Optical Link of the ATLAS Pixel Detector

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Outline

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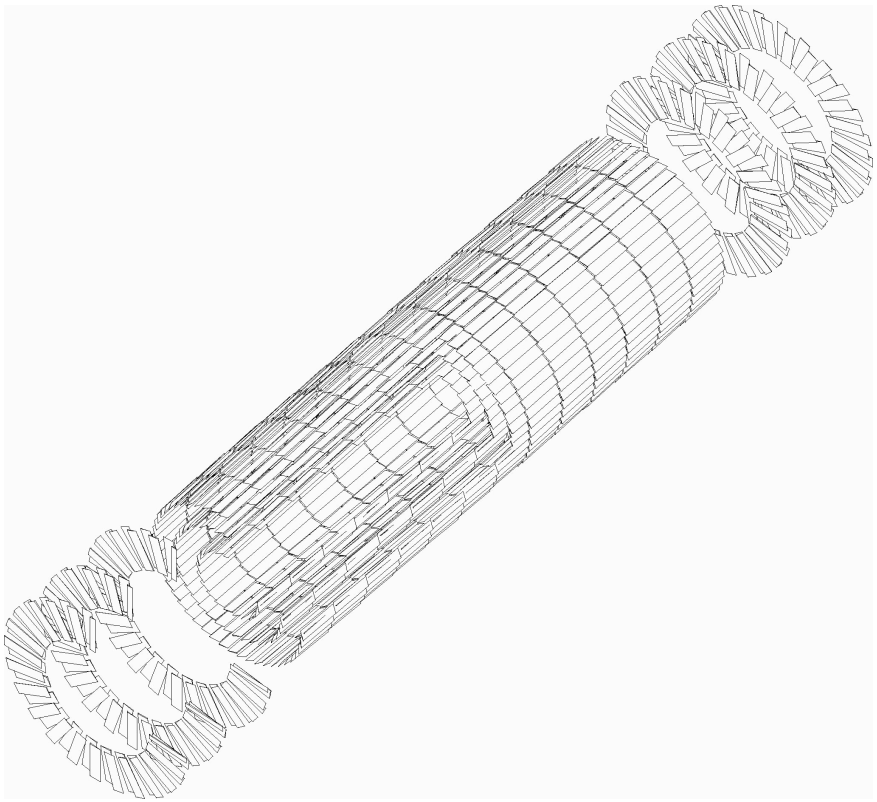
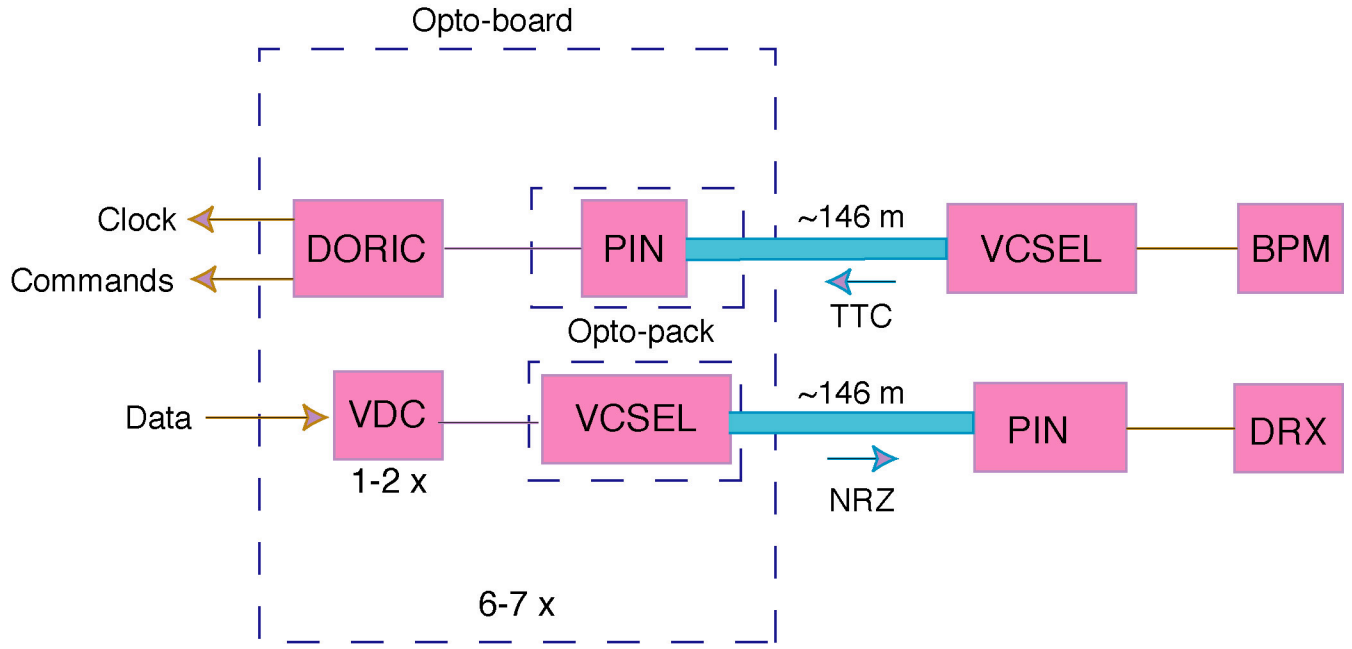
- Proton Irradiation Studies
- Production Status
- Summary

