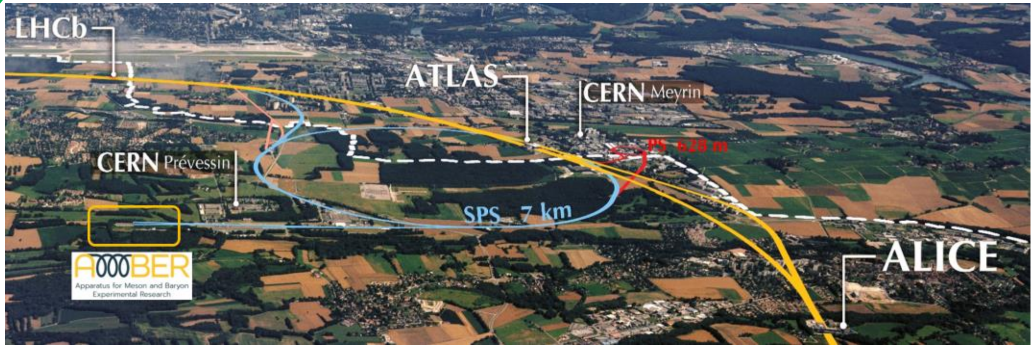
Development of a new large area Micromegas detector and its ToRA-based readout electronics for AMBER experiment at CERN

M. Alexeev on behalf of the design working group

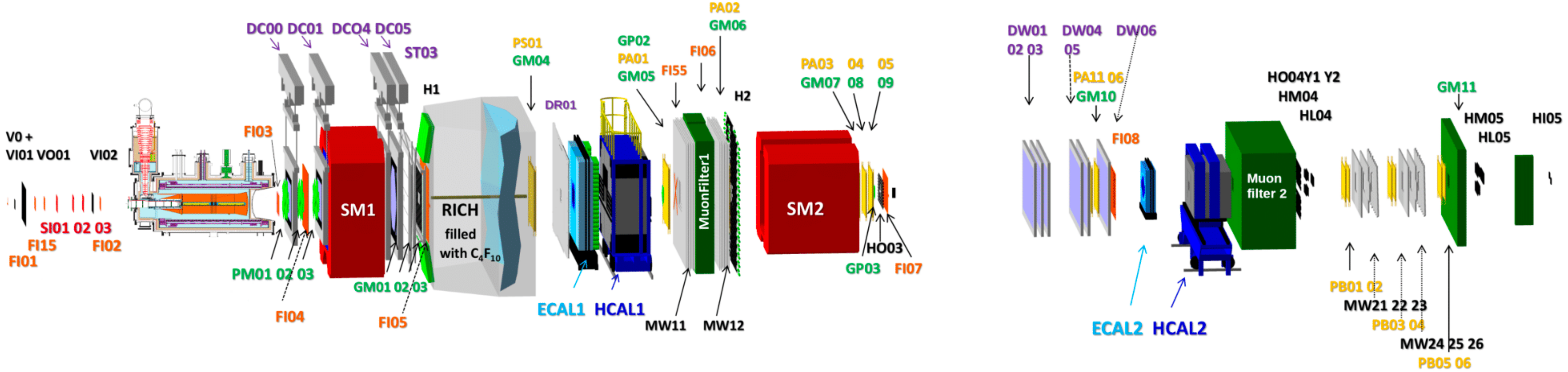
Università di Torino & INFN Torino & CERN

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

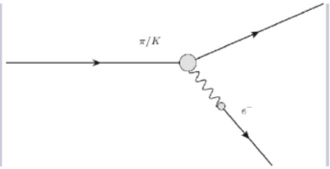


Phase-2 proposal in preparation
Post LS4 ->



Join us!

AMBER program

	Beam	Target	Additional Hardware
Proton radius measurement	100 GeV muons	high pressure Hydrogen	active target TPC, tracking stations (SciFi, Silicon)
Antiproton production cross section	50 GeV - 280 GeV protons	LH_2, LHe	Liquid He target
Drell-Yan measurements with pions	190 GeV charged pions	Carbon, Tungsten	vertex detector
Drell-Yan measurements with Kaons	~100 GeV charged Kaons	Carbon, Tungsten	vertex detectors, 'active absorber'
Prompt photon measurements	> 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		

Done (2023 – 2024)

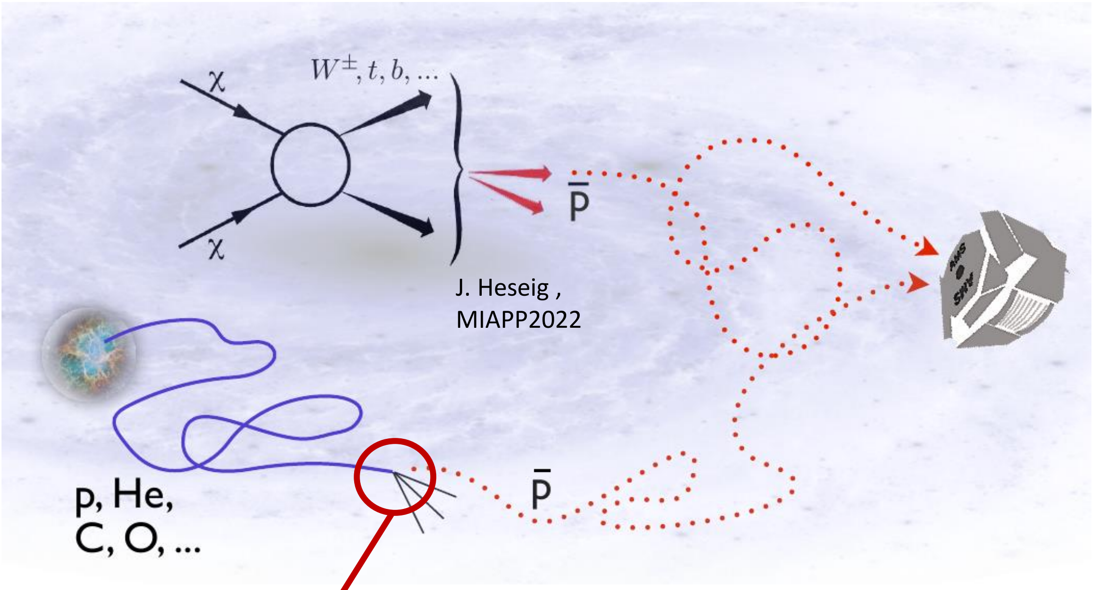
Phase 1 (approved)

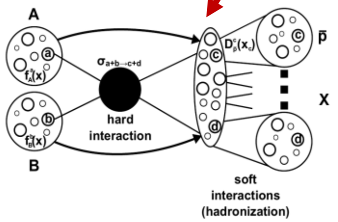
Phase 2 (in preparation)

2023 -> 2032

Beyond LS4

AMBER APXs (2023-2024)





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

Antiprotons arise from spallation processes and possible 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 1 week Test run APXS	May-July 2023 Physics APXS	May-July 2024 Physics APXS

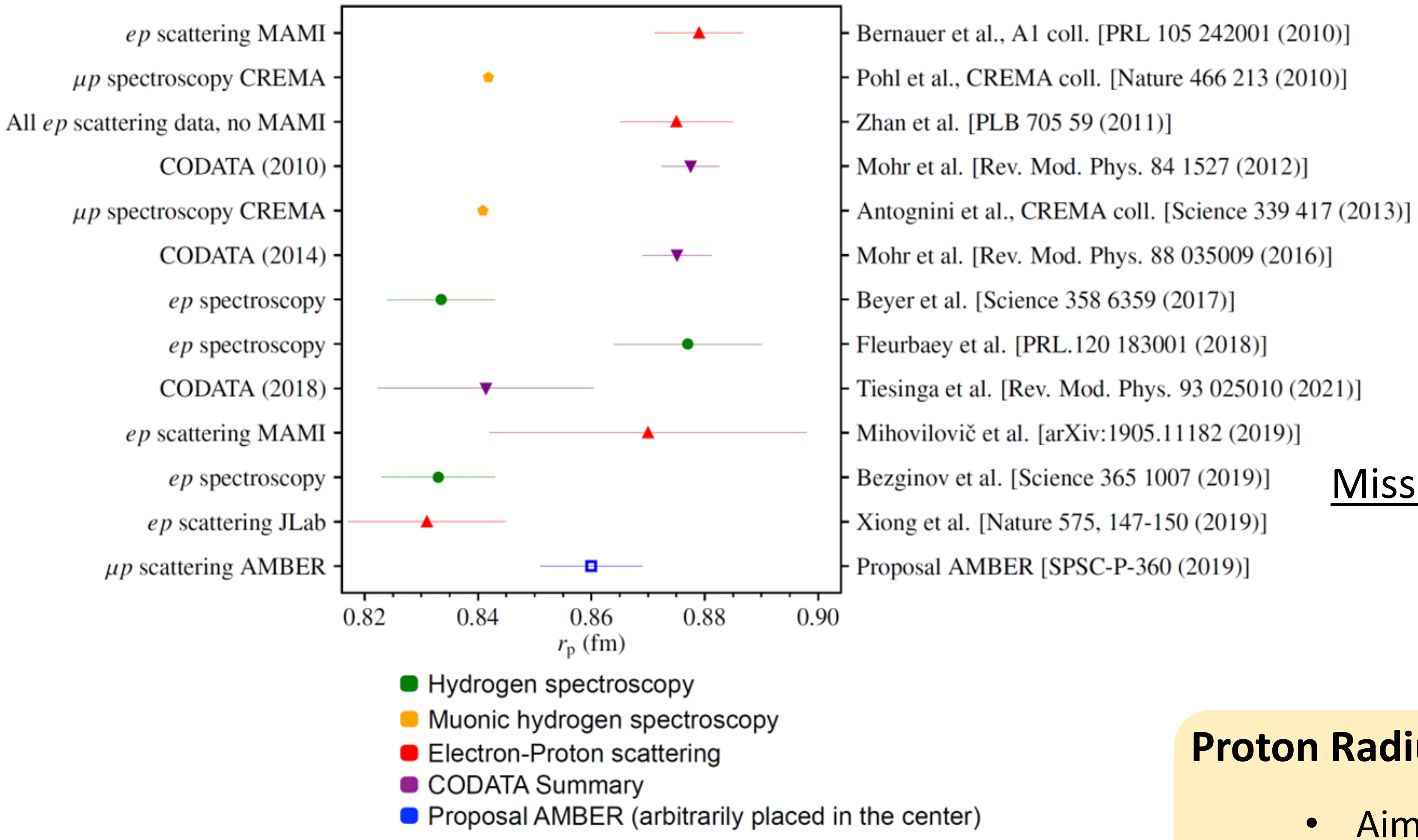
Minimum bias trigger: beam trigger with veto on non-scattered beam particle

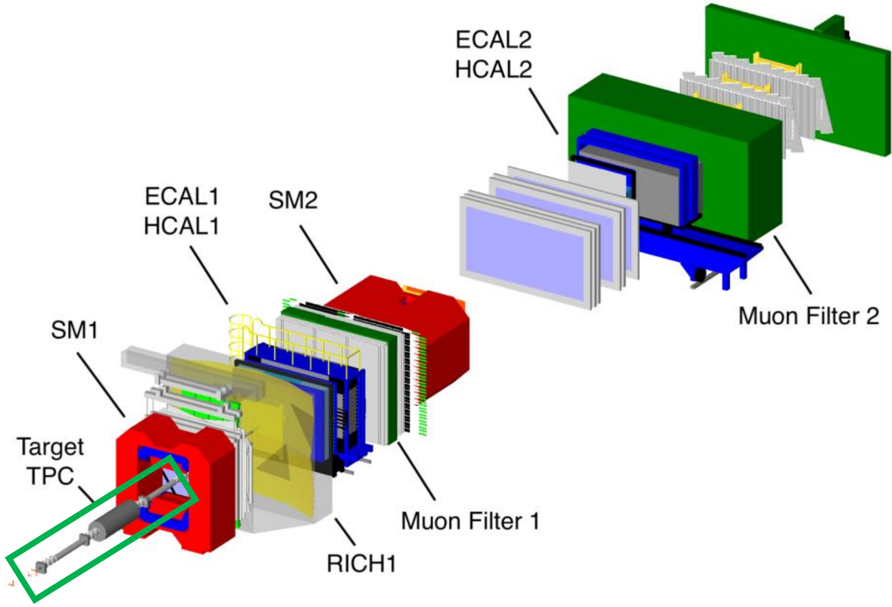
The major uncertainties in the current antiproton flux interpretation stem from the poor knowledge of the antiproton production from prompt reactions (mainly p+p and p+He) and from antineutron decays.

