High-Speed/Radiation-Hard Optical Links

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Outline

- Introduction

- Results from 1st Prototype ASIC

- Results from 2nd Prototype ASIC

- Summary

Use of VCSEL Arrays in HEP

- Widely used in off-detector (no radiation) data transmission
- First on-detector implementation in pixel detector of ATLAS
  - experience has been positive
    - ⇨ use arrays for the second generation opto-links
    - ⇨ logical for HL-LHC ATLAS pixel detector to use 12-channel arrays as in the 1st and 2nd generation optical modules (opto-boards)

Opto-Board for HL-LHC ATLAS Pixel Detector

- Use experience from building two generations of opto-boards
  to develop an opto-board capable of operation at 5 Gb/s
  or higher for HL-LHC ATLAS pixel detector (ITK-Pixel)

- What is required to demonstrate that
  the opto-board concept is a logical solution?
  - 5 Gb/s per channel VCSEL arrays
  - radiation-hard VCSEL array driver
  - robust high speed array based packaging with thermal management

- A working prototype has been constructed

Opto-Pack for ITK-Pixel

array

guide pin
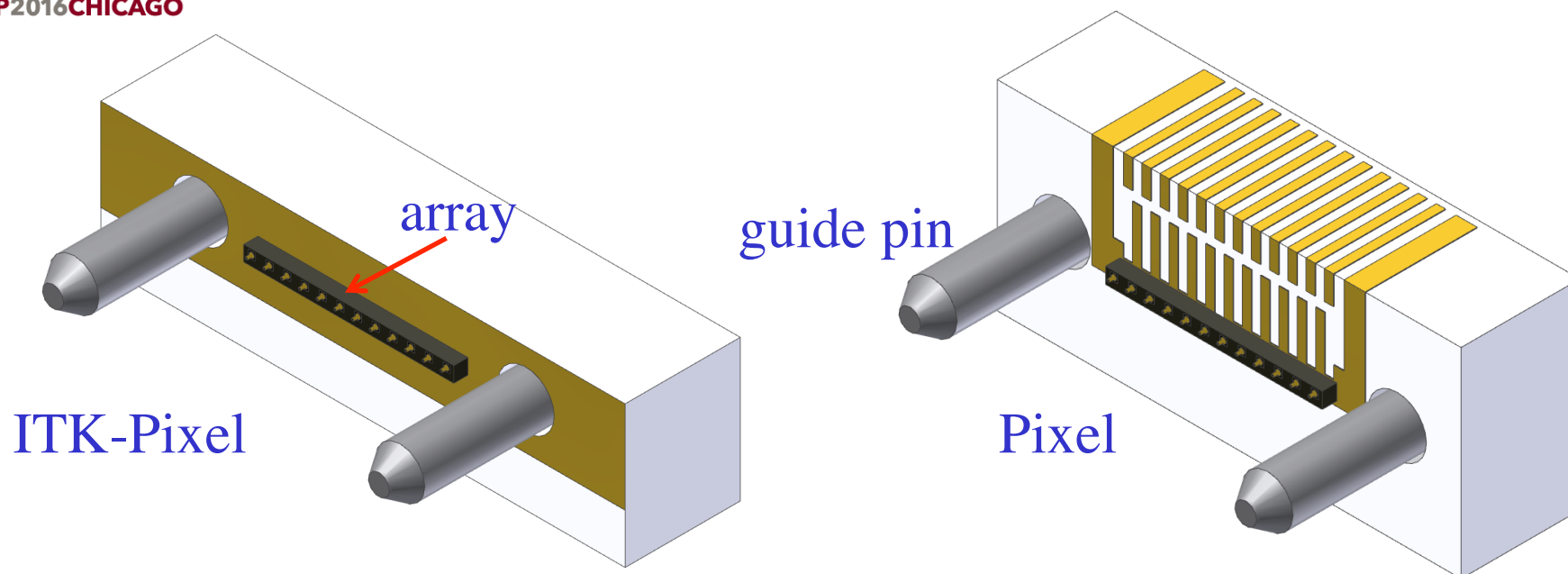
ITK-Pixel

Pixel

- Proposed opto-pack for ITK-Pixel has simpler design
  - continue to use BeO as substrate for heat management
- experience in building large quantity of opto-packs
  - fabricated 1,200 opto-packs for pixel opto-boards
  - fabricating 300 PIN opto-packs for off-detector opto-receivers
 - equivalent to 18,000 channels

