MU2E FRONT END BOARDS AS A READOUT / DIGITIZATION SOLUTION FOR DUNE

JOEL MOUSSEAU, STEN HANSEN, MATT TOUPS, RORY FITZPATRICK, JOSHUA SPITZ, CLAIRE SAVARD

UNIVERSITY OF MICHIGAN

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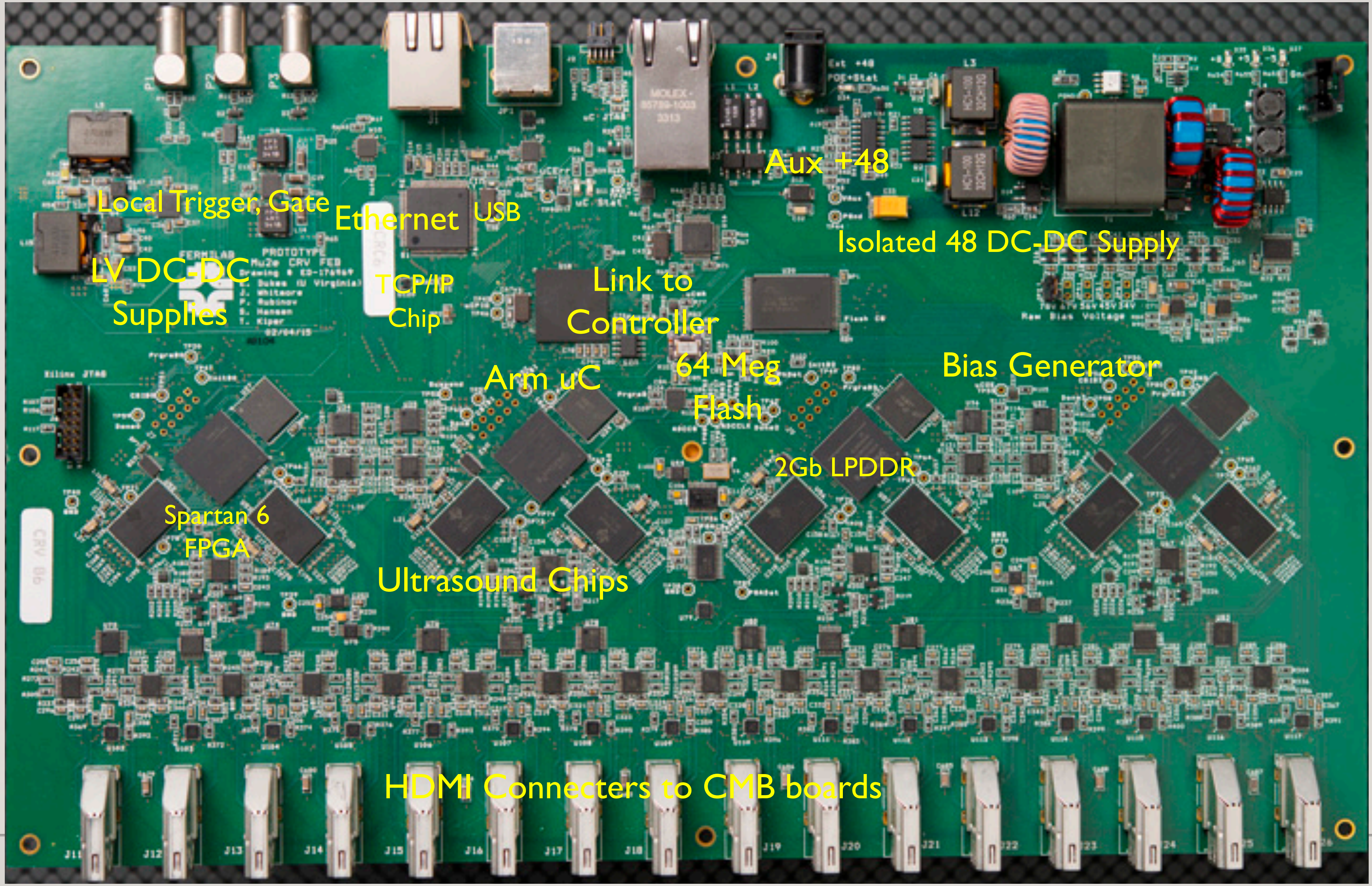
OUTLINE

- Mu2e Front End Boards (FEBs): introduction and specs.
- FEB tests:
  - 6 mm SiPMs (passively ganged in parallel).
  - 6 mm SiPMs (passively ganged in Series).
  - SBND tests
- Future plans (re SBND).
- Applications for DUNE.

MU2E FRONT END BOARDS (FEB)

- Designed for cosmic ray veto shield for Mu2e.
- Core technology: analog to digital converters (ADCs) used in ultrasound transducers.
  - Each chip is 8 channels, 12 bits.
  - 80 M Samples per second sampling rate.
- Low noise, high gain with high dynamic range.
- Centroid fit allows 3 ns timing resolution.
- Chips manufactured by Texas Instruments, mounted on a Mu2e pre-production front end board (FEB) which reads out 64 channels.
- Controlled by 4 FPGAs, and on-board controller. 1 GB of RAM total (250 MB per FPGA).
- Boards controlled by system-level controller, firmware is custom and programmable.

