Design Testing for a Large-Area Photon Detection System

Light-Collecting Paddles and Silicon Photomultipliers

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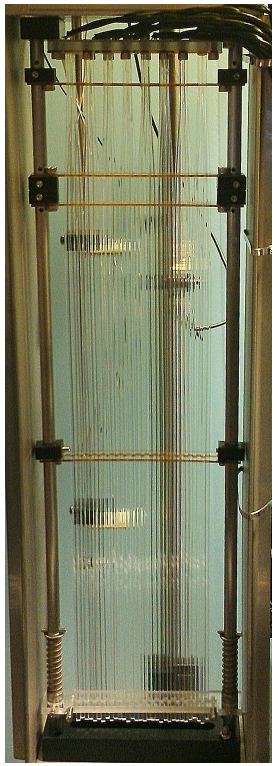
for the LBNE Collaboration
Photon Detection group

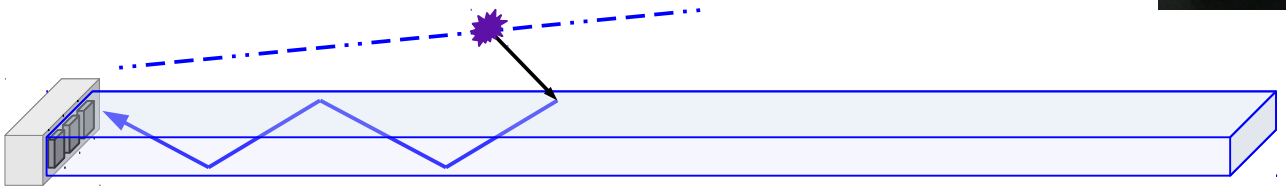
July 8, 2014

- Features of Silicon Photomultipliers
  - (At cryogenic temperature)

- Testing lightguide designs
  - Local testing with cosmic rays and alpha sources
  - Cosmic-ray studies at TallBo facility

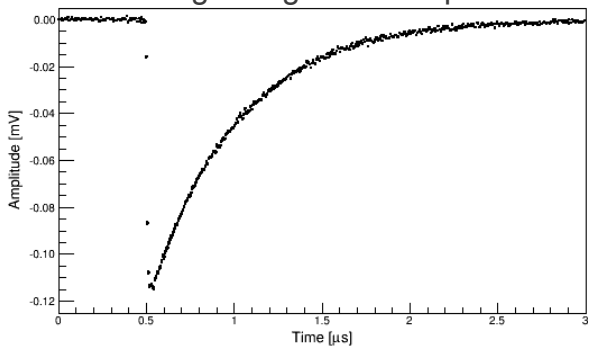


- Characterization of scintillation signal on SiPMs

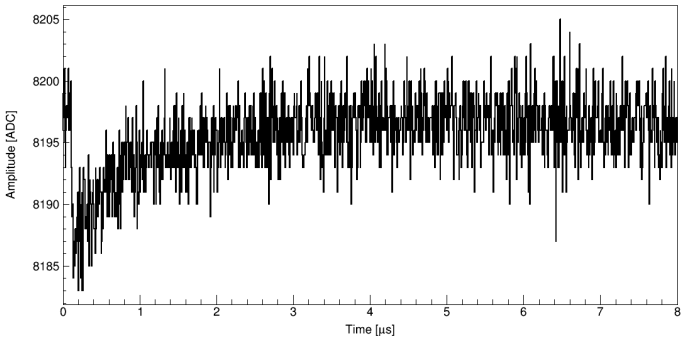


- Silicon Photomultipliers (SiPM) end of lightguides
  - SensL 6 mm x 6 mm active area (18960 microcells)
  - Read out using SiPM Signal Processor (SSP)
    - See R. Wasserman's talk
  - Sharp rising edge
    - (Few ns rise time)
  - Long capacitive tail
    - τ_{RC}~500 ns

