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Title: ICF GAMMA-RAY MEASUREMENTS ON THE NIF

Author(s): H.W. Herrmann, N.M. Hoffman, Y. Kim, C.S. Young, J.M. Mack, D.C. Wilson, R.C. Shah, S.E. Caldwell, S.H. Batha (LANL), W. Stoeffl, P.W. Watts, A.C. Carpenter, J. Liebman, L. Bernstein, L. Dauff (LLNL), C.J. Horsfield, M. Rubery (AWE), E.K. Miller (NSTec, STL), E. Grafil (CSM)

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Los Alamos
NATIONAL LABORATORY
EST. 1943

ICF GAMMA-RAY MEASUREMENTS ON THE NIF

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[5]*Colorado School of Mines, Golden, CO 80401, USA*

The primary objective of the NIF Gamma Reaction History (GRH) diagnostic is to provide bang time and burn width information in order to constrain implosion simulation parameters such as shell velocity and confinement time. This is accomplished by measuring DT fusion gamma-rays (DTγ, and HTγ in THD implosions) with energy-thresholded Gas Cherenkov detectors that convert MeV gamma-rays into UV/visible photons for high-bandwidth optical detection. Timing reference relative to the laser pulse is provided by laser-induced x-rays generated from a silver foil placed at target chamber center. For these "timing shots", the GRH is operated with an x-ray sensitive scintillator in place of the gamma-to-electron convertor. The x-rays provide a "t0" from which to calibrate optical timing fiducials which are injected directly into the GRH optical path before the PMT. Directly-driven DT exploding pushers are used for in-situ cross-calibration of the detector response against independent neutron yield measurements. In this way, gamma-rays can be used to make Total DTn Yield inferences on indirectly-driven, cryogenically-layered implosions which achieve high areal density and hence scatter a significant fraction of DTn out of the 14 MeV primary peak. In addition, the four GRH detectors can perform thresholded γ-ray spectroscopy to explore other nuclear processes from which additional significant implosion parameters may be inferred (e.g., plastic ablator areal density). Implementation is occurring in 2 phases: 1) four PMT-based channels mounted to the outside of the NIF target chamber at ~6 m from TCC (GRH-6m) for the 3e13-3e16 DT neutron yield range expected during the early ignition-tuning campaigns; and 2) several channels located just inside the target bay shield wall at ~15 m from TCC (GRH-15m) with optical paths leading through the wall to well-shielded streak cameras and PMTs for the 1e16-1e20 yield range expected during the DT ignition campaign. This suite of diagnostics will allow exploration of interesting γ-ray physics well beyond the ignition campaign. Recent data from OMEGA and NIF will be shown.

NIC

ICF Gamma-Ray Measurements on the NIF
IFSA, Sept, 2011
Bordeaux, France

H.W. Herrmann

Los Alamos National Laboratory

LA-UR 10-07461

This work performed under the auspices of the U.S. DOE by Los Alamos and Lawrence Livermore National Laboratories under Contracts DE-AC52-06NA25396 and DE-AC52-07NA27344

Acknowledgments

Y.H. Kim, N. Hoffman, D.C. Wilson, C.S. Young, J.M. Mack, J.R. Langenbrunner, S. Evans, T. Sedillo, S. Batha,…

Los Alamos Nat'l Lab

W. Stoeffl, L. Bernstein, J. Church, A. Carpenter, P. Watts, L. Dauffy, S. Azevedo, J. Liebman, D. Sayre **and the *NIF* Team**

Lawrence Livermore Nat'l Lab

C.J. Horsfield, M. Rubery, W. Garbett

Atomic Weapons Establishment

E.K. Miller, R. Malone, M. Kaufman, B. Cox, Z. Ali, T. Tunnell,…

Nat'l Security Technologies

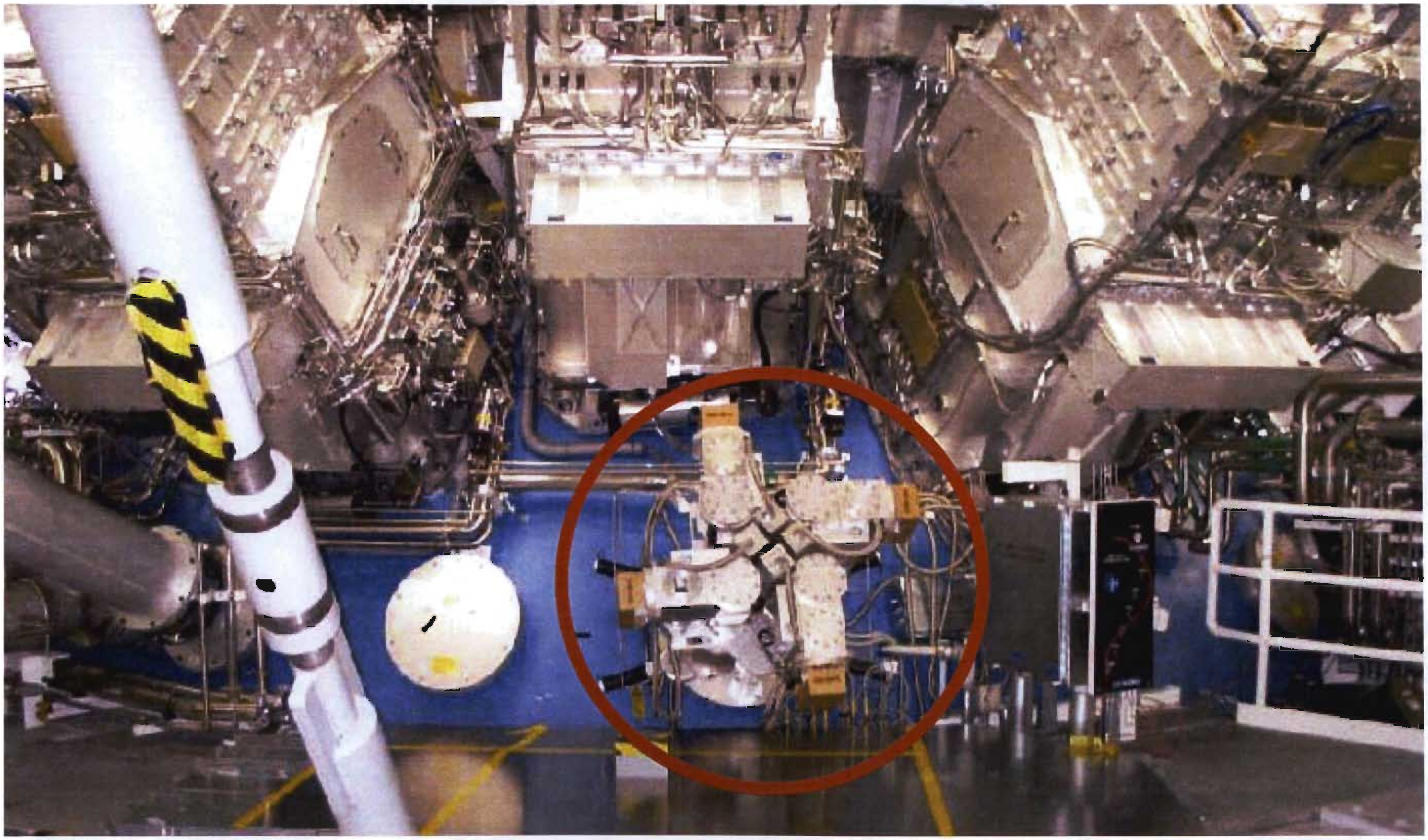
E. Grafil

CO School of Mines

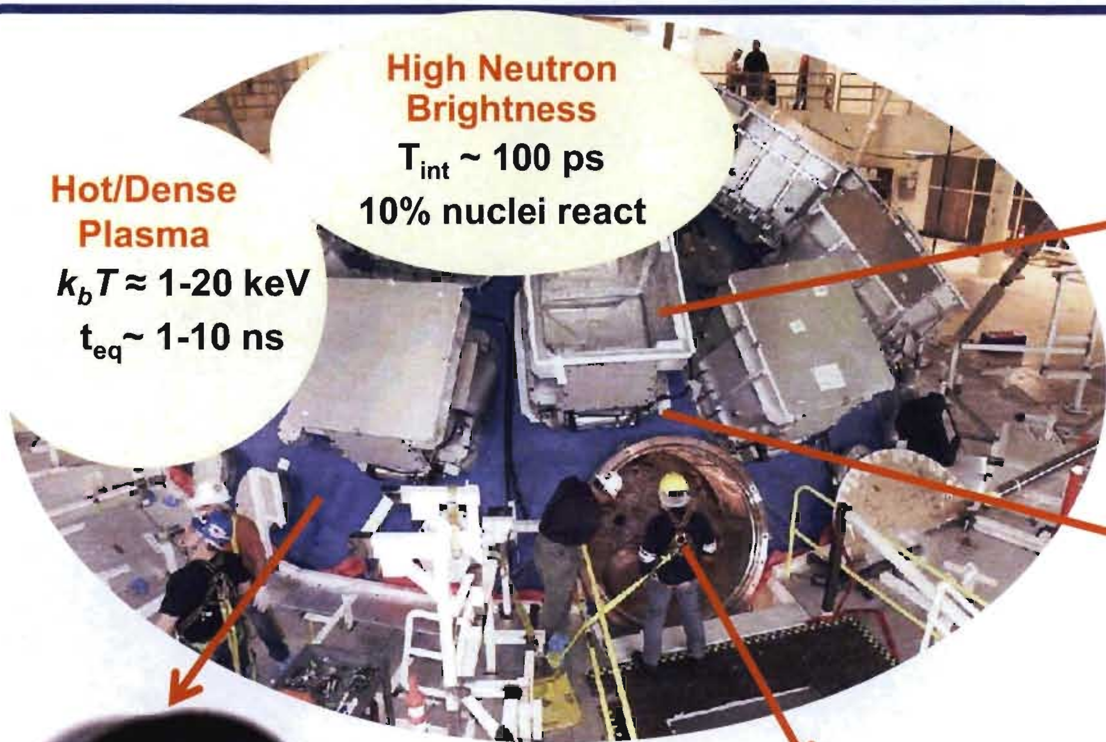
V. Yu. Glebov, T. Duffy and the *OMEGA* Team

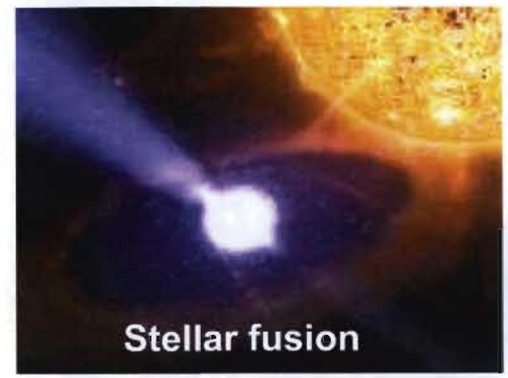
Laboratory for Laser Energetics

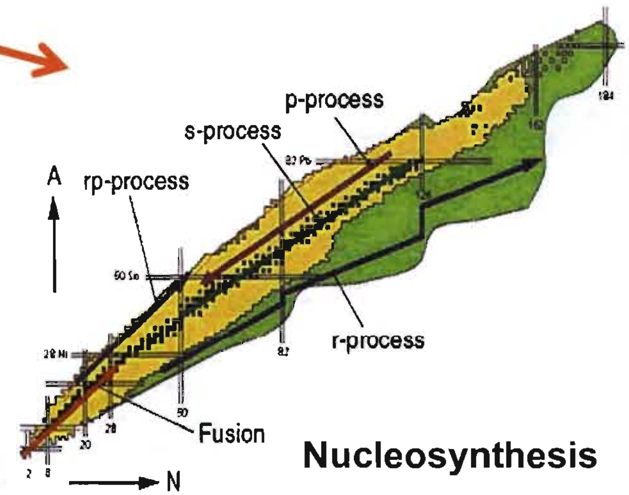
GammaReactionHistory at NIF



Unique conditions achievable at NIF open new avenues of investigation for nuclear science – Nuclear Plasma Science

