AIDAinnova and FCC

P. Giacomelli

INFN Bologna

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101004761.

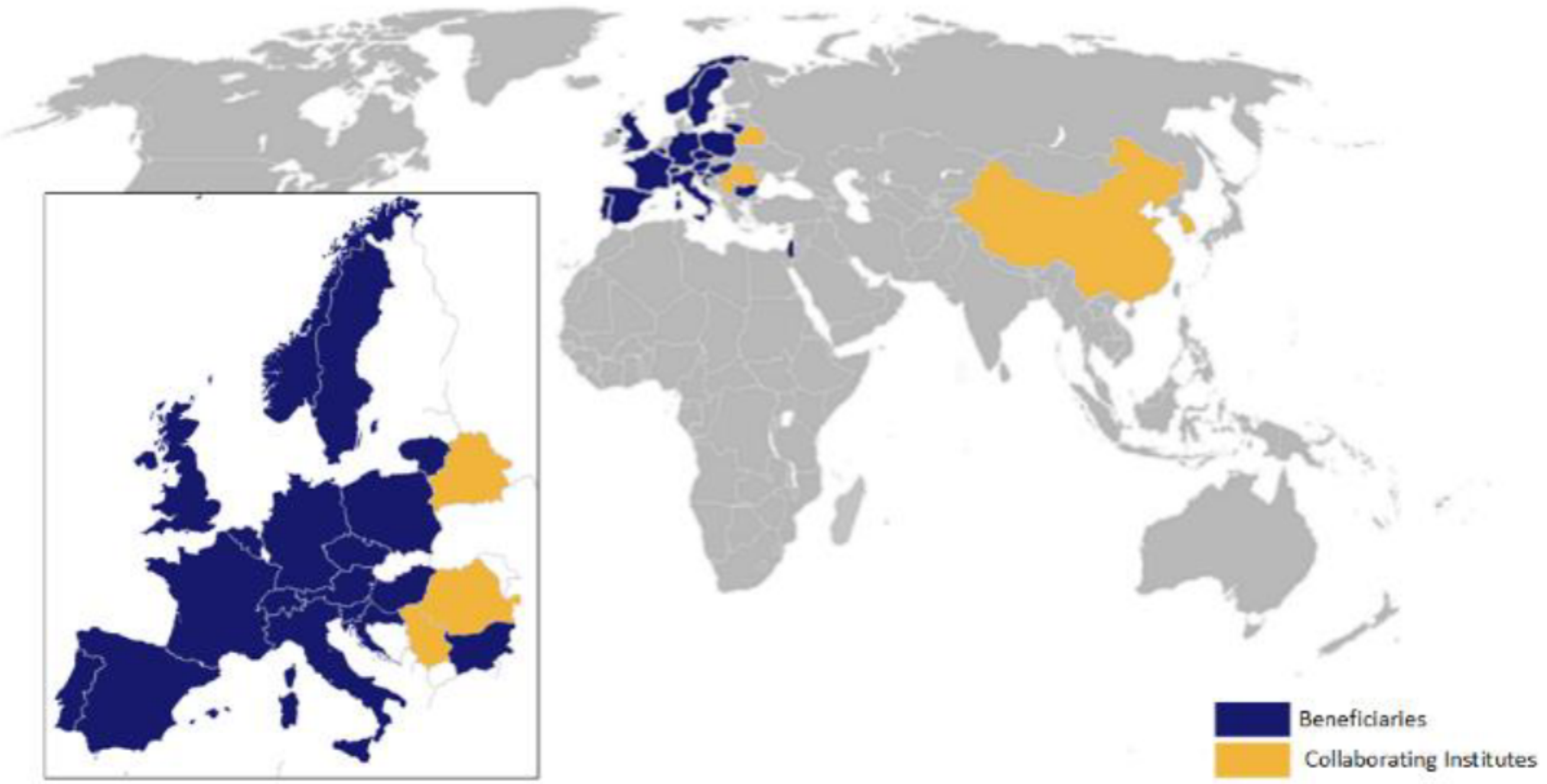
AIDAinnova

- Collaborative framework
- Infrastructure: common interest

- ~20 countries
- 45 beneficiaries
  - 34 academic + 11 industrial and RTOs
  - + 10 associated partners
- Coordinated by CERN

- Total budget **~26 M€**
- EC contribution **10.0 M€**

- Activities:
  - Joint Research & Networks



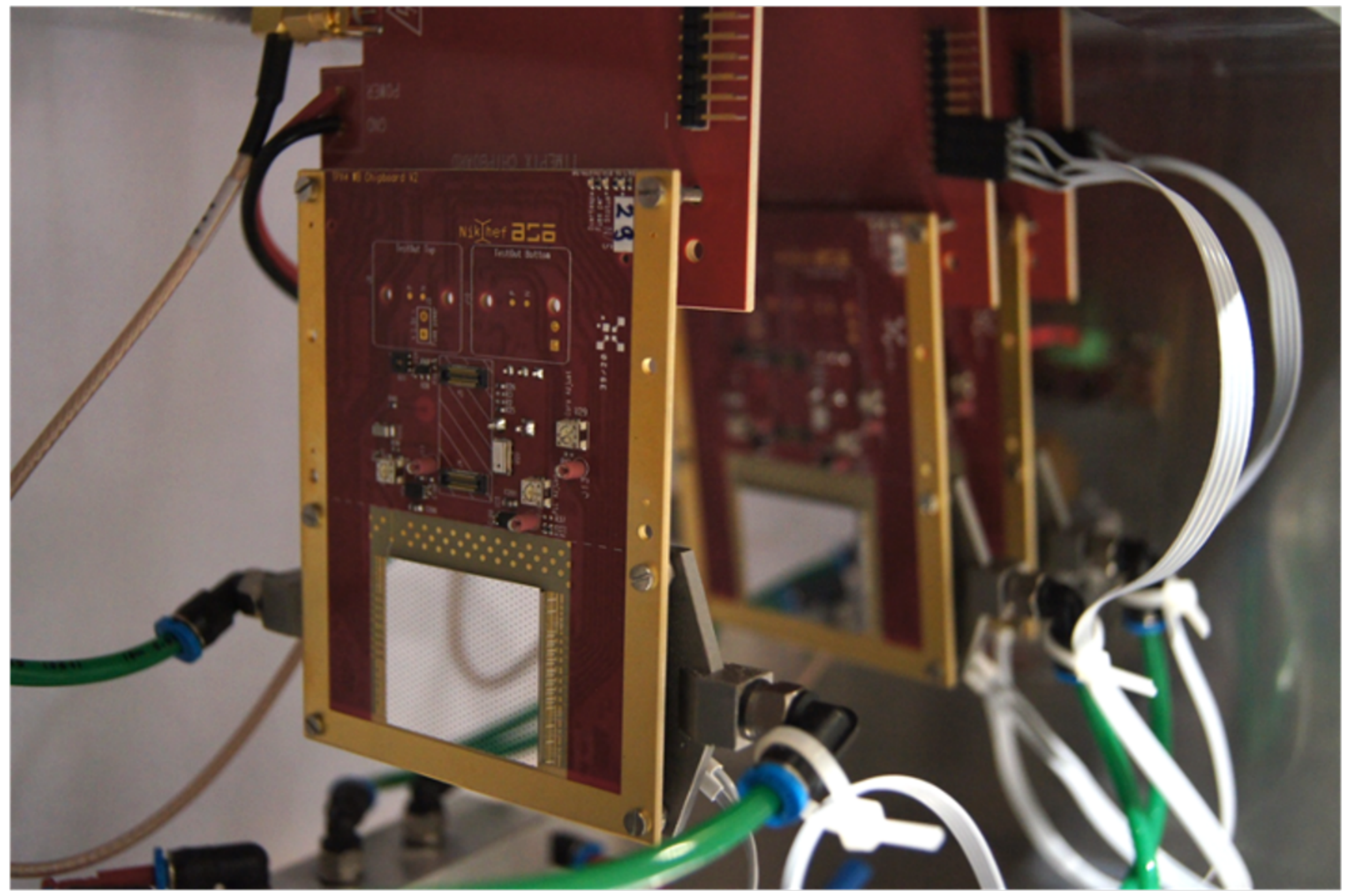
Participants bring in complementary competences and a balanced coverage of projects.

AIDAinnova structure

- **13 Work Packages (WPs)**
  - **2 Administration WPs**
  - **10 Scientific WPs**
  - **1 “Blue-sky” WP**
- **2 coordinators/WP**

WP1	Project management and coordination	Felix Sefkow (DESY) Svetlomir Stavrev (CERN)
WP2	Communication, Outreach and Knowledge Transfer	Antoine Le Gall (CERN) Margherita Marini (CERN)
WP3	Test beam and DAQ infrastructure	Marcel Stanitzki (DESY) Matthew Wing (UCL)
WP4	Upgrade of Irradiation and Characterization Facilities	Federico Ravotti (CERN) Fernando Arteche (ITAINNOVA)
WP5	Depleted Monolithic Active Pixel Sensors	Sebastian Grinstein (IFAE) David-Leon Pohl (UBONN)
WP6	Hybrid pixels sensors for 4D Tracking and Interconnection Technologies	Anna Macchiolo (UZH) Claudia Gemme (INFN)
WP7	Gaseous detectors	Silvia Dalla Torre (INFN) Burkhard Schmidt (CERN)
WP8	Calorimeters and Particle Identification detectors	Katja Krüger (DESY) Roman Pöschl (CNRS) Roberto Ferrari (INFN)
WP9	Cryogenic neutrino detectors	Dario Autiero (CNRS) Andrzej Michal Szelc (UNIMAN)
WP10	Advanced mechanics for tracking and vertex detectors	Paolo Petagna (CERN) Marcel Vos (CSIC)
WP11	Microelectronics	Christophe De La Taille (CNRS) Angelo Rivetti (INFN)
WP12	Software for Future Detectors	Frank-Dieter Gaede (DESY) Graeme Andrew Stewart (CERN)
WP13	Prospective and Technology-driven Detector R&D	Peter Krizan (JSI)
WP14	Ethics requirements	Felix Sefkow (DESY) Svetlomir Stavrev (CERN)

Highlights of WP3: test beam and DAQ



- Mass production of 30 TLUs at DESY.
- Many lessons learnt on prototype to production process
- Delivered to users.
- Now working pn picosecond TLU.