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.

AMBER PRM (2025/2026)

Proton-radius puzzle





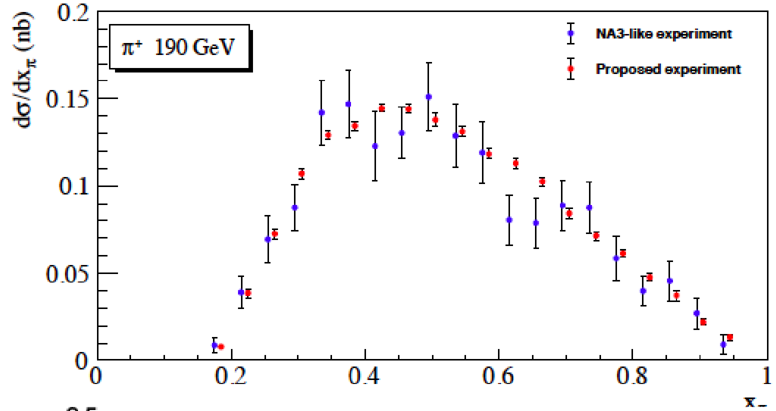
Missing: muon-proton with E_μ of 10 - 100 GeV

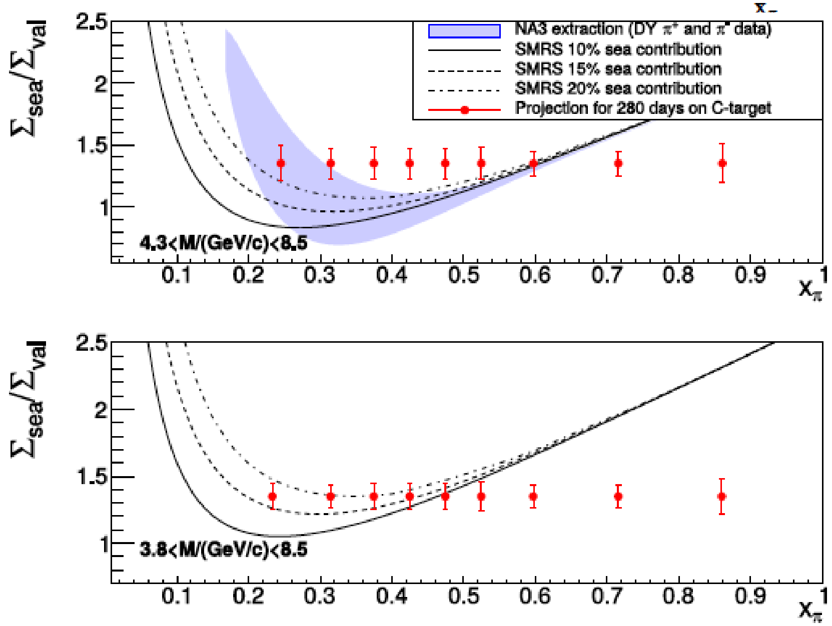
- Test of lepton universality
- Different systematics compared to others

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)





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

Studying of the di-muon angular distributions (λ, μ, υ) provides a direct input to the EHM

- $\Sigma_V = \sigma^{\pi^- C} - \sigma^{\pi^+ C}$: 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

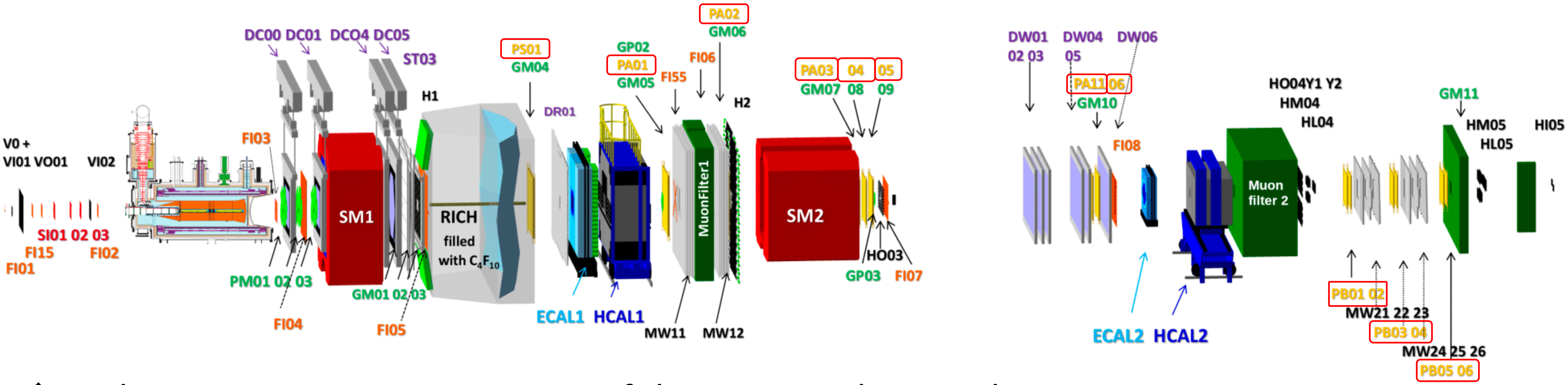
Experiment	Target type	Beam energy (GeV)	Beam type	Beam intensity (part/sec)	DY mass (GeV/c^2)	DY events
E615	20 cm W	252	π^+ π^-	17.6×10^7 18.6×10^7	4.05 – 8.55	5000 30000
NA3	30 cm H_2	200	π^+ π^-	2.0×10^7 3.0×10^7	4.1 – 8.5	40 121
	6 cm Pt	200	π^+ π^-	2.0×10^7 3.0×10^7	4.2 – 8.5	1767 4961
NA10	120 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*

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

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>

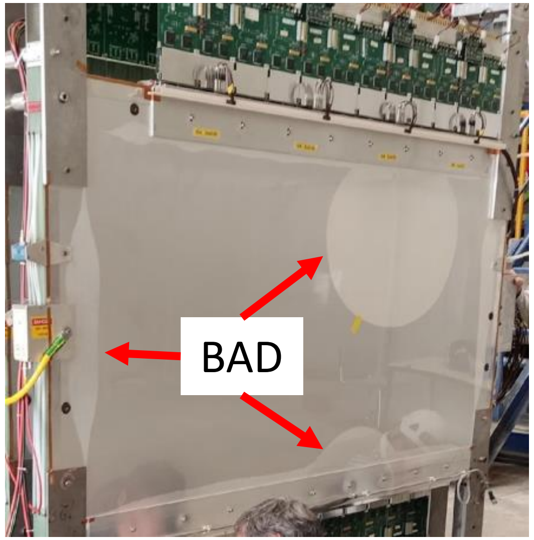
- ✓ Triggered DAQ
- ✓ Degraded detectors
- ✓ Limited Team

<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

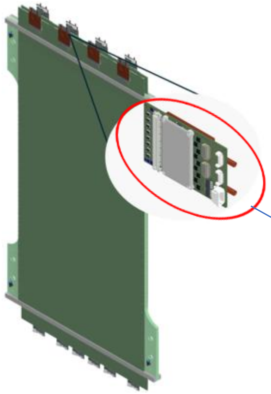
Till 2024



COMPASS MWPCs possible path to the future

After 2024

Existing detectors

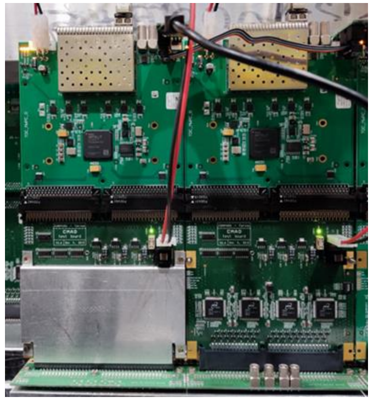


New detectors

Trigger less DAQ

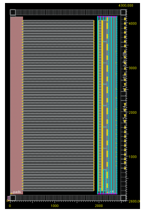
New FE

New FE



FPGA based

New ASIC



New ASIC

We see that 2 developments could go together -> **ToRA**

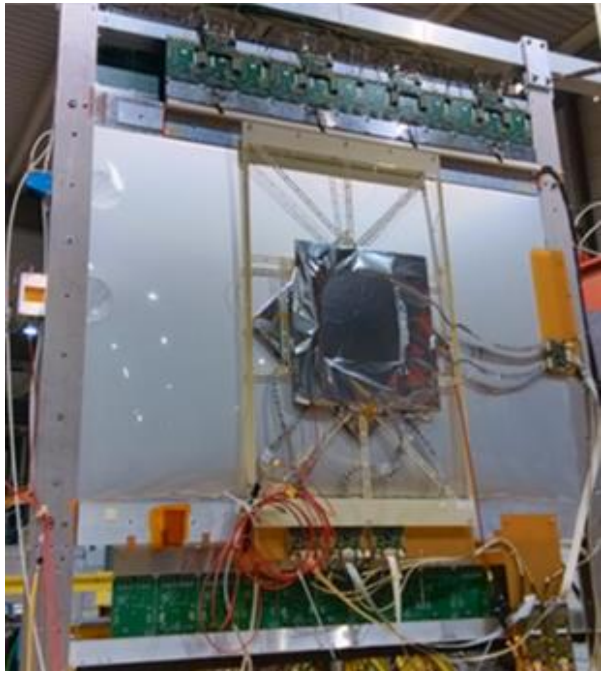
Base requirement

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 ⊘ (mm)	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

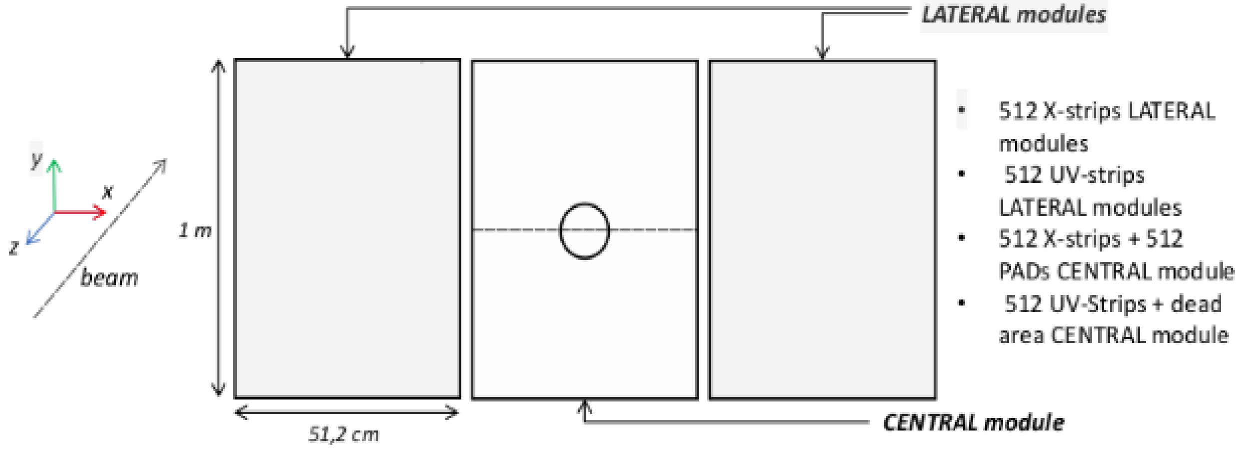
- To reasonably match the existing MWPCs
- To see if we can be better at low cost

MPGD to substitute it?

