DE LA RECHERCHE À L'INDUSTRIE

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# PURCHASE AND QA/QC OF LEM + ANODES

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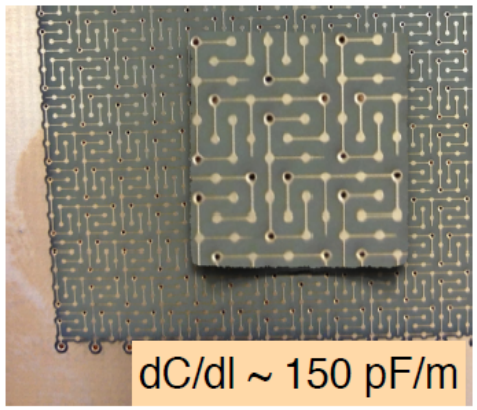
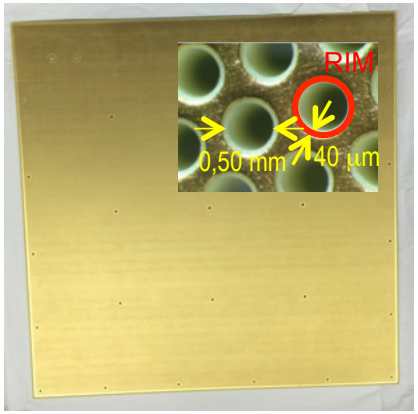
Anode




LEM




WA105 Collaboration meeting, march 22nd-23rd 2017

# OUTLINE

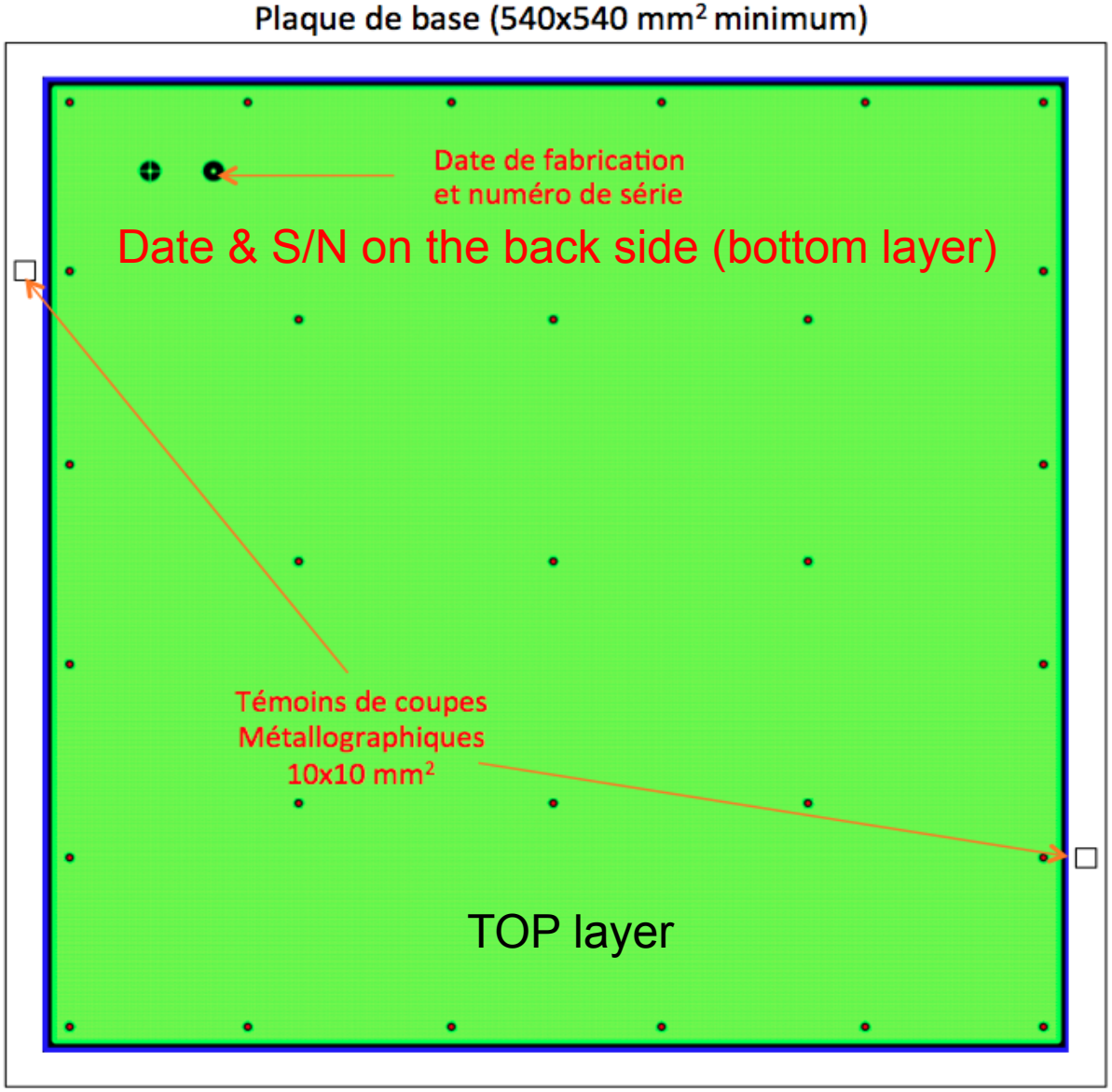
- LEM specifications
- Production and QA/QC procedures of the LEMs
  - ✓ In the PCB industry
  - ✓ By the WA105 collaboration @ Saclay
    - Assembly and cleaning + baking
    - Final qualification for Breakdown Voltage @ $P_{abs}$≈3.3 bar
  - ✓ By the WA105 collab. @ CERN : LEM + Anode + assembly on CRP
- Status of the call for tender for the LEM production
- Anode PCB : specifications, finalization of the design for production
- Conclusion

# 50X50 CM² LEM (3X1X1 m³ DESIGN) SPECIFICATIONS FOR WA105 DEMONSTRATOR

| | |
|---|---|
| Raw material | Procurement in one batch with thickness selection |
| Material | PANASONIC R-1566W (halogen free) |
| Dimensions | 540 mm x 540 mm |
| FR4 mean thickness | 1 mm (-0.04 /+0 mm according to the specifications of the delivered batch) |
| Copper layer thickness | 105 μm on both sides |
| Mean total thickness | 1,21 (-0.04/+0) mm +/- 0.04 mm (mean thickness of all the LEMs produced) |
| Total Thickness uniformity | +/- 0.04 mm (thickness uniformity over each LEM surface) |
| Produced LEM | |
| Dimensions | 499.5 mm x 499.5 mm +0/-0.2 mm |
| Ni/Au finish | YES: 5 μm Ni + 0.1 μm Au |
| Screen printing | YES (for LEMs serial number printing) |
| Solder resist mask | NO |
| Final thickness (Ni/Au included) | 1.15 (-0.04/+0) mm +/- 0.04 mm (mean thickness of all the LEMs produced) +/- 0.04 mm (thickness uniformity over each LEM surface) |
| « active » holes with RIM | ≈ 400 000 non-plated 0.5 mm diameter holes |
| RIM (after Ni/Au treatment) | 40 μm +/- 4 μm |

These specifications are the ones used in the call for tender

# LEM GERBER FILES
# DESIGN MODIFICATIONS VS 3X1X1 m$^3$

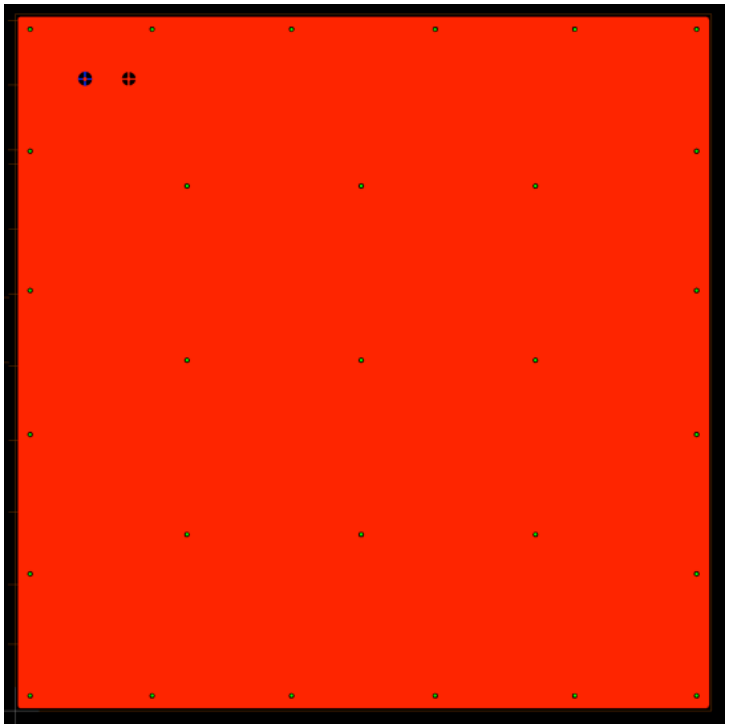


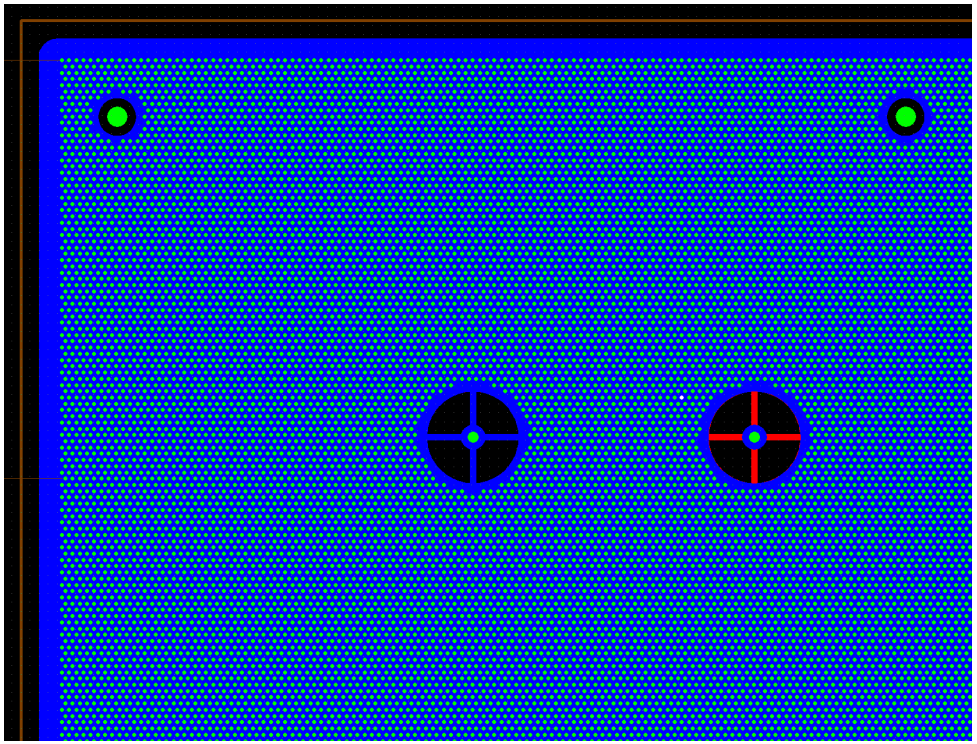

The gerber files which will be used for the production are those of the 3x1x1 m$^3$ LEMs with the following modifications (next slide)

