Diode radiation tests, setup and first results

- Background / Motivation
- Test requirements
- Test setup & Measurement procedure
- Status & preliminary results
- Outlook

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Introduction

- **Subject**: Following TCC recommendation (meeting #29, May 2017), the option of using **cold by-pass diode** in order to protect the **HL-LHC Inner Triplets** in case of **quench** has been studied, the project started in **September 2017**.

- **Purpose**: In order to select the **future potential diodes** which could be used during the **whole operation time** of HL-LHC and in order to be sure that they will be **reliable** during this time, a **dedicated test setup** has been **designed** and **built**.

- This test setup, located at **CHARM**, allows to **characterise** diodes @ **4.2K** and @ **77K** up to **18kA** with a **particle spectrum representative** of their future location in the **Inner Triplets area** (~ **30kGy** (**dose**) and ~ **2.10^{14}n.cm^{-2}** (**1MeVneq fluence**)).

See slides by Y. Leclercq (location) G. Lerner (expected radiation levels)

- This characterisation consists of following the **evolution** of the diode **electrical parameters** (forward voltage, turn-on voltage, reverse blocking voltage, capacitance) as a function of **radiation** (dose & 1MeVneq fluence). To sum up for forward, turn-on and reverse blocking voltage:

Performing weekly measurements (specific test sequence) & Data acquisition

I = f(U)

Data processing

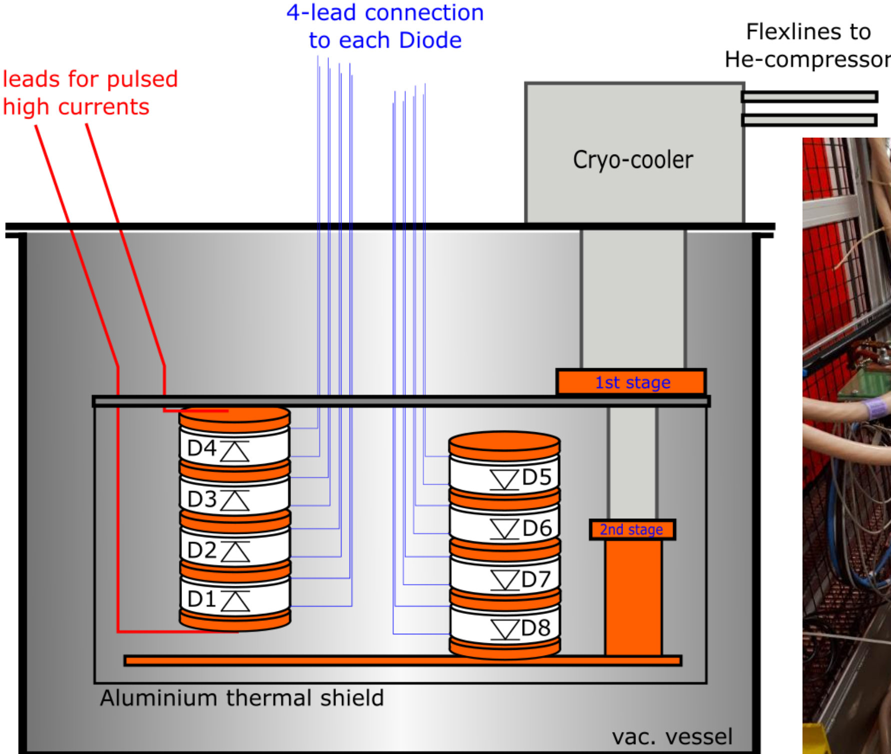
Final plots

U = f(dose) & U = f(1MeVneq fluence)

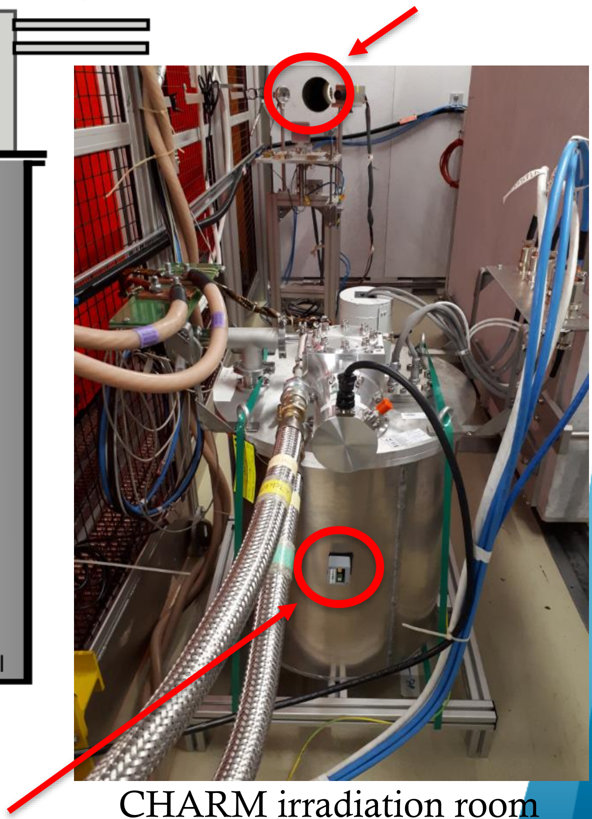
I. Cryostat

- **2 diode stacks** (4.2K & 77K): 2 LHC, 2 thin base, 4 very thin base diodes, **temperature sensors**, **heaters** …
- **Designed** by ourselves and **installed** at a specific test position inside the **CHARM** (Cern High energy AcceleRator Mixed field facility) **irradiation room** : **Particle spectrum representative of the HL-LHC Inner triplets area** and **fast dose, fluence accumulation** (Fluka factors calculated by A. Infantino with R2E & RP teams).
- Radiation Monitors (RadMons) data are calibrated data scaled with the protons-on-target (PoT).


Cryostat opened



Cut view



CHARM irradiation room

I. Rack

- A **test bench**, **built from scratch** by **ourselves**, containing all the electronic systems needed for the weekly measurements. Installed in **the CHARM control room** (safe from a radiation point of view).

- **Several purposes**:

  - To measure different diode electrical parameters (U_f, U_{to}, U_r) as a function of current: I = f(U), and display the corresponding characteristics.

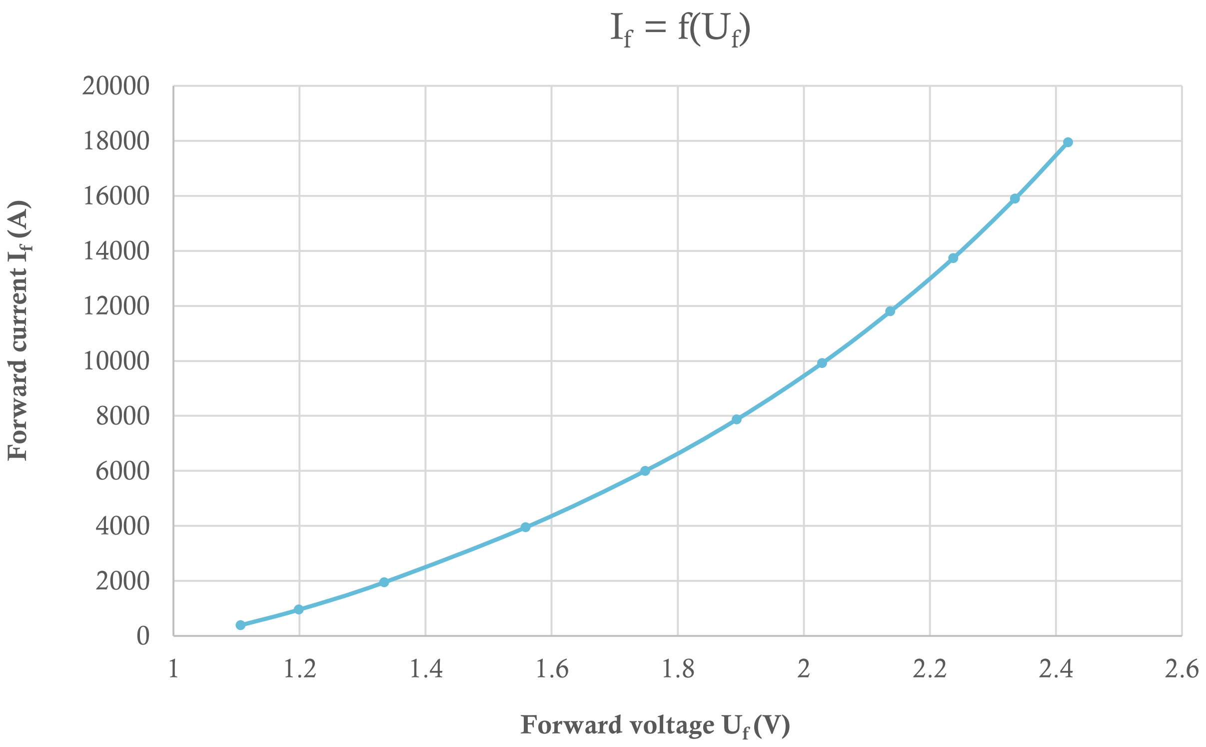
  - To monitor and control the temperatures (4.2K & 77K).

