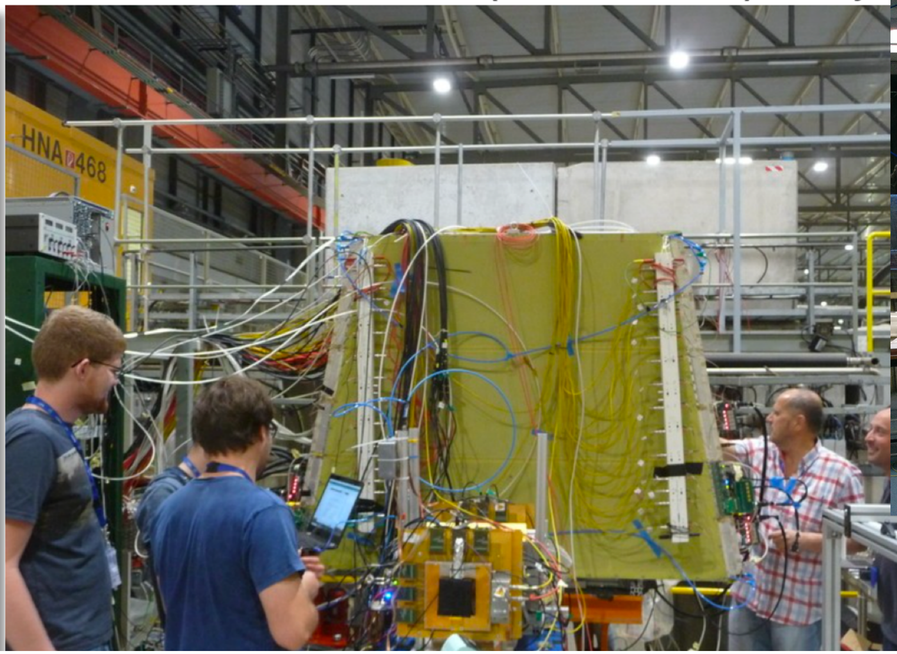
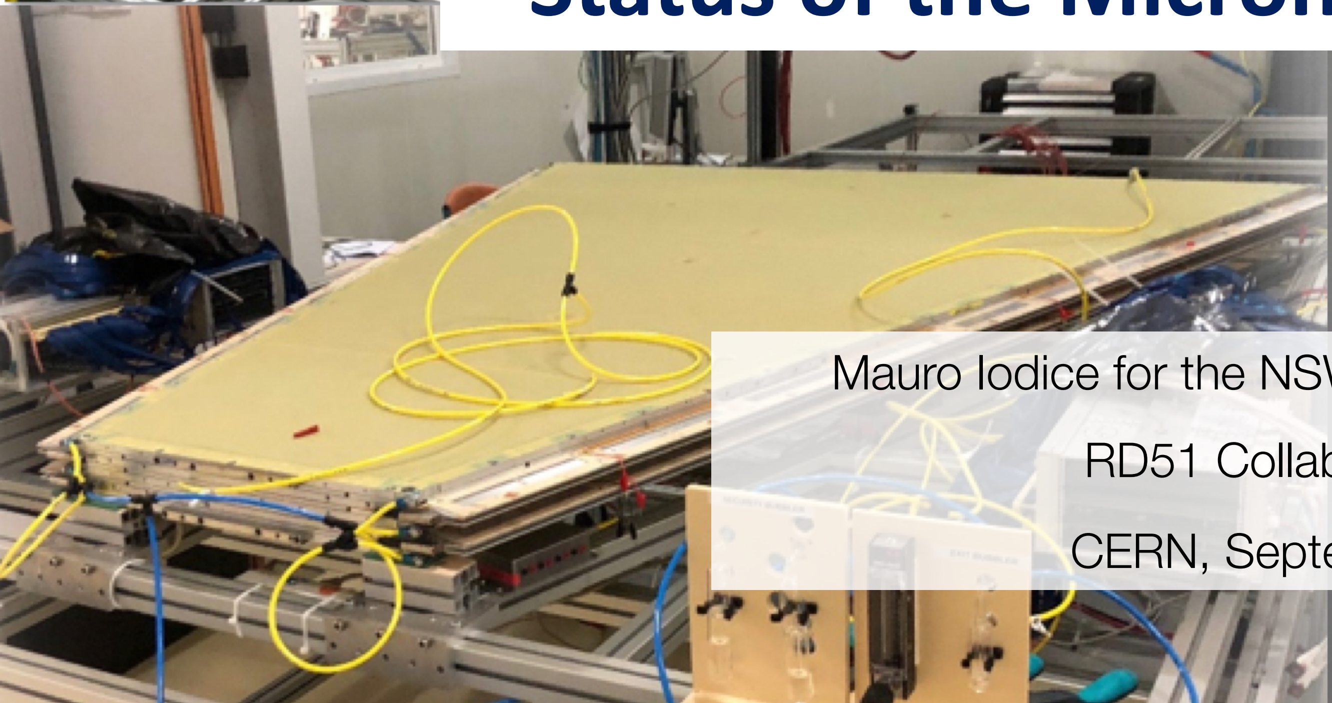


Status of the Micromegas NSW Production



Mauro Iodice for the NSW Micromegas Collaboration

RD51 Collaboration Meeting

CERN, September 27th, 2018

Reminders on Micromegas Quads Composition

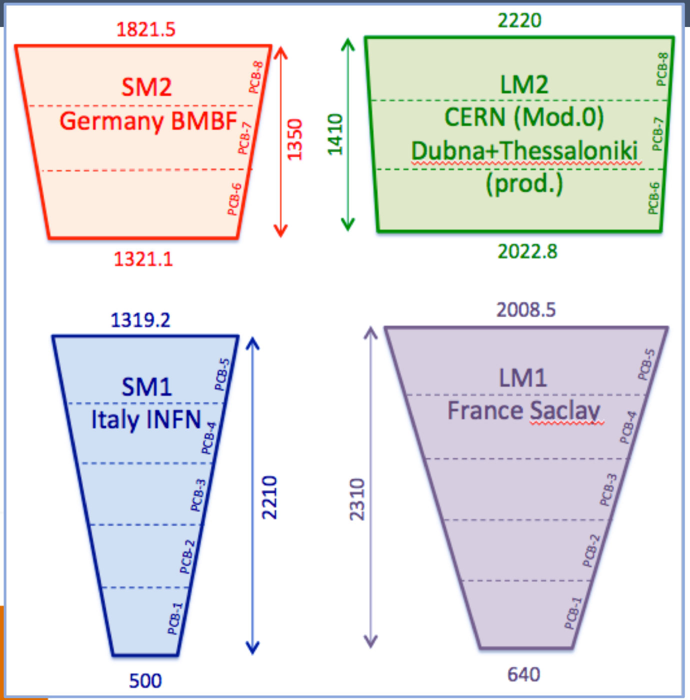
Four types of quadruplets: SM1, SM2, LM1, LM2.
Need to build and certify 128 Micromegas Quadruplets

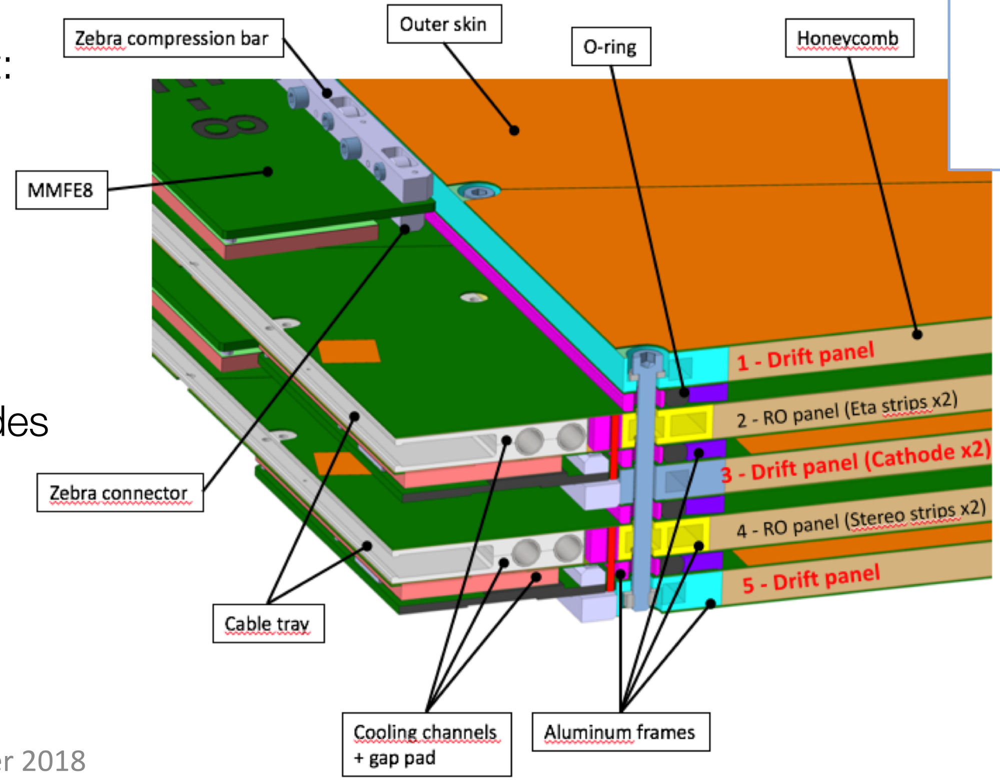
Two types of **Readout panels** on each quadruplet: **eta** strips and **stereo** strips

- Each panel is "double-sided" with readout strips on both sides
- Each side is composed by 5 (SM1, LM1) or 3 (SM2, LM2) separate boards glued on the planes

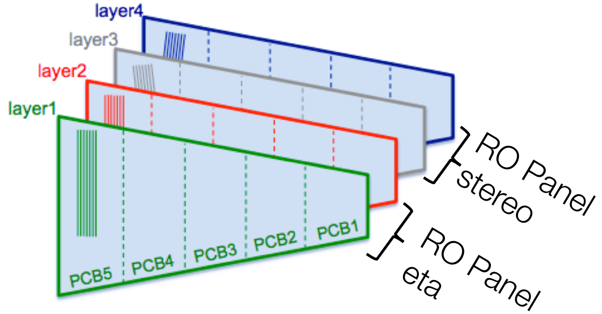
Two types of **Drift panels** on each quadruplet:

- Outer or External Panel (single drift):
  - Side 1 : Cathode plane + mesh
  - Side 2 : Pure FR4 skins
- Central Panel (double drift):
  - Cathode plane + mesh on BOTH sides

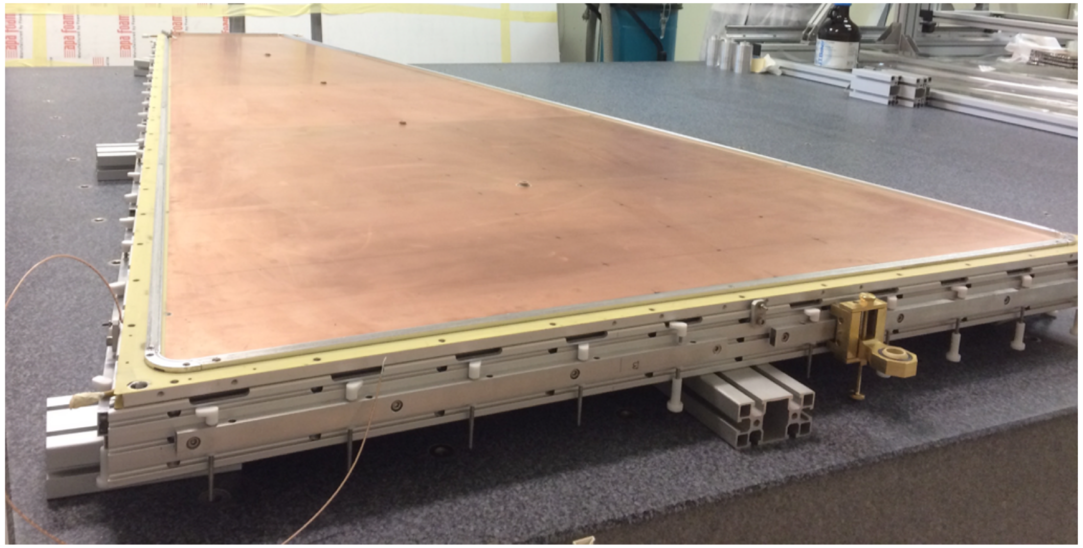




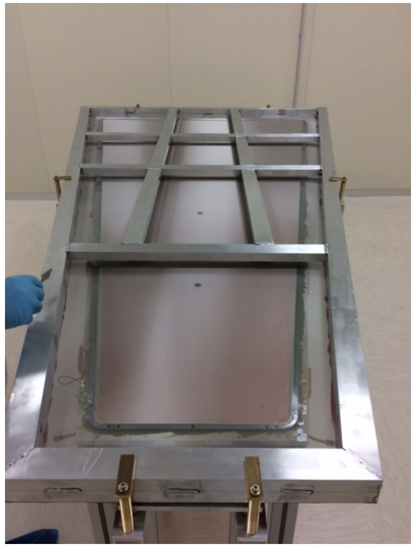
Strips orientation of the 4 RO planes



Panels and Quadruplets

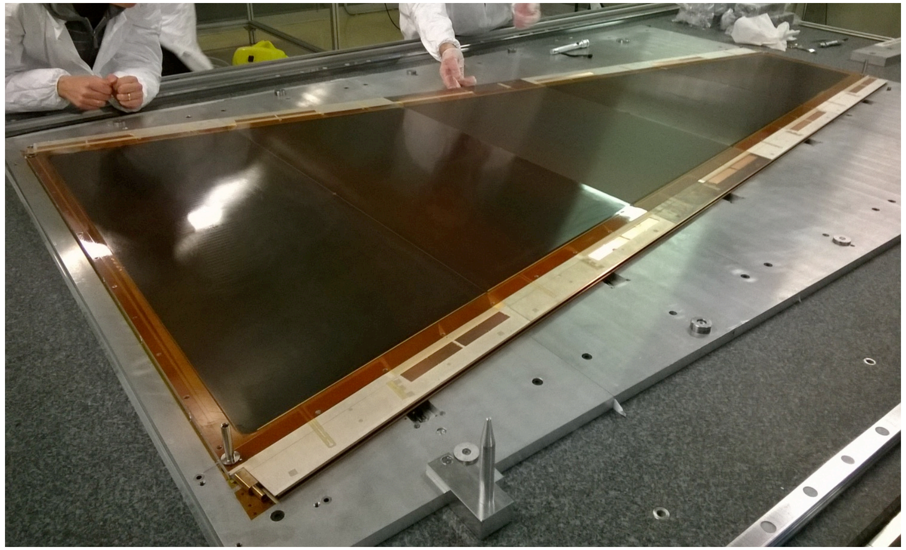


A bare Drift panel (with mesh-frame)

