EUROPEAN
SPALLATION
SOURCE

“Field emission experience with ESS elliptical cryomodule in TS2"

On behalf of ESS SRF team

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2023-12-05 TTC

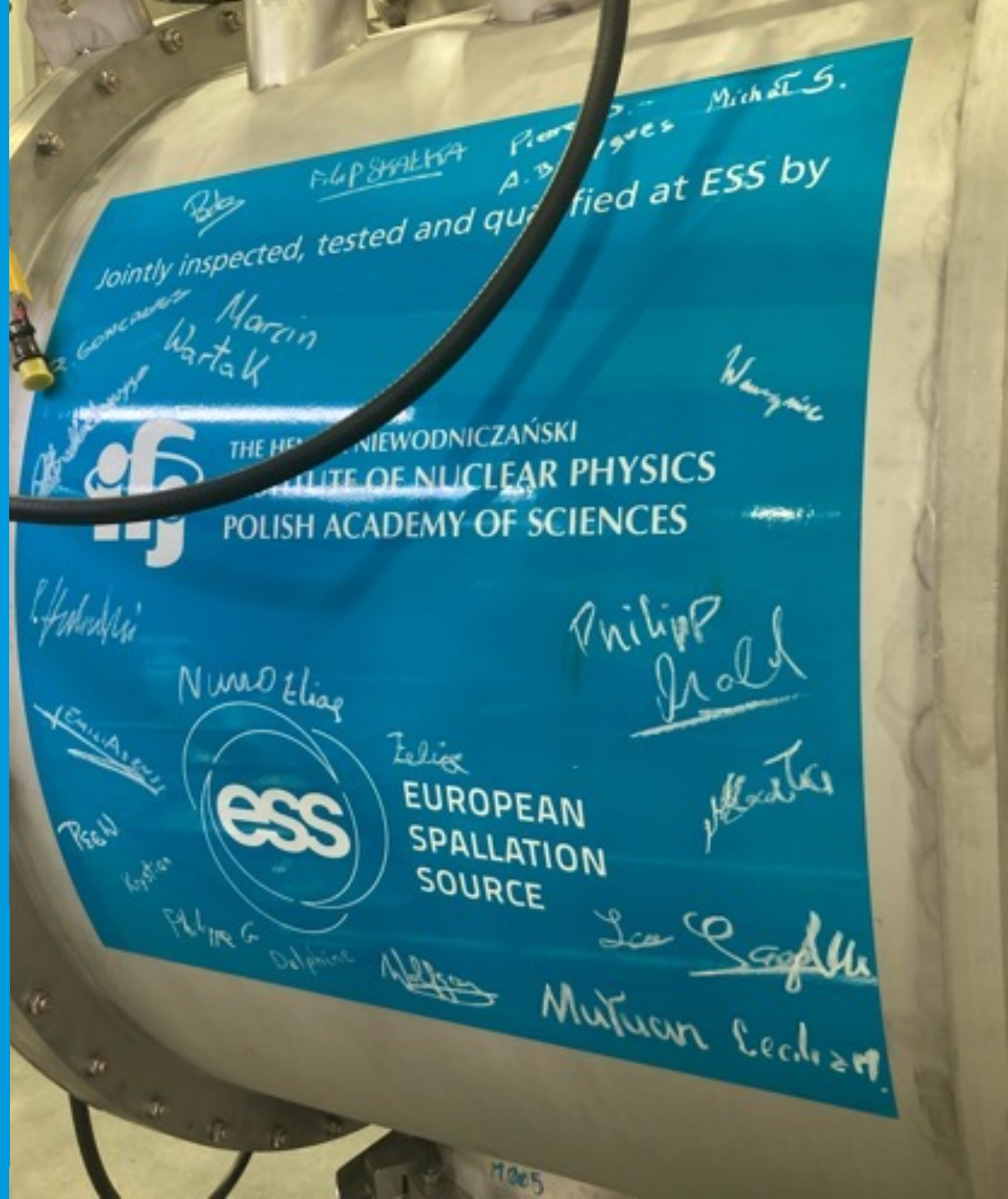
Agenda

1 Introduction on cryomodules measurement flow at Lund Test Stand
- FE equipment

2 Cryomodules field emission operation experience
- Analysis tools
- Measurements results
- Comparison between CEA Montecarlo simulation and measurements
  - MC prediction of outcome + MC explaining outcome

1

Cryomodules Measurements flow at ESS TS2



ELL CM: ESS Test Stand

The workflow is split in phases

CM lifecycle is intensively documented

=> Cryomodule Assembly from (INFN/STFC) CEA

=> Cryomodule testing phase (Mec/Vac/Cryo/SRF)

(this includes FE reports)

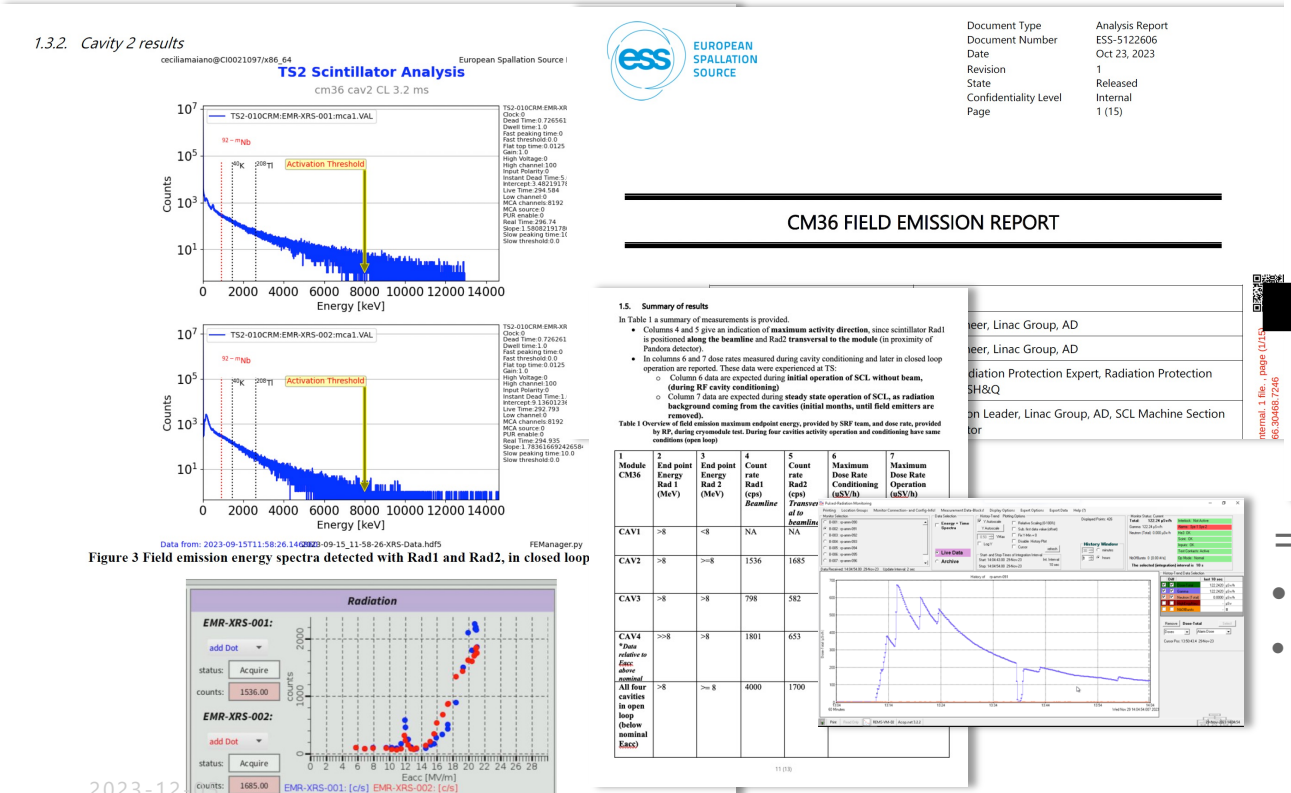


Figure 3 Field emission energy spectra detected with Rad1 and Rad2, in closed loop

Table 1. Phases of the CM Workflow

#	Phase	Areas	
		From	To
1	Cryomodule reception	G02-CXL	CM-IRA
2	Cryomodule preparation	CM-IRA	
3	Cryomodule installation	CM-IRA	Bunker
4	Cryomodule Warm Validation	TS2 Bunker	
5	Cryomodule Cold Validation		
6	Cryomodule Warm-up		
7	Cryomodule Disconnection	Bunker	CM-IRA
8	Cryomodule Preparation for Dispatch	CM-IRA	G02-CXL
9	Cryomodule Dispatch	G02-CXL	HLB Hall or Storage

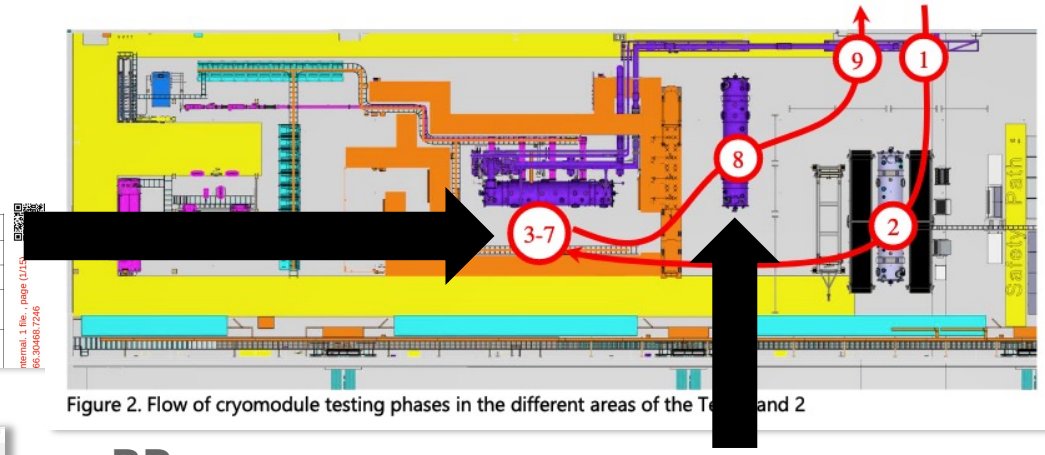


Figure 2. Flow of cryomodule testing phases in the different areas of the Te and 2

