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Title: ICF GAMMA-RAY YIELD MEASUREMENTS ON THE NIF

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Los Alamos
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Abstract: ICF GAMMA-RAY YIELD MEASUREMENTS ON THE NIF*

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 with energy-thresholded Gas Cherenkov detectors that convert MeV gamma-rays into UV/visible photons for high-bandwidth optical detection. At sufficiently high threshold, the integrated GRH signal is proportional to the DT fusion yield by the d(t,n)a/d(t,g)^{5}He branching ratio. Absolute uncertainties in this branching ratio and detector response are removed by using directly-driven DT exploding pushers, having negligible areal density and cross section for neutron downscatter, for in-situ cross-calibration of detector response against independent neutron yield measurements. The GRH signal can then be used to make Total DTn Yield inferences on indirectly-driven, cryogenically-layered DT implosions which achieve high areal density and hence scatter a significant fraction of DTn out of the 14 MeV primary peak. By comparing the Total DTn Yield from γ-ray measurements with the Primary DTn Yield (13-15 MeV) from neutron measurements, the Total Downscatter Fraction (TDSF) can be inferred. Results of such recent measurements will be presented.

*This work supported by US DOE under contract DE-AC52-06NA25396.

NIC

ICF GAMMA-RAY YIELD MEASUREMENTS ON THE NIF
APS-DPP, Nov 16, 2011
Salt Lake City, UT

Hans W. Herrmann

Los Alamos National Laboratory

LA-UR 10-07461

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Y.H. Kim, N. Hoffman, D.C. Wilson, C.S. Young, J.M. Mack, J.R. Langenbrunner, G. Hale, S. Evans, T. Sedillo, S. Batha,…
Los Alamos Nat'l Lab

W. Stoeffl, L. Bernstein, J. Church, E. Grafil, A. Carpenter, P. Watts, L. Dauffy, S. Azevedo, J. Liebman, D. Sayre, A. Mackinnon, J. Kilkenny, D. Schneider, D. Fortner **& 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

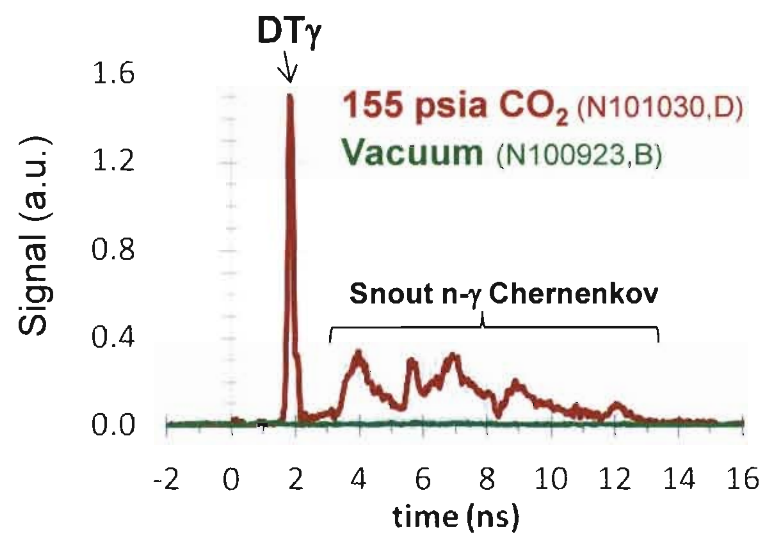
J. Frenje, H. Rinderkinecht, A. Zylstra, M. Gatu, D. Casey, R. Petrasso
Massachusetts Institute of Technology

V. Yu. Glebov, T. Duffy, C. Sangster **& the *OMEGA* Team**
Laboratory for Laser Energetics

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

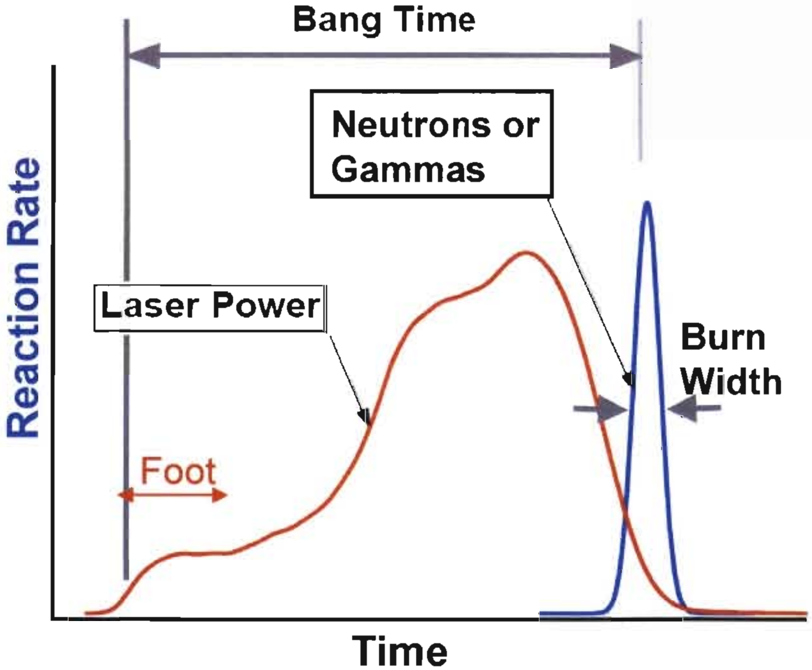
NIF

Doppler broadened — no escape (hopefully)

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

Y. Kim
APS-DPP

C. Horsfield
O.Tu_C.8

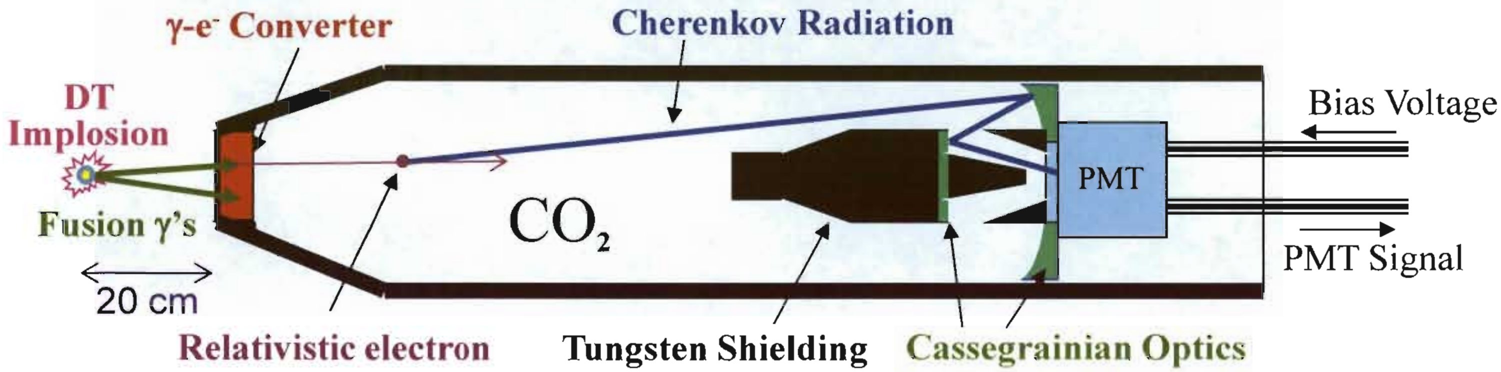


- **Bang Time** - used to establish laser energy coupling to target (shell velocity)
- **Burn Width** - used for failure mode correlation

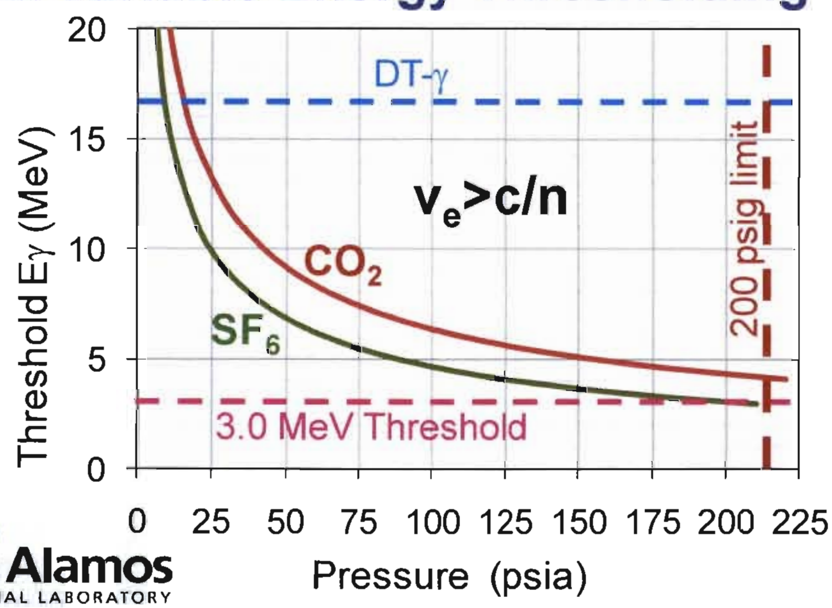
Why use a Gas Cherenkov Detector (GCD)?

