Developing rad-hard Chip-on-Board Fiber-Optics

https://indico.phys.sinica.edu.tw/event/104/

- **Fiber rad-hard**
  MM Ge-doped Co60 TID
- **Opto CMOS rad-hard**
  850 nm VCSEL, PD
  NIEL, TID
- **HEP opticl links**
  experience, future
  Chip-on-Board assembly

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Active Devices

1963:
Semiconductor laser
high threshold (~Amps)
Low temp (77K)

1969
Alferov (USSR) and Pannish & Hayashi (Bell Labs) Rm Temp. CW, semiconductor lasers

1989
Payne et al (U. Southampton) Er-doped fiberamplifier (EDFA)

Optical Fibers

1966:
C. Kao predicted Fiber attenuation low limit
20 dB/km (in 1966, **~1000dB/km**),
Nobel Prize '09

1969
Uchida (Nippon Sheet Glass, Japan) Multi-component Selfoc fiber (~100dB/km)

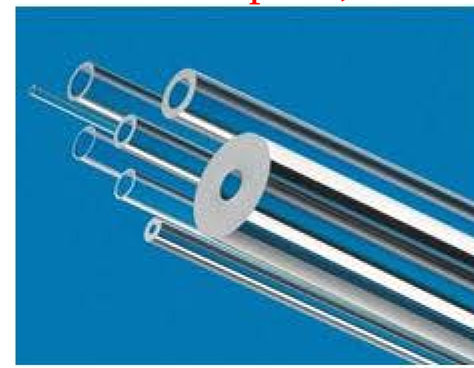
1970
Kapron, Keck, & Maurer (**Corning**) Low loss Silica fiber (**20dB/km**)

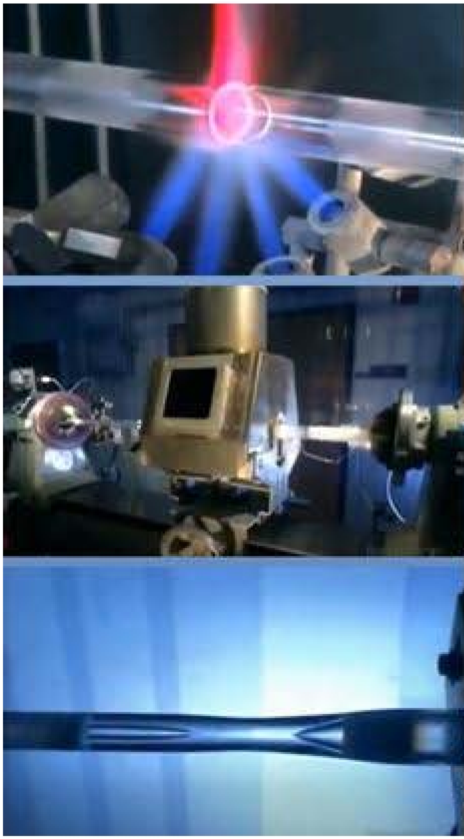
1974
MacChesney (**AT&T**)
1dB/km

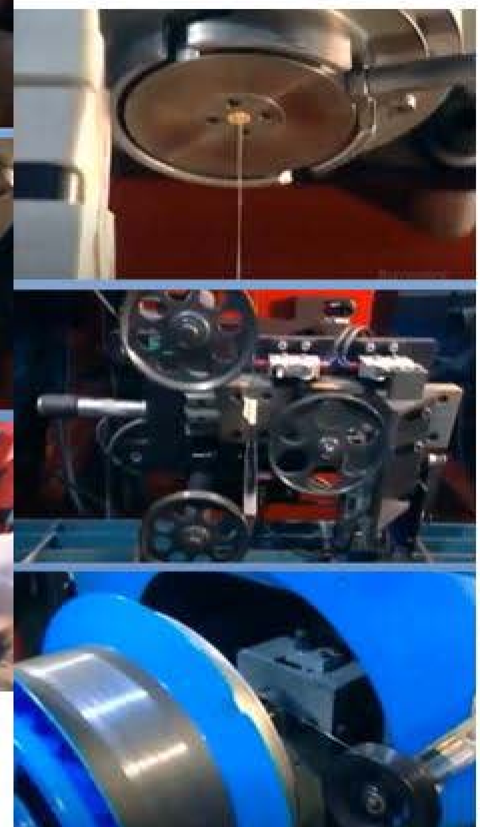
Optical fiber making

PCVD plasma chemical vapor Deposition
MCVD modified chemical vapor deposition
OVD outside vapor deposition
VAD vapor axial deposition

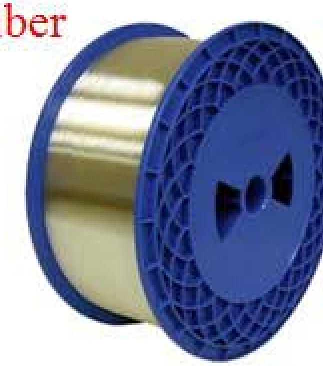
Fused Silica Tubes,
pure SiO_2
for Fiber Optics,







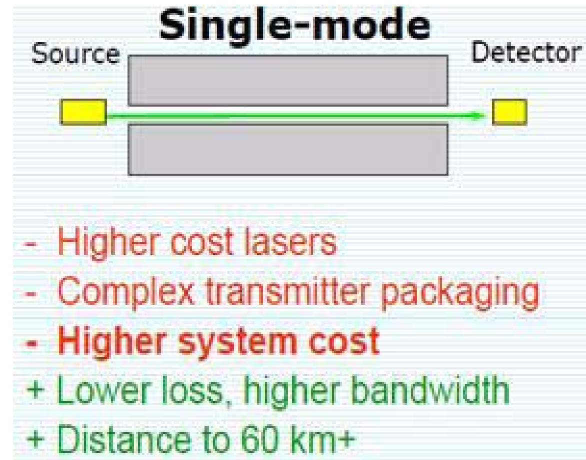
Bare Fiber
Reel



Fiber Cable

Looking for testing 武漢 YOFC
长飞光纤 Ge-doped, Rad-hard fibers

Fiber optical loss

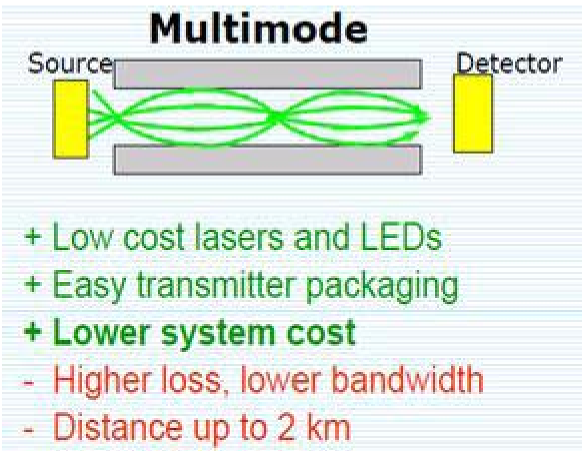


Silica glass fiber:

Low-mass, high bandwidth, little loss over long distance

− Absorption Scattering losses (Rayleigh, Raman…)

− Bending losses (micro bending)

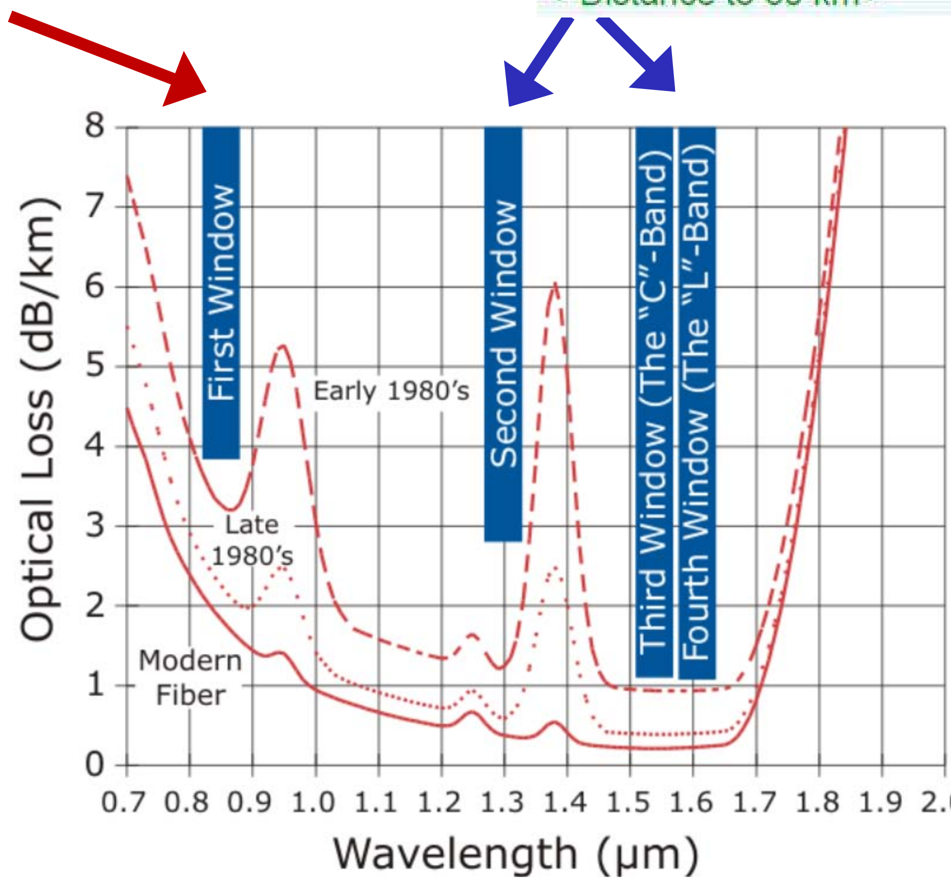


1st generation, ~1975, 0.8 µm fiber-MM, Laser GaAs

2nd generation, ~1980, 1.3 µm, fiber MM SM, InGaAsP FP-laser

3rd generation, ~1985, 1.55 µm, fiber SM InGaAsP DFB-laser

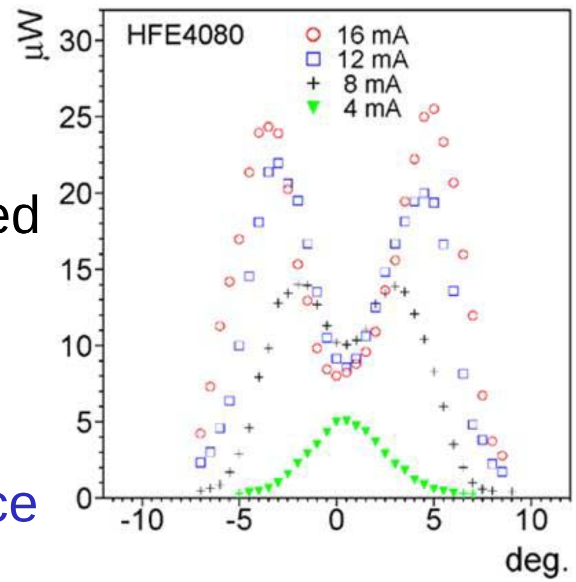
4th generation, 1996, 1.55µm WDM

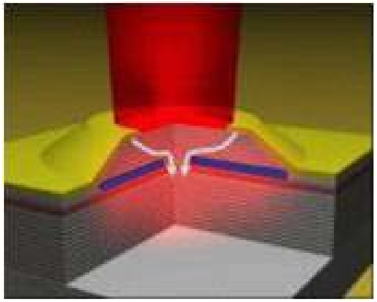


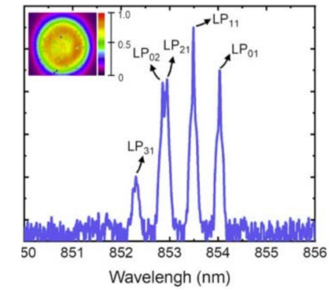
Light Coupling efficiency

- **VCSEL far-field distribution**
  at low current, 0th mode is centralized
  higher modes pop-up in outer-rings
  wider angles

