Optical Links for ATLAS Liquid Argon Calorimeter Front-end Electronics Readout

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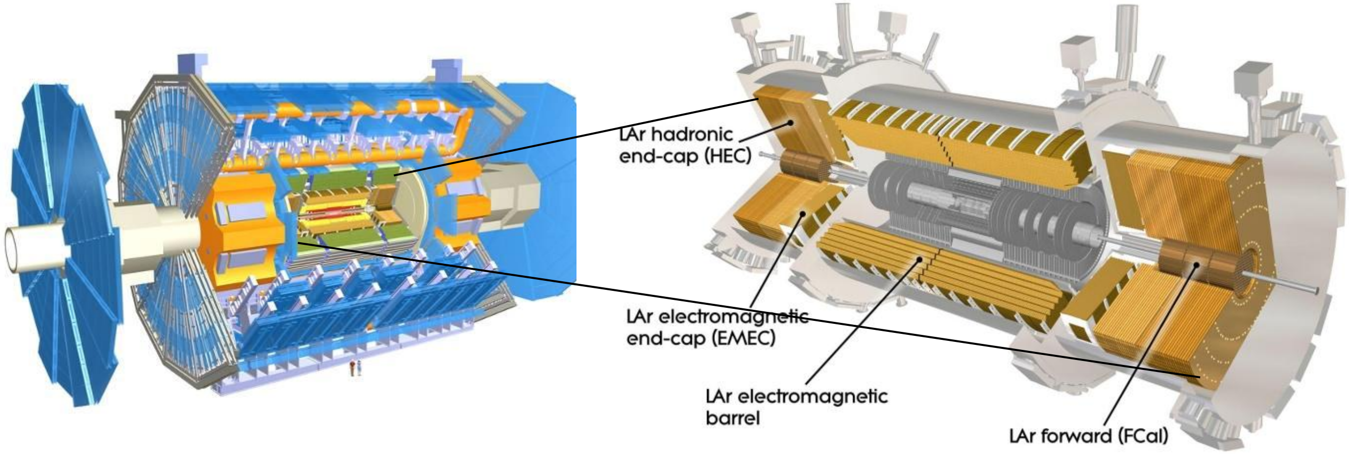
Outline

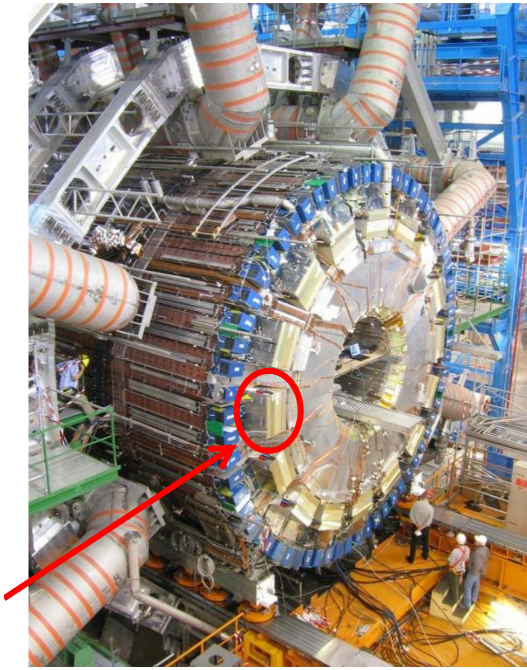
1. ATLAS LAr optical links overview
2. VCSEL problem and the possible fixes
3. Lessons learned in the optical links development
4. Summary

ATLAS Liquid Argon Calorimeter (LAr)

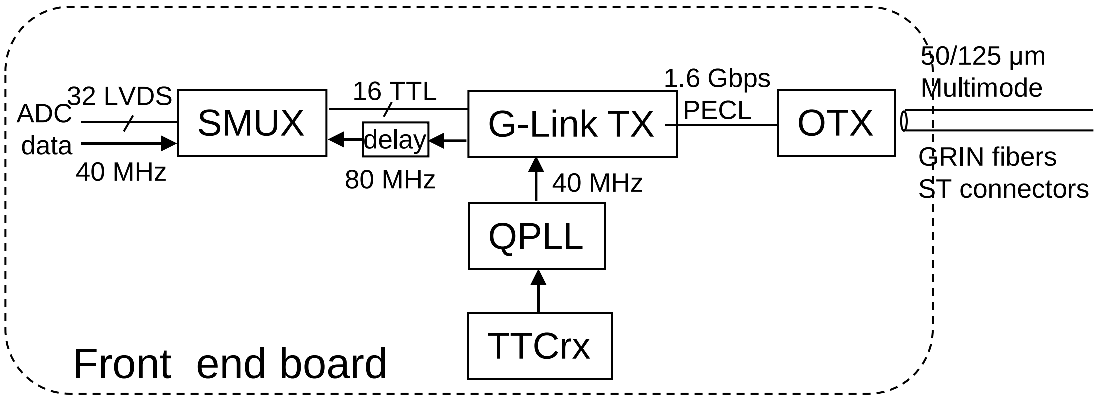


- **~180,000 detector channels**
- **Front-end Electronics on the detector**
  - **58 Front End Crates**
  - **1524 Front End Boards (FEB)**
  - **128 channels per FEB**
- **Back-end Electronics (150 meters away)**
  - **16 Back End Crates**
  - **192 Read Out Driver (ROD) Boards**
- **Fiber optical links between FE and BE**
  - **1524 links, 1.6 Gbps per link**
  - **1 fiber per FEB (128 channels)**

Front End Crate



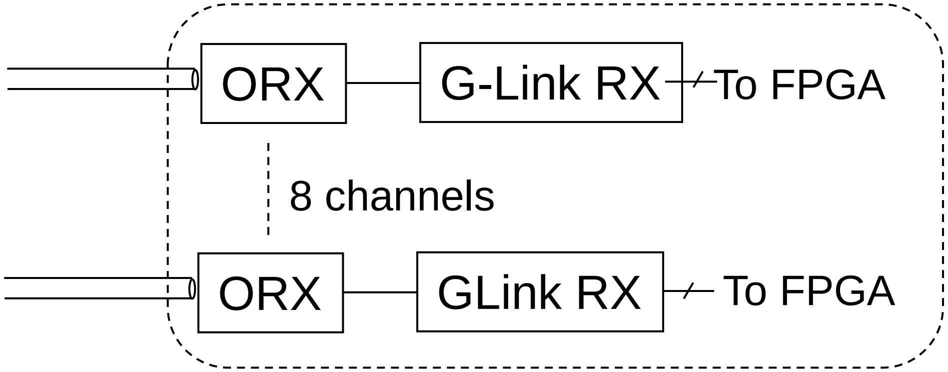
ATLAS LAr optical links overview



- Developed by a collaboration of 5 institutions: CPPM, IPAS, ISN, KTH and SMU.
- Lasted for 6+ years: 1998 - 2004