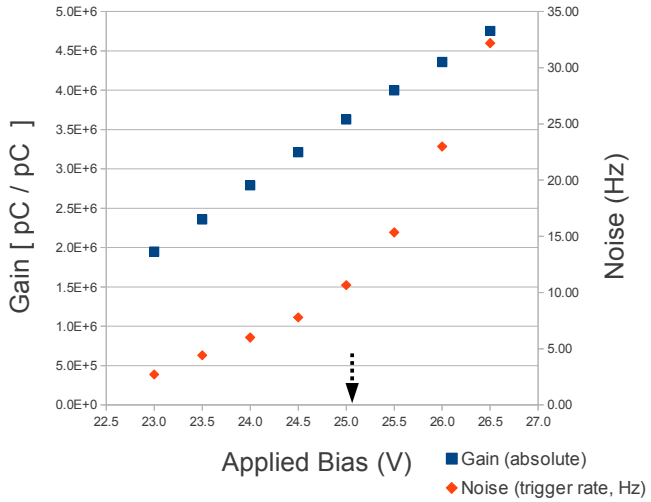
Average Single-PE Response

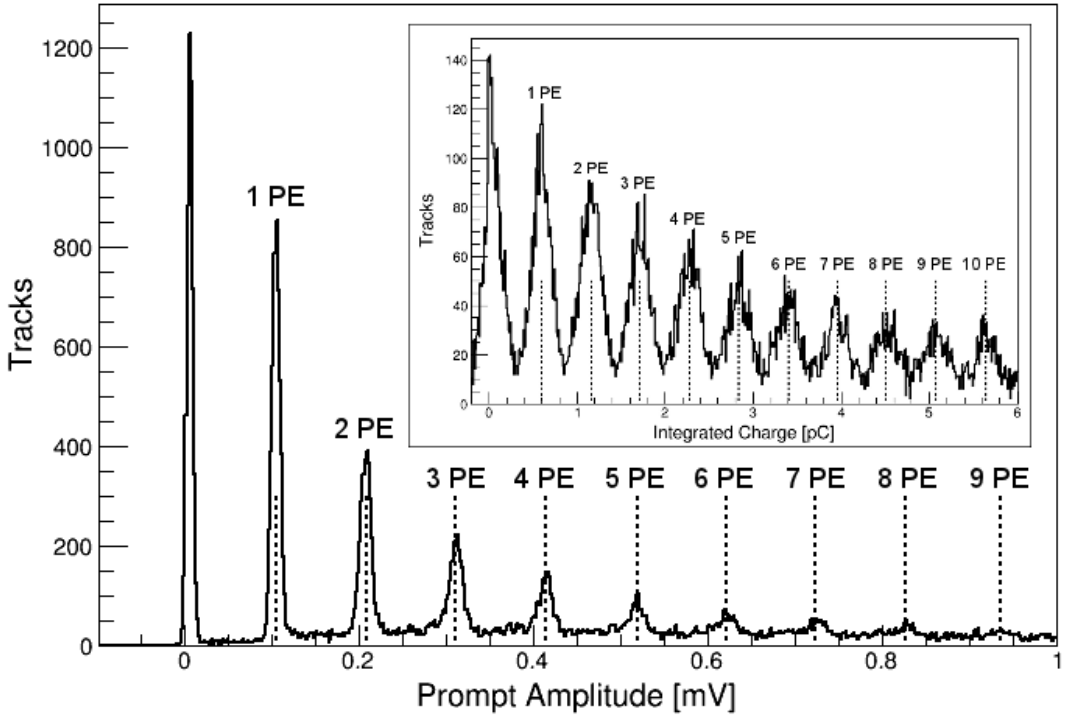


Example Single-PE Waveform

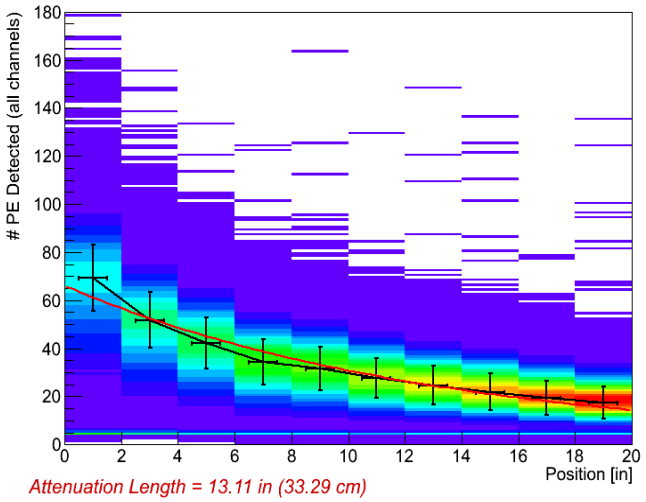


- Appealing features at 87 K
  - Quantized, discrete signals
  - High gain (~3x10^6) + low noise

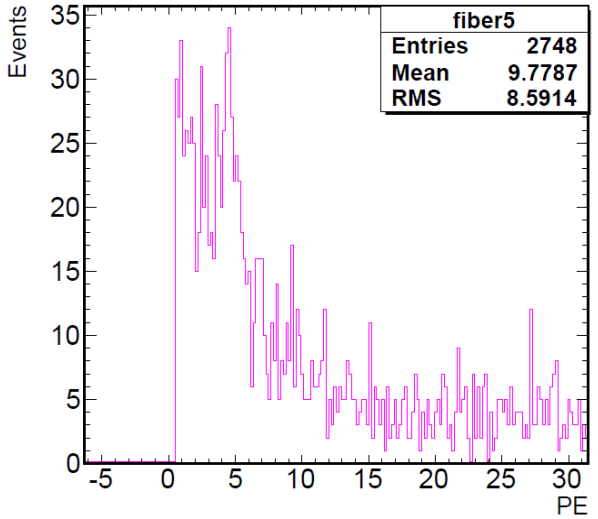




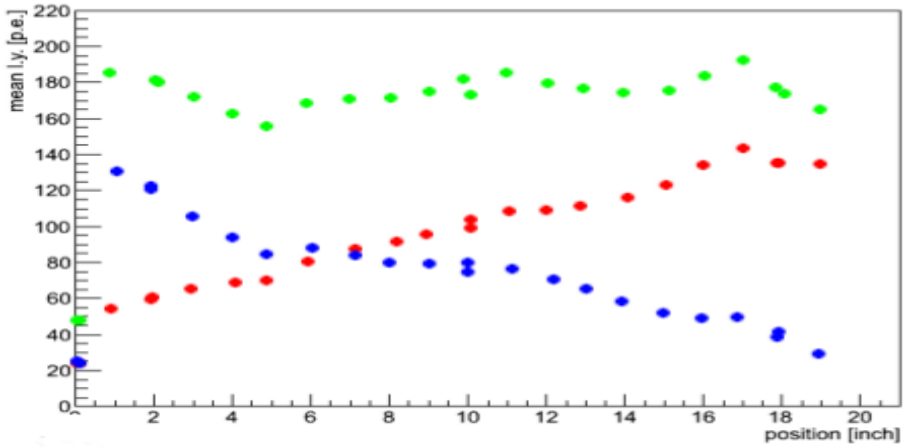
- Tests are ongoing in open dewars at various institutes
  - Alpha sources and cosmic rays
- Attenuation studies with alpha sources indicated the need for shorter modules (IU 2013)
- Testing of the LSU plate design at CSU shows promise for double-ended readout (LSU, CSU 2014)



Attenuation in a bar measured at IU using an alpha source.



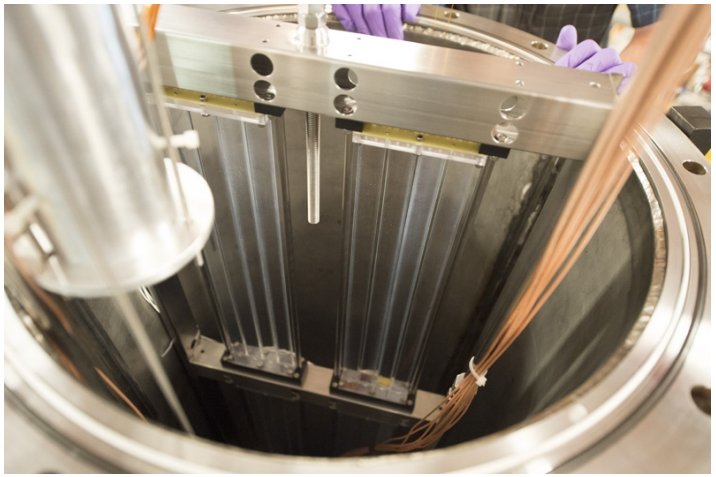
LAr scintillation from cosmic rays detected at CSU using 4 of 32 TPB-doped polystyrene fibers.

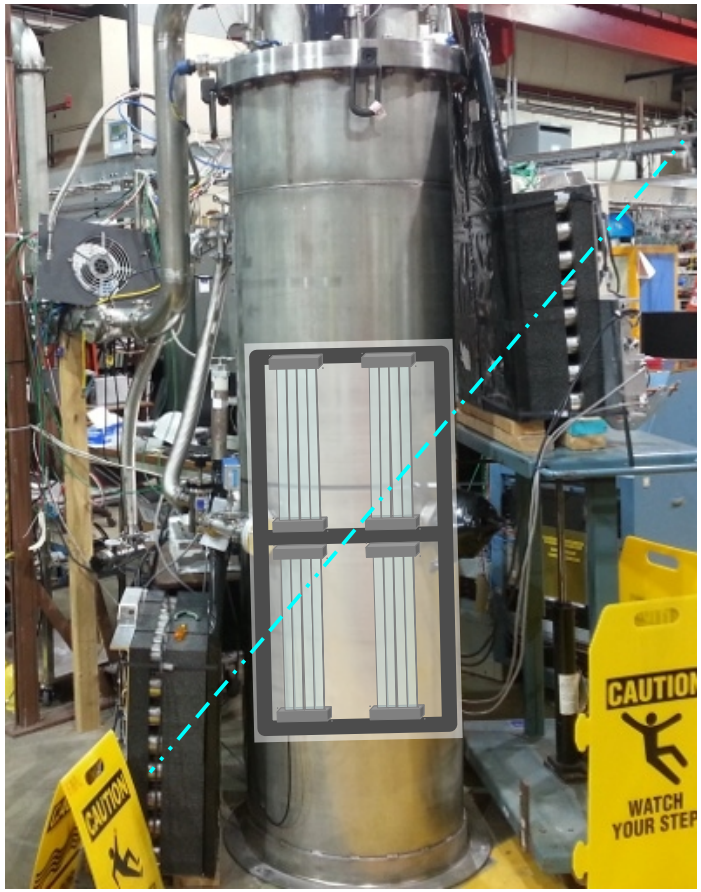


Readout of signals from an alpha source by the LSU paddle module, performed at CSU. Combining signals from both ends compensates for attenuation in the fiber.