CRV READOUT BOARD



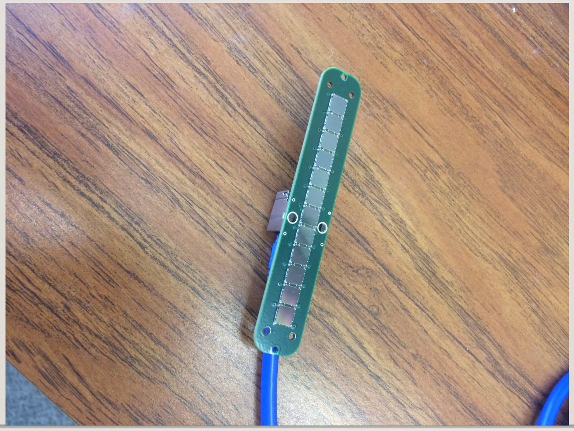
Courtesy Sten Hansen

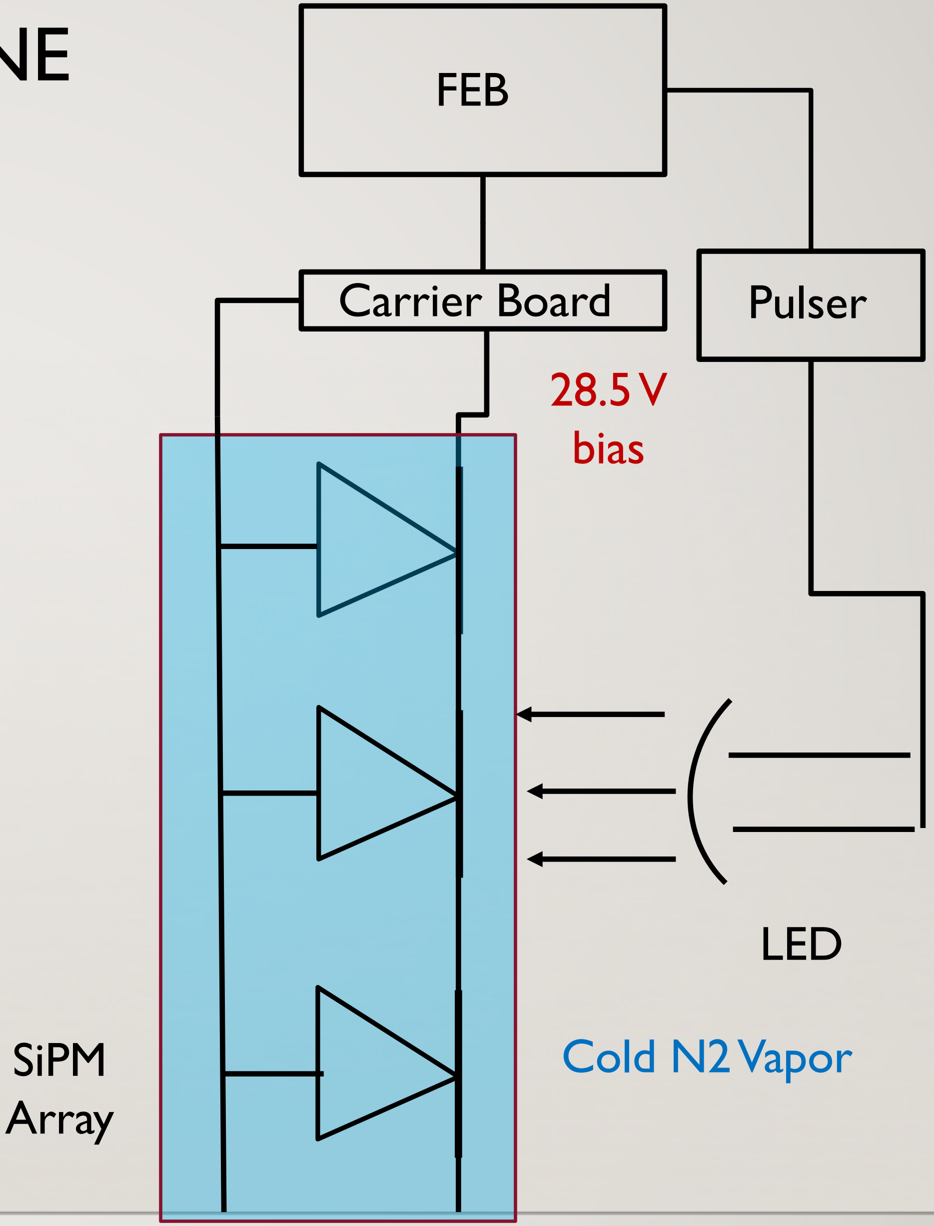
FEB COSTS

- Primary advantage of the Mu2e FEBs from our perspective has been the low cost.
- All components are commercial, ADCs for example are mass produced. Even DUNE would be a tiny order for TI.
- The tradeoff is a tiny hit in performance (which we do not think will be noticeable), and less user customization.
- As a practical example, for SBND we are re-writing all of the FEB and controller firmware, with pulse finding and fitting being preformed as offline-reconstruction.
- But we are estimating costs at $10 – $50 per channel including cables, and carrier boards.

CRV TESTS WITH SIPMS (PROTO-DUNE GANGING)

- Cut one end of a Cat6 cable, untwisted the pairs, and soldered the anode and cathode to solder points on the Mu2e carrier board.
- Tested three different cable lengths, ~ 1 m, 25 m and ~50 m.
- Use an LED flasher to detect multiple PEs.
- Tested multiple cable lengths as well as multiple ganging methods (parallel, series).