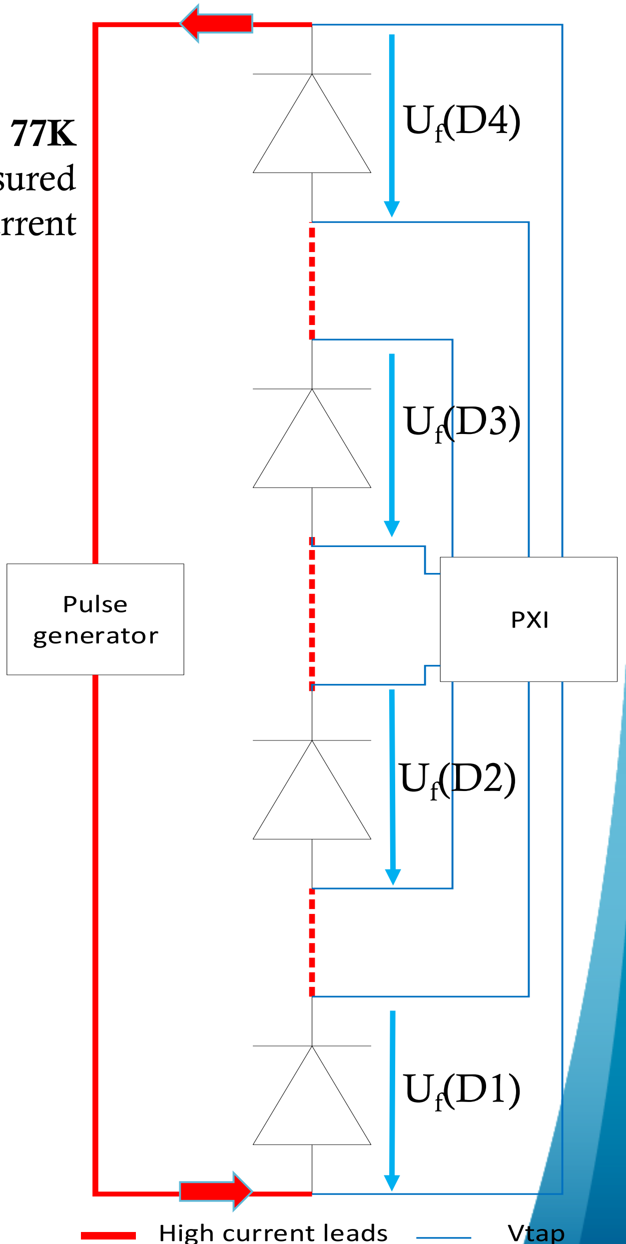
  - To store data (measurements with the different parameters: **temperature**, **diode type**, …) in a database.

  - To control high voltage power supply, as the high current pulses require 1kV on capacitor bank.

II. $I_f = f(U_f)$ forward characteristic @ 77K

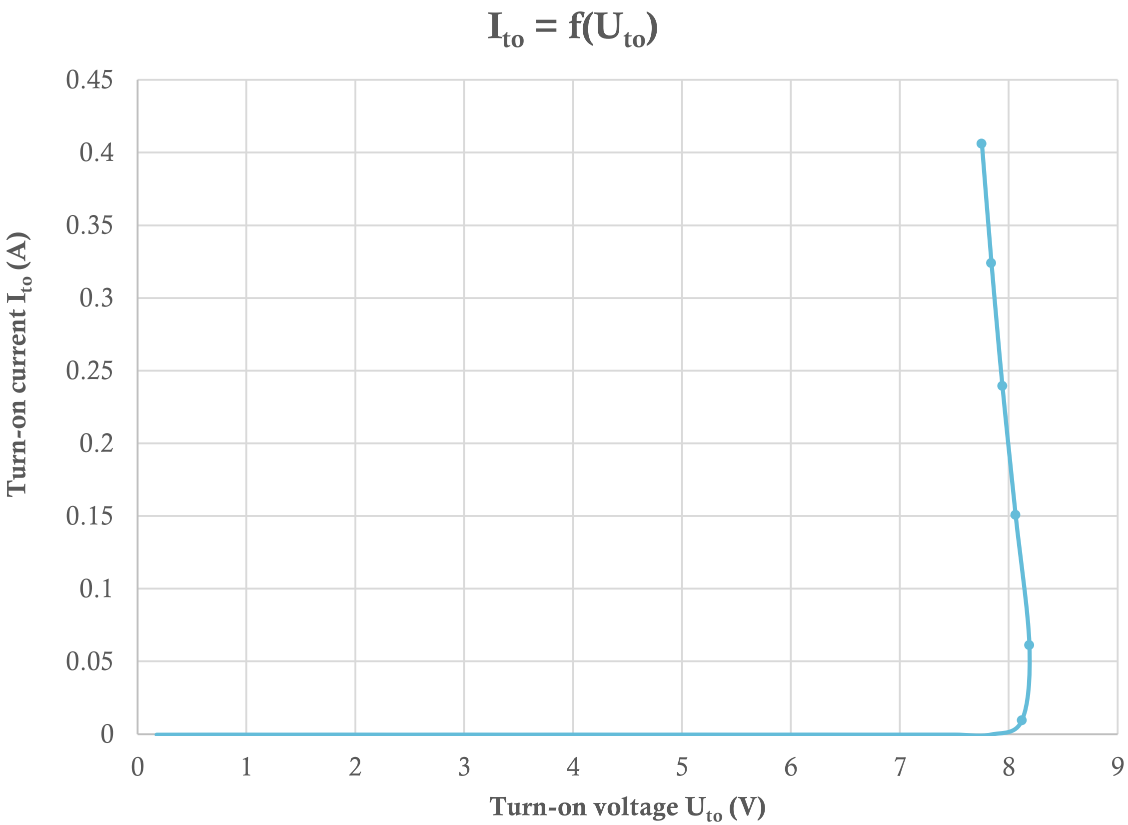
- A **high current pulse I_f** is sent from the **pulse generator** to the **4 diodes** @ **77K** (connected in series). At the **same time**, thanks to **PXI**, we measured **individually** the **voltage drop U_f** of each diode at the **peak** of the high current pulse (i.e. **$dI_f/dt=0$**).
- **500A, 1, 2, 4, 6, 8, 10, 12, 14, 16, 18kA.**

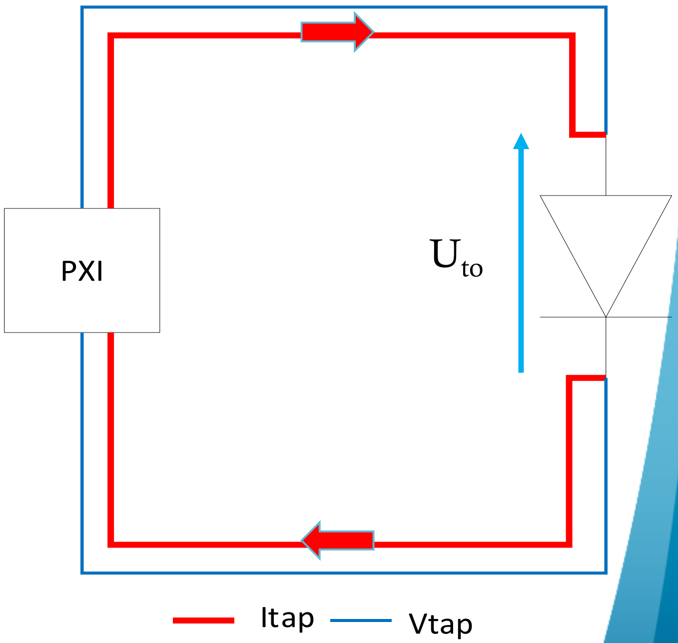




II. $I_{to} = f(U_{to})$ turn-on characteristic @ 4.2K & 77K

- The turn-on voltage, $\mathbf{U_{to}}$, is measured @ 4.2K & 77K by generating a **voltage ramp** with a fast enough rise rate (100 V/s) on **each diode individually** and measuring the **voltage drop** across it, i.e. the current $\mathbf{I_{to}}$.





