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Organic Scintillators for Active Detection Using an Intense Pulsed Bremsstrahlung Source

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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INTRODUCTION TO IPAD EXPTS

IPAD concept

- Intense photon beam used to discriminate fissionable and non-fissionable material
  - In fissionable material beam induces photofission
  - In non-fissionable material beam induces (γ, n) nuclear reactions
- Detect the induced neutron and gamma radiation
- Discriminated based on the intensity, type, and time signature of the radiation

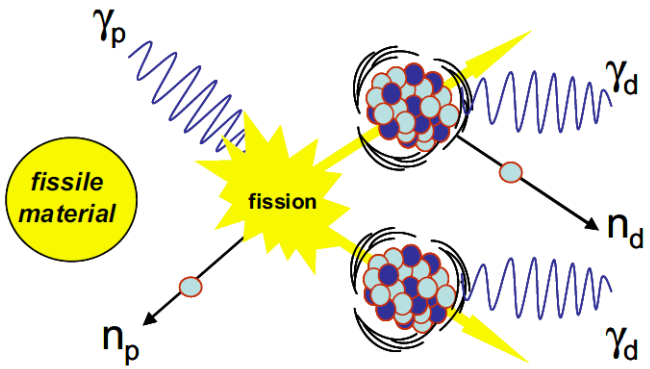


Diagram from Swanekamp et al.

HERMES III

- High-Energy Radiation Megavolt Electron Source (HERMES)
  - Pulsed power (13 TW)
  - 700 kA, 28 ns electron beam
  - Peak electron energy 19 MeV
- Tantalum target used to create bremsstrahlung photons
- Three modes of operation
  - “Full machine” 16-18 MeV
  - “Half machine” 7-8 MeV
  - “No reset” 11-13 MeV

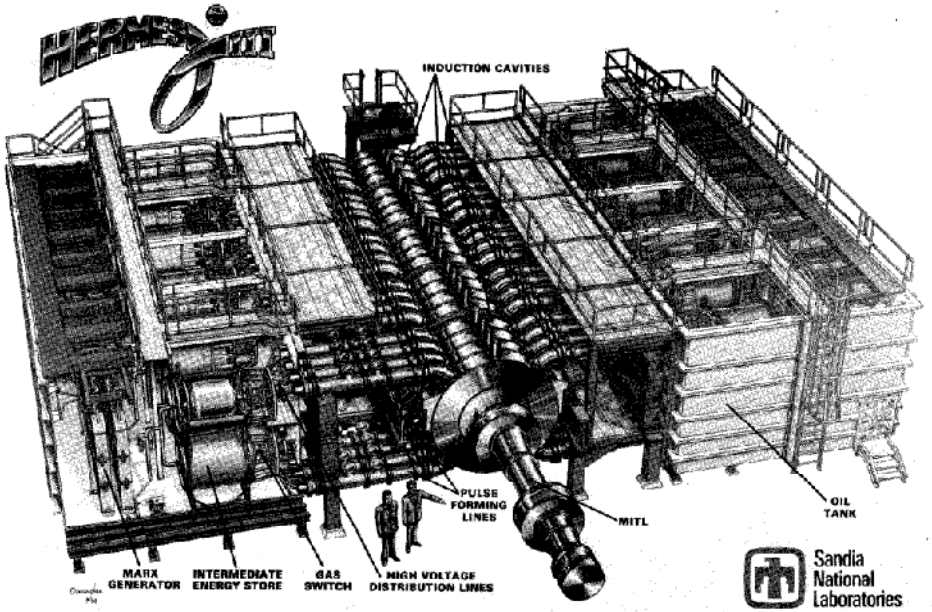
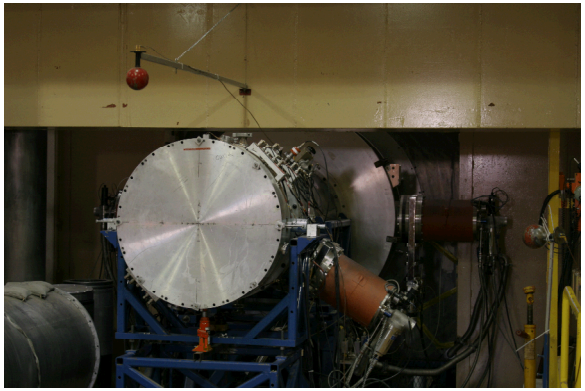
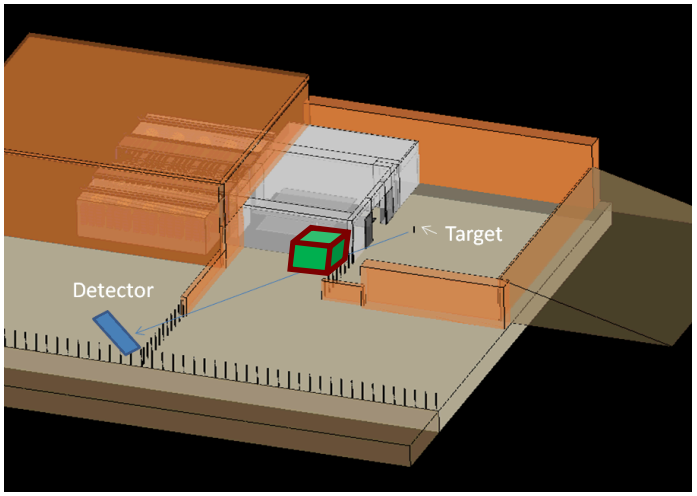


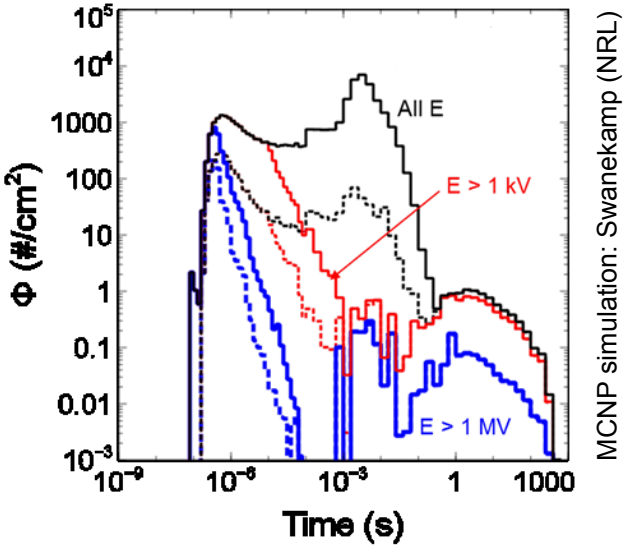
Fig. 2 - Hermes III



IPAD experiment at HERMES

- Gamma beam from HERMES III directed towards target in outdoor courtyard
- Detectors placed 45 m from target
- Induced neutrons (γ,f) can identify fissionable material in target
  - Competes with neutrons from active background processes (γ,n) in target and environment
  - Large gamma backgrounds from interrogating pulse & other nuclear processes.
- Targets included:
  - No target (control)
  - Depleted Uranium (DU)
  - Lead
  - Other configurations





