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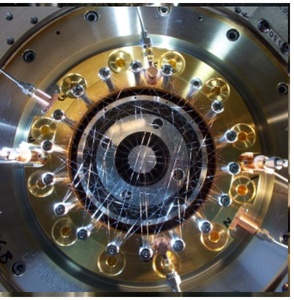

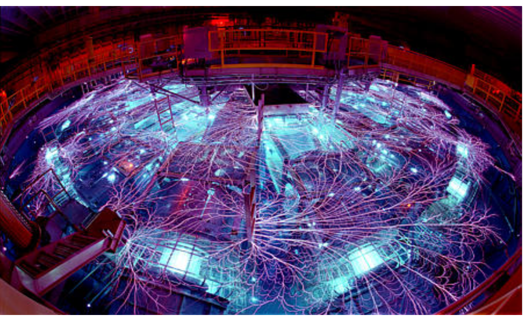

Neutron Time-of-Flight (nTOF) Diagnostic Improvements on Z

Kelly Hahn, Gordon Chandler, Carlos Ruiz, Edward Norris[1], Brent Jones, Jose Torres, Perry Alberto
Sandia National Laboratories

Gary Cooper and Jed Styron
University of New Mexico

Vladimir Glebov
University of Rochester, Laboratory of Laser Energetics

Ken Moy and Rob Buckles
National Security Technologies

Sandia National Laboratories

Exceptional service in the national interest

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

Nov 29, 2016

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1. PhD student at Univ. Missouri ST&T

Outline

- **Overview of present nTOF diagnostics on Z**
- **Implementation of new gated (Photek) detectors**
- **Characterizing nTOF instrument response functions**
- **Modeling neutron scattering environment on Z**

Key questions

What are our main concerns on Z?

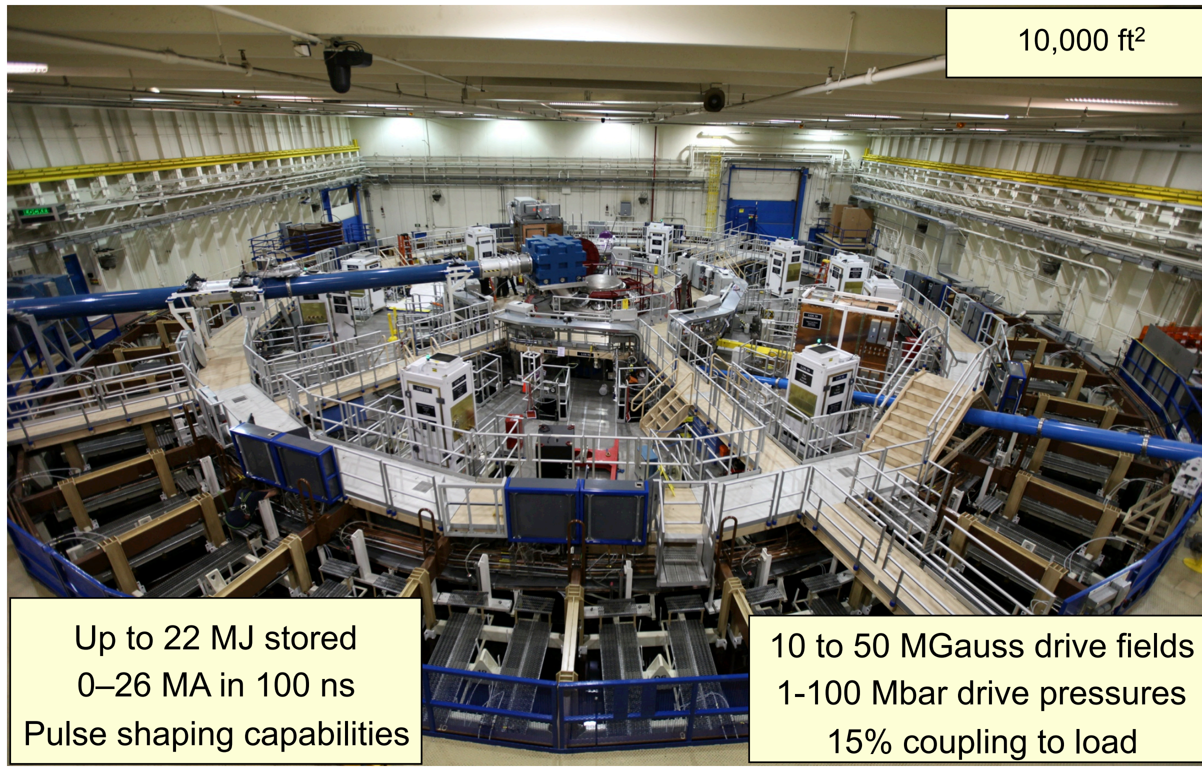
How do we extract information (i.e., Tion) from our measurements?

How much more information can we extract?

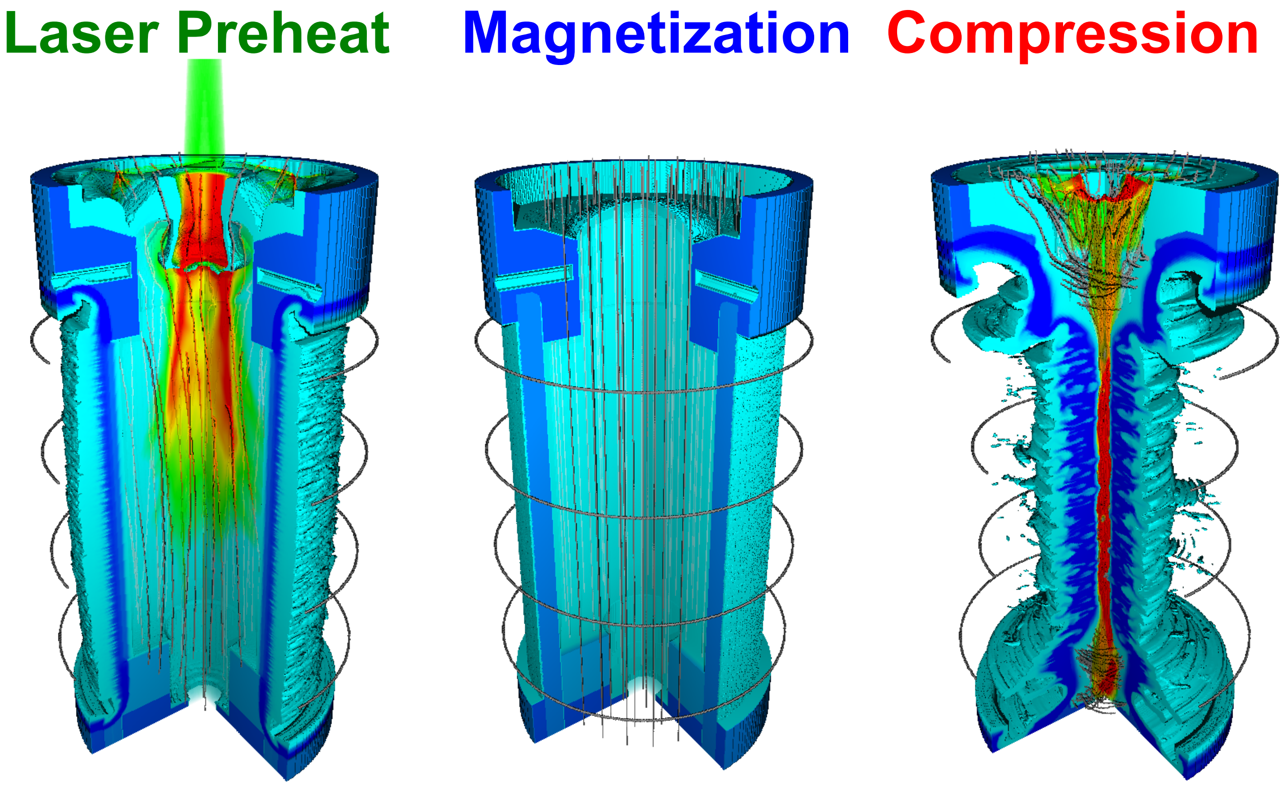
What are we missing and what do we need?

We are developing ICF sources at the Z pulsed-power accelerator at Sandia.

- **Z is very different than laser-driven facilities.**
- **Very high brems photons (1-10+ MeV)**
- **Significant debris, shrapnel**
- **High neutron scattering**
- **Deuterium fuel**
  - 0.1-1% trace tritium expt’s have begun

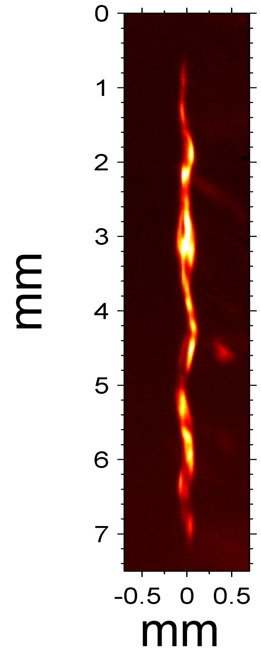


Since 2013, we have been conducting Magnetized Liner Inertial Fusion* (MagLIF) experiments on Z.



Results from 3-D Gorgon simulations by Chris Jennings.

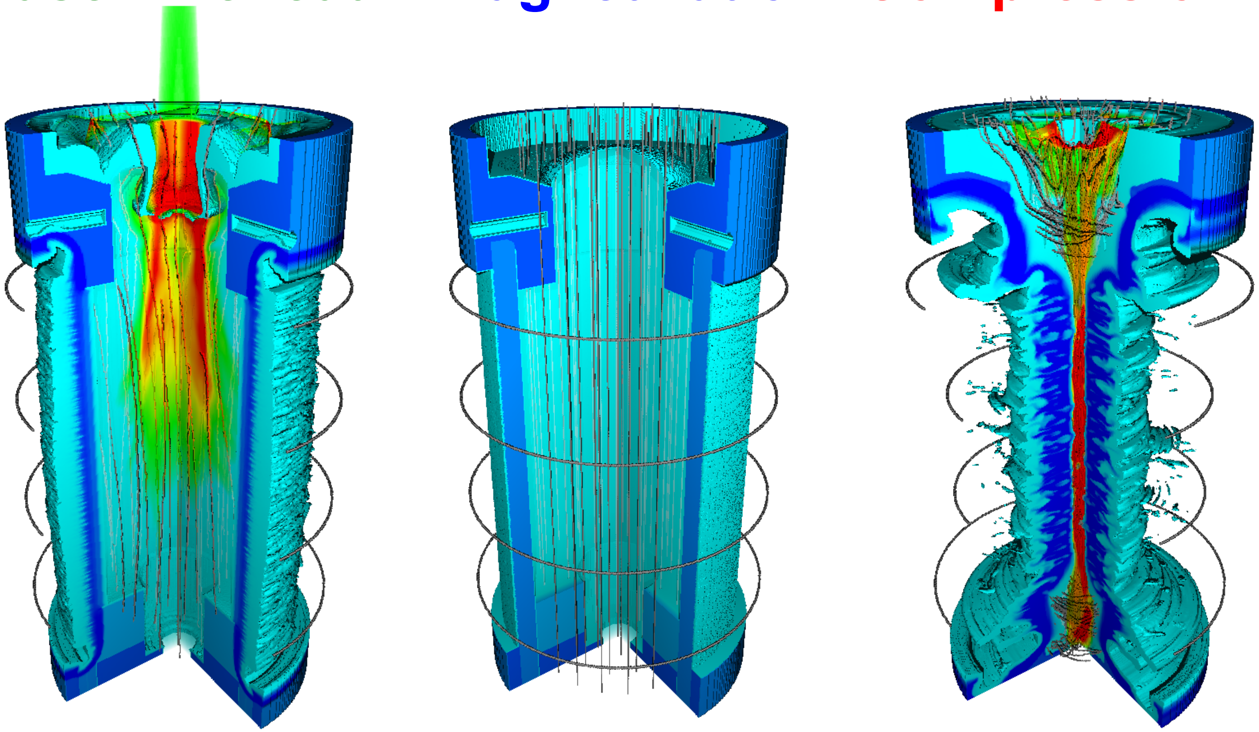
Measured time-integrated self-emission image



*S. A. Slutz, *et al.*, Phys. Plasmas **17** 056303 (2010).

The collection of measurements from our first MagLIF experiments are consistent with a magnetized, thermonuclear plasma.

Laser Preheat **Magnetization** **Compression**



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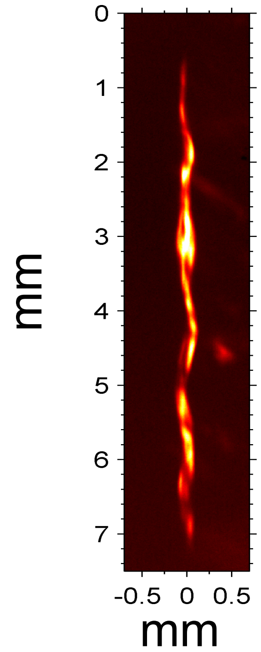
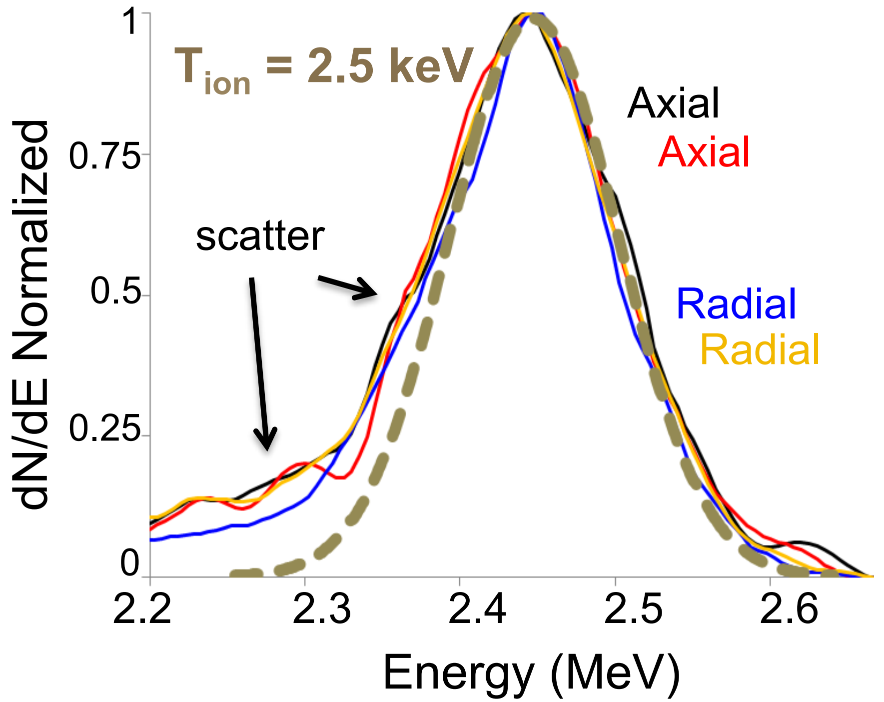


*S. A. Slutz, *et al.*, Phys. Plasmas **17** 056303 (2010).

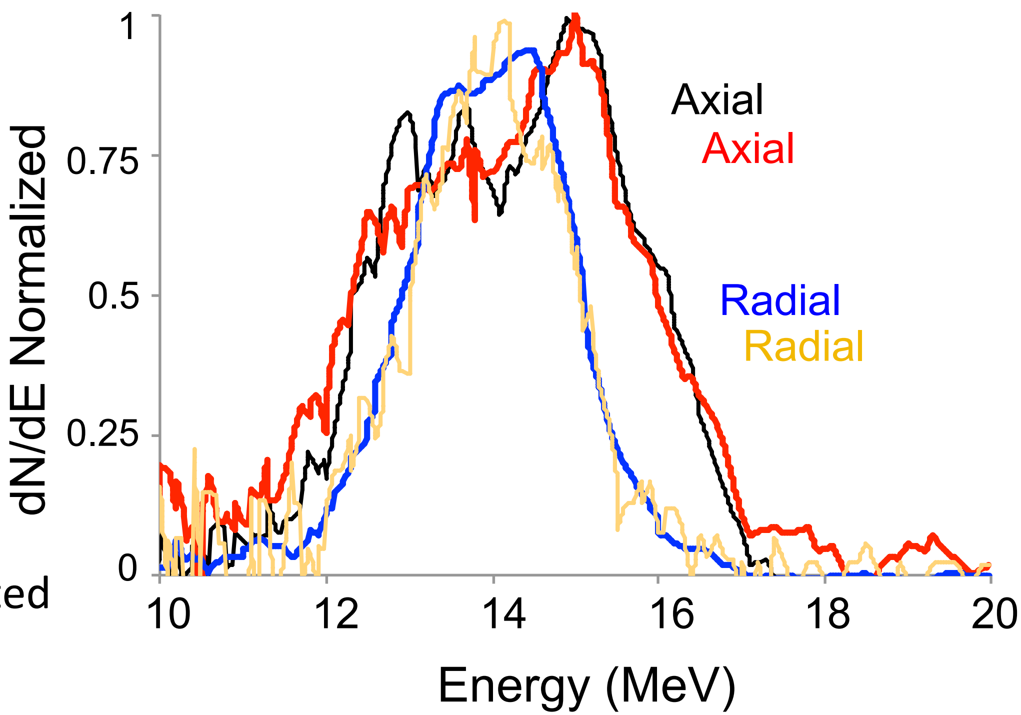
Neutron diagnostics give us essential information about our MagLIF experiments.