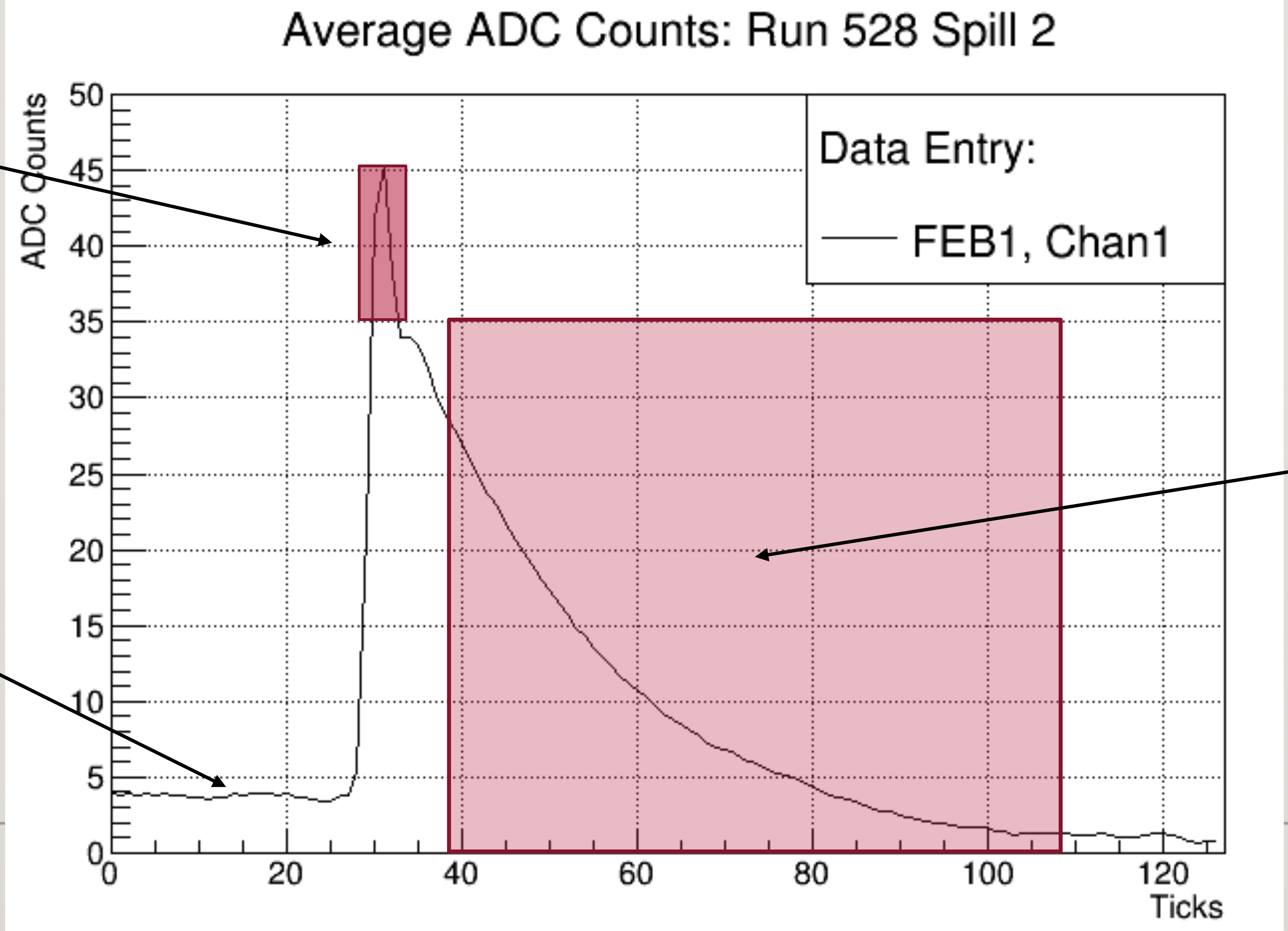




CHARACTERIZING WAVEFORMS

Peak area, proportional to deposited charge

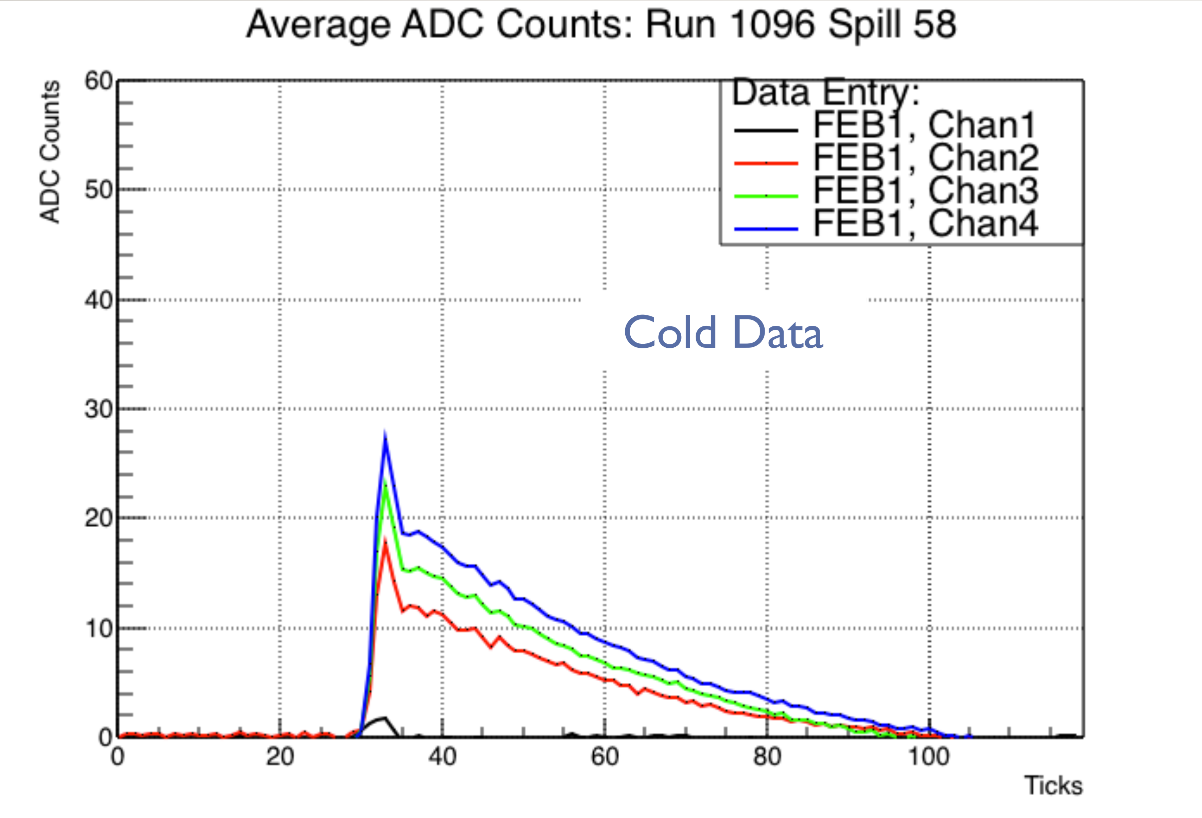
1 Tick is approximately 12 ns



Average waveform example

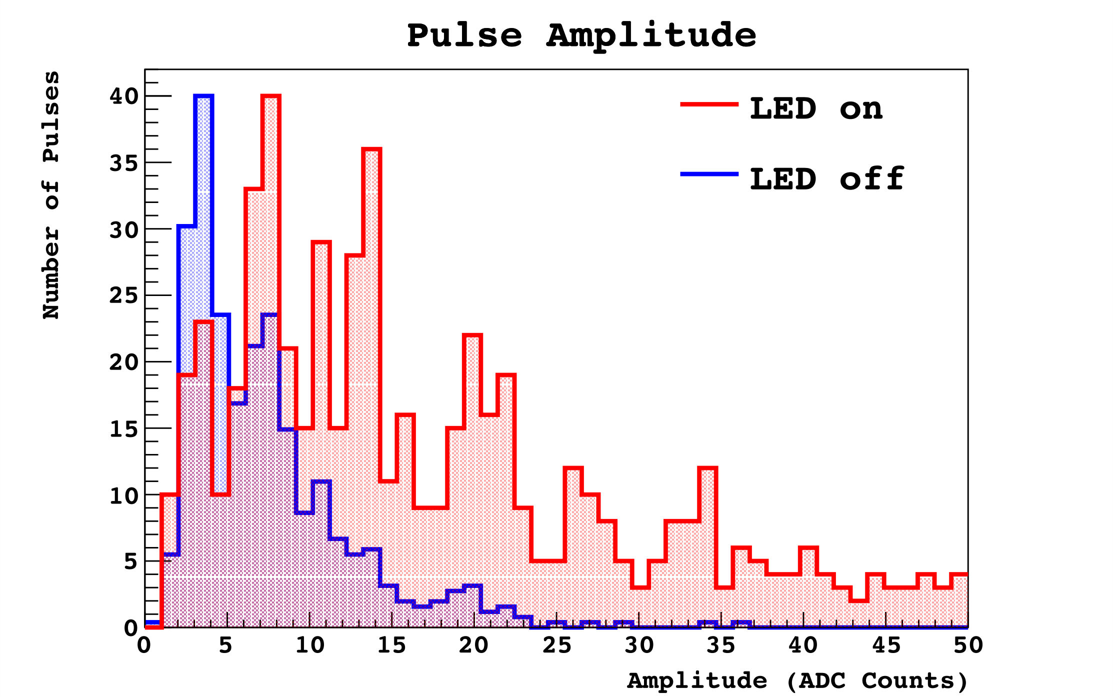
Fall time proportional to SiPM capacitance

PARALLEL GANGING: PROTO-DUNE BOARD



- Average waveform of three different channels on Proto-DUNE board.
- Shielded cable reduces noise.
- Long recovery time of the pulse due to increased capacitance of connecting SiPMs in parallel.