10 Gb/s VCSEL Array Driver

- R&D funded via CDRD program (FY13-15) of DOE (USA)
- Fabricated 4-channel test chips in 65 nm CMOS
  - 2 mm x 2 mm
  - 1st prototype submission: October 2014
  - 2nd prototype submission: March 2016
- Uses only core transistors to achieve maximum radiation-hardness
- 8-bit DACs to set the VCSEL modulation and bias currents
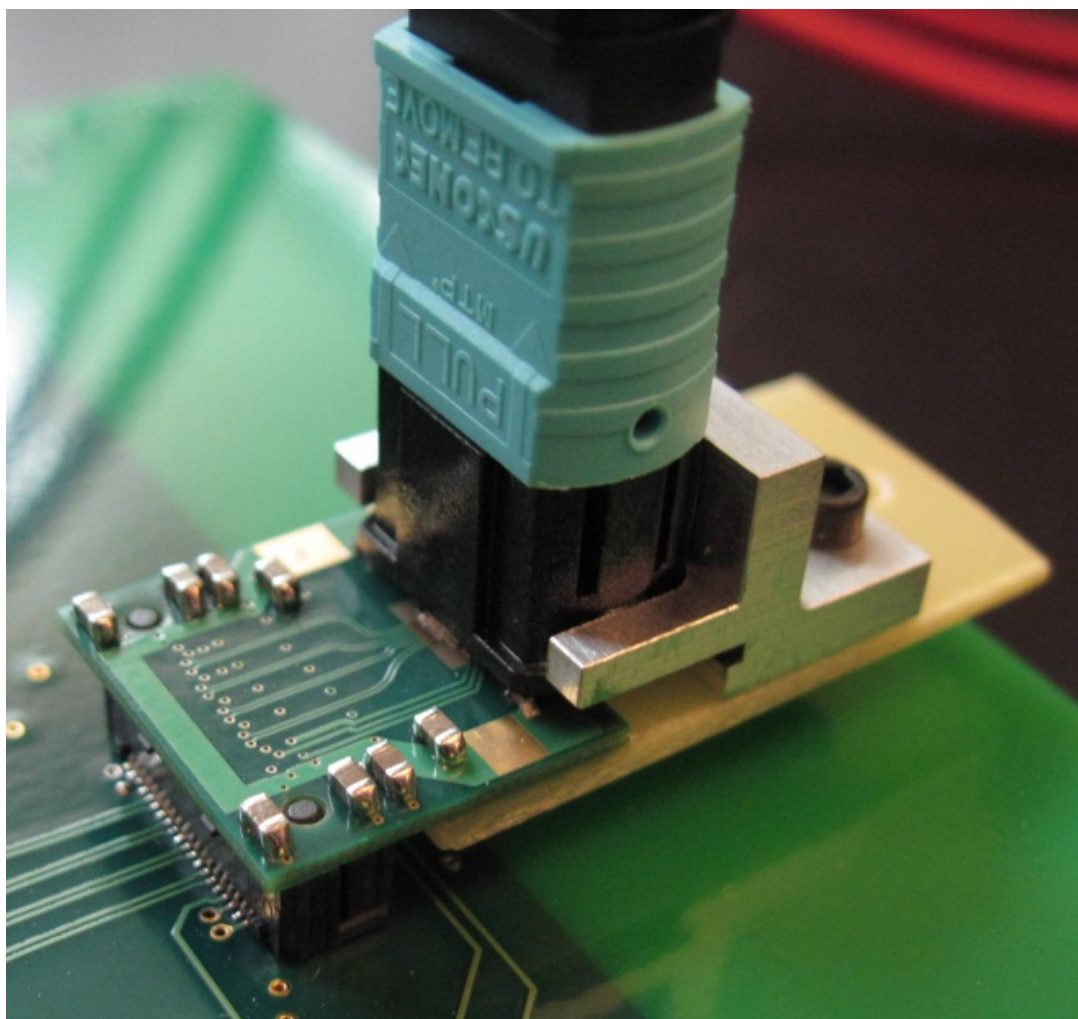 - DAC settings stored in SEU tolerant registers

Rev. 1   2 mm   Rev. 2
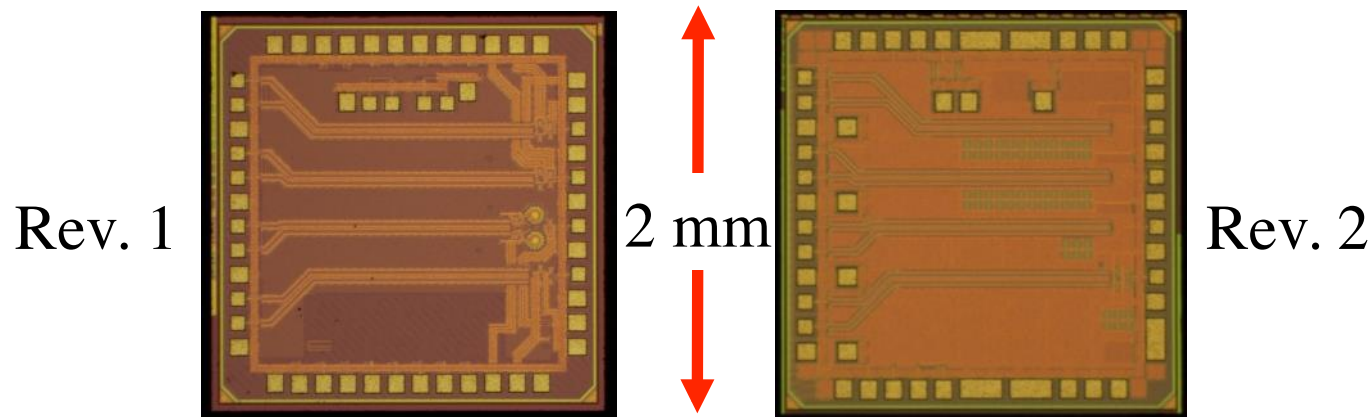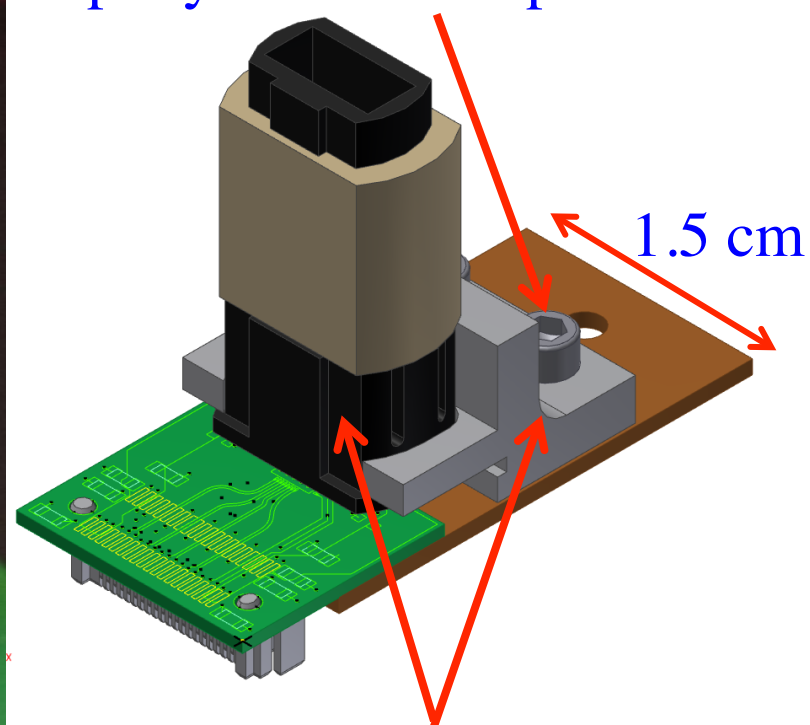
ITK-Pixel Opto-Board Concept

