04/06/2026 PhD Hours, Subatech Second year

PHD TITLE

DETECTOR DEVELOPMENTS FOR RADIATION PHYSICS APPLICATIONS AT ARRONAX CYCLOTRON.

RANIA JBARA

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Ferid Haddad

Supervisors:
Charbel Koumeir & Marie-Laure Gallin-Martel

Outline

1. **Context**
2. **Challenges**
3. **Objectives**
4. **DIAMMONI**
5. **PAF**
6. **PEPITES**
7. **Conclusion & Upcoming work**

1. Context

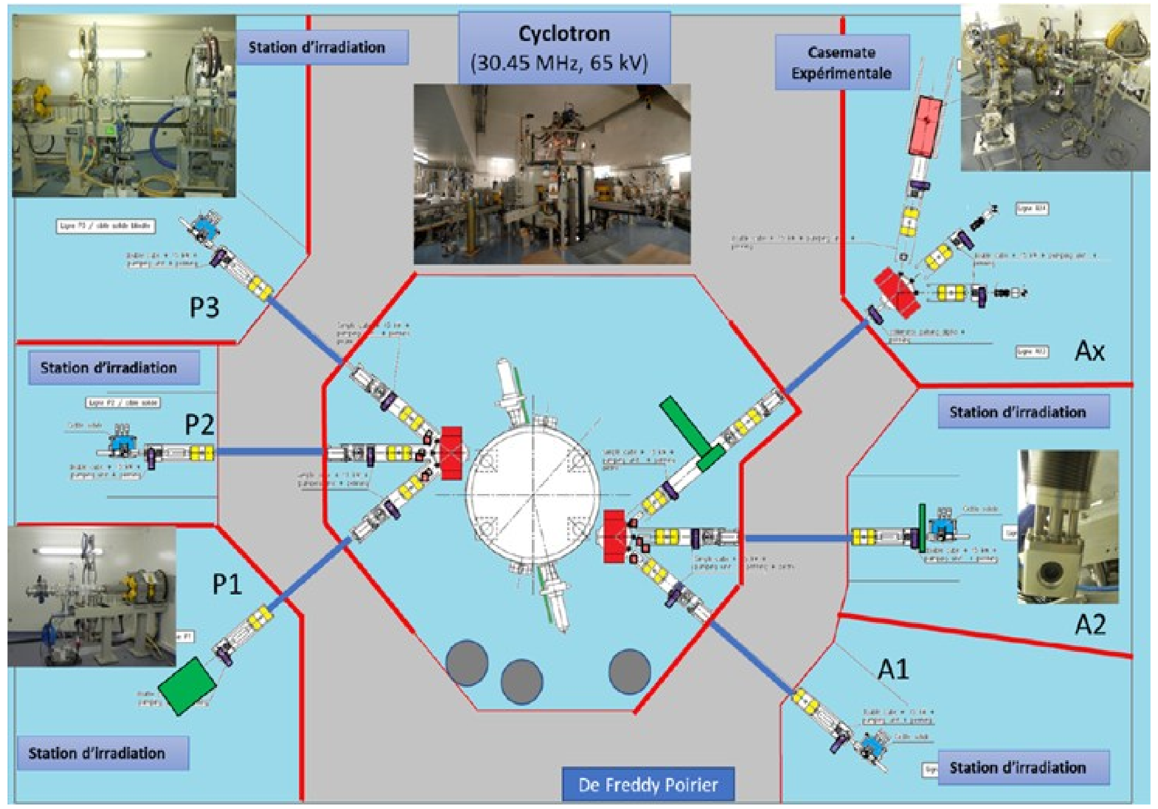
ARRONAX

(The Accelerator for Research in Radiochemistry and Oncology in Nantes Atlantic X)

- Operates a cyclotron accelerator (RF=30.45MHz).
- Delivers different types of beams: Protons, alpha up to 70 MeV & deuterons up to 35 MeV.
- 6 vaults:

-Five for Radionuclide production.

-One AX vault dedicated to research.



F. Poirier *et al.*, "EPD110 - THE ARRONAX PLATFORM FOR PROTON FLASH IRRADIATION: FROM BEAM PRODUCTION TO THE TARGET," *Phys. Med.*, vol. 94, p. S105, Feb. 2022, doi: 10.1016/S1120-1797(22)01681-7

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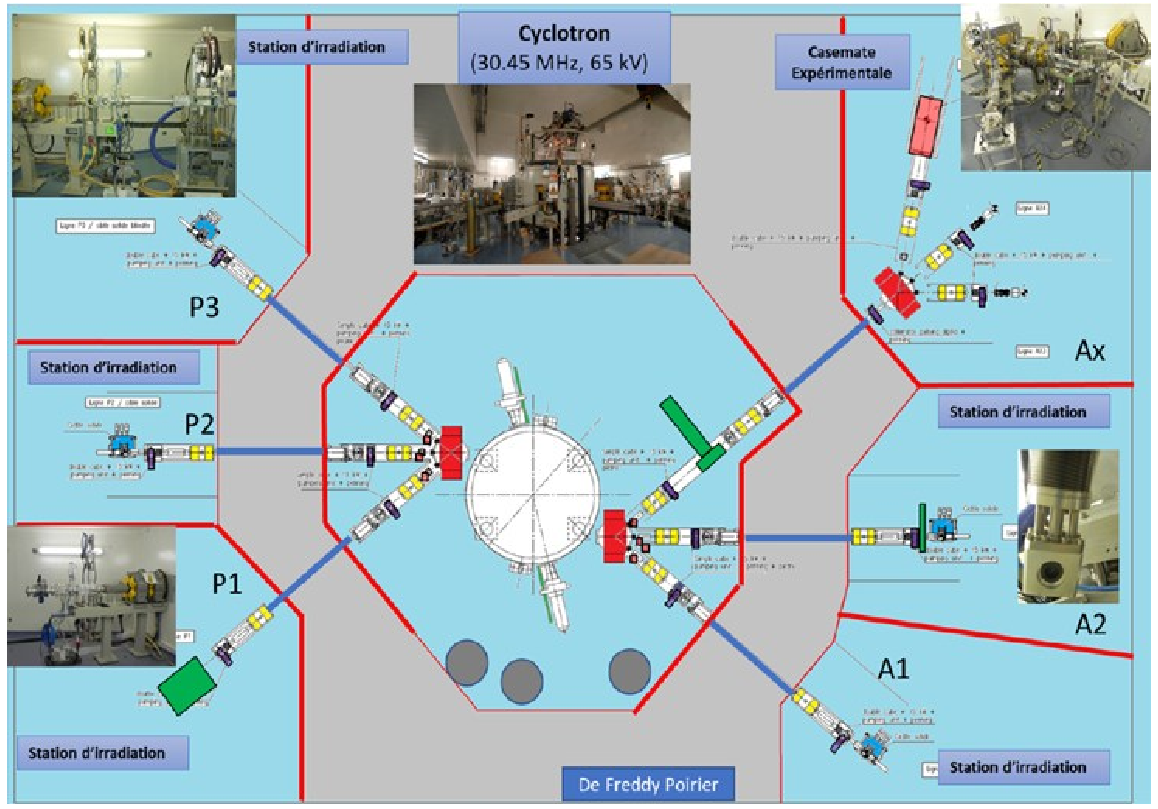

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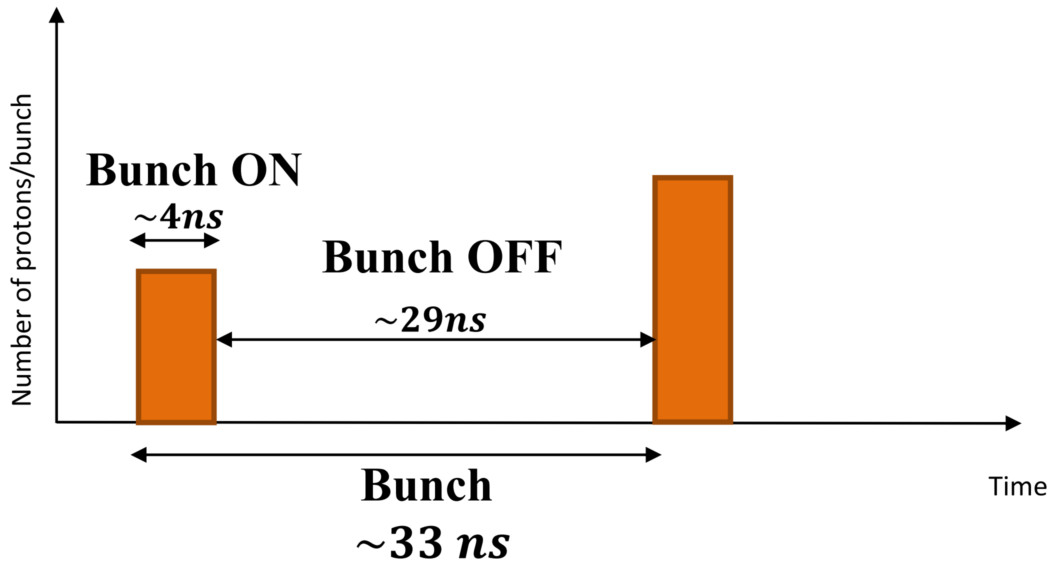
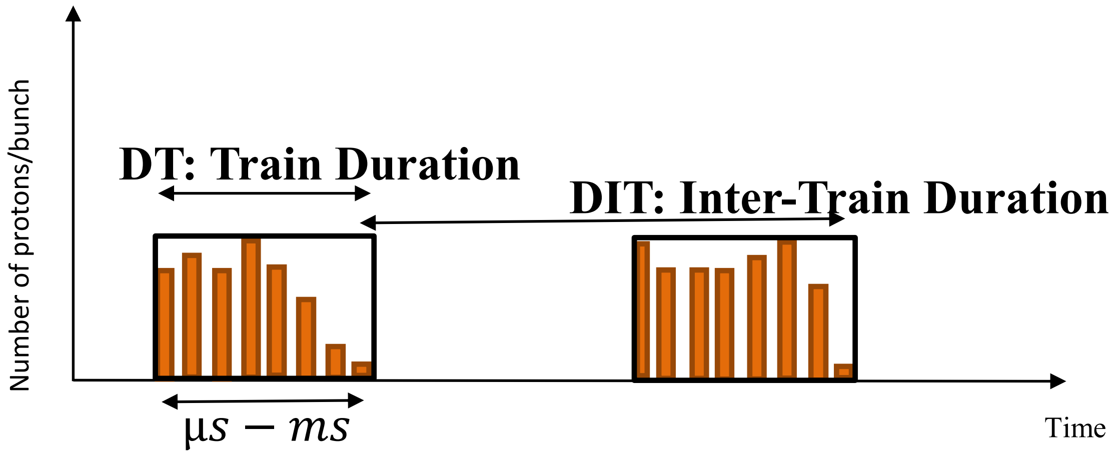
Continuous mode: Bunches of ions can be delivered with the beam's intensity varying from low <1 pA to high (up to 350 μA for protons and 70 μA for alpha).



Pulsed Mode: Trains of a few μs are constituted of bunches of 4 ns ON and 29 ns OFF. "Train duration" (DT) and "inter train time" (DIT) are tunable.



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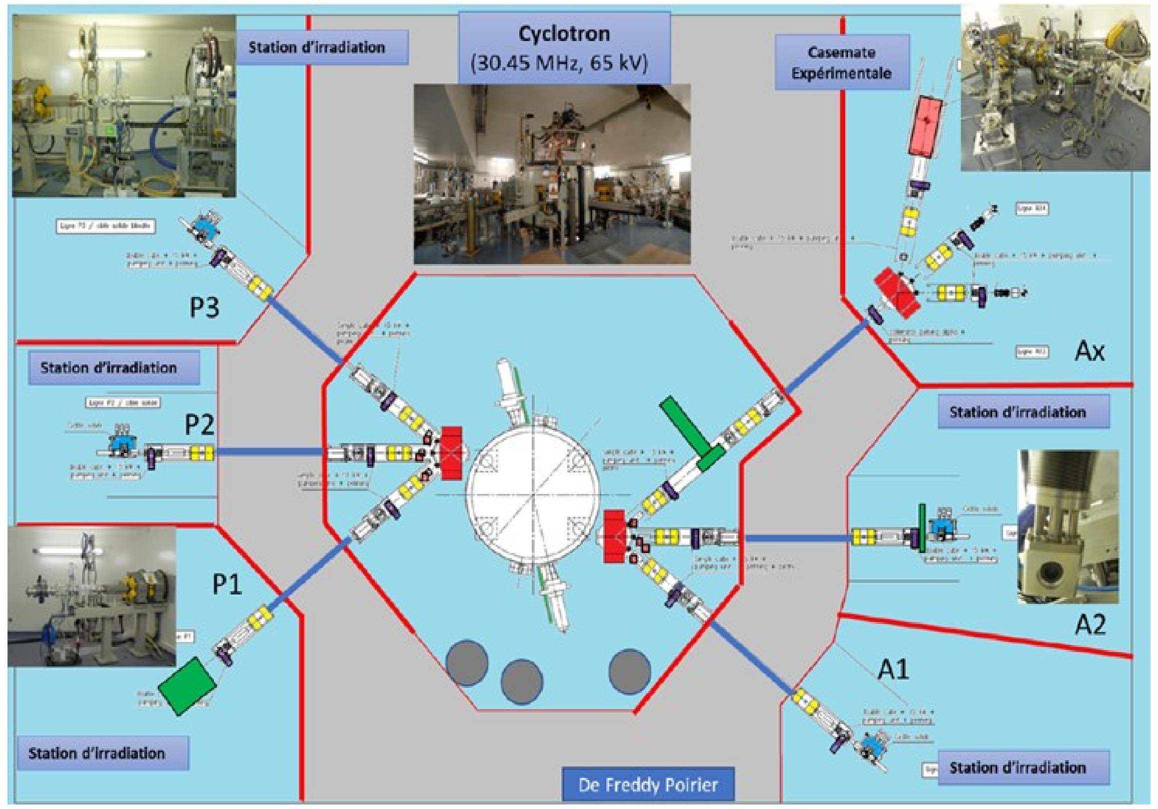

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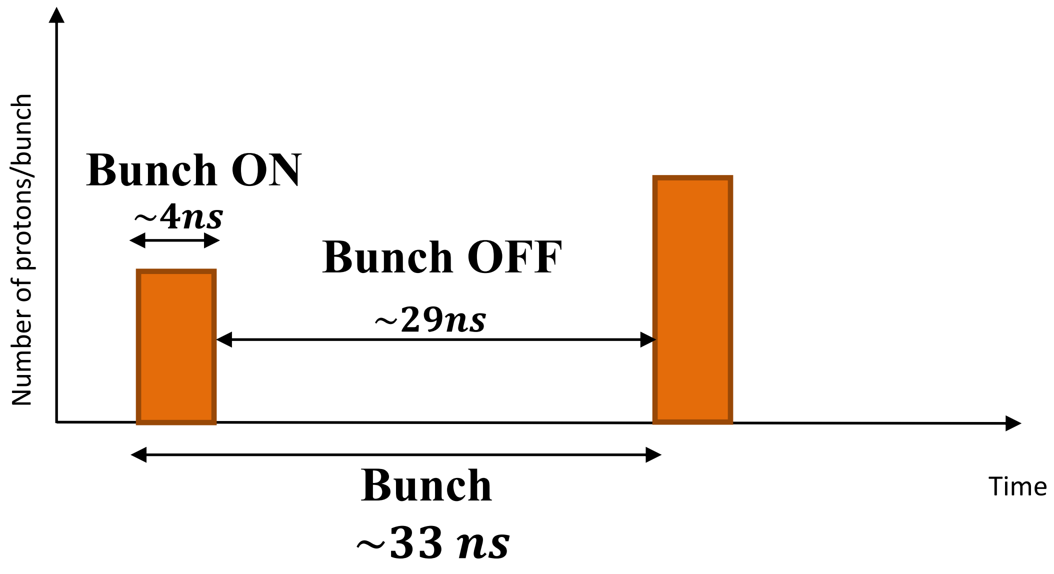

Conventional (Conv)
0.03 Gy/s

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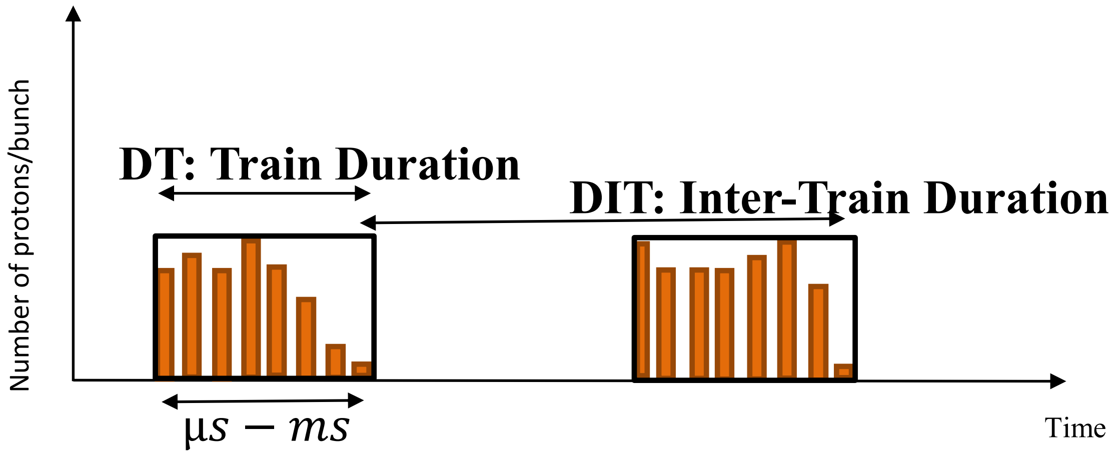
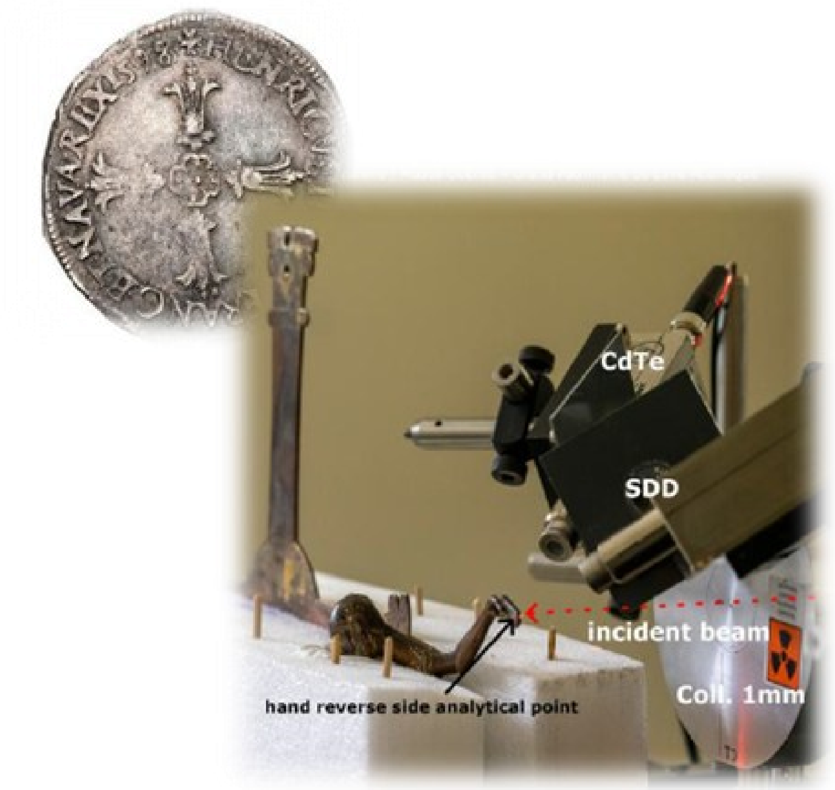


Ultra-high dose rate
>40 Gy/s

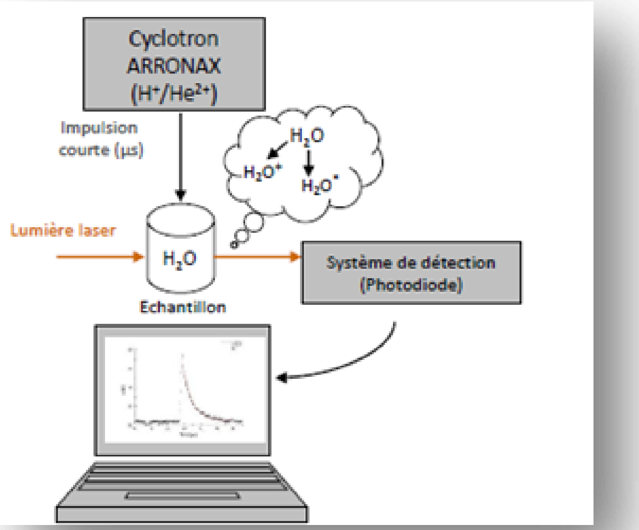
1. Context

Radiation physics and pre-clinical applications

AX beamline

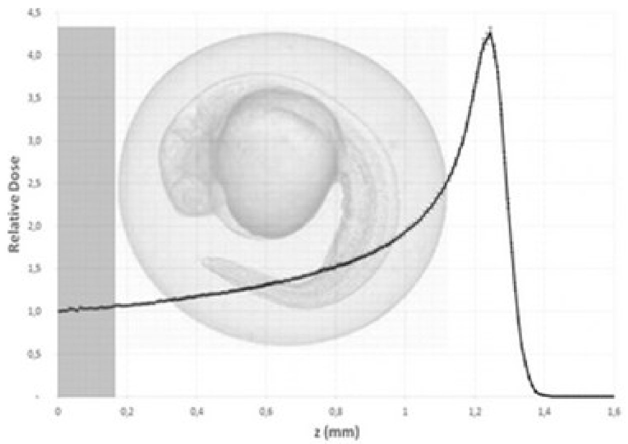


Cultural heritage objects analysis
A.Gillon,
J.Luabanya-Mubabinge (ongoing thesis)

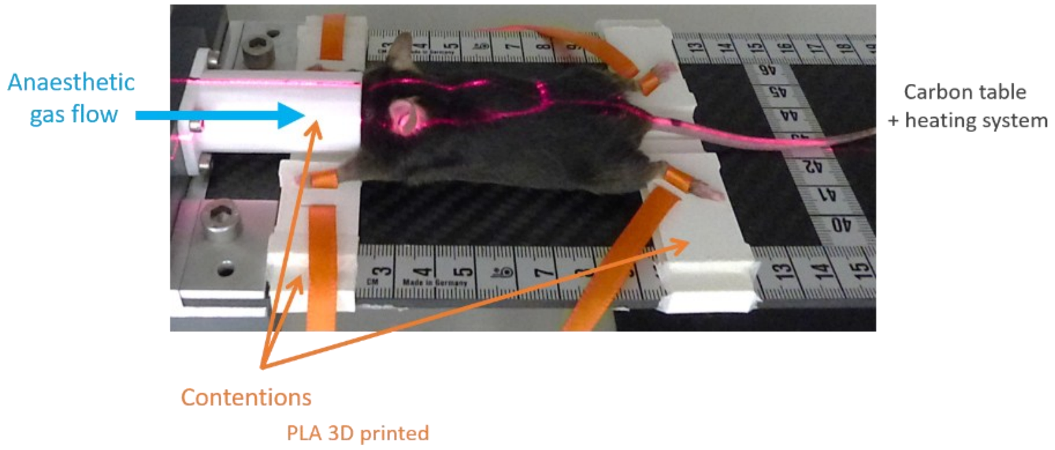


Radiolysis of water
S. Tarraf

Preclinical radiotherapy studies



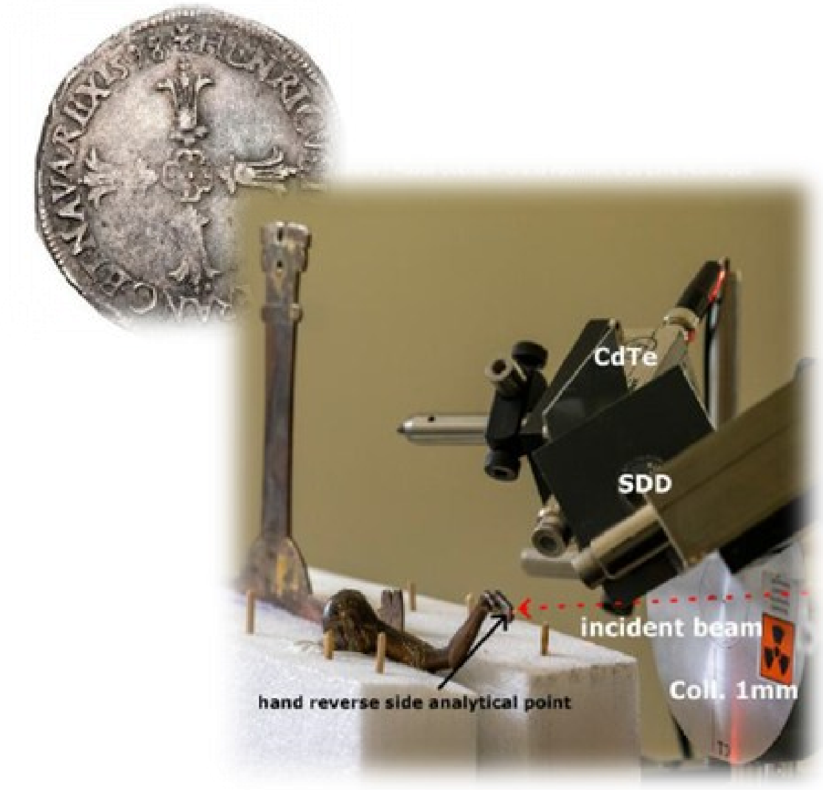
Examining the effect of sparing healthy tissues with ultra-high irradiation in a short duration (known as Flash therapy)
zebrafish embryos
Youssef Ghannam



Conv. & UHDR mice irradiations
M. Evin

Radiation physics and pre-clinical applications

AX beamline



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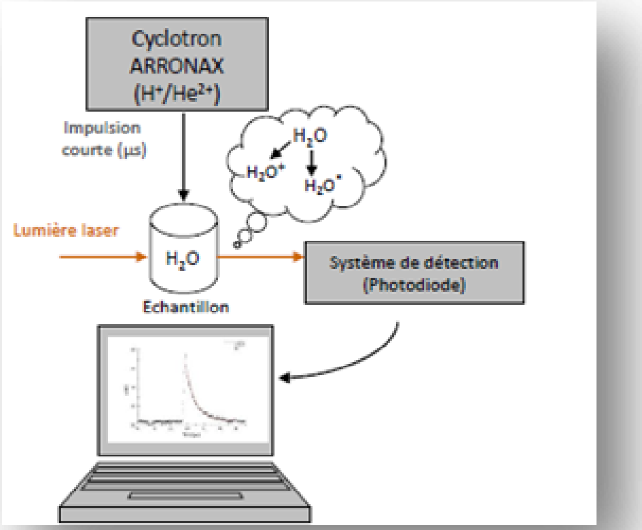

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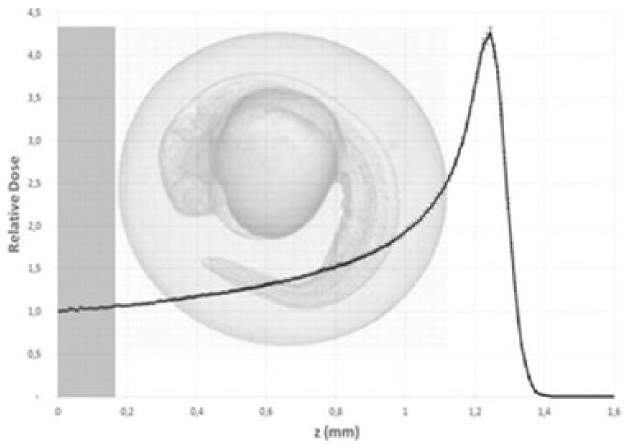
What confirms the accuracy of the delivered dose?

Verify beam parameters accuracy.

How?

Preclinical radiotherapy studies



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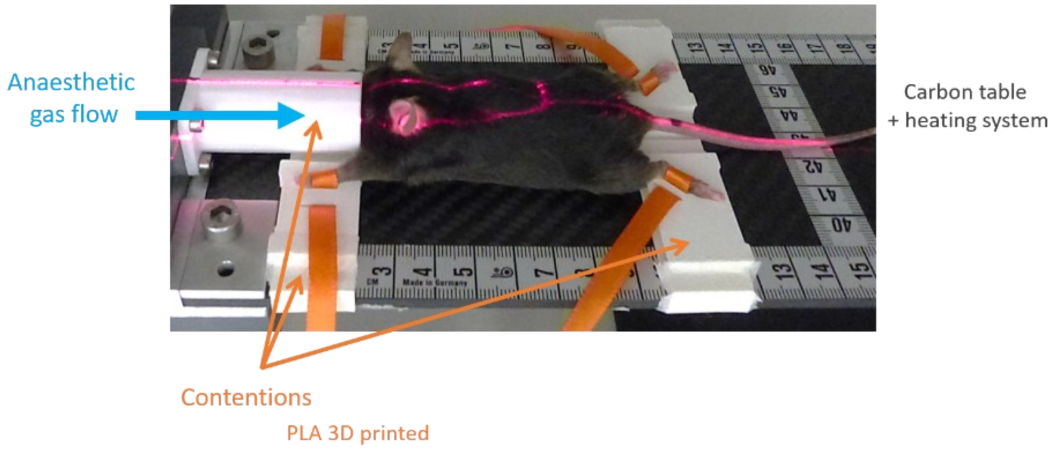

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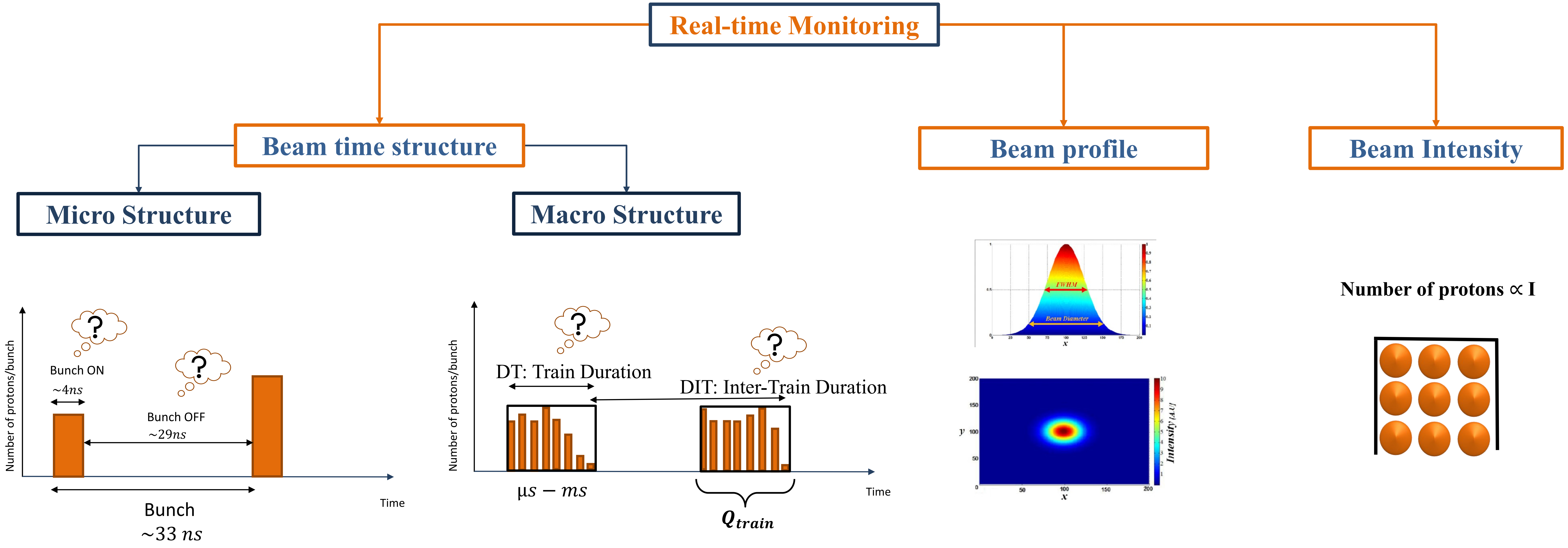
2. Challenges

A Precise **Real-time monitoring** of the **AX** beam characteristics:
Beam time structure, geometric profile, and Intensity are essential for these applications.

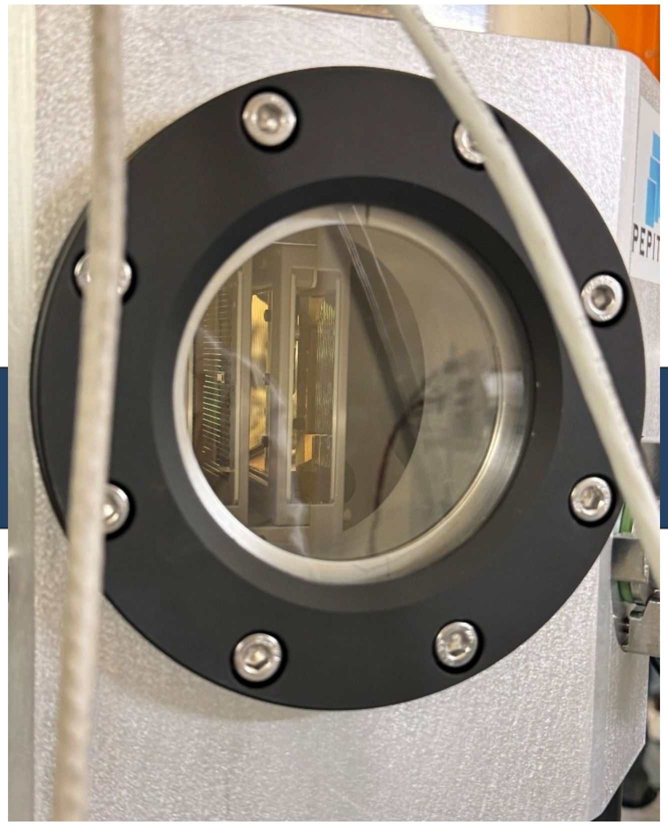


4. Objectives

Main: To enable **real-time monitoring** of the beam, **complementary detectors** will be installed on the beamline of the **AX vault at ARRONAX**.