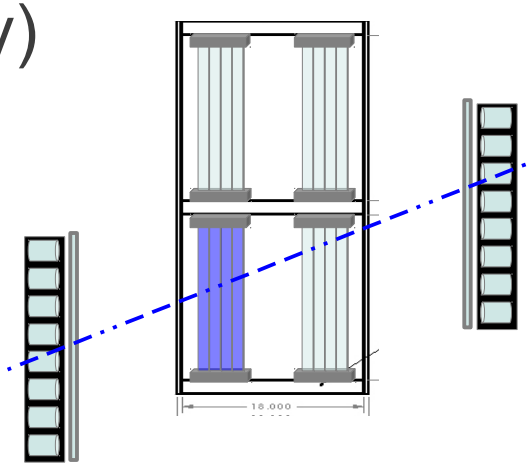
Design Testing at TallBo

- TallBo Facility at FNAL (PAB)
  - 84”-tall Liquid argon dewar
    - Ultra-high purity Liquid Argon
    - Condenser to maintain level
  - Visited Oct. 2013 & March 2014
- Primary Goals
  - Compare lightguide designs
    - Flash-Heated Spray-Coated Acrylic Bars (IU)
    - Dip-Coated Acrylic Bars (MIT)
    - Doped Polystyrene Fibers (CSU)
    - Cast Acrylic (IU) & Polystyrene (LBNL) Bars
  - Deploy and test prototype readout (SSP)
  - Characterize late light signal from muons
- Two operating modes
  - Hodoscope (cosmic ray) trigger
    - CREST cosmic-ray balloon exp't.
      - 2 8x8 Arrays of PMTs + BaF crystals
    - Scintillator paddles for gamma rejection
    - Provides shower rejection
    - Allows track selection & reconstruction
  - Free run (self-triggered)

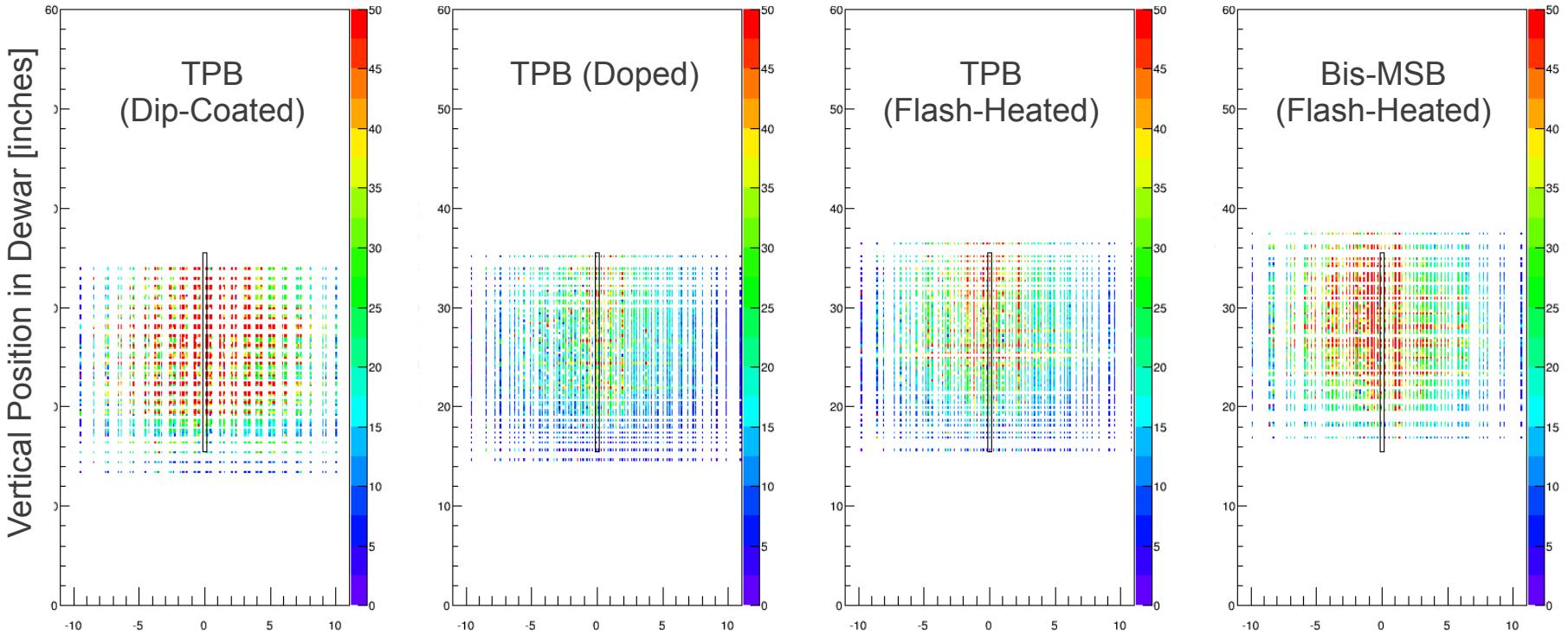




- Four-fold coincidence (single hit on each array)
  - Good comparison of response of each bar
    - Cross-module comparisons difficult
  - Identify non-uniformities & asymmetries
  - Select and study response to single-track events
  - Working to extract photon detection efficiency and attenuation properties

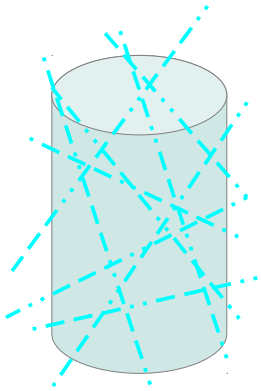


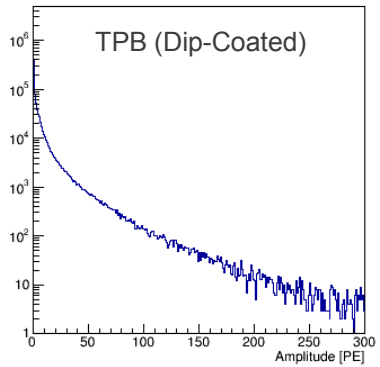
Average Light Collected per Track vs Position of Closest Approach to Bar

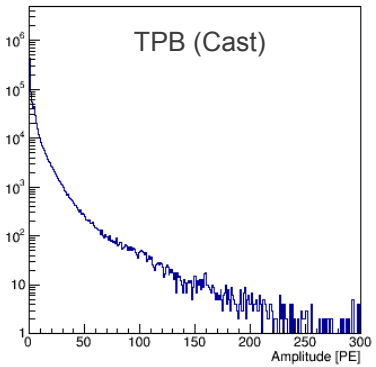


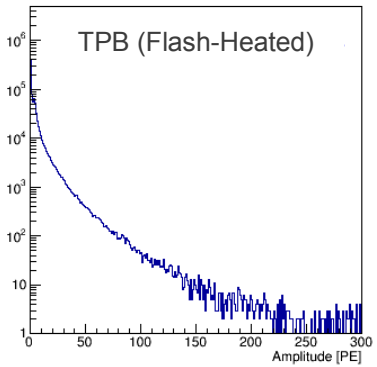
CAEN DT5740 Digitizer
+ Shaper/Amplifier (Nevis Labs)