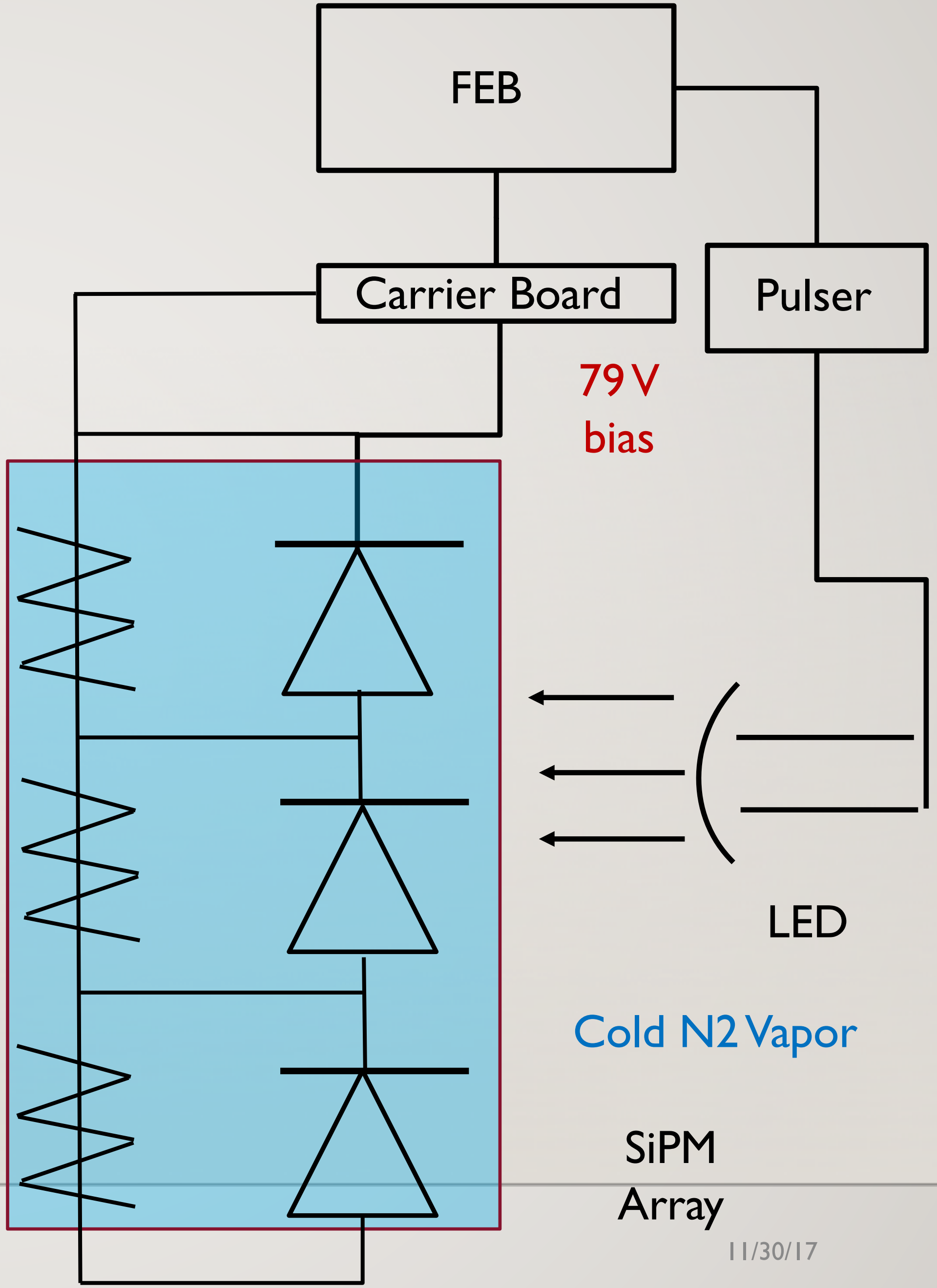
RESULTS WITH PROTO-DUNE BOARD



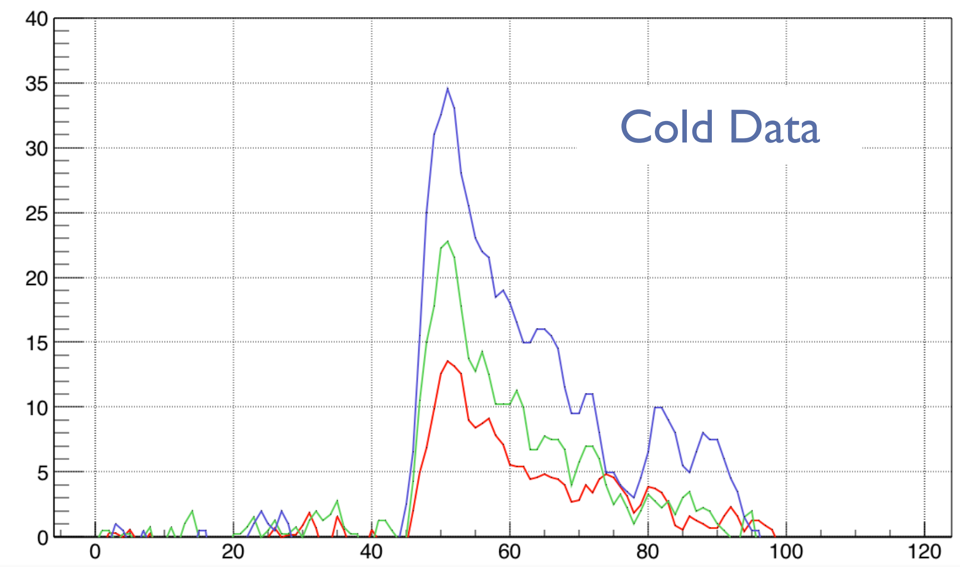
- With no added cable, we are able to make out single PE peaks in pedestal (blue) and LED (red) data.
- This is an early result, and I believe we could get better data now that we know how to tune the LED / FEB settings.
- But it showed us the FEB is roughly capable of what we're looking for.

SERIES CONNECTION TEST

- Connected 3 SiPMs in series, used 500 kOhm resistors as a voltage divider.
- Results in same active area as 3 SiPMs in parallel, only capacitance is reduced by a factor of 9.
- Disadvantage is we needed to increase the bias voltage, we can just barely get 78 – 79 V from the CRV FEB.
- Tested only the long cable (~50 m)