Beam

PEPITES profiler

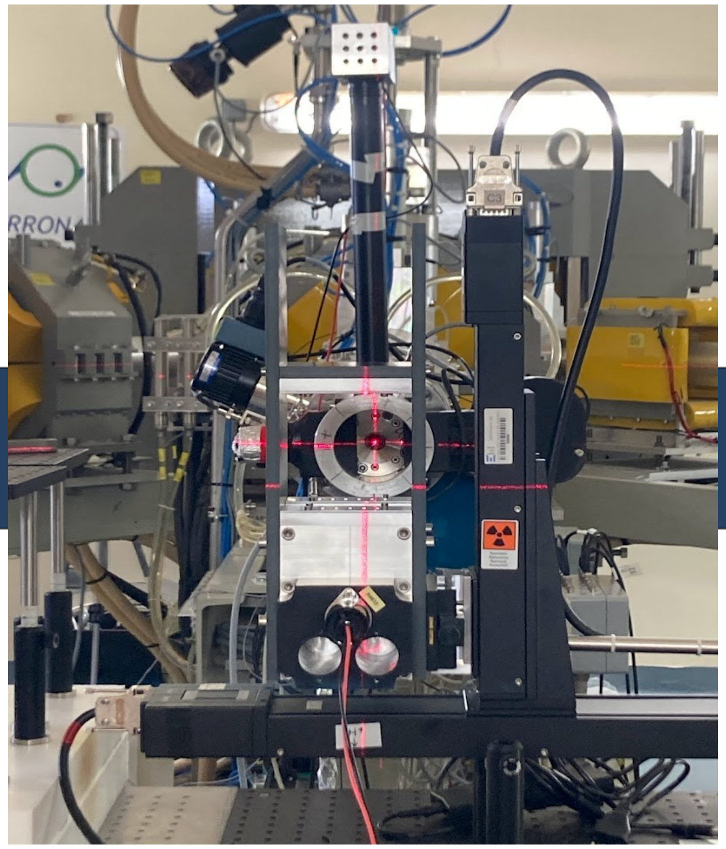


Beam profiler
Based on Gold secondary electrons emission

At low intensities <20 nA
Installed inside the beamline

Kapton exit

PAF profiler



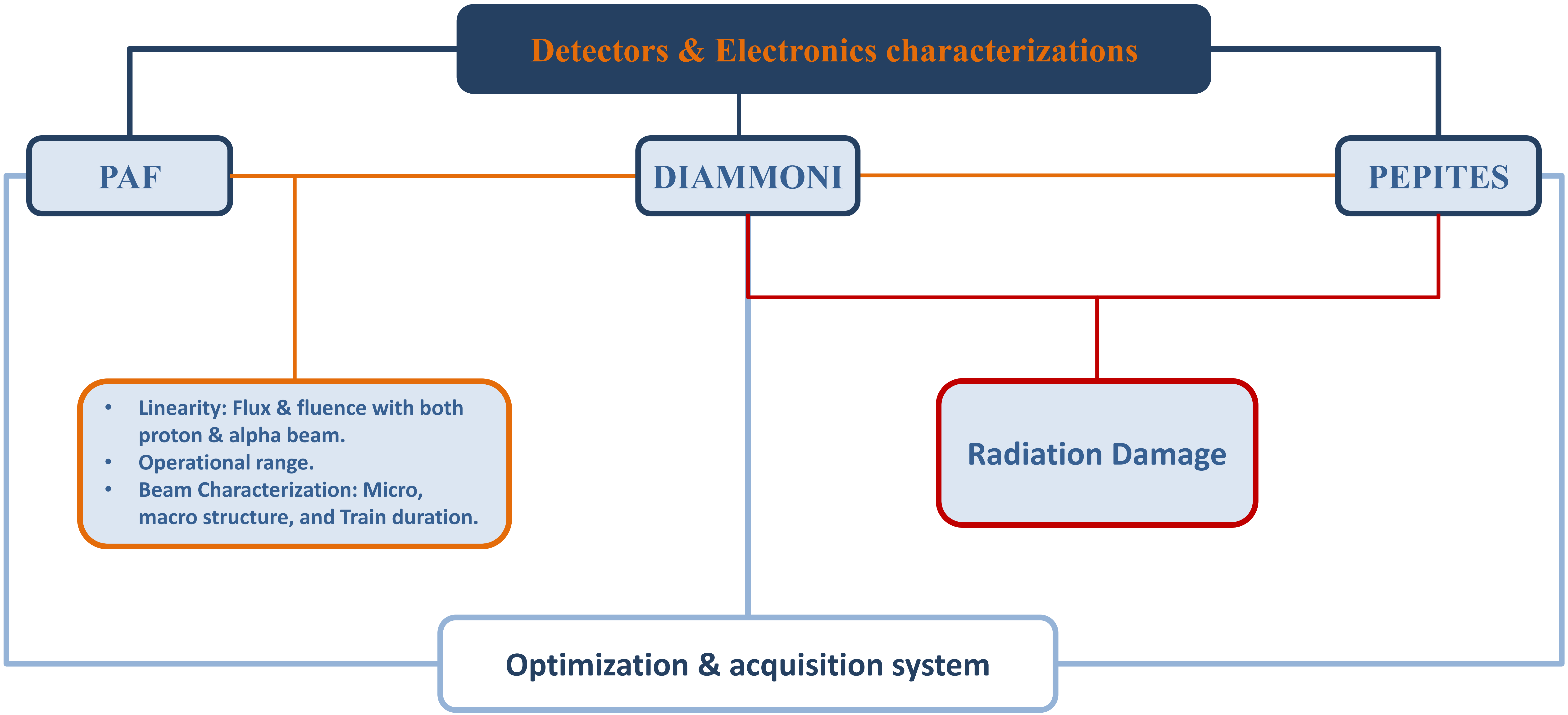
Beam profiler, Beam Intensity & time measurements
Based on induced air scintillation

For high intensities(20 µA)
At the exit window

DIAMMONI(R.Molle thesis)

Beam Intensity, Timing & halo measurements
Based on diamond semiconductor

For low & high intensities (<pA-µA)
Close to the target

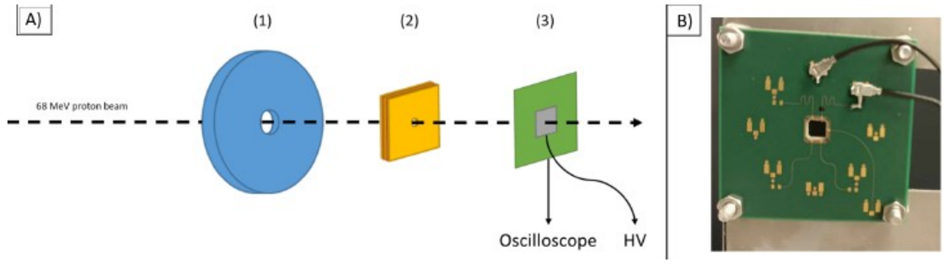

Detectors & Electronics characterizations
PAF
DIAMMONI
PEPITES
• Linearity: Flux & fluence with both proton & alpha beam.
• Operational range.
• Beam Characterization: Micro, macro structure, and Train duration.
Radiation Damage
Optimization & acquisition system

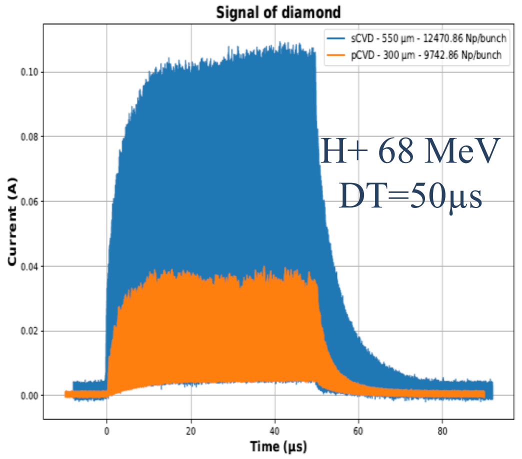
5. DIAMMONI-State Of Art

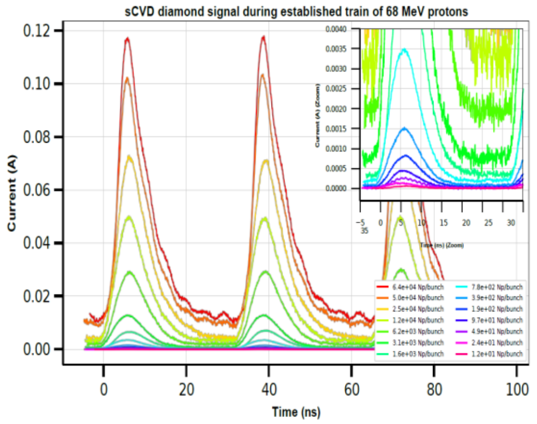
Macro & Micro structure of the beam by Diamond detectors

R.Molle Thesis

Independent of the readout electronics







Linearity of Diamond

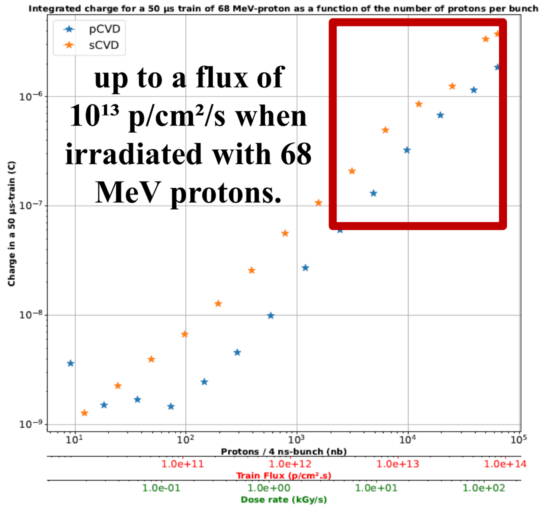
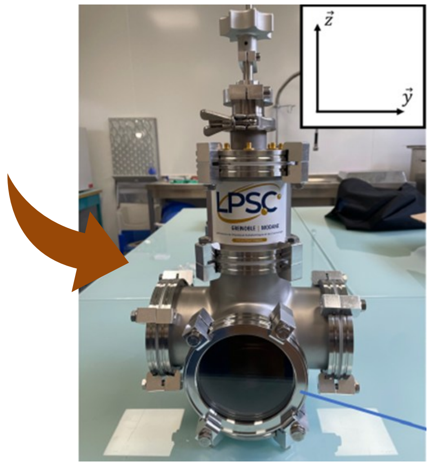


FIGURE 4.8 – Signal d'un diamant irradié par un train de 50 μs de protons de 68 MeV, en échelle logarithmique

DIAMMONI prototype



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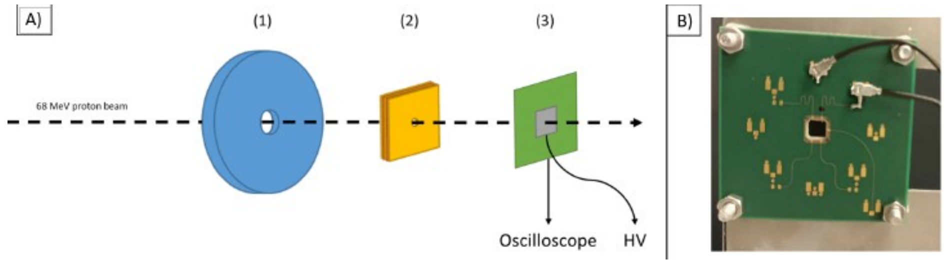

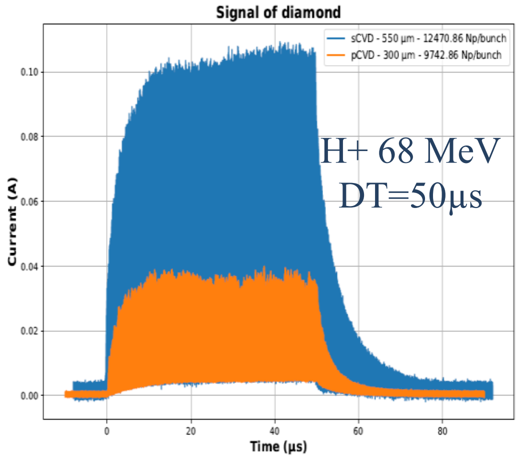

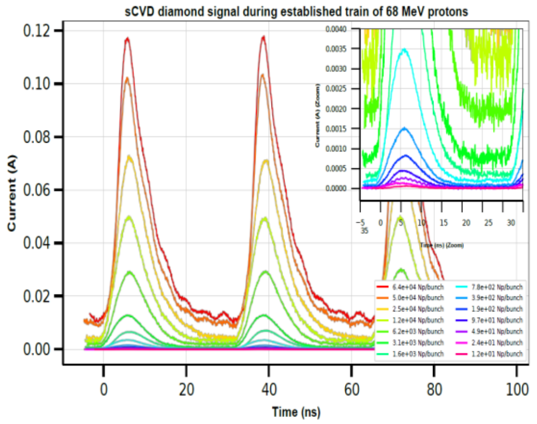

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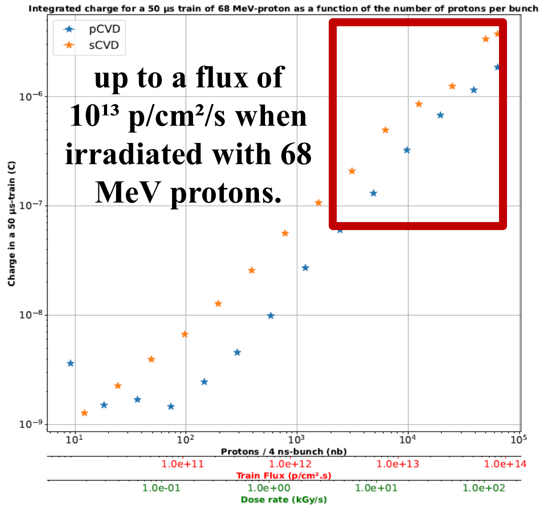

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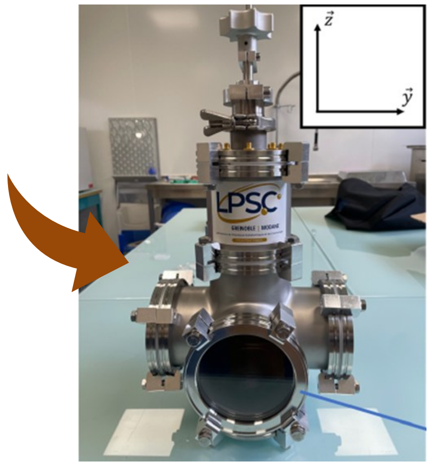
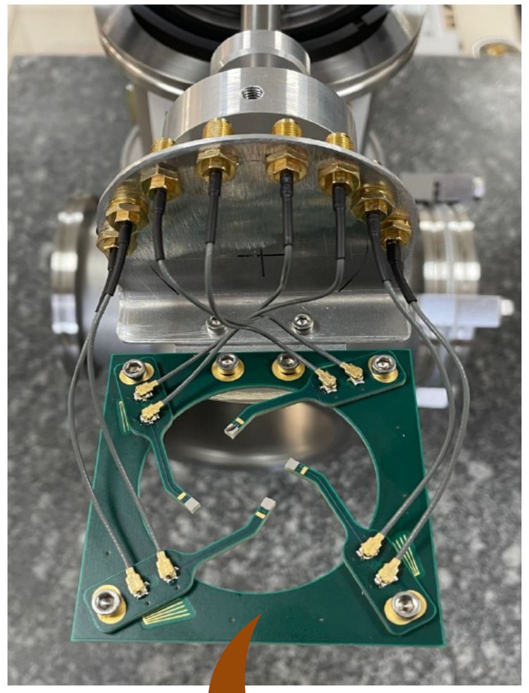
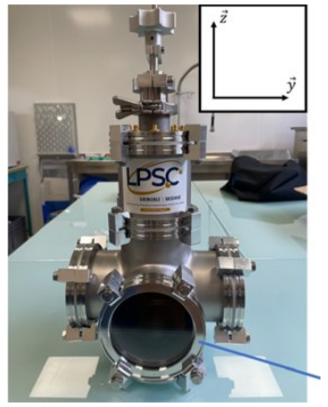


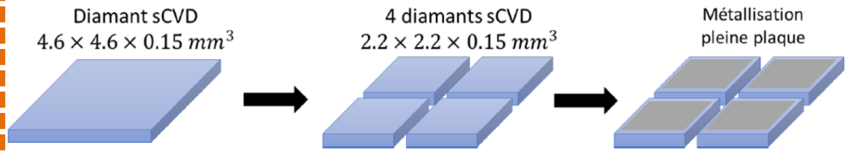
DIAMMONI prototype

DIAMond instrumentation for pulsed beam MONItoring

Train Mode



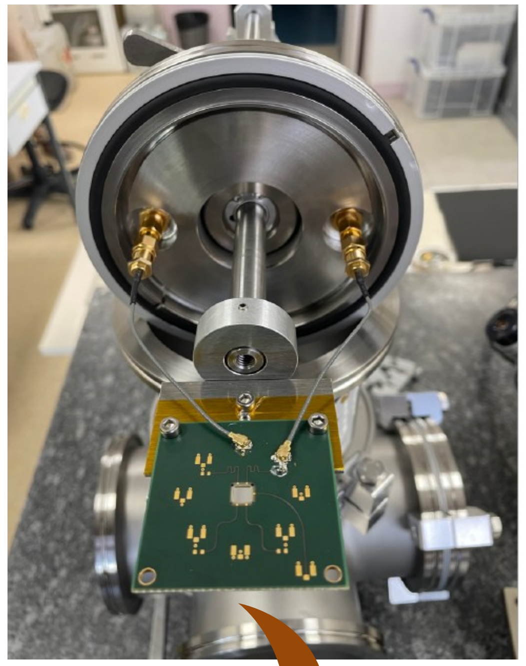


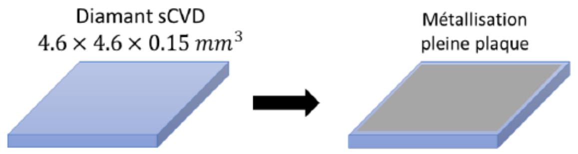


At high flux, where it integrates the total charge per train of bunches

> 100 particles per bunch up to 1µA (FLASH)

Bunch Mode





At low flux, which counts the number of particles per bunch

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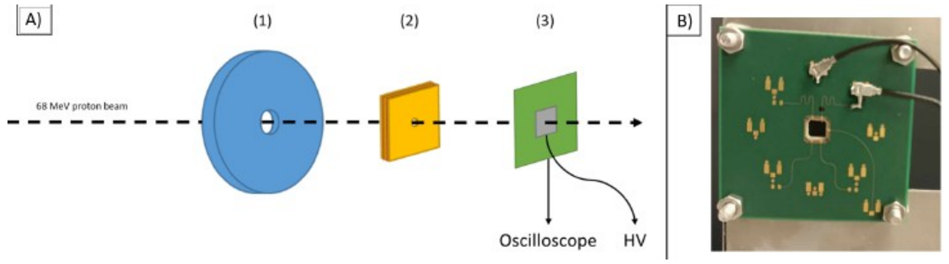
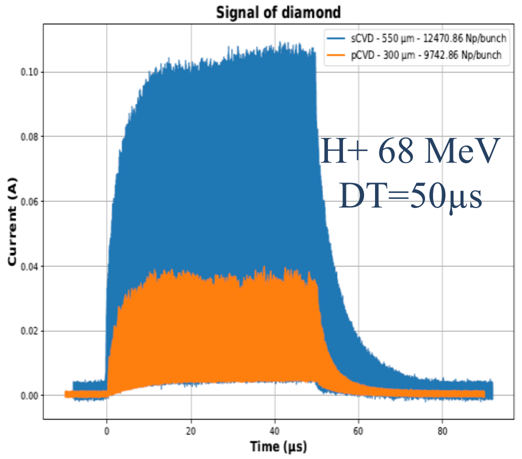
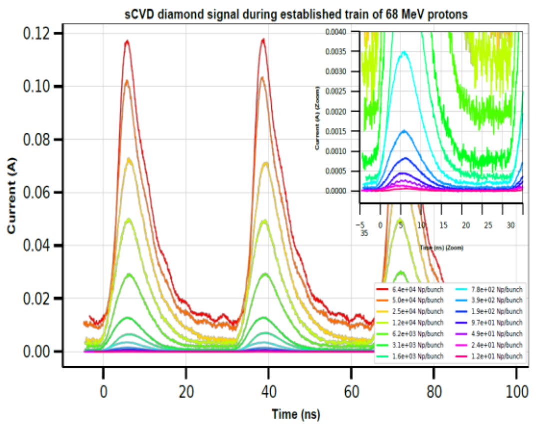
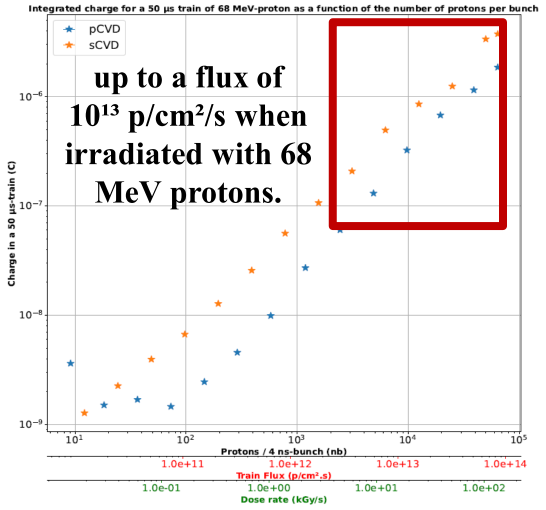






Linearity of Diamond



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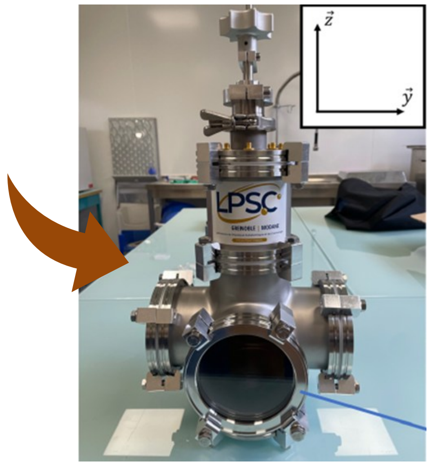

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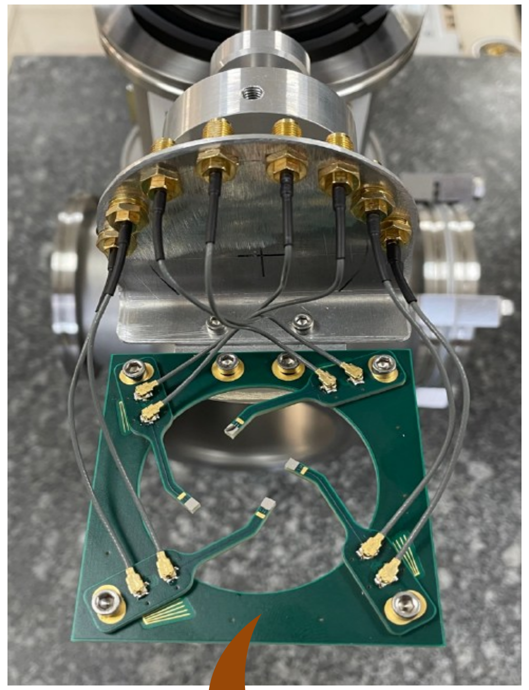

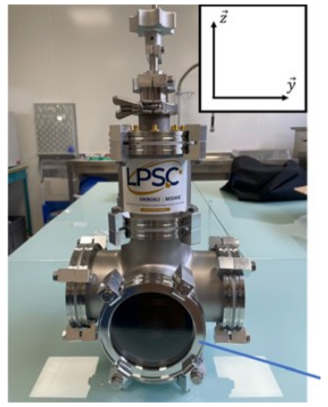

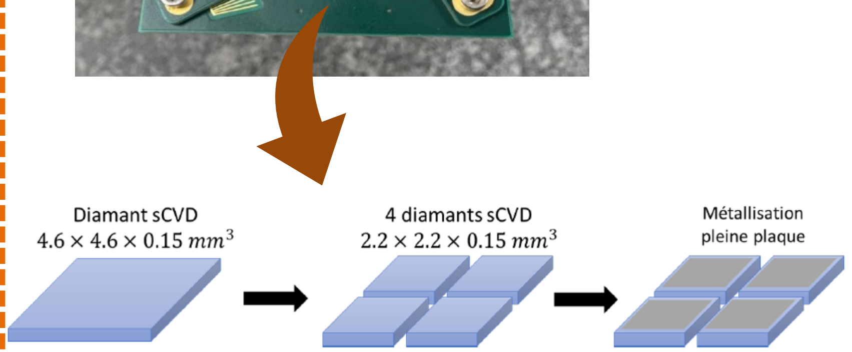

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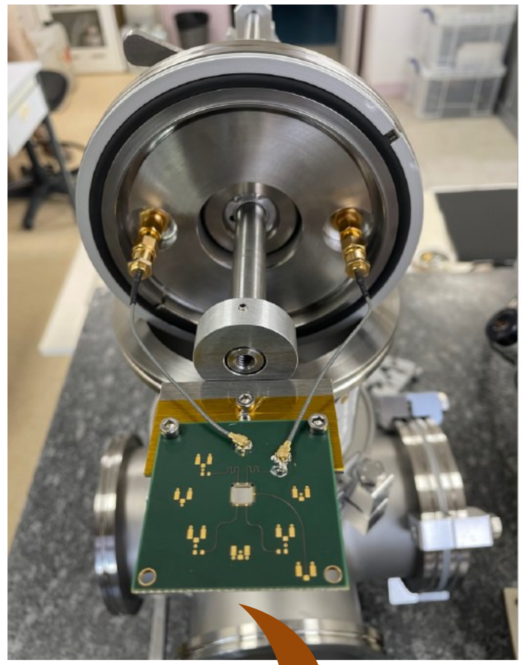

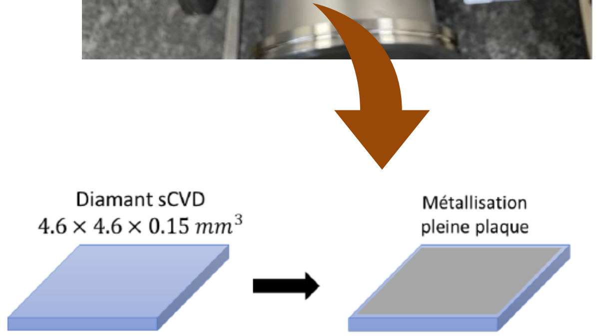

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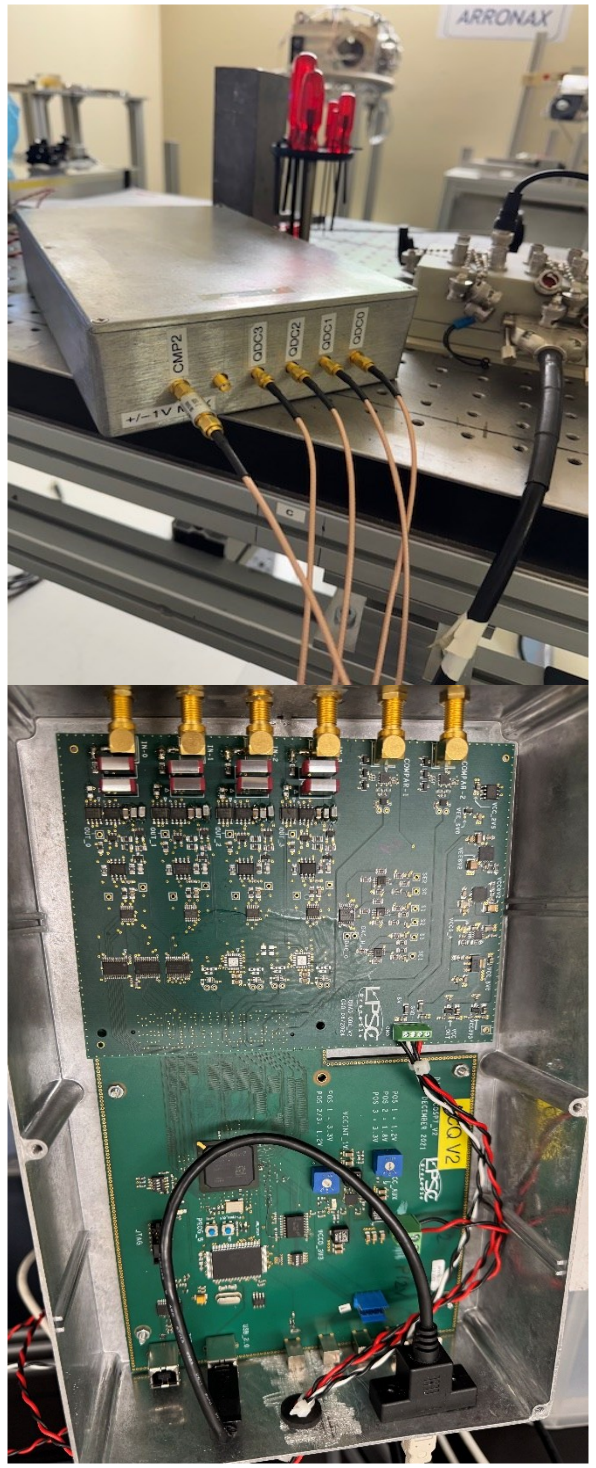
Electronic Board



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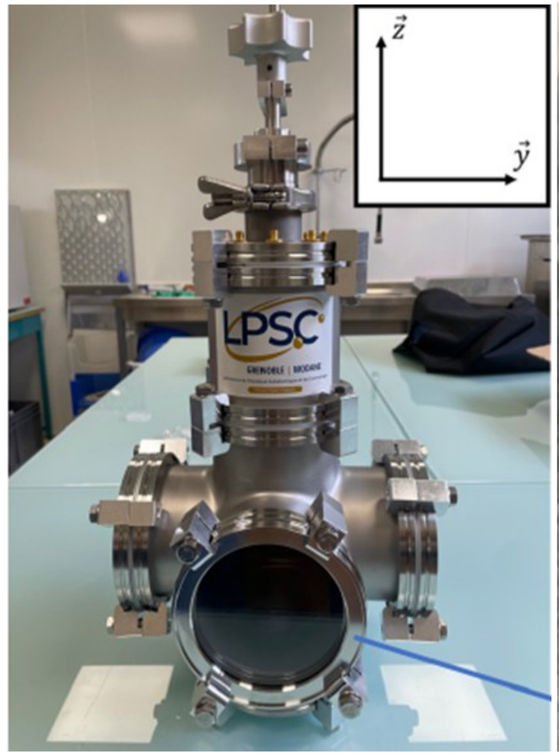
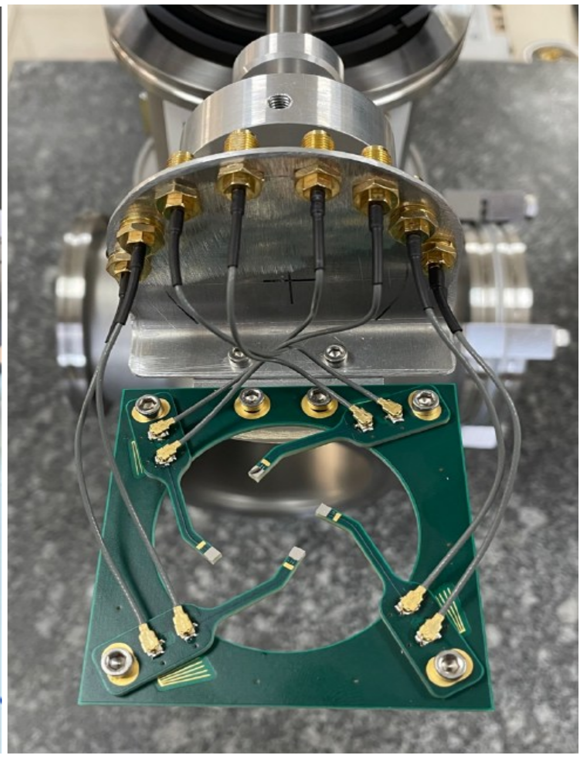
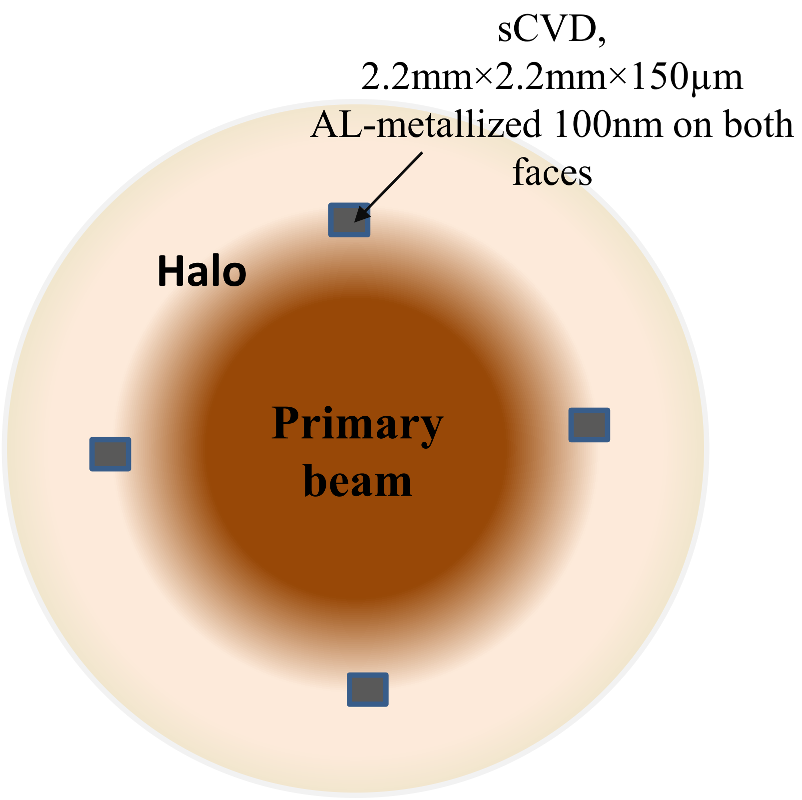
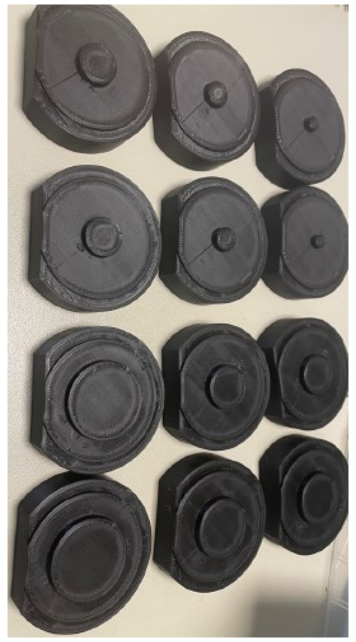
Train mode

This development aims to monitor an ultra-high-dose-rate beam: Charge per train & train duration.









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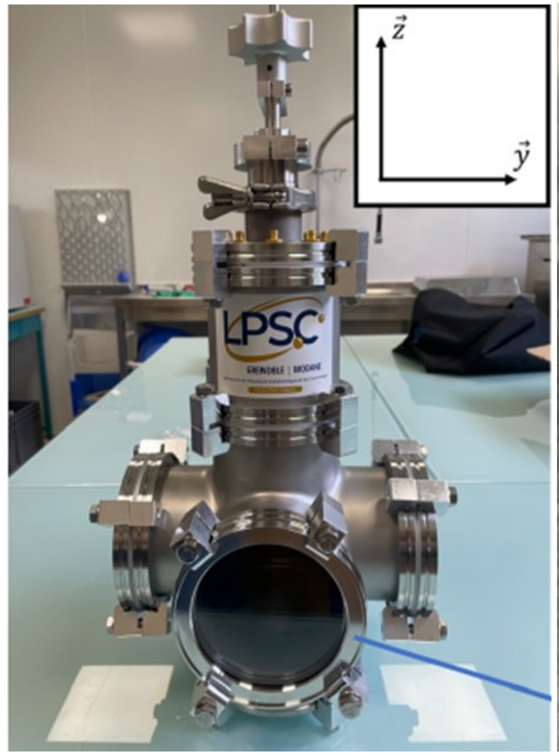
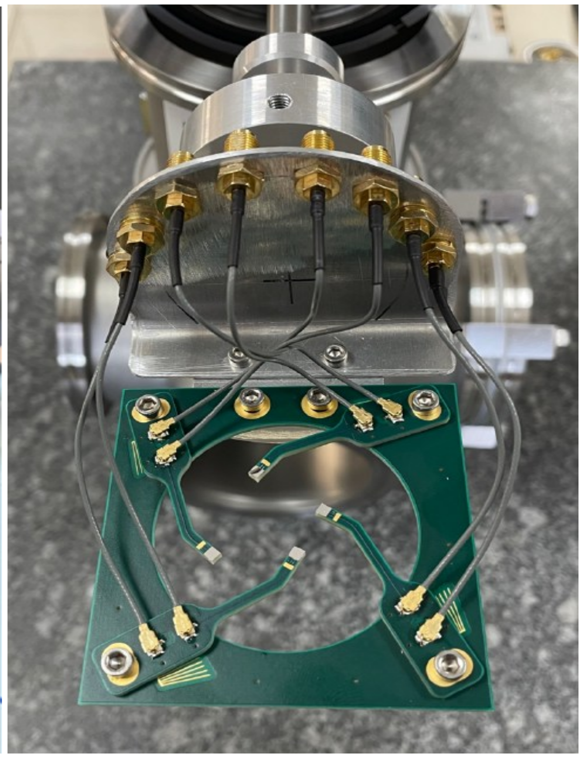
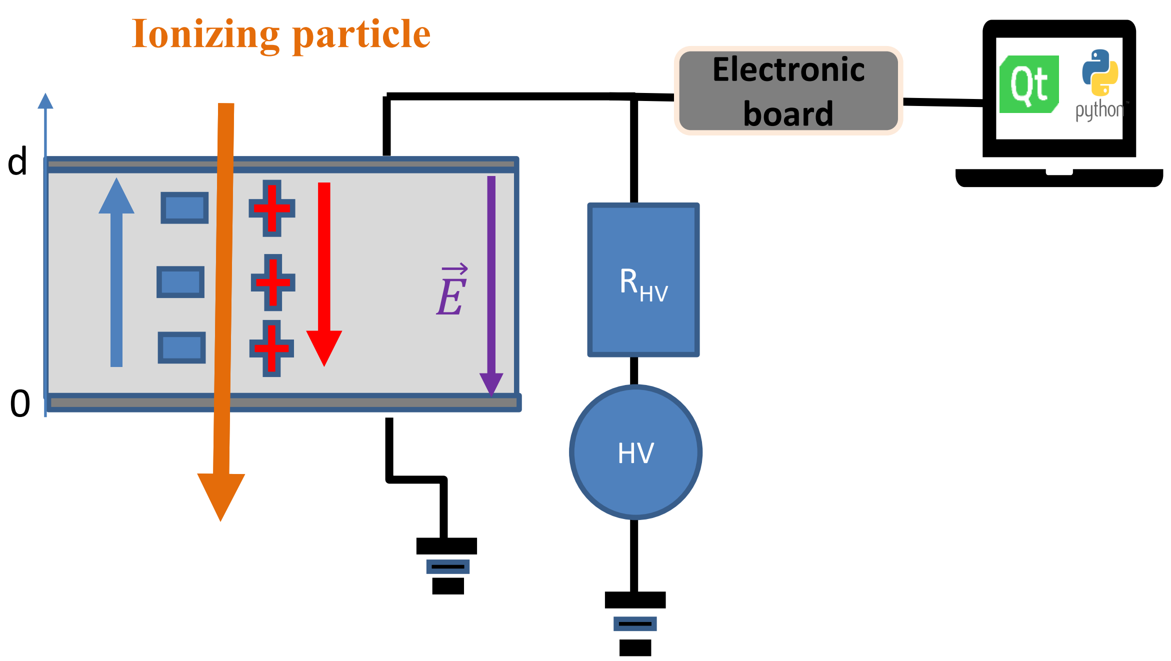
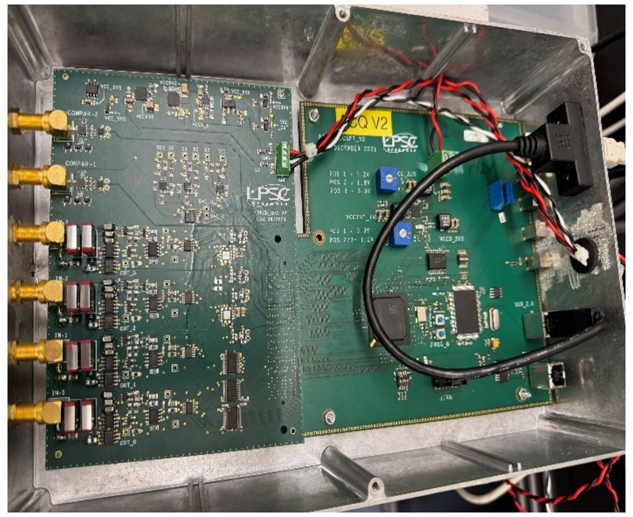


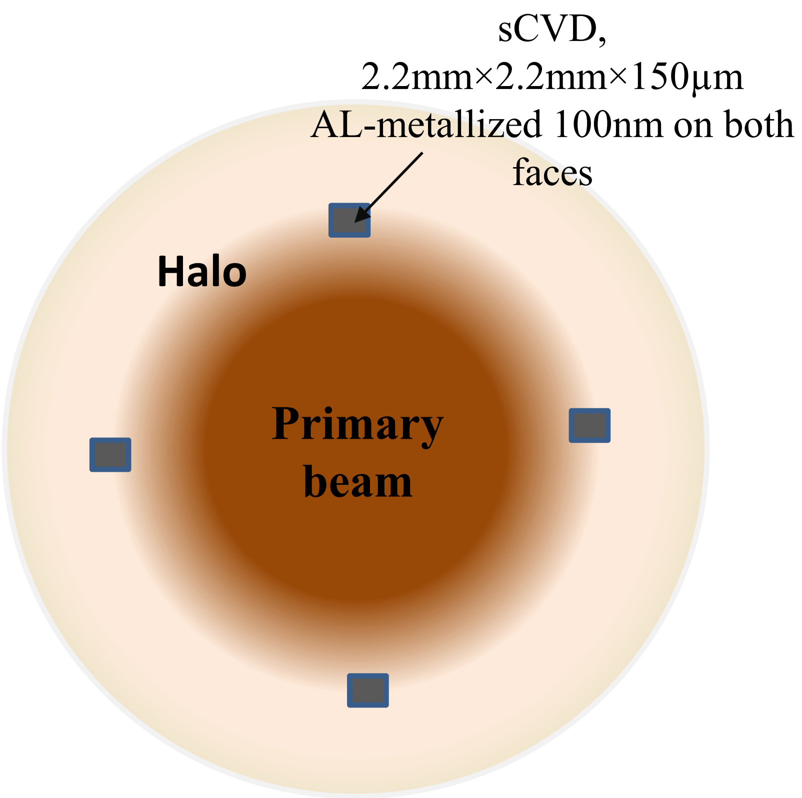


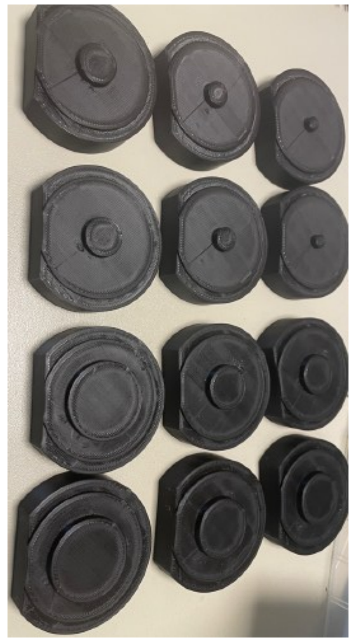




- Study the Linearity and sensitivity of DIAMMONI connected to the electronic board.
- Define DIAMMONI Operational range.

