Optical Wireless Communications for HEP

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Introduction

Motivations:

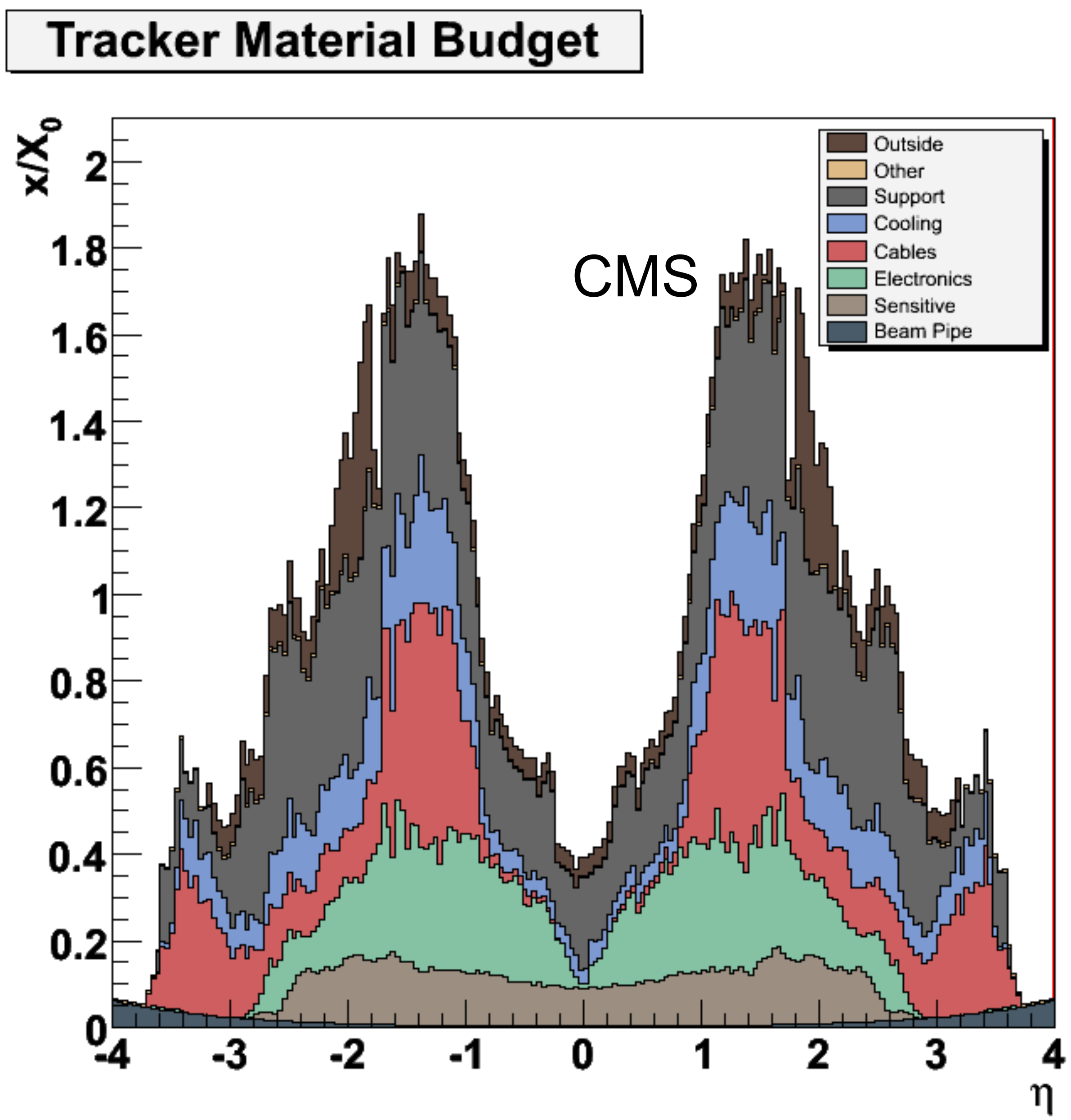
- Reduce the material budget
- Allow intermodule communication

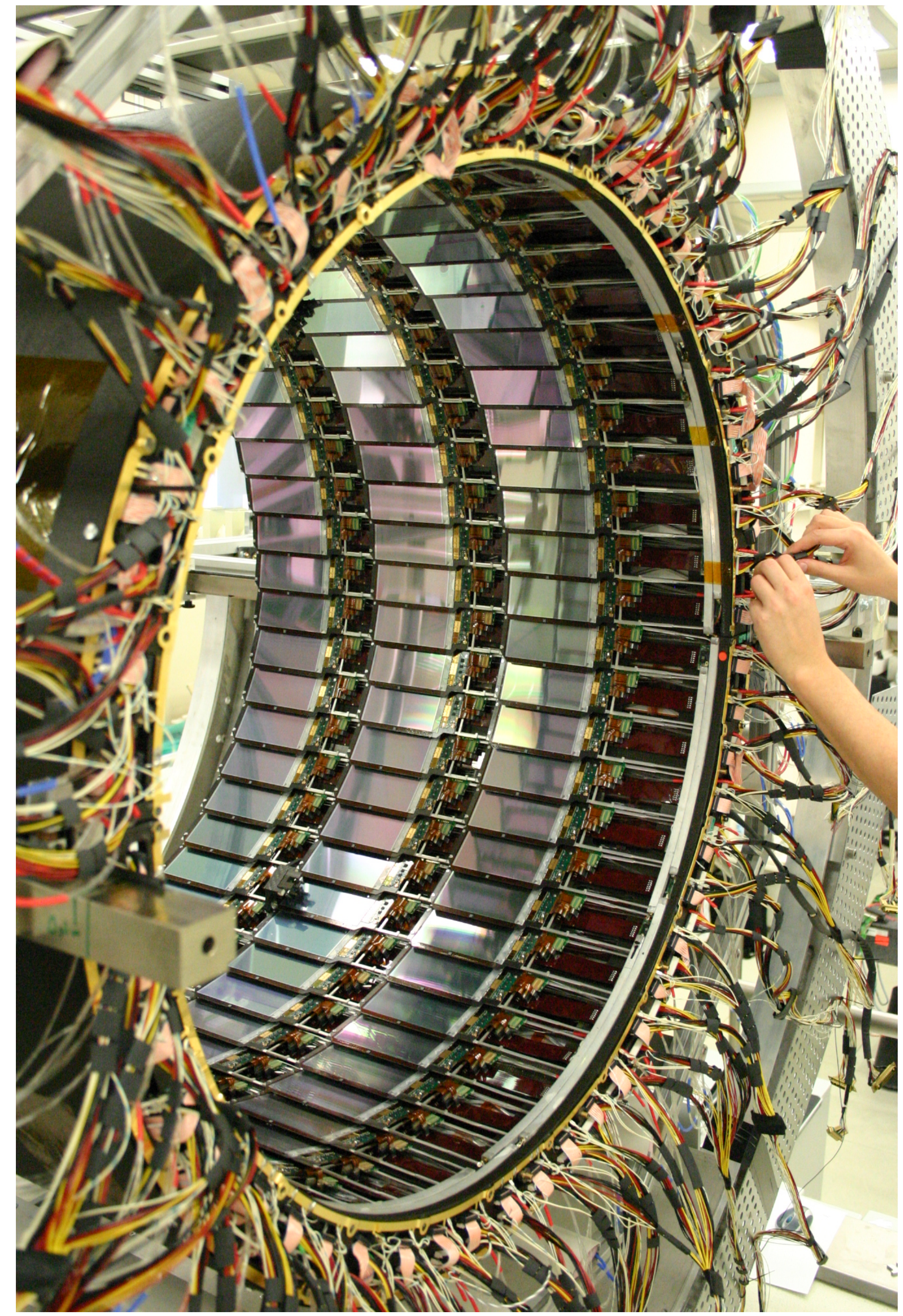
Requirements:

- Transmission distance: [5-15] cm
- Transmission bitrate: a few Gbit/s [2-10]
- Target bit error rate (BER): 10^{-12}
- Tolerance to misalignment O(<250 μm)
- Low latency
- Harsh radiation environment

A lighter Tracker

- **Light weight tracker**
- **Most of the material is coming from Services**





FCC-hh Tracker (much less than a problem for FCC-ee)

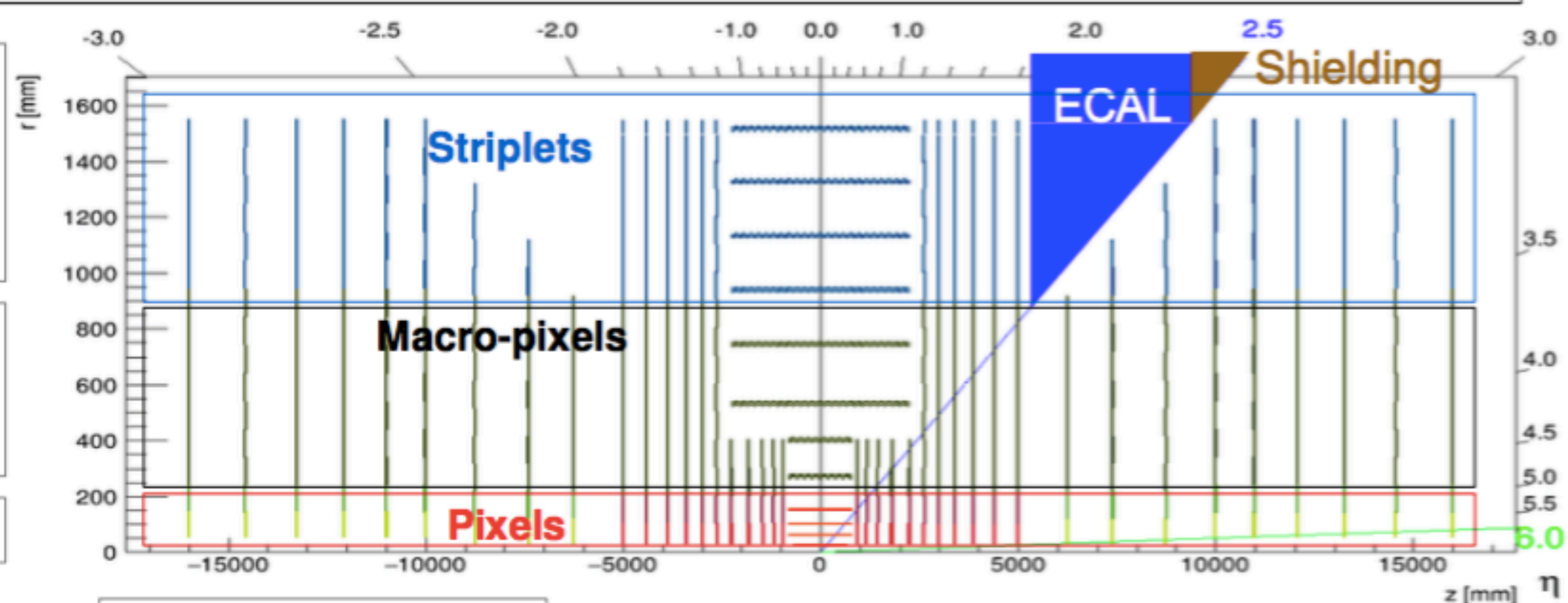
Zbyněk Drásal talk at FCC Workshop in Berlin 2017

Baseline Tracker Layout (v3.03)

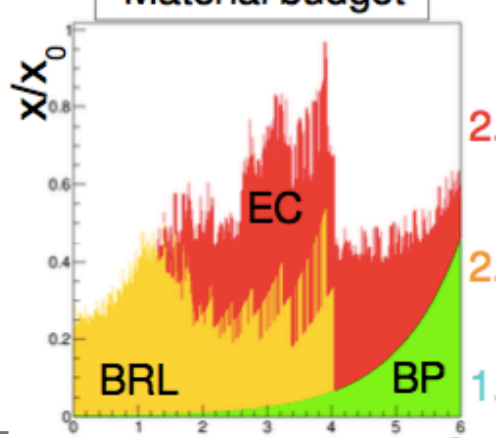
Surface: ~430m^2
#Channels: **489.4M**
9964.4M
5460.9M

Pixel R ↗0.9 (0.6) m due to occupancy (6T → 4T)

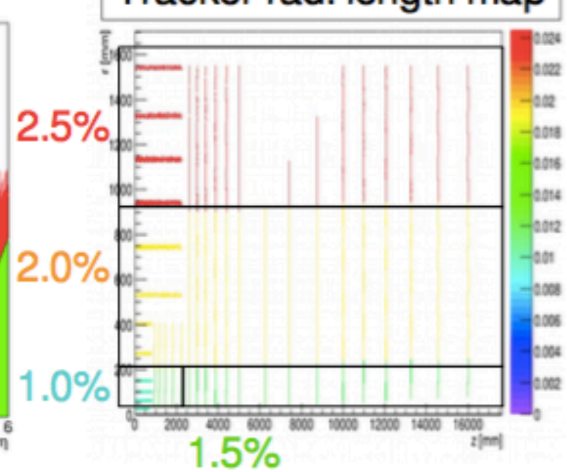
4 (seed) BRL layers



Material budget

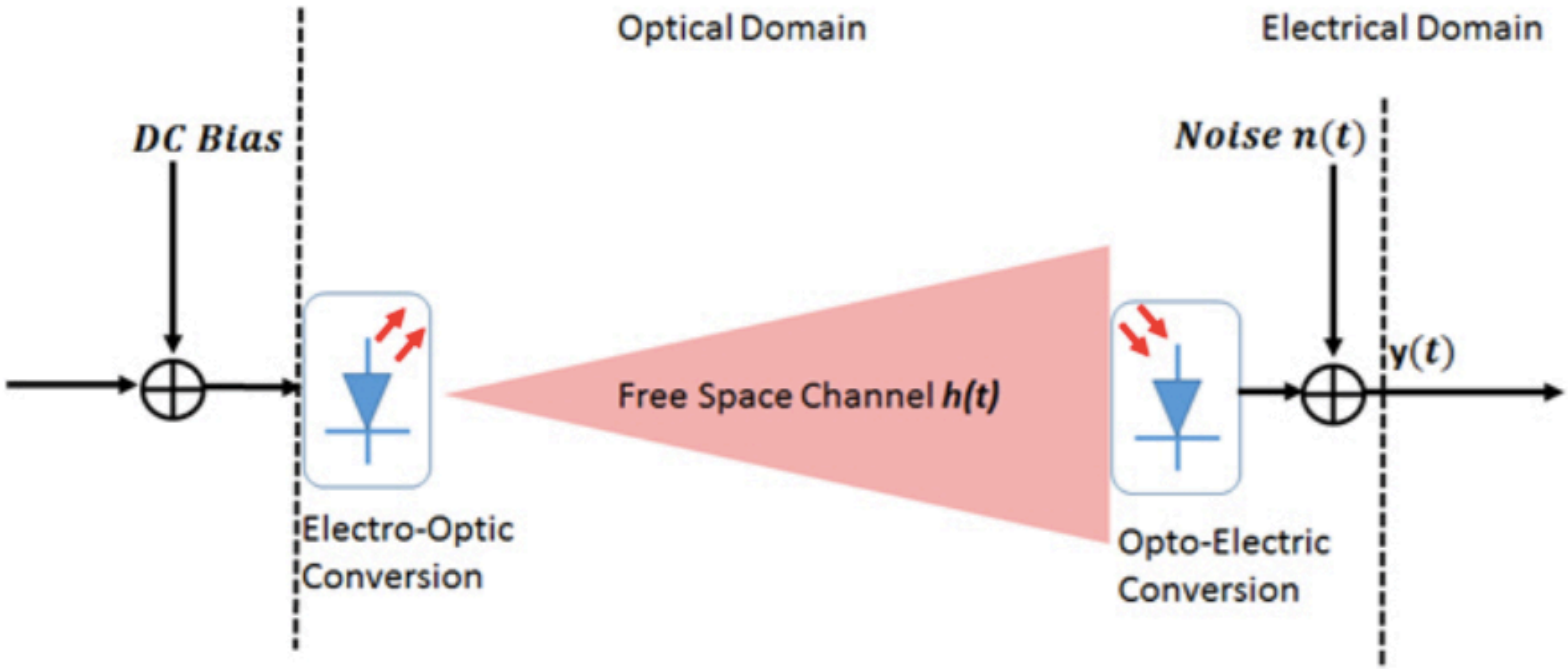


Tracker rad. length map



Pixels : 25x50um^2 (1-4th BRL layers, EC R1), 100/3x100um^2 (R2), 100/3x400um^2 (R3,R4)
Macro-pixels: 100/3x400um^2
Strips : 100/3umx50mm (BRL), 100/3umx10mm (EC)

