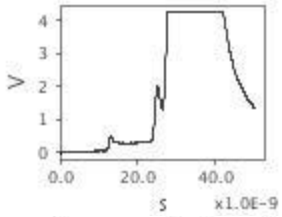


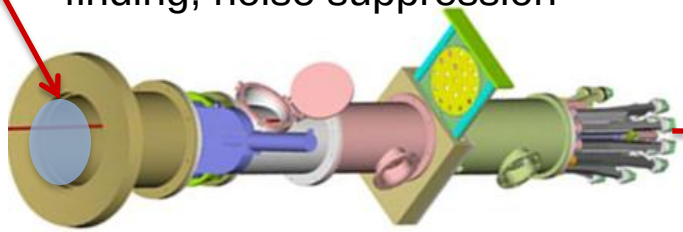


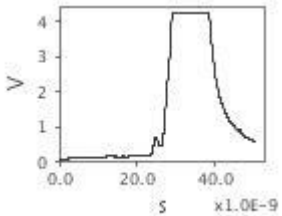


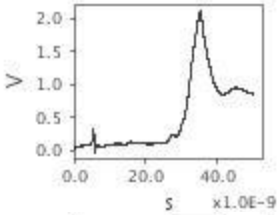


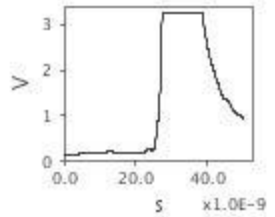
Remove system response of specialized diagnostic hardware

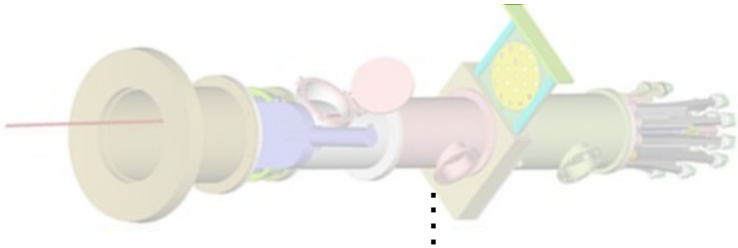
Examples: Compensate for subsystem responses using parametric minimization or deconvolution, linear gain compensation, peak finding, noise suppression











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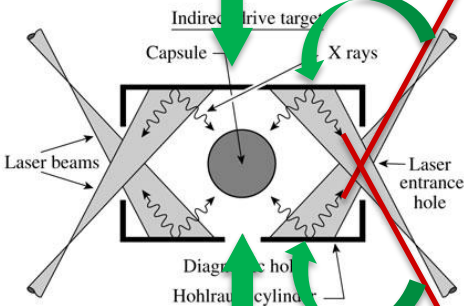
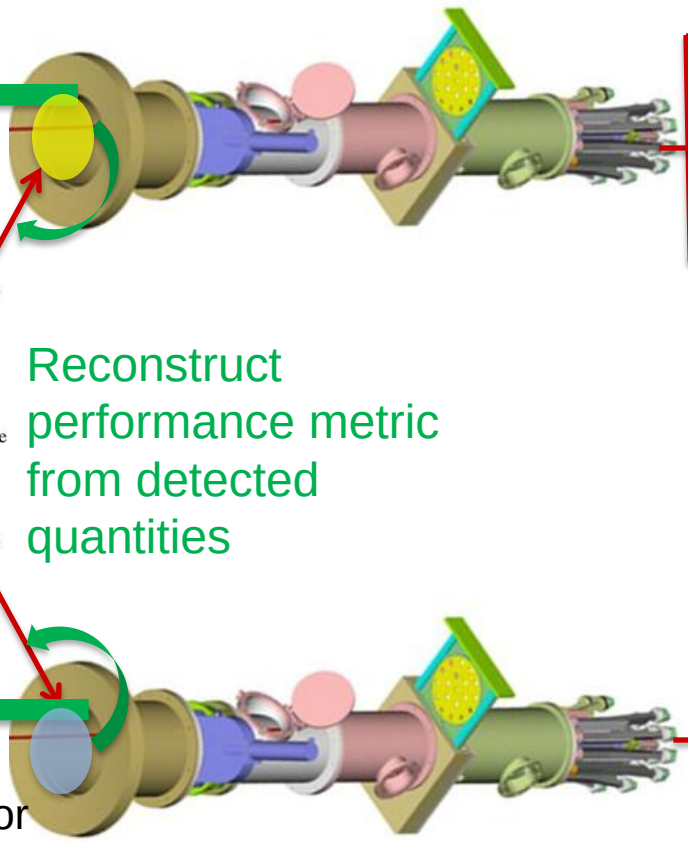
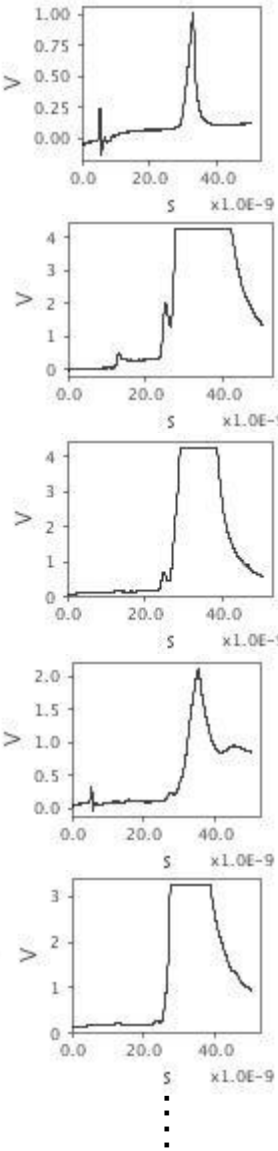


Reconstruct performance metric from detected quantities





Examples: linear or nonlinear optimization for spectrum reconstruction, yield integration, peak fitting for timing, image segmentation and reconstruction

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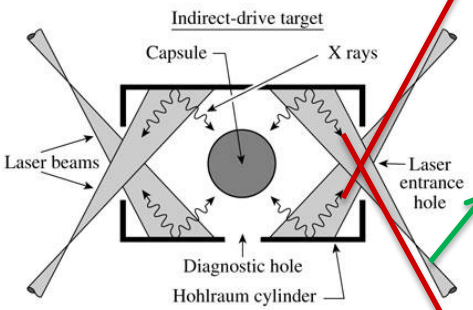
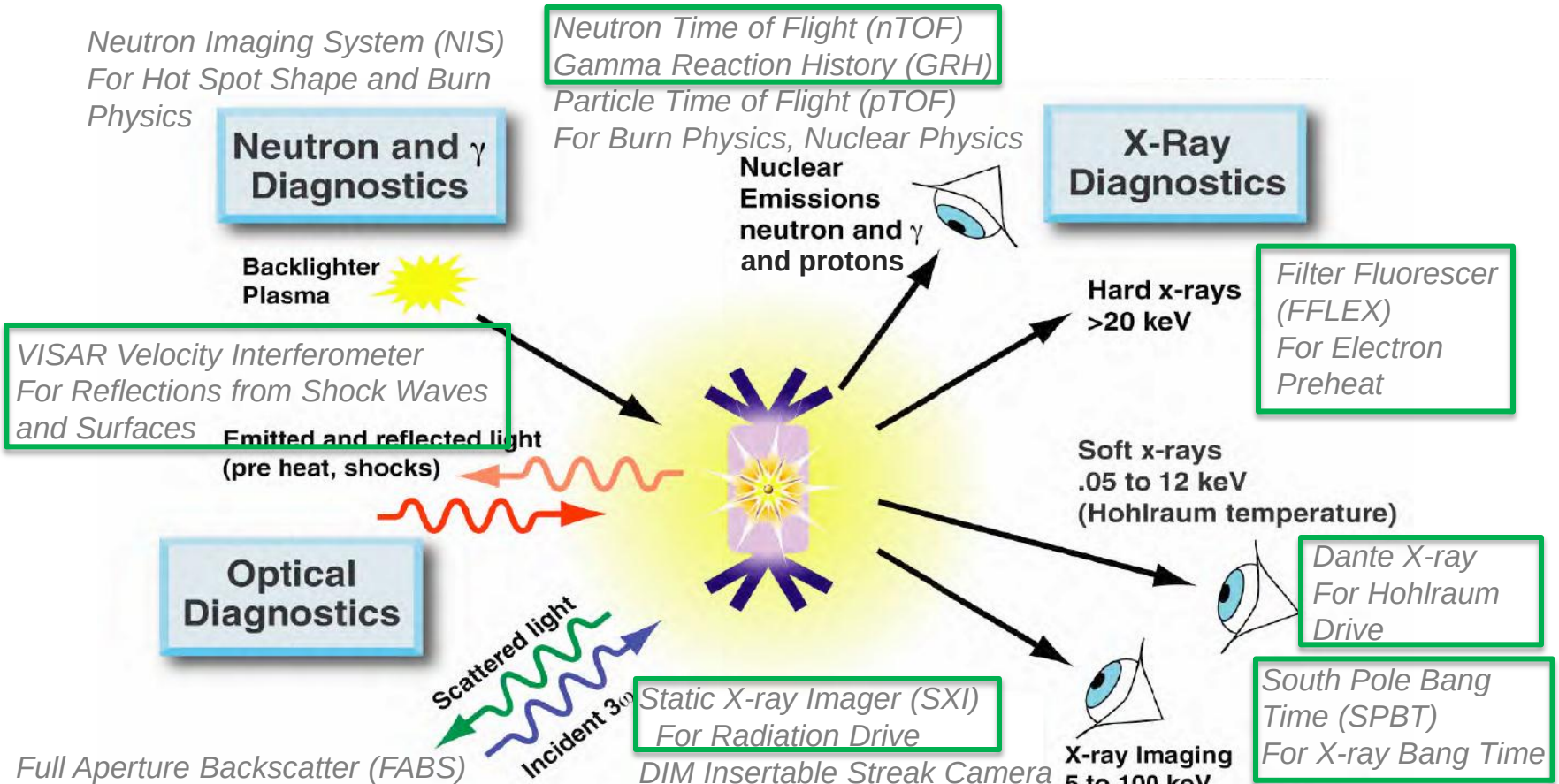


