Experiences with the ATLAS Pixel Detector Optolink and Researches for Future Links

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Workshop: Detector Developments for the SLHC

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In behalf of the
ATLAS Pixel Collaboration

Overview

- ATLAS optical links & Requirements
- ATLAS silicon detector optical links
- Pixel Experience and conclusions for future links
- Wuppertal group optical link research fields
    - Readout hardware, off-detector optical interface
    - VCSEL packaging, on-detector laser study
- Conclusions

Current Optical Links in ATLAS

- Several kinds of optical links are installed in the ATLAS detector, i.e.:
  - Silicon (SCT / Pixel) in the Inner Detector have a very radiation resistant link, bandwidth 40-160 Mb/s
  - Liquid Argon calorimeter: Gigabit optical link, faster but not as radiation hard
  - **H**igh **S**peed **O**ptical **L**ink for ATLAS (HOLA) is used for off-detector data transfer
- There are special custom links and a more or less common one (HOLA)
- Probably, similar situation in CMS

Requirements

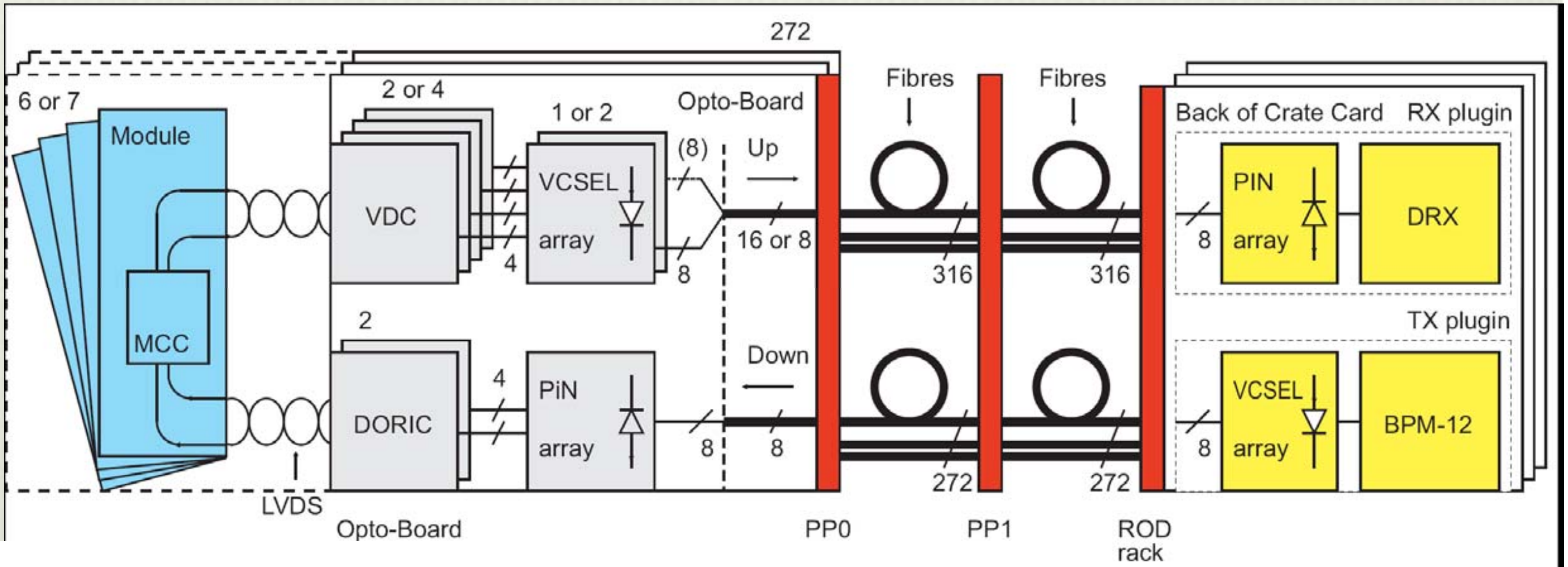
- Requirements are certainly detector dependent:
  - Occupancy / granularity
  - Close distance to beam pipe
  - Trigger contribution
  - Material budget
- Speed: high bandwidth contra material, granularity, radiation tolerance
- Radiation: inner detector for sure have higher constrains as outer ones
- Reliability: error checking, redundant links, hardware lifetime
- Low mass: small radiation length to be introduced in the detector
- …