ATLAS Pixel Detector



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

ATLAS Pixel Opto-link



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

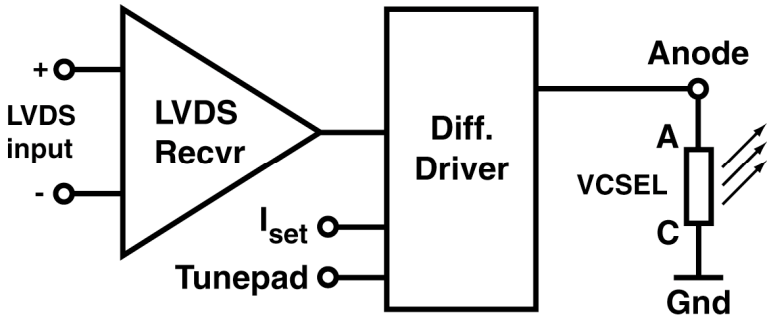
VDC: **VCSEL Driver Circuit**

PIN: **PiN diode**

DORIC: **Digital Optical Receiver Integrated Circuit**

VDC: VCSEL Driver Circuit

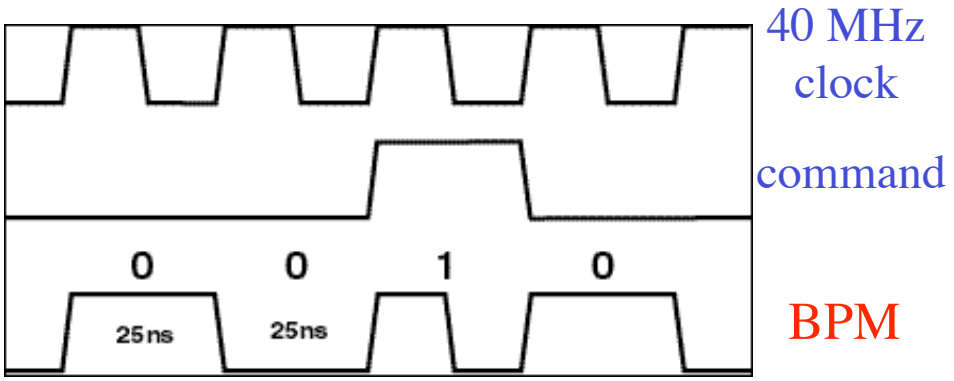
- Convert LVDS input signal into single-ended signal appropriate to drive VCSEL diode
- Output (bright) current: 0 to 20 mA
  - controlled by external current I_{set}
- Standing (dim) current: ~ 1 mA
  - improve switching speed

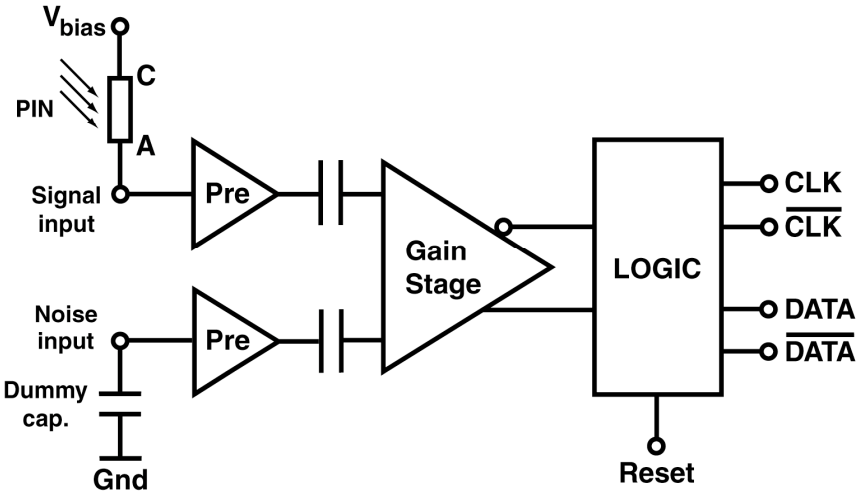


- Rise & fall times: 1 ns nominal for 40 MHz signals
- "On" voltage of VCSEL: up to 2.3 V at 20 mA for 2.5 V supply
- Constant current consumption!
- Use IBM 0.25 μm CMOS
- Use Truelight high-power oxide common cathode VCSEL array

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 IBM 0.25 μm CMOS
- Use Truelight common cathode PIN array (Taiwan)

