# Lessons Learned & To Be Learnt

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- A brief overview see draft note for details (from TWEPP agenda page)
- Installed links
  - quality
  - problems
  - Long term monitoring
  - QA
- Costs of current links
- Technology choices

# Quality - CMS

- **Very high quality**
  - **Dead : 0.04%**
  - **Problematic: 0.33%**
- **Deaths: broken fibres (ribbons could be repaired or bypassed because of dark fibre).**
- **Problematic: high attenuation due to dirty connectors etc. Not very significant because of gain equalization.**

# Quality - SCT

- **Data links**
  - **Dead : 0.8%**
  - **Problematic: 0.6%**
- **Deaths: ESD VCSELs, broken single fibres on detector, damaged tracks on Al/kapton tapes.**
- **Problematic: “slow turn”-on VCSELs (see later).**

# Quality - SCT

- **TTC links**
  - **Dead : 0.2%**
  - **Problematic: 37%**
- **Deaths: broken single fibres on detector, damaged tracks on Al/kapton tapes.**
- **Problematic: low *p-i-n* current channels (see later).**

# Quality - pixels

- **Data links**
  - **Dead : 0.06%**
  - **Problematic: 6%**
- **Deaths: ESD (could be bypassed by moving a type 0 cable to a spare channel).**
- **Problematic: slow turn-on and difficulty with tuning.**

# Problematic Channels

- **Difficulty to tune some pixel opto-boards**
  - **Common drive current for all 6/7 VCSELs in array**
  - **Limited dynamic range of receiver ASIC DRX-12**
  - **Slow tail in Si *p-i-n* diode signal.**
  - **Can’t accept a big spread in light o/p between channels because too bright channels have too big signal tails if you increase I(VCSEL) to give acceptable light o/p for faintest VCSEL in array.**

# Pixel System Test

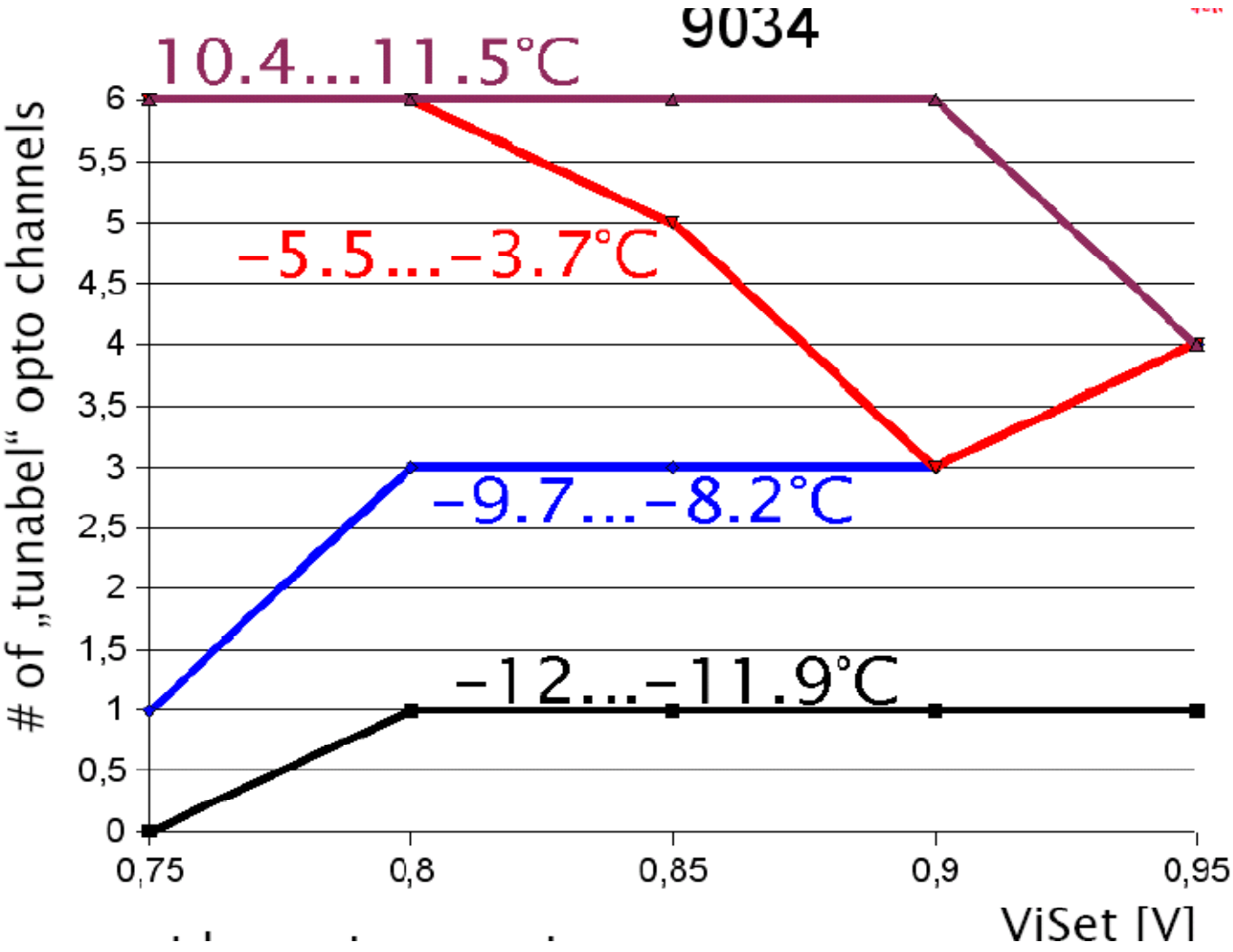
**Can tune all 6 VCSEL links on optoboard warm for range of I(VCSEL)**

