

Radiation Resistance of Ge-doped Multi-Mode Fibers for Optical Links in Collider Experiments



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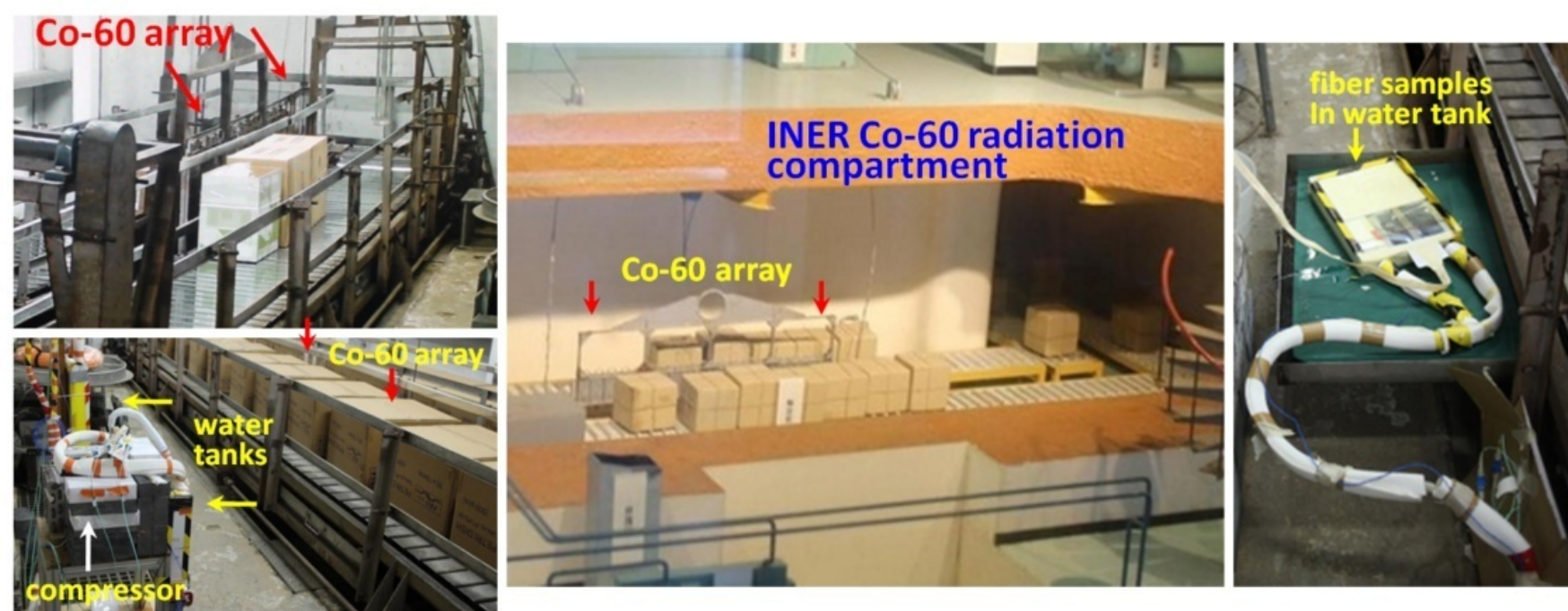
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Optical Links in collider experiments provide high-speed, low-mass data transmission for distances of a few hundred meters. The 850 nm multi-mode (MM) technology is developed with radiation tolerant optoelectronics and ASICs for applications up to 25 Gbps per channel [1-3].

