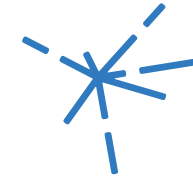



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INSTITUTE FOR
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Results of lpGBT and VTRx+ irradiation campaign

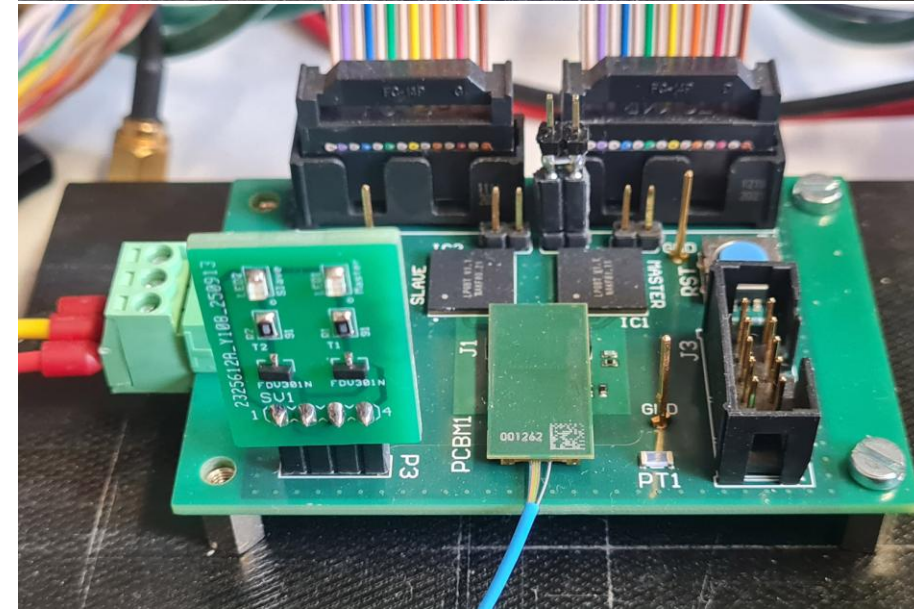
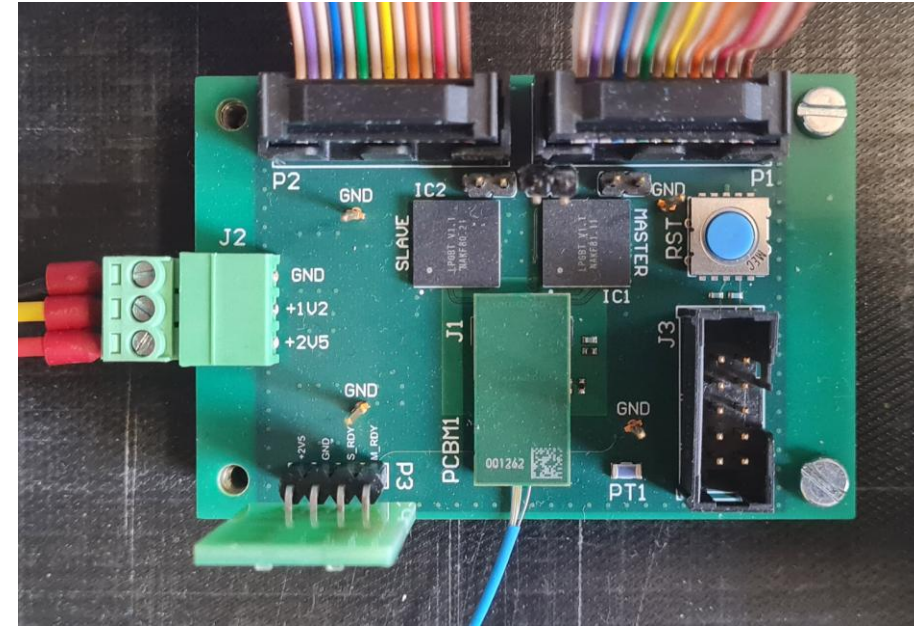
M. Friedl, H. Steininger, F. Buchsteiner

22 April 2026

Dual-lpGBT

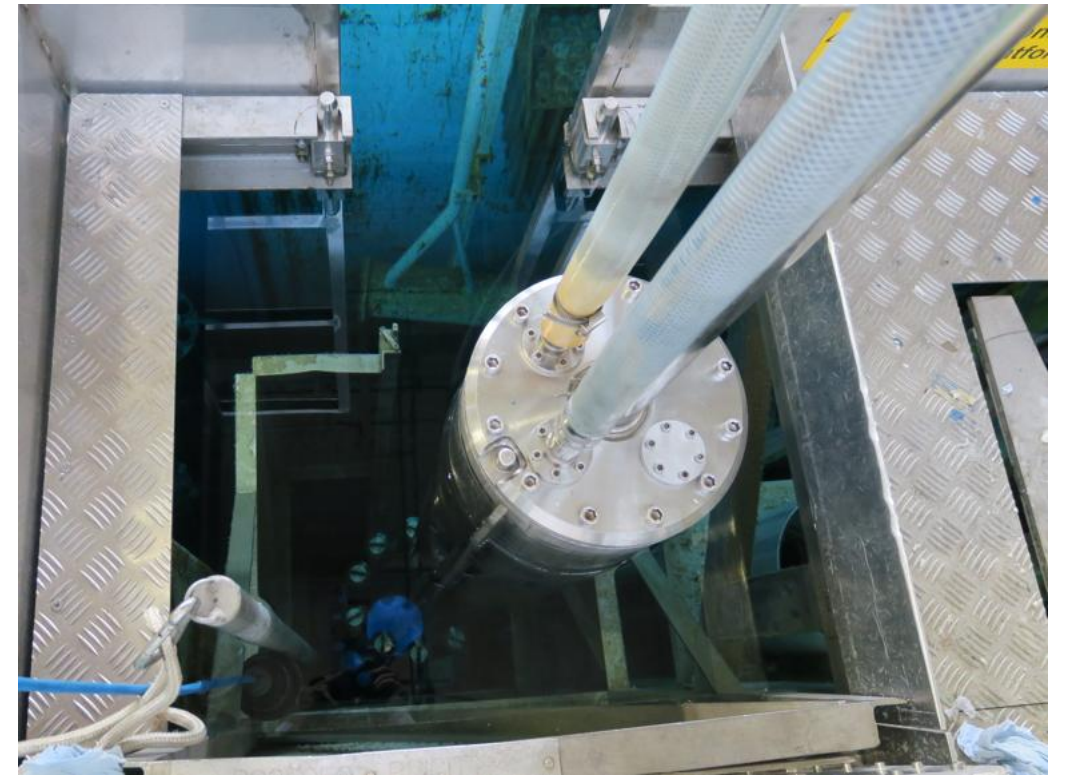
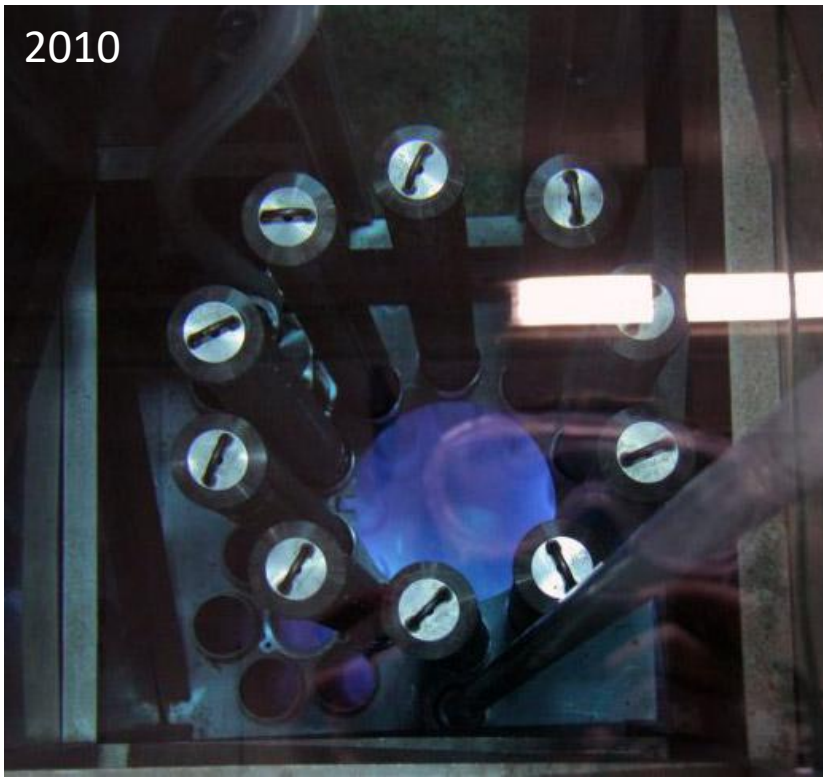
Dual-lpGBT board V2

