Quality assurance and control of LEM and Anode at IRFU-Saclay

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Based on the talk given by A. Delbart at the March 2017 WA105 Collaboration Meeting

Anode

LEM

dC/dl ~ 150 pF/m

Proto DUNE DP Technical Design Review, April 24 2017
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 @ $P_{abs} \approx 3.3$ bar
✓ By the WA105 collab. @ CERN : LEM + Anode + assembly on CRP

Status of the call for tender for the LEM production

Anode PCB : specifications, QA/QC

Conclusion
IRFU CEA Saclay has a long experience in building large detectors, in particular tracking detectors (e.g., CDHS, NA48, DELPHI TPC, NOMAD,...)

- Since 1996 it has played together with CERN a pioneering role in the development of MicroPattern Gas Detectors with the invention of Micromegas detectors.

- Our group has designed and built the Micromegas for the first large TPCs based on MPGD for T2K (9 m²), operating flawlessly since 2010.
x50 cm² LEM (3x1x1 m³ design) specifications for WA105 demonstrator

<table>
<thead>
<tr>
<th>Raw material</th>
<th>Procurement in one batch with thickness selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>PANASONIC R-1566W (halogen free)</td>
</tr>
<tr>
<td>Dimensions</td>
<td>540 mm x 540 mm</td>
</tr>
<tr>
<td>FR4 mean thickness</td>
<td>1 mm (-0.04/+0 mm according to the specifications of the delivered batch)</td>
</tr>
<tr>
<td>Copper layer thickness</td>
<td>105 μm on both sides</td>
</tr>
<tr>
<td>Mean total thickness</td>
<td>1.21 (-0.04/+0) mm +/- 0.04 mm (mean thickness of all the LEMs produced)</td>
</tr>
<tr>
<td>Total Thickness uniformity</td>
<td>+/- 0.04 mm (thickness uniformity over each LEM surface)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Produced LEM</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>499.5 mm x 499.5 mm +/-0/-0.2 mm</td>
</tr>
<tr>
<td>Ni/Au finish</td>
<td>YES: 5 μm Ni + 0.1 μm Au</td>
</tr>
<tr>
<td>Screen printing</td>
<td>YES (for LEMs serial number printing)</td>
</tr>
<tr>
<td>Solder resist mask</td>
<td>NO</td>
</tr>
<tr>
<td>Final thickness (Ni/Au included)</td>
<td>1.15 (-0.04/+0) mm +/- 0.04 mm (mean thickness of all the LEMs produced)</td>
</tr>
<tr>
<td></td>
<td>+/- 0.04 mm (thickness uniformity over each LEM surface)</td>
</tr>
<tr>
<td>« active » holes with RIM</td>
<td>~ 400 000 non-plated 0.5 mm diameter holes</td>
</tr>
<tr>
<td>RIM (after Ni/Au treatment)</td>
<td>40 μm +/- 4 μm</td>
</tr>
</tbody>
</table>

These specifications are the ones used in the call for tender
The gerber files which will be used for the production are those of the 3x1x1 m³ LEMs with the following modifications (next slide).
LEM gerber files for 6x6x6 m³
design modifications Vs 3x1x1 m³

- 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

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/</td>
<td>LEM thickness metrology</td>
</tr>
<tr>
<td>2/</td>
<td>Soldering of HV pins</td>
</tr>
<tr>
<td>3/</td>
<td>Mounting on aluminum handling plate (dismounted when LEM is packed for shipping)</td>
</tr>
<tr>
<td>4/</td>
<td>“Saclay Cleaning”</td>
</tr>
<tr>
<td></td>
<td>3 mn Ultrasonic bath with “soap NGL 17.40 ALU” at 65°C</td>
</tr>
<tr>
<td></td>
<td>+ regular water rinsing BEFORE DM water</td>
</tr>
<tr>
<td>5/</td>
<td>Gluing of HV insulating MACOR cylinders</td>
</tr>
<tr>
<td>6/</td>
<td>Final qualification @ 3.3 bar (abs)</td>
</tr>
</tbody>
</table>

