Lessons Learned & To Be Learnt

K.K. Gan (ATLAS/pixel), Francois Vasey (CMS) & Tony Weidberg (ATLAS/SCT)

- **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

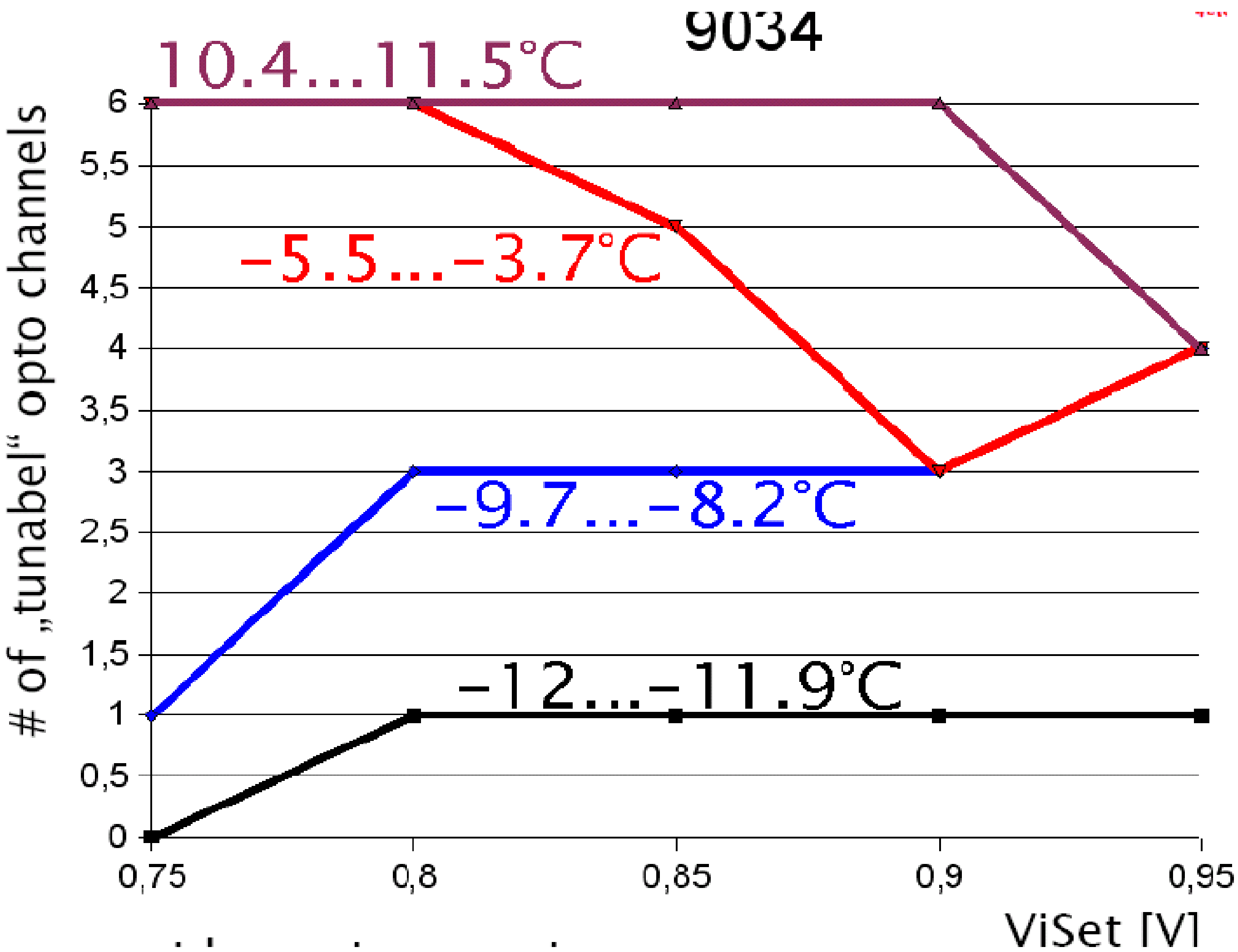
Can tune all 6 VCSEL links on optoboard warm for range of I(VCSEL)

