A new large-area Micromegas detector and its readout electronics for AMBER experiment at CERN

AMBER
Apparatus for Meson and Baryon Experimental Research

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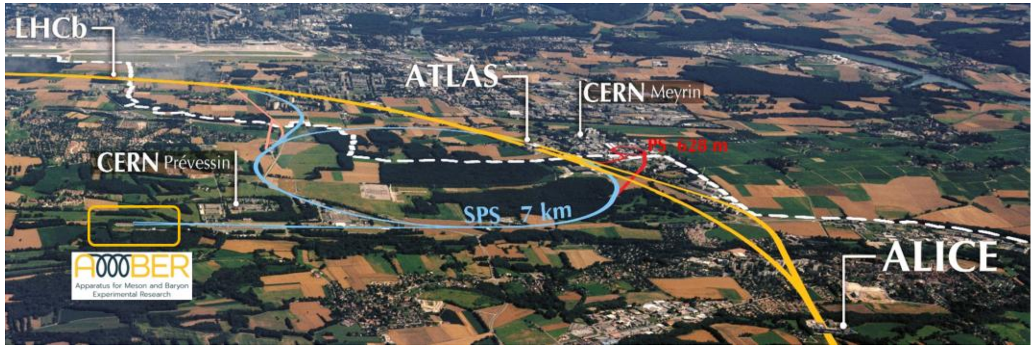
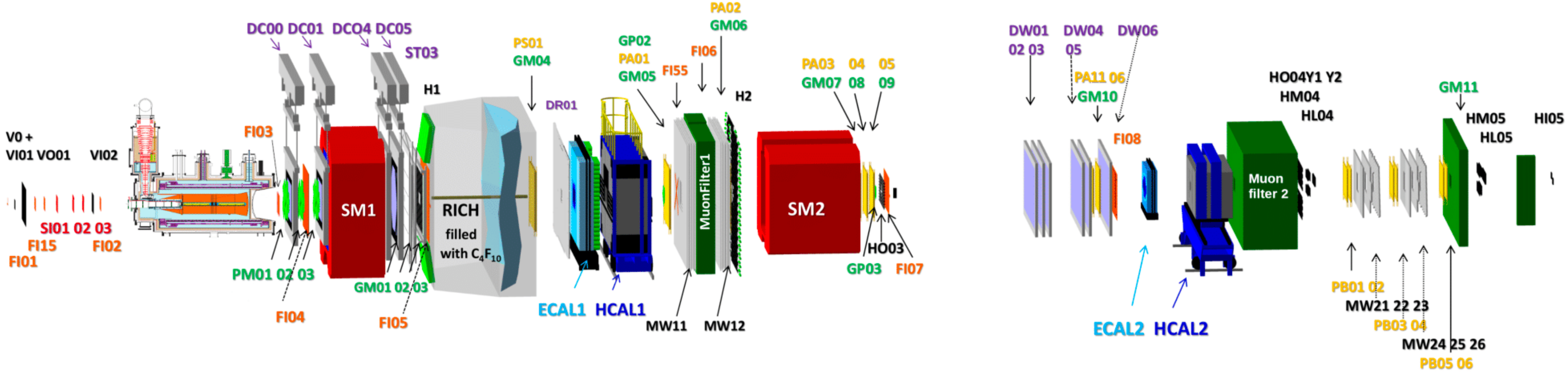
Apparatus for Meson and Baryon Experimental Research (AMBER,NA66)

- 2018: Letter of Intent
  arXiv:1808.00848
- 2019: Formation of a Proto-Collaboration
- 2019: AMBER Phase–1 Proposal
  CERN-SPSC-2019-02
- 2020: Recommendation of the Proposal by SPSC and approval by Research Board
- 2021,2022: AMBER Pilot Run
- 2023: Start of AMBER data taking

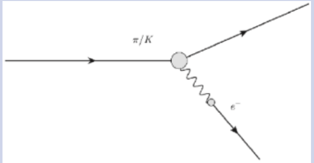


Phase-2 proposal in preparation
Post LS4 ->



Presently 33 institutes from 14 countries, but there is no upper limit on the values.

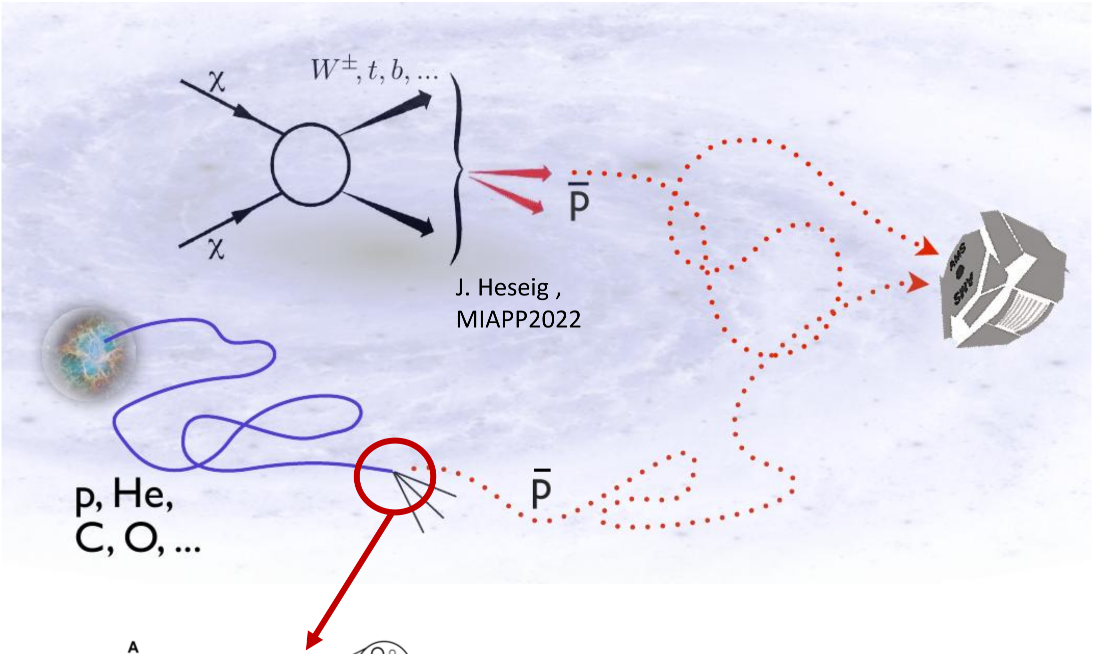
AMBER program

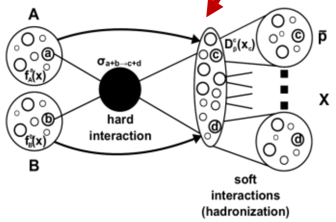
	Beam	Target	Additional hadware
Antiproton production crosse section	50 GeV – 280 GeV protons	LH_2, LHe Done (2023 – 2024)	Liquid He target
Proton radius measurement	100 GeV muons 2025(test) – 2026	High pressure Hydrogen	Active target TPC, tracking stations (SciFi,Silicon)
Drell-Yan measurement with pions	190 GeV charged pions	Carbon, Tungsten	Vertex detector
Drell-Yan measurement with Kaons	~100 GeV charged Kaons	Carbon, Tungsten	Vertex detectors, “active absorber”
Prompt photon measurement	> 100 GeV charged Kaon/pion beams	LH_2, Nickel	hodoscopes
K-induced spectroscopy	50 GeV – 100 GeV charged Kaons	LH_2	Recoil ToF forward PID
Meson radii	50 GeV to 280 GeV charged pions and Kaons		

Phase 1
(approved)
2023 -> 2032

Phase 2
(in preparation)
Beyond LS4

AMBER APXs (2023-2024)





$$f = f^0_{\bar{p}}(2 + \Delta_{\mathrm{IS}} + 2\Delta_{\Lambda})$$

Antiprotons arise from spallation processes and <u>possible</u> DM decays. Their flux interpretation needs good parametrization of the standard production in the typical occurring reactions.

$\mathrm{p} + \mathrm{H} \rightarrow \bar{\mathrm{p}} + X$

$\mathrm{p} + \mathrm{D} \rightarrow \bar{\mathrm{p}} + X$

$\mathrm{p} + \mathrm{He} \rightarrow \bar{\mathrm{p}} + X$

Oct 2022 1 week Test run APXS	May-July 2023 Physics APXS	May-July 2024 Physics APXS

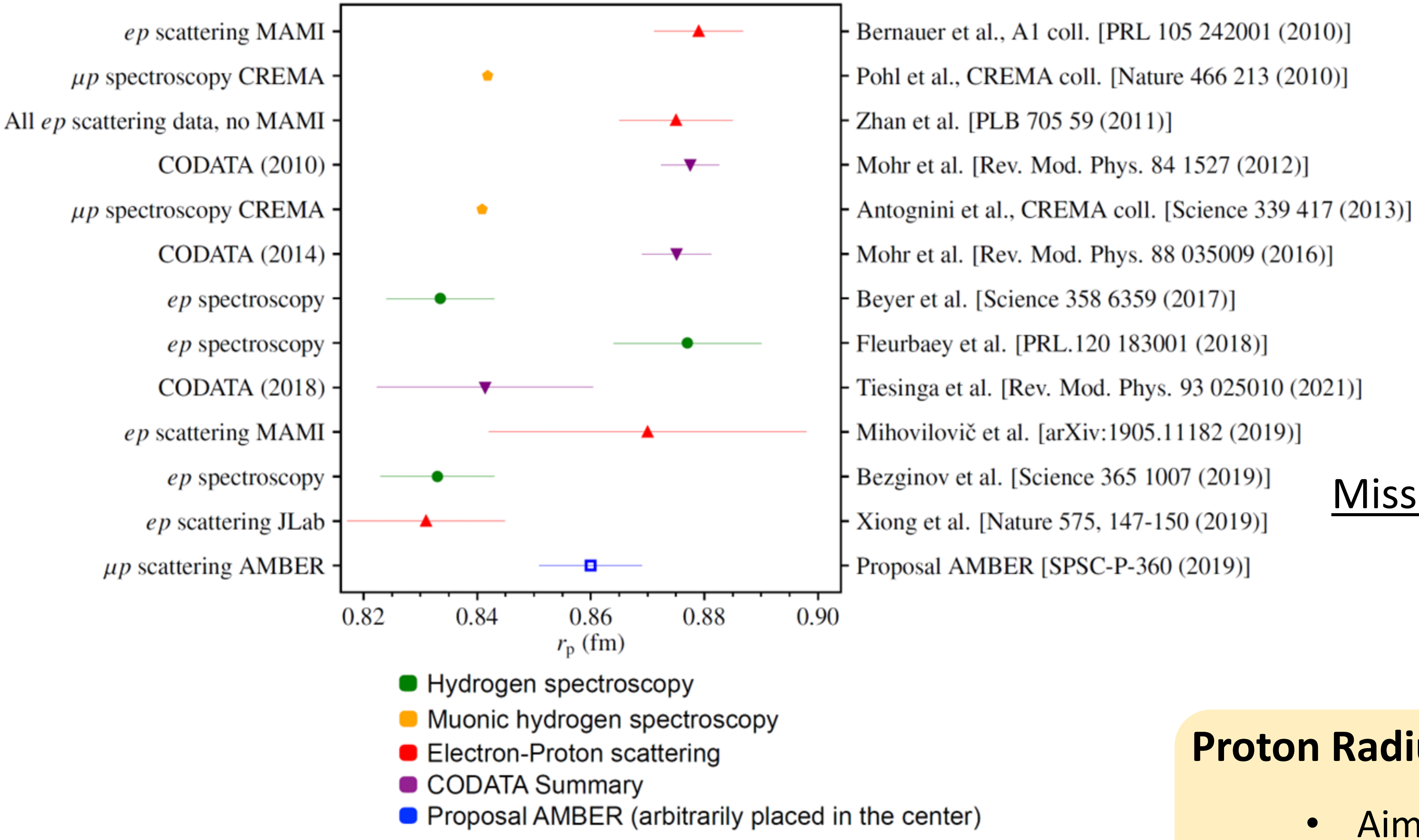
Minimum bias trigger: beam trigger with veto on non-scattered beam particle

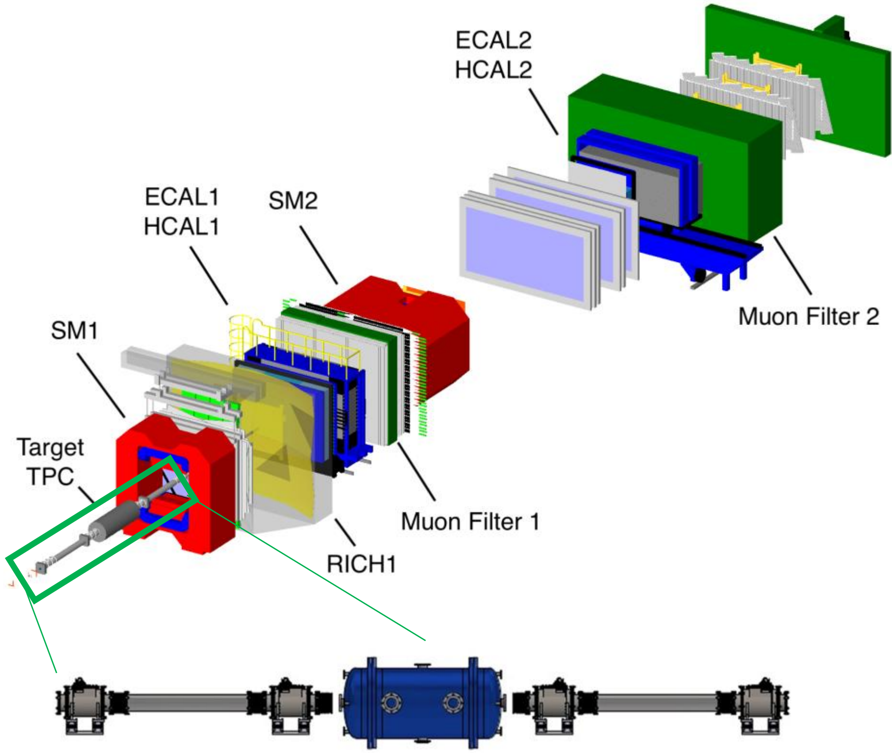
The major uncertainties in the current antiproton flux interpretation stem from the poor knowledge of the antiproton production from prompt reactions (mainly p+p and p+He) and from antineutron decays.

<u>AMBER collected data at different collision energies ($\sqrt{s_{NN}}$ = 10.7 – 21.7 GeV) to precisely measure p+He, p+H and p+D.</u>

AMBER PRM (2025/2026)

Proton-radius puzzle





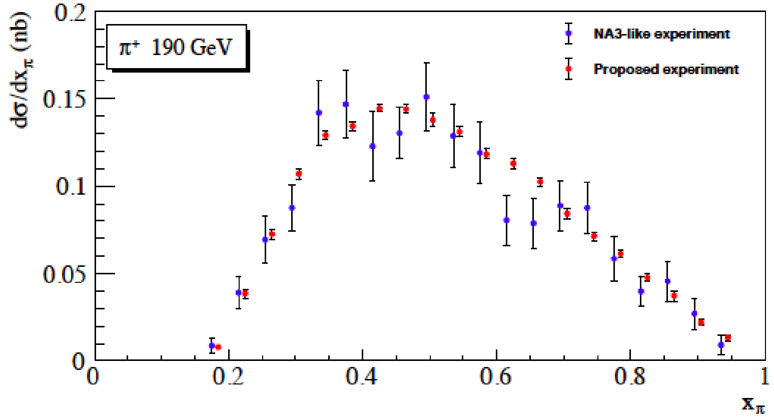
Missing: muon-proton with E_μ of 10 - 100 GeV

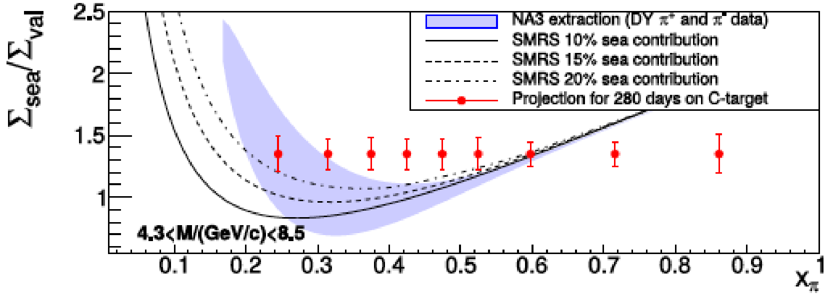
- Test of lepton universality
- Different systematics compared to others

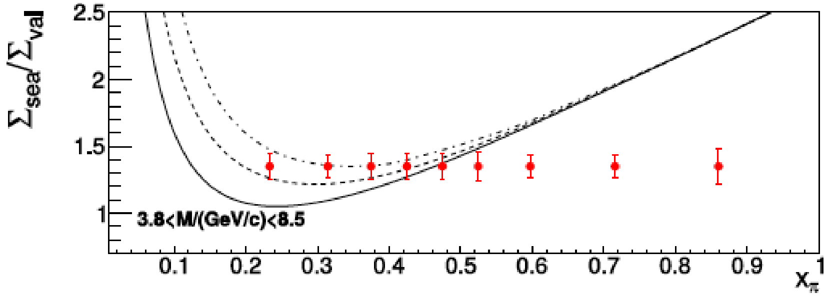
Proton Radius Measurement @ AMBER

- Aimed precision of charge-radius below 1%
- Aimed Q^2-range: 0.001 GeV^2/c^2 to 0.040 GeV^2/c^2

AMBER DY (post LS3)







Sea quark content of pion can be accurately measured at AMBER for the first time

Pion structure in pion induced DY
Expected accuracy as compared to NA3

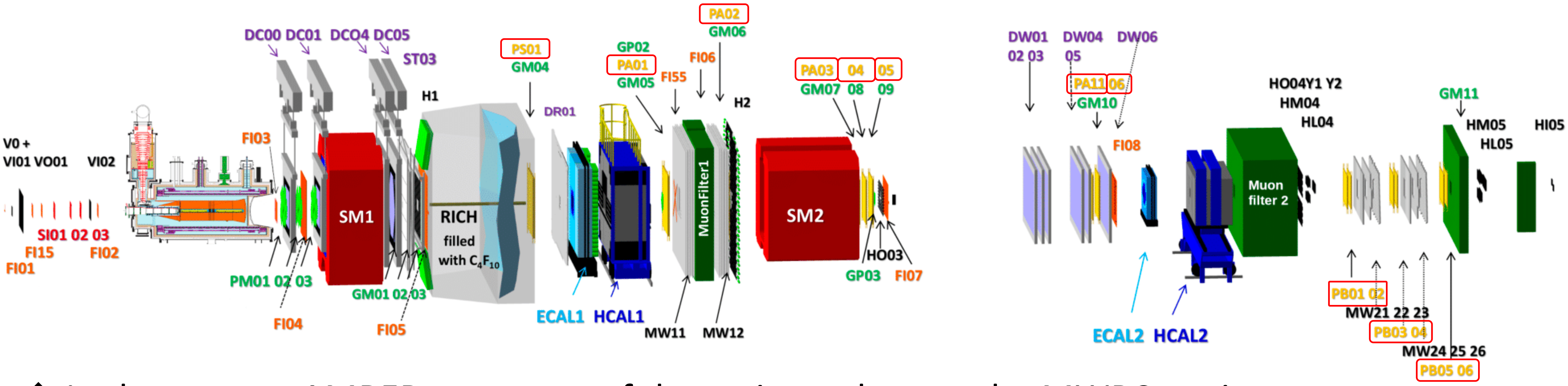
- $\Sigma_V = \sigma^{\pi^- C} - \sigma^{\pi^+ C}$: only valence-valence
- $\Sigma_S = 4\sigma^{\pi^+ C} - \sigma^{\pi^- C}$: no valence-valence
- Collect at least a **factor 10 more statistics** than presently available
- Minimize nuclear effects on target side
  - Projection for 2×140 days of Drell-Yan data taking
  - π^+ to π^- 3:1 time sharing
  - 190 GeV beams on Carbon target ($1.9\lambda^{\pi}_{int}$)
  - Improvement of shielding to double the intensity is under investigation

Experiment	Target type	Beam energy (GeV)	Beam type	Beam intensity (part/sec)	DY mass (GeV/c^2)	DY events
E615	20 cm W	252	π^+ π^-	17.6×10^7 18.6×10^7	4.05 – 8.55	5000 30000
NA3	30 cm H_2	200	π^+ π^-	2.0×10^7 3.0×10^7	4.1 – 8.5	40 121
	6 cm Pt	200	π^+ π^-	2.0×10^7 3.0×10^7	4.2 – 8.5	1767 4961
NA10	120 cm D_2	286 140	π^-	65×10^7	4.2 – 8.5 4.35 – 8.5	7800 3200
	12 cm W	286 194 140	π^-	65×10^7	4.2 – 8.5 4.07 – 8.5 4.35 – 8.5	49600 155000 29300
COMPASS 2015 COMPASS 2018	110 cm NH_3	190	π^-	7.0×10^7	4.3 – 8.5	35000 52000
AMBER	75 cm C	190	π^+	1.7×10^7	4.3 – 8.5 4.0 – 8.5	21700 31000
		190	π^-	6.8×10^7	4.3 – 8.5 4.0 – 8.5	67000 91100
	12 cm W	190	π^+	0.4×10^7	4.3 – 8.5 4.0 – 8.5	8300 11700
		190	π^-	1.6×10^7	4.3 – 8.5 4.0 – 8.5	24100 32100

Isoscalar target + *Both positive and negative beams* + *High statistics*

Probing valence and sea quark contents of pion at AMBER
Expected statistics 8 to 20 times higher than available

Why we work on the MM project



❖ In the present AMBER setup one of the main tracker are the MWPC stations

<u>Present situation</u>

- ✓ Triggered DAQ
- ✓ Degraded detectors
- ✓ Limited Team

<u>Reasonable situation</u>

- ❑ Trigger less DAQ
- ❑ Maintenance available for a long period of time
- ❑ Collaboration between, experts, ASIC teams and CERN MPT & GDD workshops

Decided path to the future

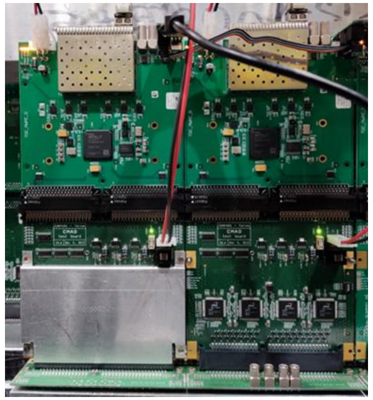
Till 2024

COMPASS MWPCs possible path to the future

After 2024

Existing detectors

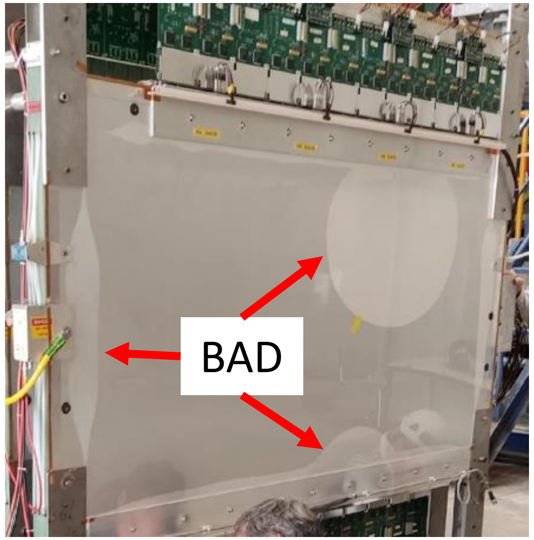
Trigger less DAQ (2025)

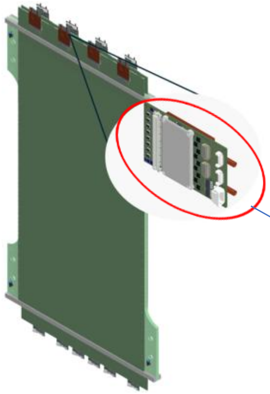


FPGA based

New FE

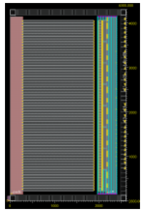
New ASIC





New detectors

New FE



New ASIC

The 2 developments could go together -> **ToRA**

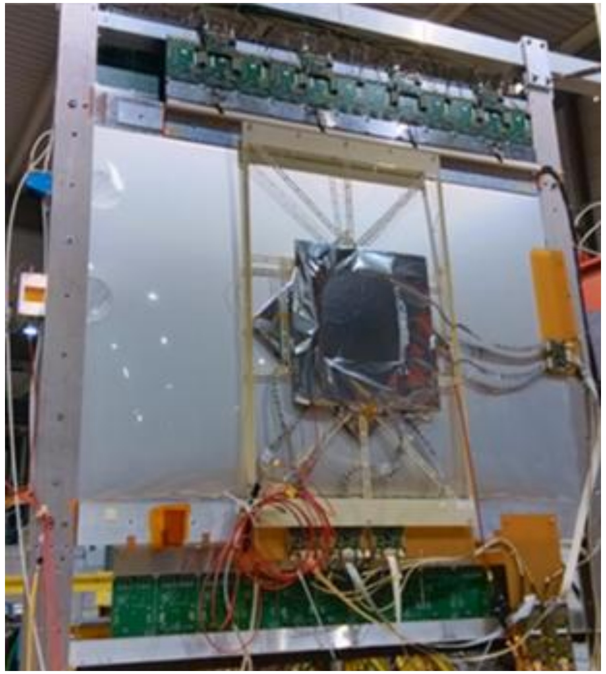
Base requirements for MWPCs replacement

Characteristics of the COMPASS MWPC detectors

	A-type	A*-type	B-type
# of chambers	7	1	6
Active area (cm^2)	178 × 120	178 × 120	178 × 90
# of layers/chamber	3	4	2
Planes	*X, U, V*	*X, U, V, Y*	*X, U/V*
Dead zone ⊘ (cm)	16–20	16	22
Wire pitch (mm)	2	2	2
Anode/cathode gap (mm)	8	8	8
# of wires/plane	752	752 (*X, U, V*), 512 (*Y*)	752

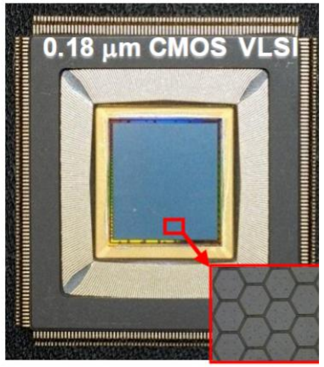
- To reasonably match the existing MWPCs
- To see if we can be better at low cost

MPGD to substitute it?

