High Energy Electronic X-Ray (HENEX) Spectrometer NIF Core Diagnostic

Presented by:

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NRL, NIST and LLNL

Presented to:

NIF Diagnostic review committee formed by the JCDT

December 12, 2000

This presentation and other HENEX documents are available on the website: spectroscopy.nrl.navy.mil

The HENEX diagnostic is being developed to meet the NIF user community needs

X-ray spectroscopy needs as identified by the NIF x-ray spectroscopy expert group

- Determination of the ion species present in the plasma by the identification of bound-bound emission features.
- Observation of the hard x-ray continuum and the electron energy distribution.
- Characterization of backlighter and hard x-ray (NWET) sources.
- Determination of the plasma temperature, density, optical depth.
- Target design and code validation.
- Basic research on the atomic structure of highly-charged ions.

Implementation of the many x-ray spectroscopic diagnostic techniques requires multiple diagnostics, the core diagnostic meets the most basic requirements

Critical need: backlighter characterization for NIF at multi-keV photon energies

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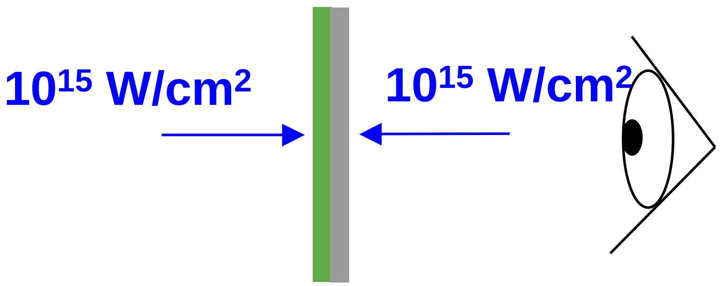
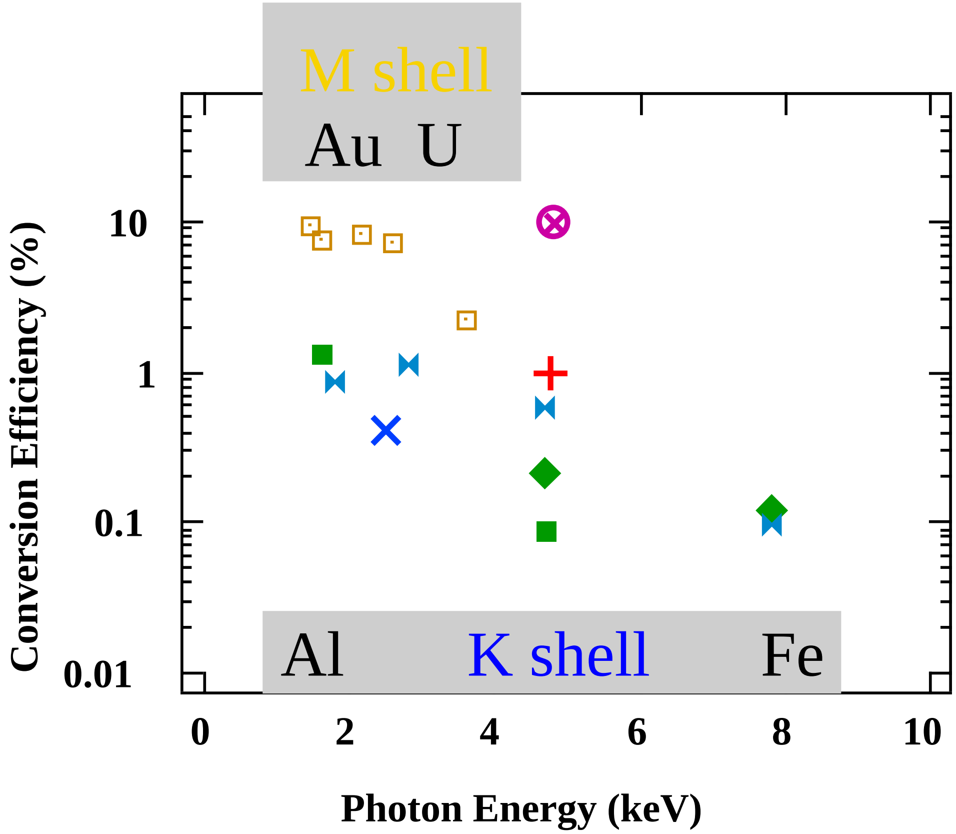
- Validating new backlighting techniques

7 μm/ 7 μm
Sc/Ti Foil
Sandwich



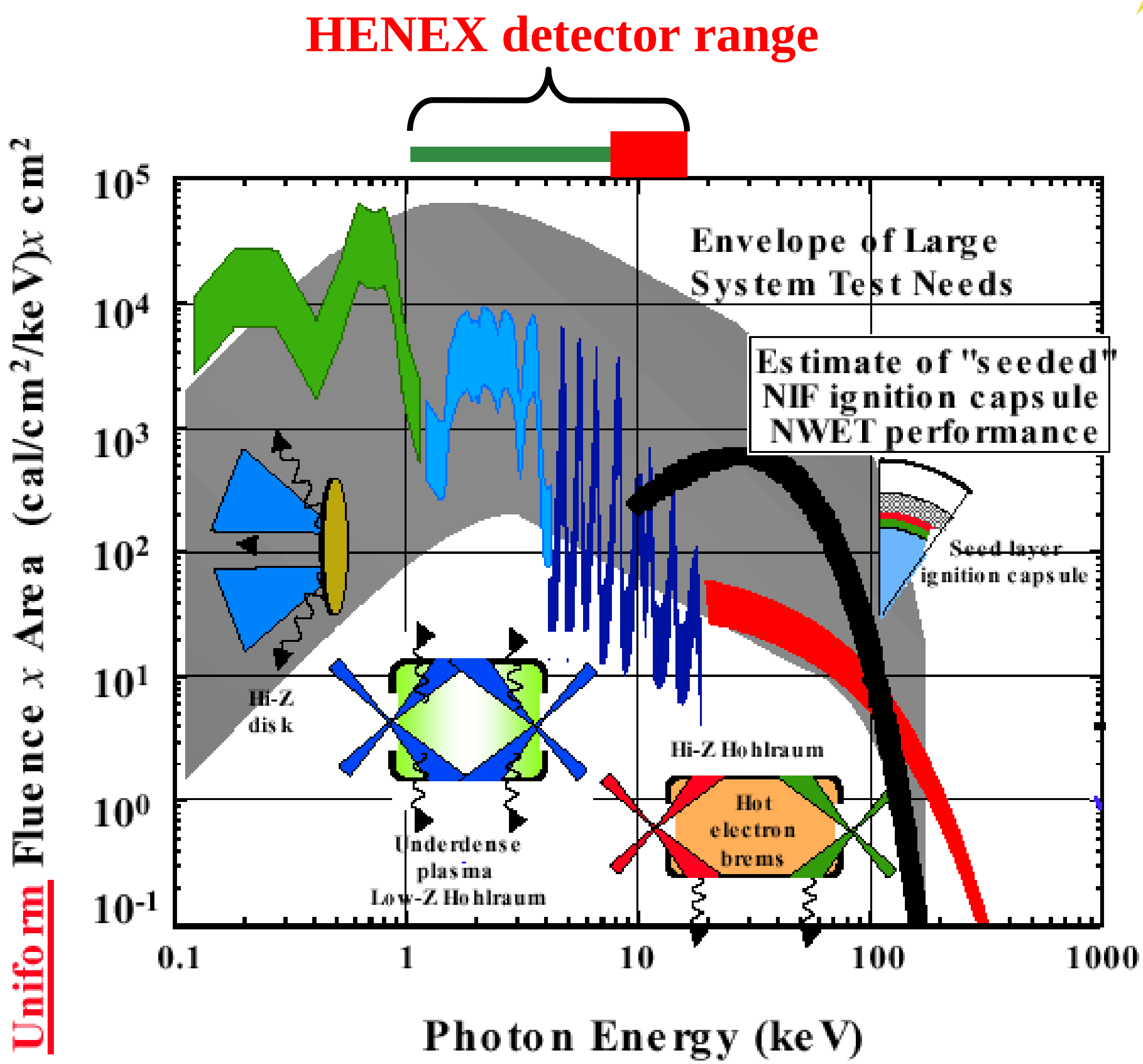
<u>HED 4.5.2</u>
Demonstrate polychromatic backlighting

- Extending conversion efficiency measurements to higher photon energies



Critical need: development of high fluence X-ray sources

- X-ray sources in the "warm x-ray" regime, 4-15 keV, are difficult to generate, yet important for thermo-structural response experiments (NWET)



The NIF core spectroscopy diagnostic must provide data with sufficient spectral resolution

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- **Unique capabilities for the core diagnostic:**
  - Measure spectrally-resolved conversion efficiency
  - Unambiguously identify emission of highly-ionized high-Z x-ray sources and backlights
- **Additional applications may include:**
  - Characterization of plasma conditions
    - electron temperatures through line ratios or bound-free continuum measurements
    - Ion temperatures by line widths
    - Electron densities by line widths
  - Scoping or feasibility studies for more advanced research using x-ray spectroscopy

HENEX diagnostic is designed to meet the NIF user requirements

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- **Spectrometer capabilities:**
  - **Surveys a wide energy range (1.1 – 20 keV)**
    - 4 reflection Bragg crystal spectrometers (approx. 1.1 - 10 keV) + 1 transmission crystal (10-20 keV)
    - Spectral-resolution is sufficient for baseline verification of target fabrication and integrity
  - **Compact design enables all spectrometers to be multiplexed on one line-of-sight**
  - **Records the time-integrated x-ray spectra on electronic (CCD) detectors**

- **Spectrometer location:**
  - **DIM mounted for flexibility with many experiments**

The present diagnostic is detailed in the paper “Hard X-ray Spectrometers for NIF” (RSI pending).

Intended applications of the core x-ray spectroscopy diagnostic

- **Comprehensive survey instrument that covers a large spectral range**
  - identification of the presence of x-rays from the targets having emission in the 1.1 to 20 keV photon energy range
- **Verification of backlight materials**
- **Relative measurements of time-integrated line ratios and time-integrated bound free continuums**
  - n.b. the minimum spectral resolution is ~ 300. Although x-ray line ratio diagnostics may require higher resolution, this instrument is appropriate for a broad range of scoping studies to determine emissivity levels of spectroscopic signals of interest. This type of information enables proof of principle studies and is essential to enable better definition of higher resolution instruments tailored to the particular plasma conditions of interest.
- **Conversion efficiency measurements and quantification of multi-keV source characteristics (* pending funds for absolute calibration)**

NIF users have requested a survey spectrometer *NIF*

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- The experimental campaigns that have requested this instrument come from two sources.
  - NIF diagnostic work sheets collated by Otto Landen at LLNL during the planning for diagnostics in 1997 (table below)
  - NIF integrated project schedule under the user module planed by Brian MacGowan of LLNL (next slide)

- The spectroscopy user group sets the instrument physics requirements

- The NIF facility sets the interface requirements

WBS 9.1	Backlighter Characterization	Kalantar LLNL
WBS 9.2	Plasma Spectra characterization	Chrien LANL
WBS 2.1, 2.2 WBS 3.2.3.4.2	Plasma Spectra & Emissivity	C. Back LLNL

The user module needs updated

Integrated Project schedule has the following experiments listed

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ID	line no.	WBS	M/ S No.	evel	Task Name
499	454	9.7			ET0251 Source development - Ti disks
500	455	9.7			ET0252 Source development - Xe gasbags
503	458	9.7			ET0255 Source development - coupling
504	459	9.7			ET0256 Source development - coupling
509	464	9.7			ET0258 Source development - Xe-filled hohlraum
510	465	9.7			ET0259 Source development - higher energy solid with prepulse
511	466	9.7			ET0260 Source development - higher energy solid with prepulse
512	467	9.7			ET0261 Source development - coupling
513	468	9.7			ET0262 Source development - coupling
519	474	9.7			ET0271 Source development - long pulse demonstration
527	482	9.7			ET0264 Source development - higher energy targets
530	485	9.7			ET0265 Source development - distributed source preparation
531	486	9.7			ET0266 Source development - distributed source demonstration
533	488	9.7			ET0268 Source development - campaign 7 , output validation
540	495	9.7			ET0274 Source development - high power
542	497	9.7			ET0275 Source development - campaign 7 output validation
543	498	9.7			ET0276 NWET - user tests - preparation
544	499	9.7			ET0277 NWET - user tests
547	502	9.7			ET0279 Demonstration of 25 cm distributed source
548	503	9.7			ET0280 Demonstration of 25 cm distributed source
549	504	9.7			ET0281 Full distributed source demonstration preparation
550	505	9.7			ET0282 Full distributed source demonstration
553	508	9.7			ET0284 Campaign 7 follow-on
554	509	9.7			ET0285 Campaign 7 follow-on
555	510	9.7			ET0286 NWET - user tests
556	511	9.7			ET0287 NWET - user tests

REQUIREMENTS: NIF X-ray crystal spectrometer

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As defined by expert user group

• Energy range of operation	1.1 - 20.1 keV
• Temporal resolution	Time-integrating
• Spatial resolution	no-imaging
• Energy resolution	2000 (1 keV) - 300 (20 keV)
• Dynamic range	2500 with CCD
• Signal-to-noise	~ 10 for significant spectral lines
• Field-of-view	5 cm

Description of compact and portable HENEX instrument

- HENEX is designed to operate in the NIF DIM and the LLE TIM.
- The x-ray dispersive elements are five crystals used in reflection or transmission.
- The standoff distance from the target is variable from 0.5 m to 2.2 m.
- Two SMA 62.5 micron fibers handle triggering and data transmission.
- The baseline CCD detectors are 12 bit resolution and controlled by low-power custom built readout/drive electronics housed inside the Drive Electronics (DE) package in the rear of the HENEX instrument.
- The instrument is designed so that no data are retained when the power is disconnected.