- Keep opto-pack
- Keep copper backed PCB
- Keep MTP connector
- Compatible with an opto-box (opto crate) concept
- No lenses/mirrors used to turn the light

MTP

ASIC

screw for thermal contact

PCB

opto-pack

copper plate
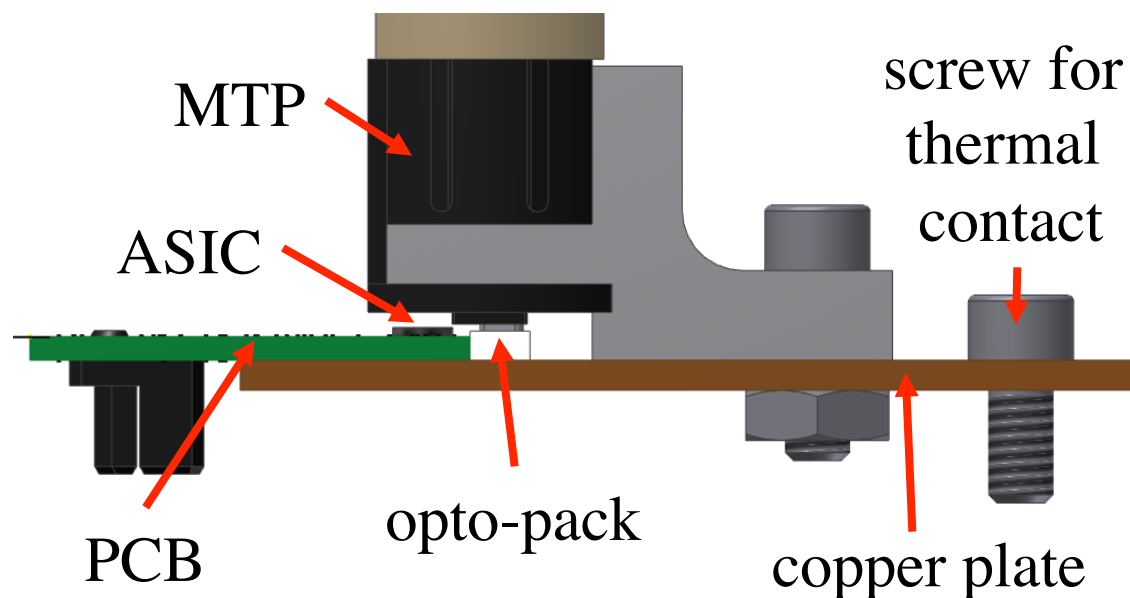
ITK-Pixel Opto-Board

Connector secured to opto-board with screws instead of epoxy in current opto-board

1.5 cm

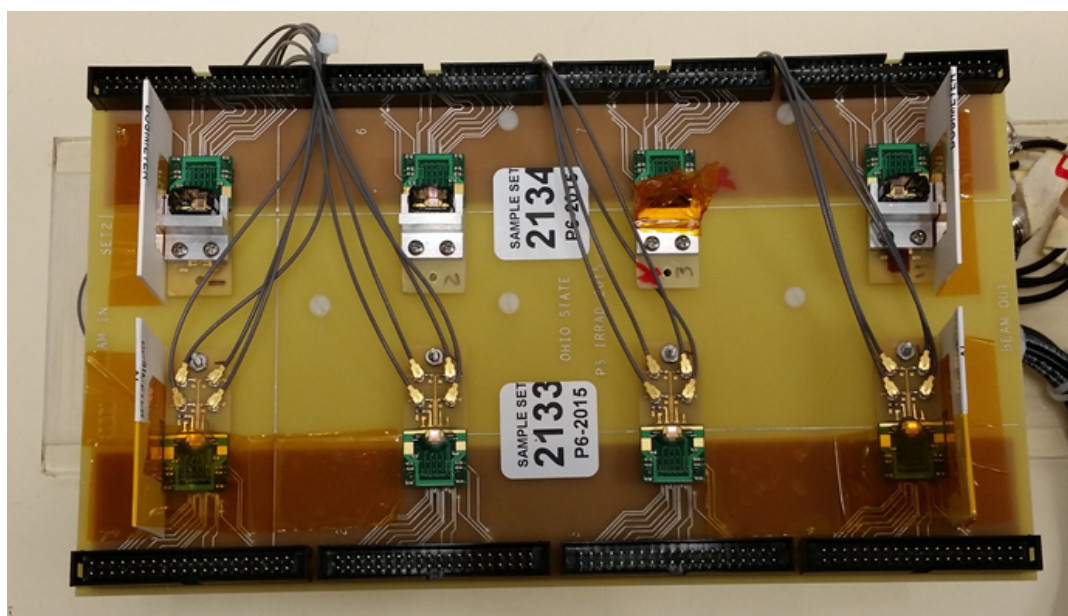Could be fabricated as one piece with mold injection