Beam test of Timepix4 sensors:

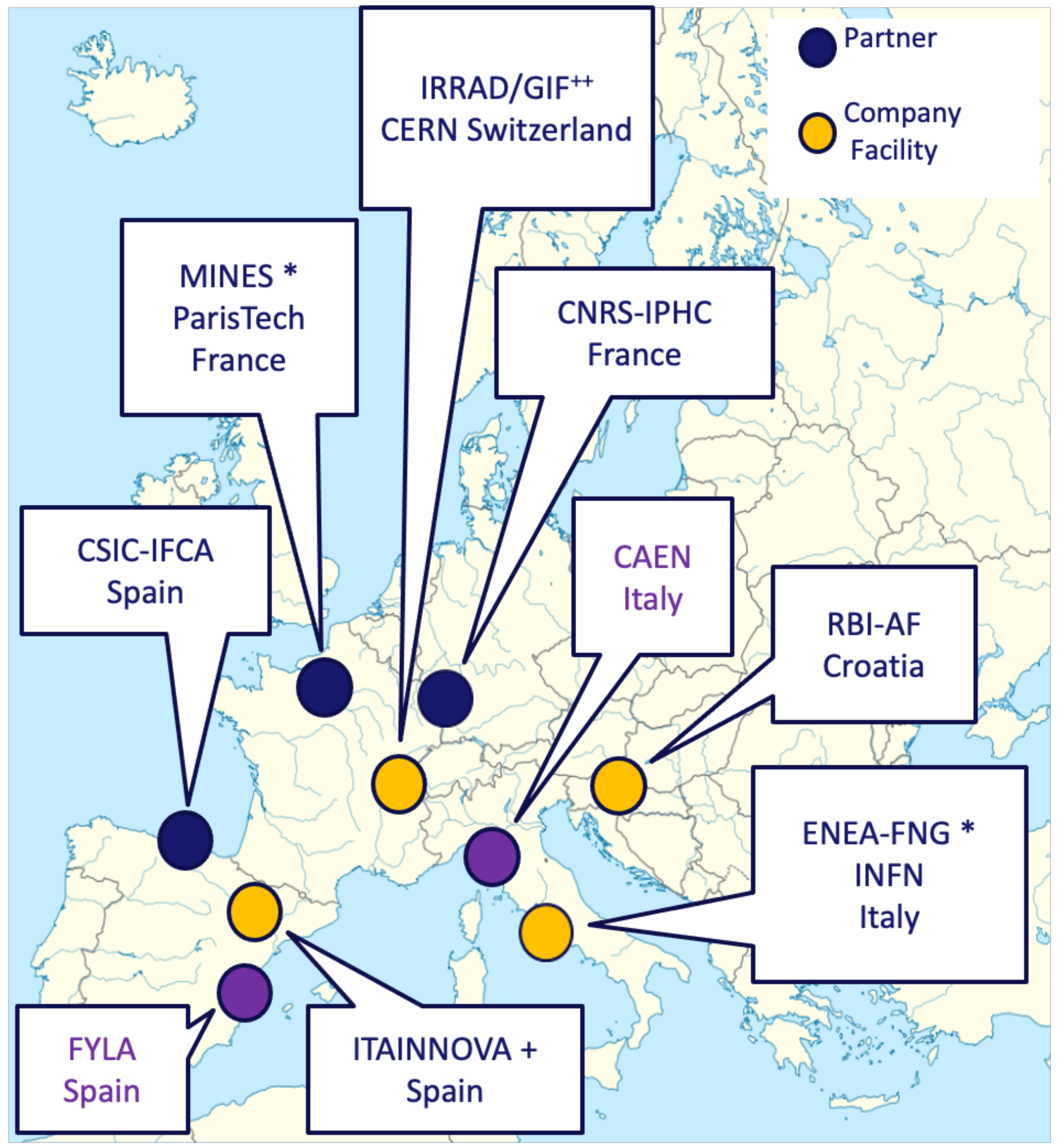
- Test DAQ.
- Test plane-to-plane synchronisation.
- Gain experience with Timepix4.

- Common readout board for silicon detector testing developed.
- VMM3 board for gas detectors also making good progress.

- Also telescopes are working well and upgrades planned.
- EUDAQ2 software upgraded to picosecond timing and monitoring being improved.

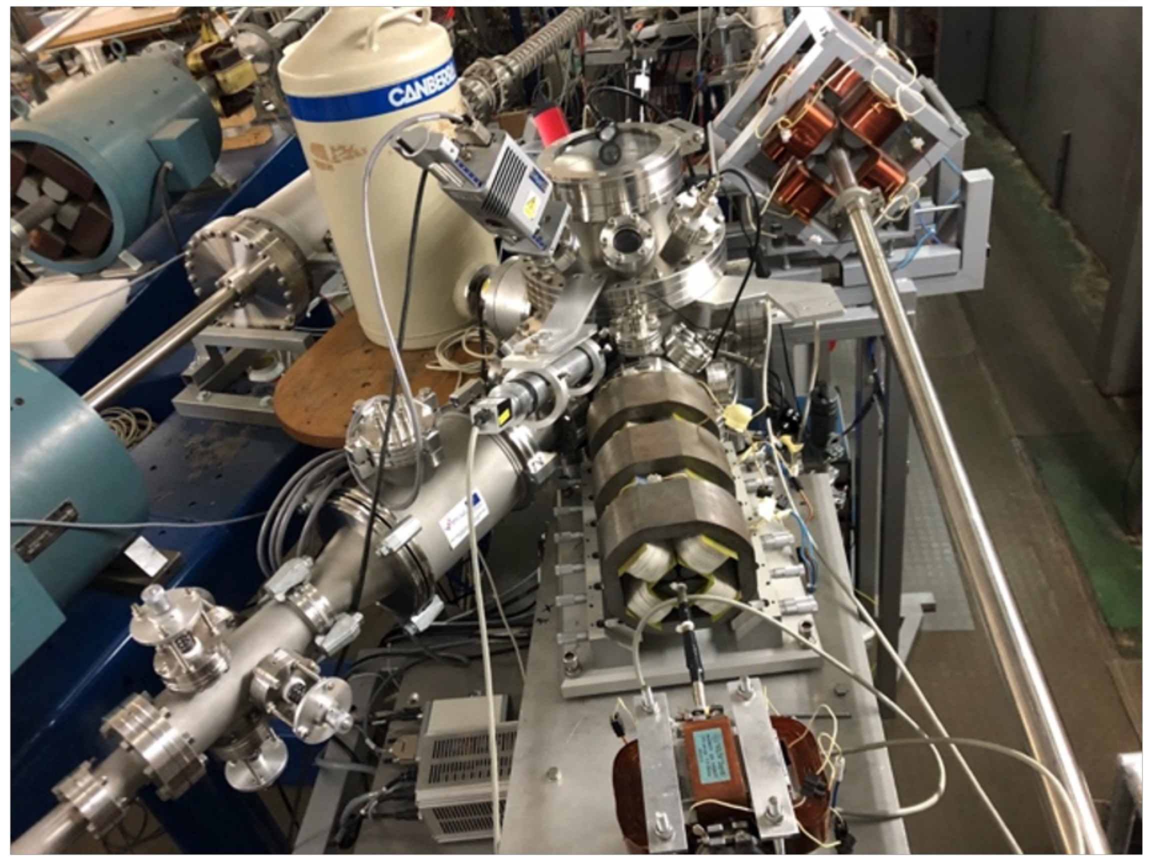
WP3 is well on track; good progress and expect upcoming milestones to be met.

WP4: irradiation/characterization facilities



New Ion microprobe at RBI

a) Sample vacuum chamber
b) Sample positioning system (inside the chamber)
a) Focusing triplet
b) Ion beam scanning system



New precise motorised sample positioning to allow to move/scan the sample

Related DAQ and control software upgrade

Sample cooling capability (Liquid nitrogen or cryo)

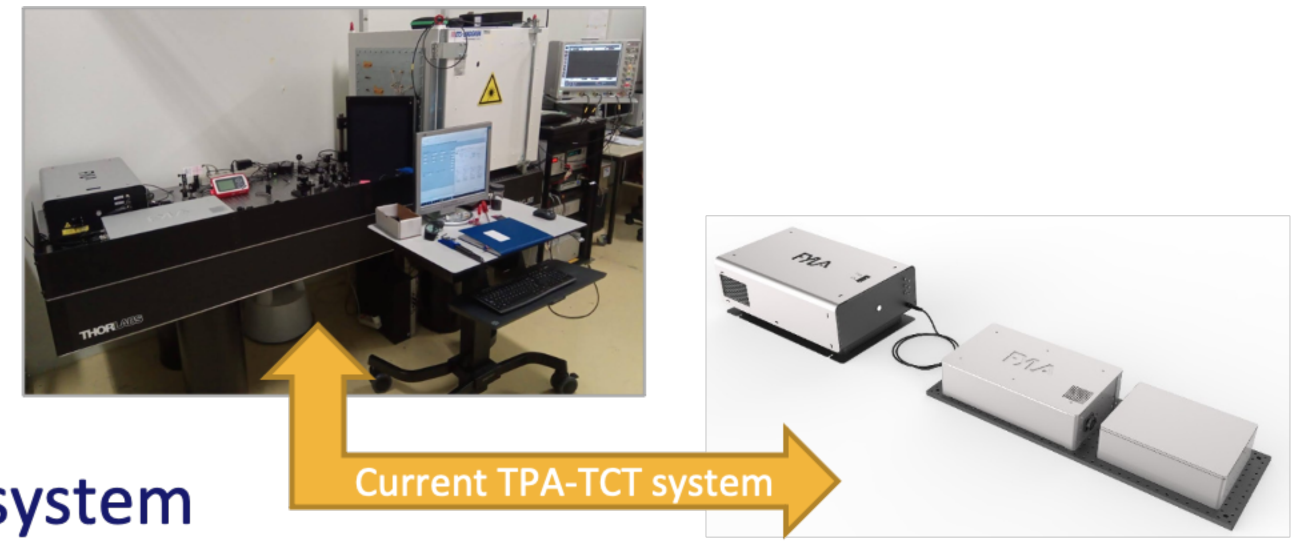
Tools for irrad facilities QC

Data manager for IRRAD interfaced with TREC and used also for other facilities

New functionalities for traceability

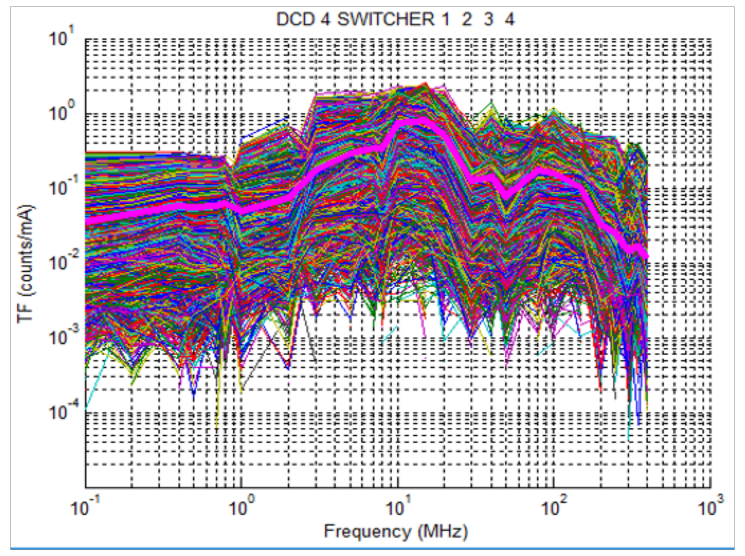
Dosimetry cross-comparison (corrections to NIEL)