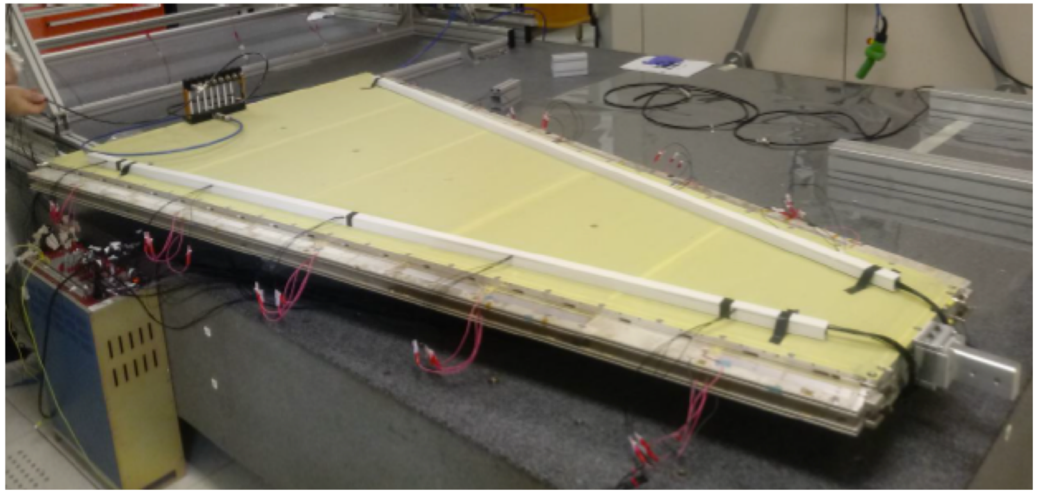


Mesh gluing

A Completed Drift Panel



A Readout Panel



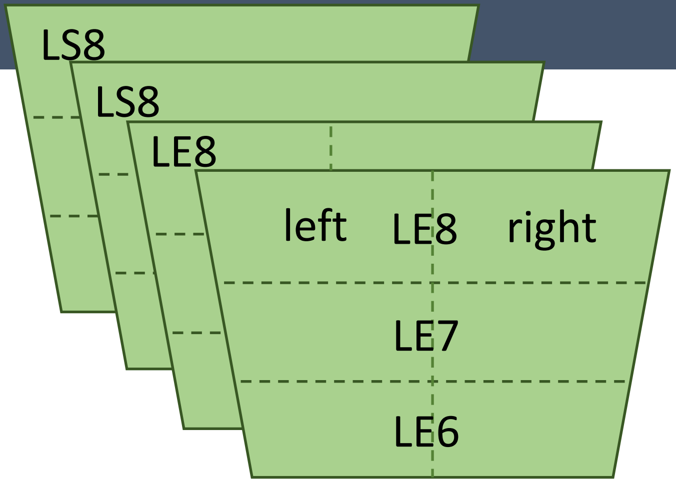
Assembled SM1 Module_1

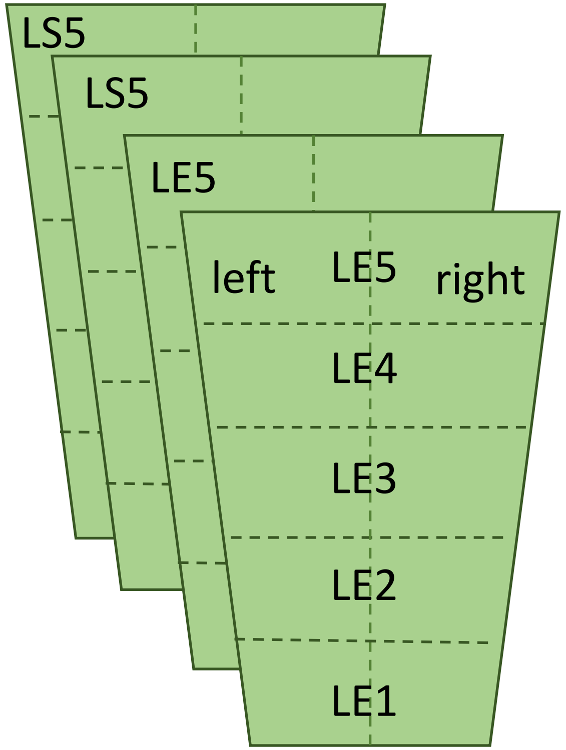
The HV Distribution scheme

In this presentation we will often refer to “HV Sectors”

- Refers to the HV Segmentation scheme:
  - Each side is composed by 5 (SM1, LM1) or 3 (SM2, LM2) separate boards glued on the planes
  - Each board has resistive strips kept at HV (mesh is at ground)
  - Each resistive layer is (electrically) divided in two sides → 2 HV sectors per PCB

- TOTAL Number of HV sectors per module:
  - 40 for SM1 and LM1
  - 24 for SM2 and LM2





Recap on recent facts

- Christmas 2017: All sites built first PRODUCTION MM Quadruplets with production, good quality, RO boards
- Issues with HV stability were reported by all sites.
  - Similar issues were observed on Modules0 thought to come from the poor quality boards used for them

  → Decided to **suspend the quadruplet assembly** and focus on the HV Stability problem

- January/February 2018:
  - Scrutiny of the results and procedures clearly pointed to non-optimal cleaning
  - TEST: Successful cleaning/HV tests conducted at CERN (Rui's Lab) (SM1 and SM2 doublets)
  - TASK FORCE has been set up to address issues of cleaning and HV stability and Modules validation

    with external members: Rui De Oliveira, Mar Capeans, Hans Daniellson, F. Gomez Perez

- March/April 2018 (within the TF effort):
  - Cleaning and HV ramp-up procedures established (though evolving – fine tuning – with experience)
  - Procedures implemented at all sites (though still with some differences – to be scrutinized)

  Cleaning Procedures solved main problems, but still a fraction of sectors showed HV instabilities

  ($ArCO_2$ 93/7)

  Tests revealed a low margin between Working Point and Breakdown limit (WP~580 V – Discharge onset ~600 V)

  → Recommended to **suspend RO Panel production and Mesh Gluing on the Drift panels** until clarified that the low margin does not depend on structural/construction/mesh-material choices

Recap on recent facts

- Decided to proceed with the production of a limited number of Modules at all sites with specific goals:
  - **HV-Test Module:** Cleaning protocol validation and HV stability tests → Bring to "best possible conditions"
  - "Mechanical Modules" for wedge assembly and integration validation (no need of full validation)
  - BB5 Electronics Integration (need full Cleaning protocol, good – but not necessarily 100% efficient – module)

→ Restarted a limited R&D Program addressing:

- Maximum sustainable voltage without high currents/ frequent discharge
  - Critically revisit possible design issues (identification of weak points)
  - Impact of Readout Panels?
  - Mesh type ? ← (See P.Iengo's talk on Wednesday)
  - Mesh polishing ?
- Working point in ATLAS and margin on it (TEST BEAM)
- Long term stability

- Target: completion by September → Scrutiny of results in the Internal Technical Review Sept. 3-4

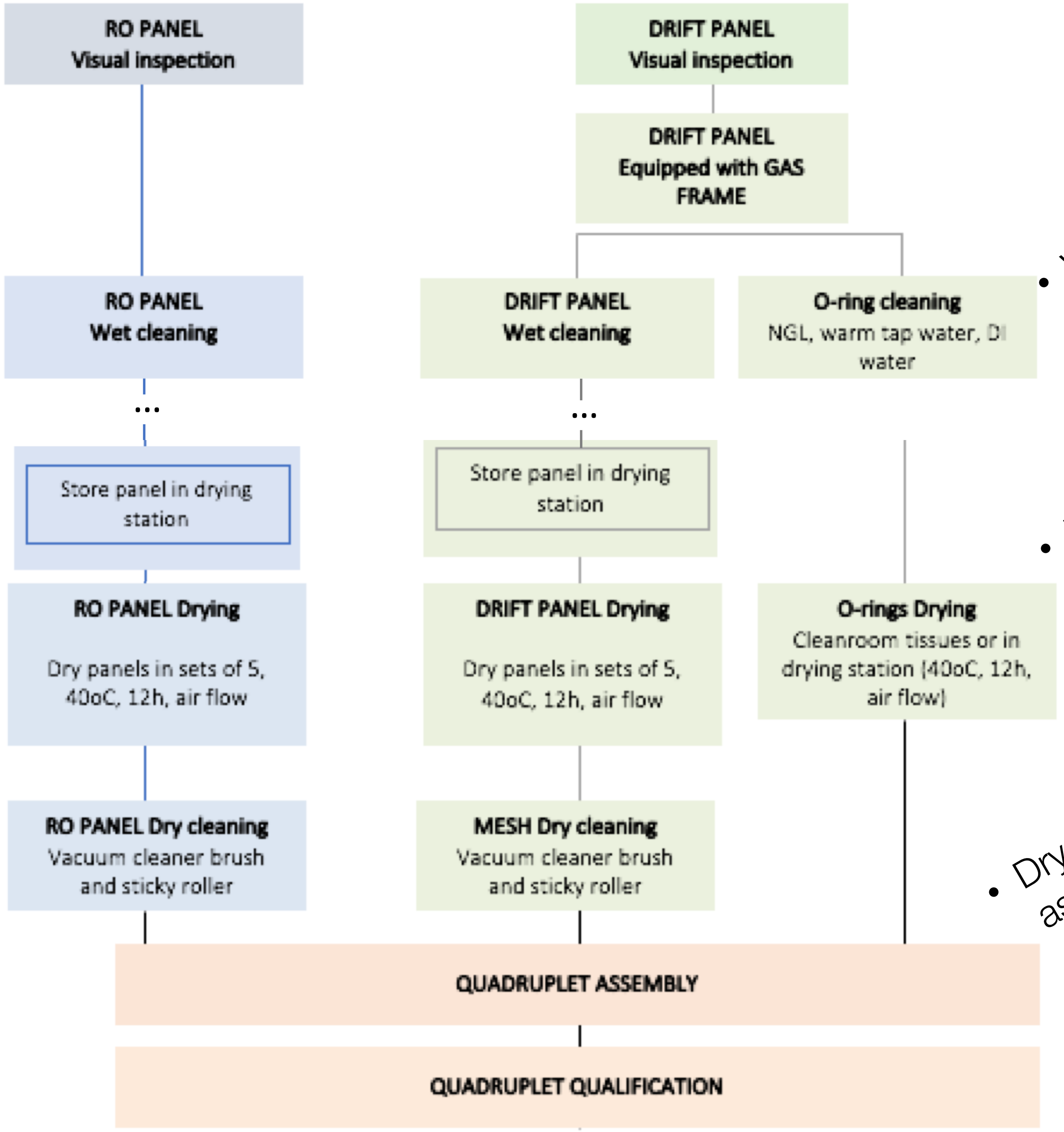
In the following:

- Quick reminder of Cleaning and Assembly basic steps ← (quick recap. More details in R. Hertenberger talk at the RD51 “MPGD Stability” Workshop, Munich 18-22 June 2018)
- Test Modules preparation and Lessons learnt
- Mesh polishing
- Humidity Control
- Long-term stability tests at all assembly sites
- TEST-BEAM: Working Point
- Impact of a lowered working point on ATLAS Muon Performance
- Conclusions and outcome of the MM Technical Review