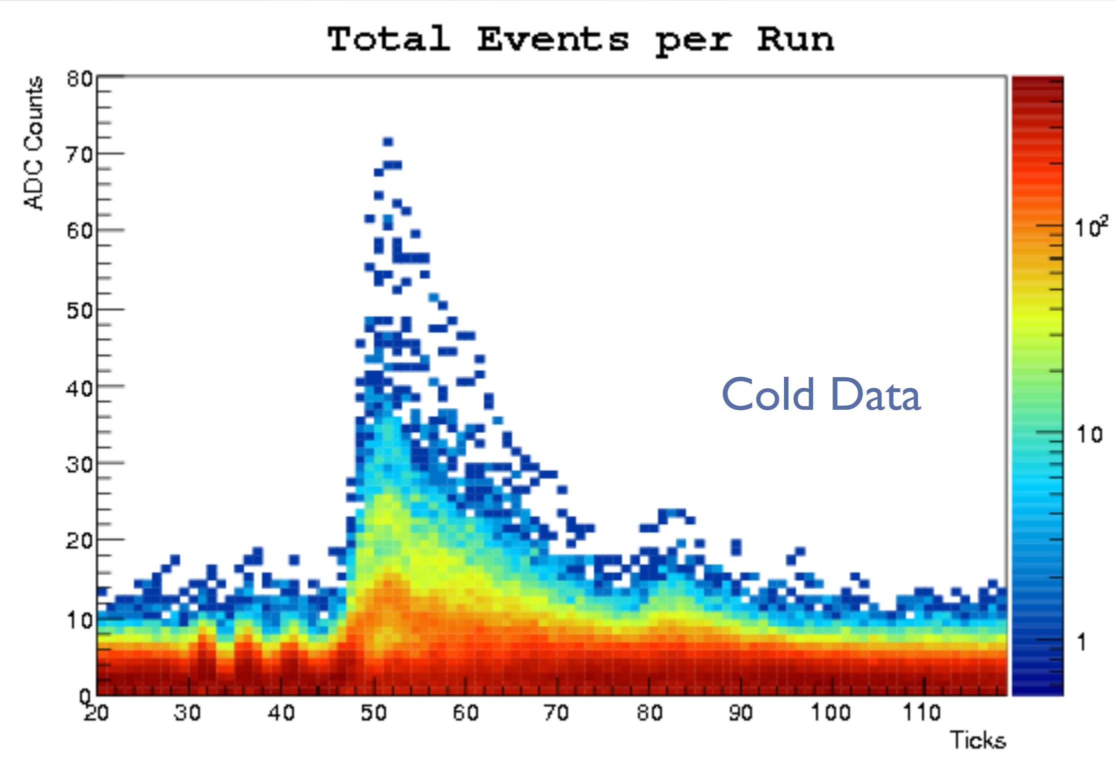


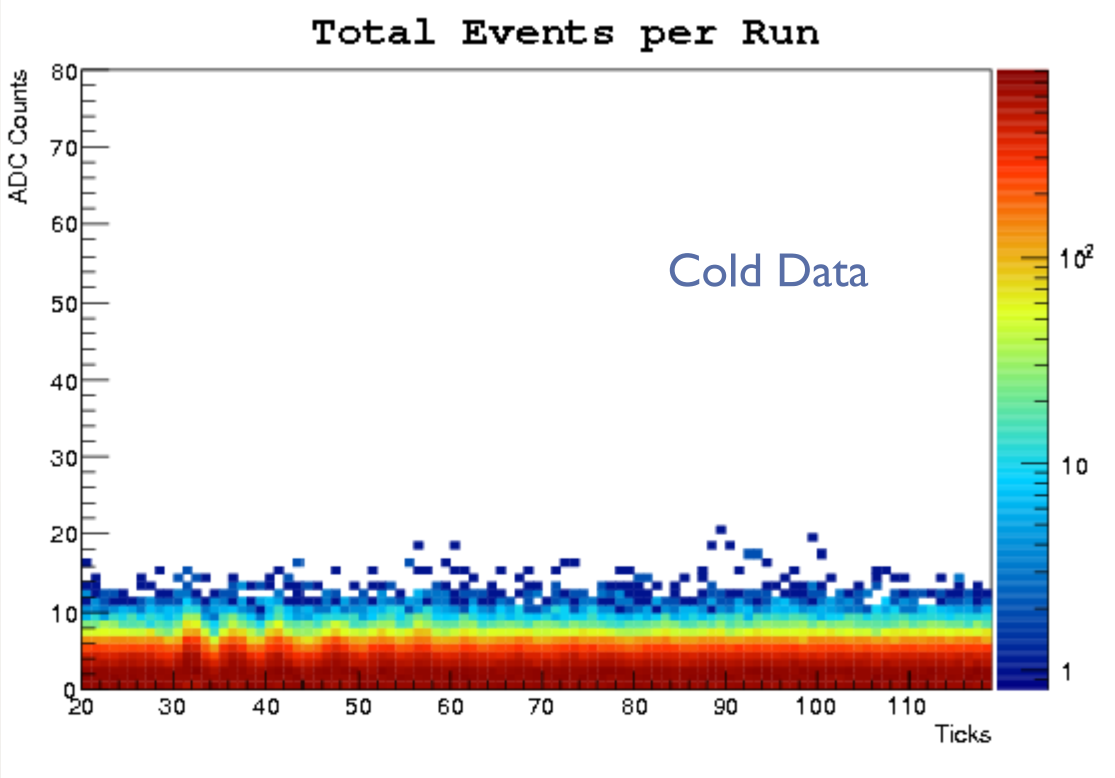
SERIES SIPM TEST



- Reflection almost disappears, pulse length is much shorter, and the pulse height is much larger.
- We think this may be a better way to connect the light collection system.
- Appears we can resolve 1 PE signals with 50m of cable.