# LEM GERBER FILES FOR 6X6X6 $m^3$ DESIGN MODIFICATIONS VS 3X1X1 $m^3$

- Raw material changed from R-1755C to R-1566W (halogen free)
- The diameter of the 2 holes for pin soldering increased to 1.2 mm
- The 2 holes for pin soldering are no longer plated

TOP gerber layer : MACOR cylinders are glued on this side
LEM identification (date & S/N on BOTTOM side)





# LEM MANUFACTURING AND QA/QC PROCEDURE

- Procurement of raw material in one batch at the beginning of the production
- Raw FR4 sheets selection for mean thickness and uniformity better than 4%

0/ QA/QC by manufacturer

By LEM manufacturer

| | |
|---|---|
| CNC drilling | Change drills every 1000 holes<br>Drilling of stack of PCBs is forbidden |
| mechanical polishing | with pumice powder<br>4 steps (+/- 90°, top/bottom) |
| permanganate bath +rince | *removes glass fiber from holes* |
| Rims by global etching | *acide sulphuric bath* |
| passivation (Chromic acid) | |
| Ni/Au plating | Baking 3 hrs at 50°<br>rinsing with DM water (R> 2 Mohm) |

1/ LEM thickness metrology
2/ Soldering of HV pins
3/ Mounting on aluminum handling plate
(dismounted when LEM is packed for shipping)

→ The handling plate is used to prevent the LEMs to be touched during the following production tasks

By WA105

| | |
|---|---|
| ultrasonic bath DM water | Dioinised water<br>(R≈18 Mohm) |
| lessive (soap) bath at 60°C | |
| karcher DM water | |
| baking 3 hrs at 80 degrees | |
| HV test | |

4/ "Saclay Cleaning"
3 mn Ultrasonic bath with "soap NGL 17.40 ALU" at 65°C

+ regular water rinsing BEFORE DM water

5/ Gluing of HV insulating MACOR cylinders
6/ Final qualification @ 3.3 bar (abs)

HV test not ok | HV test ok → storage

If Breakdown Voltage (BV) and spark rate test in air is passed, **final polymerization @ 160°C can be done**

→ Thickness metrology will be done on the first LEM batches to check the conformity with the raw material thickness measurements by the manufacturer

# 0/ LEM Q/C BY MANUFACTURER

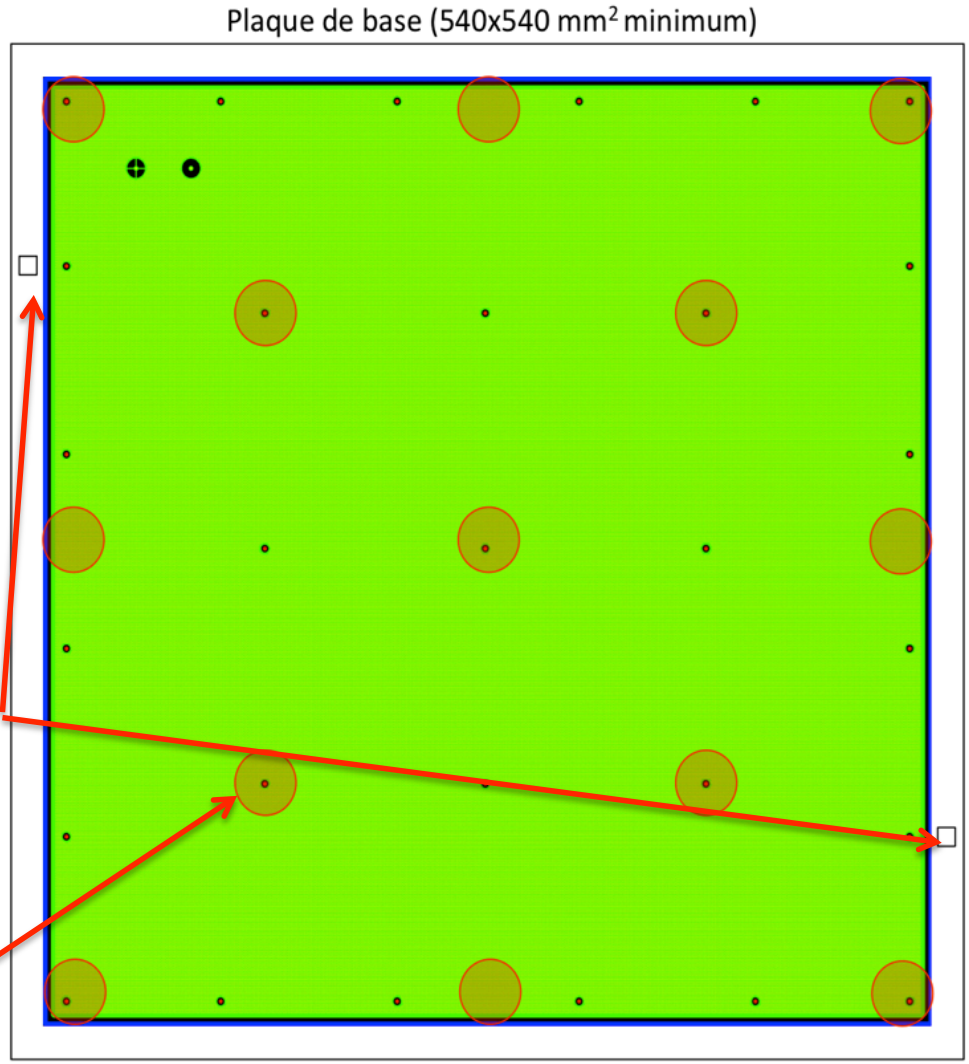
1/ Raw FR4 thickness selection (1.21 -0.04/+0 mm)

2/ LEM visual inspection

a/ Copper apect : scratches, …
b/ Copper etching defects (Vs gerber)
c/ Defects in hole locations.
d/ Defects of LEM holes : « filled » hole, drilling defect (diameter, cylindricity)

A picture of the defects is joint to the LEM travelling sheet.

Type a/ defect requires LEM validation by WA105. Other types of defects are considered critical and the LEM rejected.




3/ LEM Automated Optical Inspection

Thicknesse and rim measurement in the 2 metallographic sections

4/ LEM Automated Optical Inspection

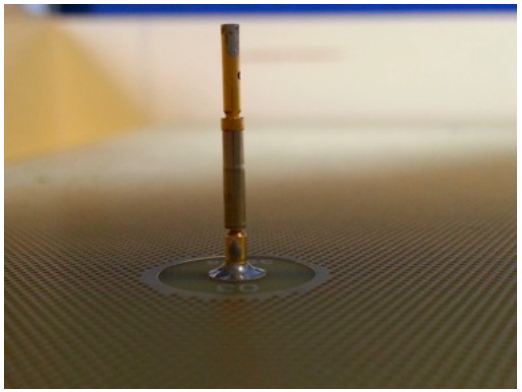
RIM dimension measurement in 13 locations

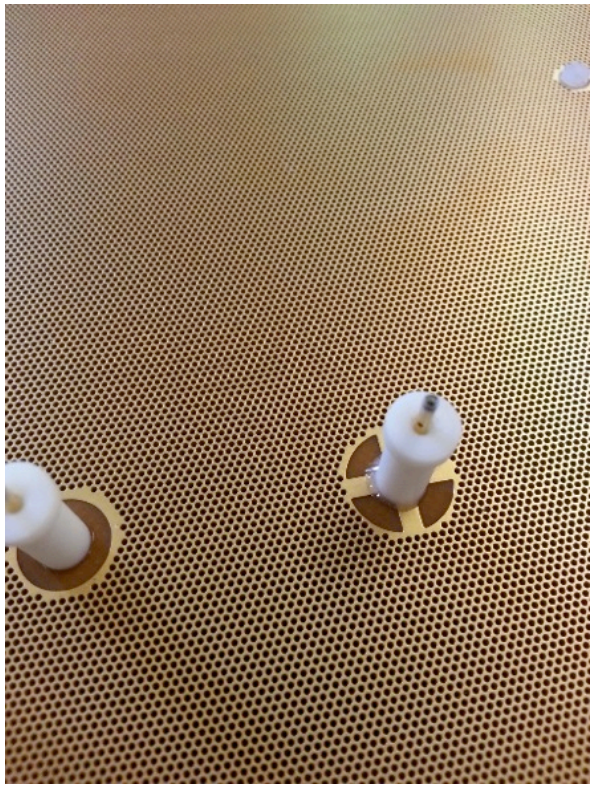
5/ LEM insulation measurement

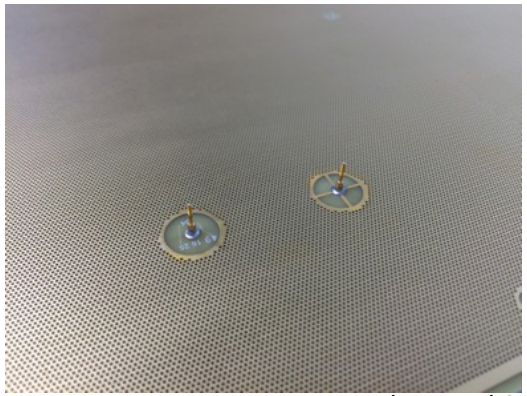
Done at least @ 500 V with R > 1 GΩ

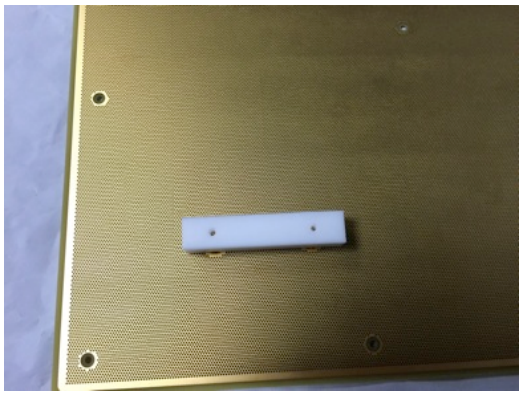
# 2/ LEM HV CONNECTIONS

- Solder pins with Core 230 no-clean wire solder
- Use of a dedicated tool to position and maintain pins while soldering
- Unplated Φ1.2 mm holes
- Gluing of the insulating cylinders with 2011 Araldite (AW 106/HV 953U) using a centering tool : POM (used on 3x1x1 $m^3$) changed to MACOR (used for 3 l prototype)
- Order to be placed : Φ4,8 mm 30 cm long Macor rod is ≈300 € (15 LEM) + machining









# 6/ LEM MANUFACTURING PROCEDURE
## LEM FINAL QUALIFICATION

By LEM manufacturer

- CNC drilling
- mechanical polishing
- permanganate bath +rince
- Rims by global etching
- passivation (Chromic acid)
- Ni/Au plating

By WA105

- ultrasonic bath DM water
- lessive (soap) bath at 60°C
- karcher DM water
- baking 3 hrs at 80 degrees
- HV test

