



# Results of VCSEL Failure Investigations and Qualifications

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# Outline

- Introduction
- Study of 2013/14 opto-boards
- Study of irradiated opto-boards
- Summary



# Previous Long-Term Reliability Study

- accelerated lifetime test using DC balanced data (40 MHz clock)
- four boards operated at 85 C/85% relative humidity in 2012/13
  - no fatality observed in ~2000 hours
- four boards operated at 50 C/50% relative humidity
  - no fatality observed in 3 years



# Failure vs. Data Transmission Modes

- IBL VCSELs transmit DC balanced data with 8b/10b encoding
- Pixel VCSELs transmit data for several  $\mu\text{s}$  every  $\sim 10 \mu\text{s}$ 
  - ◆ not an industrial standard
  - ◆ copy of SCT data transmission mode from late 1990's
    - SCT observed no failures from Truelight VCSELs
  - ◆ could frequent on/off caused the failures?
- ⇒ repeat study of 2013/14 opto-boards
  - 4 boards operate with DC balanced data (40 MHz clock)
  - 4 boards operate with 3  $\mu\text{s}$  burst of simulated data every 10  $\mu\text{s}$
  - compare failure rate at 85 C/85% relative humidity to see if the burst mode causes more failures



# Opto-Boards in Environment Chamber

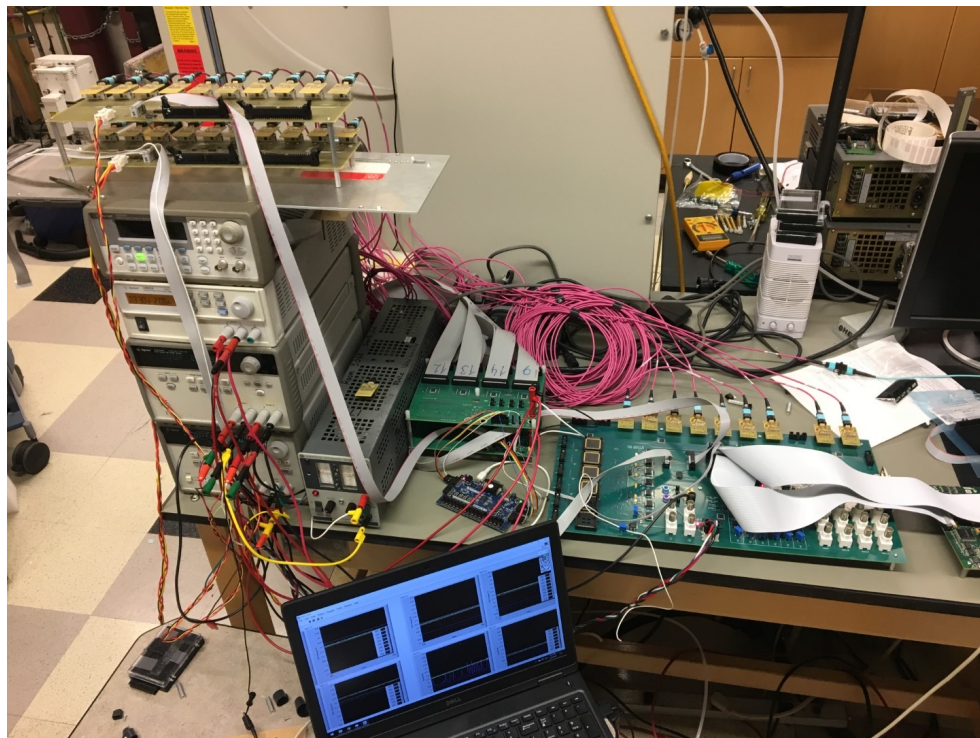


Opto-board





# 85/85 Test System



Custom RX to save \$\$



# 2013/14 Opto-boards Test History

- 8 opto-boards were studied
  - ran for ~3 days at room temperature
  - one VCSEL array from two boards produce no optical power within few hours of operating at 85 C/85% RH
    - both arrays confirmed to have no power at QA system
    - no new failures after several days of testing at room temperature, 85 C, 85% RH
      - ⇒ resume operation at 85 C/85% RH
      - ⇒ one more array from one of the two boards failed few days later...
      - ⇒ VCSELs recovered if pressed on wire bond encapsulant
      - ⇒ VCSEL arrays detached at 85 C due to thermal stress
      - ⇒ both boards are labeled “second class” and “no opto-pack reinforcement” in database
      - ⇒ resume operation at 85/85