Upgrade of TPA-TCT system design



Upgrade to an all-fiber system

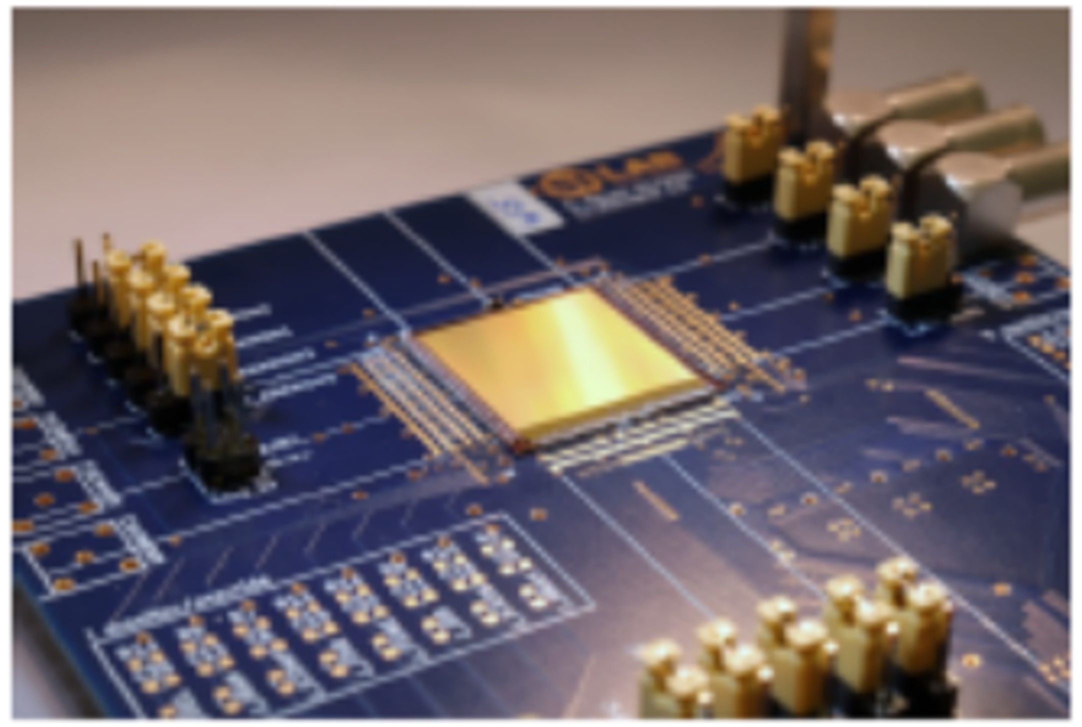
New characterization system for EMC control



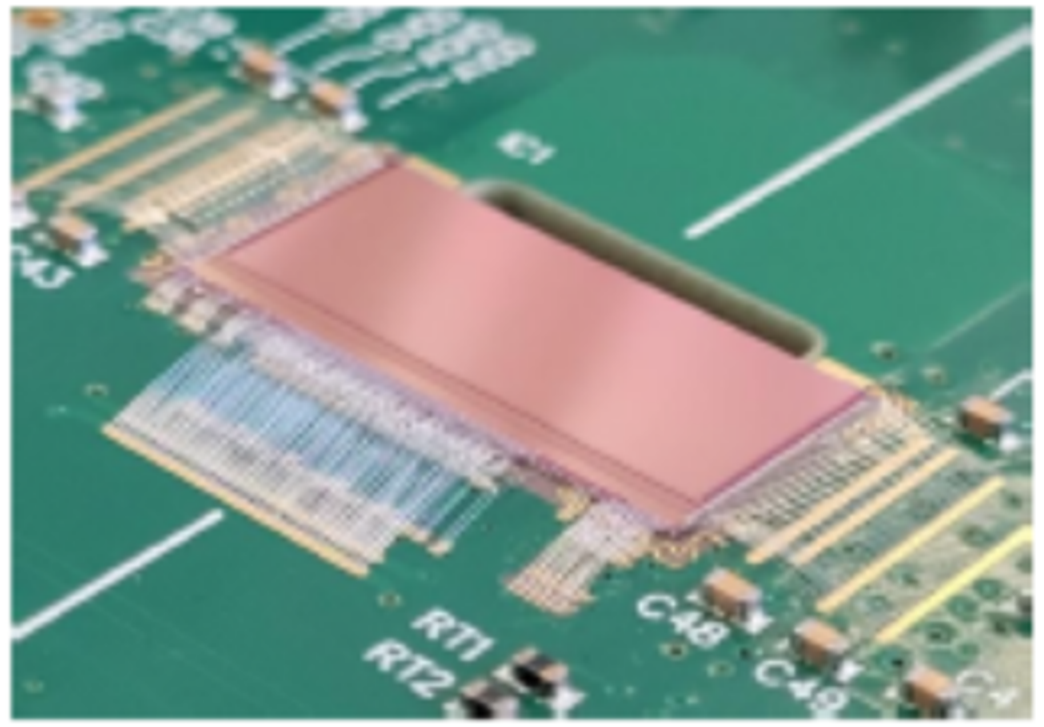
WP5 Depleted Monolithic Active Pixel Sensors

- Aim is to advance DMAPS, specially towards high granularity and radiation hardness
  - Also exploring timing resolution
- Link to deployment at experiment if possible
  - Example: of Belle II and ALICE upgrade

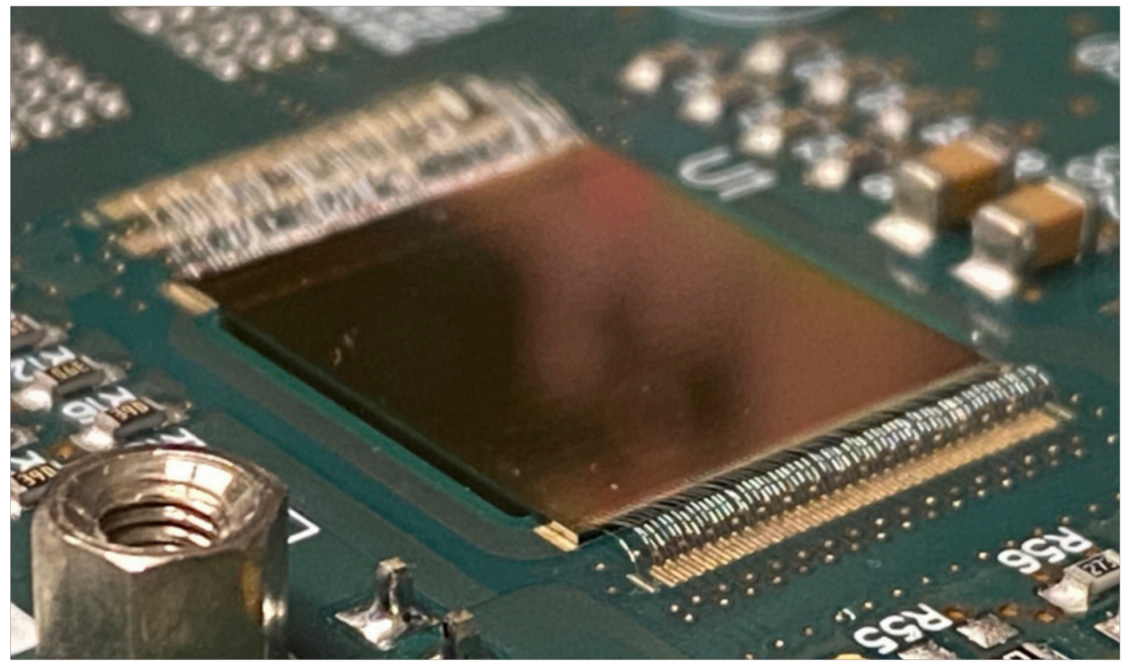
- First **milestone** reached:
  - Fabricated first batch of high granularity prototypes
- In fact, all activities produced first devices
  - Intense characterization effort starting



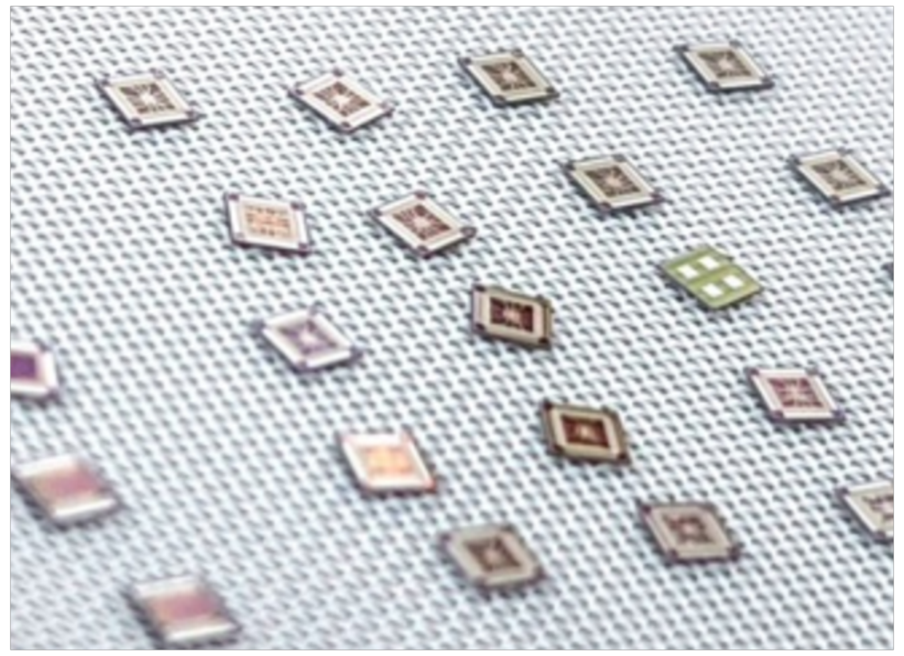
TJ Monopix 2:
2x2 cm^2 with 33x33 μm^2



MALTA 2: 2x1 cm^2
with 34.6x34.6 μm^2



ARCADIA MD1:
1.3x1.3 cm^2 with 25x25 μm^2



TPSCo 65 nm:
test structures

WP5 Depleted Monolithic Active Pixel Sensors

- Sensor spatial resolution
  - Key requirement for Higgs factories: $\sigma_{sp} \lesssim 3$ µm
  - ALICE-ITS3 ~5 µm, Belle II 5-10 µm

