Radiation-Hard Optical link for the ATLAS Pixel Detector

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September 13th, 2005

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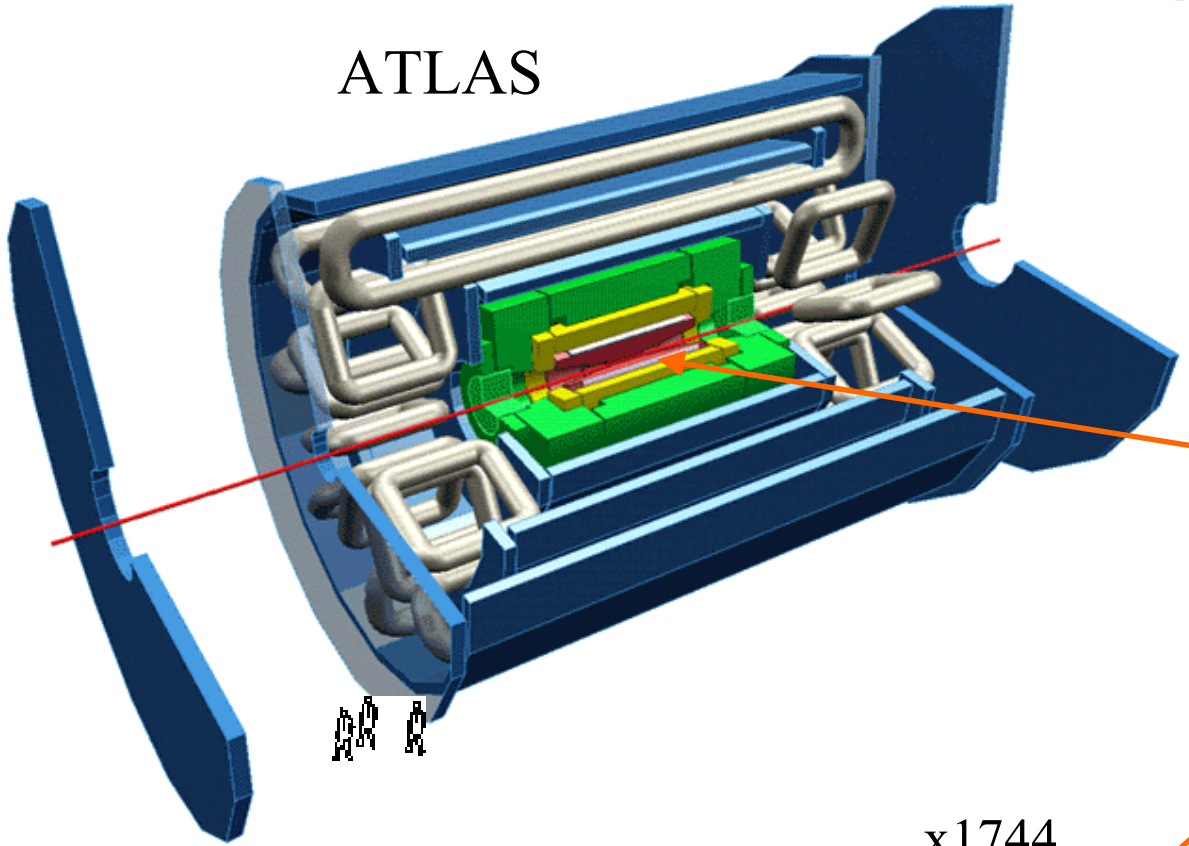
Overview

- ATLAS pixel detector
- Pixel Opto-link system
- The VDC and DORIC
- BeO Optoboard
- Proton Irradiation studies
- Production status

Overview: The scale of things

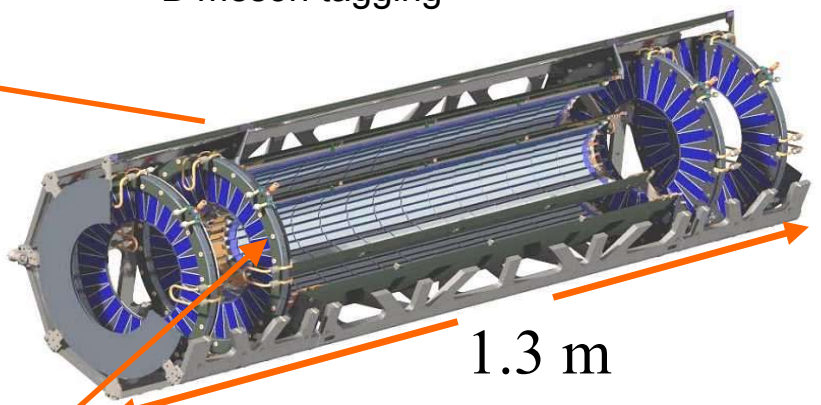
ATLAS



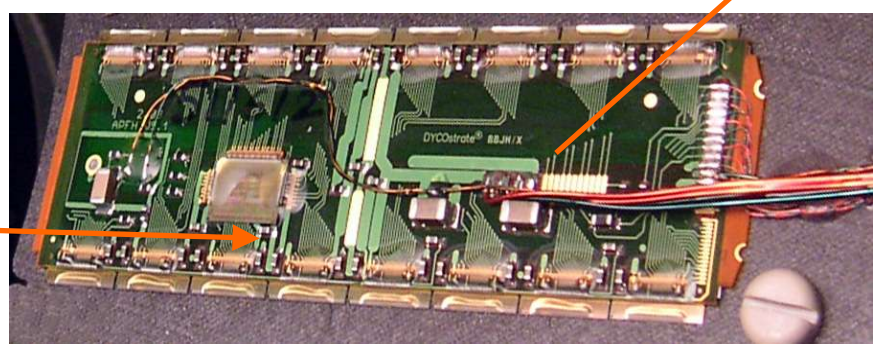
–ATLAS Pixel Detector

Innermost sub detector, provides

- precise tracking in high multiplicity environment
- 3D-vertexing
- B meson tagging



