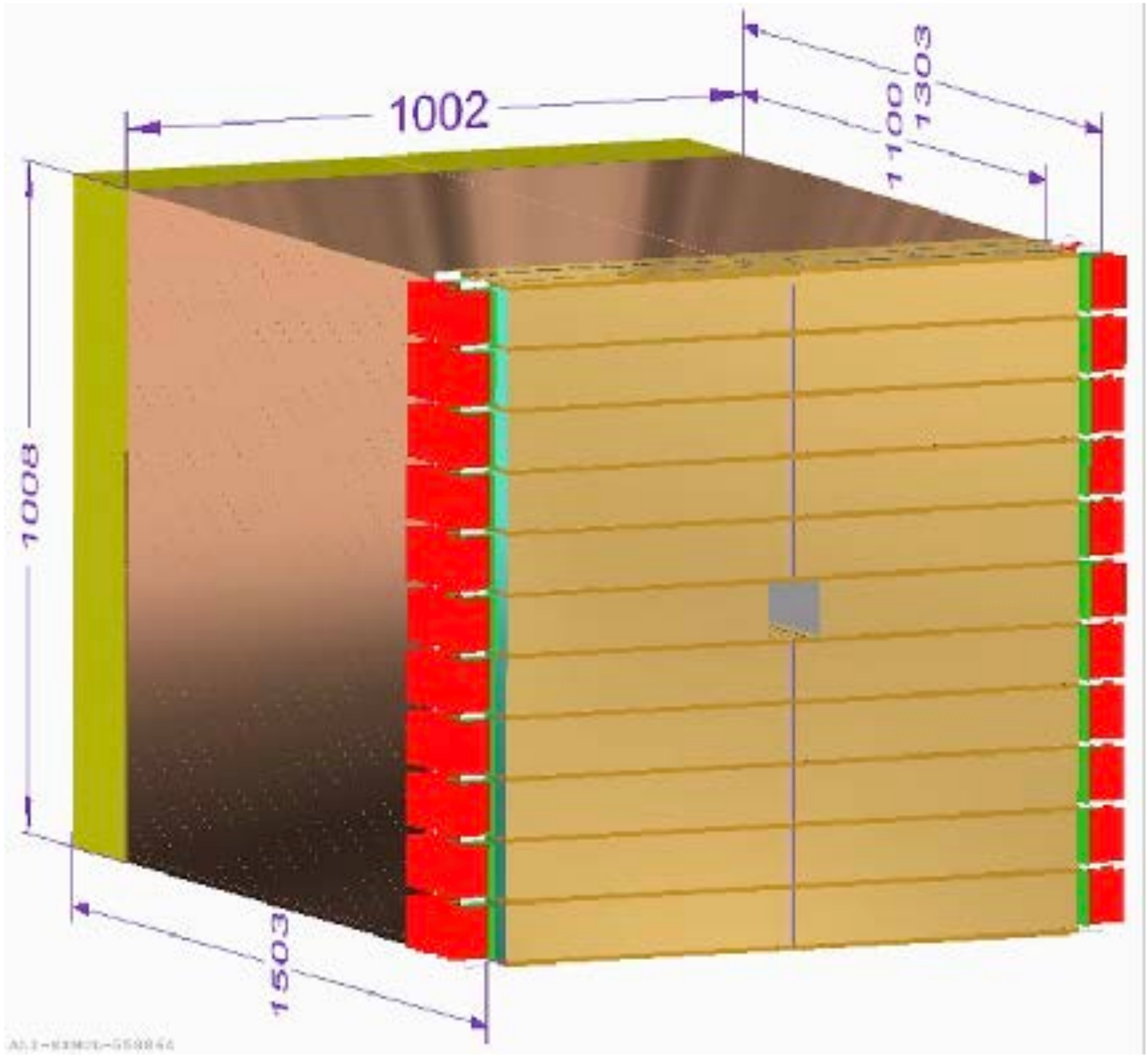
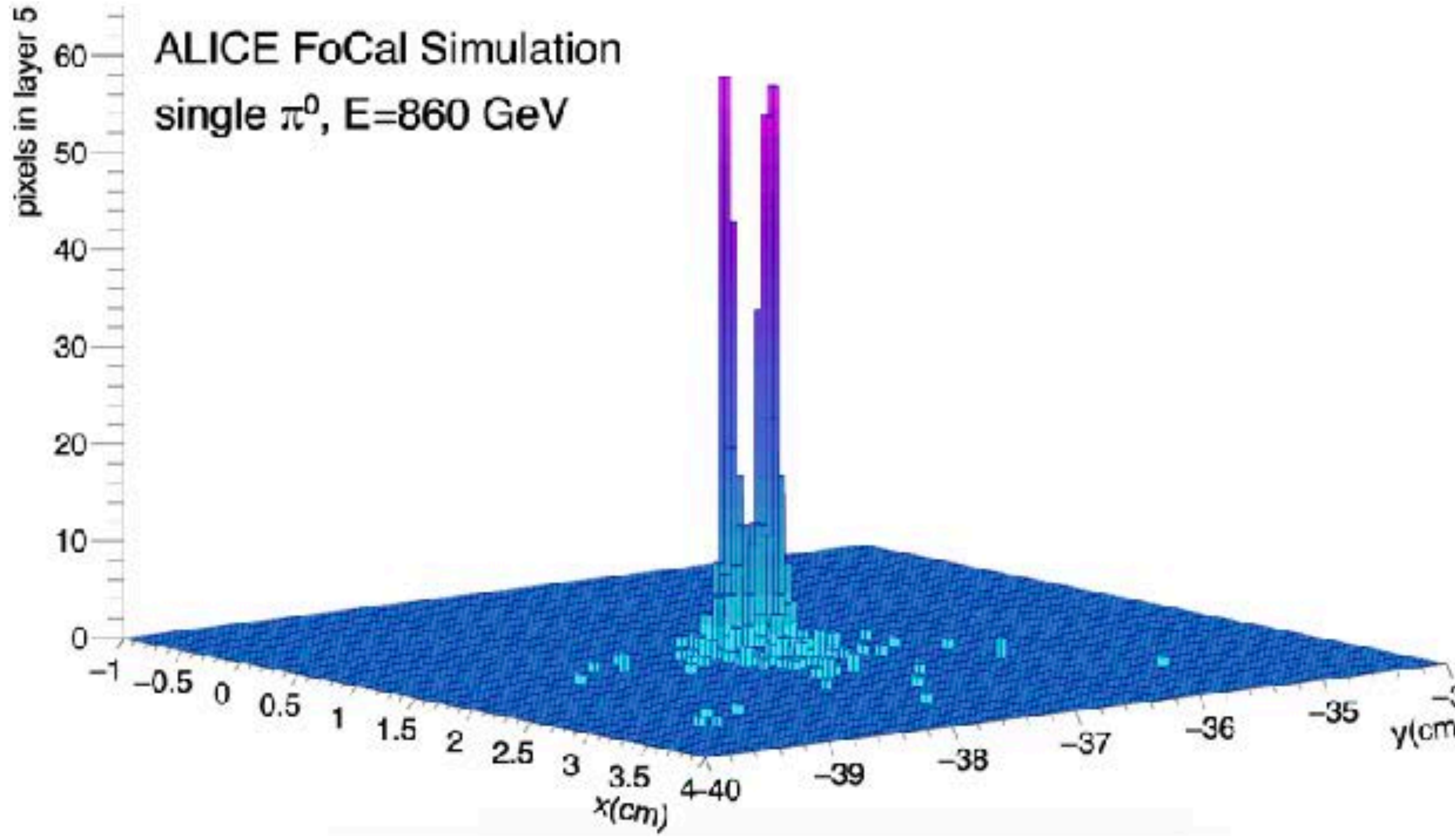
FoCal summary and outlook



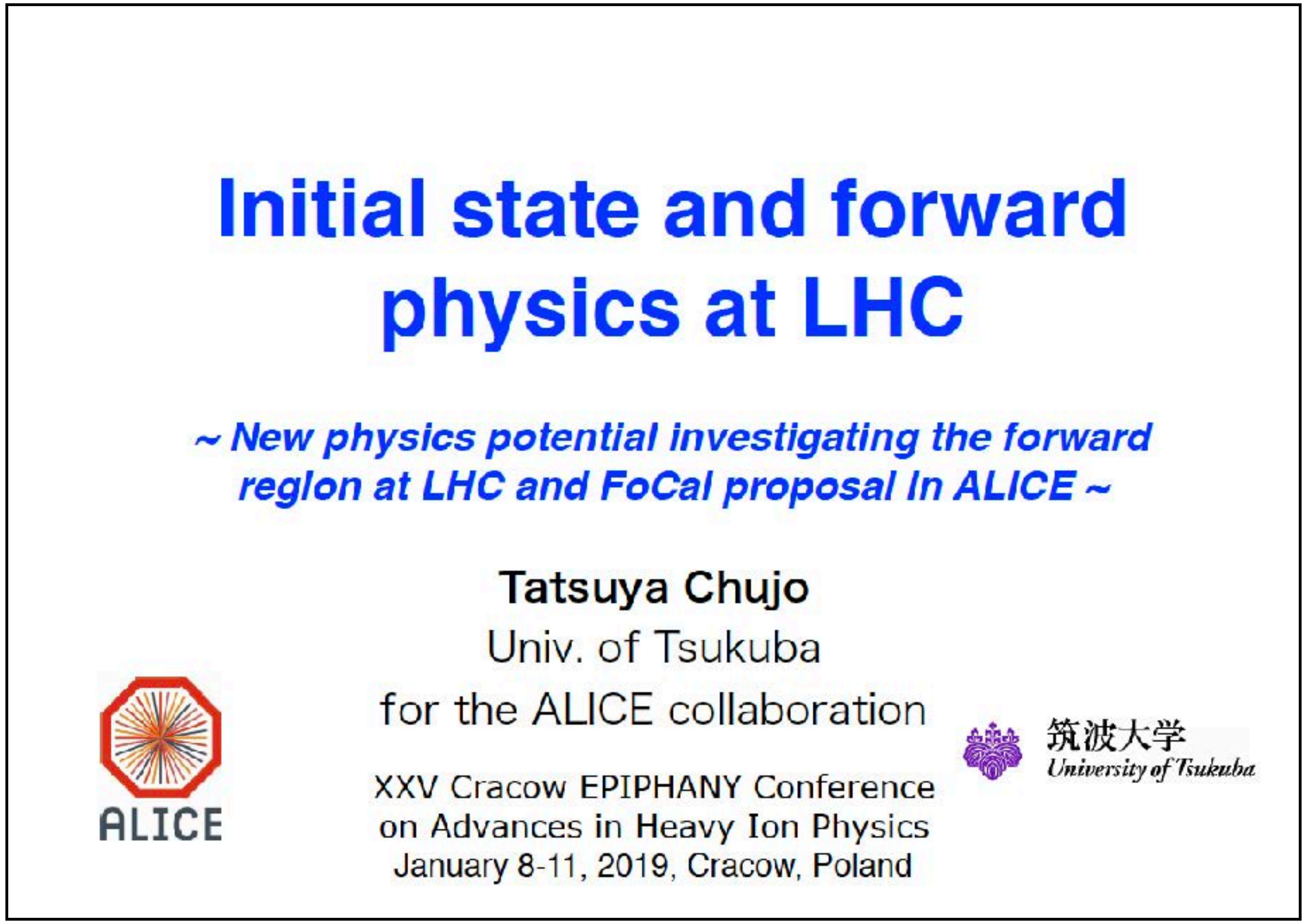
Ian Gardner Bearden
(Univ. of Copenhagen)
and
<u>Tatsuya Chujo</u>
(Univ. of Tsukuba)



5th ALICE UPGRADE WEEK in Kraków, October 11th, 2024

From 2019 to 2024

EPIPHANY conferente (2019)



Initial state and forward physics at LHC

~ New physics potential investigating the forward region at LHC and FoCal proposal in ALICE ~

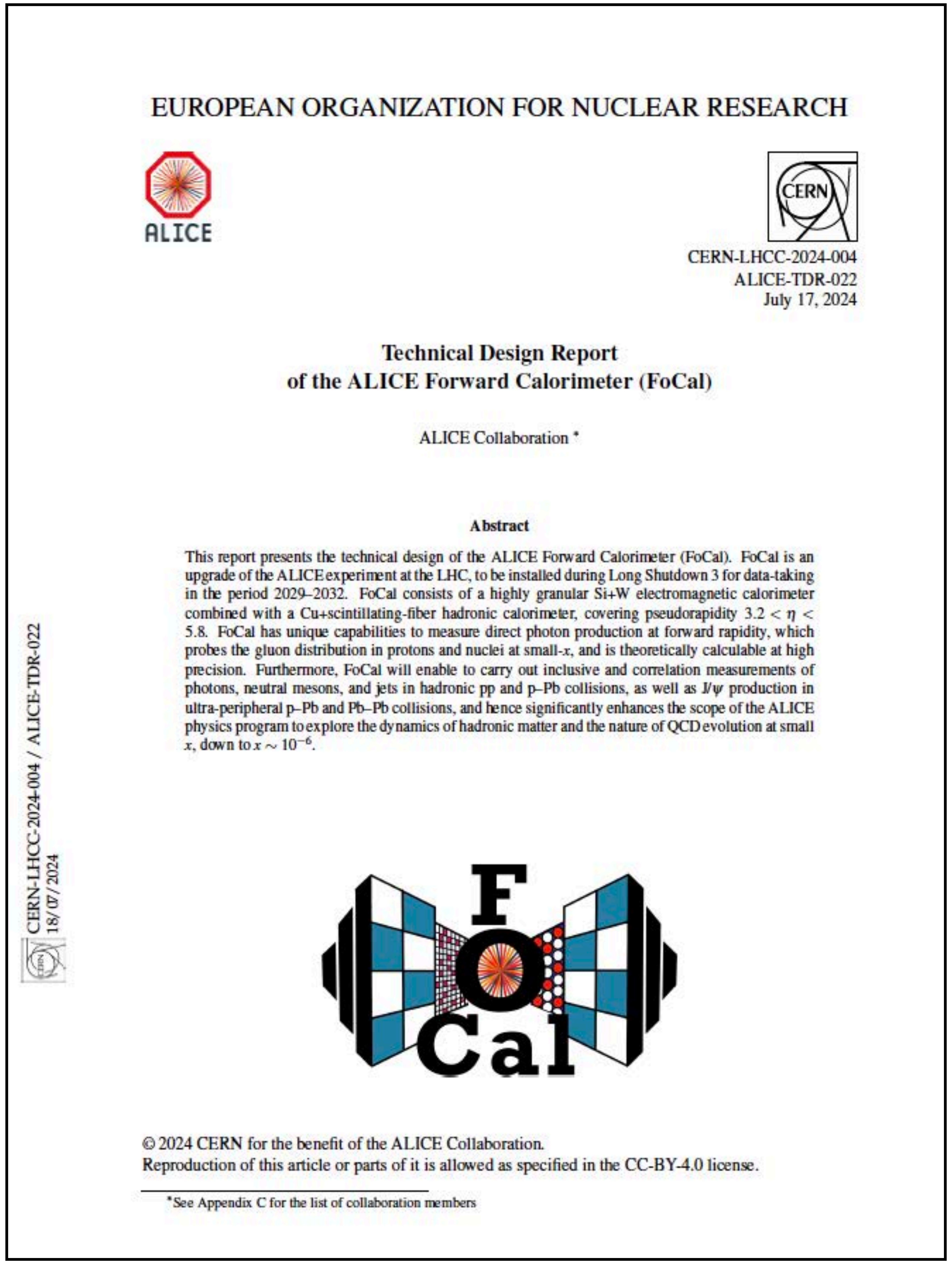
Tatsuya Chujo
Univ. of Tsukuba
for the ALICE collaboration

XXV Cracow EPIPHANY Conference
on Advances in Heavy Ion Physics
January 8-11, 2019, Cracow, Poland

ALICE

筑波大学
University of Tsukuba

FoCal TDR (2024)



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

ALICE

CERN

CERN-LHCC-2024-004
ALICE-TDR-022
July 17, 2024

Technical Design Report
of the ALICE Forward Calorimeter (FoCal)

ALICE Collaboration *

Abstract

This report presents the technical design of the ALICE Forward Calorimeter (FoCal). FoCal is an upgrade of the ALICE experiment at the LHC, to be installed during Long Shutdown 3 for data-taking in the period 2029–2032. FoCal consists of a highly granular Si+W electromagnetic calorimeter combined with a Cu+scintillating-fiber hadronic calorimeter, covering pseudorapidity $3.2 < \eta < 5.8$. FoCal has unique capabilities to measure direct photon production at forward rapidity, which probes the gluon distribution in protons and nuclei at small-x, and is theoretically calculable at high precision. Furthermore, FoCal will enable to carry out inclusive and correlation measurements of photons, neutral mesons, and jets in hadronic pp and p–Pb collisions, as well as J/ψ production in ultra-peripheral p–Pb and Pb–Pb collisions, and hence significantly enhances the scope of the ALICE physics program to explore the dynamics of hadronic matter and the nature of QCD evolution at small x, down to $x \sim 10^{-6}$.

CERN-LHCC-2024-004 / ALICE-TDR-022
18/07/2024

FoCal

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*See Appendix C for the list of collaboration members

FoCal collaboration meeting in Krakow (Oct. 2024)

FoCal General Meeting
Monday 7 Oct 2024, 09:00 → 12:25 Europe/Zurich
Institute of Nuclear Physics Polish Academy of Sciences
Ian Gardner Bearden (University of Copenhagen (DK)), Tatsuya Chujo (University of Tsukuba (JP))
Videoconference: FOCAL meeting — Join

- **09:00 → 09:25** Cooling & Mechanics: Krakow Update (25m) — Speaker: Jacek Michal Swierblewski (Polish Academy of Sciences (PL))
- **09:25 → 09:50** FoCal-E pad: toward the mass production in Japan (25m) — Speaker: Motoi Inaba (University of Tsukuba (JP)) — FoCalGene...
- **09:50 → 10:00** Tungsten plate machining (10m) — Speakers: Takashi Hachiya (Nara Women's University (JP)), Takashi Hachiya — 20241007_...
- **10:00 → 10:15** FoCal-E pad detector development in India (15m) — Speaker: Sanjib Muhuri (Department of Atomic Energy (IN)) — P type R&D...
- **10:15 → 10:30** FoCal-E: Pixels Status and Plans (15m) — Speaker: Max Philip Rauch (University of Bergen (NO)) — PixelStatus...
- **10:30 → 11:00** Coffee Break
- **11:00 → 11:20** Fast Shower Simulations (20m) — Speaker: Emilia Majerz (AGH University of Krakow (PL)) — ALICE-upgr...
- **11:20 → 11:35** FoCal-H: SiPM radiation tests (15m) — Speaker: Yury Melikyan (Helsinki Institute of Physics (FI)) — SiPM studi..., SiPM studi...
- **11:35 → 11:50** Neutron dose estimation at RANS (15m) — Speakers: Motoi Inaba (University of Tsukuba (JP)), Yuka Sasaki (Nara Women's University (JP)), Yuka Sasaki (Nara Woman's University) — neutron_do...
- **11:50 → 12:00** Test beam and lab results in Japan for FoCal-E pad (10m) — Speaker: Jonghan Park (University of Tsukuba (JP)) — 241007_A...
- **12:00 → 12:05** Test beam plan in Japan (2024-2025) (5m) — Speaker: Shingo Sakai (University of Tsukuba (JP)) — AUW_Foca...
- **12:10 → 12:20** Synergy of FoCal and EIC detector R&D in Japan (10m) — Speaker: Yuji Goto (RIKEN (JP)) — FoCal-E_eP...

14:30 → 18:00 FoCal - Parallel Session — NO2 Room — Join
Conveners: Prof. Ian Gardner Bearden (University of Copenhagen (DK)), Tatsuya Chujo (University of Tsukuba (JP))

- **14:30** FoCal Session Introduction (10m) — Speaker: Prof. Ian Gardner Bearden (University of Copenhagen (DK))
- **14:40** FoCal Readout Status and Plans (30m) — Speaker: Nicola Minafra (The University of Kansas (US)) — Readout_Status_Kra..., Readout_Status_Kra...
- **15:10** Pixel Status and Plans (20m) — Speaker: Max Philip Rauch (University of Bergen (NO)) — MxR_20241008_Pix...
- **15:30** Pads Status and Plans (30m) — Speakers: Motoi Inaba (University of Tsukuba (JP)), Tatsuya Chujo (University of Tsukuba (JP)) — Pads_Status_and_P...
- **16:00** Coffee Break (30m)
- **16:30** FoCal-H Status and Plans (20m) — Speakers: Prof. Ian Gardner Bearden (University of Copenhagen (DK)), Venelin Kozhuharov (University of Sofia - St. Kliment Ohridski (BG)) — AUW2024FoCalH.pdf
- **16:50** Concepts, design and manufacturing of the FoCal-E cooling system. Status of the work performed by IFJ PAN Team (20m) — Speaker: Tomasz Cieslik — 20241008.pdf
- **17:10** HGCROC2 firmware modification and plan for many HGCROC chip test in Japan (15m) — Speaker: Osana Yasunori (Kumamoto University) — 24-10-alice-upgrade...
- **17:25** HGCROC2 chip test & plans for HGCROC3 (15m) — Speaker: Taichi Inukai (University of Tsukuba (JP)) — Inukai_HGCROC2_t...
- **17:40** Mechanics Update (20m) — Speaker: Maciej Czarnynoga (Warsaw University of Technology (PL)) — FoCal_mechanics_a..., FoCal_mechanics_a...

16:00 → 18:00 Plenary session: Mechanics and cooling — Main Auditorium (Aula) — Join
Convener: Federico Antinori (Universita e INFN, Padova (IT))

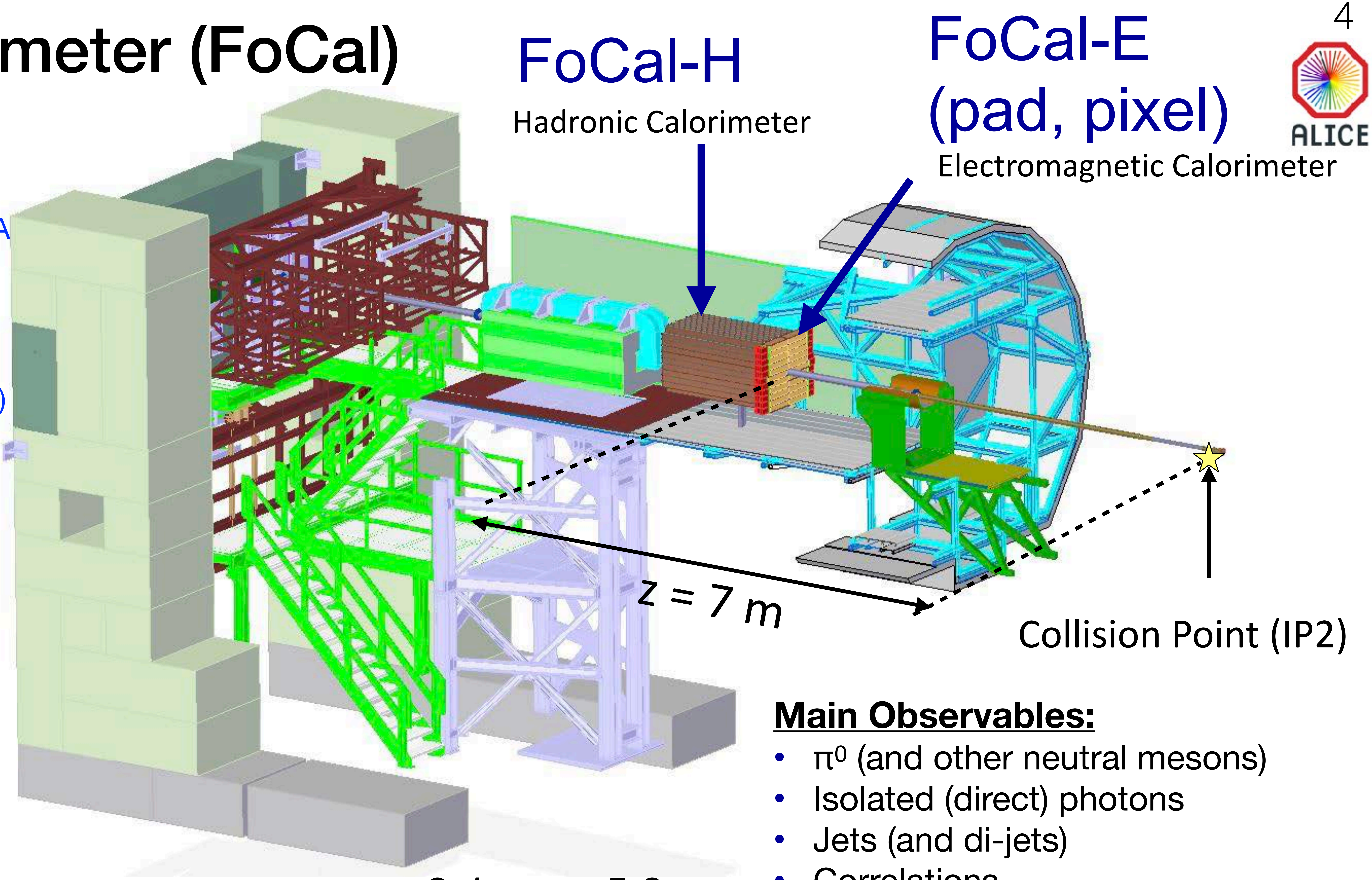
- **16:00** IFJ PAN in-kind contribution to the FoCal-E cooling system with respect to the quality assurance based on IFJ PAN projects experience (20m) — Speaker: Jacek Michal Swierblewski (Polish Academy of Sciences (PL)) — Quality_TQM_FOCA..., Quality_TQM_FOCA...

- 12 talks on Monday
- 9 talks on Tuesday
- 1 talk on Thursday
- 1 talk on Friday (this talk)

Total: 23 talks

Forward Calorimeter (FoCal)

- LHC ALICE, $\sqrt{s_{NN}}$ = 8.8 TeV, pp, pA
- Non-linear QCD evolution, Color glass condensate, initial stages of Quark Gluon Plasma (QGP)
- Physics in LHC Run 4 (2030-2033)
- **TDR approved by LHCC on March 2024**



$3.4 < \eta < 5.8$

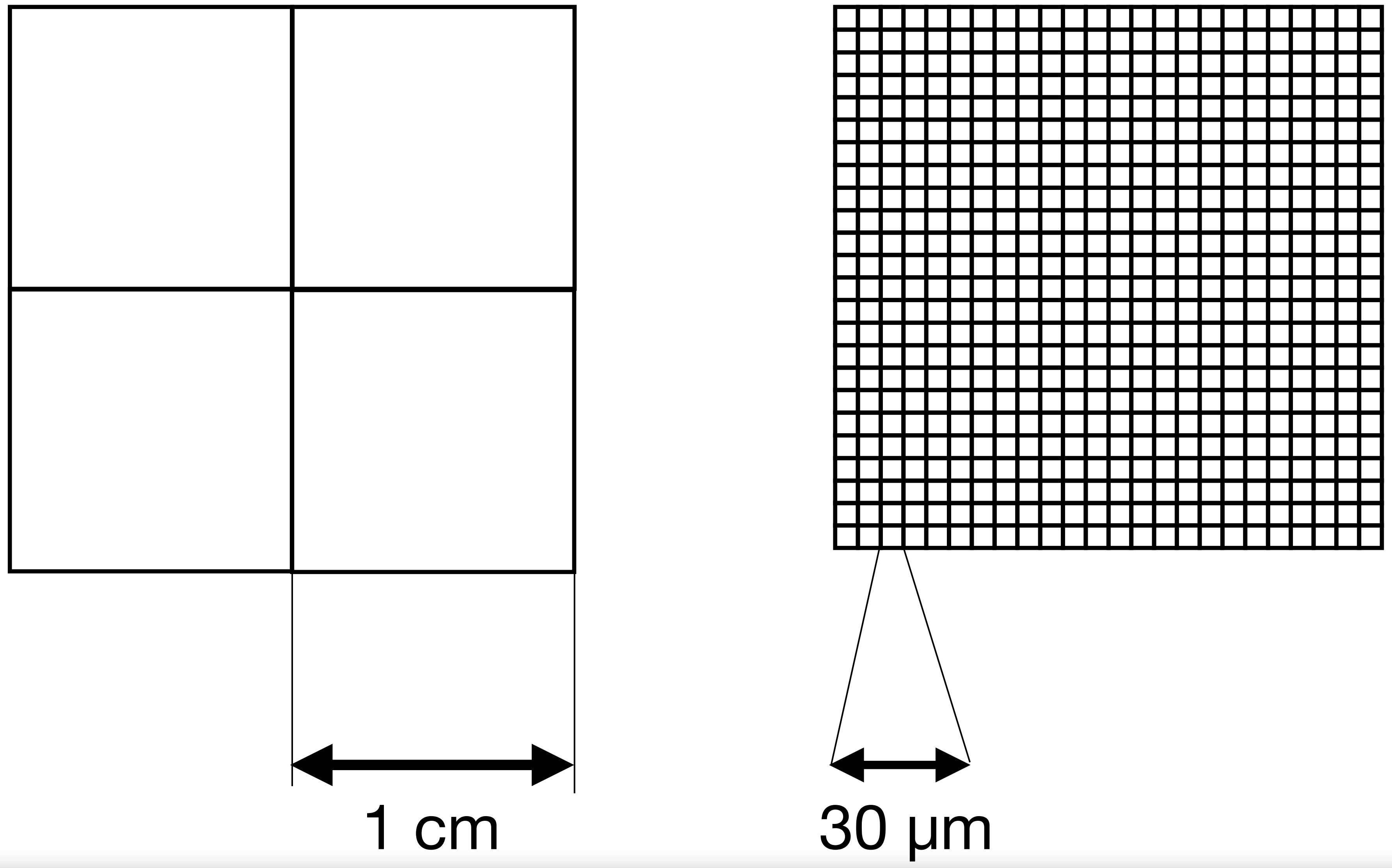
$\eta = -\ln(\tan(\theta/2))$

Main Observables:

- π^0 (and other neutral mesons)
- Isolated (direct) photons
- Jets (and di-jets)
- Correlations
- J/Ψ in UPC

FoCal LoI : CERN-LHCC-2020-009
FoCal TDR : CERN-LHCC-2024-004

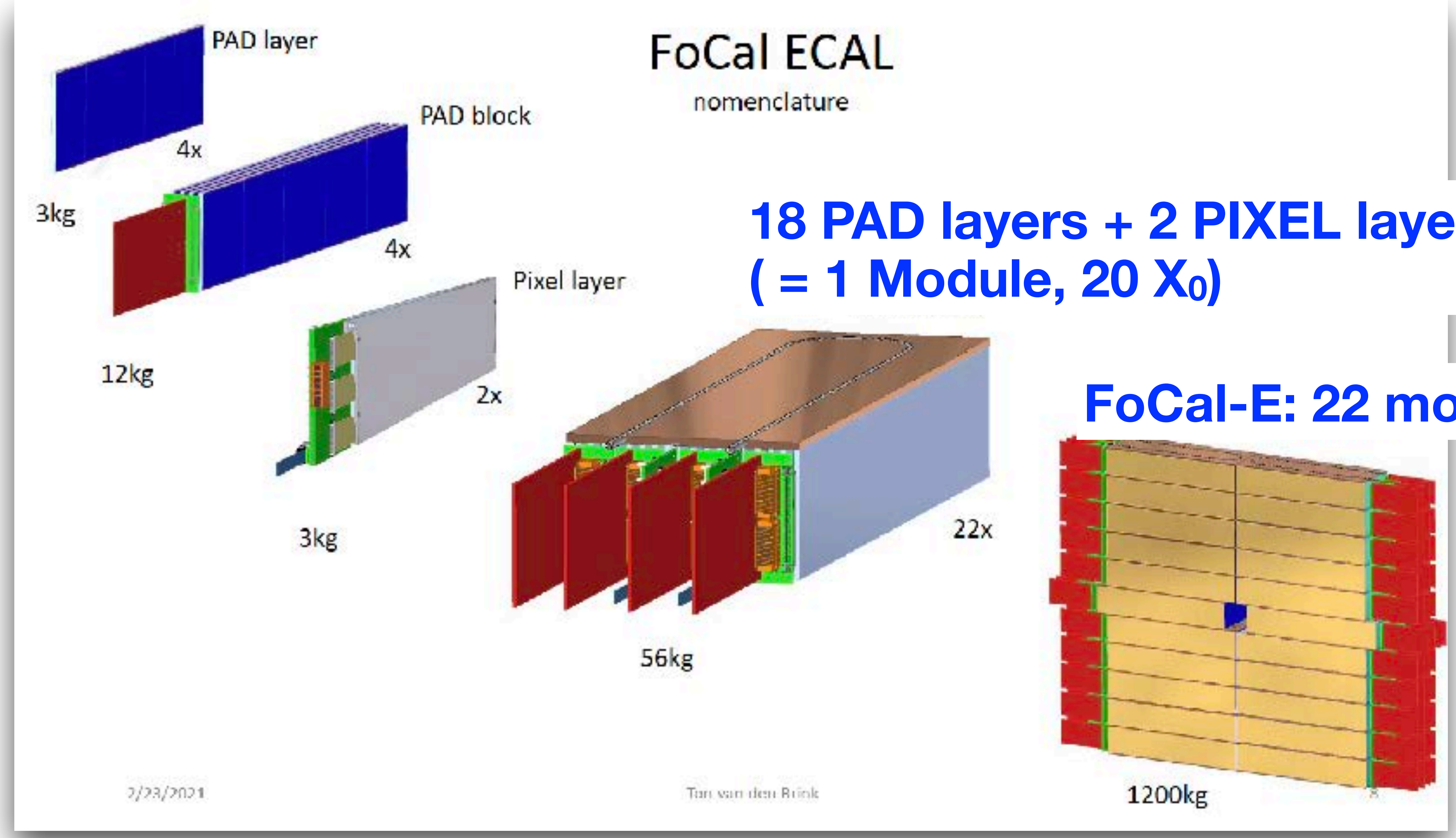
FoCal detector design



FoCal-E (pad, pixel)