⇐ critical benefit of 65nm for task 5.2

- Detection layer with material budget: 0.05 to 0.15 % X_0
  - Achieved through large stitched & curved sensors
    - Key requirement for ALICE-ITS3, strong interest for Higgs factories
  - Low power <<100 mW/cm^2, compatible with air-cooling
    - Important for Higgs factories & ALICE-ITS3

⇐ possible with other techno BUT attractive in 65nm due to 12" wafer size

⇐ benefit of 65nm, critical for task 5.2

- Hit rate and time resolution (highly dependent on experiment)
  - Few 10 MHz/cm^2/s for Higgs-factories
  - > 100 MHz/cm^2/s for Belle II
  - Time resolution ~ns for CLIC
  - Specific for PID or 4D tracking: time resolution in 10-100ps range

⇐ benefit of 65nm, critical for task 5.3

- Radiation tolerance to NIEL fluence
  - Up to 10^{12} $n_{eq(1MeV)}$/cm^2 for task 5.2
  - Mimimum 10^{15} $n_{eq(1MeV)}$/cm^2 and beyond for task 5.3

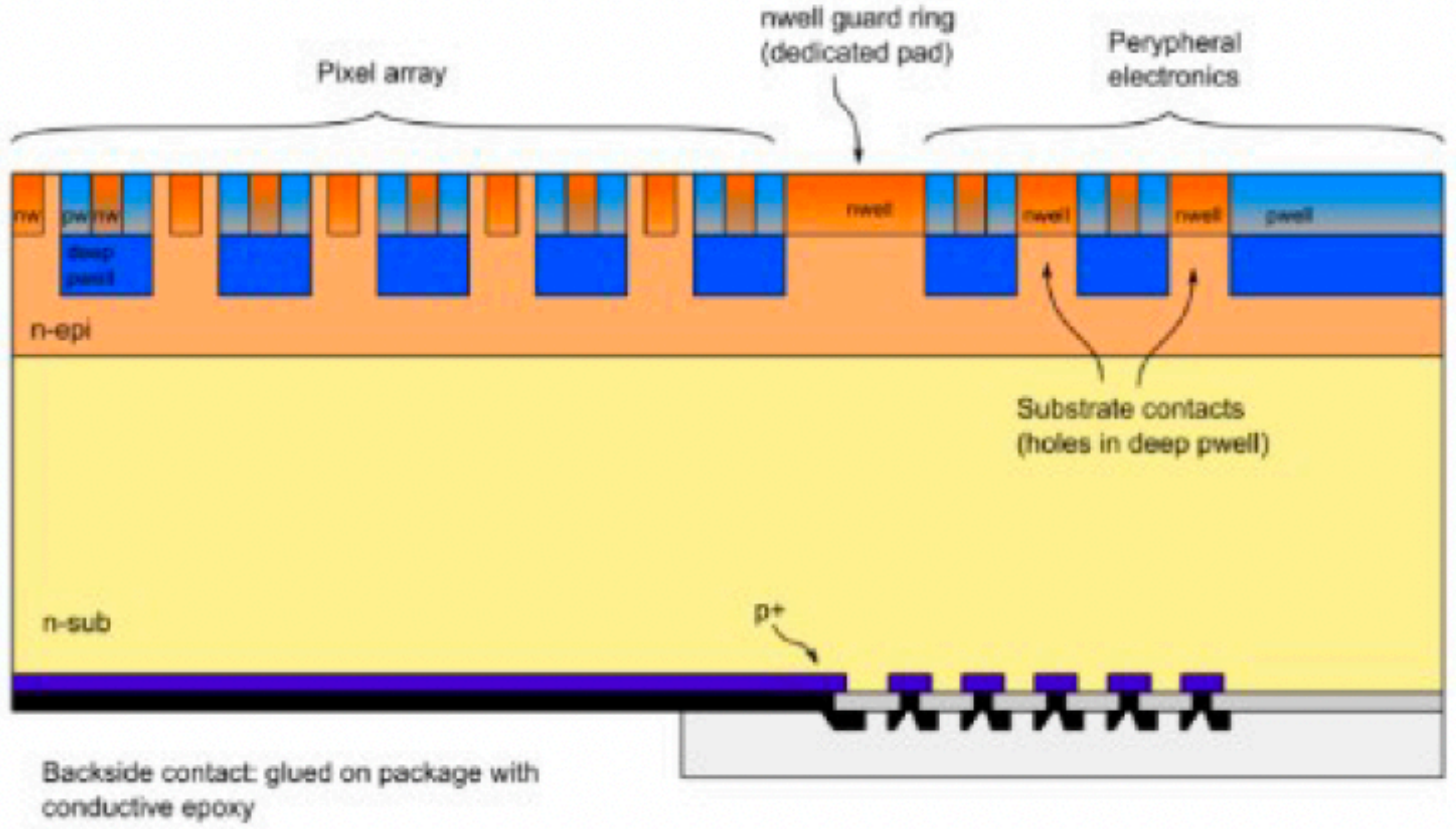
⇐ 65nm tolerance to be checked, critical for task 5.3

WP5 Depleted Monolithic Active Pixel Sensors

Advanced Readout CMOS Architectures with Depleted Integrated sensor Arrays

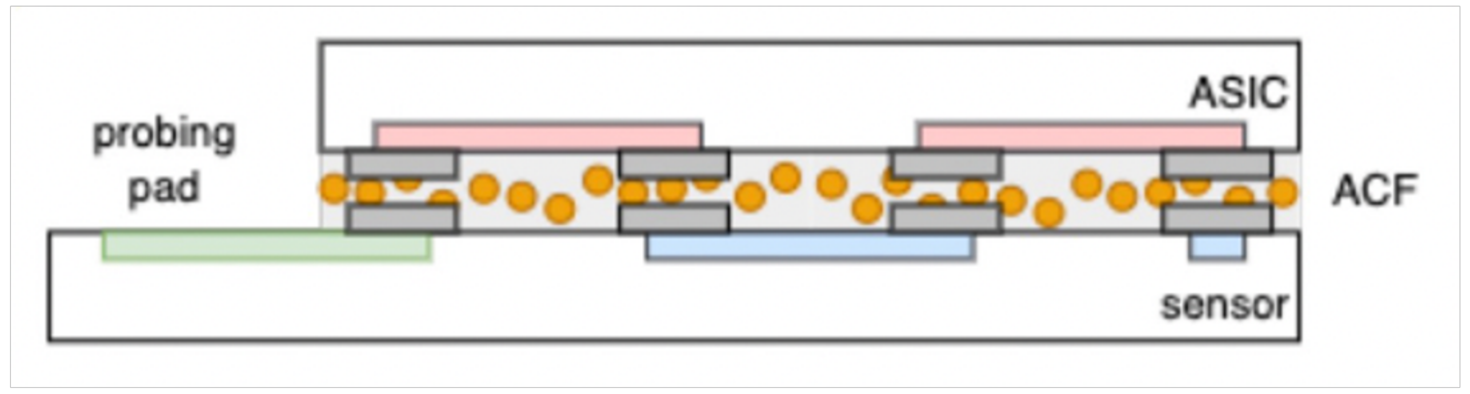
Ongoing activity towards a CMOS sensor design and fabrication platform allowing for:

- Active sensor thickness in the range 50 µm to 500 µm or more;
- Operation in full depletion with fast charge collection by drift, small collecting electrode for optimal signal-to-noise ratio;
- Scalable readout architecture with ultra-low power capability (O(10 mW/cm2));
- Compatibility with standard CMOS fabrication processes: concept study with small-scale test structure (SEED), technology demonstration with large area sensors (ARCADIA)
- Technology: 110nm CMOS node (quad-well, both PMOS and NMOS), high-resistivity bulk
- Custom patterned backside, patented process developed in collaboration with LFoundry

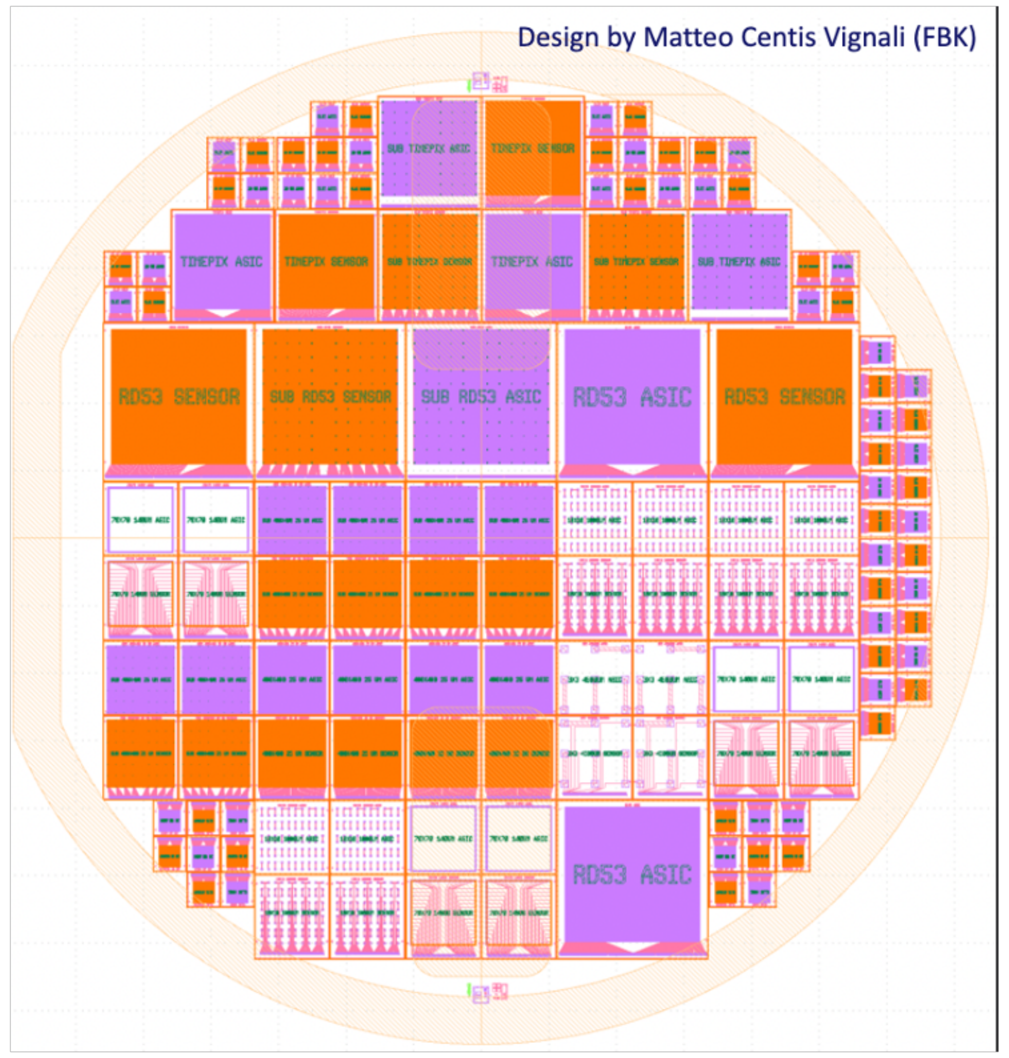


WP6: hybrid pixel sensors for 4D tracking and interconnection technologies

Anysotropic conductive films (ACF)