HENEX x-ray crystal spectrometer specifications

Meets The NIF Core Diagnostic Specifications.

Photon Energy Range	1.1 keV to 20 keV
Field of View	5 mm
Minimum Spectral Resolution	$\lambda/\delta\lambda = 300$
Dynamic Range	2500
Data Acquisition	CCD

Channel	Diffraction Crystal	Lattice Spacing (Å)	Energy Range (keV)	Bragg Angle Range (deg)	Resolving Power
1	Qz(10-10)	4.26	8.6 to 20.1	9.7 to 4.2	818 to 303
2	Ge(400)	1.41	7.0 to 10.9	38.7 to 23.7	2840 to 1290
3	Si(111)	3.14	3.6 to 7.3	33.4 to 15.7	2130 to 850
4	KDP(011)	5.10	2.2 to 4.0	34.4 to 17.5	2260 to 940
5	Mica(002)	9.92	1.1 to 2.3	33.7 to 15.7	2150 to 850

Energy coverage for 0.5 & 2.2m deployment

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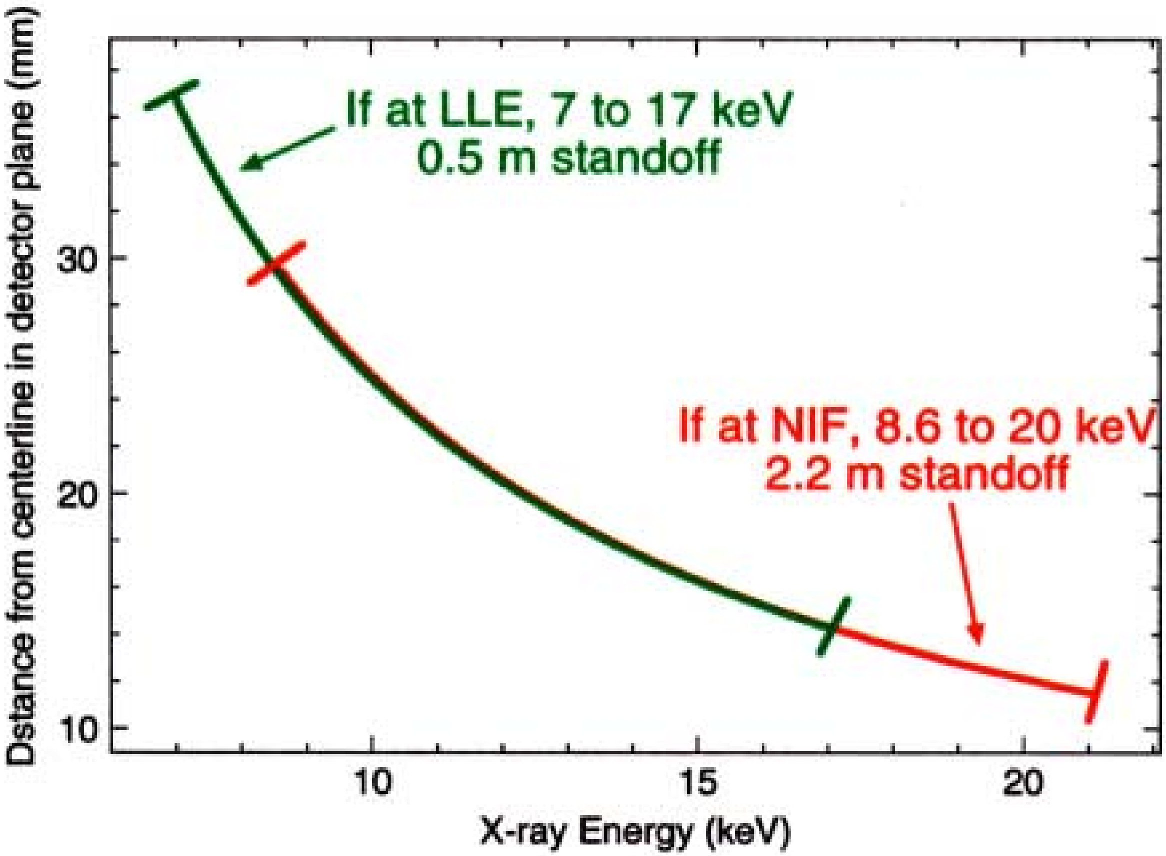
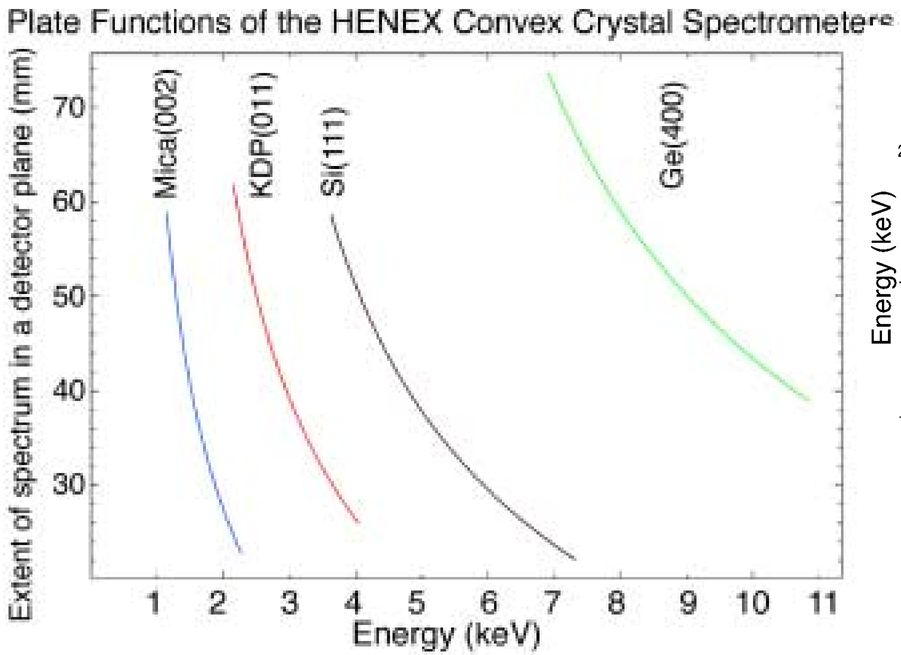
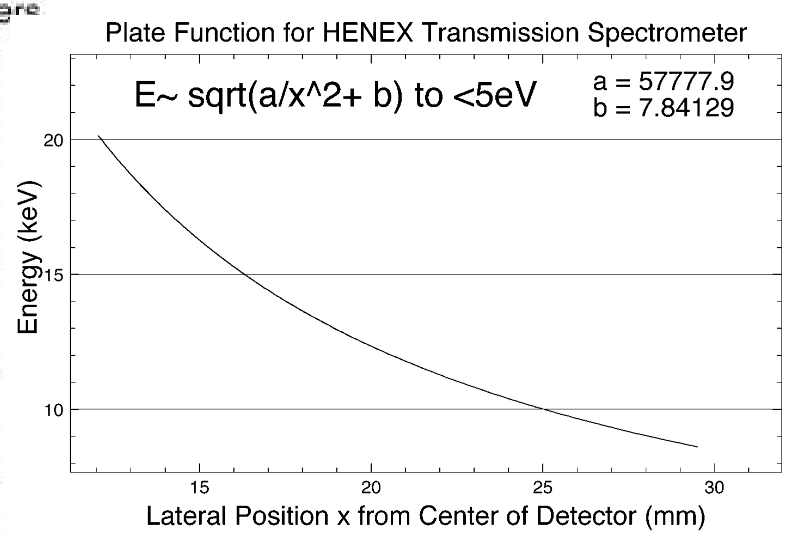
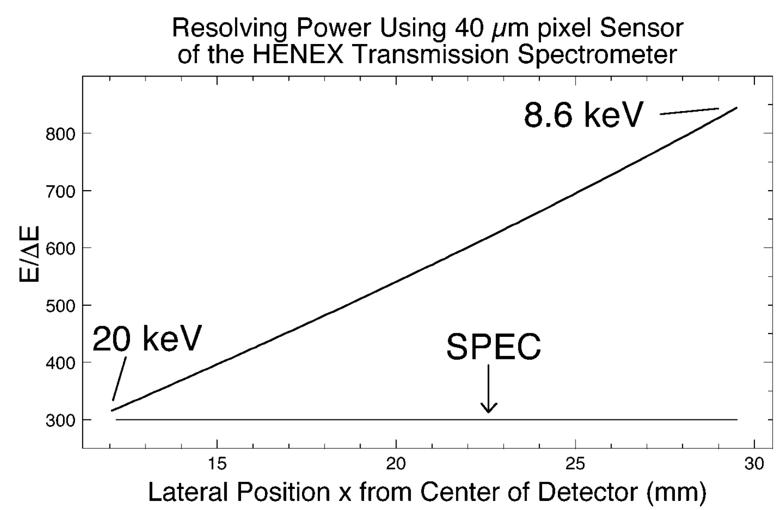
- Reflection crystal channels have minimal energy shift.
- Transmission crystal channel shifts to 7-17 keV.



HENEX energy coverage 2.2 meters from TCC







REQUIREMENTS: environmental

- **Neutron Shielding:**
  Diagnostic will withstand low levels of neutron yield < 1 x 10^{9} DD neutrons.

- **X-ray shielding:**
  To enable withstanding the harsh x-ray environment which will exist on laser-produced plasma experiments, shielding should protect detectors and crystals for x-ray fluxes up to 5 x 10^{13} W/sr. Also, adequate shielding of background multi-keV x-rays, requires transmission of hard x-rays through the spectrometer body must be less than 1 x 10^{-4} for a reasonable signal to noise ratio.

- **Debris shielding:**
  The instrument has a 2 meter stand off distance from TCC. It can also have a fairly robust filter in the line of sights some channels. The instrument could be ultimately damaged by target debris. A risk analysis should be done to look at the cost benefit of a fast valve verse damaged component replacement.

REQUIREMENTS: environmental (continued)

- **Electrical grounding, shielding and isolation:**
  Instrument shall comply with the NIF electrical grounding and shielding plan

- **Cleanliness and vacuum:**
  The instrument shall adhere to 300/A requirement in accordance with the "The National Ignition Facility target chamber cleanliness, material compatibility and vacuum out-gassing specifications and guidelines" document

- **Standoff Distance from Target Chamber Center:**
  The instrument working distance shall be > 50 centimeters from TCC

HENEX shielding specifications

- No direct line of sight from the x-ray source to the CCD detectors facilitates radiation shielding.
- Minimal use of materials that may fluoresce, become activated, or degrade.
- Baseline shielding against target flux:
  - 10^9 DD neutrons
  - 5×10^{13} W/sr x-rays up to 20 keV.
- Additional lead shields the CCDs from target x-rays up to 0.5 MeV.
- Instrument enclosure attenuation factor of 10^{-4} for up to 100 keV x-rays incident from all sides.
- Faraday cage, internal battery power, and fiber optic communication facilitate shielding against EMP and EMI.

HENEX environmental specifications

• Operate in vacuum	$1x10^{-5}$ to $5x10^{-7}$ torr
• Leak rate into target chamber	< 0.01 torr liter/sec
• Thermal dissipation	~ 11 watts max into target chamber @ 25C
• Space envelope	Length 58”, width 7”, height 7”
• TIM & DIM compatible	The instrument size allows deployment in an LLE TIM, NIF DIM, or other comparable vacuum enclosure.
• Total weight	~85 LBS.