DIAMMONI objectives





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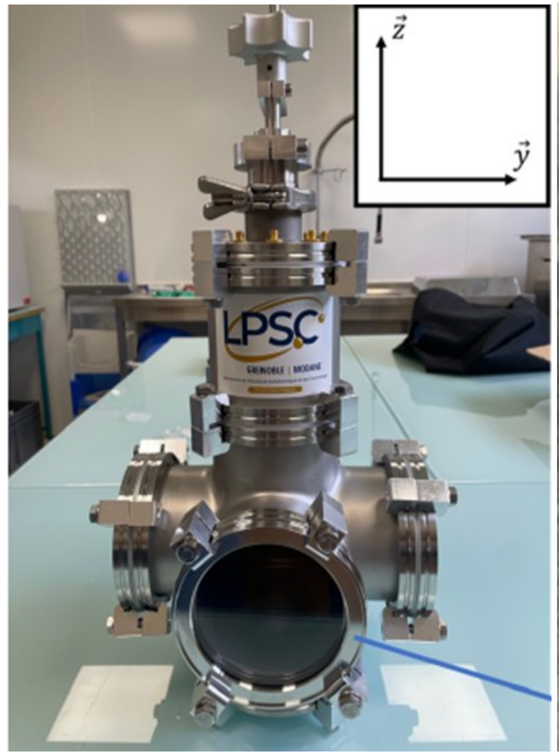
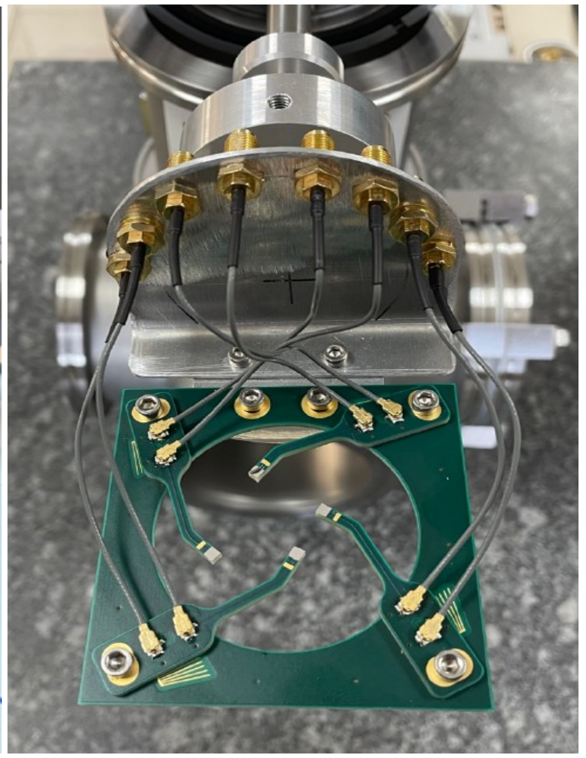
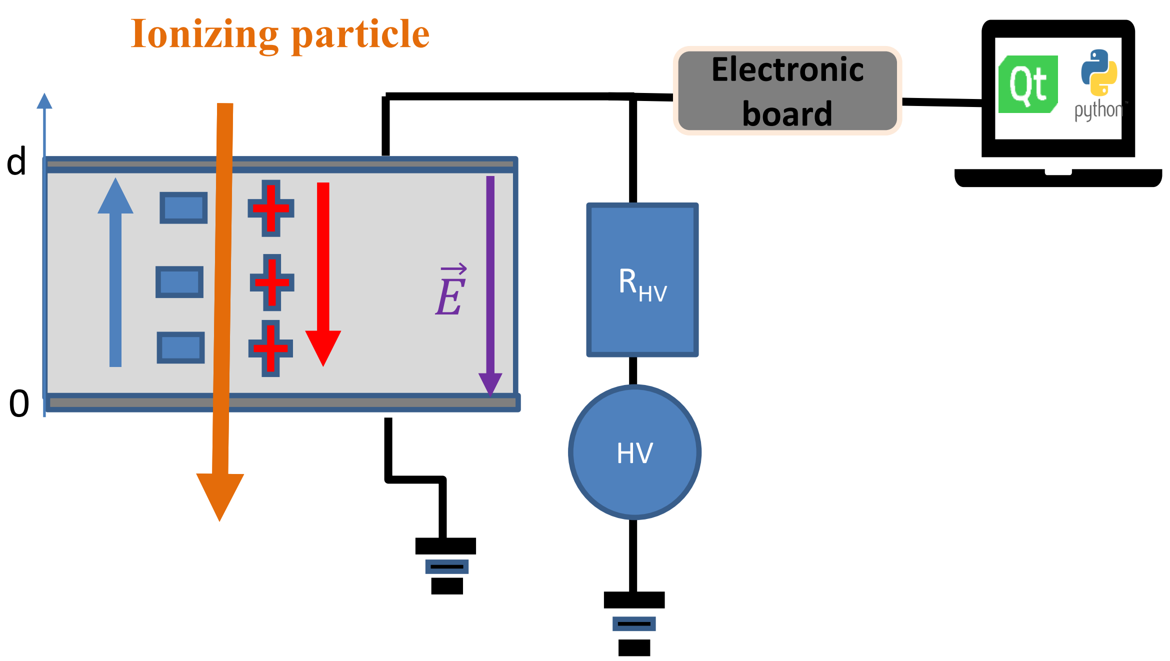
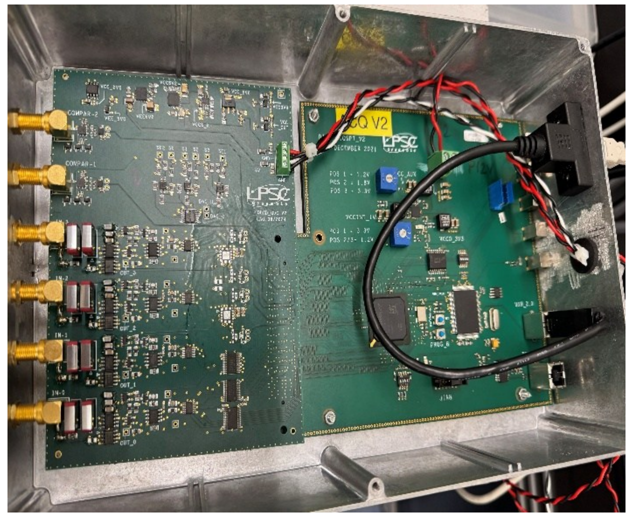




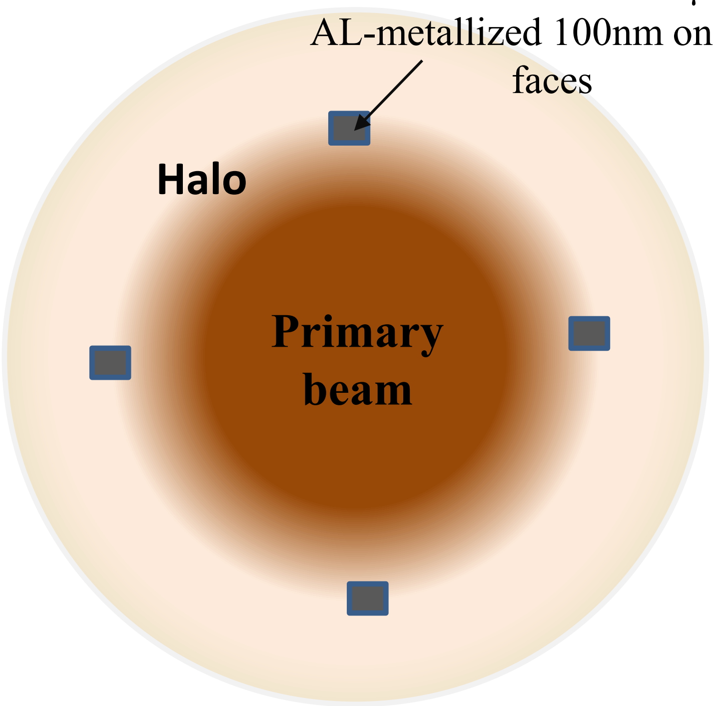


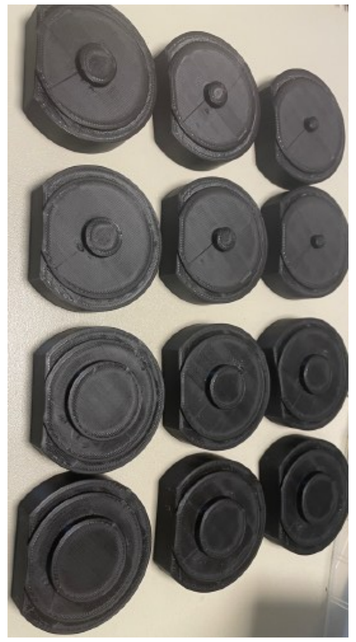


- Study the Linearity and sensitivity of DIAMMONI connected to the electronic board.
- Define DIAMMONI Operational range.

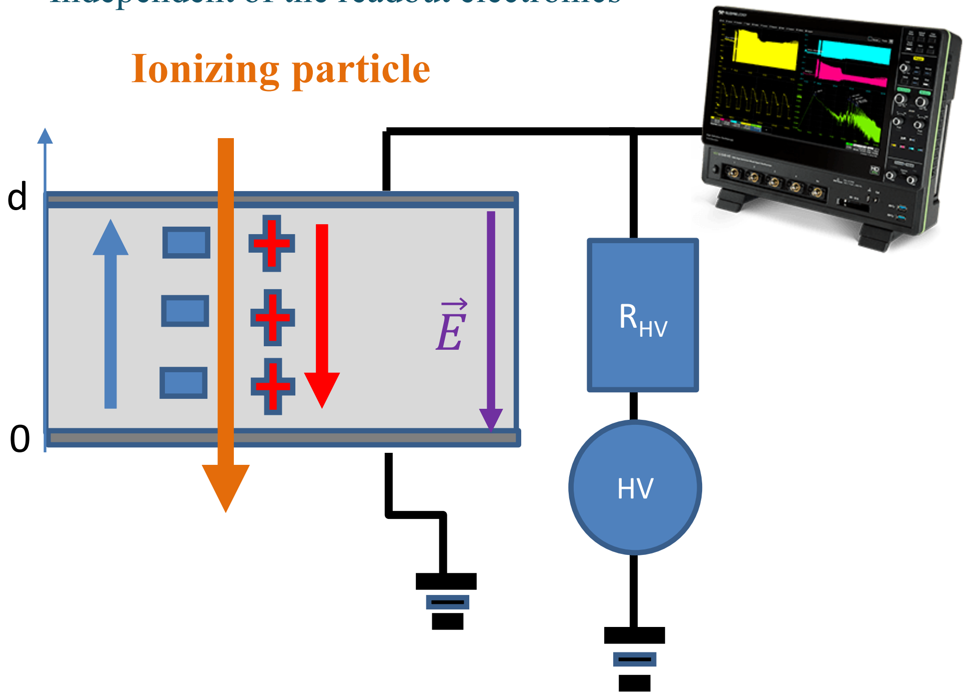
DIAMMONI objectives

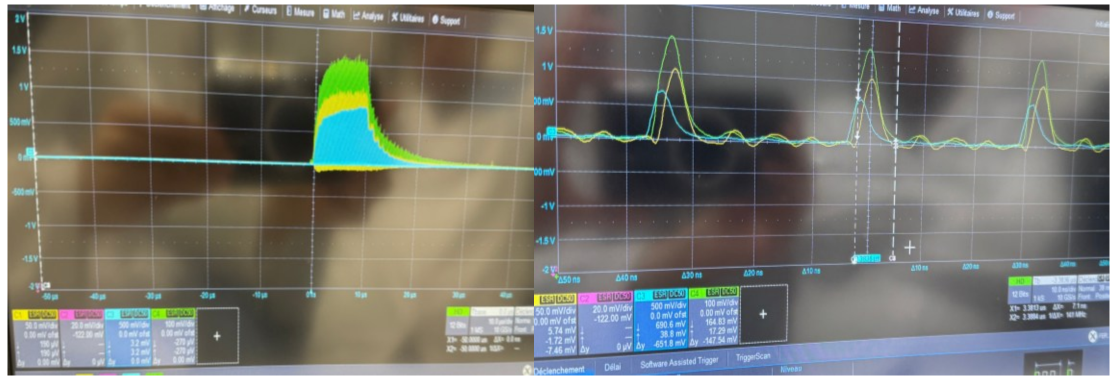
sCVD,
2.2mm×2.2mm×150µm
AL-metallized 100nm on both faces





Independent of the readout electronics



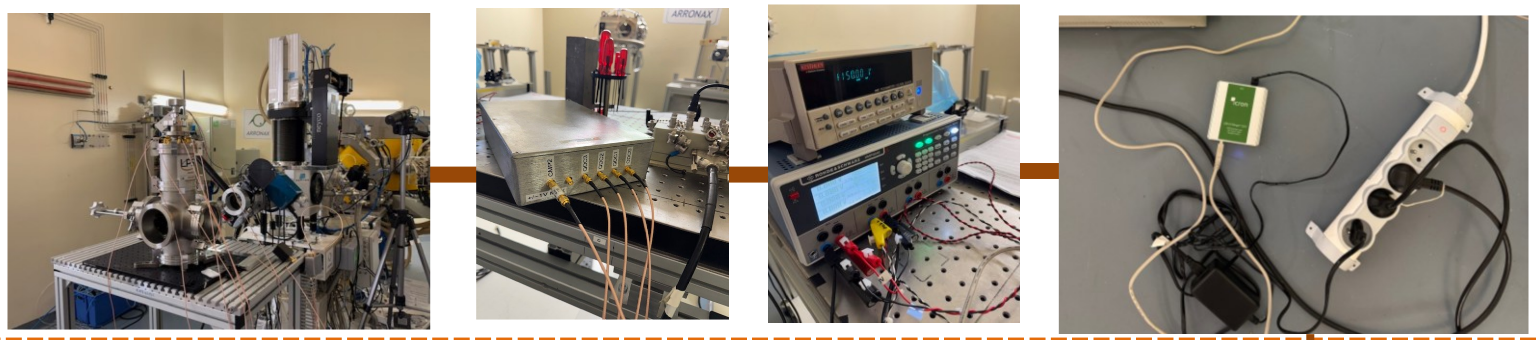


- Characterize the macro & micro time-structure vs intensity.
- Extract Train Duration(DT) from the macroscopic time structure.

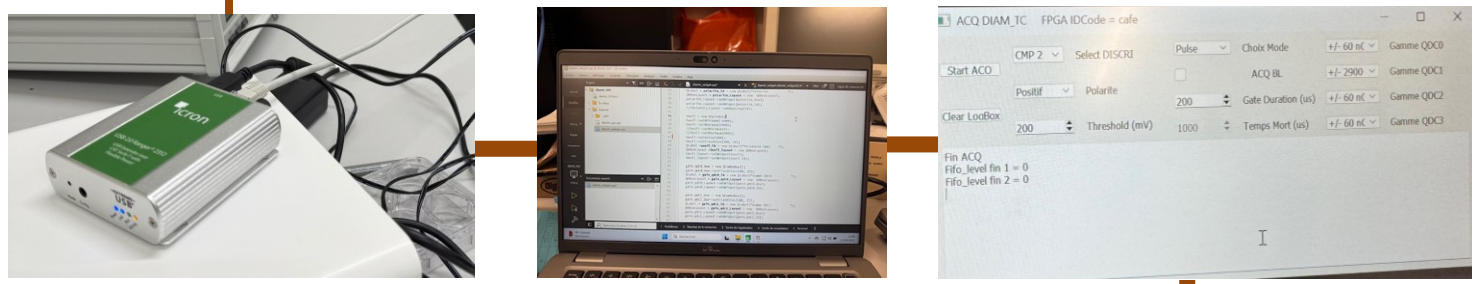
DIAMMONI objectives

5. DIAMMONI-Linearity- By Electronic Board

Zone room



Acquisition room

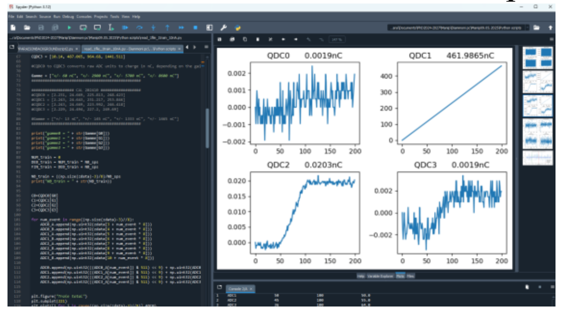


zData.bin

Python

One Train script | **All trains script**

Developed by Laurent, LPSC,Grenoble



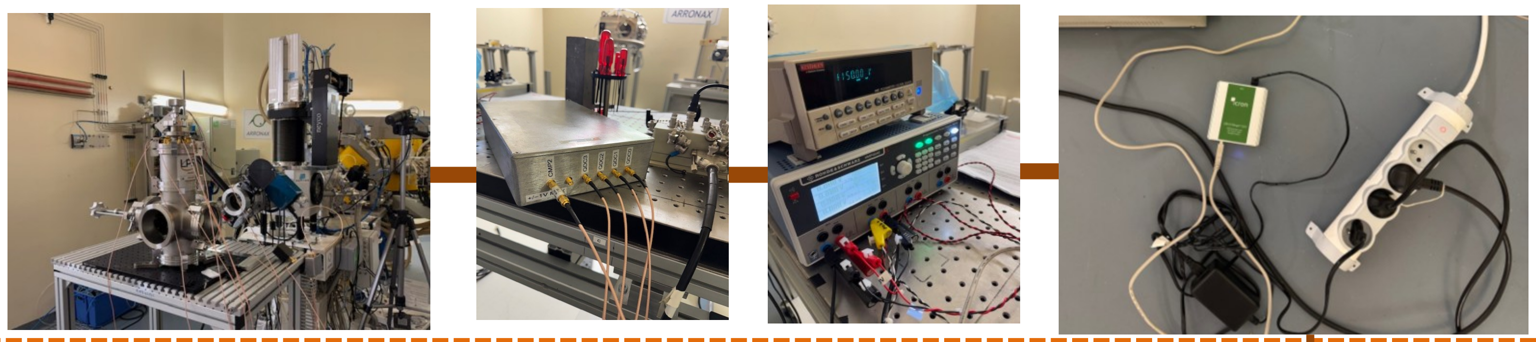
$Q_{measured}$ *for one train*

$Q_{measured}$ *for all trains*

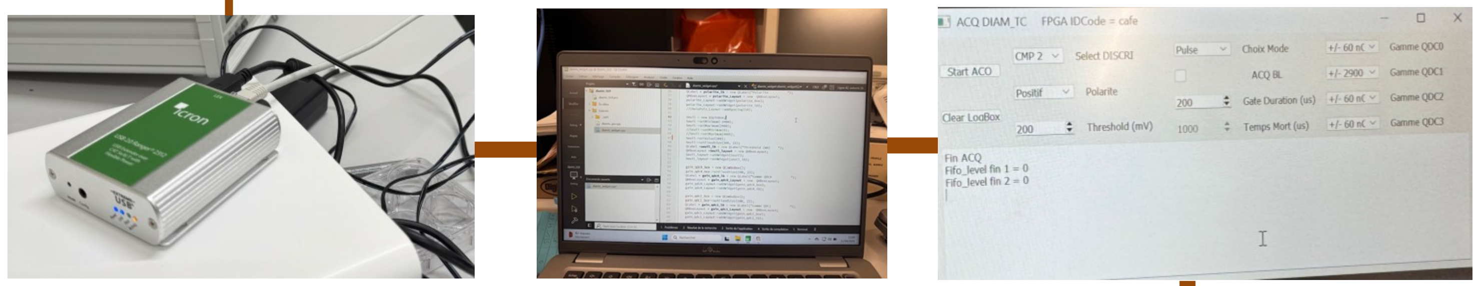
$Q_{measured} = \int i_{induced}(t)dt$, Train Duration , *Inter – train Duration and Trains number.*

5. DIAMMONI-Linearity- By Electronic Board

Zone room



Acquisition room

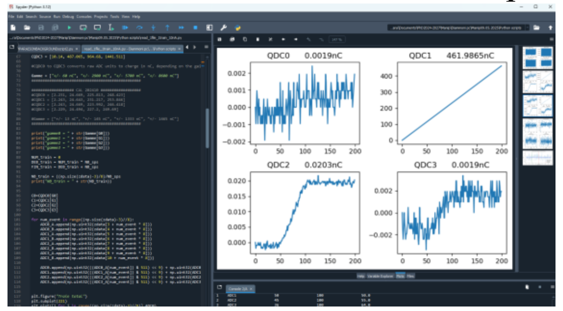


zData.bin

Python

One Train script | **All trains script**

Developed by Laurent, LPSC,Grenoble



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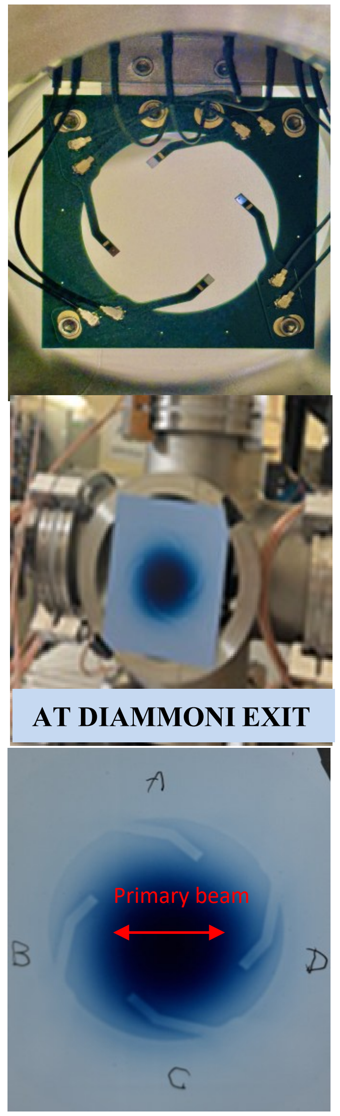
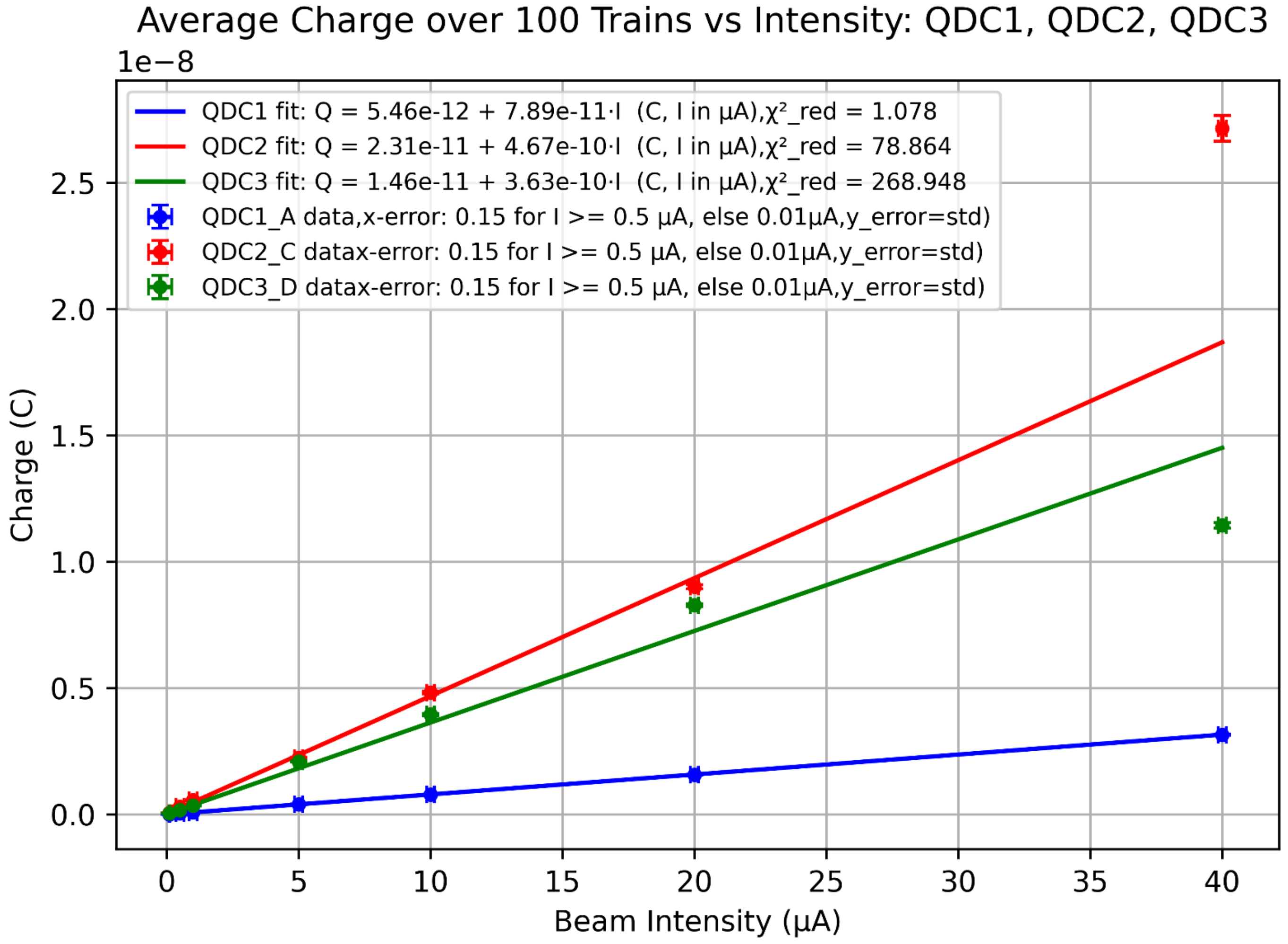


$D_{aperture}$=3 cm

68 H^+, DT=10µs, DiT=10 000µs, 100 pulses, with a wide range of intensities, from 100nA➔40µA

QDC1_A: Bkg noise range: 4pC
QDC2_C: Bkg noise range: 2pC
QDC3_D: Bkg noise range: 4pC

Linearity

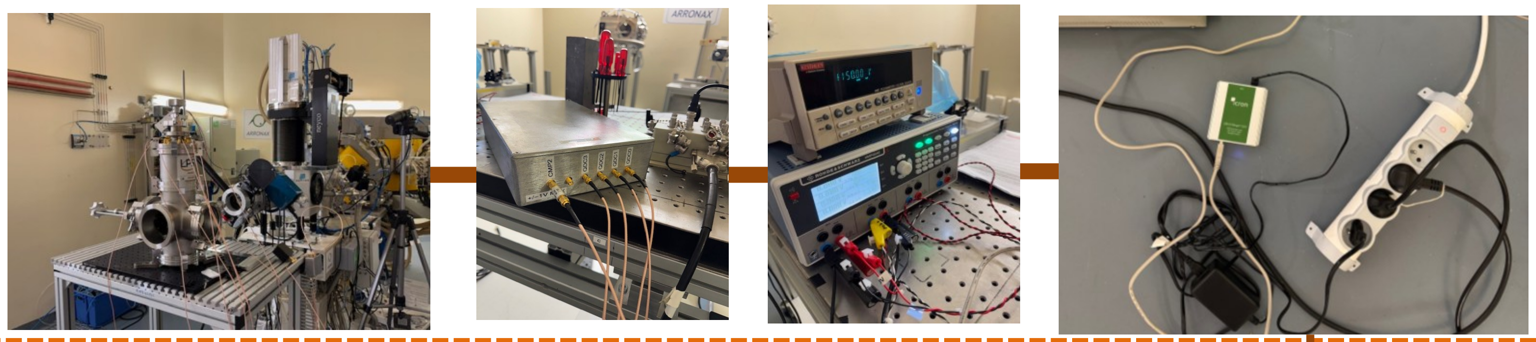


The response of the QDC1(A), which receives the lowest intensity, is more linear than the other two; QDC2(C) & QDC3(D) behave oppositely as a function of beam intensity.
Therefore, the non-linearity could arise from changes in the beam geometry as the beam intensity changes.

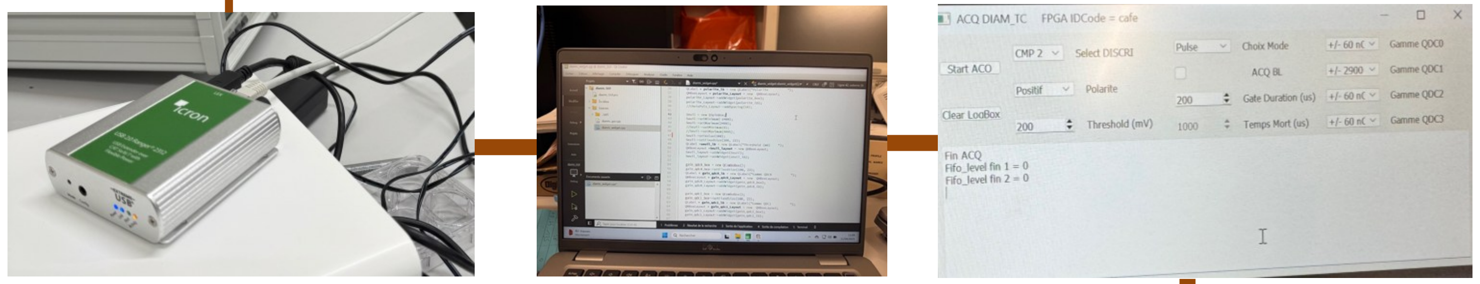
✓ Linear response across a wide 100 nA–40 µA dynamic range

5. DIAMMONI-Sensitivity- By Electronic Board

Zone room



Acquisition room



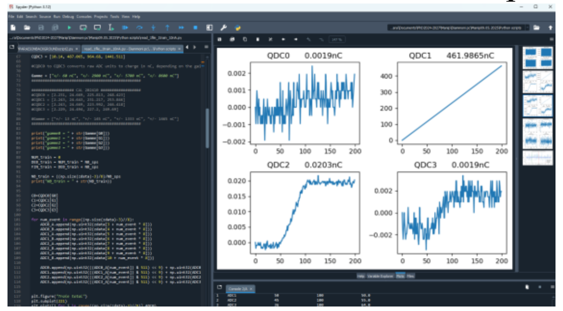
zData.bin

Python

One Train script

All trains script

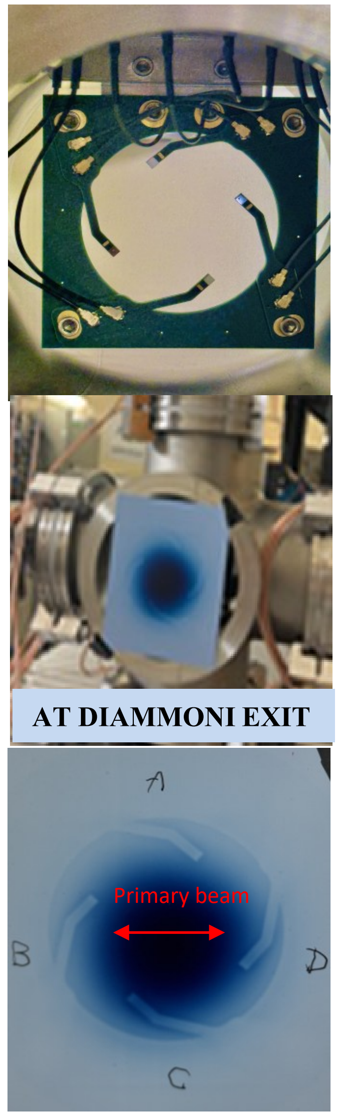
Developed by Laurent, LPSC,Grenoble



$Q_{measured}$ *for one train*

$Q_{measured}$ *for all trains*

$Q_{measured} = \int i_{induced}(t)dt$, Train Duration , *Inter – train Duration and Trains number.*

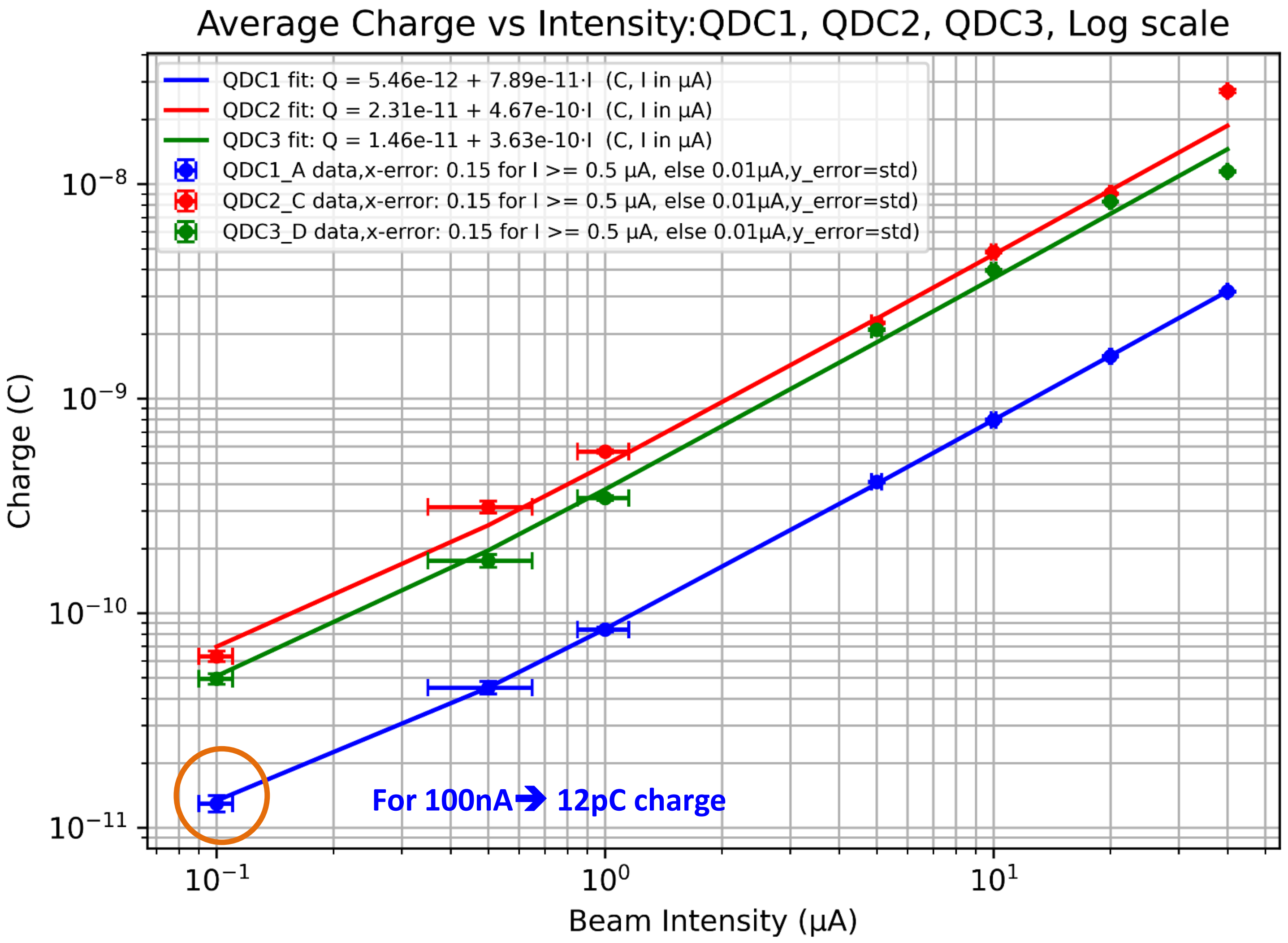


$D_{aperture}$=3 cm

68 H^+, DT=10µs, DiT=10 000µs, 100 pulses, with a wide range of intensities, from 100nA➔40µA

QDC1_A: Bkg noise range: 4pC
QDC2_C: Bkg noise range: 2pC
QDC3_D: Bkg noise range: 4pC

Sensitivity

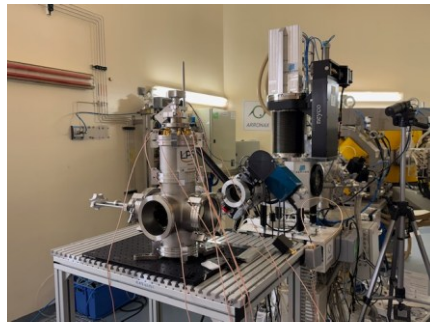


For this beam geometry of 30 mm diameter, we are measuring 3 times more than the Background noise for a 100nA beam intensity.