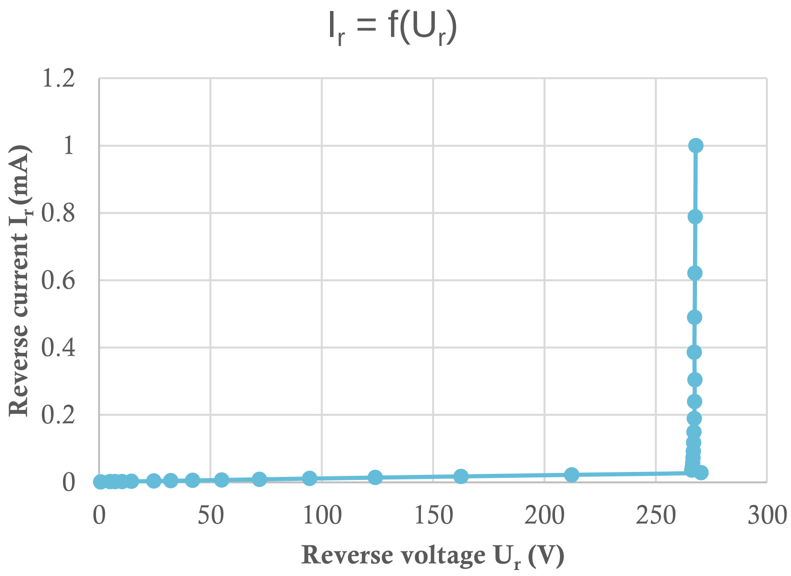
II. Reverse blocking voltage & Capacitance @ 4.2K & 77K

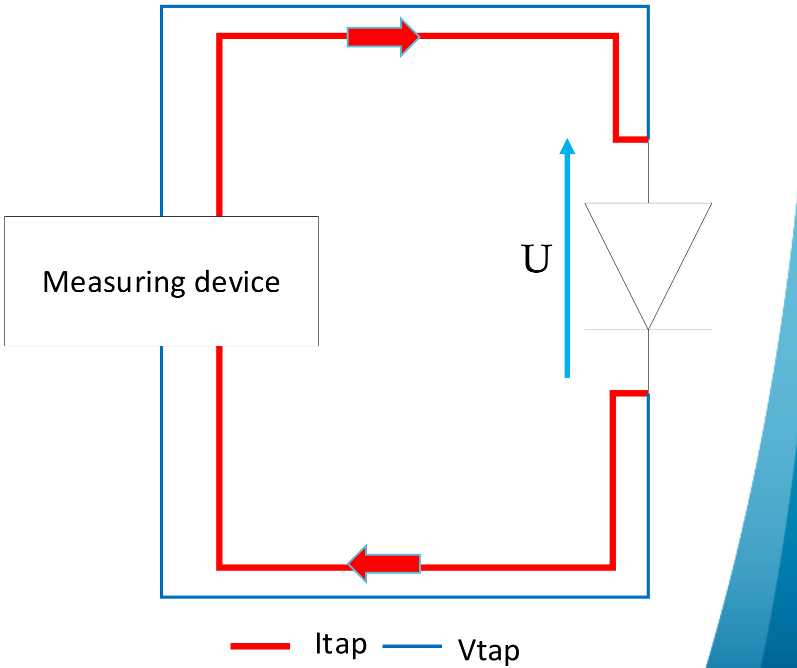
Reverse blocking voltage

- A **current I_r** generated by the "**Keithley 2410 Source Measure Unit**" is sent to **one** diode and we measured the **voltage U_r** on this diode at the **same time**. These measurements are done for the **8 diodes**, @ **4.2K** & **77K**.
- The measuring device communicates with **PXI** (GPIB) and is controlled by a **LabVIEW** software.
- Logarithmic sweep from about 1µA up to 1mA.

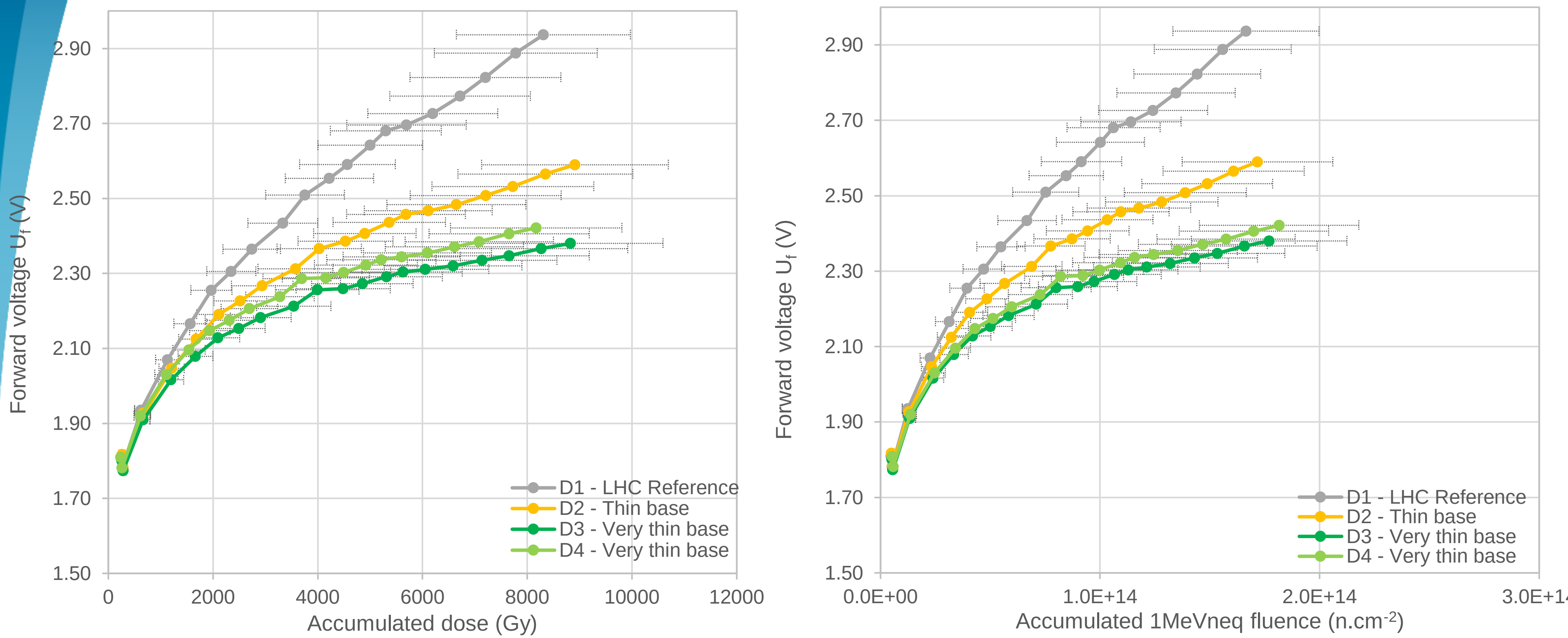
Capacitance

- The measurements are performed using a **LCR meter**. This device generates an excitation voltage (amplitude = 250mV & f = 1kHz) below conducting threshold voltage (= 300mV) at room temperature.





