Large area micromegas detector for AMBER: lateral module prototype test

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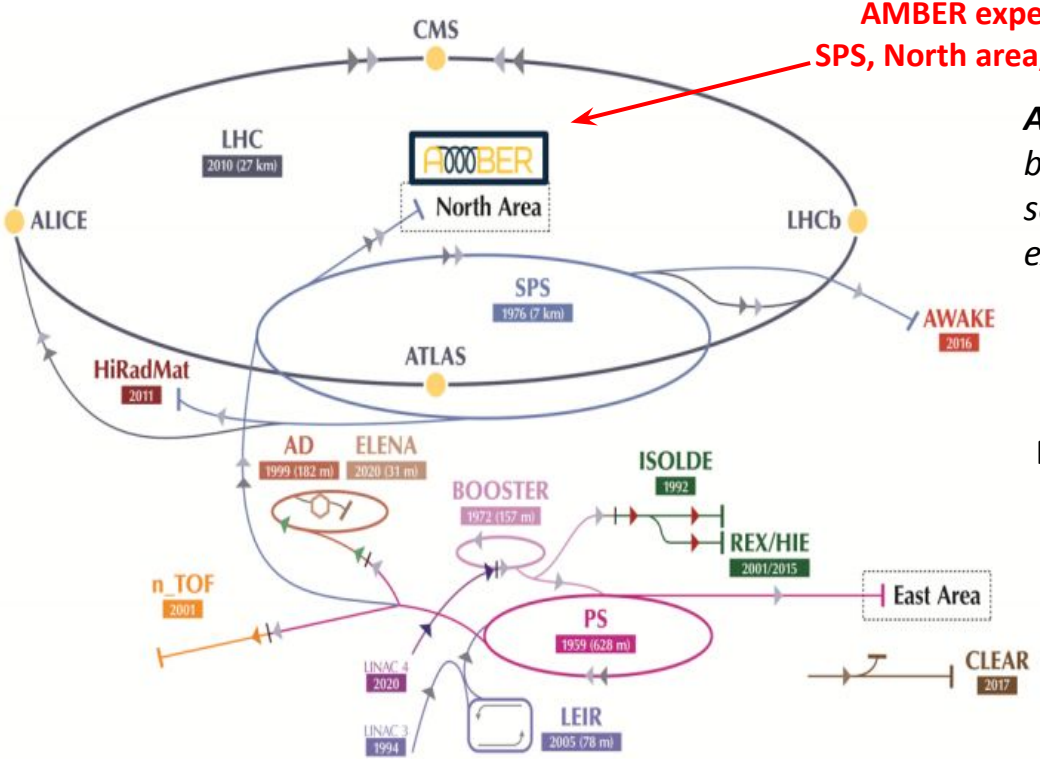
on behalf of AMBER-micromegas group
University of Torino
INFN Torino
CERN

DRD1 collaboration meeting 10.12.2024

AMBER experiment at CERN



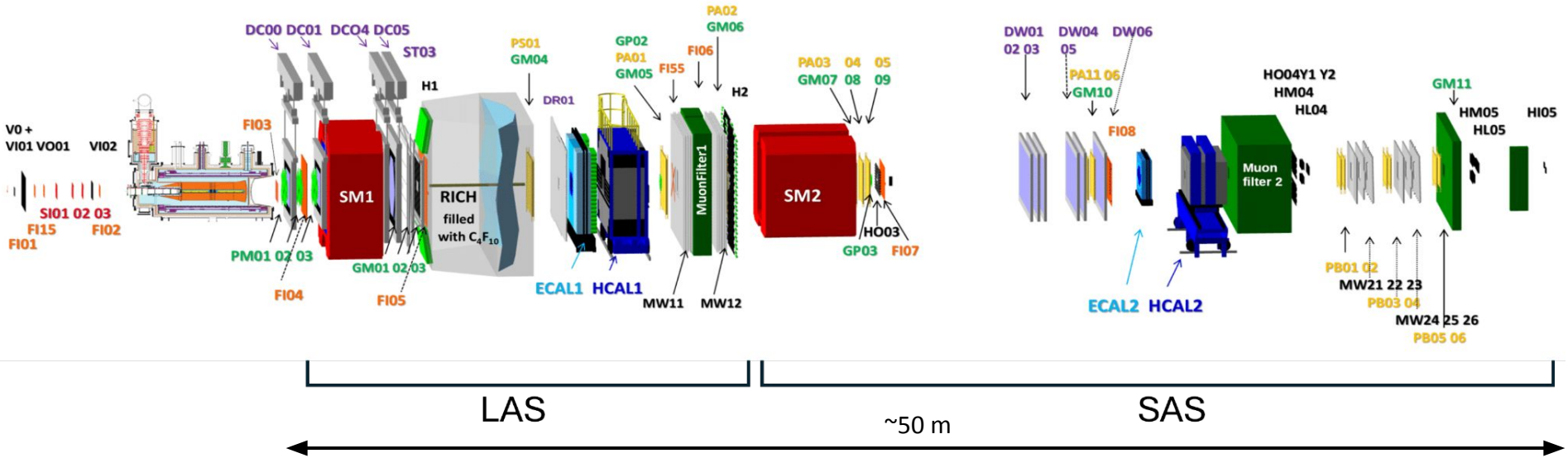
AMBER (NA66) *is a fixed target experiment at the M2 beam-line in the North Area of CERN. It is located in the same experimental hall (EHN2) in which COMPASS experiment was.*

Physics program Phase-I

- Antiproton production cross-section for indirect Dark Matter search (APX)
- Proton radius measurement (PRM)
- Drell-Yan processes for Kaon and Pion PDFs (DY)

AMBER experiment at CERN

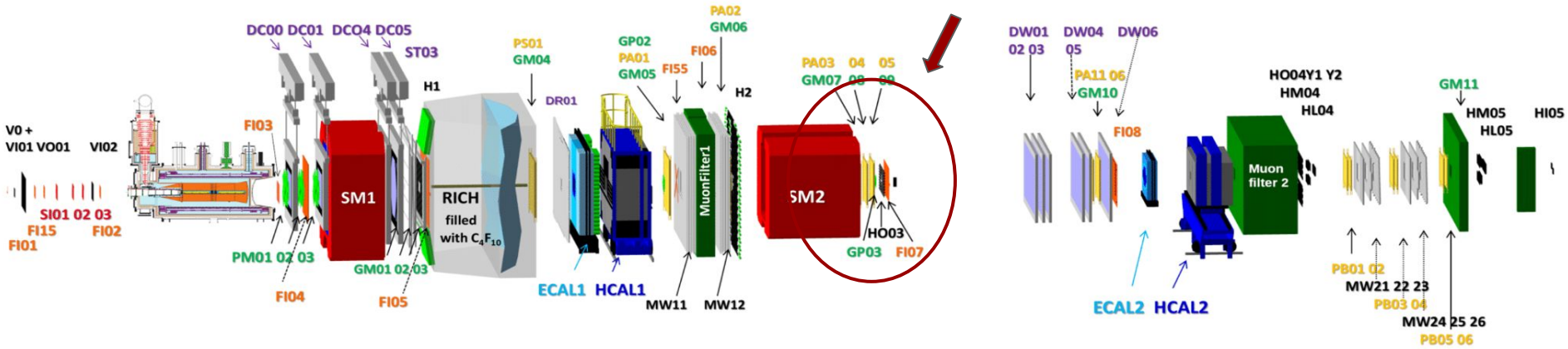
AMBER spectrometer



*The former COMPASS spectrometer is being used for APX measurement and will undergo several **upgrades** for the mid- and long-term program.*

AMBER experiment at CERN

AMBER spectrometer



*The former COMPASS spectrometer is being used for APX measurement and will undergo several **upgrades** for the mid- and long-term program.*

Torino group is responsible for the Multi-Wire Proportional Chamber (**MWPC**) tracking stations and the **Rich Wall** Mini-Drift Tubes (MDTs) detector.
Part of the MWPCs will be substituted by Micro-Pattern Gaseous Detectors (**MPGD**) to face their structural aging.

