Fusion Gamma-ray Measurements using Gas Cherenkov Detector

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GRH Team
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GCD/GRH has been developed by LANL in collaboration with AWE and LLNL

- Gas Cherenkov Detector (GCD)
  - Fusing $\gamma$'s
  - DT Implosion
  - Be Compton Converter
  - Cherenkov Radiation
  - $\text{CO}_2$
  - Relativistic electron
  - Tungsten Shielding
  - Cassegrainian optics
  - PMT
  - PMT Signal
  - Bias Voltage
  - Threshold Energy = down to 6.3 MeV ($\text{CO}_2$ @ 100 psi)
  - PMT & Streak Camera-based (tested)
  - $\sim 10^{11}$ min. n-yield @ 20 cm

- Gamma-ray Reaction History (GRH)
  - NIF
  - Fusing $\gamma$'s
  - DT Implosion
  - Be Compton Converter
  - Cherenkov Radiation
  - $\text{CO}_2$, or $\text{SF}_6$
  - Off-axis Parabolic Mirror
  - Pressure Window
  - Adjustable flat mirror
  - Threshold Energy = down to 3.5 MeV ($\text{SF}_6$ @ 200 psi)
  - PMT & Streak Camera-based
  - $3 \times 10^{13}$ min. n-yield @ 6m

- Omega (TIM-based)
  - Threshold Energy = down to 6.3 MeV ($\text{CO}_2$ @ 100 psi)
  - PMT & Streak Camera-based (tested)
  - $\sim 10^{11}$ min. n-yield @ 20 cm
Threshold GCD captures 16.75 MeV DT Fusion Gamma-rays

\[ \gamma \rightarrow (\gamma, e) \text{ Cherenkov Radiation (e, } \lambda) \]

PMT scope

Two stage converter
GRH is an essential instrument for NIF fusion reaction studies

Bang Time Accuracy

<table>
<thead>
<tr>
<th></th>
<th>GRH6m</th>
<th>GRH15m</th>
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<tbody>
<tr>
<td>THD(1e14)</td>
<td>&lt; 25 ps</td>
<td></td>
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<tr>
<td>THD(1e16)</td>
<td>&lt; 25 ps</td>
<td>&lt; 20 ps</td>
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<tr>
<td>DT(1e19)</td>
<td>&lt; 20 ps</td>
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minimum n-Yield = \(3 \times 10^{13}\) for 100 detected DT-\(\gamma\)'s with a 8 MeV threshold

Burn Width Accuracy

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<td>&lt; 3 ps</td>
</tr>
<tr>
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minimum n-Yield = \(\sim 10^{16}\)

minimum n-Yield = \(\sim 3 \times 10^{14}\)
A challenge faced by the GRH is potential interference of $\gamma_p$ with various $\gamma_s$

- NIF indirect implosions generate various gamma-rays
- Fusion gammas ($\gamma_p$)
  - DT (16.75 MeV)
  - HT (19.8 MeV)
- n-induced secondary gammas ($\gamma_s$): (n,$\gamma$), (n,n')$\gamma$, (n,p)$\gamma$ …
  - Capsule materials (12C @ 4.44 MeV, 16O @ 6.1 MeV)
    - May be used to bolster GRH signal (~synchronous)
    - Possible time-dependent $\rho R$ diagnostic
  - Hohlraum materials (Au, U, Al, Si)
    - May also be used to bolster signal, but must be aware of BT shift (< 60 ps)
N-induced Secondary Gammas from Hohlraum & TMP can be thresholded out (calculation by Lucille Dauffy)

- ~100x more Secondary $\gamma$'s than Fusion $\gamma$'s
  - Cross sections uncertain, needs experimental validation
- ~60 ps delay between Fusion & Secondaries $\gamma$'s
  - Insignificant Bang Time shift (<10 ps) down to ~6 MeV threshold
Hohlraum $\gamma$’s never dominate the signal (by Hans)

- DT $\gamma$’s dominate signal (i.e., >3x) for Thresholds 7.5 to 15 MeV
- C12 $\gamma$’s dominate at <4.5 MeV
- Hohlraum $\gamma$’s never dominate, but can be comparable to DT $\gamma$’s at 4.5 to 7.5 MeV thresholds
Experimental goal is to simulate $\gamma_s$ from a NIF hohlraum & Proximity Sources