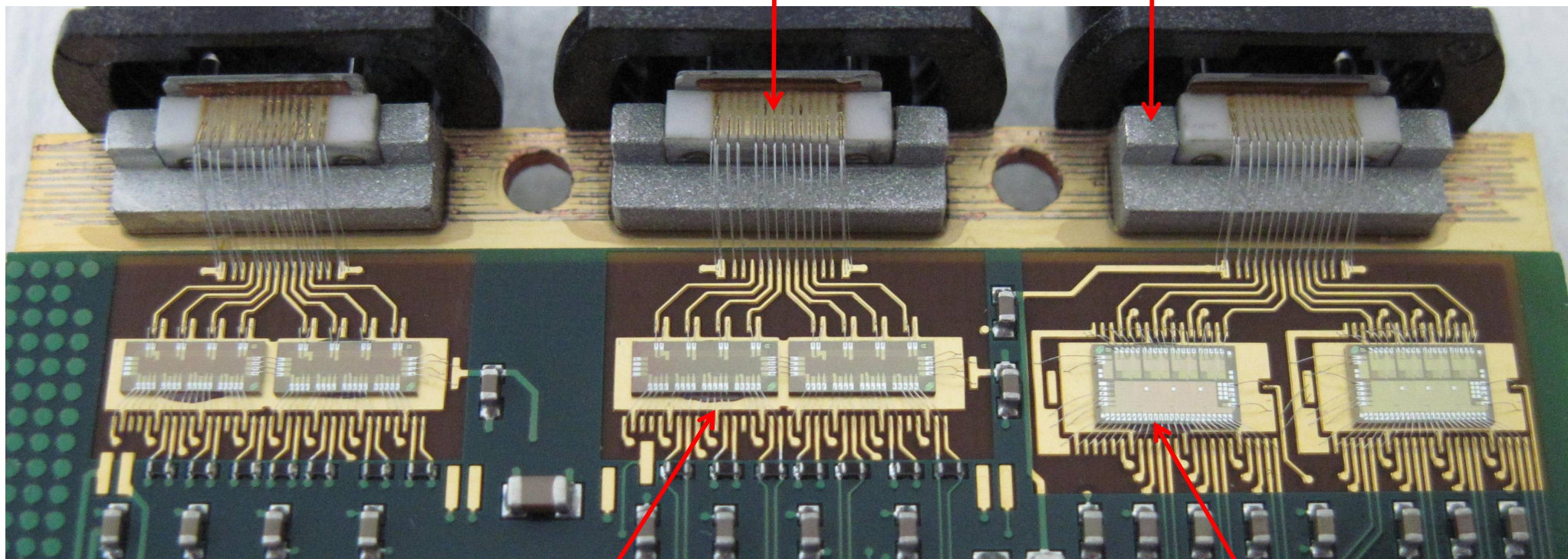




# Opto-Pack Reinforcement

Opto-pack

Aluminum brace



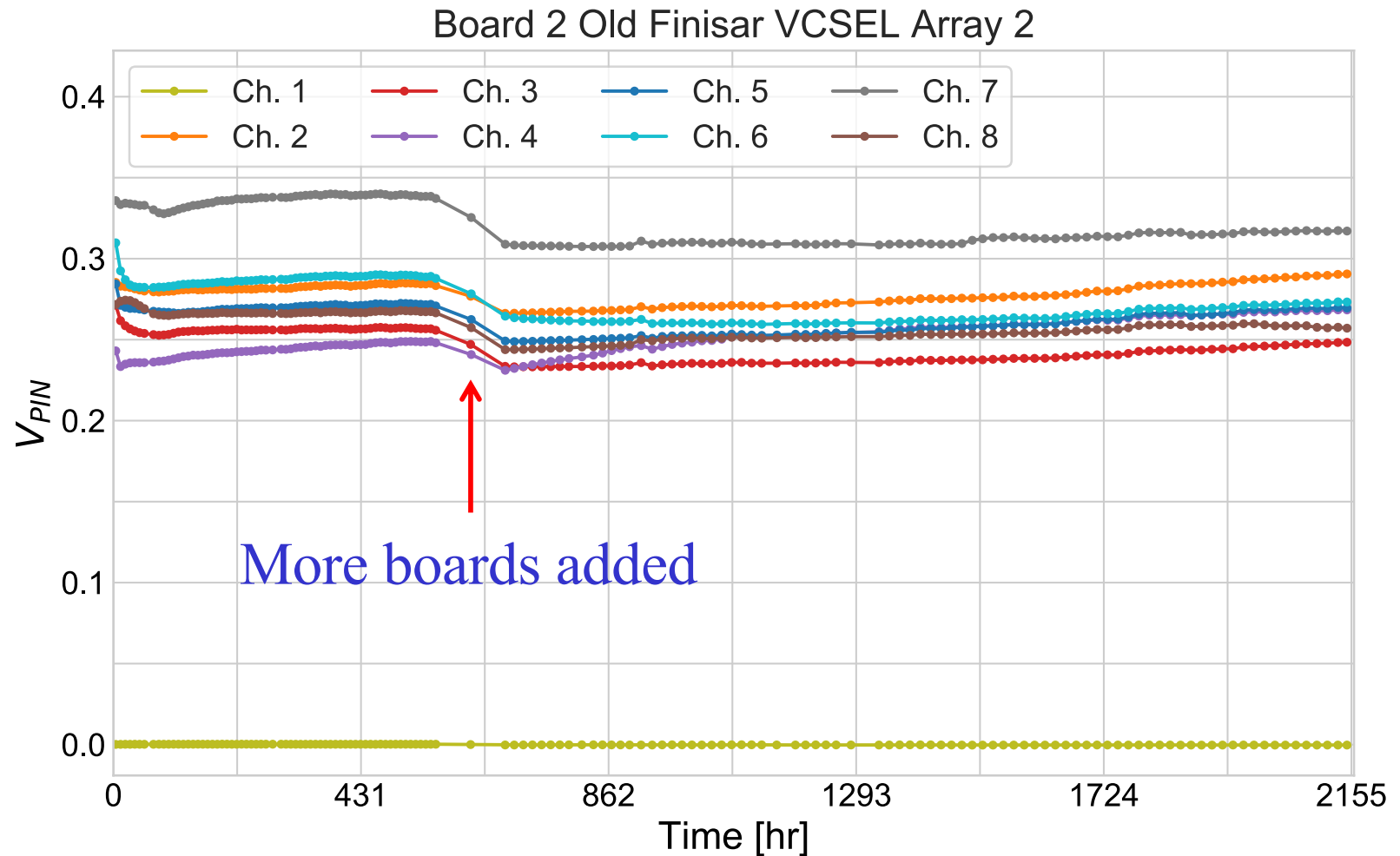
VDC  
(VCSEL driver)

DORIC  
(PIN receiver/decoder)



