Scintillator-PMT Calibration and Noise Reduction for NICE using Cosmic Rays

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U.S. DEPARTMENT OF ENERGY

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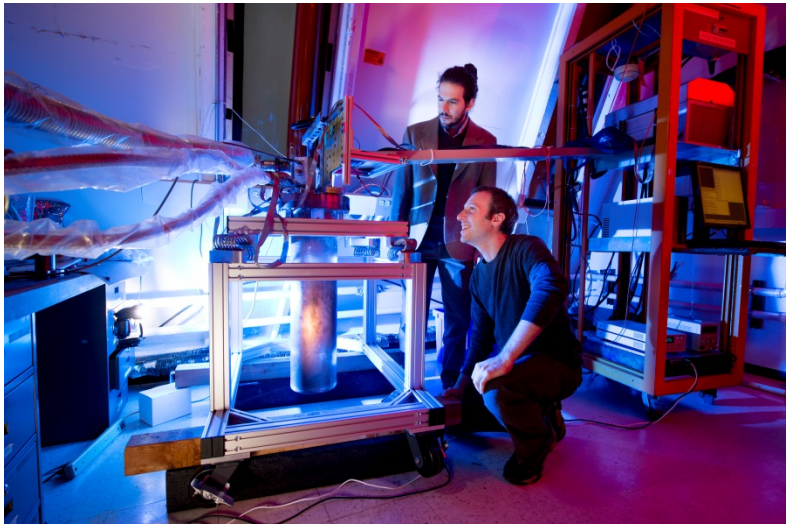
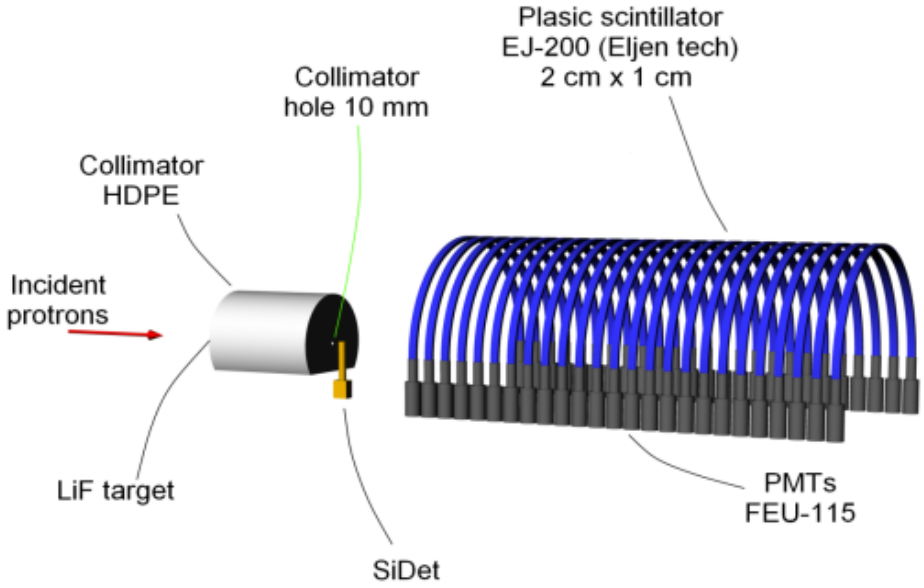
Background: Big Picture

- Dark Matter Particles: WIMPs
  - Particle
  - Cold
  - Weakly interacting
  - Mass
- Nuclear Recoil
  - Temperature
  - Bubbles
  - Ionization
  - Also produced by a neutron



- DAMIC (Dark Matter in CCDs)
  - CCDs
  - Ionization
  - Searches for possibly low mass WIMPs
- Need to distinguish between signals produced by neutron and dark matter particles with silicon
- This is NICE