x1744



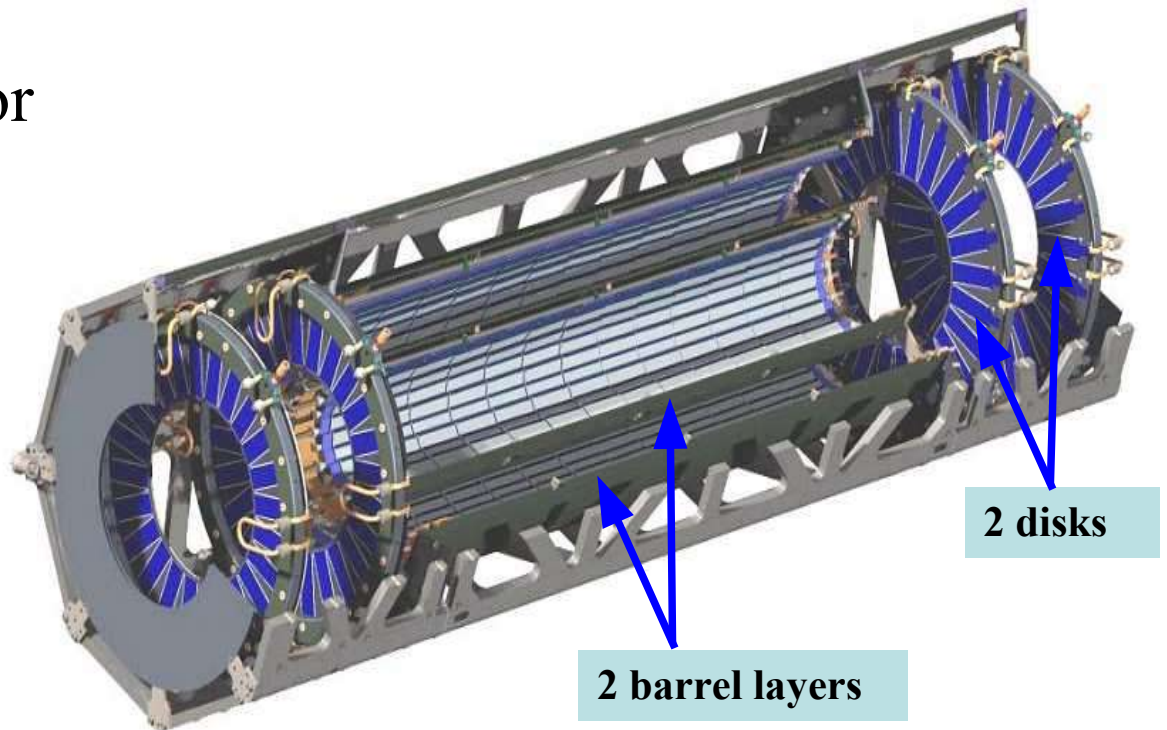
x46080

50 x 400 μm

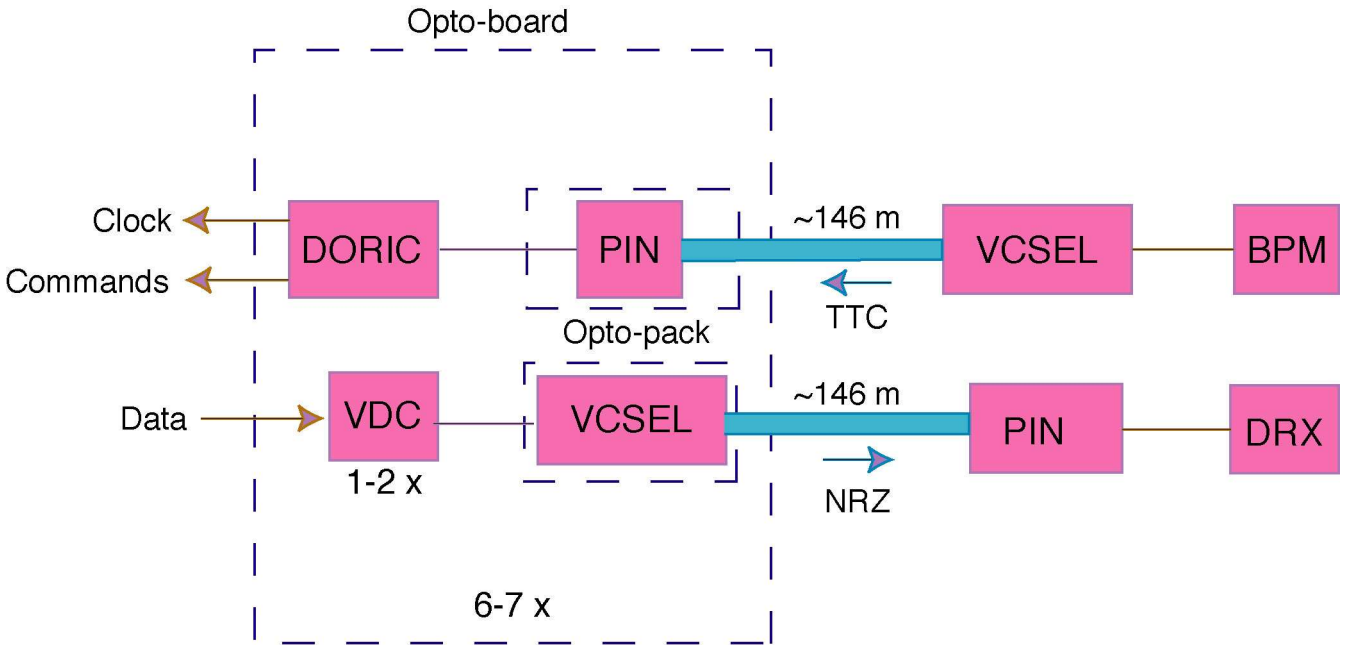
ATLAS Pixel Detector Module. Production is underway. Will focus on optical electronics today.

ATLAS Pixel Detector

- Inner most tracking detector
- Pixel size: 50μm x 400μm
- ~100 million channels
- Barrel layers at r = 5.1 and 12.3 cm
- Disks at z = 50 and 65 cm
- Dosage after 10 years ⇨ optical link: 17 Mrad
  or 3.7x 10^{14} 1-MeV n_{eq}/cm^2



ATLAS Pixel Opto-link



VCSEL: **Vertical Cavity Surface Emitting Laser diode**

VDC: **VCSEL Driver Circuit**

PIN: **PiN diode**

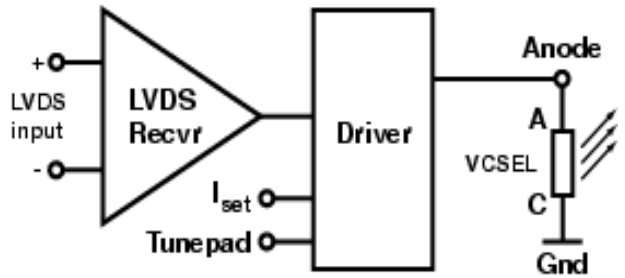
DORIC: **Digital Optical Receiver Integrated Circuit**

Opto-link system design

- A simple and elegant solution for the pixel detector optolink
- Only 3 flavours of boards: B boards, left D and right D boards
- Modular design reduces complexity and is easier to build
- Problems have been tracked down relatively quickly
- Wirebonds encapsulated for ease of handling and protection against breakage due to vibrations.
- Optoboard construction has been fast (~7 months to complete)

VDC: VCSEL Driver Circuit

- Convert LVDS input signal into single-ended signal appropriate to drive VCSEL diode
- Output (bright) current: 0 to 20 mA controlled by external current I_{set}



- Standing (dim) current: ~1 mA improve switching speed
- Rise & fall times: 1 ns nominal for 40 MHz signals
- "On" voltage of VCSEL: up to 2.3 V at 20 mA for 2.5 V supply
- Constant current consumption!
- Use Truelight high-power oxide common cathode VCSEL array

DORIC: Digital Optical Receiver IC

Decode Bi-Phase Mark encoded (BPM) clock and command signals from PIN diode

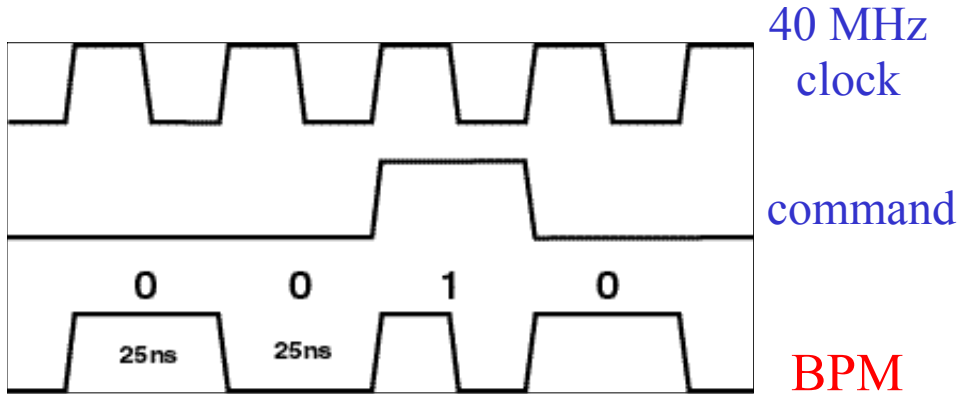
Input signal: 40-1000 μA

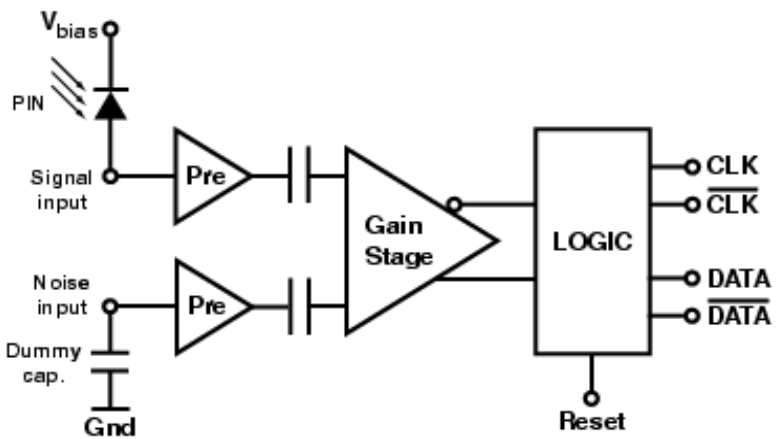
Extract: 40 MHz clock

Duty cycle: (50 ± 4)%

Total timing error: < 1 ns

Bit Error Rate (BER):
< 10^{-11} at end of life
Use Truelight common cathode PIN array