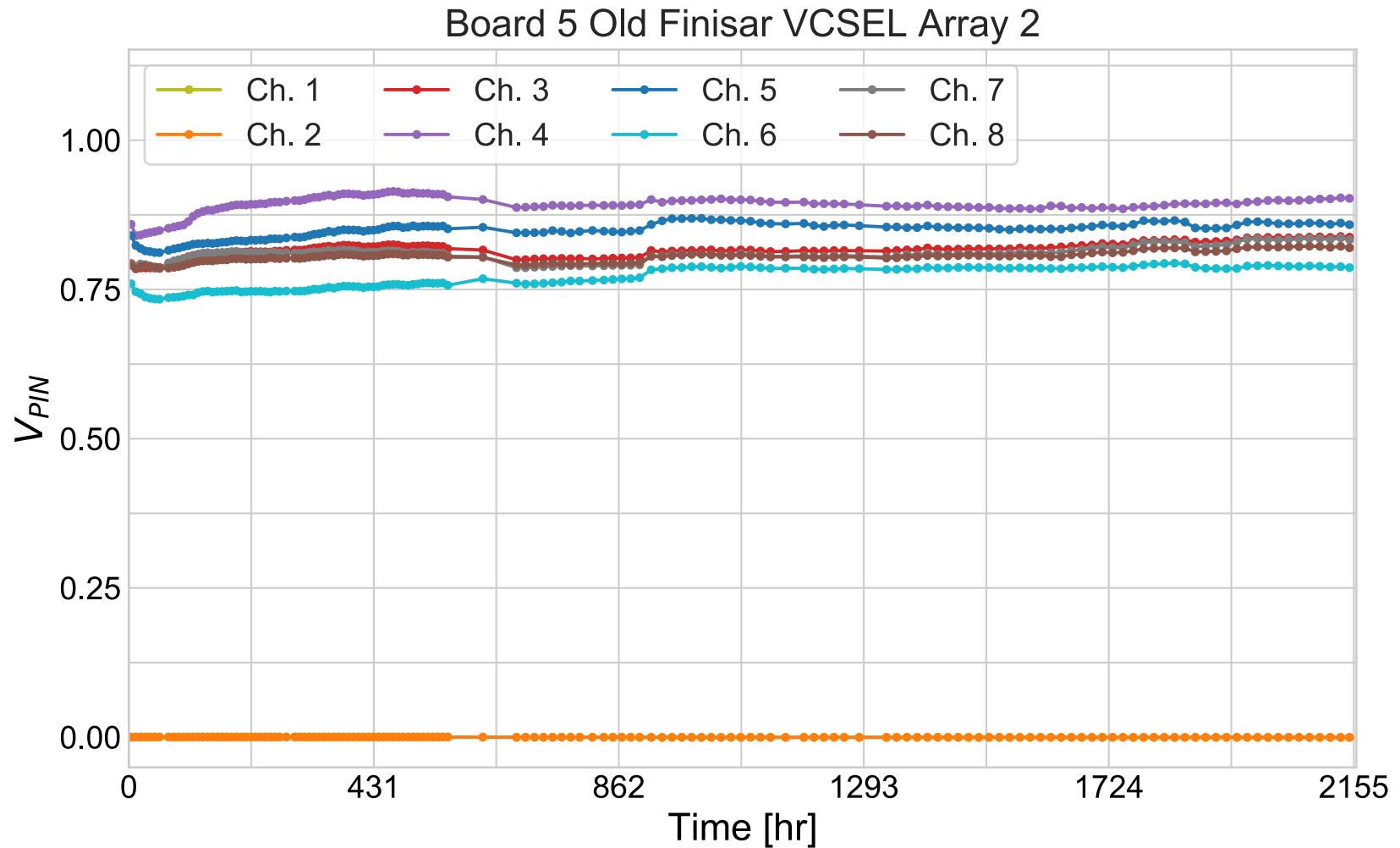


# Optical Power vs. Time (Burst)



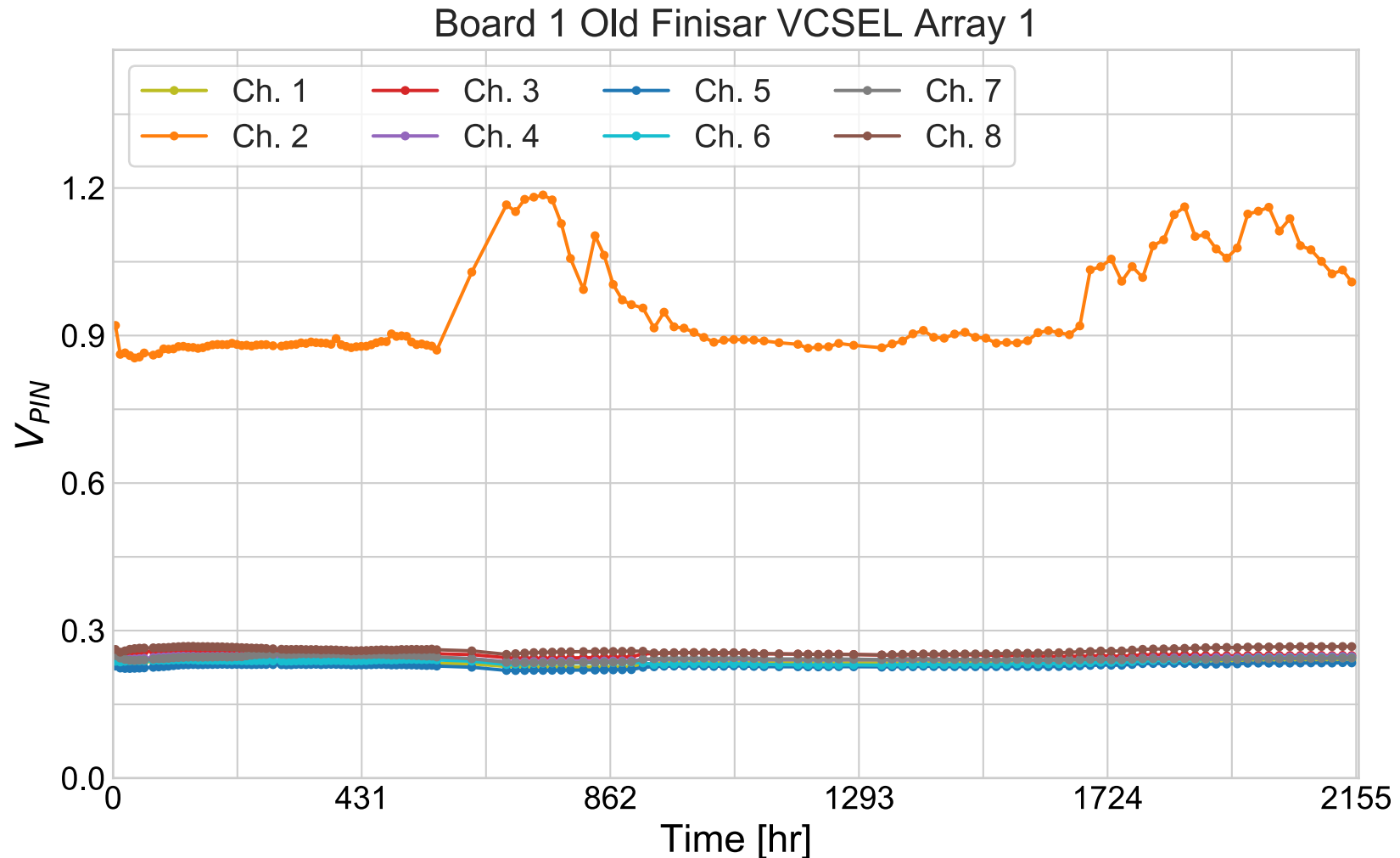


# Optical Power vs. Time (Clock)





# Optical Power vs. Time (Burst)



- 1 out 112 channels has connection problem: receiving all “1”
- VCSEL not dead!!



