SciFi SiPMs irradiation study

Monitoring of the radiation damage induced aging of the LHCb SciFi tracker SiPMs during the first 9 months of Run 3.

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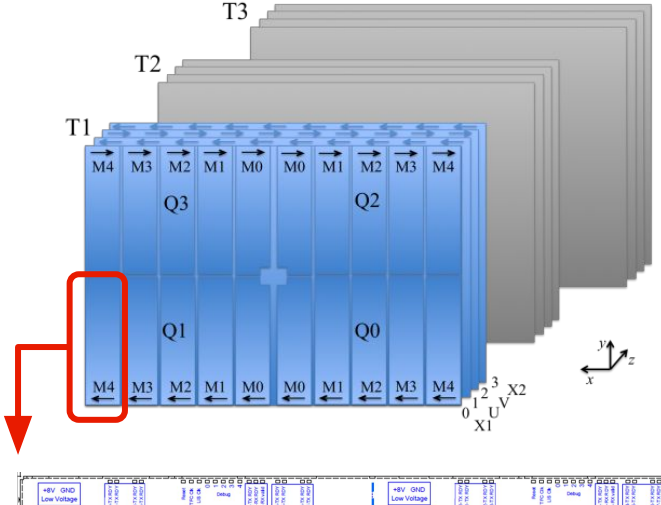
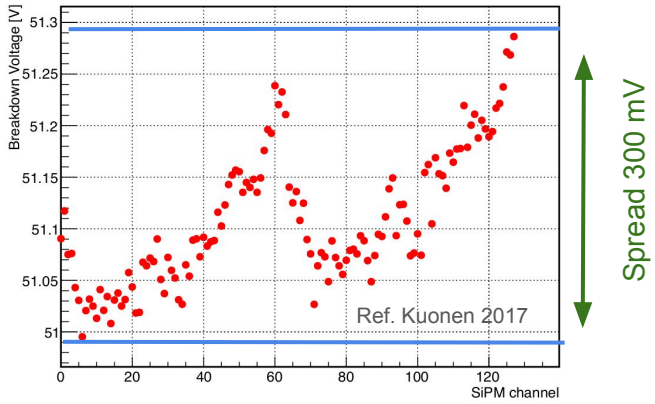
Introduction: CAEN channels

- The SciFi HV power supply system is organised in **CAEN channels**
- Each CAEN channel provides the bias (Vbias) to **4 SiPM arrays** in a SciFi Mat
- Vbias is 3.5 V above the SiPM breakdown → **averaged Vbd(T)** over 4 SiPM arrays

$$\Delta V = V_{bias} - V_{BD}(T)$$



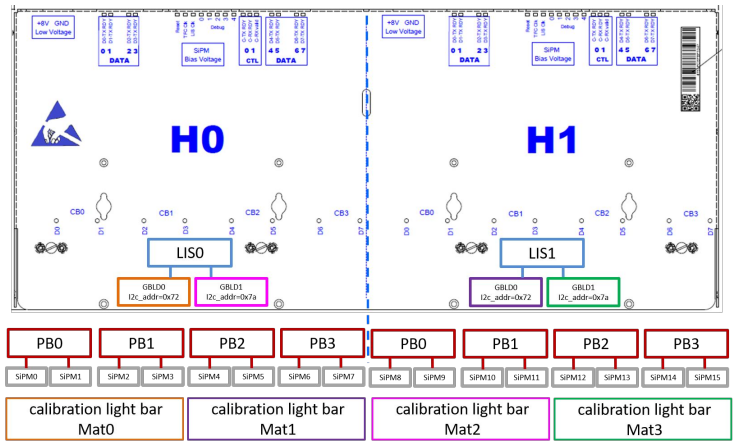


Spread 300 mV

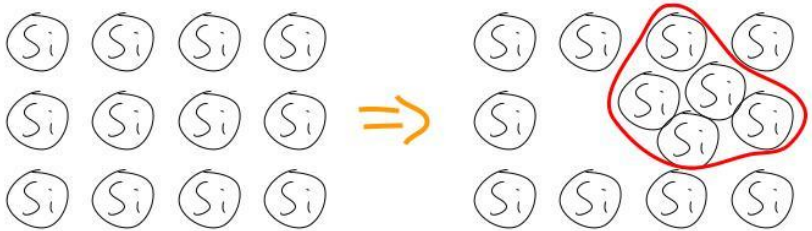
1 Module = 1 FE box

→ 4 Mats

1 CAEN channel = 1 MAt



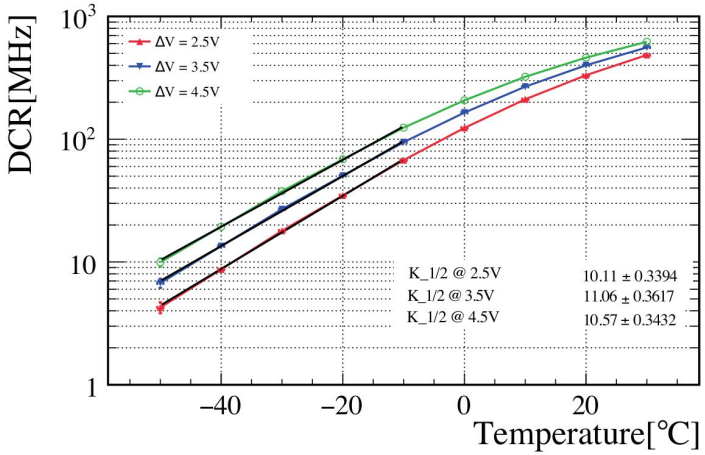
Introduction: radiation damages



- Radiation provokes **displacements of Si atoms** in the bulk → imperfections in the lattice
- **Increase of the DCR** in every channel

- Expected DCR for 6×10^{11} n_{eq}/cm^2 ≈ **14 MHz** @-40°C and ΔV=3.5V
- Expected fluence from FLUKA ≈ 4.7×10^{11} n_{eq}/cm^2 at T3 after 50 fb^{-1}