- NIF hohlraum simulation experiment at OMEGA
  - GRH performance study (threshold response)
  - Gamma interference study (bang time, burn width)
  - Code (MCNP/ACCEPT) validation
    - If neutron rate and $(n,\gamma)$ cross-sections are known, $\gamma_s$ can be a GRH code validation source
    - cf) Calibrated ‘electron’ (LINAC) and ‘gamma’ (HIGS) source are also used for validation
      - Uncertainty in fusion gamma branching ratio
- $\gamma_s$ as a GRH calibration source
  - $\gamma_s$ serves as in-situ GRH calibration source
  - $\gamma_s$ serves as a broad energy source
  - various puck materials are available (Al, Al2O3, Cu,…)
  - Provide one method for Branching Ratio ($=T(d,\gamma)/T(d,n)$) determination
    - Multiple methods needed to reduce uncertainty
‘Hockey Puck’ experiments are conducted at the OMEGA laser facility (Nov. 2008 and April 2009)

Diameter of Al puck = 3 cm
Thickness of Al puck = 0.5 cm (+ 0.2 cm holder side)
**GCD Signal Configuration**

**LANL Gas Trigger**
T-0 = 4999.9680 μs

**PMT 110-001**
QE~20%
Air hose
EMI

*assuming 1.2 ns/ft for signal cable*
Clean Signals but improperly located puck

- gamma attenuation
  \[ 1 - \frac{\gamma_p}{\gamma_{po}} = \sim 0.081 \]
  \sim 8.1 \% measured
  (more scattering)

- \sim 550 \text{ ps } \gamma_s \text{ pulse}
Data Analysis: Primary/Secondary ratio & timing (by Hans)

- Secondary/Primary ratio = 21.6%
- Secondary signal shifted by 704 ps
  - γ's: c = 29.98 cm/ns (33 ps/cm); 14.1 MeV n's: v_n = 5.19 cm/ns (193 ps/cm)
    - Neutrons are delayed 160 ps/cm relative to γ's
  - Face of Puck is at 704/160 = 4.40 cm
  - Back end of secondary signal should be smeared out by ~90 ps relative to the primary signal (80 ps for 0.5 cm thick puck + 10 ps for Doppler spreading), but appears to only be smeared by ~20 ps
Secondary gamma production and Primary gamma attenuation are observed.

![Graph showing SCD2 Voltage / (Gain * Neutron Yield * 1e-13) vs Time (ns) with different materials and shots.

Key:
- Red: Without Puck (shot 5,8)
- Blue: Al puck (shot 2,4)
- Green: Al2O3 (shot 6,7)
- Dashed blue: Shot 9
- Dotted blue: Shot 10 Al]
\[ \frac{\gamma_s}{\gamma_p} (\text{Al, 100psi}) = 0.107, \quad \frac{\gamma_s}{\gamma_p} (\text{Al2O3, 100psi}) = 0.076 \]
\[ \frac{\gamma_s}{\gamma_p} (\text{Al, 65 psi}) \sim 0.017, \quad 992\text{ps} / 160\text{ps} = 6.2 \text{ cm} \]
Summary

• Successful day at OMEGA on Nov. 2008
  – Aluminum puck (D = 3 cm, t = 0.5 cm) at two locations
  – $\gamma_s/\gamma_p \sim 0.216$ and $\gamma_s/\gamma_{po} \sim 0.198$ at 4.4 cm or less location

• Successful day at OMEGA on April 8, 2009
  – $\gamma_s/\gamma_p \sim 0.107$ at Al, 6 MeV
  – $\gamma_s/\gamma_p \sim 0.076$ at Al2O3, 6 MeV
  – $\gamma_s/\gamma_p \sim 0.017$ at Al, 8 MeV

• Next OMEGA shot day on May 13-14 or later
  – Additional puck materials (Cu, Si, SiO2)

• A coupled MCNP/ACCEPT calculation (by Jamie, Carl, Joe)
  – Provide one method for Branching Ratio ($=T(d,\gamma)/T(d,n)$) determination