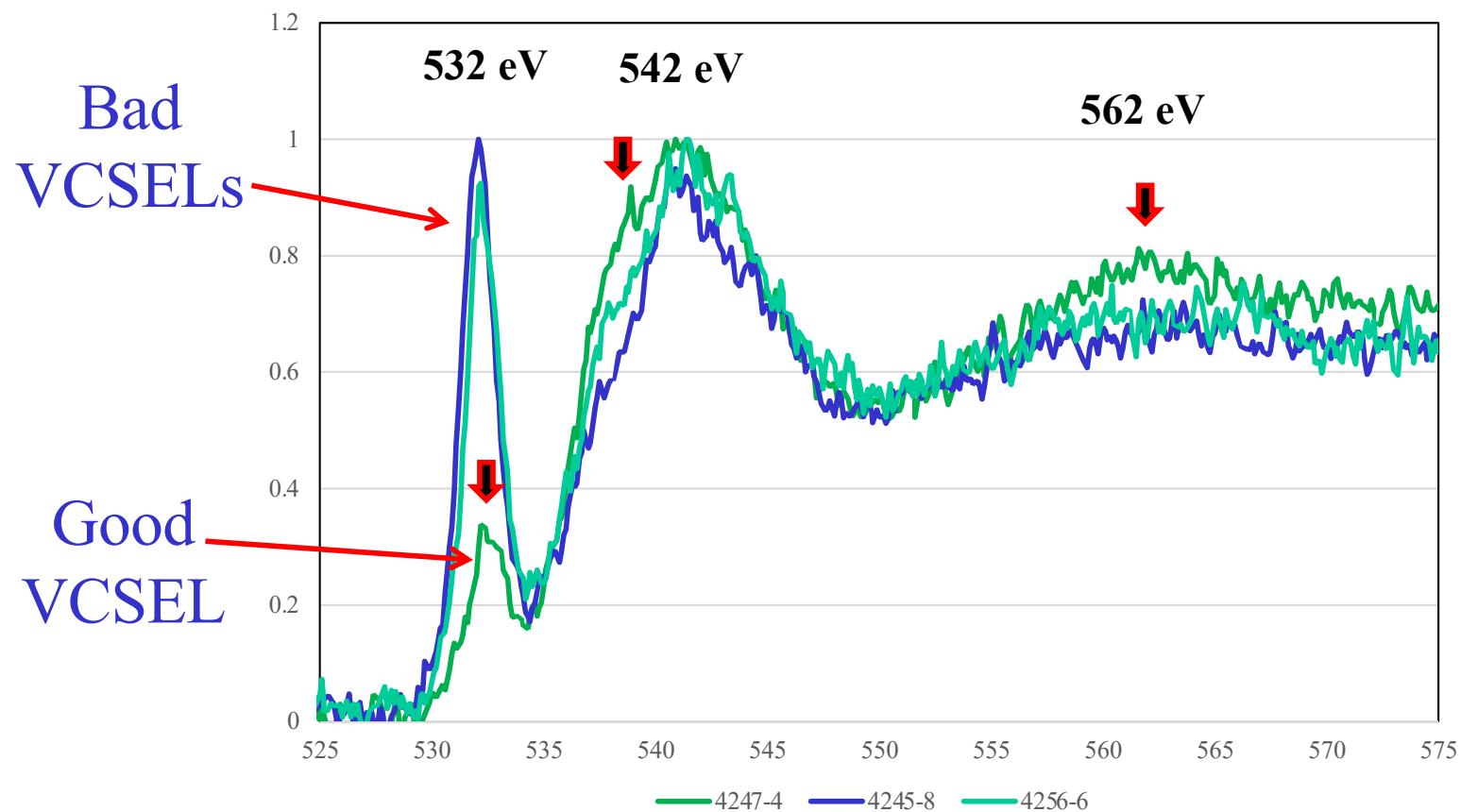
# Summary: 2013/14 Opto-Boards

- accumulated 2100 hours of operation at 85 C/85% RH
  - no VCSELs have died yet...
  - no difference between burst vs. clock operations
  - is humidity the cause of failure?
  - EAG believes the failure is due to humidity but Finisar would not confirm it
  - EAG did electron energy loss spectroscopy (EELS) with aberration corrected scanning transmission electron microscopy (ACSTEM)





# ACSTEM-EELS





# ACSTEM-EELS

Here is the data work up from the experiment we recently performed. The EELS shows that there is a significant difference between the Failed VCSELs and the Good Reference VCSEL with regards to the Oxygen K edge fine structure. The failed VCSELs show a large increase in the 532eV pre peak as compared to the Good VCSEL control. If you have time this afternoon...

While we have found evidence in the literature for this pre-peak to be associated with dehydration of Al hydroxide, we are still unsure of its true source as there are also references that show this more associated with molecular Oxygen, O<sub>2</sub>. My hypothesis was that there might be excess water uptake in the bad VCSELs, and using the reference I found this would seem to support that theory, but I am not comfortable making that conclusion just yet. More work needs to be done to understand the origin of this oxide chemistry difference and whether this correlation of the 532 eV peak with failed VCSELs can be repeated.



# Humidity Induced Failure?

- EAG believe humidity is the cause of failure
  - consistent with the observation of no failure in IBL opto-boards located in a dry environment
  - should Finisar expect few percent failures in commercial operation after three years?