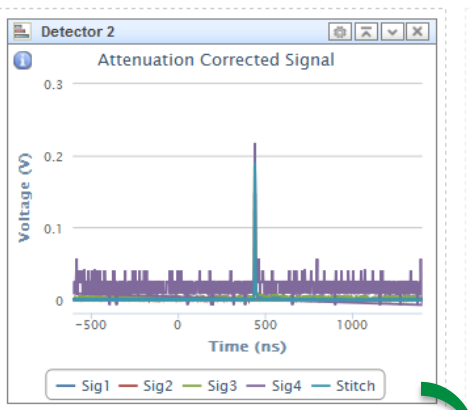
Timing analysis must be accurate to tens of ps, usually subpixel

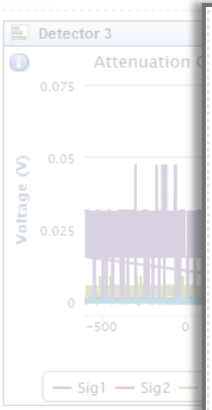
Examples: accurate & precision peak finding, data dependent delay calculations, calibration dependent delays, cross timing with laser system

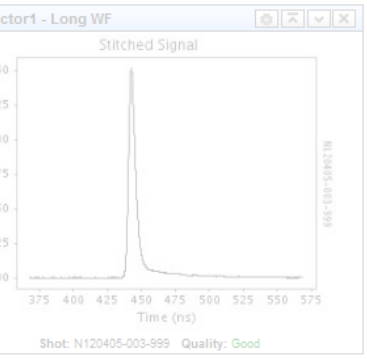
Automated analysis is run after each shot for all of these diagnostics, analysis team's recent accomplishments are highlighted

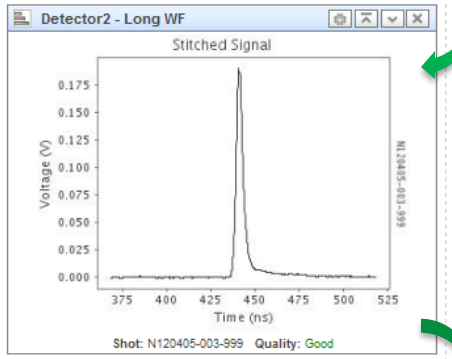


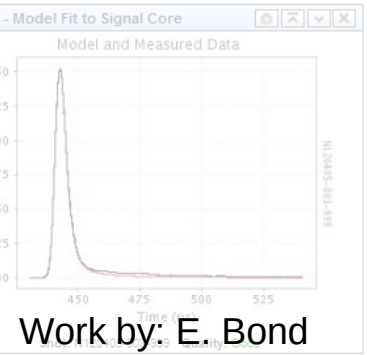
New nTOF analysis solves inverse problems from raw data through burn physics performance metrics, Essex Bond will review his work with a focus on time domain deconvolution

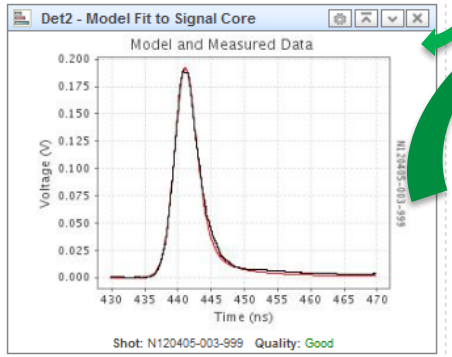


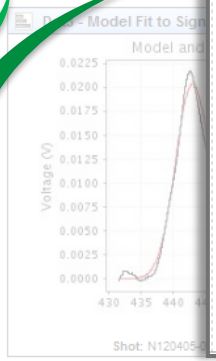


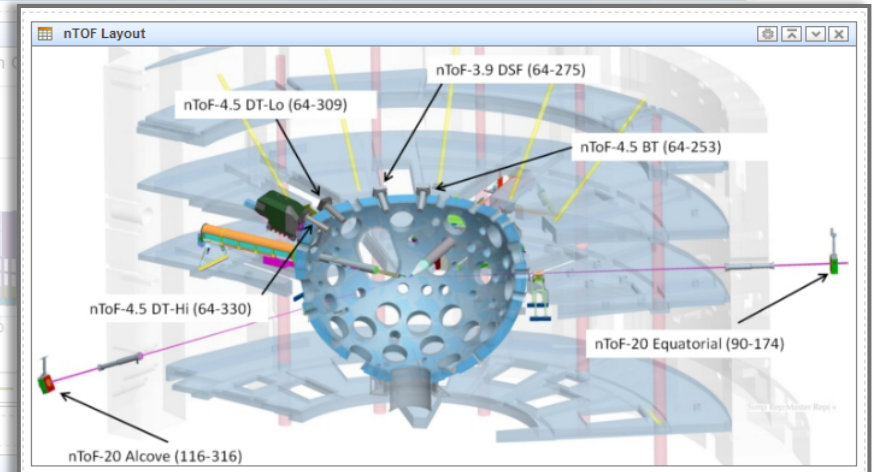












Yield

Hot Spot Temperature

Detector Summary (DT)

	Diagnostic	Location	Detect		(%)	Q							
	20M-IGNHI	TC116-316	DET01	1.31E14	10.5	Y	1.90	0.1	Y			N	3.2	FWD_FIT_DT
	20M-IGNHI	TC116-316	DET01	1.27E14	10.6	Y	1.92	0.1	Y			N	0.5	FWD_FIT_DSR_DT
	20M-IGNHI	TC116-316	DET01	1.32E14	10.5	Y	1.72	0.1	Y			N	0.0	DECONV_NEUTRON_DT
	20M-IGNHI	TC116-316	DET02	1.20E14	11.4	Y	1.55	0.2	Y			N	0.7	FWD_FIT_DT
	20M-IGNHI	TC116-316	DET03	2.29E13	11.0	Y	4.59	0.5	Y			N	12.7	FWD_FIT_DT
	20M-IGNHI	TC116-316	DET04	1.47E14	14.9	Y	1.94	1.2	Y			N	1.6	FWD_FIT_DT
	20M-SPEC	TC090-174	DET02	1.15E14	7.0	Y	1.36	0.1	Y			N	2.2	FWD_FIT_DT
	20M-SPEC	TC090-174	DET02	1.19E14	7.0	Y	1.30	0.1	Y			N	0.0	DECONV_NEUTRON_DT
	20M-SPEC	TC090-174	DET02	1.12E14	7.0	Y	1.38	0.1	Y			N	4.4	FWD_FIT_DSR_DT
	20M-SPEC	TC116-316	DET02	1.12E14	7.0	Y	1.58	0.2	Y			N	2.9	FWD_FIT_DT
	20M-SPEC	TC116-316	DET02	1.12E14	7.0	Y	1.60	0.2	Y			N	6.8	FWD_FIT_DSR_DT
	20M-SPEC	TC116-316	DET02	1.18E14	7.0	Y	1.34	0.1	Y			N	0.0	DECONV_NEUTRON_DT
	3M-DSF	TC064-275	DET01	7.94E13	10.0	N	0.03	2.5E-3	N			N	154.7	FWD_FIT_DT
		TC064-275	DET01	1.07E14	10.0	Y	1.82	0.2	Y			N	0.0	DECONV_NEUTRON_DT
	4M-BT	[illegible]	DET01	1.57E14	10.0	Y	2.67	0.5	Y	22.86	2.3	Y	10.6	FWD_FIT_DT
	4M-BT	TC[illegible]	[illegible]ET03	1.41E14	10.0	Y	2.01	0.3	Y	22.84	13.7	Y	1.5	FWD_FIT_DT
	4M-DTHI	TC[illegible]	[illegible]ET01	1.29E14	7.0	Y	1.58	0.2	Y			N	12.9	FWD_FIT_DT
	4M-DTHI	TC064-330	DET01	1.31E14	7.0	Y	2.68	0.3	Y			N	0.0	DECONV_NEUTRON_DT
	4M-DTLO	TC064-309	DET01	4.12E11	4.8	N	0.03	3.0E-3	N			N	188.4	FWD_FIT_DT
		TC090-315	DET01			Y	1.89	0.1	Y			N	-1.0	FWD_FIT_DT

Detector Summary (DD)

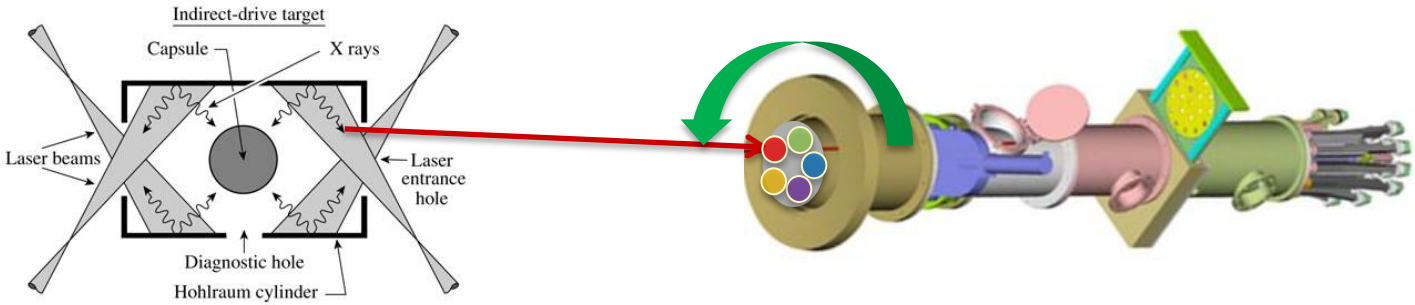
DSR Summary (DT)