HV test not ok | HV test ok → storage

Uniform electric field between two // plates at ΔV

$$G = \exp(\alpha.d) \qquad \alpha = \frac{P}{T} A \exp\left(-\frac{B}{E}\frac{P}{T}\right)$$

$G$ : Gain (primary charge multiplication)

$\alpha$ : first Townsend coefficient

$A$ and $B$ : parameters depending on the gas

$P$ : Pressure $T$ : Temperature $d$ : amplification gap

Gas density @ 88 K / 1 bar (Dlar) ⇔ @ 293 K / 3.3 bar

Same BV and same gain (assuming same gas purity and no A,B dependance with P,T)

LEM final test

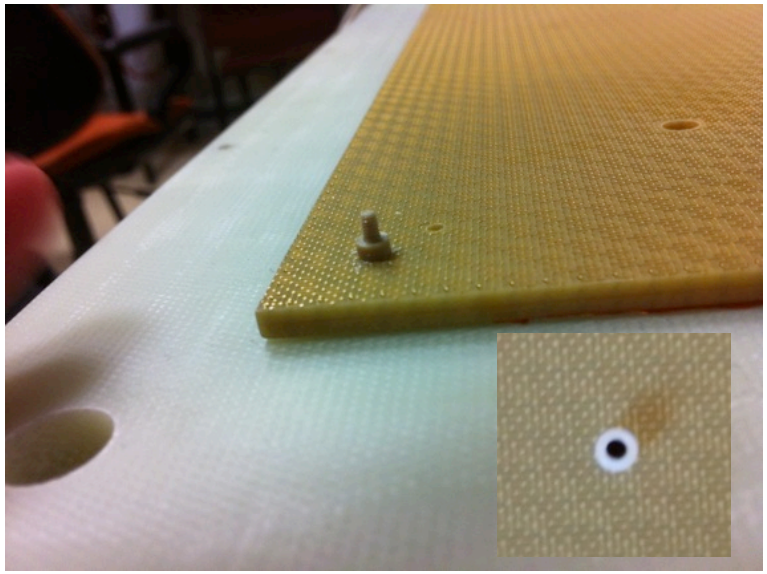
Breakdown voltage and sparking rate measurement at $P_{abs} \approx 3.3$ bar

*Optional Gain measurement at $P_{abs} \approx 3.3$ bar with $^{241}Am$*

Acceptance criteria (BV & sparking rate) will be fixed after the tests of the first 6 LEMs

# LEM + ANODE ASSEMBLY ON CRP

Dealing with the 20 individual spacers which are free to move during LEM+Anode assembly on CRP

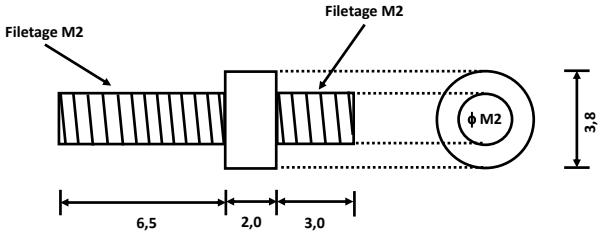


- Baseline solution: gluing the spacers on the anode PCB in CR185 with a dedicated tool (to be done). Mount the LAS on CRP with the 20 peripheral screws.

- Solution 2: using specific M2 screws + 2 nuts. First mount & align anode on CRP, then assemble LEM with nuts.

→ On-going review to choose the best solution (ETHZ, LAPP, IRFU)

Entretoise CRP WA105

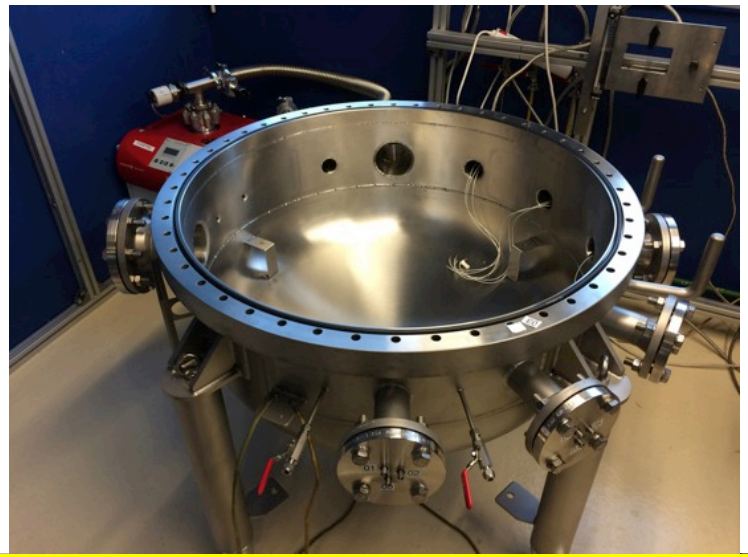



Matériau : PEEK

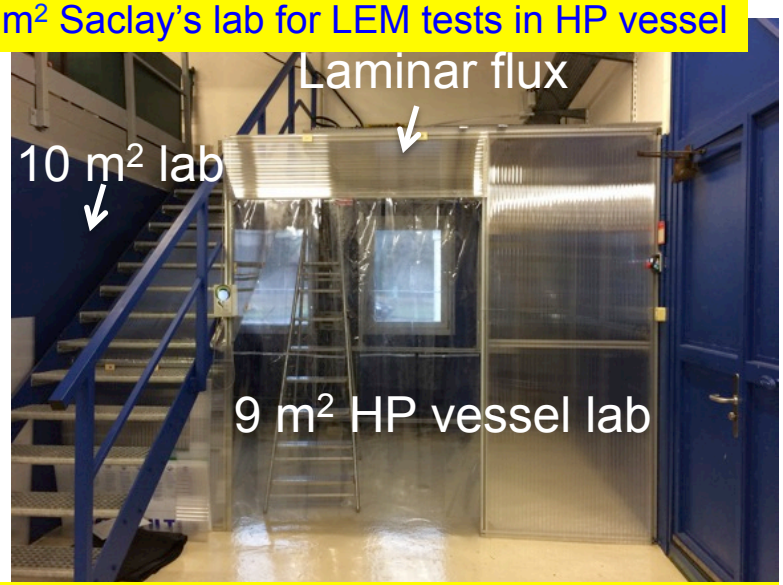
1.18 €/ spacer for an order of 4500

# HIGH PRESSURE VESSEL TEST BENCH FOR LEM FINAL QUALIFICATION @ $P_{ABS}$≈3.3 BAR

HP vessel (with gas P,T monitoring)

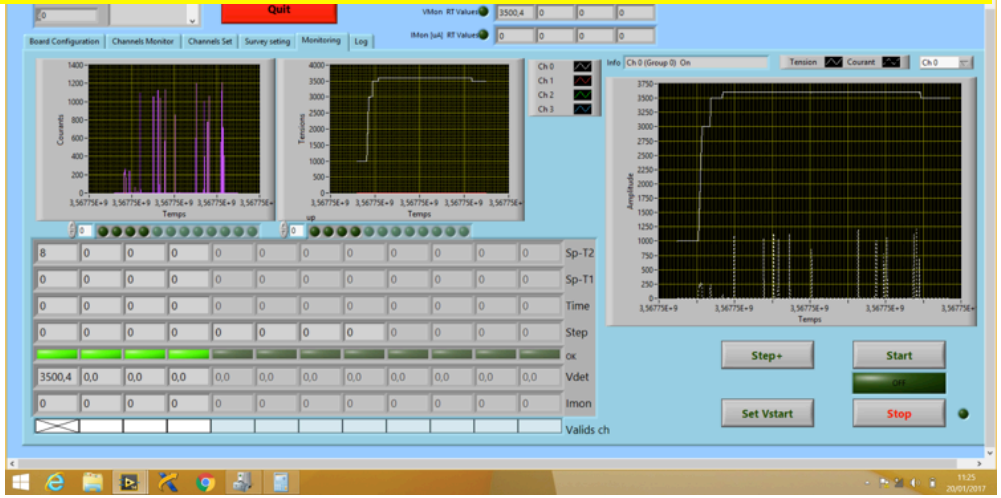


9 m² Saclay's lab for LEM tests in HP vessel




A tower of 6 LEMs can be simultaneously tested in the HP vessel

Labview automated procedure to increase LEM HV up to Breakdown Voltage with sparking rate measurement



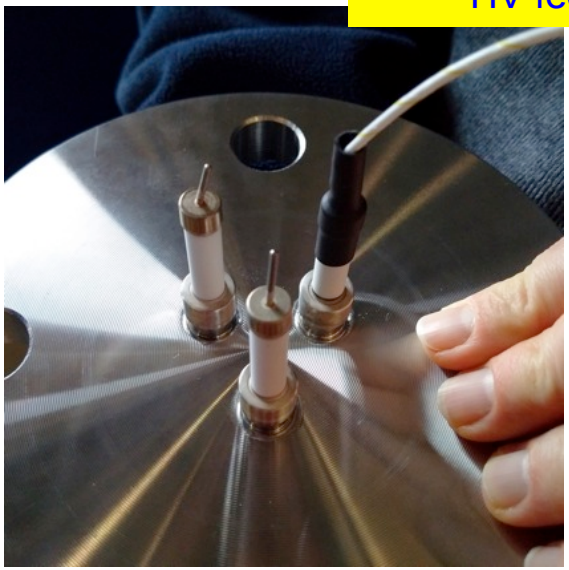
# WA105 3,3 BAR VESSEL : FEEDTHROUGHS NEED TO BE "CERTIFIED"

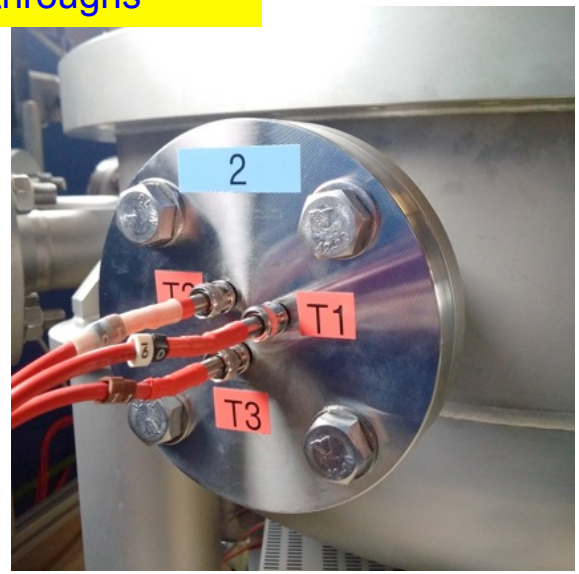
- CEA-Saclay safety division does not allow the operation of the vessel at the nominal 3.3 bar mainly because feedthroughs are not "fully" certified in compliance with Under Pressure Equipment regulations.

- We are dealing with this issue with the APAVE certifying agency in order to find the better way to converge with a solution.

- We got the authorization to operate at 0.5 bar maximum above atm pressure and authorization to use the $^{241}$Am source in the vessel.

