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Gamma Reaction History of Sandia's Z Machine

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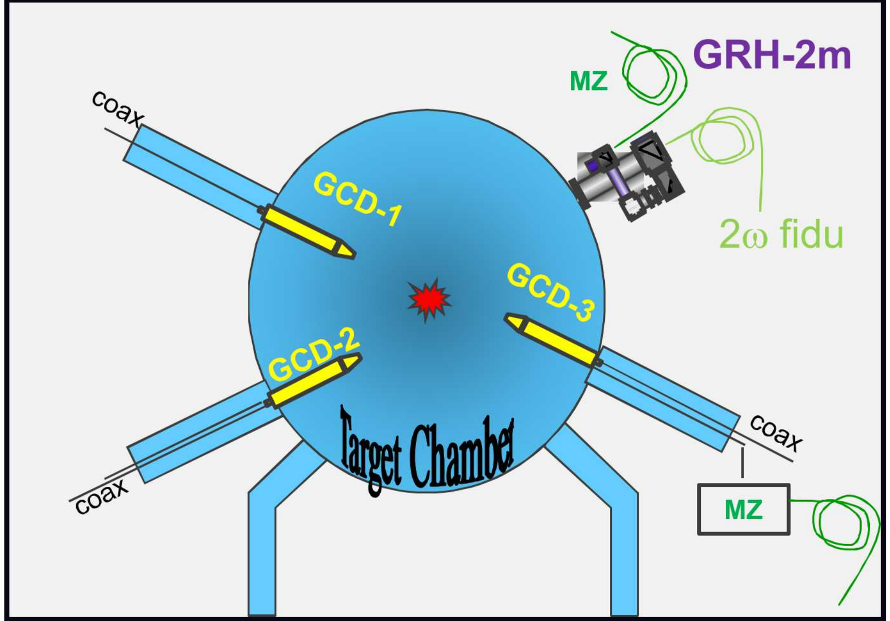
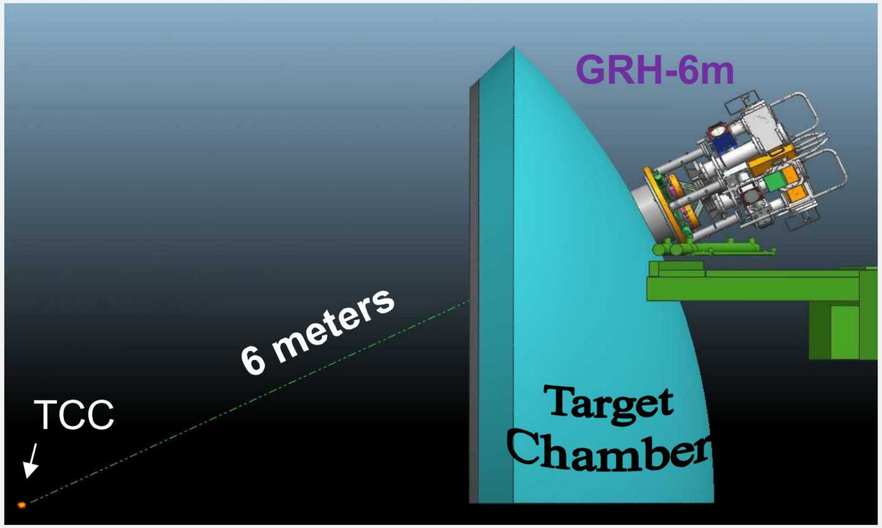
Gas Cherenkov Detectors have been in operations at OMEGA & NIF for many years