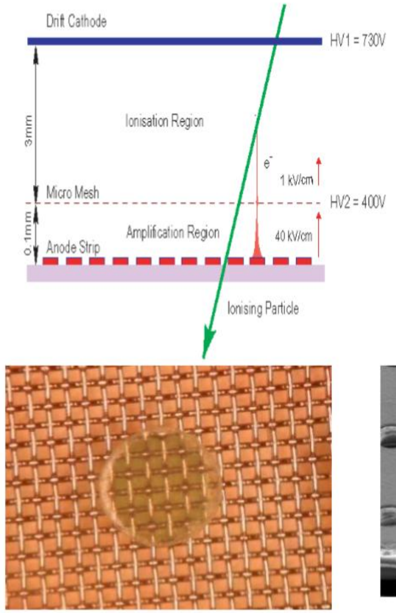


Micro Pattern Gaseous Detectors

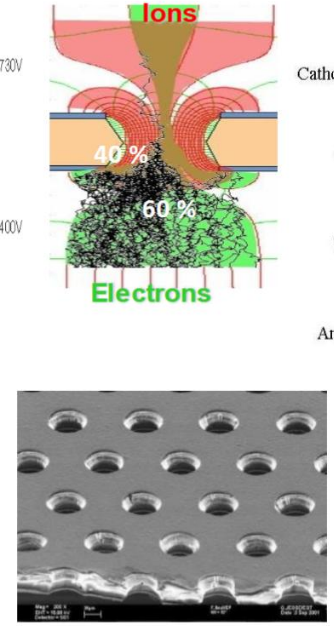
- MSGC
- Micromegas
- GEM
- Thick-GEM, Hole-Type Detectors and RETGEM
- MPDG with CMOS pixel ASICs
- Ingrid Technology



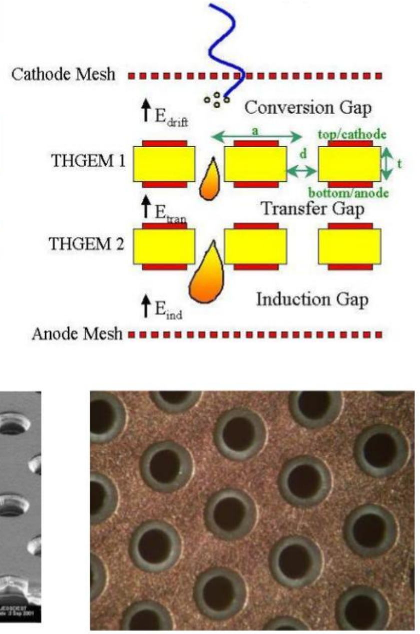
CMOS high density readout electronics



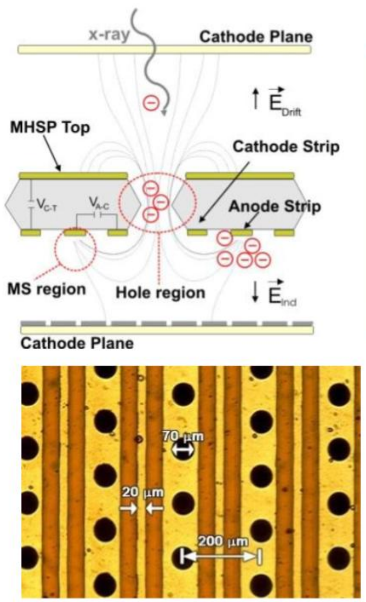
Micromegas



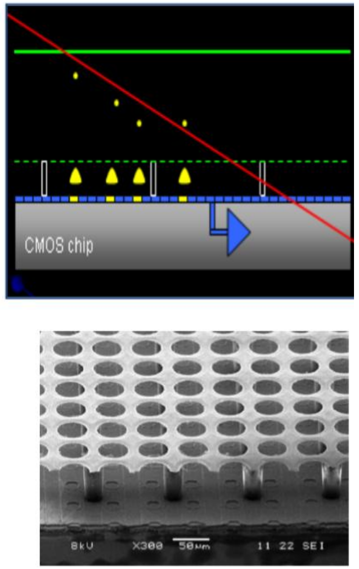
GEM



THGEM

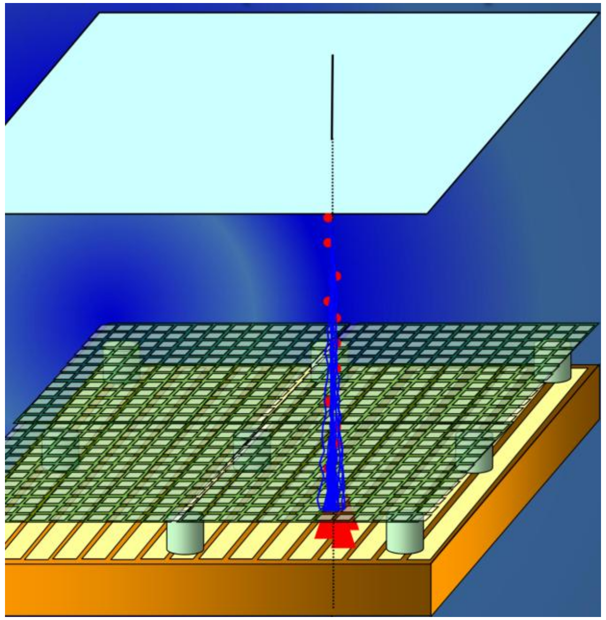


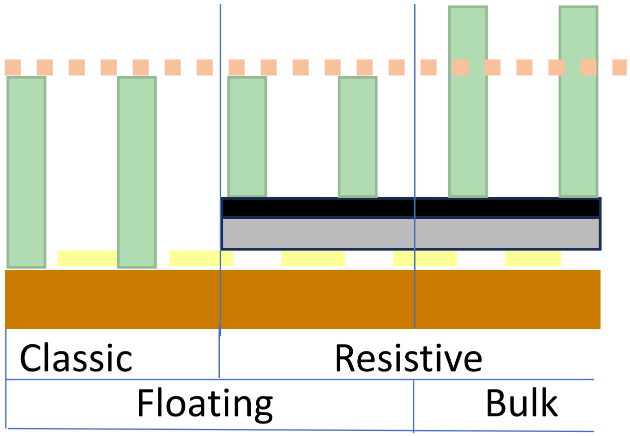
MHSP



Ingrid

Micro Mesh Gaseous Structure aka Micromegas aka MM





Concept design (1)

Reduce the material budged?

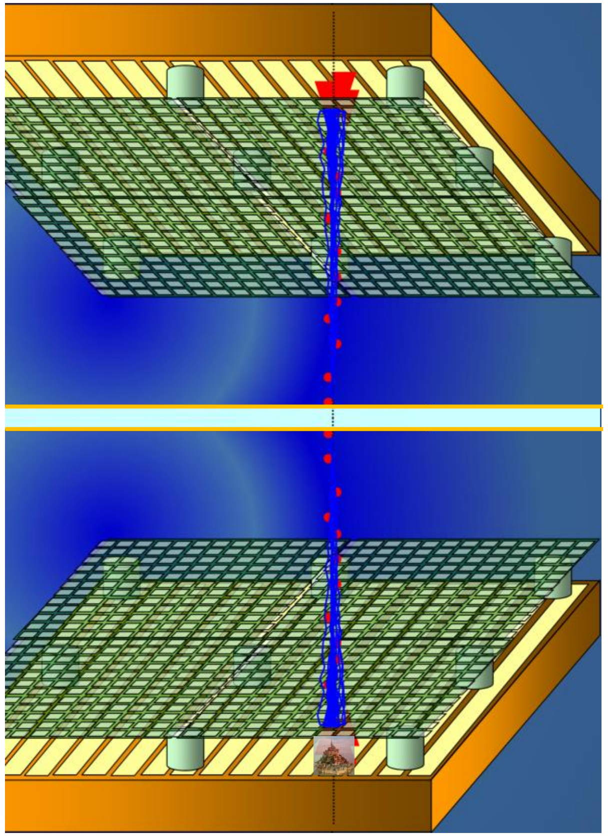
- ✓ Common cathode configuration

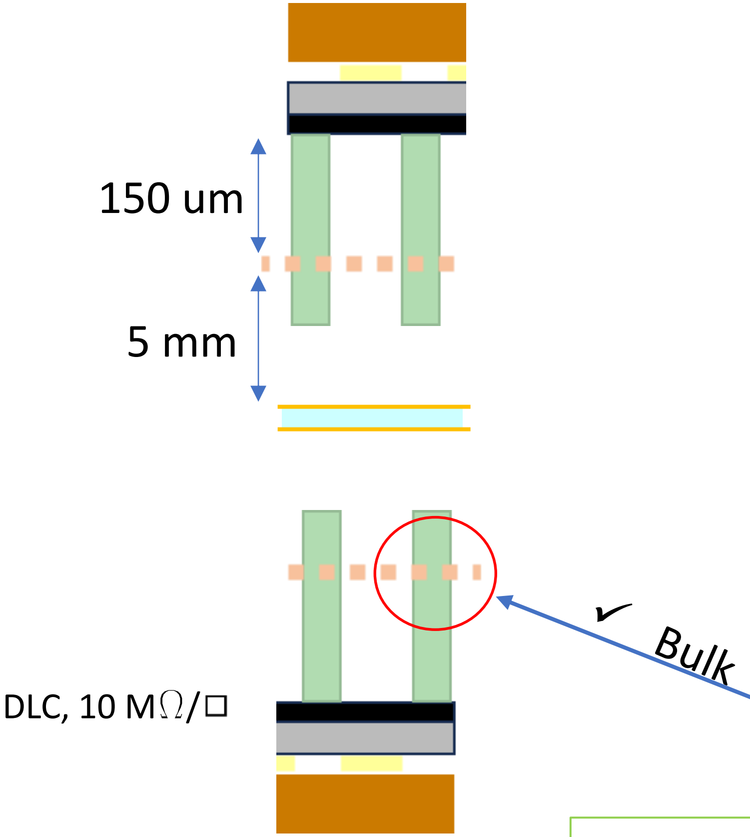
Spark reduction?

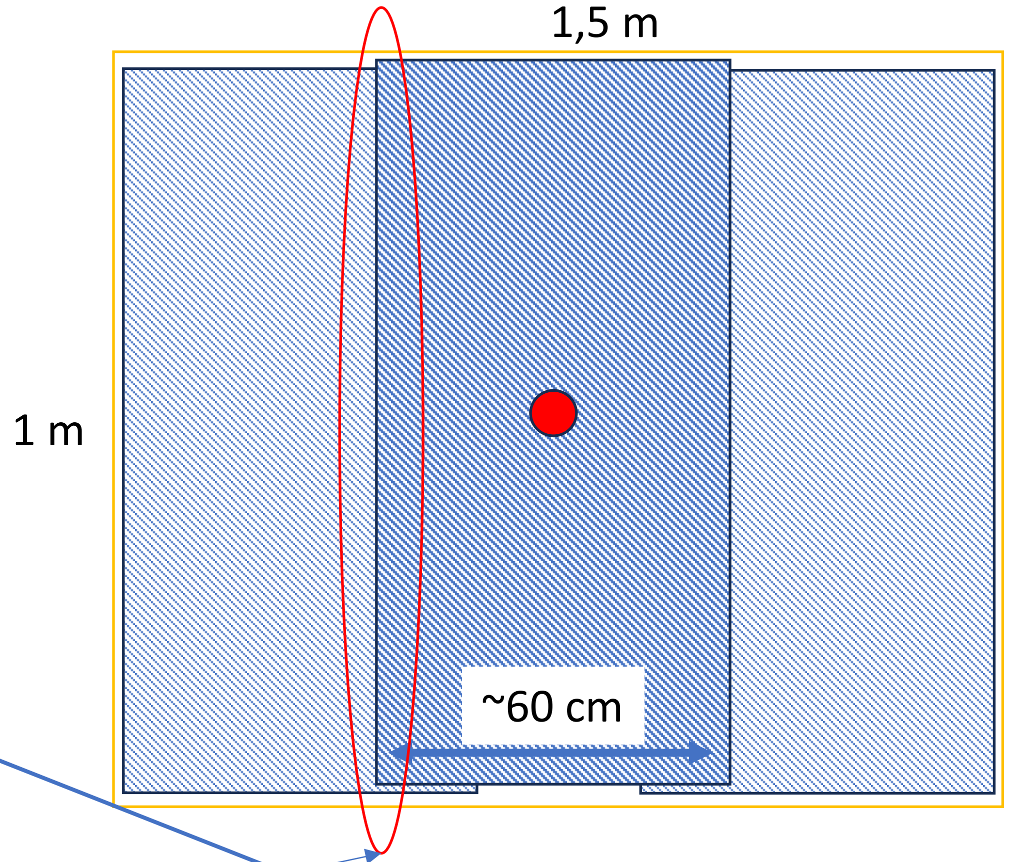
- ✓ Resistive configuration

Technology limitation?

- ✓ Staggered detector configuration



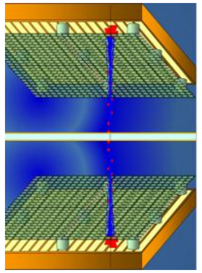


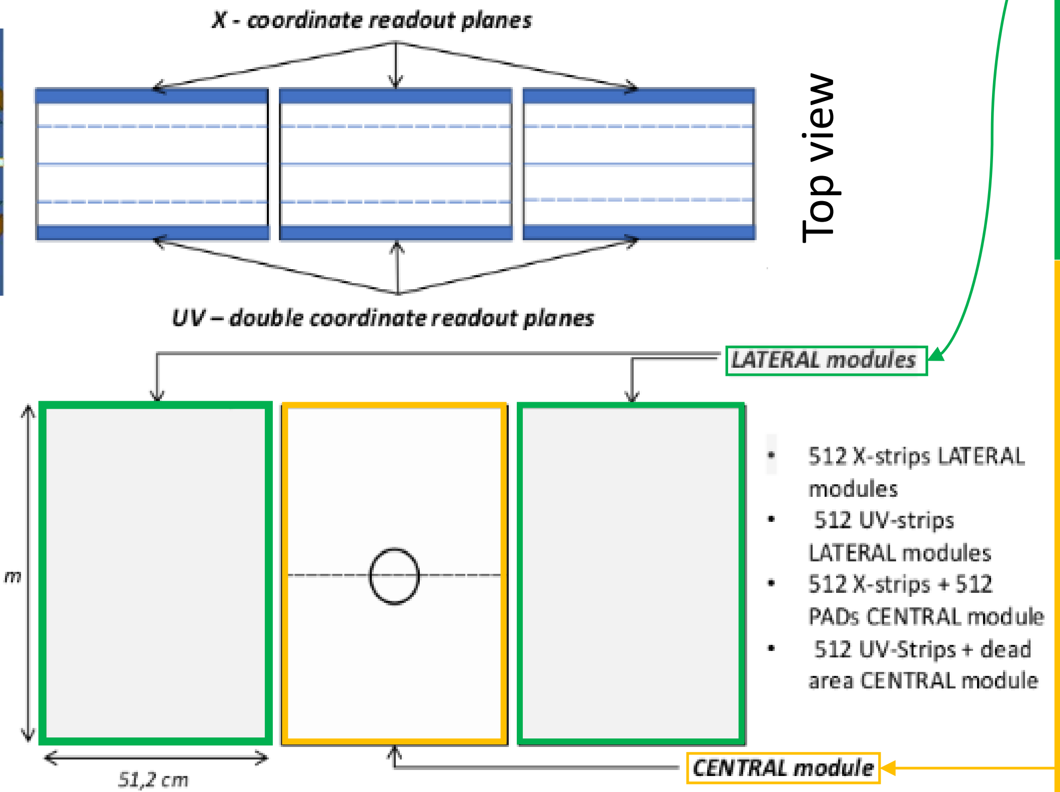


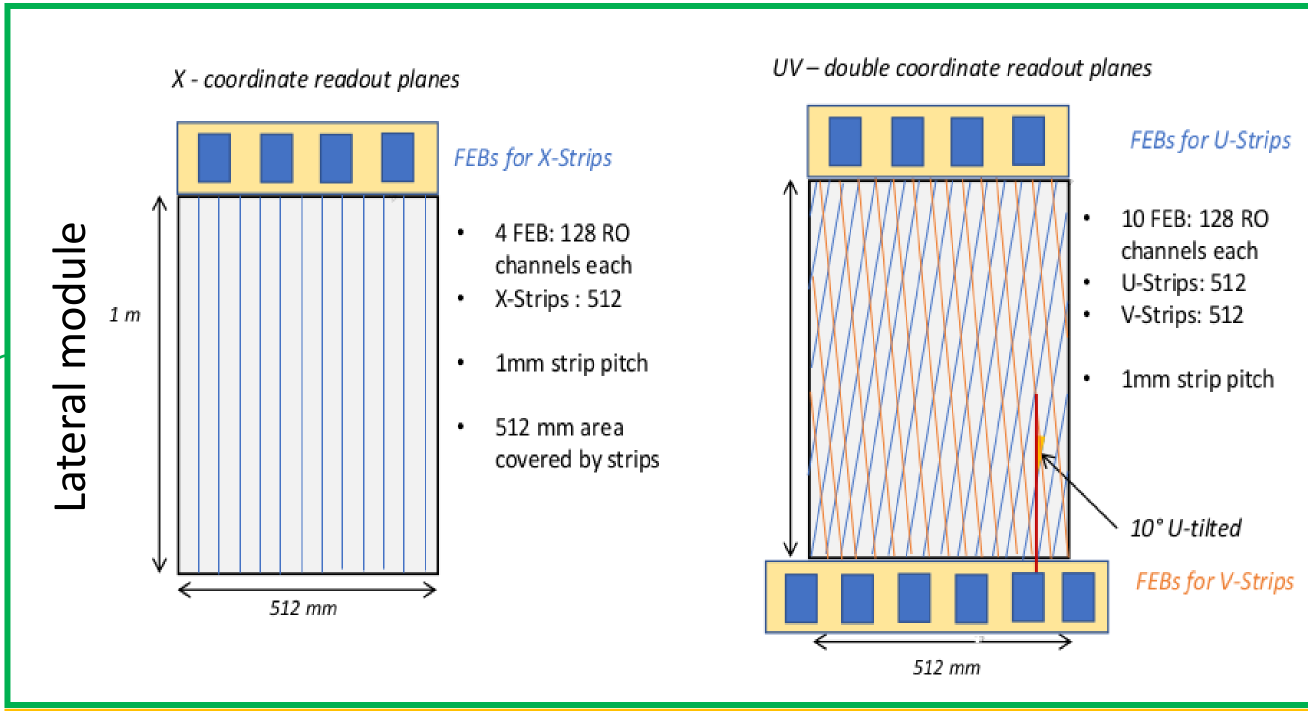
No thick frame allowed in the acceptance?