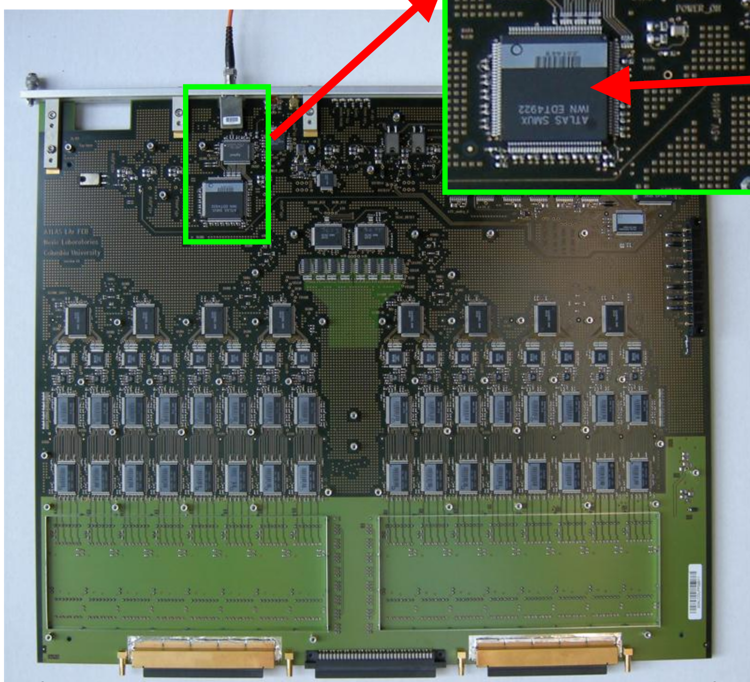
- G-Link: commercial serializer/deserializer, specially ordered from Agilent, operating outside of specifications
- SMUX: an ASIC fabricated in DMILL, interface between G-Link TX and ADC data
- OTX, ORX: custom assembled optical interface modules, commercial VCSEL, PIN, laser driver, and TIA
- Components on front-end: radiation tolerant