OMEGA-60



3 GCDs (20cm), 1 GRH (187cm)

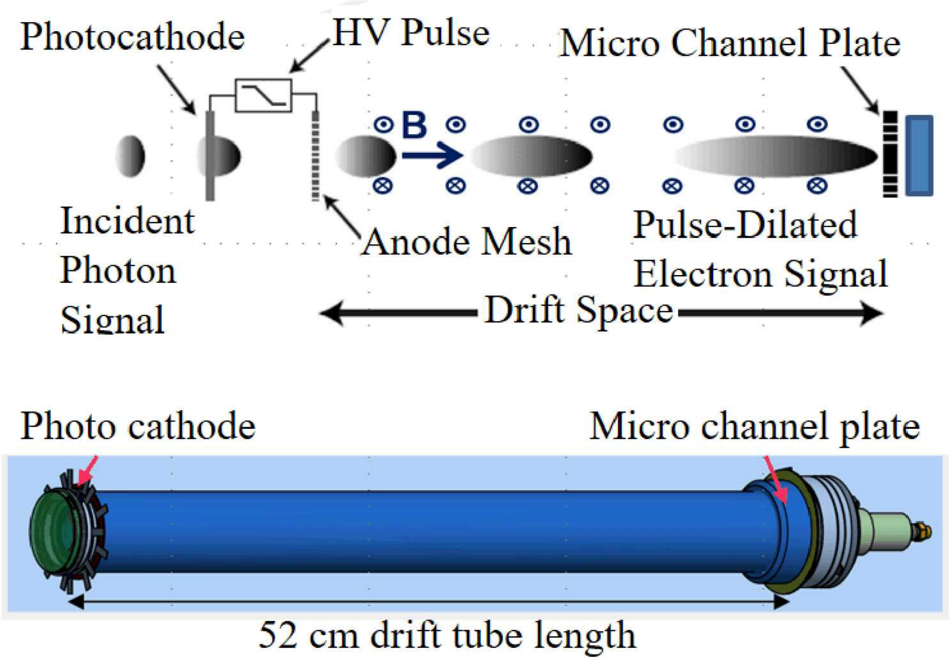
NIF

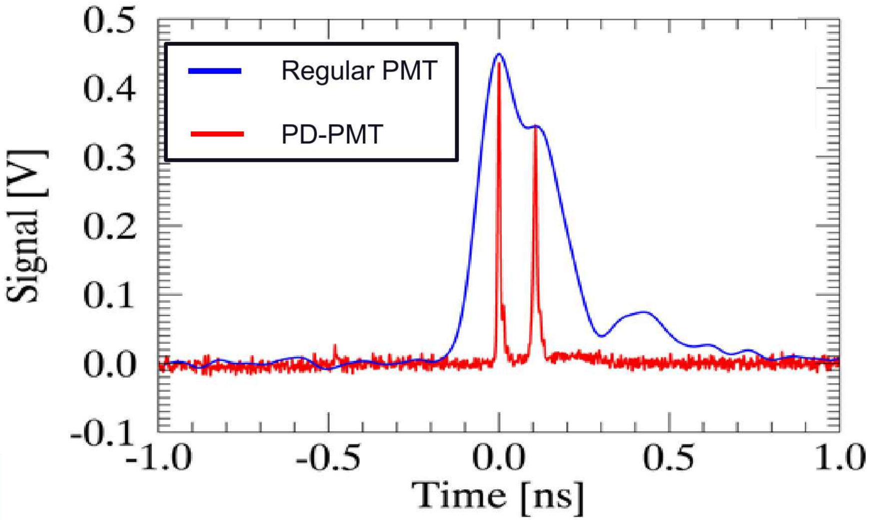


4 GRHs (607 cm)

Existing NIF GRH-6m has limited sensitivity due to large standoff distance

LANL/LLNL met a L2 Milestone – introducing 10x faster detector based on Pulse-Dilation PMT (Dec. 2018)



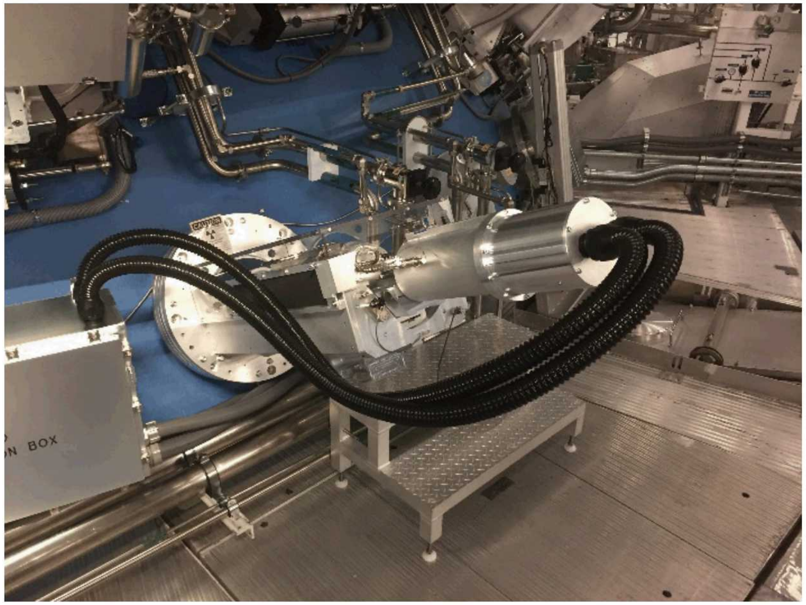


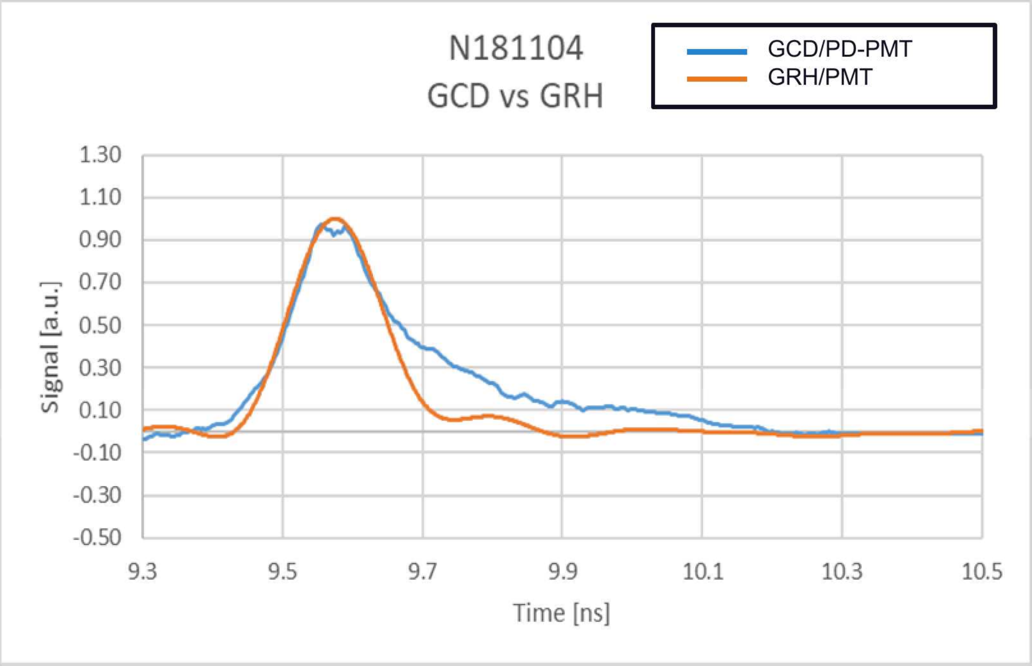
Pulse-Dilation (PD-PMT) was able resolve two pulse of 12ps wide peaks separated 130ps (red line) in test measurements

LANL can now measure details of thermonuclear burn

DT fusion gamma-ray measurement at NIF reveals structure in reaction history not seen in sister instrument GRH

PD-PMT installed on the back end of the Gas Cherenkov Detector on the NIF (Aug 2018)

