Long term strategy for LHC DS cold diodes

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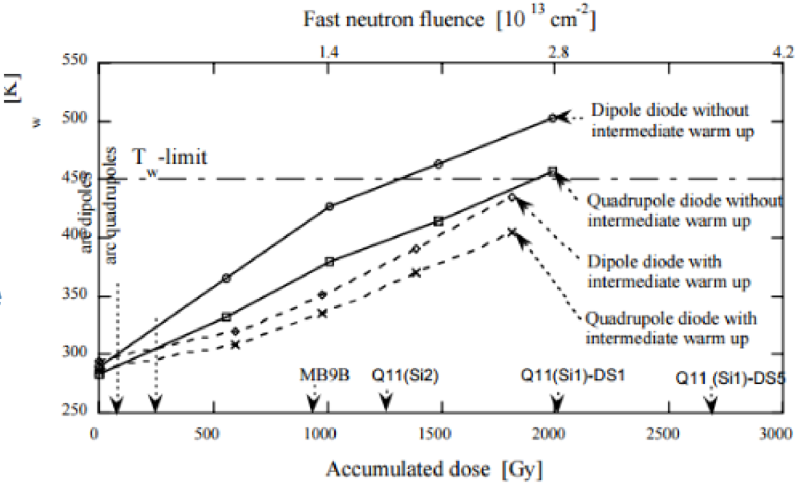
LHC Cold diode radiation qualification (2003)

- Specially developed by-pass diodes manufactured in industry.
- Irradiation tests in TCC2 at liquid nitrogen temperature.
- Installed inside magnet cryostat, relatively close to the beam.
- Effect: wafer temperature increase due to radiation (forward bias increase, 13 kA current).
- Qualified lifetime: **2 kGy and 3×10^{13} n cm^{-2}** (largely sufficient for by-pass diodes at LHC ARC locations; in DS, annual annealing and even replacement was foreseen).



R. Denz, LHC project note 688 (2003).

Studies on LHC Cold Diodes radiation

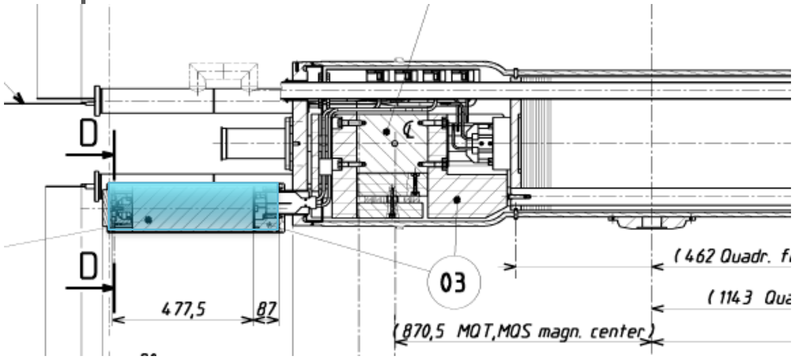
- In order to evaluate the **need** of diode replacement due to **radiation degradation**, TE/MPE asked Ruben's team (EN/STI) to estimate the dose level received by the LHC by-pass diodes up to end of 2017, up to LS2 and later for HL-LHC.

- The evaluation of radiation level is based on:
  - For present machine: BLM measurements near diodes scaled with FLUKA for specific diode locations
  - For HL-LHC: FLUKA simulations

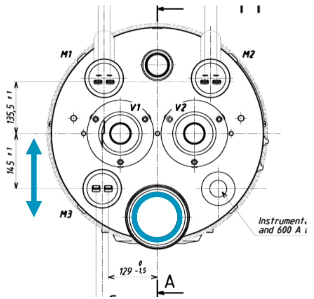
- General assumption: levels in the "deep arc" (i.e. cell 16+) are below 1 Gy/year (beam-gas interaction baseline) and excluded from the analysis.

BLM and diode position

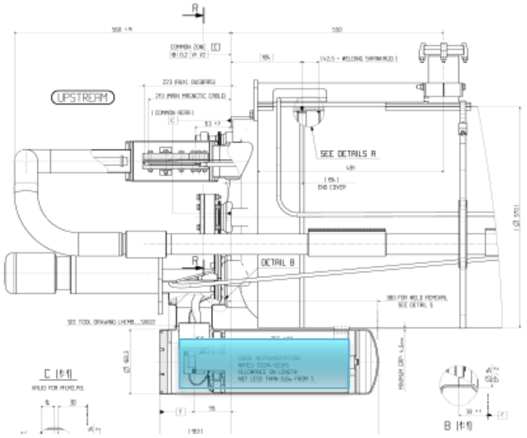
- MQ Diode position:



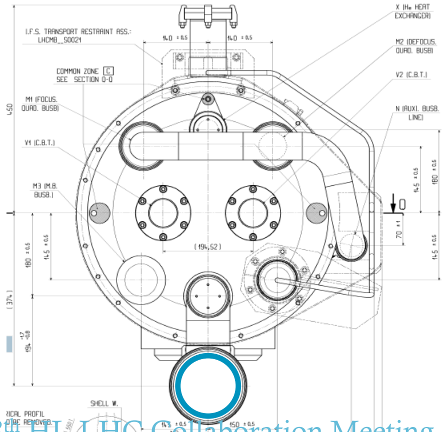
274 mm



- MB Diode position



374 mm



courtesy of Ruben Garcia Alia

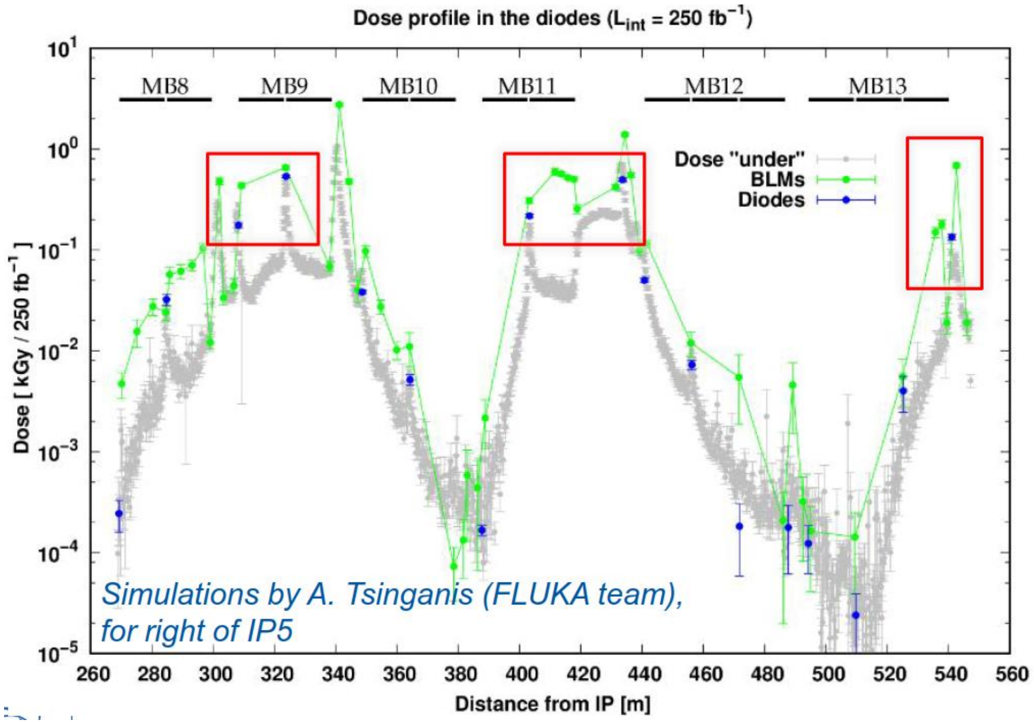
Summary of considered BLMs

Diode	BLM dist. to IP [m]	Position (u,v) [cm]	Dose R1 [Gy]	Dose R5 [Gy]
MBA.9	309.3	-51, 0	**8**	**125**
MBB.9	323.6	0, 56	**42**	**42**
MQ.11	434	-51, 0	**47** **(47)**	**47** **(47)**
MQ.13	542.6	-51, 0	**19**	**19**
			Dose L1 [Gy]	**Dose L5 [Gy]**
MBA.9	-323.6	0, 56	**25**	**23**
MBB.9	-341.2	-0.51, 0	**98**	**99**
MBB.11	-418.8	0, 56	**1.2** **(21)**	**0.4** **(143)**
MBC.13	-542.5	-0.51, 0	**2.3**	**18**
			Dose L2 [Gy]	**Dose R2 [Gy]**
MQ12.R2	488.7	51, 0	**196**	
MB.B10L2	-381.5	-51, 0		**306**

- All considered BLMs are ± 2m from magnet start (side opposite the IP)
- Dos value im black are for 2016 pp (in green, 2015 PbPb)
- Strong gradients expected, both longitudinal and radial

courtesy of Ruben Garcia Alia

Ratio between BLMs data and diodes



Ratios between nearest BLM (type) and diode radiation level:

- *MBA9: 2.5 (Q)*
- *MBB9: 1.2 (D)*
- *MBB11: 1.4 (D)*
- *MQ11: 2.8 (Q)*
- *MQ13: 5.1 (Q)*

*Conservative approach: **factor 1** for dipole BLMs, **factor 1.5** for quadrupole BLMs (in beam plane, thus larger losses)*

courtesy of Ruben Garcia Alia

Estimated diode dose: today and until LS2

Estimated diode dose: today and LS2 projection

BLM	BLM dose (Gy)	dcum (m)	Diode	Total Dose now (Gy)	Ion Dose (Gy)	Total Dose LS2 (Gy)
BLMQI.08R1.B1E30_MQML	41.0	309.3				
BLMBI.09R1.B0T10_MBA-MBB_08R1	54.0	323.6				
BLMQI.11R1.B1E10_MQ	184.1	434.4	MQ11	123	23.5	192
BLMQI.13R1.B1E10_MQ	46.7	542.6				
BLMQI.13L5.B2E10_MQ	36.9	12787.6				
BLMBI.11L1.B0T20_MBA-LEFL_11L1	41.6	26240.1				
BLMQI.09L1.B2E10_MQM	178.5	26318.4	MBB9	119		155
BLMBI.09L1.B0T10_MBB-MBA_08L1	31.3	26335.3				
BLMBI.11L5.B0T20_MBA-LEFL_11L5	154.9	12910.6	MBB11	186	143	437
BLMQI.09L5.B2E10_MQM	195.6	12988.9	MBB9	130		170
BLMQI.08R5.B1E30_MQML	212.7	13638.7	MBA9	142		185
BLMQI.11R5.B1E10_MQ	285.2	13763.9	MQ11	190	25.5	283
BLMQI.10L2.B2I10_MQML	305.5	2950.9	MBB10	204	153	474
BLMQI.12R2.B1I10_MQ	196.3	3821.1	MQ12	131	98	304