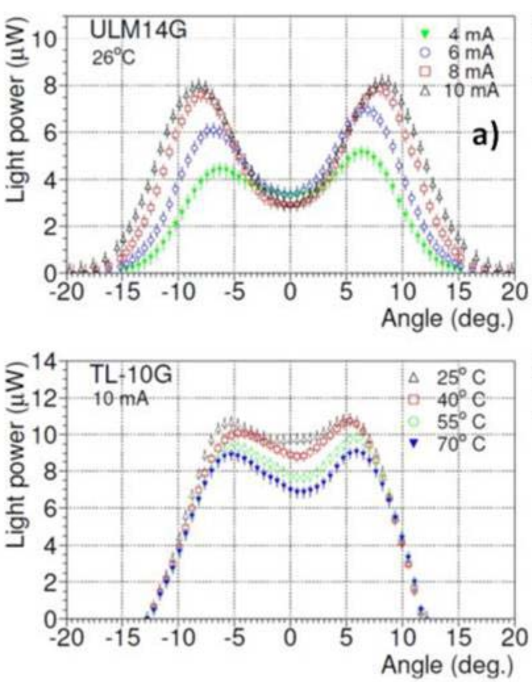
- **Coupling to Lens**
  loss to reflection, angular acceptance



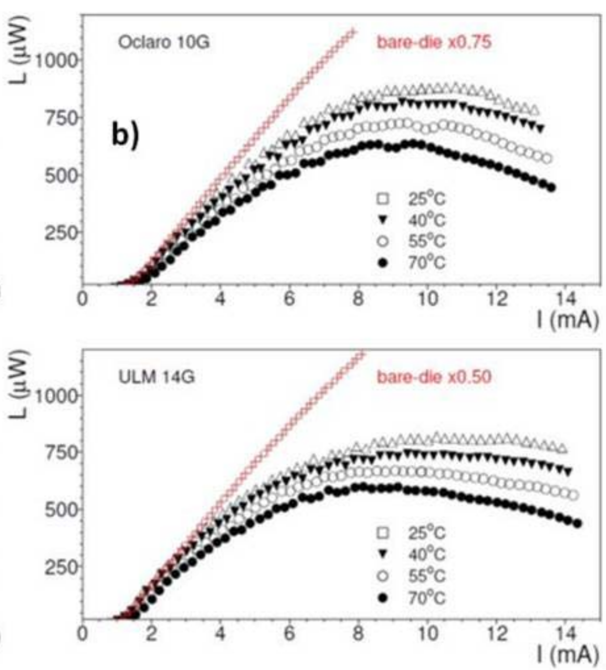




Far-field angle vs I, T



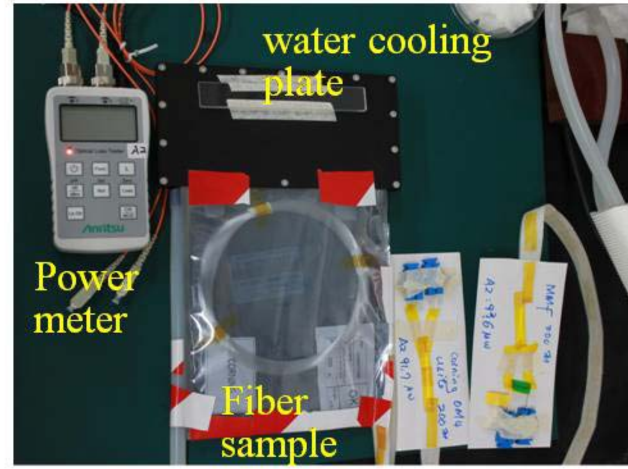
L-I, FOCI lens coupled

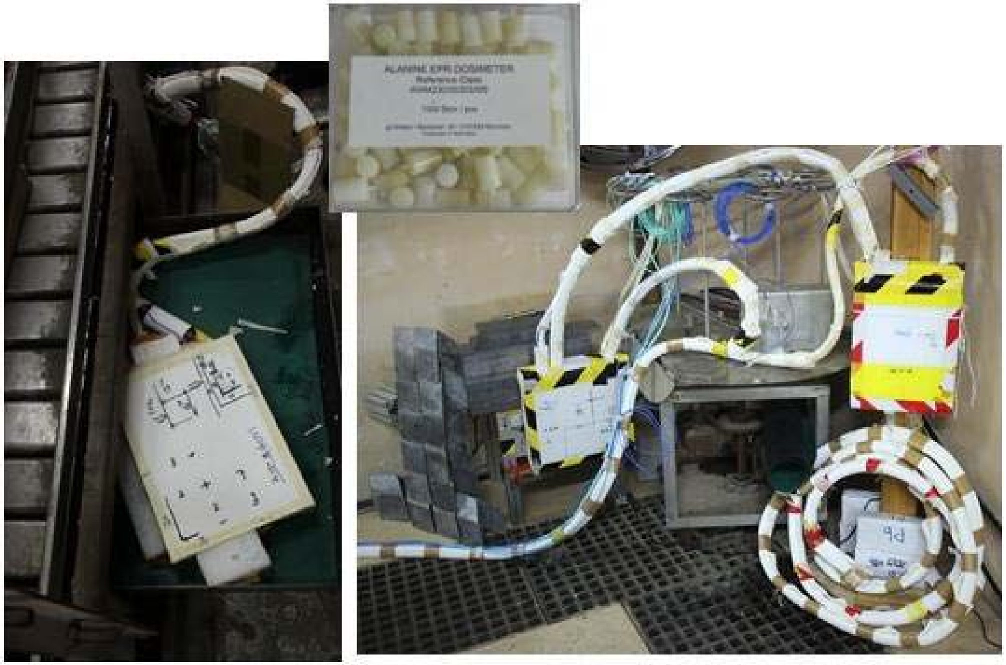


VCSEL+Lens in Oven

Fiber Co-60 TID test

Bare fiber sample in bag, with SC connectors in water bath, online DAQ at const ºC





Ge-doped MM fiber, Co-60 test

Fiber Radiation Induced Attenuation (RIA)

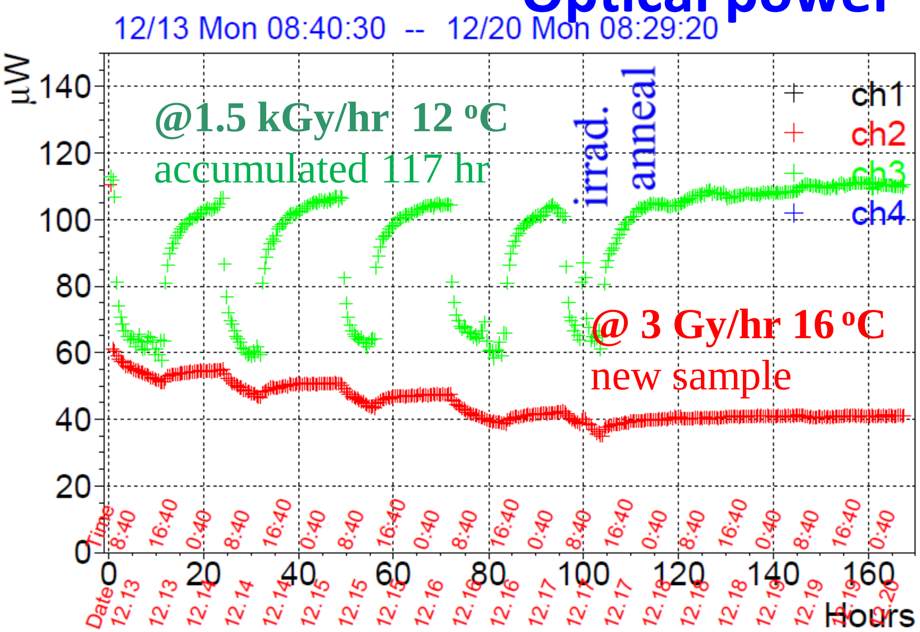
$$\text{RIA} = (\text{IL}(0) - \text{IL}(t))/\text{Length}$$
$$\text{IL(dB)} = 10 \times \log 10 \, (P_T/P_R)$$

IL insertion loss
P_T transmitter, P_R received

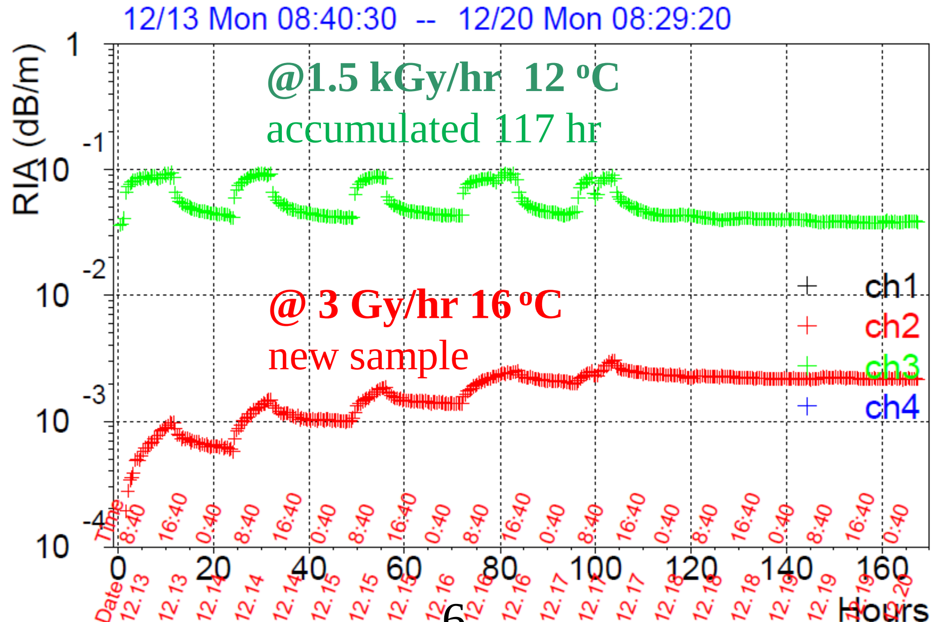
Dependences : **Dose rate, Temperature**

Fibers tested at Dose rate 1.5kGy/hr
Irrad ~8hr daytime, anneal overnight, over 1 week