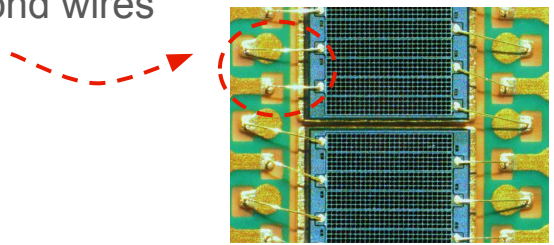
$$f_R = 2^{\Delta T / K_{1/2}}$$



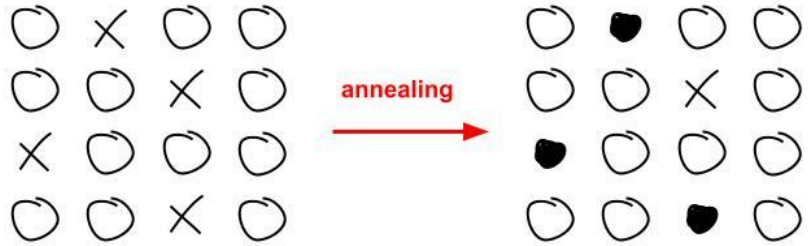
Ref. Kuonen 2018

Introduction: annealing

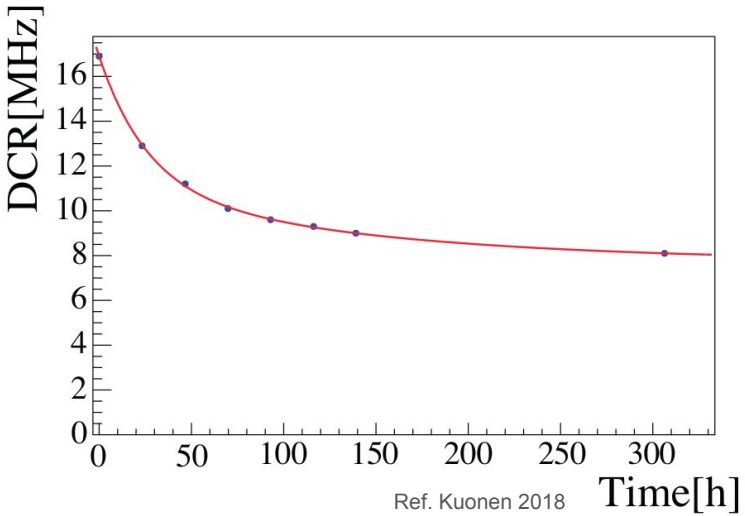
- Damages can be **recovered** by **heating up** the detector at room temperature or beyond
- Maximum temp. 35°C or deformation of the thin epoxy layer may damage the bond wires



- The annealing plateaux depends on the temperature
- Complete annealing can be performed in **few weeks in YETS periods**

