Codesigning a new front-end ASIC together with a new micromegas detector for AMBER at CERN

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Bormio

Outline

- AMBER experiment at CERN
  - Project framework : AMBER spectrometer upgrade during LS3

- Large area micromegas project
  - Micromegas detector development
    - design
    - production

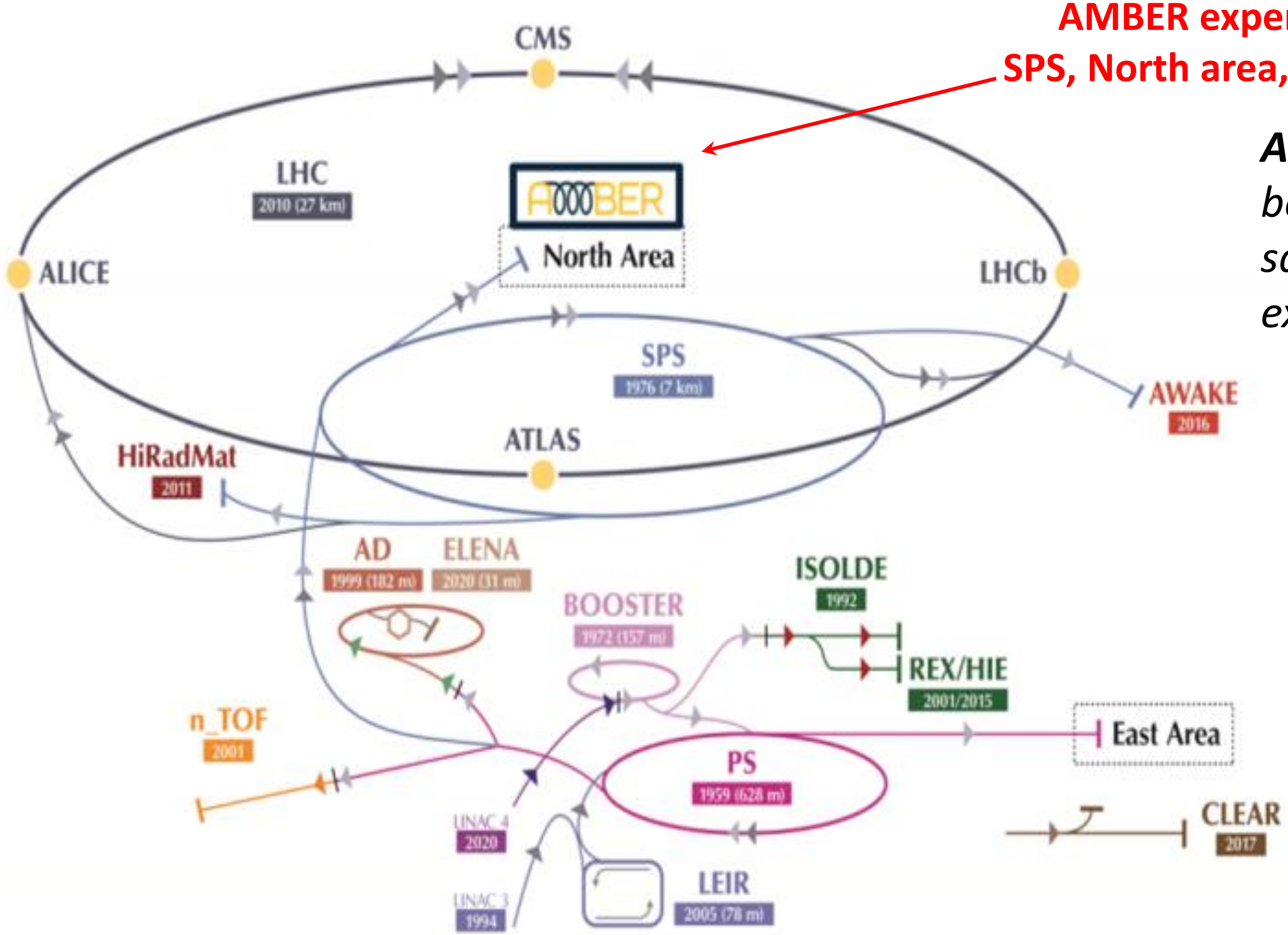
- Signal trasmission study
  - Signal generation on the micromegas anode
  - Signal path modeling from the detector anode to the ASIC amplification stage
  - Front-end architecture design

- Front-end electronics: towards continuos readout
  - Development of ToRA-based fee

- Conclusions

- Acknowledgments and references

AMBER experiment at CERN



AMBER experiment:
SPS, North area, EHN2 hall

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.*

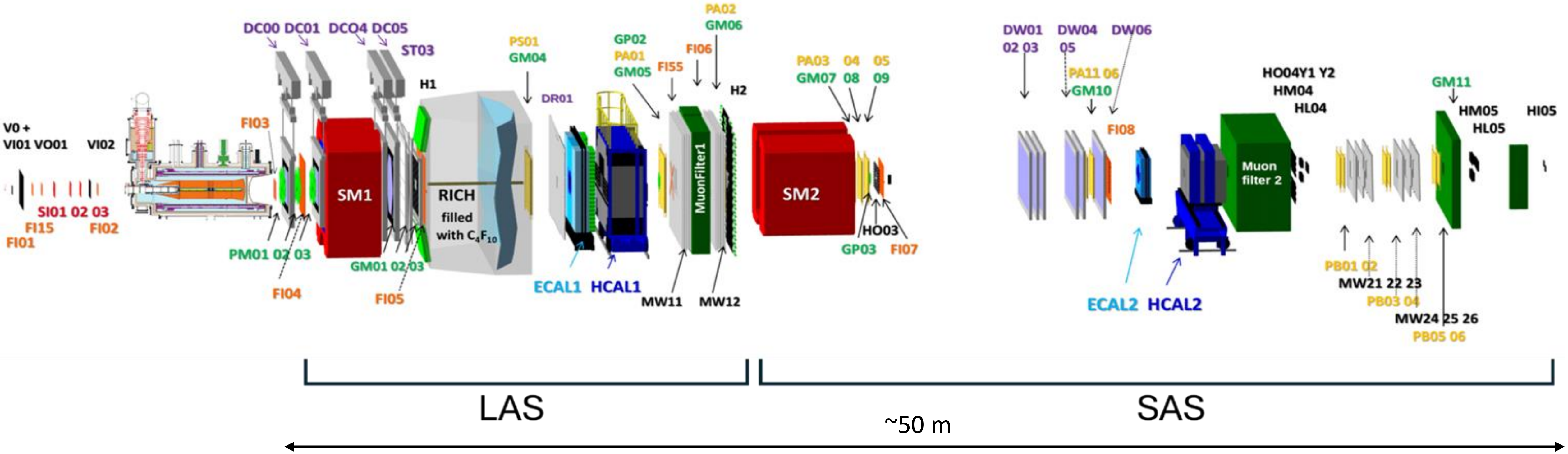
More details on Maxim Alexeev's talk of yesterday

Physics program before LS3

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

AMBER experiment at CERN

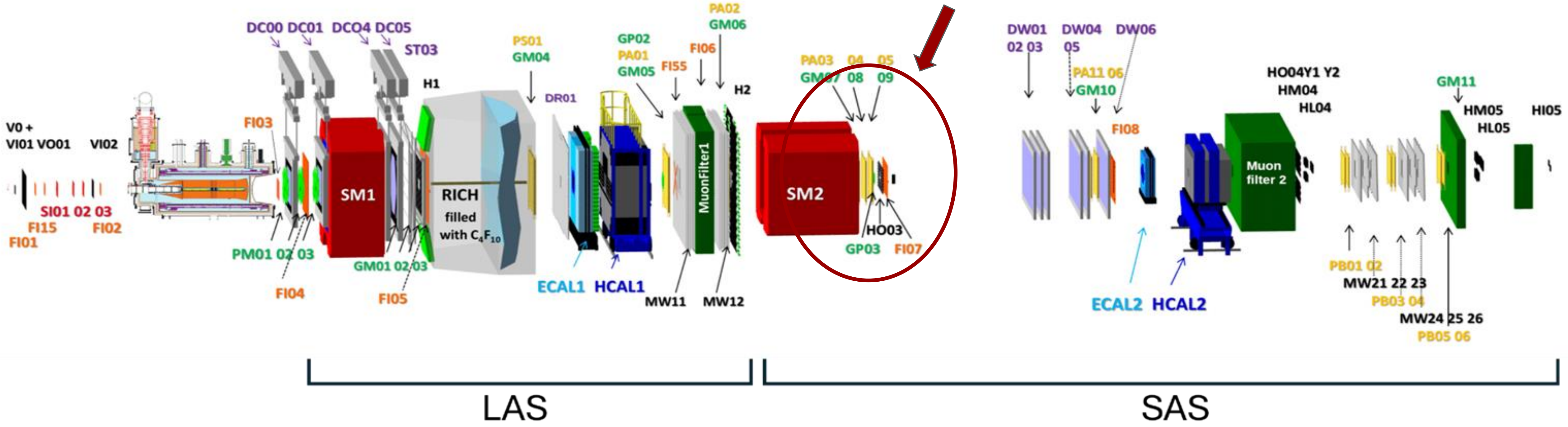
AMBER spectrometer



*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

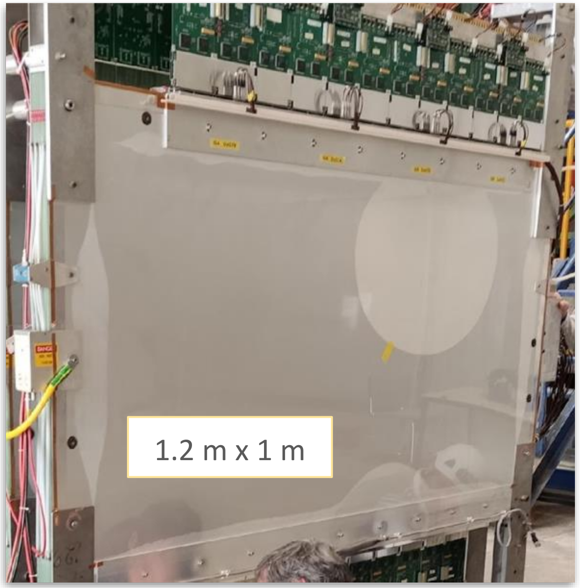


*The former COMPASS spectrometer is being used for APX measurement and will undergo several **upgrades** for the mid- and long-term program.*

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.