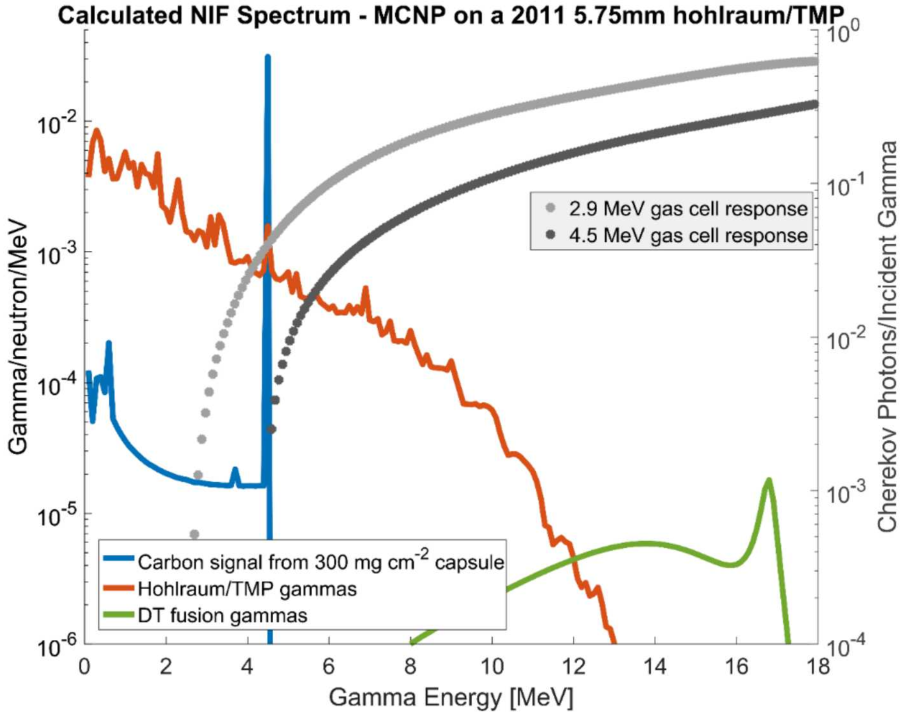


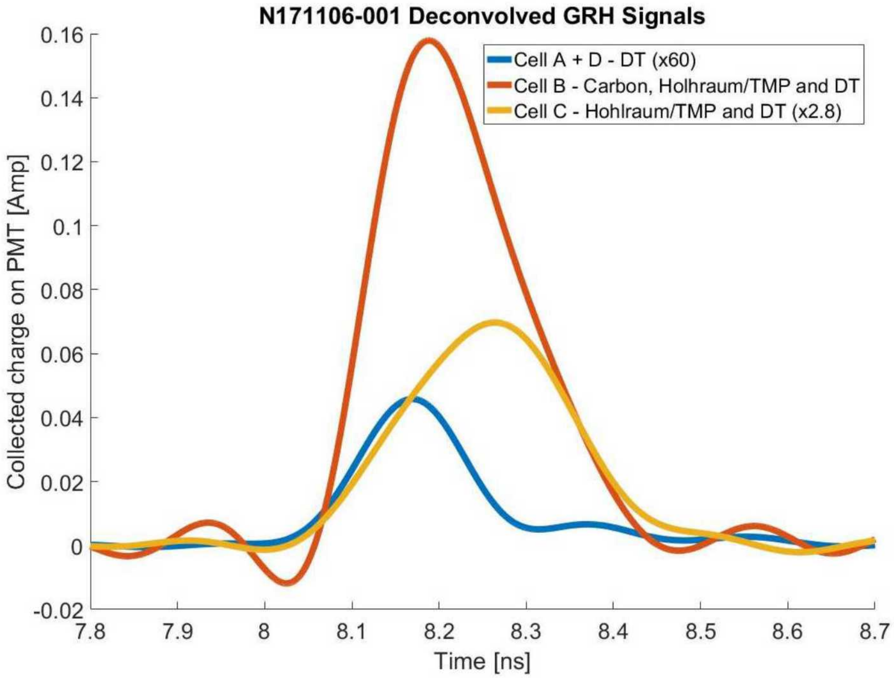


The newly installed GCD/PD-PMT confirms the burn width (FWHM) of existing GRH/PMT agree with GCD/PD-PMT

GRH uses different gas pressures at NIF to isolate the 4.4 MeV carbon γ from the background to determine carbon ρR

- Different gas pressures, different index of refraction, different energy cutoffs
- Two gas thresholds (2.9 MeV and 4.5 MeV) to isolate carbon gammas

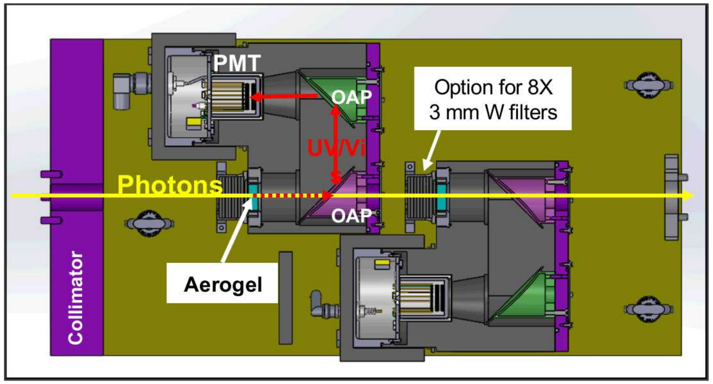




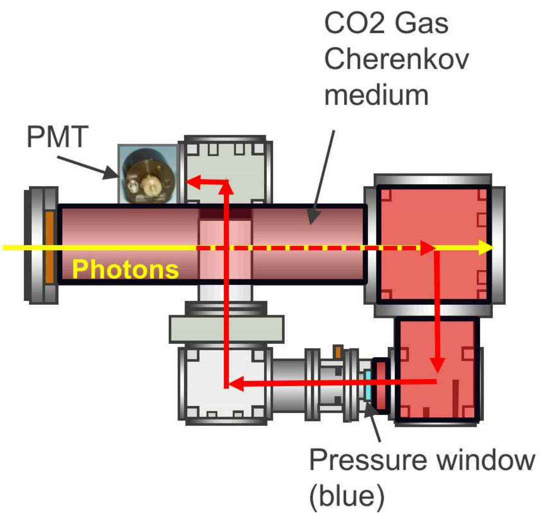
Cherenkov Detectors fielded on Z will provide time-resolved x-ray and gamma detection in photon energy range >0.3 MeV

Cherenkov Detector steps:

- High-energy photons are Compton scattered to create high-energy electrons
- Relativistic electrons pass through Cherenkov medium → emits VIS/UV photons
- VIS/UV photons are relayed to PMTs



ACD: 2 module configuration (0.3-3.0 MeV)

