

Displaced vertex trigger hodoscopes

- Hardware delivered this year:
 - ▶ Hodoscope boxes and prototypes
 - ▶ Readout and calibration systems
 - ▶ Power supply system
 - ▶ FPGA trigger
- Installed and commissioned at Fermilab, and recorded physics data

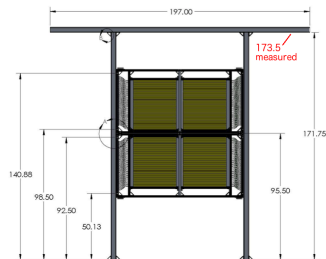
Detector design

- Extruded scintillator bars detect charged particles, wavelength-shifting fibers collect light and transport it to the SiPMs
- Station 1: four boxes, 80 1-cm bars each
- Station 2: four boxes, 50 2-cm bars each



Mechanical structure

- Frame modified to minimize material in the detector acceptance (decision made and design sketched 2017-03-02, work complete mid-March)
- Survey monuments for reproducible positioning (done at some point late April/early May)
- Boxes are light-tight with patch panels for signals and voltages, ventilation flanges for air cooling (if necessary)
- Quadrants are bolted together using 80-20 hardware, then bolted to I-beams (rough plan done 2017-01-18, beams arrived mid-April, plan tweaked lots leading up to installation)



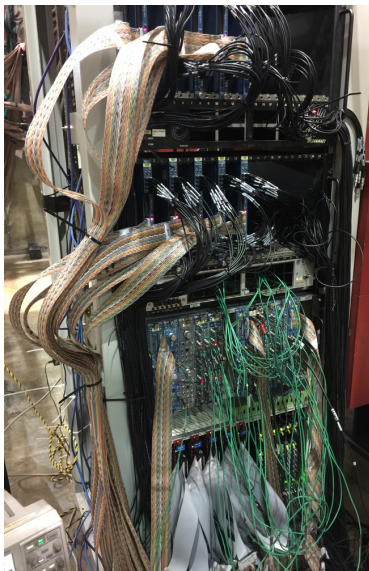
Readout electronics: preamps

- “Postage stamp” x10 preamp design contributed by Fermilab, with modification to the pulse shaper (preamp design tested and output cap changed 2016-10-07, released for full production after B-field test below, production complete 2017-02-13)
- Benchtop tests confirm gain degradation in magnetic field is acceptable (tested 2017-01-18)
- SiPMs and preamps are mounted on “preamp plate” (foamcore mockup 2016-12-20, 7-bar mockup mid-Feb., machined plates complete mid-March)
- All components electrically isolated from plate to avoid noise pickup (mounting of SiPMs and preamps to preamp plates started early March, done mid-March)
- Twisted-pair pigtail connects SiPM to preamp (prototyping and testing started Jan., done mid-Feb., production started 2017-03-02, done mid-March)



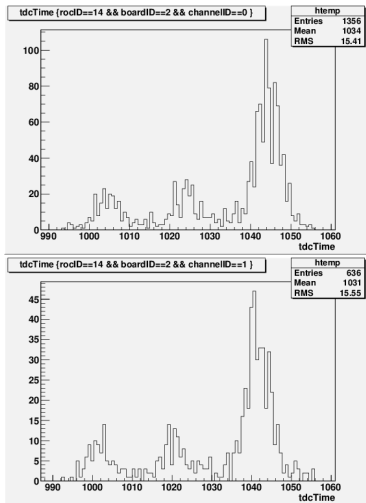
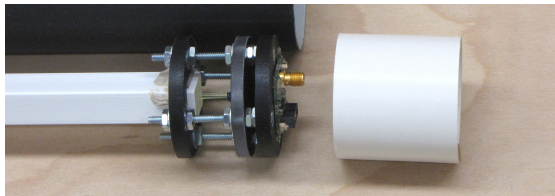
Readout electronics: cabling