NIF
The National Ignition Facility

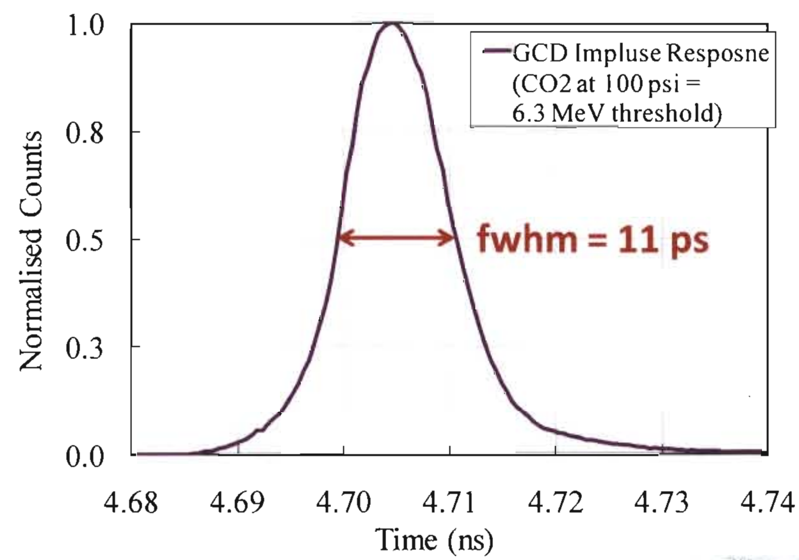
1. Convert MeV γ-rays to UV/Visable photons



2. Variable Energy Thresholding



3. Fast Time Response



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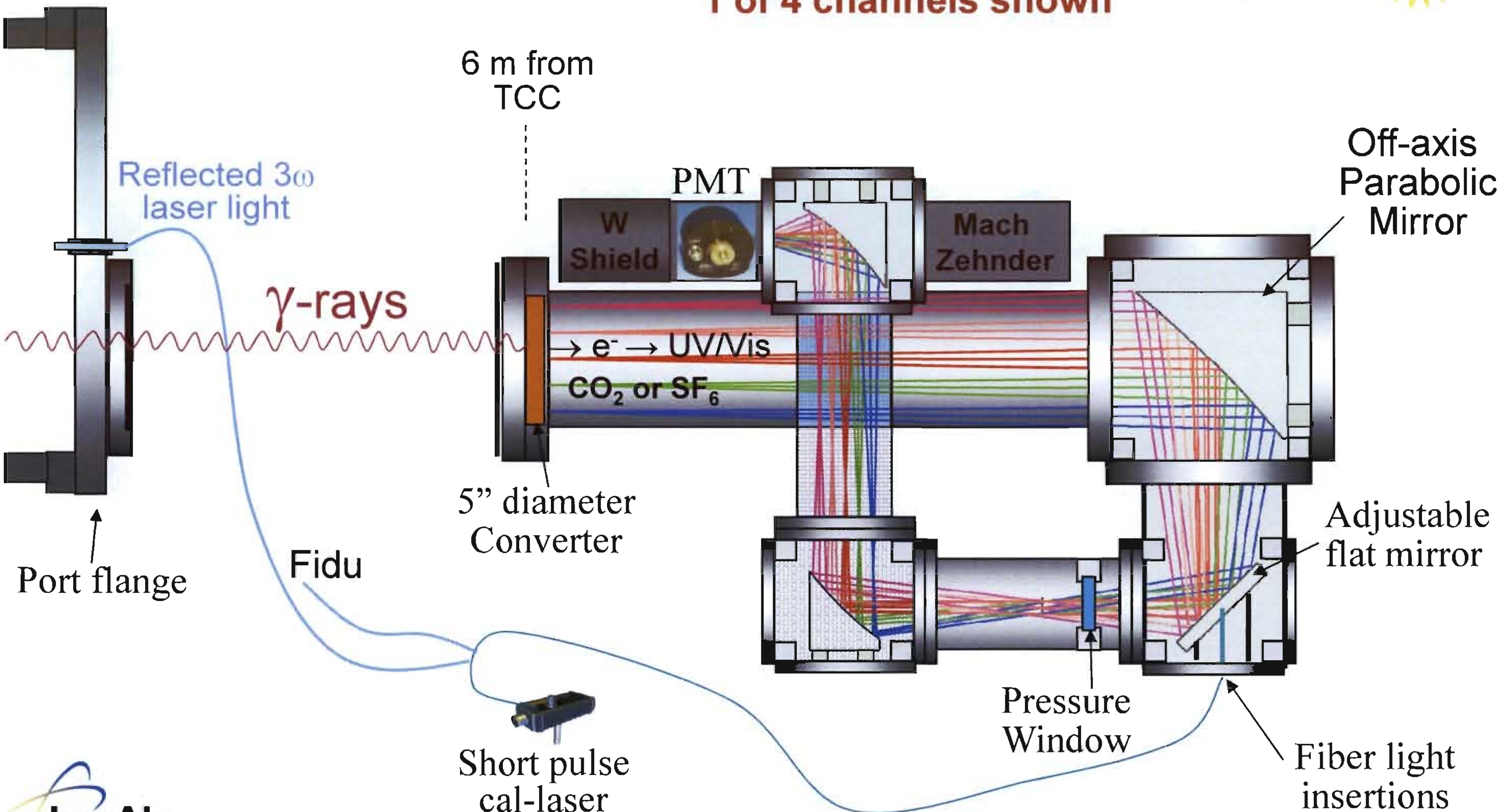
LA-UR 11-05256, H.W. Herrmann, IFSA'11

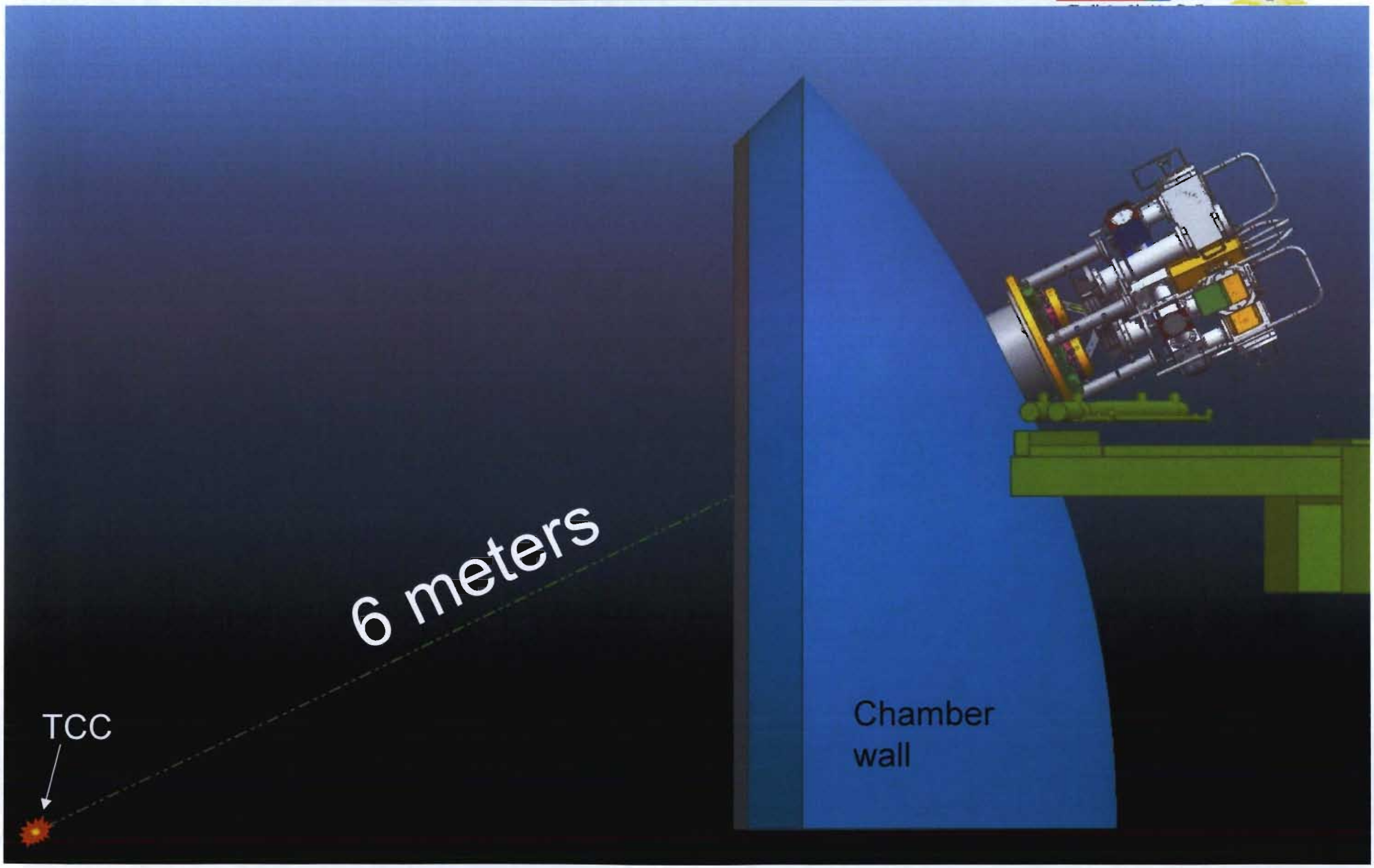
For NIF, Gamma Reaction History diagnostic has been optimized to measure γ-rays outside the chamber