**Tuning becomes impossible cold**

**L decreases**

**Spread increases and suffer from common ViSet for all 6/7 channels.**

**Worst opto-boards removed & operate warm**



# Long Term Monitoring

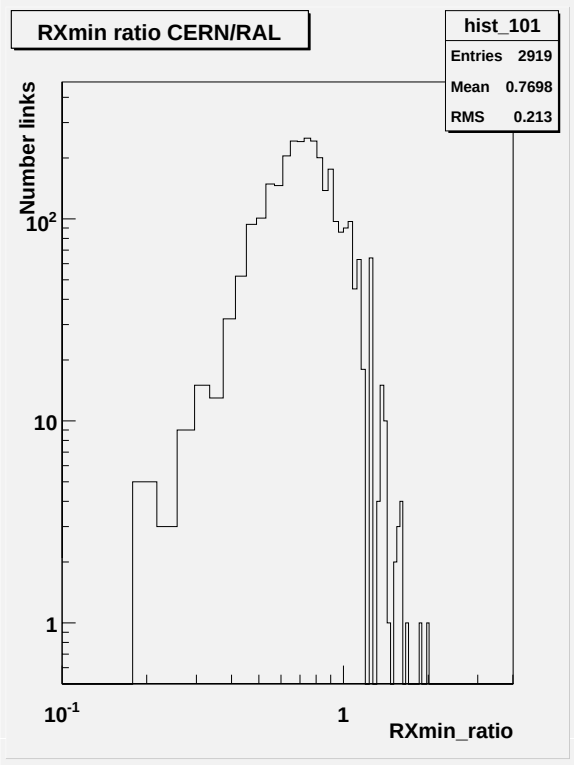
- **CMS**
  - **Analogue links: easy to implement automatic monitoring: measure amplitude of test pulses.**
  - **loop back spare fibres.**
  - **digital links: monitor lost tokens.**
- **ATLAS SCT/Pixels**
  - **Data links, perform RX threshold scans**
  - **TTC links, measure p-i-n currents.**