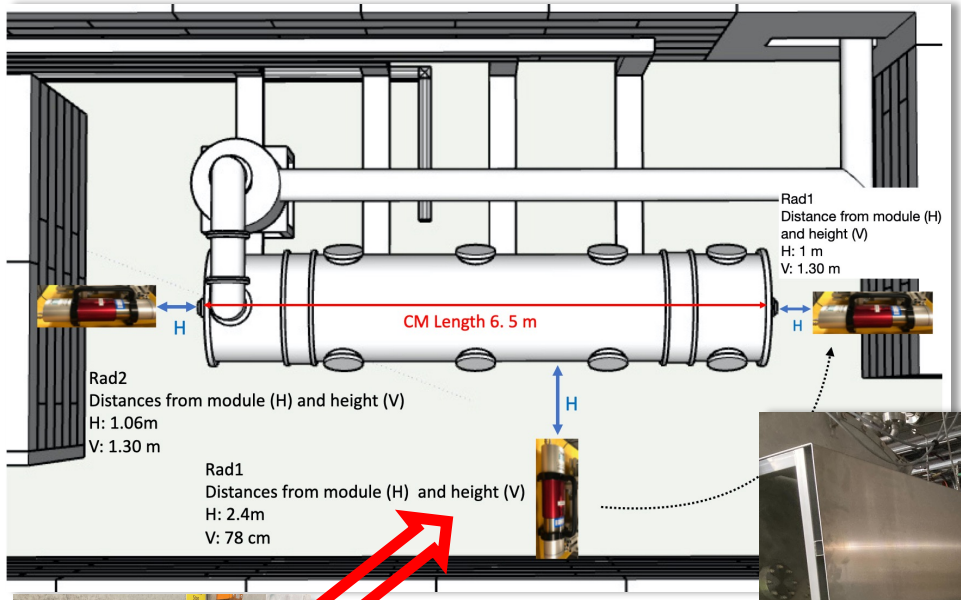
=> **RP surveys:**

- Daily during HB cryomodule operation **3-7**
- Before moving modules from Supervised Area (max 3 uSv/h) to storage white area (< 0.5 uSv/h) **8**

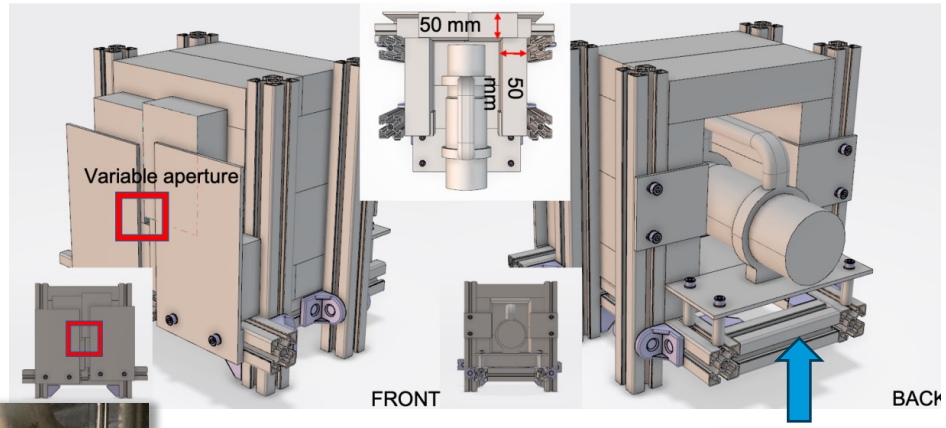
Equipment description

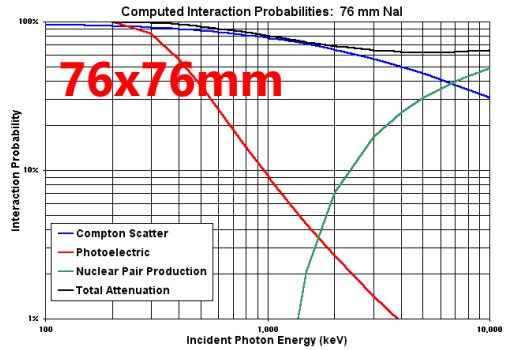
NaI(tl) detectors with Pb shielding (AMPTEK Gammarad5 76x76mm)

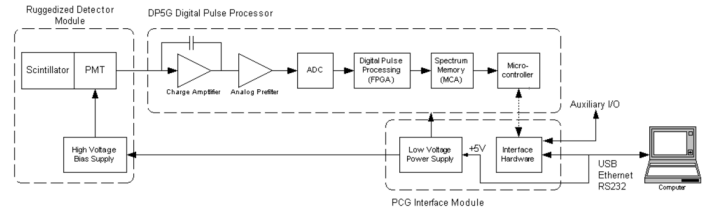
https://www.amptek.com/-/media/ametekamptek/documents/resources/products/user-manuals/gammarad5-user-manual-b0.pdf?la=en&revision=afb7309f-7ab0-4490-8e10-db88