HV feedthroughs

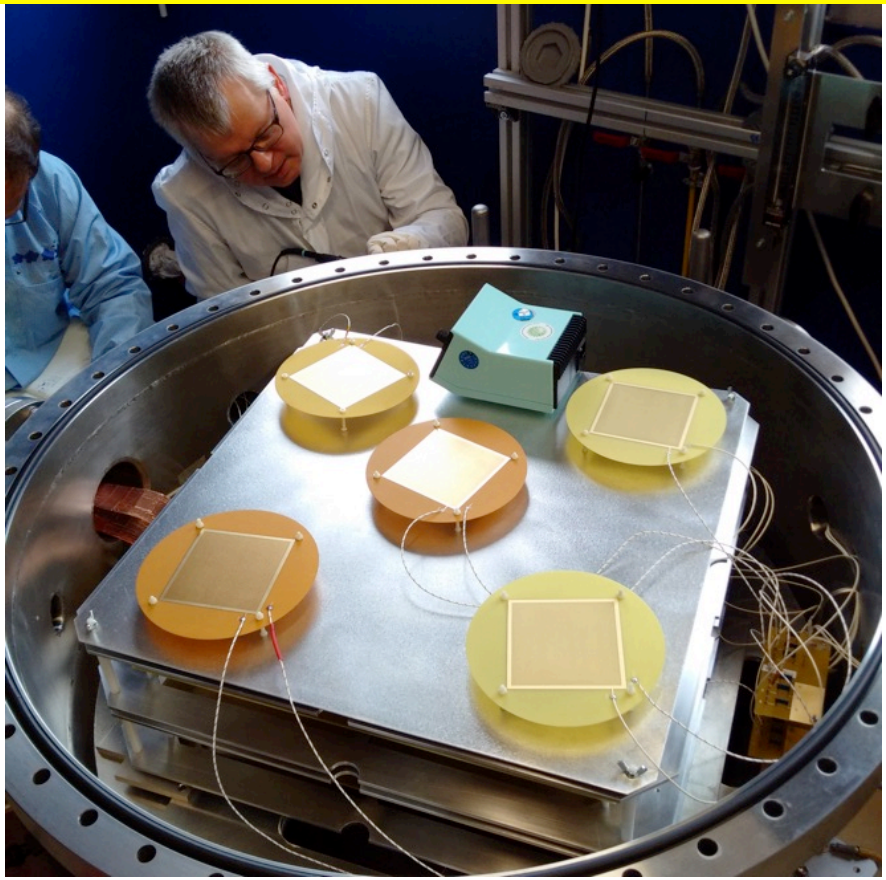





Front-End electronics feedthroughs

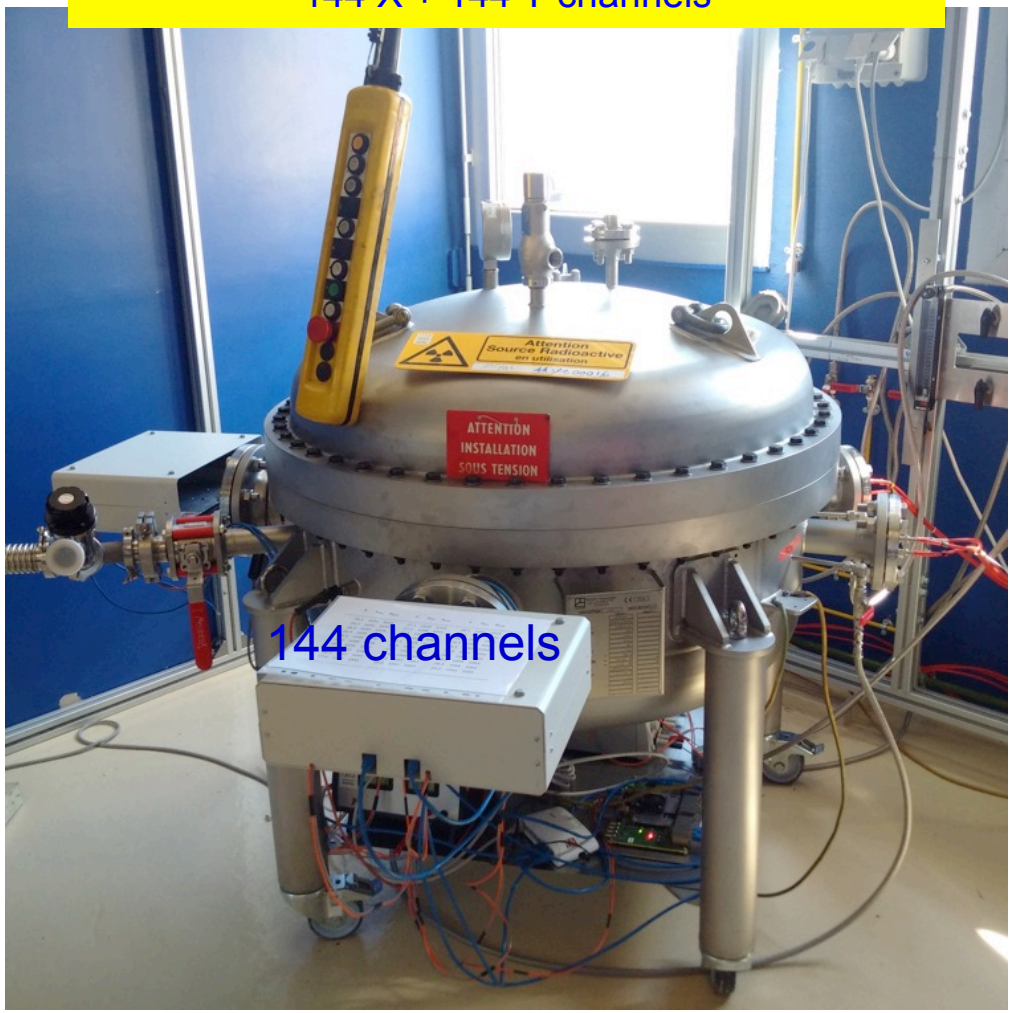
# WA105 PRESSURE WESSEL
# BV MEASUREMENT @ NTP (AIR & ARGON)

Mounting of a tower of 5 LEMs in the HP vessel
Tuning of the Labview Automated procedure for BV



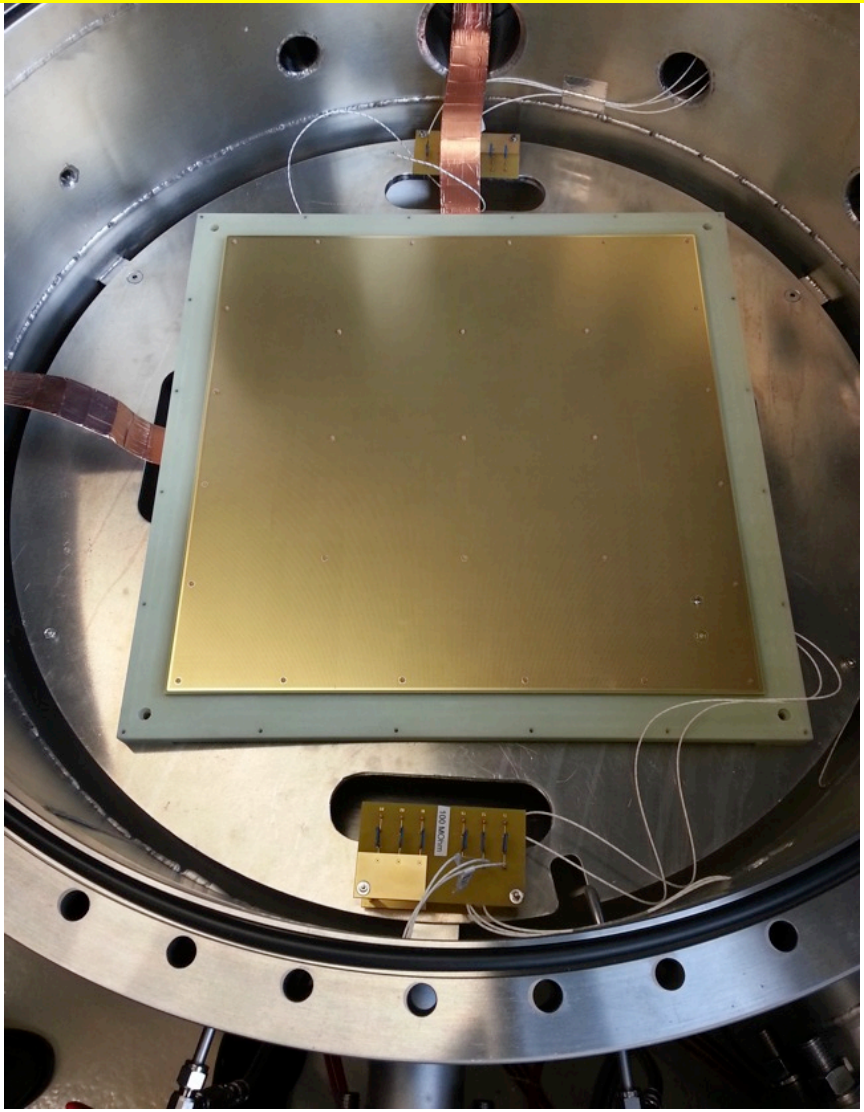
Tuning with four 50x50 $cm^2$ LEMs polarized through 2 polarization schemes :
ELTOS#2, ELTOS#3 (60 μm RIM) → 100 MΩ
2 x ELVIA LEMs → 1 GΩ resistor

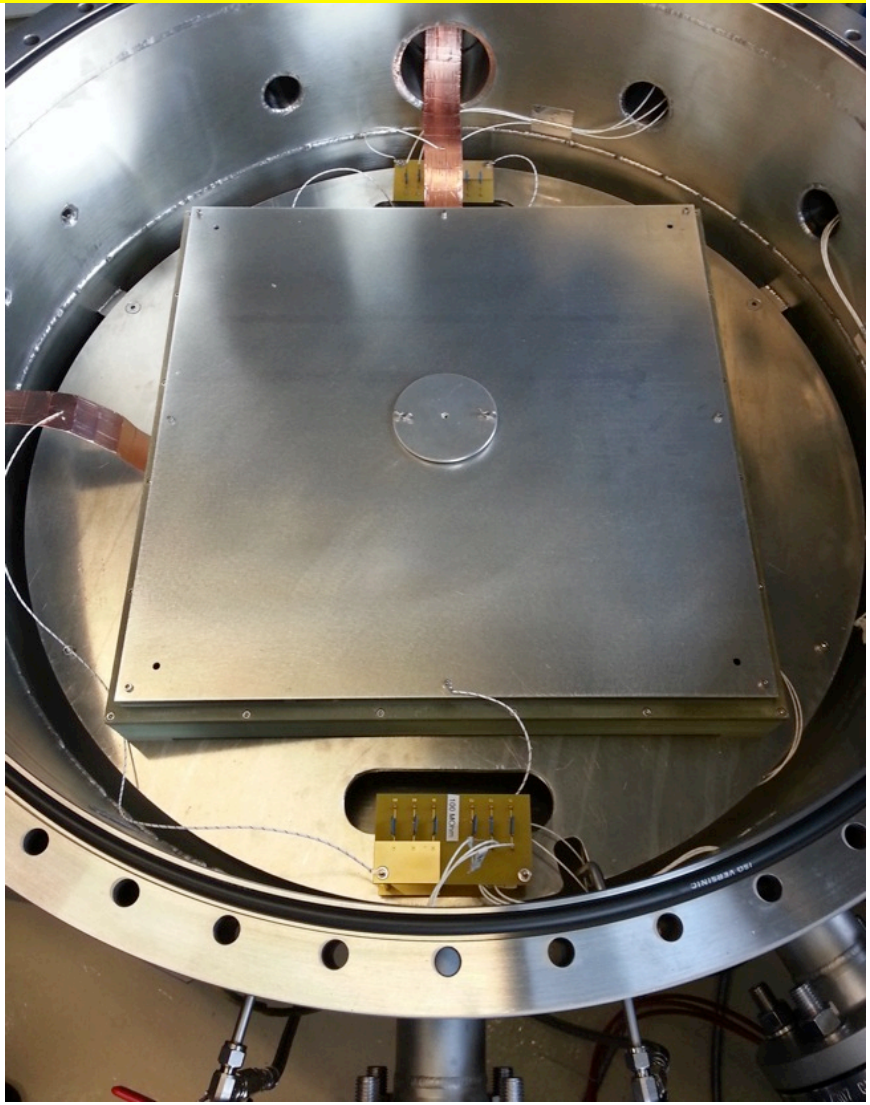
AFTER based electronics readout
144 X + 144 Y channels



