Optical Links R&D in HEP
Versatile Link Status

Tony Weidberg on behalf of the VL team

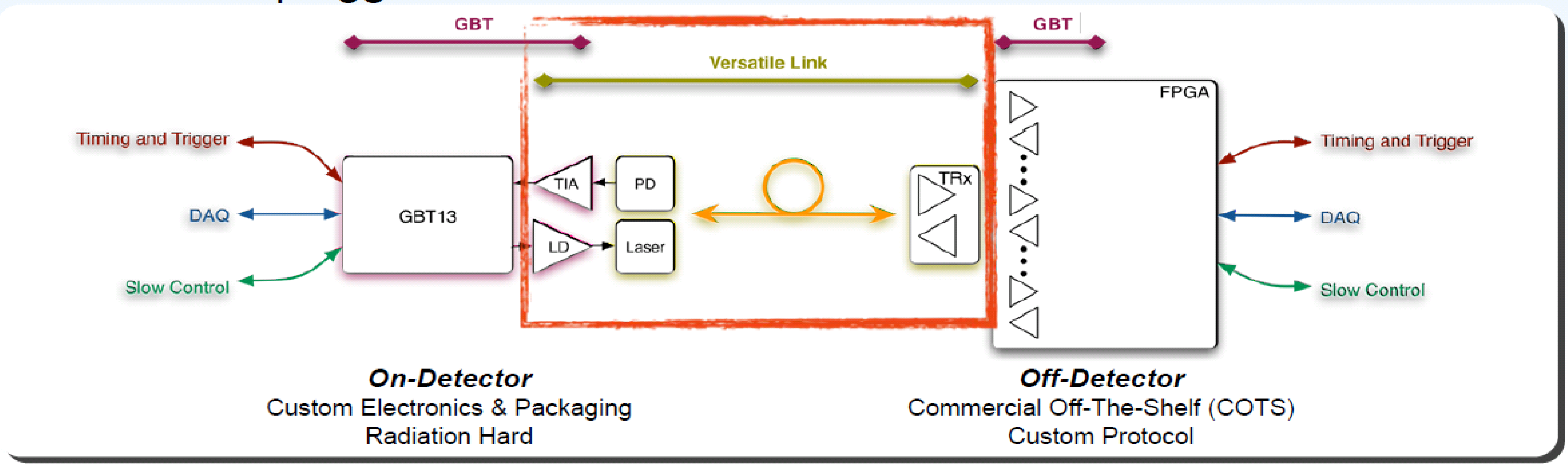
1st Detector Readout Link Topical Workshop of the Helmholtz Alliance

15th February 2011

- Link system and specs
- Packaging for on-detector optoelectronics
- Radiation tests
  - Total fluence for lasers & pins
  - SEU for *p-i-n* diodes
  - Total dose for fibres and passive components
- Backend optoelectronics

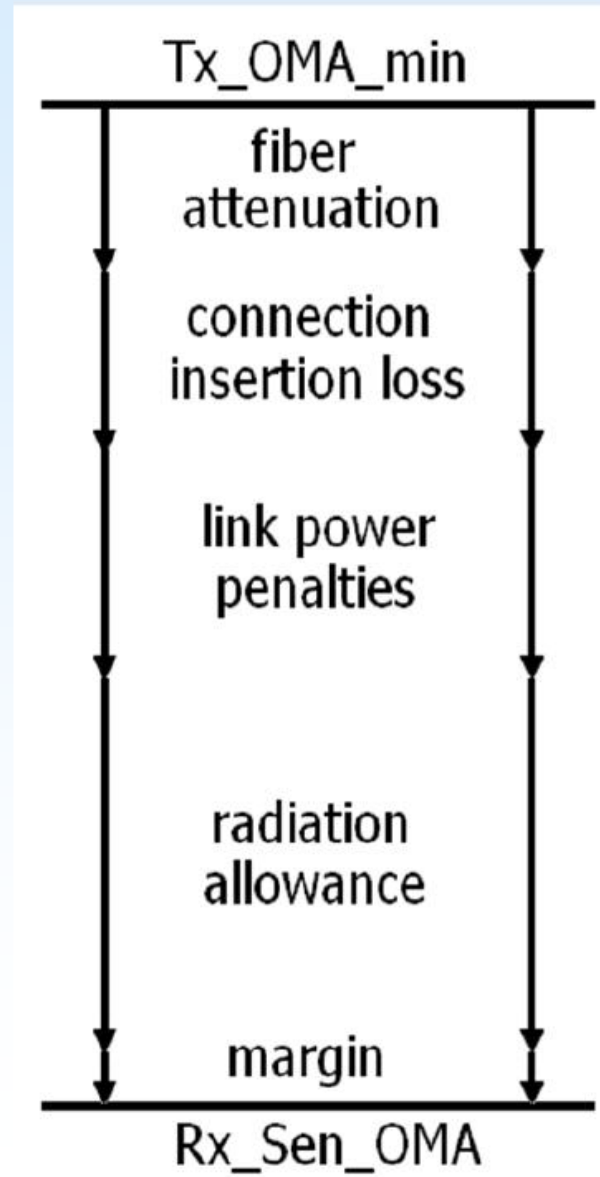
Versatile Link Project

- Optical Physical layer linking front- to back-end
- Bidirectional, ~5Gbps
- Versatile
  - Multimode (850nm) and Singlemode (1310nm) versions
  - Point to Point and Point to Multipoint architectures
- Front-end pluggable module
- Joint Project Proposal submitted to ATLAS & CMS upgrade steering groups in 2007 and endorsed in 2008
- Project Kick-off: April 2008
  - Phase I: Proof of Concept *(18mo)*
  - **Phase II: Feasibility Study *(18mo)***
  - Phase III: Pre-prodn. readiness *(18mo)*



VL Power Budget (SMU)

- TX Power and RX sensitivity depend on available components
- Measure losses (connectors, fibres)
- Determine radiation degradation:
  - Lasers
  - p-i-n diodes
  - Fibres
- Link Penalties
  - Conservative estimates to ensure that if components satisfy specs, link will work.
  - Simulations based on industry documents:
    http://www.ieee802.org/3/ae/public/adhoc/serial_pmd/documents/



VL Power Budget (SMU)

configuration/parameter	MM_VTx_Rx	MM_Tx_VRx	SM_VTx_Rx	SM_Tx_VRx
Transceiver power level				
Tx OMA min	-3.8 dBm	-2.0 dBm	-3.2 dBm	-2.8 dBm
Rx Sensitivity OMA	-11.1dBm	-13.1dBm	-12.6 dBm	-15.4 dBm
Power budget (Tx - Rx)	7.3 dB	7.3 dB	9.4 dB	9.4 dB
Fiber attenuation	0.6 dB	0.6 dB	0.1 dB	0.1 dB
Connection and splice loss	1.5 dB	1.5 dB	2.0 dB	2.0 dB
Link penalties	1.0 dB	1.0 dB	1.5 dB	1.5 dB
Tx irradiation degradation	-	-	-	-
Rx irradiation degradation	-	7.0 dB	-	9.0 dB
Fiber irradiation degradation	1.0 dB	1.0 dB	-	-
Margin	3.2 dB	0.0 dB	5.8 dB	0.0 dB

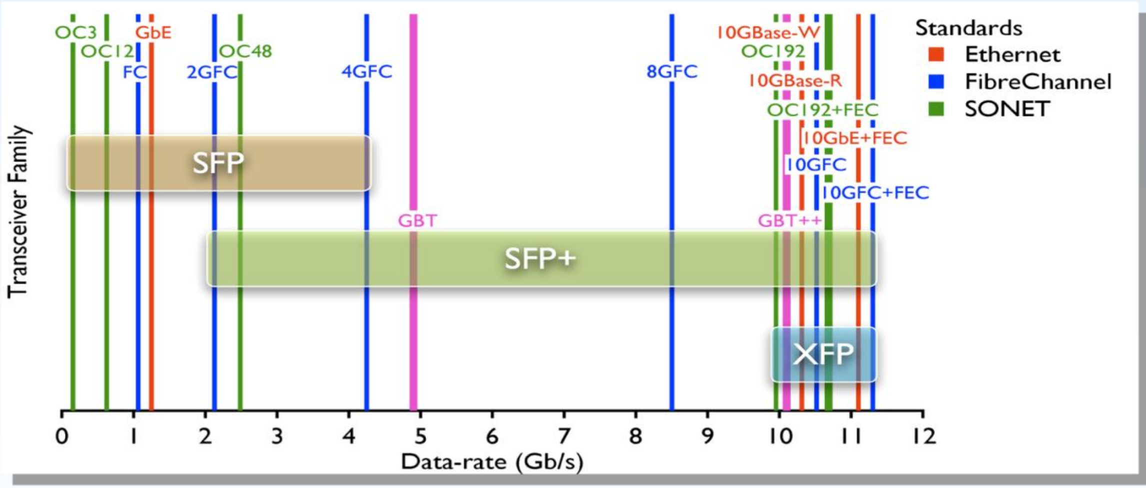
- TX links harder because of p-i-n radiation damage ➔
  - higher power TX (select lasers)
  - increased RX sensitivity (expect VRx to achieve this)
- RX links could run faster/longer distances

VTRx (SMU)

- Packaging
- Prototype ASICs
  - GBLD
  - GBTIA

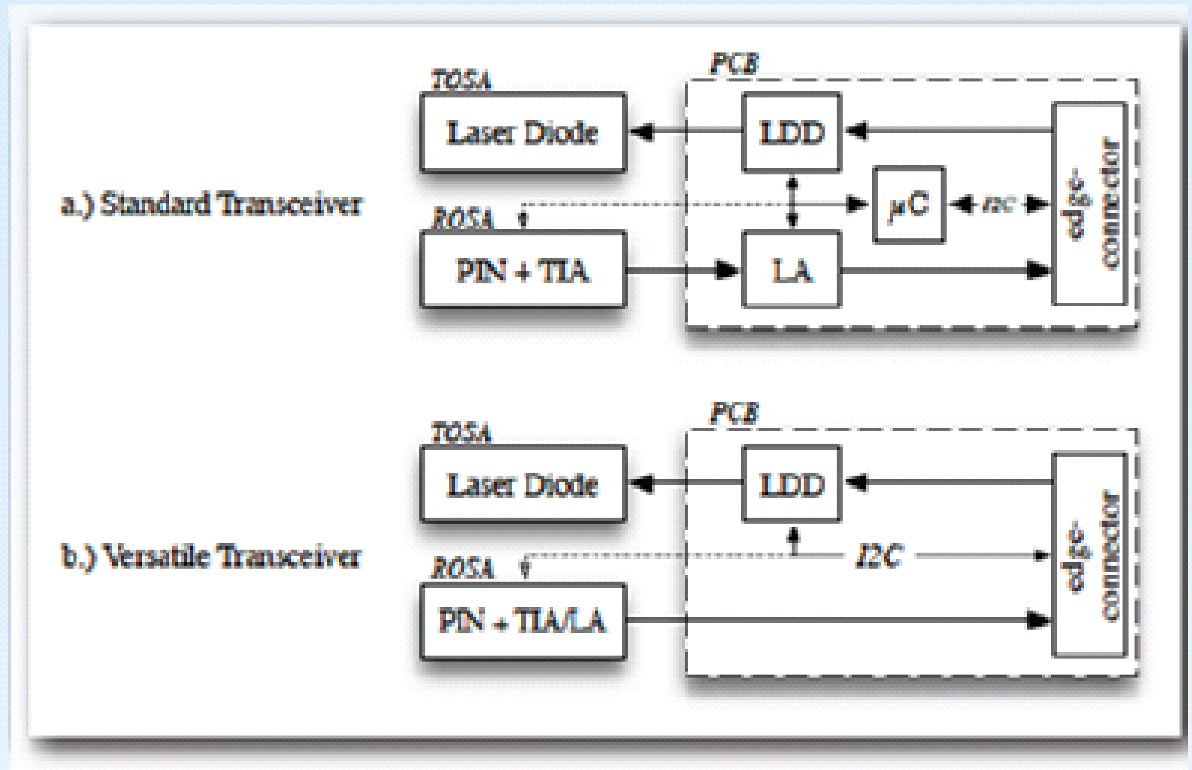
Packaging (CERN)

- On-detector duplex (TRx) package based on industry standard SFP+.
- Progressive modifications
  - Work in magnetic field
  - Radiation hard ASICs
  - Lower mass package



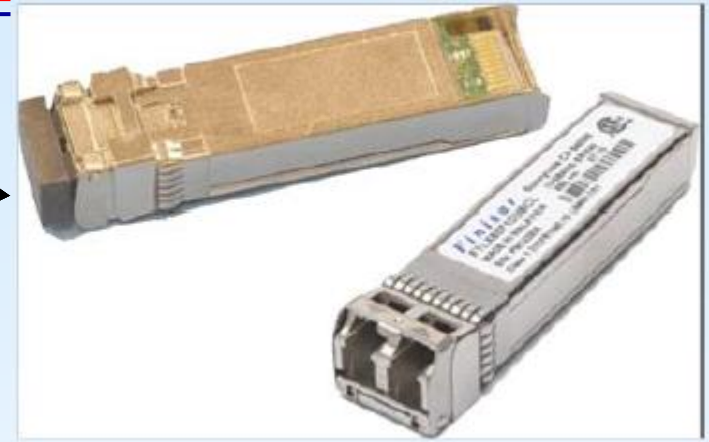
Front-end Transceiver: VTRx (CERN)

