

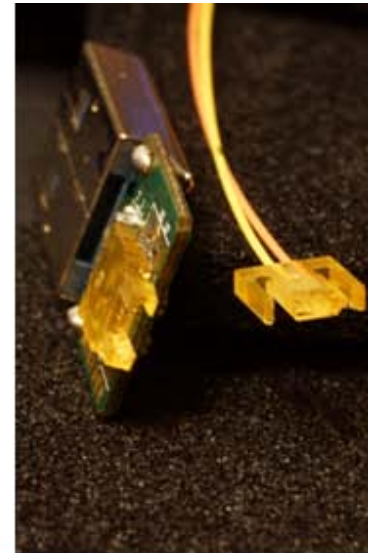
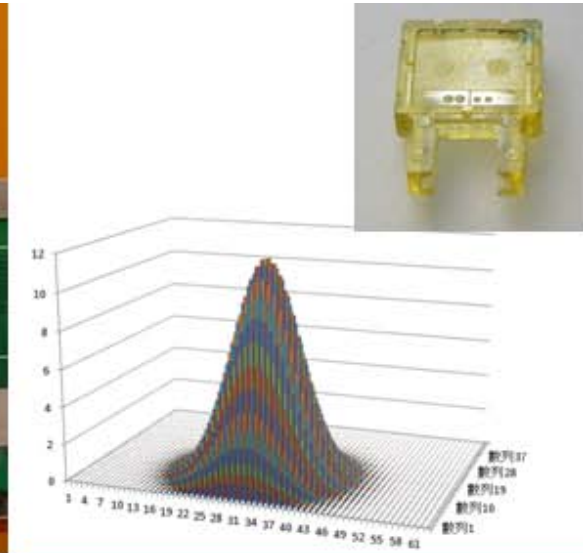
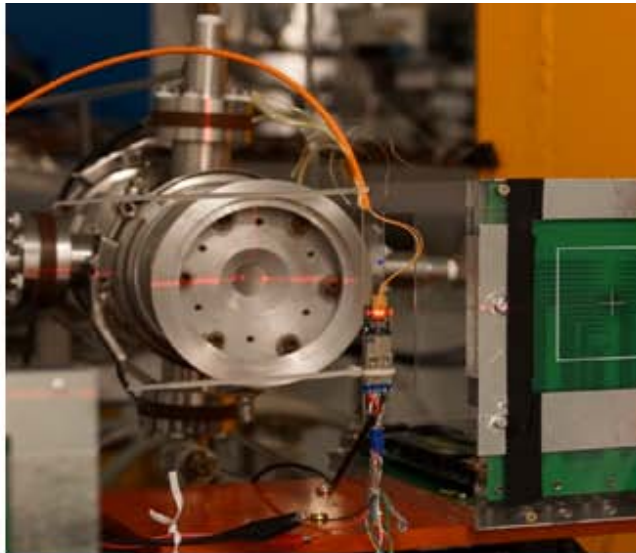
Radiation testing of commercial Opto-electronics

Suen Hou

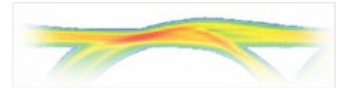
Academia Sinica,
Taiwan

21 March 2014

Opto Working Group
Mini Workshop



Outline



- **New commercial opto transceiver**

 - bare die assembly with prism/lens

 - FOCI optical engine, USB3 5 Gb, SFP+ 10Gb

 - Truelight QSFP+ 40Gb

- **Radiation tests**

 - Co⁶⁰ on PEI prism at INER

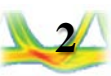
 - 30 MeV proton on FOCI VCSEL, driver, at INER

 - X-ray BER at SMU

 - neutron at LosAlamas

- **Activities and plan**

 - Prototyping ATLAS phase-I transmitter



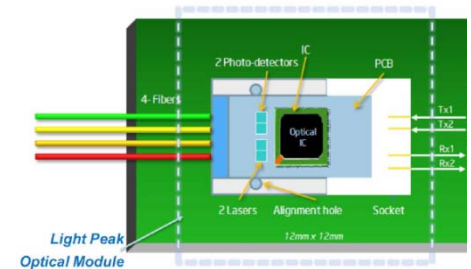
Compact commercial optical transceiver

- Intel Light Peak

initiated household 10 Gb/s links, IDF2010

multiple I/O protocols over a single cable

connection between peripherals, workstations, displays ...



IDF2010
INTEL DEVELOPER FORUM

- Developments of commercial products in Taiwan

bare-die + lens/prism in USB, SFP+, QSFP

variety in lens/prism design, fiber cabling,

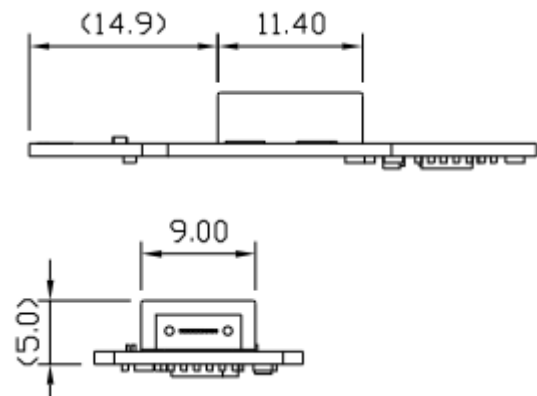
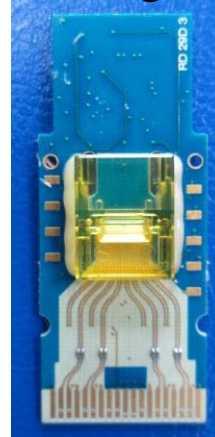
FOCI 5Gb USB3