HENEX packaging and EMI/EMP protection

- **The Drive Electronics (DE) package resides inside a Faraday cage**
    - **vented through sintered stainless steel pump-out disks (electrically conductive shield)**
- **The electronics are chosen to minimize response and degradation**
    - **EMI/EMP**
    - **x-rays**
    - **DD neutrons.**
- **Only requires fibers and the non metallic water lines to run the DE package.**
    - ***Cooling to maintain room temperature is needed for long-duration operation in the vacuum environment.***
- **Internally-powered device**
    - **ground of the battery as the single point ground**
    - **operates on internal battery power for ~12-16 hours.**

REQUIREMENTS: layout and utility interface

- Location requirements and restrictions
  - DIM based to allow for multiple locations
- Diagnostic interference and envelope requirements
  - TIM compatible
- Utilities and cable tray requirements
  - DIM provided
    - Requires two 62µm fiber optic cables for communications
    - Requires water cooling
    - Power is provided via battery
- Timing requirements
  - T-10 seconds
- Fiducial requirements
  - *None*

HENEX-NIF interface specifications

• Power	7.2 VDC from Internal Battery Pack (IBP) that resides inside the DIM. The 30Ah IBP is removable and rechargeable off-line.
• Trigger Signal	T-10 second trigger from NIF or LLE.
• DIU Optical Trigger	62.5/125 micron graded index multi-mode fiber with SMA connectors.
• Remote control	
• Protocol	Ethernet OIP commands or equivalent.
• Optical link	62.5/125 micron graded index multi-mode fiber with SMA connectors.
• Cooling lines	Two 3/8" O.D. lines with Parker Dry fittings with flow rates up to 1 gpm.
• Pointing to TTC	Removable laser pointer.

HENEX timing and trigger specifications

- **Timing:**
  - **T-10 trigger is sent by the NIF/LLE facility 10 sec before the laser pulse arrives at TCC.**
  - **The T-10 pulse triggers the DIU which is remotely located from the target chamber.**
  - **DIU sends a trigger pulse to HENEX via a fiber optic link.**
  - **HENEX CCDs integrate from T-0.5 to T+0.5 sec.**
- **Facility trigger specifications:**
  - **Jitter ~100 nsec rms.**
  - **Positive pulse with 250 nsec duration**
  - **4 volts into 50 ohm**

REQUIREMENTS: operational

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- Alignment and pointing:
  - 500 µm accuracy in x,y to designated targeting position
  - 250 µm z
- Shot life cycle:
  - Capable of acquiring data every two hours
- Controllers:
  - Compatible with the JCDT diagnostic interface document
- Data acquisition and archive:
  - Compatible with the JCDT diagnostic interface document
- Classified operation :
  - None
- Remote operations requirements
  - None

Operational specifications

- **Alignment and pointing:**

  Alignment can be done in one of two methods

  A pointer can be attached to the diagnostic and run to TCC then back out and removed, if the repeatability of the DIM is adequate (To be determined).

  A diode laser can be attached to the instrument on a kinematic mount interface. The diode laser pointer will be controlled by the DIM operator

- **Shot life cycle:**

  Data analysis within 15 minutes following a shot.

  Allows for adjustments to the following shot based on data analysis.

- **Controllers:**

  Will follow the diagnostic communications protocol as set by the requirements document. Will interface to the Target diagnostic FEP

Operational specifications continued

- **Data acquisition and archive:**
  Each CCD sensor is ~ 5 Mbytes, HENEX will have 6 CCD sensors. We will have 30Mbytes of data images per shot and 30Mbytes of dark images (background images). So the total data storage will be ~60Mbytes per shot.

- **Classified operation :**
  Will have the ability to swing. The data will be stored temporally in the diagnostic in a “volatile” way during image down load. If the power is interrupted then the data are erased.

- **Remote operations:**
  The diagnostic by the design of the ICCS interface is capable of remote operation. Currently there is no requirement for remote operations

Locations of DIM's where HENEX could be fielded

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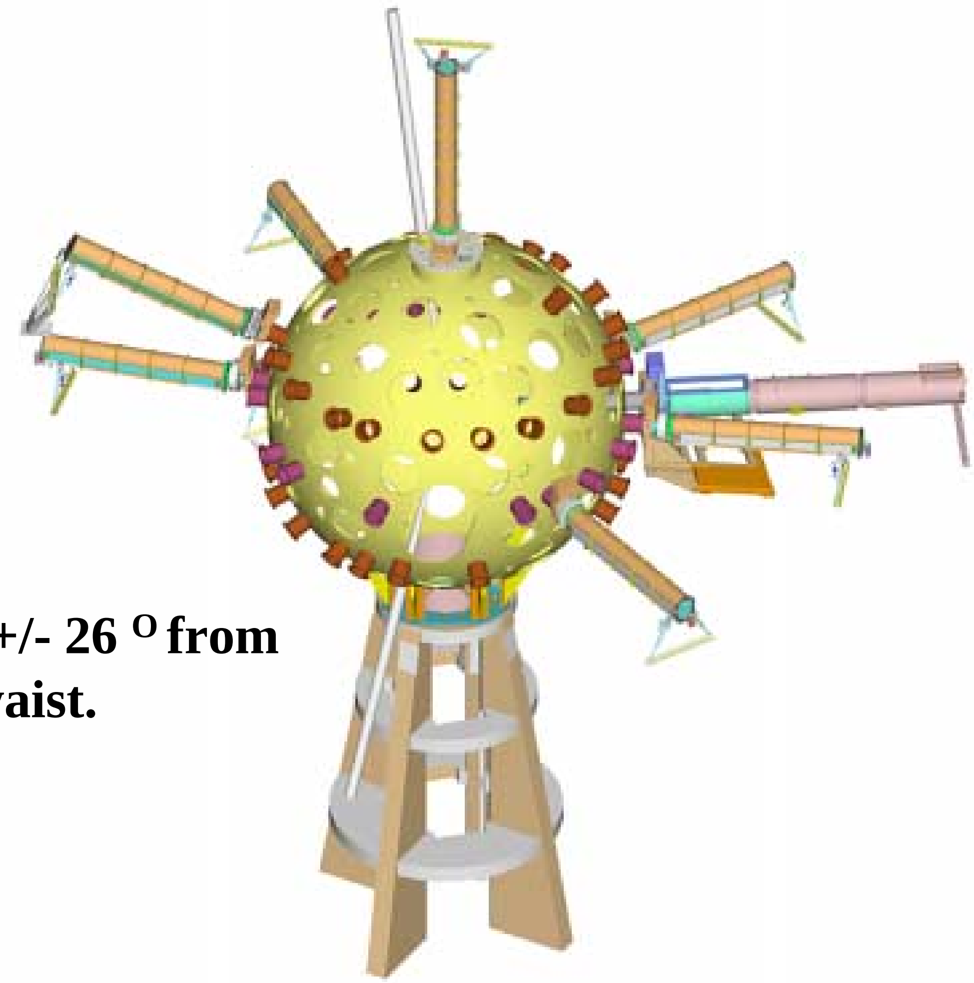

DIM's can go +/- 26 ^{O} from the chamber waist.

The DIM locations need to be put under configuration management

HENEX instrument concept

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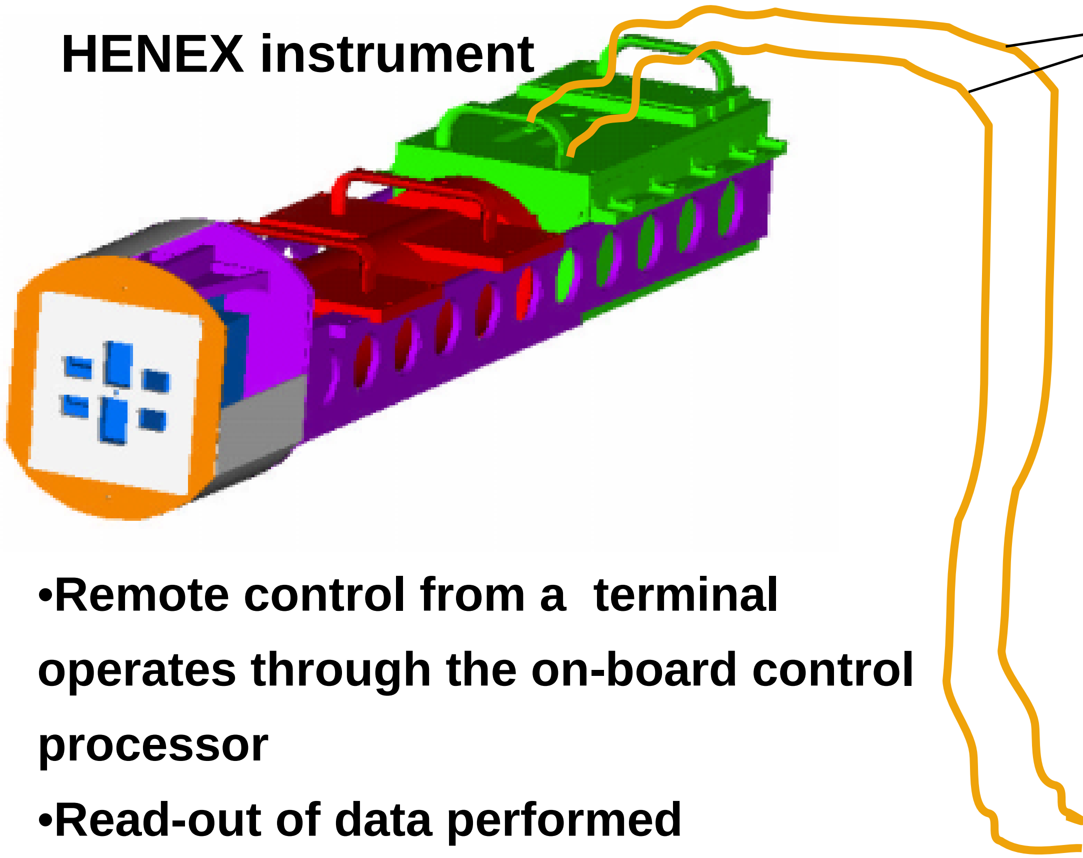
HENEX instrument



62.5 micron fiber optic cables

- **Remote control from a terminal operates through the on-board control processor**
- **Read-out of data performed automatically after each shot**

LLE HXS DCP & DIU is pictured.