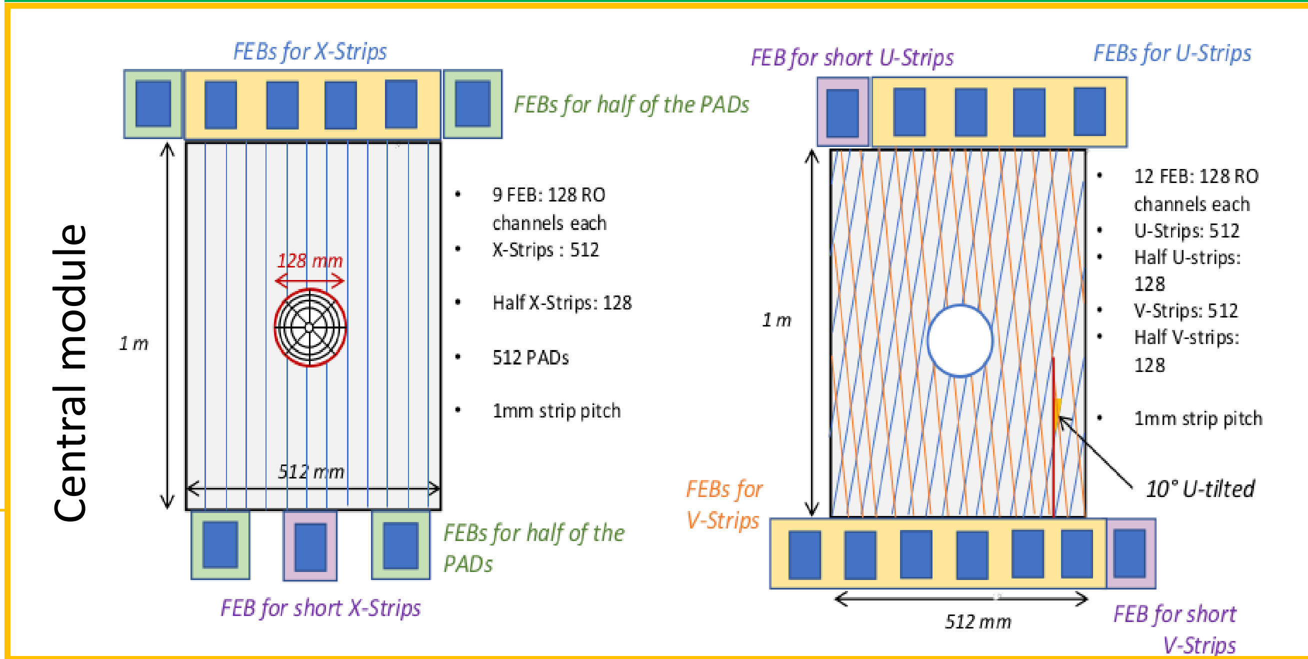
Concept design (2)

- common cathode design
- 2 types of modules
  with different anodes









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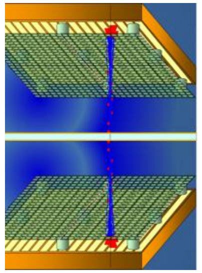
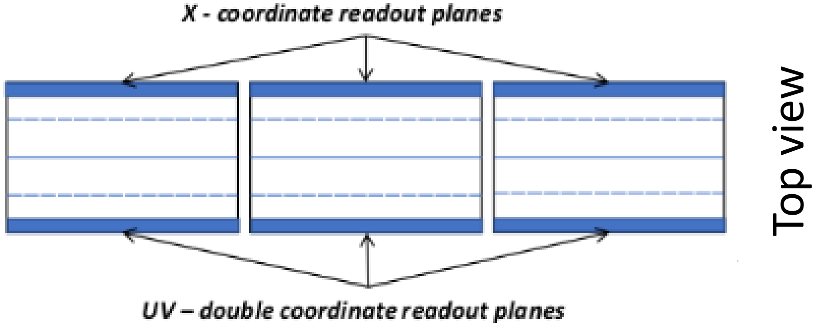
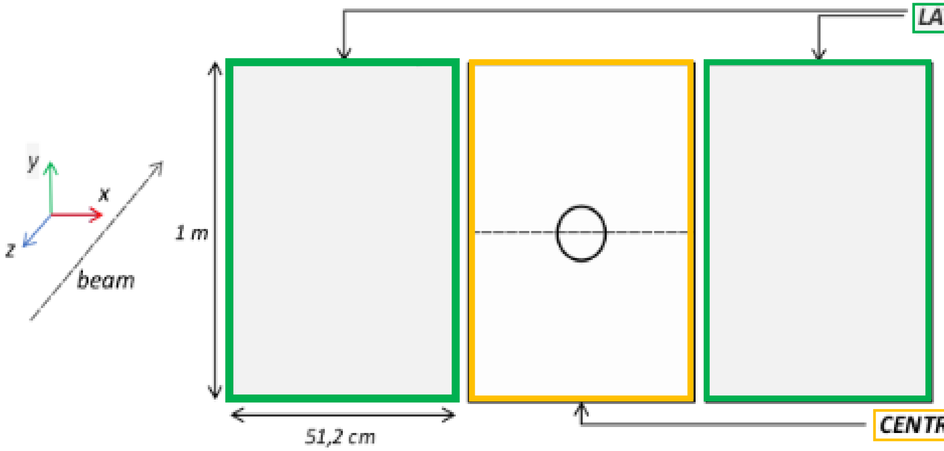
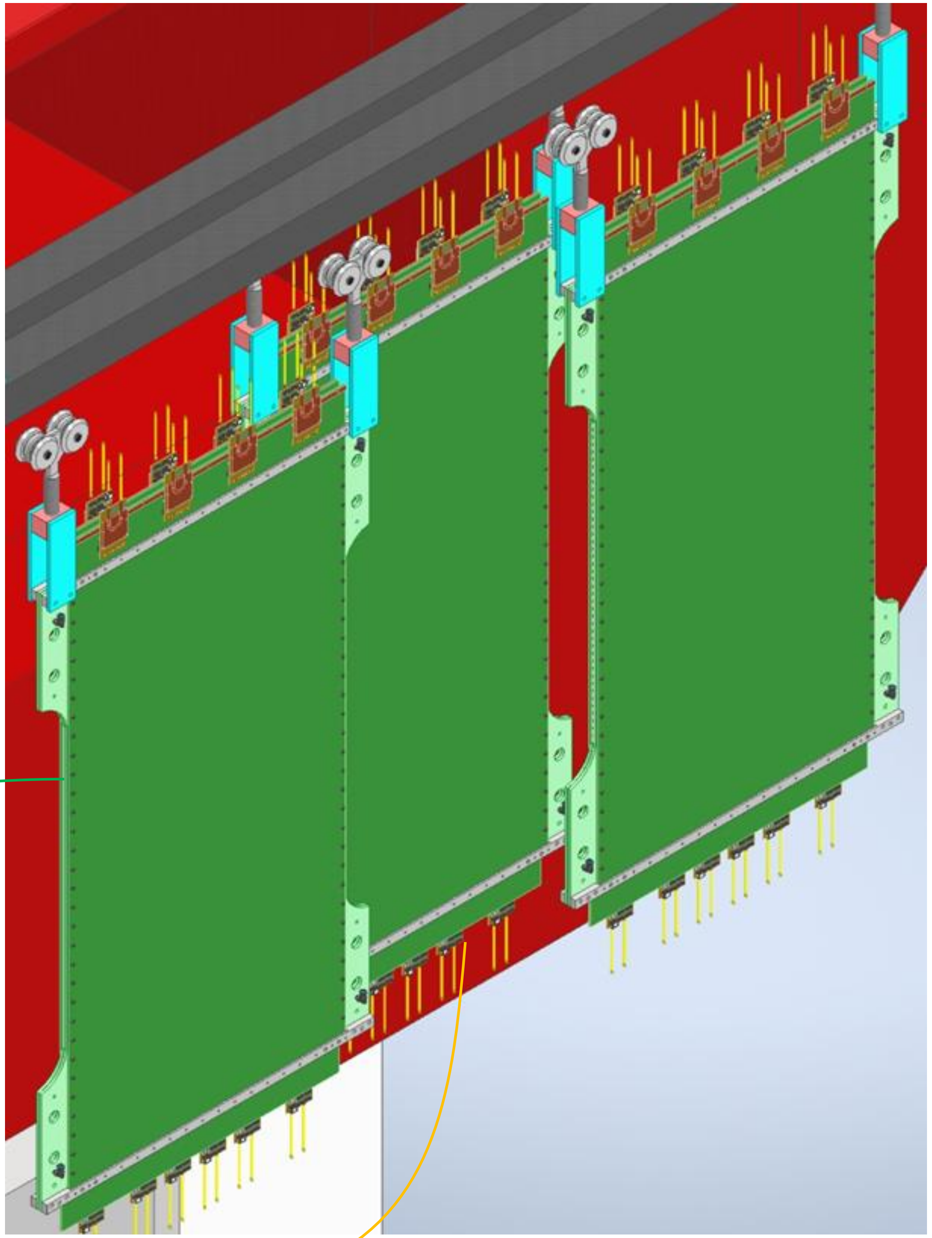






- 512 X-strips LATERAL modules
- 512 UV-strips LATERAL modules
- 512 X-strips + 512 PADs CENTRAL module
- 512 UV-Strips + dead area CENTRAL module



Concept design (3)

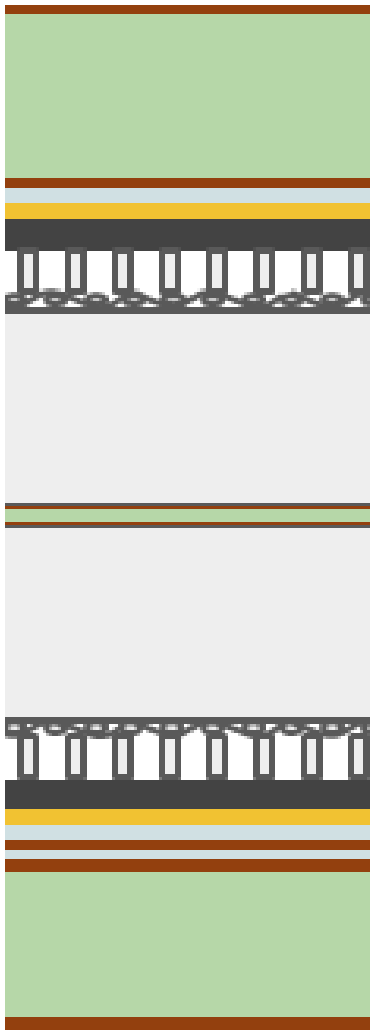
X shielding and connector layer : 35um copper
-3.2mm Glass epoxy
X strip layer : 35um Copper
-50um Prepreg
-50um Kapton
X DLC layer
-pillars 150um
X mesh: 45/18

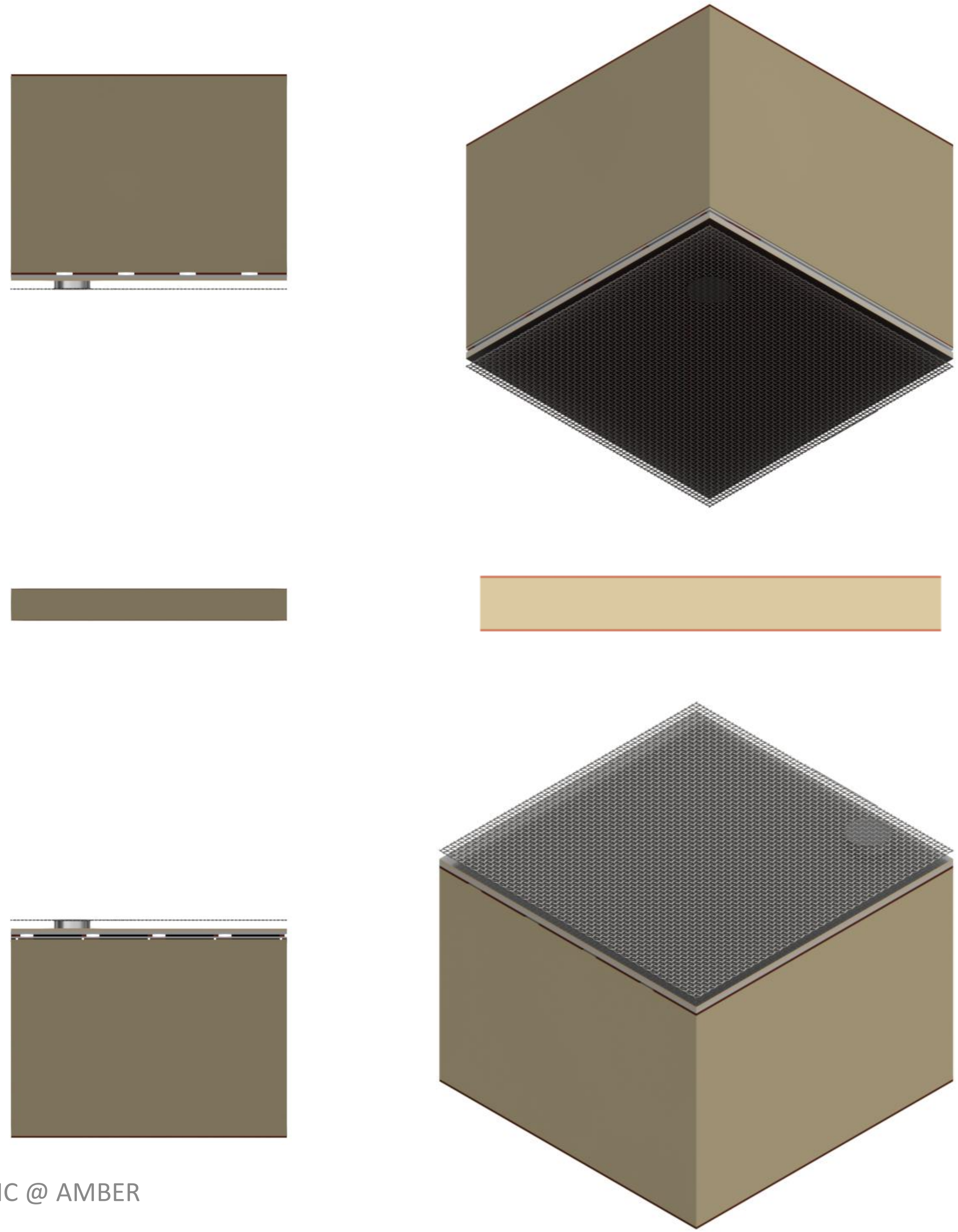
Drift gap : 5mm

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





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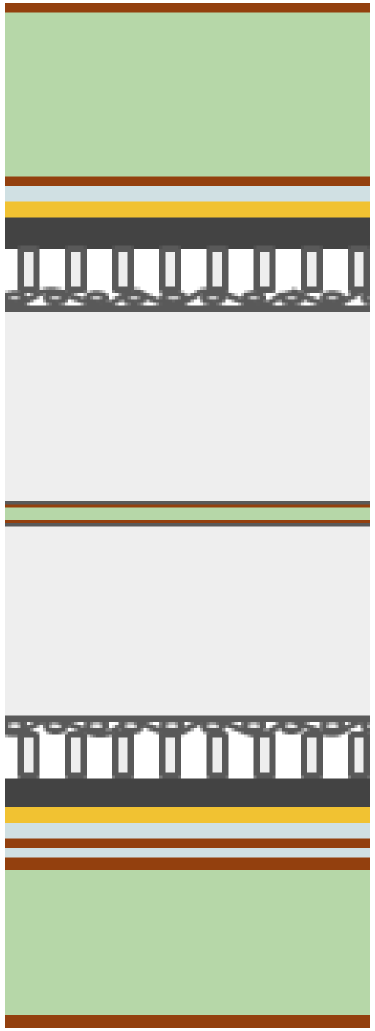
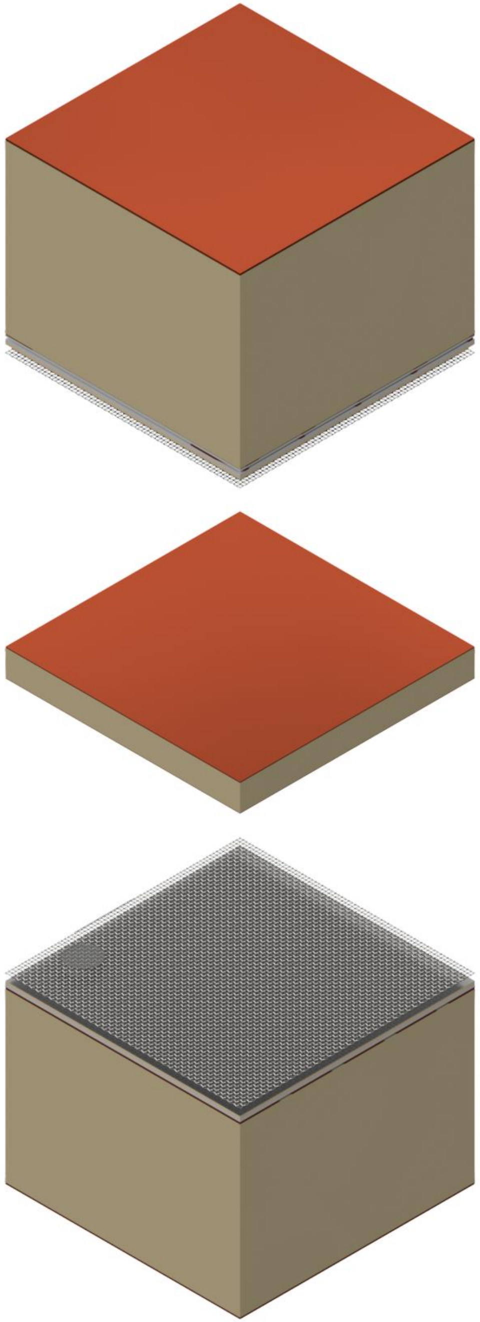
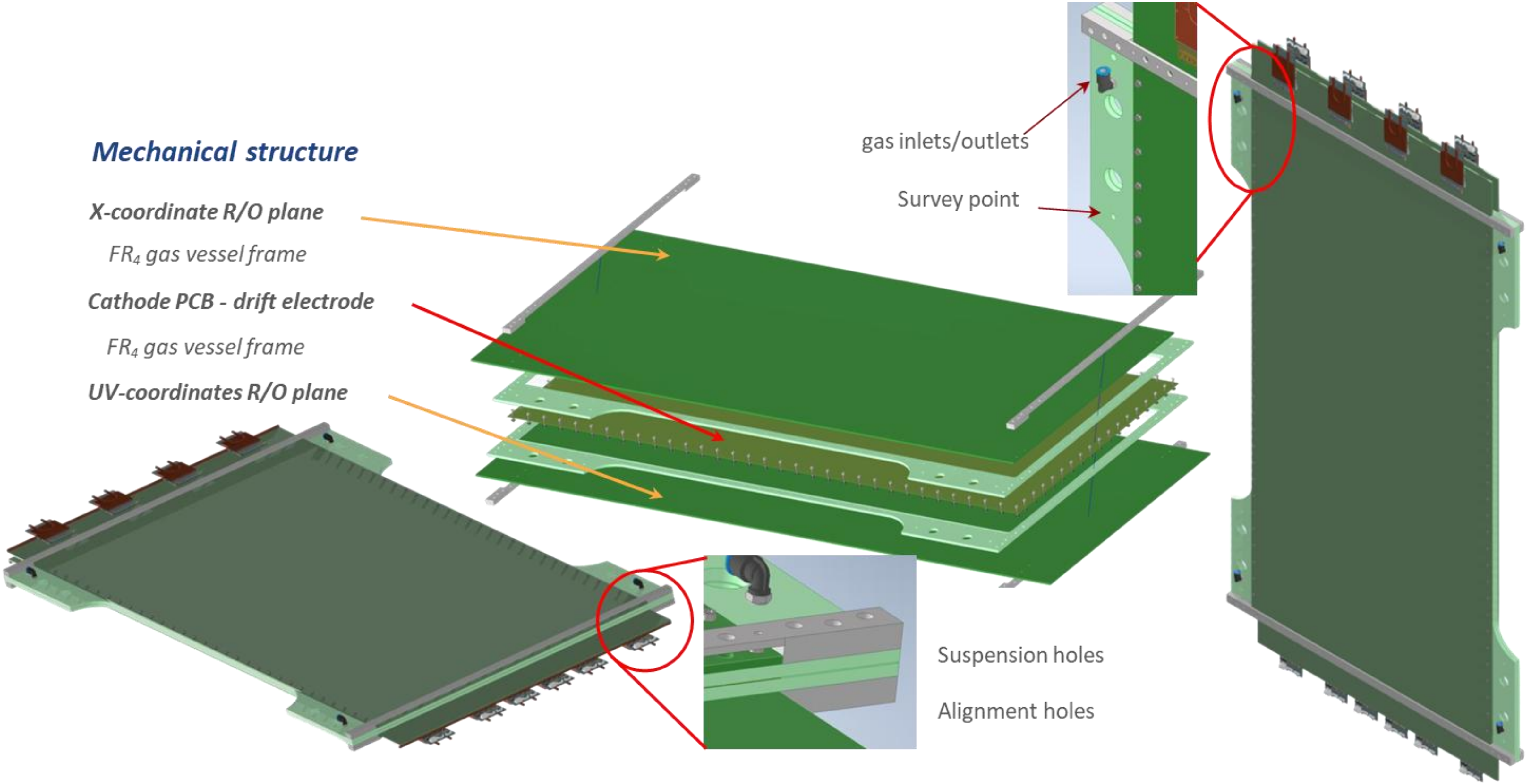