- Change drills every 1000 holes
- Drilling of stack of PCBs is forbidden
- Drilling with pumice powder
- 4 steps (+/- 90°, top/bottom)
- Removes glass fiber from holes
- Acide sulfuric bath
- Baking 3 hrs at 50°
- Rinsing with DM water (R > 2 Mohm)

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

Alain Delbart, Purchase and QA/QC of LEM + anodes, WA105 collaboration meeting, CERN, March 22\(^{nd}\) - 23\(^{rd}\), 2017
0/ LEM Q/C by manufacturer

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

2/ LEM visual inspection

a/ Copper aspect : 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

Thickness 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 m³) 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
LEM manufacturing procedure
LEM final qualification

By LEM manufacturer
- CNC drilling
- Mechanical polishing
- Permanganate bath + rinse
- 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

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

Optional Gain measurement at \( P_{abs} \approx 3.3 \) bar with \(^{241}\text{Am}\)

Uniform electric field between two \(//\) plates at \(\Delta V\)

\[
G = \exp(\alpha \cdot d) \quad \alpha = \frac{P}{T} A \exp\left(-\frac{B \cdot P}{E \cdot T}\right)
\]

\(G\): Gain (primary charge multiplication)
\(\alpha\): first Townsend coefficient
\(A\) and \(B\): parameters depending on the gas
\(P\): Pressure
\(T\): Temperature
\(d\): amplification gap

Same gas density 88 K / 1 bar (Dlar) \(\leftrightarrow\) 293 K / 3.3 bar

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

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

Alain Delbart, Purchase and QA/QC of LEM + anodes, WA105 collaboration meeting, CERN, march 22\textsuperscript{nd} - 23\textsuperscript{rd}, 2017
Dealing with the 20 individual spacers which are free to move during LEM+Anode assembly on CRP

Assembly: using specific M2 screws + 2 nuts + spacers. First mount & align anode on CRP, then assemble LEM with nuts. A new solution with a PE spacer with smaller inner diameter has been adopted.
High pressure vessel test bench
for LEM final qualification @ $P_{\text{abs}} \approx 3.3 \text{ bar}$

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

HP vessel (with gas P,T monitoring)

9 m$^2$ Saclay’s lab for LEM tests in HP vessel

9 m$^2$ HP vessel lab

10 m$^2$ lab

Laminar flux
WA105 3.3 bar vessel: feedthroughs

**HV feedthroughs**

**Front-End electronics feedthroughs**
Mounting of a tower of 5 LEMs in the HP vessel
Tuning of the Labview Automated procedure for BV

AFTER based electronics readout
144 X + 144 Y channels

Tuning with four 50x50 and five 10x10 cm² LEMs
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

$V_{\text{cath}} = -2800 \text{ V}$

$V_{\text{LEM up}} = -1800 \text{ V}$

$V_{\text{LEM bottom}} = -1350 \text{ V}$

Alain Delbart, Purchase and QA/QC of LEM + anodes, WA105 collaboration meeting, CERN, march 22$^{nd}$ - 23$^{rd}$, 2017
The Labview procedure can handle up to 12 HV independent channels. \( V_{\text{det}} \) and current \( I_{\text{mon}} \) are monitored, on-line displayed and recorded in an ASCII file at 1 Hz. Sparks are detected and counted when \( I_{\text{mon}} > I_{\text{max}} \) with \( V_{\text{det}} = V_{\text{set}} \pm \Delta V \).

Timers \( T_1 \) and \( T_2 \) only count the time the LEM is at \( V_{\text{det}} = V_{\text{set}} \pm \Delta V \).