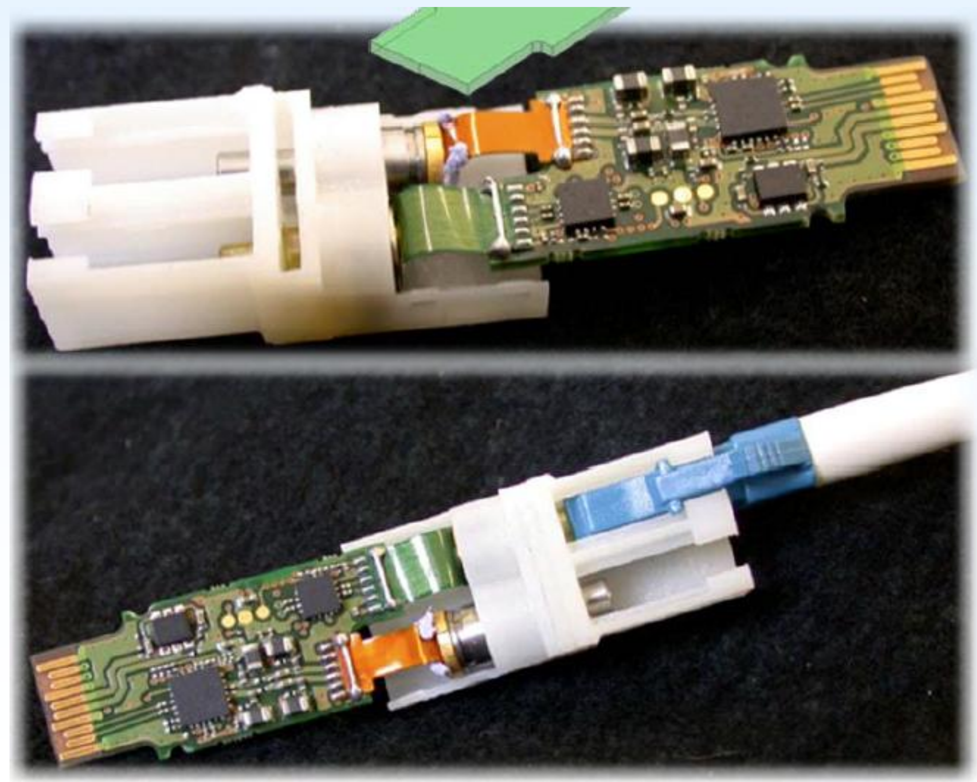
- Adapt commercial SFP+ Transceiver
  - Low mass, small & non-magnetic
  - Radiation-tolerant
- Two flavours
  - 850/1310 nm
- Bitrate 5 to 10 Gbps
  - Depends on ASICs
- Radiation-tolerant ASICs (GBT project)
  - Laser Driver: LDD
  - p-i-n receiver: TIA/LA



VTRx Low Mass Latch (CERN)

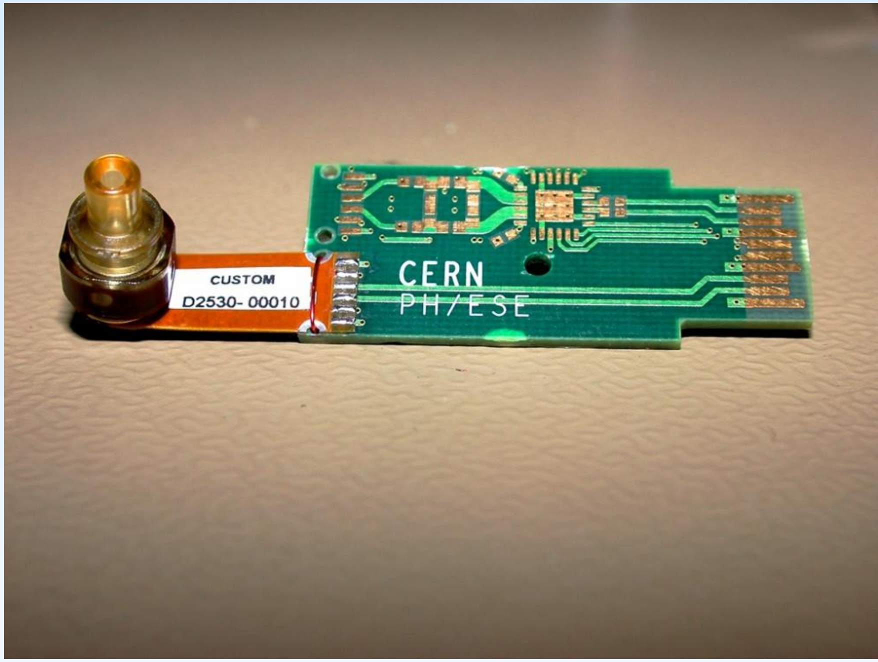
- Replace metal housing but optical/electrical connectors compatible with SFP+
- Low mass plastic latch design.
- Rapid-prototype plastic latch successful
- Latches LC connector for TOSA and ROSA

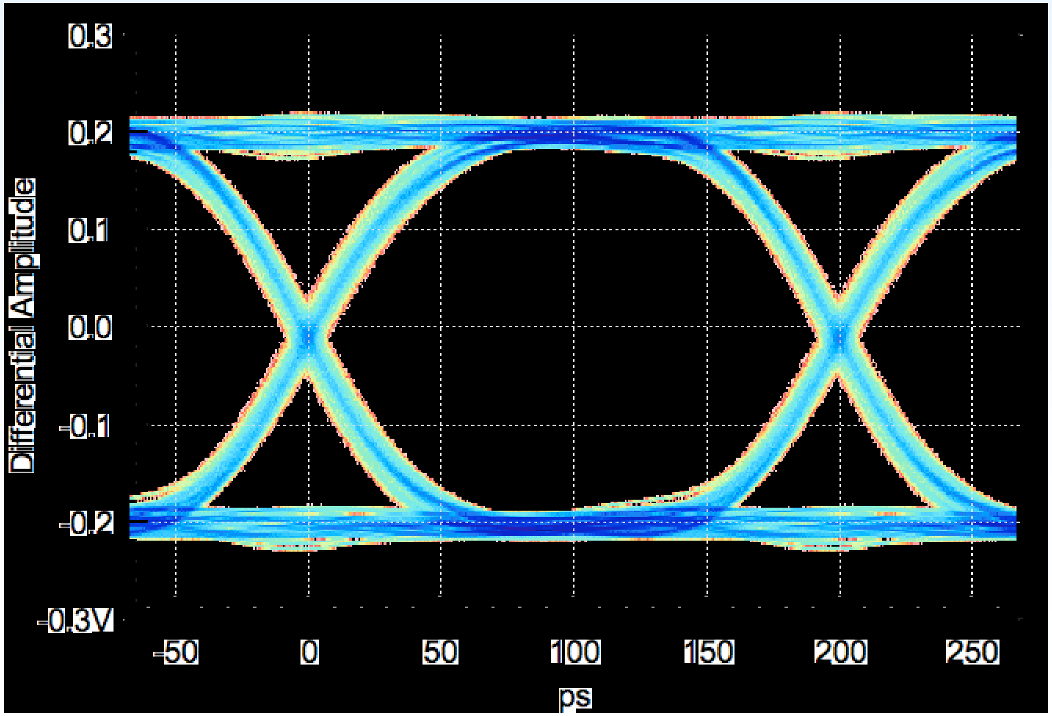




ROSA integration on VTRx (CERN)

- GBTIA – ROSA on VTRx
  - Flex circuit from ROSA to VTRx PCB to minimise inductance
- Clean electrical eye @ 5 Gbps
  - Low jitter

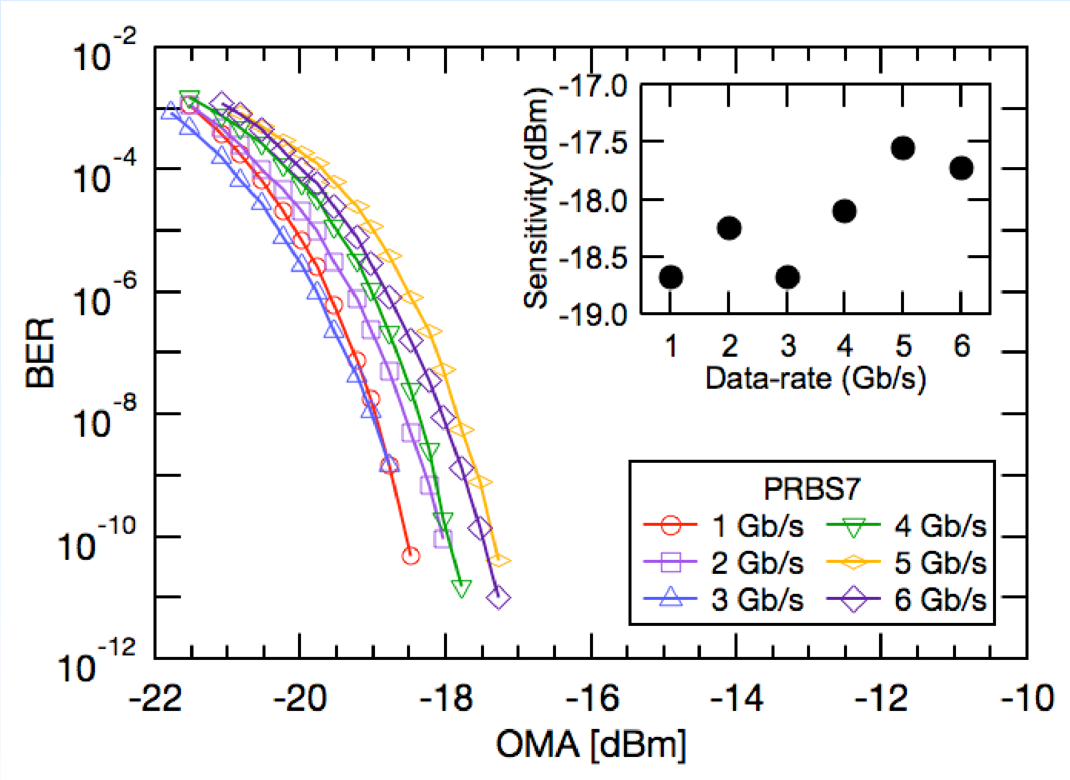




GBTIA Performance (CERN)

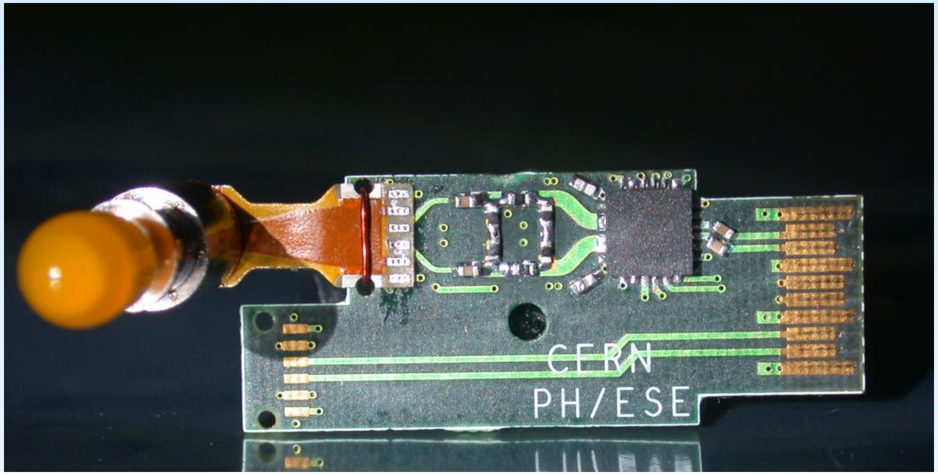
Versatile Link

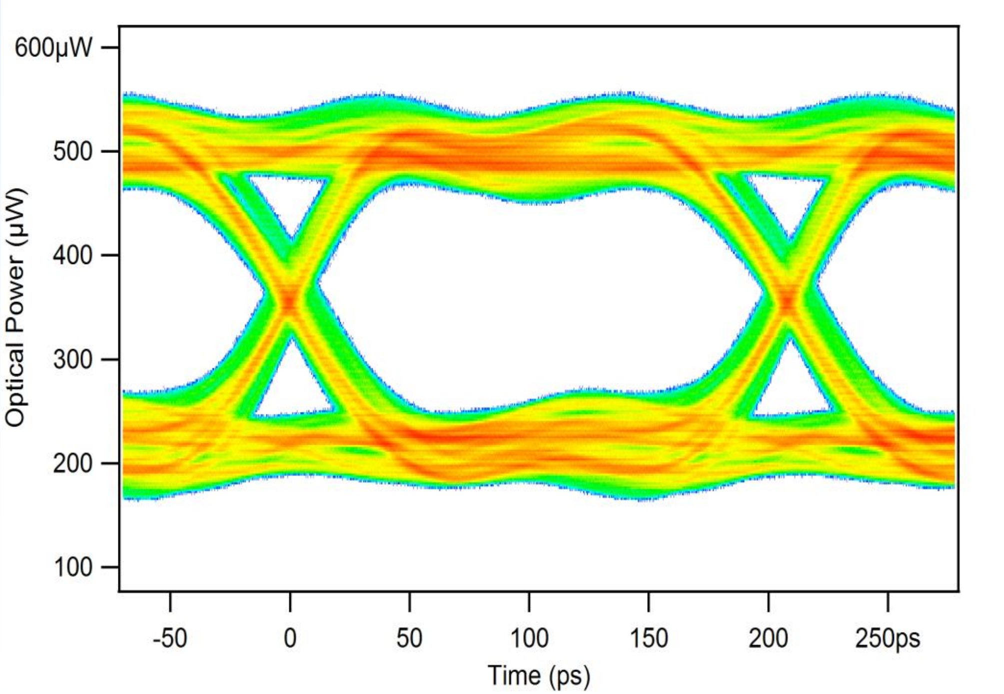
- Measure BER vs OMA using attenuator.
- BER independent of packet length.
- Sensitivity: minimum OMA for BER<10^{-12}.
- Expected sensitivity reduction as data rate increases (see insert)
- No degradation cf bare die for ROSA



TOSA Integration on VTRx (CERN)

- Similar flex circuit from TOSA to VTRx PCB.
- Commercial LD chip on VTRx PCB
- Clean optical eye diagram @ 5 Gbps.
- For GBTLD there are some speed issues which the designers are trying to resolve.