20 layers of W(3.5 mm ≈ $1X_0$) + silicon sensors:
Two types: **Pad (1x1 cm²)** and **Pixel (30 x 30 μm²)**

- Pad: shower profile and total energy
    - Si PAD sensor
- Pixel: position resolution to resolve overlapping showers
    - CMOS MAPS technology (ALPIDE)

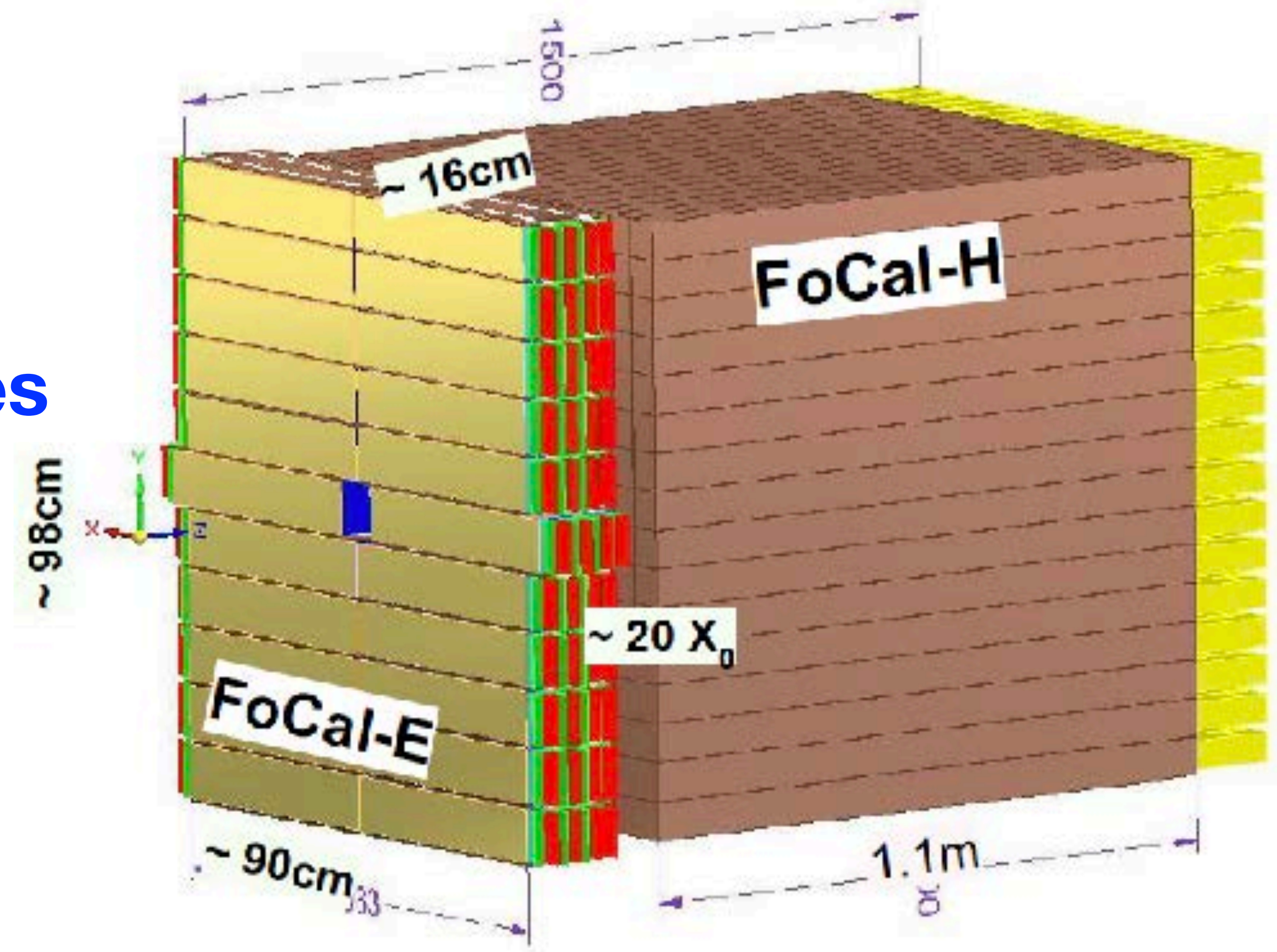


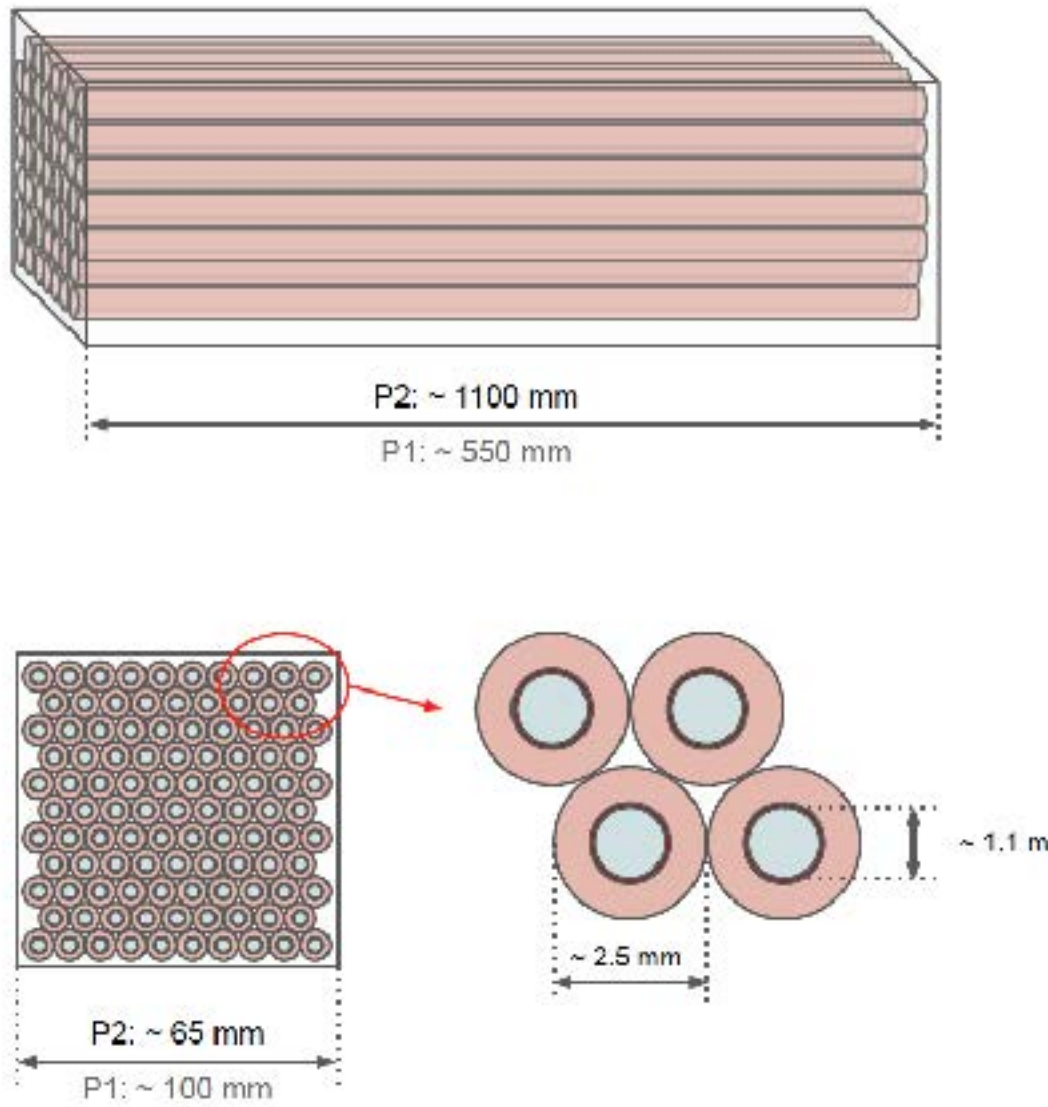
18 PAD layers + 2 PIXEL layers (= 1 Module, 20 X_0)

FoCal-E: 22 modules

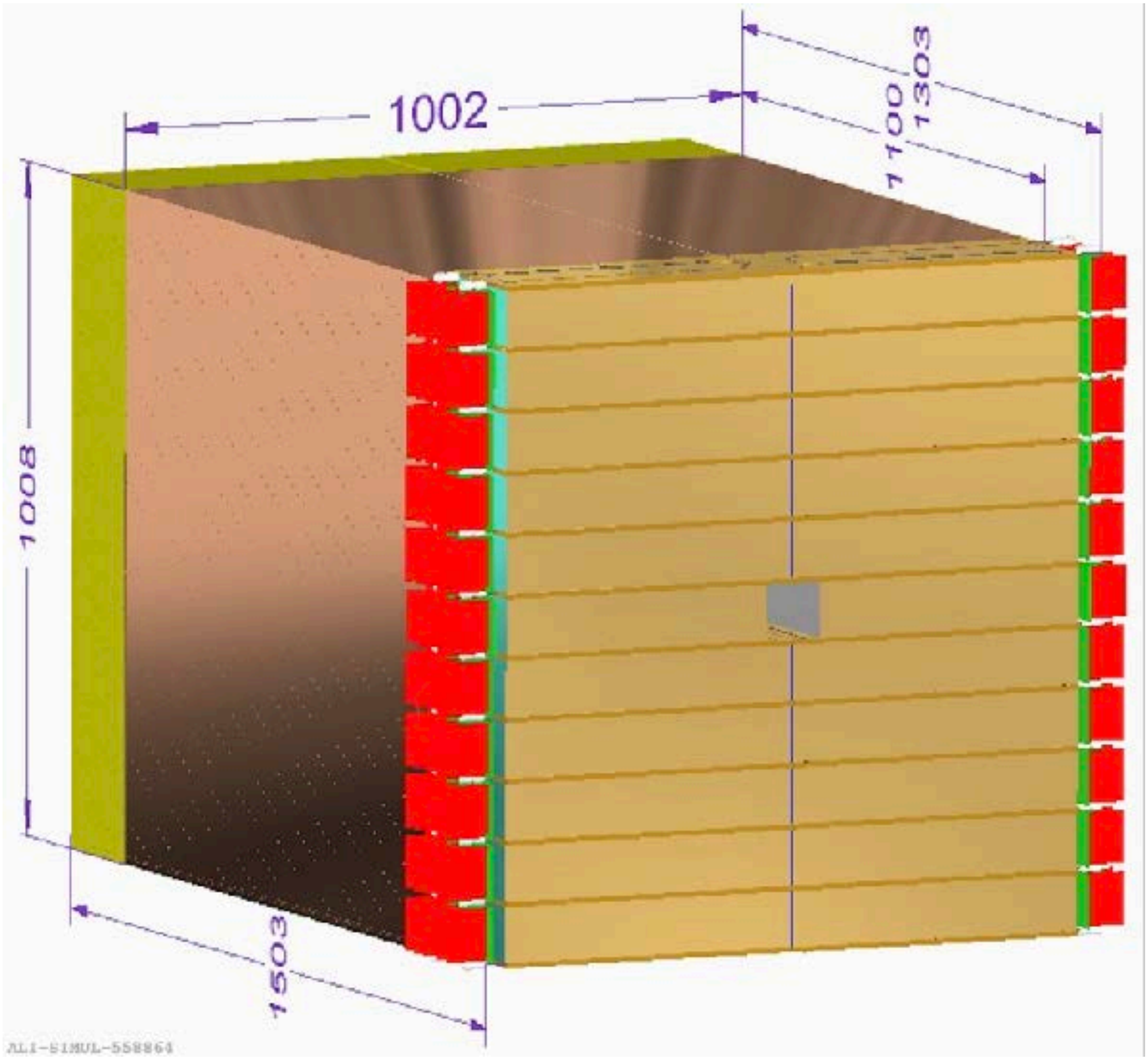
FoCal-H

Conventional metal-scintillator design
Cu capillary-tubes enclosing BCF scintillating fibers
SiPM readout





FoCal status

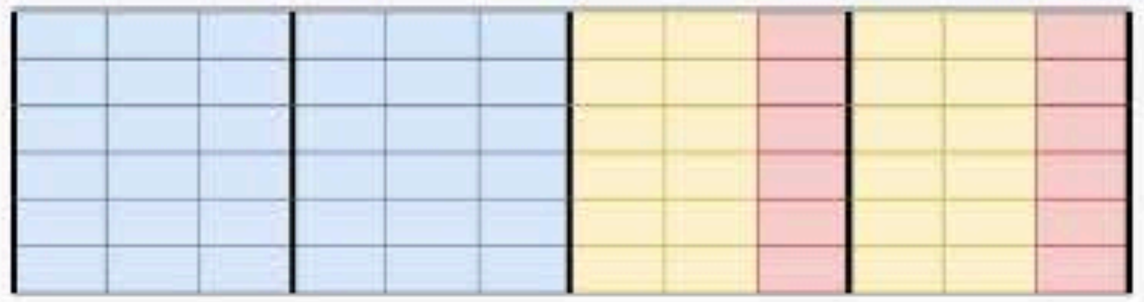


1) FoCal-E PIXEL
2) FoCal-E PAD
3) FoCal-H
4) Readout
5) Cooling and Mechanics

1) FoCal-E PIXEL

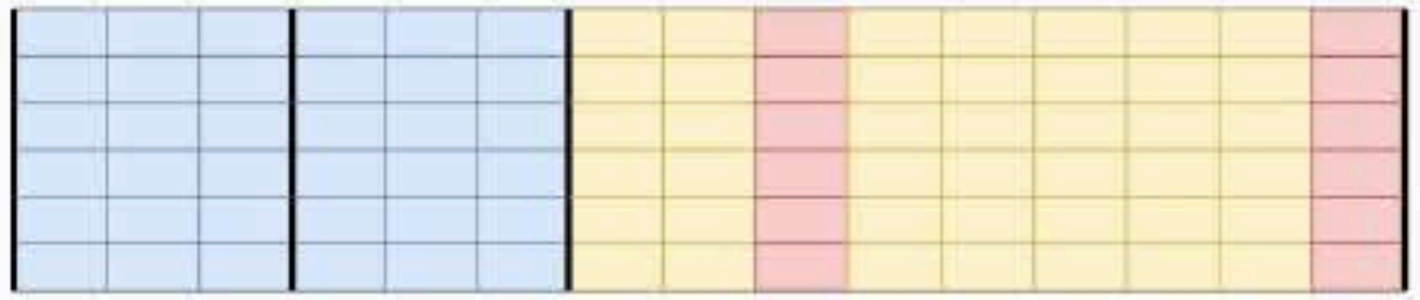
Reminder: FoCal-E Pixel layer structure

12-chip string inner layers
- 6 inner mode ALPIDEs per string @1.2 Gbps links
- 6 outer mode ALPIDEs per string @400 Mbps links



72 ALPIDEs per layer
4 layers
288 ALPIDEs

15-chip string inner layers
- 6 inner mode ALPIDEs per string @1.2 Gbps links
- 9 outer mode ALPIDEs per string @400 Mbps links

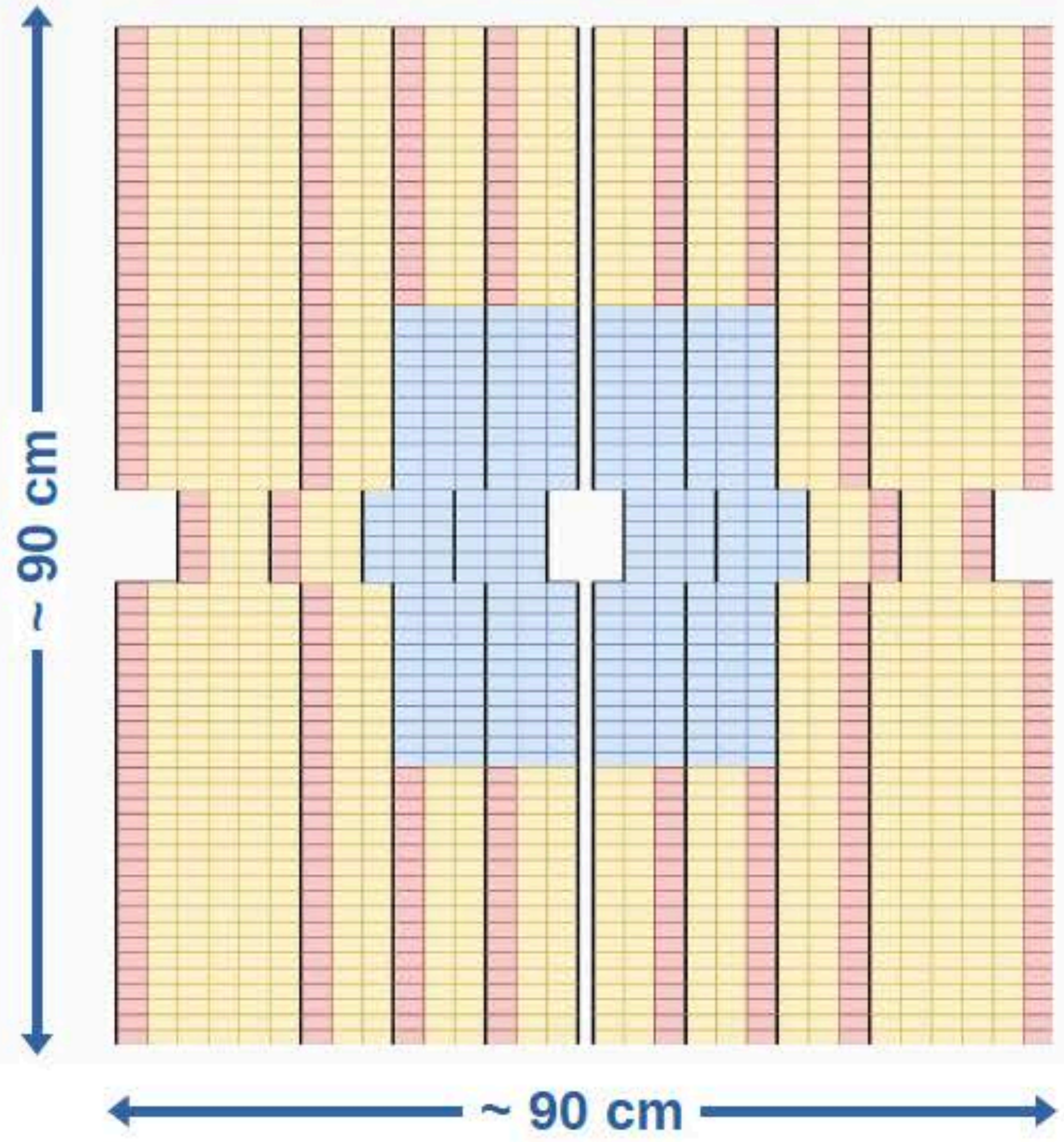


90 ALPIDEs per layer
16 layers
1440 ALPIDEs

15-chip string outer layers
- 15 outer mode ALPIDEs per string @400 Mbps links

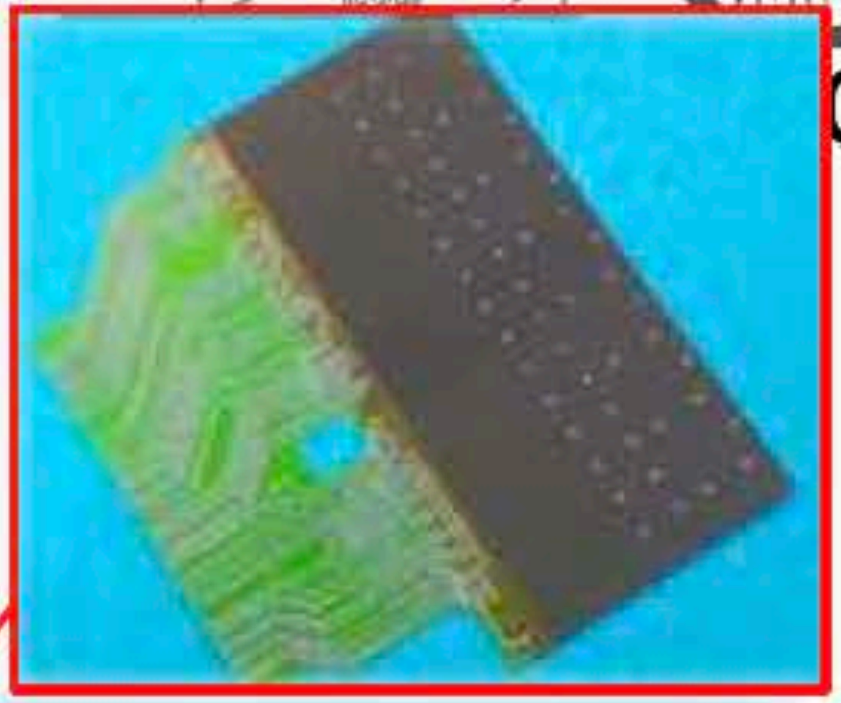
90 ALPIDEs per layer
24 layers
2160 ALPIDEs

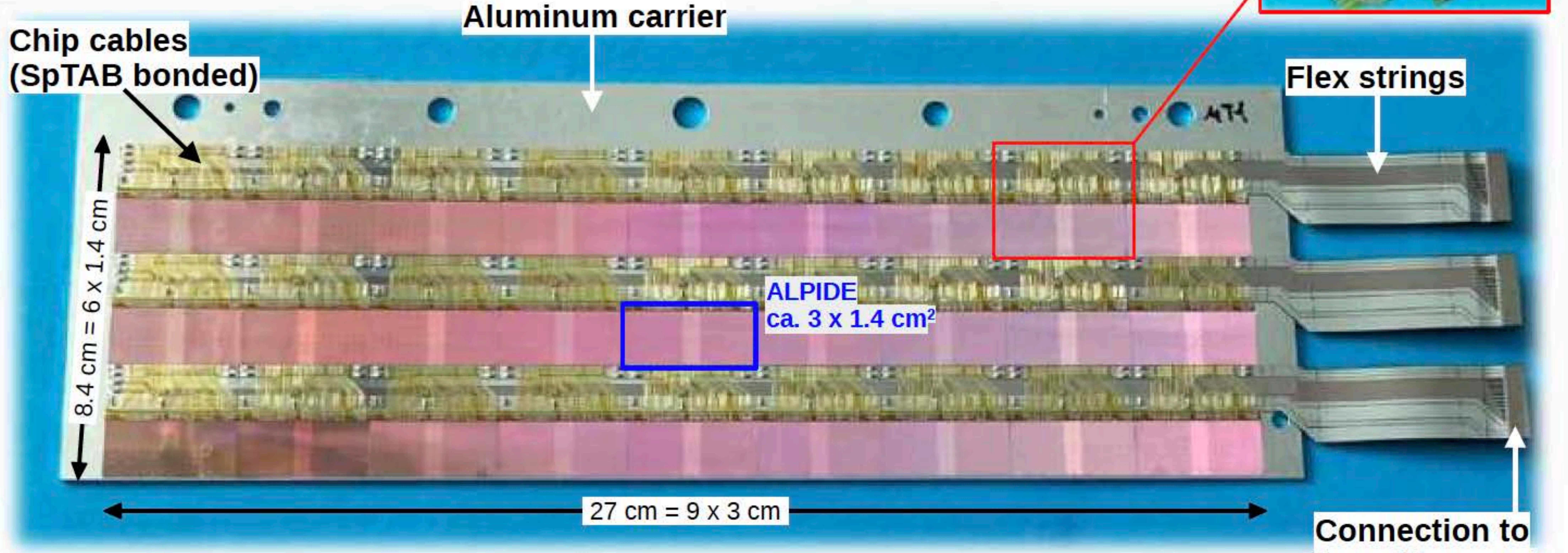
- FoCal-E Pixel Layer 5 and 10
- **44 pixel layer assemblies**
- 3888 ALPIDE chips
- 1944 ALPIDE chips per layer



Reminder: FoCal-E Pixel layer string prototype

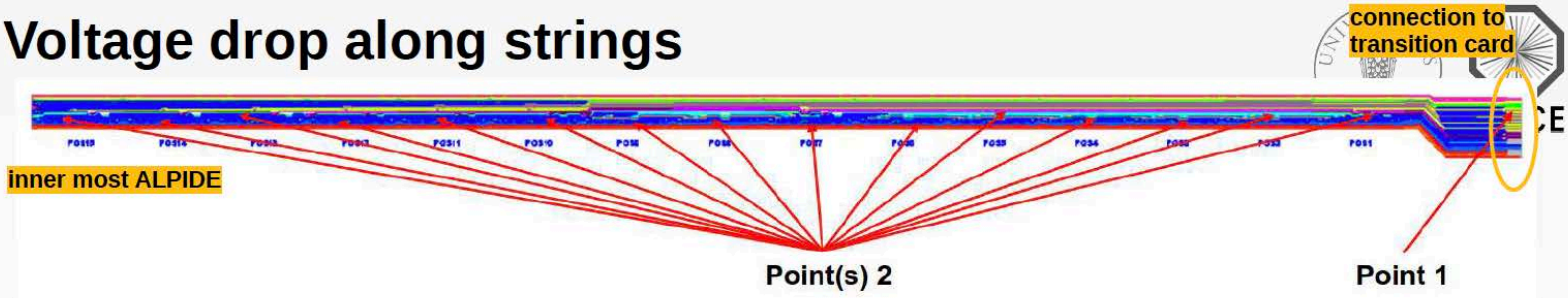
- Photo shows fully assembled pixel half-layer prototype for Bergen protonCT detector
- Base plate is a 5 mm thick aluminum carrier (Al-carrier)
- FoCal will use 12 or 15-chip strings (9-chip string shown)

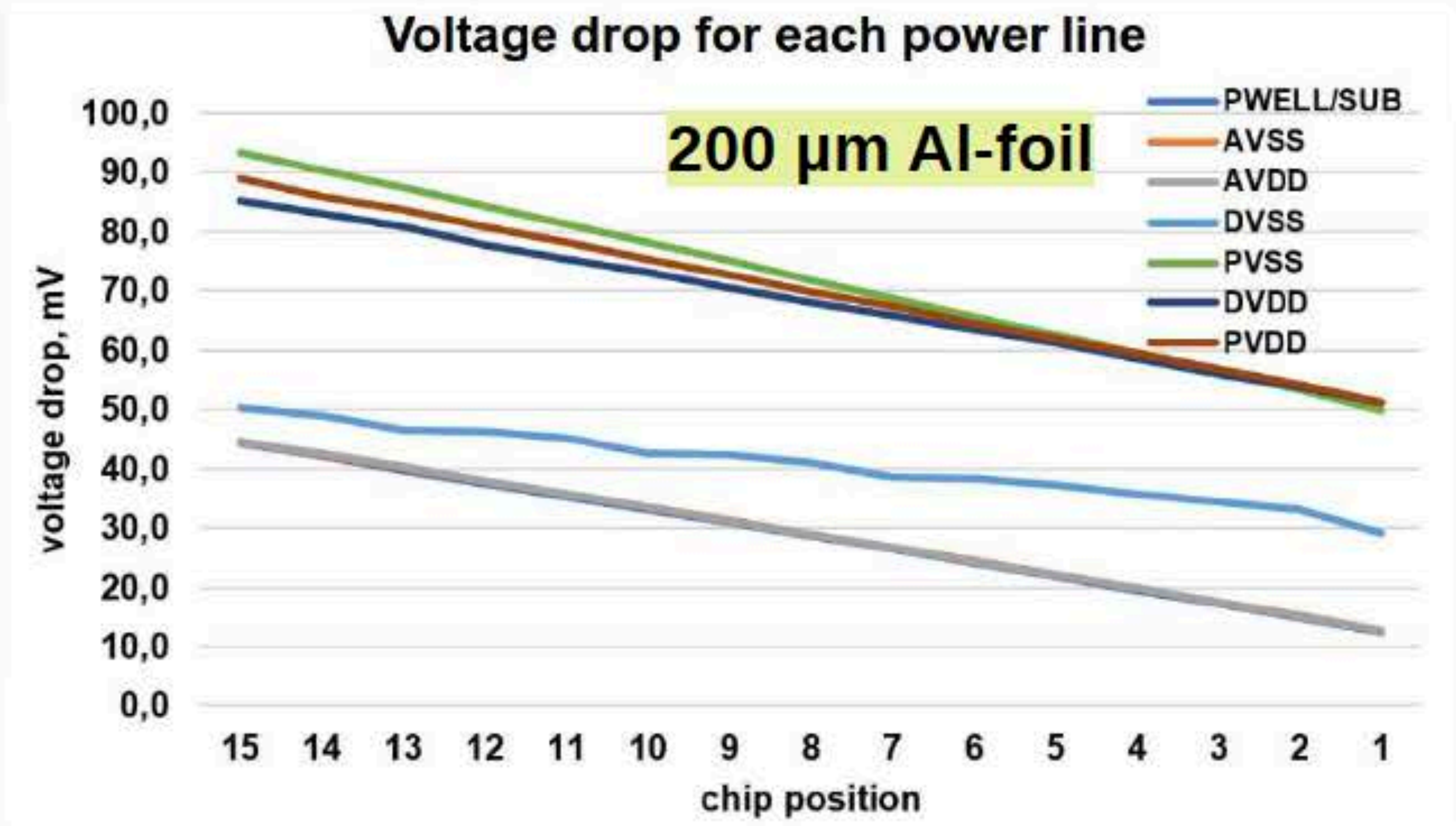


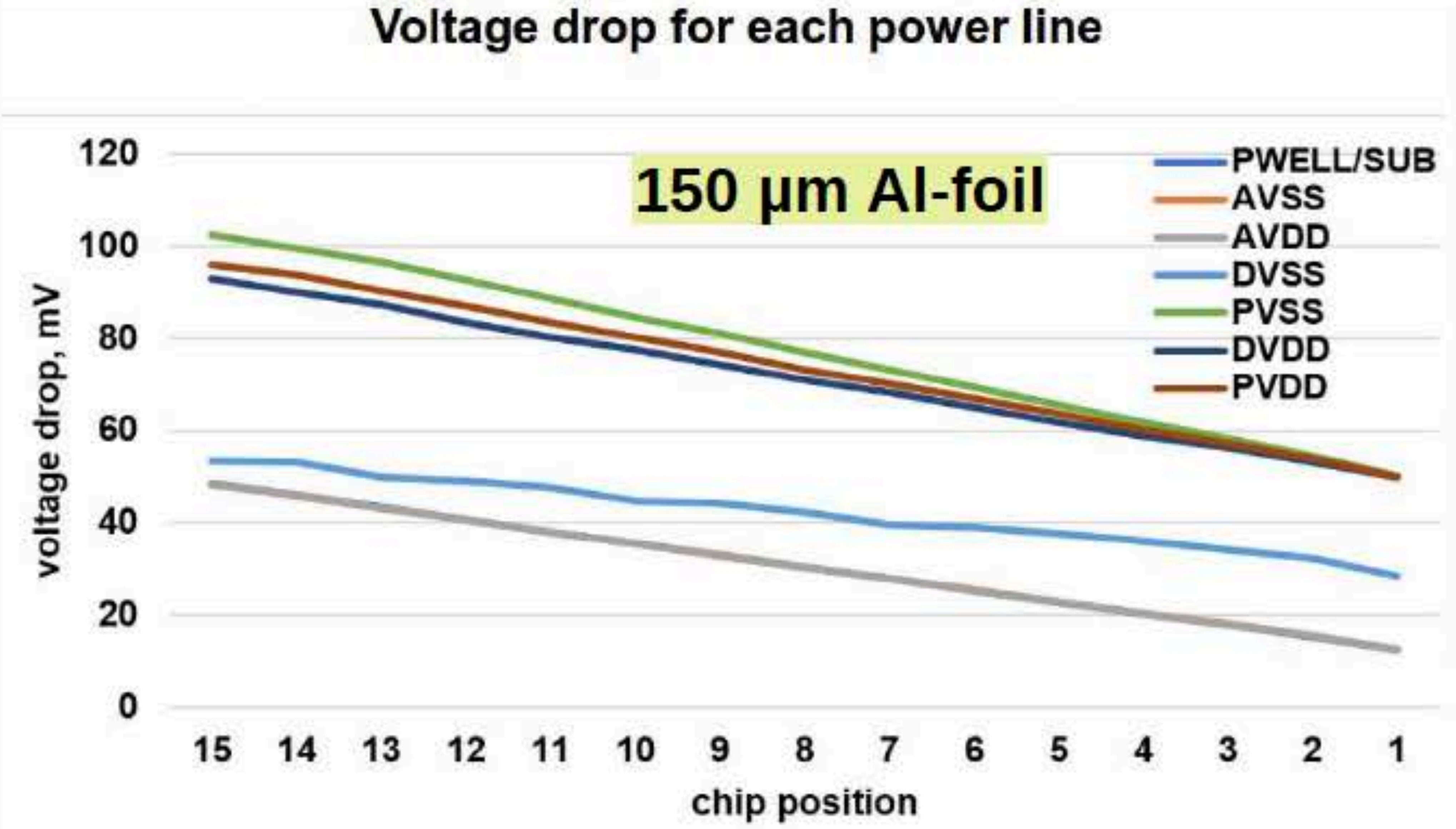


88 such half-layers needed → 44 layers (+ spares)