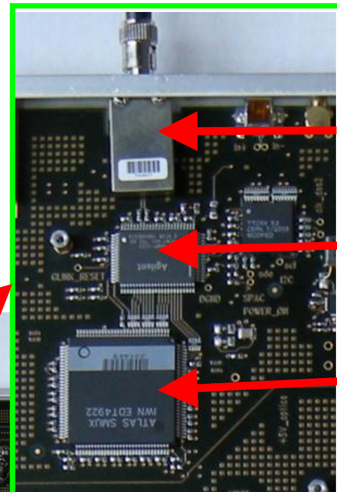
Back end – readout driver board



LAr optical links

Fend-end board





OTX

G-link TX

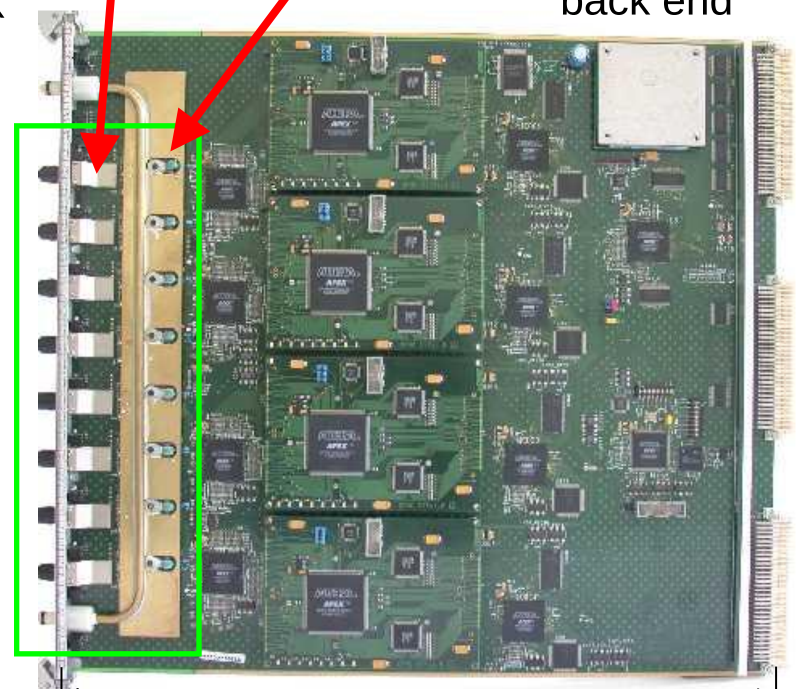
SMUX

~ 400 mm

ORX

G-Link Rx

Readout driver board on back end



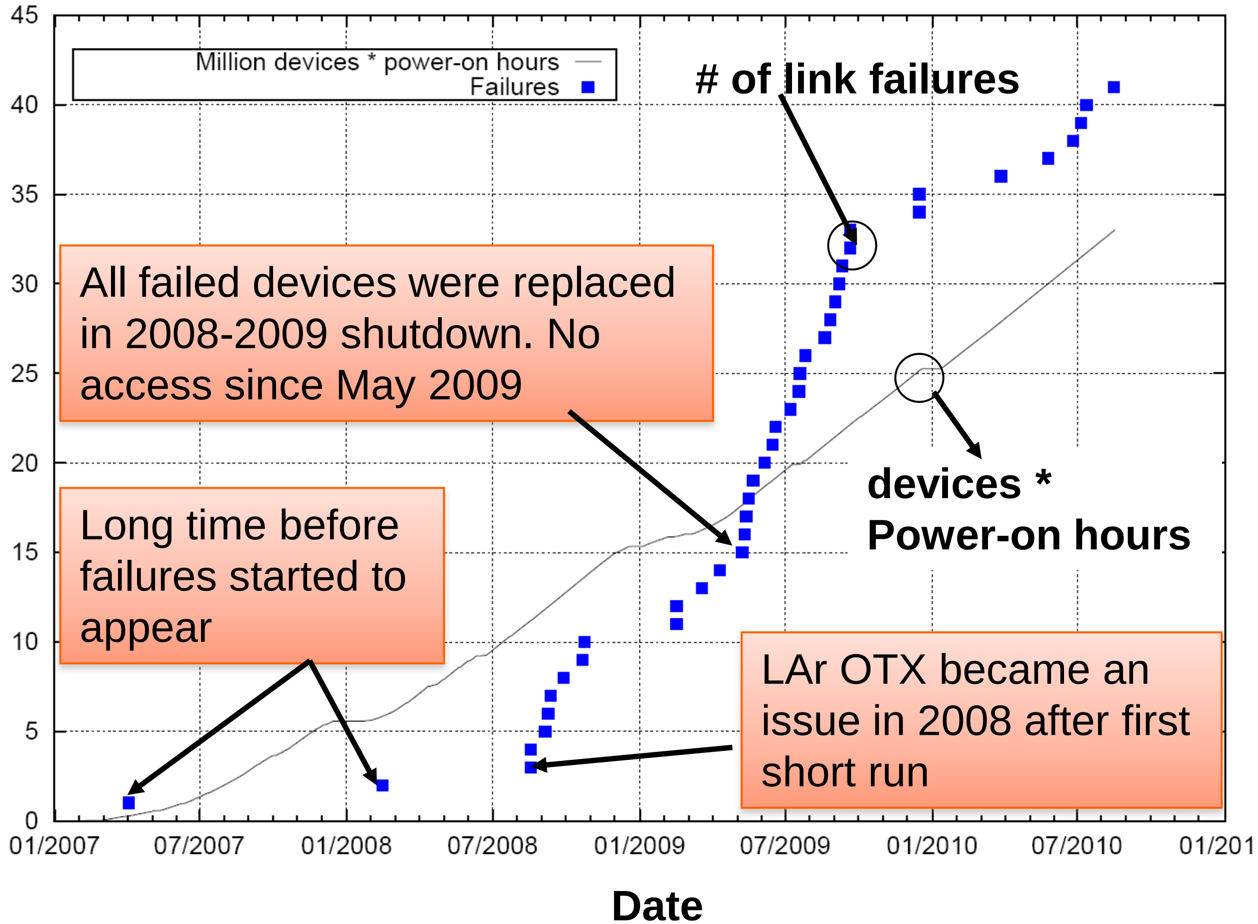
~ 400 mm

Outline

1. ATLAS LAr optical link overview
2. VCSEL problem and the possible fixes
   - Current Status
   - Failure analysis
   - Backup plans
3. Lessons learned in the optical link development
4. Summary

VCSEL failure (S. Simion)

- The loss of one link means the loss of data of 128 channels. There are 1524 links in total.
- By now 24 dead OTXs are still inside the detector (+3 used for read back configuration of FEBs)
- Visually all OTX failures are either confirmed VCSEL failures when the parts were accessible and replaced or consistent with VCSEL failures (no light)



Failure analysis

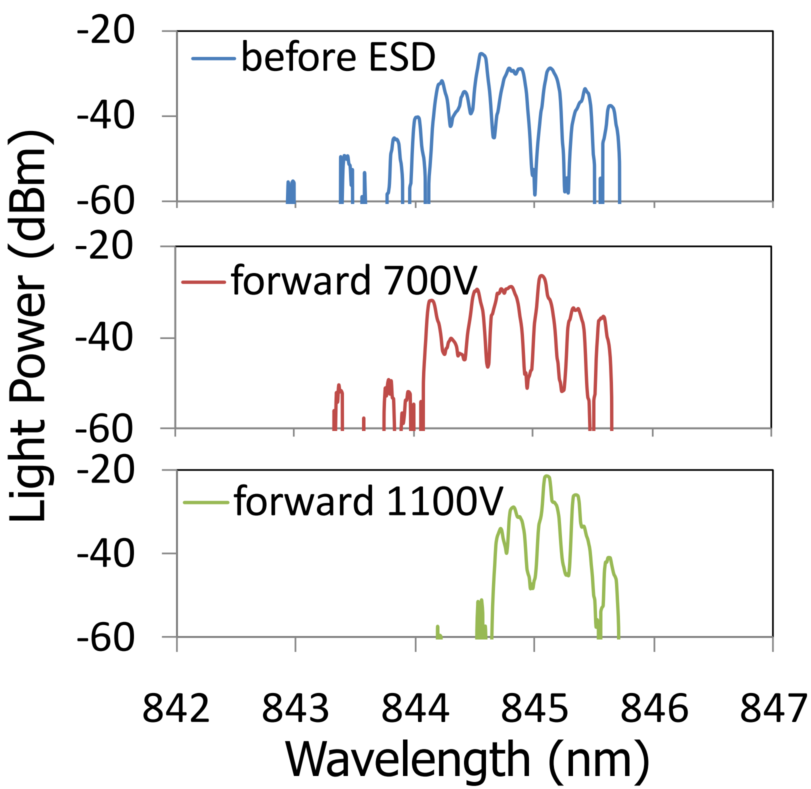
- A task force was created in December 2008 to deal with the VCSEL issue.
  - Plan A: replace the failed parts with similar devices IF the cause is understood and removed
  - Plan B: replace all parts with new production
- **Although a lot of attempts have been made to understand the failure cause,**
  - Humidity
  - Magnetic field
  - Electrostatic discharge (ESD)
  - Electrical overstress (EOS)
  - VCSEL fabrication defects
  - …

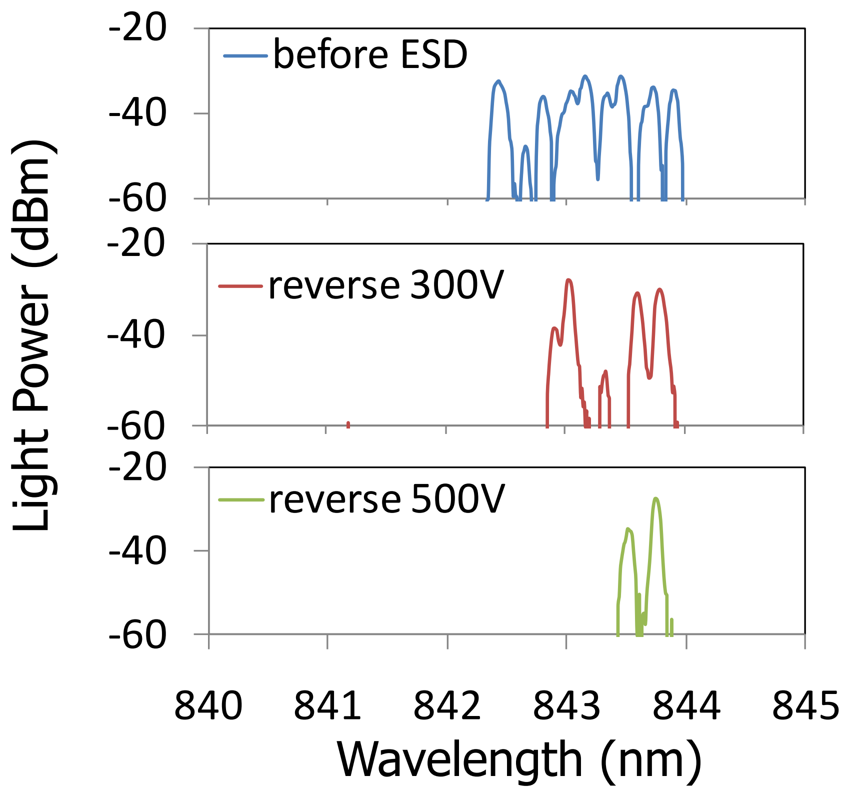
  so far we have not got to the root cause.