MCNP simulation: Swanekamp (NRL)

NEUTRON SIGNATURES, SNL DETECTORS

Three neutron signature timescales

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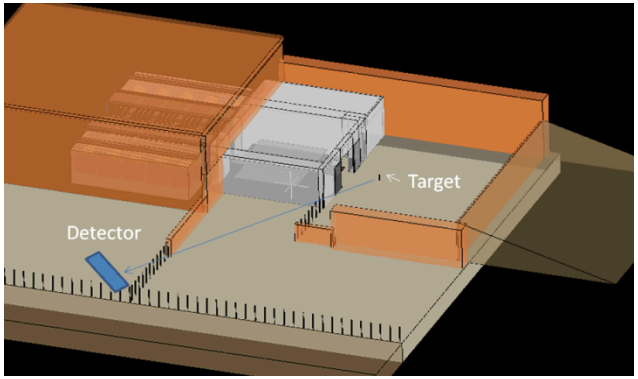
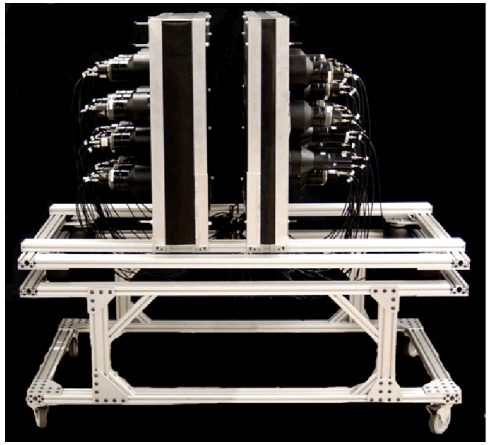
	10^{-6} s	10^{-3} s	1 s
	Prompt	**Delayed prompt**	**Beta-delayed**
Source	Fissions induced by interrogating pulse	Fissions induced by thermalized neutrons	Decays of fission daughters
Timescale determined by	Source-target distance, target-detector distance	Moderating material and geometry	Species lifetimes
Sensitive to	Fissionable	Fissile	Fissioned
Backgrounds	Direct & scattered source particles, other nuclear processes (γ,n)	Metastable state decays, other?	Low
Issues	Difficult timescale, not specific	Depends on potentially unknown materials, geometry	Low-energy neutrons, long times, low rate

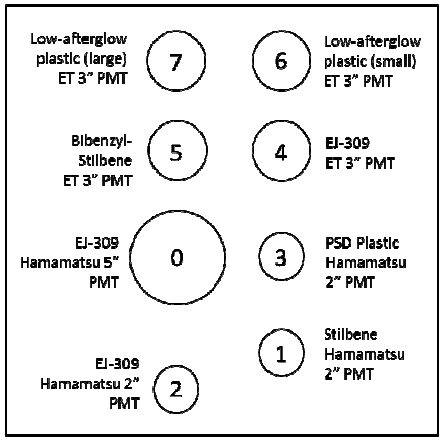
Scintillator Detectors Fielded

- Goal: Investigate the accessibility of the three timescales using organic scintillator detectors.
  - Large detector mass for relatively low cost.
  - Simultaneously sensitive to gamma, neutron, but isolated pulses distinguishable via pulse shape discrimination.
  - PSD not possible when multiple event pileup occurs.
- Equipment: Neutron scatter camera and Experimental detector array (right top, bottom).
  - Detectors situated in trailer 45 m from target, with clear line of sight (below).
  - Lots of shielding from direct HERMES III radiation.

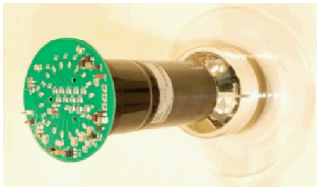




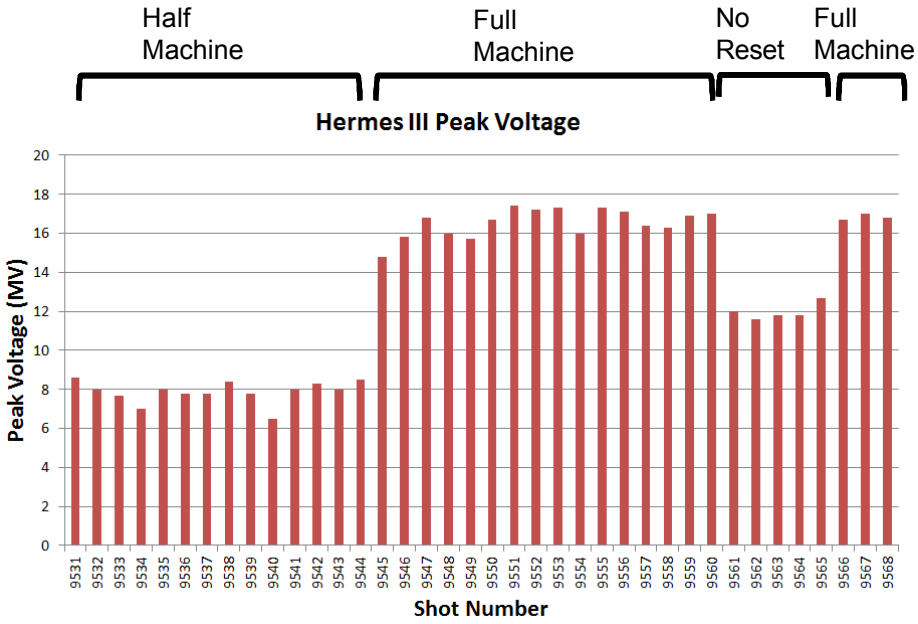
Neutron Scatter Camera
- 24-channel liquid scintillator array
- 5”D x 5” cells, 5” Hamamatsu PMTs
- 250 MS/s digitizer readout

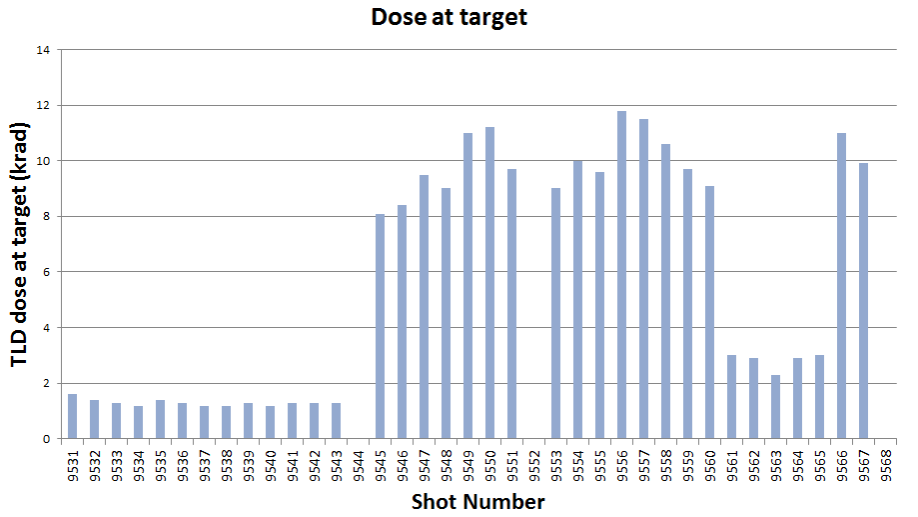


Experimental Detector Array
- Various liquid & solid organics
- 2”, 3”, 5” PMTs, some gated
- Struck SIS3350 500 MS/s digitizers