- **3e12 primary DD neutrons, isotropic** (inferred from activation)
- **5e10 secondary DT neutrons** (inferred from activation)
- **Tion ~ 2-3 keV** (inferred from nTOF primary DD spectra)

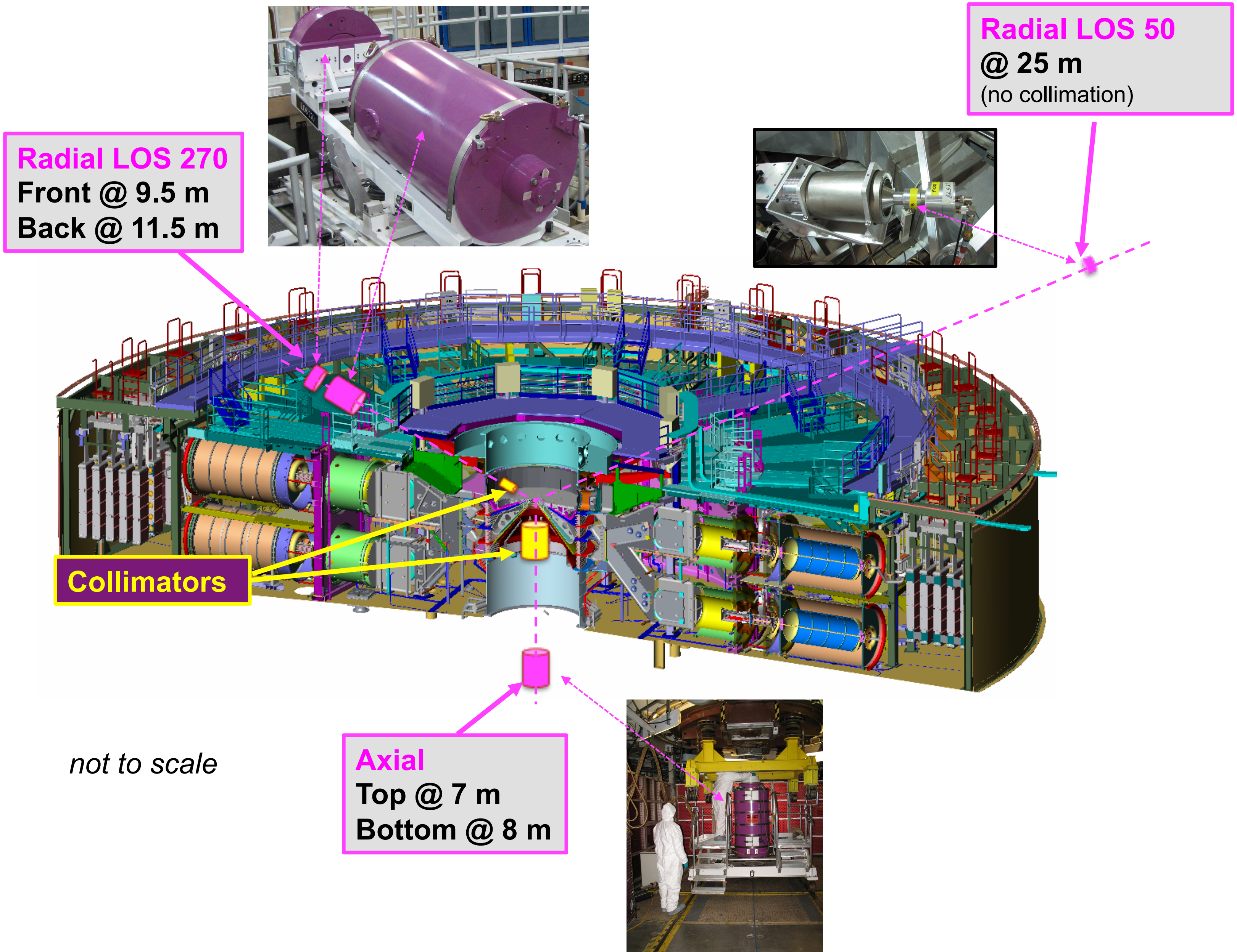


Neutron diagnostics give us essential information about our MagLIF experiments.

- **3e12 primary DD neutrons, isotropic** (inferred from activation)
- **5e10 secondary DT neutrons** (inferred from activation)
- **Tion ~ 2-3 keV** (inferred from nTOF primary DD spectra)
- **Fuel magnetization** (inferred from nTOF secondary DT spectra, yields)
  - BR = 0.5 MG-cm
- **Neutron emission profile** (inferred from secondary DT spectra)
  - Secondary DT neutrons are generated from a long skinny cylinder.
- **Liner areal density** (inferred from nTOF primary n-Be spectra)



There are 5 nTOF locations on Z.



not to scale

We are updating our nTOF detectors with new PMT's and scintillators (and suggestions are welcome!).

Older Detectors (2007-present)

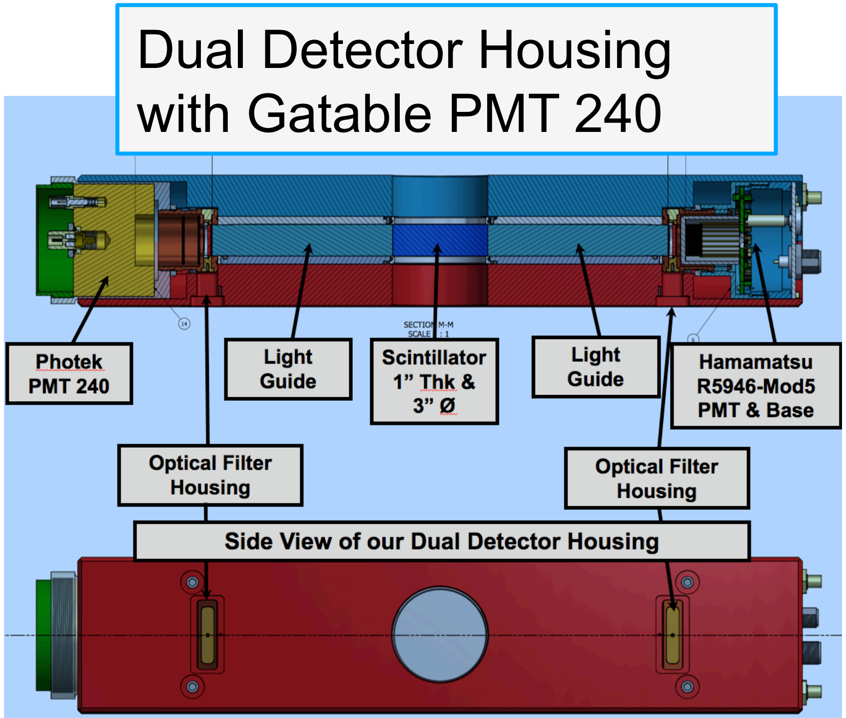
- Hamamatsu 5946mod4
- 2.54-cm thick, 7.62-cm diam BC422Q (1%) scintillators

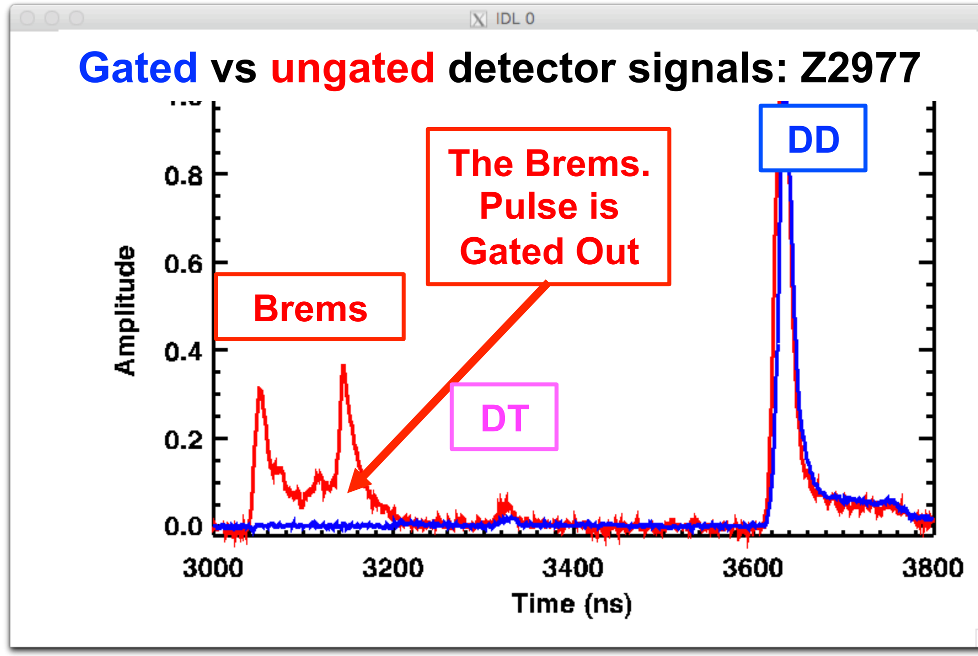
Newer Detectors (2016 - ?)

- "Dual-style" detectors
- Hamamatsu 5946mod5
- Photek 240 gated MCP
- 2.54-cm thick, 7.62-cm diam Eljen 228 (BC418 equiv) scintillators

NSTec builds our nTOF detectors and performs some characterizations of them.

To mitigate some limitations from photon-induced signals, we are implementing gated detectors.





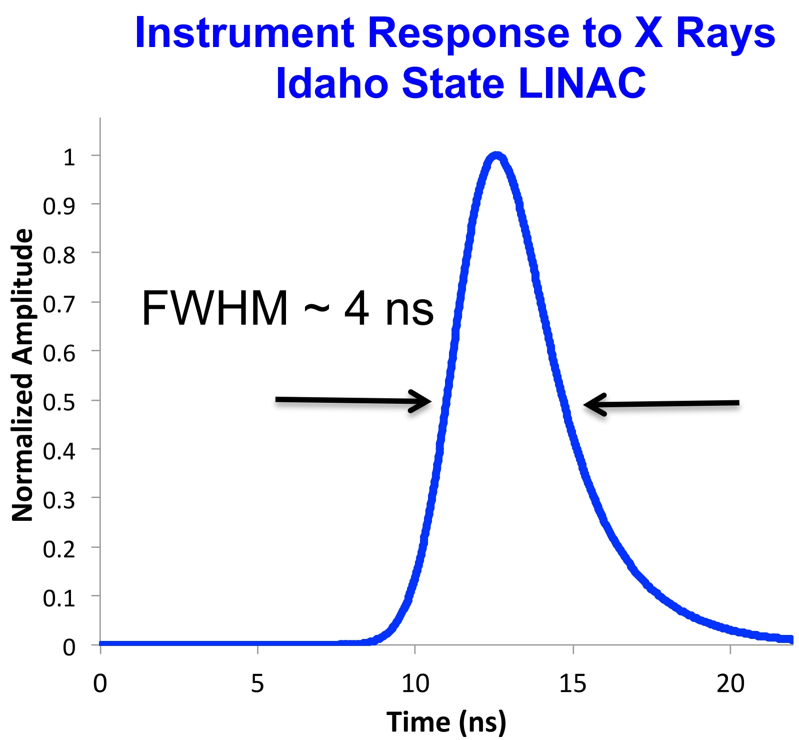
Thanks to the ICF diagnostic workshops, Vladimir is collaborating with us one the implementation of gated detectors on Z.

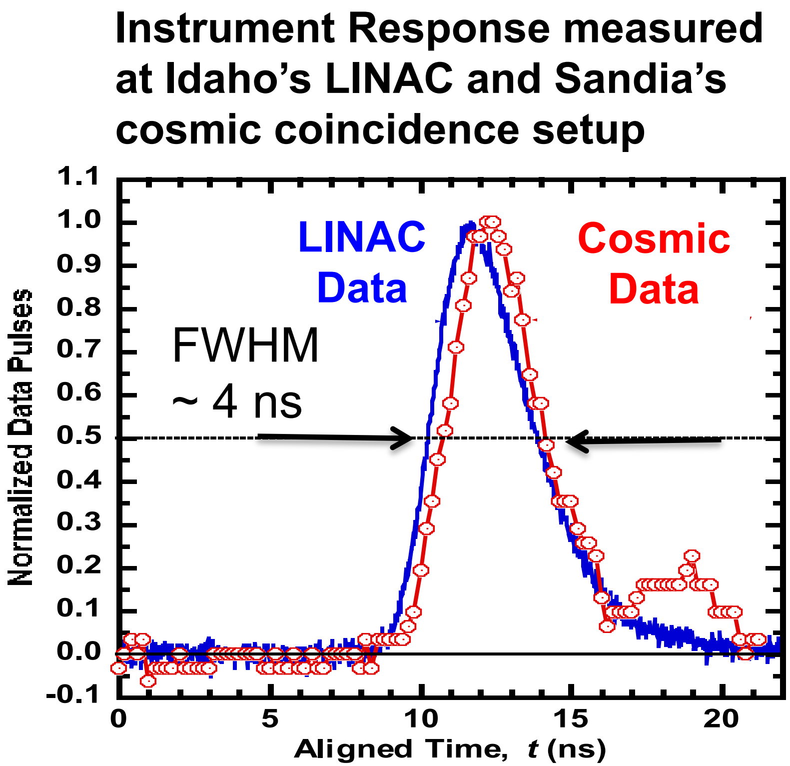
We are investigating several ways to measure the Instrument Response Function (IRF) for our nTOF detectors.

- **Idaho National Laboratory's LINAC**
  - High-energy (16-MeV), 25-ps bremsstrahlung photons
  - Work done in 2007-2008; expensive $$
- **Cosmic rays**
  - Sandia's cosmic-ray coincidence test stand[23]
  - Starting 2014 – present
  - Soon: in-situ on Z
- **Sandia's Controlatron** (DT neutrons)
  - ~1e7 DT neutrons per 10 μs pulse
  - Starting 2016
- **Sandia's Ion Beam Laboratory** (DD & DT MeV neutrons)
  - Steady state beam, relies on coincidence of charged particle associated with neutron
  - Starting 2016
- **Future:** Omega's short-duration neutron sources?

[23] M. A. Bonura, *et al.*, RSI 11D633 (2014)

We obtain similar responses with photons (Idaho LINAC) and cosmics (high-energy particles….), but cosmics are more practical (and cheap).