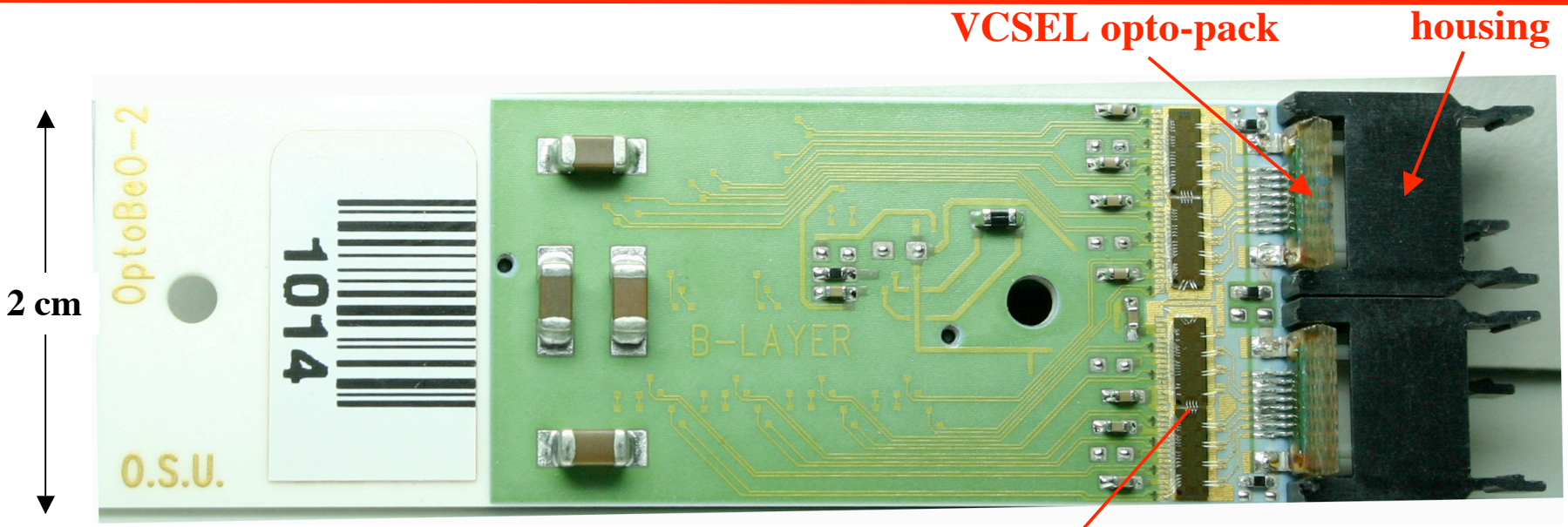


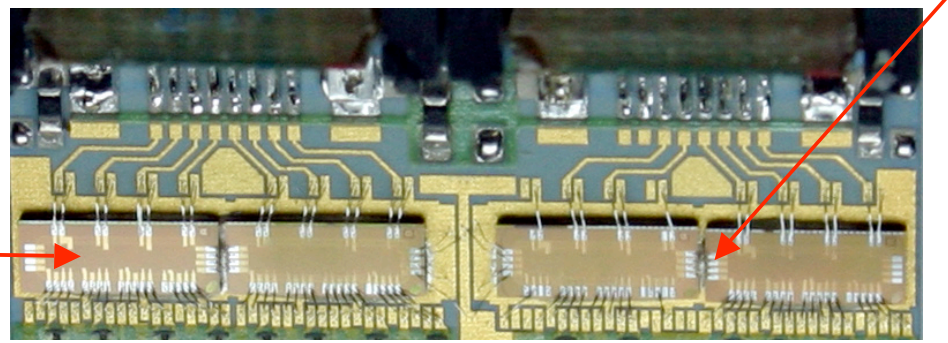


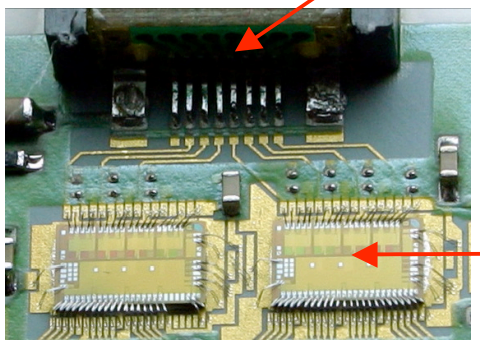
Opto-board Design/History

- converts: optical signal ↔ electrical signal
- contains 7 optical links
- use BeO for heat management but prototype initially in FR-4 for fast turnaround and cost saving
- 1st BeO vendor:
  - either under or over filling of vias
  - ⇨ use more experienced/expensive vendor
- 2nd BeO vendor:
  - 1st prototype: 1-2 SMD detached from few boards
    - ⇨ remove gold under SMD pads
  - 2nd prototype: SMD pads have much better adhesion
    - ⇨ remove gold under 80-pin connector pads
    - ⇨ order production opto-boards

