NPM for ESS

(Non invasive Profile Monitors)

Café du Dédip → 21 novembre 2023

jacques marroncle

ESS in few words

Neutrography: neutrons are product by spallation reactions of a 2 GeV proton beam impinging on a tungsten target. Then, only very few neutrons are slowed down and guided to neutron lines for proceeding to experiments for based research.

Proton beam:

- E = 2 GeV
- I = 62.5 mA
- Pulse = 2.86 ms
- Frequency: 14 Hz
- Duty cycle: 4 %
- Peek power: 125 MW
- Mean Power: 5 MW
- Pulse energy : 357 kJ

Tungsten target:

- Rotating tungsten 23.3 r/mn + rastering
- Cooled with He (10 bar)
- Moderator: H_2O at 20°C or LH_2 (20 K)

Experimental neutron lines:

- 44 neutron lines

Project: 13 founding countries, more than 40 European partner institutions, more than 130 collaborating institutions worldwide

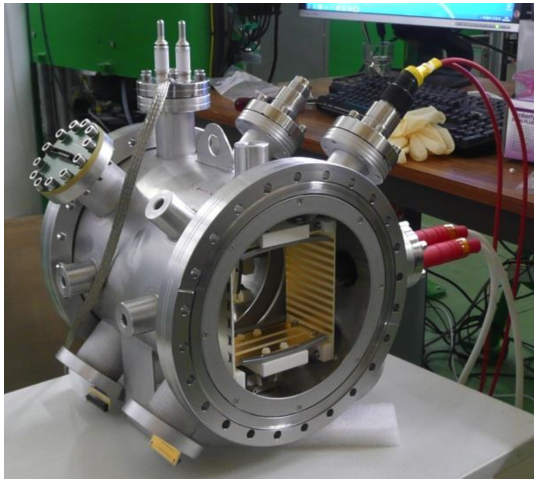
End 2025: 1^{st} beam on target – 2026: start of User progs

A bit about my IPM history

LIPAc (Linear IFMIF Prototype Accelerator – Rokkasho, Japan)

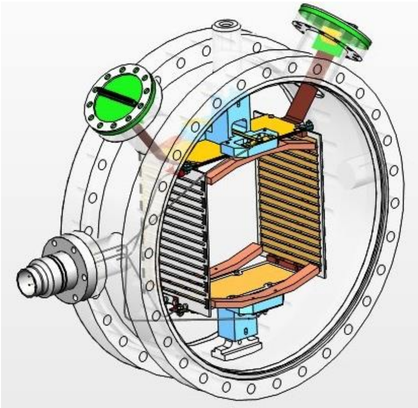
- Jan. 2008: I left SPhN to join SIIEV (Service d'Ingénierie IFMIF-EVEDA) → diagnostics (total neophyte)
- Design & manufacturing of 3 IPMs for LIPAc (Linear IFMIF Prototype accelerator) in collaboration with Sédi (Philippe Abbon, Fabien, Thomas Papaevangelou, Julien Pancin, JP Mols)
- Tests at IPHI, then validation before shipping to Japan on 2014
- Nov. 2011: I become Sédi member (dismantling of SIIEV)

→ Up to now, we never see any IPM signal at LIPAc since experimental conditions were never achieved (low current and very low duty cycle)



ESS (European Spallation Source – Lund, Sweden)

- March 2015: invitation at ESS for giving a seminar about LIPAc diagnostics
  - → Start for collaboration contract for providing IPMs
  - → Starting a discussion with Tom Shea (diag. manager, ex SNS Los Alamos) about BLM based on Micromegas → nBLM
- May 26, 2016: Kick-off meeting at CEA Saclay
  - → Postdoc: Francesca Belloni & PhD student: Florian Bénédetti (Nov. 2016)

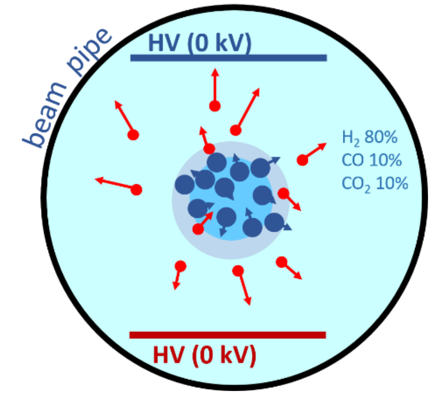


IPM (Ionization Profile Monitor)

IPM

- Non-invasive transverse profile monitor
- Principle: based on the residual gas ionization produced by the beam particle when passing through it
  By-products e^-/ion$^+$ drift under $\vec{E}$ influence to the electrodes
  → collection ion signals (pixel, strip…)
- is a parallel plates detector → relevant = good $\vec{E}$ uniformity
- Degraders → to reinforce the $\vec{E}$ uniformity (avoid mirage effect…)

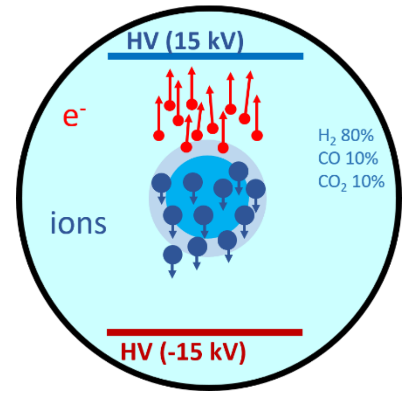
Electric field **OFF**



Pros

- Ionization = quite high cross-sections (σ) wrt fluorescence
- Good by-products collection thanks to $\vec{E}$
- Ability to work at high beam energy

Electric field **ON**



Cons

- High sensitivity to the space charge effect → profile modification
- Deviation of the beam due to $\vec{E}$ → safety
- Complicated mechanics: detector inside beam pipe or vacuum chamber
- Very expensive

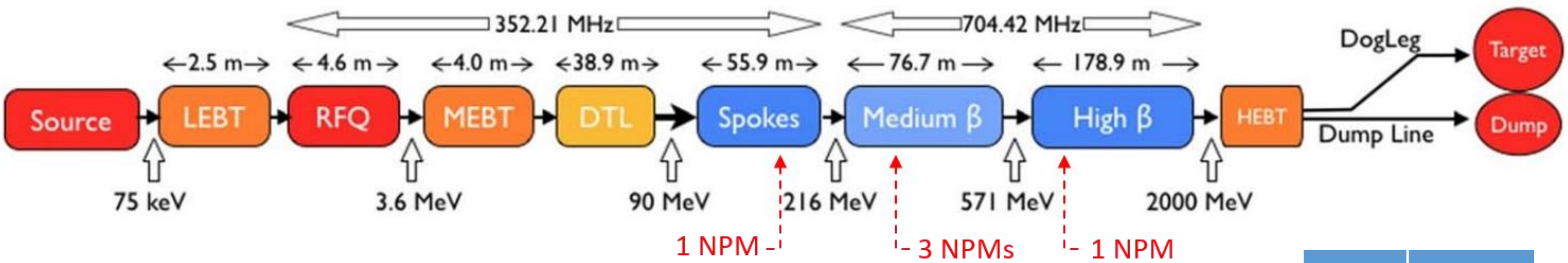
Why ESS choose IPMs? They have no choice!

- Signal $\alpha\ N_{beam} \times N_{target} \times \sigma$
  with $N_{beam}\ \alpha\ I_{beam} = 62.5$ mA and $N_{target}\ \alpha\ P_{residual\ gas} < 10^{-9}$ mbar
  ➔ IPMs are located above 90 MeV (cryogenic beam line) and fluorescence profilers below (room temperature)

NPM (Non-invasive Profile Monitor)

Two NPM types at ESS

- 1 NPM = 1 IPM_X + 1 IPM_Y
- at ESS, there are two NPM-types
  - IPM → residual gas **ionization**
  - FPM → residual gas **fluorescence**



NPM	E (MeV)
Spoke	97.2
MβL-1	231.4
MβL-2	278.9
MβL-3	315.8
HβL-1	628.3

NPM (ionization) for ESS

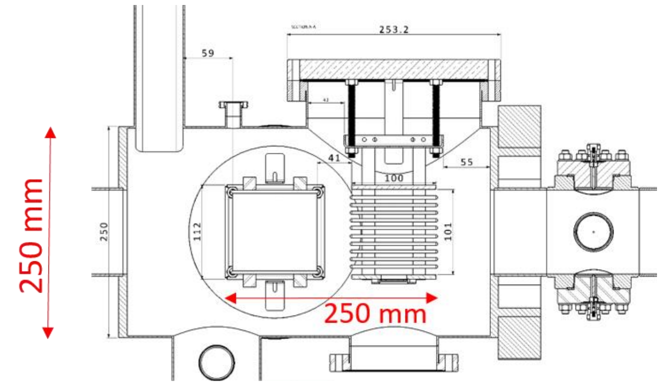
- To be provided: 5 NPMs
- Schedule 1.6 (AIK 7.3)
  - Kick-off meeting: May 26th 2016
  - PDR meeting: January 31th 2017
  - CDR meeting: February 11th 2019

NPM challenges

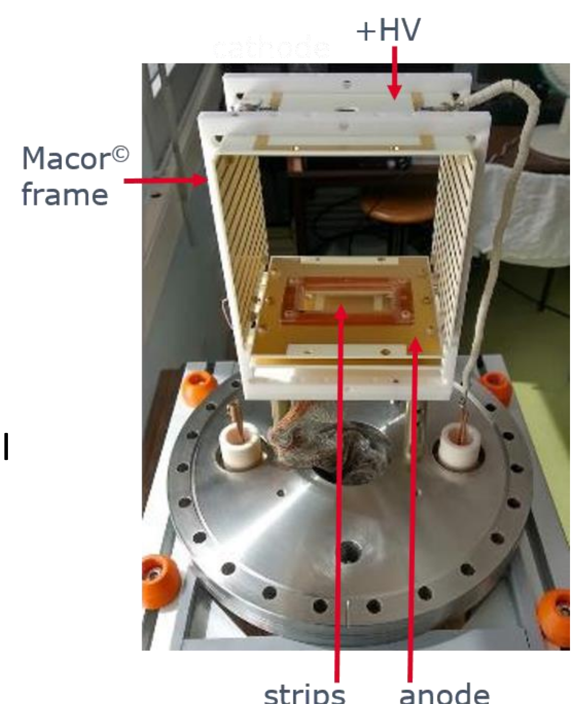
Go-NoGo gate:

due to the feasibility of such monitors in ESS environment, mainly for these raisons:

- Is there enough room inside LWU to insert both IPMs and for insuring a good electric field uniformity? Influence of the electric field of each cage set at 90° to the other one?
  ➔ Florian
- Space Charge effect: ESS requirements is 10% reconstruction tolerances on the profile width.
  ➔ Francesca: software simulation over months
- Read-out: enough signal? Which one? ➔Philippe
- Effect of background particles on the profile?
  ➔ all



a LWU: **L**inear **W**arm **U**nit



Preliminary tools and answers were given at the PDR

- Ok to resume the project
- Development of a test bench with IPMs for data taking at IPHI

Results & CDR

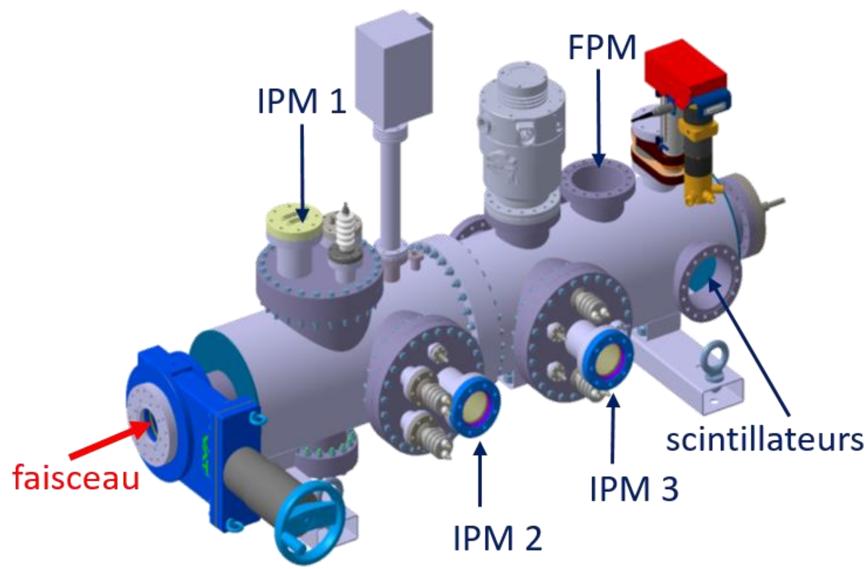
- Data obtained at IPHI allowed us to extrapolate data to ESS beam conditions, showing the project feasibility.