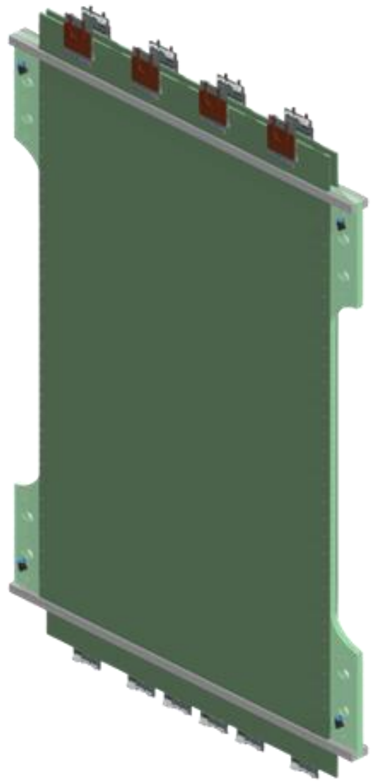


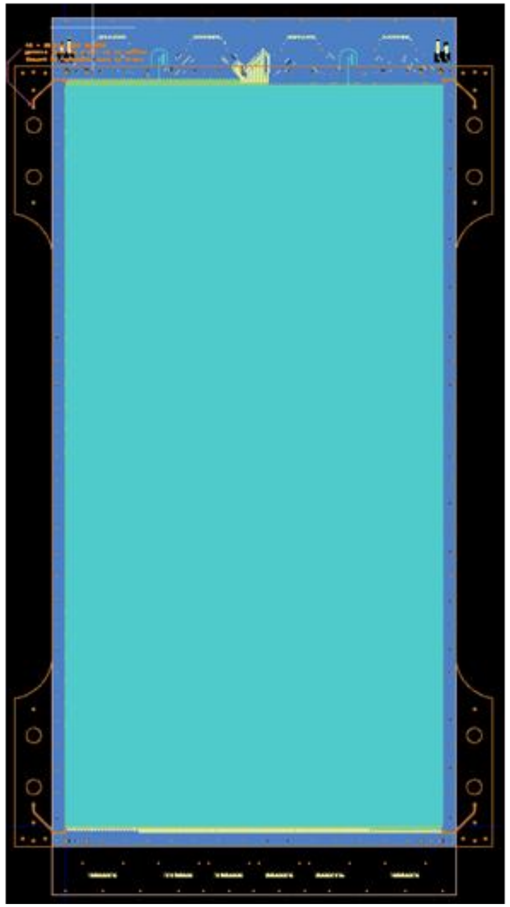
Lateral module prototype design



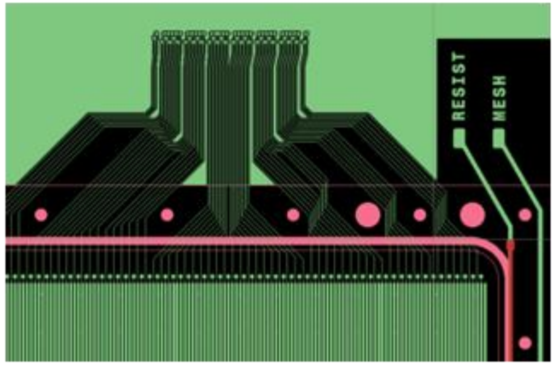
Lateral module prototype production

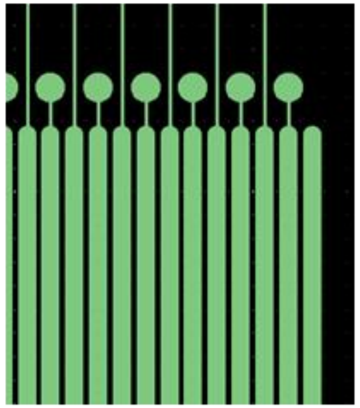
Readout PCB design and production





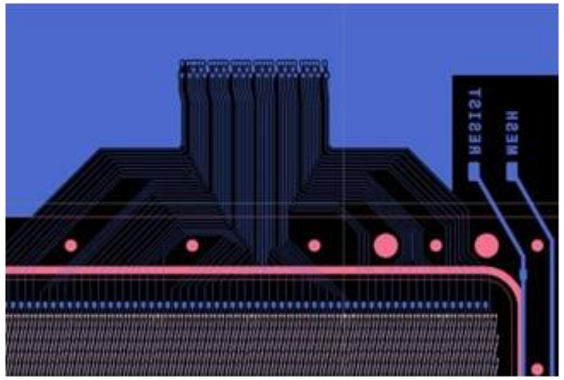
X-coordinate R/O plane

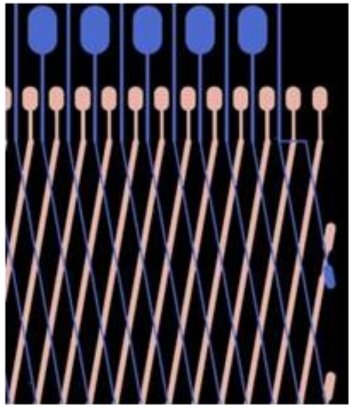




- 512 strips
- 1mm pitch
- 750 um width
- 4 FEBs: 512 fe channels

UV-coordinate R/O plane

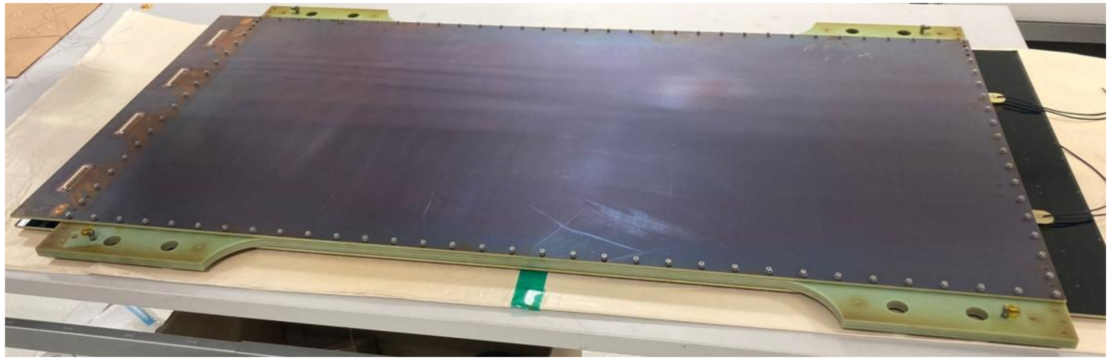




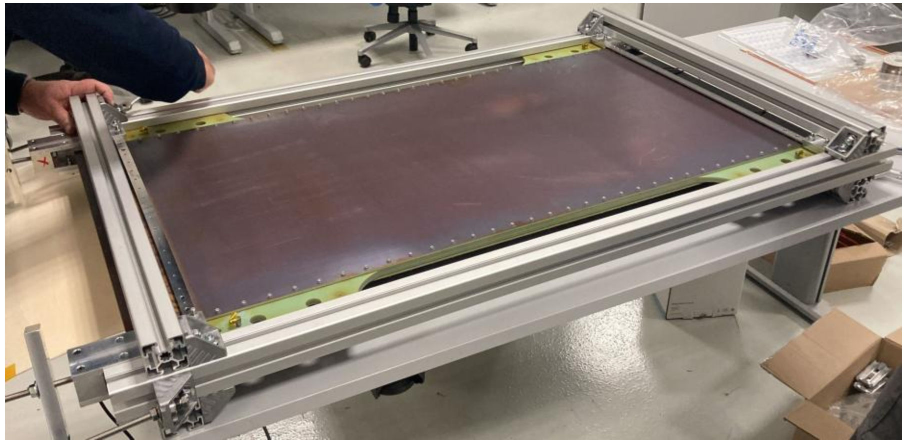
- 1280 strips
- 1mm pitch
- 250 um U strips width
- 150 um V strips width
- 10 FEBs: 1280 fe channels

Lateral module prototype testing

Delivered on 11.10.24



Mechanics for transport and suspension mounted
11.10.24



Transported and installed in the AMBER experiment
12.10.24

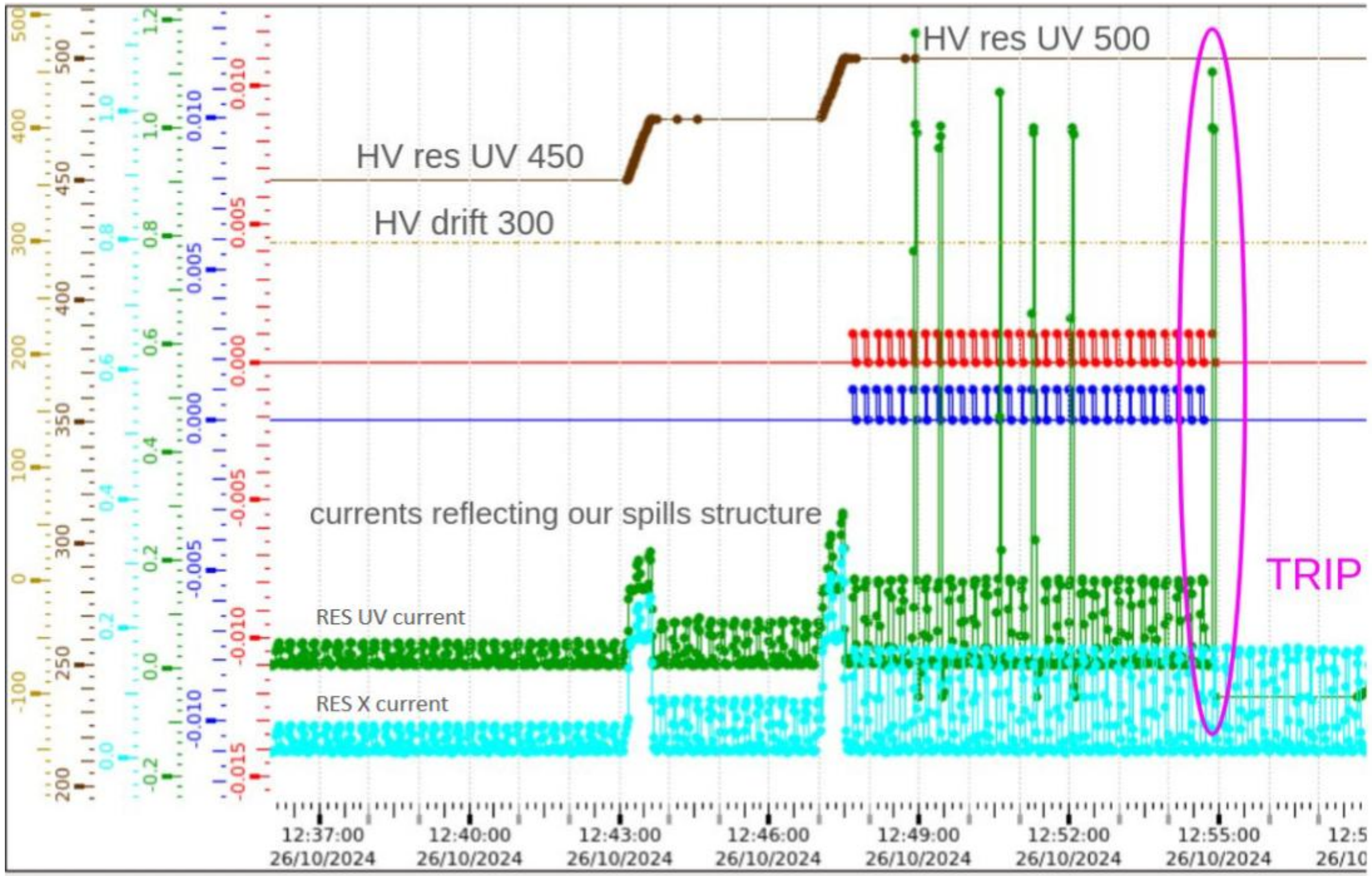
HV stability verified by MPT workshop experts
17.10.24

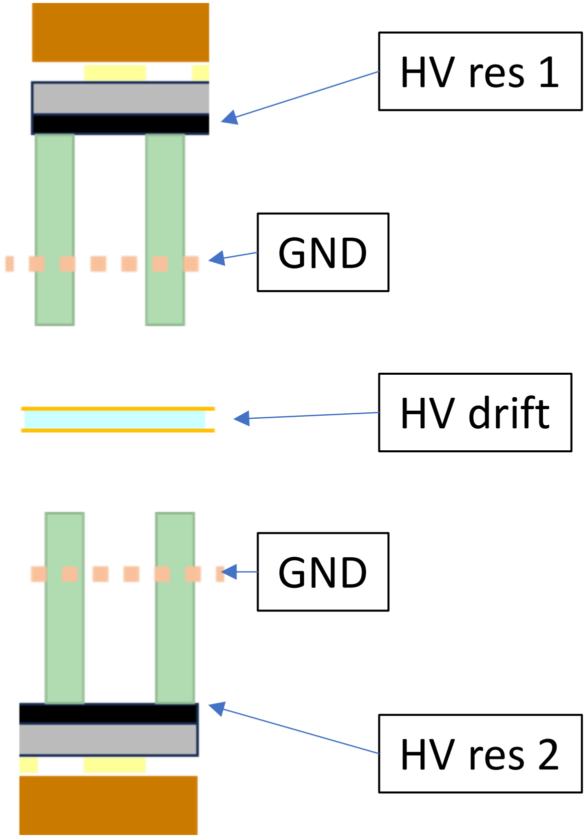
450V resistive layers
325V cathodes planes

resistive UV	~5nA
resistive X	~7nA
drift UV	~1,5nA
drift X	~3nA

We express our gratitude to MPT and GDD labs colleagues and all the community that supports us in the task

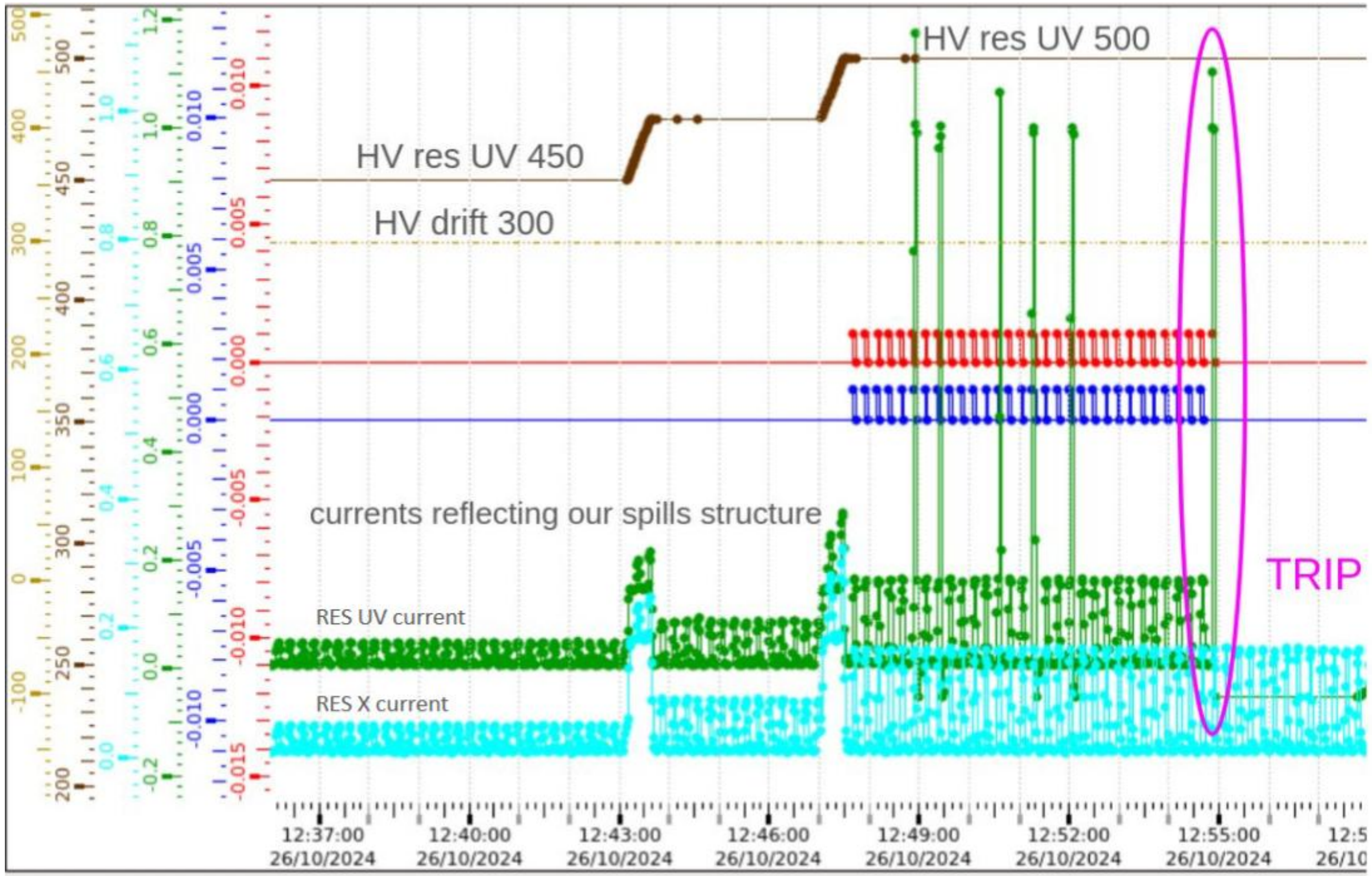
Glimpse of the first operation 1

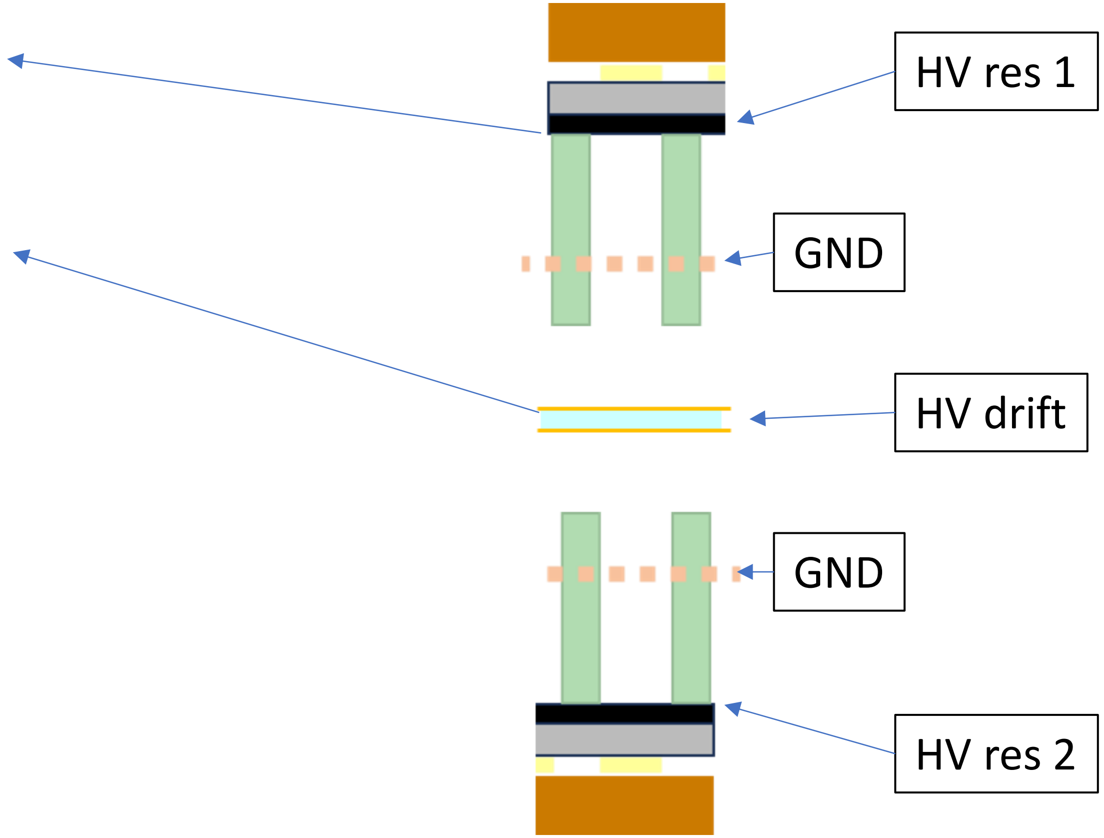




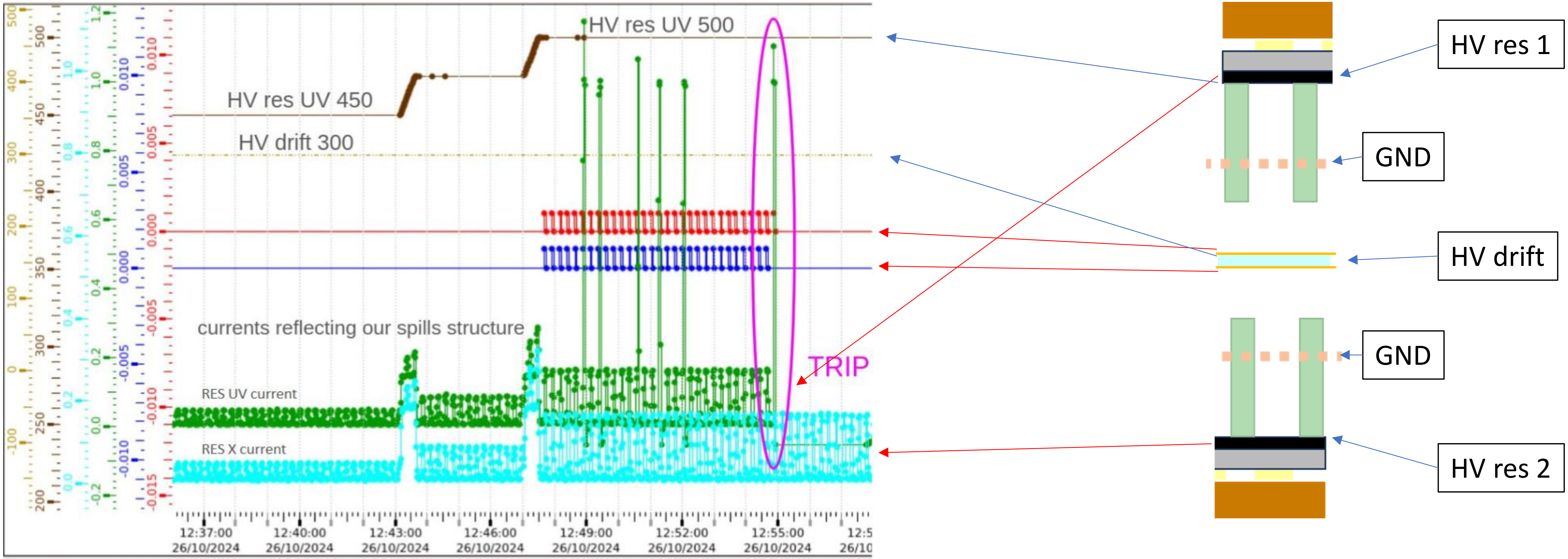
Some trips were observed only in the initial operation period

