Results on ITK-Pixel Optical Links R&D

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Outline

- Introduction
- ITK-Pixel opto-board design
- ITK-Pixel opto-pack design
- Results from first prototype ITK-Pixel opto-board

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
- Versatile Links now developing 4-channel array links
  - ⇨ more logical for ITK-Pixel to use 12-channel arrays as in the 1st and 2nd generation opto-boards
    - build 3 x times fewer modules with 12-channel arrays

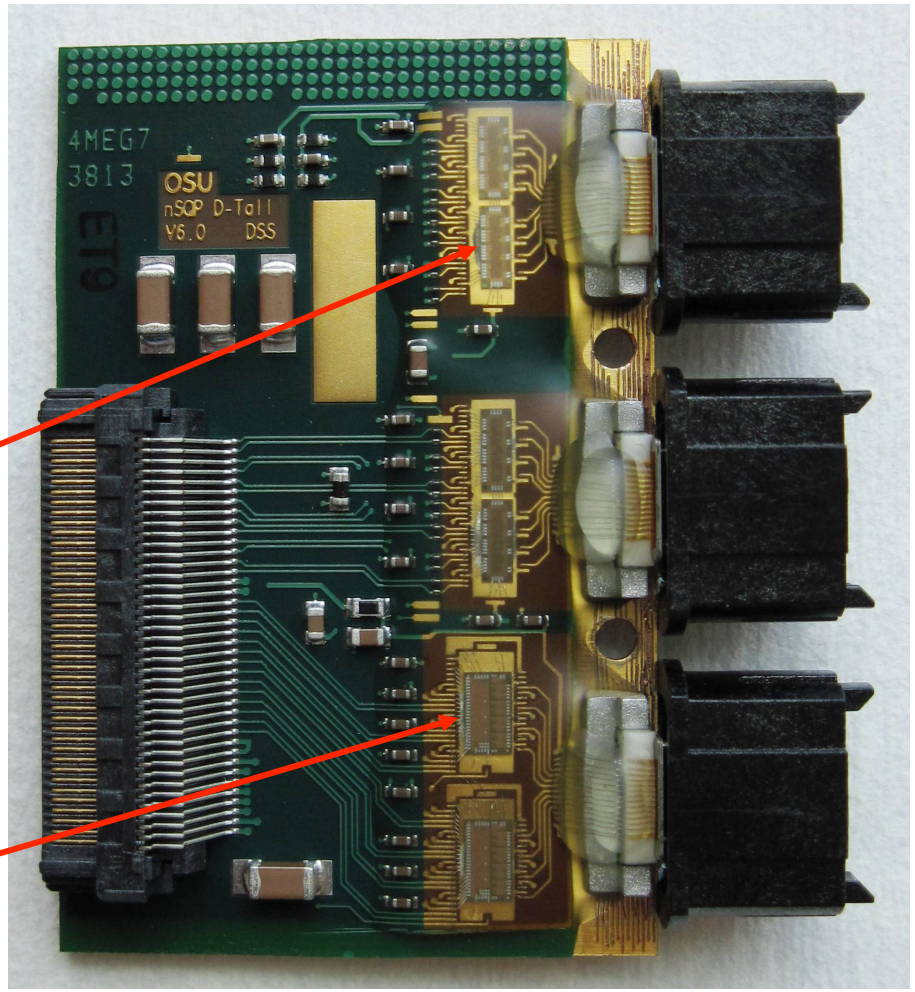
Opto-Links of Pixel Detector

- Built two generations of opto-links for the pixel detector
  - pixel detector initially has 3 barrel layers + 3 disks on each side
    - opto-links built by OSU had ~0.1% broken links
  - added insertable barrel layer (IBL) in 2014
    - move opto-links to more accessible location
    - 300 opto-modules (opto-boards) are needed
      - ~6,000 opto-links
      - fabricated 400 opto-boards