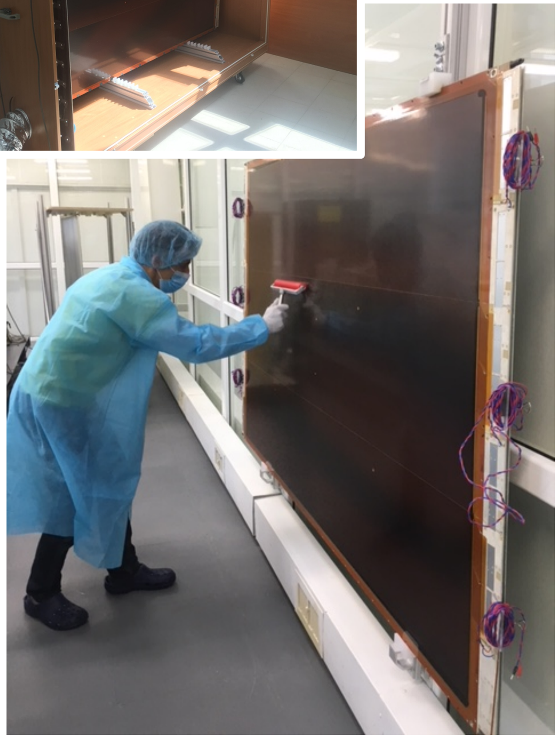
Cleaning/Assembly Protocol

R. Hertenberger reported with details in Munich 18-22 June 2018

Cleaning Flow Chart

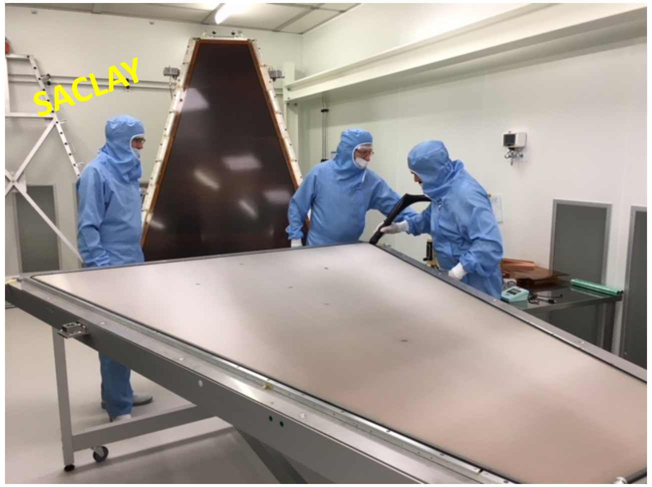


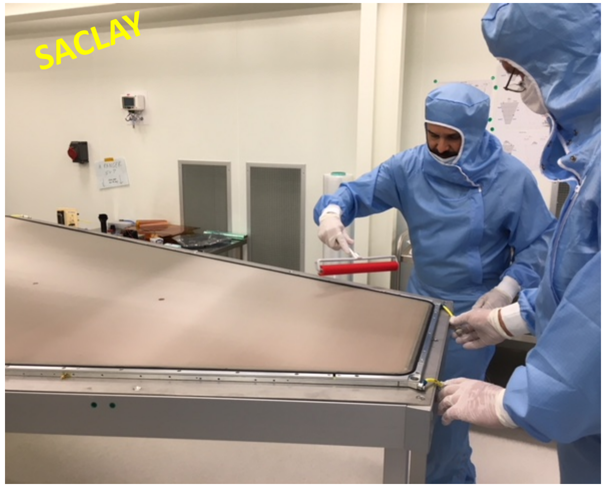
- Wet Cleaning (WASHING) of Readout and Drift panels
- Drying in controlled box (oven)
- Dry Cleaning just before assembly

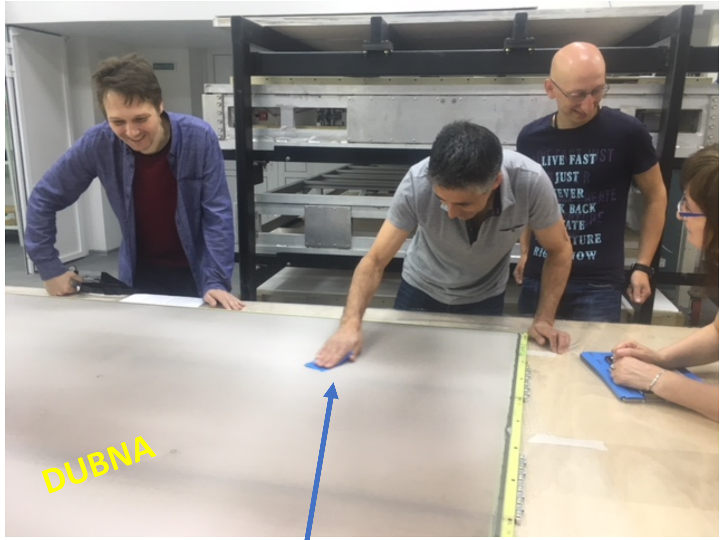


Test Modules preparation

- Visits at 3 sites done by the Task Force, always with Rui De Oliveira (CERN-DT MPGD expert) leading the operations, evaluating the infrastructures, giving suggestions for improvements
- Main purpose of the visit was the transfer of knowledge to the local team.
    - Saclay: April 10-12
    - Dubna: May 28 – June 1
    - Frascati: June 3-4







Mesh Polishing

Mesh Polishing

- MESH POLISHING Proposed after the observation of small defects on the mesh wires

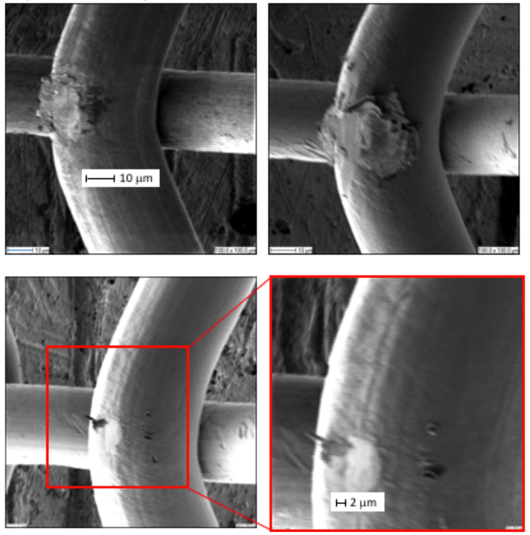


Photo 31st Jan, 2018

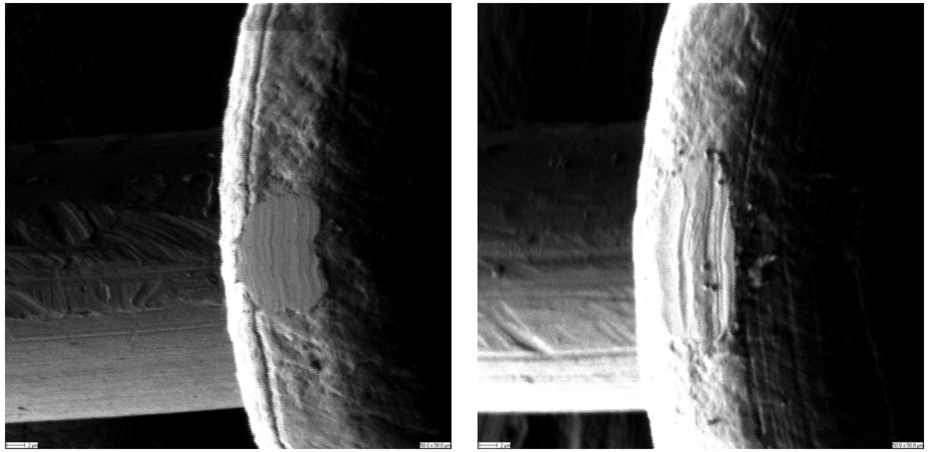
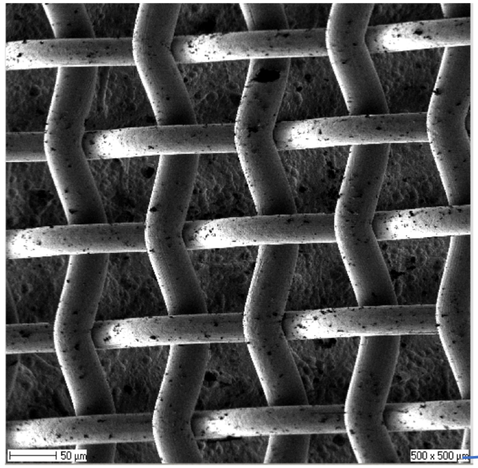


Photo April, 2018

In both cases we don't know which side was photographed

June, 2018



SIDE A ("the fine side") The only SEM sample of side A we have

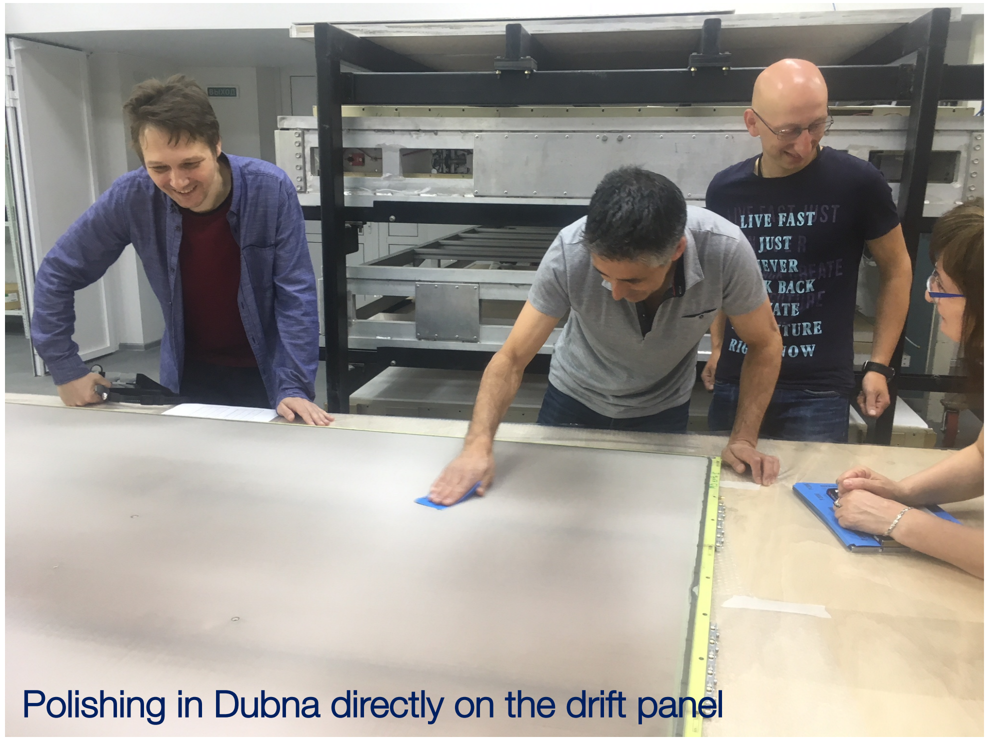
RECENT Contacts with BOPP Engineers revealed that:

- ***The upper side of the mesh is <u>the fine side</u> that does not have friction contact with any surfaces.***
- ***It is therefore important when mounting the mesh on the frame that this <u>upper side is looking in direction to the electrode</u>.***

Mesh Polishing

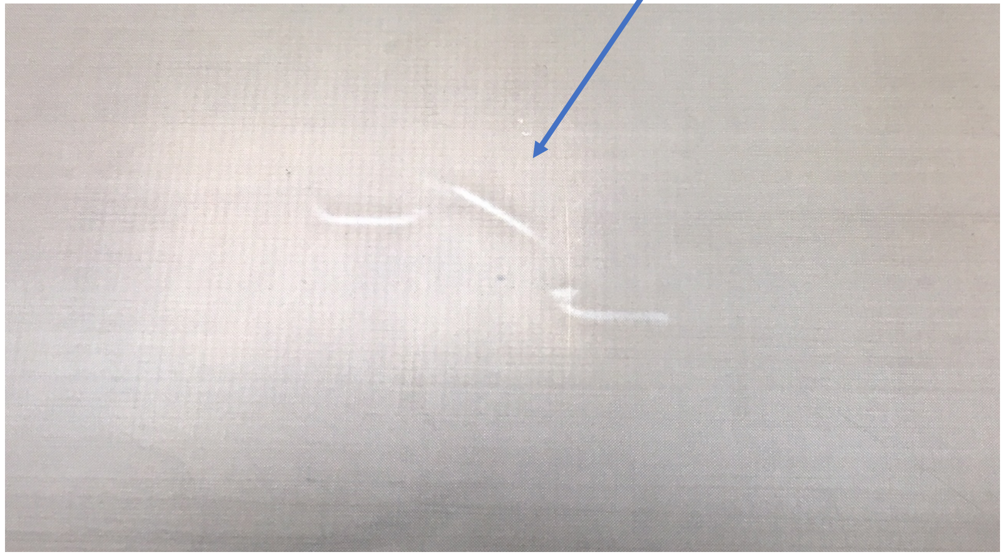
- Several Lab tests done, comparing small test-mesh polished and non-polished
  - No evidence of improvement with mesh polishing with the small test-mesh!
- However, polishing seems to be effective if mesh has defects (… and defects scale with surface!)