Glimpse of the first operation 1



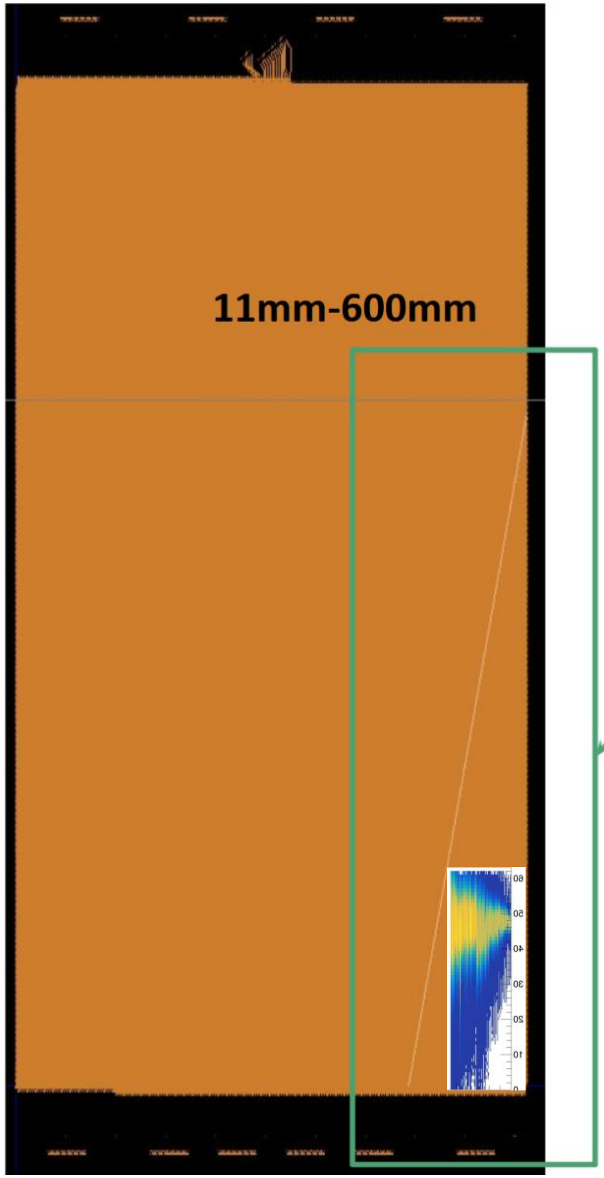


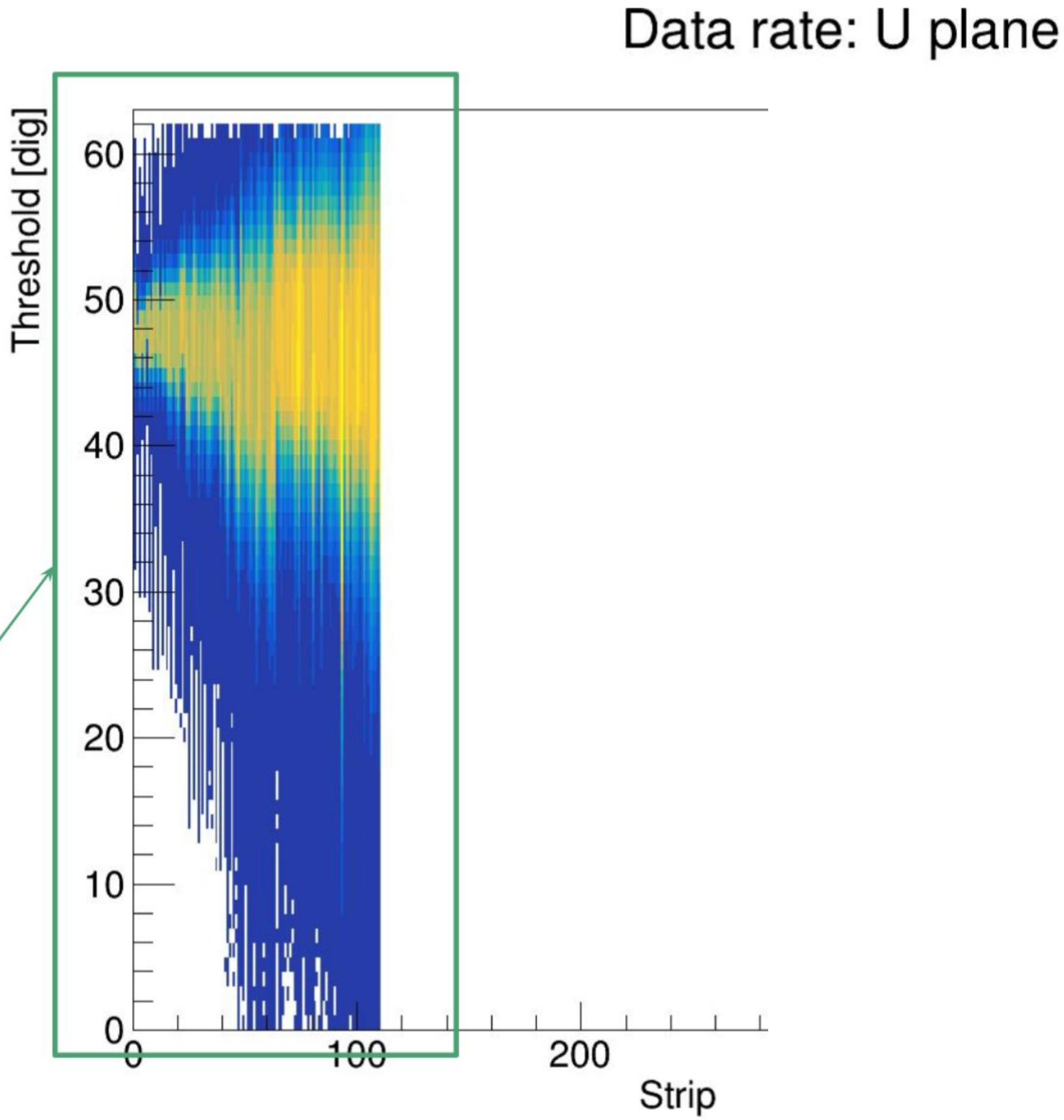
Glimpse of the first operation 1



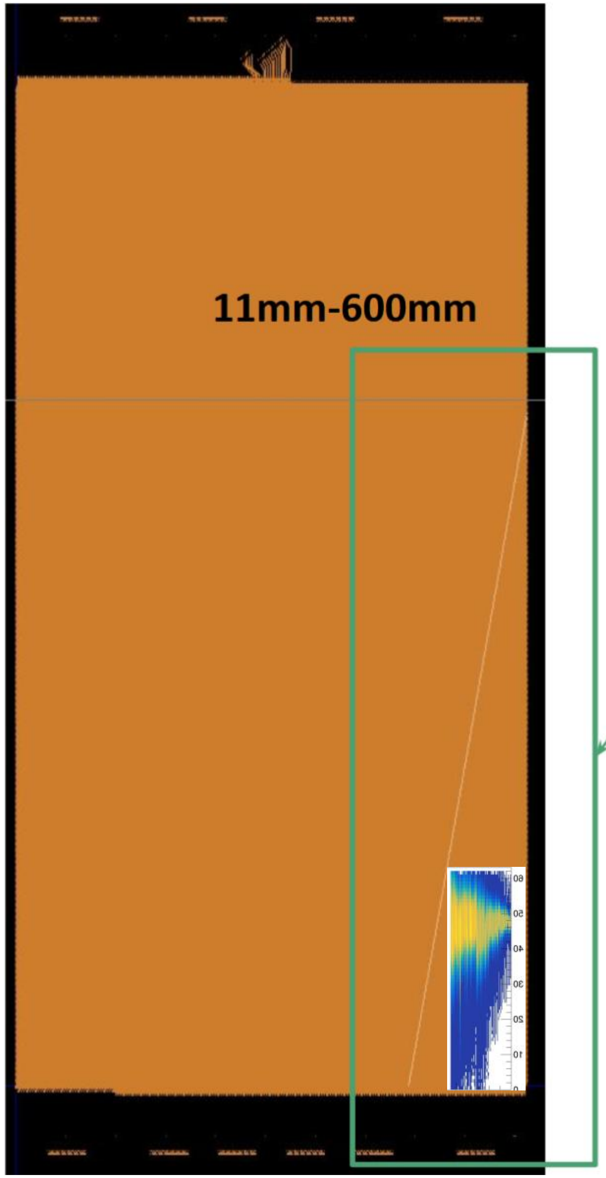
Gas gain was observed as expected

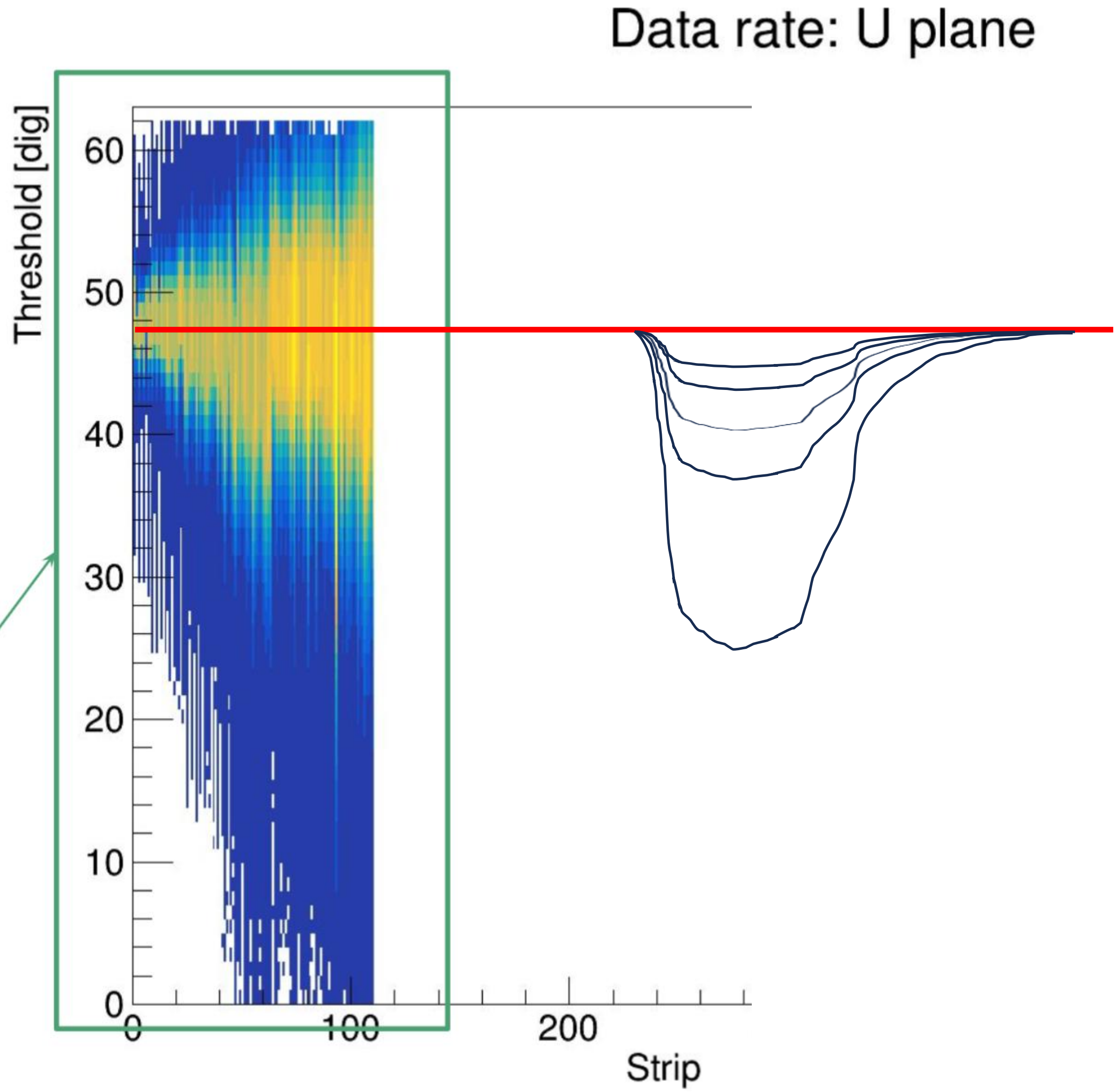
Glimpse of the first operation 2

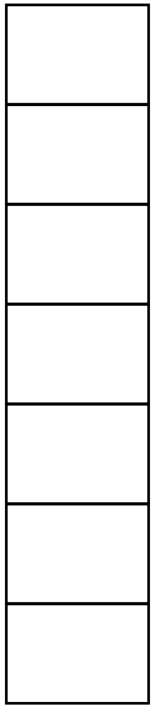




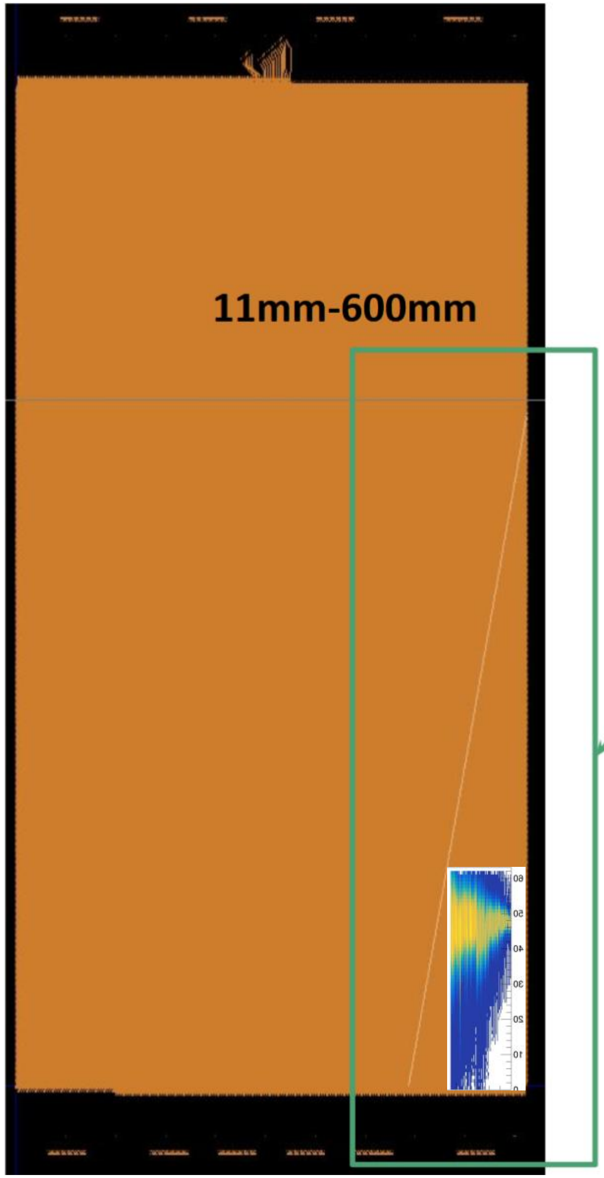
Glimpse of the first operation 2

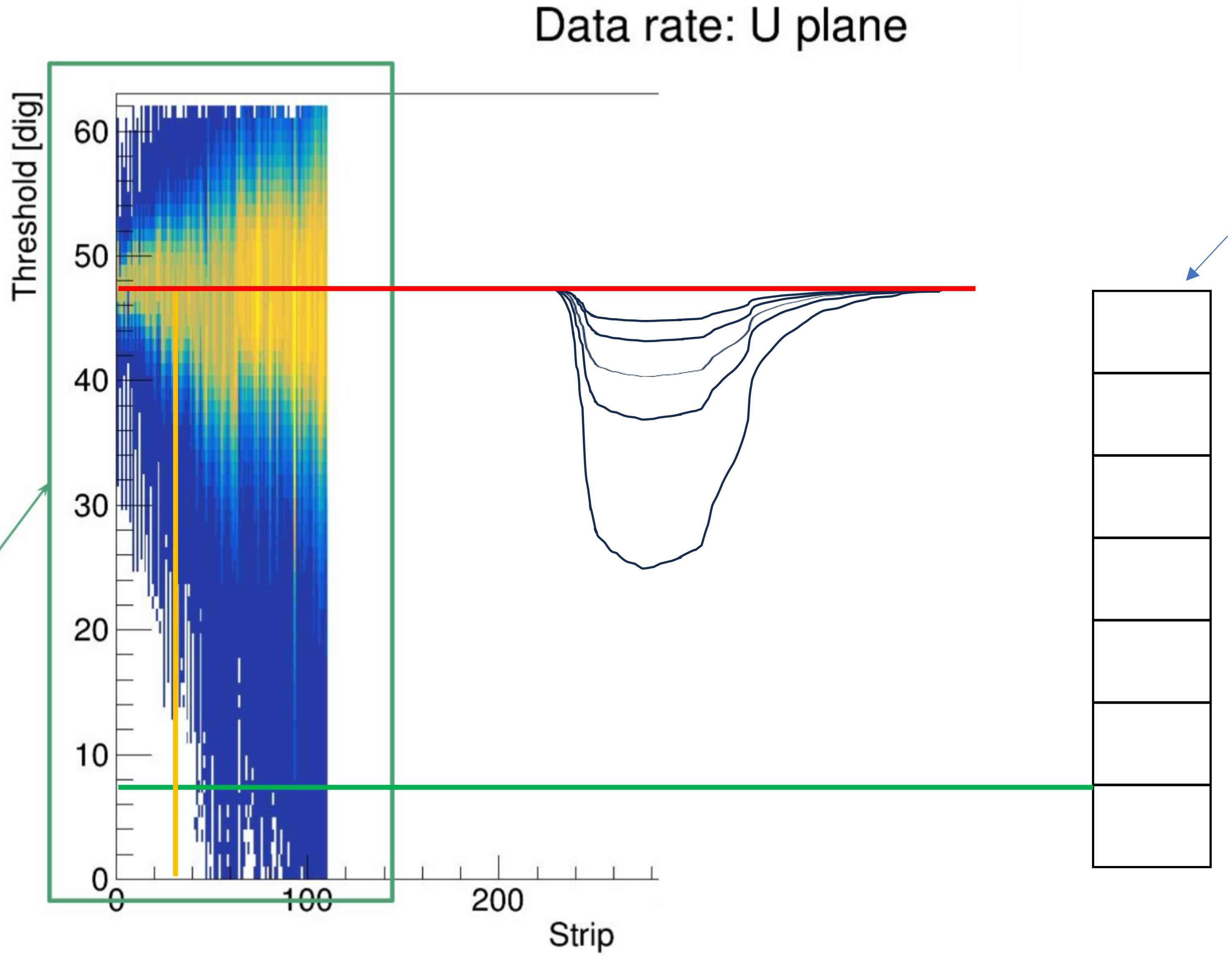






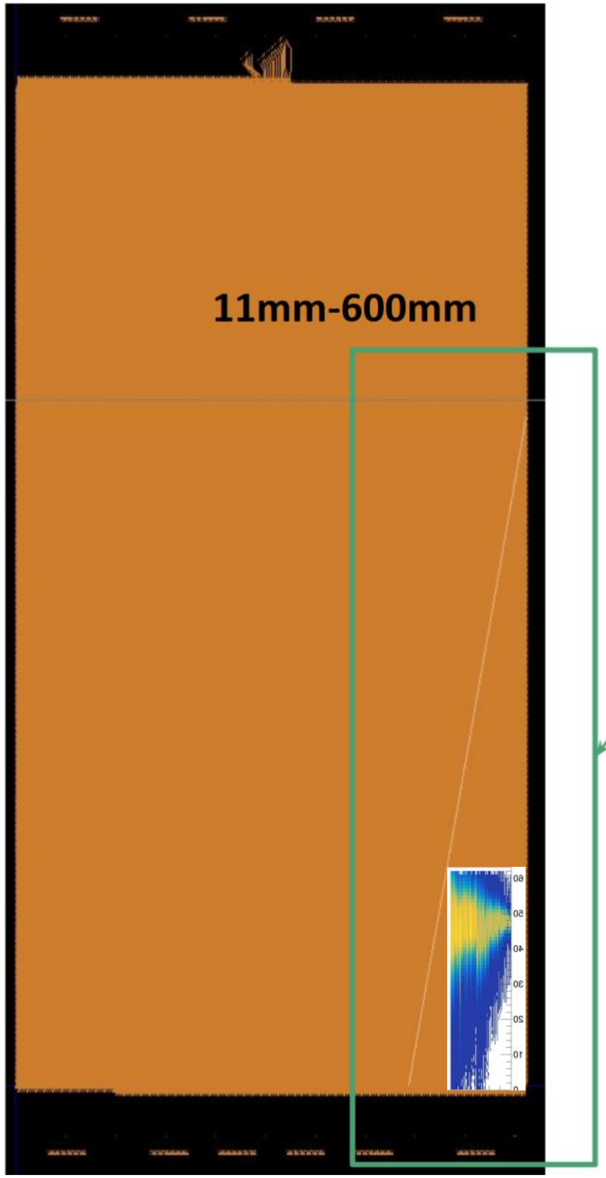
Glimpse of the first operation 2

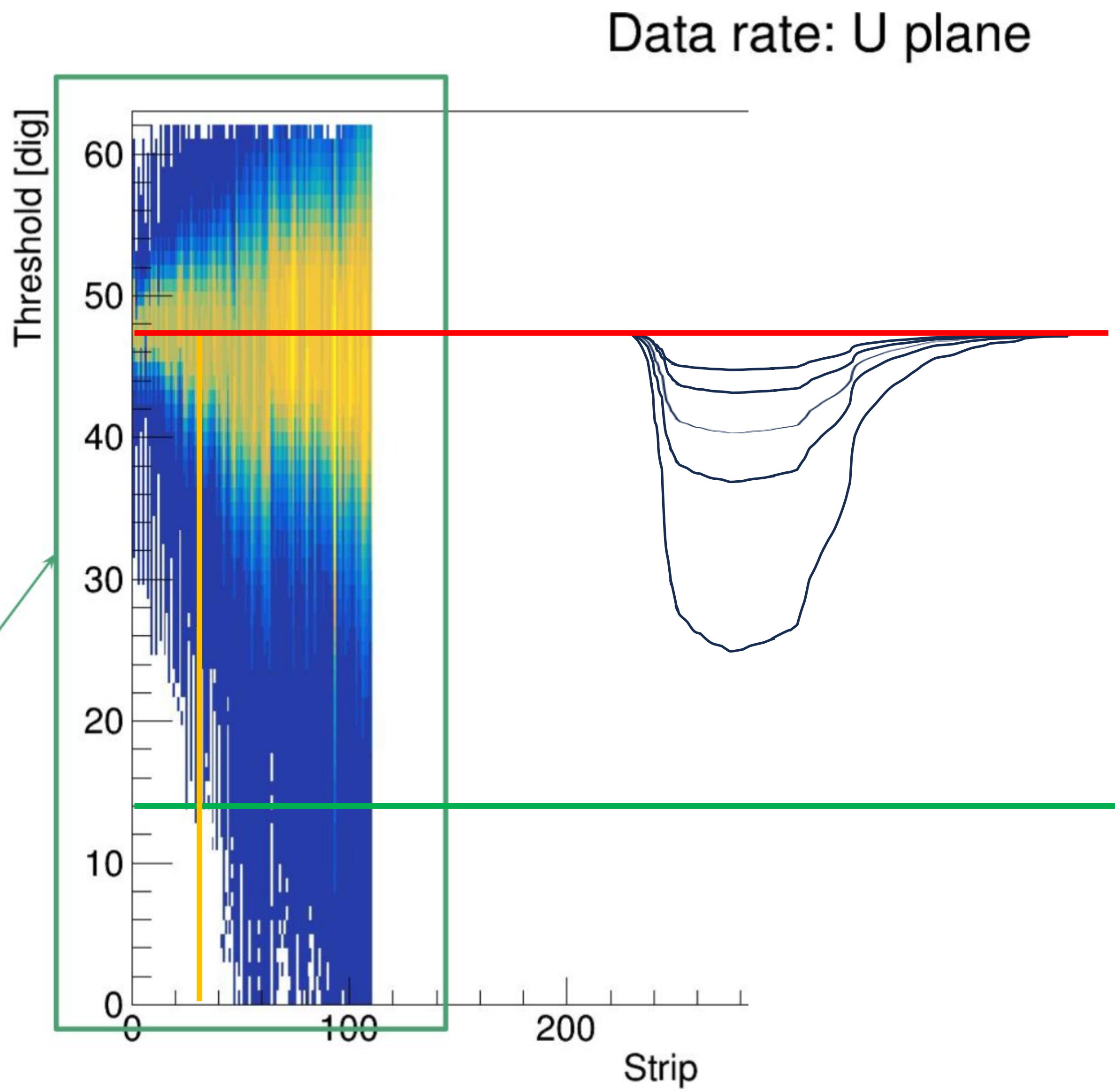




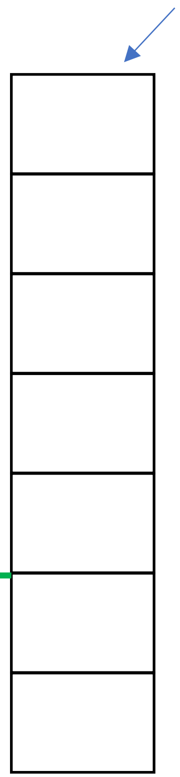
Counts above threshold over a fixed time interval