1 of 4 channels shown

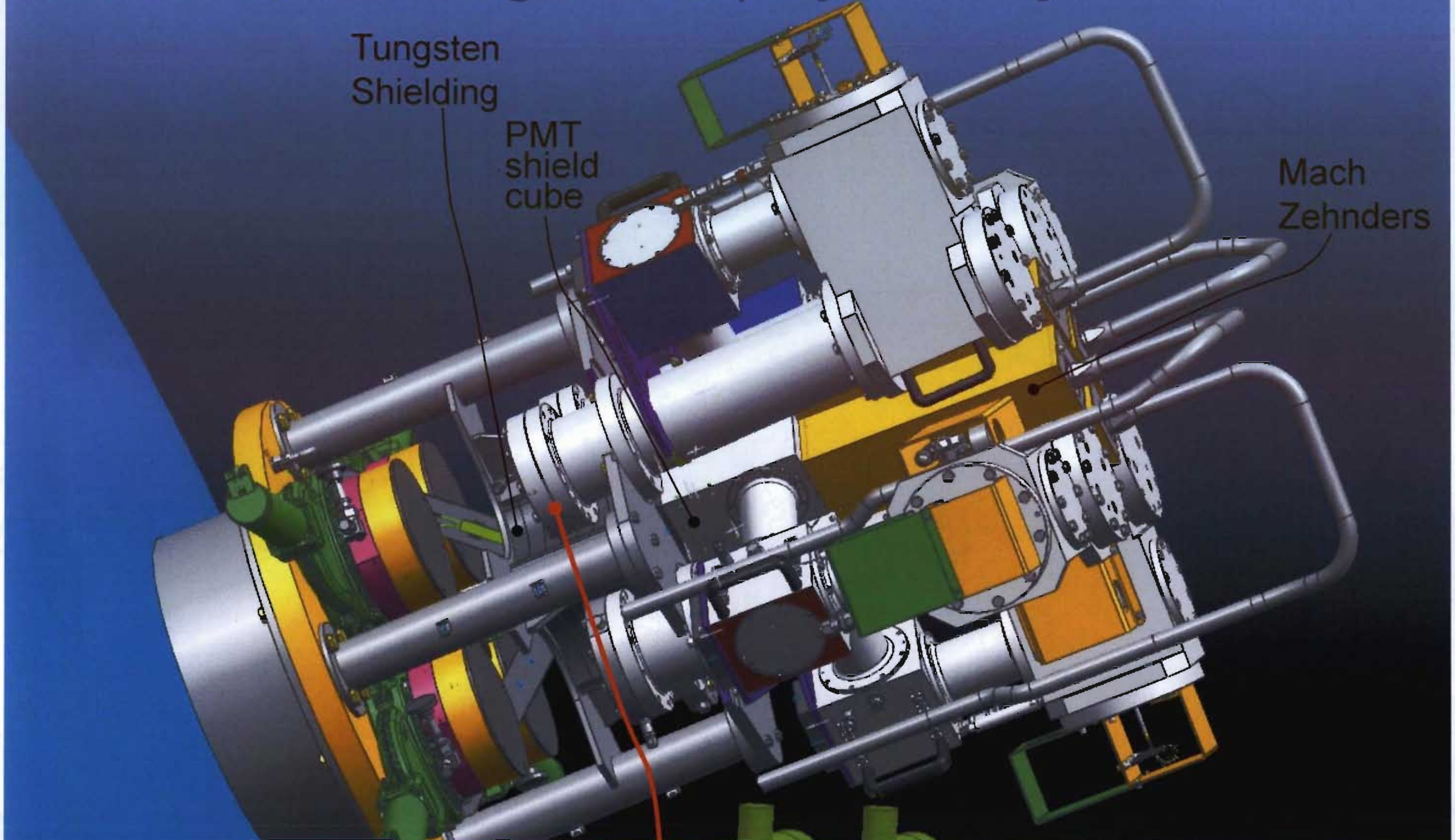


4-channel GRH-6m mounted outside the NIF chamber

NIF



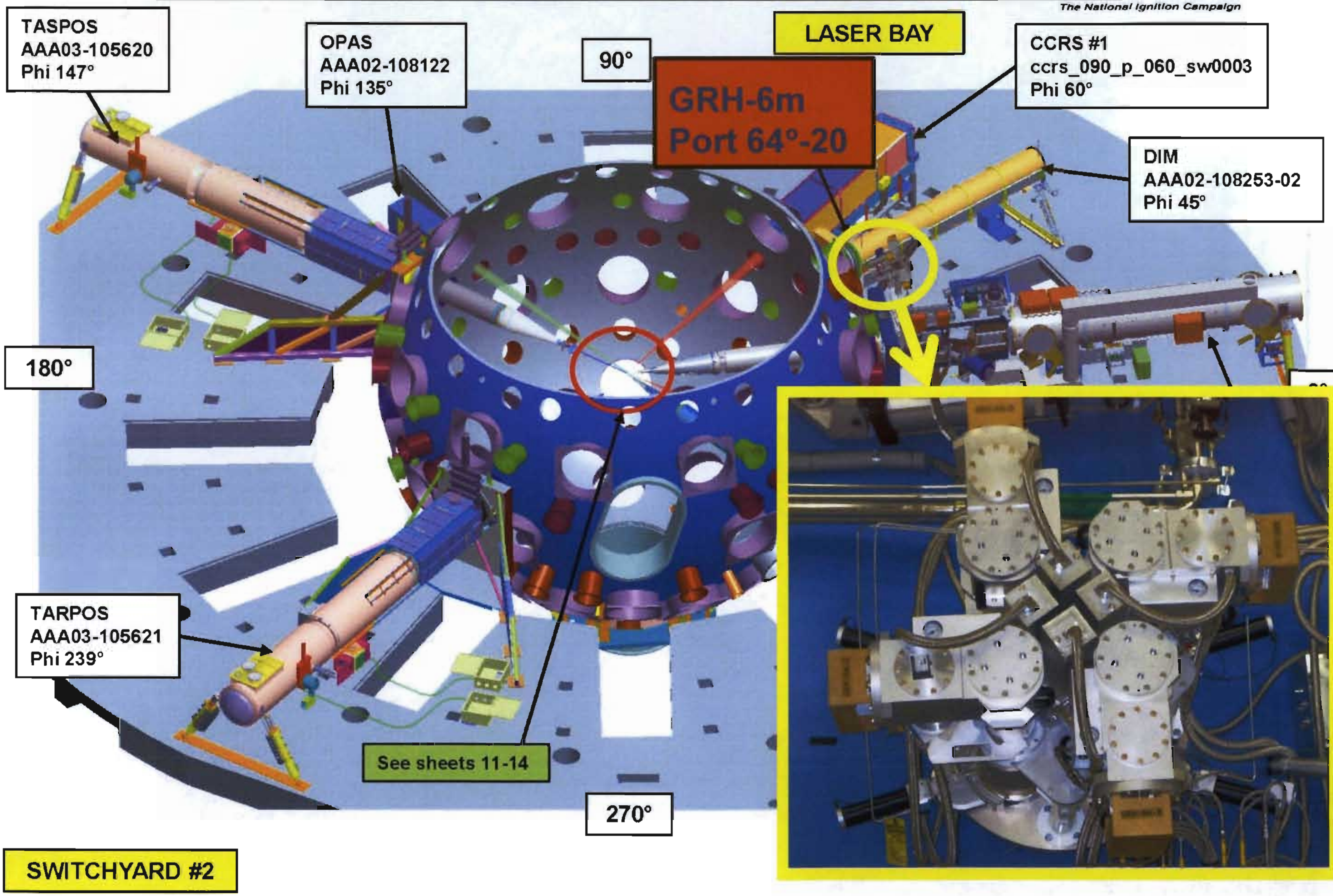
GRH-6m can be configured for γ-rays or x-rays