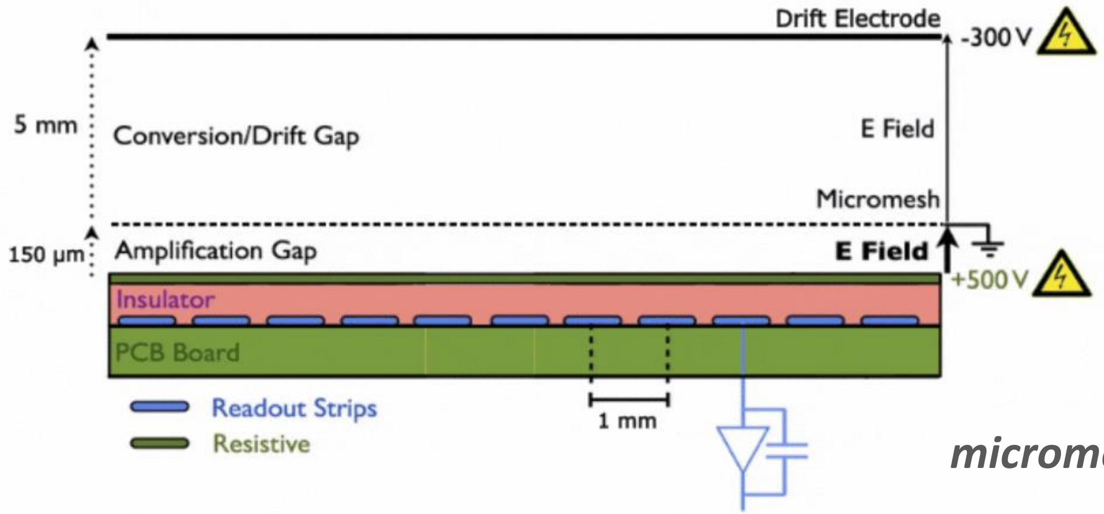
Detector development motivation:

- 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



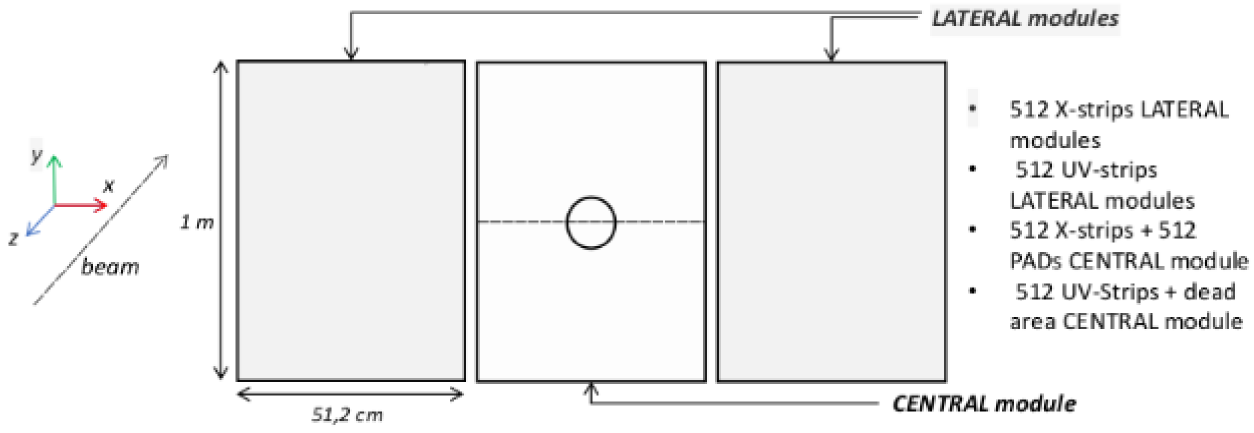
micromegas working principle

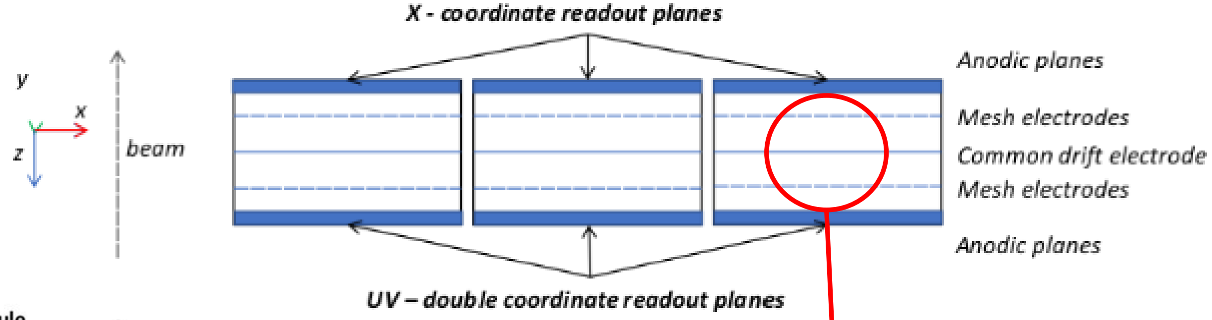
Large area micromegas project: detector development

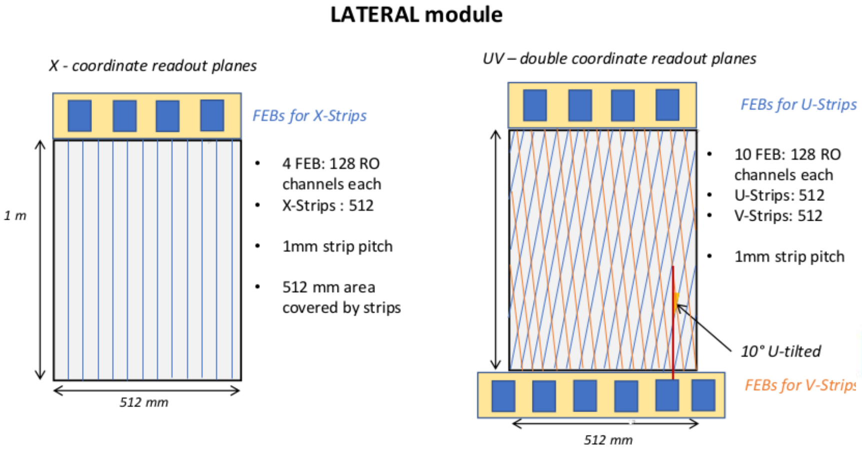
Detector concept:

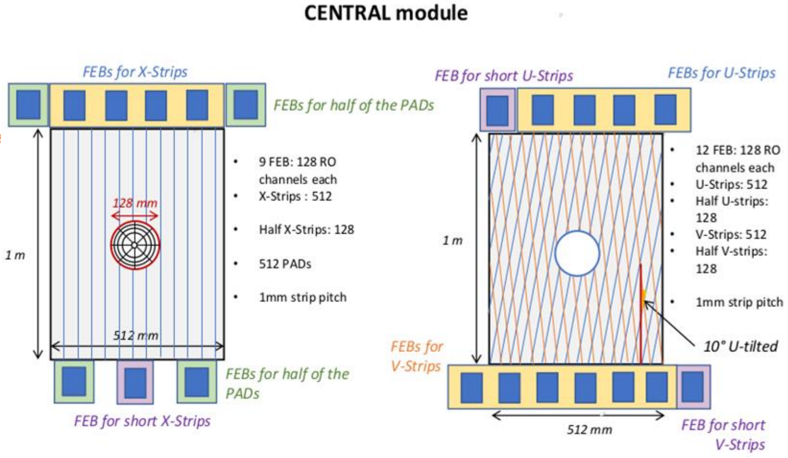
The **large-area MM detector (LMM) for AMBER** will be composed of three different modules covering a total active area of **1.5 m x 1 m**

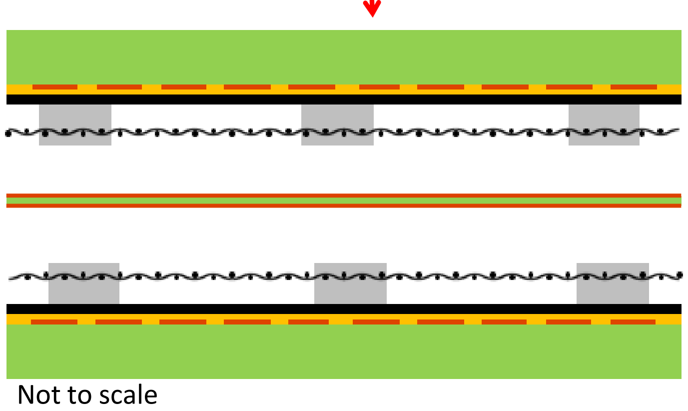
Each indipendent module will be a **bulk resistive** micromegas in a «**face-to-face**» configuration











