Design and testing of a new large area Micromegas detector for AMBER experiment at CERN

AMBER
Apparatus for Meson and Baryon Experimental Research

M. Alexeev on behalf of the design working group

Università di Torino & INFN Torino

INFN SEZIONE DI TORINO
ISTITUTO NAZIONALE DI FISICA NUCLEARE

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

2018: Letter of Intent
arXiv:1808.00848

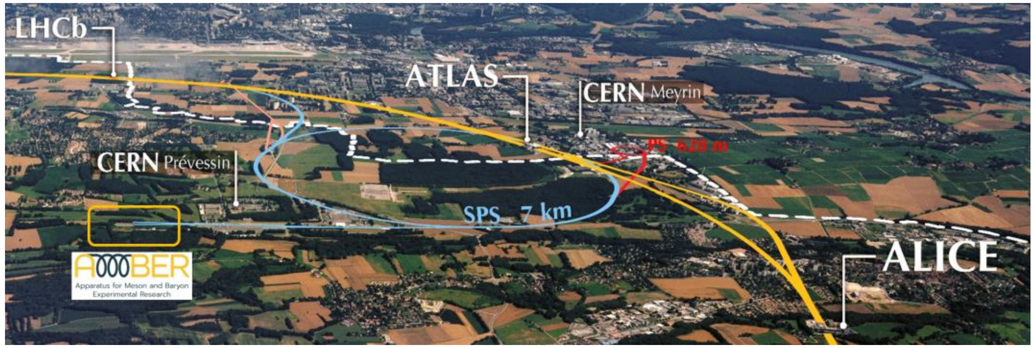
2019: Formation of a Proto-Collaboration

2019: AMBER Phase–1 Proposal
CERN-SPSC-2019-02

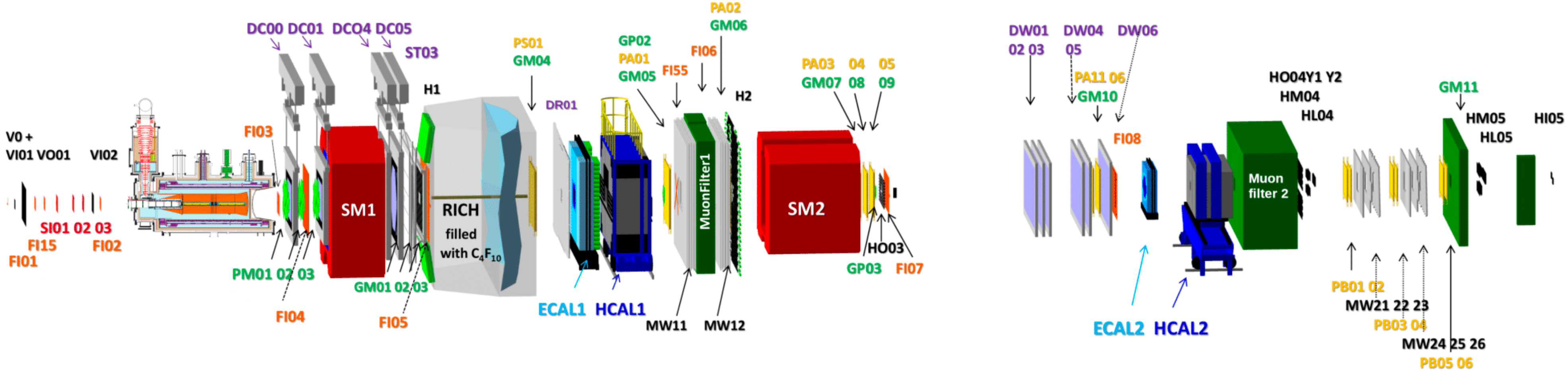
2020: Recommendation of the Proposal by SPSC and approval by Research Board

2021,2022: AMBER Pilot Run

2023: Start of AMBER data taking

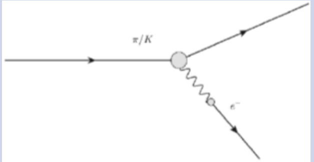


Phase-2 proposal in preparation
Post LS4 ->



Presently 32 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 – 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		

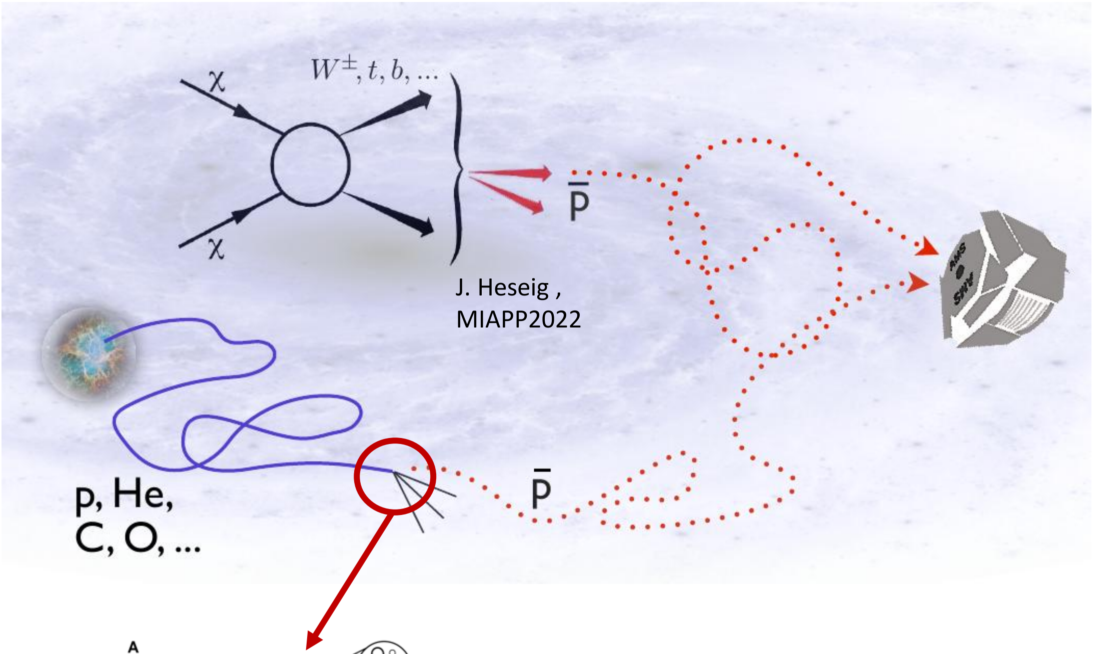
Phase 1 (approved)

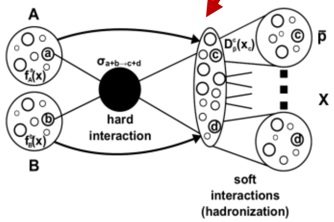
2023 -> 2032

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.

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

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

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

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

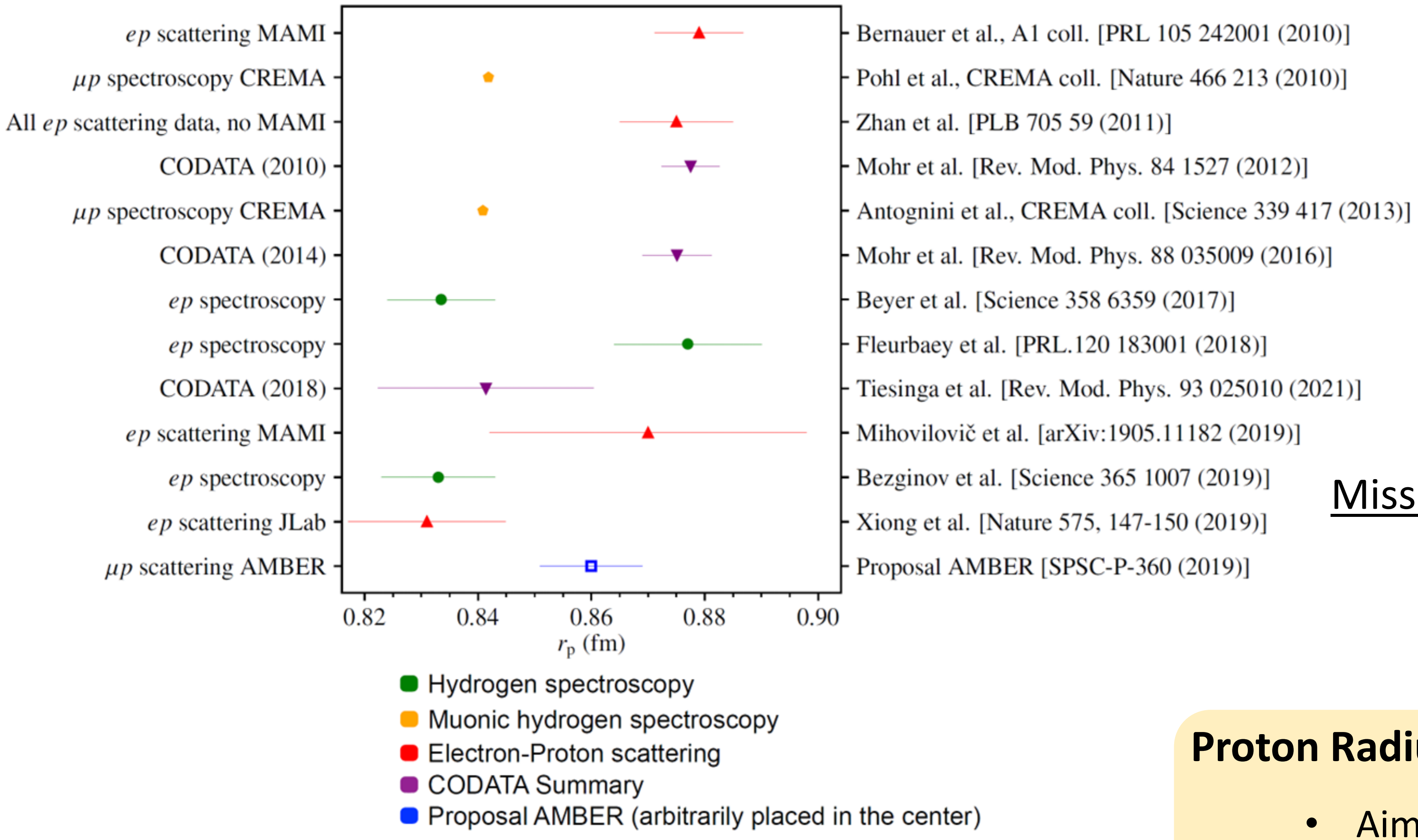
Minimum bias trigger: beam trigger with veto on non-scattered beam particle

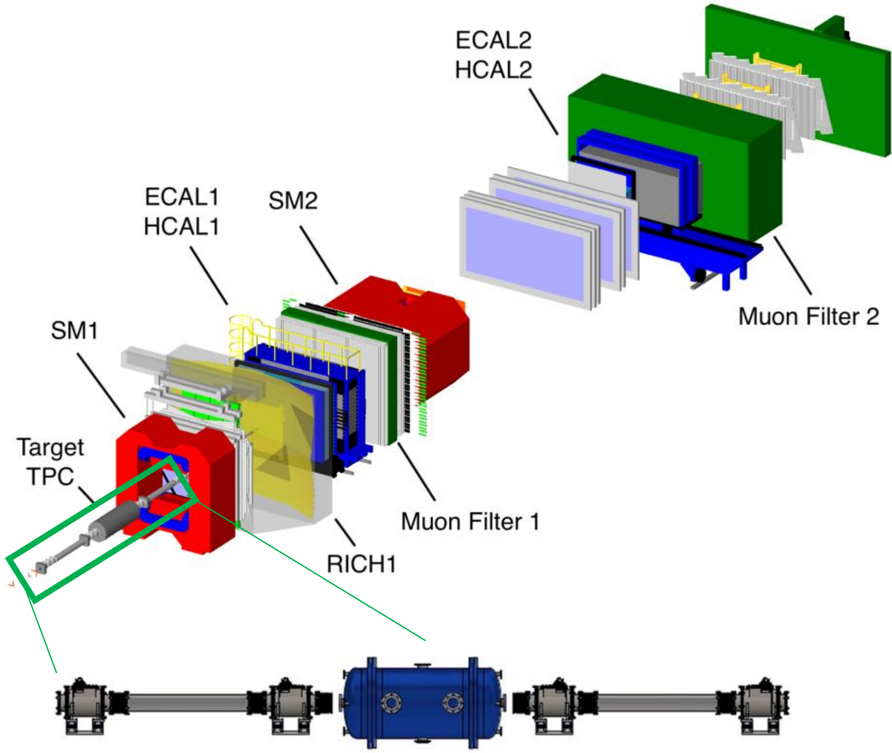
The major uncertainties in the current antiproton flux interpretation stem from the poor knowledge of the antiproton production from prompt reactions (mainly p+p and p+He) and from antineutron decays.

<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





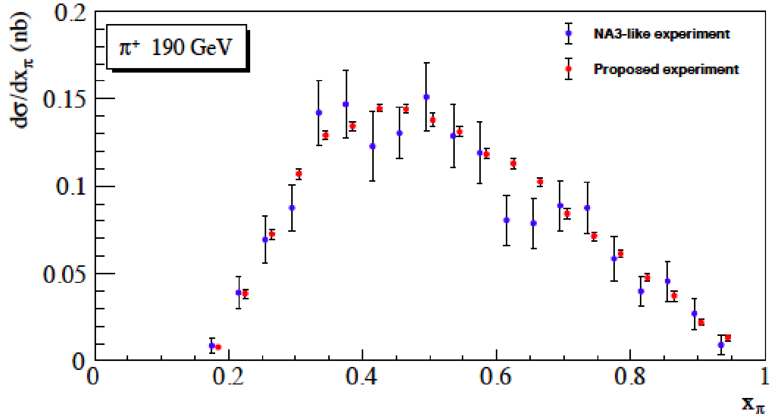
Missing: muon-proton with E_{μ} of 10 - 100 GeV

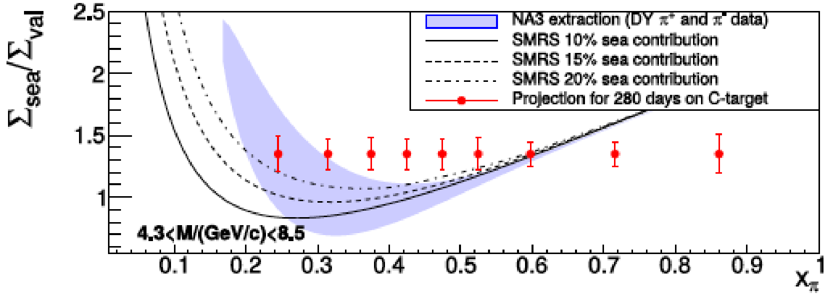
- Test of lepton universality
- Different systematics compared to others

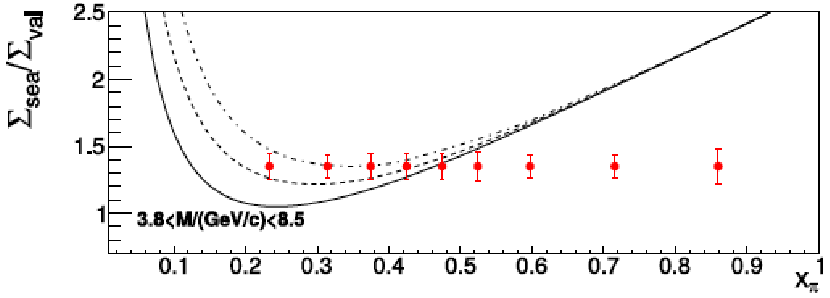
Proton Radius Measurement @ AMBER

- 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

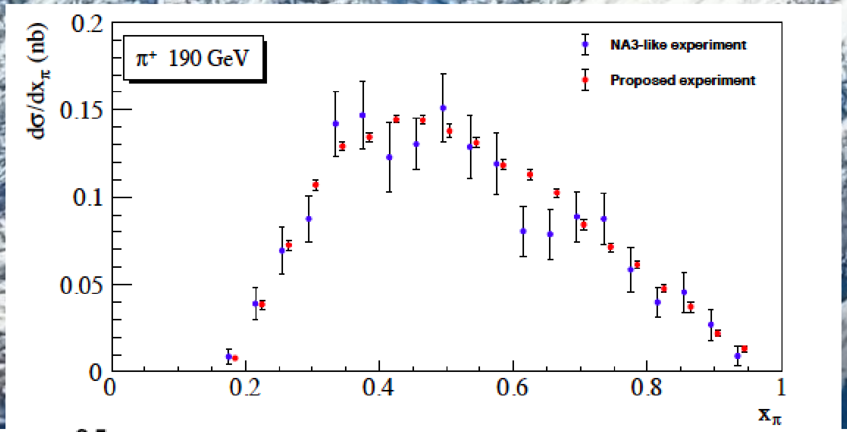
- $\Sigma_V = \sigma^{\pi^- C} - \sigma^{\pi^+ C}$: only valence-valence
- $\Sigma_S = 4\sigma^{\pi^+ C} - \sigma^{\pi^- C}$: no valence-valence
- Collect at least a **factor 10 more statistics** than presently available
- Minimize nuclear effects on target side
  - Projection for 2×140 days of Drell-Yan 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

AMBER DY (post LS3)



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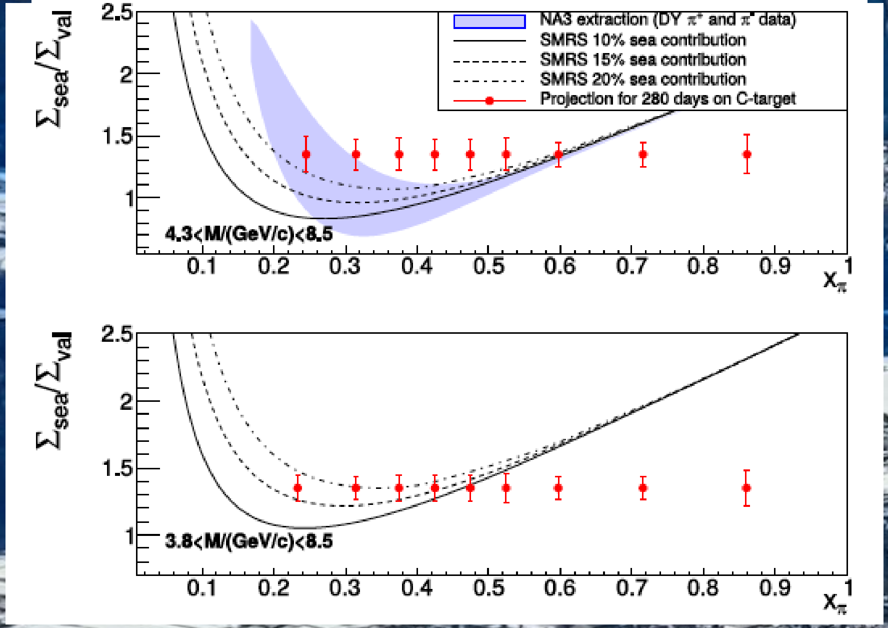

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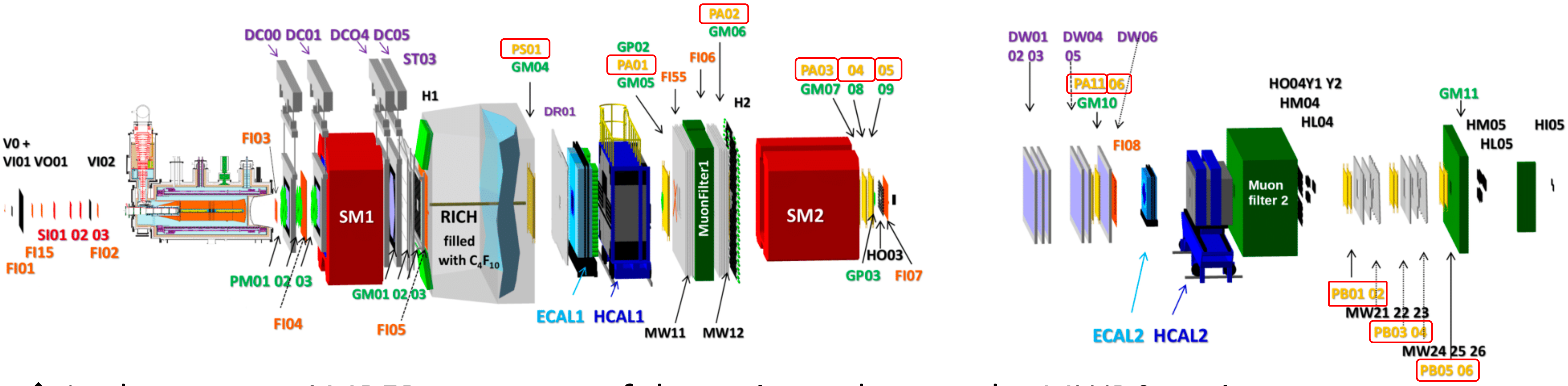
Isoscalar target + *Both positive and negative beams* + *High statistics*

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

https://indico.cern.ch/event/1459380/

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

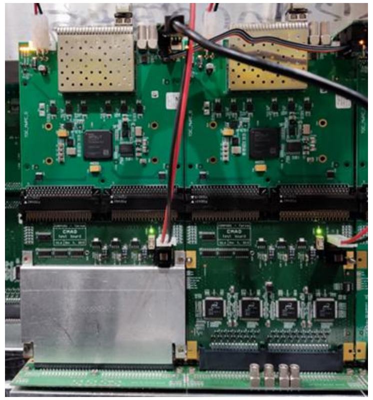
Till 2024

COMPASS MWPCs possible path to the future

After 2024

Existing detectors

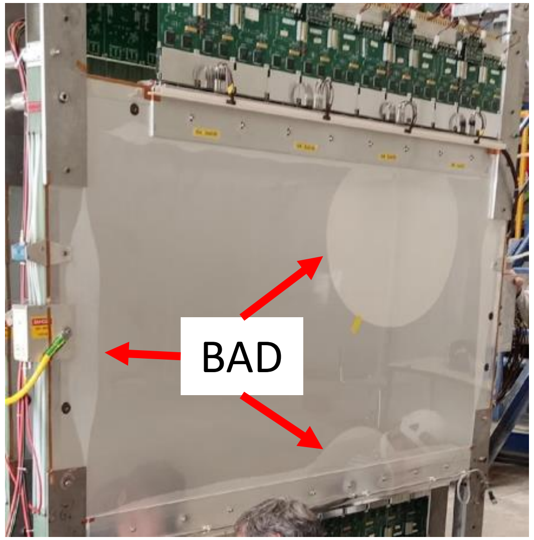
Trigger less DAQ (2025)

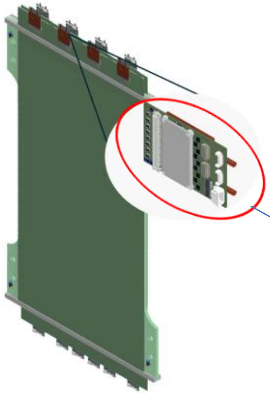


FPGA based

New FE

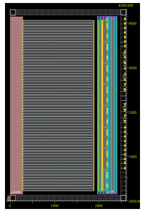
New ASIC





New detectors

New FE



New ASIC

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

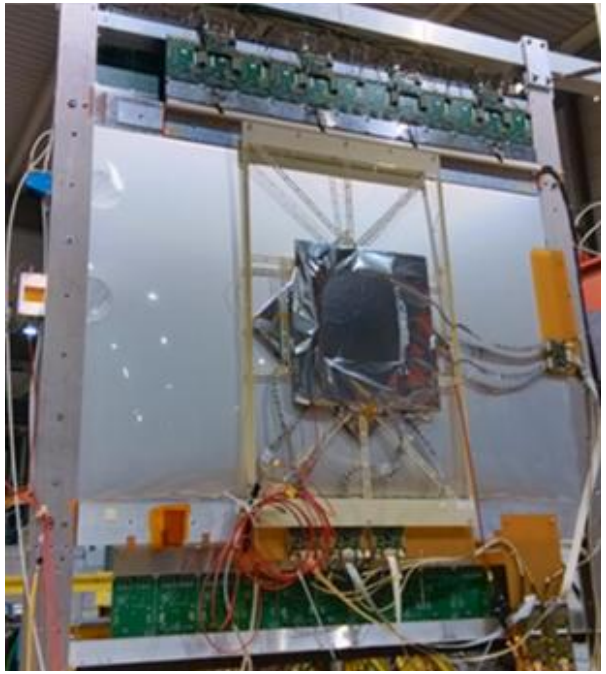
Base requirements

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

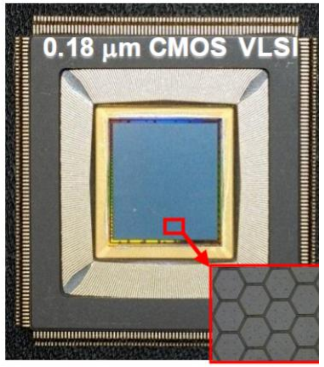
- To reasonably match the existing MWPCs
- To see if we can be better at low cost

MPGD to substitute it?