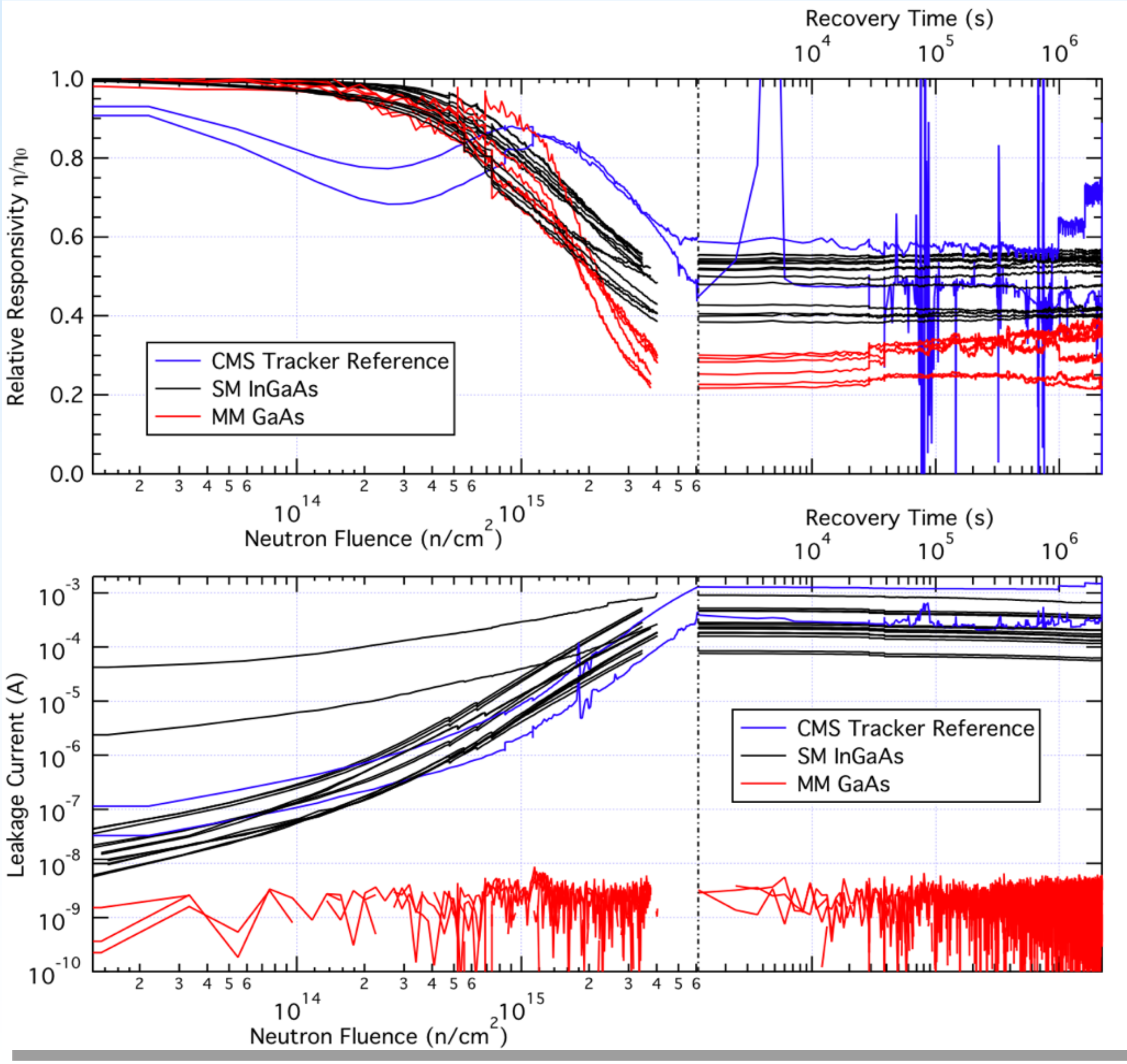
Radiation Tolerance Results

- Total Fluence tests for
  - Lasers & *p-i-n* diodes
- SEU tests for *p-i-n* diodes
- Dose tests for fibres

p-i-n Diodes (CERN)

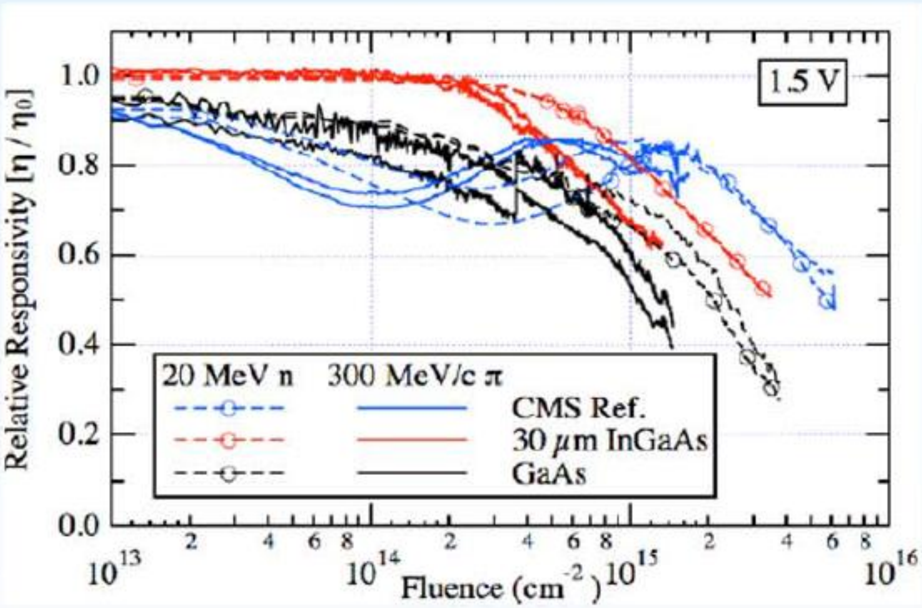
Versatile Link

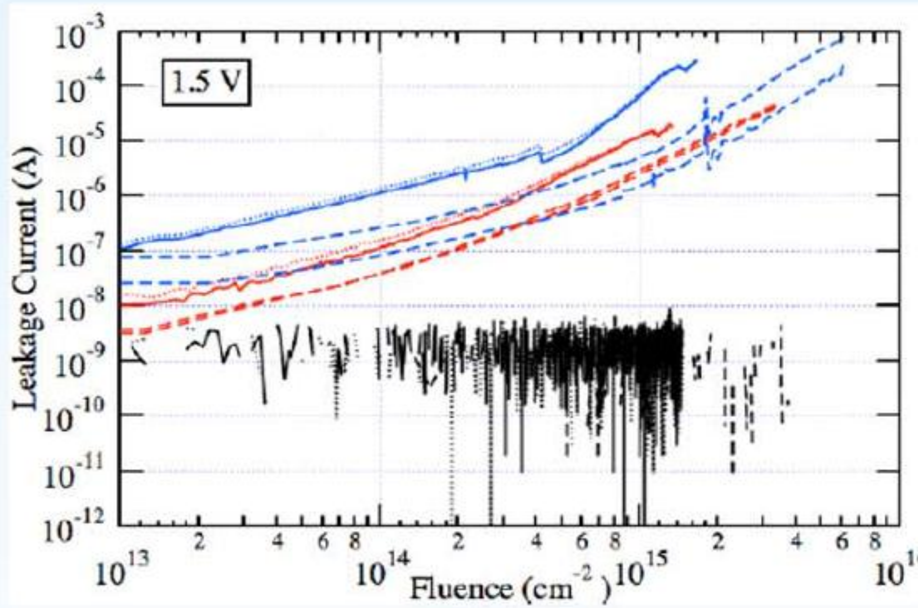
- **Relationship between 20MeV Neutrons in Louvain with SLHC tracker not yet known**
  - **Previous comparison carried out for CMS InGaAs devices**
  - **200MeV pions found to be 2.3x damaging than Louvain CRC neutrons based on I_{leak} damage**
- **Assume SLHC is 5x LHC fluence**
  - **Revisit this?**



Total Fluence p-i-n Diodes (CERN)

- Easy comparison since very little annealing of damage
  - Thus no (little) flux dependence expected

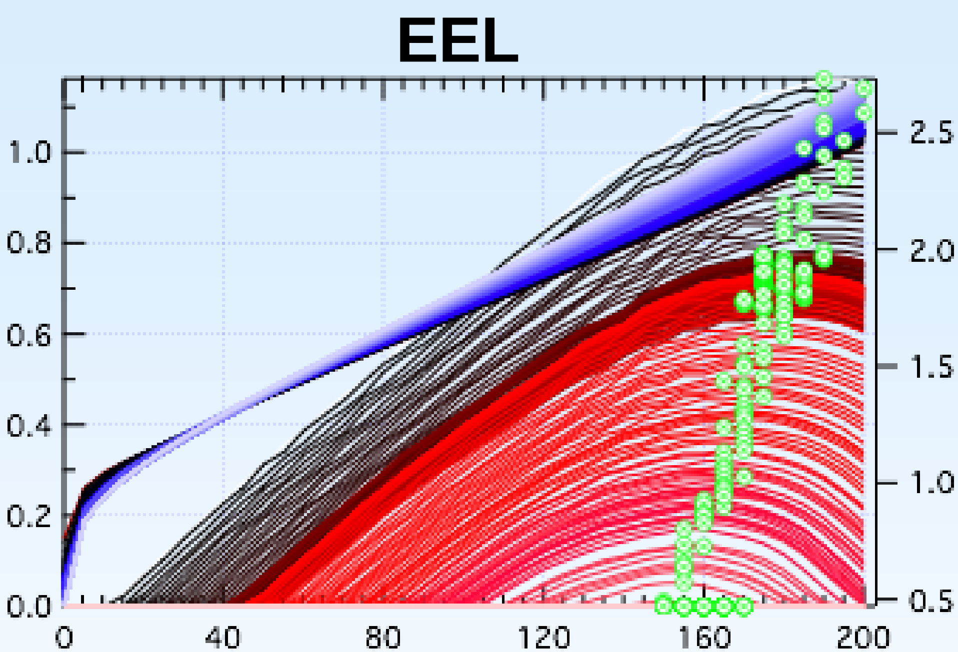


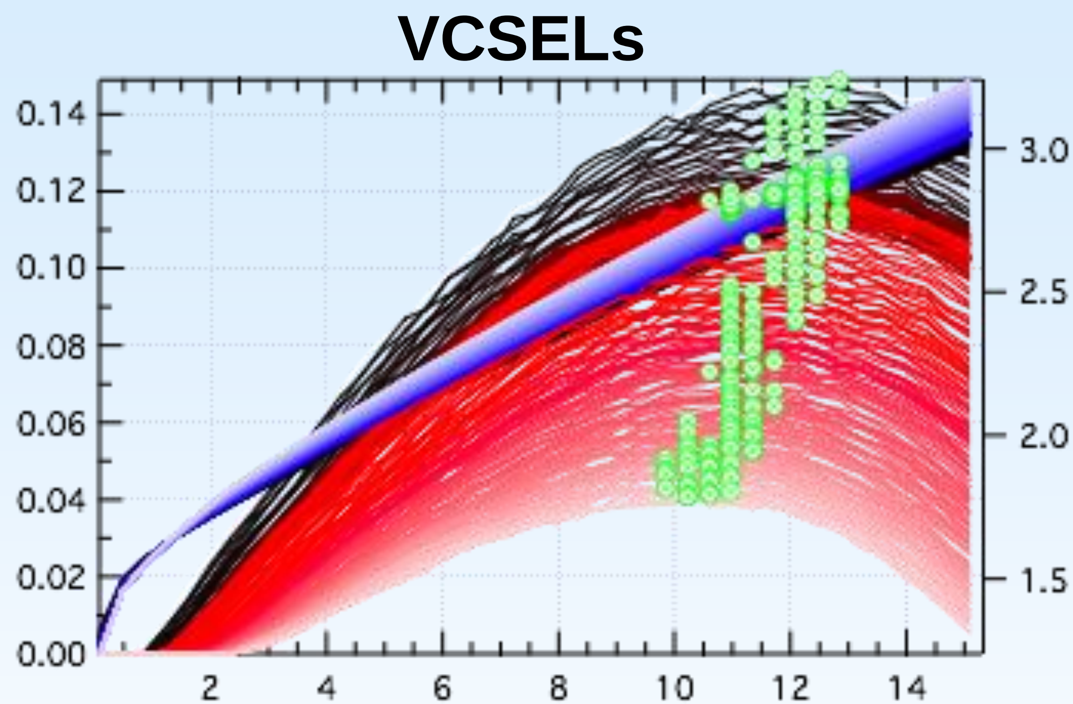


- Approximate damage factors indicate that 300 MeV/c pions are around twice as damaging as 20 MeV neutrons
  - Smaller relative factor for newer devices w.r.t. CMS reference parts
- InGaAs devices' responsivity less affected than GaAs devices
- GaAs devices show no increase in leakage current