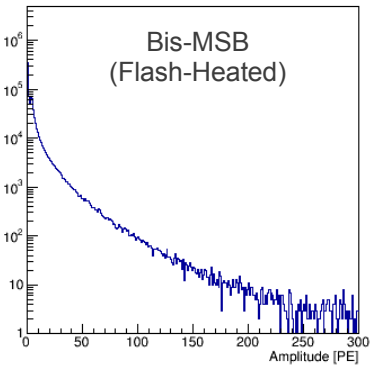
- Self-triggered readout
  - Consider distribution and rate of light collected by each bar
  - Uniform exposure of PD modules to light from all cosmics through dewar
  - Direct comparisons between all bars (agrees with hodoscope)





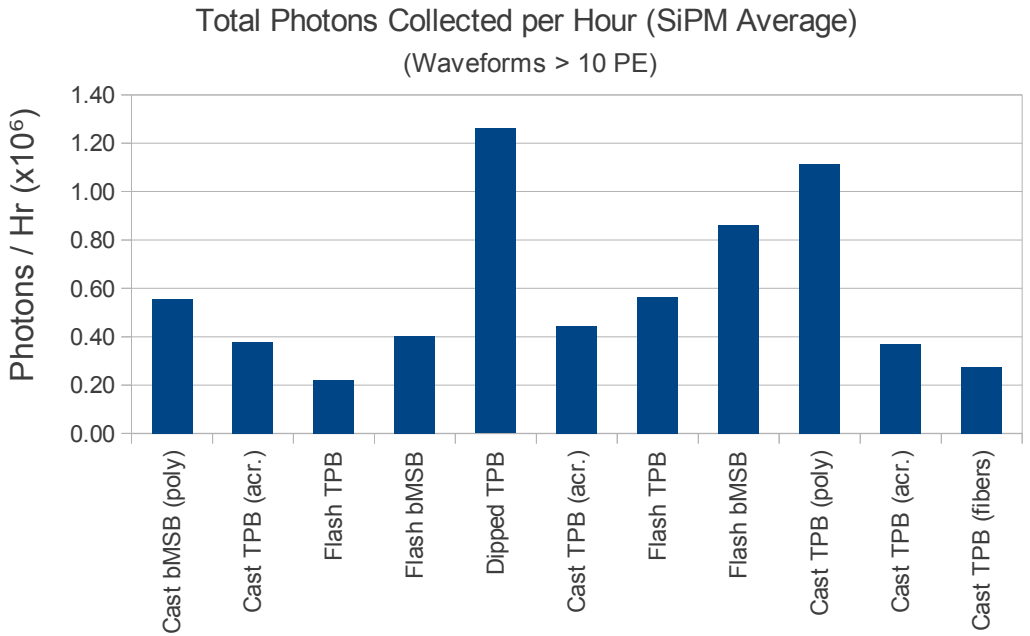




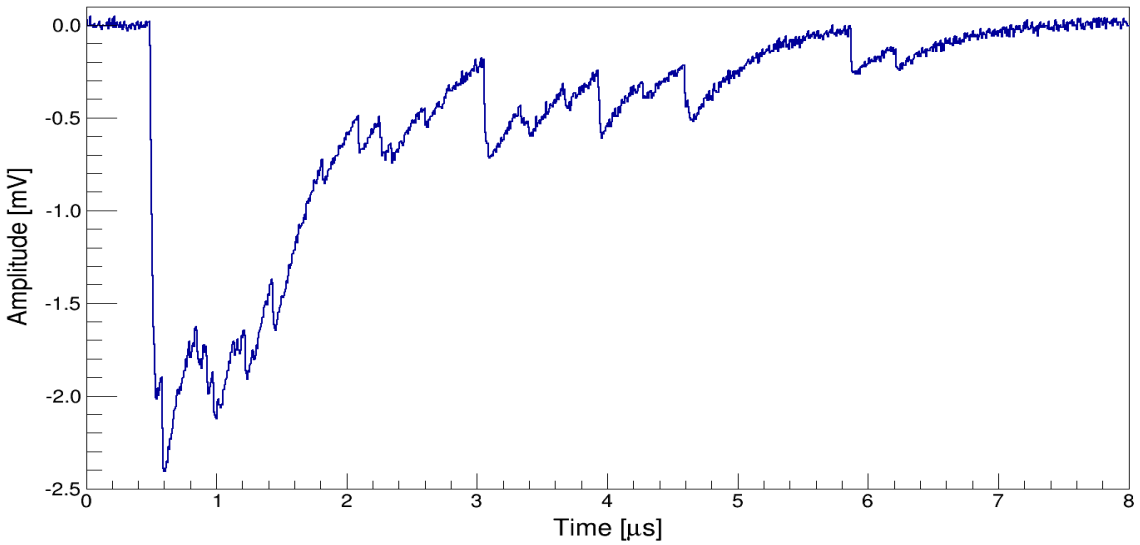


  - (Small correction for effects from cylindrical geometry)

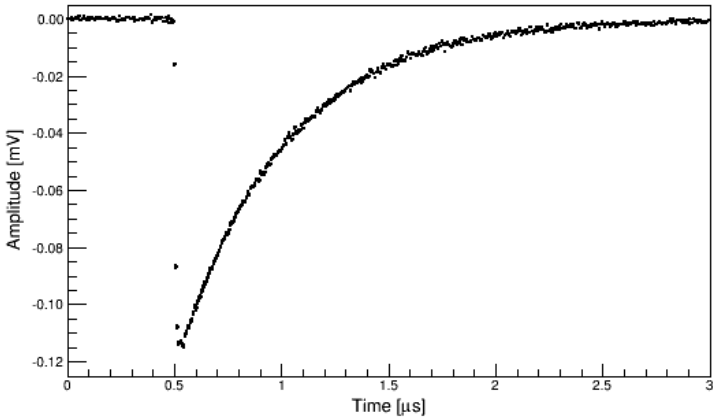
- Most promising (brightest!)
  - Acrylic dip-coated with TPB
  - Polystyrene cast with TPB
    - Possible self-scintillation detected using hodoscope-triggered tracks
  - Flash-heated bis-MSB
    - Lower-cost waveshifter