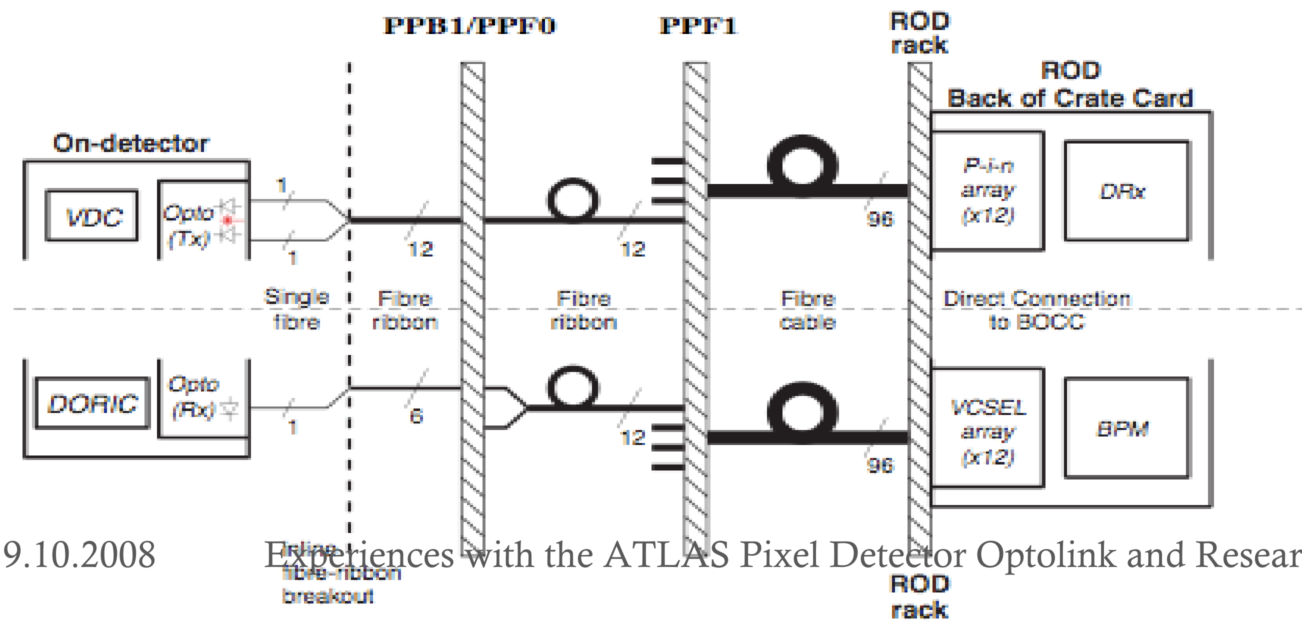
ATLAS Silicon Detector Links

- Combined development of SCT and Pixel groups
- Off-detector hardware the same, fibers similar, on-detector different
- Used modularity differs slightly
- Transmission using 850 nm VCSELs on multi mode fibers
- Speed: 40 Mb/s as baseline
  - Pixel has 80 Mb/s or 2*80Mb/s bandwidth for some detector parts