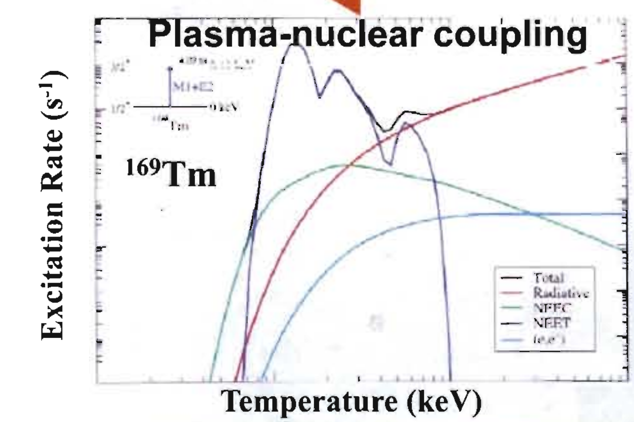






Nucleosynthesis

Neutronic coupling/
excited states

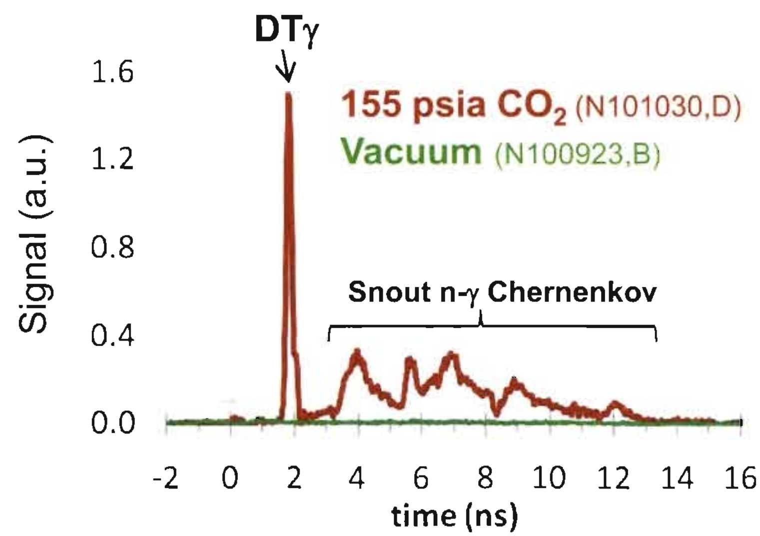


Bill Goldstein, LLNL
Nuclear Science Panel
NIF Users Wkshp
DC, May 2011

Summary

- **Gamma-Rays provide the opportunity to measure:**
  - **Fusion Reaction History**
    - **Bang-Time & Burn-Width**
  - **Yields of various nuclear reactions from which to infer:**
    - **Plastic Ablator Areal Density (ρR)**
    - **Total DT neutron yield**

- **ICF Gamma-Ray Diagnostics:**
  - **are now operating on both OMEGA & NIF**
  - **provide fertile ground for HEDP & Nuclear Plasma Science**



Outline

- **Intro**
  - Fusion Reaction History
  - γ-Ray Gas Cherenkov Detectors
  - Gamma Reaction History Diagnostics (GRH-6m) on NIF
- **NIF γ-ray Measurements**
  - Timing Calibrations
  - Reaction History (Bang Time & Burn Width)
  - Gamma-ray Spectrum & Yields
- **Future Directions & Summary**

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- **Summary**

Fusion Reaction History can be determined through time-resolved measurements of escaping fusion products

NIF
The National Ignition Facility

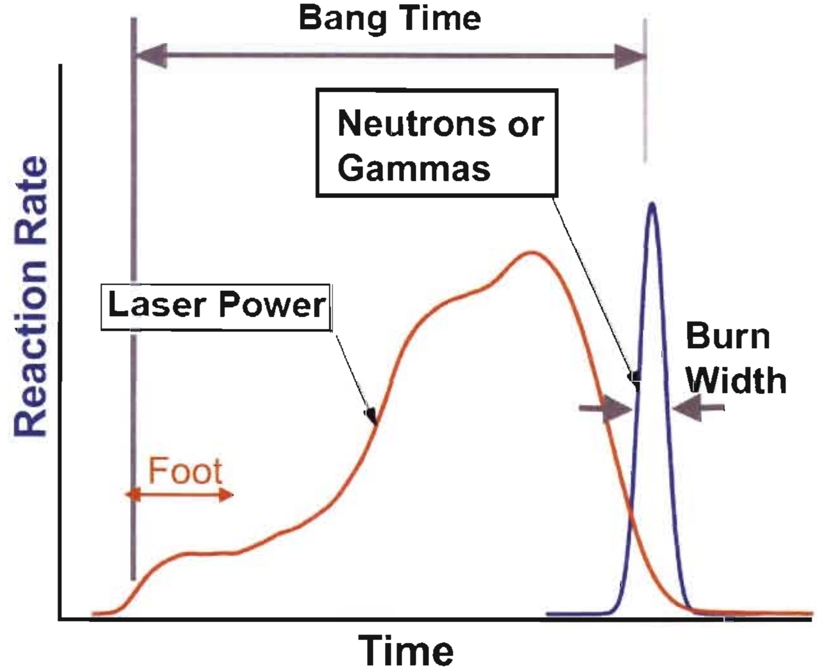
Doppler broadened

no escape (hopefully)

$$D + T \rightarrow {}^5He^* \begin{cases} \xrightarrow{\sim 1} n(14.1\ MeV) + \alpha(3.5\ MeV) \\ \xrightarrow{\sim 3e-5} {}^5He + \gamma(16.75 MeV) \rightarrow n + \alpha \end{cases}$$

Y. Kim
APS-DPP

C. Horsfield
O.Tu_C.8

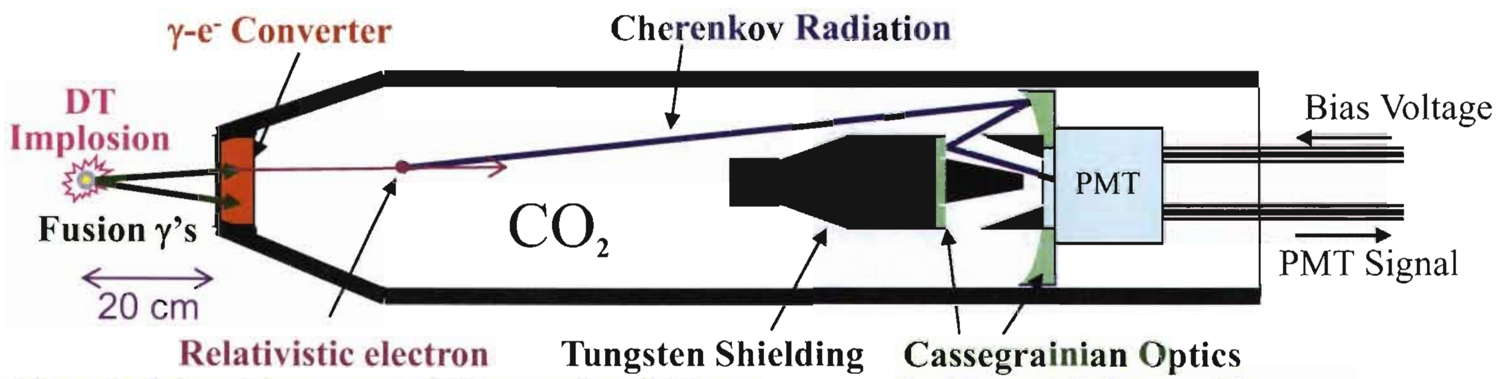


- **Bang Time** - used to establish laser energy coupling to target (shell velocity)

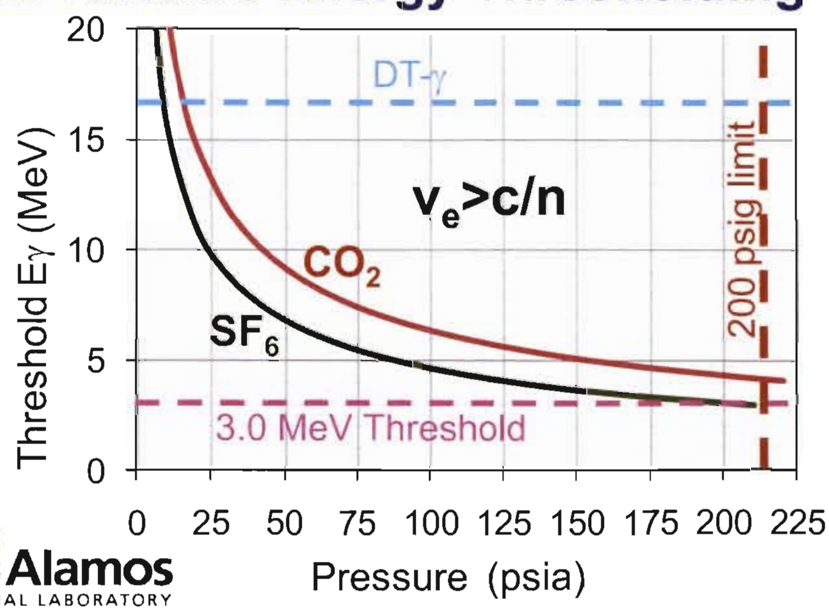
- **Burn Width** - used for failure mode correlation

Why use a Gas Cherenkov Detector (GCD)?

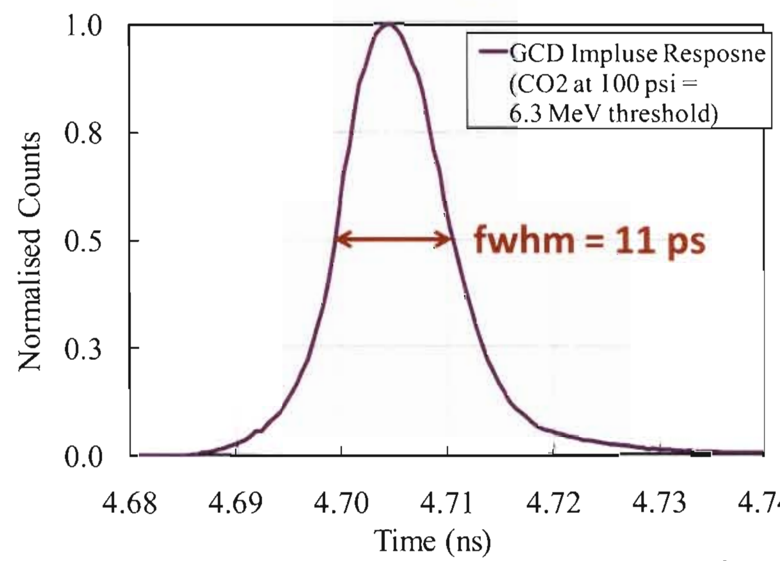
1. Convert MeV γ-rays to UV/Visable photons