- Short coaxial cables connect preamp outputs to patch panel
- Long coaxial cables connect patch panel to CAMAC discriminators (ordered early April after finalizing rack layout, 1/4 order arrived late April, full order arrived late May)
- Ribbon cables connect discriminators to trigger boards and TDCs (ribbons and short coax cables connected+laced late March, this was the last thing done before shipping)



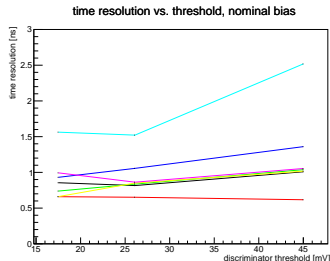
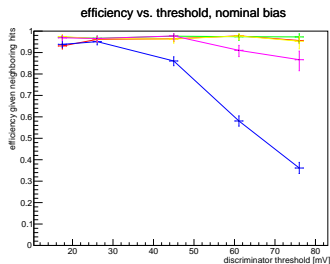
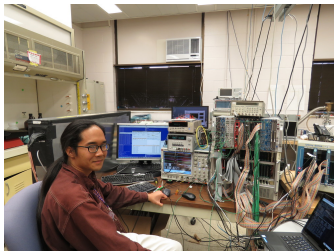
Single-bar beam test

- Single-bar test units: 1-cm and 2-cm units built and tested on the beam at SeaQuest in March (built last week of Feb., data seen 2017-03-10)
- Plots on right (2-cm on top, 1-cm on bottom) show hit times relative to E906 Drell-Yan trigger
 - ▶ Small peaks are random particles from other beam buckets, big peak is in time with the trigger
- Proved the system works with real beam, in the real environment



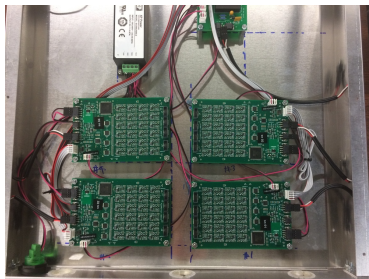
Seven-bar cosmic test

- Instrumented the first seven bars of a St-2 hodoscope box, take data with a test setup of the E906 DAQ (DAQ setup started late January, 7-bar test started mid-Feb., done 2017-02-22)
- Understand efficiency and time resolution as a function of threshold, debug light collection issues, test different options for the long coaxial cables (efficiency/threshold studies done by end of Feb., coax cable tests started and done sometime mid-March)



Power supply

- SiPMs need individually controllable bias voltages (520 channels!); preamps need 6V
- SiPM bias board design contributed by Fermilab, modified to match our requirements (first communication with Sergey/dcc 2016-10-21, forgot about it, picked up 2017-01-23, design work started 2017-01-31, board ordered 2017-03-07, arrived 2017-03-30)
 - ▶ Each board takes bulk HV and LV supplies, regulates down 24 bias voltages and a single 6V supply
 - ▶ Voltage and current readbacks for all channels, plus temperature readout
- 24 “power boards” total, housed in 6 “power boxes” (boxes machined late March, loaded and cabled April-May)



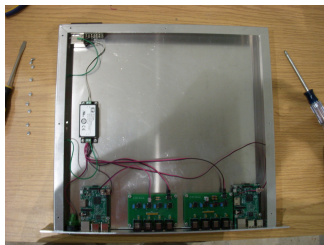
Power supply: distribution

- “Distribution board” passes bias and 6V into the box (design started late Jan., boards ordered 2017-02-13, loaded by shop, done 2017-03-24)