III. Forward plots @ 77K, 18kA

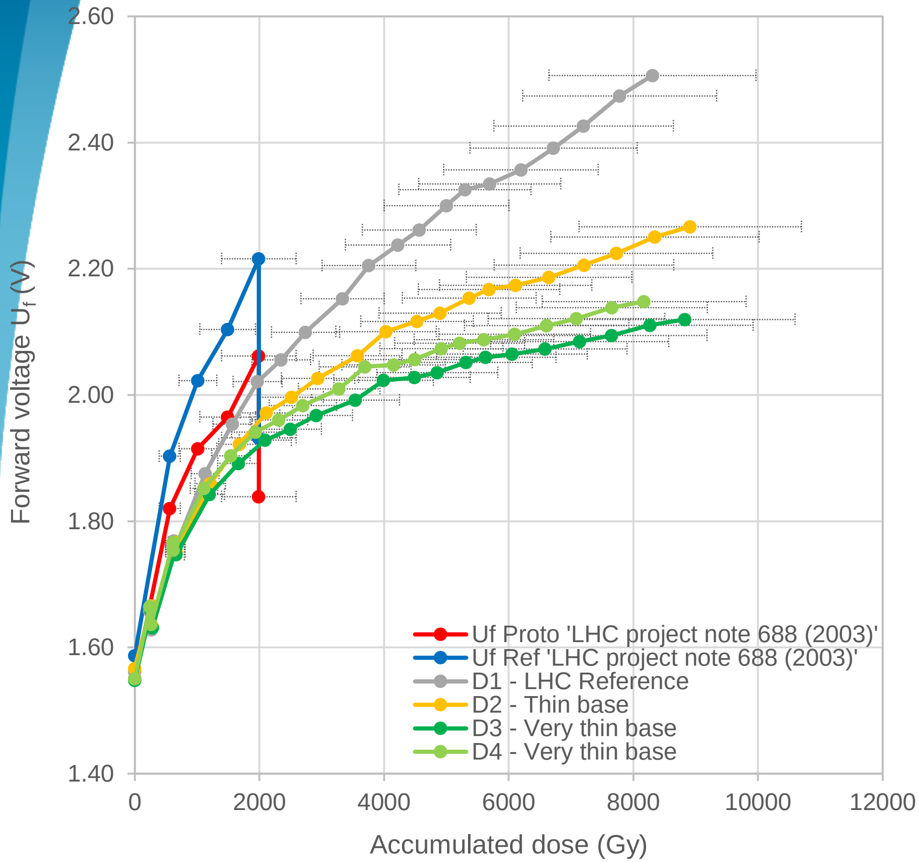


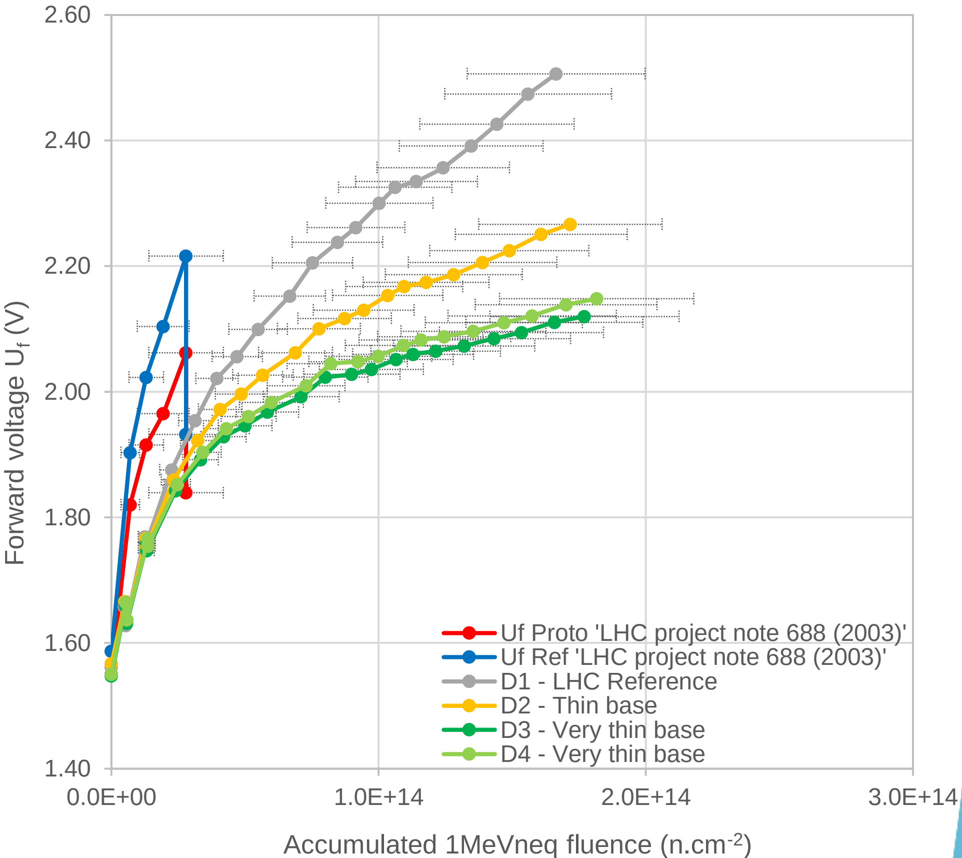
- **Forward voltage U_f increases due to radiation**: Radiation introduce **defects** in the **structure of the silicon wafer**. Due to the **correlation** between **radiation tolerance** and **base width**, from the **most** to the **least** impacted by radiations: D1>D2>D4>D3.

- Last measurements have been done during the **previous week**. Measurements until **November 11th, 2018** (end of the 2018 CHARM irradiation campaign): ~ **10kGy** (dose) and ~ **2.10^{14}n.cm^{-2}** (1MeVneq fluence).

Dose and **1MeVneq fluence** data have been simulated thanks to **FLUKA** (+/- 20%) based on Protons-on-Target (PoT).