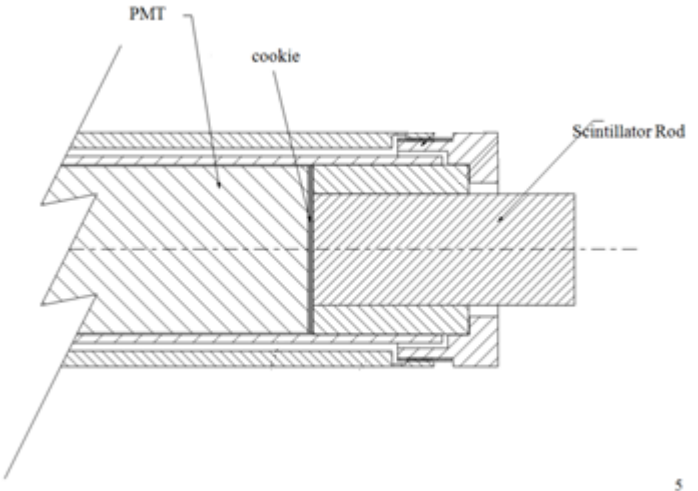
What is NICE?

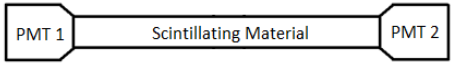


- Neutron Incident Calibration Experiment
- How does NICE work?
  - Scatter a neutron off of the silicon detector.
  - Measure energy and time of collision with scintillator-PMT (Photomultiplier Tube) setup.
  - Use calculated incoming and outgoing neutron momentums to determine the ionization produced in the silicon.
- Previously, used a neutrons filtered for a particular energy
  - NICE allows an increased rate
- Requires calibration of scintillator-PMT setup
  - Also need to determine if the scintillator-PMT setup is sensitive enough to detect low-energy neutrons.
  - 100-500keV (kinetic energy) neutron scattering from silicon produces a ~1keV ionization

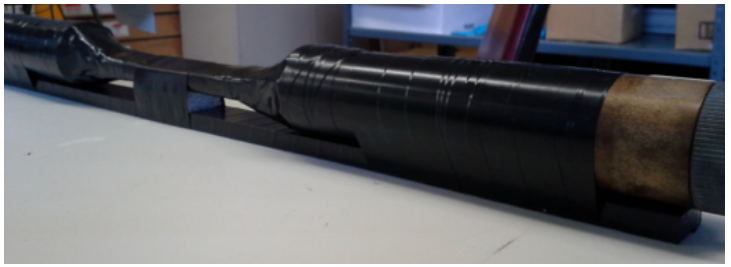
Calibration of Scintillator-PMT setup

- Couplings being considered
  - Acrylic cookie: 2 bars
  - Gel cookie: 1 bar
  - Optical grease: 1 bar
- Is it sensitive enough?
  - Time Resolution
  - Identify particles by TOF (Time of Flight)
  - Propagation speed (future)
- How does the charge reading relate to the actual energy?
  - Average number of photoelectrons produced
  - Larger number of photoelectrons = more accurate low energy readings
- Which are phantom signals and how can they be remove it?
  - Amplifier
  - Internal PMT Sparking
  - Clipping