Glimpse of the first operation 2

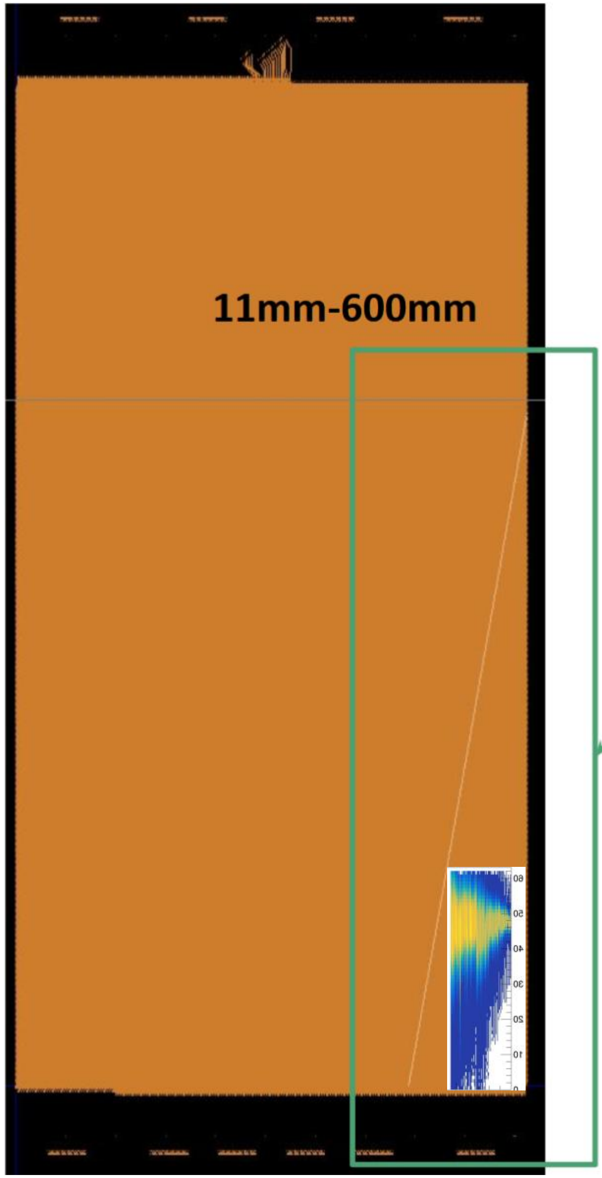


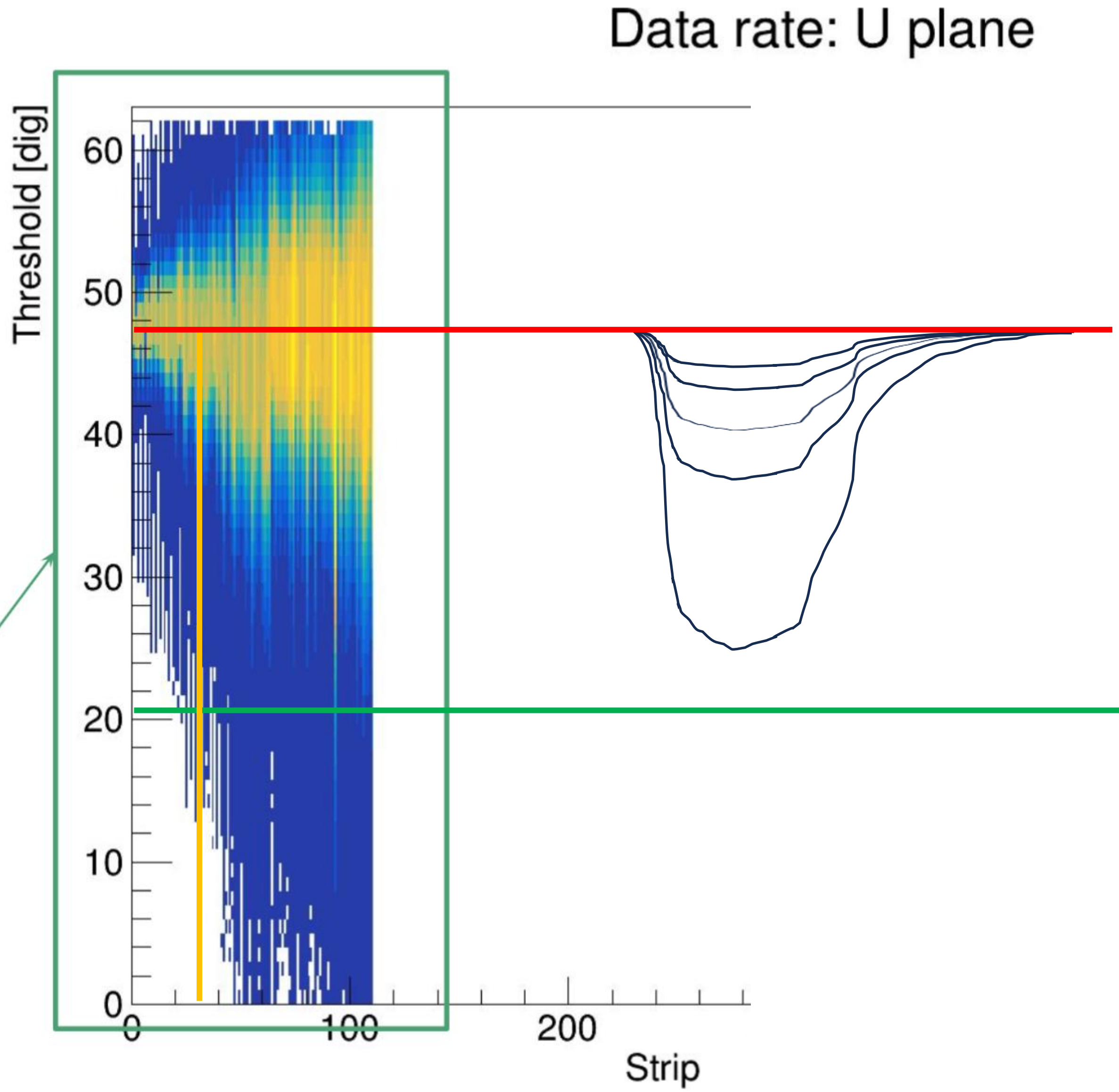


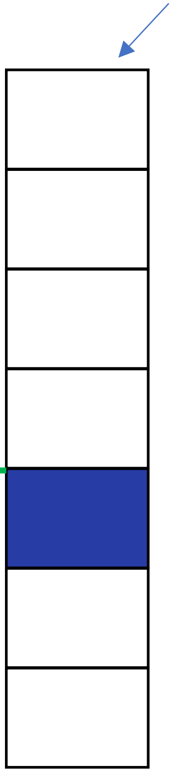
Counts above threshold over a fixed time interval



Glimpse of the first operation 2

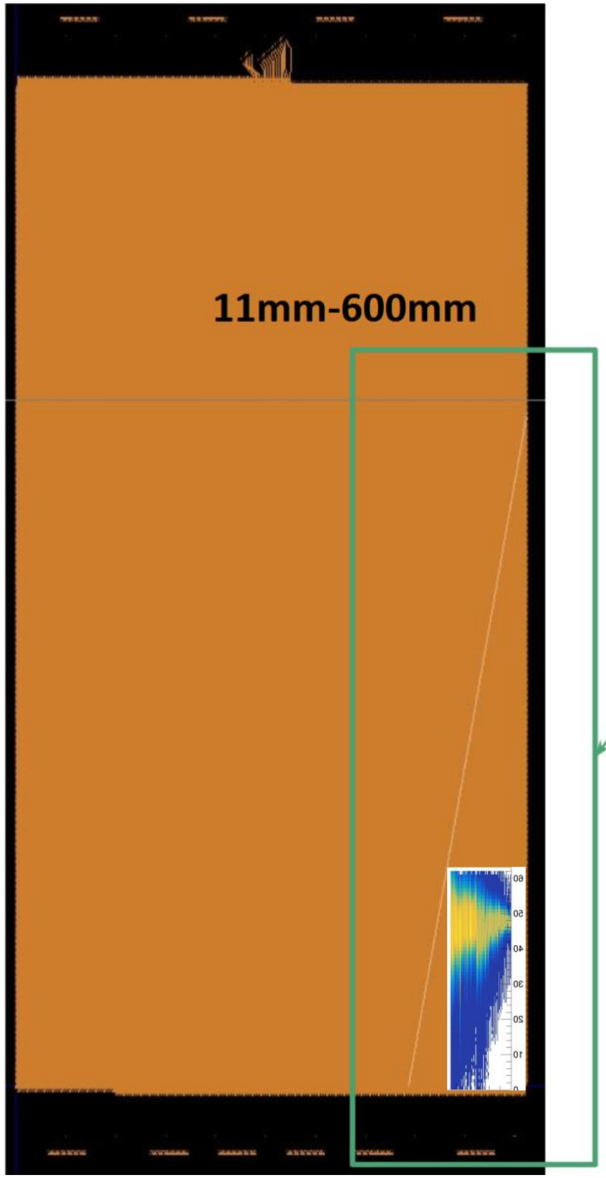


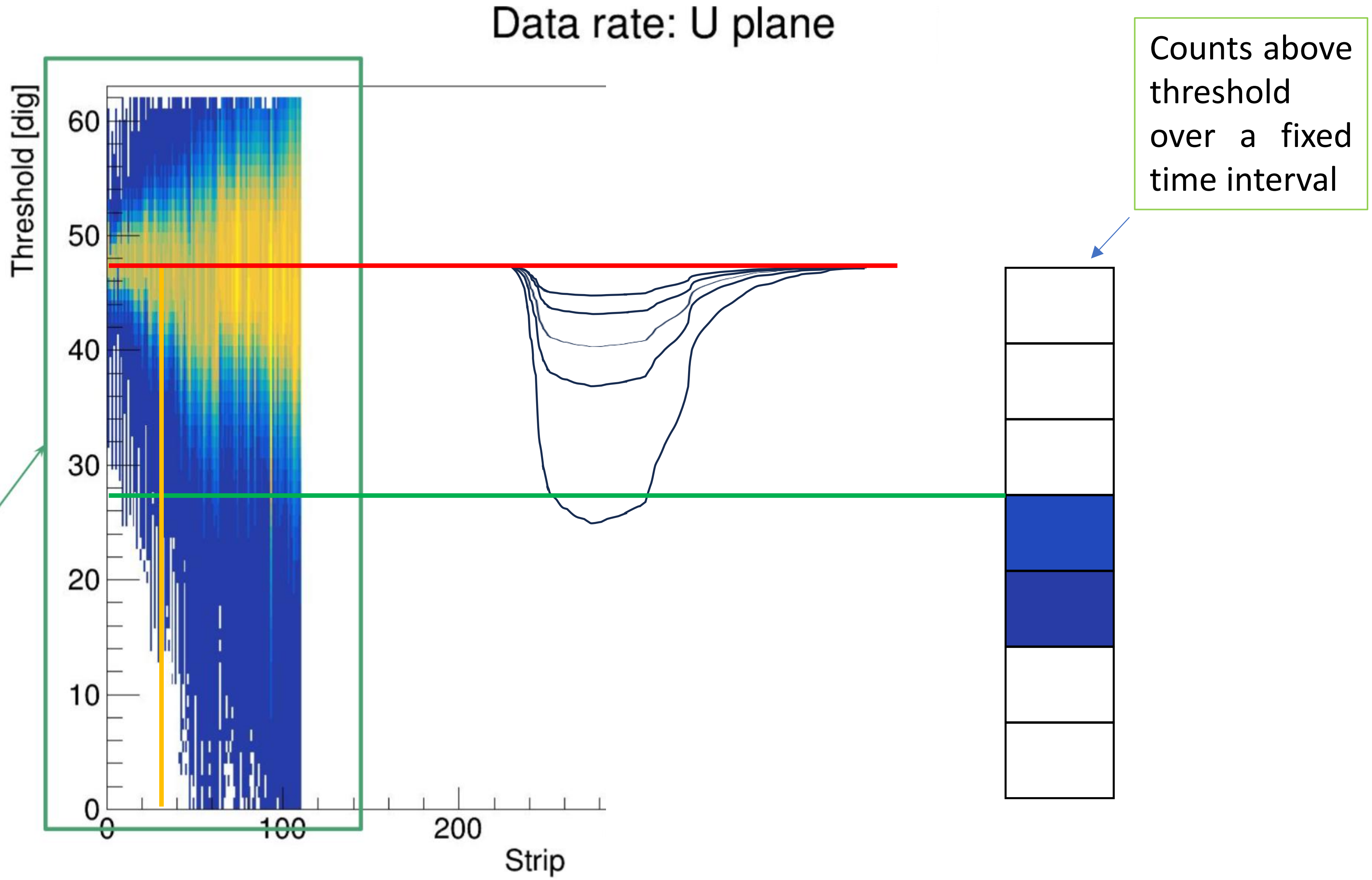




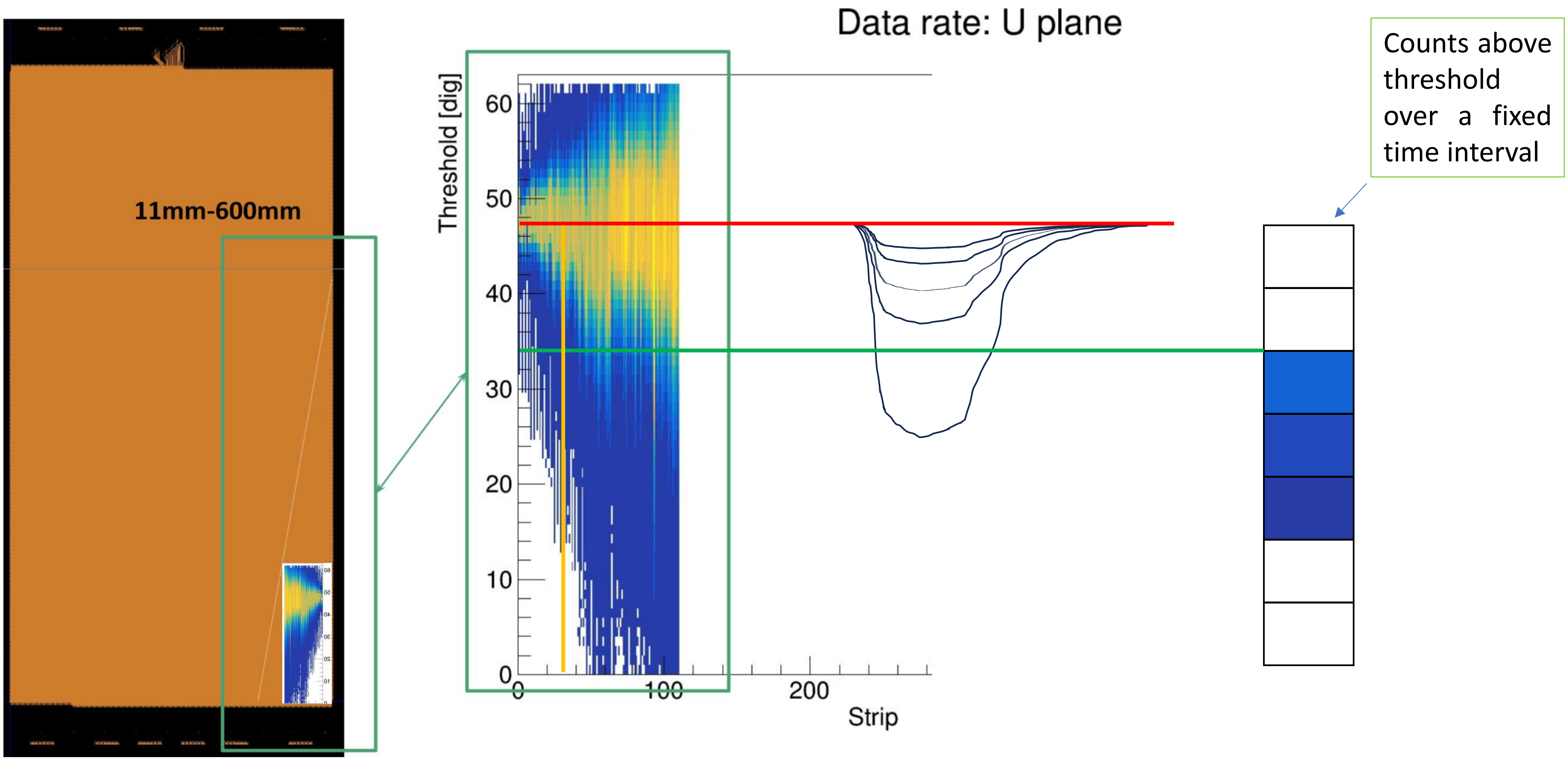
Counts above threshold over a fixed time interval