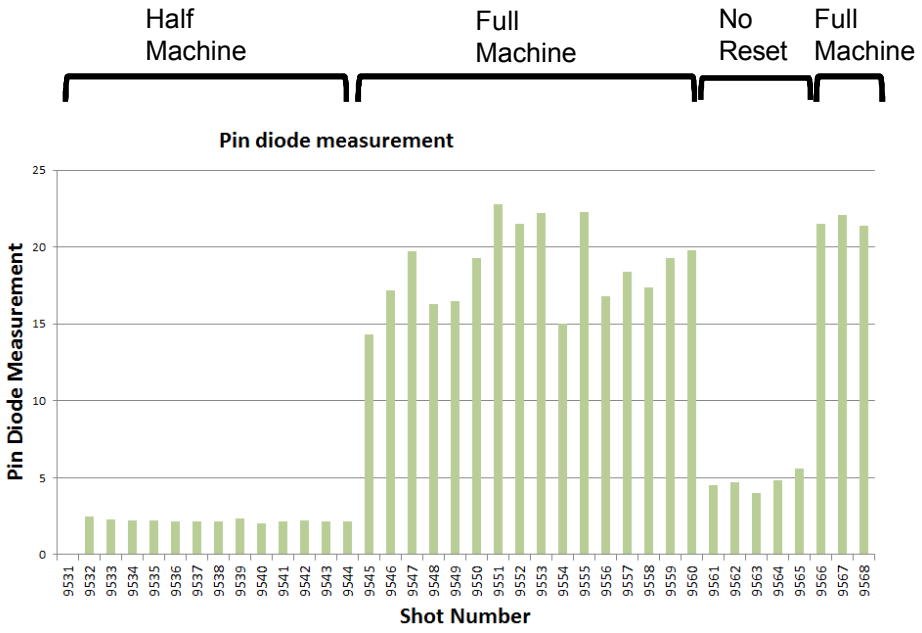


Shot-to-shot variation





- 37 recorded shots (subset)
  - 18 “full machine” (16 MV)
  - 14 “half machine” (8 MV)
  - 5 “no reset” (12 MV)



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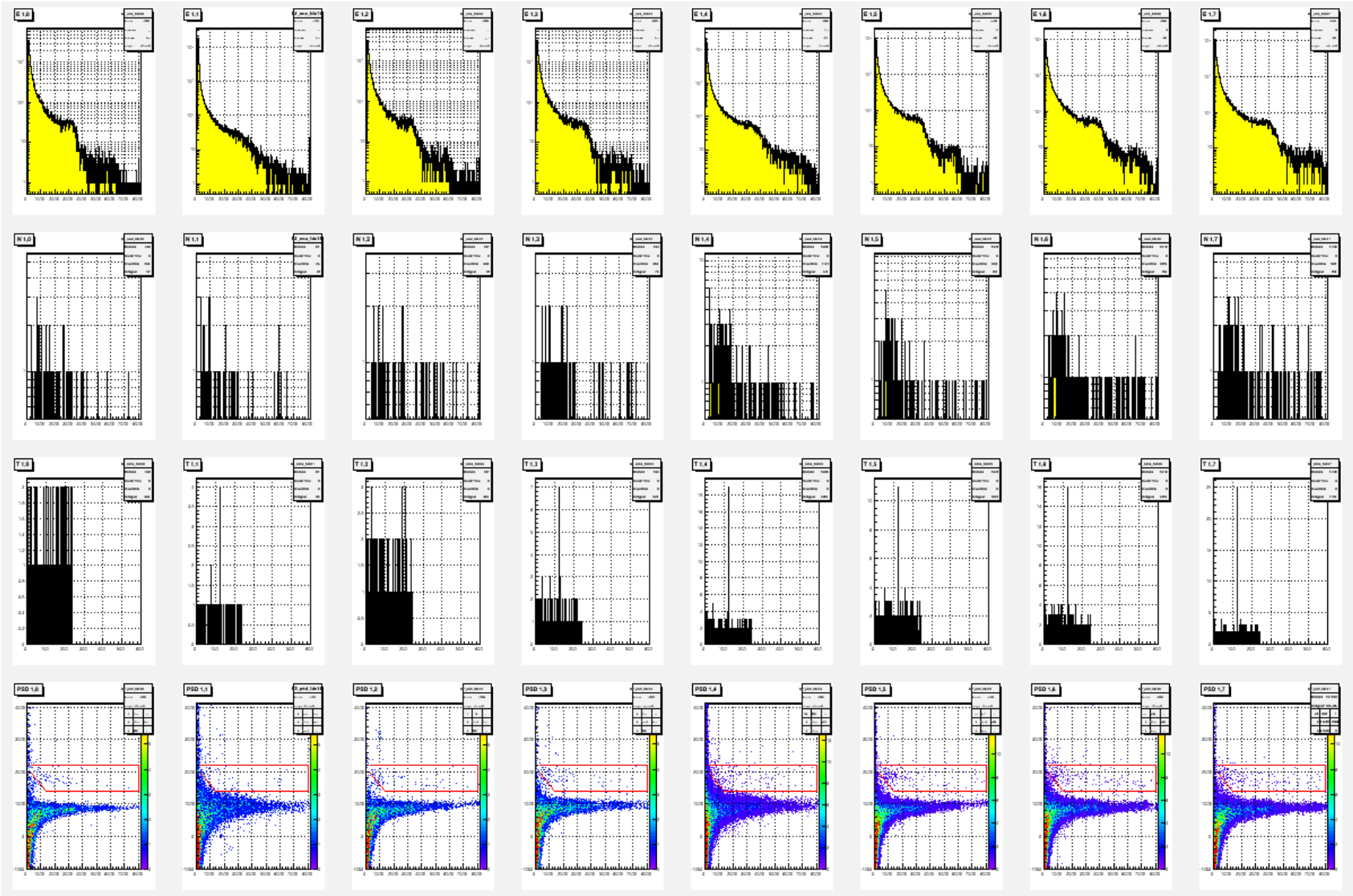
EXPERIMENTAL RESULTS

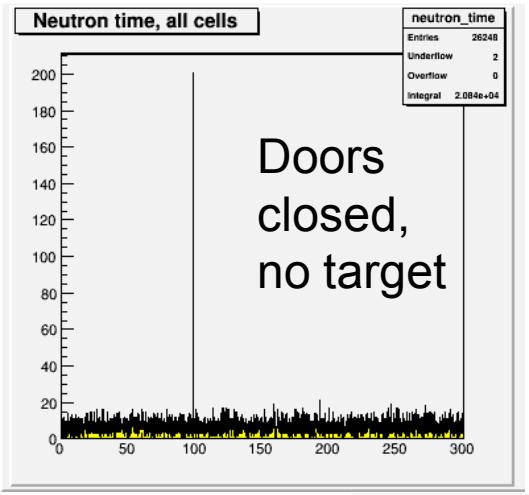
* BETA-DELAYED TIMESCALE
* DELAYED PROMPT TIMESCALE
* PROMPT TIMESCALE