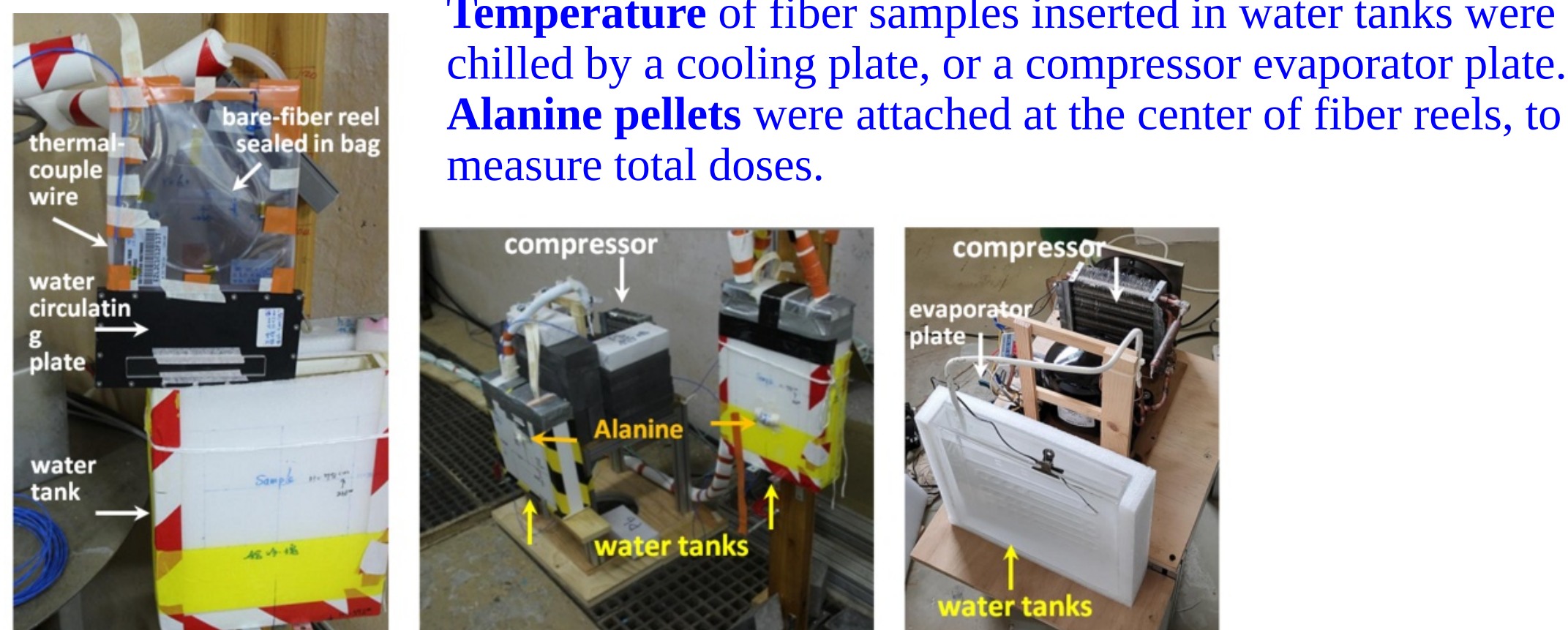
INER facility Co-60 facility has a pellet-array paved to 45×300 cm². Irradiations of MM fibers were conducted at dose rates of 3 Gy(SiO₂)/hr to 1.4 kGy(SiO₂)/hr, at temperature between -15 °C and 45 °C

Ge-doped MM fibers have been investigated for radiation resistance in ionizing dose for data transmission in collider experiments. Commercial 10 Gbps types were irradiated with Co-60 gamma rays [4,5]. Degradation of optical power transmitted through fiber is formulated for Radiation Induced Attenuation (RIA) versus total ionizing dose (TID):

$$RIA = 10 \cdot \log_{10} \left(\frac{P_{t=0}}{P_t} \right) \quad P_t = \text{optical power transmitted at dose } t$$