New Opto-Board Irradiation

- October 2015: irradiated 8 opto-boards with Rev. 1 array driver using 24 GeV protons at the CERN PS Irradiation facility
- 4 pcs. optical: driving Finisar VCSEL arrays (V850-2174-002)
  - dose: 13 Mrad
- 4 pcs. electrical: driving resistive load
  - dose: 111 Mrad
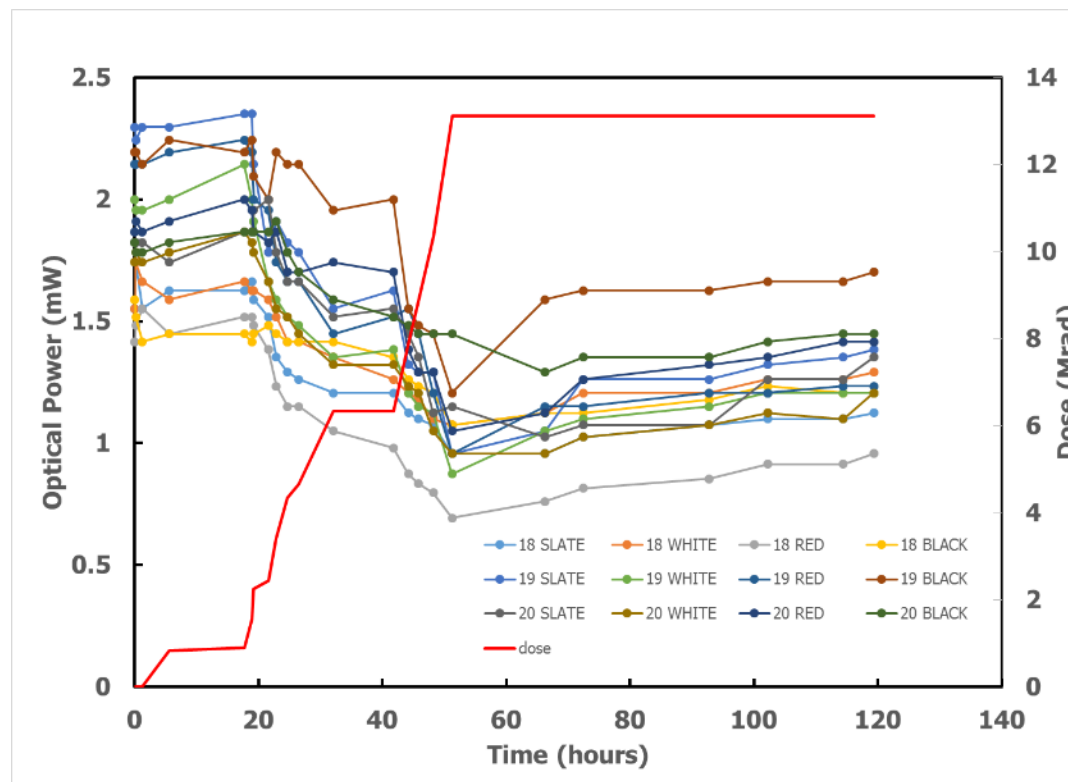
optical

electrical

New Opto-Board Irradiation

- Chips were powered and monitored during the irradiation at reduced speeds due to the irradiation facility cabling infrastructure

- All channels survived the irradiation and the cooled down chips have been returned to our lab for a study of their performance at high bit rates
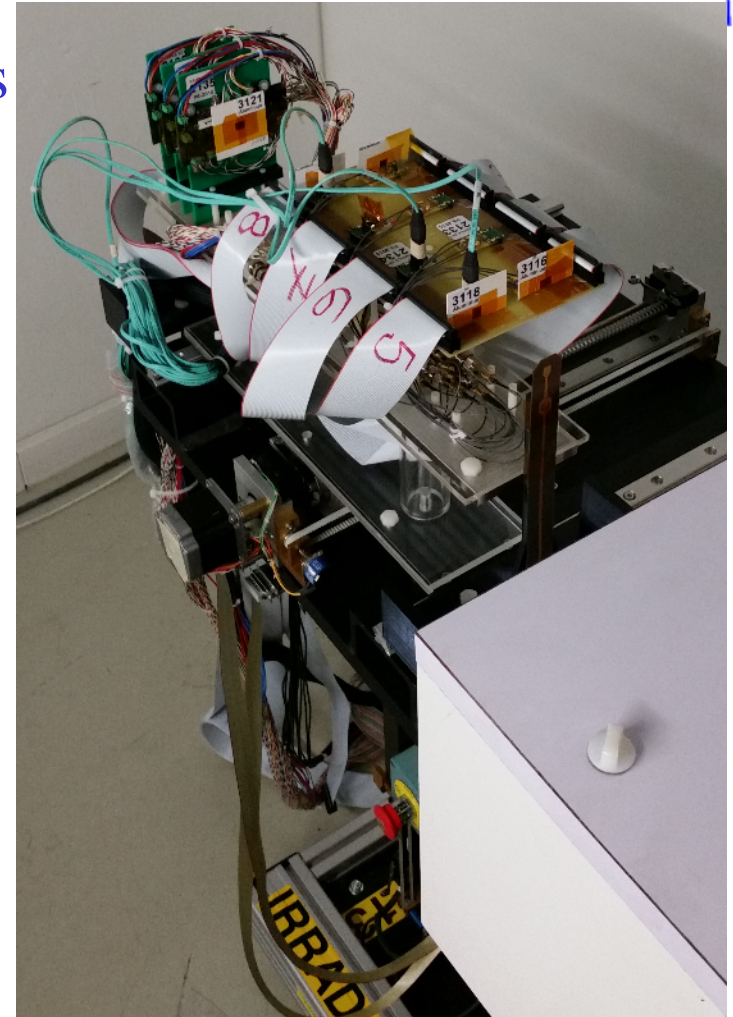
VCSEL Optical Power vs. Dose

- Optical power of irradiated VCSELs decreased with dose as expected

- Annealing occurred (slowly) during times when the VCSELs were removed from the beam

- Monitored 12 out of the 16 VCSEL channels during irradiation due to limited number of fiber connections

Post Irradiation Results – 10 Gb/s

- All channels operational after irradiation
- Optical amplitude reduced from 2.07 mW to 1.19 mW
  - consistent with power loss seen during irradiation
- BER < 5×10^{-14} (run error free for more than 30 minutes)
- First demonstration of radiation hardness of an array driver/VCSEL combination at 10 Gb/s with a dose greater than 10 Mrads!