Introduction: LMM lateral module prototype

Mechanical structure and readout PCBs

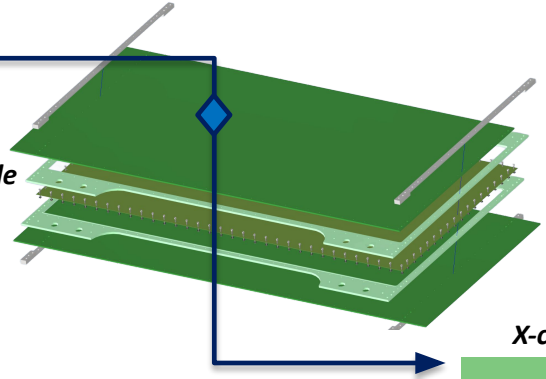
X-coordinate R/O plane

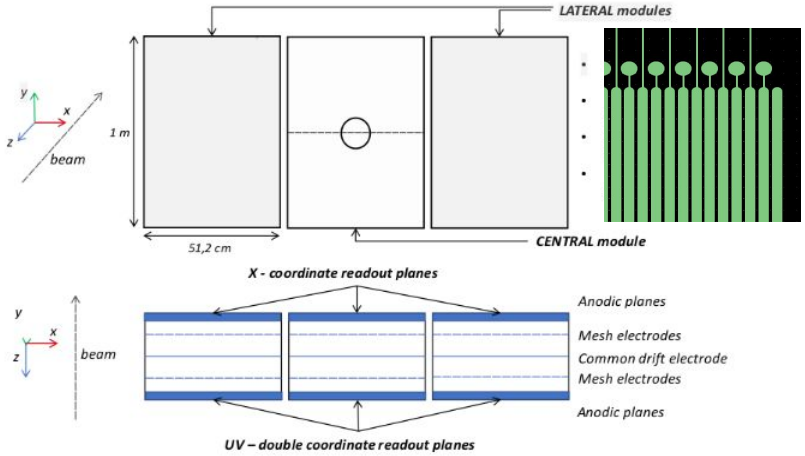
FR_4 gas vessel frame

Cathode PCB - drift electrode

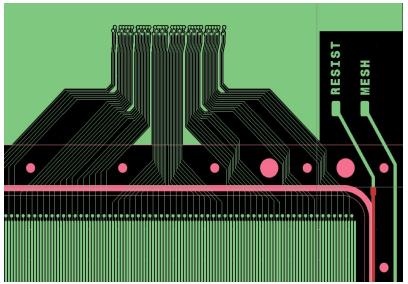
FR_4 gas vessel frame

UV-coordinates R/O plane

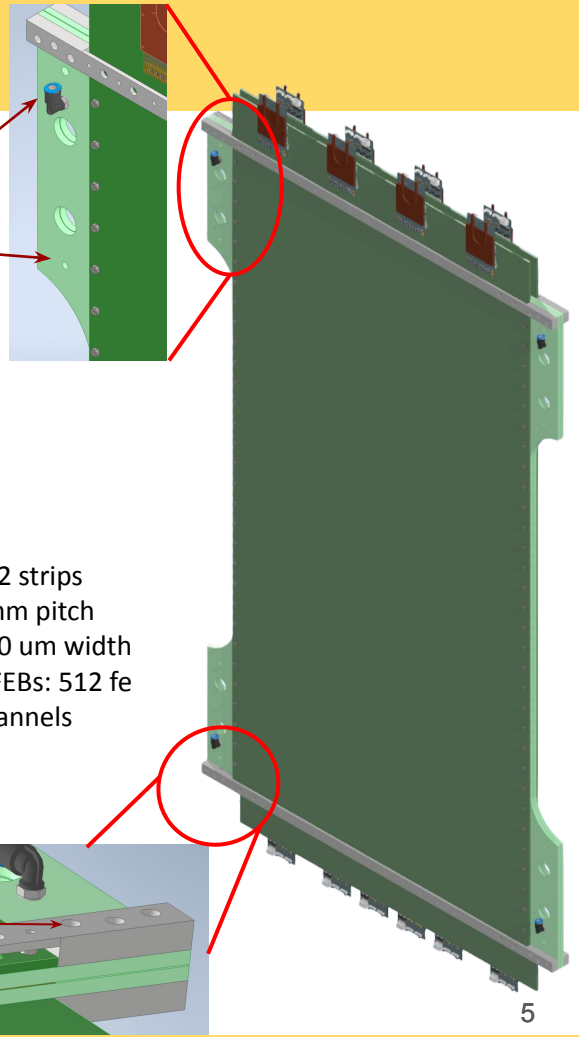




X-coordinate R/O plane



- 512 strips
- 1mm pitch
- 750 um width
- 4 FEBs: 512 fe channels



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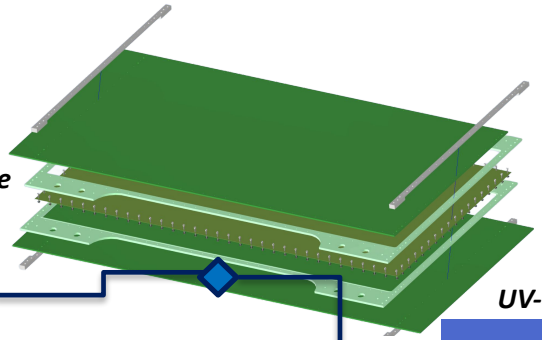
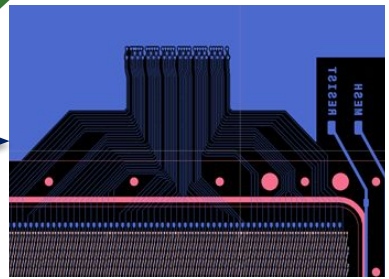
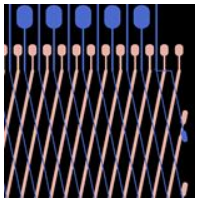
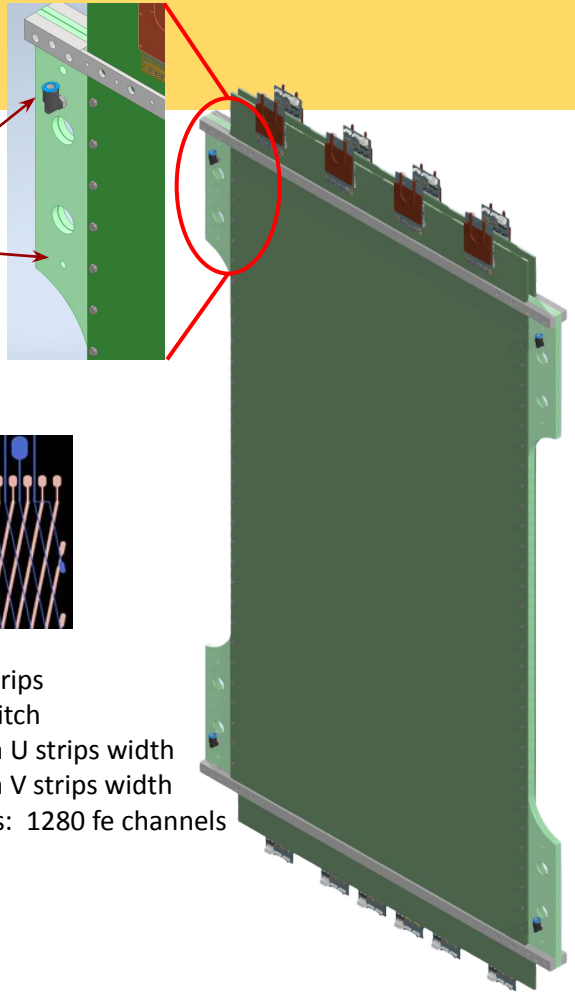


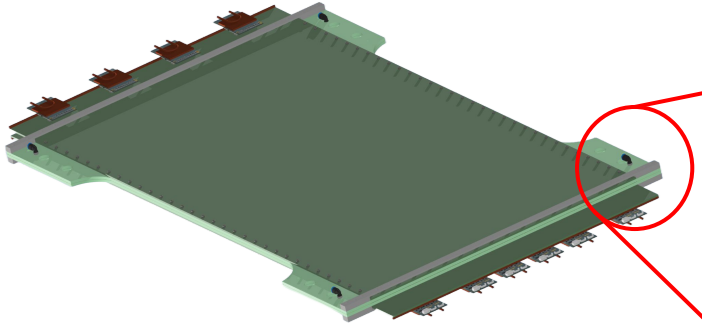
UV-coordinate R/O plane

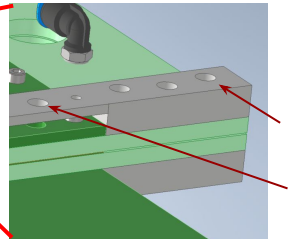




- 1280 strips
- 1mm pitch
- 250 um U strips width
- 150 um V strips width
- 10 FEBs: 1280 fe channels







Introduction: LMM lateral module prototype

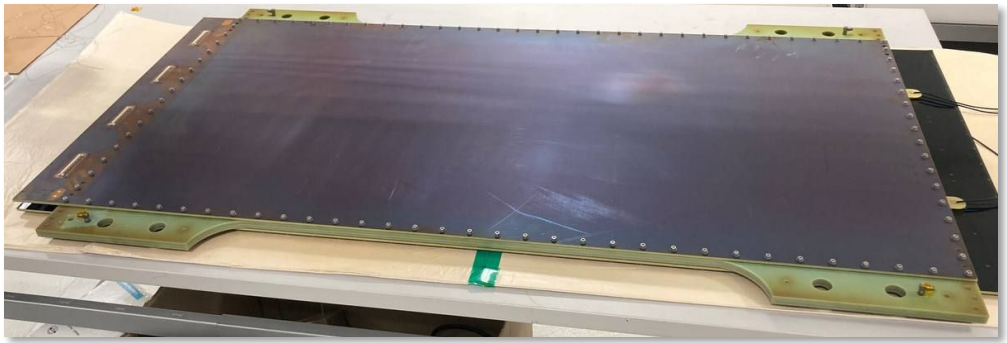
Detector production

After PCB production the DLC deposition is performed followed by “bulkage” process

FR4 frame with cathode electrode

Diamond-like carbon (DLC) resistive layer: 10 MΩ/cm^2

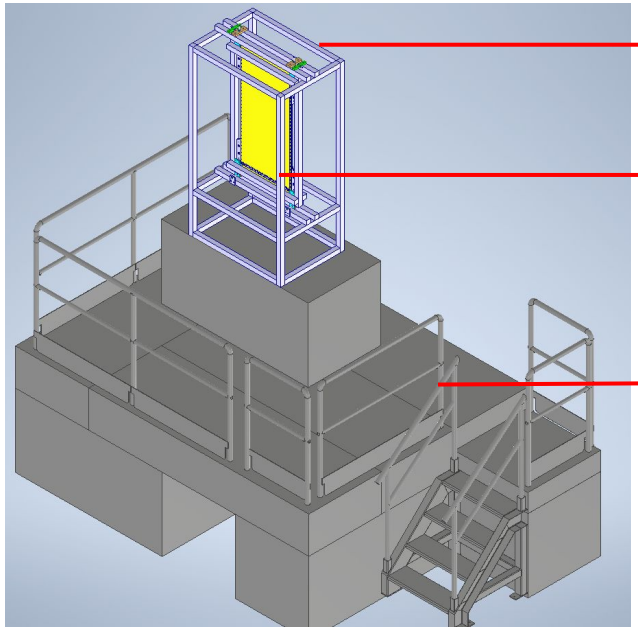
Mesh electrode high: 150 um



Micromegas detector assembled

Current leakage test carried out in the clean room before assembling.

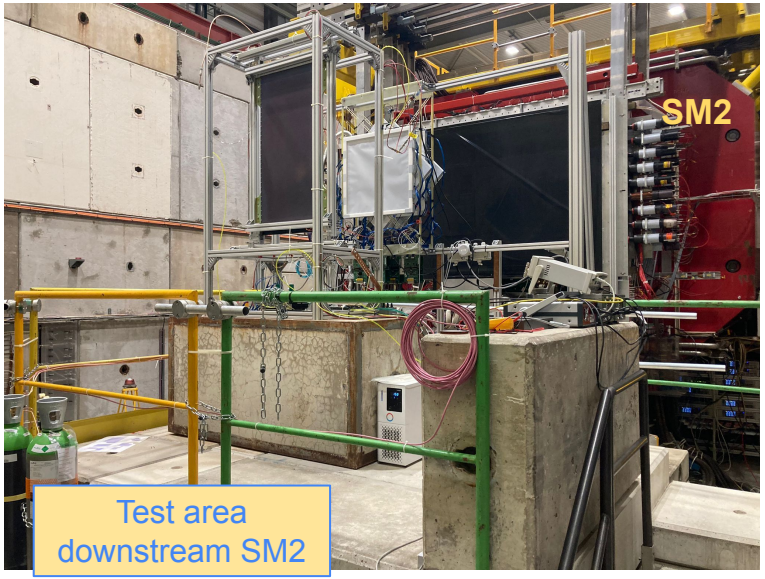
LMM test setup @ AMBER

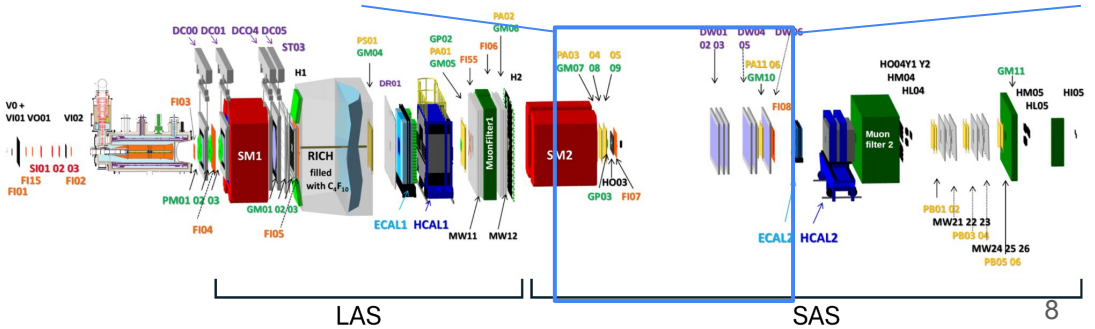


Detector holding structure made out of bosch profiles

Micromegas detector lateral module

Concrete platform





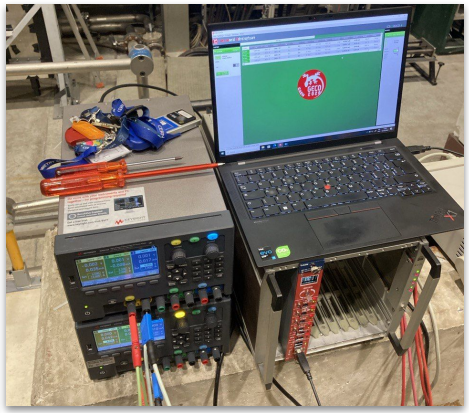
✓ *Detector installed on 12.10.2024*

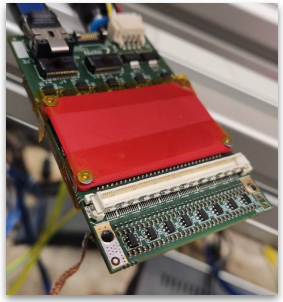
✓ *Safety visit passed on 14.10.2024*

LMM test setup @ AMBER

Beam test facilities

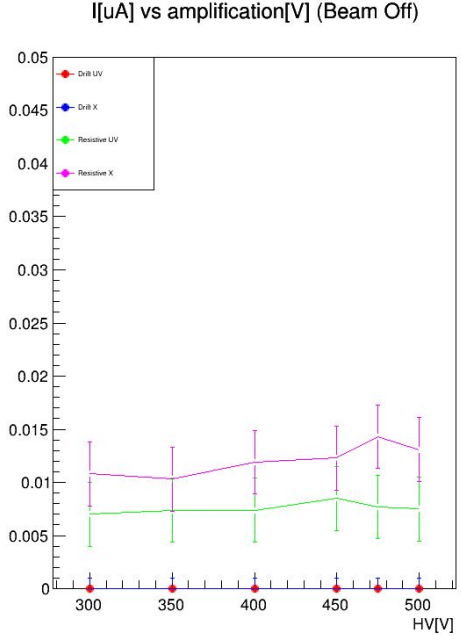
- GAS lines:
  - Ar/CO_2 70/30 ⟶ Rich Wall line
  - Ar/CO_2 93/7 ⟶ Gas bottle
  - $Ar/CO_2/iC_4H_{10}$(isobutane) 93/5/2 ⟶ Gas bottle
- LV power supplies: KEYSIGHT E36313A
- HV power supplies: CAEN A18221HN (negative), CAEN A1560HDP (positive)
- NETGEAR 10Gb Network switch for data transmission.
- TIGER-based electronics:
  - 6 front-end boards ⟶ 2 TIGERs each ⟶ 128ch/feb
  - 3 GEMROCs DAQ modules ⟶ capable to read 12 FEBs

