Apparatus for Meson and Baryon Experimental Research

Design and testing of a new tracking system for the PRM measurement at AMBER experiment at CERN

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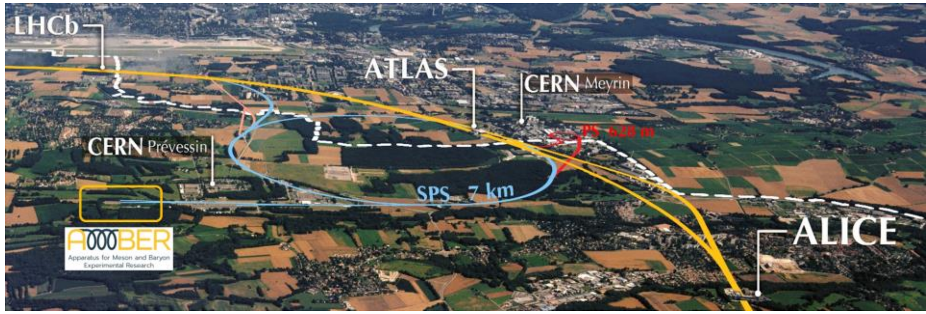
Università di Torino & INFN Torino & CERN

INFN SEZIONE DI TORINO
ISTITUTO NAZIONALE DI FISICA NUCLEARE

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

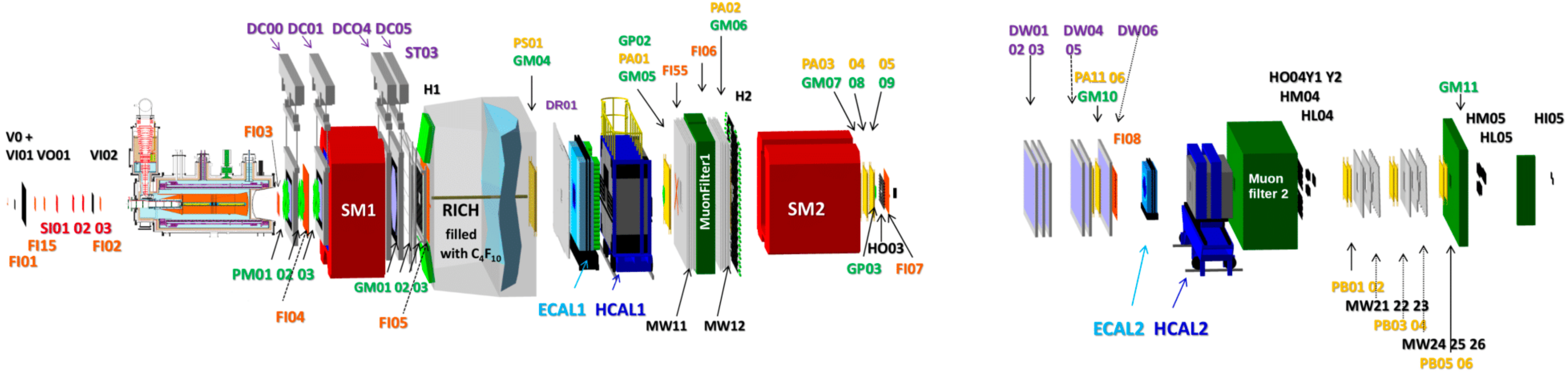
- 2018: Letter of Intent arXiv:1808.00848
- 2019: Formation of a Proto-Collaboration
- 2019: AMBER Phase–1 Proposal CERN-SPSC-2019-02
- 2020: Recommendation of the Proposal by SPSC and approval by Research Board
- 2021,2022: AMBER Pilot Run
- 2023: Start of AMBER data taking



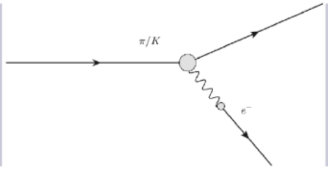
Phase-2 proposal in preparation
2029 ->

Taste it right now!

?



AMBER program

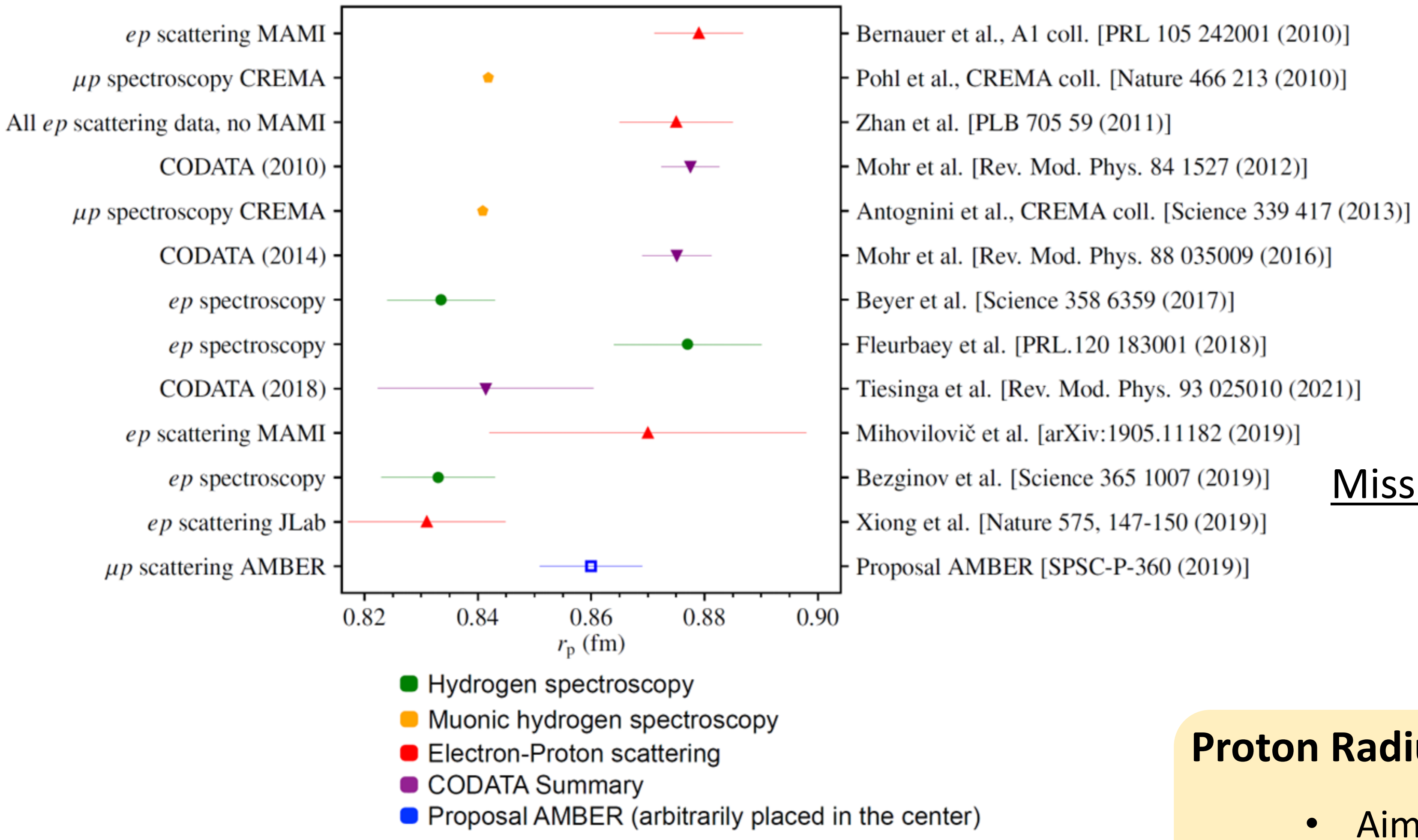
	Beam	Target	Additional Hardware
Proton radius measurement	100 GeV muons	high pressure Hydrogen	active target TPC, tracking stations (SciFi, Silicon)
Antiproton production cross section	50 GeV - 280 GeV protons	LH_2, LHe 2023	Liquid He target
Drell-Yan measurements with pions	190 GeV charged pions	Carbon, 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		

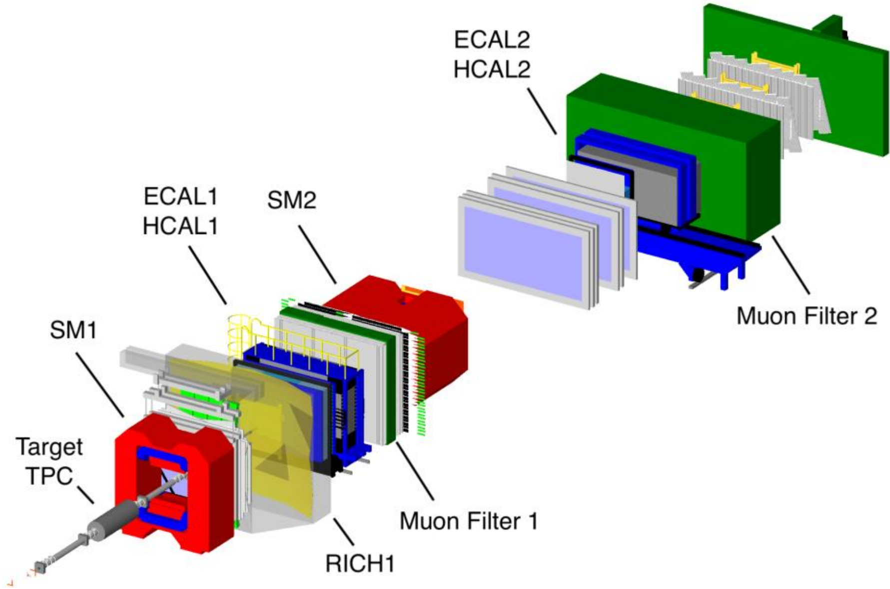
Phase 1 (approved): 2023 -> 2029

Phase 2 (in preparation): 2029 ->

AMBER PRM

Proton-radius puzzle





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

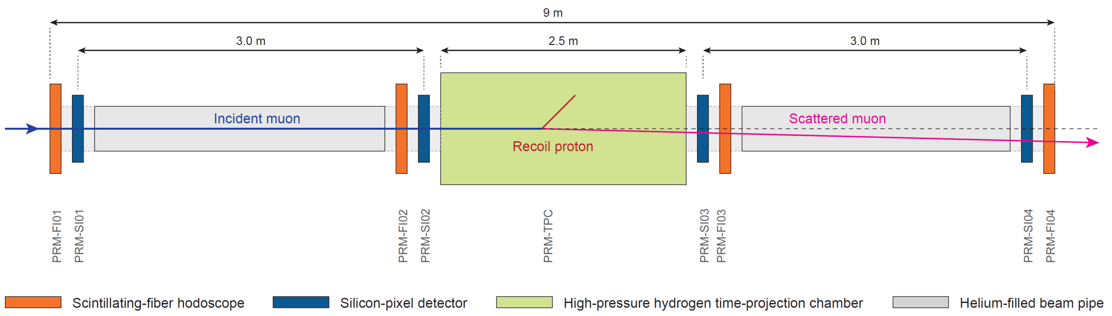
- Test of lepton universality
- Different systematics compared to others

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 PRM vertexing requirements

- Measurement of low-Q^2 elastic-scattering events



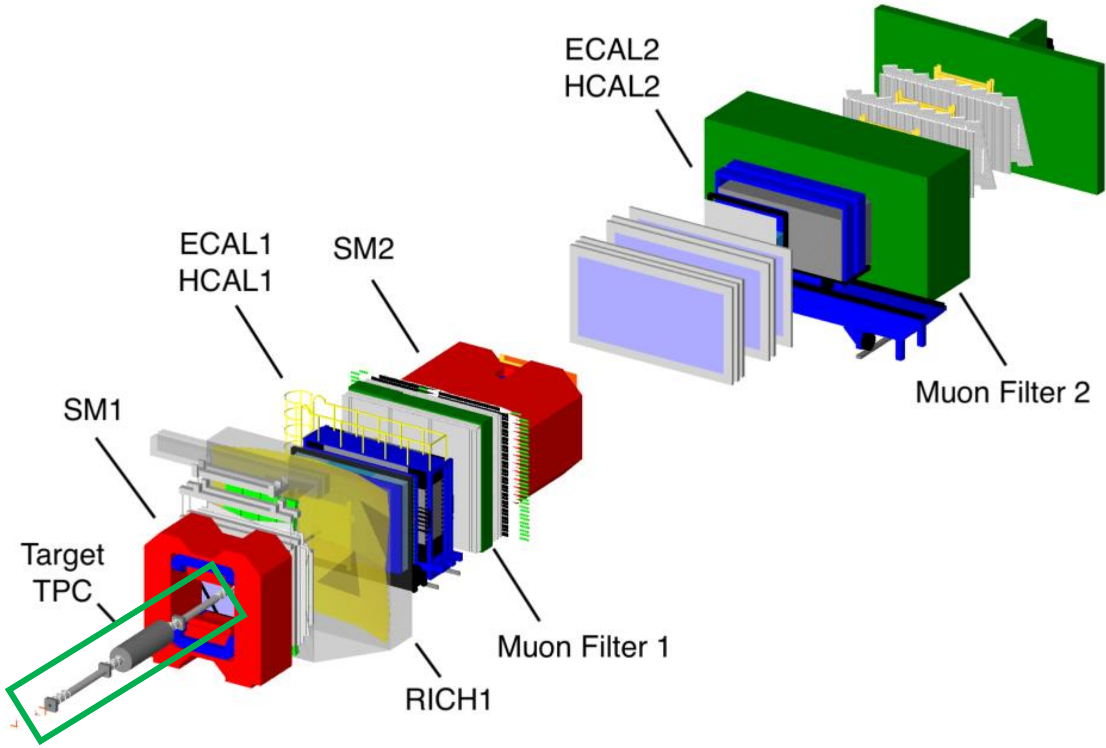
AMBER approach: Combined measurement of low energetic recoil-protons and scattered muons at small scattering-angles.