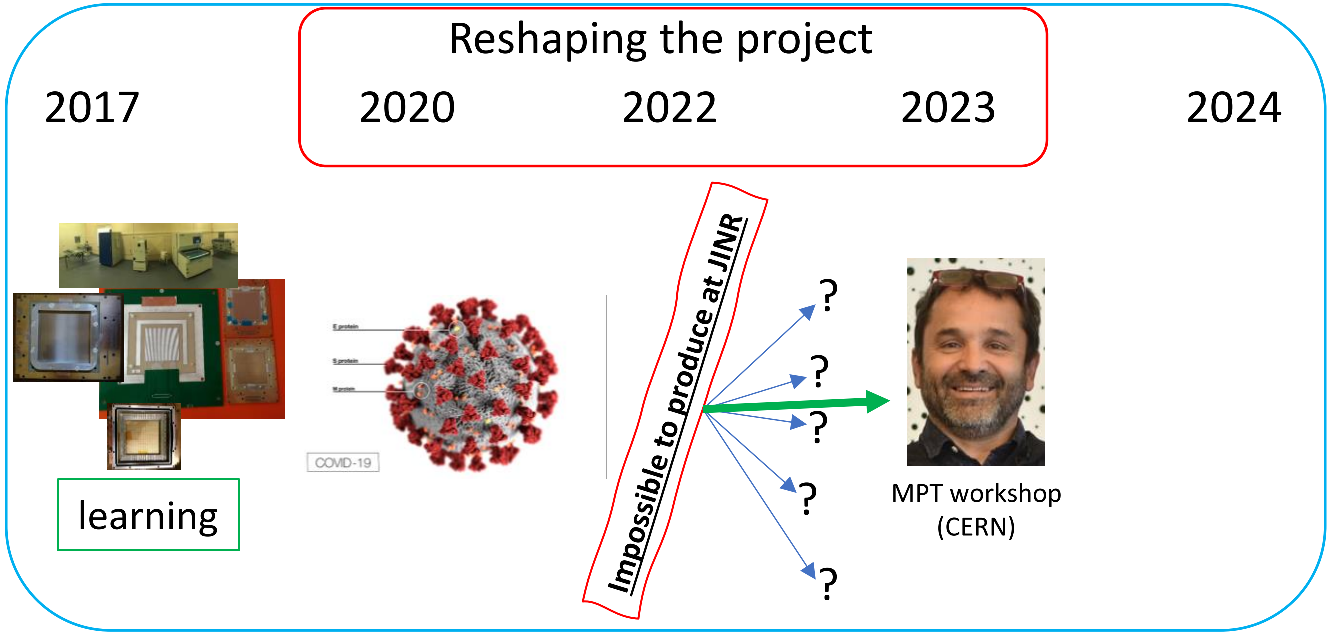


Concept design

- 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

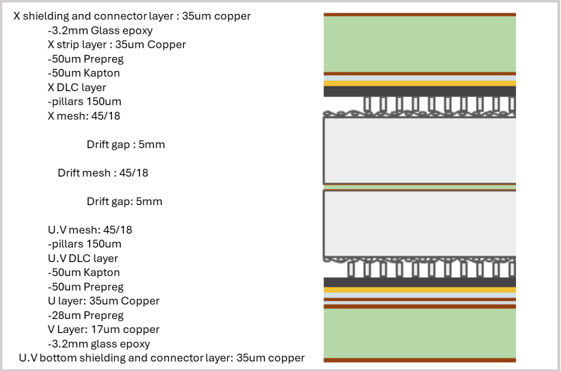


Very tight schedule → Reduce the R&D time and risks

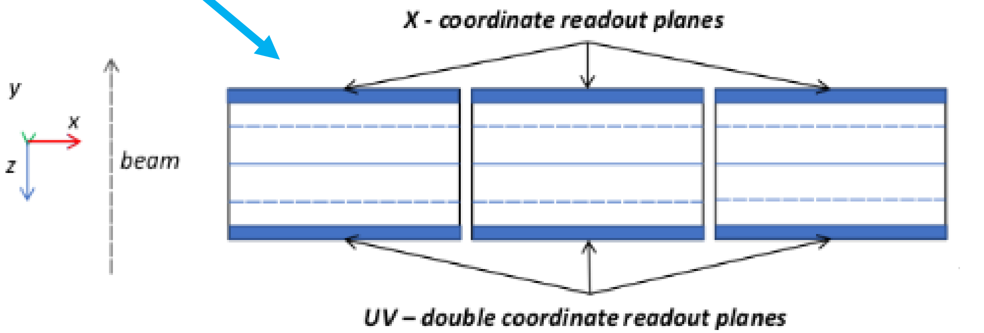


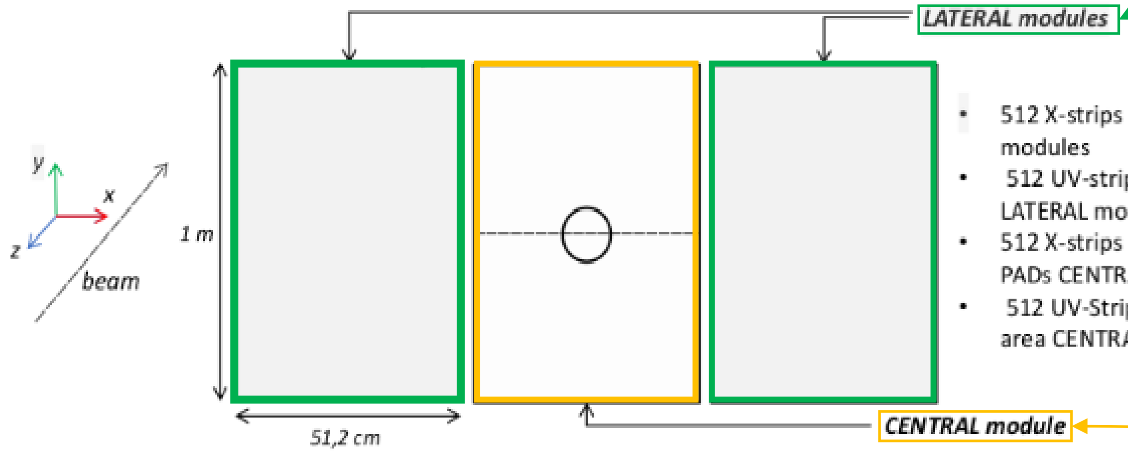
- ➢ Full size lateral module prototype in autumn 2024
- ➢ Full size central module prototype in autumn 2025/2026