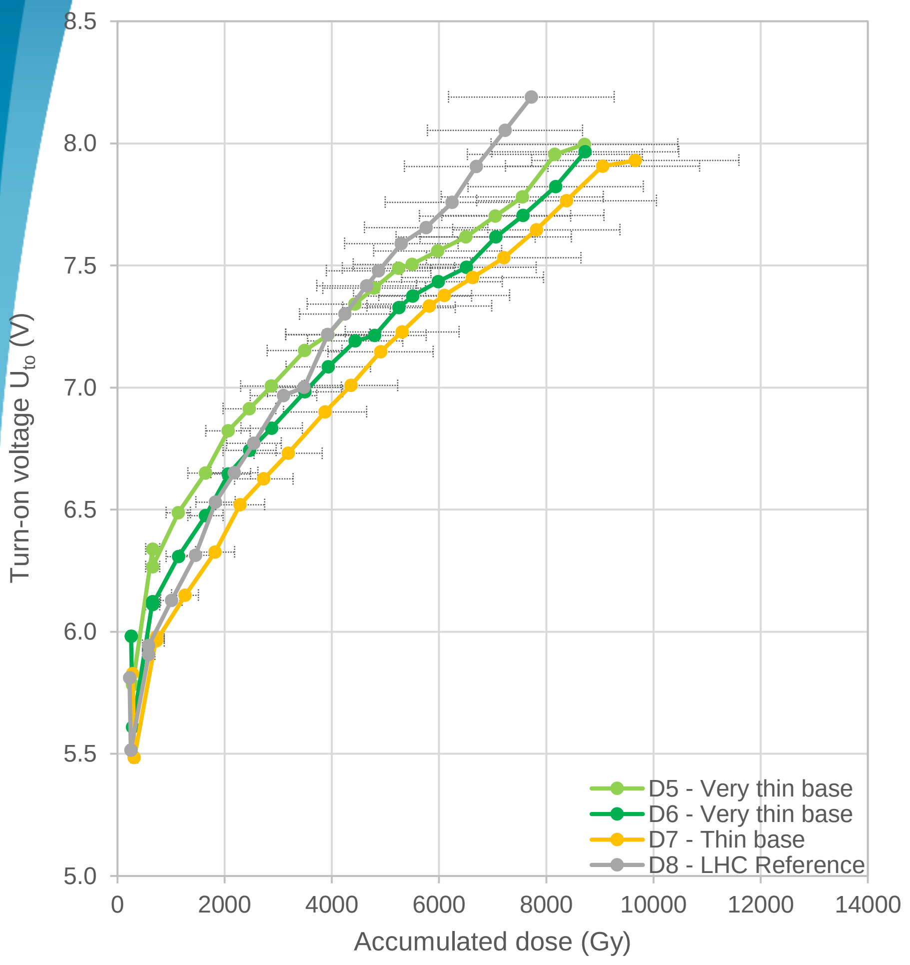
III. Forward plots @ 77K, 12kA

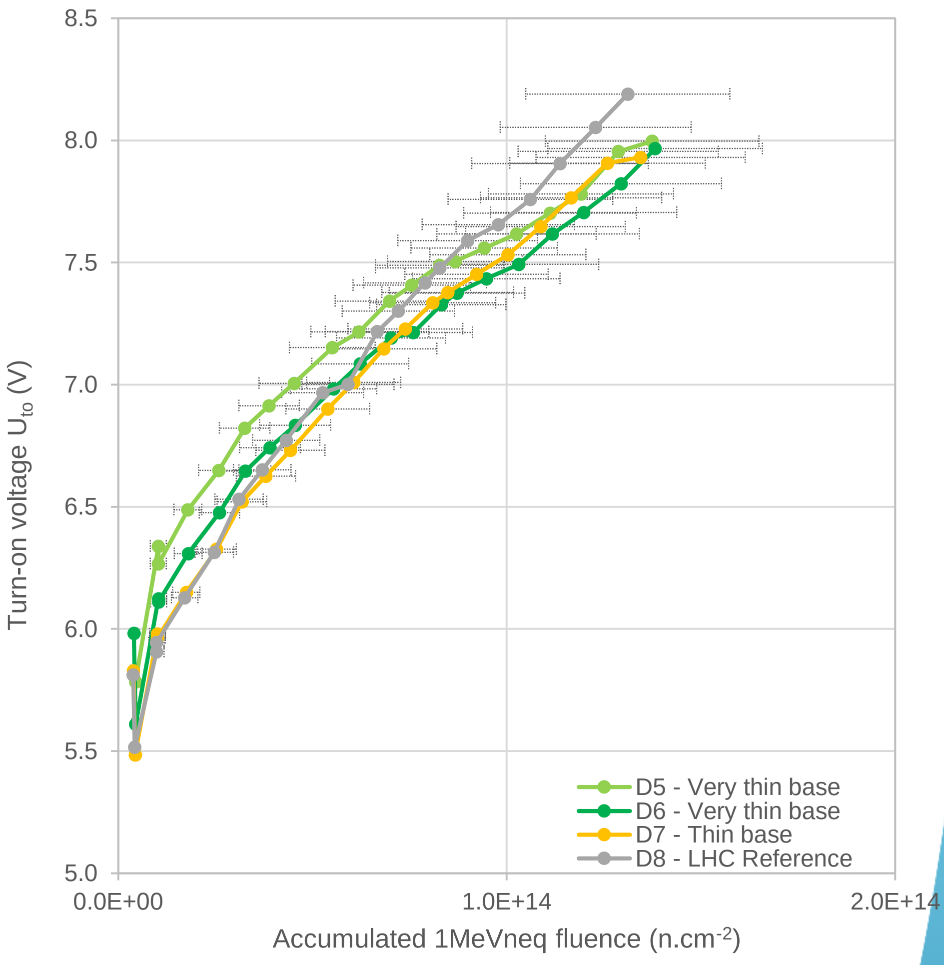




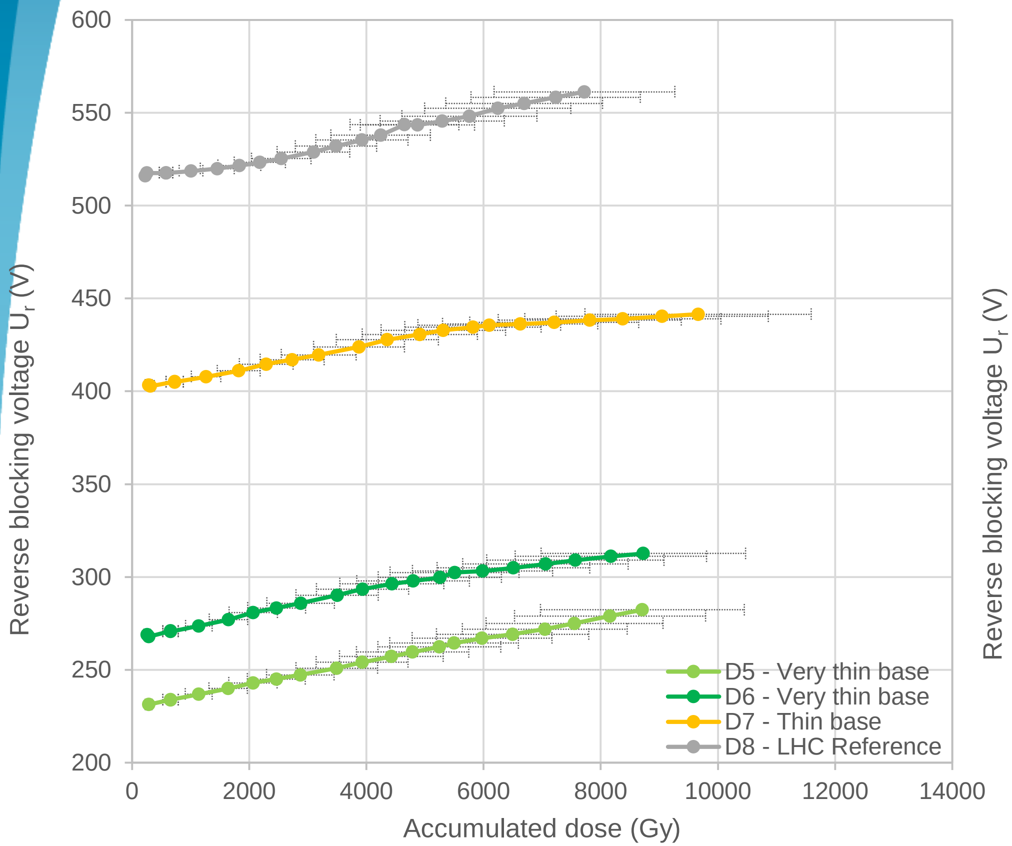
- **Forward voltage U_f differences** between our results (CHARM) and the other results (TCC2) can be mainly explained by **test setup** and **dosimetry accuracy** (+/- 30% for dose, +/- 50% fluence) differences.