Optical power

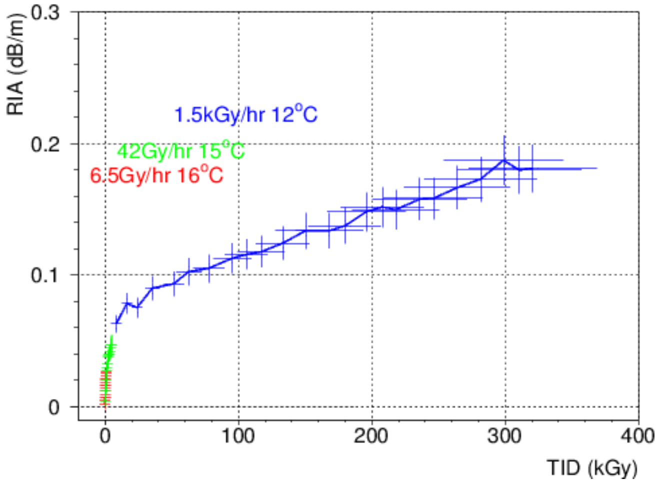


RIA

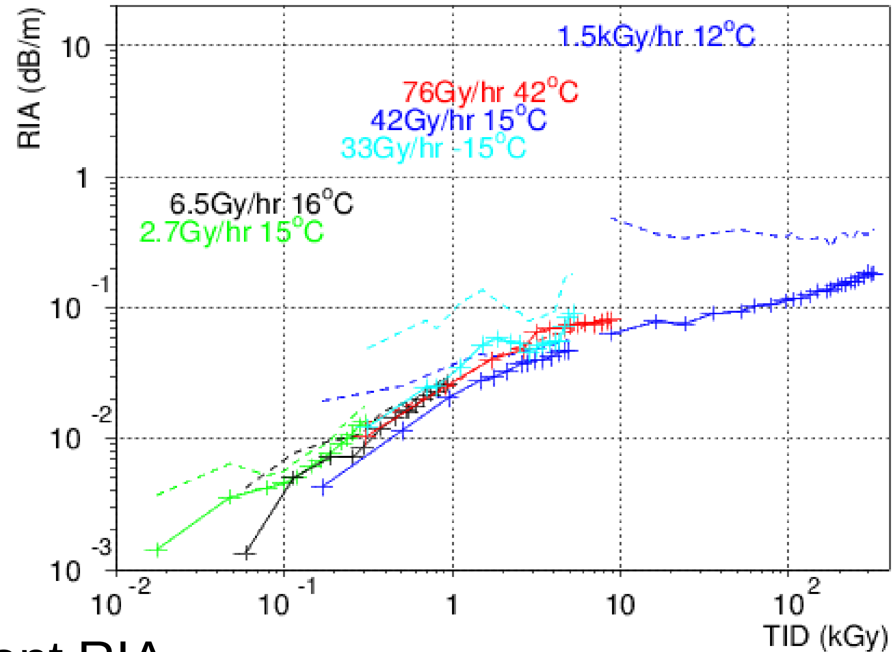


RIA, Ge-doped MM fiber (POFC fibers)

Plot Instant RIA, at daily max dose,
Plot RIA after 10 hr annealing

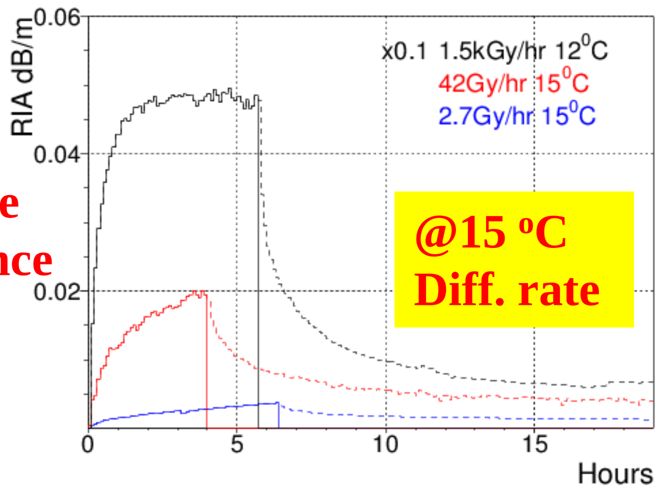


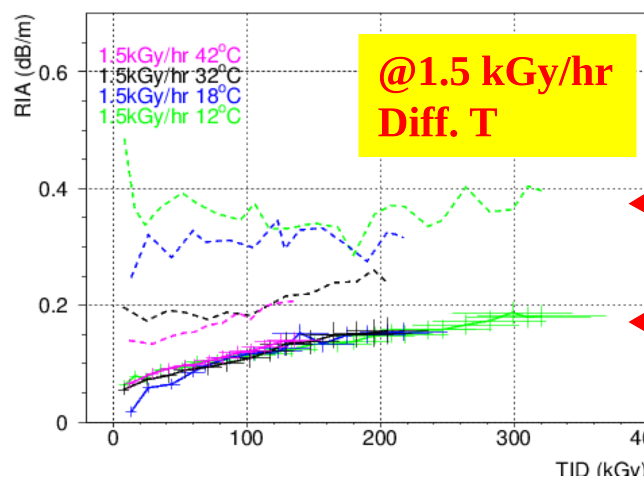
Annealed RIA



- **Dose Rate :** higher rate → higher instant RIA
- **Temperature :** lower T → higher instant RIA

Dose Rate dependence





Temperature dependance

Inst. RIA

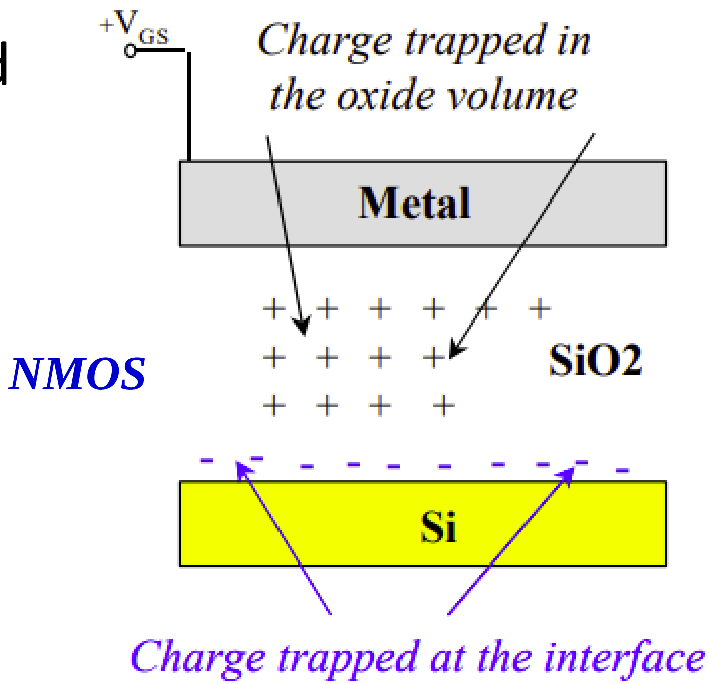
10hr Annealed

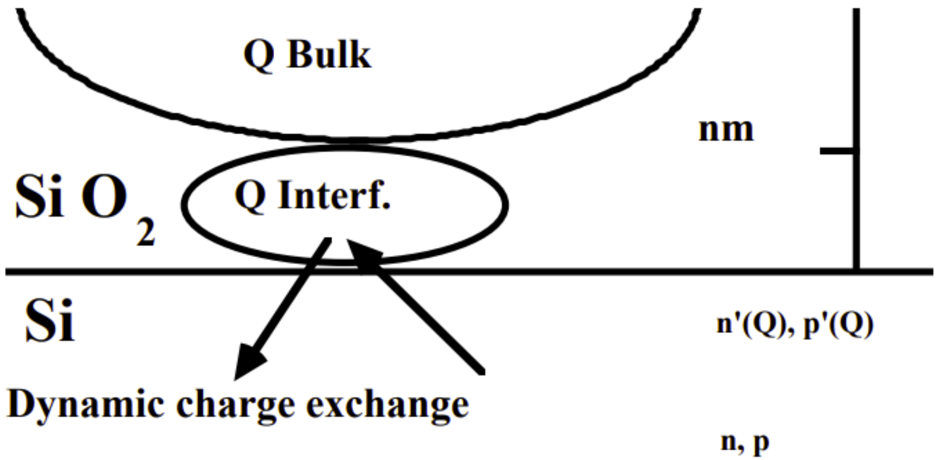
TID effects on CMOS

[J. Gasiot CERN Training]

Total Ionizing Dose (TID) induces charge-trapping at **Si-SiO2 interface**
Dependence : total dose, dose rate, annealng

- new interface states formed.
- interface state density vs. energy changed
- interface state density changes with time
- construction after irradiation
- static and dynamic electrical response of the Si-SiO2 altered



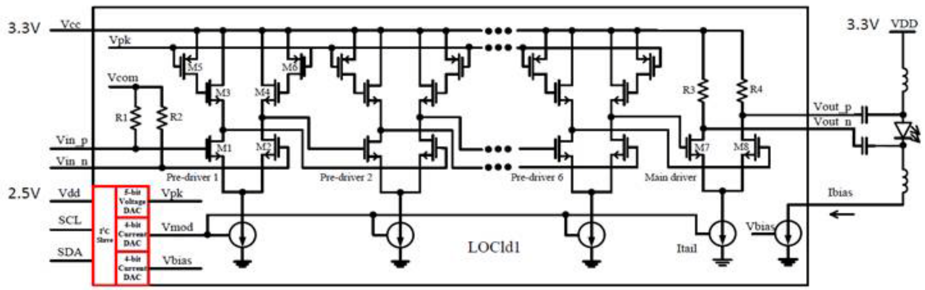


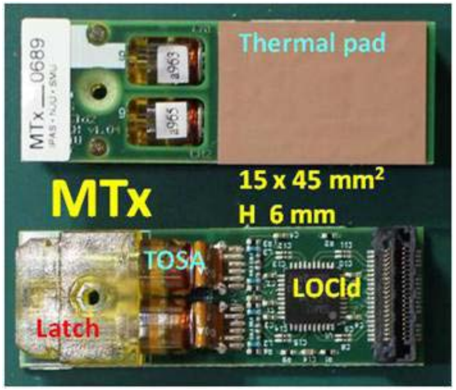
Threshold voltage degradation as a function of the total Dose

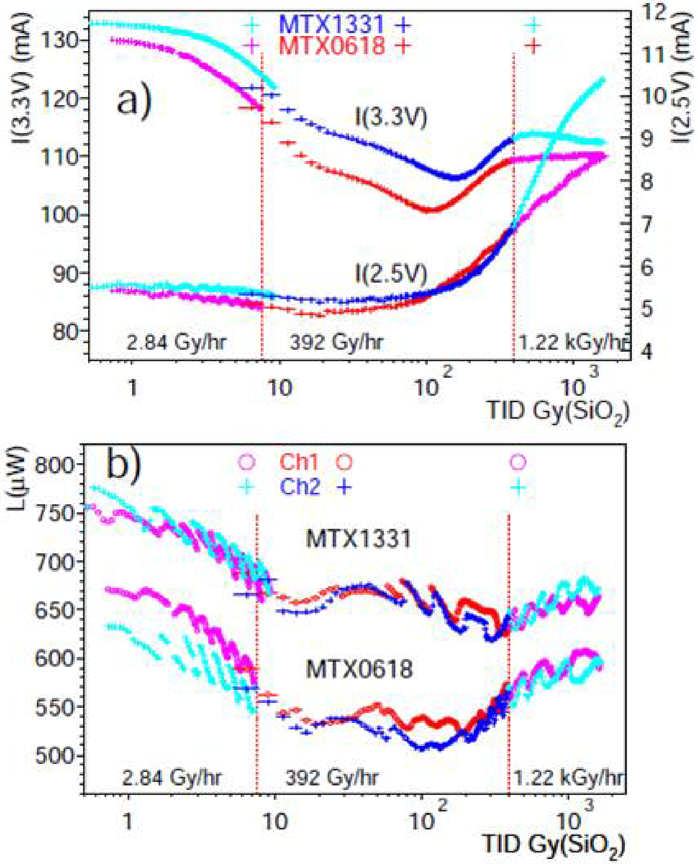
X-ray TID on MTX LOCld of ATLAS LAr

X-ray, 3 dose-rates in 280 min to 1.62 kGy(SiO_2)