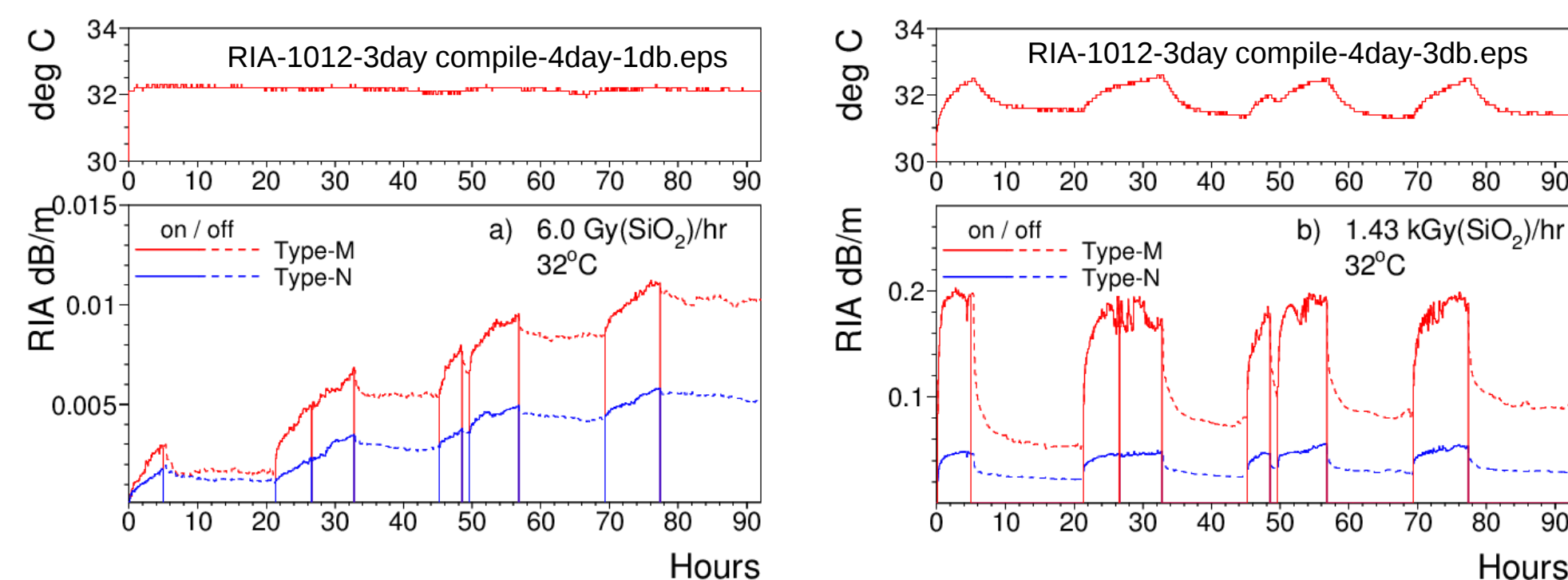


INER has a Co-60 pellet-array between service conveyors for irradiation. Fiber samples in water tanks were located at chosen distances to vary dose rates.