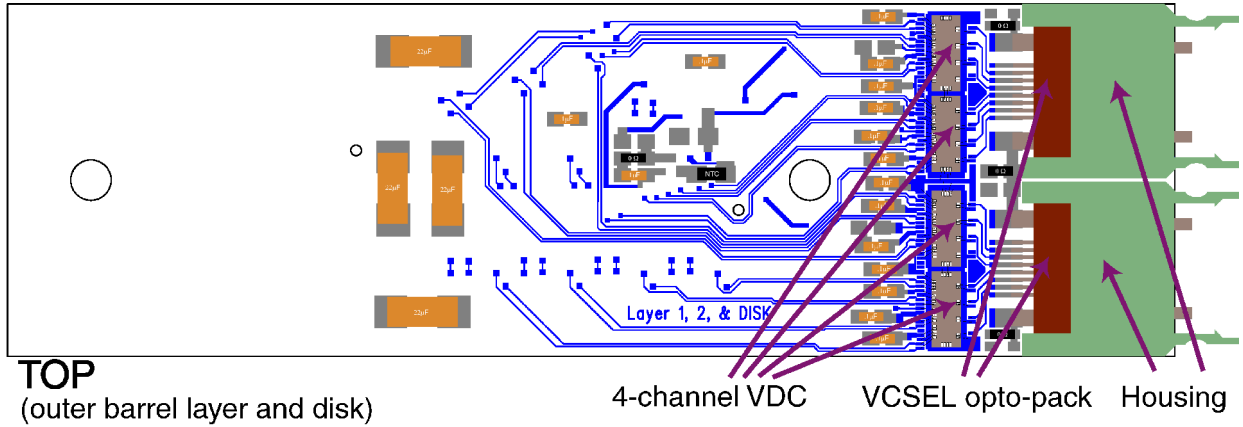


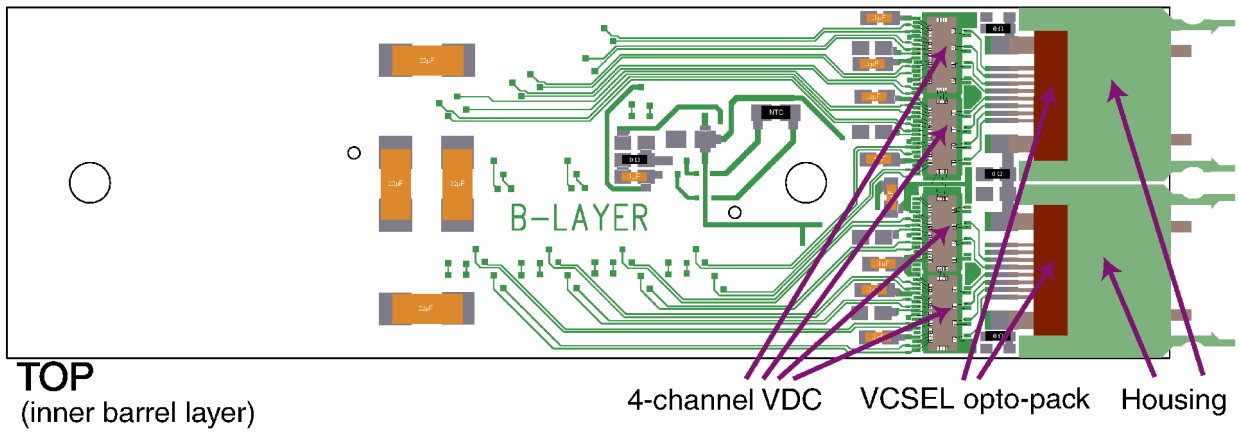


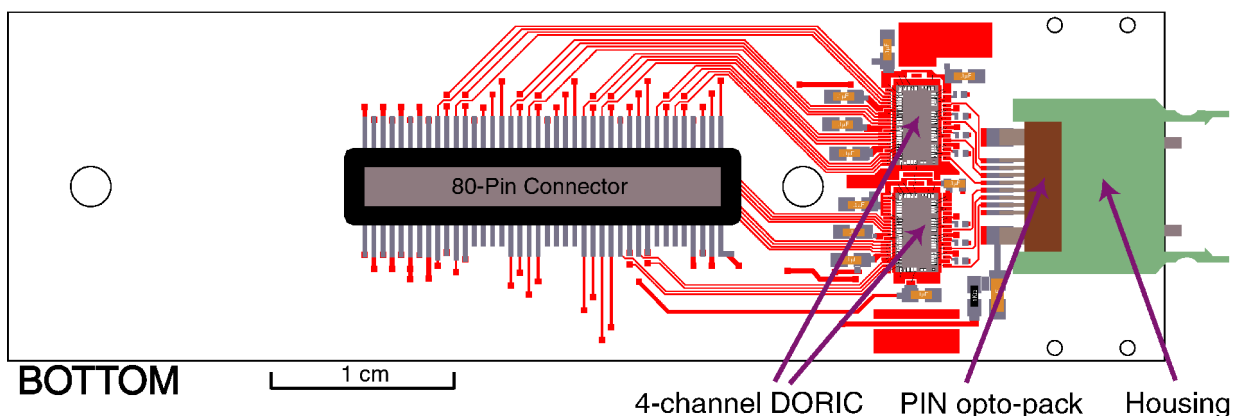
Optoboard

- Converts: optical signal ⇔ electrical signal
- Contains 7 optical links, each link serving one pixel module
  - Layer D: for outer barrel and disks, only one data link per module (228 boards).
  - Layer B: for inner barrel, two data links per module to accommodate for high hit occupancy (44 boards).
- Fabricated with BeO for heat management