Downscattered Ratio

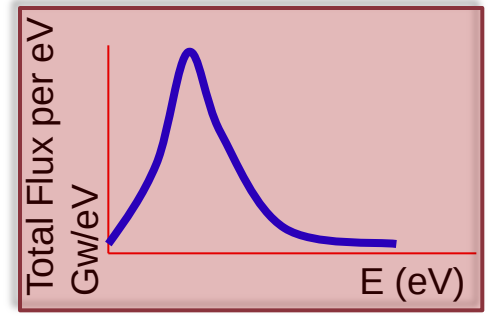
	Diagnostic	Location					Q
	NTOF-20M-IGNHI	TC116-316	[illegible]			[illegible]_DSR_DT	Y
	NTOF-20M-IGNHI	TC116-316	DET01	0.052	17.4	DECONV_NEUTRON_DT	Y
	NTOF-20M-SPEC	TC090-174	DET02	0.052	11.8	DECONV_NEUTRON_DT	Y
	NTOF-20M-SPEC	TC090-174	DET02	0.046	11.1	FWD_FIT_DSR_DT	Y
	NTOF-20M-SPEC	TC116-316	DET02	0.057	12.7	DECONV_NEUTRON_DT	Y
	NTOF-20M-SPEC	TC116-316	DET02	0.052	11.1	FWD_FIT_DSR_DT	Y

Work by: E. Bond

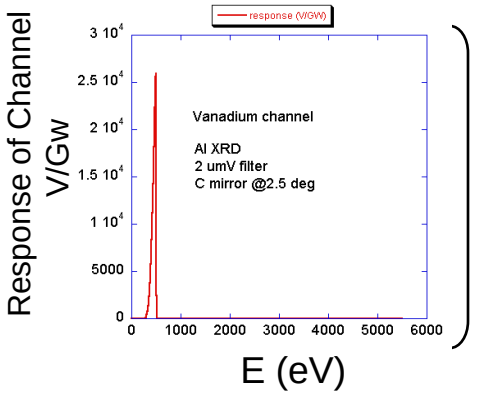
New Dante spectrum reconstruction uses an evolutionary algorithm to estimate radiation drive, Abbie Warrick will present details of her work at the poster session



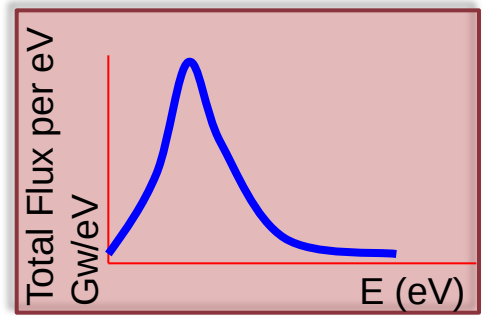
$$\text{Calculated } V_{ch1,\,time1} = \sum_{\text{energy bins}} \left(\text{Total Flux per eV (Gw/eV)} \times \text{Response of Channel (V/Gw)} \right)$$



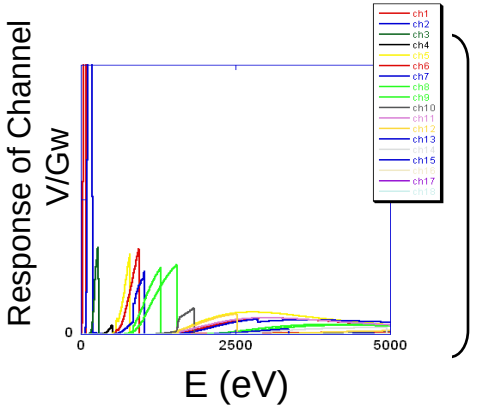
Unknown spectrum to be estimated



$$\text{Calculated } V_{ch18,\,time1} = \sum_{\text{energy bins}} \left(\text{Total Flux per eV (Gw/eV)} \times \text{Response of Channel (V/Gw)} \right)$$



Unknown spectrum to be estimated

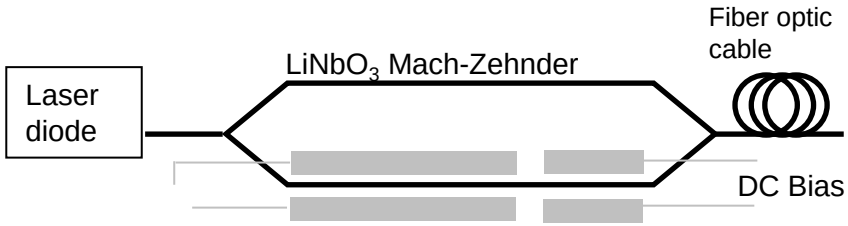


Work by: A. Warrick

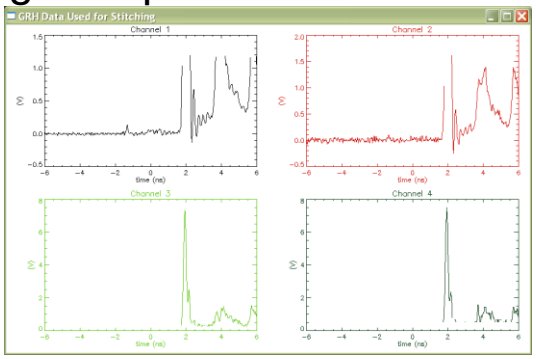
GRH automated analysis now reports gamma bang time and burn width with tens of ps accuracy

GRH Inverse Problems Include:

- Demodulating amplitude modulated signal from Mach-Zehnder hardware



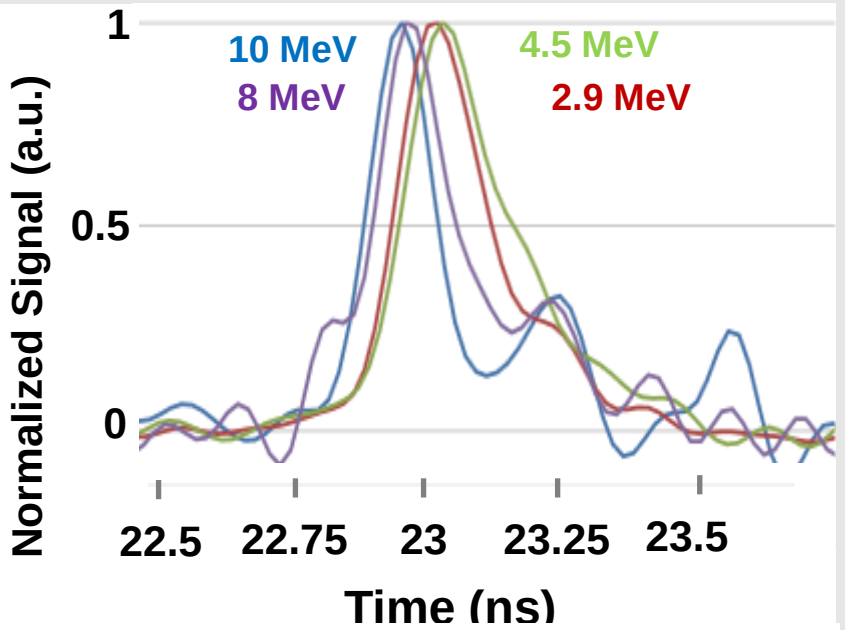
- Stitching multiple channel data



- Deconvolving system responses of PMT and Cherenkov Gas cells using constrained least squares filtering in the frequency domain

$$H(f)^{-1} = X(f) \,.\, \frac{Conj(Y(f)}{(Y(f)^2 + G))}$$

Deconvolved Cherenkov Peaks

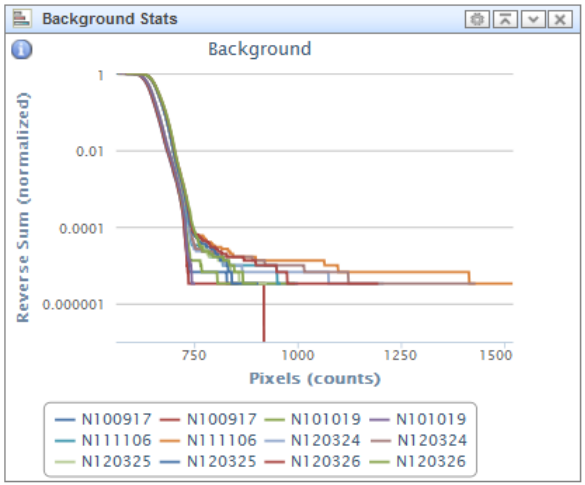


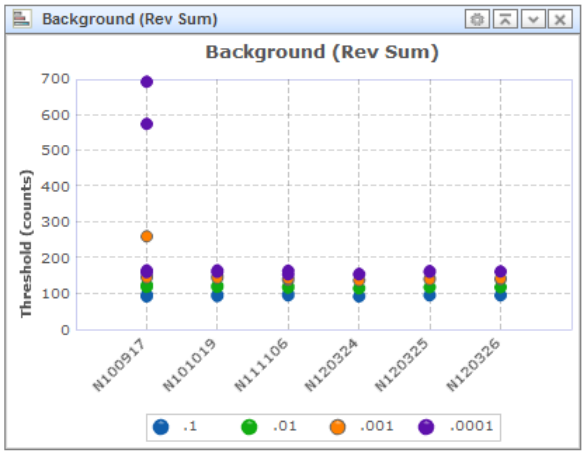
GRH Summary

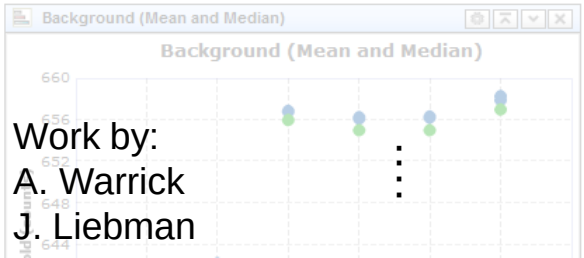
	Scope	Peak Time (ns)	Peak Width (ps)	Peak Area	Gas Thresh (MeV)
	SCOPE-1	22.956	141.581	4358.268	10
	SCOPE-2	23.020	190.374	3.601E6	2.9
	SCOPE-3	23.039	216.940	3.577E5	4.5
	SCOPE-4	22.974	159.349	6422.004	8