Target area

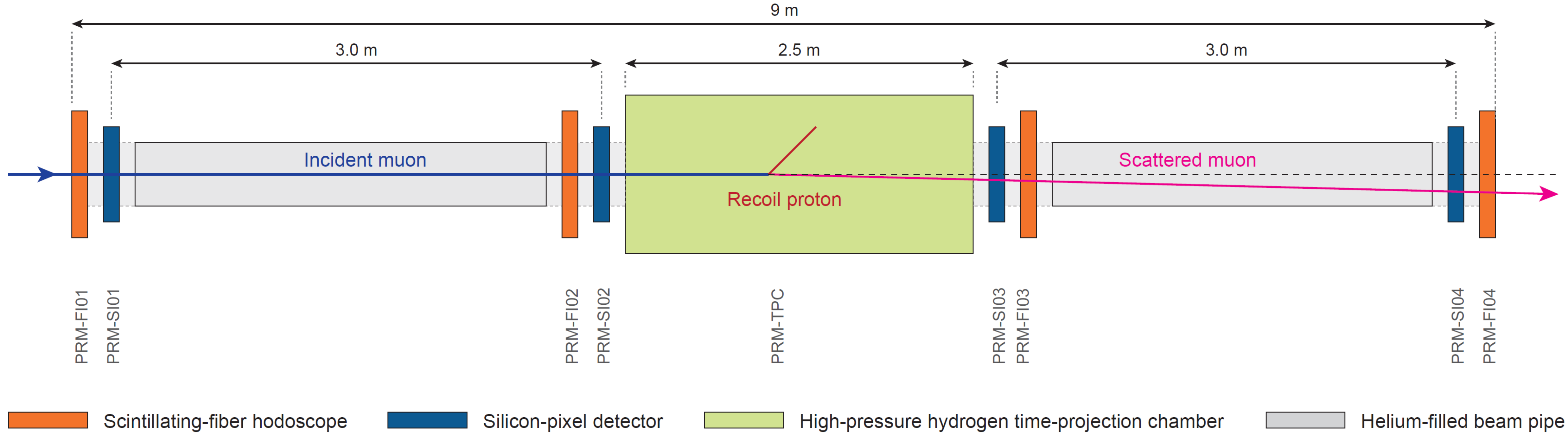
- Hydrogen filled Time-Projection-Chamber (TPC) as an active target to measure recoil protons
- Silicon trackers along long leaver-arm to measure small scattering-angles (<100 μrad)
- Scintillating fibers for timing (~1ns) and tracking
- New continuously-running DAQ required

spectrometer

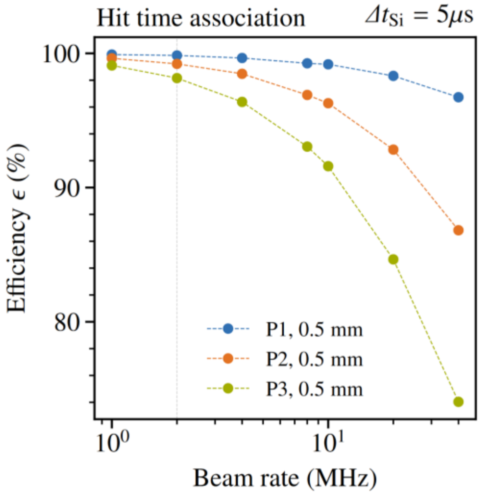
- Momentum measurement of scattered muon
- Radiative background using electromagnetic calorimeter
- Muon identification with muon filter and hodoscope

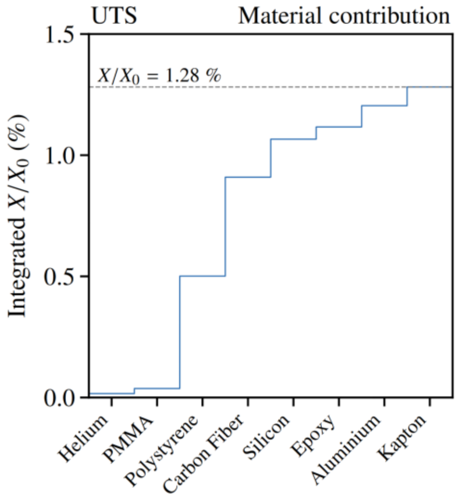


AMBER PRM vertexing requirements

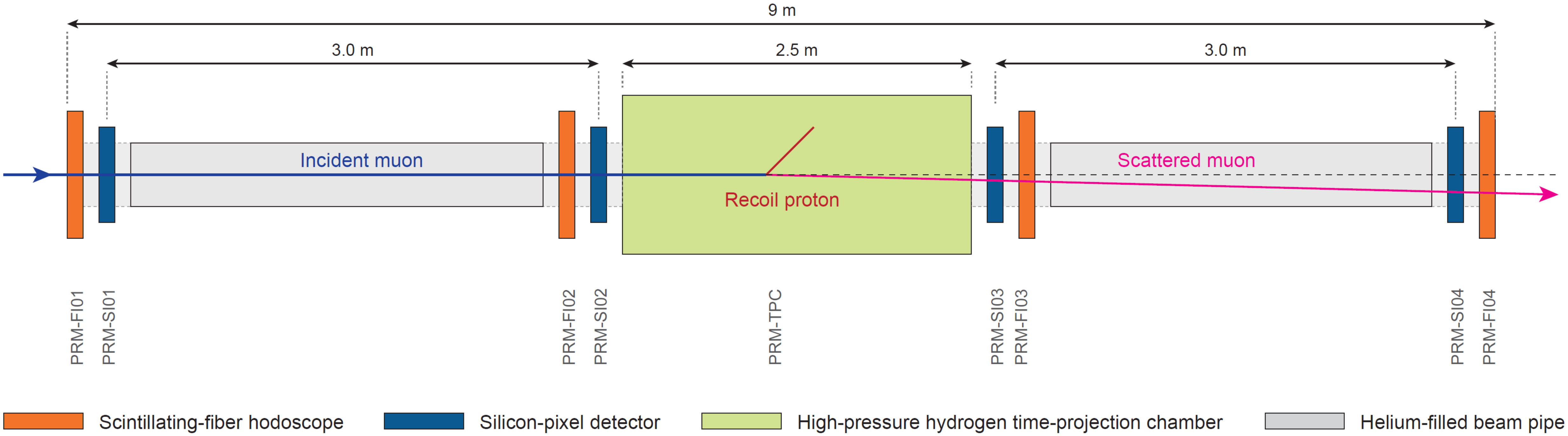


- Planned beam rates 2-10 MHz μ/s
- To disentangle the space coordinates measurement at higher rates a hit time association was proposed, and it was decided to group SciFi and Silicon sensor
- For the measurement of small angles, the material budget of the trackers should be minimized
  - ❑ We target a total material budget of 3-5% X/X_0 in the vertexing region resulting in ~30urad multiple scattering