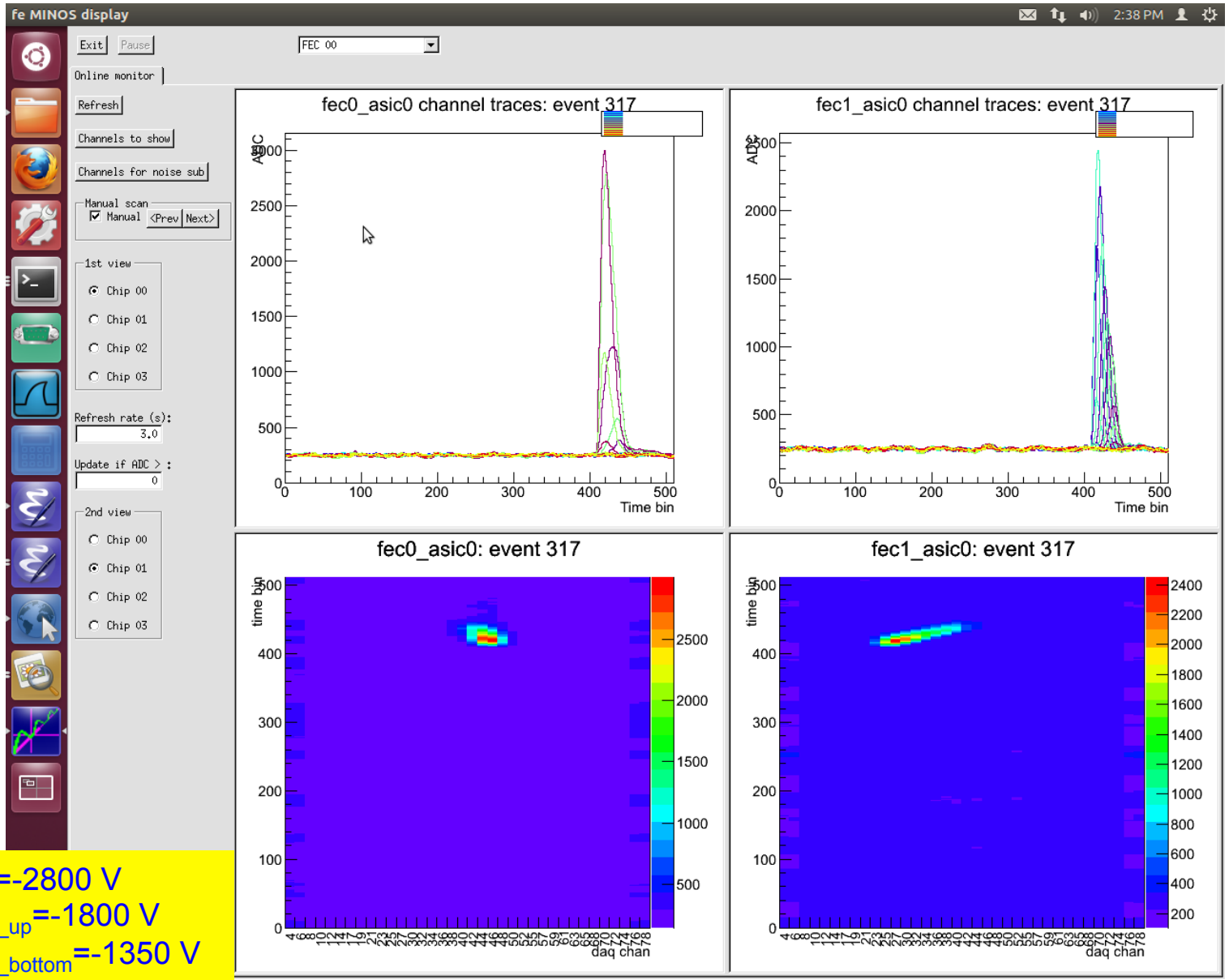
# WA105 PRESSURE WESSEL
# $^{241}$Am SOURCE SETUP @ NTP 5.7 ARGON

## ELTOS# LEM + anode + cathode with $^{241}$Am source (5 cm above LEM)





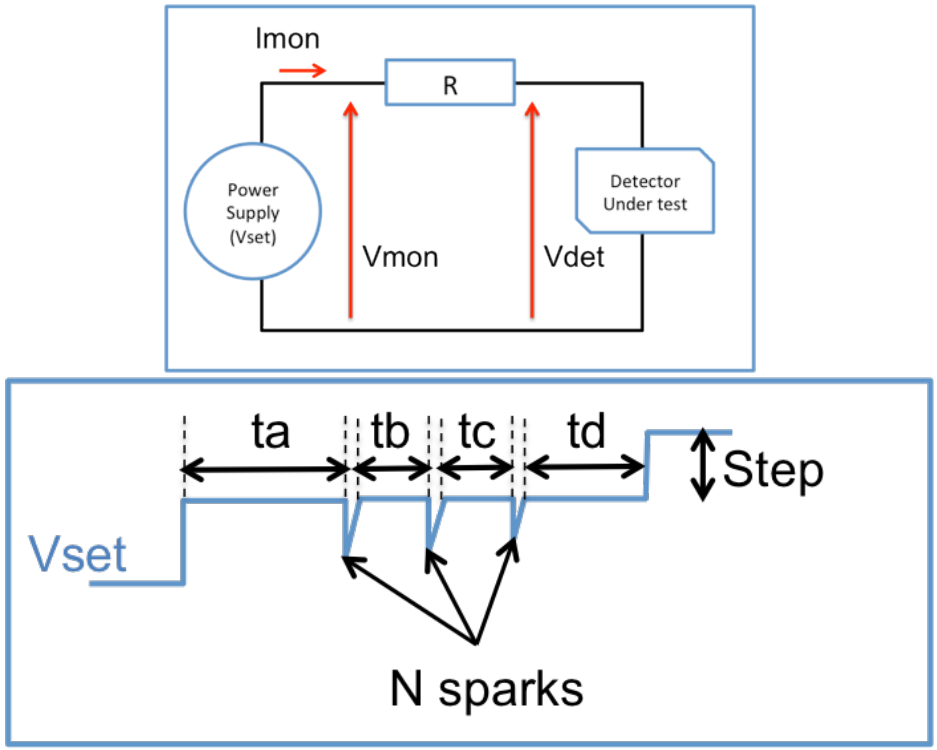
# FIRST $^{241}$Am SOURCE TRACK ON A 50X50 CM$^2$ LEM+ANODE IN NTP 5.7 Ar

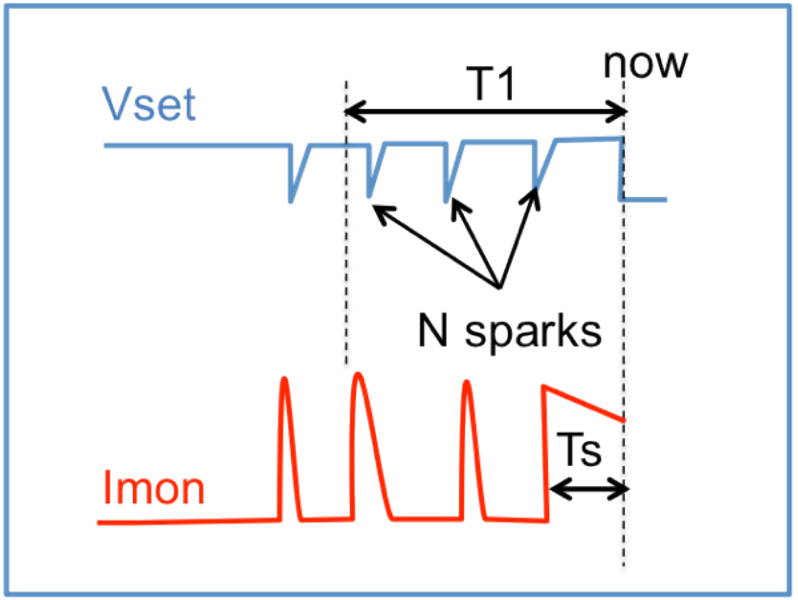



$V_{cath}$=-2800 V
$V_{LEM\_up}$=-1800 V
$V_{LEM\_bottom}$=-1350 V

# LABVIEW AUTOMATED PROCEDURE TO INCREASE LEM HV UP TO BREAKDOWN VOLTAGE

- The Labview procedure can handle up to 12 HV independent channels. $V_{det}$ and current $I_{mon}$ are monitored, on-line displayed and recorded in an ASCII file at 1 Hz. Sparks are detected and counted when Imon>Imax with Vdet=Vset +/- **ΔV**
- Timers T1 and T2 only count the time the LEM is at Vdet=Vset +/- **ΔV**