→ a “mild” polishing (~10 sandpaper pass) is now applied at all sites. Some evidence of improvements have been confirmed



Polishing in Dubna directly on the drift panel

Polishing effect: if not solving problems, it clearly enhance the probability to spot them



Lessons Learnt in the last months

- **Cleaning procedures** are well under control and uniform within the sites, many details have been addressed
  - After wet cleaning no more evidence of **ionic contamination** → this problem is solved at all sites
- **Humidity conditions** different and not well under control → not easy evaluation of achieved results

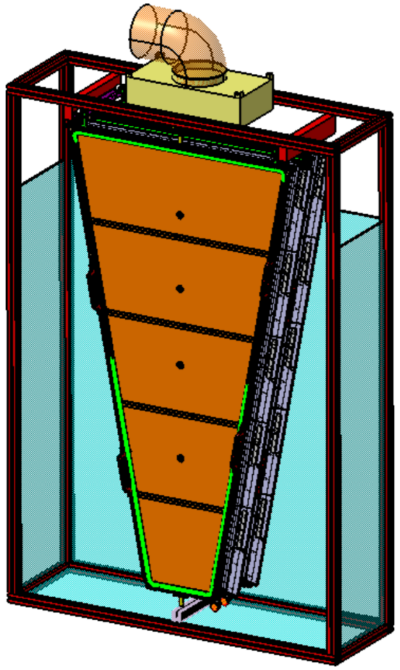
High level of humidity was identified as a major concern as it can distort the interpretation of the HV tests

Drying Box (oven) after wet cleaning:

- The drying station should be a hermetic and clean box very close to the Assembly Clean Room.
- Temperature should reach at least 50 ^{o}C
- Monitor of humidity
- Filtered air flow (must use good performing filters – HEPA)

Drying Box are available in Dubna and LMU since several months.

Under completion in Frascati and Saclay



HV Ramp-up and validation Procedure

- During the HV Tests, currents must be kept below O(10 nA) (conservative limit) to avoid (permanent) damages (Discharges effects: See Rania's talk in the DISCO Session - Wednesday)

- Relative Humidity in the chamber is a relevant issue and can bias the validation process

  → reduce to **below 10%** in the gas mixture

Relation between Humidity of the gas coming out of the detector and max Voltage:

RH	Maximum voltage (V) in air	Maximum voltage (V) in Ar/CO2 [TBC]
50%	800	500
30%	900	560-570
10%	940	590
1-3%	from 940V to 1000V or above for a short period	600-610

[STRONG DEPENDENCE ON HUMIDITY]

To be validated

- Time plays a role (RH reduction and/or possible burning of residual impurities)

  "conditioning" at currents higher than ~50-100 nA must be done for very short time.
  If currents does not decrease → lower the voltage

HV long term stability Tests

Long term HV Stability tests were planned for the summer period (August) as an important part of the project status evaluation, to be thoroughly scrutinized during the Sept 3-4 MM Technical Review

- Tests done with Quadruplets assembled using *almost* final washing/drying/assembly procedures
- A Target, “safe”, HV is defined for each Construction Site (in Ar/CO_2 93/7 – i.e. nominal gas):
  - 570 V according to the $\varepsilon > 90\%$ working point found at the Test-Beam (see later)
  - Small corrections depending on the altitude of the constr. site (~+/- 10 V)

- Goal of the HV Stability test:
  - Reach the target HV with currents < 10 nA and keep it for long time
  - Count the fraction of sectors reaching this condition
  - Monitor current behavior/sparks, other effects

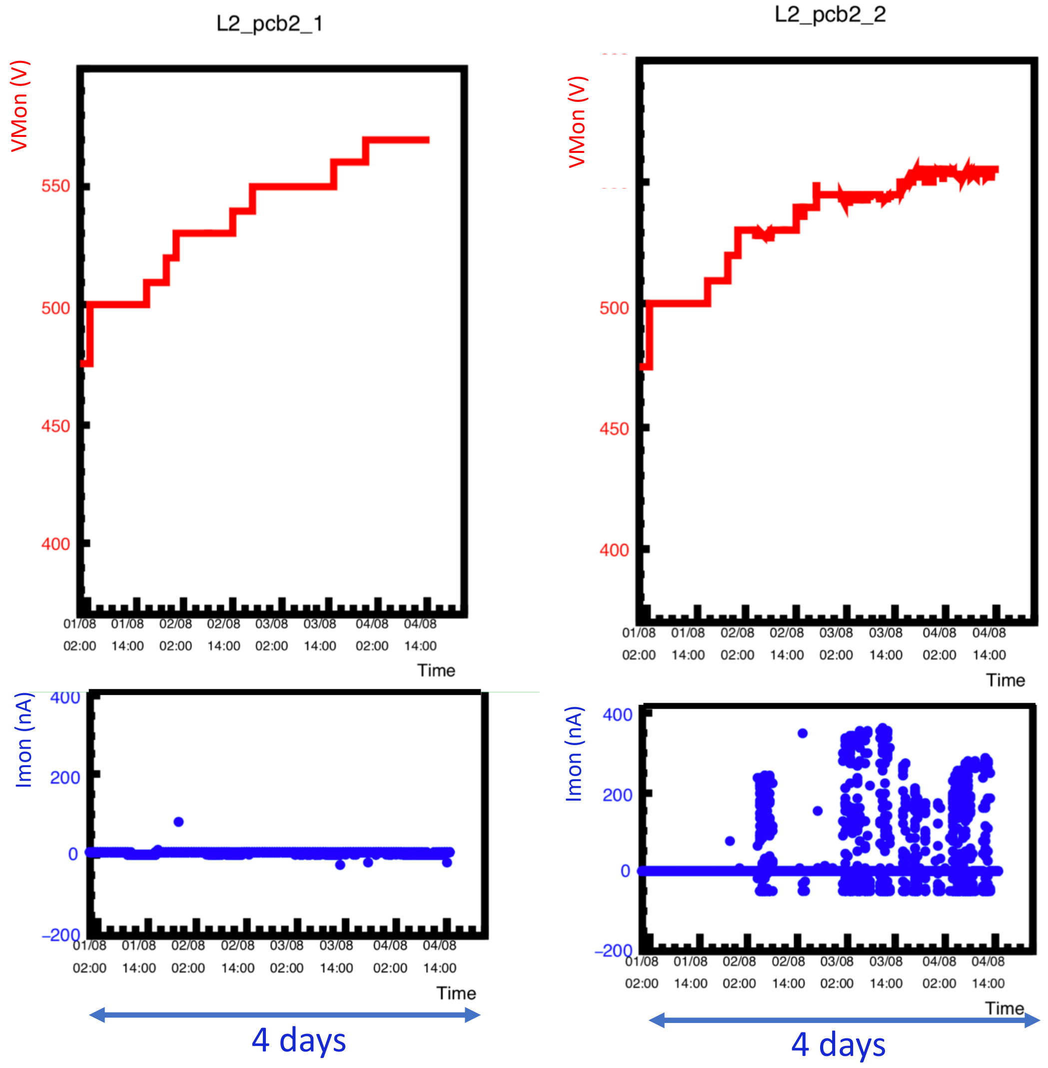
- <u>Relative Humidity in the gas: not monitored consistently in all sites during these tests</u>
  → Now we’ll use the same monitoring system at all sites

HV Stability – August tests – SM1 (Frascati)

- Target HV for stability test: 575 V
- very slow HV ramp-up with Ar/CO2 flow at 10 l/h
- HV ramp-up Protocol followed without exceptions
- HV Set-point reached (**575 V**) after 4-6 days
- Humidity not monitored during ramp-up and stability test
- Measurement of humidity only possible after ~ 1 month of continuous flow

  RH Inlet: 3.1 %

  RH Outlet: outlet 12%



HV Stability – August tests – SM1 (Frascati)

M3 HV status at 26th August

L1-1D	575	L2-1D	575	L3-1D	575	L4-1D	575
L1-1U	575	L2-1U	565	L3-1U	575	L4-1U	575
L1-2D	575	L2-2D	575	L3-2D	575	L4-2D	575
L1-2U	575	L2-2U	575	L3-2U	575	L4-2U	575
L1-3D	570	L2-3D	575	L3-3D	575	L4-3D	575
L1-3U	575	L2-3U	575	L3-3U	575	L4-3U	575
L1-4D	575	L2-4D	575	L3-4D	575	L4-4D	575
L1-4U	575	L2-4U	575	L3-4U	575	L4-4U	575
L1-5D	575	L2-5D	570	L3-5D	575	L4-5D	575
L1-5U	575	L2-5U	570	L3-5U	565	L4-5U	575

35 out of 40 Sectors OK (~all can also reach ~590 V - not tested beyond)

5 sectors reached 565-570 V

Fraction good: 87%

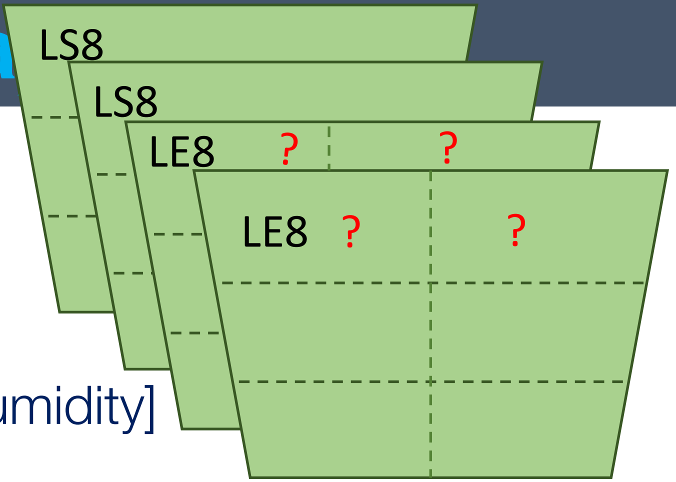
Interpretation of the results and open issues:

- Many volumes exchange in one week have reduced the humidity significantly
- Very long time for ramp-up:
  - Reducing humidity
  - Possibly beneficial for a good conditioning (to be investigated)

Humidity reduction:

- It took 1 month to reach 12% (!) (so, gas flow is not very effective)
- Inlet RH of 3.1% in any case is high (used short – 30cm - rilsan tubes)

HV Stability – August tests – LM2 (Dubna



- Problems (in air and in Ar/CO_2) with one type of PCB: the LE8xx (4 sectors out of 24). Issue present with two different RO and Drift panels
  → Under investigation
- Preliminary test in dry air with huge gas flow (up to ~500 l/h) [Reduction of humidity]
- Ar/CO2 long term test 20 l/h

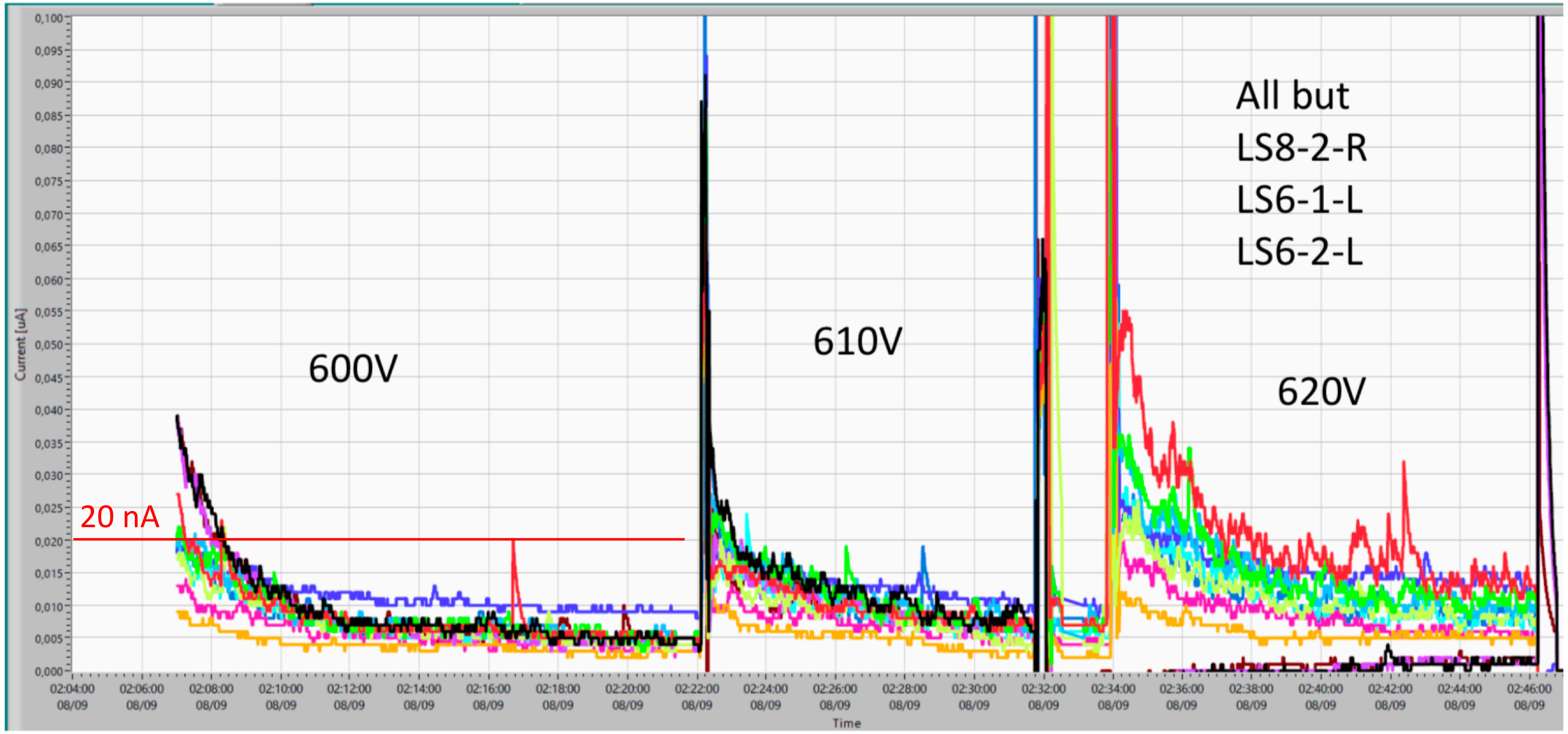
After 1 month operation:

15/24 excellent sectors stably working at 590V
(in many cases can go to >600 V)

4/24 good sectors, stably working at 570V with 15 nA

5/24 bad sectors, among them the four eta-LE8xx

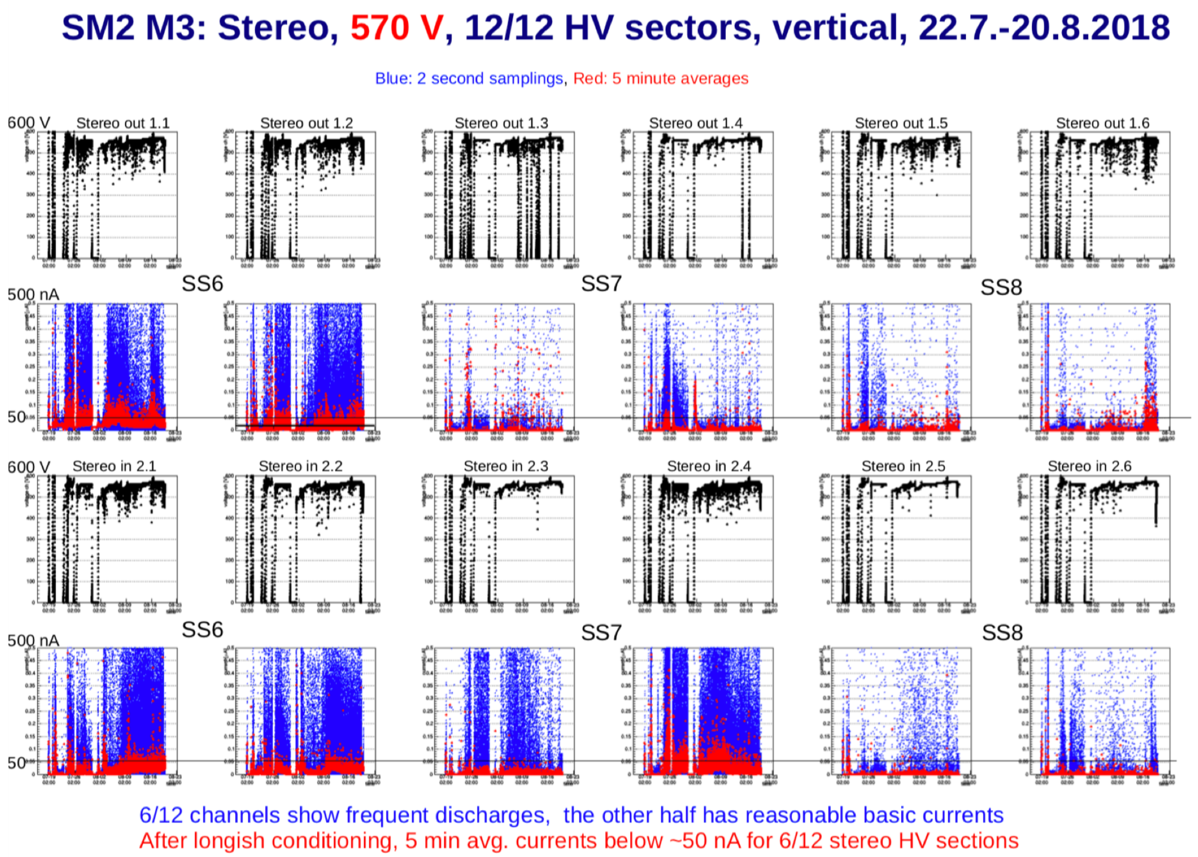
Fraction good: 79%
(but different issue in 4 sectors)



Short summary of the results – SM2 (LMU)

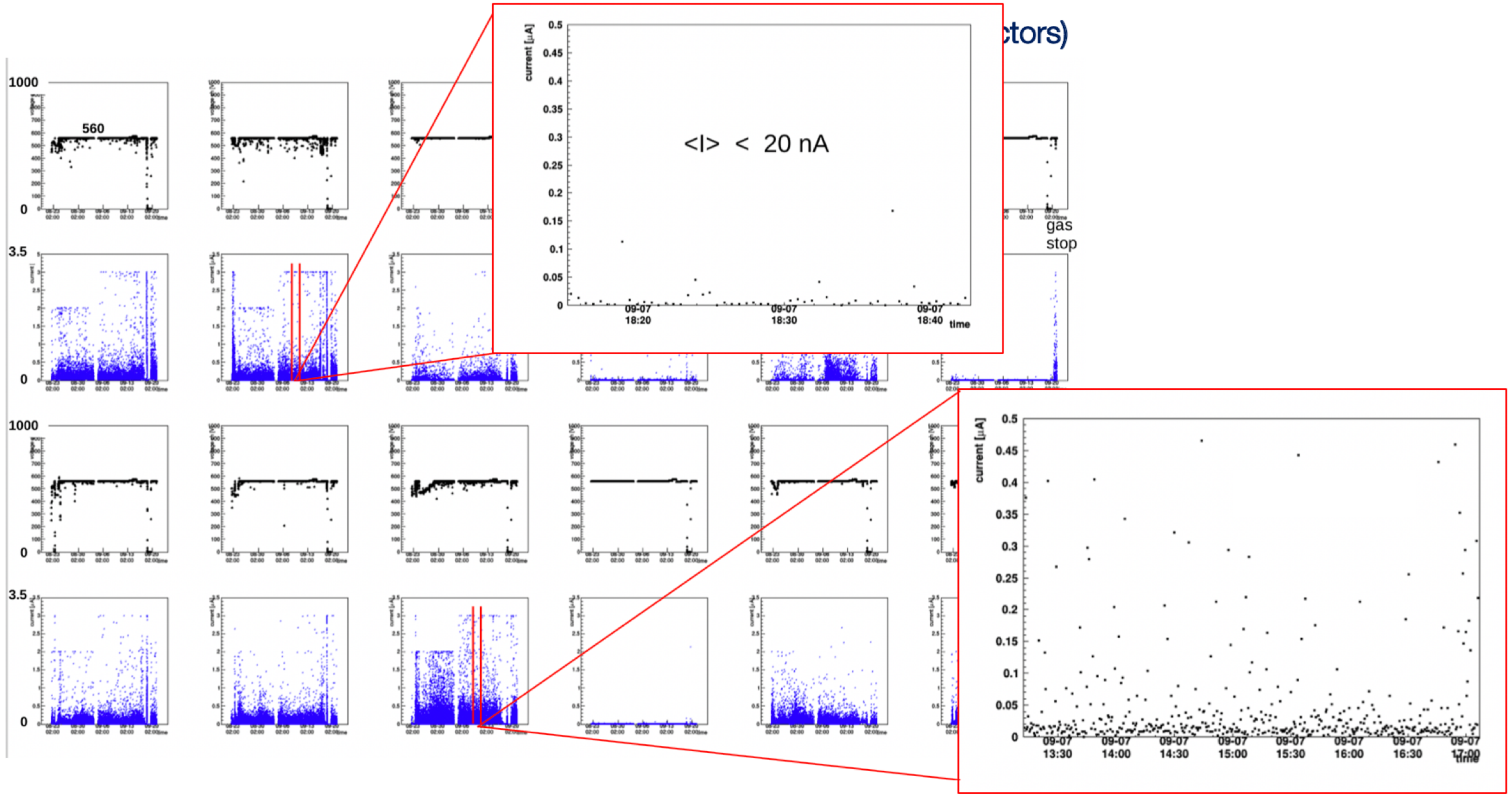
- After dry air test and problems fix
  →Ar/CO2 flow rate 20 l/h
- Humidity only "roughly" measured but < 10%
- Fast ramp-up:
  - 1h up to 800 V and 1 h from 800 to 990 V (air)
  - Similar in Ar/CO_2
- Long term results at 570 V in Ar/CO2:
  - **Stereo panel: 6/12 sectors with *<i> < 50 nA***
  - **Eta panel: 10/12 sectors with *<i> < 50 nA***
- Observed:
  - 2 sectors degradation after reaching 590 V
  - 1 sector degradation during stability test

EXAMPLE – stereo panel 22/7 – 20/8



Fraction good: 67%

Short summary of the results – SM2 (LMU)



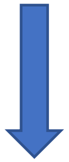
Stable behavior at 560 V

- Still high currents (50 – 100 nA) for a few sectors of the stereo panel
- Quieter situation at 560 V for the eta panel

Fraction good+acceptable close to 100%

Interpretation of the results and open issues:

- Fast ramp-up
  - o Not enough time for conditioning ?
- Tests with currents higher than recommended ?
- Cleanliness ?



Cleanliness – ”complete removal of dust and dirt” – remains one of the most serious problems at all sites
Can be improved but up to a limit

Short summary of the results – LM1 (Saclay)

Very short summary of the results:

LM1 – Saclay

- After dry air test and problems fix →Ar/CO2 flow rate 11 l/h
- Measured Humidity: [RH] Inlet 15% (!) and outlet 18%
- Ramp-up and conditioning with large currents (up to ~200 nA)
    - Initially 19/40 sectors < 560V to keep current < 200 nA
- After 2 weeks:
    - 26 sectors (out of 40) at 560 V and higher

- Similar behavior in current for many sectors
    - Indication of common issue? Humidity?

Fraction good (acceptable): 65%

Interpretation of the results and open issues:

- Humidity too high both at inlet and outlet
- High currents reached during ramp-up ?
- Conditioning steps to be revisited ?

HV Tests – Summary

- Yield of "good" sectors at all sites in the range between ~65% and ~90% → TO BE IMPROVED !
- Results are clearly affected by the humidity: RH too high and/or not monitored/controlled

  → High currents due to humidity can mimic and mask real problems due to defects, dust,… etc

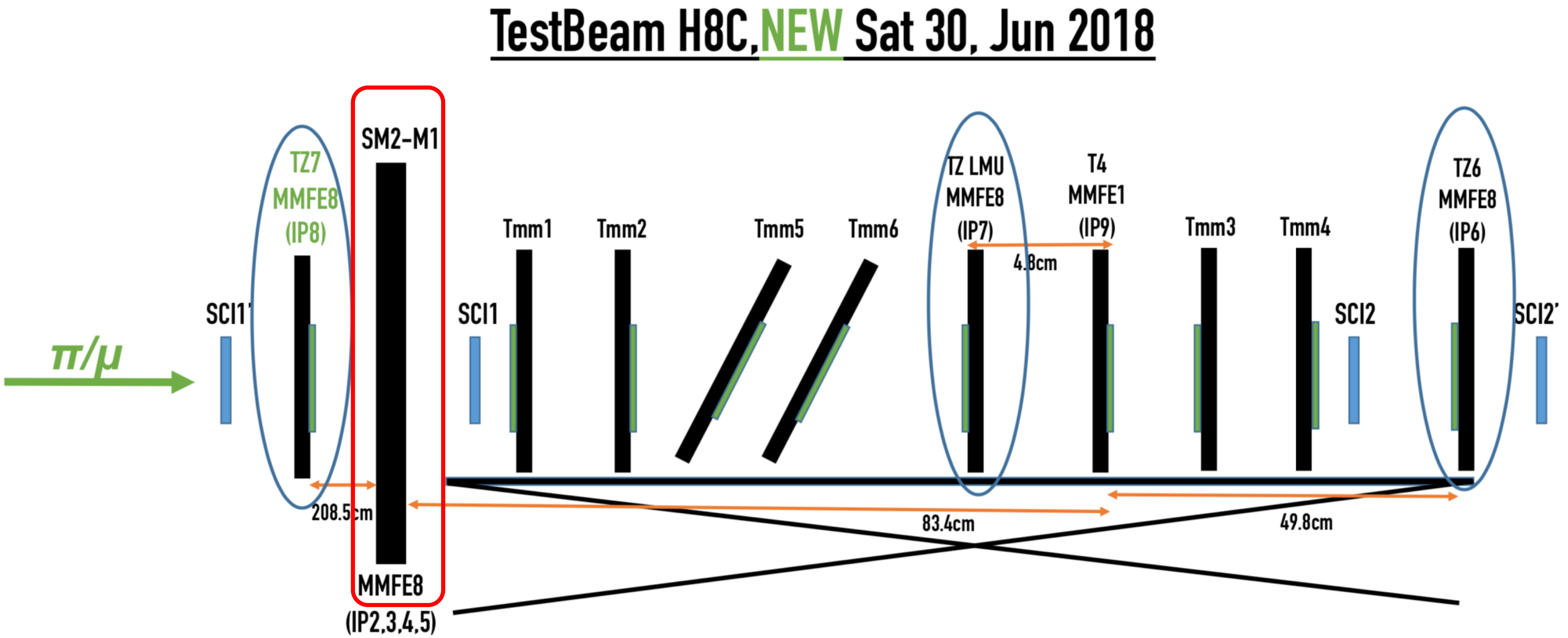
  In principle, if the high current is (only) due to humidity, this is not an issue since the detector will operate in dry environment