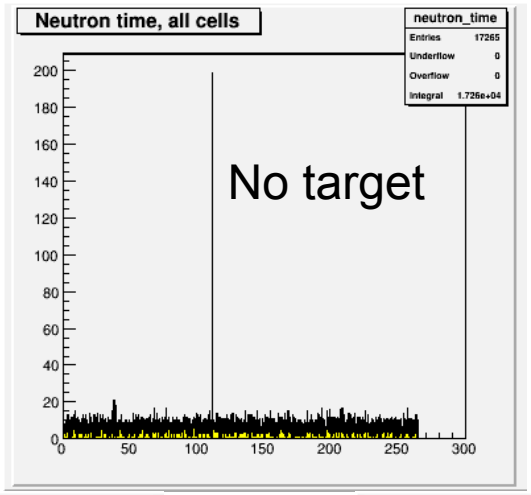
LS array background/calibrations

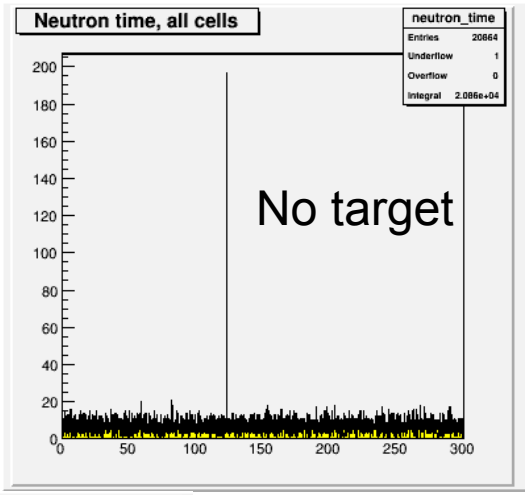


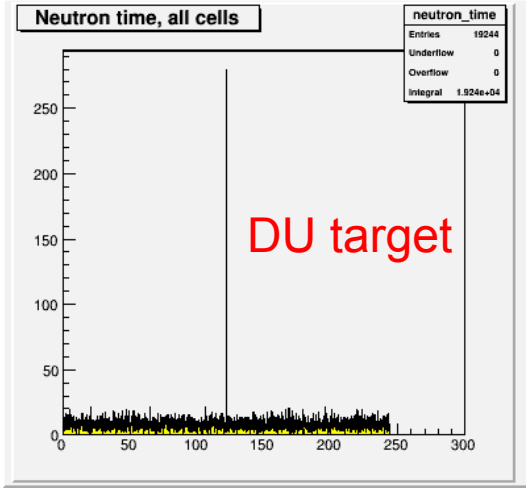
LS array beta-delayed signal

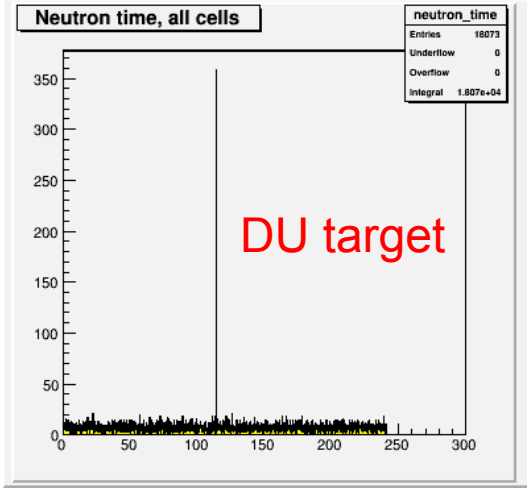
- Plots show 300 s, shot at ~100 s.
- No difference on long timescales for identified neutrons.











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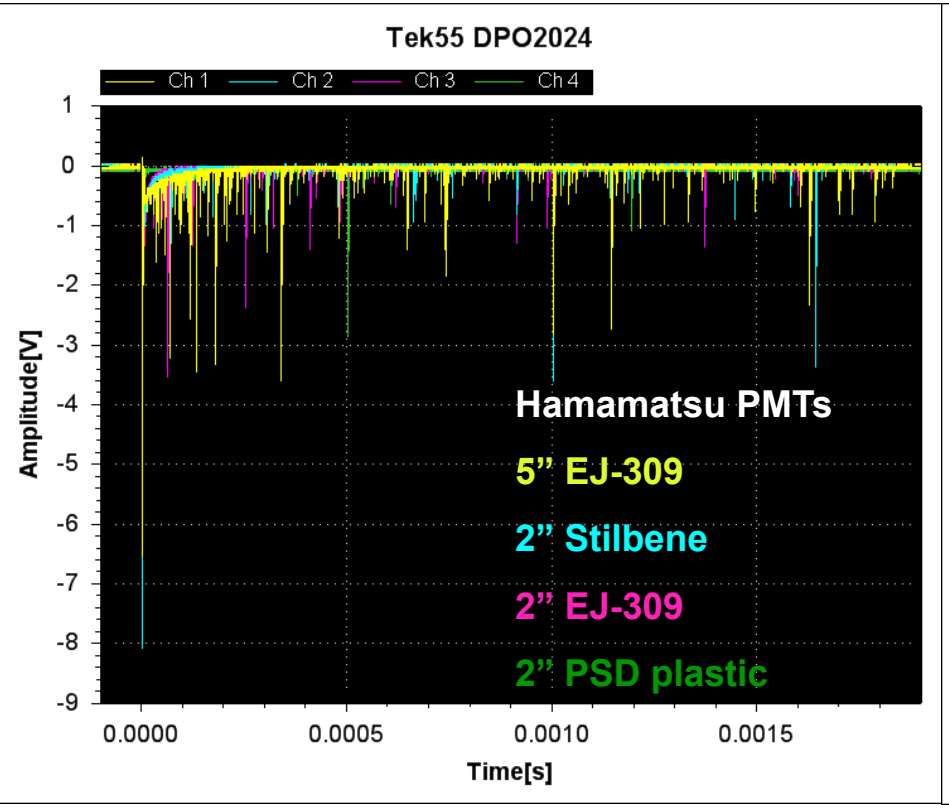
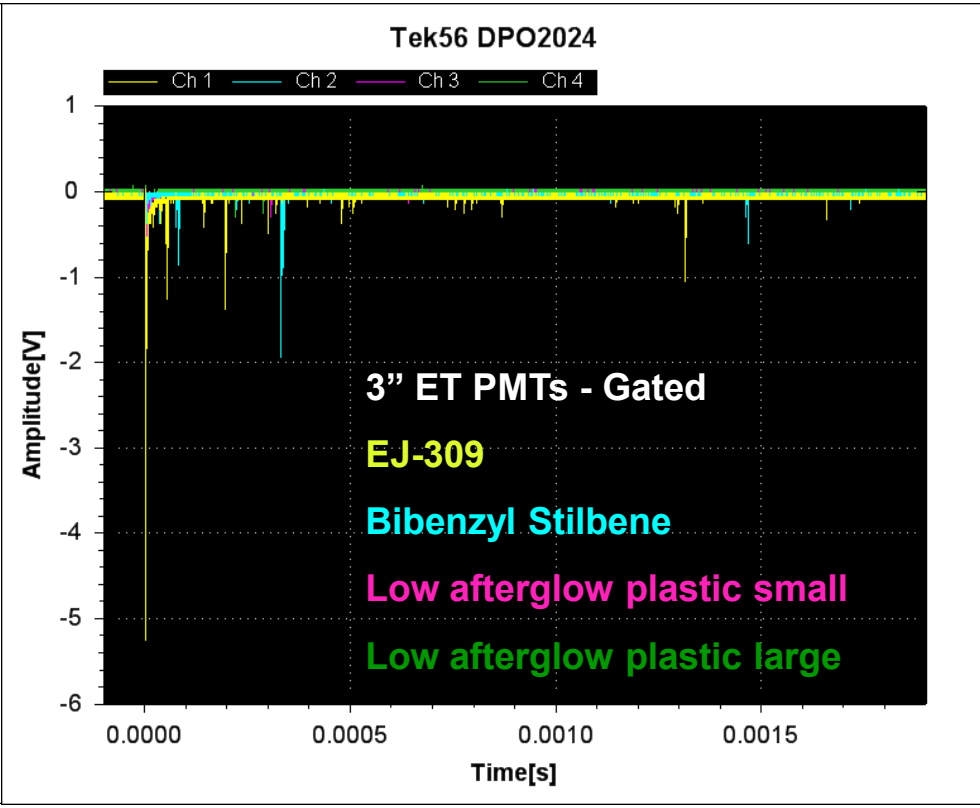
EXPERIMENTAL RESULTS