- 15 boards used for irradiation with VDD applied
- Each contains 2 lpGBTs (master+slave), but only master recovers clock from incoming (optical) data stream which invokes its PLL
- We found that slave always works as long as it gets the reference clock, i.e. both master and slave have the very same f_{\max} in this configuration
- Slave doesn't use its PLL which is the limiting factor, so only master performance is relevant



Irradiation @ SCK-CEN (Mol, Belgium)

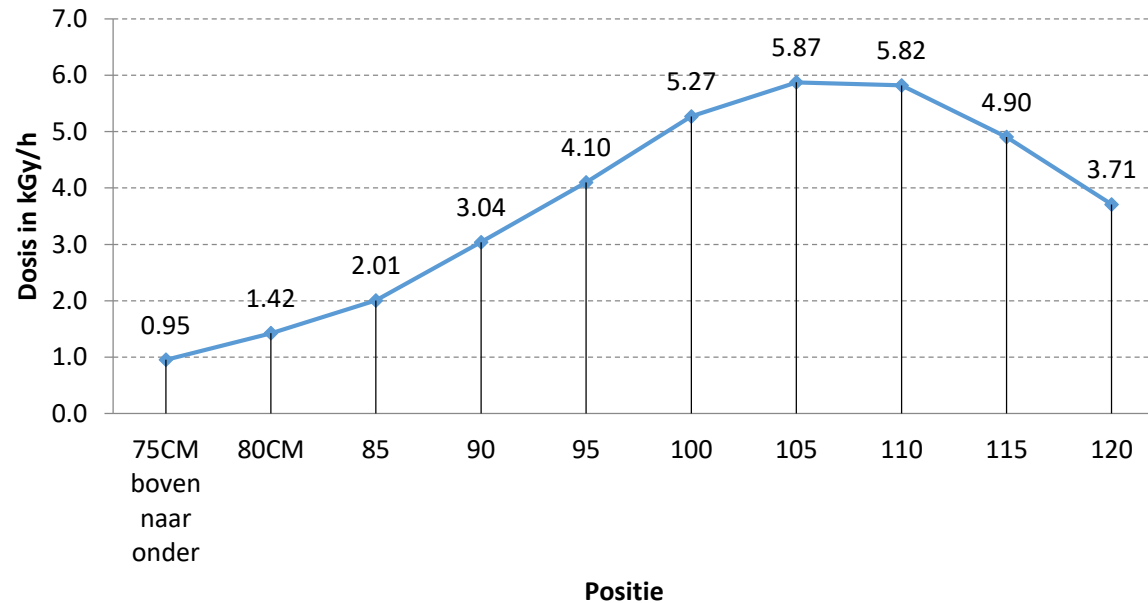
- Cobalt-60 irradiation under bias; (up to) 100 Mrad (=1 MGy)
- BRIGITTE peaks at ~600 krad/h (1 week to 100 Mrad)
- Irradiation from 13...20 March 2026