LOCld laser driver shows degradation





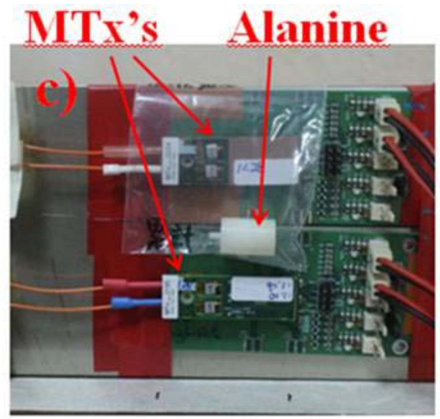


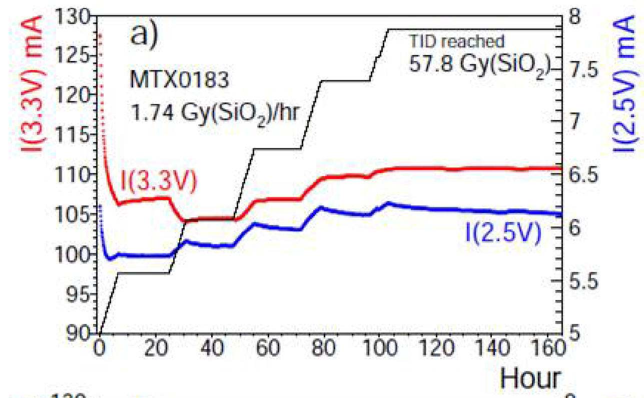
Co-60 TID on MTX LOCld

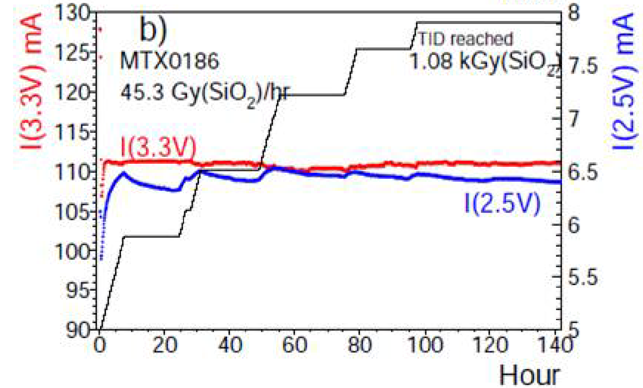
Co-60 varying dose-rates 0.14 to 45 Gy/hr

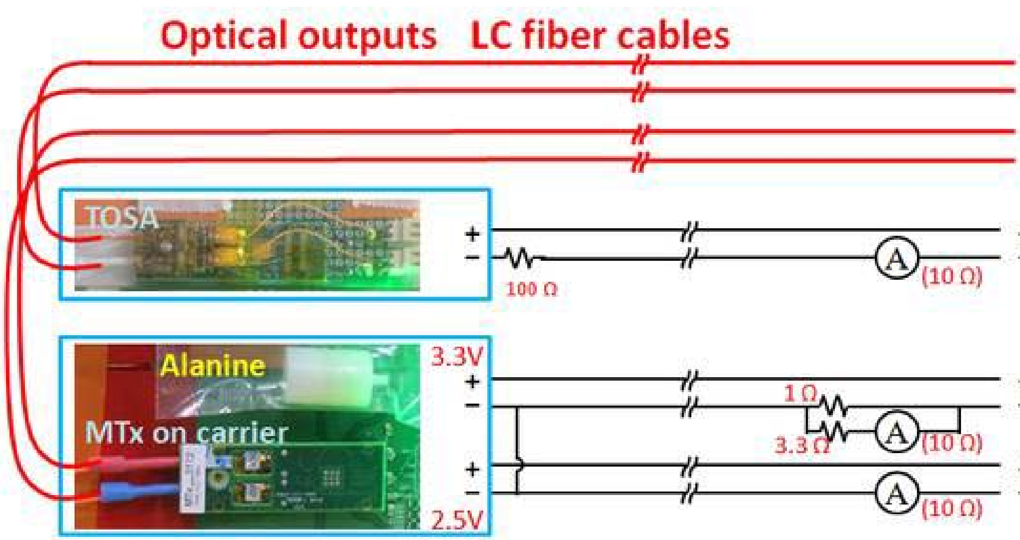
Irradiation in daytime, annealing overnight

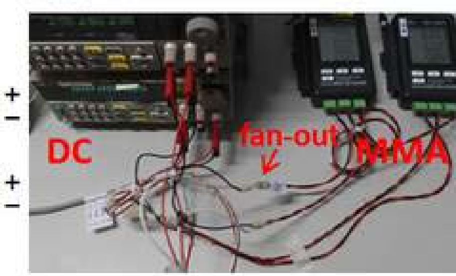
Dose calibration using Alanine









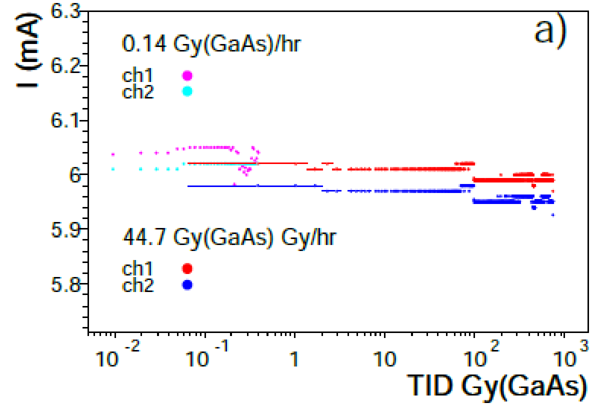


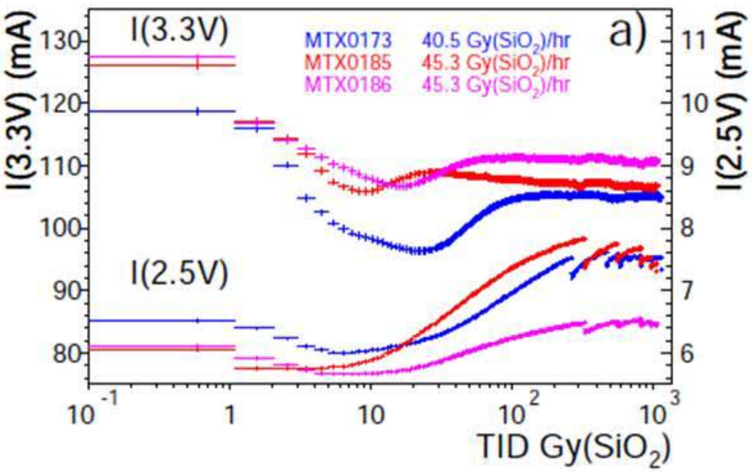
Co-60 TID on MTX LOCld

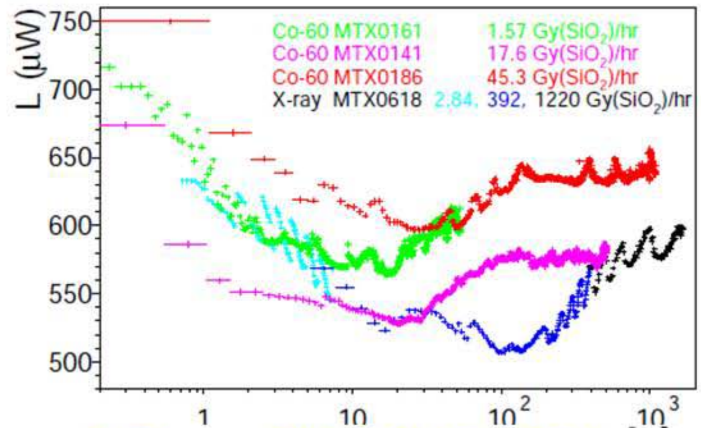
Co-60 lower rate to X-ray, mio

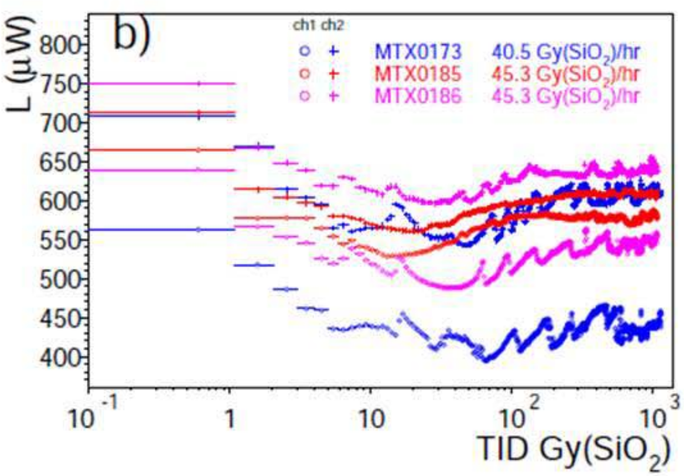
VCSEL not effected by TID

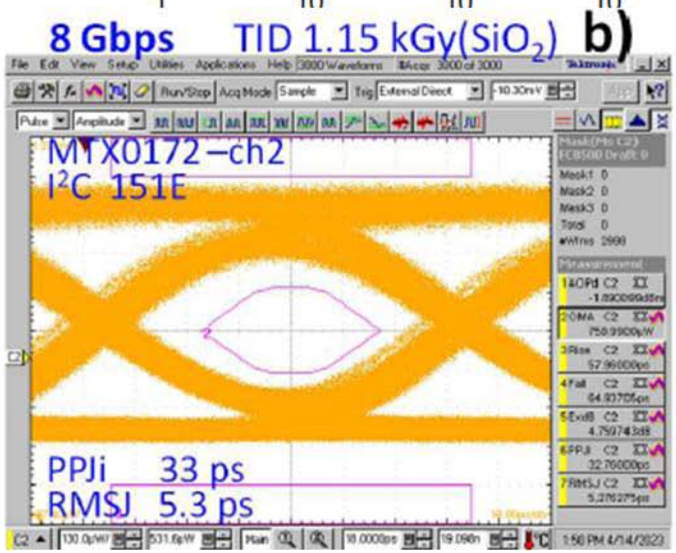
CMOS current drops ~ 10-100 Gy(SiO_2)