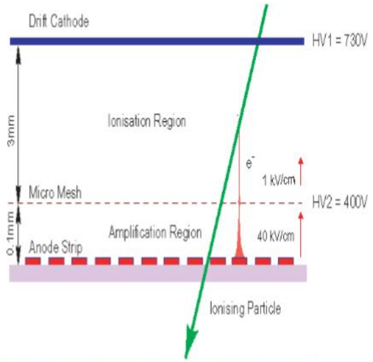


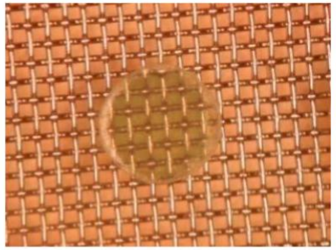
Micro Pattern Gaseous Detectors

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

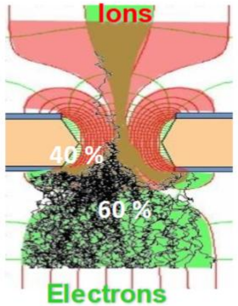


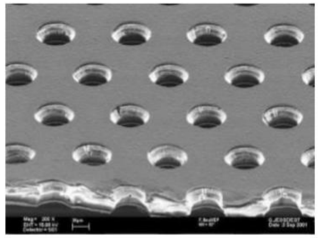
CMOS high density readout electronics



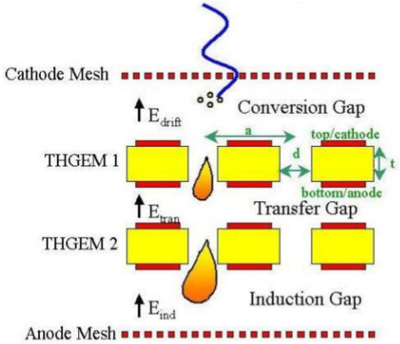


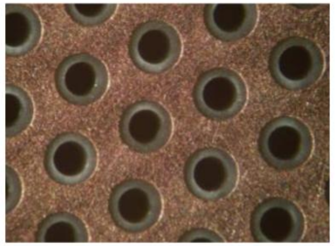
Micromegas



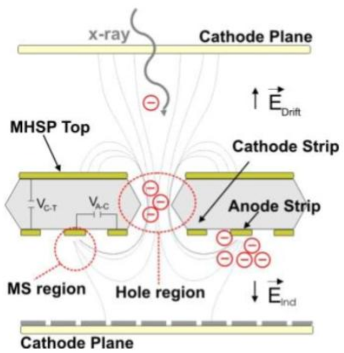


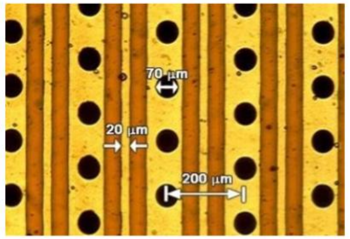
GEM



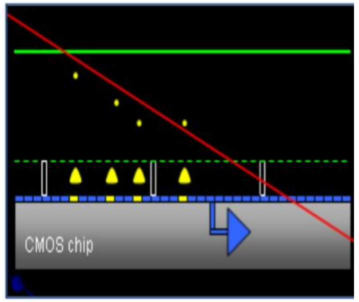


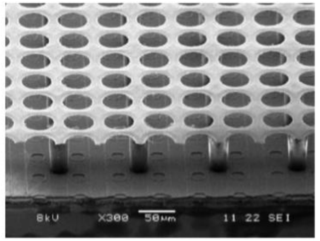
THGEM





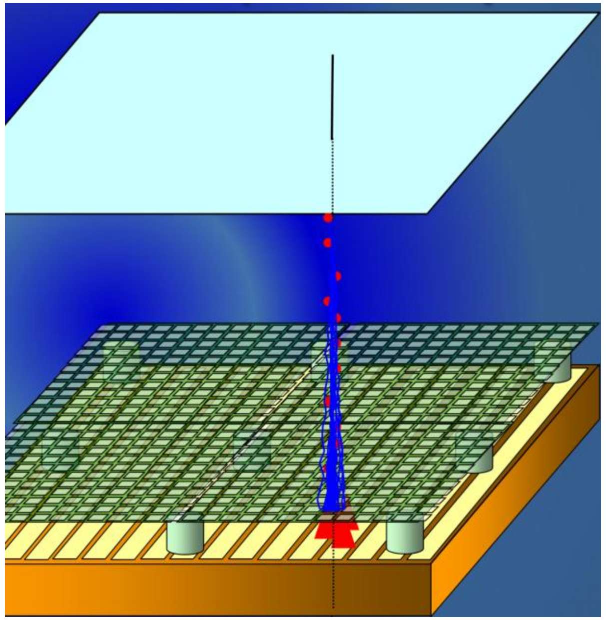
MHSP

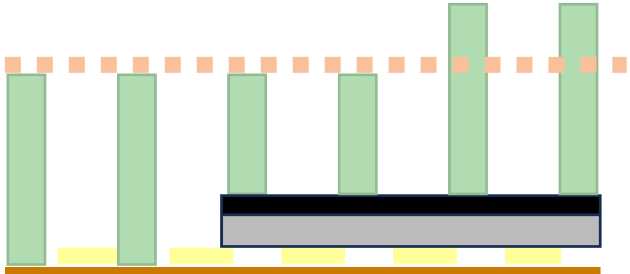




Ingrid

Micro Mesh Gaseous Structure aka Micromegas aka MM





Classic	Resistive
Floating	Bulk

Concept design 1

Reduce the material budged?

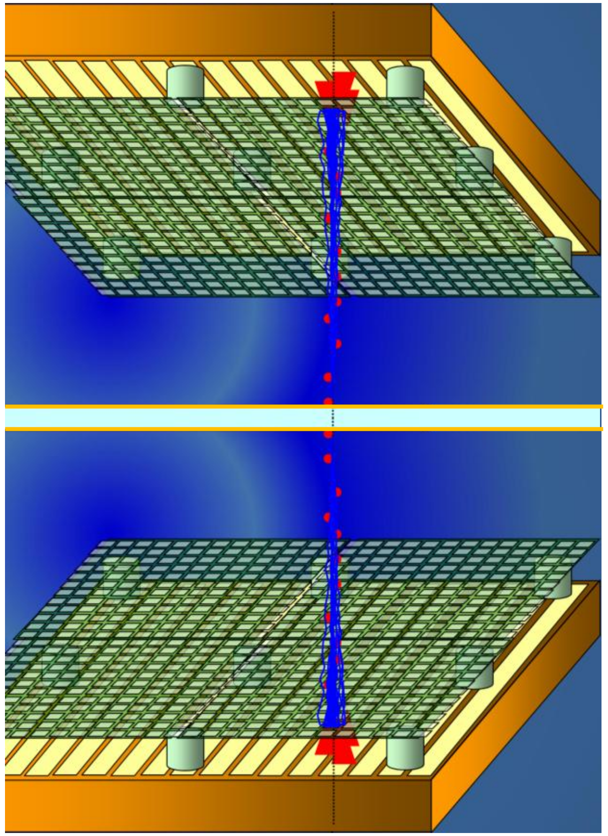
✓ Common cathode configuration

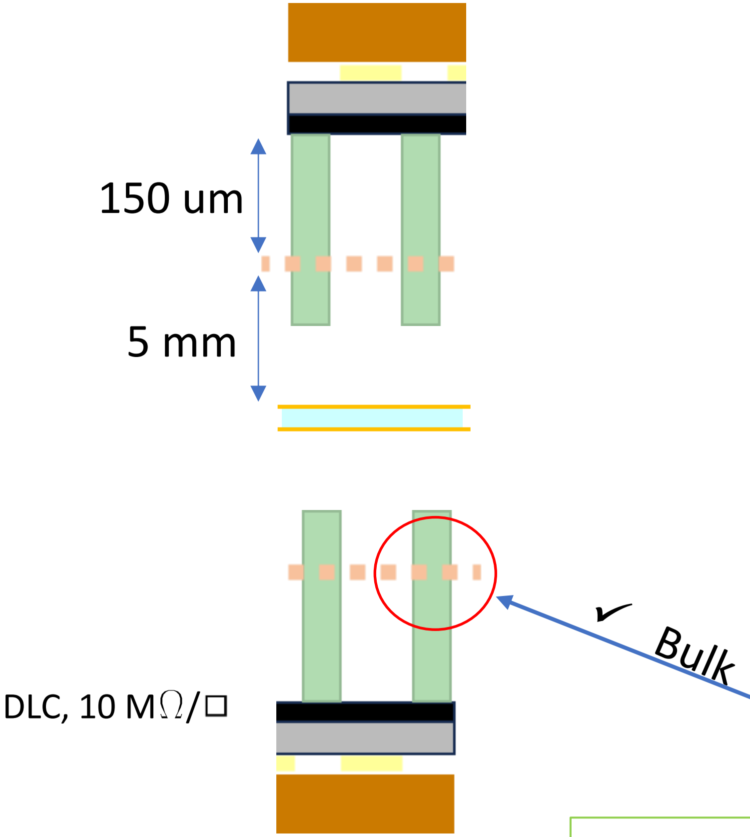
Spark reduction?

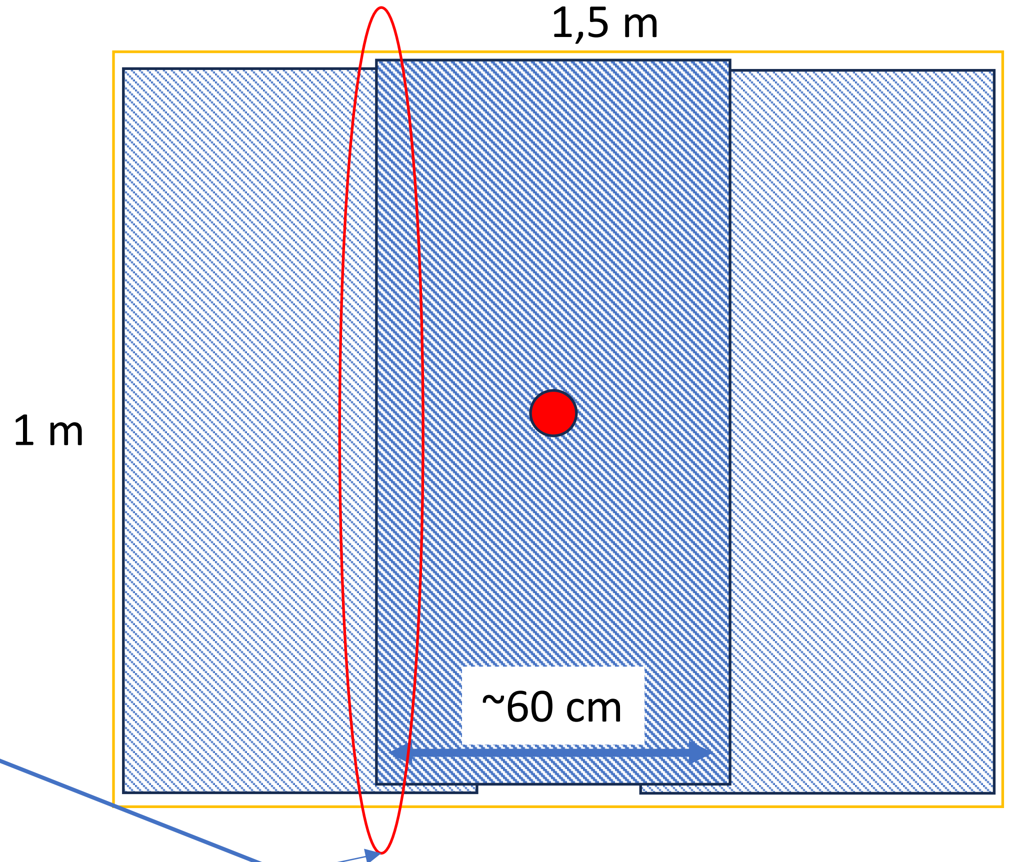
✓ Resistive configuration

Technology limitation?

✓ Staggered detector configuration

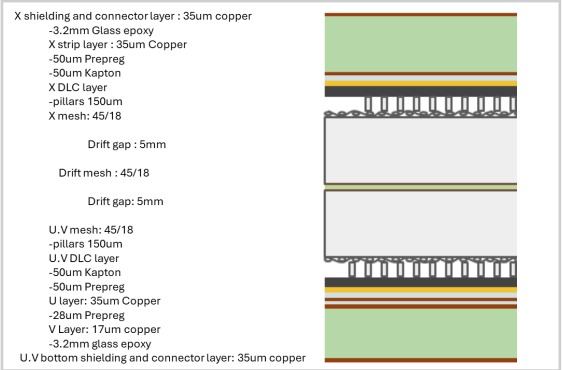




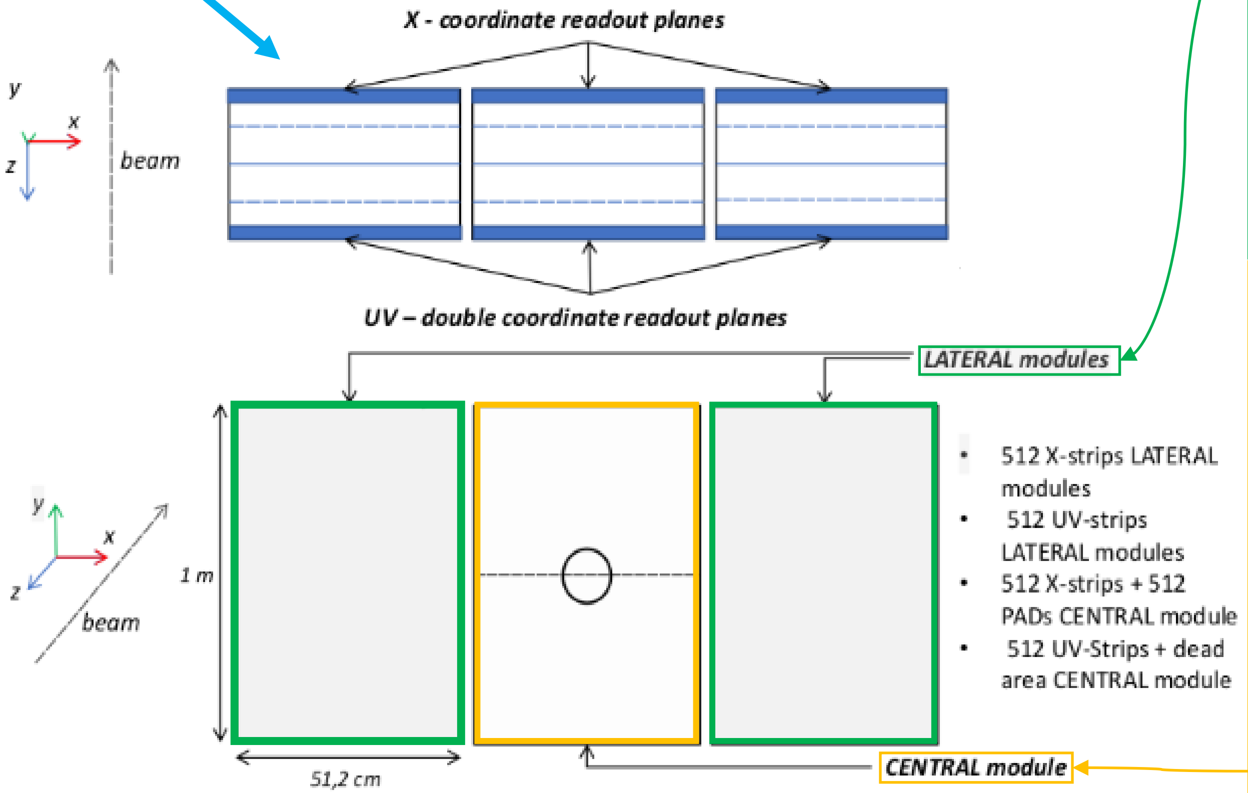


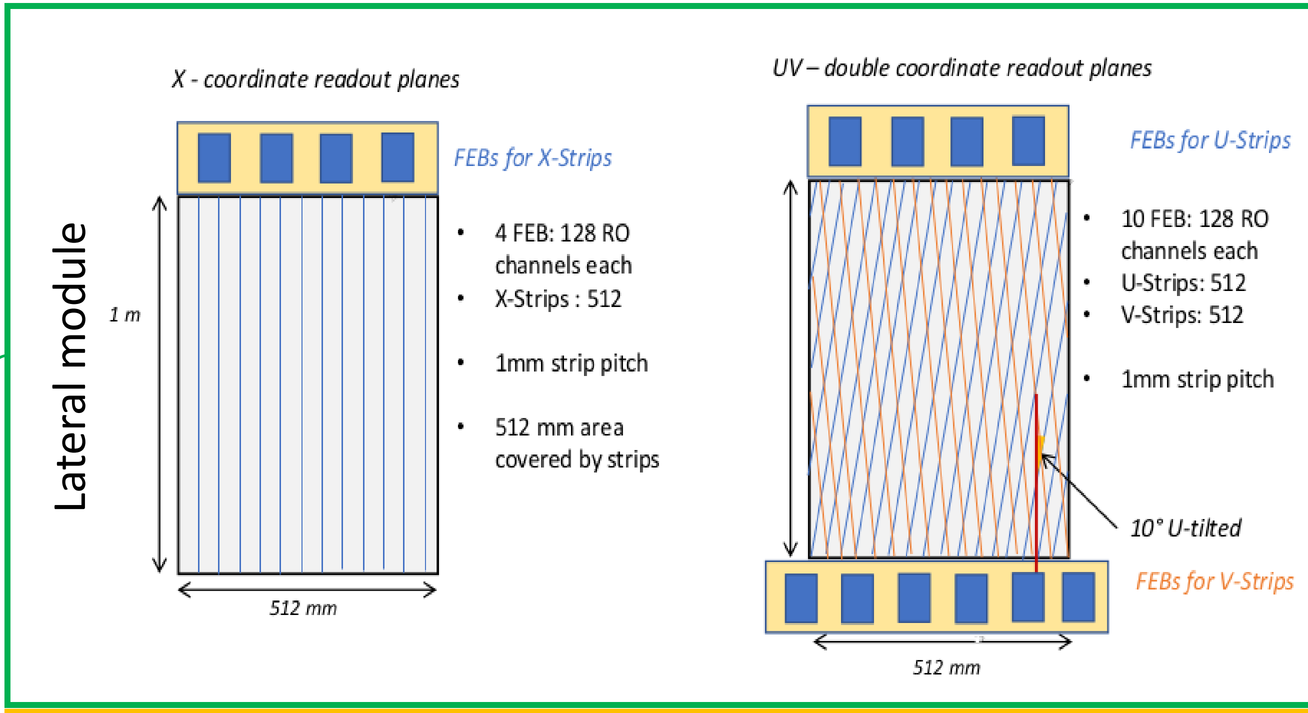
No thick frame allowed in the acceptance?

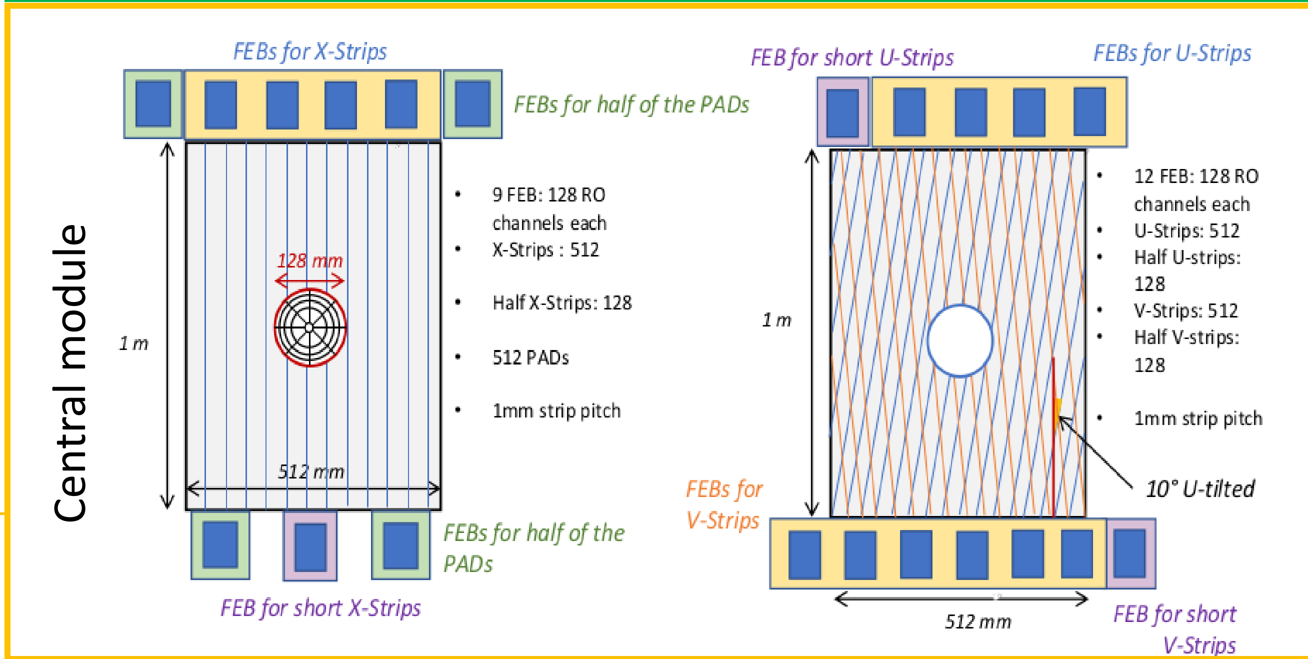
Concept design 2



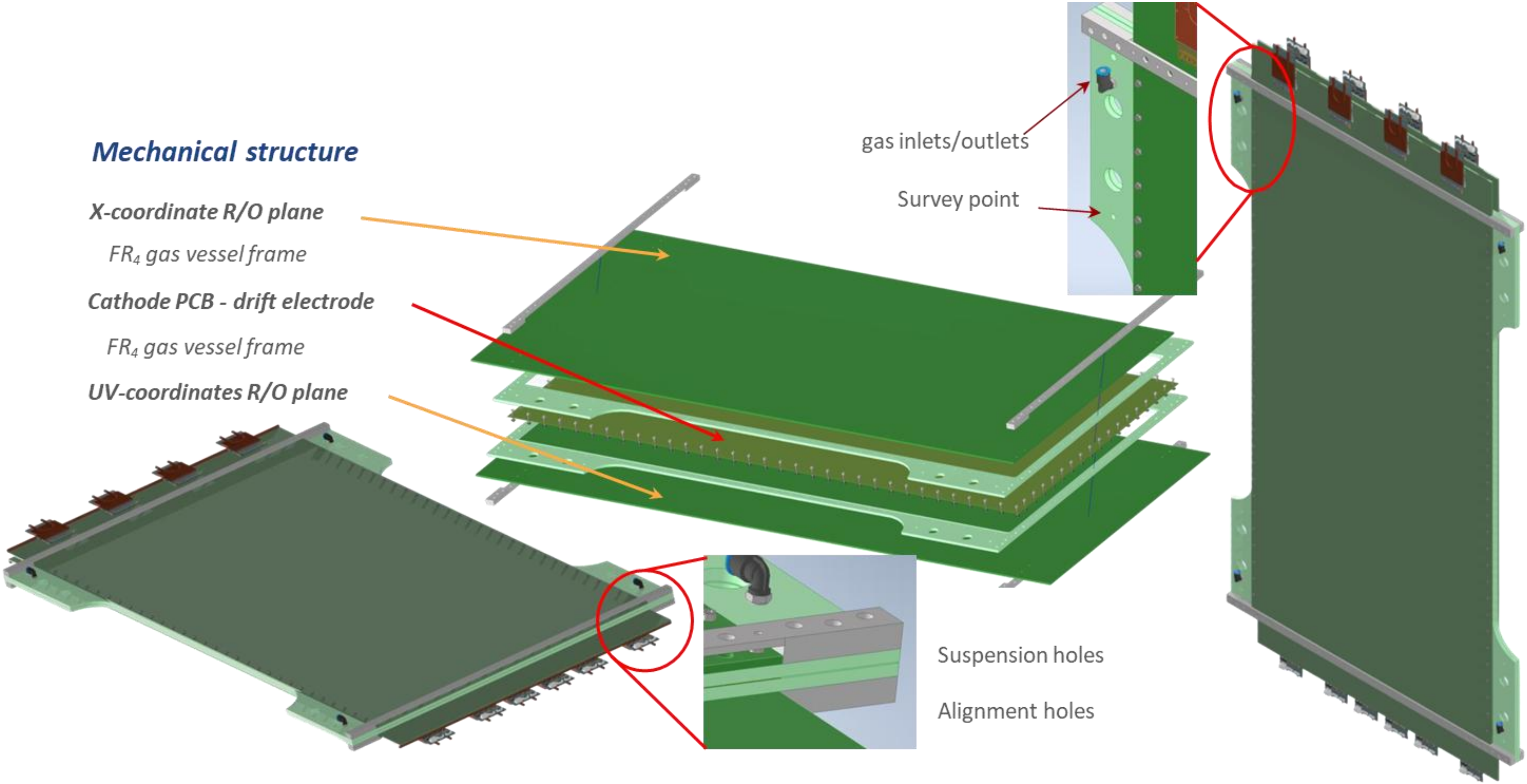
- common cathode
- 2 types of modules





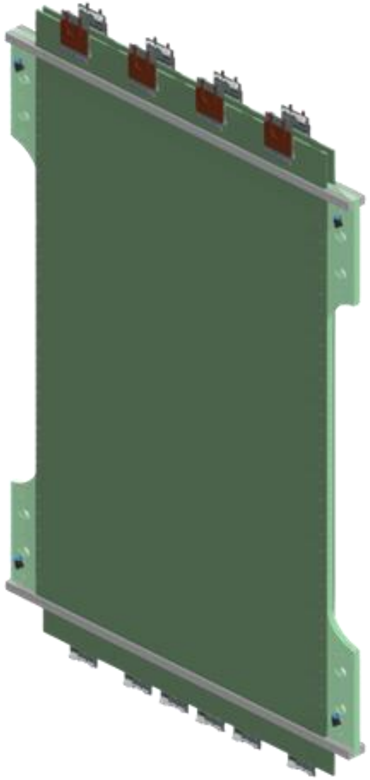


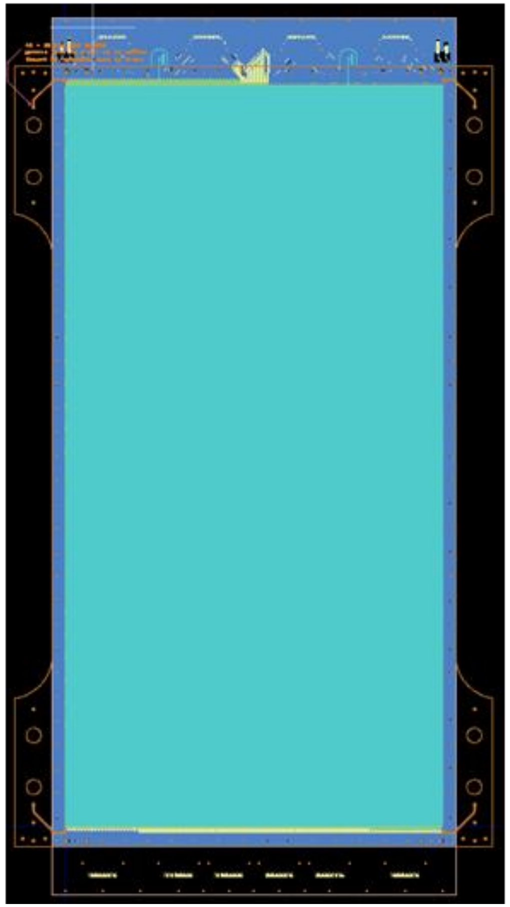
Lateral module prototype design



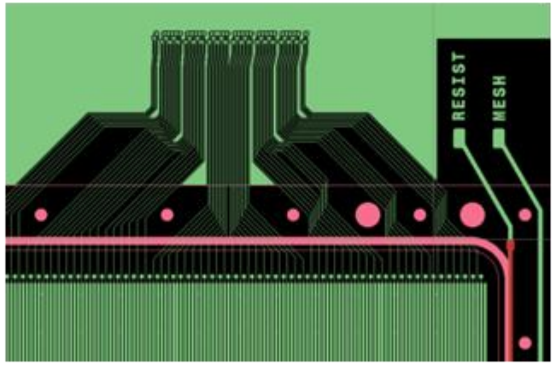
Lateral module prototype production

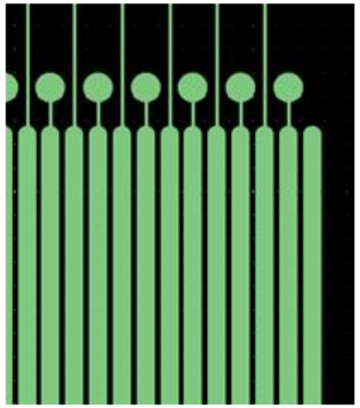
Readout PCB design and production





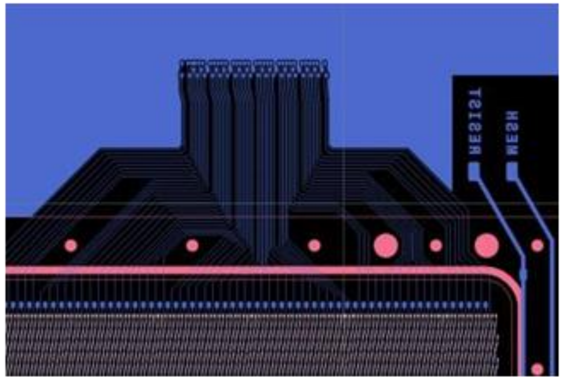
X-coordinate R/O plane

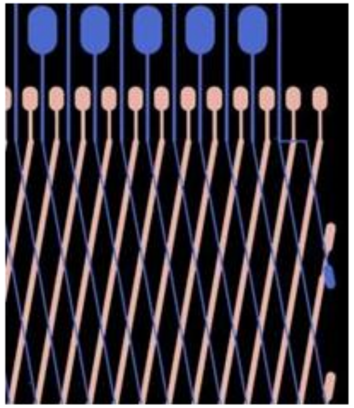




- 512 strips
- 1mm pitch
- 750 um width
- 4 FEBs: 512 fe channels

UV-coordinate R/O plane

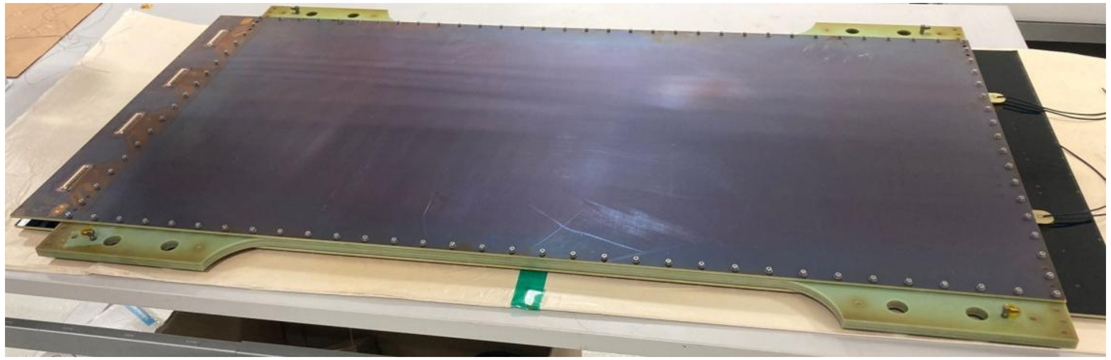




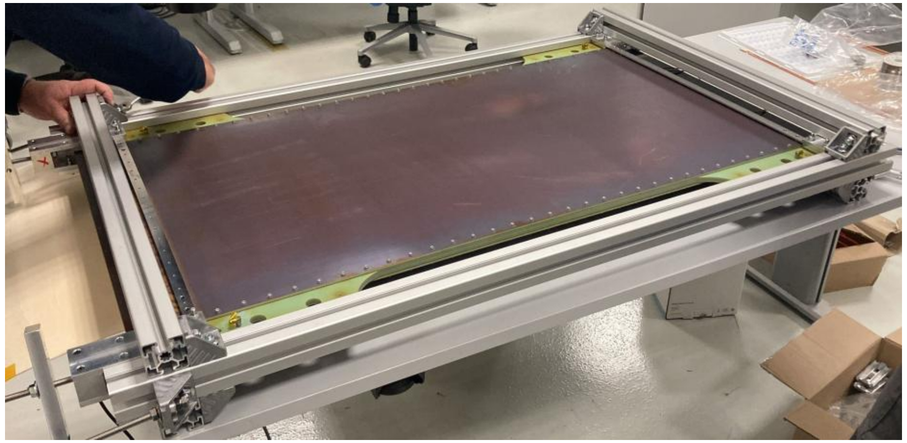
- 1280 strips
- 1mm pitch
- 250 um U strips width
- 150 um V strips width
- 10 FEBs: 1280 fe channels