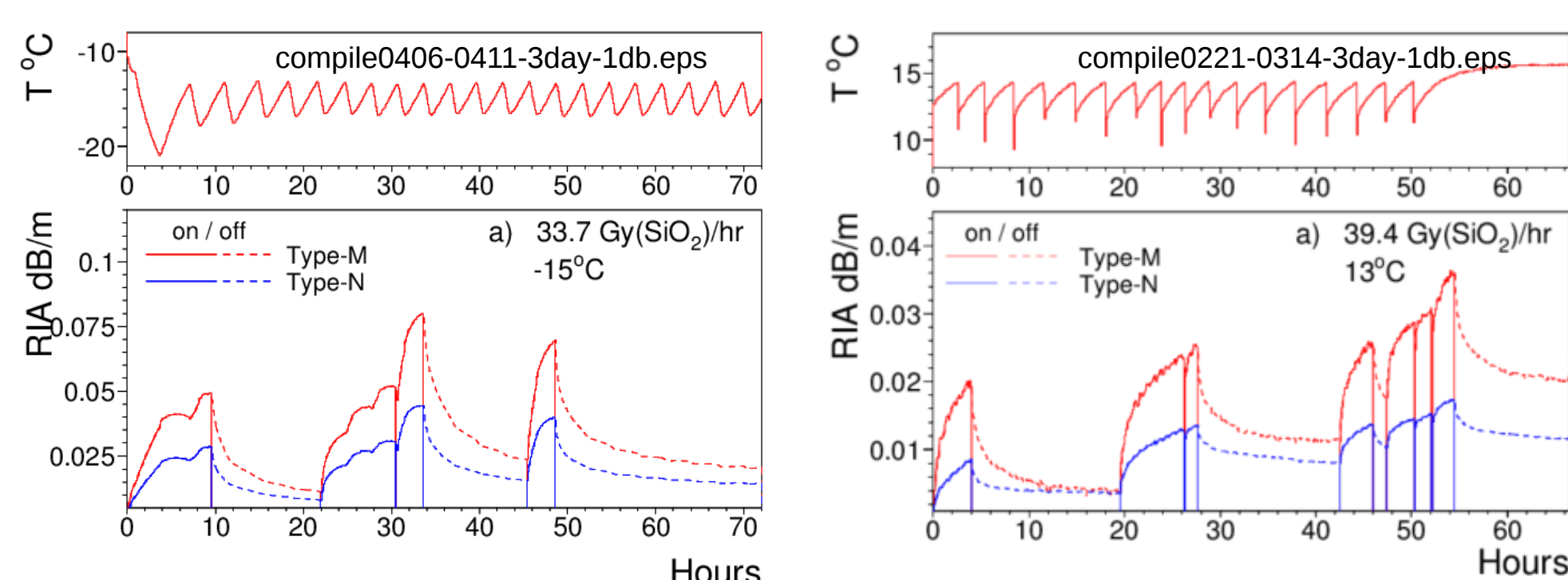


Temperature of fiber samples inserted in water tanks were chilled by a cooling plate, or a compressor evaporator plate. **Alanine pellets** were attached at the center of fiber reels, to measure total doses.

Radhard fibers, dose-rate, temperature dependencies: two of the 10 Gbps MM types show fast annealing in a few hours after the Co-60 source being shielded. At low dose rate (6 Gy/hr, 32 °C), radiation induced defects are quickly expelled; annealing is not significant. At very high rate (1.43 kGy/hr, 32 °C) the radiation induced defects pile-up to twice higher RIA than after annealing. At cold (34 Gy/hr, -15 °C) the recovery is stagnant; the instant RIA is three times higher than the annealed. The rate at 34 Gy/hr is the level of inner tracker expected at hadron collider.



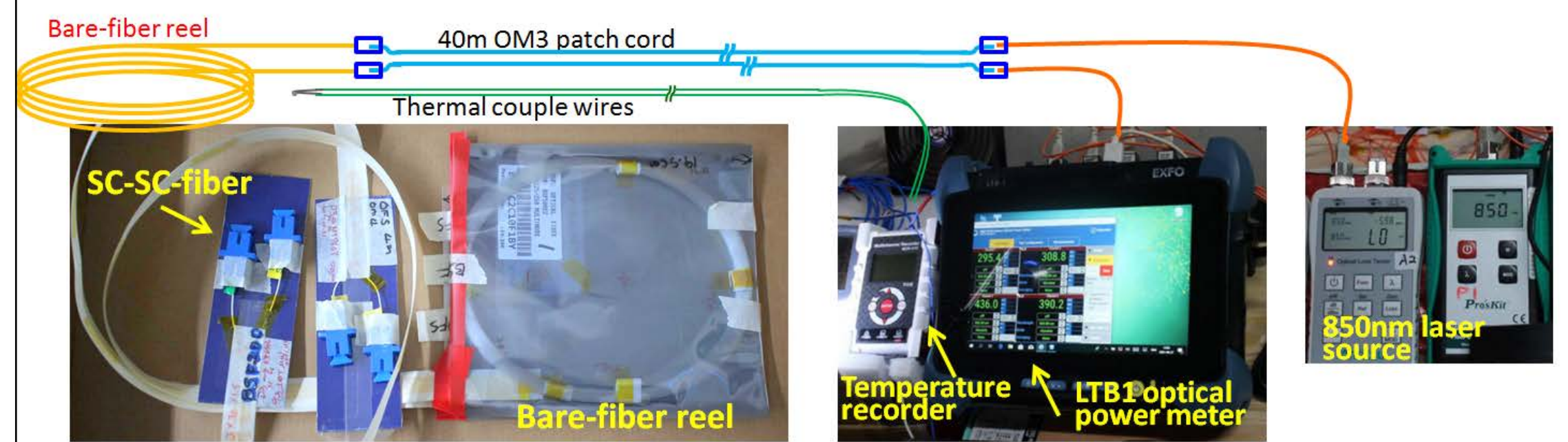
Radhard fibers dose-rate, compared for 6 Gy/hr versus 1.43 kGy/hr at 32 °C. During irradiation, pileup of defects causes higher RIAs than after annealing, by a factor two to three at the extreme 1.43 kGy/hr rate.