Considerations: For quadrupole BLMs: level on diodes 1.5 smaller; for dipole BLMs: level on diode same as BLM + 20% more for Run 1; 2018 luminosities: 50fb^{-1} for protons, 1nb^{-1} for ions

courtesy of Ruben Garcia Alia

Estimated integrated dose and fluence during HL-LHC

Integrated dose and fluence during HL-LHC

Magnet	TID (kGy)	1MeV neq (cm-2)
MBA9	2.11	2.37E+13
MBB9	6.44	7.87E+13
MBB11	2.61	3.39E+13
Q11	5.95	3.80E+13
Q13	1.61	1.29E+13

- *Considering **only proton runs, right of IP5**, and normalized to full HL-LHC lifetime of 3000 fb^{-1}*

HiLumi HL-LHC PROJECT

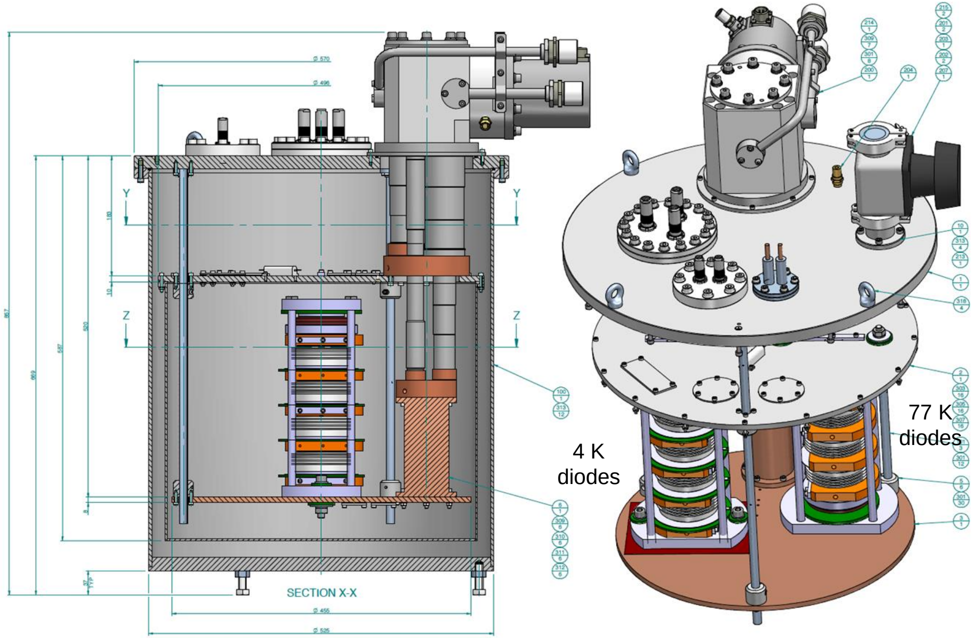
courtesy of Ruben Garcia Alia

Cold diodes for LHC and HL-LHC

- Re-established the contact with **Dynex** and ensured that they still have the **"know how"** to produce similar diffusion diodes as for the **LHC** (reference).
- Asked Dynex to **specially develop and produce** diffusion by-pass diodes **more radiation tolerant** (thin and very thin base width), in a **short delay time** in order to **qualify** them in a dedicated radiation area at CERN, in CHARM test facility, **during 2018 RUN**.
- Stage approach proposed for radiation testing: first testing campaign to **reproduce earlier radiation test results** foreseen in CHARM in 2018, and **compare with new prototype diodes**. Then to **study their behaviour with the maximum radiation** we could get until end of 2018, close to HL-LHC requirements.
- **Designed and produced a cryo-cooler based system** in order to qualify the diodes at **77K** and **4K** being exposed to **radiation**.
- **Designed and produced** the entire diodes **test bench** (power and control part) according to the HL-LHC diodes parameters, and **integrate** the system into **CHARM** test facility.
- Perform **specific electrical tests** on the diodes as a function of different parameters (temperature, integrated dose) and monitor their **characteristics**.