✓ **Operational range (100 nA-40µA).**

5. DIAMMONI-Macro & Micro time structure - By Oscilloscope

Zone room

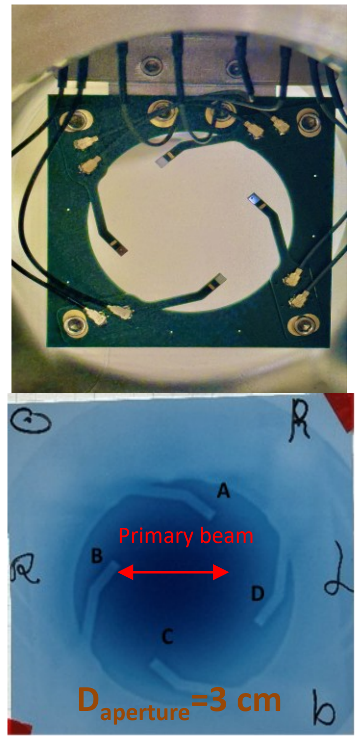


Acquisition room

file.csv

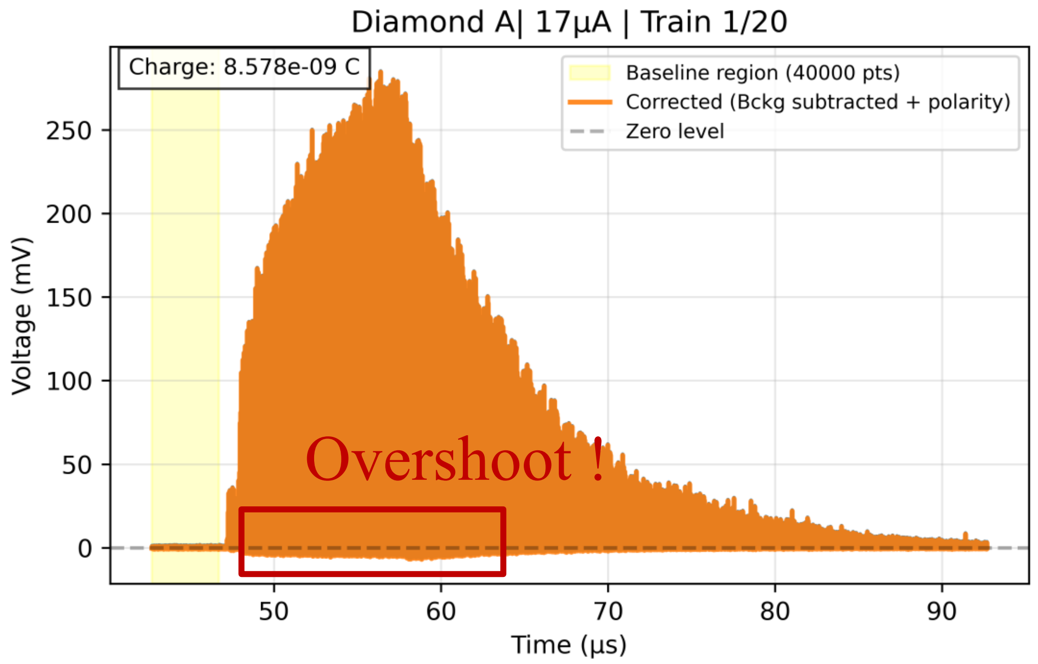
Python

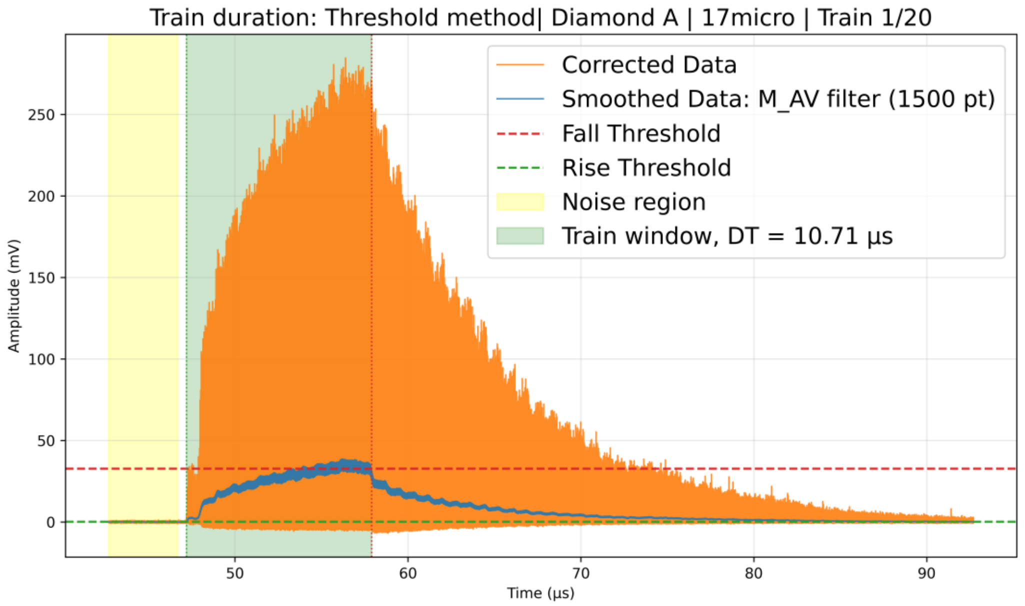
Macrostructure	Microstructure
$Q_{measured}/train$	Bunch Evolution vs Intensity
Train Duration	



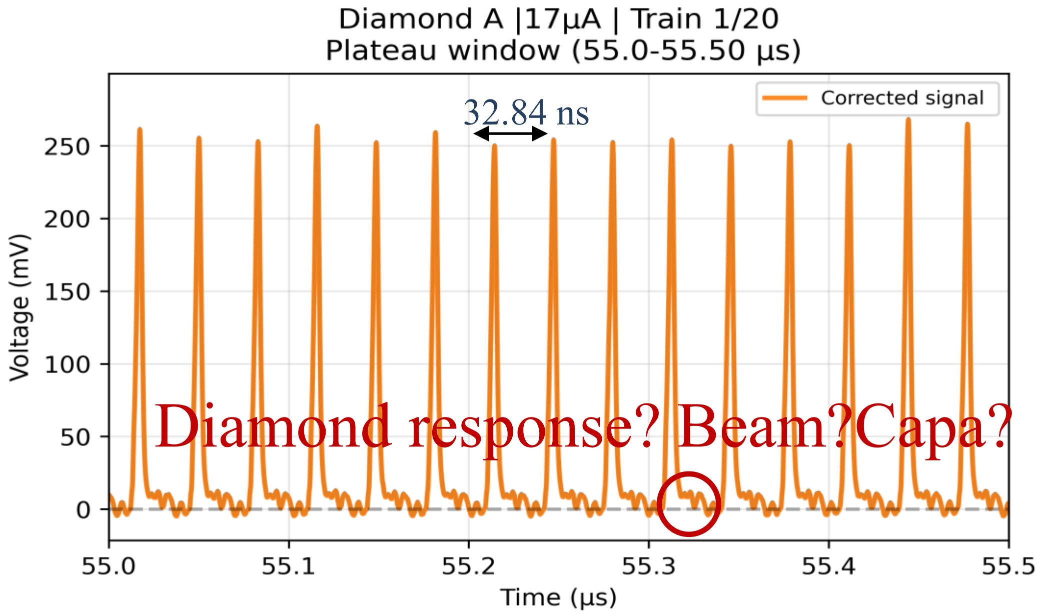
68 H^+, DT=10µs, with a wide range of intensities, from 1µA➔17µA

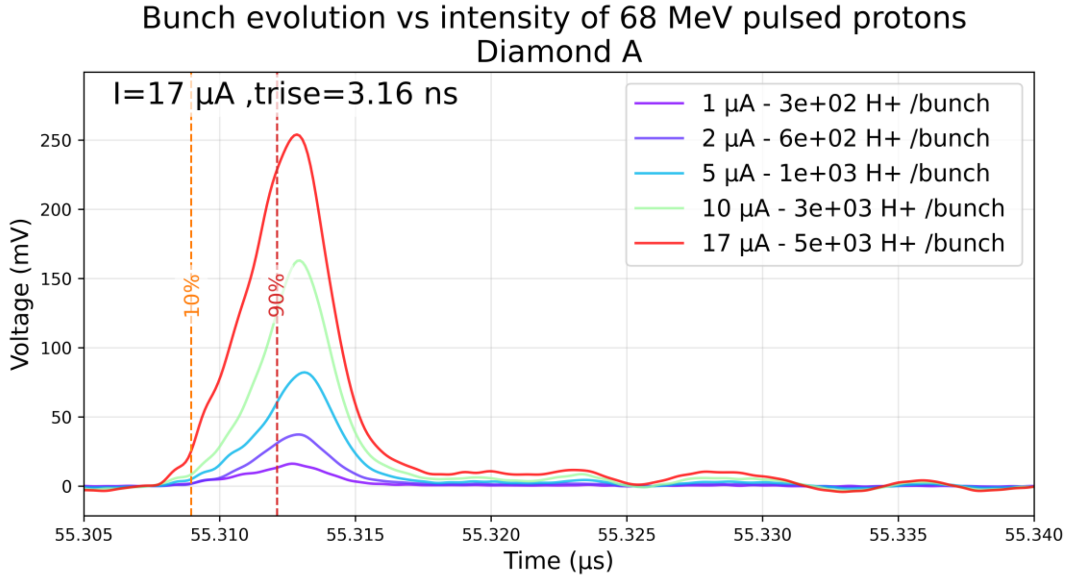
Macro-time structure





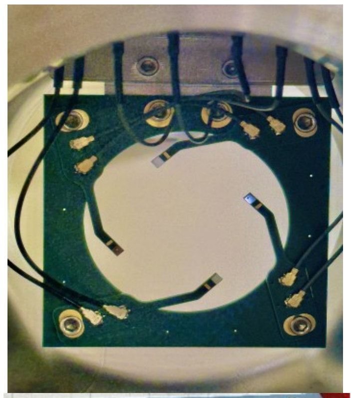
Micro- time structure

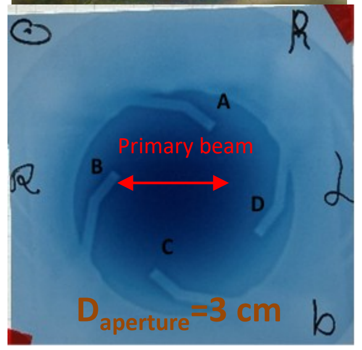




- ✓ **Precise measurement of micro/macro structures & DT.**
- ✓ **Successfully resolved structured bunches at ~32.84 ns ($RF_{cyclotron}$ =30.45MHz).**
- ✓ **Further investigation required for intensity-dependent FWHM fluctuations(3.30-3.70ns) , overshoot & tail behavior.**

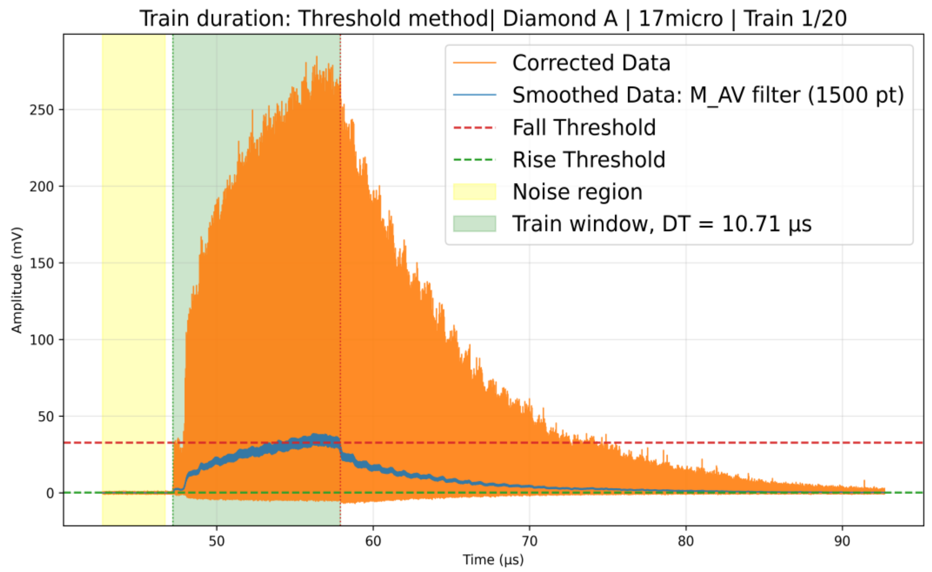
5. DIAMMONI-Train Duration Extraction Method





68 H$^+$, DT=10µs, with a wide range of intensities, from 1µA➔17µA

Macro-time structure



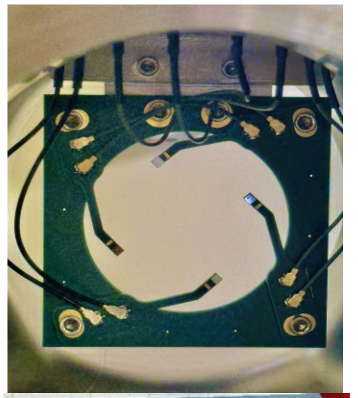
✓ The results agree well with the theoretical value of 10 µs, with small deviations within the measurement uncertainty.

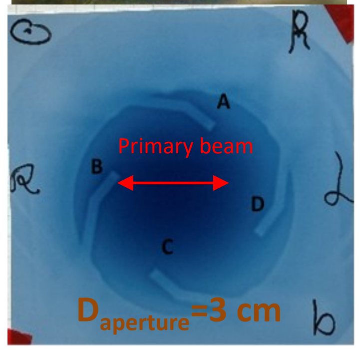
DT Experimental (µs)

	µA	Diamond A		Diamond C		Diamond D	
		Mean /all trains	std over all trains	Mean /all trains	std over all trains	Mean /all trains	std over all trains
HV=-150V	1	10.37	0.288	9.97	0.205	9.99	0.614
	2	10.51	0.167	10.11	0.230	10.29	0.248
	5	10.65	0.024	10.58	0.082	10.60	0.078
	10	10.71	0.022	10.69	0.039	10.65	0.025
	17	10.73	0.017	10.69	0.027	10.72	0.022
	Mean /all intensities	**10.59**		**10.41**		**10.45**	
	std over all intensities	**0.135**		**0.307**		**0.274**	

	µA	Diamond A		Diamond C		Diamond D	
		Mean /all trains	std over all trains	Mean /all trains	std over all trains	Mean /all trains	std over all trains
HV=+150V	1	10.15	0.399	9.10	1.831	9.45	0.531
	2	10.44	0.195	10.11	0.219	10.19	0.249
	5	10.59	0.139	10.68	0.088	10.35	0.218
	10	10.71	0.029	10.70	0.03	10.63	0.145
	17	10.72	0.024	10.71	0.018	10.68	0.028
	Mean /all intensities	**10.52**		**10.26**		**10.26**	
	std over all intensities	**0.214**		**0.623**		**0.444**	

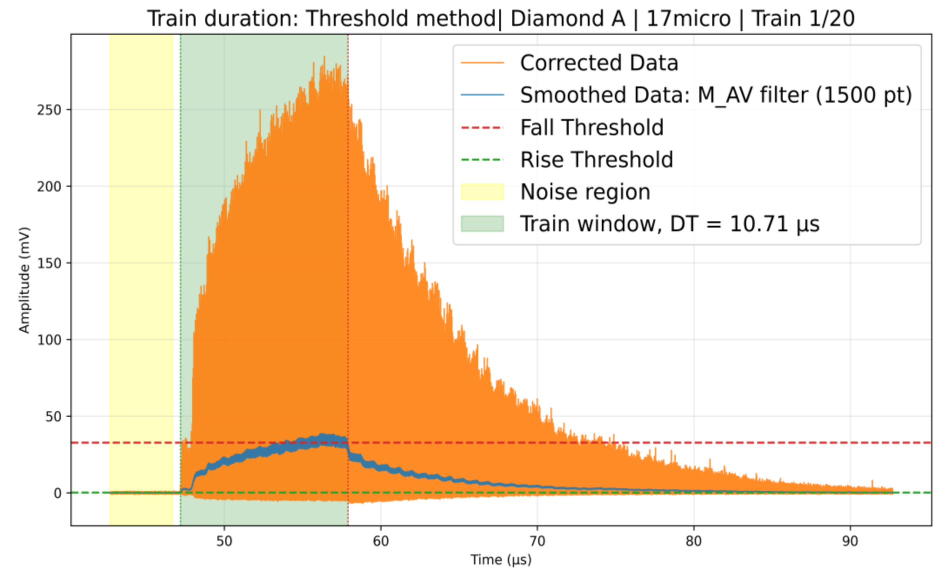
5. DIAMMONI-Train Duration Extraction Method





68 H^+, DT=10µs, with a wide range of intensities, from 1µA➔17µA

Macro-time structure



- ✓ The results agree well with the theoretical value of 10 µs, with small deviations within the measurement uncertainty.
- ✓ Std smaller for diamond A compared to diamonds C and D, which show closer agreement with each other. Given that diamond A receives the highest proton flux, followed by C and then D, this trend may suggest that the proton flux influences the measurement spread.

DT Experimental (µs)

HV=-150V

µA	Diamond A		Diamond C		Diamond D	
	Mean /all trains	std over all trains	Mean /all trains	std over all trains	Mean /all trains	std over all trains
1	10.37	0.288	9.97	0.205	9.99	0.614
2	10.51	0.167	10.11	0.230	10.29	0.248
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10	10.71	0.022	10.69	0.039	10.65	0.025
17	10.73	0.017	10.69	0.027	10.72	0.022
Mean /all intensities	**10.59**		**10.41**		**10.45**	
std over all intensities	**0.135**		**0.307**		**0.274**	

HV=+150V

µA	Diamond A		Diamond C		Diamond D	
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2	10.44	0.195	10.11	0.219	10.19	0.249
5	10.59	0.139	10.68	0.088	10.35	0.218
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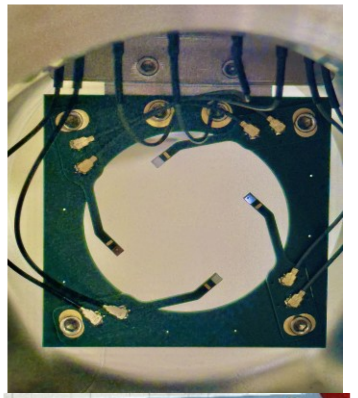
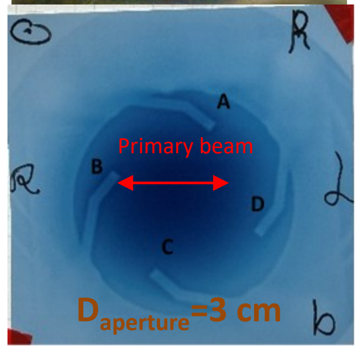
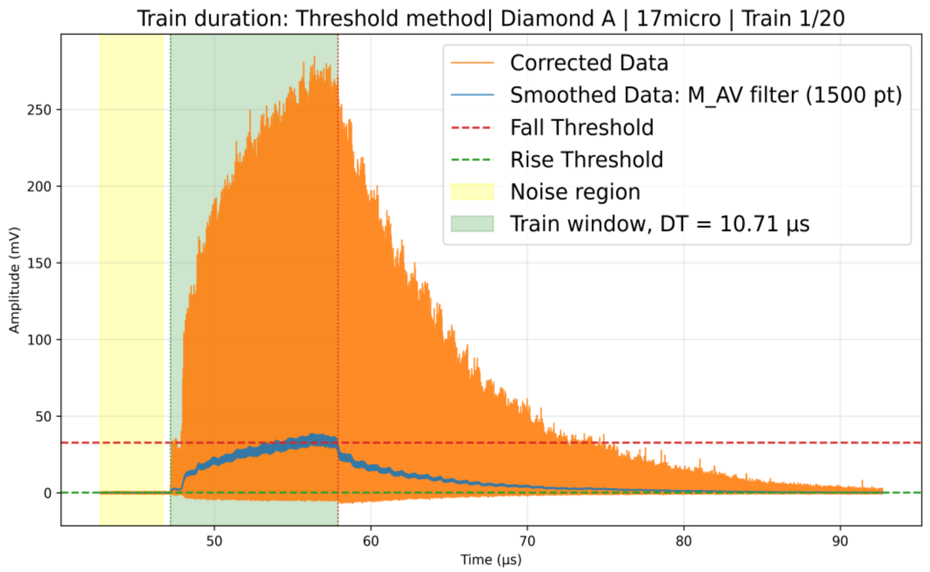
5. DIAMMONI-Train Duration Extraction Method





68 H^+, DT=10μs, with a wide range of intensities, from 1μA➔17μA

Macro-time structure



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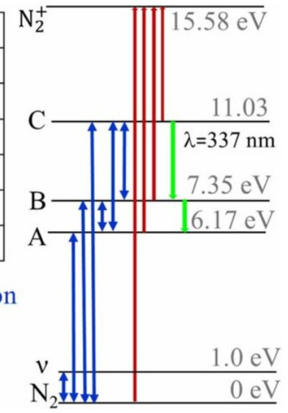
- ✓ The results agree well with the theoretical value of 10 μs, with small deviations within the measurement uncertainty.
- ✓ Std smaller for diamond A compared to diamonds C and D, which show closer agreement with each other. Given that diamond A receives the highest proton flux, followed by C and then D, this trend may suggest that the proton flux influences the measurement spread.
- ✓ The std is systematically larger at HV = +150 V, where holes are collected, which may reflect a physical difference between hole and electron drift.

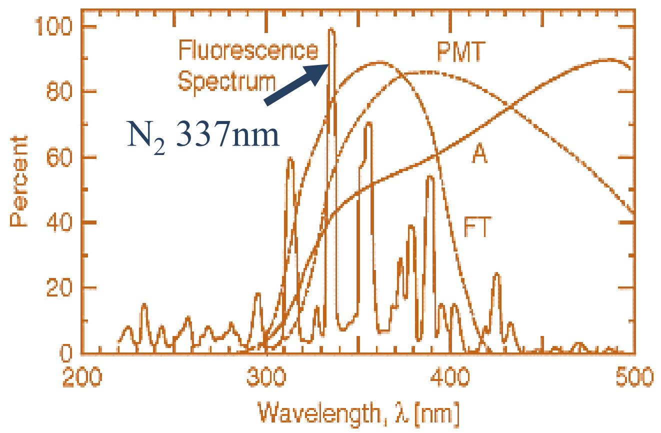
Therefore, both points require further investigation..

- **An ionizing particle traversing air ionizes and excites N_2 molecules producing excited/ionized nitrogen species: N_2^*, N_2^{+*}, and N^{+*}.**
- **De-excitation of these species yields the UV-light known as air scintillation in the 300-430 nm range.**

species	$\Delta(eV)$
N_2	0
$N_2(\nu)$	1.0
$N_2(A^3\Sigma_u^+)$	6.17
$N_2(B^3\Pi_g)$	7.35
$N_2(C^3\Pi_u)$	11.03
N_2^+	15.58

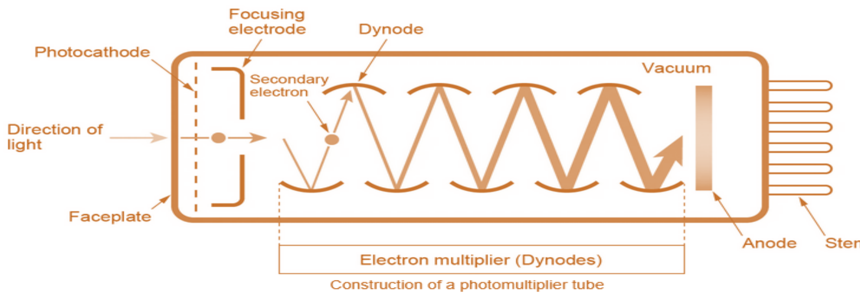


excitation/de-excitation
ionization
radiative transition



D. Kaganovich, G. Petrov, and B. Hafizi, "Utilization of self-lasing radiation for characterization of plasma discharge waveguides," J. Phys. D: Appl. Phys., vol. 57, no. 9, p. 095203, Dec. 2023, doi: 10.1088/1361-6463/ad0ef7.

Atmospheric Fluorescence *Sringer Verlag. Peter K.F. Grieder* https://link.springer.com/chapter/10.1007/978-3-540-76941-5_17



- **UV photons are collected and quantified with a photomultiplier tube (PMT).**
- **PMT must have good temporal resolution to enable beam profiling in FLASH Irradiation.**

6. PAF-State Of Art

- **An ionizing particle traversing air ionizes and excites N_2 molecules producing excited/ionized nitrogen species: N_2^*, N_2^{+*}, and N^{+*}.**
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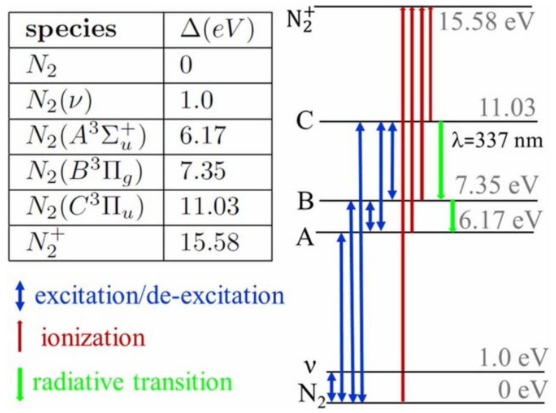
N_2^+	15.58



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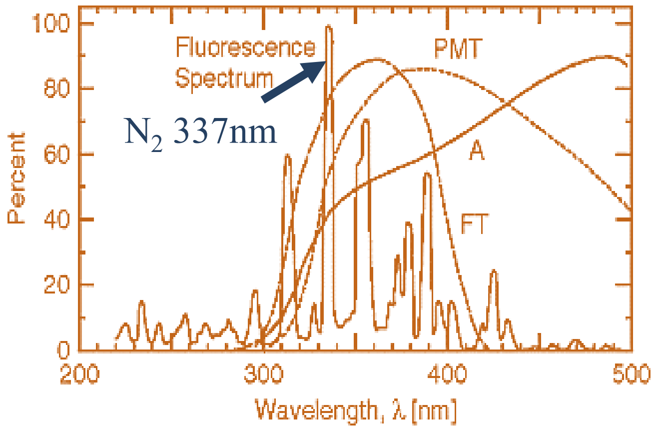

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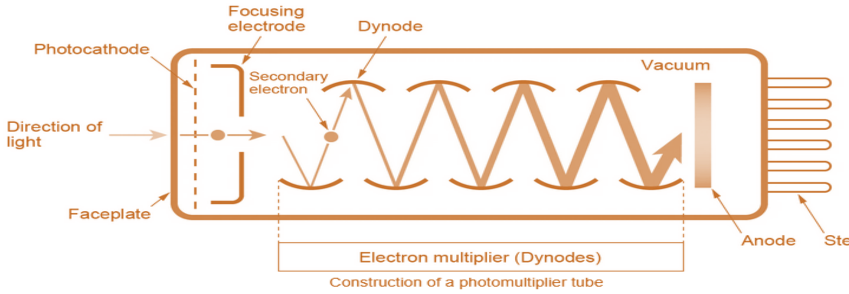

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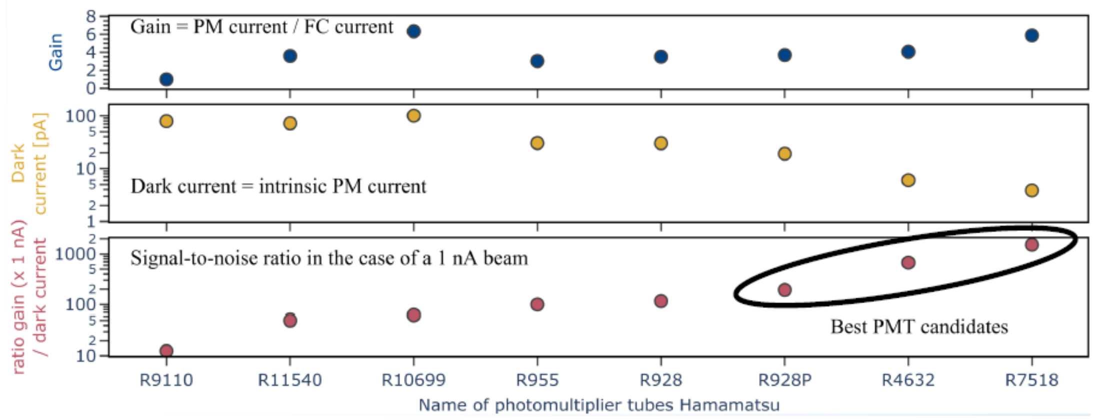
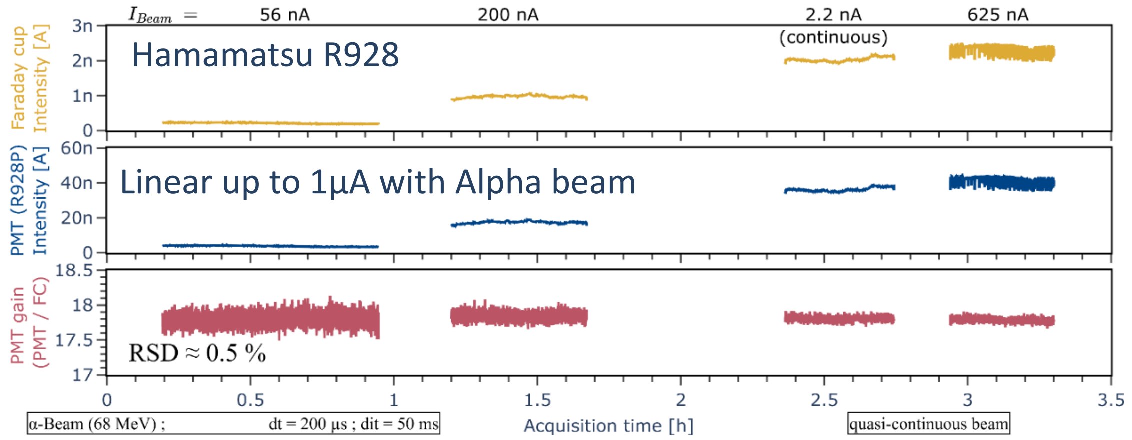
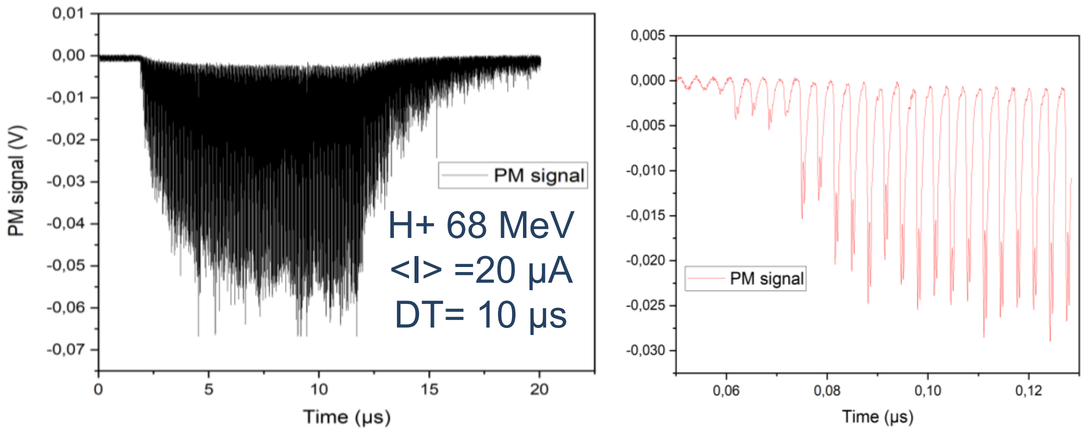
- **PMT must have good temporal resolution to enable beam profiling in FLASH Irradiation.**

Macro & Microstructure by induced air scintillation-PM detector







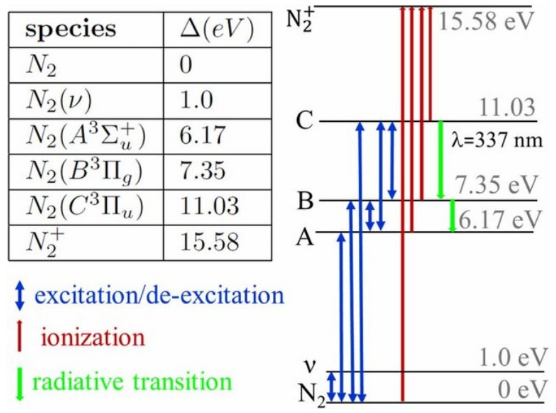
✓At high intensity, the PM can see each bunch.
✓The beginning of the train can be detected with a ns precision.

Poster FRPT 2022: "UPGRADE OF THE FLASH BEAM MONITORING SYSTEM AT ARRONAX CYCLOTRON" Q. Mouchard, N. Servagent, C. Koumeir et al.

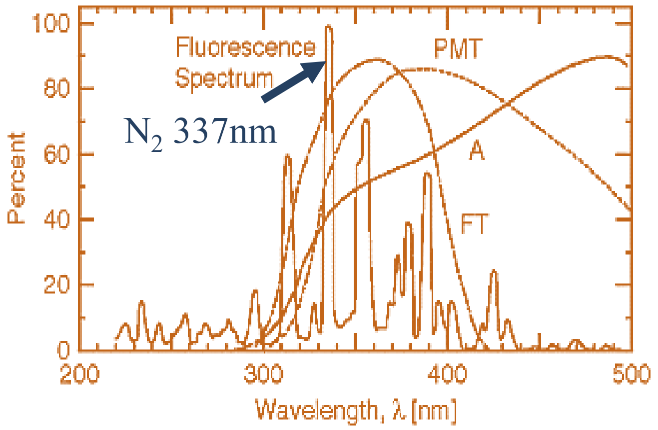
N. Servagent *et al.*, "Proton beam FLASH online monitoring at ARRONAX cyclotron," in *1st FLASH Radiotherapy and Particle Therapy Conference (FRPT 2021)*, https://imt-atlantique.hal.science/hal-03934393.

6. PAF-State Of Art

- **An ionizing particle traversing air ionizes and excites N_2 molecules producing excited/ionized nitrogen species: N_2^*, N_2^{+*}, and N^{+*}.**
- **De-excitation of these species yields the UV-light known as air scintillation in the 300-430 nm range.**

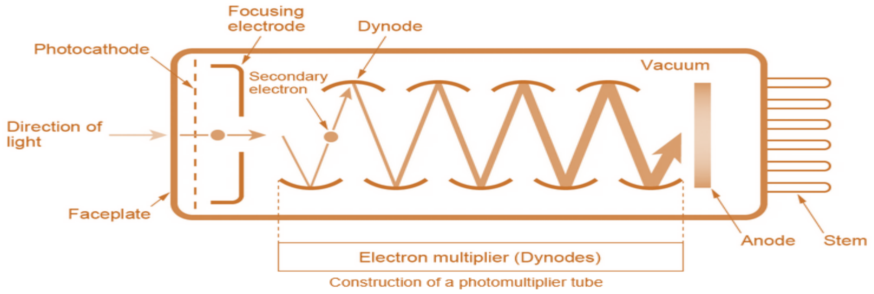


species	$\Delta(eV)$
N_2	0
$N_2(\nu)$	1.0
$N_2(A^3\Sigma_u^+)$	6.17
$N_2(B^3\Pi_g)$	7.35
$N_2(C^3\Pi_u)$	11.03
N_2^+	15.58



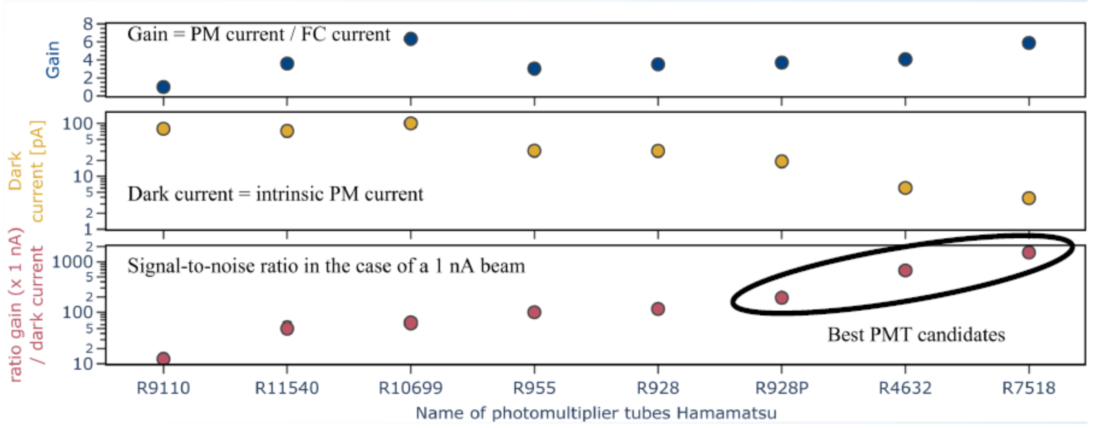
D. Kaganovich, G. Petrov, and B. Hafizi, "Utilization of self-lasing radiation for characterization of plasma discharge waveguides," J. Phys. D: Appl. Phys., vol. 57, no. 9, p. 095203, Dec. 2023, doi: 10.1088/1361-6463/ad0ef7.