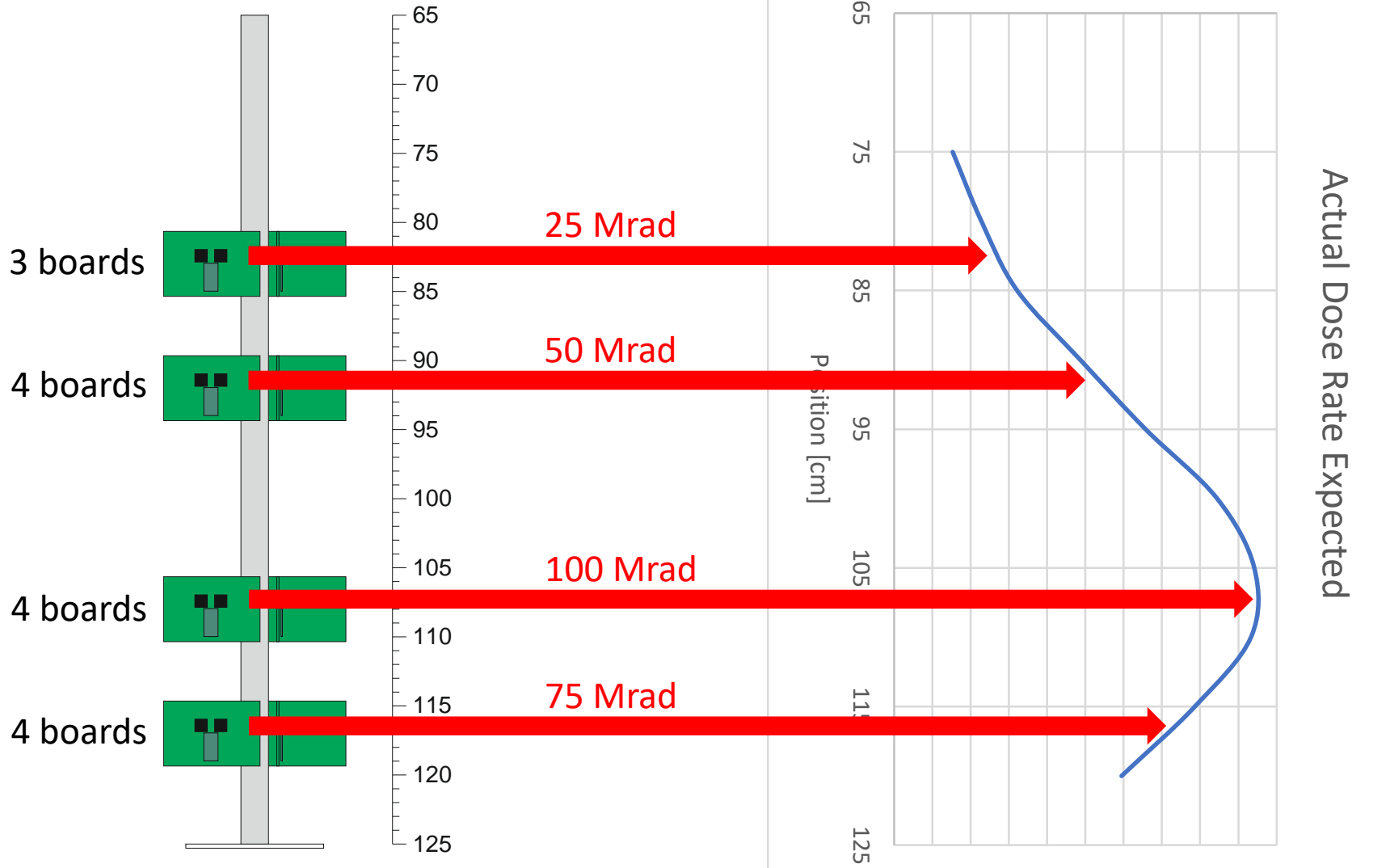
Dosimetry

- Performed in November 2025
- Now already ~5% weaker; $T_{1/2}=5.3y$

Dosimetrie in Brigitte



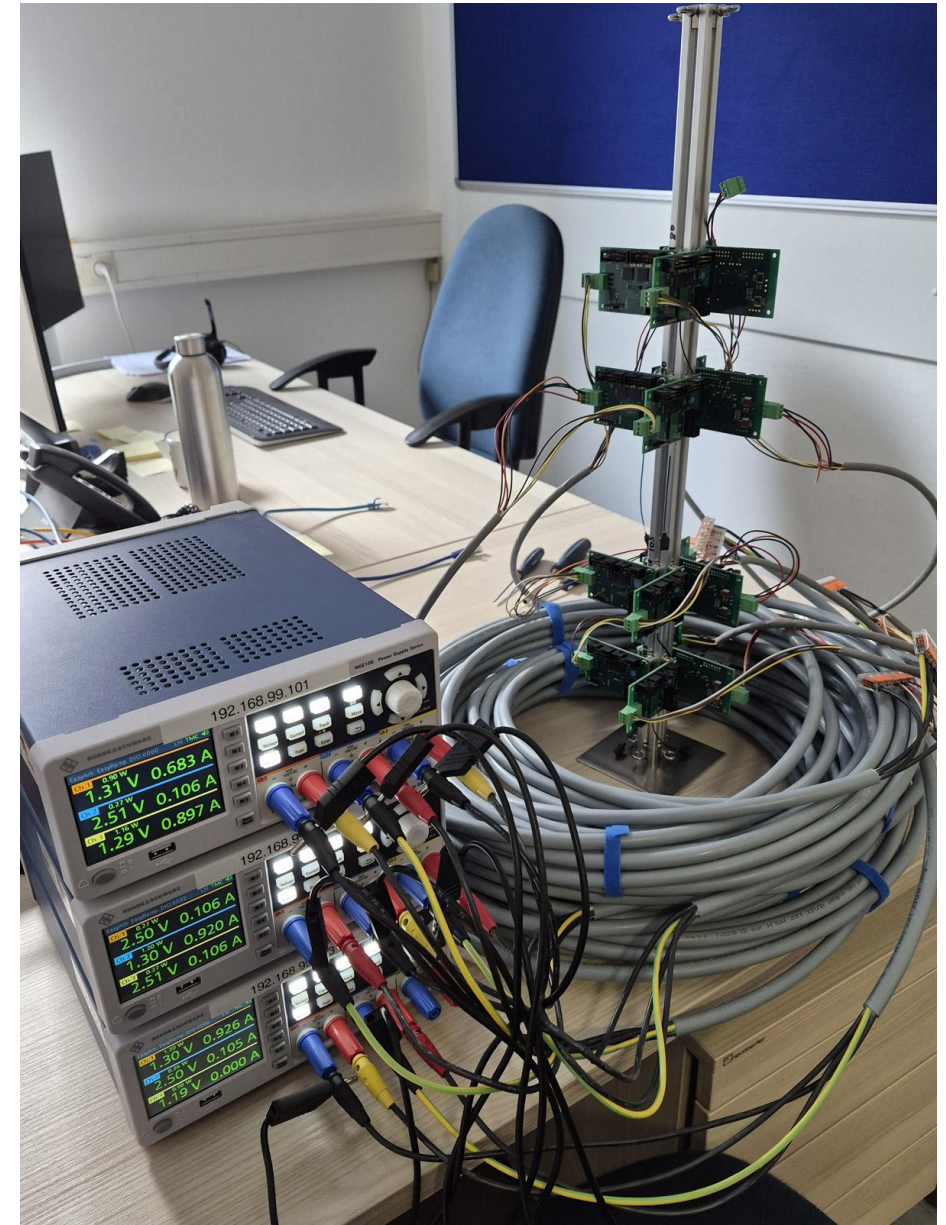
Plan



We also irradiate
2 VTRx+ in each
height position
(Thanks to Pisa!)