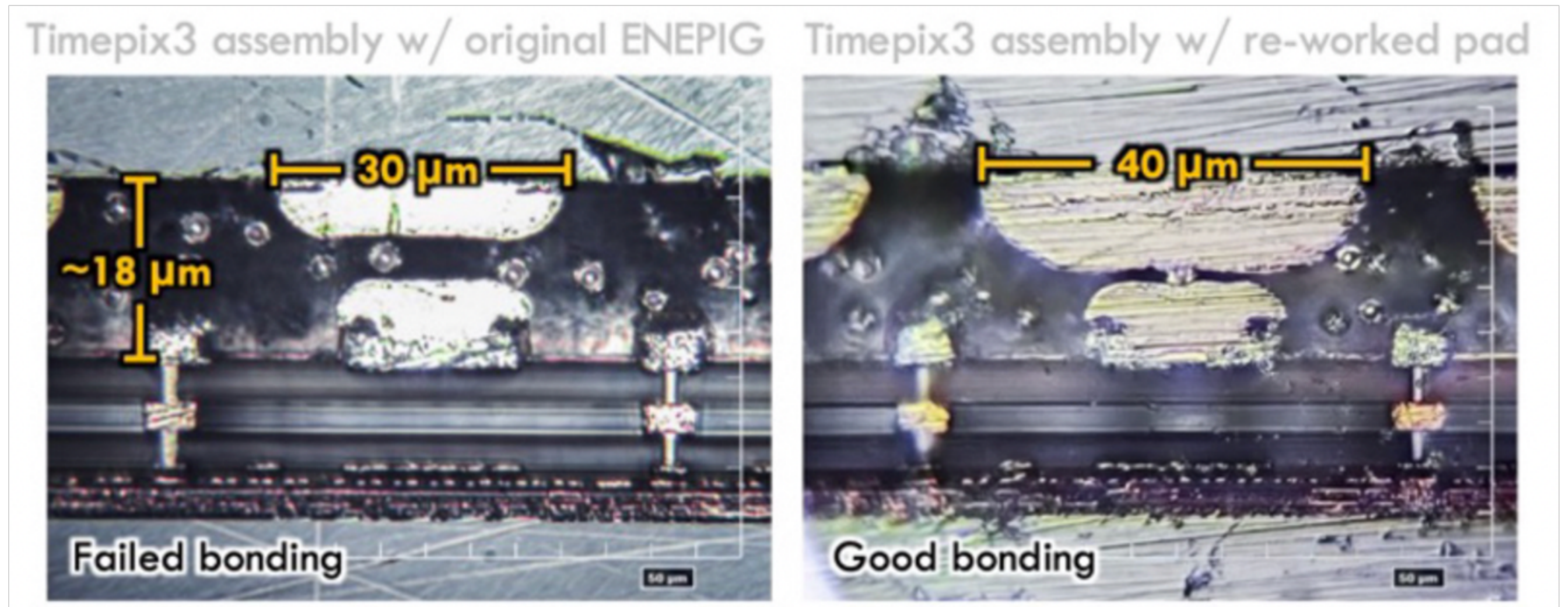
Pixel sensors with different sizes/pitches/geometries from AIDA-2020 planar active-edge production



Dedicated production of conductive chain devices to precisely characterise interconnections

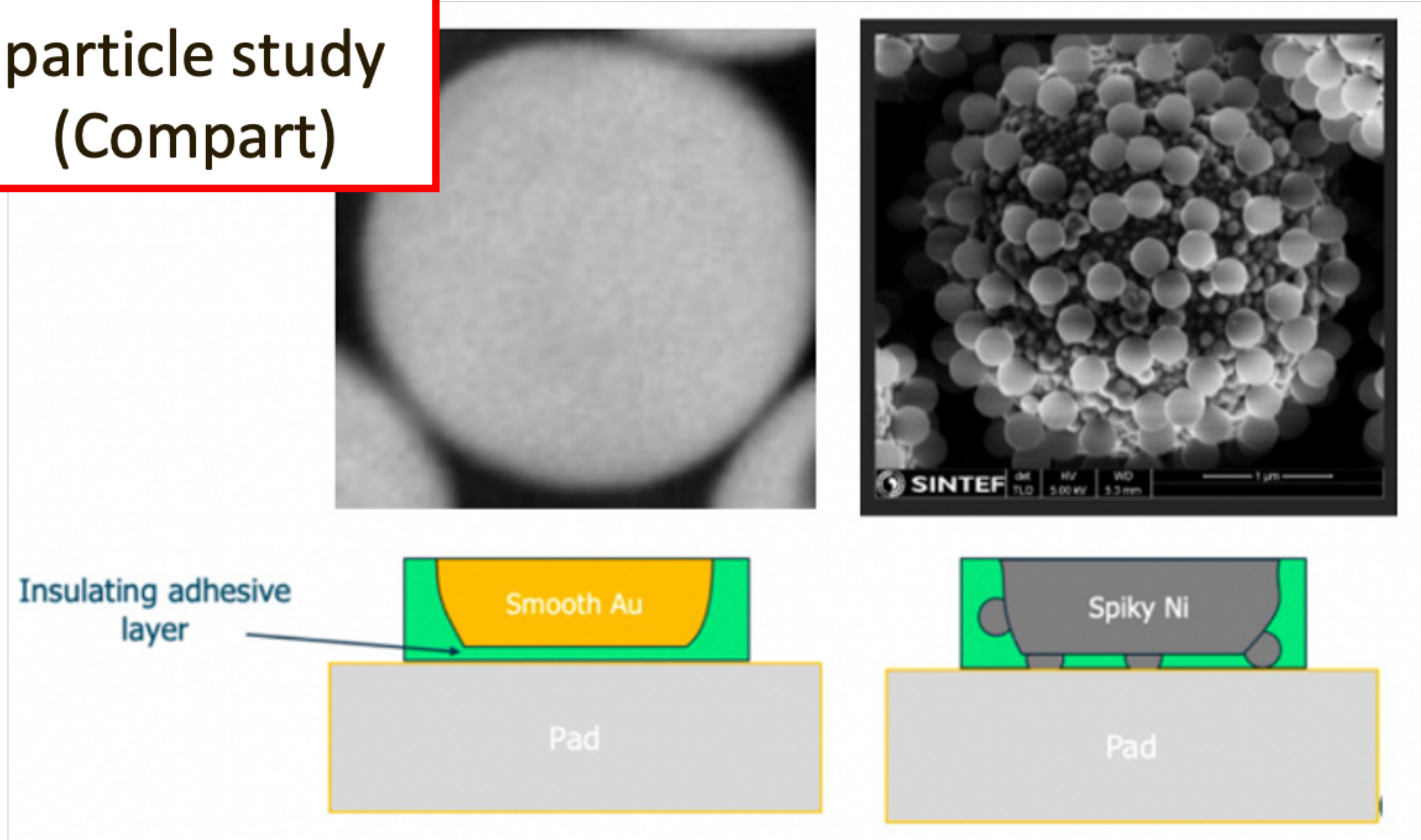
ENIG process optimization

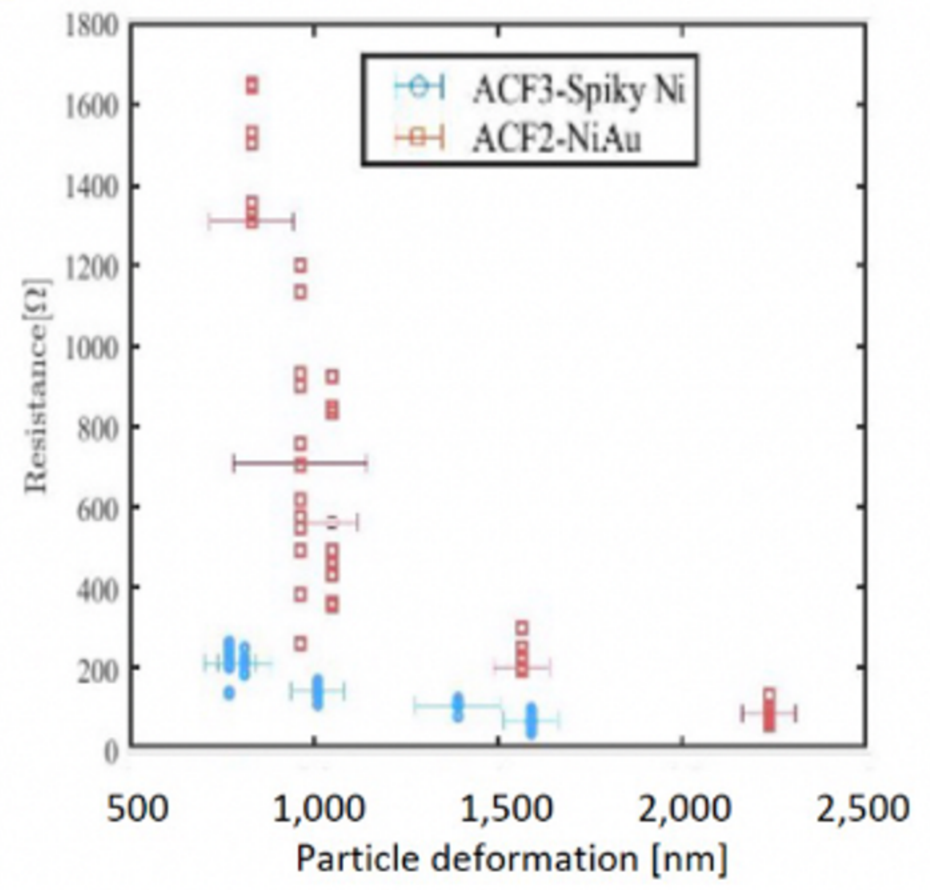
Contact quality
- Uniformity control
- Reproducibility