FOCI 10Gb SFP+



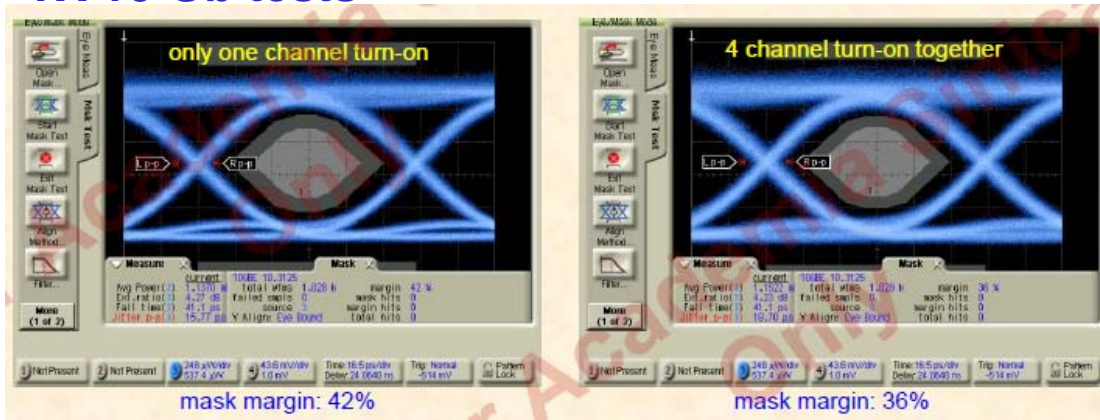
Truelight 40Gb QSFP



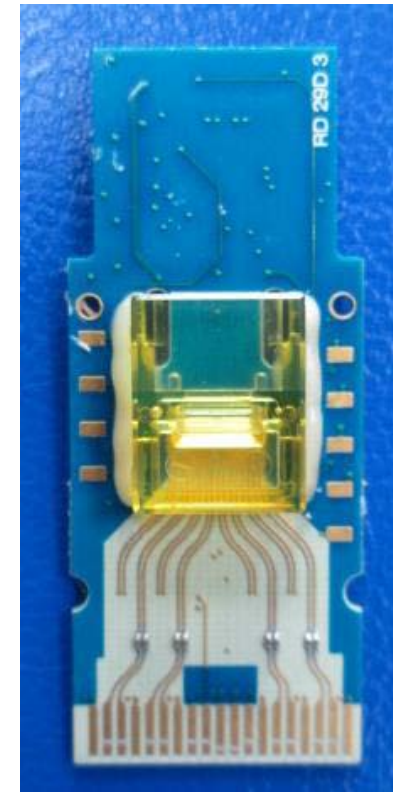
Chip-on-Board, QSFP of TrueLight

- Assembly service to customer
- VCSEL, PIN arrays of TrueLight
- Lens, driver, circuit provided by customer,
- MT ferrule, 4-in 4-out, 40 Gb QSFP optical engine