Voltage drop along strings

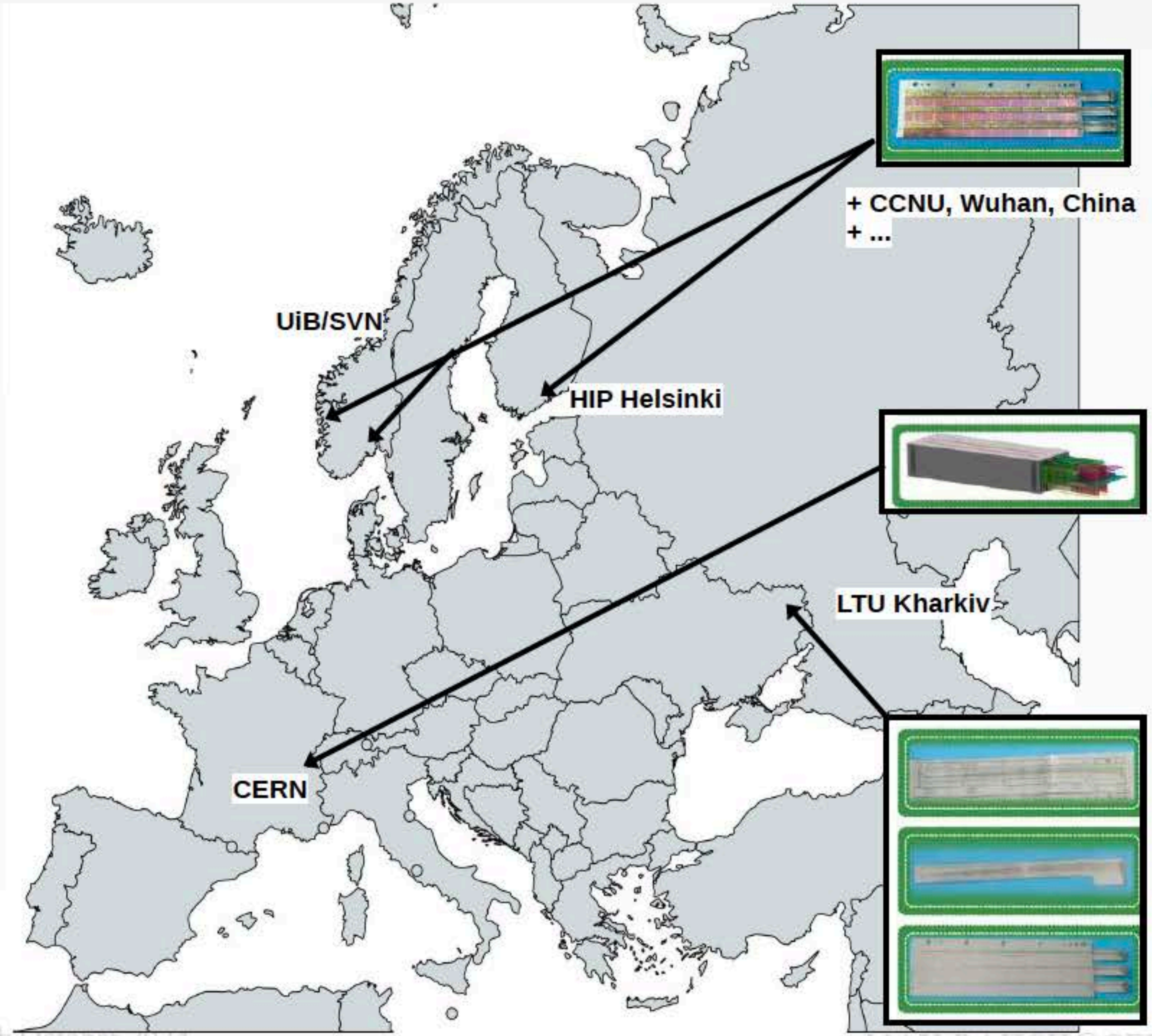






- Voltage drop along the flex < 100 mV → within specifications for both Al-foil thicknesses
- **Decision to use 150 µm Al-foil technology** (preferable etching properties)

Pixel layer production sites



Stage 4 – Assembling modules **2**

Stage 5 – Assembling detector **3**

Stage 1 – Manufacturing components

Stage 2 – Assembling components **1**

Stage 3 – Assembling units (carriers)

ALPIDE glue-jigs

- Glue-jigs produced by CCNU, Wuhan, China, arrived at University of South-Eastern Norway
- Use case
  - Aluminium carrier boards with 3 flex-cables premounted will be received
  - Glue of ALPIDE chips to the Al-carrier boards
- Different versions of 9-chip, 12-chip and 15-chip layers
- Waiting for aluminum carriers fro Al-carriers from LTU, Ukraine

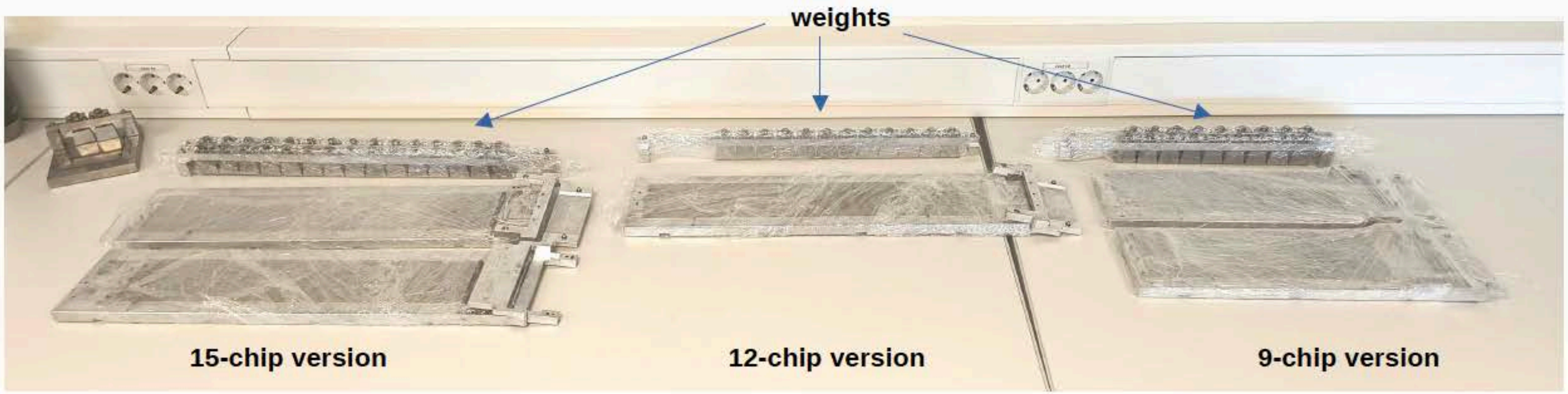
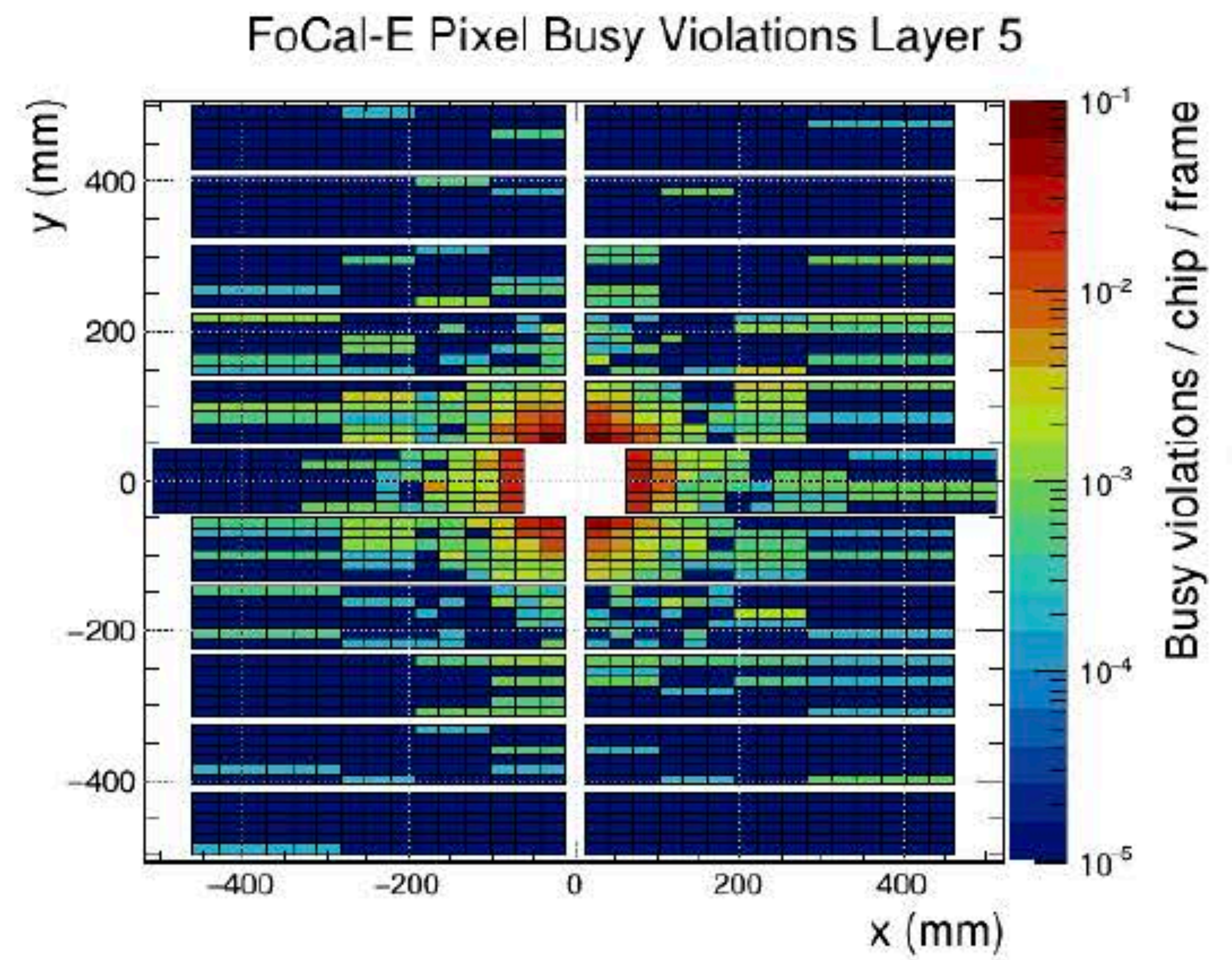
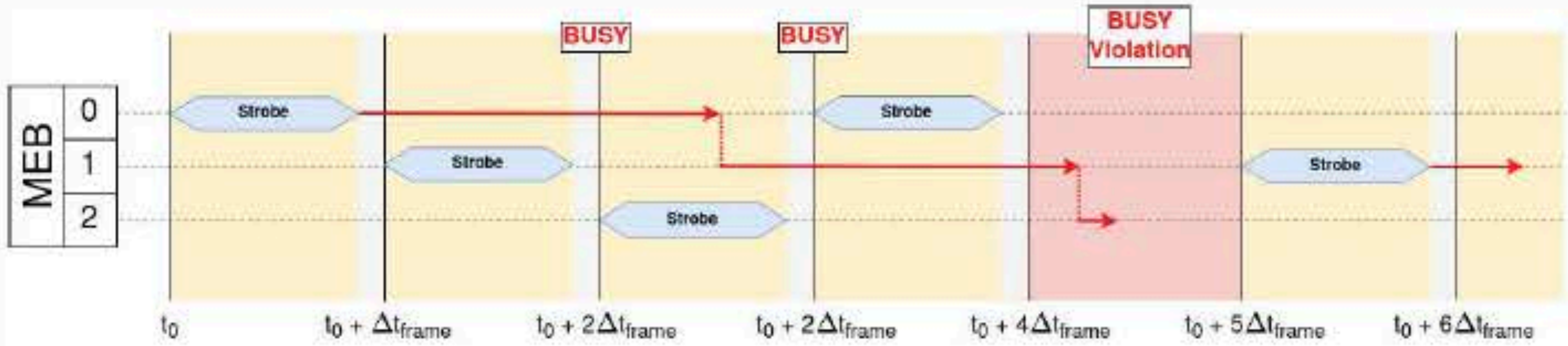


Photo: Jørgen Lien, USN

FoCal-E Pixel BUSY Violation Overview

- Main objective during our short Pixel test series: occupancy in the pixel layers
- Dead time because BUSY violations expected at LHC (pp, pPb, PbPb)
- Possible measures of occupancy reduction
  - Grid masks of the ALPIDEs (data taken May 2023)
  - Decreased trigger frequency / longer frame length (*incomplete* data taken May 2023 + Sep 2024)
  - Back bias voltage → less occupancy (data taken September 2024)



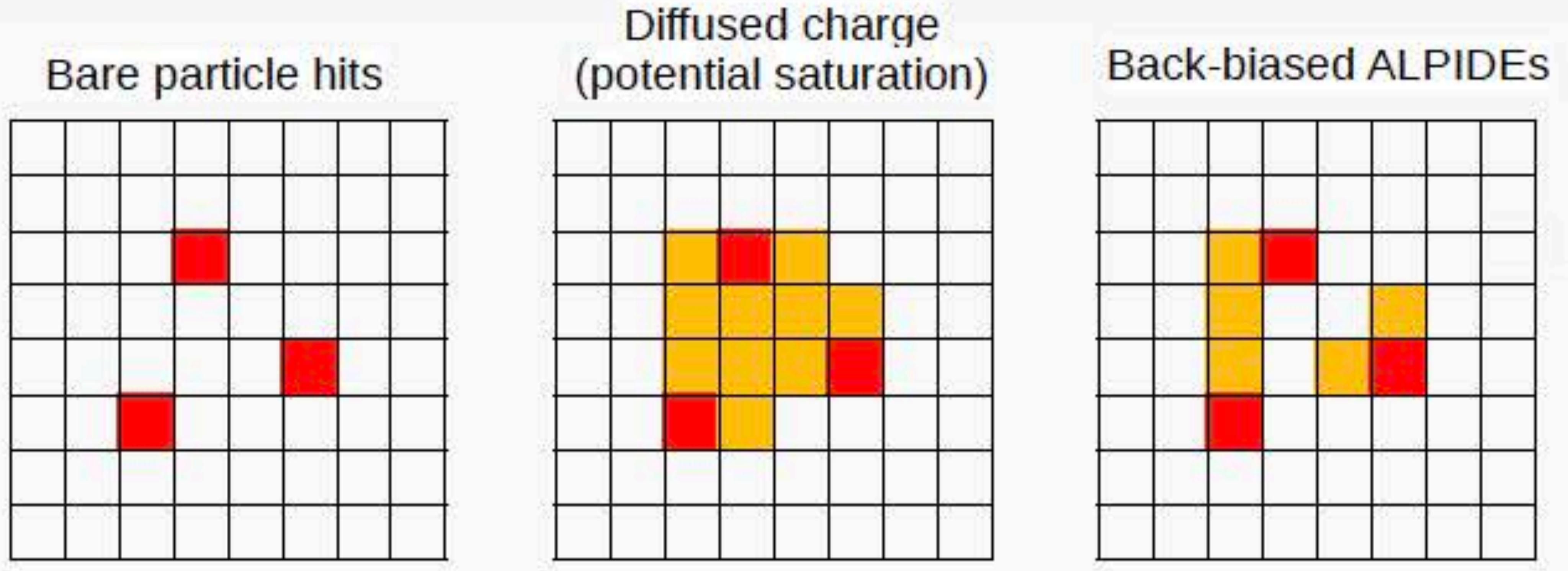


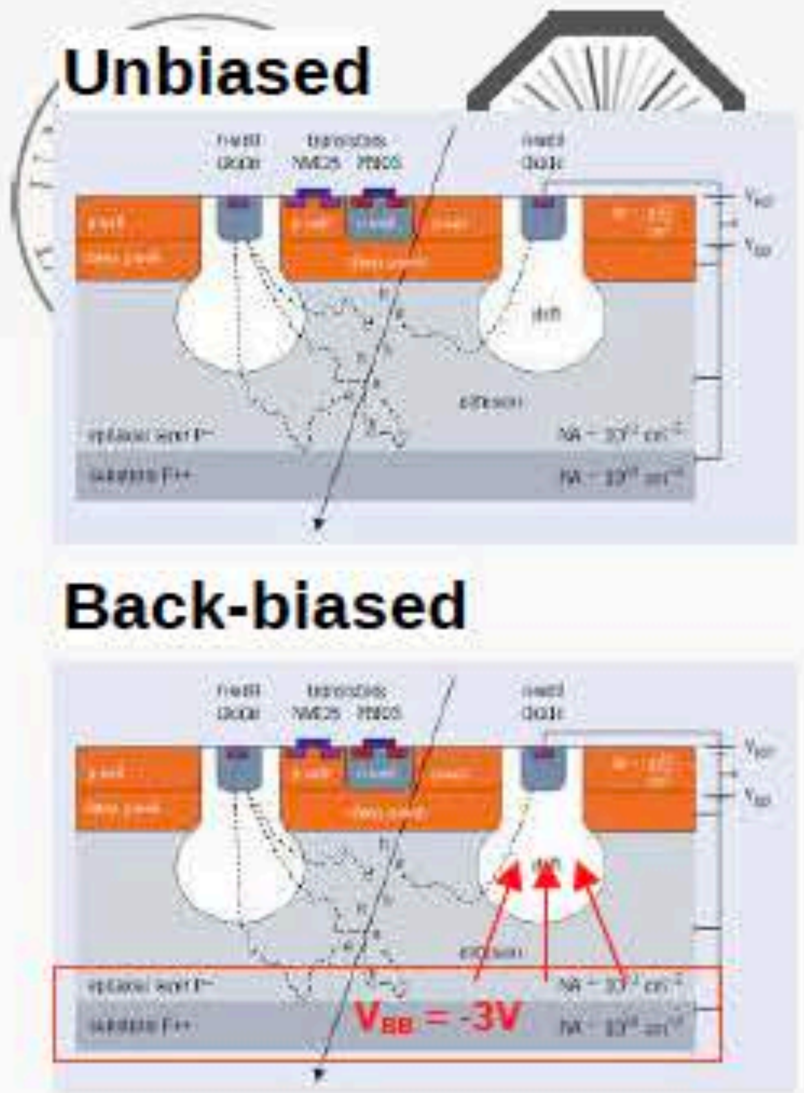
Occupancy with back-bias voltage

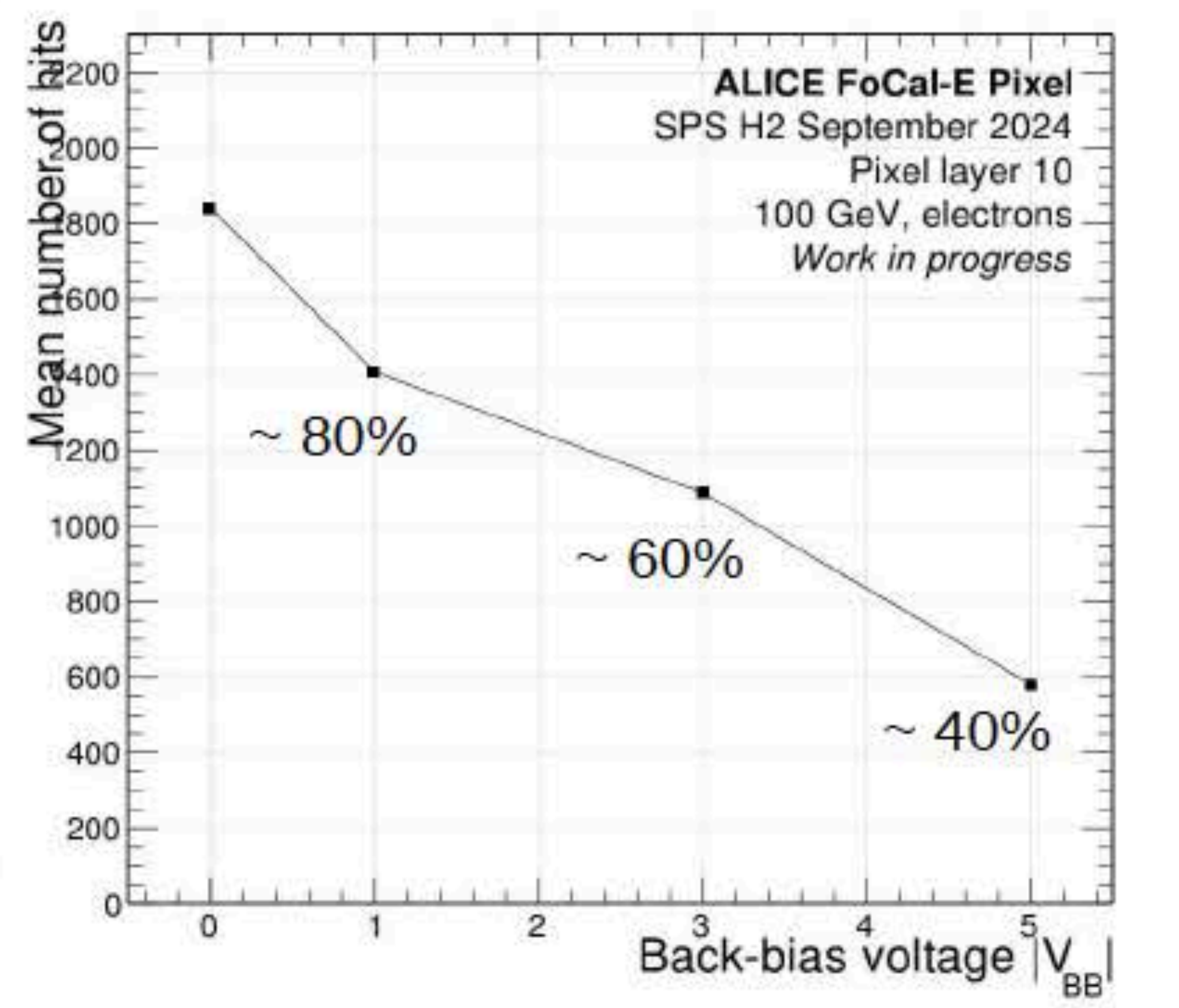
- TDR assumption: Reduction of average pixel cluster size by 75%
  - Pixel cluster size reduced from 4 to 3 in simulation
- Back-bias tests indicate ~60 % occupancy reduction at 3 V back-bias

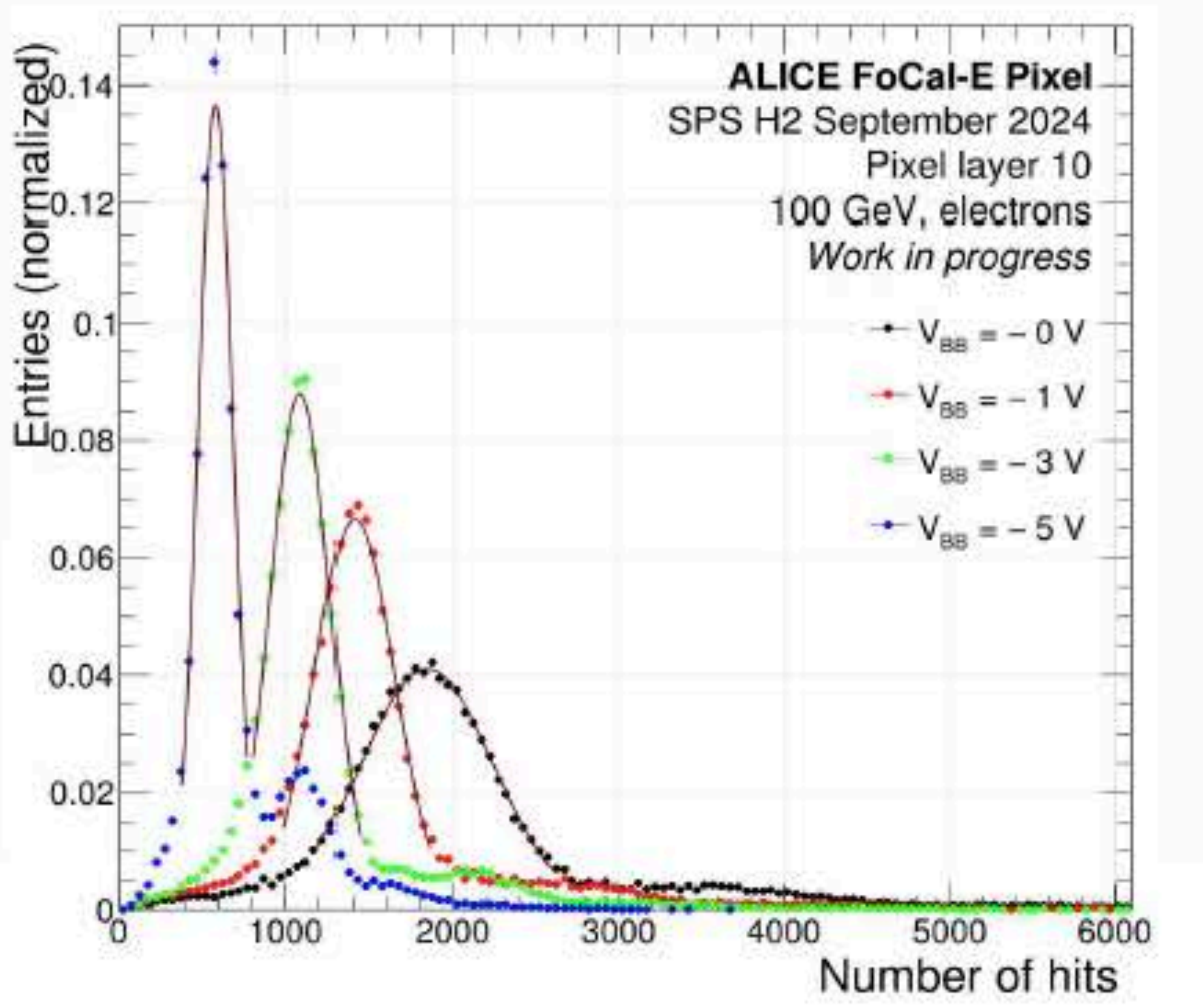
- **Advantages**
  - Less hits → less BUSY violations → less detector deadtime
  - Reduced data rate

- **Potential problems**
  - ALPIDE yield that can stand back-bias
  - Back-bias distribution on the carriers
  - Radiation damage under back-biased condition