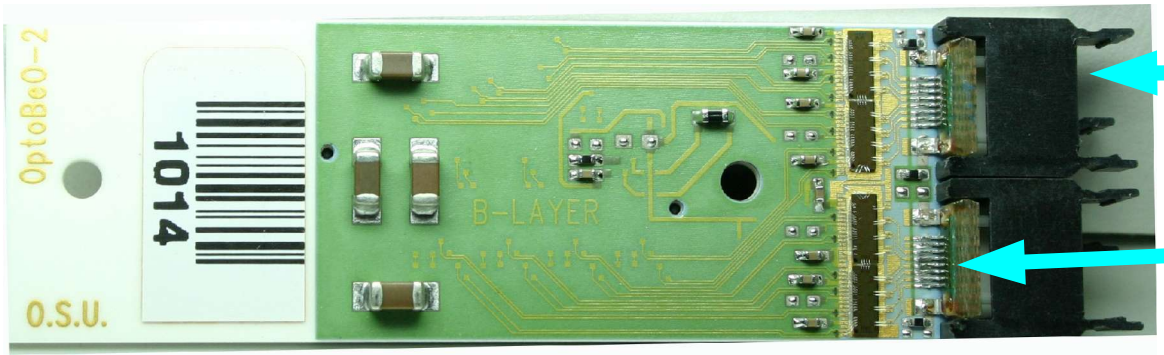
Optoboard design and Layout

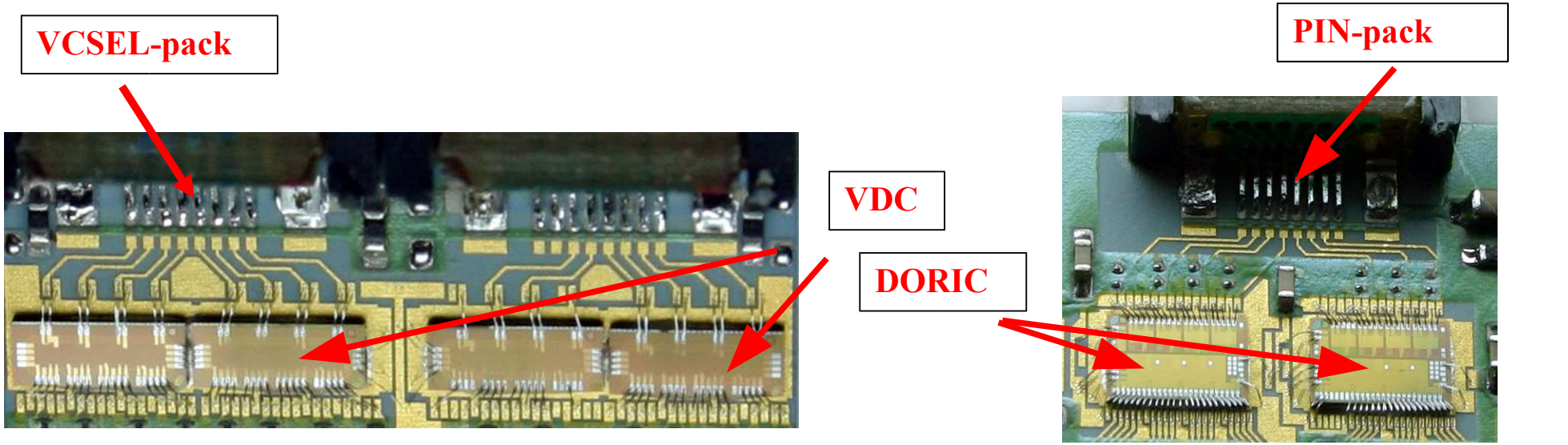




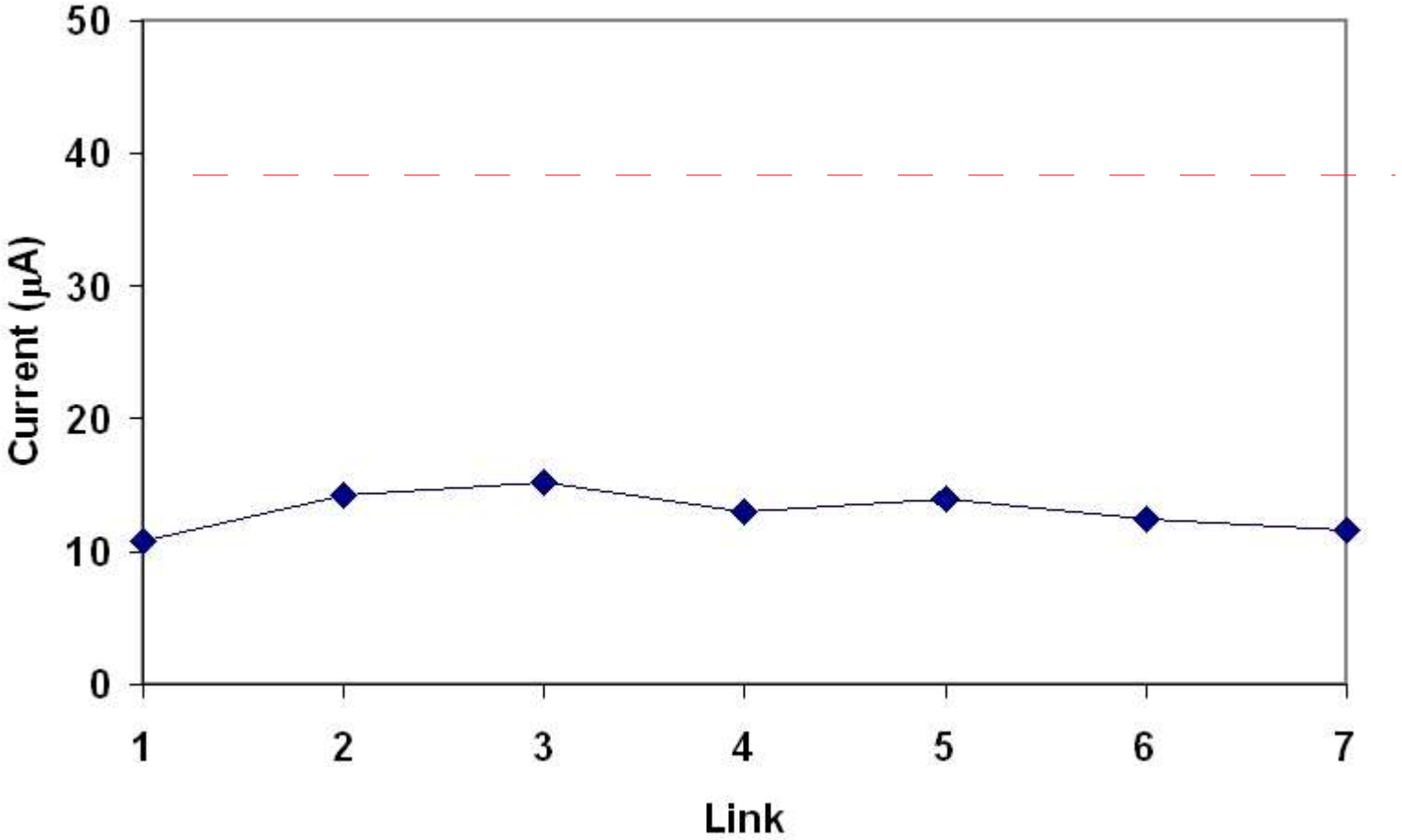


BeO Optoboard



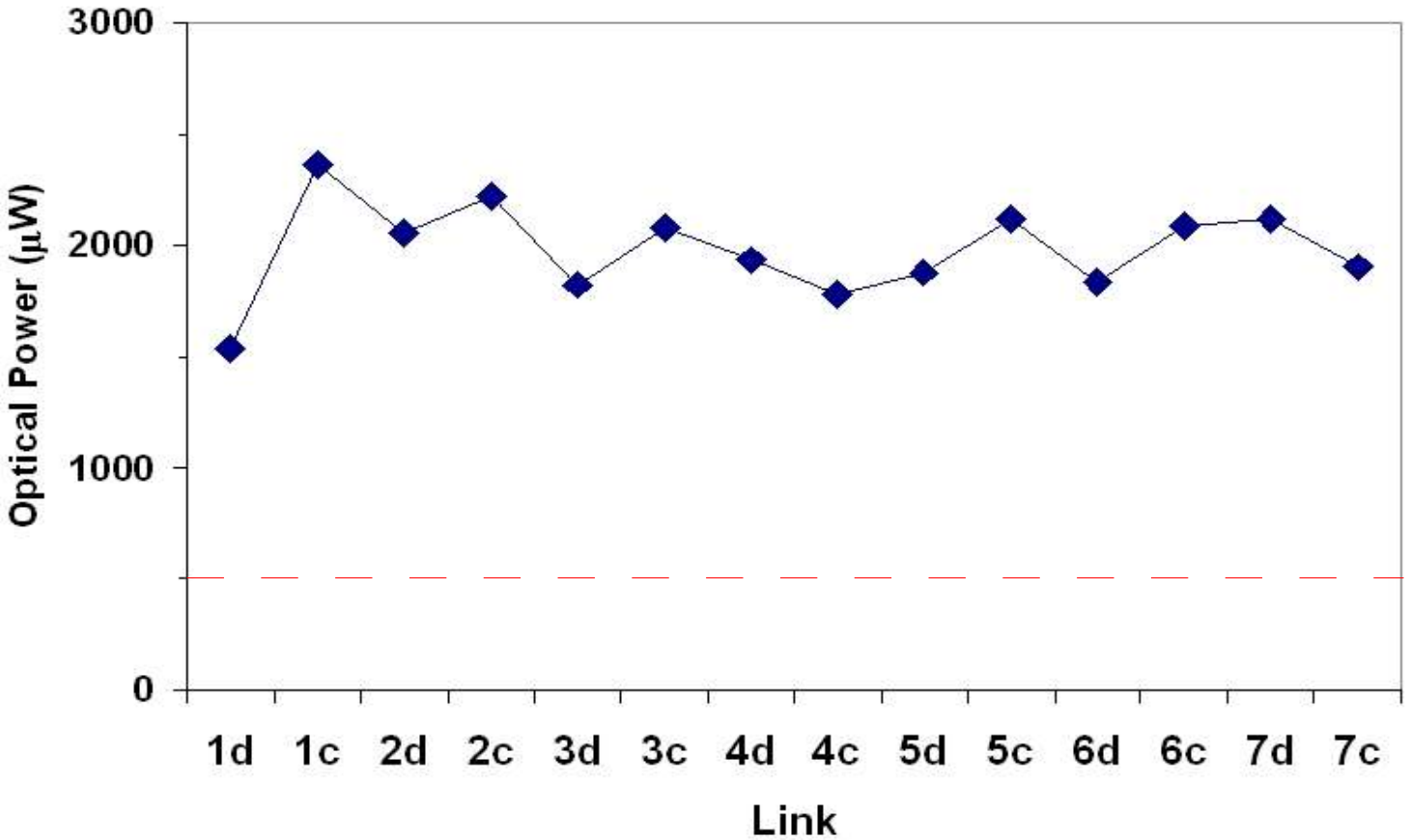


Minimum PIN Current for No Bit Error



- Minimum PIN current for no bit error for all links active is significantly below the spec. of 40µA