- The HV Ramp-up procedure for the validation phase, in some sites was not followed correctly
  - Deviations from the rule to start Ar/CO_2 measurements only if RH<10% (~for all)
  - Currents often exceeding the max allowed 20 nA for long time
  - Fast ramp-up ? – short waiting time in stable conditions at each step

Now Working on:

- Control of Humidity
- Update the protocol of HV ramp-up and Module validation (according to recent experience)

Working Point - SM2 Production Module1 – Test Beam results



- 4 Scintillators
- 10 small micromegas
- SM2-Module1

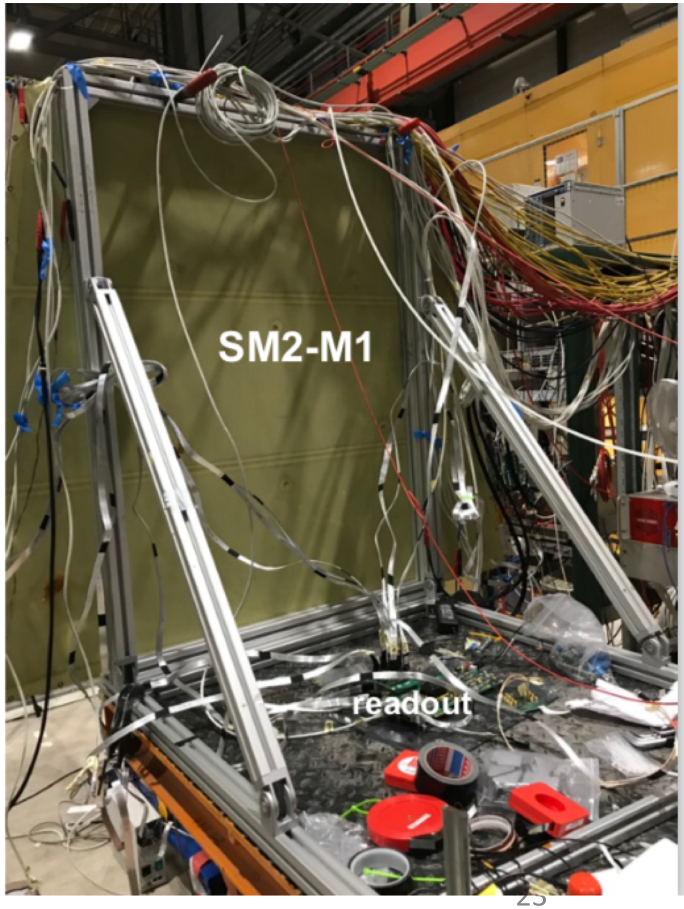
- 4xMMFE8 on SM2 (MMFE8 equipped with VMM3)
- 3xMMFE8 on TZ7, TZ6, TZ-LMU (as telescope)
- 1xMMFE1 on T4 (part of telescope)
- 4xTmm1-4 with APV/SRS readout (X-Y telescope)
- 2xTmm5-6 with APV/SRS readout (on rotated frame)

- MMFE8 readout
- APV/SRS readout
- Combined readout

SM2 Module1 TEST BEAM – July 2018

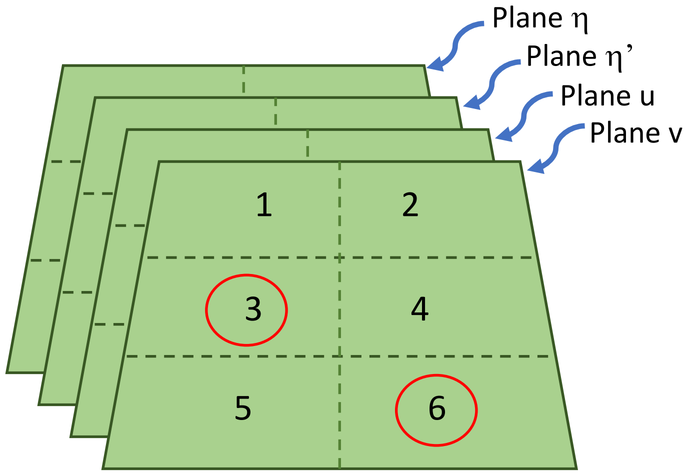
July H8C Test BEAM for SM2 Studies

SET UP

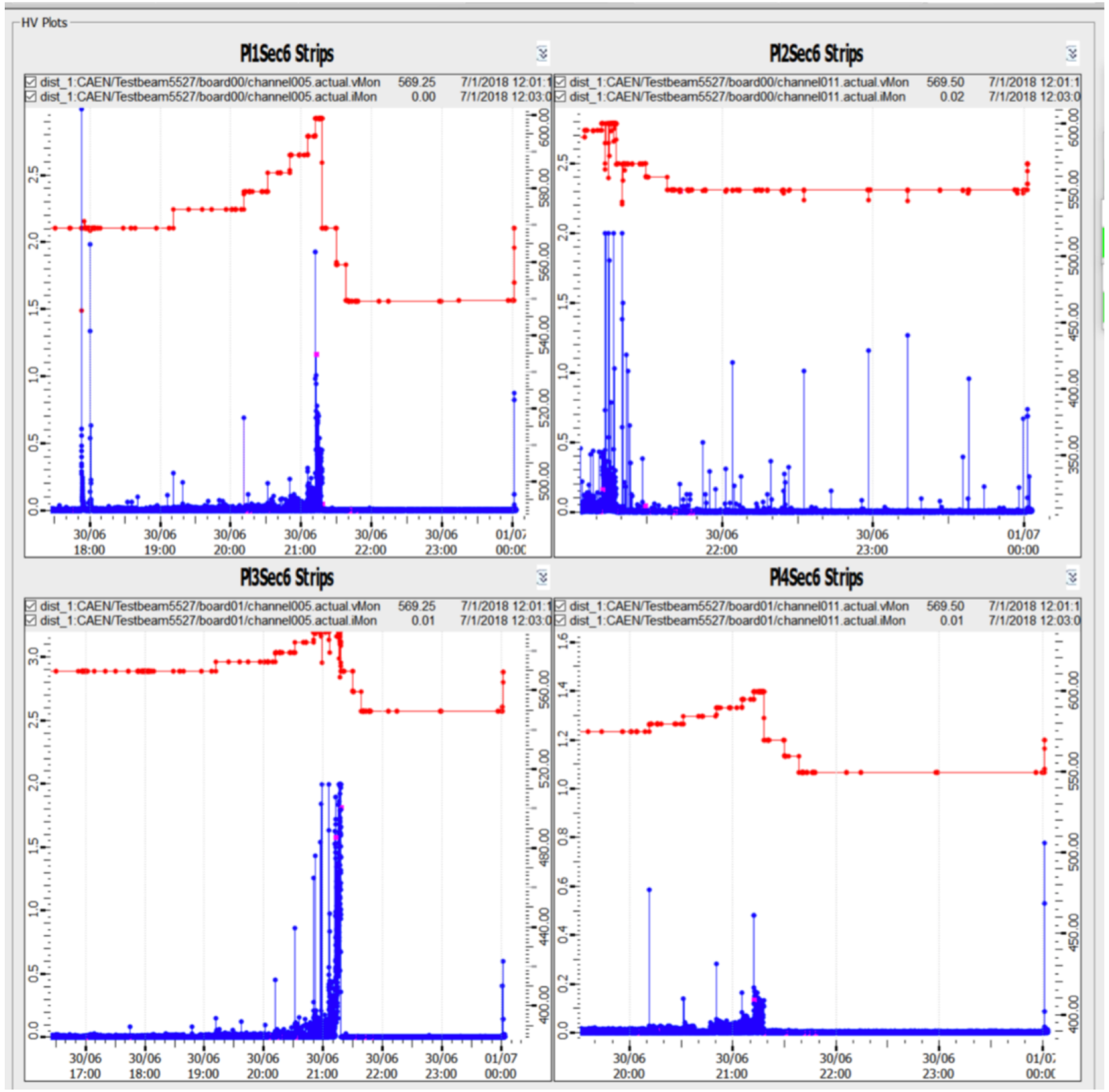


SM2 M1 Status @ H8C

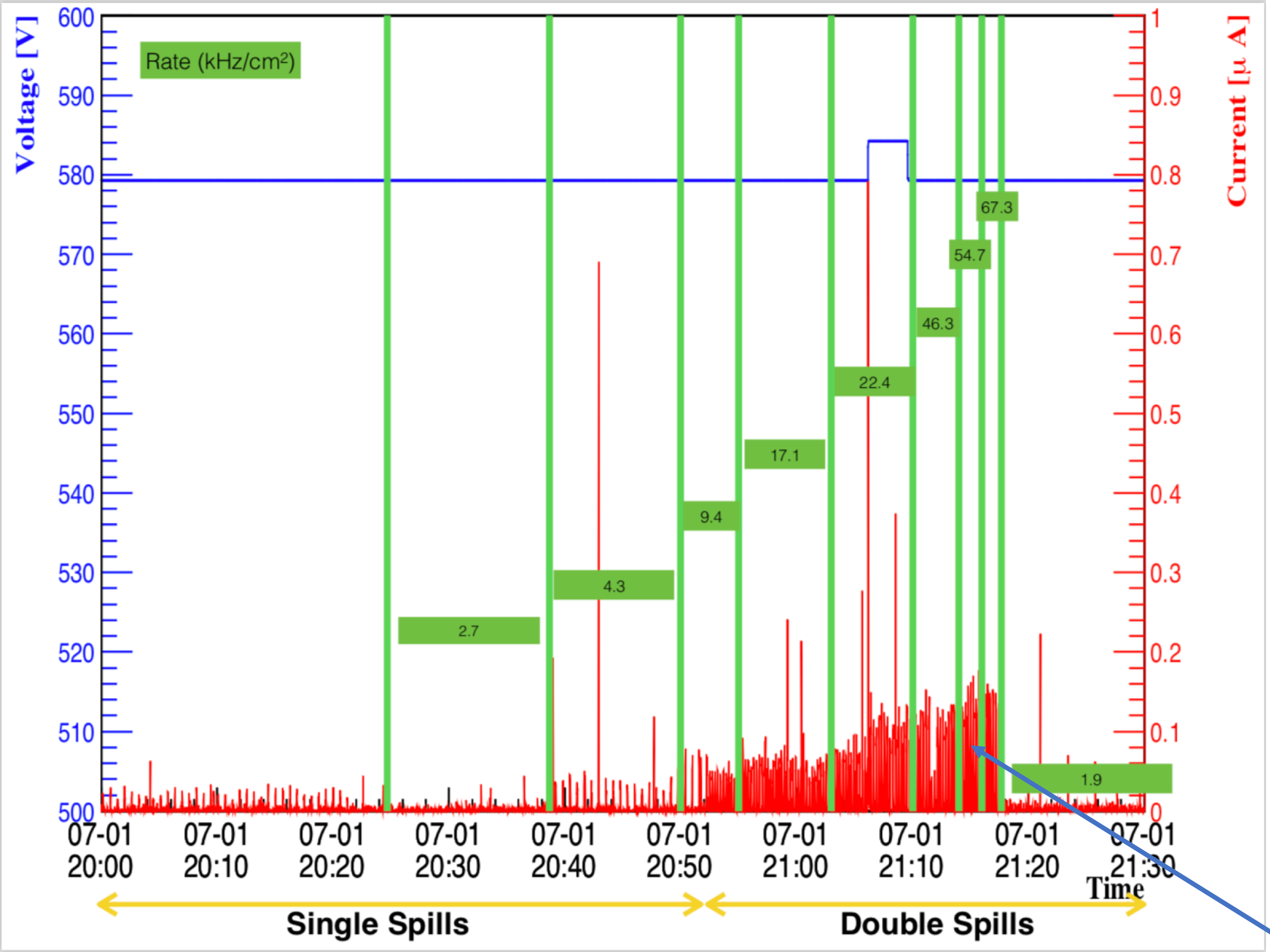
- Module assembled in May/June at LMU
- Known issue with stereo layers (Planes u-v) sectors 1 and 2 : many missing pillars (bad HV behavior)
- Can operate 18 sectors at >570 V with *i* < 20 nA
- SM2 behaved similarly as in Munich
- Analysis mainly on sectors 3 and 6



LEAKAGE CURRENT (no BEAM)



SM2 M1 Status @ H8C -- Intensity Scan



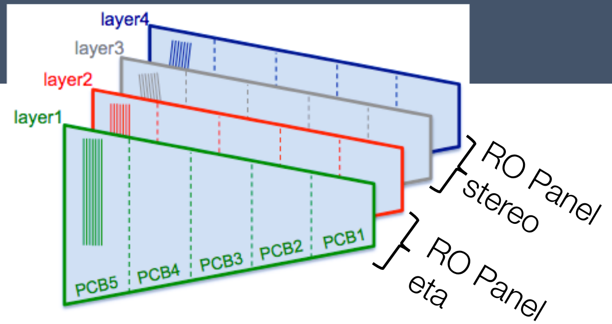
Intensity scan @ 580V

# per spill	rate [kHz/cm²]
6.47E+04	2.7
1.03E+05	4.3
2.23E+05	9.4
4.07E+05	17.1
5.32E+05	22.4
1.10E+06	46.3
1.30E+06	54.7
1.60E+06	67.3
4.60E+04	1.9