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

GRH-6m & NIF Target Chamber Diagnostics

NIC
The National Ignition Campaign



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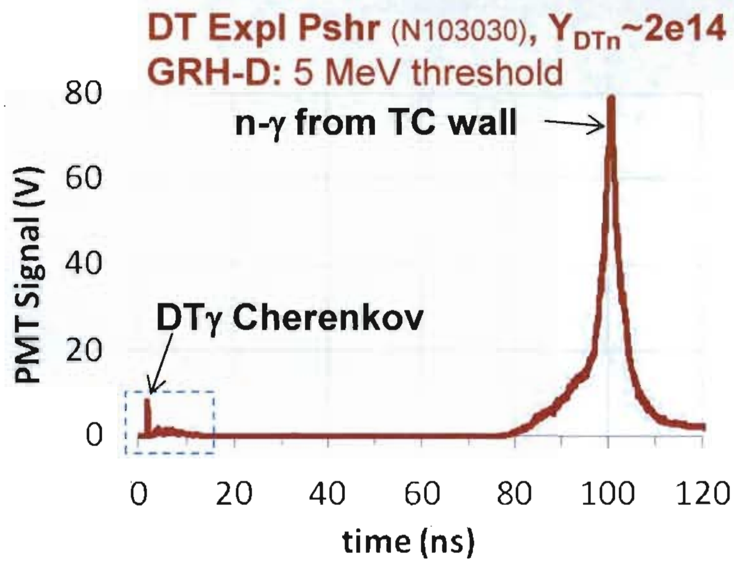
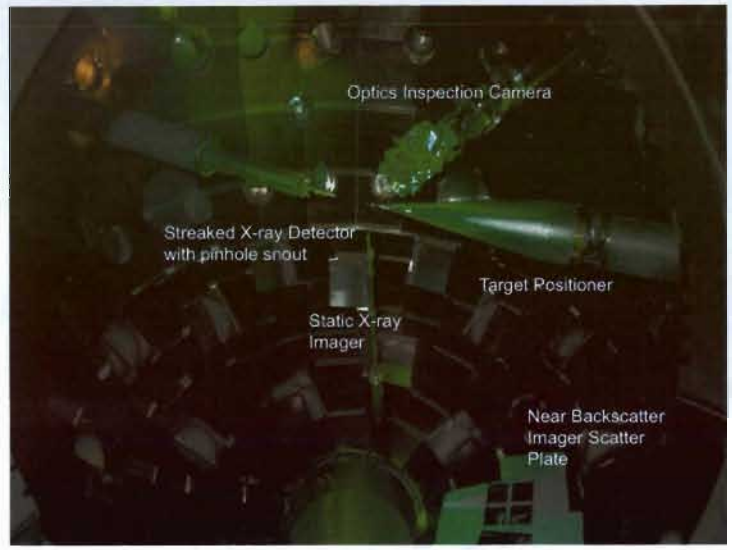
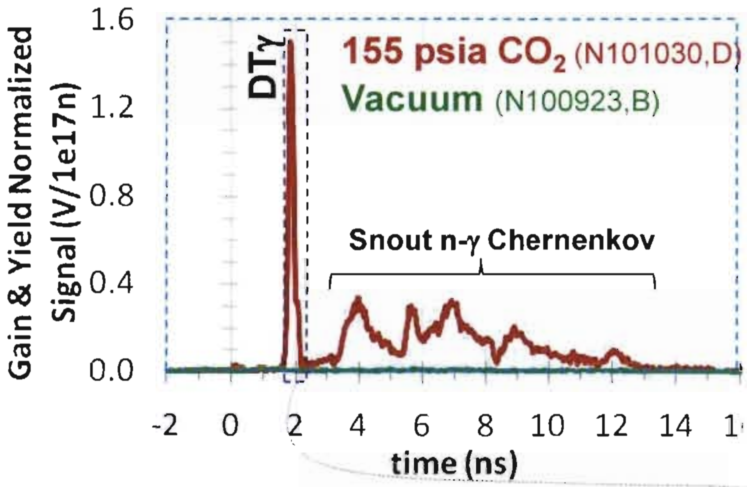
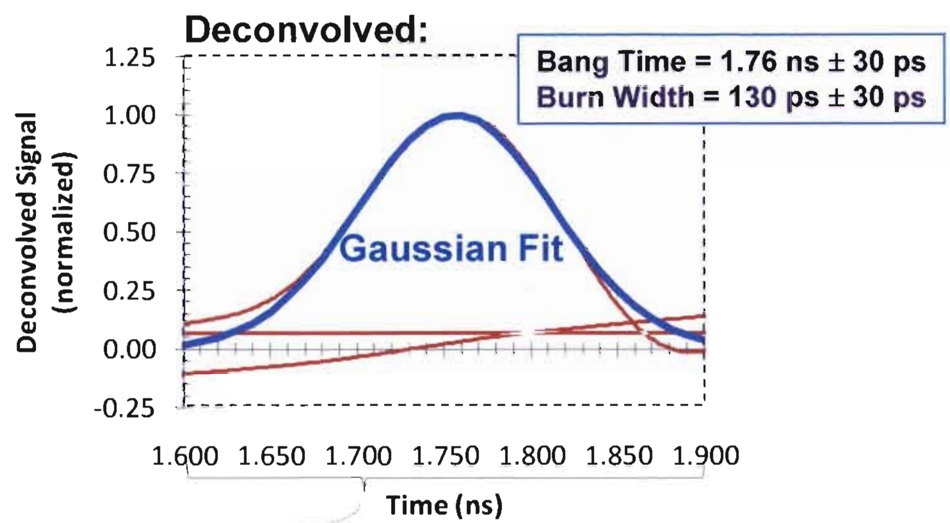
Gamma Reaction History (GRH) diagnostic temporally resolves fusion & delayed n-induced γ-Rays (n-γ)



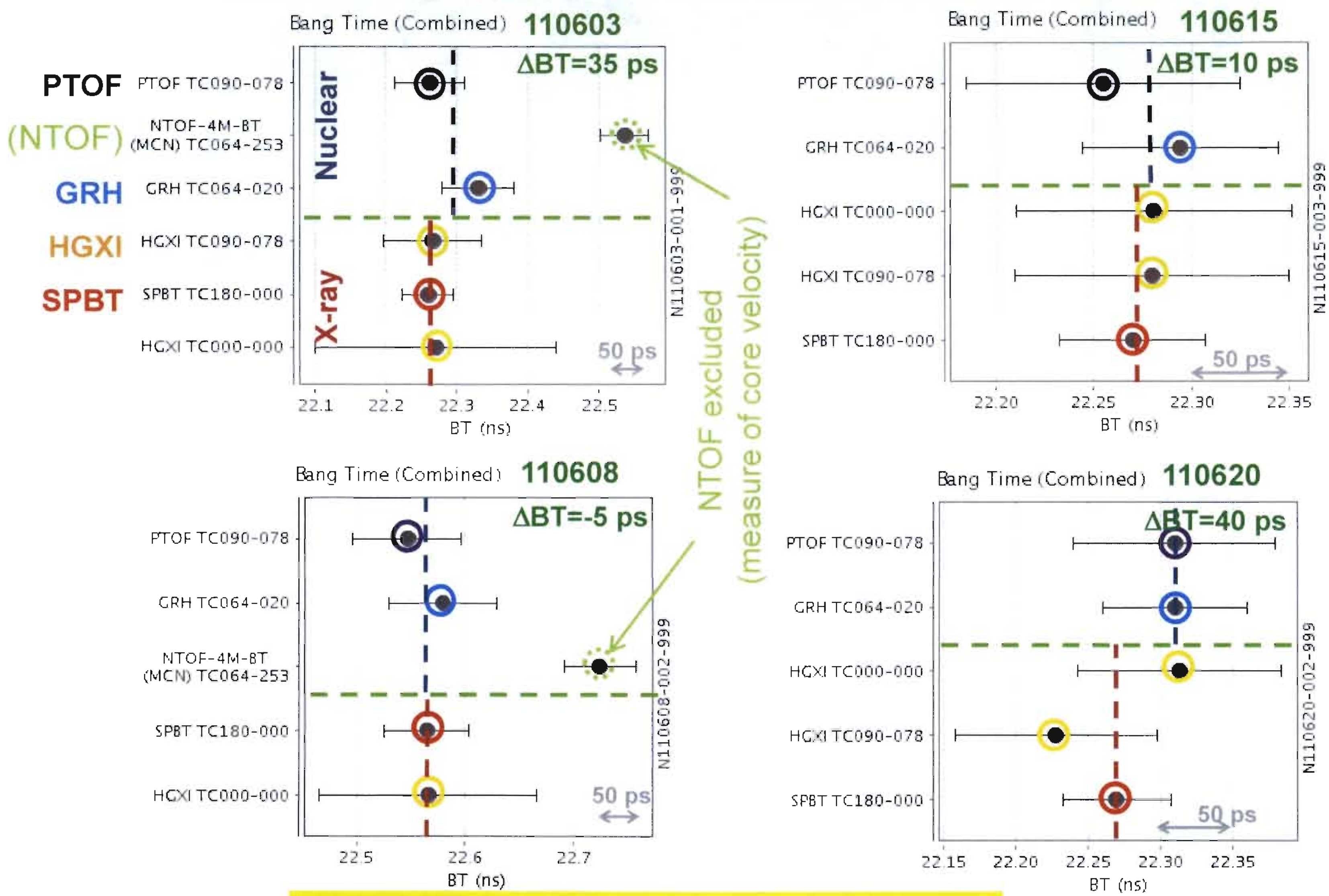






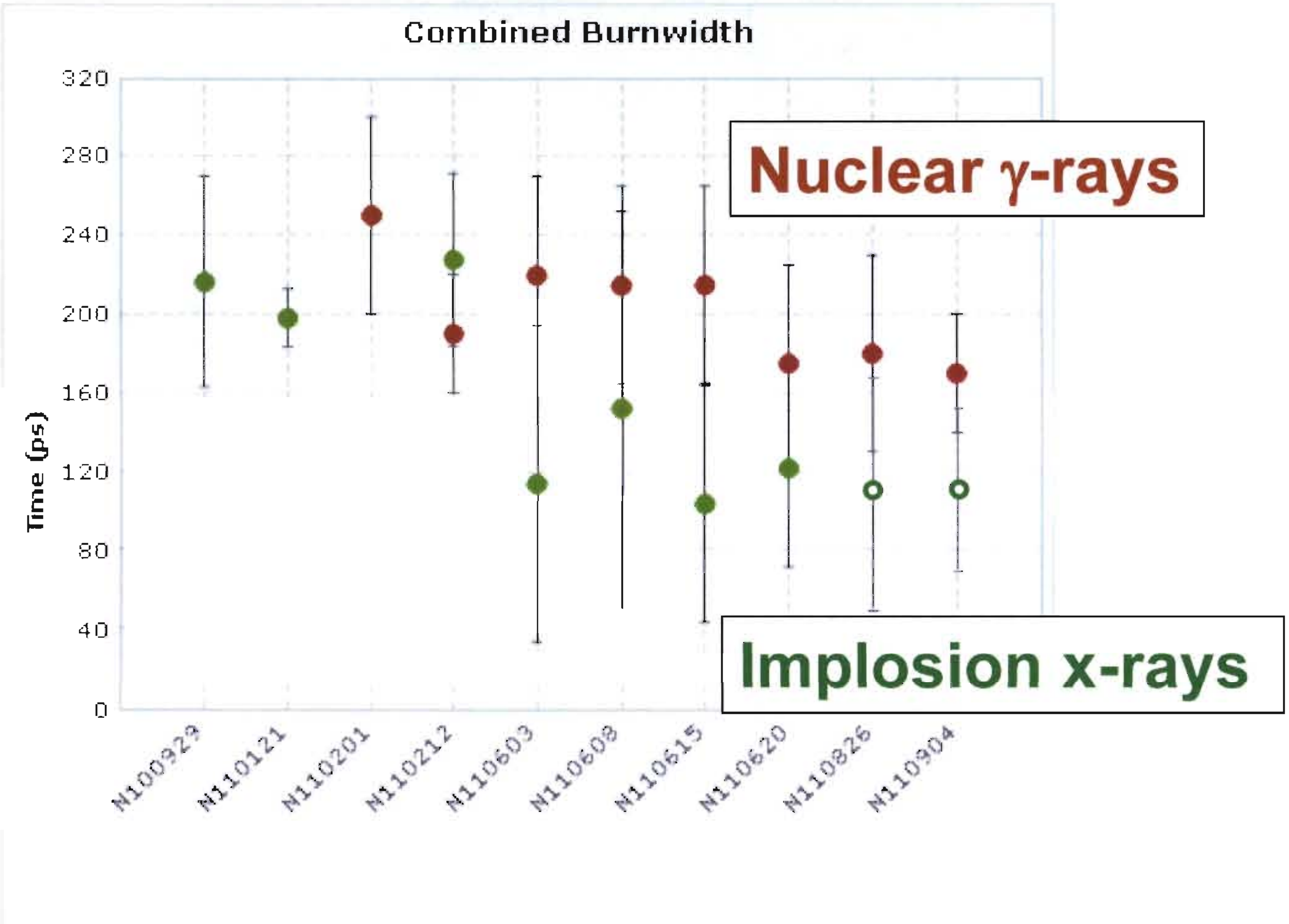
Absolute Time Base based on X-ray Timing Shots