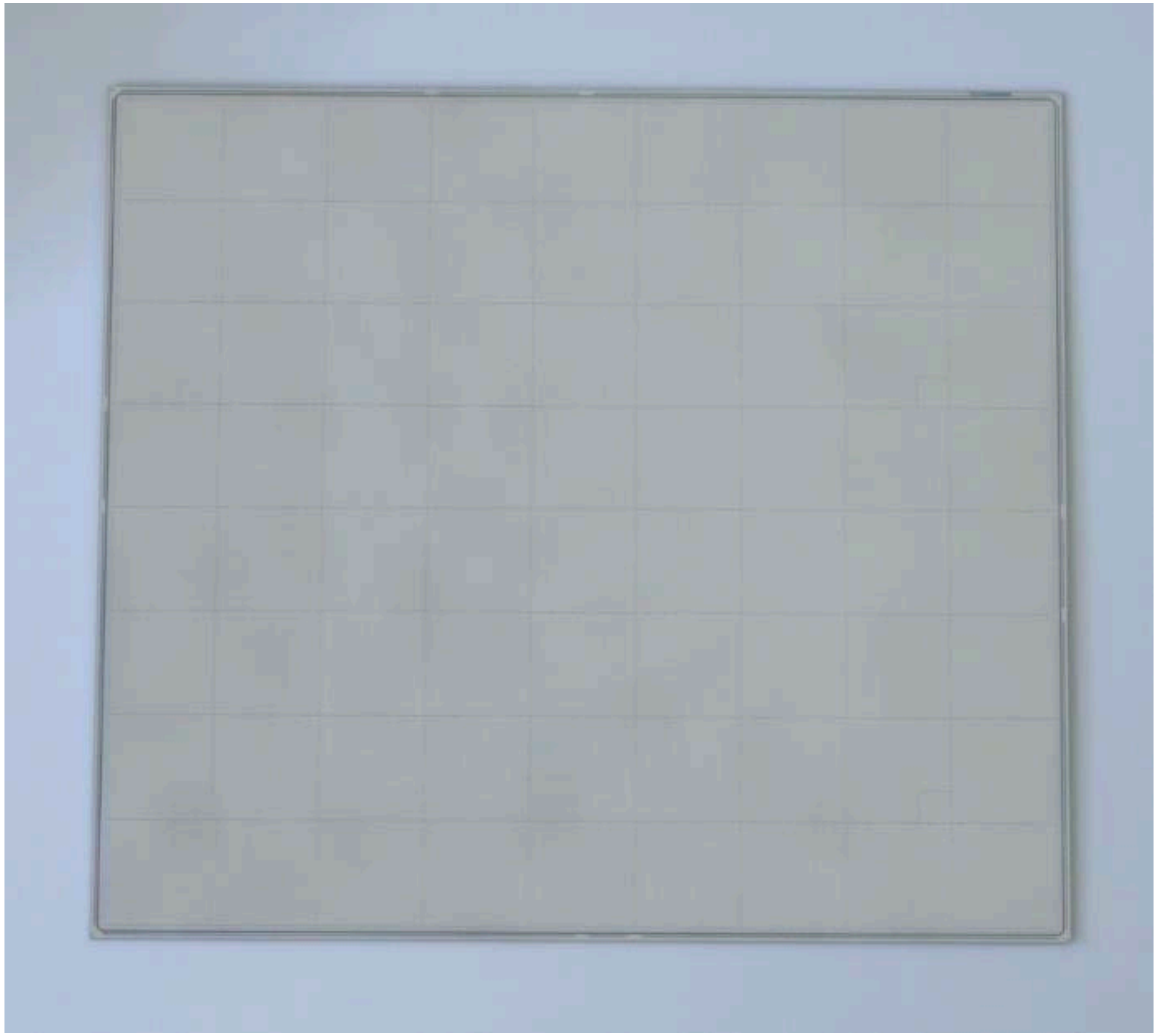






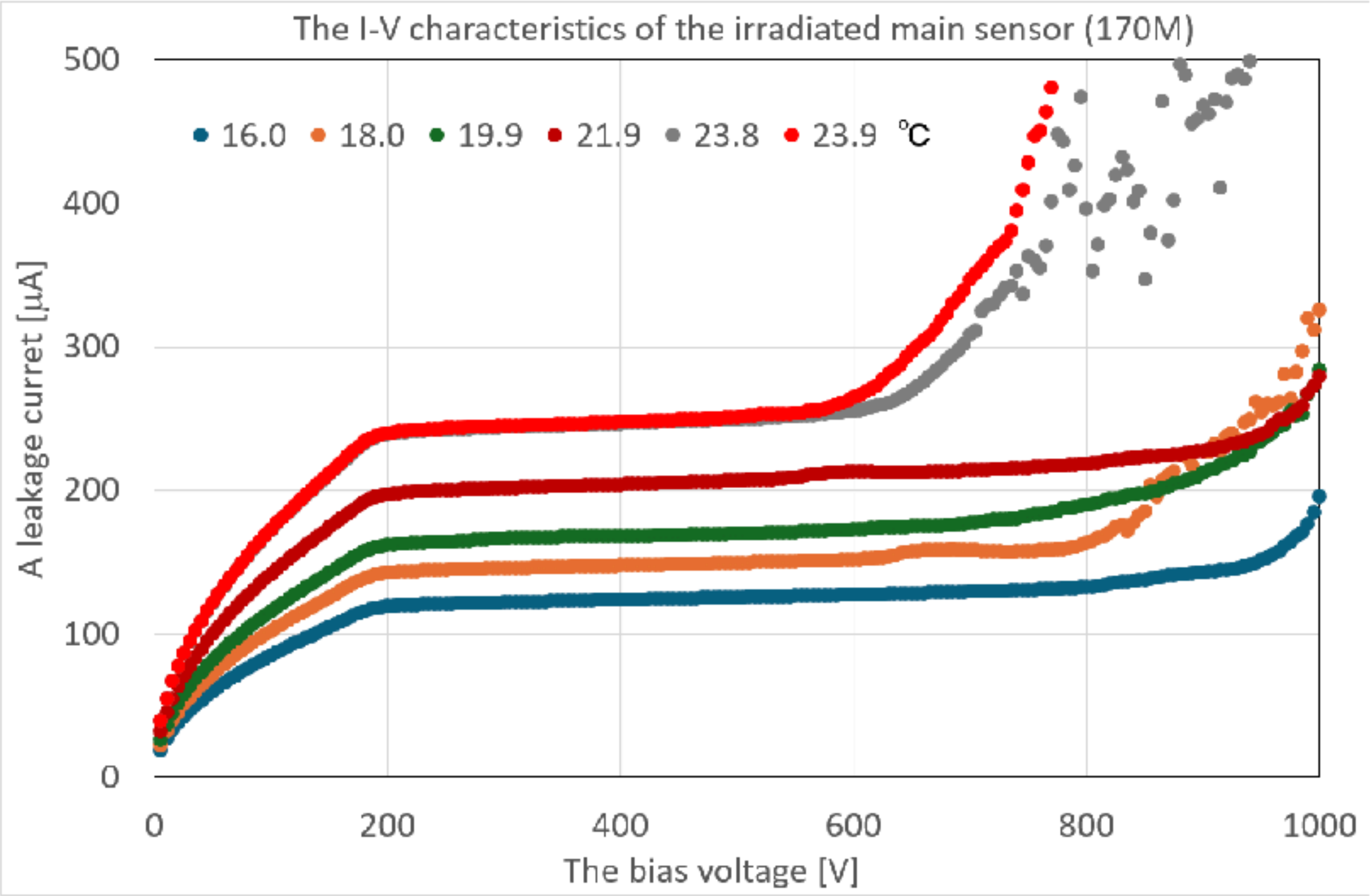
2) FoCal-E PAD

Silicon Pad sensor



Ver. 6 was the latest version (delivered in December, 2023)

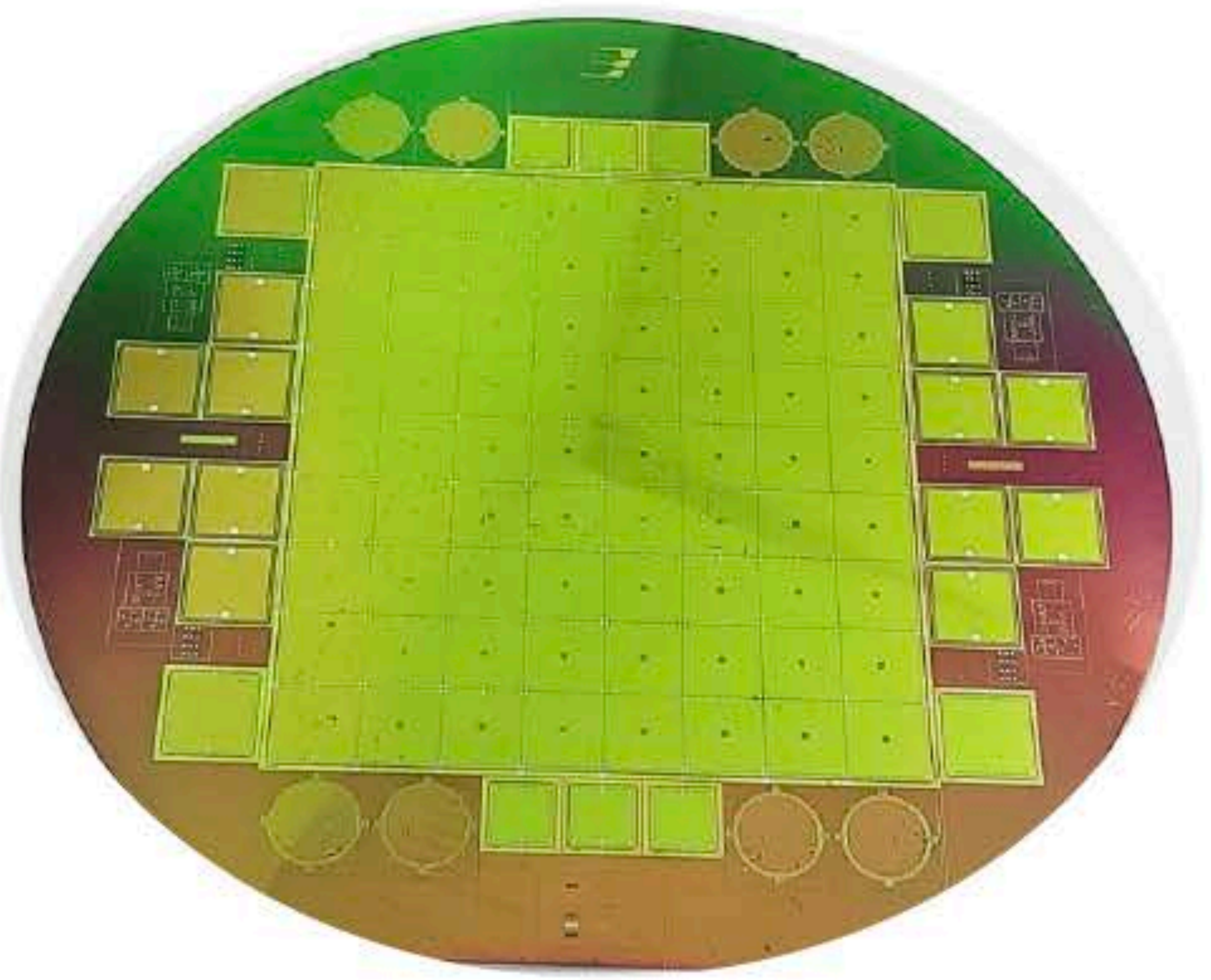
- Done: The I-V characteristics (0-to-1kV),
- Done: The C-V characteristics (MPD only so far),
- Done: The irradiation test at Riken RANS facility in May 2024
  (Two main sensors, 1x1 baby sensors and MPDs on the half-moon wafers),
- Done: The temperature dependence test.
- Not yet: The MIP measurement → Coming beam tests in December and February.
- Not yet: The dynamic range test (?) → Using a high-intensity laser source.

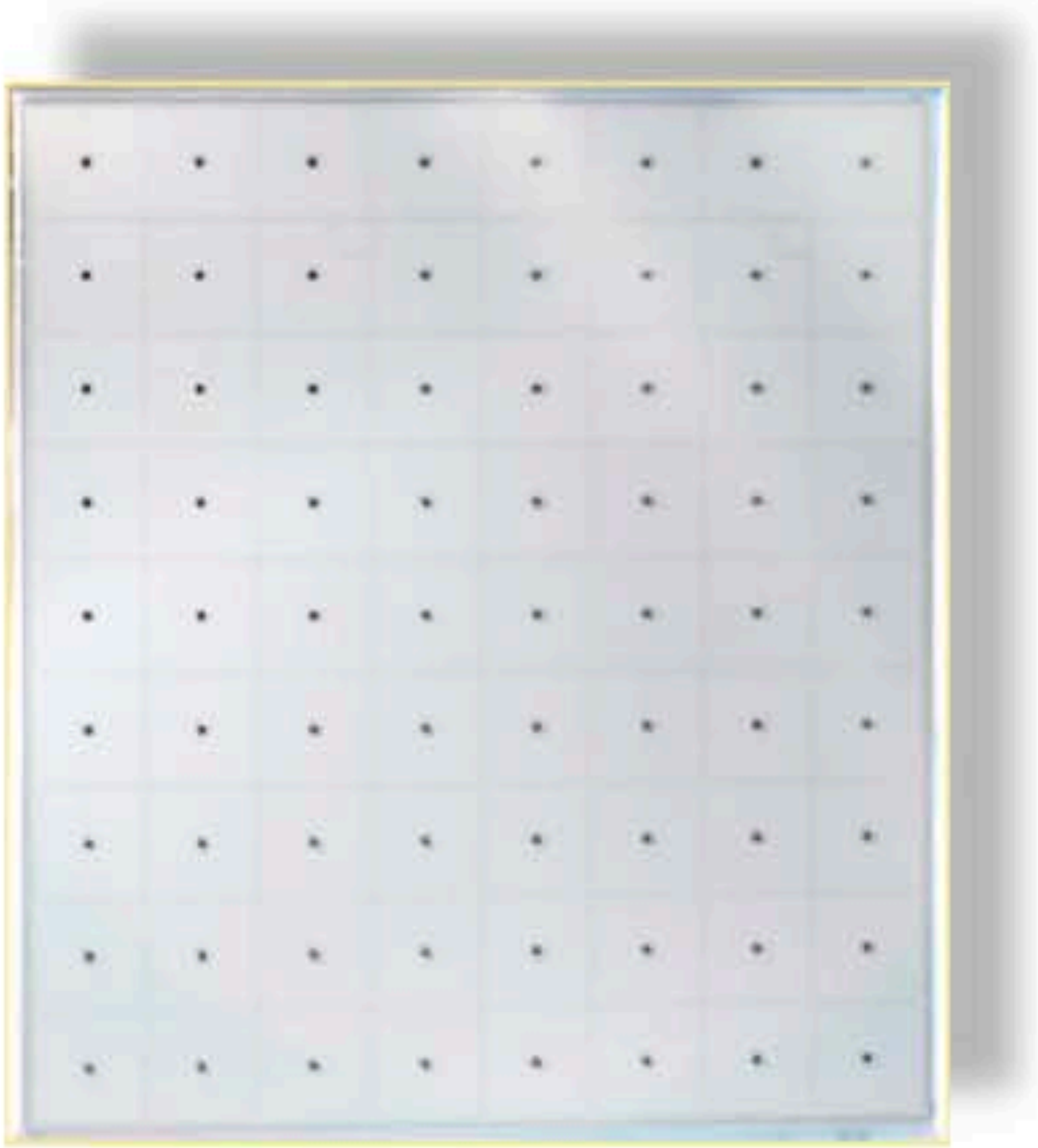


Indian p-type sensor

8*9 Detector array

Beam test at PS is planed in the end of October 2024 with HGCROC2





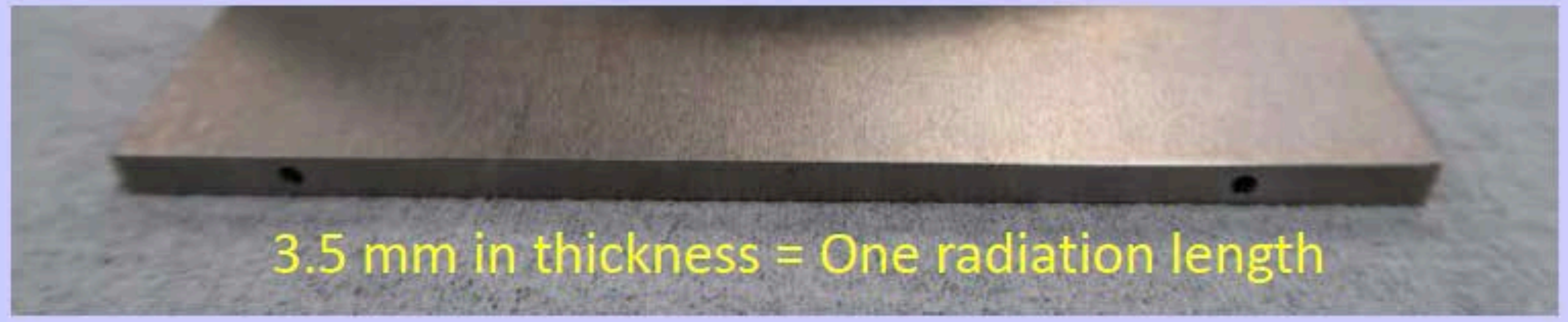
Summary
- ✓ 5 good detectors made
- ✓ IV, CV done for them
- ✓ $I_{leakage}$ is ~ 80nA

Status
- ✓ One detector reached VECC
- ✓ PCB attachement done
- ✓ Test setup and checks started.

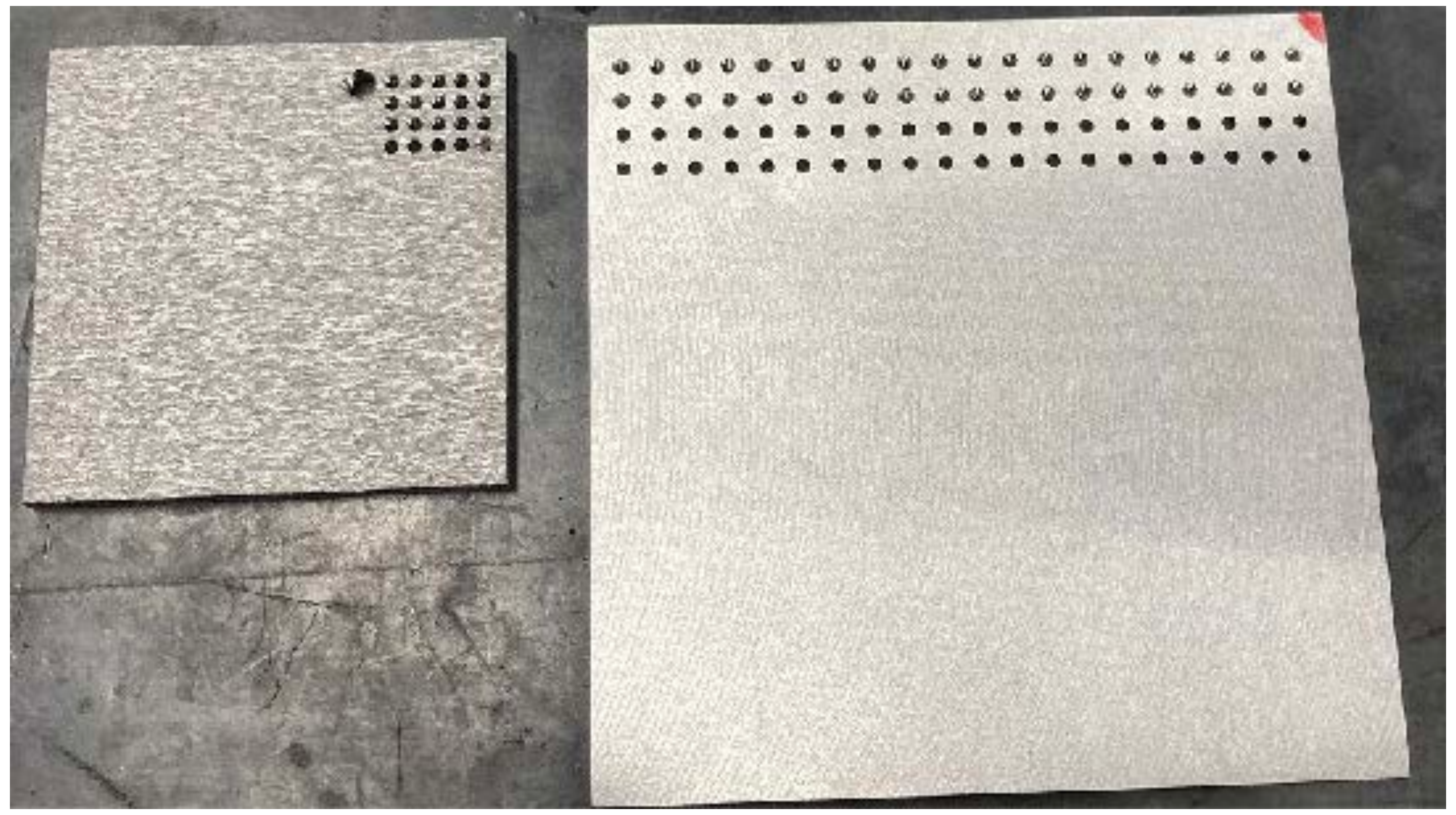
Motoi Inaba
Takashi Hachiya

Tungsten alloy plates

- **Materials: HAC2,**
- **HRB: 103,**
- **Density: 17.8 g/cm³,**
- **Size and thickness:**
  464 x 84 mm² and 3.5 mm in thickness.



- **Blind-hole and screw-thread machining:**
  3 blind-holes on the bottom side and 4 screw holes on the sides.
  A depth < 4 mm → An ordinary cutting machining,
  A depth > 4 mm → An electrical discharge machining (= Expensive).
- **Mass production:**
  A new fabrication method will be available for our wide plate.
  Old: A standard press method.
  New: Plastic processing (rolling) method. → W particles become elliptical such as a shape extending in the L (horizontal) direction.
  FP-1013_A → **44 plates for the pixel layers.**
  FP-4013_F → **396 plates for the pad layers.**
  } **A first half in 2025 and a second half in 2026 (+ 1 spare)**
- **Quality control:**
  All plates will be tested using a new test station with high-precision thickness sensors and edge-extractable digital microscopes.

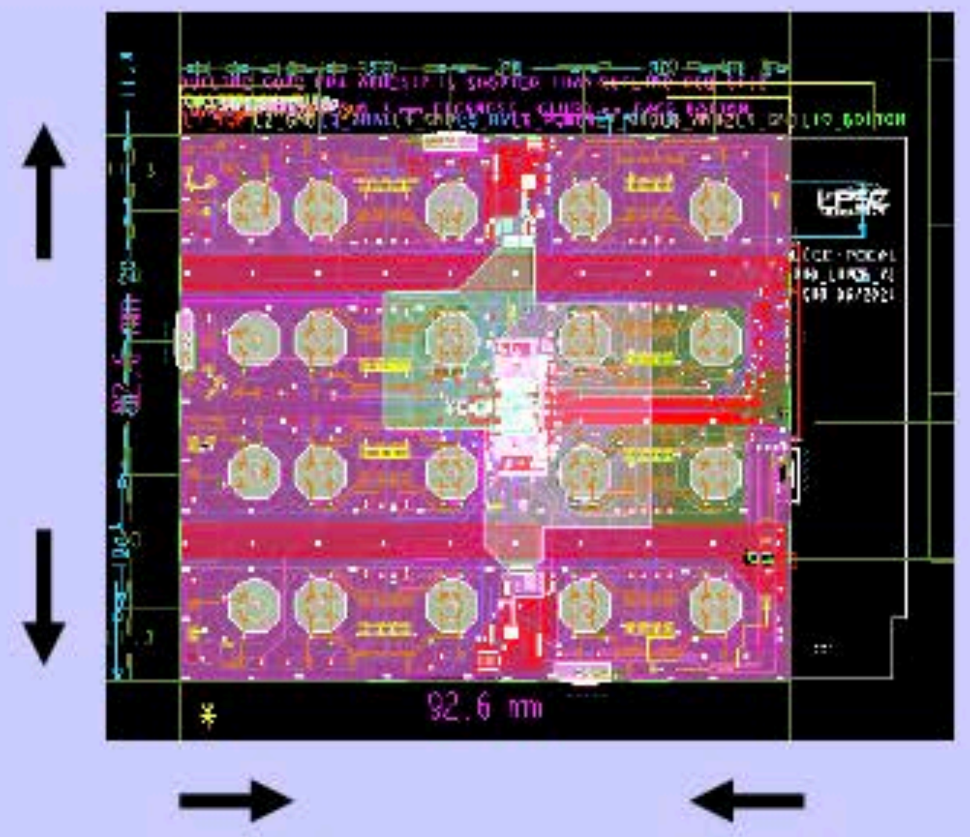


- Test production (3 plates) in 2024
- Mass production in 2025/2026
- Quality control system on flatness

Motoi Inaba
Nicola Minafra

Single pad PCB

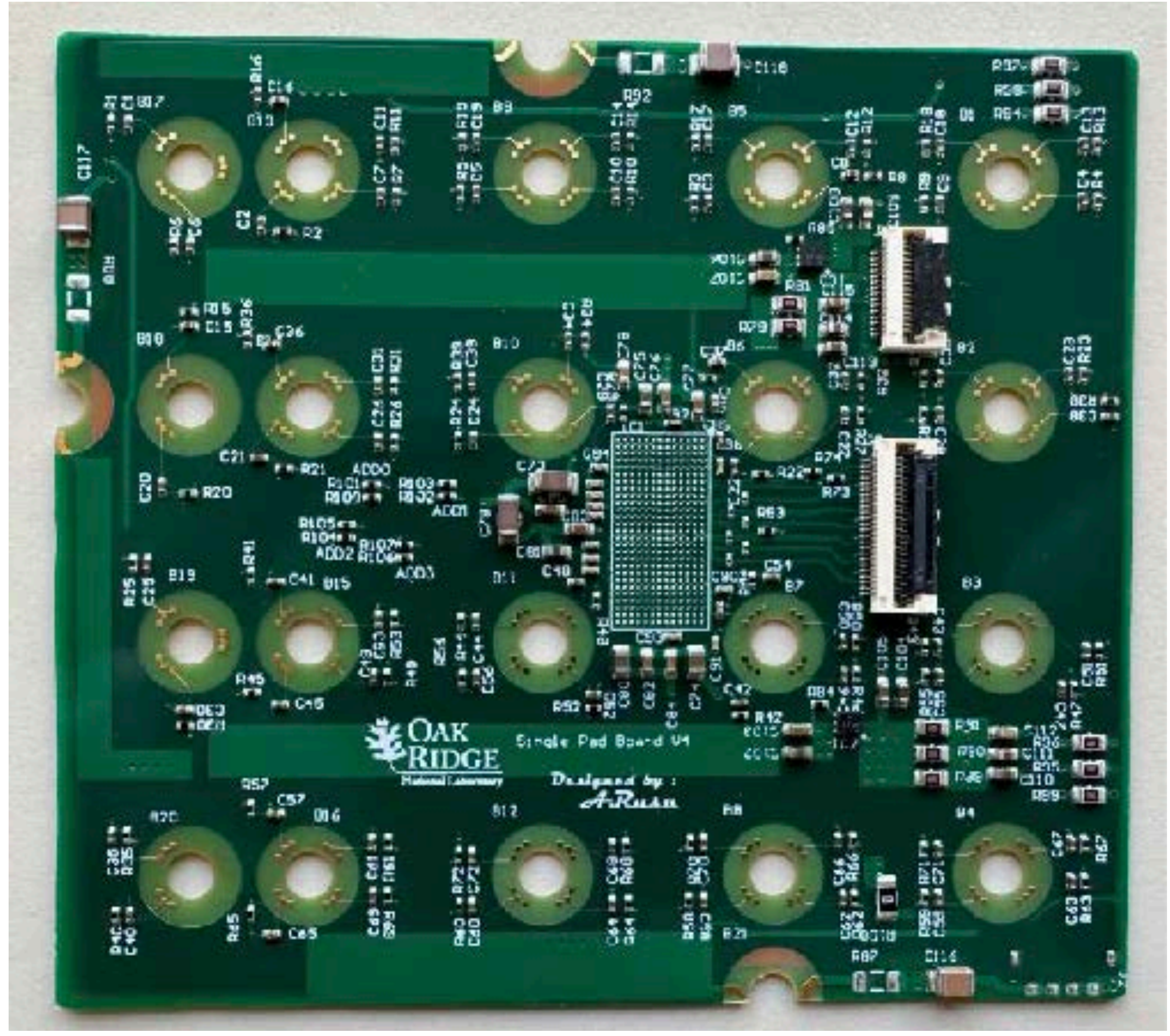
We have two designs of the single-pad PCB with the HGCROC2 ASIC, and it is better to compare them with each other in the same condition.
→ Beam tests at the KEK and ELPH-PARIS in December this year and in February in 2025, respectively, is a good opportunity to do it.



- A good S/N for the MIP measurement.
- A good insulation from a heat of the HGCROC ASIC and LDOs to the sensor.
- A good electrical insulation to the sensor.
- A good flatness.

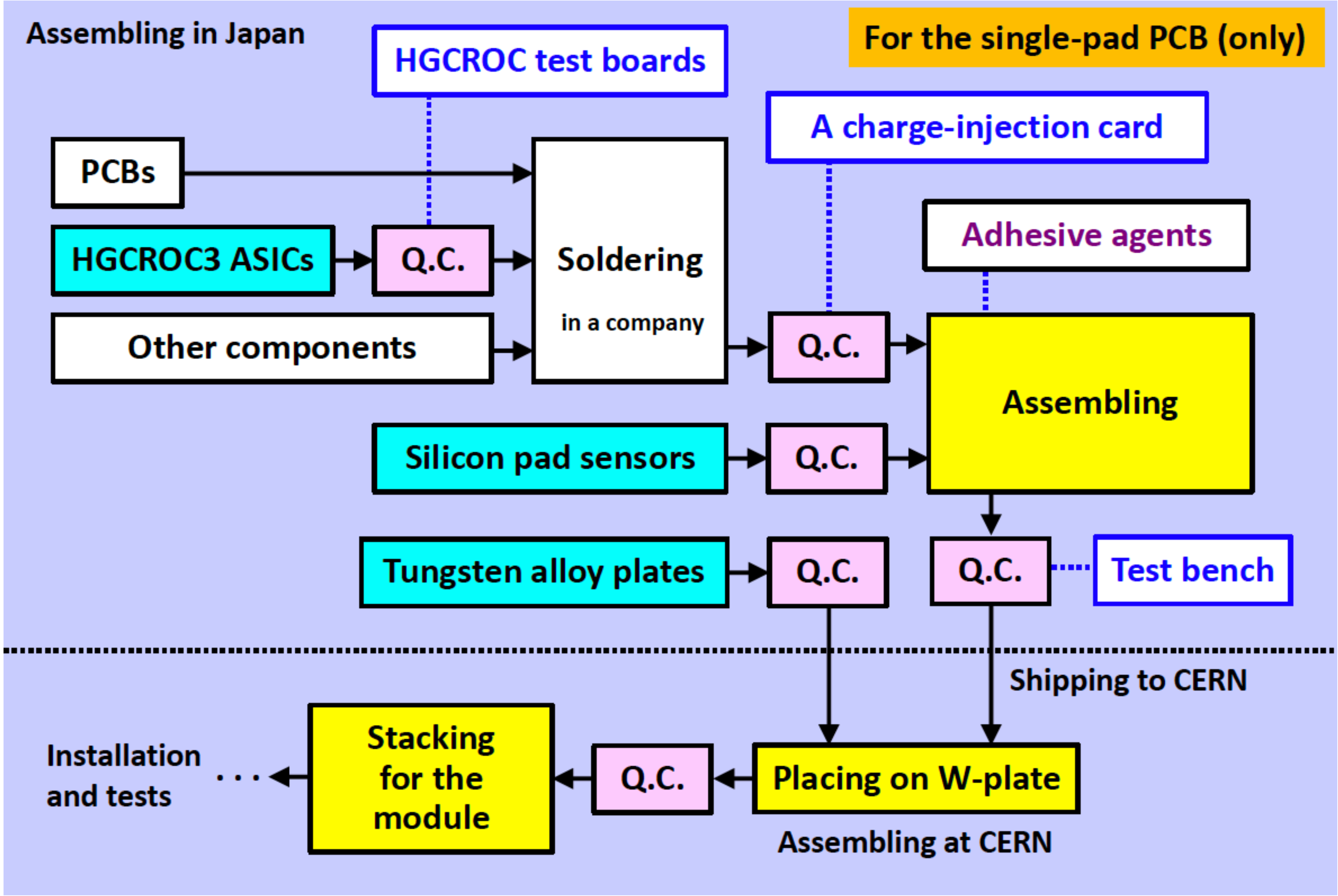
Single-pad PCBs with the HGCROC-series ASIC in Japan.

- Based on the 10-layer design by Grenoble which showed good performances.
- There is no fear of wire bonding.
- Some PCBs will be available by the end of this year.
  - The PCB with HGCROC2 for KCU105 (Additional fabrication)
  - The PCB with HGCROC2 for the flat-cable connection,
  - The PCB with HGCROC3 (and 3A) for KCU105 (to develop / study a firmware)
  - The PCB with HGCROC3 (and 3A) for the flat-cable connection (for the final ver.)