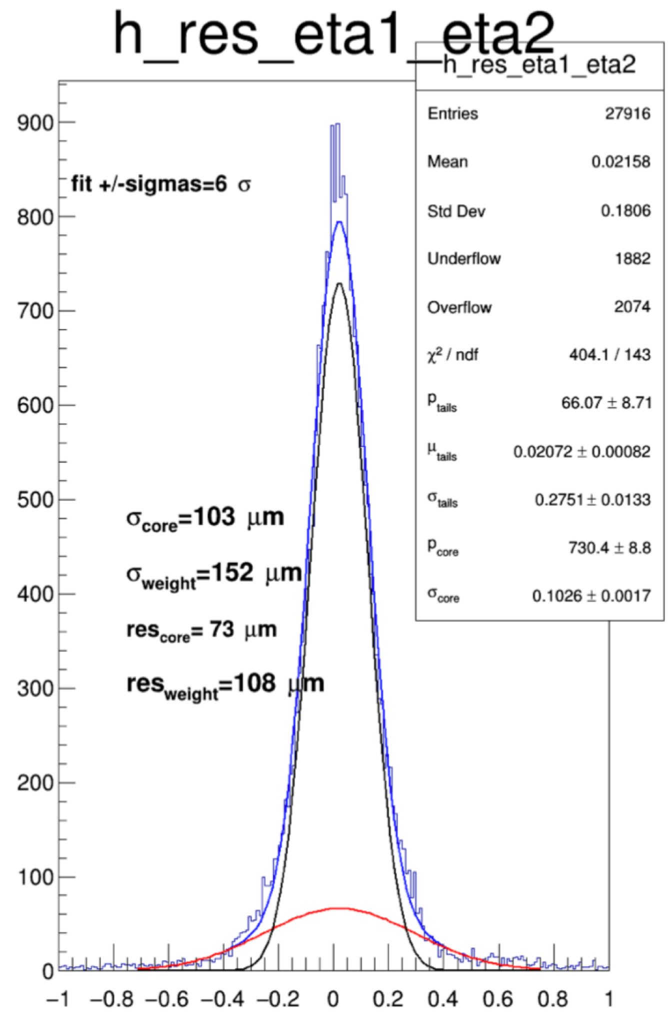
Reminder: at HL-LHC Max intensity is ~20 kHz/cm²

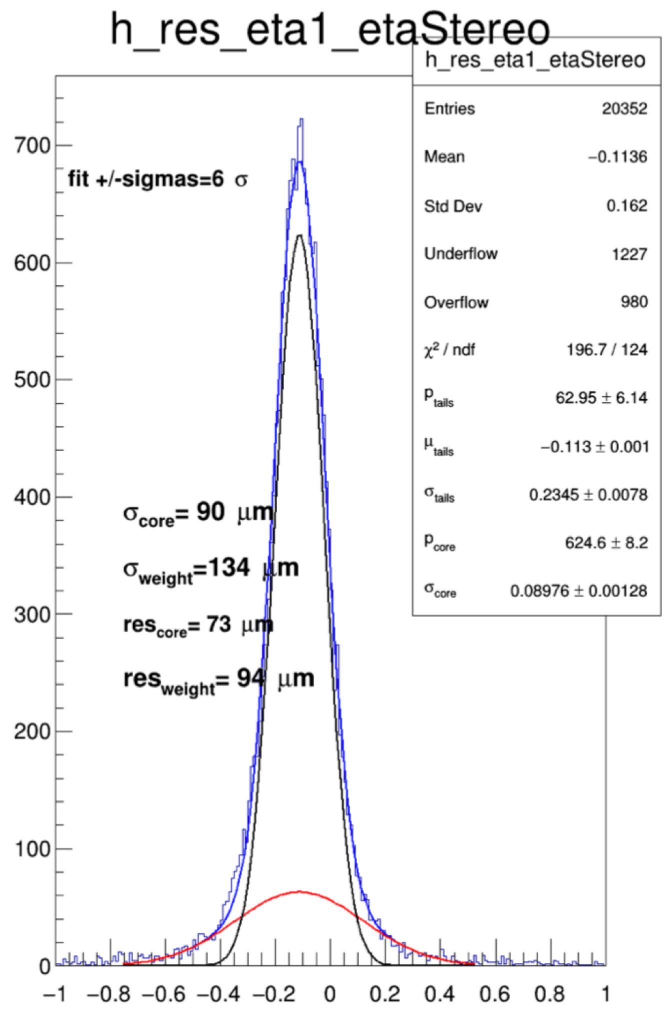
Currents ~7 x expected

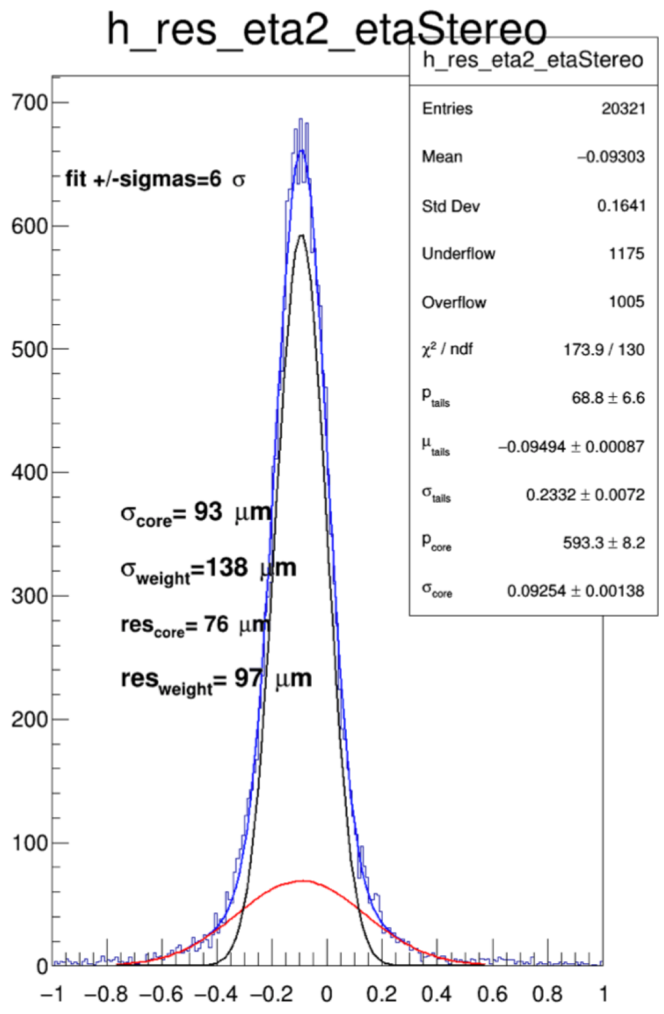
Resolution for perpendicular tracks



Online resolution using the two eta planes and also the eta calculated from the two stereo planes

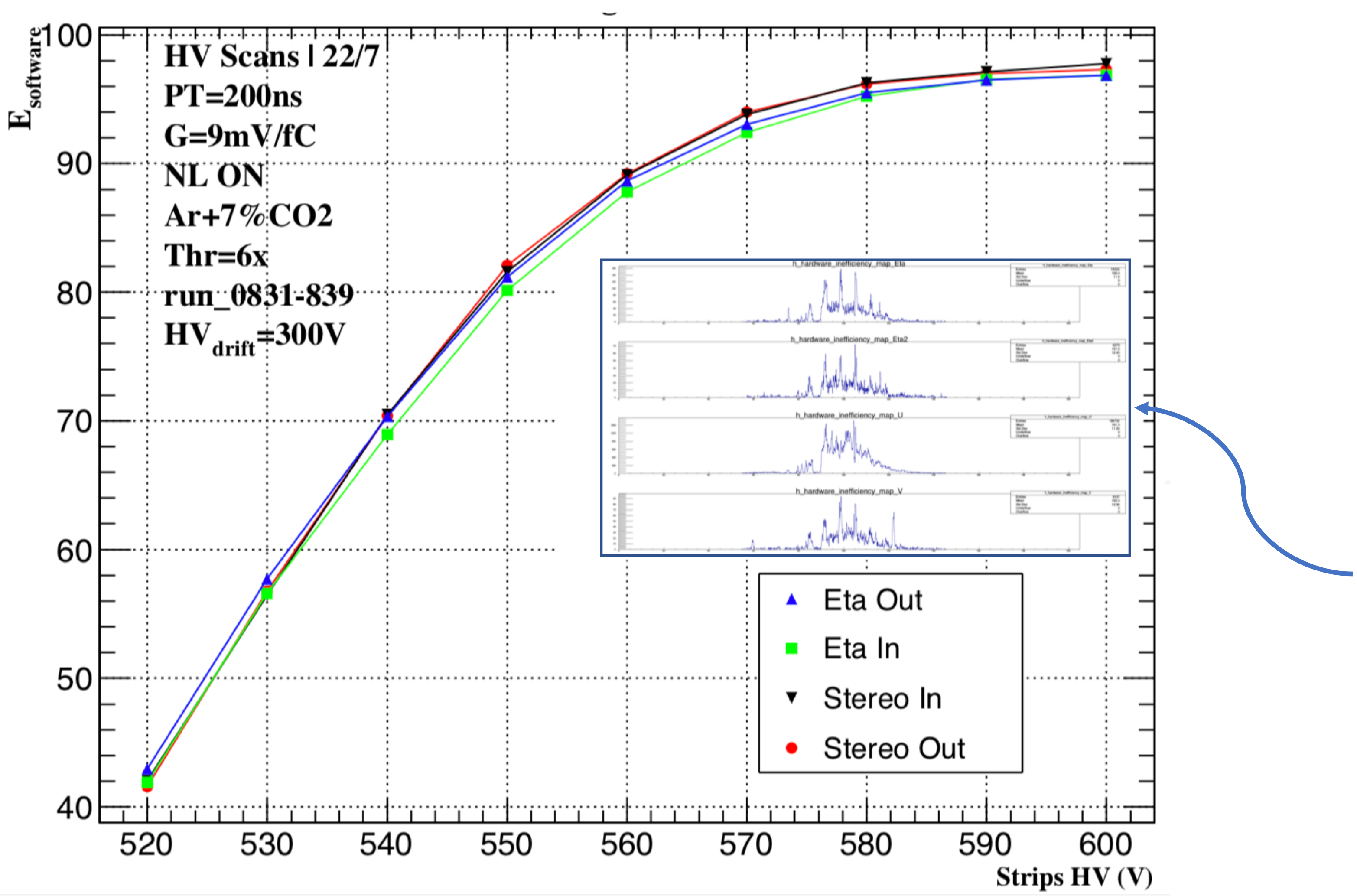


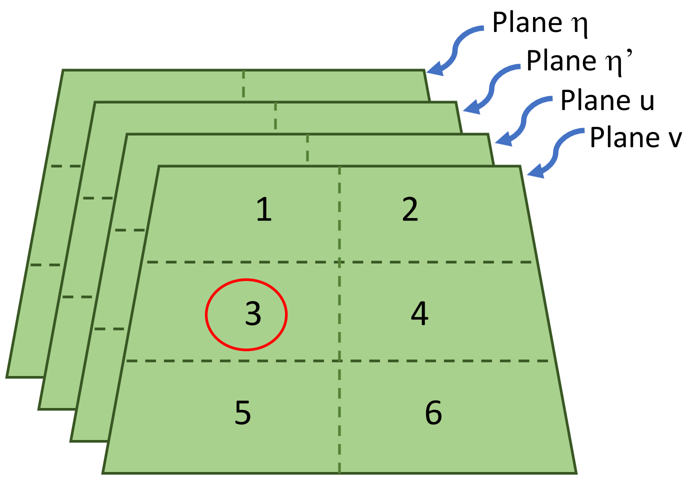




Efficiency Vs HV

Software Efficiency (cluster in a window of 1 mm) – HV Scan @ 0°





Beam on Sector 3

Inefficiency maps.
The inefficiency peaks correspond to the pillars positions

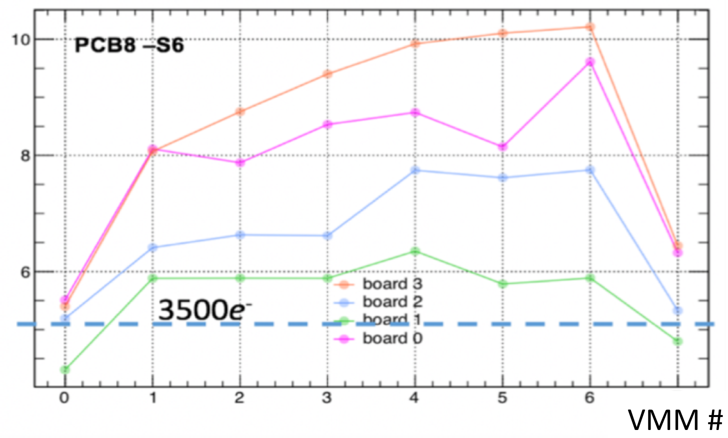
Inclined tracks

- For inclined tracks the charge is distributed over more strips → higher inefficiency