Optical Power

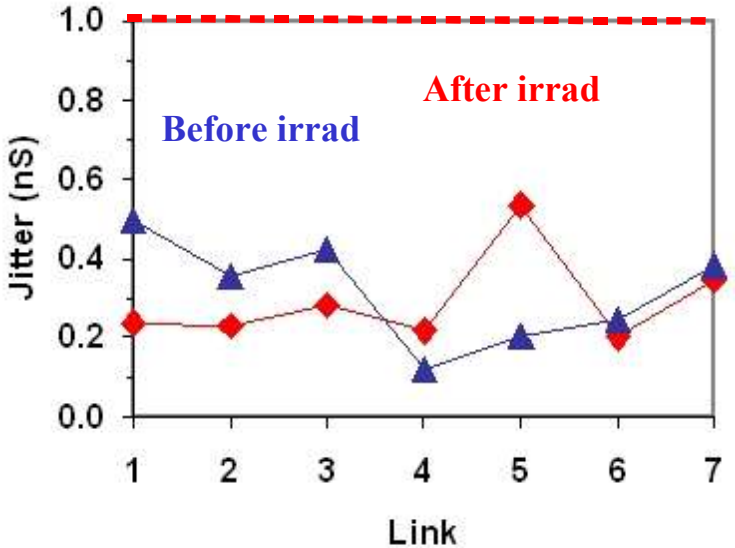


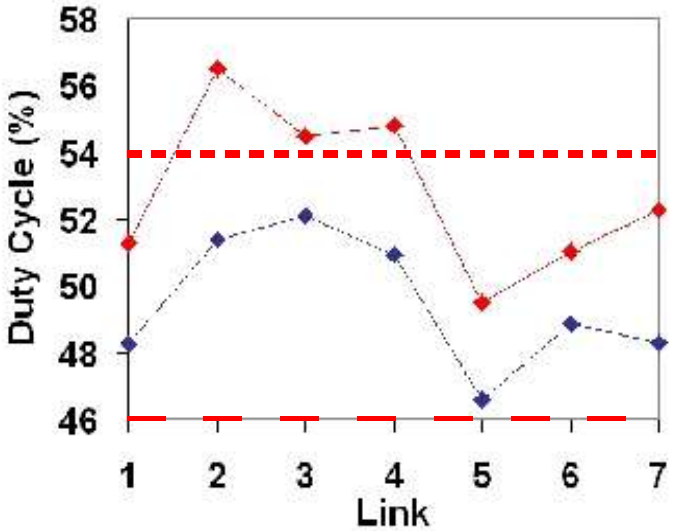
- Excellent optical power
  - Significantly above the minimum requirement of 500µW

Radiation Hardness Measurements of Opto-boards

- Use CERN's T7 beam (24 GeV Proton) for radiation hardness
  - T7 shuttle setup
    - Boards can be moved in and out of beam remotely for annealing
  - Real time testing of opto-board system using loop-back setup
    - Compare transmitted and decoded data
    - measure minimum PIN current for no bit errors
    - Measure optical power
- Last irradiation in June 2004
  - Four BeO opto-boards were irradiated with up to 32 Mrad
  - Received at OSU late 2004