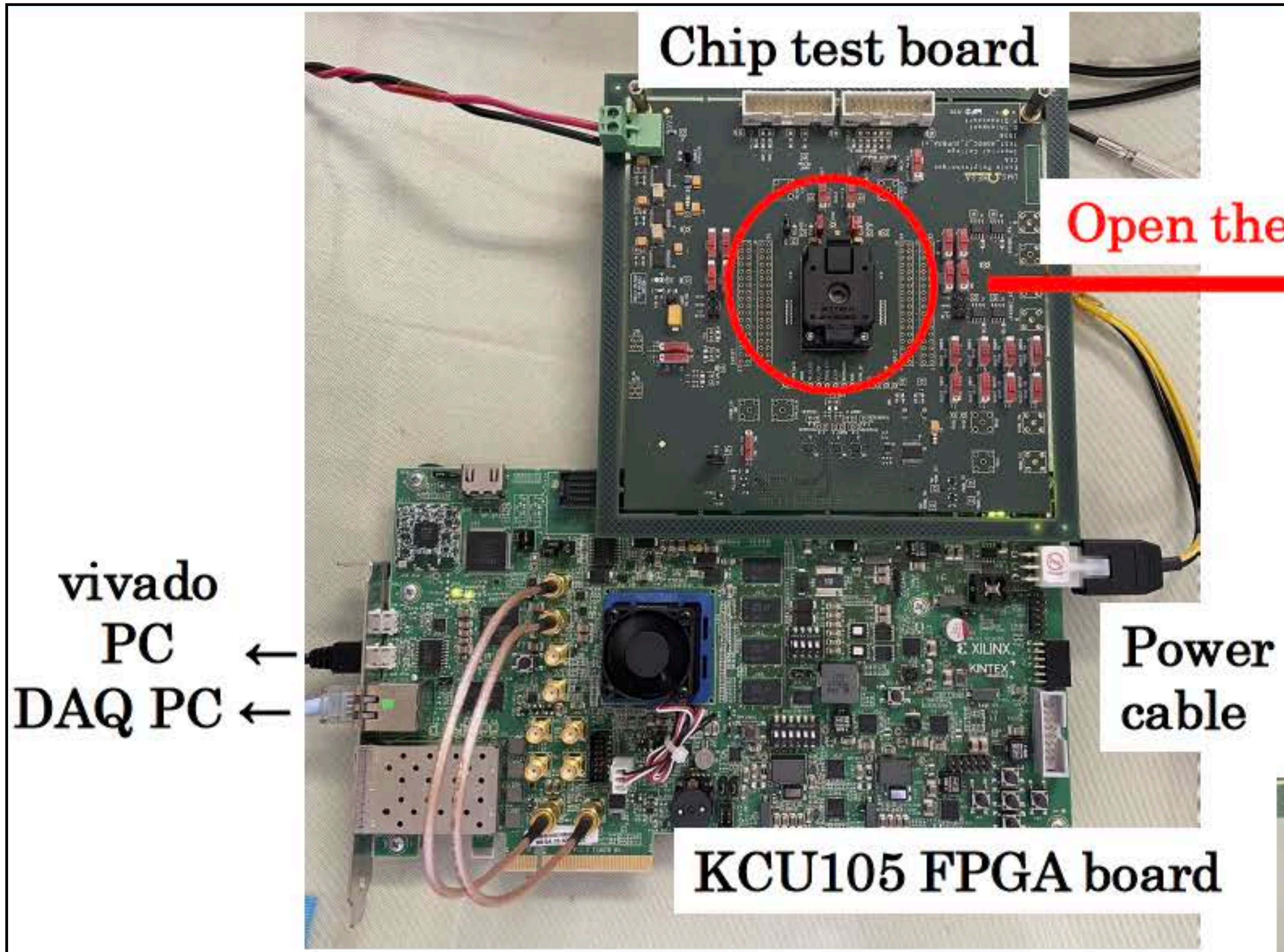


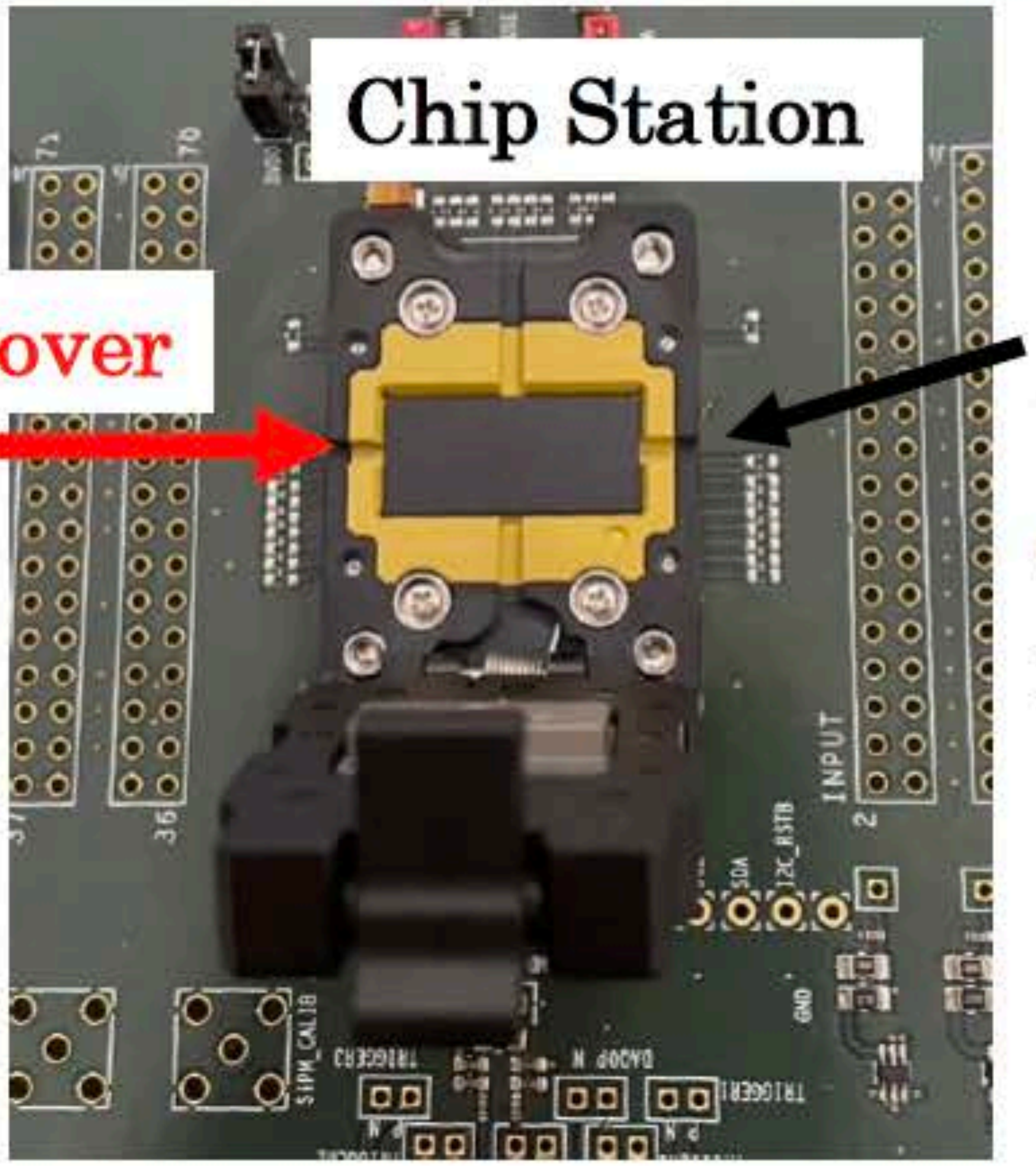
- Designing of PCB in Japan is ongoing
- Comparison of two design in 2024 with HGCROC3 in Japan
- Fix the design by the end of 2024, production in 2025

Pad model assembly



HGCROC test station





Put the HGCROC chip into the socket

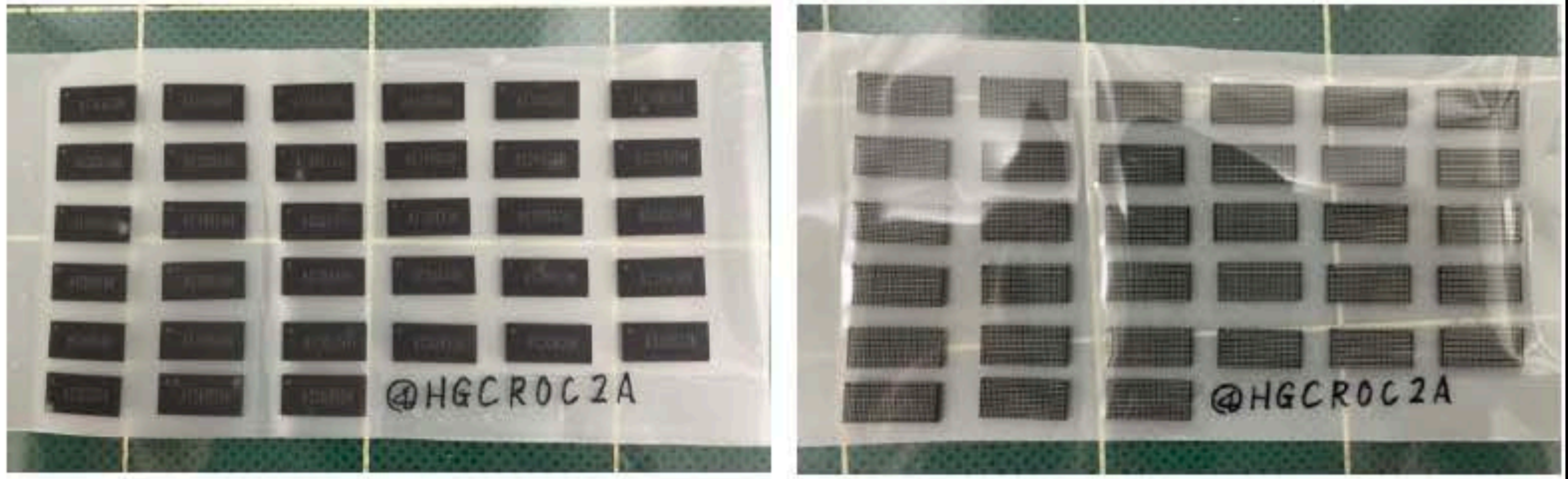
Test Board creates an internal charge

→inject to chip

→test the performance

- 344 HGCROC2&2A chips were packaged in Japan
- We measured

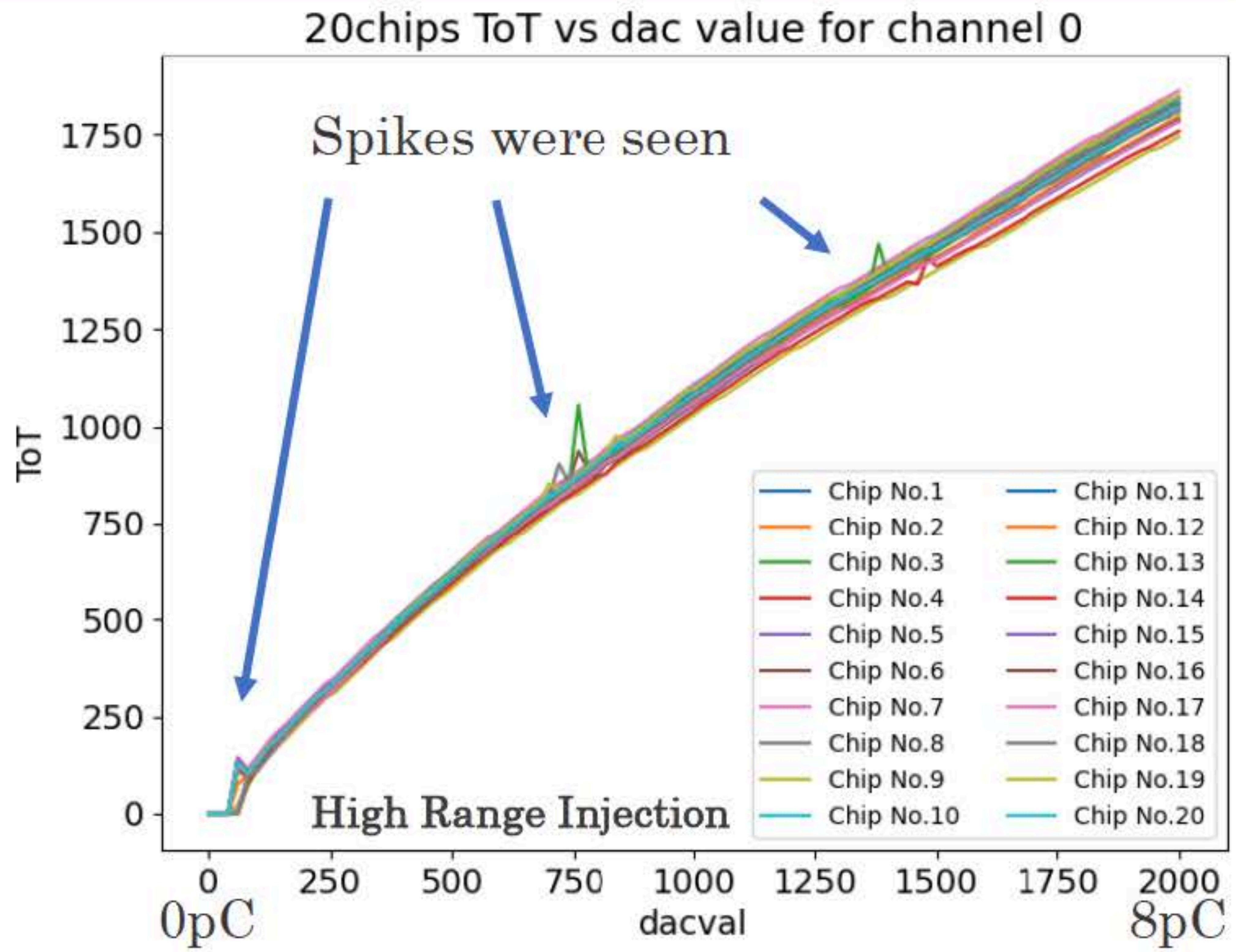
HGCROC2 : 10 chips
HGCROC2A : 10 chips
} Total 20 chips

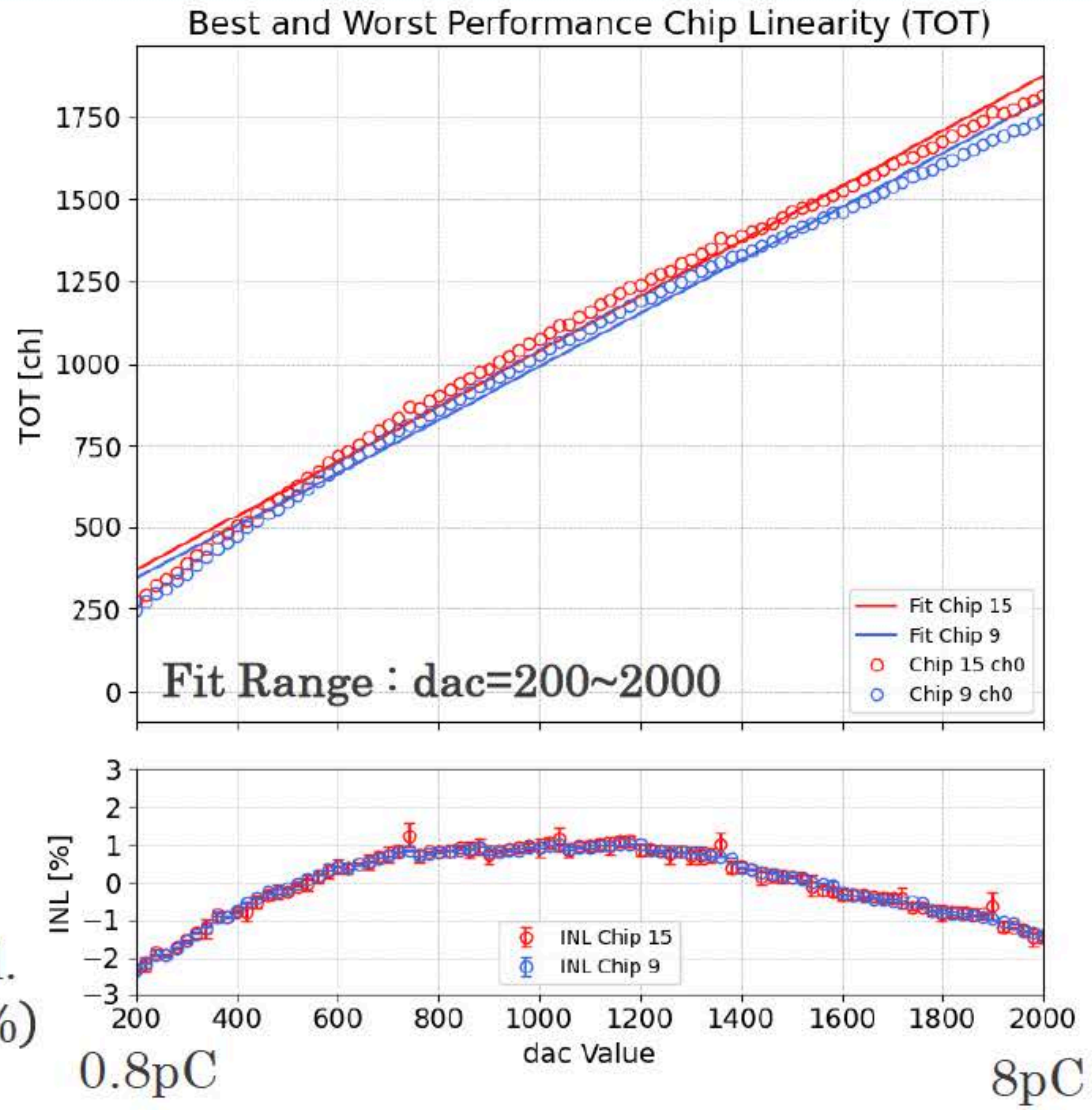


HGCROC2A chip package

HGCROC2 test results

Important step for mass production: obtain own calibration procedure and put in DB





- Linearity differences between chips are very small.
- Best and Worst chip Linearity : −2% ~ + 1% (< 3%)
- HGCROC2 Datasheet : −2% ~ + 1% (< 3%)

→All chips TOT satisfy FoCal's requirements (< 3%)

6

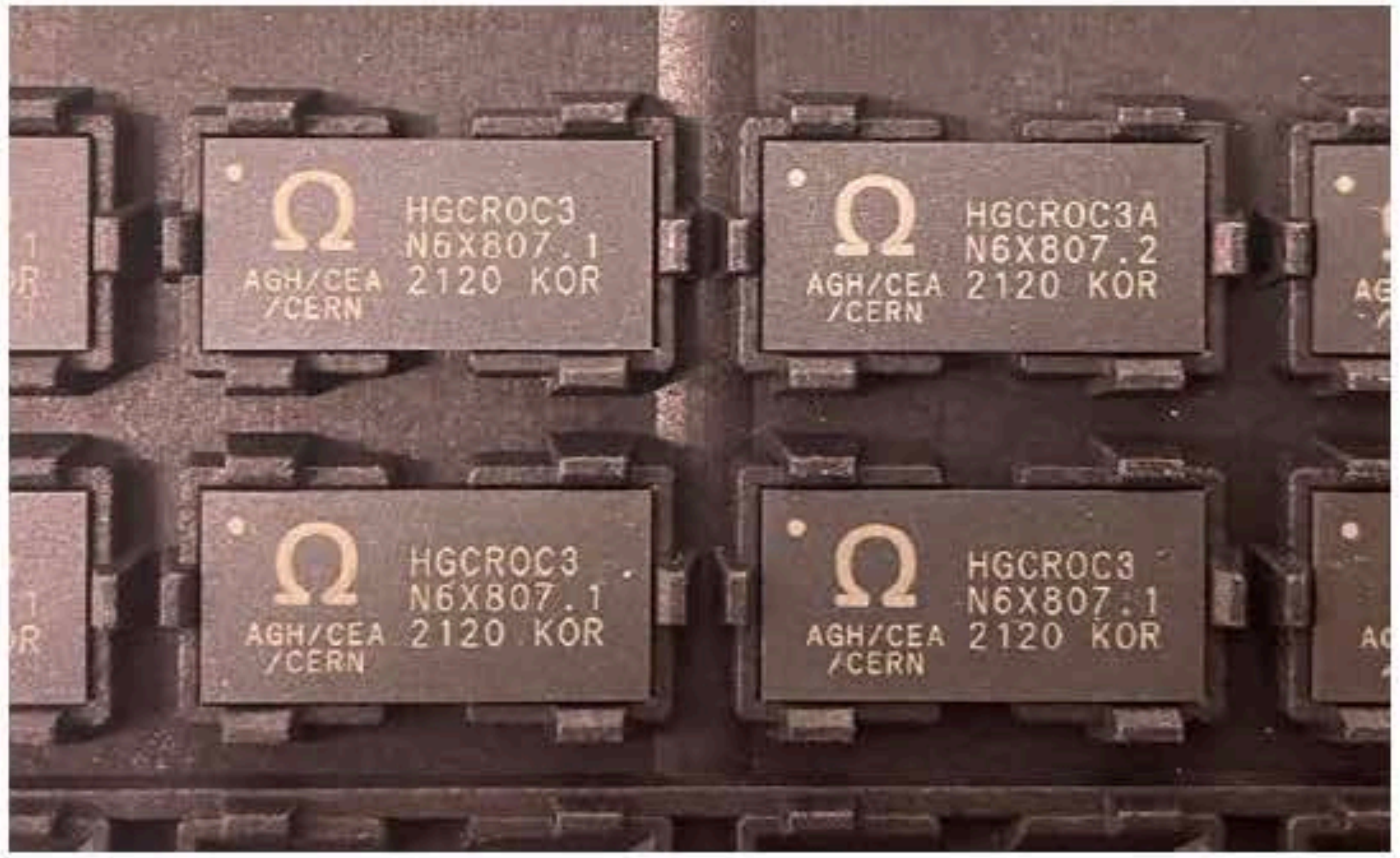
Scope for HGCROC3

◆Set up the test environment for HGCROC3

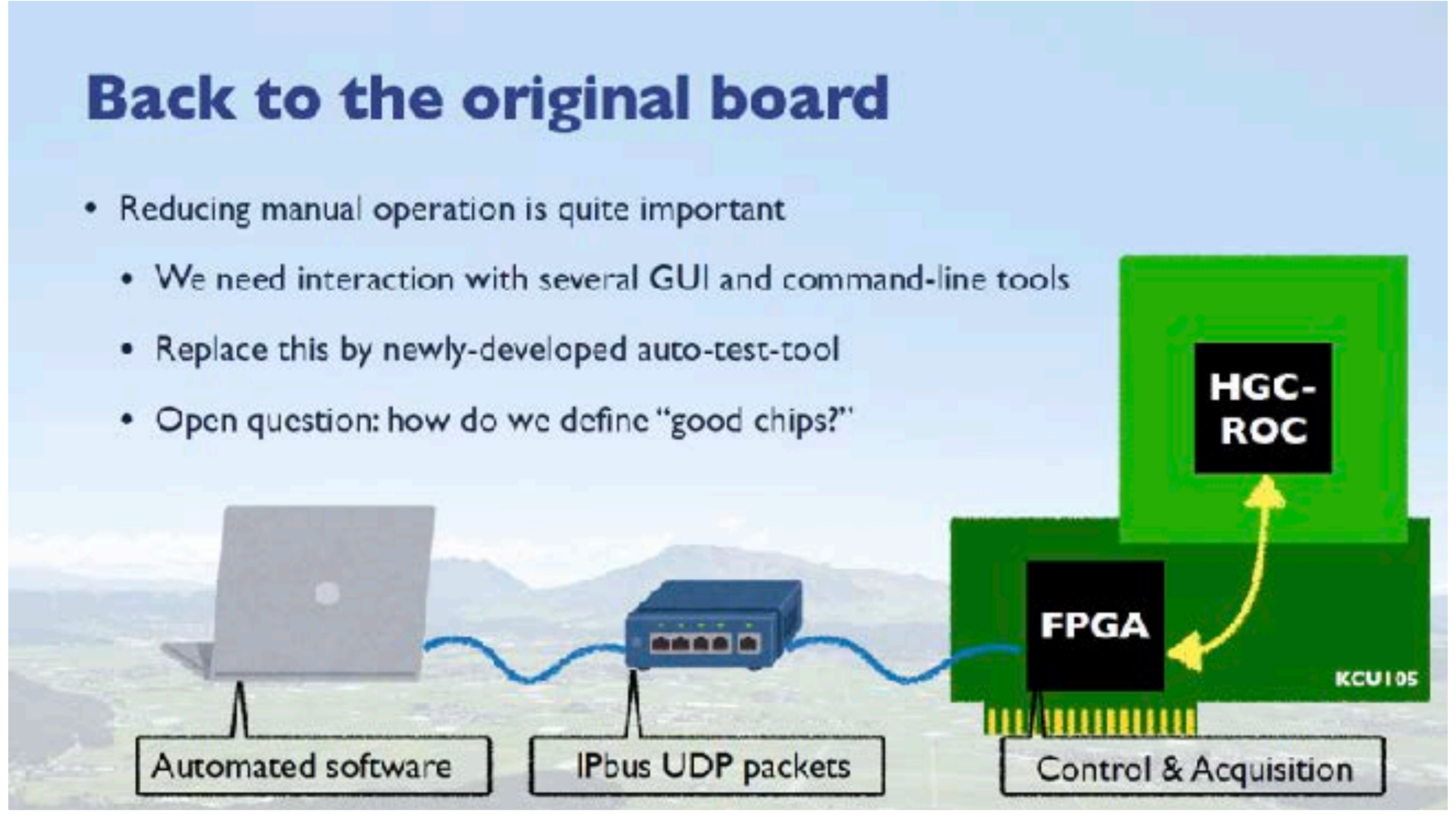
12 HGCROC3 chips were already provided from OMEGA

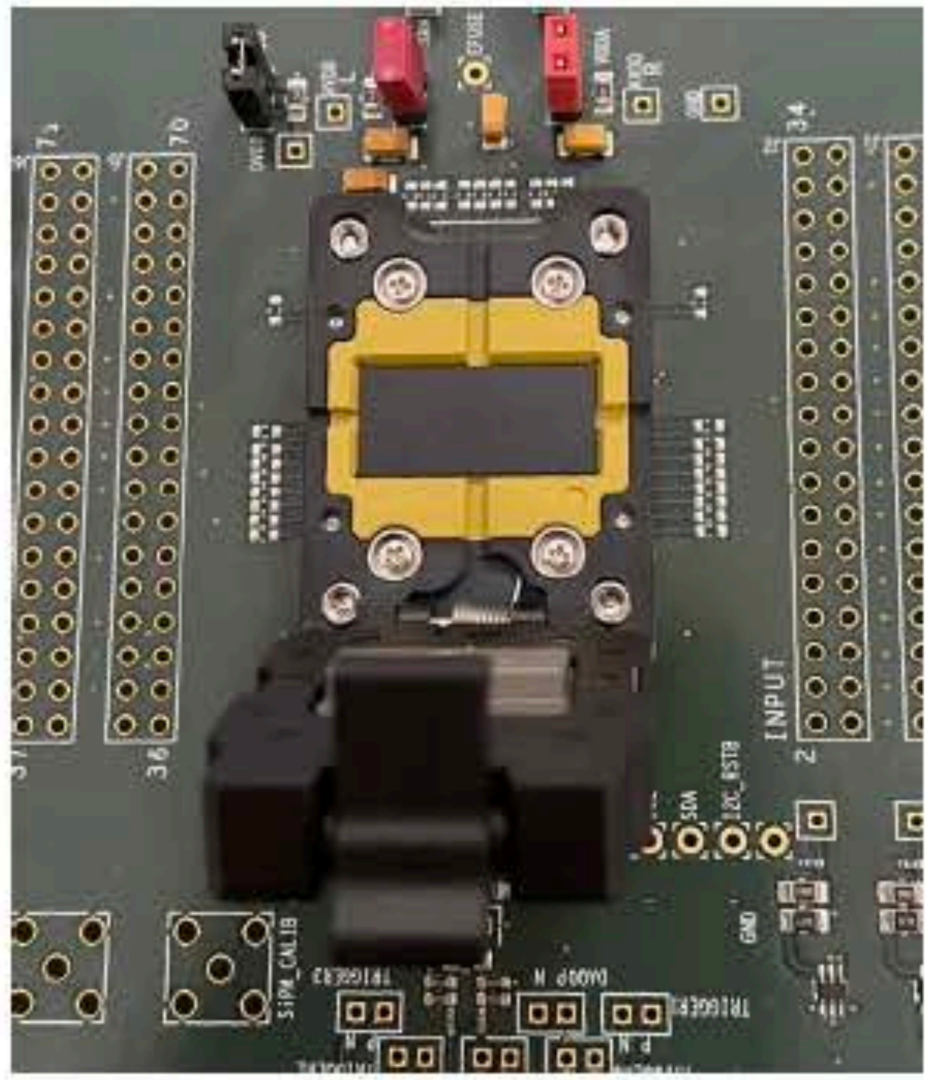
- We want to use current setup
- Need to upgrade v2 firmware for v3 (by Prof. Osana)
- Need to check pin assignment (almost same)
- ORNL comes to Tsukuba to set up testing environment (next November?)