Very nice example of in-house process, allows die-level

Conductive particle study (Compart)





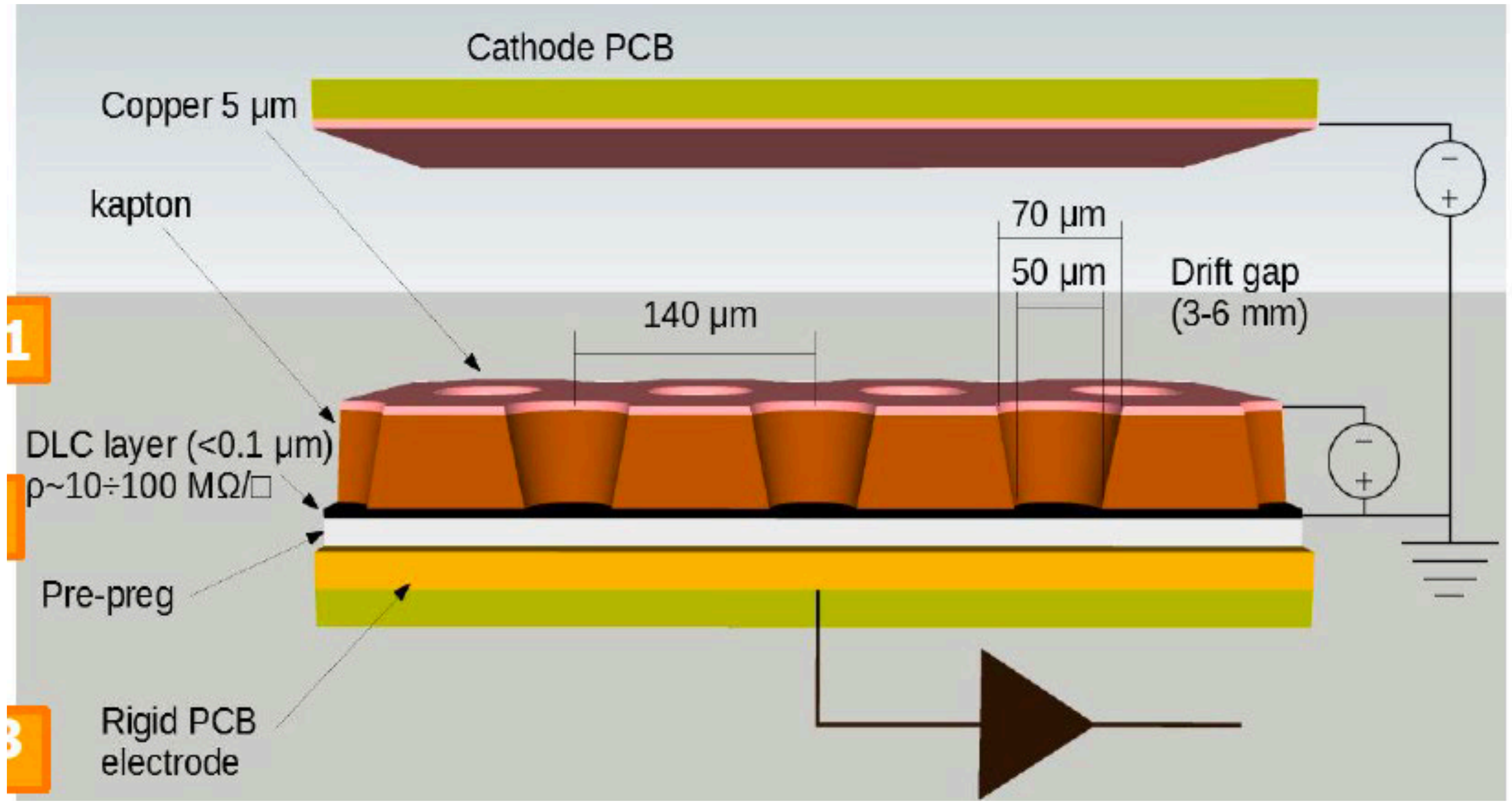
WP7: Gas detectors

SECTOR	TASK		APPLICATIONS
RPC	7.2.1	MRPCs for fast timing	CBM, SoLID, SHiP, ALICE upgrade, Muography
	7.2.2	Shower development in SDHCAL	e+ e- colliders and more
	7.2.3	Eco-friendly gas mixtures for RPCs	LHC exp.s and all RPC applications
MPGD technologies	7.3.1	Resistive electrodes for MPGDs	resistve MMs, GEMs for time time resol., μR-WELL
	7.3.2	Industrial Engineering of high-rate μR-WELL	large size μR-WELL systems (LHBc, EIC, ...)
Large volume gaseous detectors	7.4.1	Electronics for cluster counting	drift chambers for e+ e- colliders
	7.4.2	High P gas TPC for ν-physics	ν-physics (T2K, HyperK, NOvA, Duve)
PID	7.5.1	PDs for h-PID at high momenta	EIC, circular e+e-, more RICH implementations

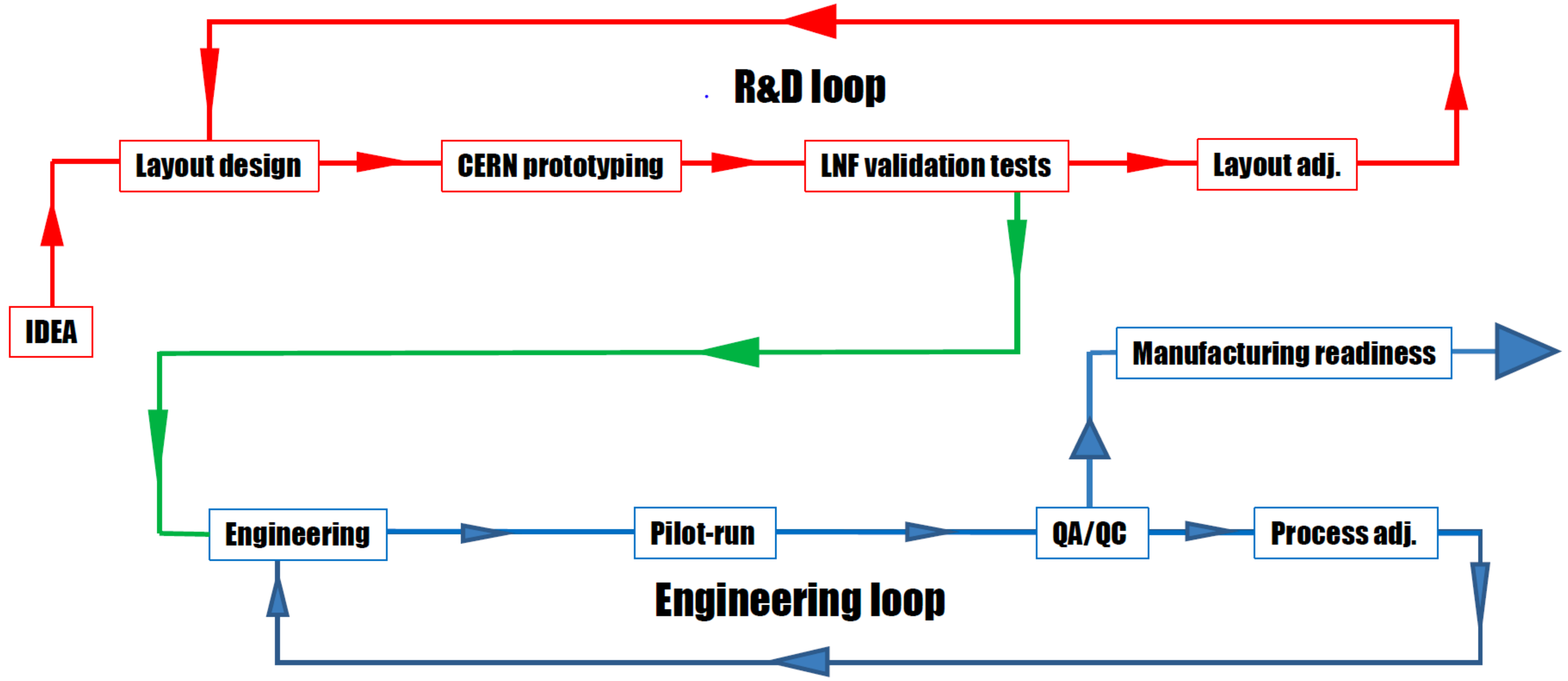
Activity robustly progressing:

The several envisaged applications will profit of the progress in the gaseous detector sector by AIDAinnova WP7

WP7: Industrial engineering of µRWELL



The road-map: R&D + Engineering



Operative meetings

21 Sept. 2021 - joint INFN-ELTOS-CERN meeting
- **standardizing manufacturing procedures of µ-RWELL layout**

1-3 Dec. 2021 - CERN-INFN meeting
- status of the **R&D on the High Rate layout**
- **measurement with high intensity X-ray beam**
- **2D layout** based on the **readout of a segmented amplification stag**

7–10 Dec. 2021 – 1st test batch in ELTOS
- **DLC patterning**
- **PCB planarizing tests**

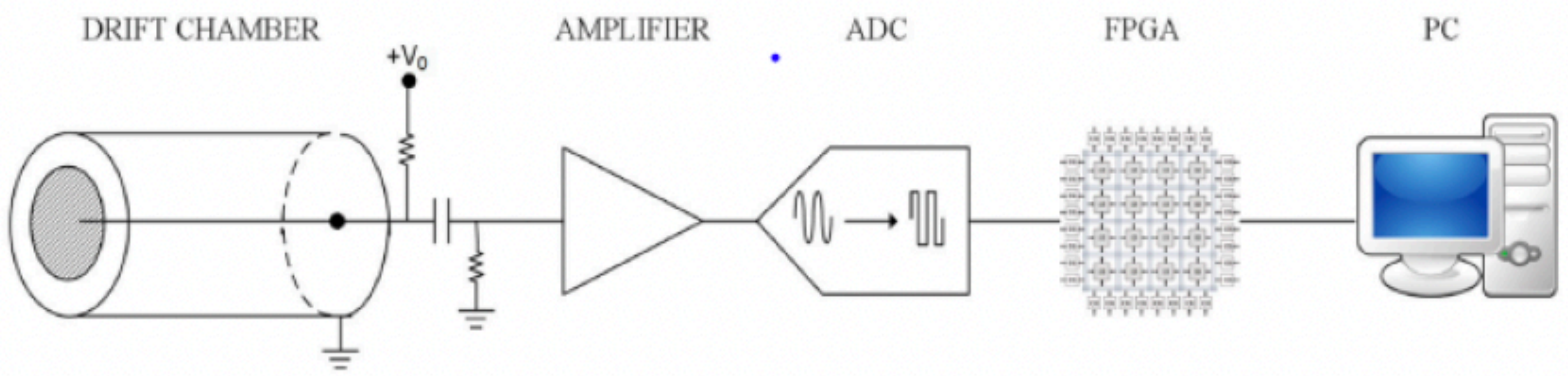
7–8 Mar. 2022 - 2nd test batch in ELTOS
- **PCB planarizing tests**
- **Kapton DLCed foil coupling with PCB-readout**