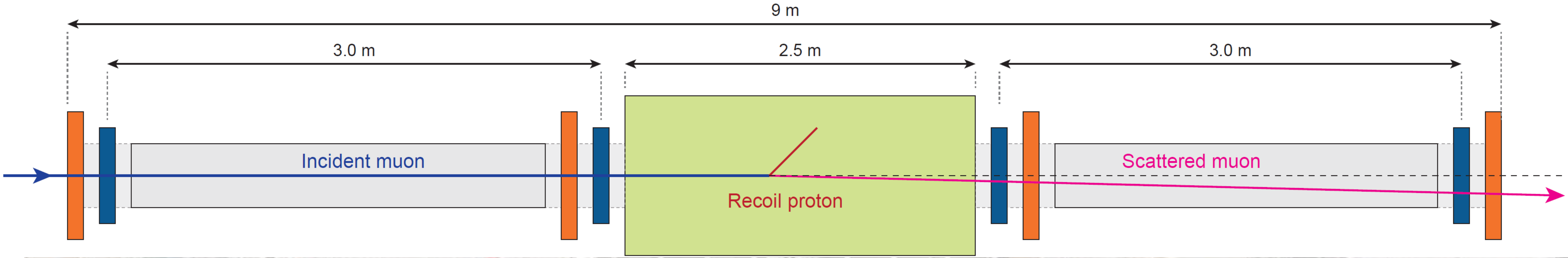


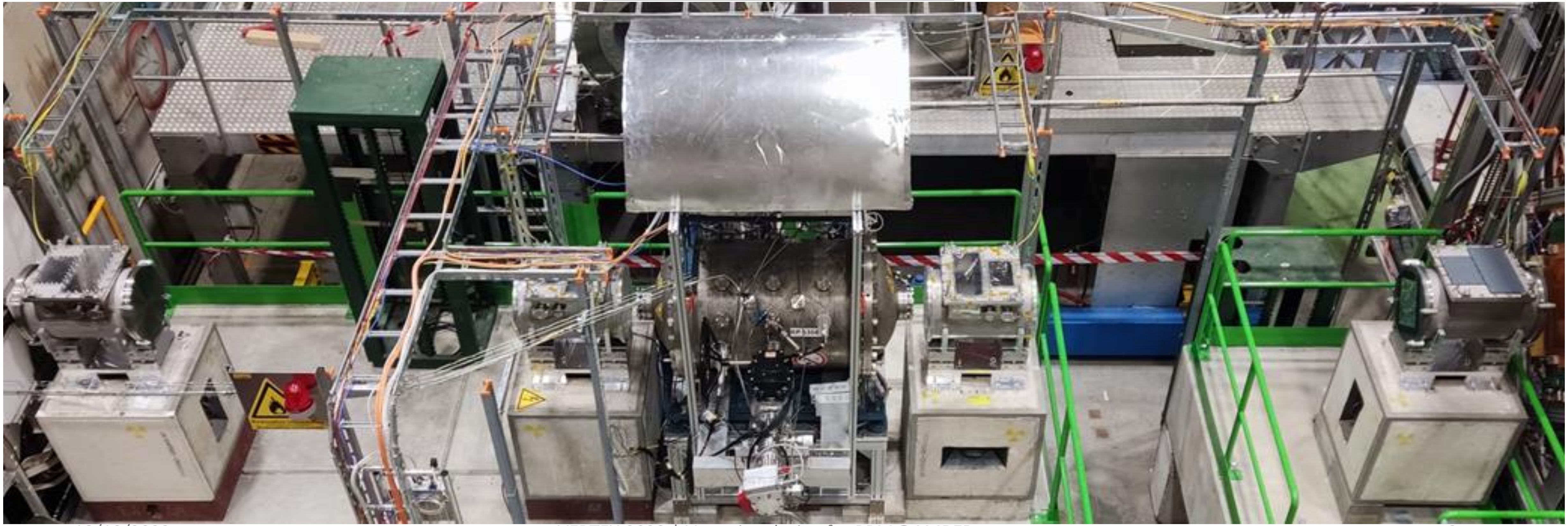


AMBER PRM vertexing requirements

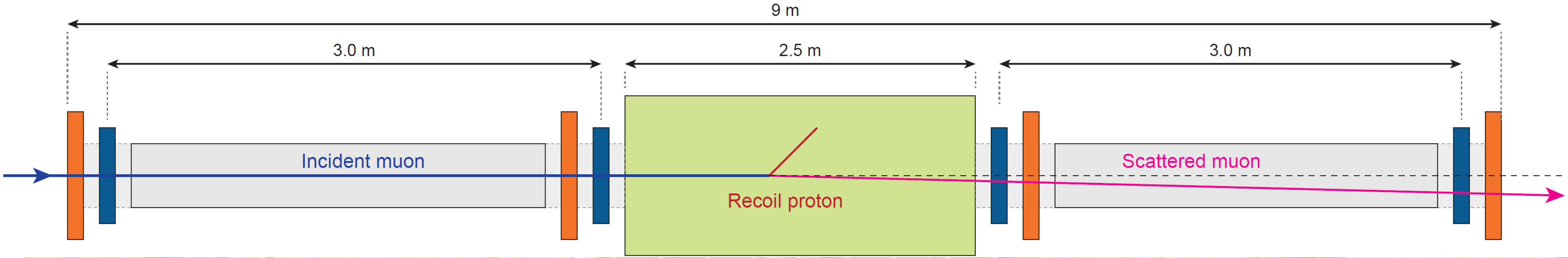


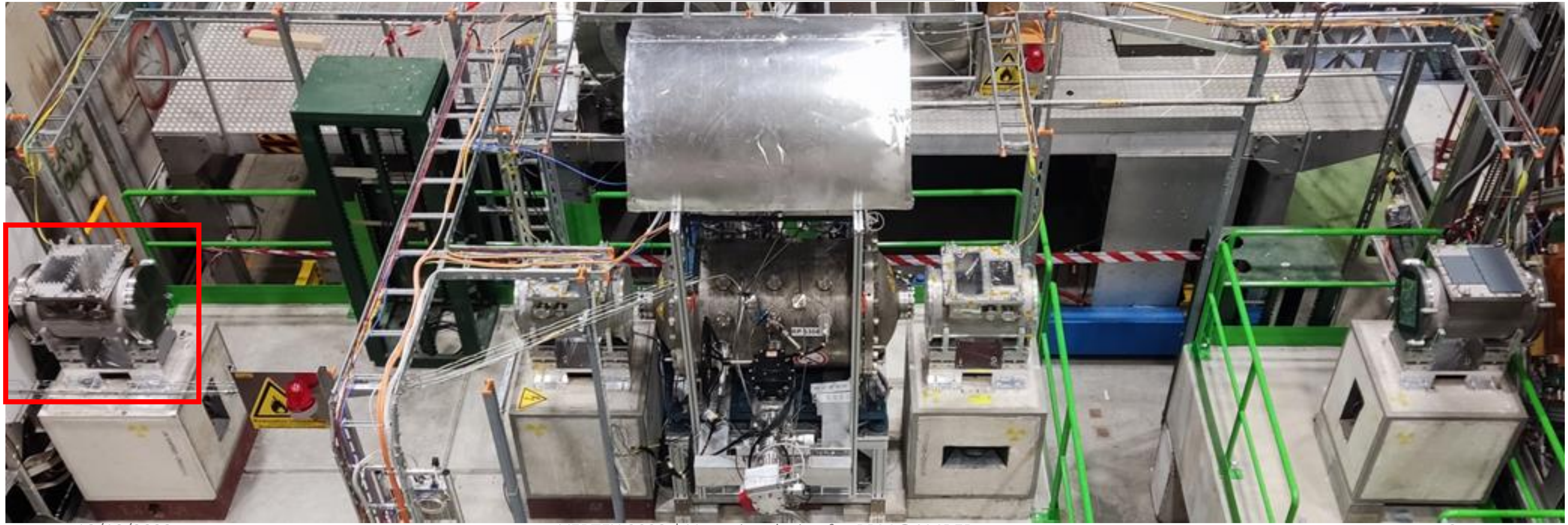
AMBER PRM vertexing requirements





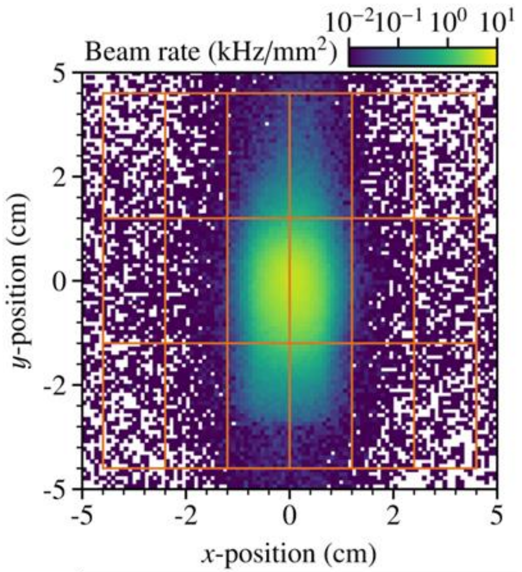
AMBER PRM vertexing requirements

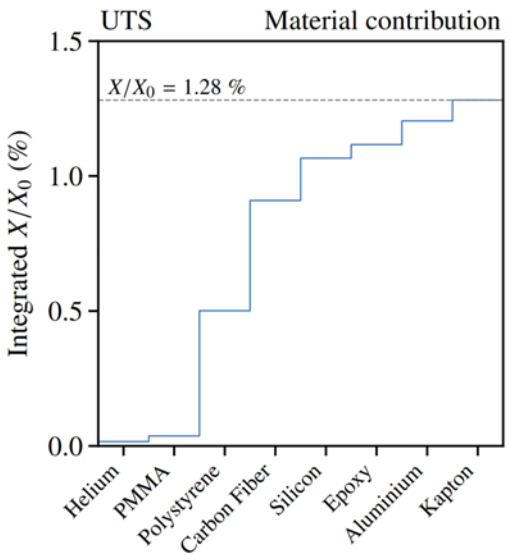


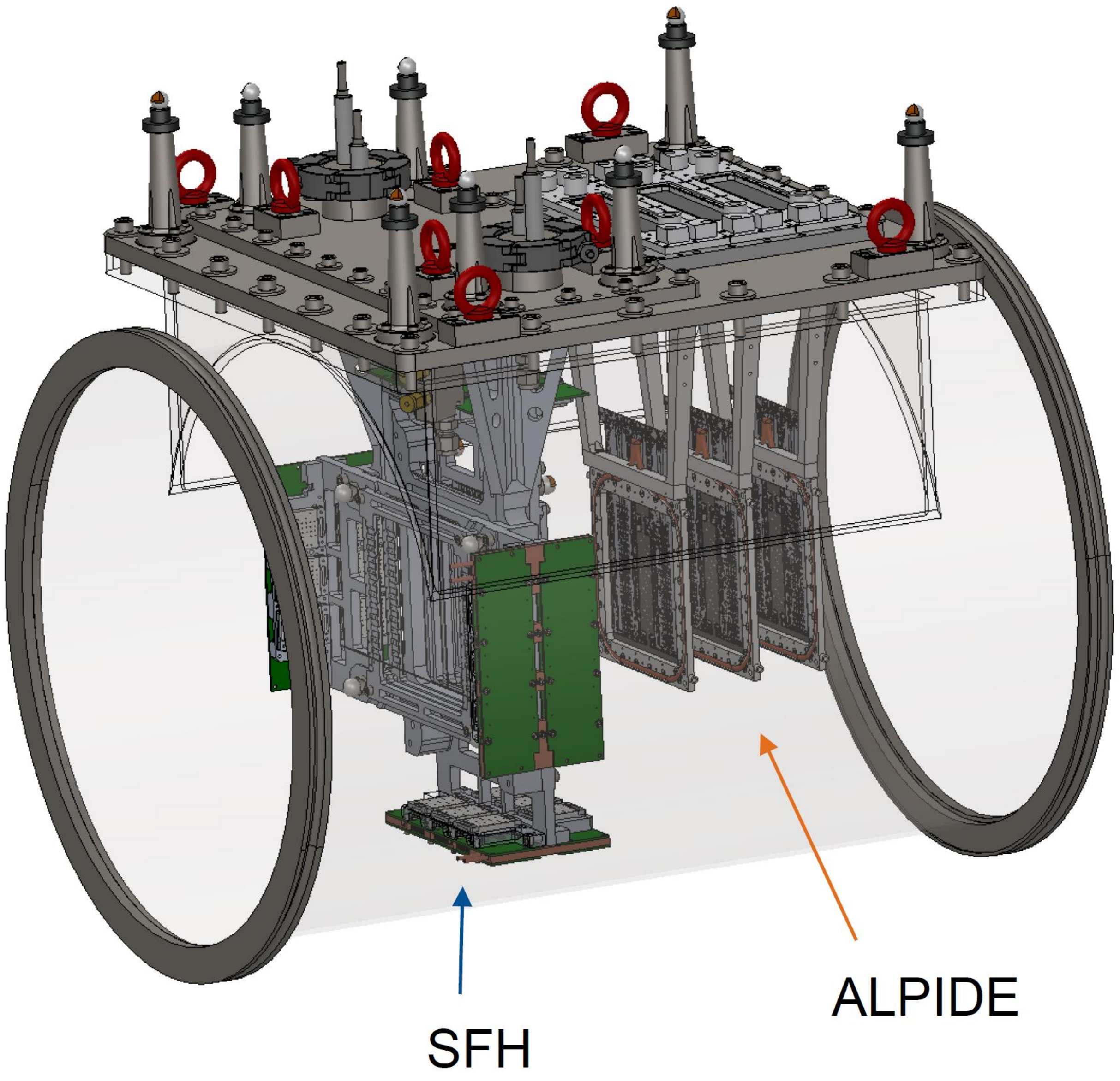


UTS concept & status

- Silicon pixel detector (ALPIDE) and Scintillating-Fiber Hodoscope (SFH) combined in Unified Tracking Station (UTS)
- Three layers of pixel detectors in combination with four planes of scintillating fibres
- Reduced material budget in the active ~10x10 cm^2 area
- He atmosphere