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Post Irradiation Results – 5 Gb/s
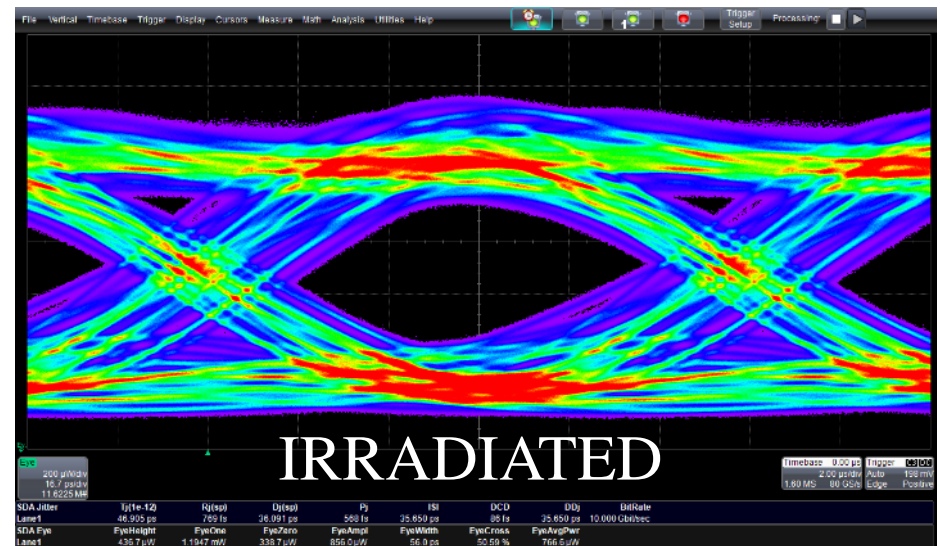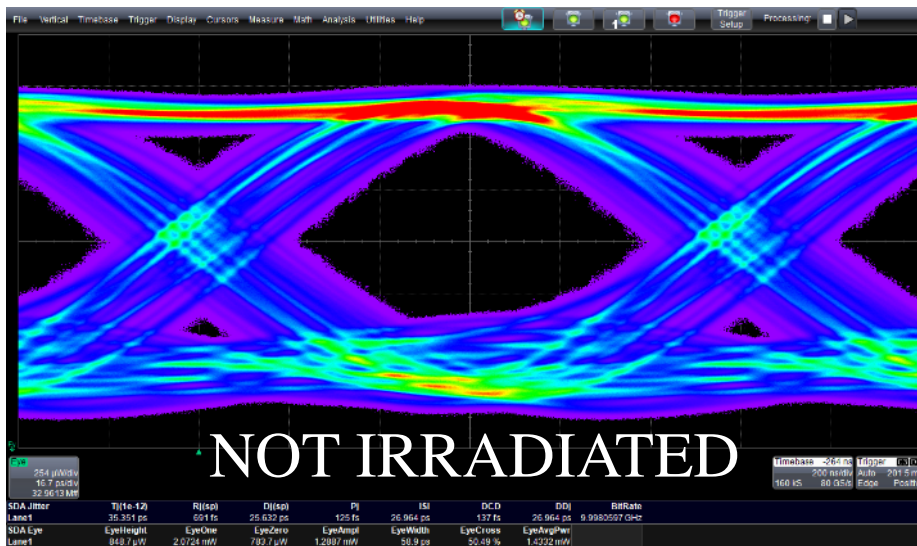

NOT IRRADIATED
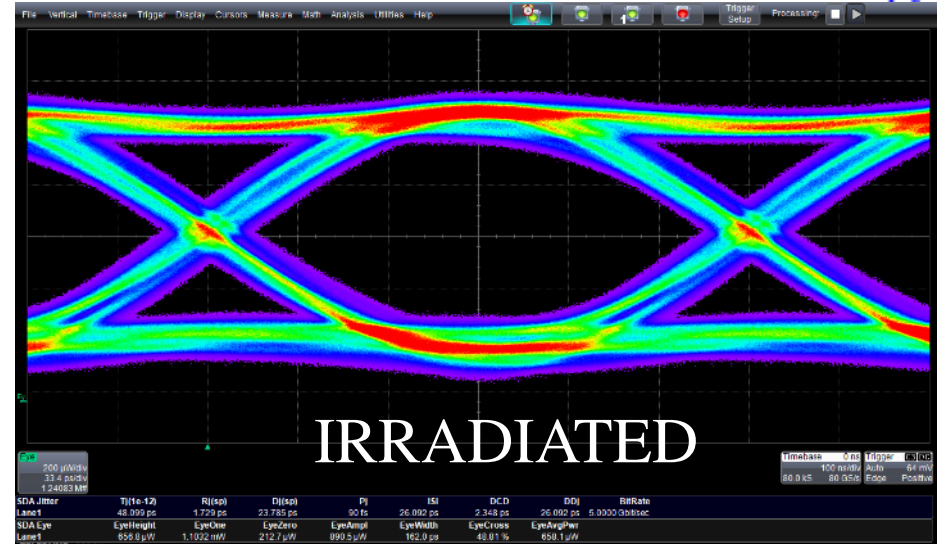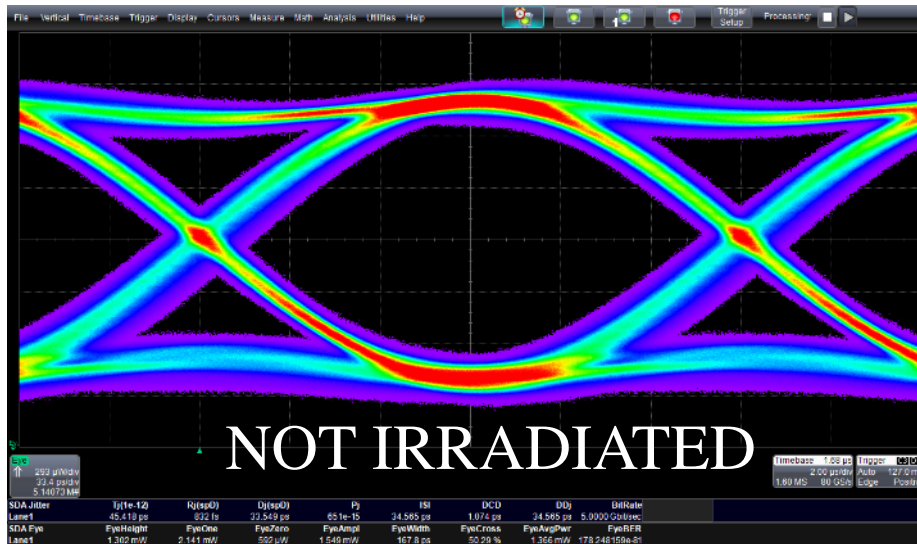
IRRADIATED