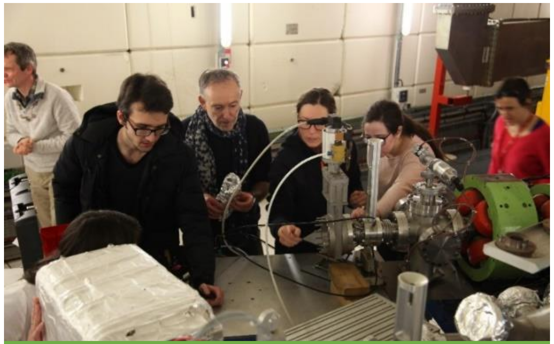
IPHI* tests during 2018

**Injecteur de Protons de Haute Intensité*

IPHI beam test conditions

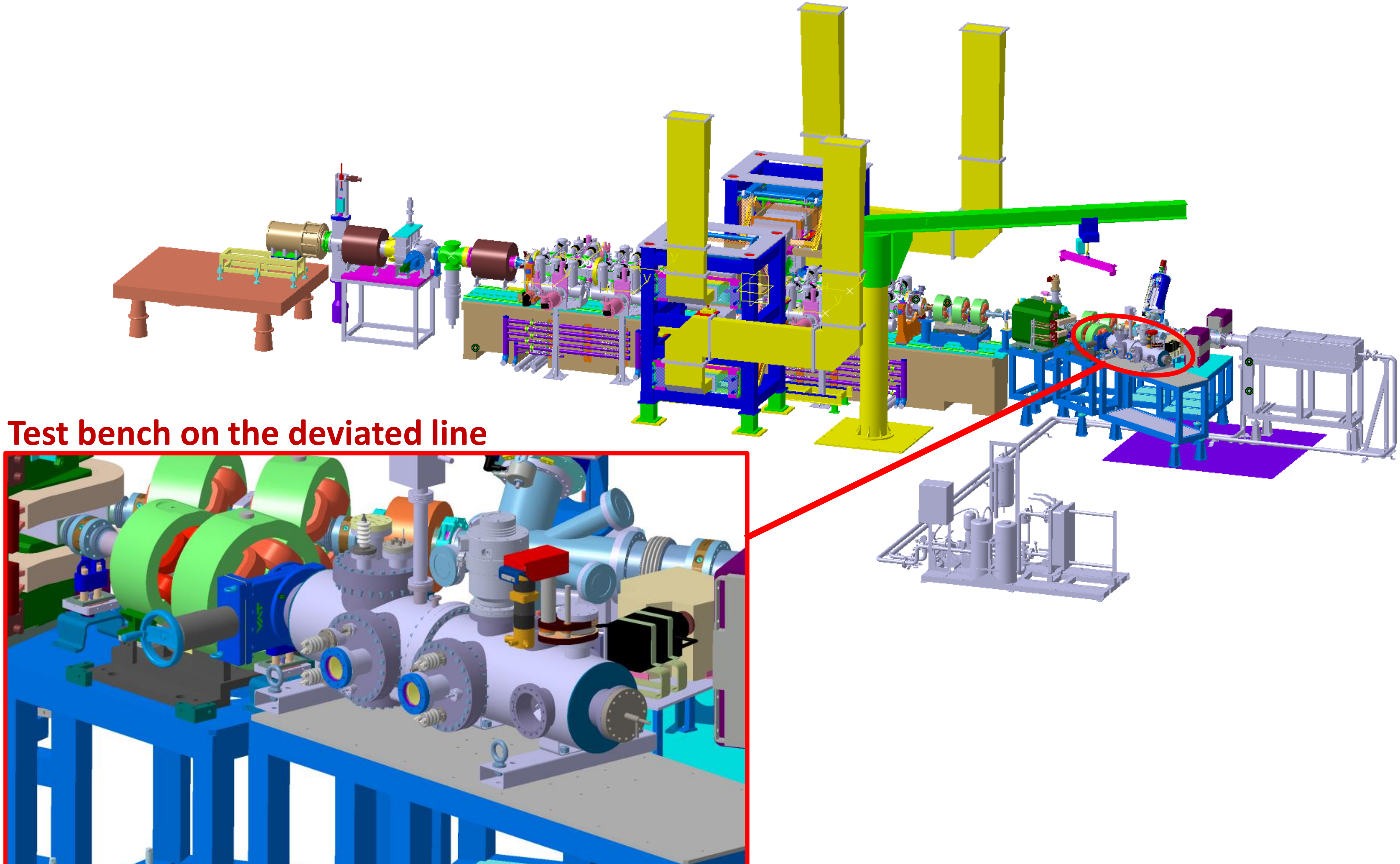
- Installation on Feb. and Sept. 2018
- Several read-out systems
  - MCP + optical system read-out
  - MCP + conductive strip readout
  - conductive strip readout (no "amplifier")
  - FPM with an image intensifier
  - 3 solid scintillating screens
- Bench equipment
  - 3 pumping systems
  - 2 pressure gauge
  - 1 RGA
  - 1 Faraday cup
- Test beam conditions:
  - proton @ 3 MeV
  - I = 0.7 to 60 mA
  - Δt_{pulse} ~ 100 µs/s



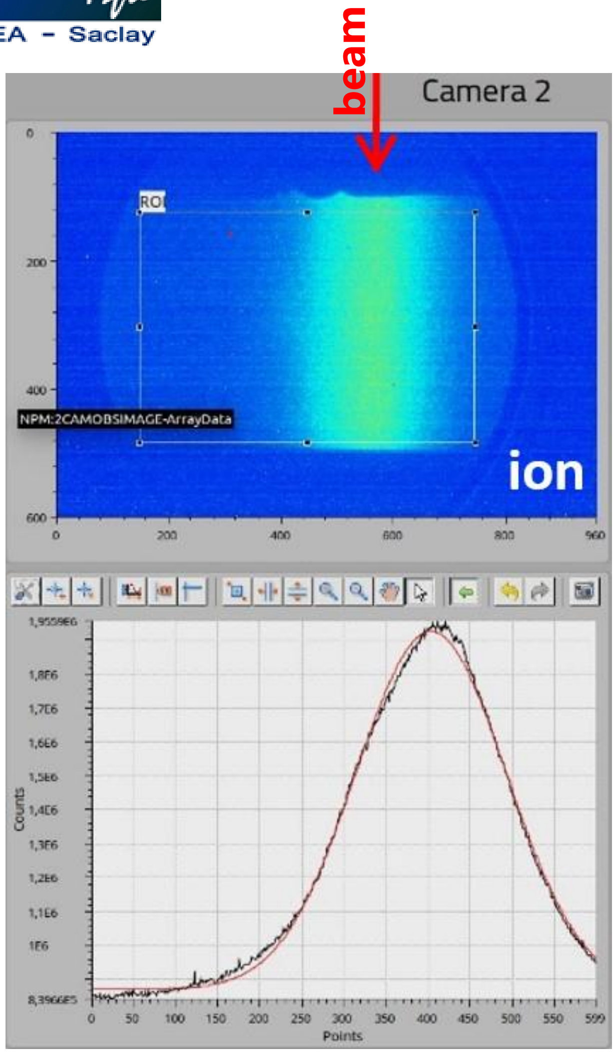


Installation: 13/02/2018

Test bench on IPHI

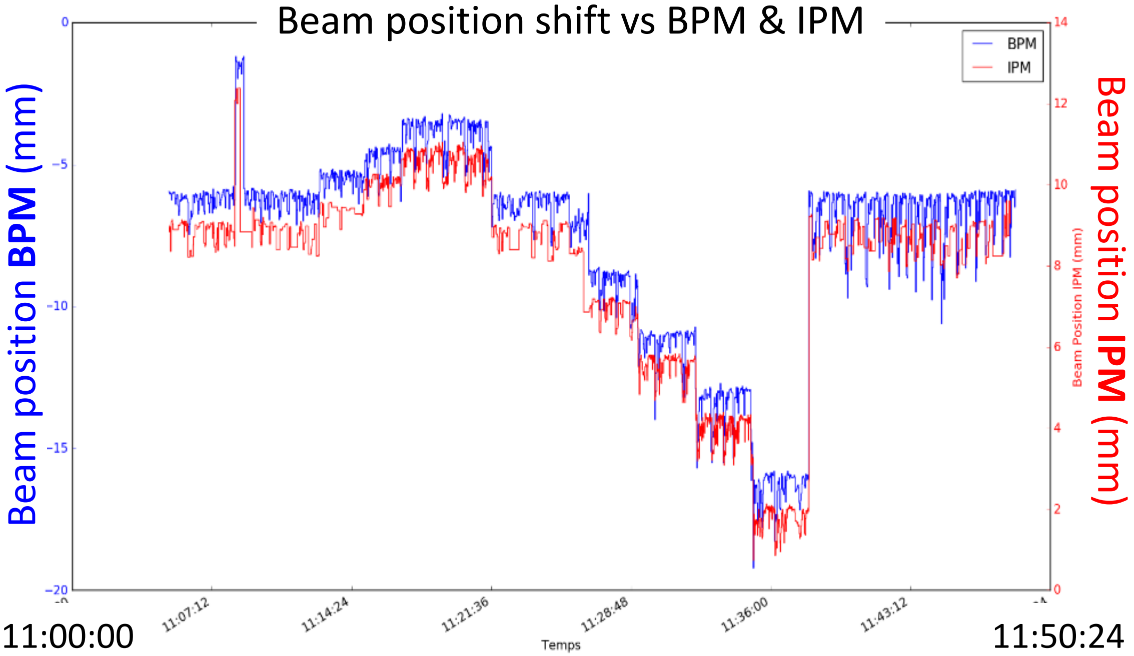


IPHI results with a proton beam



It took us about 10 days before to see the first profile!
We were blind, no other diags…

After a while of good functioning of the IPM, we noticed that there is a “slow” shift of the profile which come back swiftly to the main position and so on.
We though about an electric loading followed by a charge release…
Finally, Michel Desmons succeed in repairing the BPM and we observe the same shift behavior.
Obviously, it came from the accelerator and one day I learnt that it was due to a power supply malfunctioning!

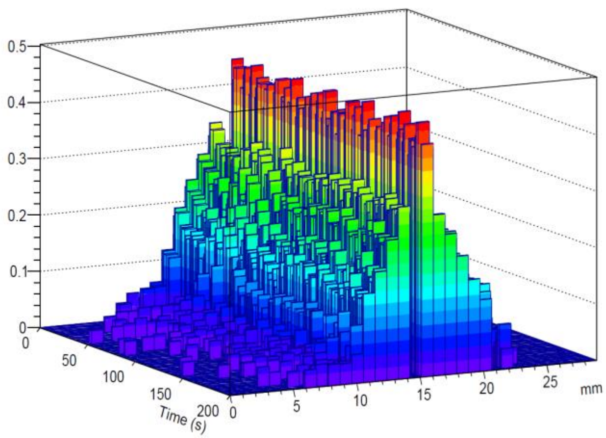


IPHI results with a proton beam

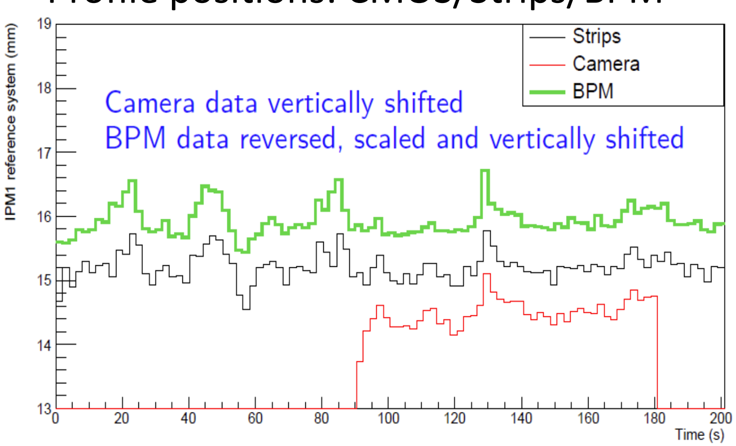
MCP + constant strips

Read-Out: D. Etasse et al., Faster system, LPC Caen.