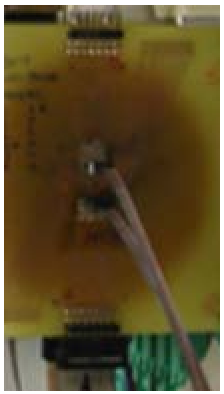
VCSEL rad-hard degradation, annealing

VCSEL light degradation ➔ linear to fluence

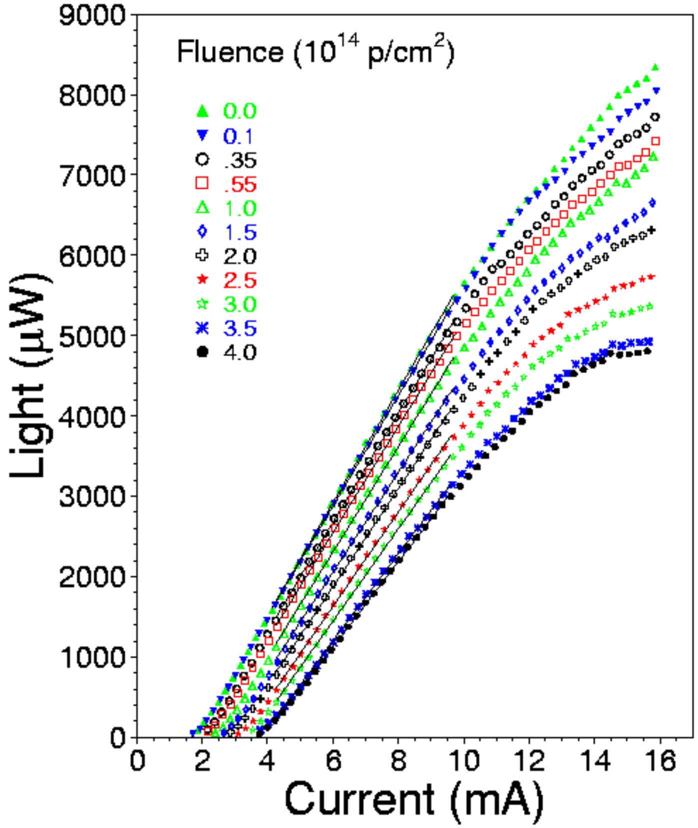
rad-hard fiber connected to readout, independent of flux rate

Fast annealing by charge injection

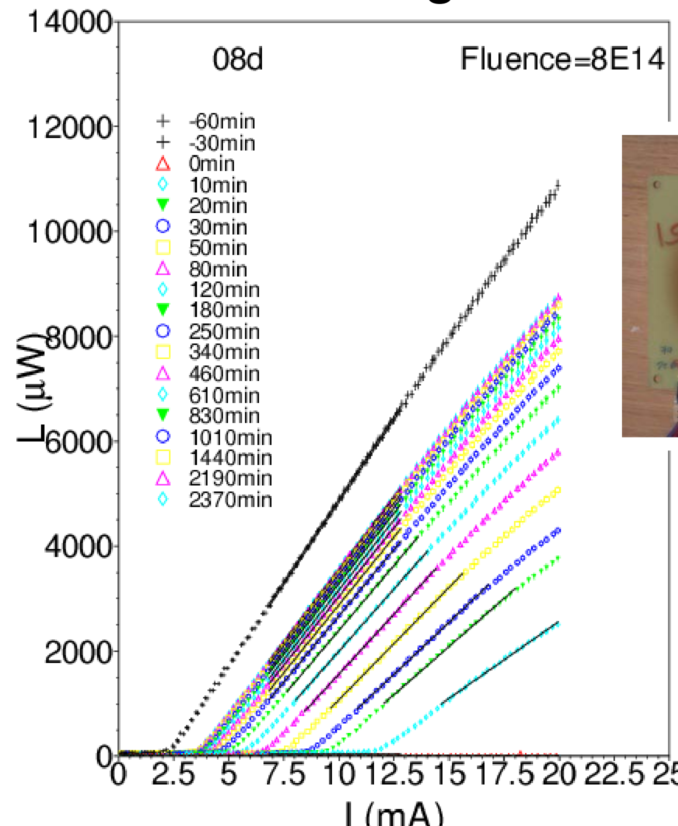
at operation current (10 nA) applied

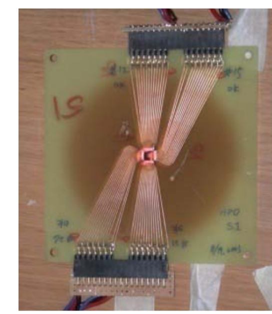


L-I of VCSEL (oxide)
vs. **online** Fluence



L-I of VCSEL (oxide)
vs. **Annealing** time





NIEL to GaAs diodes

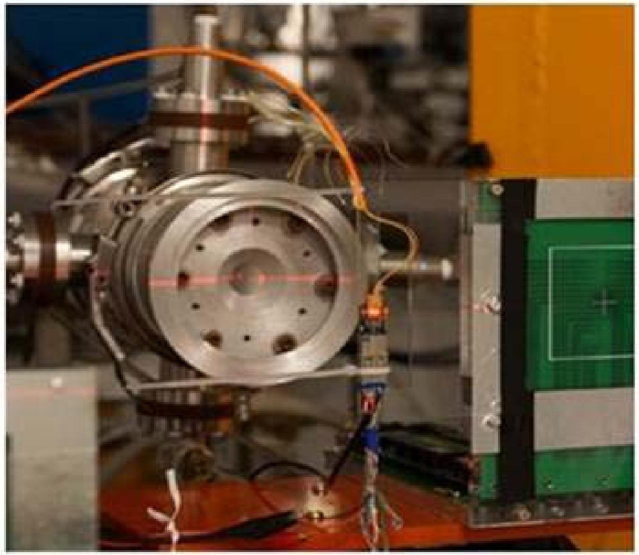
Laser diodes (850 nm VCSELs, 1 Gbps)

NIEL damage

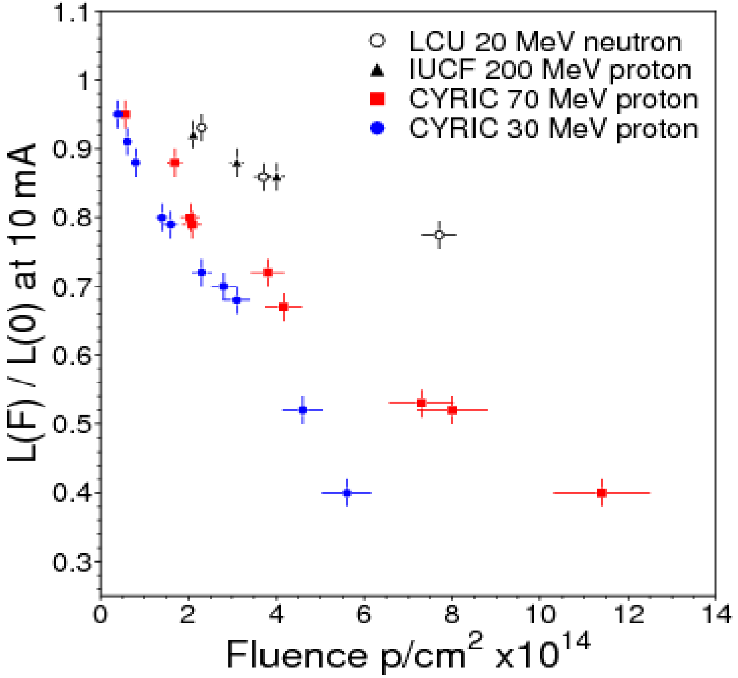
→ light degradation linear to fluence

Higher proton momentum

→ less damage to GaAs components (contrary to theoretical calculations)

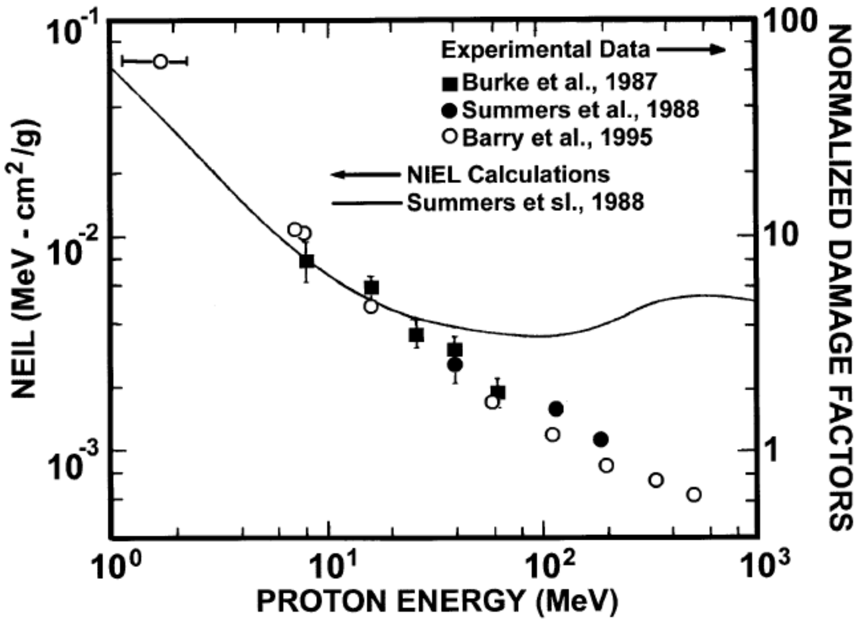


VCSEL (GaAs) light degradation



GaAs solar cell measurements

Srour, IEEE TNS 50, 653 (2003)



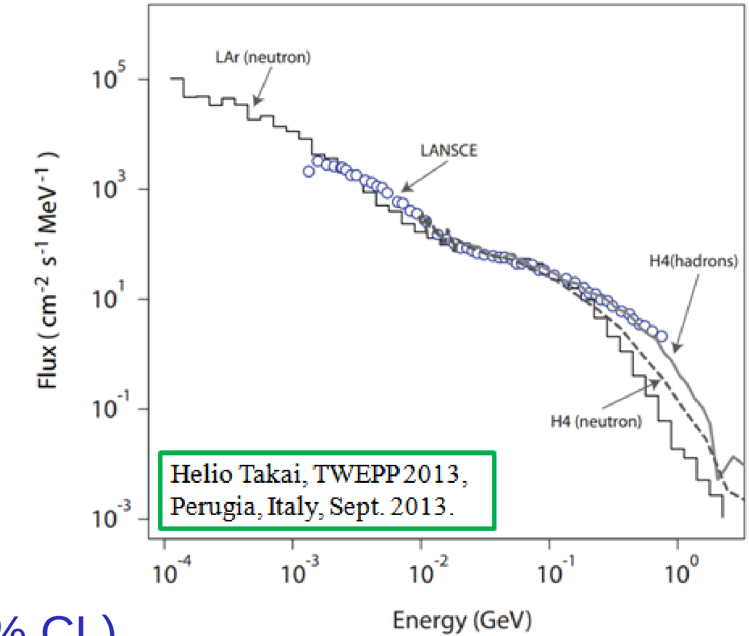
LANSCE neutron test

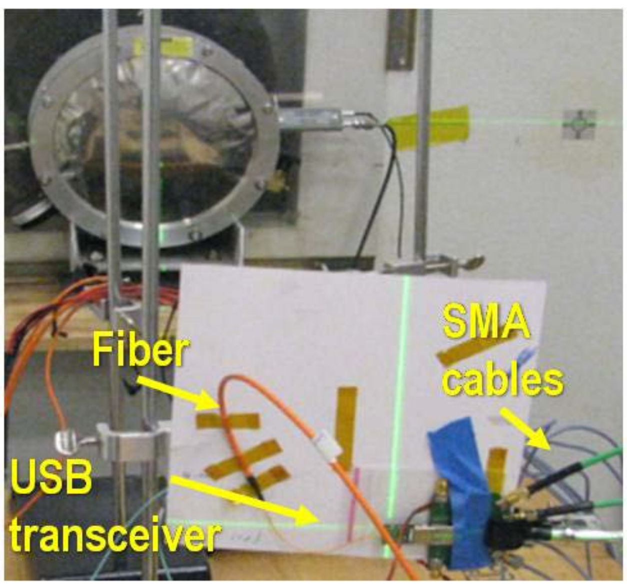
- Beam profile similar to ATLAS
- **USB transceiver in Bit-Err-Rate**
  Straitix II GX, PRBS 2^7-1 bit pattern
  TX path, RX path tested separately