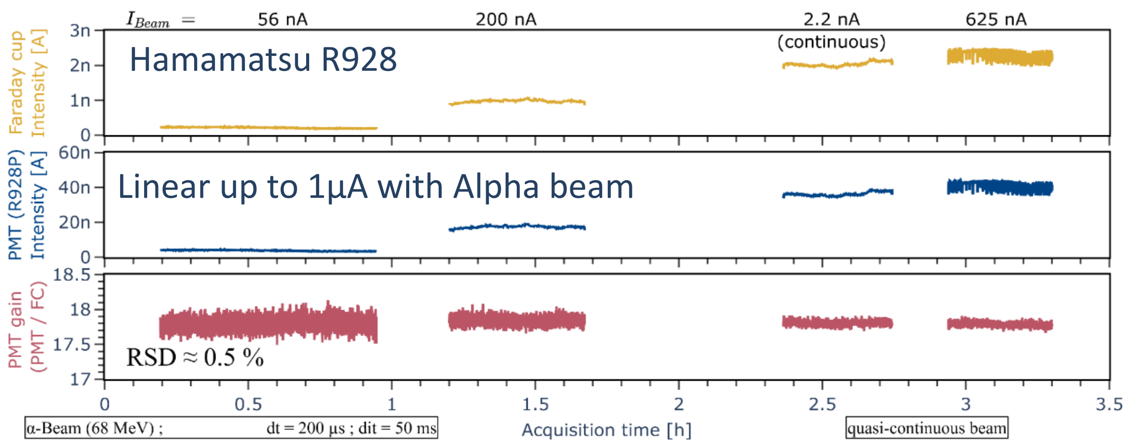
Atmospheric Fluorescence *Sringer Verlag. Peter K.F. Grieder* https://link.springer.com/chapter/10.1007/978-3-540-76941-5_17

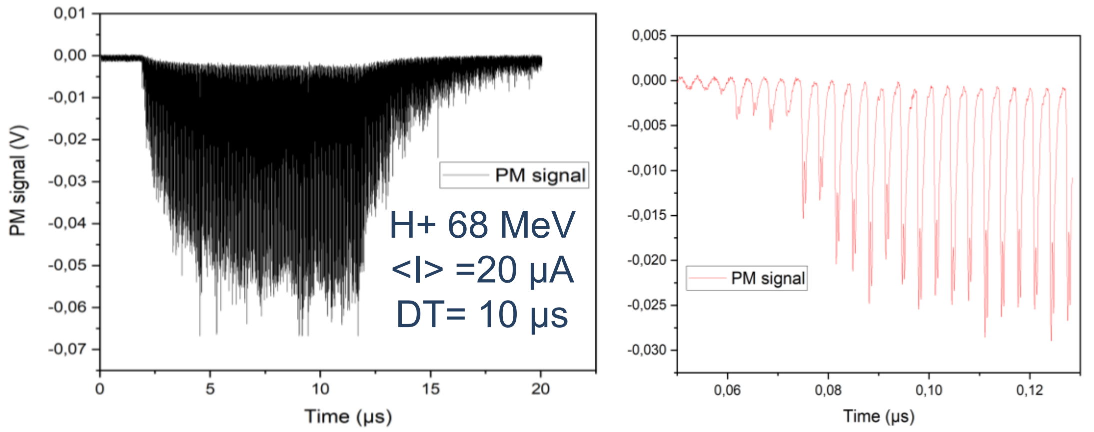


- **UV photons are collected and quantified with a photomultiplier tube (PMT).**
- **PMT must have good temporal resolution to enable beam profiling in FLASH Irradiation.**

Macro & Microstructure by induced air scintillation-PM detector







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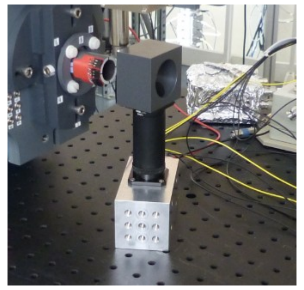
From 1 PM to 24 PMTs Prototype

By: Noel Servagent



24 PMTs Prototype

- *Hamamatsu R928 (Used at ARRONAX)*
- Tube size = 28mm
- Anode sensibility = 2500A/lm @1kV
- Rise time = 2,2ns
- Dark current = 3nA

PAF objectives

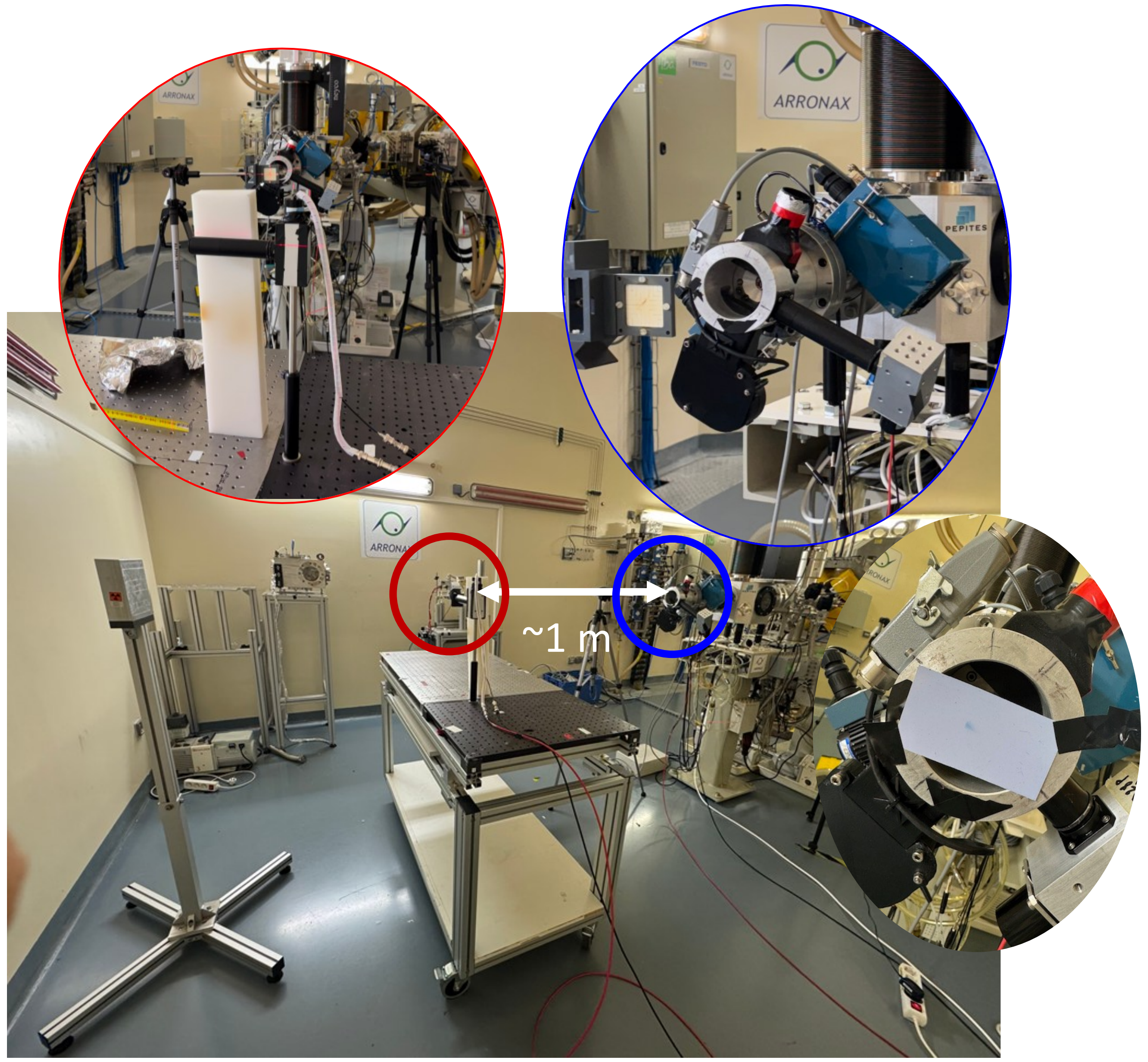
- Finalizing the 24 PMTs prototype.
- Test & characterize it.

In parallel:

PAF objectives

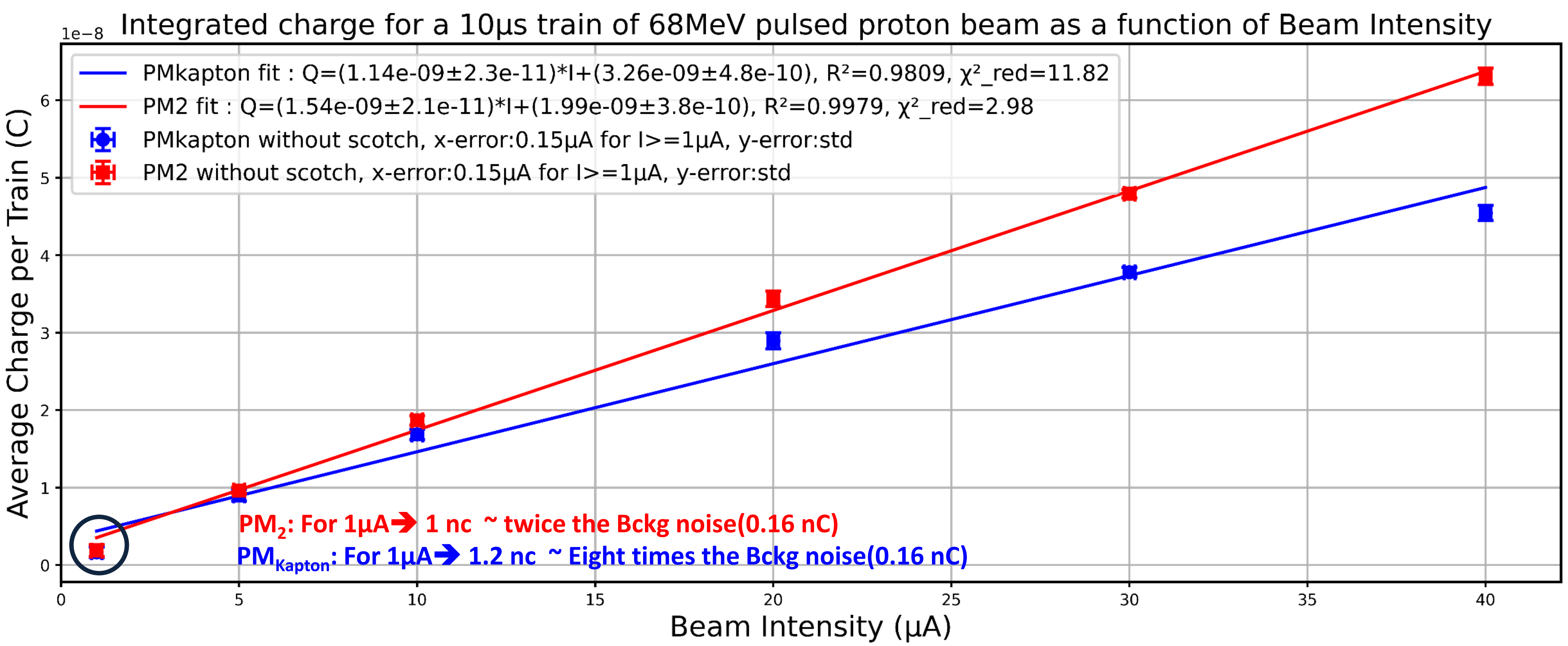
- Study the linearity of PM at high intensity > 1μA.
- Study the micro & macro time structure.
- Study the evolution of the bunch structure with intensity.
- Compare the results with that of with DIAMMONI.

6. PAF-Linearity



68 H^{+},DT=10µs, with a wide range of intensities, from 1µA➔40µA

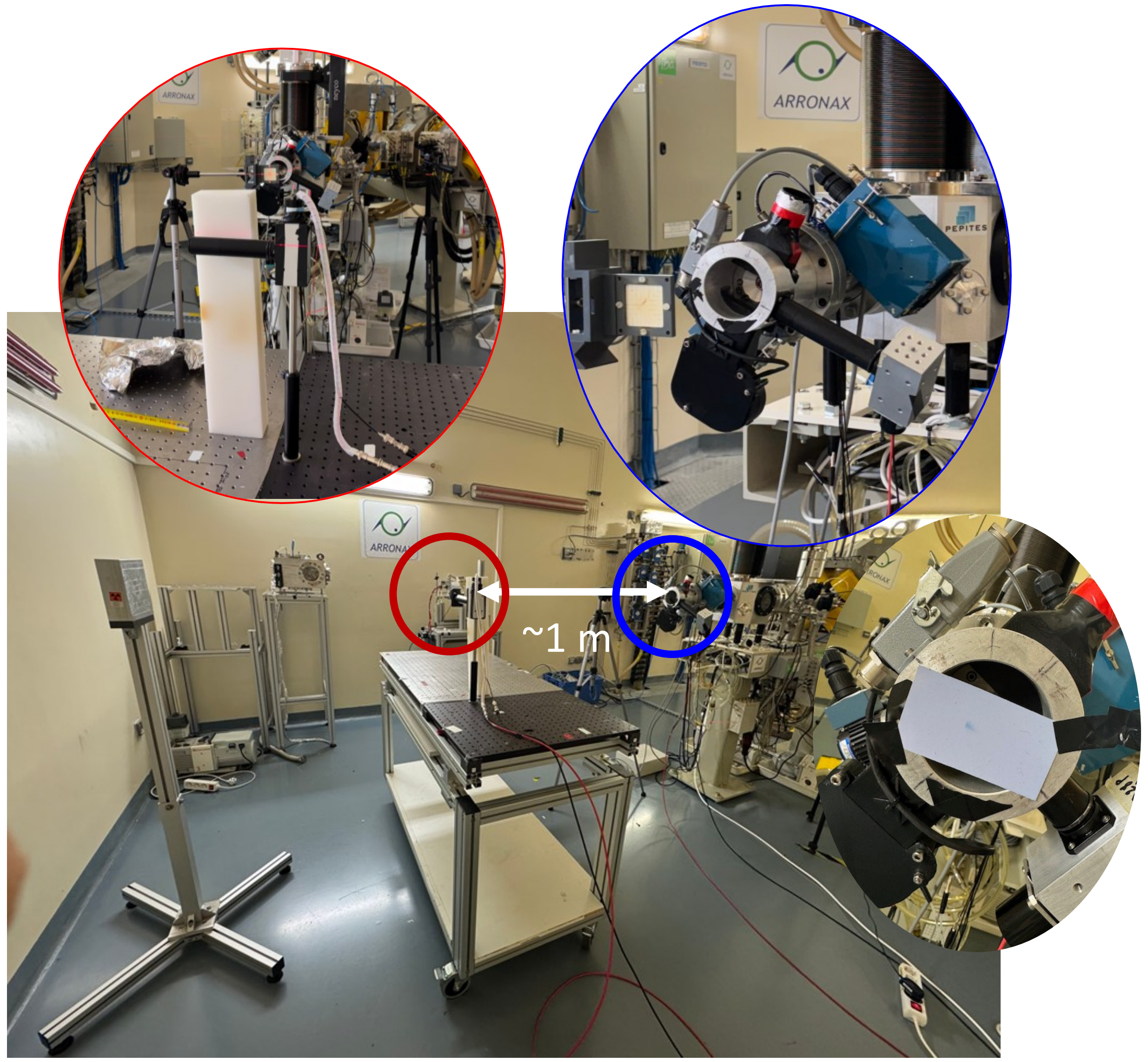
Linearity



- PM_{Kapton} and PM_2, show a comparable overall trend.
- The slight deviation in linearity is likely due to geometric effects, since the beam spot at the Kapton exit is smaller and more focused than at PM2.
- **At 1 µA, PMKapton measures 1.2 nC**, estimated using a window equal to the length of the train in the train region, corresponding to **about eight times the background noise (0.16 nC),** estimated using the same window length in the noise region before the start of the train.
- **PM2 measures 1 nC**, **about twice its noise level (0.55 nC),** using the same approach.

✓ **Good linearity (1µA-40µA).**
✓ **Operational range (~ 1µA up to ~ 40 µA).**

6. PAF-Macro & Micro time structure-By PM_{kapton}



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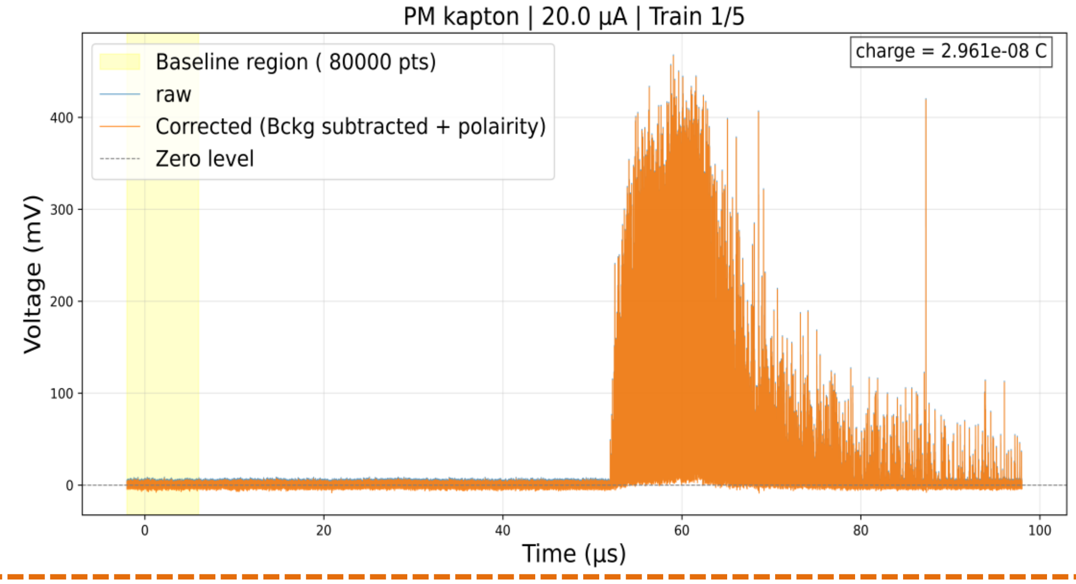
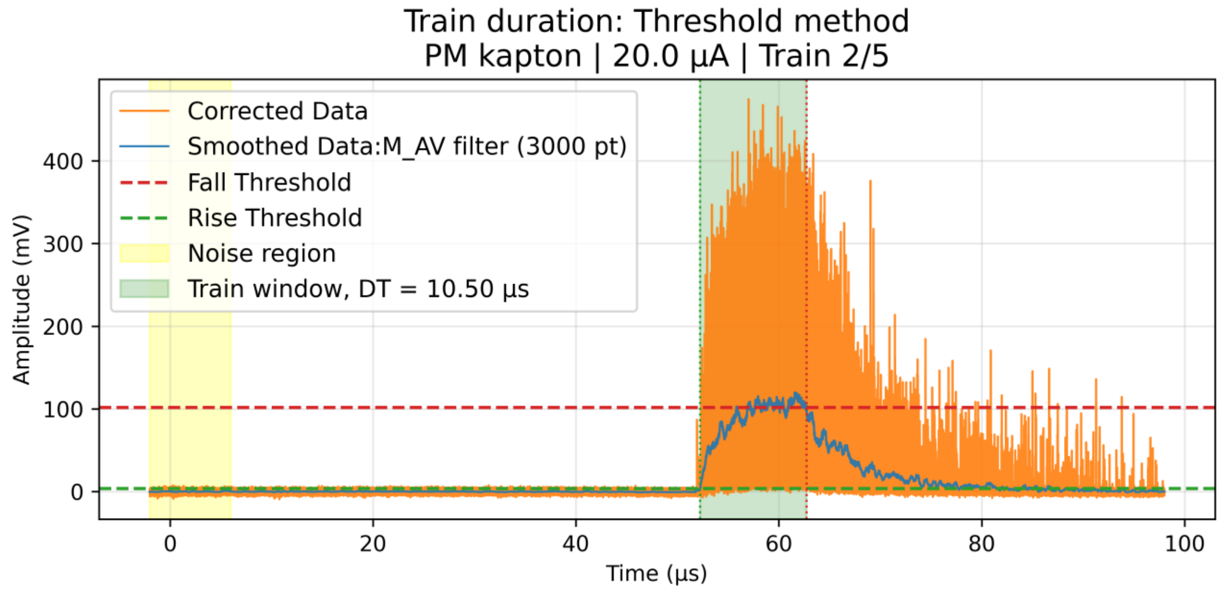
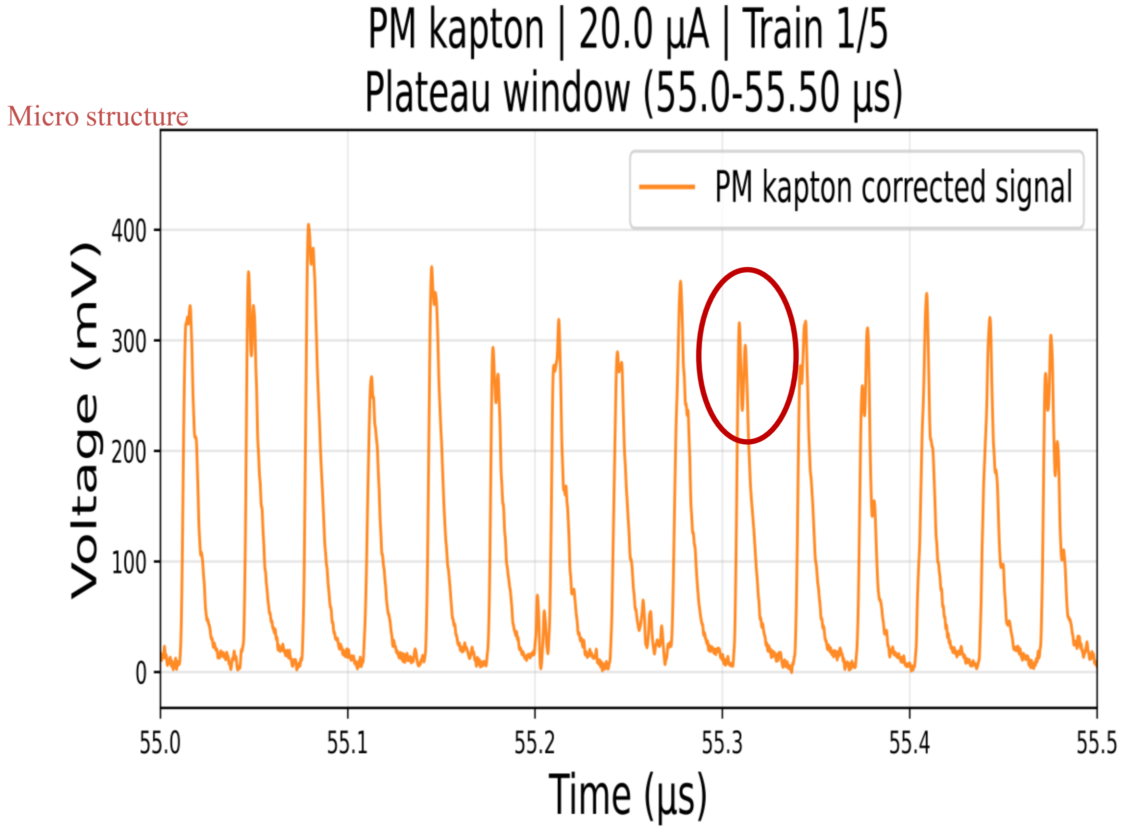
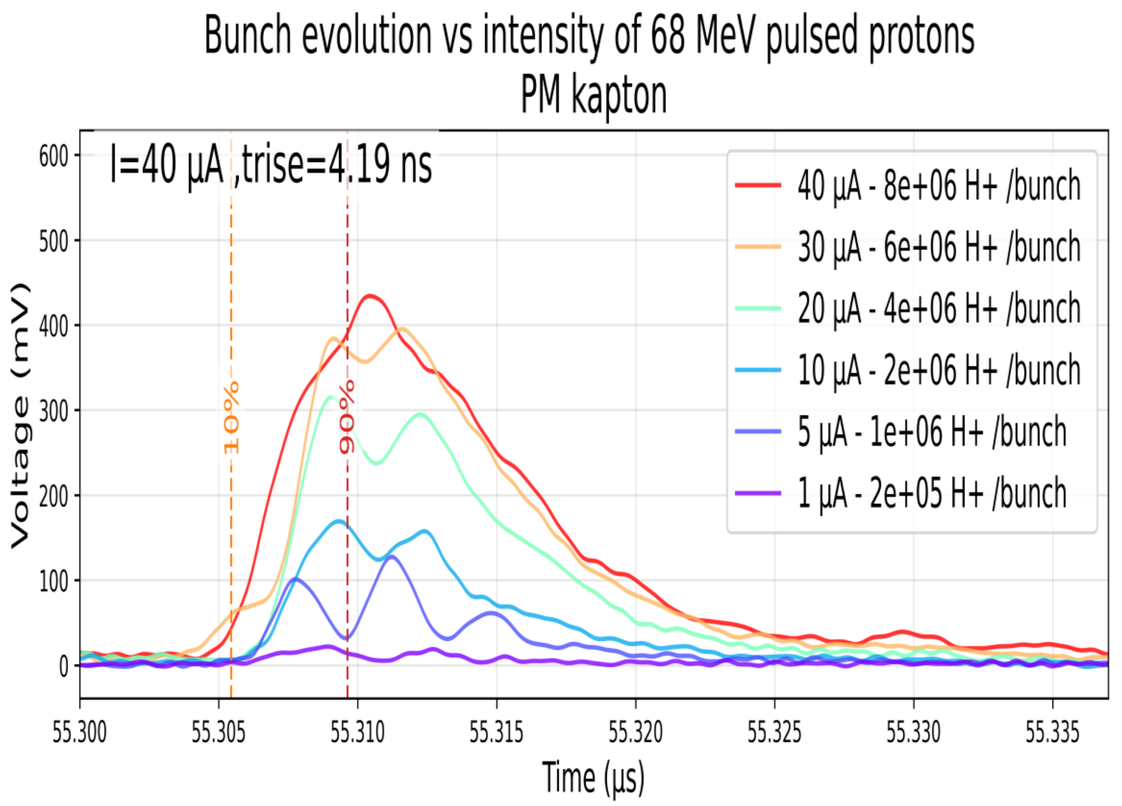
Macro-time structure





Micro- time structure

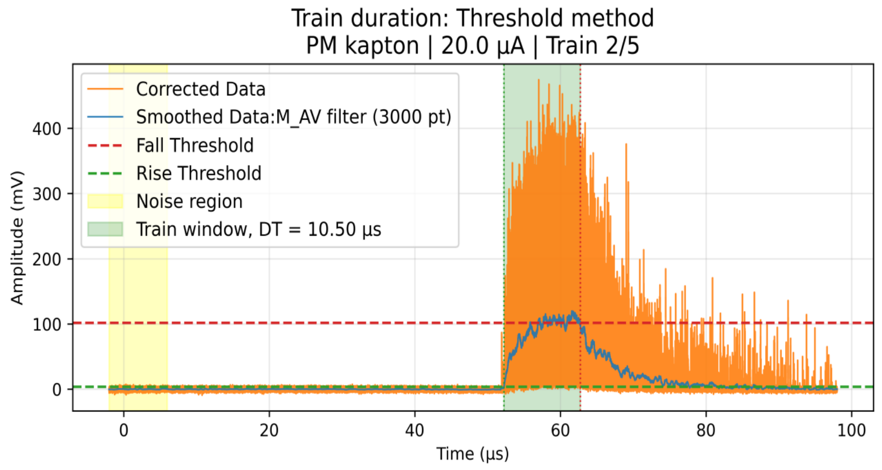


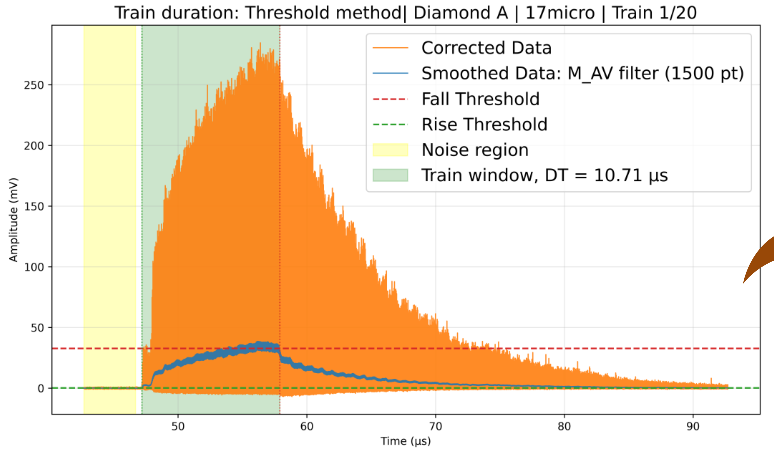


- ✓ **Measurement of micro/macro structure and DT.**
- ✓ **Bunch structure to be investigated.**

6. PAF vs DIAMMONI-Threshold Method

Macro-time structure: PAF vs DIAMMONI





DT theor=10µs	DT Experimental (µs)	
	PM Kapton	
µA	mean over 5 trains	std over 5 trains
40	10.72	0.13
30	10.60	0.18
20	10.61	**0.34**
10	10.39	0.39
5	9.37	1.42
1	8.52	**1.04**
Mean over all intensities	10.04	
std over all intensities	0.82	

DT theor=10µs	DT Experimental (µs)	
	Diamond A	
µA	mean over all trains	std over all trains
17	10.72	**0.02**
10	10.71	0.03
5	10.59	0.14
2	10.44	0.20
1	10.15	**0.40**
Mean over all intensities	10.52	
std over all intensities	0.21	

Both methods can extract the train duration; however, the diamond detectors are more sensitive, and the optical gain of PM should be enhanced.

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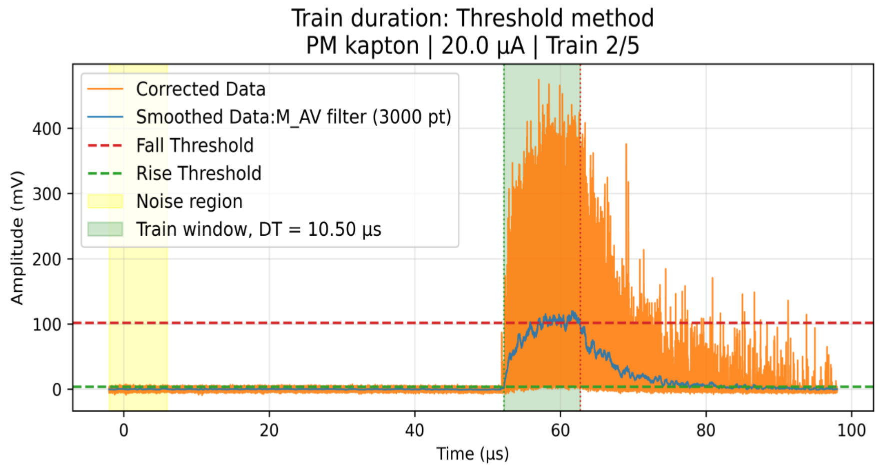

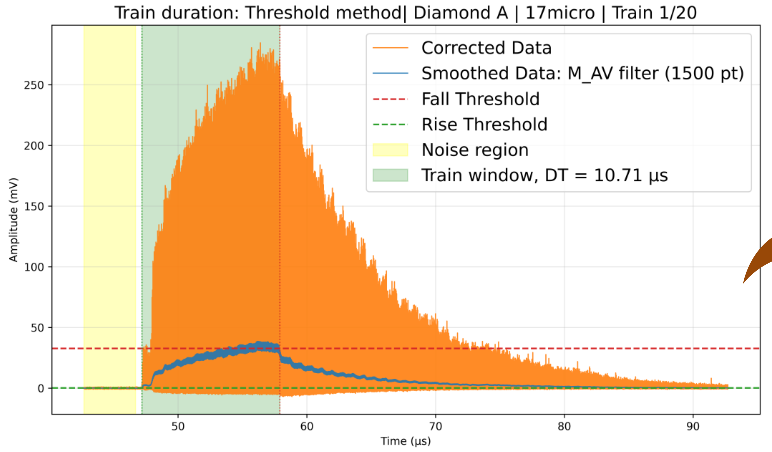

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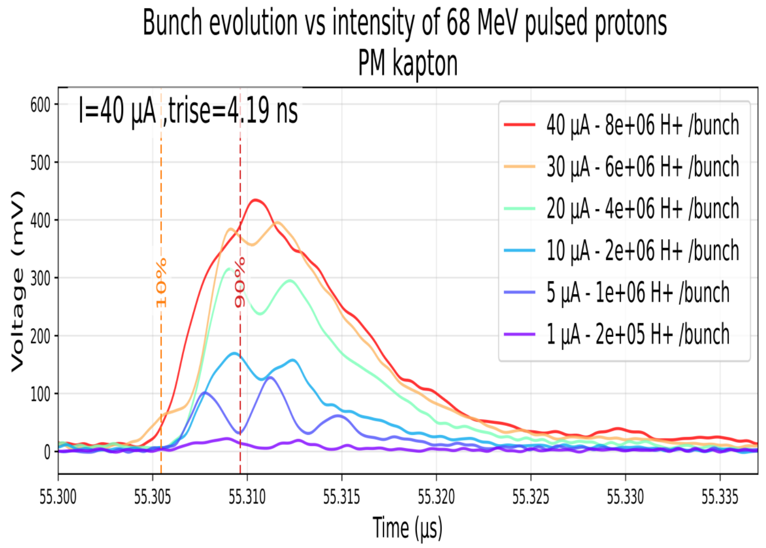

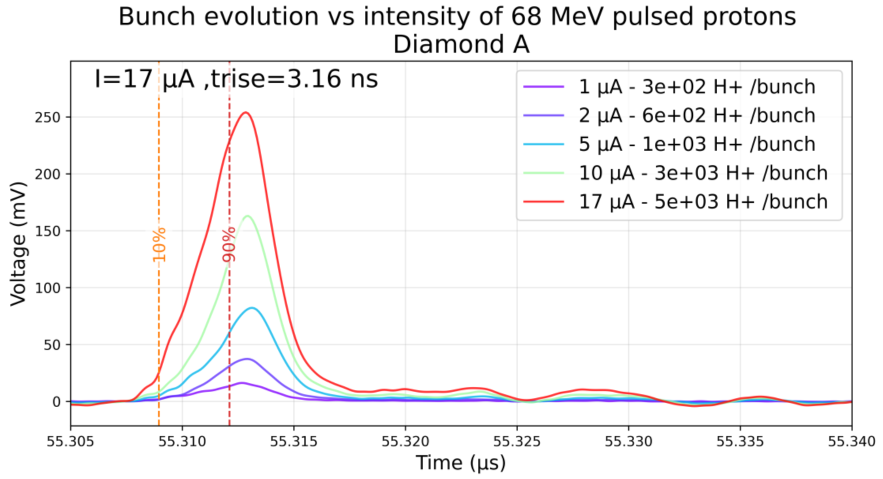

Both methods can extract the bunch structure; however, the diamond detectors yield a more precise estimate owing to their superior temporal resolution and faster rise time.

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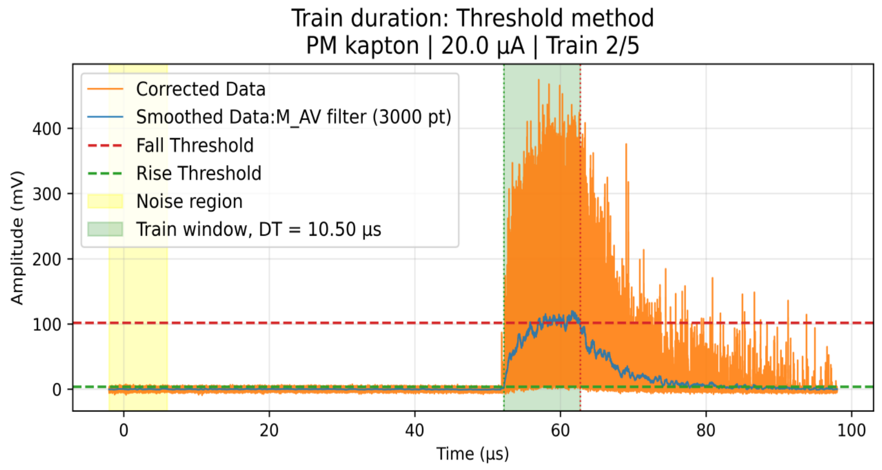

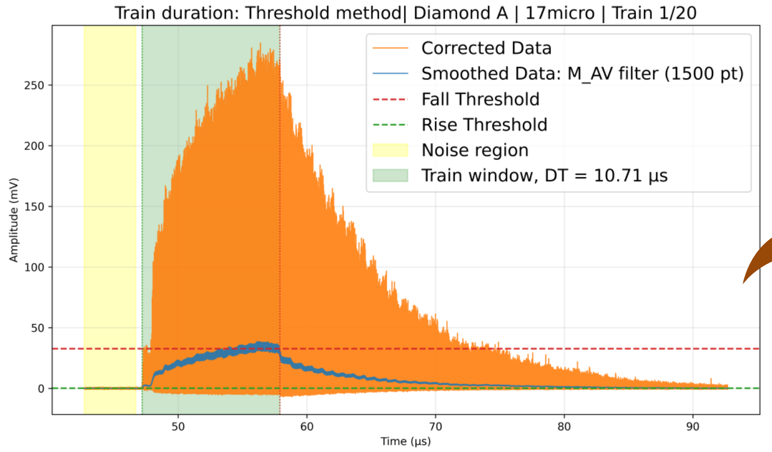

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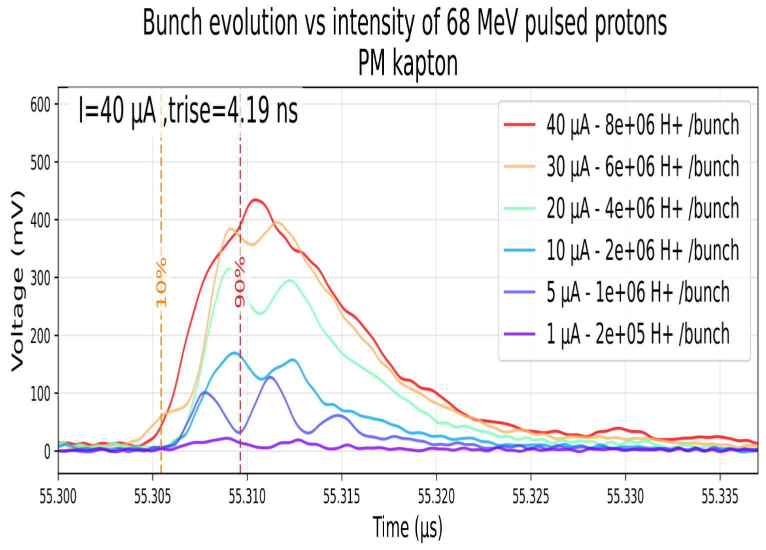
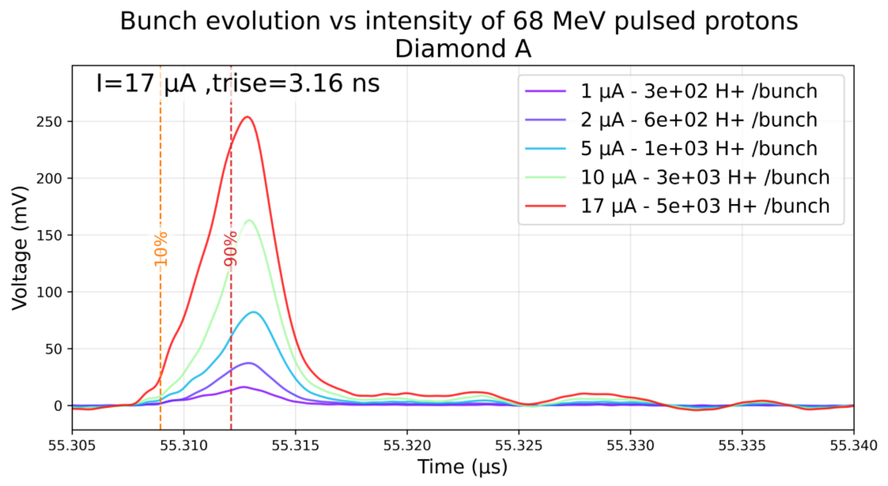




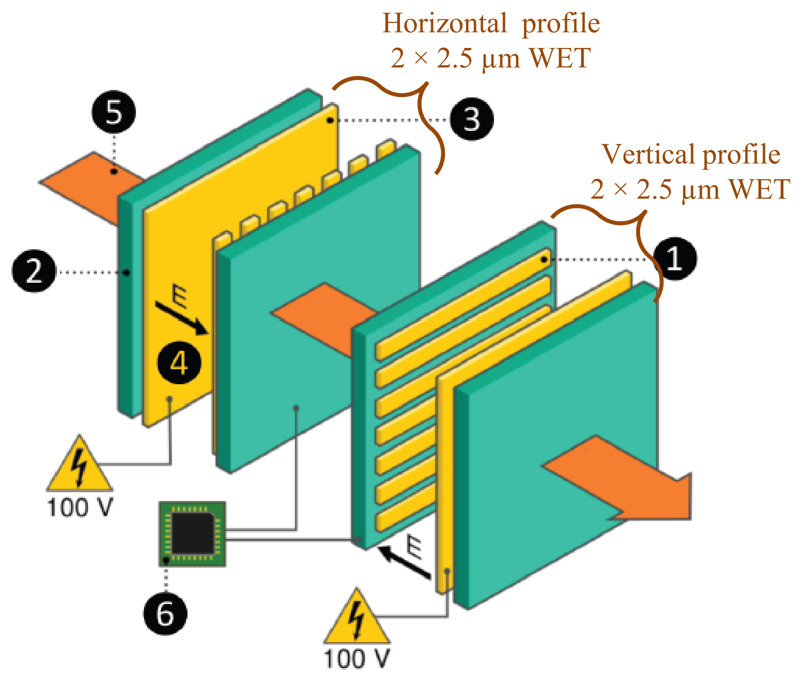
Both methods can extract the bunch structure; however, the diamond detectors yield a more precise estimate owing to their superior temporal resolution and faster rise time.