$\sigma_{beam} \approx 3.3$mm



Profile positions: CMOS/Strips/BPM

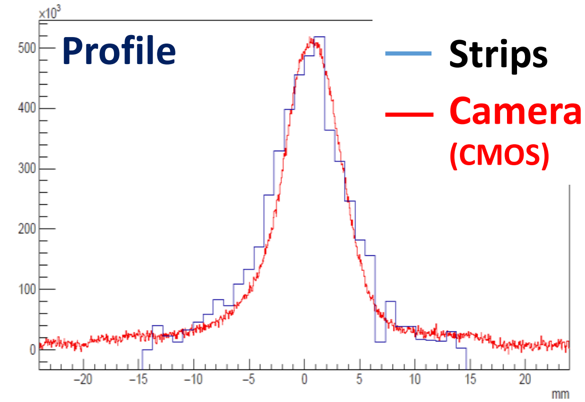


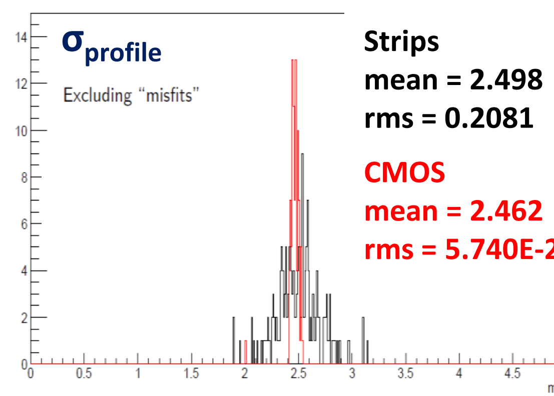
Comparison Strip/MCP

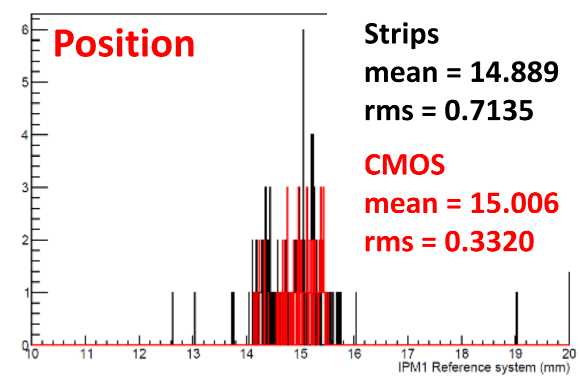
I_{beam} = 32 mA

P = 10^{-7} mbar

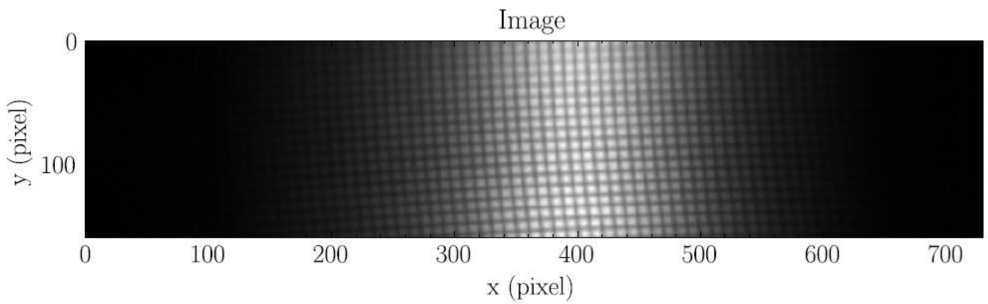
Δt = 100 μs (1 Hz)

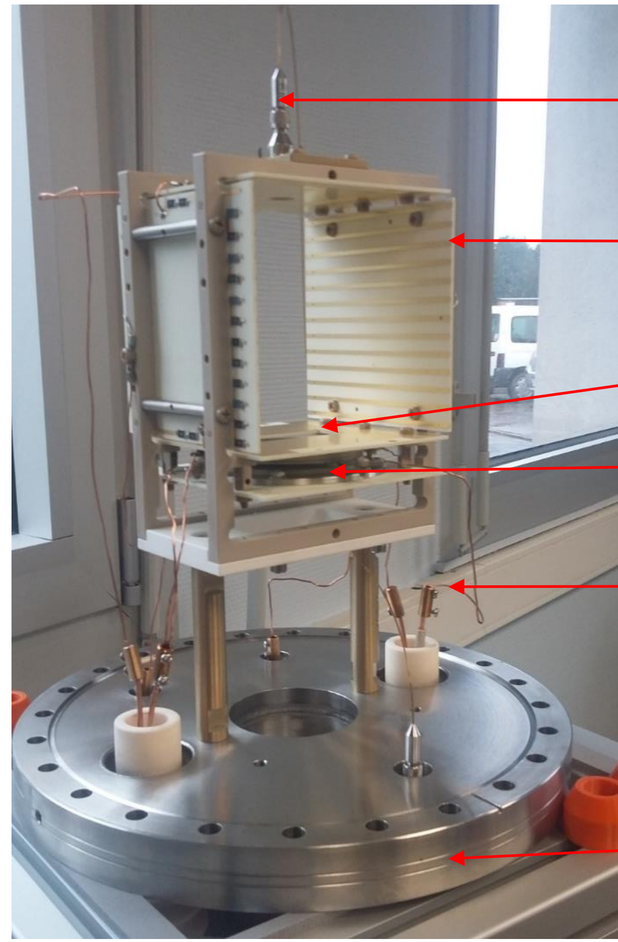






IPHI: IPM for proton beam tests

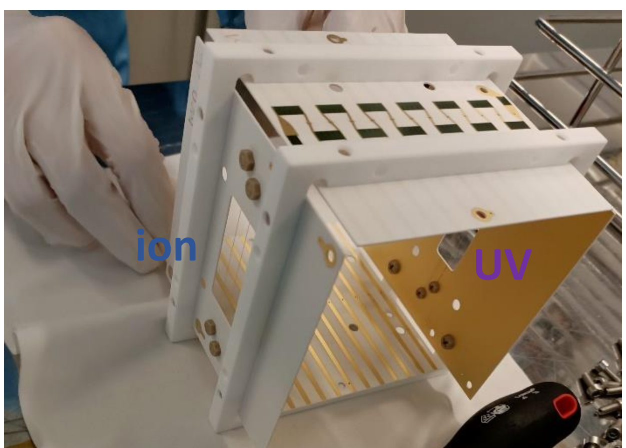


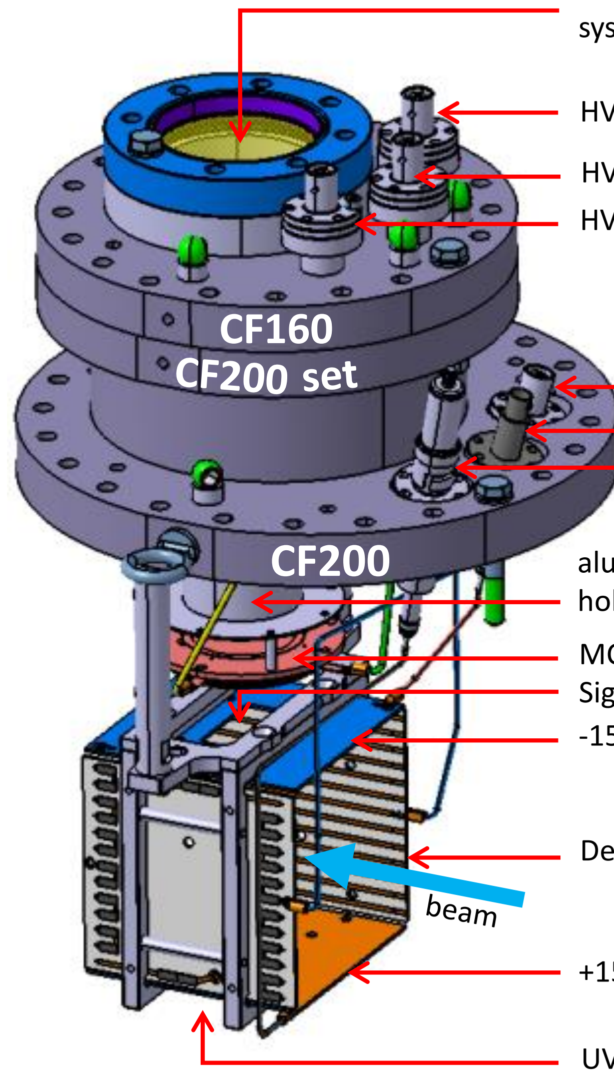


CDR summary

- Double MCP with phosphorescent screen (Photonis)

  APD 2 PS 40/12/10/8 I 60:1 MGO P43
- Symmetric HV (±15 kV)
- ISO-5
  - Ceramics plates for electrodes
  - Ceramics plates for degraders with serigraphied resistors

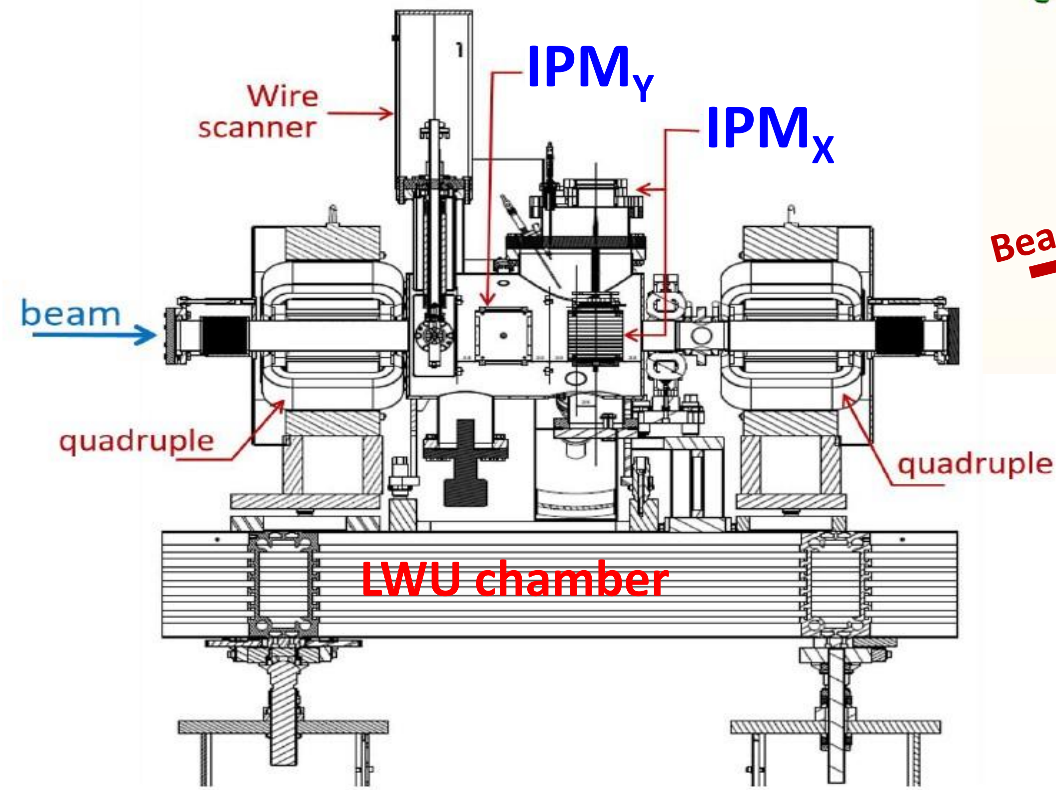


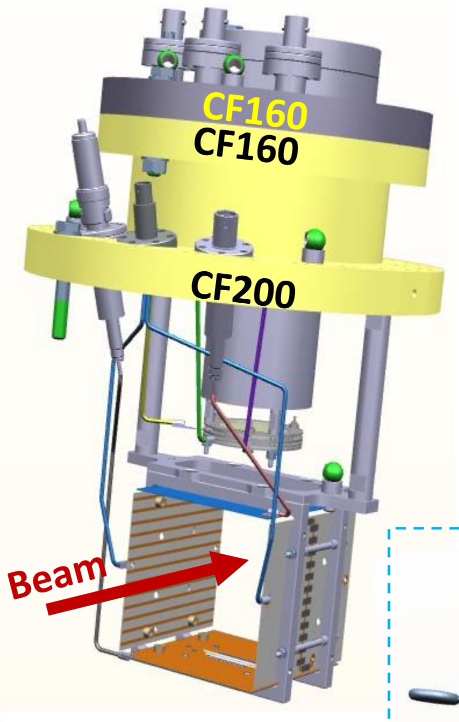


IPMs & NPM

Rotating CF160 by 180° wrt CF200 allows to get IPM_X or IPM_Y

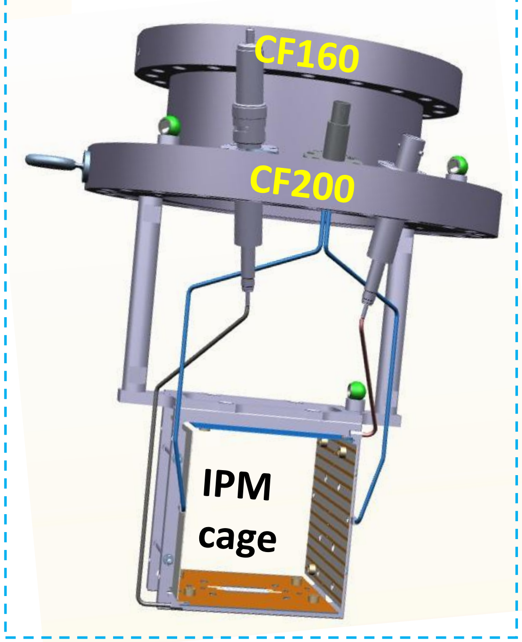
…nice trick, Loris!