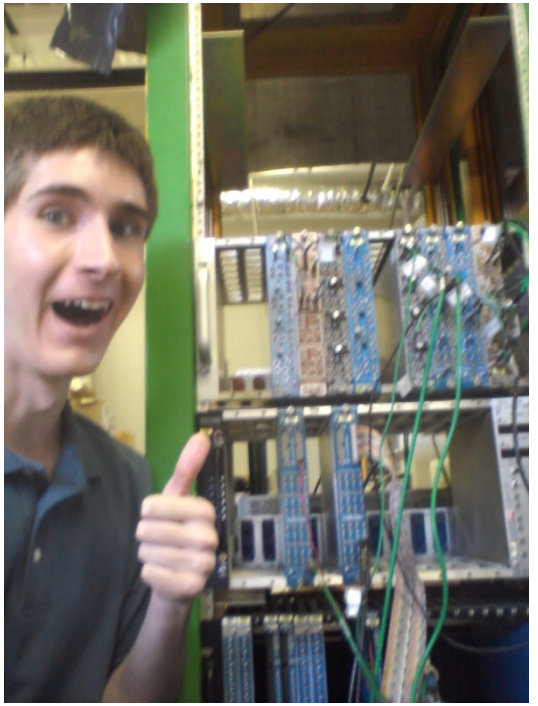




Equipment and Values Recorded

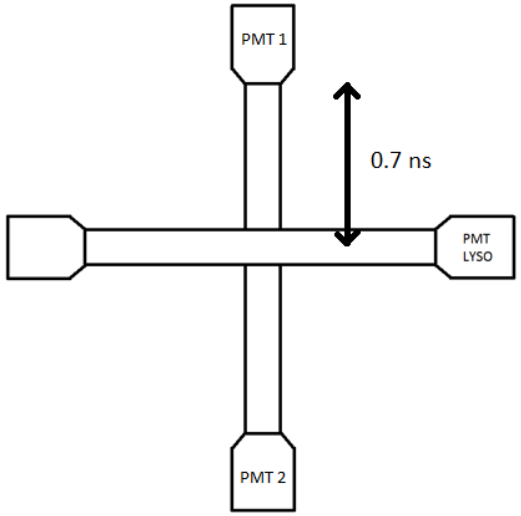


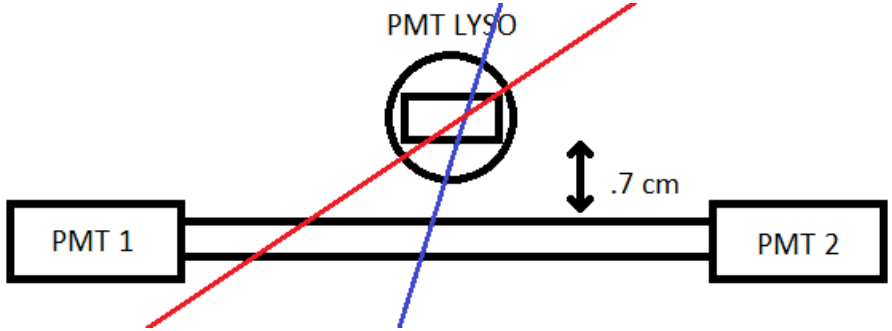
- Models used for circuit
  - Constant-Fraction Discriminator
  - Coincidence unit
  - Gate/Delay Generator
  - ECL-NIM-ECL Converter
  - CC-USB CAMAC Controller
  - Scintillator: 1cm x 2cm x 20cm EJ-200
- Data Collected
  - TDC (Time to Digital Converter)
    - Timing data giving in .5 ns counts
    - Common Stop generated by coincidence with delay
  - ADC (Analog to Digital Converter)
    - Integrated value of the pulse (Voltage over Time)
    - Proportional to the total charge of photoelectrons produced
    - 10 bit value (so maximum of 1024)



Time Resolution: Method

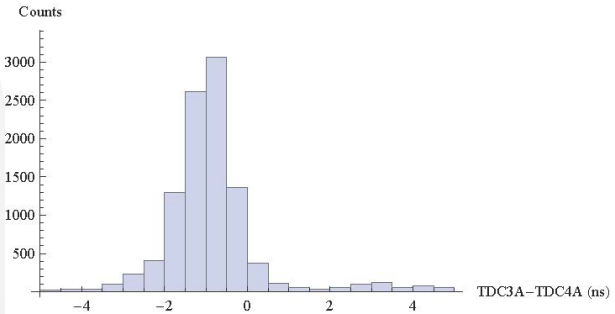
- TDC of PMT 1 - TDC of PMT 2
  - Independent of the particles speed
  - Only a function of position on the rod and rod length
  - Roughly constant for crossed setup
  - Larger spread from shallow angle collisions
- What to measure
  - FWHM (Full Width at Half Maximum)
  - Proportional to the Time Resolution
  - Restricted by TDC readings (given in 0.5 ns counts)
  - Coincidence required between all 3 PMTs