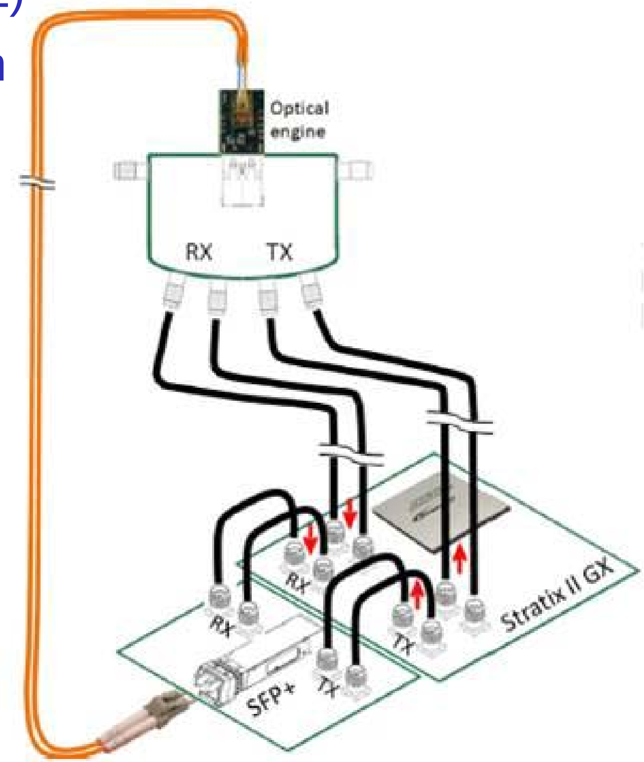
  neutron flux 2.9×10^5 n/cm^{2}s
  over 1.5 days to 3.8×10^{10} n/cm^2

  TX: 0 error, upper limit 1.0×10^{-10} cm^2/ch (95% CL)

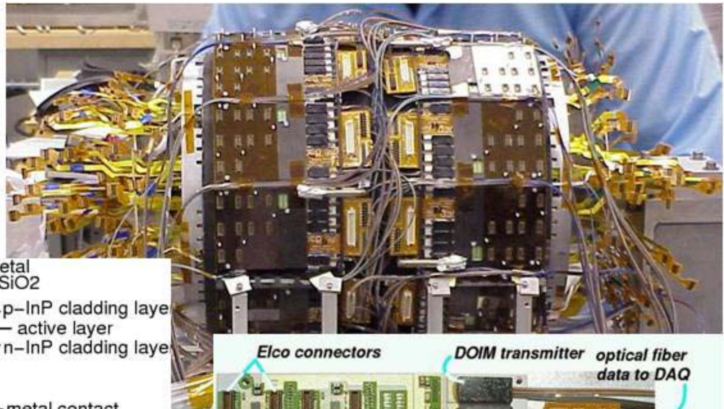
  RX: 11 errors SEE cross section 2.9×10^{-10} cm^2/ch



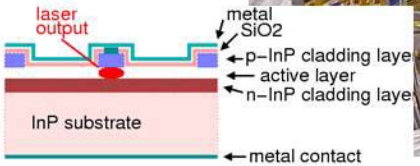


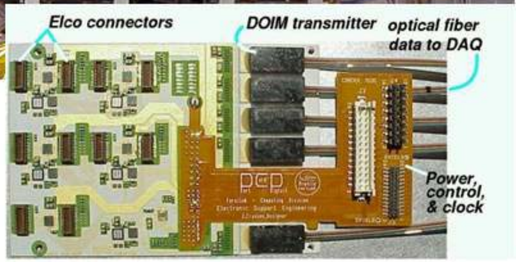


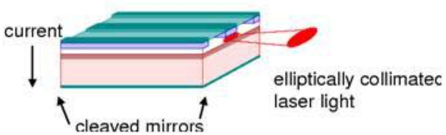
CDF optical link assembly



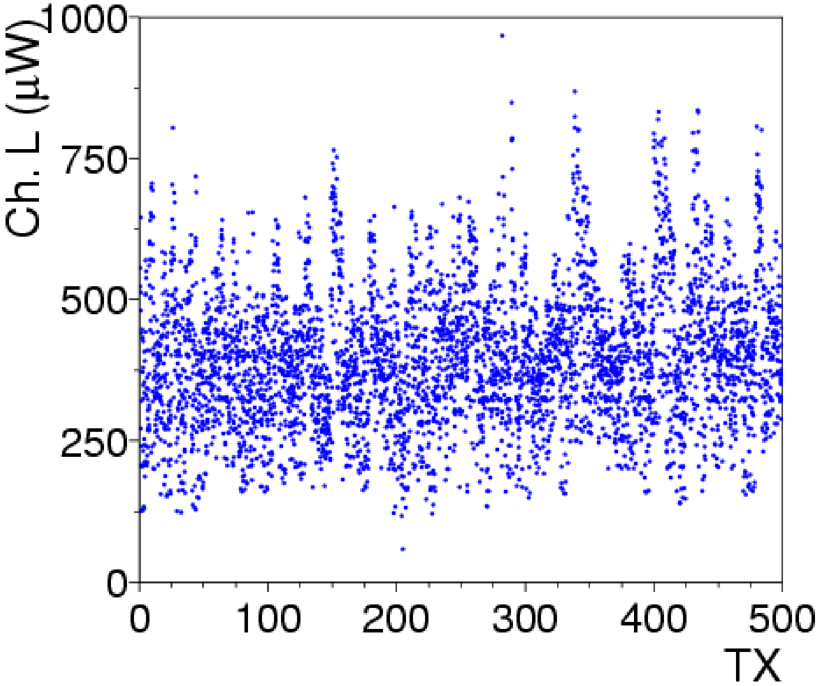
- 570 modules of Byte-wide parallel links
- Edge-emitting laser diode array
- 22 meter MM Ge doped fiber cable
- 53 Mbyte/sec, BER$<10^{-12}$

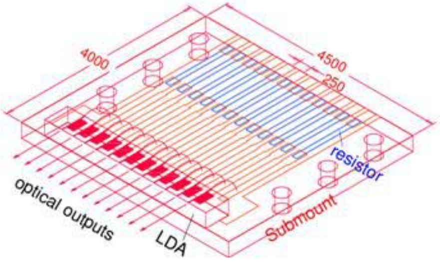


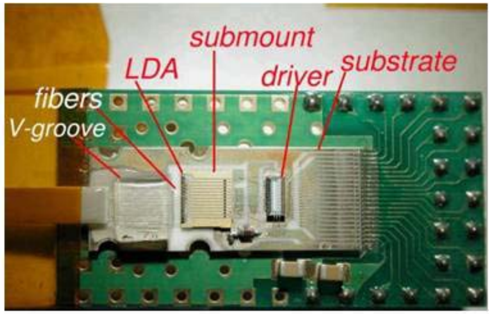


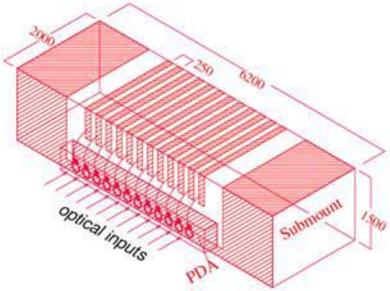


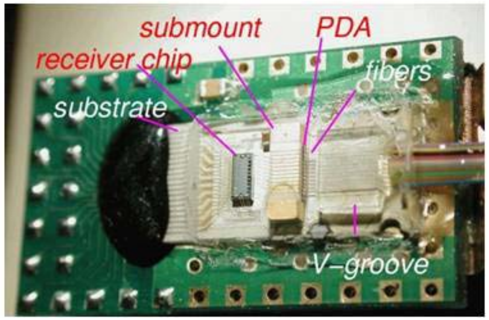
Each column is plotted with light levels of the 8 channels of a module





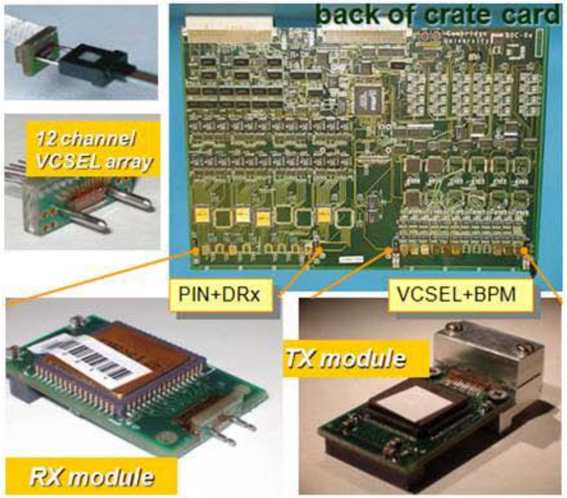




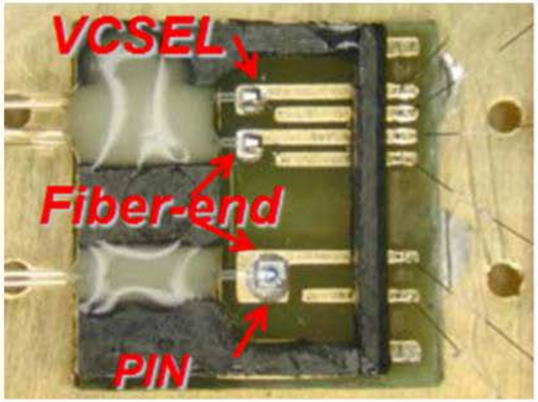


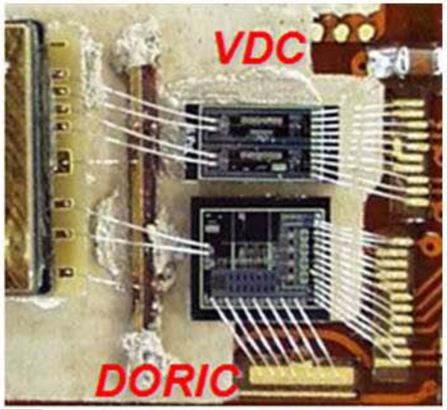
ATLAS ITk 1st optical link

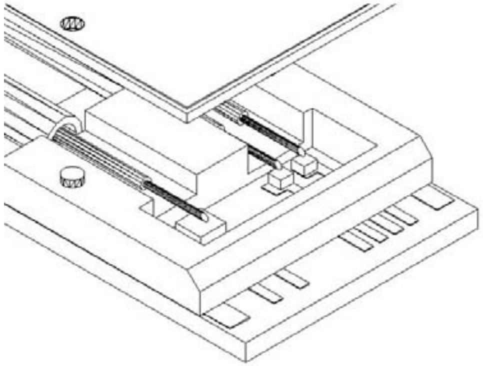
- VCSEL 850 nm matched to Epi Si PIN diodes.
- low thresholds (~3 mA).
- ***Very radiation hard***