Various Bang Time Diagnostics are in good agreement



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

Burn Width (BW): Implosion x-rays appear to be narrower than Nuclear γ-rays (but difference may not be statistically significant)

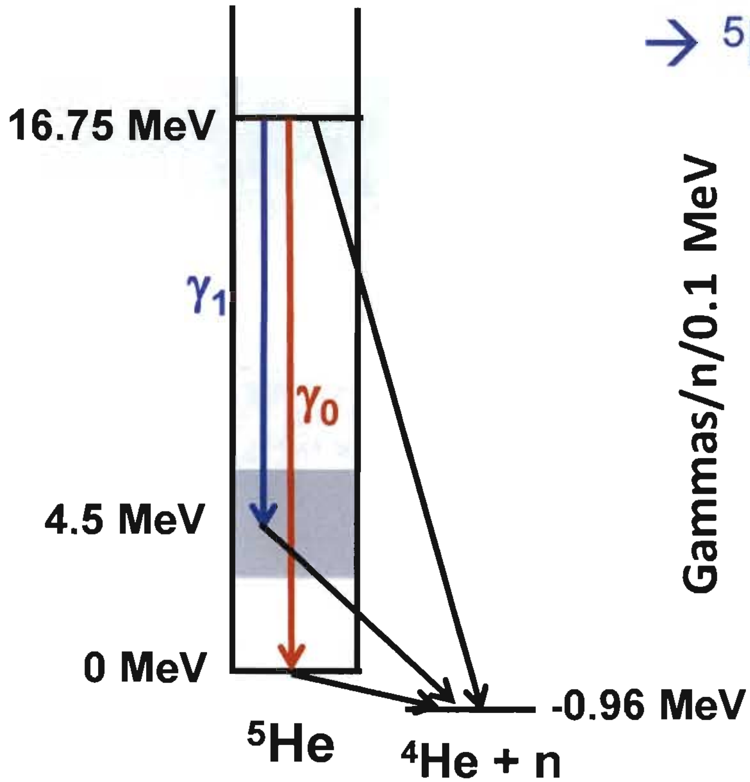


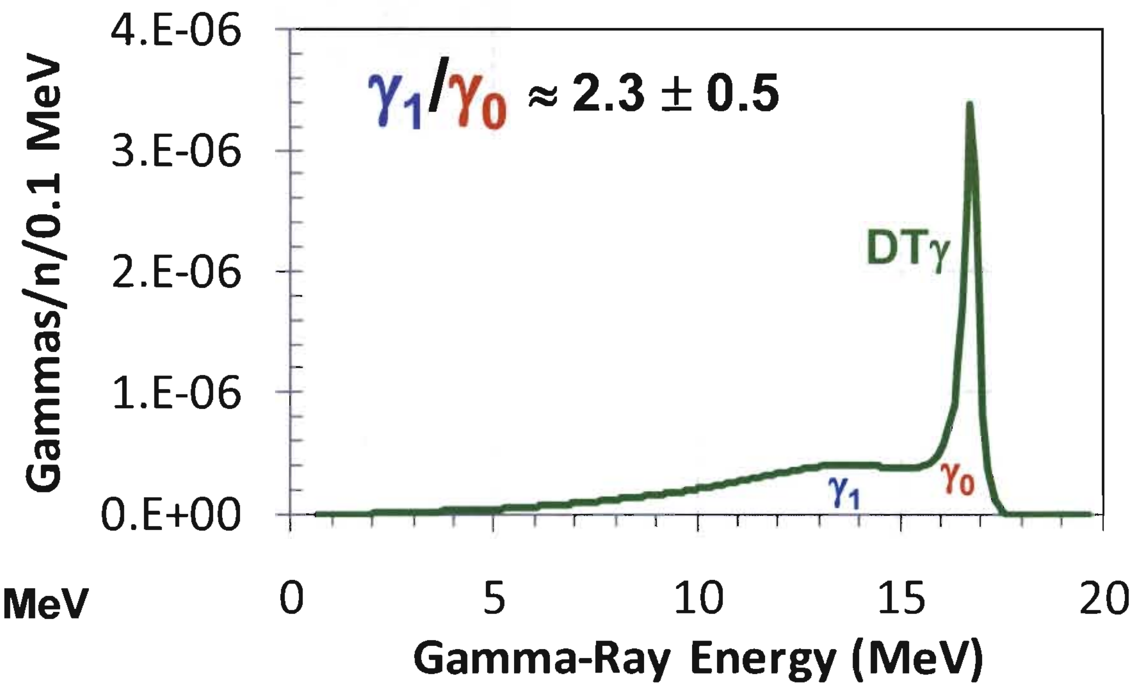
DT Gamma-Ray Spectrum has been mapped out with threshold scans on OMEGA (C. Horsfield, O.Tu_C.8)

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

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

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

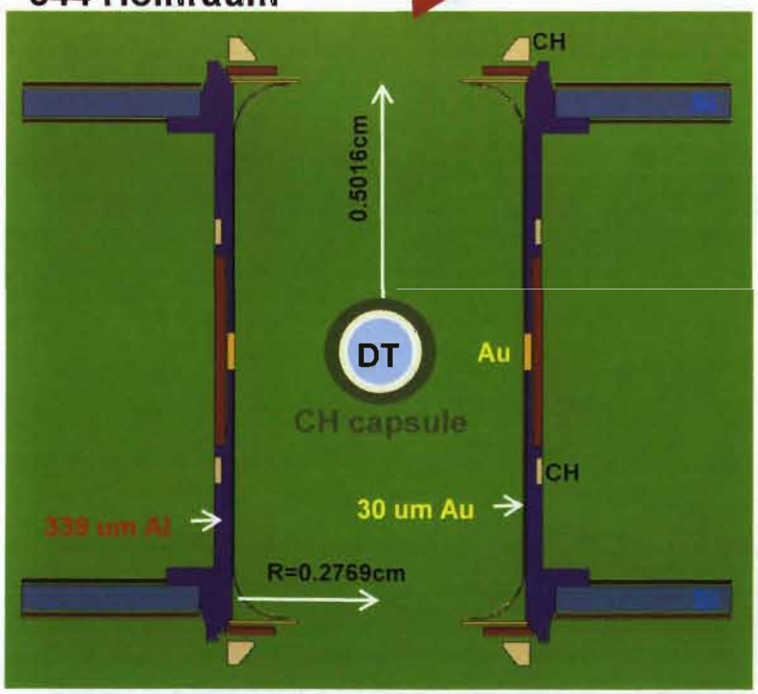




E. Cecil, G. Hale

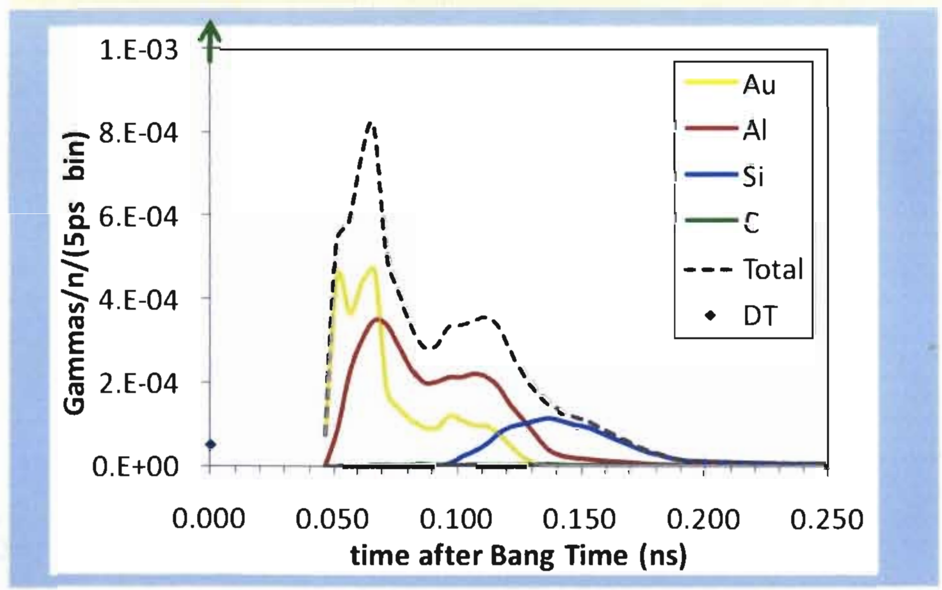
14 MeV neutron-induced γ-Rays from CH Capsule & Hohlraum assembly are simulated in MCNP