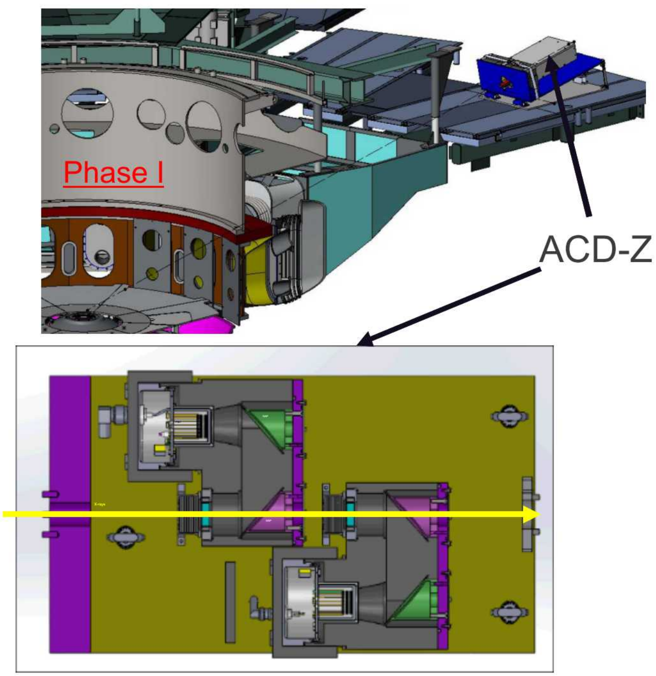


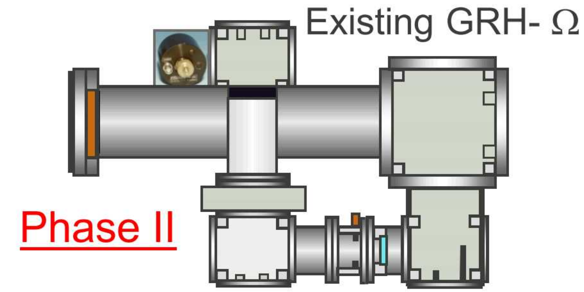
GRH in LLE OMEGA configuration (>3.0 MeV)

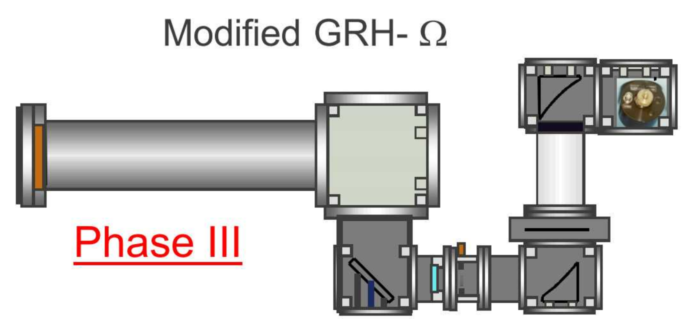
Staged approach to mitigate background risk and successfully measure reaction history on Z

- Phase I (FY19Q1-Q3): Assess bkgd with existing ACD
- Phase II (FY20Q2): Field Omega GRH on Z
- Phase III (FY21Q3): Field Omega GRH on Z in modified configuration
- Phase IV (FY21+): Feed Omega GRH experience into Z-specific GRH