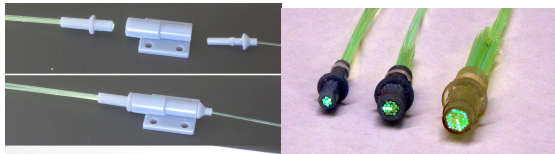
Power supply: control

- Power boards are controlled using I2C protocol; we developed a system to control all 24 boards from a pair of Raspberry Pi computers (mux and master boards designed late Feb., ordered 2017-03-06, arrived 2017-03-16, tested same day, done late March)
 - ▶ “Mux board” in each power box contains an I2C switch and an I2C buffer to drive a long Ethernet cable
 - ▶ Cables run to “master boards” with corresponding buffers; single “master box” holds Pis and master boards
- This solution keeps sensitive electronics away from the beam, and simplifies control software
- I2C is widely used and this scheme can be used to network any set of boards with I2C control



Calibration system

- LED calibration system tests/monitors function of all channels
- LED pulser boards generate narrow light pulses (designed Feb., boards arrived March, done late March)
- 3D-printed fiber couplers fan out a single pulser channel from a commercial connector to 19 bare fibers (I think this work started December, design done end of January)
- Fibers couple light into the scintillator bars



Trigger FPGA development

- Dark photon trigger uses the CAEN V1495 FPGA board (same as E906 trigger)
 - ▶ Four “L1” V1495s, one for each quadrant, trigger on displaced single tracks in St-1, St-2, and E906 hodoscope H4
 - ▶ “L2” trigger is a coincidence between L1 boards with matching vertex Z
 - ▶ Dark photon trigger firmware is based on E906 firmware, with modifications
- Lookup table redesigned for dark photon trigger (Kun+Andi)
- A full quadrant needs $80+50+8=138$ inputs per V1495, E906 firmware only supports 96
 - ▶ Modified various parts of the E906 firmware (TDC, data format, interface to DAQ software) to allow for up to 160 inputs (work started January, done 2017-03-29)

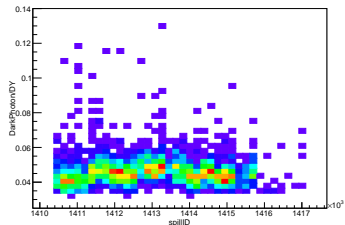
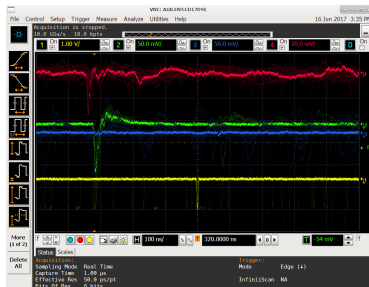
Installation

- Detectors shipped to Fermilab April 3-7
- Installation requires a full-day scheduled downtime: St-2 installed May 15, St-1 installed June 7
- Operational approval granted June 13



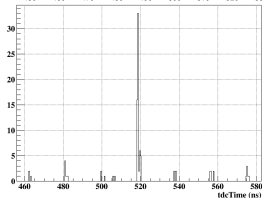
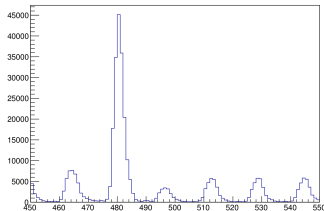
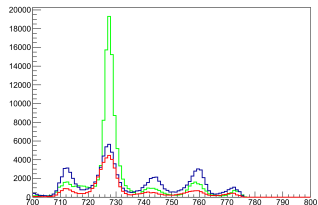
Commissioning

- Coincidences seen June 16 (red: St1, green: St2, yellow: H4)
- Dark photon trigger added to main DAQ June 30
 - ▶ Dark photon trigger rate is $\sim 5\%$ of E906 Drell-Yan trigger: well within bounds for parasitic running, and reasonable agreement with $O(10\%)$ expectation from Monte Carlo