More details on Maxim Alexeev's talk of yesterday

LMM lateral module prototype: detector design

Mechanical structure and readout PCBs

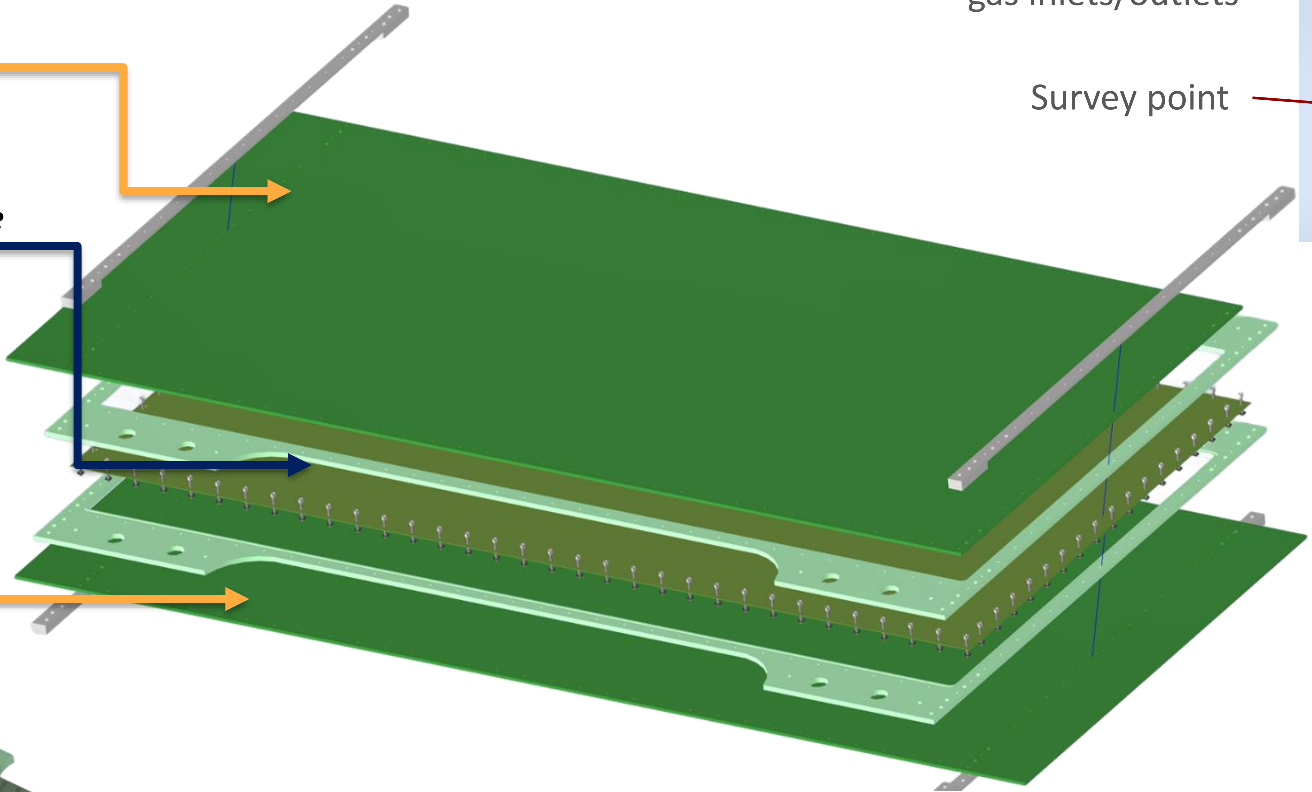
X-coordinate R/O plane

FR_4 gas vessel frame

Cathode PCB - drift electrode

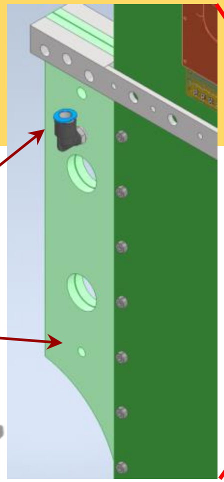
FR_4 gas vessel frame

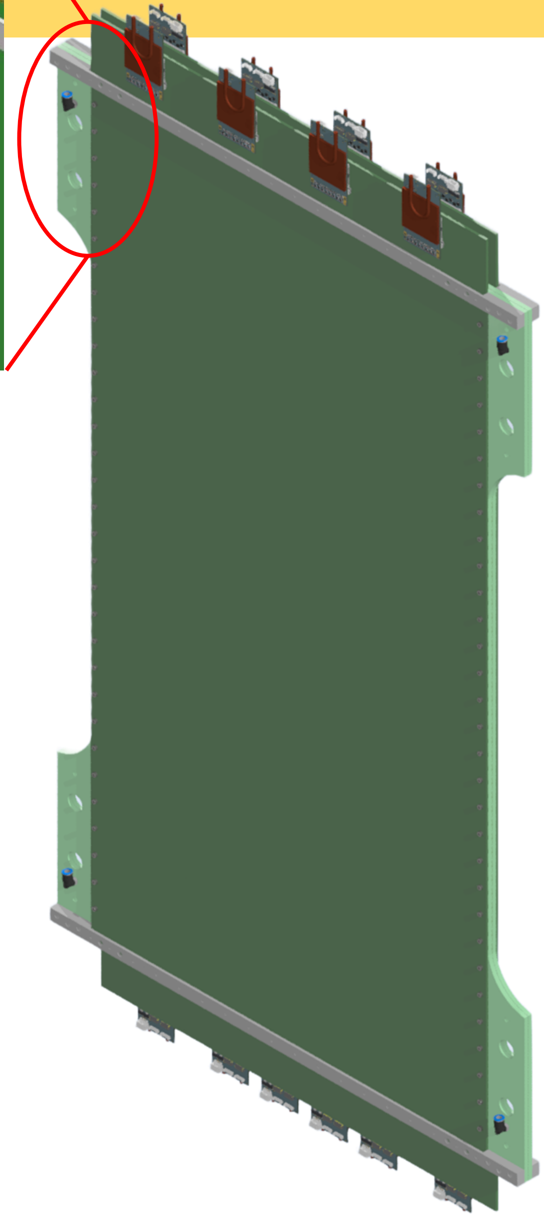
UV-coordinates R/O plane

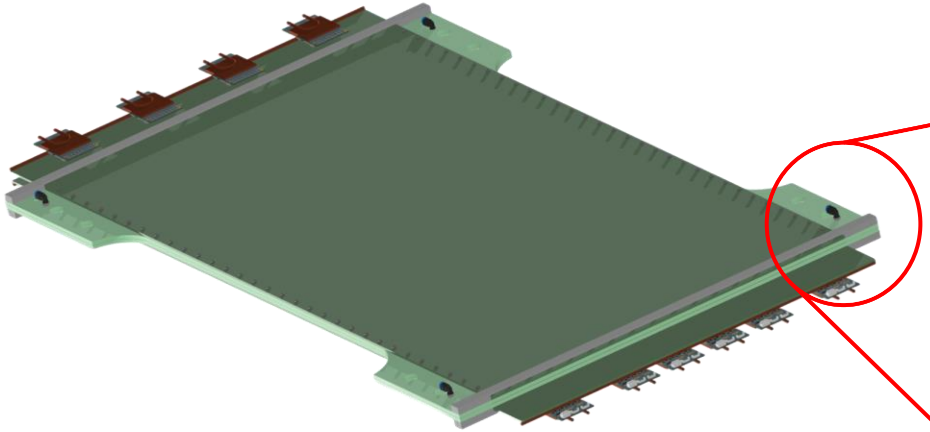


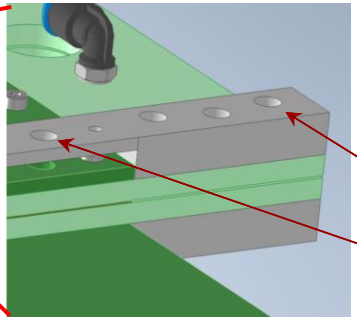
gas inlets/outlets

Survey point







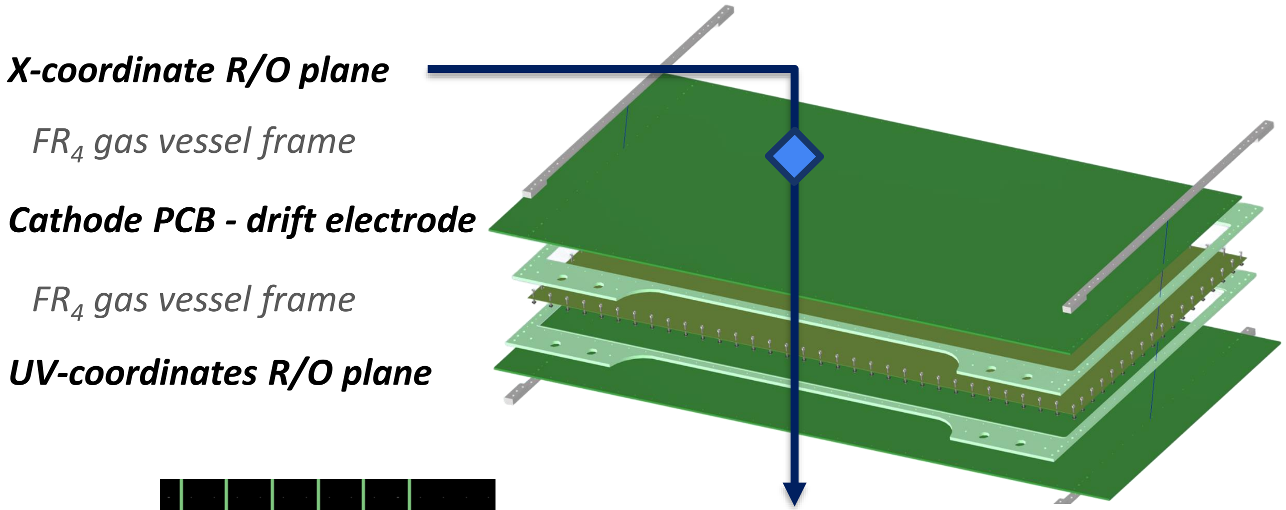


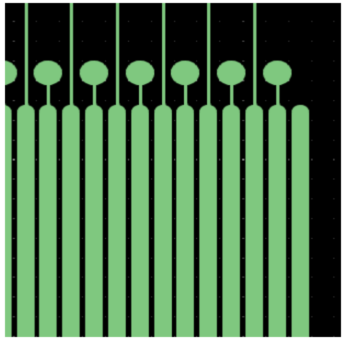
Suspension holes

Alignment holes

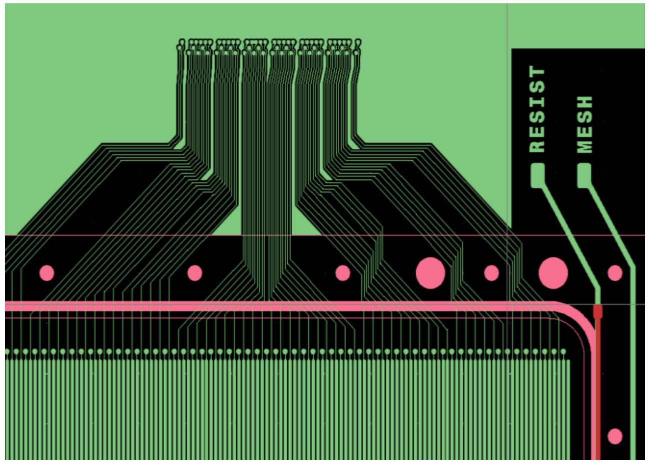
LMM lateral module prototype: detector design

Mechanical structure and readout PCBs

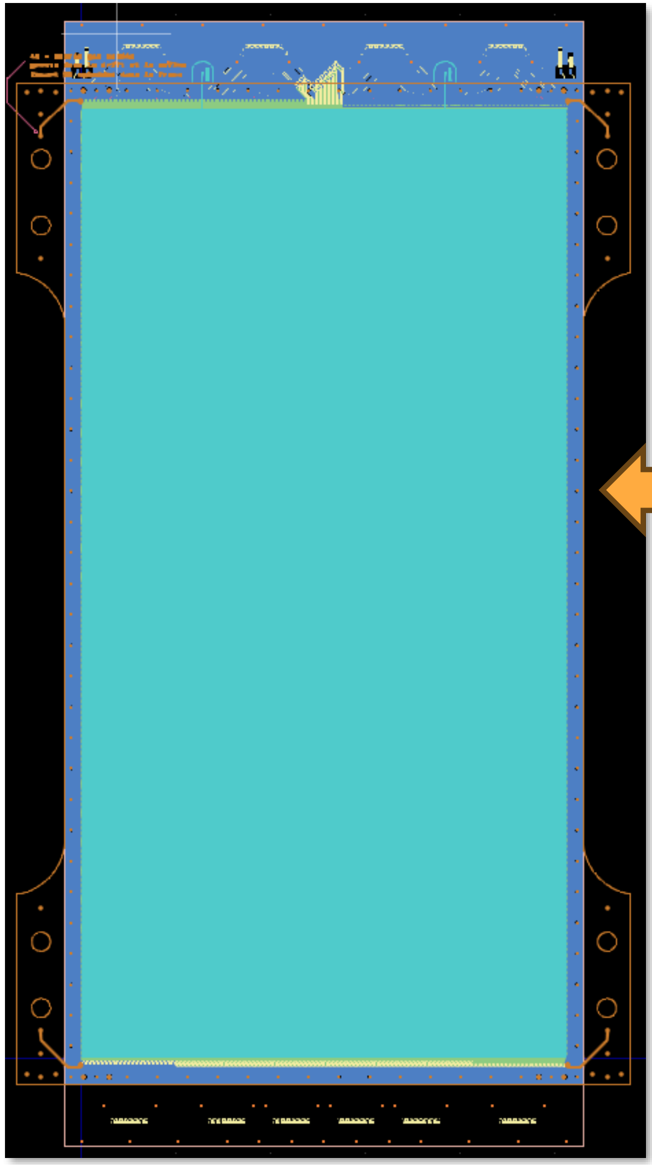


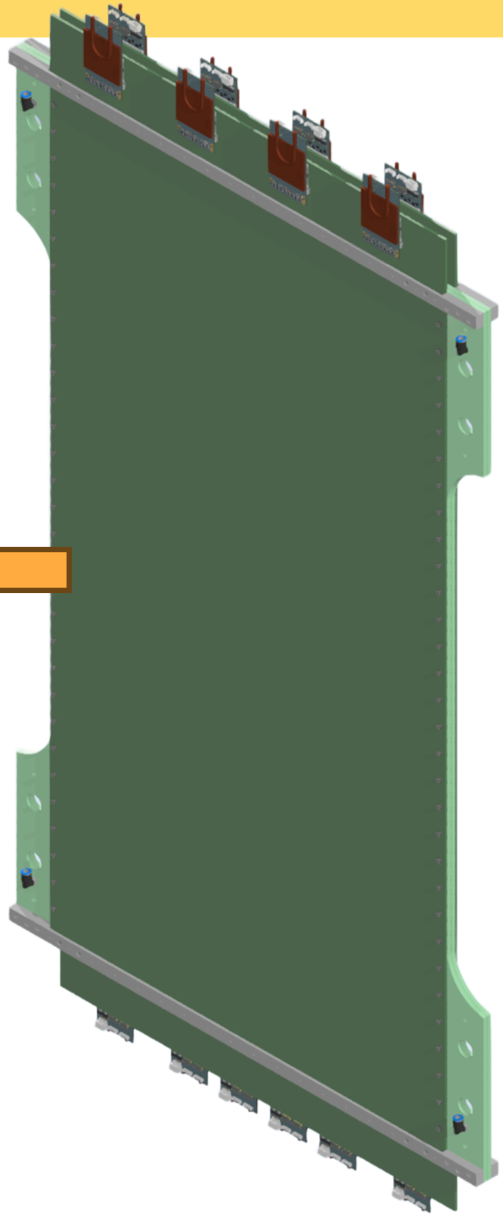


X-coordinate R/O plane



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





LMM lateral module prototype: detector design

Mechanical structure and readout PCBs

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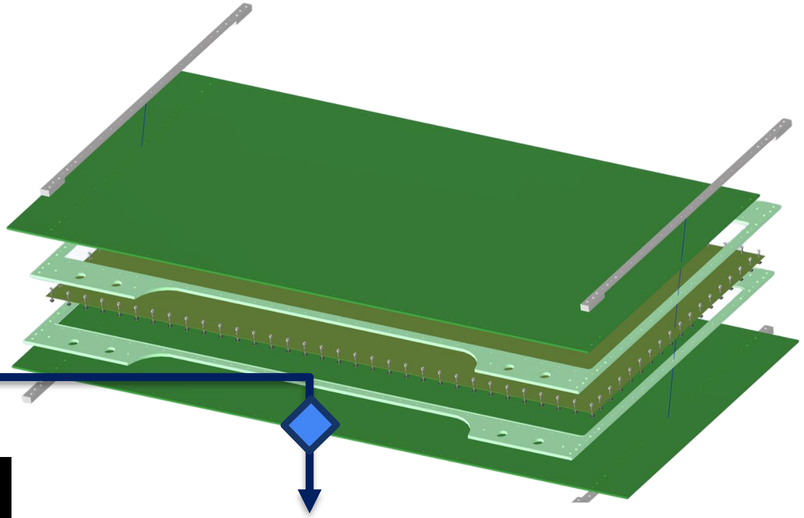
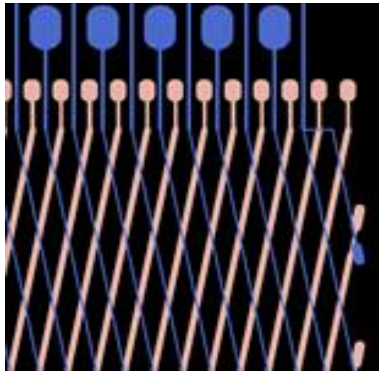
FR_4 gas vessel frame