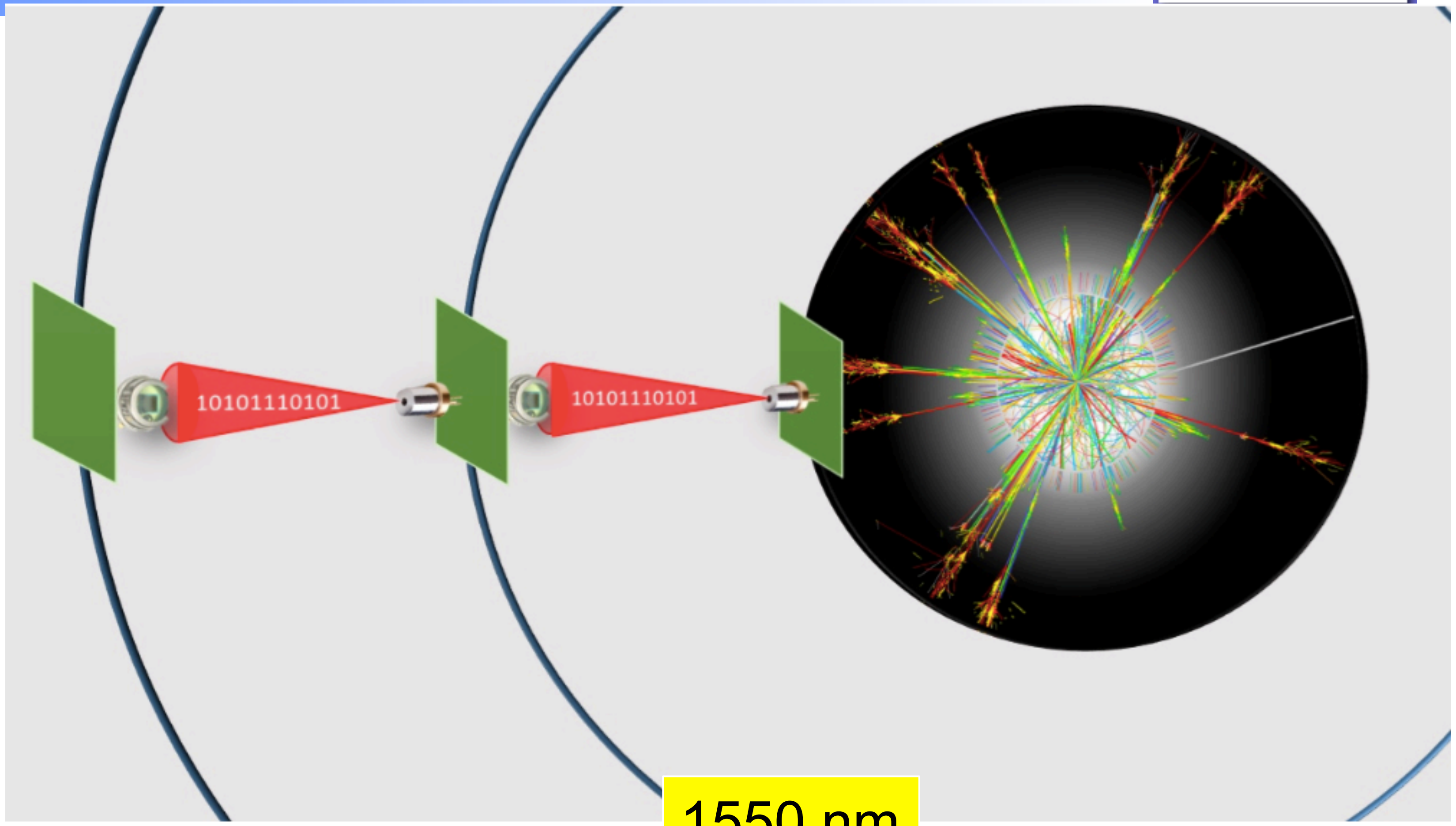
Principle of operation



Light source

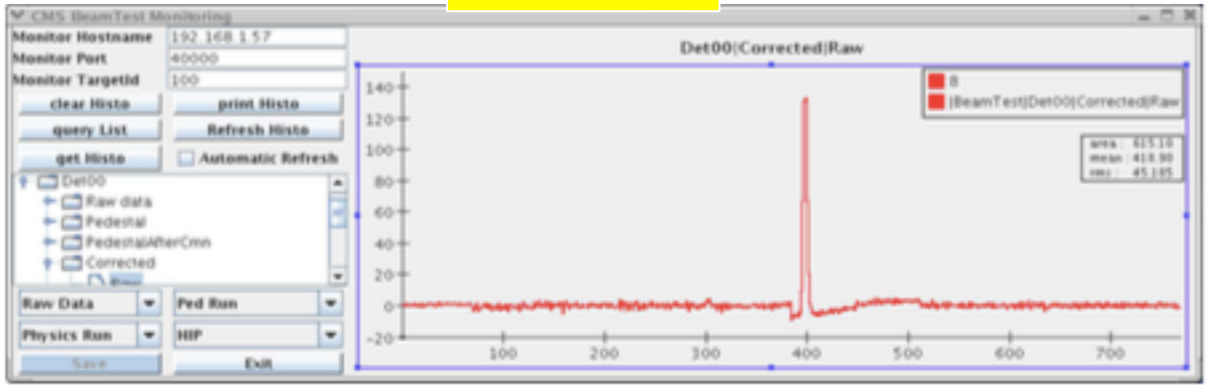
PIN diode receiver

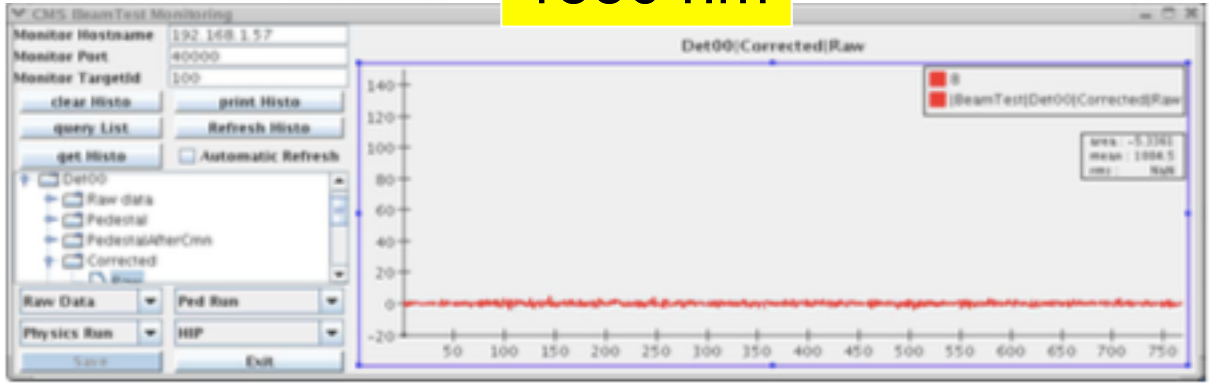
Intra-module connectivity



1060nm

1550 nm

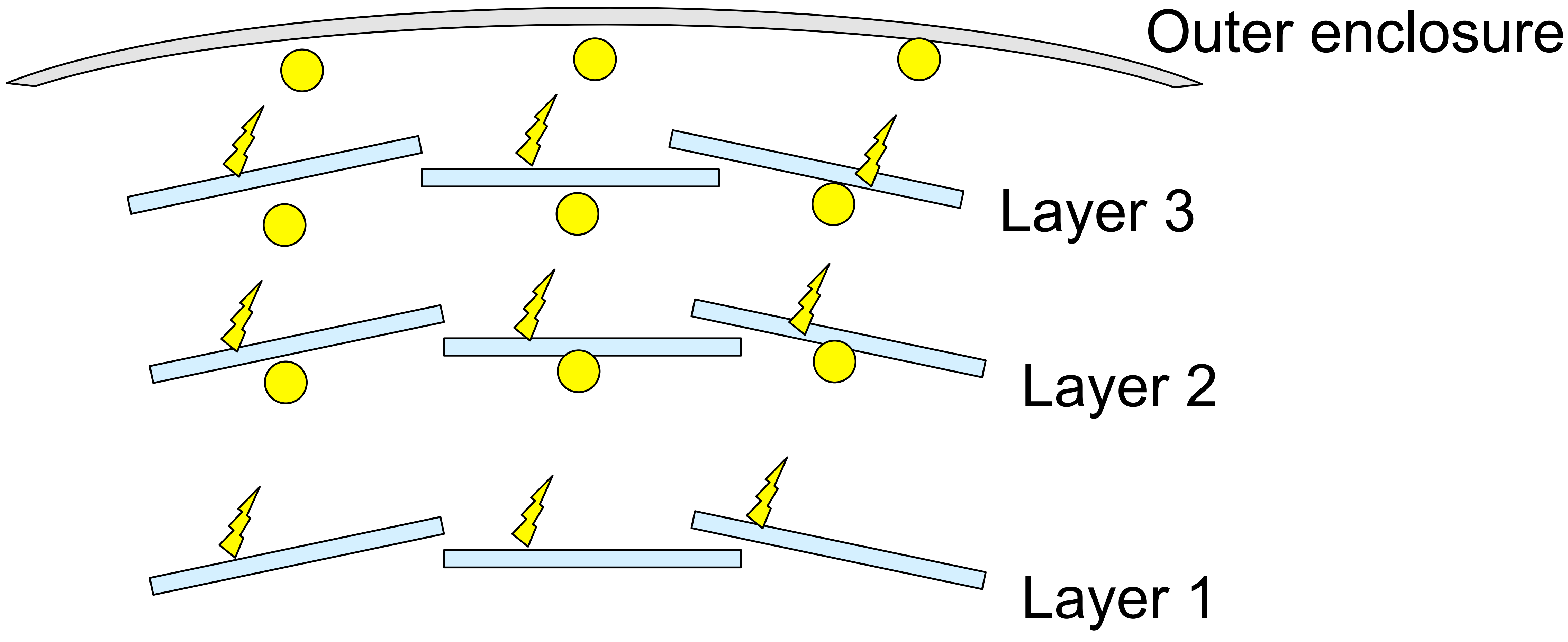




CMS Module irradiated with two different laser wavelengths

1550 nm wavelength is transparent to Silicon

Simple architecture

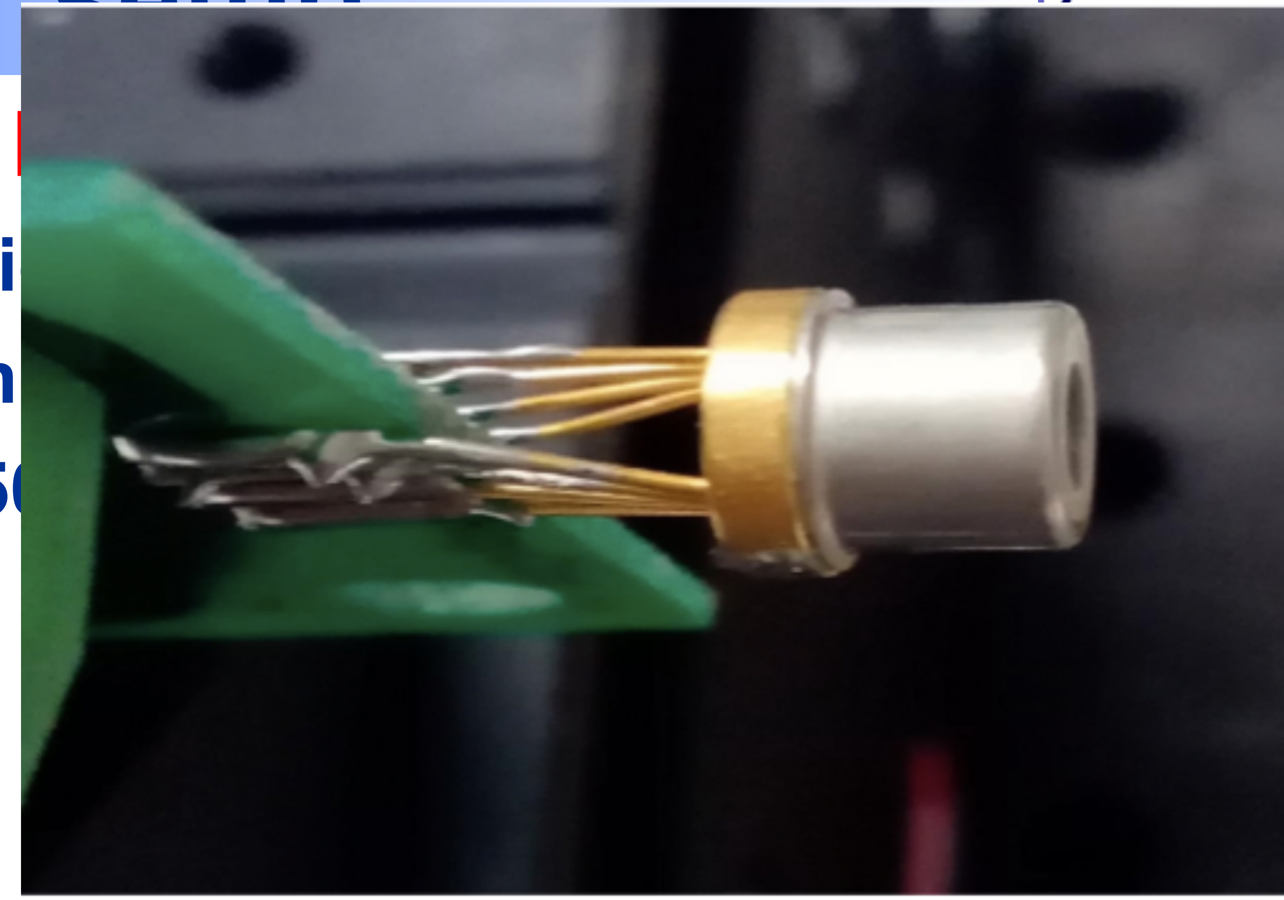


Can transfer information between modules without interference, since beam waist can be reduced using collimators at the VCSEL

OWC for HEP – Experimental setup

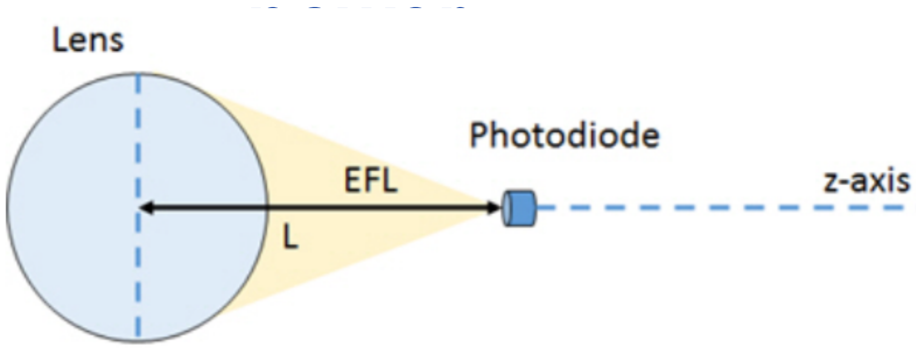
Tx: Vertical Cavity Surface

- Relatively high output opti
- Medium divergence full an
- Emission wavelength: 155
  material)
- Beam waist 10 μm