TX 10 Gb tests



RX 10 Gb tests



Non-hermetic VCSEL and GaAs PIN array

-TSA-8B04-xxx 1X4 VCSEL



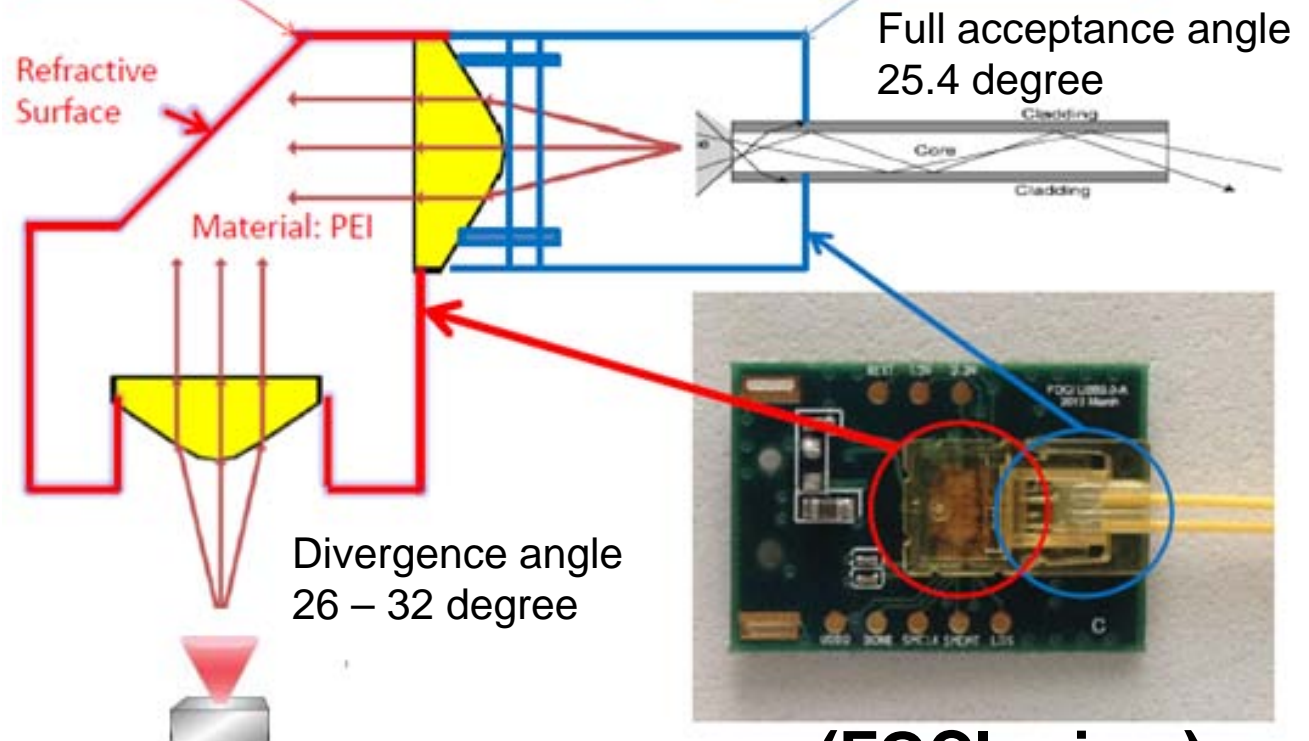
-TPA-8D04-xxx 1X4 GaAs PIN



Optical transceiver with Lens/Prism

- **Assembly** : OEM service provided *die, driver, circuits* and *lens*, Issues: alignment, hermeticity ...
- **Lens/Prism** : precision PEI molding ..

Prism Receptacle + Plug Ferrule



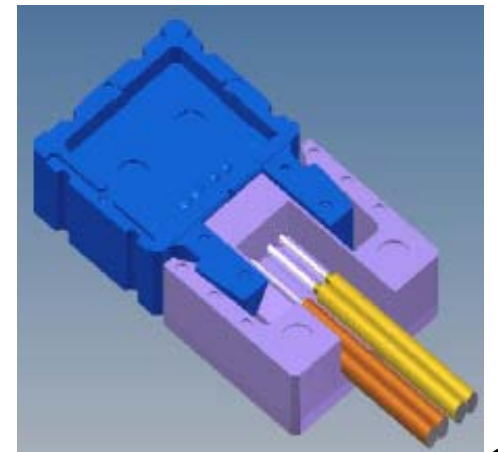
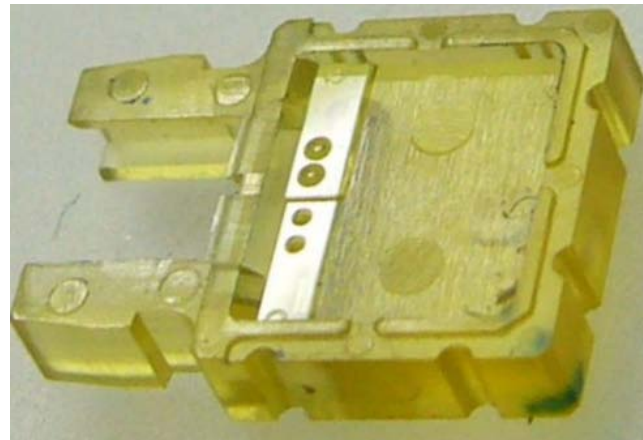
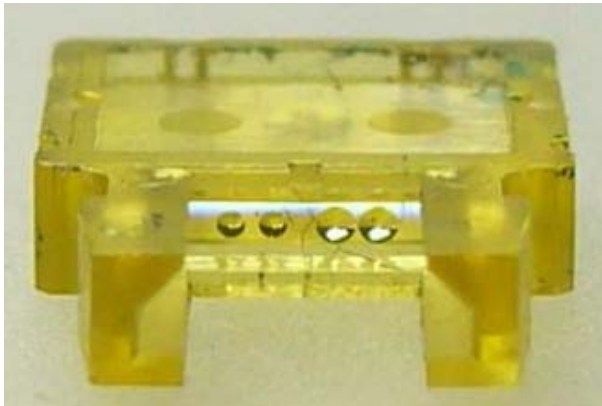
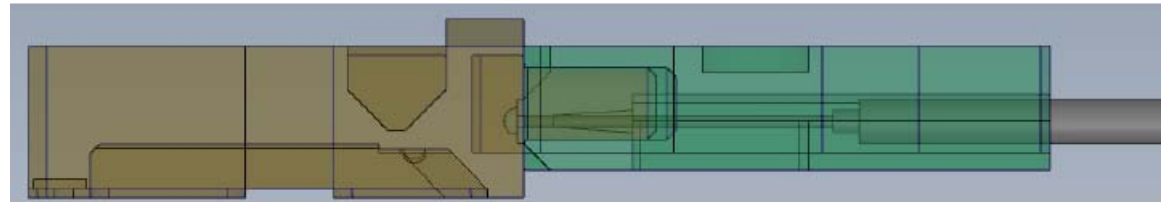
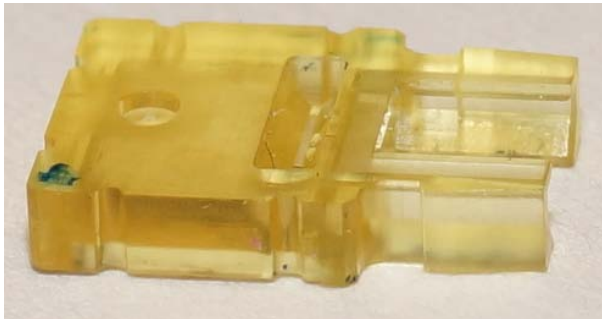
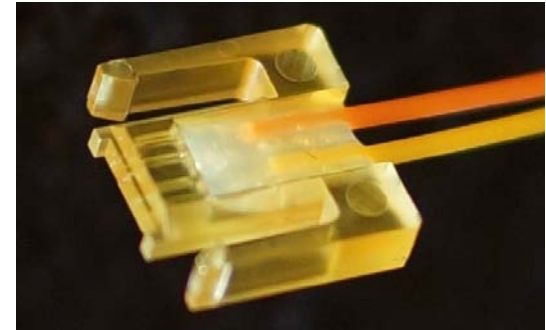
Spherical-aberration free
Plano-Convex
Hyperbolic Lens