Laser Radiation Damage (CERN)

Versatile Link





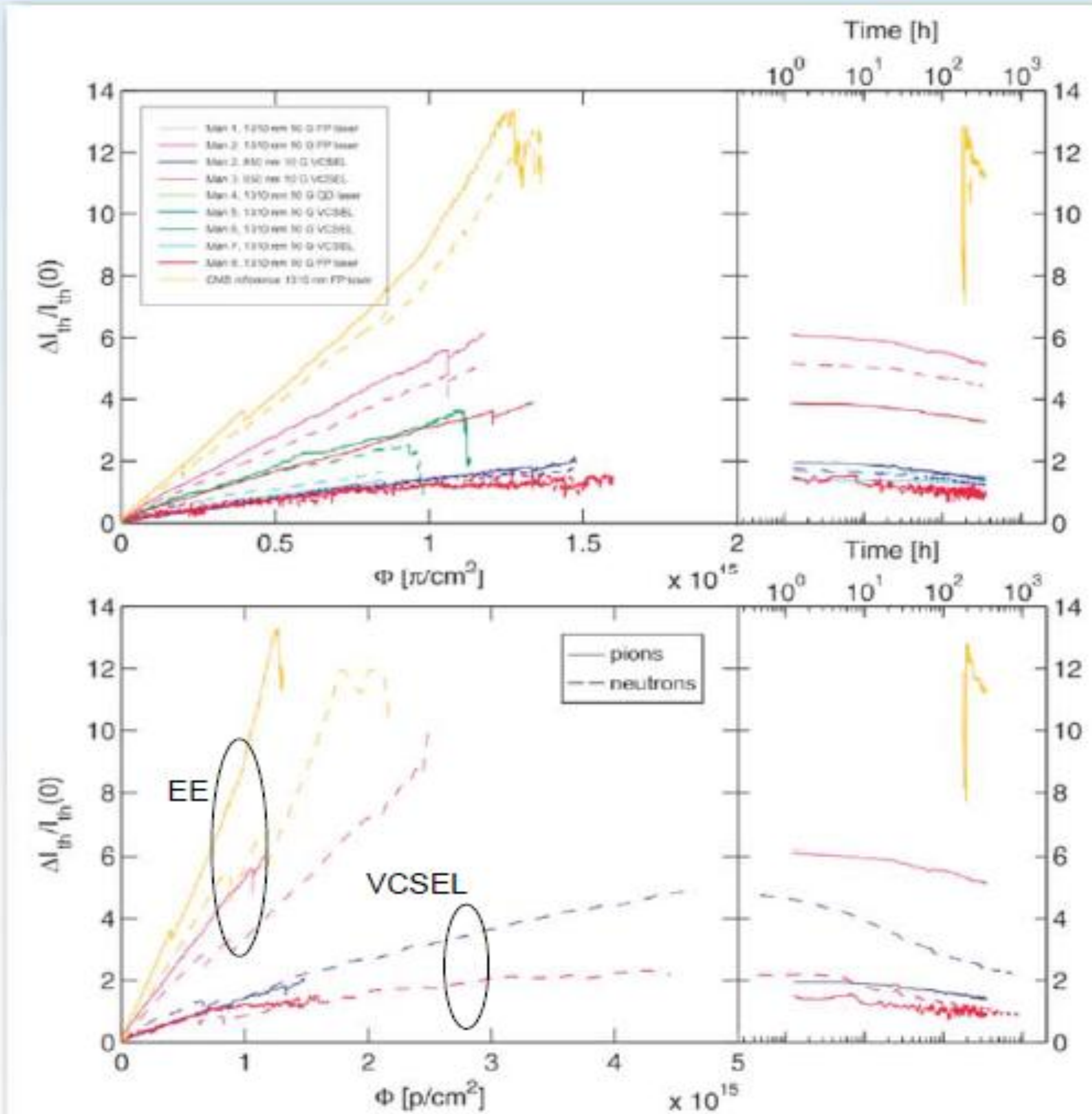
Family of curves show effect of increasing radiation damage on laser. No significant changes in IV but LI curves show:

- **Increase in threshold**
- **Decrease in slope efficiency**
- **Lower thermal roll over**

Allows for predictions of ultimate fluence for functional operation

Pion Total Fluence Test (Lasers) (CERN,

- Overall, VCSELs appear to be more radiation resistant than edge-emitters (EELs)
  - 850 nm VCSELs appear to be more resistant than 1310 nm variants
- Newer EELs are significantly more resistant than older designs
- A full source comparison taking annealing into account is in progress
  - Fast comparison shown



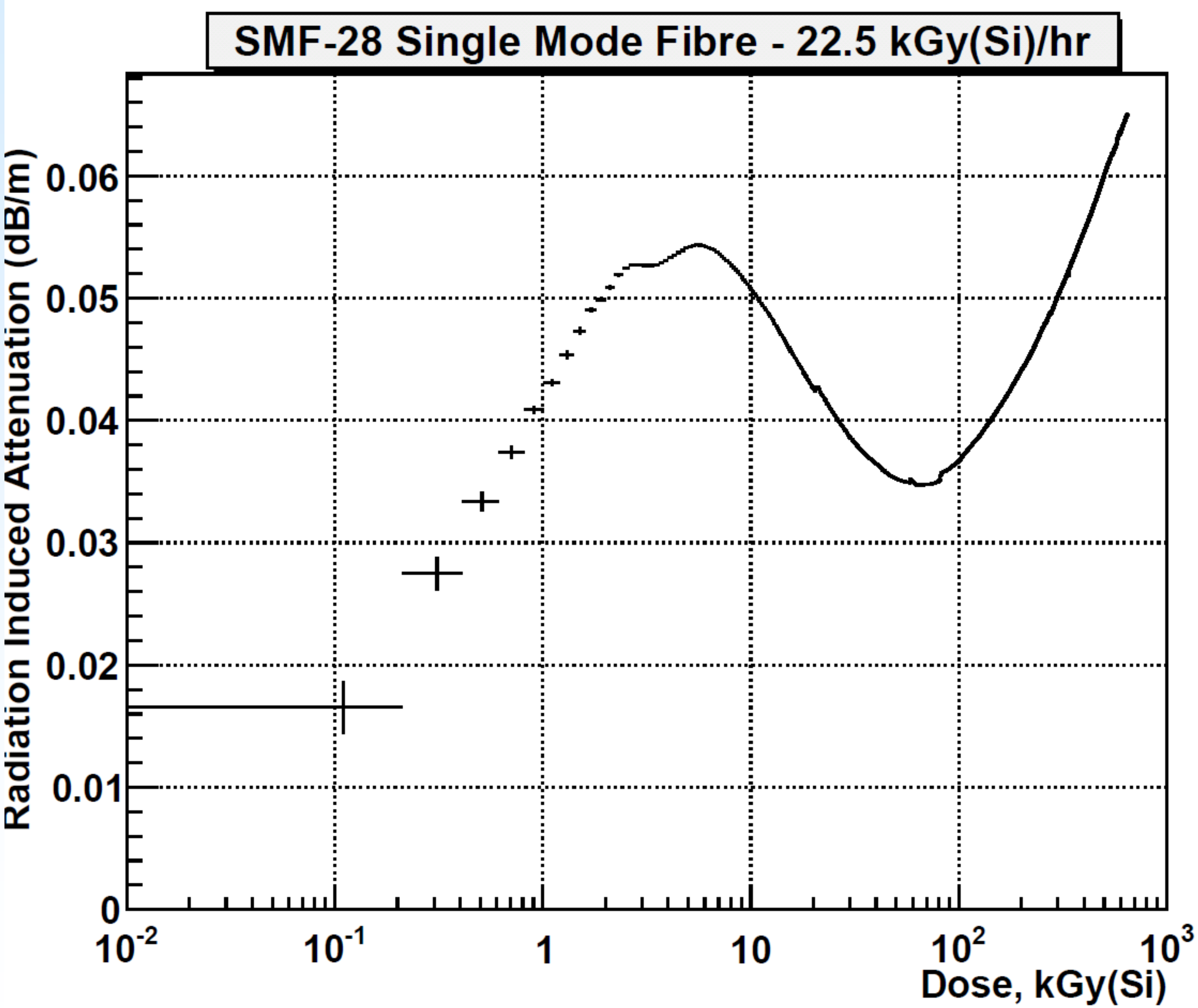
Radiation Tolerance Passive Components (Oxford)

Versatile Link

- Fibres for 850 and 1310 nm.
  - RIA for cold irradiation
  - Mechanical properties of fibre (radiation effects not studied before?)
  - Fibre cable (radiation effects also not previously considered)
- Connectors:
  - MT/MPO for ribbons
  - LC for single fibres
- PLC Couplers (splitters)
  - For architecture with P2MP eg TTC distributes same trigger information to many modules ➔ reduce number of fibres but requires higher power lasers in counting room?

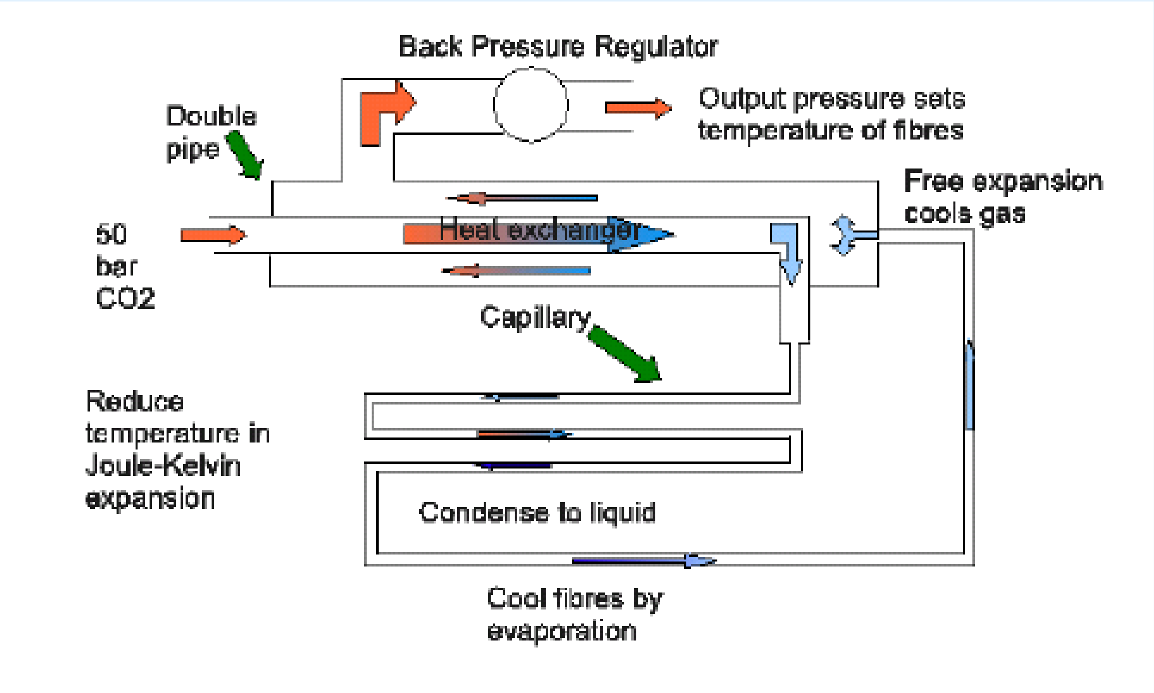
Warm Fibre RIA

- Acceptable SM and MM fibres found from warm tests of fibres to SLHC dose.
- Spike at low doses corresponds to T rise in vessel ➔ annealing important.
- Some results in literature show strong T dependence



Cold Fibre RIA

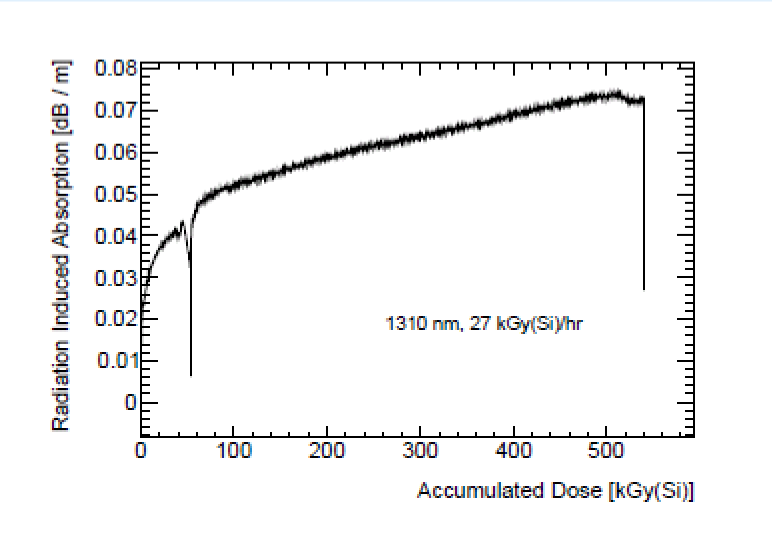
- Blow-off CO_2 cooling system: keep fibres at T~ -25C during irradiation.