CF160: MCP Part

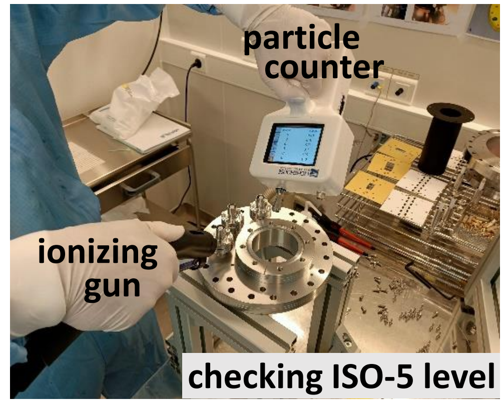
CF200: cage Part

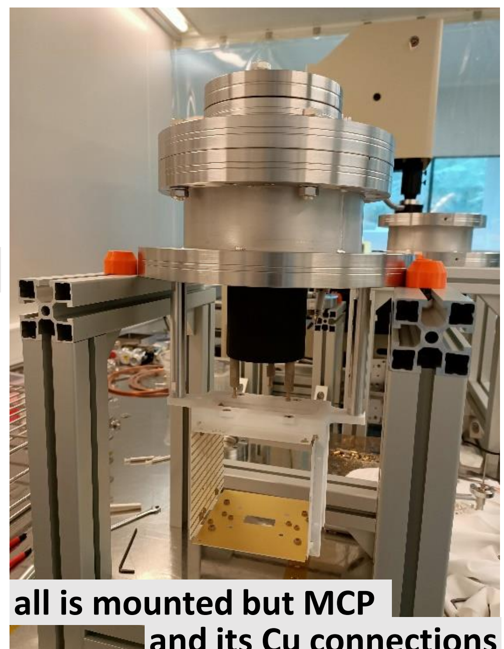


IPM integration: B. 546

Each IPM is assembled in ISO-5 cleanroom, ***except the MCP, the CF16 quartz and the CF60 viewport***.

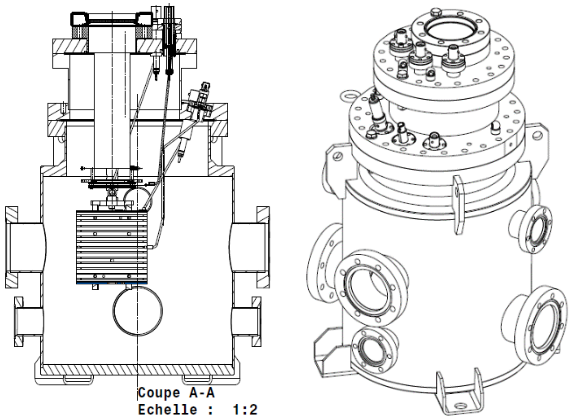
Once done, the set VC+IPM is wrapped into 2 clean plastic bags and stored in our laboratory waiting to be completed.





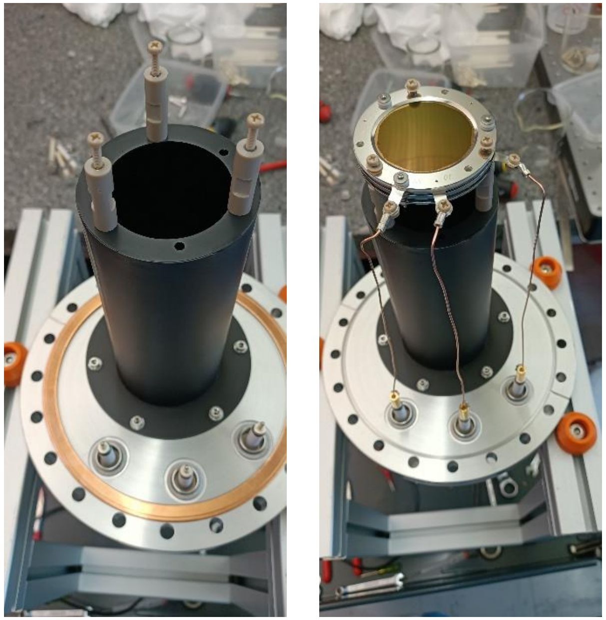
Cleanroom to laminar flux room

- All IPMs were assembled in the ISO-5 cleanroom, then inserted in these VC.
- Then stored and transported from B.536 to B.534/43C wrapped in a double plastic bags.
- When the 10 IPMs were completed, they are moved into the air laminar flux room (B.534/40) for mounting MCP and inserting an IPM pair in the test bench similar to a LWU.

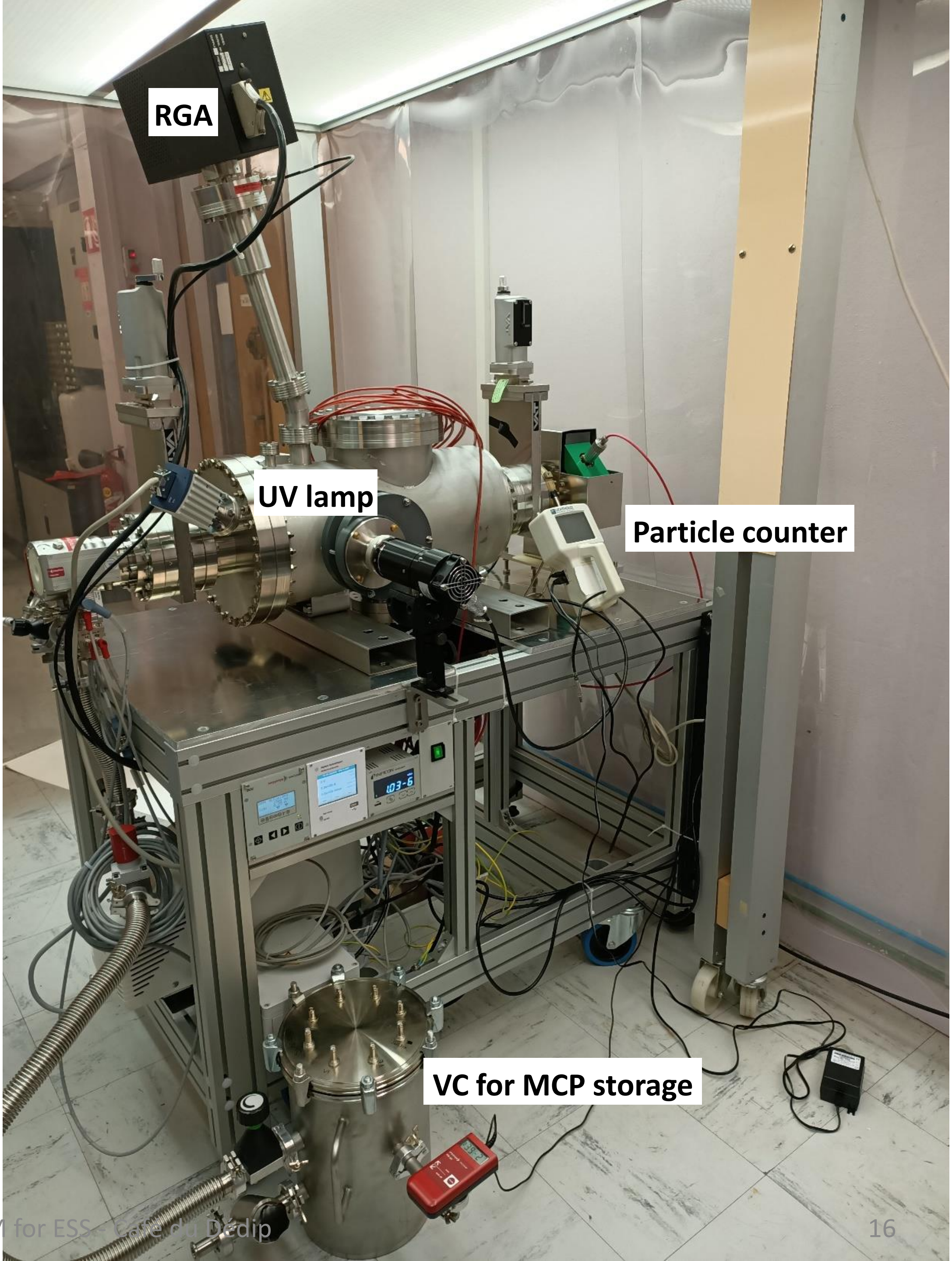


Pumping system inside the laminar air flux 534

MCP mounting



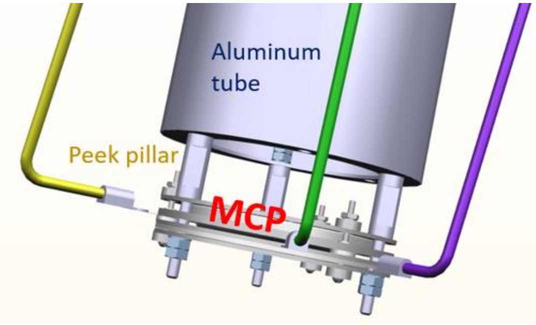
Test bench inside the laminar air flux B. 534/40

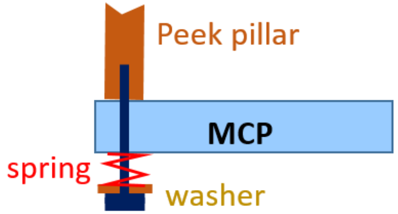


Inside the laminar air flux room

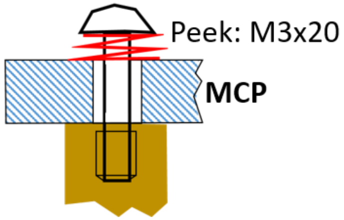
Mounting the MCP on the IPM

We have broken numerous IPM due to thermo-mechanical stress during baking.