HENEX instrument is compact and portable

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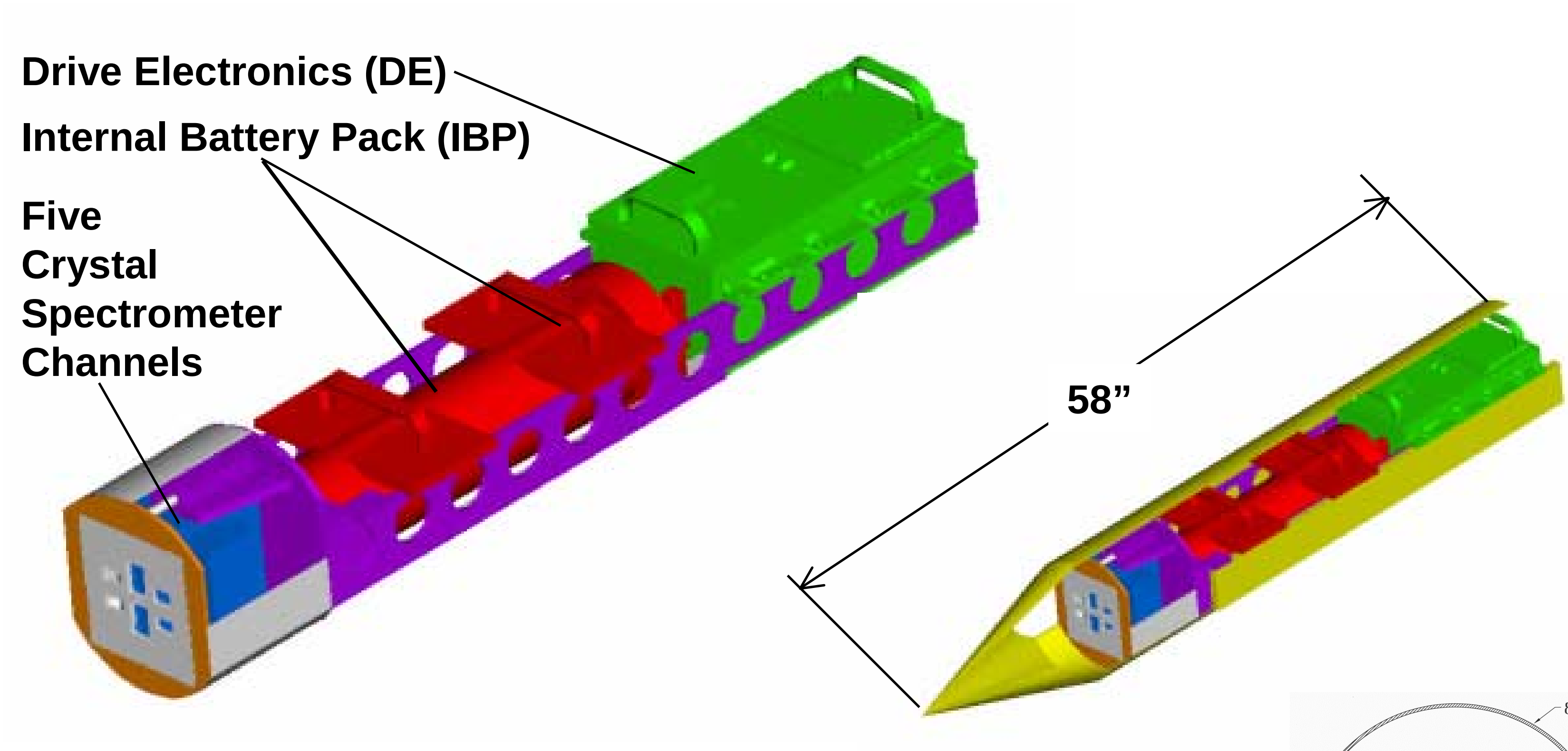
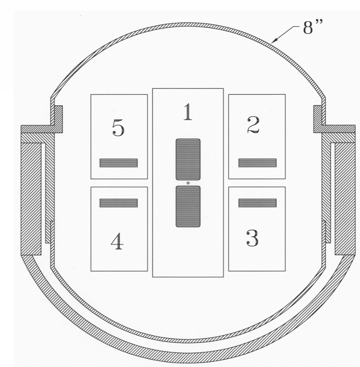
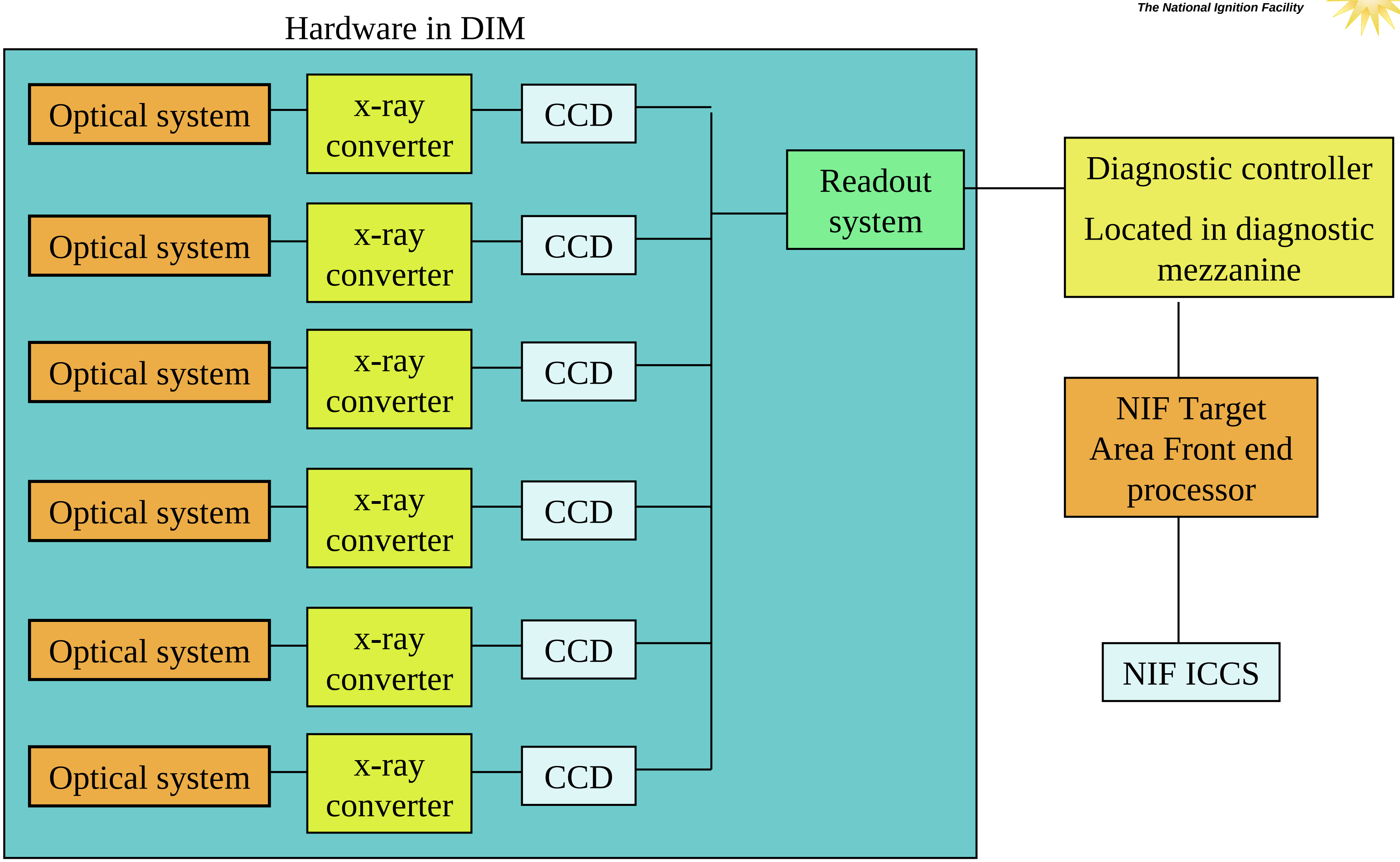


LLE’s TIM instrument size limits:

- **Maximum length including snout is 58” without special permission for use in the chamber.**



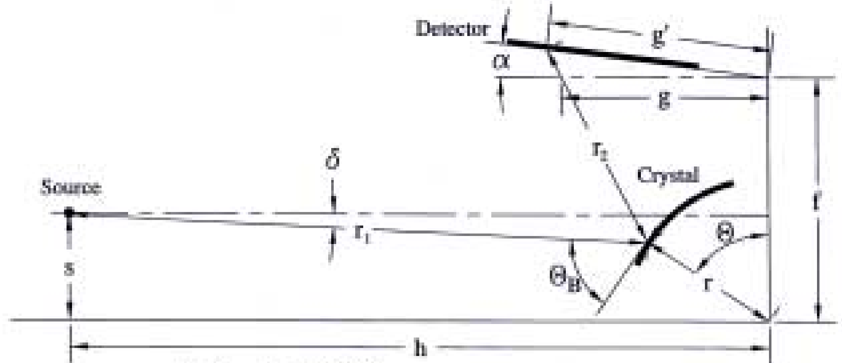
Block diagram of HENEX



Optical system – reflection crystals

- **Four convex reflection crystals:**
  - **Cover 1.1-10.9 keV**
  - **Similar to LLNL/HENWAY**
  - **The example shown is KDP and the other channels will utilize other crystals.**

CONVEX CRYSTAL DISPERSION GEOMETRY

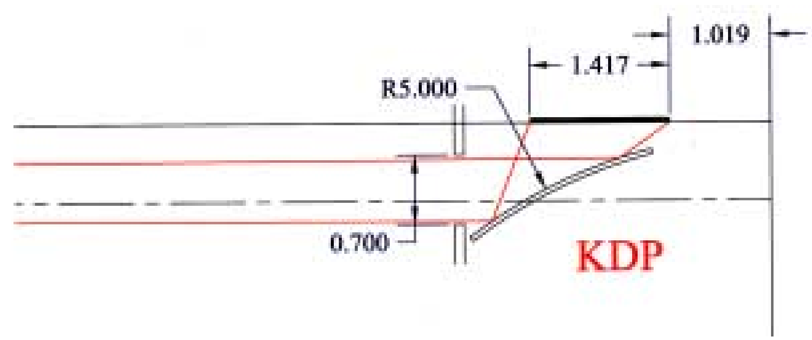


$$\delta = \tan^{-1}\left(\frac{s - r\cdot\cos\Theta}{h - r\cdot\sin\Theta}\right) \qquad \Theta_B = \Theta + \delta$$

$$g = r\cdot\sin\Theta + (r\cdot\cos\Theta - f)/\tan(2\cdot\Theta+\delta)$$

$$g' = g\cdot\frac{\sin(2\cdot\Theta+\delta)}{\sin(2\cdot\Theta+\delta+\alpha)} \qquad r_1 = (h - r\cdot\sin\Theta)/\cos\delta$$

$$r_2 = (f - r\cdot\cos\Theta)/\sin(2\cdot\Theta+\delta) + g\cdot\frac{\sin\alpha}{\sin(2\cdot\Theta+\delta+\alpha)}$$



Optical system – transmission crystal

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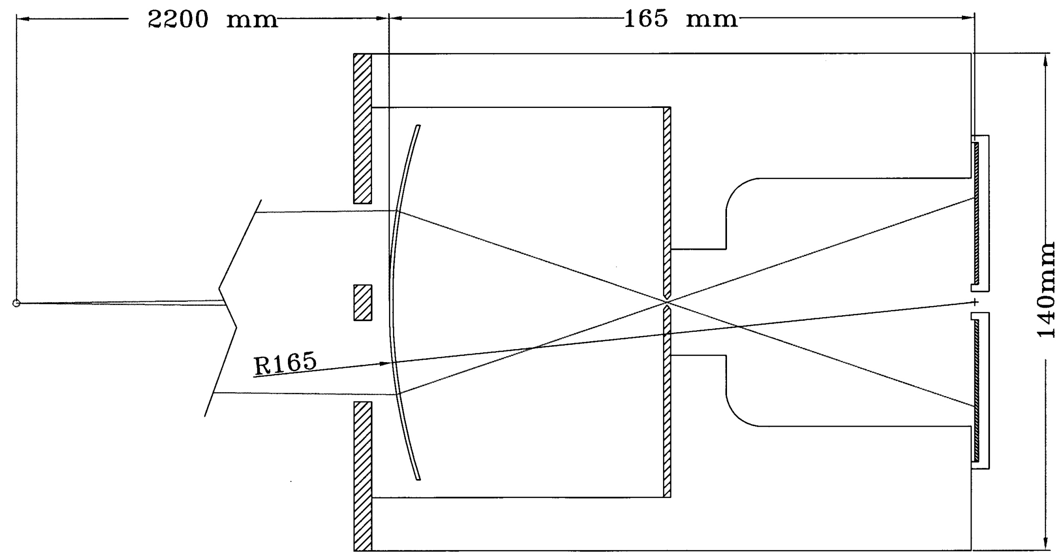
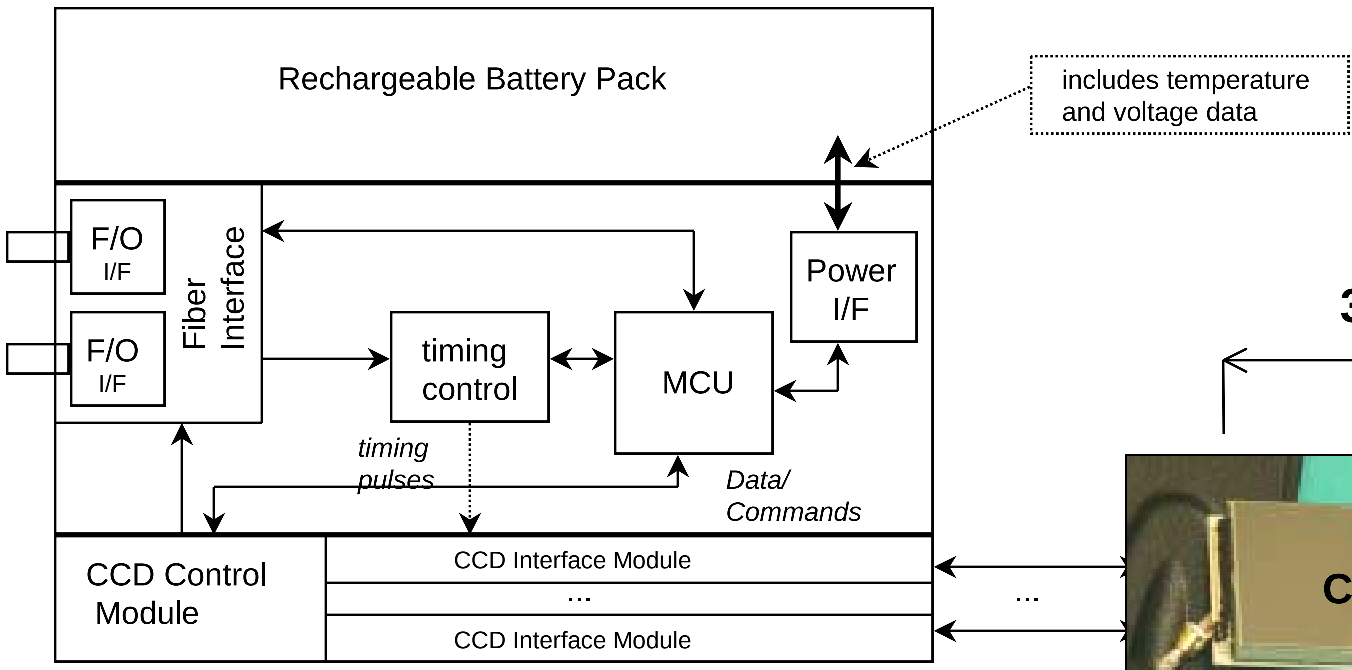
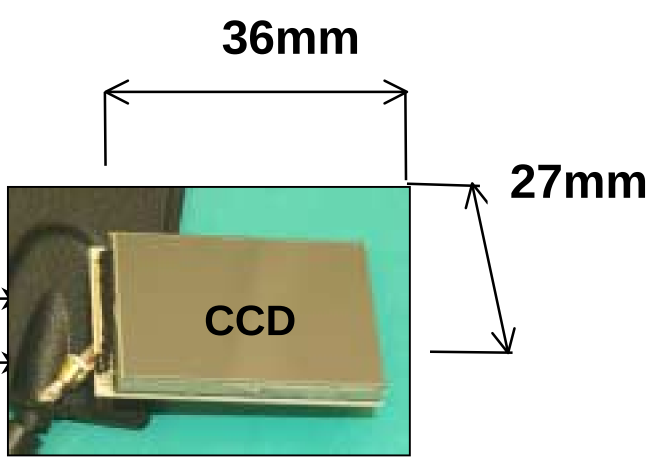
- **One transmission crystal:**
  - **Covers 8.6-20.1 keV**
  - **Developed at NIST**
  - **Similar to LLE/HXS**