2. Variable Energy Thresholding



3. Fast Time Response



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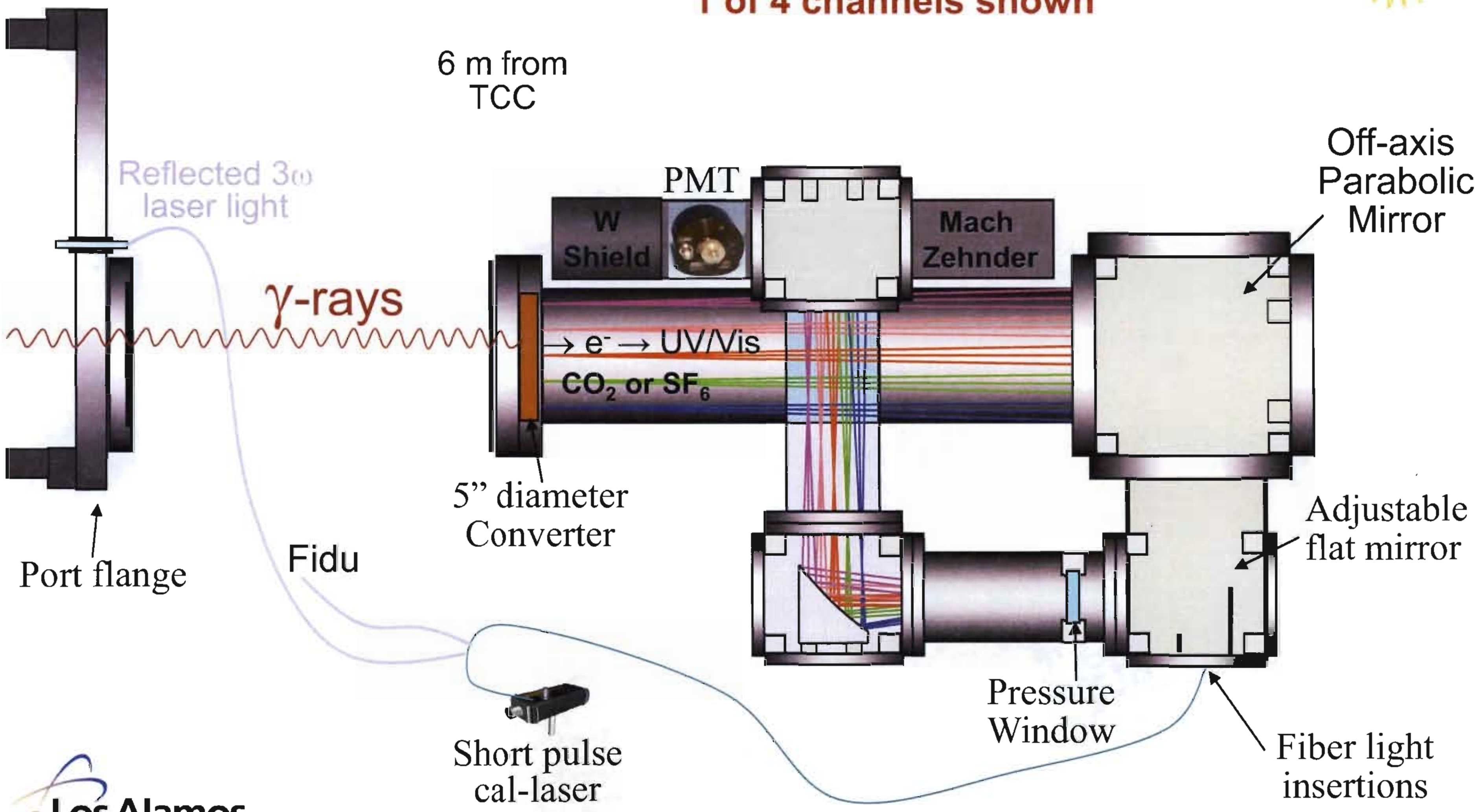
For NIF, GRH diagnostics have been optimized to measure γ-rays outside the chamber