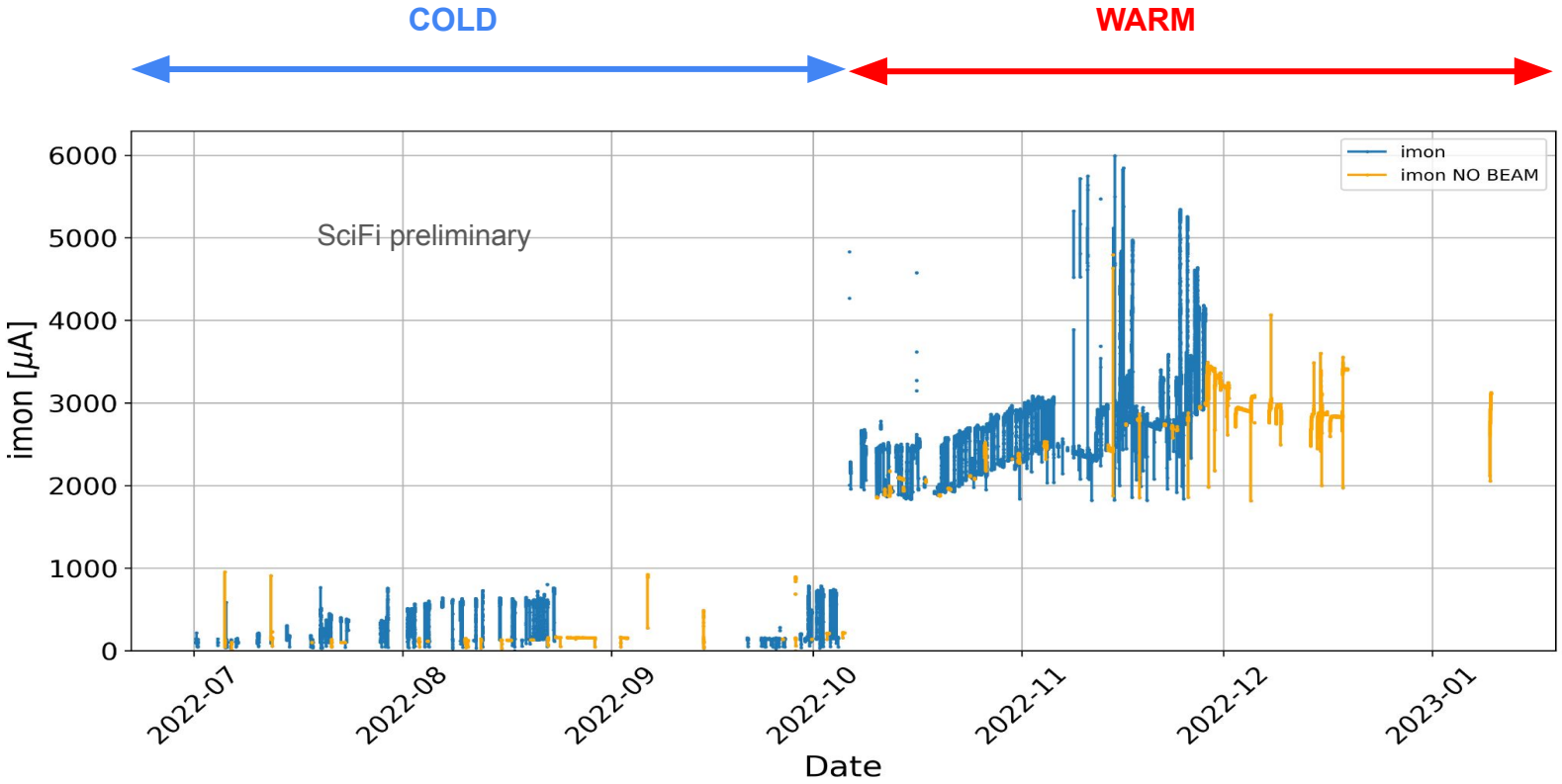


X → damage or not recovered
● → recovered by annealing



Ref. Kuonen 2018

Snapshot of one Mat current July 2022 - January 2023

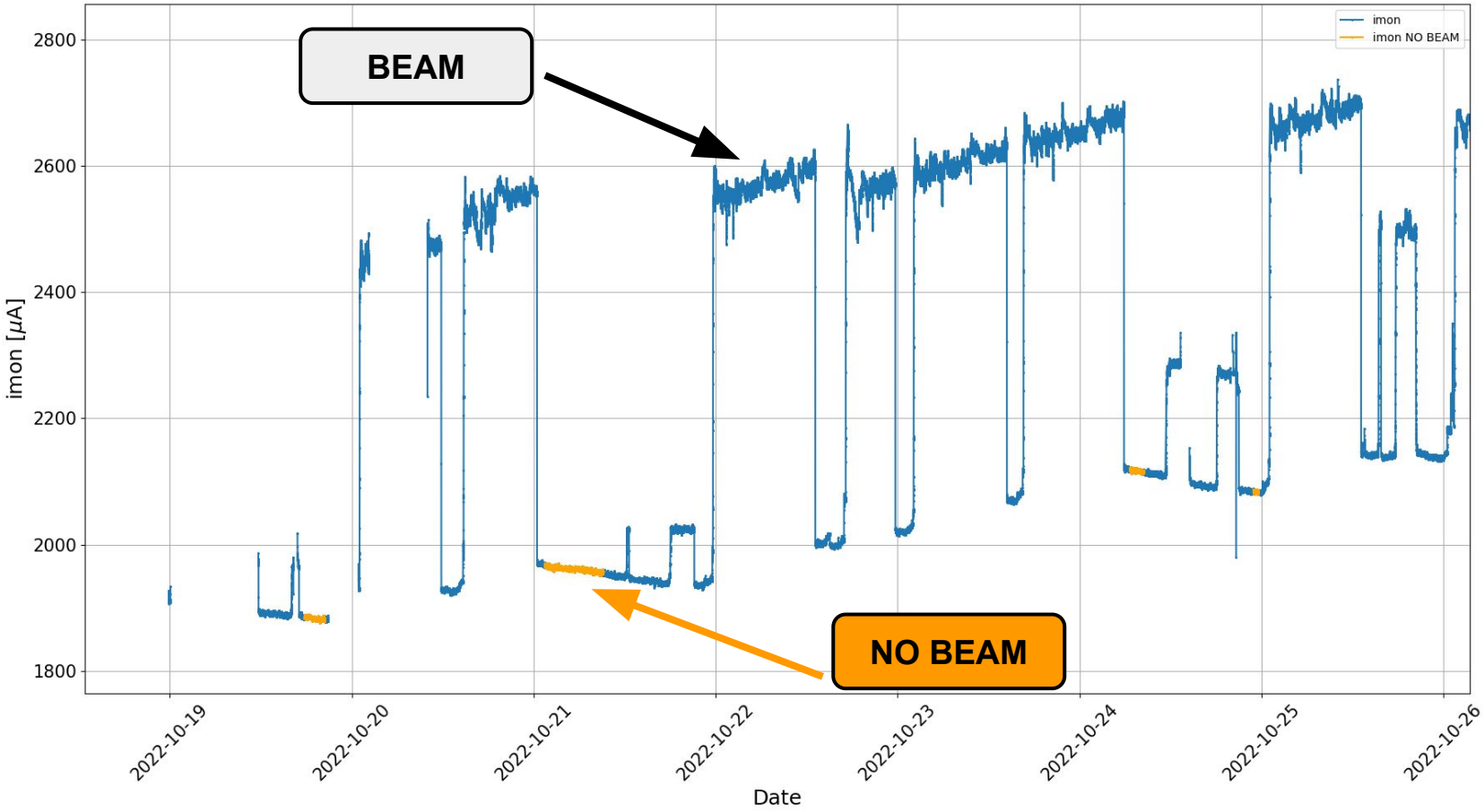


Channel T1L0Q0M0Mat0

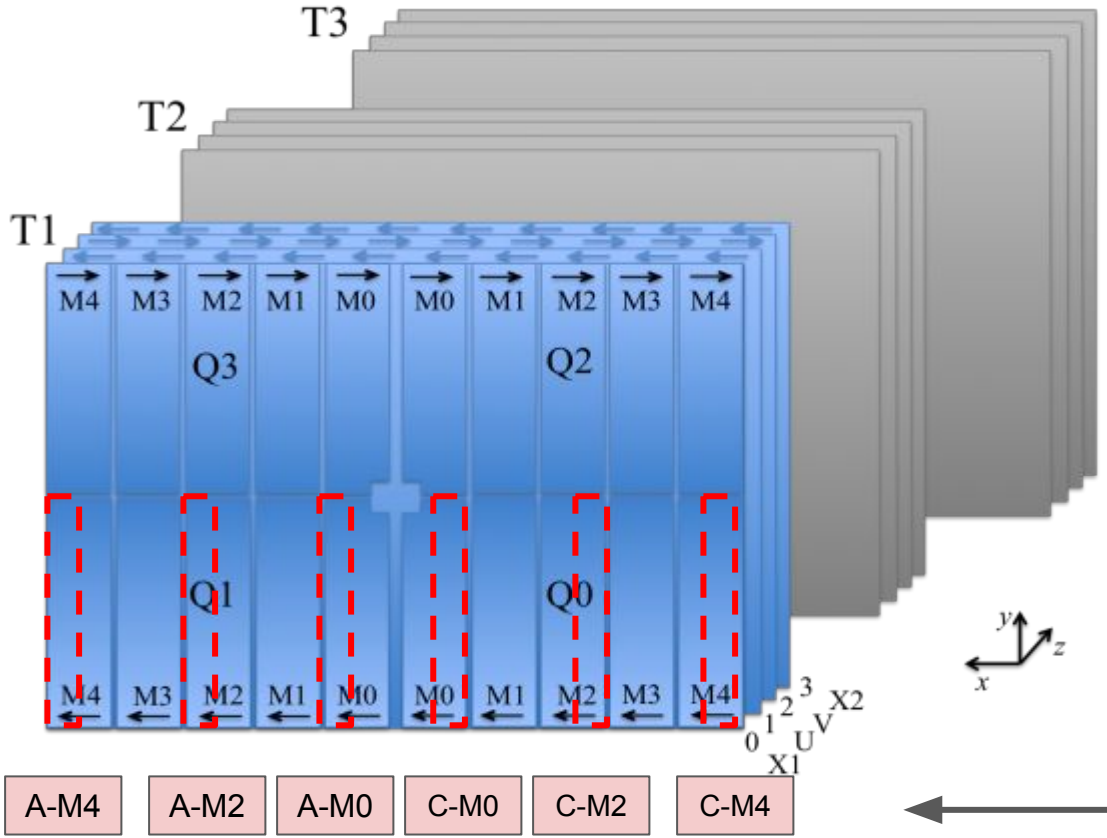
Reminder

→ DCR increases with radiation damage