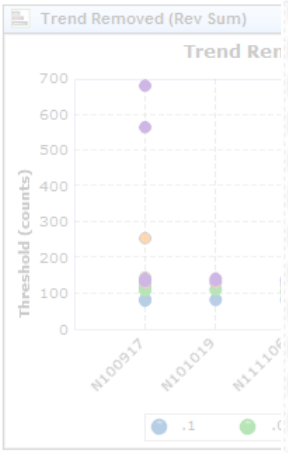
Work by: J. Liebman

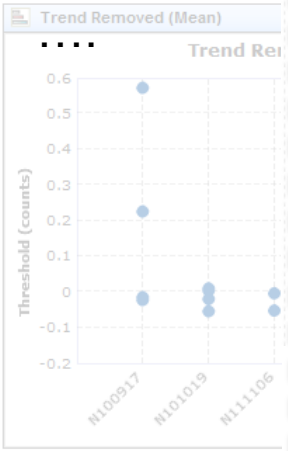
SXI analysis now reports camera health statistics and calculates effective hohlraum laser entrance hole size

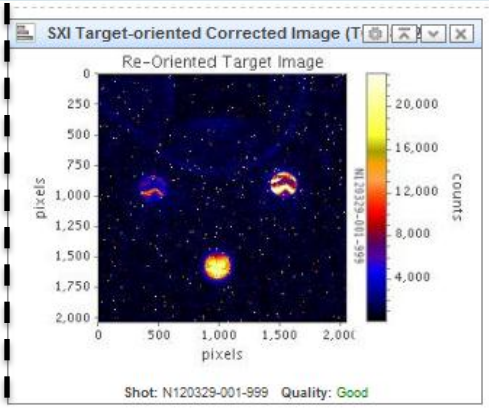


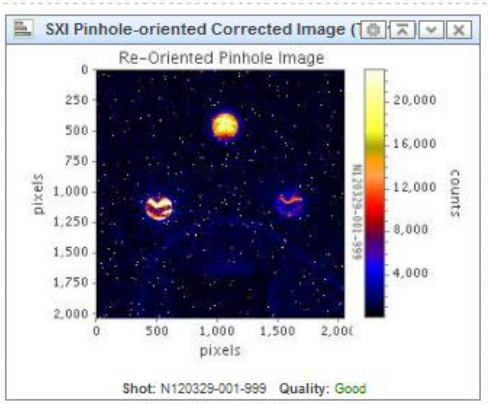


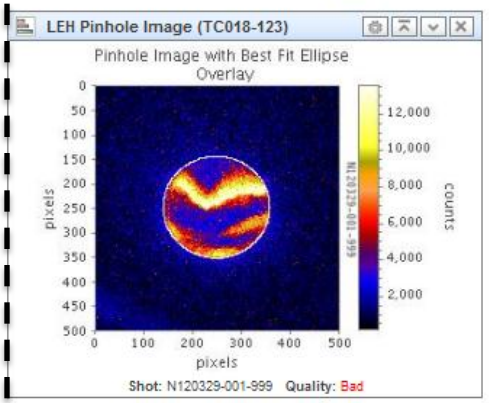


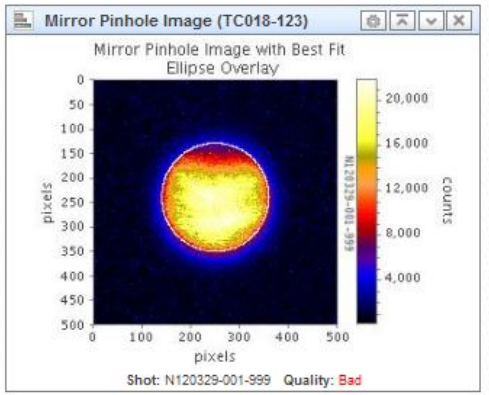










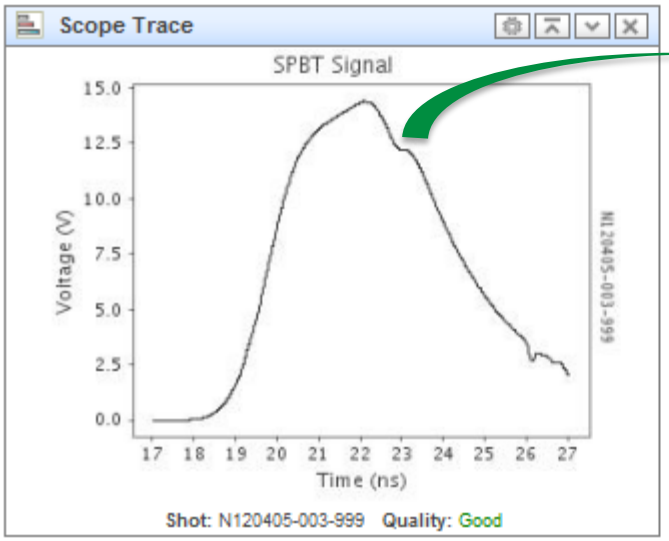


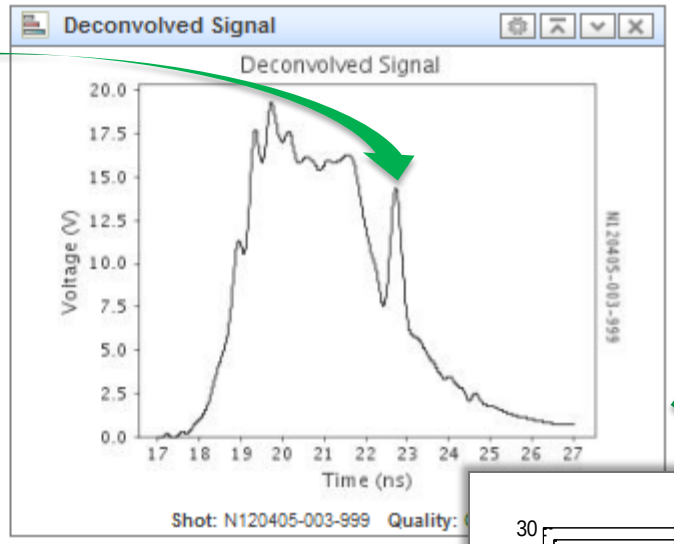
SXI LEH size analysis includes:

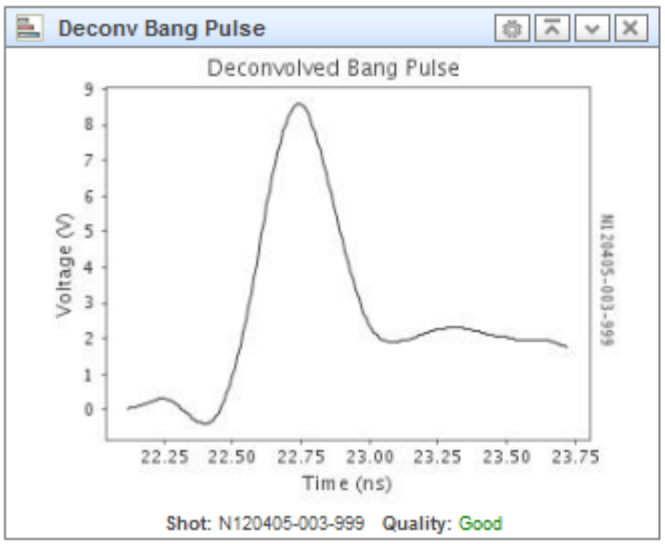
- Recording instrument corrections
- Neutron noise removal
- Robust region selection
- Image segmentation: minimum perimeter thresh
- Best fit ellipse: Hough space
- Match filtering to identify all pinhole centers

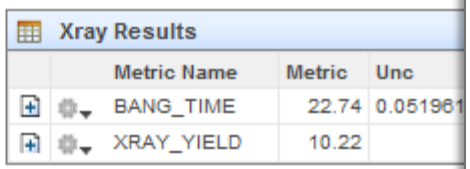
Work by:
A. Warrick
J. Liebman

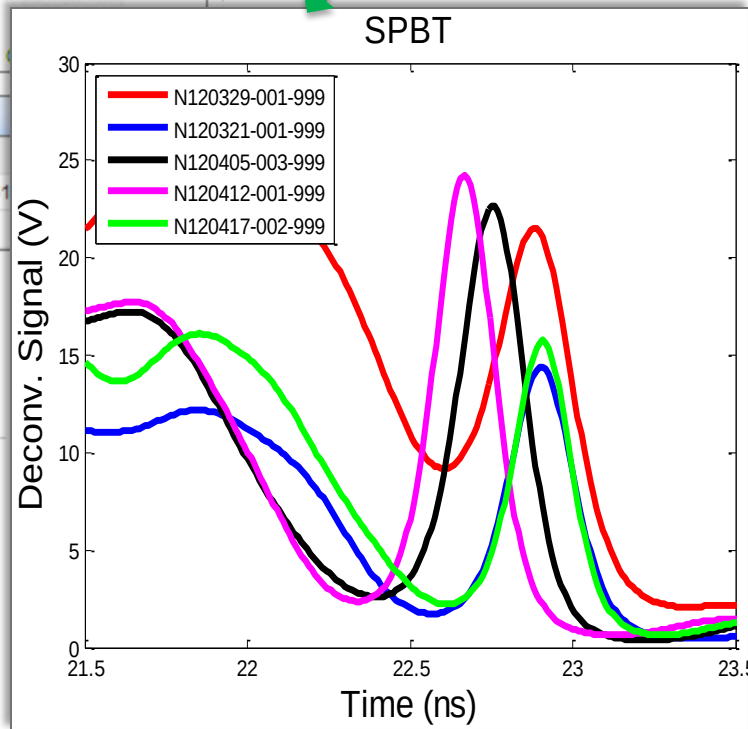
New SPBT Analysis reports X-ray bang time with error bars