Cathode PCB - drift electrode

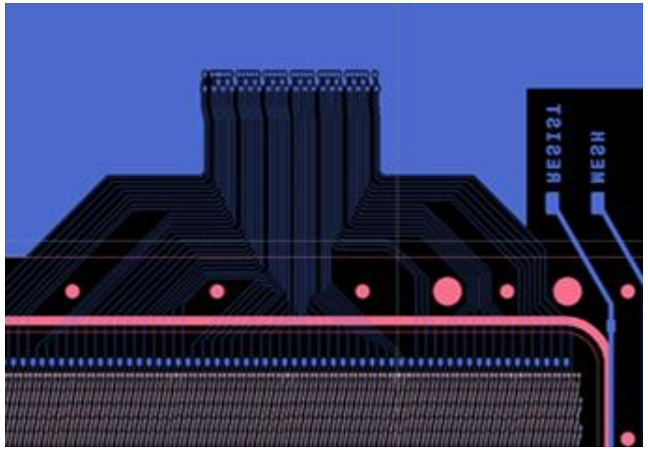
FR_4 gas vessel frame

UV-coordinates R/O plane

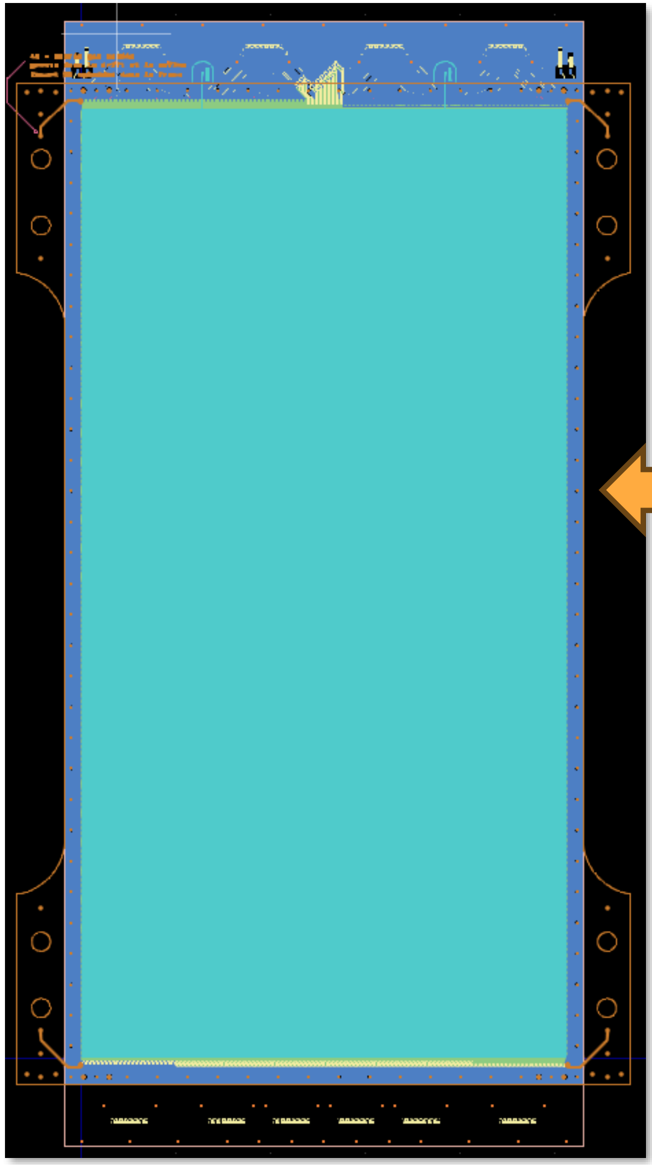


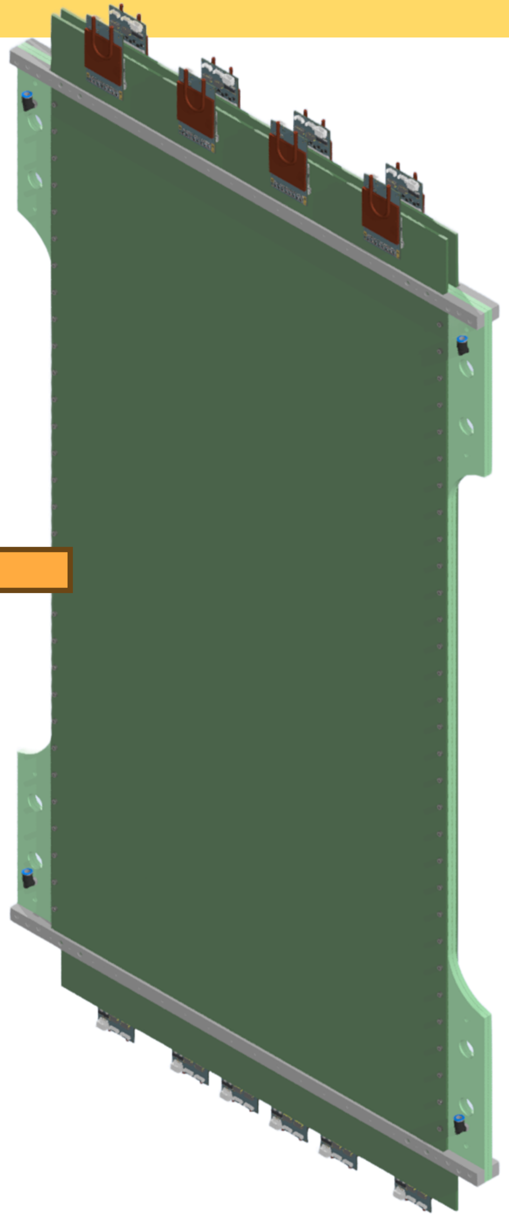


UV-coordinate R/O plane



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



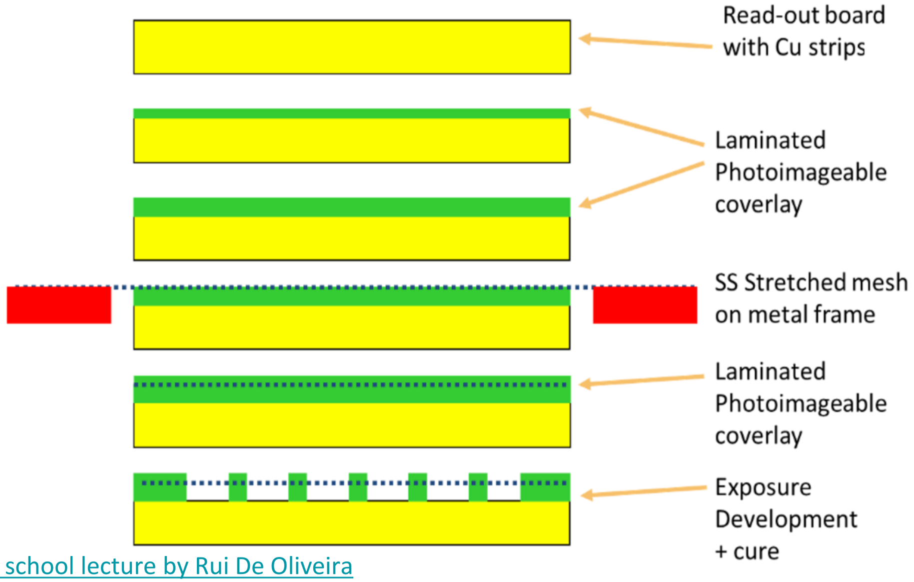


LMM lateral module prototype: detector production

LMM lateral module prototype production

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

FR4 frame with cathode electrode



[Manufacturing techniques - RD51 school lecture by Rui De Oliveira]

Diamond-like carbon (DLC) resistive layer: 10 MΩ/cm^2
Mesh electrode high: 150 um

Micromegas detector assembled

CERN

Signal trasmission study

- **Ionization and gas amplification modeling**
  - Micromegas detector working principle
  - Gas multiplication mechanism
  - Signal induction on the anode
- **AMBER Large-area MicroMegas (LMM) detector simulation**
  - Detector stackup
  - ANSYS HFSS FEM description
- **Signal path modeling**
  - Signal path description and simulation
  - TDR impedance measurements
  - SPICE modeling

Optimization of the readout ASIC front-end

Signal trasmission study

- **Ionization and gas amplification modeling**
    - Micromegas detector working principle
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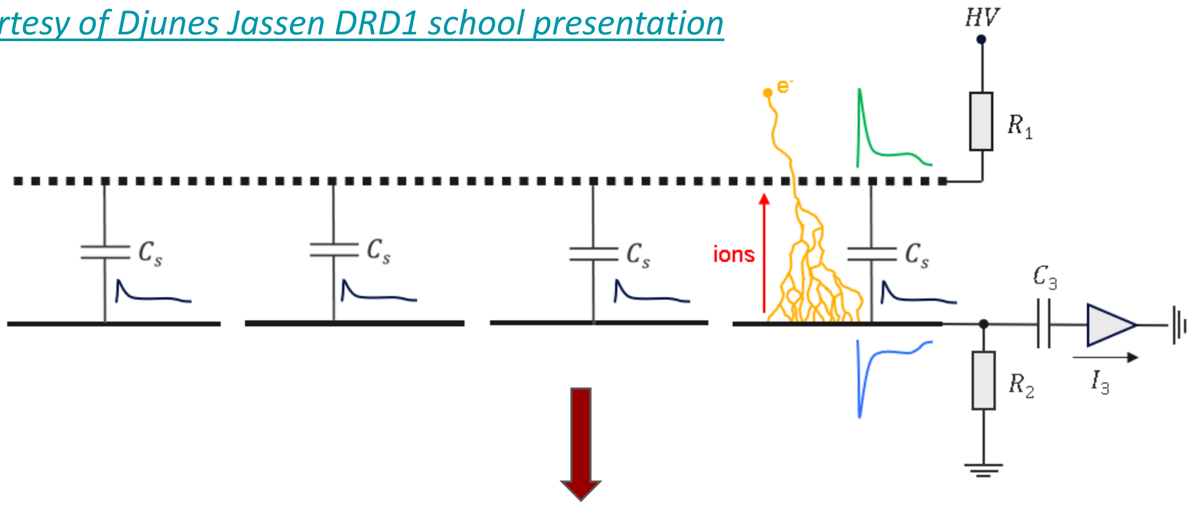
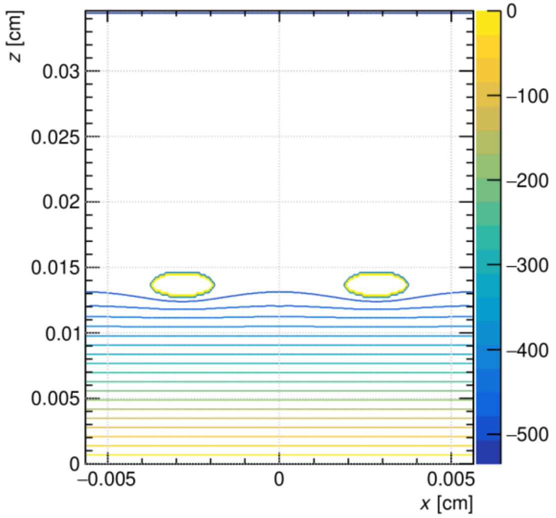
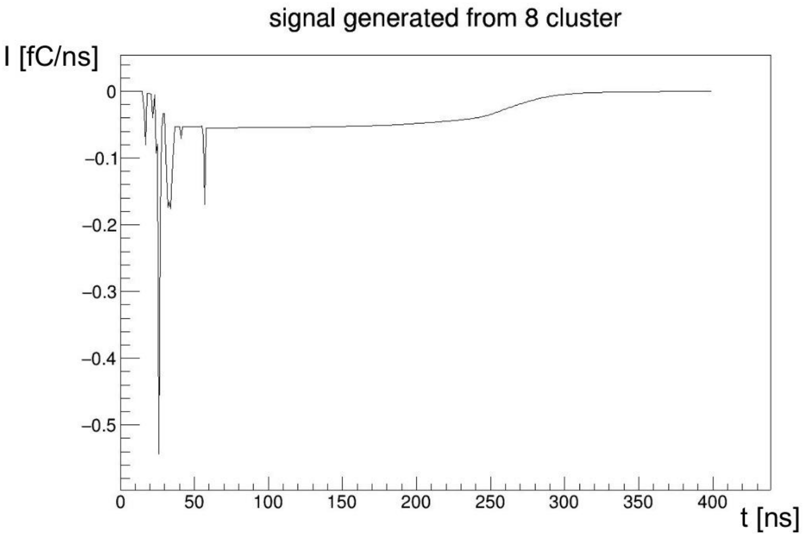
Courtesy of Djunes Jassen DRD1 school presentation