RP Pandora certified and calibrated Detector. Dose rate: Neutrons and gamma

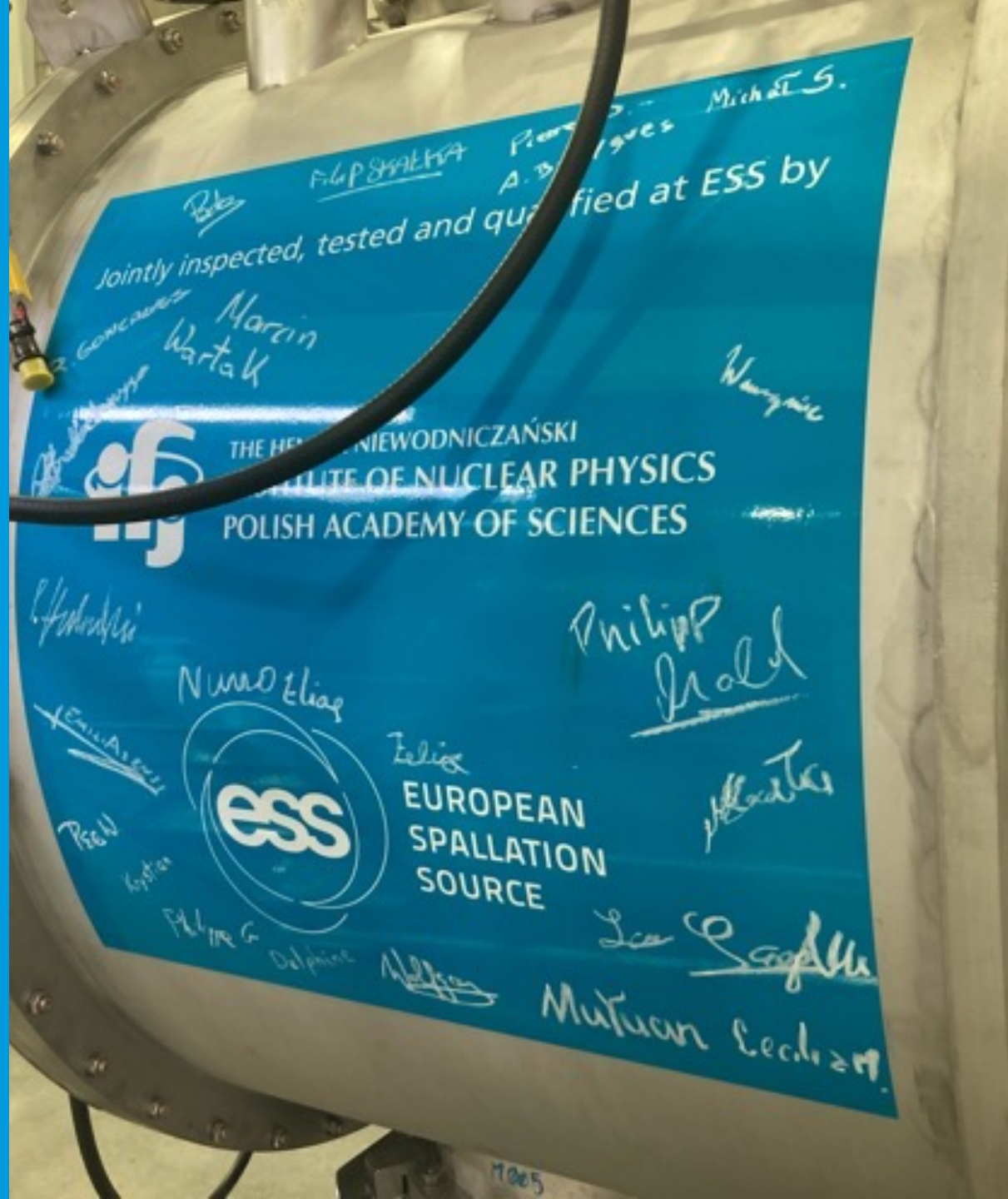






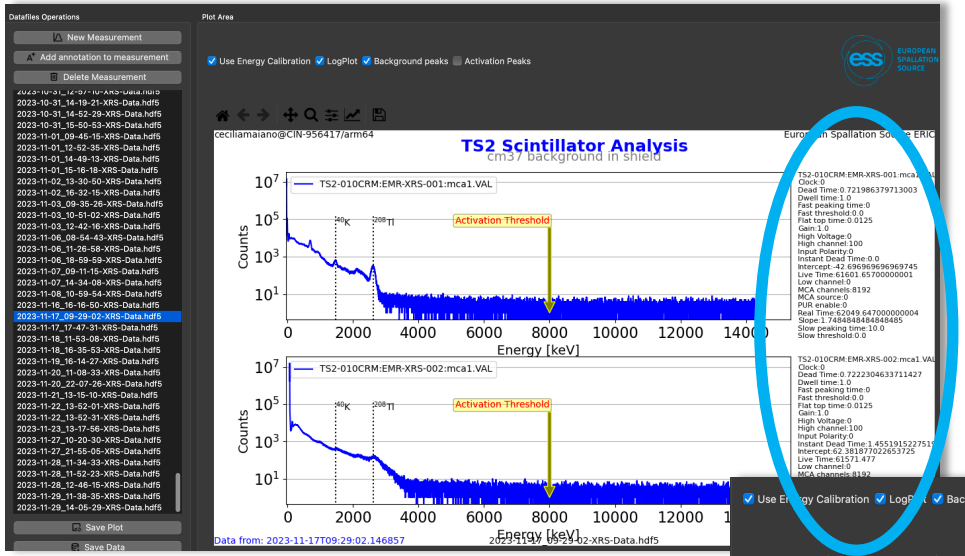
2

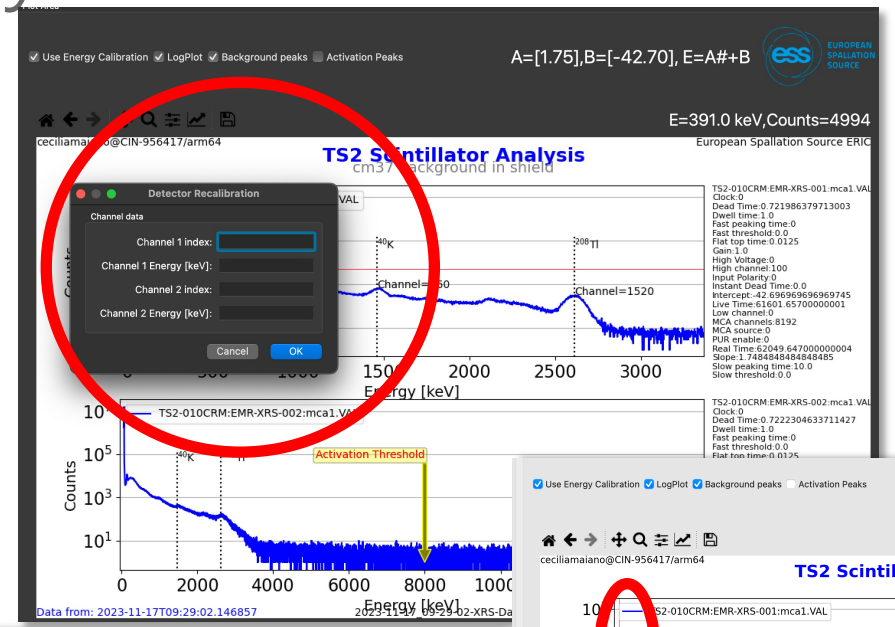
Cryomodules field emission experience

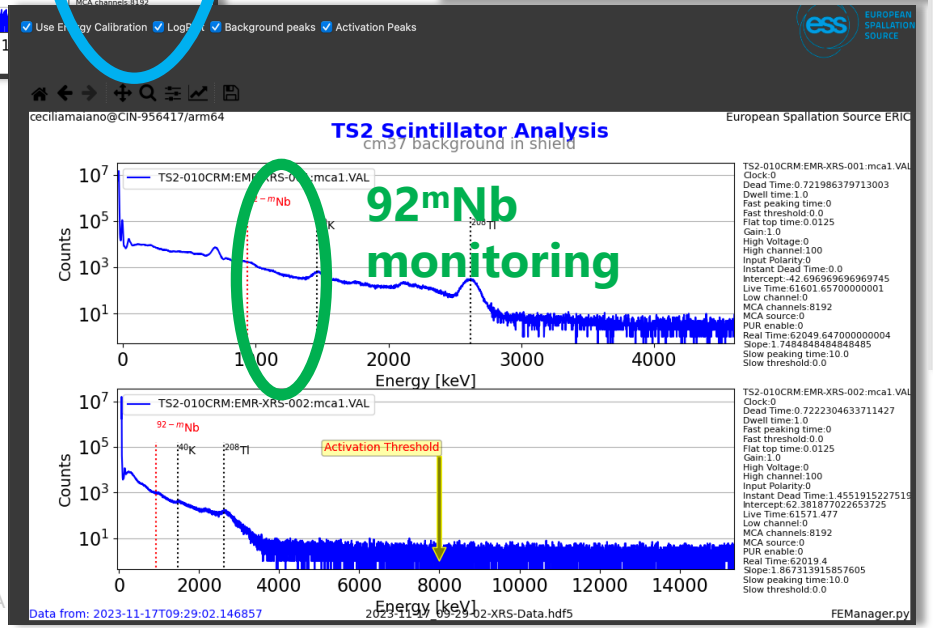


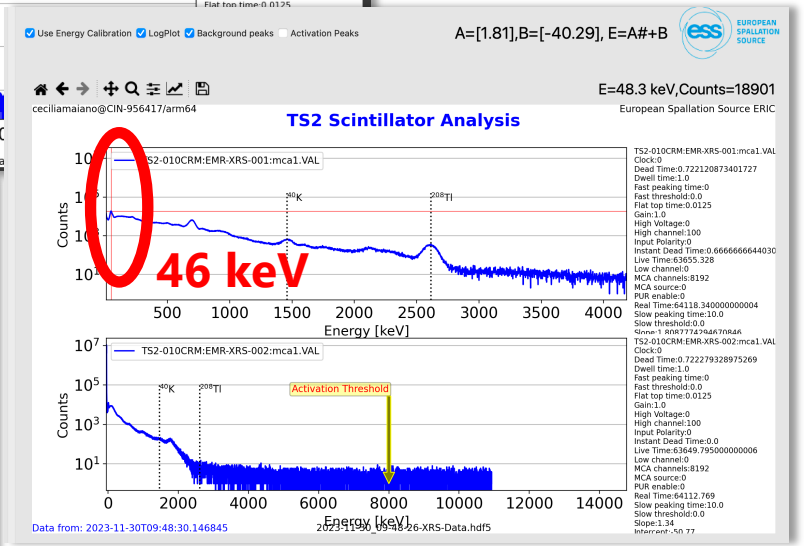
Acquisition and Analysis tool

- NaI(Tl) integrated in EPICS
- Tools with python scripts









Recalibration, using

- 208Tl
- 40K
- Pb x-ray 46 keV

Regular measurements

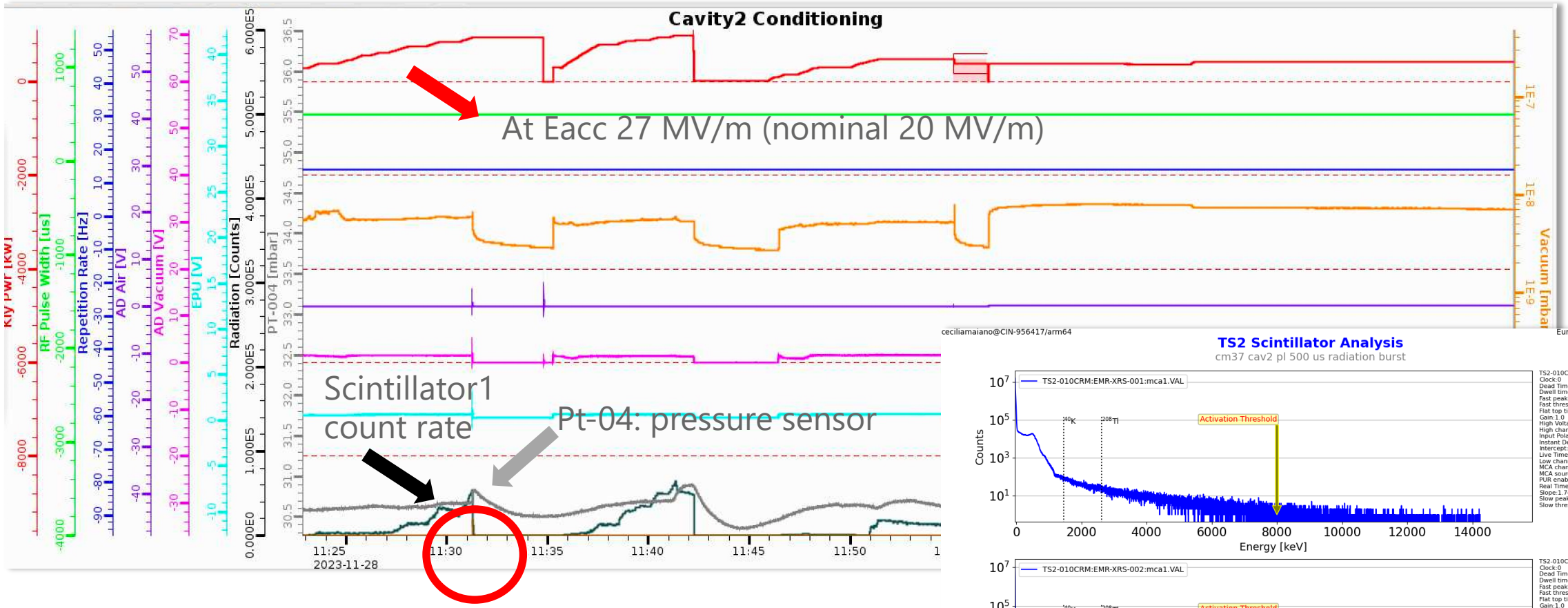
- BKG
- FE meas
- **Configuration parameters**