Optical Link for the ATLAS SCT and Pixel Detektor

Pixel

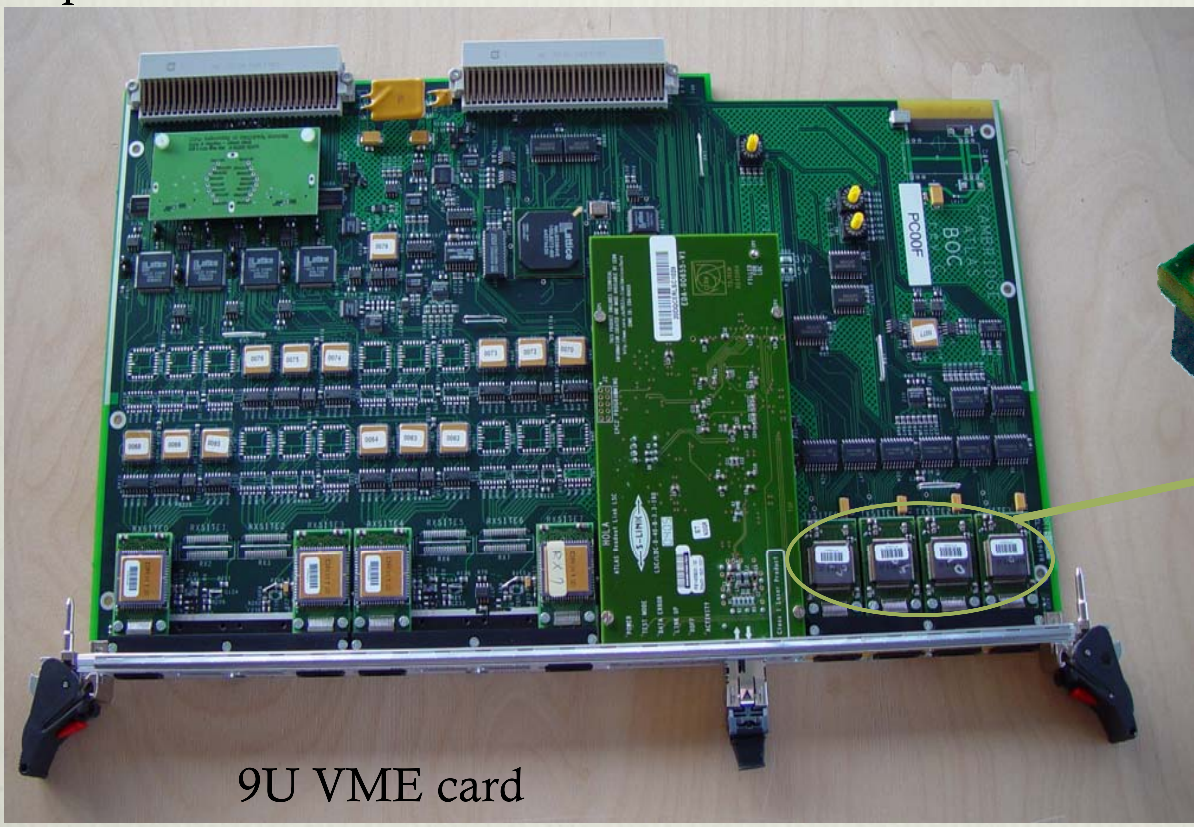




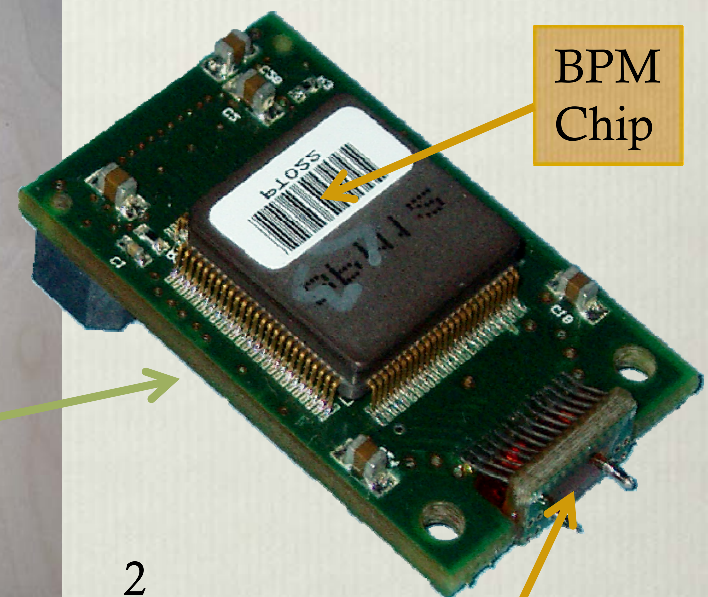
SCT

Off-Detector Hardware

Optical interface: Back of Crate Card

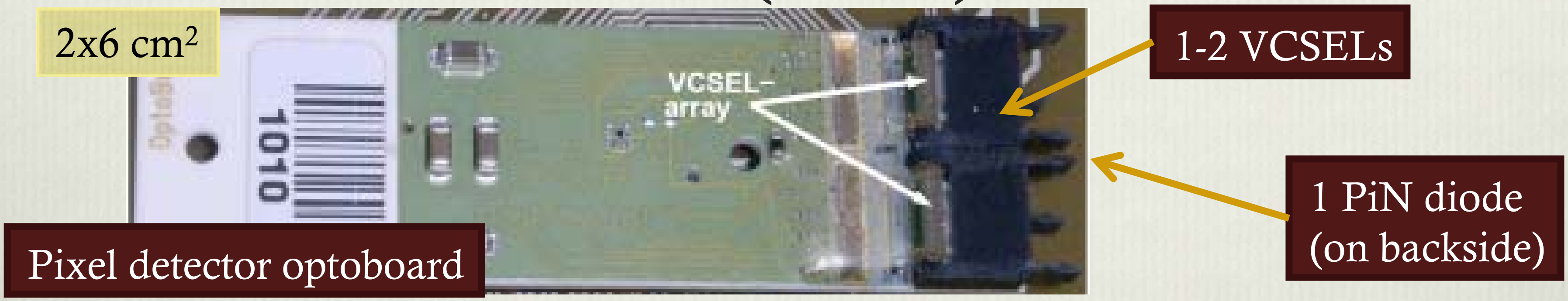


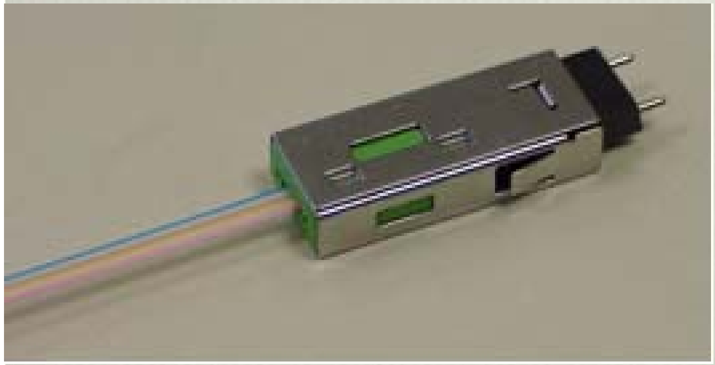
Optical compnonent: Tx-Plugin



2 x 3 cm^2

On-Detector Hardware and Fibers (Pixel)





- Optoboard as on-detector optical interface serves 6 or 7 modules
- Fiber connection always with 8 way ribbons down- and upwards
- Two flavors installed (innermost layer need higher uplinks bandwidth)

Optical Link for the ATLAS SCT and Pixel Detector

- Each module has an individual optical connection
- On-detector hardware need high radiation tolerance / hardness
- Inner fibers need to be radiation hard
- On-detector optical components either on the detector modules (SCT) or on a separate board (optoboard) connected electrically to the modules.
- Components: Laser (VCSEL), PiN diodes, driver and receiver chips, decoder and encoder for used signals
- Bandwidths is 40 Mb/s (SCT and outer Pixel layers) or 80 Mb/s and 160 Mb/s (inner layers of Pixel)
- Data links are doubled in SCT (1 downlink, 2 uplinks per modules)

Upgrade Tasks

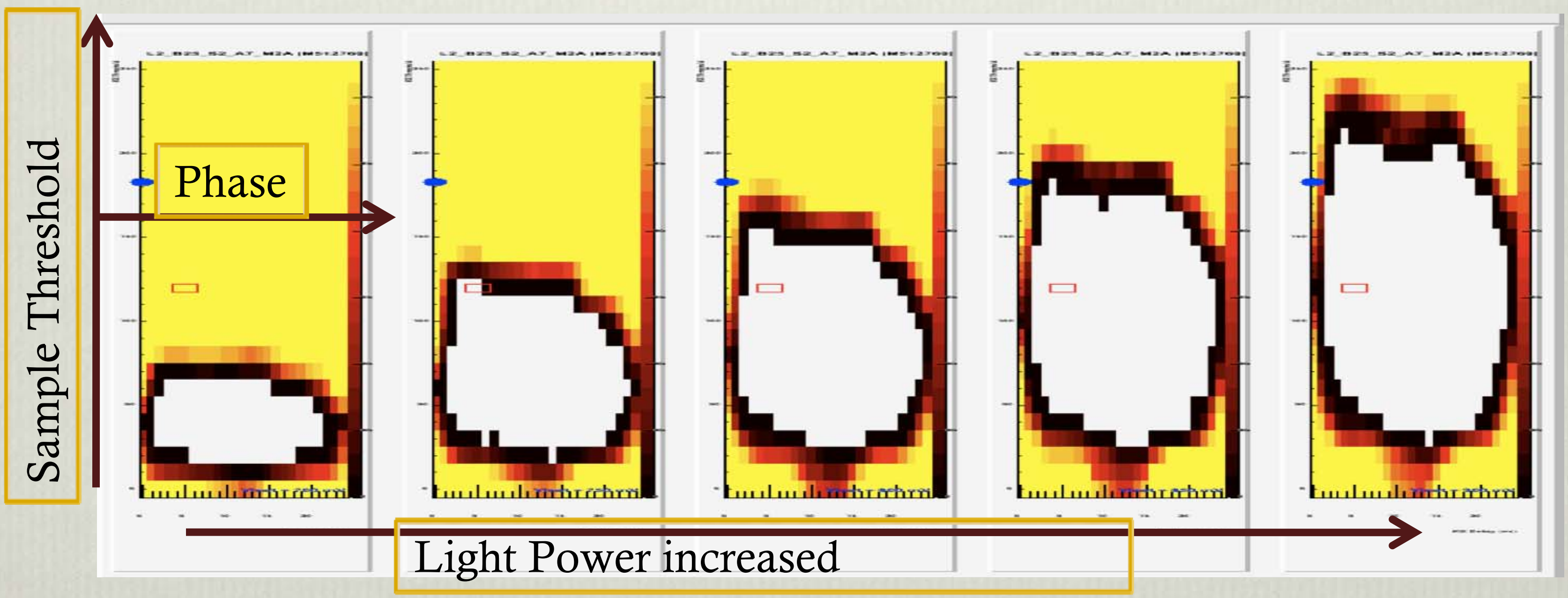
- Higher luminosity influences higher data rate, higher radiation levels, …
- Higher occupancy in the detectors causes the need of a higher transmission bandwidth
- Higher radiation levels inside the detector: hardware must withstand this for the duration of operation
- Again low mass, not to disturb outer detector data.