→ DCR is T dependant


BEAM
NO BEAM
imon
imon NO BEAM
imon [μA]
2800
2600
2400
2200
2000
1800
2022-10-19
2022-10-20
2022-10-21
2022-10-22
2022-10-23
2022-10-24
2022-10-25
2022-10-26
Date

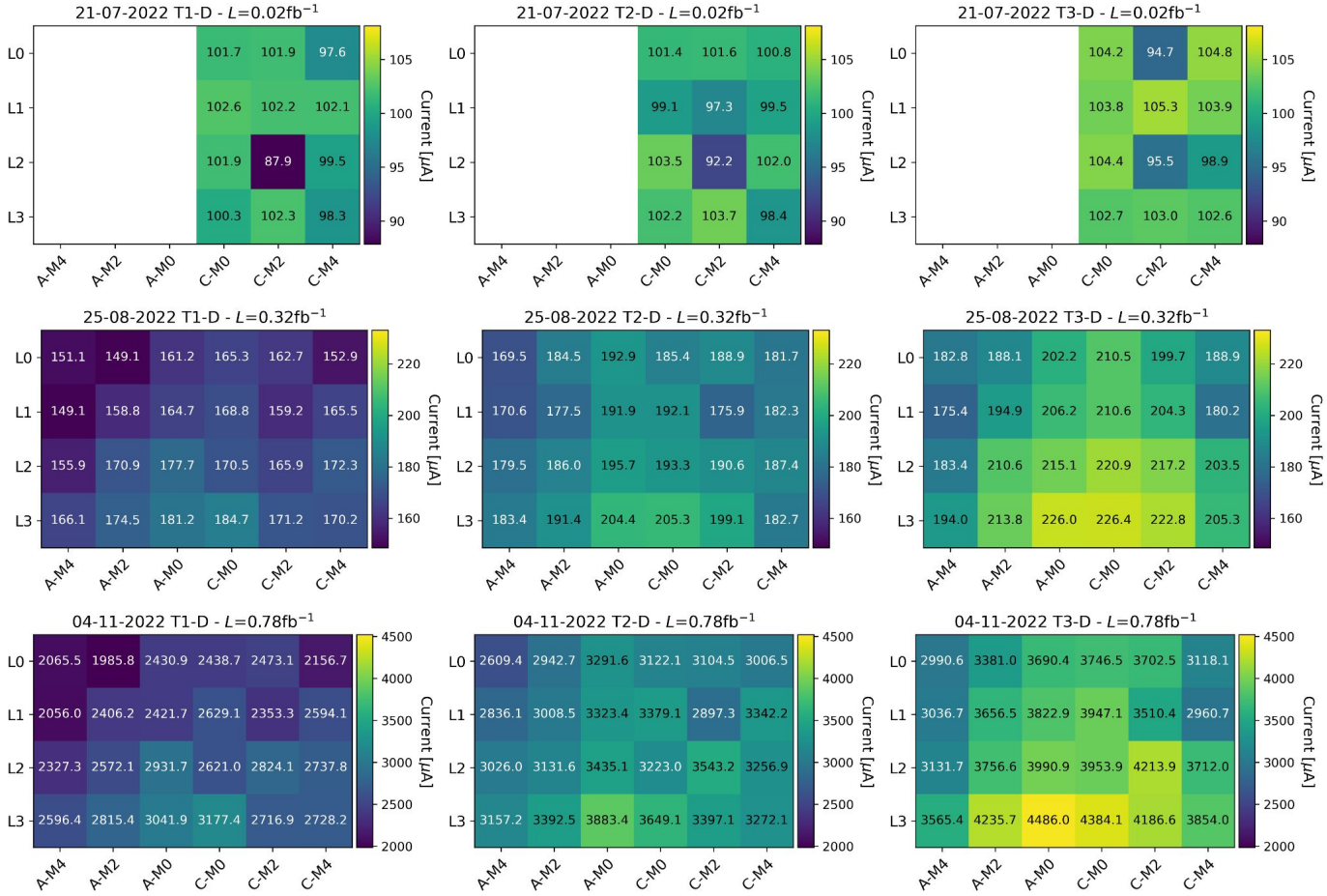
Method to extract dark current



NO BEAM selection

SiPMs ON (HV > 50V)