Proposed HENEX Transmission Spectrometer



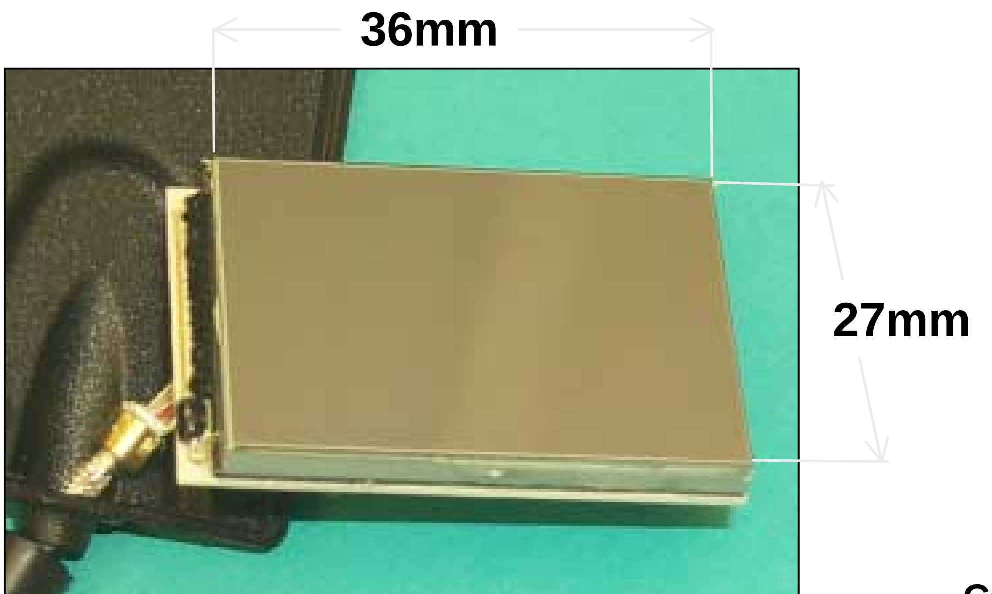
The HENEX electrical/mechanical drive electronics are driven by an on-board battery

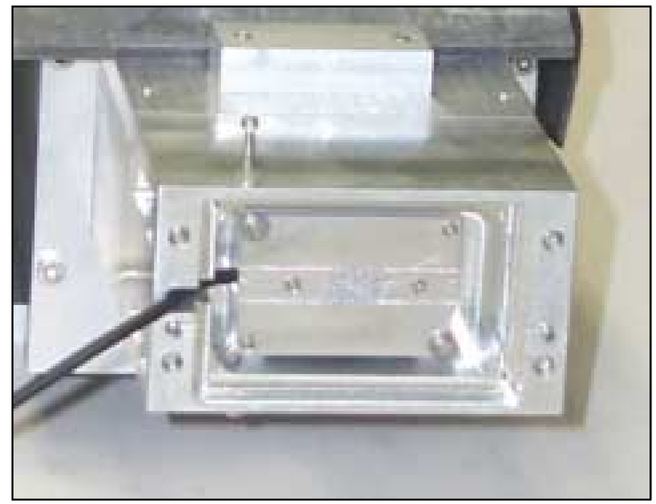




- **Data read from the CCD's into local, volatile memory as soon as shot is complete.**
- **Transferred via fiber-optic link to the Diagnostic Control Processor (DCP) for storage, display, etc**
- **CCD's and CCD I/F only powered when needed (low-power mode via commands from DCP)**

HENEX baseline CCD detector module





CCD Package mounted on NRL/NIST HXS instrument deployed at OMEGA 11/13-21/00

Front view of CCD package.

57.15mm x 38.15mm x 18.25mm

Side view of CCD package.

Rear view of CCD package.

Baseline HENEX CCD detector specifications

• Detectors (six CCD's) :	
• Active area	36 x 27mm
• Pixels	1840x1360, 19.5 microns
• Fiber optic input	Yes
• Replaceable device	Yes
• Cooling needed	No
• Integration time	1- 40 seconds
• X-ray detection technique	Scintillator converter screen optimized for each energy range
• Imaging specifications	
• CCD spatial resolution	20 lp/mm
• Dynamic range	2500

HENEX electronic system overview

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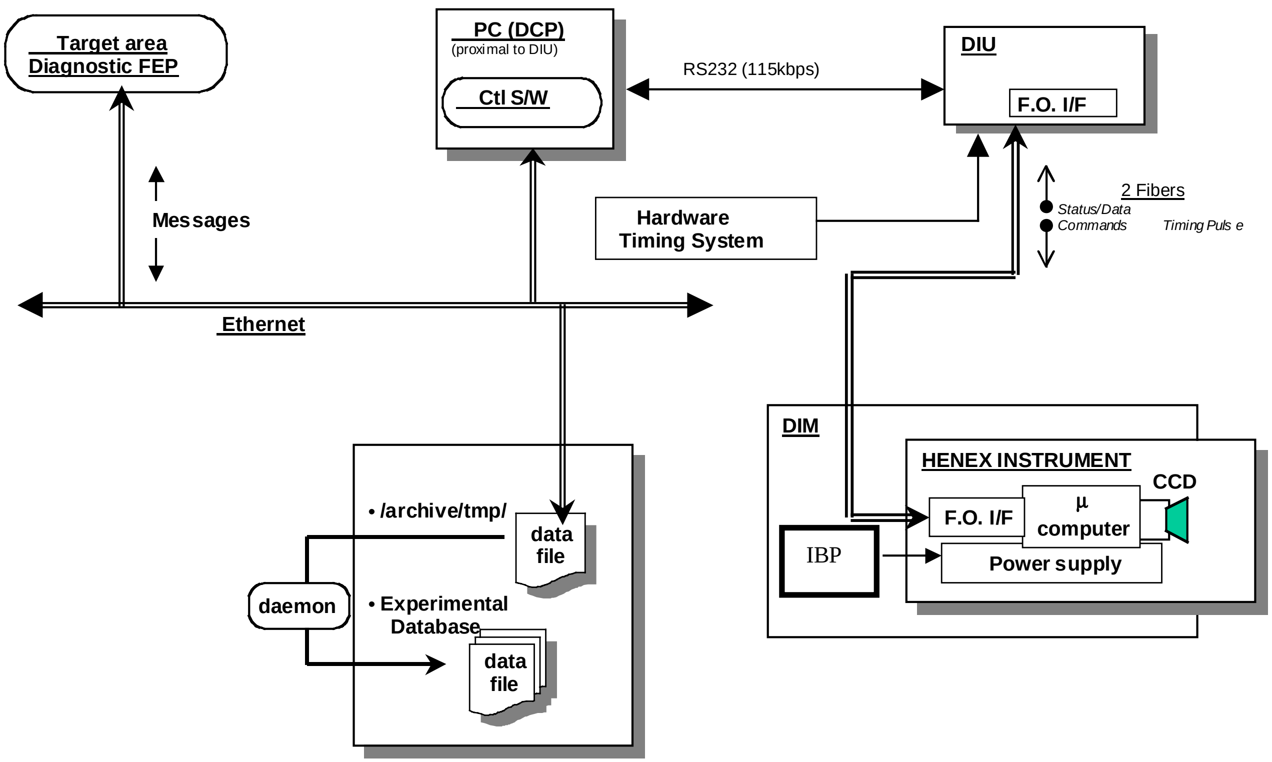

HENEX system consists of three basic parts:

- **Diagnostic Control Processor (DCP)**
- **Diagnostic Interface Unit (DIU)**
- **The diagnostic instrument itself**

HENEX electronic system detail (DCP)