Photos (1/3)

- Test setup in Vienna



Photos (2/3)

- Installation at Mol



Photos (3/3)

- Insertion into the container

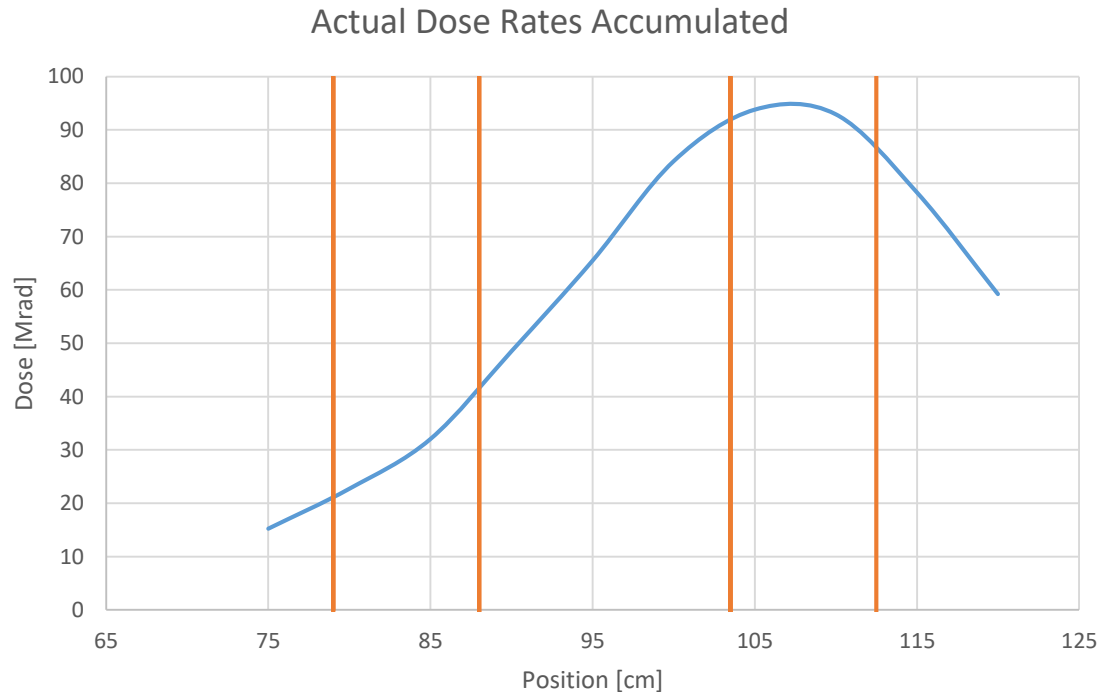


Procedure

- 11-12 March 2026: Florian and I drove from Vienna to Mol
- Friday, 13 March 2026: installation at Mol, insertion into Co-60
 - During irradiation, modules were under power with currents recorded, but no optical communication
 - Florian and myself did not stay in Mol, but worked for the NUCLEUS experiment at Chooz during that period
- Friday, 20 March 2026: uninstallation at Mol
- 21-22 March 2026: Florian and I drove from Mol to Vienna

Reality

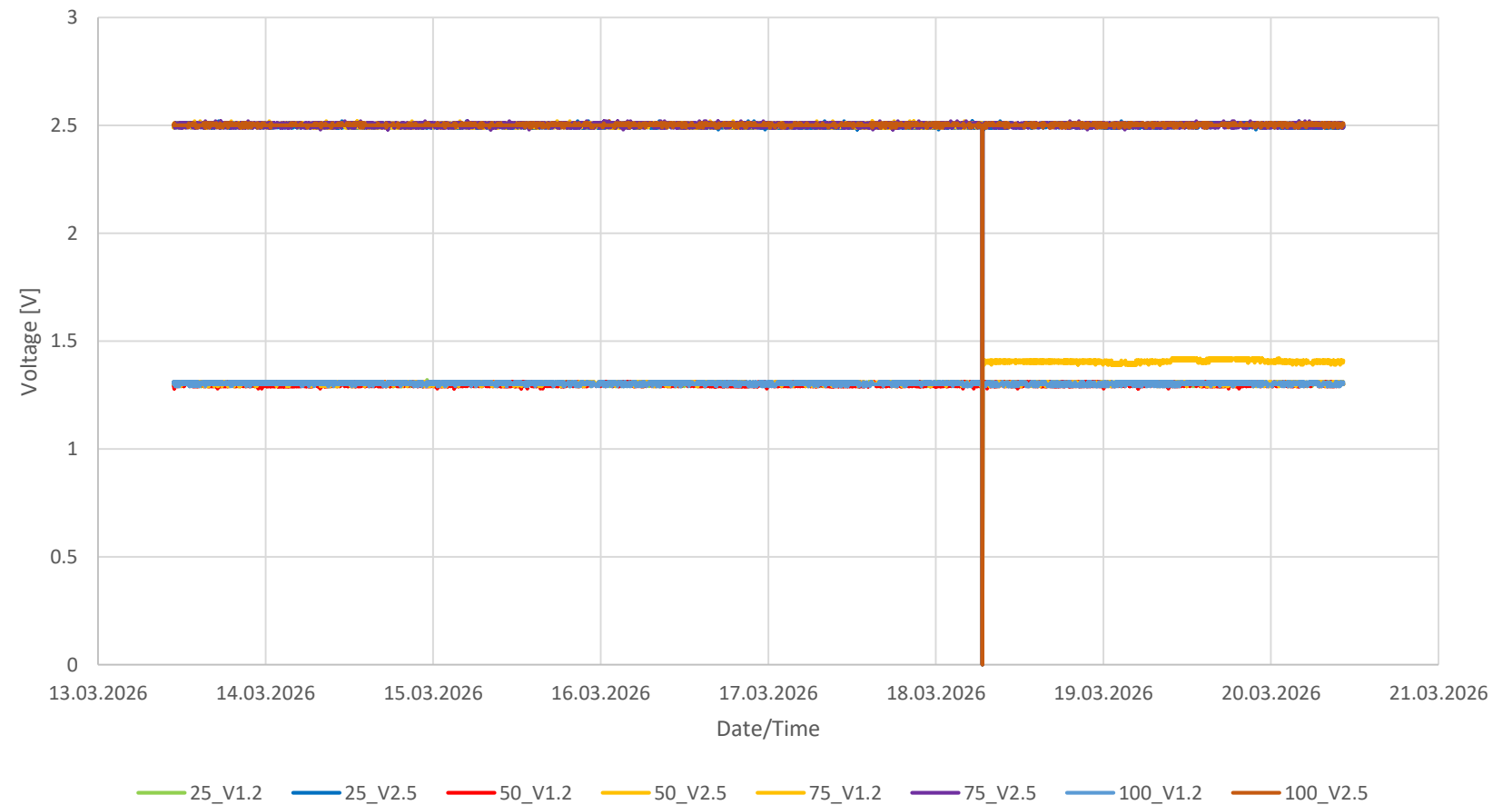
- 167.4 hours in total (almost a full week = 168 hours)
- **Actual positions** slightly off from desired ones
- Actual doses:
 - "25" → 21 Mrad
 - "50" → 42 Mrad
 - "75" → 87 Mrad
 - "100" → 92 Mrad