Cryo-cooler setup for HL-LHC cold diodes

- 3D model



- Diode assembly

Measuring system for HL-LHC cold diodes

- Complete new test bench, built from scratch, for HL-LHC diodes: **18kA**, **40m** distance, radiation environment and capable to:
  - Measure diodes electrical parameters: $\mathbf{U_{TO}}$, $\mathbf{U_{FWD}}$, $\mathbf{U_{REV}}$
  - 77 and 4 K temperatures monitoring
  - Heaters control and regulations
  - Database results

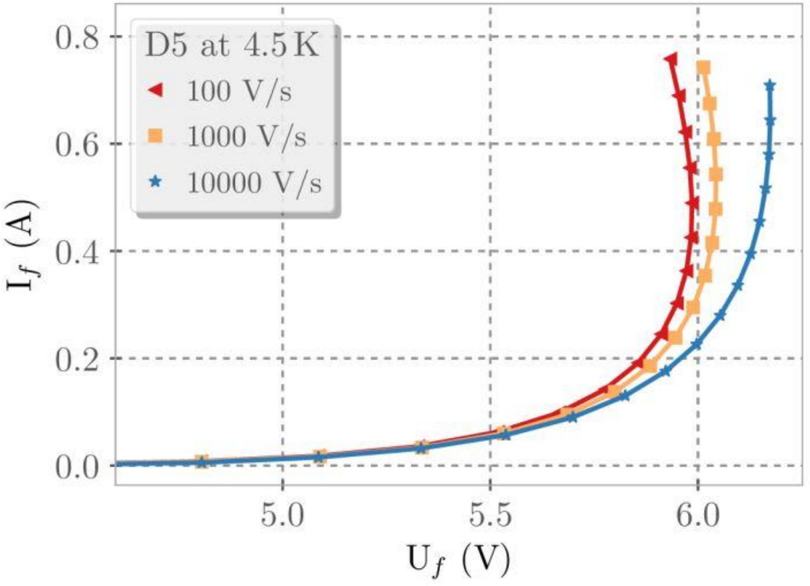
Measuring setup located in control room

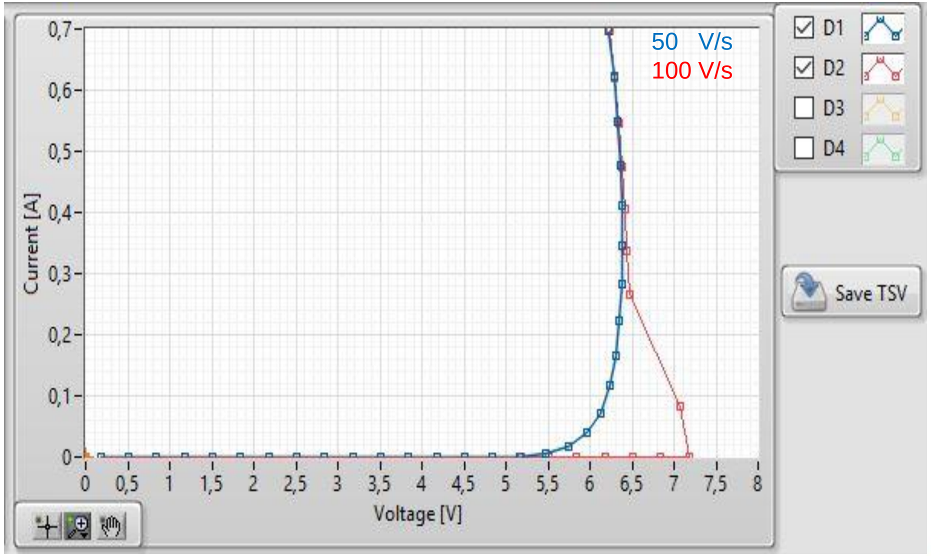
Cryo-cooler and diodes in radiation area

HiLumi HL-LHC PROJECT

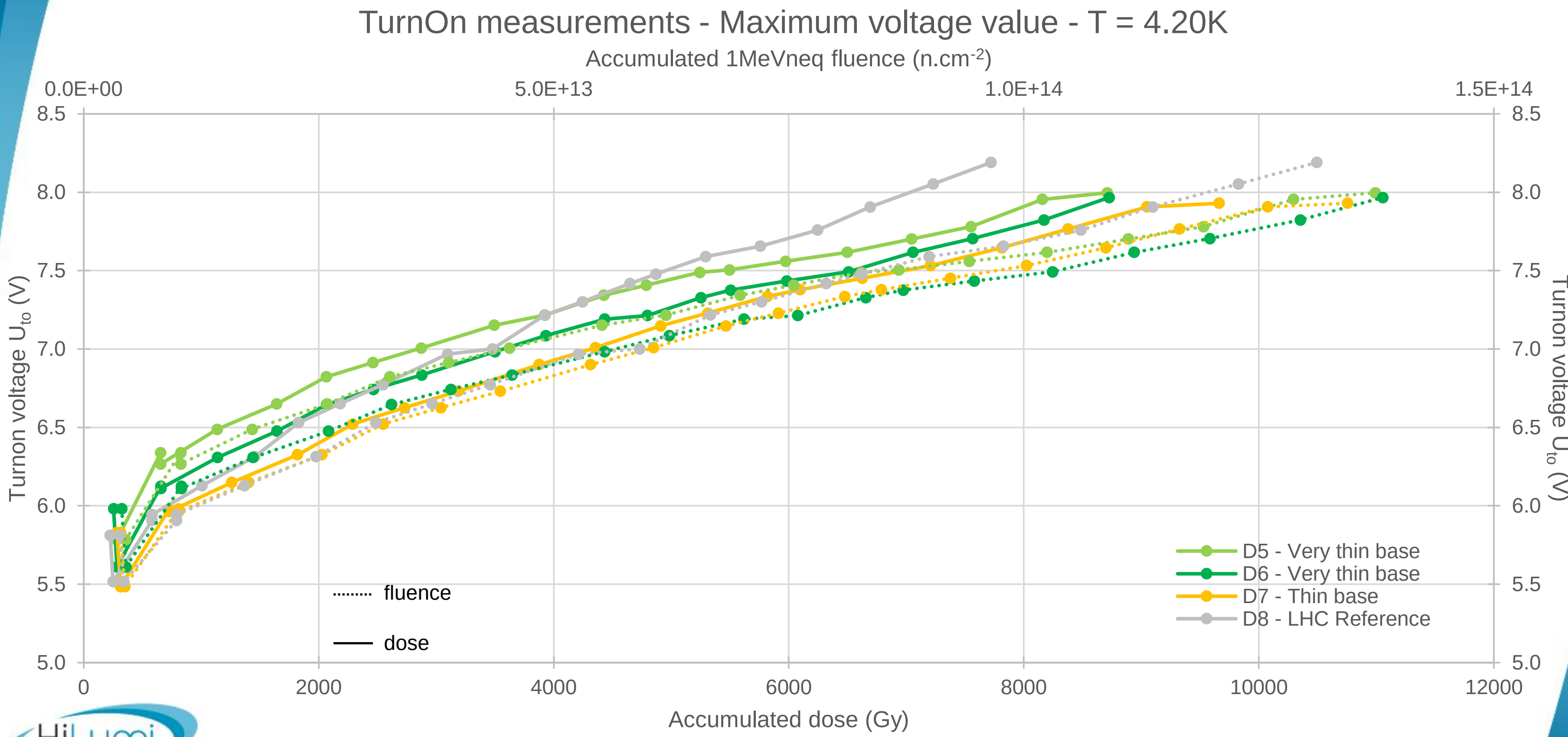
Typical data recorded on a weekly rate basis: U_{to}