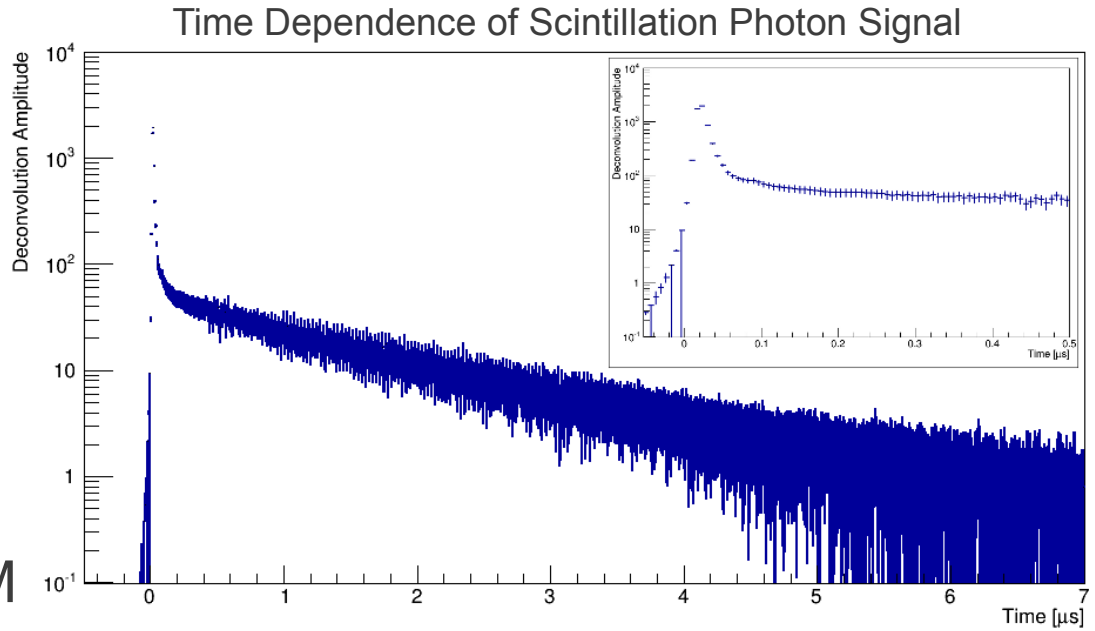
- Example waveform from cosmic-ray muon
  - Bright prompt signal
  - Single-PE pulses from long-lifetime component



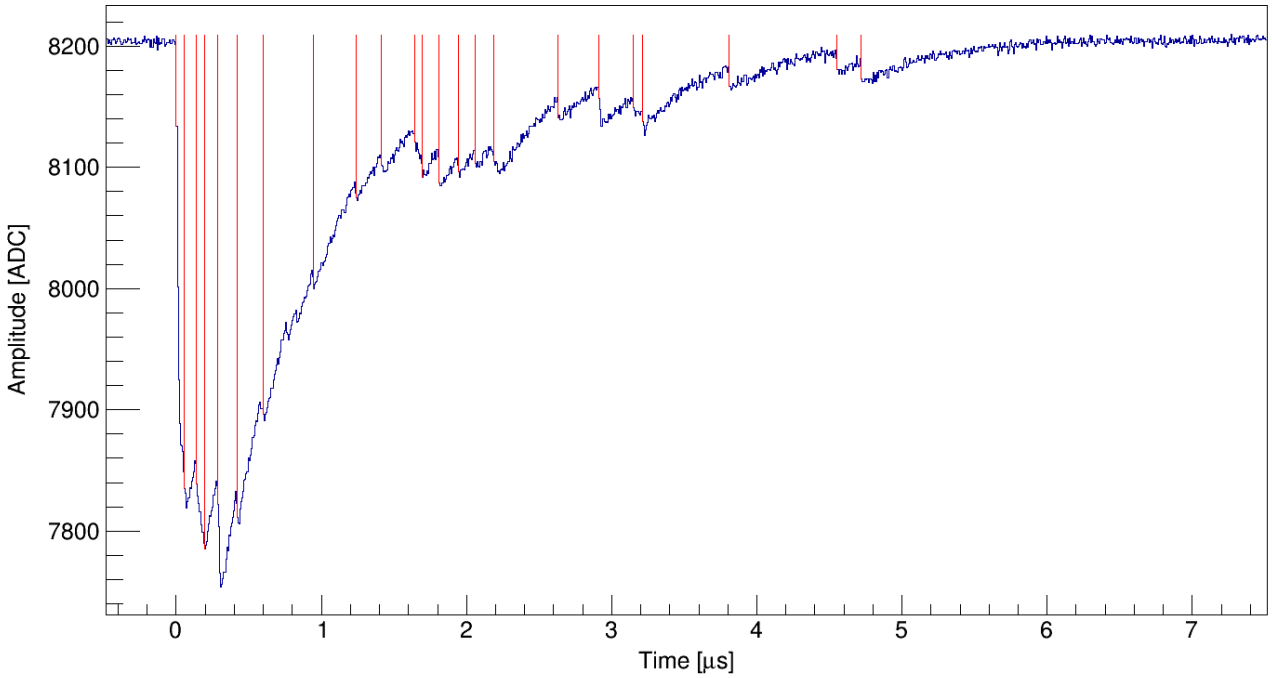
- Average single-PE response of SiPM
  - Sharp rising edge, but ~500 ns tail



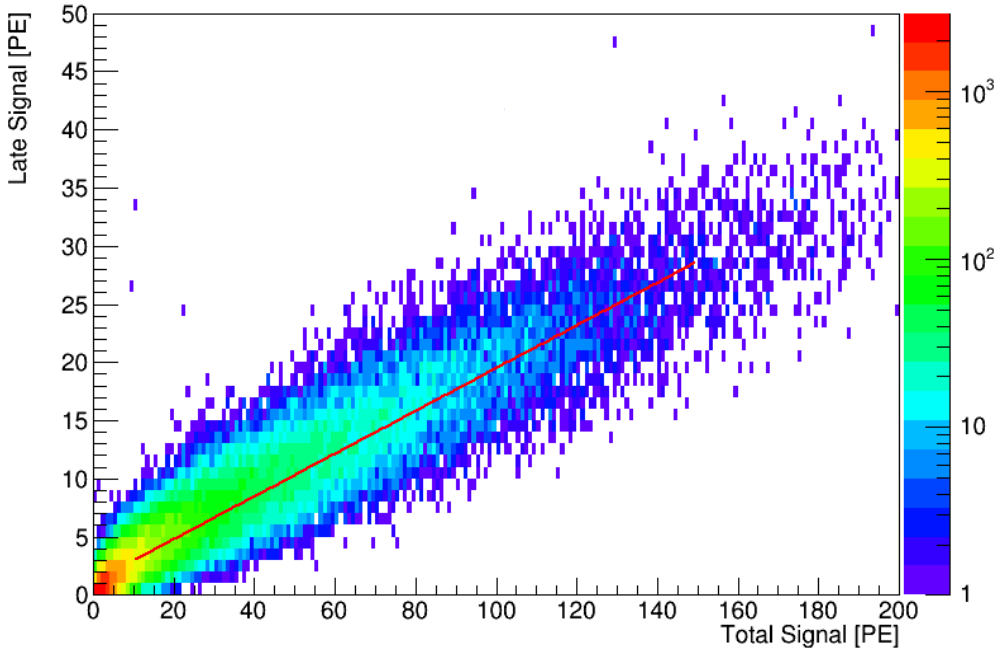
- Deconvolution of average waveform from cosmic rays
  - Time structure of signal at SiPM
    - analysis forthcoming



- Single-PE resolution o SiPM promising for fast digital signal processing
  - Simple threshold-tag algorithm could identify single PE arrival times (leading edges)
    - Possible future firmwa implementation