Take few channels for every station



July - Cold
0.02 1/fb

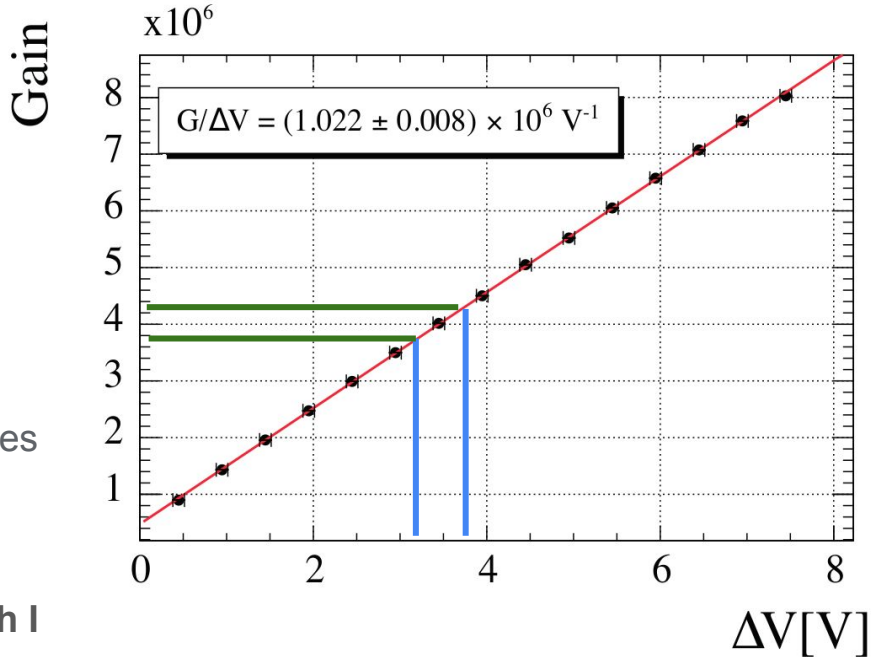
August - Cold
0.32 1/fb

November - Warm
0.78 1/fb

Dark Count Rate (DCR)

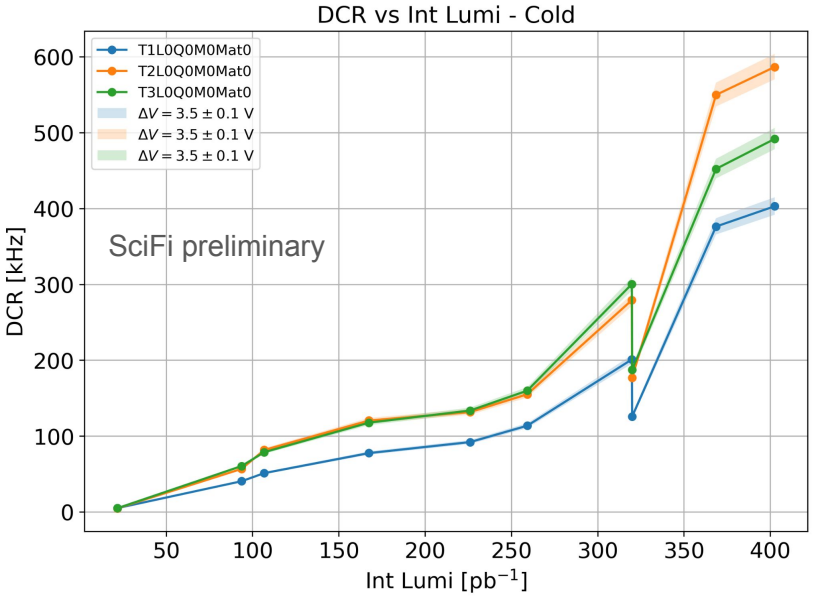
$$I = DCR \cdot G \cdot 512 \cdot e$$

- 512 = number of SiPM channels in one HV line (one Mat)
- I measured, **G** from gain measurement
- NOTE: G vs ΔV is a **steep curve** → small differences in ΔV = **big spread in G**
- **Long cables**: real applied voltage can differ by 100 mV from the nominal applied one (especially at **high I values**) due to voltage drop in the cables (compensated in the future)



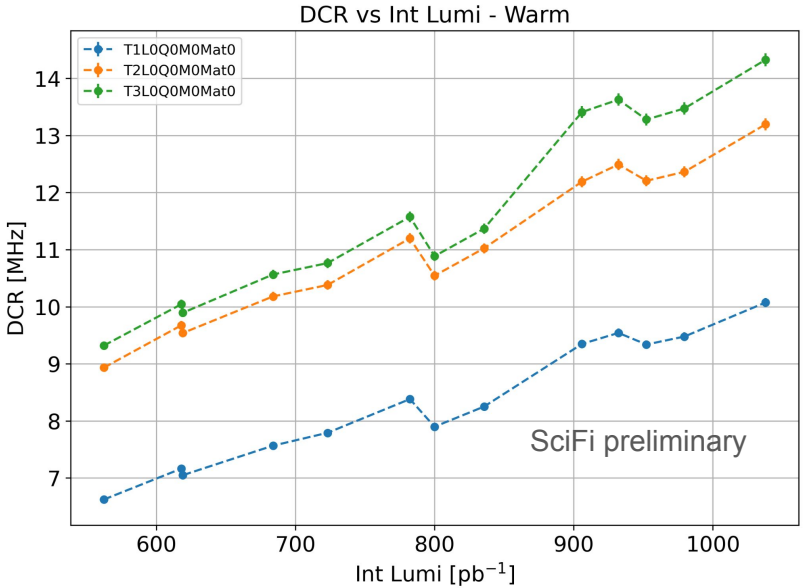
source: Kuonen

DCR COLD



- Huge differences in temperature → difficulties to study the behaviour
- From 23 July 2022 to 5 October 2022