Concept design 2

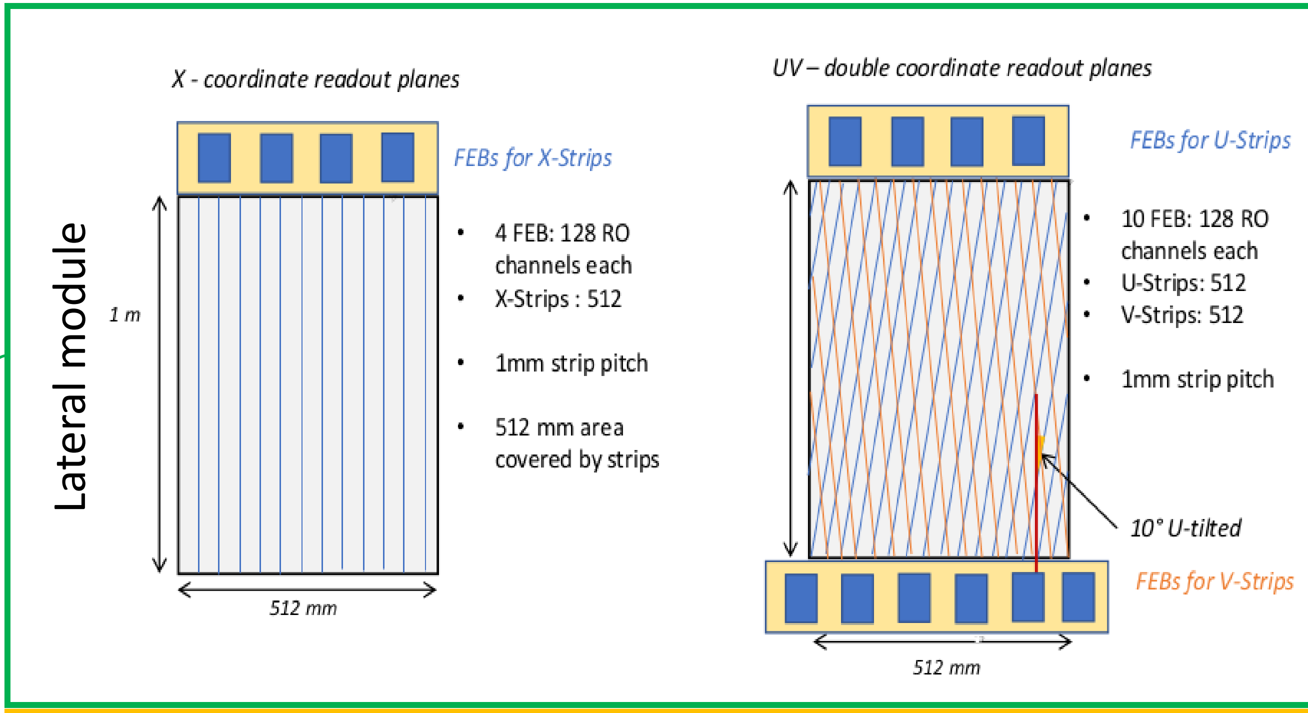


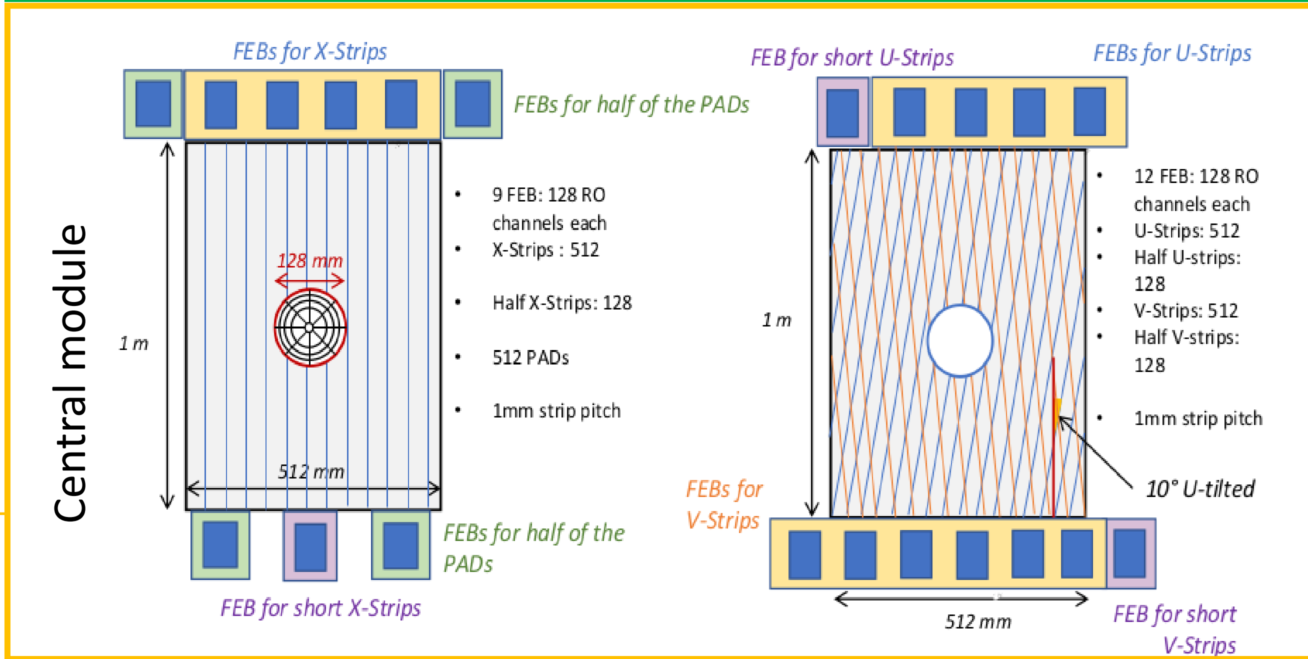
- common cathode
- 2 types of modules



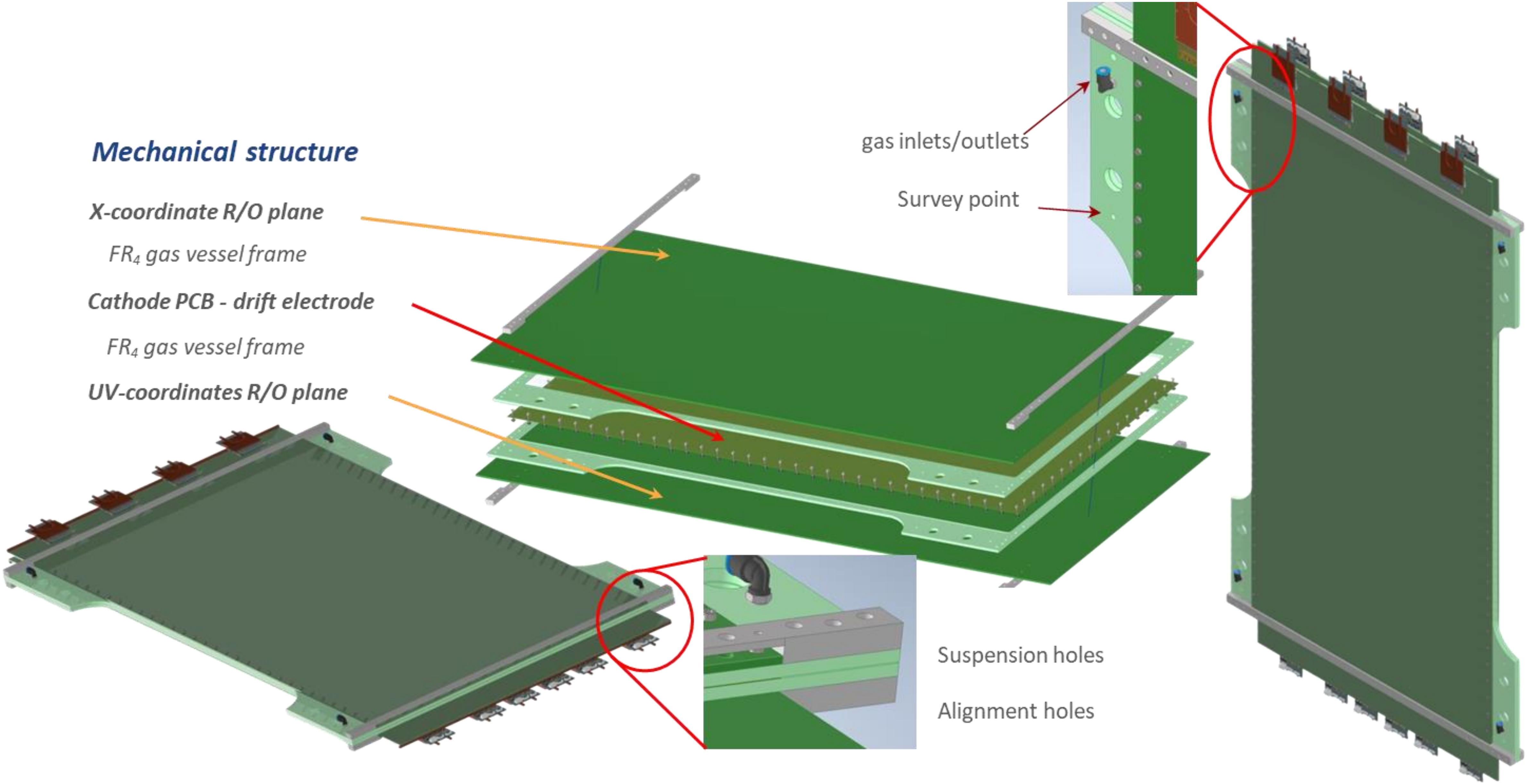


- 512 X-strips LATERAL modules
- 512 UV-strips LATERAL modules
- 512 X-strips + 512 PADs CENTRAL module
- 512 UV-Strips + dead area CENTRAL module



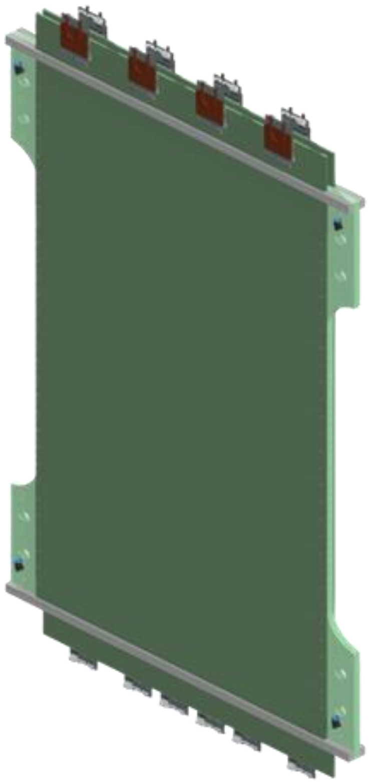


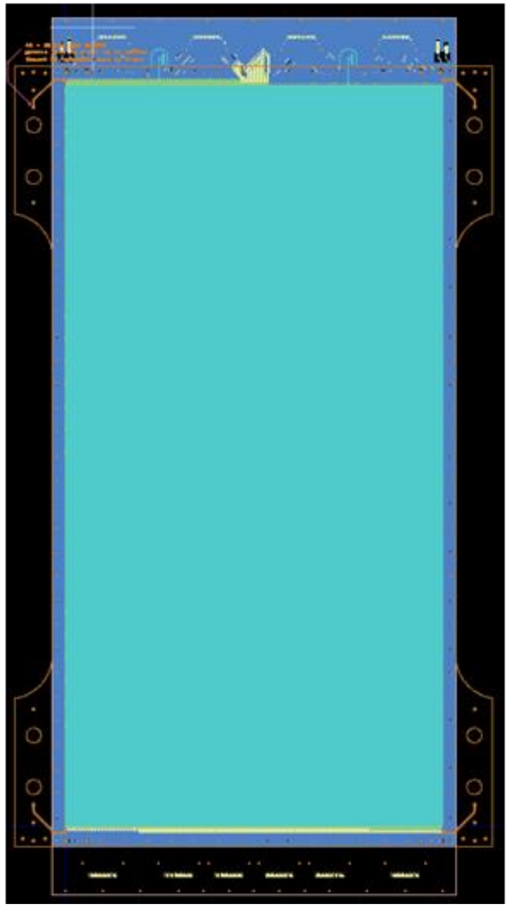
Lateral module prototype design



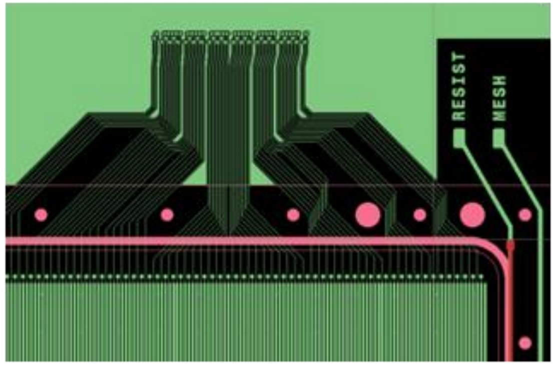
Lateral module prototype production

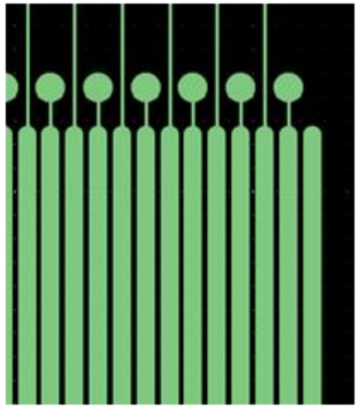
Readout PCB design and production





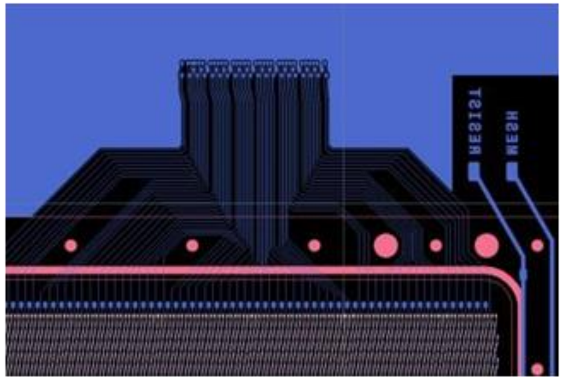
X-coordinate R/O plane

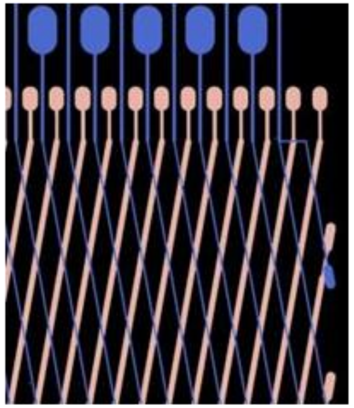




- 512 strips
- 1mm pitch
- 750 um width
- 4 FEBs: 512 fe channels

UV-coordinate R/O plane

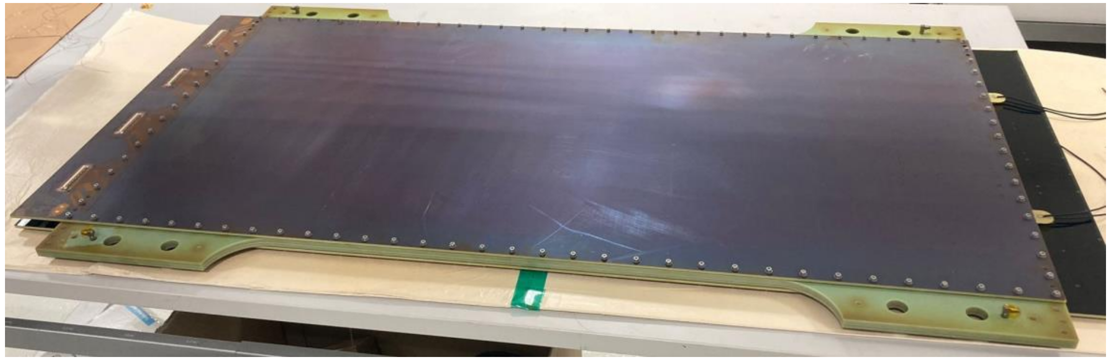




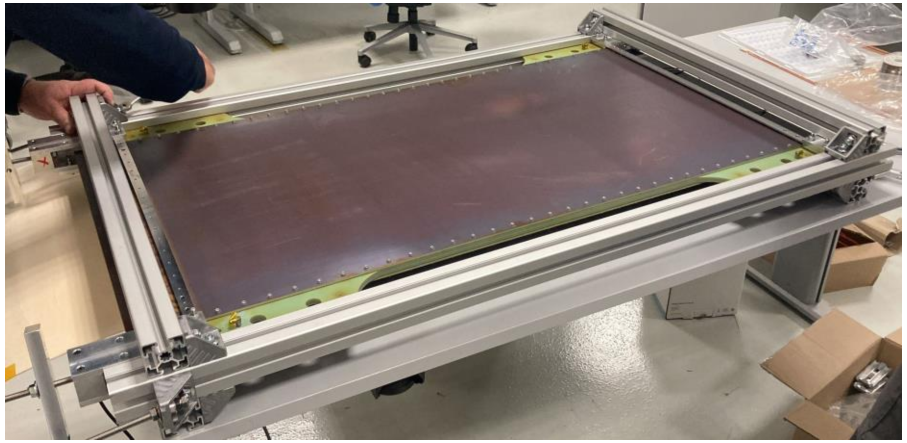
- 1280 strips
- 1mm pitch
- 250 um U strips width
- 150 um V strips width
- 10 FEBs: 1280 fe channels

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

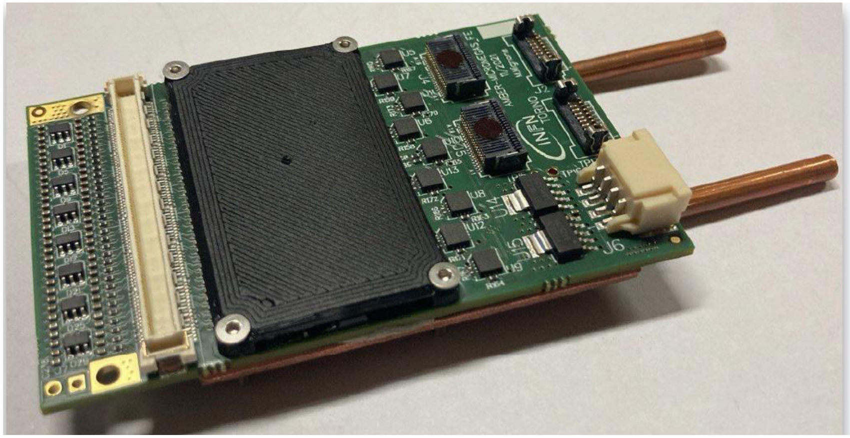
- High Voltage stability
- Noise performance & shielding optimisation
- First data (beam/cosmics)
- Compare $ArCO_2$ (93/7) and $ArCO_2Iso$(93/5/2)