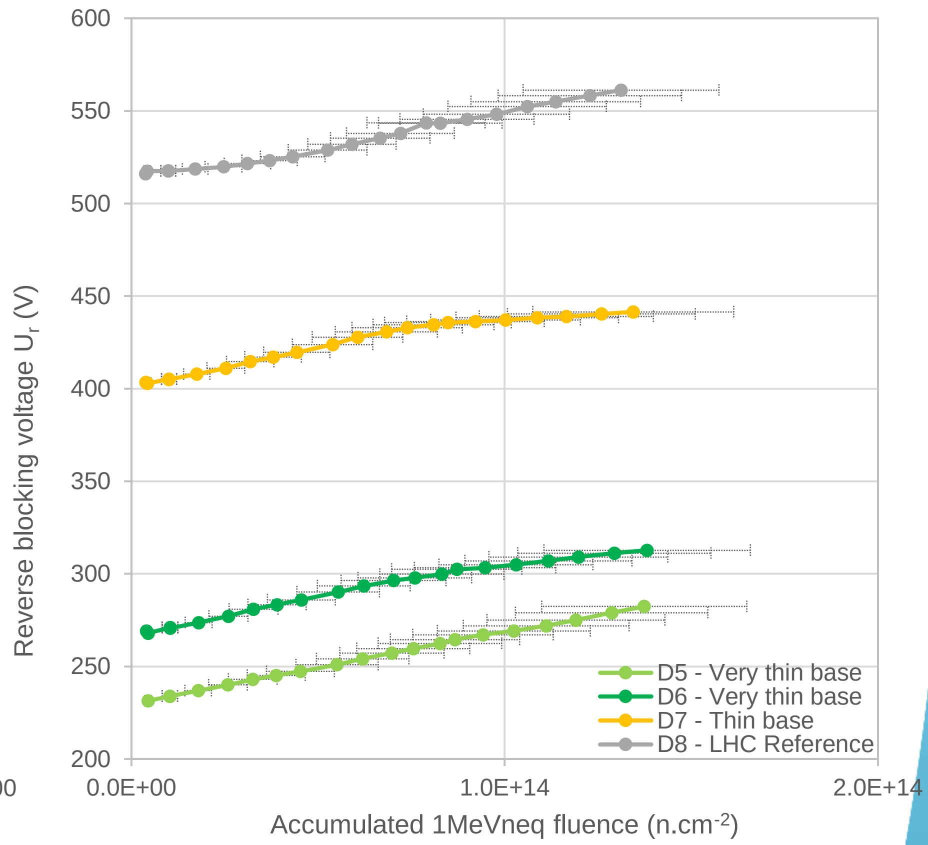
III. Turn-on plots @ 4.2K & 77K



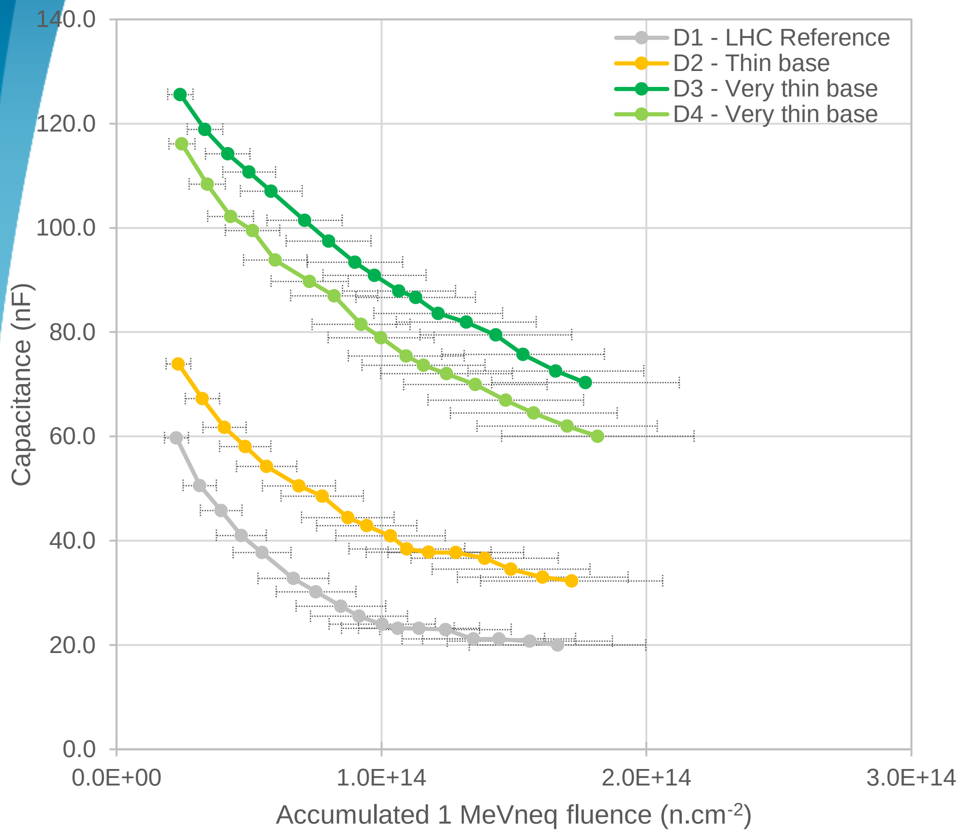


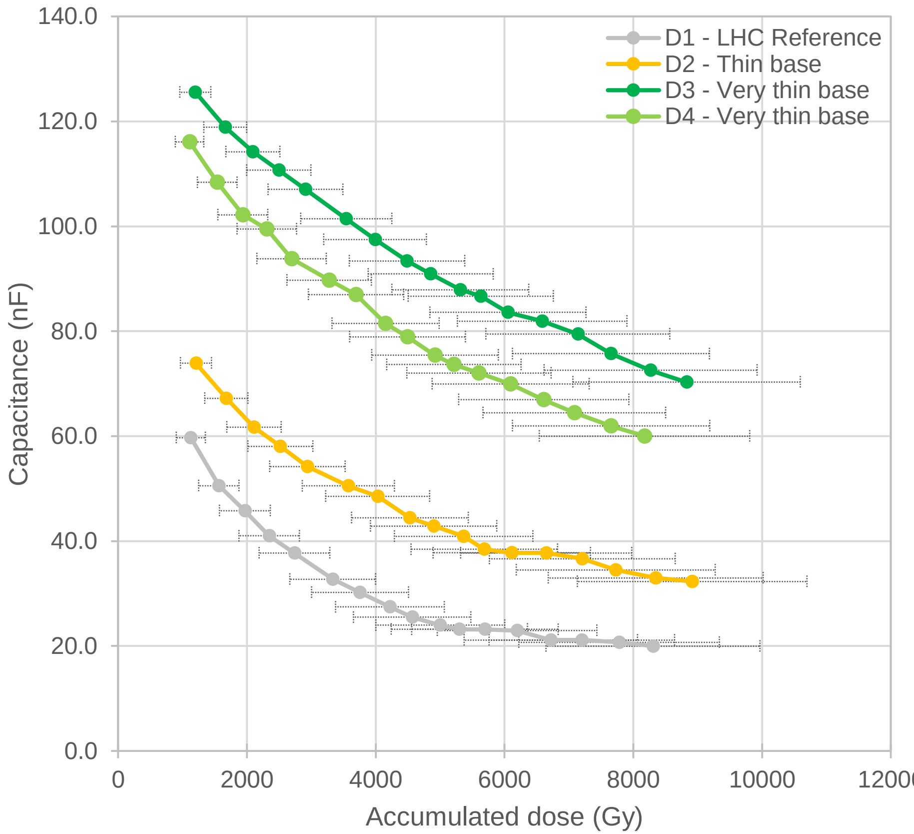
III. Reverse plots @ 4.2K & 77K





III. Capacitance plots @ 4.2K & 77K





- Capacitance **decreases** with radiation. Since capacitance **is inversely proportional** to the base width: From the **lowest** to the **highest** capacitance: **D1>D2>D4>D3**.

- Capacitance measurements @ 4.2K didn't vary in **4** months. It can be explained by a **very low carriers mobility** due to the very low temperature or by **diodes already saturated** when we began these measurements.

Outlook

1. Forward voltage
   Turn-on voltage
   Reverse blocking voltage
   Capacitance

   } 1. Used as a measurement of radiation degradation for the diodes @ 4.2K or 77K.
   2. Differences as a function of base width.

→ According to the results, **very thin base diodes**: best applicants for the cold by-pass diodes.

2. **Characterisation** (still in progress until the November 11th) of very thin base diodes for HL-LHC Inner Triplets:
   - ✓ ~ **2.10^{14}n.cm^{-2} (1MeVneq fluence)**.
   - × ~ **10kGy** instead of **30kGy** (**dose**).

→ **Dose & fluence data**: **Semi-theoretical** (Fluka) and **experimental** (radiation monitors) **values** are in a **good agreement** (roughly factor 2).

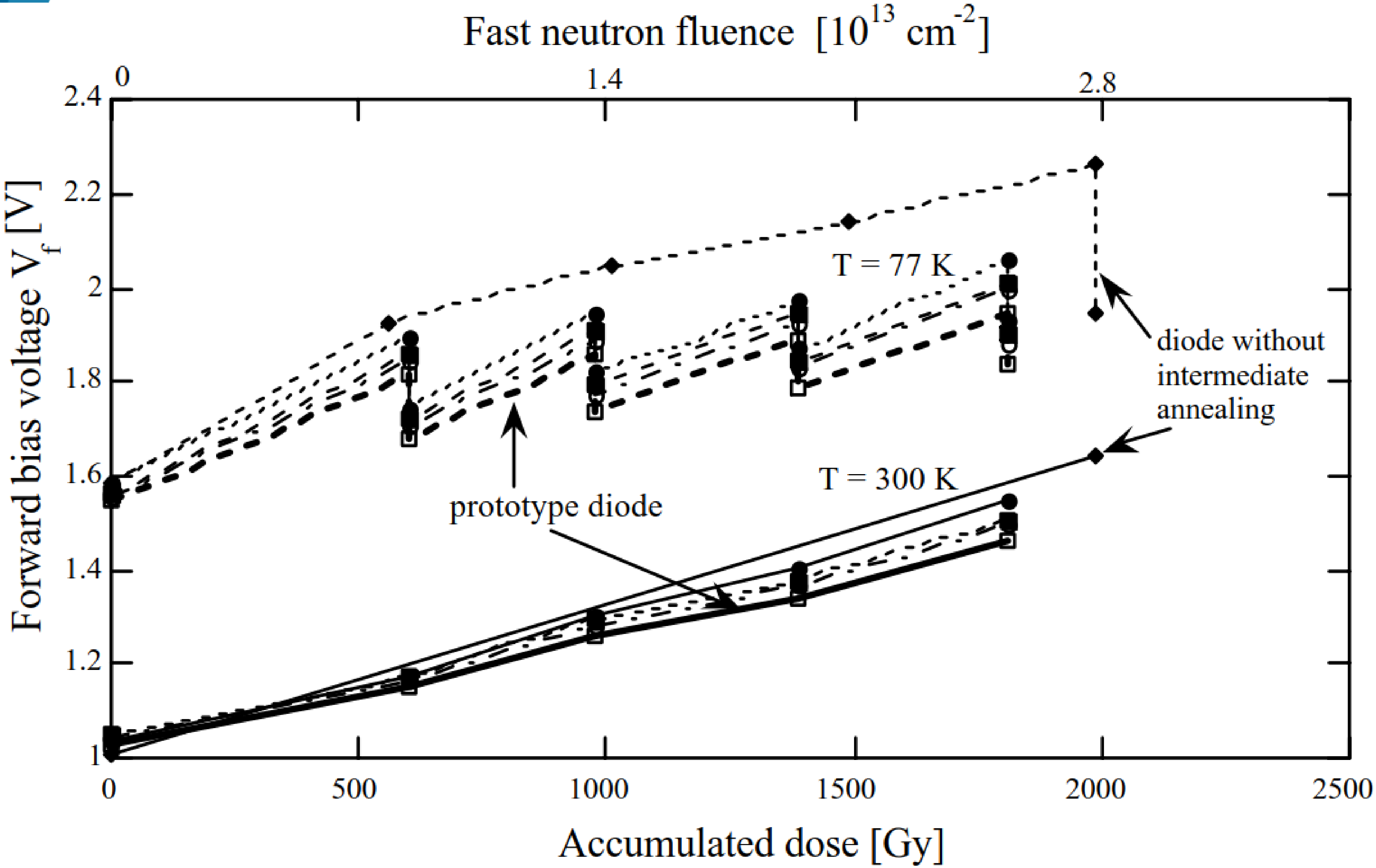
3. **Forthcoming tasks**:
   a) Studying the **Annealing effect due to temperature** (after November 11th).
   b) To further the dose characterisation : Up to **30kGy** by using the **same** diodes or using **other** diodes (same production series).

Acknowledgements

- **Working team** (G. D'Angelo, S. Deleage, R. Denz, M. Favre, D. Hagedorn, F. Rodriguez Mateos, A. Siemko, K. Stachon, L. Vammen Kistrup, A. Will, D. Wollmann).
- **Radiation To Electronics (R2E)/Fluka** (R. García Alía, A. Infantino, M. Krawina, …).
- **CHARM activities** (C. Cangialosi, S. Danzeca, J. Lendaro, …).
- **TE-VSC group**.