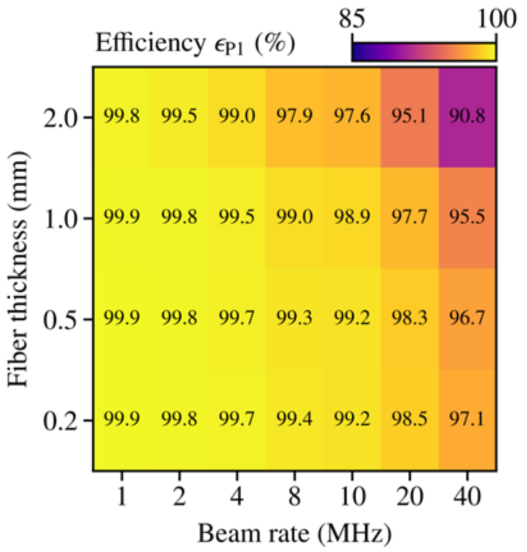


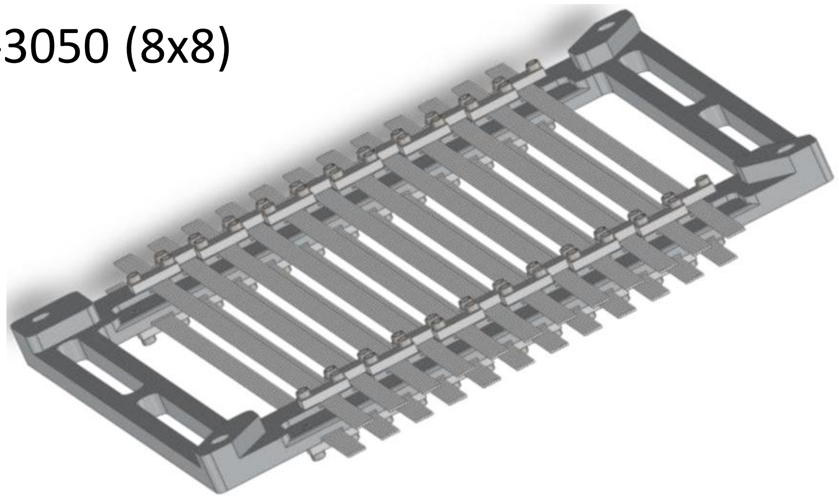


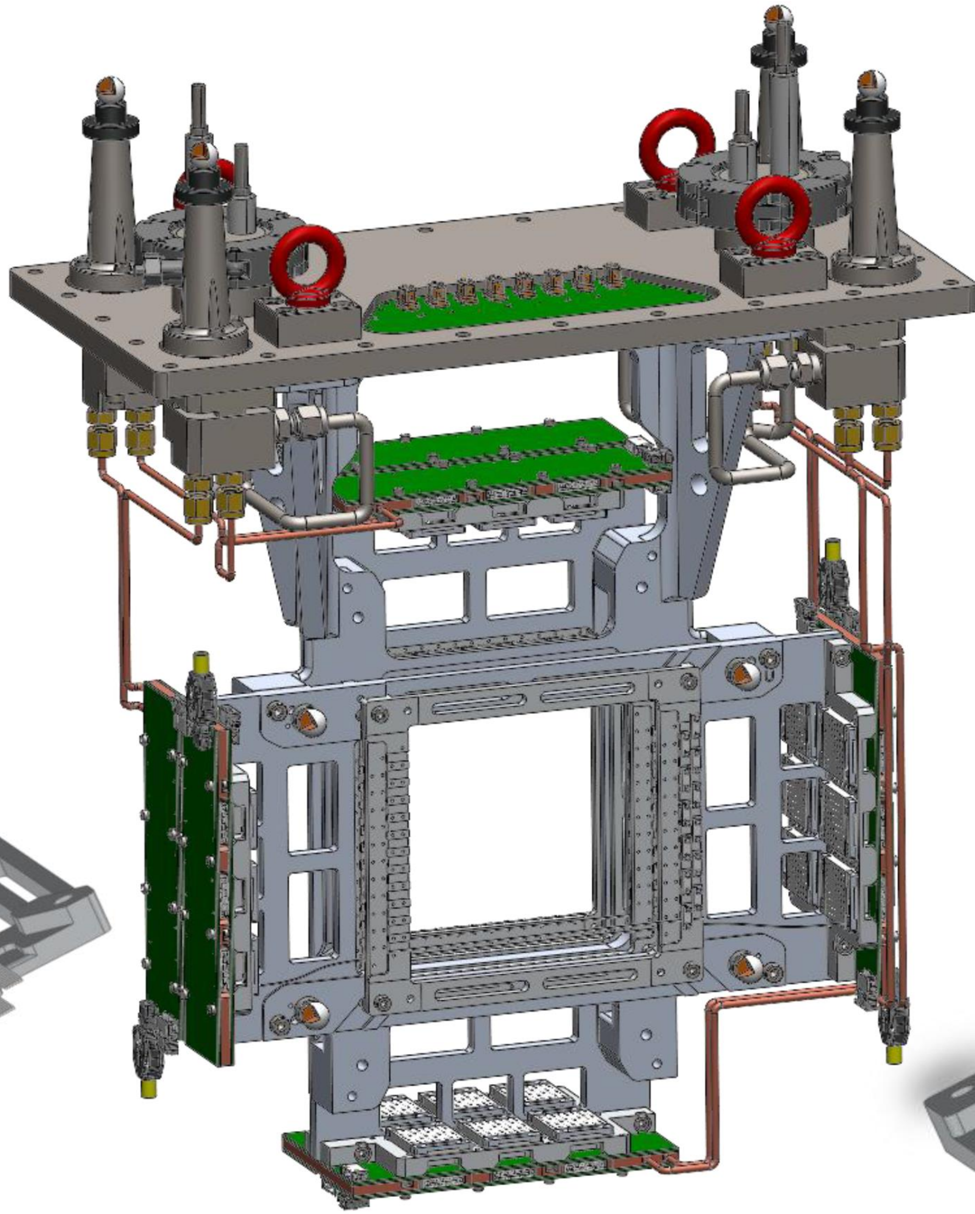


SFH design

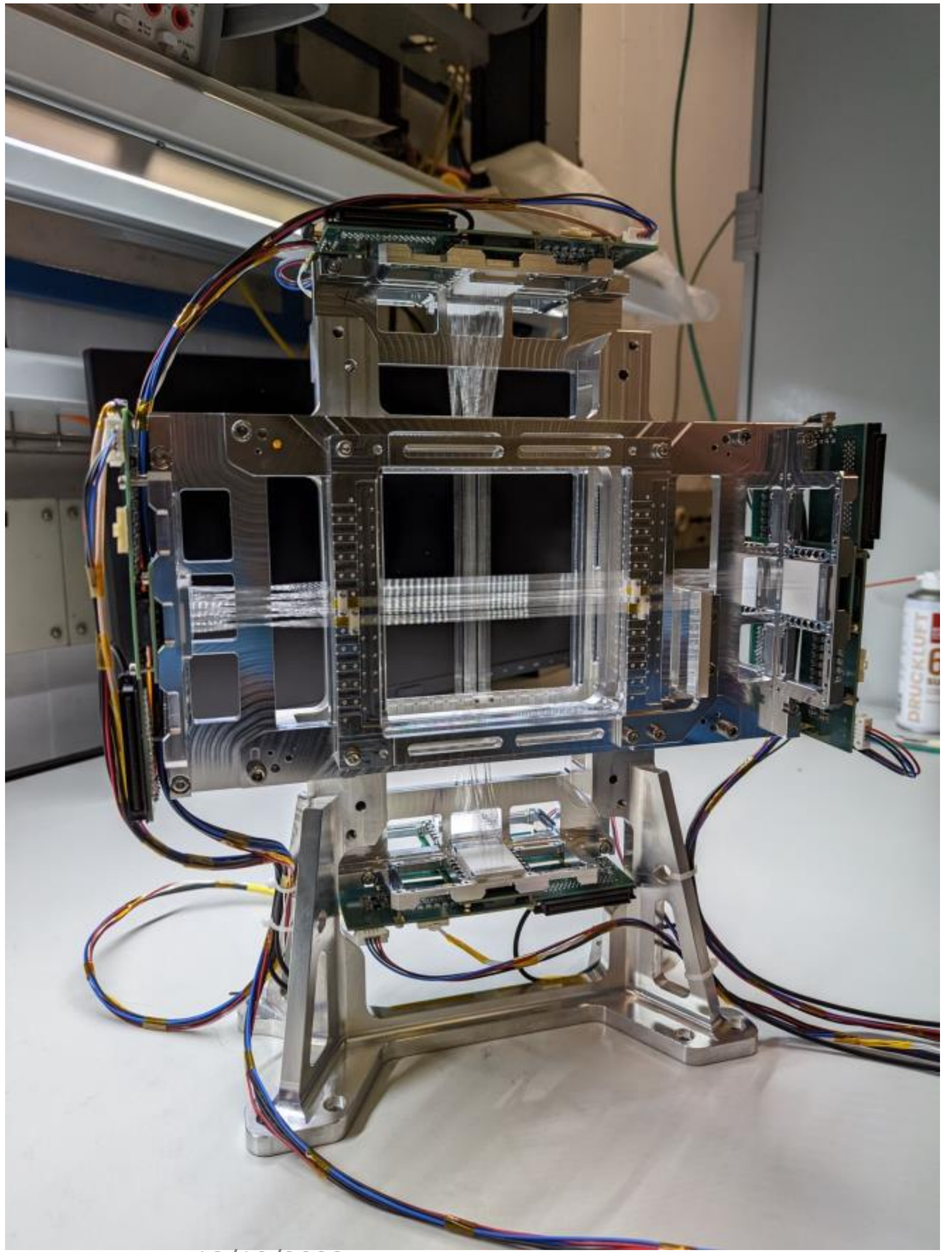
- Four planes of square scintillating fibers (500 µm edge length, Kuraray SCSF-78)
- 196 fibers per plane, active area of ~9x9 cm^2
- Packages containing eight fibers each
- SiPM arrays: Hamamatsu S13361-3050 (8x8)
- CITIROC's discriminator, ifTDC readout



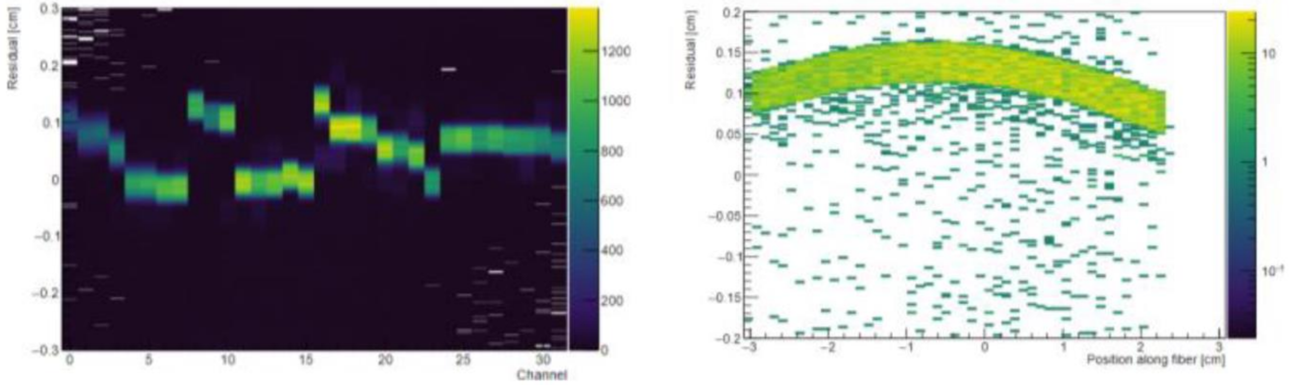




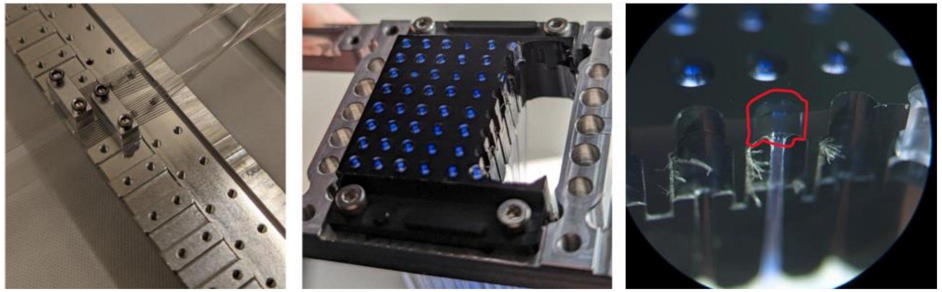
SFH detector first results



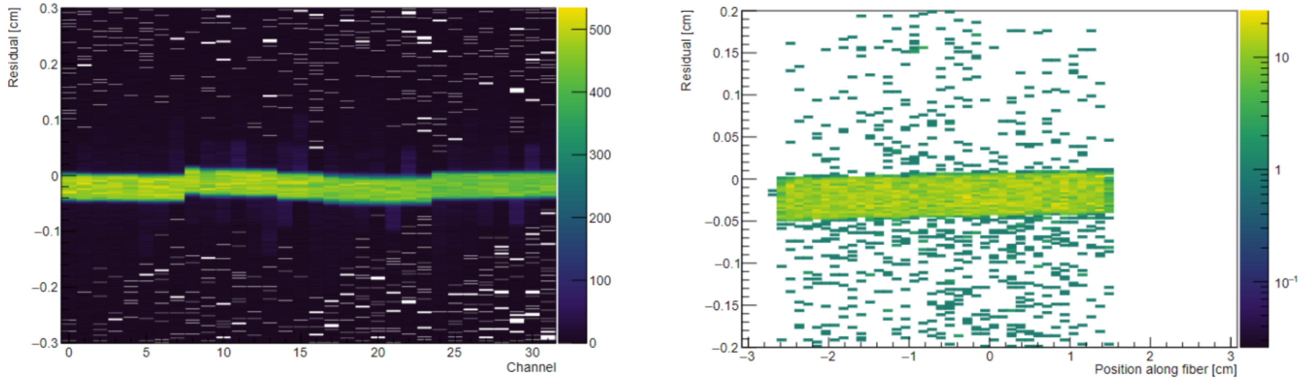
2022



Improved prototype with changes in SiPM coupling, fiber clamping and assembly procedure for two new detector planes