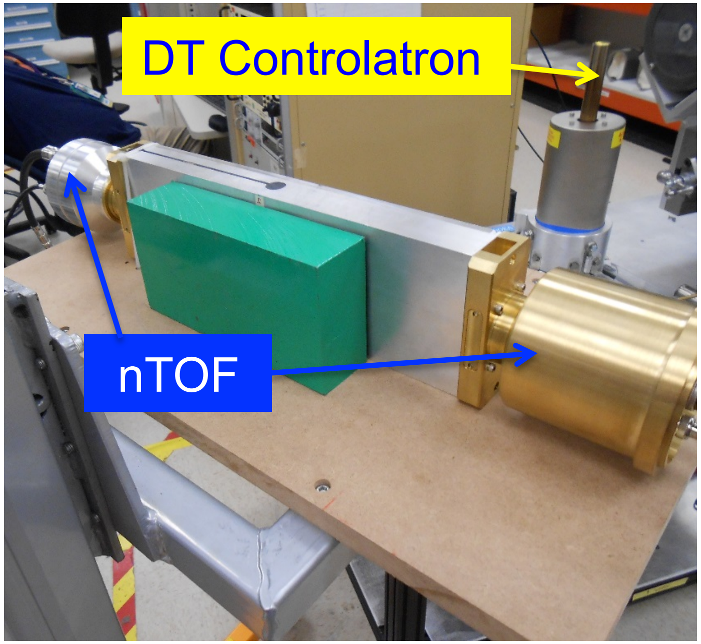
Results are shown for older style nTOF detector:

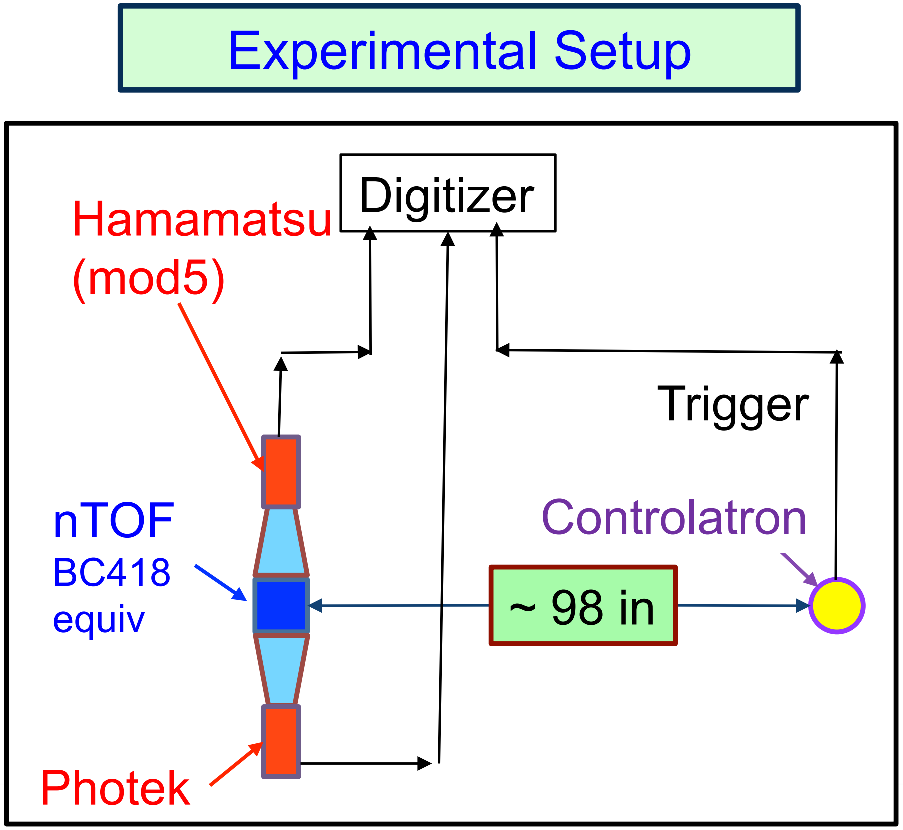
2.54-cm thick, 7.62-cm diam BC422Q (1%)

Hamamatsu 5946mod4 PMT

In 2016, we started characterizing the IRF with neutron sources at Sandia.

- **Controlatron**
  - ~ 1e7 DT neutrons per 10 μs pulse
  - “Single event” responses

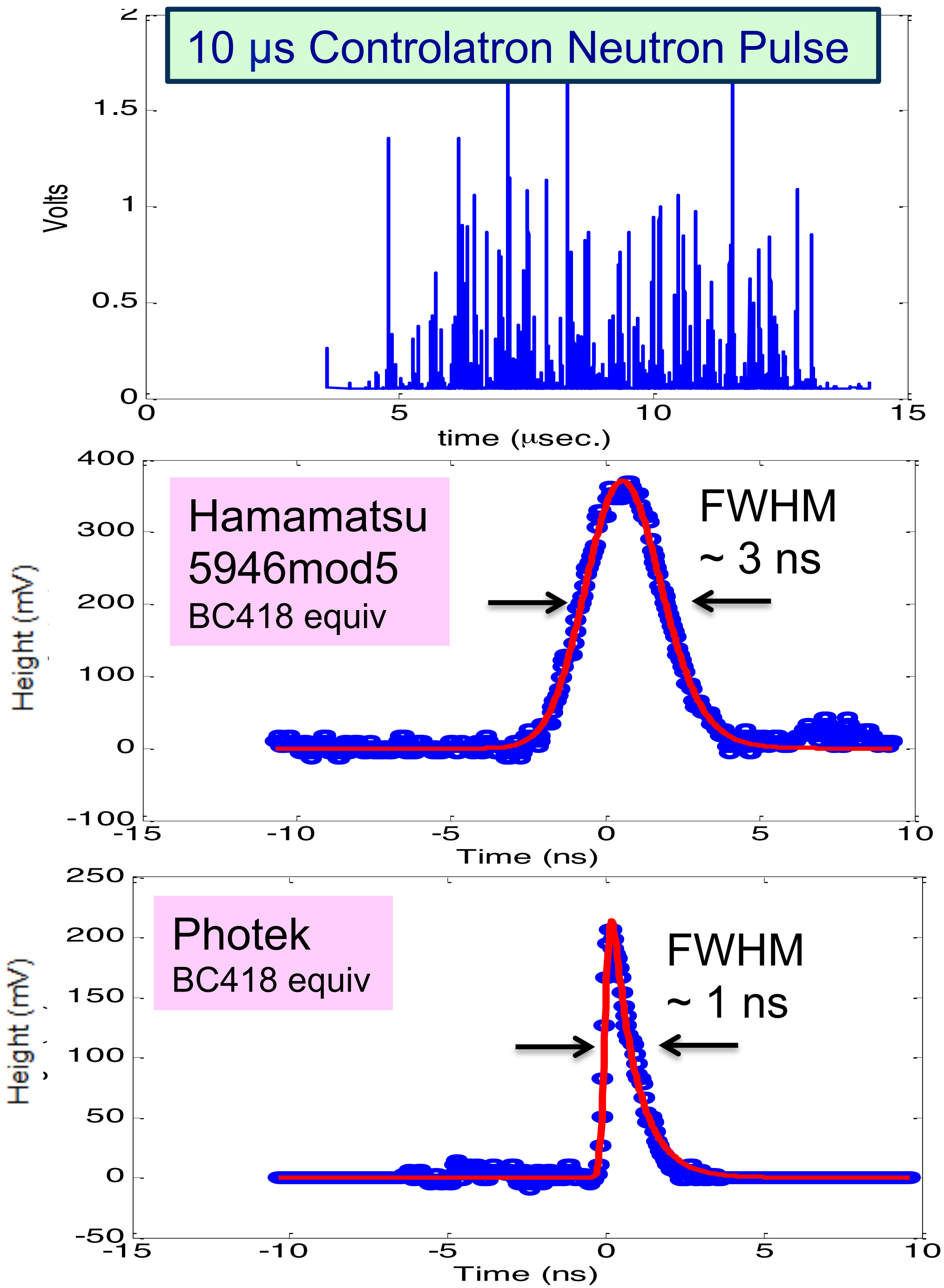




In 2016, we started characterizing the IRF with neutron sources at Sandia.

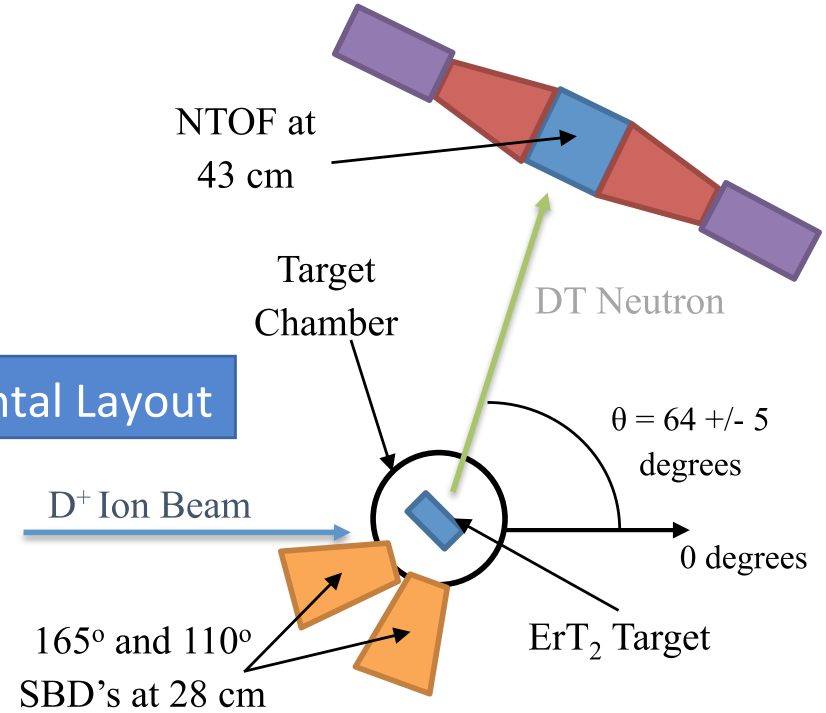
- Response to single event neutrons produces "uglier" data

We cannot distinguish the neutron and photon interactions for these experiments.



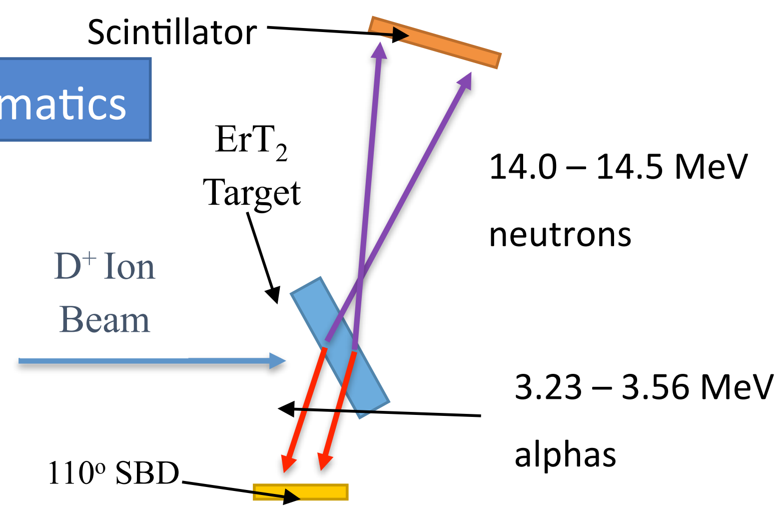
We are verifying the actual <u>neutron</u> response with more advanced techniques.

Experimental Layout

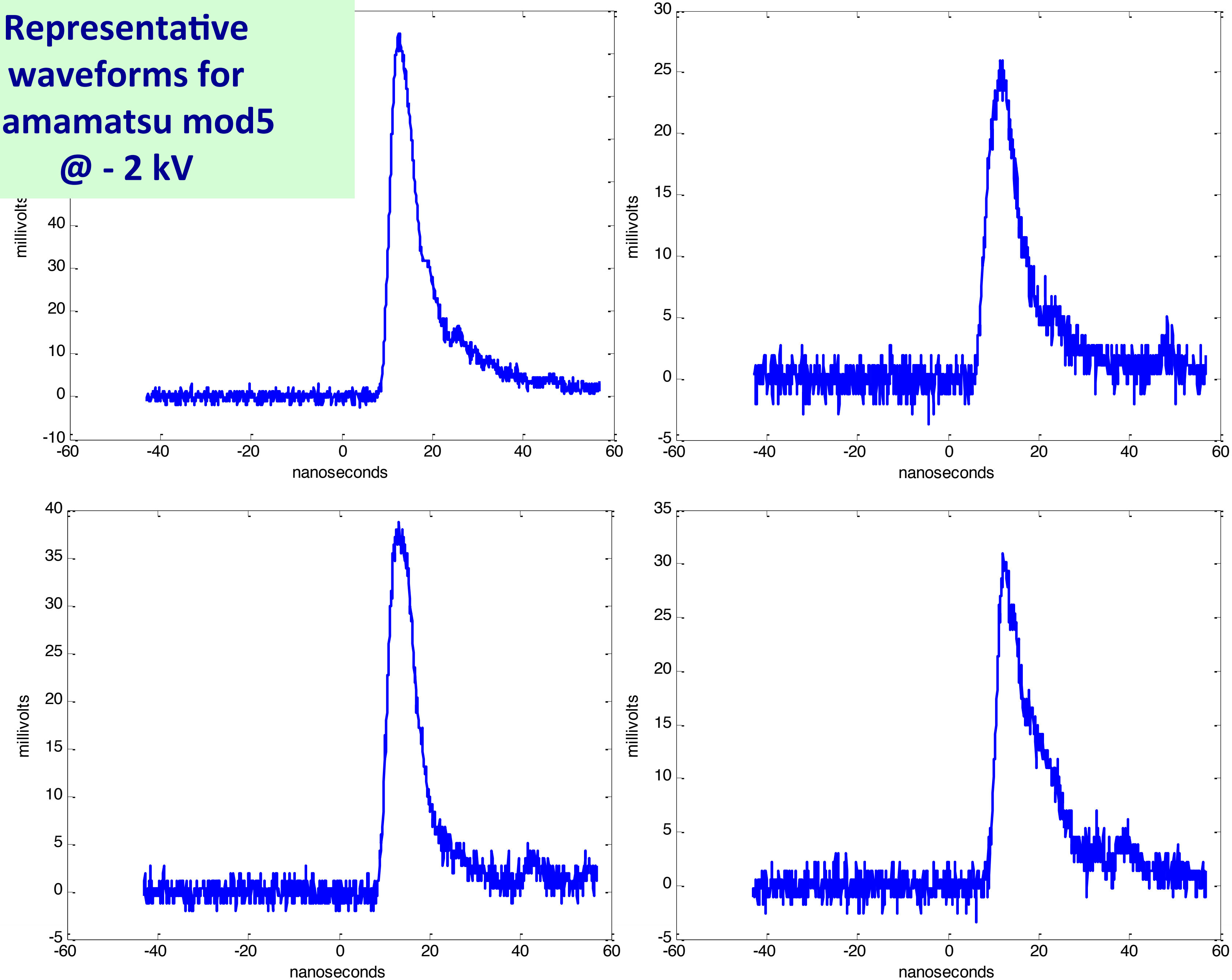


- Work conducted at Sandia's Ion Beam Laboratory
- Deuteron beam strikes ErT or ErD target.
  - DT studies conducted so far
- Associated particle method
- Coincidence of charged particle (alpha) with neutron
- Random coincidences appear to be ~ 1%