Glimpse of the first operation 2

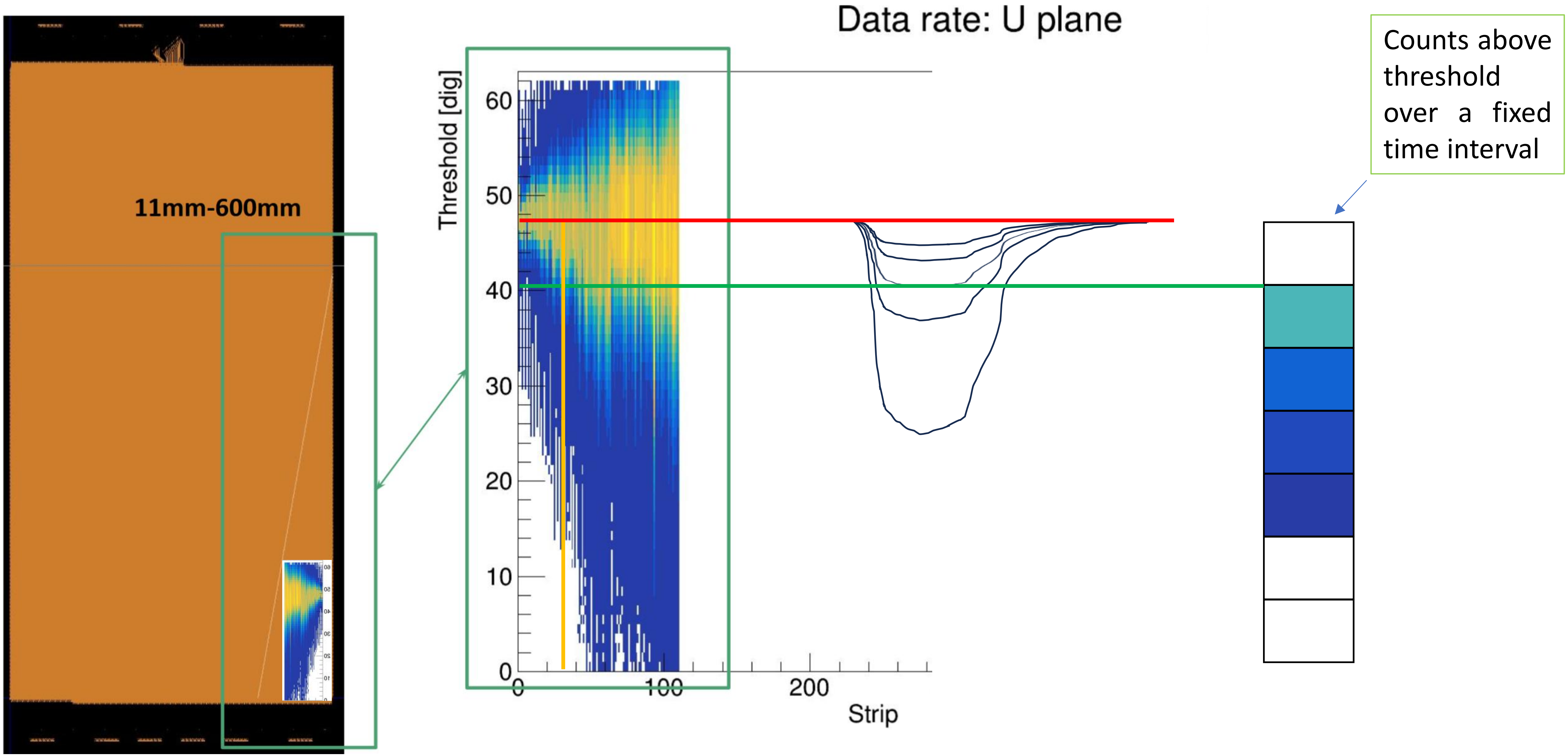




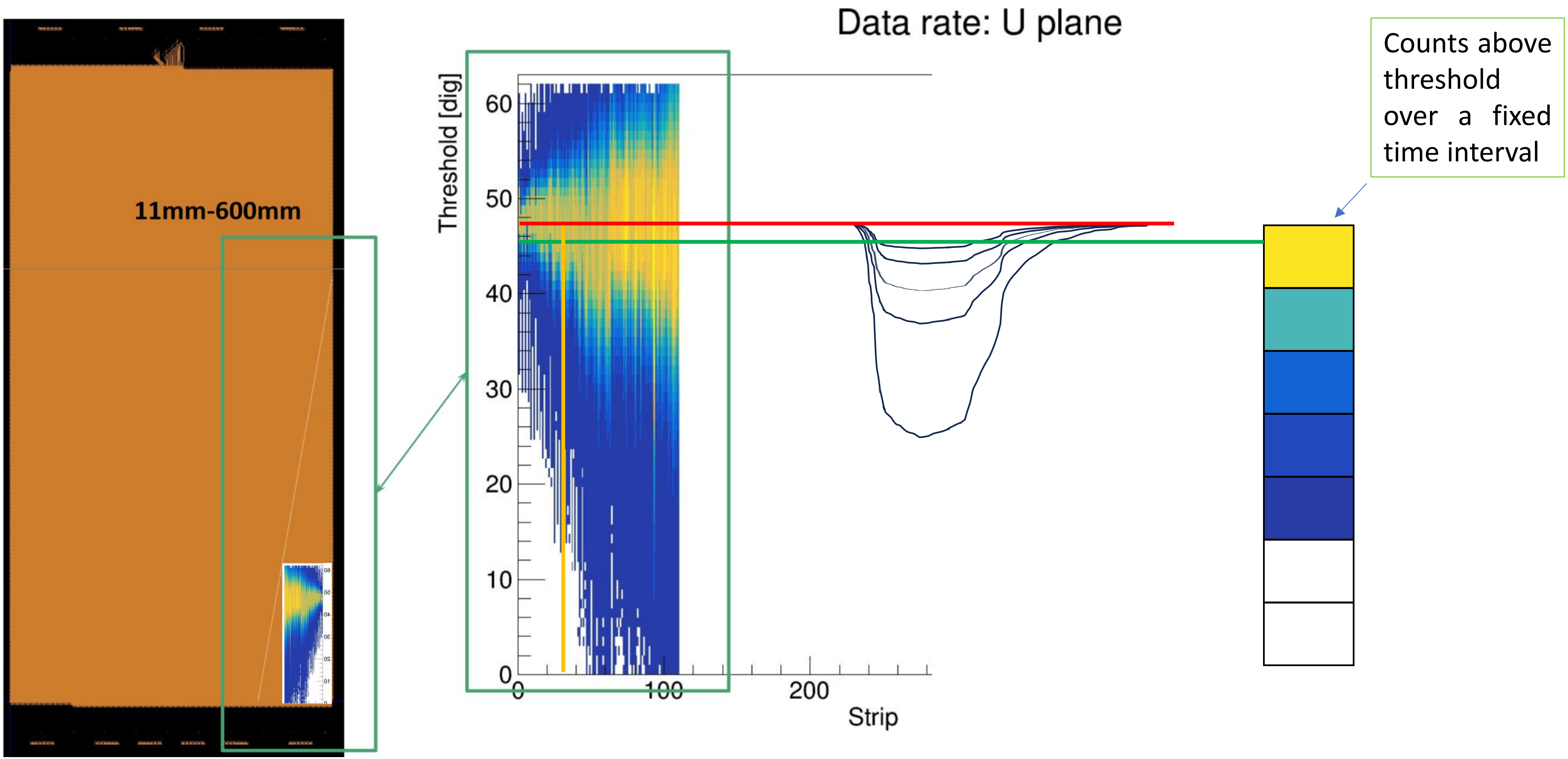
Glimpse of the first operation 2



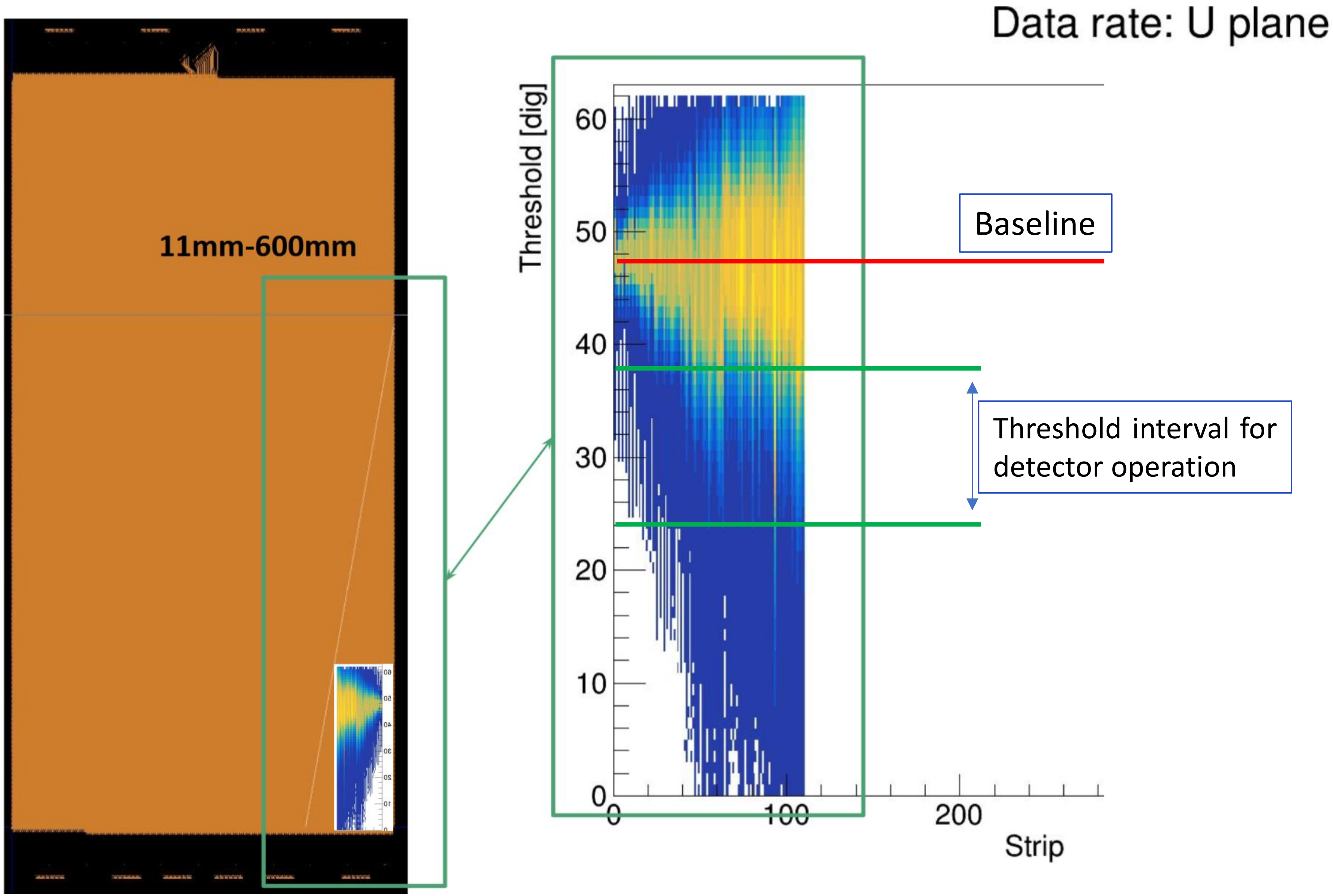
Glimpse of the first operation 2



Glimpse of the first operation 2

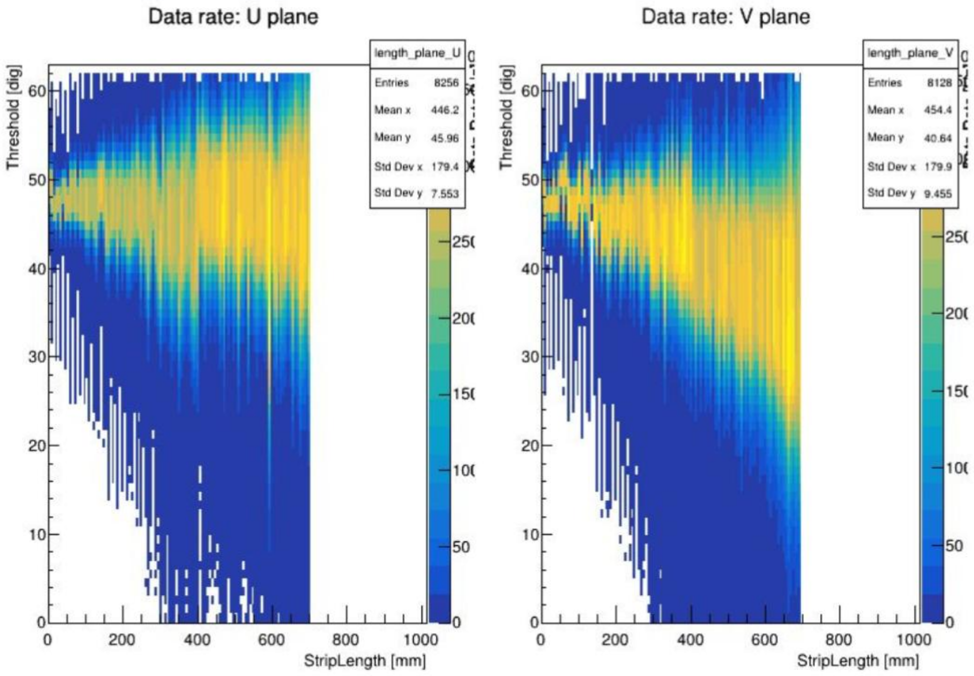


Glimpse of the first operation 3

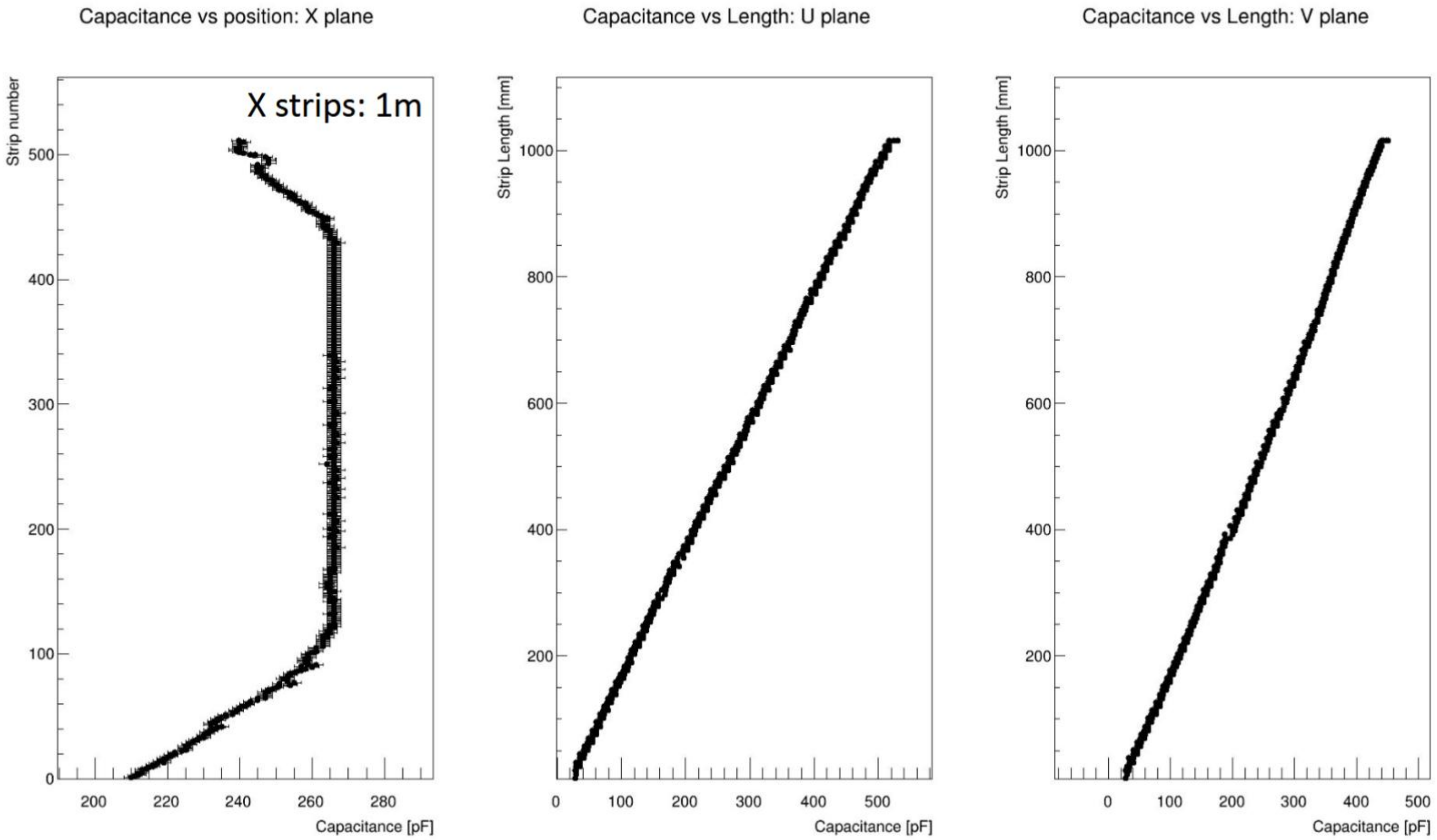


- Data tacking only possible on the short strips
- Unexpected behaviour to be understood and corrected

Glimpse of the first operation 4



Why we see such a behaviour



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

We had to update the ASIC design features

21

Chiara Alice - DRD1 collaboration meeting - 10.12.2024

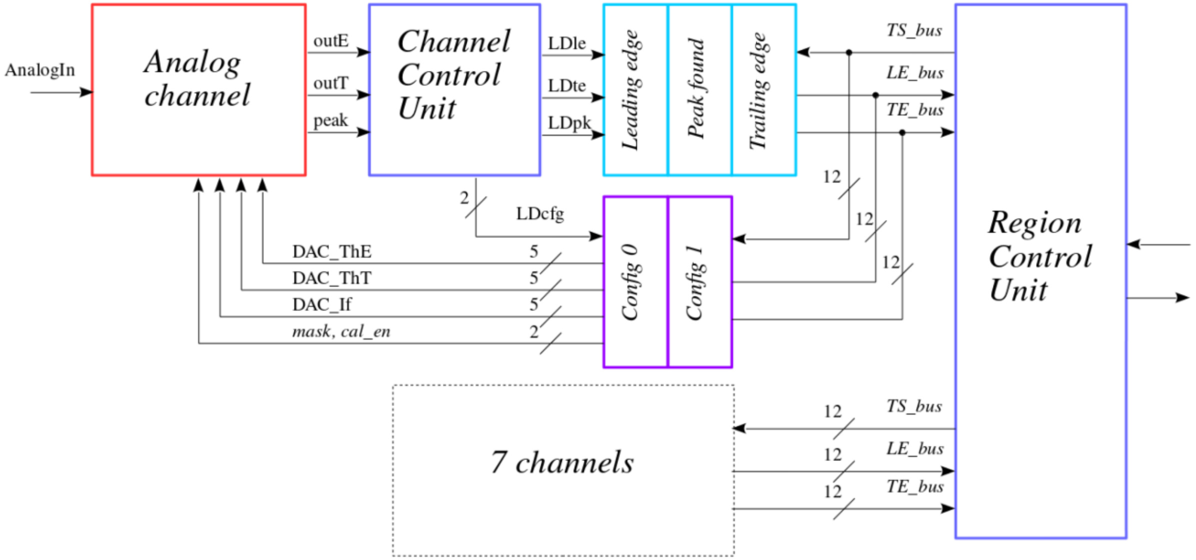
Torino Readout for AMBER (ToRA) ASIC

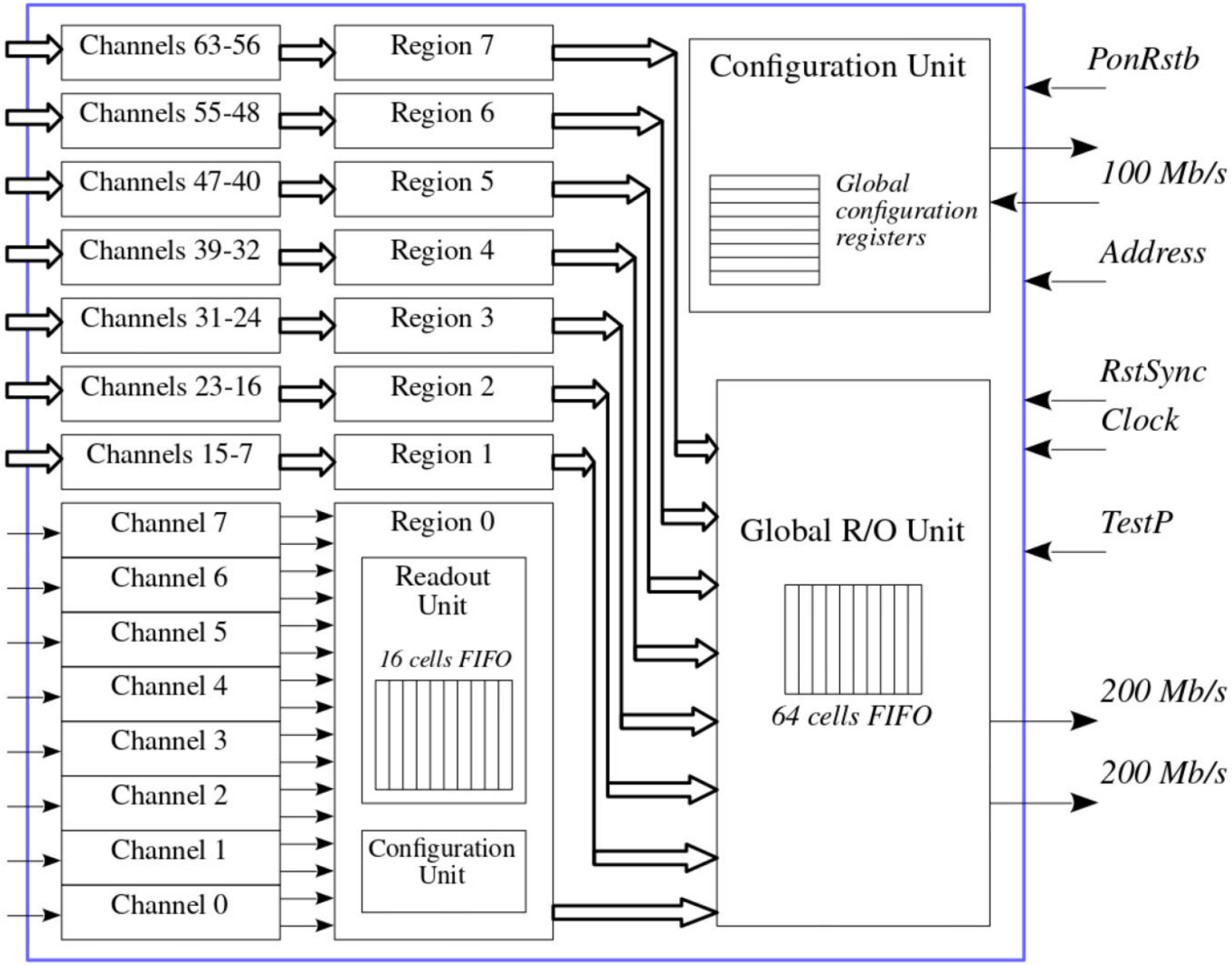
- MPGD and Wire detectors compatible
- Target specific application
- Limited complexity
- Reuse existing solutions
- 65nm
- 2 step design

Detector	MM	Straw	
Channels/ASIC	64	64	
Power/channel	≤5	≤10	mW
Input capacitance	≤550	20-100	pF
Input charge	1-100	1-1000	fC
Input impedance	≤50 Ω	*tbd*	Ω
Max rate	≤2	≤0.18	MHz
Peaking time	150	75-150	ns
Time resolution	1-2	≤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

Channels	64		
Size	4.3×2.6	mm^2	
Power	640	mW	
Supply voltage	1.2	V	
Gain	2,6,9,12	mV/fC	
Peaking time	25,50,150,250	ns	
Main clock	200	MHz	
Time resolution	1.44	ns	r.m.s.
Input polarity	both		

ASIC structure

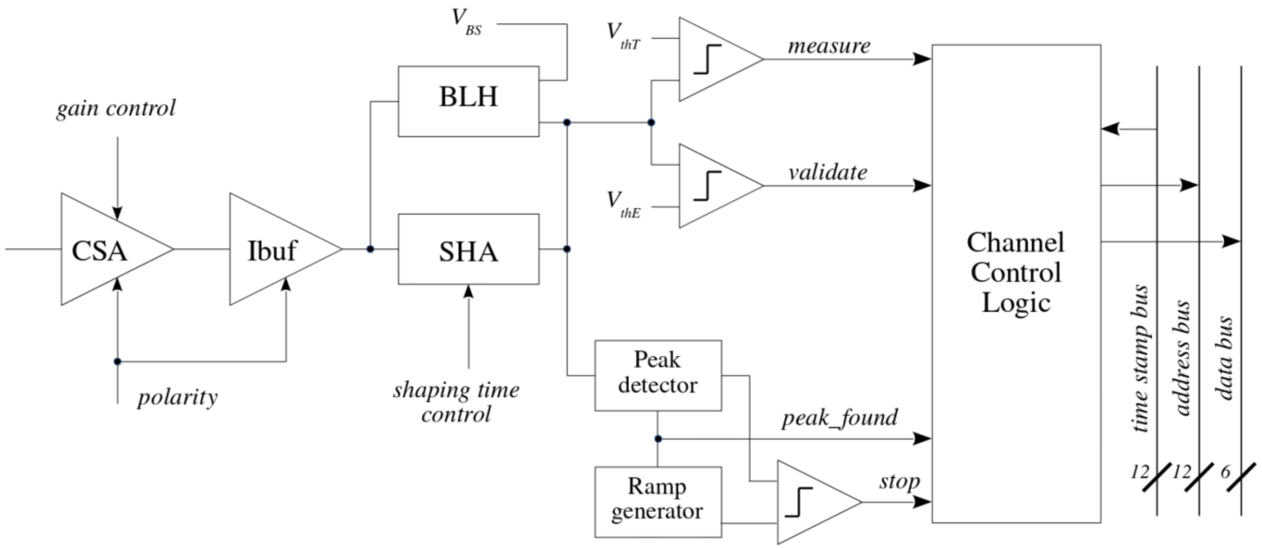


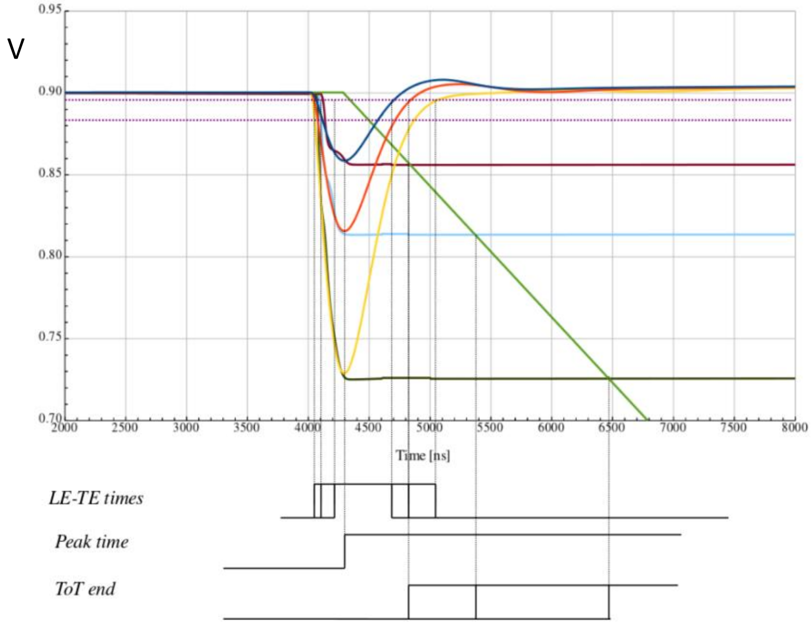


- Common time stamp distributed to all channels
- 3 data registers for time acquisition
- 2 configuration registers
- Threshold and discharge current fine tuning

Analog part (single channel)

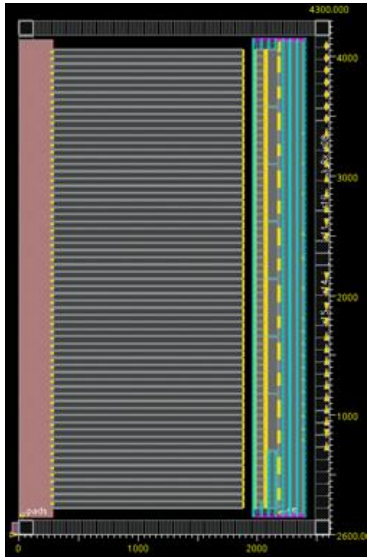
- Charge Sensitive Amplifier
  - Four gains : 2,6,9 and 12 mV/fC
  - Possibility to accept inputs from both polarities
- Shaper
  - 3rd order, one real and two cc poles
  - Programmable peaking time : 25, 50, 150 and 250 ns
- Double threshold signal detection
  - Lower threshold for time measurement, higher threshold for validation
  - Peak detector signal
  - Peak holder for charge measurement (via ToT)
  - Linear ToT measurement

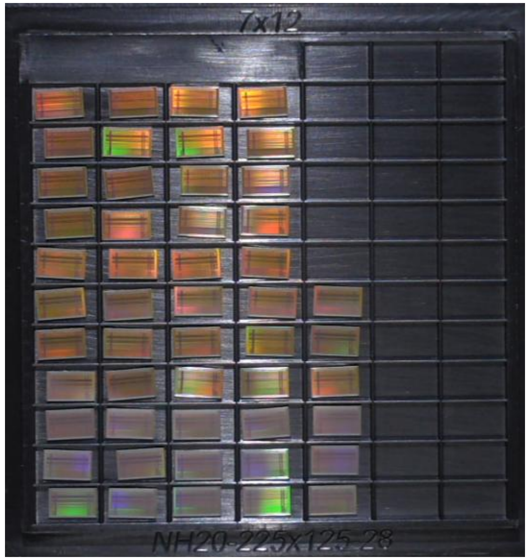


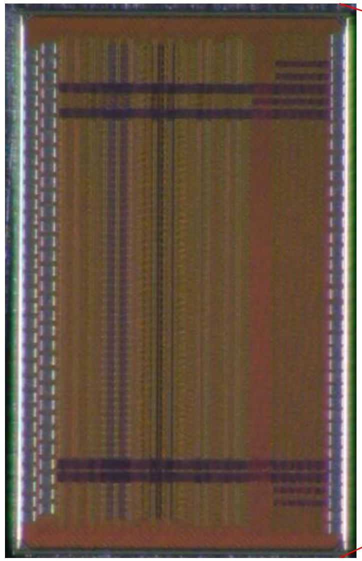


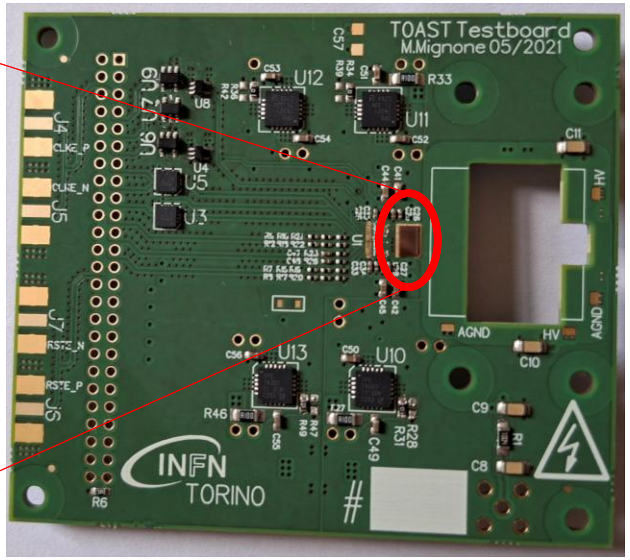
Ongoing work

- ✓ The design of the ToRA_v1 has been completed in 05.2025
- ✓ Delivery of the ASICs from TSMC on 11.09.25
- ✓ Initial inspection in Torino on 15.09.25
- ✓ Bonding of the ToRA_v1 on a test PCB and smoke test passed on 18.09.25