Radhard fibers temperature, at cold (-15 °C) the stagnant recovery at 34 Gy/hr has the RIA pile-up by a factor 3 higher than after annealing. In room temperature (13 °C) the ratio is 1.5.

- [1] "Radiation hardness of optoelectronic components for the optical readout of the ATLAS inner detector", S. Hou et al., Nucl. Instrum. and Meth. A 636, S137 (2011)
- [2] "Characteristics of the MTx optical transmitter in Total Ionizing Dose", D. Gong et al., Nucl. Instrum. and Meth. A 1064, 169378 (2024)
- [3] "Prototyping of a 25 Gbps optical transmitter for applications in high-energy physics experiments", C.-P. Chao et al., Nucl. Instrum. and Meth. A 979, 164399 (2020)

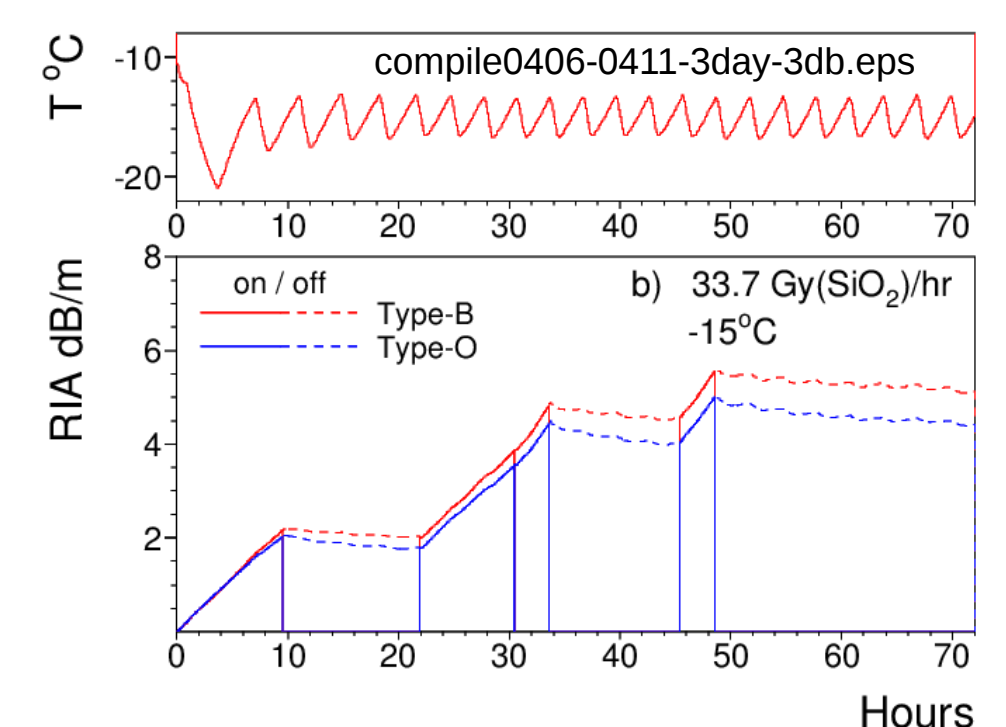
Radiation at Collider, the TID at HL-LHC inner pixel is estimated for a total 10 MGy, at ~200 Gy/hr [6]. Detectors are kept at -20 °C to enhance radiation tolerance. Opto-link on peripheral is required for a total 1 MGy. The CEPC vertex is specified for radiation of 34 kGy/y [7], which is an order of magnitude lower than at HL-LHC.