* BETA-DELAYED TIMESCALE
* DELAYED PROMPT TIMESCALE
* PROMPT TIMESCALE

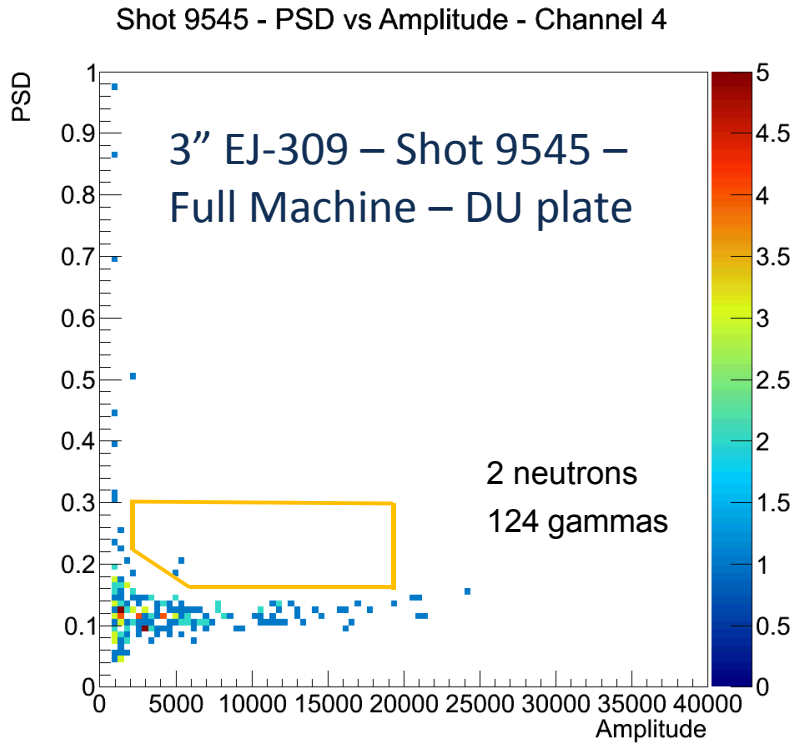
Scope traces, 1 ms timescale

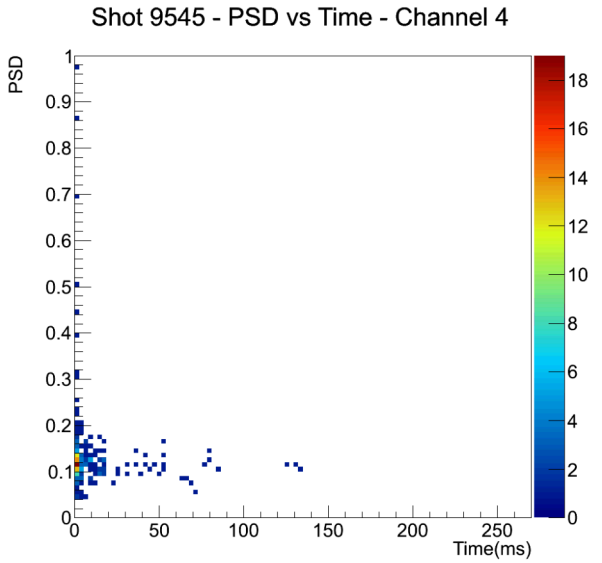


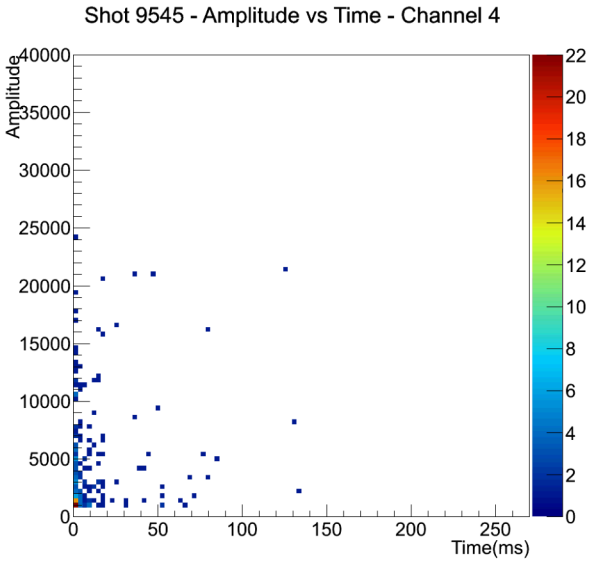


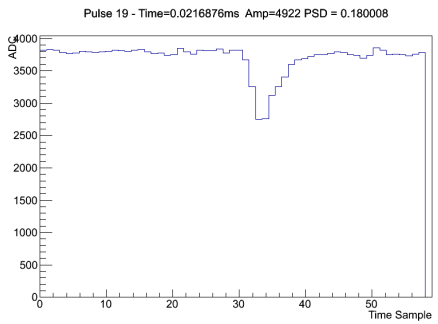
Shot 9545 – Full Machine – DU target

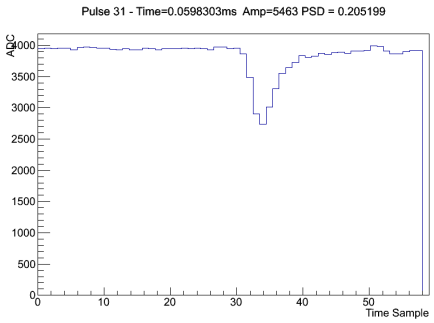
Delayed prompt analysis example



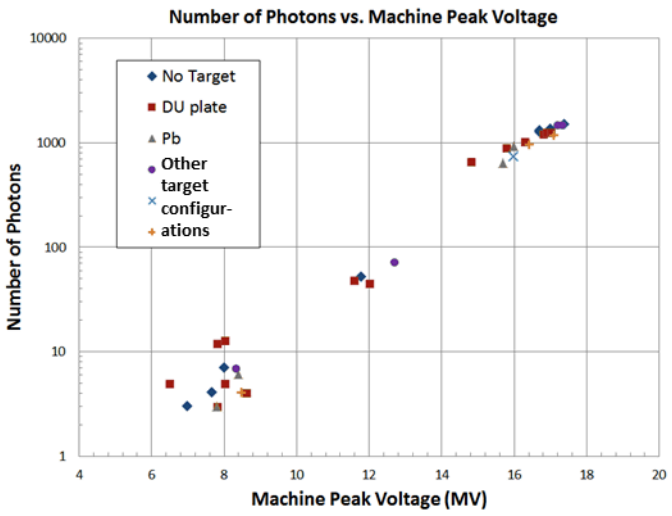


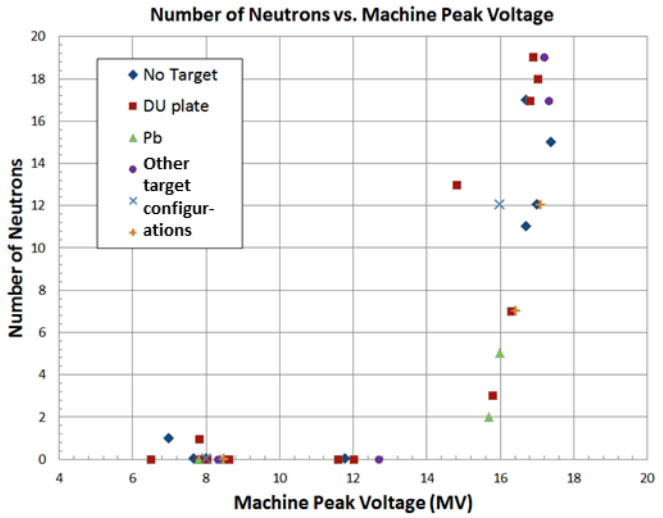






5” EJ-309 cell delayed prompt timescale





On 250 ms timescale, γ and n rates primarily correlated with machine output, not target—need good source diagnostics!