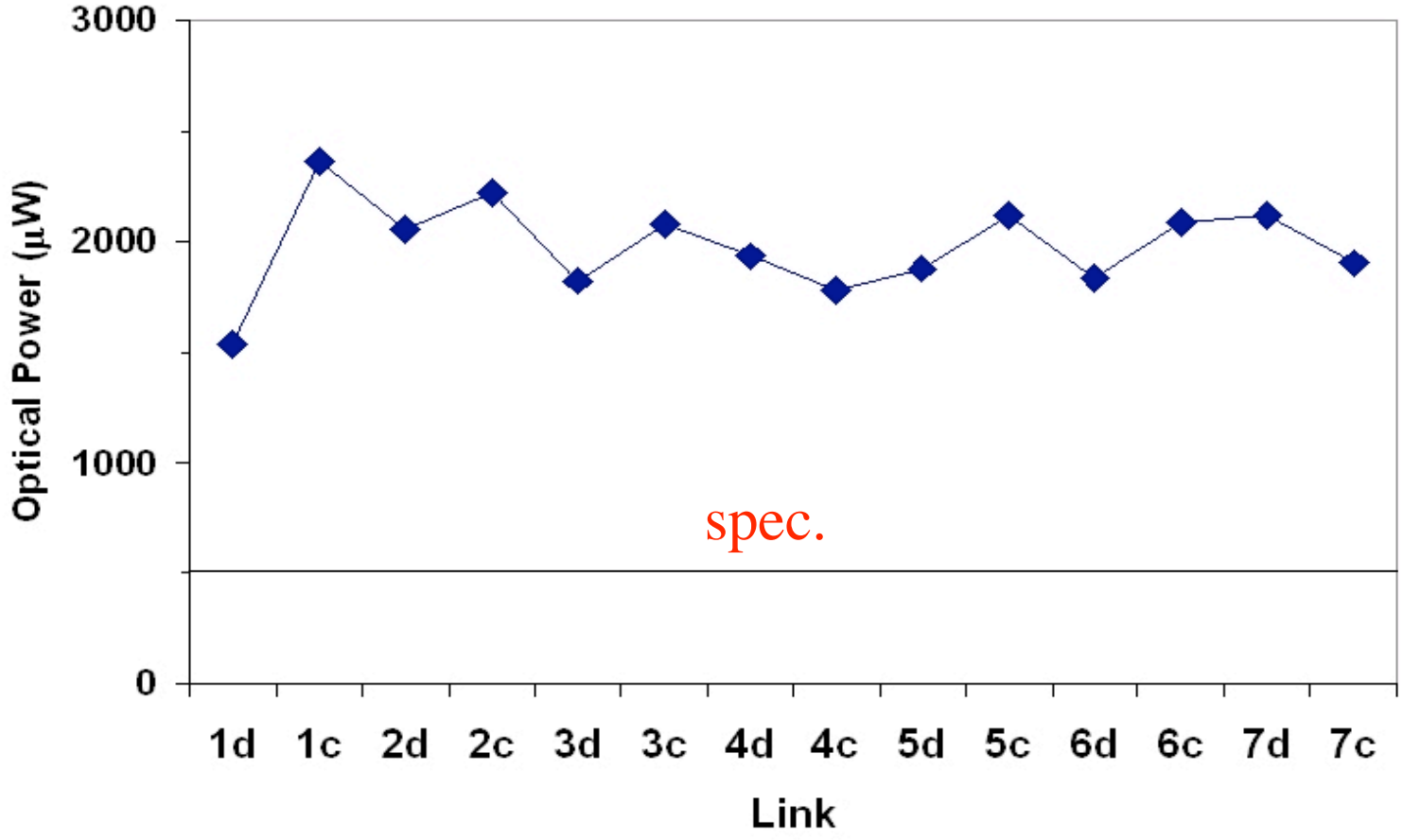
BeO Opto-board





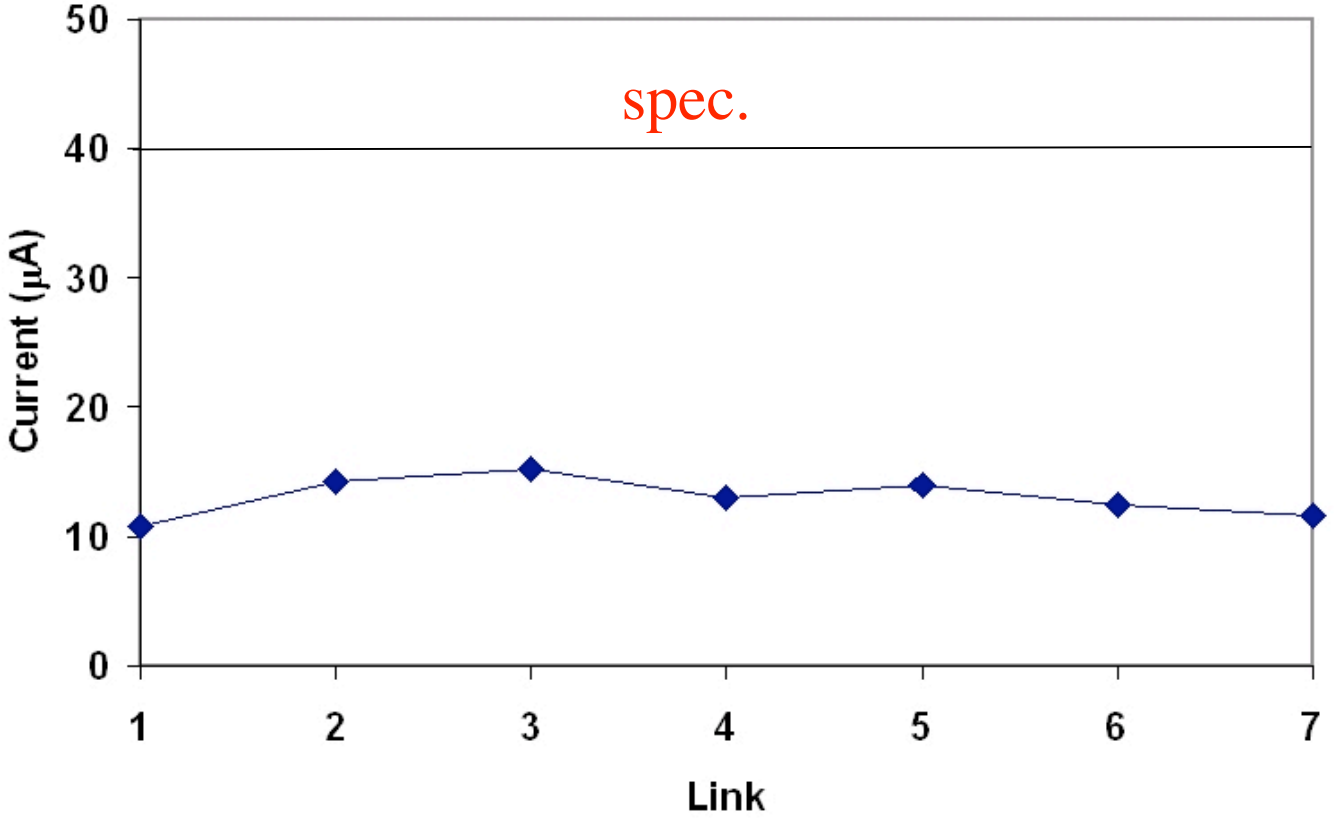