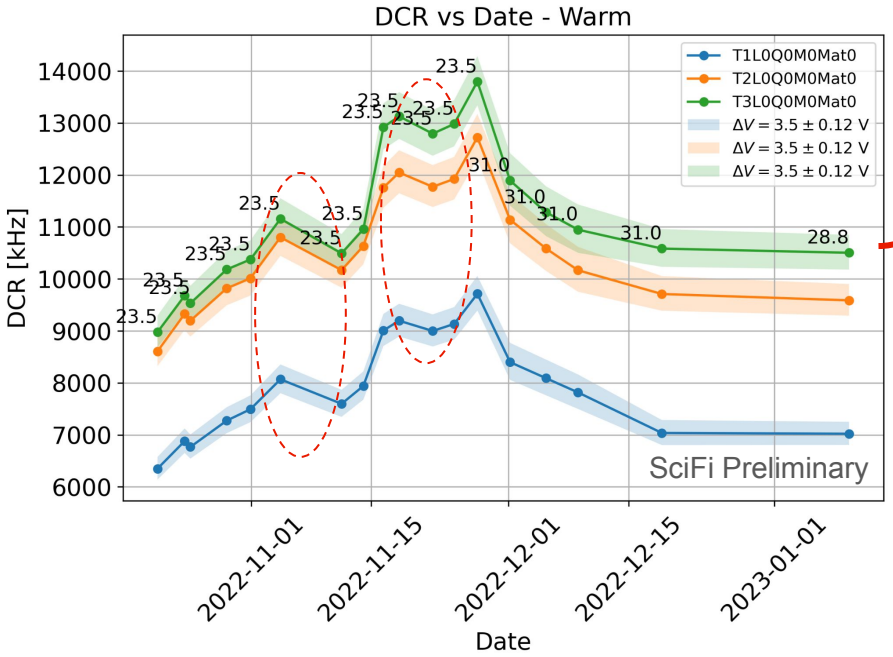
DCR WARM

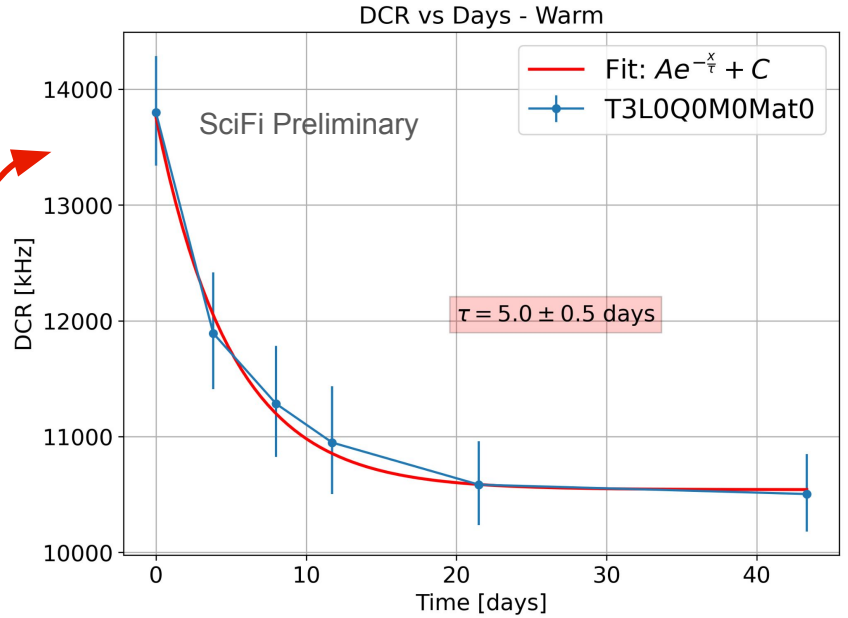


- Warm detector = end of life conditions → 14 MHz DCR x channel
- First effects of annealing seen during operations
- From 21 October 2022 to 9 January 2023

Annealing at room temperature

- Detector at ~30°C in december + not monitored temperatures during winter shutdown
- REMEMBER: the annealing started as soon as the detector was warmed up

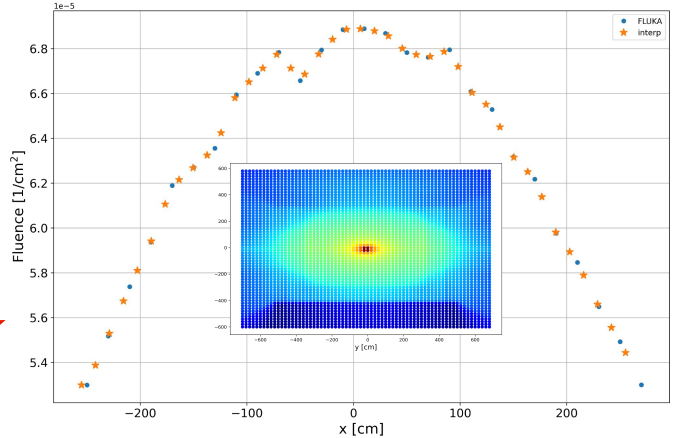


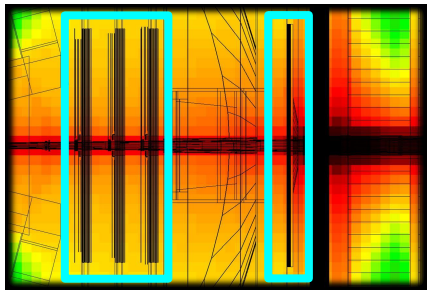


Annealing during YETS

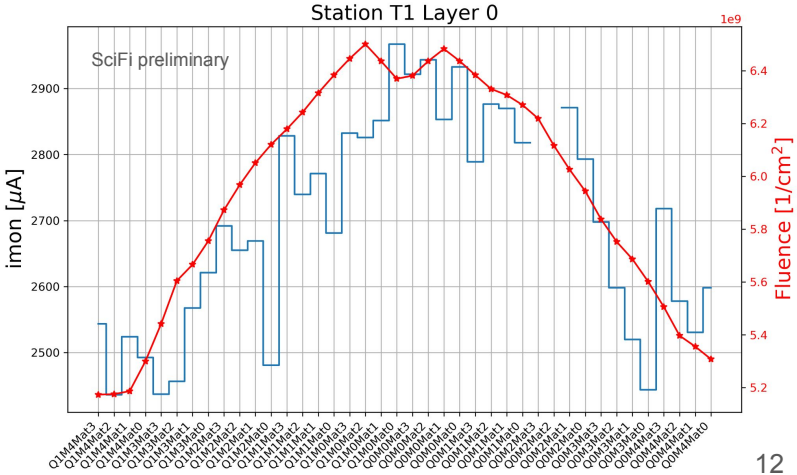
FLUKA simulation comparison

- **FLUKA simulation** datapoints by Matthias Karacson
- Each bin is 20x20x20 cm^3 in xyz extracted for 3 z positions
- **Interpolation** of points in the center of every Mat
- Scaling for 1.058 fb^{-1}