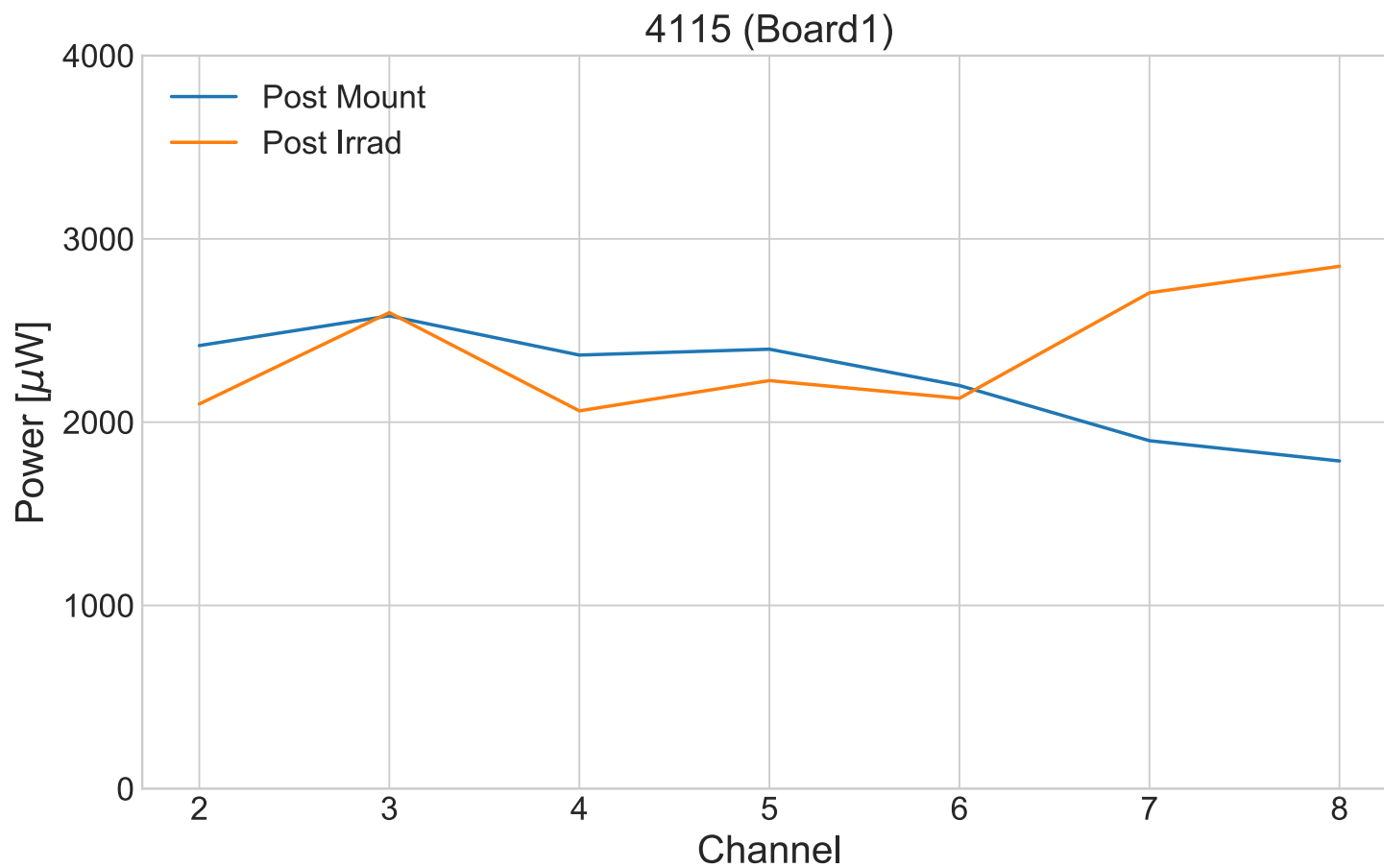
# VCSEL/PIN Qualification Plan

- 2018 opto-boards:
  - irradiation I:
    - 4 Finisar and 4 ULM opto-boards
      - ◆ 64 Finisar and 64 ULM VCSEL channels
      - ◆ 32 Finisar and 32 ULM PIN channels
  - irradiation II:
    - 4 II-VI, 1 Finisar, 1 ULM opto-boards
      - ◆ 32 II-VI VCSEL channels
      - ◆ 8 Finisar and 8 ULM VCSEL channels
  - target dose with 24 GeV protons:  $3 \times 10^{12}$  p/cm<sup>2</sup> for 200 fb<sup>-1</sup>
    - ◆ received dose:  $\sim 3.8 \times 10^{13}$  p/cm<sup>2</sup>
  - compare failure rate at 85 C/85% relative humidity to select vendor with less failures in 1,000 hours