Lessons Learned

- Producing, testing, installing, and commissioning the Pixel optical link showed things to take care off:
  - Pixel on-detector opto-components are separated from the detector modules ✓
  - Downlink works pretty well, an encoded clock and data signal is sent, decoding is done on-detector. Decoding chip has an automated threshold adjustment ✓
  - Uplink sends a "Non-Return-to-Zero" Signal, off-detector threshold adjustment not ideal for this, phase adoption necessary ✗
  - No error checking possibility for the uplink ✗
  - Production of optical components is critical, very ESD sensitive parts must be handled

System Tuning

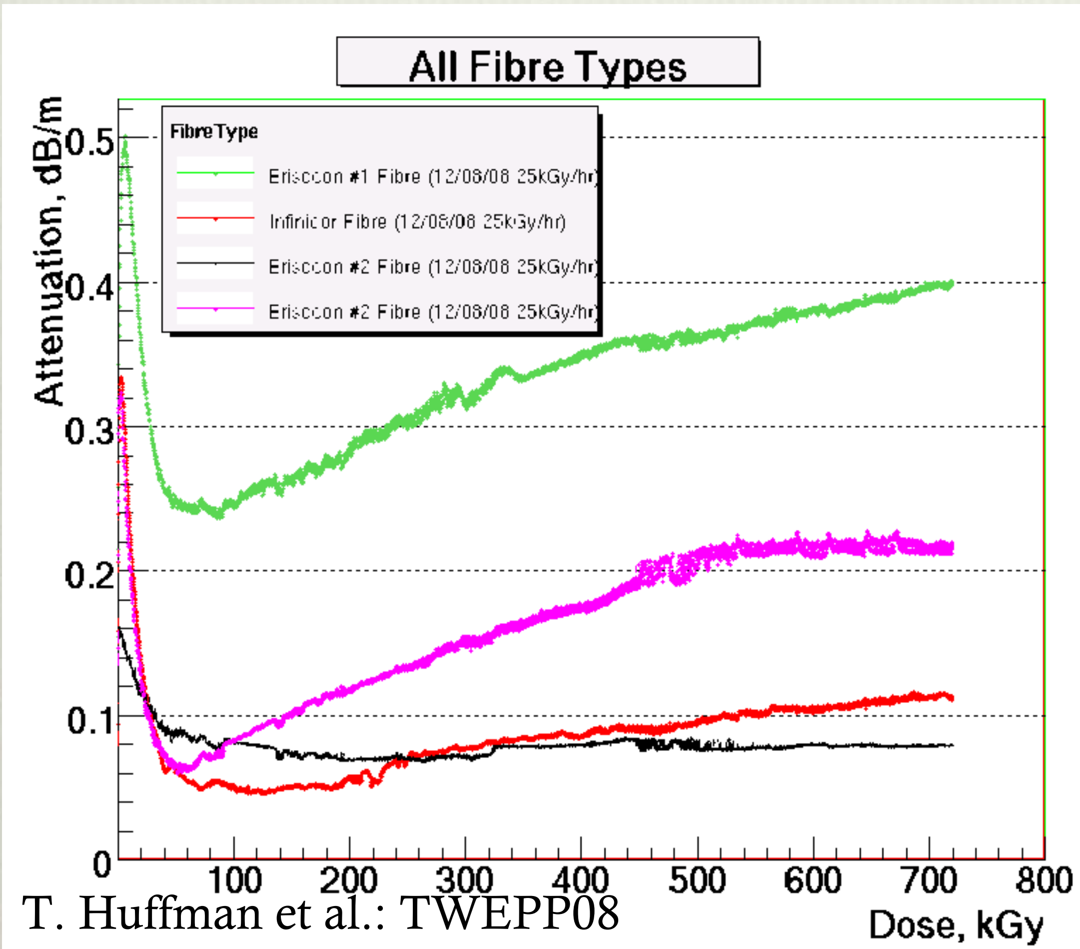
- Account for all parameters in the system
- Many are buried: Apply to the downlink, but need to measure the uplink
- NRZ signal being sent from the detector with no phase constrain to the readout hardware clock
- Nasty modularity in the on-detector optical component control



Upgrade Approaches

- Things going on:
  - Versatile Link (→ GBT)
    - Upgrade proposal for CMS and ATLAS
    - Several aspects taken into account
      - Experience of the former (now installed and operated) links
      - Radiation studies to account for the higher doses
      - Speed upgrade (~5 Gb/s)
      - Structure (point to point, point to multipoint, …)
  - Custom Link Updates studied by the individual groups
    - New components (active and passive) specific for certain detectors
    - Fibers, if not chosen from an overall study
    - Irradiation tests, because levels are very different