	T1/T3
FLUKA no shield	0.58
FLUKA w shield	0.74
SciFi (27/11/22)	0.70 ± 0.05
SciFi (22/02/23)	0.68 ± 0.04



Bias voltage calculation

- Vbias calculated by Vbd (known from R&D studies) and corrected for the temperature

$$\mathbf{Vbias = 3.5V + Vbd + 60mV\,(T - 25°C) + Voffset}$$

- Vbias is **highly** T dependant and so the response of the SiPMs
- REMEMBER: this is the applied Vbias at the CAEN module, the bias reaching the SiPM is lower due to the **voltage drop** along the cables

Temperature SiPMs ©	Correction in Volts 0.059V*(T-25) H2015
20	-0,295
10	-0,885
5	-1,18
0	-1,475
-10	-2,065
-20	-2,655
-30	-3,245
-39	-3,776
-40	-3,835
-45	-4,13
-50	-4,425

Line Drop Recovery

We need to compensate for the voltage drop from D3 to the SiPMs (120 m cables round-trip).

The distributions of HV lines is very complicated, return lines are shared in groups of 11.

CAEN module is compensating automatically (new firmware)

Inputs: resistance of line and return

Rline = resistance of the outgoing cables

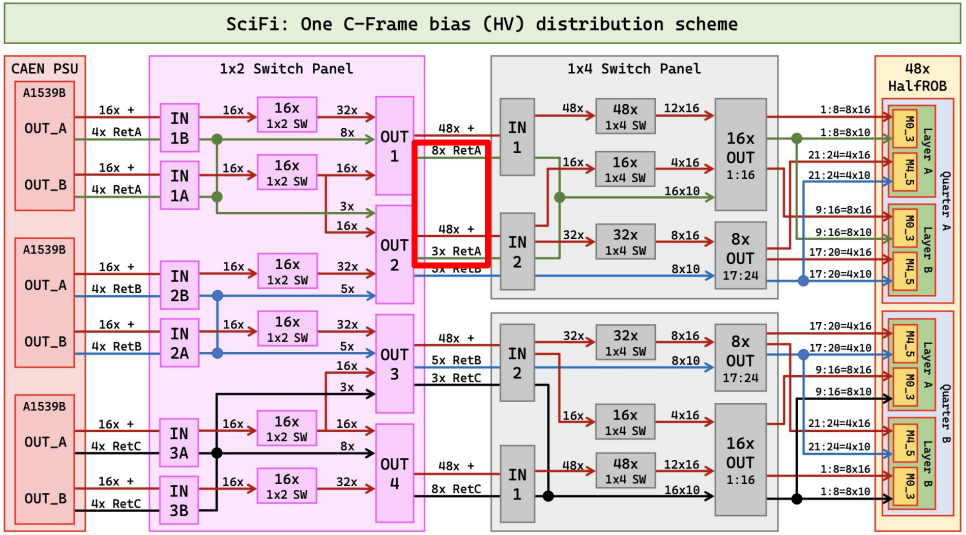
Rret = return line cables

We can only set the **Rline** and **Rreturn every 16 channels** assume have similar resistances.

Computed from cable characteristics:

147 Ohms/km at 20°C → SciFI 120 m

→Rexpected = 17 Omh



Scheme by Ulisses C.

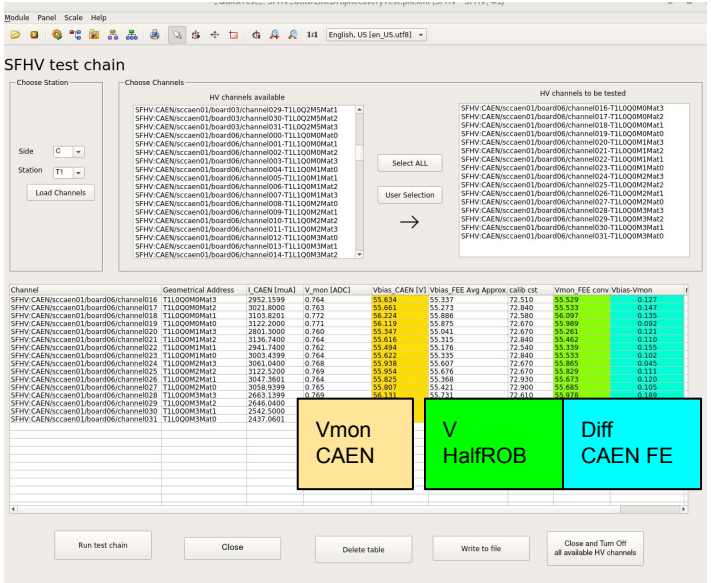
Line Drop Recovery

Implemented in WinCC control

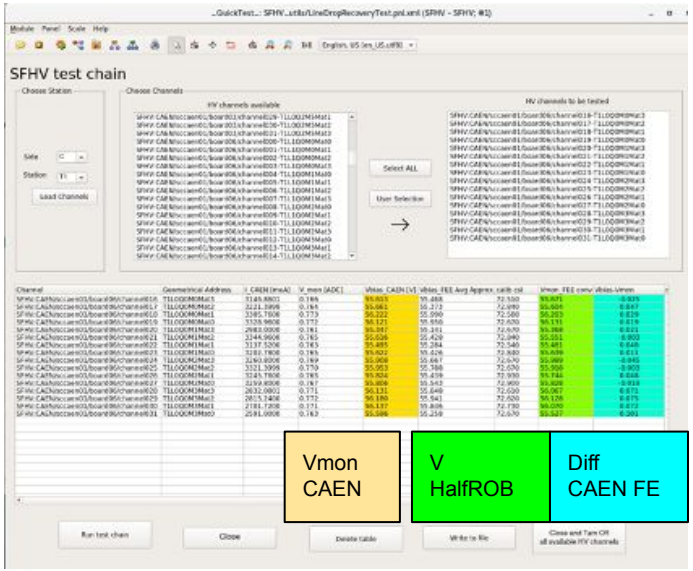
Test using monitoring circuit in the FE after calibration