- **Turn On** characteristic $I_{to} = f(U_{to})$ of each diode at 4.20K and 77.00K is measured by applying a voltage ramp with proper rise rate on each diode individually and measuring the voltage drop over it, e.g. the current flowing through it.



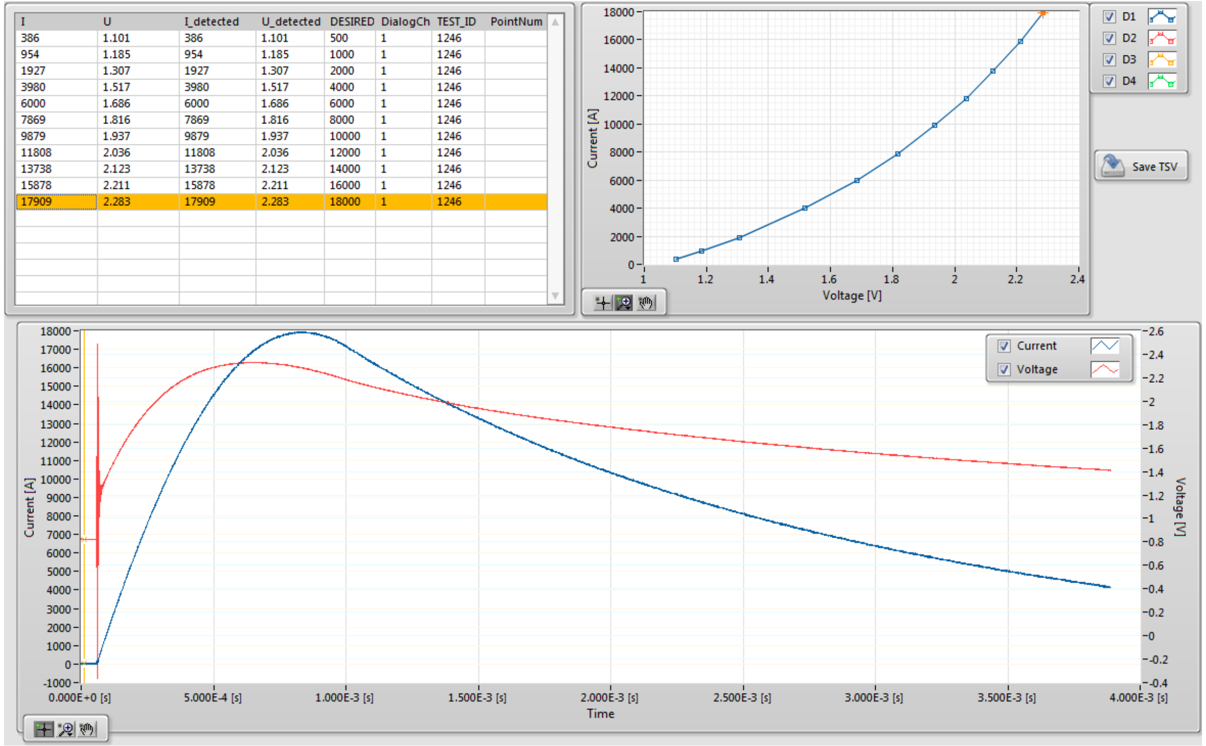


Evolution of U_{to} at 4.20K since the beginning



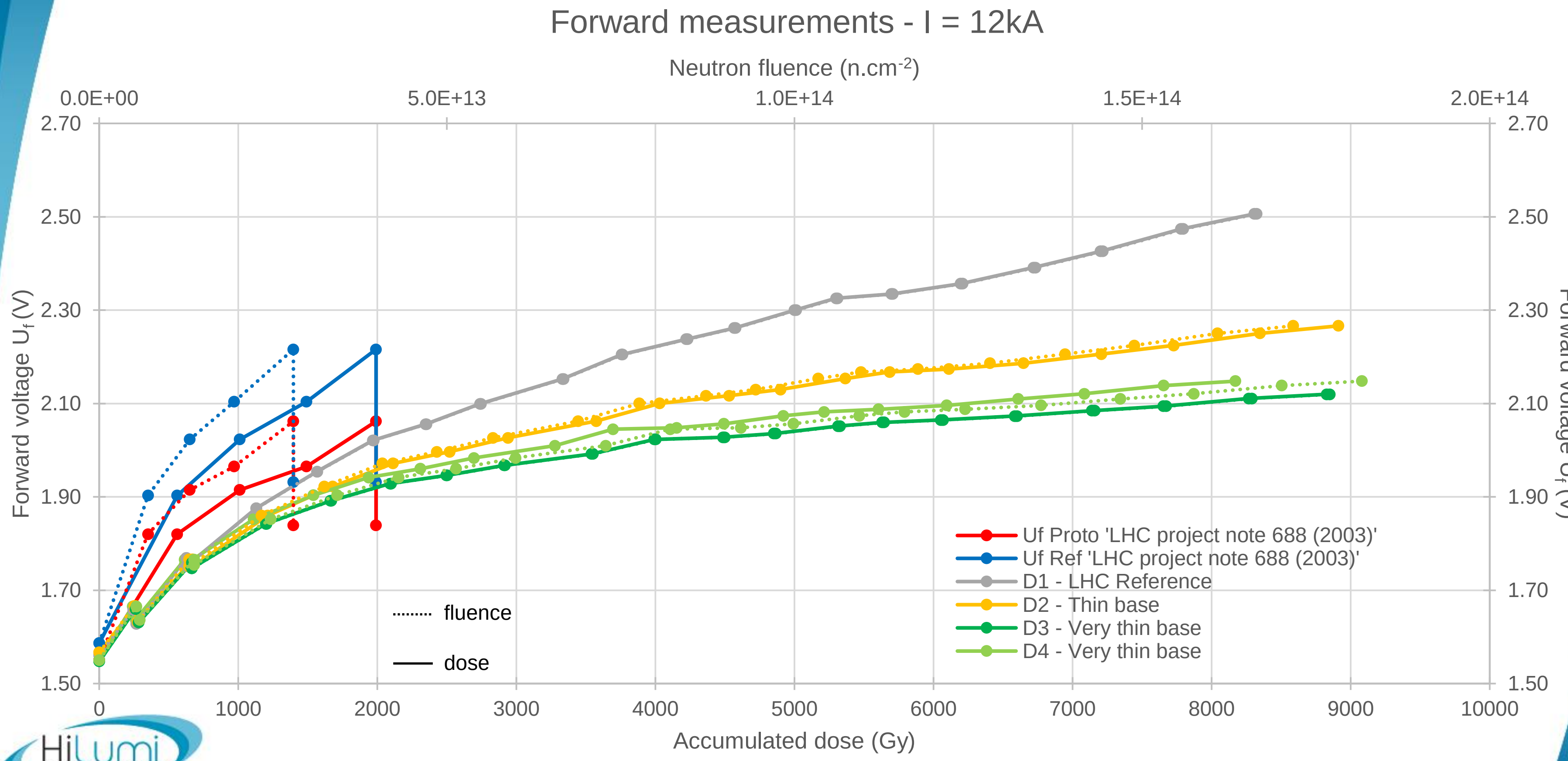
Typical data recorded on a weekly rate basis: U_{FWD}

- To measure the $\mathbf{U_{FWD}}$, a pulse of current is sent through the entire 77K diode stack. The voltage drop on each diode is measured individually at the peak of the current pulse, where dI/dt = 0. The pulse is generated by the pulse generator, located at the rack in the control room, 40 m away.