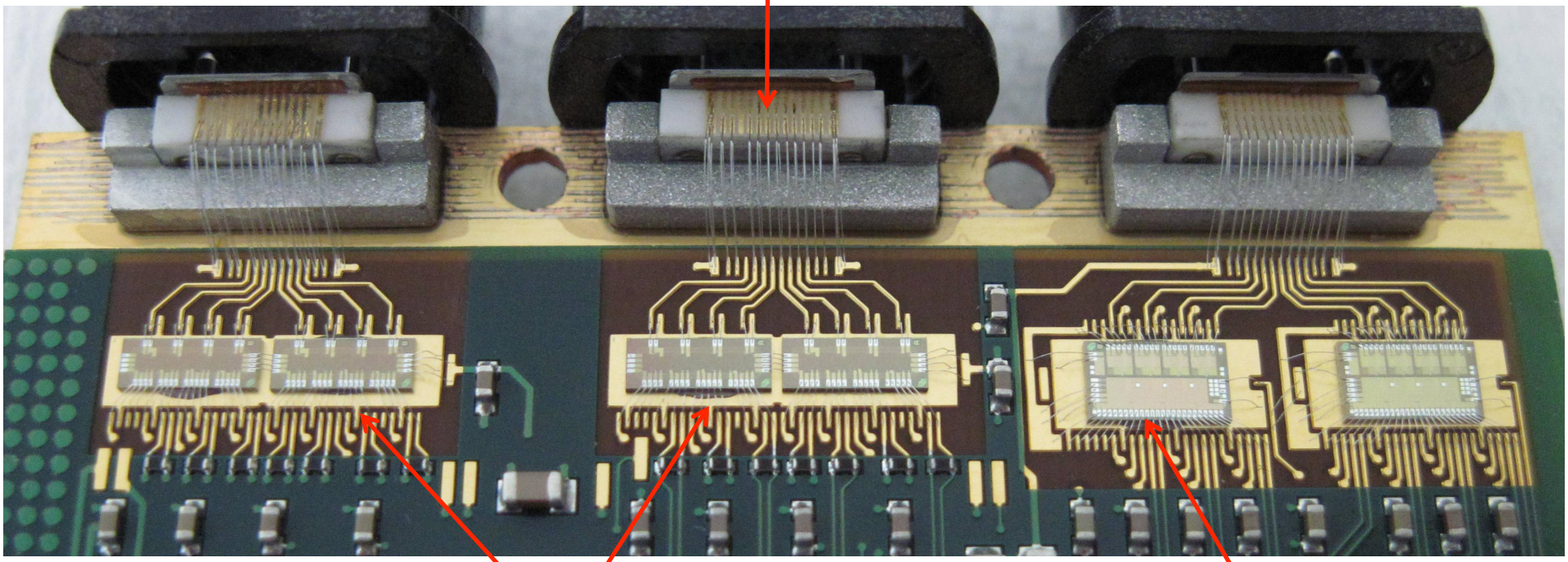
Proposed ITK-Pixel Opto-Board

- Use experience from the original pixel, nSQP, and IBL, to develop an opto-board capable of operation at 5 Gb/s or higher for ITK-Pixel
- What is required to demonstrate that the opto-board concept is a logical solution for ITK-Pixel?
  - 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

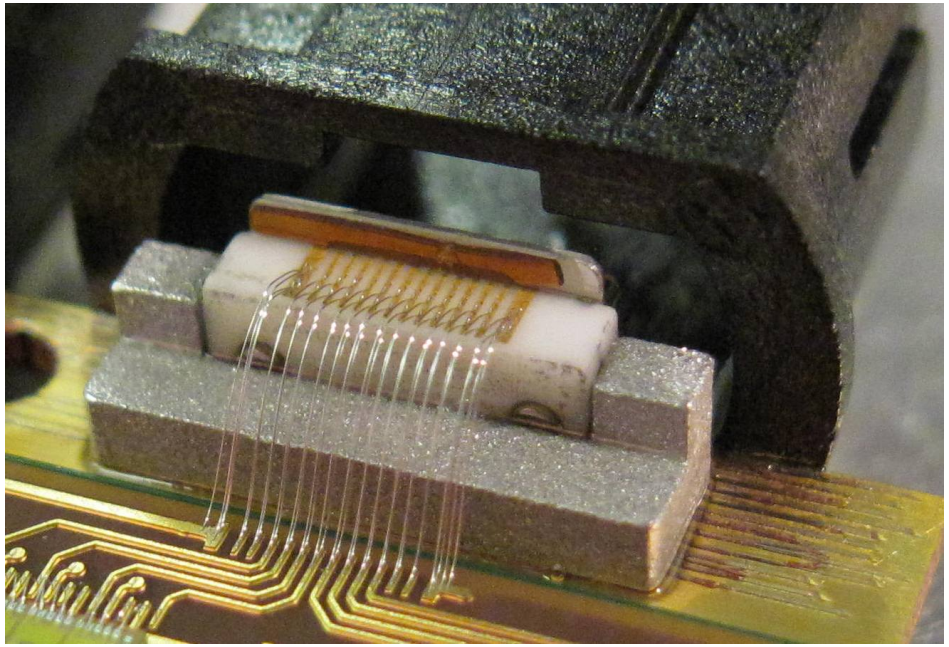
2nd Generation Pixel Opto-Board



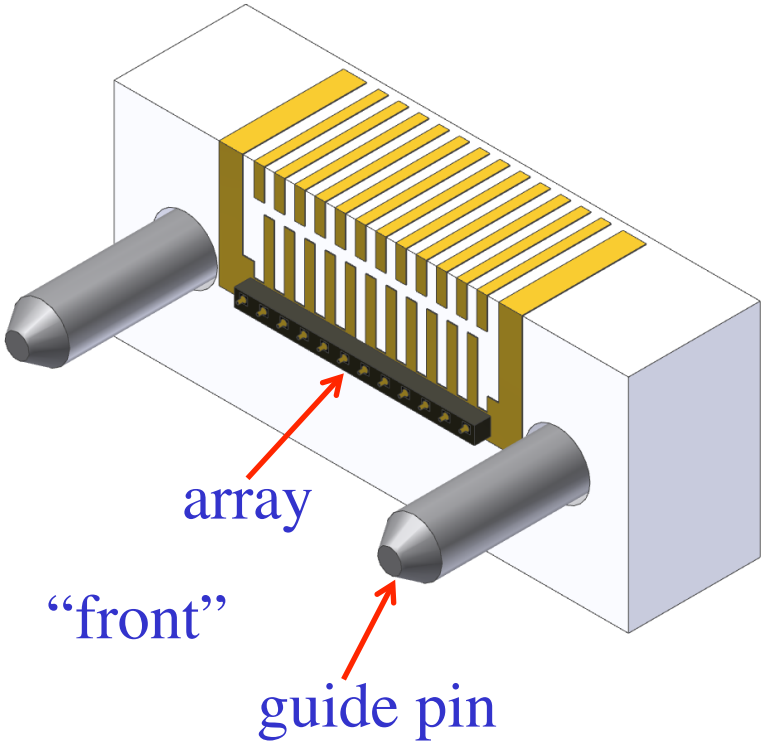
Close Up View



Opto-Pack

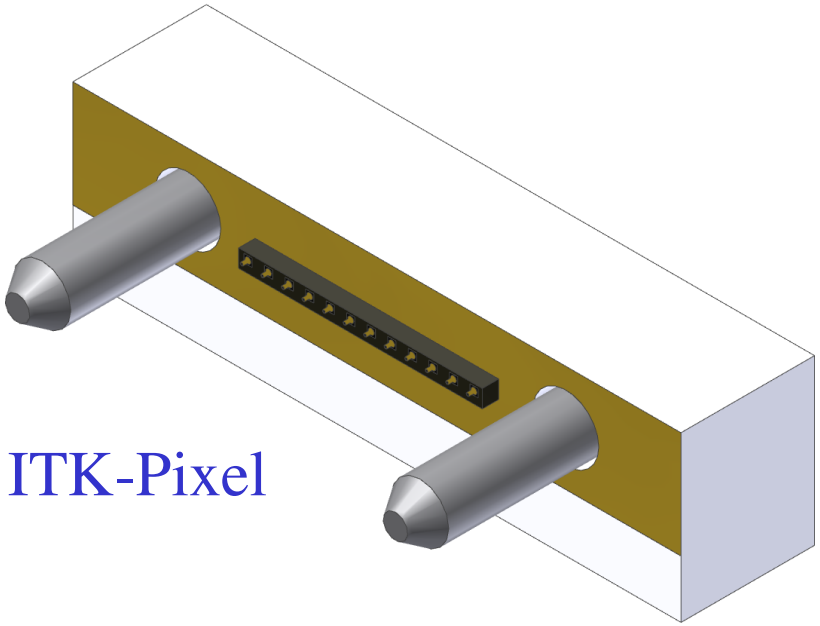


"back"