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

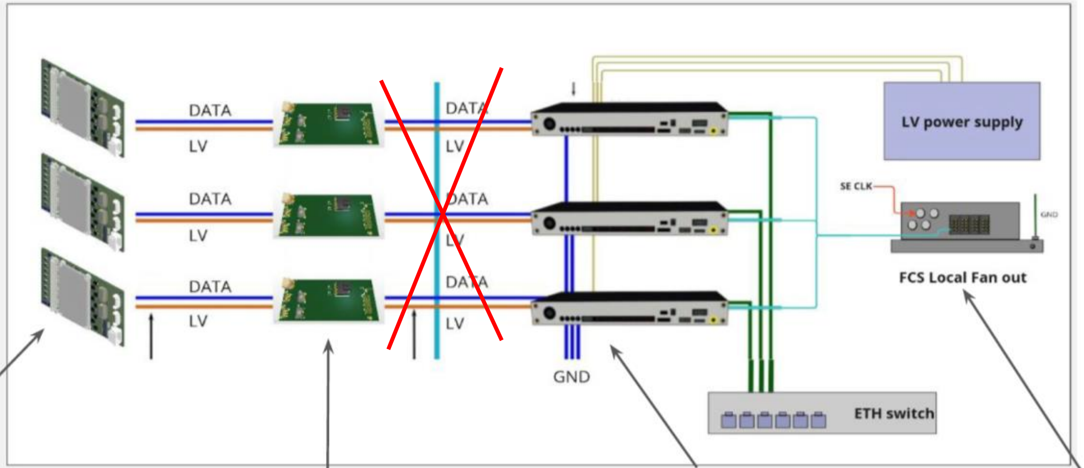
The 2024 RO system

❖ TIGER ASIC based stand alone



- The DAQ has been verified with a STRAW detectors setup
- The updated FE cards did not present noise data communication problems
- We have 6 cards available, 8 are on order (delayed)
- DLVPC v2 cards has been assembled at CERN
- Some safety/production issues with the FireFly cables. MIGHT be worth considering to change the data cable for the next FE designs

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

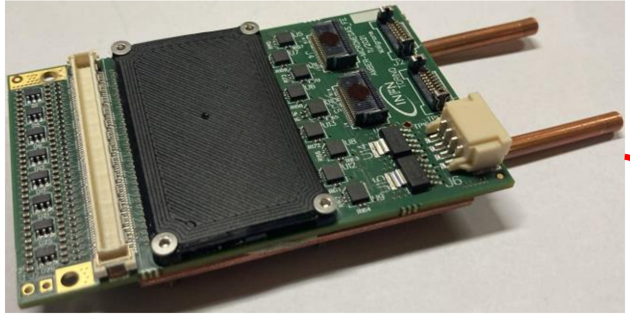
Trigger and clock distribution

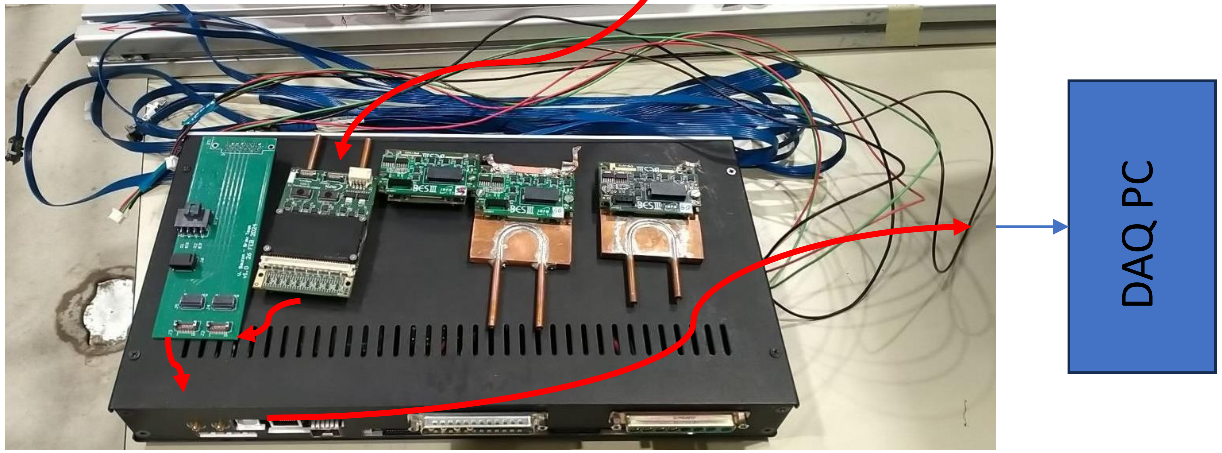
Future RO considerations

Stand-alone and fall-back option

❖ Based on the TIGER ASIC

- Uses existing equipment
- Well known
- Known issues
- Limited ASIC availability

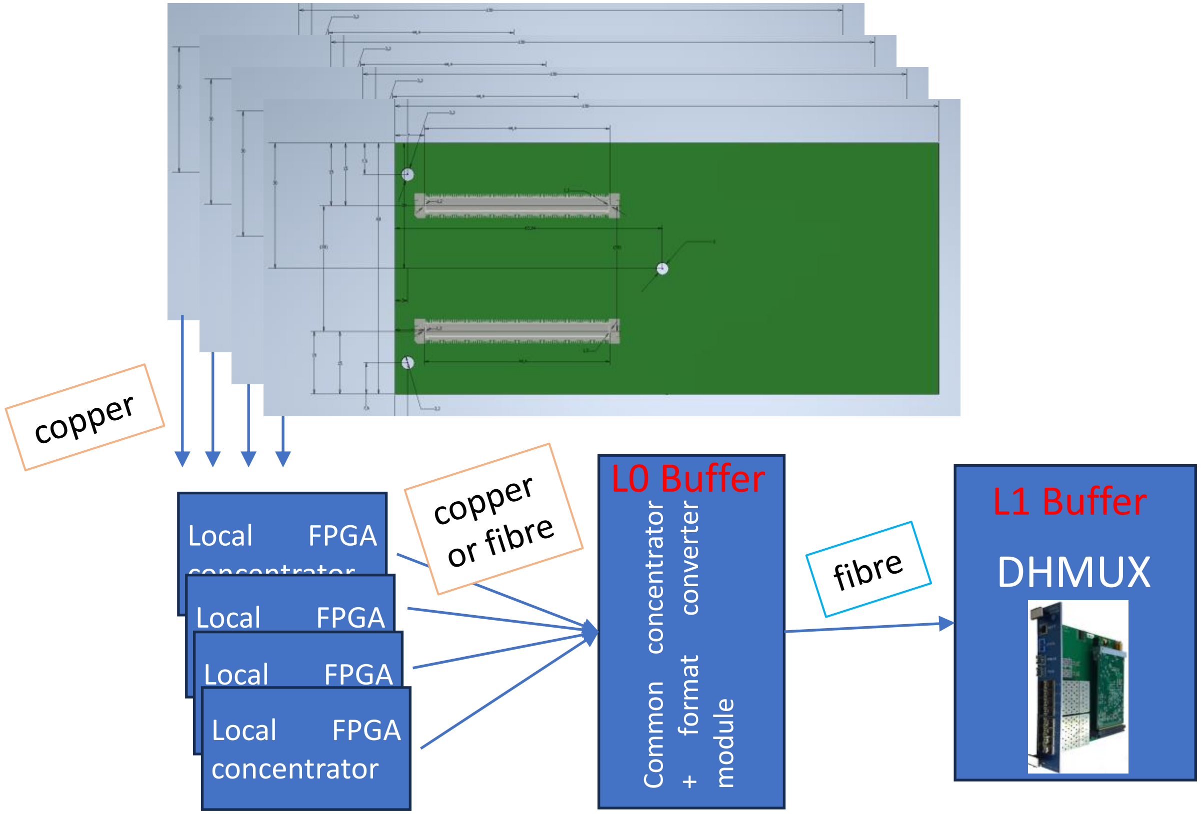




Base option for the 2025 AMBER integration

❖ Based on the ToRA ASIC

- All the elements are new



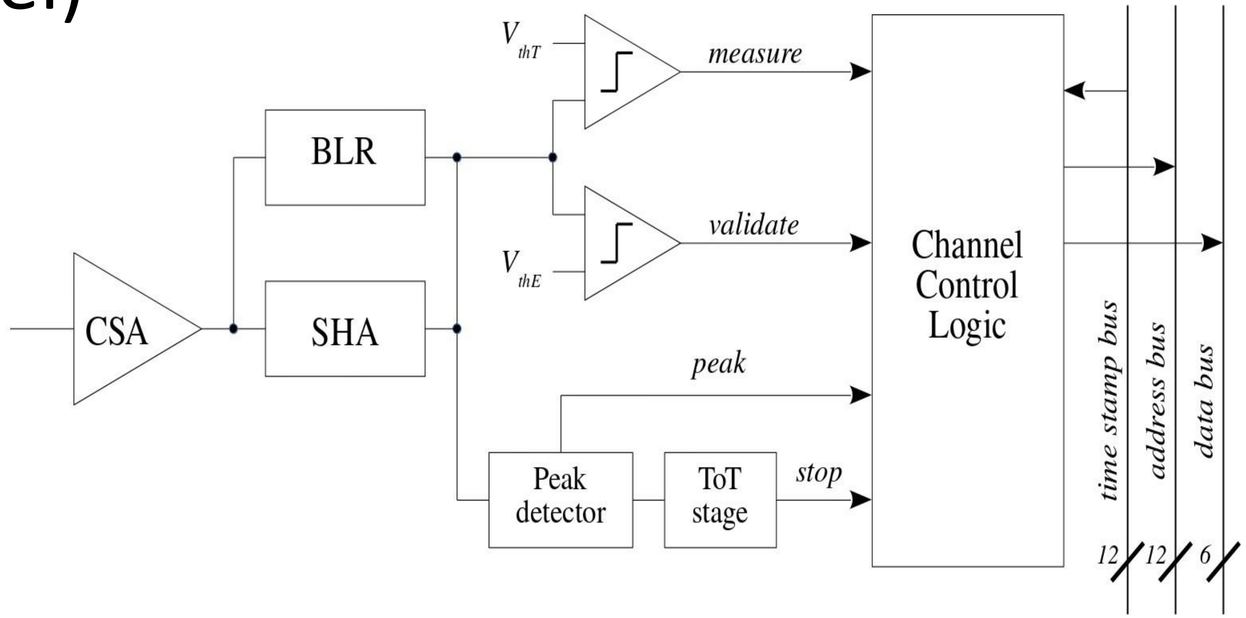
ToRA ASIC

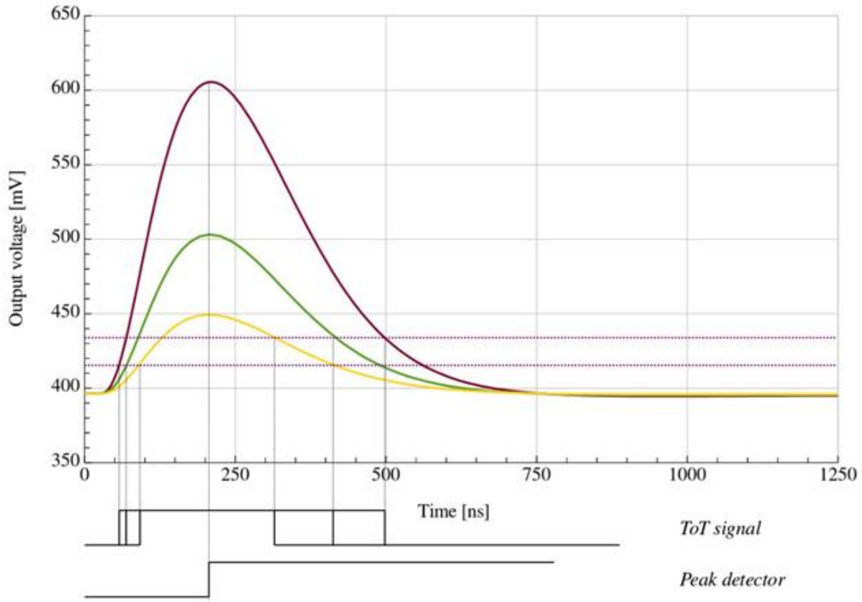
- MPGD and Wire detectors compatible
- Target specific application with limited complexity
- Reuse existing solutions
- 2 step design