Activation check

- mainly **92mNb** due to giant resonance (y,n) activation

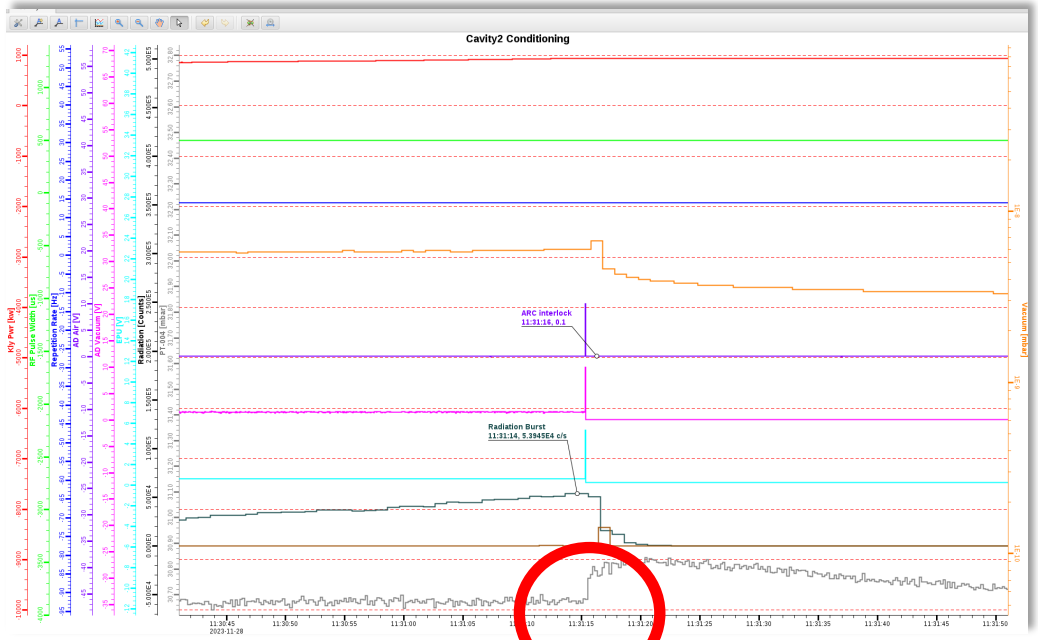
FE as limiting mechanism – at high fileds - (1)

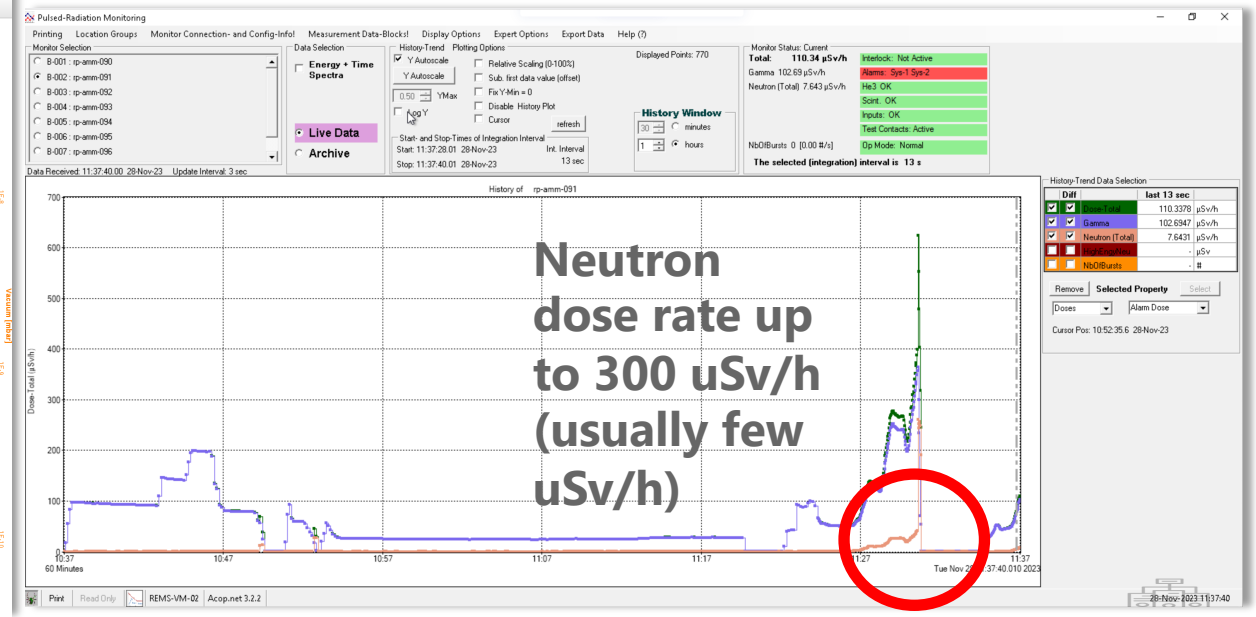
Ex: high beta cryomodule cm37, cav2 conditioning (Pl 500 us, open loop)



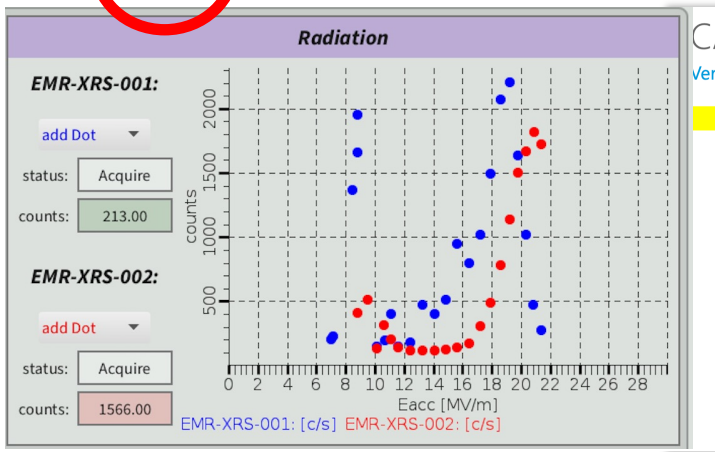
FE as limiting mechanism (2)

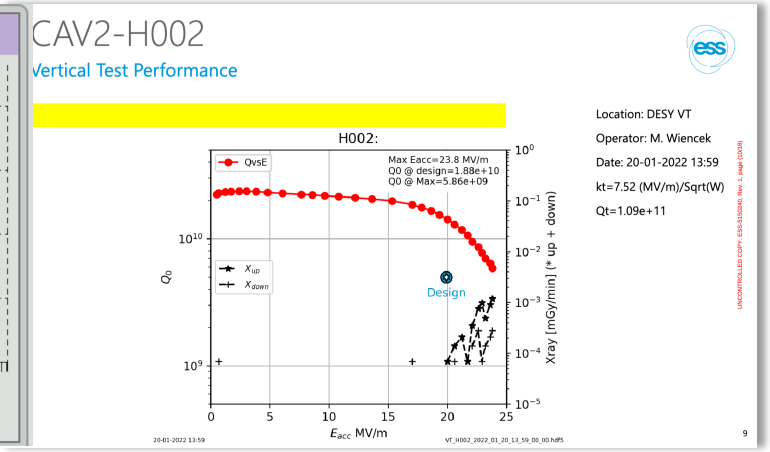
Ex: high beta cryomodule cm37, cav2 conditioning (PI 500 us, open loop)