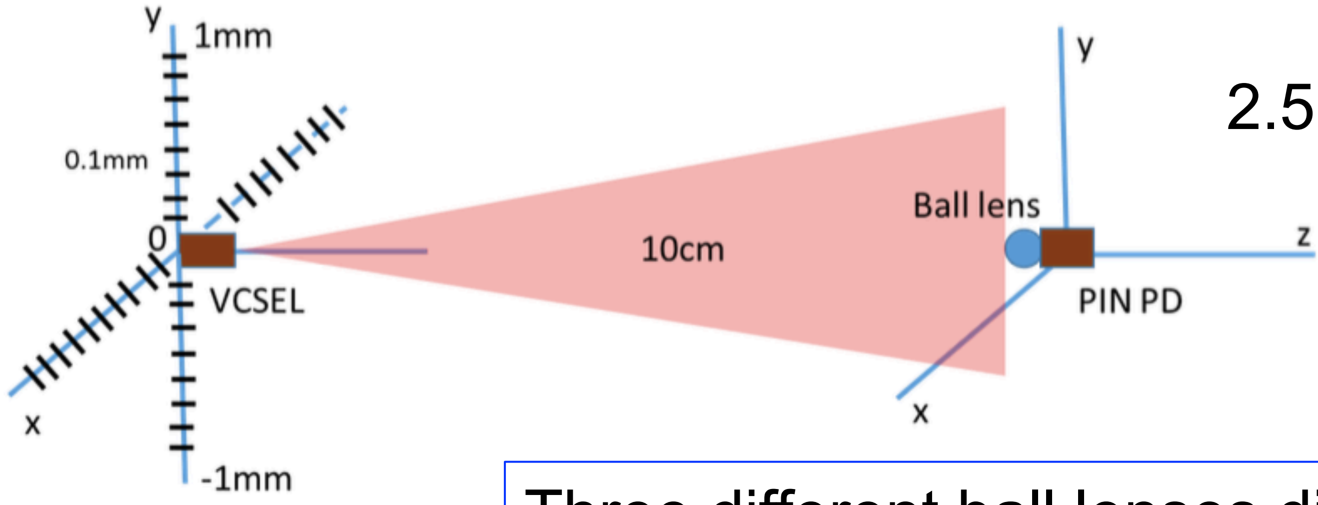


Rx: PIN Photodiode

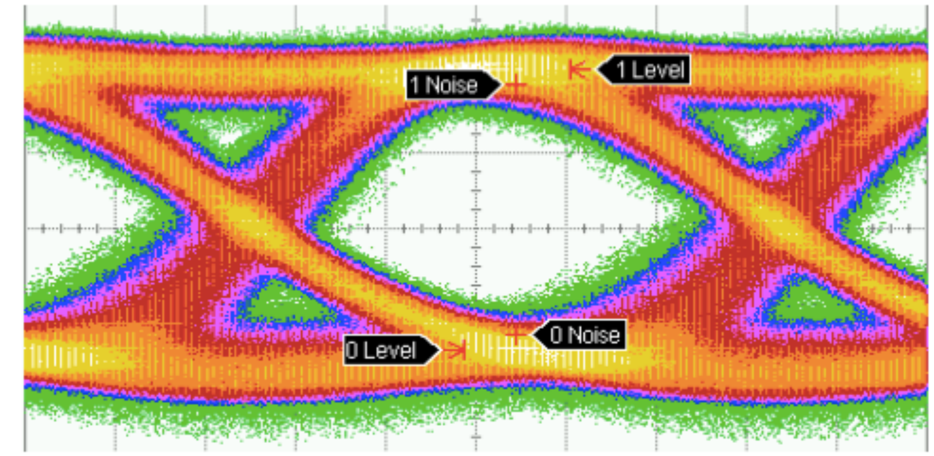
- Active area: 60 μm diameter
- Ball lens to increase receive



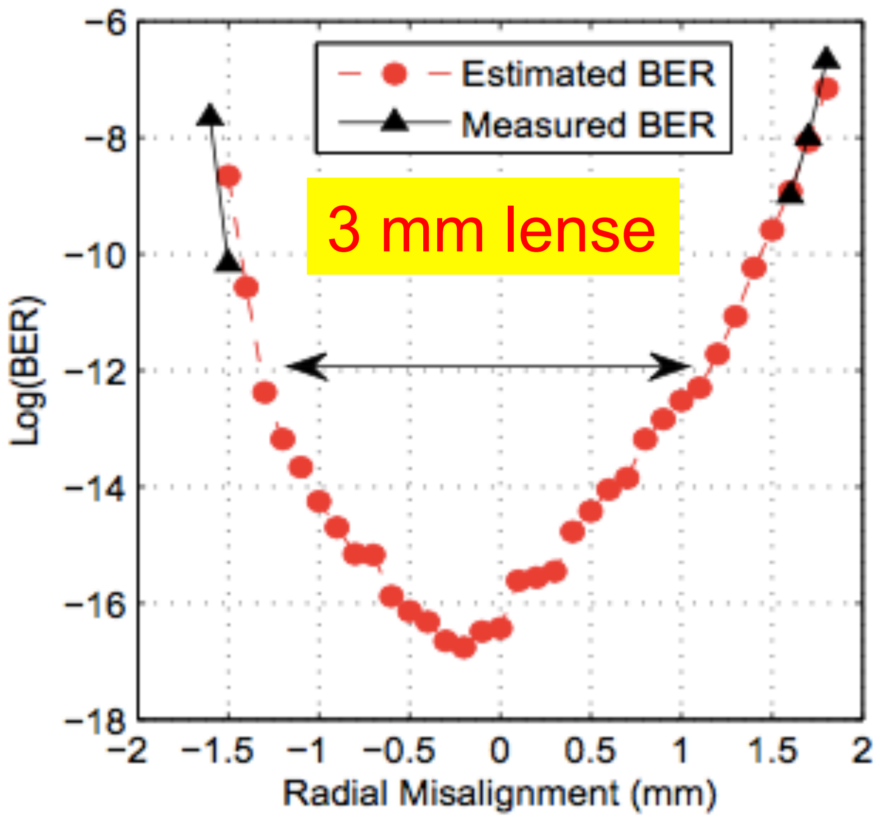
System characterization

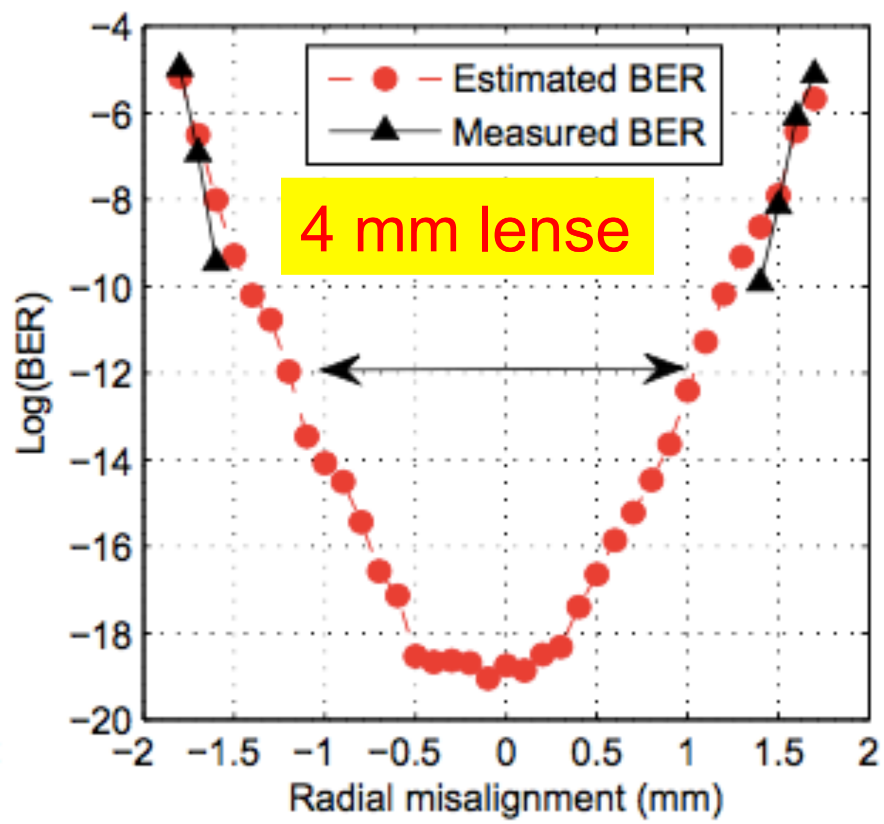


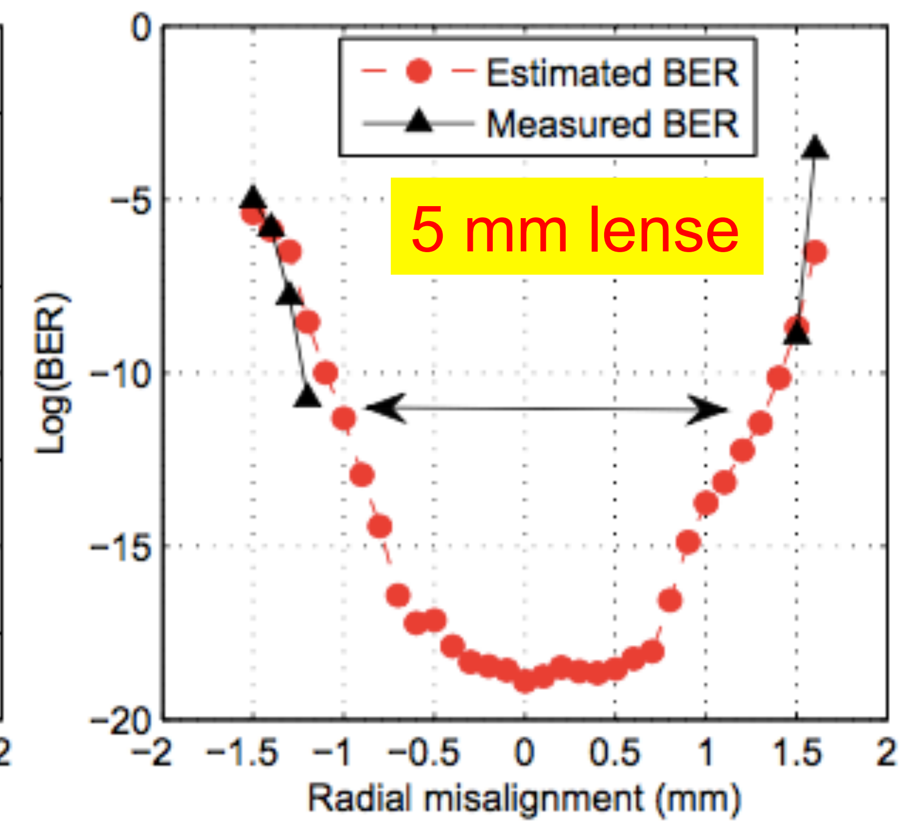
2.5 Gb/s



Three different ball lenses diameters
Radial misalignment tolerance limit (10^{-12} BER) is ~1 mm