Fiber Irradiation

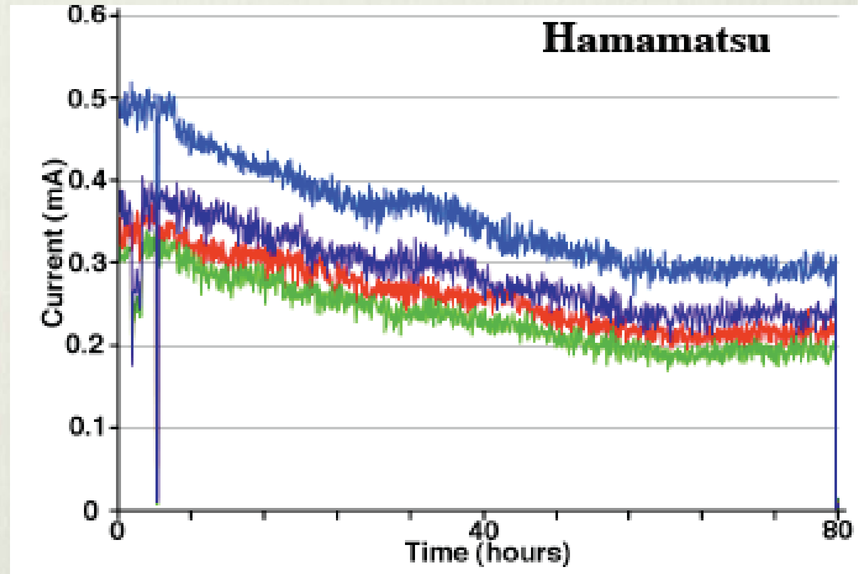


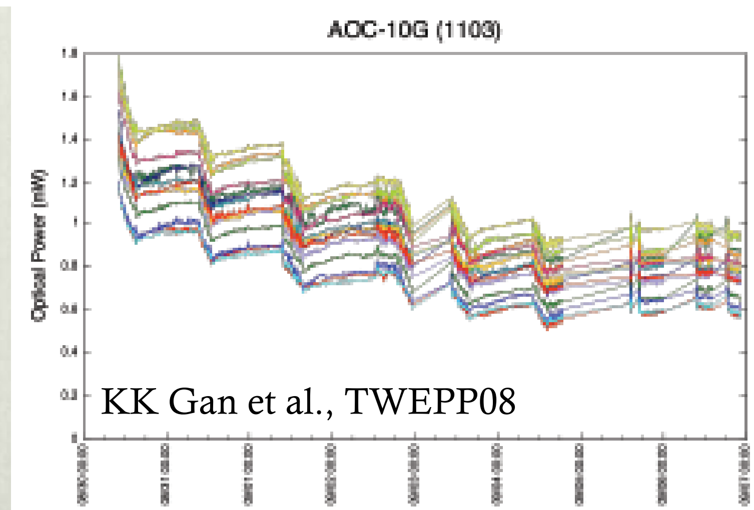
T. Huffman et al.: TWEPP08

- Irradiated at different γ rates:
  - Oxford (UK):
    - 25.1 kGy/hr
    - 1.12 kGy/hr
  - SMU:
    - <0.5 kGy/hr
- Best two fibers result in a loss of 0.4 dB for 60m fibers in an assumed sLHC layout.

Optocomponents

- Irradiation of PiN diodes and VCSELs
- SLHC dosage (24 GeV Protons):
  - 2.6×10^{15} p/cm^2 (1.5×10^{15} 1-MeV neq/cm^2)
- There are some candidates
- Also driver and receiver chips under study





KK Gan et al., TWEPP08

Wuppertal Group Contribution

- The design of the overall readout system is under discussion at the moment (electrical and optical components)
- Off detector readout hardware has to be adopted to higher clock rates and bandwidth, first step 320 and 640 MHz
- New fibers need to be installed due to higher radiation levels
- Characterization of on-detector VCSEL packaging will be studied in Wuppertal and at CERN
- Development of test stands is important. Do it as early as possible and get both end of the links connected for studies

Off-detector hardware

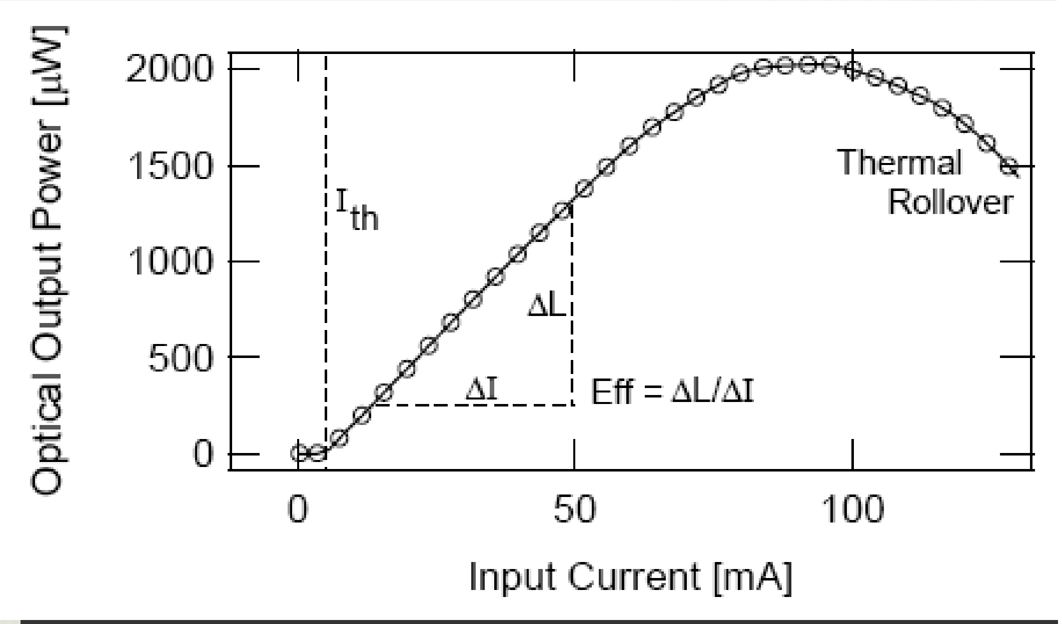
- A new design of the off-detector optical interface needs to be done to account for transmission bandwidths and clock speeds
- Commercial components usable (counting room installation), design and layout on the way
- Currently interface is separated from ROD as an additional VME board. Go for a mezzanine solution, but keep optical components (VCSEL and PiN diodes) pluggable
- Implement monitoring capabilities for the data stream to be able to error check
- Uplink needs most action: sample threshold adjustment, phase adjustment, error checking