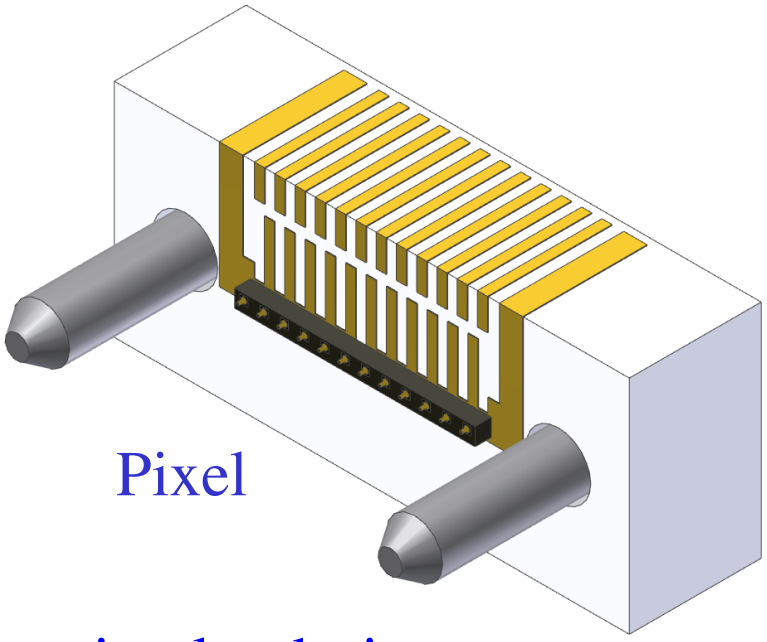


- Use BeO as substrate for heat management

Opto-Pack for ITK-Pixel



ITK-Pixel

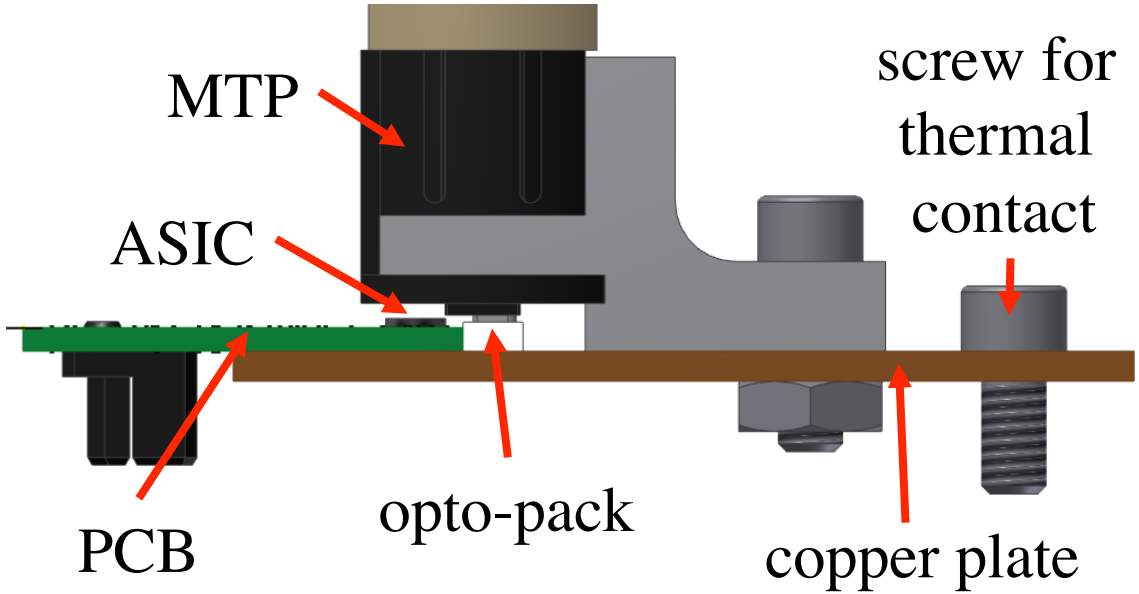


Pixel

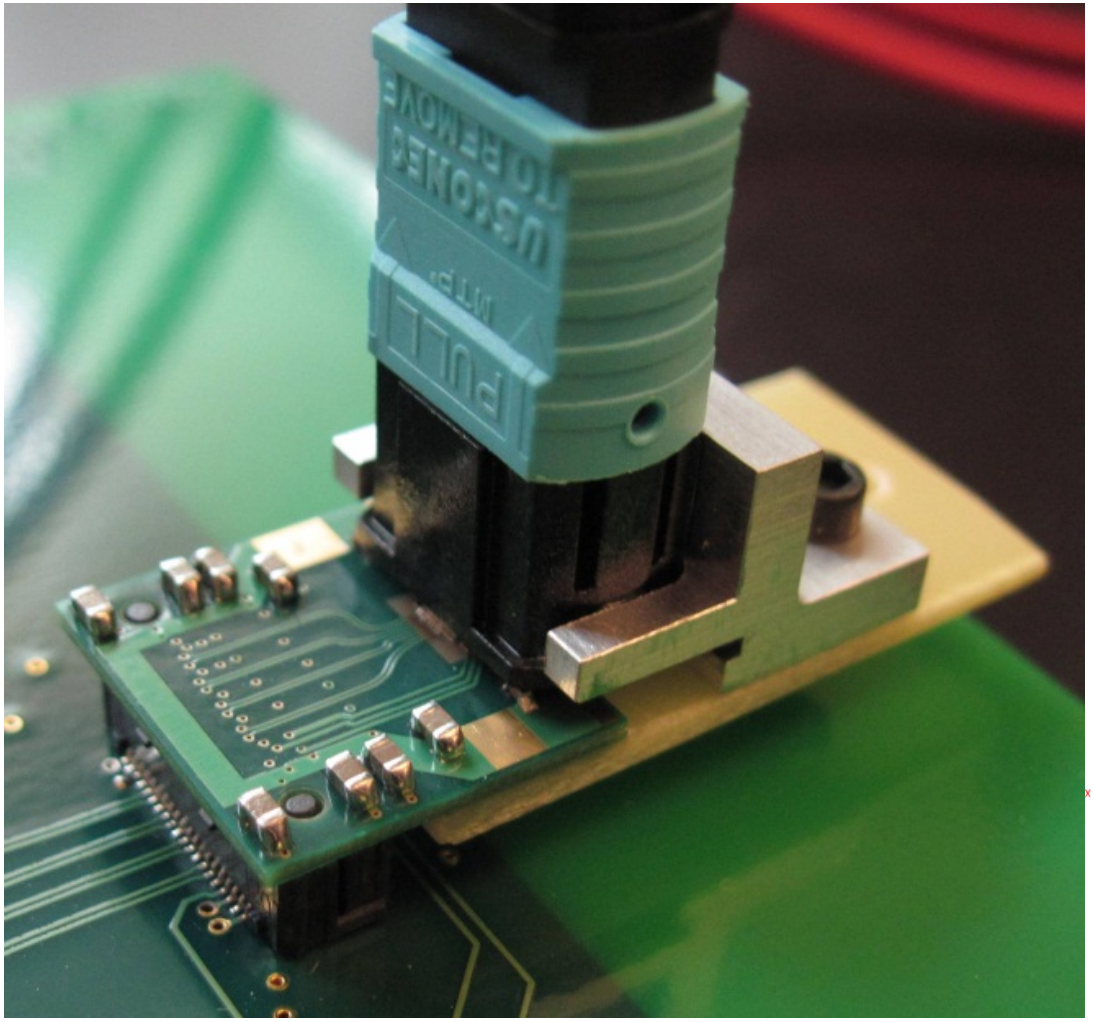
- Proposed opto-pack for ITK-Pixel has simpler design
- experience in building large quantity of opto-packs:
  - fabricated 1,200 opto-packs for pixel opto-boards
  - fabricating 280 PIN opto-packs for off-detector opto-receivers