Voltages and Currents (1/3)

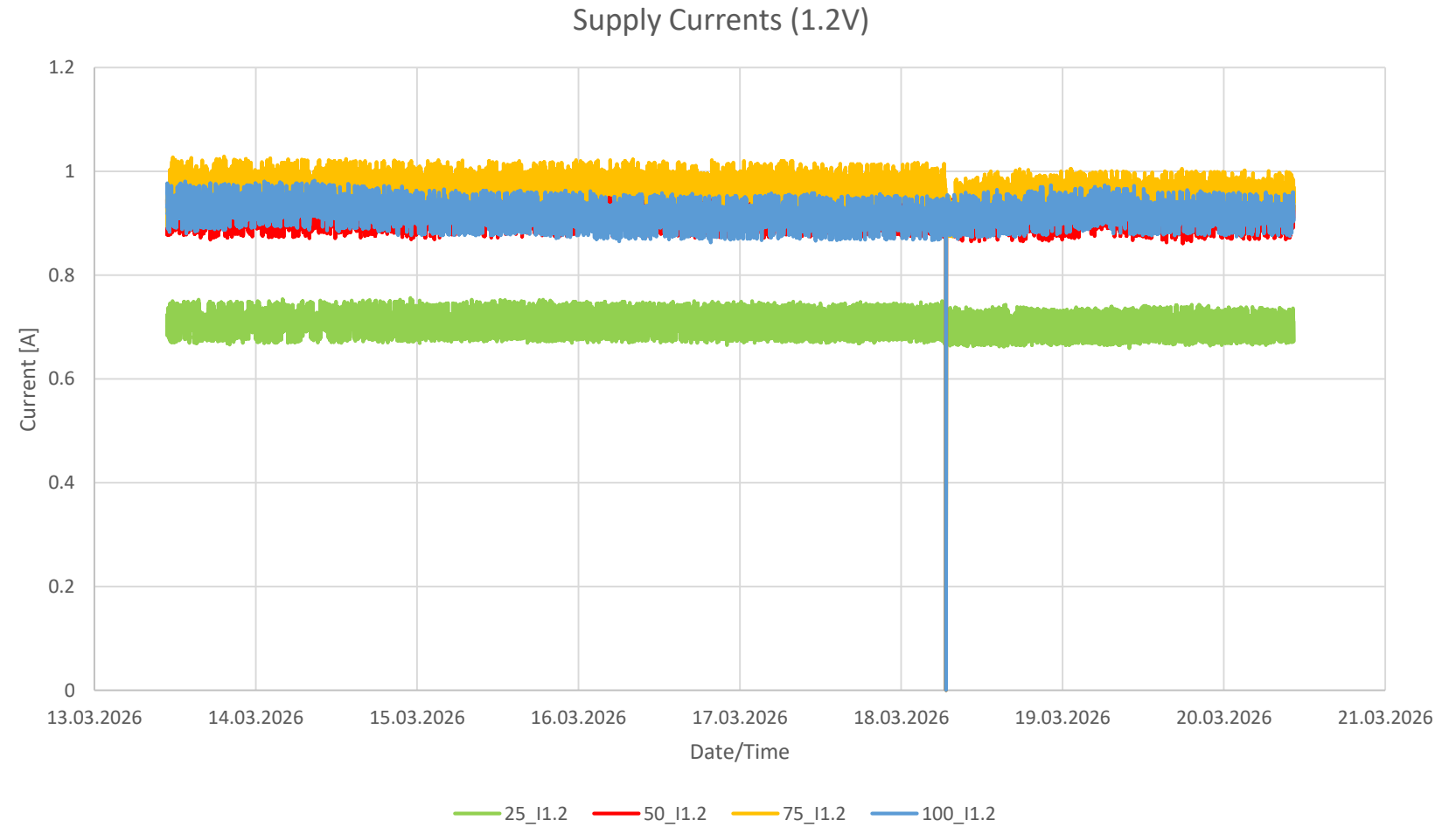
- There was a short power cut on 18 March
- After that, the 2.5V of “50Mrad” only recovered to 1.4V for unknown reason