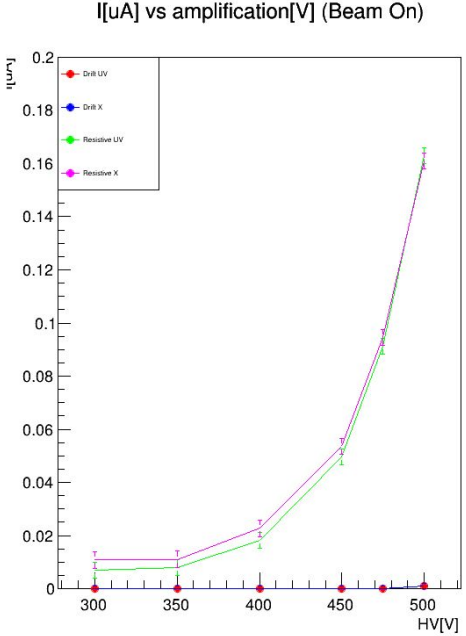


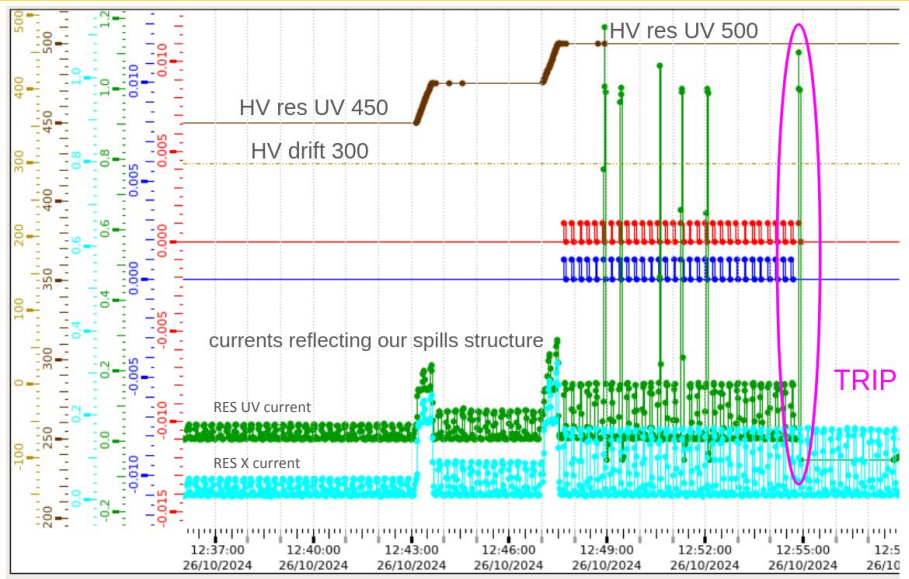


LMM test @ AMBER: HV stability

Ar/CO_2 93/7



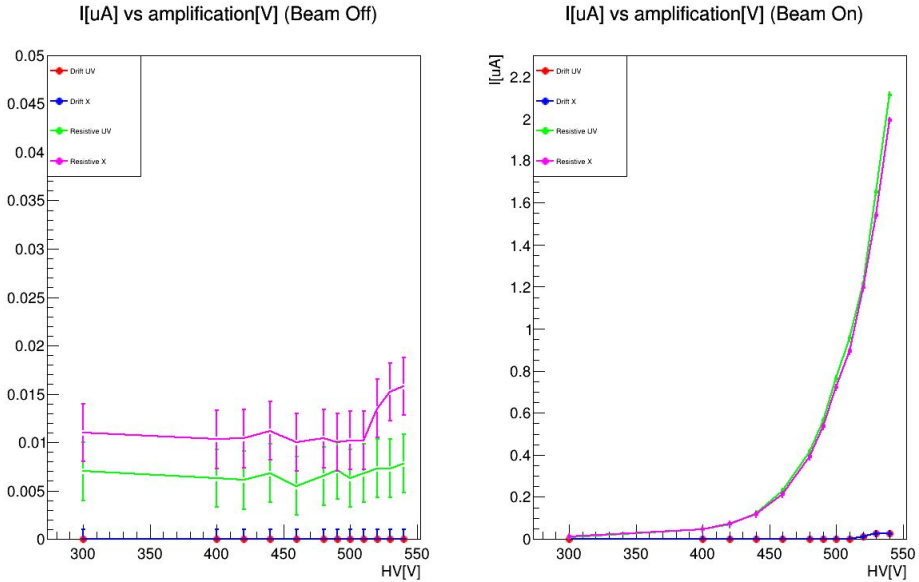


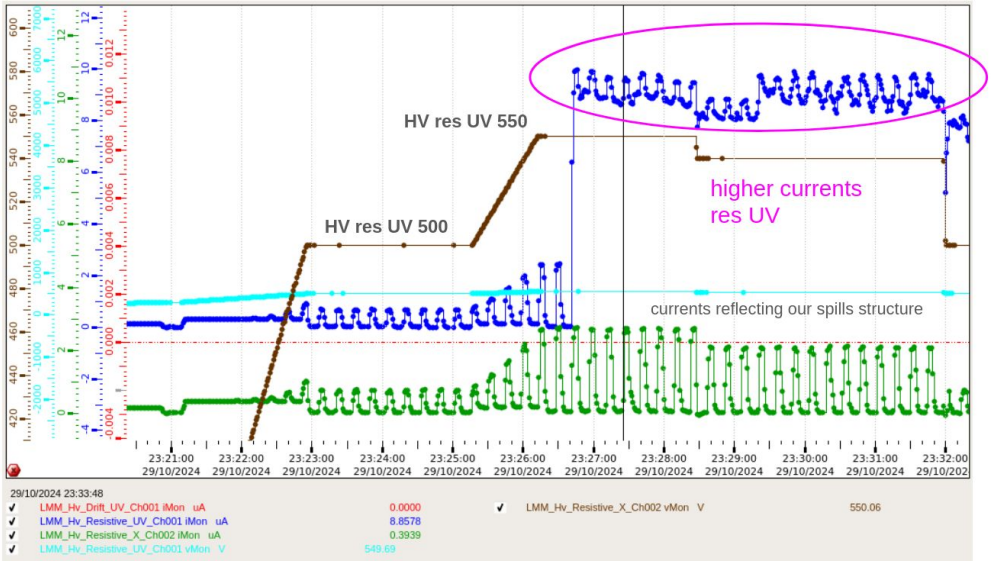


- **drift** electrodes stable up to 550 V
- **Resistive X** : stable up to 550 V
- **Resistive UV**: stable up to 500 V

LMM test @ AMBER: HV stability

Ar/CO2/iC$_4$H$_{10}$(isobutane) 93/5/2

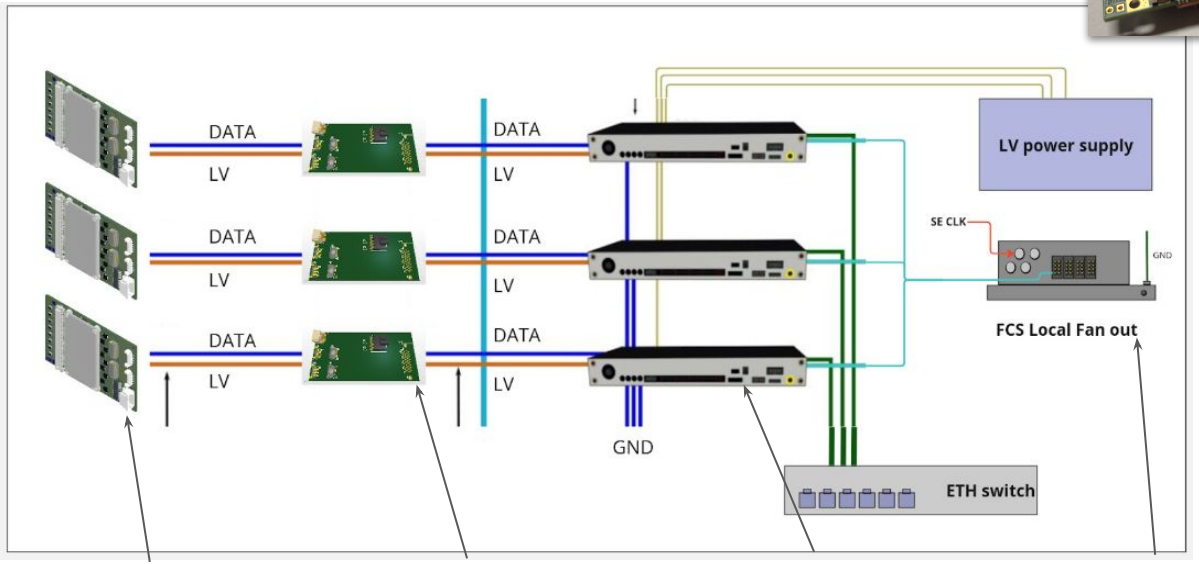




- **drift** electrodes stable up to 550 V
- **Resistive X** : stable up to 540-550V
- **Resistive UV**: stable up to 540 V

LMM test @ AMBER: readout chain

AMBER TIGER-based readout chain:



AMBER-micromegas_FE
designed at INFN To

TIGER-based front-end board

Data and Low Voltage Patch Card - DLVPC
designed at JINR

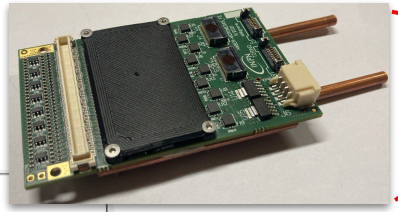
adapter for data and LV

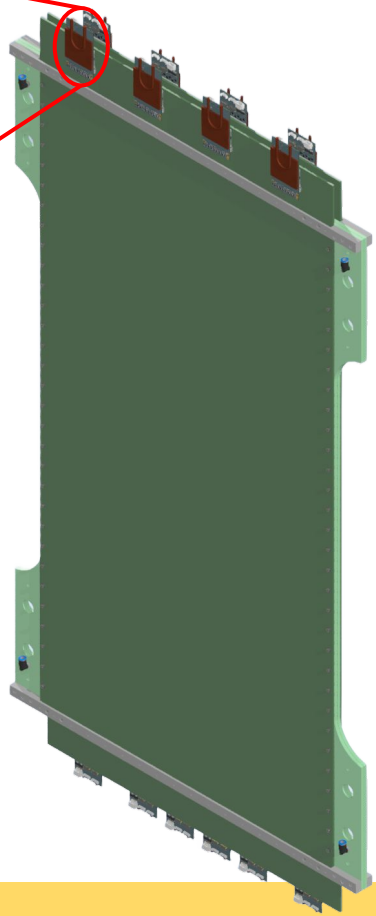
GEMROC modules
designed at INFN Fe

Configuration and control signal distribution
Data concentration

Local FAN OUT
designed at INFN Fe

Trigger and clock distribution





6 TIGER-febs available:

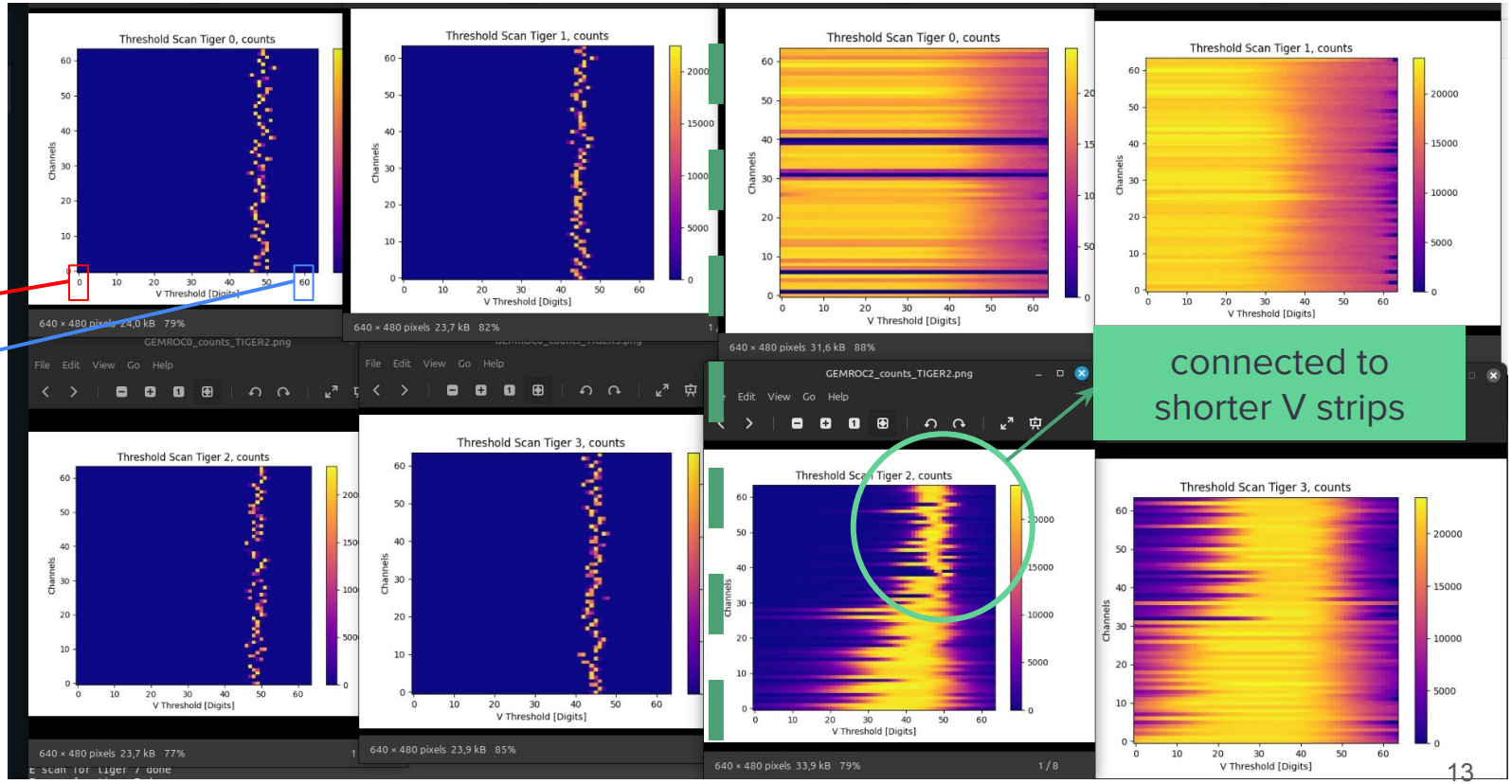
- 768/1280 UV
- 512/512 X+ 256/1280 UV connected (from shorter strips)