Detector	MM	Straw	
Channels/ASIC	64	64	
Power/channel	$\leq$5	$\leq$10	mW
Input capacitance	$\leq$150	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

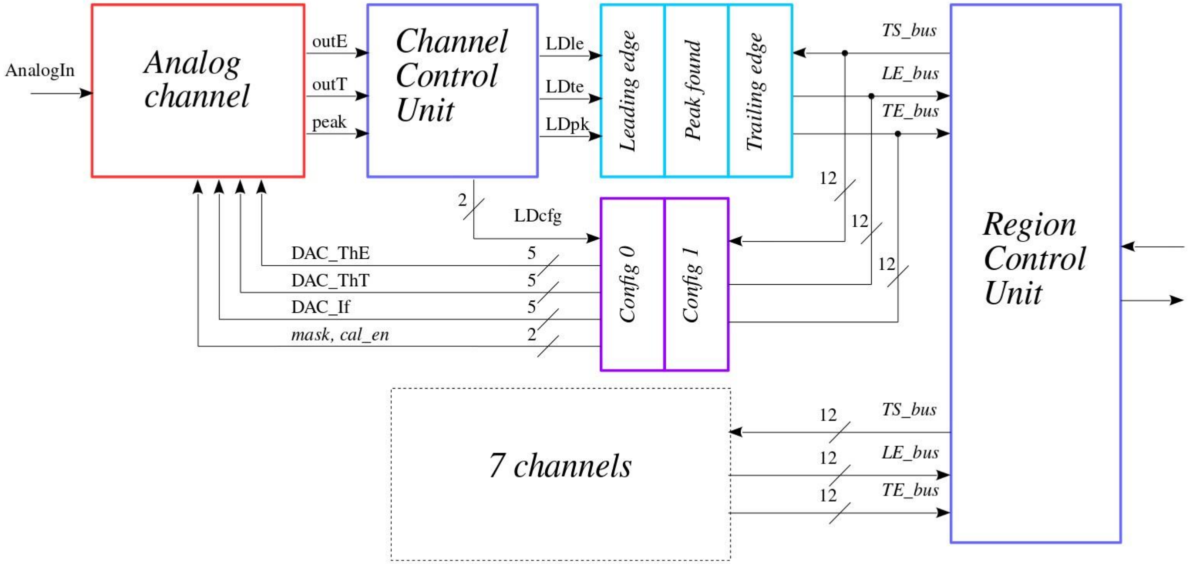
Analog part (single channel)

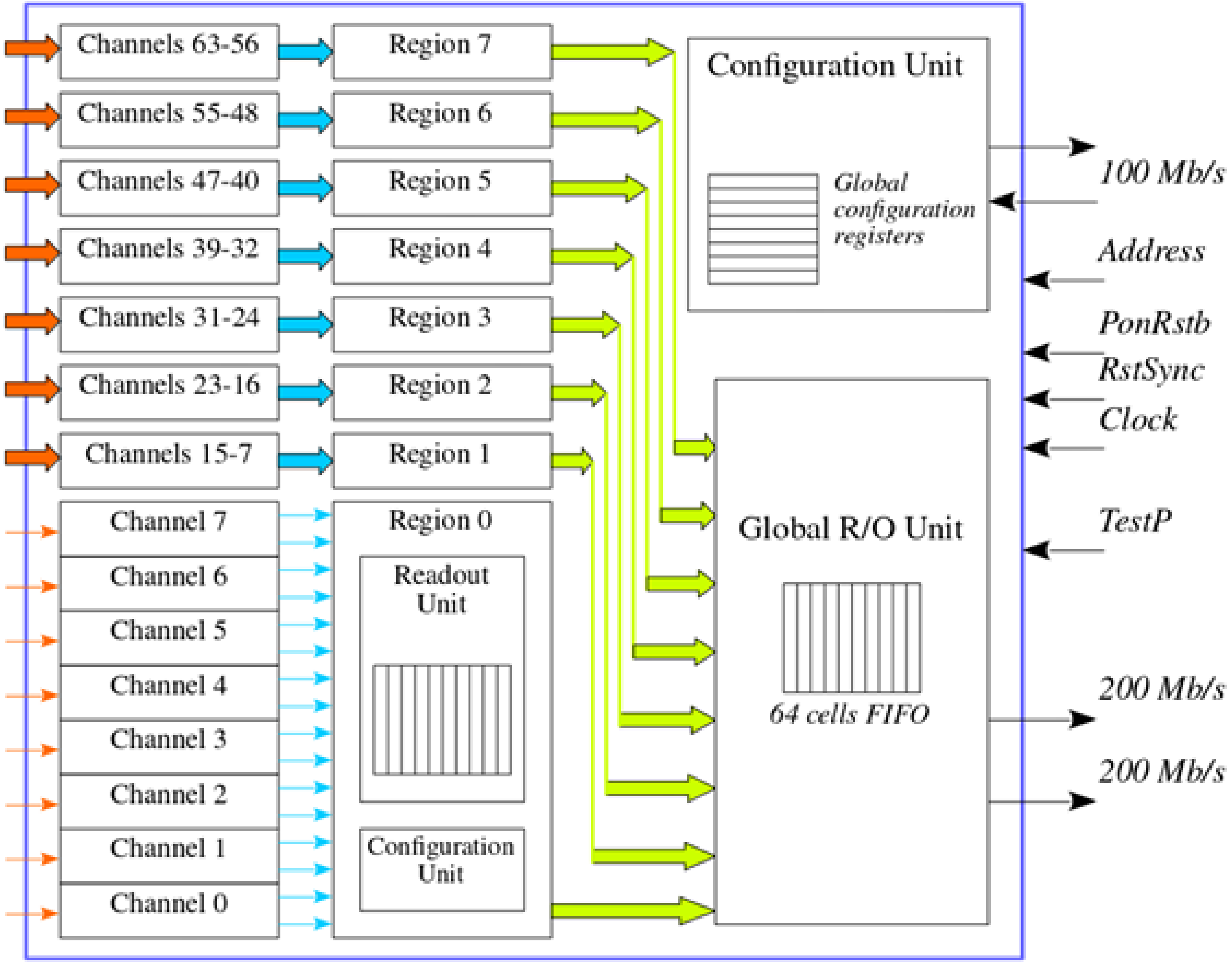
- Charge Sensitive Amplifier
  - Fours gains : 2,6,8 and 12 mV/fC
  - Possibility to accept inputs from both polarities
- Shaper
  - 3rd order, one real and two cc poles
  - Programmable peaking time : 25, 50, 150 and 250 ns
- Double threshold signal detection
  - Lower threshold for time measurement, higher threshold for validation
  - Peak detector signal
  - Peak holder for charge measurement (via ToT)
  - Linear ToT measurement under evaluation





ASIC structure





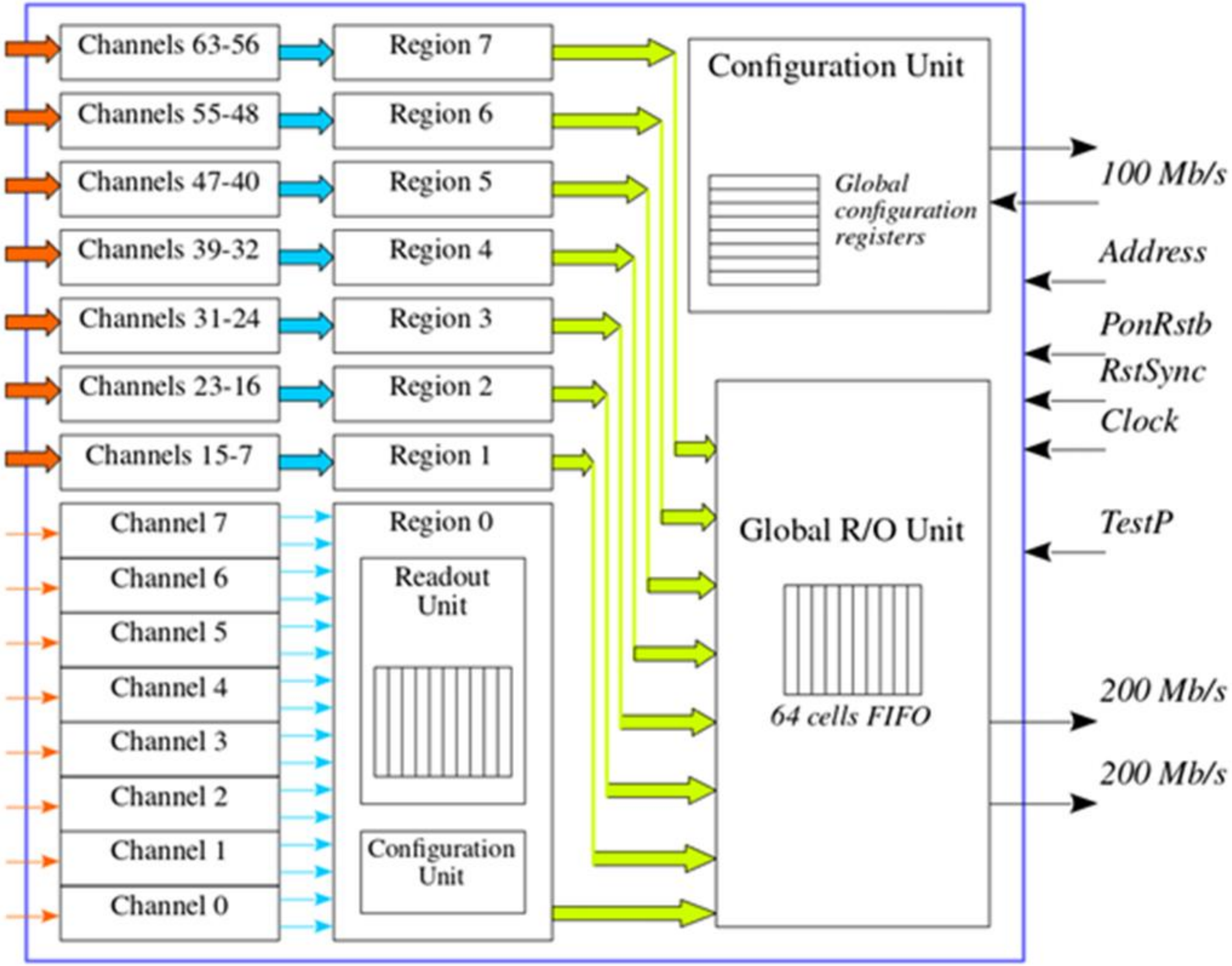
- Common time stamp distributed to all channels
- 3 data register for time acquisition
- 2 configuration registers
- Threshold and discharge current fine tuning

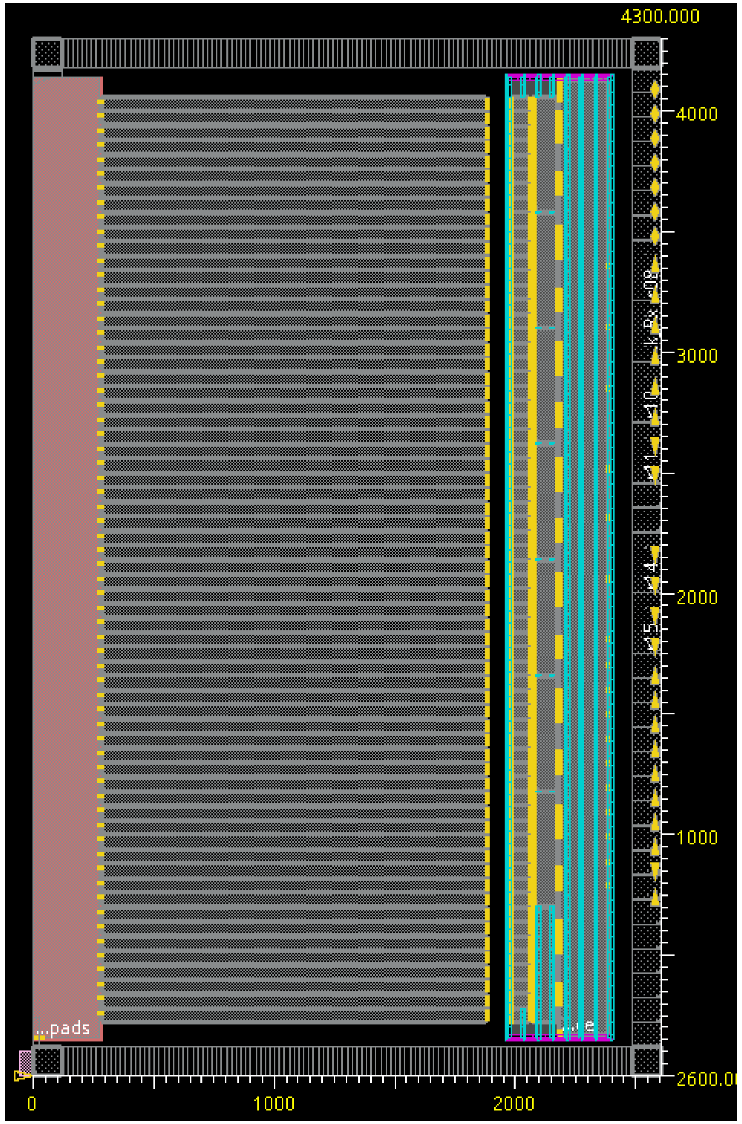
Output data format

- Data output in 32 bits words over 200 Mb/s serial links
- It can be configured to use 1 or 2 links
- Frame length : 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 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]	