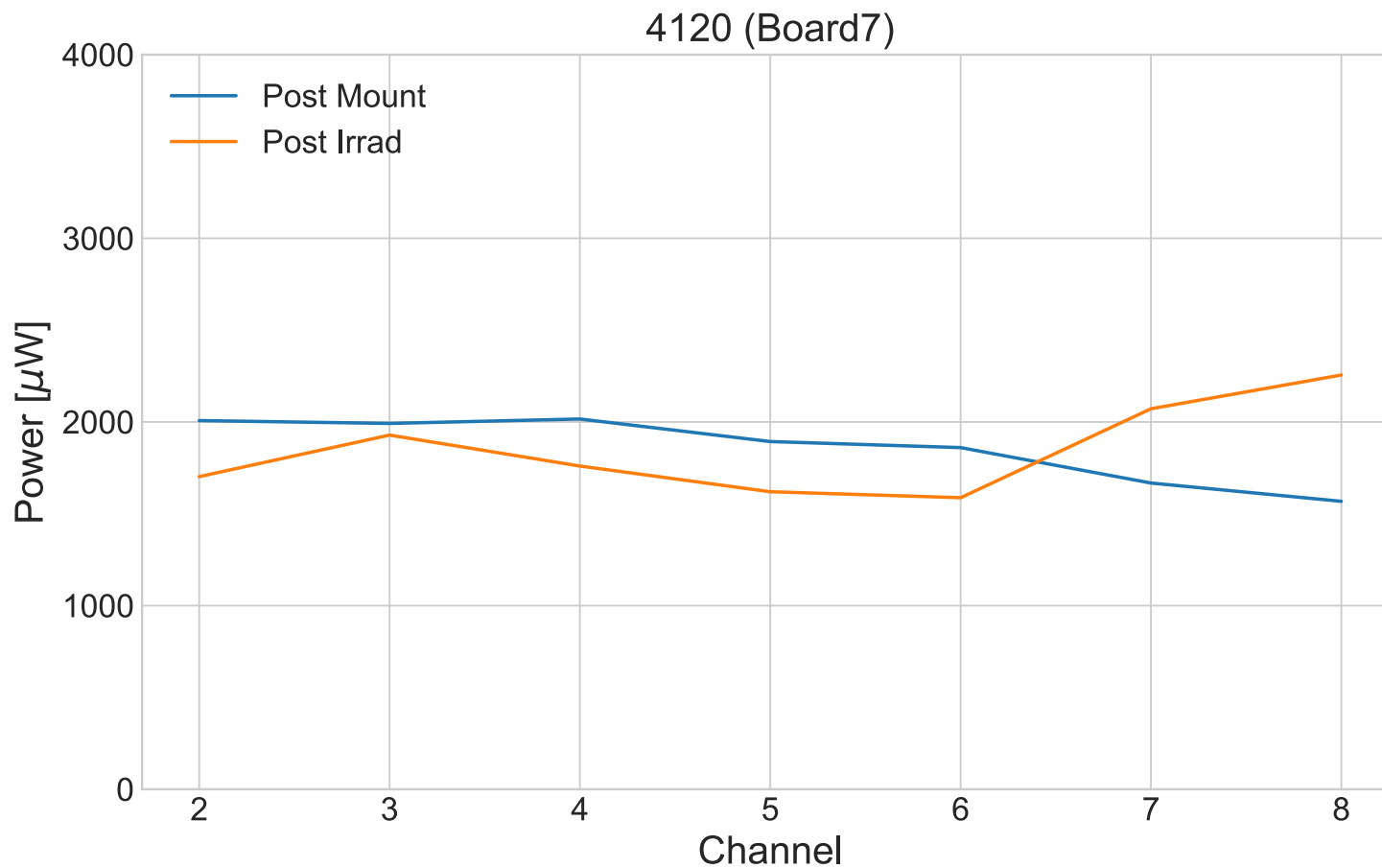
# Irradiation I



- Finisar: all channels are still operational with good optical power



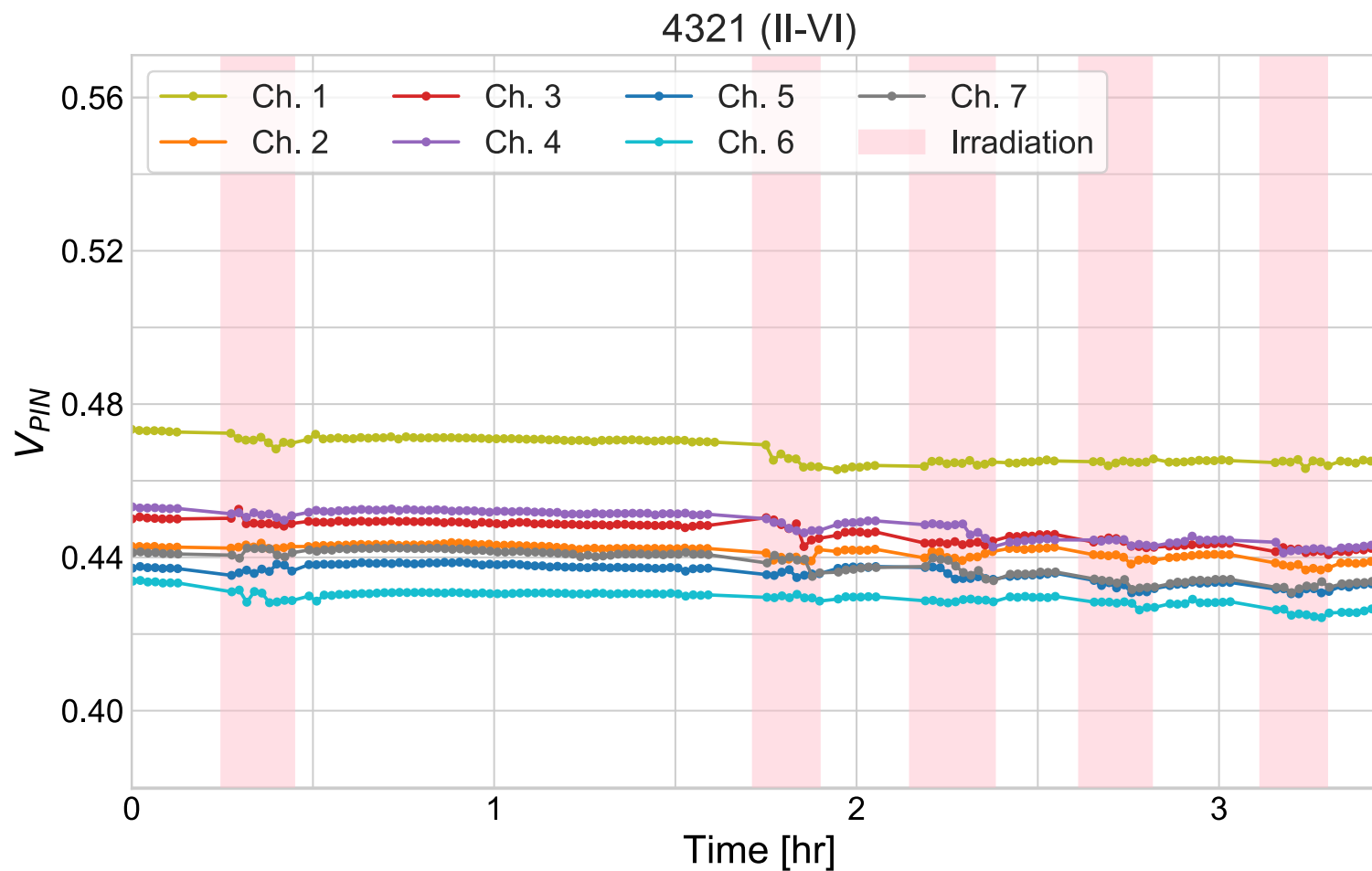
# Irradiation I



- ULM: all channels are still operational with good optical power