28 Mar. 2022 - joint INFN-ELTOS-CERN meeting
- **discussion with Rui about the results obtained**

WP7: Cluster counting

- **Cluster counting in gaseous detectors is, up to a large extend, matter of read-out electronic chain**
- **Needed: reading at 2.0 GSPS and local data reduction to limit the band-width requirements**
- **Realized for a single channel :** 12-bit monolithic **pipeline sampling ADC** at conversion rates of up to **2.0 GSPS followed by** fast readout algorithm (**CluTim**) running on a Virtex 6 FPGA

The verified solution for a **single channel**



- **GOAL of task 7.4.1: realize a 4-ch.s implementation as first step towards large-size systems**

WP8: calorimeters

Task 8.1. Coordination and Communication - Roberto Ferrari, Katja Krüger, Roman Pöschl

Task 8.2. Towards next generation highly granular calorimeters

8.2.1 Integration aspects of highly granular calorimeters – Vincent Boudry
DESY, CNRS-IJCLab, CNRS-LLR, CNRS-LPNHE, JGU, CERN, TAU, FZU

8.2.2 Future Liquid Noble Gas Calorimeters – Jana Faltova
CERN, CNRS-IJCLab, CUNI

Task 8.3. Innovative calorimeters with optical readout

8.3.1 Crystal detectors – Etiennette Auffray Hillemanns
CERN, FZU, VU, INFN-PG, INFN-LNF, INFN-TO (→ GLASSTOPOWER)

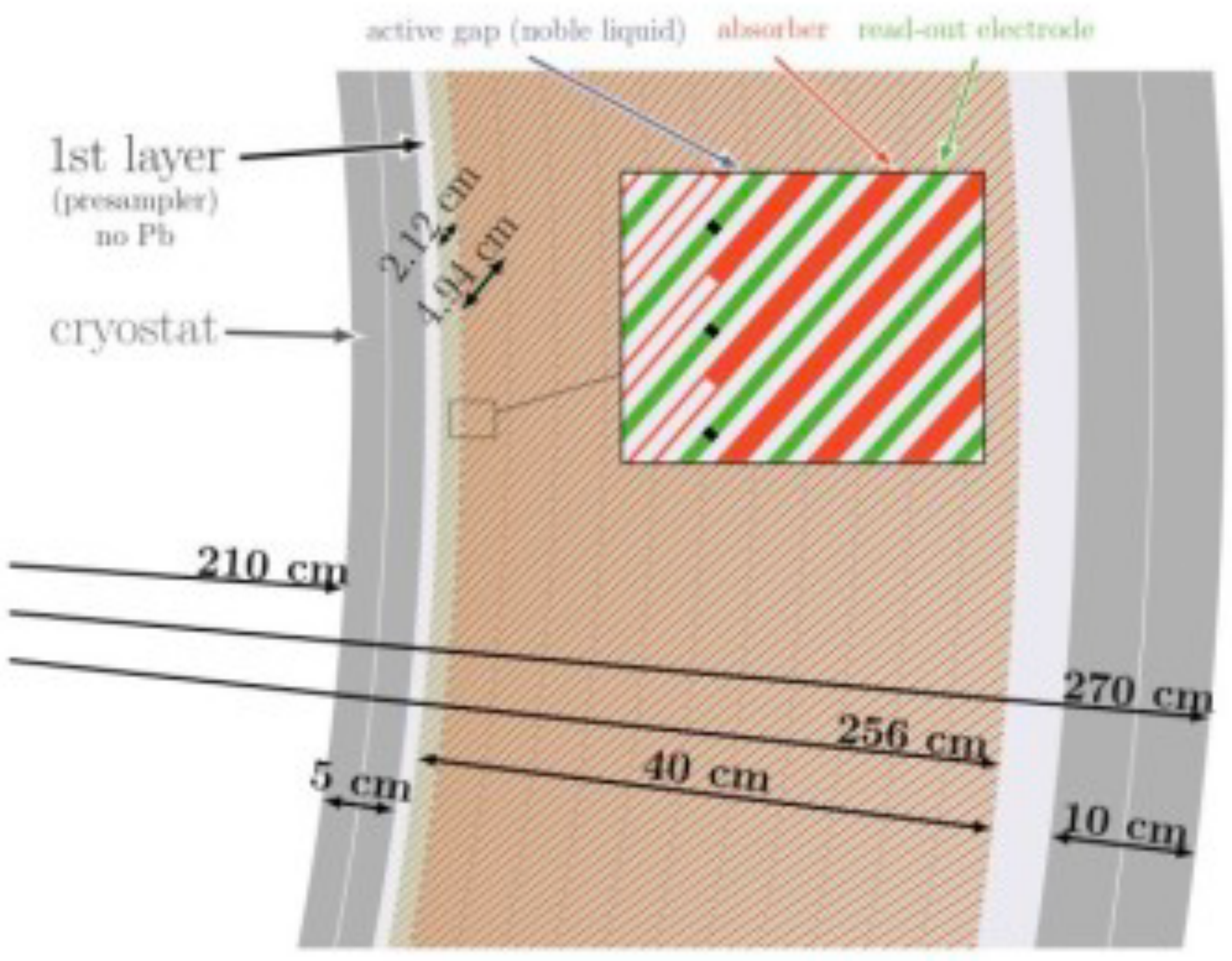
8.3.2 Large area scintillator detectors - Frank Simon
MPP-MPG, DESY, INFN-BO, INFN-LNF, JGU

Task 8.4. Innovative solid-state light sensors and highly granular dual-readout fibre-sampling calorimetry

8.4.1 Innovative SiPMs and future applications in PID detectors – Rok Pestotnik
JSI, INFN-PD, INFN-TO, CERN, FBK, UiB, FZU (→ FOTON)

8.4.2 Development of highly-granular dual-readout fibre-sampling calorimeters – Romualdo Santoro
INFN-PV, INFN-MI, INFN-PI, INFN-BO, UOS, CAEN

- **Electromagnetic calorimeter for FCC-ee**
- **1536 absorbers in 2π, inclined by ~50.4°, |z| ≤ 2 m along the beam axis**
  - Sandwich of 2 mm Pb absorber – active gap – 1.2 mm readout PCB – active gap
  - 19 - 22 X_0 reached after 40 cm with LAr as active material



High granularity achieved by usage of straight multilayer readout

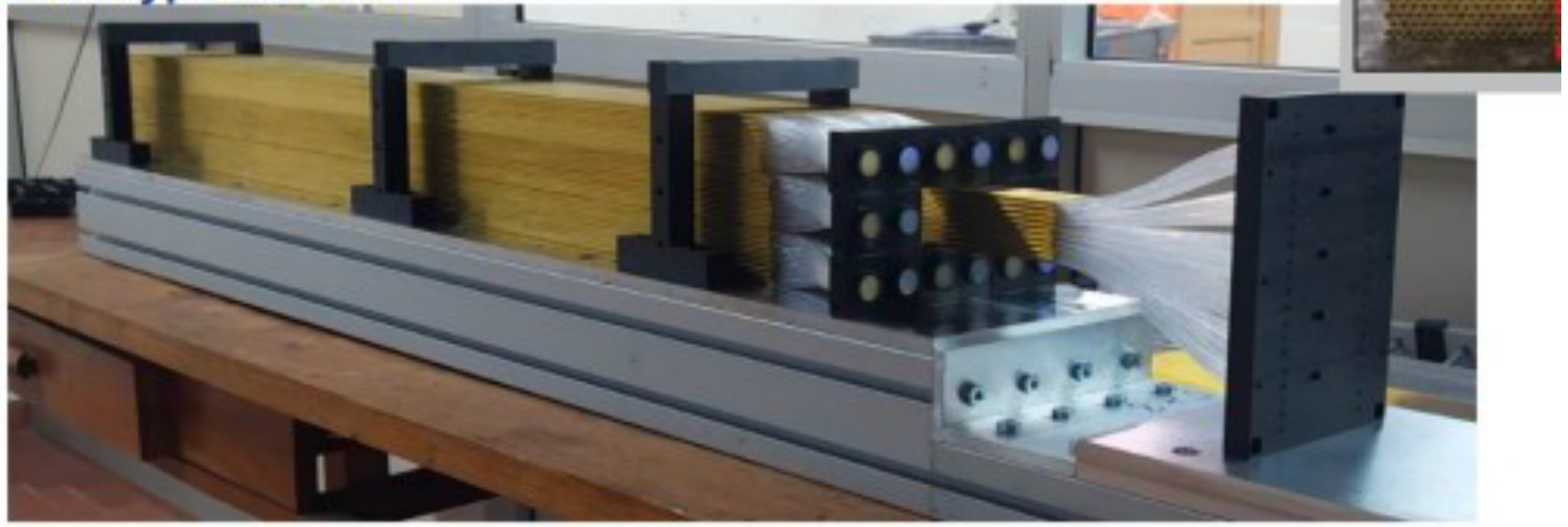
- **New calorimeter concepts have to optimize electronics noise (crucial for e+e- colliders)**

- Two approaches
  - **Warm electronics**: ATLAS EM-calorimeter like:
    - **Advantages:** Maintainability of front-end electronics (no active components inside the cryostat), upgradeability, possibility to adapt calorimeter to new requirements (e.g. as for HL-LHC upgrade)
    - **Disadvantages:** Long transmission lines (attenuation, noise), high-density signal feedthroughs
  - **Cold electronics**: ATLAS HEC-calorimeter or DUNE like:
    - **Advantages:** Much shorter transmission lines, cold preamplifiers have less serial noise, one optical fibre can carry signal of 100's of channels
    - **Disadvantages:** No possibility to repair or upgrade