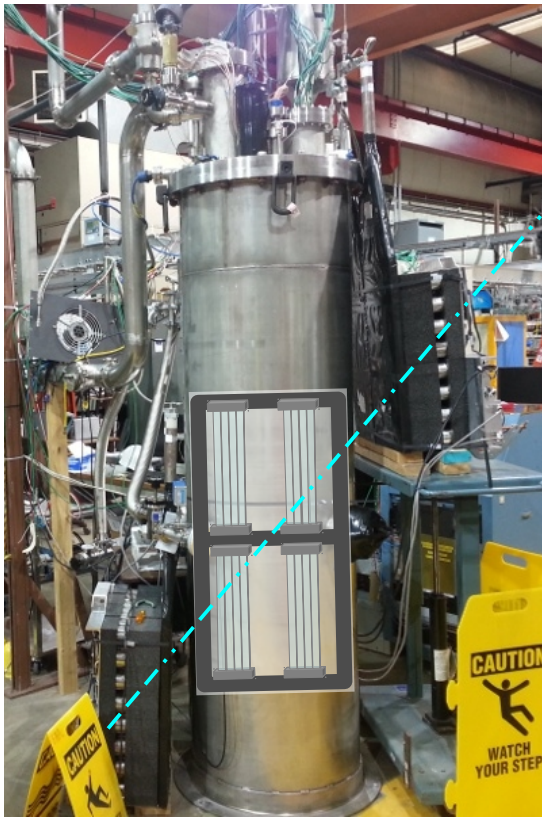


- Potential for event-by-event pulse-shape discrimination
  - For example, count number of photons in waveform tail
    - (here, between 1.5 – 5.5 µs)



Promising Outlook for Large-Volume LAr Photon Detection

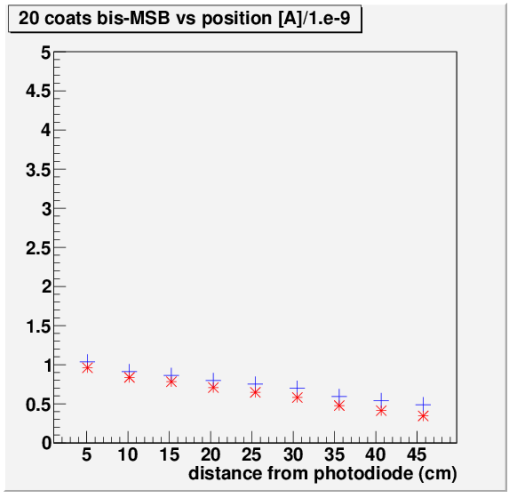
- Exploring and *converging* on detector designs
  - Effectively *evaluating* and *comparing* designs
  - Identifying and improving promising technologies
  - SiPMs exhibit many appealing features
- *Scintillation signal* provides valuable info
  - Timing for TPC
  - Potential for *particle identification*
- More exploration on the horizon
  - 35-ton Phase 2 LAr cryostat (FNAL, beginning of 2015)
  - 500-L dewar at CDDF (CSU, operating summer 2014)
  - Continuing operations at TallBo (FNAL, fall 2014)
  - Continuing work at local dewar facilities
- *Lots of effort from many folks in many groups*
  - Indiana U.
    - Stuart Mufson, Jim Musser, Mark Gebhard, Brice Adams, Mike Lang, Brian Baugh, Paul Smith, Brian Baptista, Bryan Martin, John Urheim, Jonathon Lowery, Bruce Howard
  - MIT
    - Janet Conrad, Matt Toups, Ben Jones, Len Bugel
  - Colorado State U.
    - Norm Buchanan, Dave Warner, Ryan Wasserman, Dylan Adams, Jay Jablonski, Tom Cummings, Forrest Craft, Andrea Shacklock
  - LBNL – Victor Gehman, Richard Kadel
  - Louisiana State U. – Thomas Kutter
  - Argonne Natl. Lab
    - Gary Drake, Patrick De Lurgio, Andrew Kreps, Michael Oberling, John T. Anderson, Zelimir Djurcic, Himansu Sahoo, Victor Guarino
  - Fermilab
    - Brian Rebel, Stephen Pordes, Marvin Johnson, Ron Davis, Bill Miner



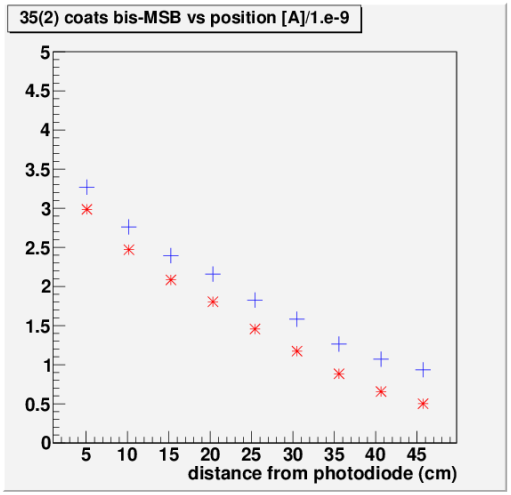
Backup

- Move 245-nm LED along bar (IU & MIT)
  - Read propagated light at end of bar
  - Measure response of bar versus position
    - Need fast quality control system at room temperature
    - UV LED to activate waveshifter
- Characterized degradation vs exposure to unfiltered/filtered fluorescent lights
  - bis-MSB definitely degraded by fluorescent spectrum
  - Both TPB and bis-MSB utterly destroyed by sunlight