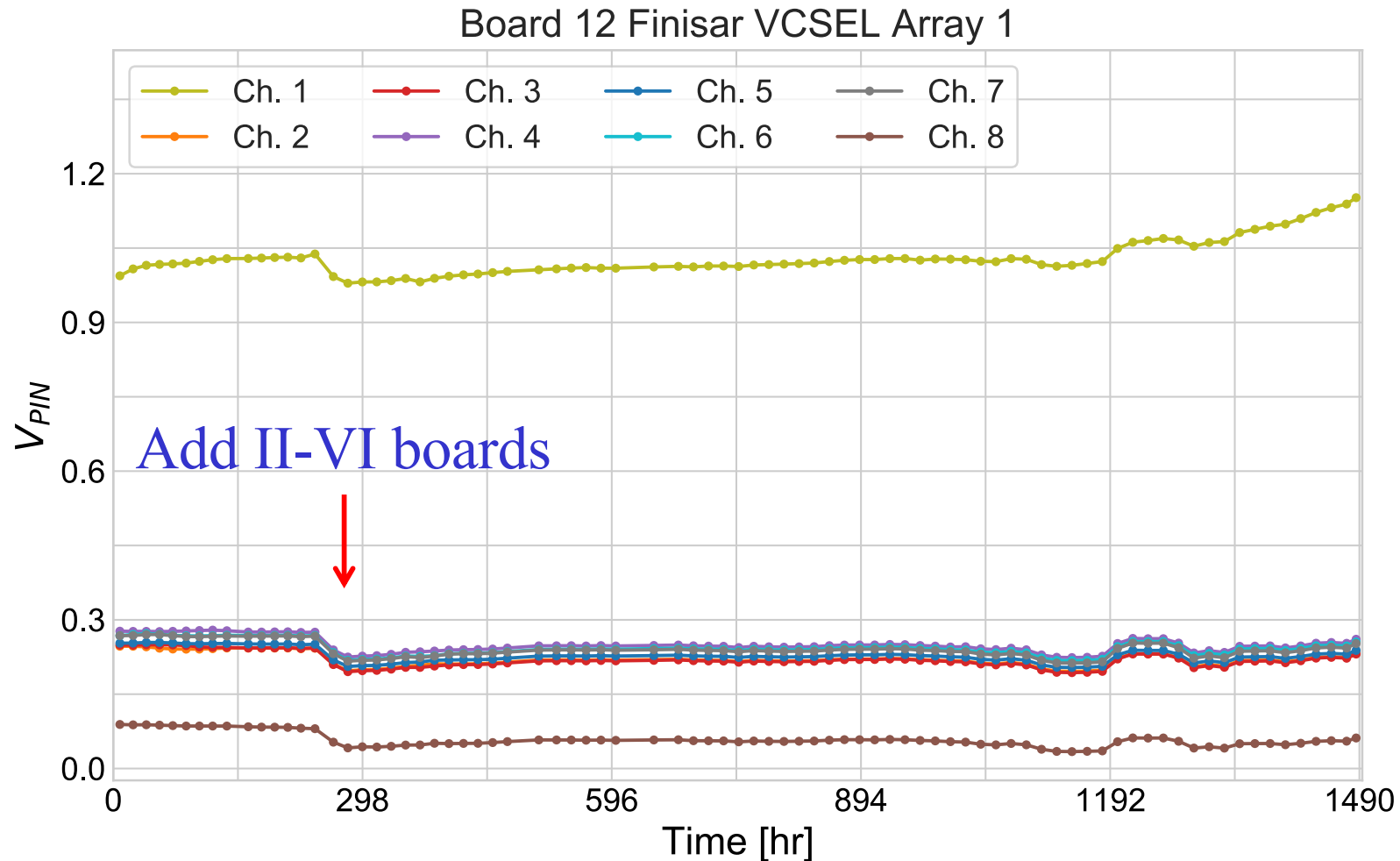
# Irradiation II



- II-VI: no VCSELs died during irradiation



# 85/85 Test on Irradiated Boards

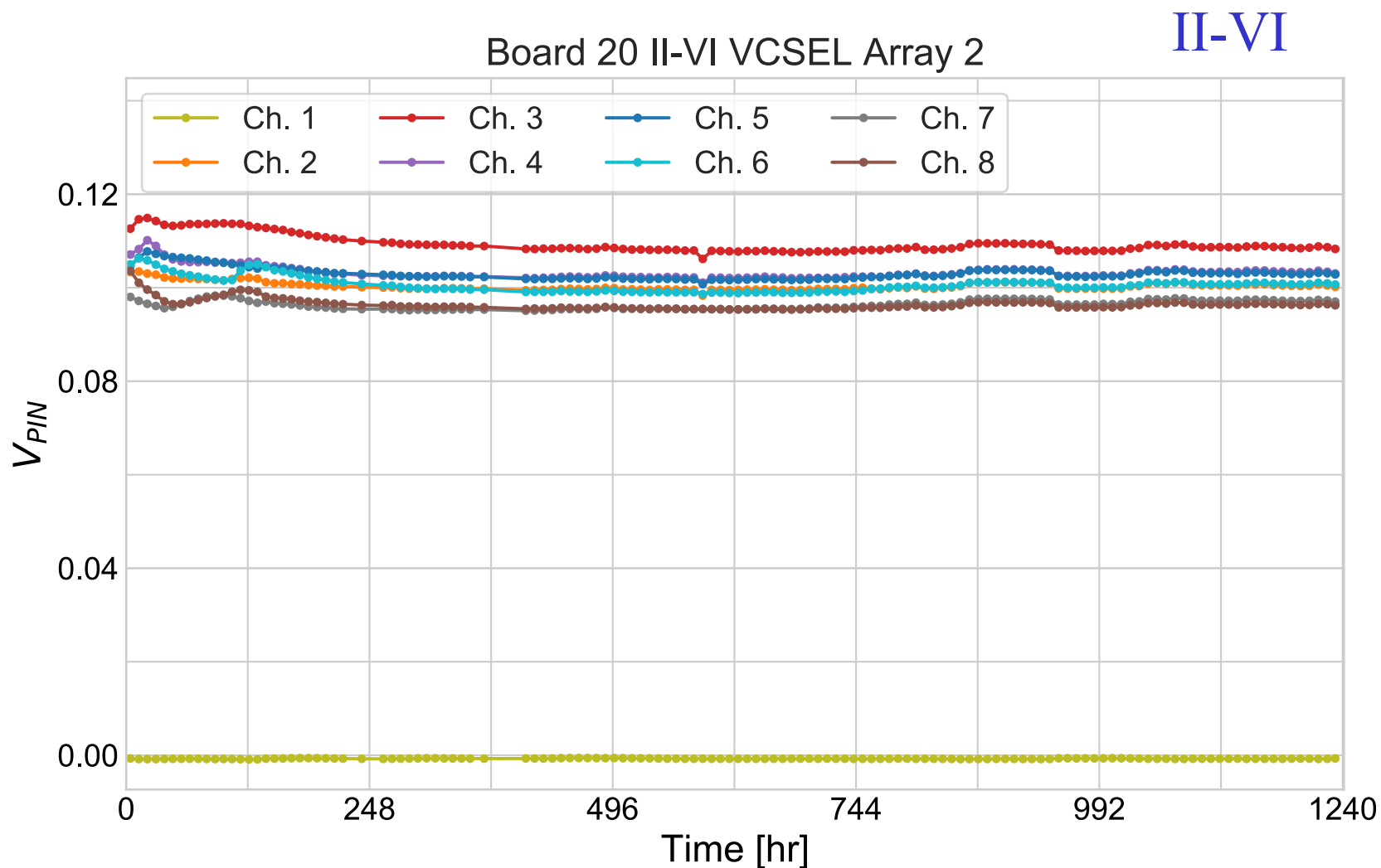


- Finisar: channel #1 has connection problem: receiving all “1”
- VCSEL not dead!!