544 Holhraum

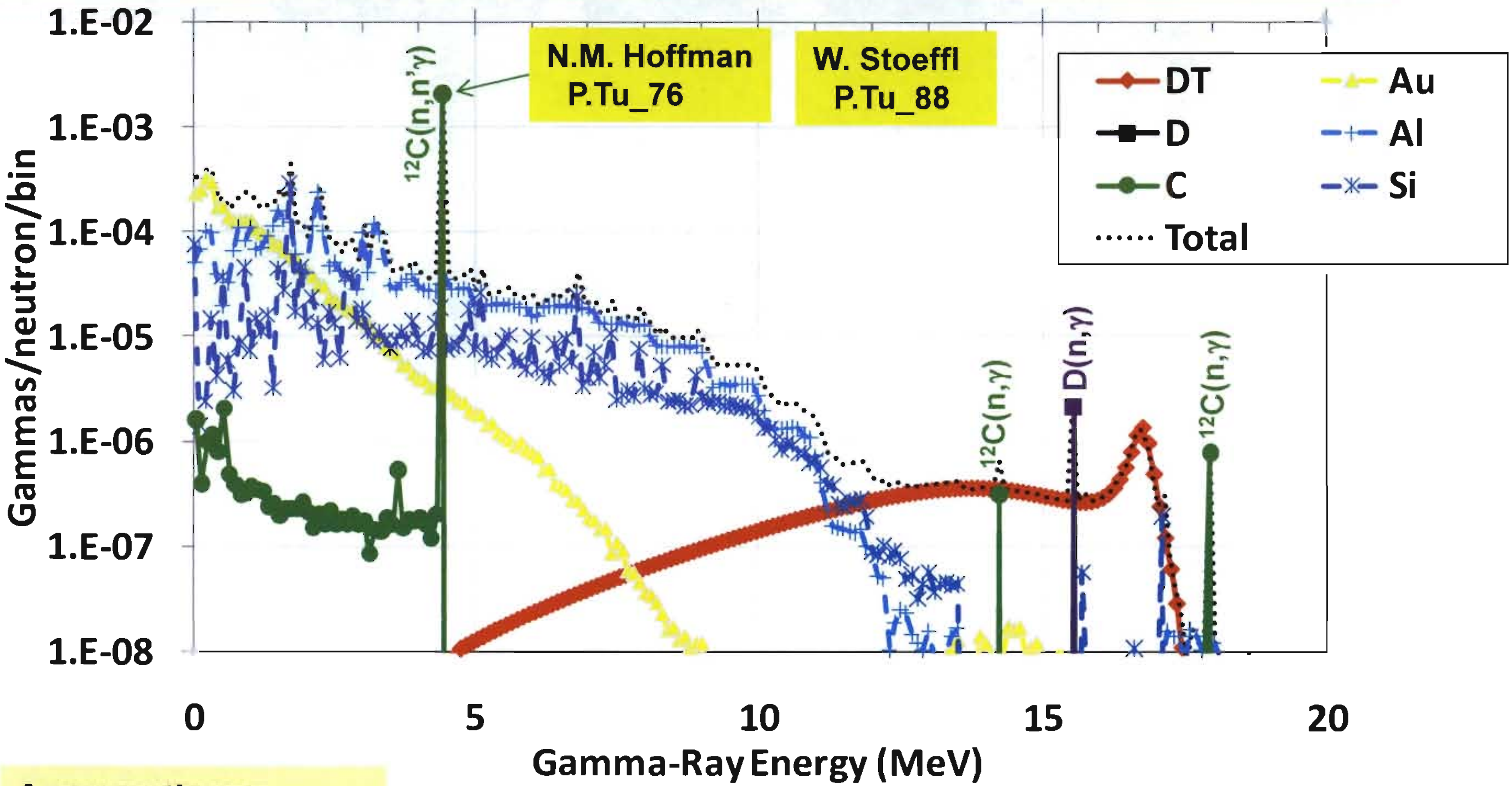


Prompt γ-Ray Temporal History

BT+¼ ns, δ(t=0) 14 MeV n-source



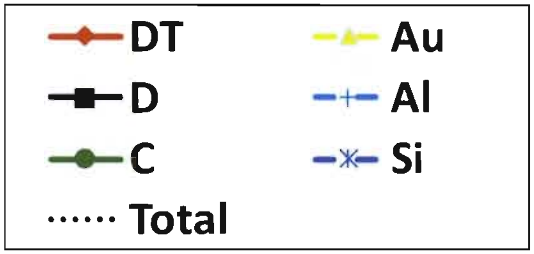
The Prompt γ-Ray Energy Spectrum from Indirect-Drive, Cryo-Layered Implosions is complicated!

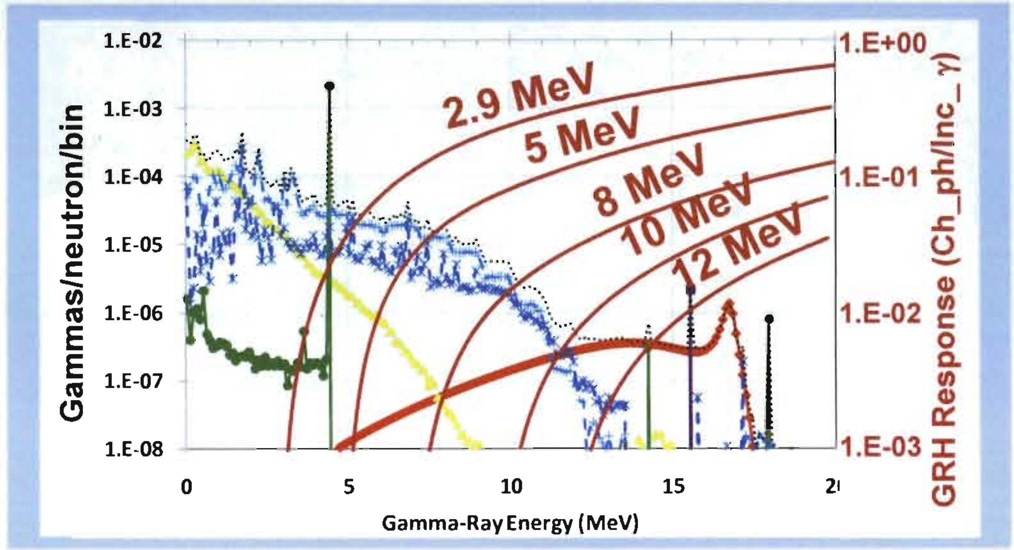


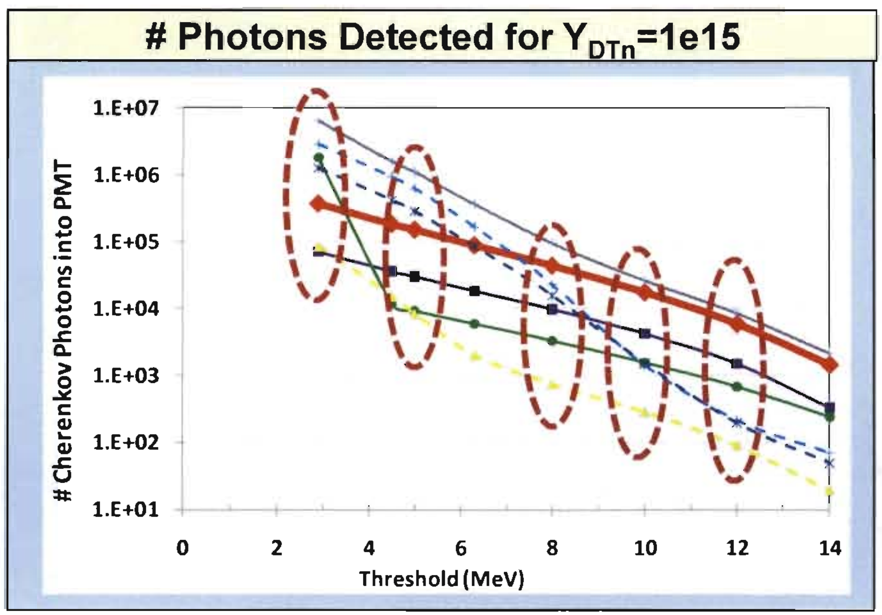
Assumptions:
- $BR(\gamma/n) = 2.7e\text{-}5\ \gamma/n$
- $\gamma_1/\gamma_0 = 2.3$
- $\rho R_{12C} = 0.2\ g/cm^2$
- $\rho R_{DT} = 1.0\ g/cm^2$