LMM test @ AMBER: noise study

Thr scan results example

before connecting FEBs to the detector

FEBs connected to the detector



LMM test @ AMBER: noise study

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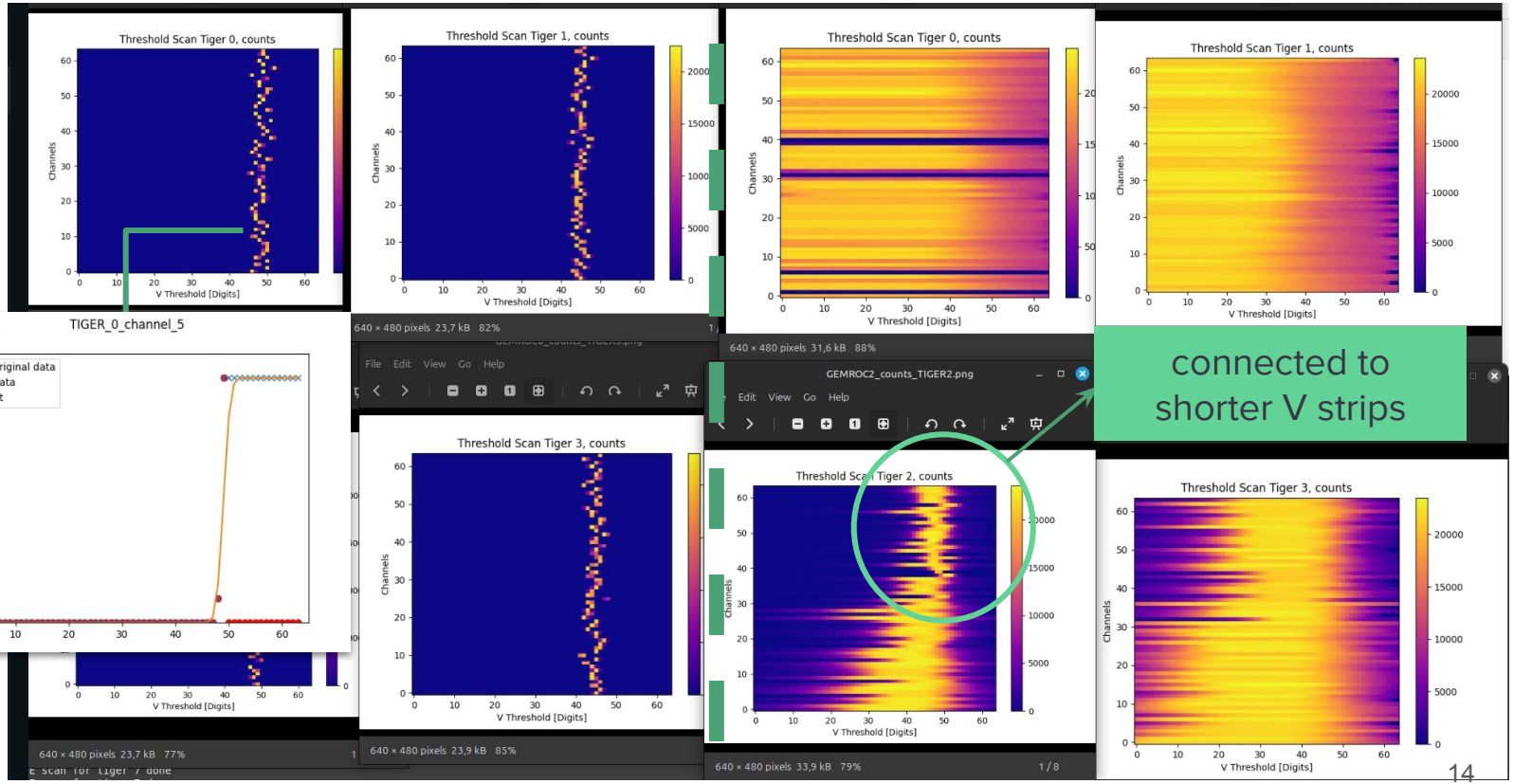

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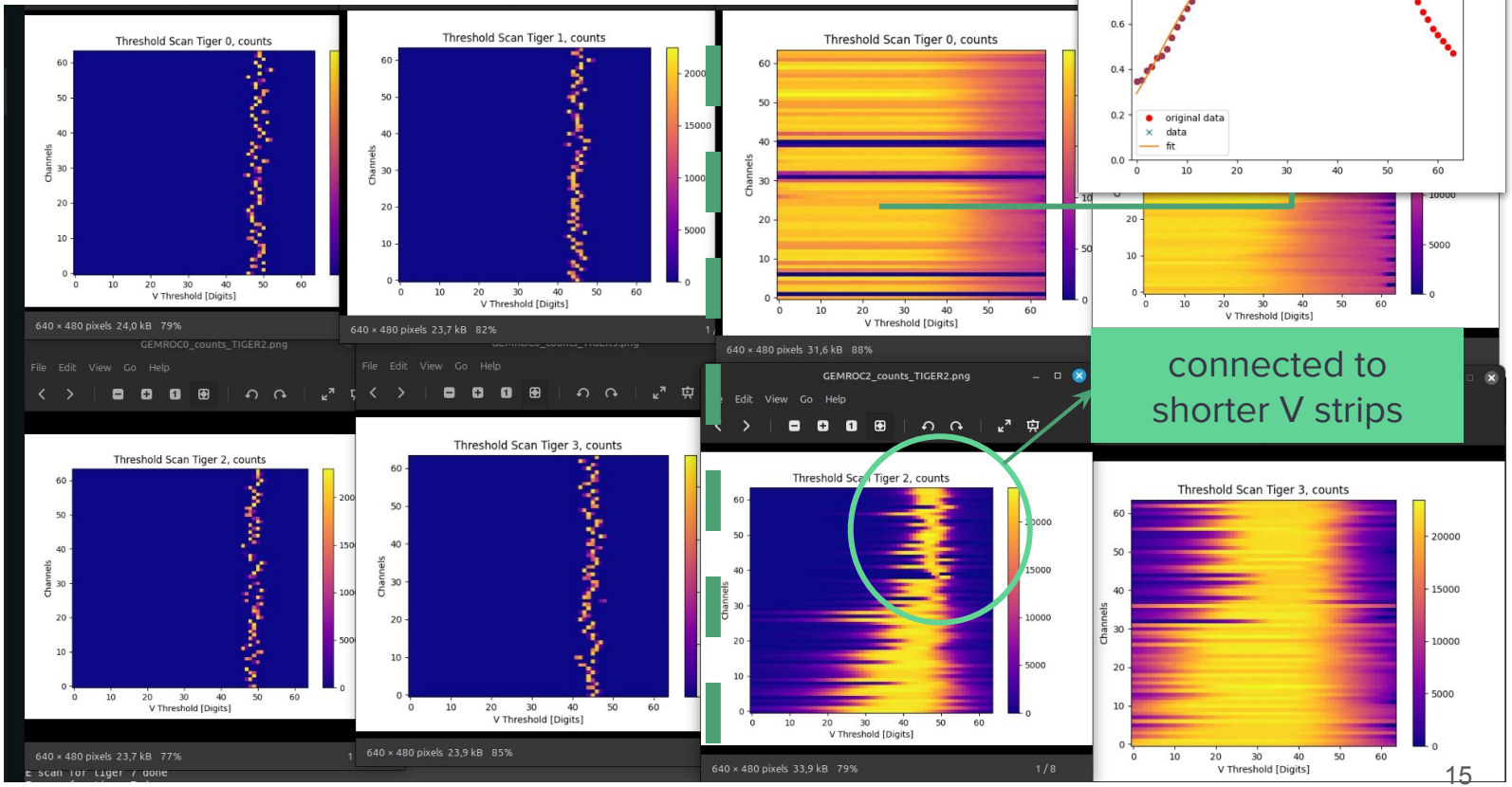

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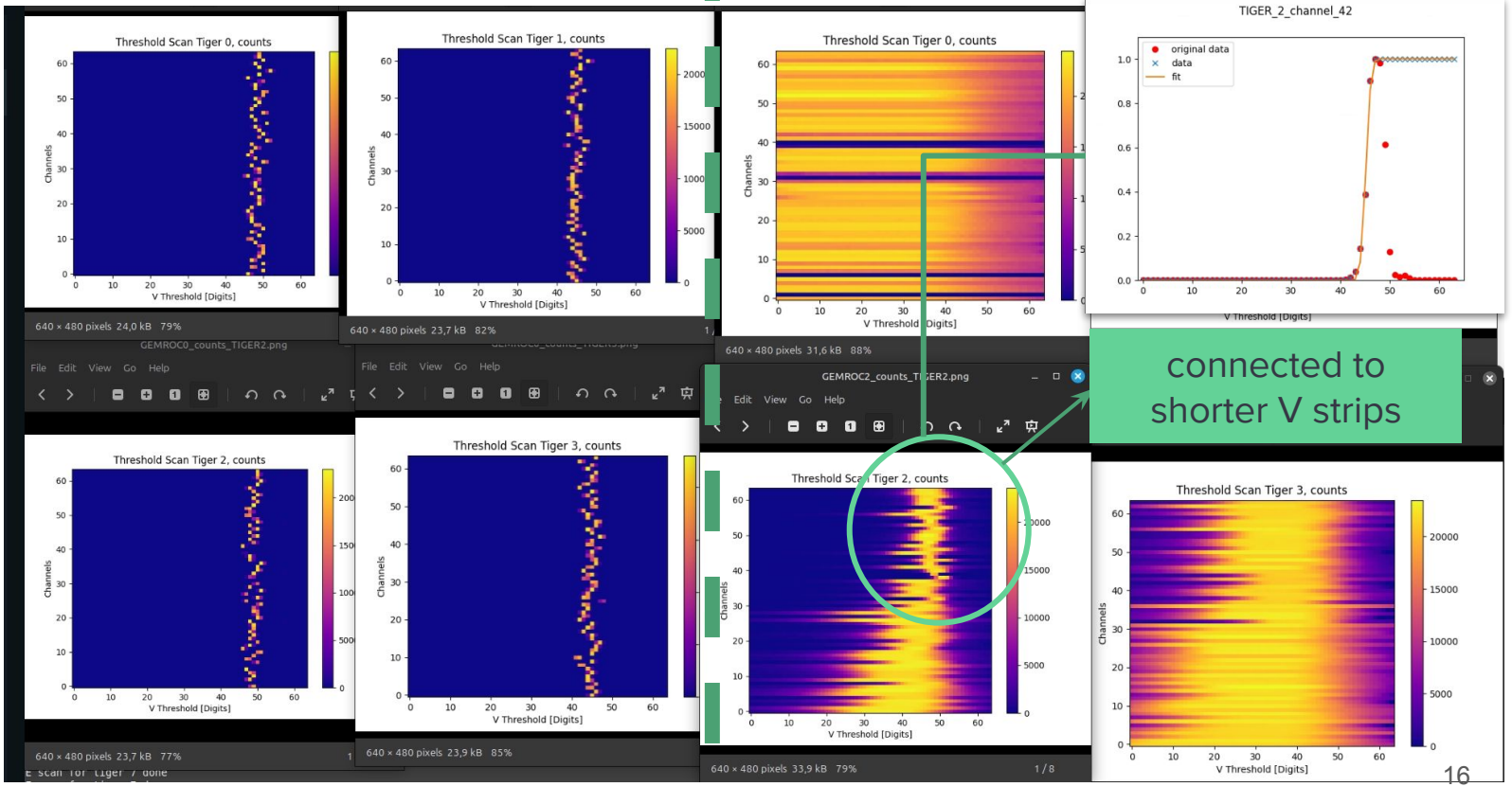
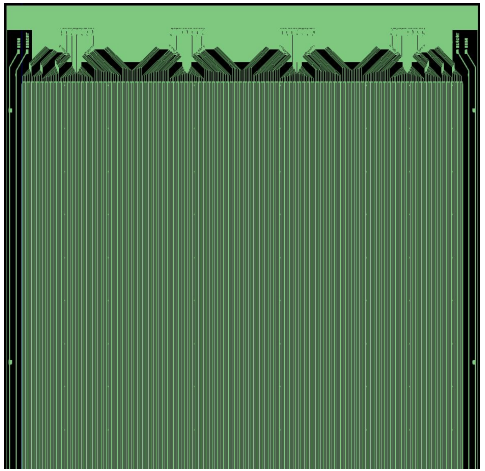
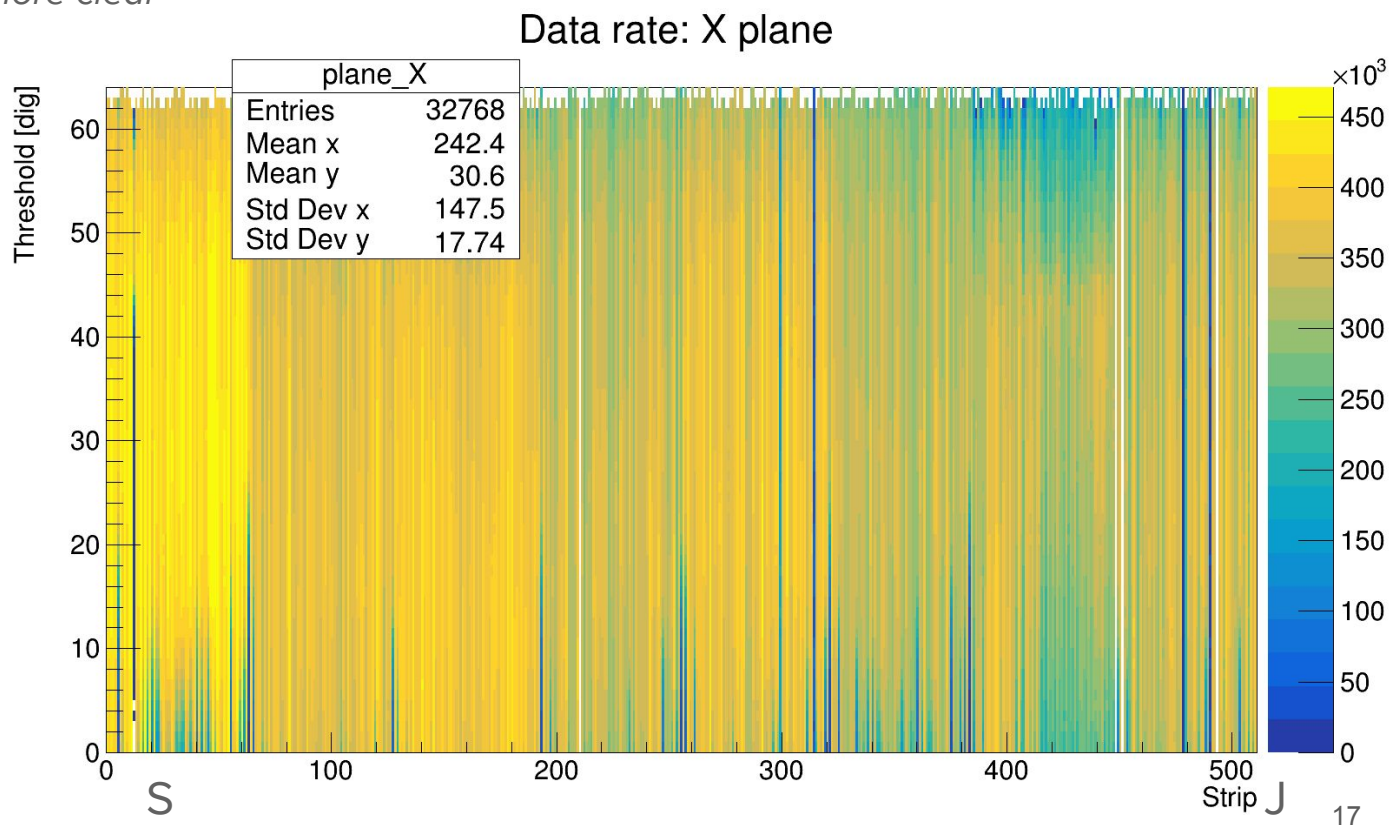