Cryomodule test CM

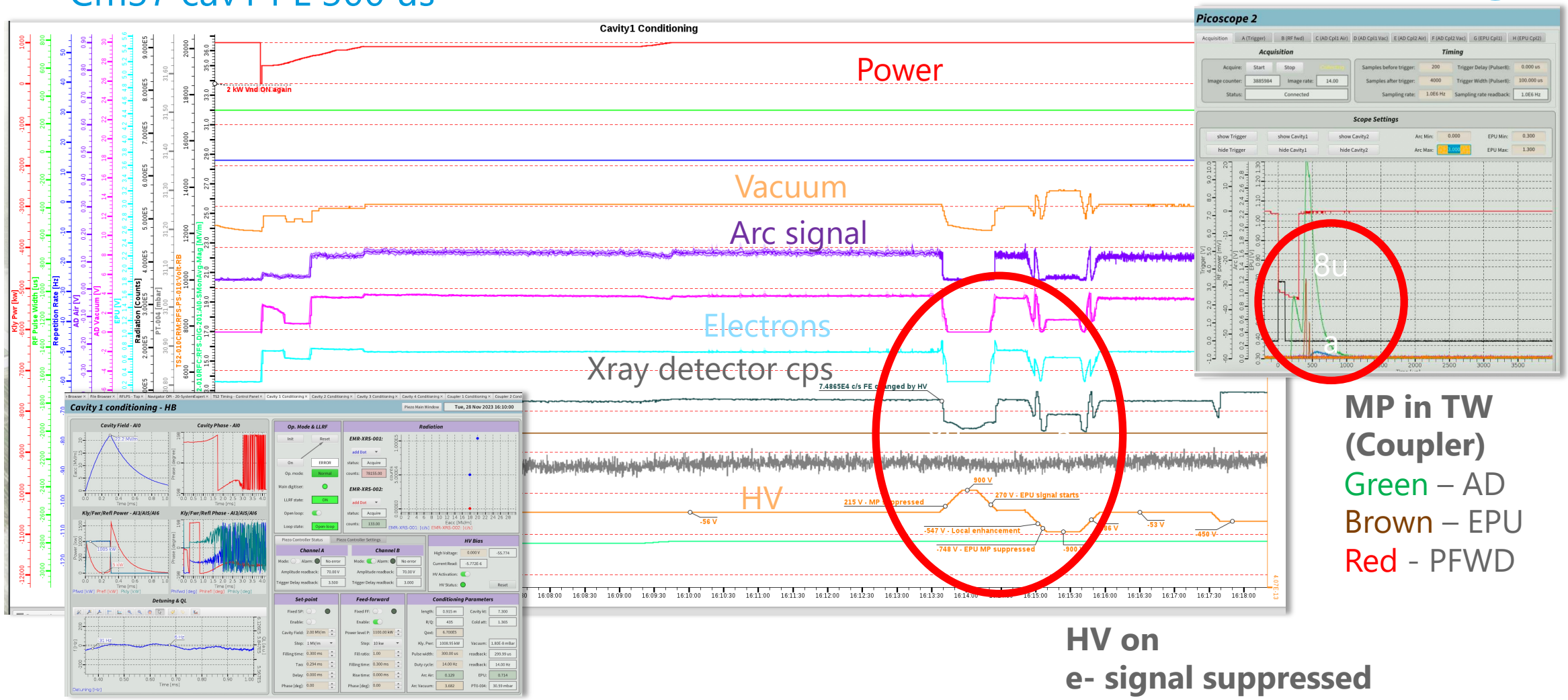




VT Vertical Test

FE fed by coupler MP: HV suppression

Cm37 cav1 PL 300 us

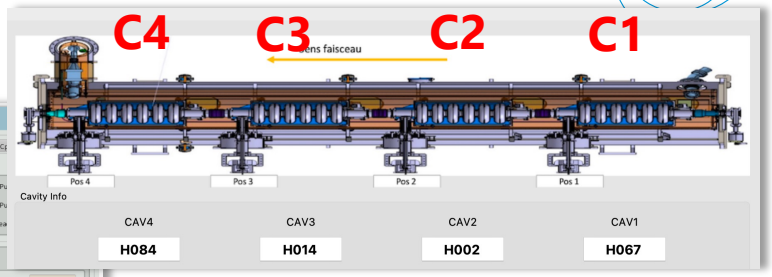


MP in TW (Coupler)
Green – AD
Brown – EPU
Red - PFWD

HV on
e- signal suppressed
Radiation suppressed

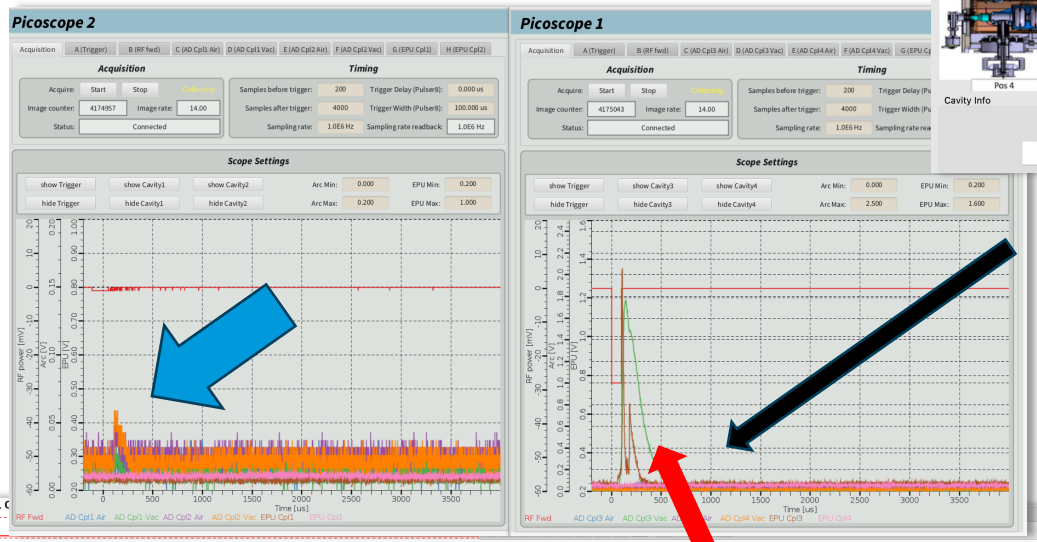
FE fed by coupler MP: scintillation in fibers (1)

Experience with HB cm37 – cav3 -



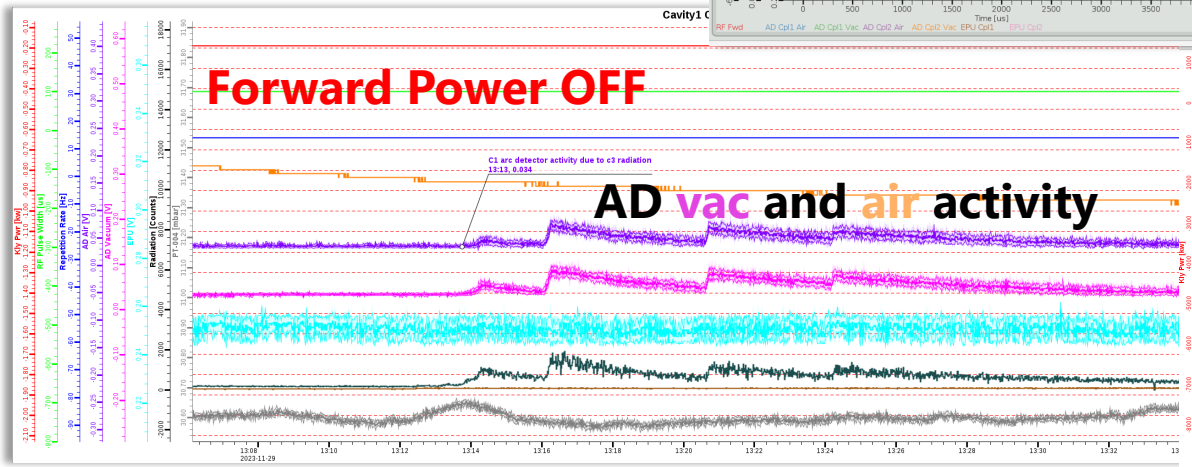
AD cav 1and cav 2 detect radiation coming from cavity 3 downstream

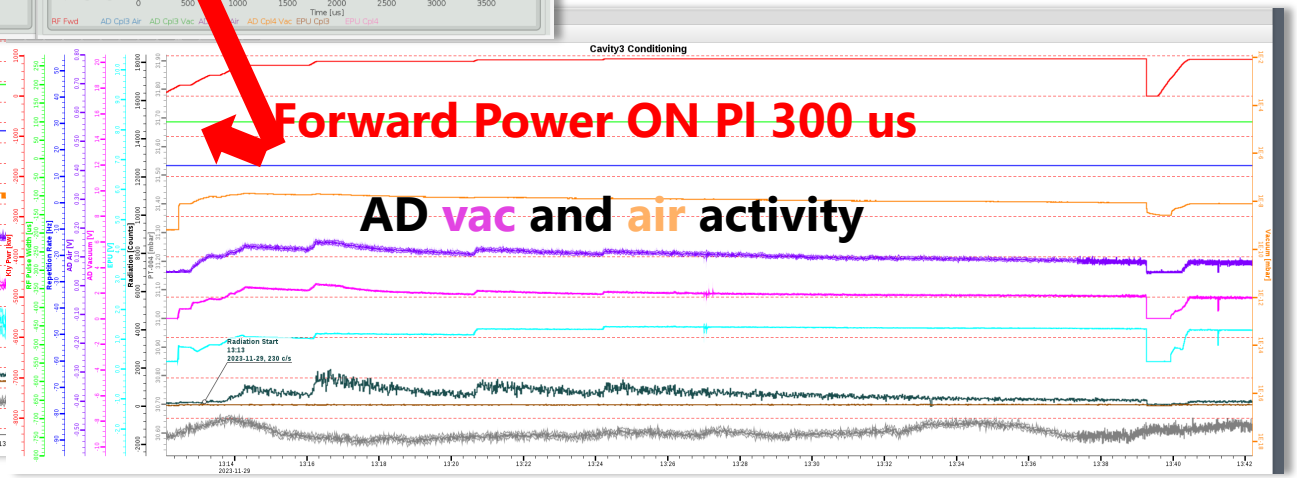
C1/C2 off



AD and e- pu signal Outside RF pulse (TW – coupler)

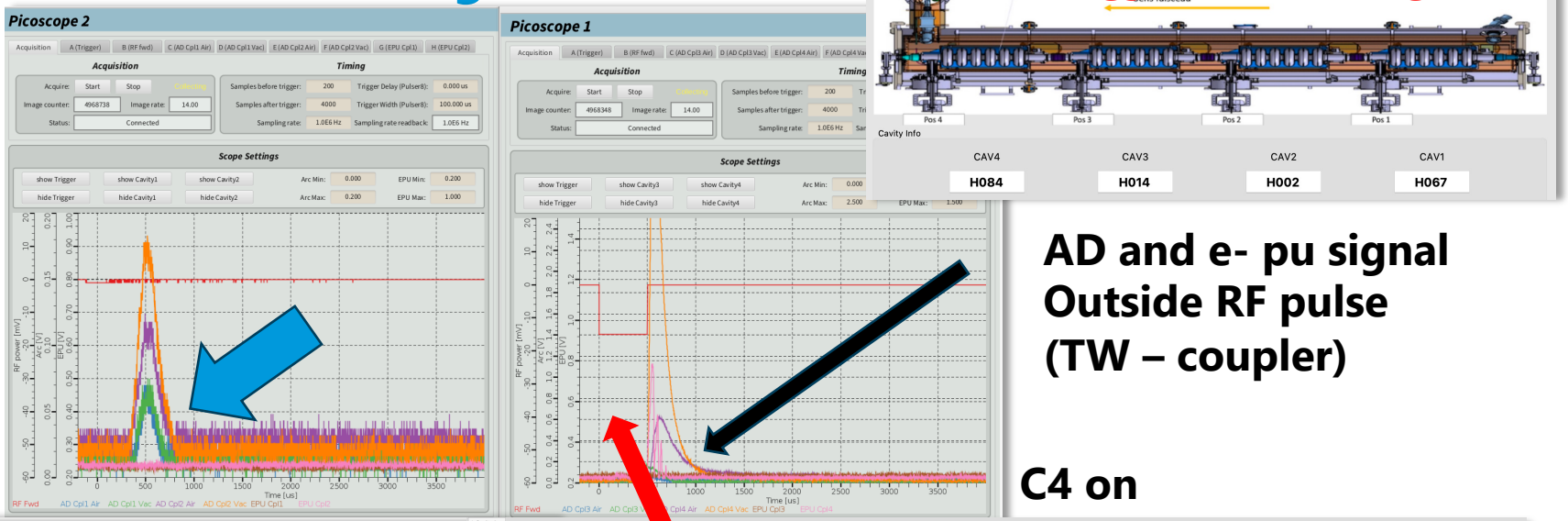
C3 on





FE fed by coupler MP: scintillation in fibers (2)