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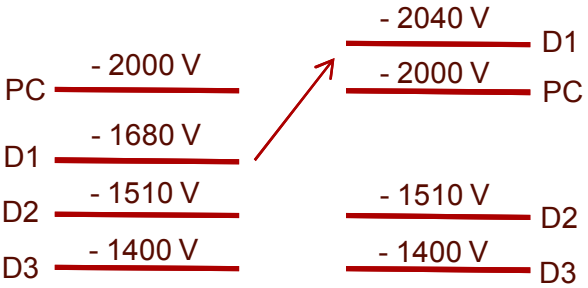
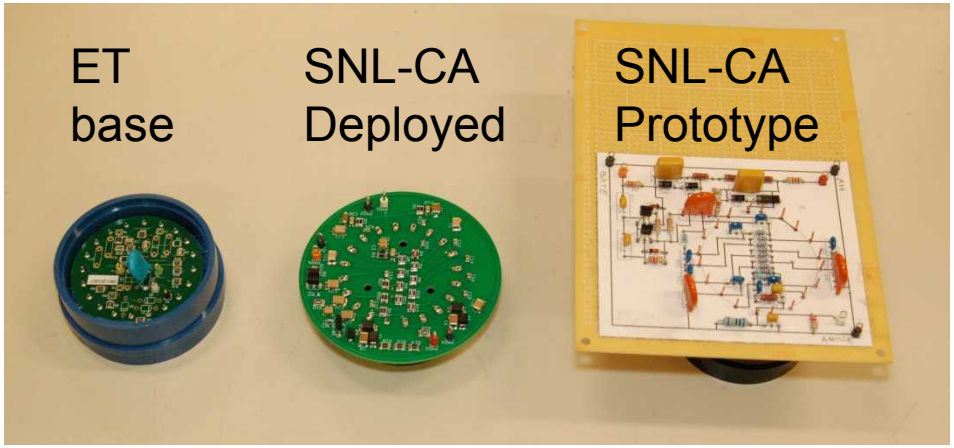
EXPERIMENTAL RESULTS

* BETA-DELAYED TIMESCALE
* DELAYED PROMPT TIMESCALE
* PROMPT TIMESCALE

Gated PMT

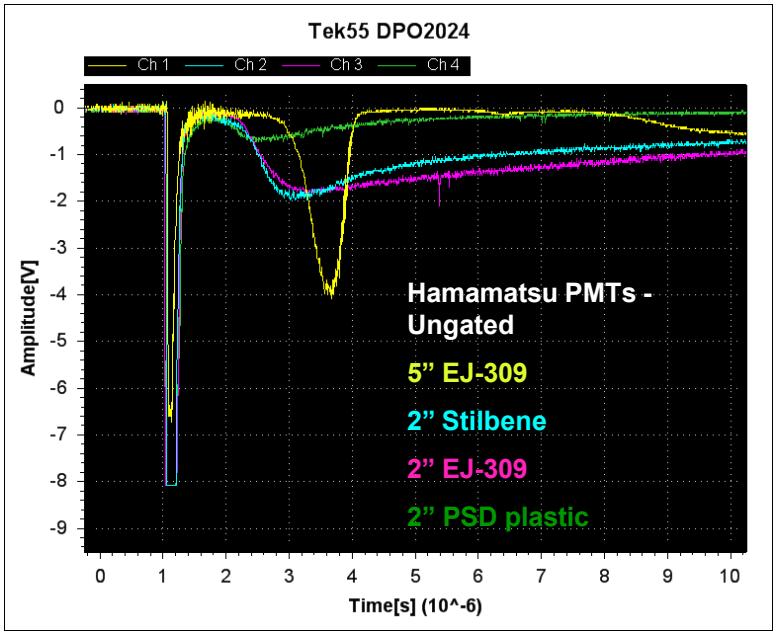
- Goal: temporarily decrease PMT gain
- 3'' Electron Tubes (ET) 9821KB
  - 12 dynodes
- Gating is accomplished by biasing the 1st dynode (D1) and focus grid (G) to be more negative than the photocathode (PC)
- Developed PMT test procedure using LEDs
- SNL-CA designed gated base decreases gain by > 1000x, return to nominal voltage with 100 ns rise time