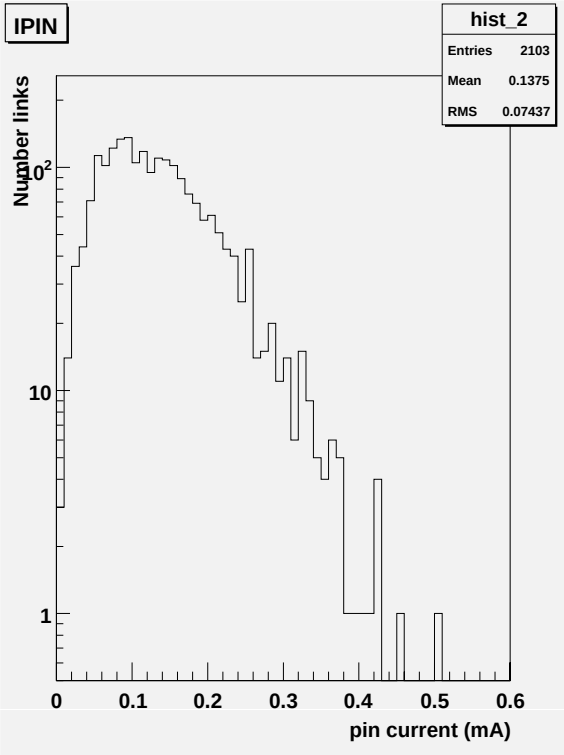
# Long Term Monitoring Digital Links

**Histogram**

**RXmin ratio**

**Pit/RAL**




**Histogram of *p-i-n* currents**

**Scan RX thresholds for data links, RXmin ➔ optical power received.**

**Plot ratio RXmin Pit/RAL**

**See decrease of 1 dB as expected from attenuation in long cabe**

**Monitor long term performance**

**For TTC links measured p-i-n currents give measure of performance.**

**(Already see problems but will fix with new TXs with ulens arrays)**

# Long Term Monitoring

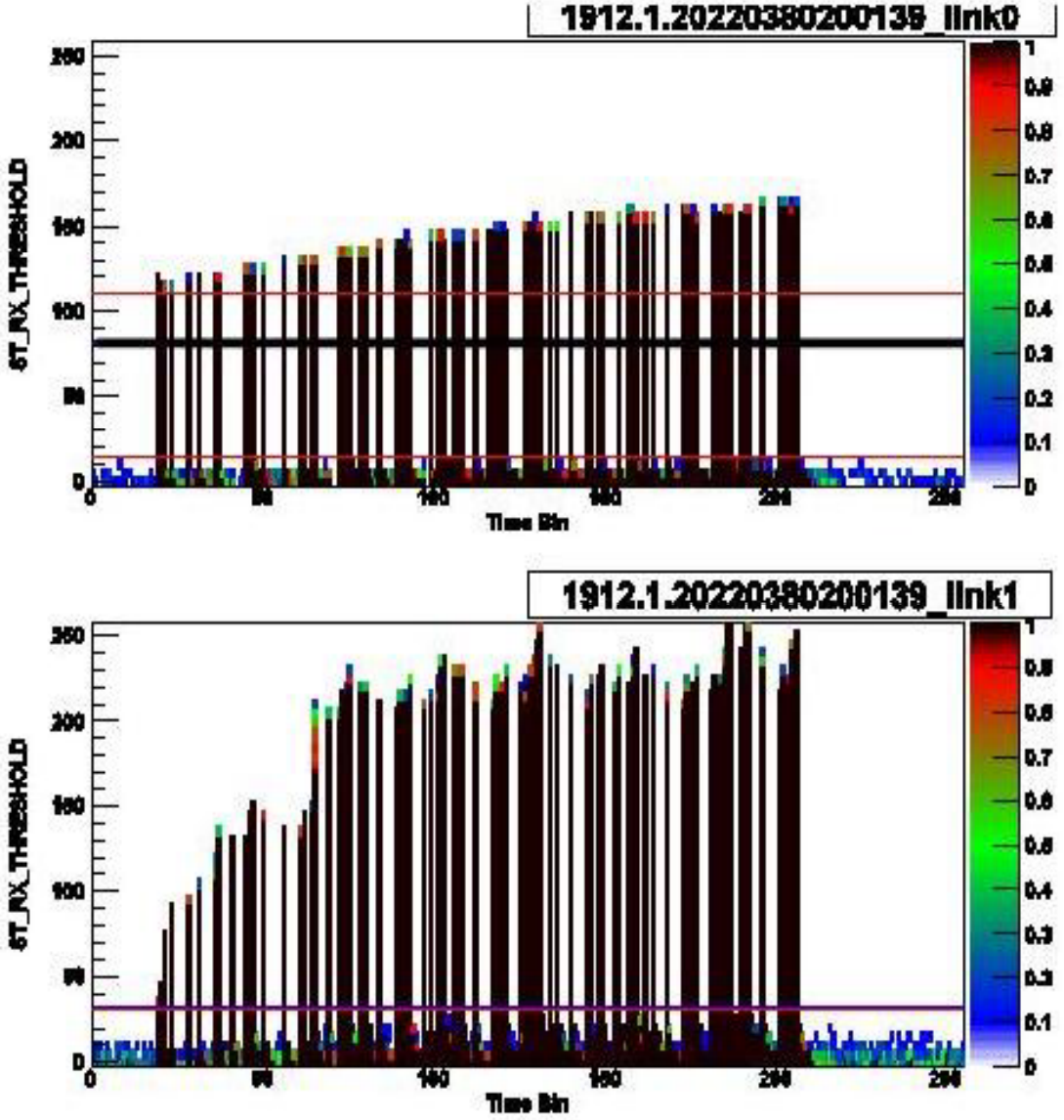
- **Easy to monitor analogue links**
  - **Need precise calibration of links for an analogue system.**
- **Can monitor digital links**
  - **Could be improved for SLHC**
    - **design long-term monitoring into the system**
    - **better dynamic range for RX and**
    - **by measuring individual p-i-n currents in RX.**
- **Conclusion 1: small but not decisive advantage for analogue links.**
- **Conclusion 2: need to see results from long term monitoring …**