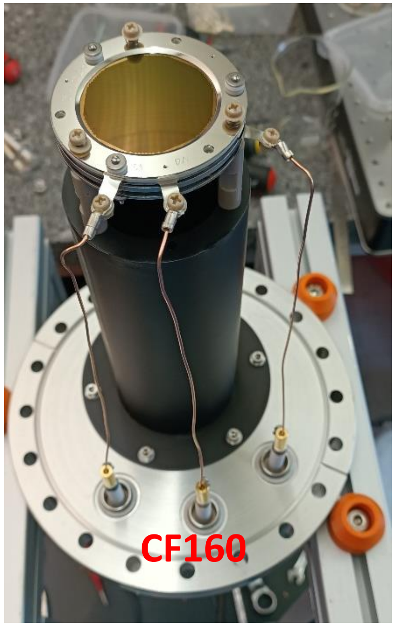


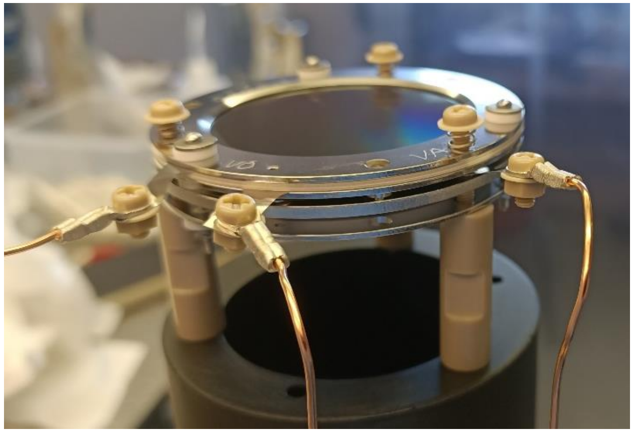
1- spring for minimizing **axial** stress



2- filing the screw upper thread part for **radial** thermal stress

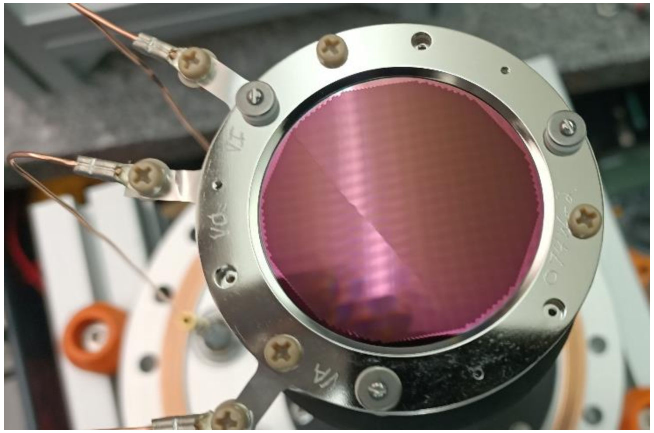
Using these 2 technics, we haven't broken the last 4 MCPs



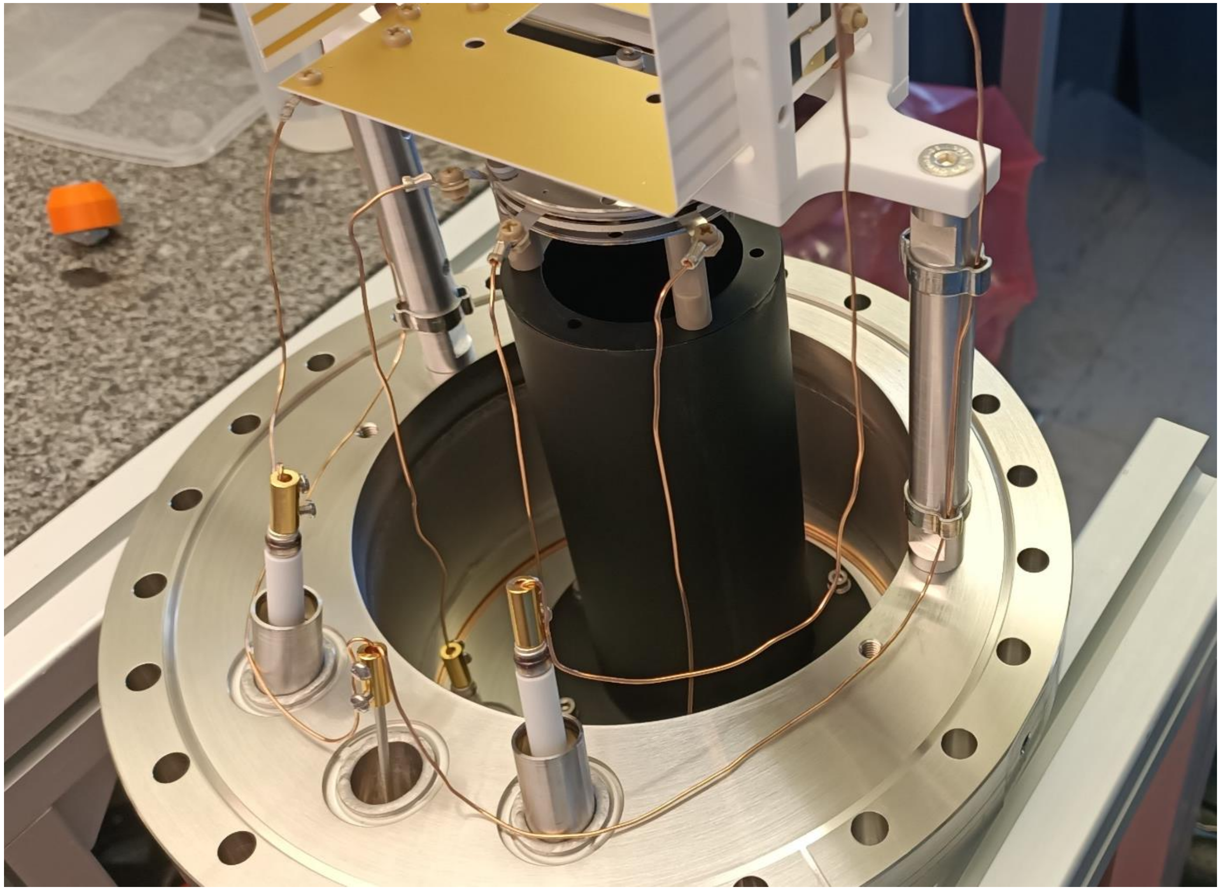


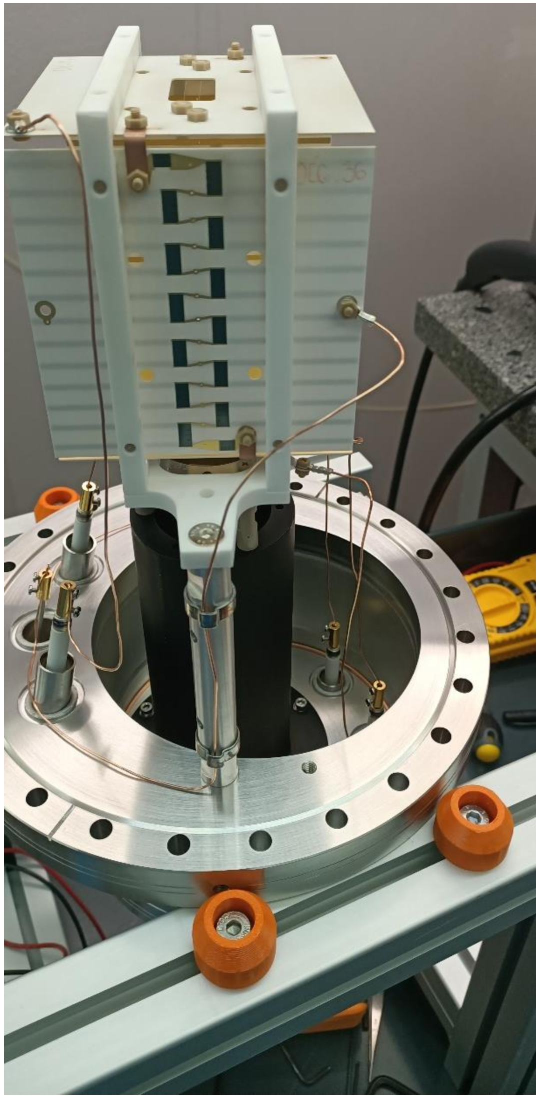
Still-live picture, but MCP alive!

Broken MCP under thermo-mechanical stress

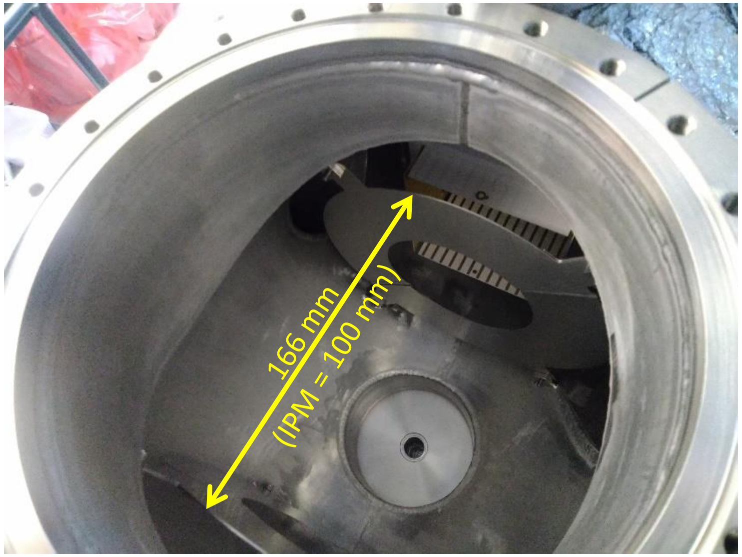


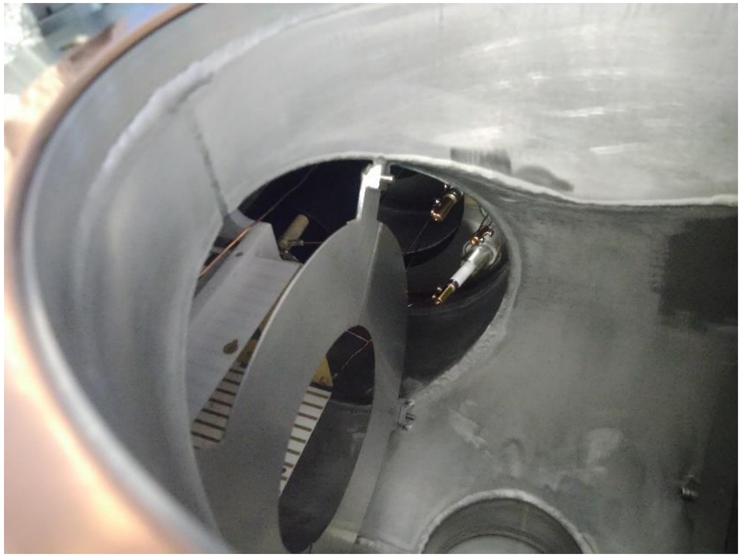
IPM connections

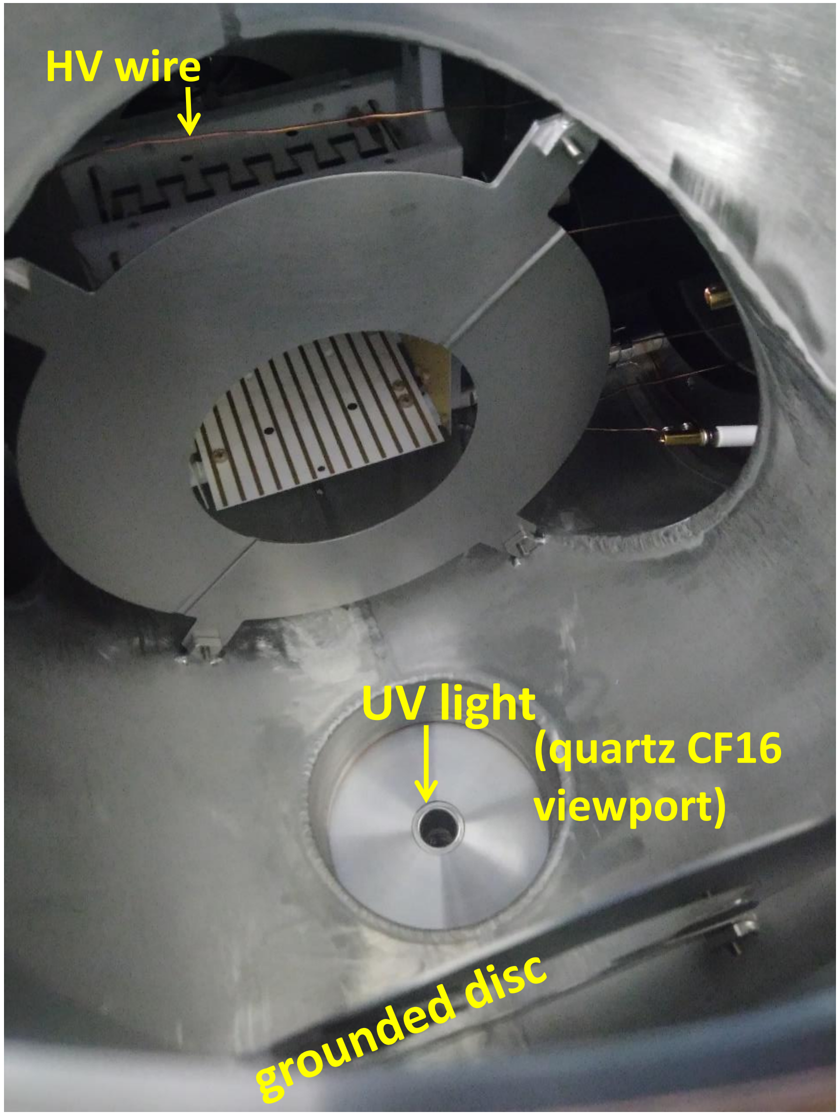




NPM chamber


166 mm
(IPM = 100 mm)