Phase I

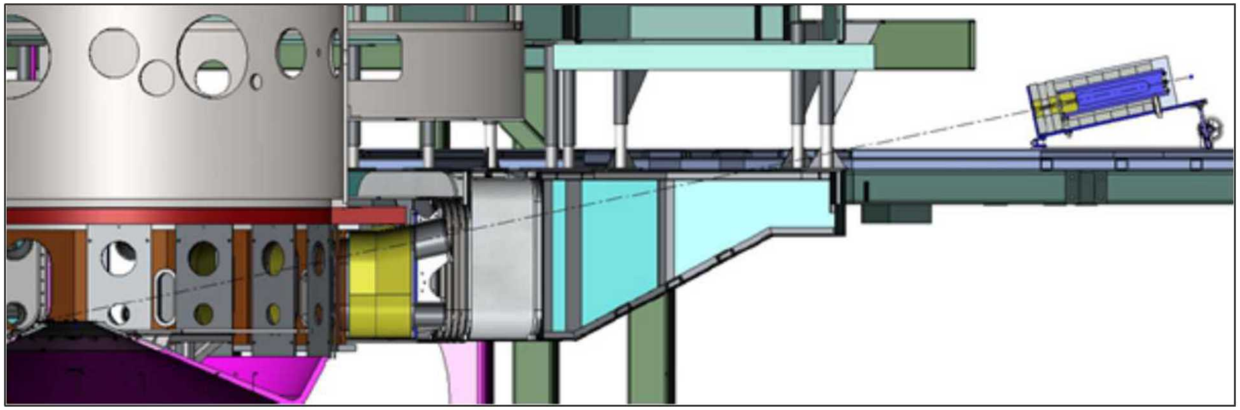




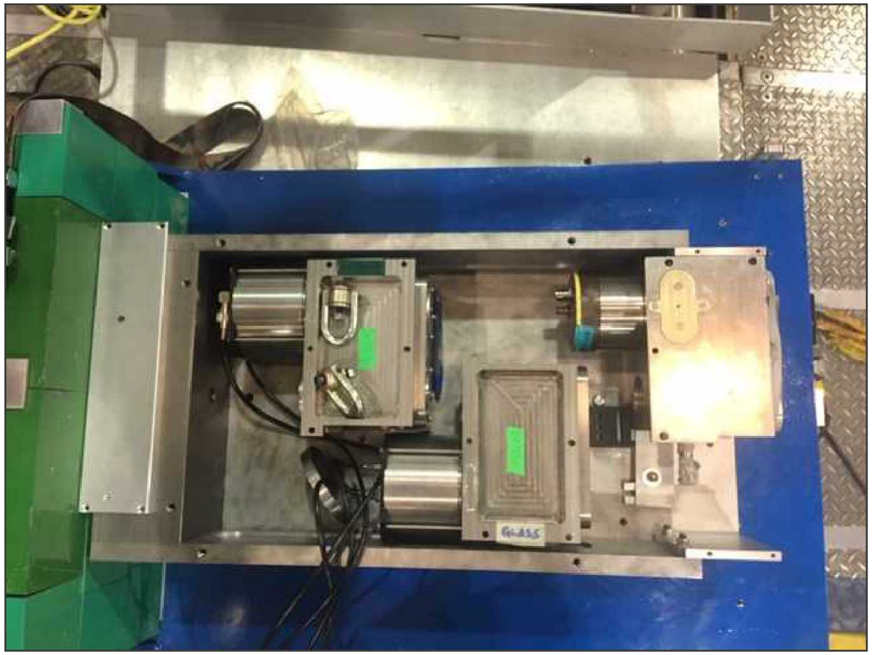


ACD with 3 modules has been fielded to assess the x-ray background radiation

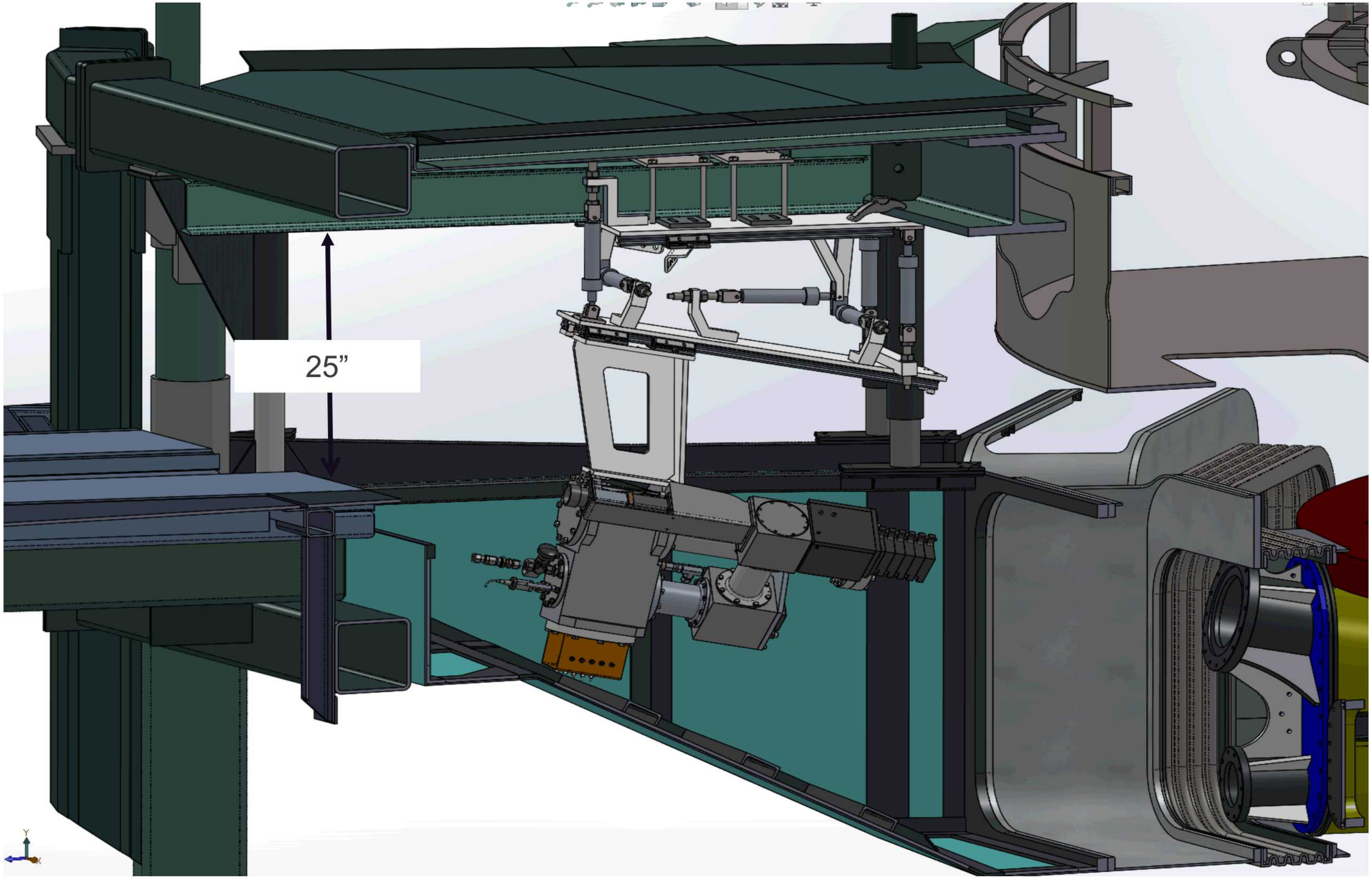
ACD modified to fit 3 modules and located ~6m from TCC



Mod 1 Empty
Mod 2 Glass (0.3MeV threshold)
Mod 3 Aerogel (2.2Mev threshold)

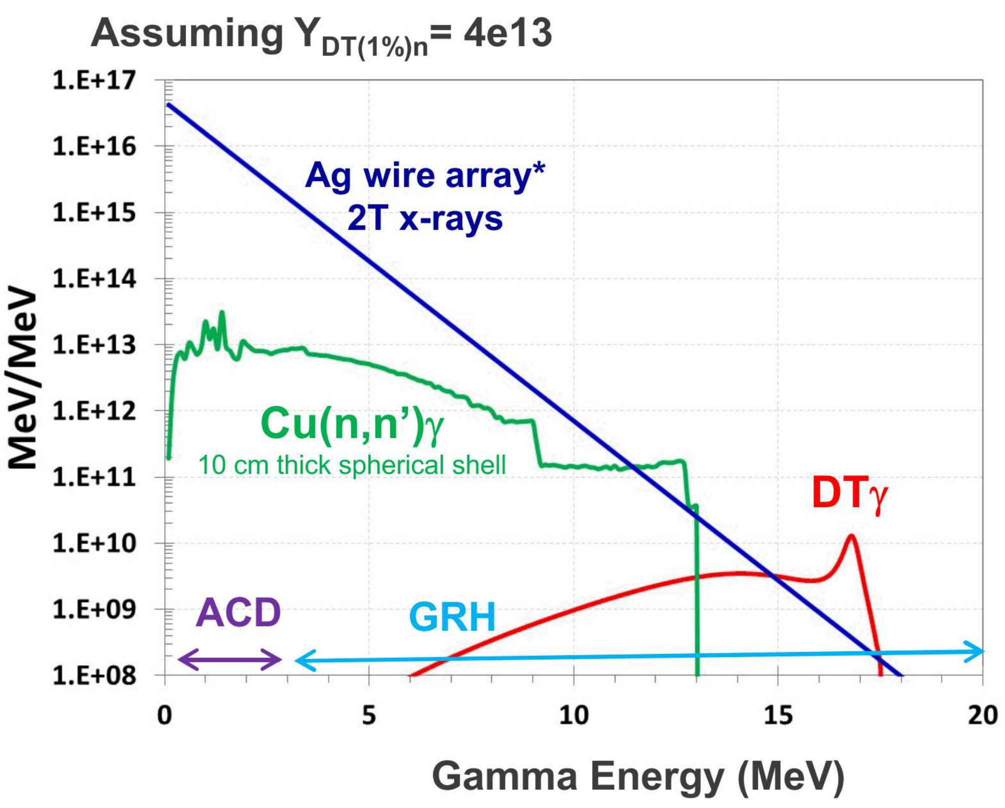


Mechanical design for implementing the GRH on Z
Expected to be in operation ~ February 2020