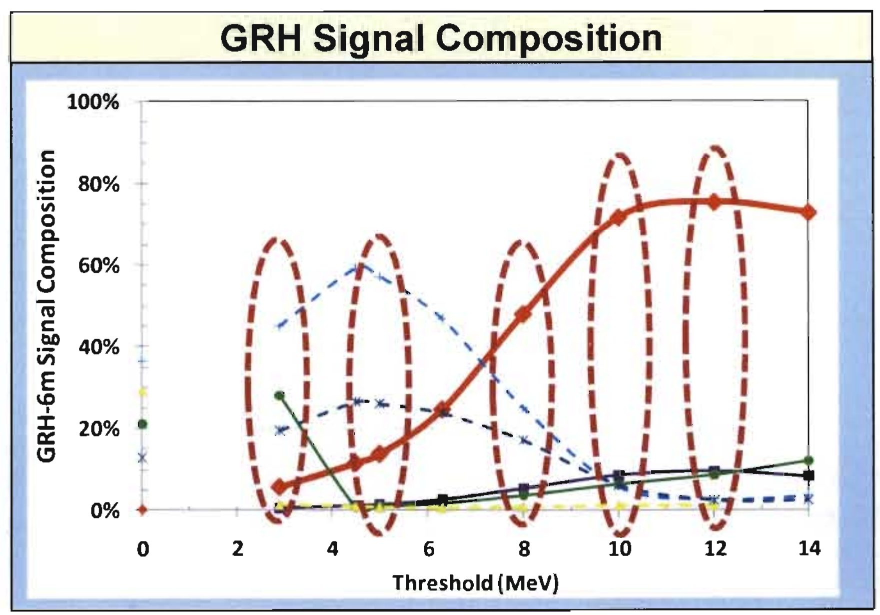
Neutron captures in fuel D & ablator ^{12}C generate high-energy γ's essentially synchronously with fusion reaction history

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







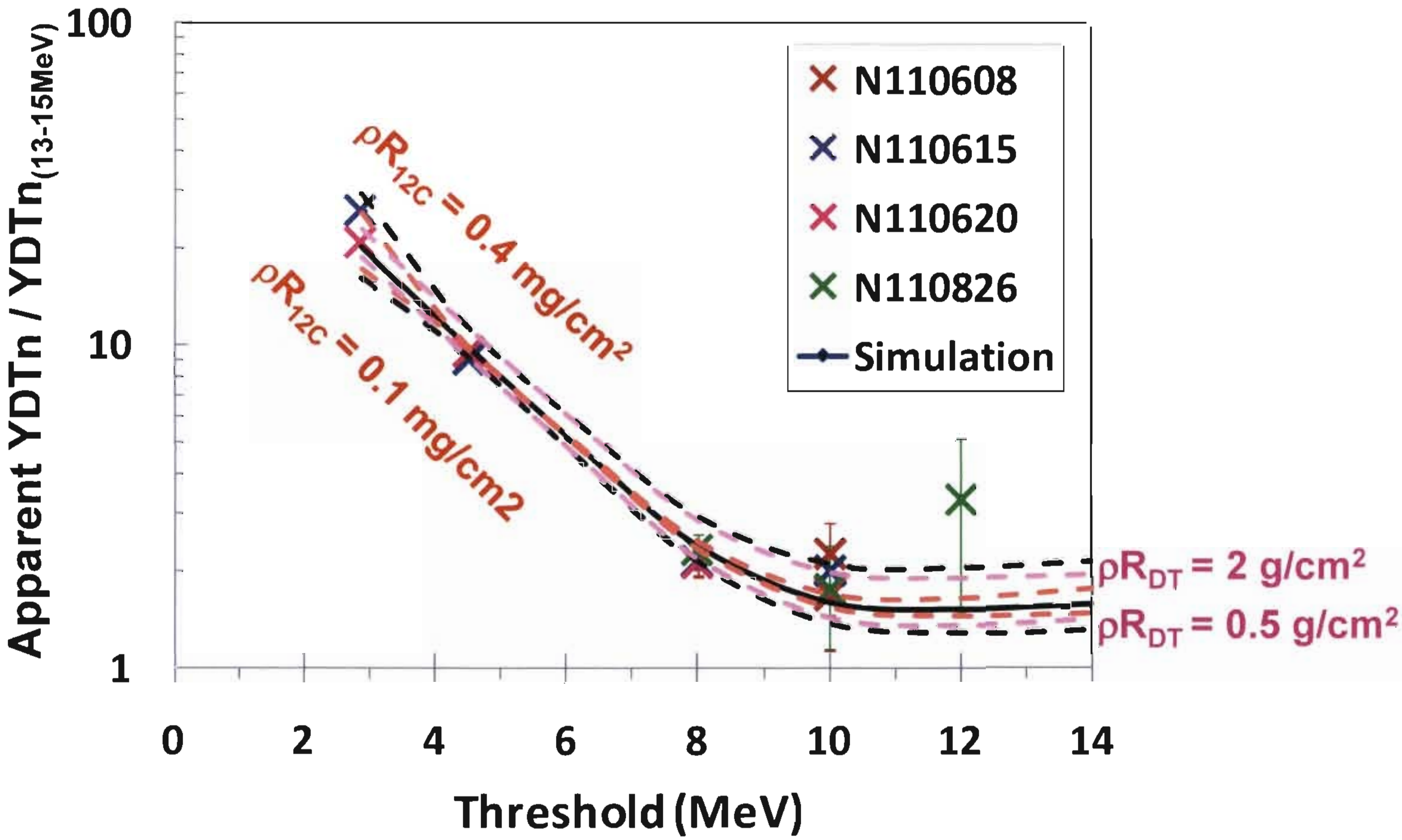


GRH integrated signal has several ρR dependencies

Base Assumptions:

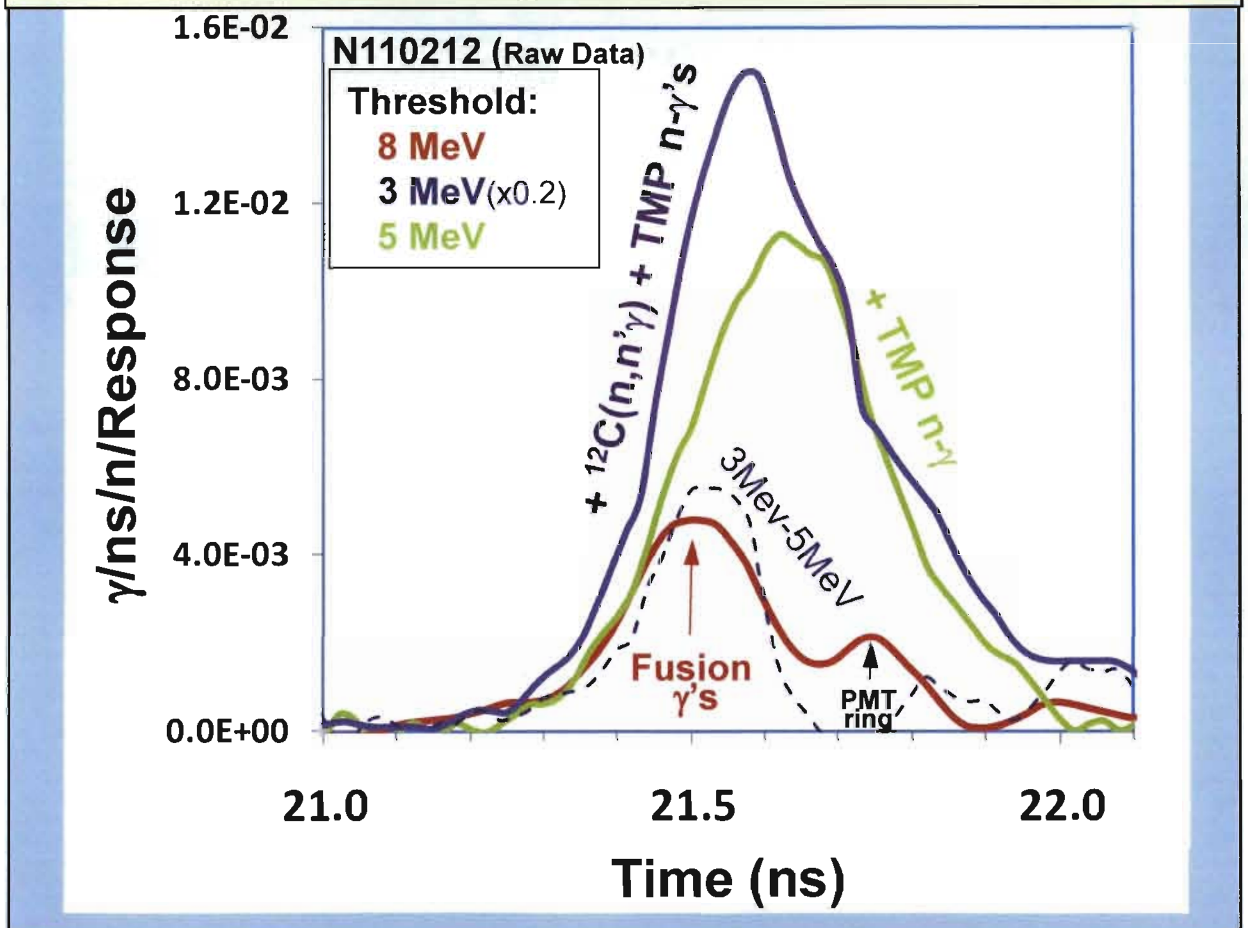
BR = 2.7e-5 γ/n — ρR_{DT} = 1 g/cm2 (DSR≈5%)