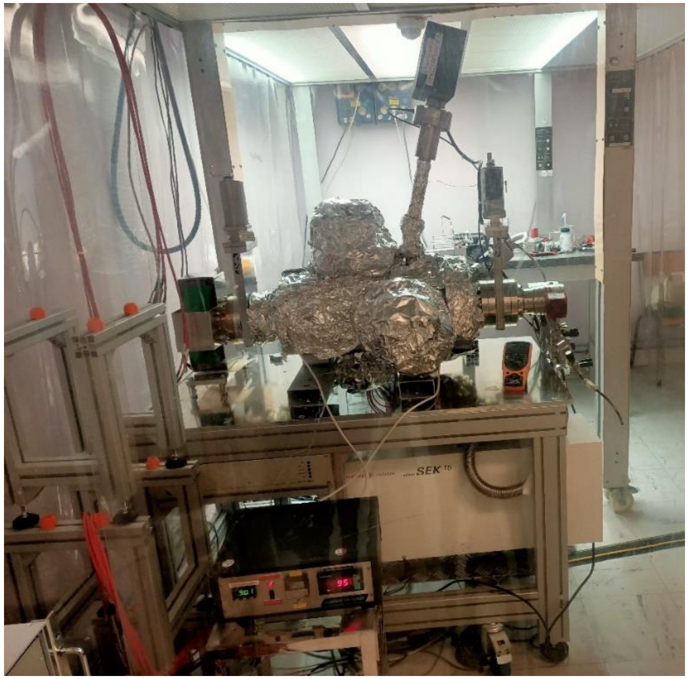

HV wire
UV light
(quartz CF16
viewport)
grounded disc

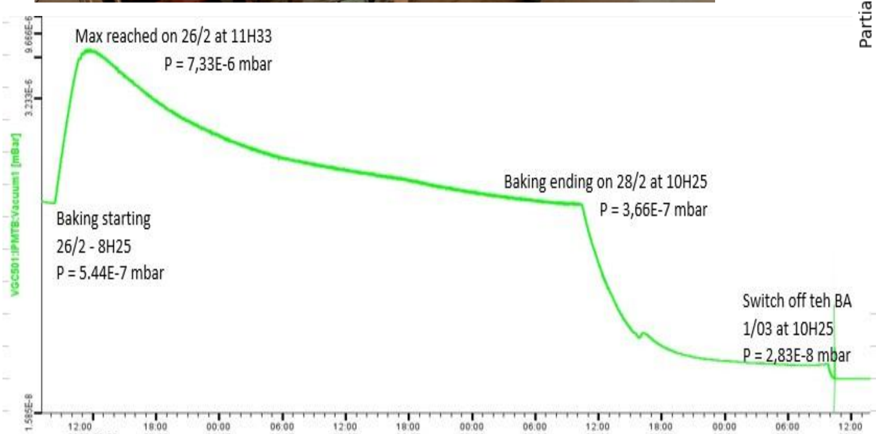
Backing

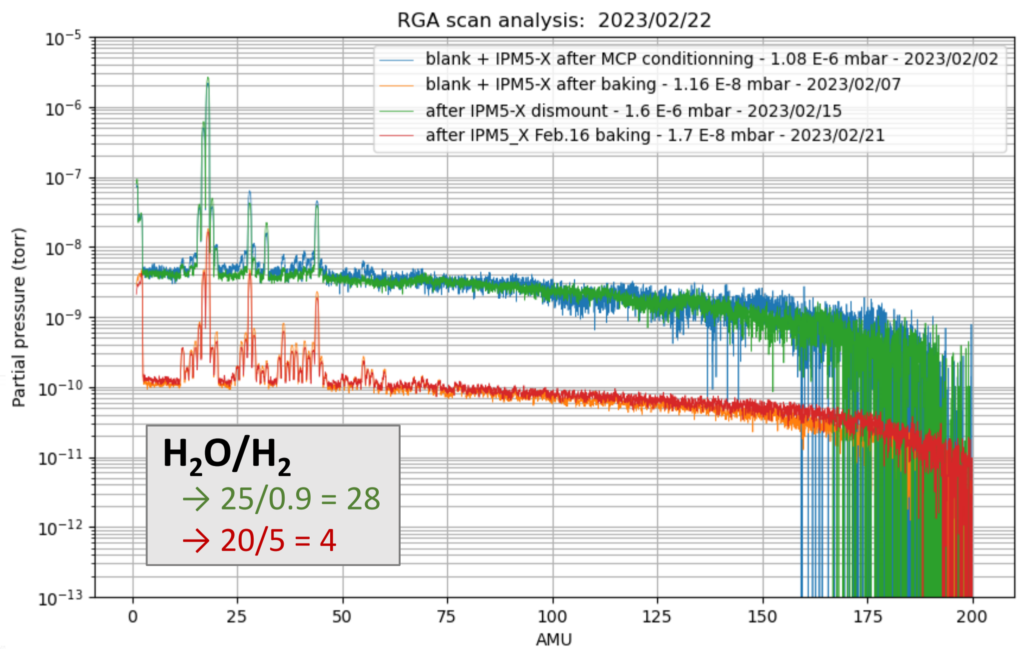
After each opening operation of the chamber, mainly for HVs and MCP tunings, a baking process is launched.

Use of a thermal controller designed by Olivier

→ During 4-5 days, baking at 100°C for helping MCPs to remove water from its narrow channels, allowing to achieve few 10^{-8} mbar.



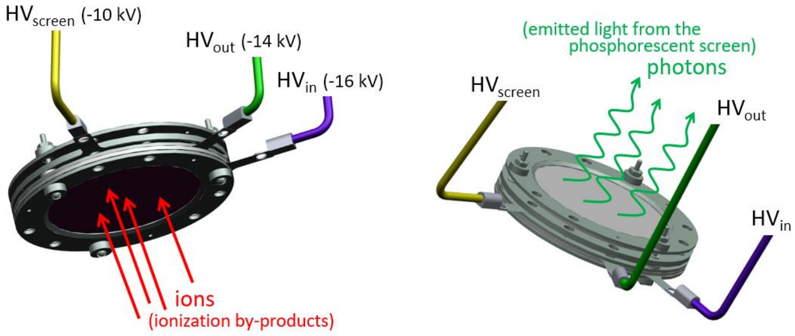




IPM polarization

MCP polarization

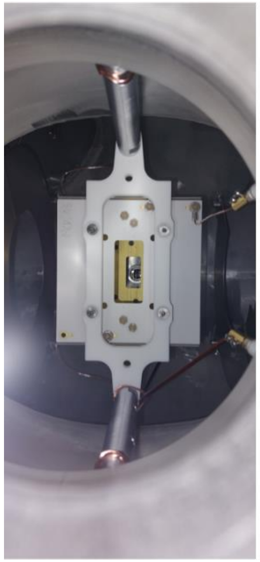
MCP gain depends on $\Delta V = HV_{IN} - HV_{Out}$
Need a connection box for insuring ΔV

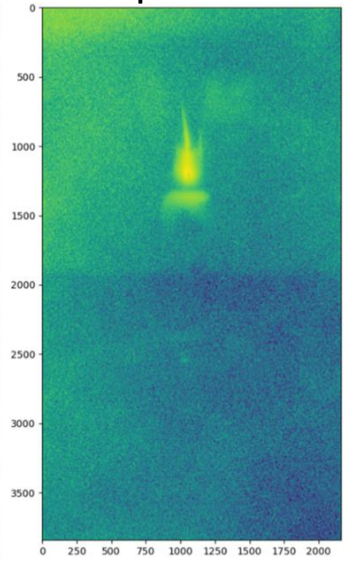


IPM cage

Electrode (e^-) → +15 kV
Electrode (ion^+) → -15 kV
MCP_{IN} → -16 kV
MCP_{out} → -16 to -14 kV
MCP_{screen} → -12 to -10 kV