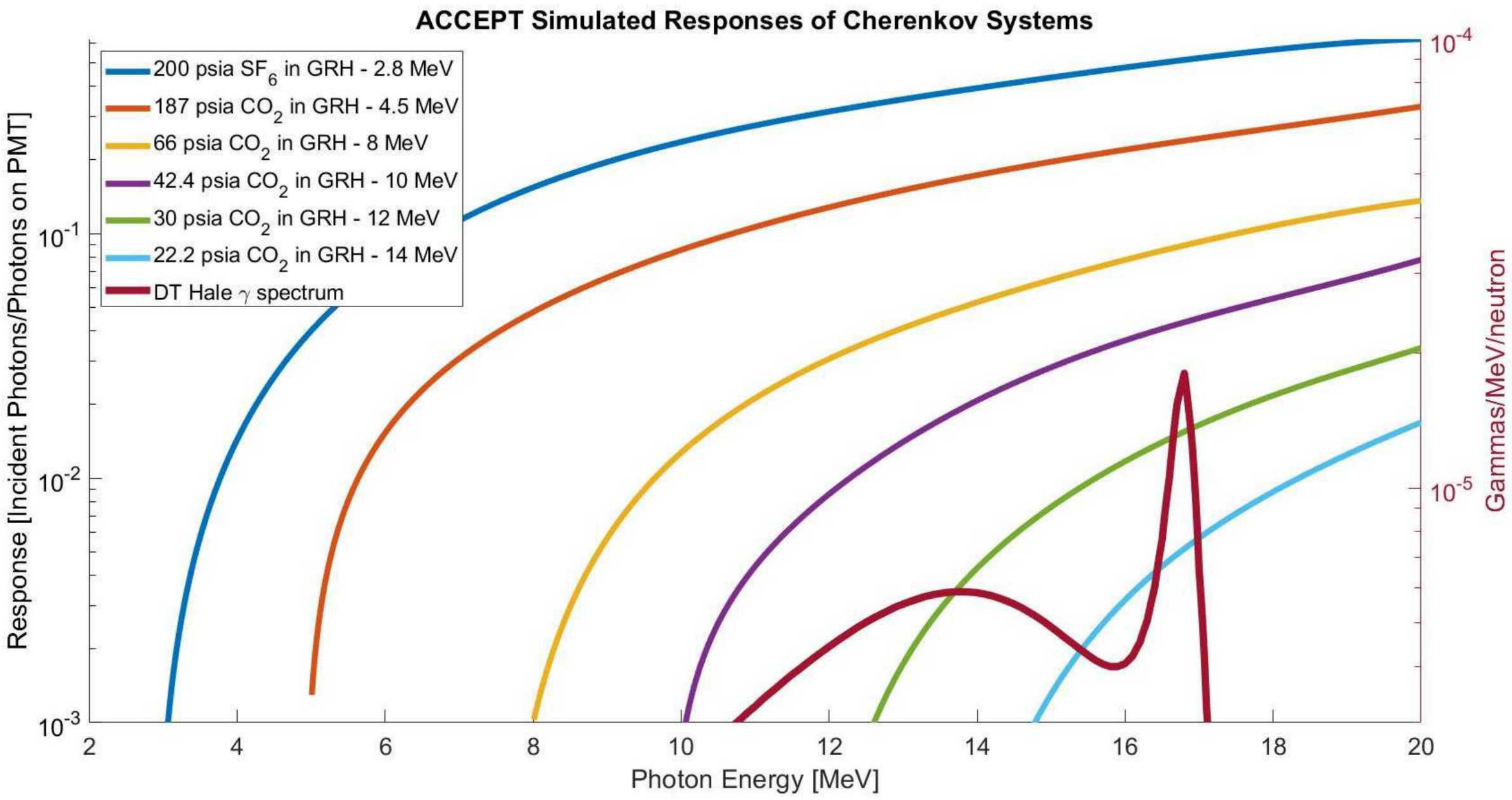
ACD and GRH will be used to assess MeV bkgds on Z & help determine path forward for isolating DTγ's

- X-rays may exceed nuclear γ rays at <10 MeV
- DT Fusion γ likely to be dominant >15 MeV
  - Possibly even at >10 MeV
- **ACD** for 0.3-3 MeV
  - Amplitude & slope of bkgds
  - Cherenkov based nToF
- **GRH** for >3 MeV
  - Can bridge the gap of bkgds near the MeV DTγ energy range
  - Isolate DTγ

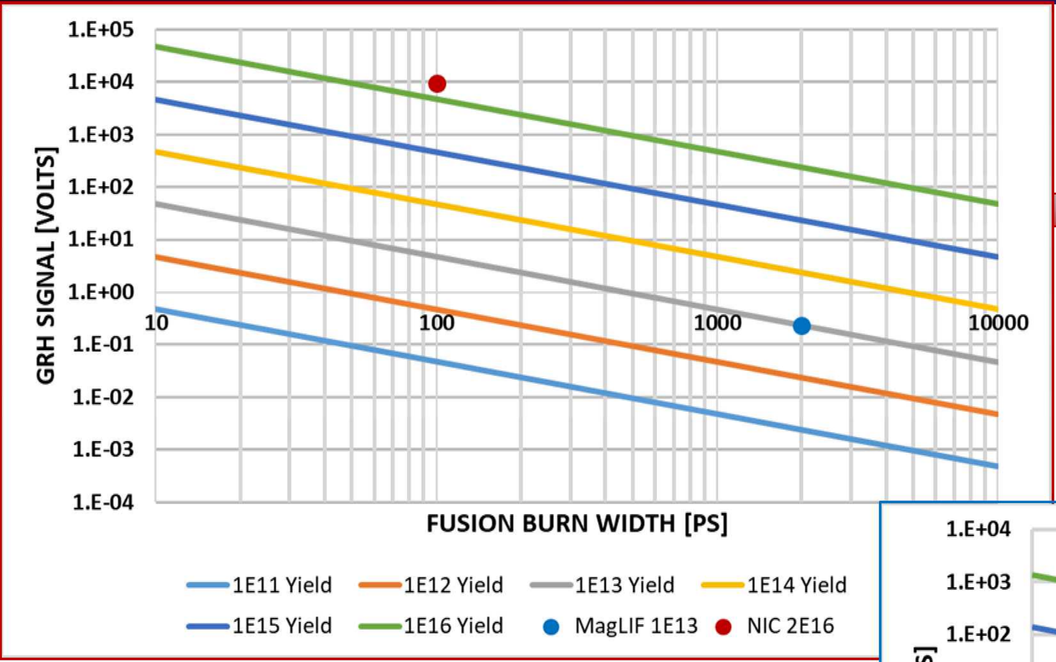


*Harper-Slaboszewicz, RSI **88**, 043501 (2017)