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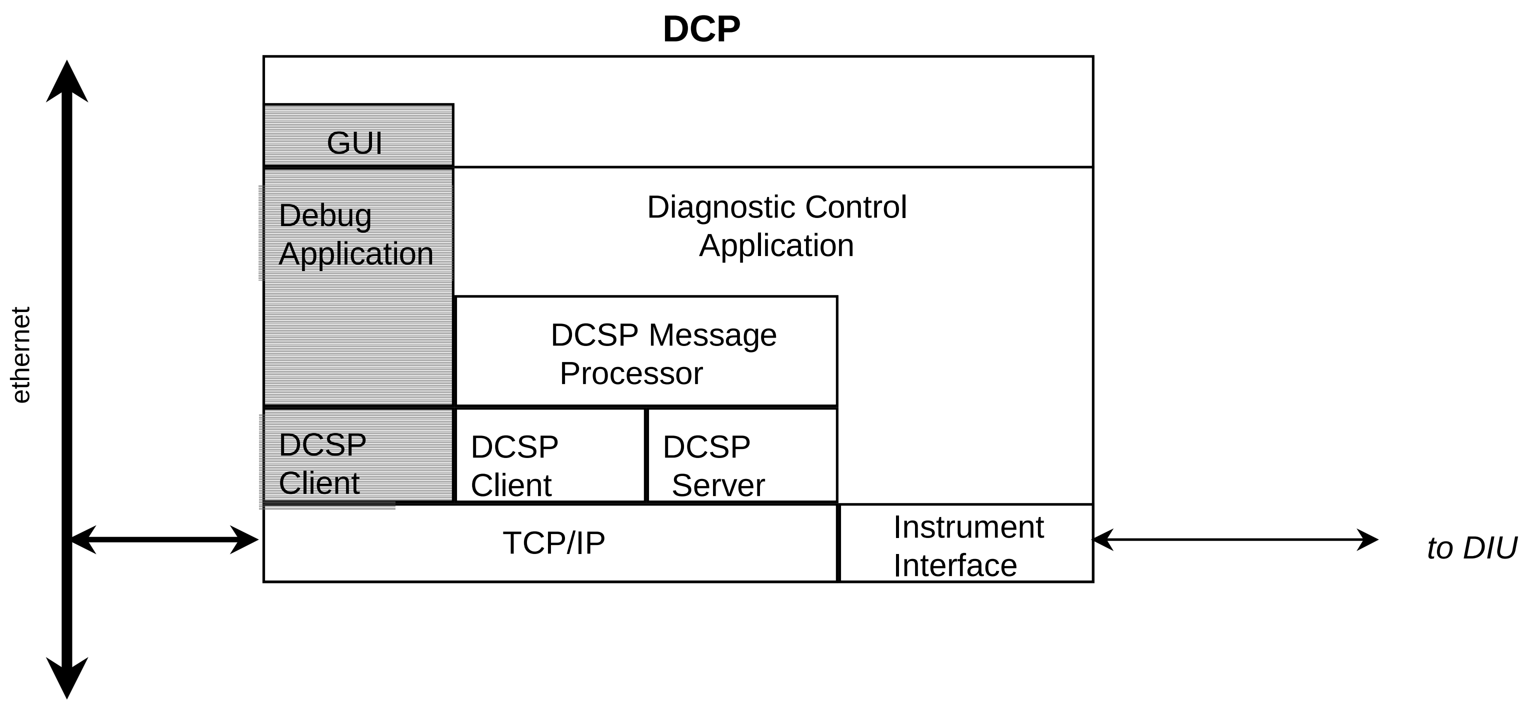
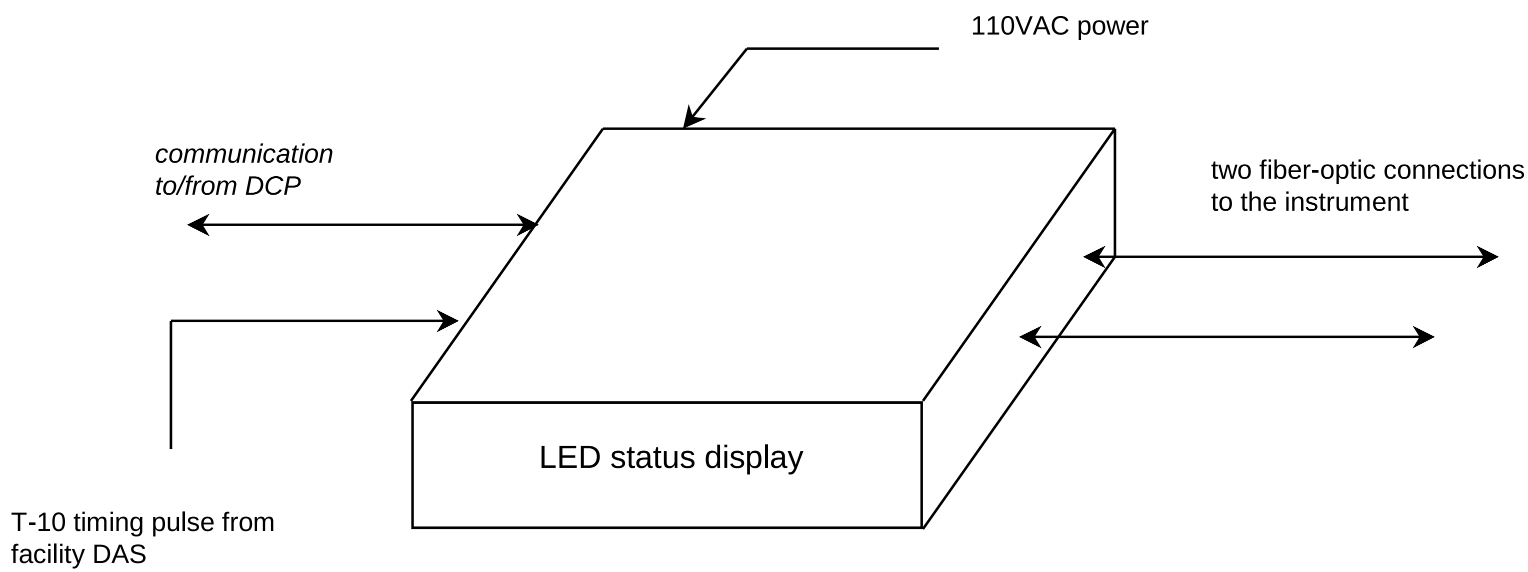


- The DCP interfaces to the NIF system via an DCSP Client. An DCSP server is provided for debug client connections.
- The DCSP Message Processor handles all message traffic, including Heartbeat, shot preparation, status, data requests.
- The Diagnostic Control Application interfaces with the diagnostic, providing all command and control functions except timing control. Communication is via a positive acknowledgement, error-checked protocol.
- A debug application can be run on the DCP (or an alternate machine) for stand-alone operation of the diagnostic.
- The DCA handles data conversion into NIF format as well as status logging on the data archive system.

HENEX electronic system detail (DIU)



- **Converts electrical communication signals to fiber and vice-versa.**
- **Receives timing pulse(s) and immediately forwards information via fiber to diagnostic.**
- **Provides testing signal generation capabilities.**
- **Provides status indicators for various operational parameters (power, optical link okay, etc).**

HENEX electronic system detail (diagnostic)

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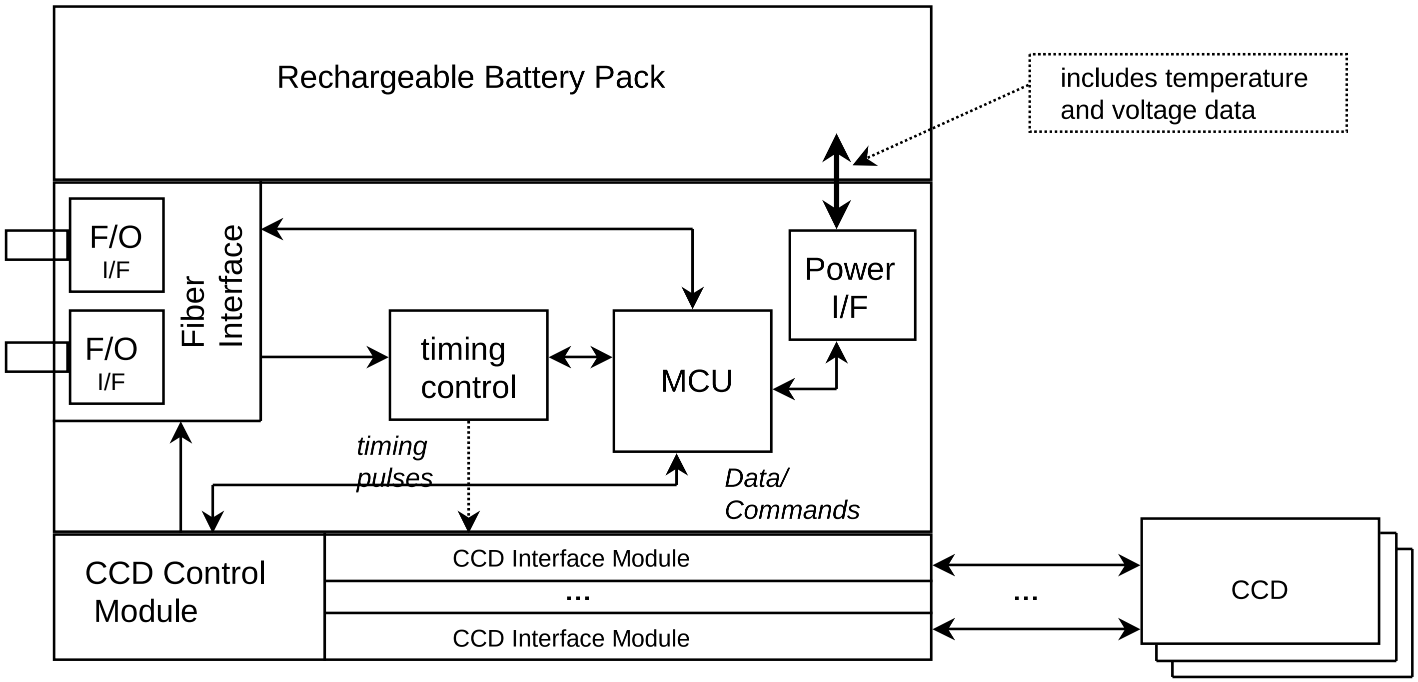


- Monitors temperatures, currents, voltages. These parameters & self-test are used to assess system ready at preshot.
- Diagnostic will run from a battery pack to limit system interference.
- Batteries are commercial NiCd cells:
    - Space-flight heritage in applications with restrictive contamination requirements.
    - No contamination if kept within temperature limits. Battery pack was deployed at LLE.
- Timing pulses managed by high-resolution timers.
- Data read from the CCDs into local, volatile memory as soon as the shot is complete.
    - Transferred via fiber-optic link to the DCP for storage, display, etc.
- CCDs and CCD I/F only powered when needed (low-power mode via commands from DCP).

REQUIREMENTS: calibration

- The instrument is required to have an absolute NIST traceable calibration standard for DTRA source characterization.

Calibration specification

- **Calibration of the diagnostic falls into three parts:**
  - **wavelength (or photon energy)**

    Wavelength calibration depends on the dispersion and geometry of the spectrometer. Calibration of the wavelength must be calibrated over the range of the active range of the detector. Appropriate K-edge filters coupled with a sufficiently bright hard x-ray calibration source (i.e. water-cooled Manson source, synchrotron, or other x-ray generator) is sufficient for this calibration.
  - **relative gain**

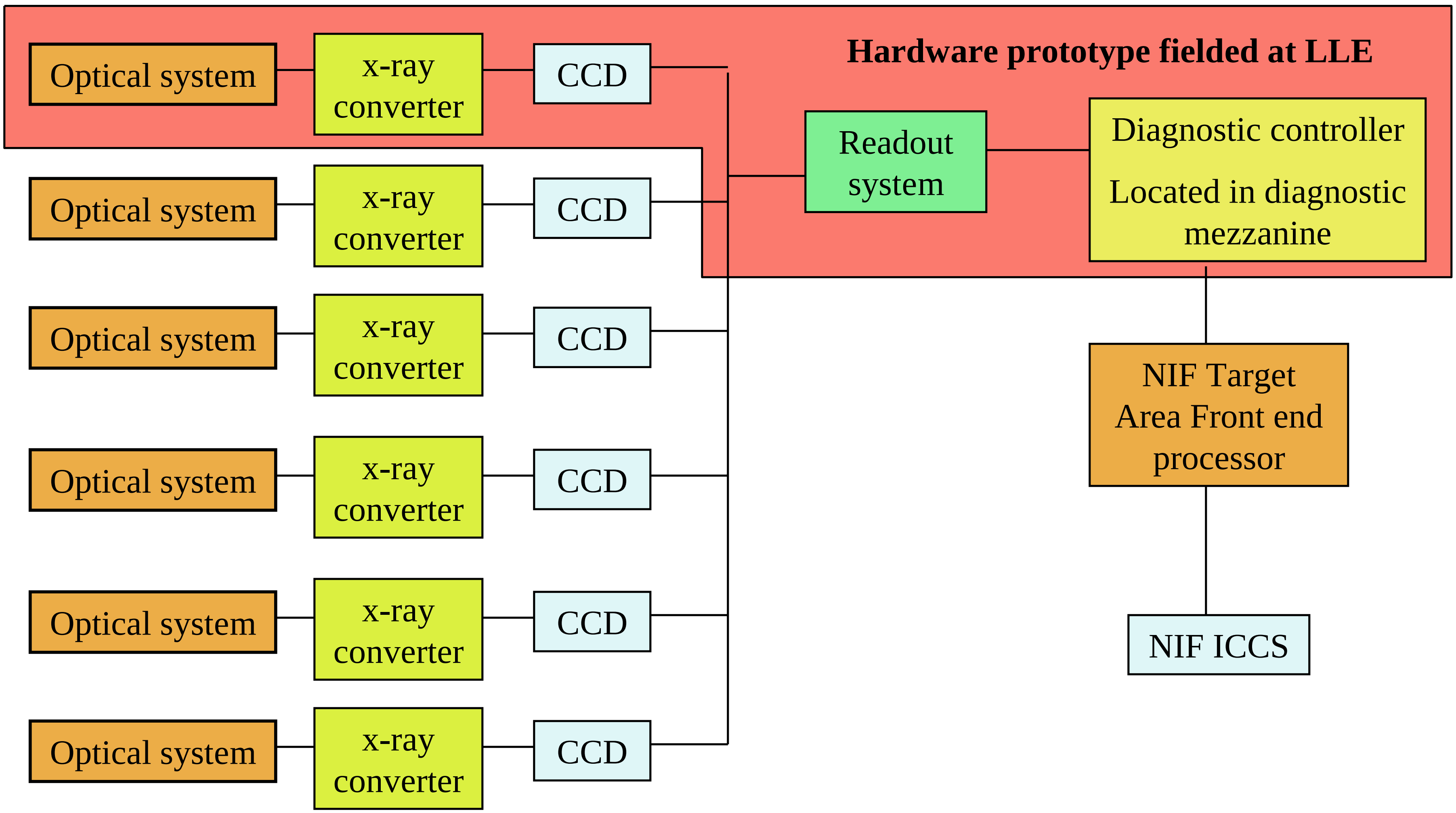
    Analysis of line intensity ratios can provide rough time-integrated measurements which bracket temperature and or density ranges if appropriate spectral lines are visible. Relative ratios of resonance lines can provide and estimates of ionic abundances. While ratios of dielectronic satellite lines to resonance lines are frequently temperature-sensitive and emission from metastable states can produce density sensitive spectroscopic signatures. For these purposes, the relative gain linearity of the CCD's must be characterized.
  - **absolute calibration**

    For measurements of conversion efficiency, the exposure on the detector must be able to be converted to total energy emitted in the x-ray spectral lines of interest. Therefore, absolute calibration of the diagnostic over a selected number of photon energies that adequately span the photon energy range of the instrument is necessary.