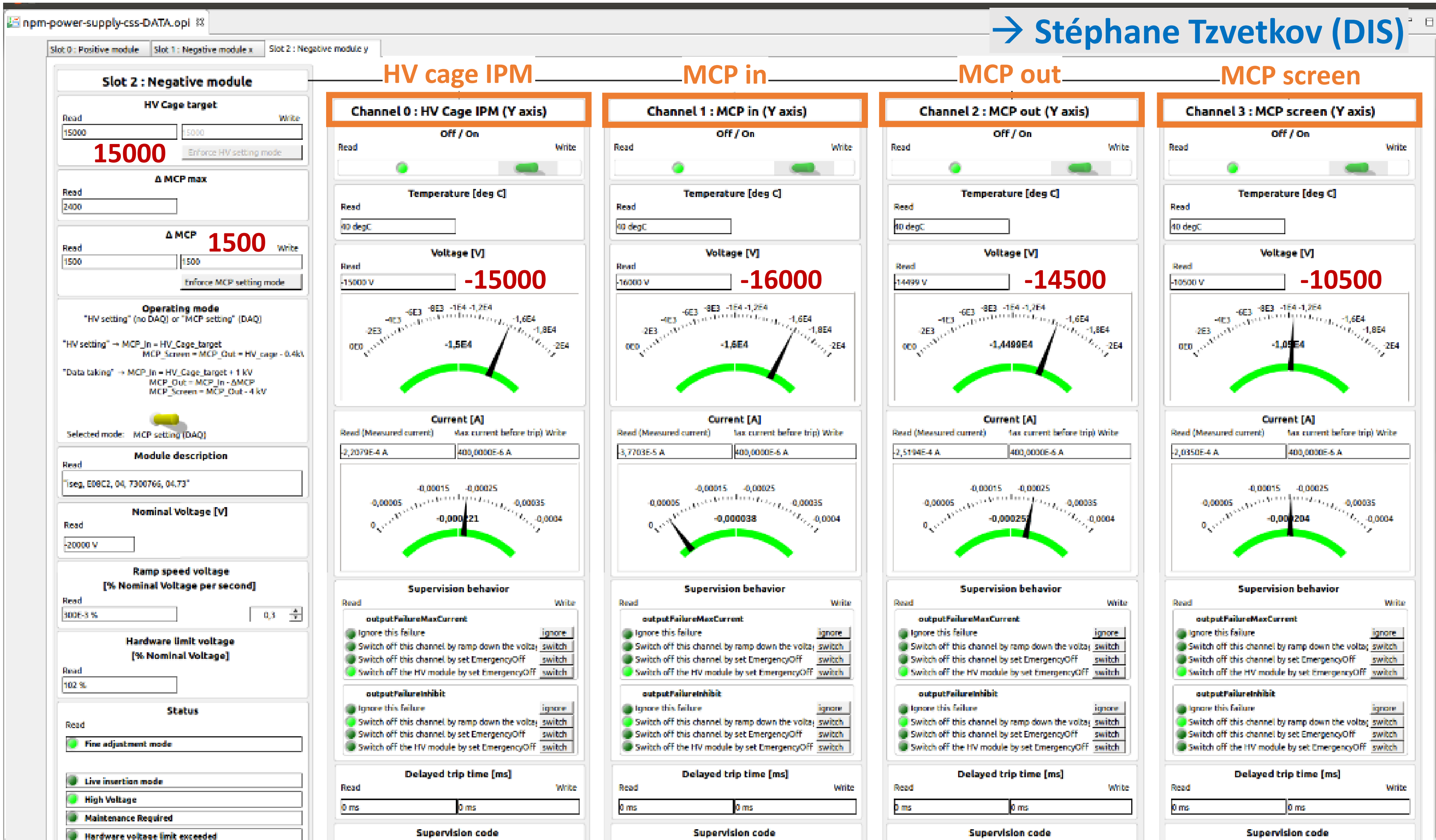
Short circuit → sparks





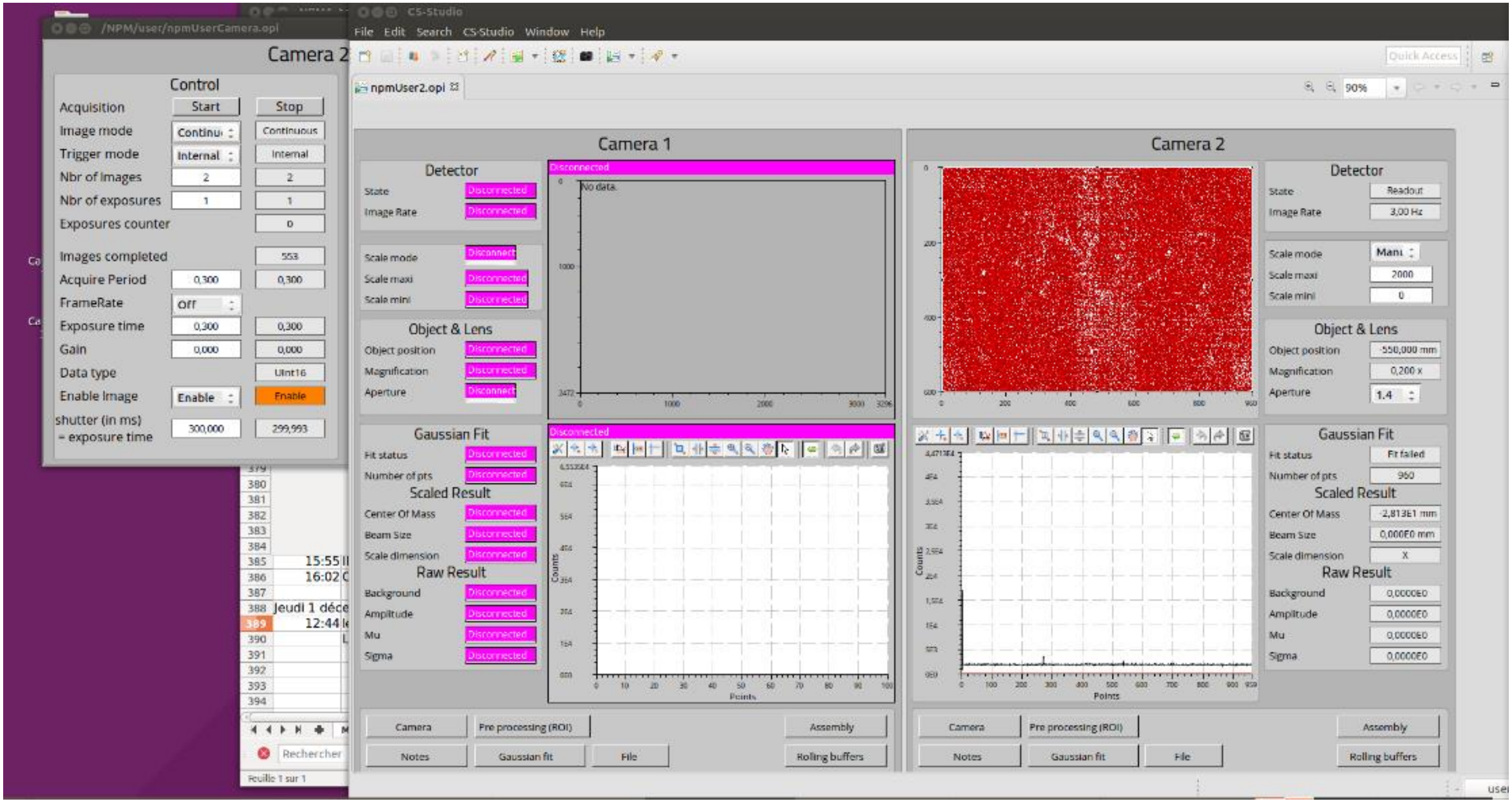
HV Control System (ISEG)

ΔV = 1500 V ➔ HV cage = ±15 kV, MCP_in=-16 kV, MCP_out=-14.5 kV, MCP_screen=-10.5 kV



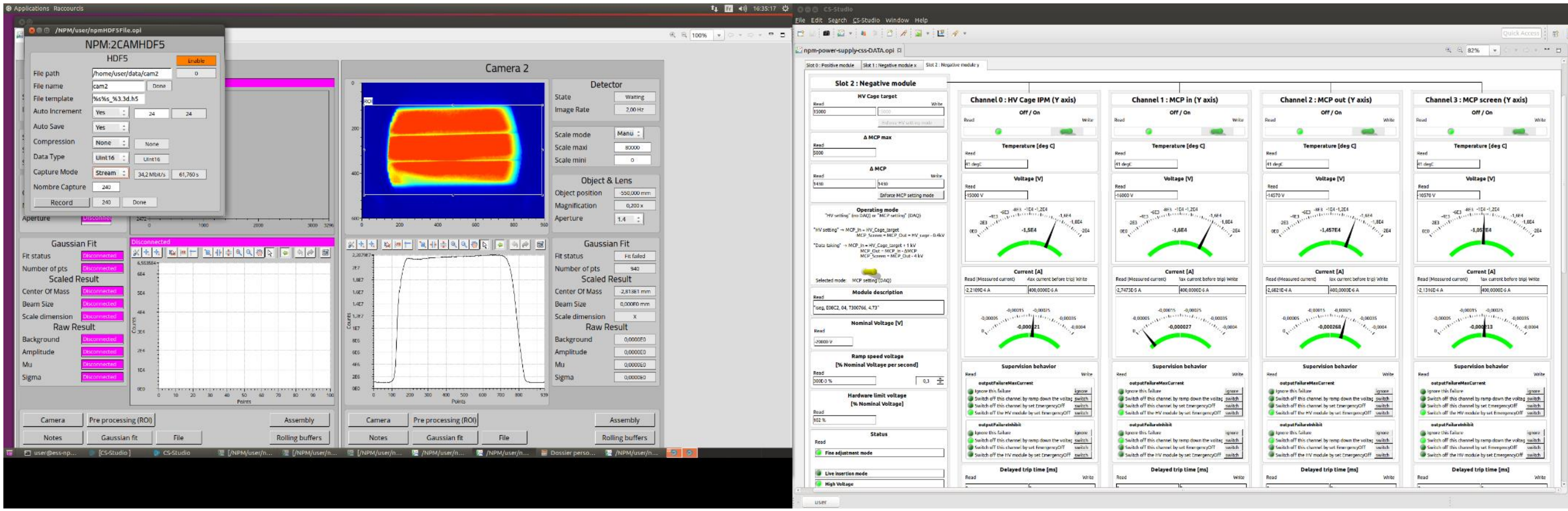
Read-Out Control System

ΔV = 1500 V (same conditions as previously), checking noise with CMOS-2 shutter = 300 ms!



Read-Out Control System (2)

Other conditions with UV lamp switched ON: the slit aperture clearly appears

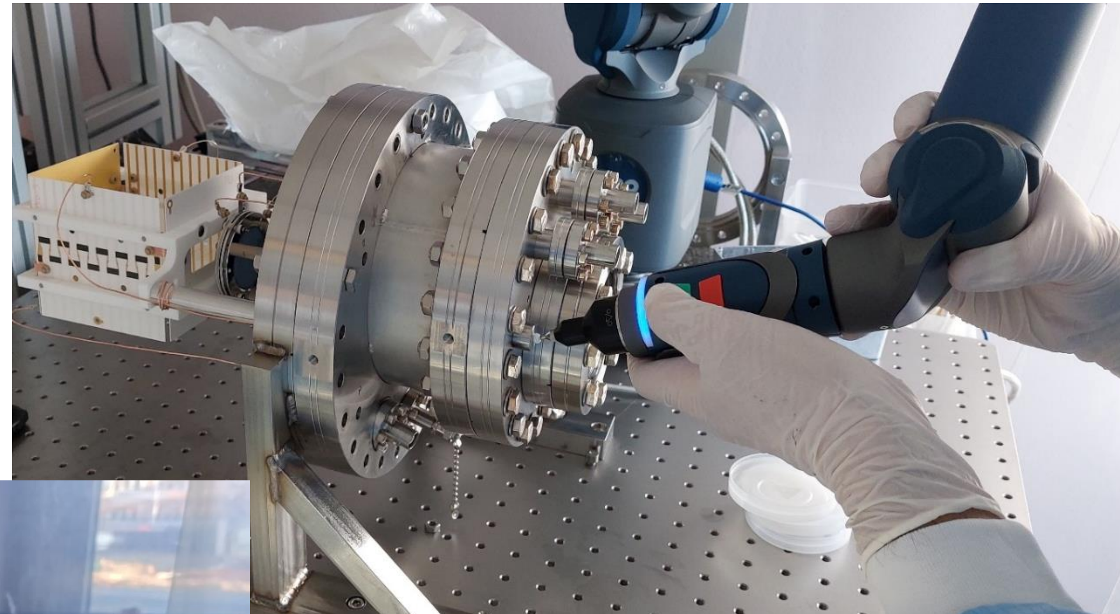


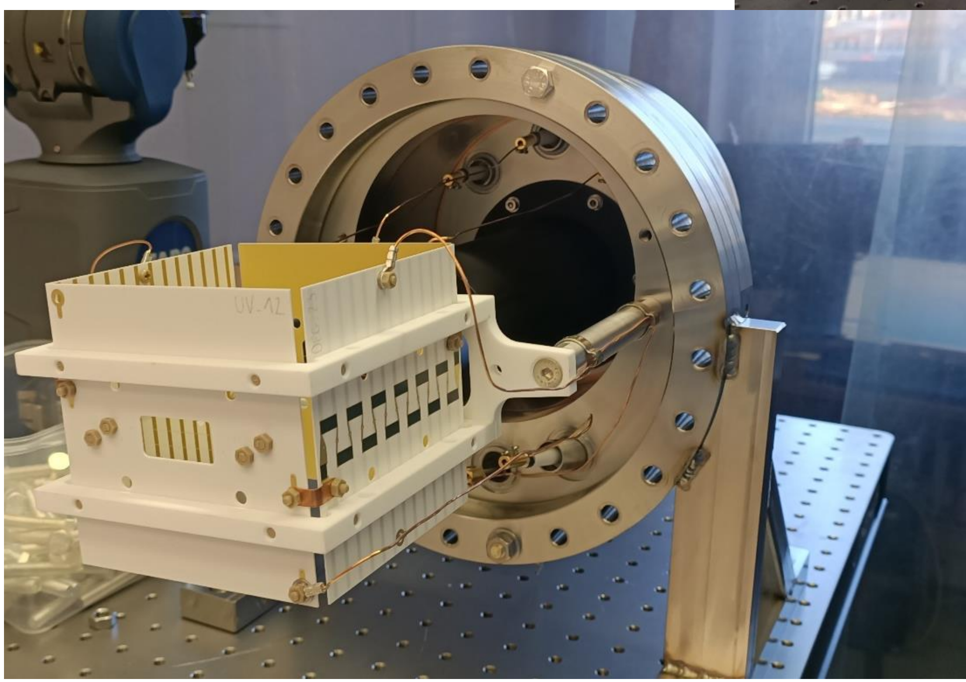
FLIR: BFLI-PGE-23S6M-C
sensor Sony IMX249

Navitar: MVL50M1 (50 mm)

Survey

Survey of the IPM with the 3-D FARO mechanical arm
(inside Laminar air flux)