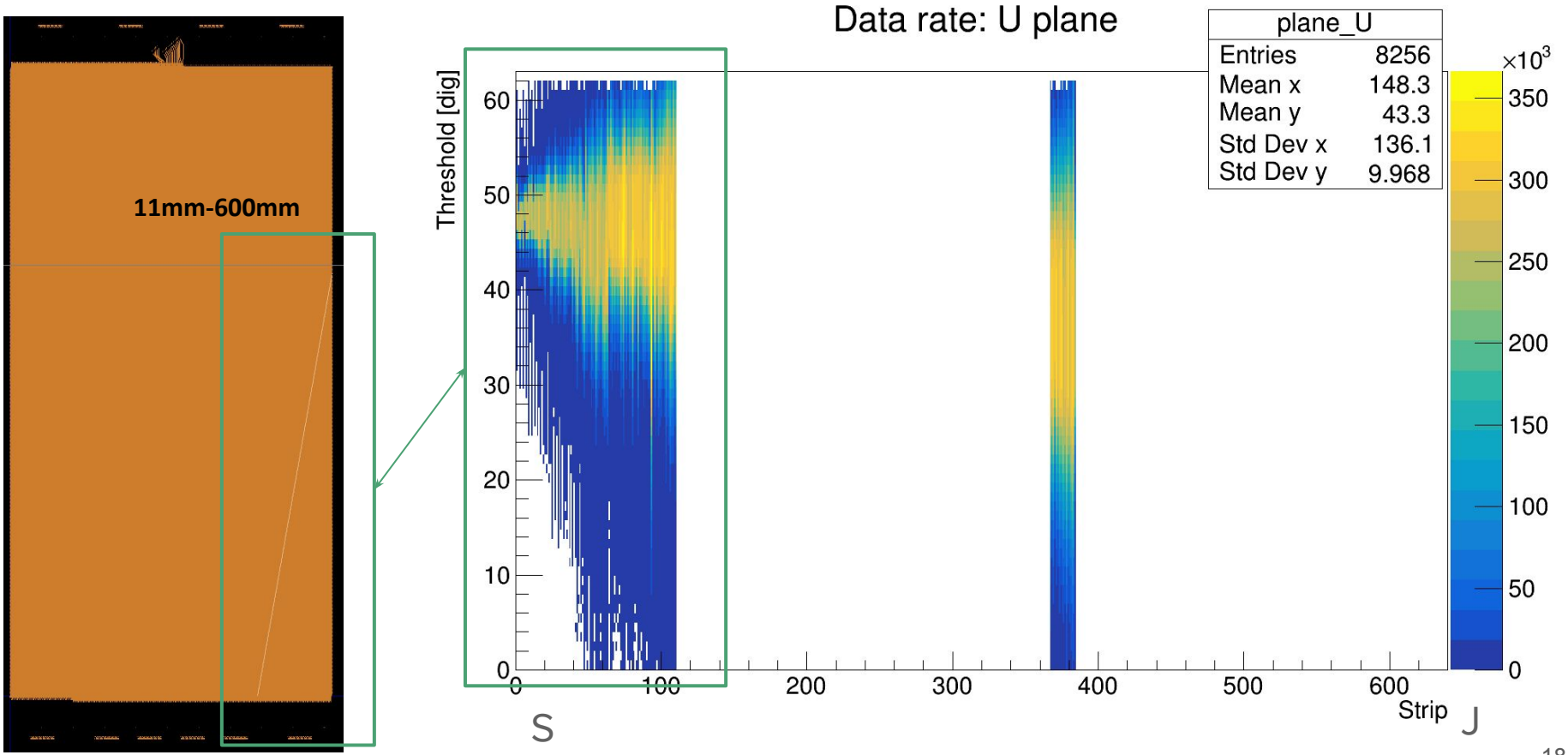
LMM test @ AMBER: noise study

Applying mapping it is even more clear





LMM test @ AMBER: noise study



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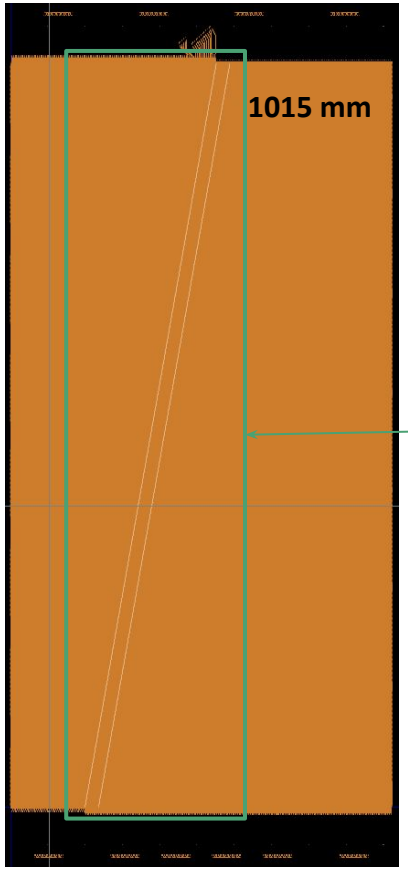