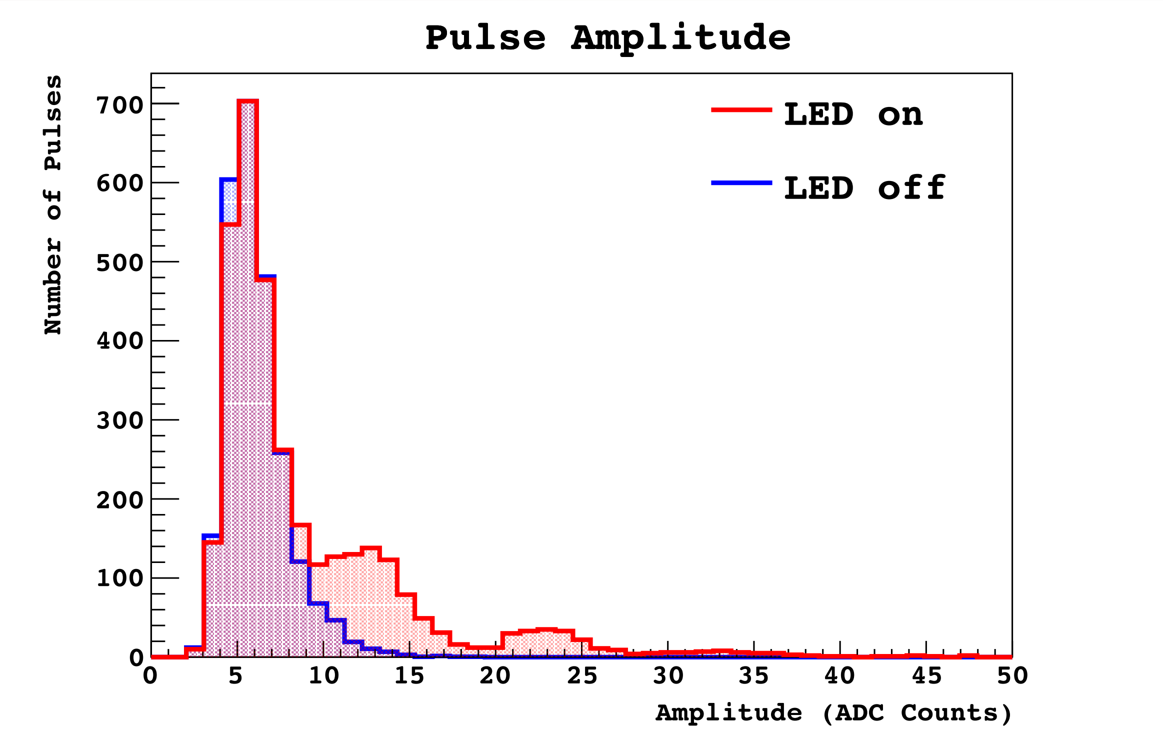
SINGLE PE RESOLUTION





- Left plot: LED flashing. Right plot: no LED for comparison.
- Visible 1PE and 2PE waveforms (distinct from pedestal)
- Periodic noise visible before pulse begins

RESULTS WITH SERIES CONNECTION



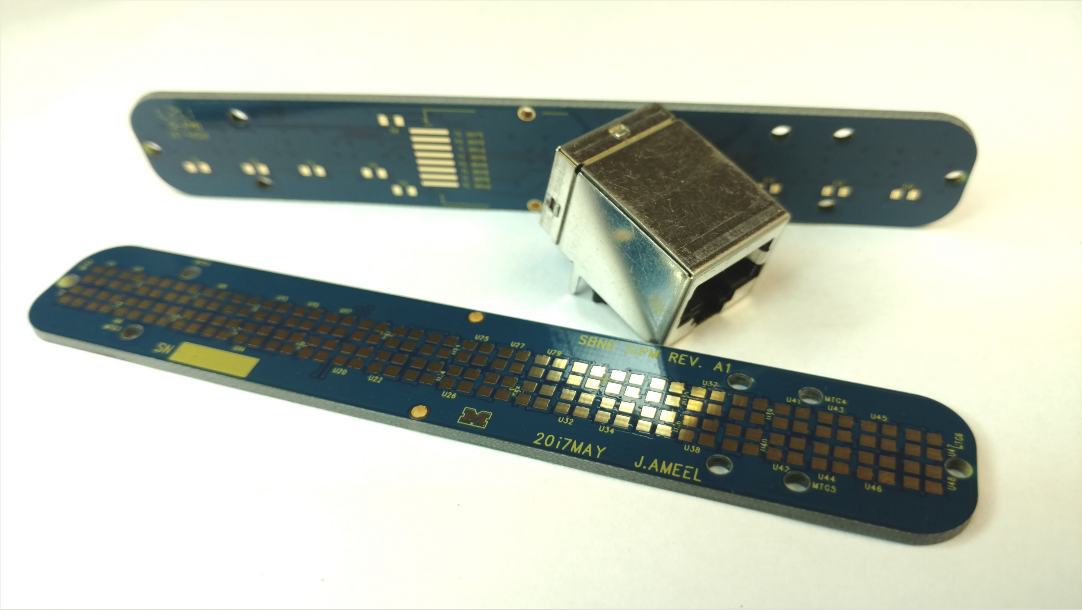
- Three 6 mm SiPMs in series, 50 m of cable and we can clearly see the 1 PE peak over the pedestal.
- This is mostly due to the larger pulse height we get with the series connection.

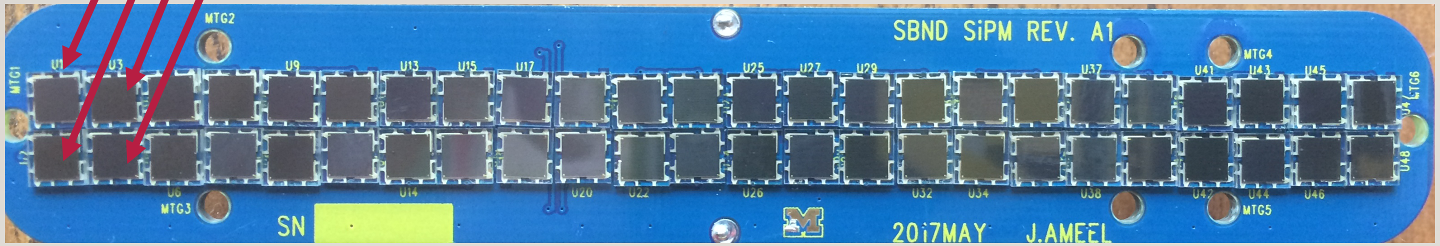
SETUP FOR SBND

- For SBND, we are proposing using the CRV FEBs + series passive ganging of SiPMs for reading out light bars.
- Light bars are similar as proto-DUNE, dipping procedure is the same but the dimensions are different.
- DUNE has three competing light collection technologies (dip-coated bars, IU bars, and Arapucas) at the moment. All 3 rely on SiPM readout and could use the SBND-style system outlined here.