2023

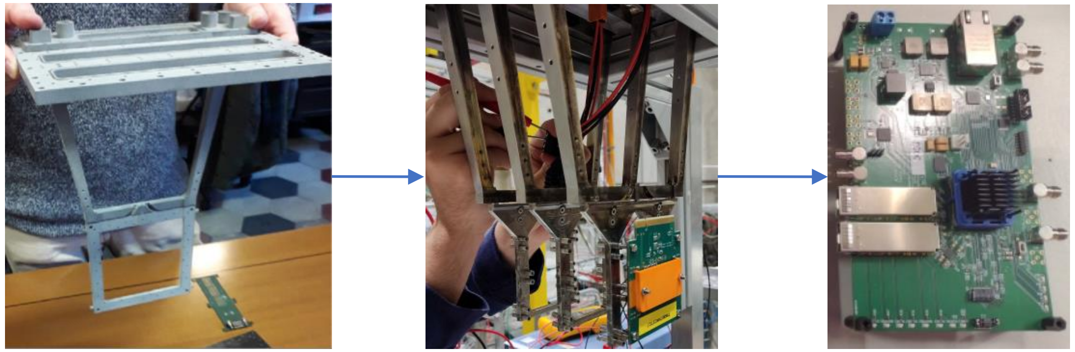


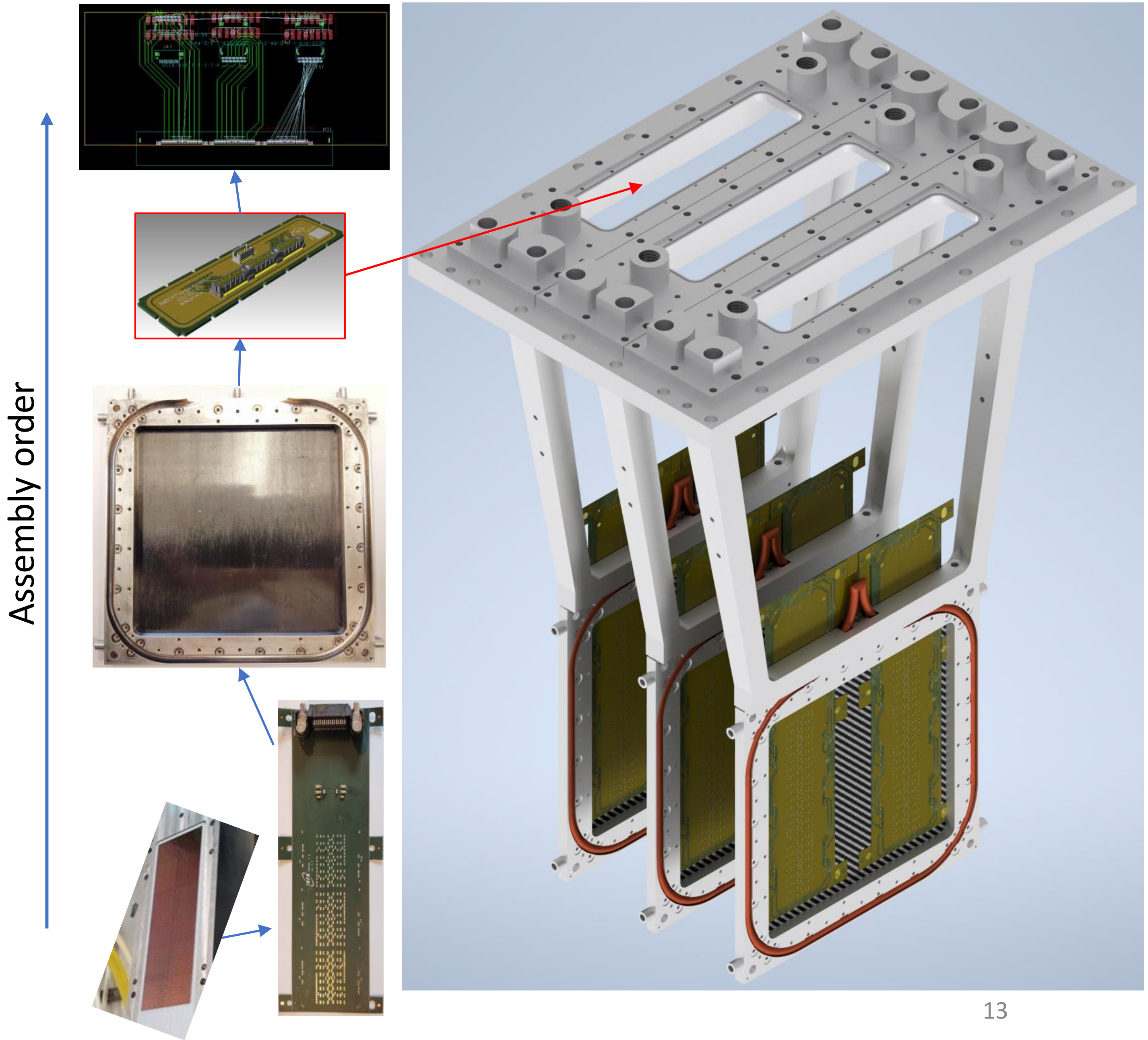
Silicon (ALPIDE) detector design

- 15 mm (Y) × 30 mm (X) sensor, 512 x 1024 pixels
- 29.24 x 26.88 (X × Y) μm^2
- Thickness 50 µm
- 1.2 Gb/s Serial Data port

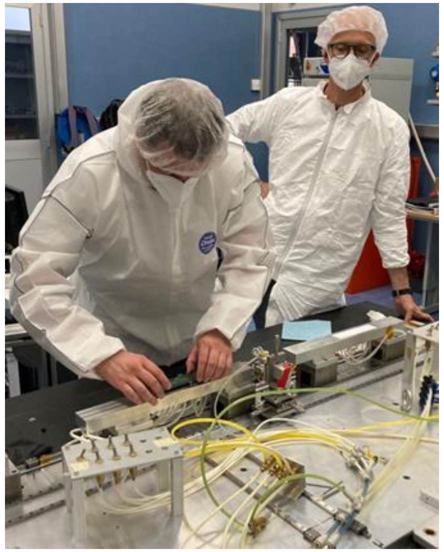
ALPIDE

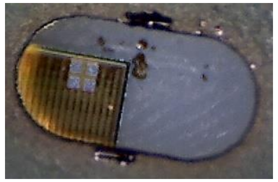
- Flex PCB with 10um thick Al conductors
- 240 um thermo-conductive carbon fibre plate
- Heat exchange through water cooling
- Gas tight mechanics