  - equivalent to 18,000 channels

ITK-Pixel Opto-Board Concept

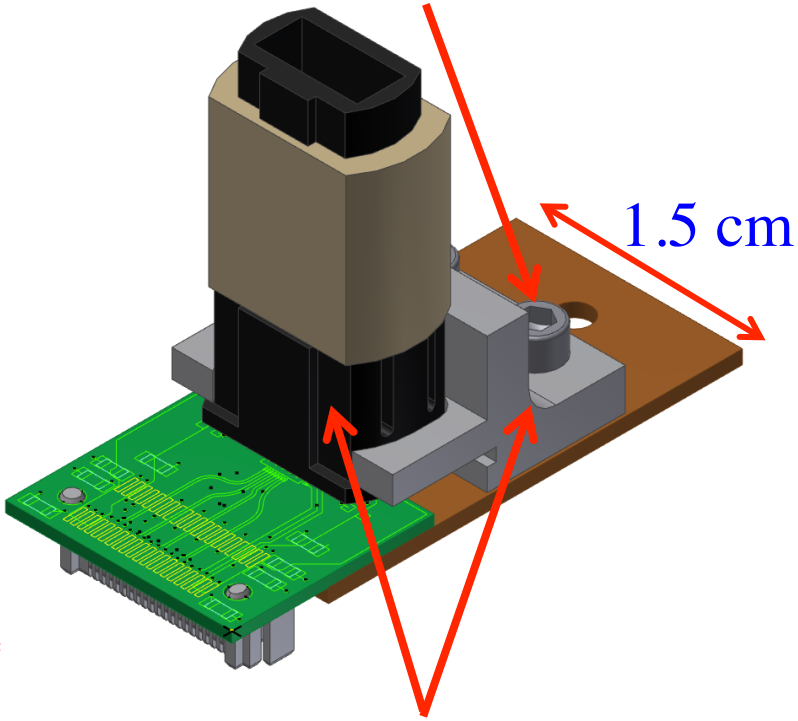
- Keep opto-pack
- Keep copper backed PCB
- Keep MTP connector
- Compatible with an opto-box concept
- No lenses/mirrors used to turn the light



ITK-Pixel Opto-Board (Version -1)



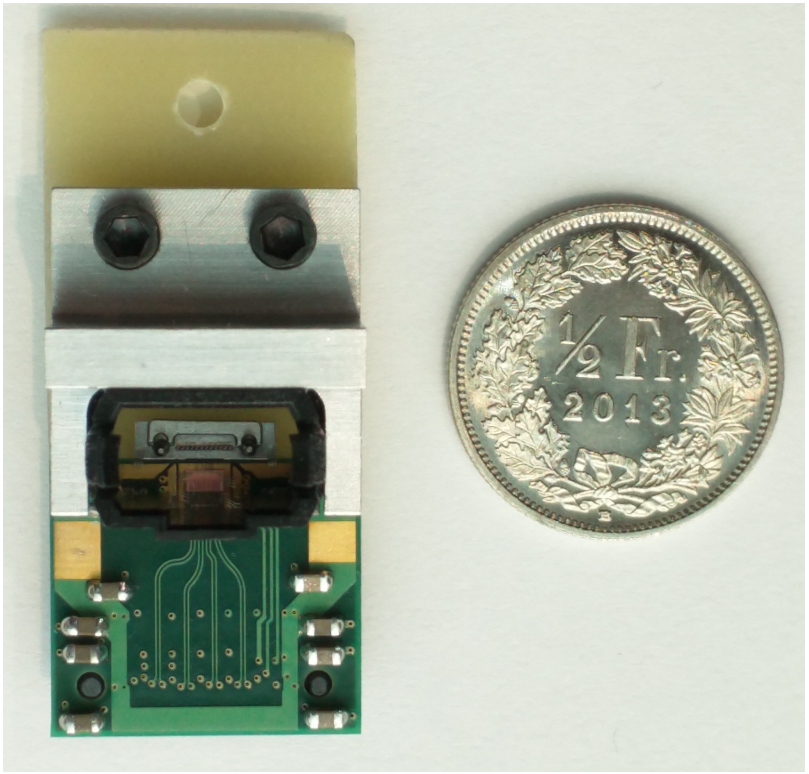
Connector secured to opto-board with screws instead of epoxy in current opto-board