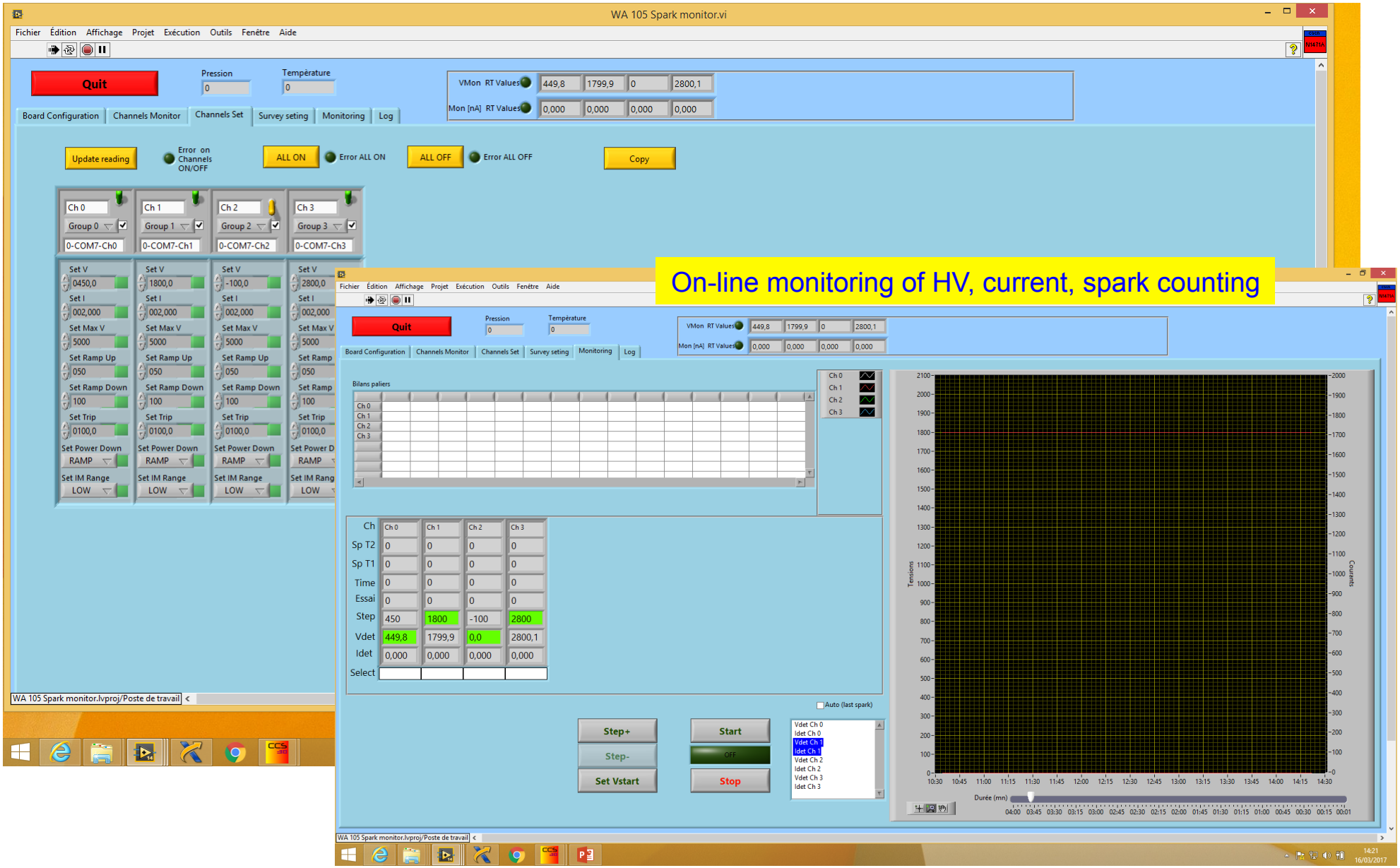



HV is increased of **HV_STEP** if :
$V_{Det}$ < Vmax AND maintained at least for **T2**
Nbre of sparks SpT2 < **$SpT2_{max}$** during **T2**

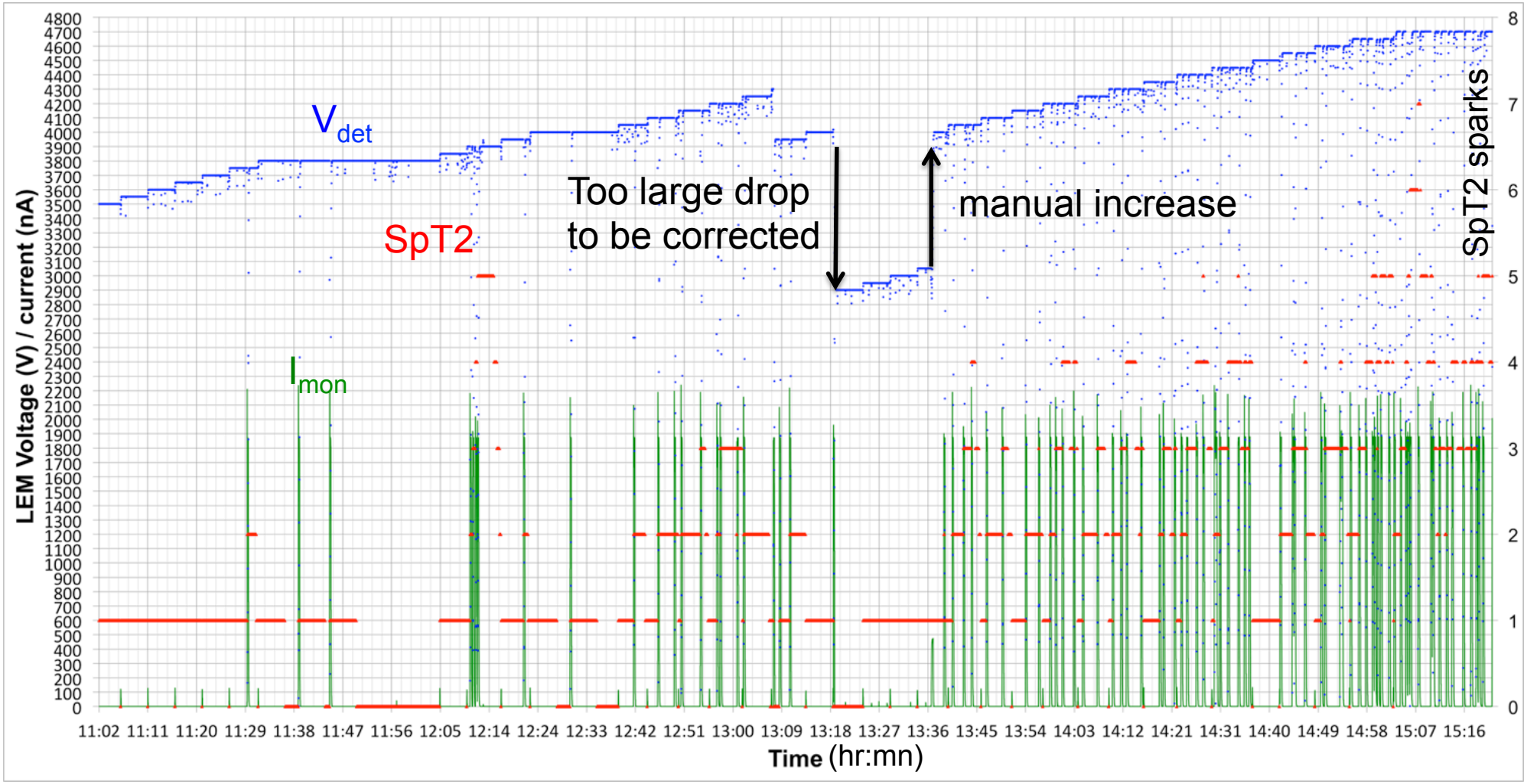
HV is decreased of **HV_STEP** if :
$I_{mon}$ > **Imax** during **TiMax**
Spark duration Ts > **TspMax**
Nbre of sparks SpT1> **$SpT1_{max}$** during **T1**

# LABVIEW AUTOMATED PROCEDURE

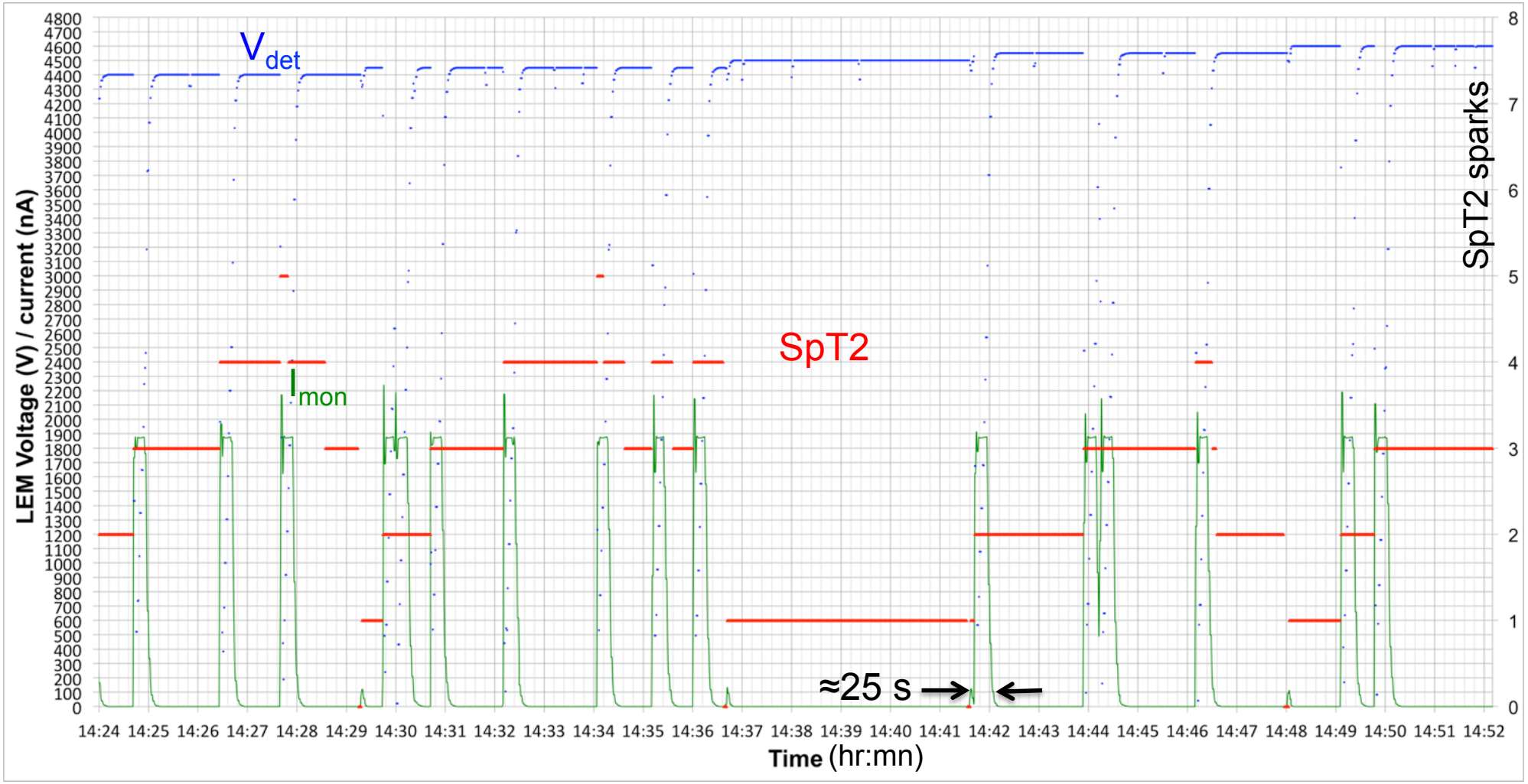


# HV INCREASE IN SYNTHETIC AIR NTP ELTOS#2

- ELTOS#2 was raised from 3400 V up to 4700 V in 4 hours
- T1=30s, $SpT1_{max}$=10, T2=300s, $SpT2_{max}$=10, $\Delta V$=100 V, HV_STEP=50 V, Imax=100 nA
- Tuning of the procedure and parameters is going on …