Return 1.8 Omega

Line 10 Omega



BEFORE LDR ~ 120 mV drop



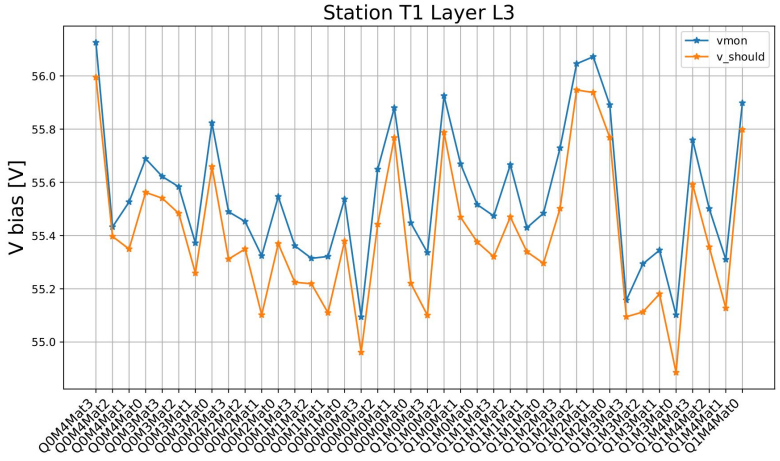
AFTER LDR ~ 5 mV drop

Importance of the right recipe

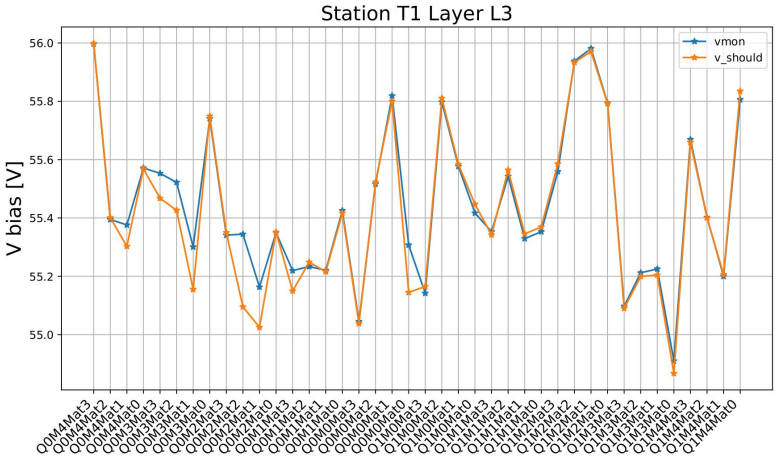
- Large differences in current between channels can be explained by a wrong recipe setting
- Take the averaged temperature and recompile the **Vbias** that should be applied **V_should**

⬇️

- Good agreement with the recipe if created just before measurement and with LDR



BEFORE LDR and new recipe



AFTER LDR and new recipe

Conclusions and prospects

- The study of the **aging** of the SciFi SiPMs is ongoing:
  - **Currents and DCR monitored** in cold and warm periods
  - Observation of **annealing effect** during warm period
- The **recipe is time dependant** → a recipe generated on the base of the measured T a few days ago is probably not valid anymore → the choice of Vbias influenced the **gain** and consequently the DCR measurement of every channel
- **LDR compensation** implemented in the CAEN

Prospects

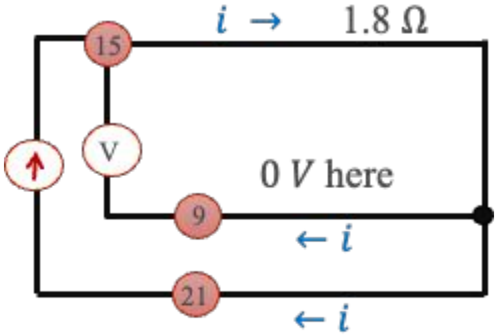
- Study of **temperature spread** in one Mat to explain differences between channels
- Looking forward to **temperature scan**
- Implement the per **channel compensation** in the PACIFIC

Thanks for the attention

LDR measurement technical details

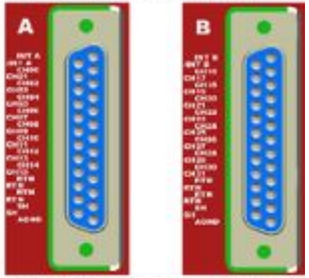
4 wires measurements on T1L3Q1M5

only return 15 , sense pin 9 current pin 21	only return 15 , sense pin 21 current pin 9	only return 3 , sense pin 9 current pin 21	only return 3 , sense pin 21 current pin 9	MEAN
1,812	1,827	[illegible]	1,872	1,8318
				0,03

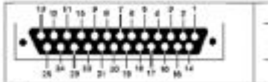


Return lines pins

DB25 connector pin assignment



INT - /INT: interlock; RTN: channel return; AGND: ea



PIN	A	B
1	AGND	AGND
2	SHIELD	SHIELD
3	RETURN	RETURN
4	RETURN	RETURN
5	CH 14	CH 30
6	CH 12	CH 28
7	CH 10	CH 26
8	CH 8	CH 24
9	CH 6	CH 22
10	CH 4	CH 20
11	CH 2	CH 18
12	CH 0	CH 16
13	INT A	INT B
14	SHIELD	SHIELD
15	RETURN	RETURN
16	RETURN	RETURN
17	CH 15	CH 31
18	CH 13	CH 29
19	CH 11	CH 27
20	CH 9	CH 25
21	CH 7	CH 23
22	CH 5	CH 21
23	CH 3	CH 19
24	CH 1	CH 17
25	INT A	INT B

Fig. 2 – DB25 connector pin assignment (32 and 24 ch

Offset from PACIFIC

- We are at digital value = 8
- Between 400 and 500 mV in Anode.
- No precise measurement oper PACIFIC available