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

Lateral module prototype testing

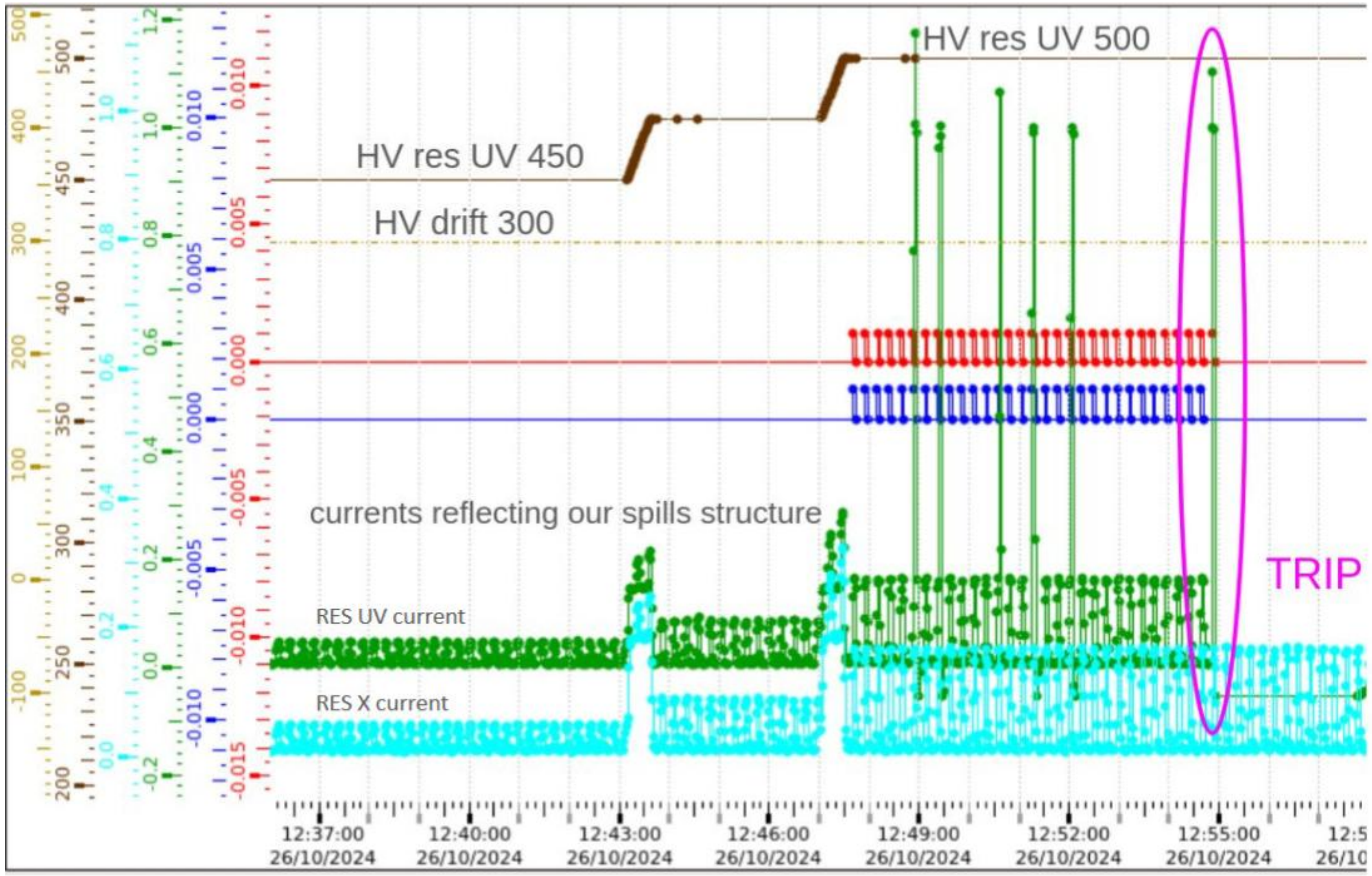
2024

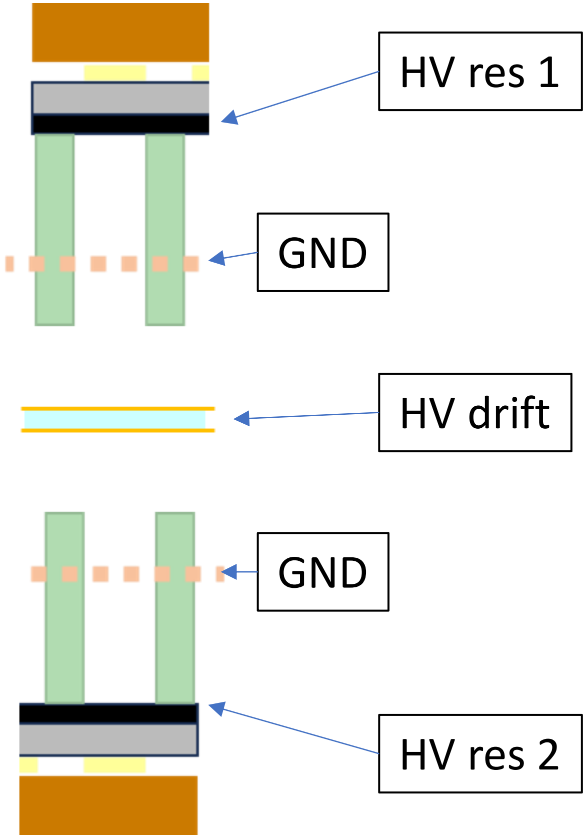
- ➢ High Voltage stability
- ➢ Noise performance & shielding optimisation
- ➢ First data (beam/cosmics)
- ➢ Compare $ArCO_2$ (93/7) and $ArCO_2$Iso(93/5/2)

2025

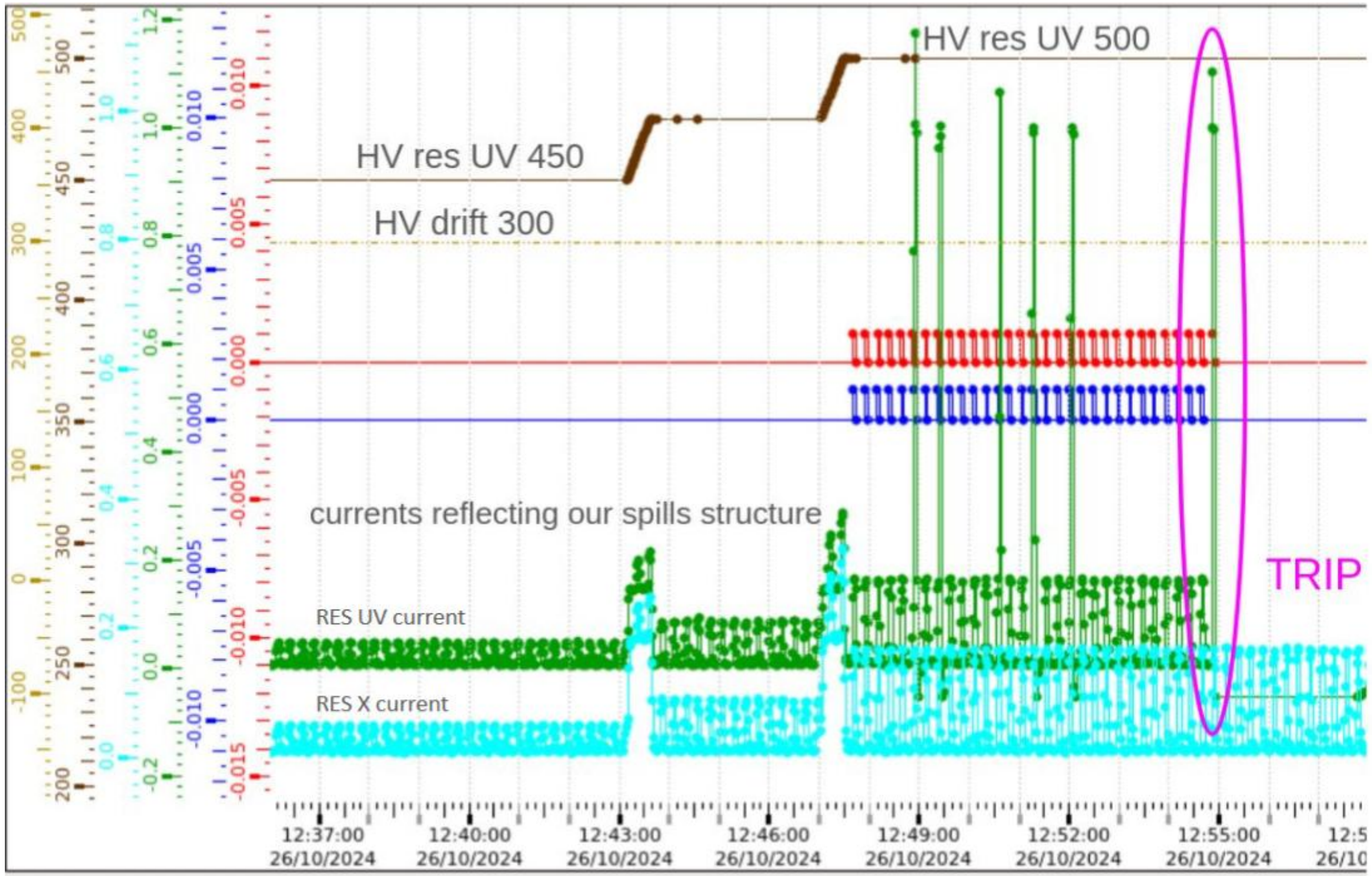
- ➢ We will have our parasitic setup in the AMBER spectrometer for the whole beam period
- ➢ We need to achieve a stable operation/understand the problems before starting the layout of the Central module
- ➢ First test with the ToRA ASIC