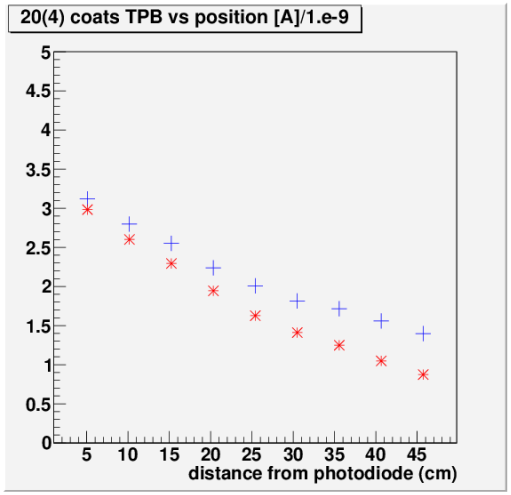
20 Coats bis-MSB



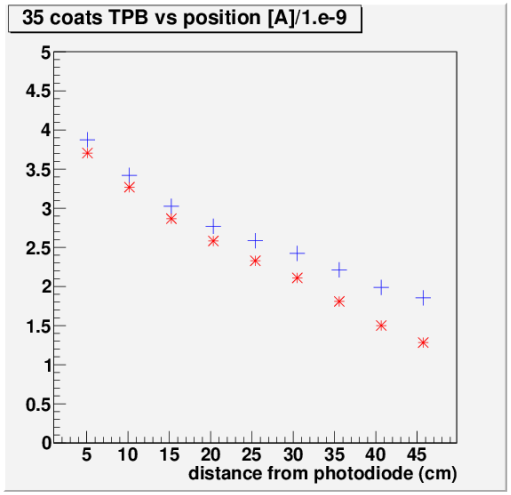
35 Coats bis-MSB



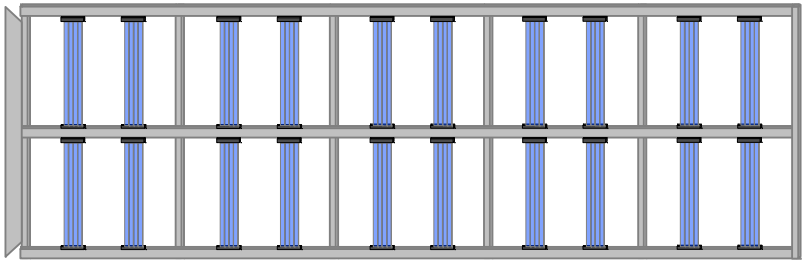
20 Coats TPB



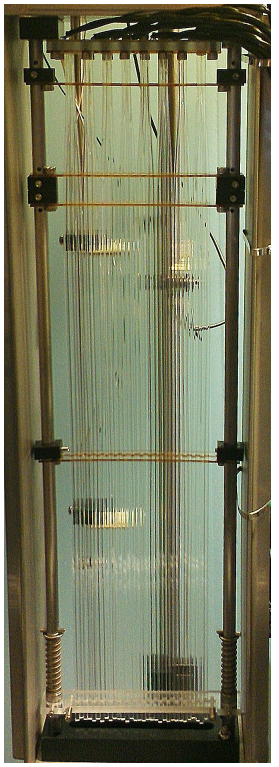
35 Coats TPB



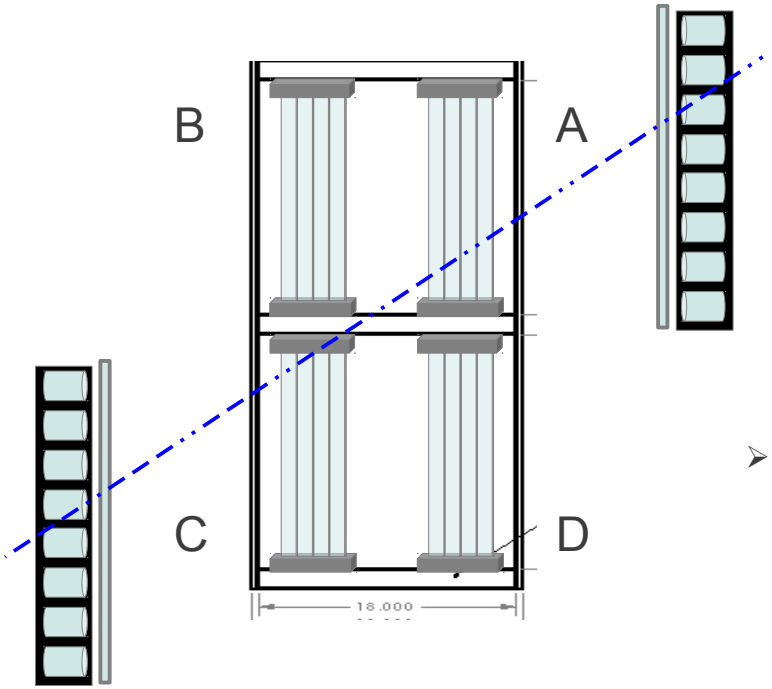
- Goal: Large photosensitive area yet small photocathode area
  - Combine lightguides into ~4-inch x ~1 meter (20-inch) paddles
    - Read out internally-reflected 430-nm light with array of SiPMs
  - Example: 1-meter PD paddles inside LBNE Far Detector anode plane assembly



- Various lightguide technologies under investigation
  - Acrylic bars with surface coat of waveshifter (TPB or bis-MSB)
  - Acrylic / polystyrene bars doped with waveshifter (TPB or bis-MSB)
  - Polystyrene fibers doped with TPB (4 per SiPM)
  - Wide acrylic paddle with surface coat of waveshifter and imbedded secondary WLS fiber (Y11)

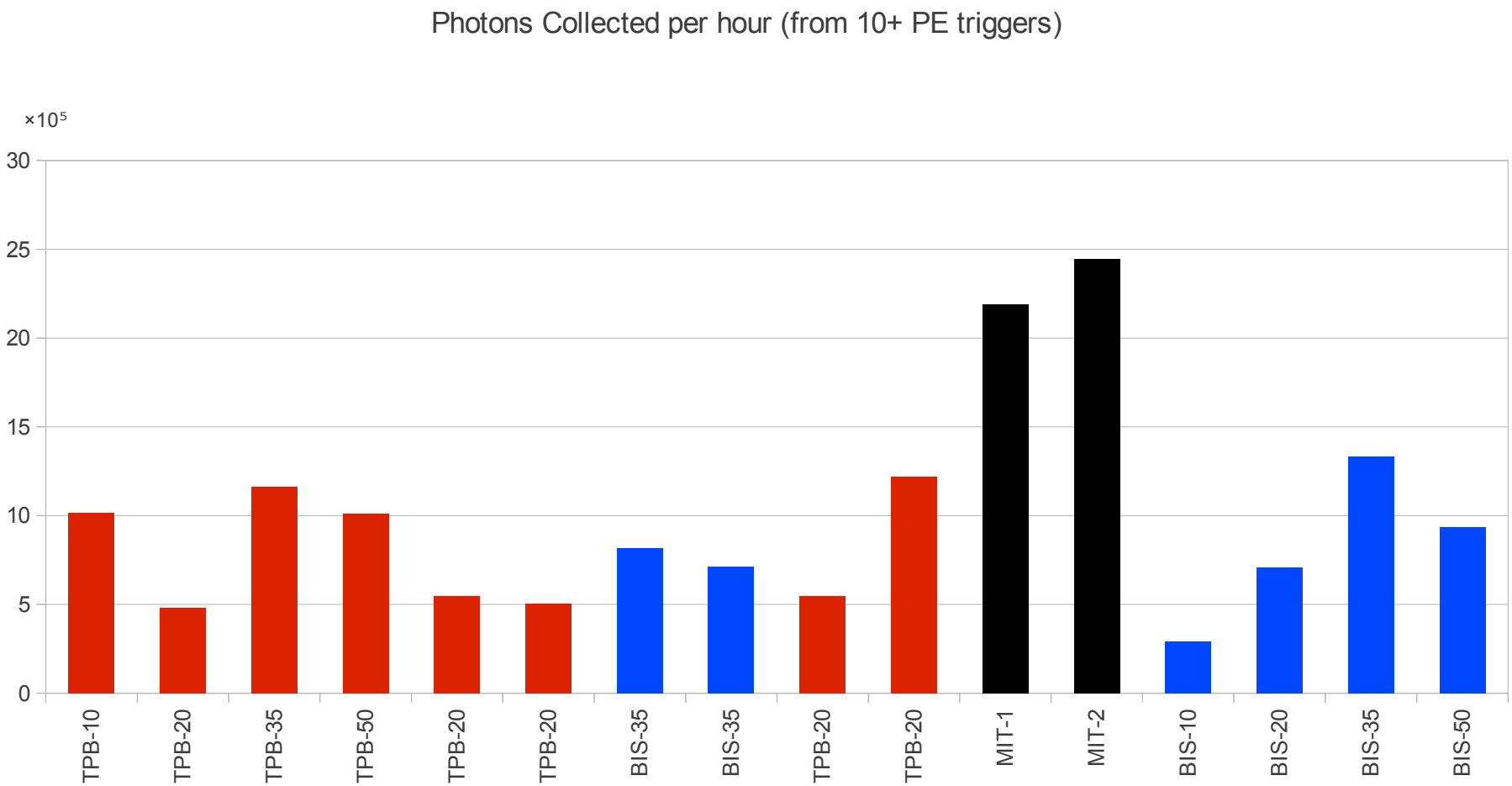


- Two 8x8 Arrays of PMTs from CREST balloon-based cosmic ray experiment
  - Barium-fluoride crystals with TPB coating
  - Positioned on opposite sides of dewar (one elevated 48” or 34”)
- Plastic scintillator paddles
  - Gamma (Compton, etc.) veto
    - BaF_2 crystals sensitive to x-rays