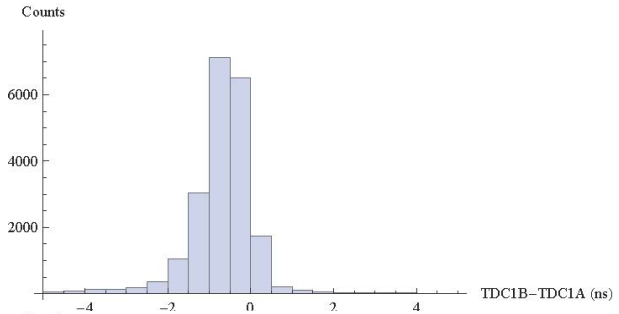


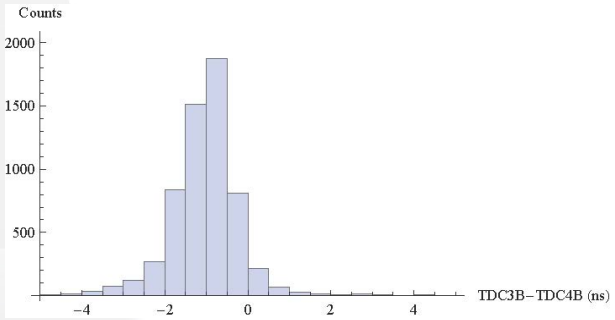


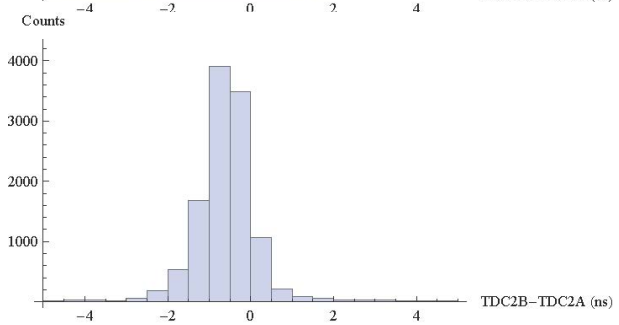
Time Resolution: Results

- 1B-1A: FWHM = <1ns Time Resolution = 0.3ns
- 2B-2A: FWHM = <1ns Time Resolution = 0.3ns
- 3B-4B: FWHM = <1ns Time Resolution = 0.3ns
- 3A-4B: FWHM = <1ns Time Resolution = 0.3ns





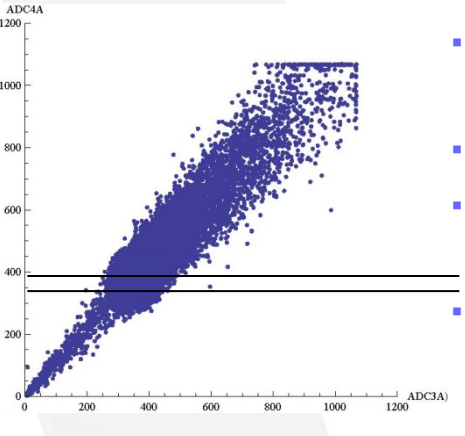


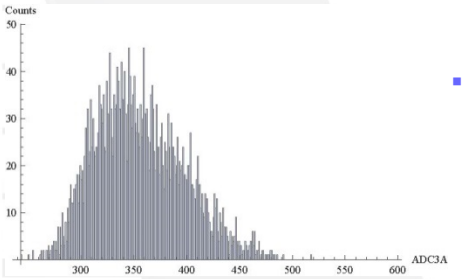


Time Resolution: Conclusion

- 0.3 ns gives an upper limit
- Can be reduced using a third rod
  - Reduce the solid angle of the setup
  - Eliminates most shallow angle collisions
  - Reduce the event rate
- Further accuracy is restricted by the electronics
  - 0.5ns bin size sets the minimum currently
- Sufficiently small to continue with the calibration
  - Neutron travels about 2cm/ns (speed of light ~ 30 cm/ns)