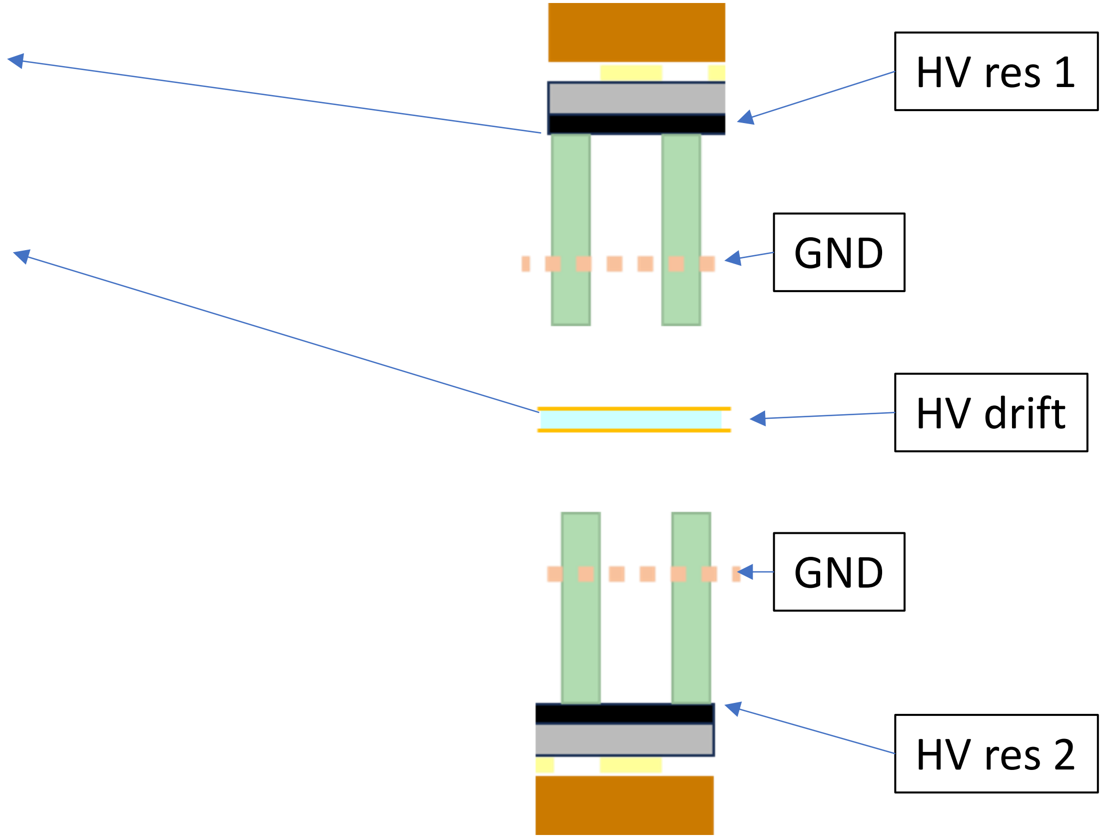
Glimpse of the first operation 1



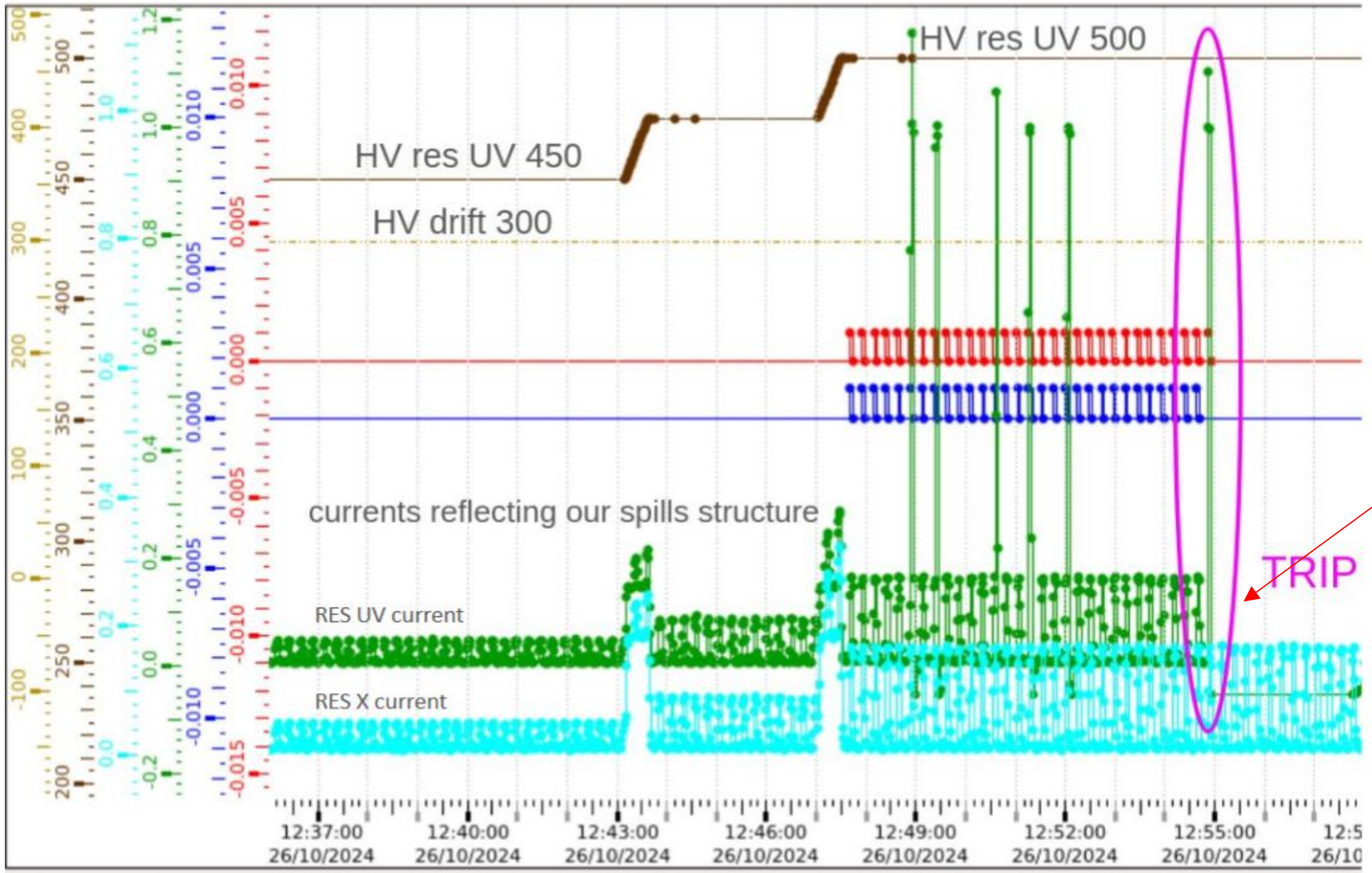


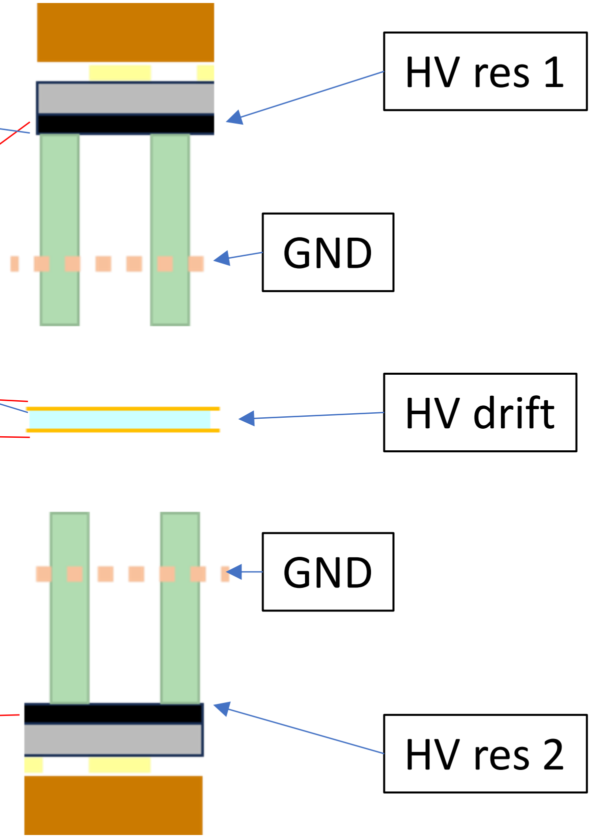
Glimpse of the first operation 1





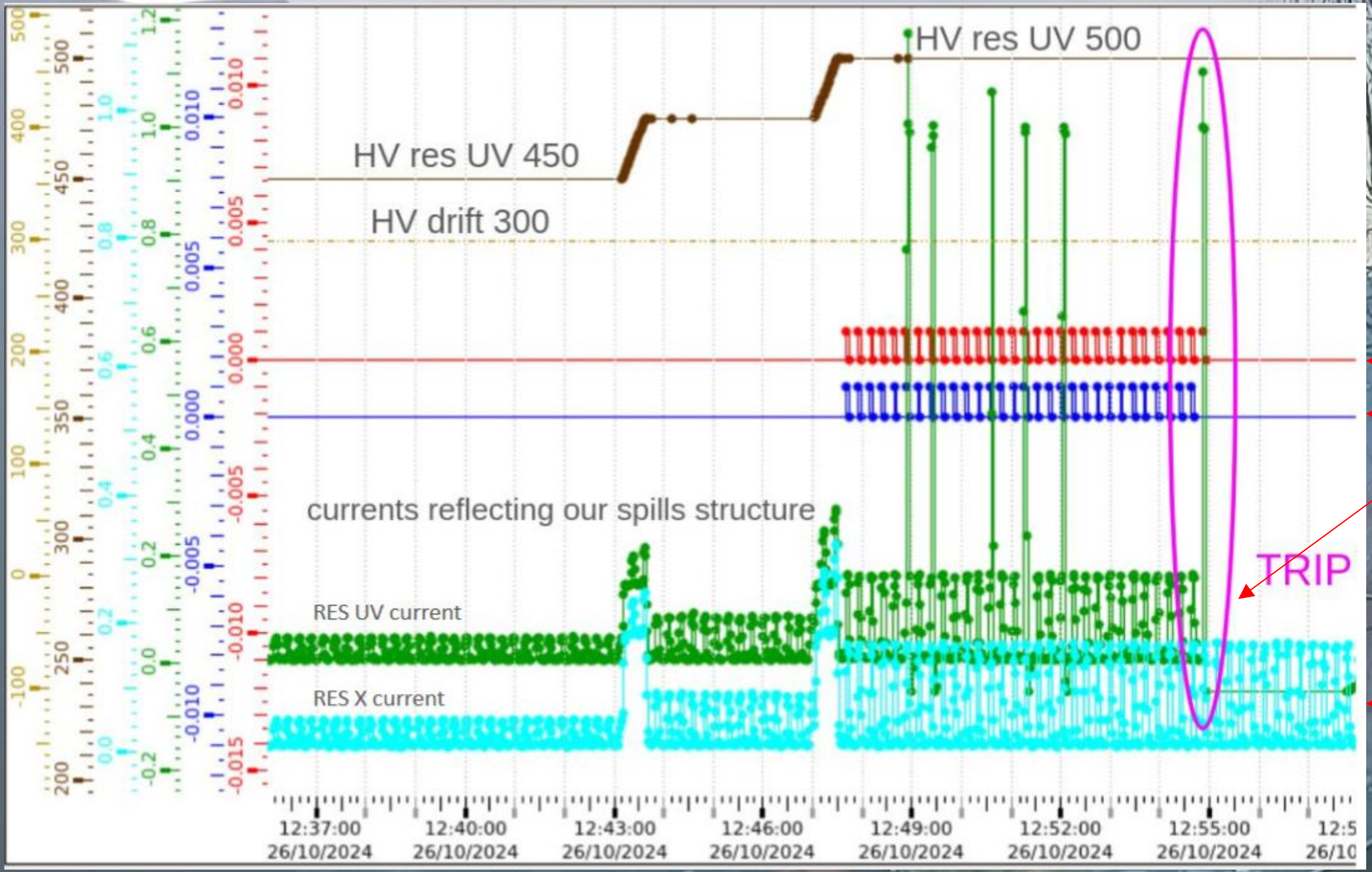
Glimpse of the first operation 1

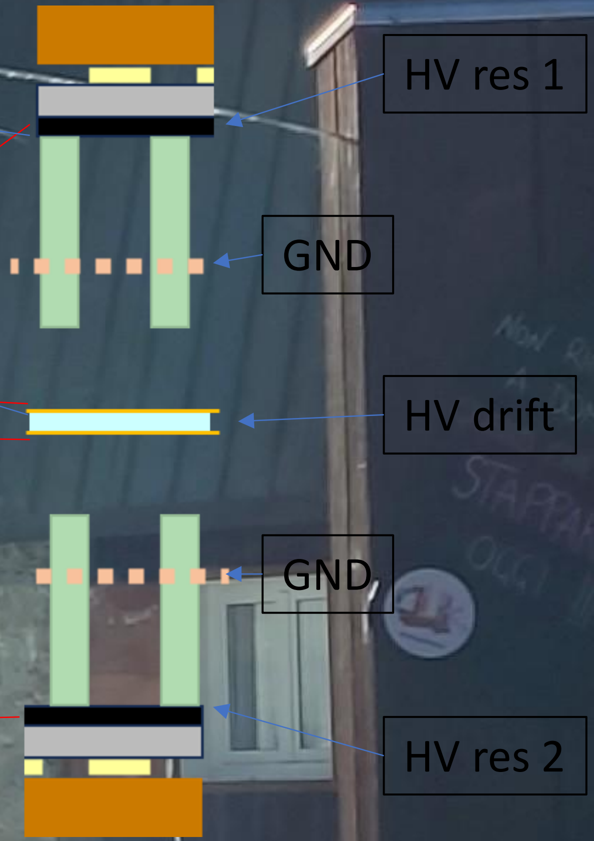




Gain operation observed

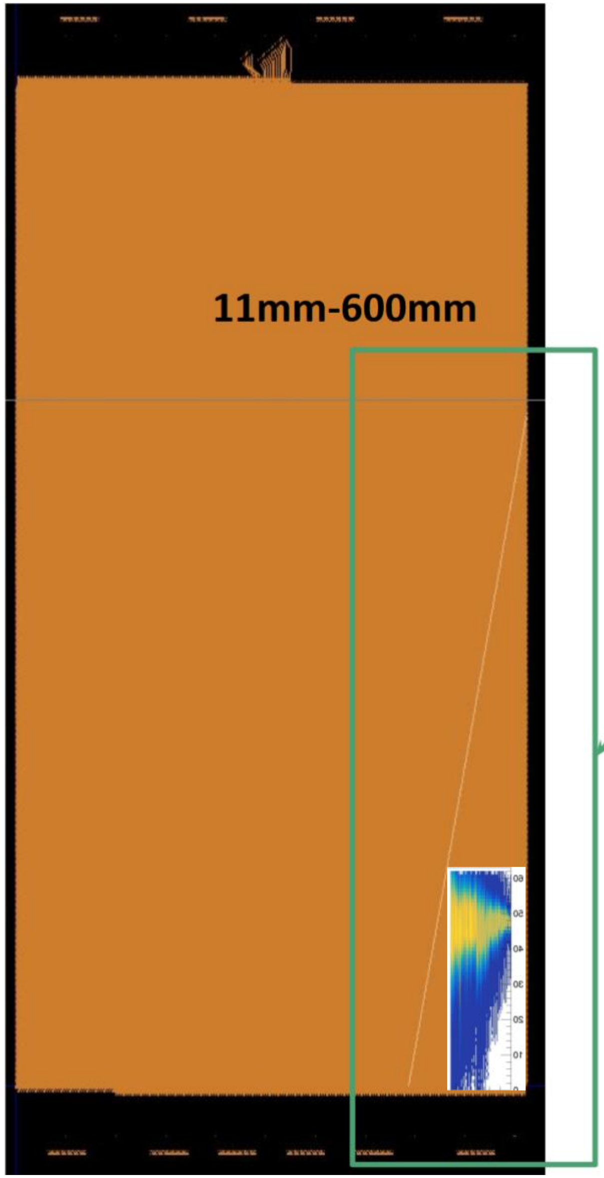
Glimpse of the first operation 1

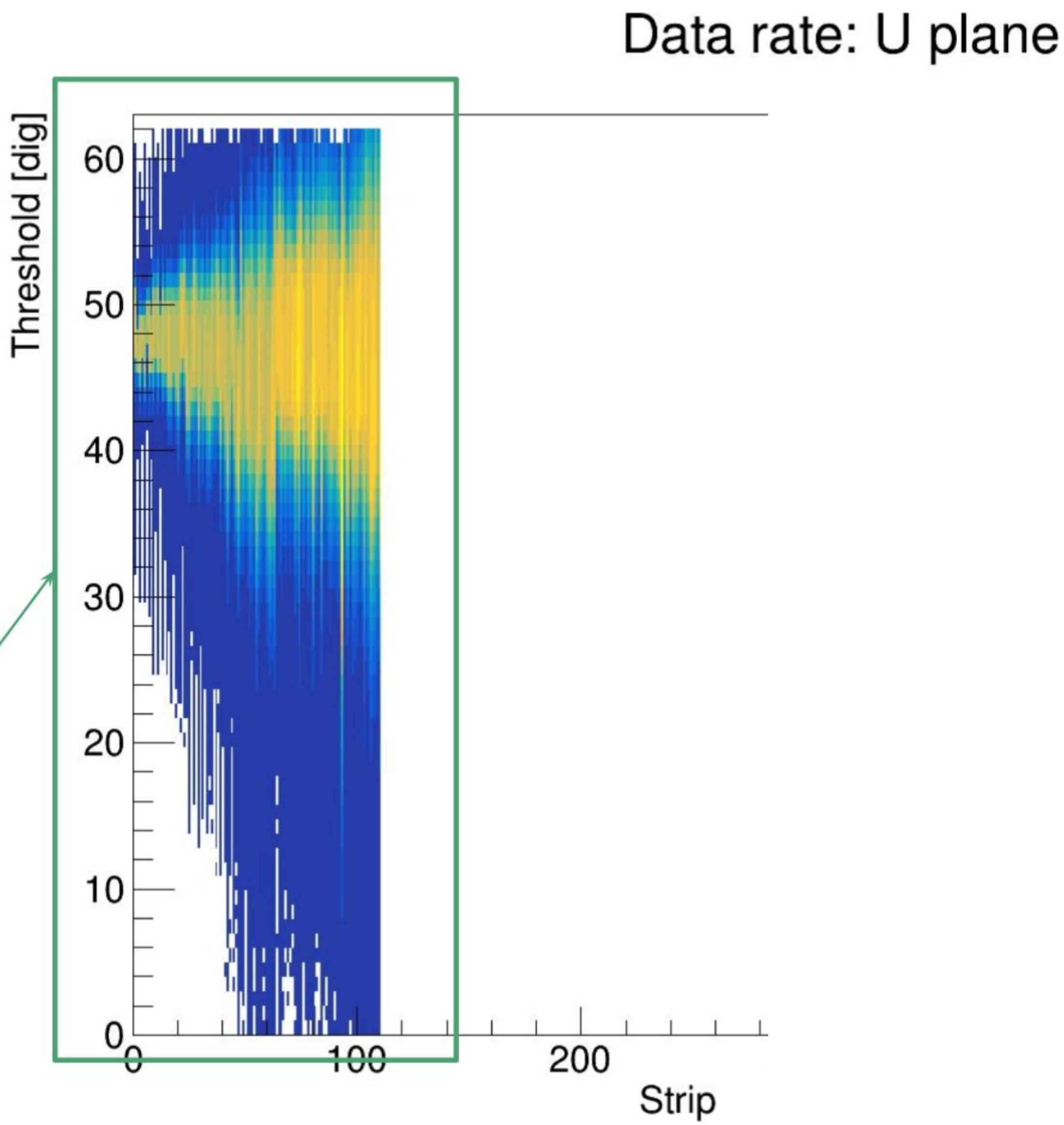




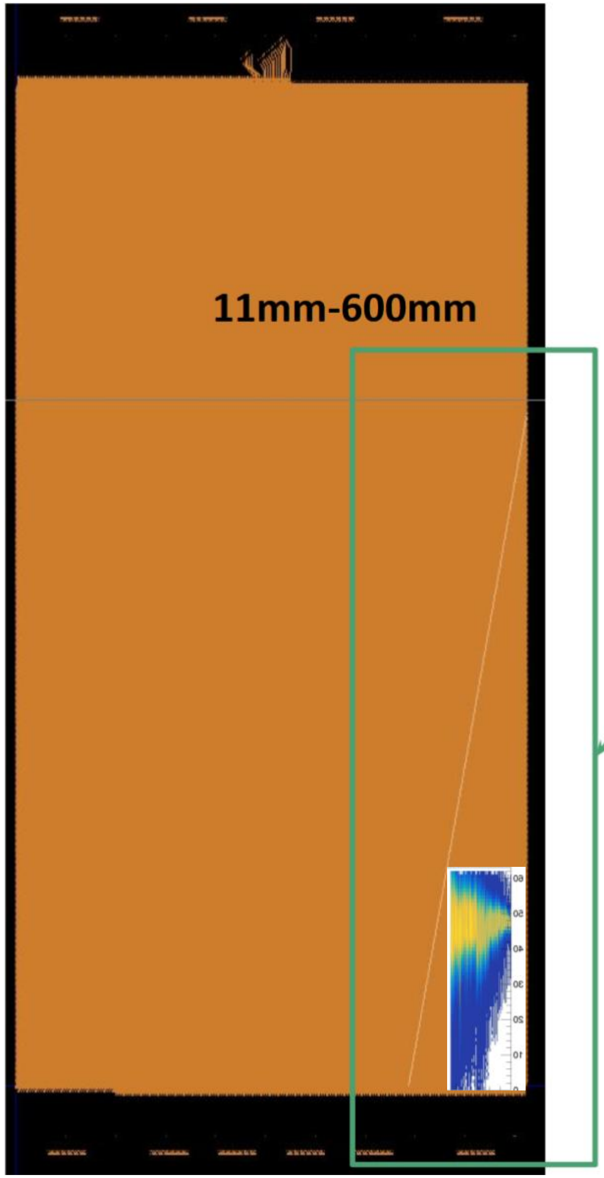
Gain operation observed

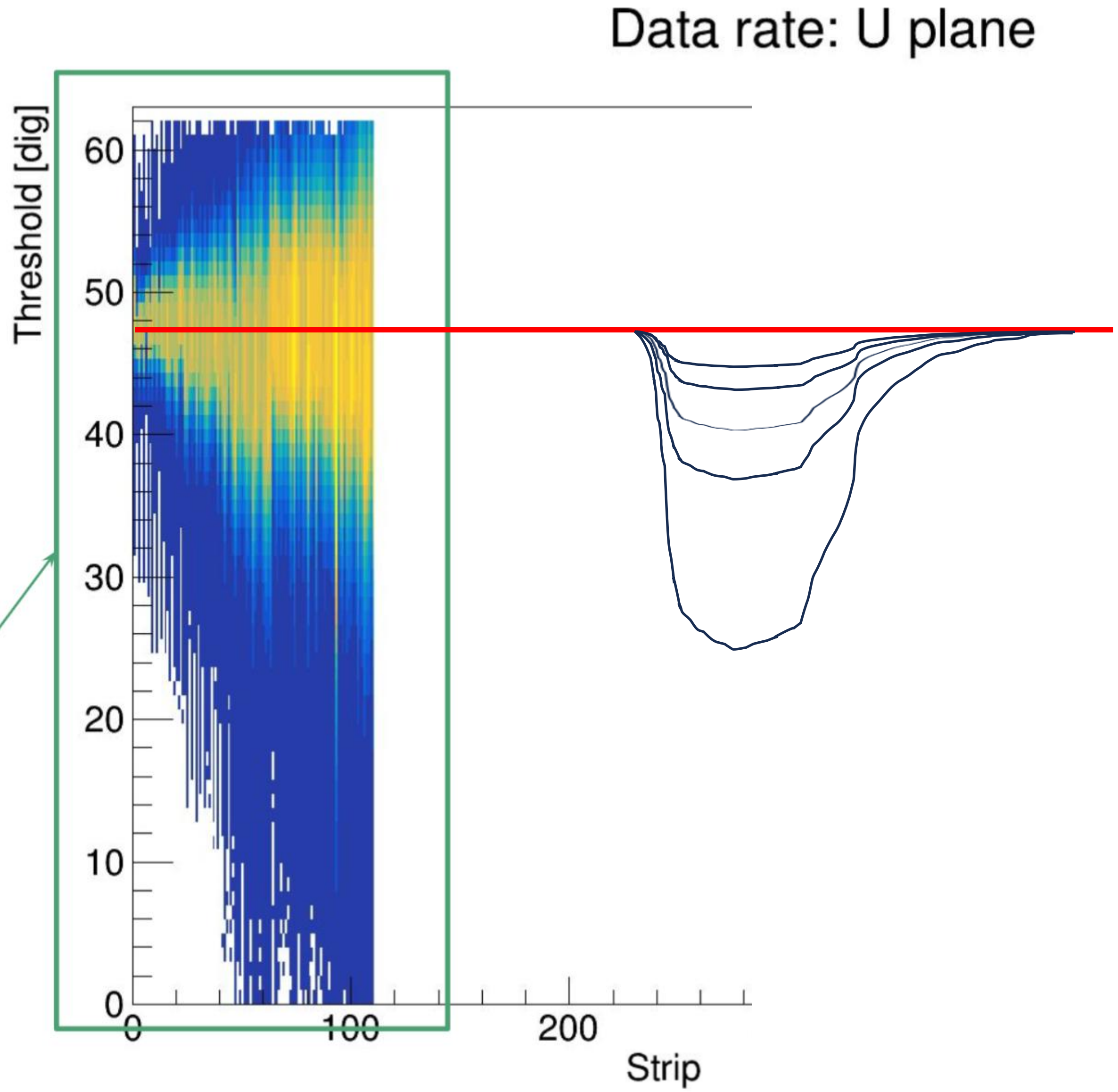
Glimpse of the first operation 2

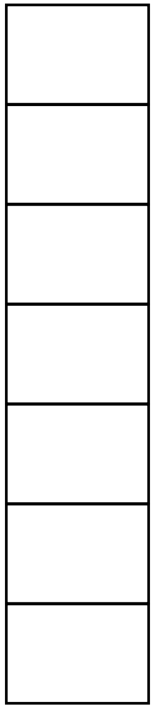




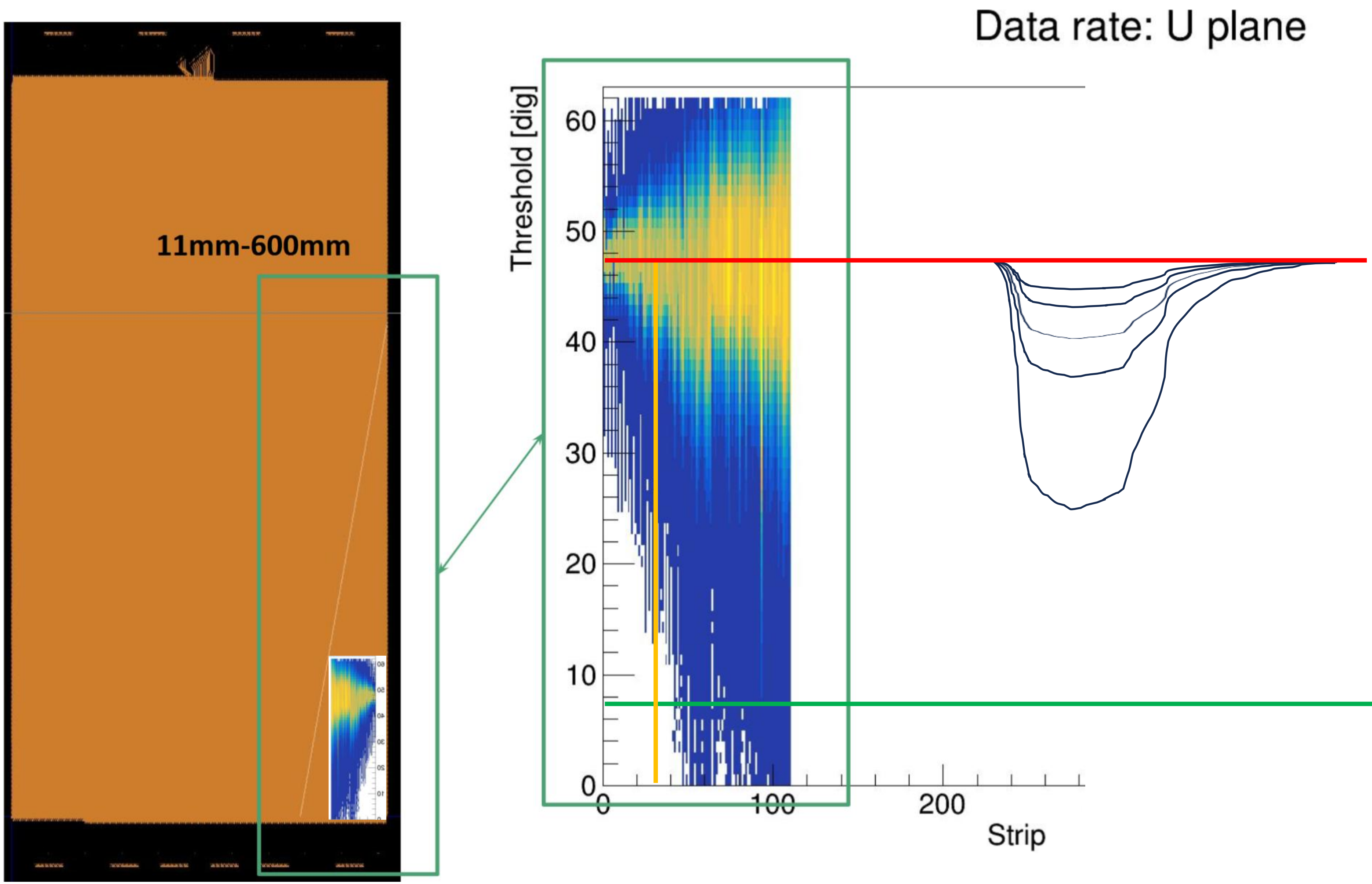
Glimpse of the first operation 2

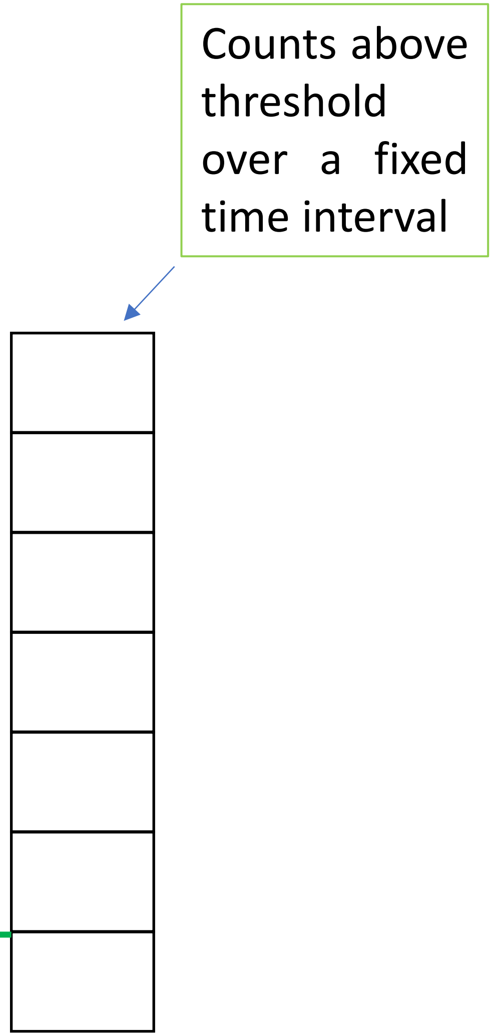




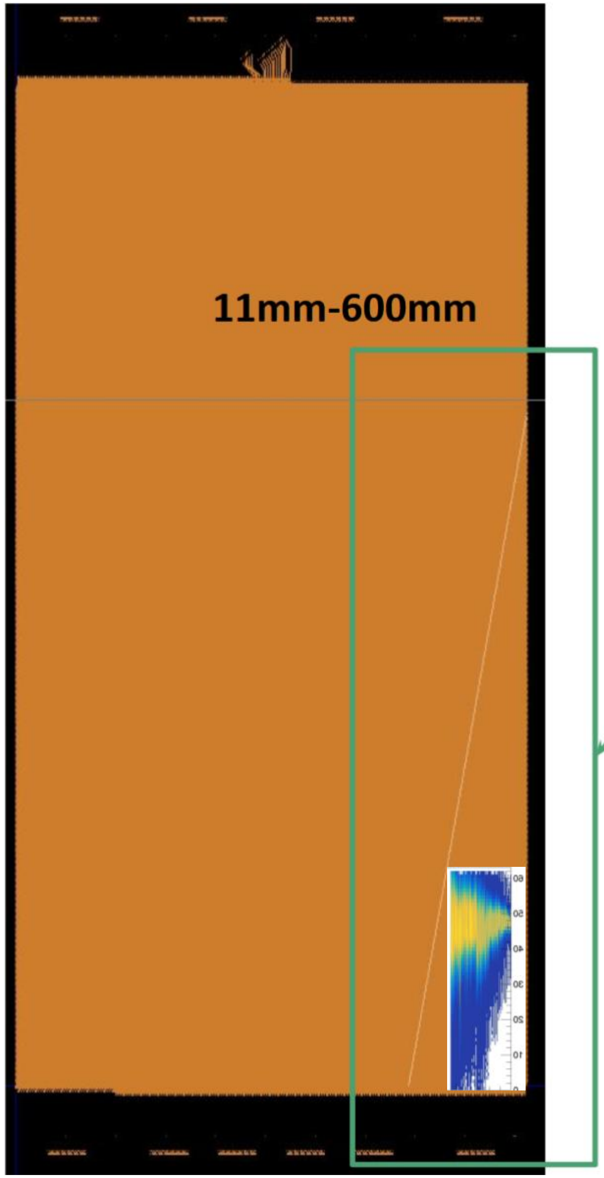


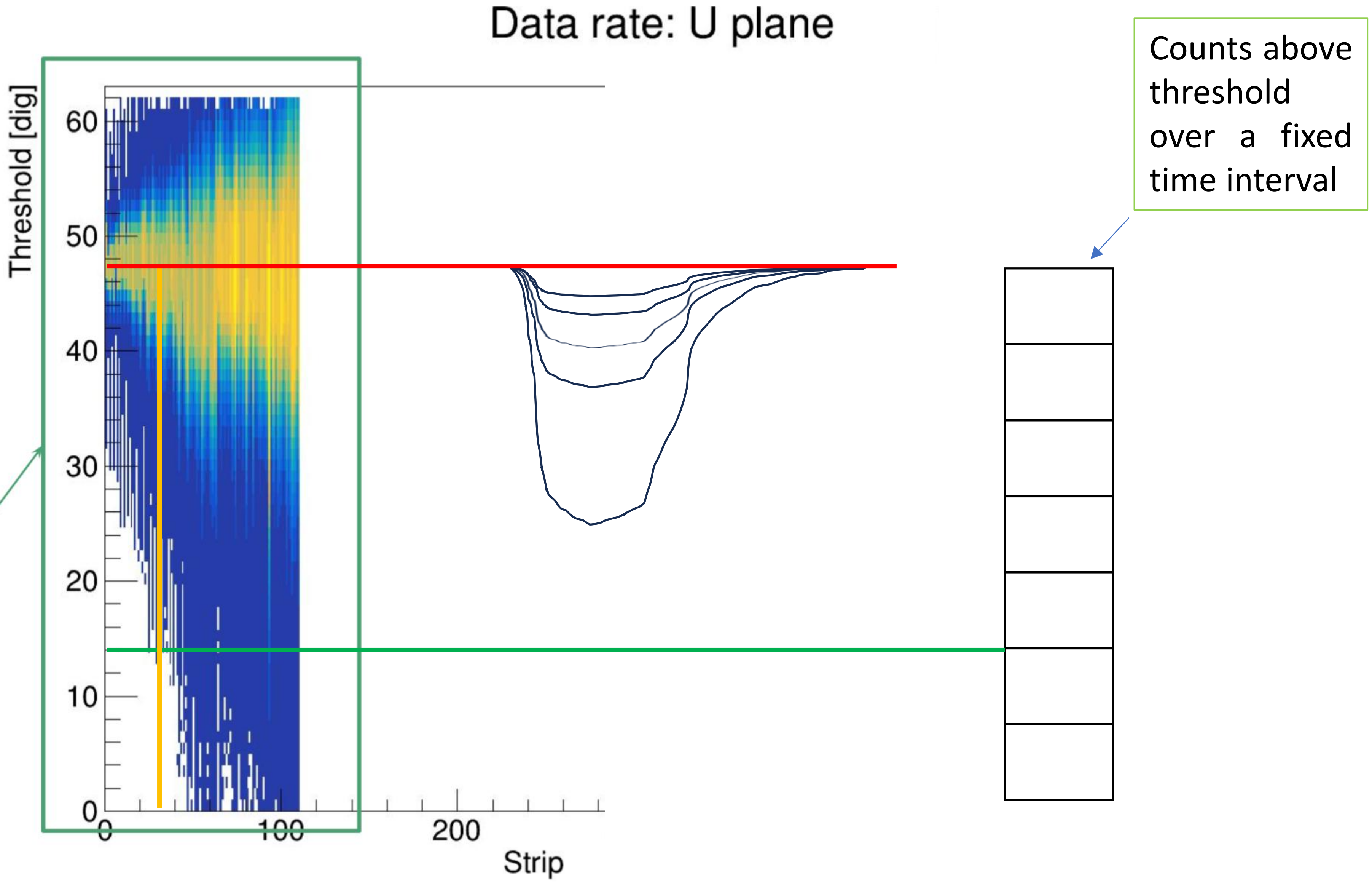
Glimpse of the first operation 2



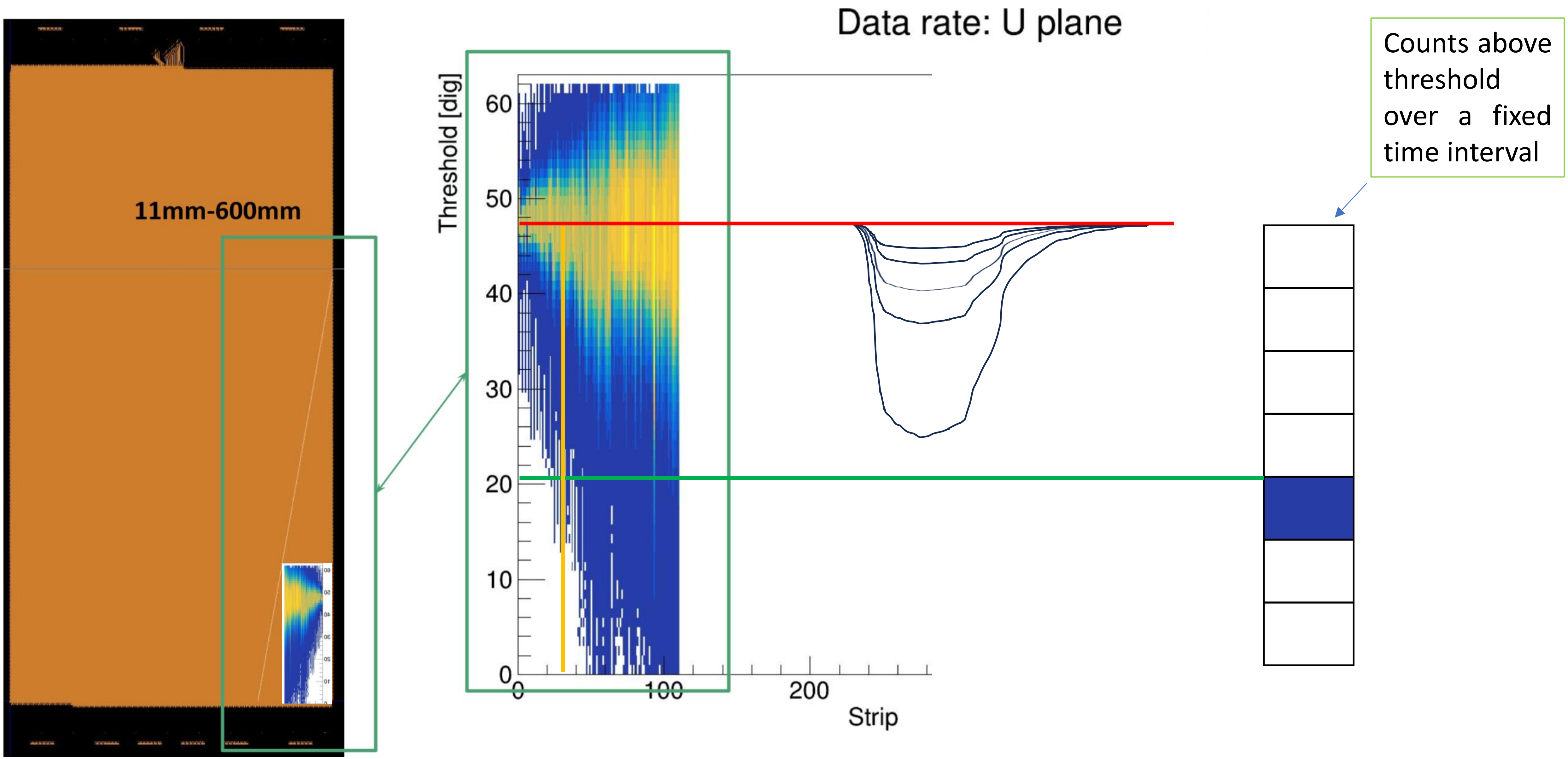


Glimpse of the first operation 2

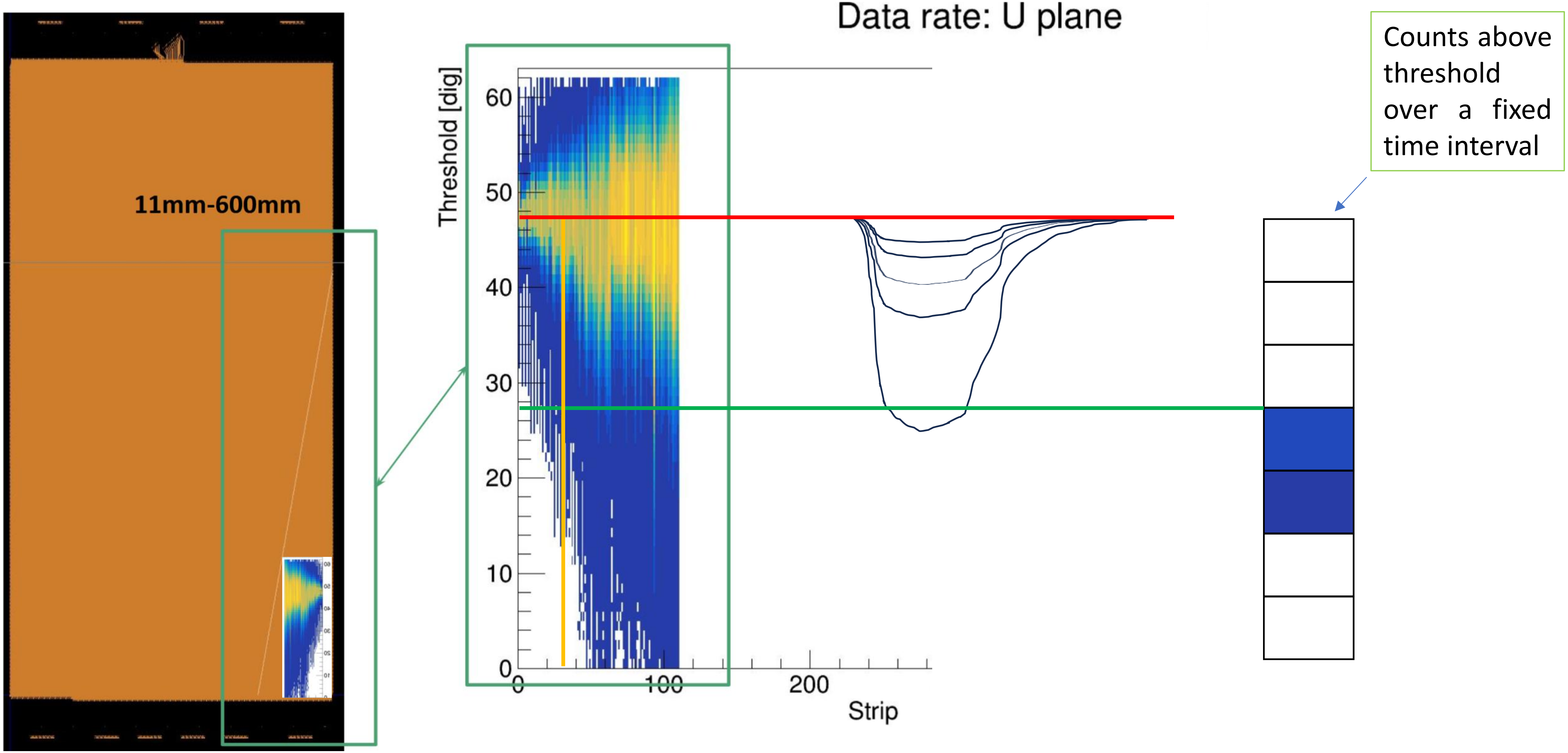