Supply Voltages



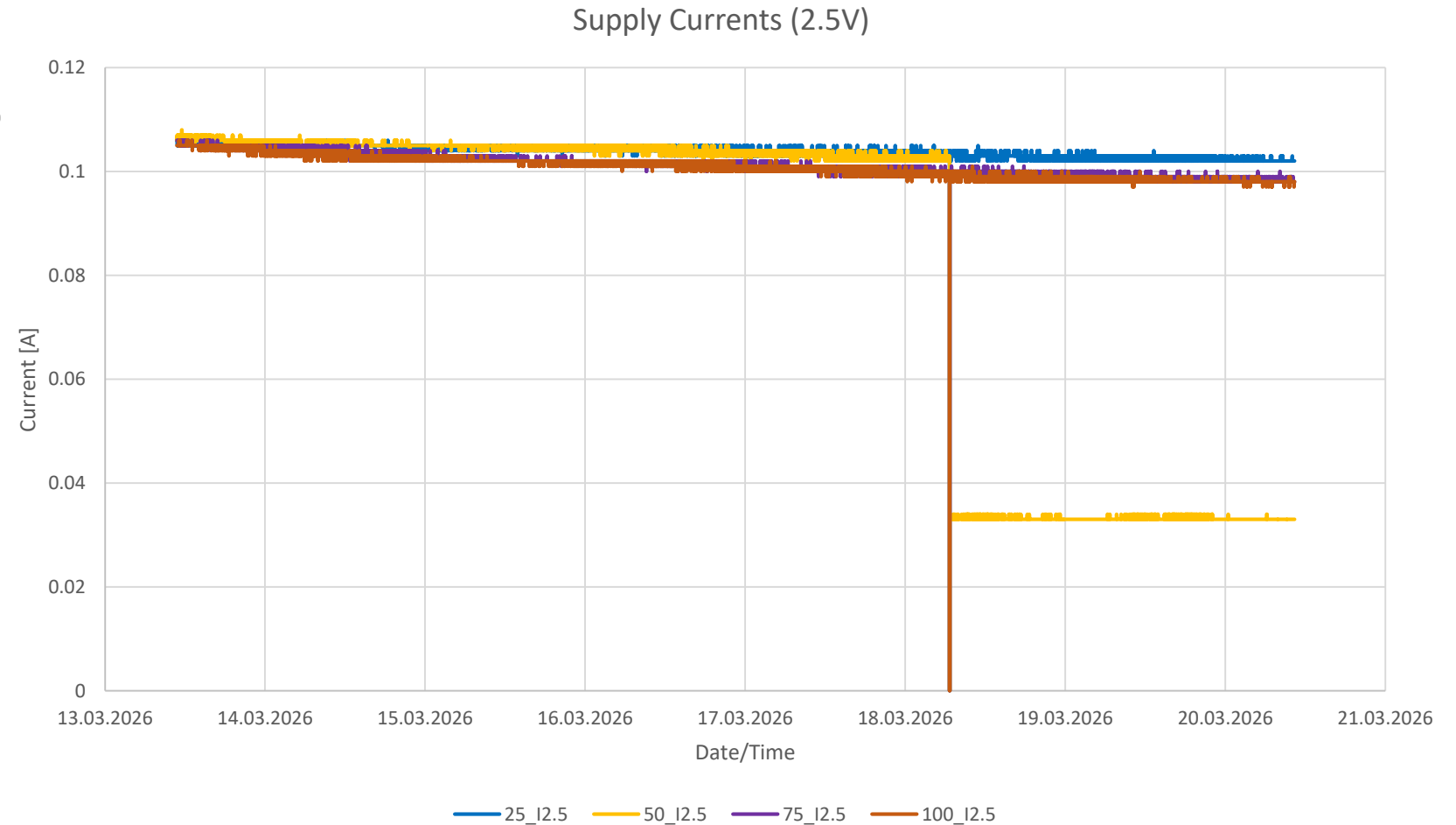
Voltages and Currents (2/3)

- 1.2V currents (lpGBT & VTRx+) stable over time



Voltages and Currents (3/3)

- 2.5V currents (VTRx+) show slight decrease over time
- Higher slope for higher dose

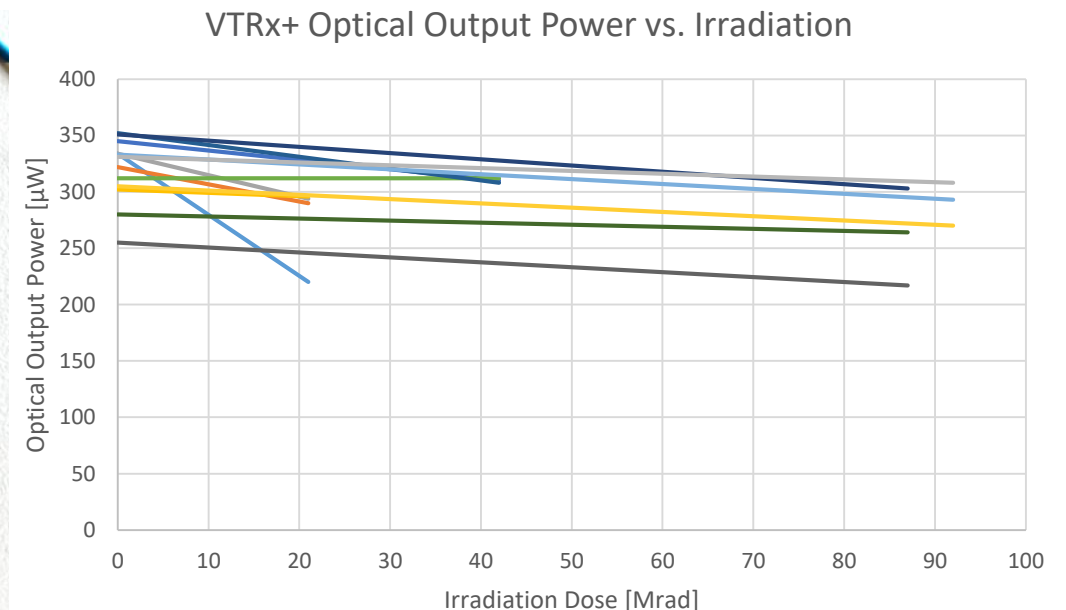
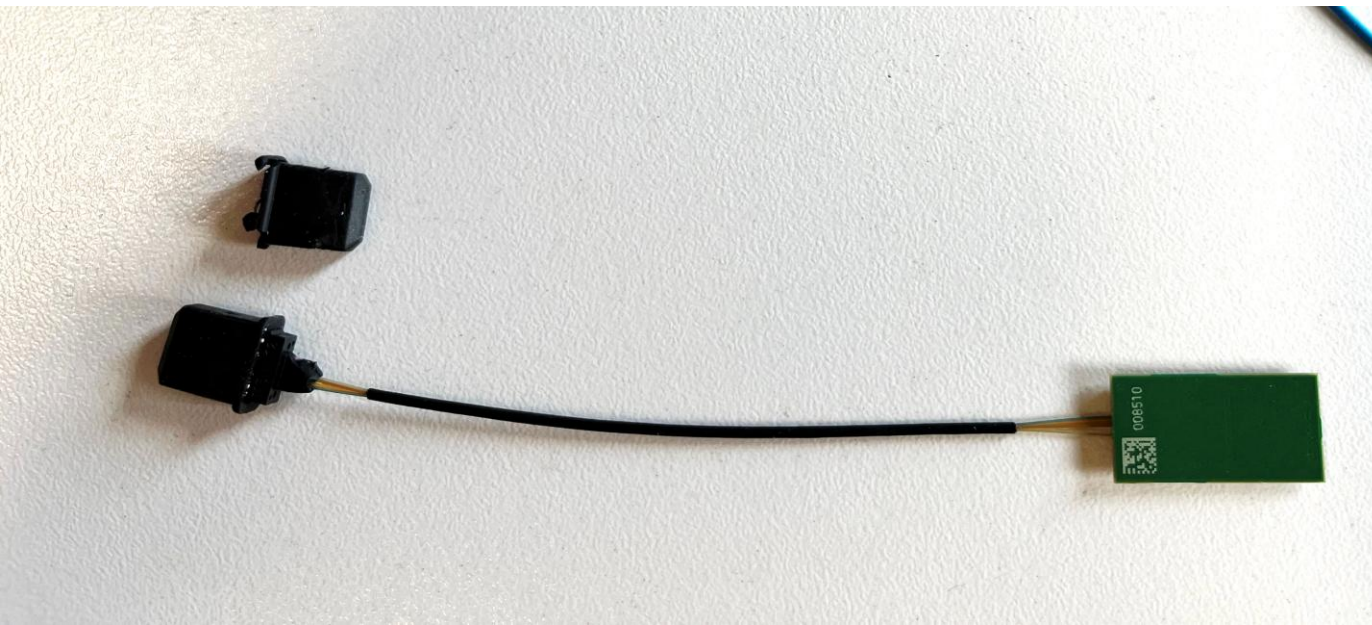