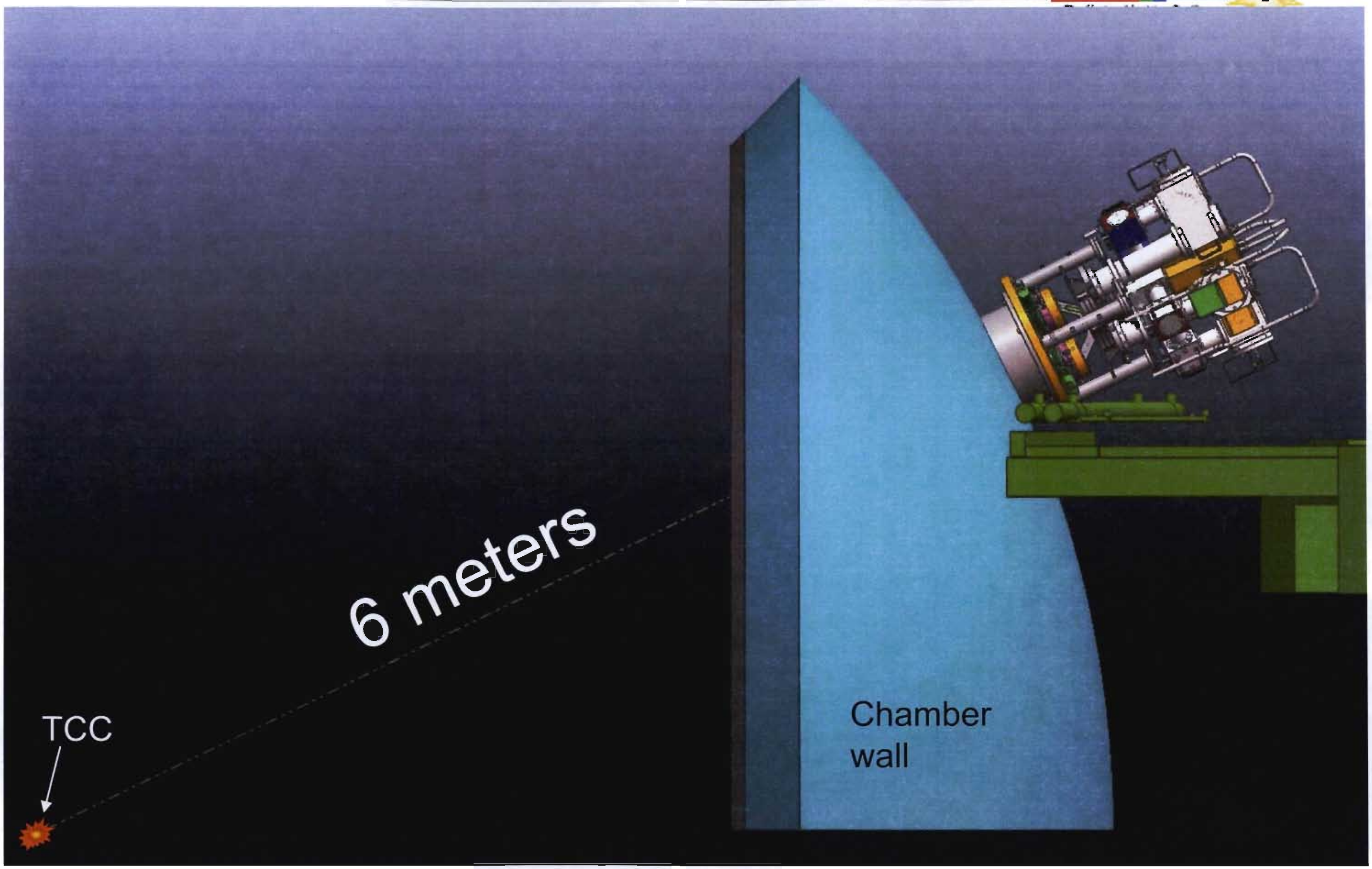
NIF The National Ignition Facility

1 of 4 channels shown

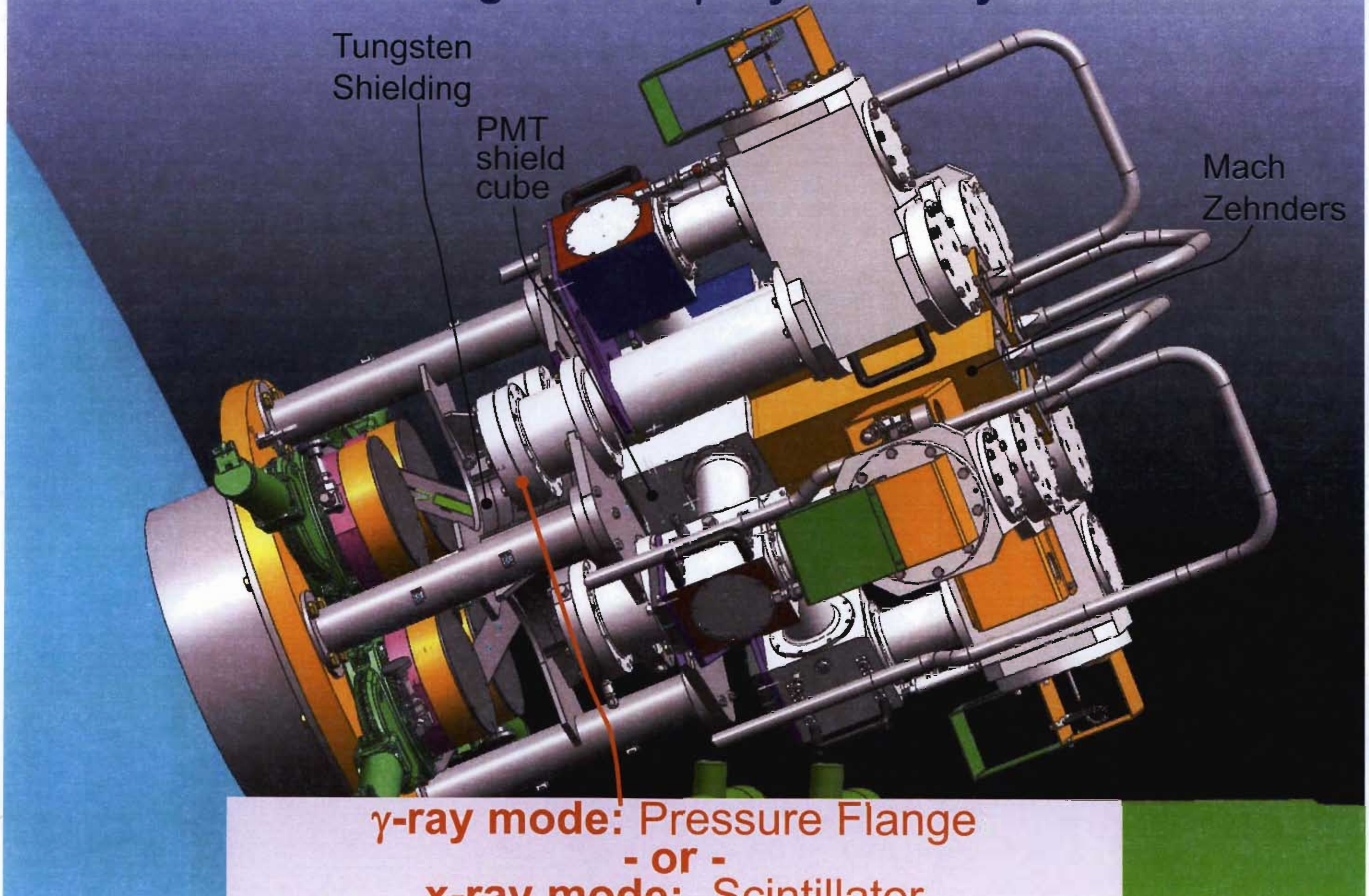


4-channel GRH-6m mounted outside the NIF chamber

NIF

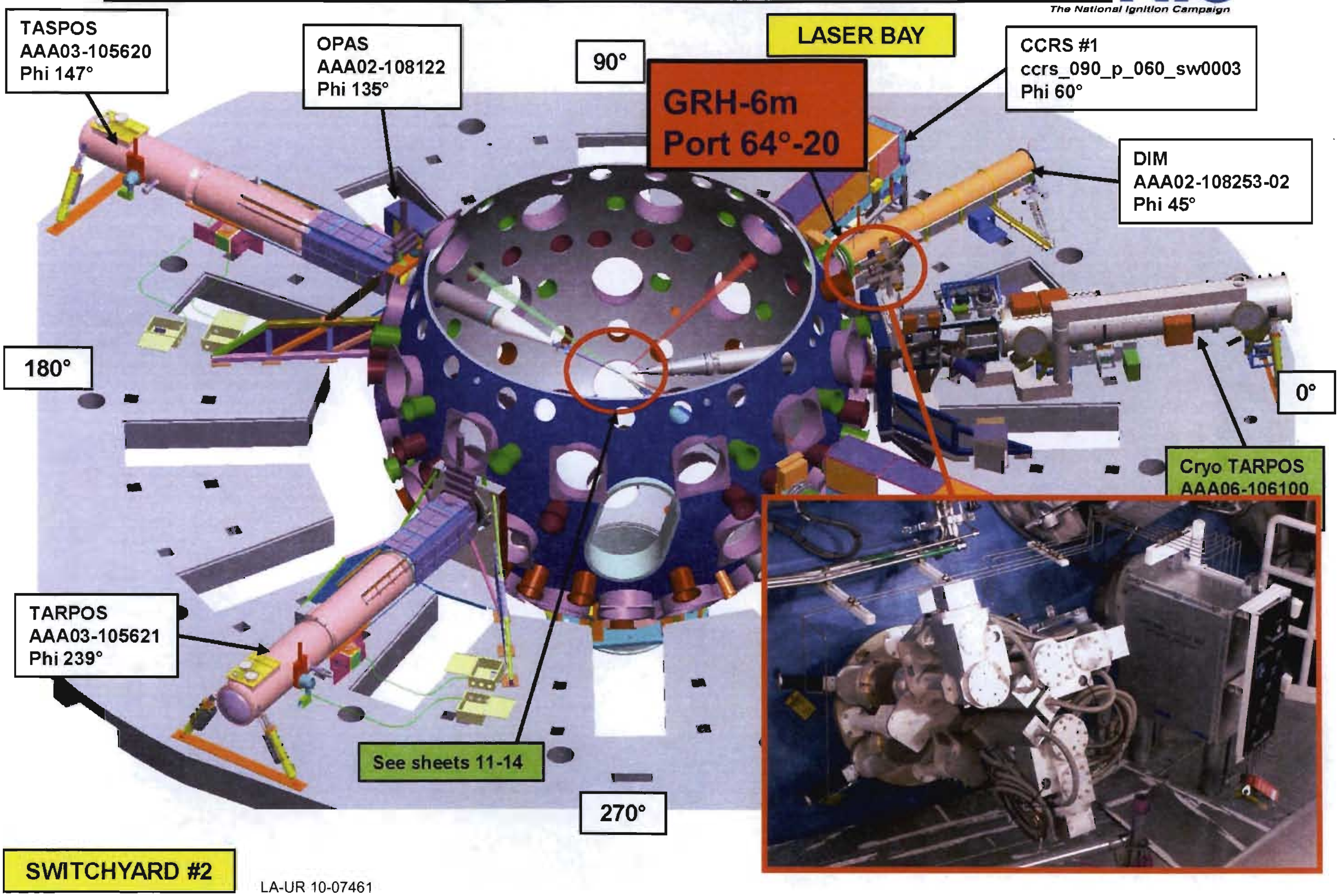


GRH-6m can be configured for γ-rays or x-rays



γ-ray mode: Pressure Flange
- or -
x-ray mode: Scintillator

GRH-6m & NIF Target Chamber Diagnostics



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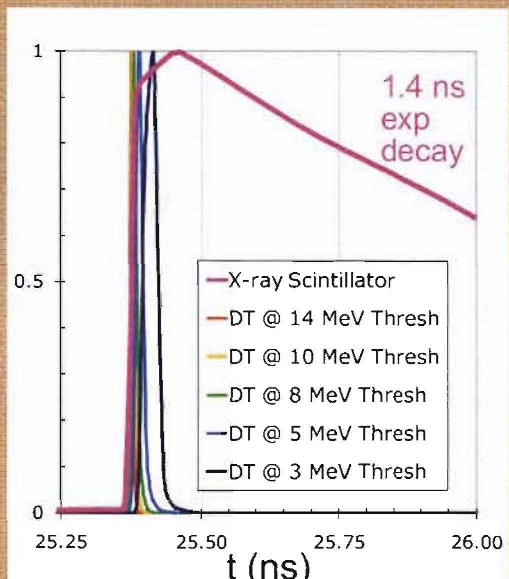
GRH-6m Impulse Response Functions used in Deconvolution

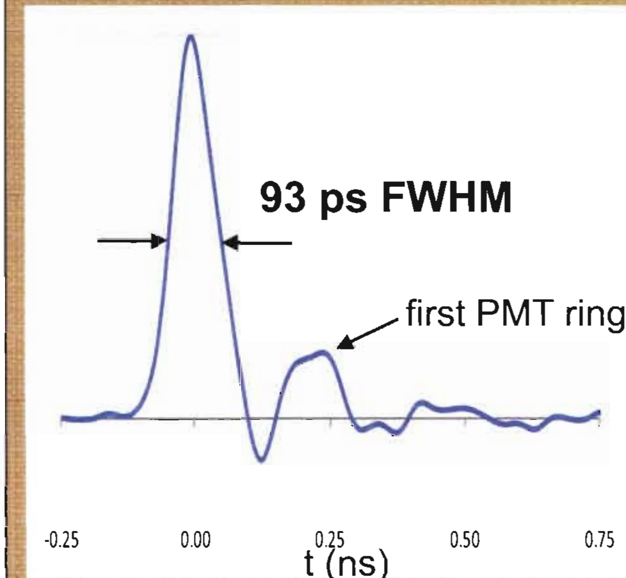
Simulated Gas Cell Impulse Response



- Needed primarily to correct peak timing
- GEANT4 & ACCEPT

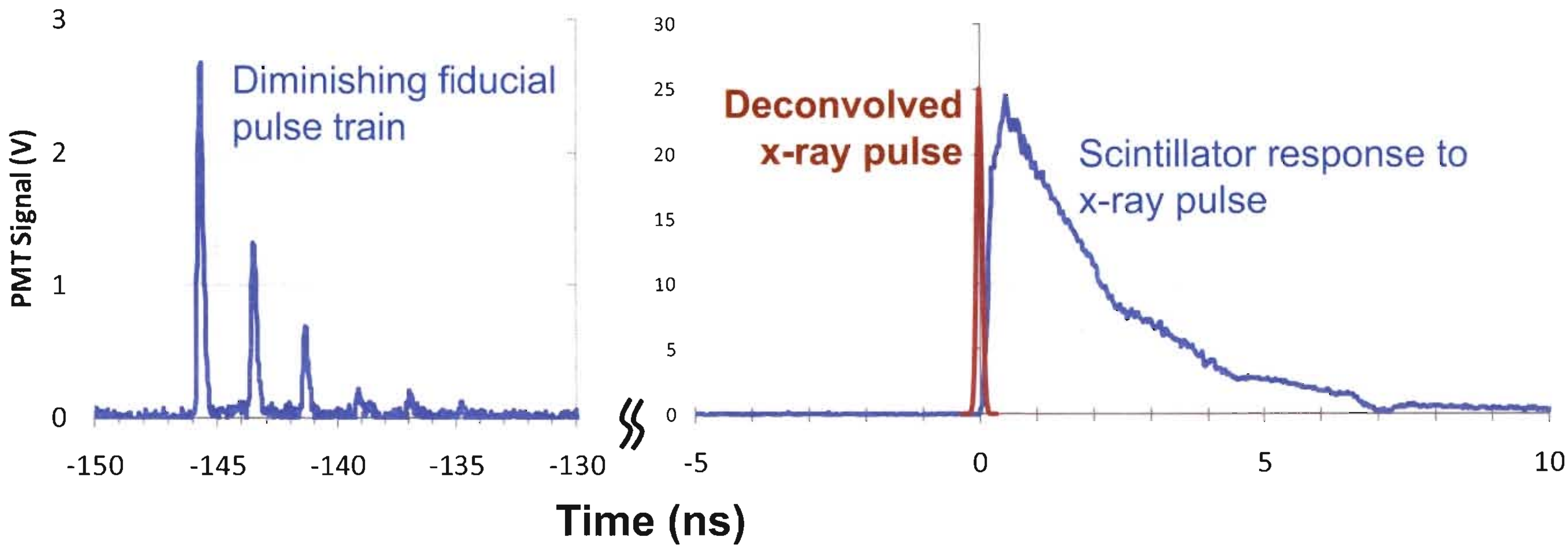
⊗

Measured Recording System Impulse Response



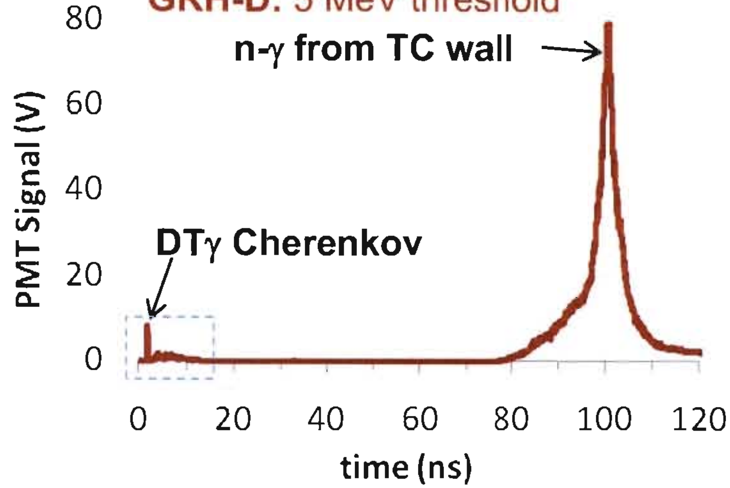
- Needed primarily to remove instrumental spreading

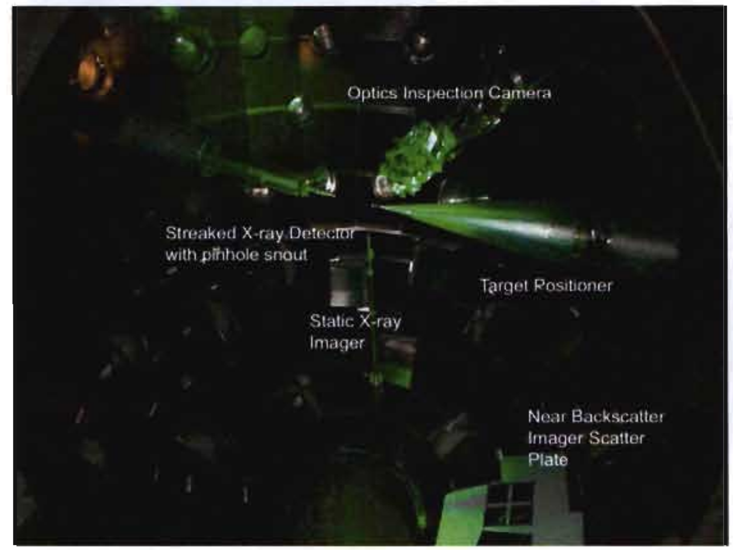
X-ray timing pulse is used to absolutely time laser timing fiducials