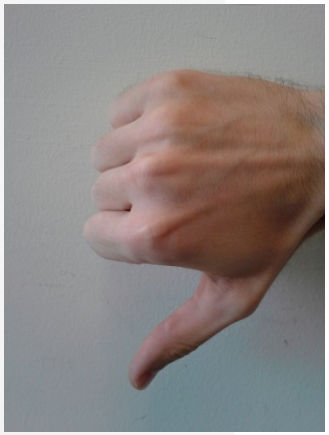
Number of Photoelectrons: Method

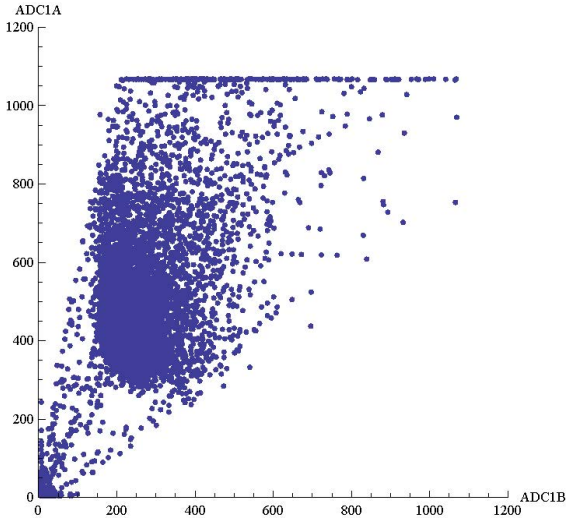


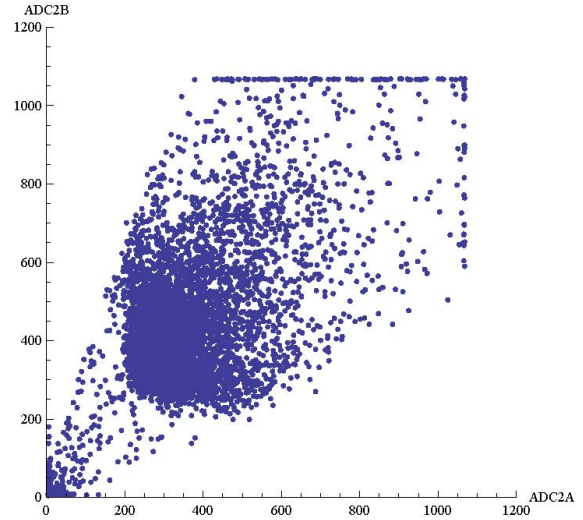


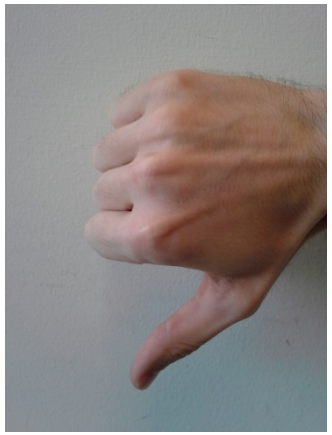
- Measure ADC of different PMTs on the same rod
  - Receive the same light for the same event
    - Error from attenuation (negligible for these rods)
  - ADC vs. ADC plot follows a linear trend
  - Slope determined by the different gains of the PMTs
    - adjust voltage source to compensate
  - Plot histogram of the ADC values of one PMT with restrictions based on the corresponding ADC value of the other PMT
    - Ex. Histogram of ADC 1 with 100 <= ADC 2 <= 120
    - Sets light from scintillator to be roughly constant
  - Should resemble a Poisson distribution
    - $P(n)=n \uparrow n / n\, e \uparrow -n$, n = average number of hits = ($mean/\sigma) \uparrow 2$
    - Proportional to the number of photoelectrons