VTRx+ Average Optical Output Power (1/2)

VTRx+ S/N	Chip ID	Dose seen [Mrad]	Ch0 before irradi [μW]	Ch0 after irradi [μW]	Ch1 before irradi [μW]	Ch1 after irradi [μW]
000941	00 00 03 bf	0	320	-	315	-
001262	00 00 04 fb	21	334	220	322	290
008305	00 00 37 ae	21	334	294	302	296
008490	00 00 36 f8	42	345	310	312	312
008494	00 00 37 01	42	352	308	309	285
008496	00 00 36 a8	87	255	217	233	178
008497	00 00 36 a9	87	351	303	280	264
008504	00 00 36 b5	92	333	293	307	263
008510	00 00	92	331	308	305	270

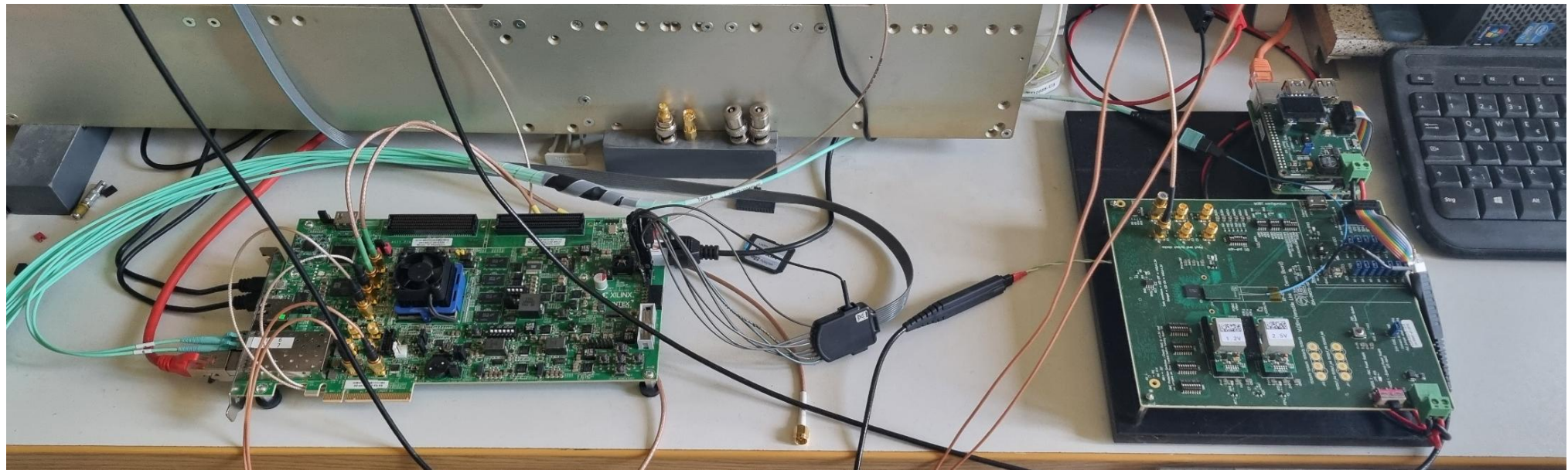
VTRx+ Average Optical Output Power (2/2)

- There is a ~15% decrease in optical power after irradiation
- Caveat: disconnection + reconnection can alter power measurement quite a bit
- Plastic parts at MPO connector suffered from irradiation



lpGBT Maximum Frequency (1/3)

- Max_f means the highest clock frequency where both conditions are met:
 1. lpGBT recovers clock from optical input data stream (involves PLL)
 2. Data sent to lpGBT on an E-Link are correctly transferred to the back-end via optical link



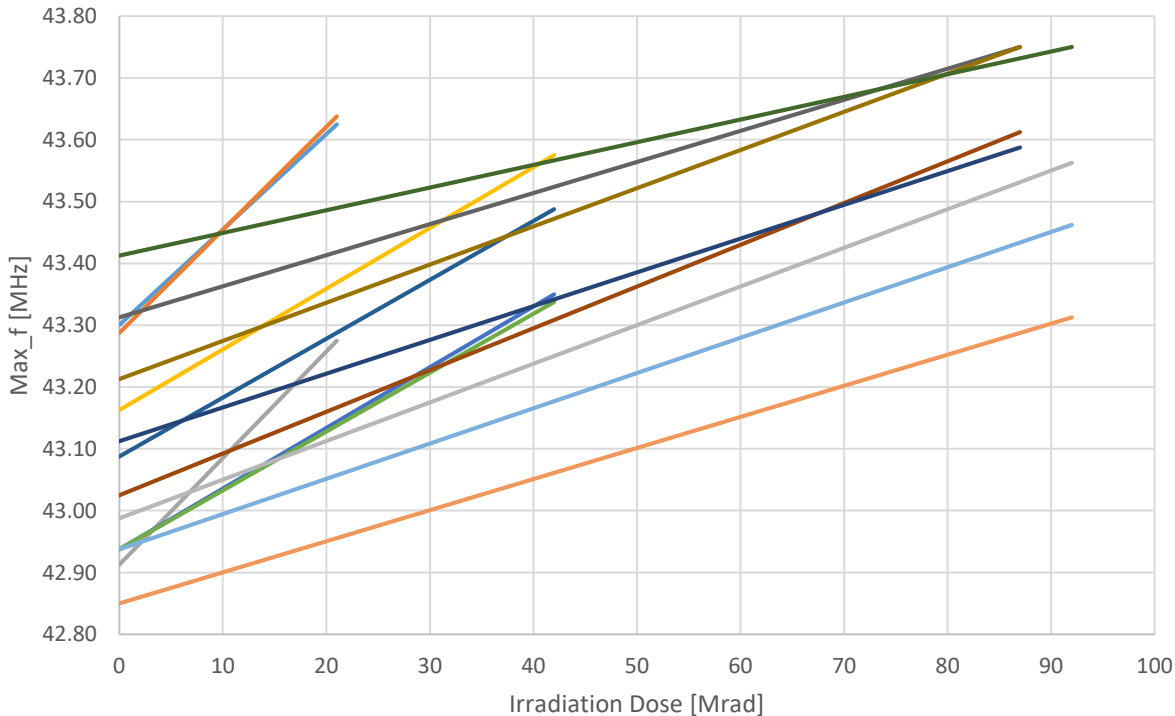
IpGBT Maximum Frequency (2/3)