HGCROC3



◆Establish the test system for 2000 chips





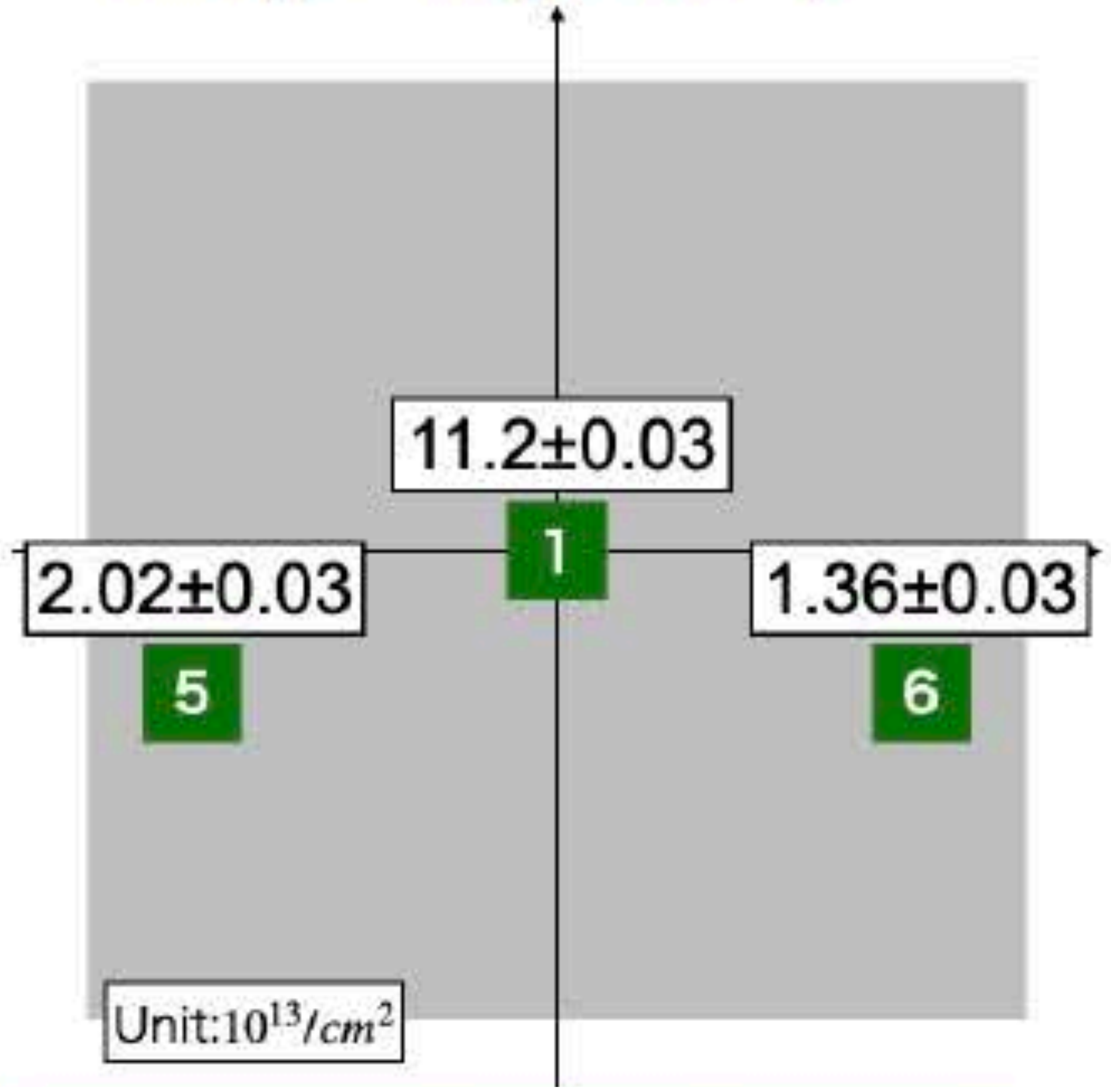
× 5

13

Neutron irradiation test at RANS

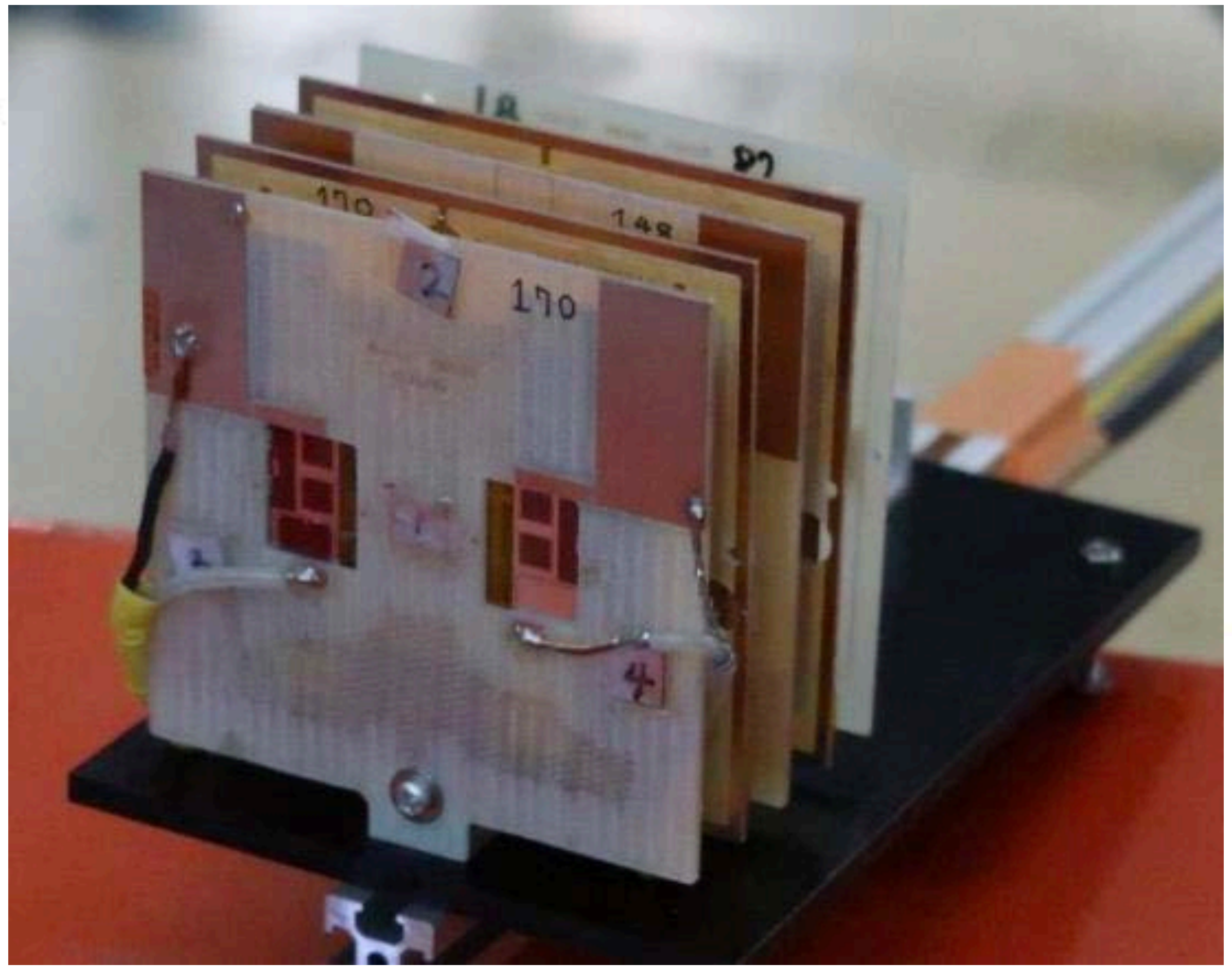
1st layer results

Last year (Run1) **2023, July**

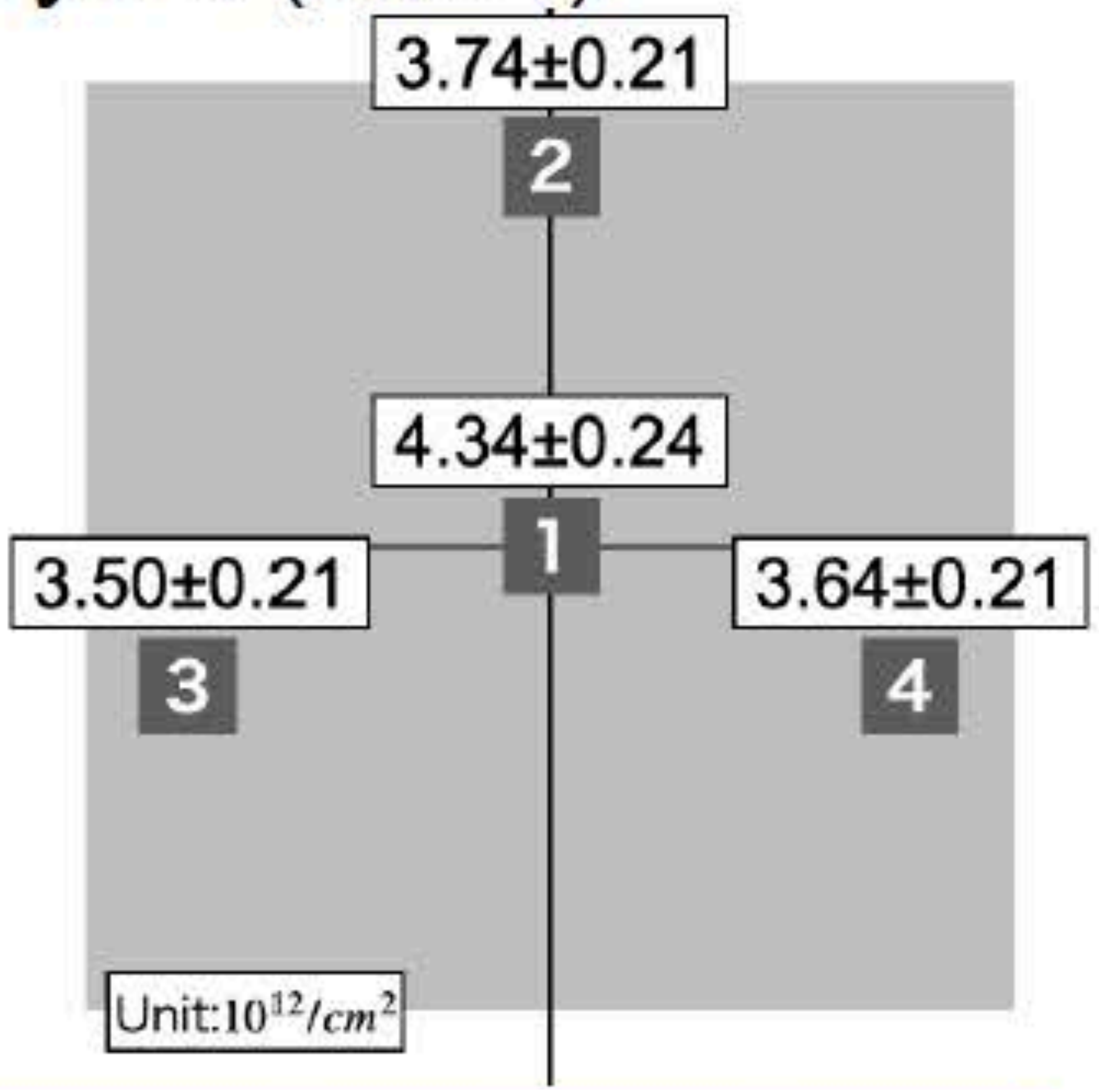


1.12 x 10^{14} (n/cm²)

→ Shown in TDR



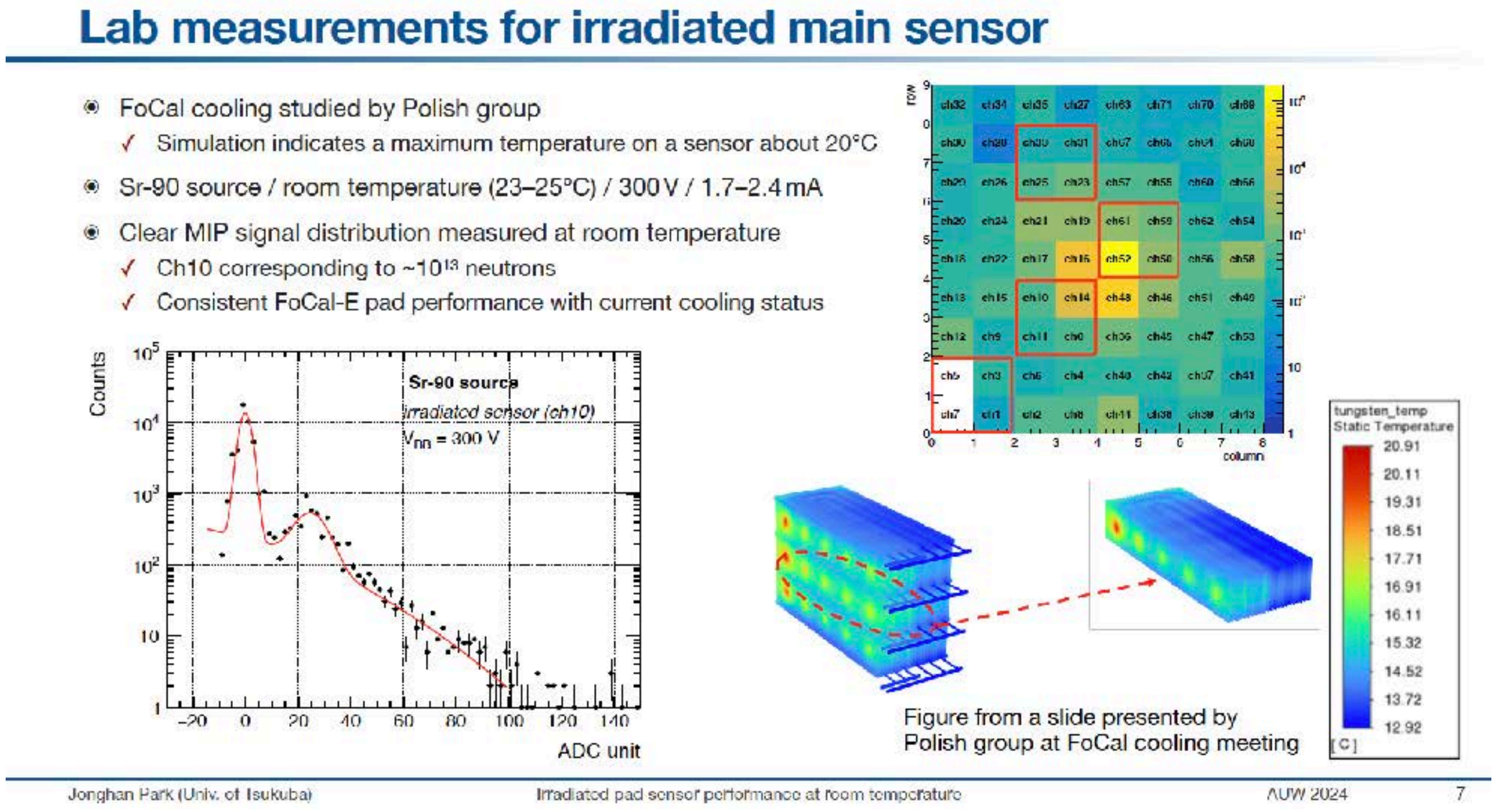
This year (Run1) **2024, May**



4.34 x 10^{12} (n/cm²)

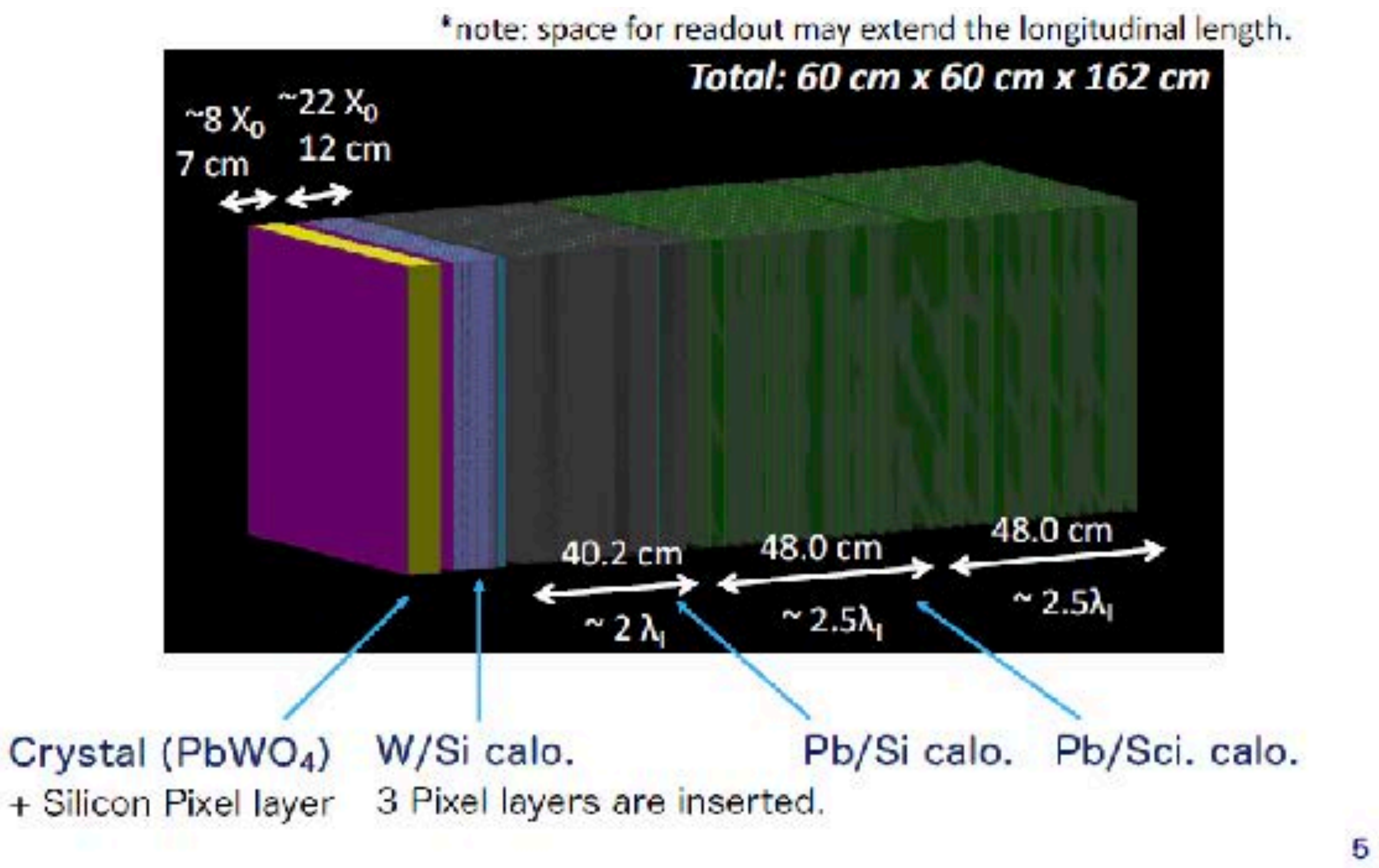
→ used final p-type sensor

Test beam in Japan, synergy with EIC



Jonghan Park

Shingo Sakai
Yuji Goto

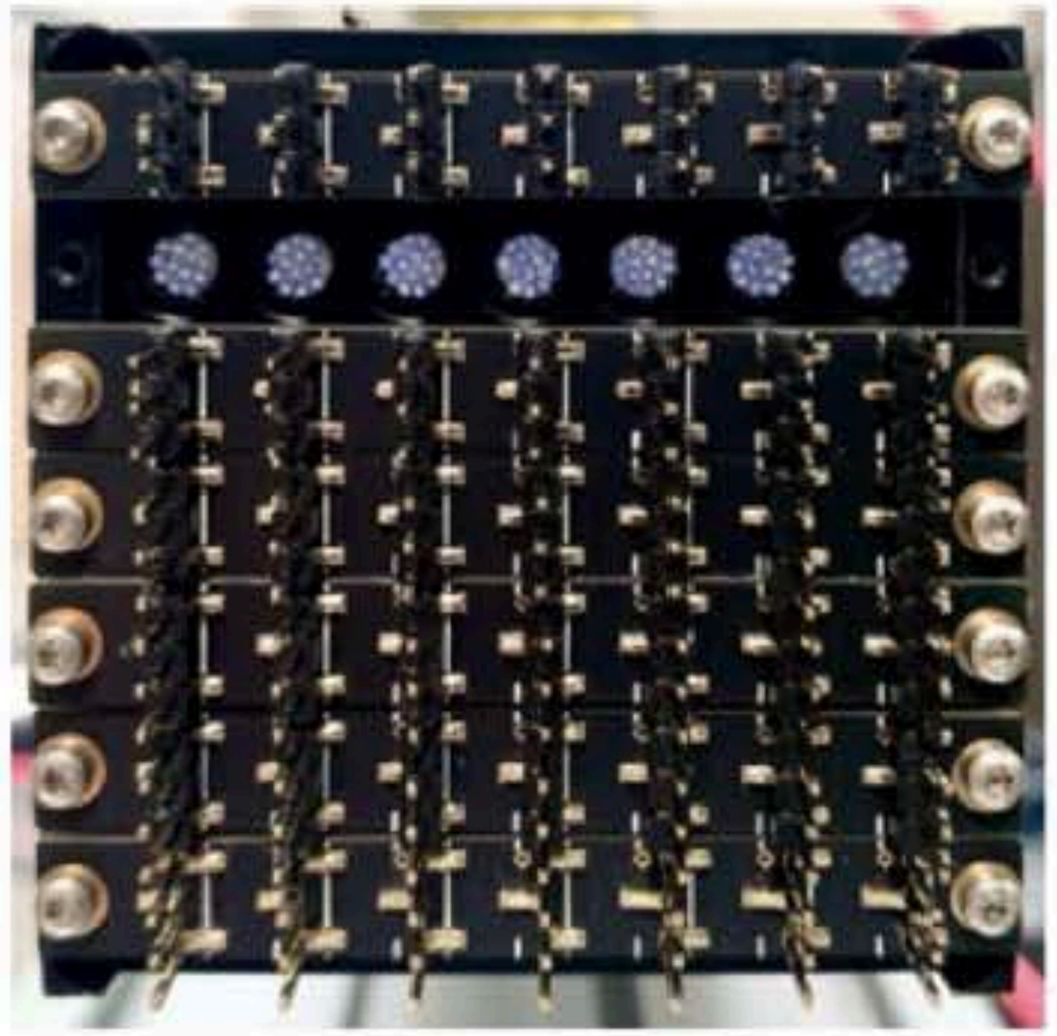


- Lab test: @ room temperature, irradiated main sensor (10^{14} (n/cm^2)) shows a clear MIP peak.
- Important feedback to cooling system.
- KEK test beam in December 11 - 16, 2024 (1-5 GeV, electron): final sensor test with MIP, irradiate sensor, temperature dep.
- ELPH test beam in Feb. 2024 (800 MeV electron): HGCROC3 test
- Discussed the strong synergy between FoCal and EIC-ZDC

3) FoCal-H

FoCal-H Prototype 2

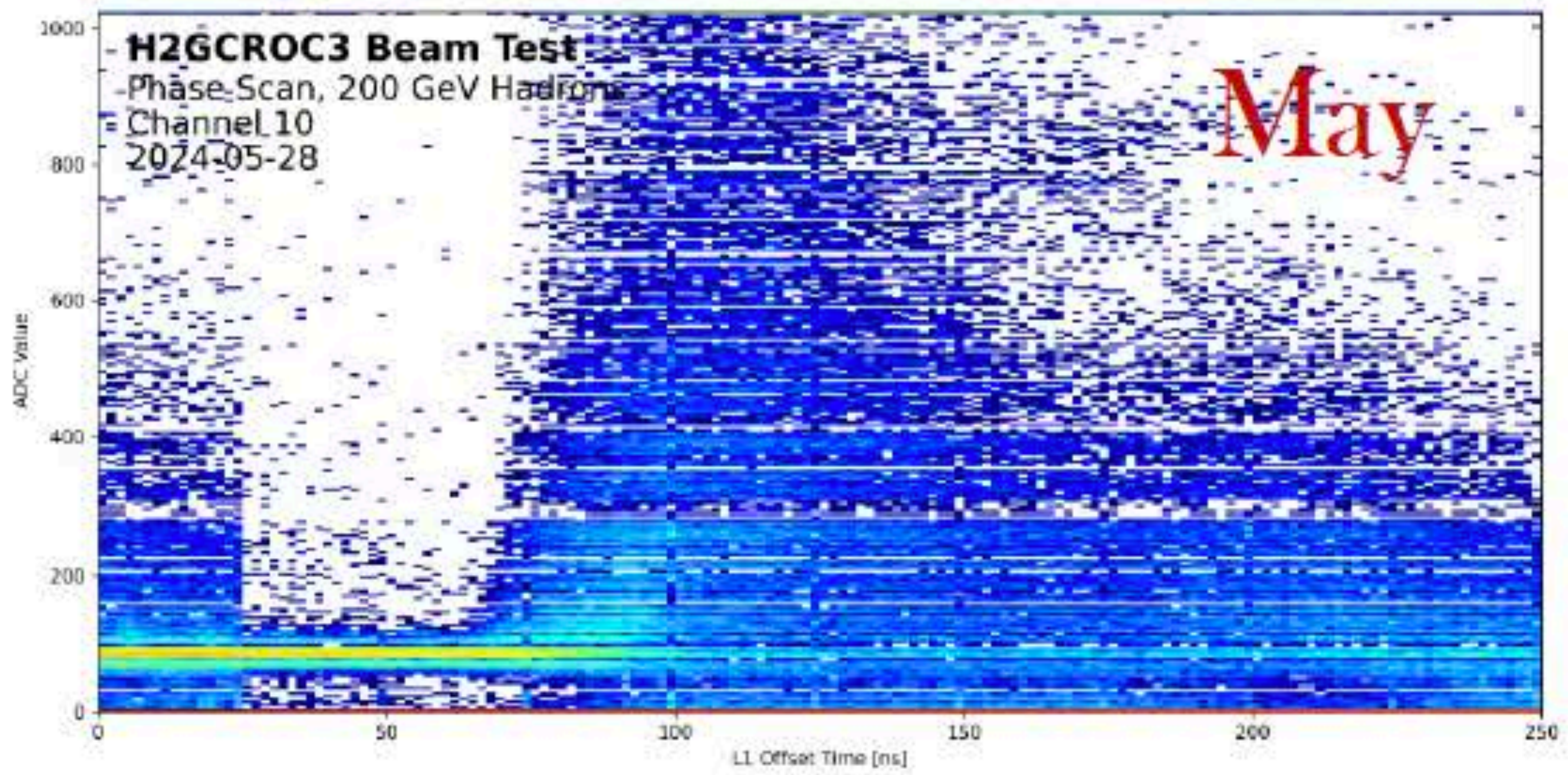


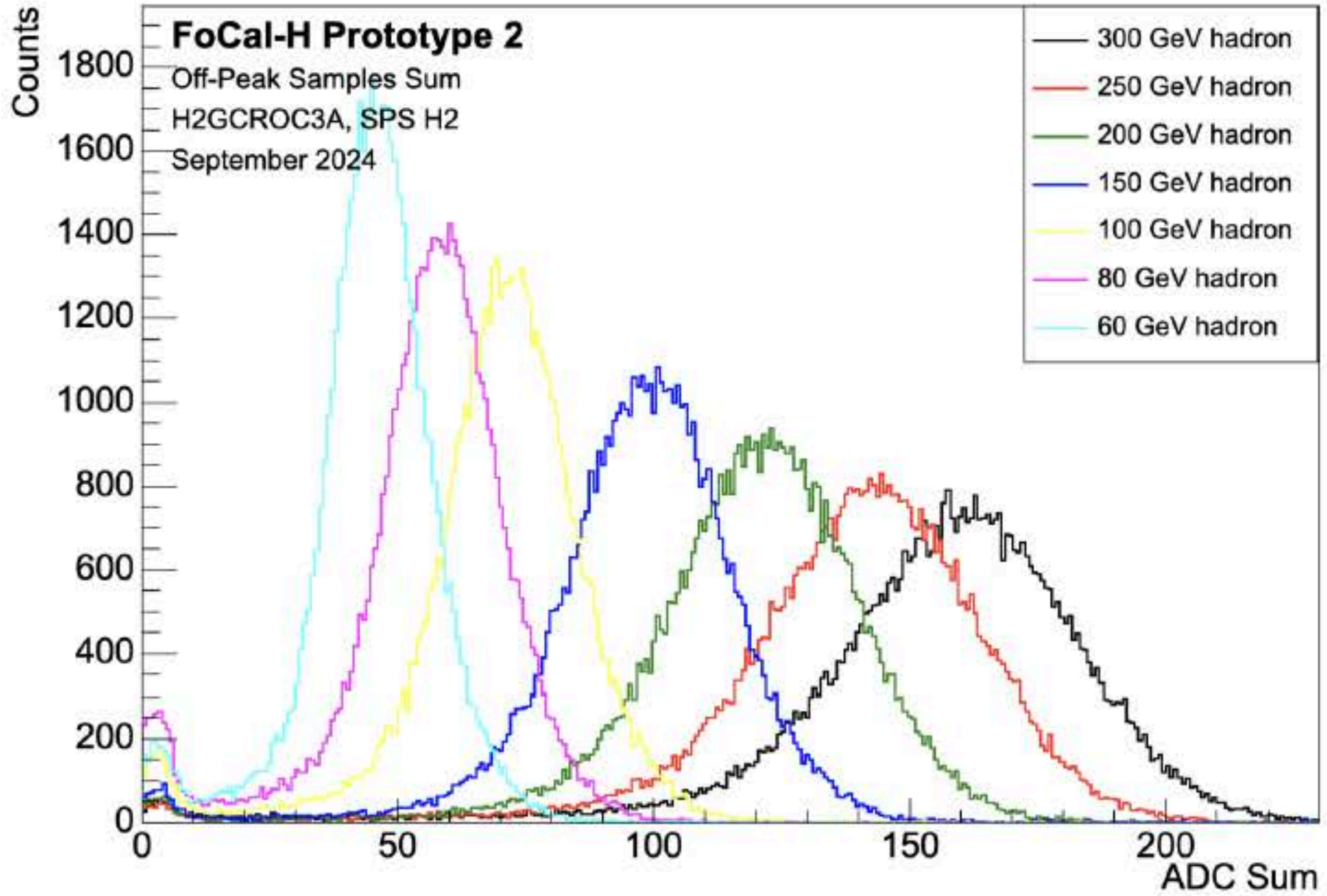


- 9 6.5x6.5x100 cm^3 modules of 668 2.5 mm OD 1.1mm ID Cu capillary tubes
- Each tube contains a 1 mm Luxium BCF-12 scintillating fiber.
- The center module is read out by a 7x7 array of SiPMs
- The outer module is read out by 5x5 arrays of SiPMs
- SiPMs: Hamamatsu S13360-6025 (6x6 mm^2 25μm SPADs)
- 249 readout channels (49 center, 8x25 periphery)

FoCal-H Test Beam September 2024

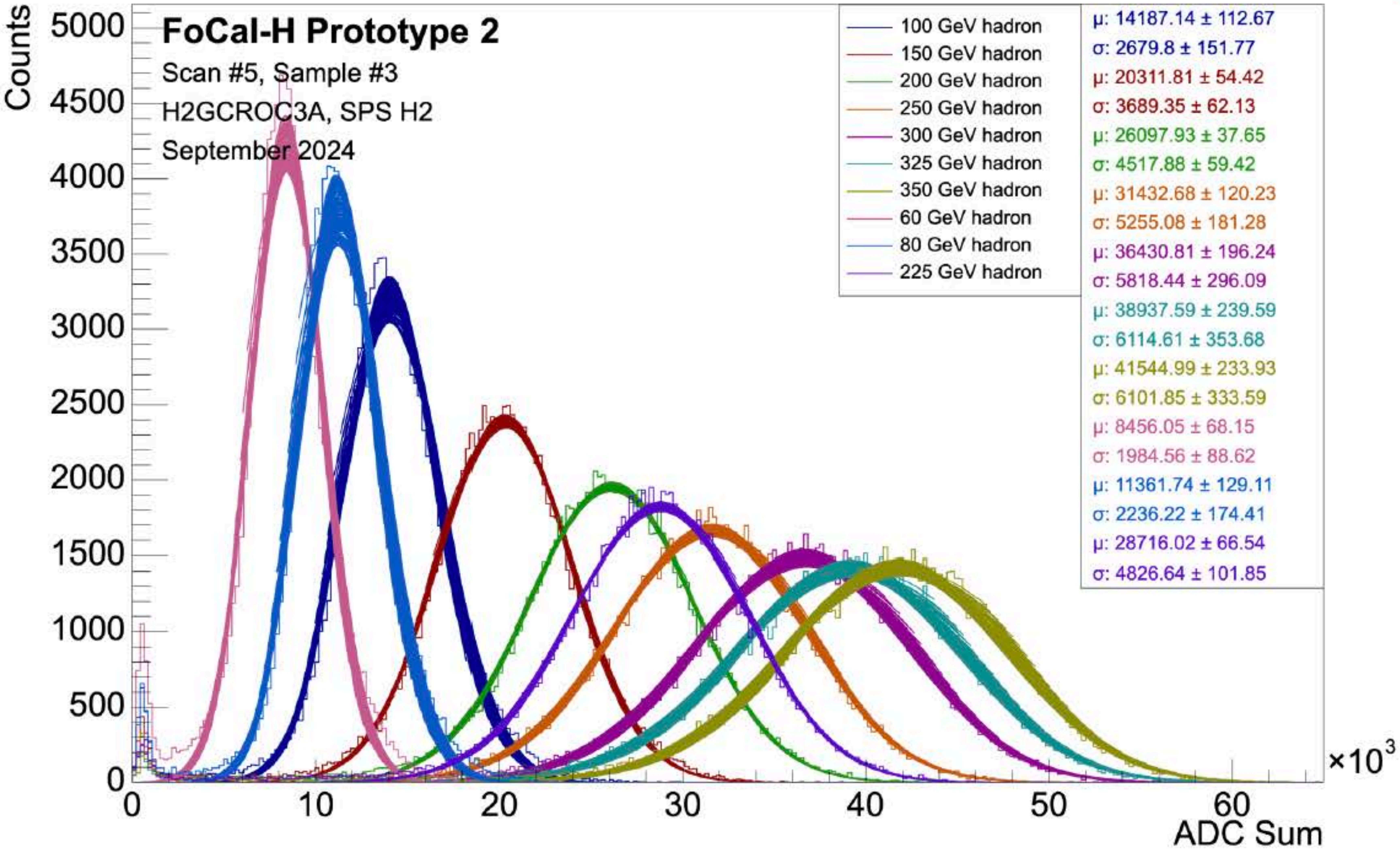
1. Analyzable physics data with H2GCROC proto readout
2. Use (and characterize) ToT for large signals
3. Collect data with different Current conveyor settings
4. “stretch goal”: combined events with Pixels





H2GCROC in beam September

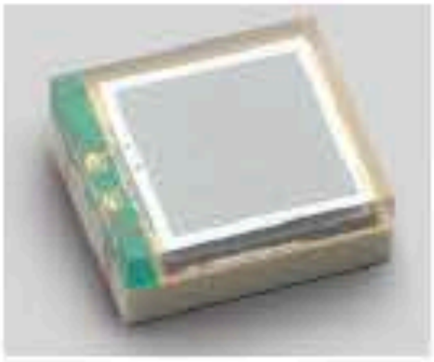
ADC distributions



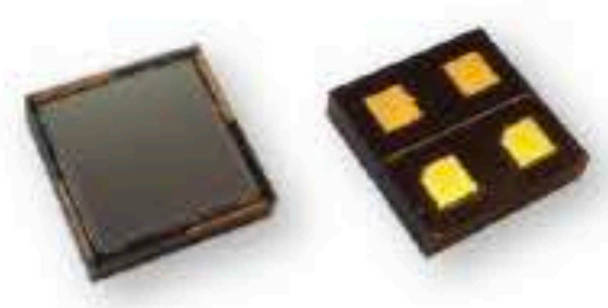
FoCal-H SiPM Radiation Tolerance?

SiPM candidates

- Large-size SiPMs considered (6x6 mm^2) to simplify bundle assembly and minimize the number of FEE channels.



Hamamatsu S13360



NDL EQR20

- Two candidates pre-selected from specs data and market availability – HPK S13360 & NDL EQR 20.