FEM weighting potential calculation



Garfield++ signal simulation

Signal trasmission study

- Ionization and gas amplification modeling
    - Micromegas detector working principle
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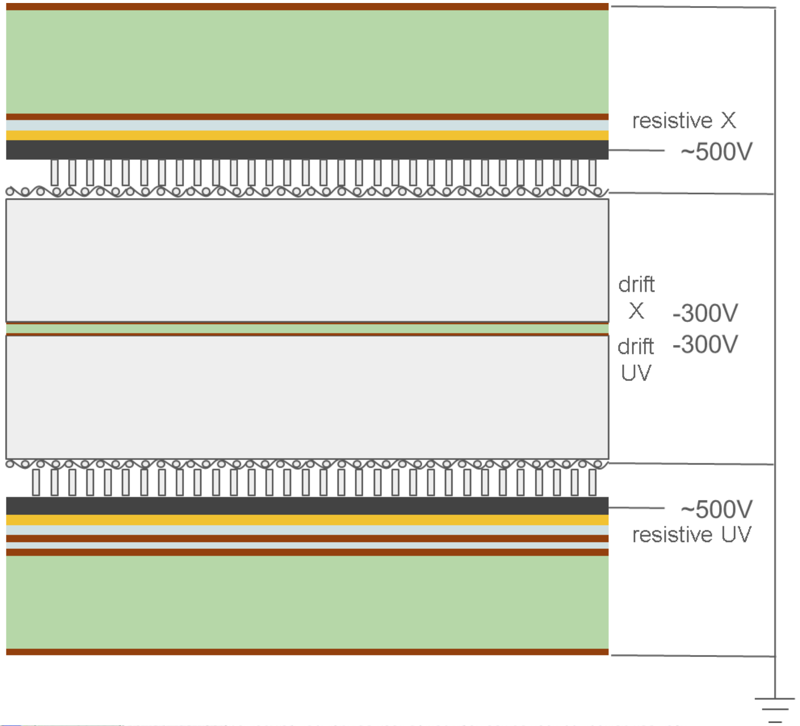
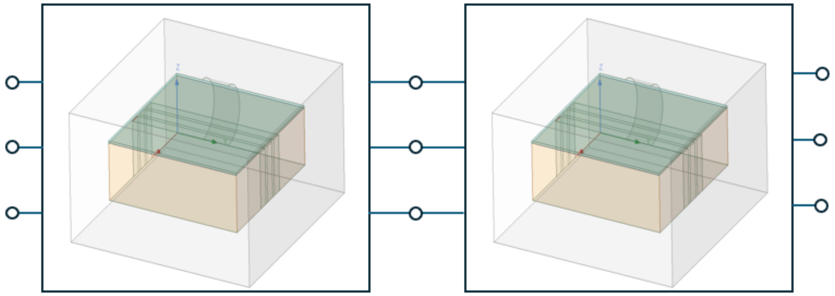
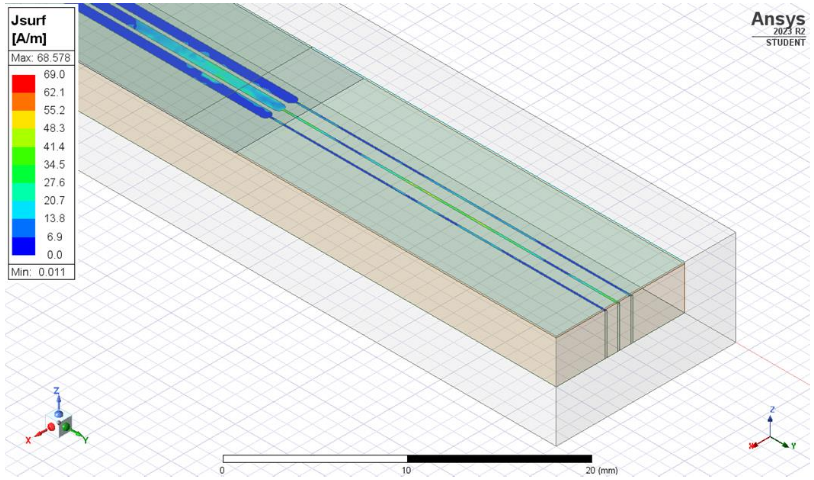


Techniques to simulate the current induced on the detector strips:

→ *cascade elements*
→ *element lenght sweep*



Extract S-Parameters in Ansys and use Matlab to merge



Signal trasmission study

LMM X-coord strip dimension plus routing line :

- **Central strip floating**
- **Side strips at ground**

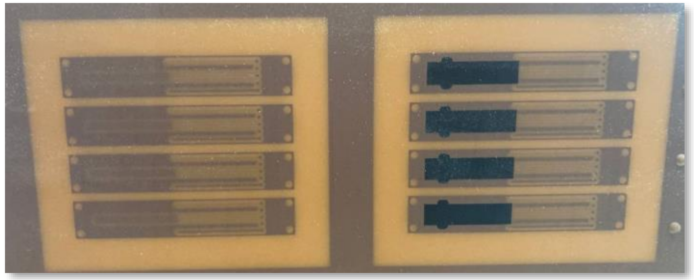
Routing line width

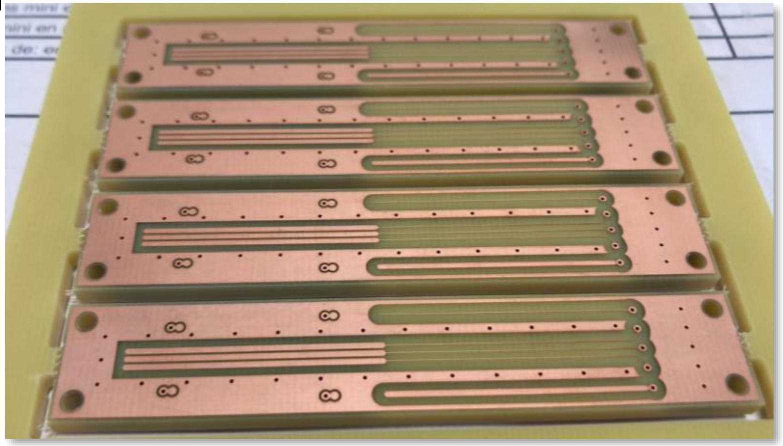
LMM X-coord strip width

Design of the PCB used to study the impedence of the singular elements of the readout pattern.

Different productions of similar elements will allow to study the effect of adding capacitive coupling with DLC layer and mesh grid.

PCBs produced @CERN MPT workshop





- **Signal path modeling**
  - **Signal path description and simulation**
  - Time Domain Reflectometer (TDR) impedance measurements
  - SPICE modeling

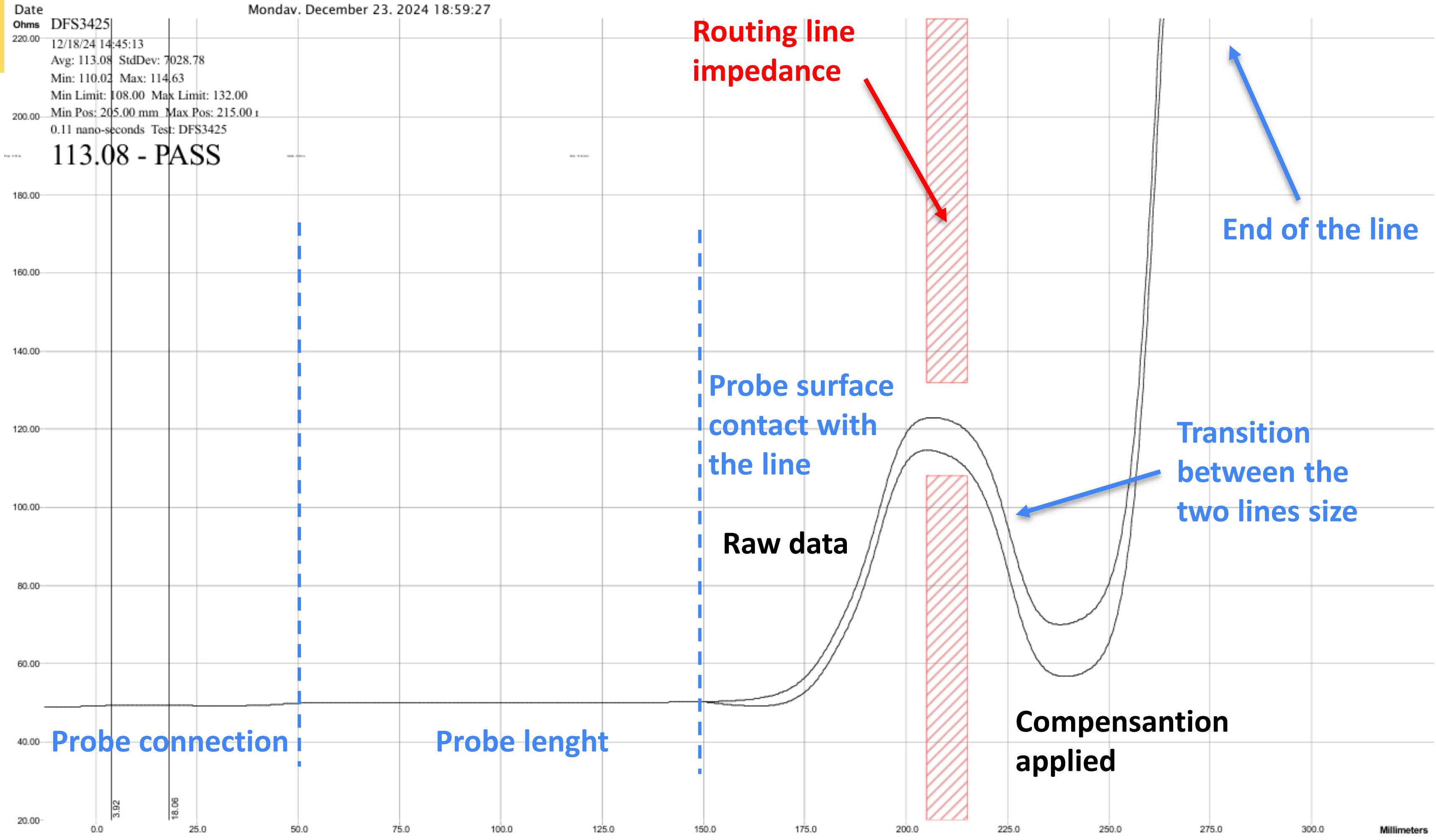
- **ITEM 1**: Cu BOTTOM, 3.2 mm FR4, Cu TOP
- **ITEM 2**: Cu BOTTOM, 3.2 mm FR4, Cu TOP, Prepreg and Kapton
- **ITEM 3**: Cu BOTTOM, 3.2 mm FR4, Cu TOP, Prepreg and Kapton, DLC
- **ITEM 4**: Cu BOTTOM, 3.2 mm FR4, Cu TOP, Prepreg and Kapton, DLC, pillars and mesh