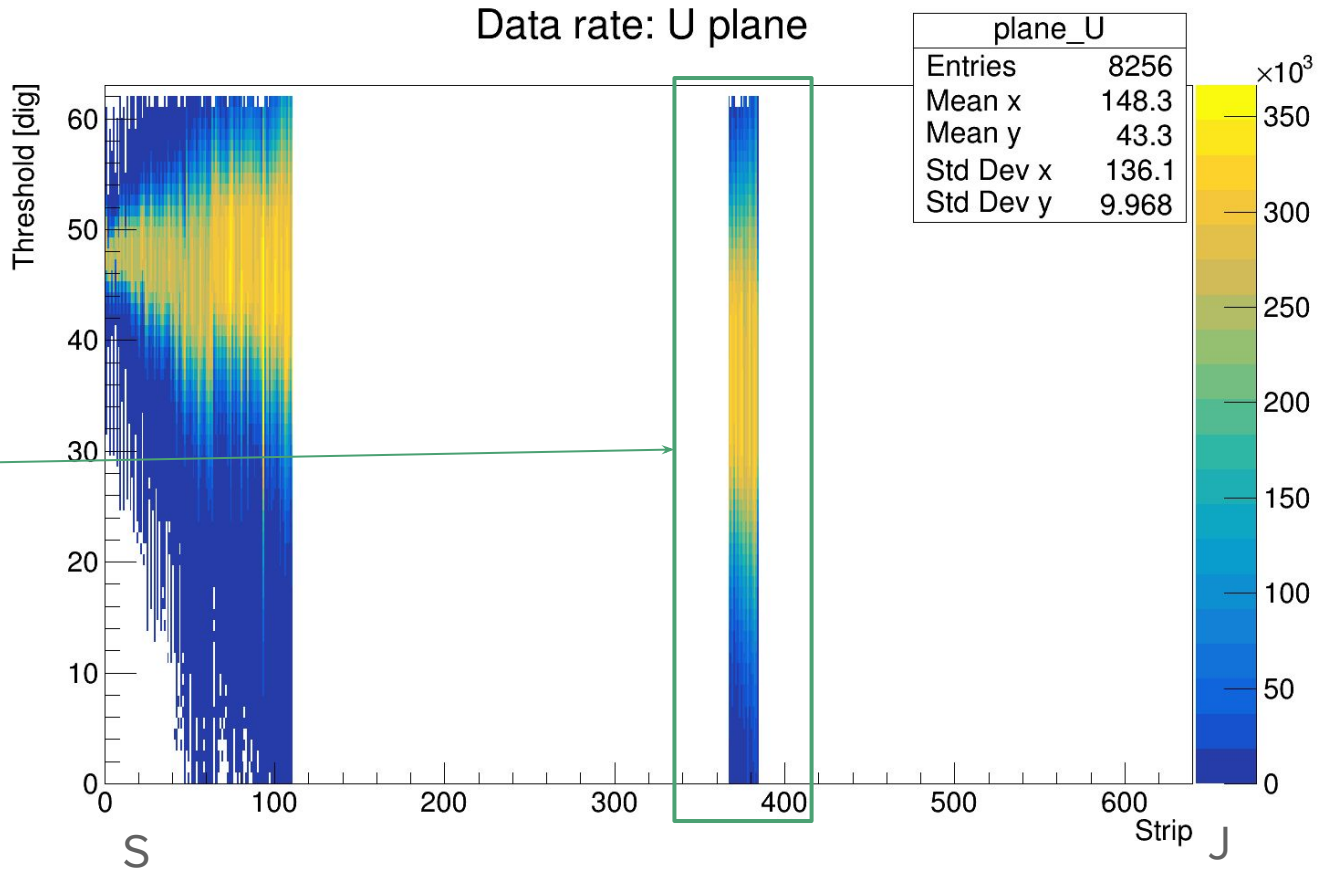

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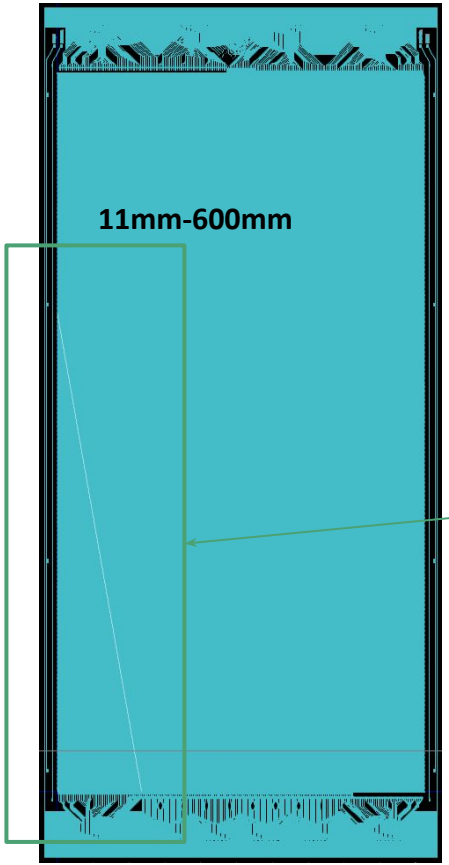
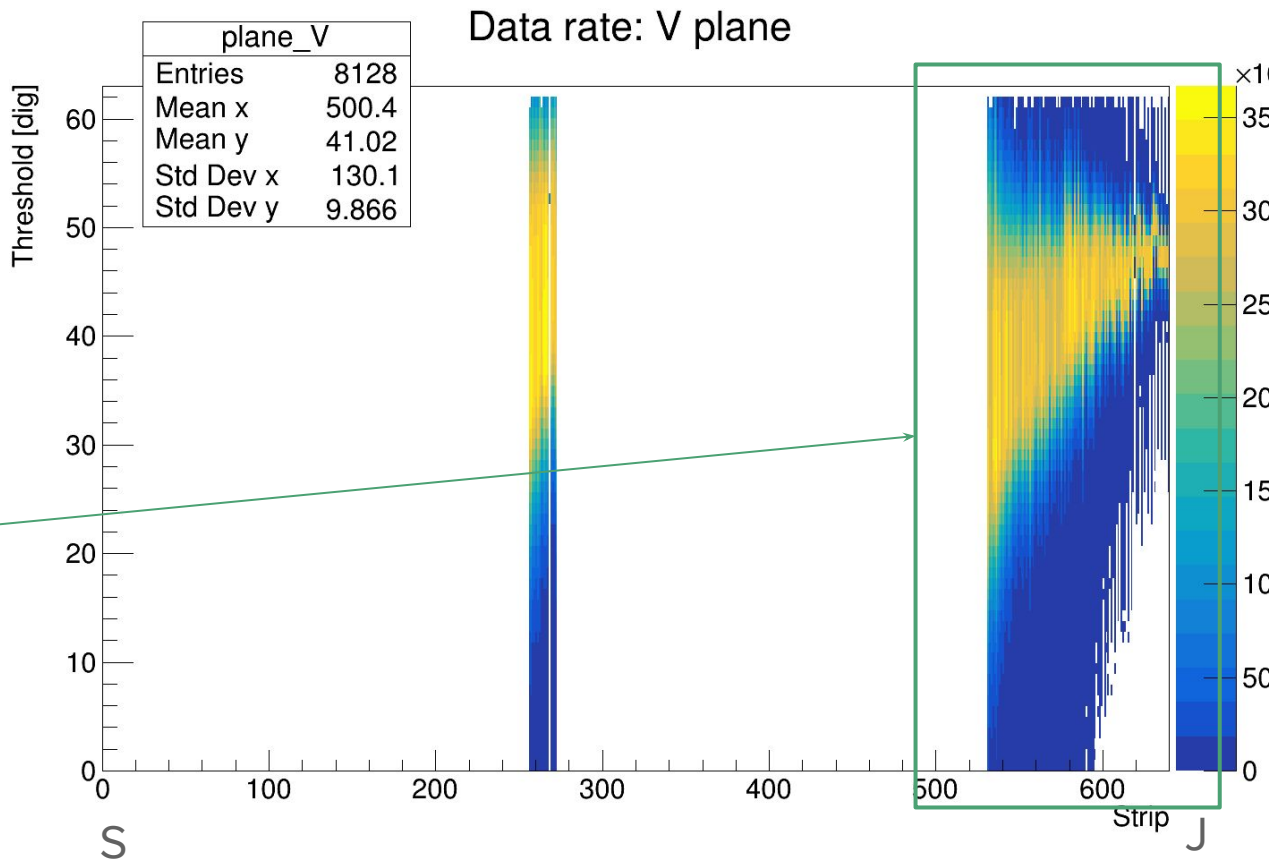
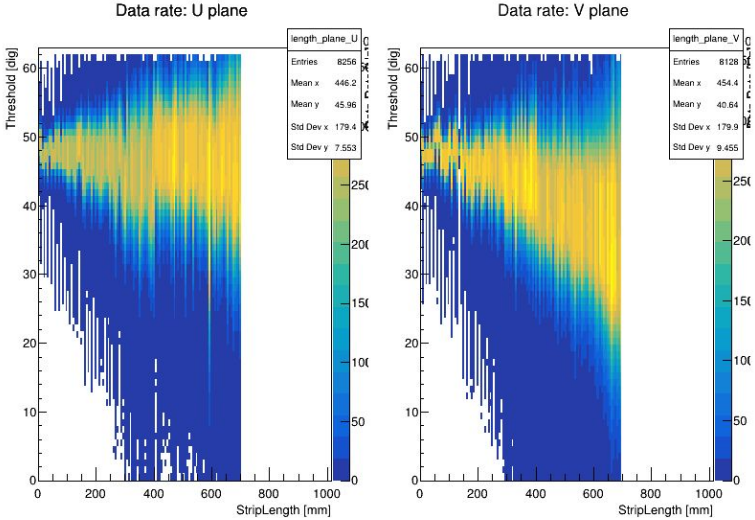




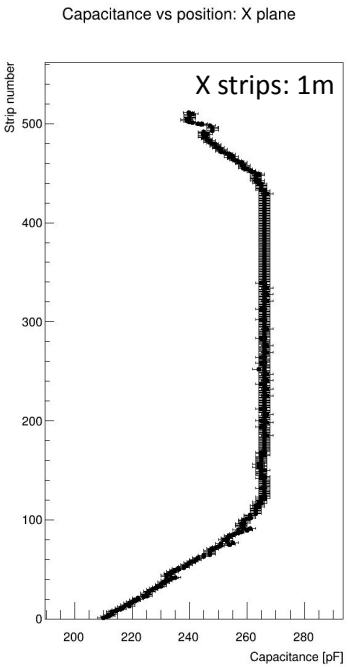
LMM test @ Torino: strip capacitance

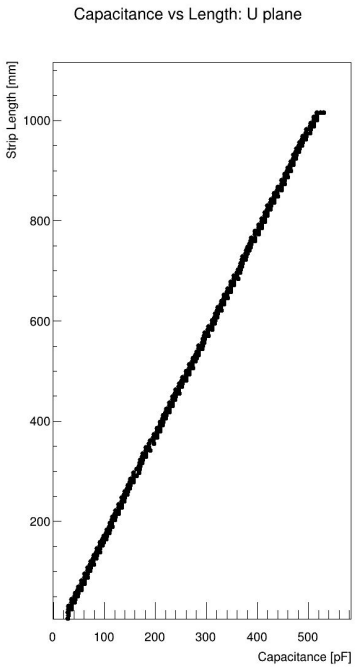


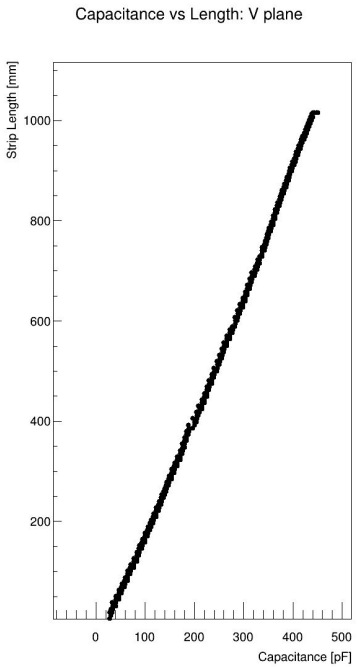
Wider thresholds distributions with longer strips

Strips capacitance measured in Torino

- X strips range: 210-250pF
- U strips range: 30-530pF
- V strips range: 28-450pF

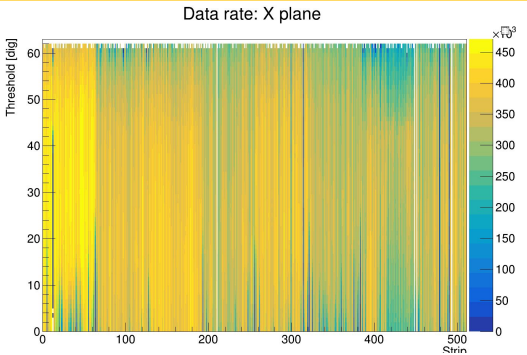


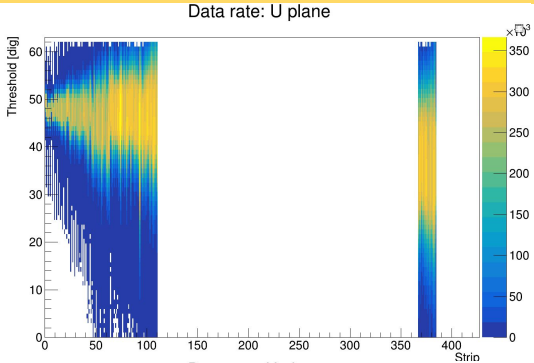


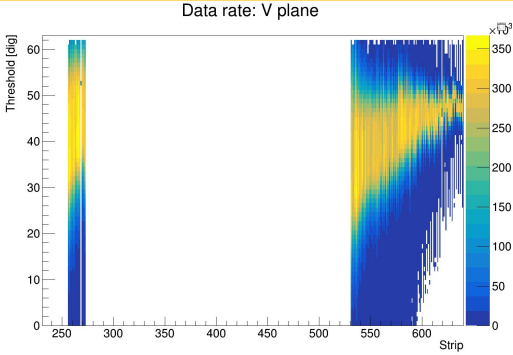


LMM test @ AMBER: grounding enhancement

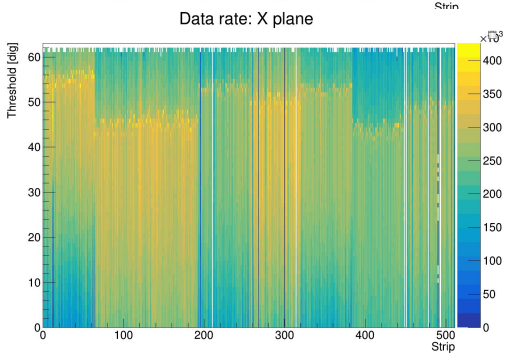
I GND scheme:
1 ground point reference

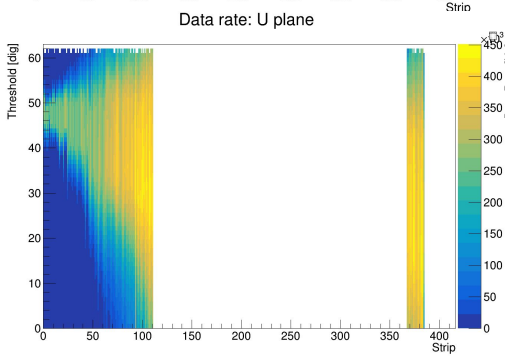


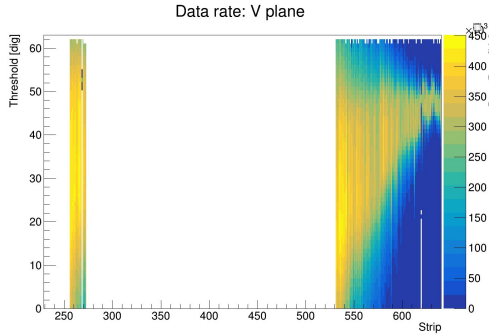




II GND scheme:
detector decoupled from holding structure

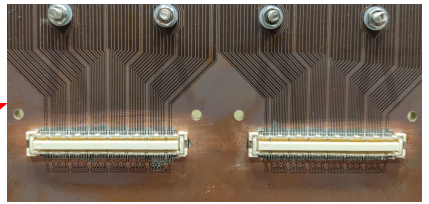






Grounding enhancement general operations (common for both GND scheme):

- Copper braids between FEBs and detector ground
- extra GND cables added on both TOP and BOTTOM side
- Aluminized Mylar wrapping → particularly effective: *copper stiplines shielding*



LMM test @ Torino: HV stability

Ar/CO_2 70/30

Custom	ISet	VSet	VMon	Pw	ChStatus	RUp	RDwn	Trip	ImonRange	IMonL	IMonH	Polarity	MaxV
00.000	1.00 uA	550.0 V	**549.9 V**	On	On	1 Vps	10 Vps	1.0 sec	Low	**0.000 uA**	**0.0 uA**	**POS**	1000 V
00.001	1.00 uA	550.0 V	**549.7 V**	On	On	1 Vps	10 Vps	1.0 sec	Low	**0.010 uA**	**0.0 uA**	**POS**	1000 V
00.002	1.00 uA	300.0 V	**299.9 V**	On	On	1 Vps	10 Vps	1.0 sec	Low	**0.004 uA**	**0.0 uA**	**NEG**	1000 V
00.003	1.00 uA	300.0 V	**299.9 V**	On	On	1 Vps	10 Vps	1.0 sec	Low	**0.004 uA**	**0.0 uA**	**NEG**	1000 V

ch1
PS offset 9nA
PS accuracy ± 1nA

test setup in Torino

- **drift** electrodes stable up to 600 V
- **Resistive X** : stable up to 630 V
- **Resistive UV**: stable up to 630 V