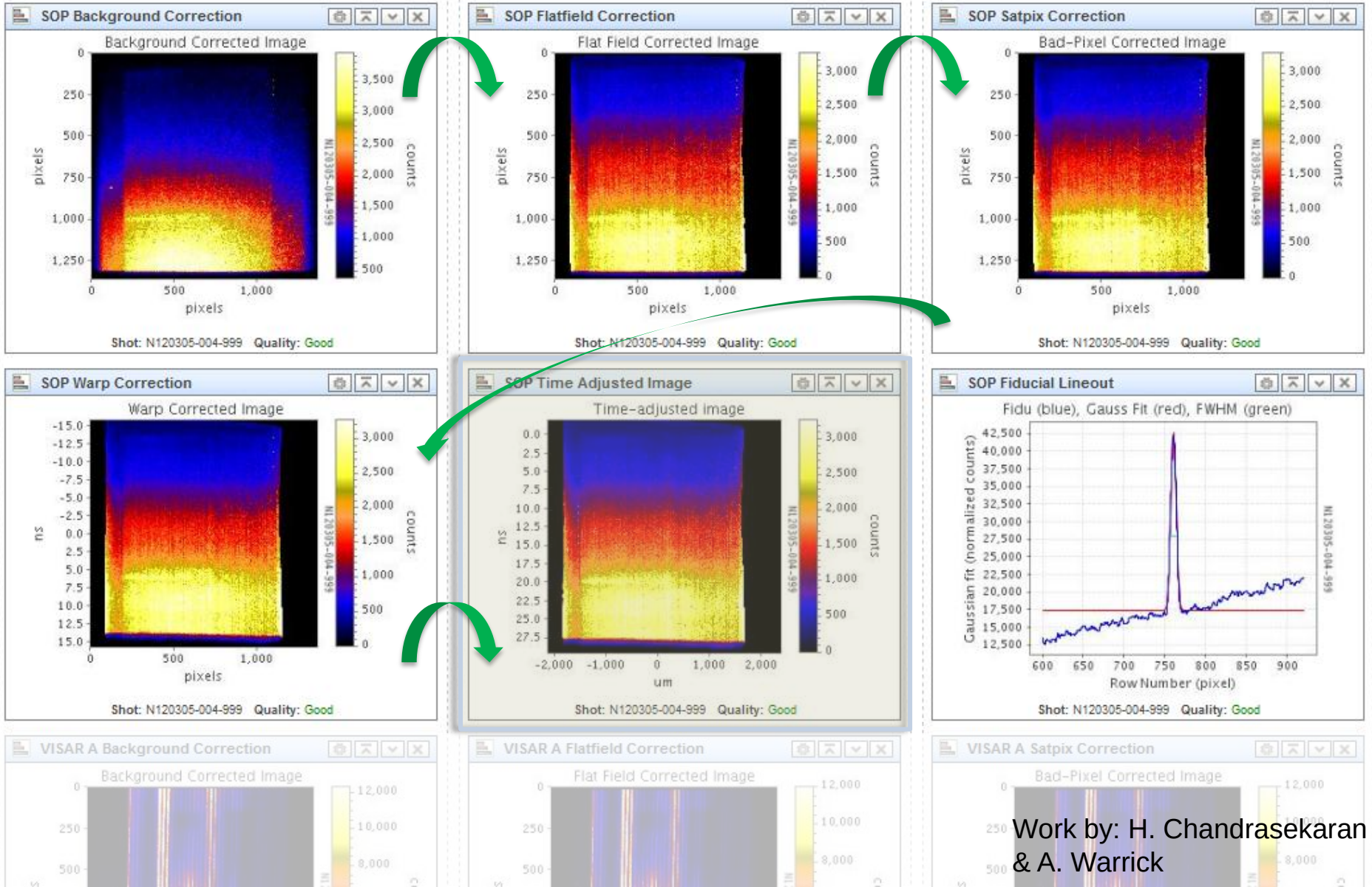






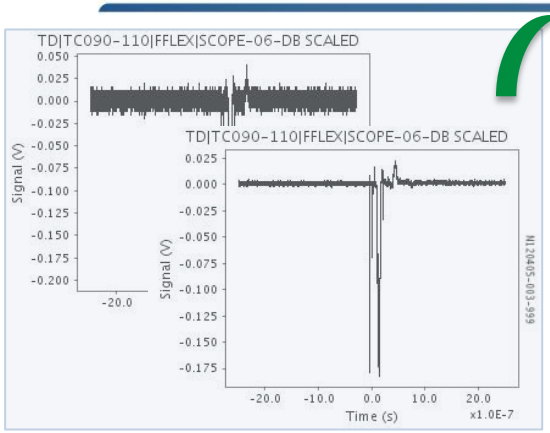
Work by: E. Bond

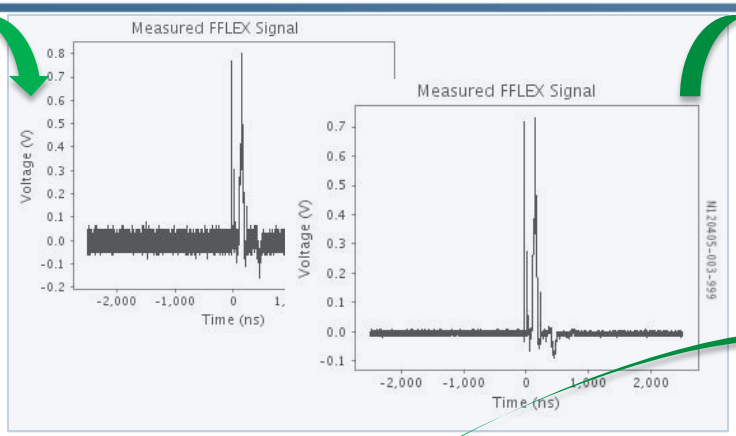
VISAR automated analysis exemplifies streak camera corrections, new fiducial and comb analysis provide cross-timed shock timing image

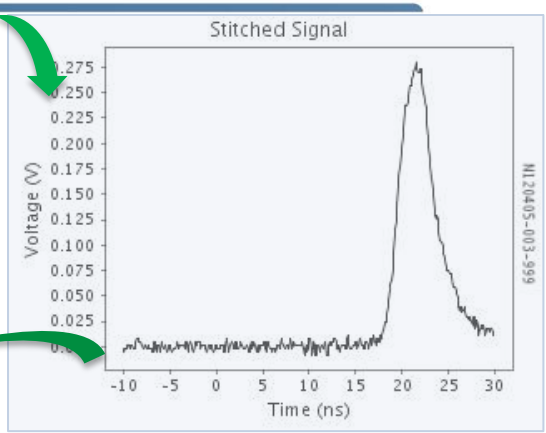


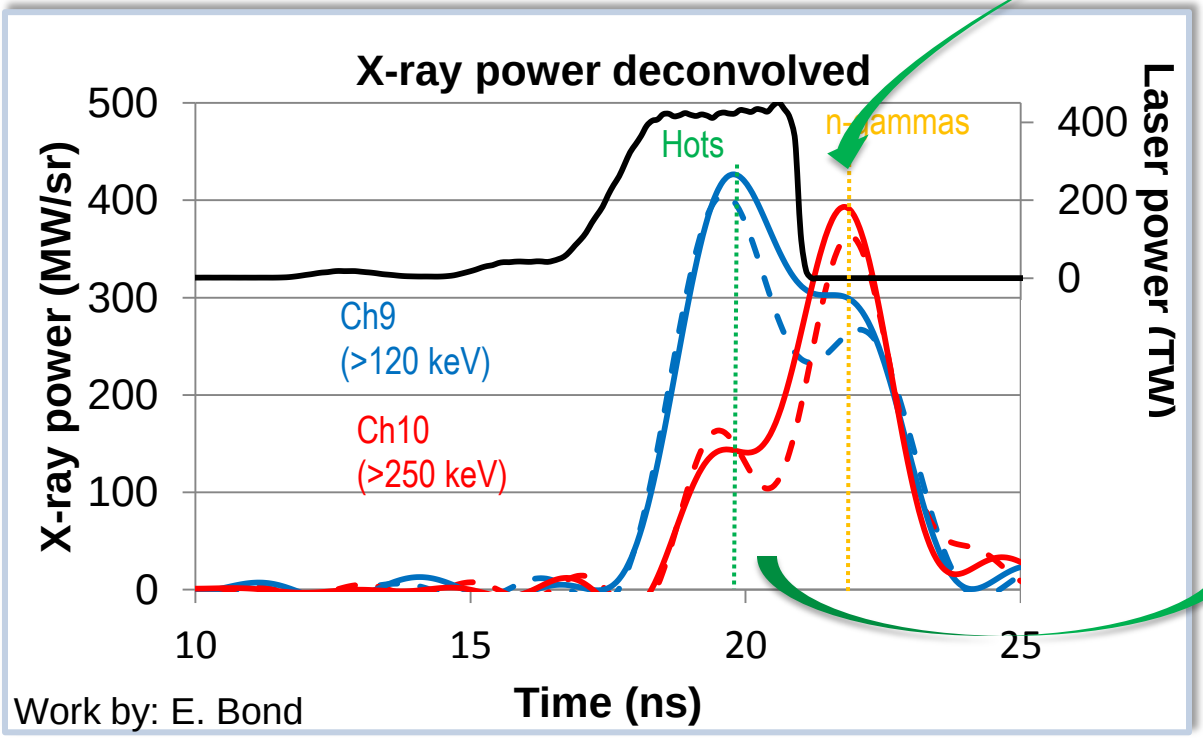
Work by: H. Chandrasekaran & A. Warrick

New time resolved FFLEX analysis produces preheat measurement as well as hot electron temperature and power over time



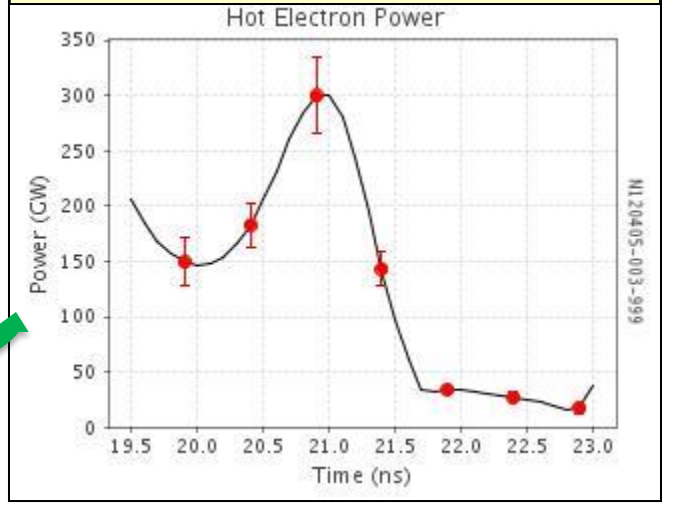






Work by: E. Bond

Results include:
Electron preheat energy integrated to the time of the end of the laser drive