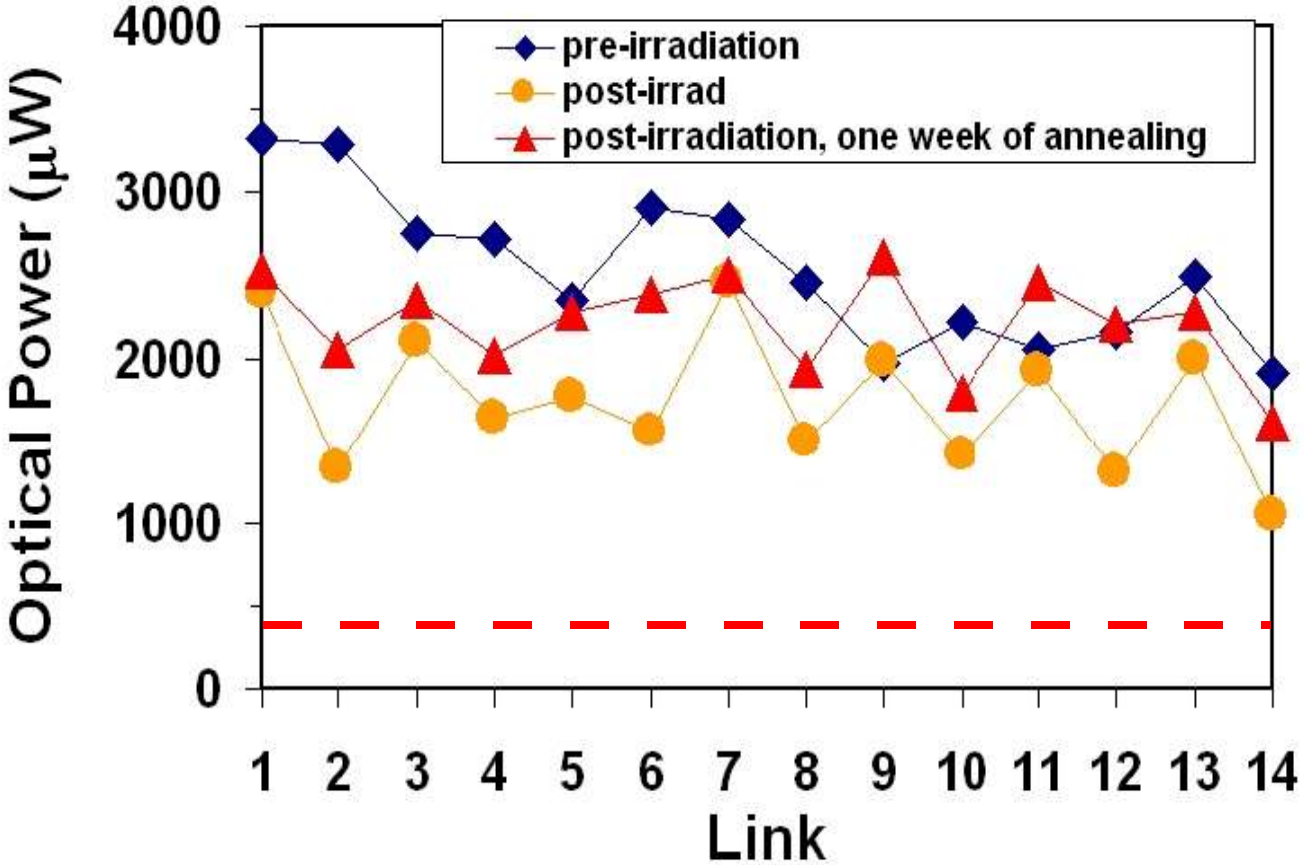
Duty Cycle, Jitter and Rise/Fall times





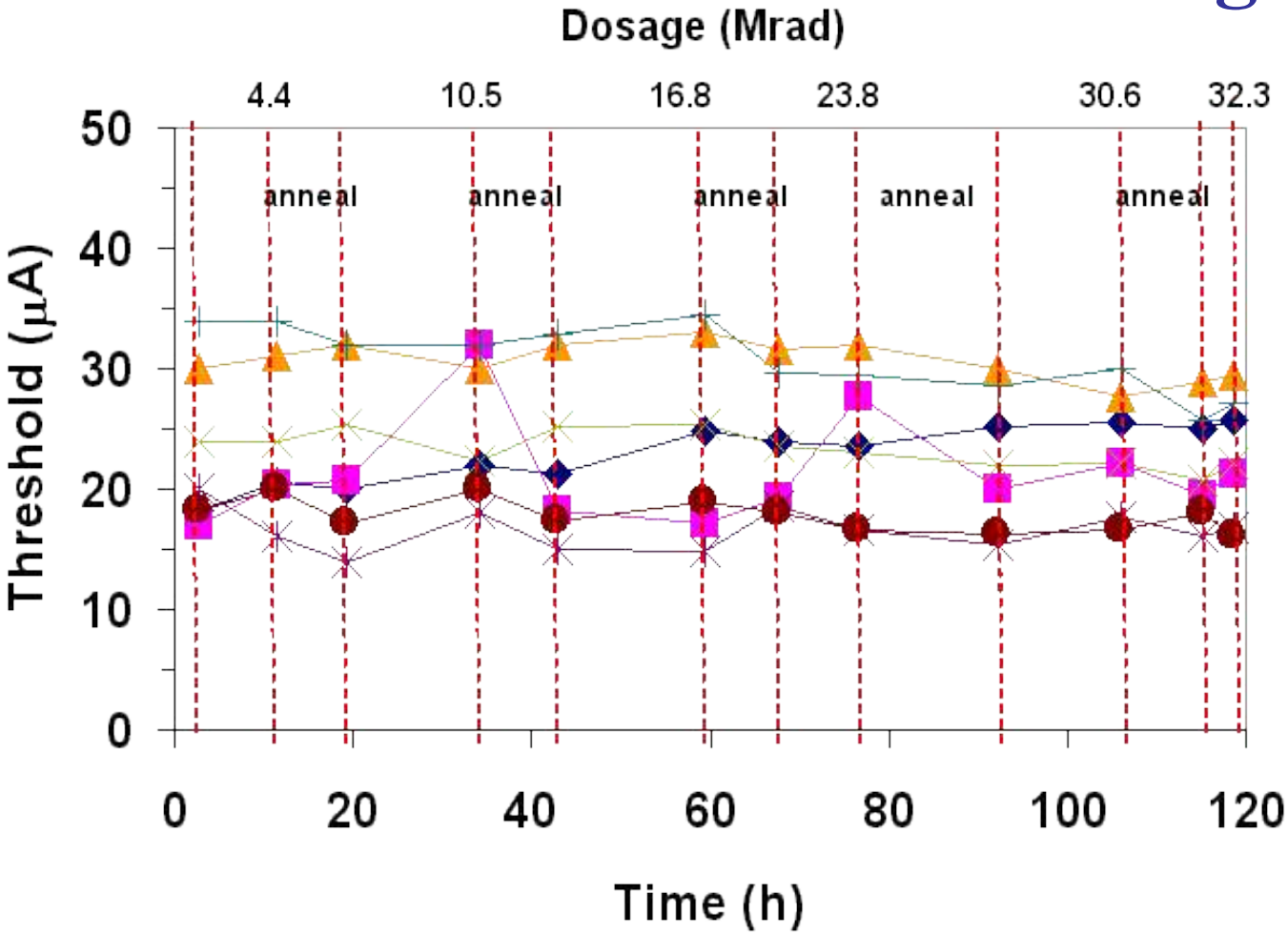
- Jitter, and rise and fall times (not shown) are within the spec.
- Duty cycle slightly higher than 54% in three of the links.

Optical Power



- Some degradation in power after irradiation
  - Power is significantly above the minimum required ~350 μW
- Annealing (for VCSELs) recovers most of the lost power