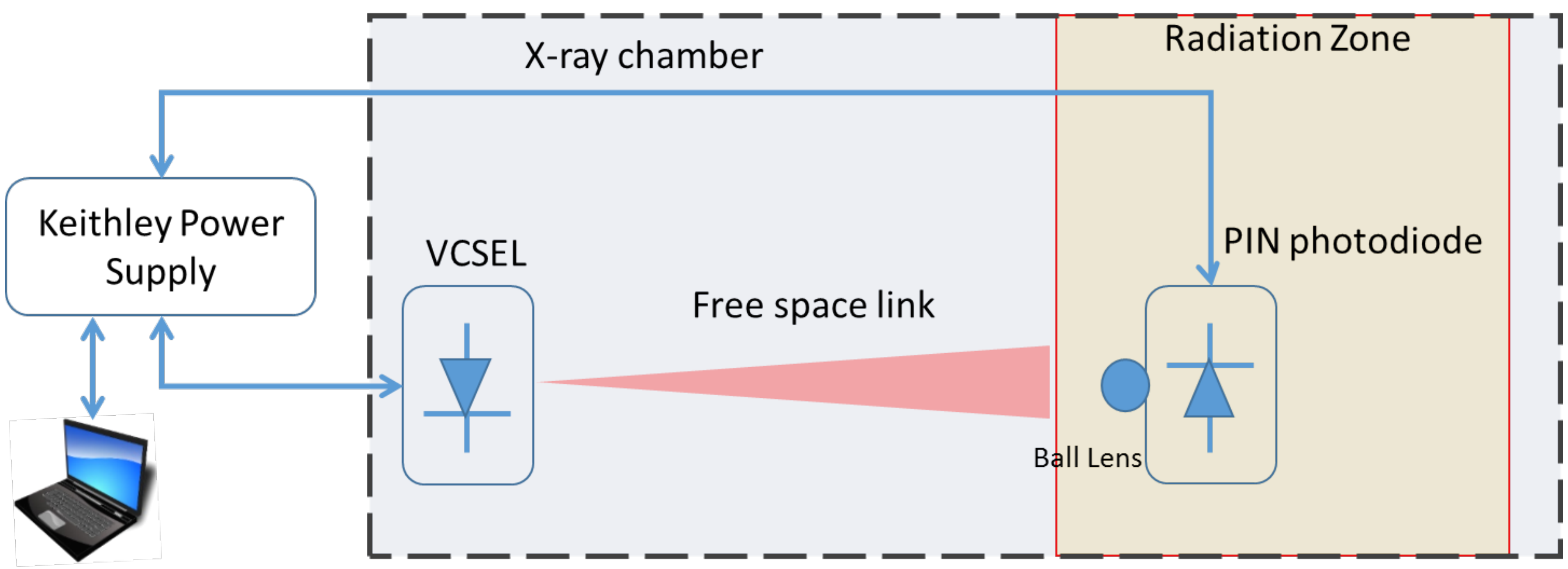


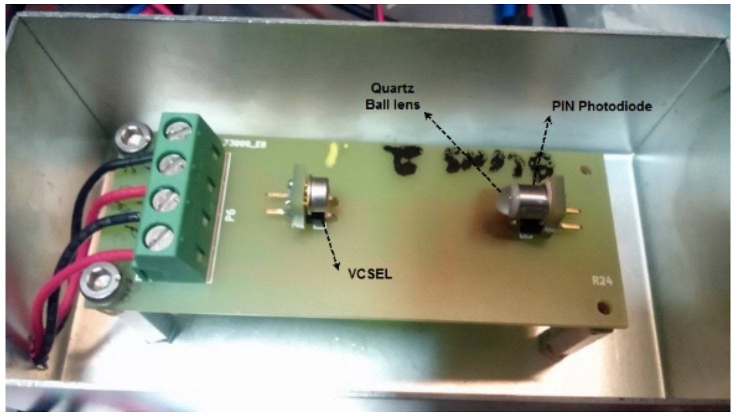




X ray irradiation tests in Padova

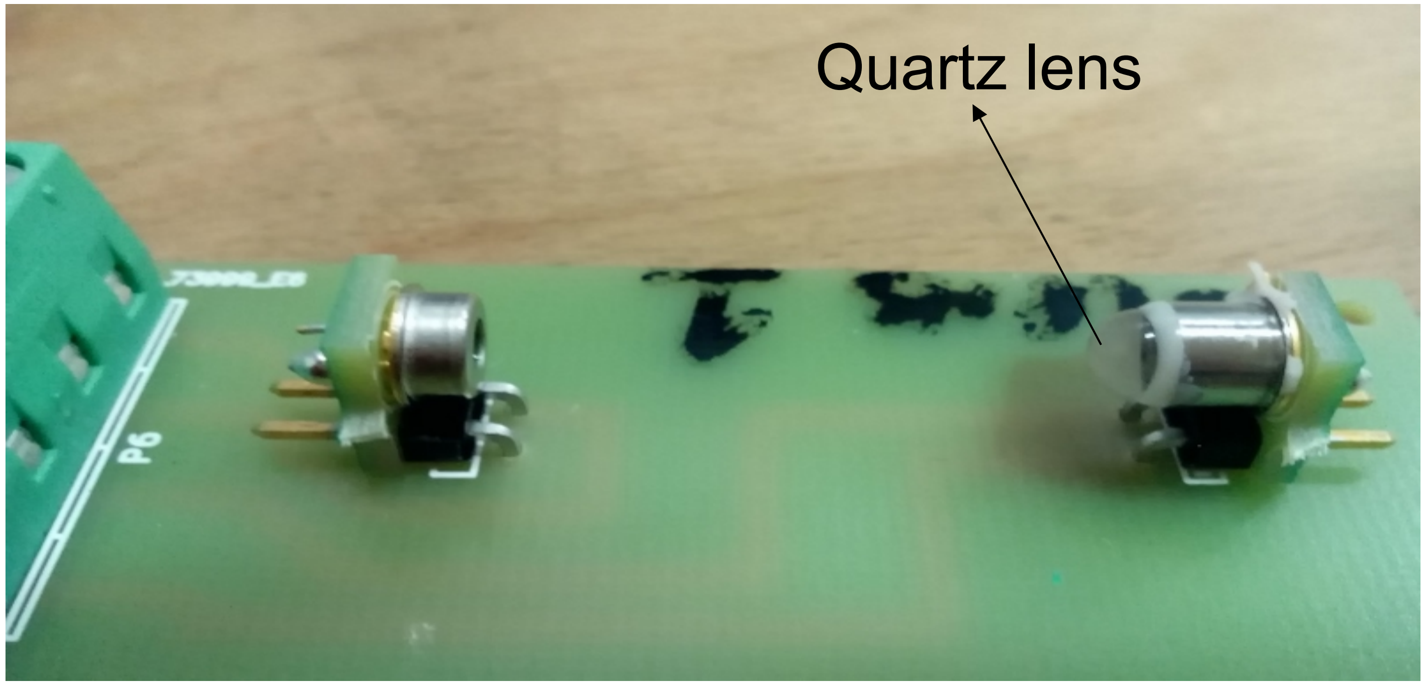
- The board with optical components were placed in a box inside X-ray chamber.
- The device to be tested was placed under the radiation beam while other components were properly shielded.
- Dose rate: 10.8 Mrad/hour
- Bias current and forward voltage of VCSEL, dark/received current of photodiode were recorded using Keithley power supply every 15 minutes





Quartz Lens Test (1)

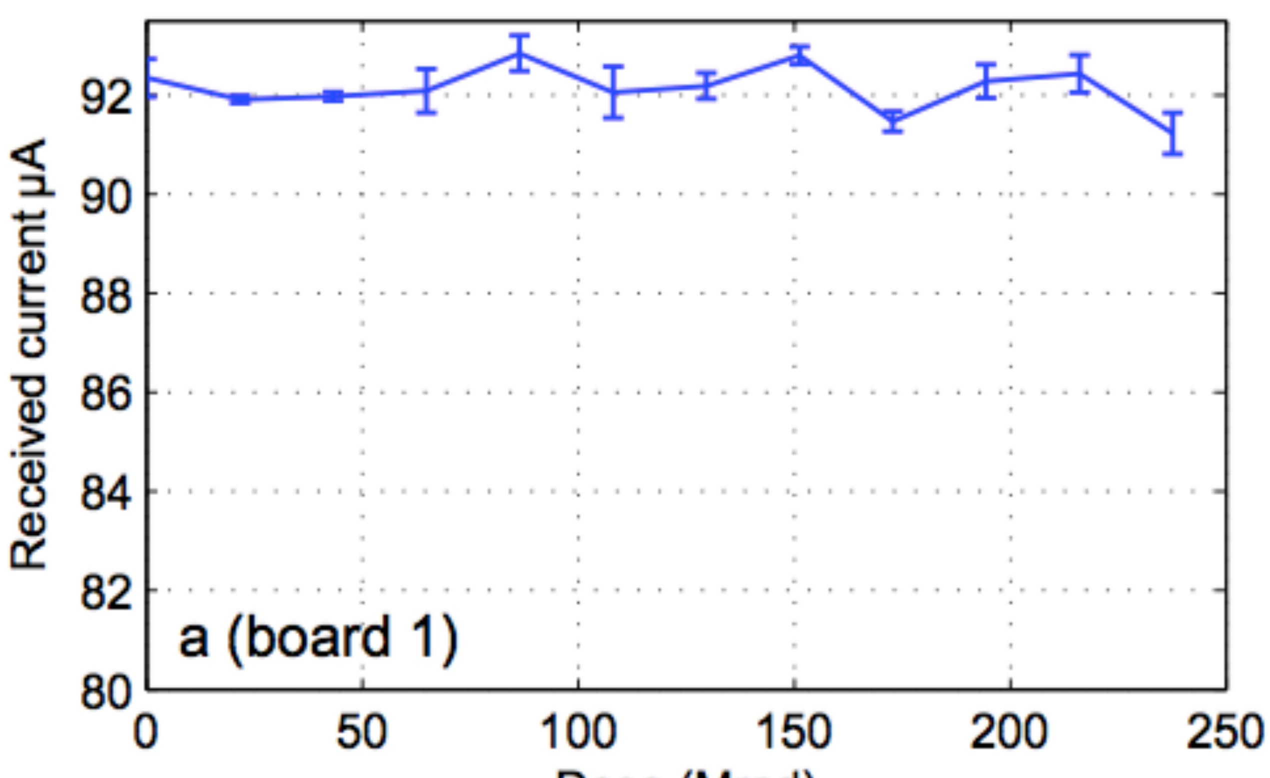
- A quartz ball lens packaged with PIN photodiode was irradiated up till 135 Mrad of dose (SiO_2).
- Irradiation effect on ball lens was observed by measuring the received current at the PIN photodiode.
- Below mentioned figure shows the irradiated quartz lens packaged with PIN photodiode.
- No darkening effect due to X-ray irradiations is observed on the lens.

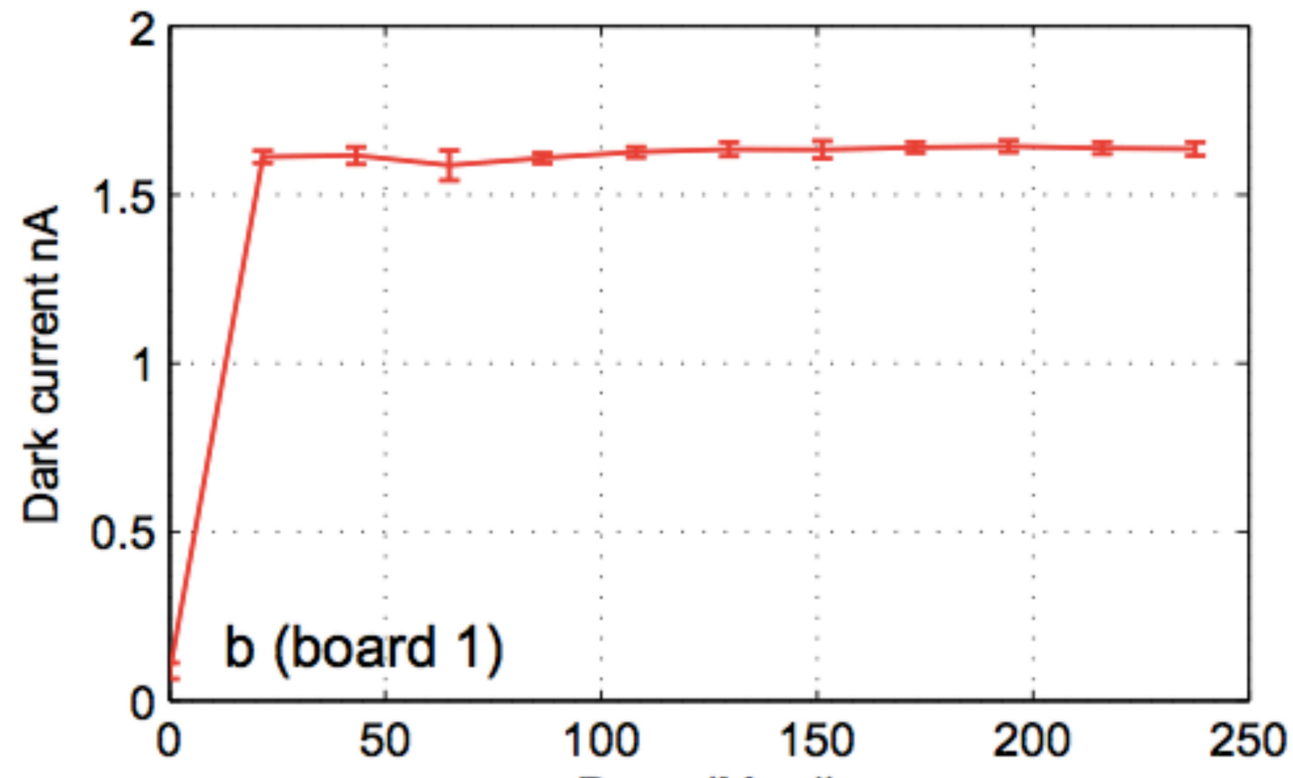


Quartz Lens Test (1)

- **Dark current is measured to analyze the behavior of photodiode during irradiation. Pre irradiation value (0 dose level) of dark current is lower than post irradiation because of X-rays effect.**
- **The stable values of received current illustrates that there is no change in the Quartz lens properties (refractive index or transmittance)**

Rx current at VCSEL I_{bias} of 7mA

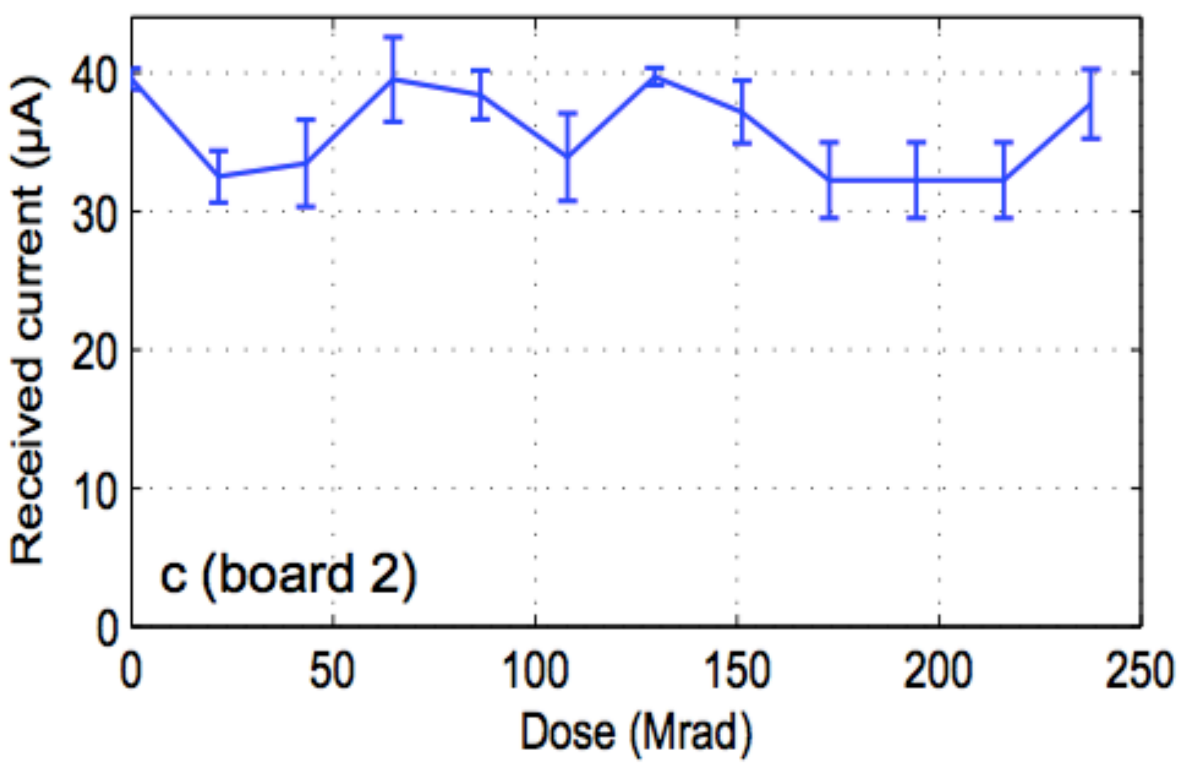


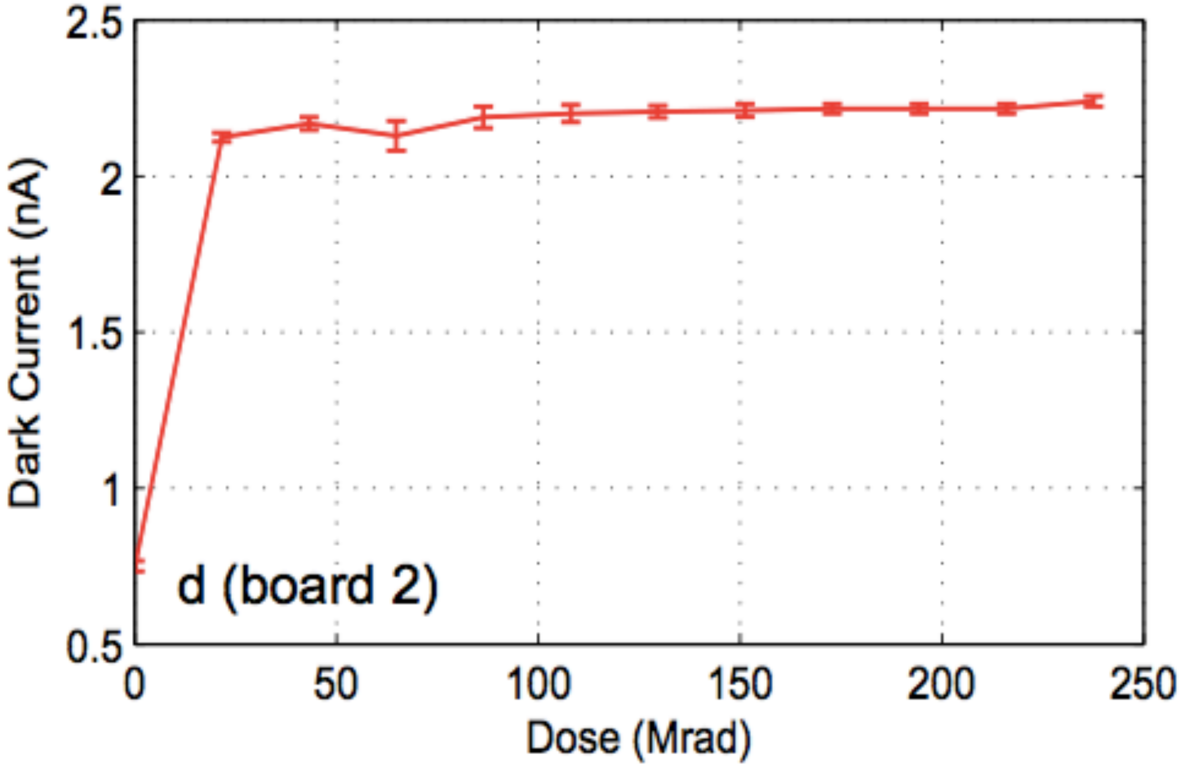


Quartz Lens Test (2)

- **No darkening is observed for 2nd quartz ball lens.**
- **The received current also remained approximately same throughout the experiment.**
- **Dark current also show flat behavior w.r.t dose levels.**