# QA Problems

- **Extensive QA was done at all stages, mostly very good but …**
- **QA must be done to fully simulate final system, otherwise problems…**
  - **Eg slow turn-on VCSELs not seen in SCT QA because tests used PSBR data or DC ➔figure next slide.**
- **Conclusion: details matter.**

# SCT Slow-turn on VCSELs

- Send fixed data pattern
- **Scan DAC RX threshold**
- **Check to see if correct bit pattern returned.**



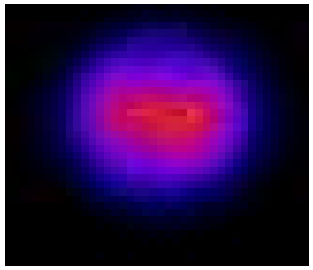
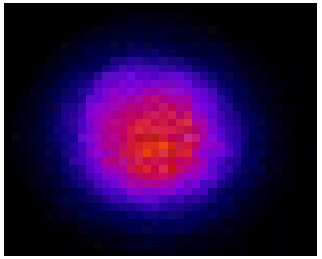
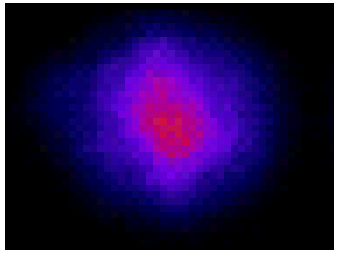
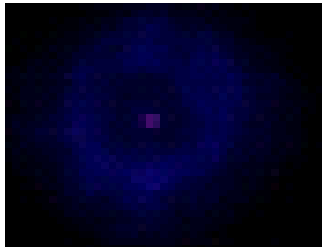
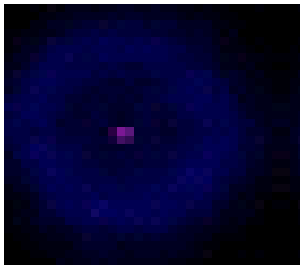
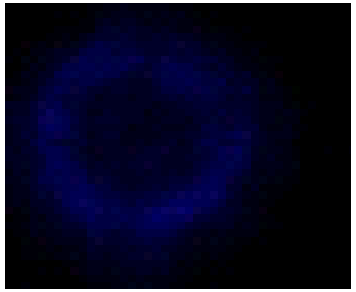
# QA

- More subtle twist to the story … pixels checked their VCSELs and didn't see any problems but…
- then found some slow turn-on VCSELs when opto-boards installed in final system. This was due to the different distance from VCSEL to face of MT because of bevelled versus flat MTs. Moral: Details matter!

# QA Problems

- **SCT fibre cable was tested after installation with LED sources (not VCSEL).**
- **Problem is LED source fills all modes, VCSEL fill only a few transverse modes and higher order modes can be “leaky”.**
- **Picture of “good” and “bad” VCSELs ➔ next slide.**
- **Can be fixed by ulens array but some mysteries remain, problem only seen for barrel fibres not EC?**

# Examples of Good and Bad

# Costs

- Production and development costs
  - See document for breakdown and effort.

| | ATLAS Pixel | ATLAS SCT | CMS tracker |
|---|---|---|---|
| **Quantity** | **4,144** | **12,264** | **42,800** |
| **Production cost (CHF)** | **1,693k** | **3,486k** | **12,597k** |
| **Development cost (CHF)** | **398k** | **250k** | **2,000k** |
| **Production cost/link (CHF)** | **409** | **284** | **294** |
| **Development cost/link (CHF)** | **96** | **20** | **47** |