Response curves for varying GRH thresholds compared to DT signal



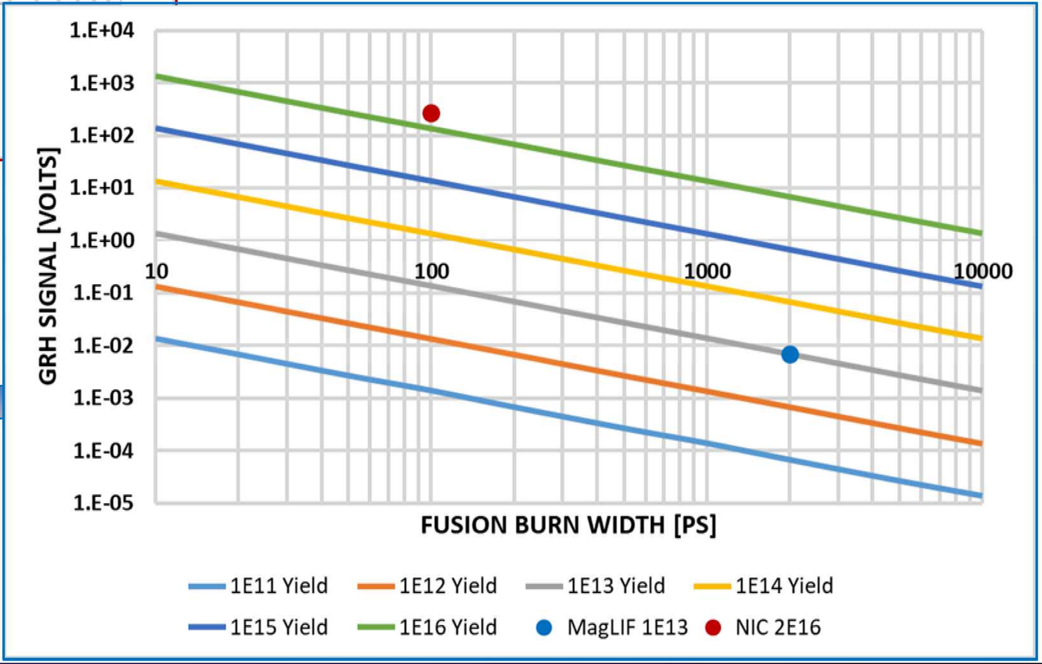
Estimated GRH voltage for 8 MeV and 14 MeV gas cell thresholds at 3.0 meters



GRH Threshold: 8 MeV

MagLIF:

~ 1 V [DT (1%) 4E13] Yield)



GRH Threshold: 14 MeV

MagLIF:

~ 7 mV [DT (1%) 4E13] Yield)

Origins of signal contamination that will complicate detection of DTγ

- DT reaction: DT (γ) + DT (n γ) + Brems + EMI

- DD reaction: DD (γ) + DD (n γ) + Brems + EMI

→ EMI removed with adequate shielding

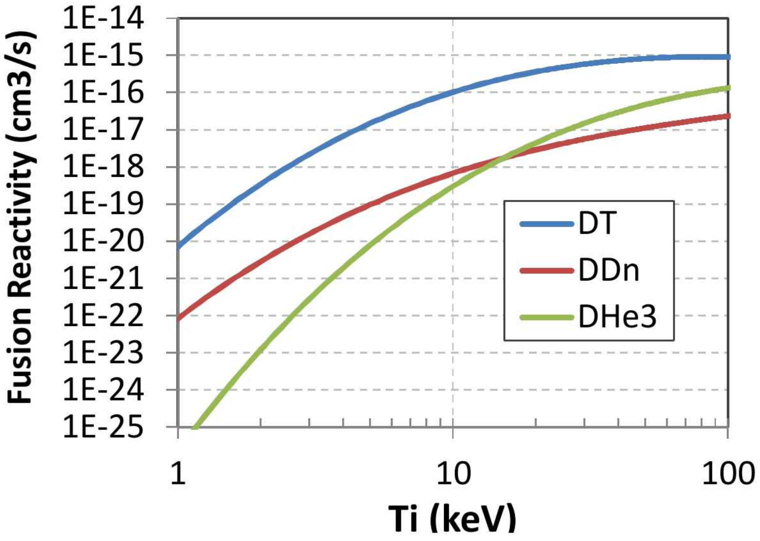
→ Brems removed via post-processing by comparing DT to DD shots

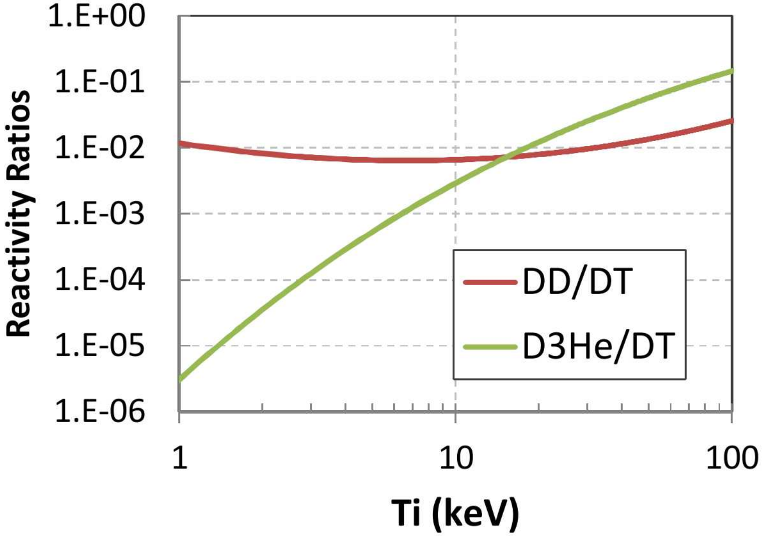
→ DD (γ) & DD (n γ) (& possibly Brems) removed with >8 MeV GRH threshold