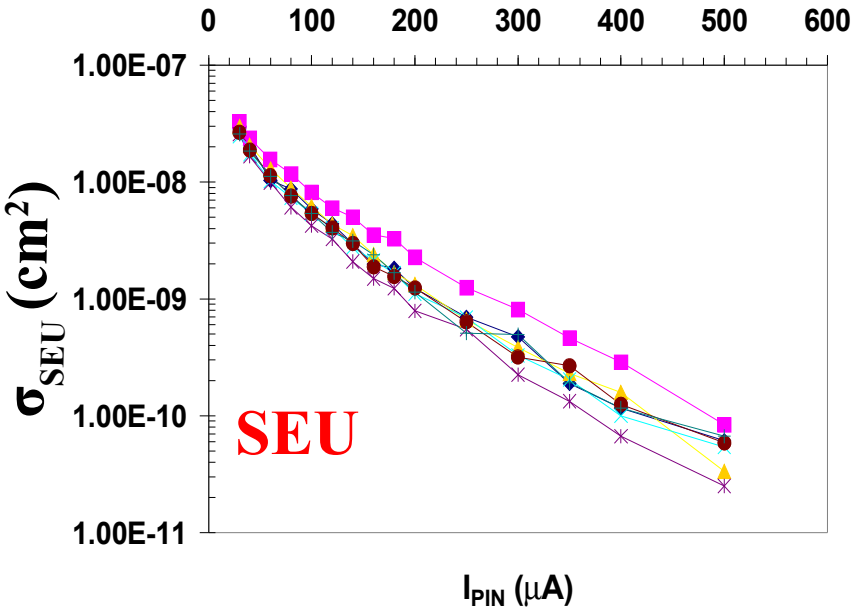
PIN Current Threshold vs Dosage

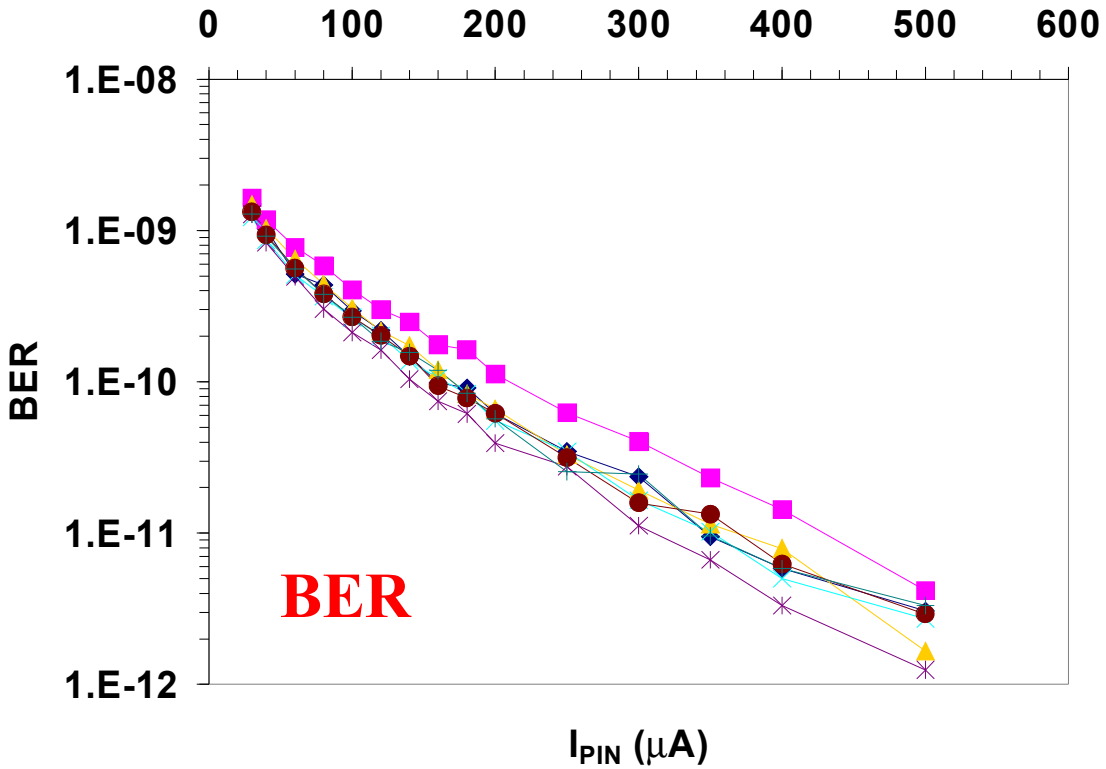


- PIN current thresholds for no bit errors remain constant

Proton Induced Bit Errors in PIN

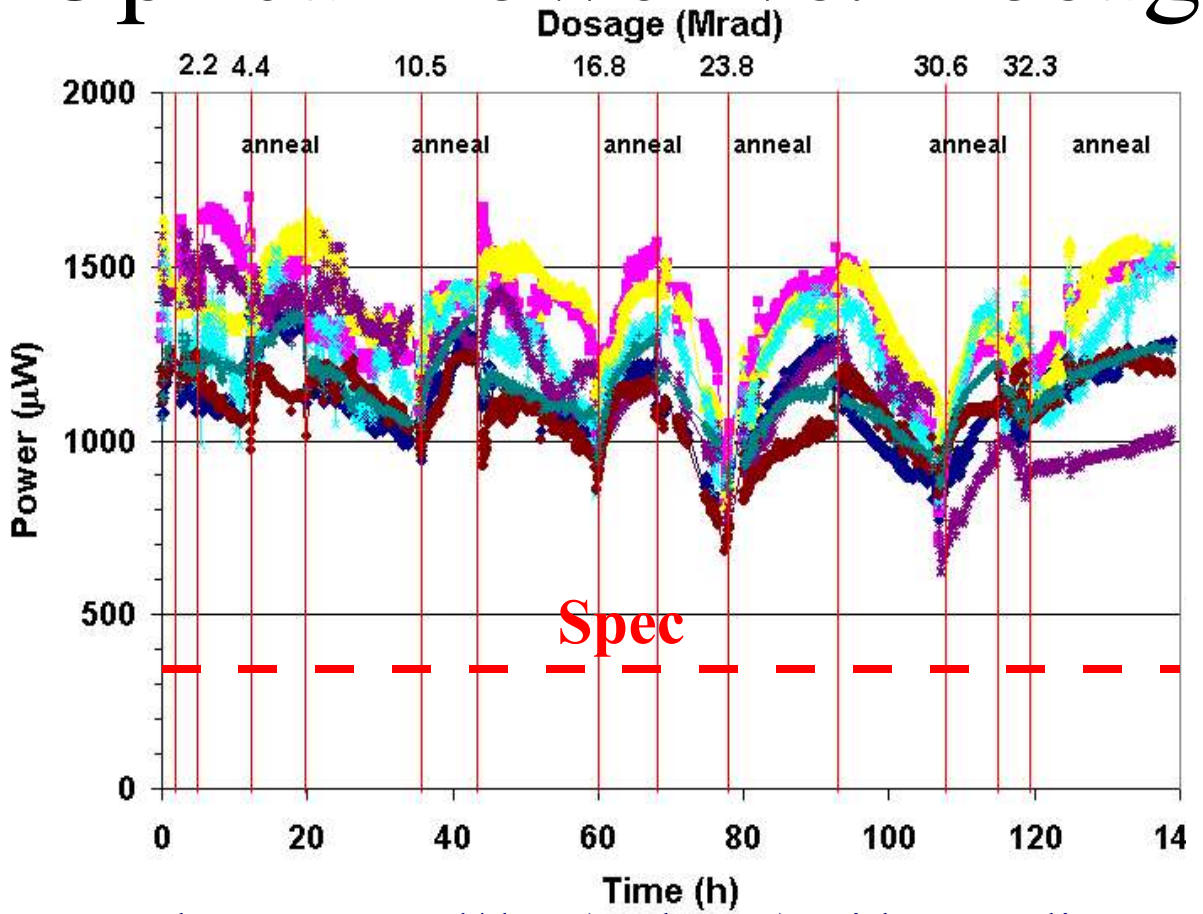
- Convert bit errors to bit error rates at opto-link





- Bit error rate decreases with PIN current as expected
- Bit error rate: ~3 x 10^{-10} at 100 μA (1.4 errors/minutes)
  - DORIC spec: 10^{-11}
  - Opto-link error rate is limited by SEU

Optical Power vs. Dosage



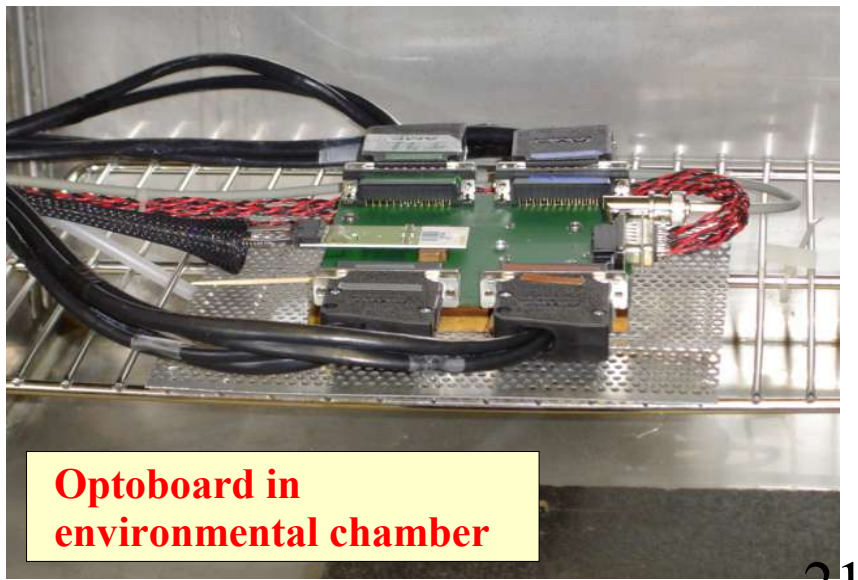
- Irradiation procedure: ~5 Mrad/day (10 hours) with annealing rest of the day
- Optical power decreases with dosage as expected
- Limited annealing recovers some lost power
- Still good power after 30 Mrad

Production Status

- We began optoboard production for ATLAS in February 2005.
- Very aggressive schedule to complete by September/October.
- Required producing ~10 optoboards/week at OSU (challenging).
- Within one week of starting production we turned everything off and moved to a new lab in a new physics building !!! Initial upheval but we now have a much larger lab space to work in.
- Our colleagues at Siegen will also be producing optoboards.

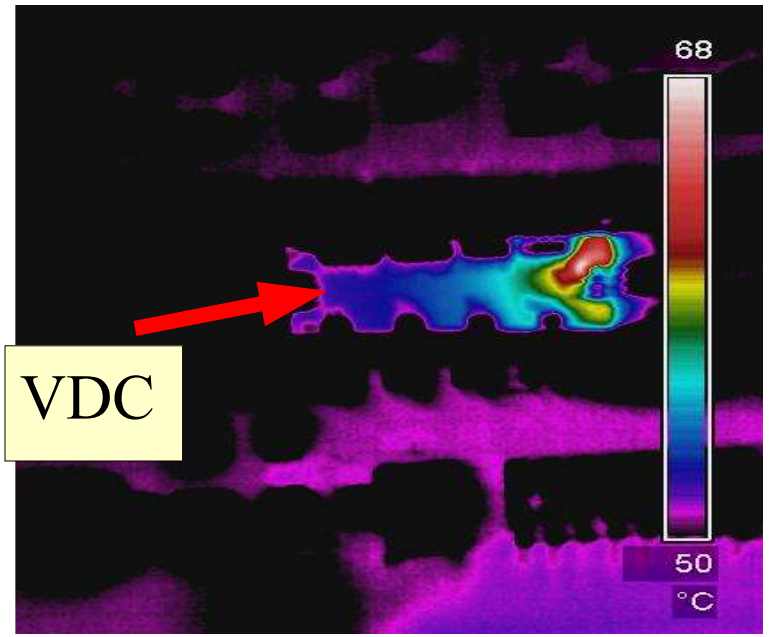
Production Challenges

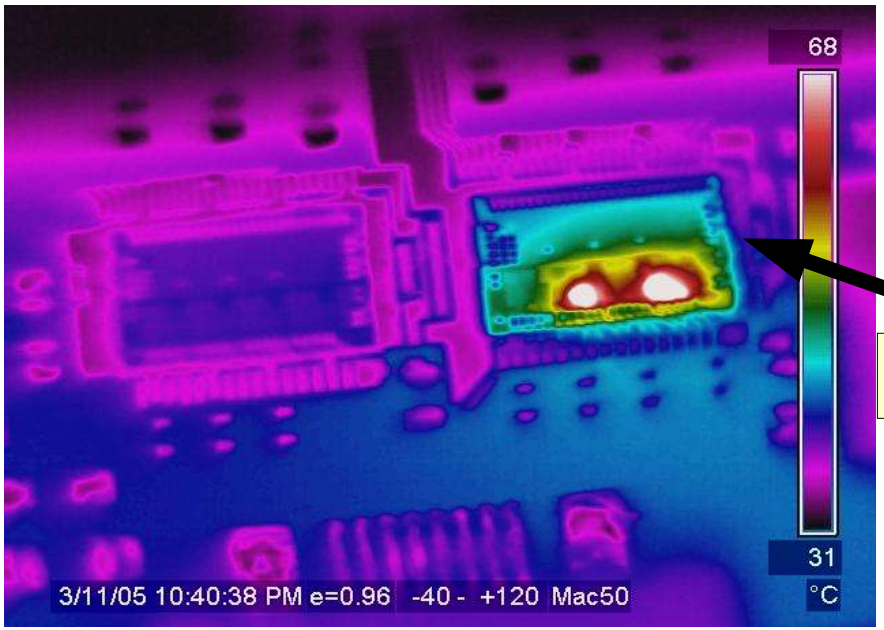
- Making many boards in a week is driven by rigorous QA procedure
- → 72 hours burn-in at 50°C
- → 10 Thermal cylces between -25°C and 50°C (takes 18 hours)
- → Testing optical and electrical QA (takes ~1 day per board)
- → We use 2 environmental chambers and 2 additional ovens.
- → Implimented an 'early shift' to extend the work day