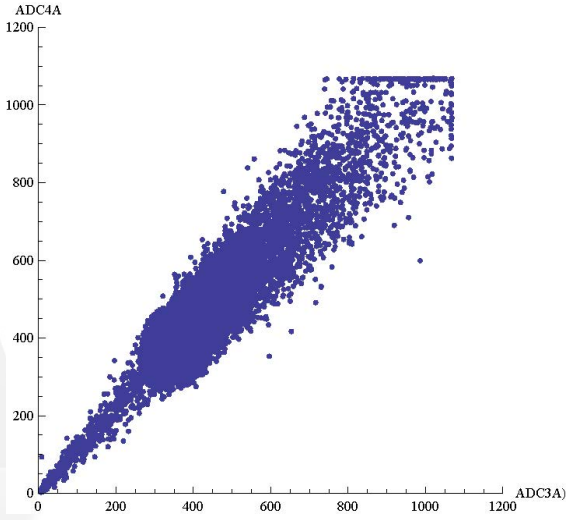
Number of Photoelectrons: Results

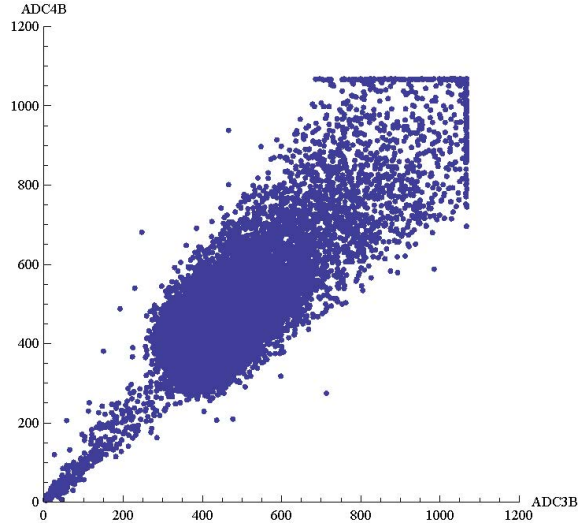


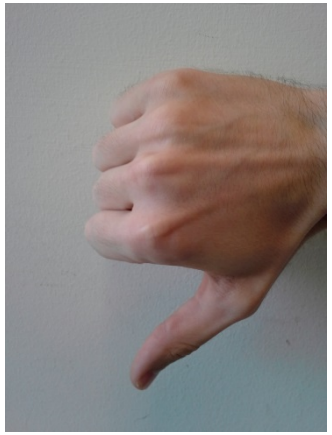








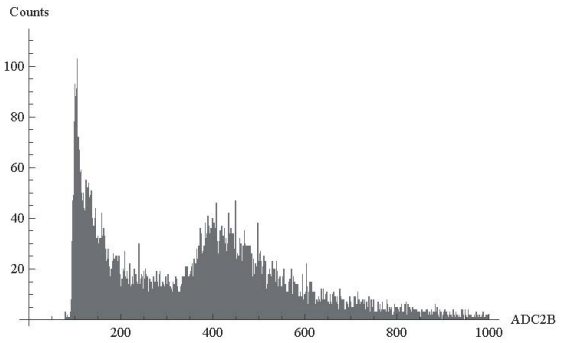




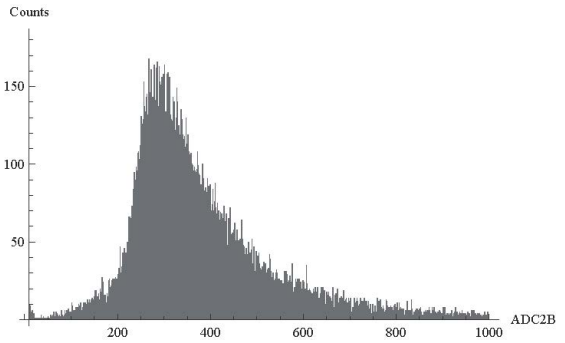
Number of Photoelectrons: Conclusion

- The smaller spread for the gel cookie coupling
  - Smaller standard deviation for the calculation
- Noticeably higher number of photoelectrons
- Optimal coupling is the gel cookie