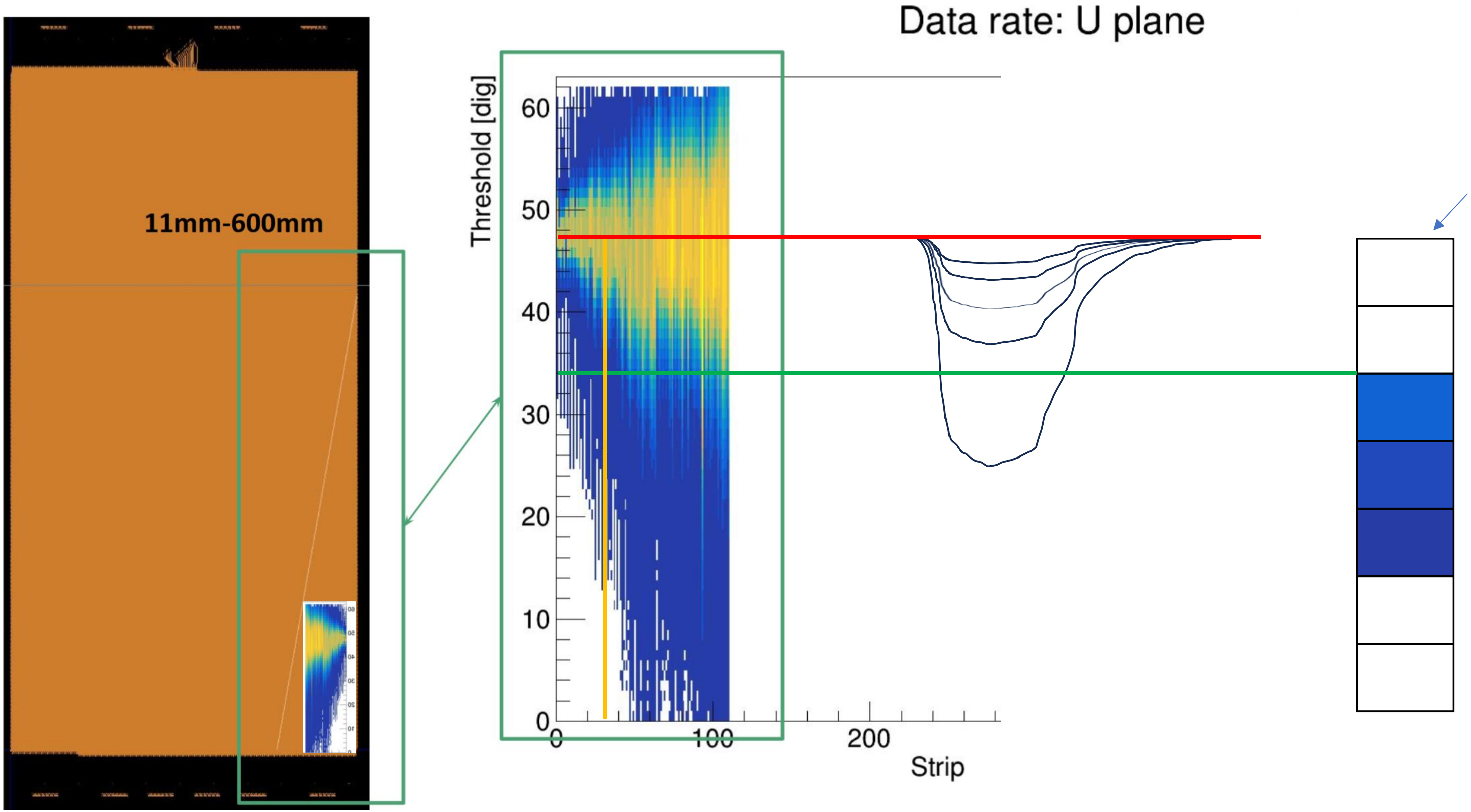
Glimpse of the first operation 2



Glimpse of the first operation 2

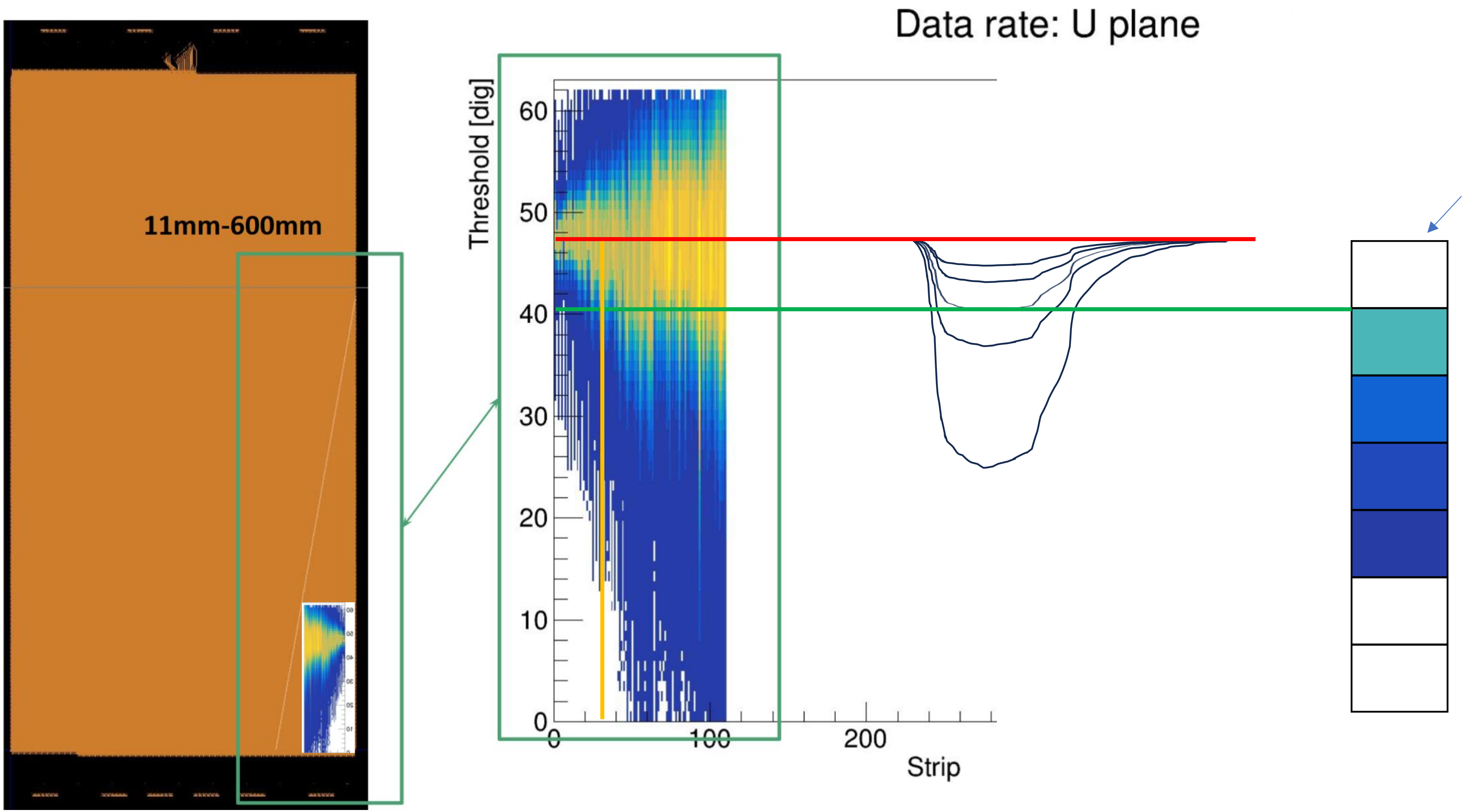


Glimpse of the first operation 2



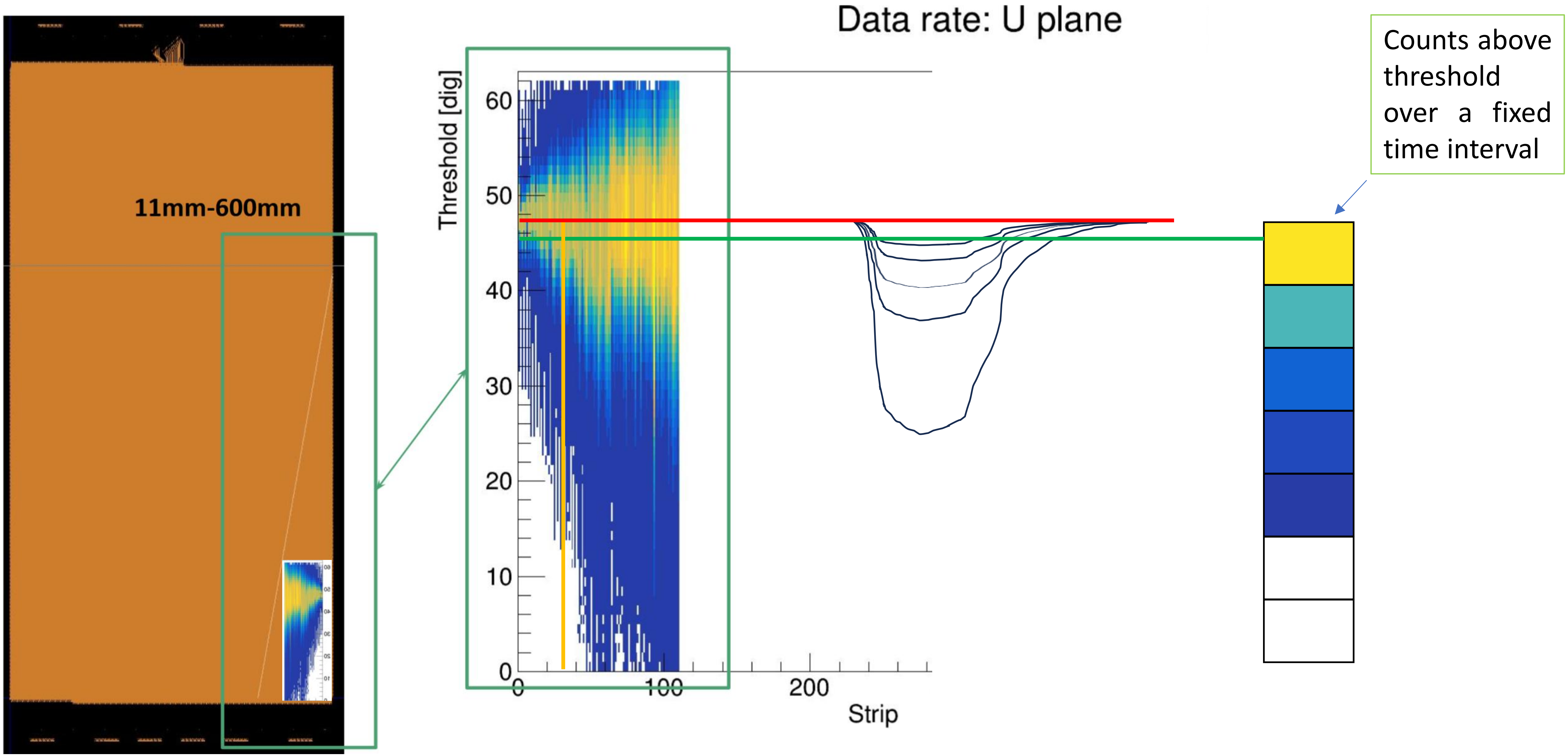
Counts above threshold over a fixed time interval

Glimpse of the first operation 2

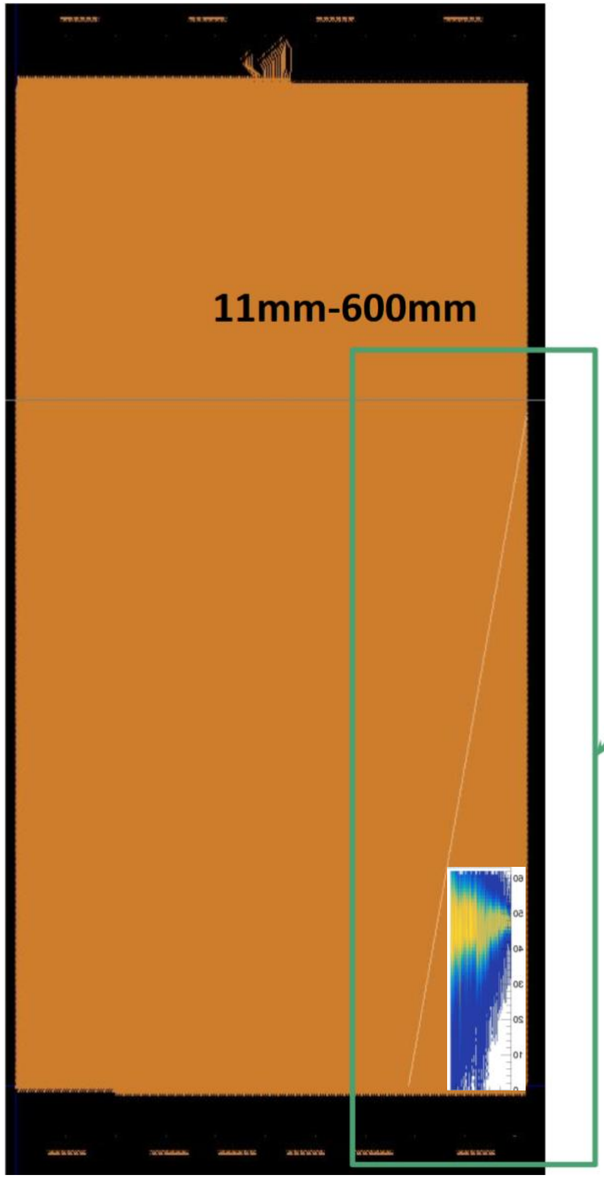


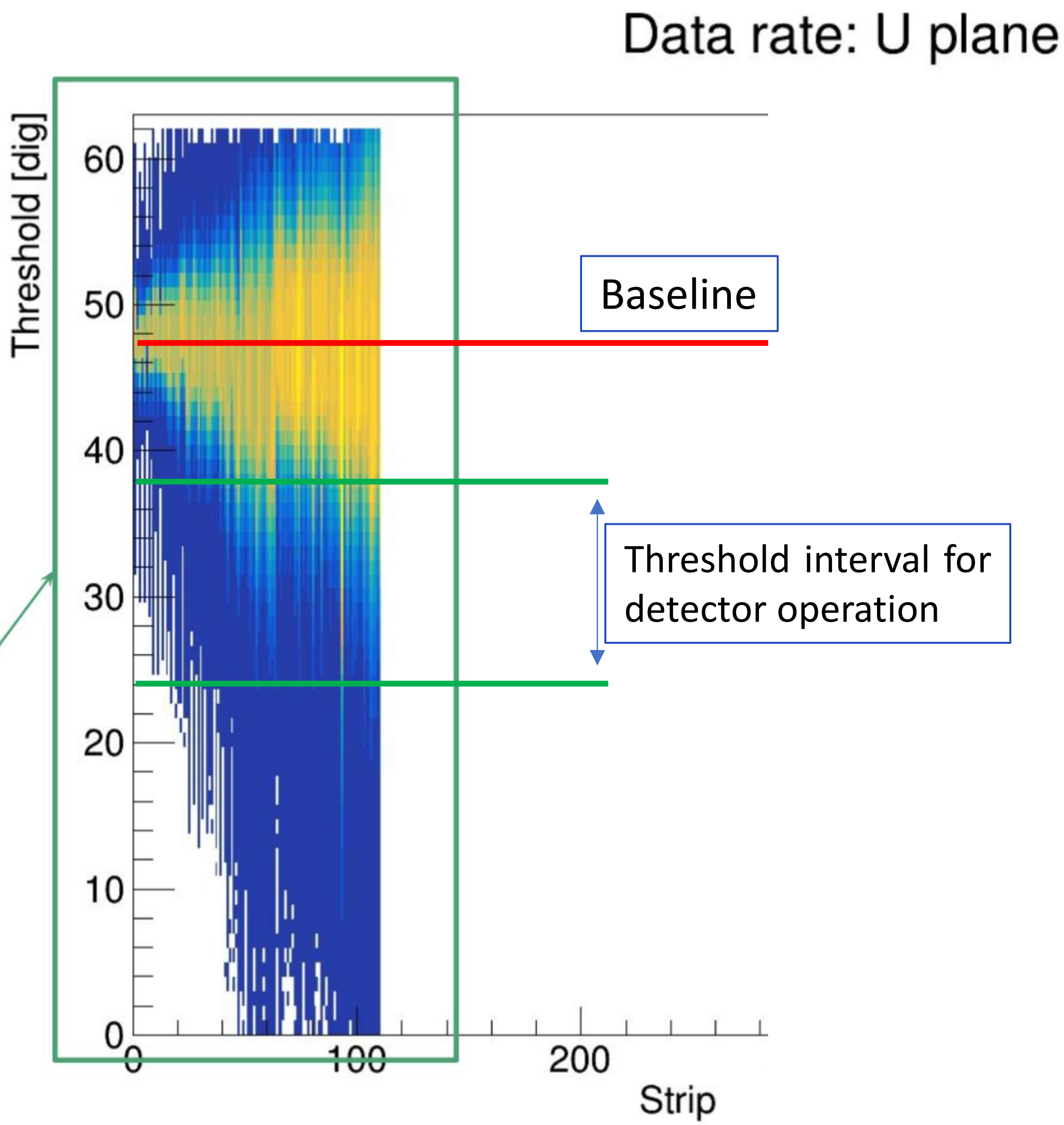
Counts above threshold over a fixed time interval

Glimpse of the first operation 2



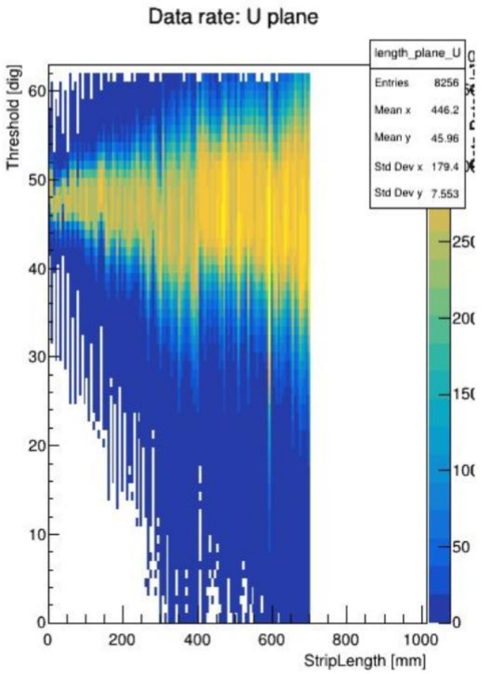
Glimpse of the first operation 3

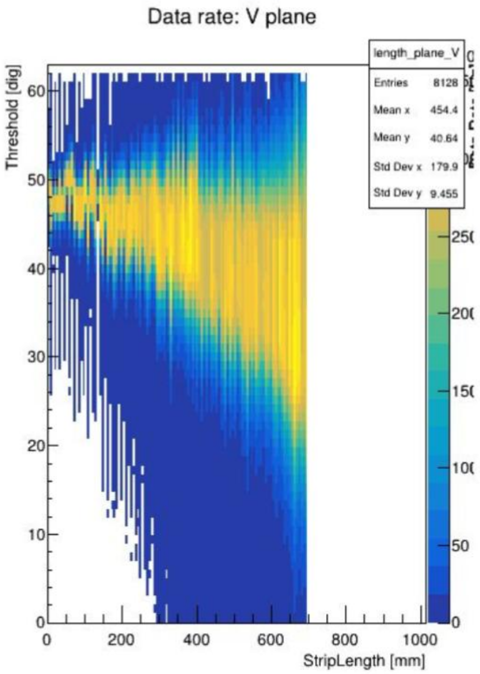




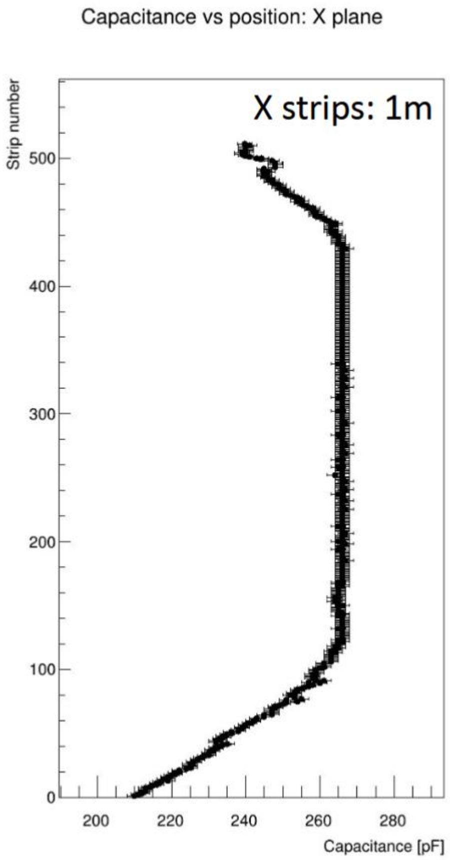
- Data tacking possible only possible on the short strips
- Unexpected behaviour to be understood and corrected

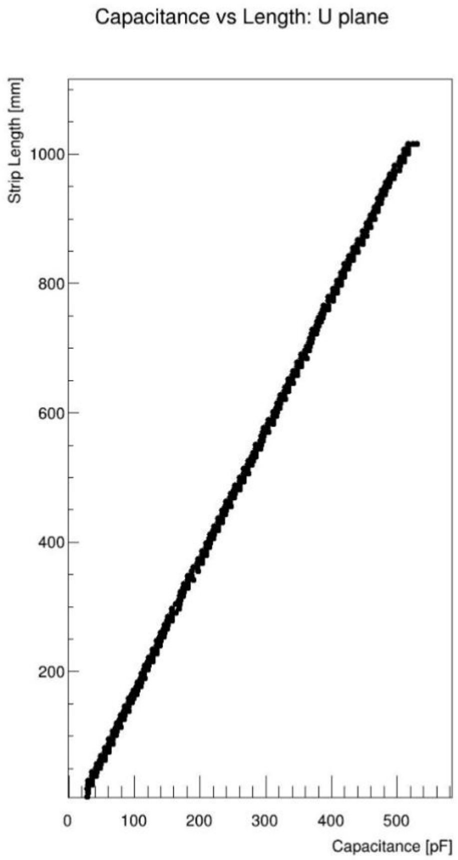
Glimpse of the first operation 4

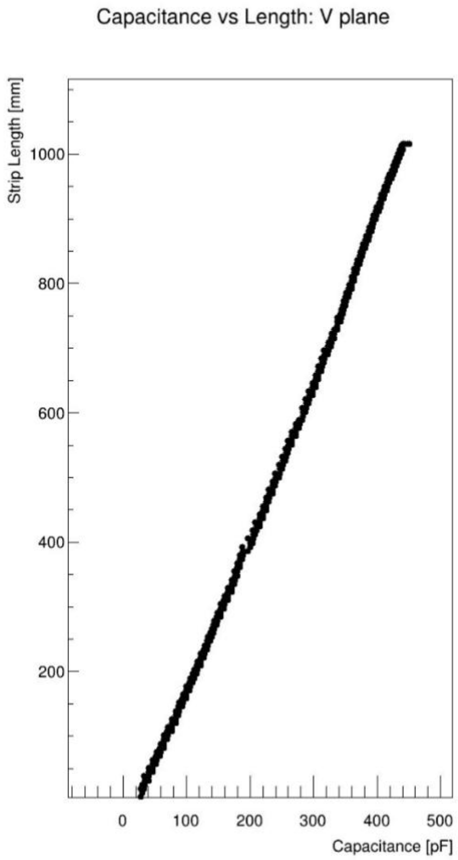




Why we see such a behaviour







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 must update the ASIC design features