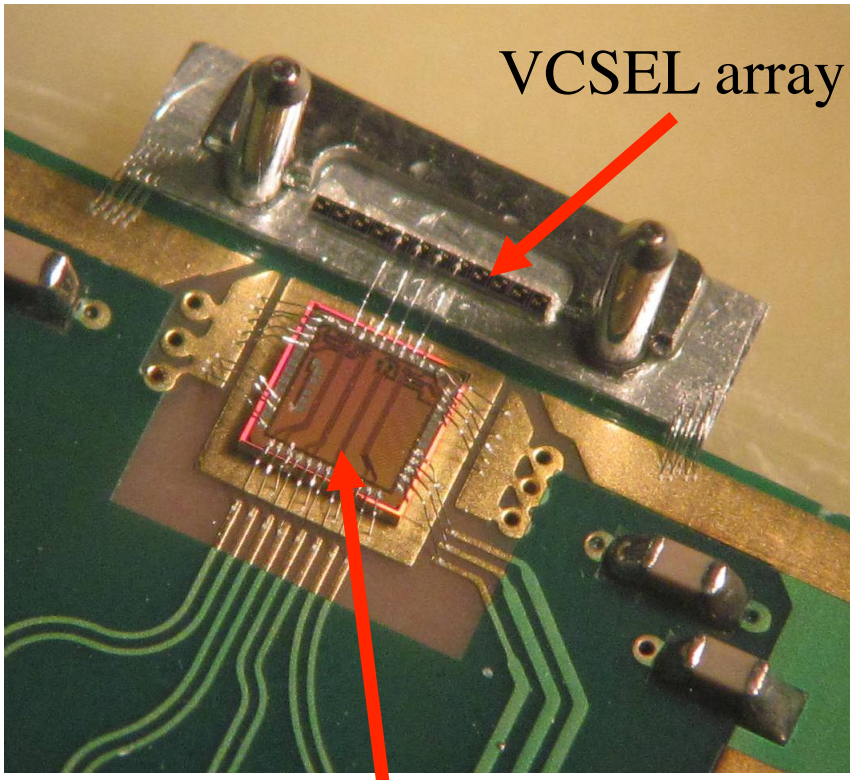


Could be fabricated as one piece with mold injection

ITK-Pixel Opto-Board

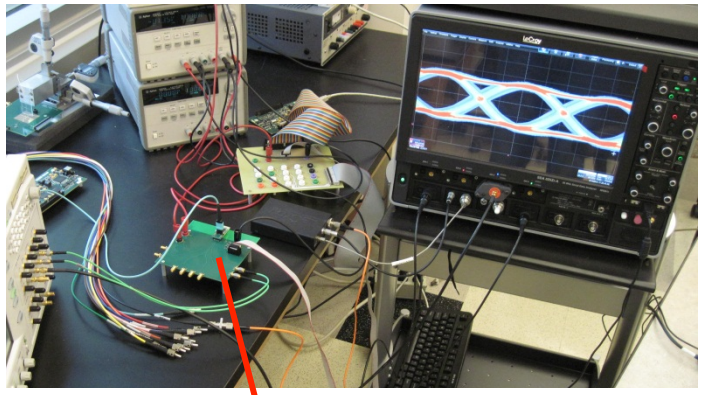
- Produced a 4-channel opto-board using our array driver ASIC
  - Scalable to 12 channels by simply replacing the ASIC
- Uses a Finisar 12-channel VCSEL array (V850-2174-002)