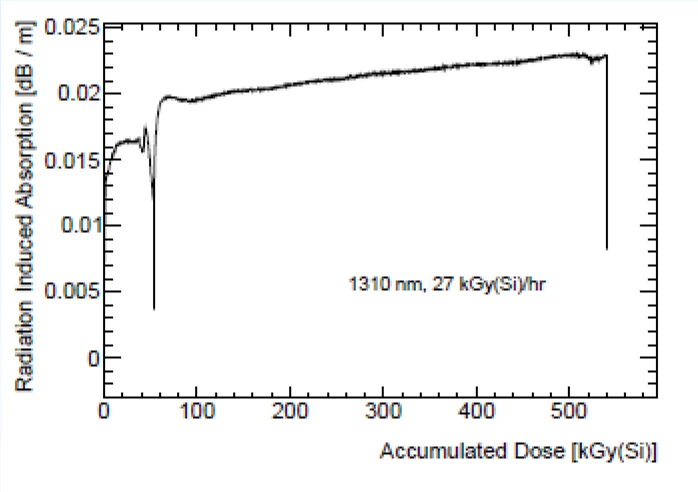
SM Fibres Cold RIA

- Two SM fibres qualified for cold RIA.

Draka SRH-SMF



Fibre X

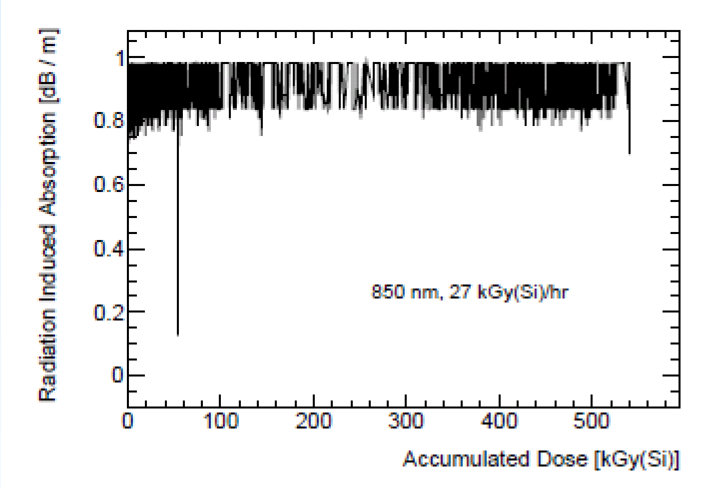


- SMF-28e did not give such good results in cold despite being qualified for warm operation.

MM Fibres

- No candidate MM fibre passed the qualification

Infincor SX+



- Insufficient dynamic range: easy to fix
- Need much lower dose rates but still with full SLHC dose
  - Much harder but we hope to do it with many bottles of liquid CO_2 and replace bottles daily during a 10 day run at RITA.

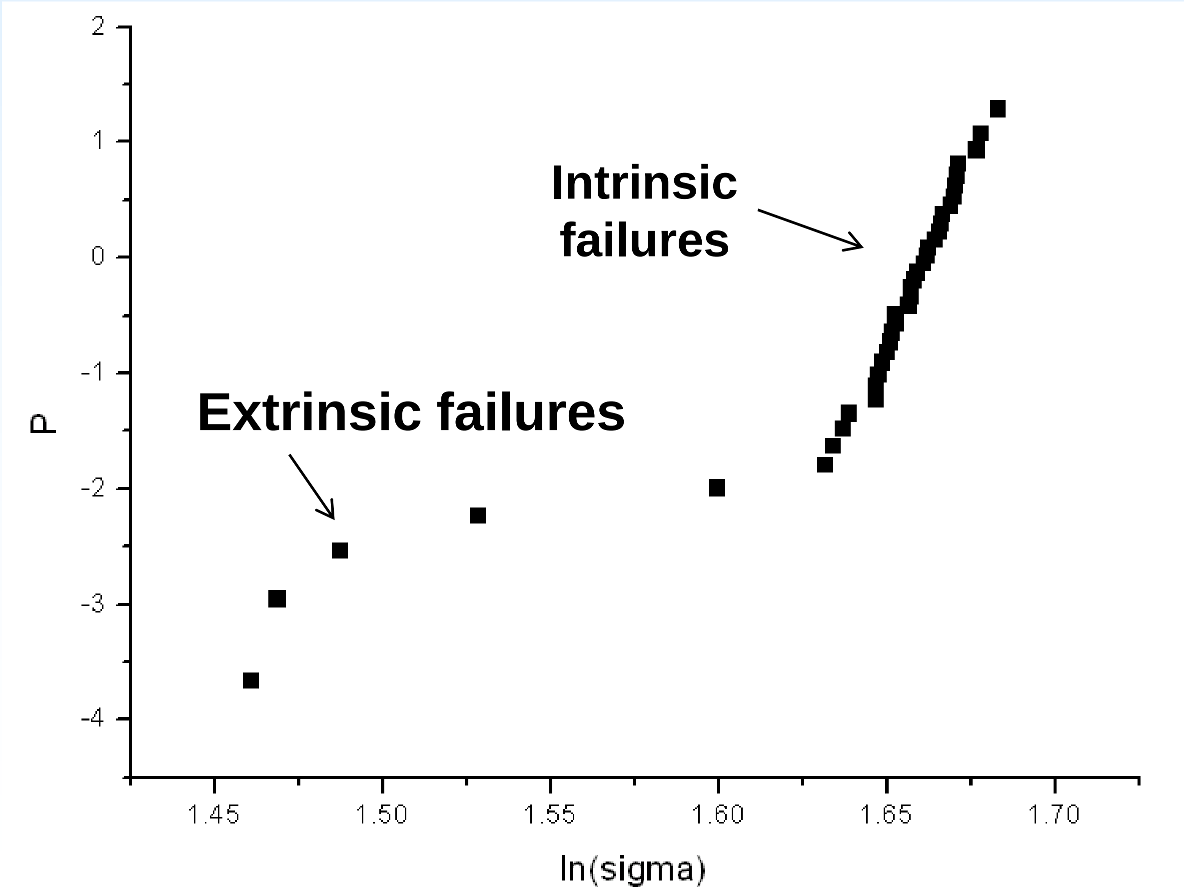
Fibre Reliability

- Fibre reliability qualified by manufacturers.
- No data available on fibre reliability after SLHC doses.
- Mechanical strength and quality of core
  - Pull tester
- Quality of buffer
  - Micro-bending test: measure attenuation with OTDR with induced micro-bending.
- Perform tests before and after radiation to SLHC doses.

Fibre Pull Testing

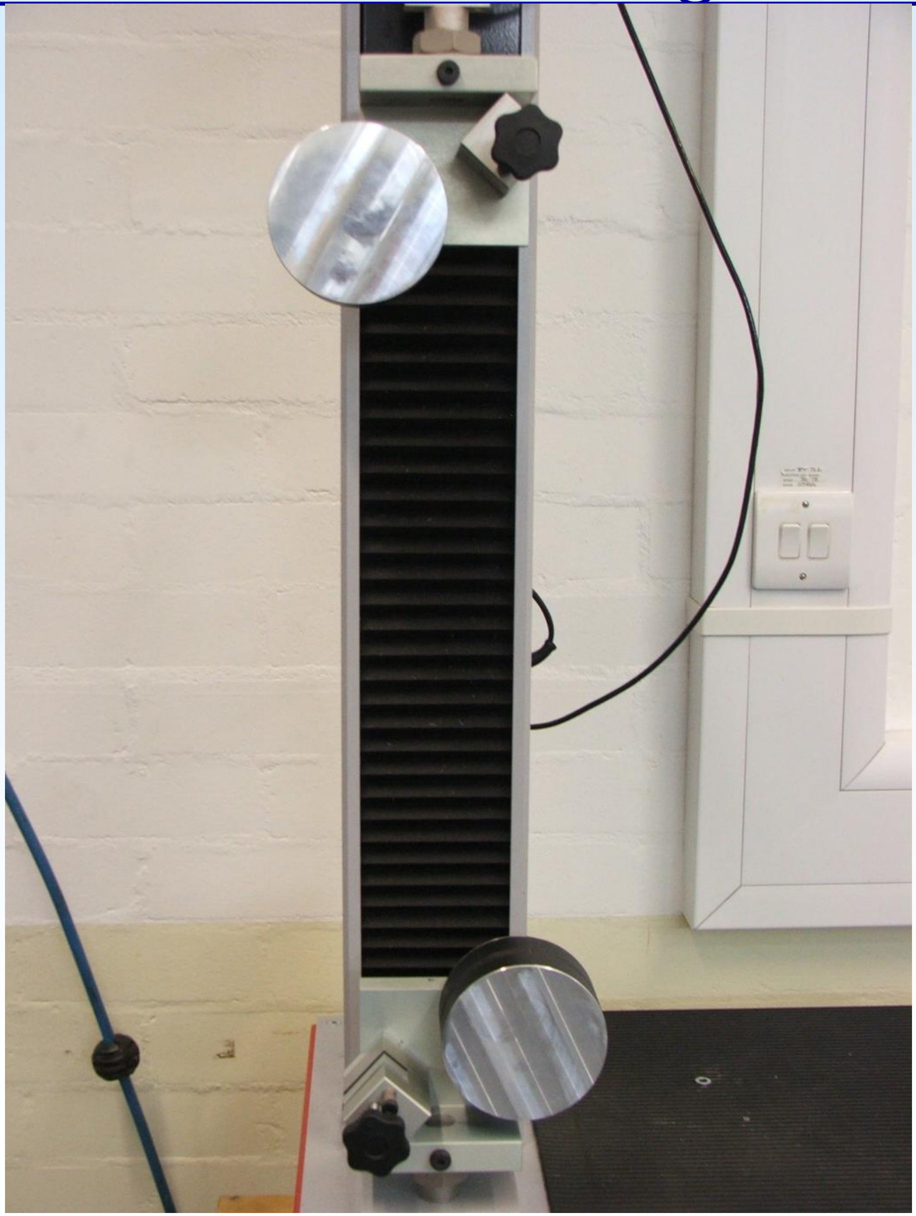
- Dynamic breaking strength measurements
- Make multiple measurements of breaking stress σ and fit probability to get σ_0 and Weibull parameter m.

$$P = e^{-\left(\frac{\sigma}{\sigma_0}\right)^m}$$



Pull Tester

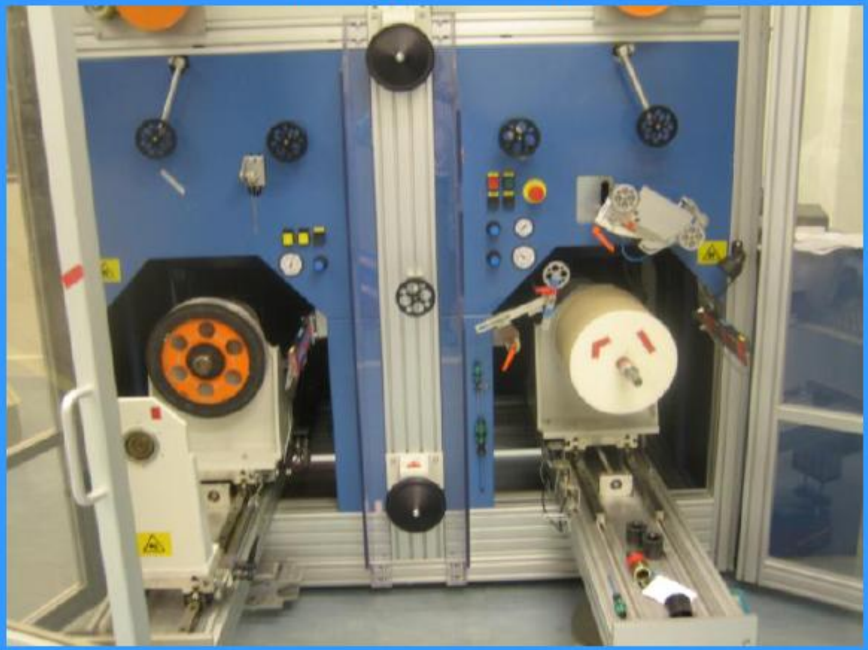
- Wind fibre around capstans and pull.
  - Record breaking strain
  - Multiple measurements at a fixed pull speed ➔ Weibull parameter, m.
  - Data sets at different pull speeds ➔ stress corrosion parameter, n.
- We have reasonable data for SMF28e.
  - Repeat for Infinicor SX+
  - Irradiate to SLHC dose and repeat measurements, check for any significant changes in m or n.
  - Qualify preferred MM & SM fibres



Cladding

- Quality of cladding monitored with micro-bending tests
  - Spool 2 km fibre onto reel with fixed grade of sandpaper to induce micro-bending.
  - Measure change in attenuation with OTDR.
  - Measure before and after radiation.
  - Measurements performed by Fibreson.