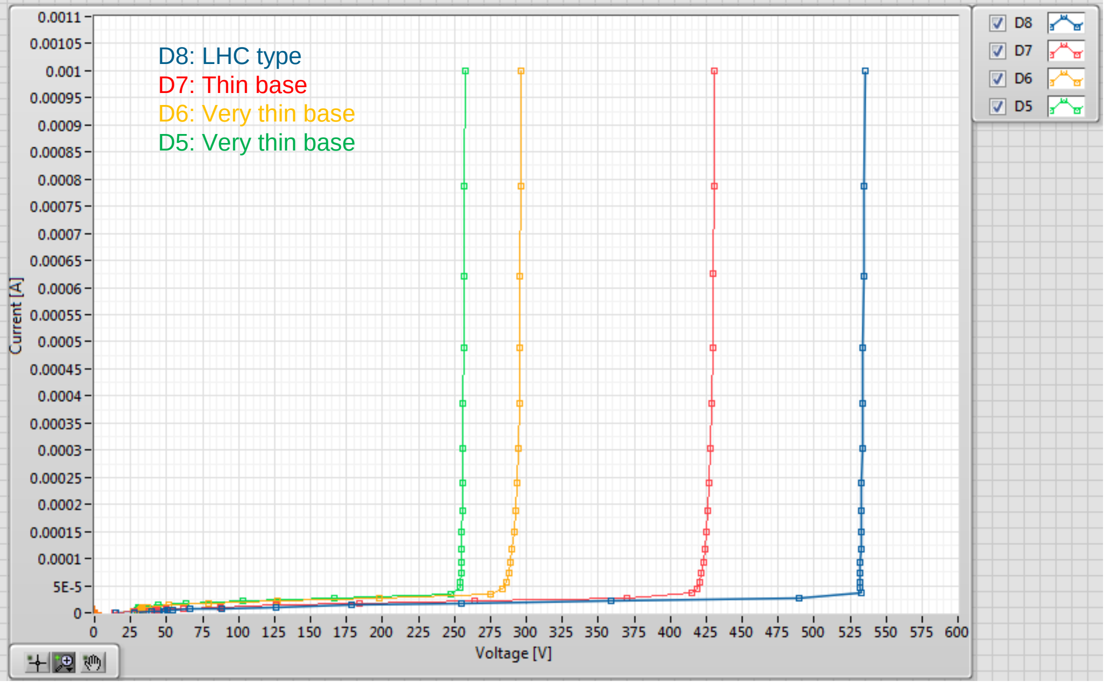
I	U	I_detected	U_detected	DESIRED	DialogCh	TEST_ID	PointNum
386	1.101	386	1.101	500	1	1246	
954	1.185	954	1.185	1000	1	1246	
1927	1.307	1927	1.307	2000	1	1246	
3980	1.517	3980	1.517	4000	1	1246	
6000	1.686	6000	1.686	6000	1	1246	
7869	1.816	7869	1.816	8000	1	1246	
9879	1.937	9879	1.937	10000	1	1246	
11808	2.036	11808	2.036	12000	1	1246	
13738	2.123	13738	2.123	14000	1	1246	
15878	2.211	15878	2.211	16000	1	1246	
17909	2.283	17909	2.283	18000	1	1246	

Evolution of U_{FWD} at 12kA since the beginning



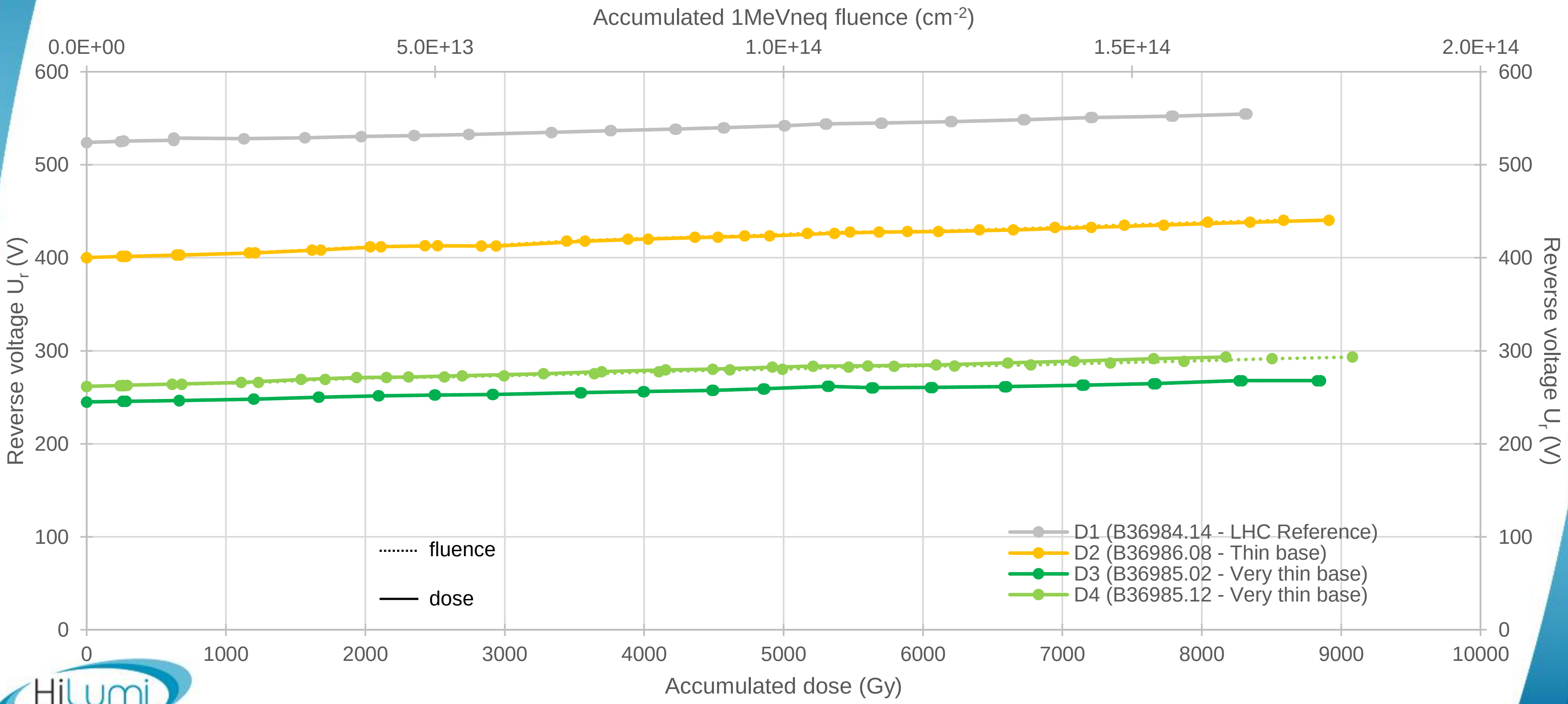
Typical data recorded on a weekly rate basis: U_{REV}

- **Reverse** characteristic Ir = f (Ur) of each diode at 4K and 77K is measured, in each diode separately, up to a maximum reverse bias current of Irmax = 1 mA.