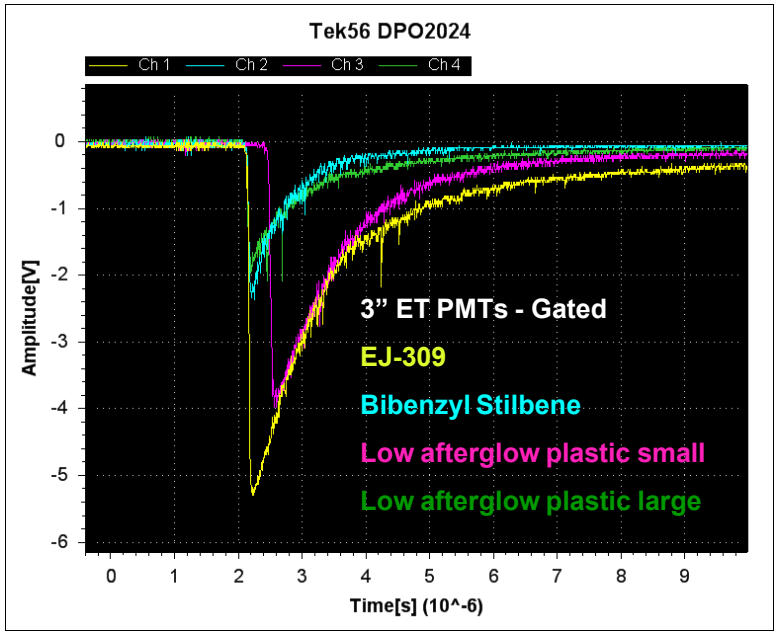




Prompt timescale scope traces

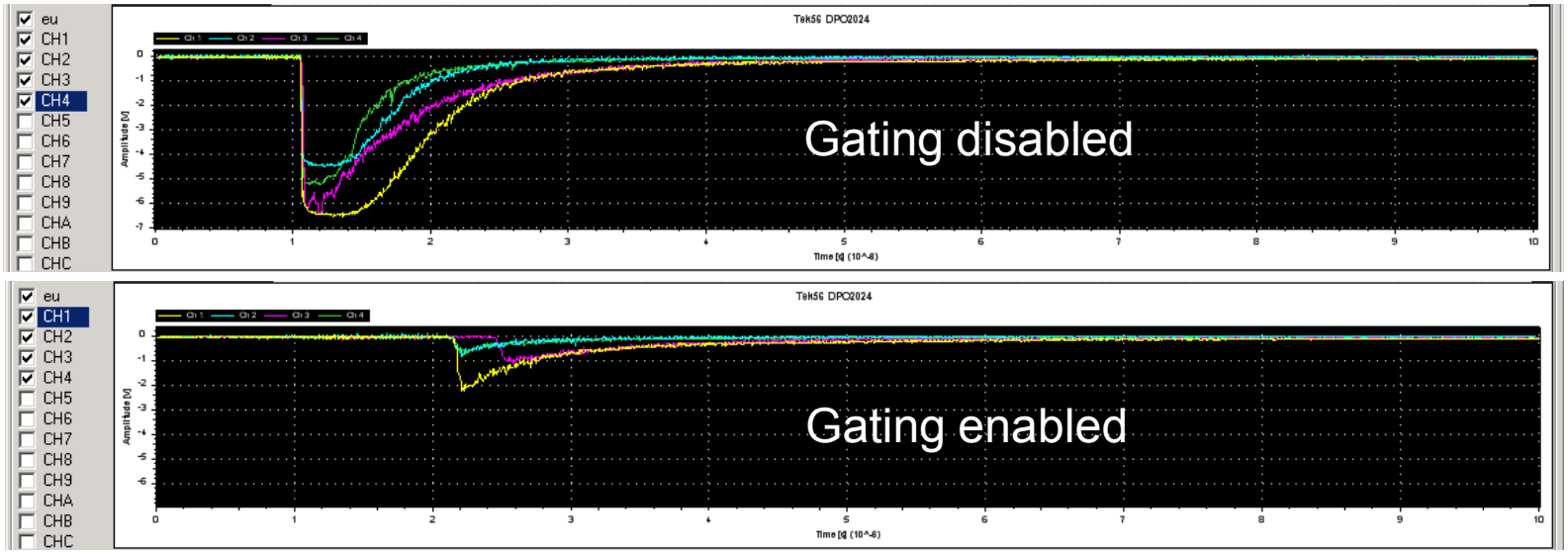
- Ungated PMTs
  - Saturate, recover (even multiple times!)
- Gated PMTs
  - Successfully turn on ~1µs after initial gamma burst
    - Isolated pulses visible
  - However, afterglow/EM noise/pileup still visible





Shot 9545
Full Machine
DU target

Effect of gating



Scope traces show half-machine shots.

- Gating successfully extinguishes the signal during the gated period.
- But transient saturation effects look identical after gating.
- Other characteristics of the gating base may be allowing quicker recovery than the ungated bases.

Conclusion

- Successfully recorded HERMES shots with a range of organic scintillator detectors and readouts
- Small number of neutrons detected at 45 m on beta-delayed timescales
- Number of gamma rays and neutrons detected on delayed prompt timescale is highly correlated with intensity of interrogating beam—active backgrounds
  - Need good machine consistency (or diagnostics) for SNM detection
- Prompt timescale neutron detection using gamma-sensitive organic scintillators has not been demonstrated due to saturation effects from the scattered interrogating photons
  - Gating is only a partial solution to overwhelmed PMTs

Acknowledgements:

- Sponsorship of DTRA/NNSA MOU on standoff detection
- NRL collaborators (Weber, Commisso, Swanekamp, et al.) for spearheading the IPAD experiments and for useful discussions
- Natalia Zaitseva (LLNL) for loan of detector materials

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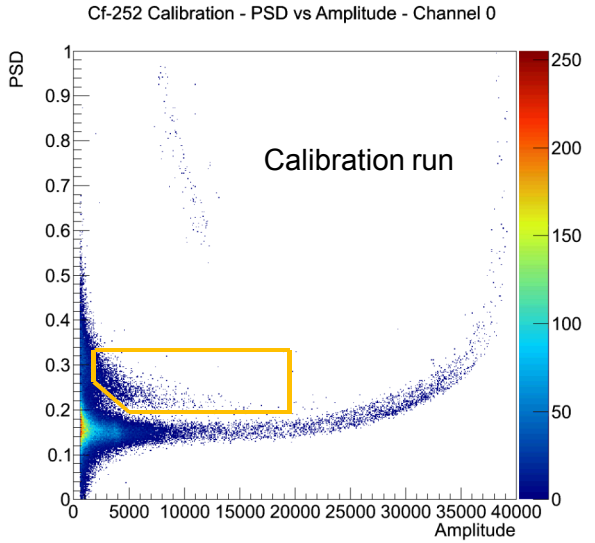
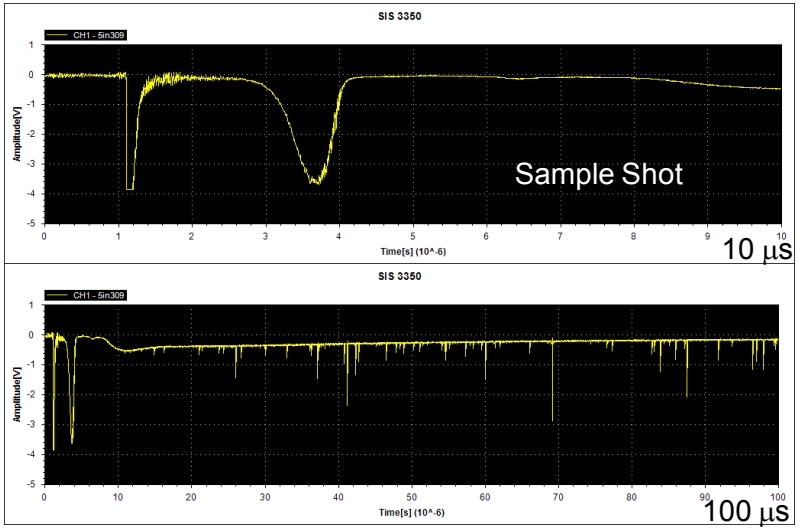
ADDITIONAL INFORMATION