21

Chiara Alice - DRD1 collaboration meeting - 10.12.2024

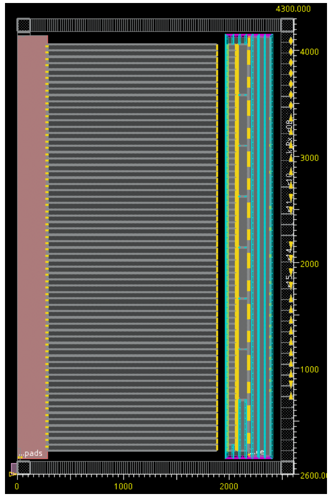
Torino Readout for AMBER (ToRA) ASIC

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

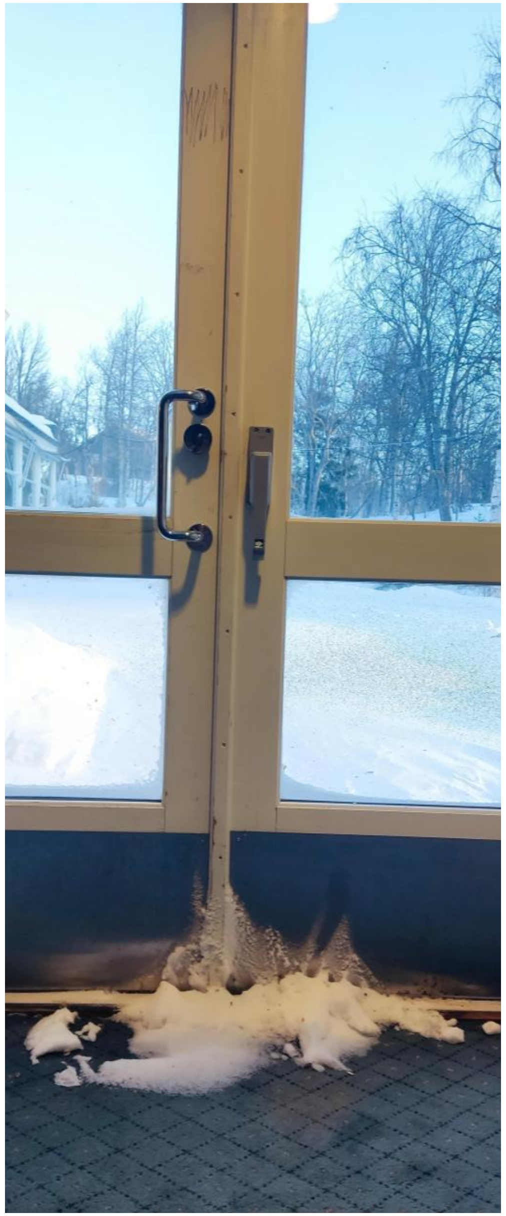
Detector	MM	Straw	
Channels/ASIC	64	64	
Power/channel	$\leq$5	$\leq$10	mW
Input capacitance	$\leq$550	20-100	pF
Input charge	1-100	1-1000	fC
Input impedance	$\leq$50 Ω	*tbd*	Ω
Max rate	$\leq$2	$\leq$0.18	MHz
Peaking time	150	75-150	ns
Time resolution	1-2	$\leq$1	ns
Charge resolution	8	10	bits
Gain	12	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

Conclusions

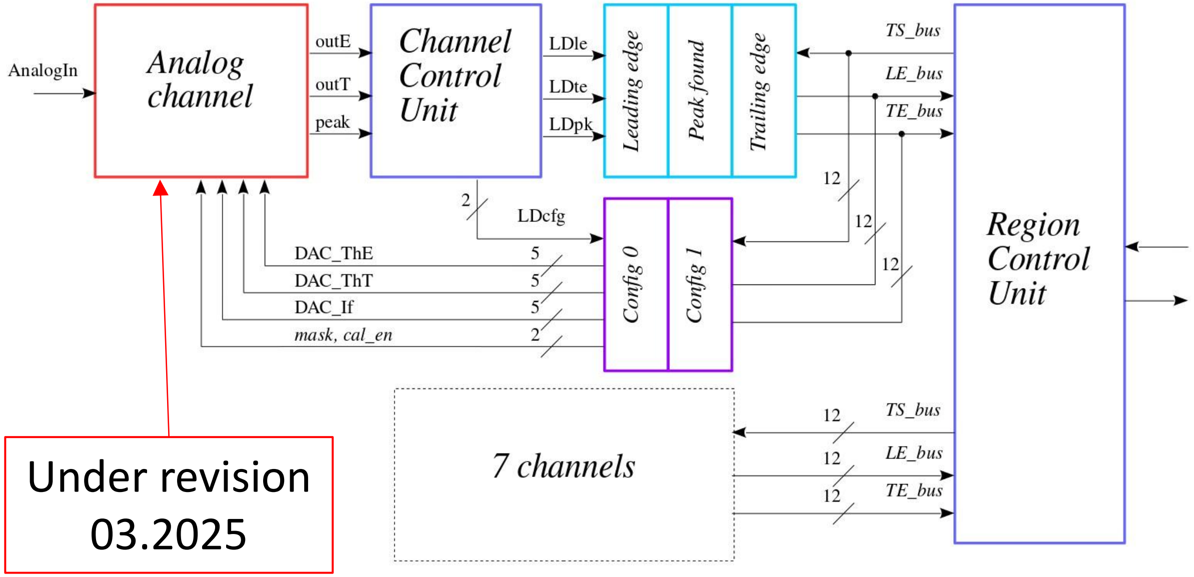
- First successful powering achieved
- Detector prototype is under test
- ToRA v1 ASIC design is optimised on the base of first detector tests and being prepared for submission
- Signal propagation and detector to FE coupling study ongoing



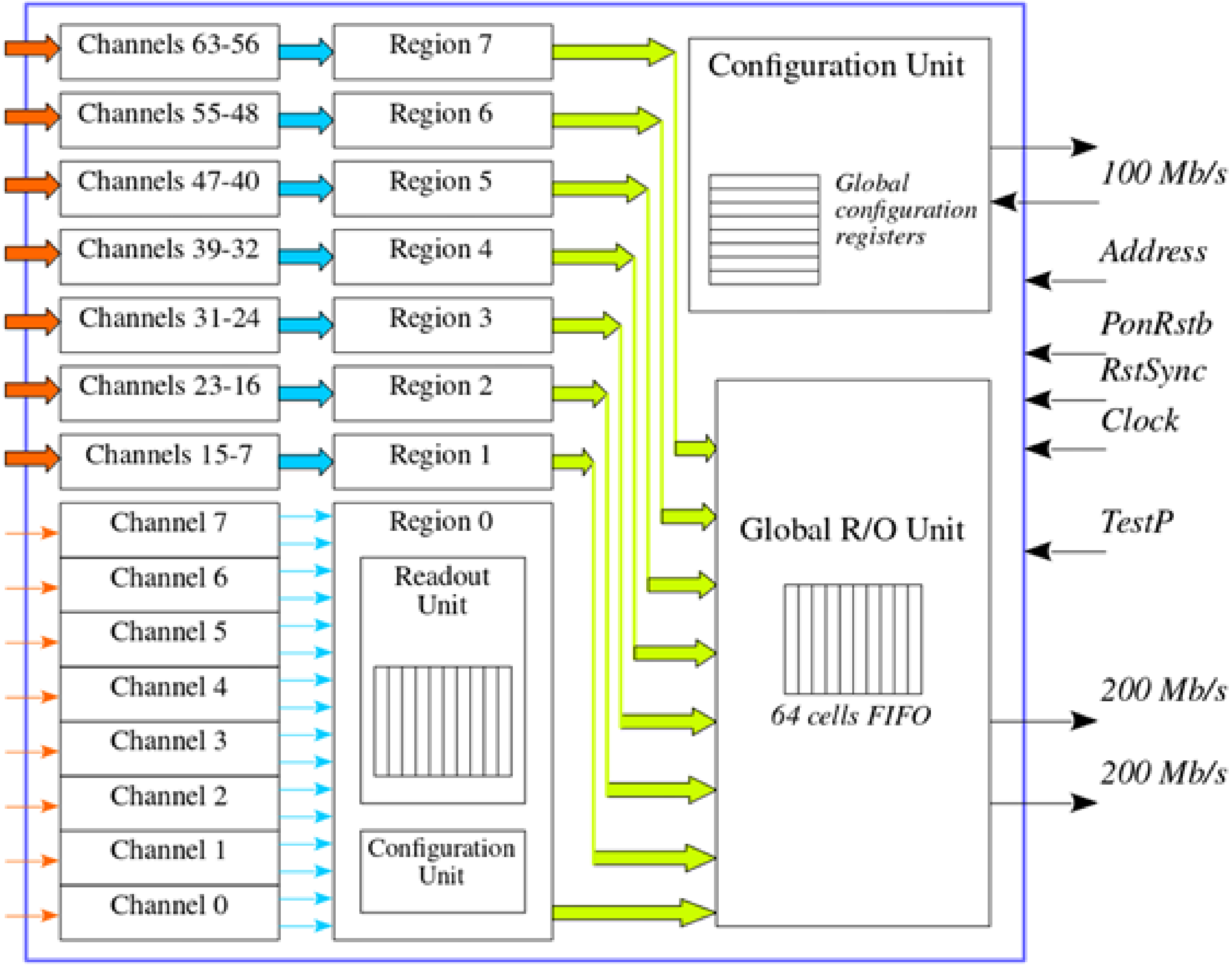
Spares



ASIC structure

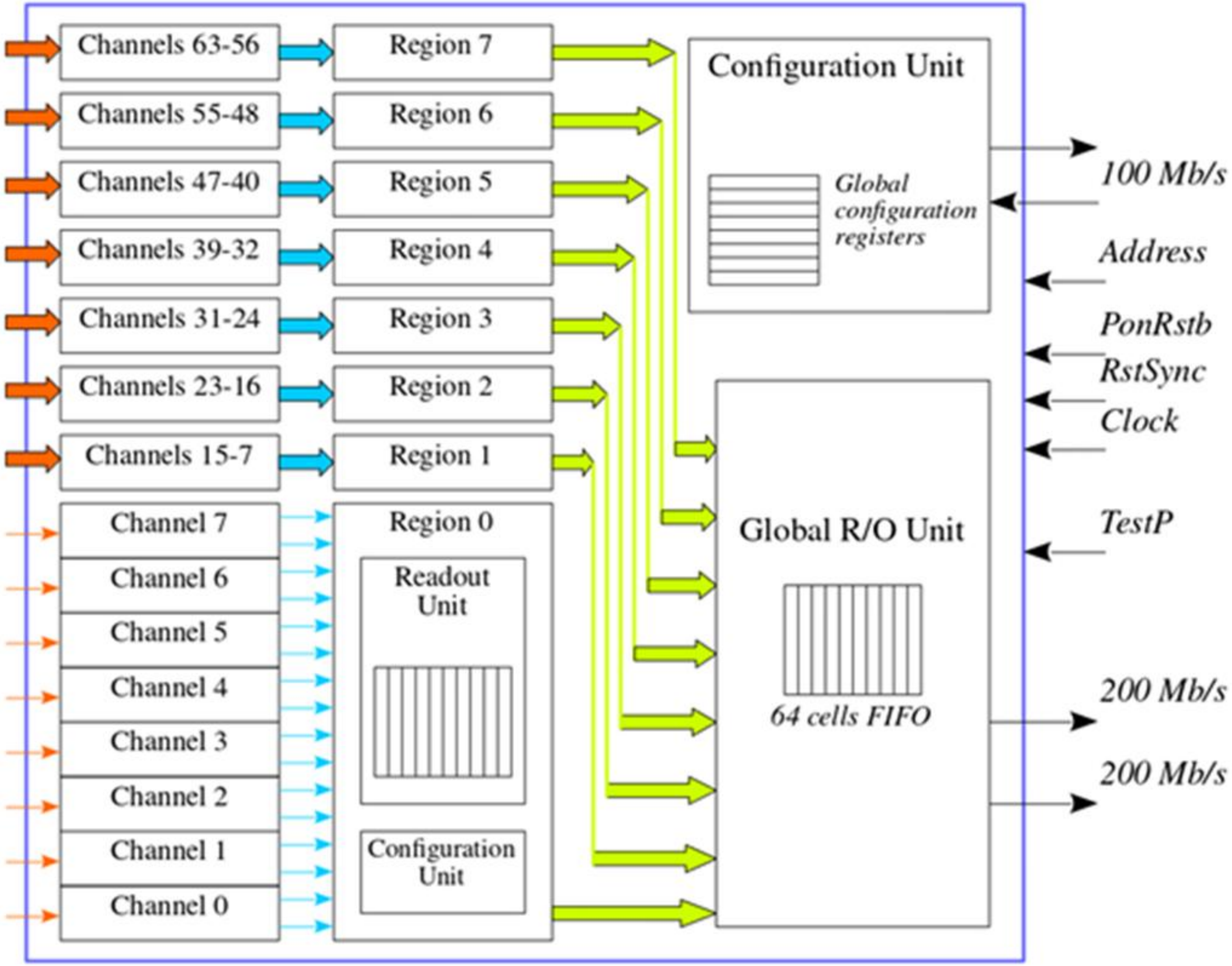


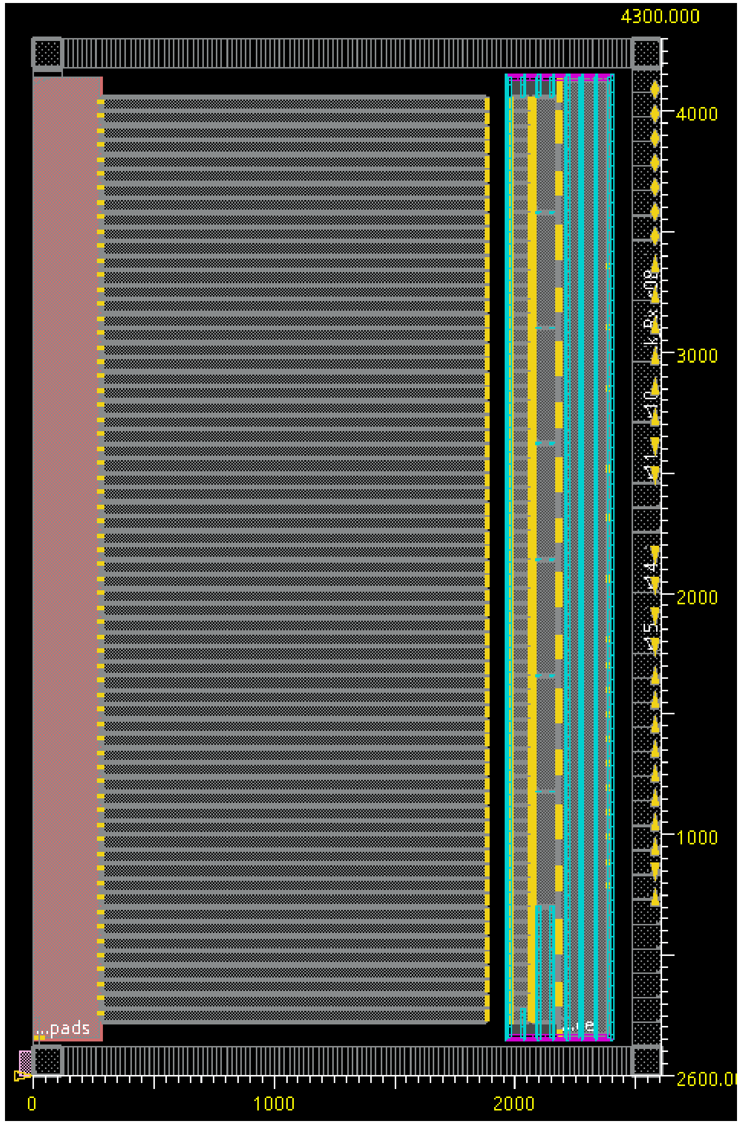
Under revision 03.2025



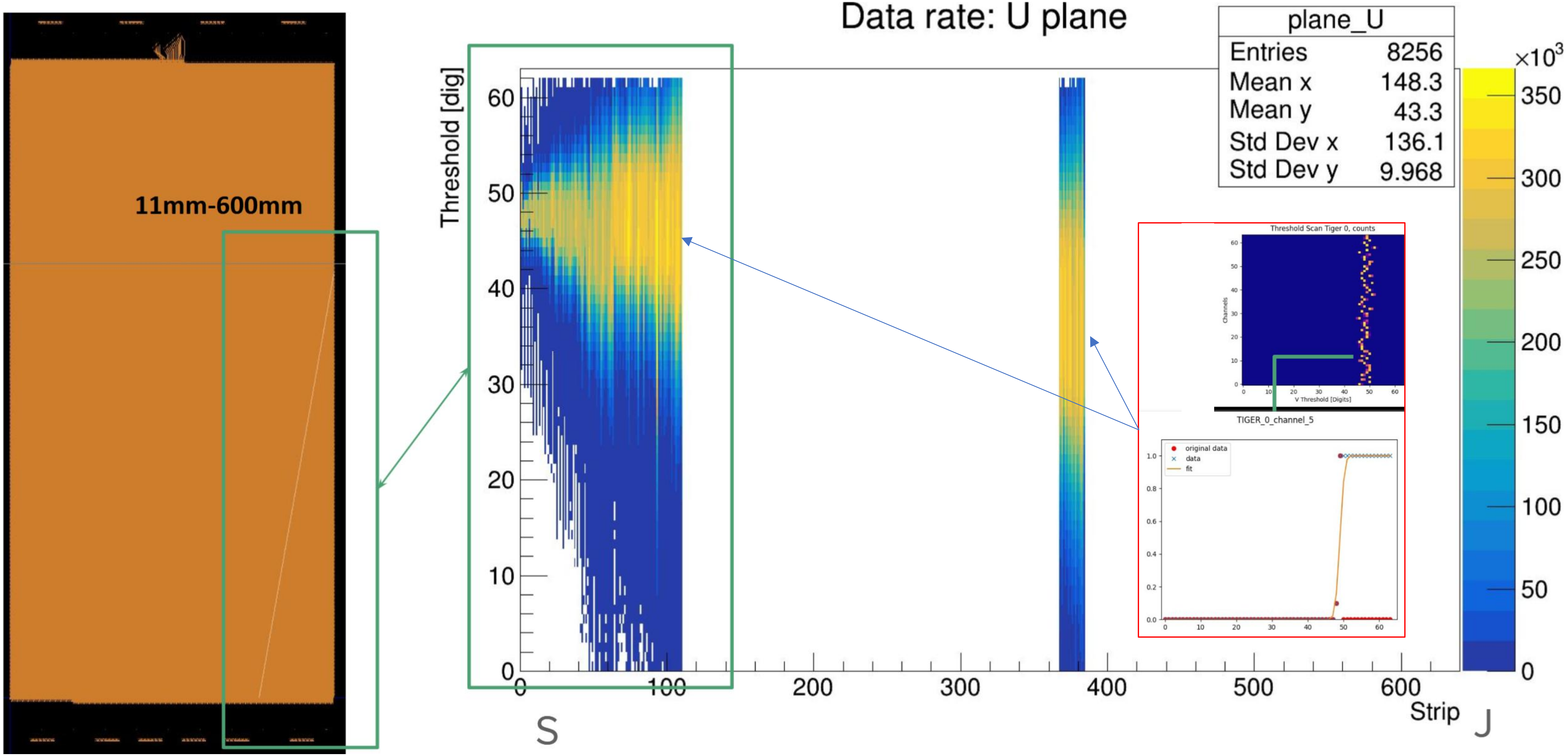
- Common time stamp distributed to all channels
- 3 data register for time acquisition
- 2 configuration registers
- Threshold and discharge current fine tuning