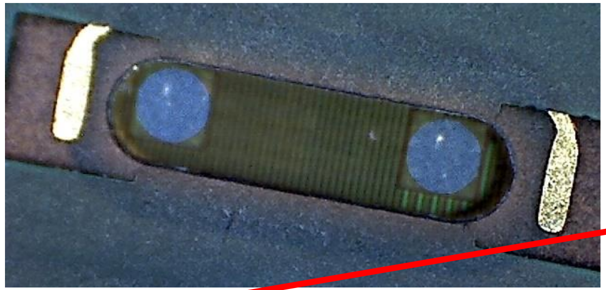


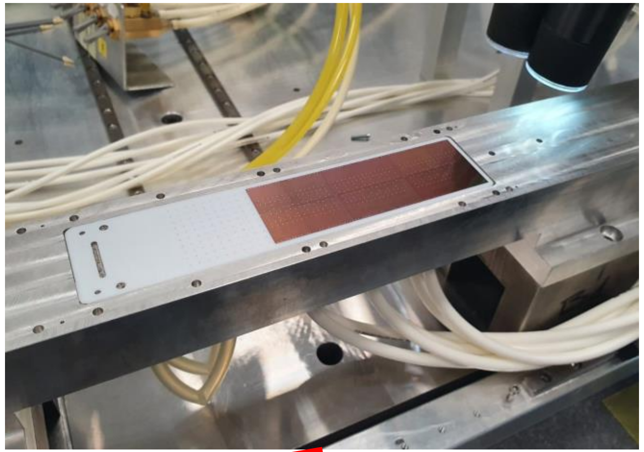


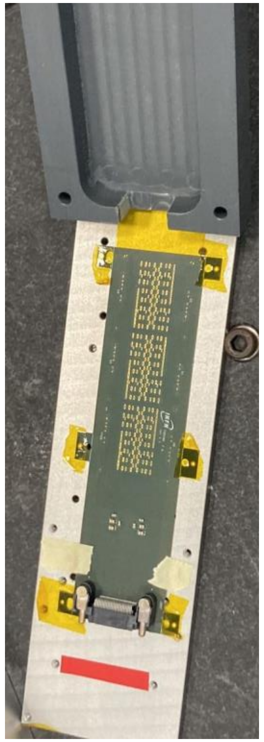
Some moments of the assembly

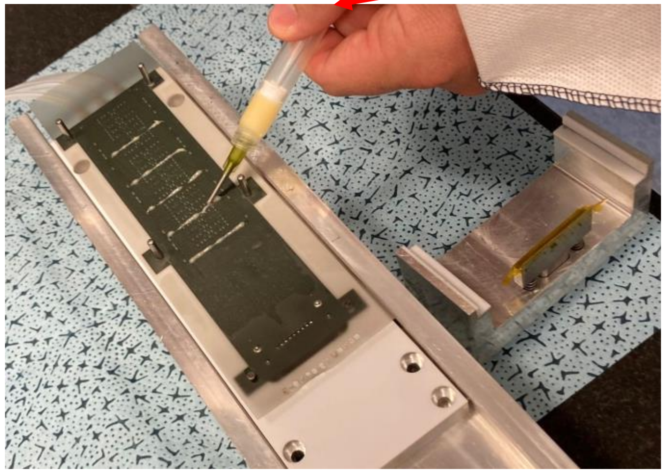


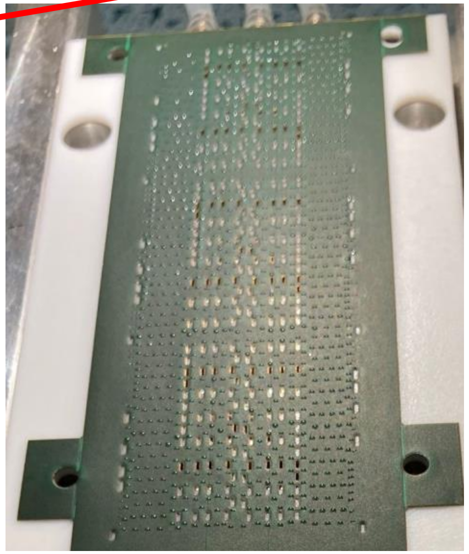


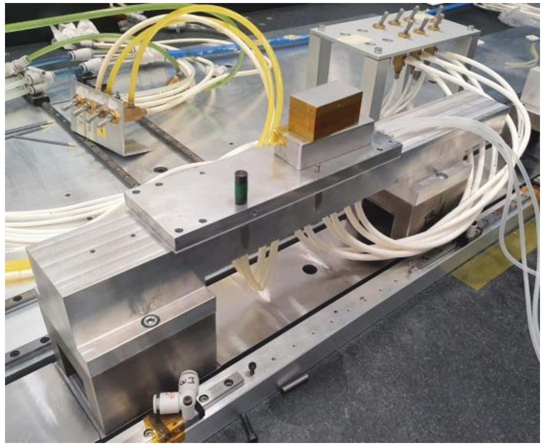




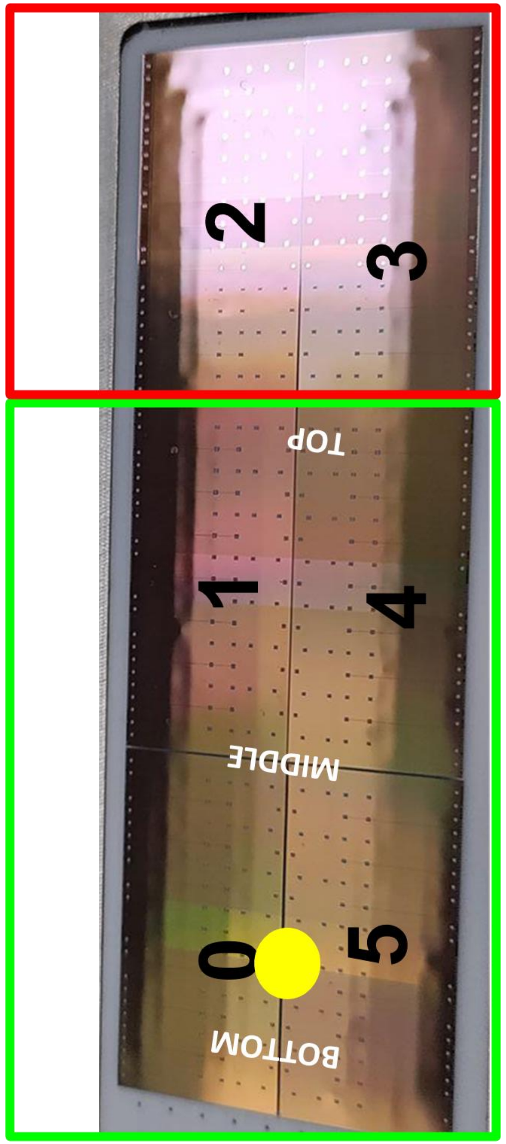


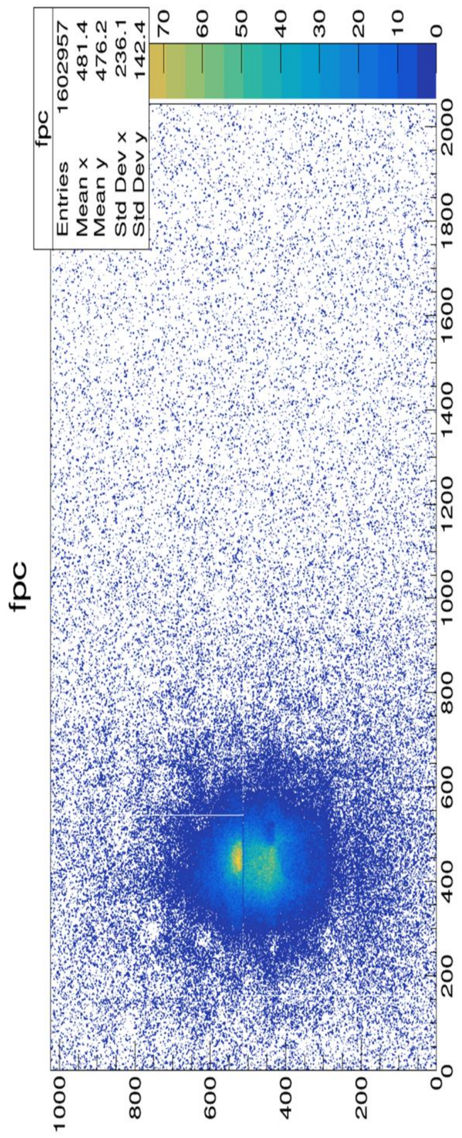


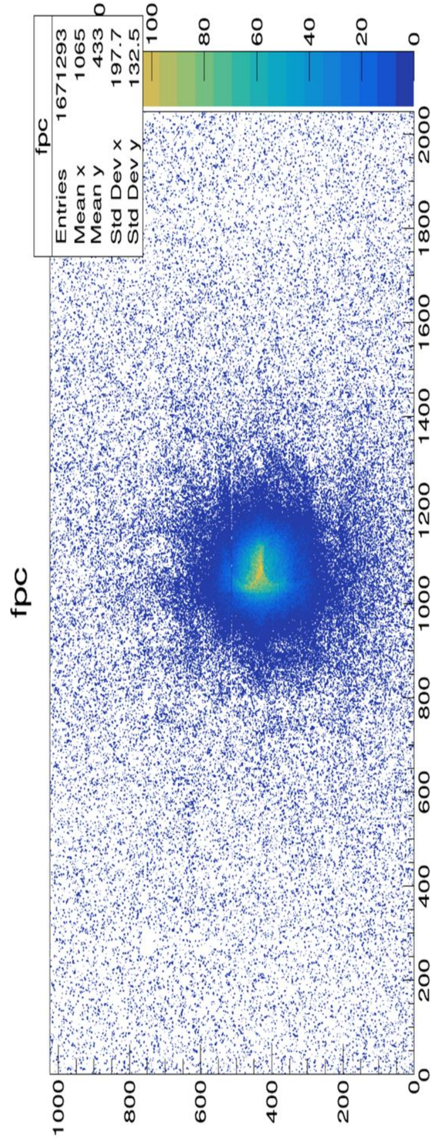


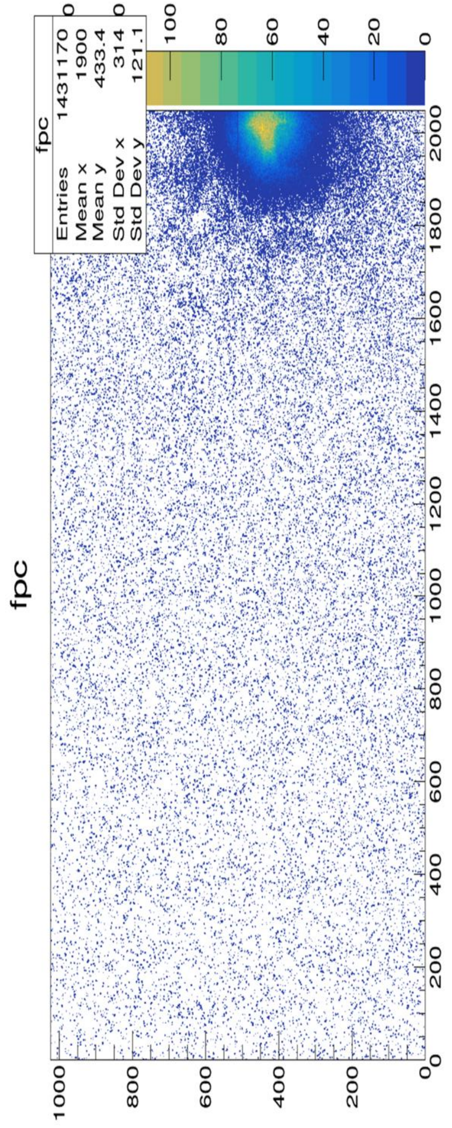


First RO of the first FPC





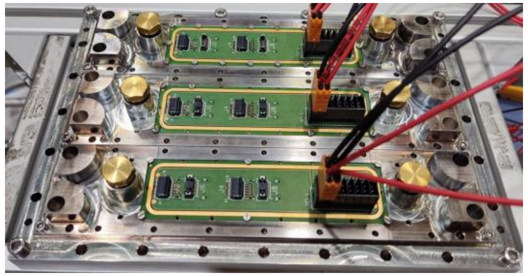
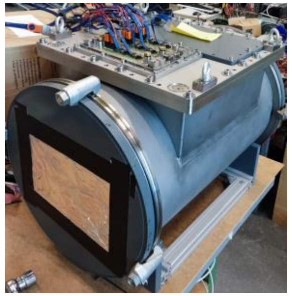
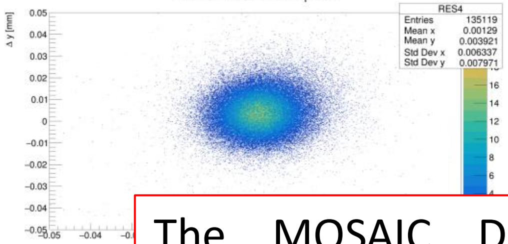




Silicon (ALPIDE) detector status

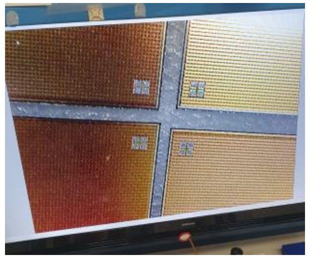
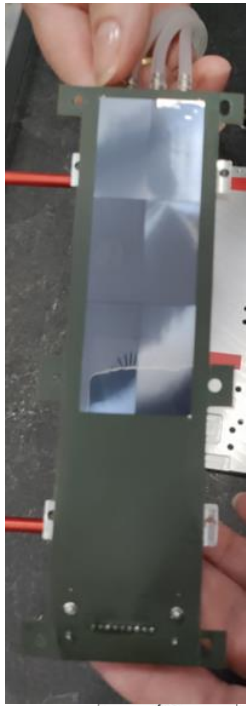
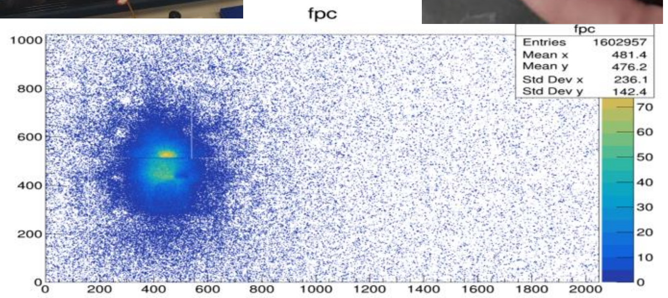
Testing of the ALPIDE for the running conditions



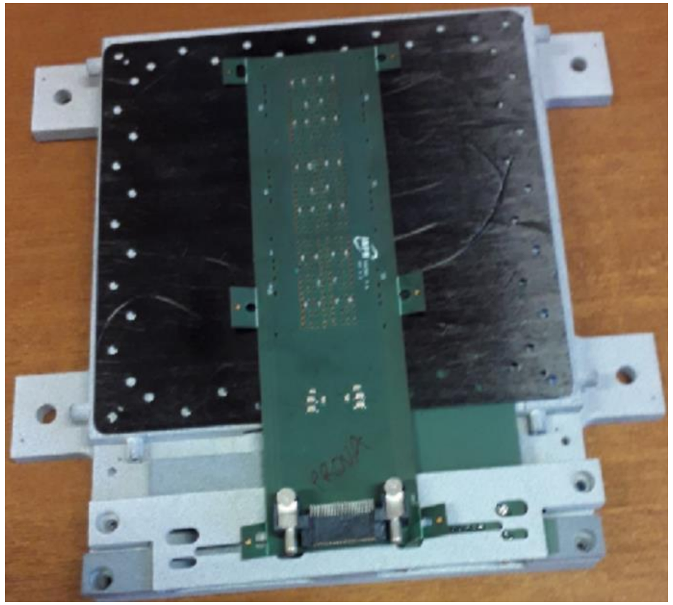
The MOSAIC DAQ has been understood but the 2 MHz are still to be tested

Assembly of the FPC

Preparing mass production

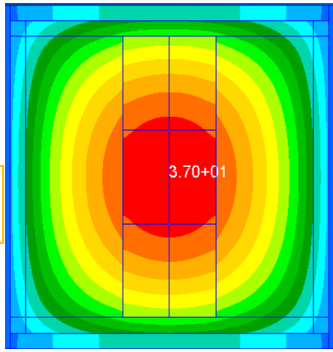
Assembly on the carbon support



Planned within 2023

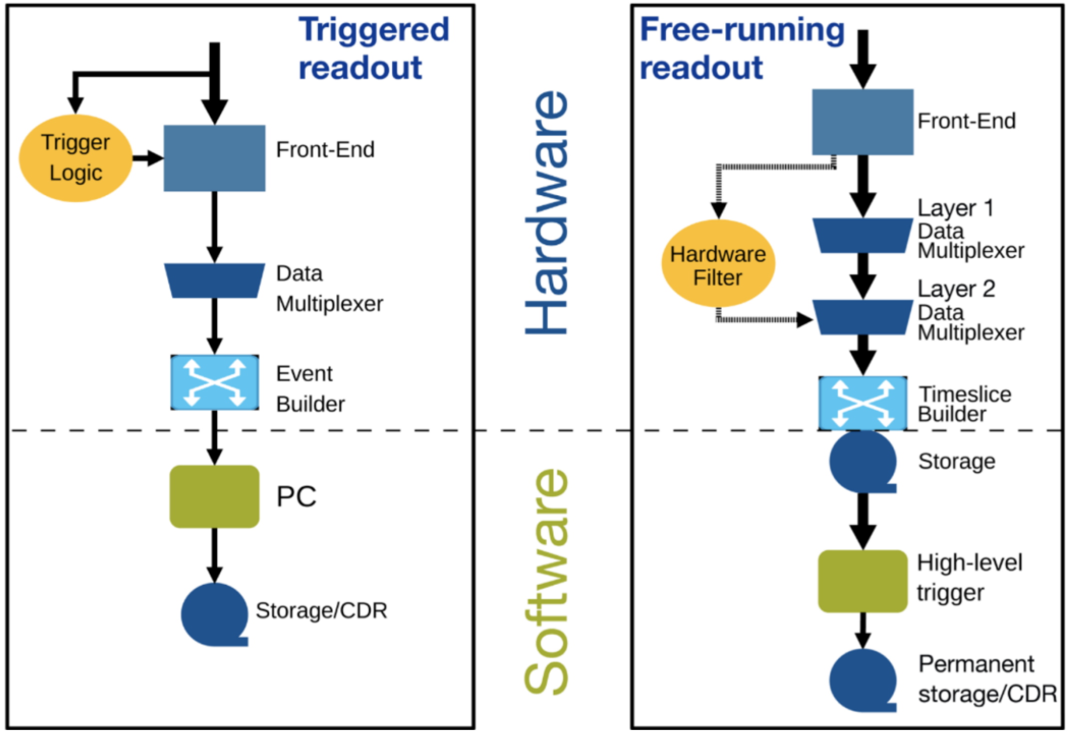
Thermal test planned

Tools design to be verified



DAQ concept

Combination of slow and fast detectors with a continuous readout and software trigger logic for data reduction.