Optical Power



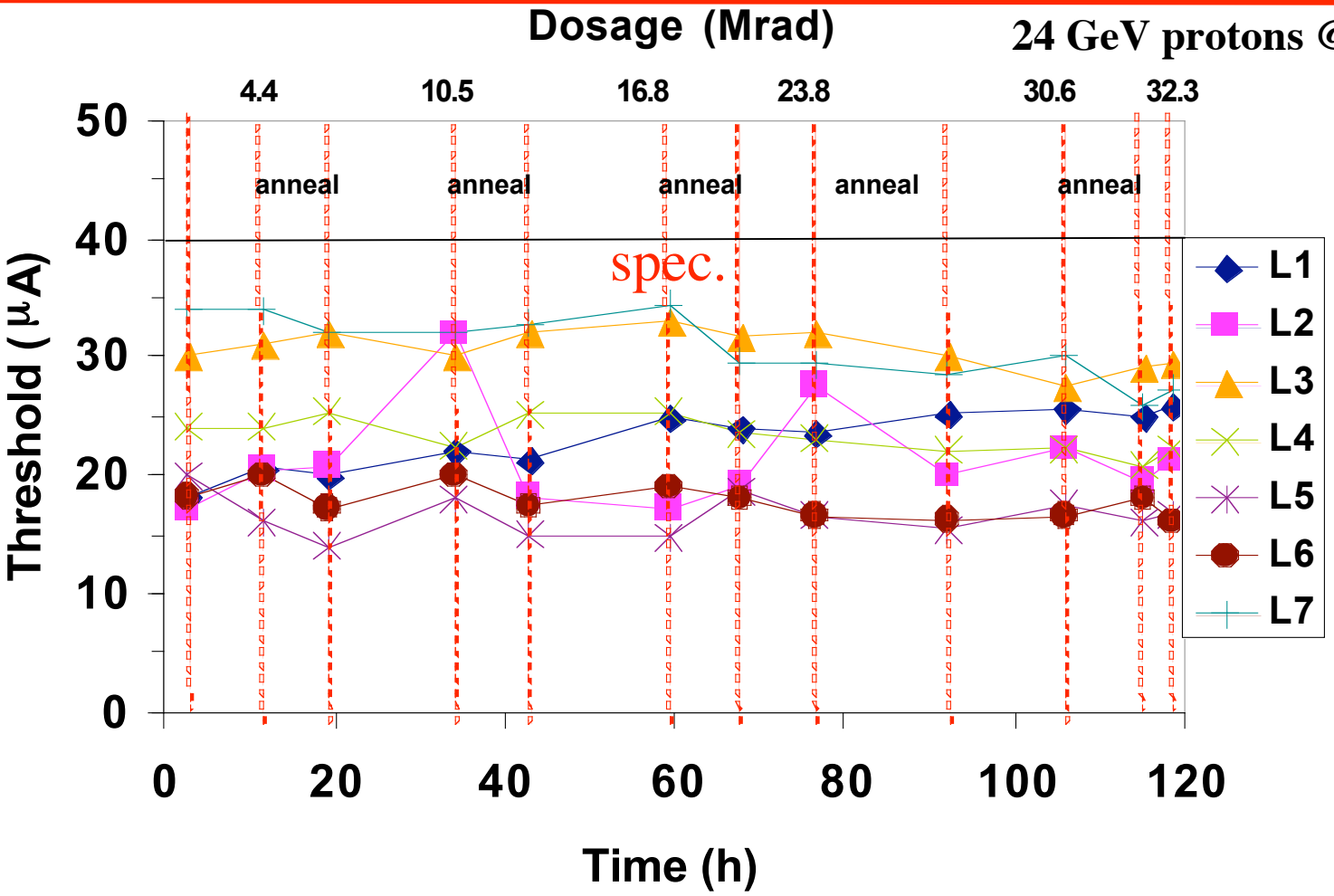
- optical power at 10 mA significantly above spec, 500 μW