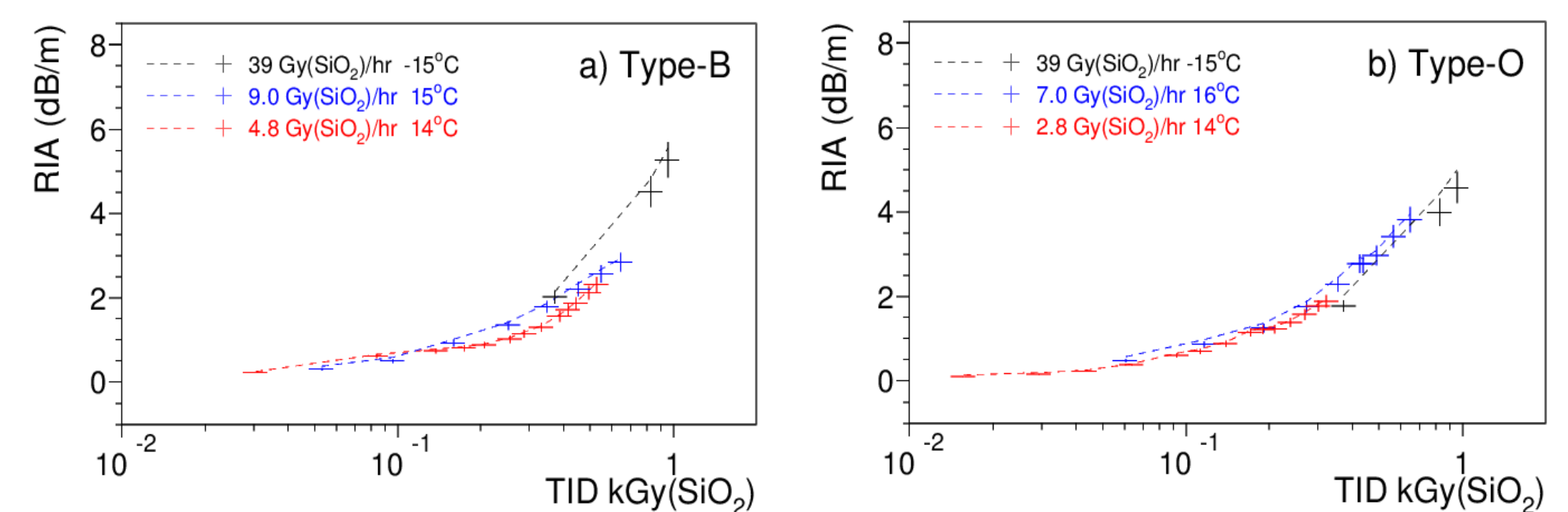
Fiber ample and DAQ: Fiber sample in bare-fiber reel was sealed with fiber ends connected to a laser source (CMA5), and returned to an LBT1 power-meter. The sealed fiber sample had a thermal couple recording temperature (MCR-4TC).

Non-Radhard fibers, due to technologies and dopants, the radiation induced defects were little recovered. Two types of 10 Gbps fibers show linear degradation, with RIAs reaching 4 dB/m at 1 kGy(SiO₂).

Non-radhard fibers in Co-60 irradiation were tested at dose rate 33.7 Gy/hr, -15 °C. The RIAs were measured during irradiation (solid) and in annealing (dashed).