- The VCSEL failures exist not only in ATLAS LAr, but also in other ATLAS detectors and LHCb.

Optical Spectrum versus ESD

- In June 2009, from literature[1], we realized that optical spectrum of a VCSEL becomes narrow after ESD damage. An experiment at SMU verified.



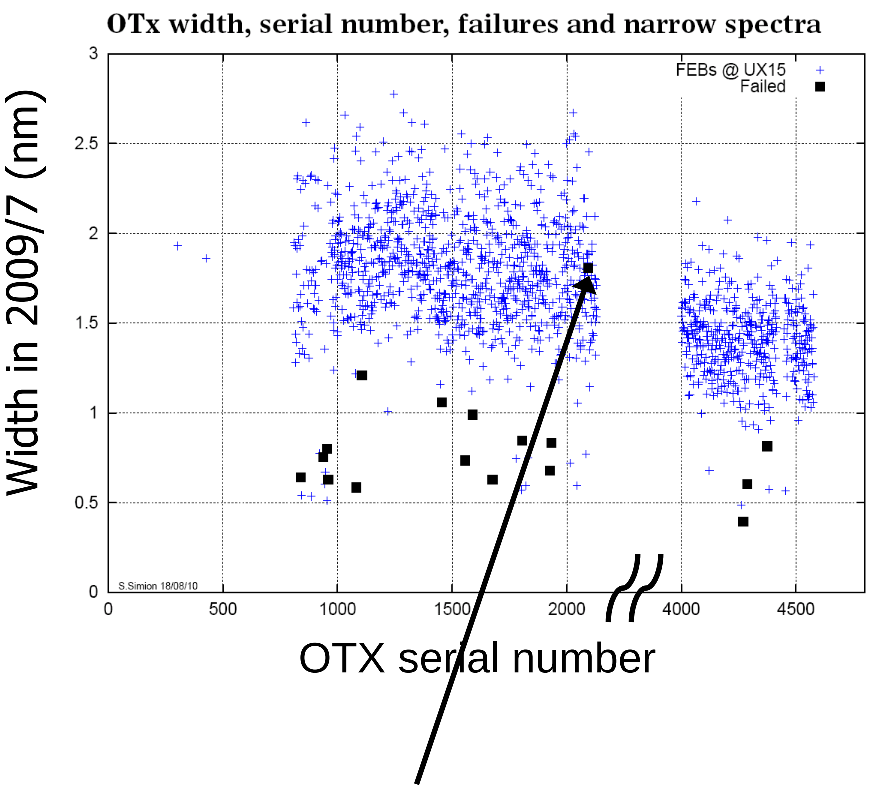


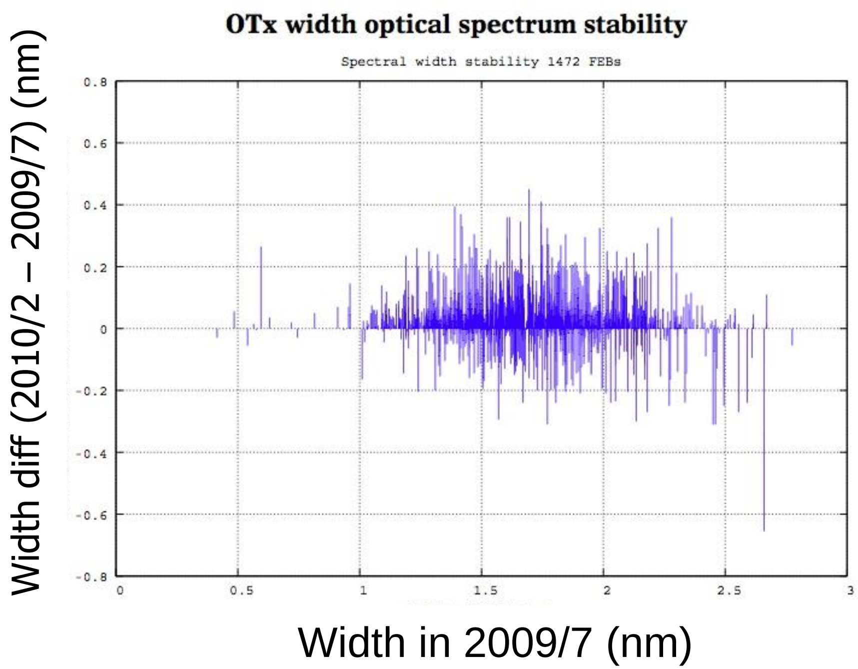
- We know ESD produces narrow optical spectrum, but we are not sure whether narrow optical spectrum is caused only by ESD

[1] T. Kim *et al*, *ETRI Journal*, Vol. 30(6), Dec 2008, pp.833-843

Failure prediction (S. Simion)

- Is a VCSEL with narrow spectrum more likely to fail? The answer seems to be: yes.
- All optical spectra at the end of fibers have been measured three times (2009/7, 2009/10, 2010/2). Optical spectrum seems stable.

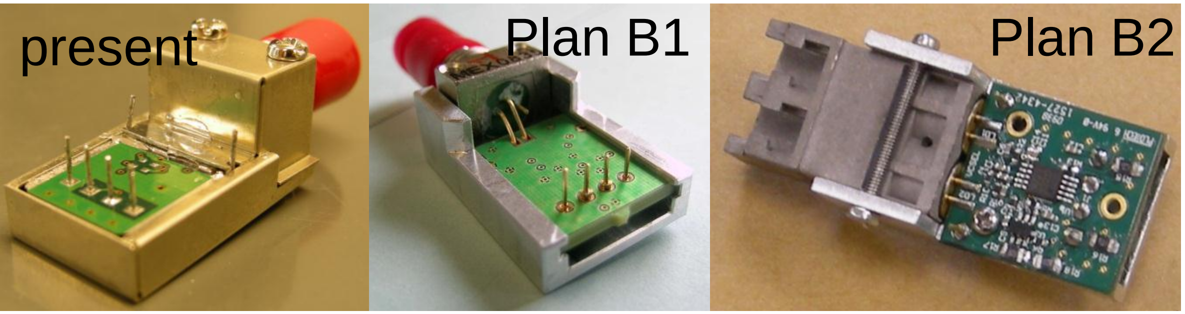




Optical link died on July 13, 2010

We suspect it is not due to the VCSEL but other component in the FEB/OTX, but we cannot know for sure until we get the board out

Plan B: backup plans

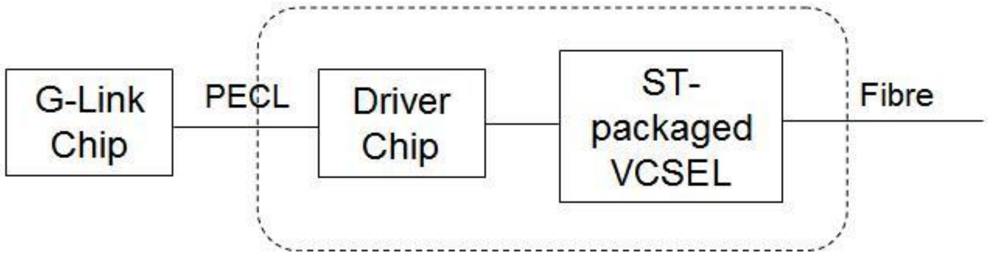


It is worth mentioning that in order to exchange OTXs with either option, the biggest problem is to get the 1500 boards out of the pit, dismount cooling plates, solder OTX off the board....