TDR measurements

Detector strip line plus routing line measurement

DC resistance compensation applied (LOSS compensation): 0.15 Ω/mm

Example of 4 identical ***ITEM 1*** measured impedance



Name	Result	Avg	S/N	Job #	LYR	Time/Date	Min Z	Max Z	Std Dev
DFS3...	Pass	113.08	20			12/18/24 14:45:13	110.02	114.63	7028.78
DFS3...	Pass	114.21	21			12/18/24 14:45:23	110.94	115.88	7028.79
DFS3...	Pass	114.41	22			12/18/24 14:45:28	111.49	115.84	7028.78
DFS3...	Pass	114.07	23			12/18/24 14:45:33	110.65	115.85	7028.79

The goal of the TDR measurement is to determine the characteristic impedence of the singular elements of the readout pattern and predict then the behaviour of the signal fed to the FE

Signal trasmission study

- Ionization and gas amplification modeling
    - Micromegas detector working principle
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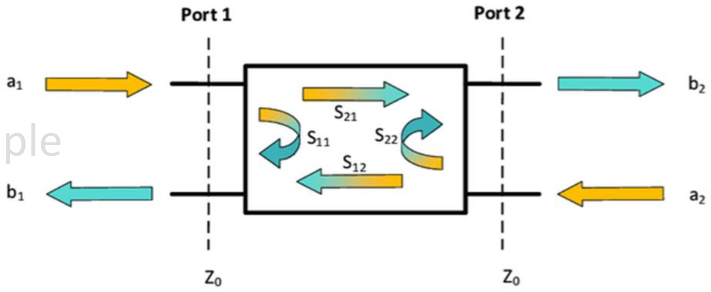


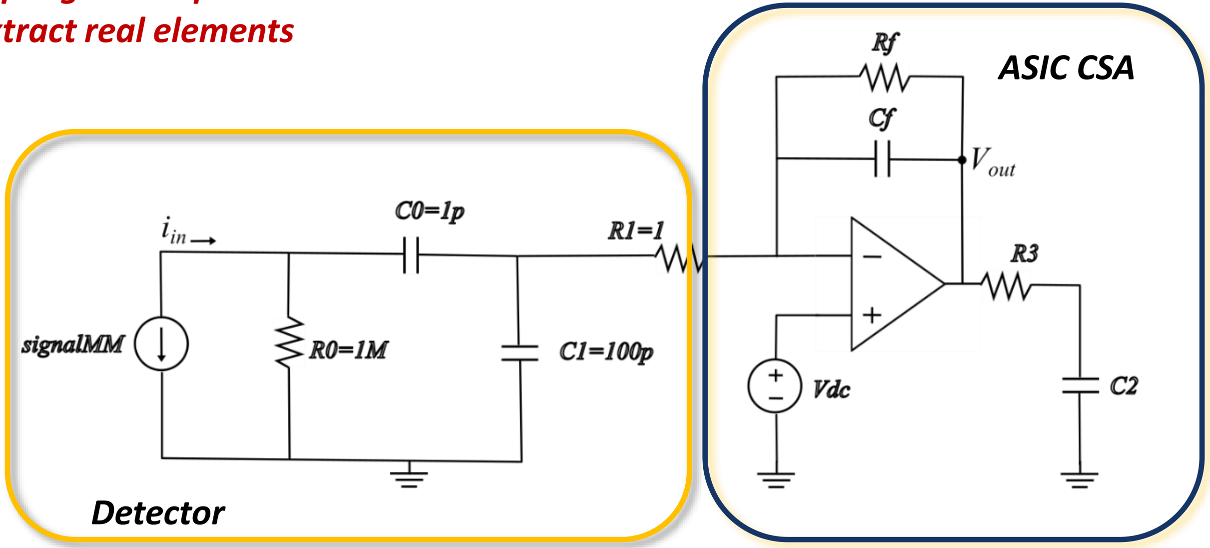
Vector Network Analyzer (VNA) + Time Domain Reflectometer (TDR) Capabilities

WavePulser 40iX High-speed Interconnect Analyzer provides unmatched characterization insight into both frequency and time domains with a single acquisition.

- Measures S-parameters (like a VNA)
- Measures impedance profile (like a TDR)
- De-embedding, simulation, emulation and time gating of results
- No calibration required

SPICE model build up on signal path model in terms of capacitance coupling and impedance. TDR measurements to extract real elements response.

ToRA ASIC front-end design driven by MPGD and wire detector signals requirements



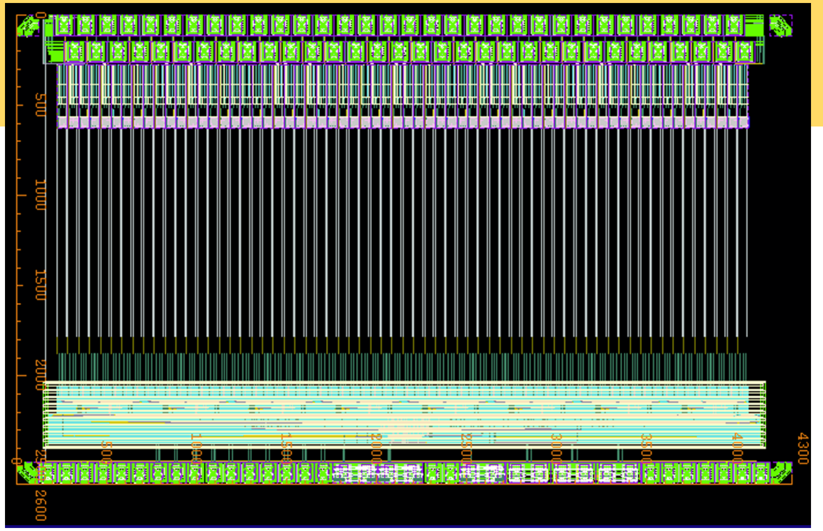
Front-end electronics: future ToRA-based FEE

Main characteristics:

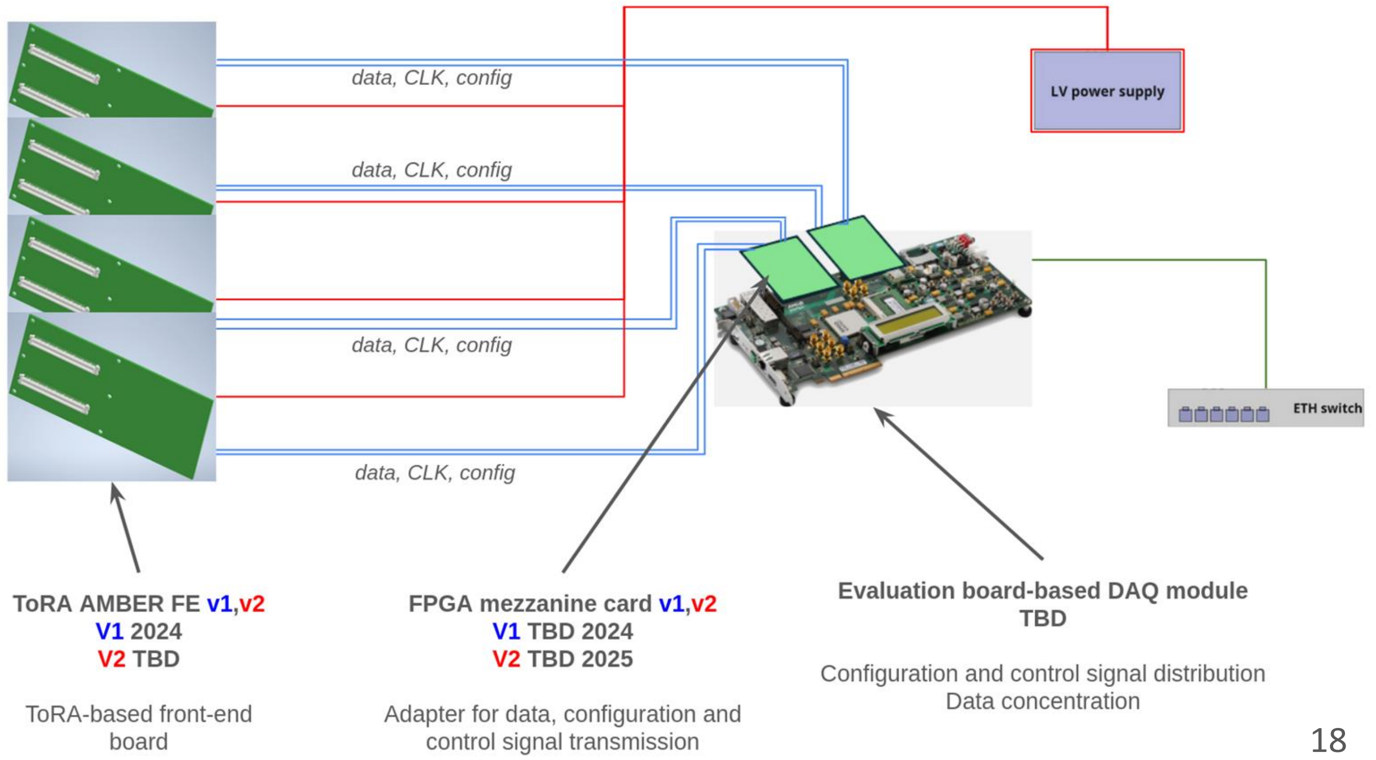
- **To**rino **R**eadout for **A**MBER will be a 64 chs ASIC with a fully digital interface at **200 MHz clock** frequency
- compatibility with MPGD and Wire chambers
- digital back-end inherited from ToASt ASIC (110 nm CMOS) to be adapted for **ToRA v1** which will be implemented in **65 nm CMOS** technology
- The ASIC front-end design development was done providing simulated signal with Garfield++ to optimize signal amplification and conditioning
- time schedule
    - ToRA v1 submission May 2025
    - ToRA readout chain design first GeneSys2 (Kintex-7 based)

Courtesy of Gianni Mazza internal INFN-To microelectronics group meeting

ToRA v1 layout



AMBER ToRA-based readout chain



Front-end electronics: future ToRA-based FEE

→ Front-end

Courtesy of Gianni Mazza internal INFN-To microelectronics group meeting

Amplification stage:

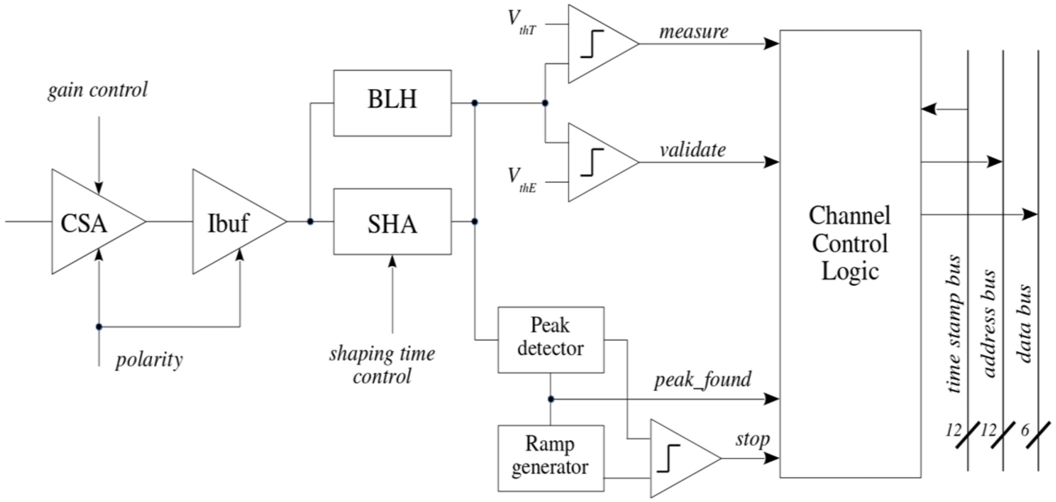
- Charge Sensitive Amplifier (CSA)
- Programmable gain: 2,6,8,12 mV/fC
- Both polarities handling using current buffer with programmable inversion

Shaping stage:

- 3rd order shaper
- Programmable peaking time: 25,50,150 and 250ns

Discriminator stage:

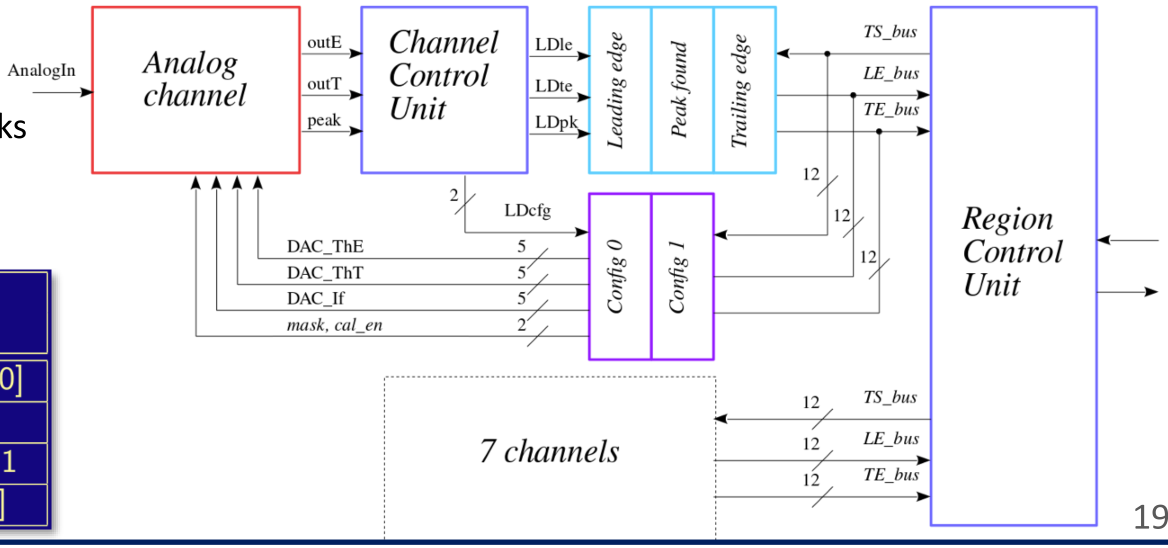
- Double threshold signal detection
- Peak detector
- Peak holder for *ToT* measurement (charge)



→ Back-end

Courtesy of Gianni Mazza internal INFN-To microelectronics group meeting

- Common time stamp distributed to all channels
- 3 data register for time acquisition
- 2 configuration registers
- Data output in 32 bits words over 200 Mb/s serial links
- It can be configured to use 1 or 2 links
- Frame lenght : 20.48 μs at 200 MHz



Packet type	Header 1 *1 bit*	Header 2 *3 bit*	Data *28/31 bits*
Header	1	010	ChipId[6:0] Reserved[12:0] FrameN[7:0]
Trailer	1	101	DataCnt[11:0] CRC[15:0]
Sync	1	000	1100 1100 1100 1100 1100 1100 1111
Data	0	Region[2:0] Channel[2:0] Le[11:0] Pk[5:0] Te[6:0]	

Conclusions

→ Summary and next steps

▪ **LMM detector for AMBER**:

✓ Design and production of the first full size lateral module prototype

Not covered in this talk…

✓ First tests in AMBER experimental hall EHN2 at CERN
- Validity of the mechanical elements
- TIGER-based DAQ infrastructure
- cooling system
- data transmission proven

○ Complete characterization of the detector ongoing
  - ✓ Strips capacitance measurement
  - ○ Grounding enhancement studies
  - ○ Test with VMM-readout at GDD lab @ CERN
  - ○ Design of the final mechanical suspension structure

▪ **Signal transmission study**:

✓ Garfield++ simulations
○ ANSYS HFSS FEM detector simulation
✓ Signal transmission emulator PCB design
○ Signal transmission emulator PCB test ongoing

▪ **ToRA V1 ASIC:**

○ Front-end architecture definition final phase
✓ Back-end and data structure defined
○ TSMC 65nm submission foreseen May 21°
○ R/O chain design to be start soon with the support of INFN-Torino electronics workshop

References

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[2] Adams et al., COMPASS++/AMBER: Proposal for Measurements at the M2 beam line of the CERN SPS Phase-1: 2022-2024, 2019.
[3] M.G. Alexeev et al., Development of a Micromegas prototype for the AMBER experiment at CERN,NIMA, Volume 1049,2023.
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[5] Giomataris et al., MICROMEGAS: A High granularity position sensitive gaseous detector for high particle flux environment, Nucl. Inst. Meth. A, 1996.
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[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.
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[10] M. Zemko et al., Free-running data acquisition system for the AMBER experiment, EPJ Web of Conferences 251, 04028 (2021)

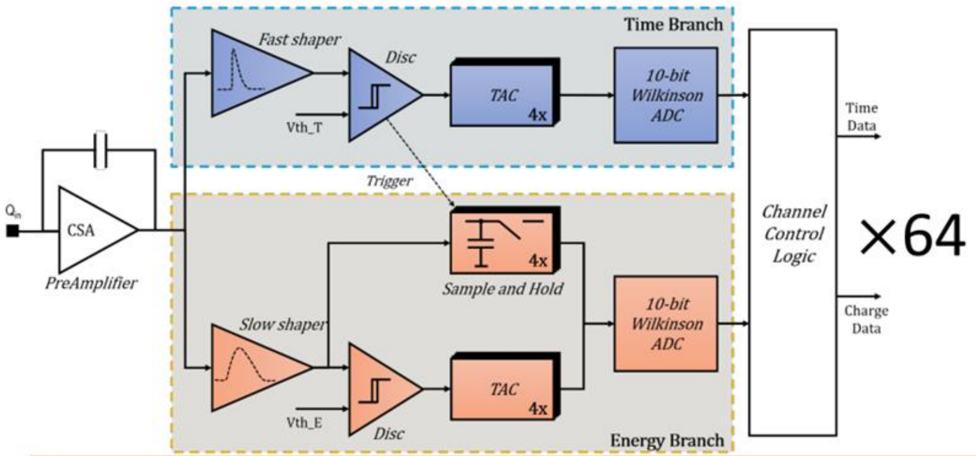
Thanks for your attention!

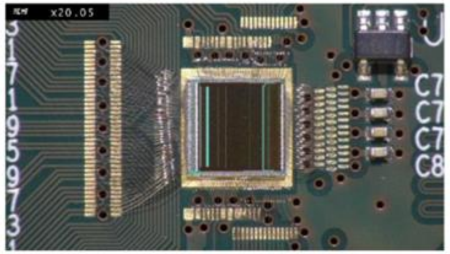
Backup slides

TIGER ASIC

Torino Integrated Gem Electronics Readout

Font end architecture





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

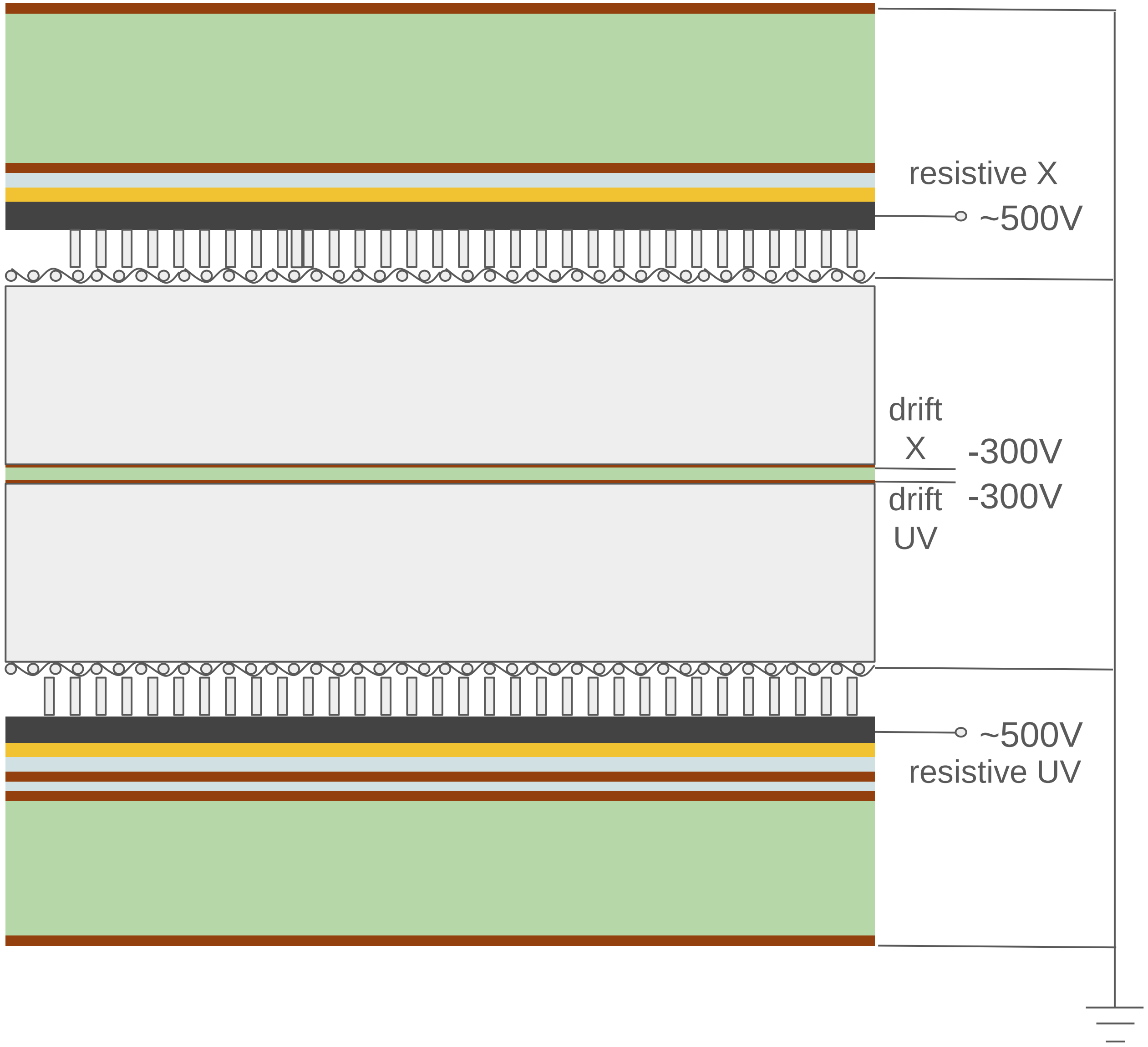
X shielding and connector layer : 35um copper
-3.2mm Glass epoxy
X strip layer : 35um Copper
-50um Prepreg
-50um Kapton
X DLC layer
-pillars 150um
X mesh: 45/18

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

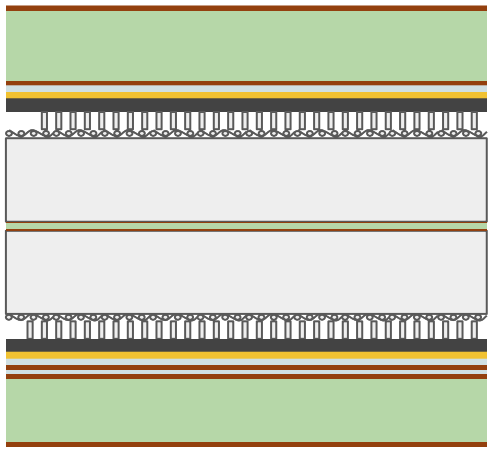
X shielding and connector layer : 35um copper
-3.2mm Glass epoxy
X strip layer : 35um Copper
-50um Prepreg
-50um Kapton
X DLC layer
-pillars 150um
X mesh: 45/18

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

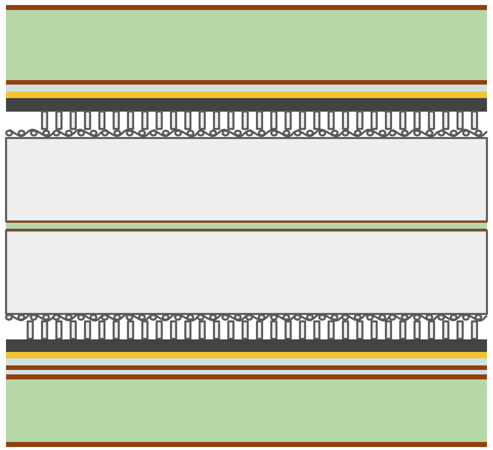
LMM lateral module detector prototype X0 calculation