Preparing the sample

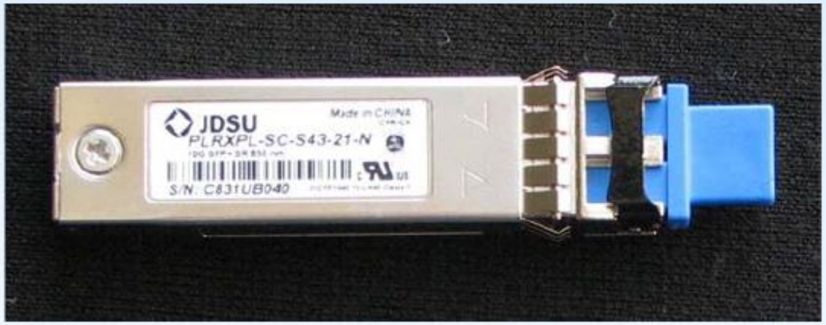


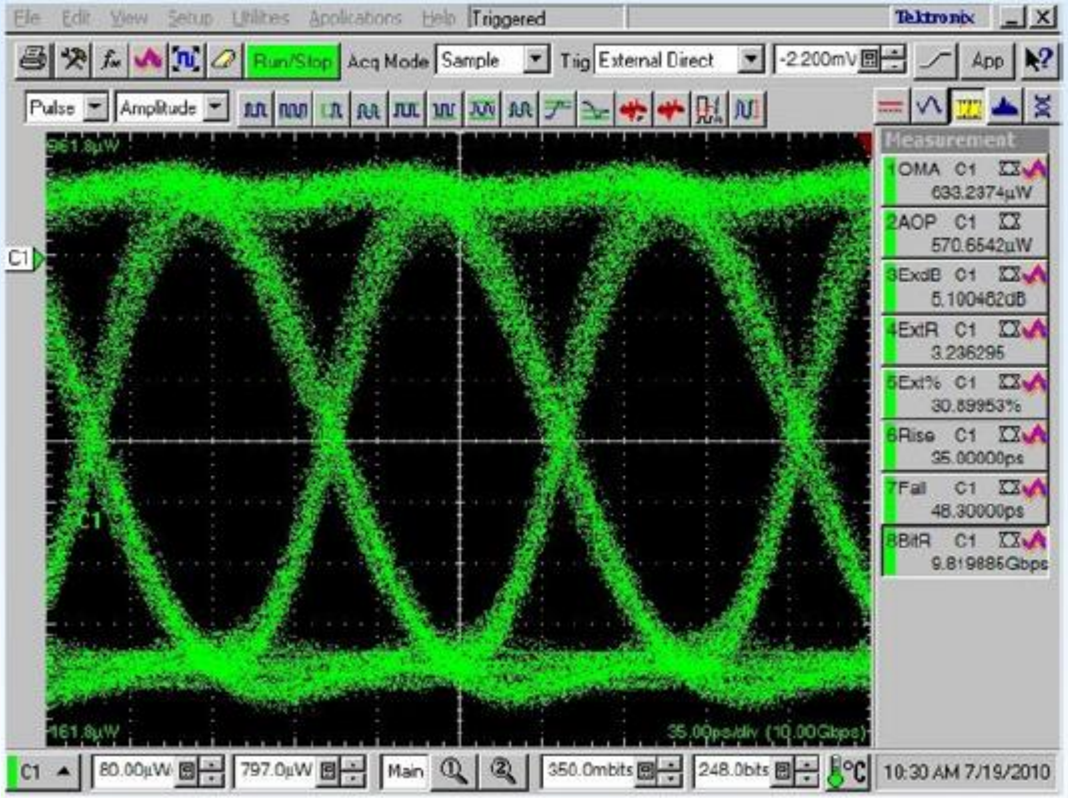
Radiation Tolerance Summary

- EELs can just survive SLHC fluence but need to allow for large increase in threshold currents.
- 850 nm VCSELs survive and show smaller increases in threshold currents.
- *p-i-n* diodes show
  - increase in leakage current (InGaAs) but not GaAs
  - significant decrease in responsivity (worse for GaAs)
  - Allow for high leakage current in GBTIA
  - Allow for responsivity loss in system specs
- Fibre losses
  - better for 1310 nm than 850 nm
  - Ok for 1310 but needs to be checked for 850 nm for cold RIA.
- 1310 nm VCSELs attractive option
  - Best of both worlds?

Backend Components (FNAL)

- SFP+ Testing



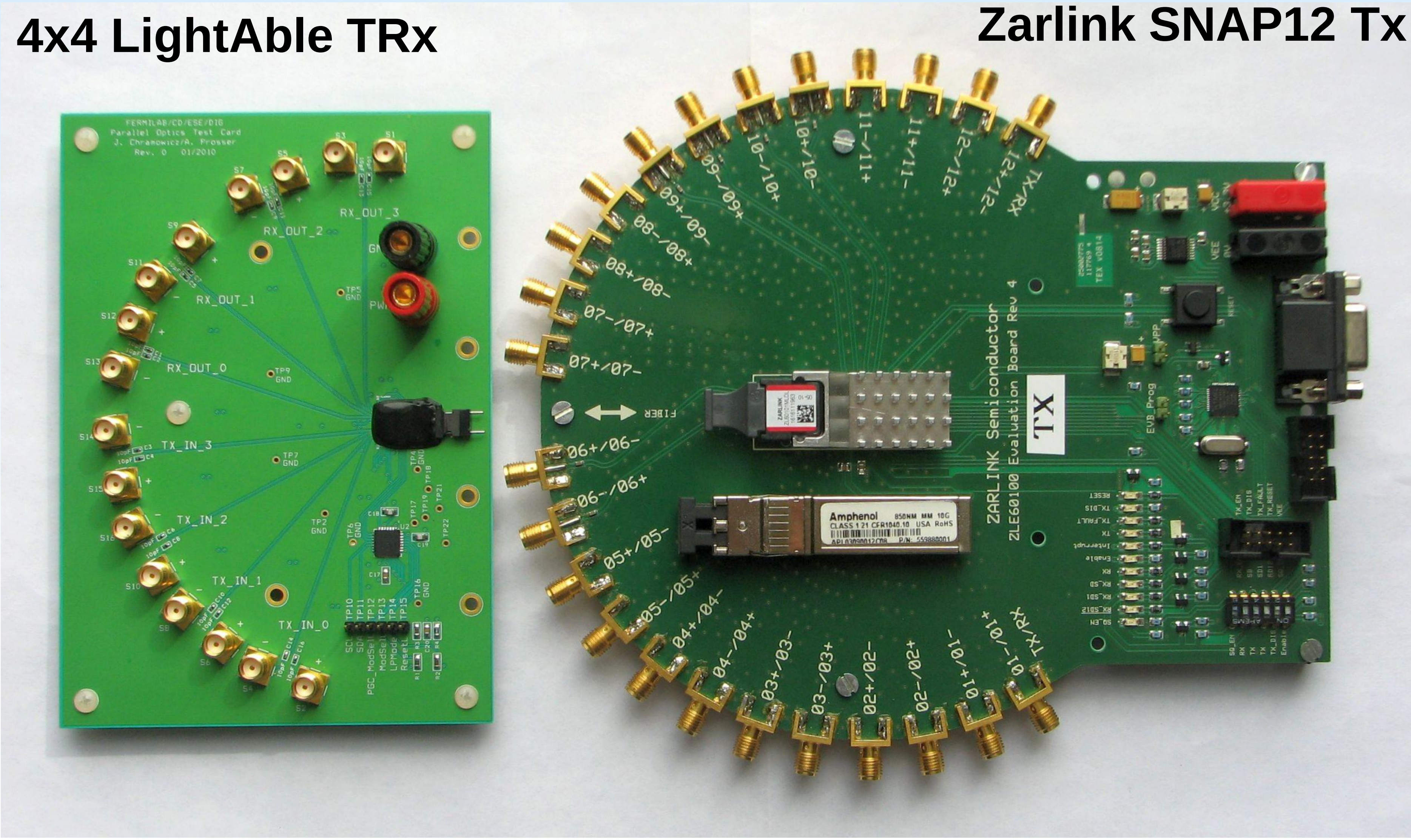


- 850 and 1310 nm tested
- Ok up to 10 Gbps
- Future: look at higher power options

Backend Arrays

4x4 LightAble TRx

Zarlink SNAP12 Tx



Summary of Options & Issues

Front-End VL TRx	Fibre	Back-End TRx
EE laser, 1310nm **Drive Current**	SM	LR-SFP+ SNAP12 Opto Engine **TX or TRx OMA**
VCSEL, 1310nm **Compliance & Availability**		
InGaAs PIN, 1310nm **Leakage Current**		
VCSEL, 850nm **Compliance & Availability**	MM **Cold fibre RIA**	SR-SFP+ SNAP12 Opto Engine **TX OMA**
GaAs PIN, 850nm **Responsivity drop radiation**		
GBLD **Availability**		

VCSEL reliability

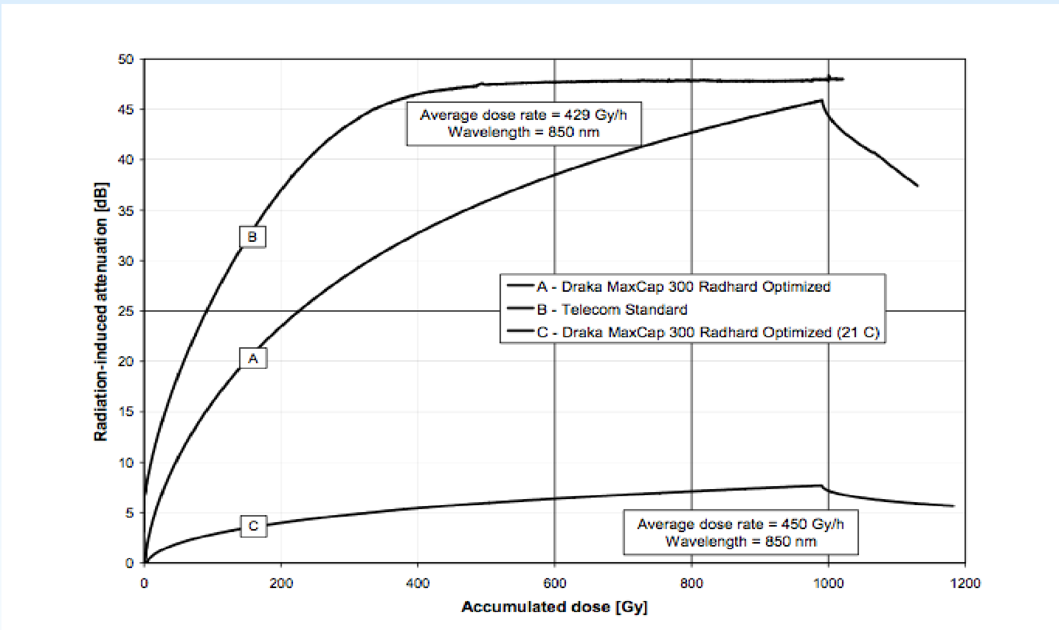
Overall Summary

- System specs being worked out.
- Packaging: progress towards low mass
- Radiation results identify candidates for lasers, *p-i-n* diodes and fibres.
- SEU ➔ error correction required
- Backend: commercial array options being evaluated.

Backup Slides

Previous research on RIA in fibre

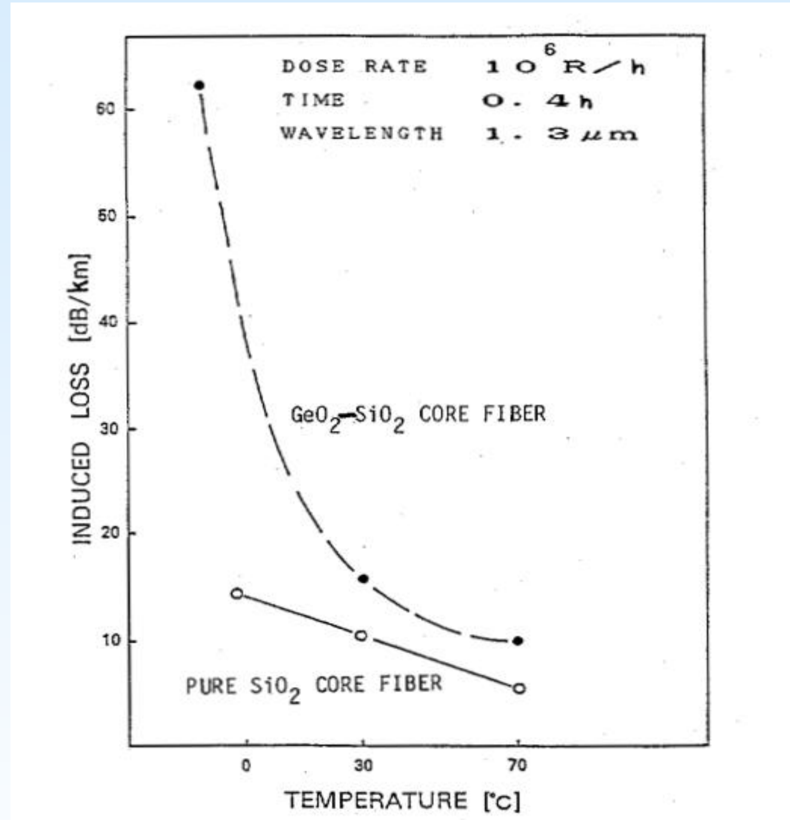
Multi-mode



850 nm GRIN fibre at room temp (curve C) and -17 C (curves A & B)

credit: Thériault Radiation effects on COTS laser-optimized graded-index multimode fibers exposed to intense gamma radiation fields