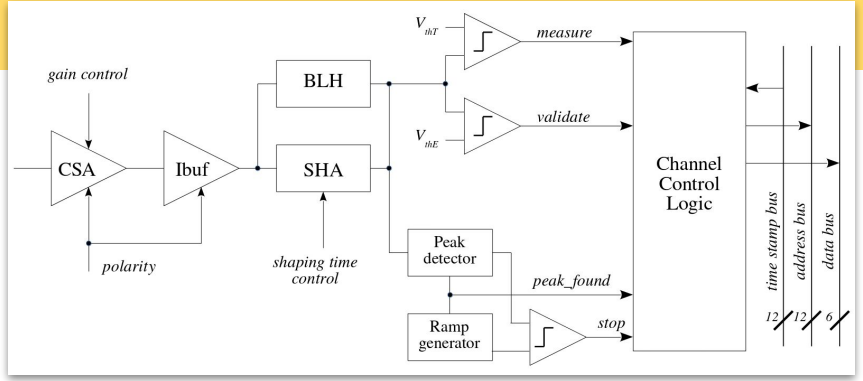
➢ *not totally clear why now the detector is more stable in terms of HV.*
➢ *currents drawn during rump up are comparable with the ones we had in October.*

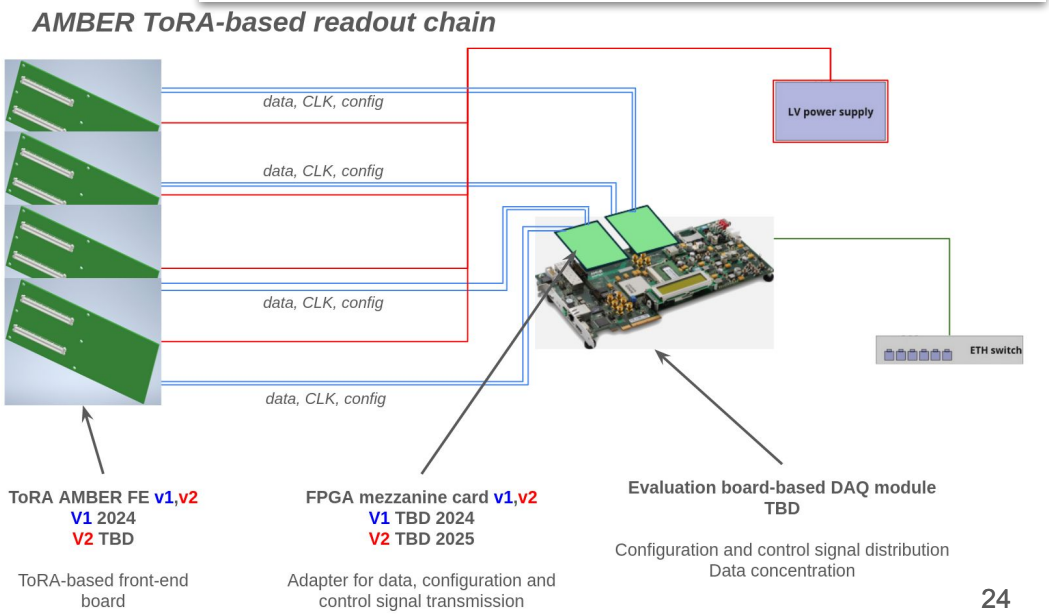
RH + oxygen sensor system could be added to better understand the detector behavior

Front-end electronics: future ToRA-based FEE

Main characteristics:

- **To**rino **R**eadout for **A**MBER will be a 64 chs ASIC with a fully digital interface
- compatibility with MPGD and Wire chambers
- digital back-end inherited from ToASt ASIC (110 nm CMOS) to be adapted for **ToRA v1** which will be implemented in **65 nm CMOS** technology
- The ASIC front-end design development was done providing simulated signal with Garfield++ to optimize signal amplification and conditioning
- time schedule
  - ToRA v1 submission Feb 2025
  - ToRA readout chain design first GeneSys2 (Kintex-7 based) board ordered.



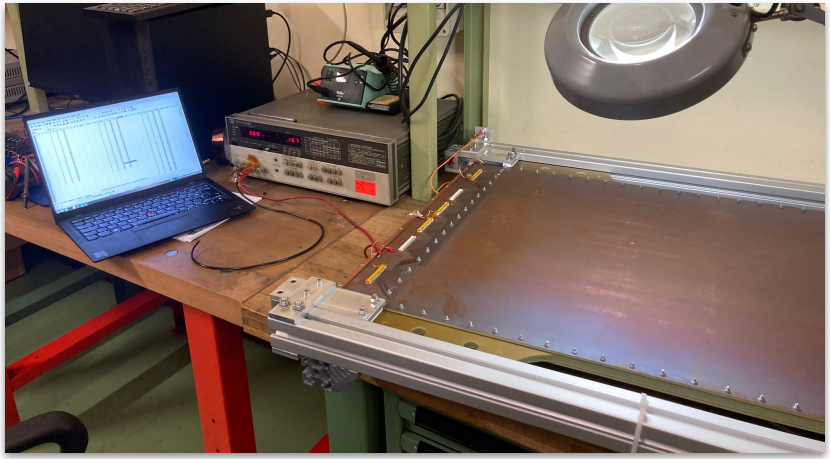


Further activities and next steps

Summary

✓ LMM detector prototype: HV stability, noise study → *proper complete characterization of the detector has to be addressed in the next months*

✓ Validity of the mechanical elements, TIGER-based DAQ infrastructure, cooling system, data transmission proven



capacitance measurement test setup in Torino

Next steps

- Test activities in Torino:
  - Grounding enhancement and shielding configurations
  - Analog readout tests with cremat/cividec pre-amp
- Test with VMM-readout at GDD lab @ CERN
- Design of the final mechanical suspension structure
- ToRA-based readout electronics design and development
  - Design of the ToRA v1 will be submitted in February 2025
  - R/O chain design to be start soon with the support of INFN-Torino electronics workshop

References

[1] Adams et al., Letter of Intent: A New QCD facility at the M2 beam line of the CERN SPS (COMPASS++/AMBER), 2019.
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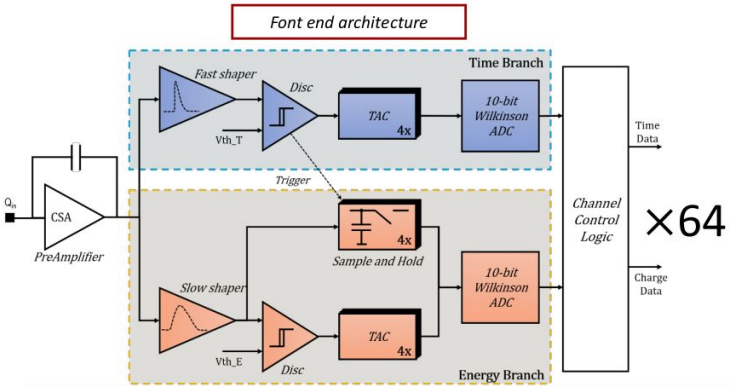
[3] M.G. Alexeev et al., Development of a Micromegas prototype for the AMBER experiment at CERN,NIMA, Volume 1049,2023.
[4] C. Alice et al., Development and test of the Micromegas detector prototype and its readout electronics for the AMBER experiment at CERN, Journal of Instrumentation, 2023.
[5] Giomataris et al., MICROMEGAS: A High granularity position sensitive gaseous detector for high particle flux environment, Nucl. Inst. Meth. A, 1996.
[6] Rivetti et al., TIGER: A front-end ASIC for timing and energy measurements with radiation detectors, Nucl. Inst. Meth. A, 2019
[7] A. Amoroso, et al., The CGEM-IT readout chain, JINST 16 (2021) P08065. doi:10.1088/1748-0221/16/08/p08065
[8] A. Bortone, Deployment of the readout electronics for the BESIII Cylindrical GEM Inner Tracker, Ph.D. thesis, UniTO, 2021.
[8] F. Cossio, A mixed-signal ASIC for time and charge measurements with GEM detectors, Ph.D. thesis, PoliTO, 2019.
[9] G. Mazza et al., ASIC developments for the AMBER MM experiment, 2nd DRD1 collaboration meeting, 2024.
[10] M. Zemko et al., Free-running data acquisition system for the AMBER experiment, EPJ Web of Conferences 251, 04028 (2021)

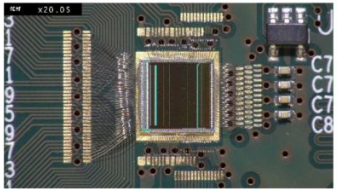
Thanks for your attention!

Backup slides

TIGER ASIC

Torino Integrated Gem Electronics Readout





TIGER bonded on PCB

Front end board (FEB)

Chip features:

- 64 channels
- Power consumption < 12 mW/channel
- Sustained event rate 100 kHz
- Input dynamic range up to 50 fC
- Time resolution < 5 ns
- ENC < 2000 e^- rms with 100 pF input capacitance
- Analog read out providing charge and time measurement
- Digital logic protected from single event upset (SEU)
- Tunable internal test pulse generator
- 110 nm technology

LMM lateral module detector prototype stackup

material	Density [g/cm^3]	radiation lenght (from PDG) [mm]
Cu	8.96	14.36
Glass epoxy	1.98	159.3*
Prepreg	1.47	354.9*
Kapton	1.42	285.7
photoresist	1	340.7
DLC	3	121.3
Stainless steel	7.93	14.22

Stackup

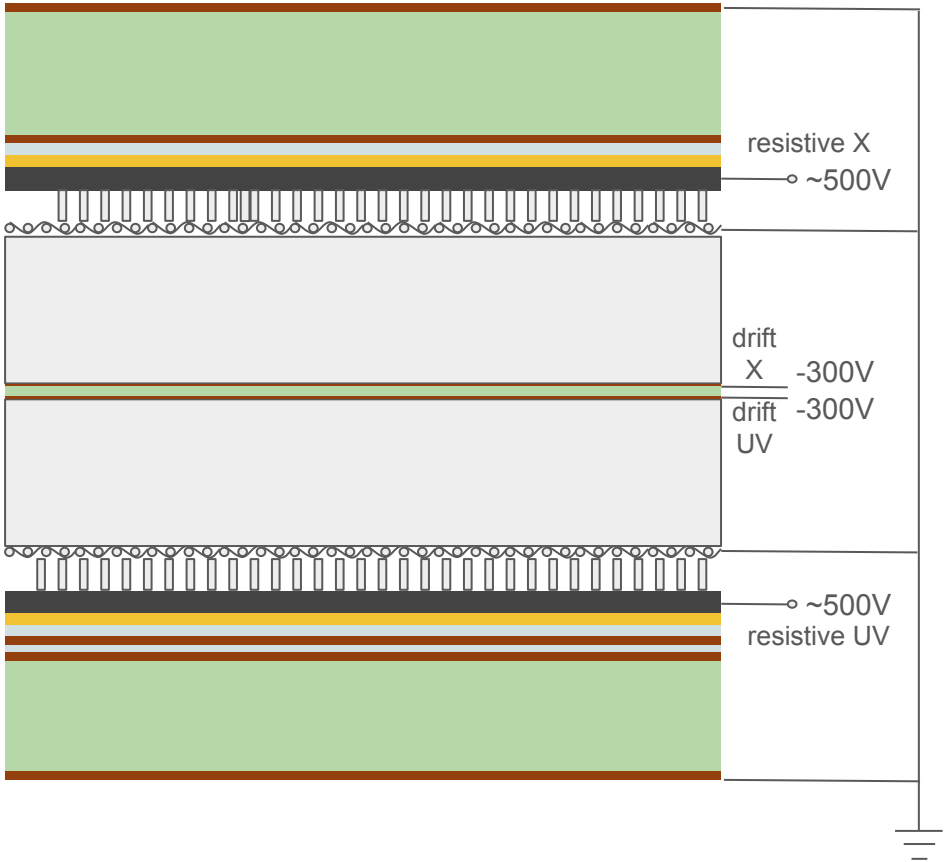
X shielding and connector layer : 35um copper
-3.2mm Glass epoxy
X strip layer : 35um Copper
-50um Prepreg
-50um Kapton
X DLC layer
-pillars 150um
X mesh: 45/18

Drift gap : 5mm

Drift PCB: 500 um glass epoxy, 17 um Cu

Drift gap: 5mm

UV mesh: 45/18
-pillars 150um
UV DLC layer
-50um Kapton
-50um Prepreg
U layer: 35um Copper
-28um Prepreg
V Layer: 17um copper
-3.2mm glass epoxy
UV bottom shielding and connector layer: 35um copper