Optoboard in environmental chamber

Initial Optoboard production problem

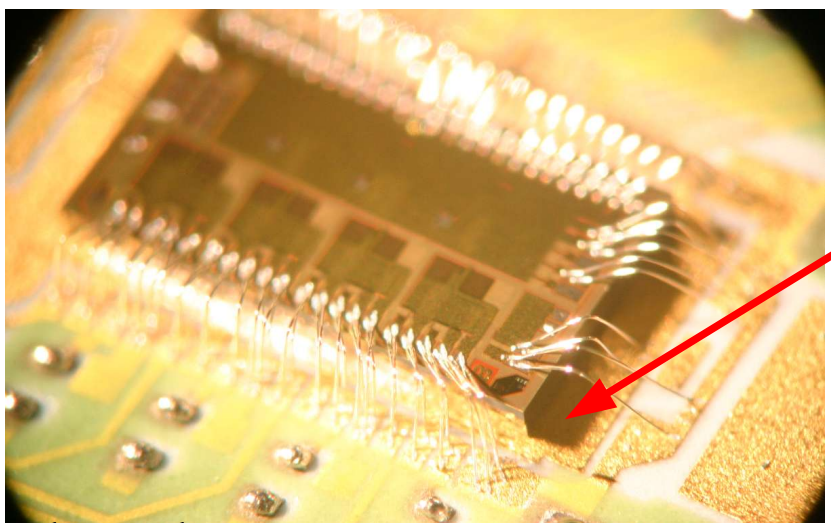




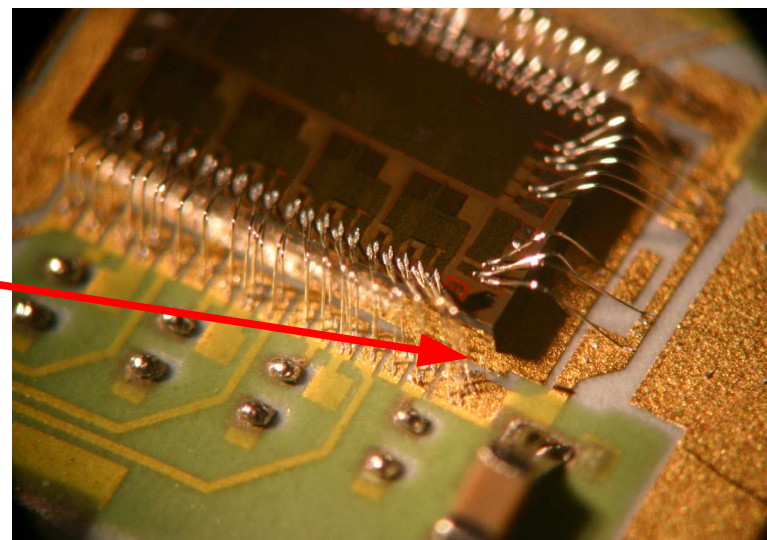
- Thermal images revealed shorts to ground through the chips where large current was being drawn.
- Since this issue, we have implimented testing of ALL chips
- Haven't seen the problem since. Also test duty cyle of DORICs.
- Reworked the boards with failed chips, remove wirebonds, put on new chip.

Reworked boards

- We implimented a procedure to salvage the boards that were populated with failed chips.
- Strip wire bonds, stick a new chip on top of the failed one, bond to that chip, then QA (burn-in, thermal cycle etc).
- So far we have recovered 12 boards in this way and have seen no obvious problems with the reworks. **ALL reworks are considered second class.**

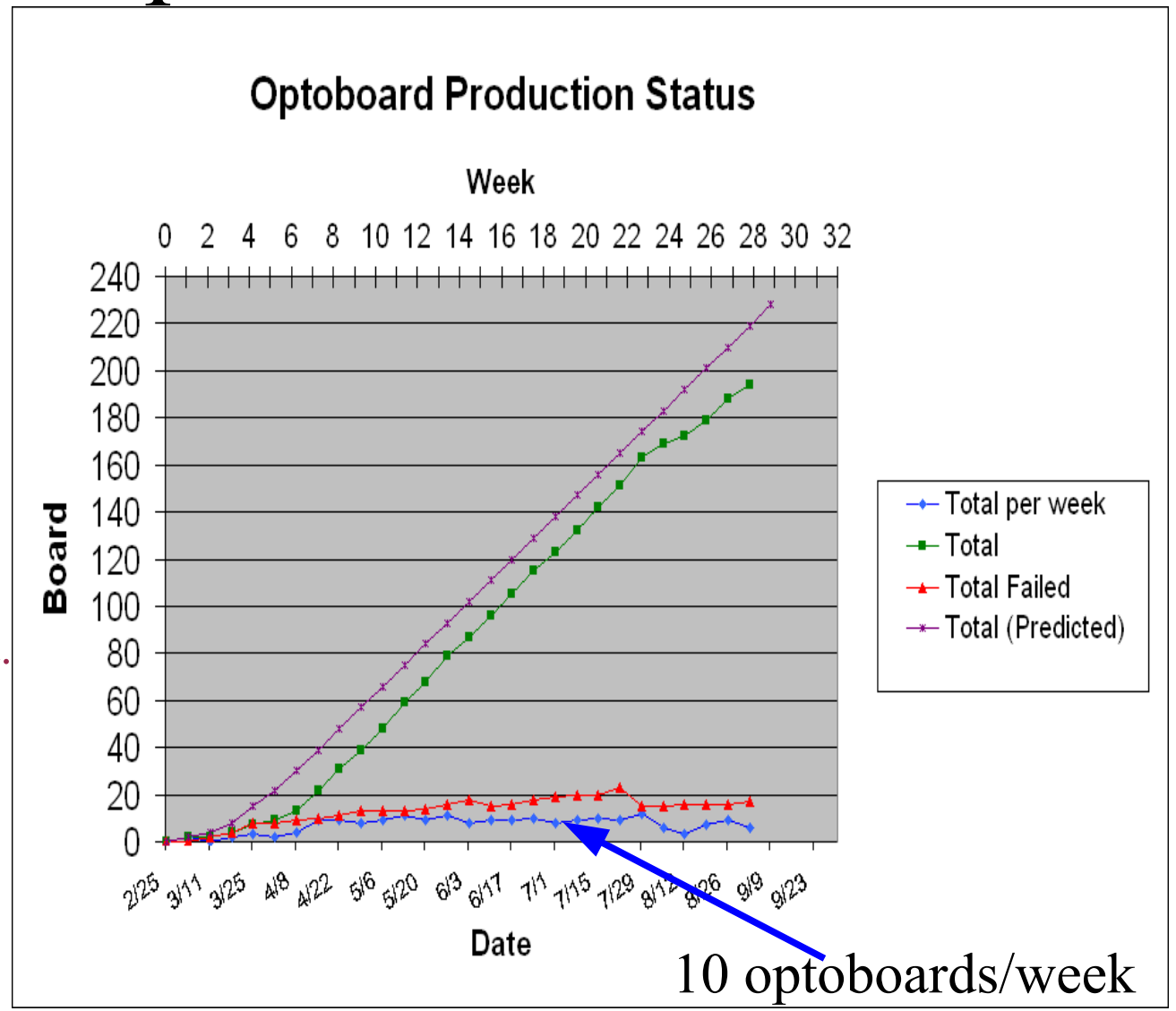


Two chips thickness seems to work fine!!



Optoboard production status

- Our rate started out slower than expected with more failures than anticipated.
- After ~6 weeks we reached target production rate.
- Maintained good yield for many weeks now.
- If we can continue at our current rate, and efficiency, reach production goal in Sept.
- Reworked failed boards to salvage them....and add them to the green curve.



Summary

- Optical link plays a crucial role in the ATLAS pixel detector
- Using BeO optoboard substrate for heat management
- VDC and DORIC chips have been tested extensively for radiation hardness.
- We are in production mode now and expect to complete all optoboards by the end of September.