# HV INCREASE IN SYNTHETIC AIR NTP ELTOS#2

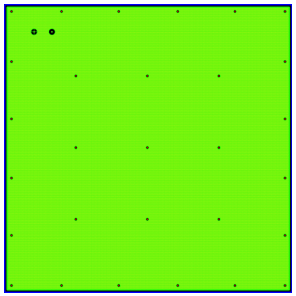


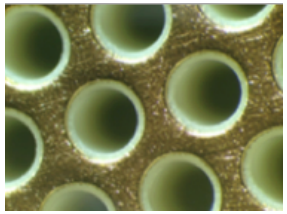
# LEM SPECIFICATIONS DOCUMENT
# FINAL VERSION « DB » VALIDATED ON FEB 16TH



## CAHIER DES CHARGES ET DES SPECIFICATIONS TECHNIQUES

## PRODUCTION DES LEM DU PROTOTYPE WA105 (DUNE/DP)





**HISTORIQUE DES MODIFICATIONS**

| Version | Date | Pages modifiées | Motifs |
|---|---|---|---|
| DRAFT | 30/09/2016 | Création | Pour diffusion restreintes et corrections |
| DRAFT2 | 19/01/2017 | | Modifications et corrections après l'appel à candidatures |
| DA | 01/02/2017 | | Version A pour corrections par la collaboration WA105 |
| DB | 16/02/2017 | | Version B pour diffusion de l'appel d'offre |
| | | | |

| | Rédacteurs | | Vérificateurs | Approbateur |
|---|---|---|---|---|
| Nom | A. DELBART | E. MAZZUCATO | Y. PENICHOT | M. ZITO |
| Fonction | Chef de Projet | Resp. Physicien | Resp. QA | Resp. Scientifique |
| Date | | | | |
| Visa | | | | |



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# LEM PRODUCTION TENDERING STATUS

- A first call for applicants was launched by the CEA Commercial Division on december 15th 2016 and several companies were selected on january 10th 2017.

- The "Technical specifications" document was finalized and validated by the WA105 Technical Board on february 16th. The commercial documents needed for the call for tender were finalized by the Commercial Division of CEA-Saclay at the end of february.

- The call for tender, restricted to the selected companies, was delayed by 3 weeks because of a heavy overload of the CEA-Saclay commercial division to get the documents validated and signed.

- The call for tender will be launched in a couple of days for an application deadline fixed 2nd or 3rd week of april. With 2 weeks needed for the contract to be signed, LEM Production by the manufacturer could be planned to start at beginning of may.

# PROPOSED DELEVERY SCHEDULE FOR LEM CALL FOR TENDER

- With help from 1 technician from the WA105 collaboration, cleaning and QA/QC of a maximum of 12 LEMs per week could be done @ Saclay (limited by ≈3.3 bar test)

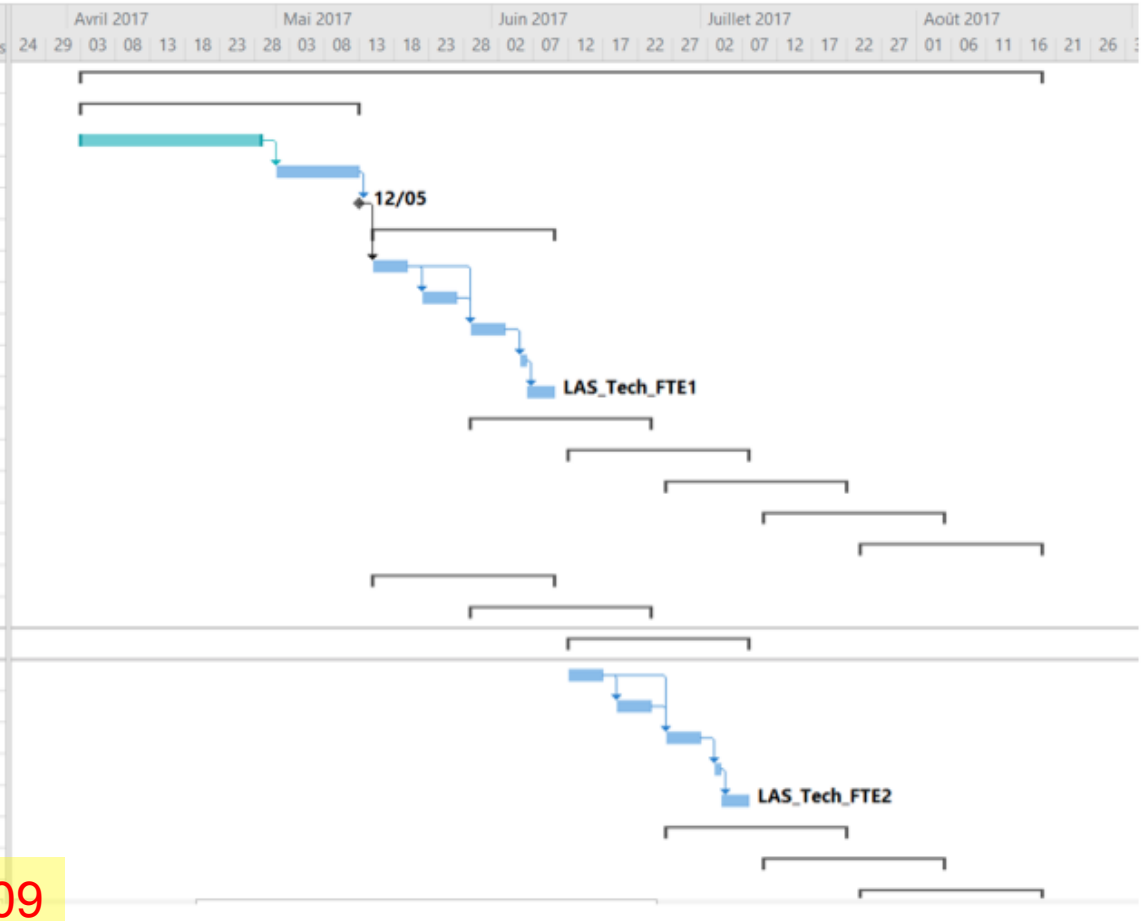
| Proposed schedule for CEA/Irfu Call for Tender (78 LEMs) | |
|---|---|
| **T0** | **Signature of the contract & kick-off meeting** |
| T0 + 2 weeks | - Pre-production kick-off meeting<br>- Delivery of the LOFC (PAQ), gerber files validation, documentation as described in section 3.1 |
| T0 + 4 weeks | - Delivery of **6** pre-series LEM and associated documentation |
| T0 + 6 weeks | - Production kick-off meeting<br>- Delivery of **12 batches of 6 LEMs every week**. |
| T0 + 18 weeks | - Delivery of the last batch<br>- Closing meeting (T0+21 semaines) |

- The second half of the 144 LEMs (and anodes) needed for the WA105 demonstrator will be provided by ETHZ through a separate Call For Tender with the same technical specifications and the same production schedule.

- The production, QA/QC and final testing at $P_{abs}$≈3.3 bar of the 144 LEMs needed for the WA105 demonstrator could therefore be done in ~20 weeks. This does not include any margins regarding the capability of the companie(s) to provide 12 LEMs per weeks, the achieved yield of quality production, and the actual time needed to perform the LEM cleaning, QA/QC, and final testing at ≈3.3 bar.

# UPDATED WA105 SCHEDULE
# TECHNICAL BOARD 03/15/2017

| Nom de la tâche | Durée | Début | Fin | Prédécesseurs |
|---|---|---|---|---|
| **LAS Supply** | **100 jours** | **03/04/2017** | **18/08/2017** | |
| **LAS Production Validation** | **30 jours** | **03/04/2017** | **12/05/2017** | |
| LEM production (Preserie 6 LEMs) | 20 jours | 07/04/2017 | 28/04/2017 | |
| LEM Preserie Tests | 10 jours | 01/05/2017 | 12/05/2017 | 64 |
| LEM Production Validated | 0 jour | 12/05/2017 | 12/05/2017 | 65 |
| **12 LAS production** | **20 jours** | **15/05/2017** | **09/06/2017** | |
| 6 LEM Batch production | 5 jours | 15/05/2017 | 19/05/2017 | 66 |
| 6 LEM Batch production | 5 jours | 22/05/2017 | 26/05/2017 | 68 |
| 12 LAS Processing at Saclay | 5 jours | 29/05/2017 | 02/06/2017 | 68;69 |
| 12 LAS send to CERN | 1 jour | 05/06/2017 | 05/06/2017 | 70 |
| 12 LAS Assembly at CERN | 4 jours | 06/06/2017 | 09/06/2017 | 71 |
| **12 LAS production** | **20 jours** | **29/05/2017** | **23/06/2017** | |
| **12 LAS production** | **20 jours** | **12/06/2017** | **07/07/2017** | |
| **12 LAS production** | **20 jours** | **26/06/2017** | **21/07/2017** | |
| **12 LAS production** | **20 jours** | **10/07/2017** | **04/08/2017** | |
| **12 LAS production** | **20 jours** | **24/07/2017** | **18/08/2017** | |
| **12 LAS production** | **20 jours** | **15/05/2017** | **09/06/2017** | |
| **12 LAS production** | **20 jours** | **29/05/2017** | **23/06/2017** | |
| **12 LAS production** | **20 jours** | **12/06/2017** | **07/07/2017** | |
| 6 LEM Batch production | 5 jours | 12/06/2017 | 16/06/2017 | 111 |
| 6 LEM Batch production | 5 jours | 19/06/2017 | 23/06/2017 | 116 |
| 12 LAS Processing at Saclay | 5 jours | 26/06/2017 | 30/06/2017 | 116;117 |
| 12 LAS send to CERN | 1 jour | 03/07/2017 | 03/07/2017 | 118 |
| 12 LAS Assembly at CERN | 4 jours | 04/07/2017 | 07/07/2017 | 119 |
| **12 LAS production** | **20 jours** | **26/06/2017** | **21/07/2017** | |
| **12 LAS production** | **20 jours** | **10/07/2017** | **04/08/2017** | |
| **12 LAS production** | **20 jours** | **24/07/2017** | **18/08/2017** | |