Experience with HB cm37 – **cav4 – strongest effect**

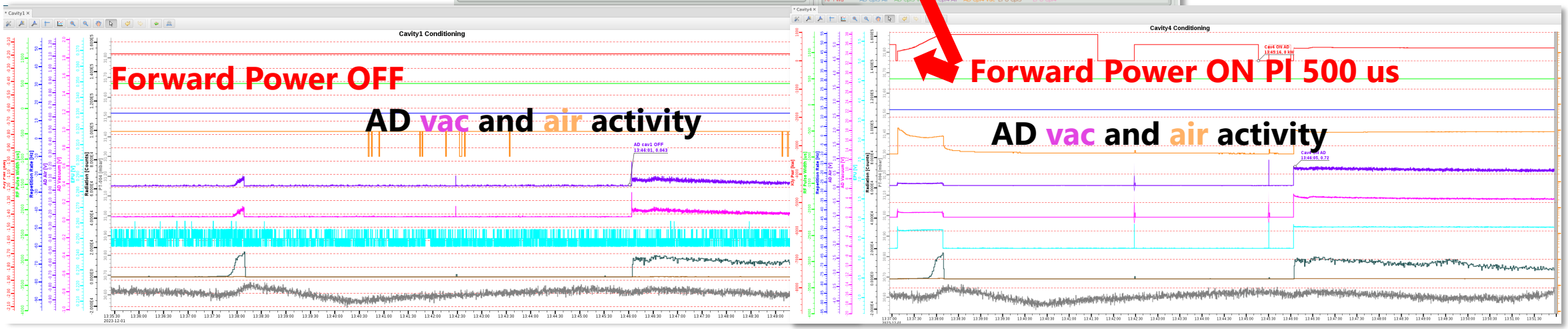


AD cav 1and cav 2 detect radiation coming from cavity 4 downstream

C1/2 off

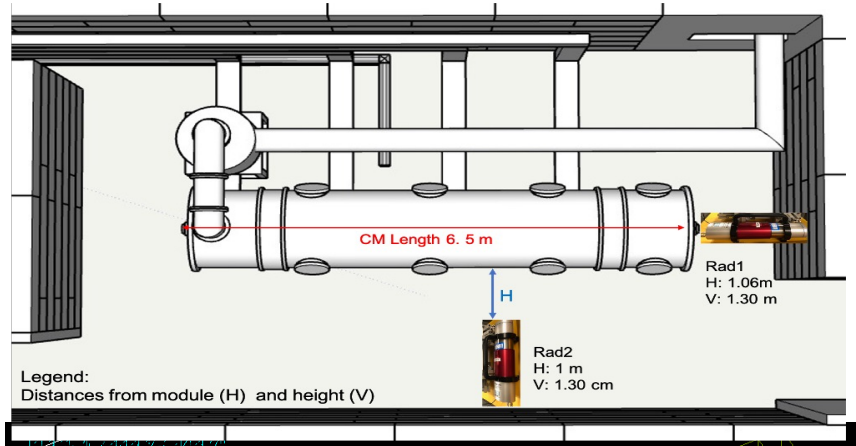
AD and e- pu signal Outside RF pulse (TW – coupler)

C4 on



Ongoing activity to discriminate MP arcing from radiation scintillation **(lambda)**

CEA Montecarlo simulations explain activation



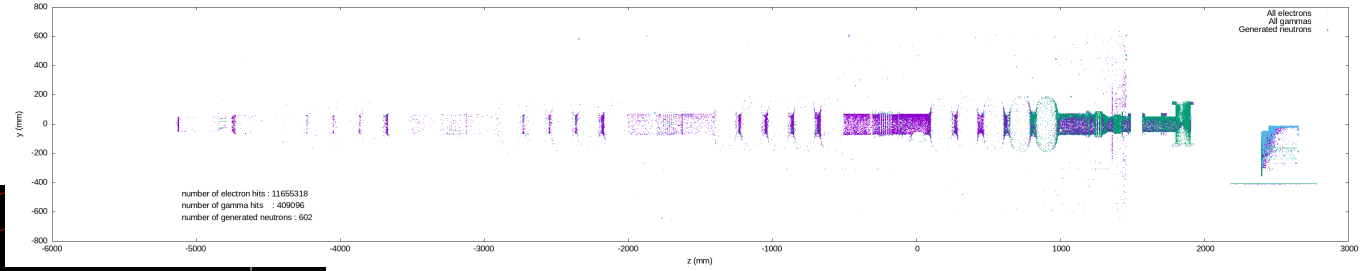
closed loop operation:

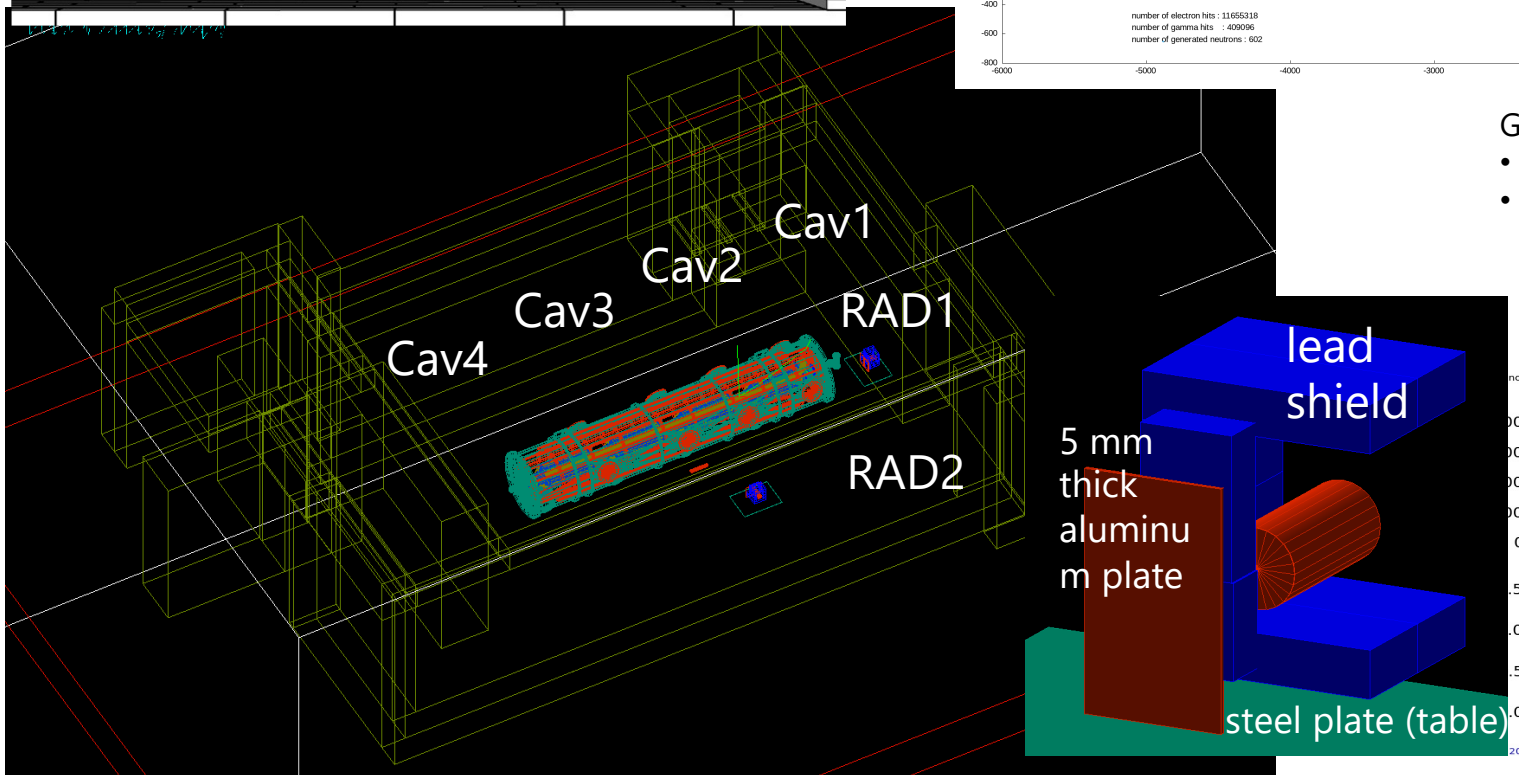
- 100 uSv/h neutron,
- >2 mSv/h gamma
- discrete emission lines on top of bremstrahlung

open loop operation

- 50 uSv/h neutron
- 1.4 mSv/h gamma

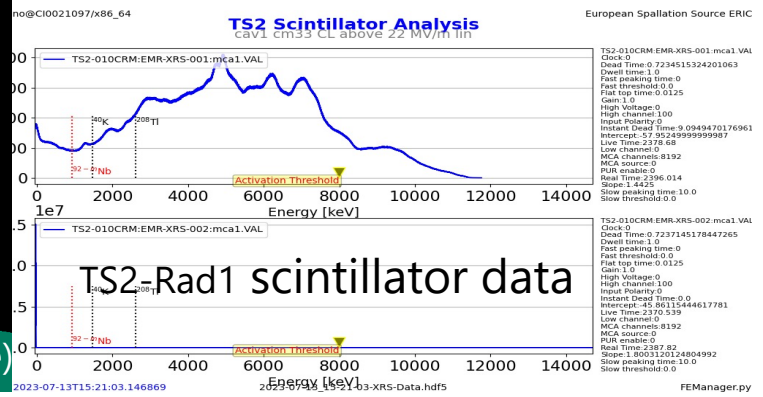
TS2-CM33_36





G4 simulation points to the following scenario:

- neutrons are generated in the lead shield of Rad1
- neutron capture by the bunker shielding material (60% Fe) is expected to generate discrete gamma lines (mostly 7.655 MeV due to ^{56}Fe then 9.298 MeV due to ^{54}Fe, then contributions of H,Ca,Si)



Montecarlo simulation CEA predicts outcome

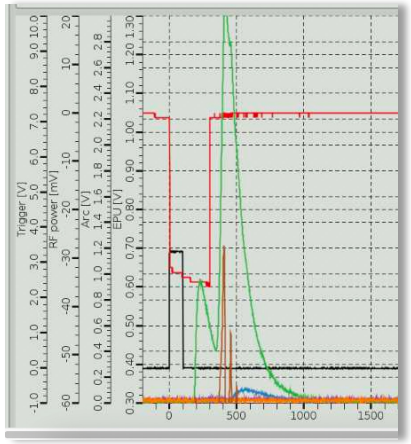
All cavities at 20 MV/m

CM is **asymmetric** : the FPC e- has to be accelerated by the cavity on its right first

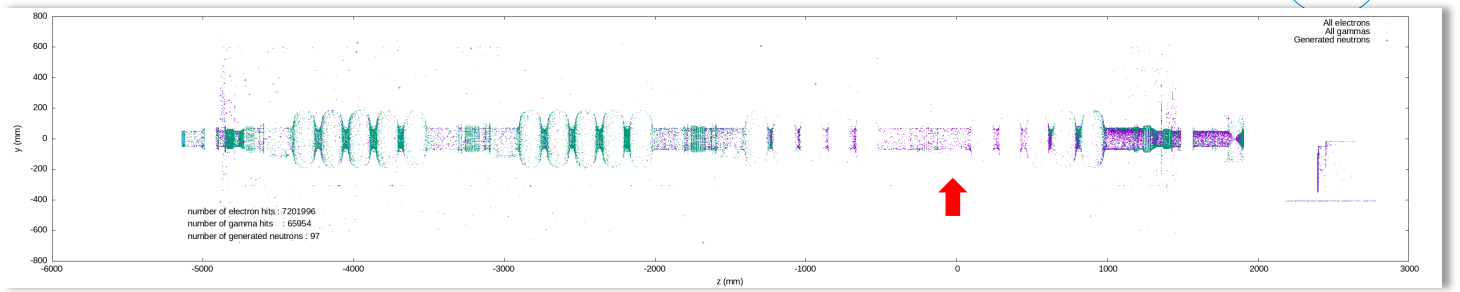
Cavity FE in general low in comparison to FPC induced radiation (checked with time domain measurements)

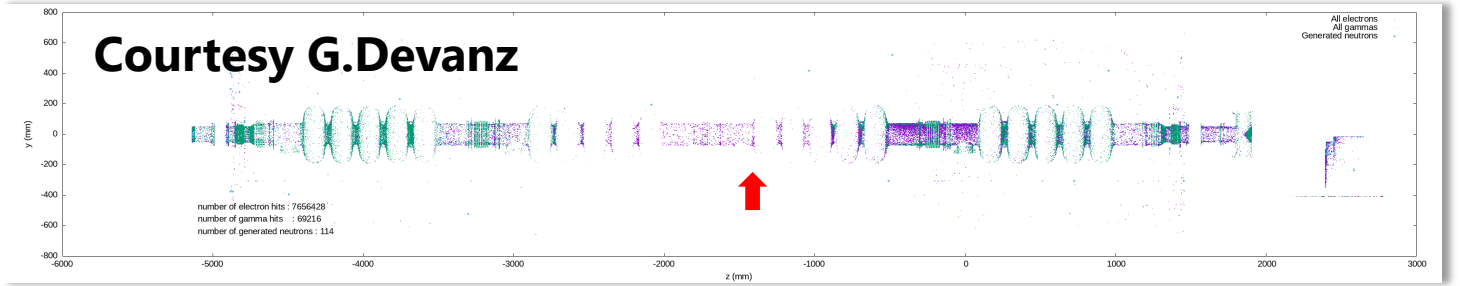
- Cavity within Pforward pulse
- FPC radiation mainly in TW at cavity discharge

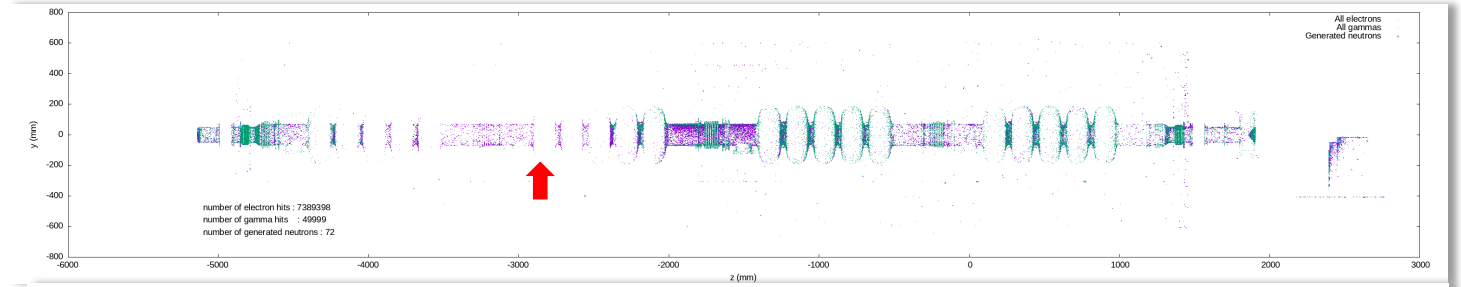
TS2-CM33_36
Valid for CM37

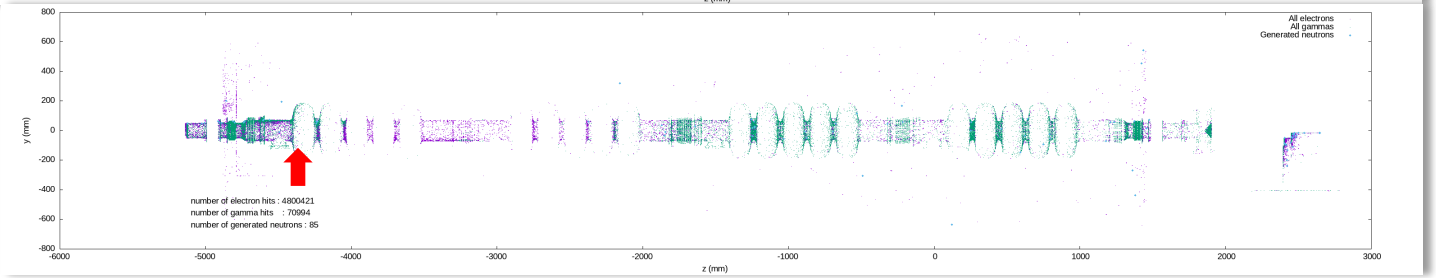


The dots are either **gammas** or **electron** interactions in the cryomodule, so see electrons and radiation spreads all along the beam line can be seen.
On the right also radiation in the lead shield of RAD1 and the table its installed on









Vertical Test vs Cryomodule test

CM	Cav	FE energy det. 1 [MeV]	FE energy det. 2 [MeV]	FE during VT	FE during CM
3	M007	4	3	Y	Y
	M018	4	4	Y	Y
	M020	3	4	N	Y
	M011	5	5	Y	Y
4	M014	4	3	Y	Y
	M016	none	none	N	N
	M030	N/A	N/A	N	N
	M031	3.2	5.8	Y	Y
5	M023	6	6	Y	Y
	M025	<4	6	Y	Y
	M029	none	none	N	N
	M034	6	6	N	Y

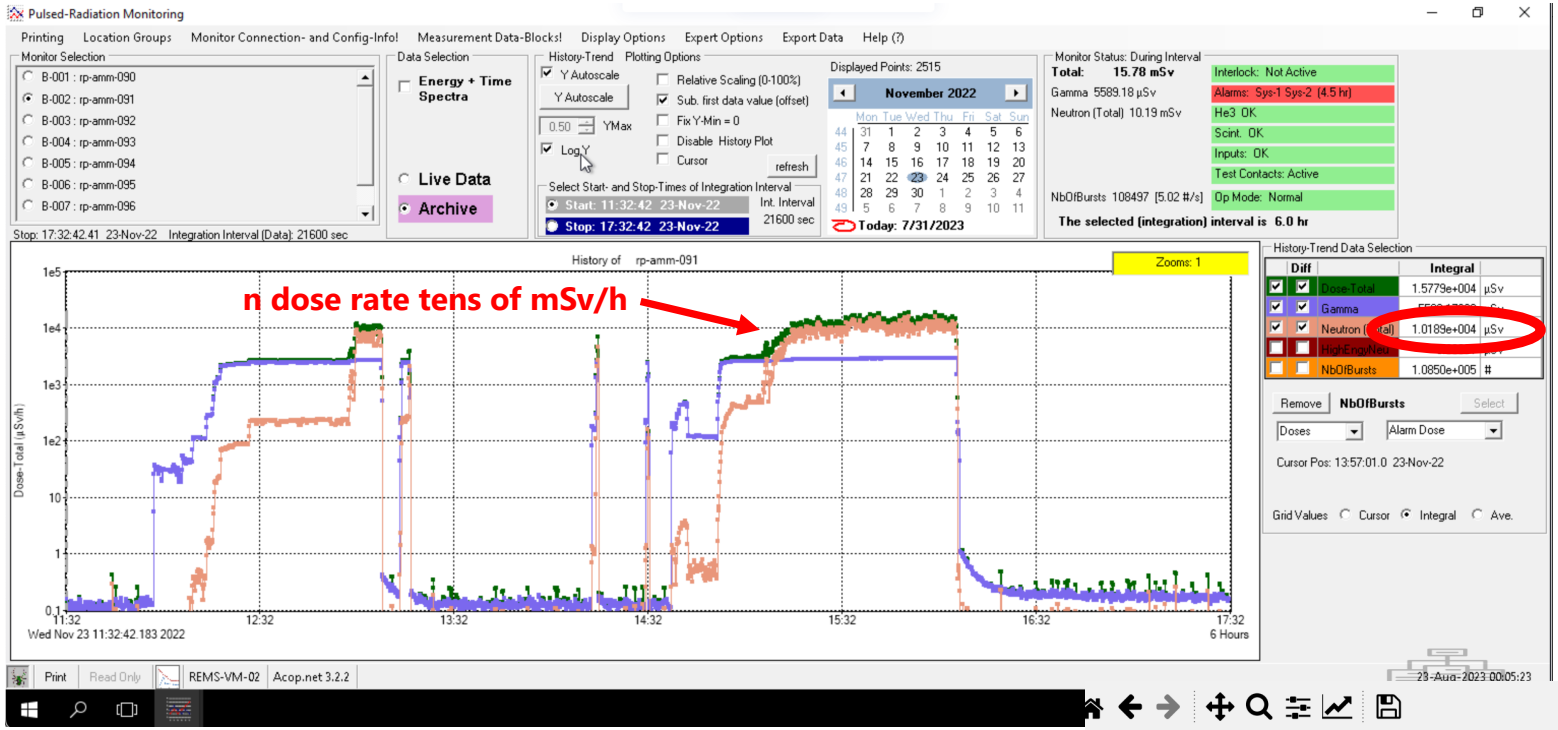
CM	Cavity from 1 to 4	VT field emission [MV/m]	CM field emission [MV/m]	
			Detector1	Detector2
4	M014	From 17 to 19	From 17 to 18	From 17 to 18
	M016	none	none	none
	M030	none	From 15 to 19	From 15 to 19
	M031	From 15 to 23	From 15 to 18	From 15 to 18
5	M023	From 12 to 18	From 10.5 to 14.5	From 12 to 17.5
	M025	at 19	From 15 to 17	From 15 to 17
	M029	none	none	none
	M034	none	From 15 to 18	From 15 to 18