Minimum PIN Current for No Bit Errors



- minimum PIN current for no bit errors with all links active significantly below spec, 40 μA

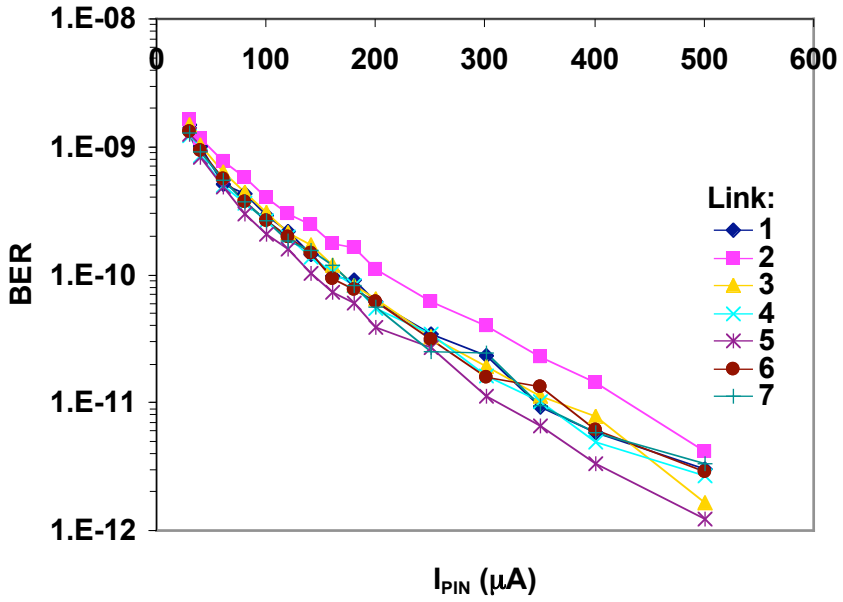
PIN Current Threshold vs Dosage

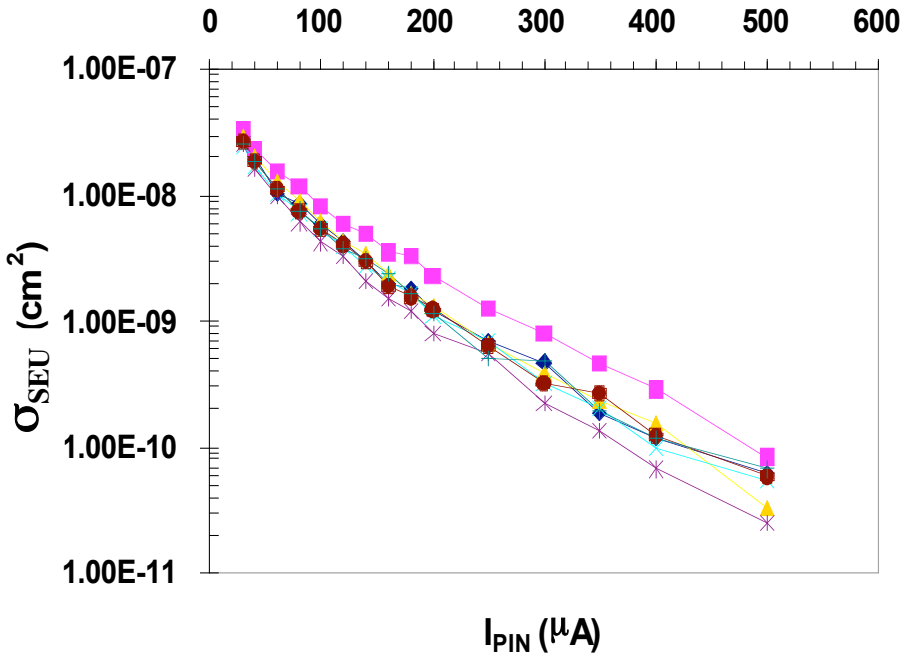


- PIN current thresholds for no bit errors remain constant

Proton Induced Bit Errors in PIN

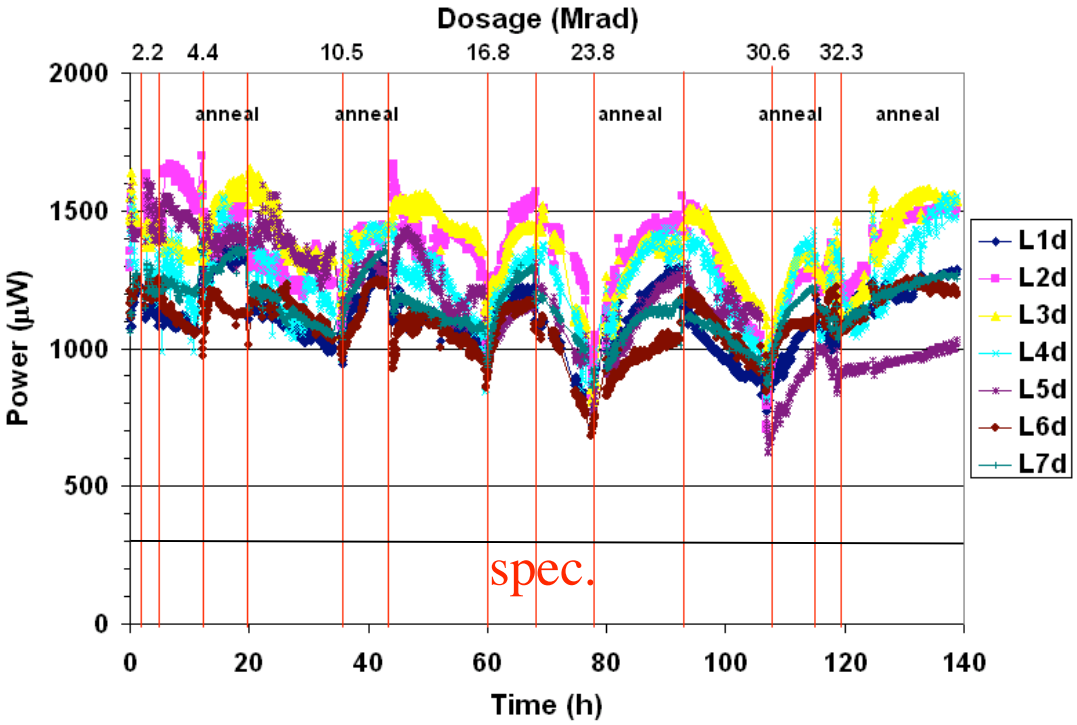
- convert observed bit errors into bit error rate at opto-link location:





- bit error rate decreases with PIN current as expected
- bit error rate ~ 3 x 10^{-10} at 100 μA (1.4 errors/minute)