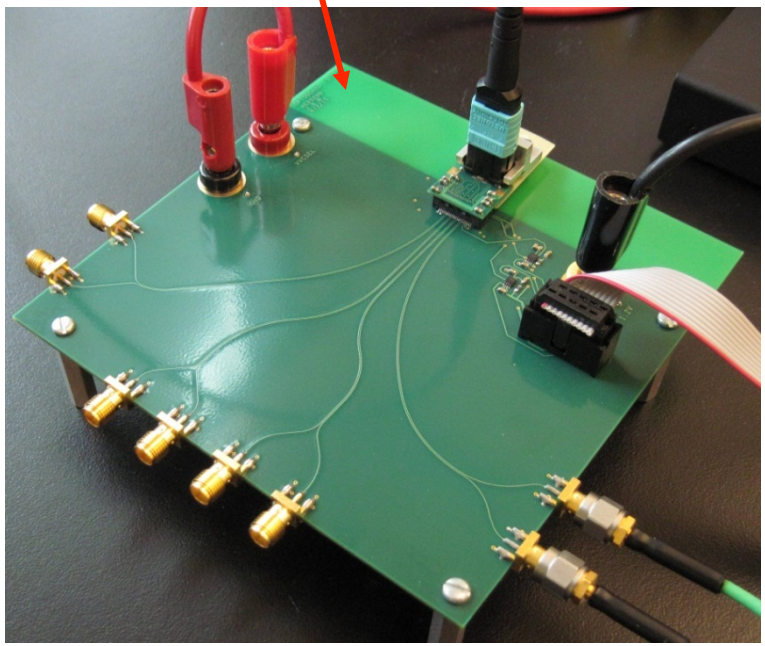




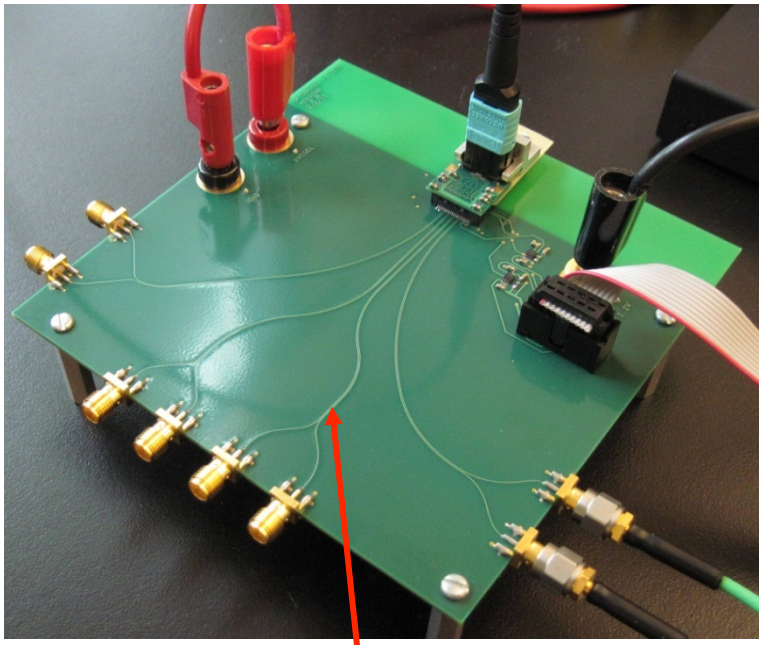
ITK-Pixel Opto-Board

- runs at 1.2 V
  - With all four channels operating consumes ~150 mA at 5 Gb/s
- cathode set to -1.3 V (~20 mA) to provide enough headroom to drive the VCSEL
- optical power > 2 mW on all channels
- BER <1x10^{-13} on all channels at 5 Gb/s with every channel active