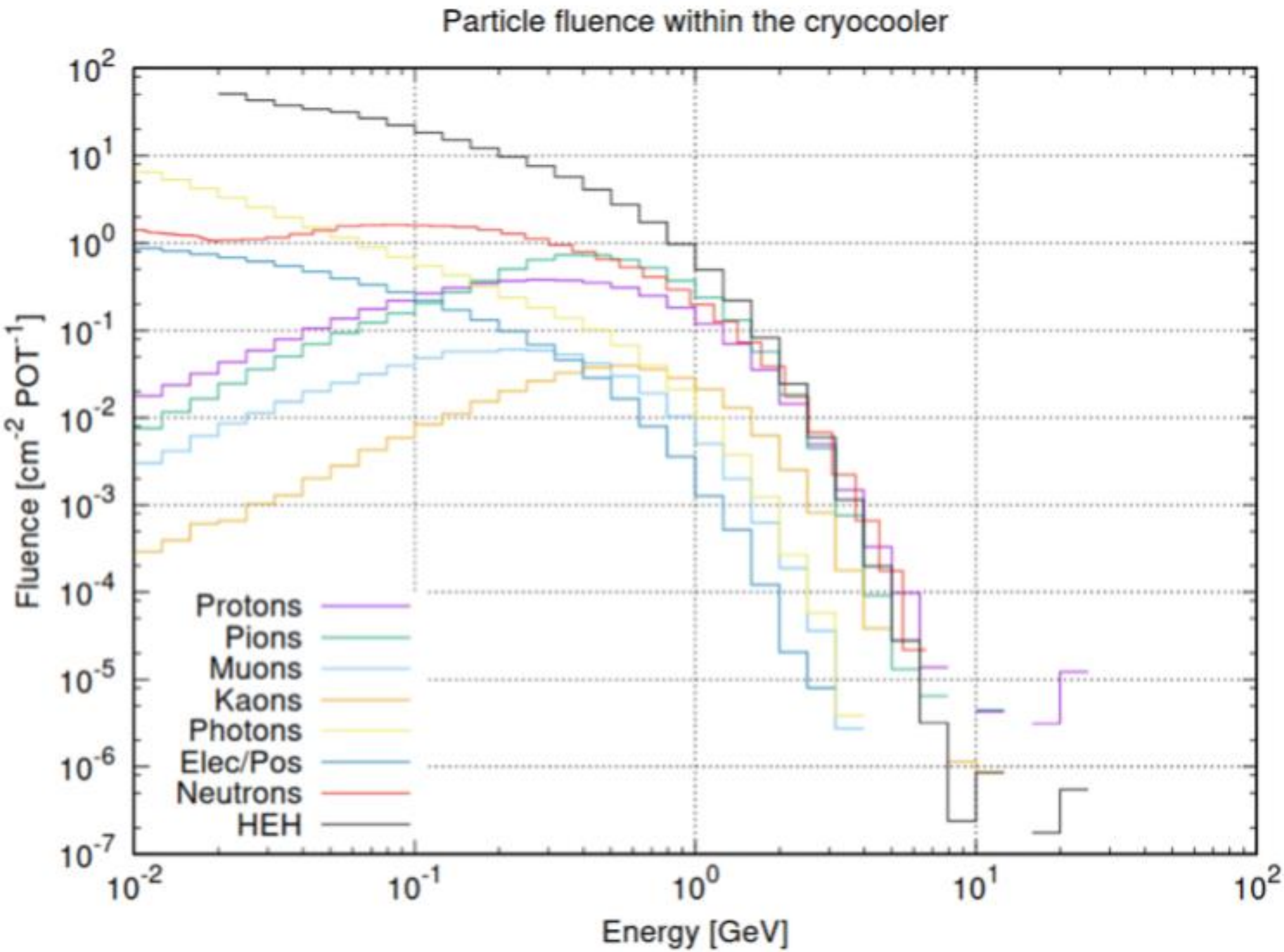
Thank you for your attention!

Back up slides



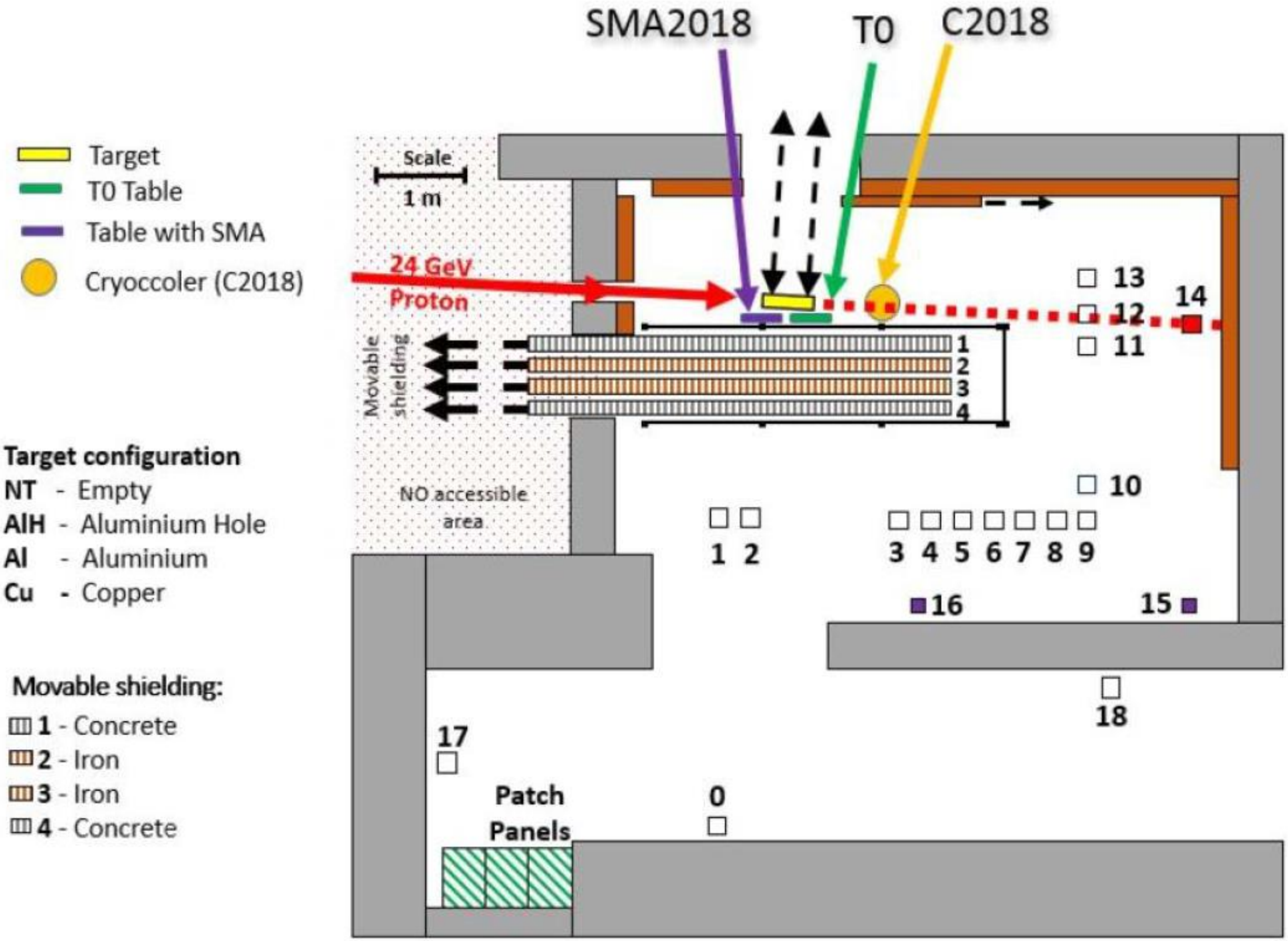
Project report 688 (2003), R. Denz, A. Gharib, D. Hagedorn.