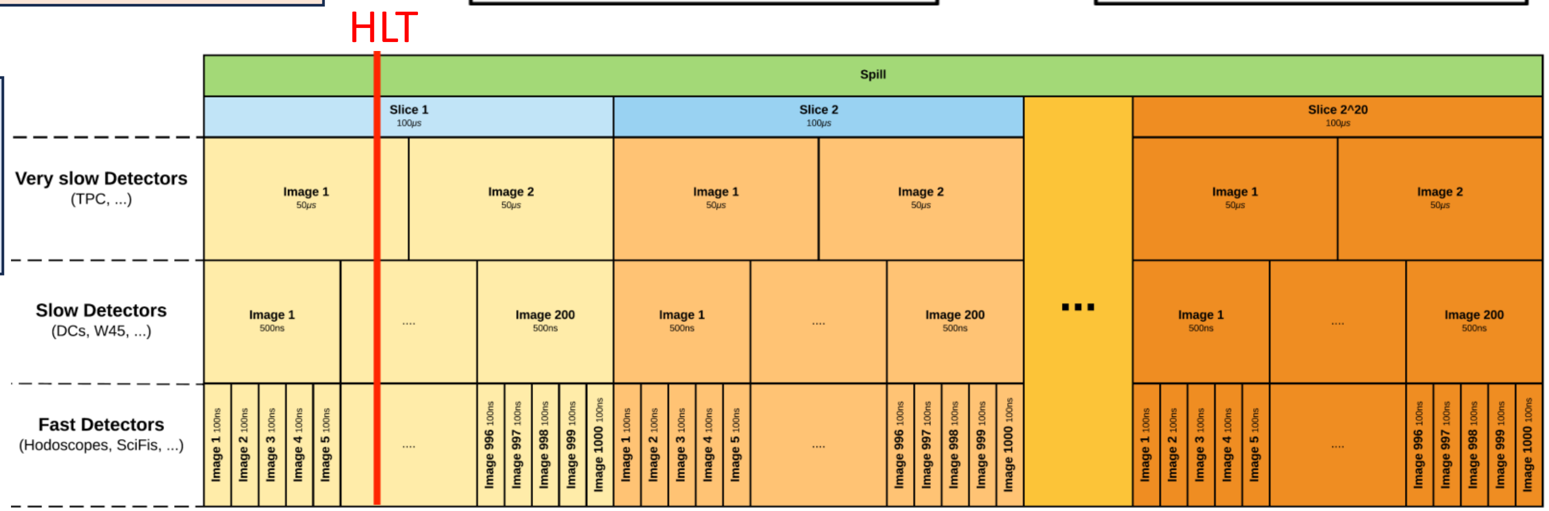


- Data stream sorted in time slices
- Detector data ordered in time images based on to resolution
- Hardware event builder stores data

FPGA

- High-level trigger selects time slices + images

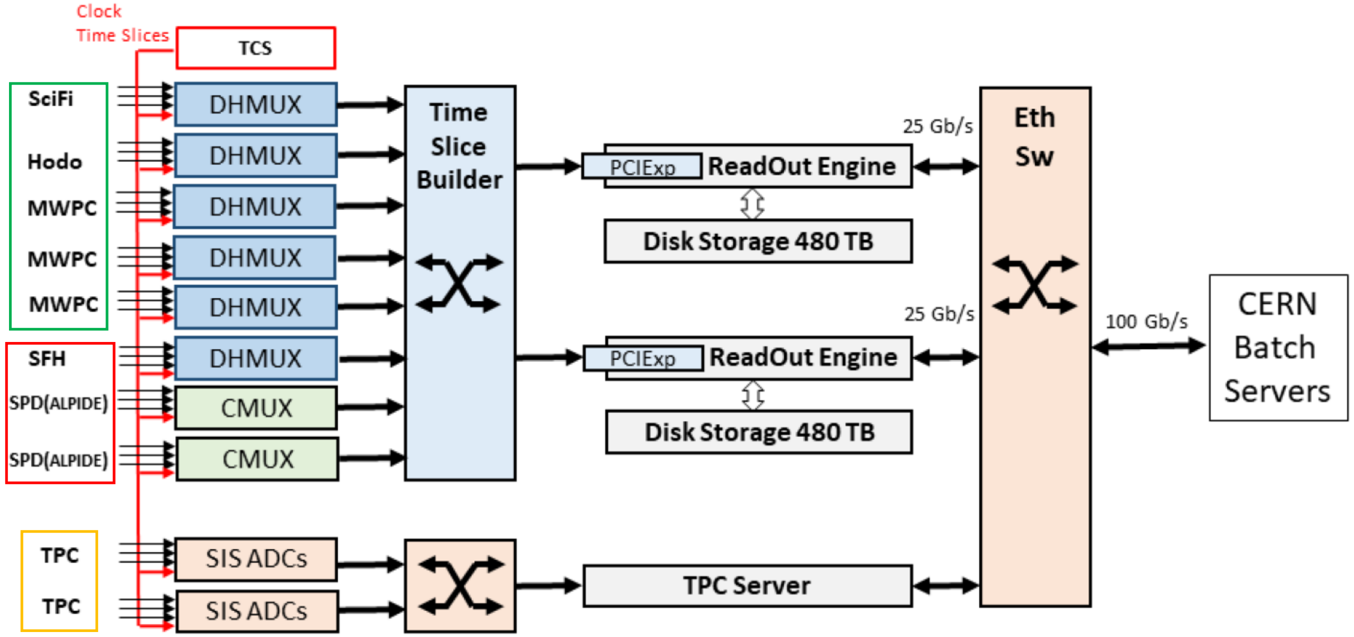
software

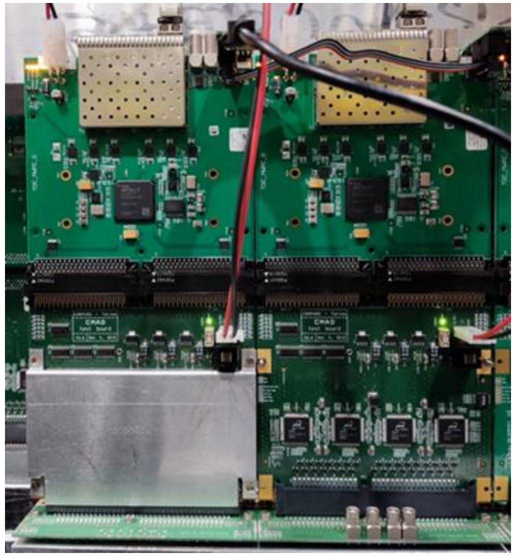


New DAQ hardware installed; tests are ongoing

DAQ status

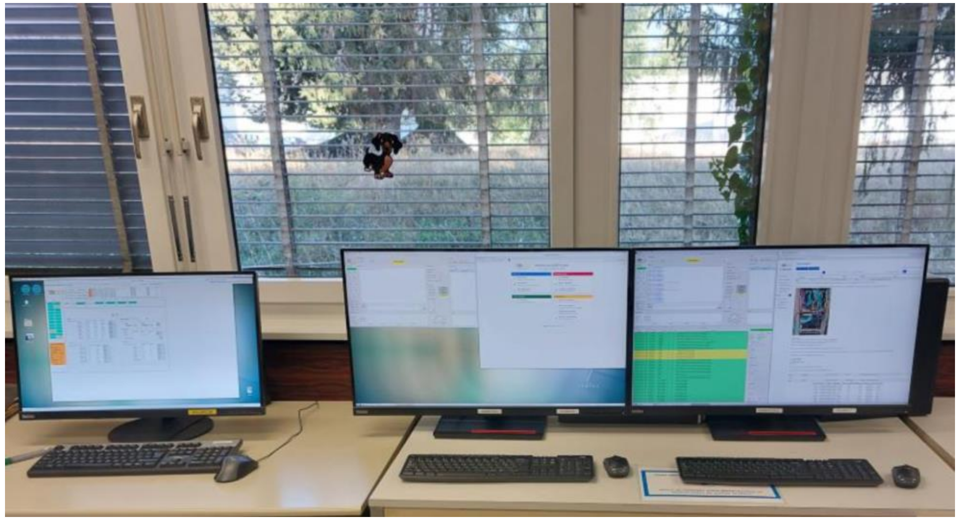
- 2023 test running was mostly dedicated to the DAQ





iFTDCs were operational

DHMUX



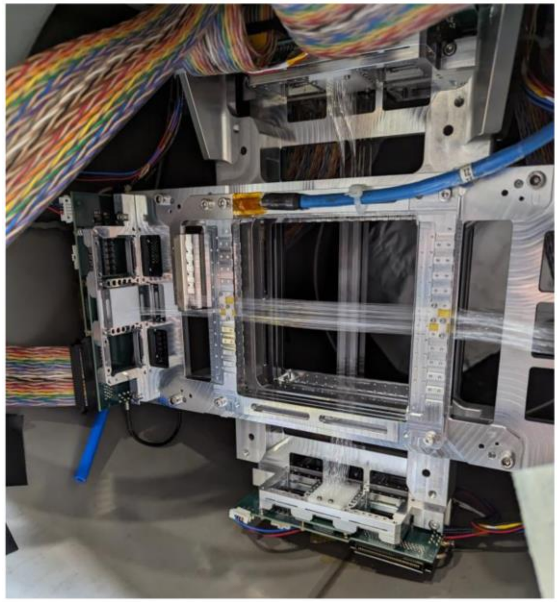
Work on the data treatment and quality checks is ongoing

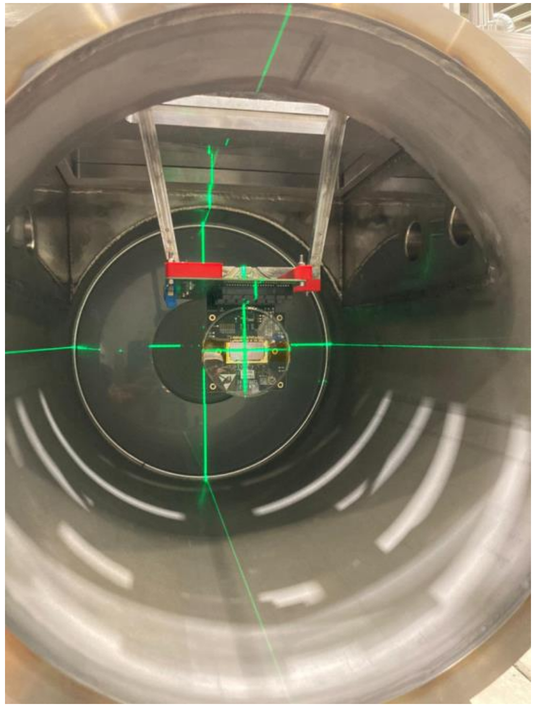
Conclusions & plans

- Presently both the parts of the UTS are preparing full size prototypes that are to be tested parasitically

- Major effort is done to be able to test a fully equipped setup in the autumn of 2024 as part of the PRM test running

- We are targeting to demonstrate the full running capability of the UTS based vertexing to support the request for 2025 full year data tacking





SPARES

Institute for Hadronic Structure and Fundamental Symmetries
Physics Department
Technical University of Munich

Proposal of a New Measurement

High-energy elastic muon-proton scattering
Measurement of the cross-section of elastic muon-proton scattering using the *CERN M2* beamline. (SPSC-P-360)

$$< r_p^2 > = -6\hbar^2 \cdot \frac{dG_E(Q^2)}{dQ^2}\bigg|_{Q^2\to 0} \qquad \frac{d\sigma^{\mu p\to\mu p}}{dQ^2} = \frac{4\pi\alpha^2}{Q^4} R\left(\epsilon G_E^2 + \tau G_M^2\right)$$

- Measure as close as possible to $Q^2 \to 0$
  → suppress influences from higher order form-factor terms
  → high-energy $\mathcal{O}(10 - 100\text{ GeV})$ — Cross-section $\propto G_E^2$
- Disagreement on experimental data: PRad and MAMI
- Sufficient range to determine radius:
  → Aimed precision of below 1 %
  → Aimed Q^2-range: 0.001 - 0.04 GeV^2/c^2
- Below Q^2 = 0.001 GeV^2/c^2:
  → Deviation from point-like proton level of $\mathcal{O}(10^{-3})$
  → Smaller than unavoidable systematic effects
- Above Q^2 = 0.04 GeV^2/c^2:
  → Non-linearity of the cross section
  → Predominant source of uncertainty