Effect of zero-fluence vs few-days-fluence vs yearly fluence

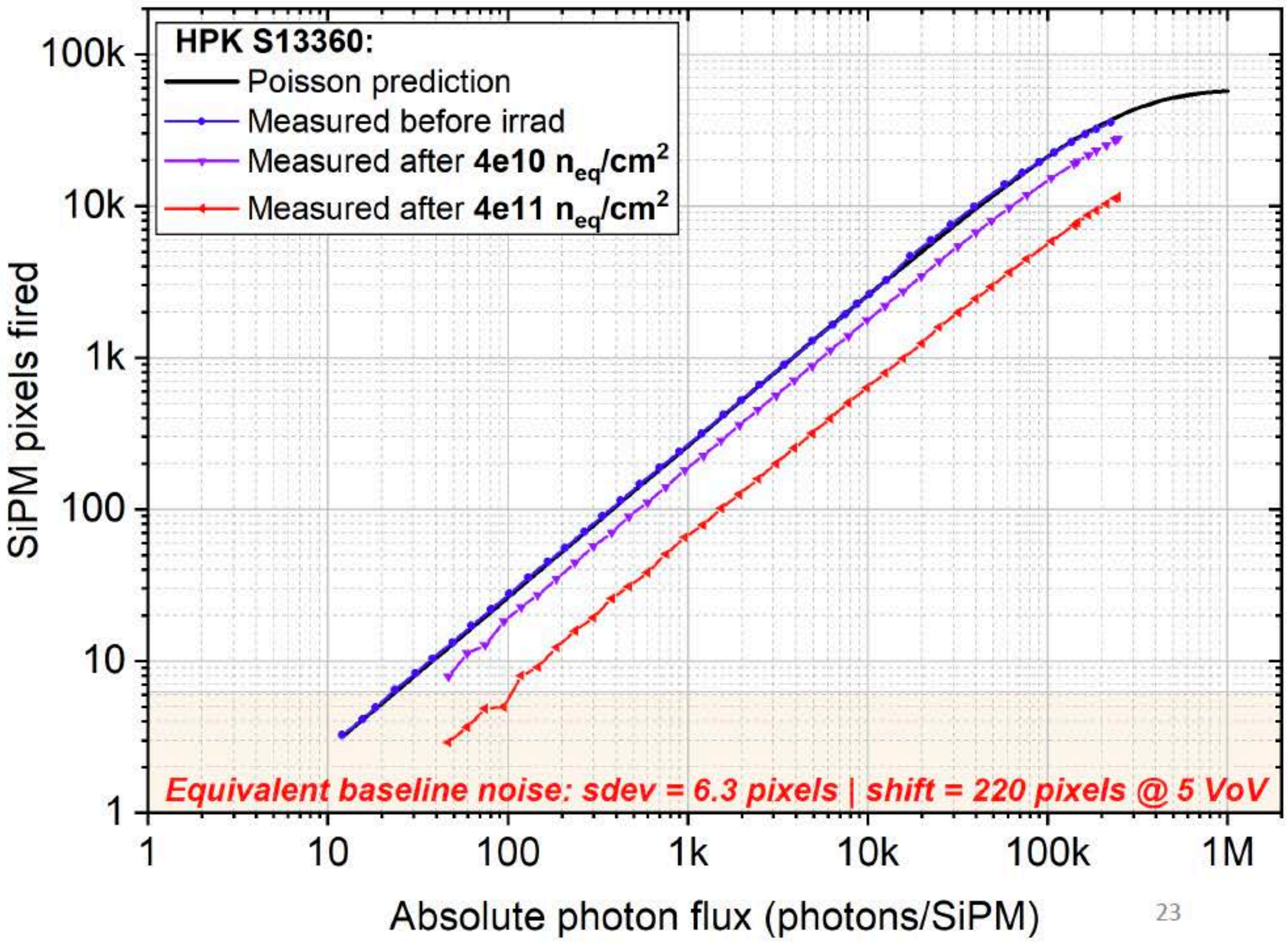
At +25°C, response of the HPK drops down to ~20% throughout the year

AND

very high digitization errors arise for pulses below ~1000 photons.

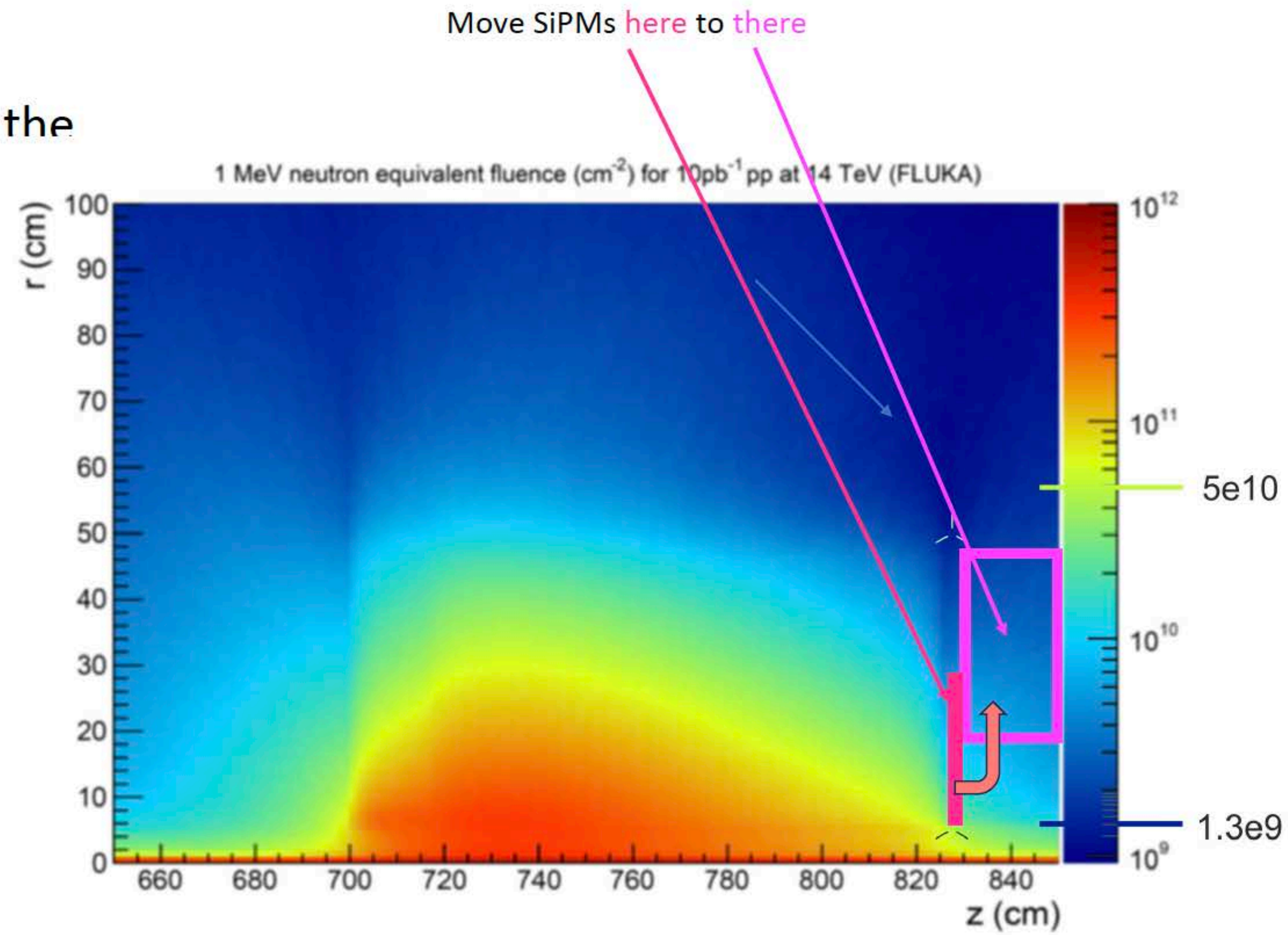
!

key plot



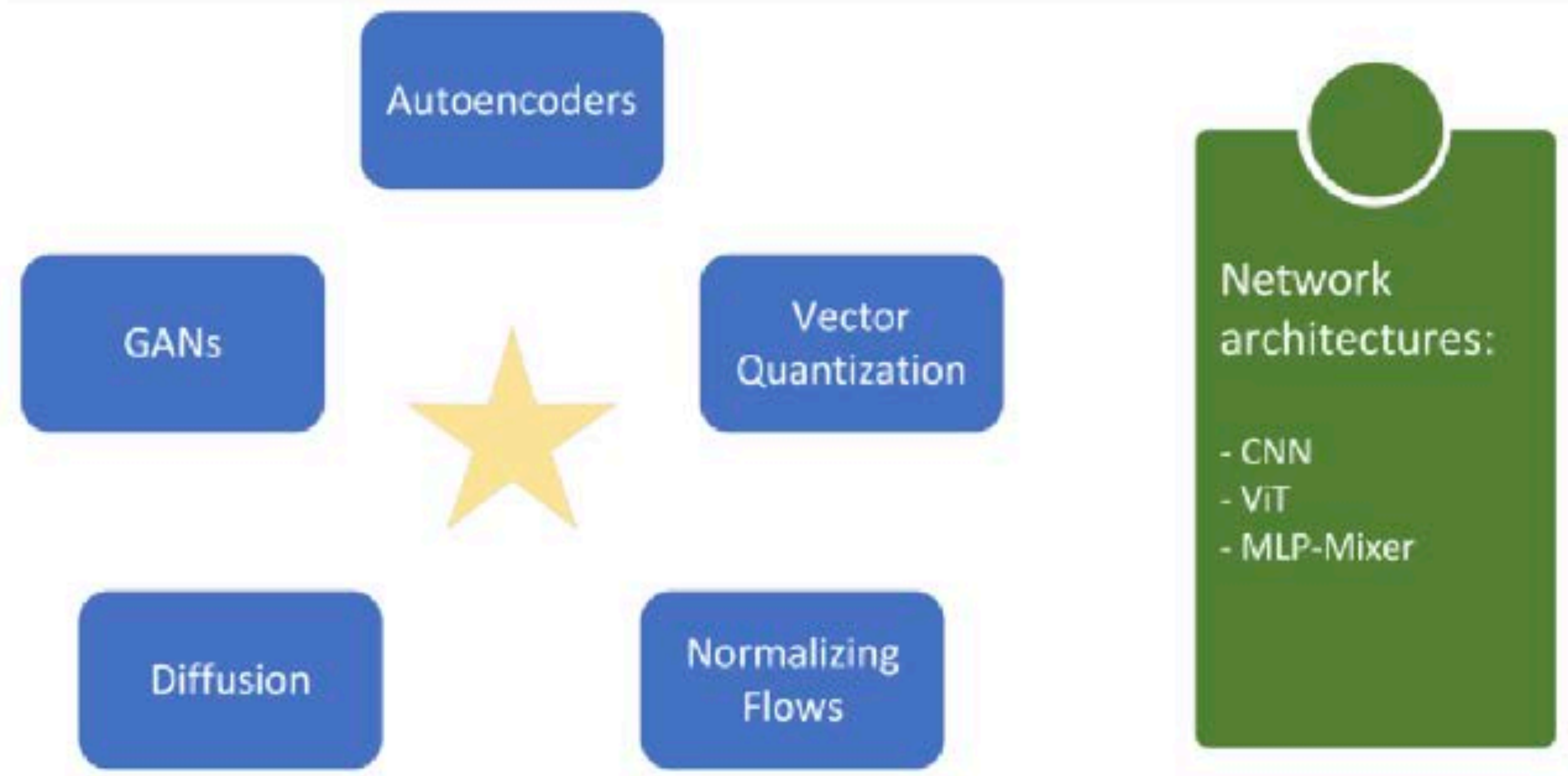
Implications:

- SiPMs cannot tolerate the dose at small R (from beam) between annealings
- Cure: cool (≈-30C) or move R>30.
- Chilled water is ≈14C
- Need to move "inner" SiPMs outward.



Fast simulation using ML for HCal

Chosen generative frameworks

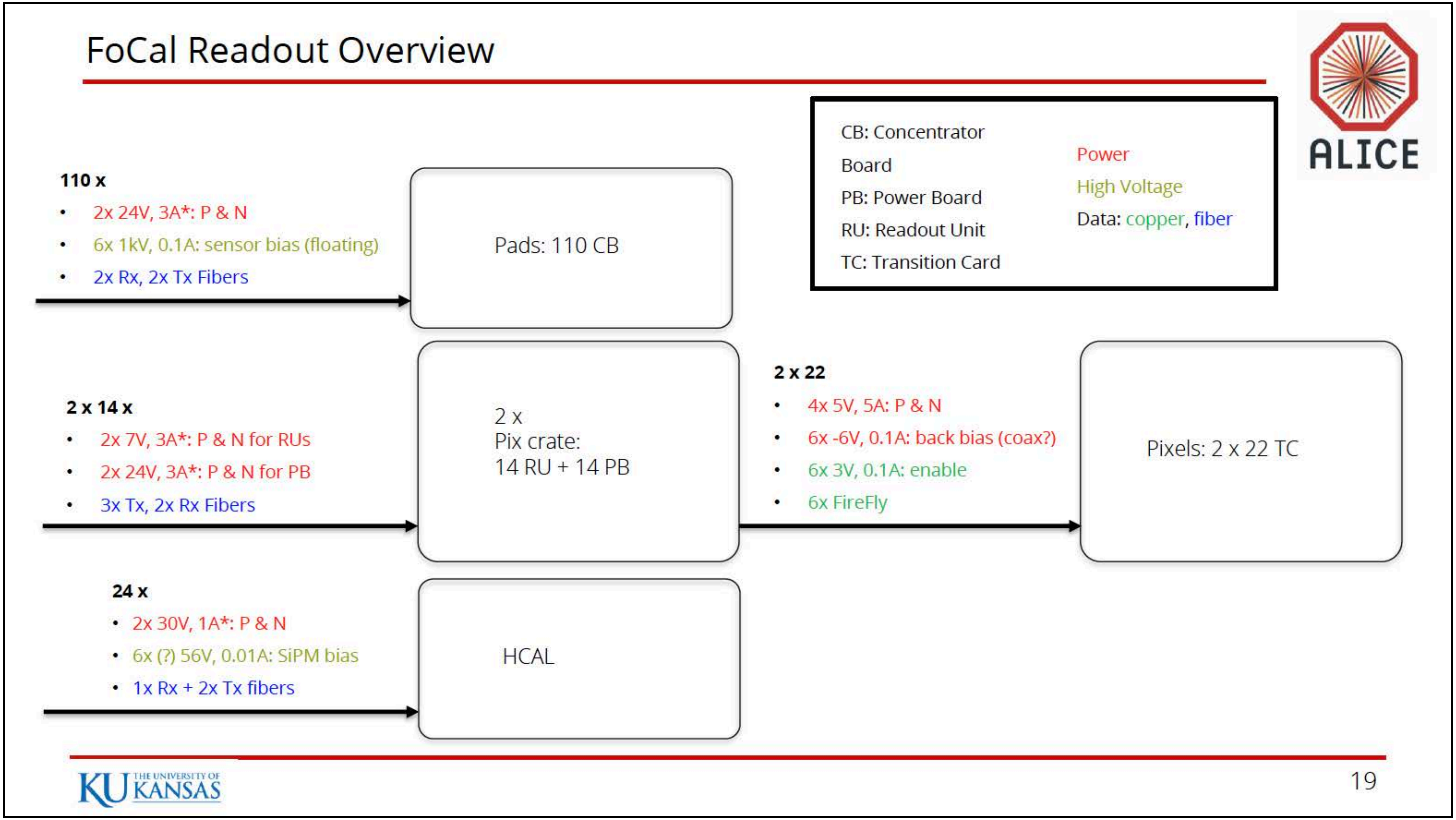


Performance of different frameworks

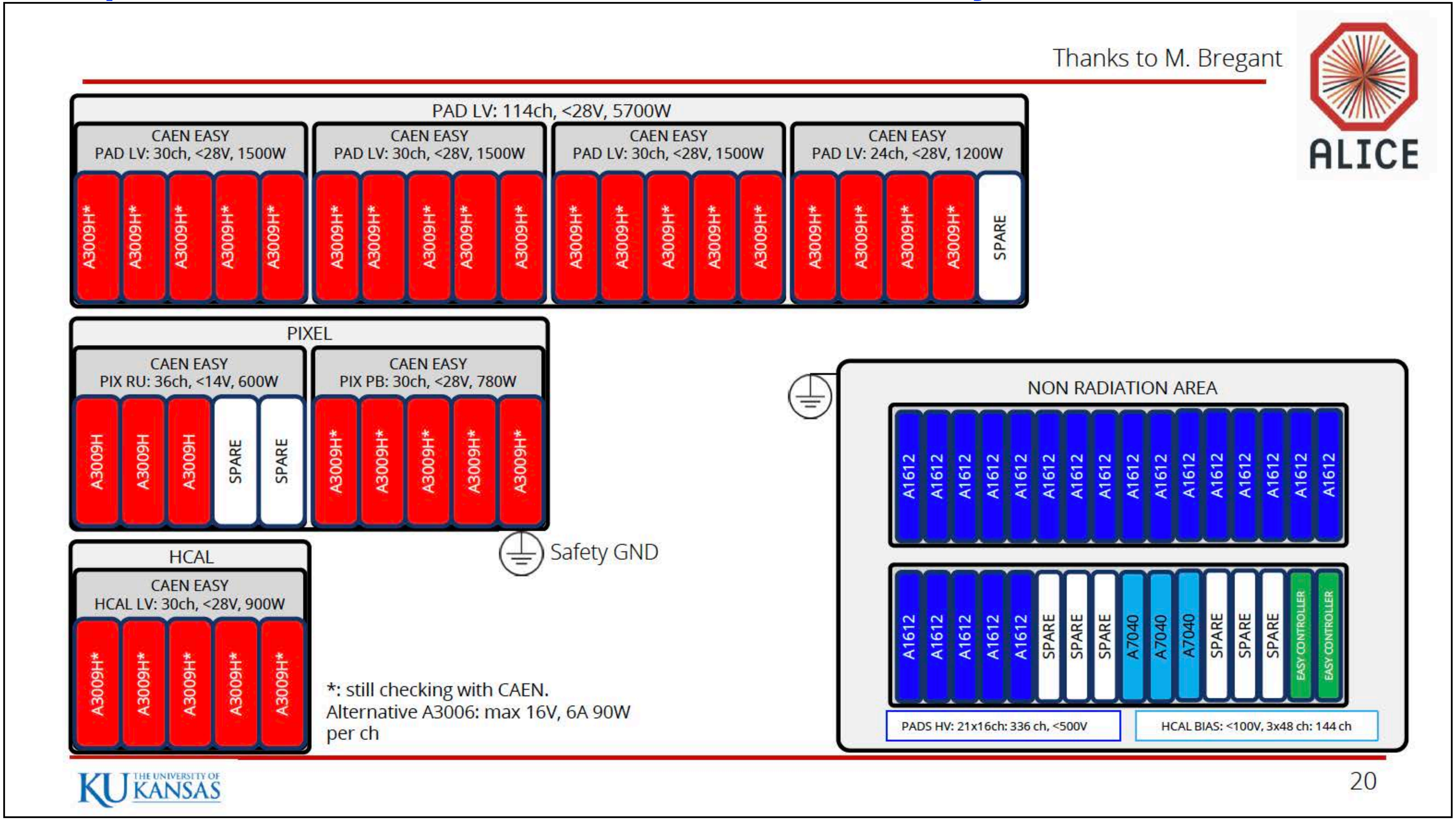
Model	Wasserstein	MAE	RMSE	Generation time [ms]
GEANT (original data)	0.53	16.41	59.87	–
Autoencoder	11.19	15.47	43.49	**0.015**
GAN	5.70	24.71	100.98	**0.023**
VQ-VAE	9.61	21.95	65.82	0.091
VQ-GAN	4.58	22.90	85.45	0.091
NF	**2.34**	16.48	69.59	160.0
Diffusion	**3.15**	20.10	73.58	5.360

4) Readout

Clear picture of readout scheme for all three subsystems and connections



Clear picture of readout scheme for all three subsystems and connections



FoCal trigger discussion

FoCal Trigger

The bottom line:

Pads and HCAL need a trigger, no problem with latency, max rate ~1 MHz

Pixels don't need a trigger (continuous mode) but using a trigger is possible to reduce occupancy (and indirectly pileup).

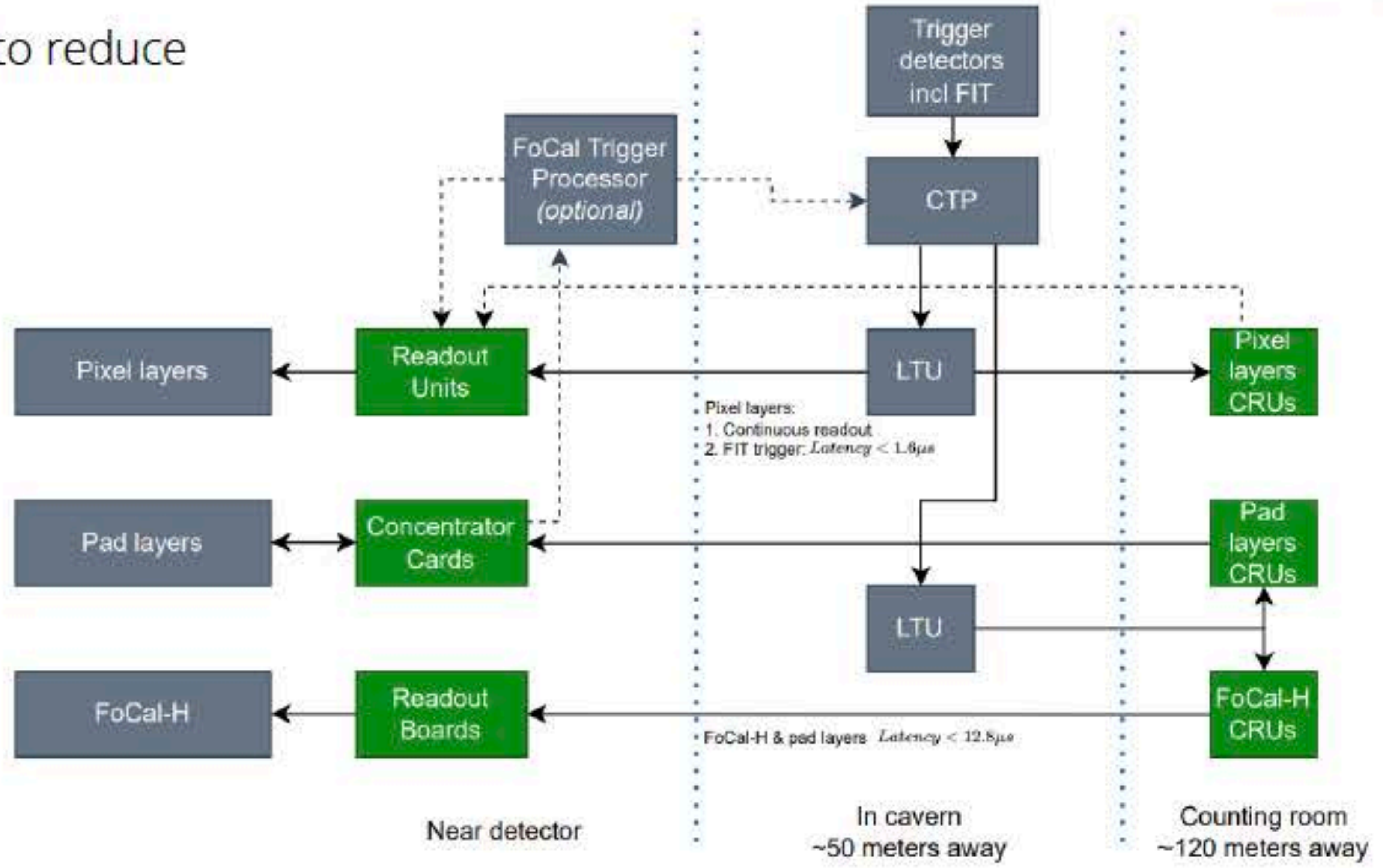
Problem: max trigger latency 1 us

Possible configurations:

- ALICE Trigger:
  CTP → LTU → CRU → RU → ALPIDE   too long?
- ALICE "fast" Trigger:
  CTP → LTU → ~~CRU →~~ RU → ALPIDE   still too long?

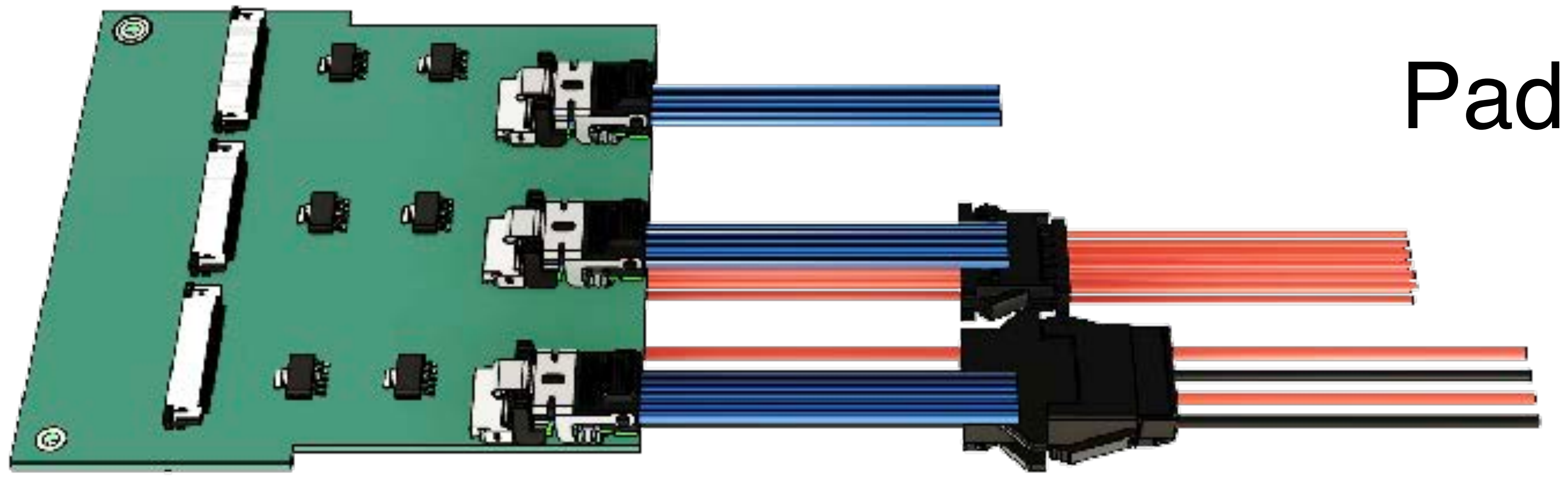
- FoCal LOCAL Trigger:
  PADs → FTP → RU → ALPIDE
- FoCal REGIONAL Trigger:
  PADs → FTP → RU → ALPIDE
- FoCal HYBRID Trigger:
  PADs → FTP → RU → ALPIDE

It requires a Focal Trigger Processor (FTP)