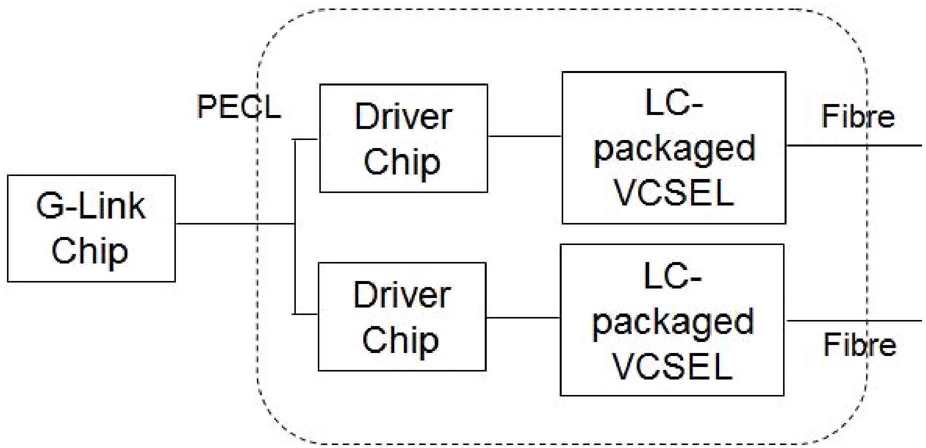
		Plan B1	Plan B2
Developed by		LAL Orsay	SMU
New VCSEL		Optek	Finisar
VCSEL driver chip		same	Same
VCSEL driving circuitry		New	Same
Redundancy		**No**	**Yes**
Compatibility	Pin	Yes	Yes
	Front panel	Yes	Requires small modification of front panel
	fibers	Yes	Requires installing new(double) fibers
Status		Testing/qualification phase	tests including radiation qualification done

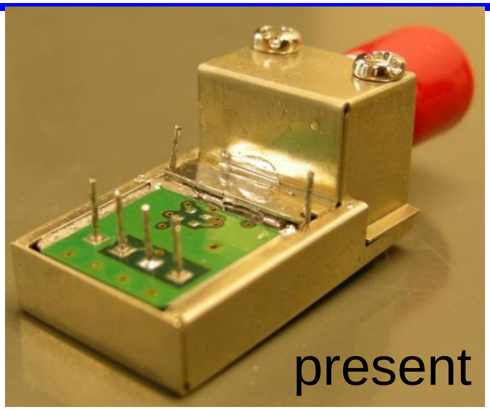
Plan B2: a plan w/ redundancy

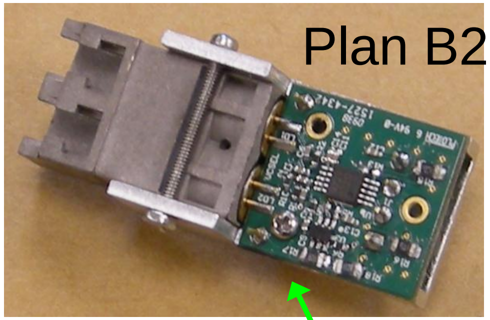
The present OTX:



The proposed dual-VCSEL OTX:



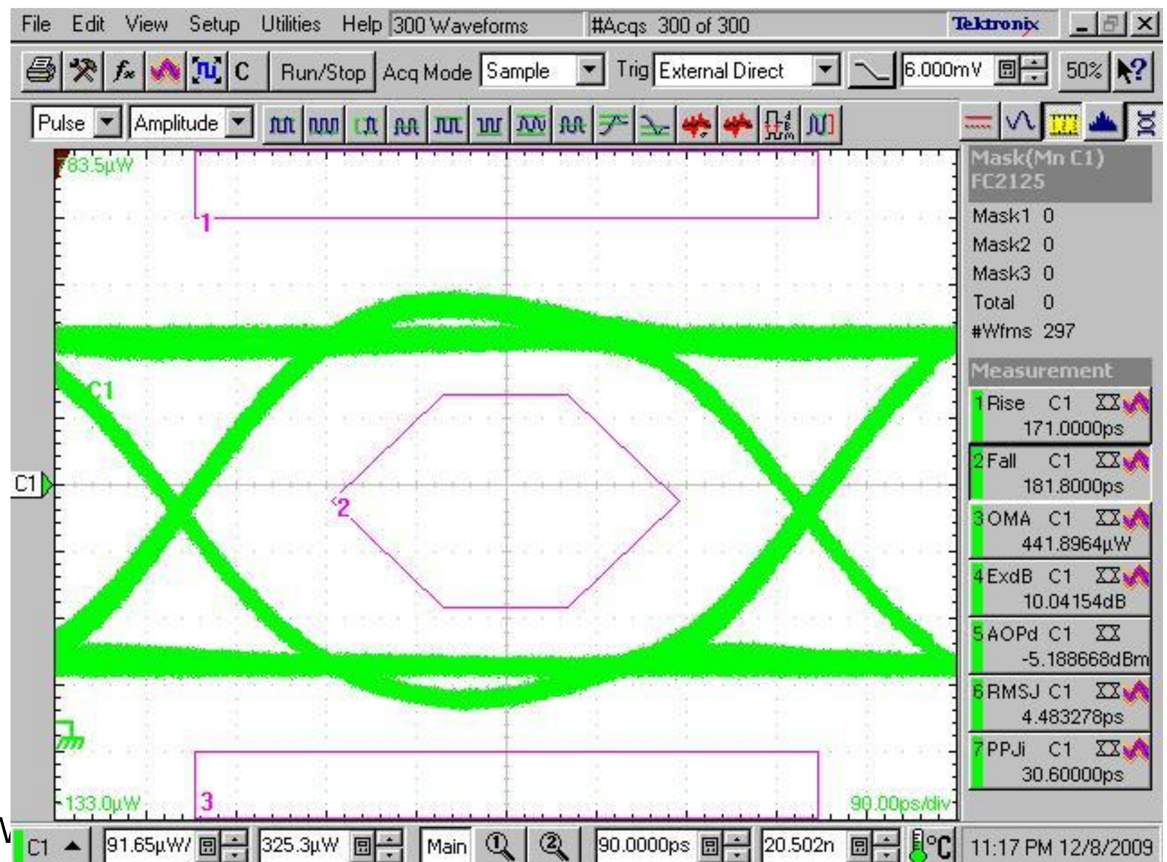




Plan B2: production readiness

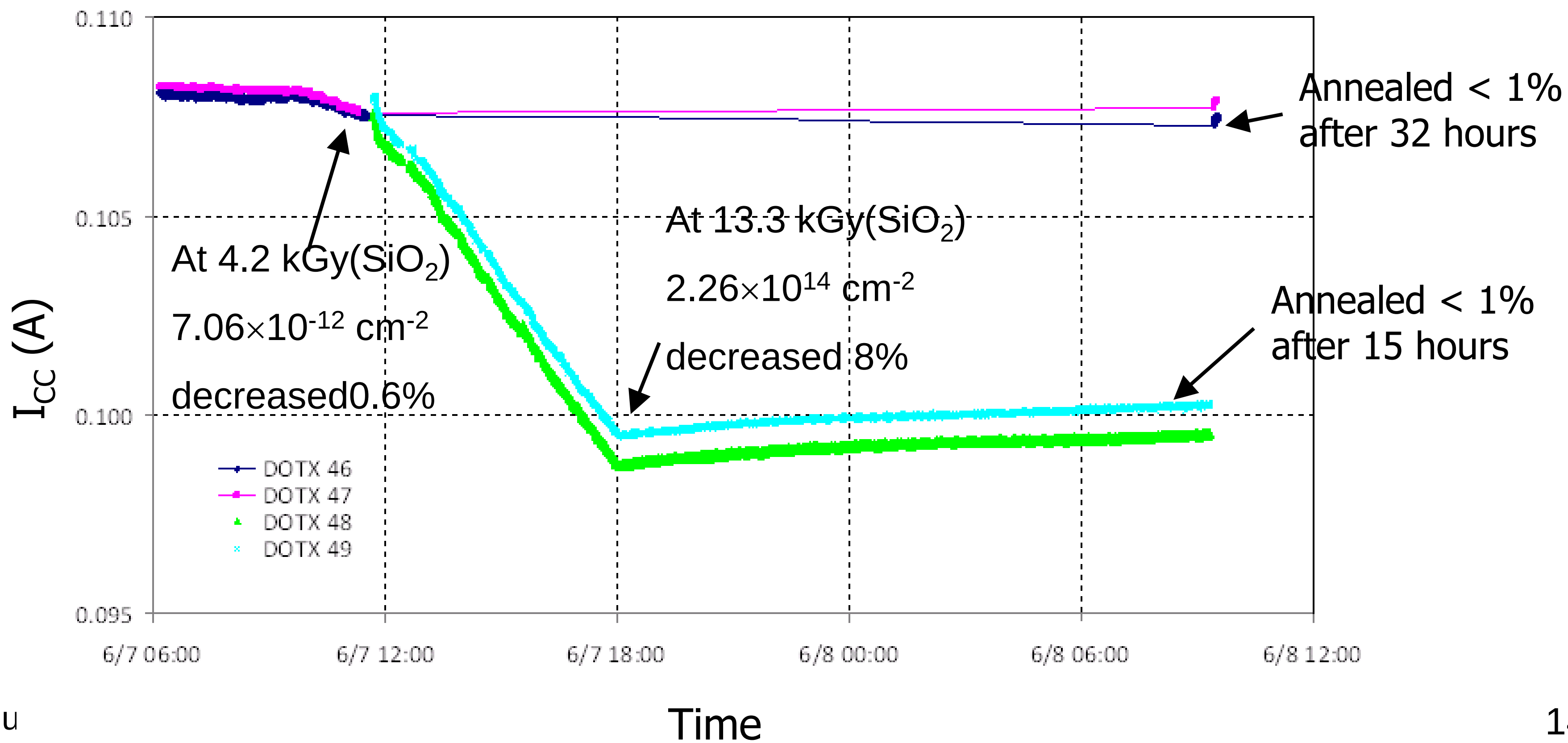
- 122 modules have been assembled at SMU
- Eye diagrams, average optical power, extinction ratio, rise/fall time, jitter, bit error rate (BER), and optical spectrum of all channels have been measured
- With 10 dB optical attenuation, BER < 10^{-12}

Thank Cotty Kerridge, Chonghan Liu, Sophia Wang, Yuan Zhang for measuring the curves



Radiation qualification of Plan B2

- 200 MeV proton beam
- All four modules continued to function throughout the test.
- The power supply current changed < 8% with 13.3 kGy(SiO_2)
- Cross section estimated < 1.8×10^{-10} cm^2. Correspondingly, the estimated BER at ATLAS LAr is < 5×10^{-14}, << the industrial standard 1×10^{-12}



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Lessons learned

- In the R&D phase
  - No system specification was studied in the beginning of R&D. In particular, no jitter requirement on the reference clock was realized until an issue occurred.
  - The importance of redundancy was not realized in the R&D. A dual channel redundancy scheme was developed in R&D, but declined in the final implementation due to the cost.
- In the integration phase
  - All components of optical links were soldered on front-end board or readout driver boards. The replacement of an OTX may damage a whole FEB. A pluggable module containing OTX or a mezzanine board containing an optical link will definitely help.
- In the production and quality assurance phase
  - We spent a lot of time to learn the OTX burn-in process.
  - We performed a reliability test on OTX, but the total device hours were too small to catch any VCSEL failure.