Rx current at VCSEL I_{bias} of 7mA

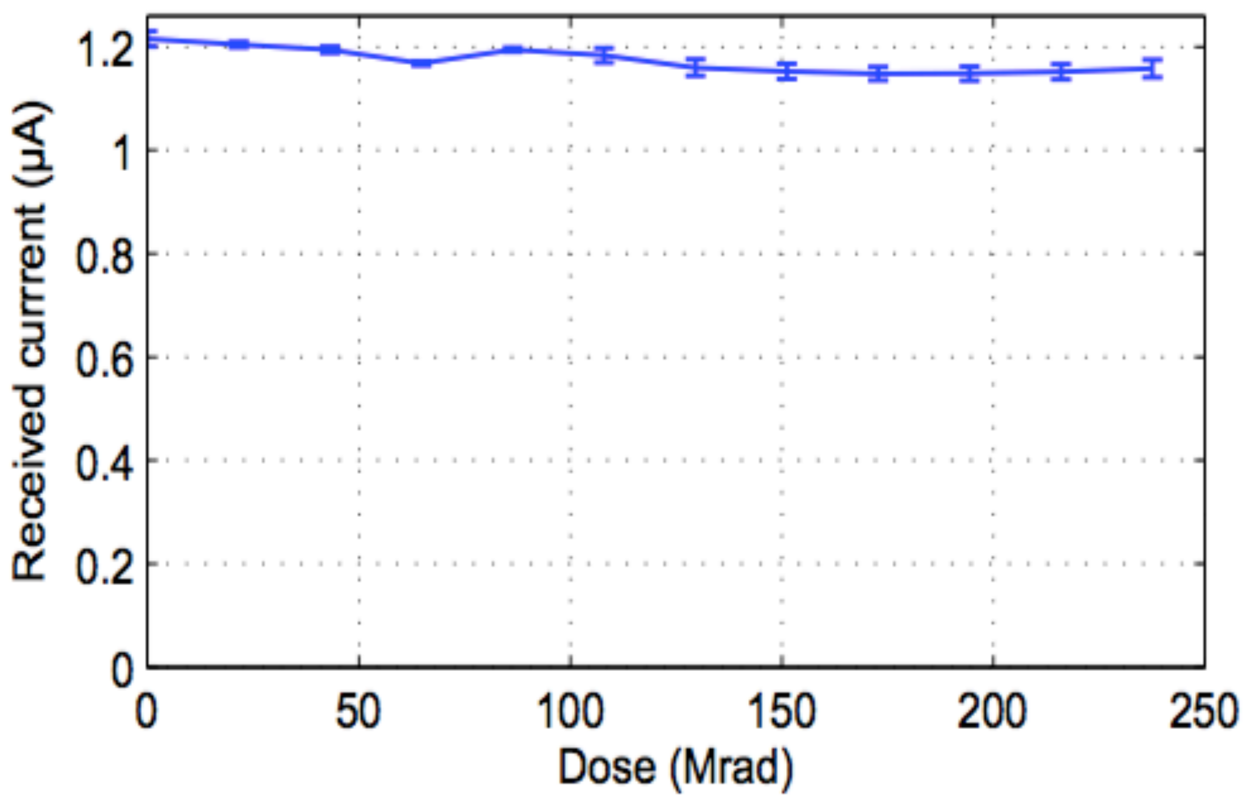


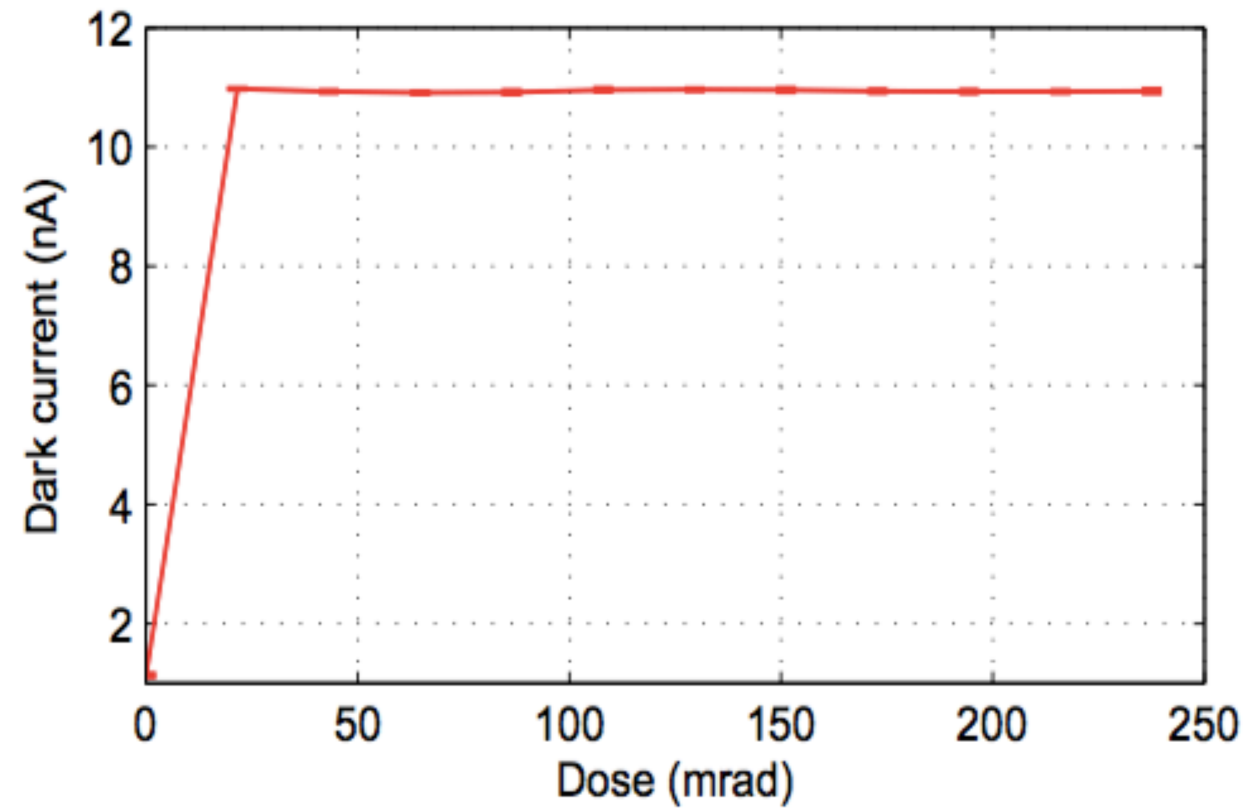


Photodiode test

- **Photodiode is tested independently.**
- **Same setup of VCSEL and photodiode on board was used.**
- **No change in dark current as well as received current was observed during irradiation as shown below.**

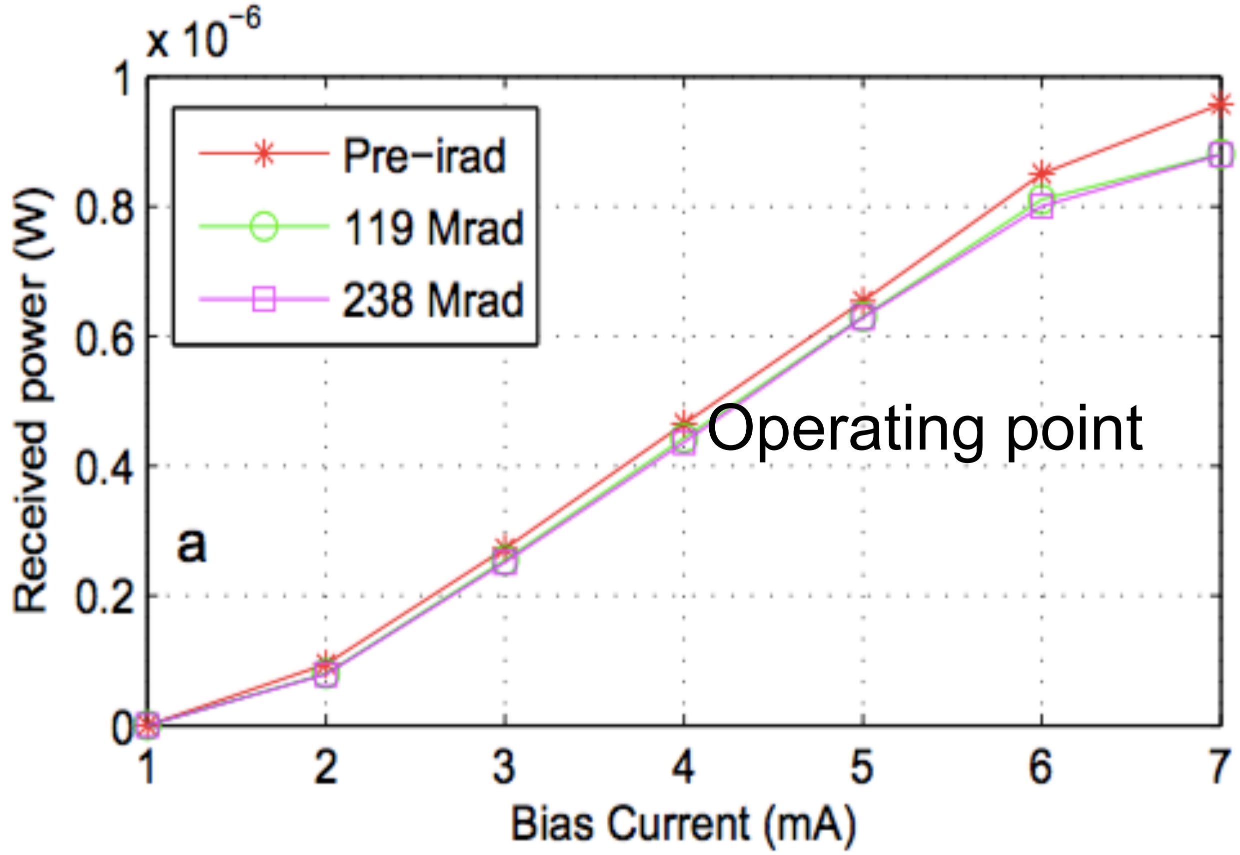
Rx current at VCSEL Ibias of 7mA

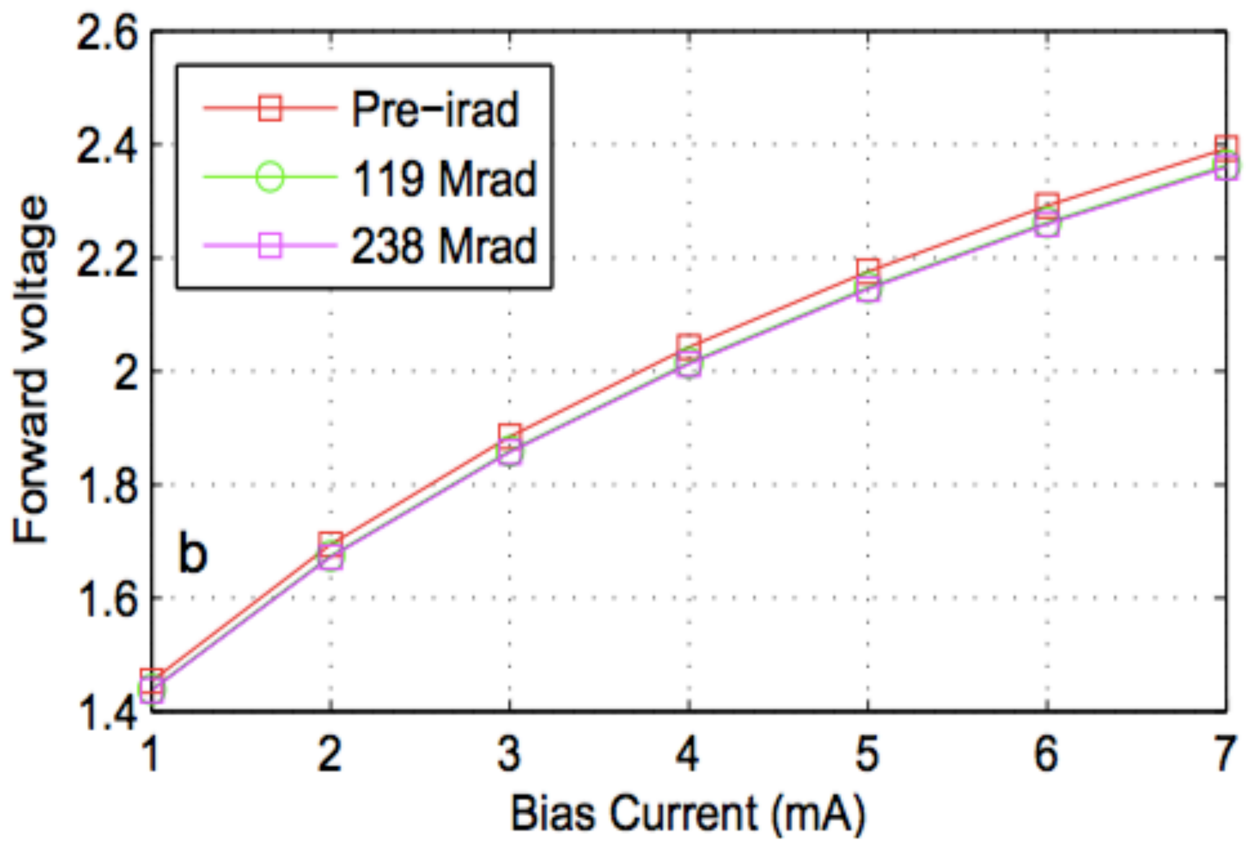




VCSEL test

- **It is evident that no change in L-I-V characteristics is observed during the irradiation process.**





Conclusion

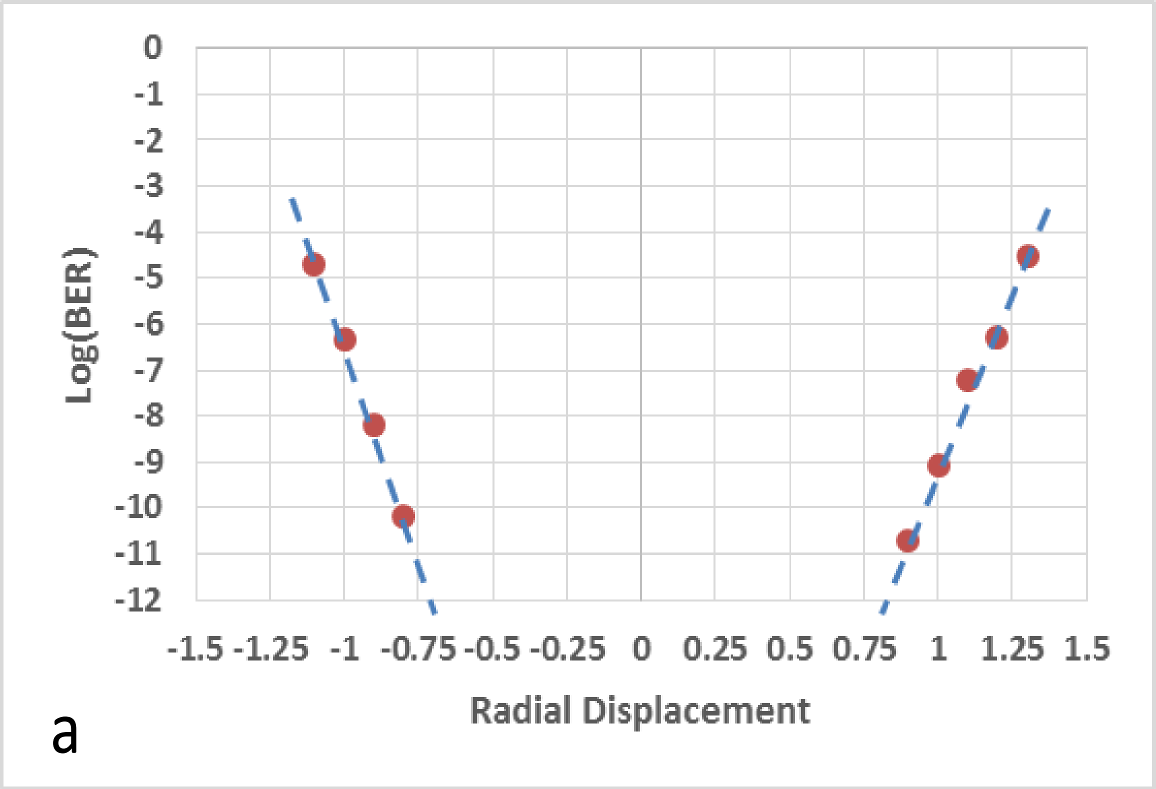
- We tested the quartz ball lens as well as PIN photodiode and VCSEL under X rays with 238Mrad dose
- No change in quartz ball lens properties was observed: lens can be used in optical wireless communication link designed for HEP particle detectors.
- PIN photodiode and VCSEL also showed no degradation under X rays.