ToRA is preparing to go silicon

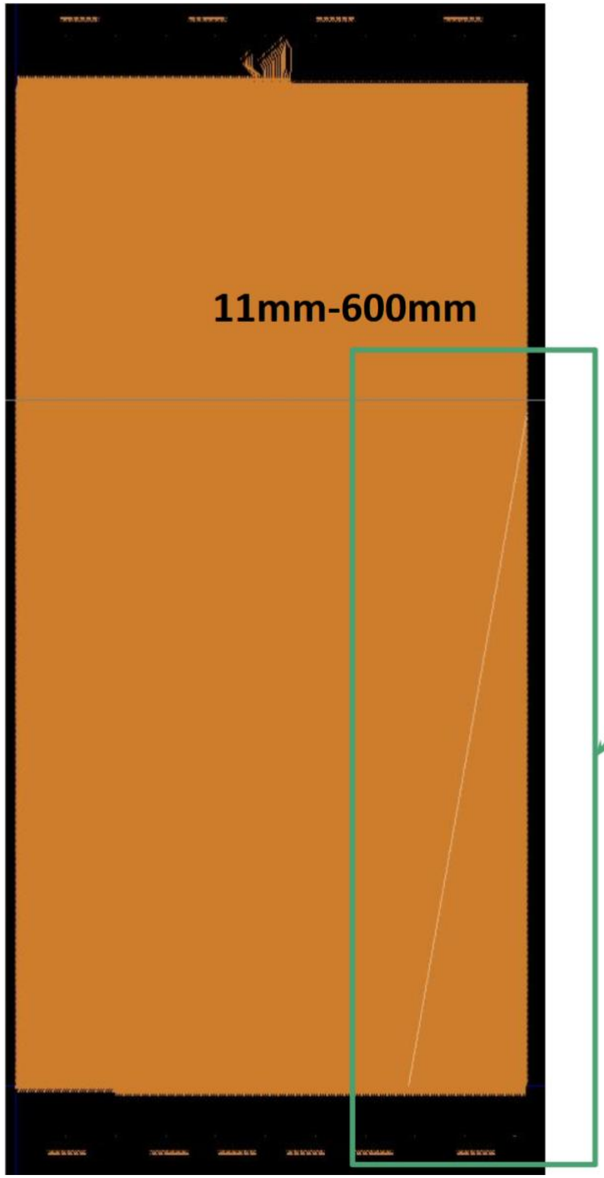


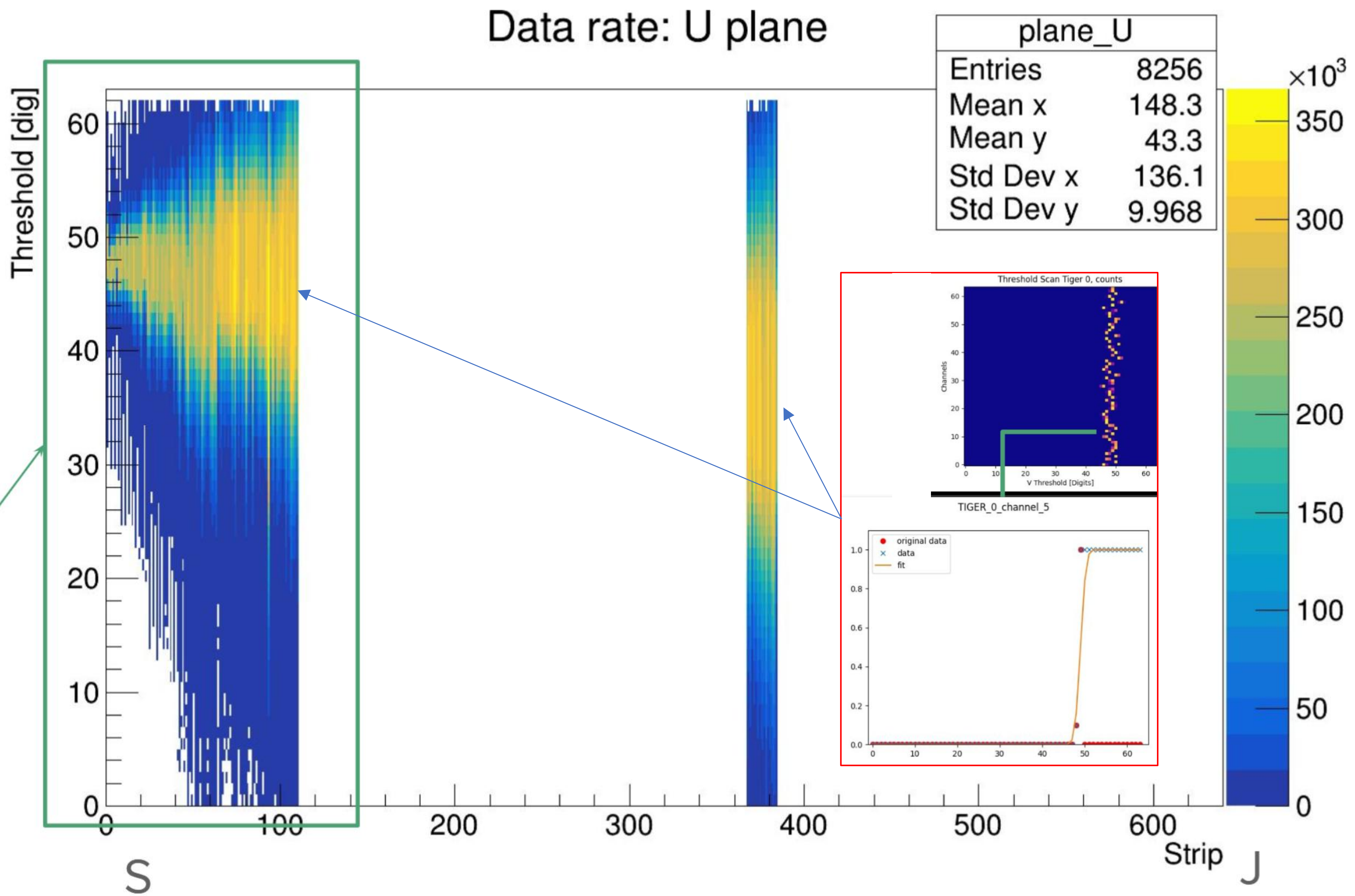


Glimpse of the first operation 2

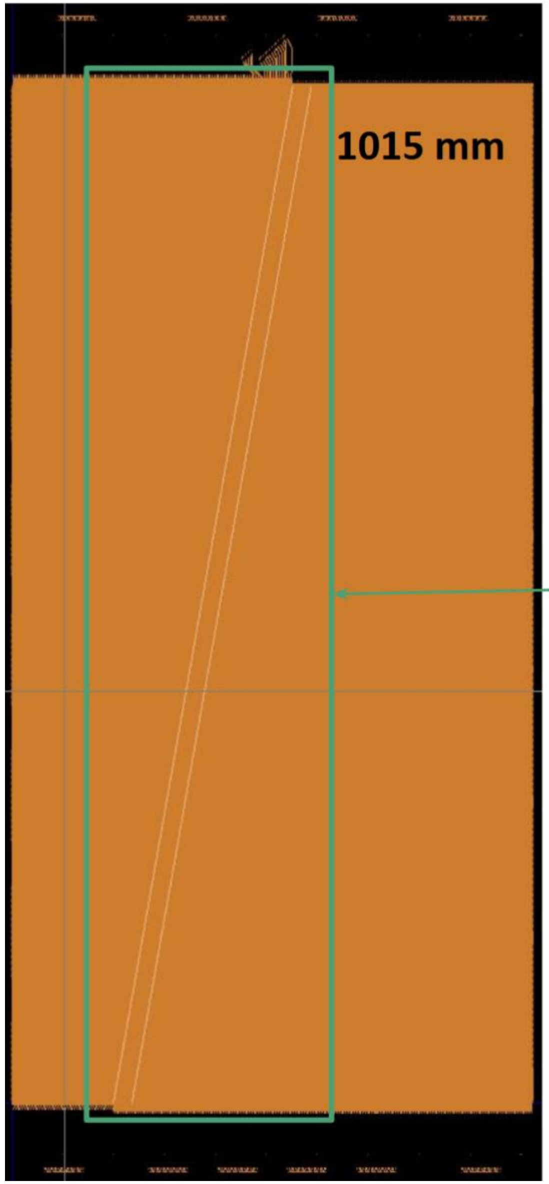


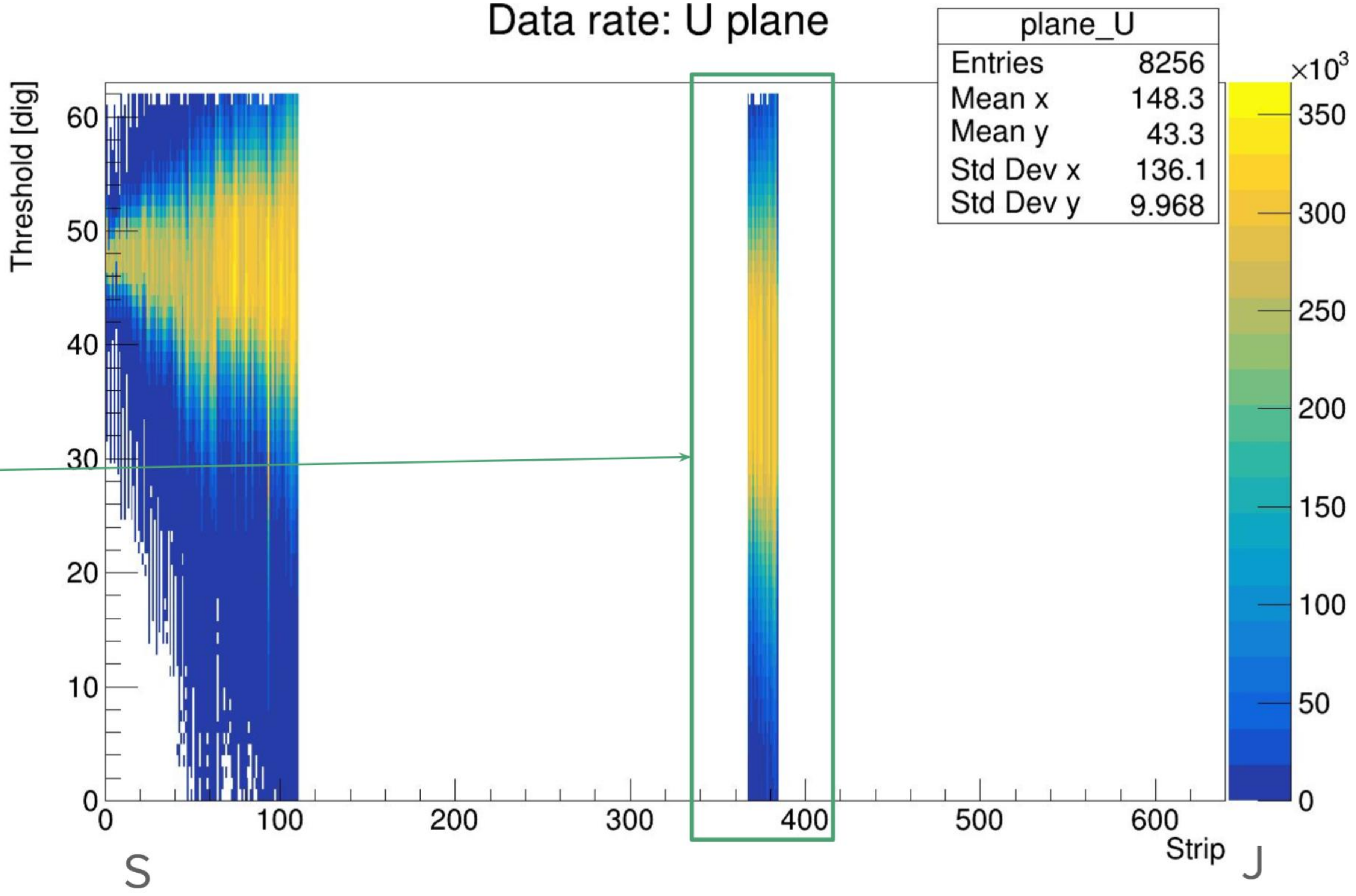
Glimpse of the first operation 2





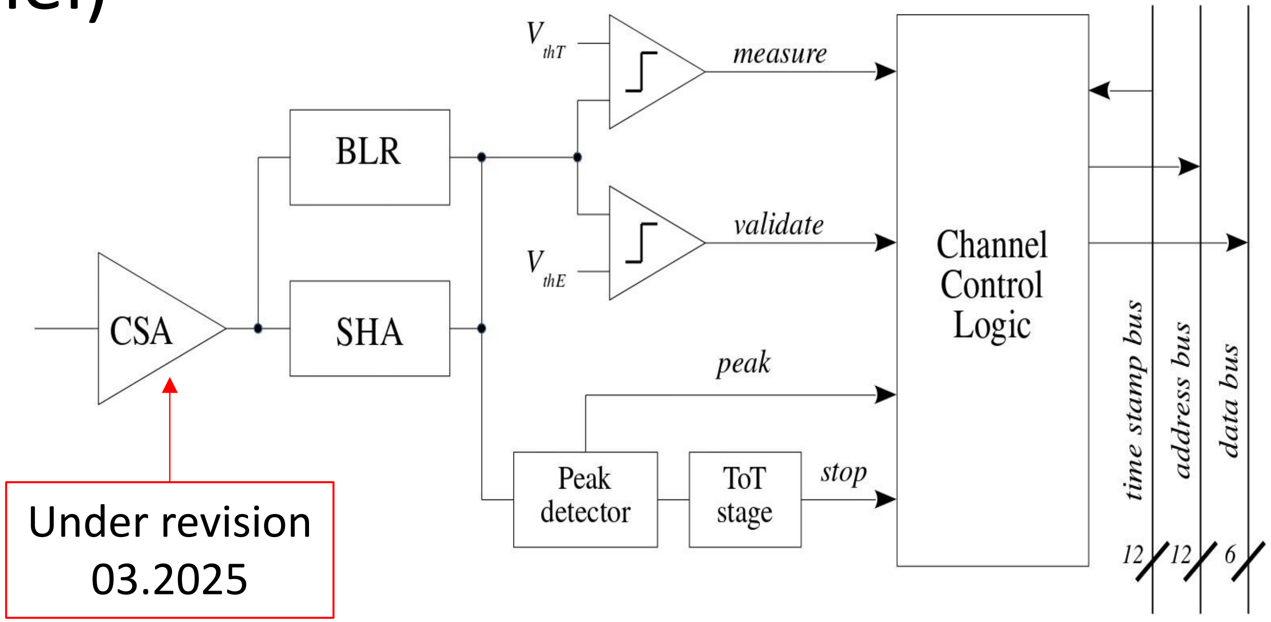
Glimpse of the first operation 3

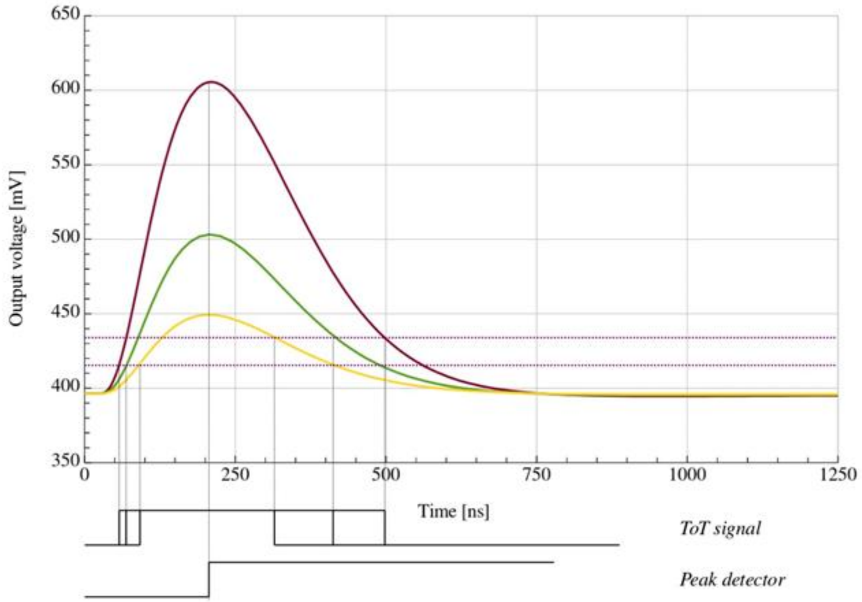


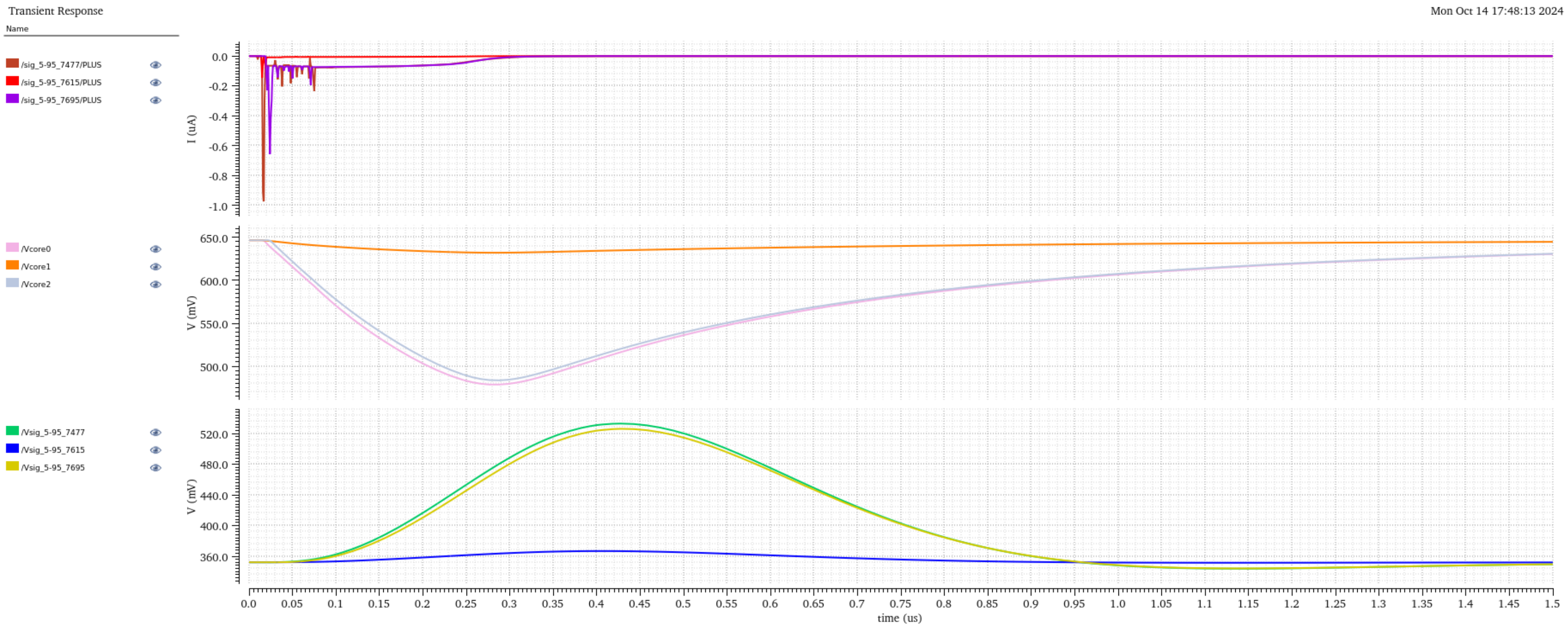


Analog part (single channel)

- Charge Sensitive Amplifier
  - Fours gains : 2,6,8 and 12 mV/fC
  - Possibility to accept inputs from both polarities
- Shaper
  - 3^{rd} 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 under evaluation

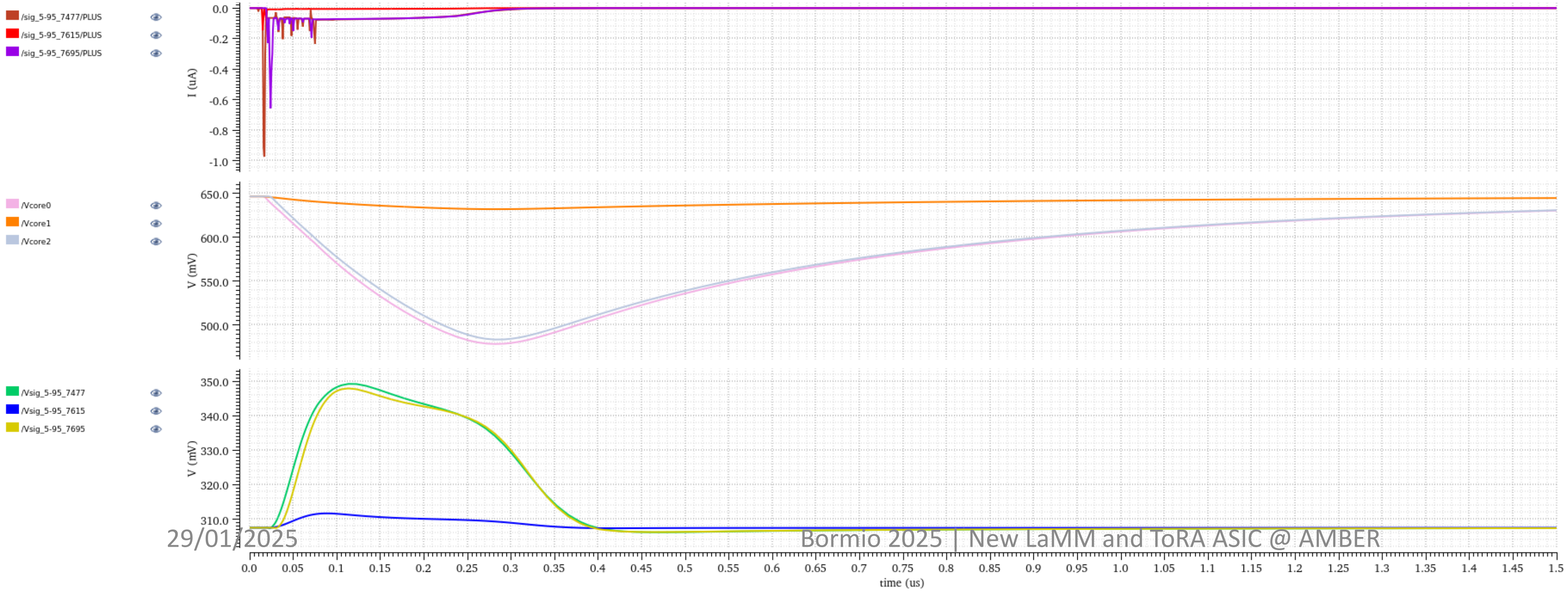






Transient Response
Mon Oct 14 17:48:13 2024 1
Name
/sig_5-95_7477/PLUS
/sig_5-95_7615/PLUS
/sig_5-95_7695/PLUS
I (uA)
/Vcore0
/Vcore1
/Vcore2
V (mV)
/Vsig_5-95_7477
/Vsig_5-95_7615
/Vsig_5-95_7695
V (mV)
time (us)

250 ns



/sig_5-95_7477/PLUS
/sig_5-95_7615/PLUS
/sig_5-95_7695/PLUS
I (uA)
/Vcore0
/Vcore1
/Vcore2
V (mV)
/Vsig_5-95_7477
/Vsig_5-95_7615
/Vsig_5-95_7695
V (mV)
time (us)

25 ns

Main ideas

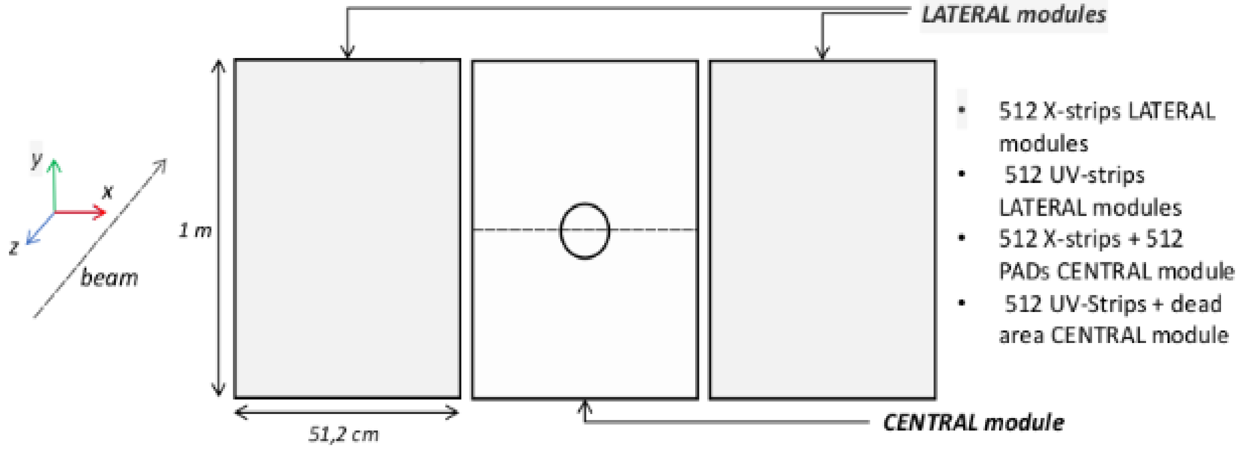
- As simple as needed
- Based on existing design
- Tuned to limited use cases
- Trigger less

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???

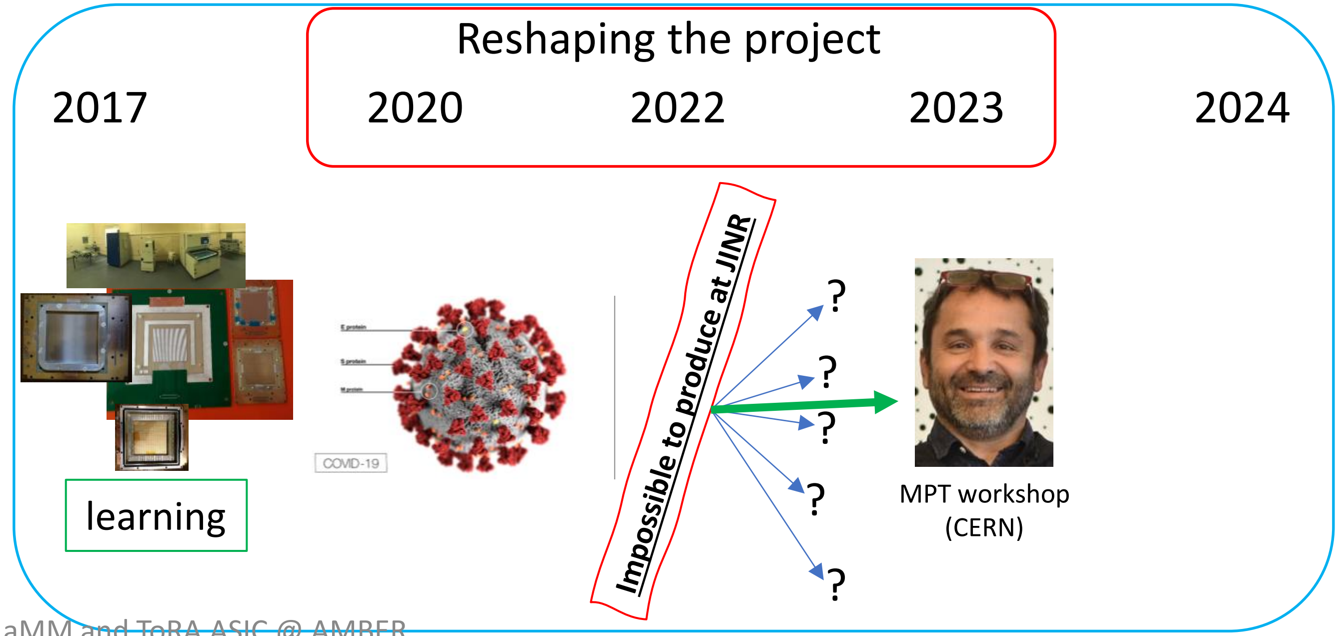
Concept design

- Micromegas based detectors
- Not exceeding the base PCB technology sizes
- Reduced material in the acceptance
- Reproduce the aged MWPCs performance
- Eventually add a pixel centre to cover the whole surface



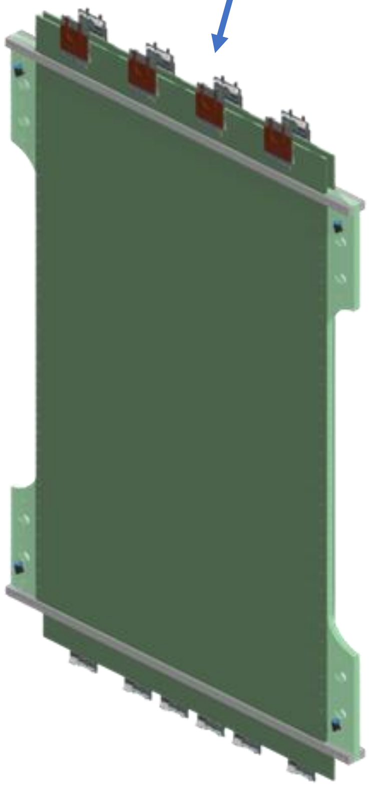
Very tight schedule → Reduce the R&D time and risks

- ➢ Full size lateral module prototype in autumn 2024
- ➢ Full size central module prototype in autumn 2025/2026



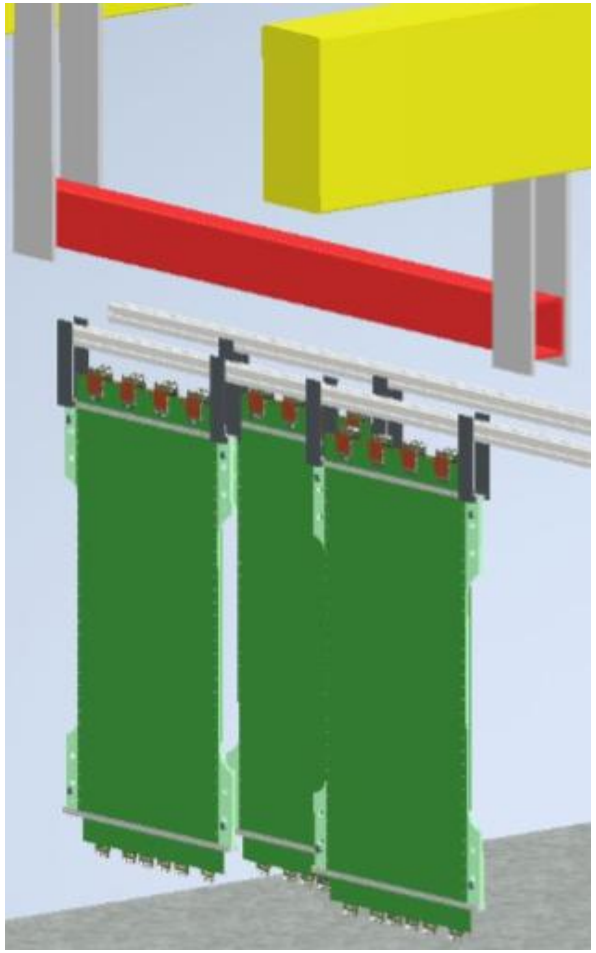
One needs to ask a true engineer

How do I fit this?



There

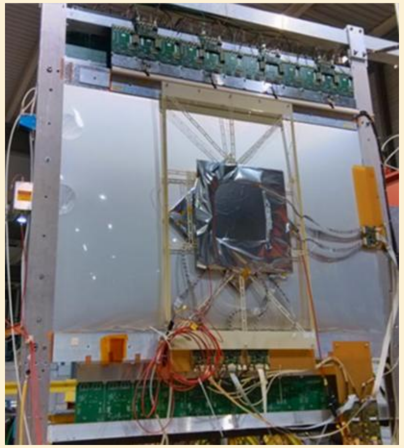
Some moments later

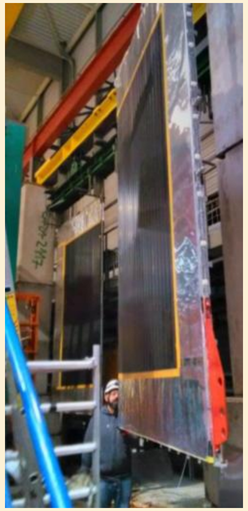


Motivation

AMBER upgrade

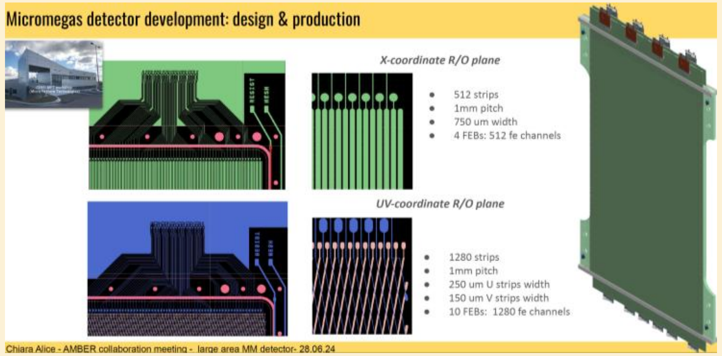
MWPC, Drift





+ Non Torino Wire detectors

Micromegas, GEMs?



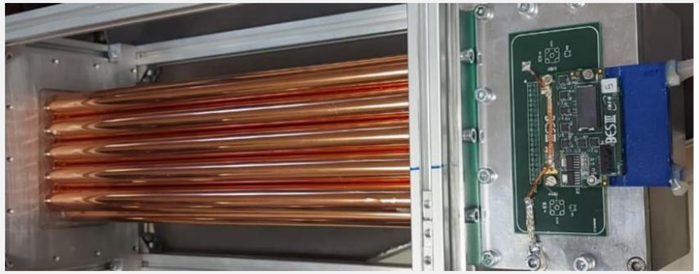
+ needed new vertexing MM?