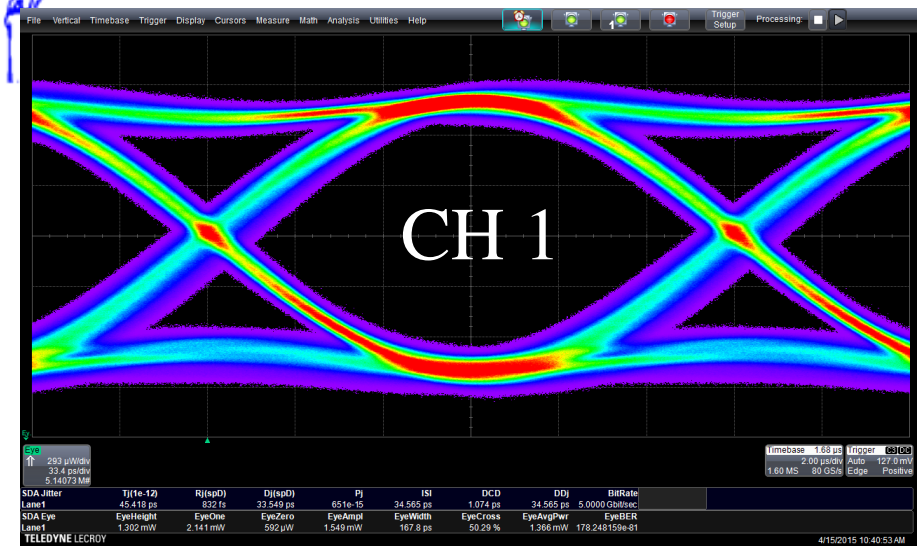


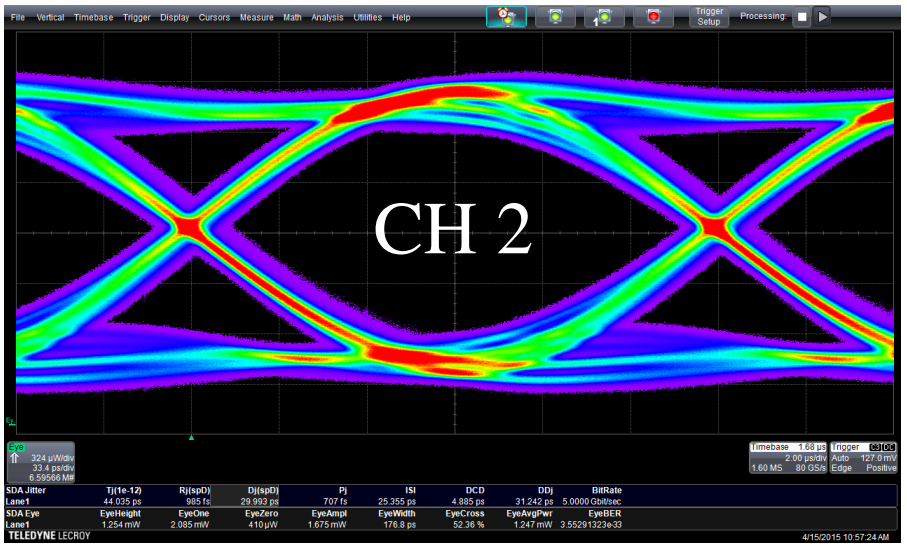
Back-Plane inside Opto-Box

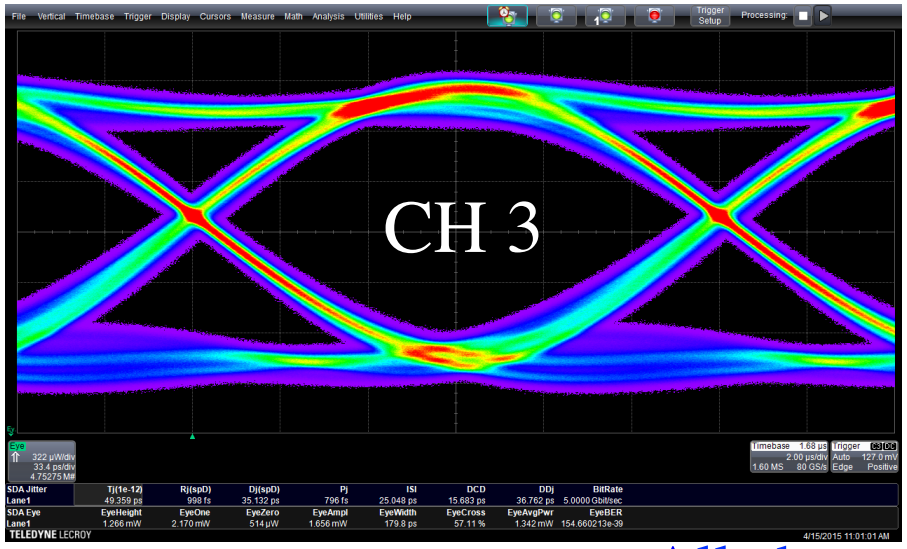


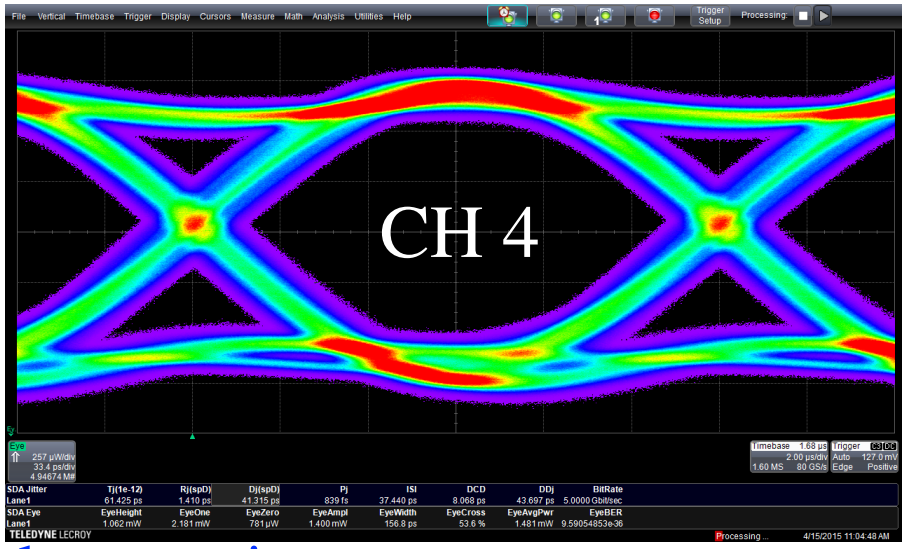
- use 175 μm space/trace controlled impedance transmission lines
- successfully transmit 5 Gb/s signals via Samtec LSHM connectors
  - ⇨ no need to connect high-speed cables directly to opto-board
  - ⇨ connect high-speed cables to “back-plane” inside opto-box

Eye Diagrams at 5 Gb/s









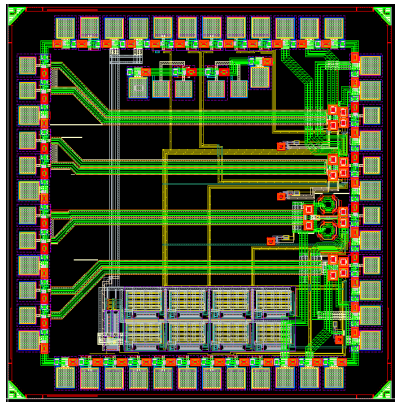
- All channels are active

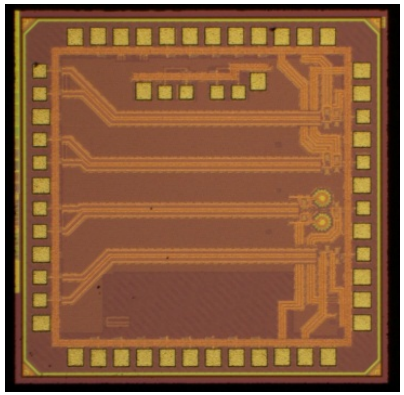
10 Gb/s VCSEL Array Driver

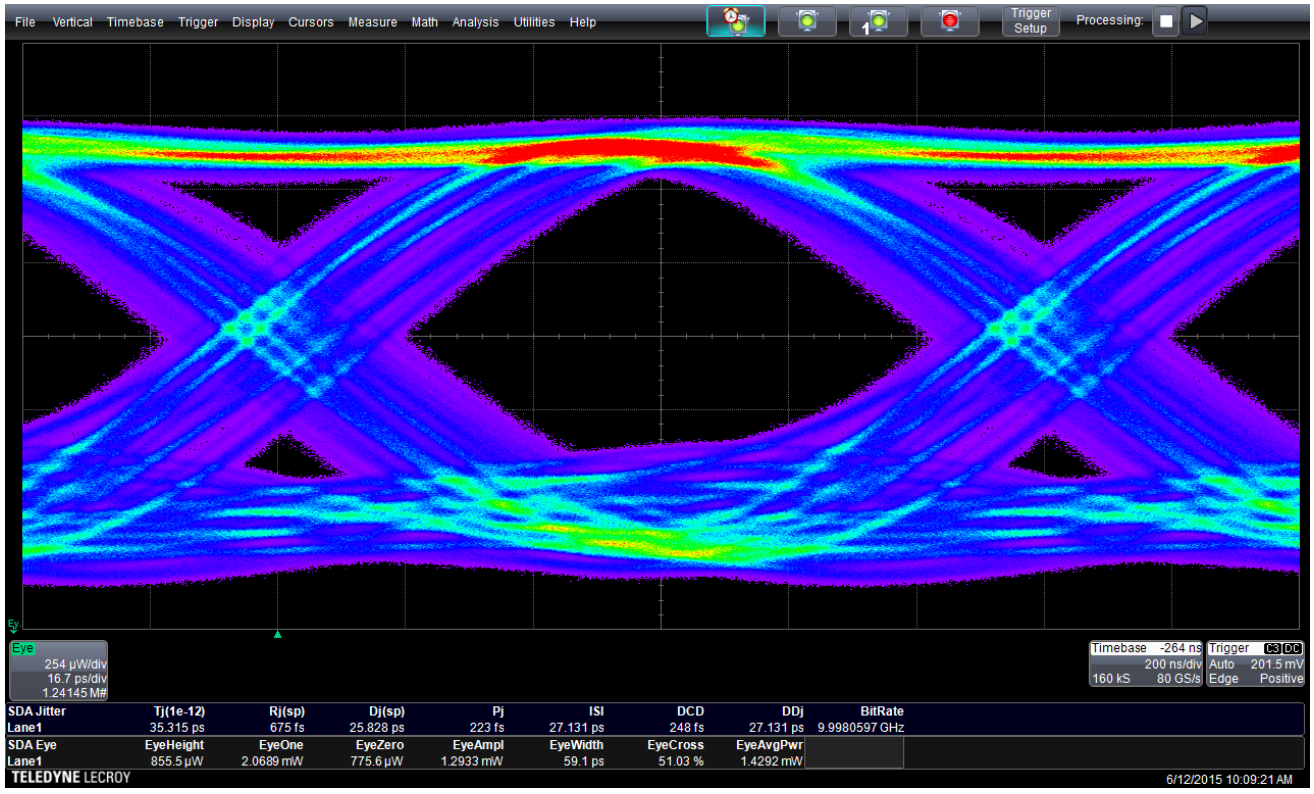
- R&D funded via CDRD in US (FY13-15)
- 4-channel test chip submitted in October 2014 (65 nm CMOS)
  - 2 mm x 2 mm
  - Each channel slightly different to explore design choices
- Uses only core transistors to achieve maximum radiation-hardness
- Includes 8-bit DACs to set the VCSEL modulation and bias currents
- DAC settings stored in SEU tolerant registers