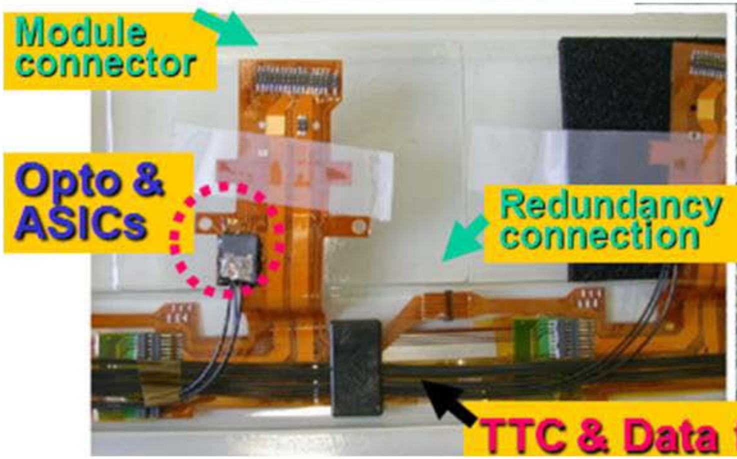


- 1 RX PIN + DORIC
- 2 TX VCSEL + VDC
- 45^{o} fibre-end mirror

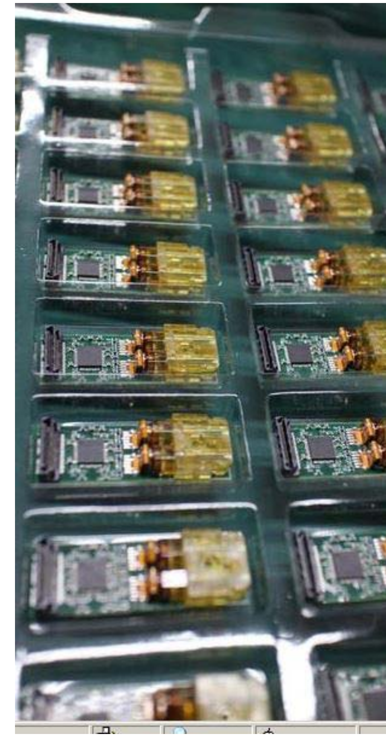






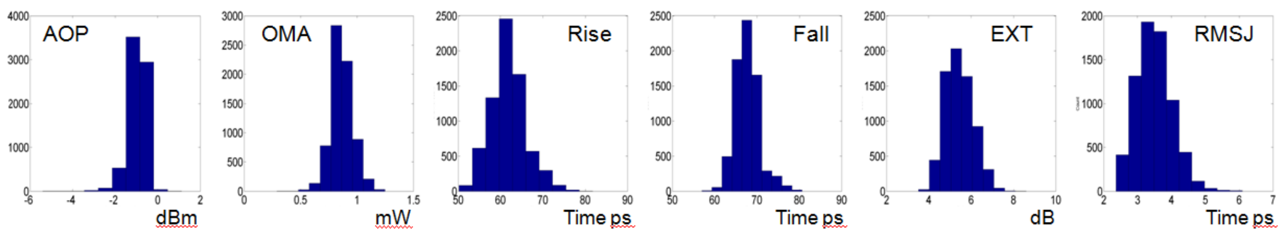


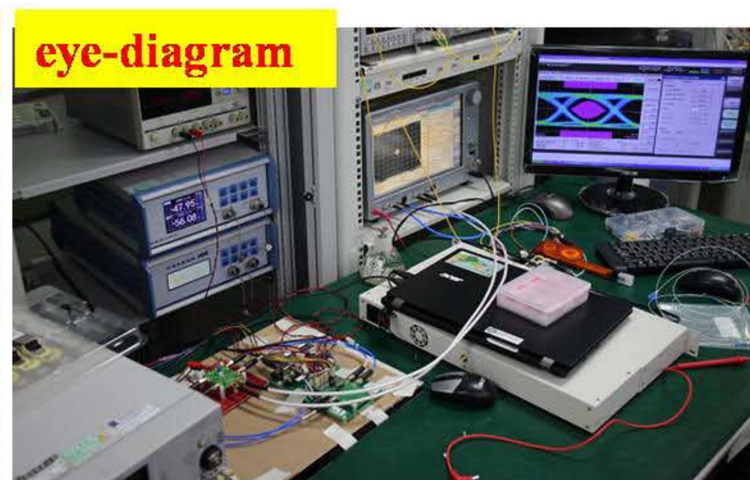
ATLAS Phase-I LAr transceivers



- ~ 5k transceivers produced by AS TW opto-electronic companies
- Quality Assurance, Quality Contract at AS:
  every channel measured for
  Chip test, TOSA L-I, eye-diagram, Bit-Error-Rate, Burn-in
  eye-diagram parameters well within specification

MTRx/MTx	AOP	OMA	Rise time	Fall time	EXT	RMJ
Criterion	> -3.5 dBm	>300 uW	<80 ps	<80 ps	>3dB	<4.5 ps



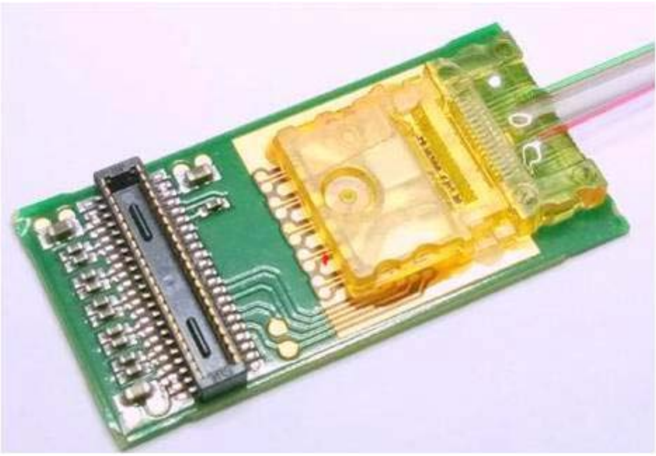


The CERN Phase-II VTRx+ (FOCI 上詮)

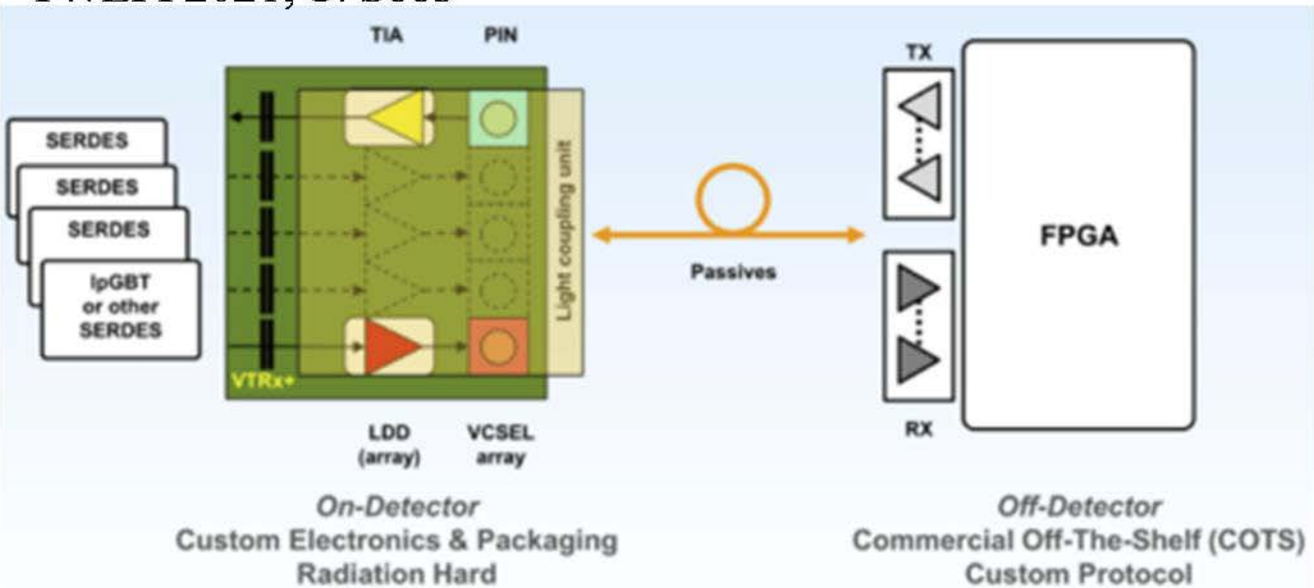
- CERN Versatile Link+ group ➔ one module for all

- 10x20 mm^2 height 2.5mm, 4.5mm
- 4TX+1RX, 10Gbps TX, 2.56 Gbps RX
- VCSEL array laser driver LQD, TSMC 65nm
- Optical Receiver GBTIA TSMC 65nm
- production 65K pcs

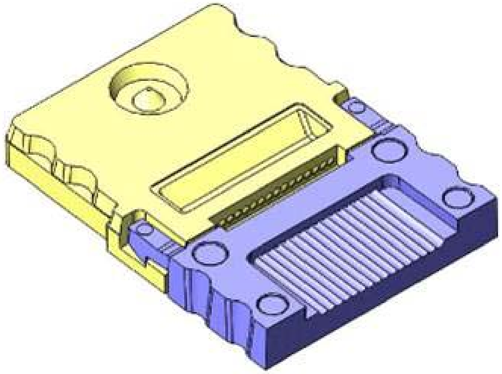
- Lens is the TW Orange-tek



TWEPP2021, C. Soos



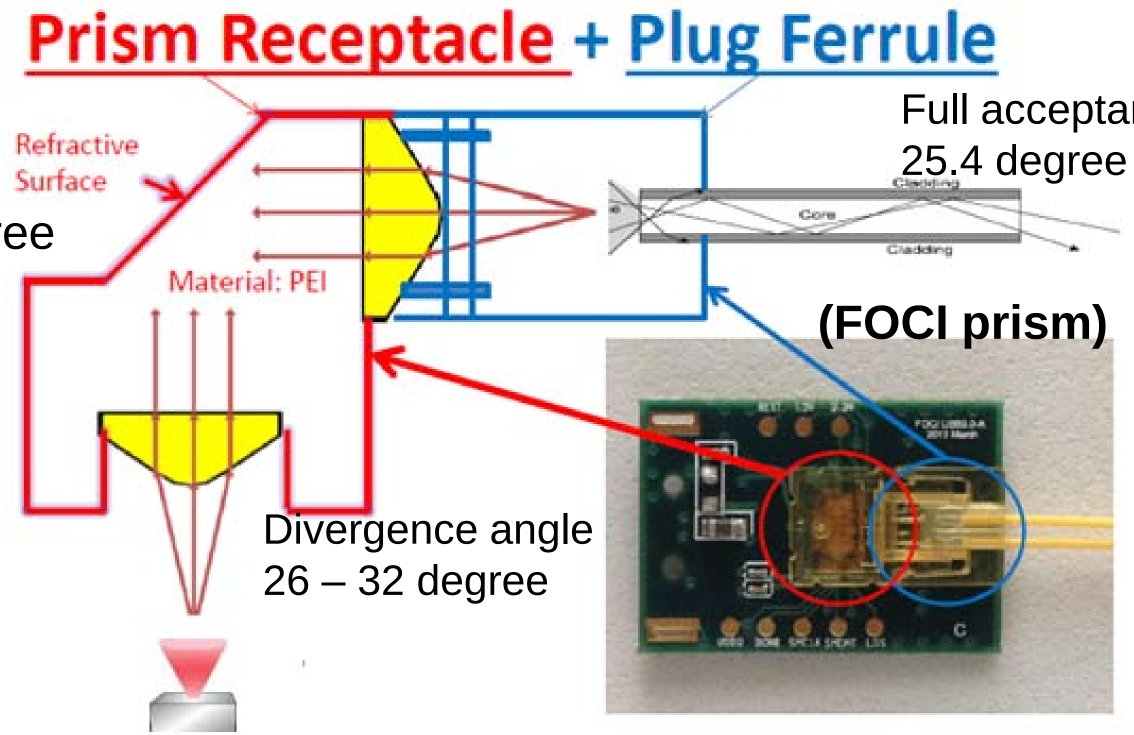
Orange-tek
OT-12, OT-13



Light coupling Technology

- **Light Peak example, Intel** technology delivers high bandwidth starting at 10 Gb/s to mainstream computing and consumer electronics
- **Lens/Prism :**