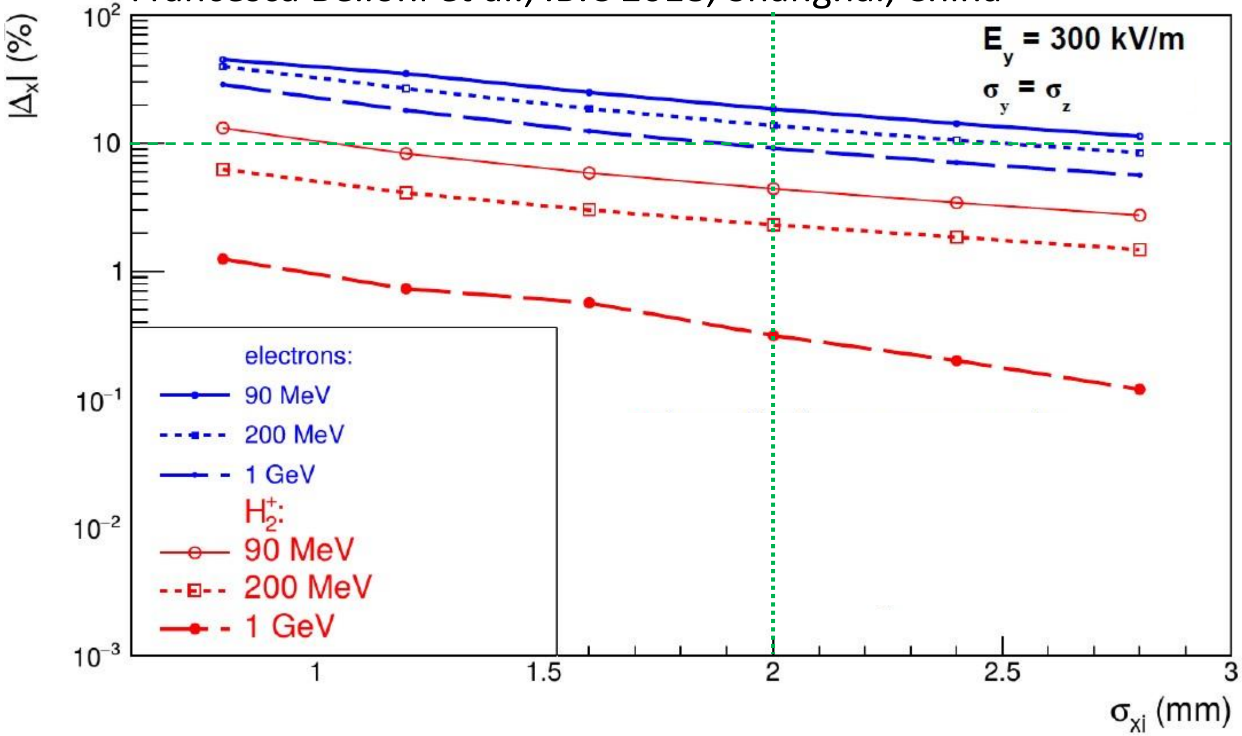
Space Charge

Space Charge effect

Following Francesca's simulation, the rms of the profile width should be below to 10%.

We can see that this is fulfilled when ions are used, but not electrons.

Francesca Belloni et al., IBIC 2018, Shanghai, China

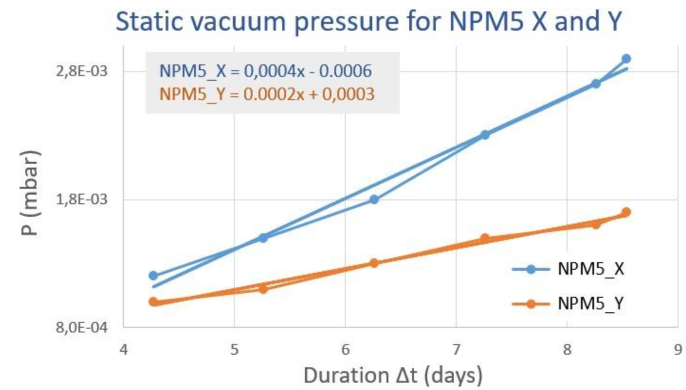


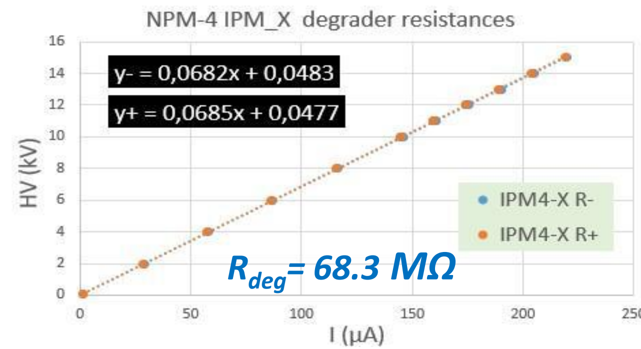
CEA - Saclay

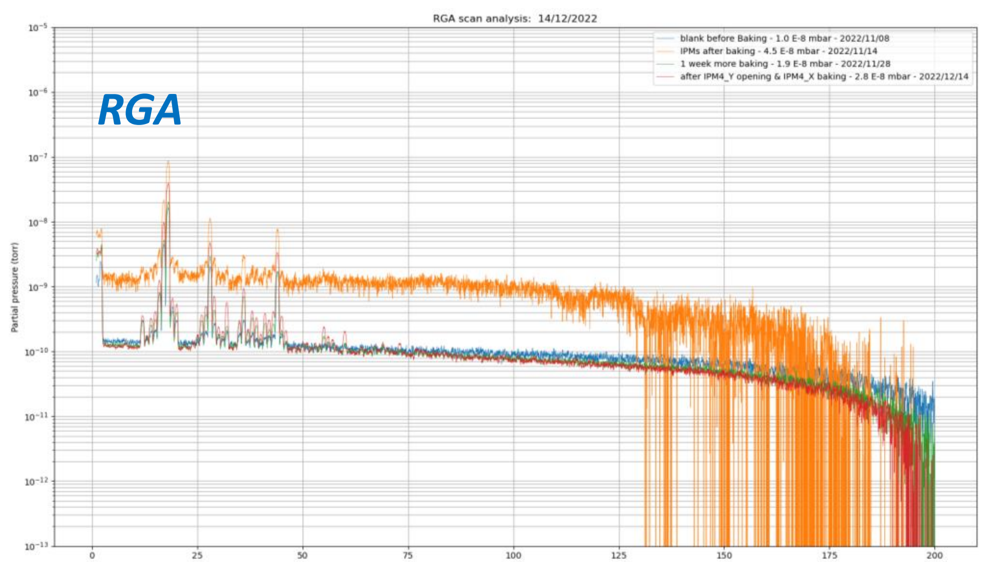
Test results provided to ESS

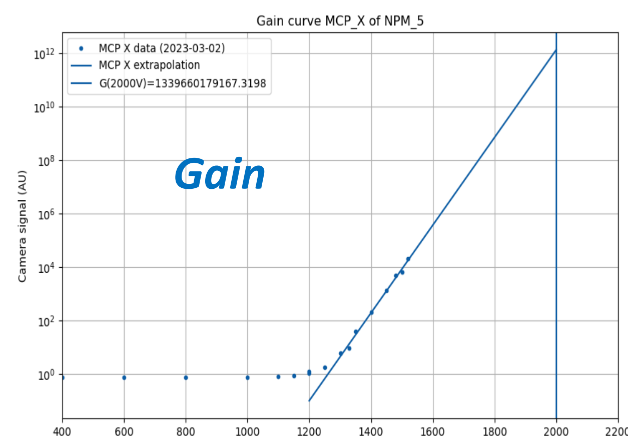
leakage

- Reaching nominal HV values → more than 24 hours
- Leakage rate < 10^{-10} mbar.l/s
- Static vacuum leakage → transport Saclay Lund
- RGA before / after baking → $H_2O/H_2 < 10$
- Degrader resistance → about 70 MΩ
- MCP resistance → 30 to 300 MΩ
- MCP gain (value extrapolated to ΔV=2000 V)
- IPM survey



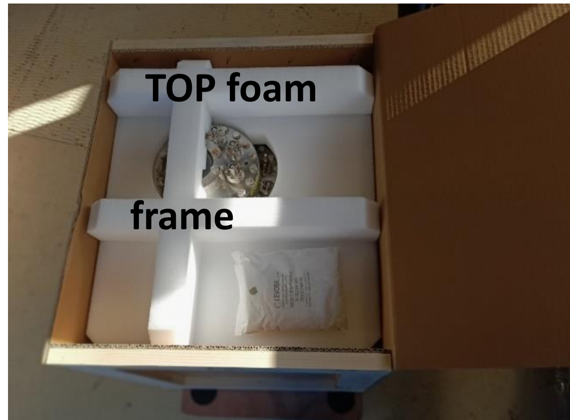






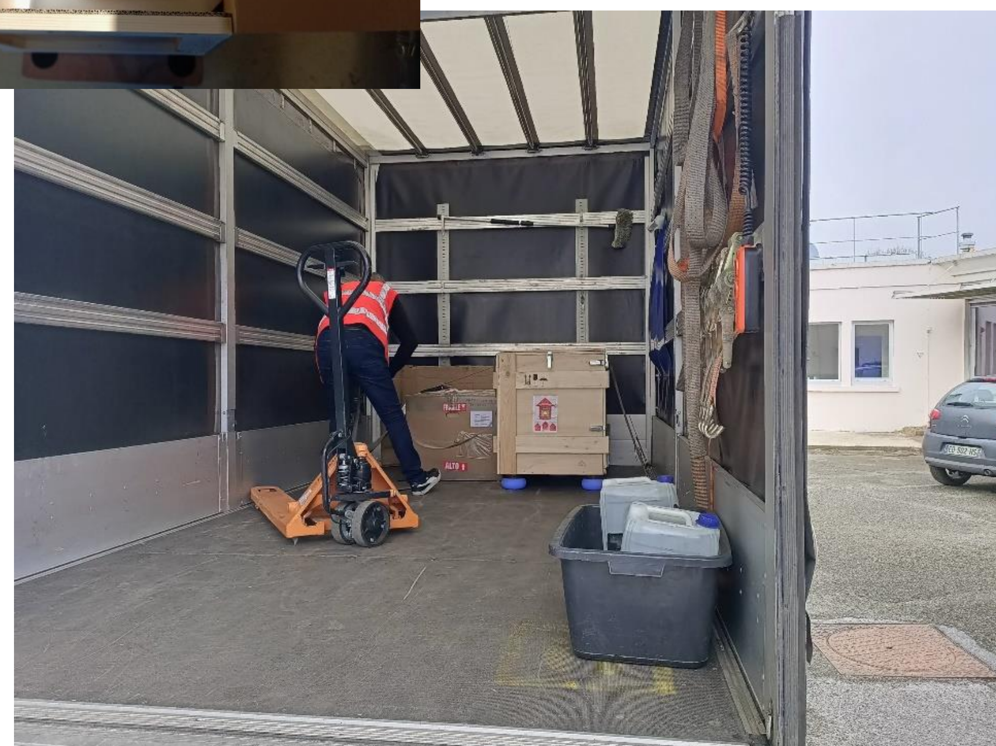
Transport

Wrapping company Somodem



Note: 2 NPMs took the same truck of the cryomodule transport to Lund.
Thanks to Nathalie & Pierre

1st NPM: Feb. 15th 2022



Conclusion

We faced to many challenges, sometimes a bit discouraging

➔ thanks to my colleagues for not giving up because it could take a long time to get them up

Finally, we learnt a lot of things in several fields… That was fun!

Delivered to ESS Lund: 5 NPMs = 10 IPMs

- NPM1 → 15/02/2022*
- NPM2 → 12/10/2022*
- NPM3 → 23/11/2022*
- NPM4 → 10/01/2023*
- NPM5 → 29/08/2023*

*NPMs leaving dates from Saclay

Thank you very much for your attention!

and special thanks to these colleagues

Saclay: P. Abbon, F. Belloni, F. Bénédetti, M. Combet, G. Coulloux, P. Legou, C. Lahonde, O. Leseigneur, Y. Mariette, J. Marroncle, JP Mols, V. Nadot, F. Popieul, L. Scola, G. Tauzin, S. Tzvetkov

IPHI team: B. Bolzon, N. Chauvin, D. Chirpaz-Cerbat, M. Desmons, Y. Gauthier, T. Hamelin, M. Oublaid, G. Perreu, B. Pottin, Y. Sauce, F. Senée, J. Schwindling, O. Tuske

ESS Lund: A. Gevorgyan, R. Tarkeshian, C. Thomas

Thanks to: S. Berry, P. Bosland, N. Franchomme, C. Madec

Final IPMs for ESS

IPM characteristics

2 independent flanges

- CF200
  - ➢ IPM cage (cubic shape 10 cm)
  - ➢ HV connectors of the cage ±15 kV
- CF160
  - ➢ CF63 viewport (Read-Out)
  - ➢ Al cylinder (0.3 mm) holding MCP
  - ➢ MCP (MicroChannel Plate)
  - ➢ MCP HV connectors

IPM

- HV electrodes ±15 kV
  → grounding in the middle of degraders
- MCP working far to ground (-16 to -10 kV)
- IPM working energy range: 90 MeV to 2 GeV
- Read-Out: optical (MCP + Phosphorescent screen)
- 1 profile/pulse
- Ion detection for improving profile meas.
- $P_{residual\ gas} < 10^{-9}$ mbar
- ISO-5
- Cage: alumina 0.65 mm.
- Degraders with serigraphied resistors