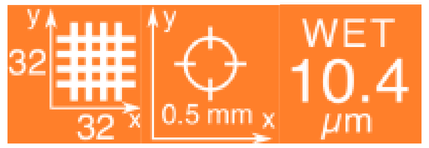
Detector	Operational range	Rise Time	Beam characterization	Radiation damage	DT EXtraction
DIAMMONI	100nA-40µA	Excellent (3.16 ns)	YES	Yes	More Precise (std= 0.21)
PAF	1µA-40µA	Good (4.19 ns)	YES	No	More signal flactuations (std=0.82)

Always a Compromise! Further investigation is required.

7. PEPITES-State Of Art

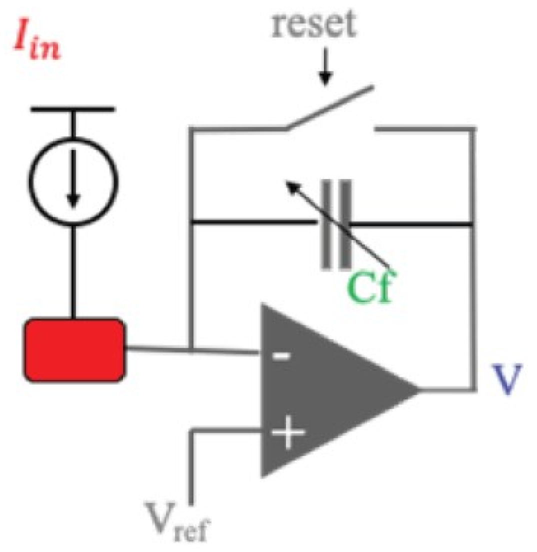
Secondary electron emission from gold strips

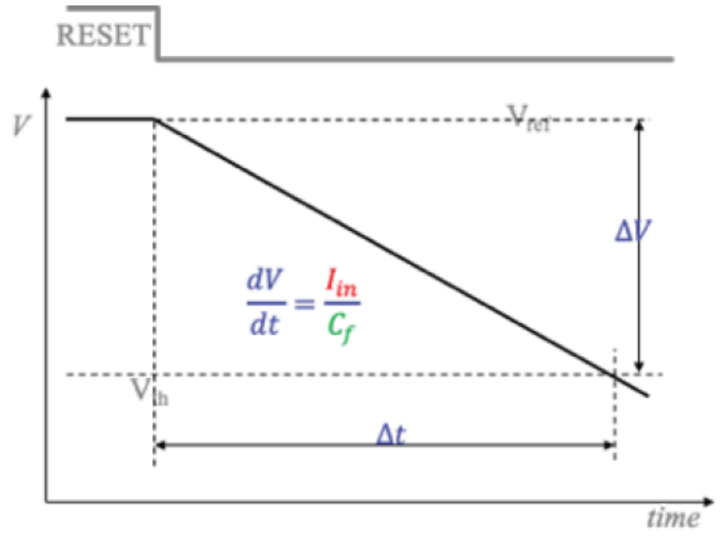




1. Polyimide ($CP1^{TM}$ 1.5 µm)
2. Cathode strips (Au 50 nm)
3. Anode (Au 100 nm)
4. Vacuum
5. Beam
6. Electronic readout (ASICS PEPITA from CEA)

- The incident beam passes through segmented electrodes consisting of nanometric-thickness gold strips deposited on a thin polymer membrane.
- The secondary electrons emitted from the surface of the gold layer provide a signal to a dedicated electronic readout(CEA)(SEE about 10% yield).





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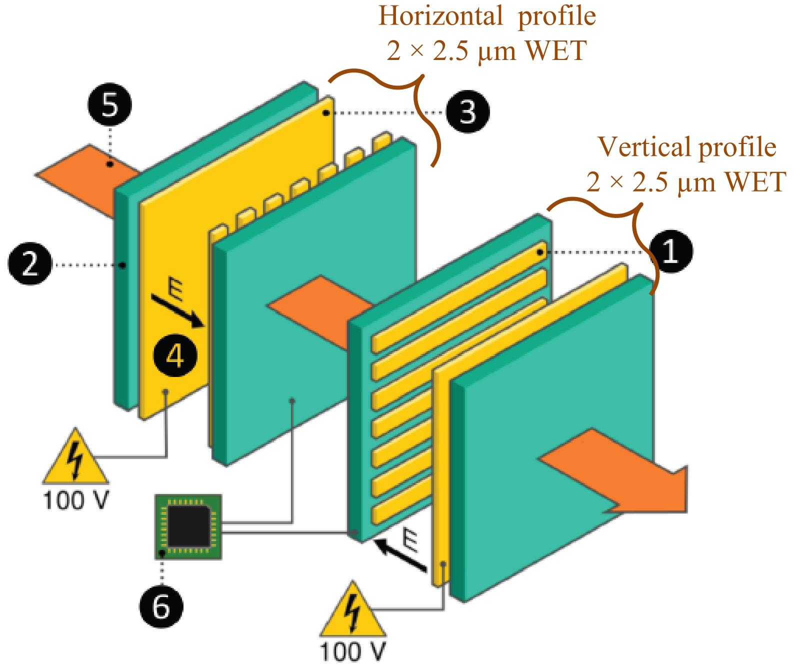

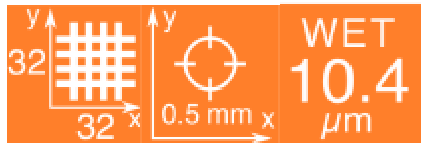

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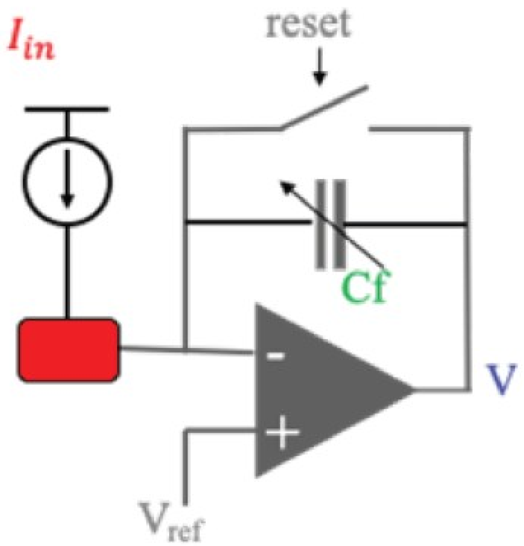
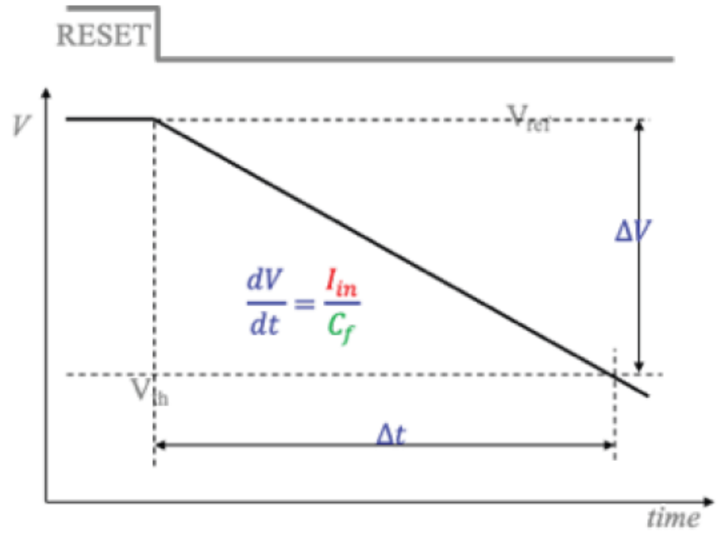
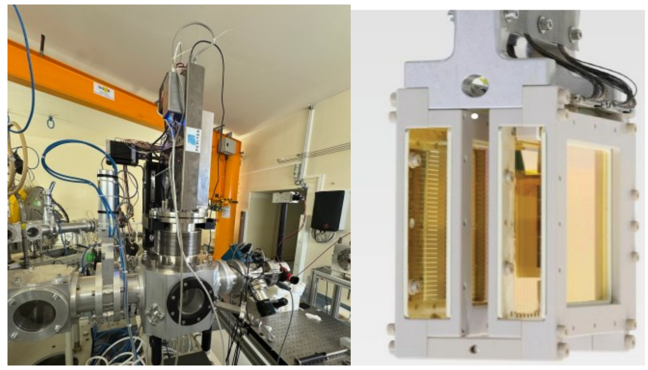


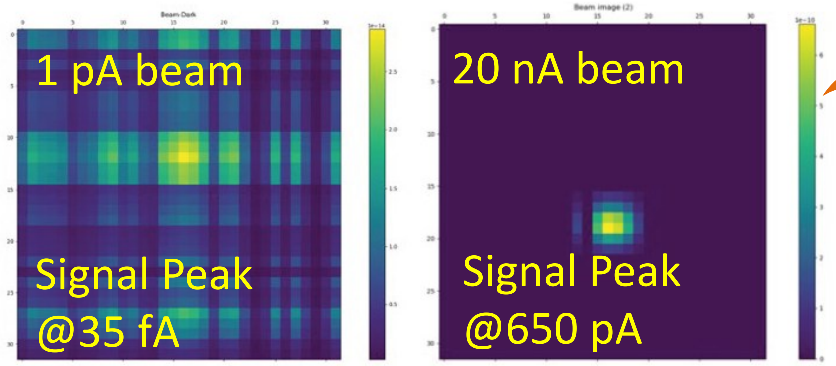


PEPITES prototype inside AX beamline at ARRONAX



Able to measure the beam profile with:

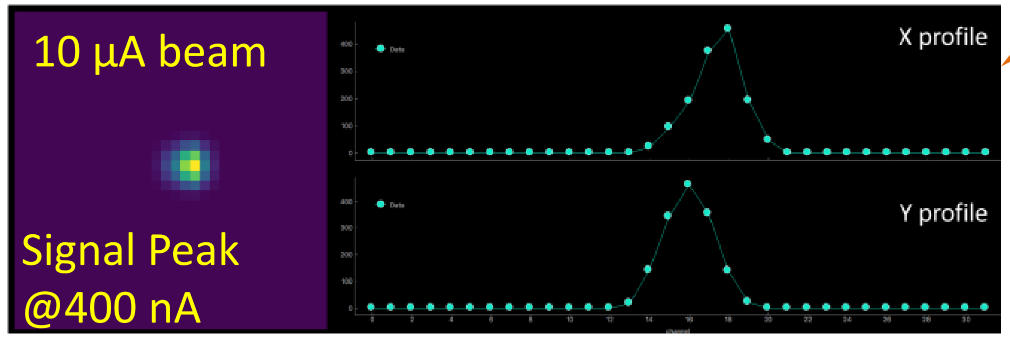
✓ **Continuos proton** beam **68**MeV from **1pA** to **20nA**



What about its response with I> 20 nA?
And under Alpha beam?

C. Thiebaux et al., "First Results of PEPITES, A New Transparent Profiler Based on Secondary Electrons Emission for Charged Particle Beams," p. 4 pages, 0.578 MB, 2022, doi: 10.18429/JACOW-IBIC2022-MOP21.

✓ **Pulsed Proton** beam **68** MeV, 10 µA, DT=**10ms**, « FLASH .»



How to enhance the electronics to operate under UHDR « FLASH therapy »? And under Alpha beam?

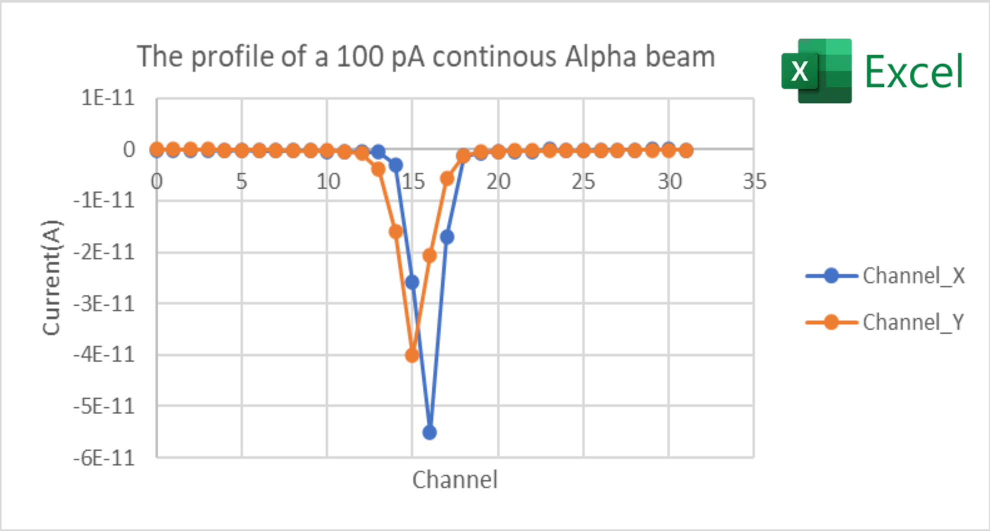
Verderi,Marc et al., "PEPITES: an ultra-thin beam profiler with wide dynamic range for charged particle beams," pp. 521-523 pages, 7.0 MB, Jan. 2026, doi: 10.18429/JACOW-IBIC2025-TUPMO24.

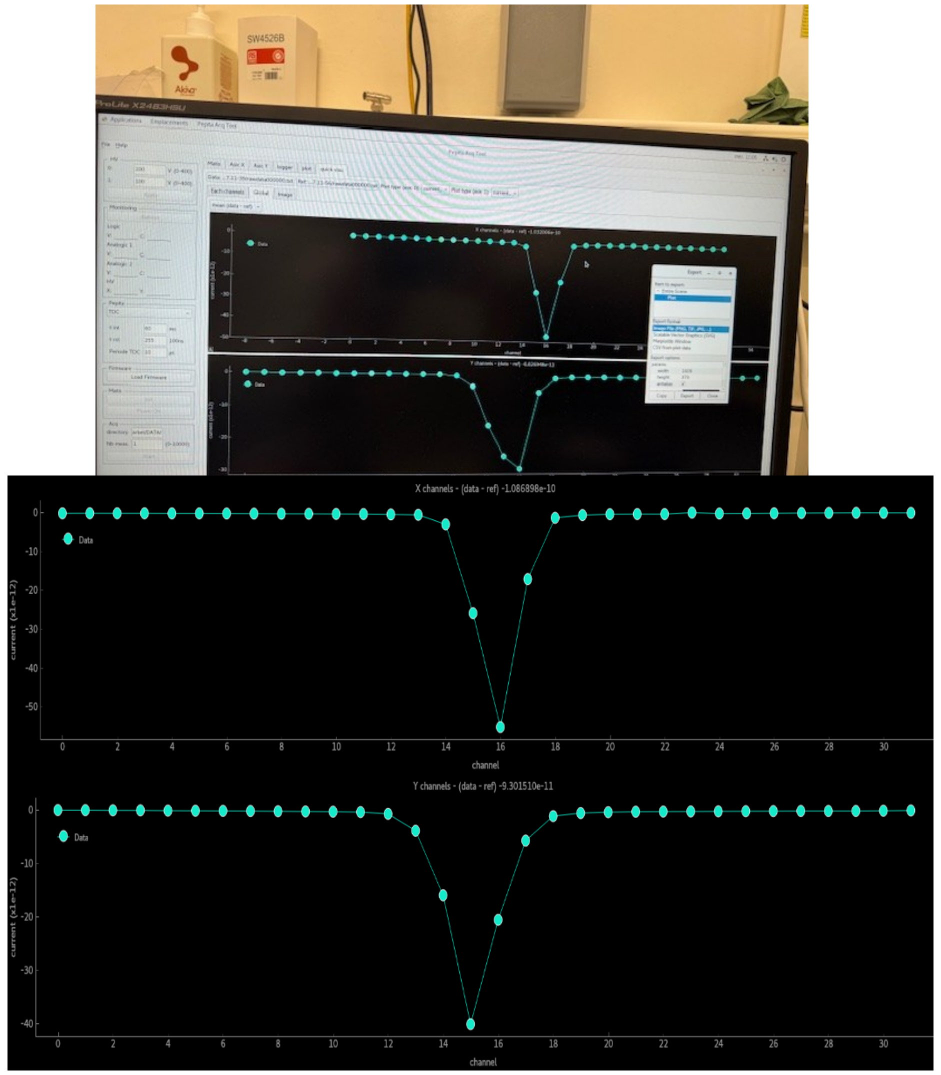
7. PEPITES-Beam Profile

Experiment: Mars 2025

Alpha 68Mev, 100 pA, continuous beam

Current run parameters= configuration (**Integartion time: 60ms**, **Gain=6**, **HV 100V** for both anodes)





100pA	**gain**	**6**
	Config 200pA;60ms	
	Channel_X	**Channel_Y**
Mean	-3.400E-12 A	-2.908E-12 A
Max	-5.516E-11 A	-4.010E-11 A
indx max(channel)	16	15
SD	1.0846E-11	8.162E-12
FWHM	1.666 (3.63 mm)	1.865(4.0 mm)

What is the impact of changing the parameters of the configuration (integration time, gain)
What about high intensities?

7. PEPITES-Beam Profile

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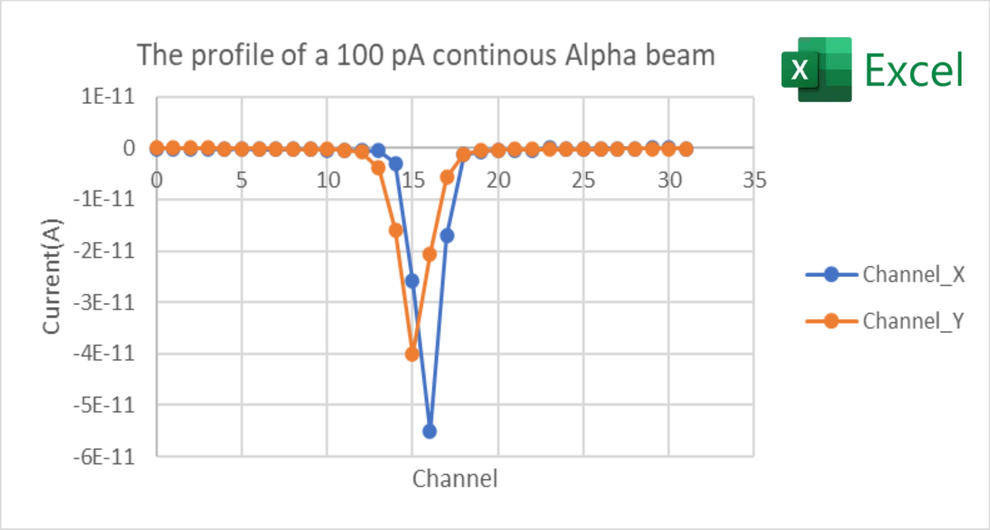

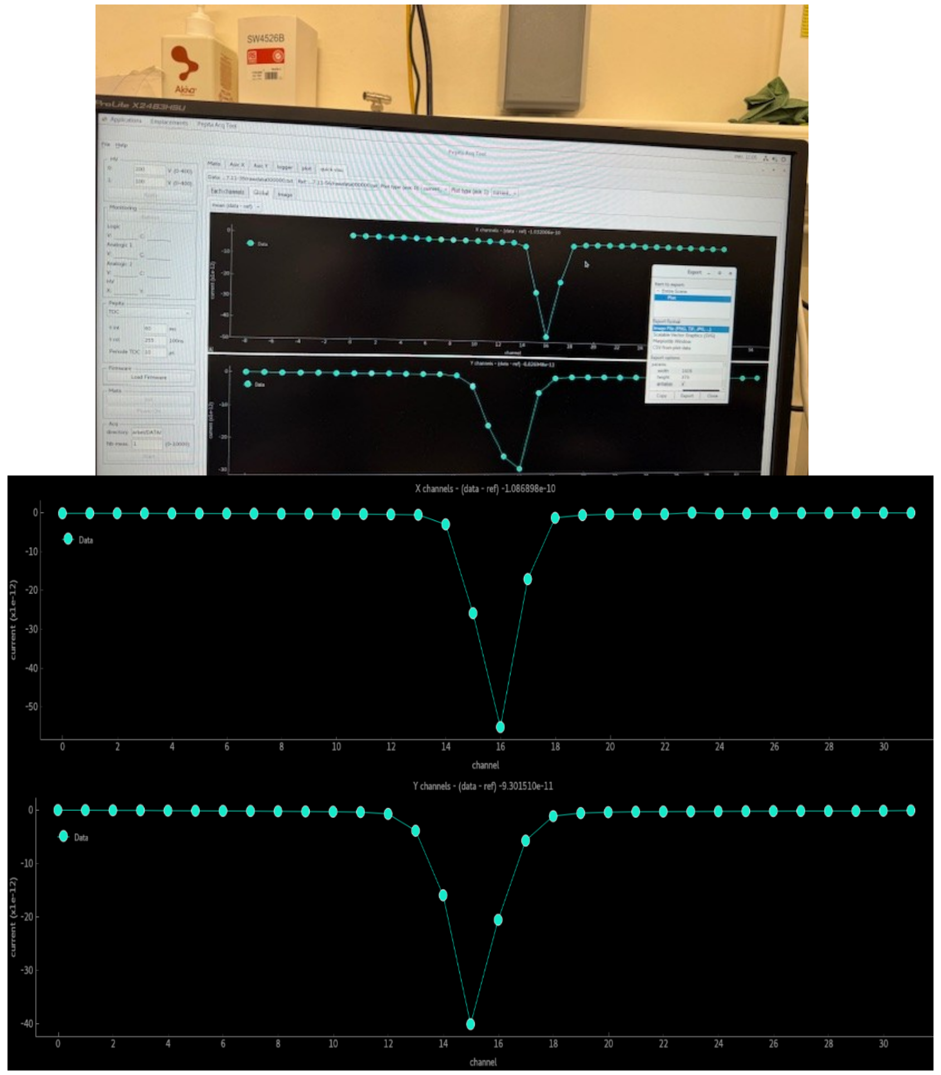

		
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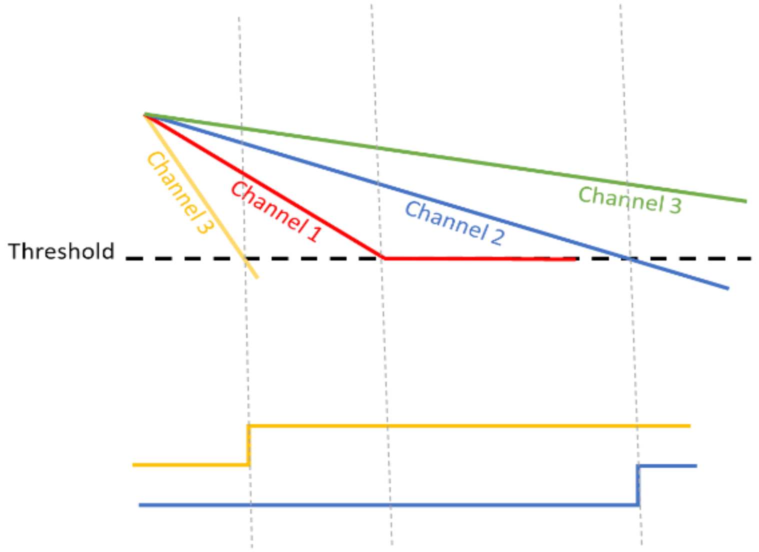
What is the impact of changing the parameters of the configuration (integration time, gain)
What about high intensities?

New Calibration: July 2025

68 MeV continuous proton beam was done using the ancient software.

Optimize the gain, integration time, and threshold potential of each channel to achieve a configuration that provides a clear and accurate beam profile.



- Proper operation: correct integration time (t_{in}) and gain.
- Two failure modes can occur: saturation (when integration time or gain is too high, clipping the signal; channel 1 (in red) and no signal (when integration time or gain is too low, preventing threshold crossing; channel 3 in green).

✓ Two configurations were established: Confg. 1 nA & Config. 100pA

Next:
- Try different configurations and check the impact of every configuration + repeatability measurements.
- Try the new trigger mode of the software.
- Do measurements with wide range of intensities to check if the electronic is suitable for UHDR

- ✓ **The preliminary results demonstrate that both DIAMMONI and PAF can effectively characterize beam parameters.**
- ✓ **These initial results are encouraging for monitoring pulsed proton beams across a wide range of intensities.**
- ✓ **Additional data with DIAMMONI is currently being analyzed.**

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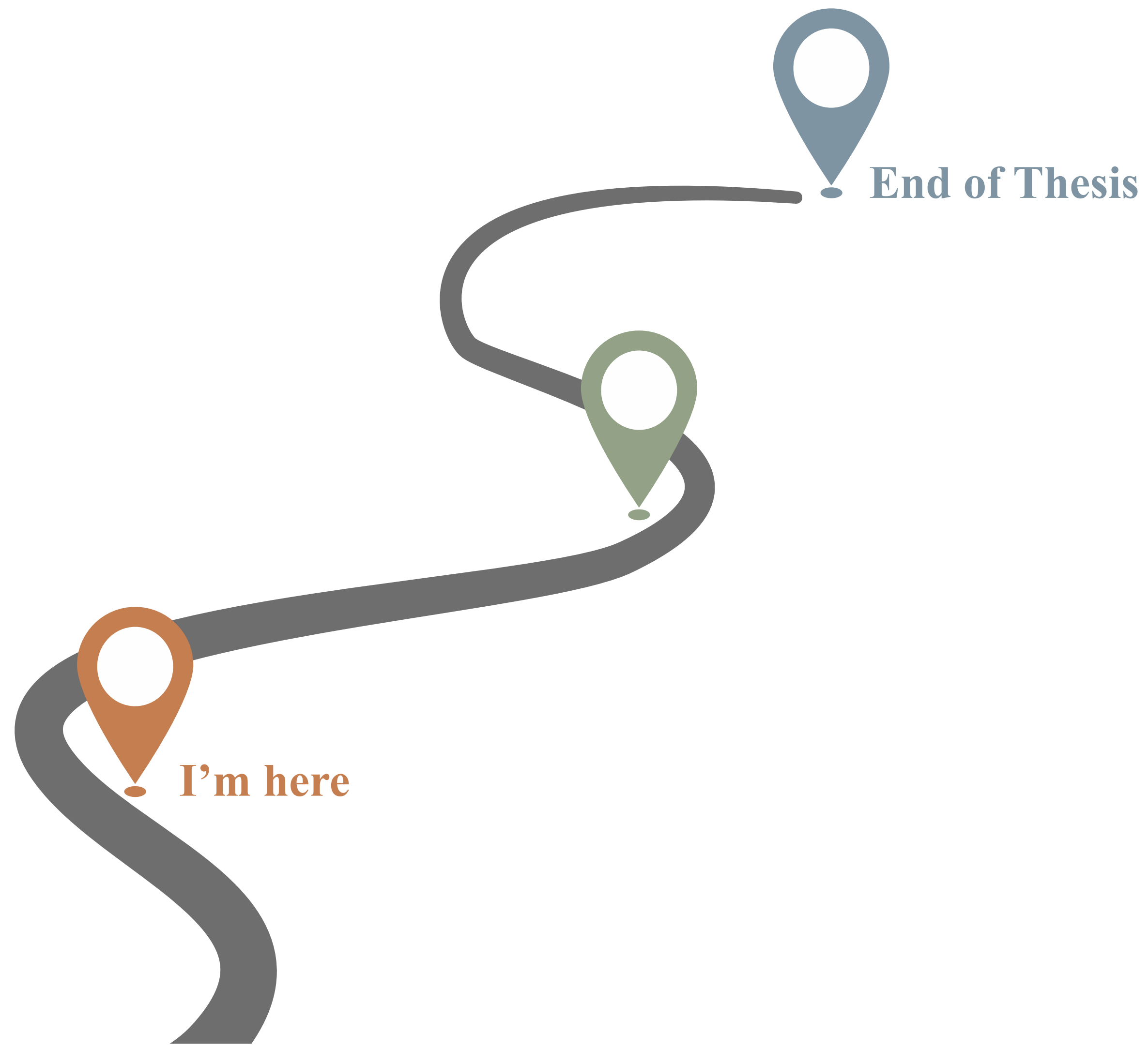
- ➢ **Extend this work to alpha particle UHDR experiments.**
- ➢ **Linearity and radiation damage experiments with Diamond.**
- ➢ **Characterize PAF prototype.**
- ➢ **Test PEPITES electronics under UHDR conditions**
- ➢ **Test the detectors on other platforms (Strasbourg: Cyrcé, Nice: Antoine Lacassagne)**

8. Conclusion & Upcoming work

- ✓ The preliminary results demonstrate that both DIAMMONI and PAF can effectively characterize beam parameters.
- ✓ These initial results are encouraging for monitoring pulsed proton beams across a wide range of intensities.
- ✓ Additional data with DIAMMONI is currently being analyzed.

- ➢ Extend this work to alpha particle UHDR experiments.
- ➢ Linearity and radiation damage experiments with Diamond.
- ➢ Characterize PAF prototype.
- ➢ Test PEPITES electronics under UHDR conditions
- ➢ Test the detectors on other platforms (Strasbourg: Cyrcé, Nice: Antoine Lacassagne)

- The three detector technologies will be compared and support other facilities with similar requirements.
- A real-time acquisition system will be developed to run them simultaneously for online beam monitoring during experiments on the AX beam line.



Thank You

For Listening

Rania Jbara

jbara@arronax-nantes.fr

Back-up Slides

ARRONAX

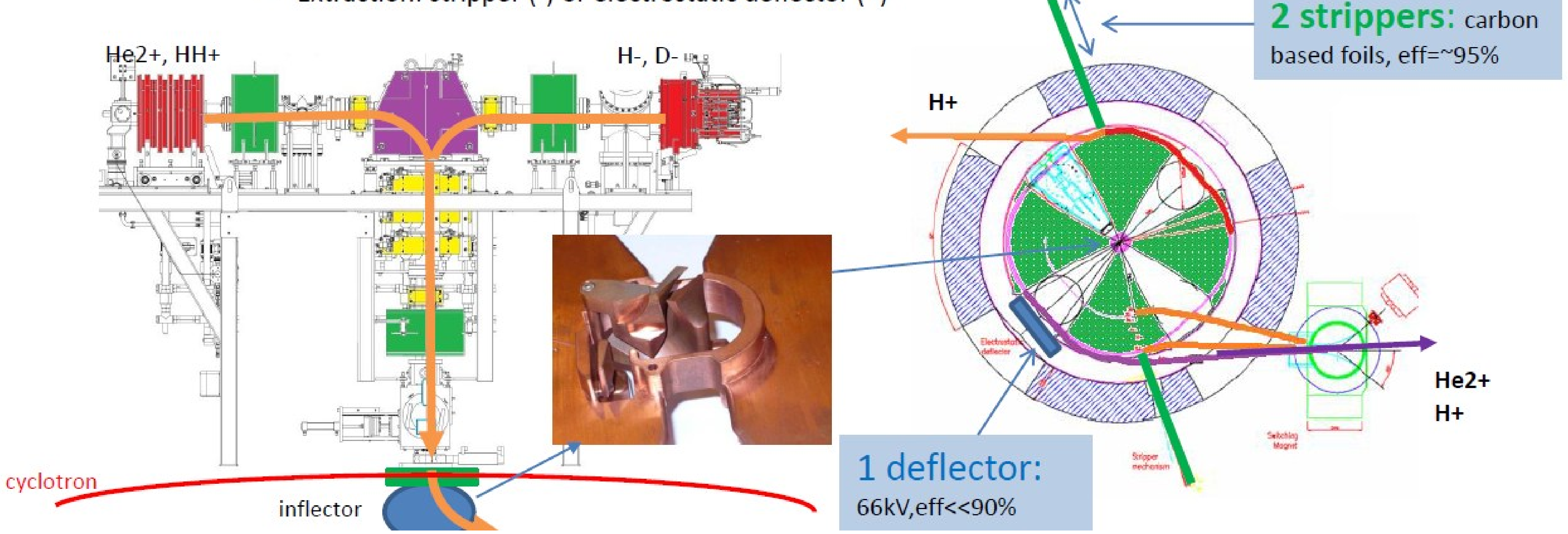
Characteristics

Subatech

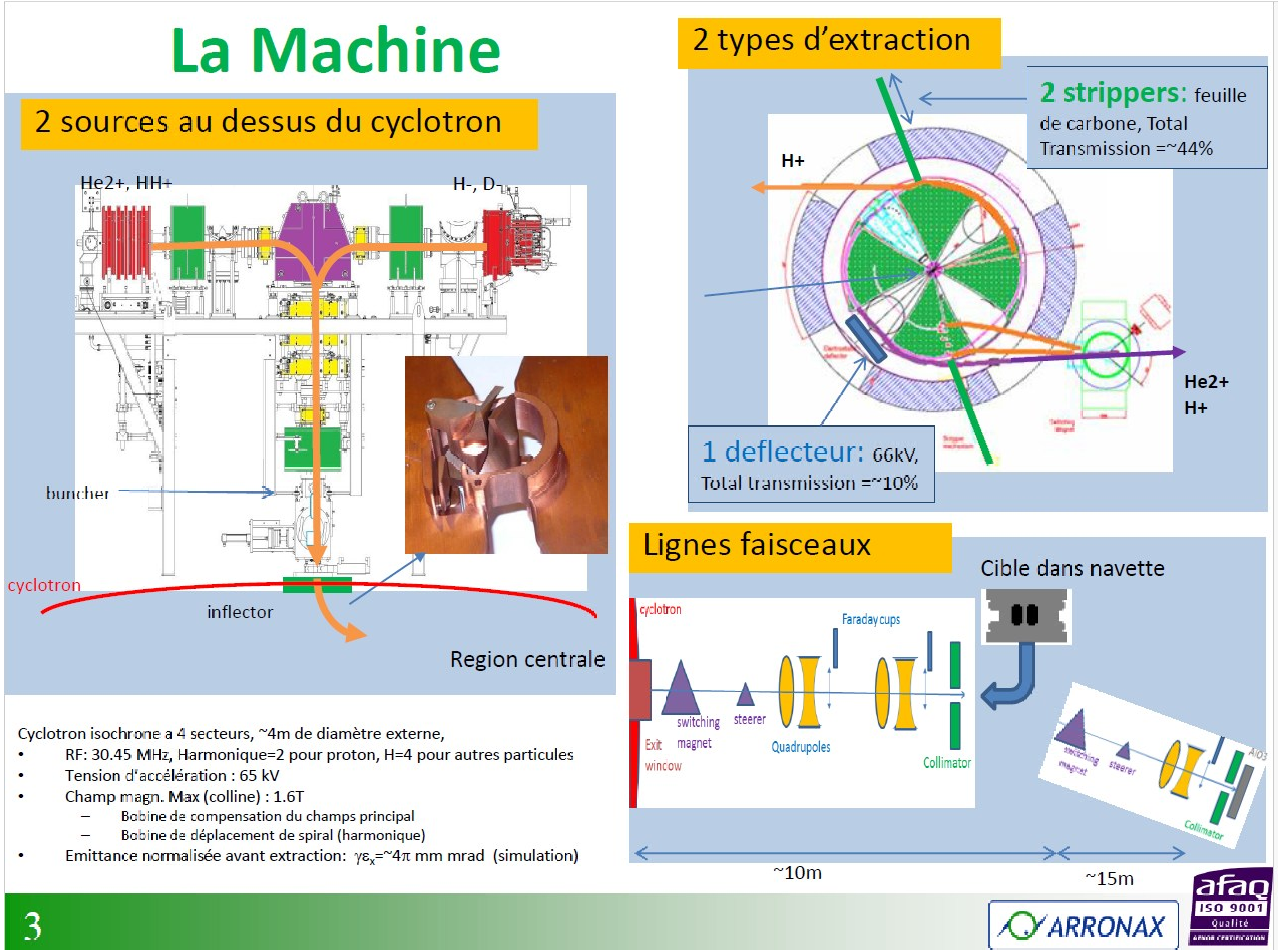
- C70 Cyclotron build by IBA:
  - Isochron cyclotron with 4 sectors
    - RF: 30.45 MHz
    - Acceleration Voltage: 65 kV
    - Max magn. field : 1.6T
  - ~4m of diameter
  - Max kinetic energy/n: 30-70 MeV
  - Normalised emittance before extraction: $\gamma\varepsilon_x$=~4π mm mrad (simulation)

Extracted Particles	Energy range (MeV)	Highest possible current (µAe)	most common current range (µAe)	Nb of particles / bunch at 1 µAe
H+	30 - 70	375 x 2	0.05 – 80 x 2	205 10^3
He2+	70	70	0.07 – 0.1	102 10^3
HH+	35	50	0.1 – 1	410 10^3
D+	15 - 35	50	0.05 – 1.2	205 10^3

- Main additional elements:
  - 2 Multiparticle sources.
    - Multicusp (H-,D-) with multiple magnets, 5mA max.
    - Supernanogan ECR ion source (He2+,HH+)
  - Injection: Series of magnetic elements (glaser, steerer, quad.) on the top of the cyclotron to adapt the beam to the entrance of the cyclotron, and finally the spiral inflector
  - Extraction: stripper (-) or electrostatic deflector (+)



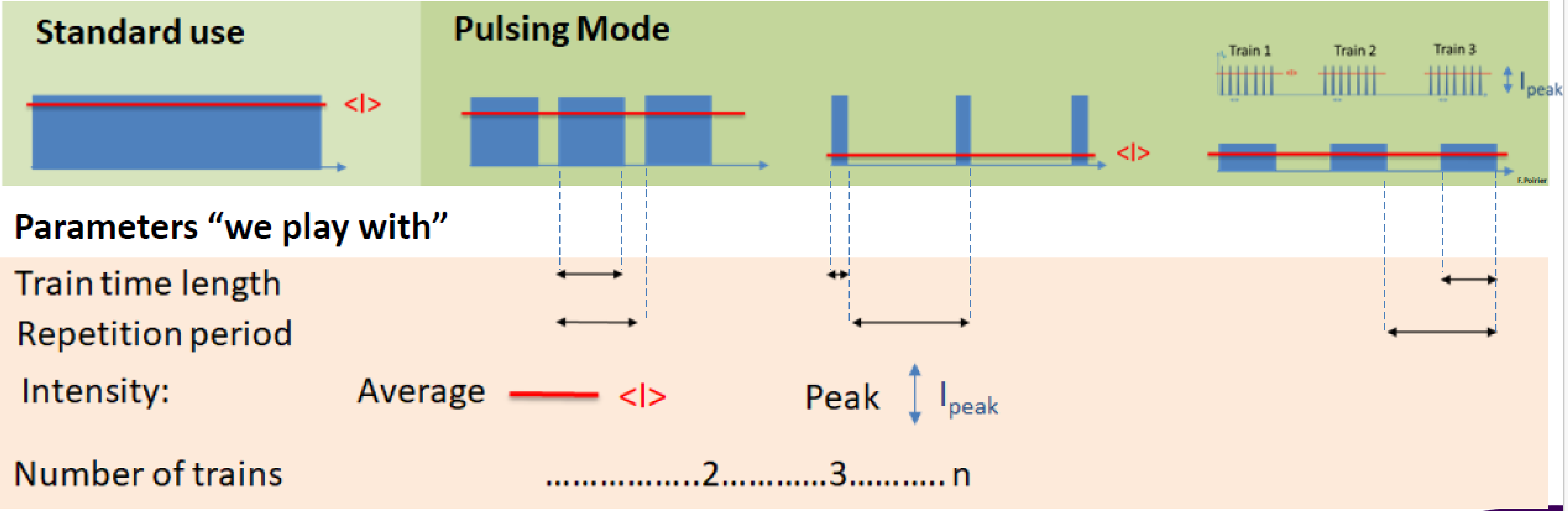
Beam	Accelerated particles	Energy range (MeV)	Range in Water (cm)	Intensity (µA)
Proton	H-	30-70	0,8-3,8	10^{-7} - 40
	HH+	17	0,3	10^{-7} - 10
Deuteron	D-	15-35	0,1-0,6	
Alpha	He++	68	0,3	10^{-7} - 2


La Machine
2 sources au dessus du cyclotron
He2+, HH+
H-, D-
buncher
cyclotron
inflector
Region centrale
2 types d'extraction
2 strippers: feuille de carbone, Total Transmission =~44%
H+
He2+
H+
1 deflecteur: 66kV, Total transmission =~10%
Lignes faisceaux
Cible dans navette
cyclotron
Faraday cups
Exit window
switching magnet
steerer
Quadrupoles
Collimator
~10m
~15m
Cyclotron isochrone a 4 secteurs, ~4m de diamètre externe,
• RF: 30.45 MHz, Harmonique=2 pour proton, H=4 pour autres particules
• Tension d'accélération : 65 kV
• Champ magn. Max (colline) : 1.6T
– Bobine de compensation du champs principal
– Bobine de déplacement de spiral (harmonique)
• Emittance normalisée avant extraction: $\gamma\varepsilon_x$=~4π mm mrad (simulation)
3
ARRONAX
afaq ISO 9001 Qualité AFNOR CERTIFICATION

Pulsing: What does it do?