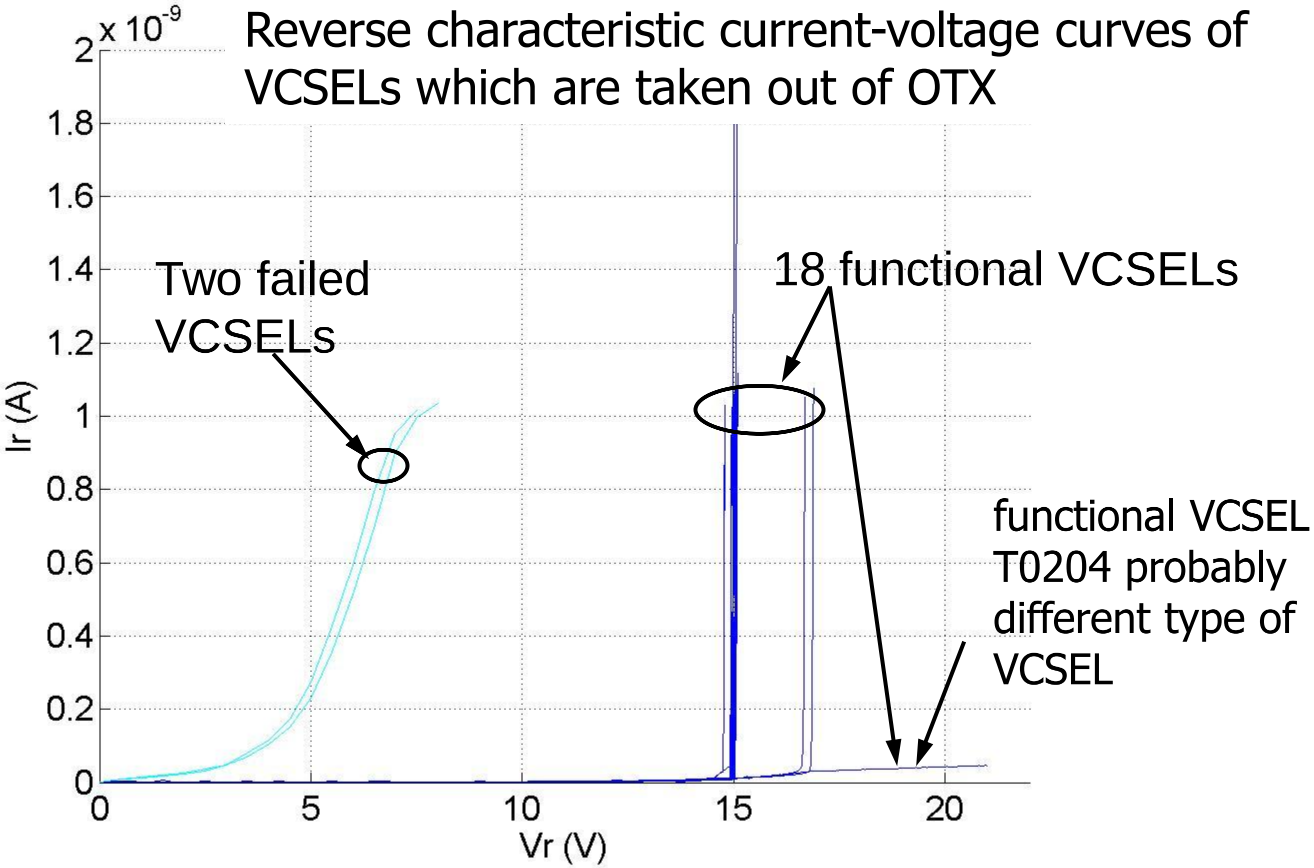
Summary

- Other than the VCSEL failure at a few percent level, the optical link system for ATLAS LAr front-end electronics readout is functioning as designed and transmitting physics data.
- Although we have made many attempts to understand the cause of VCSEL failures, so far we failed to get to the root cause. However, optical spectrum seems effective at predicting which OTX is likely to fail.
- Two backup plans are under development and will be production ready before the next LHC shutdown.
- At some point, we have to make a decision among Plan A, B1 or B2:
  - Plan A : replace dead and narrow spectrum OTXs IF spectrum indication is still effective. We have enough good spares.
  - Plan B1 and B2: replace all OTXs with compatible design (B1) or redundant design (B2)
- The most profound lesson learned is that we cannot overemphasize the importance of redundancy in a system without much access.

Backup slides

VCSELs' reverse I-V curves

- An attempt conducted at SMU is to look for the ESD symptoms, the reverse leakage current and forward voltage threshold/slope.
- The I-V curves of functional VCSELs are different from the curves of dead VCSELs.
- No indication of ESD damage is found in the spare OTXs.



VCSELs' forward I-V curves

- The I-V curves of functional VCSELs are different from the curves of dead VCSELs.
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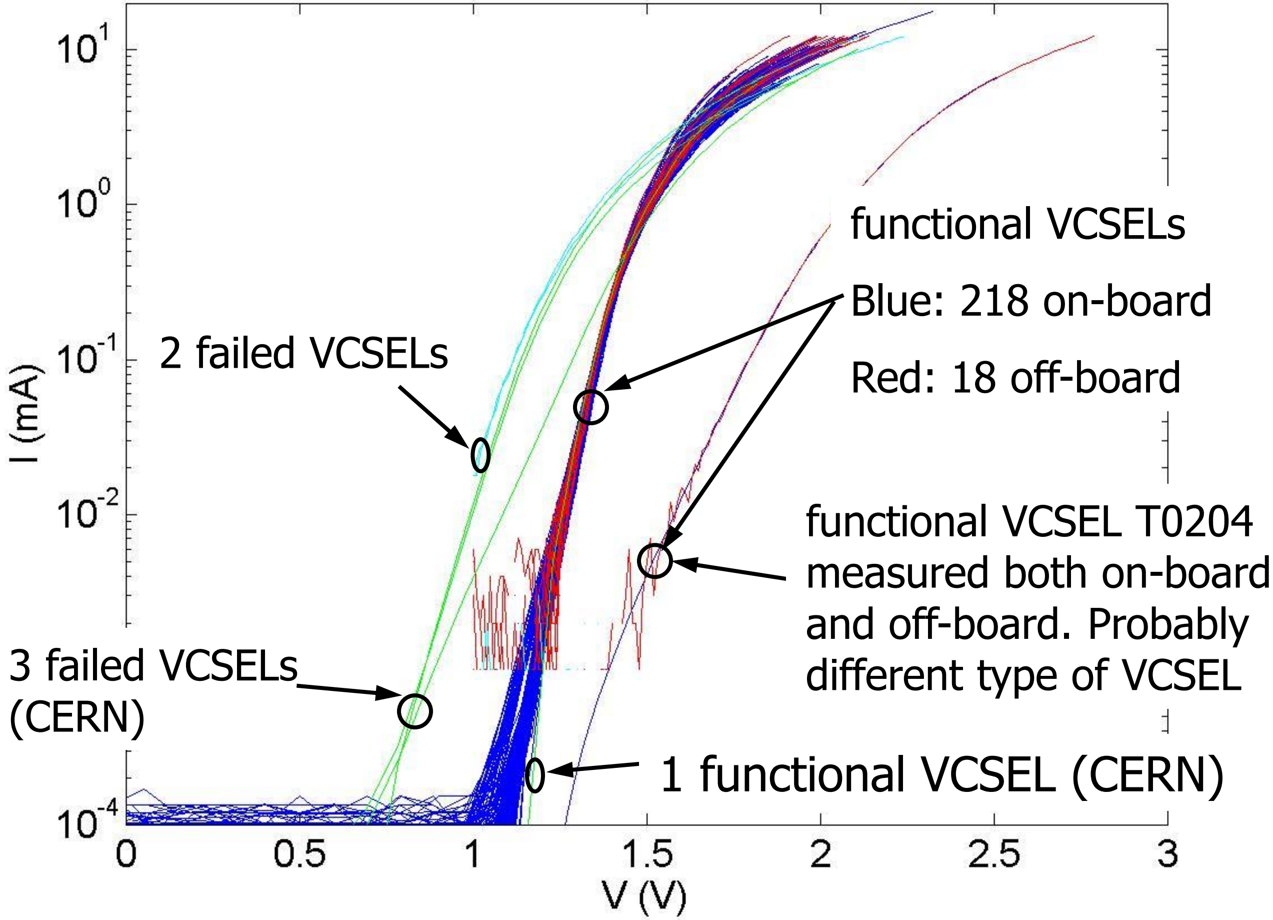