VCSELs aperture
from t Ø 5 to 20 µm

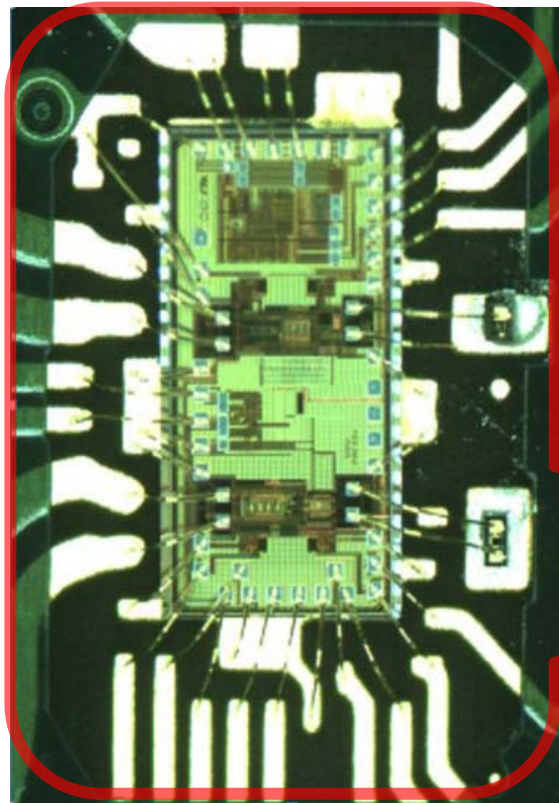
Light-coupling prism, the FOCI design

- **Lens** : diameter differs for VCSEL, PIN
- **Focus** : step adjusted for VCSEL, PIN surface
2-in, 2-out, LightPeak spec

Lens, light coupling alignment required for $5\ \mu\text{m}$



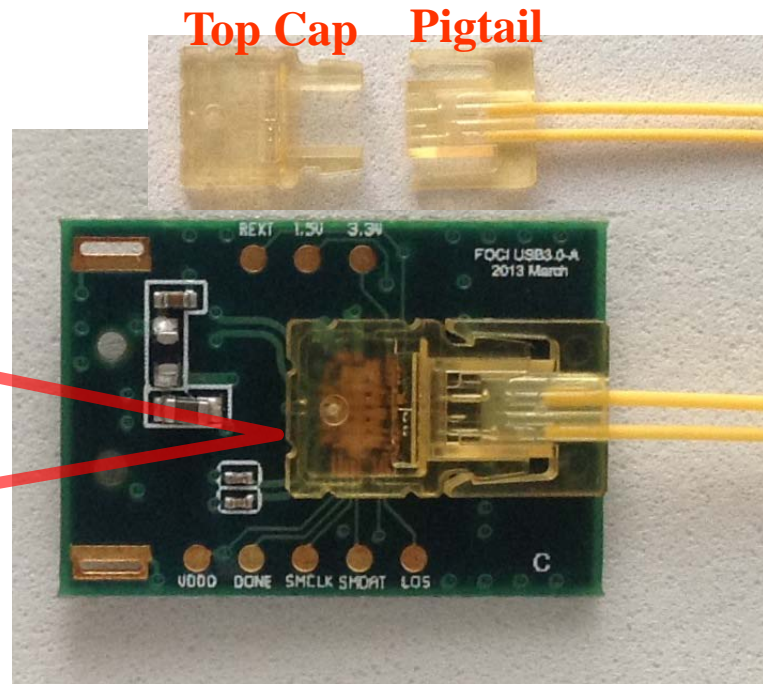
Optical driver, USB3 5 Gbps



TSMC 90nm process

PIN

VCSEL



Optical IC

VIA Labs USB 3.0 Active Optical Cable Solution Demonstrated at CES 2012
Collaboratively developed with FOCI, PCL, OpTarget and UMEC, the VIA Labs V0510 optical transceiver extends the reach of USB 3.0 to over 100 meters