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)

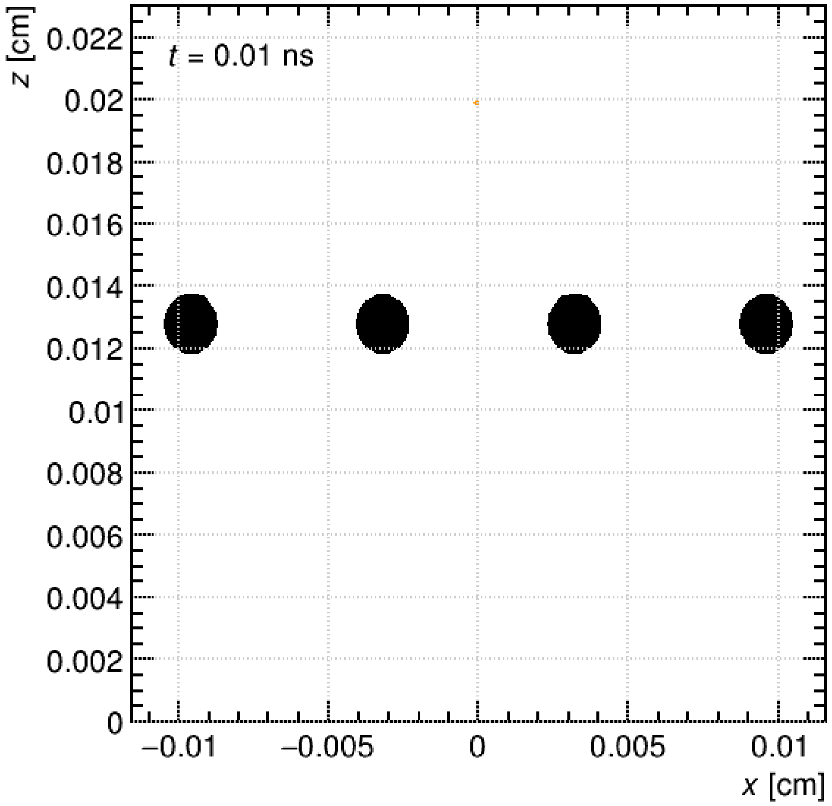
- FR-4 (PCB): 6.4/159.3 = 0.04
- Cu: 0.0157/14.36 = 0.001
- Prepreg: 0.0128/354.9 = 0.00004
- Kapton: 0.01/285.7 = 0.000035
- DLC: 0.002/121.3 = 0.00002

$X_0 \approx 4$ %

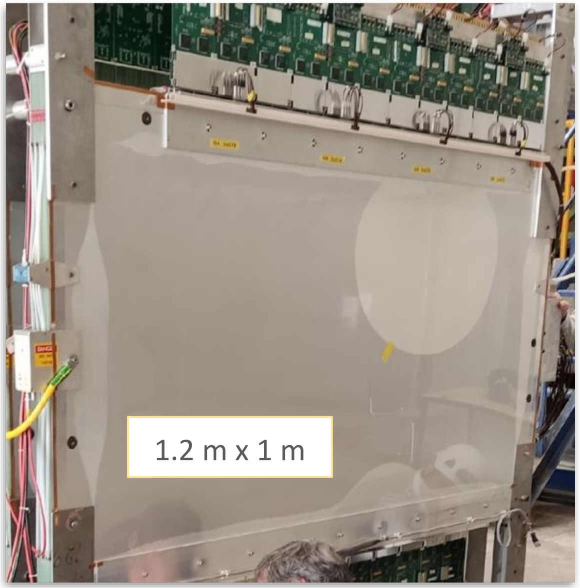
BACKUP : Large area micromegas project: detector development

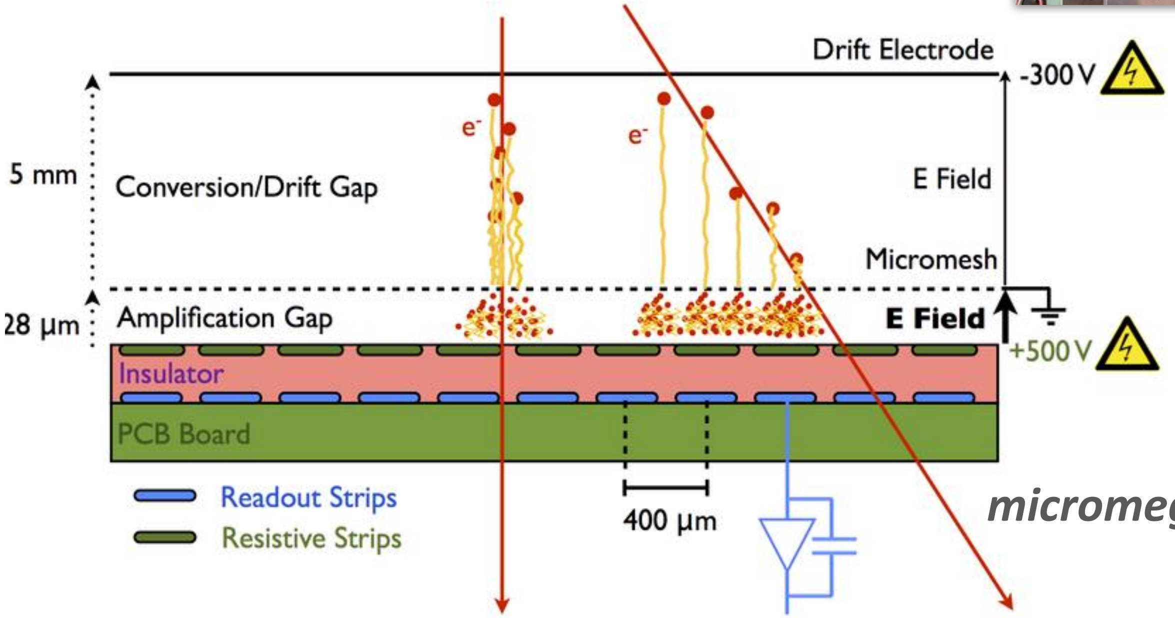
Detector development motivation:

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



ım we decide to substitute a part of the detector.

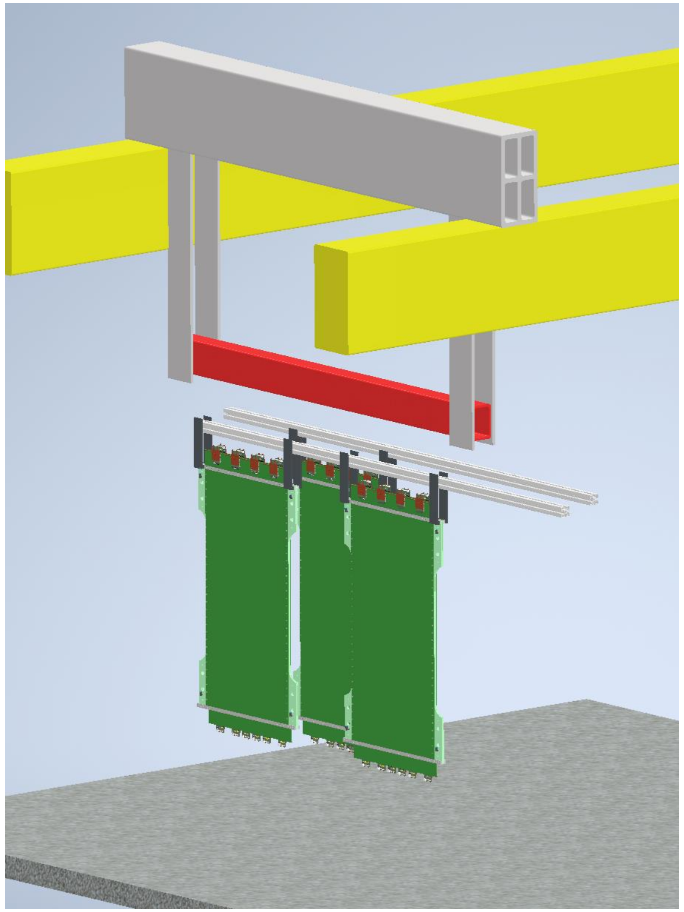


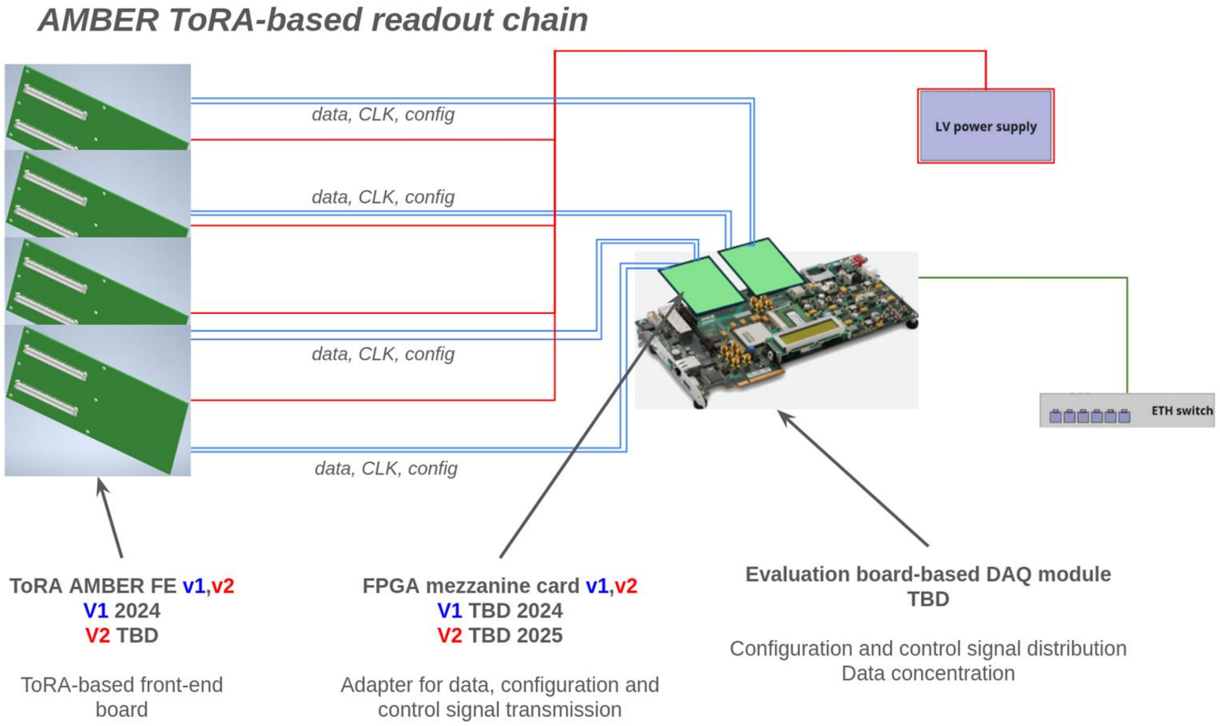


micromegas working principle

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.

Torino Readout for AMBER (ToRA) ASIC

- MPGD and Wire detectors compatible
- Target specific application
- Limited complexity
- Reuse existing solutions
- 65nm
- 2 step design

Detector	MM	Straw	
Channels/ASIC	64	64	
Power/channel	$\leq$5	$\leq$10	mW
Input capacitance	$\leq$550	20-100	pF
Input charge	1-100	1-1000	fC
Input impedance	$\leq$50 Ω	*tbd*	Ω
Max rate	$\leq$2	$\leq$0.18	MHz
Peaking time	150	75-150	ns
Time resolution	1-2	$\leq$1	ns
Charge resolution	8	10	bits
Gain	12	2	mV/fC
ENC @10 pF	500-1000		e^-
ENC @150 pF	1000-2000		e^-
ENC @60 pF		3000	e^-
Threshold range	*tbd*	0-15	fC
Clock frequency	200	200	MHz

Courtesy of Maxim Alexeev HEPNP2025