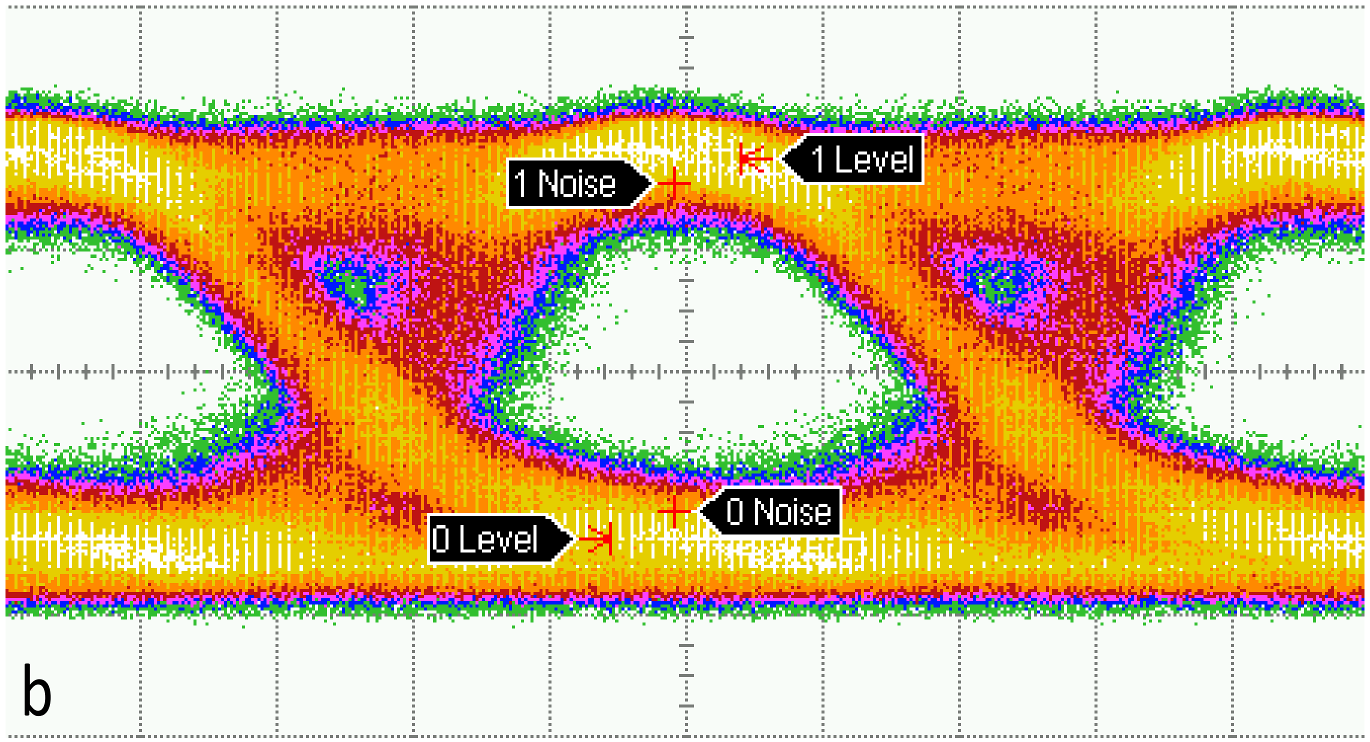
Next activities – bid in CSN5

- **Radiation hardness qualification**
  - TID (up to 10 MGy (1Grad)) and neutrons up to fluences of several 10^{16} cm^{-2}.
- **Selection and qualification of COTS components (VCSEL, PIN diode, ball lenses) and packaging material**
  - Radiation tolerance, magnetic susceptibility, humidity and temperature
  - Possible ad-hoc packaging could be studied
- **Mechanical integration on Silicon modules**
  - Module integration
  - Mounting tolerances
  - Thermal cycling movements after mounting
  - Hysteresis

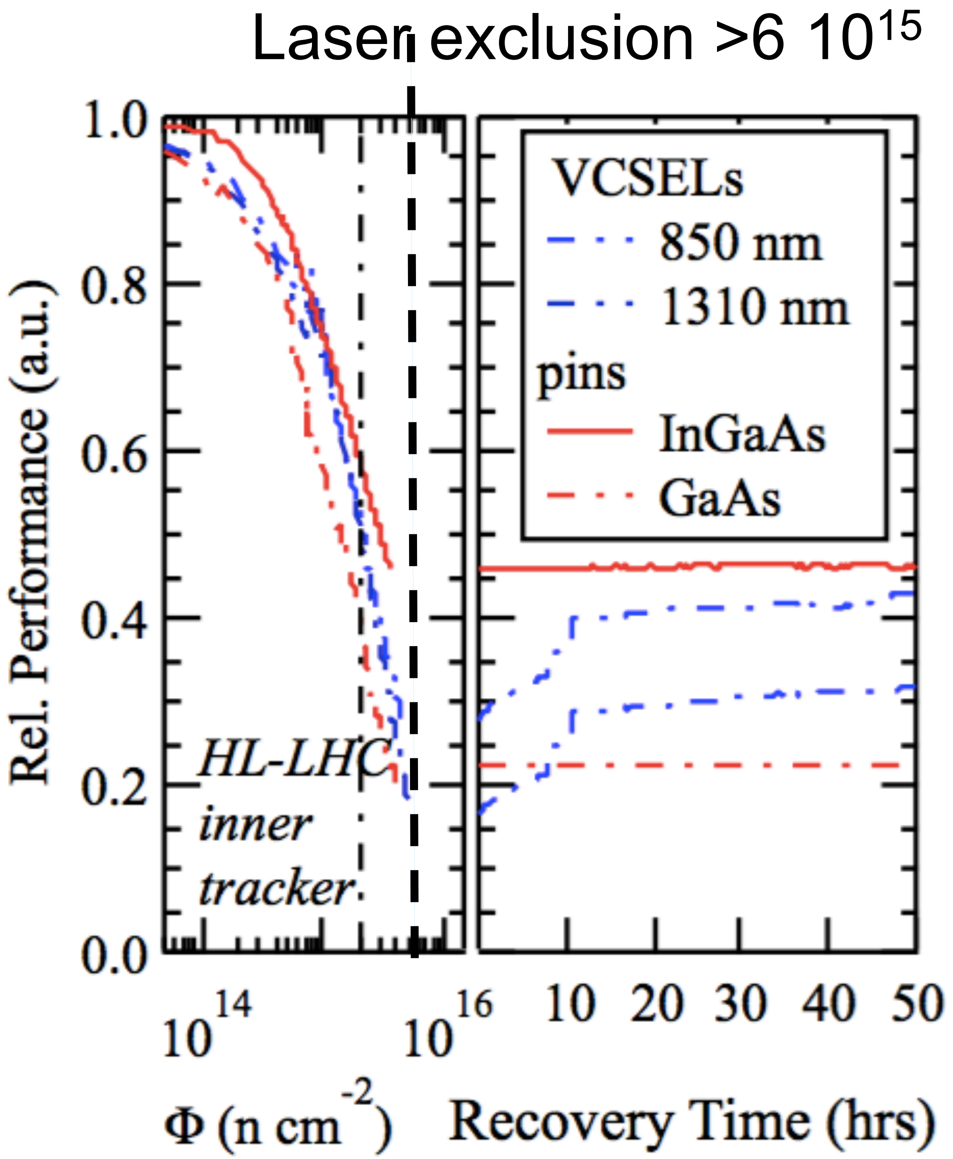
4.25 Gb/s OWC (Preliminary Results)

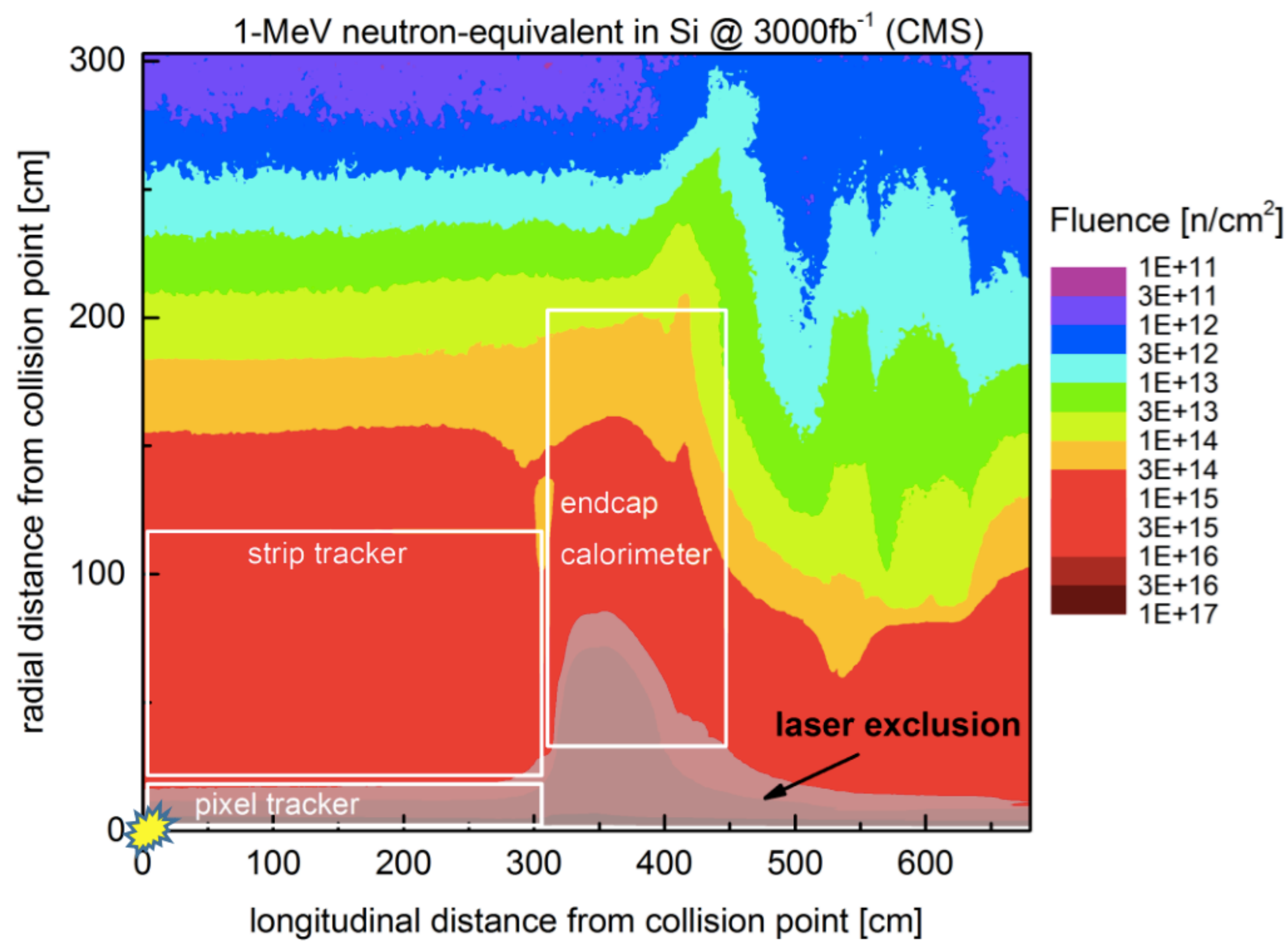
- **Because of obtaining high SNR in 2.5 Gb/s setup we tried to improve the data rate up till 4.25 Gb/s at an expense of reduced tolerance to misalignment range (±0.75mm).**





VCSEL and PIN diode





S. Seif El Nasr-Storey, S. Detraz, L. Olantera, G. Pezzullo, C. Sigaud, C. Soos, J. Troska, F. Vasey, and M. Zeiler, "Neutron and X-ray Irradiation of Silicon Based Mach-Zehnder Modulators," Journal of Instrumentation, vol. 10, 2015.

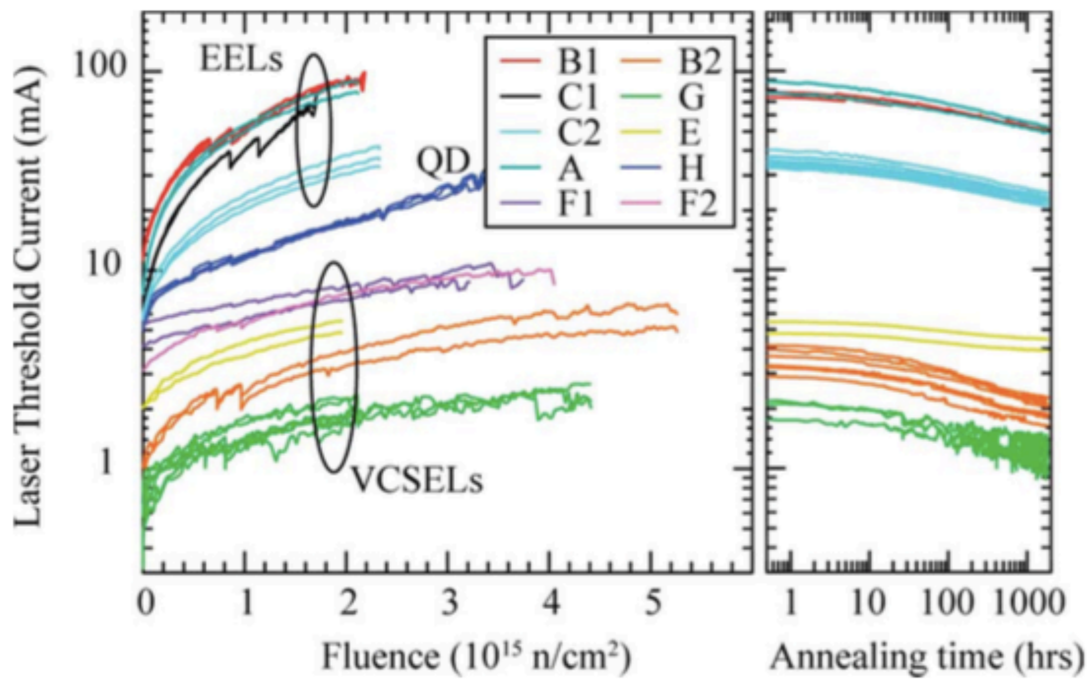


Fig. 7. Effect of irradiation and annealing on the threshold current of all lasers tested with 20 MeV neutrons.