At 560 V ε~90% for perp tracks
→ ε~70-80% at 30°

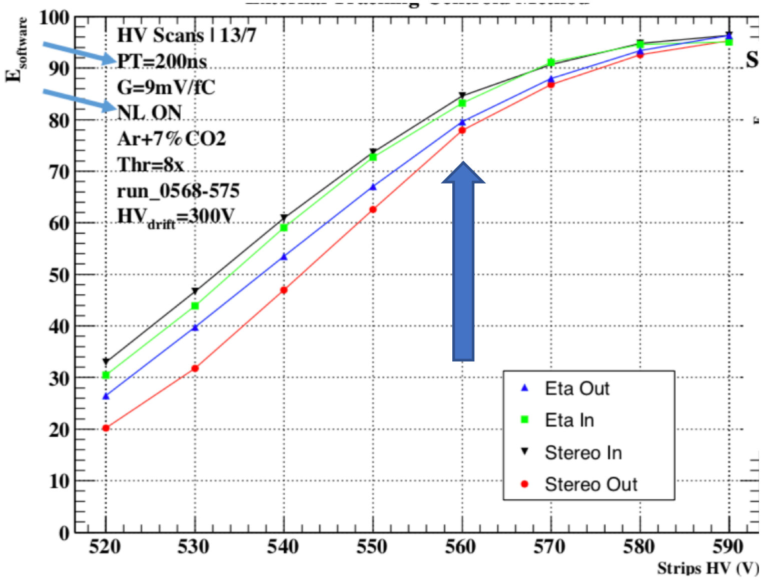
- Quite high threshold (noise level) could have a significant impact.
- Ongoing studies of noise level on VMM (on MMFE8 on chamber)

VMM noise level (8 VMM x 4 layers)

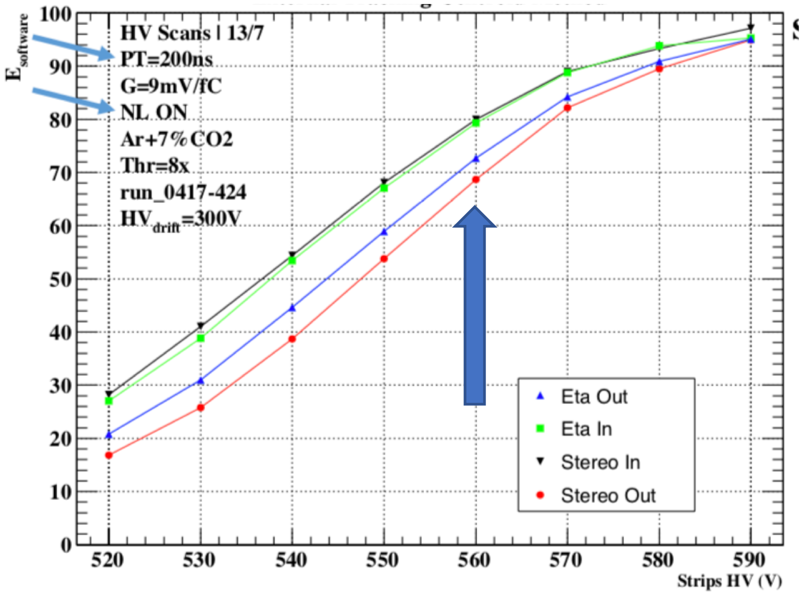


Higher level for eta Out and Stereo Out can explain the different layers behaviour

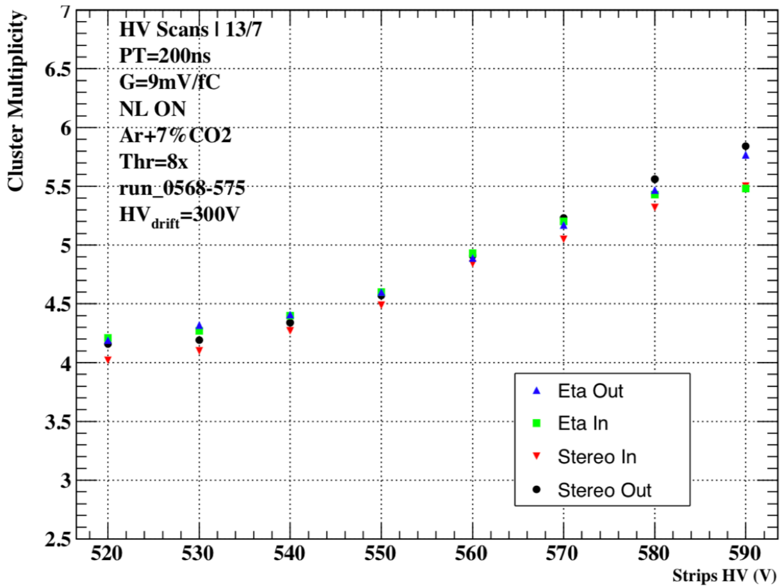
Software Efficiency @ 20°



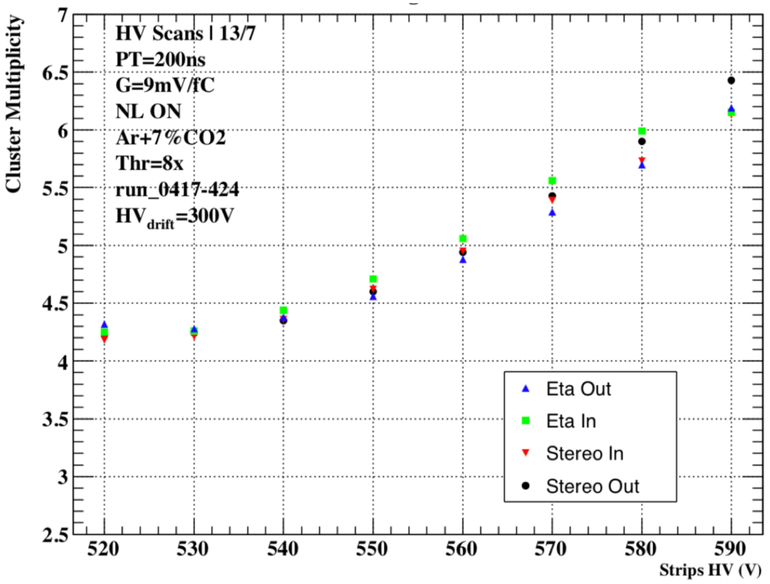
Software Efficiency @ 30°



Cluster multiplicity @ 20°



Cluster multiplicity @ 30°



Working Point studies -- Summary

Efficiency:

- The efficiency plateau at ~97% is reached at HV~580 V. Very close to the discharge limit (~600 V)
- In order to keep a safety margin from the onset of discharges, must operate at HV lower than ideal.
- At 570 V ε ~95% at 0^o , decreasing to ~90% at 30^o
  - THIS IS CONSIDERED SAFE → New "safe" Working Point set at 570 V

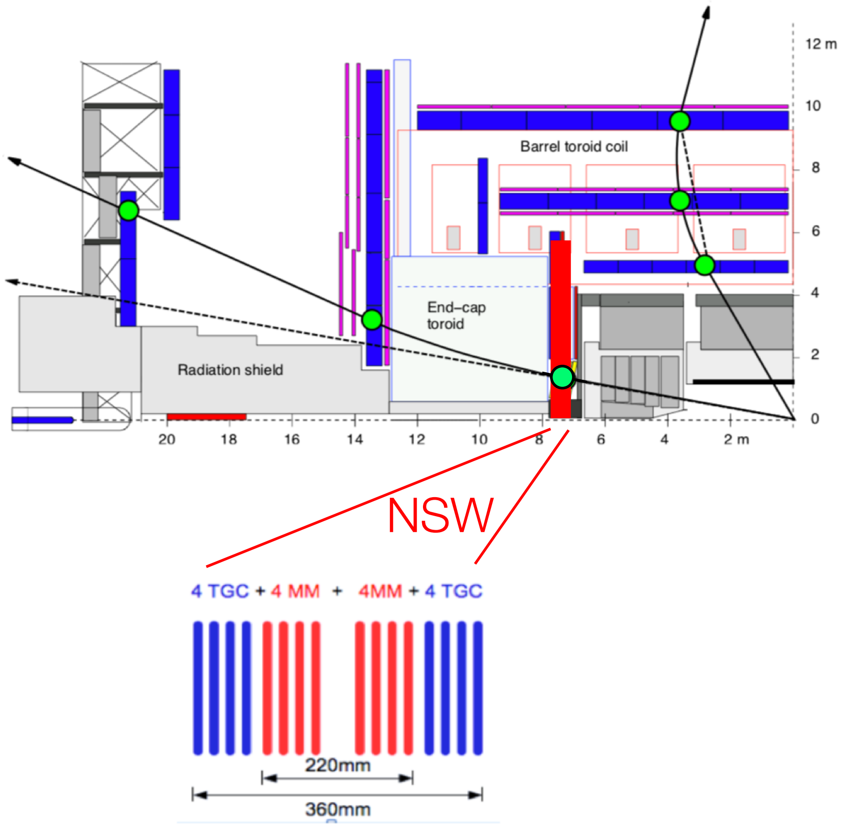
Spatial Resolution:

- Better than 100 μm for perpendicular tracks (as expected)
- For inclined tracks still studies on μTPC in progress (VMM tdo, time measurements calibrations ongoing)

→ CAN WE OPERATE EFFICIENTLY THE MM, IN THE NSW, AT A REDUCED WP ?

Global Muon Reconstruction performance from simulations

Momentum Measurement



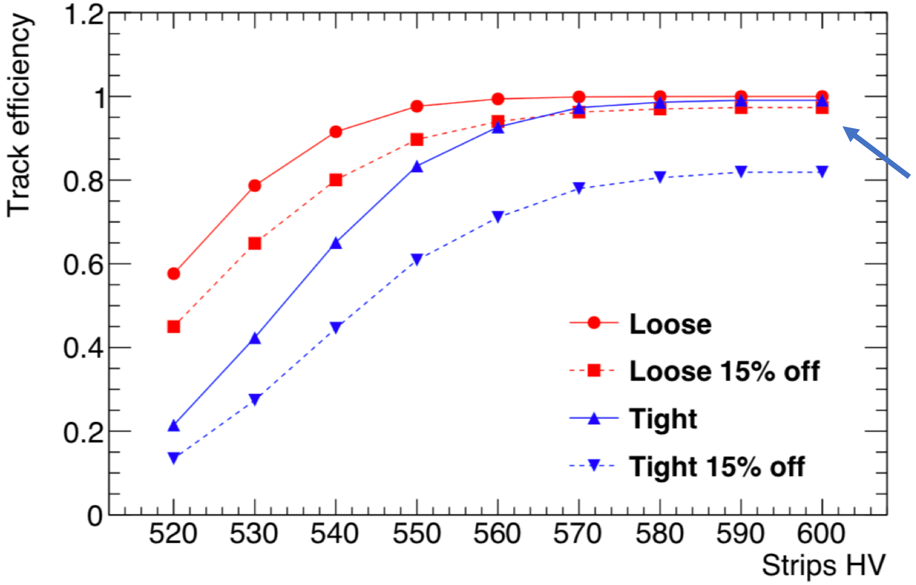
The NSW is a highly redundant system with 16 measurement planes

Simulation based on a simple toy-MC

- No background hits included yet (from pileup, cavern background and other sources)
- Only gaussian smearings

Courtesy S. Rosati

Efficiency for MM standalone segments



Loose: at least 2 eta and 2 stereo hits in the MM
Tight: at least 3 eta and 3 stereo hits in the MM

- MM Efficiency parametrized Vs HV
- small dependence on HV for 560 – 600V range

Can operate MM down to ~560 V

Still to be optimized

Similar studies done for **momentum resolution performances**, for the combined system sTGC+MM confirm the **high level of redundancy implicit in the NSW design**

Conclusions

- Huge progress was done in the last 10 months to achieve good/acceptable results
  - **Still quality/yield need to be improved**
- Design/structural issues have been carefully studied
  - Tests on different meshes have shown from prototype chambers (ExMe – see P. Iengo Wednesday) possible advantages with other mesh types.
  - Decision taken not to change the mesh was mostly driven by time (need to enter a full phase of R&D), mesh availability in large size, and cost
- **Outcome of the MM Technical Meeting was a unanimous consensus in our community to resume Q-plet assembly in all construction sites.**
- We will implement measures to further control and reduce humidity in all sites, advance to higher HV during ramp up procedure only when gas is dry, improve as much as possible all the procedures

In parallel, studies are ongoing for further possible improvements:

- Better gas mixtures (Ar/CO2 with different proportions, addition of Isobutane – work ongoing at CERN)
- Minor improvements in the cleaning procedures (tests at CERN – Rui's Lab - soon)
- Speed up Q-plet drying to avoid RH effects during validation (tests at CSs and tests and at CERN)

Acknowledgments

We are extremely grateful to all the “external” expert colleagues helping us in this challenging project

In particular:

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And Leszek, Alain, Paul, Eraldo,… attending our MM Technical Review Meeting, providing extremely important feedback

A BIG BIG THANK YOU !