Single-mode



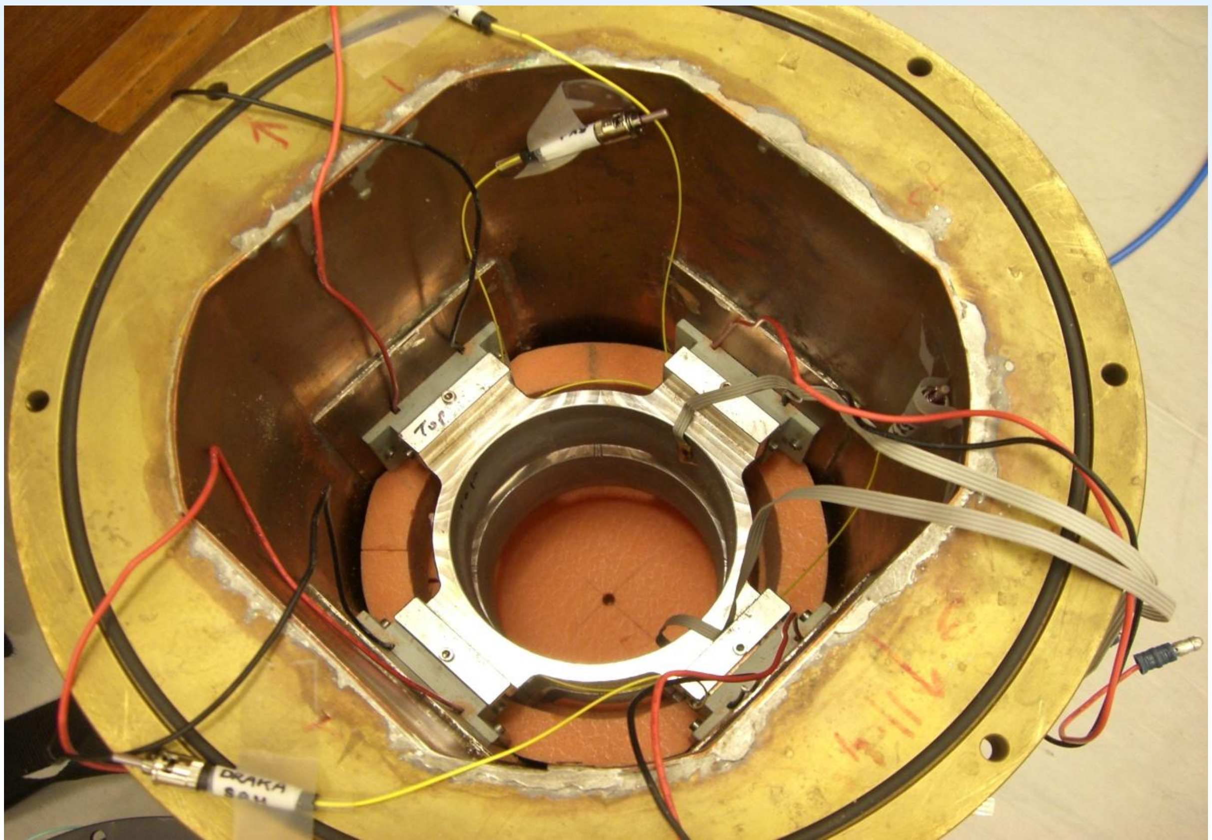
Single-mode RIA as fcn of temp.

credit: Kanamori et al. *Transmission Characteristics and Reliability of Pure Silica-Core Single-Mode Fibers*

RIA is temperature-dependent!

Cold Irradiation of Fibres

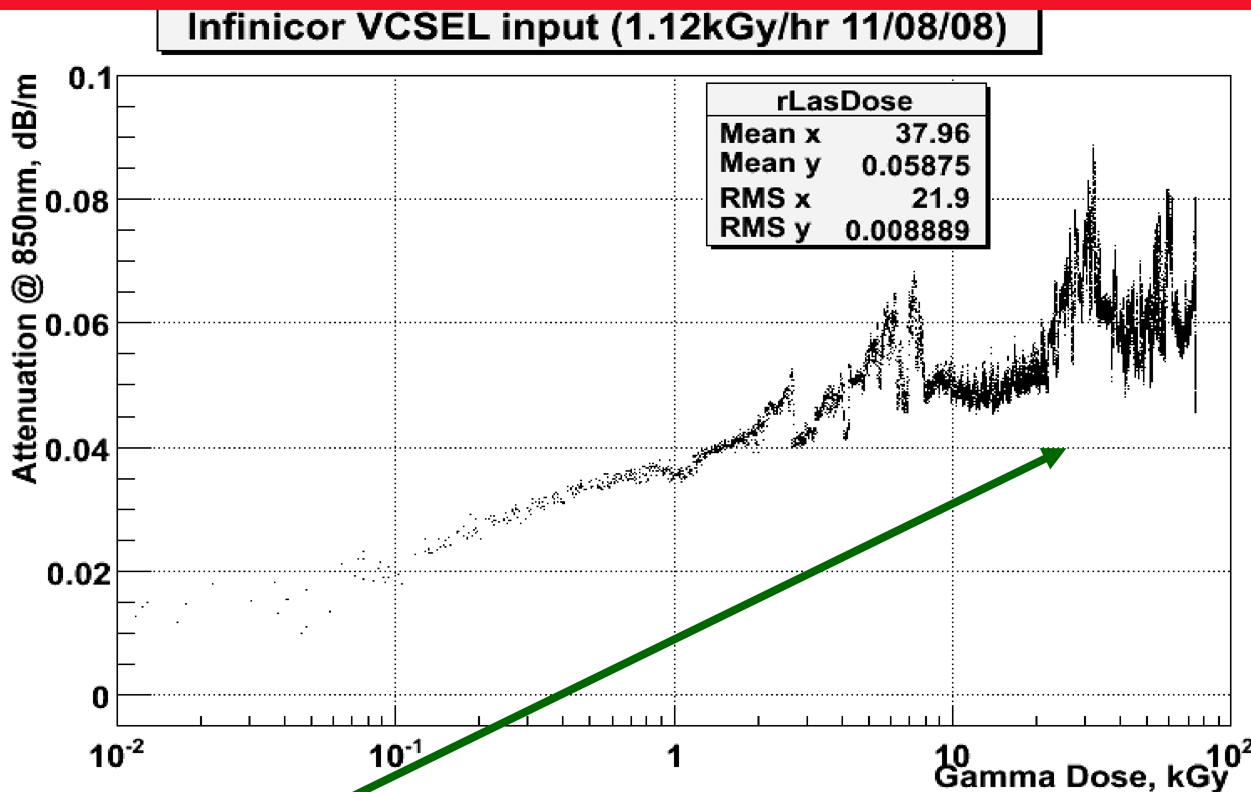
- First tests at Rita ➔ low dose rates
- Use Peltier coolers ➔ -25C.



4 Peltiers take heat from Al spool and dump it into water outside the cylinder.

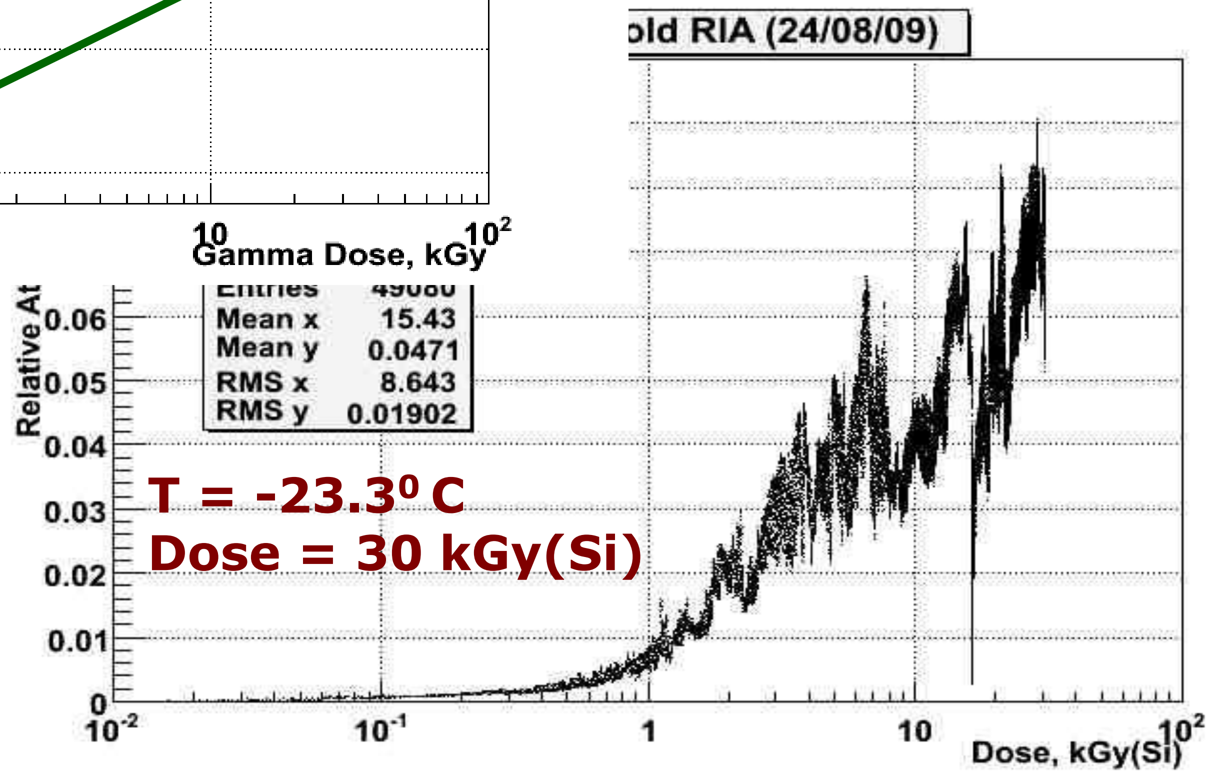
Worked ok for low dose but can’t work for high dose because heat load too big and radiation resistance of Peltiers not good enough.

Comparisons, InfinicorSX+



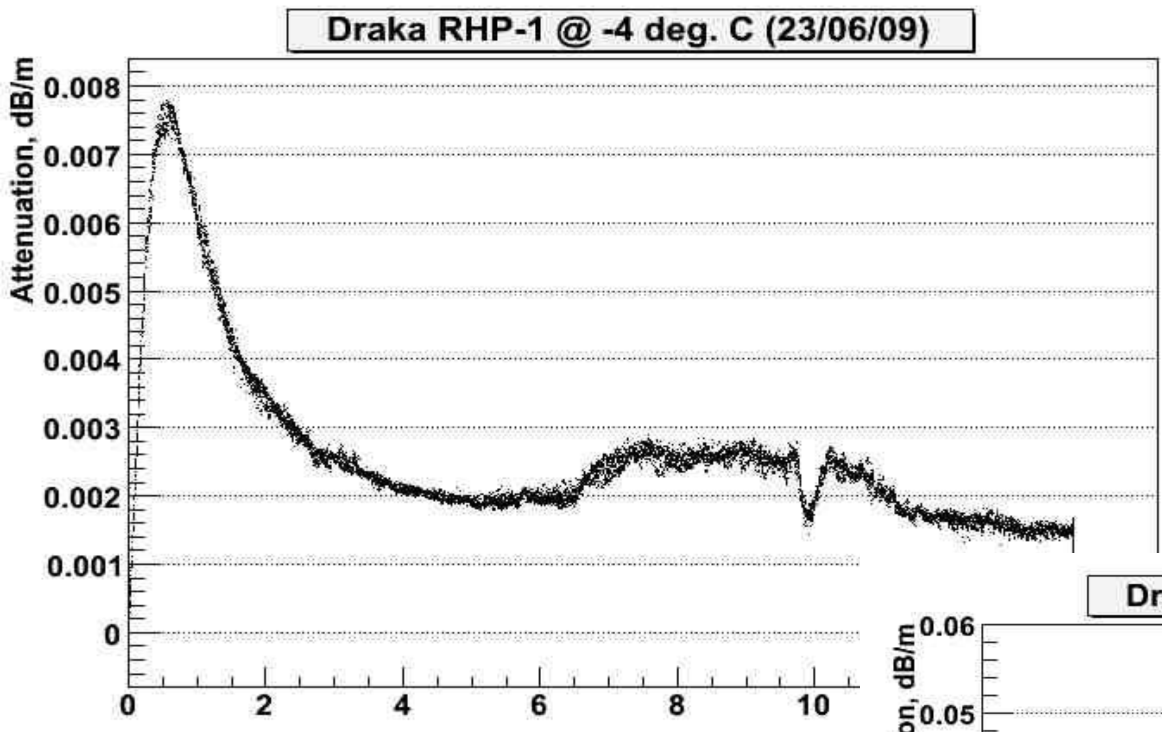
T = +30^0 C
Dose = 65 kGy(Si)

Gamma source
at room temperature.
Variation is from prev.
Stability limitations.