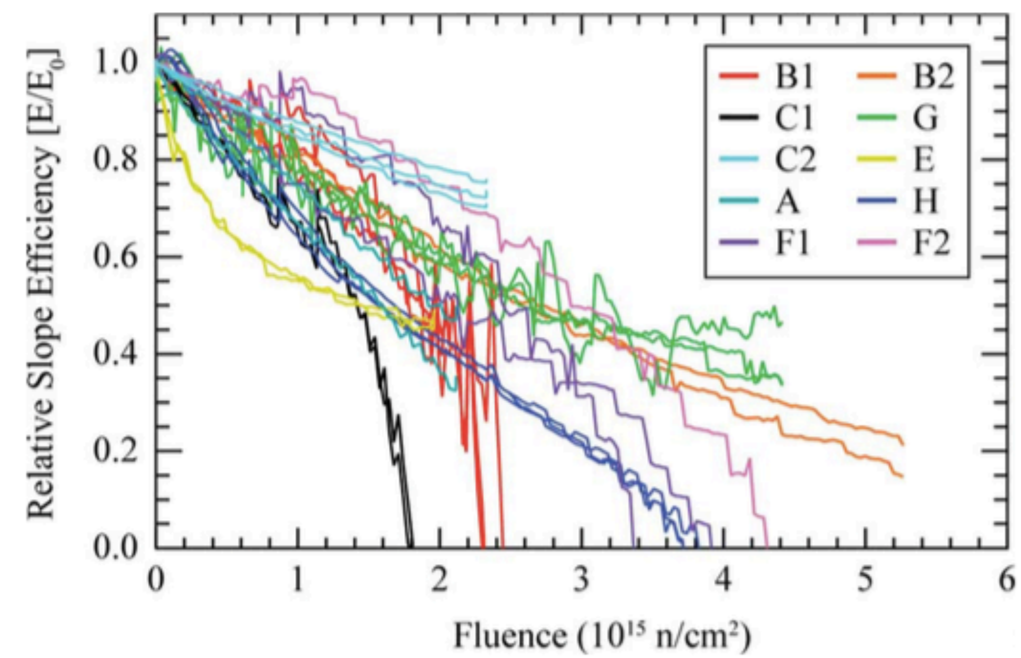
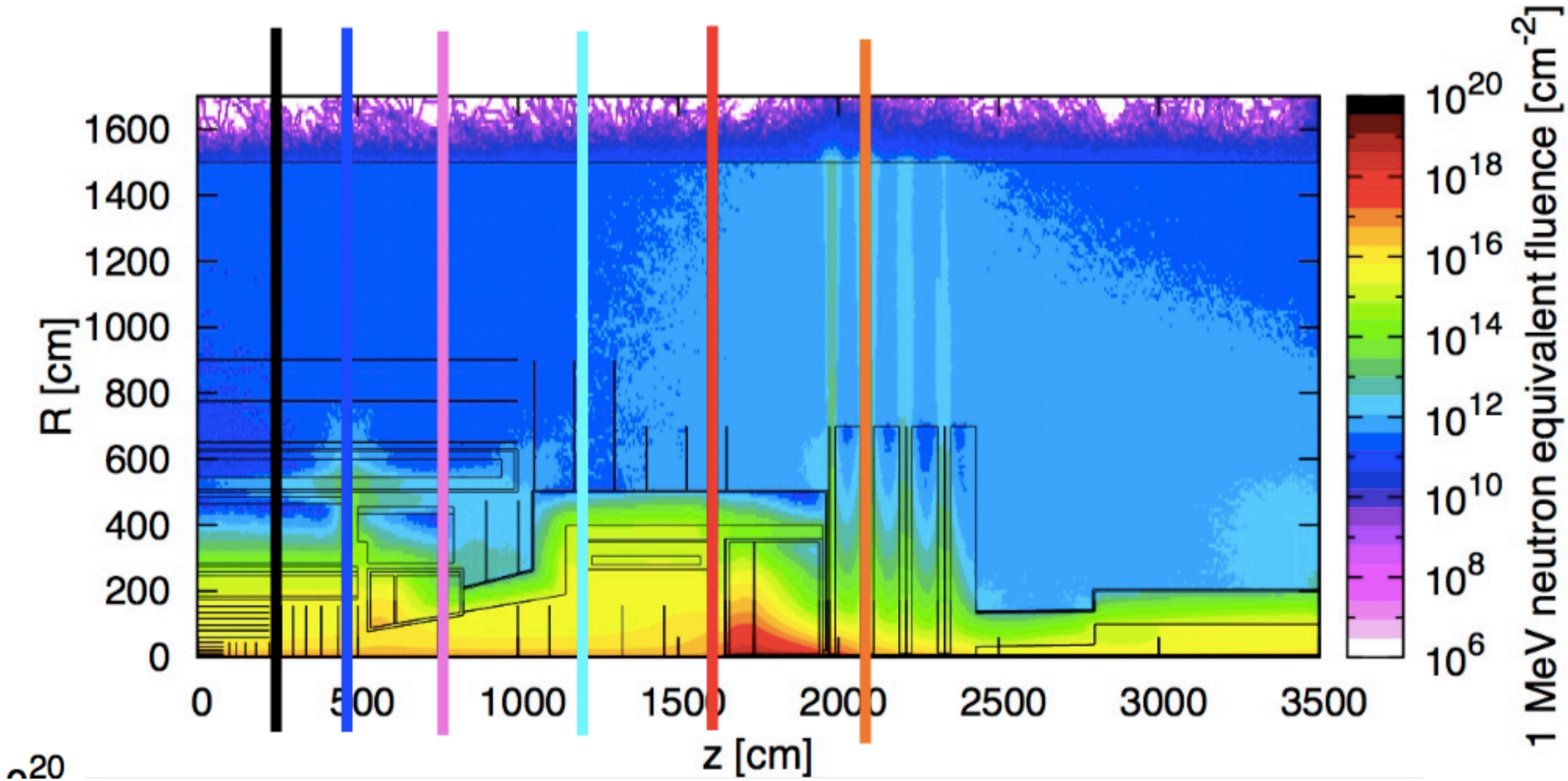
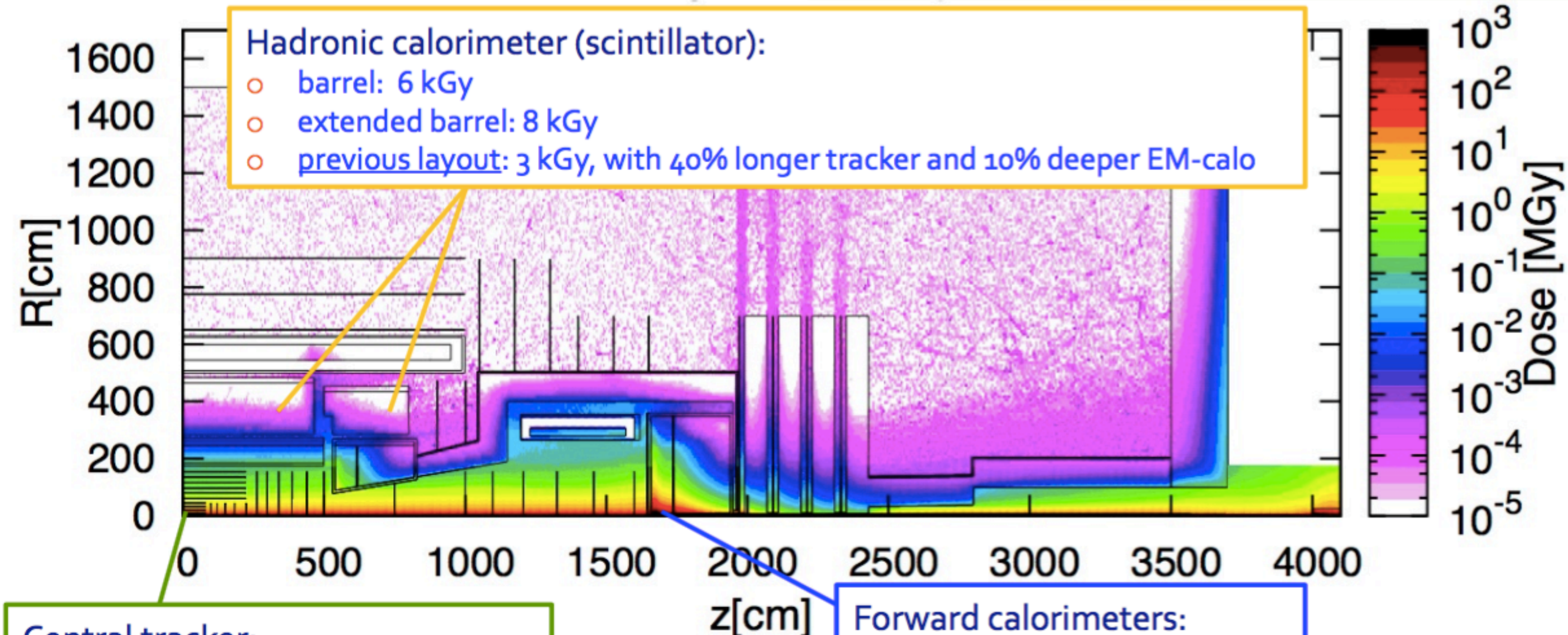


Fig. 8. Effect of irradiation on the slope efficiency of all lasers tested with 20 MeV neutrons. Some devices reached zero efficiency which indicates that they stopped lasing during the test.


R [cm]
1600
1400
1200
1000
800
600
400
200
0
0
500
1000
1500
2000
2500
3000
3500
z [cm]
1 MeV neutron equivalent fluence [cm^{-2}]
10^{20}
10^{18}
10^{16}
10^{14}
10^{12}
10^{10}
10^{8}
10^{6}

Dose for 30 ab^{-1}



Hadronic calorimeter (scintillator):

- barrel: 6 kGy
- extended barrel: 8 kGy
- previous layout: 3 kGy, with 40% longer tracker and 10% deeper EM-calo

Central tracker:

- first IB layer (2.5 cm): ~400 MGy
- external part: 0.1 MGy

Forward calorimeters:

- EM-calo: 5000 MGy
- HAD-calo: ~1000 MGy
- at R=2 m the dose is ~1 MGy

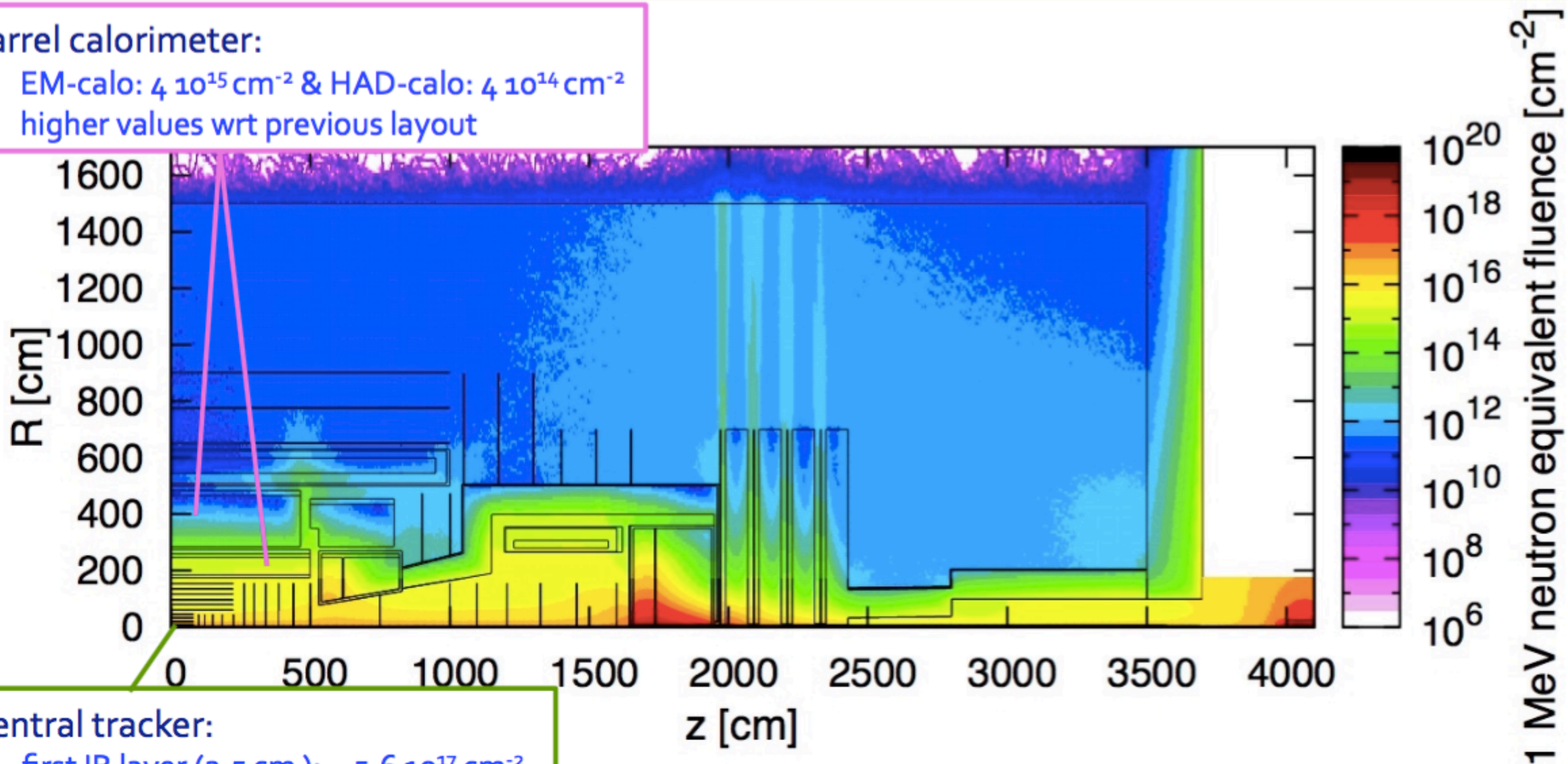
31/05/17

M.I. Besana, FCC week 2017

12

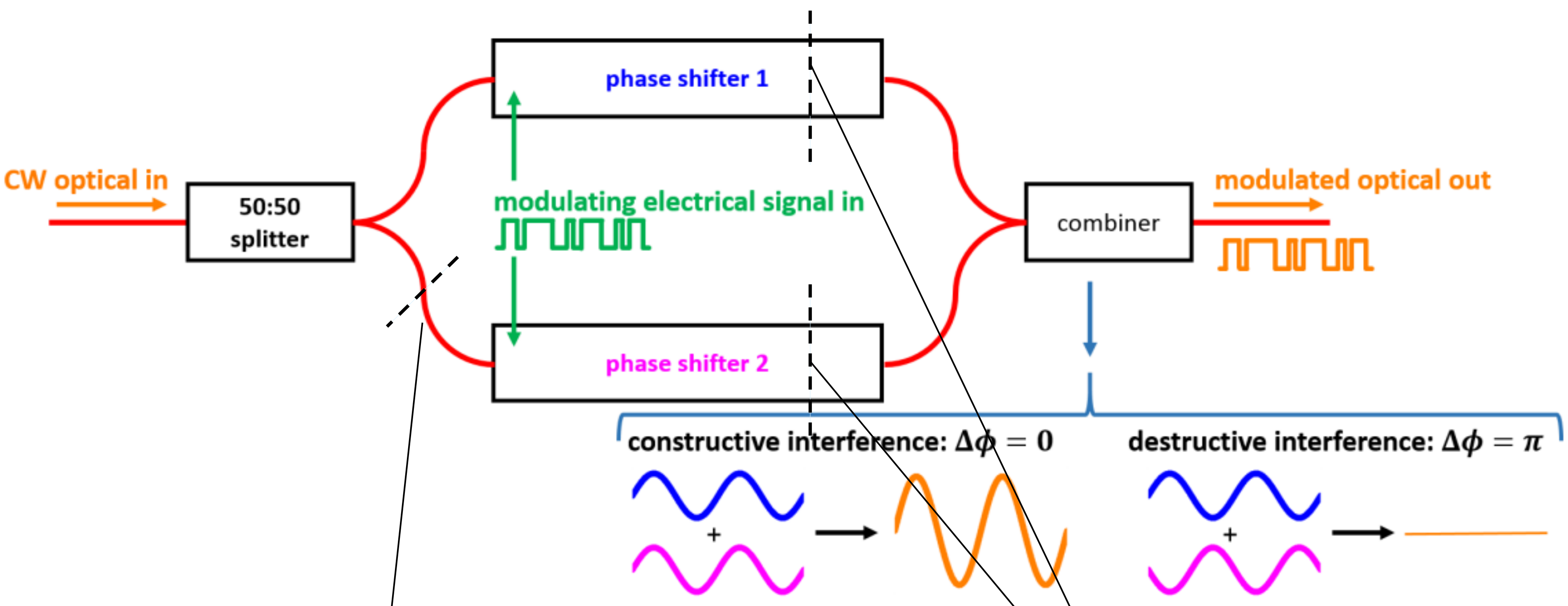
1 MeV Neutron Equivalent Fluence for 30 ab^{-1}