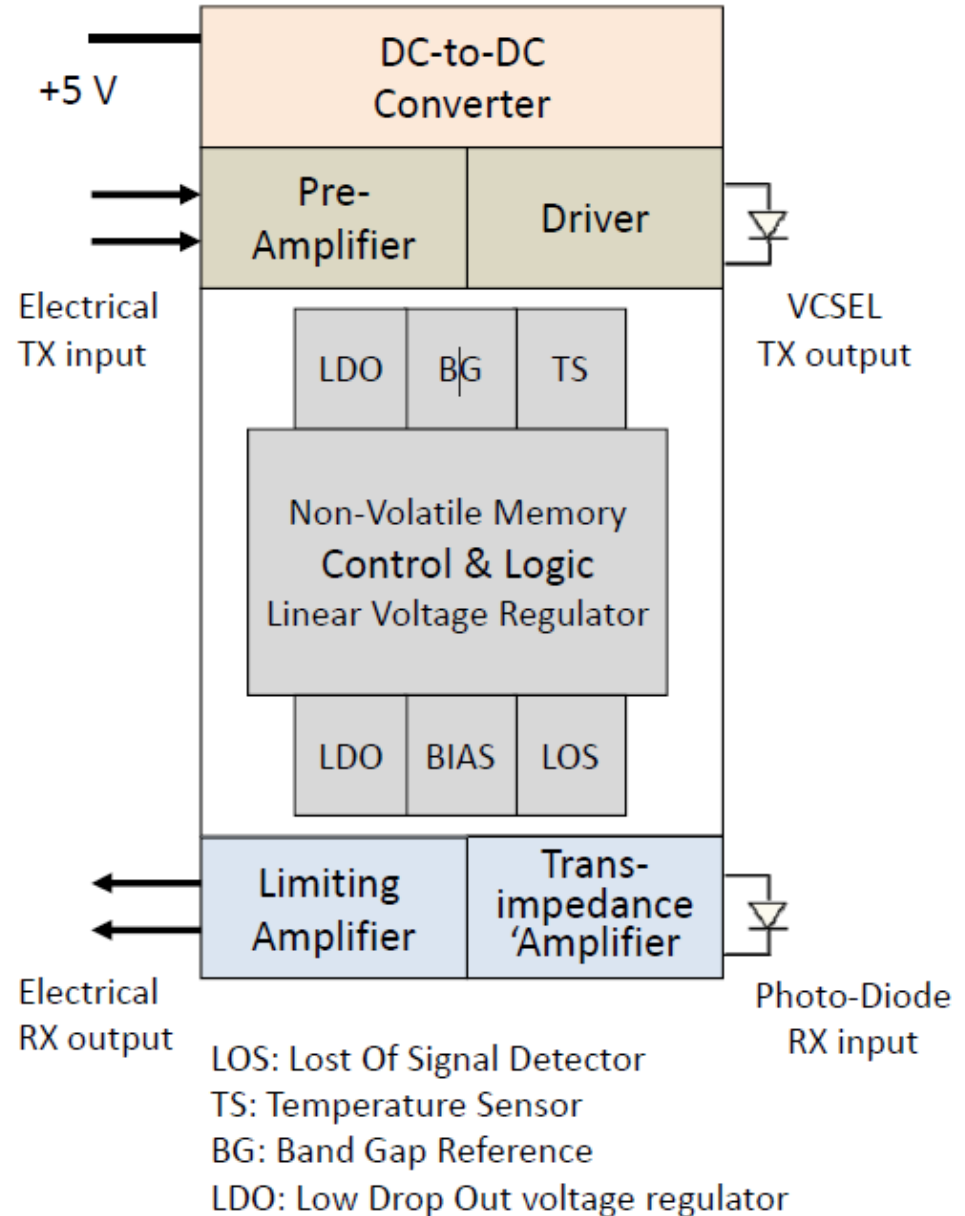
FOCI optical engine functional diagram

VCSEL/PIN:

- 850 nm bare die,
- 4.8 Gb/s or 10 Gb/s
- >0 dBm (1mW)