VCSEL packaging

- In context of the ATLAS/CMS versatile link project a test stand for measuring the thermal resistance of VCSEL packages is set up
- Radiation destruction and heating up the device effect the light power output in nearly equal parts
- Since radiation damage can not be prevented, the heat coupling can be optimized
- Determine internal thermal resistance of a laser device by measuring the shift of the optical spectrum in dependence of temperature

Thermal Rollover

- Heating of the VCSEL through introduced power (current)
- The measured optical power drops down at a certain power value → thermal rollover
- **Solution: Get the heat out**



Thermal Properties

- Thermal resistance:

$$R_{th} = \frac{\Delta T}{P_{diss}} = \frac{T_j - T_{amb}}{P_{in} - P_{opt}} \approx \frac{T_j - T_{amb}}{P_{in}}$$

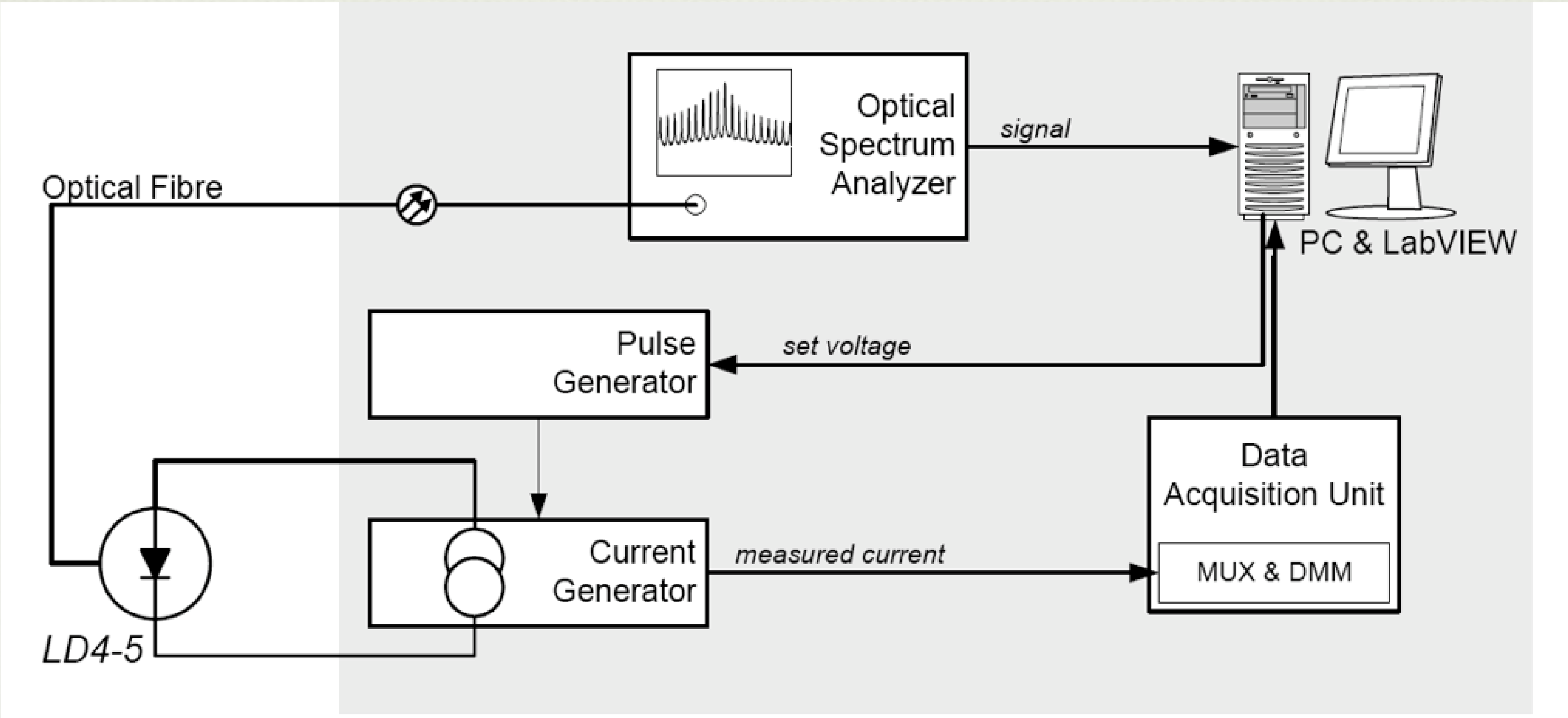
- Measurement of the change in wavelength depending on the temperature or on the input power determines resistance:

For a know temperature dependance:

$$R_{th} = \frac{\Delta\lambda / \Delta P_{in}}{\Delta\lambda / \Delta T_{amb}}$$