Barrel calorimeter:
- EM-calo: $4\ 10^{15}\ cm^{-2}$ & HAD-calo: $4\ 10^{14}\ cm^{-2}$
- higher values wrt previous layout

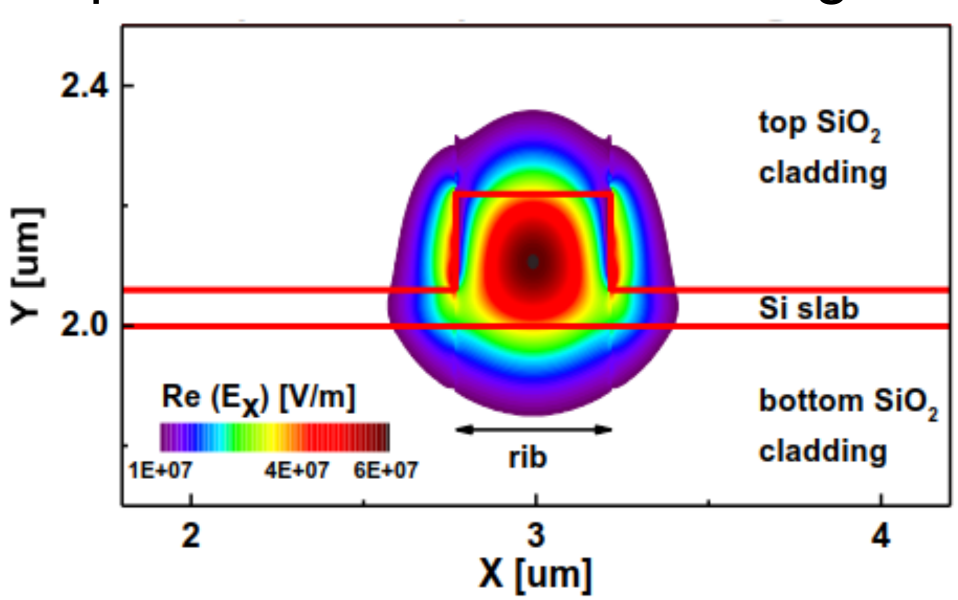


Central tracker:
- first IB layer (2.5 cm): ~5-6 $10^{17}\ cm^{-2}$
- external part: ~5 $10^{15}\ cm^{-2}$

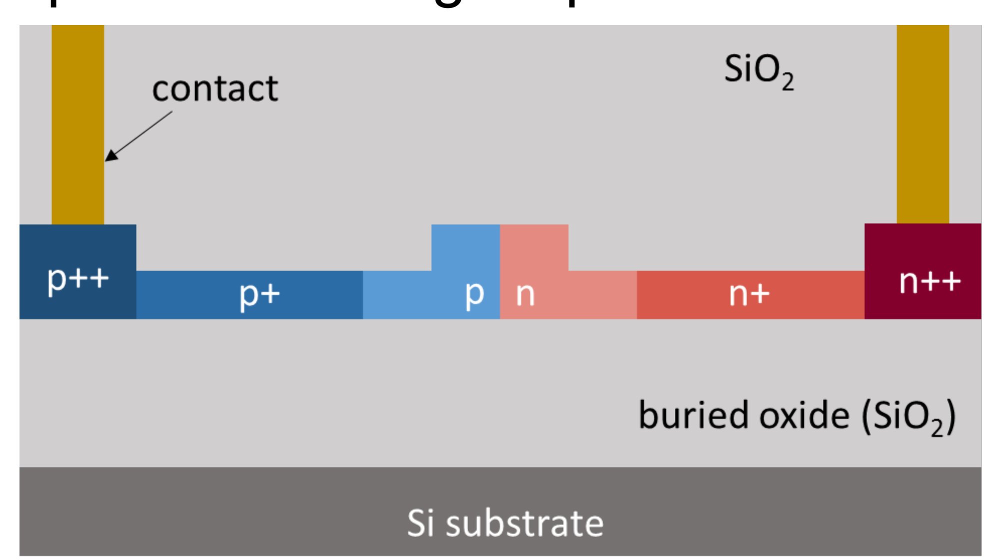
Silicon photonics MZM



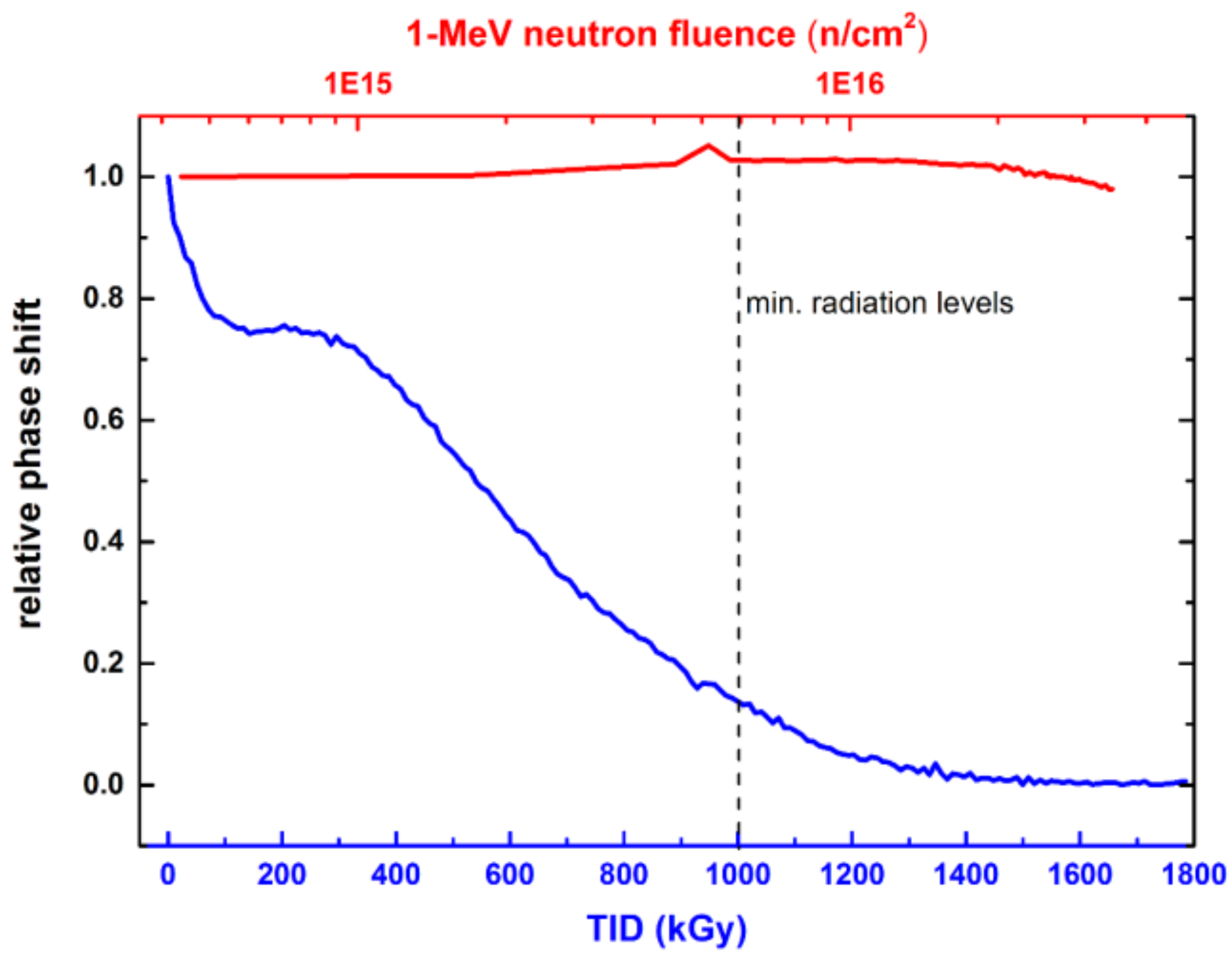
Optical mode in silicon waveguide



pn-diode acting as phase shifter



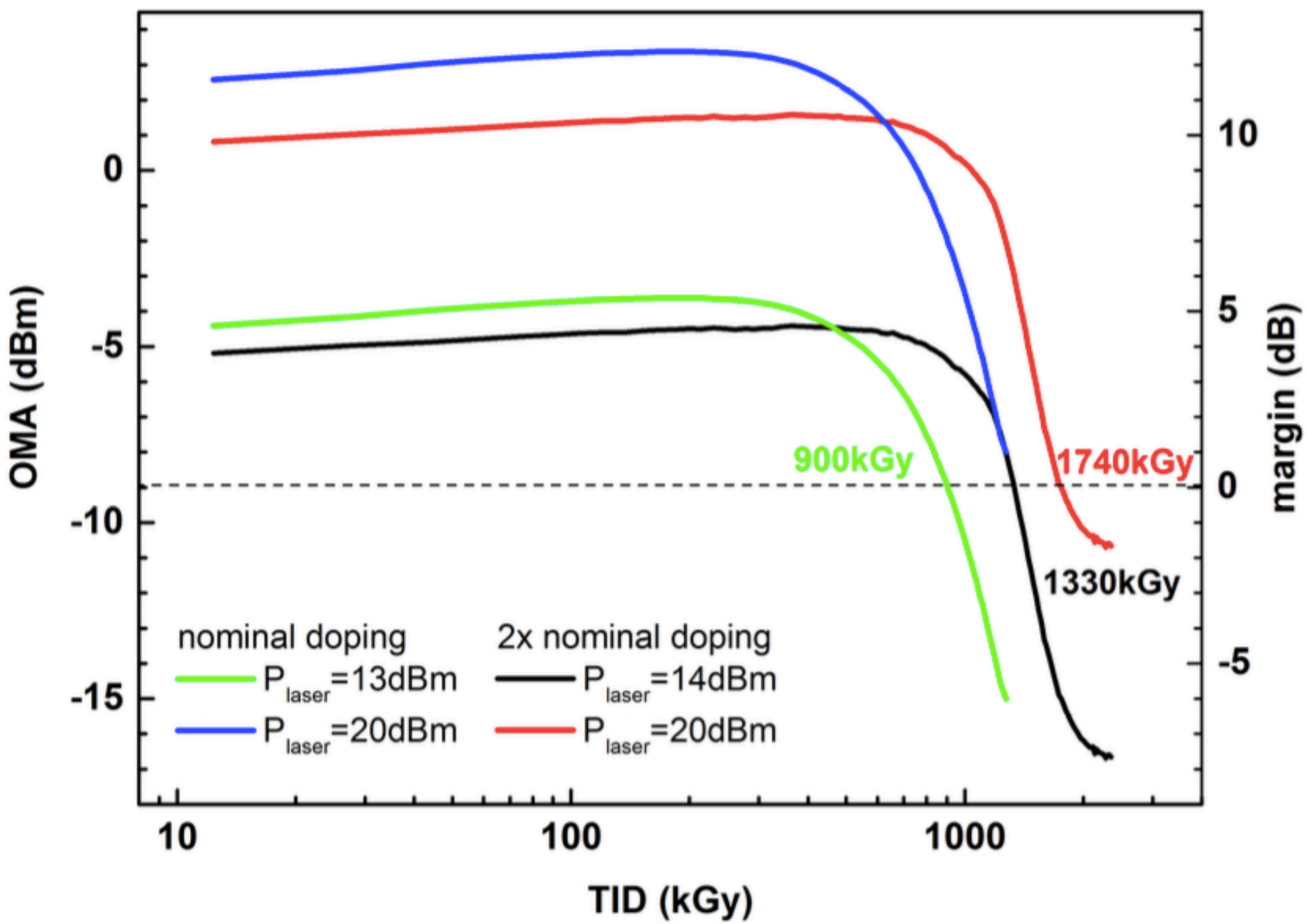
First radiation test of standard SiPh MZMs



- No significant performance degradation due to displacement damage
- Very sensitive to ionizing radiation

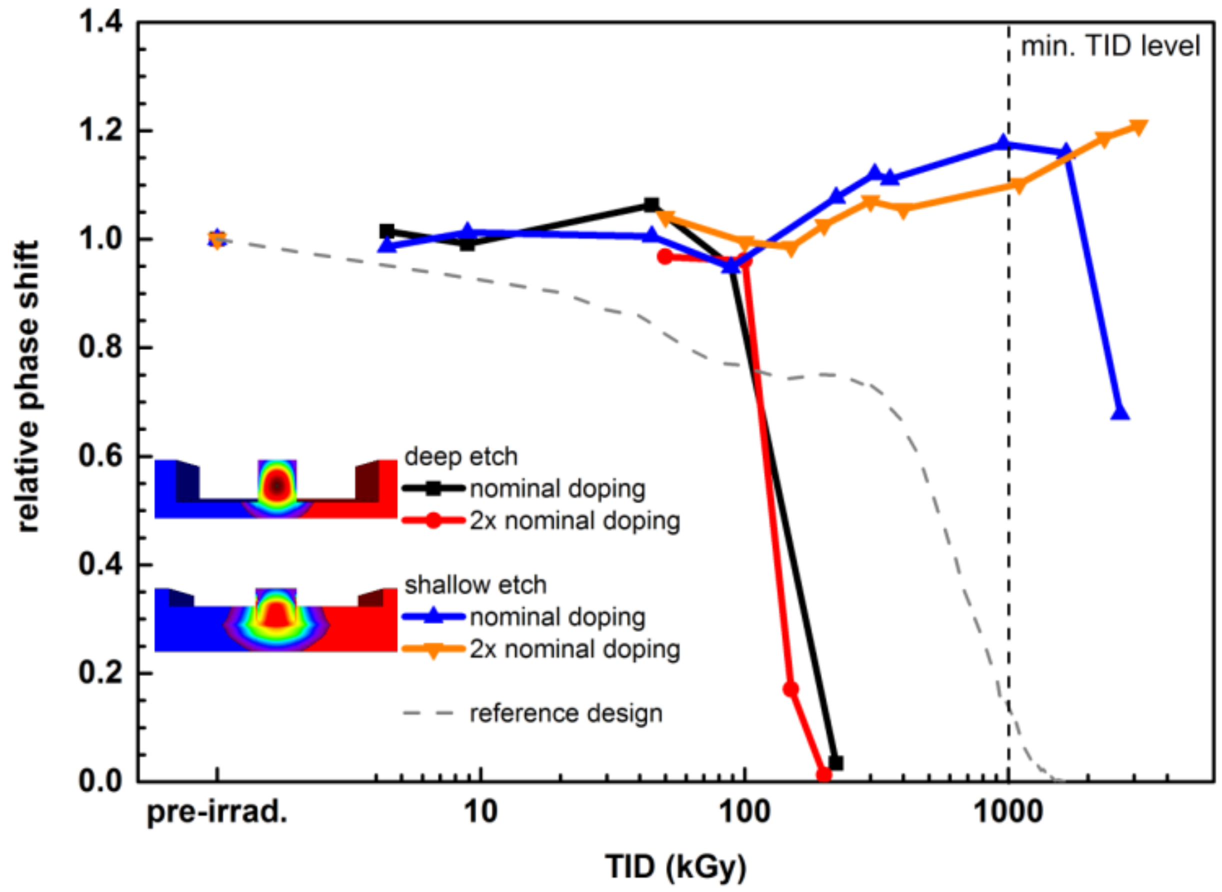
→ **Goal**: understand radiation damage and develop a customized design to increase resistance to ionizing radiation

MZM



OMA (dBm)
0
-5
-10
-15
10
100
1000
TID (kGy)
margin (dB)
10
5
0
-5
900kGy
1740kGy
1330kGy
nominal doping
P_{laser}=13dBm
P_{laser}=20dBm
2x nominal doping
P_{laser}=14dBm
P_{laser}=20dBm

Improved hardness by design



- **Phase shift of deep etch MZMs degrades at TID levels far below minimum required**
- **Shallow etch MZMs do not degrade up to TID of more than 2MGy**