- performance of the array driver/VCSEL combination at 5 Gb/s is acceptable after irradiation

10 Gb/s Array Driver ASIC Rev. 2

- Rev. 2 has improved architecture for the first three channels, including programmable pre-emphasis current and delay

- One channel was simply a copy of the old design to check for consistency between the versions

- Rev. 2 ASIC is much easier to tune for operation at 10 Gb/s

- Need to use new opto-packs to reduce the length of wire bonds
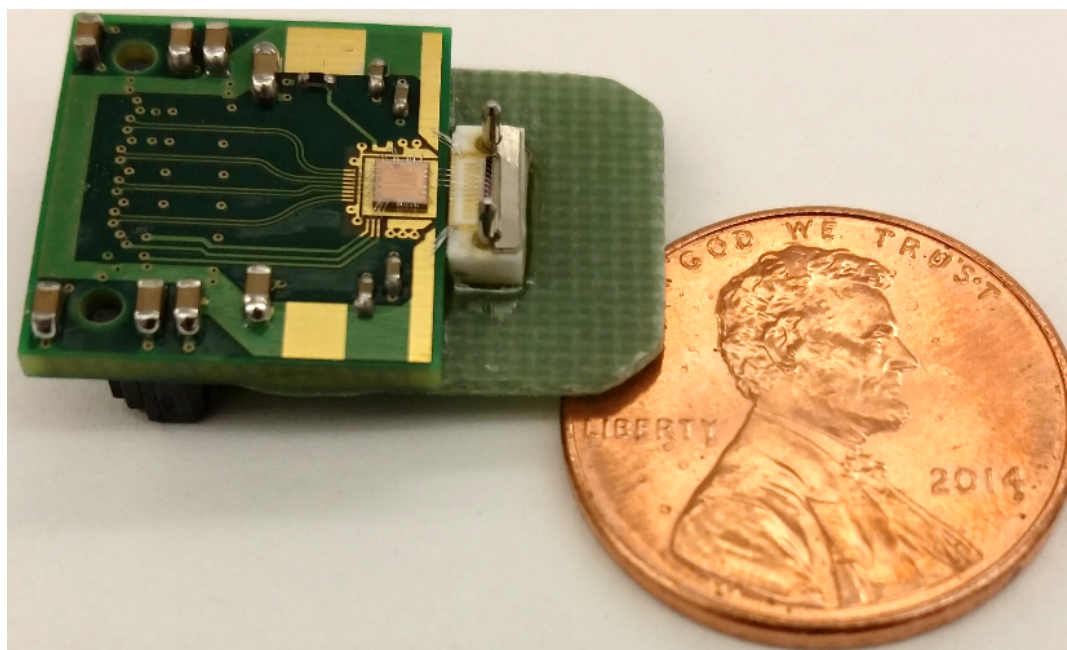
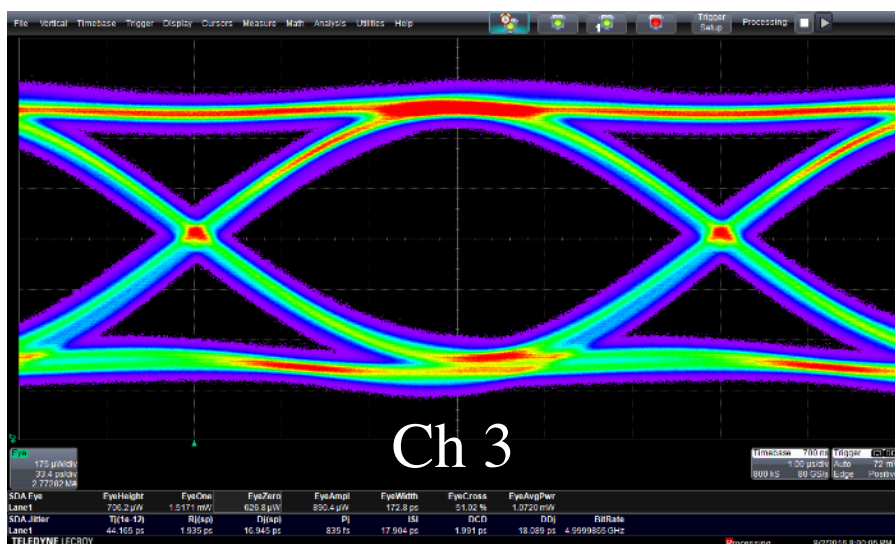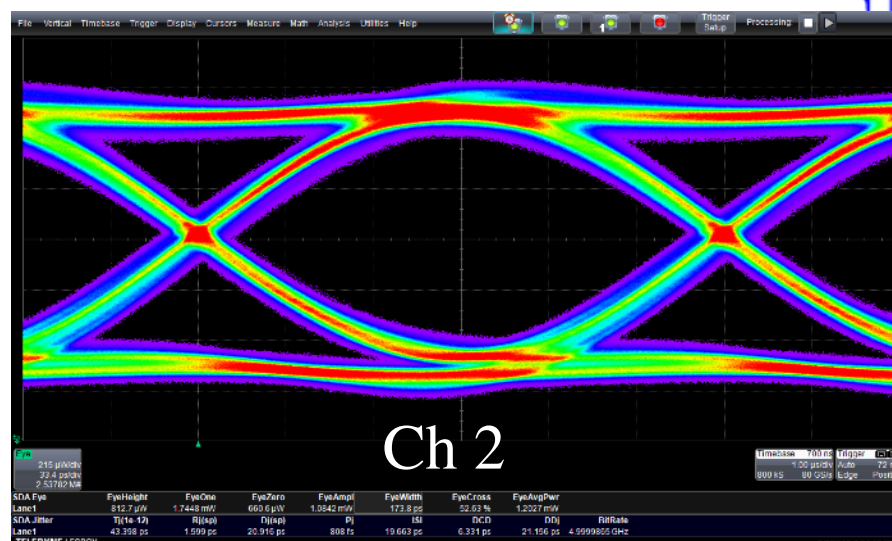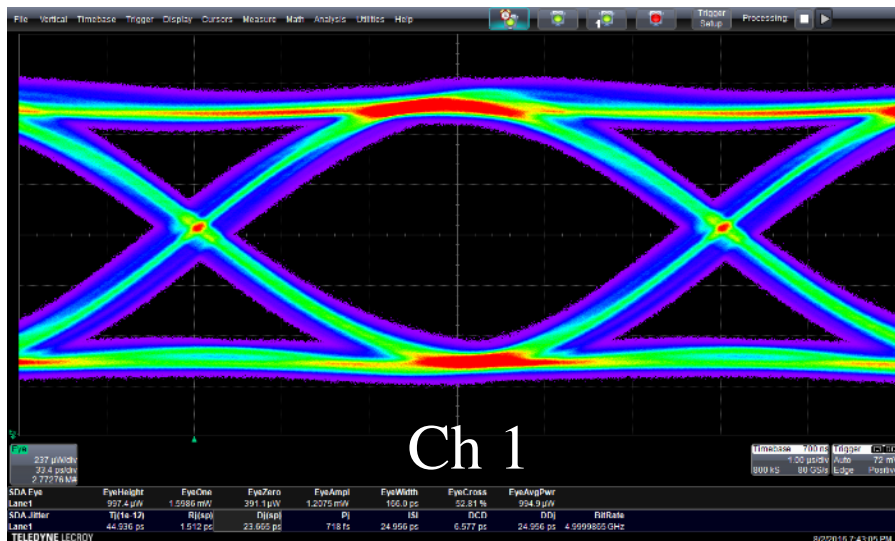# 10 Gb/s Array Driver ASIC Rev. 2