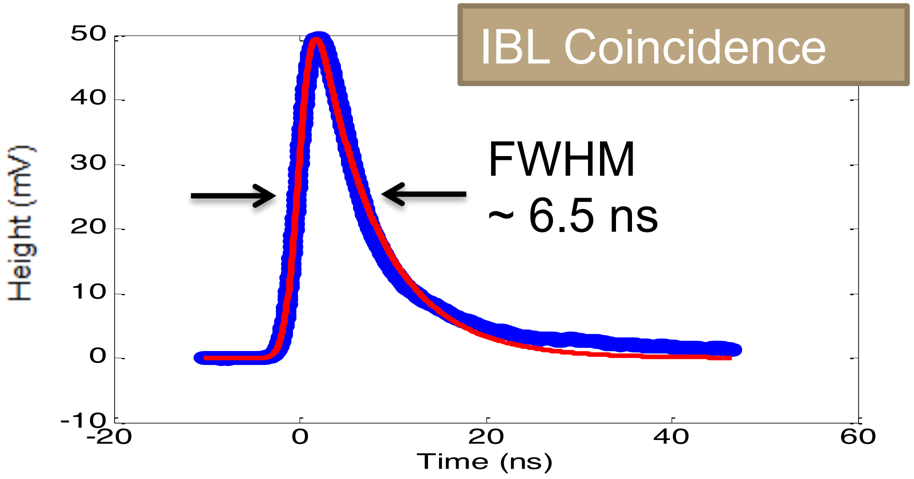
Kinematics



Representative waveforms for Hamamatsu mod5 @ - 2 kV



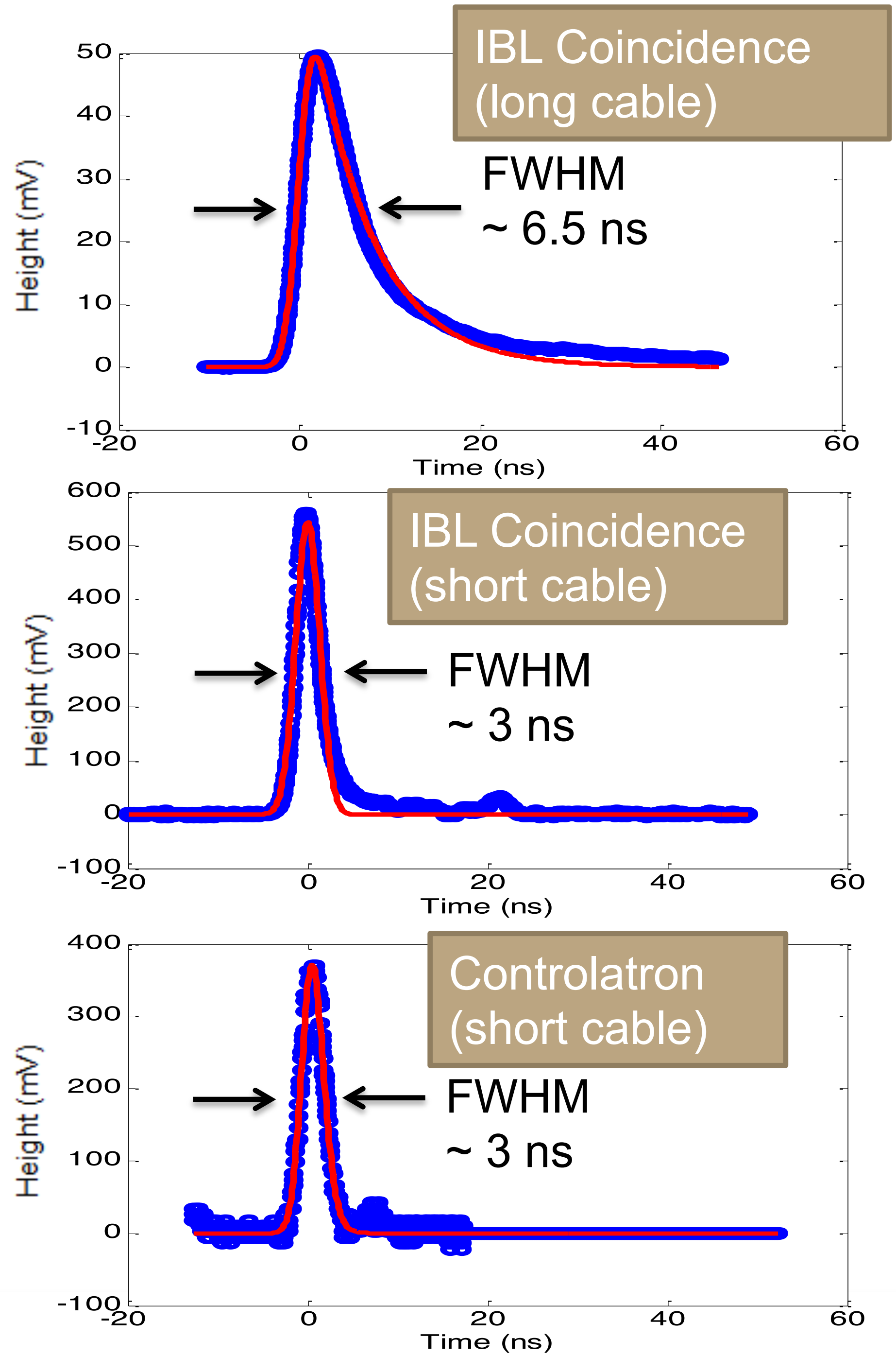
Hamamatsu - Expected versus Measured Shape



- IBL Coincidence (120 ft of RG-223 and 50 ft of RG-58)
  - Gaussian + Exponential
  - FWHM = 2.80 ns
  - Tau = 6.59 ns
  - Width at Half Maximum = 6.54 ns

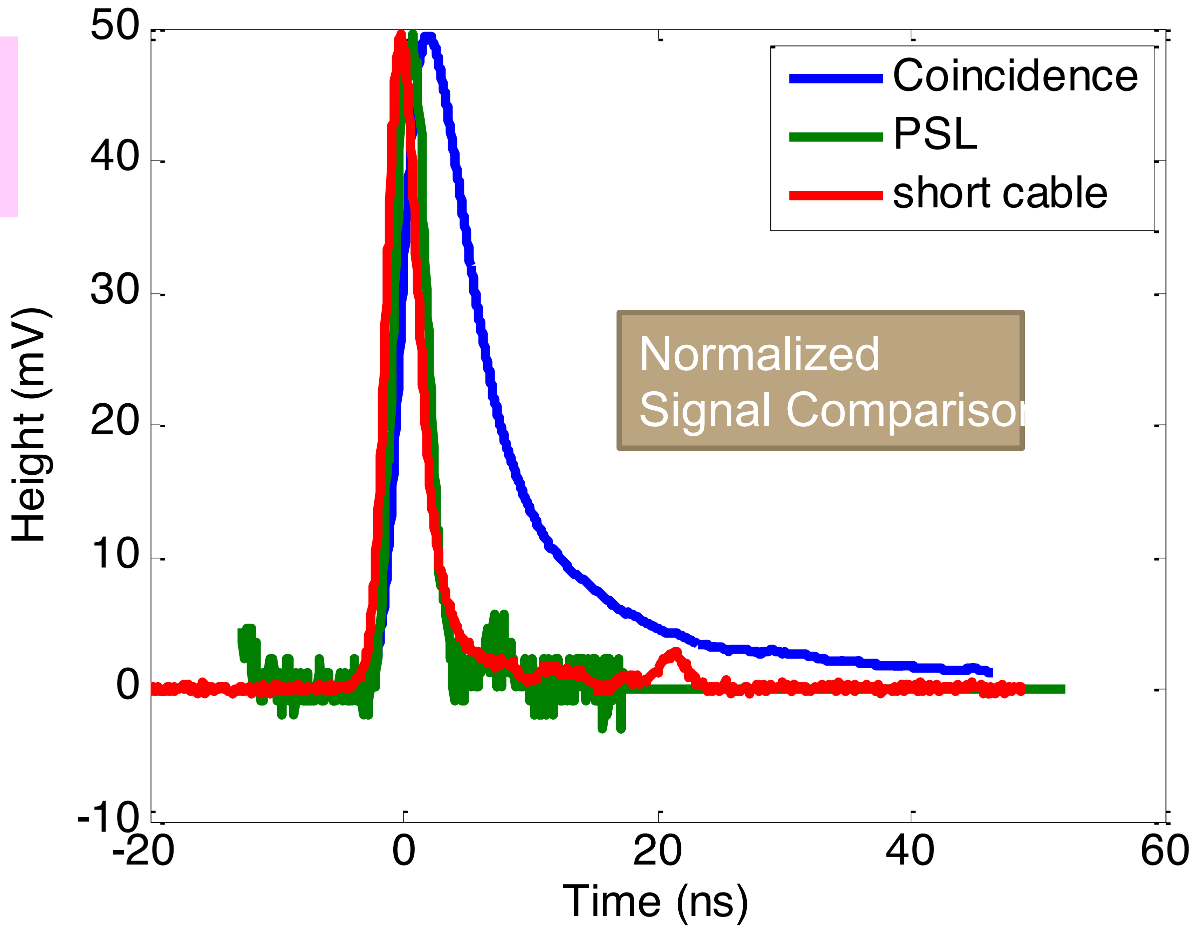
Hamamatsu - Expected versus Measured Shape

- IBL Coincidence (120 ft of RG-223 and 50 ft of RG-58)
  - Gaussian + Exponential
  - FWHM = 2.80 ns
  - Tau = 6.59 ns
  - Width at Half Maximum = 6.54 ns
- IBL Short Cable (10 ft of RG-58)
  - Gaussian
  - FWHM = 3.16 ns
- PSL (15 ft of RG-58)
  - Gaussian
  - FWHM = 2.93 ns

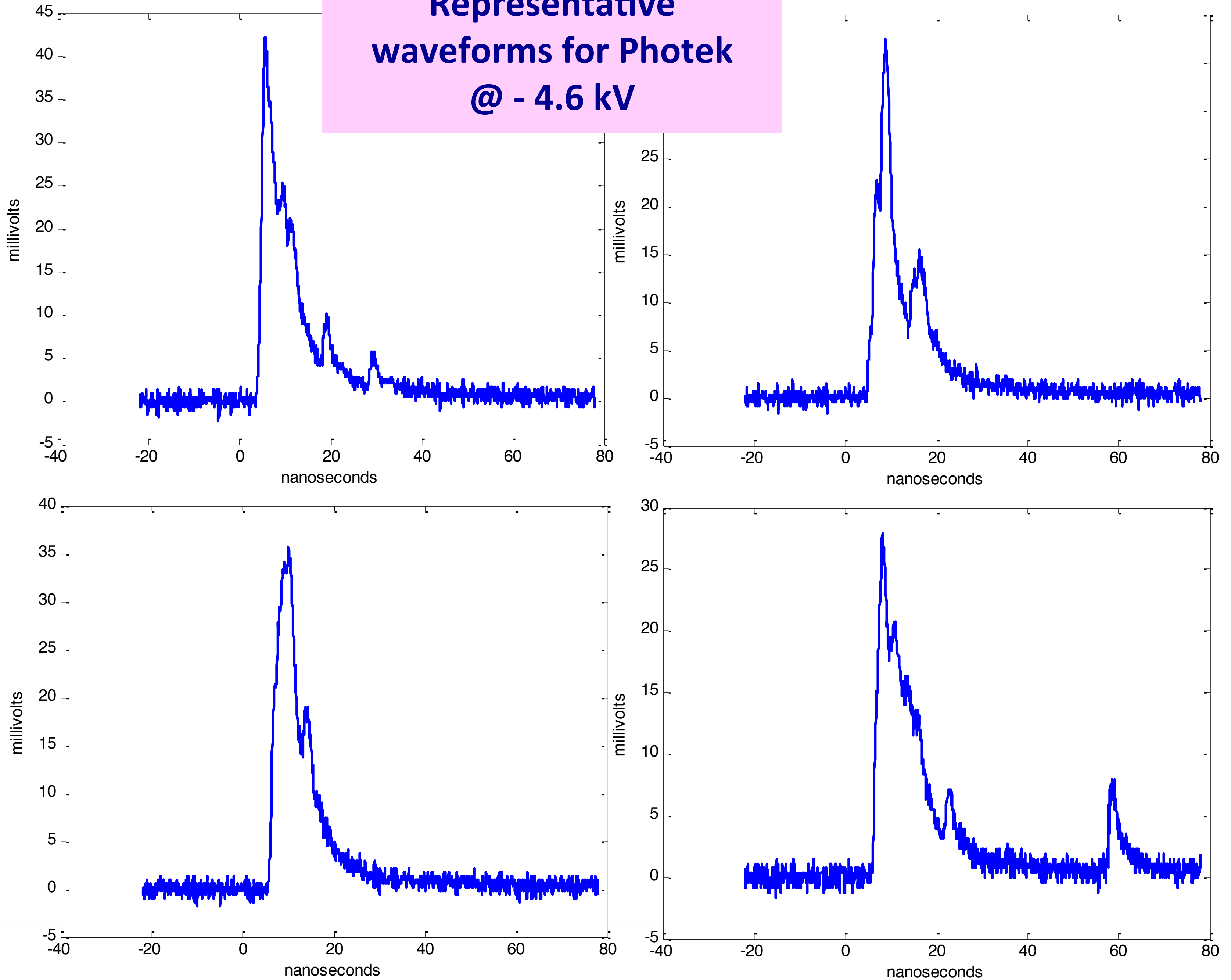


We need to apply corrections for long cables – how is this done at NIF and Omega?

Hamamatsu
5946mod5
BC418 equiv

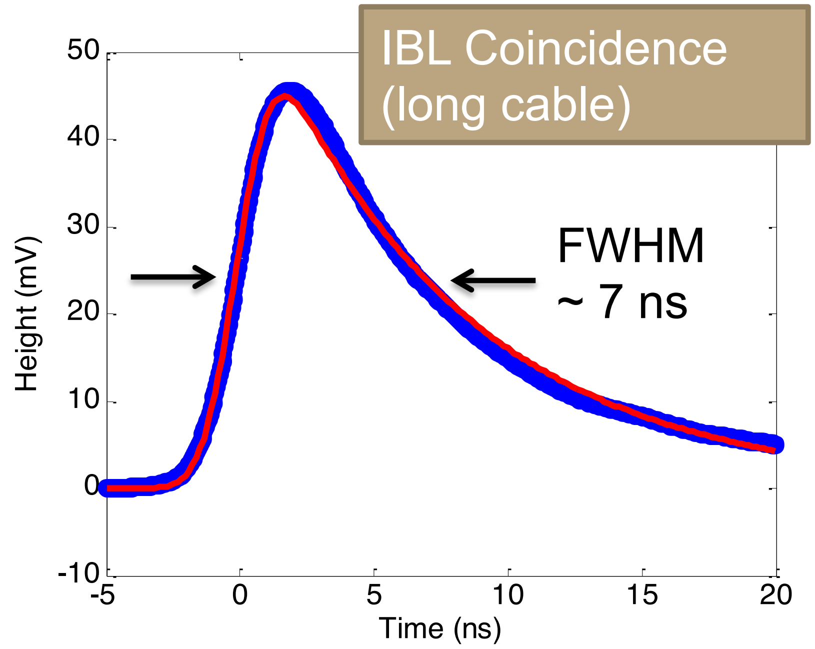


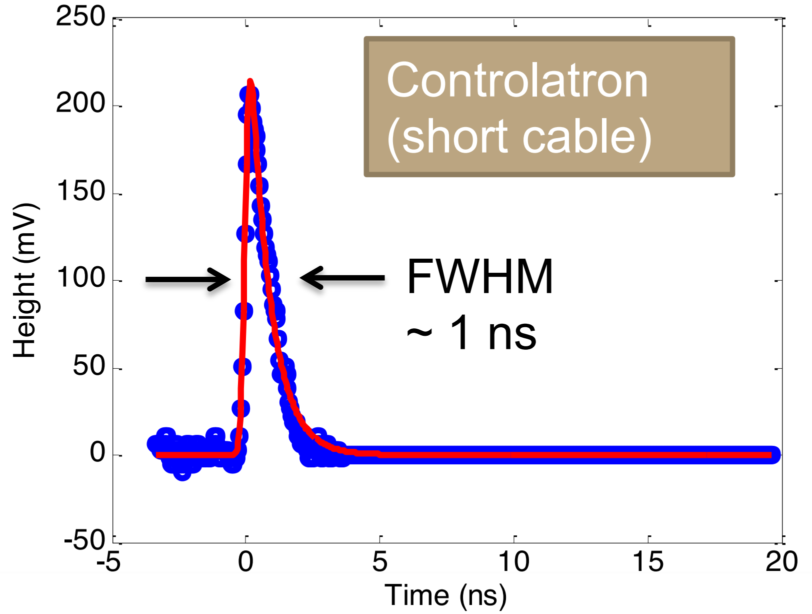
Representative waveforms for Photek @ - 4.6 kV