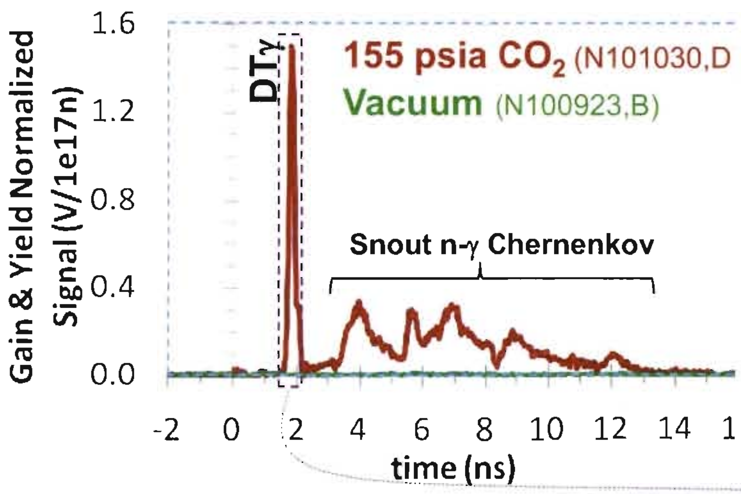


Deconvolved x-ray pulse representative of “88 ps” laser pulse defining t_0

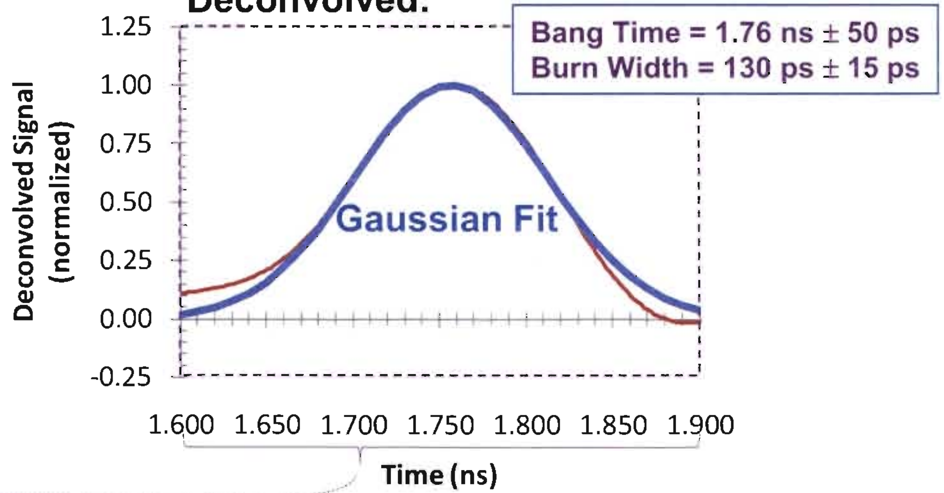
Gamma Reaction History (GRH) diagnostic temporally resolves fusion & n-induced γ-Rays (n-γ)





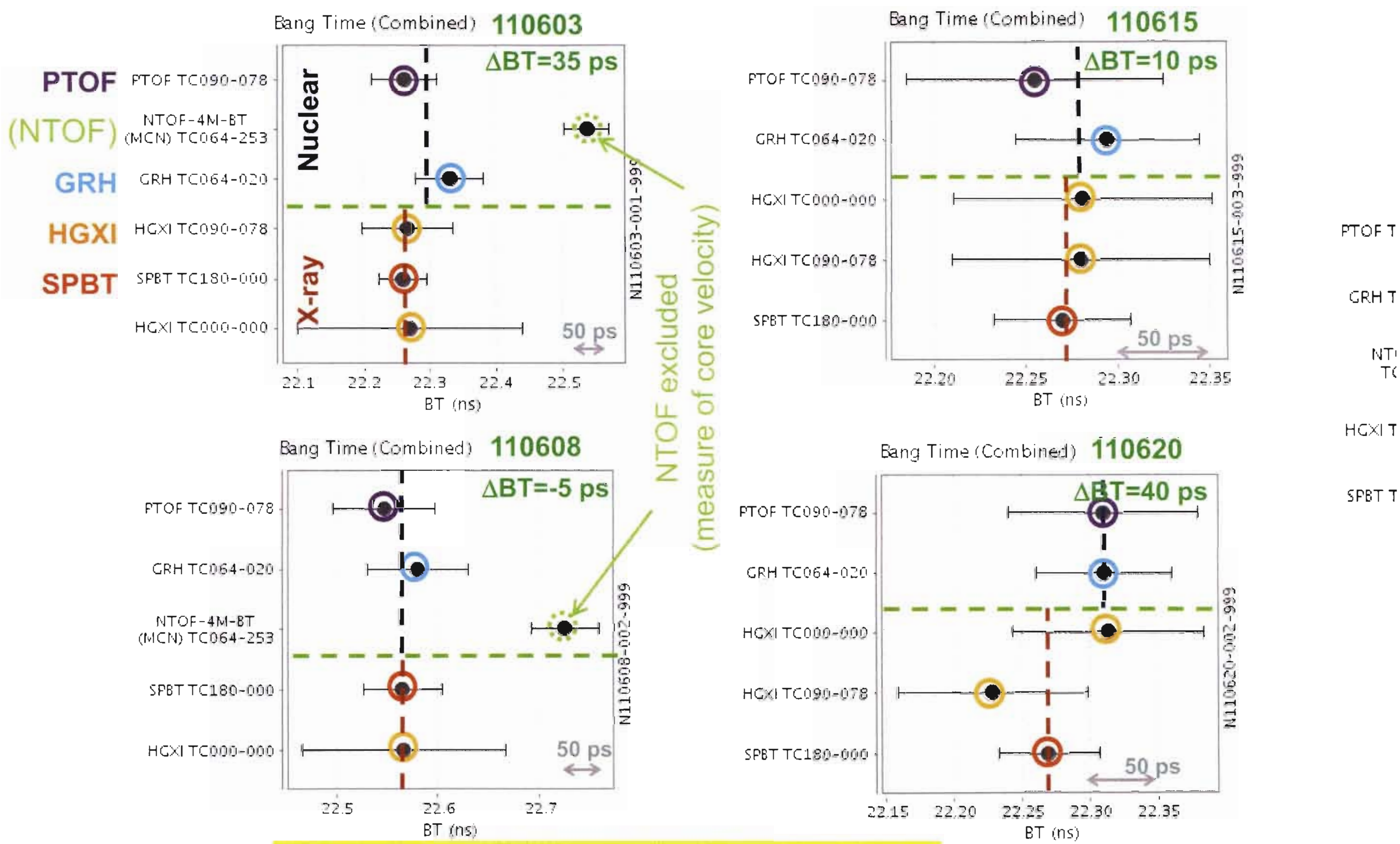


Deconvolved:



Absolute Time Base based on X-ray Timing Shots

Various Bang Time Diagnostics are in good agreement



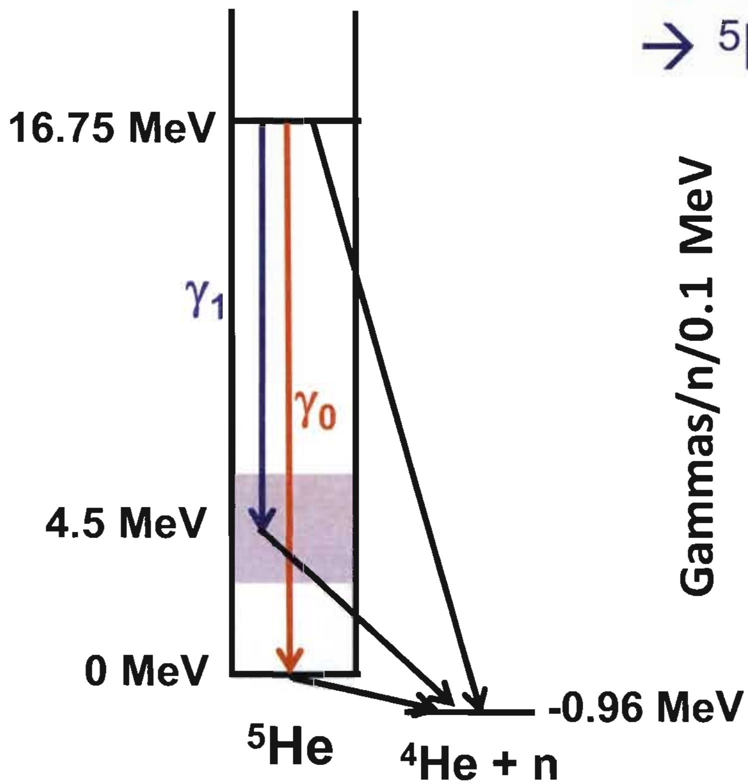
➢ **X-ray BT is ~20±20 ps earlier than Nuclear BT**

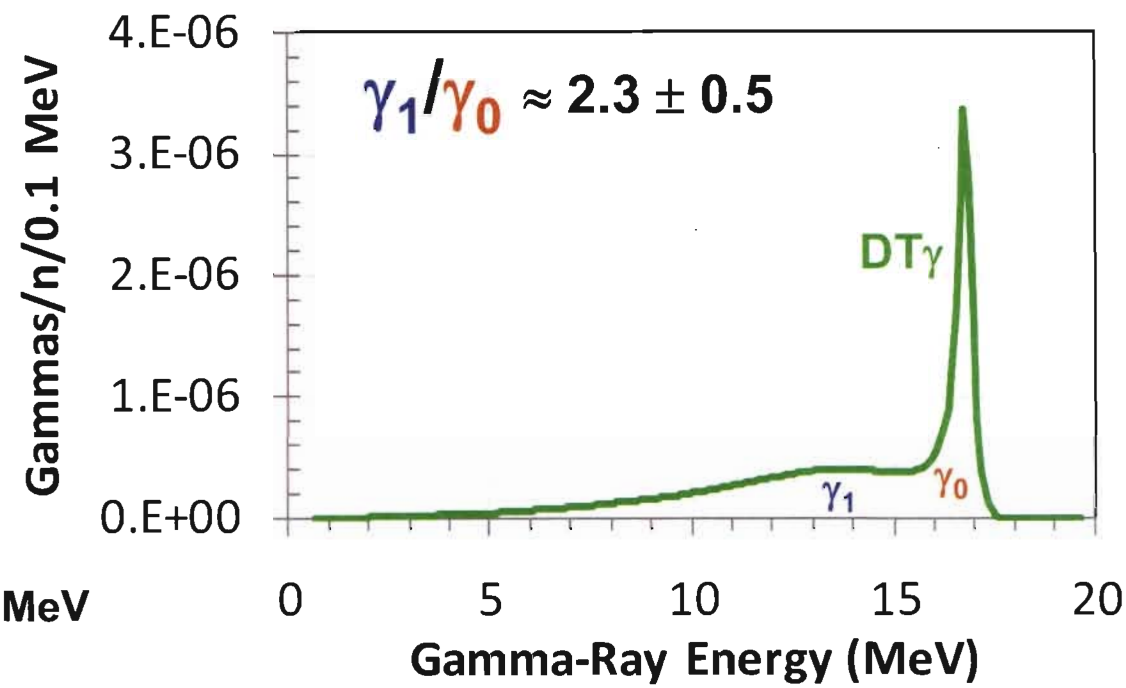
DT Gamma-Ray Spectrum has been mapped out with threshold scans (C. Horsfield, O.Tu_C.8)