- Four-fold coincidence trigger
  - Shower vs single particle discrimination
  - Track selection & reconstruction

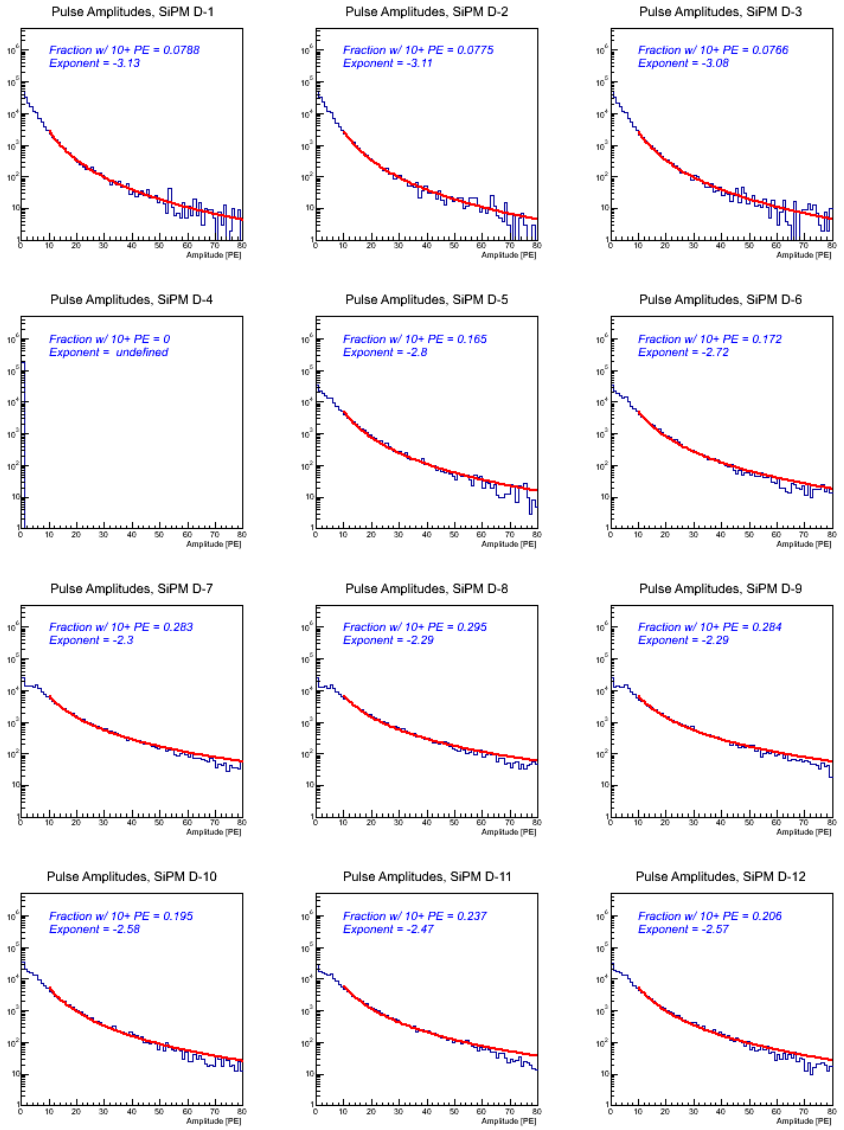
- Total number of photons collected per hour by each bar
  - Averaged over functional SiPMs



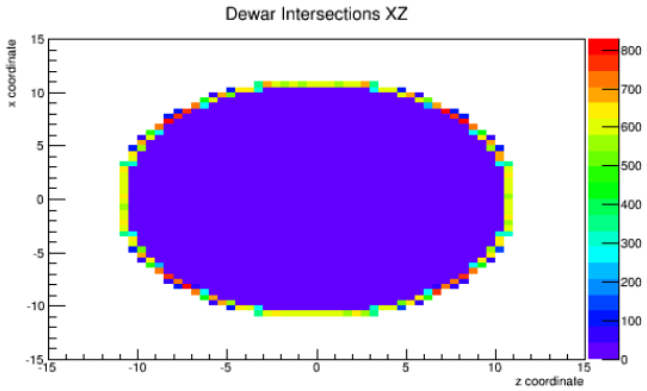
- 35 coats looks best for both TPB & bis-MSB
- Hand-painted bars most efficient (but not a scalable method)

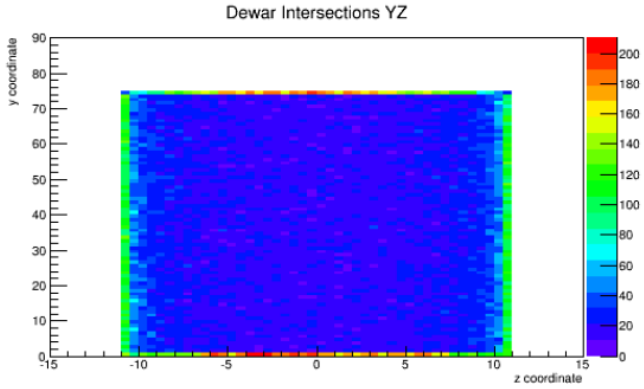
Light Yield Comparisons from October 2013 (Free Run)

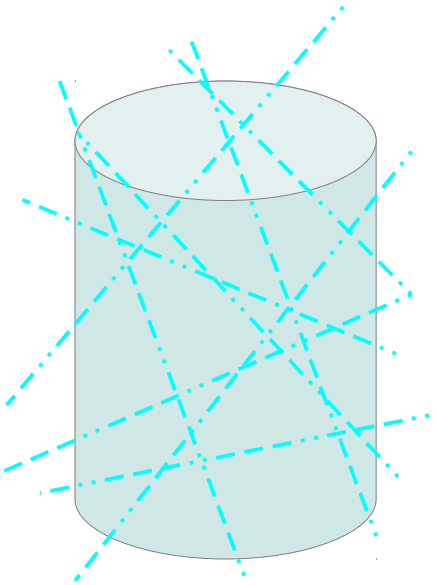
- "Free run" mode (self-triggered, OR of all SiPMs in a paddle)
  - Light from all cosmics through dewar
  - Look at distribution of calibrated signal amplitudes on each SiPM
- Each bar receives approximately the same light exposure
  - Studied with toy MC
- Look for relative differences in light yield distributions
  - Total number of photons collected per hour
  - Shape of power-law fit to distribution
    - Longer tail indicates better efficiency



- Simulate light from cosmics through LAr volume
  - Jonathon Lowery (IU)
  - Throw cosmic ray, throw photons along track, see how much hits each bar along length







- Scintillation exposure versus position along bar
  - All bars receive approximately the same number of photons along length
  - Minimal variation between bars in different paddles
  - Confident this is a good metric