Wire

MPGDs

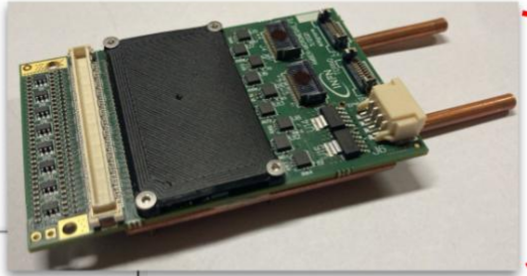
General use

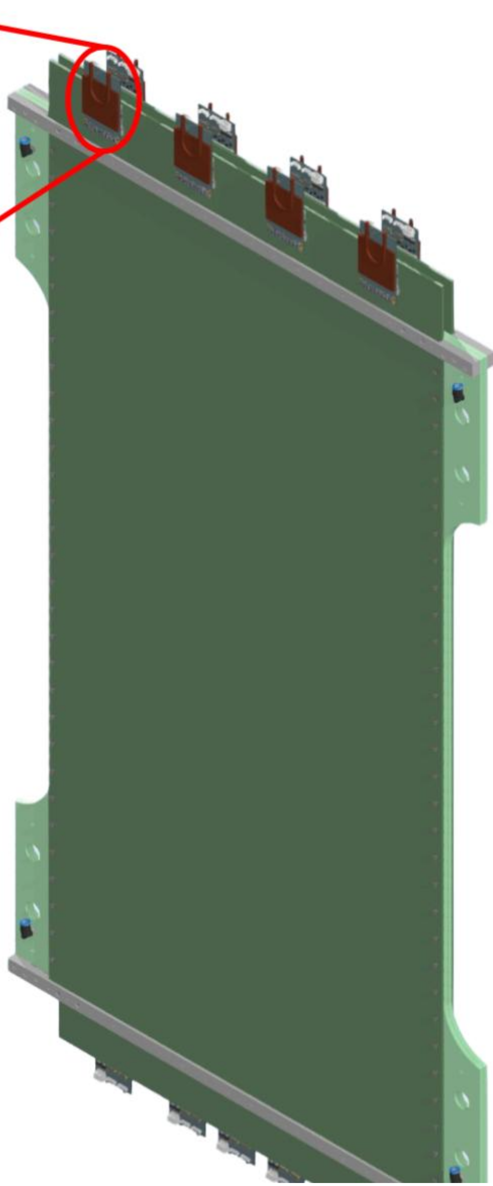
STRAWs

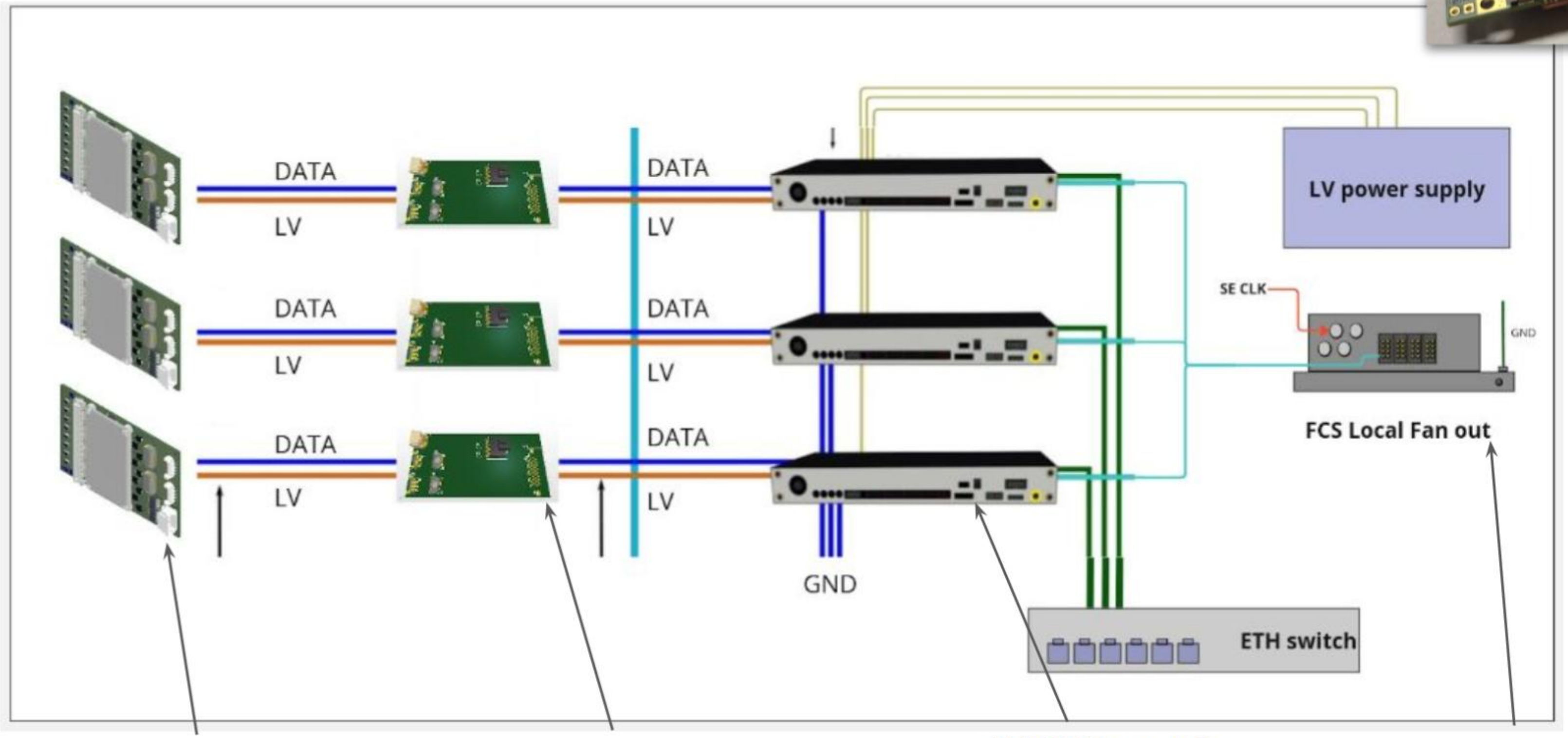


MPGDs

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

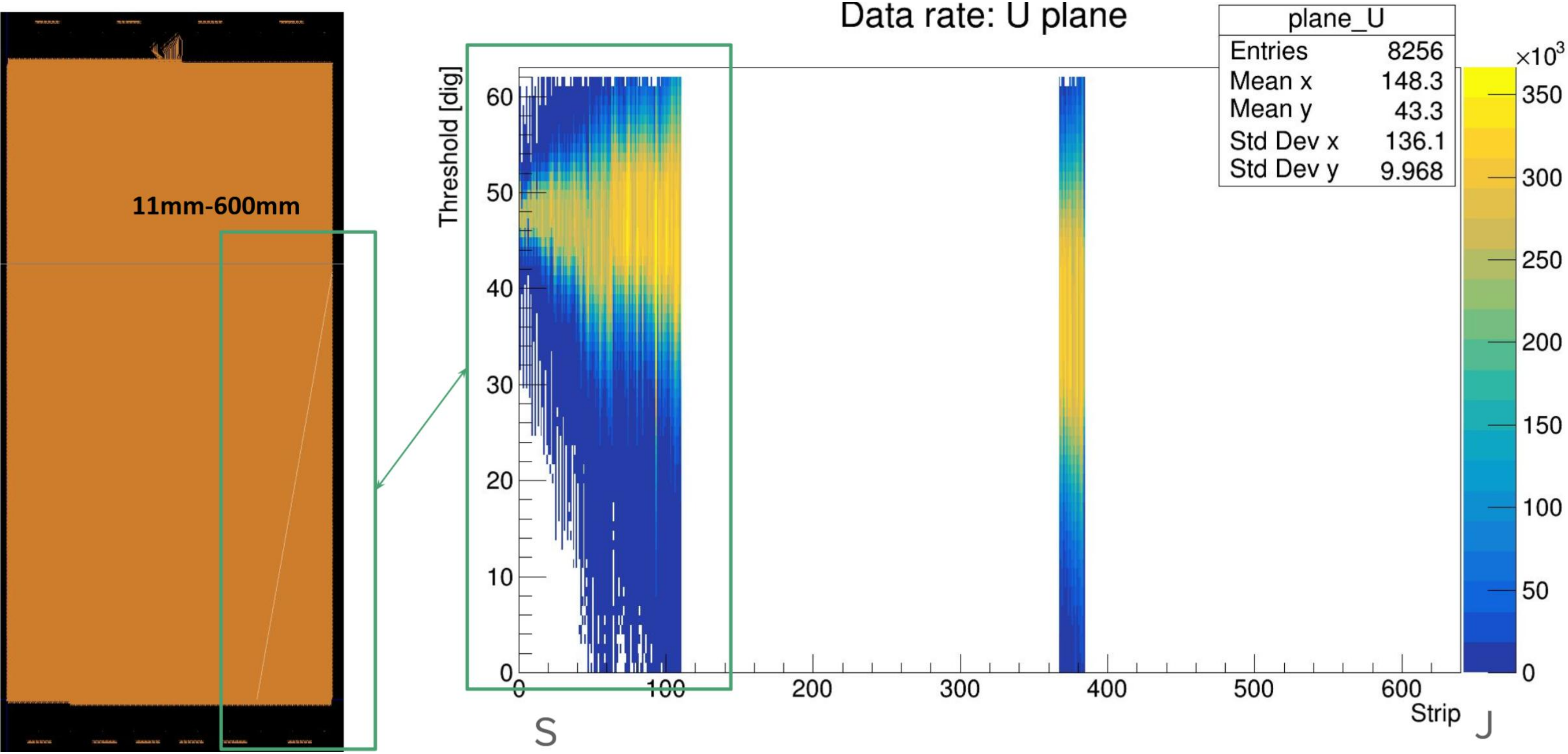
Configuration and control signal distribution
Data concentration

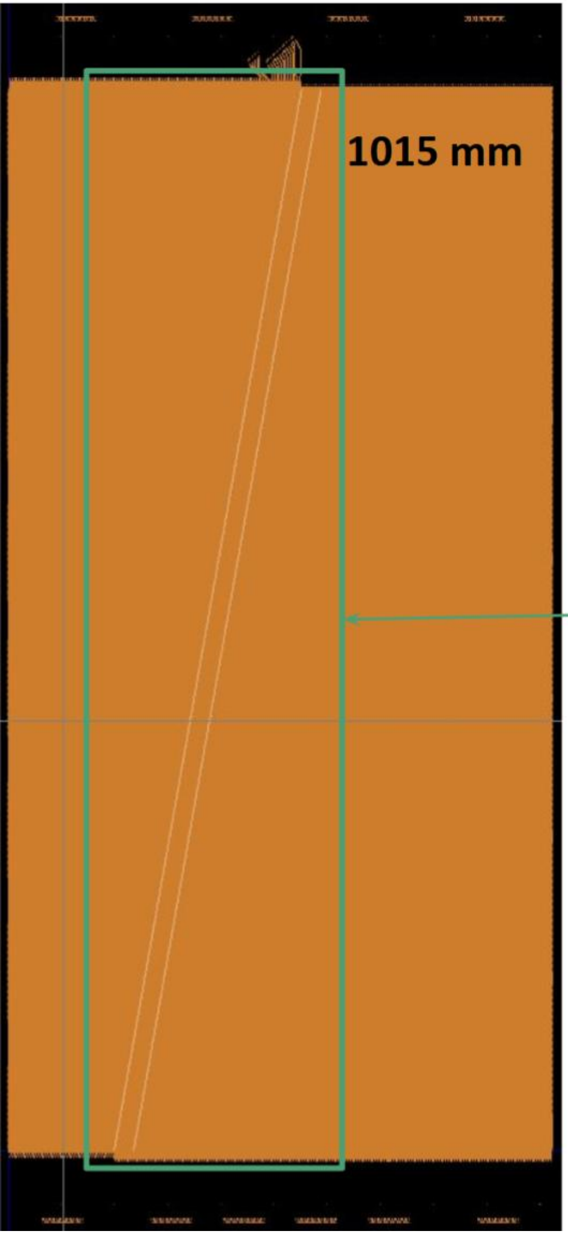
Local FAN OUT
designed at INFN Fe

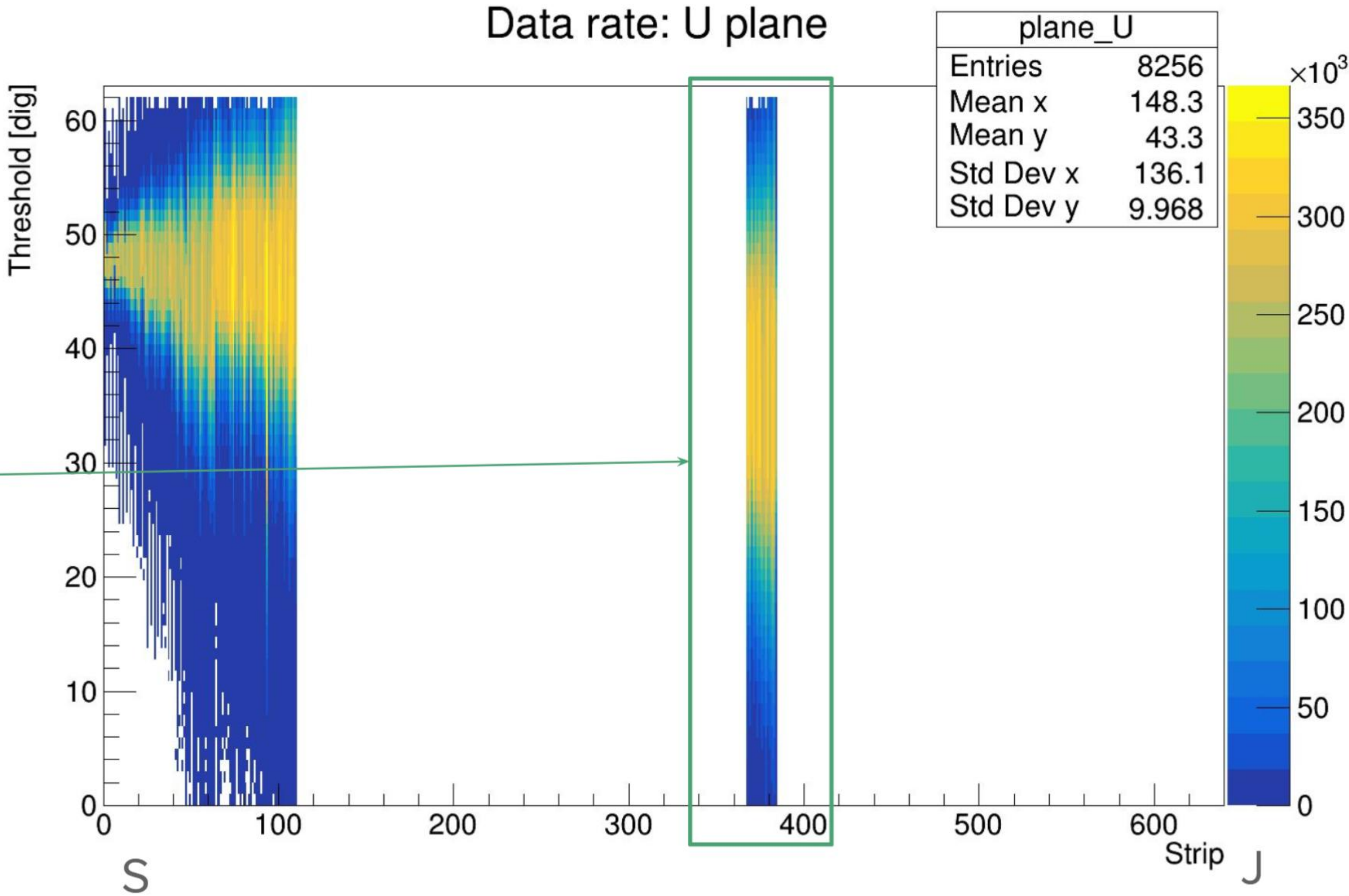
Trigger and clock distribution

6 TIGER-febs available:

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


11mm-600mm
Data rate: U plane
plane_U
Entries 8256
Mean x 148.3
Mean y 43.3
Std Dev x 136.1
Std Dev y 9.968
Threshold [dig]
Strip
S
J
$\times10^3$


1015 mm


Data rate: U plane
plane_U
Entries 8256
Mean x 148.3
Mean y 43.3
Std Dev x 136.1
Std Dev y 9.968
Threshold [dig]
Strip
×10³
S
J

ToRA (**To**rino **R**eadout for **A**MBER) ASIC development remark

- Main idea to have a fully digital relatively simple ASIC adapted to the MPGD and Wire detectors

- The design approach seems to be agreed

  V1(sub. 2024) – base features set targeting the MM

  V2(sub. 2025) – extended features set for MM + Wire (time+charge)

- We have some ~2 mouth delay due to the decision taken in June to change from 110 nm node to the 65 nm

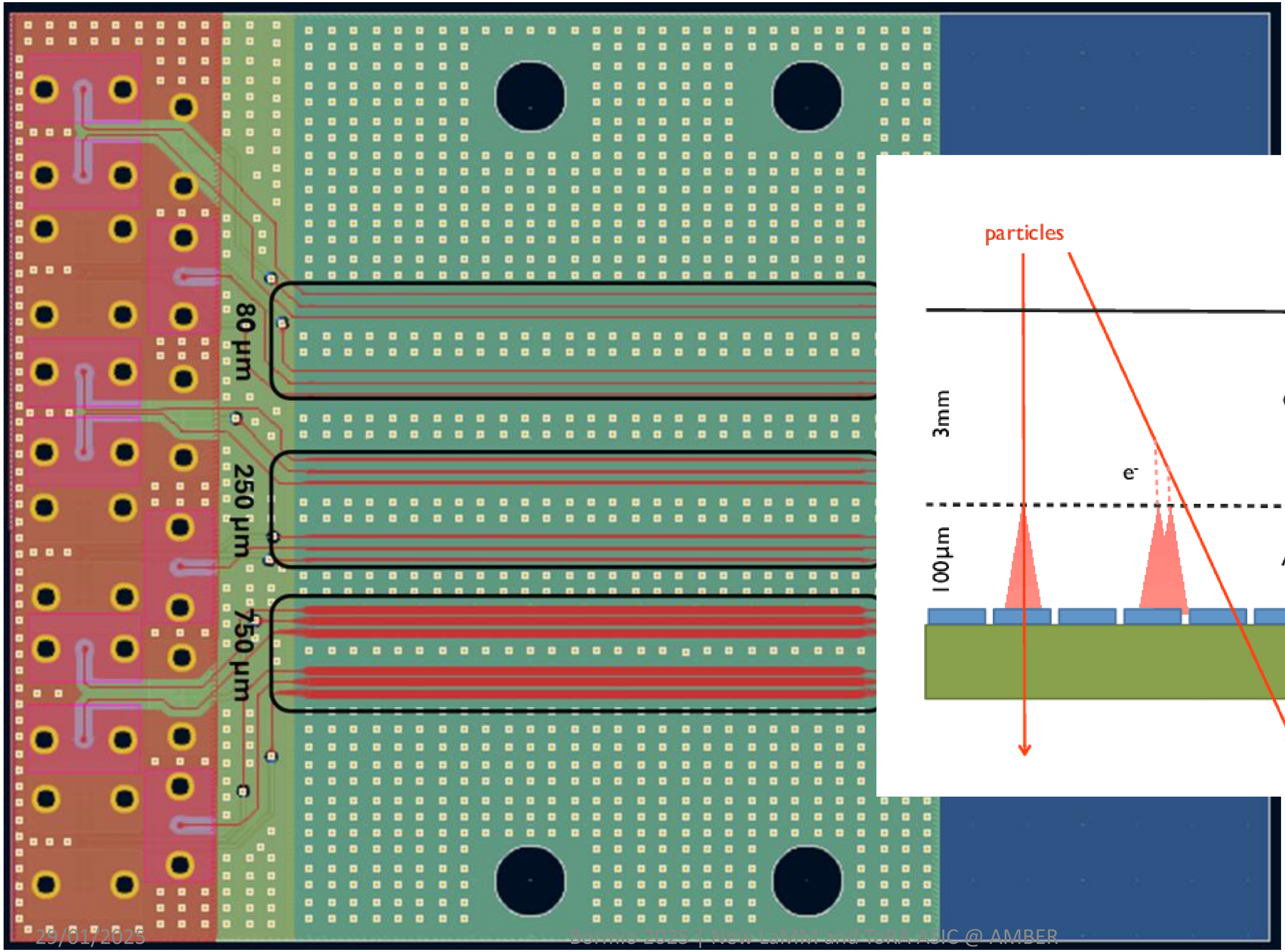
- Presently the submission is expected for 11.2024

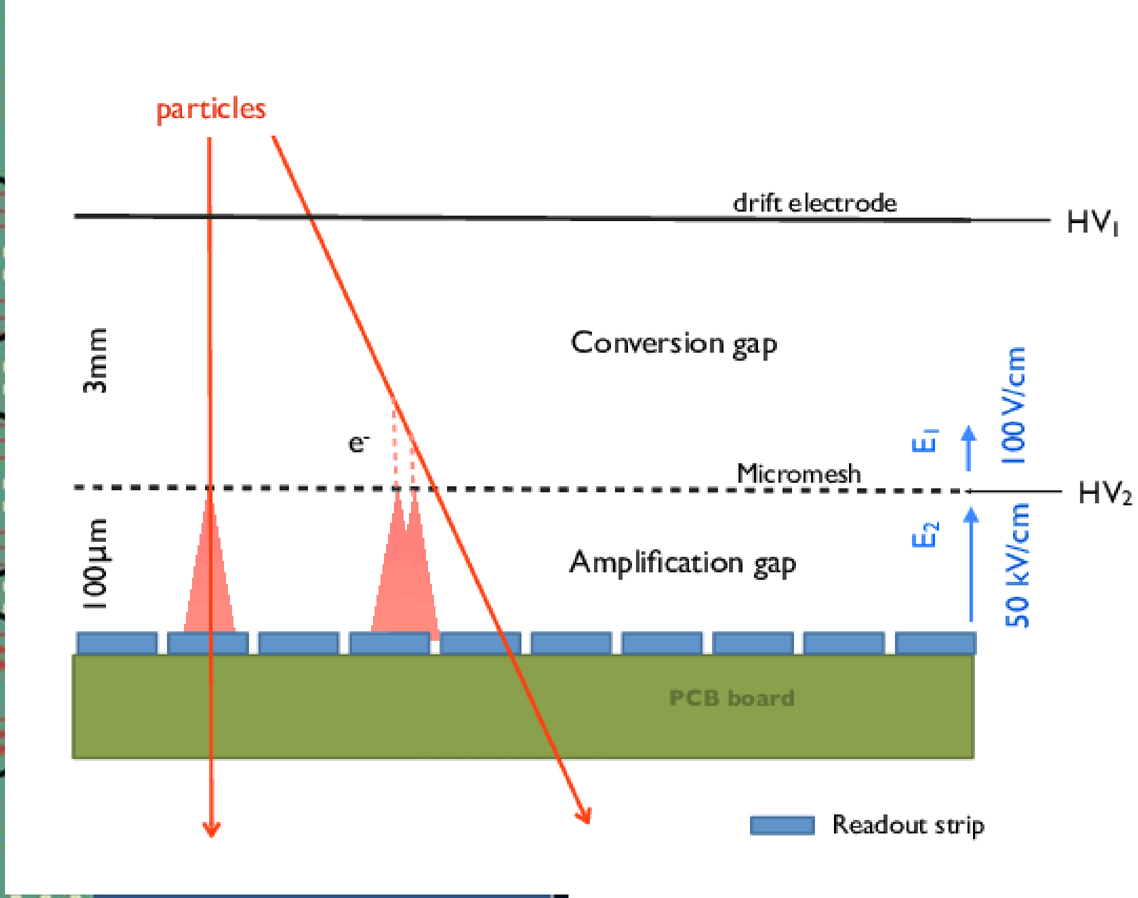
- Delivery expected in 01.2025

- Characterization DAQ manpower has been allocated

V1 specific		
Node		65nm, TSMC
Size, mm2		~4x3
Power, mW		~10/ch
Ref_CLK, MHz		40-200
Sustained rate on 64ch, kHz		
Doble hit resolutin on ch, ns		1000
CH config		
	Impedance	<= 50 Ω (const) to 1 GHz
	Coupling	DC
	Polarity	Pos/Neg
	Noise, ENC	1000 @ 150pF
	Gain, mV/fC	2,7,12
Shpaer		
	Peakig time, ns	25/150/250
TDC		
	type	Thr. Crossing (rising edge)
	Resol (bin), ns	5 ns
ADC		
	type	Falling edge - Peak time stamp
	Discharge DAC	8 bit resol

Any contribution interest to test is welcome, pls. contact us


80 µm
250 µm
750 µm

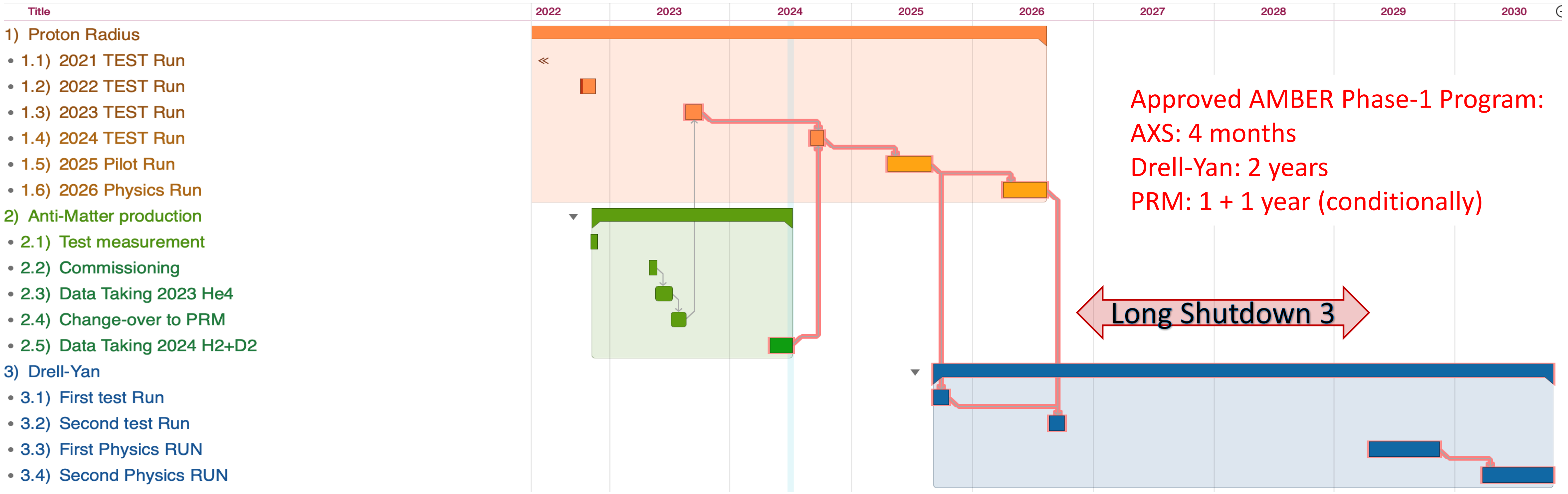

particles
drift electrode
HV1
Conversion gap
3mm
e-
Micromesh
HV2
E1
100 V/cm
E2
50 kV/cm
100µm
Amplification gap
PCB board
Readout strip

AMBER Phase-1 running plan

Apparatus for Meson and Baryon Experimental Research

Milestones:

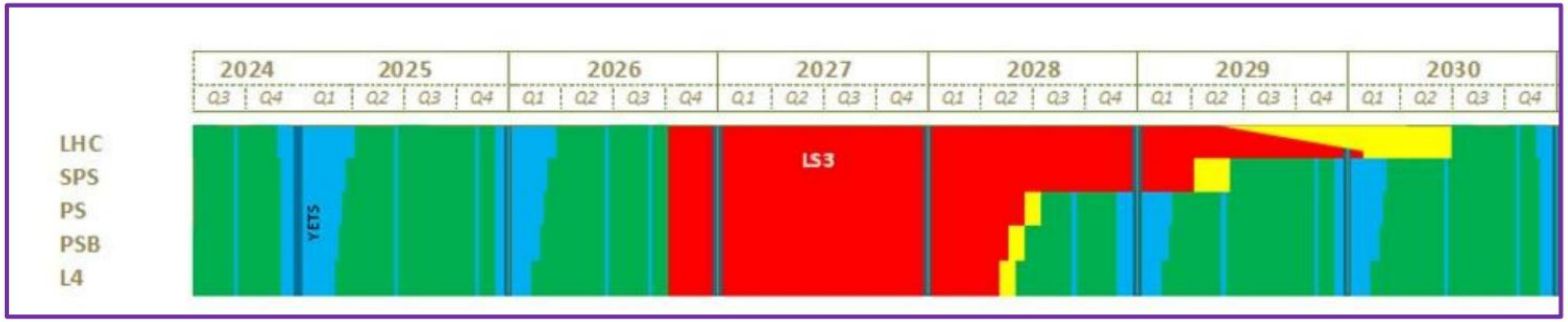
1. May 1st 2023, 2024 – Antimatter production Run (Std. DAQ)
2. Sep. 1st 2024 – PRM Test (FriDAQ, very limited setup)
3. June. 1st 2025 – PRM Pilot (FriDAQ, limited setup)
4. May. 1st 2026 – PRM Physics (FriDAQ, PRM setup)
5. Sep. 1st 2025, 2026 – DY Test (FriDAQ, all trackers + mu id)
6. May 1st 2029/30 – DY Run (FriDAQ, full Drell-Yan setup)



Approved AMBER Phase-1 Program:
AXS: 4 months
Drell-Yan: 2 years
PRM: 1 + 1 year (conditionally)

LHC and Injectors (PS, SPS) long term schedule

Revised timeline being considered



- Provisional schedule
  Feasibility and acceptability being evaluated
- Start in October 2026, ions run in September 2026
- Beam back in the LHC in July 2030
  - LHC experiments caverns closure : 16.06.2030
  - LHC beam vacuum valves opening : 28.06.2030
- LS4 delayed by one year