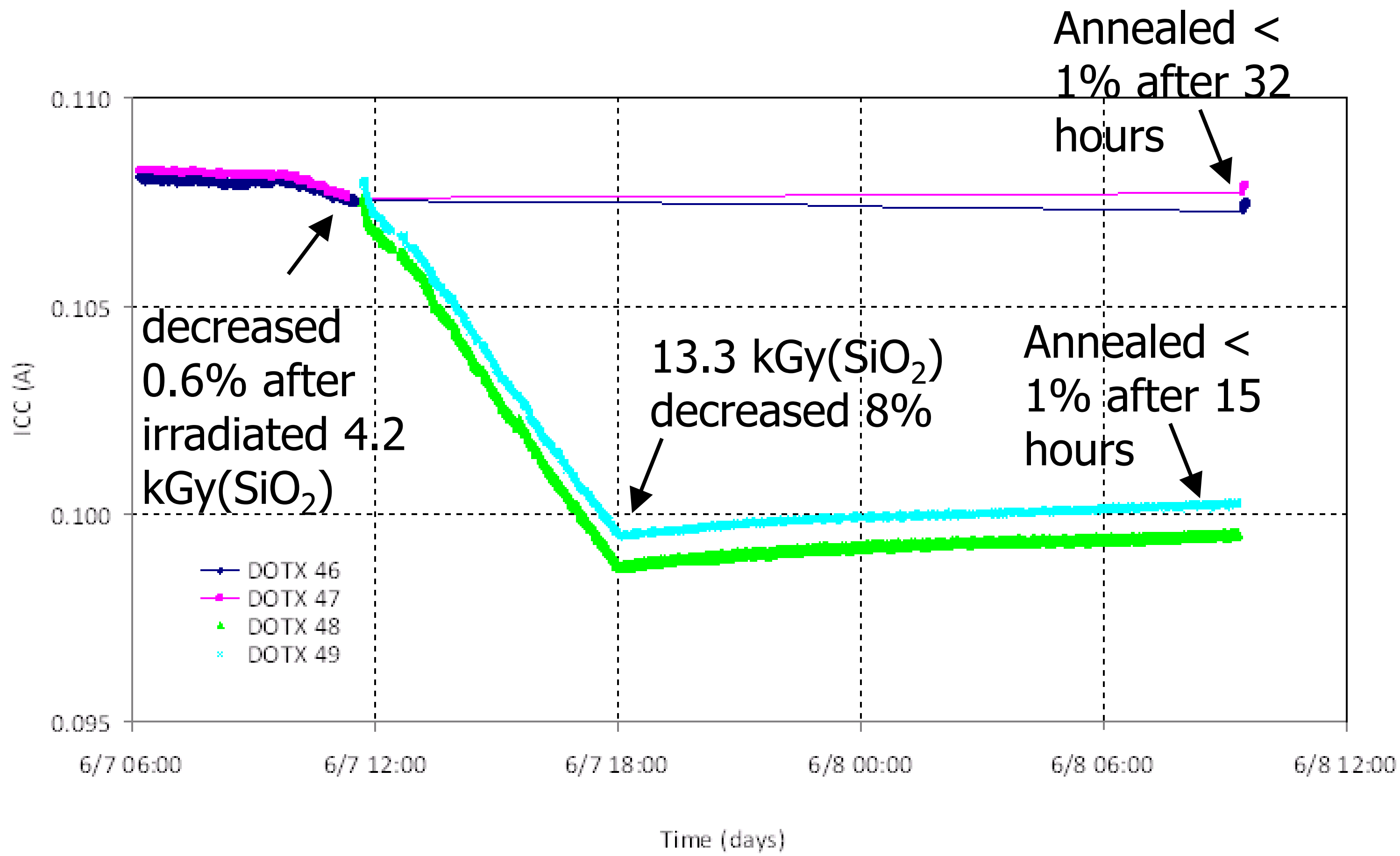
Thank Joseph Hashem and Chonghan Liu for measuring the curves

Radiation qualification of Plan B2

- November 17-18, 2009 at Indiana University Cyclotron Facility (IUCF)
  - Conditions:
    - 4 modules, 8 channels
    - 198 MeV proton beam
    - Flux from 4.86×10^{6} to 3.41×10^{9} protons/cm^2/s
    - Total ionization dose 7.51 kGy(SiO_2)
    - Total fluence 1.27E13 cm^{-2}
  - Results:
    - **Comparing the pre-irradiation and post-irradiation parameters, we did not observed any radiation induced change in any channels**
    - The optical spectra pre-irradiation were not measured, so we cannot compare channel by channel pre- and post- spectral width. The post-irradiation spectral widths of all channels are within $\mu \pm 3\sigma$ of the other twelve modules. All of the spectral widths of these four post-irradiation modules are higher than the average spectral width of the other twelve modules.
- June 7, 2010 at IUCF
  - Conditions:
    - 4 modules, 8 channels
    - 200 MeV proton beam
    - Flux from 1.33×10^{7} to 1.39×10^{10} protons/cm^2/s
  - Results: next slide

TID effects

- All four modules continued to function throughout the test.
- The power supply current changes < 8%



Single event effects

Cross section estimated < 1.8×10^{-10} cm^2. Correspondingly, the estimated bit error rate at ATLAS LAr is < 5×10^{-14}, << the industrial standard 1×10^{-12}.

Module ID	Ch#	# of errors (bit)	fluence (cm^{-2})	σ (cm^2)	BER at ATLAS LAr
46	1	202	7.06×10^{12}	$(28.6 \pm 2.0)\times10^{-12}$	$(70.7 \pm 5.0)\times10^{-17}$
	2	331		$(46.9 \pm 2.6)\times10^{-12}$	$(115.8 \pm 6.4)\times10^{-17}$
47	1	1284		$(181.9 \pm 5.1)\times10^{-12}$	$(449.3 \pm 1.3)\times10^{-16}$
	2	385		$(54.5 \pm 2.8)\times10^{-12}$	$(134.7 \pm 6.9)\times10^{-17}$
48	1	194	2.26×10^{14}	$(85.8 \pm 6.2)\times10^{-14}$	$(21.2 \pm 1.5)\times10^{-18}$
	2	351		$(155.3 \pm 8.3)\times10^{-14}$	$(38.4 \pm 2.0)\times10^{-18}$
49	1	164		$(72.6 \pm 5.7)\times10^{-14}$	$(17.9 \pm 1.4)\times10^{-18}$
	2	259		$(114.6 \pm 7.1)\times10^{-14}$	$(28.3 \pm 2.8)\times10^{-18}$