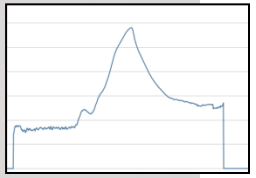


Automated diagnostic analysis is used to estimate key performance metrics and enable NIF optimization

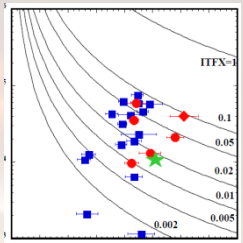
Key performance metrics

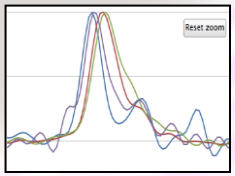
- **Temperature**:
  - Hot spot temperature
  - Hohlraum radiation temperature
- **Density** – areal density of hot spot
- **Yield** of fusion reaction– total production of neutrons or gammas
- **Velocity** – measure of capsule radius over time
- **Shape** – symmetry of the implosion
- **Timing**
  - Shock timing
  - Bang time – time of peak fusion reaction
- **Preheat** of the ablator

Dante analysis estimates radiation temperature

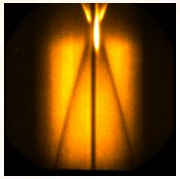


nTOF analysis reports hot spot temp, neutron yield and density metrics



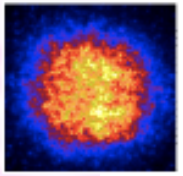


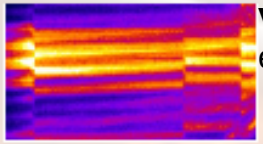
Gamma yield depends on **GRH** analysis



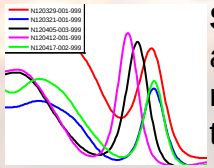
DISC uses camera corrected images

Shape metrics rely on **GXD, Ariane, NIS** timing and image analyses



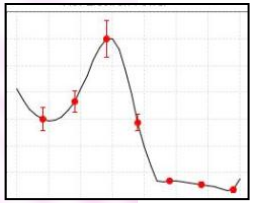


VISAR interferometry analysis enables shock timing



SPBT & GRH analyses report bang time

FFLEX analysis reports hot electrons & preheat



Acknowledgements

Shot Analysis and Visualization team:

- R. Bettenhausen (automation engine & director)
- A. Casey (Shot Data Systems)
- R. Fallejo (dataset & database table definitions)
- M. Hutton (visualization & frameworks lead)
- A. Marsh (database ETL, datasets & database table definitions)
- T. Pannell (frameworks, director & database ETL)
- M. Shor (QA Testing)

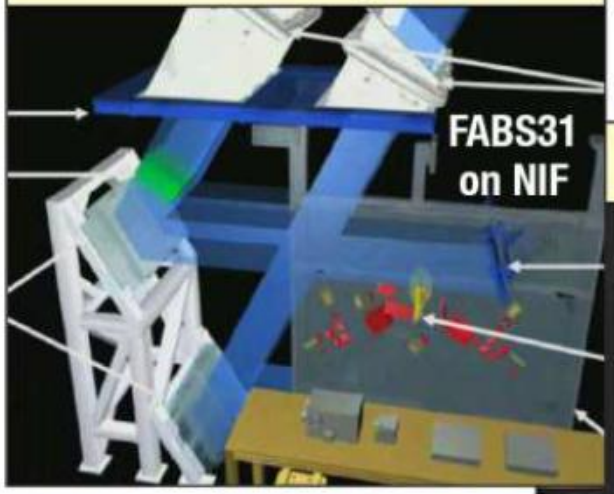
Diagnostic Responsible Scientists:

- nTOF: J. McNaney, J. Caggiano, S. Friedrich, R. Hatarik, M. Moran
- GRH: H. Herrmann, W. Stoeffl
- FFLEX: E. Dewald, G. LaCaille
- Dante: K. Widmann, J. Kline, A. Moore, C. Thomas
- SPBT: D. Edgell, A. MacPhee
- SXI: M. Schneider, N. Palmer, A. Teruya
- VISAR: P. Celliers, M. May