Photek - Expected versus Measured Shape

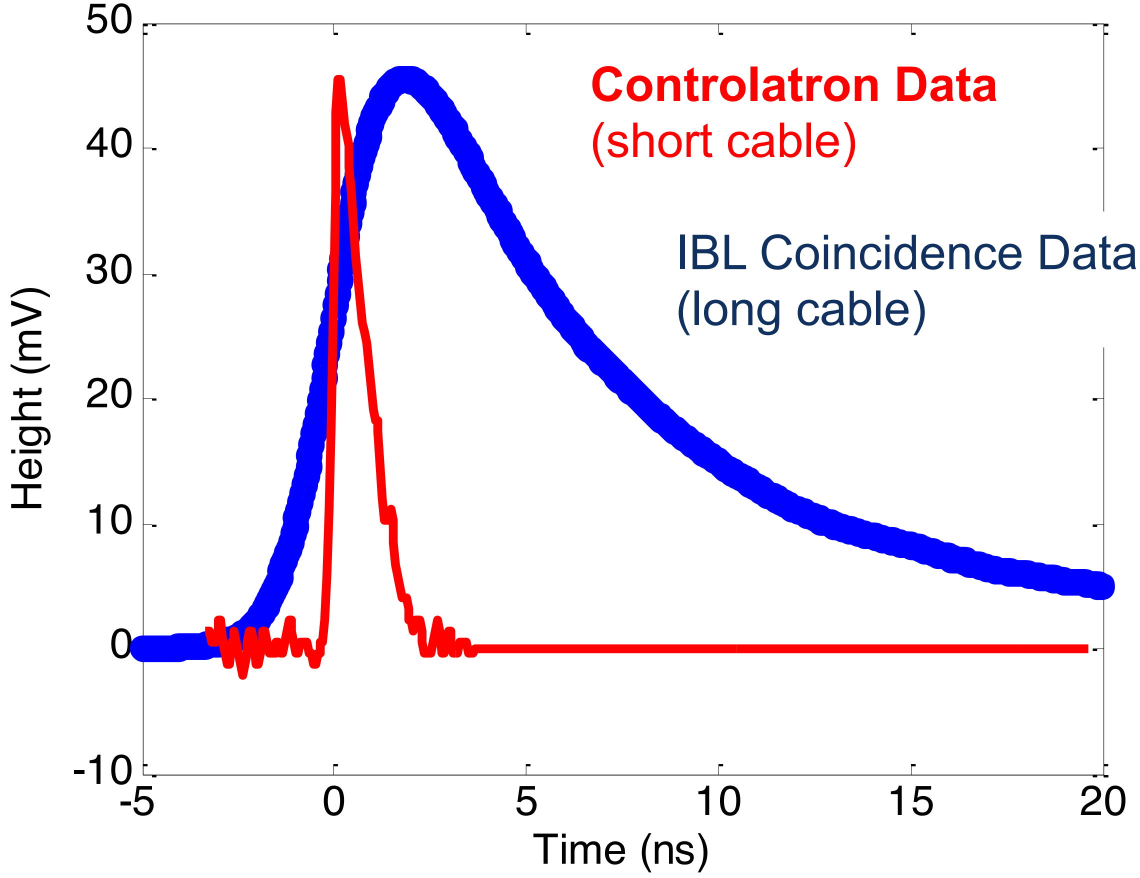
- Controlatron data
  - Gaussian + exponential
  - FWHM = 0.34 ns
  - Tau = 0.7 ns
  - Width at Half Maximum = 0.95 ns
- IBL Coincidence data
  - Gaussian + exponential
  - FWHM = 2.53 ns
  - Tau = 6.75 ns
  - Width at Half Maximum = 7.1 ns





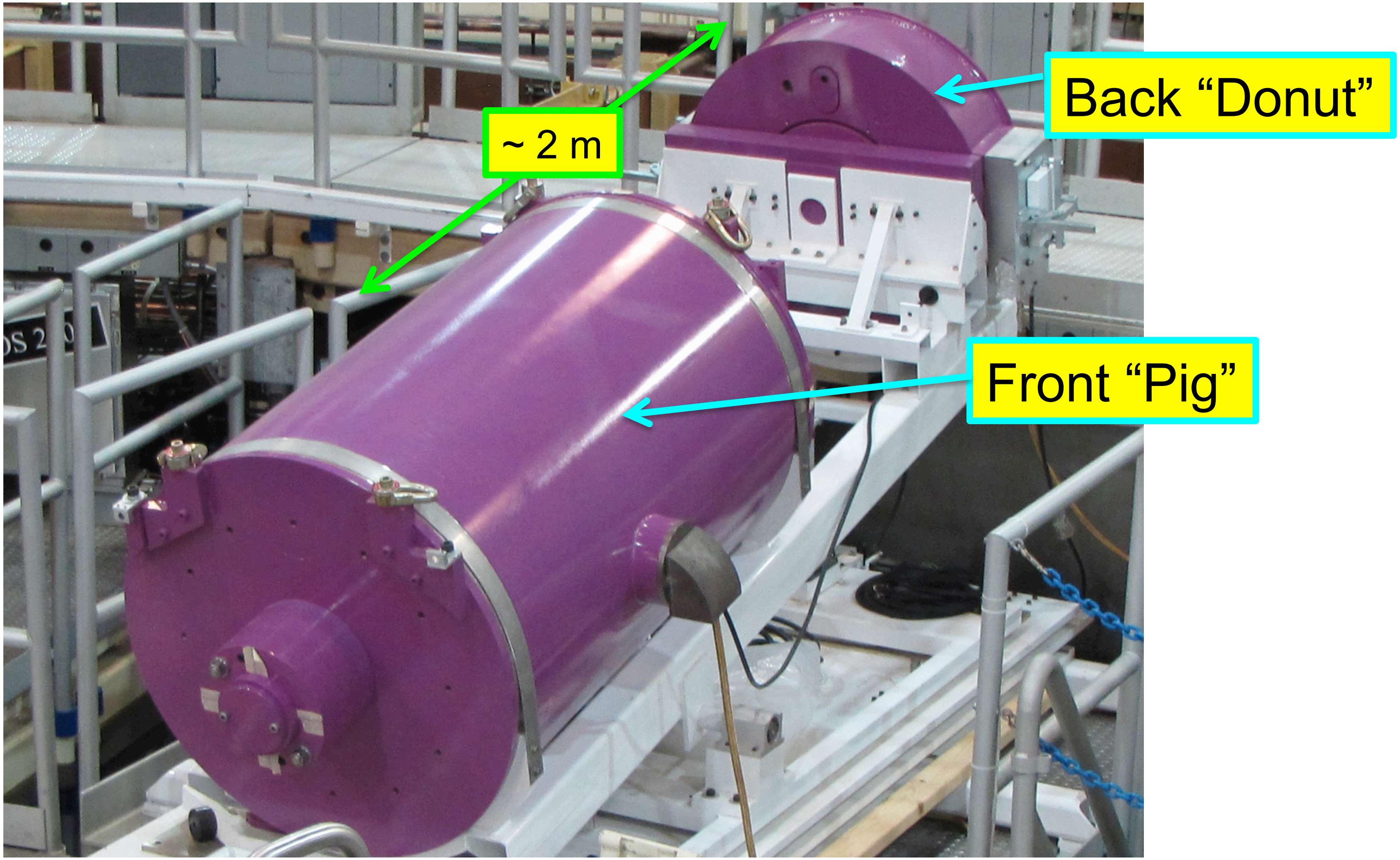
Normalized Comparison of IBL and Controlatron Data

Photek
BC418 equiv



And now let's shift to our favorite topic (at Z) of neutron scattering

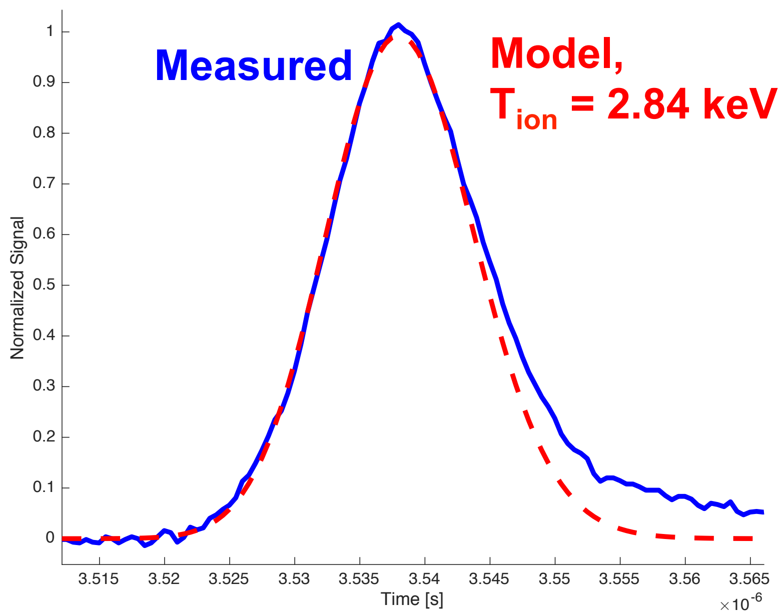
The shielding/collimation for the front and back detectors along LOS 270 is very different.



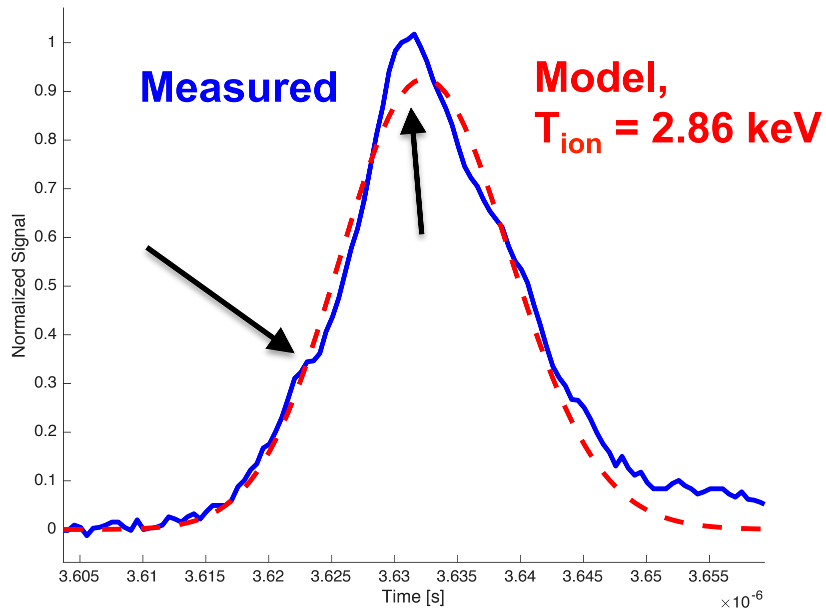
We observe early-time "features" on several nTOF detectors that may or may not be related to target physics.

- **Forward model uses Ballabio (~Gaussian) dN/dt which is corrected for light-output, then convolved with estimated IRF and burn time (2 ns).**
- **Signals are measured along the same LOS, but have different shapes:**
  - Front detector has "best" collimation/shielding.
  - Back detector has worse collimation/shielding.

Radial Front LOS 270 @ 9.5 m

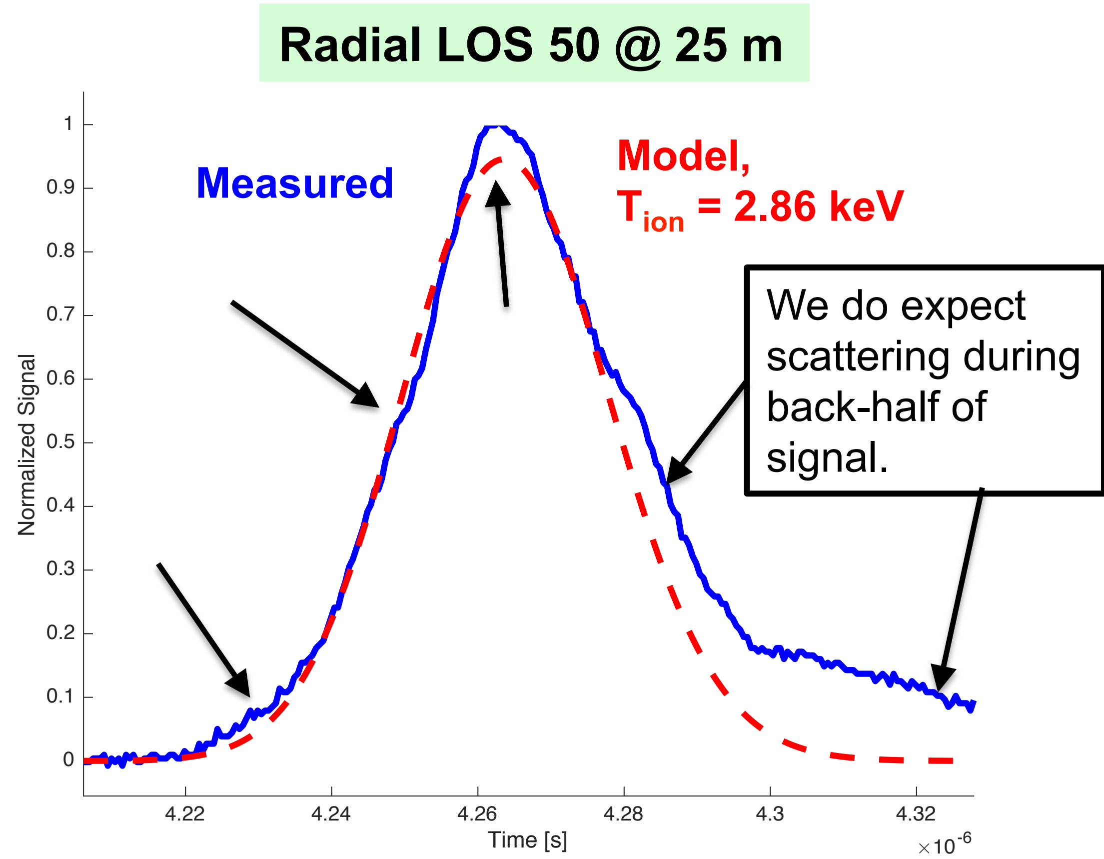


Radial Back LOS 270 @ 11.5 m

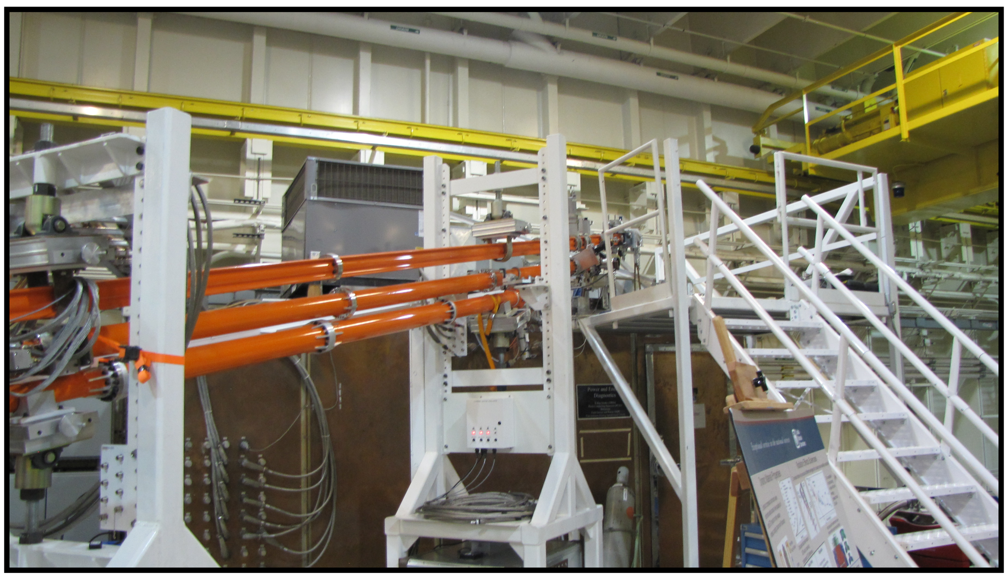


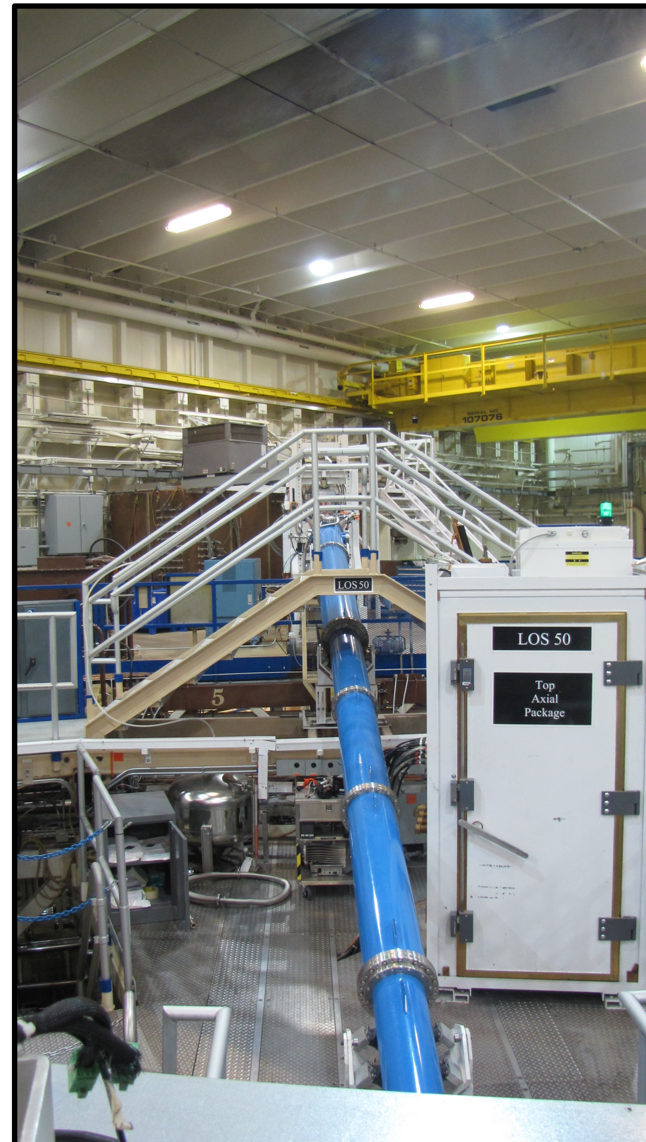
This FY17, we intend to improve the collimation and shielding for our farthest (best energy-resolution) nTOF detector.