Testing and Validation at NIST and NRL

- The calibration effort is not funded in the CDR cost
- NIST should do the first calibration
    - Best capability / expertise of personnel
    - Lowest cost for an absolute traceable calibration
- Calibration cost is currently being finalized

A sub set of the instrument has been prototyped at LLE



The hard x-ray prototype spectrometer was deployed at the Omega laser in November 00

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•**Prototype HENEX components:**

- •**Transmission crystal (covering 12 - 60 keV).**
- •**CCD detector with 36mm x 27mm active area**
- • **and 19.5 micron pixels.**
- • **Drive Electronics (DE) package inside the TIM**
- • **was powered by an internal battery pack.**
- • **Command/control and data transmission via**
- • **fiber optic links to the instrument from a**
- • **remote computer/interface unit that was**
- • **connected to the host facility network.**

•**It can be fielded in a TIM or a DIM**

- •**testing in progress on Omega**

Example of raw HXS data

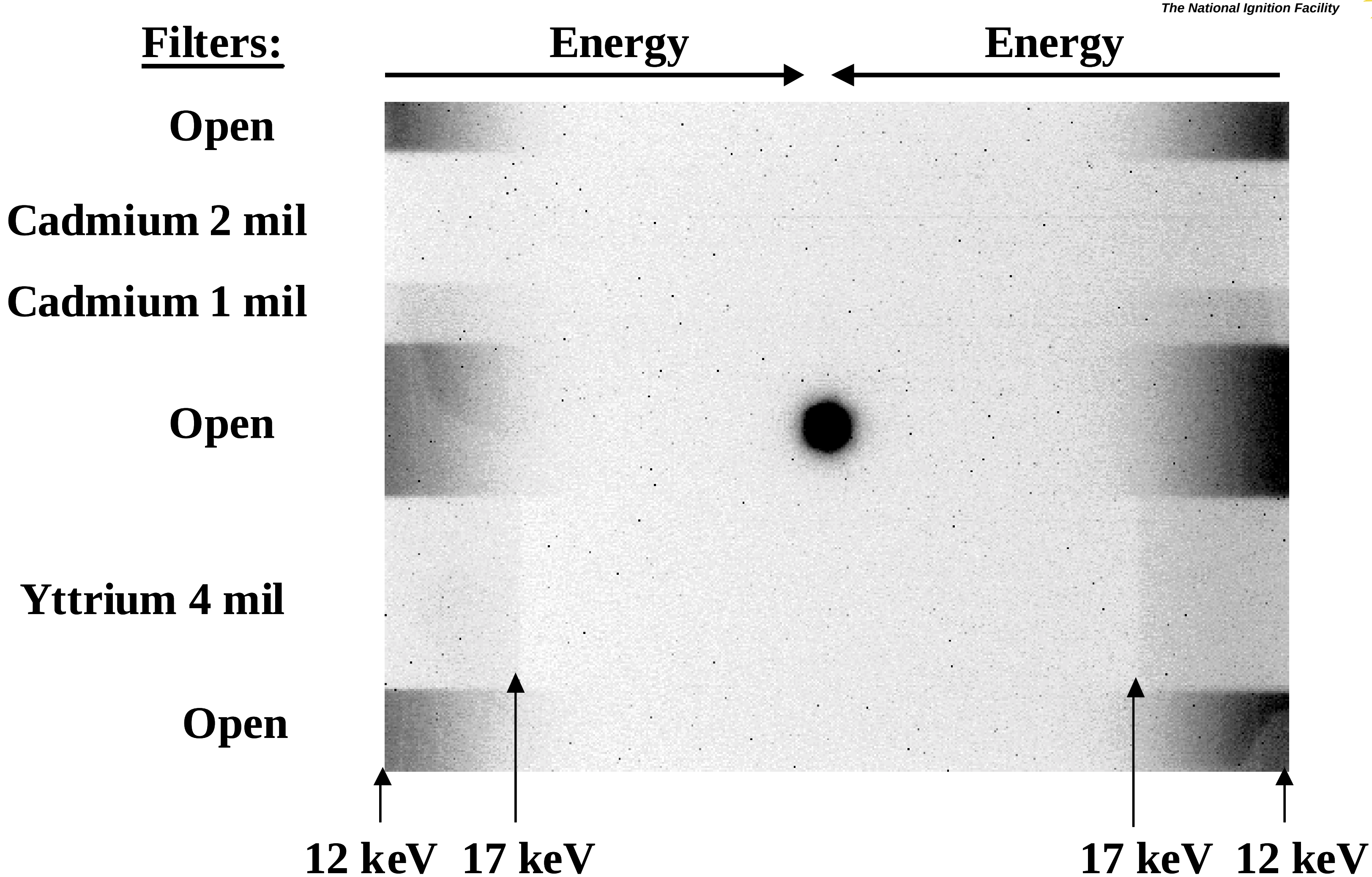

Fig. 5. The x -ray spec tral CCD image from shot #9 on Tu esday , Nov ember 14.

Hard X-Ray Spectrometer (HXS) results

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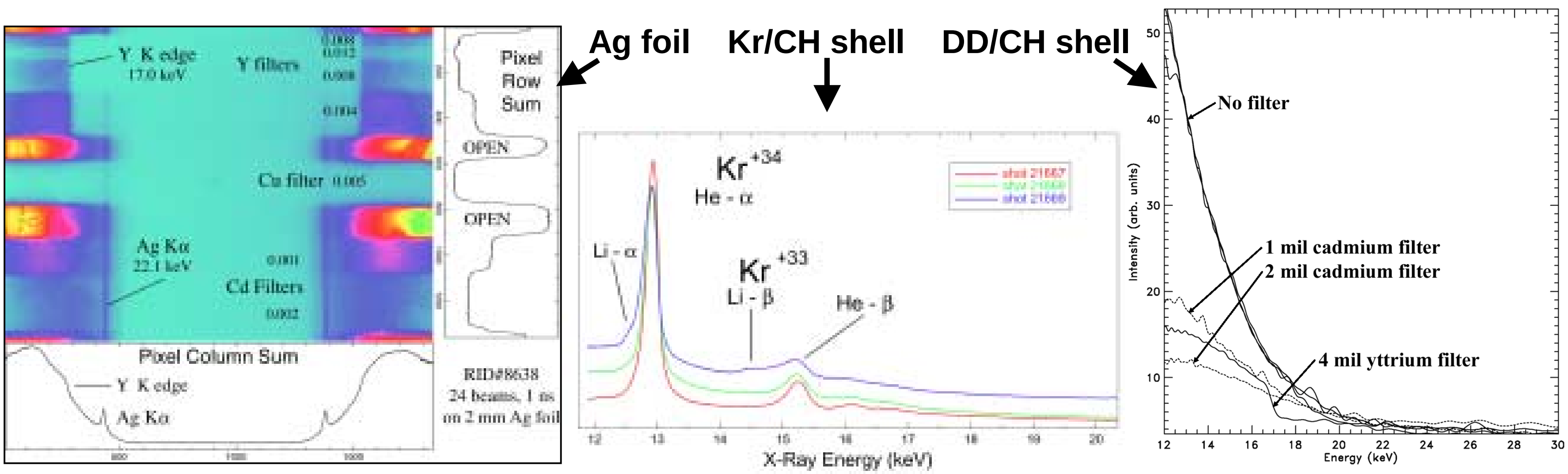
- **Technical issues were resolved during 11/13-17/00:**
  - **Upgraded the TIM#2 FO vacuum feedthrough and umbilical cabling.**
  - **Added ½" lead shielding to the Drive Electronics box.**
- **Spectral images were successfully recorded on all 11 shots on 11/21/00:**
  - **Two gold foils and one silver foil.**
  - **Five gold spheres (dedicated to the French DMX instrument).**
  - **Three krypton-filled CH shell targets.**
- **All HXS field test results are on the website spectroscopy.nrl.navy.mil.**



X-rays at 13 keV have been detected on the HXS transmission crystal spectrometer

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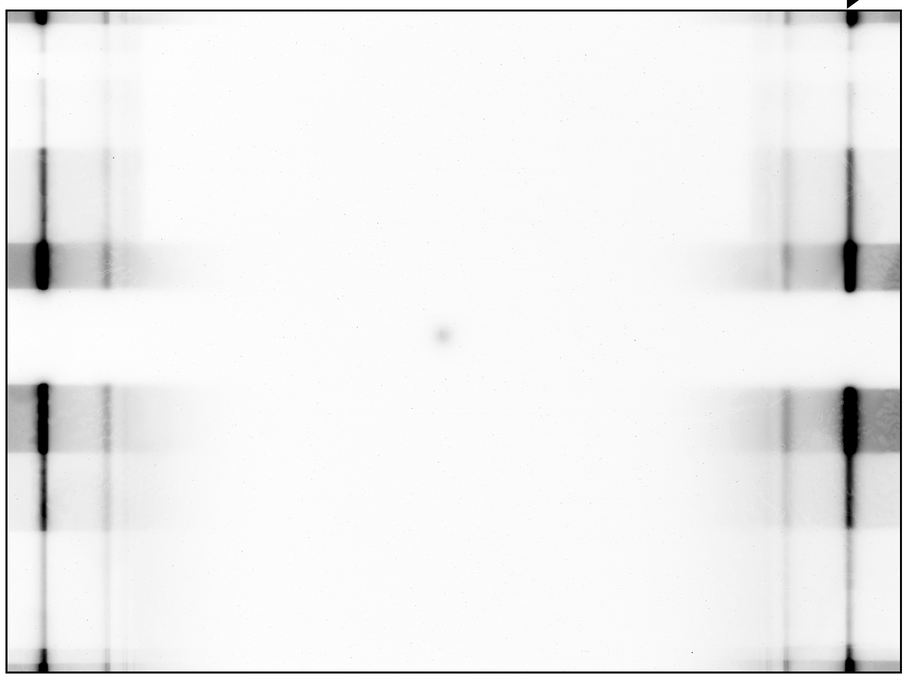
- **This diagnostic is NOT YET FUNDED to enable absolute calibration**

Kr K-shell
(13.1 keV)



Data taken on ride-along tests on
direct drive Kr gas-filled capsule experiments at Omega

HENEX data analysis capabilities

- Quick-look data:
    - Spectral lineouts are displayed within 15 minutes of the shot.
    - Relative intensity vs. x-ray energy for all 5 channels.
- Data files are archived to the facility data acquisition system.
- Filter transmittances are provided for each channel.
- NIST and NRL test and validation results are provided.