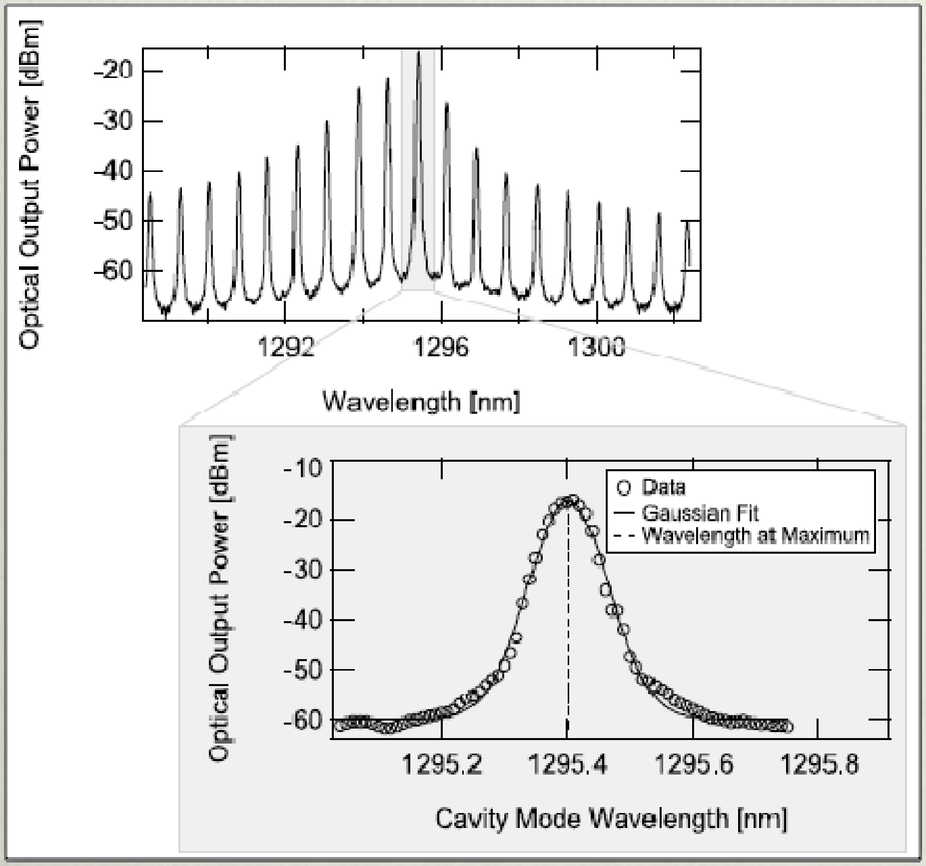
$$T_j = \frac{P_{in} \cdot (\Delta\lambda / \Delta P_{in})}{0.09 nm / °C} + T_{amb}$$

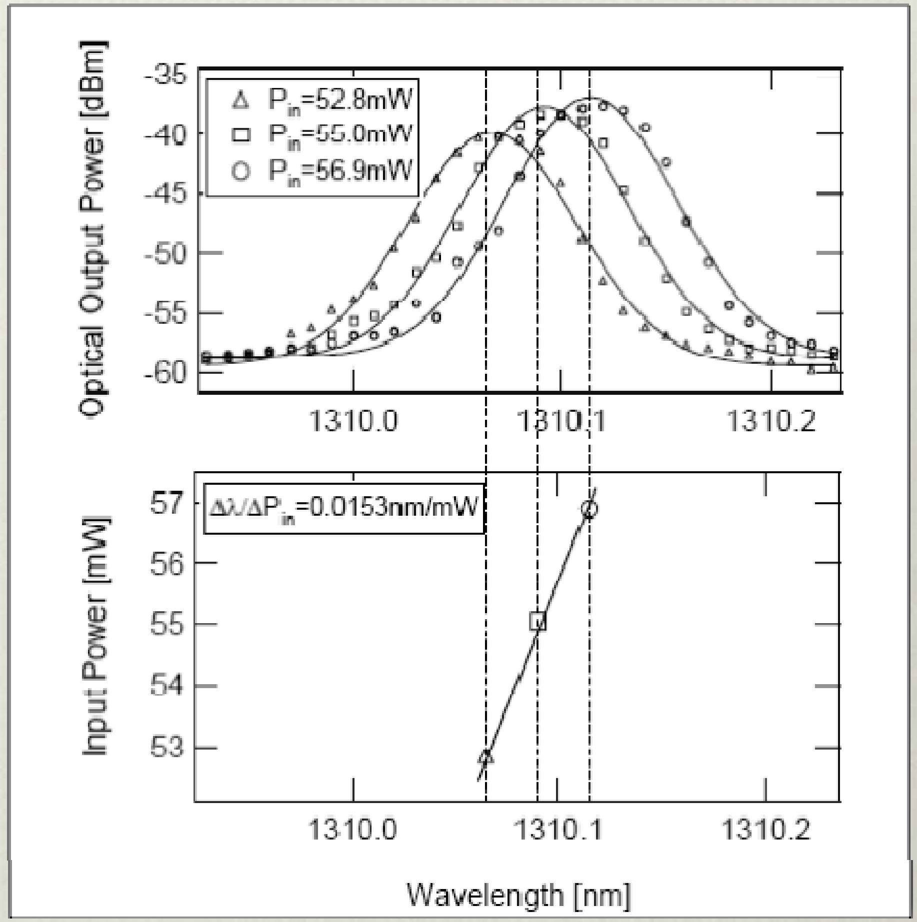
How we want to measure



From:
M. Axer et al: First High Fluence Irradiation Tests of Lasers for Upgraded CMS at SLHC