Qualitative check: affected by different geometry (efficiency) and sensitivity

FE in VT && CM

Concern: HB produce neutrons

CM31 at TS2, Nb activation by Field emission from cavities



Will it harm operation?

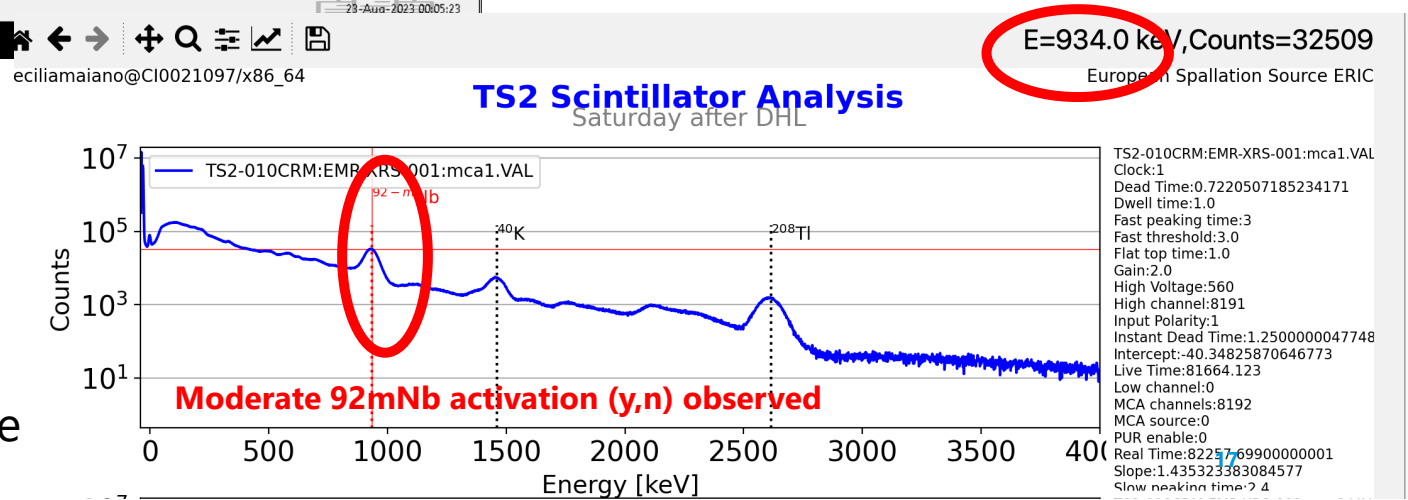
Severe radiation background already affects cavity protection diagnostics (fibers for arc detectors), how do we differentiate from beam losses? Activity with BI to mitigate by filtering background

HB testing shows much more radiation than MB

Pandora - RP -dose rate (uSV/h)

Joint work with RP to document TS2 rad measurements during RF excitation

Scintillators - Energy Spectrum (dN/dE) count rate



Warm coupler conditioning

Evidence of no radiation => licensing aspects (SSM)

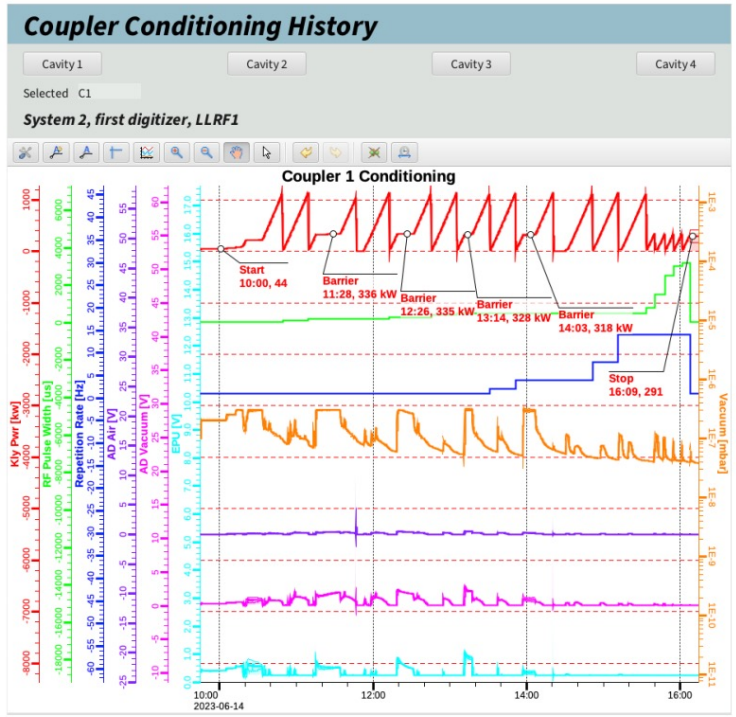
Coupler trends

1. CAVITY 1

1.1. Duration

Start	2023-06-14 10:00
End	2023-06-14 16:09
Duration	06:09 h
Events	Some barriers approximately at the same power level (300 kW). Vacuum, arcs and EPU activity correlation observed.

1.2. Trends during the conditioning process



Sundays radiation background

4.4. Radio Protection data taken during warm couplers conditioning

4.4.1. Background measurement

Data taken with Pandora detector, which belongs to RP, are shown in background data (acquired on a Sunday before and after warm couple measurements data (with RF on) are reported: they show no activity a measured during CM33 warm coupler conditioning.

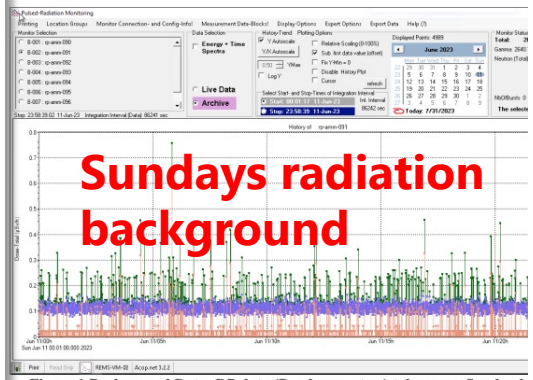


Figure 1 Background Data: RP data (Pandora system) taken on a Sunday b warm conditioned. Nothing above backgrou

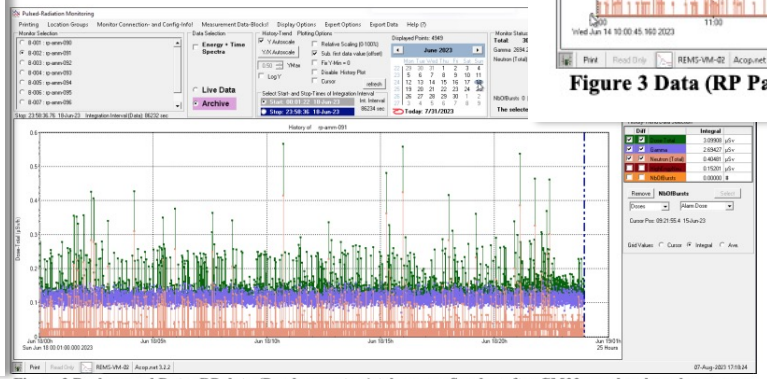


Figure 2 Background Data: RP data (Pandora system) taken on a Sunday after CM32 couplers have been warm conditioned. Nothing above background detected.

Coupler radiation data

4.4.2. Couplers

Data (RP Pandora system) taken during couplers conditioning are shown below.

Figure 3 Data (RP Pandora system taken during coupler 1 conditioning). Nothing above background detected.

SUMMARY

Total time summaries

Cavity 1	06:50 h
Cavity 2	06:30 h
Cavity 3	16:45 h
Cavity 4	11:00 h
Total	16:05 **h**

rm coupler conditioning required 16 h and 05 m of uninterrupted RF operation.

Activity started with scintillators data and landed with radioprotection certified Pandora data

Thanks

Aknowledgments

* ESS: TS2 SRF, IFJ, CRYO, VAC, RP teams

* CEA in-kinds: Guillaume Devanz, Enrico Cenni, Olivier Piquet