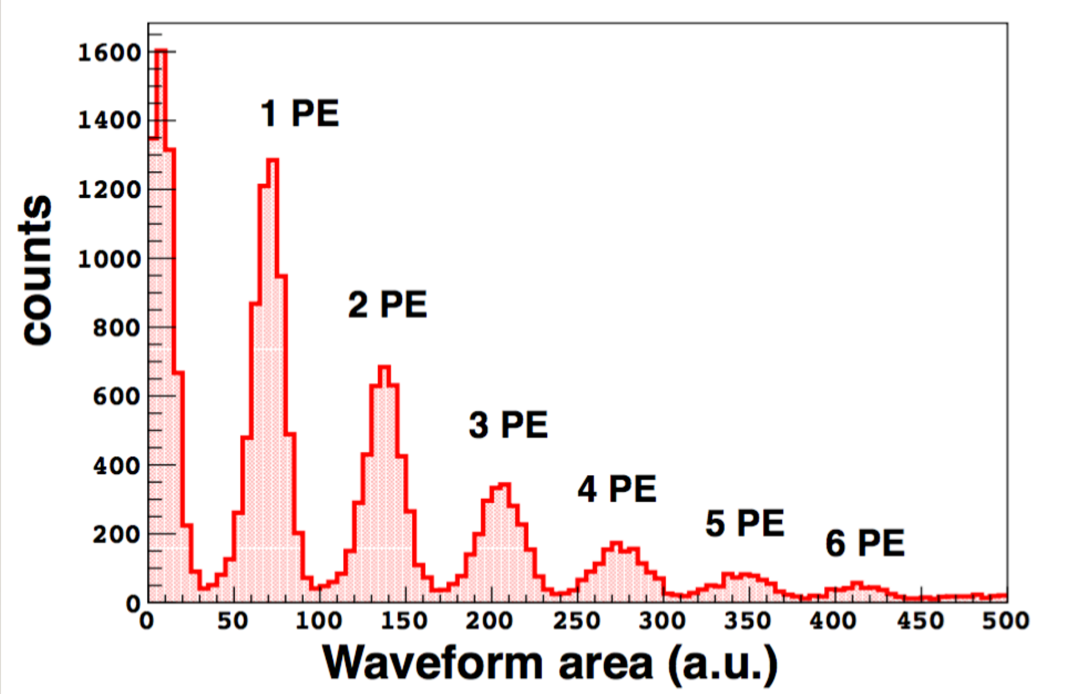
SETUP FOR SBND

Four 3 mm SiPMs, ganged in parallel to make one 6 mm active area array.



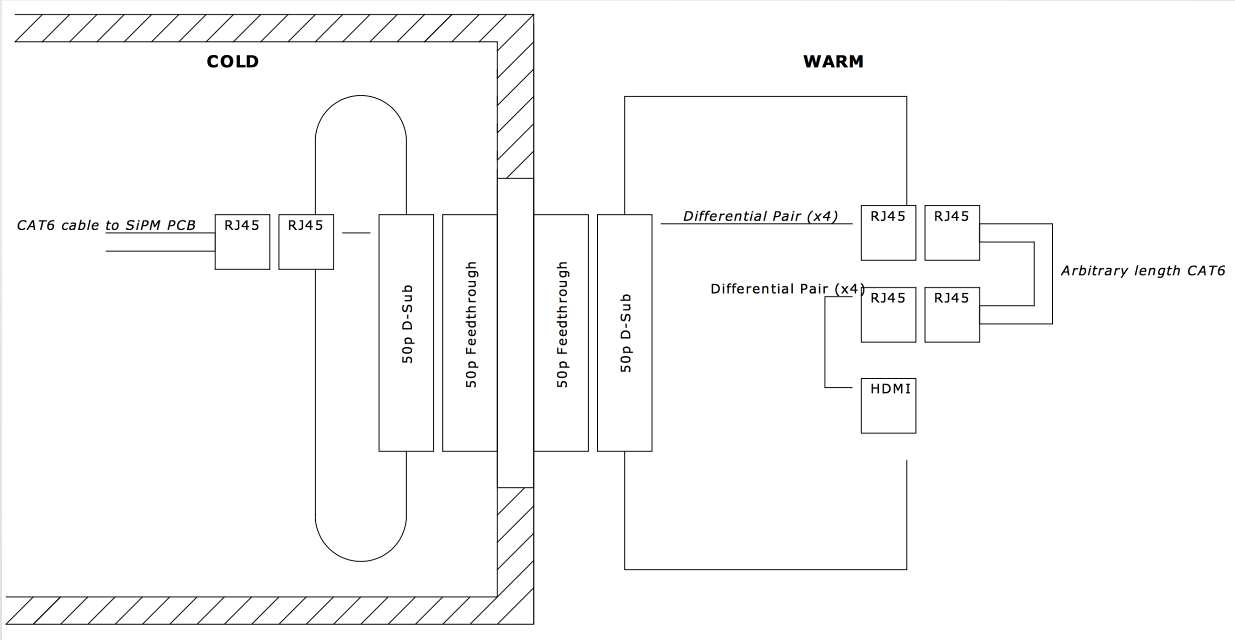


RESULTS FOR SBND SETUP



- Best results to date with SBND setup.
- This plots peak area, rather than peak amplitude, but the peak amplitude distribution looks the same.
- This was taken with 25m of cable, 50m of cable gave similar but slightly degraded resolution.
- This test exercises the full readout chain (SiPMs, carrier board, cables and FEBs)
- **This design could be adapted for DUNE.**

SBND TESTS



Courtsey J. Ameel

- Planning to use a cryo-cooler on 14th floor for more tests of SBND SiPMs, as well as Q&A of assembled boards.
- Assembling a breakout-board at the moment to make use of the flange, converts cat 6e to HDMI.

MOVING FORWARD WITH DUNE

- We think the CRV FEBs should be a candidate for reading out the DUNE PD system.
- Inexpensive, mainly commercial system that is being adapted for SBND.
- Most of the drawbacks seem minor, especially in light of the fact that we are writing custom firmware.
- This could be a significant cost-cutting measure for the entire PD system.
- We also think DUNE should seriously consider series ganging of SiPMs, independent of choice of readout electronics.

CONCLUSIONS

- DUNE should consider using CRV FEBs for the SiPM signal digitization.
- Our tests have shown this board should be suitable for a variety of SiPM configurations DUNE is considering.
- Ganging SiPMs in series appears to be superior to parallel ganging. This should be considered regardless of readout decision.
- We have time in our SBND testing schedule to look at a few different DUNE configurations.