* from Radiation length of the ALICE TRD

LMM lateral module detector prototype weight

material	Density [g/cm^3]
Cu	8.96
Glass epoxy	1.98
Prepreg	1.47
Kapton	1.42
photoresist	1
DLC	3
Stainless steel	7.93

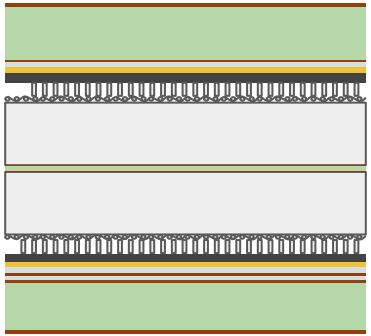
X shielding and connector layer : 35um copper
-3.2mm Glass epoxy
X strip layer : 35um Copper
-50um Prepreg
-50um Kapton
X DLC layer
-pillars 150um
X mesh: 45/18

Drift gap : 5mm

Drift mesh : 45/18

Drift gap: 5mm

U.V mesh: 45/18
-pillars 150um
U.V DLC layer
-50um Kapton
-50um Prepreg
U layer: 35um Copper
-28um Prepreg
V Layer: 17um copper
-3.2mm glass epoxy
U.V bottom shielding and connector layer: 35um copper



Total mass first estimation: 7.812 kg

- Cu:
  SHIELDING x2: (0.0035*100*51.2)*2 cm3 = 17.92*2 cm3
  X strips: (0.0035*100*25.6)cm3 = 8.96 cm3
  U strips: (0.0035*100*32)cm3 = 11.2 cm3
  V strips: (0.0017*100*32)cm3 = 5.44 cm3
  Total copper = 550.5 g
- Glass epoxy:
  x2 (0.32*100*51.2)*2 cm3 =1638*2 cm3
  Total glass epoxy = 6486.5 g
- Prepreg:
  x2 (0.005*100*51.2)*2 cm3 = 25.6*2 cm3 ;
  x1 (0.0028*100*51.2)cm3 = 14.336 cm3
  Total Prepreg : 96.338 g
- Kapton:
  x2 (0.005*100*51.2)*2cm3 = 25.6*2 cm3
  Total Kapton: 72.704 g
- Photoresist (uniform layer approx):
  x2 (0.0150*100*51.2)*2 cm3= 65.536*2 cm3
  Total photoresist: 127,072 g
- DLC:
  x2 (0.01*100*51.2)*2 cm3 = 51.2*2 cm3
  Total DLC: 307.2 g
- Stainless Steel (uniform layer approx):
  x3 (0.0018*100*51.2)*3 cm3 = 9.216*3 cm3
  Total SS: 219.25 g

LMM lateral module detector prototype X0 calculation

material	Density [g/cm^3]	radiation lenght (from PDG) [mm]
Cu	8.96	14.36
Glass epoxy	1.98	159.3*
Prepreg	1.47	354.9*
Kapton	1.42	285.7
photoresist	1	340.7
DLC	3	121.3
Stainless steel	7.93	14.22

Radiation length in composite materials: $1/X_o = \sum w_i/X_i$

w_i and X_i are the fraction by weight and the radiation length for the i-th element

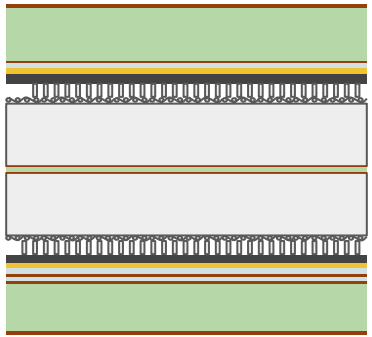
X shielding and connector layer : 35um copper
-3.2mm Glass epoxy
X strip layer : 35um Copper
-50um Prepreg
-50um Kapton
X DLC layer
-pillars 150um
X mesh: 45/18

Drift gap : 5mm

Drift mesh : 45/18

Drift gap: 5mm

UV mesh: 45/18
-pillars 150um
UV DLC layer
-50um Kapton
-50um Prepreg
U layer: 35um Copper
-28um Prepreg
V Layer: 17um copper
-3.2mm glass epoxy
UV bottom shielding and connector layer: 35um copper



Radiation length (avoiding pillars)

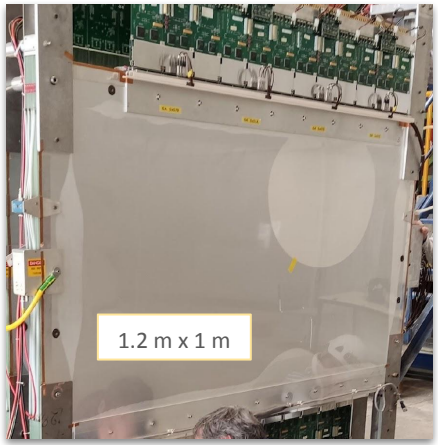
- FR-4 (PCB): 6.4/159.3 = 0.04
- Cu: 0.0157/14.36 = 0.001
- Prepreg: 0.0128/354.9 = 0.00004
- Kapton: 0.01/285.7 = 0.000035
- DLC: 0.002/121.3 = 0.00002

$X_0 \approx 4$ %

BACKUP : Large area micromegas project: detector development

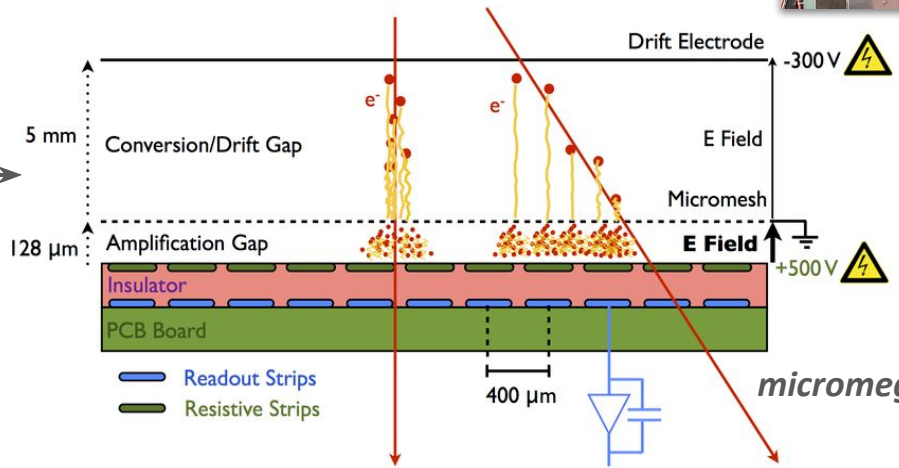
Detector development motivation:

- AMBER MWPC stations are **structurally aged**. During last years we carried out a refurbishment campaign for MWPC-PB type.



- For AMBER mid and long-term program we decide to substitute a part of the MWPCs (PA-type) with a **micromegas** detector.

MICRO-MEsh GAseous Structure

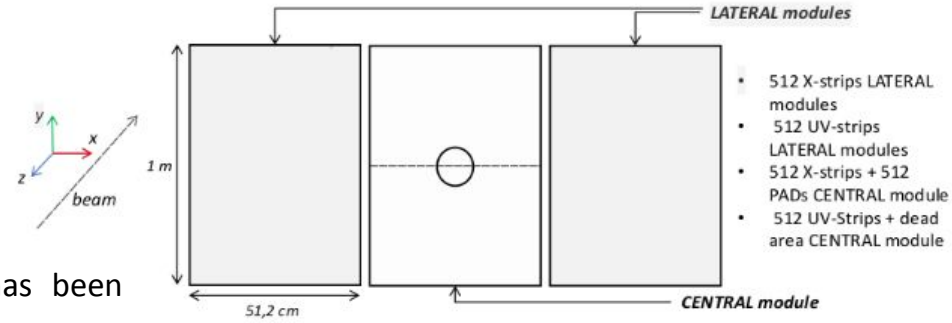


micromegas working principle

BACKUP: Large area micromegas project: detector development

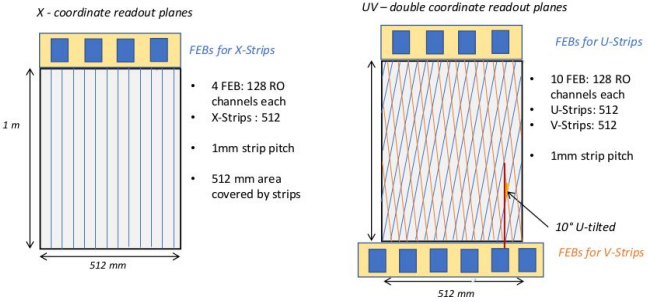
Large-area micromegas design:

The large-area **MM detector** will be composed of three different modules covering a total active area of **1.5 m x 1 m**

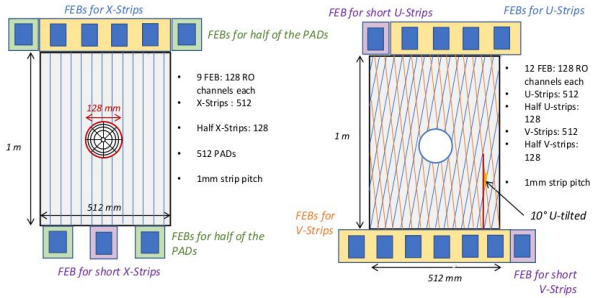


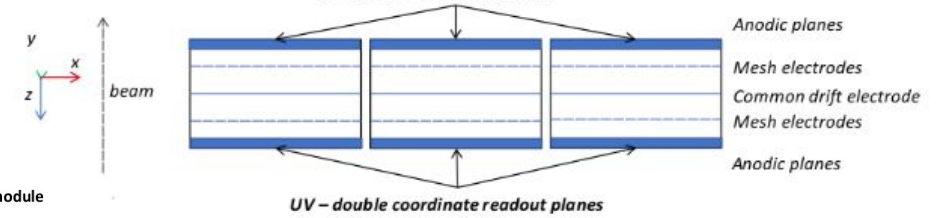
✓ Design of the first prototype for the lateral module has been completed within Torino group and CERN MPT Workshop.

LATERAL module



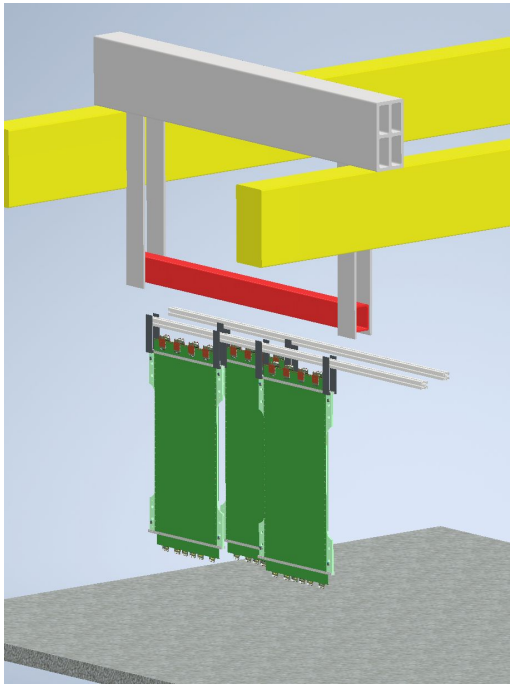
CENTRAL module

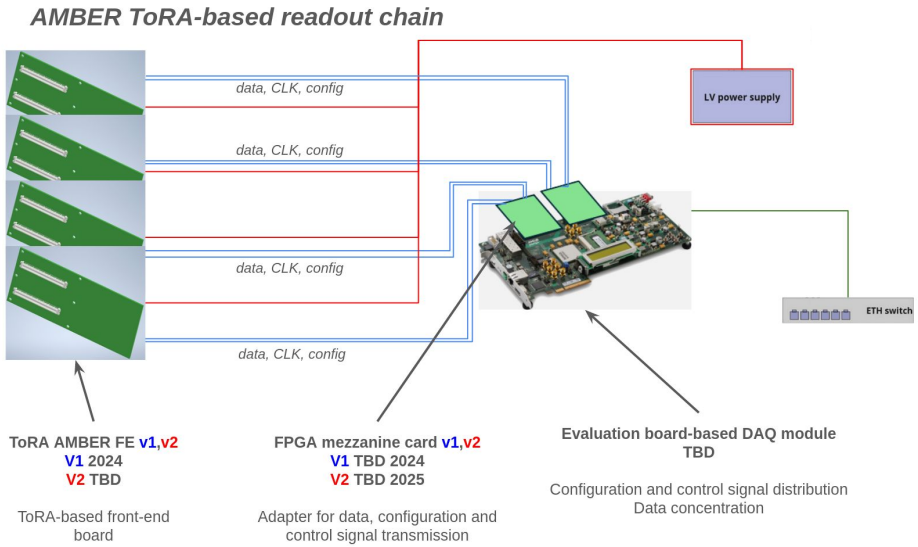




Backup slides: DY test run

For Drell-Yan test run (2026) definitive suspension structure + FEE should be finalized:





DAQ still not defined, we are at the stage of stand-alone readout chain design. AMBER integration to be defined.