$D + T \rightarrow {}^5He^* \rightarrow {}^4He\ (3.5\ MeV) + n\ (14.1\ MeV)$

$\rightarrow {}^5He + \gamma_0\ (16.75\ MeV)$

$\rightarrow {}^5He^* + \gamma_1\ (13\ MeV)$

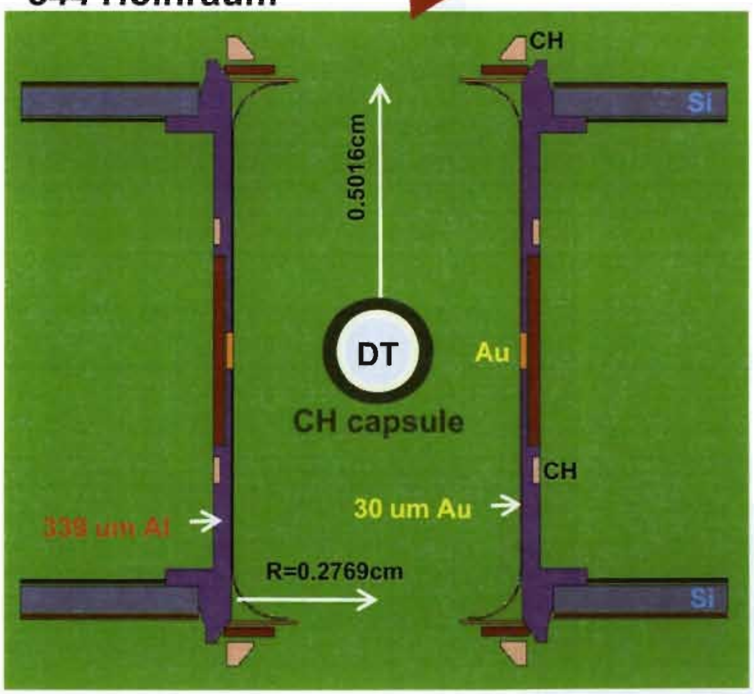




E. Cecil, G. Hale

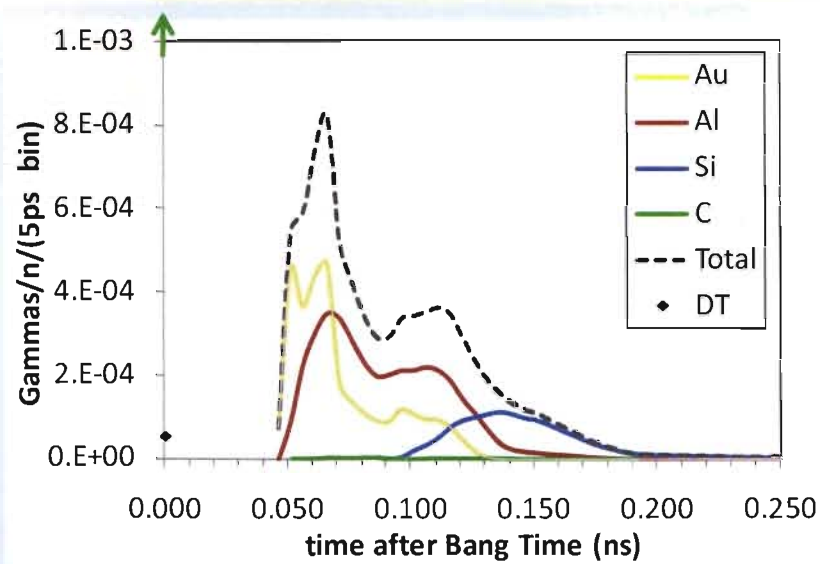
14 MeV neutron-induced γ-Rays from CH Capsule & Hohlraum assembly are simulated in MCNP

544 Holhraum

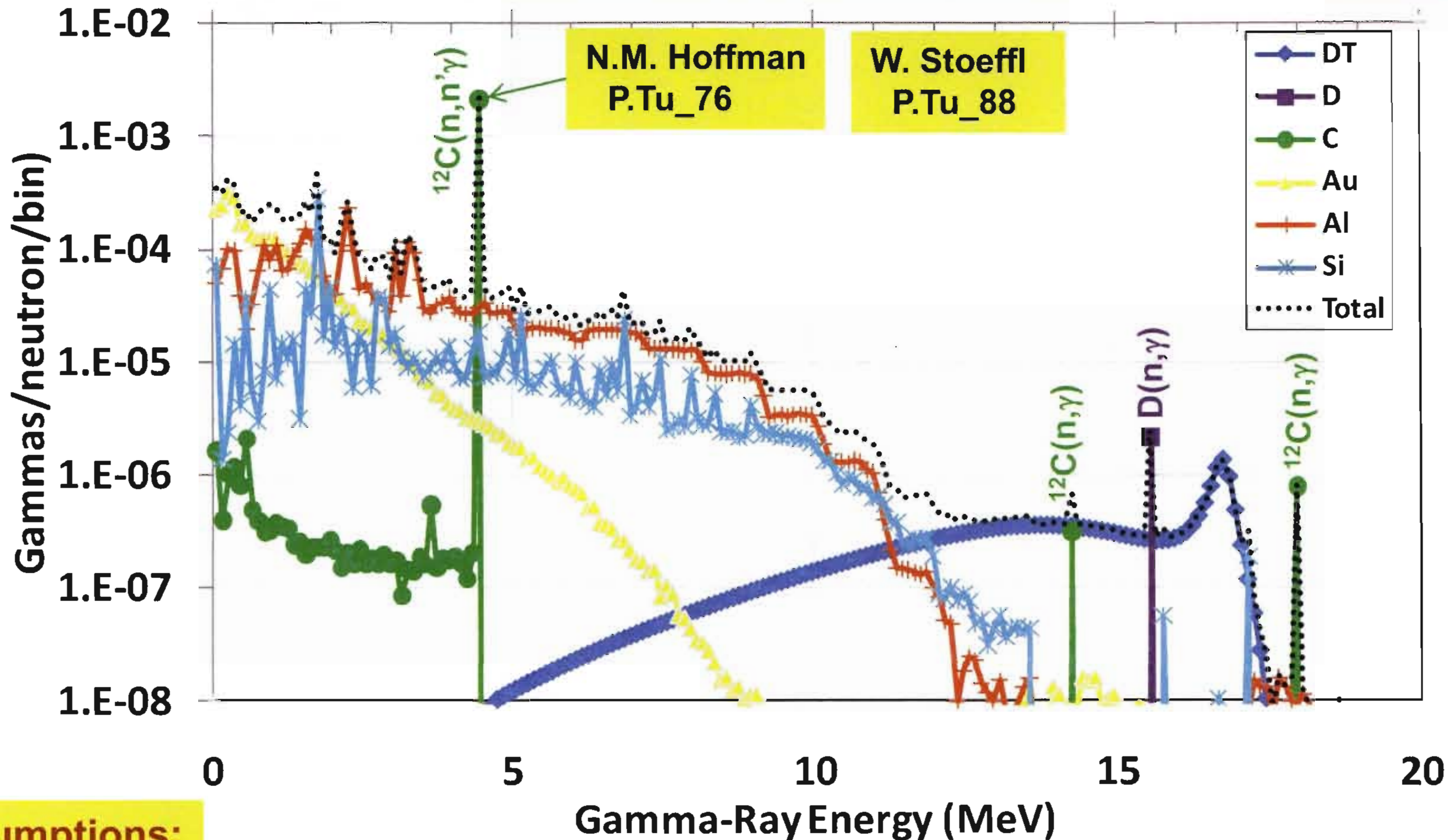


Prompt γ-Ray Temporal History

BT+¼ ns, δ(t=0) 14 MeV n-source



The Prompt γ-Ray Energy Spectrum from Indirect-Drive, Cryo-Layered Implosions is complicated!

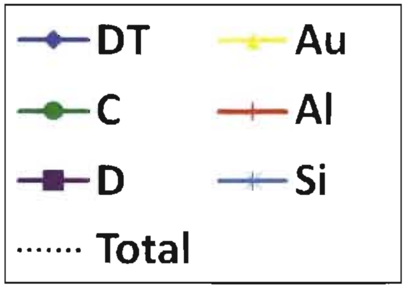


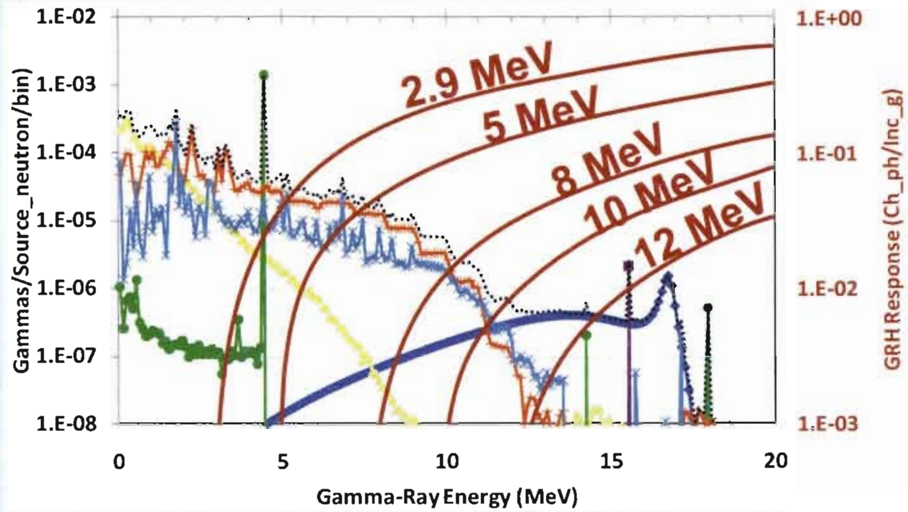
Assumptions:

BR (g/n) =	2.7E-05
g1/g0 =	2.3
12C RhoR (mg/cm2) =	200
Fuel RhoR (mg/cm2) =	1000

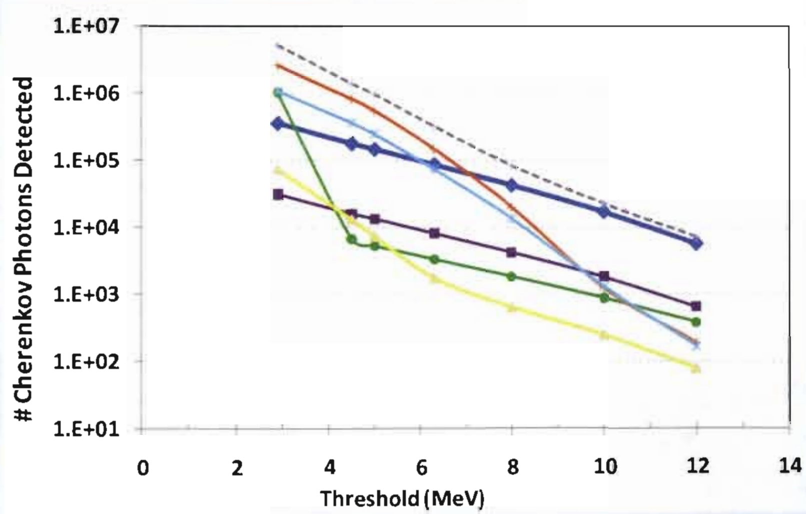
Neutron captures in fuel D & ablator ^{12}C generate high-energy γ's essentially synchronously with fusion reaction history

GRH isolates DT fusion γ-rays (& "synchronous" γ-rays) well at high threshold (10 MeV)