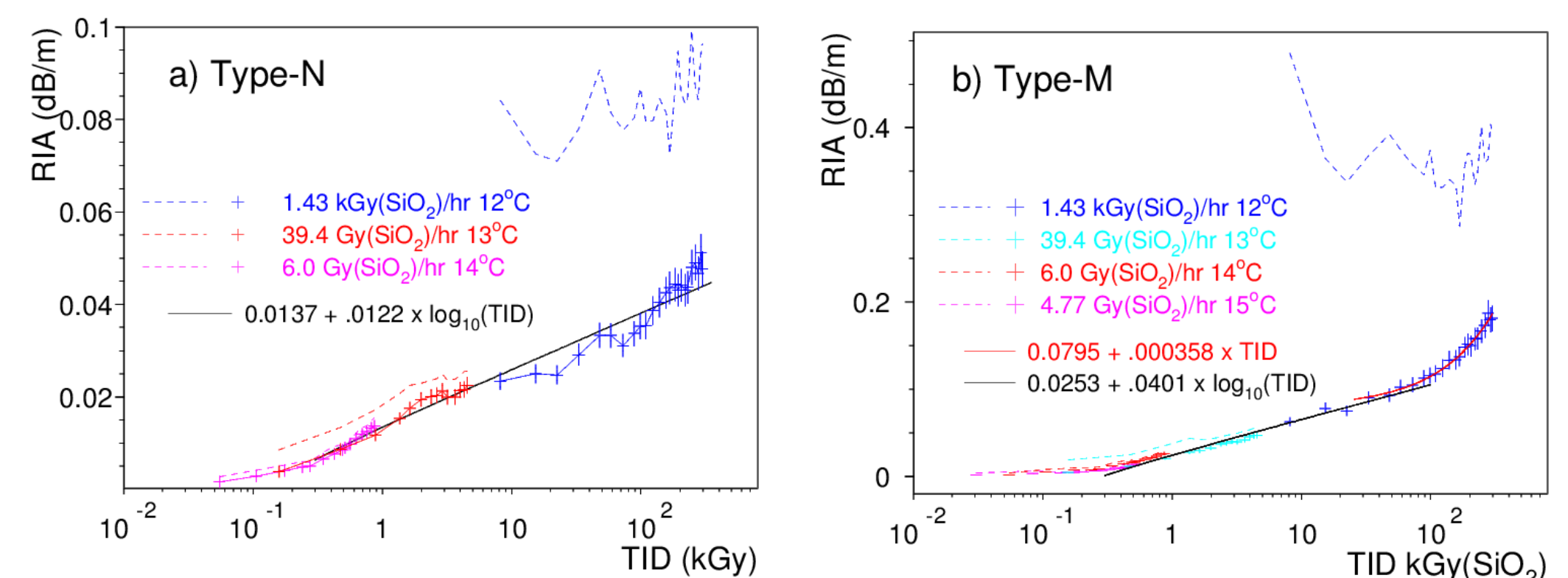


Non-radhard RIA vs TID, the dash lines are the RIAs in radiation at the daily accumulated doses; the points are the corresponding RIAs after 10 hours annealing. The radiation induced defects are little recovered.



Radhard RIA, logarithmic fit, the annealed RIAs of two radhard types of fibers are logarithmic to TID. No dependencies on the dose rates and temperatures during irradiation. Type-M fiber at very high dose is better interpreted with a linear function. The fits of RIAs to TID are

$$RIA = a + b \cdot \log_{10}(TID); \quad RIA = a + b \cdot TID$$



Radhard logarithmic fits, for two fiber types of RIAs accumulated at various dose rates, with fits to logarithmic and liner functions. The dashed lines are instant RIAs at the end of daily exposures in tests. The data points are the corresponding RIAs after 10 hours annealing. The pile-up of defects during irradiation is obvious at very high rate of 1.4 kGy/hr.

Summary: telecom grades of 10 Gbps Ge-doped MM fibers of chosen technology show outstanding radiation tolerant. Annealing of TID induced defects is effective in a few hours. The annealed RIAs show no rate, temperature dependencies. The tests at 34 Gy(SiO₂)/hr, -15 °C represents condition of fibers for inner tracker at HL-LHC. The cold temperature causes instant RIA to fluctuate by a factor 3 higher than the annealed. The radhard fiber type-N has the RIA of 0.05 dB/m after 300k Gy(SiO₂).

- [4] "The radiation induced attenuation of optical fibres below -20 °C exposed to lifetime HL-LHC doses at a dose rate of 700 Gy(Si)/hr", D. Hall et al., JINST 7, C01047 (2012)
- [5] "Tolerance of Ge-doped multi-mode fibers in total ionizing dose", D. Gong et al., RDTM (2025), <https://doi.org/10.1007/s41605-025-00589-7>
- [6] ATLAS Collaboration, Radiation Simulation Public Results.
- [7] "CEPC CDR", <https://arxiv.org/ftp/arxiv/papers/1811/1811.10545.pdf>