Eye Diagram at 10 Gb/s

- Eye diagram at 10 Gb/s is open but improvement is needed
  - Bit error bit < 1.3×10^{-15}
  - ASIC is quite adequate for operation at 5 Gb/s

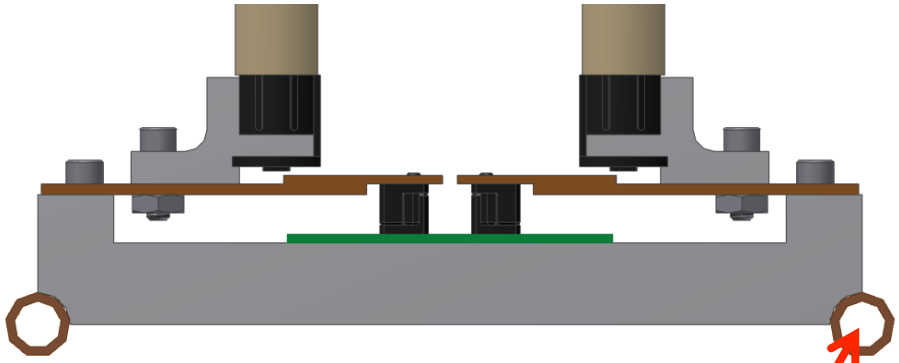


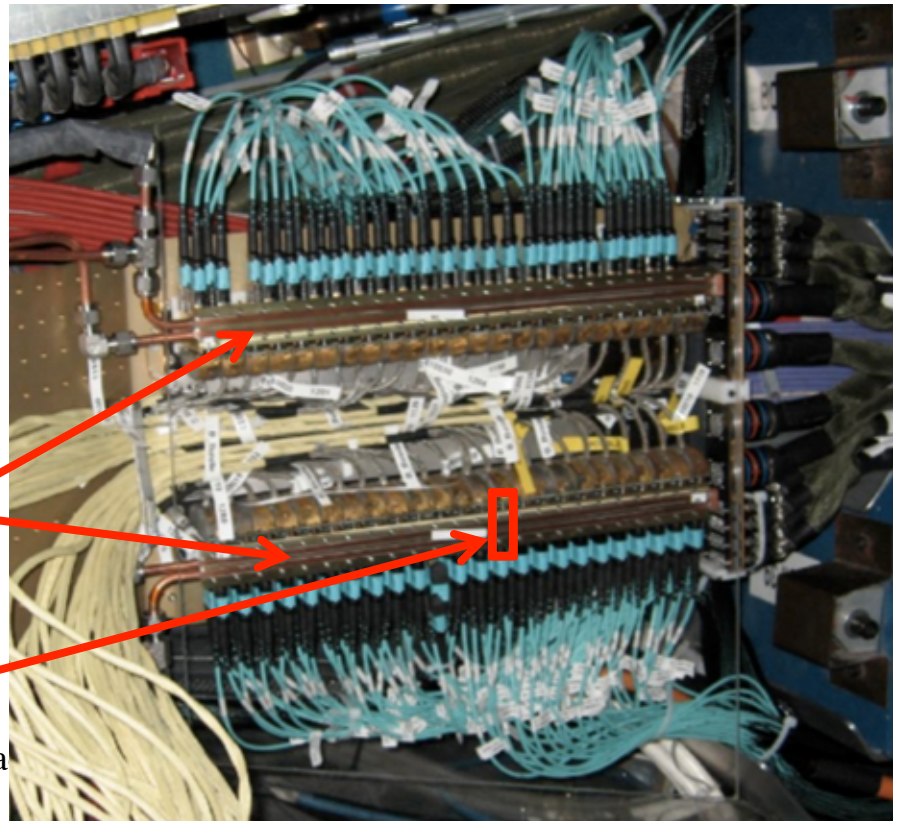




ITK-Pixel Opto-Box Concept

- ITK Opto-board allows for opto-box like mounting and cooling
- achieve similar density of fiber connectors
- all fiber cables exit vertically rather than from both sides
  - more compact packing/less messy





How About the Downlinks?

- It is more logical to also use 12-channel PIN arrays
  as in the 1st and 2nd generation pixel optical links (opto-boards)
- Highly desirable to have 1:1 ratio for uplink and downlink
  instead of one downlink per stave
  - ✔ prevent the lost of an entire stave with a broken downlink
    - no need to develop ASIC to steer a downlink in case of failure
    - saving in fibers will be offset by ASIC development cost
  - ✔ simpler opto-board design with MTP connectors only
    instead of mixture of fiber connectors
  - use low-mass carbon fibers to send 160 Mb/s signal to FEs?
- Could simply use a stripped-down version of GBT
  and layout a 12-channel version for ITK-Pixel

Summary

- successfully designed and prototyped an opto-board for ITK-Pixel
- include an ASIC and optical packaging
- satisfactory performance for 5 Gb/s optical data transmission