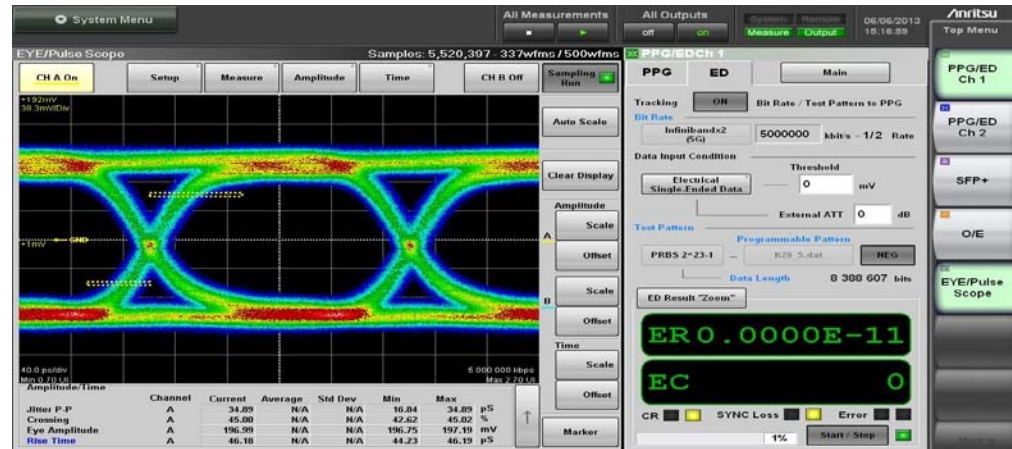
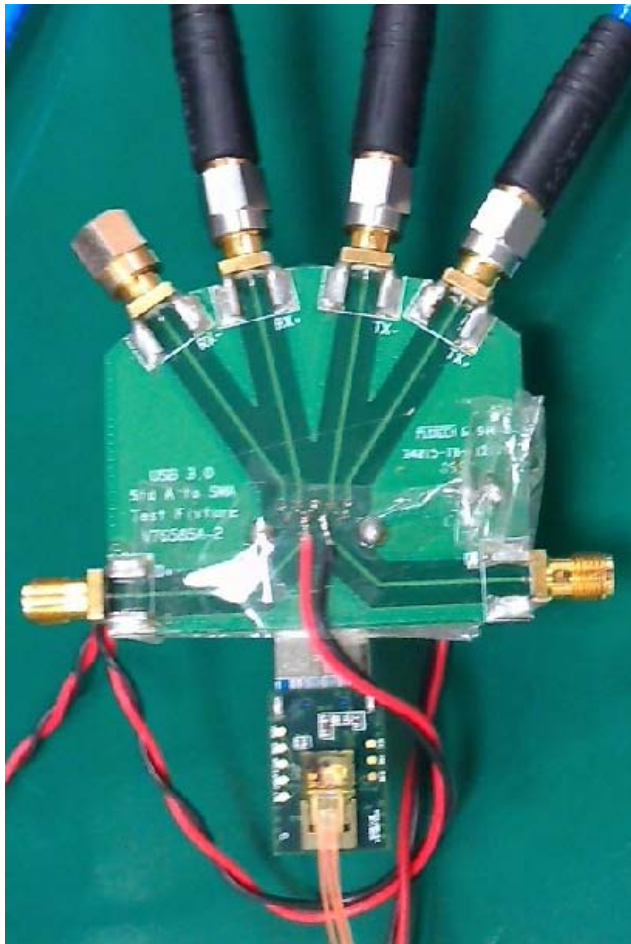
Optical IC:

- VIA Labs V0510,
- TSMC 90nm technology
- USB-3 protocol, ~60 mW,
- 4.8 Gb/s TX/RX driver + regulator/controller

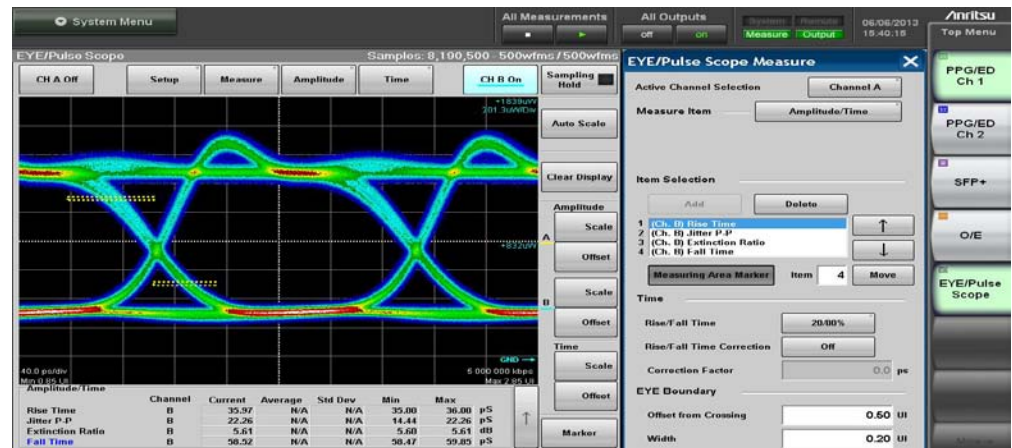


Bit Error Rate test

RX – Jitter P-P 34.89 ps, Crossing 45 %, Eye Amplitude 197 mV, Rise Time 46.18 ps



TX – Rise Time 35.97 pS, Jitter P-P 22.26 ps
Extinction Ratio 5.61, Fall Time 58.52 ps



Rad-hard of Prism Receptacle

- **Prism Receptacle**

Spherical-aberration free Plano-Convex Hyperbolic Lens

Material: **PEI** (polyetherimide)