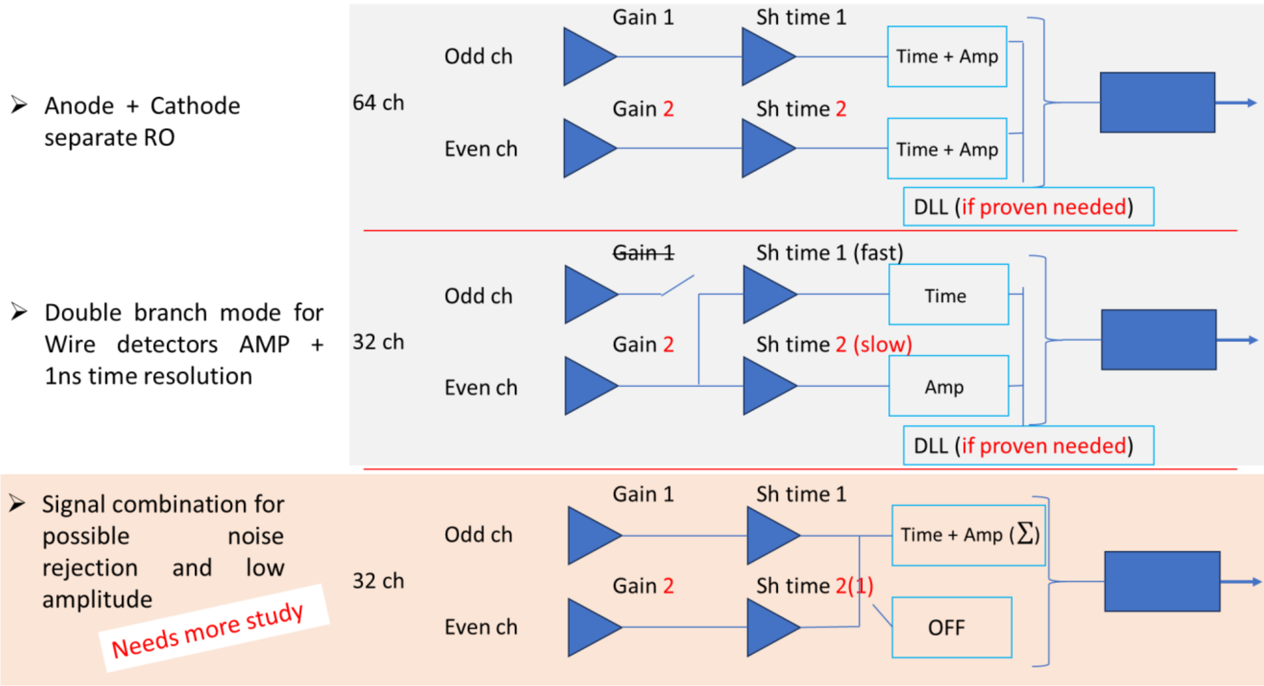
ToRA is preparing to go silicon





Options for the ToRA v2

- 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.



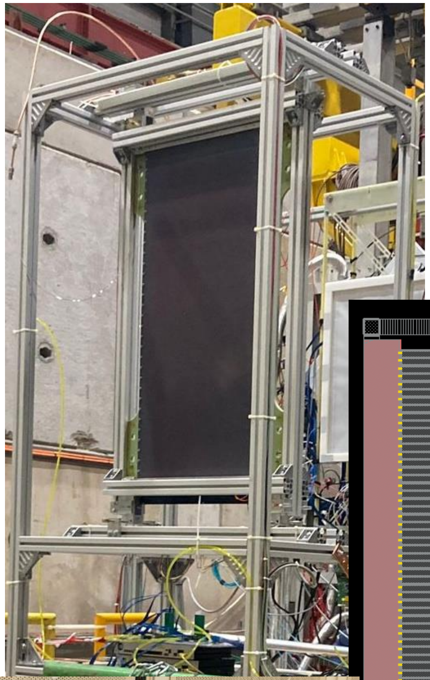
Ideas are welcome

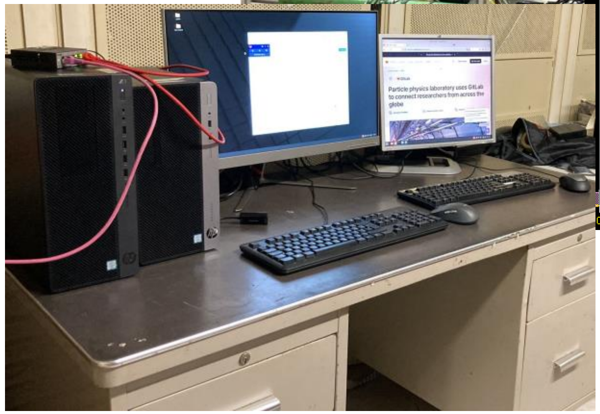
Conclusions

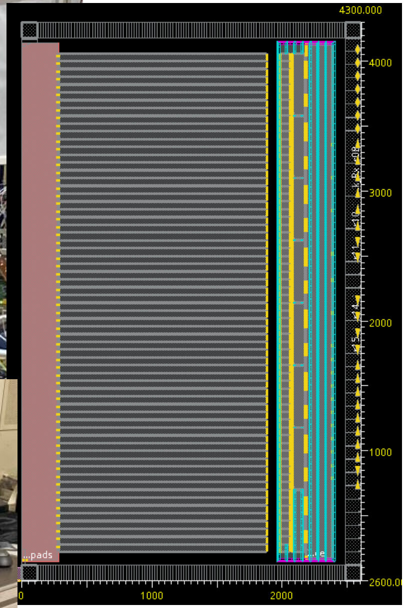
Detector is in the test area

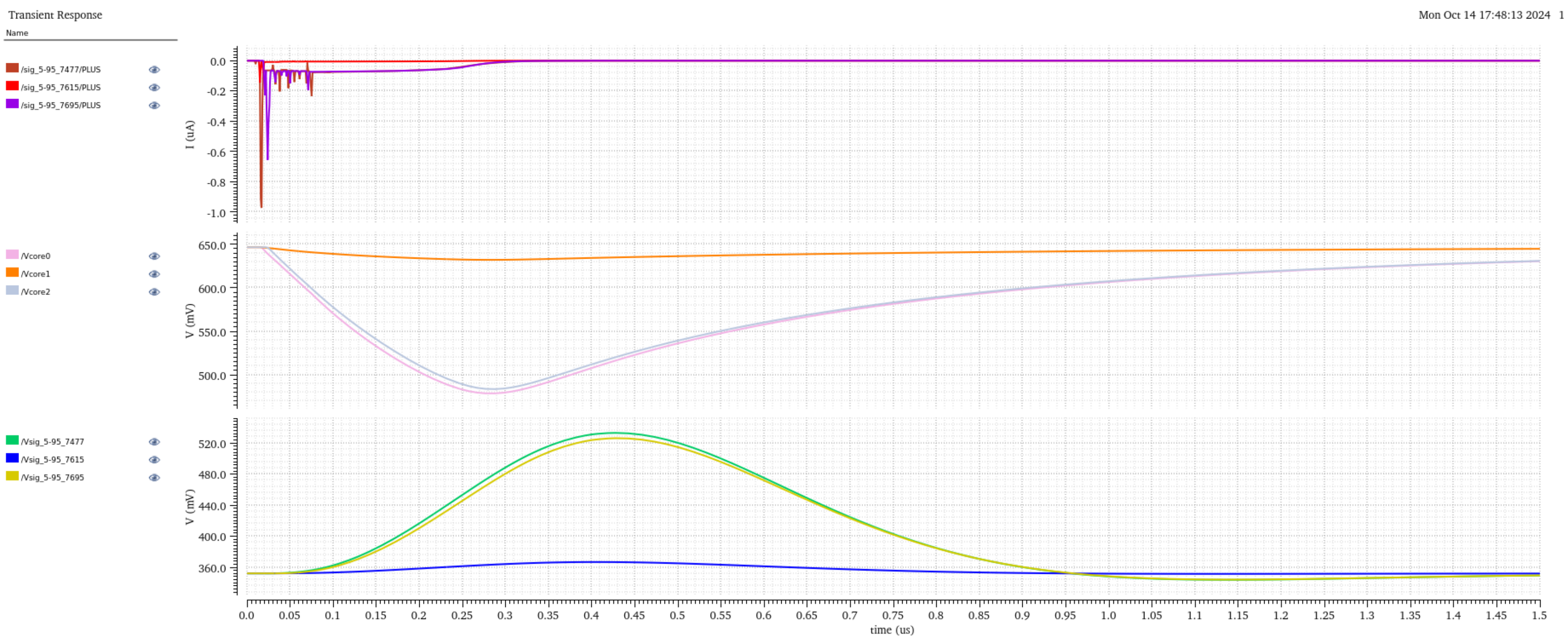
ToRA v1 ASIC preparing for submission

Time to go to CERN!








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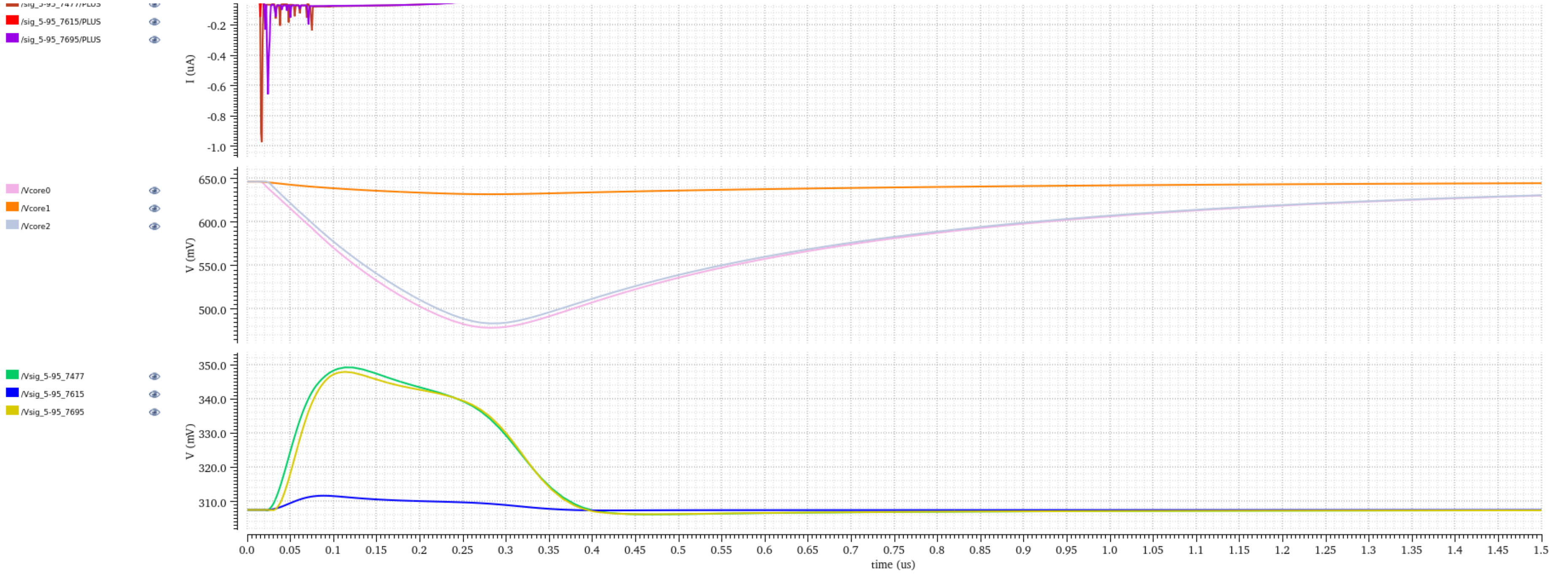
/sig_5-95_7615/PLUS
/sig_5-95_7695/PLUS
I (uA)
/Vcore0
/Vcore1
/Vcore2
V (mV)
/sig_5-95_7477
/sig_5-95_7615
/sig_5-95_7695
V (mV)
time (us)