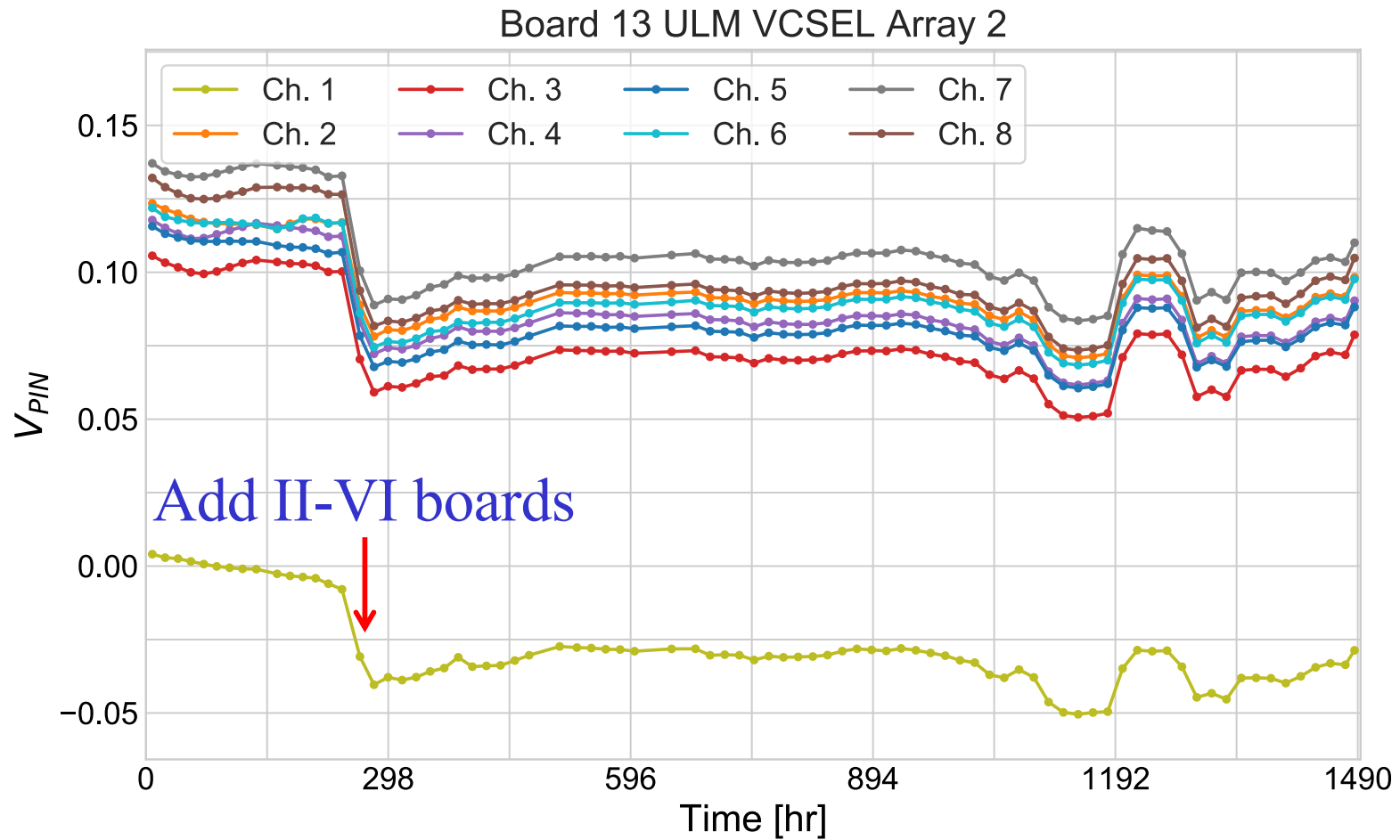
# 85/85 Test on Irradiated Boards





# 85/85 Test on Irradiated Boards

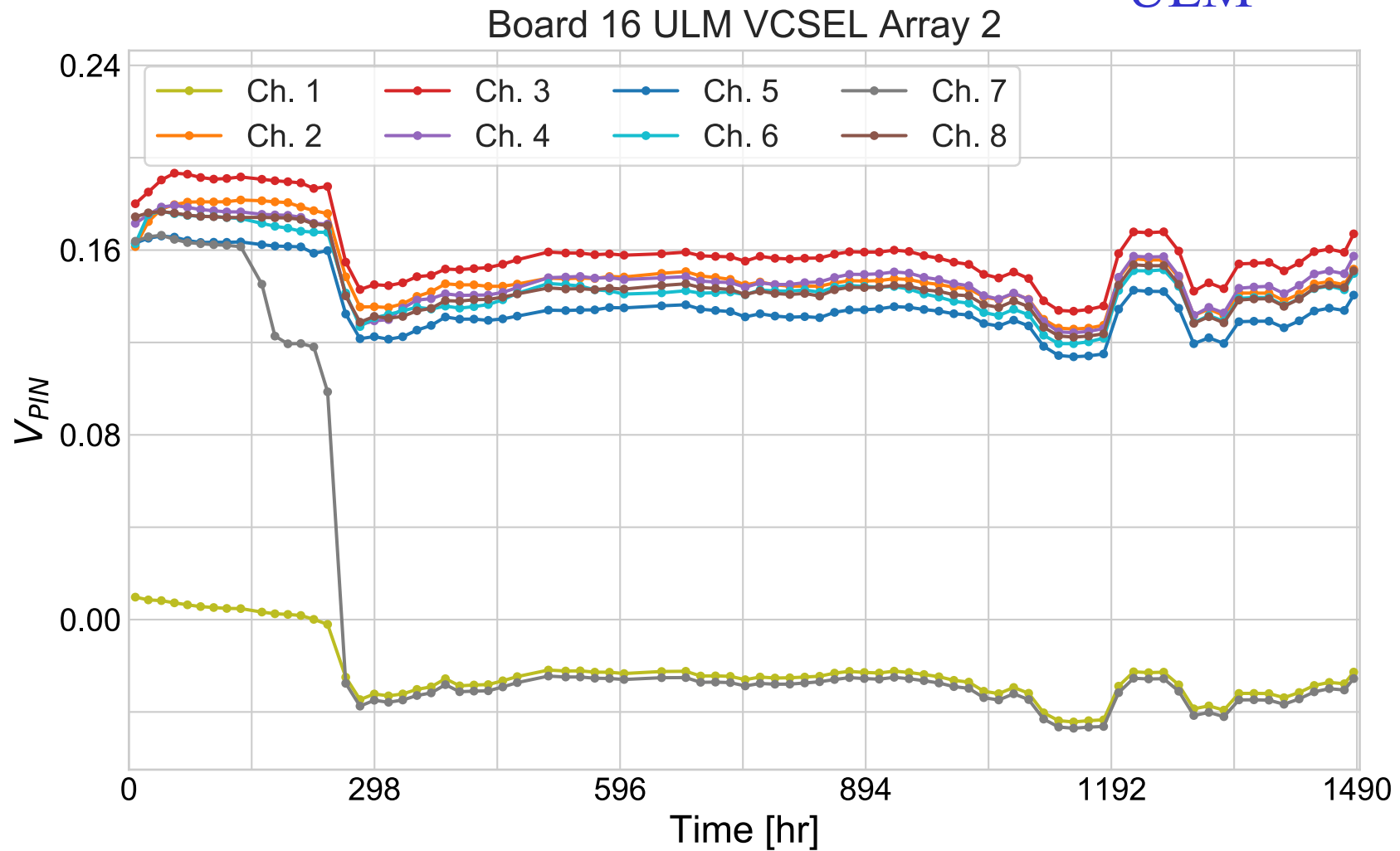
ULM





# 85/85 Test on Irradiated Boards

ULM





# Summary of Failed ULM VCSEL

- power of one channel started to decrease after ~140 hours at 85 C/85% RH
  - died at ~250 hour
- no additional fatality in other 55 channels in next 1200 hours
- Is this infant fatality?
- Can check for ESD after removal of opto-pack at 2000 hour





# Summary: Irradiated Opto-Boards at 85/85

- opto-boards with VCSEL/PIN arrays from three vendors have been irradiated
  - good optical power at end of irradiation
- accumulated 1400 hours of operation at 85 C/85% RH for 4 Finisar + 4 ULM opto-boards
- accumulated 1200 hours of operation at 85 C/85% RH for 4 II-VI opto-boards
- 1 ULM channel started to fail at ~140 hour
- 139 channels are still alive
  - 7 channels have connection problems which will be verified



# Conclusion

- accumulated 2100 hours at 85C/85% RH for 2013/14 opto-boards
    - no VCSELs have died in both burst and clock modes
    - no different between burst vs. clock modes
    - EAG believes humidity is cause of failure
  - opto-boards with VCSEL/PIN arrays from three vendors have been irradiated
    - good optical power at end of irradiation
  - accumulated 1400/1200 hours at 85C/85% RH for irradiated opto-boards
    - 1 ULM channel started to fail at ~140 hour
    - 139 channels are still alive
- ⇒ see next talk on choosing vendor