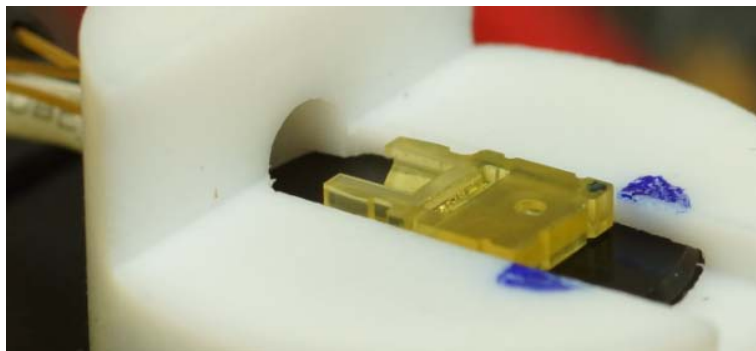
- **Co⁶⁰ Ionizing at INER**

flux: 3.5 kGy/hr, total: **117 kGy**

→ **NO LOSS !!**

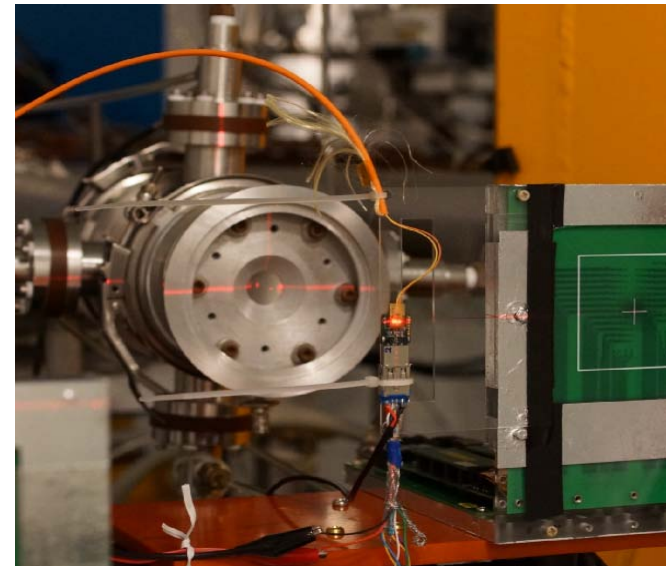
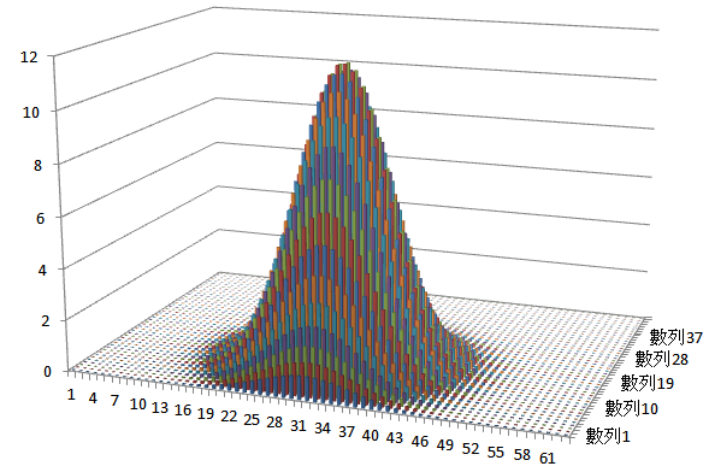
for light transmission

within the 2% systematic error



INER 30 MeV proton to FOCI engine

- **30 MeV Proton at INER**
direct beam, beam current $>1\text{nA}$
- **Beam profile**
1 mm pitch strip and pad chambers
flux: 3.5×10^{10} p/cm²s
total 1.2×10^{14} , about 1hr
equivalent to 8.9×10^{14} n(1MeV)/cm²s
- **FOCI engine**
light degradation
DC biased, for mid-level light
online light power
 - VCSEL light degradation
 - Optical IC function



NIEL to FOCI engine, 30 MeV proton

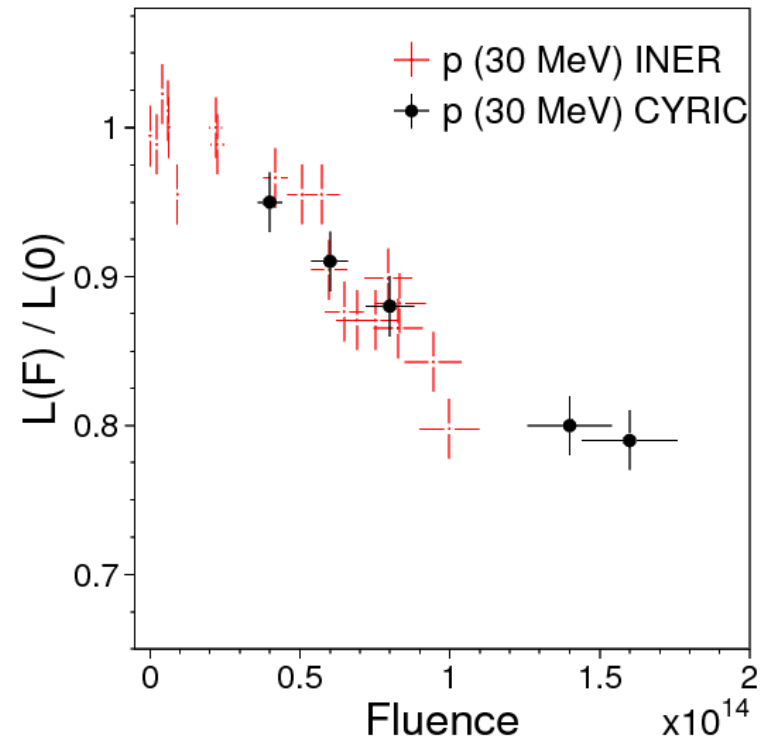
- VCSEL degradation

- VO510 DC biased, (1.5 V to TX driver)
- Annealing during irradiation
- Linear loss to fluence