250 ns


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

25 ns

Spares

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) – <u>base features set</u> targeting the MM

  V2(sub. 2025) – <u>extended features set</u> 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

Main ideas

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

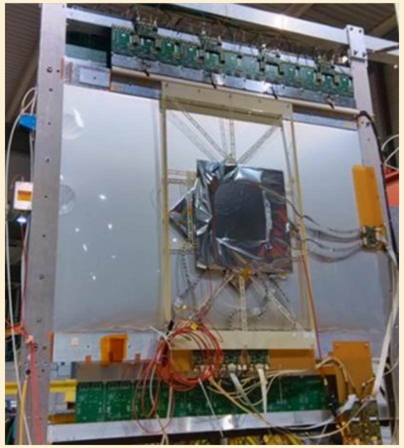
Design in 2 steps based on feature set

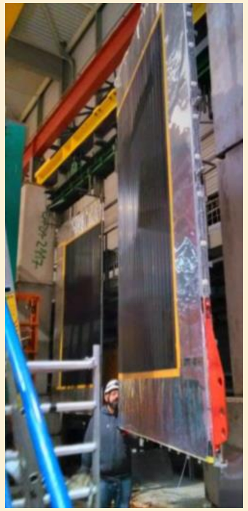
V1 (2024)	V2 (2025)
Limited flexibility	Implement MPGD+Wire
Power may not be optimised	Power tuning (moderate)
Mostly full backend	Inter channel commutation
Complete single channel structure	Time resolution???

Motivation

AMBER upgrade

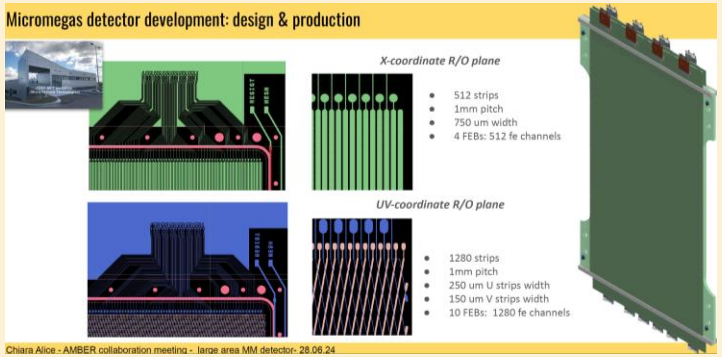
MWPC, Drift





+ Non Torino Wire detectors

Micromegas, GEMs?



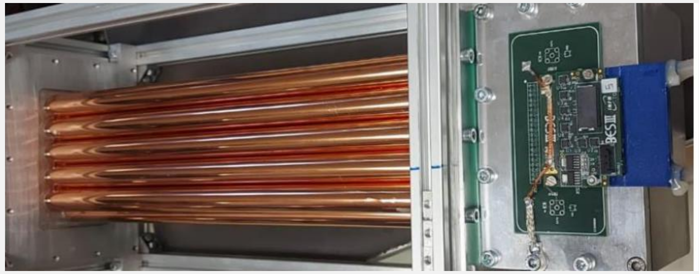
+ needed new vertexing MM?

Wire

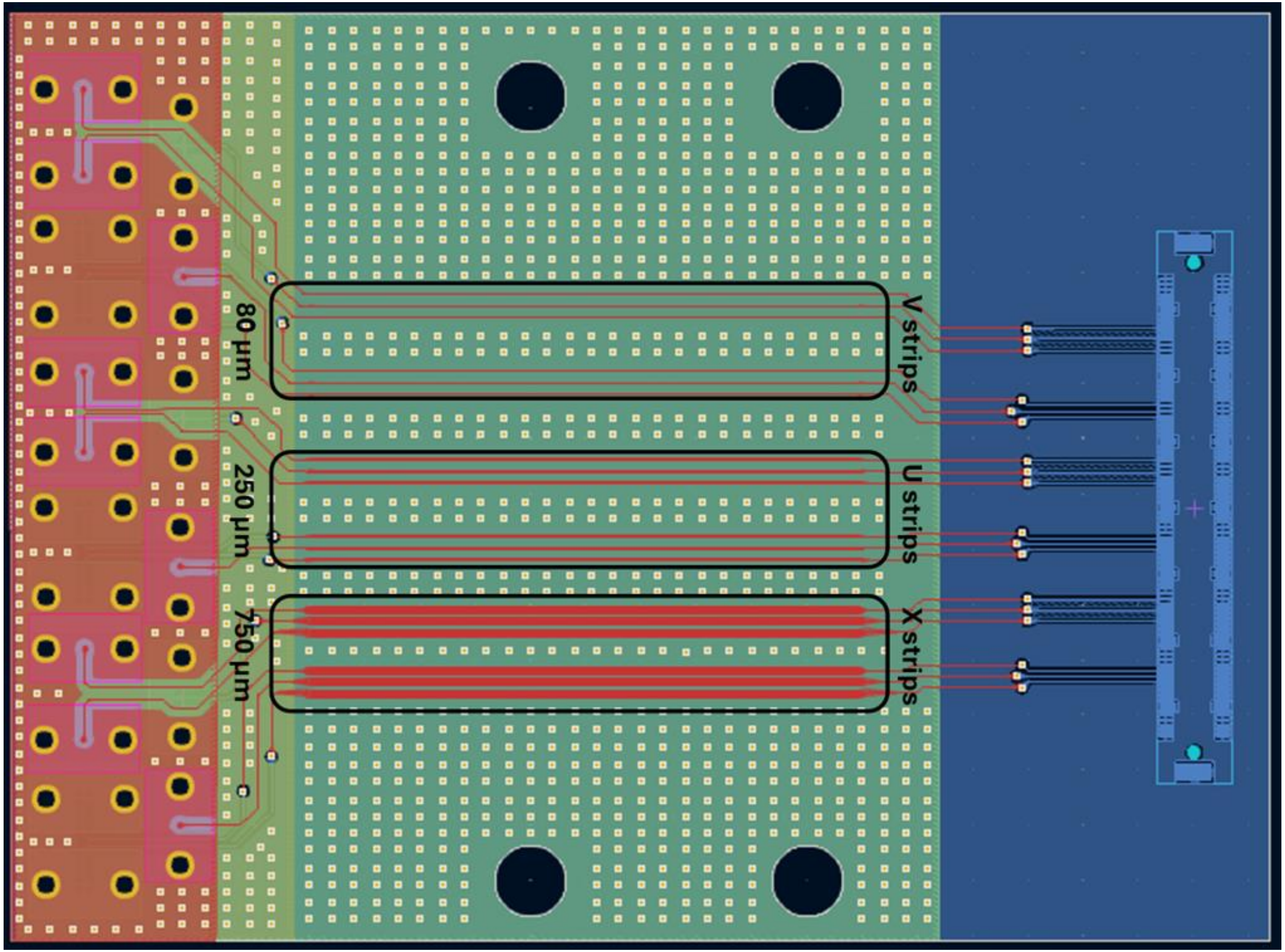
MPGDs

General use

STRAWs



MPGDs

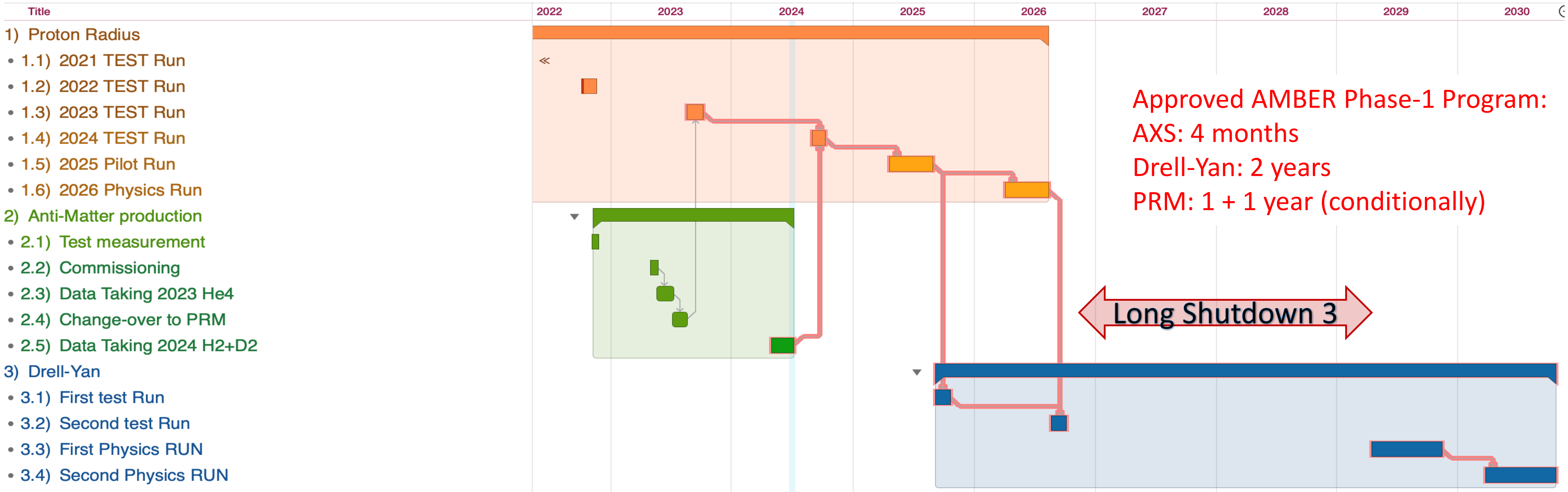

80 μm
250 μm
750 μm
V strips
U strips
X strips

AMBER Phase-1 running plan

Apparatus for Meson and Baryon Experimental Research

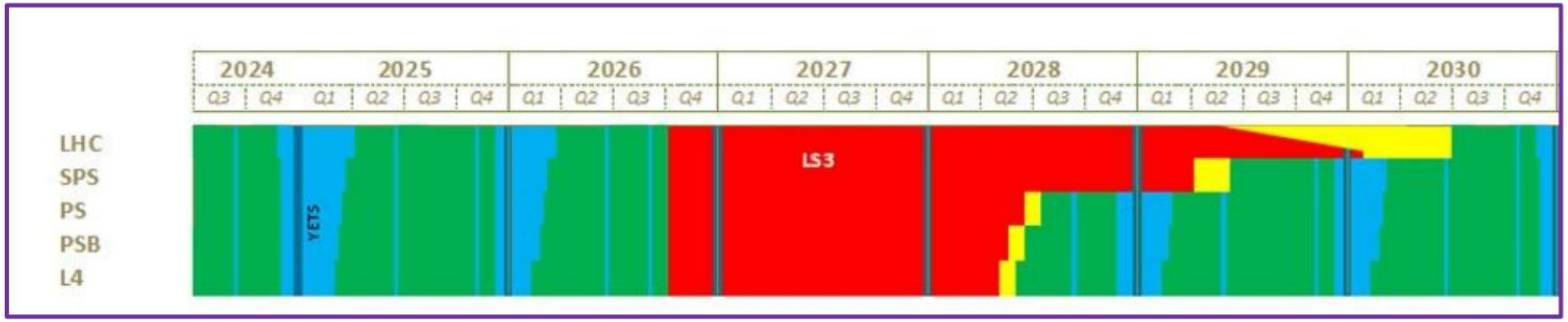
Milestones:

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)

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