Total cost

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Total cost by year

	DESC	TOTAL	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008
2.10.4.3.5 Survey X-Ray Spectrmtr (Henex) 1 ea.											
F	ICF Scientists Labor	91	3	15	15	15	24	20			
L	LLNL Lasers	1532	451	409	436	43	135	59			
TOTAL	**435**	**1624**	**454**	**424**	**451**	**58**	**159**	**79**			
	REPORT TOTAL	**1624**	**454**	**424**	**451**	**58**	**159**	**79**			

Total cost breakdown

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FTE's man months by year & milestone

ACT CODE	DESCRIPTION	TOTAL	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006
1	M1 Conceptual Design	14.8	1.7	3.6	2.8	2.8	2.8	1.2	
2	M2 65% Design Review	0.5		0.5					
4A	Fabrication & Assemb								
4B	Offline Testing Comp	1.5			0.1	1.4			
5	M5 Dry Run Review	1.3				1.3			
6	M6 1st Use on NIF	1.7				0.4	1.3		
7	M7 Functional Operat	7					7		
8	M8 Facility Acceptan	12.1					5.4	6.7	
	REPORT TOTAL	**38.9**	**1.7**	**4.1**	**2.9**	**5.8**	**16.5**	**7.9**	

Procurements costs by year & milestone

ACT CODE	DESCRIPTION	TOTAL	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005	FY 2006
1	M1 Conceptual Design	197797	197797						
2	M2 65% Design Review	619494	239103	380391					
4A	Fabrication & Assemb	420000			420000				
	REPORT TOTAL	**1237291**	**436900**	**380391**	**420000**				

NRL HENEX project cost breakdown

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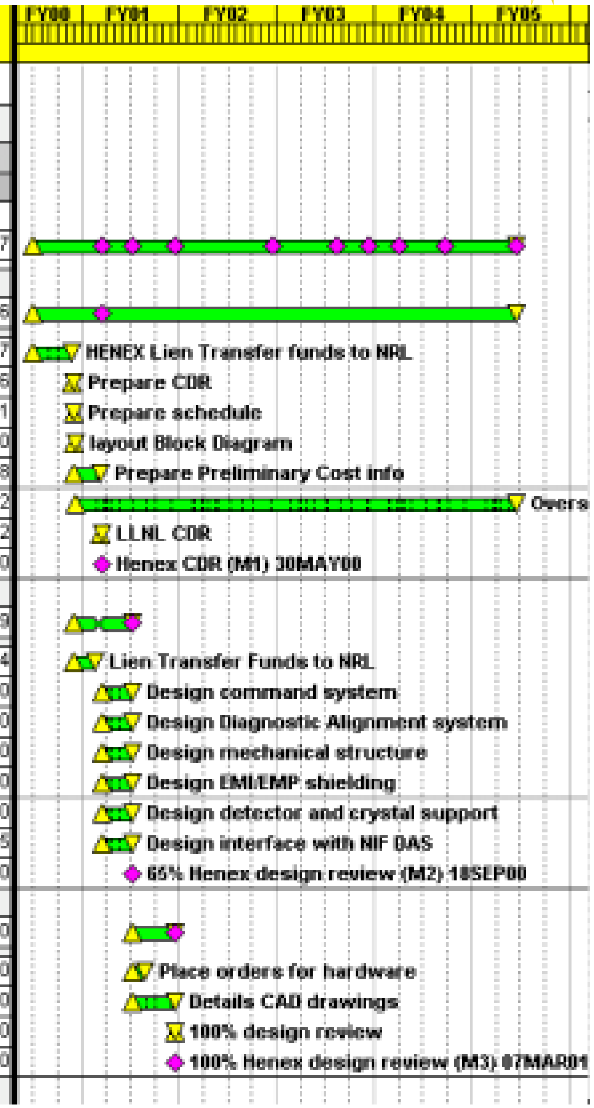
	CONCEPTUAL DESIGN FY00 (6 mos.)	CAD DESIGN & PROCUREMENTS FY01 (6 mos.)	FABRICATION FY01 (6 mos.)	ASSEMBLY & TESTING FY02 (3 mos.)	EXPERIMENTS AT LLE FY02 (3 mo.)	TOTAL 24 mos.
FUNCTION						
PI (J. Seely)	20	10	10	10	10	60
Co PI (R. Deslattes)	40	10		50	10	110
Proj Scientist (C. Brown)	10	10		10	10	40
Proj Engineer (L. Marlin)	10	20	20	10		60
INSTRUMENT						
Mechanical Tech. (G. Holland)	10	10	10	20	20	70
Software Eng. (R. Feldman)	20	20		20	10	70
Electrical Eng. (J. Moser)	20	20		20		60
Optical Scientist (L. Hudson)	20	10	30	50		110
Optical Tech. (NIST)		10	20	20		50
Quality Assurance (J. Batterton)		10				10
TOTAL BY QUARTER	150	130	90	210	60	640
HARDWARE						
Crystals and mounts		30				30
Spectrometer boxes			40			40
Instrument structure and shielding			35			35
8 CCDs,mounts,cabling,phosphors	20	140				160
Computer control & DAS		60				60
Software tools		6				6
Validation hardware and x-ray source				75		75
TOTAL BY QUARTER	20	236	75	75	0	406
TRAVEL AND DELIVERY						
Travel to LLNL (4 RT, 2 days each)	2	2				4
Travel to LLE (4 RT, 1 week each)					4	4
Shipping container (1 instrument)					1	1
TOTAL BY QUARTER	2	2	0	0	5	9
TOTAL COST	**172**	**368**	**165**	**285**	**65**	**1055**

Integrated Project Schedule

NIF
NRL
The National Ignition Facility

Activity ID	Total Float	Activity Description	Orig Dur	Early Start	Early Finish	Budgeted Quantity	Budgeted Cost
2 NIF OPERATIONS							
2.10 TARGET EXPERIMENTAL SUPPORT							
2.10.04 DIAGNOSTICS							
2.10.04.03 CORE DIAGNOSTICS							
2.10.04.03.05 X-RAY SPECTROMETER (HENEX) 1 EA							
Subtotal	40		1,235	29MAR00	15MAR05	1,060,595	1,623,487
2.10.04.03.05.01 REQUIREMENTS DEFINITION							
Subtotal	40		1,235	29MAR00	15MAR05	174,135	354,616
2A48010	61	HENEX Lien Transfer funds to NRL	102	29MAR00	22AUG00	171,997	197,797
2A44990	61	Prepare CDR	5	23AUG00	29AUG00	80	6,246
2A45000	153	Prepare schedule	2	30AUG00	31AUG00	16	1,071
2A44995	128	layout Block Diagram	4	30AUG00	05SEP00	70	3,950
2A45005	61	Prepare Preliminary Cost info	70	31AUG00	11DEC00	168	10,178
4351000	40	Oversite of Project	1,125	05SEP00	15MAR05	1,800	135,082
2A48020	61	LLNL CDR	1	12DEC00	12DEC00	4	292
2A45010	61	Henex CDR (M1) 30MAY00	0		12DEC00	0	0
2.10.04.03.05.02 65% DESIGN							
Subtotal	61		149	30AUG00	06APR01	533,069	625,569
2A48090	153	Lien Transfer Funds to NRL	57	30AUG00	17NOV00	532,999	619,494
2A48030	61	Design command system	77	13DEC00	06APR01	0	0
2A48040	61	Design Diagnostic Alignment system	77	13DEC00	06APR01	0	0
2A48050	61	Design mechanical structure	77	13DEC00	06APR01	0	0
2A48060	61	Design EMI/EMP shielding	77	13DEC00	06APR01	0	0
2A48070	61	Design detector and crystal support	77	13DEC00	06APR01	0	0
2A48080	61	Design interface with NIF DAS	77	13DEC00	06APR01	70	6,075
2A45090	61	65% Henex design review (M2) 18SEP00	0		06APR01	0	0
2.10.04.03.05.03 100% DESIGN							
Subtotal	61		110	10APR01	13SEP01	0	0
2A48120	139	Place orders for hardware	30	10APR01	21MAY01	0	0
2A48110	61	Details CAD drawings	108	10APR01	11SEP01	0	0
2A48130	61	100% design review	2	12SEP01	13SEP01	0	0
2A45165	61	100% Henex design review (M3) 07MAR01	0		13SEP01	0	0
2.10.04.03.05.04 FAB & OFFLINE ACCEPTANCE							



Integrated Project Schedule (continued)

NIF NRL
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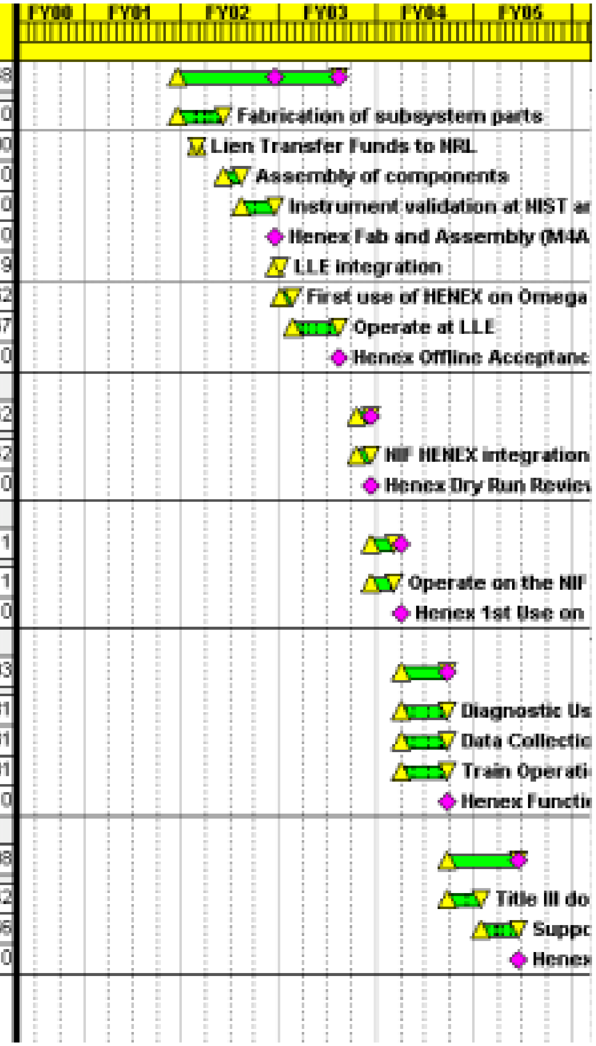
Activity ID	Total Float	Activity Description	Orig Dur	Early Start	Early Finish	Budgeted Quantity	Budgeted Cost
Subtotal	101		415	14SEP01	16MAY03	350,211	432,548
2A48140	61	Fabrication of subsystem parts	115	14SEP01	05MAR02	0	0
2A48160	171	Lien Transfer Funds to NRL	1	27NOV01	27NOV01	350,000	420,000
2A48150	61	Assembly of components	46	06MAR02	09MAY02	0	0
2A48170	61	Instrument validation at NIST and NRL	90	10MAY02	17SEP02	0	0
2A45290	61	Henex Fab and Assembly (M4A) 08MAY02	0		17SEP02	0	0
2A48190	61	LLE integration	14	18SEP02	07OCT02	21	1,219
2A48220	61	First use of HENEX on Omega	30	08OCT02	18NOV02	48	2,862
2A48235	61	Operate at LLE	120	19NOV02	16MAY03	142	8,467
2A45318	101	Henex Offline Acceptance Tests (M4B) 06JAN03	0		16MAY03	0	0
2.10.04.03.05.05 DRY RUN REVIEW							
Subtotal	20		40	17JUL03	11SEP03	191	12,842
2A48245	20	NIF HENEX integration	40	17JUL03	11SEP03	191	12,842
2A45315	20	Henex Dry Run Review (M5) 05MAR03	0		11SEP03	0	0
2.10.04.03.05.06 1ST USE ON NIF							
Subtotal	6		74	12SEP03	30DEC03	240	14,311
2A48255	20	Operate on the NIF	60	12SEP03	08DEC03	240	14,311
2A49205	6	Henex 1st Use on NIF (M6) 30MAY03	0		30DEC03*	0	0
2.10.04.03.05.07 HENEX FUNCTIONAL OPERATION							
Subtotal	6		120	02JAN04	23JUN04	1,008	64,893
2A48210	6	Diagnostic Used as a Tertiary on Shots	120	02JAN04	23JUN04	336	21,631
2A48215	6	Data Collection and Analysis	120	02JAN04	23JUN04	336	21,631
2A48225	6	Train Operation Staff	120	02JAN04	23JUN04	336	21,631
2A45330	6	Henex Functional Operation (M7) 18NOV03	0		23JUN04	0	0
2.10.04.03.05.08 HENEX FACILITY ACCEPTANCE							
Subtotal	40		179	24JUN04	15MAR05	1,741	118,708
2A48230	40	Title II documentation	90	24JUN04	29OCT04	1,014	68,442
2A48240	40	Support for Secondary or Primary Diagnostic	89	01NOV04	15MAR05	727	50,266
2A45390	40	Henex Facility Accept Rview (M8) 10AUG04	0		15MAR05	0	0



Summary of CDR on the HENEX 12/12/00

- **HENEX diagnostic has been designated as a core diagnostic for NIF**
  - All user requirements have been incorporated into the specifications
- **A compact and portable design has been presented**
- **<u>All</u> diagnostic capabilities have been demonstrated in previous instruments**
- **A prototype has proven to be operationally robust**
  - unaffected by EMP
  - withstands neutron yields of up to 1 x 10^9 neutrons
- **Funding is needed for absolute calibration !!**
  - NIST proposal is in-hand, cost is forth coming
- **We have reduced the NIF waste stream by the use of electronic readout**
- **We have vastly improved data availability to enable real-time assessment of experiments**