- There is NO intentional collimation for this detector.
- Shielding consists of 2.5” Pb right in front of detector.
- **We observe very similar non-ideal “features” in this detector as we do for the poorly collimated/shielded back LOS 270 detector…..**



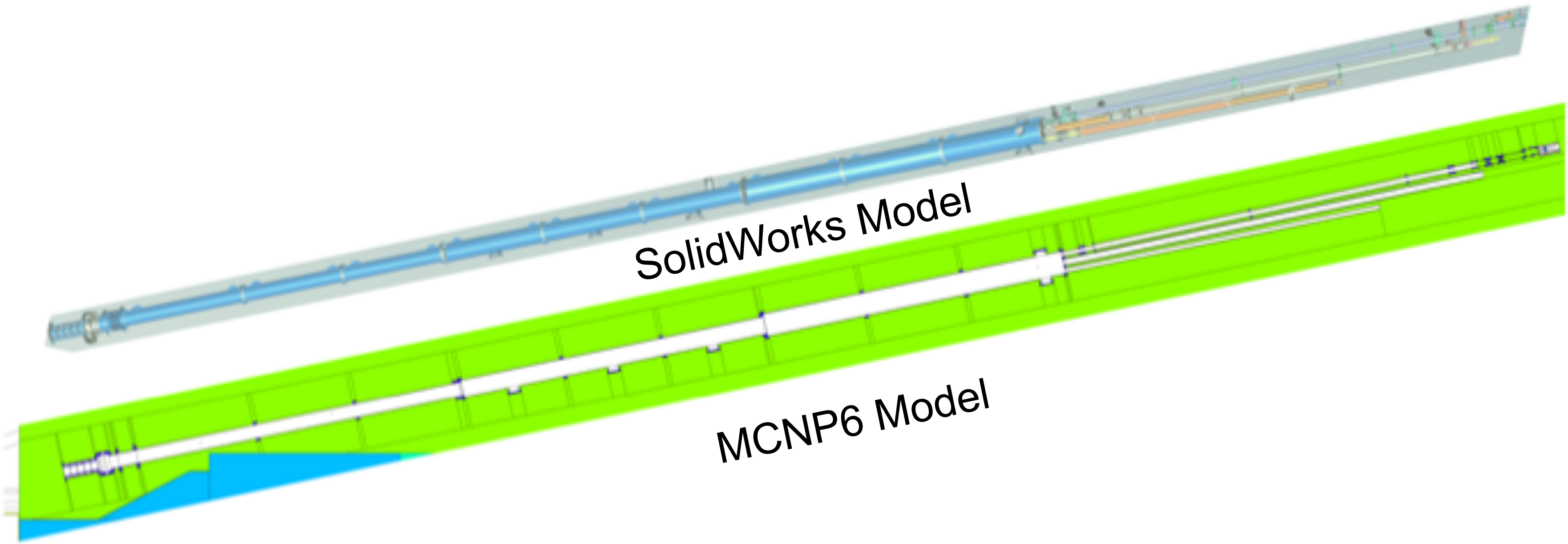
This summer, Edward Norris developed a detailed MCNP model of the LOS 50 nTOF.





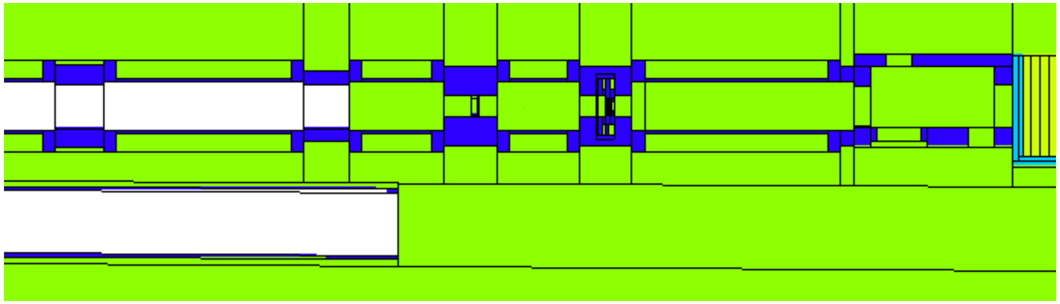
LOS 50 Model

- LOS 50 nTOF is 25.1 m from TCC.

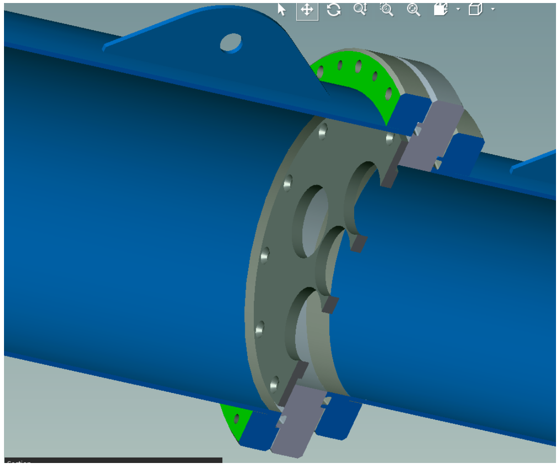


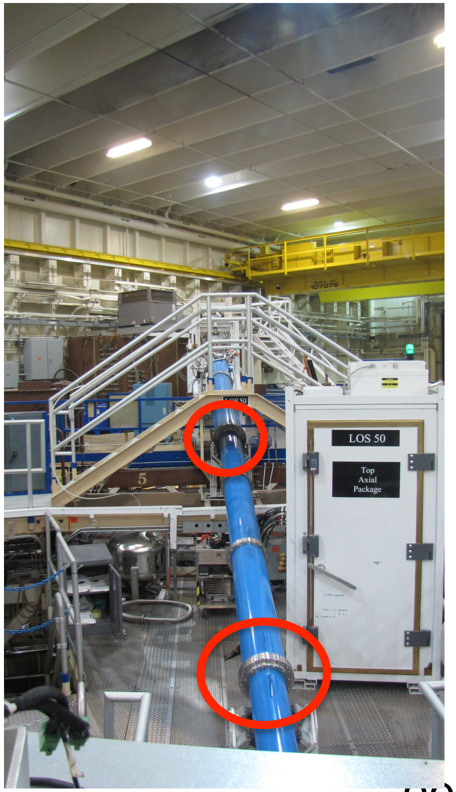
LOS 50 Model

- There are numerous objects directly in the LOS



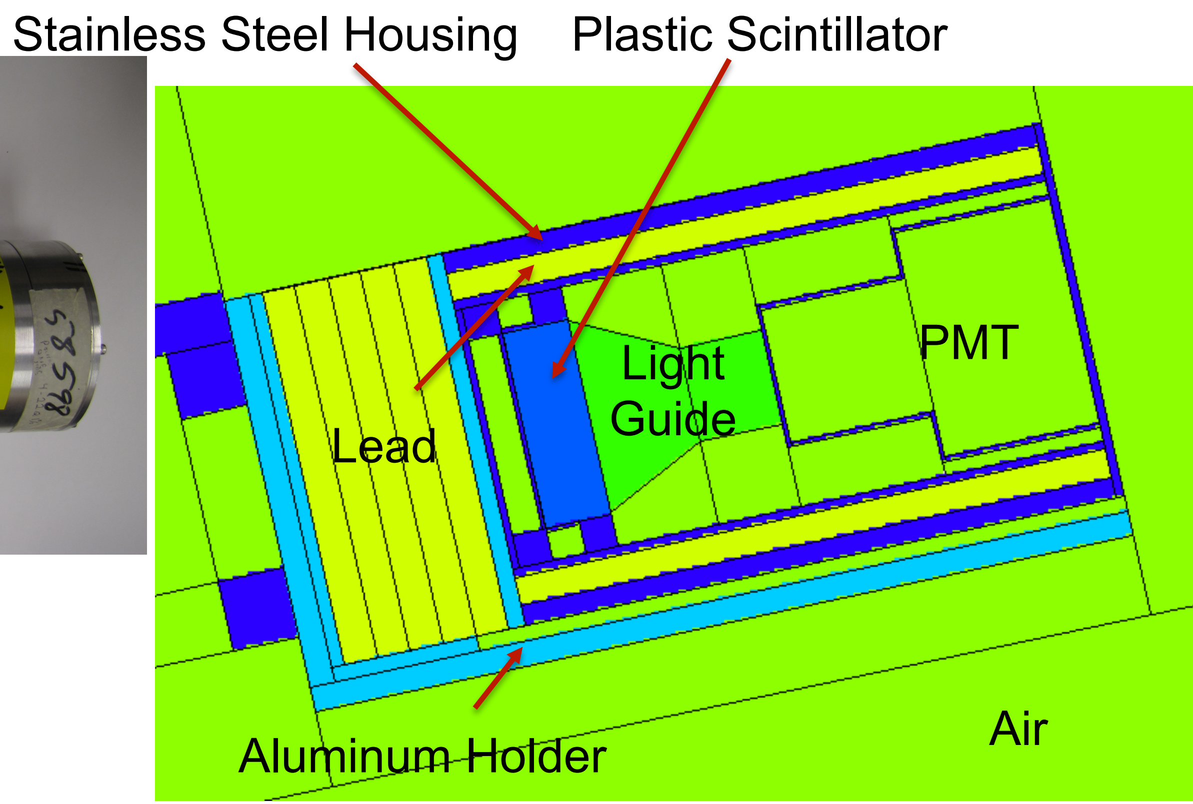
- There are baffles when sections get larger



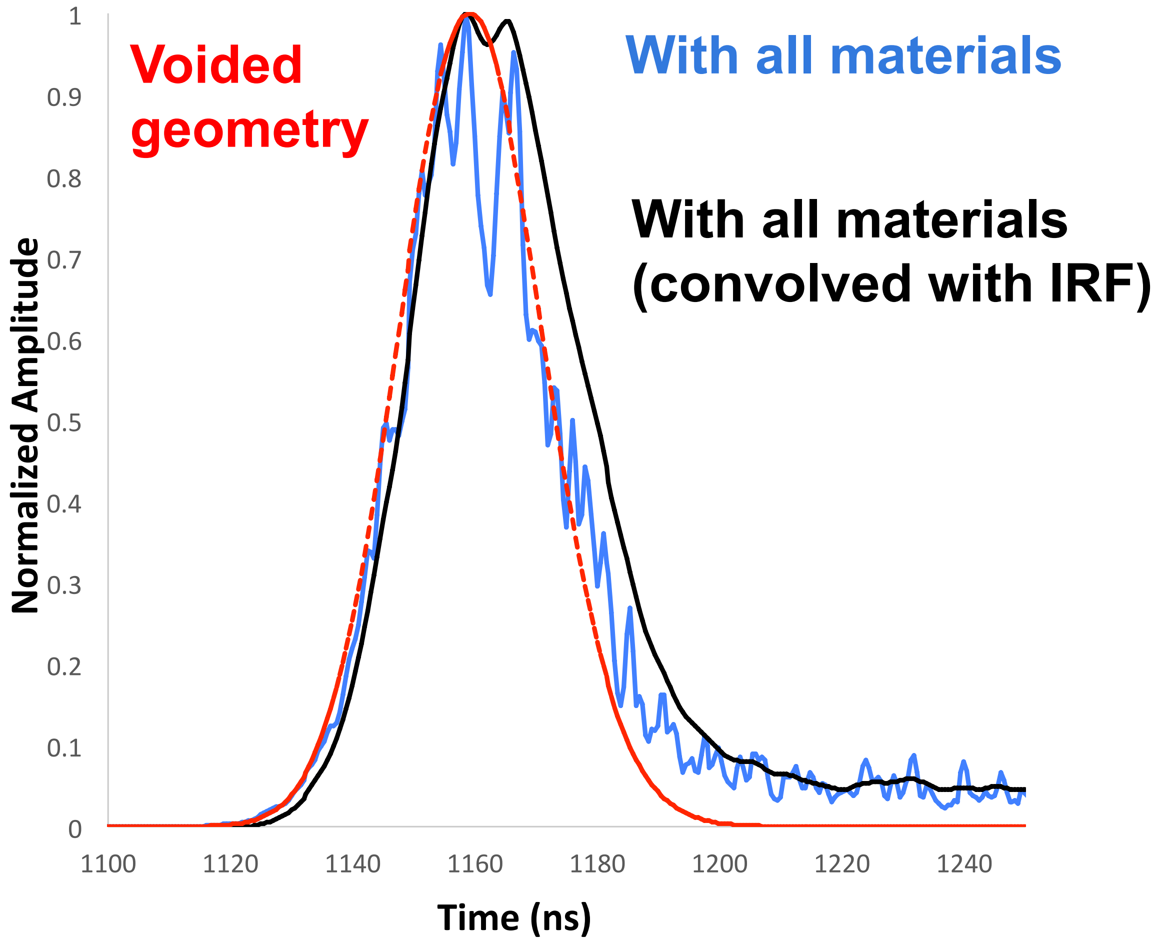


LOS 50 Model

- Detector system digitizer resolution is 0.5 ns.
- Scintillator is 3 inches diameter and 1 inch thick



Though some features in model compare with measurements, there is a lot more work to do.

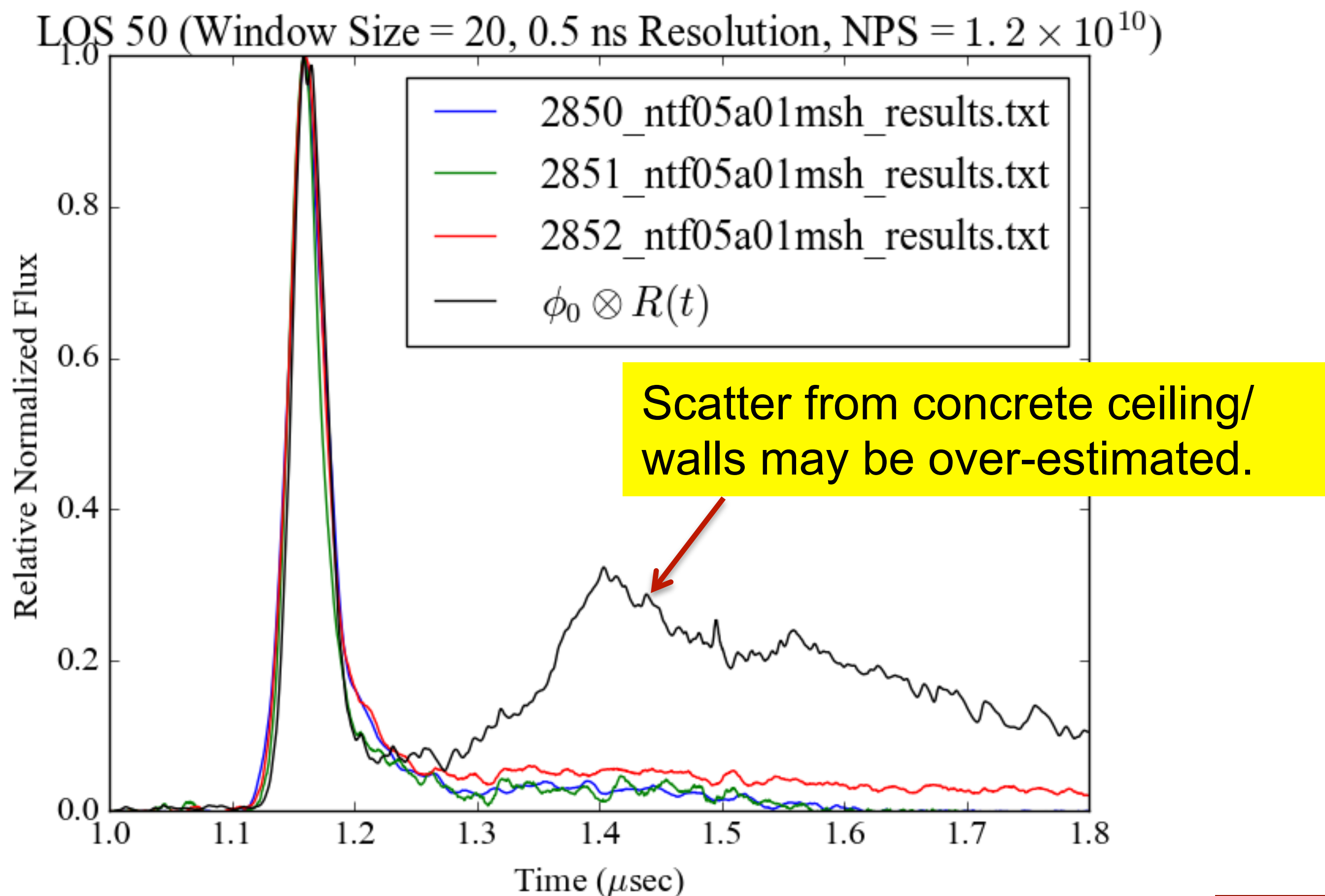


Status of modeling:

1. There are still numerical issues associated with variance reduction to be addressed.

Very challenging to model LOTS of scatter from everywhere

2. Initial stages of designing LOS 50 collimator and shielding has begun (which may alleviate issues with present model)**.**

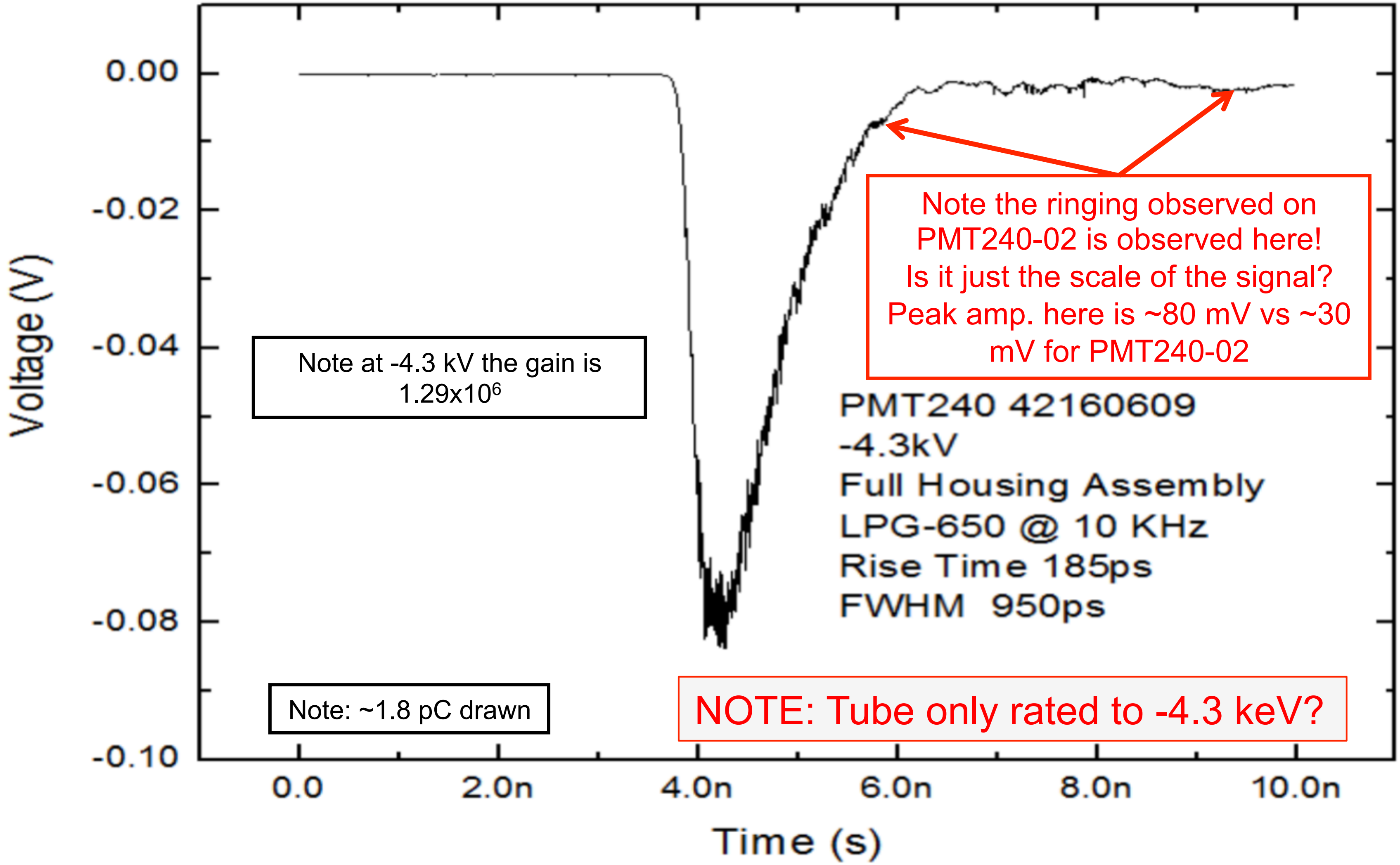


Summary and Plans for Further Improvements

- **nTOF IRF**
  - Continue neutron-based IRF's for DT (and DD)
  - Determine best path forward to interpret responses (leading, centroid)
  - Understand cable-compensation corrections
  - Evaluate the most functional way to obtain IRF's for lots of detectors with multiple settings (i.e., biases)
- **Modeling**
  - LOS 50 @ 25 m
    - Validate scattering in present model/measurement with experiment where we block direct LOS neutrons with plastic plug to look for scatterers
    - Design collimation and shielding that is feasible on Z
  - LOS 270 @ 9.5 m and 11.5 m
    - Can we explain difference between front/back detectors along the same LOS with n scatter? Or n-induced gammas? Or what?

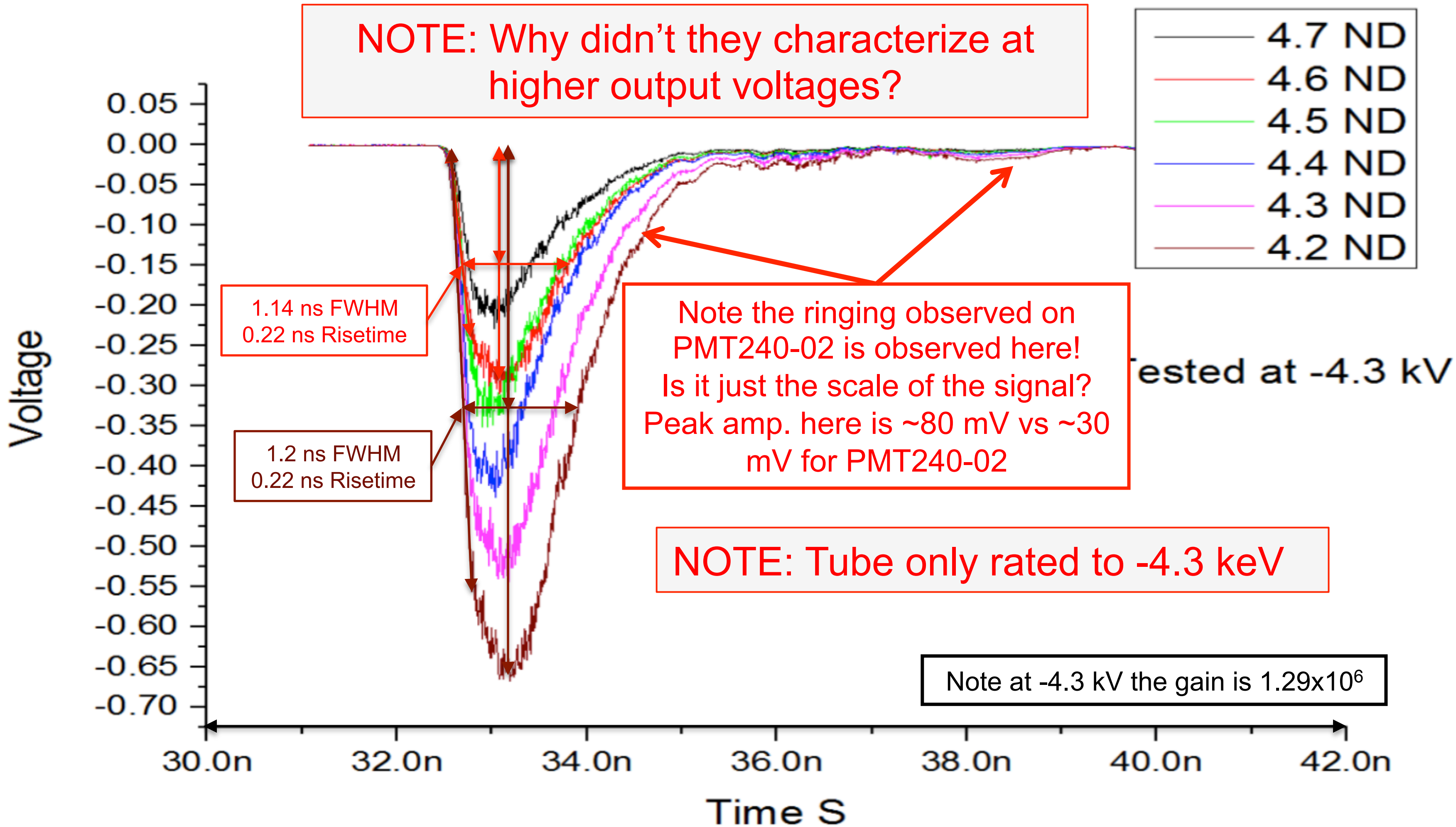
Extra Slides

The impulse response of the Sandia Photek PMT240-04 (S/N: 42160609) purchased 4/28/16 has a 185 ps risetime and a 950 ps fwhm

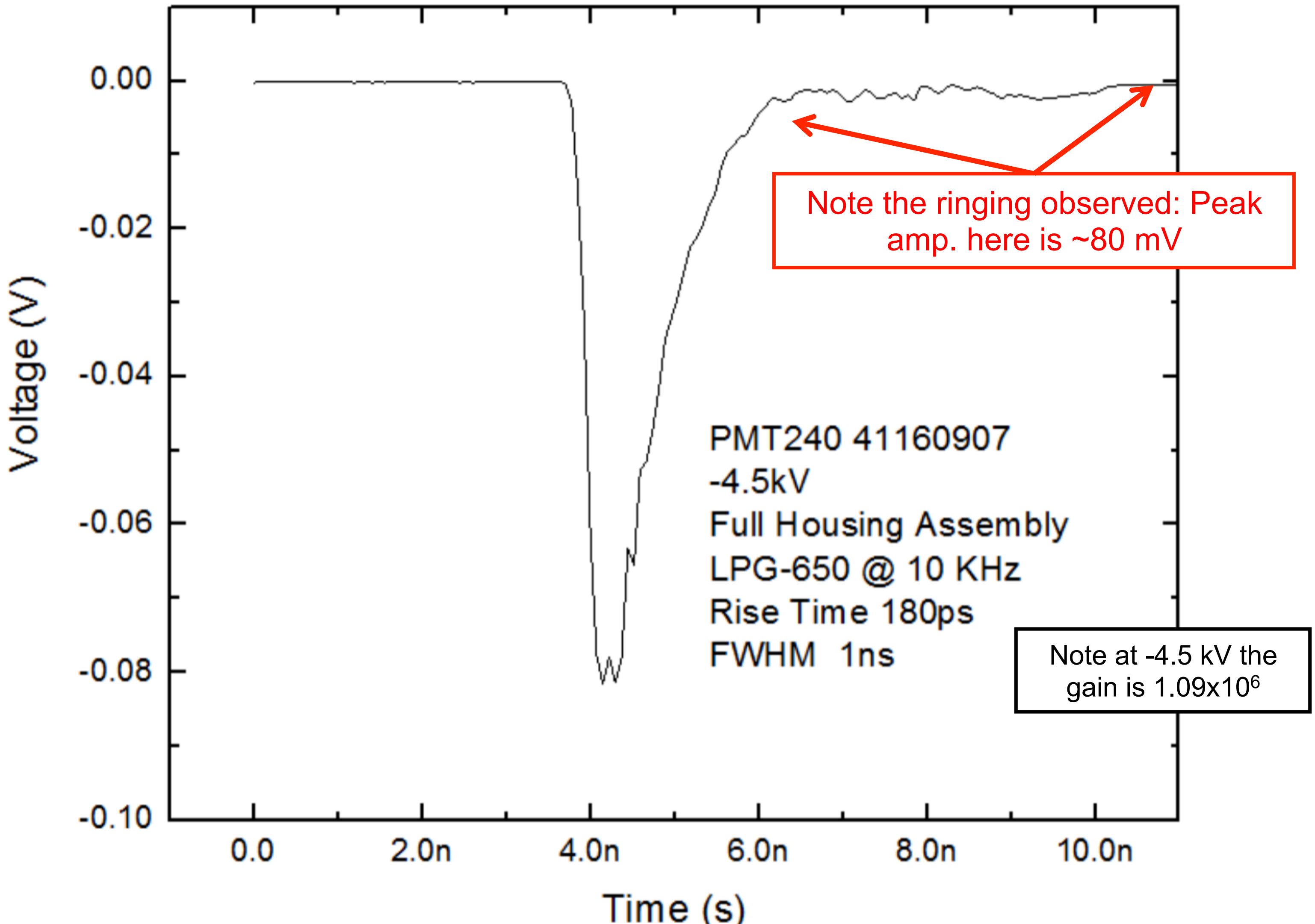


Note: with ~1.8 pC drawn and a Photek measured gain of 1.29×10^6 the number of photoelectrons in this measurement is ~9.

The impulse responses of the Sandia Photek PMT240-04 (S/N: 42160609) purchased 4/28/16 at -4.3 keV bias with different output voltages

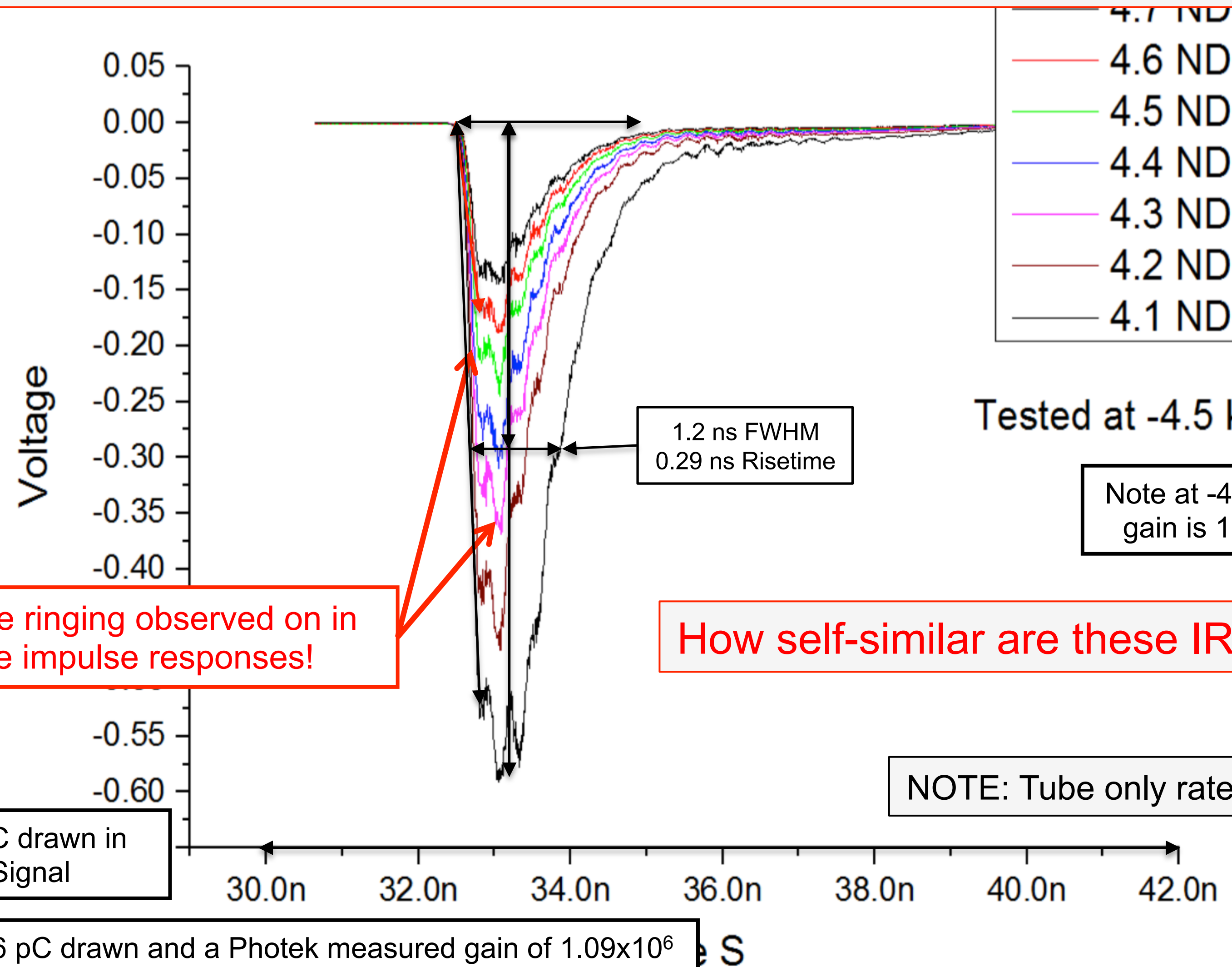


The impulse response of the Sandia Photek PMT240-05 (S/N: 41160907) purchased 4/28/16 has a 185 ps risetime and a 950 ps fwhm



The impulse responses of the Sandia Photek PMT240-05 (S/N: 41160907) at -4.5 keV bias with different output voltages shows lots of ringing!