- A system designed to give a fast kick in the injection with a high voltage applicable to various particles.
- Integrated into the new cyclotron control network based on EPICS
- It allows, by modifiying the time structure, to lower the average intensity on target <I> (C/sec) but still keep a high peak intensity (C) if needed.

Viewpoint of the present intensity diagnostics at Arronax <I>:



DIAMMONI

DIAMond instrumentation for pulsed beam **MONI**toring

Diamond properties useful for particle detection:

- Radiation hardness
- Very fast response (ns)
- High mobilities of charge carriers
- Carbon atom (z=6, very close to water and human tissue)
- Wide gap semi-conductor (dark current low even at higher voltages and temperatures)

Beam monitoring:

- Time structure of the beam: DT, DIT
- Number of particles per bunch
- Shape of the beam
- Beam intensity

5. DIAMMONI

Property	**4H–SiC**	**Si**	**Diamond**
Energy bandgap [eV]	3.27	1.12	5.45
Intrinsic carrier concentration [cm^{-3}]	5×10^{-9}	1×10^{10}	$\sim 10^{-27}$
Critical (breakdown) electric field strength [MV/cm]	2.2	0.25	1-10/5.6
Saturated electron drift velocity [10^{7} cm/s]	2.0	1	2.7
Electron mobility [cm^{2}/ Vs]	1000	1400	1900
Hole mobility [cm^{2}/Vs]	115	600	2000
Thermal conductivity (W/cm K)	3.7	1.49	6-20
Relative dielectric constant	9.76	11.9	5.7
e–h pair creation energy [eV]	7.78	3.6	13
Atomic number [Z_{eff}]	14–6	14	6
Density [g/cm^{-3}]	3.21	2.33	3.52
Threshold displacement energy [eV]	22–35	13–20	40–50

Energy bandgap → Low leakage current

Saturated electron drift velocity → Fast response and high CCE

Thermal conductivity → Negligible changes with increasing temperature in conductive behaviour

e–h pair creation energy → High sensitivity and signal to noise ratio

Threshold displacement energy → High radiation hardness

5. DIAMMONI-Chemical Vapor Deposition

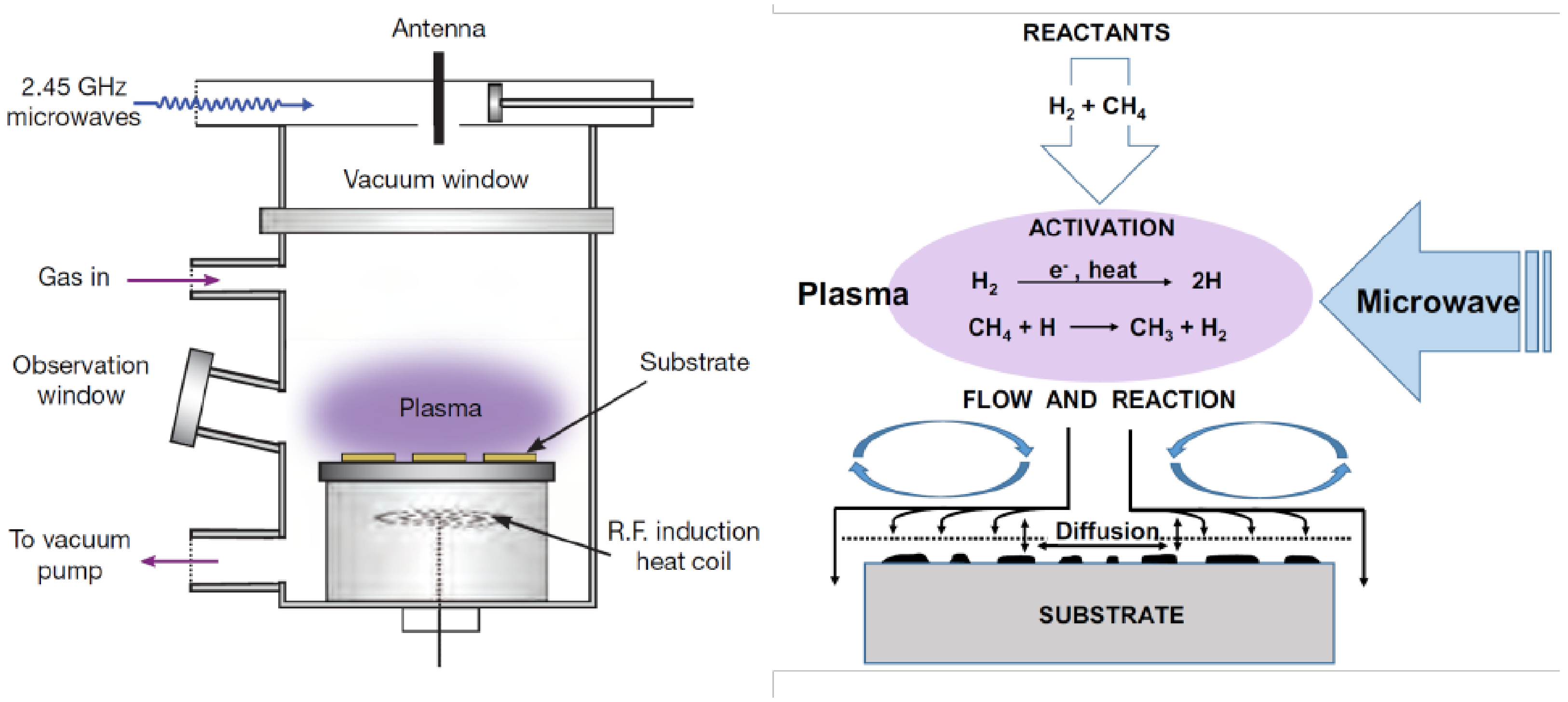


FIGURE 2.4 – Gauche : schéma de principe d'un réacteur pour le dépôt chimique en phase vapeur assisté par plasma micro-ondes de diamants synthétiques [Eaton-Magaña, 2012]. Droite : schéma de principe du procédé d'épitaxie de diamant par dépôt chimique en phase vapeur assisté par plasma micro-onde [Kasu, 2016].

- ✓ Gas mixture ($CH_4 + H_2$) is excited into a plasma state via microwave energy.
- ✓ H_2 dissociates into atomic hydrogen, which reacts with methane to form methyl radicals (CH_3).
- ✓ CH_3 radicals adsorb onto the substrate (seed), acting as the building blocks for diamond growth.
- ✓ Atomic hydrogen activates surface bonds and maintains sp^3 hybridization of carbon — essential for diamond structure.
- ✓ Hydrogen also etches away graphite and suppresses sp^2-hybridized CH_2 radicals, keeping growth purely diamond.
- ✓ Growth proceeds by successive adsorption of CH_3 radicals, each shedding H atoms to allow new radicals to bond and form C–C bonds.

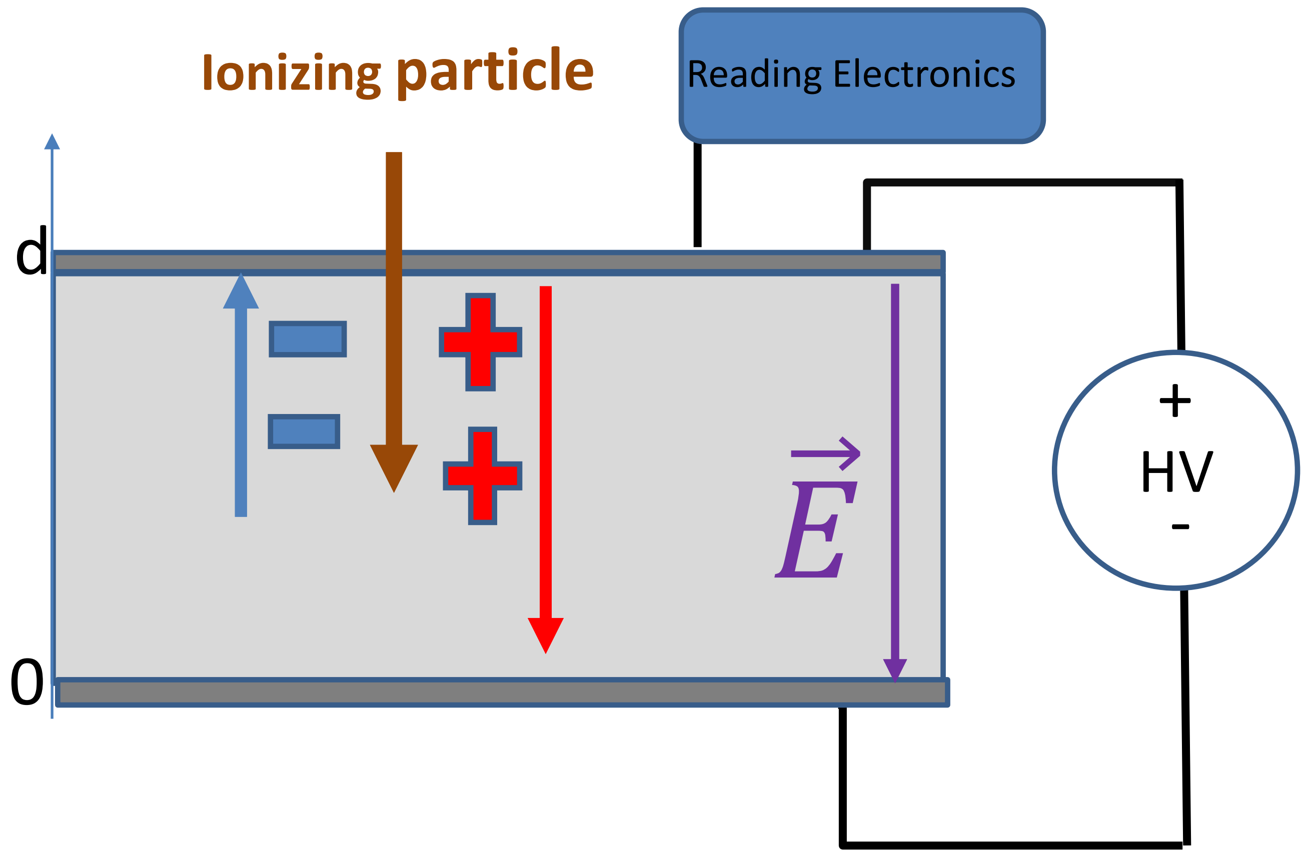
Principle:Diamond

Solid Ionization Chamber

Ionizing radiation absorbed in the material excites electron-hole pairs in direct proportion to the energy deposited.

$$Q_{created}(\text{c})=\frac{E_{deposited}}{\varepsilon_{pair}} \times q$$

Charge carriers then move in an external electric field and induce charge on the surface electrodes.



Electron: elementary particle with a negative charge
Hole: quasiparticle representing the absence of an electron with positive charge

$Q_{created}(\text{c})=\frac{E_{deposited}}{\varepsilon_{pair}} \times q$

The induced current can be described by Shockley-Ramo theorem

Théorème de Schokley-Ramo :

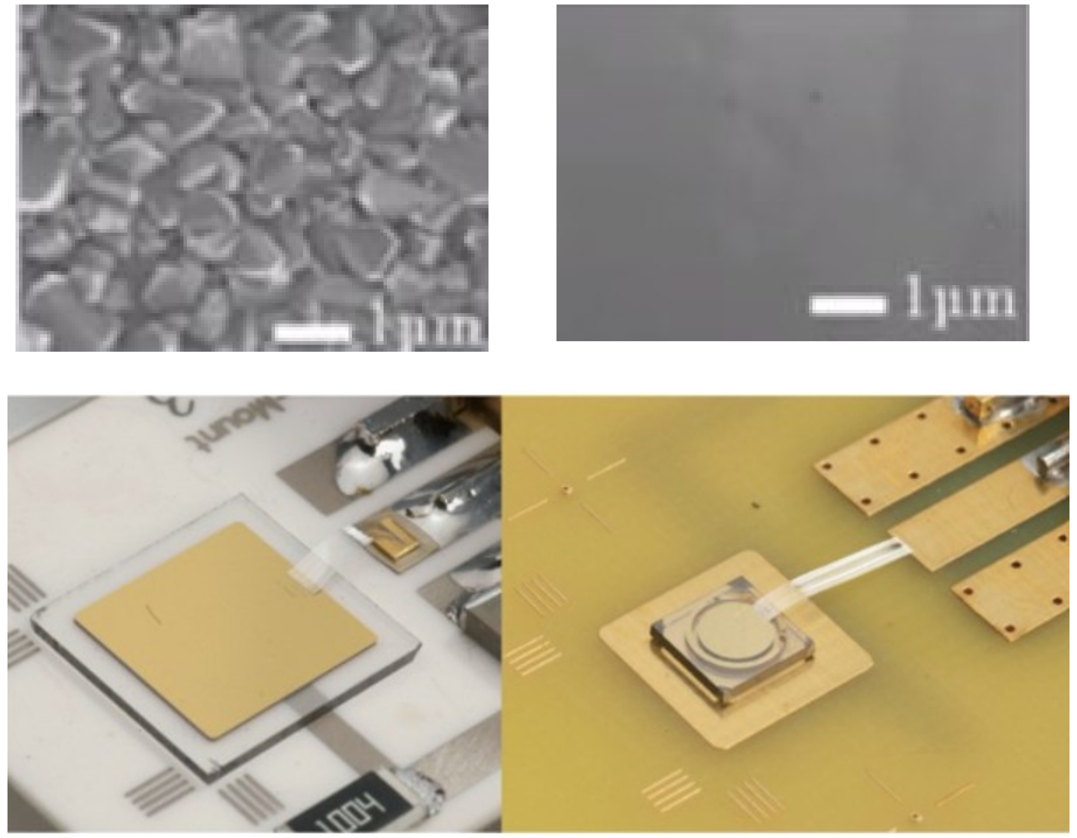
$$i_k = q\vec{v} \cdot \overrightarrow{E_w^k}$$

$$i_k = \sum_{holes} (+q)\overrightarrow{v_h} \cdot \overrightarrow{E_w^k} + \sum_{electrons} (-q)\overrightarrow{v_e} \cdot \overrightarrow{E_w^k}$$

Where v is the local drift velocity of electron or hole (cm/s), $\overrightarrow{E^k{}_w}$ weighting field (cm^{-2})

$$Q_{collected}(\text{c})= \int i_{induced}$$

$$\text{CCE}=\frac{Q_{collected}}{Q_{created}}$$



pCVD sCVD

pCVD = polycrystalline Chemical Vapor Deposition (10x10 mm² x 0.5 mm)

sCVD = single-crystal Chemical Vapor Deposition (5x5 mm² x 0.5 mm)

The inhomogeneity of the pCVD diamond material due to the presence of grain boundaries, leads to serious disadvantages limiting the implementation of such devices in a broader field of detector applications.

E. Berdermann, K. Blasche, P. Moritz, H. Stelzer, B. Voss, The use of CVD-diamond for heavy-ion detection, Diam. Relat. Mater., vol. 10, p. 1770, 2001

sCVD provides fast timing and counting of protons inside a bunch, while pCVD is not able to perform counting at low intensity.

Indeed, for higher beam intensity, sCVD diamond sensor thickness is certainly to be optimized to prevent long time drift which may result in a pile-up phenomenon at highest RF frequencies up to 160MHZ.

At high intensity, pCVD may present an advantage relative to sCVD.

Since charge trapping occurs while charge carriers are drifting to the electrodes, it results in a shorter signal as observed in Fig. 9 at ∼2 nA (∼400 protons/bunch at 30.45 MHz).Such a beam current is close to clinical conditions.

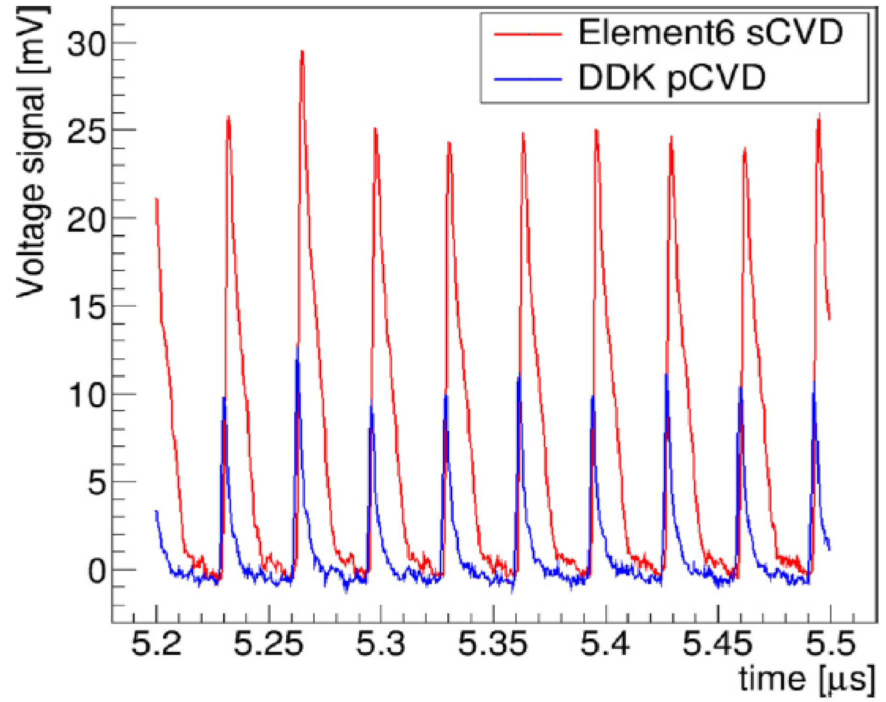
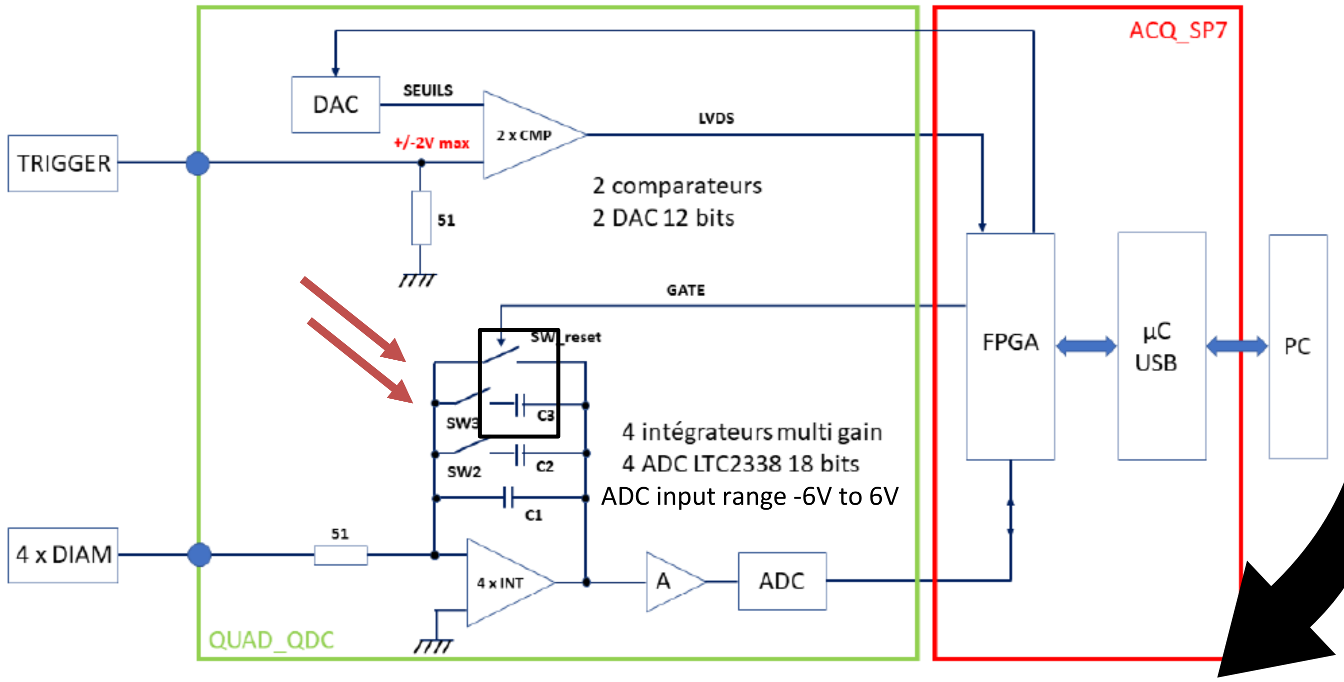


Fig. 9. Compared time-domain responses of the Element6 sCVD and the DDK pCVD detectors, irradiated with the ARRONAX proton beam at I_{beam} ∼ 2 nA (with an accelerator radio-frequency of 30.45 MHz). The induced currents produced by the detectors are converted into voltage signals through a 50 Ω resistor.

6.a. DIAMMONI - Electronic Board

The QUAD_QDC board:
-Operates in Pulsed/continuous mode.
-Four integrators associated with 18-bit ADCs.

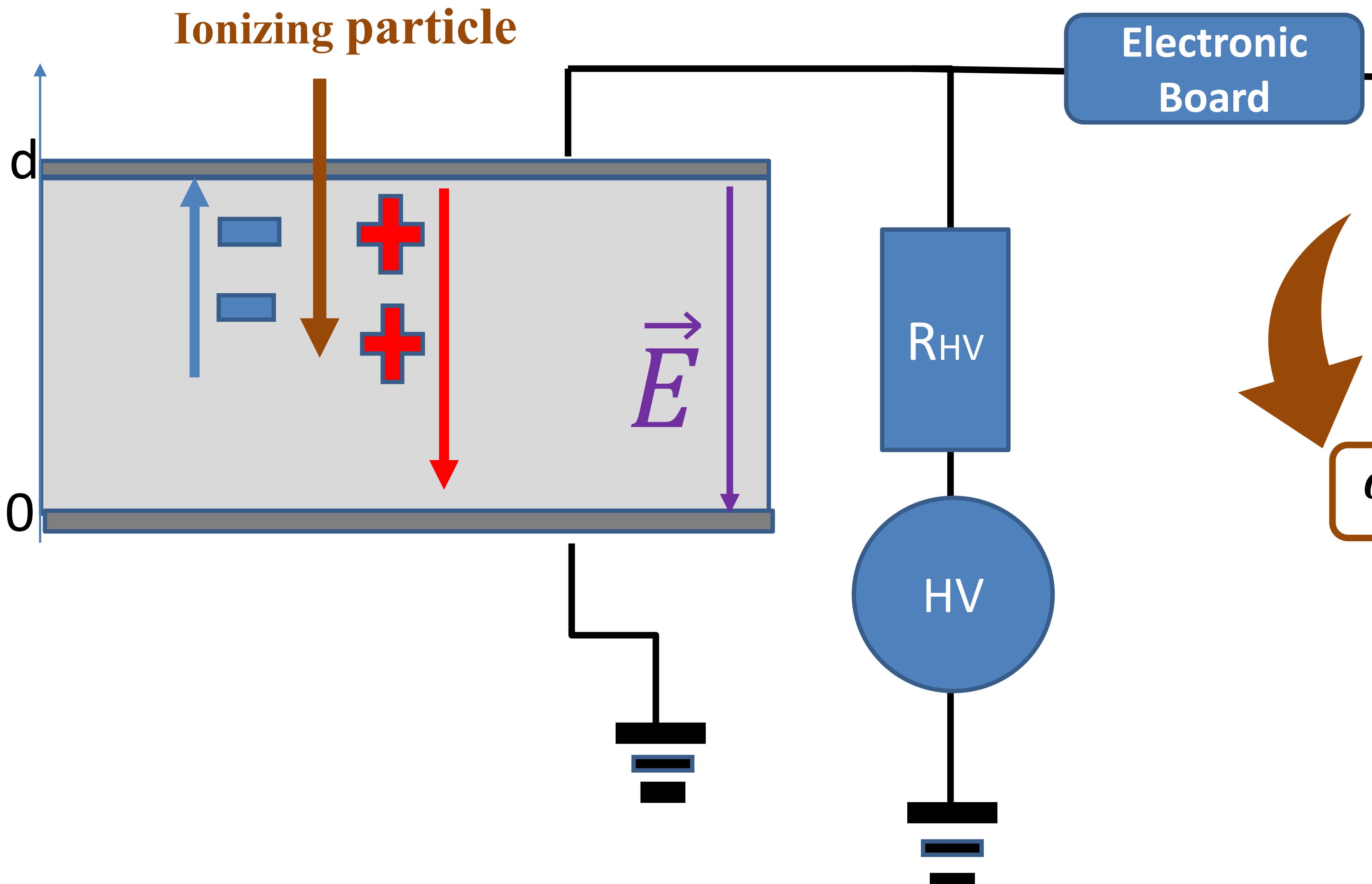


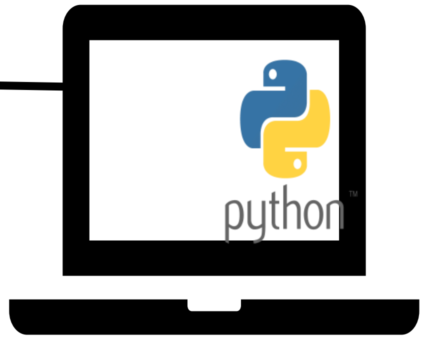
The ACQ_SP7 configures and controls QUAD_QDC (thresholds, integrator gain, GATE duration, etc.) and stores ADC data. It communicates with the PC via a USB link.

Three integration capacitors are available for each channel (C1, C2, C3).

Switches SW2 and SW3 allow C2 & C3 to be connected in parallel to C1 leading to four integration ranges (C1, C1+C2, C1+C3 and C1+C2+C3).

Range(+/-60nC,+/-2900nC,+/-5700nC,+/-8600nC)





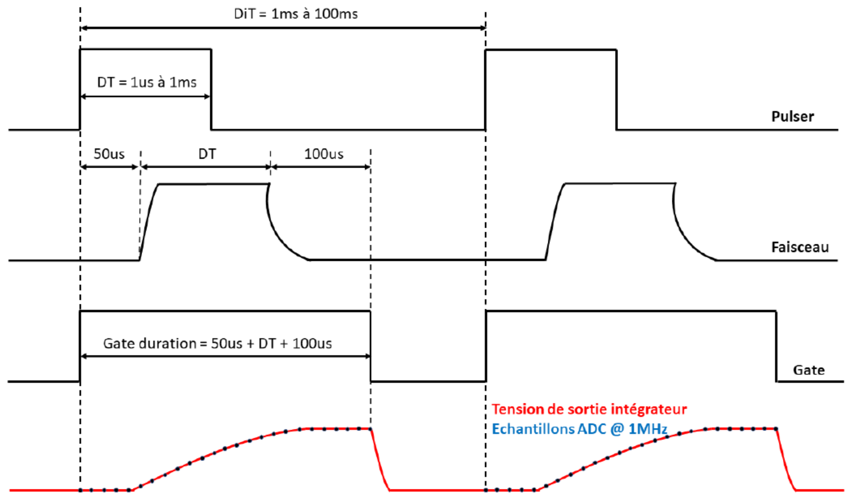
Python scripts developed by Laurent, LPSC,Grenoble

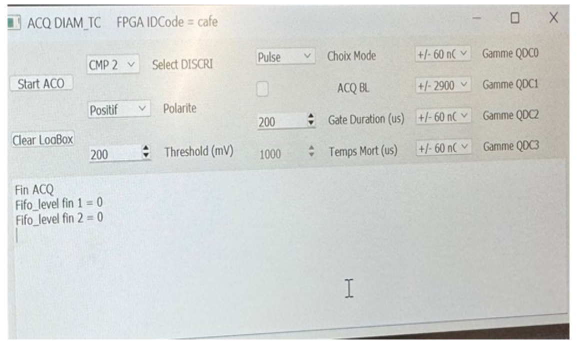
$$Q_{measured} = \int i_{induced}(t)\, dt$$

Train Duration

Inter-Train duration

Number of Trains

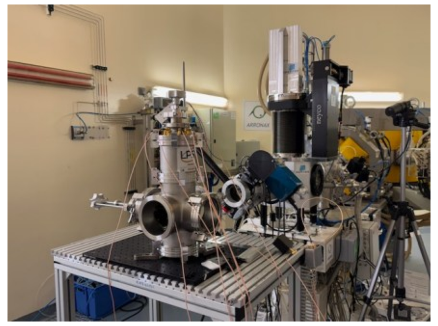




Pulser signal is used as a trigger.
-Then, FPGA opens the integration gate .
-The integration time is set by the user in the QT GUI.
-Integration time 50µs+DT+100µs.
-Encode integrator output voltage at 1MHz during all the integration duration.

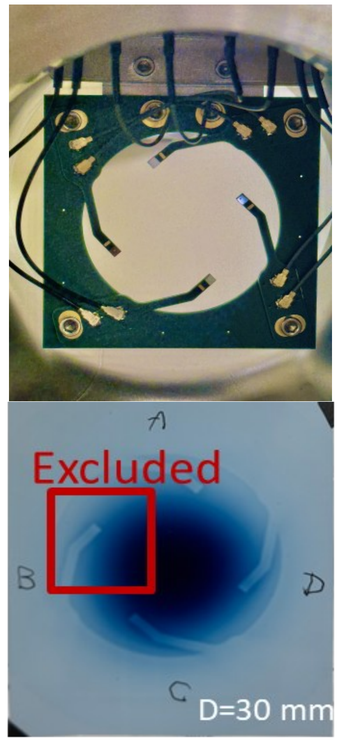
5. DIAMMONI-Macro & Micro time structure - By Oscilloscope

Zone room



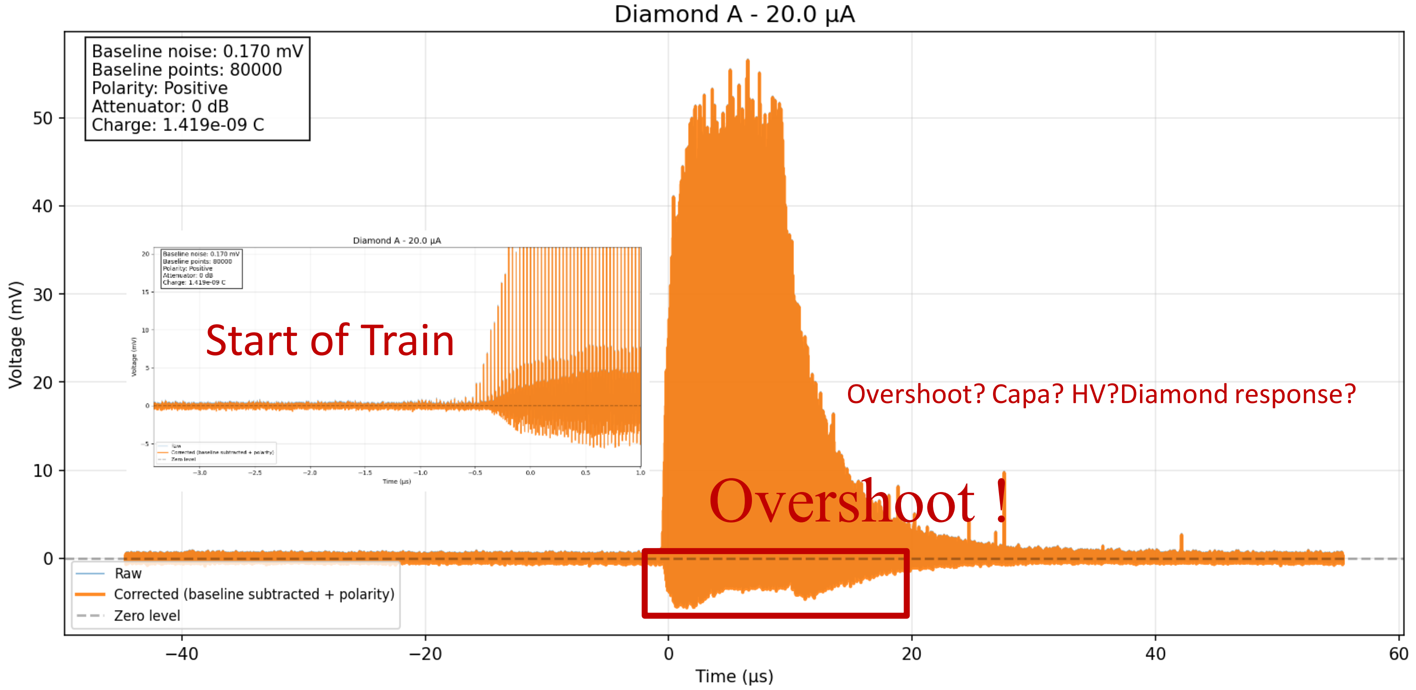
Acquisition room

- file.csv
- Python
  - Macrostructure
    - $Q_{measured}/train$
    - Train Duration
  - Microstructure
    - Bunch Evolution vs Intensity



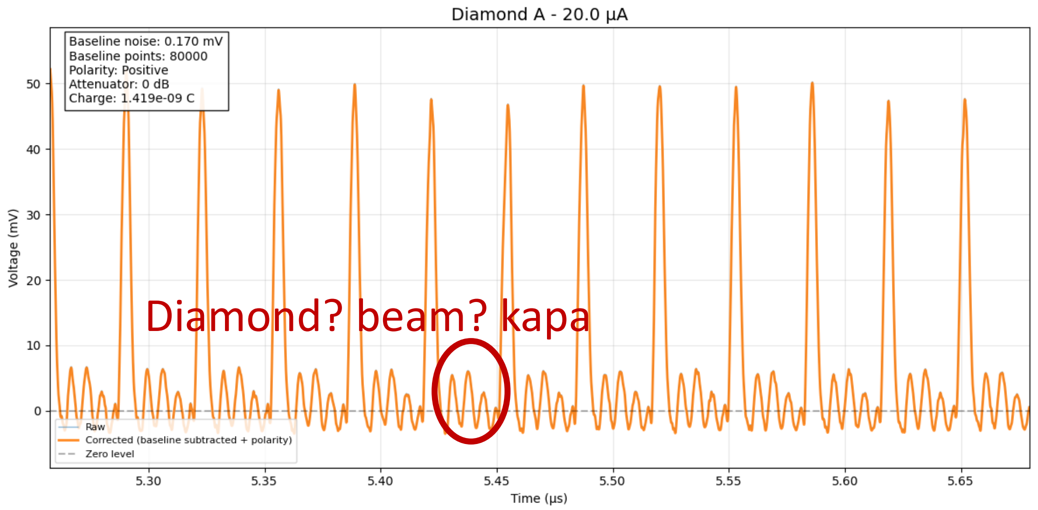
68 H^+, DT=10µs, DiT=10 000µs, 100 pulses, with a wide range of intensities, from 100nA➔40µA