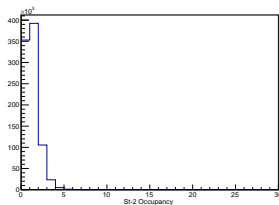
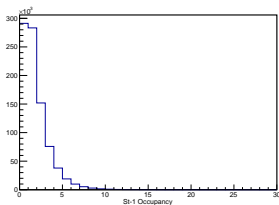
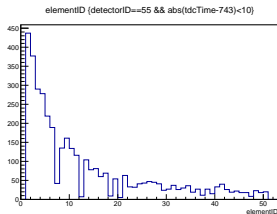
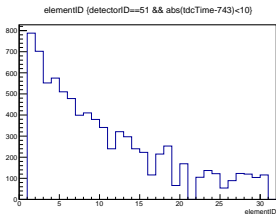
Timing in

- Input delays must be adjusted to compensate for time-of-flight and cable delays
- All quadrant triggers must fire in time with each other, and the final dark photon trigger must have the same latency as the E906 DY trigger
- Top: hit times after delay adjustment (green: St1, blue: St2, red: H4)
- Middle: time distribution of one quadrant's trigger signal
- Bottom: time distribution of final dark photon trigger

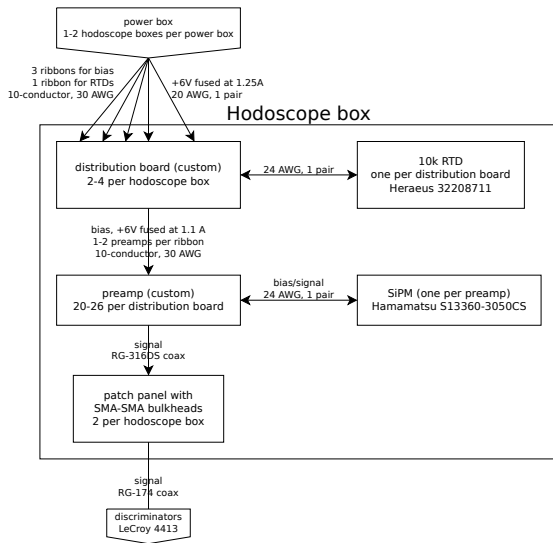


Performance

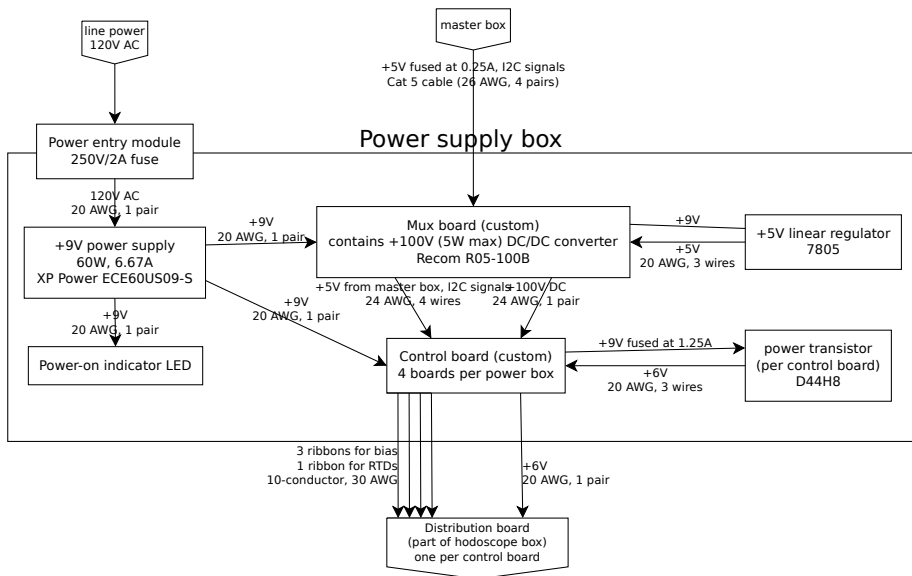
- St-1 on left, St-2 on right; hit rates on top, occupancy on bottom
 - ▶ Note: for commissioning, only 30/80 innermost St-1 bars were read out (outer bars do not correspond to displaced tracks)
- Consistent performance aside from a few bad channels



Backup: hodoscope block diagram



Backup: power box block diagram



Backup: master box block diagram