Noise Reduction: Amplifier

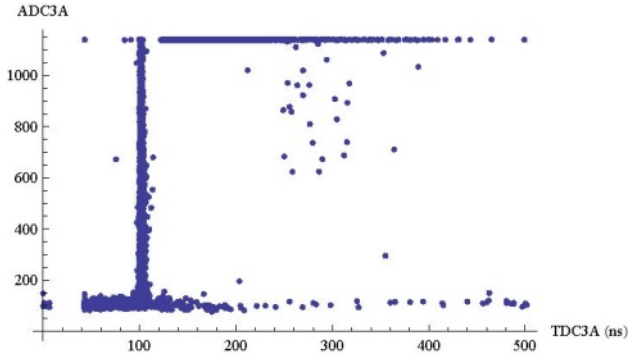


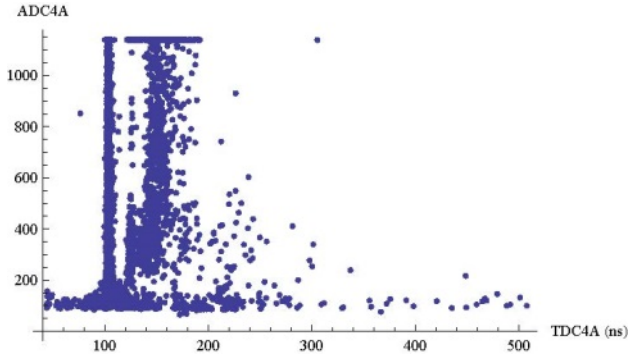
- Amplifier used to split signal from the PMT
  - TDC
  - ADC
- Use of electronics produced large oscillating pulses
  - Lights, AC, etc.
  - Recorded as a large burst of low ADC pulses at earlier times
- Phantom signals originated from the amplifier
  - All pulses came through the same amplifier
  - Poor grounding
  - Separate grounding for the two outputs
- Switched to a stacked setup
  - Removed the need for signal splitting

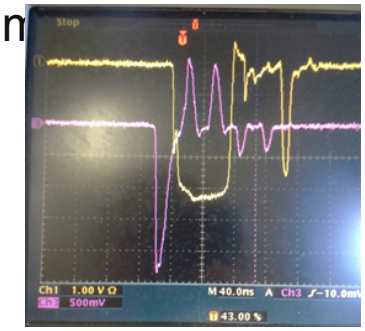


Noise Reduction: Internal PMT Sparking

- Observed for Time Resolution analysis of the gel cookie bar
  - Many saturated ADC values for PMT3A
  - Correspond to wide range of ADC values for PMT4A
  - >30ns earlier than expected
  - “Double bar” behavior observed for PMT4A
  - Second bar corresponded to all saturated values of PMT3A
- Large pulse observed from PMT3A
  - >3 Volts at the peak
  - Saturated the amplifier
- Due to internal sparking
- Data is still usable with filters on tim difference or maximum ADC cuts

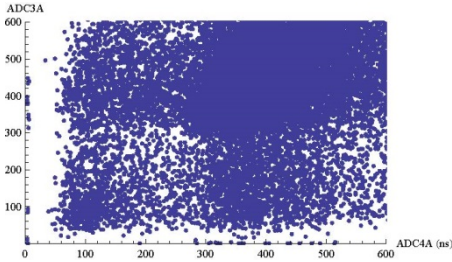


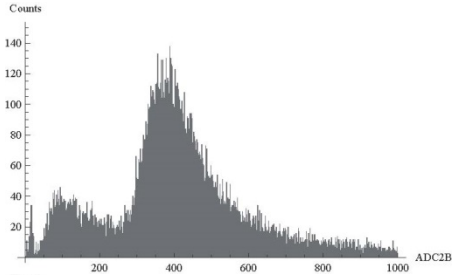


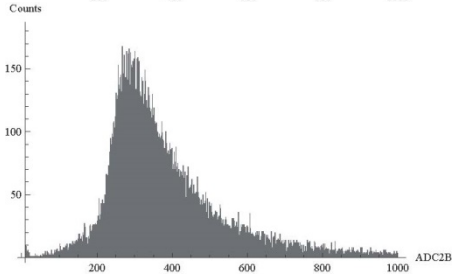


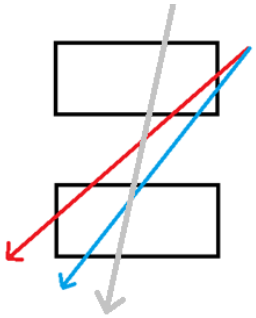
Noise Reduction: Clipping

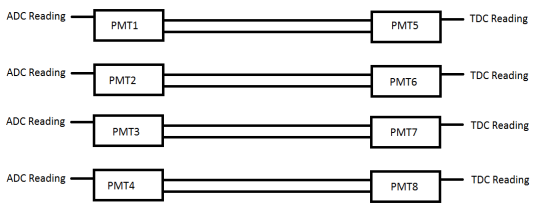
- Still small peak after the amplifier was removed
  - Perfectly in time (not removed with time difference cut)
  - Increased voltage = shifting of the peak
  - Note: ADC values taken from different rods
- Values in the small peak came in distinct groups
  - Small ADC – small ADC
  - Small ADC – large ADC
  - Large ADC – small ADC
  - Groups observe for ADC vs. ADC
- Due to clipping
- Tested using a stack of 4 rods
  - Should observe no peak on the middle two rods
- No a problem for neutrons