- **runs at 1.2 V**
  - ◆ consumes ~150 mA at 10 Gb/s with all four channels operating

- **cathode set to -1.3 V to provide enough headroom to drive the VCSEL**

- **optical power > 2 mW on all channels**

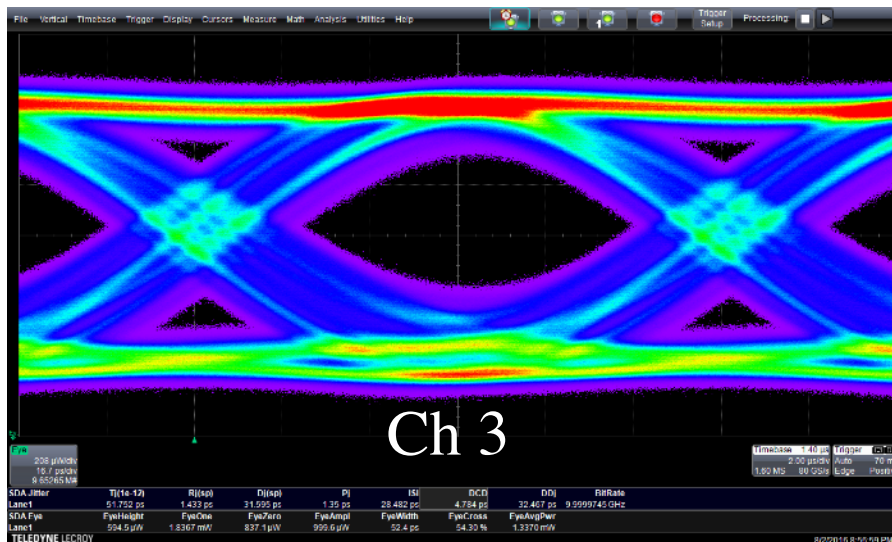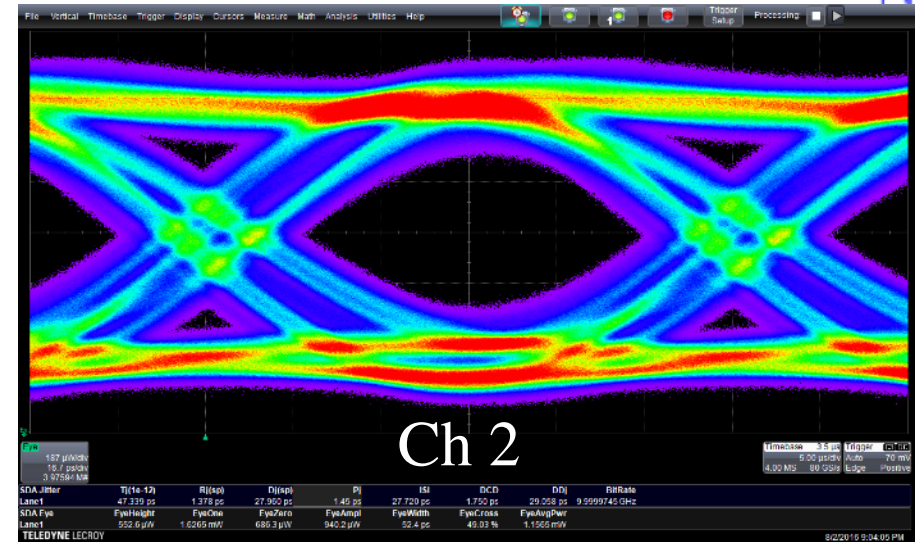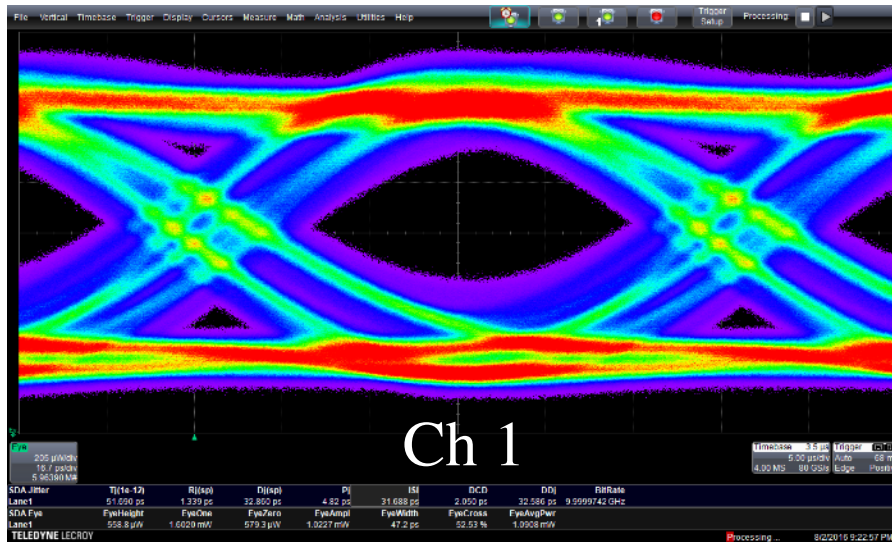- **BER < 5×10^{-14} on all channels at 10 Gb/s with every channel active**

175 μm space/trace controlled impedance transmission lines

Array Driver ASIC Rev. 2: 5 Gb/s

Ch 1

Ch 2

Ch 3

Ch 4 – worse than Rev. 1, wire bonds too long?