Macro-time structure

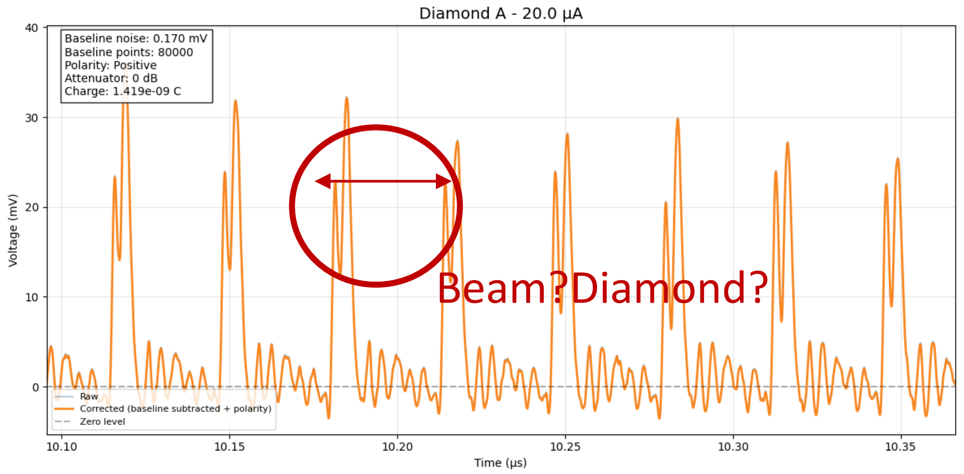


Micro- time structure

Inside Plateau

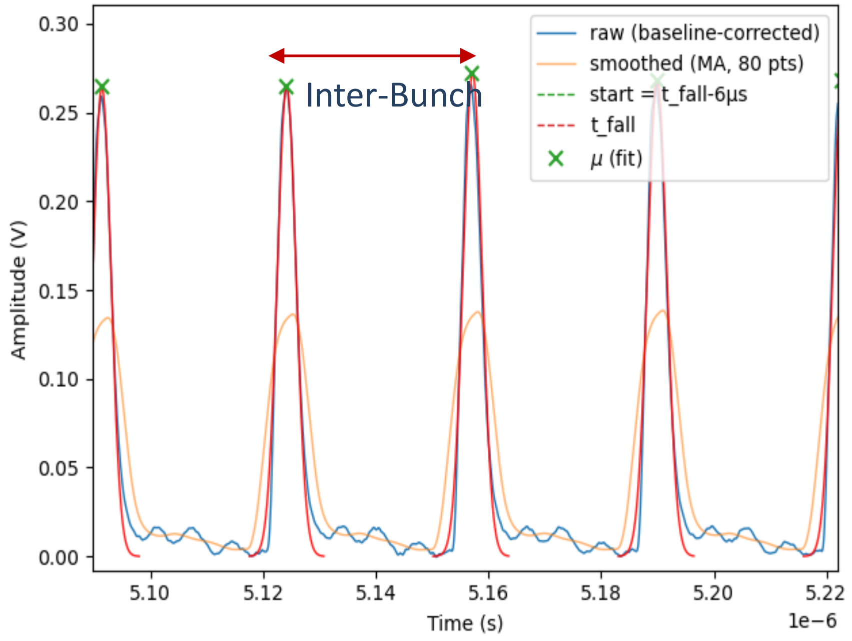


After Plateau



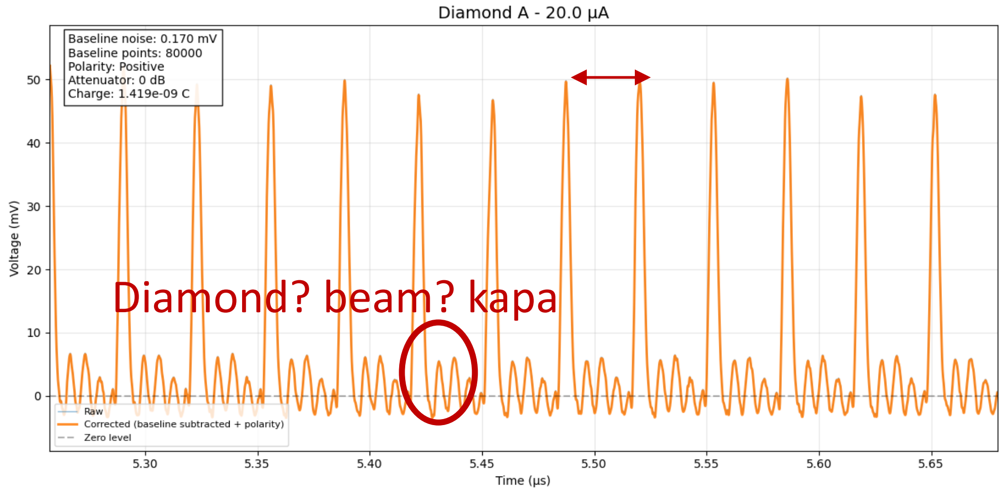
5. DIAMMONI-Macro & Micro time structure - By Oscilloscope

Gaussian fit for every bunch inside the plateau region

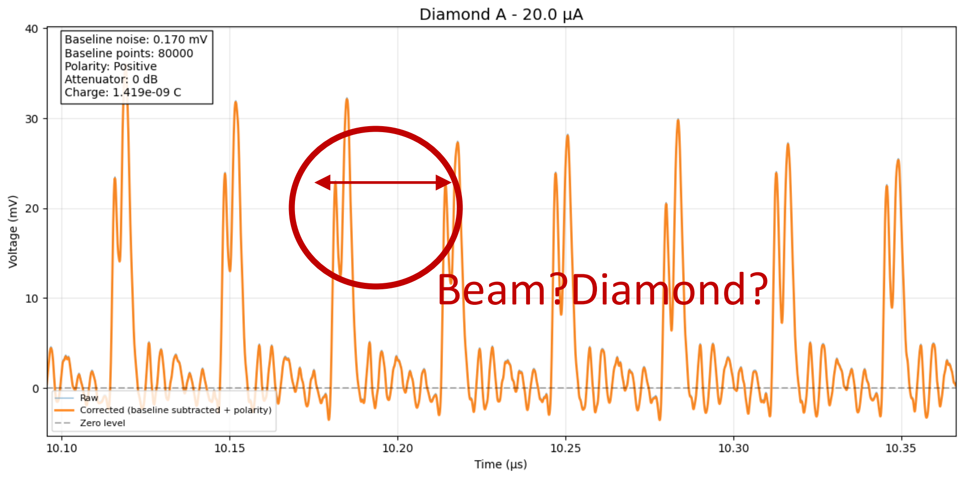


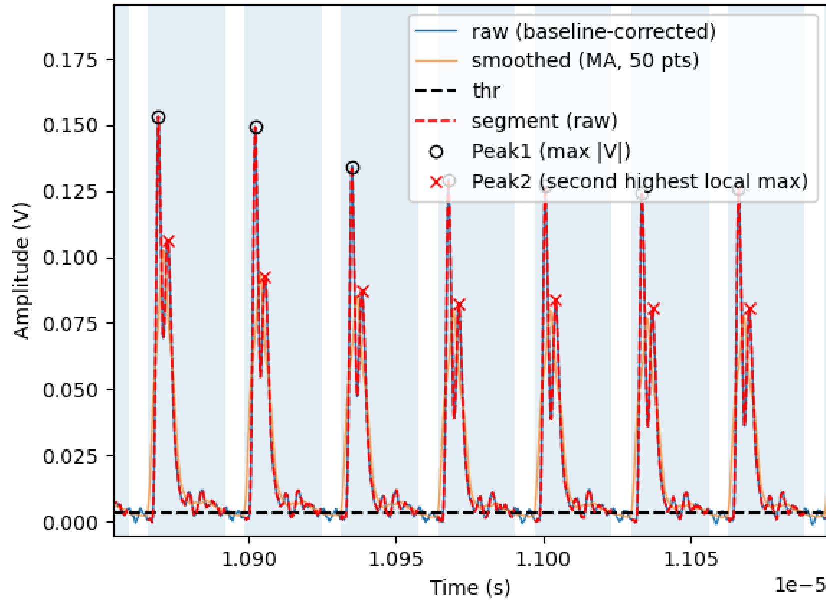
Micro- time structure

Inside Plateau

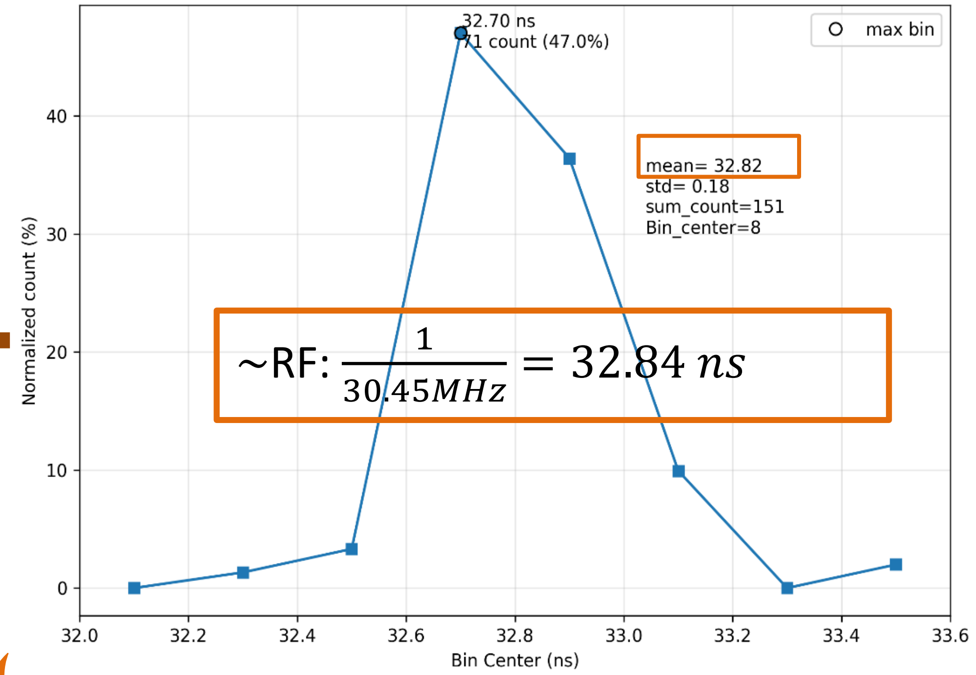


After Plateau

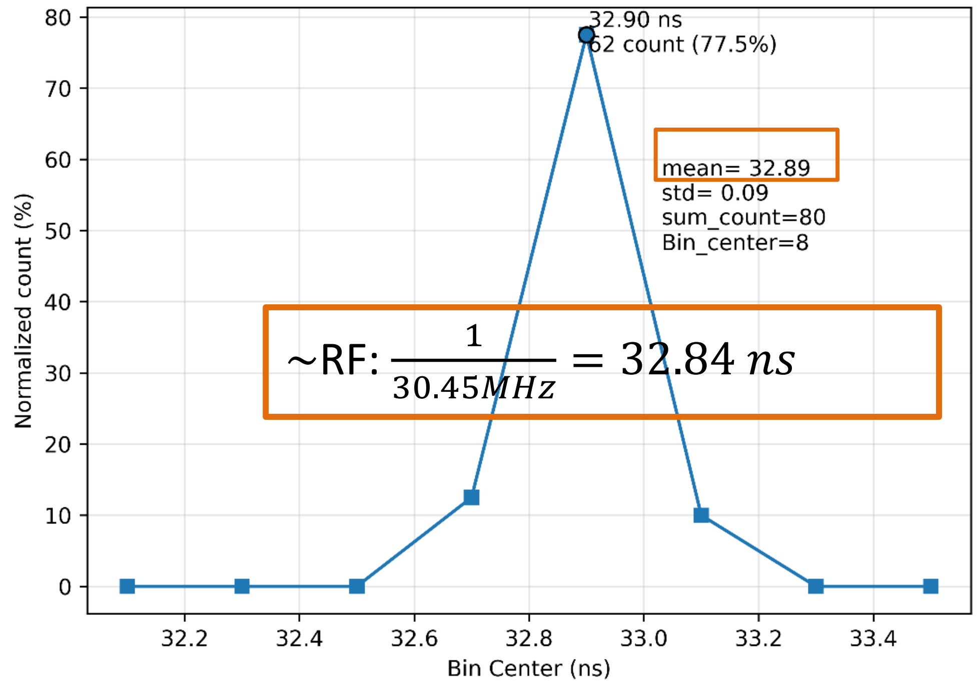




Diamond A, 20μA
Inter-bunch distribution

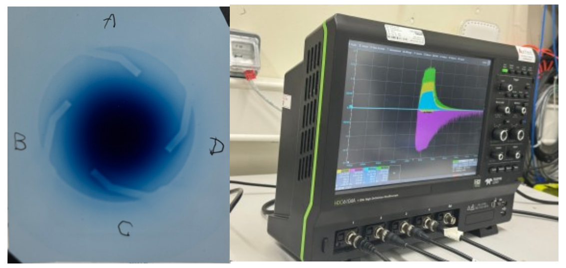


Diamond A, 20μA
Double peak distribution



- ✓ **Diamond resolved the nano bunch at ~32.82 ns ($RF_{cyclotron}$ =30.45MHz).**
- ✓ **The second peak originates from the beam rather than from the diamond detector itself.**
- ✓ **Further experiment was needed to prove our hypothesis.**

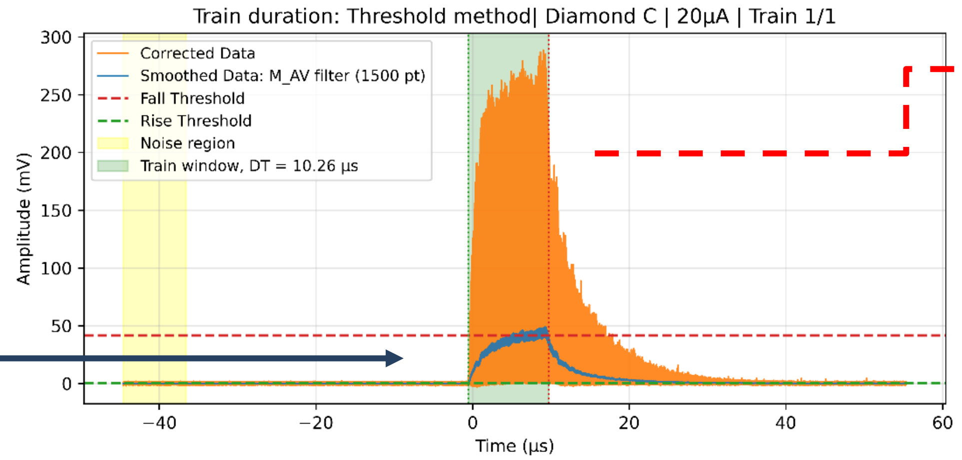
5. DIAMMONI-Train Duration: Threshold method

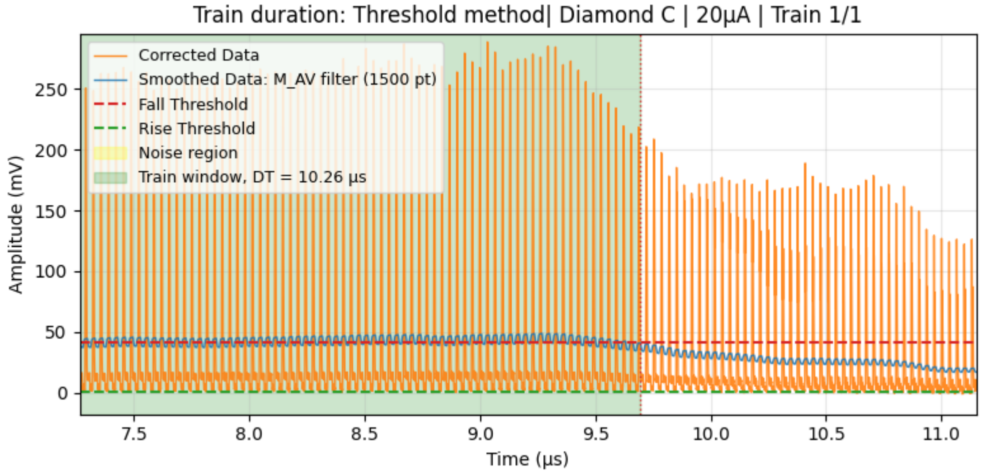


1-Apply a moving average filter of a 150 ns window(1500 points).

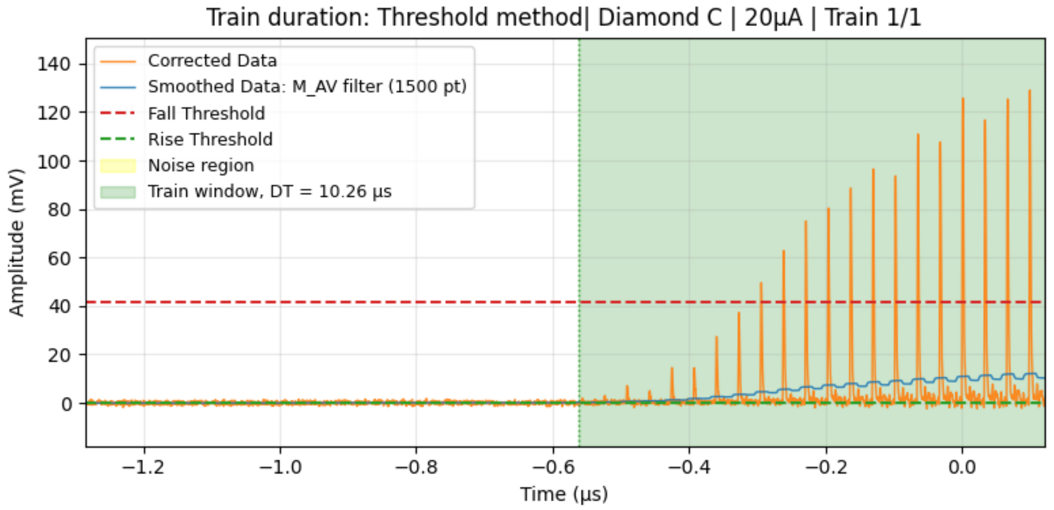
2-Find the global maximum peak inside the smoothed data(v_peak_glob_sm)

Macro-time structure





5-thr_fall = TFALL_REL_SM * v_peak_glob_sm
Where TFALL_REL_SM=0.85
6-t_fall: first peak of a run of 20 consecutive peaks BELOW thr_fall



3-thr_rise = K_RISE_SIGMA * sigma0
where K_RISE_SIGMA=5 & σ_0:1.4826*mad=1.4826*median(abs(x-median))of the first 80,000 points on the smoothed data.
4-t_rise: first peak of a run of 20 consecutive peaks ABOVE thr_rise.

DT=t_fall - t_rise

	DT_Experimental (µs)		
	Diamond C	**Diamond D**	**Diamond A**
µA			
40	10.13	10.77	10.12
30	10.09	10.78	10.13
20	10.26	10.72	10.16
10	10.11	10.36	10.03
5	10.16	10.13	10.06
1	10.06	9.89	9.53
Mean	10.1	10.4	10.0
std	**0.06**	**0.34**	**0.22**

- ✓ The preliminary results with this method are promising.
- ✓ To be tested with different trains DT.

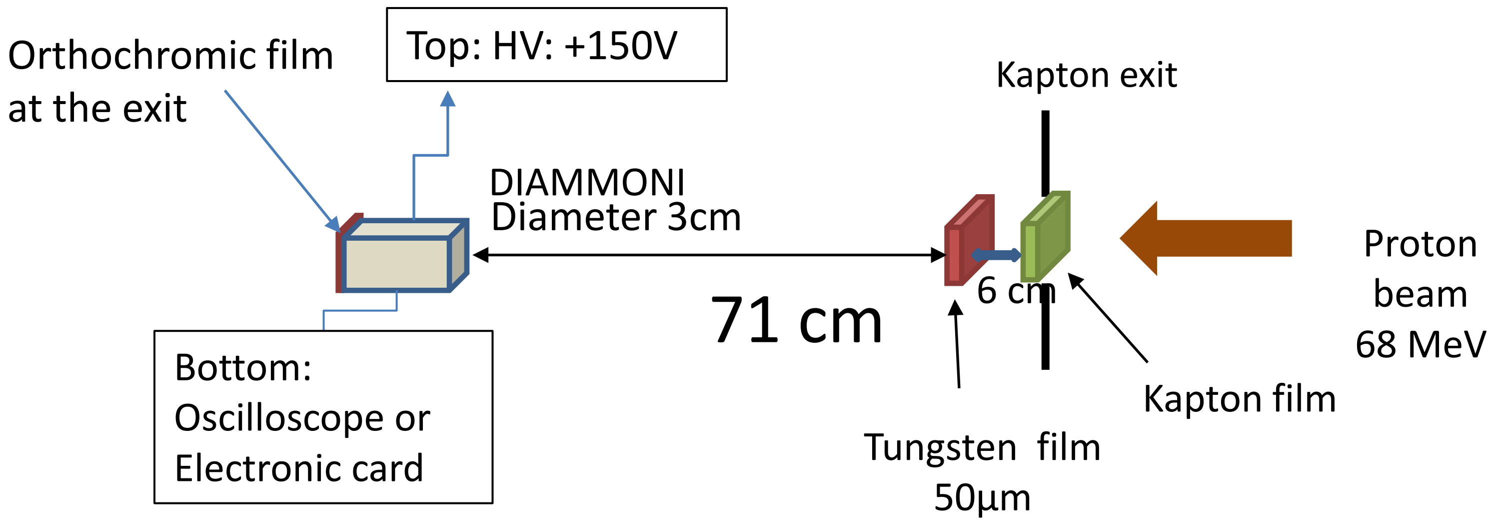
Experimental DT for Diamond C = 10 +/- 0.06 µs

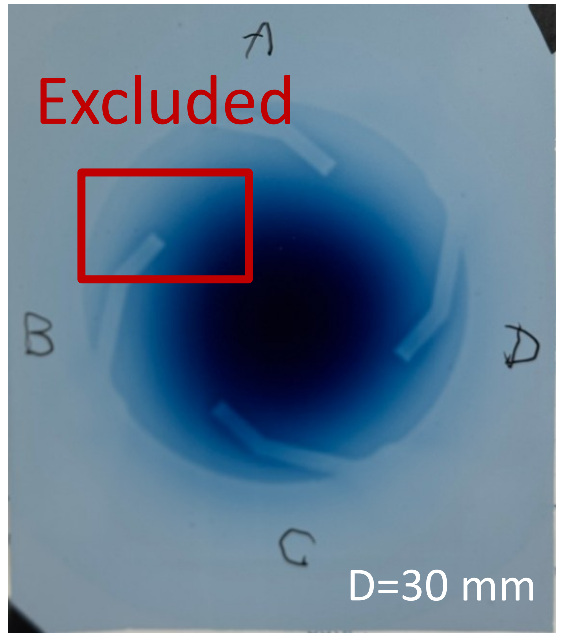
Theoretical DT=10µs

5. DIAMMONI

The same set-up was repeated to all the previous the questions:

Manip 08/08/2025-DIAMMONI-three diamonds+oscilloscope and electonic board

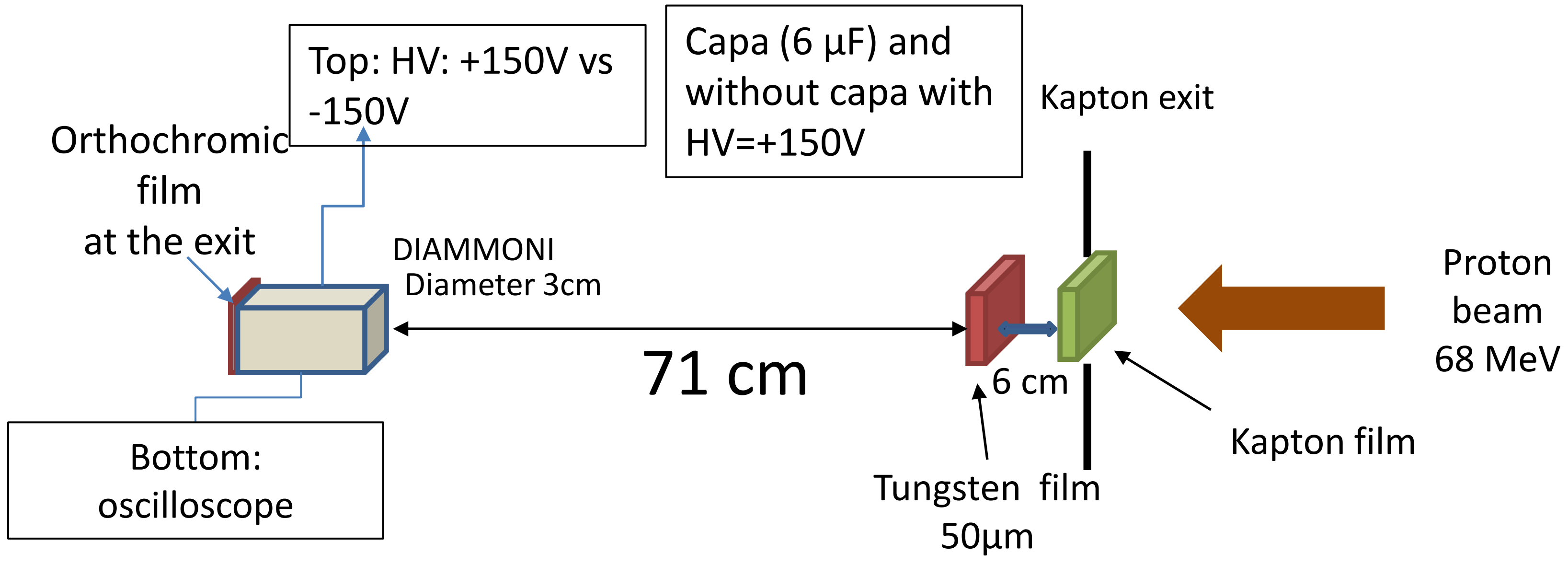


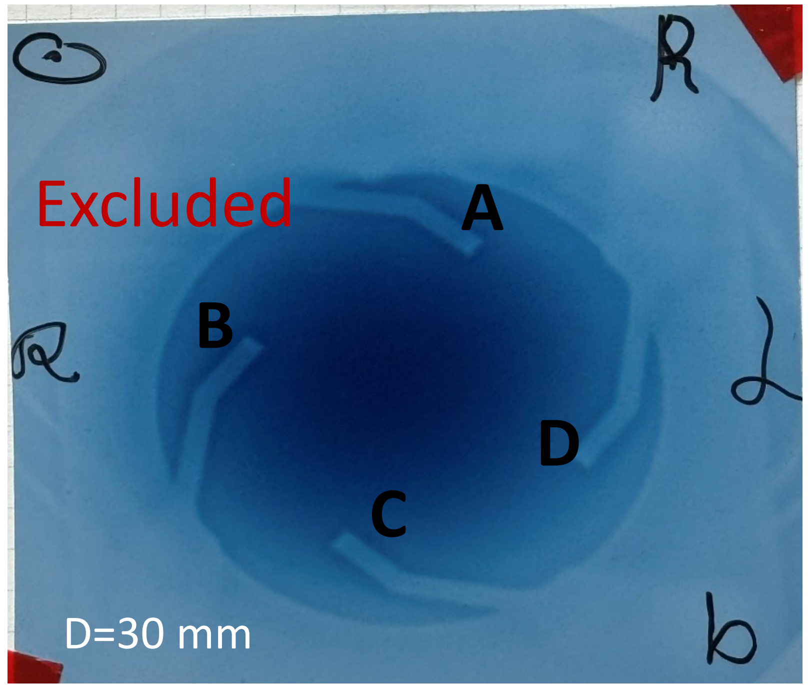


I=41µA

I=[100nA,500nA,1µA,5µA,10µA,20µA,30µA,40µA]
DT=10 µs

Manip 12/02/2026-DIAMMONI-three diamonds+oscilloscope

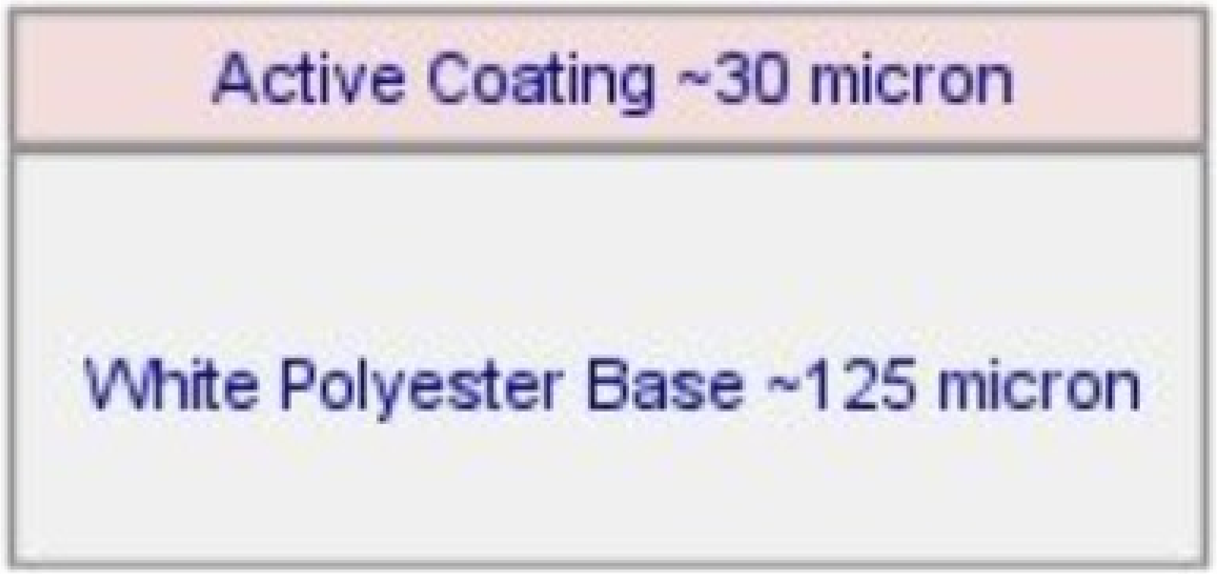




I=[1µA,2µA,5µA,10µA,17µA]
DT=10 µs

A: ch2
C:ch3
D:Ch4

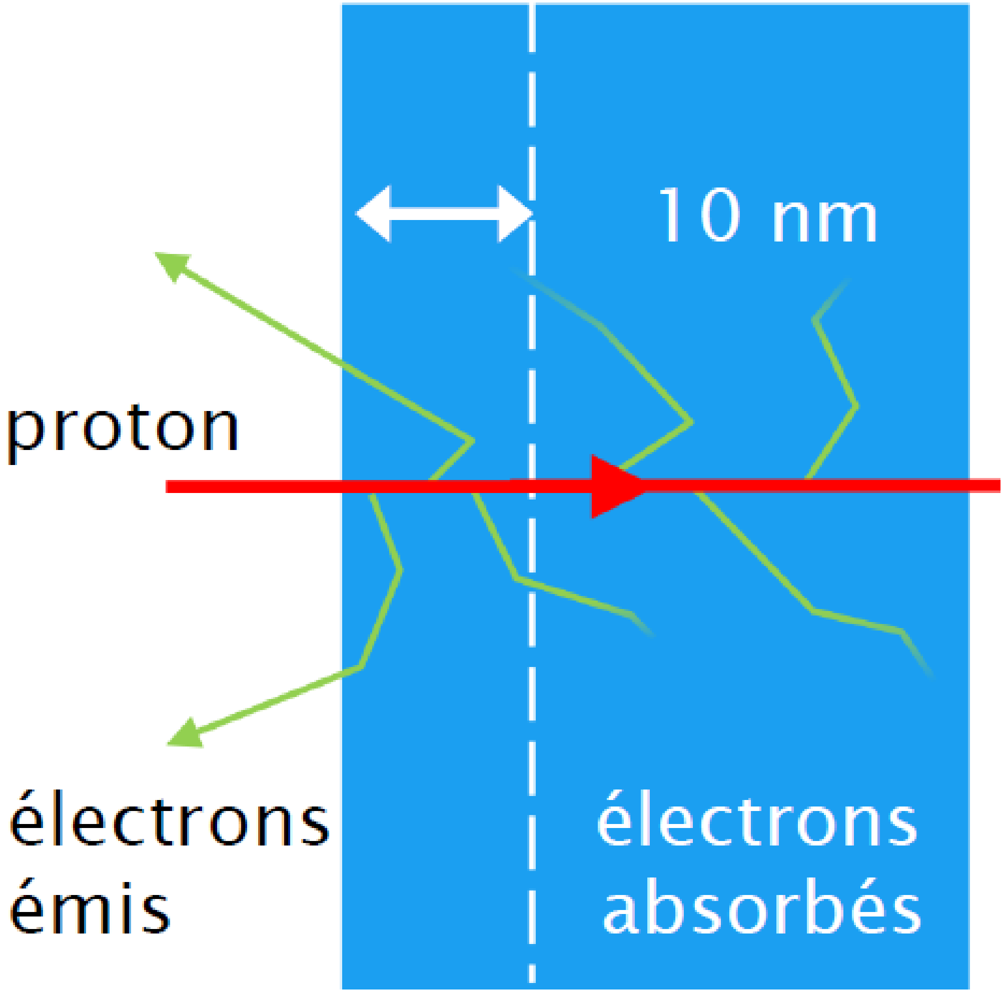
Orthochromic film is a dosimetric film that darkens proportionally to the radiation dose it receives, allowing precise 2D dose mapping without any chemical development.

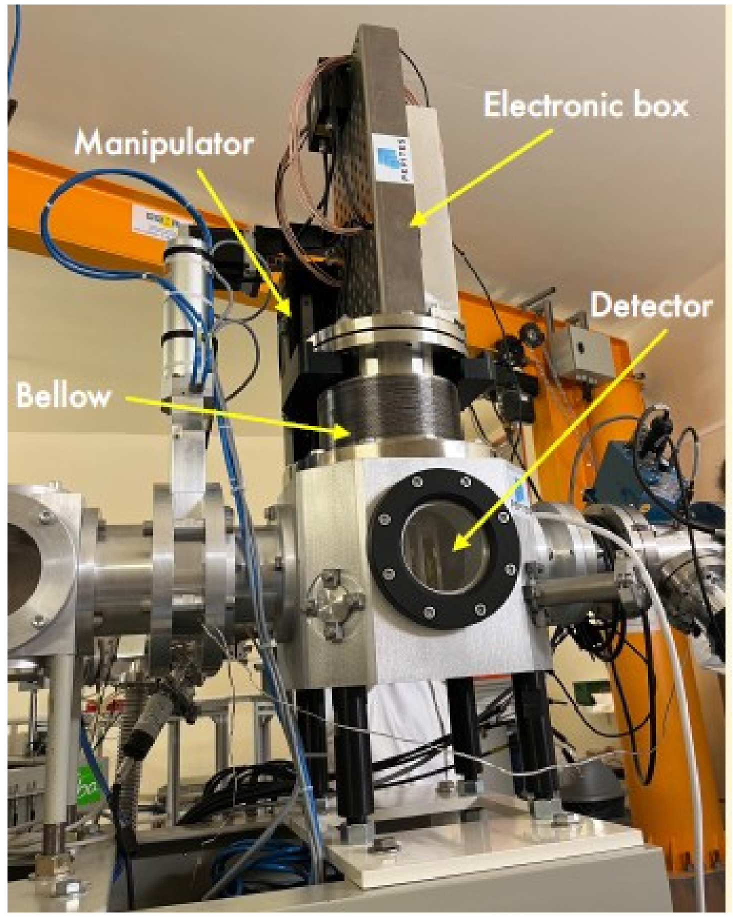


PEPITES

Profileur à **E**lectrons **secondaires P**our **Ions T**hérapeutiqu**ES**

Signal:
Secondary Electron Emission (SEE)





Minimal beam perturbation:
Material budget 10 µm WET

Continuos monitoring :
Radioresistance (up to 10^8 Gy/year)

Linearity of SEE signal ➠ Large dynamic range

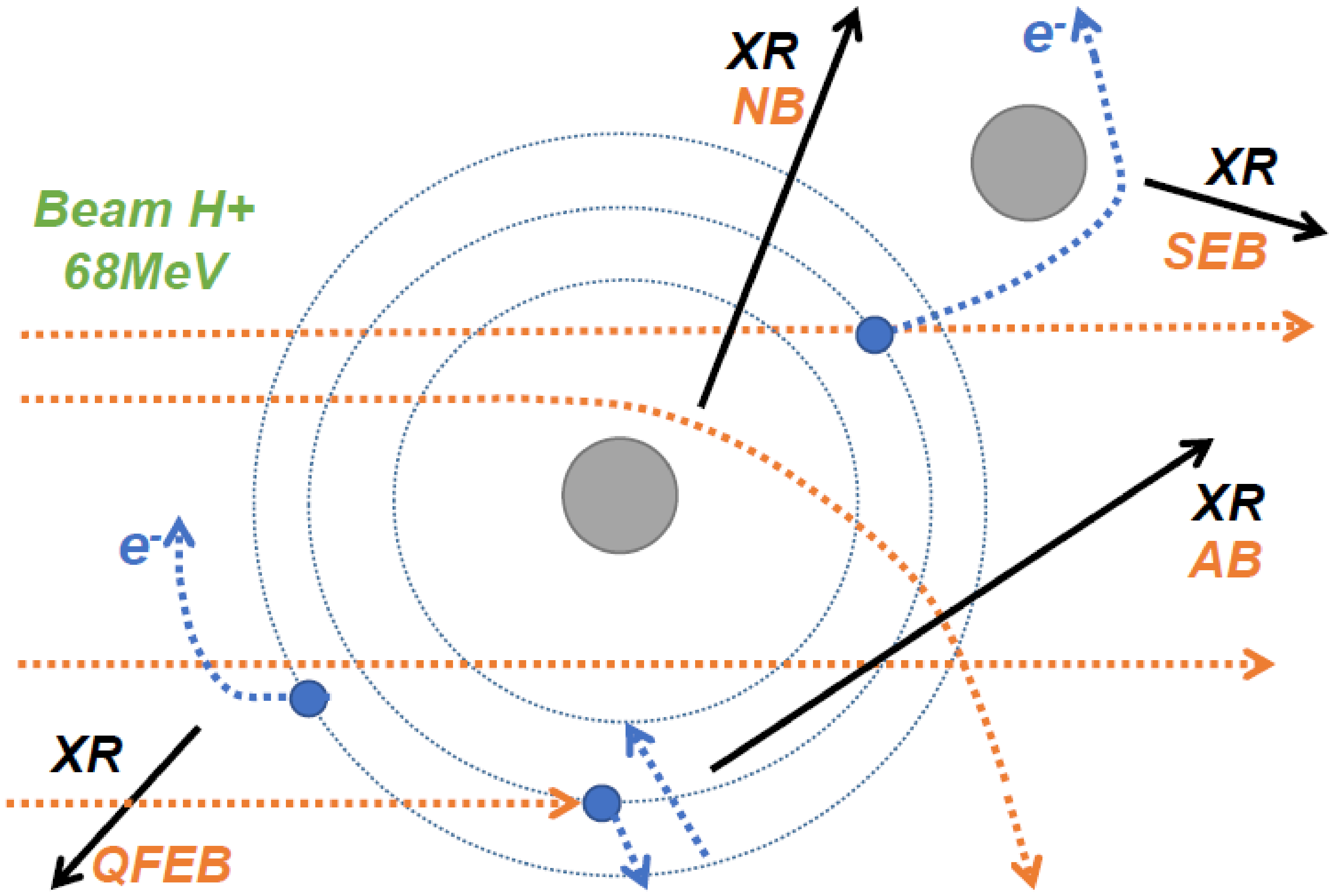
PTCOG 63 BUENOS AIRES 2025

PEPITES

RESULTS AND DEVELOPMENTS OF A TRANSPARENT BEAM PROFILER FOR CONVENTIONNAL AND FLASH HADRONTHERAPY

C. Thiebaux[1], L. Bernardi[1], M. Donetti[2], R. Duhamel[1], A. Esper[1], F. Gastaldi[1], R. Guillaumat[1], O. Gevin[3], C. Koumeir[4], M. Pullia[2], M. Verderi[1], C. Viviani[2].
[1]Laboratoire Leprince-Ringuet, CNRS-Ecole polytechnique, Institut Polytechnique de Paris, Palaiseau, France.[2]CNAO Foundation, Pavia, Italy. [3]IRFU, CEA Université Paris-Saclay, Saclay, France. [4]GIP Arronax, Saint-Herblain, France.

Arronax Nantes


XR
NB
e-
XR
SEB
Beam H+
68MeV
e-
XR
AB
XR
QFEB

6. PAF-24 PMTs Protoype

PAF Prototype: 24 PMTs

By: Noel Servagent

- ✓ Assembly was done.
- ✓ Noel’s new baby was tested last week; interesting work is on the road!

To do Next:

- ➢ Create a simulation model (Python) to be verified by experimental data.
- ➢ Compute sensitivity as a function of the solid angle