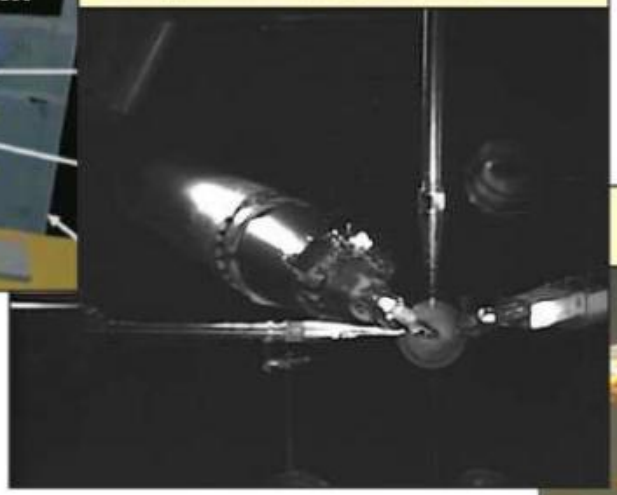

NIF

Fifty diagnostics on NIF for ignition, HED science, and basic science

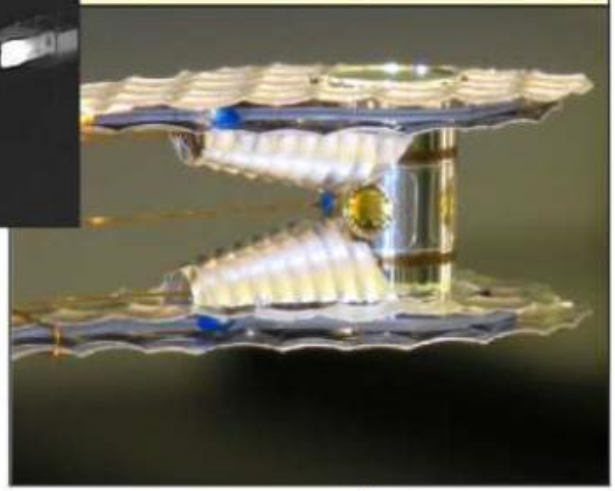
Hohlraum diagnostics



Capsule diagnostics



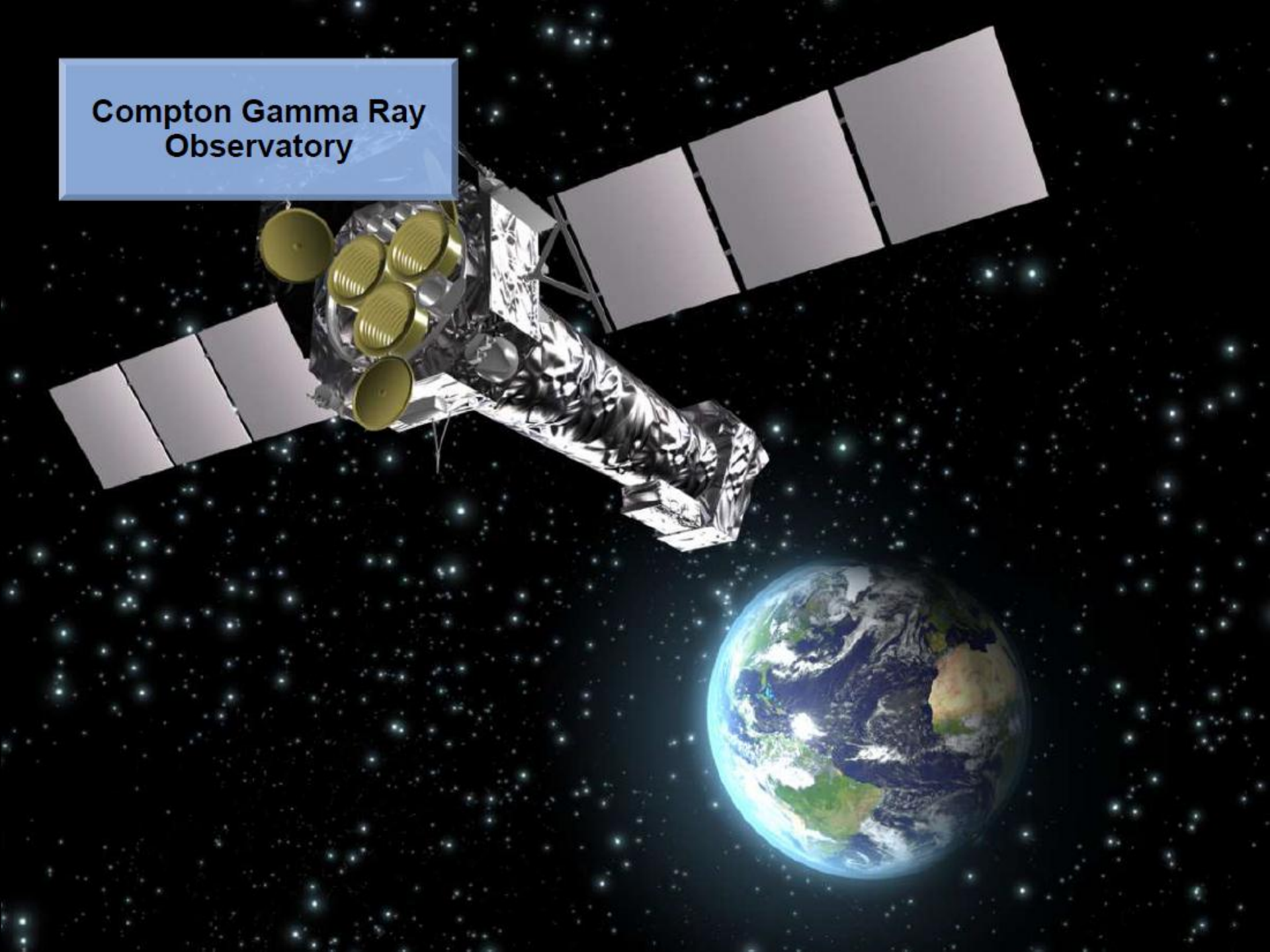
Ignition diagnostics

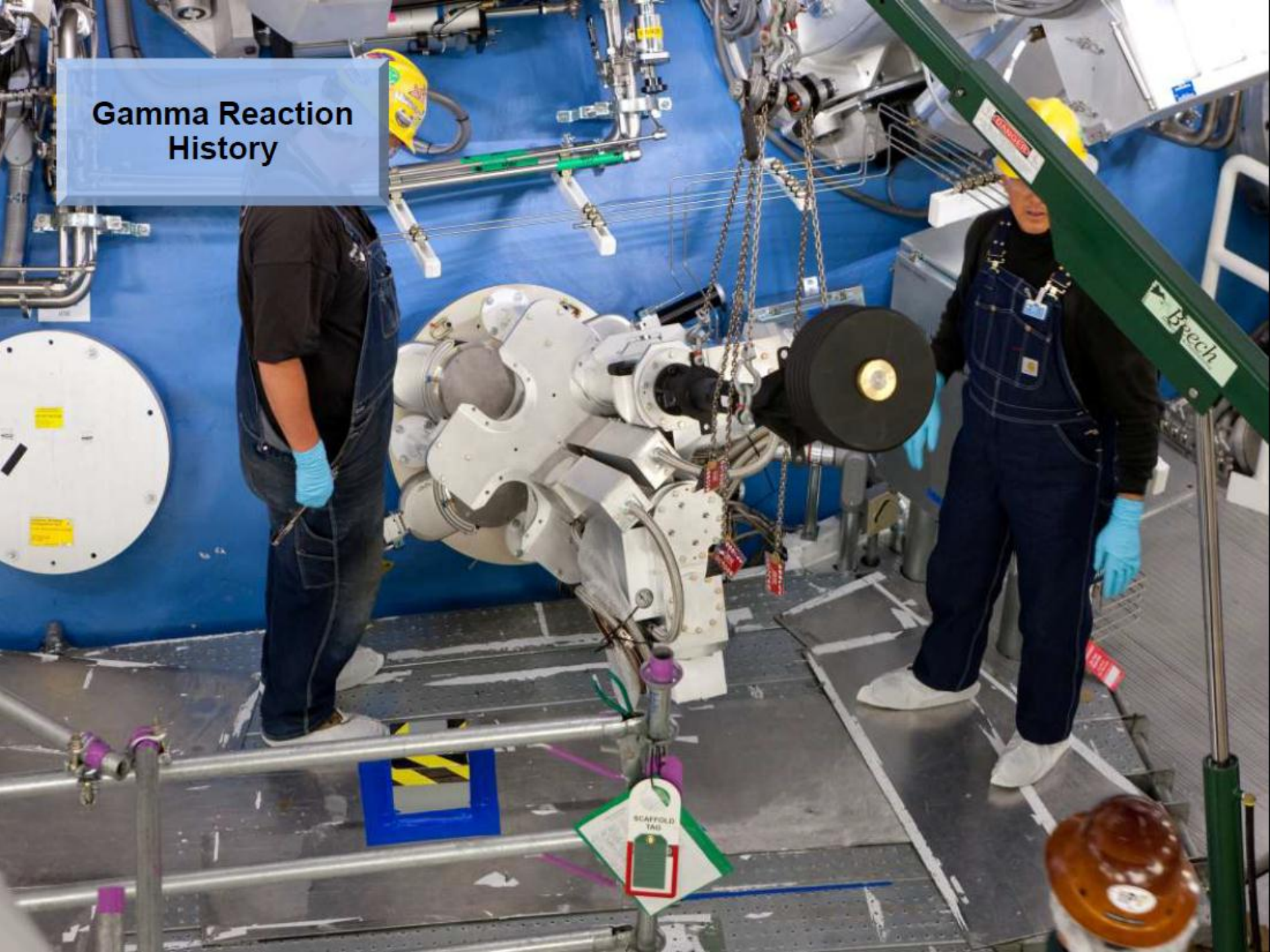


A focused national effort has developed new diagnostics providing a foundation for many programs

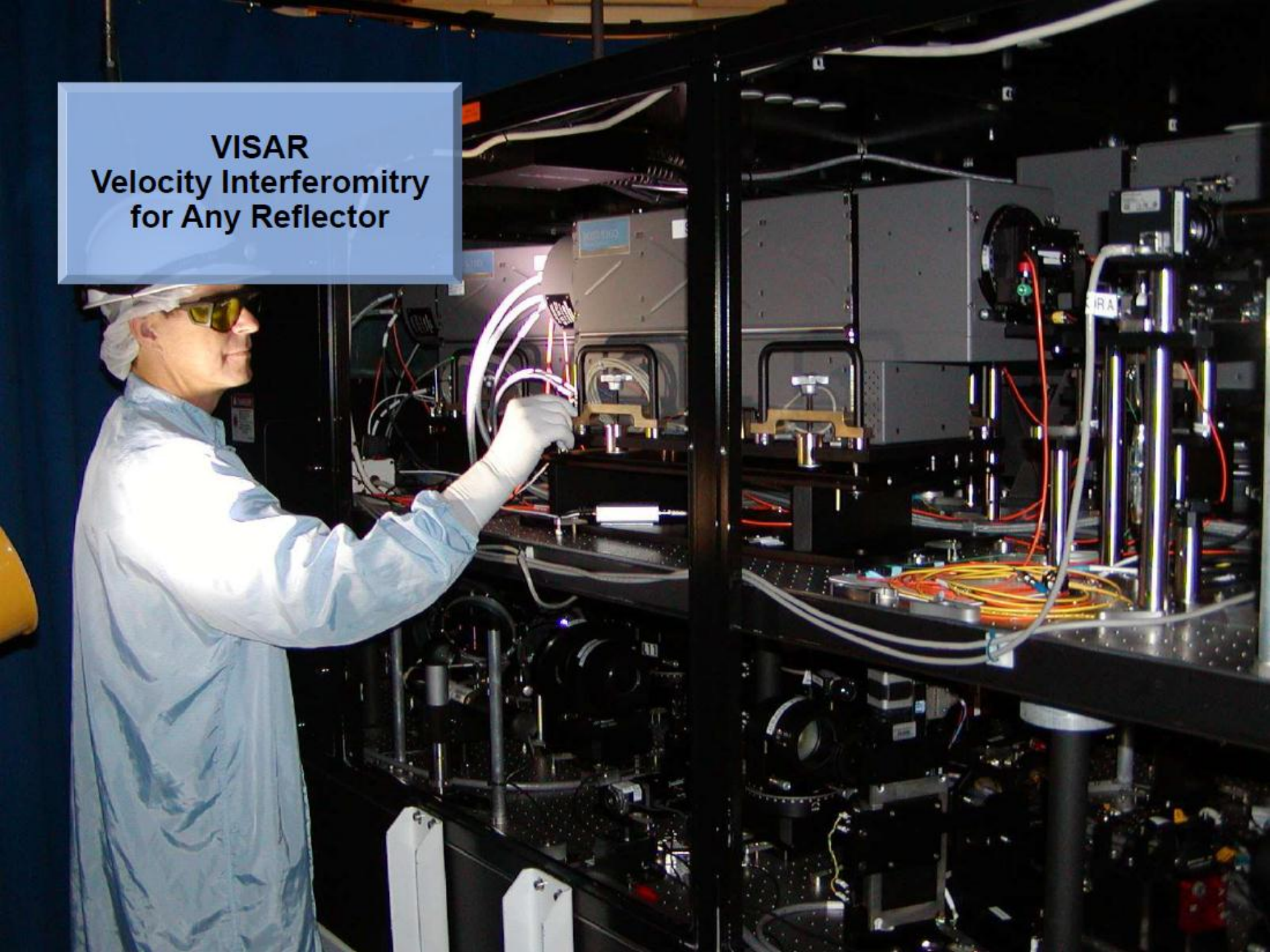

Chandra X-ray
Observatory


Dante


Compton Gamma Ray
Observatory


Gamma Reaction History
Breech
SCAFFOLD TAG

Hubble Space Telescope


VISAR
Velocity Interferomitry
for Any Reflector

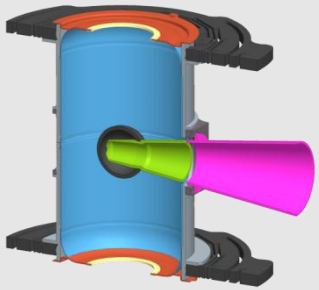
NIF is in the midst of the National Ignition Campaign where performance is optimized around four key metrics

α Adiabat

Measure of heat transfer or entropy through the ablator

Goal: Low

Can cause preheat of the Deuterium Tritium fuel



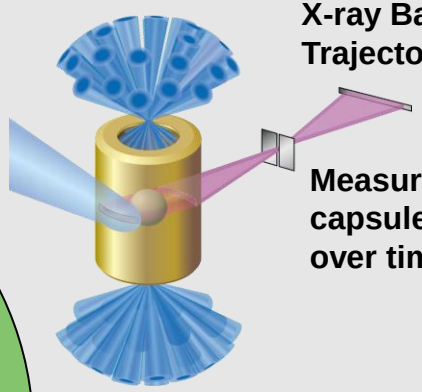
"Keyhole"