# Costs

- **Cost of all optical links inside trackers are expensive and were sometimes underestimated at the start.**
  - **Some reduction in cost/link with number of links but effect small.**
  - **No such thing as a cheap/simple link.**
  - **Costs are not dominated by one component ➔ very difficult to gain dramatic reduction.**
  - **Installation effort large and underestimated.**
- **Can't afford to scale up current systems by an order of magnitude ➔ use fibre bandwidth ➔ high speed digital links.**
- **R&D effort large ➔ share effort for SLHC**

# Technology Choices

- **Many details but main conclusion is that details matter!**
- **Fibre Cables as an example.**
  - **They look simple but …**
  - **Many problems in CMS (had to change buffer coating for single fibres and took a long time to develop the fibre cable).**
  - **ATLAS SCT TTC system has many channels with low *p-i-n* currents. Still not fully understood.**

# Technology Choices for SLHC

- 1310 nm
  - Pro: rad hard commercial SM fibre available.
  - Con: EEL show large threshold shifts for SLHC fluences.
- 850 nm
  - Pro: VCSELs show smaller threshold shifts after SLHC fluences.
  - Con: rad-hard SIMM fibre has very low bandwidth. Single source. GRIN fibre radiation hardness marginal. Mixed SIMM/GRIN as in current pixel system?
- Best of both worlds: VCSELs at 1310 nm?
  - Small threshold shifts + rad-hard, high bandwidth SM commercial fibre
  - Don't yet know if this technology will become widely available
  - Need to continue R&D on 850 nm VCSELs and 1300 nm EEL for now.

# DC/AC codes

- **Assuming we transmit digital data should we use DC or AC codes?**
  - **SCT chose to use NRZ code (DC) based on LED links to minimize bandwidth requirement. This argument not very relevant for lasers.**
- **Lesson learned from SCT/pixels: DC code introduces vast complexity into system compared to (balanced) AC code.**
  - **Difficult to tune and maintain RX thresholds for large system of DC links**
  - **Sensitive to turn-on effects and drifts ➔ big effort to maintain optimal values of RX thresholds.**
- **Conclusion: use standard digital (balanced) codes for SLHC.**

# Technology Choices for SLHC

- **Many details are important…eg**
- **Only use non-magnetic materials?**
  - **Obviously shouldn't put large amount of magnetic material inside solenoids!**
  - **Should we stick to this religiously?**
  - **ATLAS had no magnetic materials, CMS had Kovar in the pin diode package.**
  - **Might mean we only have one source for opto-package.**
  - **My proposal: aim to minimise magnetic materials but carefully evaluate effect of small amounts of weakly magnetic material in a proposed opto-package.**

# Reliability

- **CMS made very extensive reliability testing: 1200 lasers radiation/lifetime tested as part of advance validation.**
- **SCT: accelerated ageing tests of 20 VCSELs.**
- **Pixels: tested 3 VCSEL arrays**
- **Open question: how much reliability testing is required for SLHC?**

# Redundancy & Reliability

- **CMS has no redundancy in data links but full redundancy for TTC.**
  - **More layers in CMS tracker ➔ can afford to lose ~ 1% data links.**
- **SCT has redundancy for data and TTC links.**
  - **Already used for channels damaged during assembly.**
- **Pixels have no redundancy but location of pixel opto-boards meant they could (and some were) be replaced relatively late in assembly sequence**
- **Question: what do we need for SLHC?**

# Location of Optoelectronics

- **On module?**
  - **Pro: minimise lengths of high speed electrical signals**
  - **Cons**
  - **fragile single fibres on detector**
  - **Non modular ➔ difficult to assemble**
  - **Fibre has to exit from cold to warm.**
  - **Can't benefit from high bandwidth of fibre ➔ cost not affordable!**

# Location of Optoelectronics (2)

- **End barrel/disk**
  - **Con: longer lengths of high speed electrical signals**
  - **Pros**
  - **Easier to assemble**
  - **Use high speed links**
  - **Replaceable during assembly?**
- **Further out eg cryostat bore for ATLAS?**
  - **Easier to replace during assembly**
  - **Outside thermal enclosure (avoids fibre feed-throughs)**
  - **Lower radiation levels for opto.**

# Summary

- Many detailed lessons learnt from current LHC experiments ➔ see write up.
- More lessons will be learnt from operational experience in the next few years …