NOTE: Photek says the 'ringing' in these pulses is intrinsic to the Tube!



Note at -4.5 kV the gain is 1.09×10^6

Note the ringing observed on in these impulse responses!

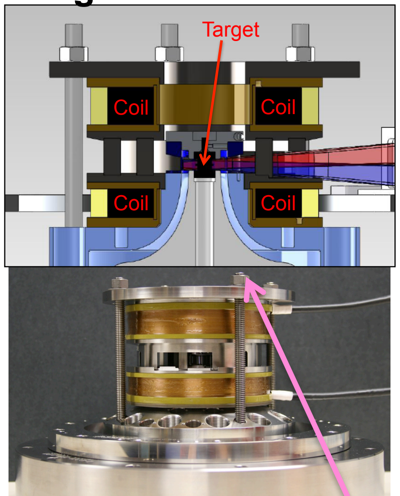
How self-similar are these IRF's

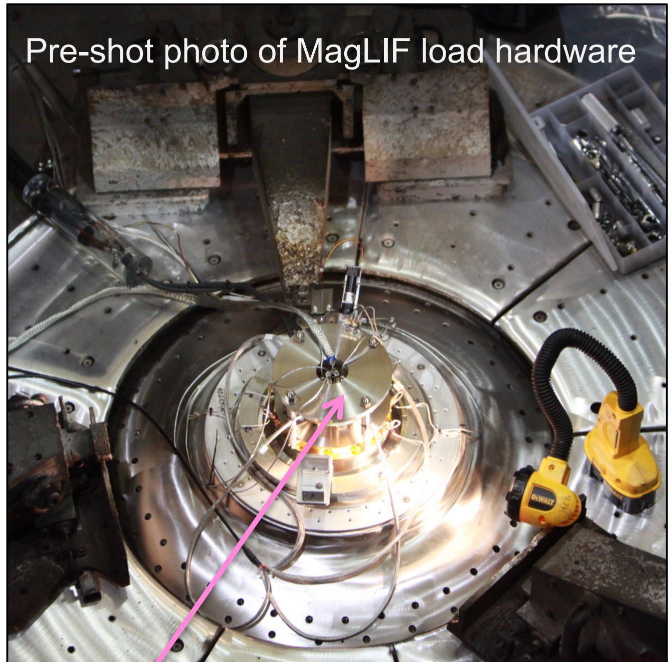
NOTE: Tube only rated to -4.5 keV

Note: ~16 pC drawn in largest Signal

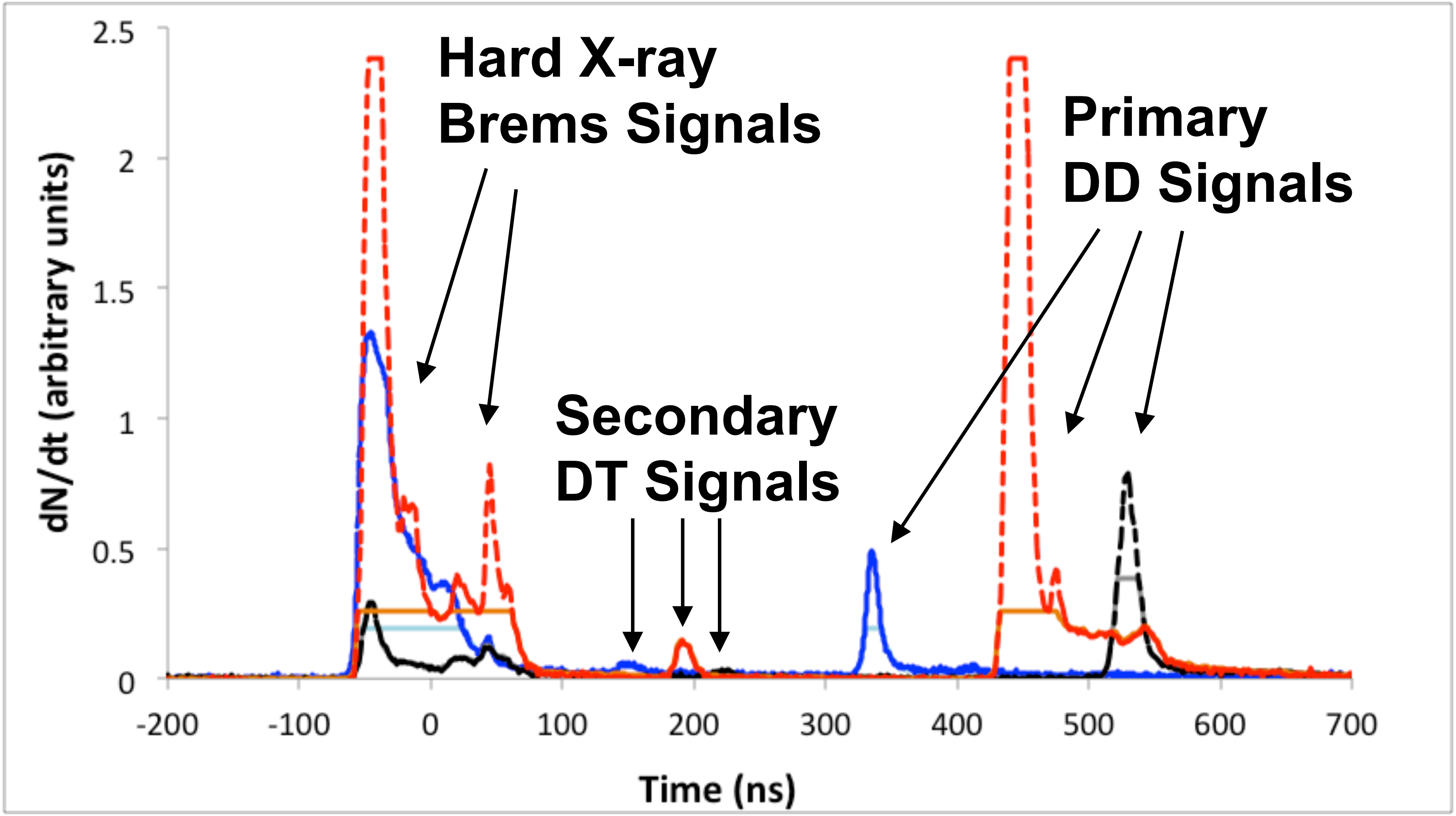
Note: with ~16 pC drawn and a Photek measured gain of 1.09×10^6 the number of photoelectrons in this measurement is ~93.

MagLIF B-field Coils

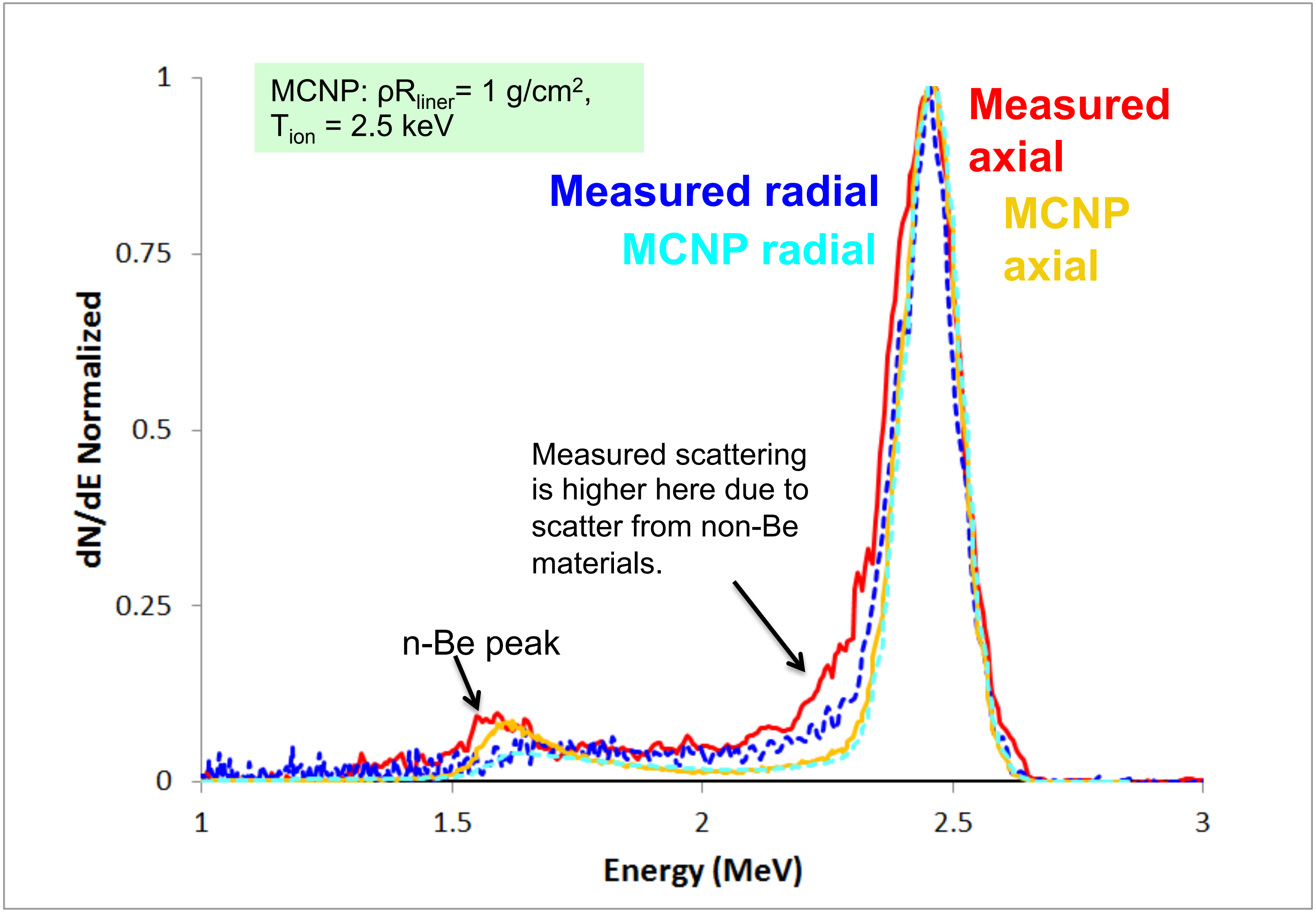




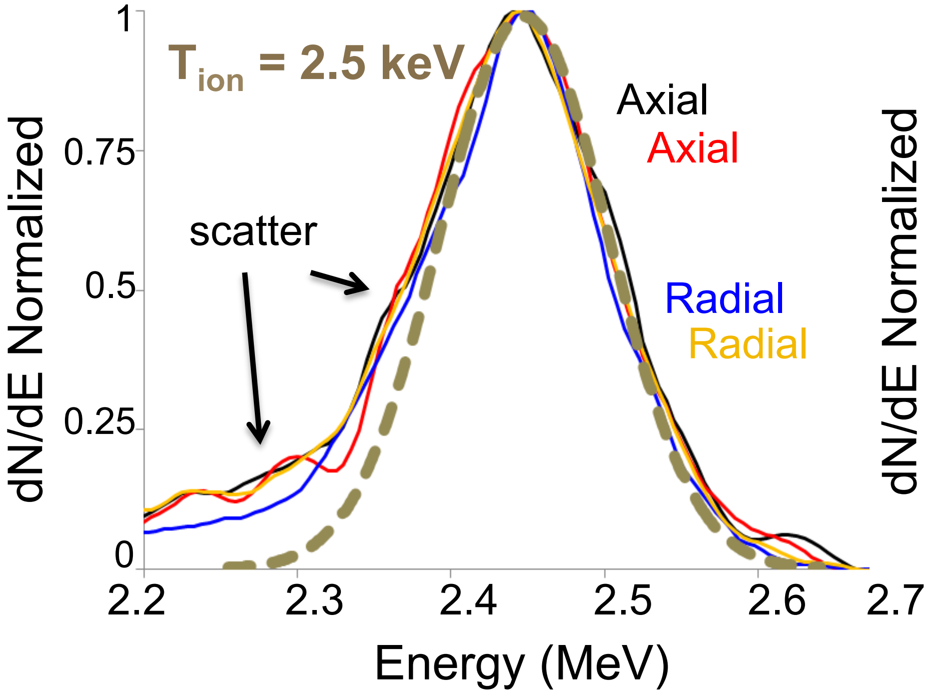
Pre-shot B-field Coils


Hard X-ray
Brems Signals
Primary
DD Signals
Secondary
DT Signals
dN/dt (arbitrary units)
2.5
2
1.5
1
0.5
0
-200
-100
0
100
200
300
400
500
600
700
Time (ns)

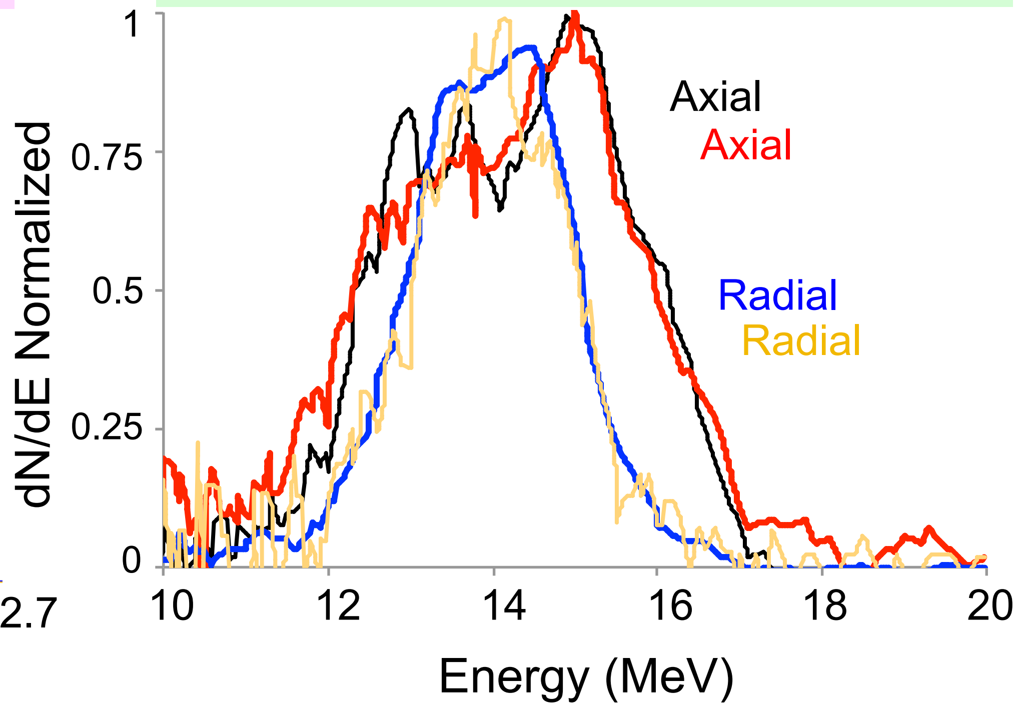
MCNP simulations suggest peak at ~ 1.6 MeV is consistent with O(1) g/cm², in agreement with x-ray measurements .



Symmetric DD neutron spectra, centered at 2.45 MeV are consistent with thermonuclear production[9-10].



Asymmetry in DT neutron spectra reveal degree of fuel magnetization at stagnation[16].



Setup for IRF measurements at IBL

Data Acquisition System