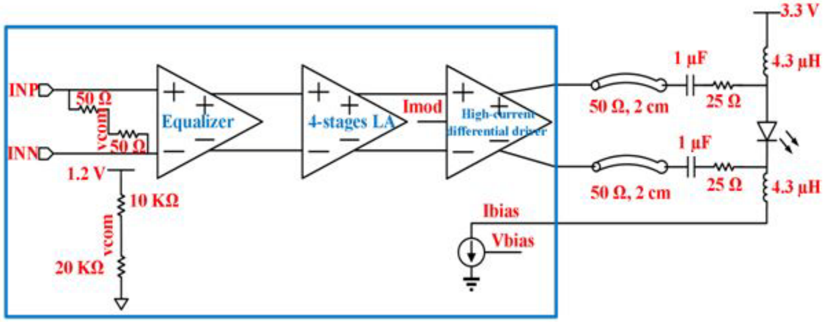
Spherical-aberration free
Plano-Convex
Hyperbolic Lens

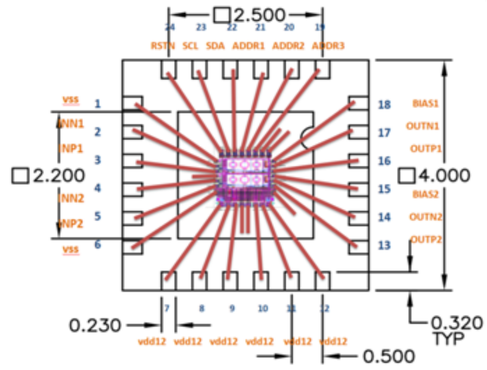


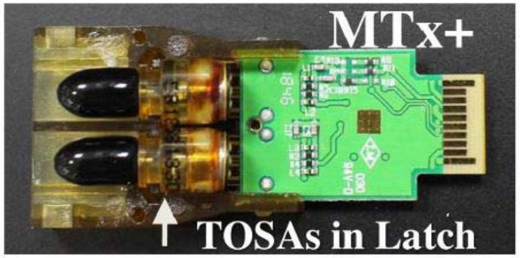
VCSELs aperture
from t Ø 5 to 20 µm

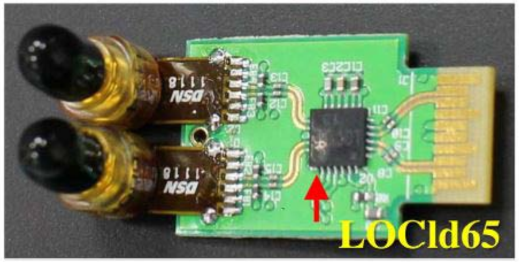
AS+SMU+前鼎: 25 Gbps Transmitter

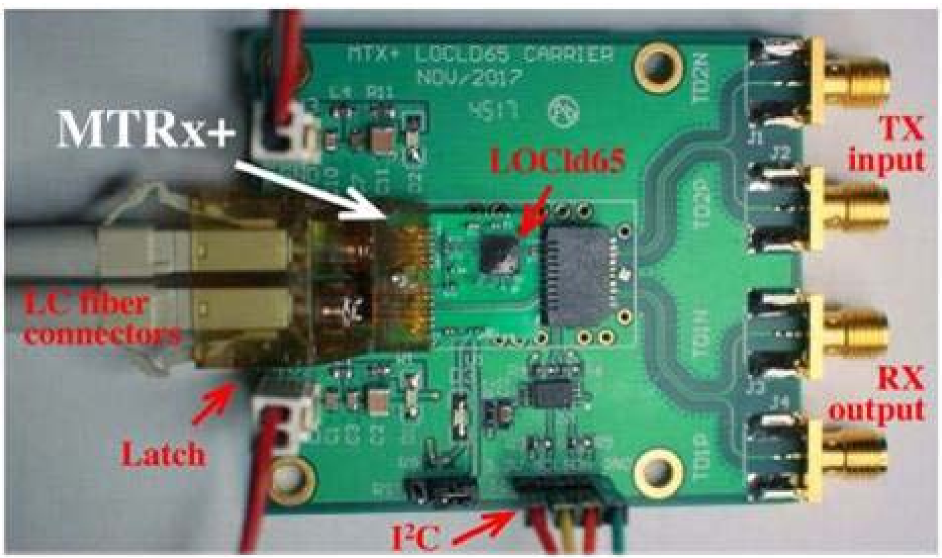
- 25 Gbps components, PCB, connectors
- Driver, LOCld65, TSMC 65nm

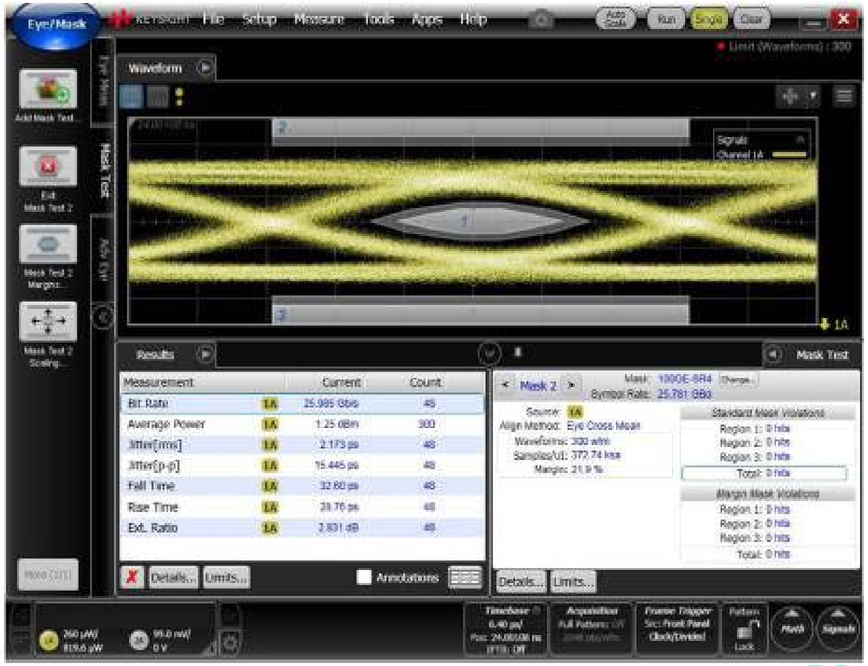




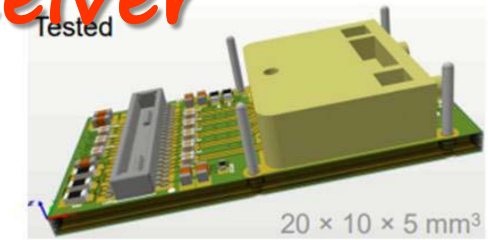








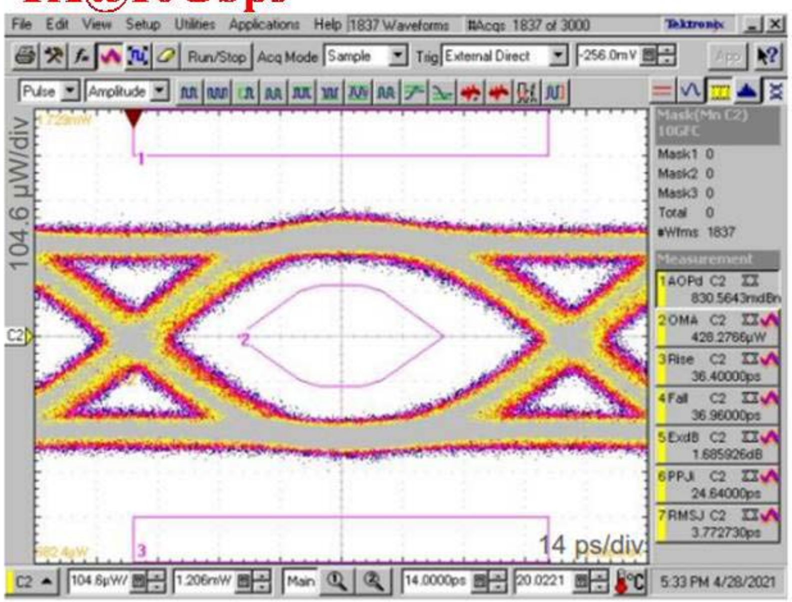
AS+SMU+前鼎 QTRx Transceiver



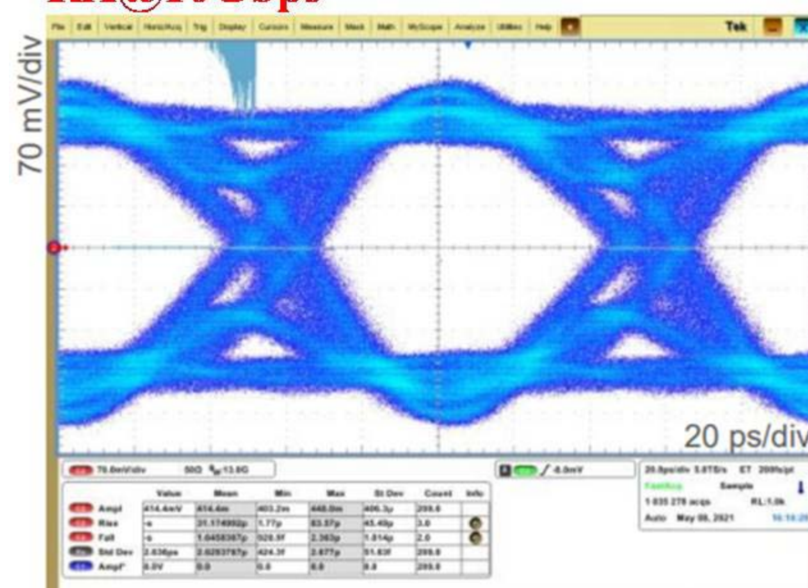
- 4TX+4RX, tested @10G, will do 25 Gbps
- VCSEL, PD, PCB all 25 Gbps qualified
- Driver, QLDD, QTIA, TSMC 65nm

QTRx	QLDD	QTIA	
Data rate	10 Gbps	2.56 Gbps	10 Gbps
Power supply	1.2 V and 2.5 V		
Sensitivity (BER =1E-12)	80 mV	-17 dBm	-8 dBm
Rise /fall time	37 ps	40 ps	50 ps
Total jitter (BER =1E-12)	-	38.5 ps	52.4 ps
Power consumption /ch	124 mW	120 mW with CP	

TX@10Gbps



RX@10Gbps



Summary

- Opto module assembly is mature industry
  ASIC packaged, wire-bonding
  Electric connectors: SFP, QSFP, Hirose, Firefly
  Optical coupling: MT, pigtail mini-formfactor
- TSMC 65 is 25 Gbps ready
  SIMC 55 re-freshing, 25 Gbps expected
- Radiation hardness
  NIEL on 25 Gbps VCSEL, PD
  TID, SEE on CMOS