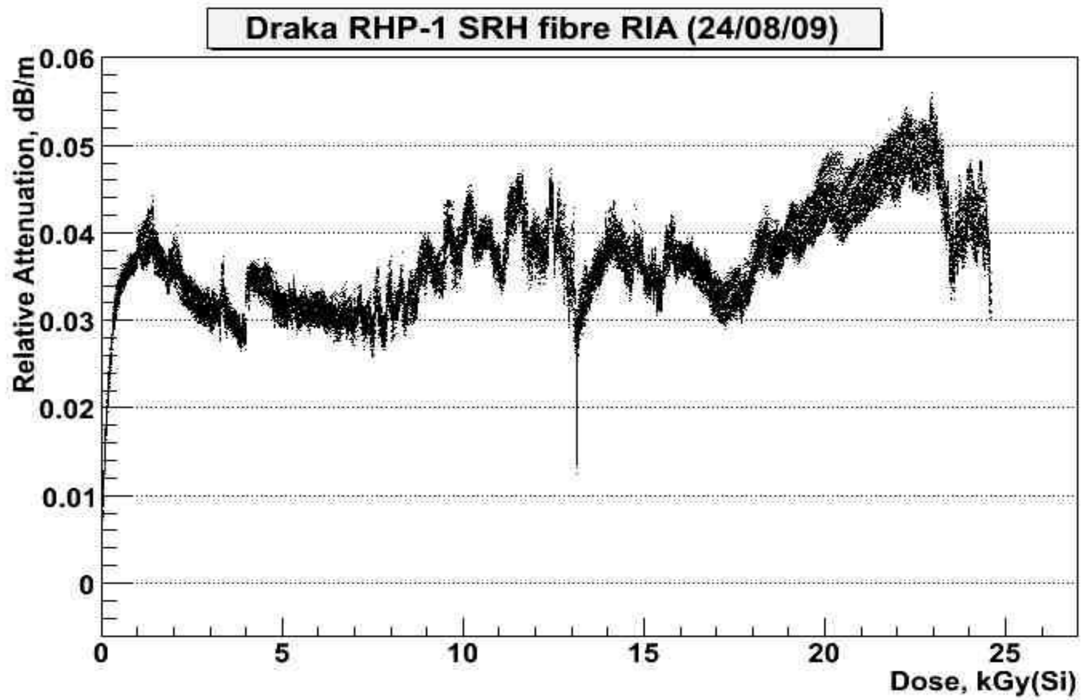
T = -23.3^0 C
Dose = 30 kGy(Si)

Draka RHP-1 SRH fibre



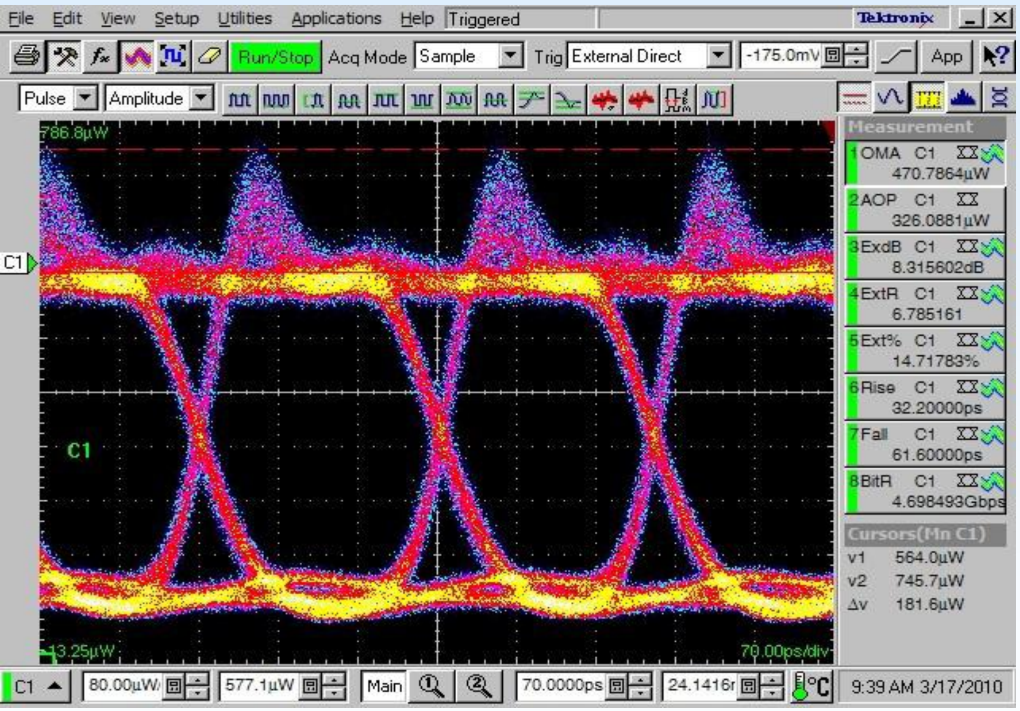
T = -4^0 C
Total Dose ~ 15 kGy(Si)

T = -25^0 C

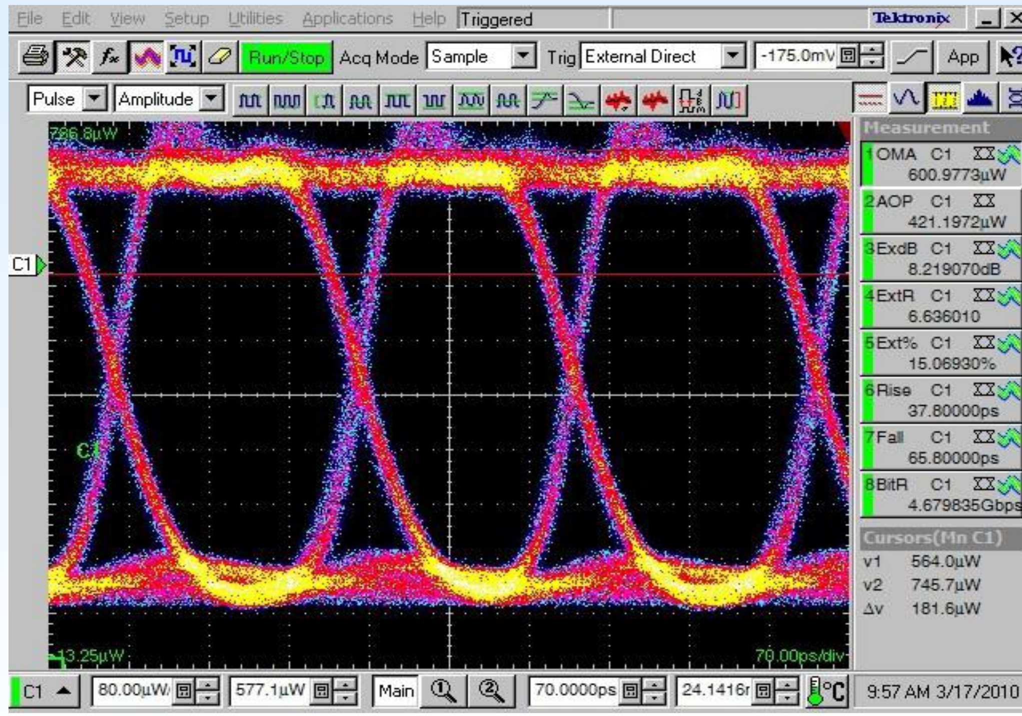


Zarlink SNAP12 Transmitter Eyes @ 5 Gbps

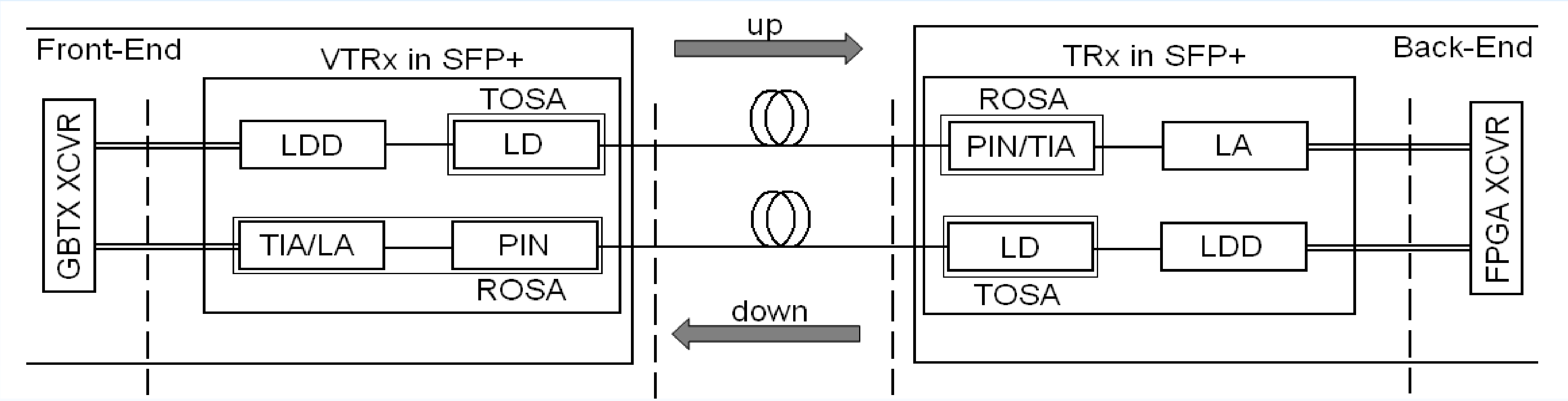
Minimium OMA Channel (Ch 1)



Maximium OMA Channel (Ch 8)

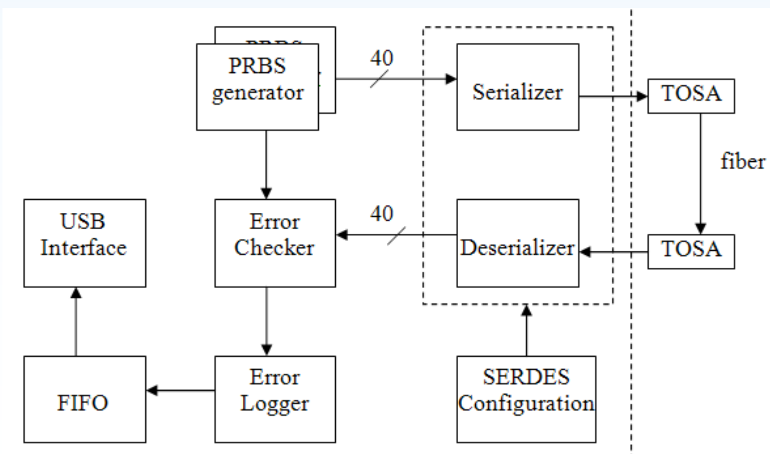


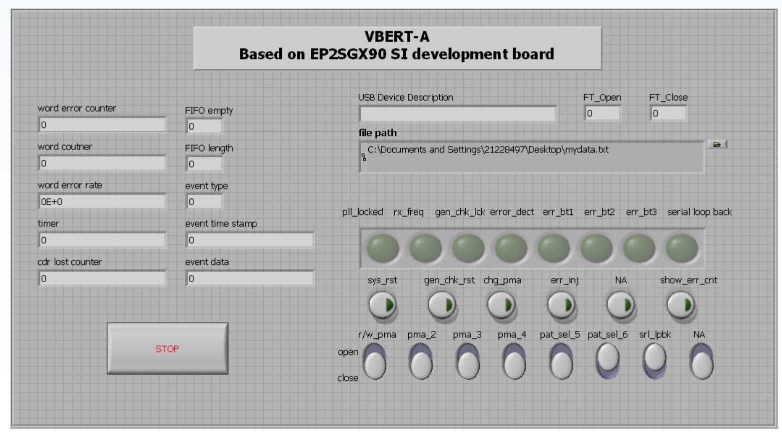
P2P VL


Front-End
VTRx in SFP+
TOSA
GBTX XCVR
LDD
LD
TIA/LA
PIN
ROSA
up
down
TRx in SFP+
Back-End
ROSA
PIN/TIA
LA
LD
LDD
TOSA
FPGA XCVR

VBERT-A Introduction

- What is VBERT-A
  - Evaluation kit for test drive versatile link components and validate system design
  - Utilize FPGA with embedded serdes to bit error rate type of
  - Currently implemented on Altera Stratix II GX signal integrity development board
  - Constitute VHDL and LabVIEW codes
- VBERT-A release 0.1 functions
  - Single duplex channel of 5Gbps
  - Un-framed PRBS7, PRBS23 transmission
  - Run-time analog setting control
  - Bit error rate statistics and link status monitoring
  - Comprehensive error logging with time stamp

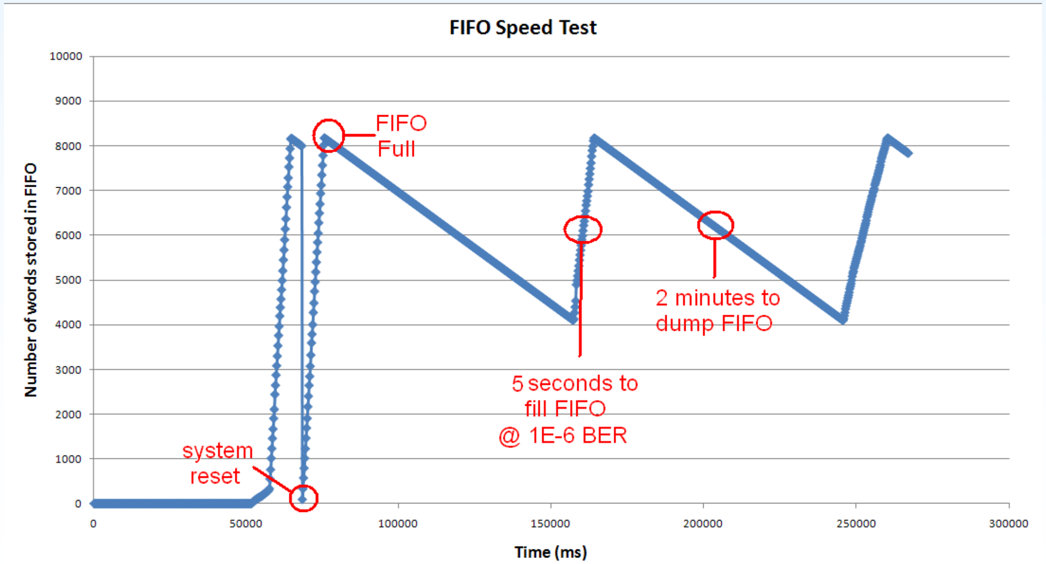




VBERT-A Features

Versatile Link

- Top level data flow supports PRBS7 and longer PRBS23 generation and detection. Given the nature of PRBS, word boundary is no longer checked. Handshake with Tx is not needed. Rx reset itself when link reestablishes.
- Error logger reports general BER counters saved and in global register; reports link lost events, time stamp and error stats saved in FIFO.
- LabVIEW front panel provides remote access to reset controls and run-time configurable parameter; emulates general GUI such as LED, push-button and dip switch.
- Congestion happens at 1E-7 BER. Dead time is limited by USB parallel read system call. Each system call adds mille-second overhead (currently per 12bytes), which can be significantly improved by moving data in bulk mode.



VL system spec backup slides