Measurements at CERN





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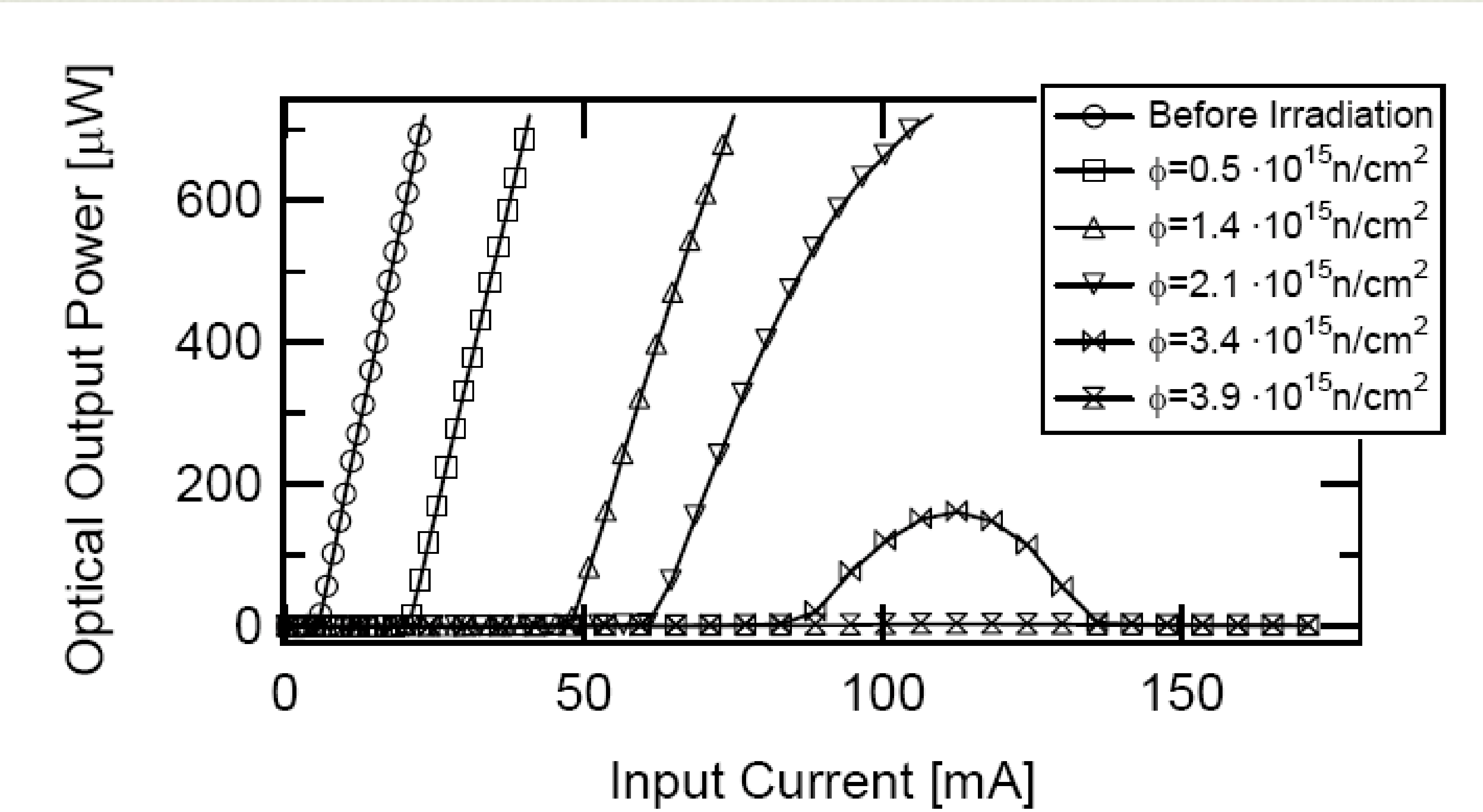
Summary

- For future experiments optical links will be used
- Research need to be done to meet the requirements of the new detectors in terms of speed, radiation resistance, and material budget
- Optical components in radiation study
- On-detector ASIC in first submission
- Wuppertal has its research field at the off-detector optical interface for the readout hardware and at the on-detector laser qualification and package optimization
- So, let's see how the LHC data taking develops and what it will tell us about the installed links further on.

Backup

Irradiation Changes Laser Threshold



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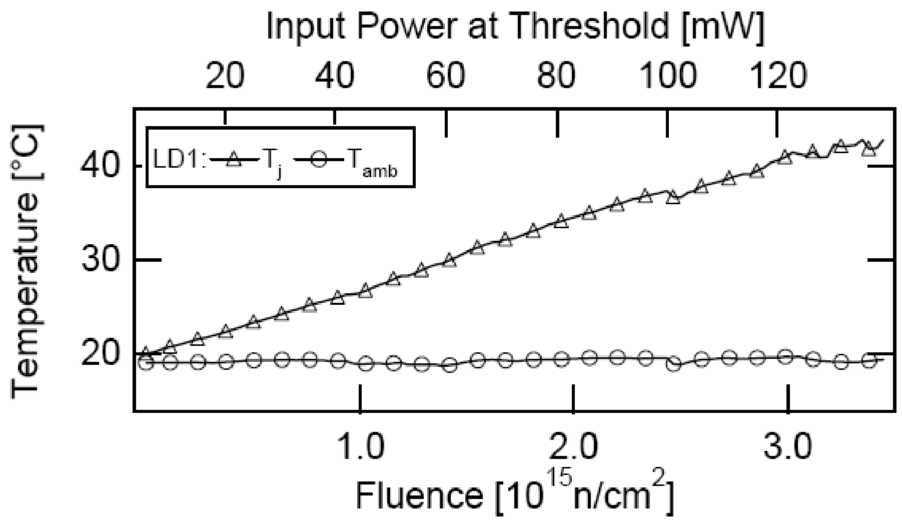
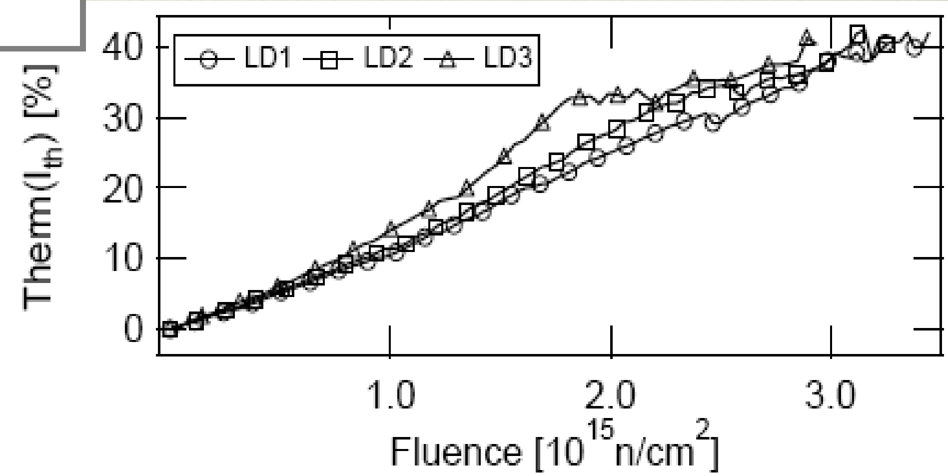
Temperature and Irradiation



Junction Temperature (extracted), environment temperature (measured) vs. Power and radiation Dose



Thermal fraction of threshold current

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