Results – 5” EJ-309

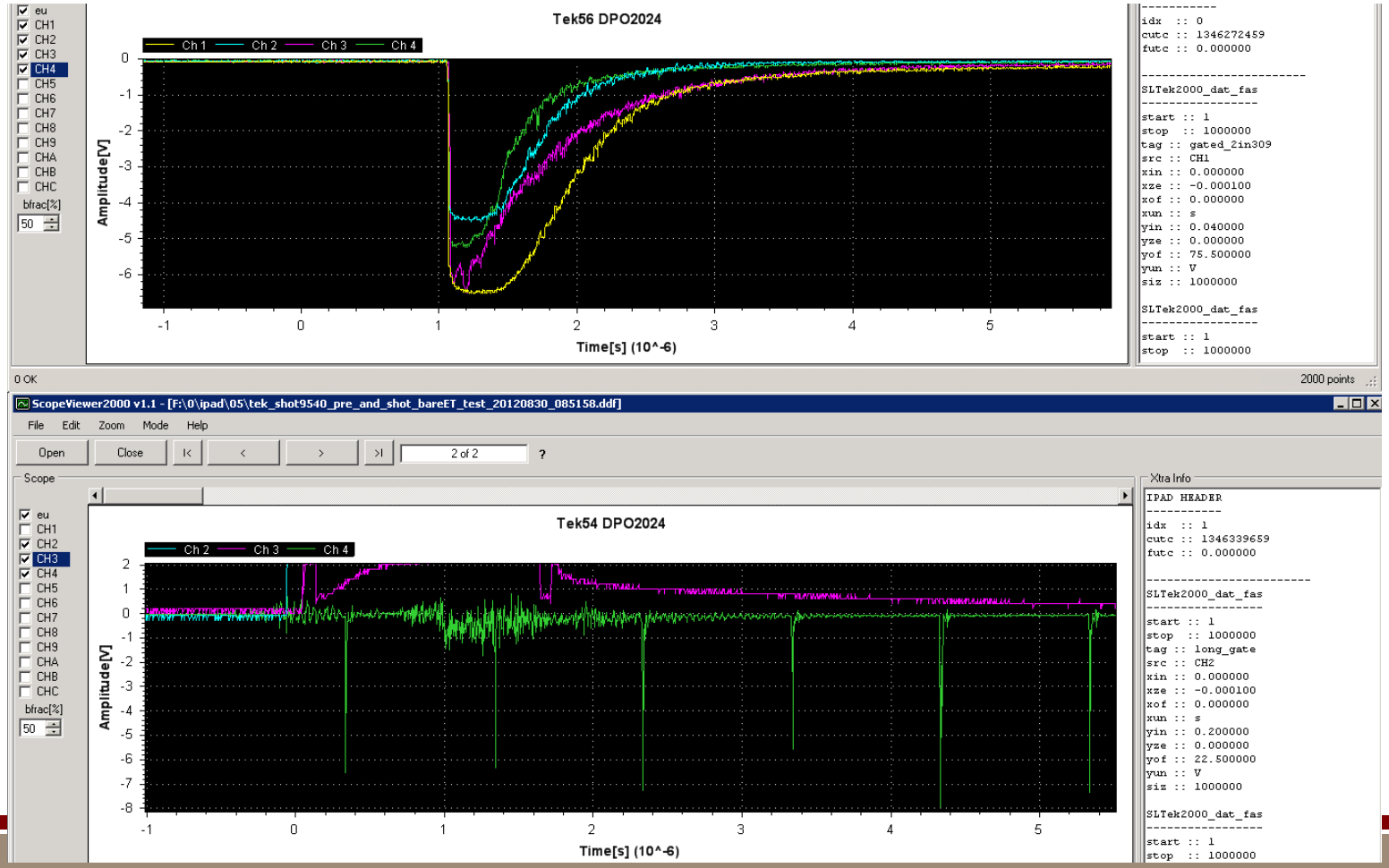
- Quality requirements
  - Amplitude > 600
  - Time > 3µs
- Gamma requirement
  - Amplitude > 2000
  - PSD < 0.19
- Neutron requirement
  - 2000 < Amplitude < 19000
  - 0.195 < PSD < 0.34
  - PSD > -0.28 x Amplitude /18000 + 0.28





Bare PMT crosscheck

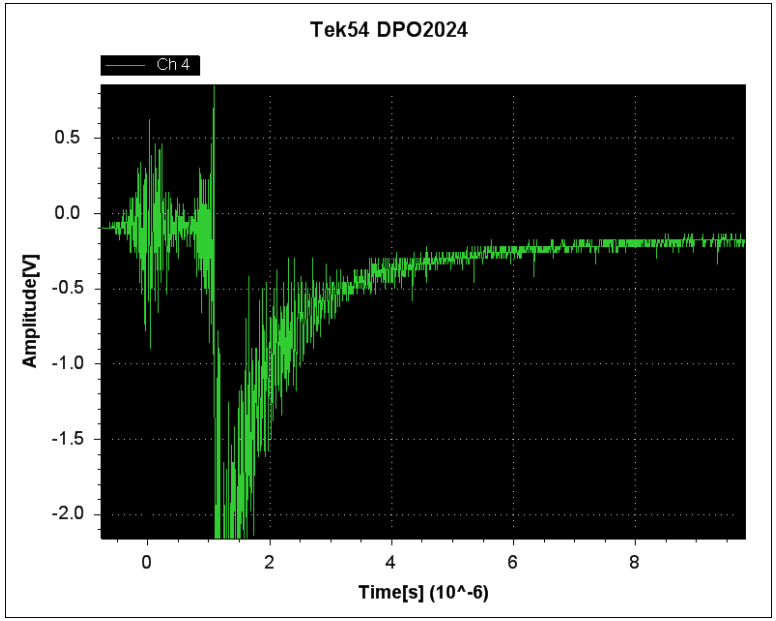
- A bare PMT with no scintillator and no mu metal was also read out.
- LED pulses demonstrate maintained gain
- ½ Machine traces



Bare PMT

- A bare PMT with no scintillator and no mu metal was also read out
- Full machine traces
- EM noise? Gammas interacting with PC or dynodes?

Bare PMT - Shot 9547 – HV on



Bare PMT - Shot 9548 – HV off