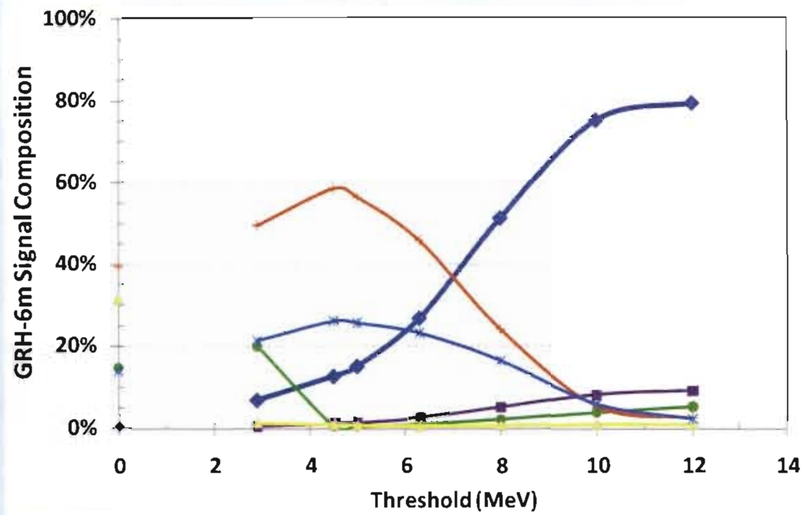




Photons Detected for Y_{DTn}=1e15



GRH Signal Composition

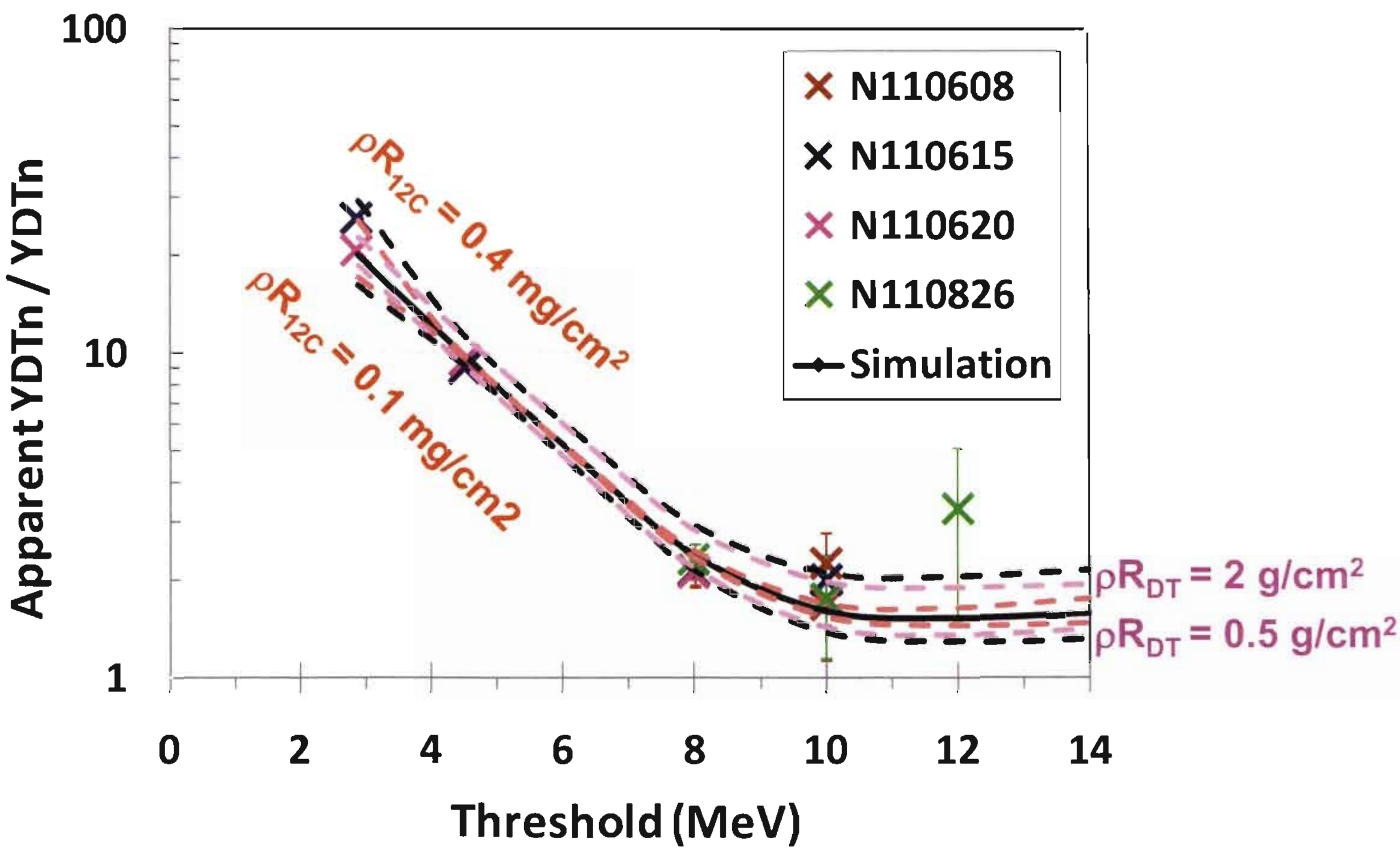


GRH integrated signal has several ρR dependencies

Base Assumptions:

BR = 2.7e-5 γ/n ρR_{DT} = 1 g/cm2 (DSR≈5%)

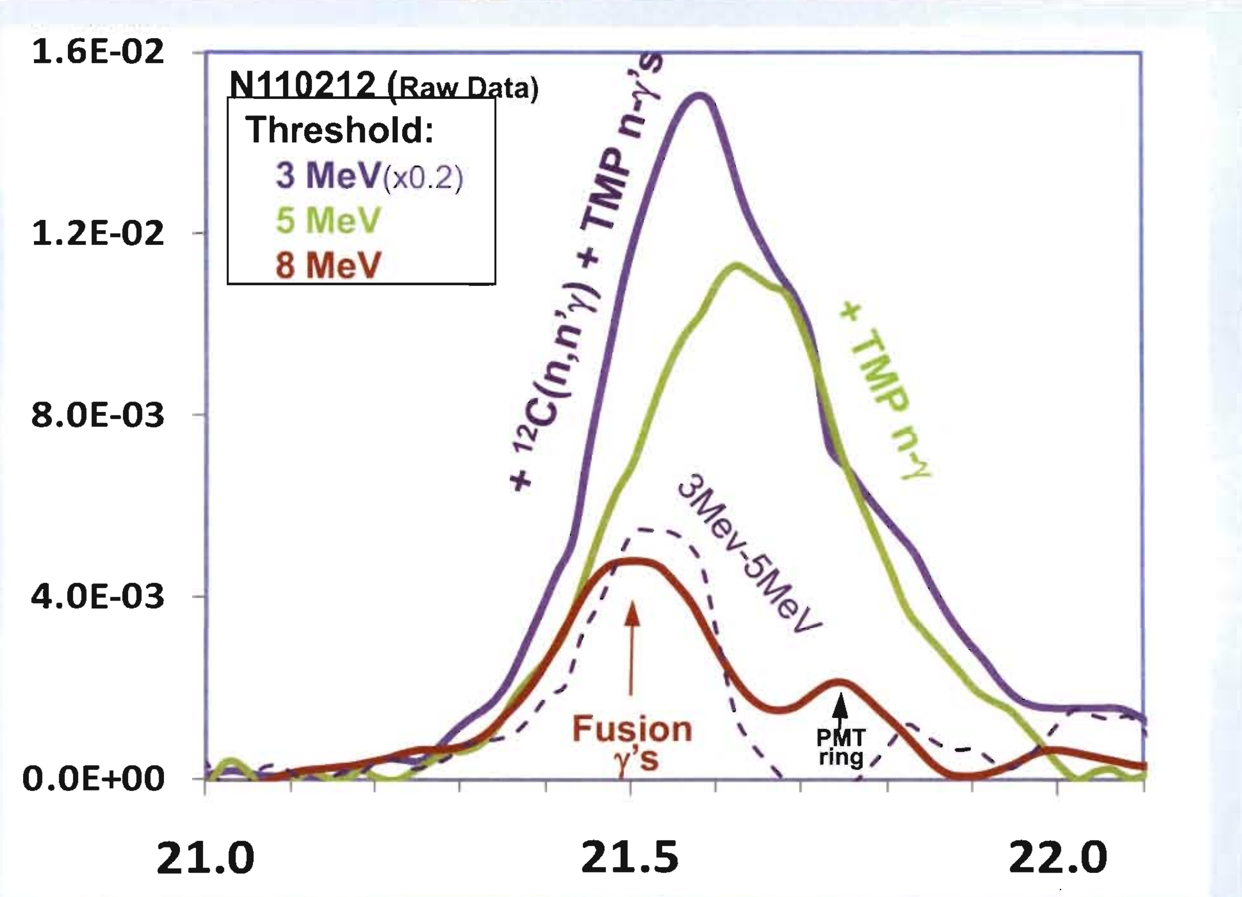
γ1/ γ0 = 2.3 ρR_{12C} = 0.2 g/cm2



γ-Ray Spectrum is beginning to emerge through GRH Energy-thresholding

NIC

Cryo-layered THD Data



^{12}C signal clearly observable from plastic ablator
→ CH Ablator ρR Measurement

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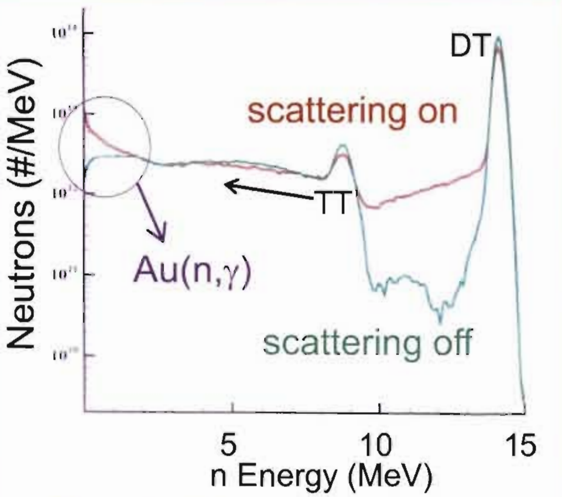
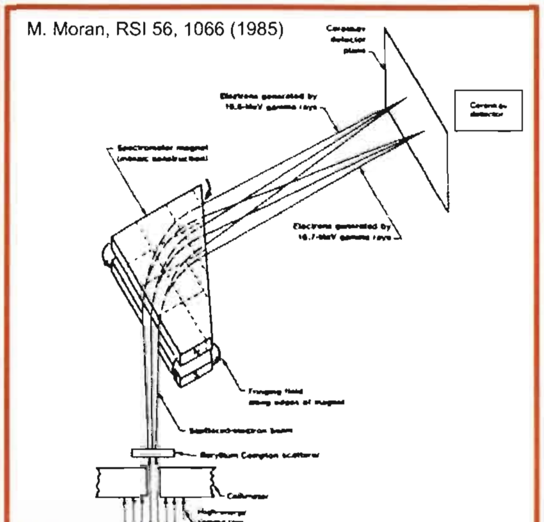
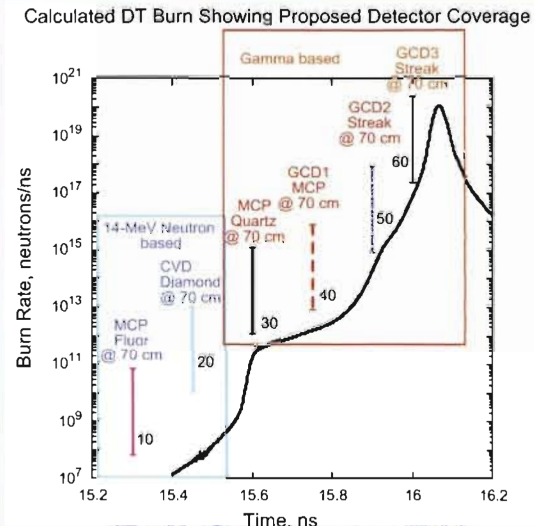
Future Directions