Wafer/Chip	Chip ID	Dose seen [Mrad]	Max_f before irradi @ 1.2V	Max_f after irradi @ 1.2V	Max_f before irradi @ 1.3V	Max_f after irradi @ 1.3V
NAK F81.16 #1	04 a8 34 cd	0	43.1 / 43.0	-	43.0 / 42.9	-
A1	ac aa 59 50	21	43.3	43.6	43.1	43.5
A2	c4 29 49 54	21	43.3	43.6	43.2	43.5
NAK F81.11 #2	2c ad ae ec	21	42.9	43.3	42.8	43.1
A3	e4 28 77 2d	42	43.2	43.6	43.0	43.4
NAK F81.11 #4	0c 2d 6f be	42	42.9	43.4	42.8	43.2
NAK F81.11 #5	84 2b 22 72	42	42.9	43.3	42.8	43.2
NAK F81.16 #2	ac a9 db 84	42	43.1	43.5	42.9	43.3
NAK F81.16 #4	2c a8 0d 76	87	43.0	43.6	42.9	43.4
NAK F80.21 #4	84 2d 17 41	87	43.3	> 43.8	43.1	43.7
NAK F80.21 #2	ec a8 8c 04	87	43.2	> 43.8	43.1	43.6
NAK F80.11 #2	8c ae ef 3d	87	43.1	43.6	42.9	43.4
NAK F80.11 #4	84 ac c5 21	92	43.4	> 43.8	43.3	> 43.8
NBSG 05.03 #4	d5 26 1c 23	92	42.9	43.5	42.8	43.3
NBSG 05.03 #5	3d 23 45 97	92	42.9	43.3	42.7	43.2
NAK F81.11 #1	24 2d 4e 1d	92	43.0	43.6	42.8	43.4

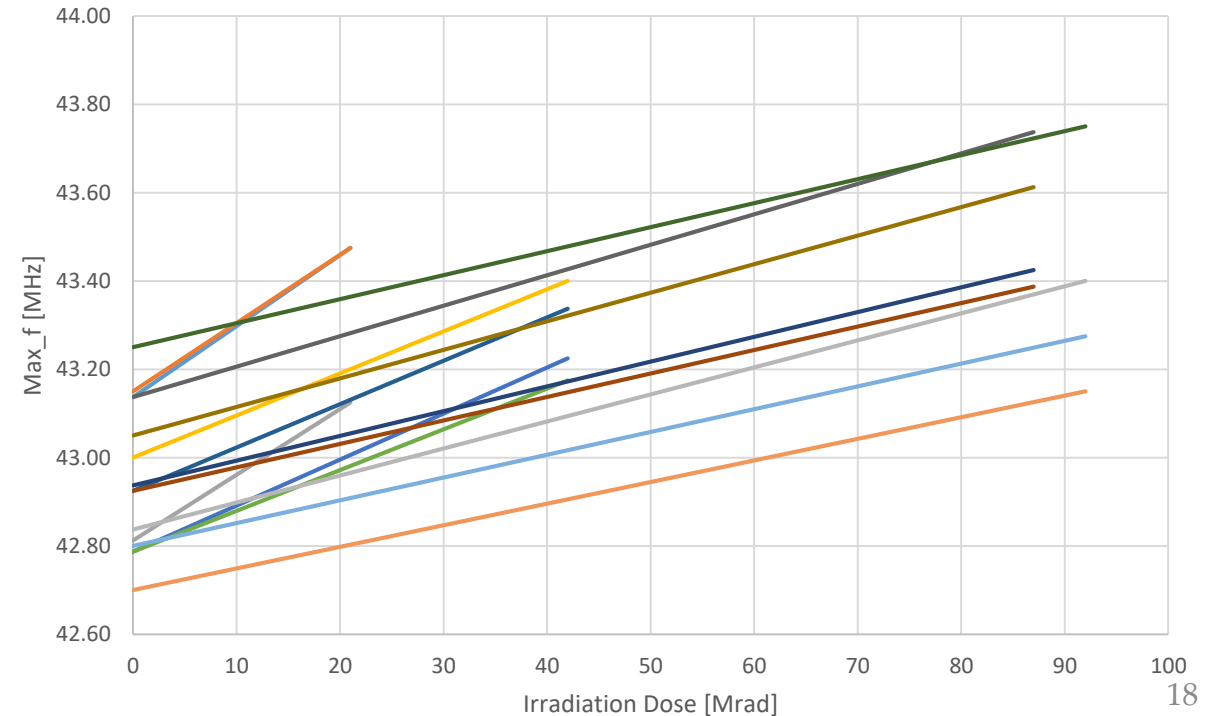
1pGBT Maximum Frequency (3/3)

- Surprise, surprise: 1pGBTs get better (~1% Max_f increase) after irradiation!

Max_f vs. Irradiation @ VDD=1.2V



Max_f vs. Irradiation @ VDD=1.3V



Summary

- We irradiated 15 (+15) lpGBTs and 8 VTRx+ up to 92Mrad under power
- Supply currents remained nearly unchanged during irradiation
- VTRx+ optical output power reduced by ~15% after irradiation
- lpGBT maximum operational frequency **increased** by ~1% after irradiation
- **Conclusion: we can use the lpGBT for the Belle II VTX at 42.4MHz (=out of specs) 😊**