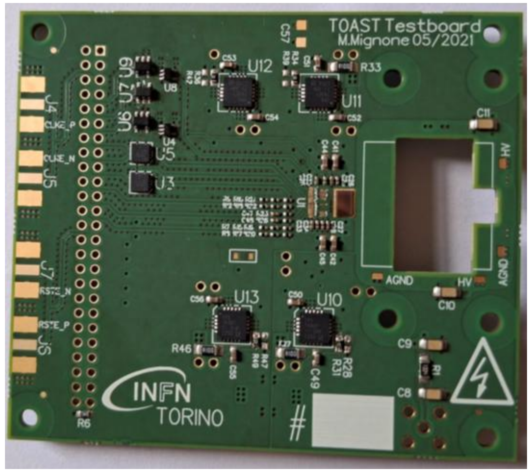




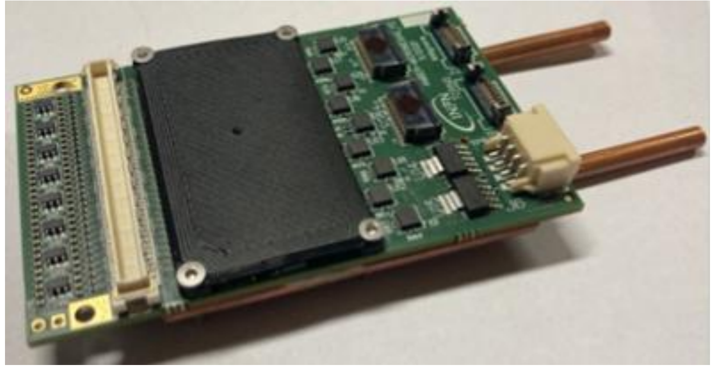


Conclusions

- First successful test operation of the Lateral MM achieved

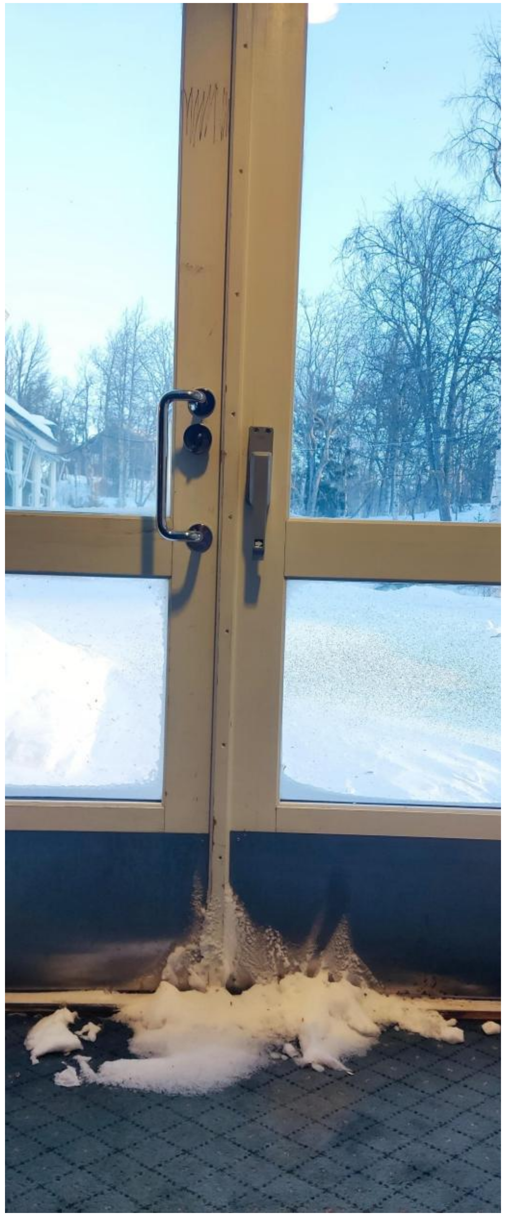


- Detector lab tests are ongoing
- ToRA v1 ASIC design was optimized on the base of first detector tests and the ASIC is being tested in lab conditions



- Test campaign in beam conditions is planned for 11.2025

Spares



Lateral module prototype testing

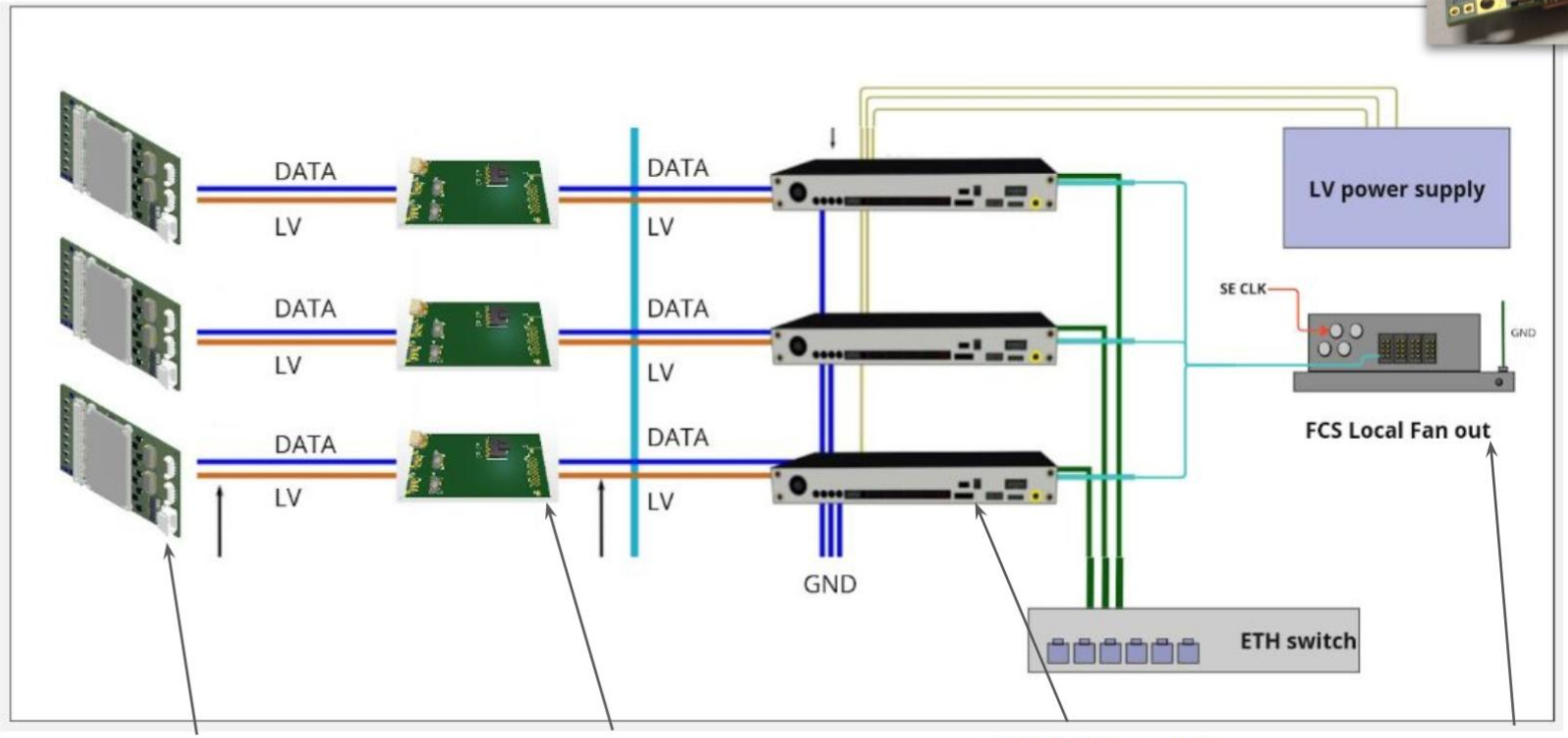
2024

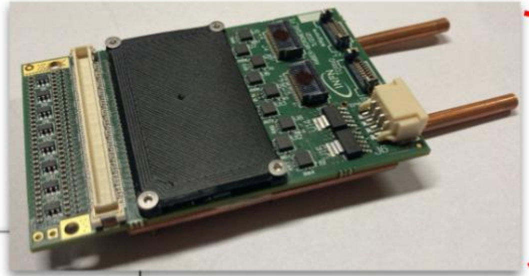
- High Voltage stability
- Noise performance & shielding optimisation
- First data (beam/cosmics)
- Compare $ArCO_2$ (93/7) and $ArCO_2$Iso(93/5/2)

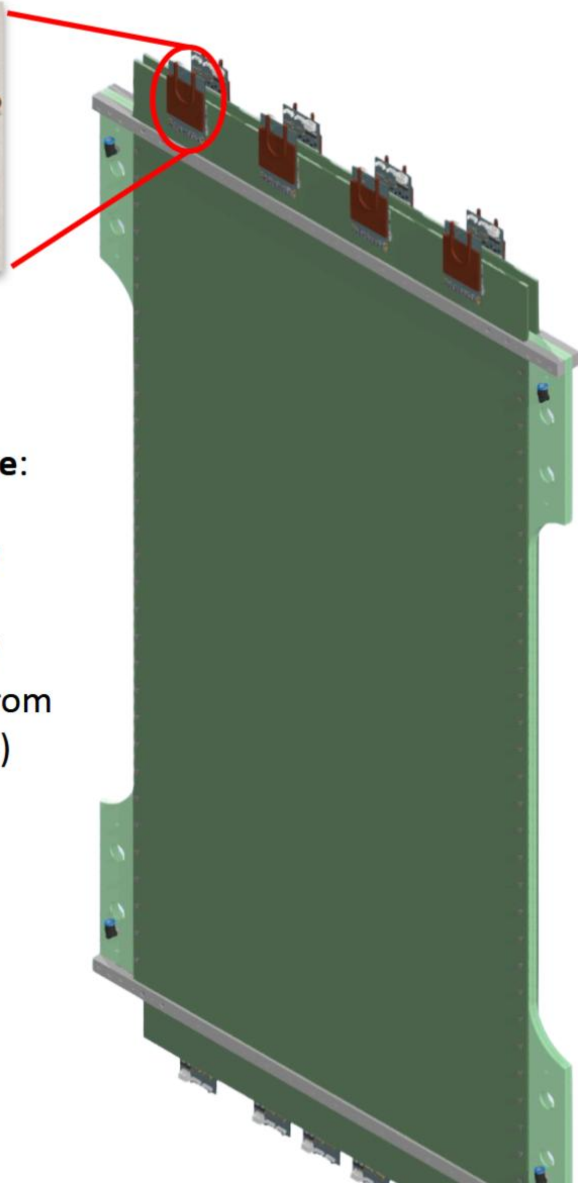
2025

- We will have our parasitic setup in the AMBER spectrometer for the whole beam period
- We need to achieve a stable operation/understand the problems before starting the layout of the Central module
- First test with the ToRA ASIC

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

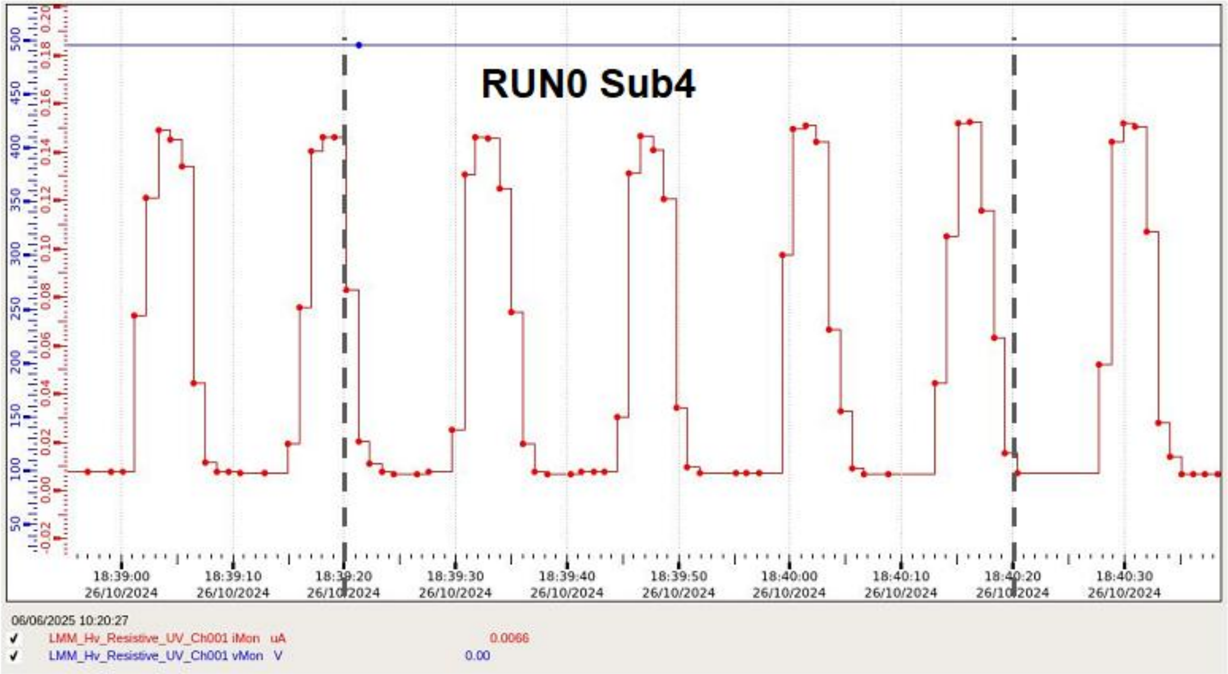
Trigger and clock distribution

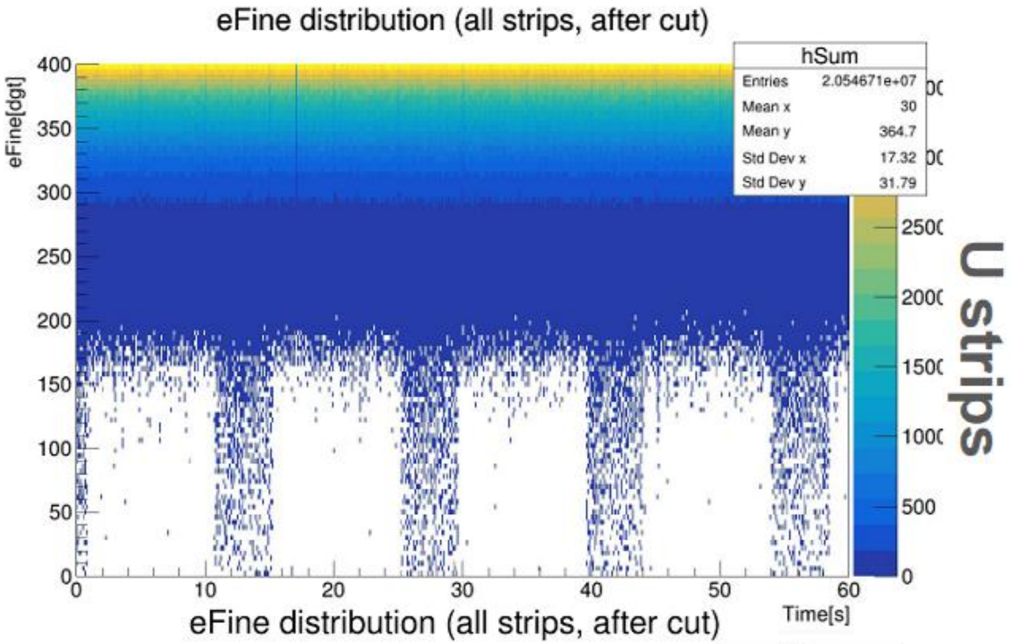
6 TIGER-febs available:

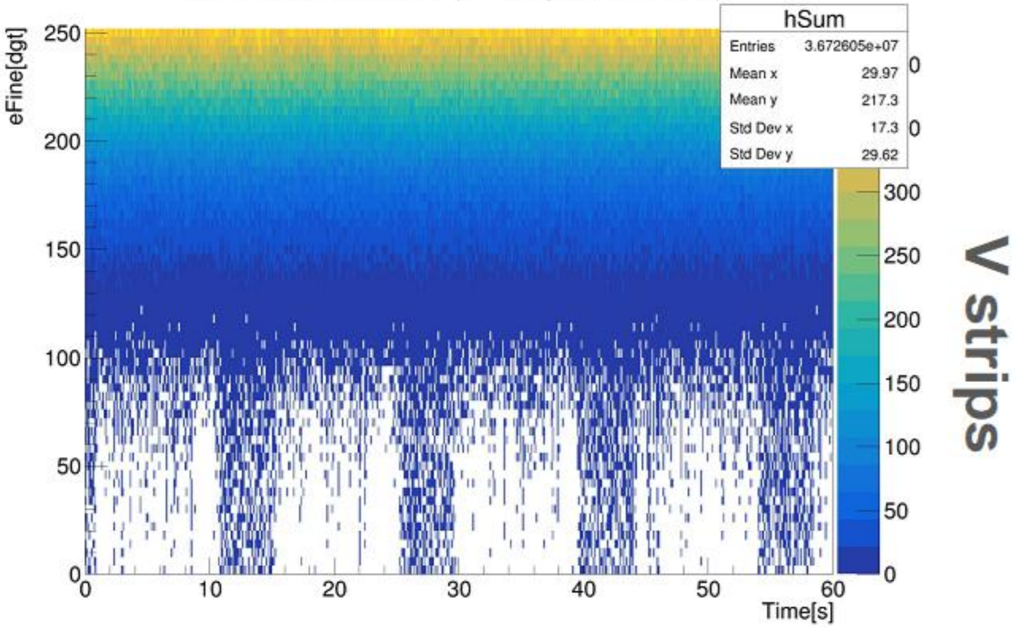
- 768/1280 UV
- 512/512 X+ 256/1280 UV connected (from shorter strips)

Analysis tools: charge distribution

	HV set	450V	475V	480V	490V	493V	495V
GAS mixture	Ar-CO2 93/7	RUN0 Sub0	RUN 0 Sub1	RUN0 Sub2	RUN0 Sub3	RUN1 Sub0	**RUN0 Sub4**
	Ar-CO2-iC 4H10 93/5/2		RUN4 Sub0	RUN5 Sub0	RUN2 Sub0	RUN3 Sub0	







Main ideas

- As simple as needed
- Based on existing design
- Tuned to limited use cases
- Trigger less

Design in 2 steps based on feature set

V1 (2024)	V2 (2025)
Limited flexibility	Implement MPGD+Wire
Power may not be optimised	Power tuning (moderate)
Mostly full backend	Inter channel commutation
Complete single channel structure	Time resolution???

ToRA 2 step design plans

v1(2025-2026)

- Base version aimed at MM (GEM) & STRAW/MWPCs
- Would be sufficient for the AMBER environment
- 4 Gains
- 4 shaping times
- Trigger less
- 1 or 2 revisions depending on performance & testing

v2 (2026-2028)

- Actions on the inter-channel analog architecture
- Minor tuning of the channels & Backend

We have a pipeline for 2 submissions that could be (v1_a,v1_b) or (v1_a,v2_a) depending on the v1_a performance

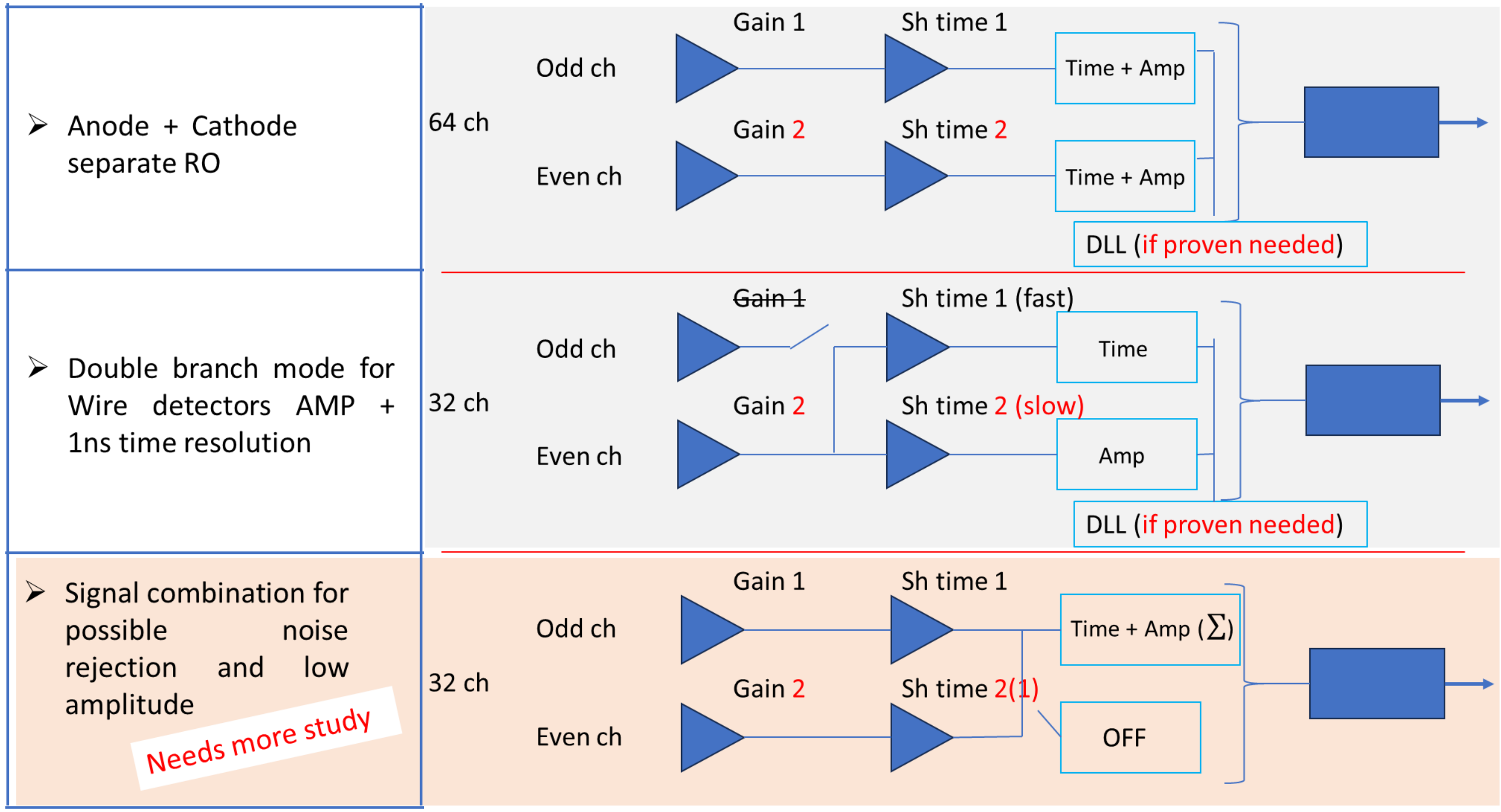
V1, Back-end & data link

- Data output in 32 bits or 64 bits words over 200 Mb/s serial links
- It can be configured to use 1 or 2 links
- Frame length is of 20.48 μs at 200 MHz
- Data within a frame are packed within a frame header and a frame trailer
- Frame header contains chip id and frame number
- Frame trailers contains the number of valid samples and CRC

Packet type	Header *2 bit*	Data *30 bits*			
Data word 0	10	Region[2:0]	Channel[2:0]	Le[11:0]	Te[11:0]
Data word 1	11	Region[2:0]	Channel[2:0]	Pk[11:0]	ToT[11:0]
Header	01	01	*Reserved[12:0]*	ChipId[6:0]	FrameN[7:0]
Trailer	01	10	DataCnt[11:0]		CRC[15:0]
Sync	00	00	1100 1100 1100	1100 1100 1100	1111

V2 (2026-2028)

- Odd/even channel individual configuration
- Odd/even channels interconnections



- If better time resolution is needed
  - Channel or region-level 8-tap delay line
  - Delay controlled by a global DLL
  - Time resolution 180 ps r.m.s.