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

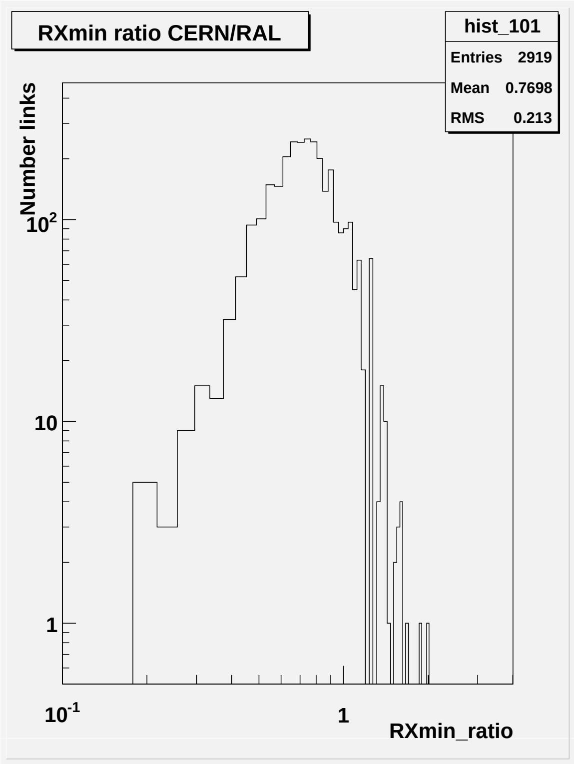
- **CMS**
  - **Analogue links: easy to implement automatic monitoring: measure amplitude of test pulses.**
  - **loop back spare fibres.**
  - **digital links: monitor lost tokens.**
- **ATLAS SCT/Pixels**
  - **Data links, perform RX threshold scans**
  - **TTC links, measure p-i-n currents.**

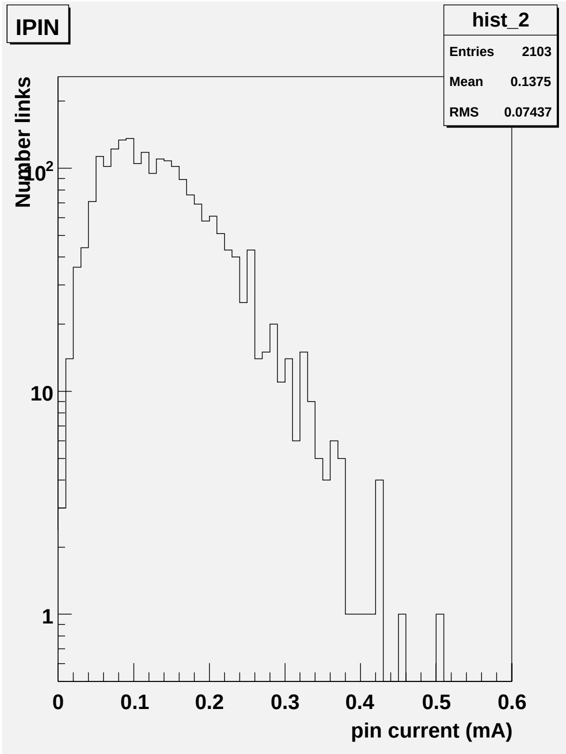
Long Term Monitoring Digital Links

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

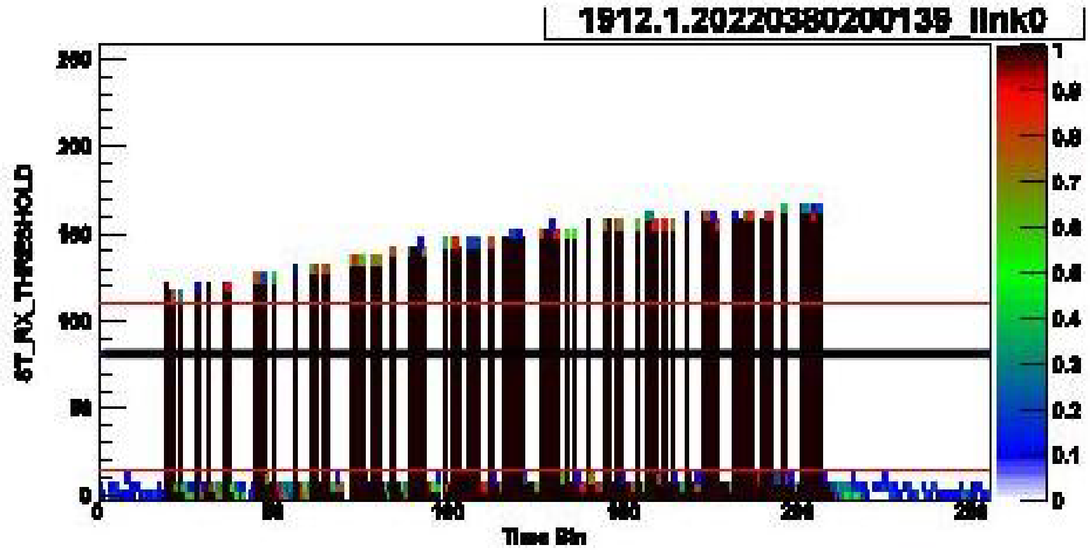
- **Easy to monitor analogue links**
  - **Need precise calibration of links for an analogue system.**
- **Can monitor digital links**
  - **Could be improved for SLHC**
    - **design long-term monitoring into the system**
    - **better dynamic range for RX and**
    - **by measuring individual p-i-n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