  - DORIC spec: 10^{-11}

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 have good optical power after 30 Mrad

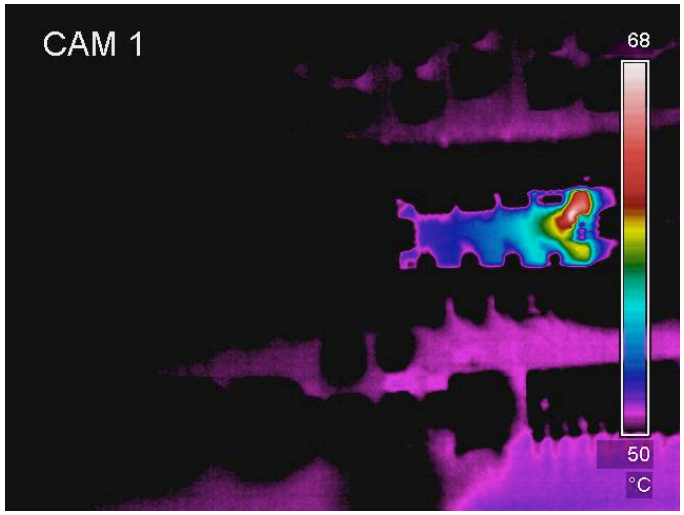
Opto-Production Challenges

- rigorous QA procedure:
  - 72 hours of burn-in at 50°C
  - 18 hours of 10 thermal cycles between -25°C and 50°C
  - 8 hours of optical and electrical measurements
- use 2 ovens and 2 environmental chambers
- implemented an "early shift" to extend the work day
- aggressive goals:
  - producing 10 boards/week
  - ⇨ completed production in early October