Back up slides



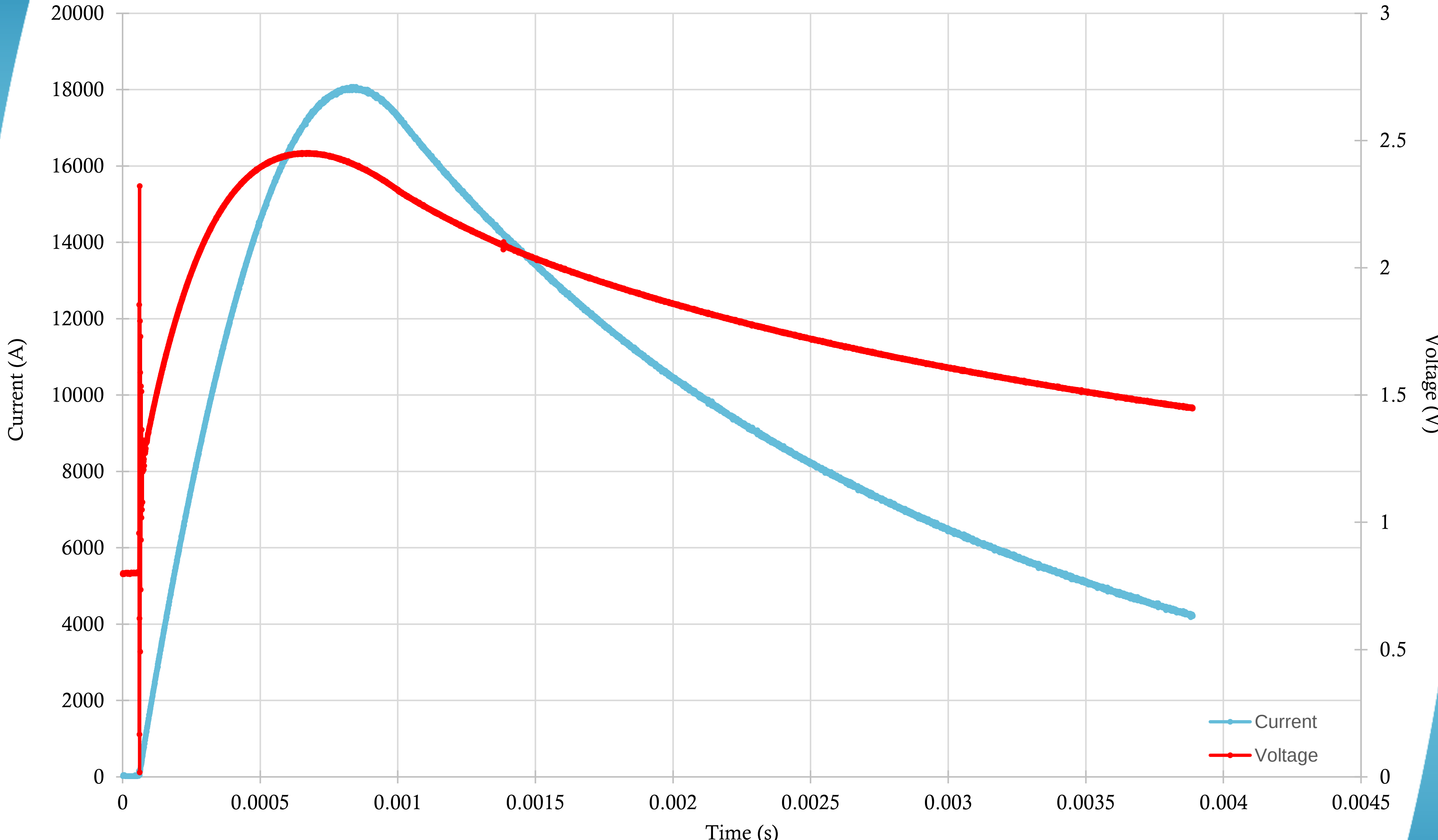
Fluka simulations from A. Infantino

Back up slides



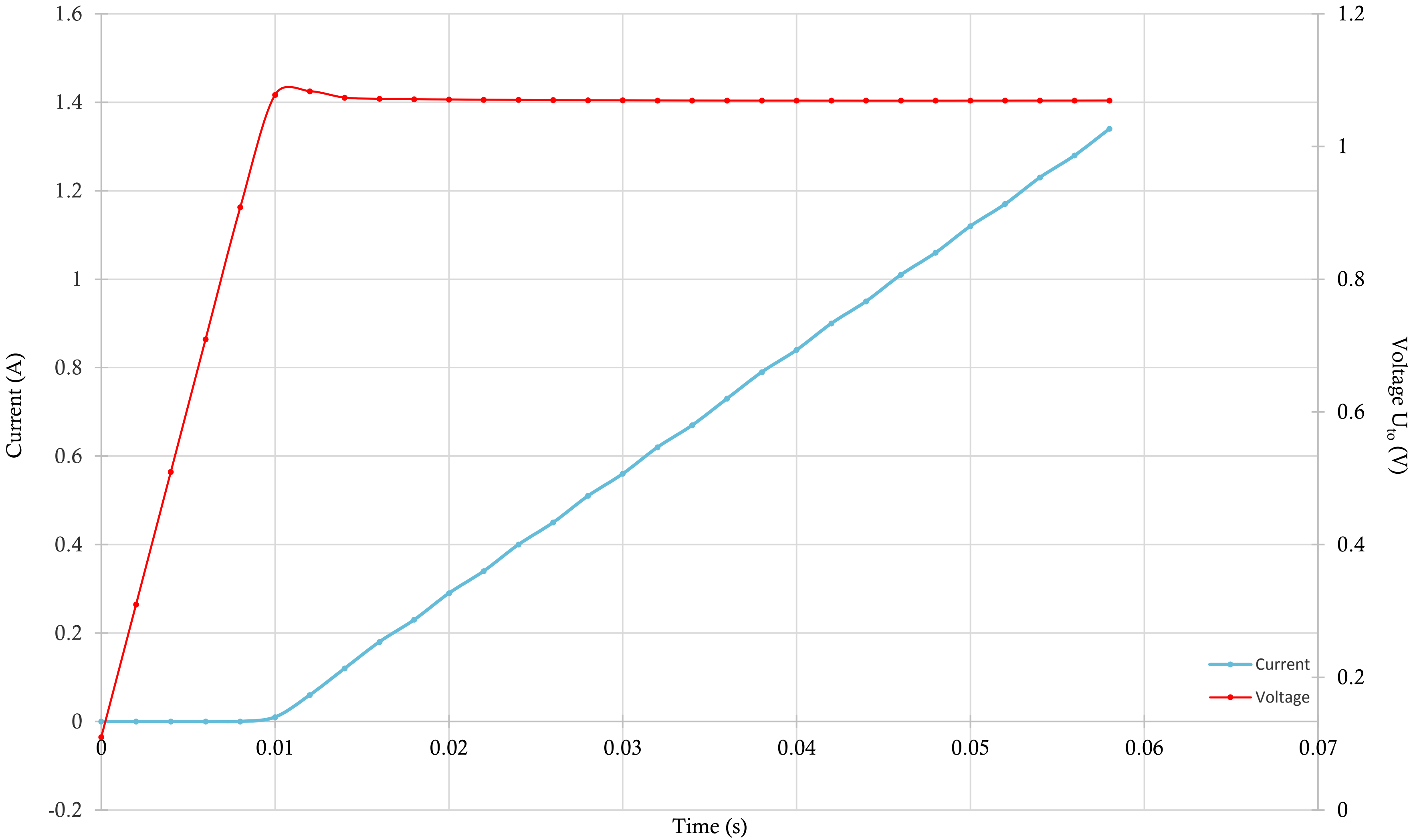
CHARM IEFC June 2018, Report 08062018, S. Danzeca.

Back up slides



Forward signal - Current pulse

Back up slides



Turn-on signal – Linear voltage ramp

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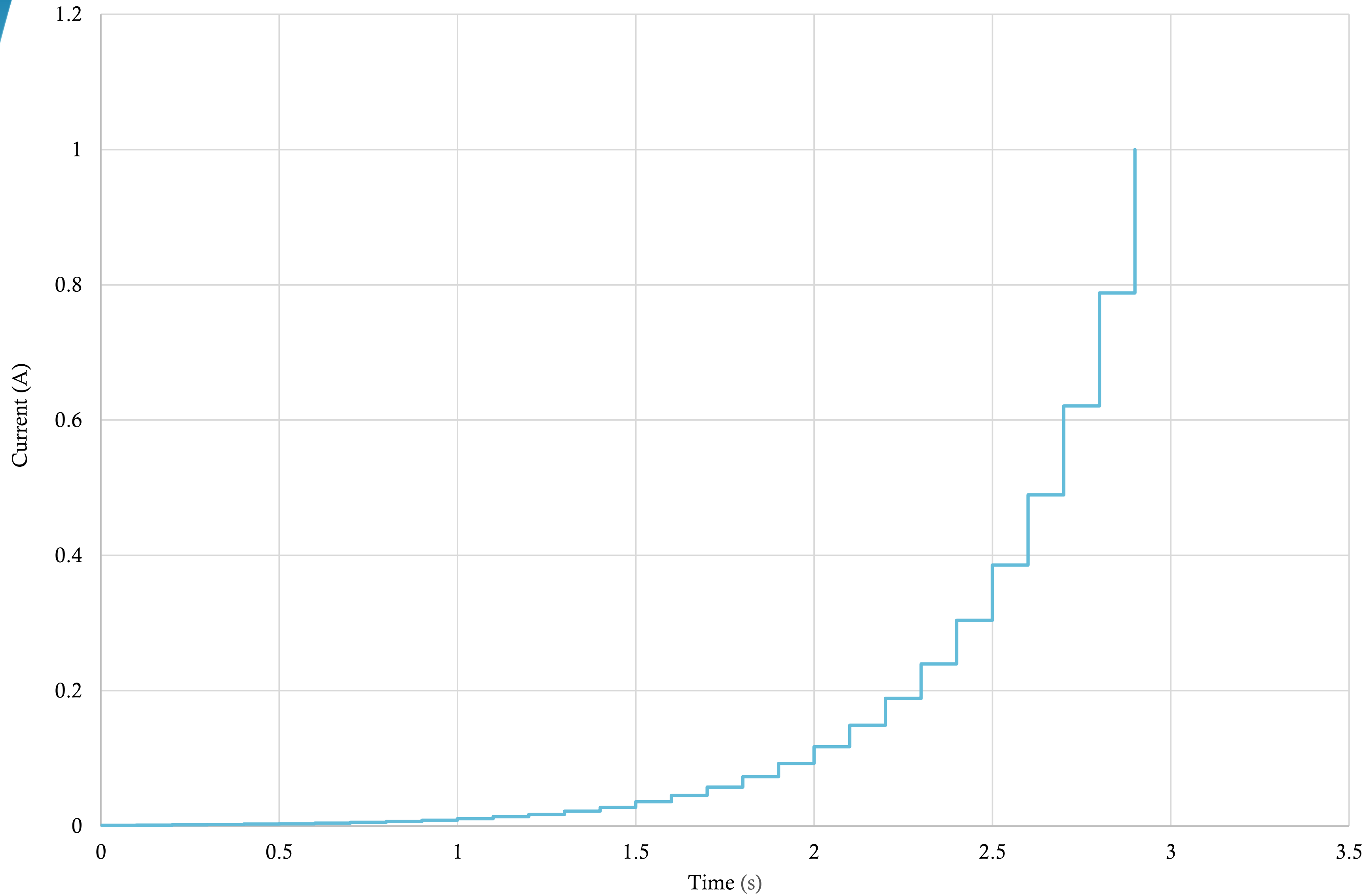

Reverse signal - Logarithmic sweep