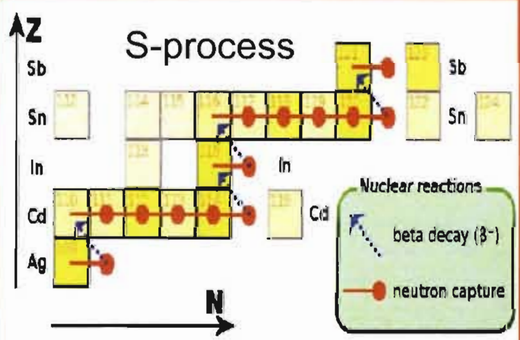
Total ρR measurement
(L. Bernstein)



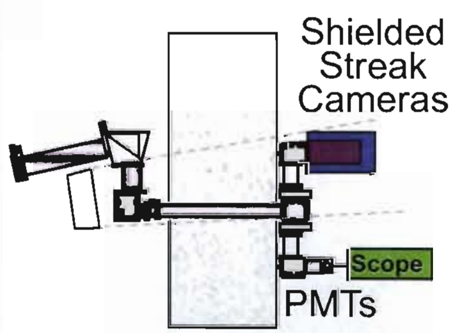
Compton Spectrometer
(Y. Kim)



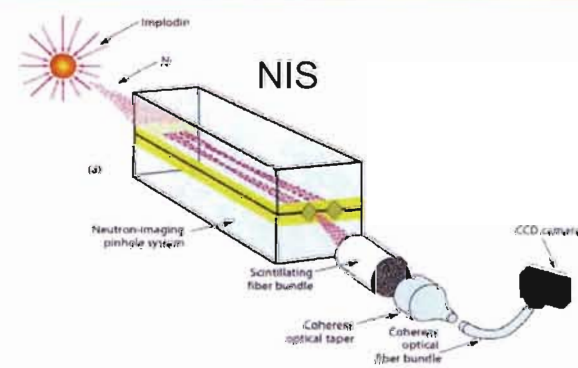
Full Coverage RH
(J. Mack)



Astrophysical Processes
(L. Bernstein)



Streaked GRH
(H. Herrmann)



γ-Ray Imaging of Ablator (^{12}C-γ)
(G. Grim)

Summary

- Gamma-Rays provide the opportunity to measure:
  - **Fusion Reaction History**
    - **Bang-Time & Burn-Width**
  - **Yields of various nuclear reactions from which to infer:**
    - **Plastic Ablator Areal Density (ρR)**
    - **Total DT neutron yield**
- ICF Gamma-Ray Diagnostics:
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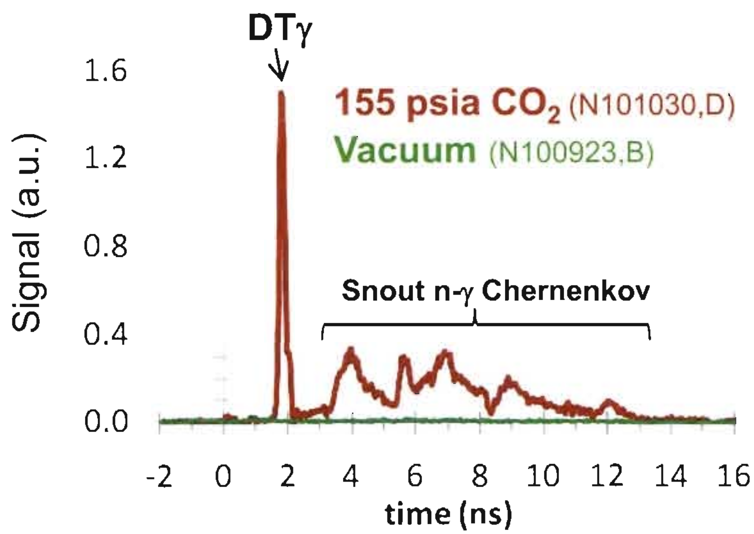
  - **provide fertile ground for HEDP & Nuclear Plasma Science**



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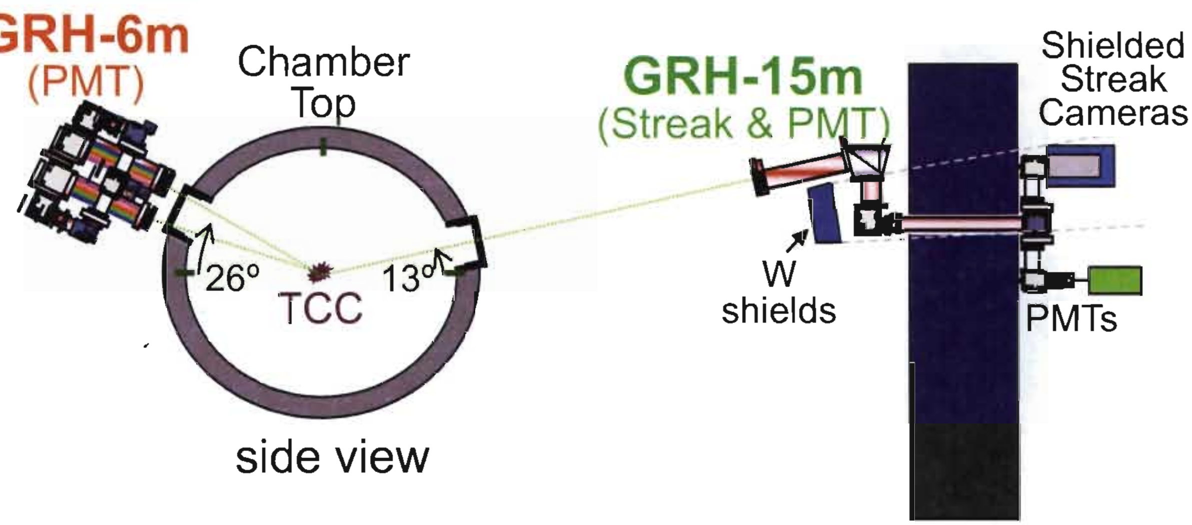
- Backups

Additional ICF Gamma-Ray Presentations

- **This Session:**
  - **Colin Horsfield** (AWE)- DT Fusion Gamma Spectrum
  - **Yongho Kim** (LANL)- DT γ/n Branching Ratio
  - **Nelson Hoffman**(LANL)- Plastic Ablator Areal Density

- **Poster Session V: Wednesday, 9:30 AM**
  - NP9.00163: **Mike Rubery** (AWE)- GRH Geant4 simulations and calibrations at HIγS

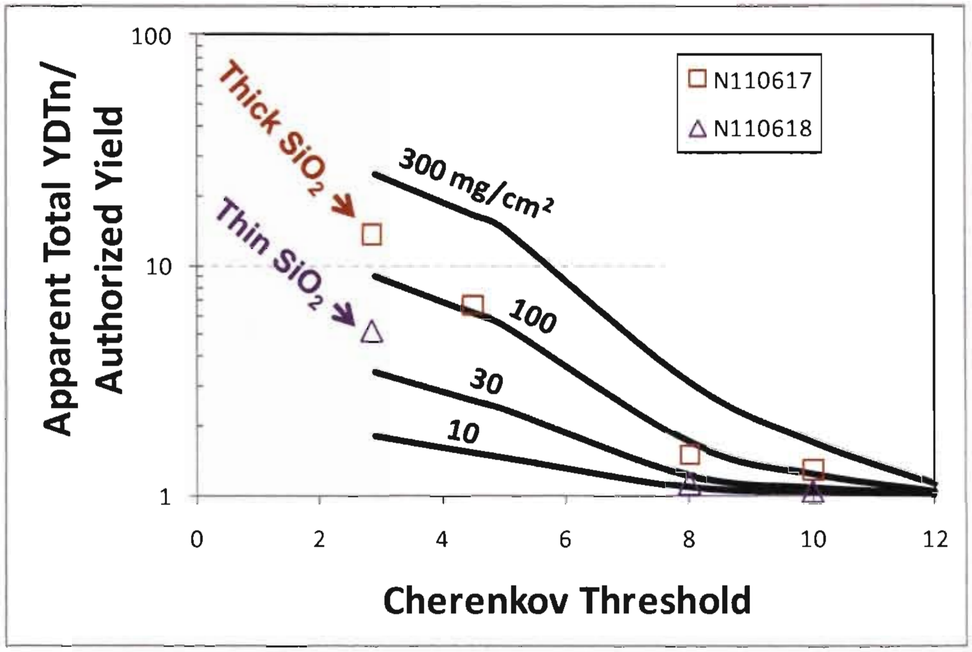
GRH-6m began operation in FY10 for THD Tuning Campaign
GRH-15m planned for Ignition



	GRH-6m	GRH-15m
Optical Detectors	PMT	Streak Camera (+PMT)
System Temporal Response (FWHM)	~100 ps	~10 ps
Yield Range (DTn)	10^{14}-10^{17}	10^{16}-10^{20}
Collimated Field of View (cm about TCC)	~100	2

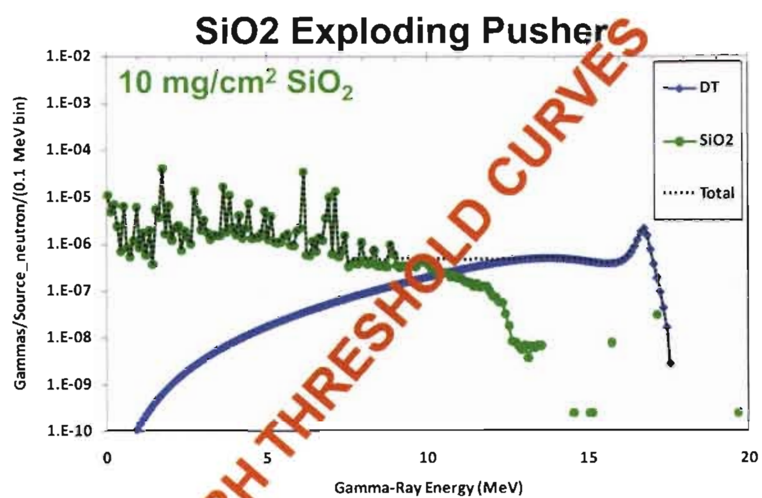
SiO2 Exploding Pushers used to establish DTn Yield Cross-Calibration

- Exploding Pusher DTn Yield Cross-calibration done at high threshold (10 MeV), thin SiO2 capsule, to minimize capusle n-γ signal contamination uncertainty
- Higher yield will allow operation at higher threshold (12 MeV) for better cross-cal
- Validation of MCNP models in progress
  - Known ρR "Pucks" near TCC
  - Acclerator-based measurements



Energy Thresholding enables isolation of DT fusion gammas from lower energy neutron-induced gammas

- Exploding Pushers used to cross-calibrate g-signal to DTn yield
  - Directly-driven, thin-glass capsules
  - "Pure" DT fusion signal at >12 MeV threshold



- Gamma-rays will be used to infer Total DTn Yield in high ρR cryo-DT
  - Reported neutron yield is for 13-15 MeV (i.e., unscatterred neutron yield)
  - γ-rays are not significantly downscattered by target ρR (<1%)
  - Total yield expected to be ~15% higher (for DSR=5%)