Velocity V

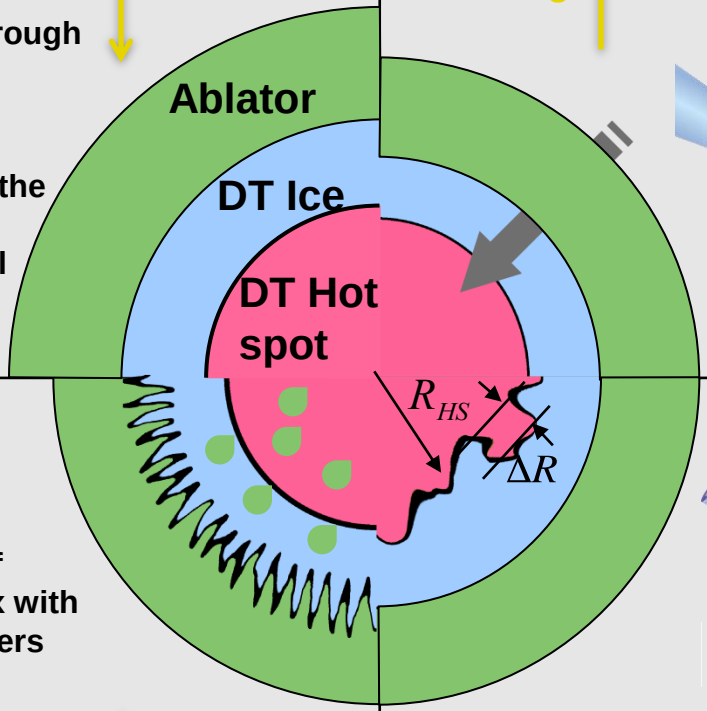
Goal: High

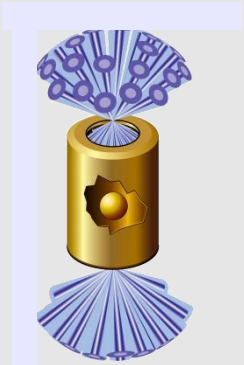
X-ray Backlit Shell Trajectory

Measure of capsule radius over time



"Convergent Ablator"





"HDT/DT"

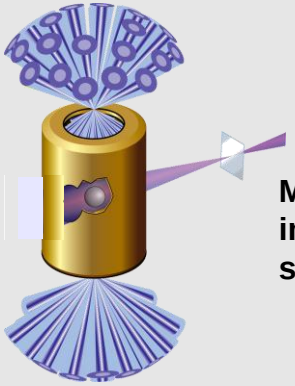
Measure of ablator mix with DT fuel layers

Can cause hydrodynamic instability

Goal: Low

M Mix

Goal: Round



"Symcap"

Measure of implosion symmetry

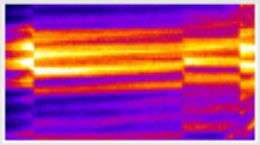
Shape S

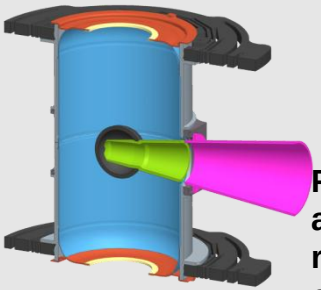
How can we measure these four key metrics as well as experiment performance variables such as radiation temperature, hot spot temperature, bang times, and fusion yields?

Accurate diagnostic analysis enables NIF optimization around key metrics

α Adiabat

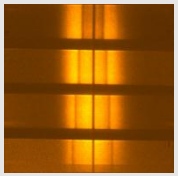
VISAR interferometry analysis enables shock timing





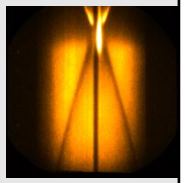
"Keyhole"

FFLEX analysis reports energetic hot electrons & preheat



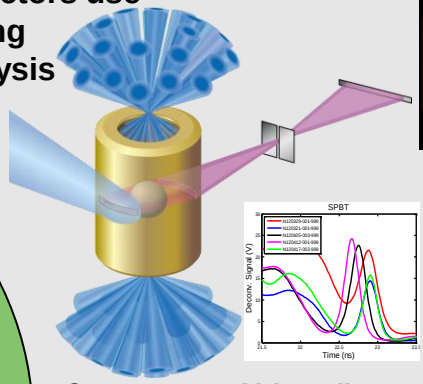
Gated X-Ray Detectors use timing analysis

Velocity V

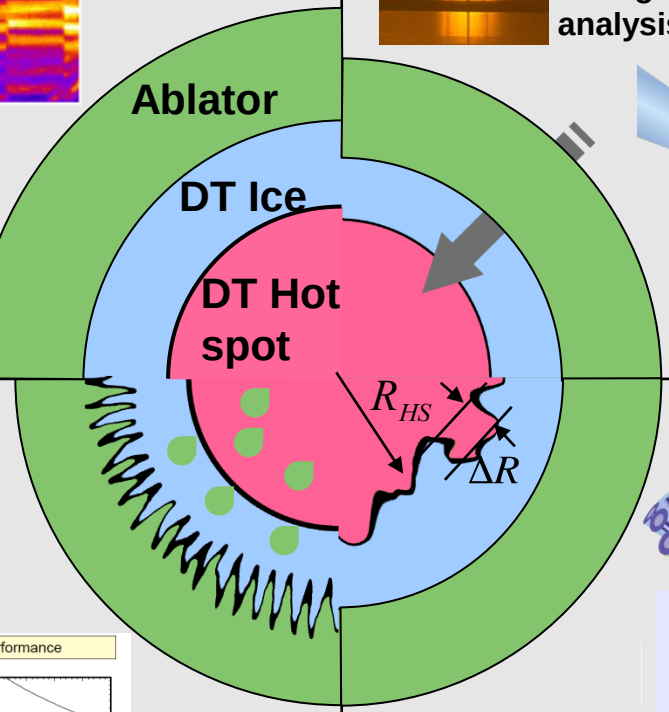


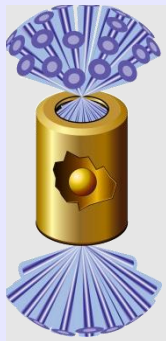
DISC uses corrected images

SPBT analysis reports bang time



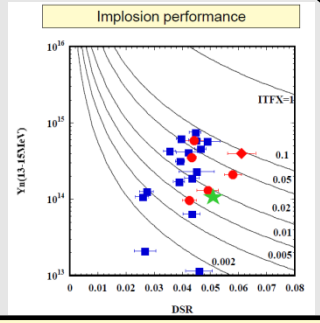
"Convergent Ablator"

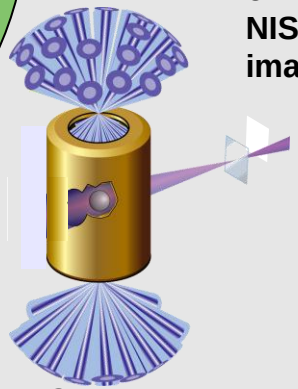




"HDT/DT"

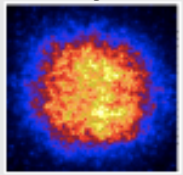
Indicators include nTOF analysis' neutron yield, Tion and DSR and GRH's gamma yield





"Symmetry Capsule"

Shape metrics rely on GXD, Ariane, NIS timing and image analysis



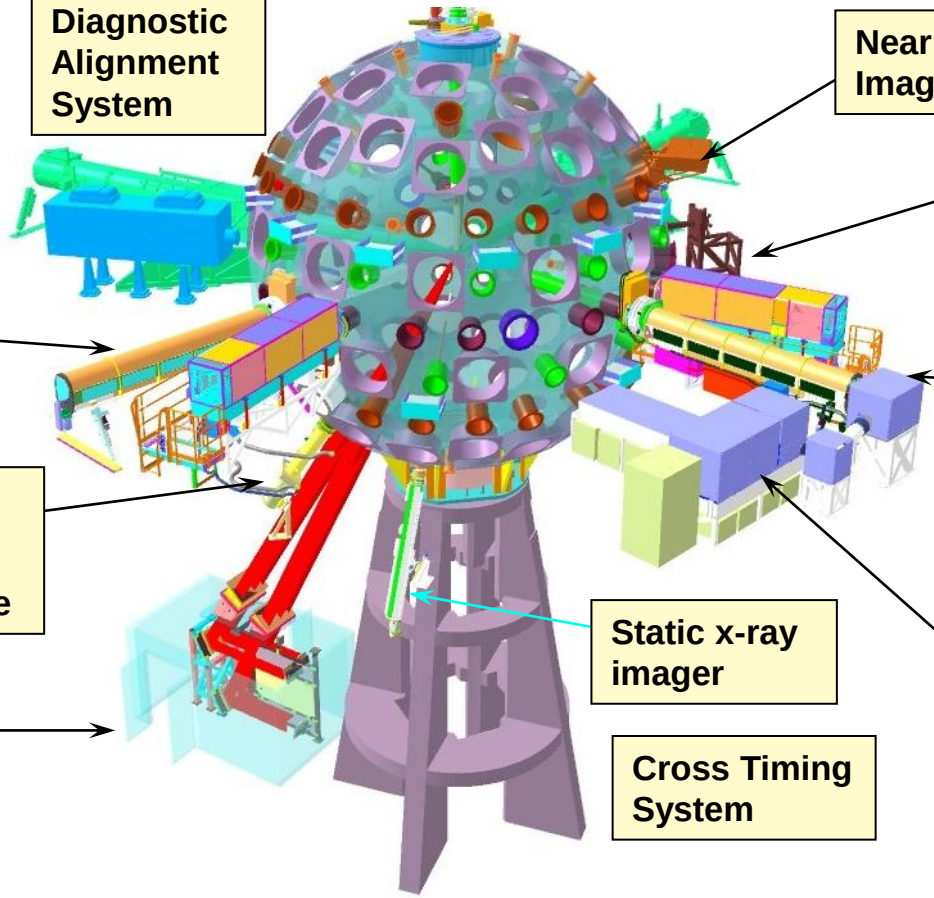
X-ray and neutron core images

M Mix

Shape S

Performance variables including nuclear bang time, X-Ray bang time, and radiation temperature are reported from the automated GRH, SPBT, Dante, & SXI diagnostic analyses.

Fifty types of diagnostic systems are planned for the National Ignition Campaign (NIC)



Diagnostic Alignment System

Near Backscatter Imager

Diagnostic Instrument Manipulator (DIM)

X-ray imager

Streaked x-ray detector

FFLEX

Hard x-ray spectrometer

Diagnostic Instrument Manipulator (DIM)

DANTE

Soft x-ray temperature

Static x-ray imager

VISAR

Velocity Measurements

Full Aperture Backscatter

Cross Timing System

The diagnostic capabilities have grown significantly