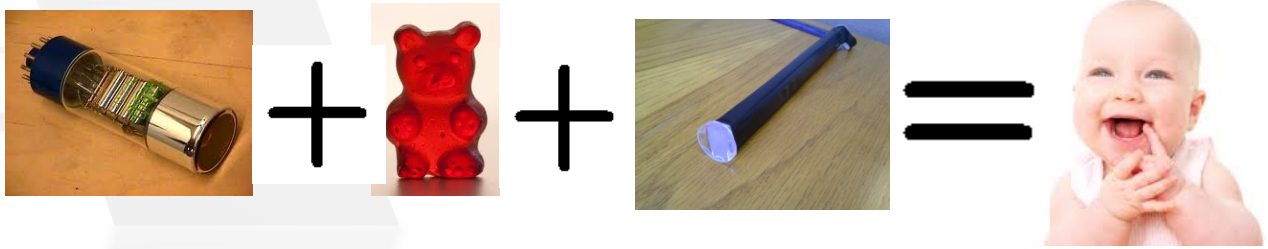


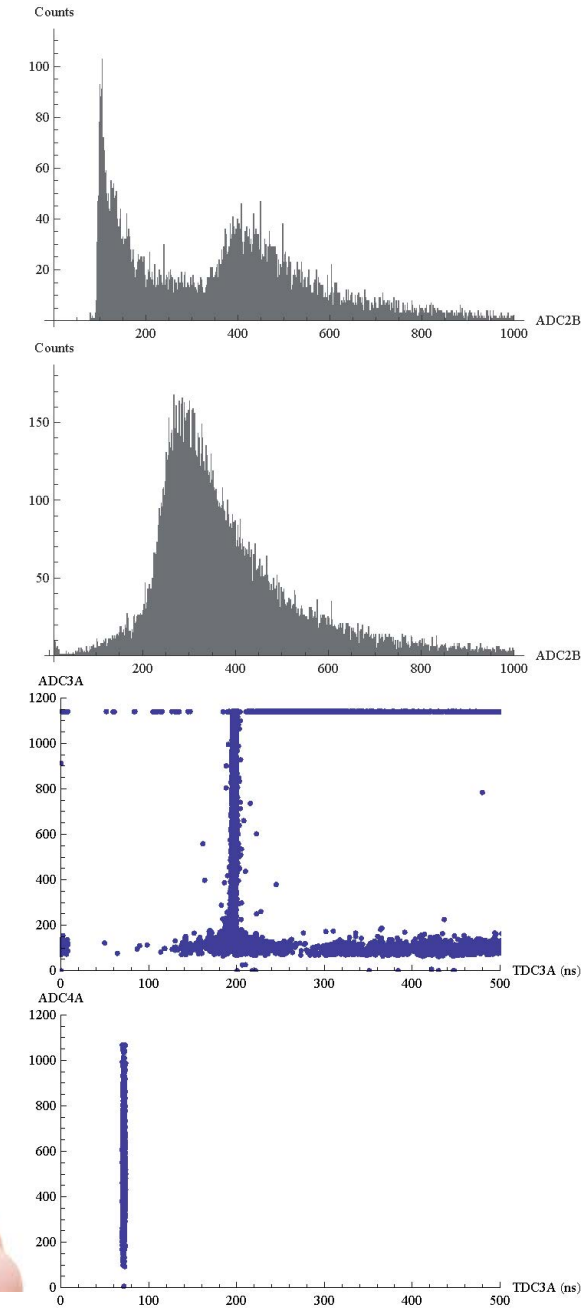




Conclusion

- With the combination of all three noise reductions found and implemented in this experiment, the TDC and ADC graphs became much cleaner.
- The time resolution of all three couplings is sufficient small for their desired purpose.
- The gel cookie produces the larges number of photoelectrons by far.





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Questions?