T0: 1/05

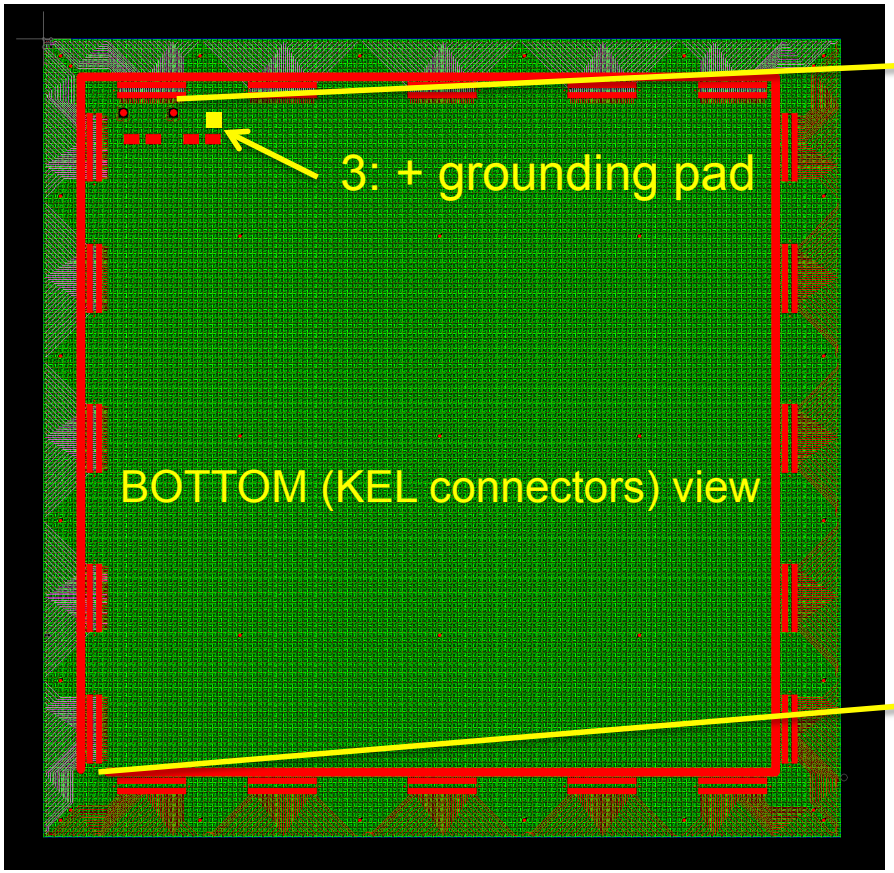
22/09

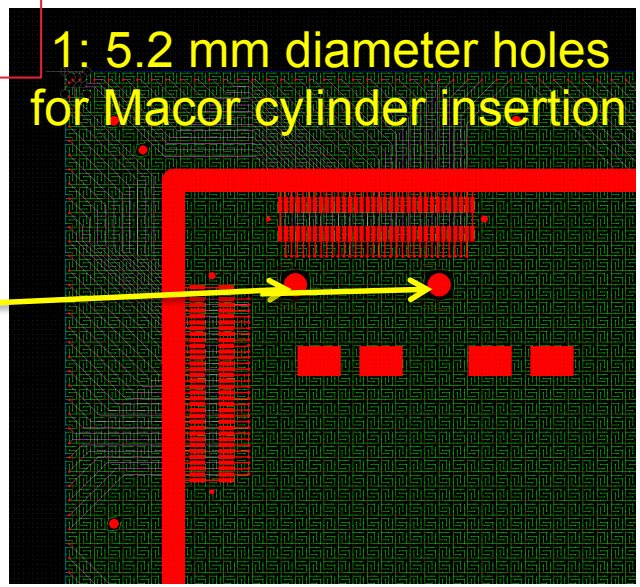
4 weeks shift due to delay of the launch of the Call for Tender
1 week shift due to CEA-Saclay closed 14-18 august
Schedule to be updated ASAP to take into account the availability of IRFU man power from july 1st to september 15th, the actual production of the LEM manufacturer, …
Without help from 1 FTE WA105 technician, add 12x5 days delay for LEM processing.

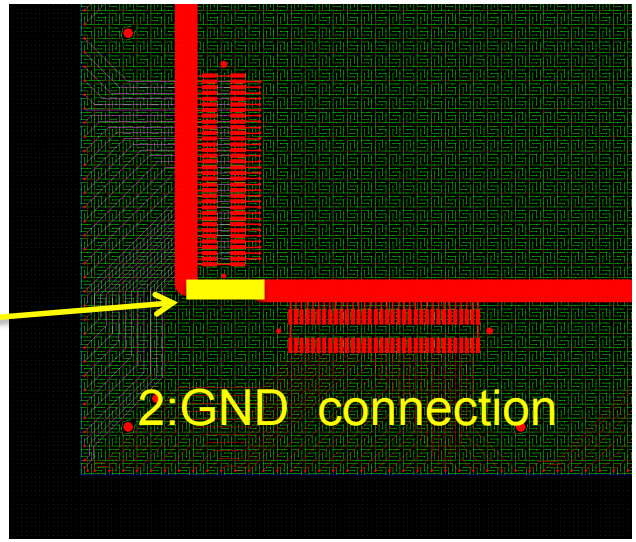
# ANODE MANUFACTURING GERBER FILES DESIGN MODIFICATIONS VS 3X1X1 $m^3$

The WA105 anode is using the same 3.5 mm thick, 4 layer PCB as for the 3x1x1 $m^3$ with the following modifications

- Modification 1 is done
- Modification 2 and 3 are still to be done



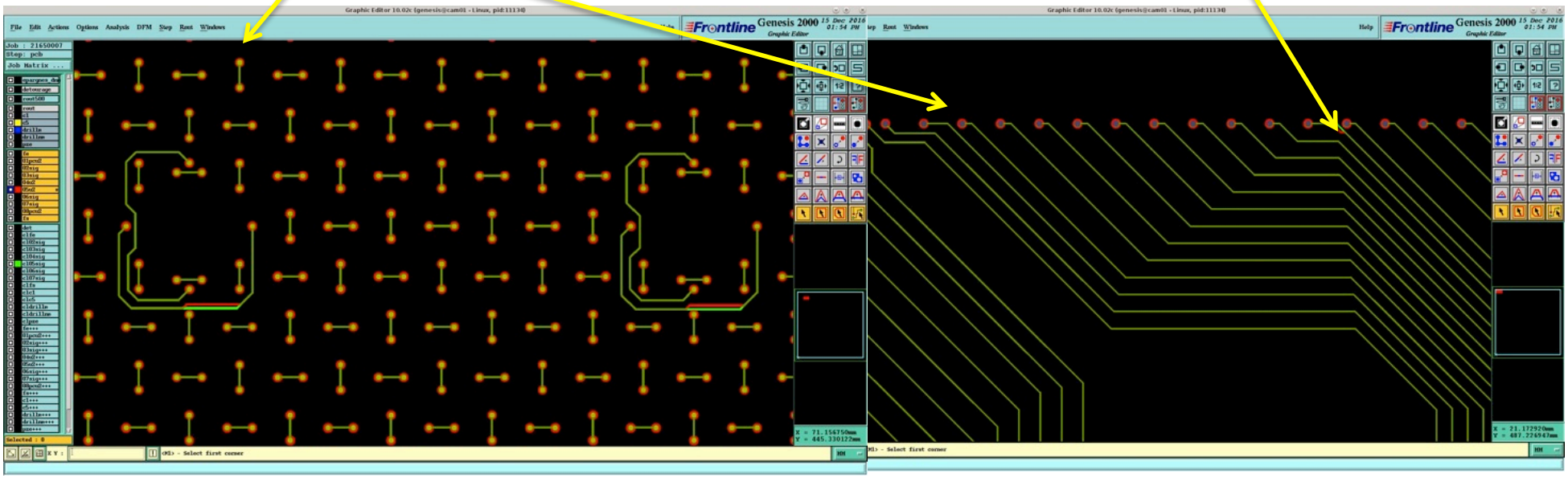



# ANODE MANUFACTURING GERBER FILES
## REQUESTED MODIFICATIONS FROM MANUFACTURERS

- 2 anode PCBs were ordered to the ELVIA company on january 15th in order to check their capability to produce the anode.
- Some modifications were requested by ELVIA to cope with their manufacturing tolerances. The ones concerning the internal layers and vias were done.
- Delivery was shifted to next week because of several errors in the management of the production tasks by ELVIA.

Φ0.45 mm holes increased to Φ0.5 mm
and corresponding vias increased to Φ0.8 mm

Example of modified routing line (red)

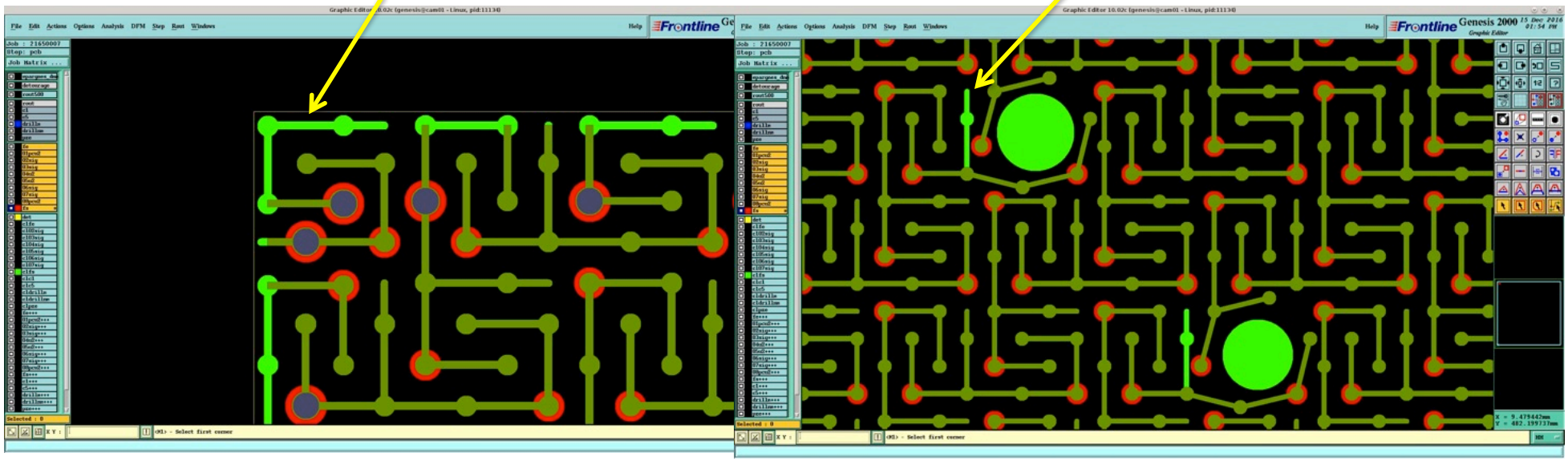


# ANODE MANUFACTURING GERBER FILES
## REQUESTED MODIFICATIONS FROM MANUFACTURERS

- Another group of modifications (light green) were requested and concern the TOP layer of active anode strips. These modifications were not done yet.
- We still have to decide with ETHZ how to proceed with these requests and fix the final gerber files for production.
- Next step will be to ask for quotations and make the order (1/2 by IRFU).
- The test bench for continuity check of the anode strips, including the soldered KEL connector connections, is to be done.

TOP strips too close to the border (200 μm required)

TOP strips too close to a via



# CONCLUSION

- The procedure for LEM production and QA/QC, both in the PCB industry and in laboratory, is well established. Tendering documents are finalized and technical specifications were validated by the Technical Board.

- Several companies were selected by a call for applicants in january.
The call for tender, restricted to these companies, will be launched in a couple of days and the start of the production expected for beginning of may.

- Most of the equipments and procedures for LEM Q/C are finalized.
The high pressure vessel is currently used at atmospheric pressure to tune the Breakdown Voltage Q/C automated procedure and to test a LAS with $^{241}$Am.
CEA/Saclay Safety Division did not yet authorize its operation at 3.3 bar ABS.

- Anode design and gerber files must be shortly fixed to update quotations from manufacturers and place the order.
The anode+LEM assembly procedure is not yet chosen and must be fixed soon.