HV is increased of \( \text{HV\_STEP} \) if:
- \( V_{\text{det}} < V_{\text{max}} \) AND maintained at least for \( T_2 \)
- Nbre of sparks \( S_{\text{pT2}} < S_{\text{pT2}}_{\text{max}} \) during \( T_2 \)

HV is decreased of \( \text{HV\_STEP} \) if:
- \( I_{\text{mon}} > I_{\text{max}} \) during \( T_{\text{imax}} \)
- Spark duration \( T_s > T_{\text{spmax}} \)
- Nbre of sparks \( S_{\text{pT1}} > S_{\text{pT1}}_{\text{max}} \) during \( T_1 \)
Labview automated procedure

On-line monitoring of HV, current, spark counting
HV increase in synthetic air NTP
ELTOS#2

- ELTOS#2 was raised from 3400 V up to 4700 V in 4 hours
- $T_1=30\text{s}$, $SpT_{1\text{ max}}=10$, $T_2=300\text{s}$, $SpT_{2\text{ max}}=10$, $\Delta V=100\text{ V}$, $HV\_STEP=50\text{ V}$, $I_{\text{max}}=100\text{ nA}$
- Tuning of the procedure and parameters is going on …
HV increase in synthetic air NTP
ELTOS#2

\[ V_{\text{det}} \approx 25 \text{ s} \]

Alain Delbart, Purchase and QA/QC of LEM + anodes, WA105 collaboration meeting, CERN, march 22nd 23rd, 2017
CAHIER DES CHARGES ET DES SPECIFICATIONS TECHNIQUES

PRODUCTION DES LEM DU PROTOTYPE V1A05 (DUNE/DP)

HISTORIQUE DES MODIFICATIONS

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<th>Date</th>
<th>Pages modifiées</th>
<th>Motifs</th>
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<td>Création</td>
<td>Pour diffusion restreintes et corrections</td>
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<tr>
<td>DRAFT2</td>
<td>19/01/2017</td>
<td>Modifications et corrections après l'appel à candidatures</td>
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<td>DA</td>
<td>01/02/2017</td>
<td>Version A pour corrections par la collaboration WA105</td>
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<tr>
<td>DB</td>
<td>16/02/2017</td>
<td>Version B pour diffusion de l'appel d'offre</td>
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Alain Delbart, Purchase and QA/QC of LEM + anodes, WA105 collaboration meeting, CERN, march 22nd and 23rd, 2017
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 has been launched March 24th for an application deadline April 14. With 2 weeks needed for the contract to be signed, LEM Production process by the manufacturer could be planned to start at beginning of May.

The quotations received are in line with our previous estimations and with the secured budget.
With help from 1 additional technician (from another lab of the WA105 coll.), cleaning and QA/QC of a maximum of 12 LEMs per week could be done @ Saclay (limited by \( \approx 3.3 \) bar test).

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 a similar production schedule.

The production, QA/QC and final testing at \( P_{\text{abs}} \approx 3.3 \) bar of the 144 LEMs needed for the WA105 demonstrator could therefore be done in \( \approx 20 \) weeks. No contingency.

---

**Proposed schedule for CEA/Irfu Call for Tender (78 LEMs)**

<table>
<thead>
<tr>
<th>Beg. of May</th>
<th>Mid May</th>
<th>Beg. of June</th>
<th>Mid June</th>
<th>October</th>
</tr>
</thead>
</table>
| T0 + 2 weeks | - Pre-production kick-off meeting  
- 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  
- Delivery of **12 batches of 6 LEMs every week** | |
| T0 + 18 weeks | - Delivery of the last batch  
- Closing meeting (T0+21 semaines) | |

**Indicative dates**

- Beg. of May
- Mid May
- Beg. of June
- Mid June
- October
The WA105 anode is using the same 3.5 mm thick, 4 layer PCB as for the 3x1x1 m³ with the following modifications:

1: 5.2 mm diameter holes for Macor cylinder insertion

2: GND connection

3: + grounding pad
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.

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

Example of modified routing line (red)
We have received a quotation (delivery in 46 working days) and will place the order (1/2 by IRFU)

- Soldering of 20 connectors per anode will be done by an external company

According to PCB industry IPC standards, 2 QCs are done to insure the quality of the circuit:
- A.O.I. tests of inner layers before assembly & external layers on the final PCB.
- Tests of electrical continuities and insulations with a Flying Probe Tester of the final PCB
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. After receiving the quotations April 14th, the start of the production is expected beginning of May.

Equipments and procedures for LEM Q/C are ready.

Production of the LEM can start middle of June with a rate of 6 LEMs/week per company.