Initial Production Problem

- initial plan was not to test chips before mounting on opto-board due to high yield during pre-production
- a bunch of produced boards drawing excessive currents
  - thermal image: power to ground shorts

⇨ test chips before mounting



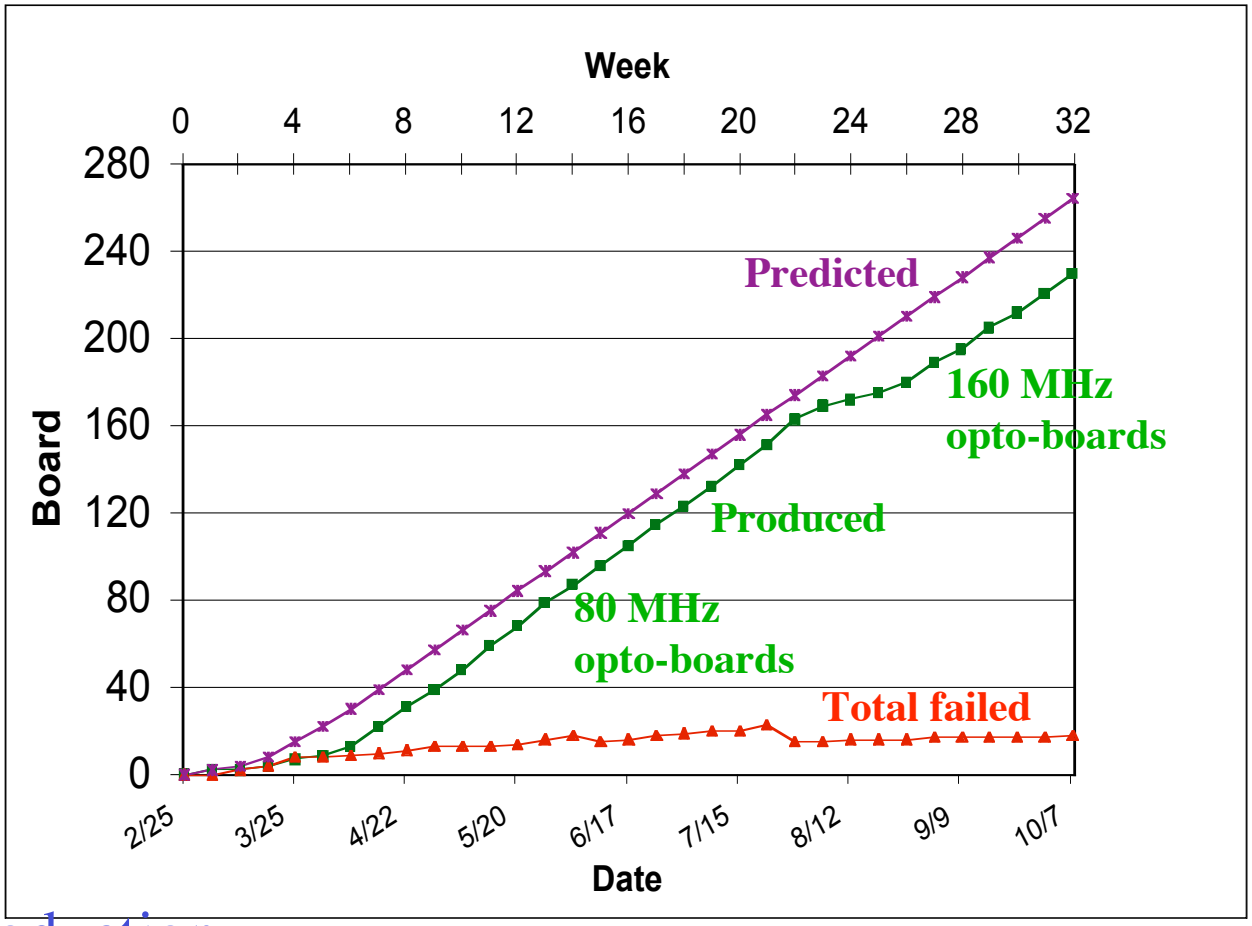
VDC

DORIC

Opto-board Rework

- recover opto-boards by stacking new chips on top of bad chips
- reworked opto-boards must pass same rigorous QA procedure
  - classified as second class for use as spare
- 18 opto-boards have been recovered

Opto-board Production Status



- relatively smooth production
- yield ~ 93%

Summary

- opto-boards of ATLAS pixel detector satisfy design spec. and radiation hardness requirement:
  - ✔ low PIN current thresholds for no bit errors
  - ✔ excellent optical power
  - ✔ radiation hard up to ~ 30 Mrad
- simple and modular design allows smooth production
  - production completed in seven months!