➔ VCSEL degraded to **80%** of the original after 1×10^{14} p(30 MeV)/cm² consistent with bare VCSEL tests

- Single Event effect to Optical IC

- Single Event Effect = 3×10^{-3} Hz @ Beam flux = 3.5×10^9 /cm²s to controller circuits, observed by VCSEL DC light level hopping
- **Fatal to Optical IC** after 1.2×10^{14} p(30 MeV)/cm²



- VCSEL die at 10 mA (Truelight)
- + VCSEL in FOCI, TX DC biased

LANSCCE neutrons, X-ray to FOCI engine (SMU)

- BER test at LANSCE

- Neutrons at LANSCE
flux: 2.9×10^5 n/cm²s
total fluence **3.8×10^{10} n/cm²** (1.5 days)

- Stratix II FPGA 5 Gbps

→ TX: no SEU, SEFI during test

→ RX: 11 SEU (1bit), no SEFI

Error cross section:

2.7×10^{11} /cm² (0 error)

2.9×10^{10} /cm² (11 error)

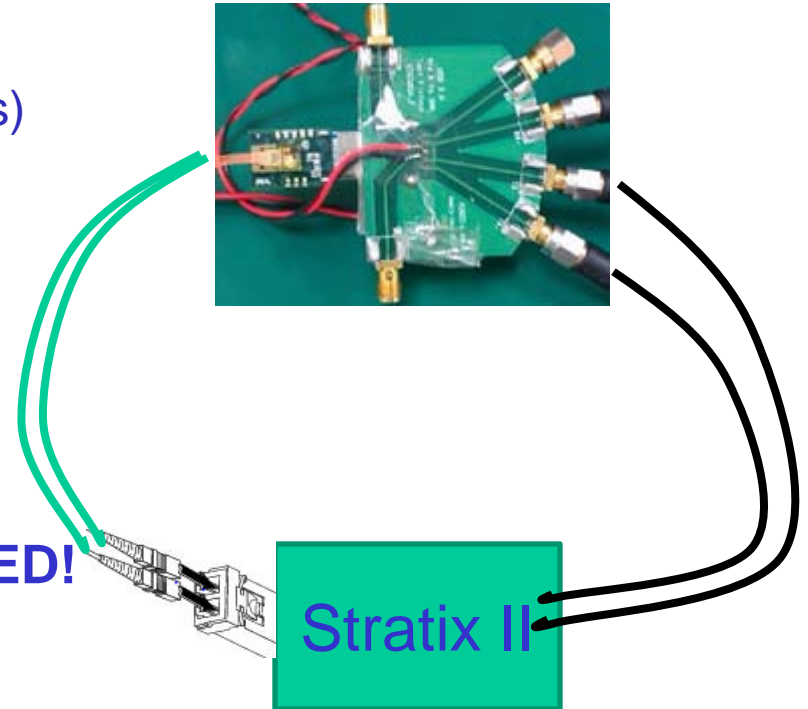
→ Power cycle, **IC initialization FAILED!**

- BER at SMU, X-ray

- 160 kV x-ray flux 167 Gy/hr
after 3.84 kGy (23 hr) → 14 bit errors

- Increase flux to 4.46 kGr/hr
total **210 kGy** (47 hr) → 5 bit errors

→ Power cycle, **IC initialization FAILED!**
DC converter checked, okay!

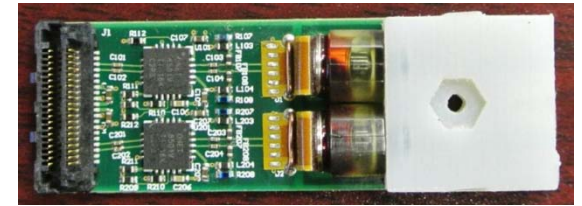


Could be the OTP?
non-volatile memory
fragile to
radiation induced charge

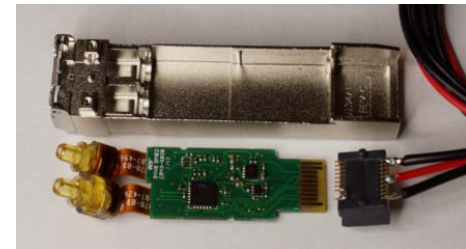
ON-going activity

- With SMU, proto-typing Phase-I modules
For ATLAS Phase-I trigger links, LAr, NSW
- With Lverage, on fabrication and QA
- Institute facility, QA and environment test setup

SMU MTx



Lverage 10 GB/s SFP+



Summary

- **Commercial development on Optical transceiver**

 - Lens/Prism** : compact light-coupling solution

 - Assembly** : Industrialized

 - ➔ fits the roadmap of VL+
the missing piece is the rad-hard driver

- **Activities and plan**

 - Prototyping Phase-I transmitter

 - Facilitate 10 Gb tests and Radhard at INER