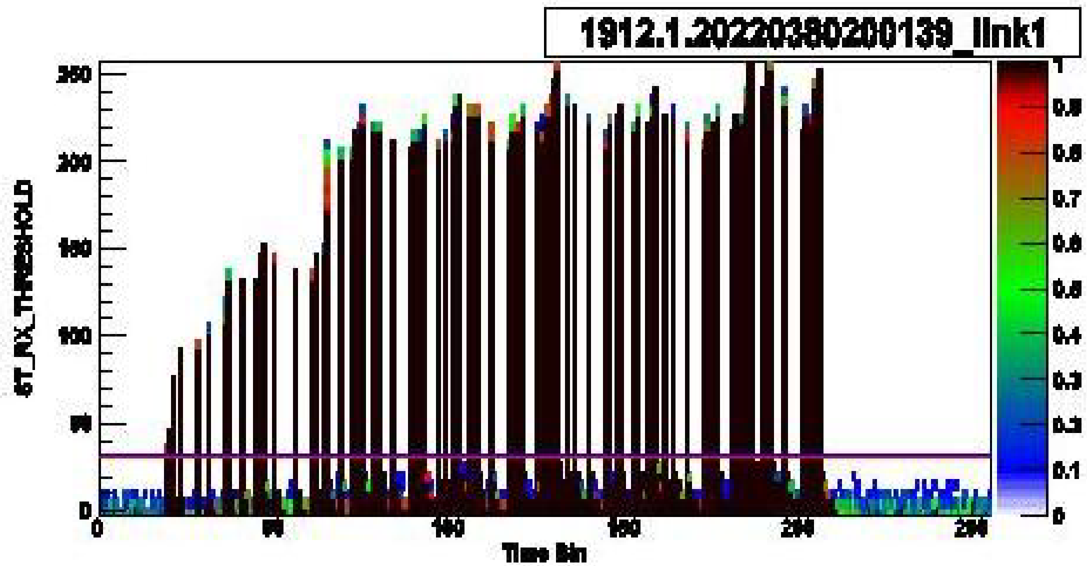
QA Problems

- **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.**





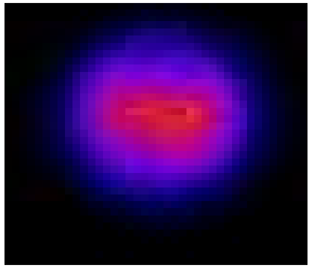
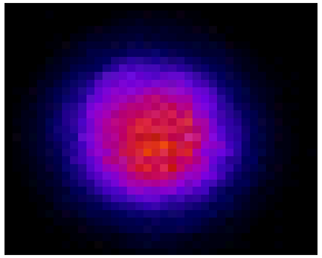
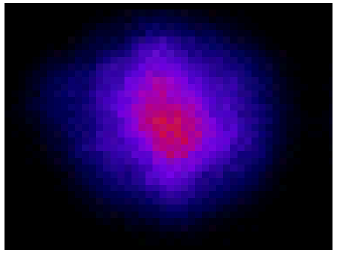
QA

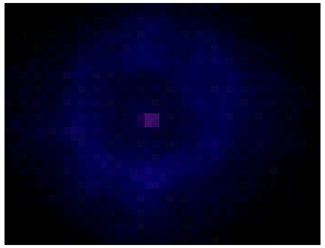
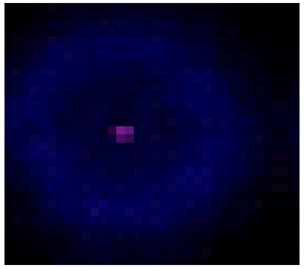
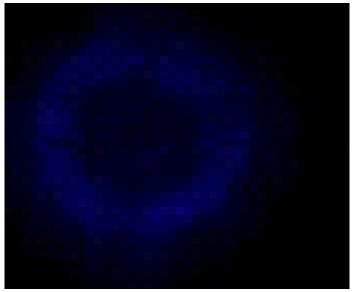
- **More subtle twist to the story … pixels checked their VCSELs and didn’t see any problems but…**
- **then found some slow turn-on VCSELs when opto-boards installed in final system. This was due to the different distance from VCSEL to face of MT because of bevelled versus flat MTs. Moral: Details matter!**

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 nmVCSELs and 130 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 …