→ DT (n γ) removed with in-chamber collimation and >10 MeV (?) GRH threshold

GRH can also be used to diagnose D^3He fusion

- **D^3He Branching Ratio (BR) is ~3x that of DT**
  - DT BR = 4.2e-5 γ/n
  - D^3He BR = 12.5e-5 γ/p
- **D^3He and DT gammas have similar energy, and hence detector response**
  - D^3He $E_{\gamma 0}$=16.66 MeV
  - DT $E_{\gamma 0}$=16.75 MeV
- **But D^3He fusion reactivity is a small fraction of DT**
  - Need high temp (or high beam energy)
  - e.g., D^3He/DT ~0.1% at 6.5 keV



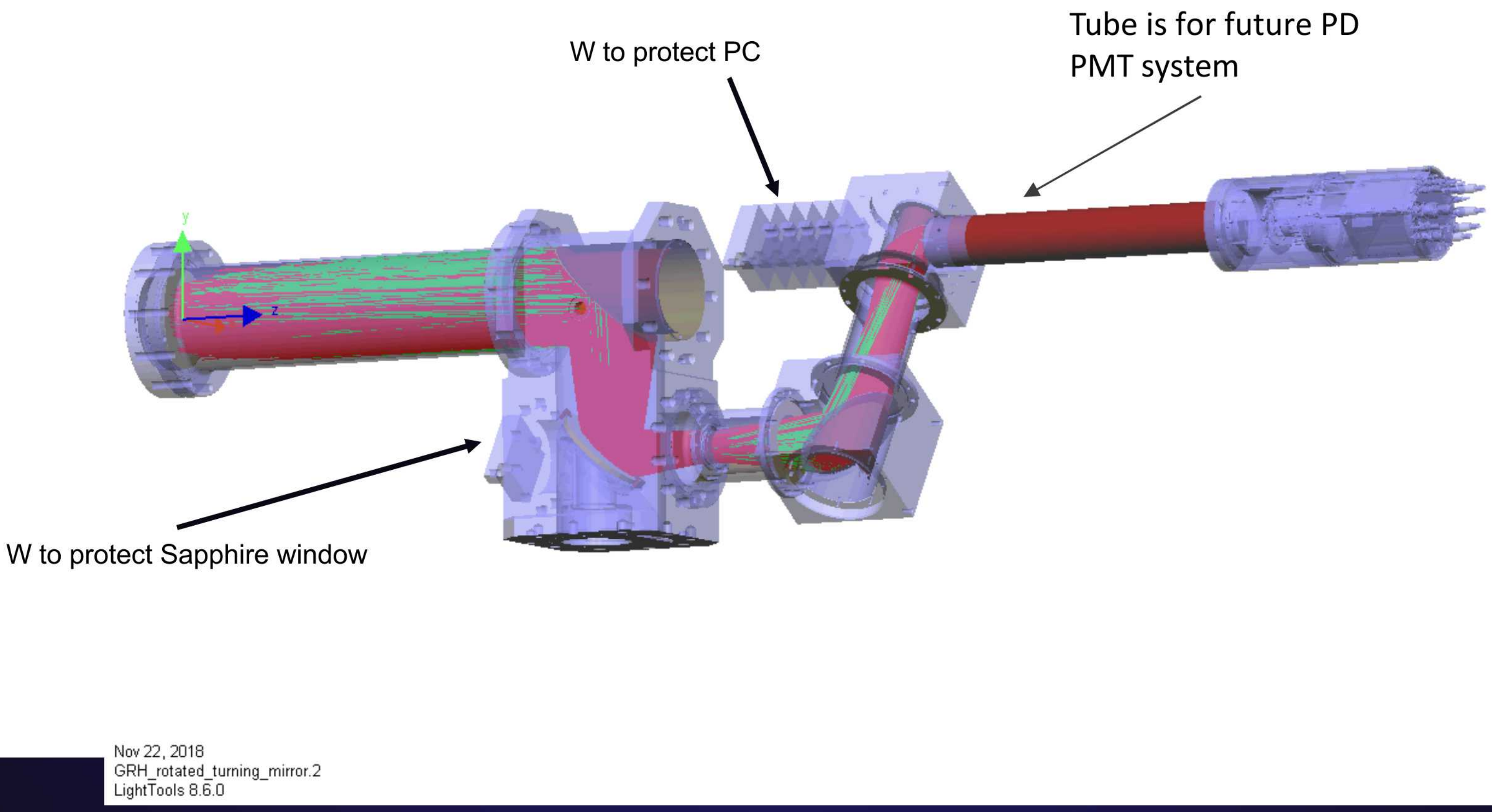


Proposed Experiment: D^3He vs DT(1%)

- Perform "hydro-equivalent" D^3He & DT(1%) implosions
  - Swap 3 D ↔ 2 ^3He atoms
  - Maintains particle pressure (i+ + e-) and Atwood # $((m_2-m_1)/(m_2+m_1))$
- If thermal ion distribution, expect:
  - $Y_{DT(1\%)\_n} \approx (100xY_{DD})(99x1/50x50) \approx 4xY_{DD}$
  - $Y_{D3He\_p} \approx Y_{DD}/10$ @ Ti=6.5 keV
  - $Y_{DT(1\%)\_n}/Y_{D3He\_p} \approx 40$ @ Ti=6.5 keV
  - $Y_{DT(1\%)\_\gamma}/Y_{D3He\_\gamma} \approx 13$ @ Ti=6.5 keV
- But steep Ti dependence of D^3He fusion reactivity makes Y_{DT}/Y_{D3He} sensitive temperature indicator
- D + 3He → p (14.7 MeV) + α
  - Fusion protons cannot be measured in Z easily
  - D^3He_γ measured by GRH will provide a yield indicator
- Comparison of "Yield Ratio Ti" with "nToF Ti" provides indication of non-thermal component of yield

GRH Z-specific configuration: addition of the pulse-dilation PMT

- Pulse dilation will provide greater time resolution; up to 10 ps
- Increased shielding will be necessary to protect from backgrounds and direct gammas
- Trigger timing of the PD-PMT on Z will need to be modified to reduce jitter



Collimation inside Z vacuum chamber might be required to reduce neutron induced γ's