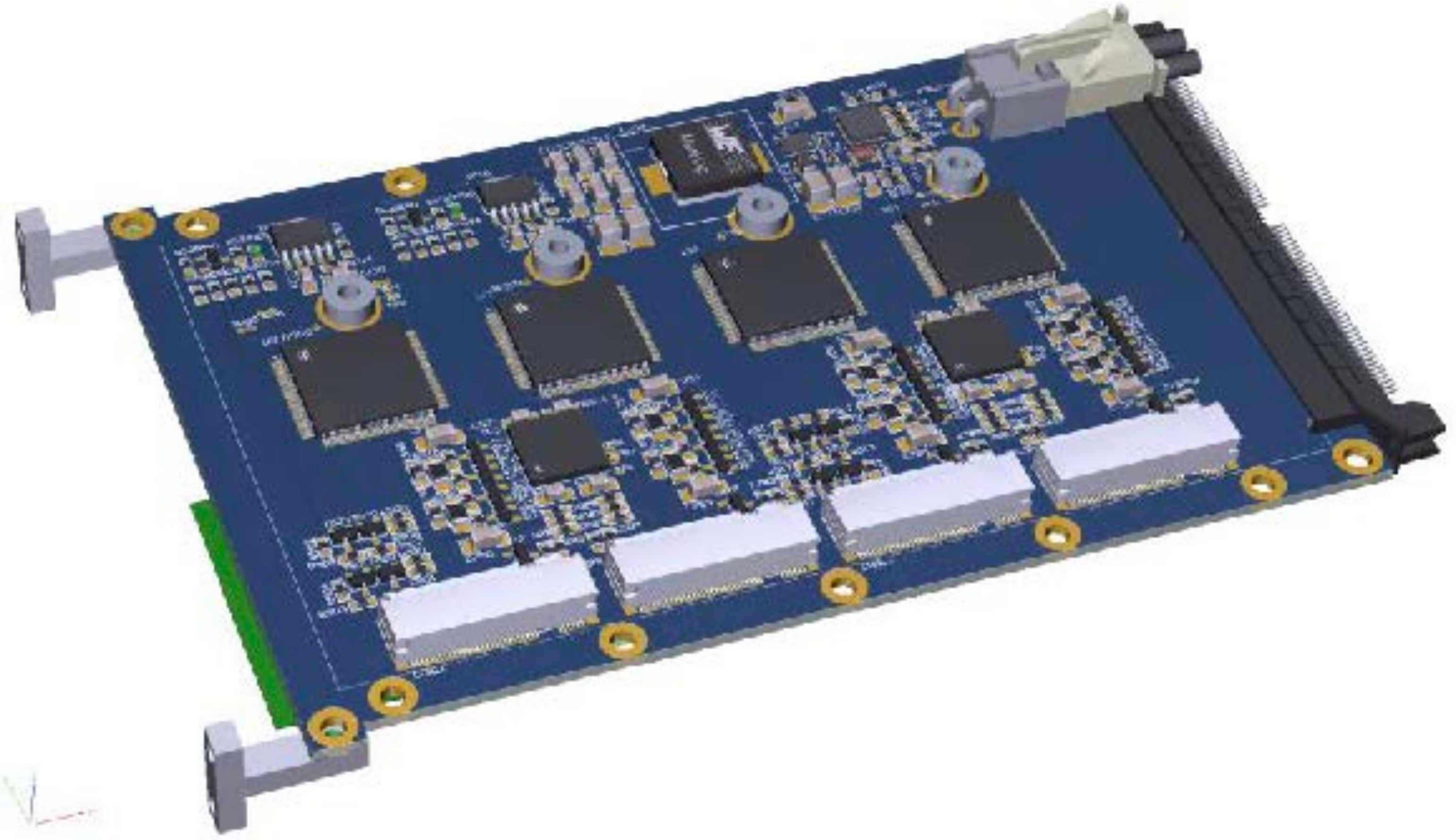


Pixels: Production Test Box

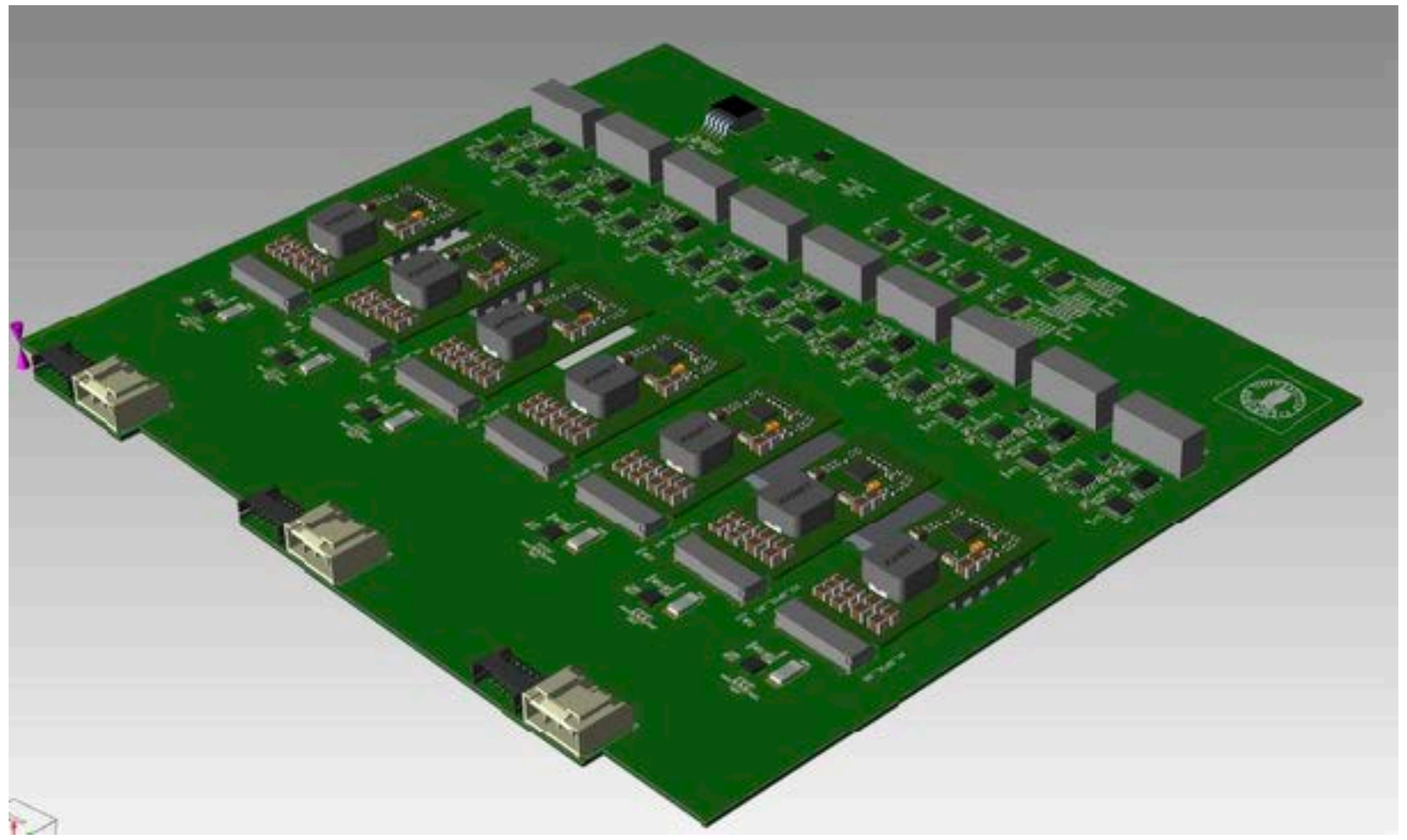
Pixels: Transition Card



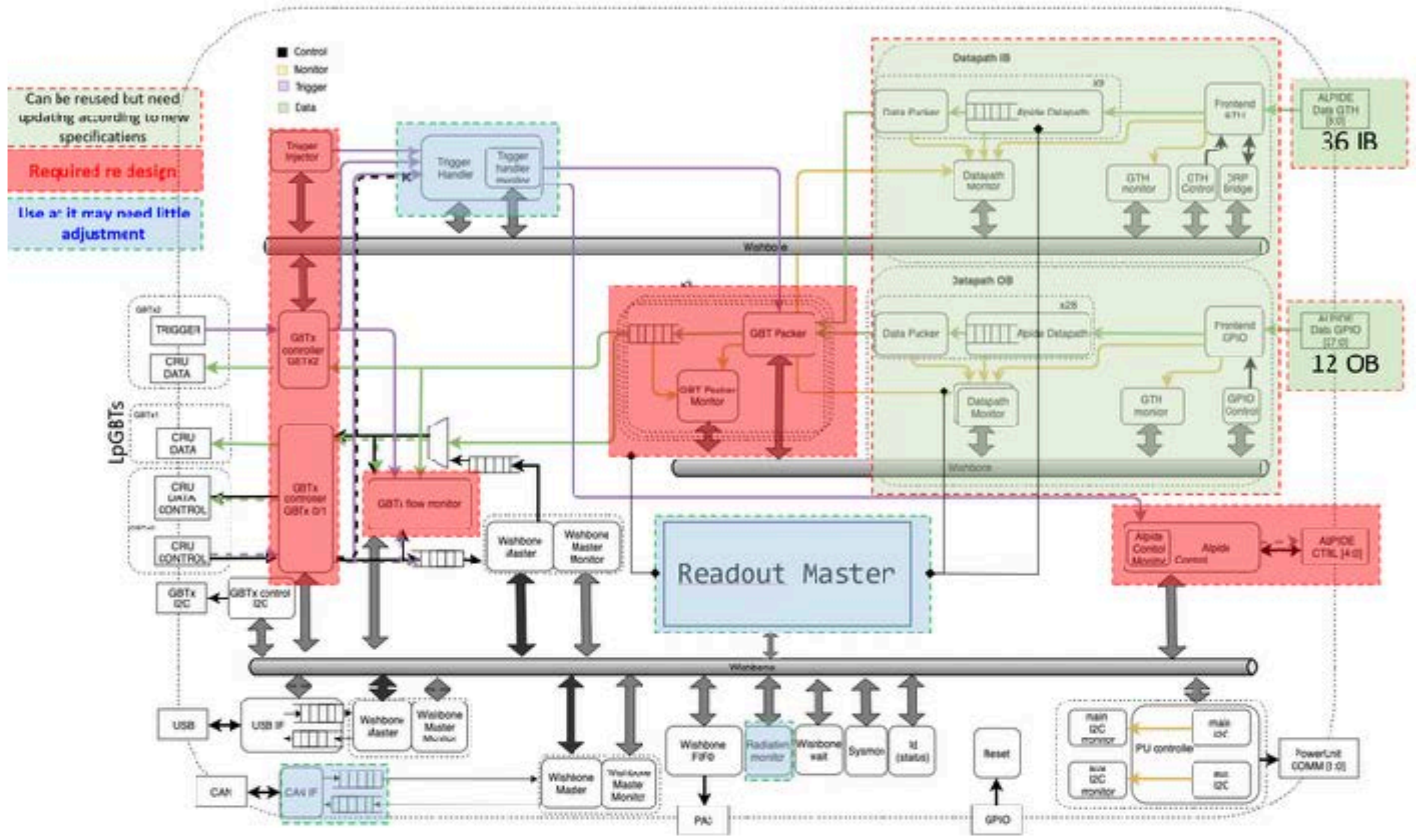
Pad: Data Concentrator Board



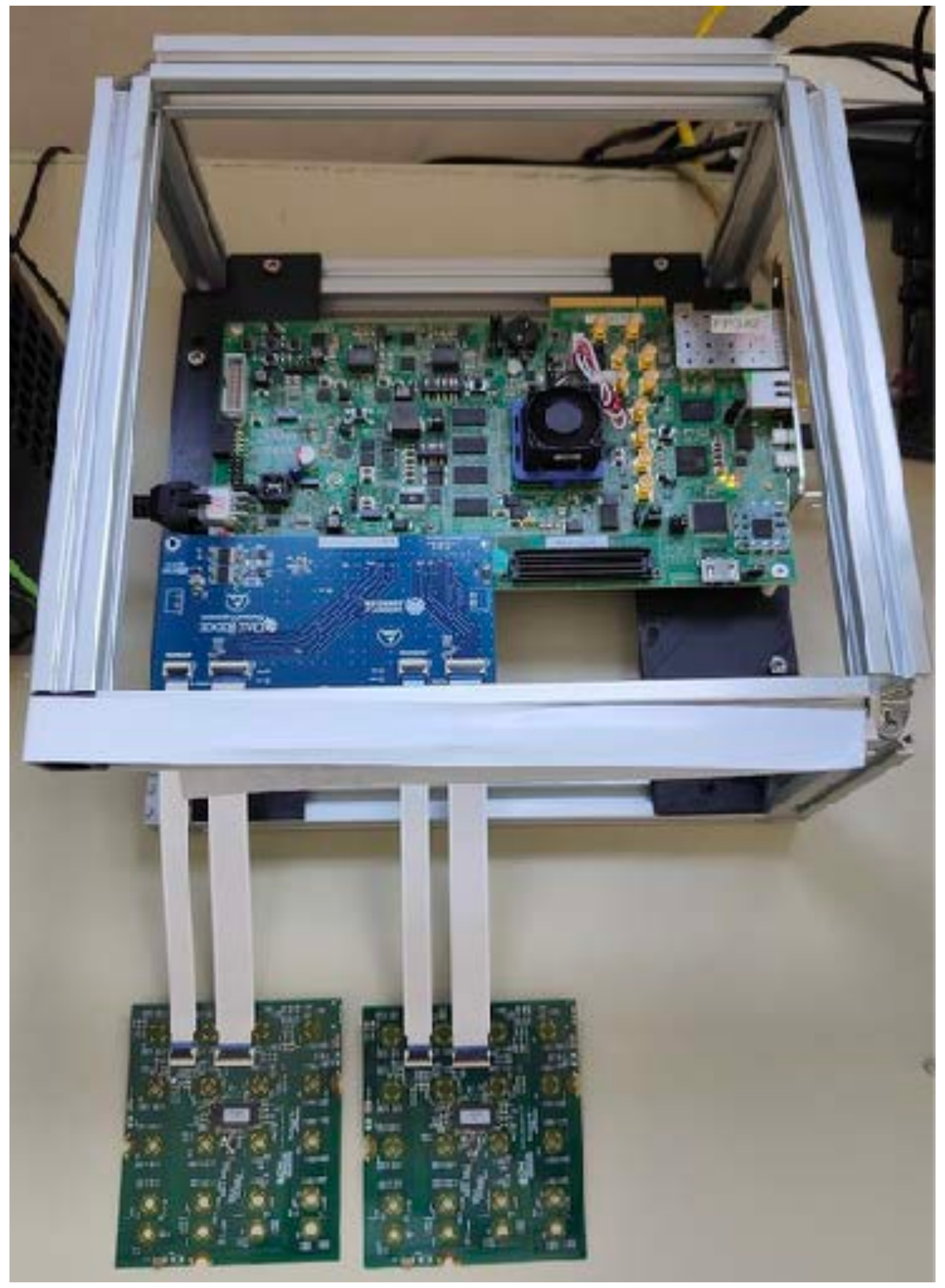
Pixels: Power board



Pixels: Readout Unit Firmware



Pad: Front-end

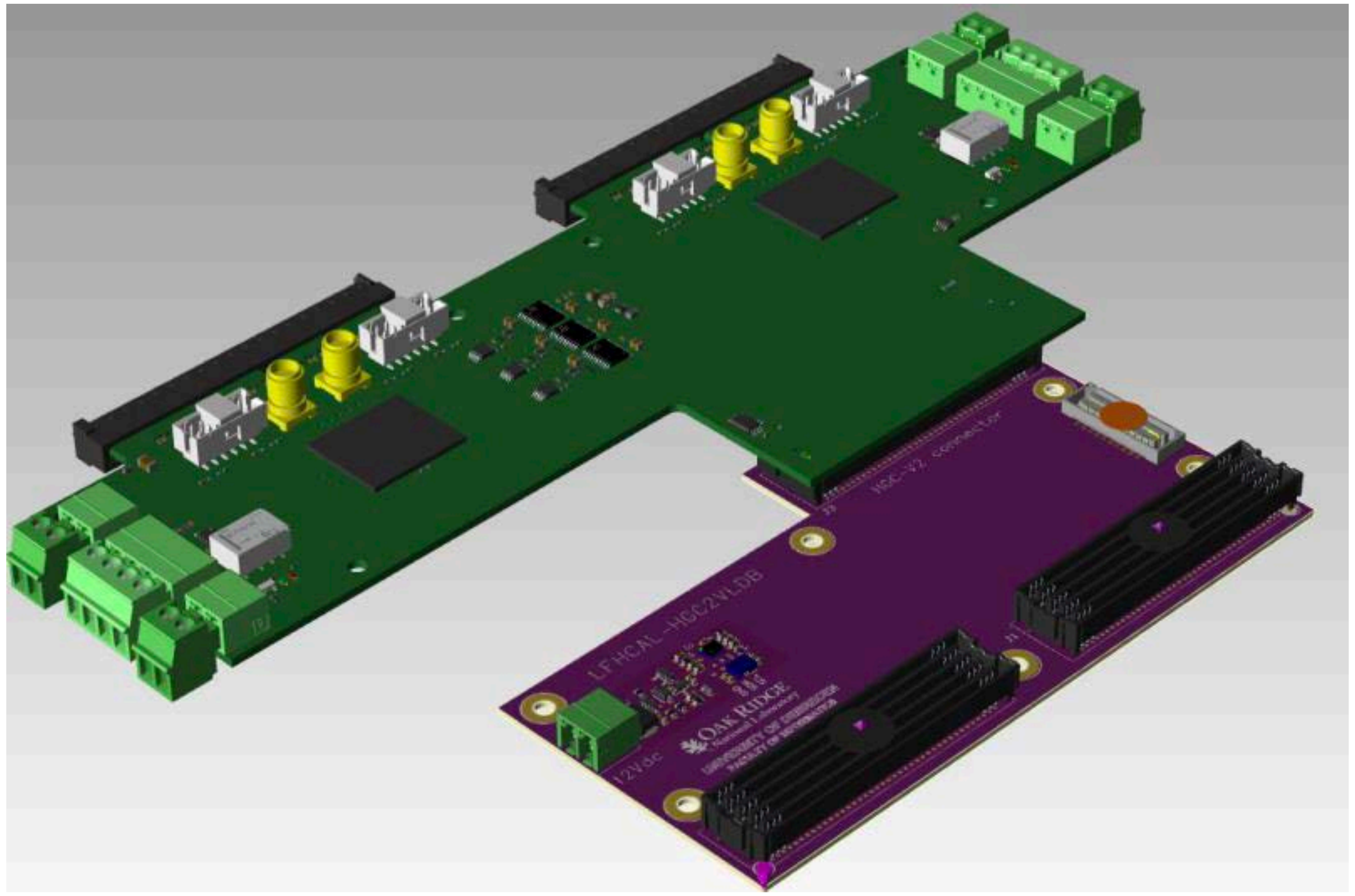


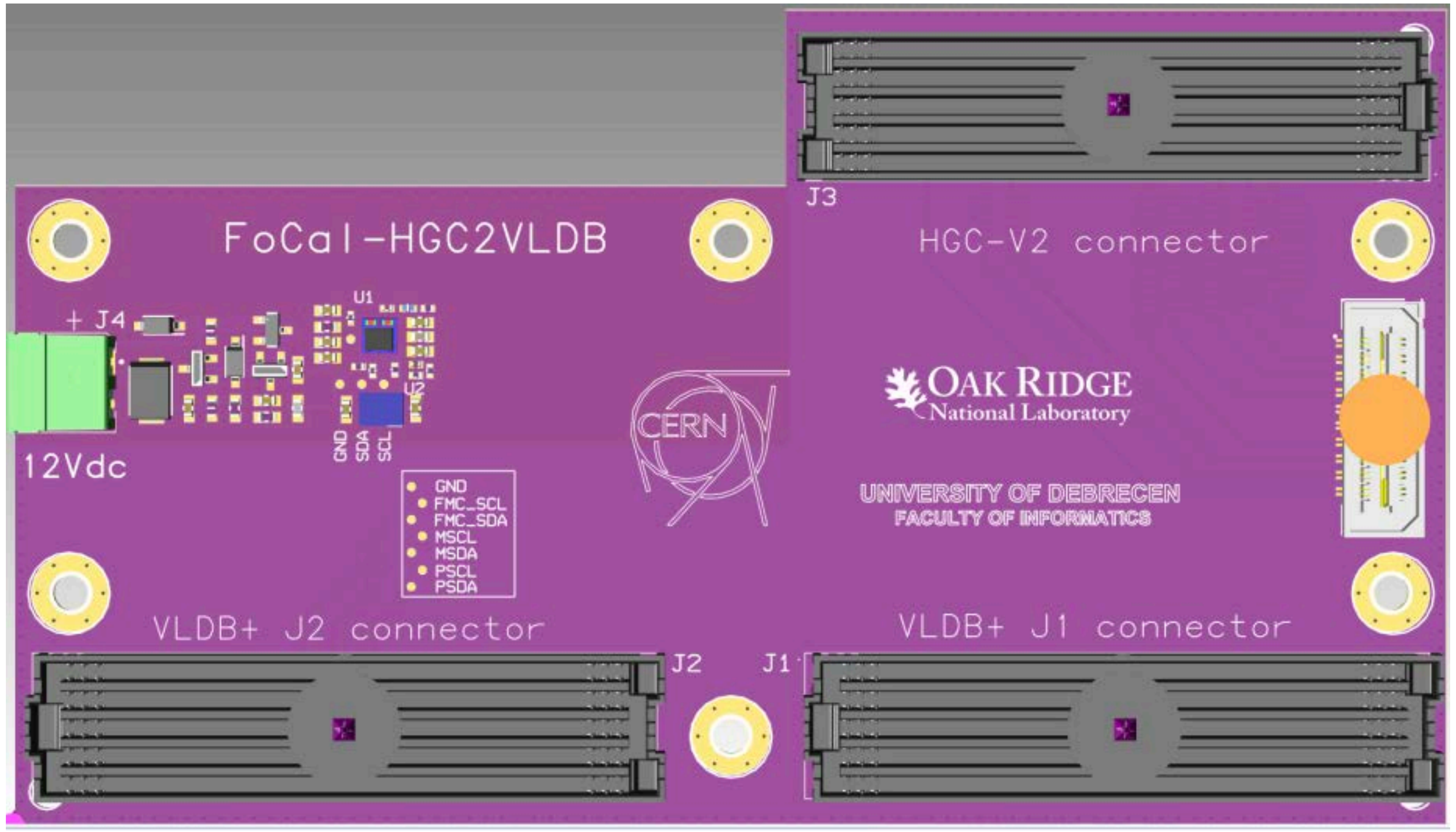
Many project are ongoing towards finalization!

HCal Readout

-Intermediate testing with a KCU or other FPGA board

-Looking forward to test with the CRU LpGBT firmware





Many project are ongoing towards finalization!

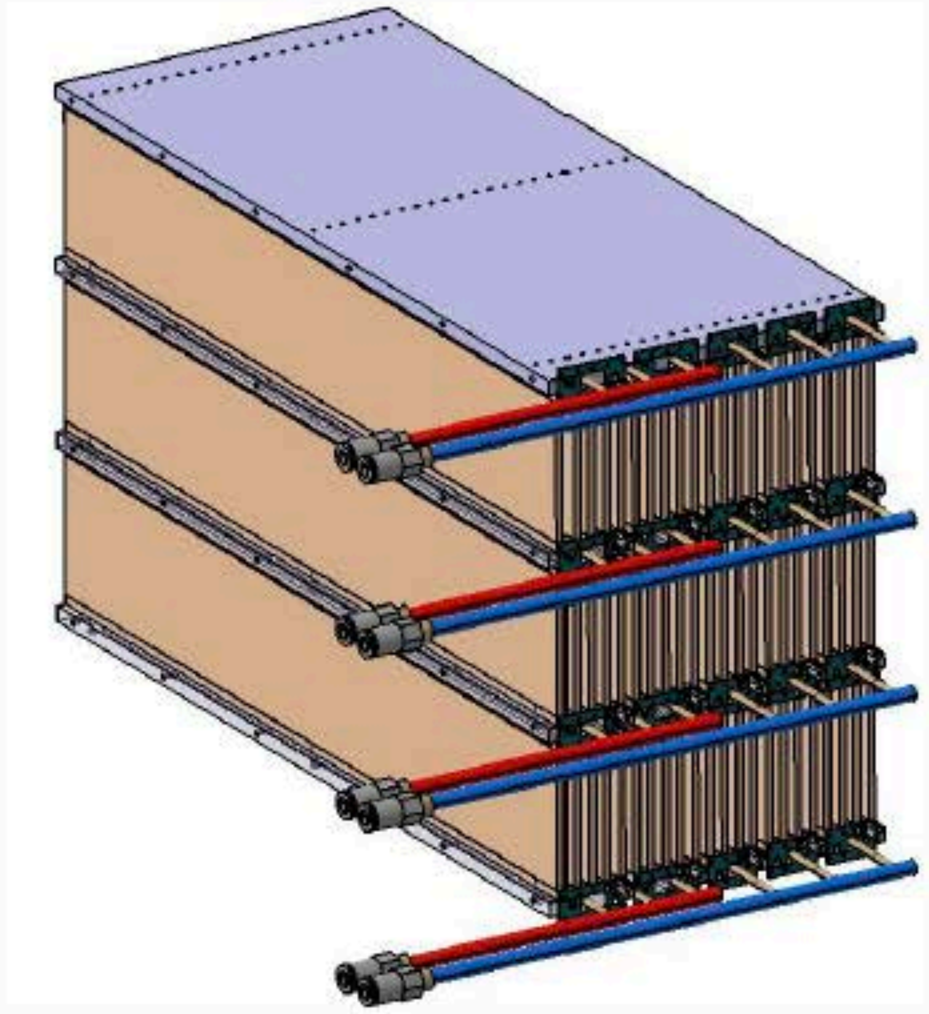
5) Mechanics and cooling

Cooling system simulation and analytical calculation

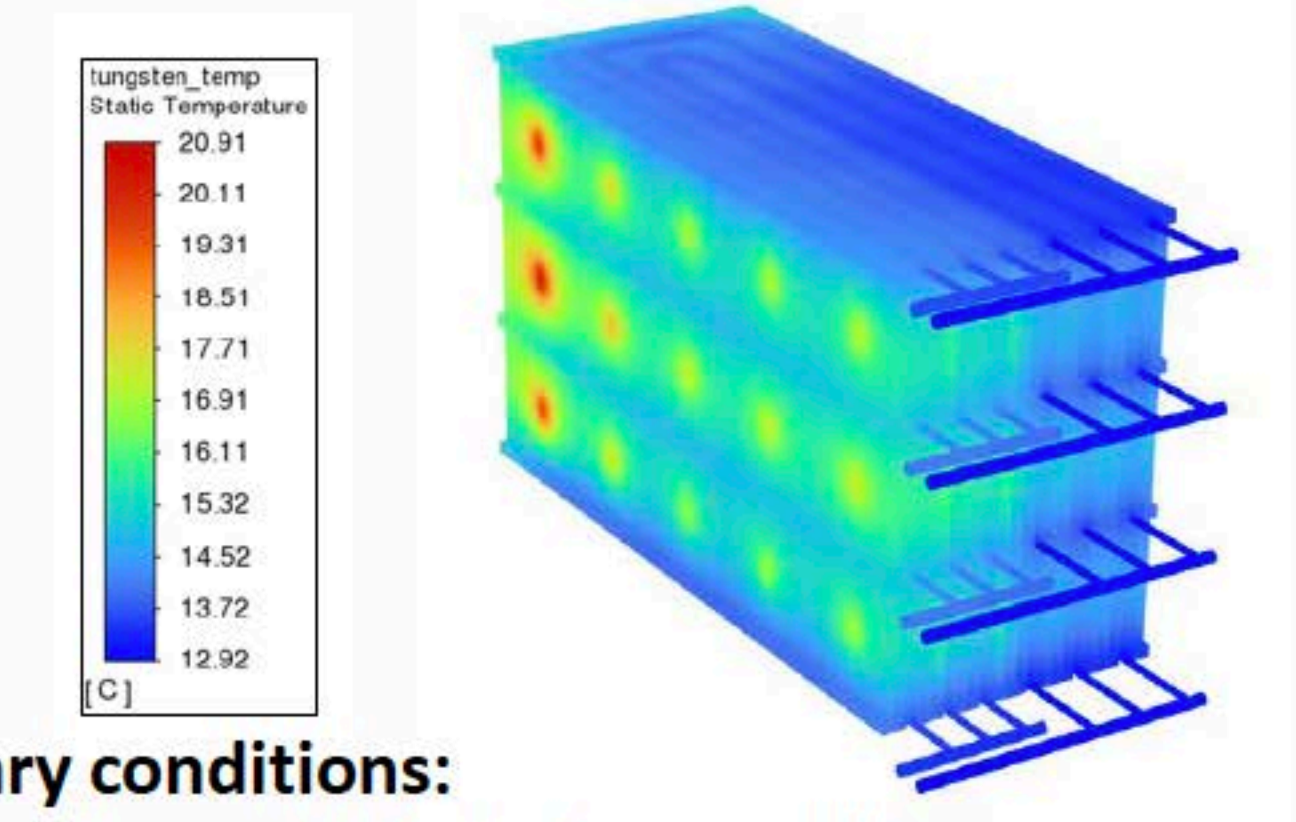
THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

FOCAL - E
MODEL AND TEMPERATURE SIMULATION FOR PROTOYPE

Focal-E: result of numerical ANSYS analysis



Focal-E: Prototype model



Boundary conditions:

- Water flow of 4 l/min for one HE
- Inlet water temeprature 12 °C
- Free Convection (air temeprature 20°C)

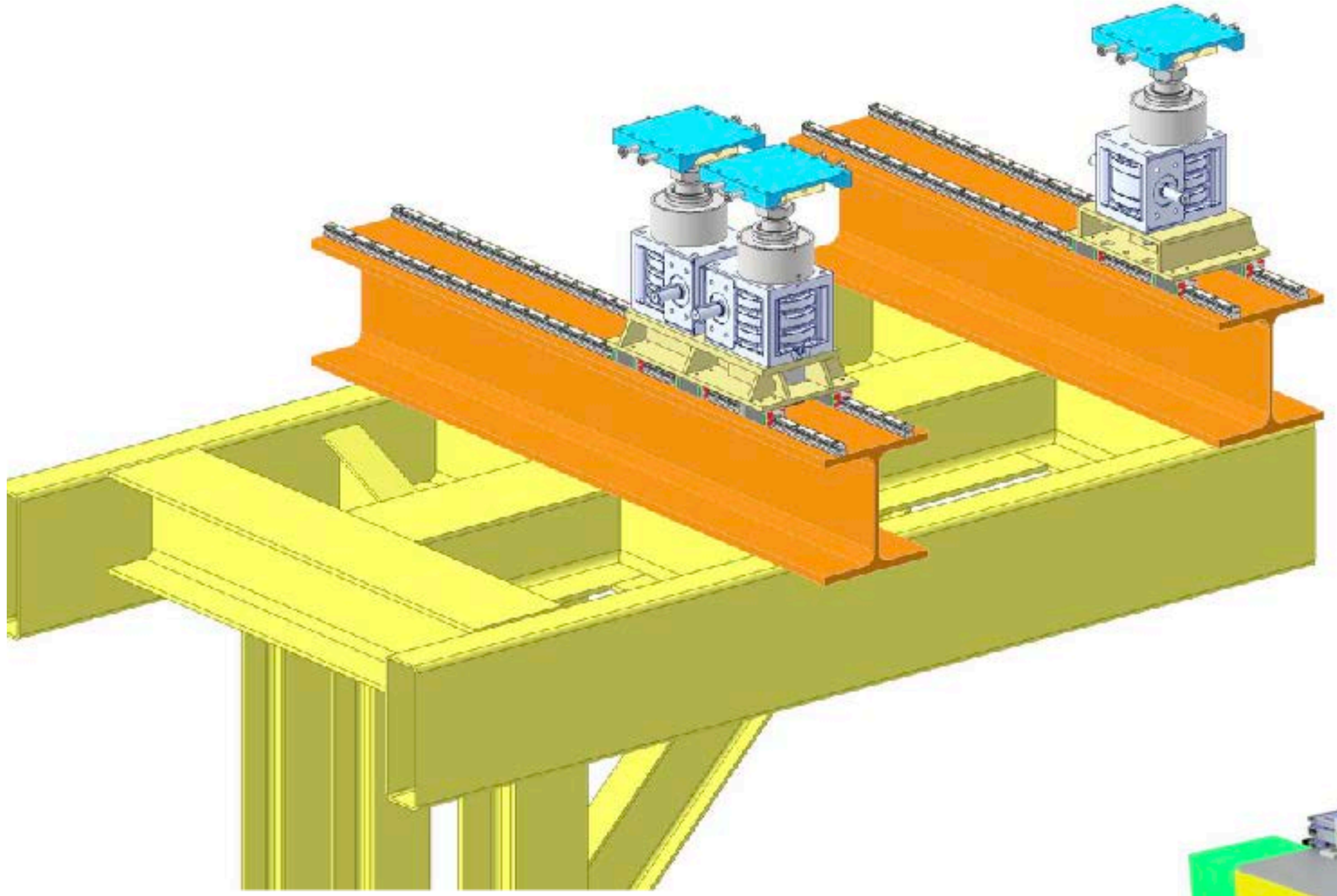
Heat value to remove (assumption)

- Plate with HGCROC: 12,5 W
- Plate with Pixel layer: 18 W

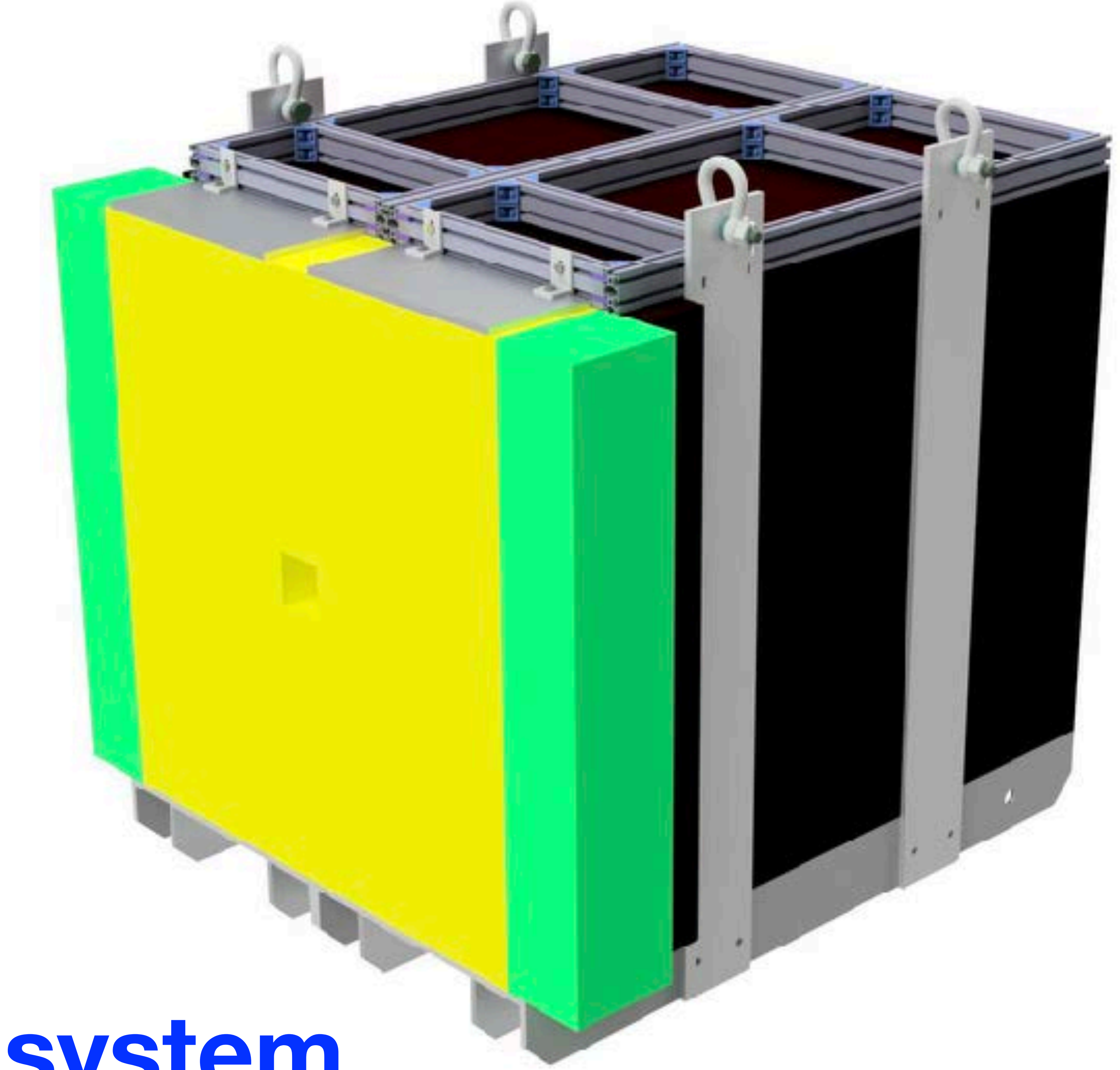
6

Cooling prototype (Al)

New FoCal platform



FoCal position system



FoCal lifting system

Summary and outlook

- FoCal TDR has been approved in March 2024
- Moving towards the construction for Run-4 physics data taking
- Three subsystems (PIXEL, PAD, HCal), readout and mechanics/cooling groups are working coherently towards the common goal
- Please join the FoCal group and let's work together!
- Service tasks on FoCal will be opened soon