γ1/ γ0 = 2.3 — ρR_{12C} = 0.2 g/cm2



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

Cryo-layered THD Data



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

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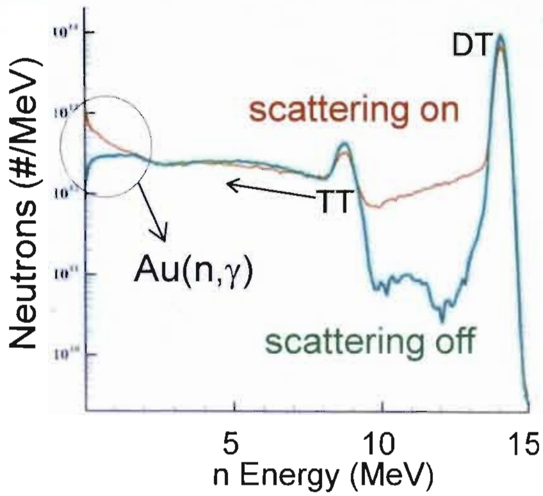
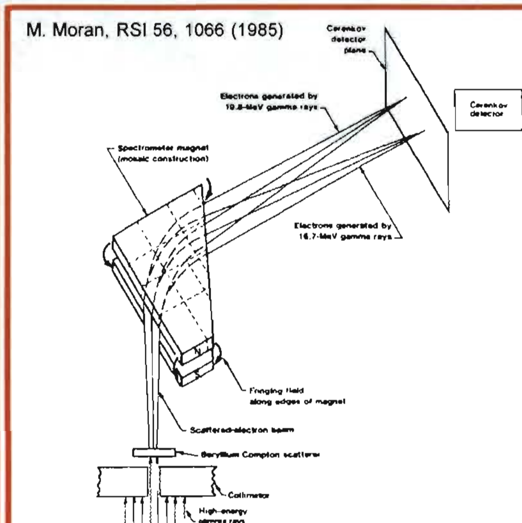
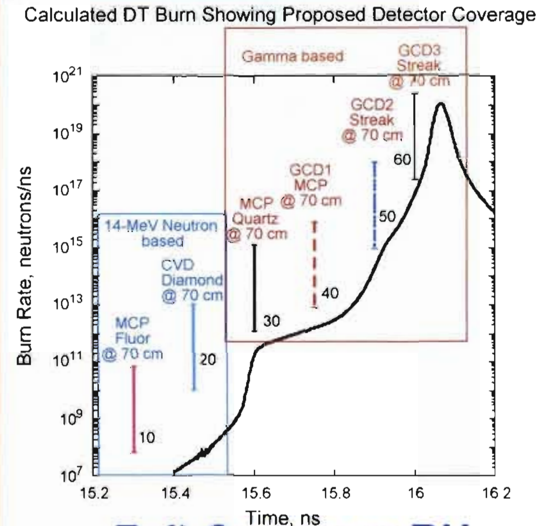


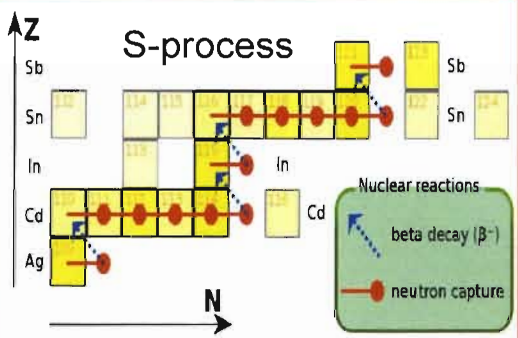
Total ρR measurement
(L. Bernstein)



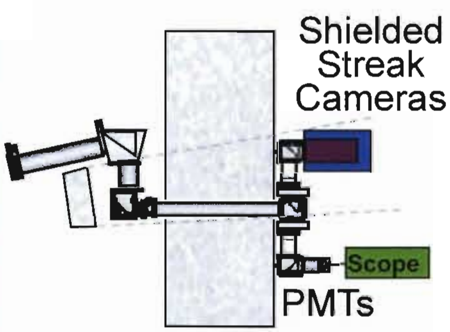
Compton Spectrometer
(Y. Kim)



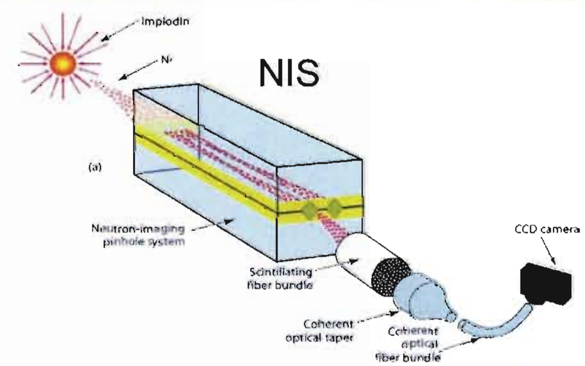
Full Coverage RH
(J. Mack)



Astrophysical Processes
(L. Bernstein)

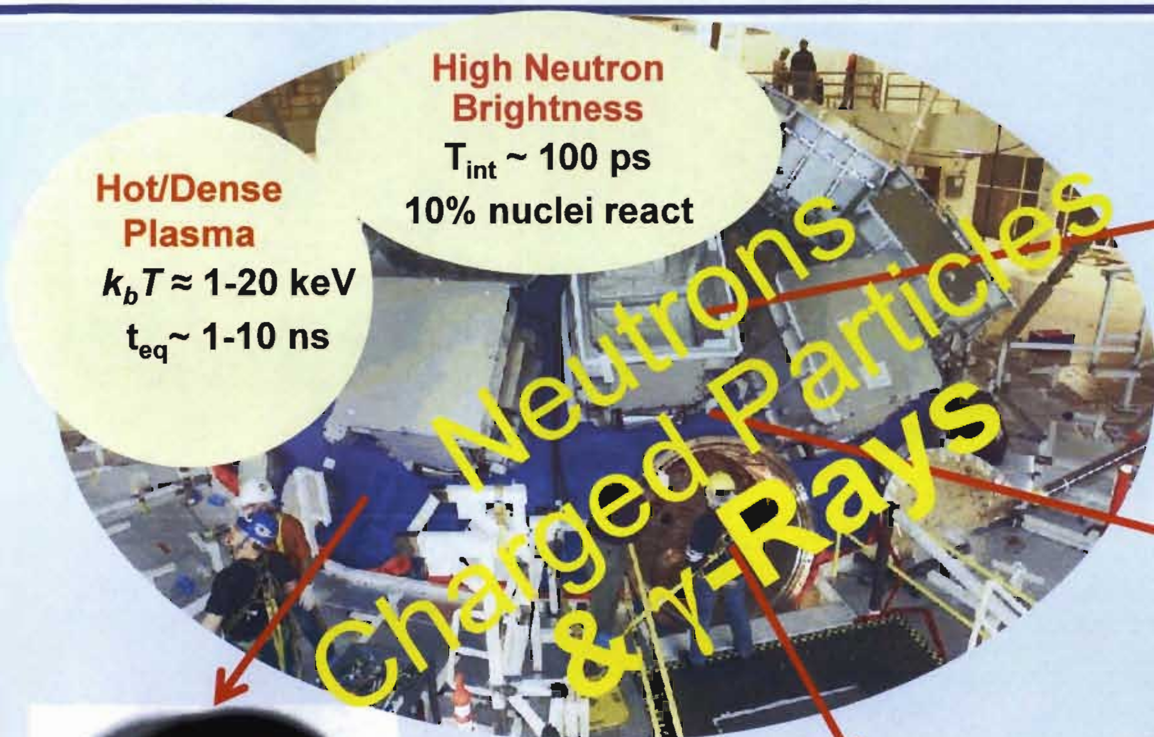


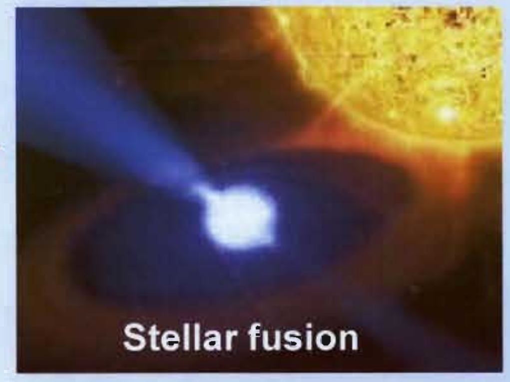
Streaked GRH
(H. Herrmann)

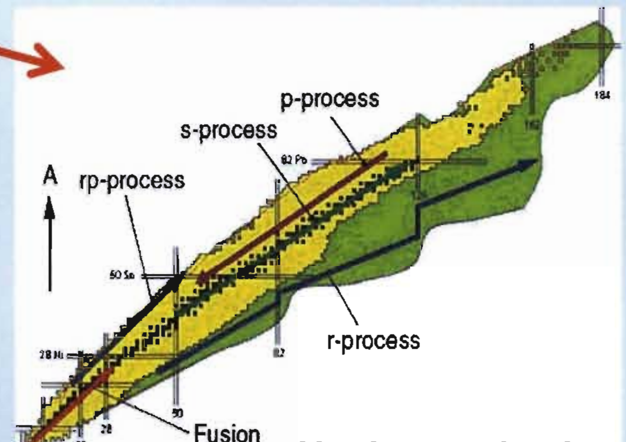


γ-Ray Imaging of Ablator (^{12}C-γ)
(G. Grim)

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

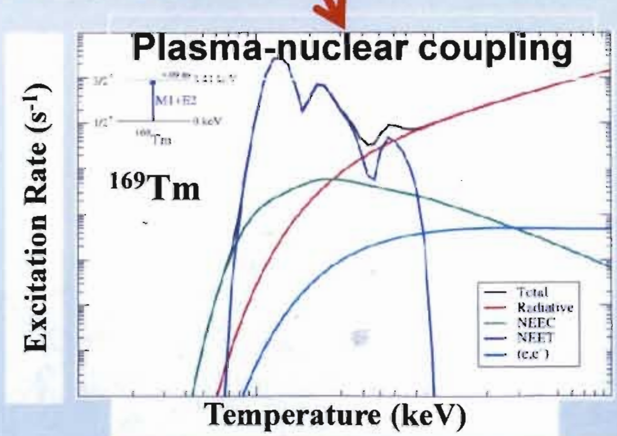






Nucleosynthesis

Neutronic coupling/ excited states



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

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