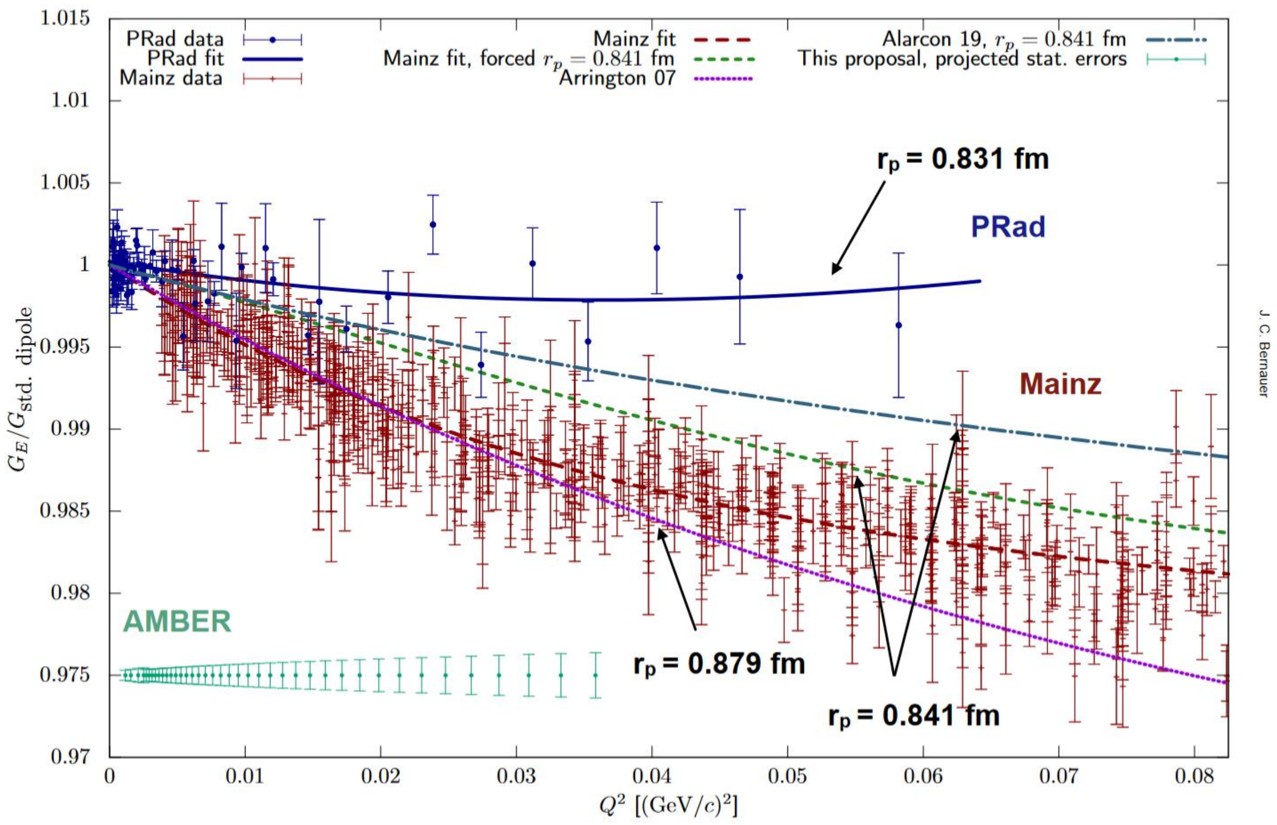


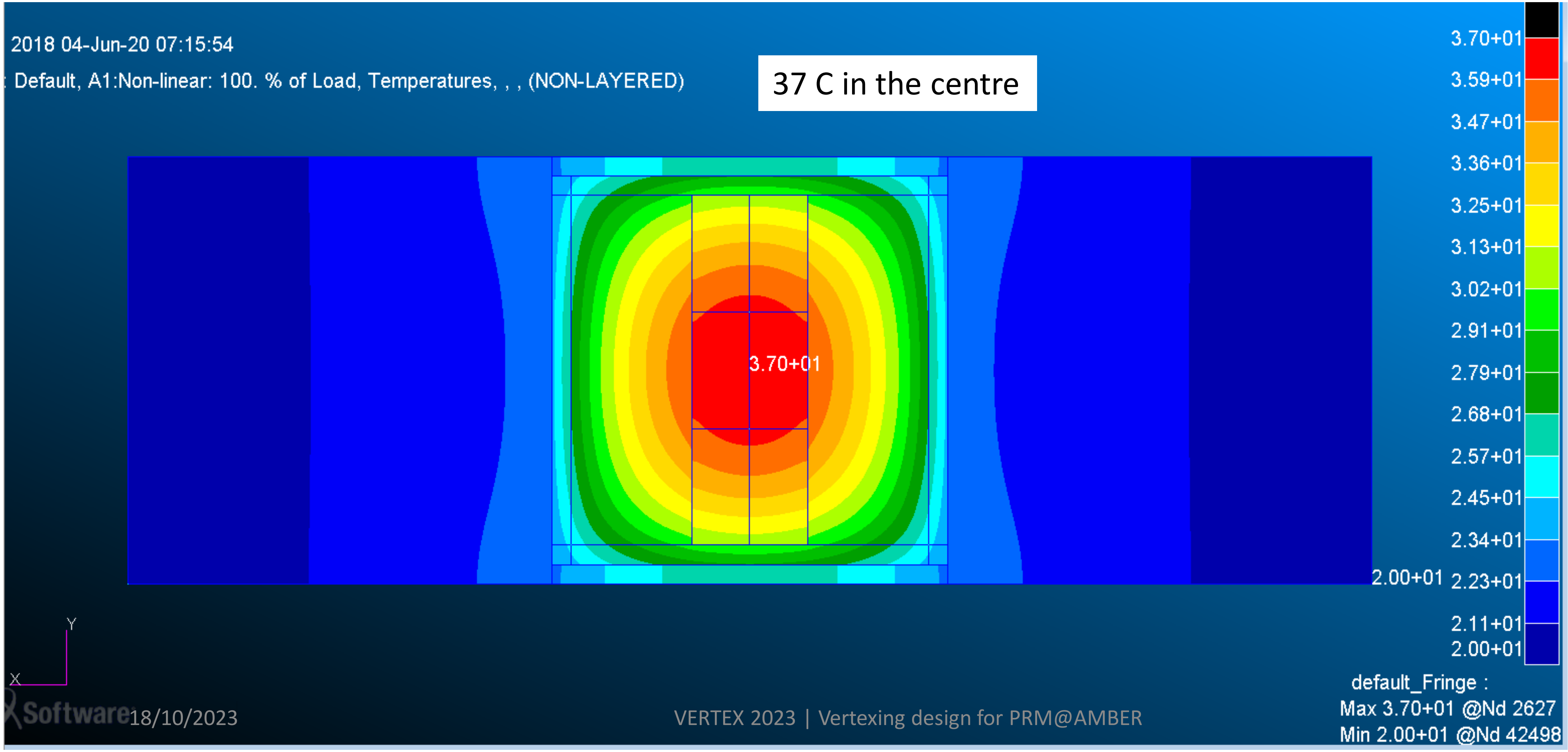
Table 1.2: Material budget for the FDI-A-24 Flex-based stack with aluminum conductors. [43]

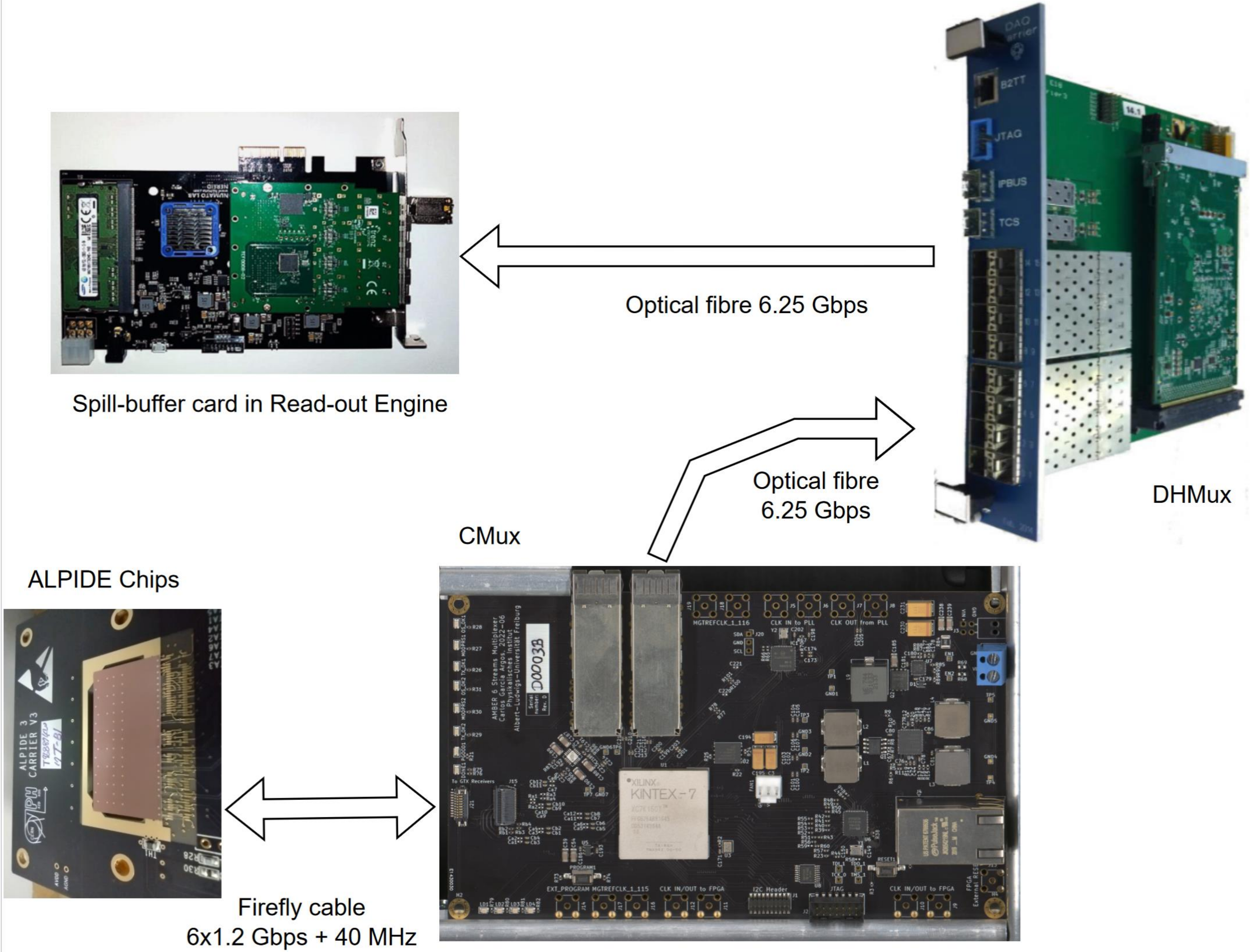
layer	item	A	Z (u)	d (cm)	density $\left(g/cm^3\right)$	X_0 $\left(g/cm^2\right)$	X/X_0 (%)	contrib. (%)
1	solder mask (epoxy)			0.0030	1.250	34.99	0.011	4.64
2	aluminum layer (Al)	26.982	13	0.0014	2.699	24.01	0.016	6.82
3	Kapton			0.0010	1.420	40.58	0.003	1.516
4	aluminum layer (Al)	26.982	13	0.0014	2.699	24.01	0.016	6.82
5	solder mask (epoxy)			0.0030	1.250	34.99	0.011	4.64
6	glue flex (C)	12.011	6	0.0050	0.958	43.01	0.011	4.82
7	ALPIDE (Si)	28.085	14	0.0050	2.329	21.82	0.053	23.12
8	glue to plate (C)	12.011	6	0.0080	0.958	43.01	0.018	7.72
9	carbon fleece (C)	12.011	6	0.0020	0.400	43.01	0.002	0.81
10	cold plate (C)	12.011	6	0.0240	1.583	43.01	0.088	38.28
11	carbon fleece (C)	12.011	6	0.0020	0.400	43.01	0.002	0.81
	Total:			0.0558			0.231	100.00

Picture 5

Power:
Heat flux= 50mW/cm2
- 0,225W/chip
- 1,350W/HIC
TOTAL Power= 4,050 W

Temperature map on the carbon support




Spill-buffer card in Read-out Engine
Optical fibre 6.25 Gbps
DHMux
Optical fibre
6.25 Gbps
CMux
ALPIDE Chips
Firefly cable
6x1.2 Gbps + 40 MHz

ALPIDE DAQ Boards

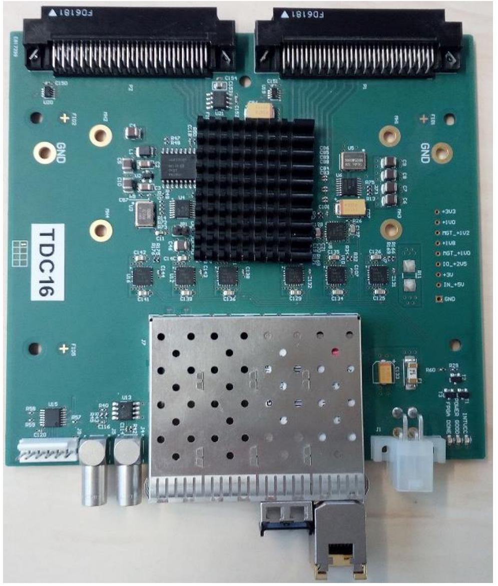
- Centred around a **Kintex-7** FPGA: K160T-FFG676.
  - 8 GTX transceivers up to 12.5 Gbps.
  - Plenty of I/Os.
- 6 transceivers for **ALPIDE** data reception.
- 2 transceivers to **SFP+**.
- 1 **Ethernet** (10/100/1000) interface.
- On-board **clock generation** with Si5344/Si5394.
- Additional clock I/Os on optional **SMA or LEMO connectors**: 2 for transceivers, 2 for FPGA fabric.
- **3 versions** designed so far, the last two meant to overcome the chip supply issues:
  - Variations to power and clock generation.
- **19 boards** have been produced.
- Next generation board based on **Kintex UltraScale**.

DHmx/DHsw

- Backbone module of DAQ
  - FPGA: XC6LX130-2
  - 4GB DDR3 Memory, 3GB/s throughput
- Firmware versions
  - LV0 MUX for iFTDC with UCF links
  - Time Slice Builder (Switch) , 5 GB/s throughput
  - Future: LV1 MUX

iFTDC

- **Specification**
  - ARTIX7 FPGA XC7A-50-2
  - 64 channels,
  - Programmable signal edge or both edges
  - **Bin size : 0.8 ns, 0.4 ns, 0.2 ns (32 channels)**
  - **Time resolution : 300ps, 170 ps, 100 ps**
  - **Differential nonlinearity : 10%, 20%, 40%**
  - **Trigger less capable data flow**



Applications

- MWPC
- Drift Chambers
- SciFi