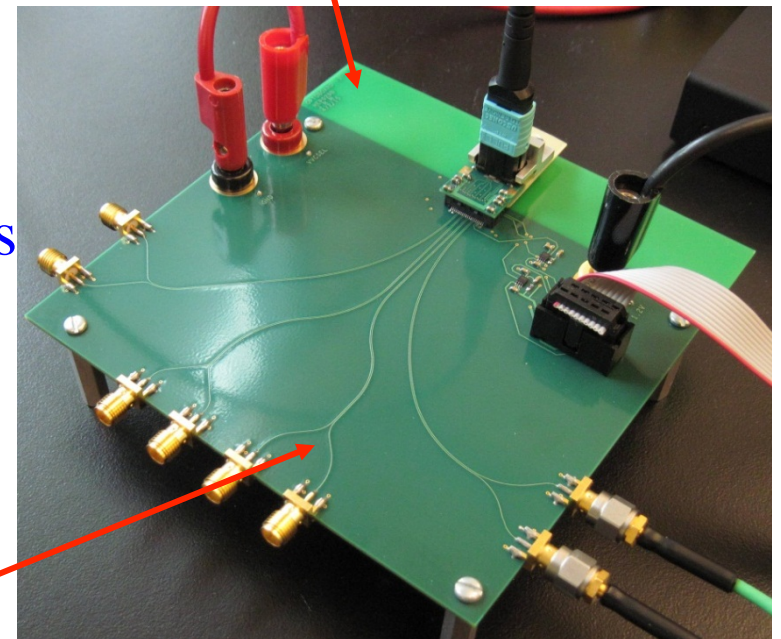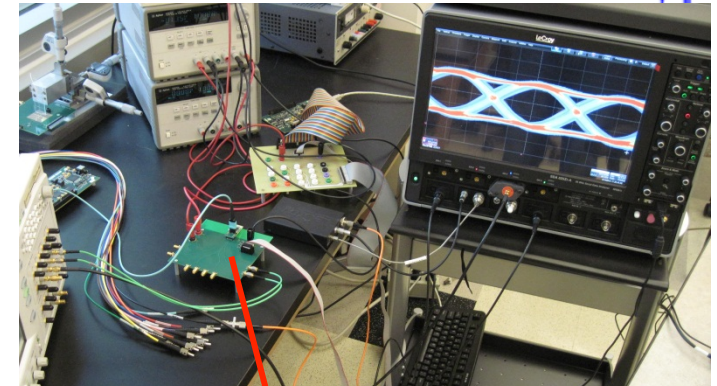
Array Driver ASIC Rev. 2: 10 Gb/s

Ch 1

Ch 2

Ch 3

Ch 4 –Poor, old design, wire bonds too long?

Summary

- designed and fabricated a new opto-board including
  an array driver ASIC and optical packaging
  to allow 10 Gb/s optical data transmission

- demonstrated the radiation hardness of the combination
  of a new VCSEL array and an array driver ASIC
  with successful 10 Gb/s operation after irradiation (> 10 Mrad)

- Rev. 2 VCSEL array driver is an improvement
  over Rev. 1 but more testing is needed