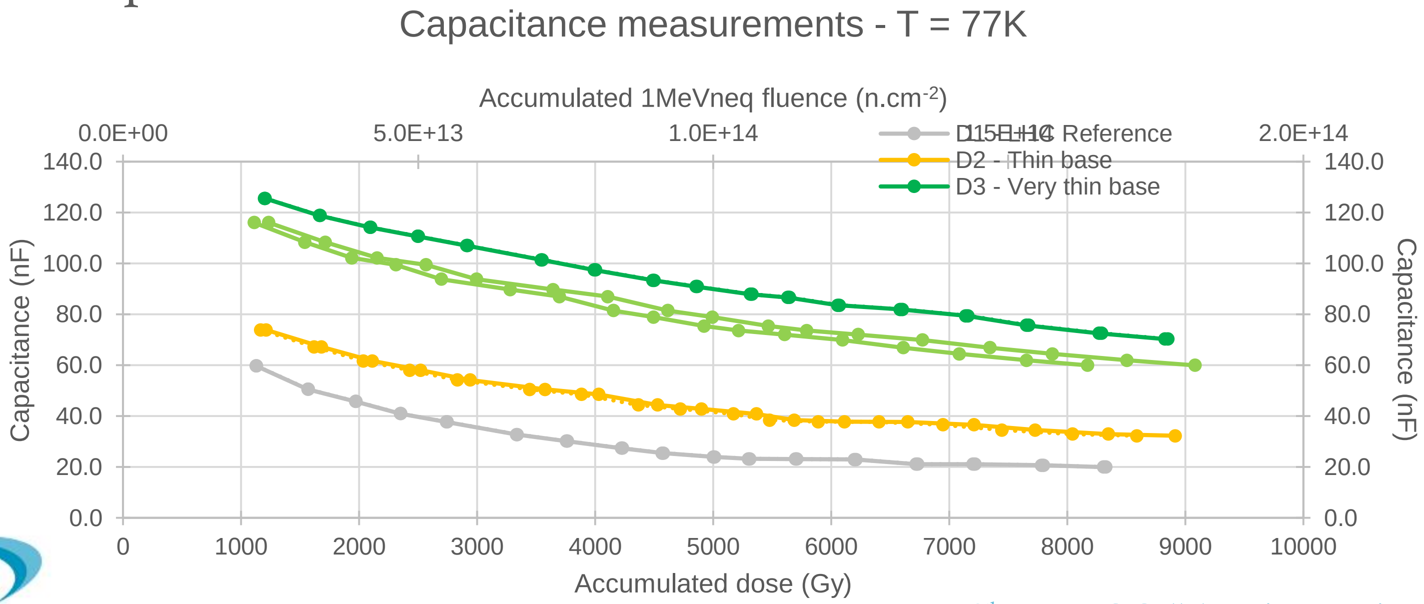
Evolution of U_{REV} since the beginning:

Reverse measurements - I = 1 mA - T = 77K ; 4.2 K very similar !



Evolution of the capacitance measurement

- The capacitance measurements at 77K can be used as a marker of the radiation level. The value decreases showing the effect of the radiation on the wafer.
- The capacitance values at 4K are not measurable.



Conclusions

- The tests currently performed in CHARM on **LHC standard diodes** type are showing **very promising results**. The actual diodes seems to be less sensitive to radiation then the qualification performed in 2003, for the actual LHC diodes. However the spectrum and uncertainty in dosimetry should be considered.
- The diode radiation level analysis was based on the **worst-case locations**: cells 9, 11 and 13 in the DS of IP1 and IP5, and those impacted by the ion BFPP losses (IP1, IP2 and IP5).
- According to the **previous diode qualification level of 2 kGy**, the situation is expected to be **safe up to LS2**.
  - For Run 3, main risk could come from ion runs, for which HL-LHC parameters will be used and an ion luminosity of 6 nb-1
- The **two diodes** that are expected to have **received more dose by LS2** are MBB11.L5 and MBB10.L2, with roughly **500 Gy**. They will be removed during LS2 for further studies.
- We plan to study the annealing effect on the diodes irradiated in CHARM in order **to extrapolate data for LHC and HL-LHC.**
- For **HL-LHC**, levels for proton operation could be as large as ~**6 kGy** and **10^{14}** neq*cm-2, already achieved in CHARM test facility.
- **Based on the current qualification performed in CHARM**, it seems that there is **no need to replace the LHC diodes in DS radiation** hot spots, also during HL-LHC runs. However the spectrum and uncertainty in dosimetry should be further studied, in particular for ion runs.

Special thanks to CHARM test facility team.

Thank you for your attention