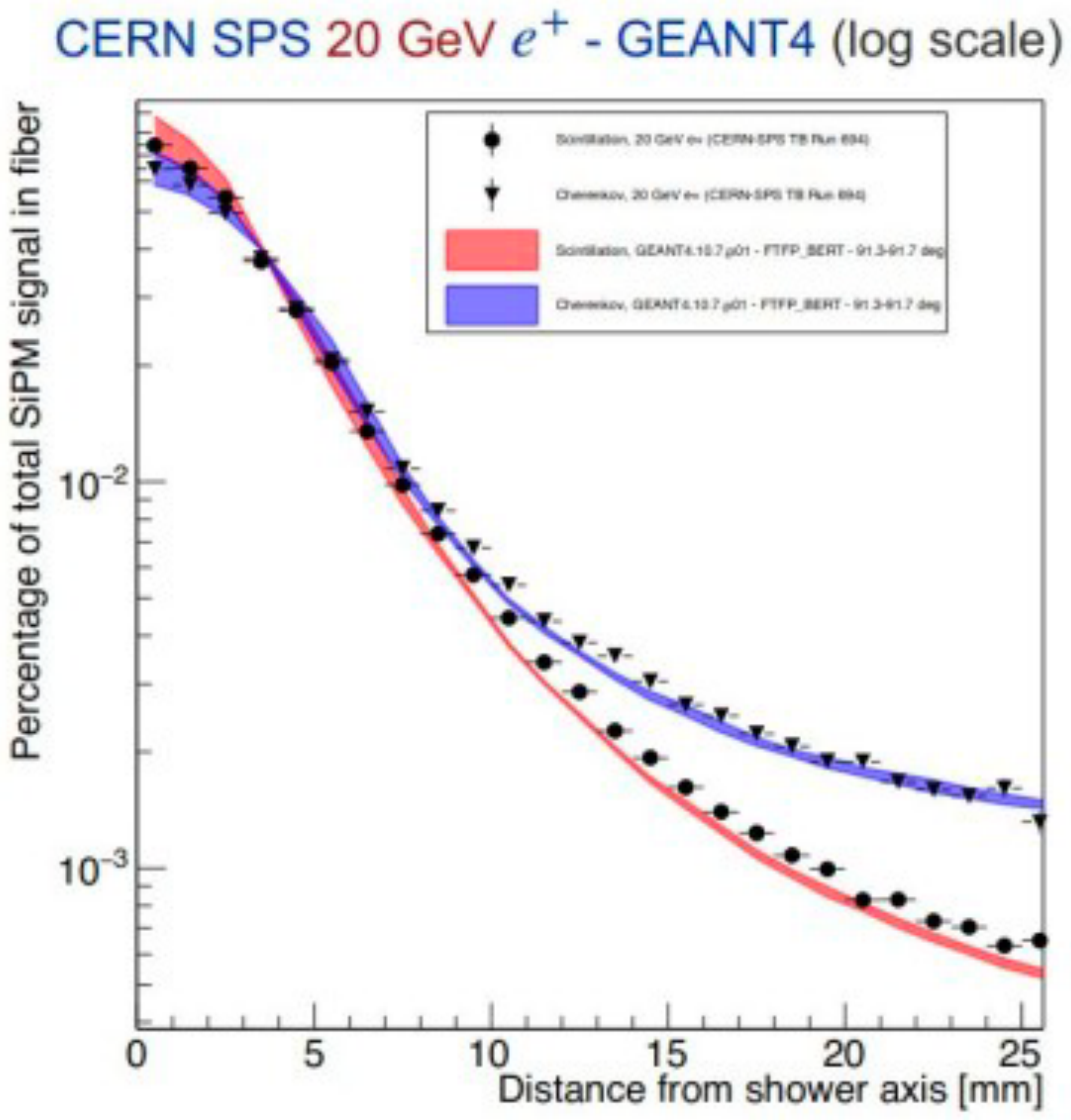
Highly-granular dual-readout fibre-sampling calorimeters

new (em) prototype (9 3x3 cm² towers) tested both at DESY and SPS
highly granular core (tower 0) w/ SiPMs

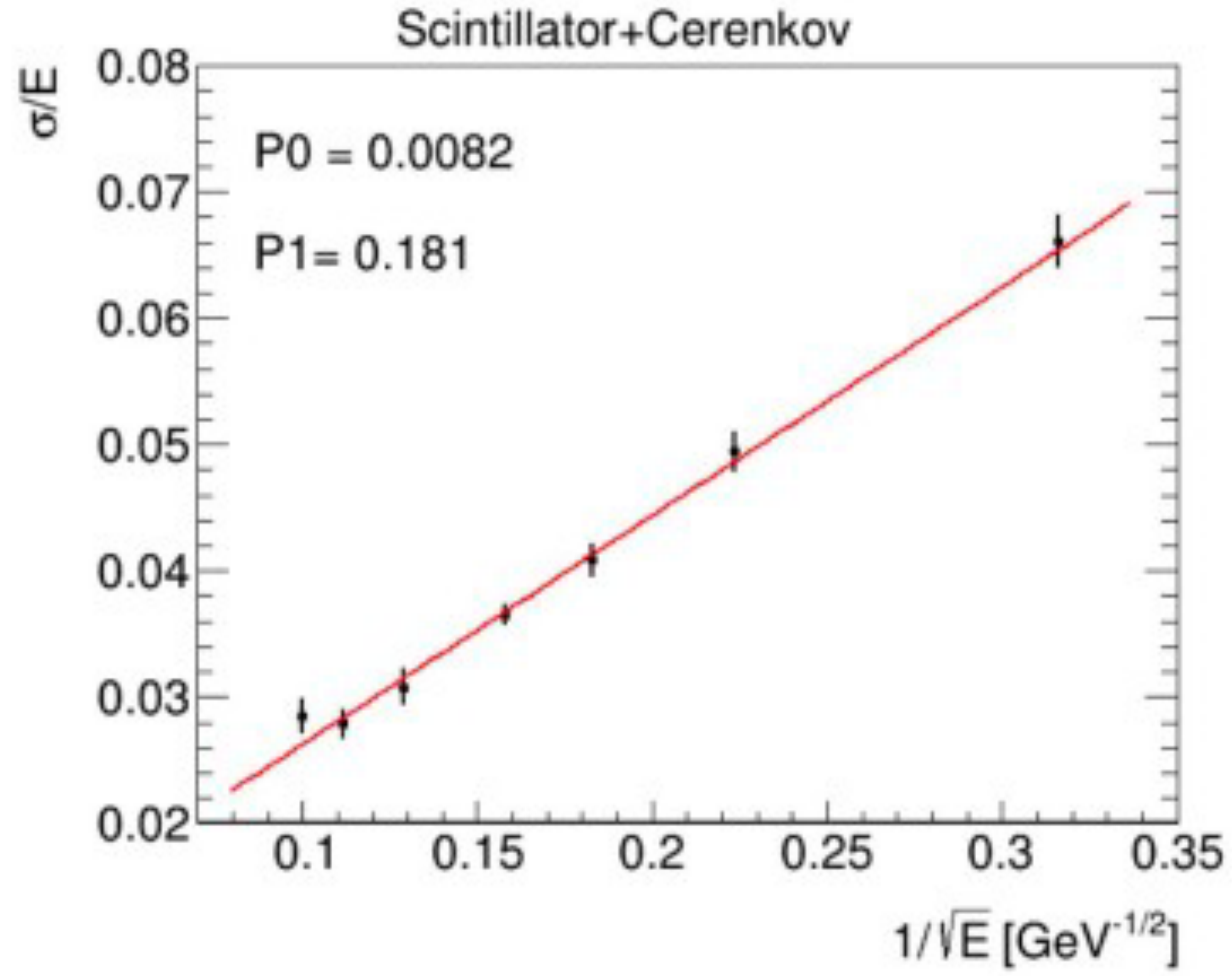
Prototype rear end



shower profile

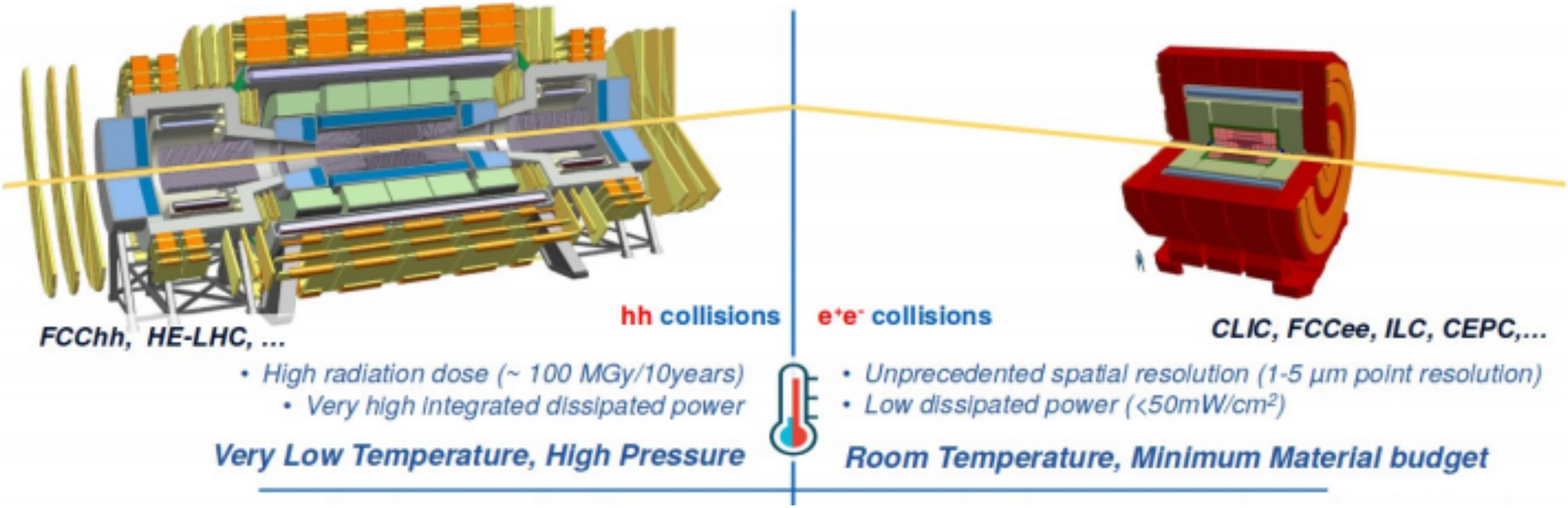


experimental resolution



WP10: Advanced mechanics

- WP10 aims at the development of technologies that can be implemented by the detector community for designs launched in the next 5-10 years



Targeted applications

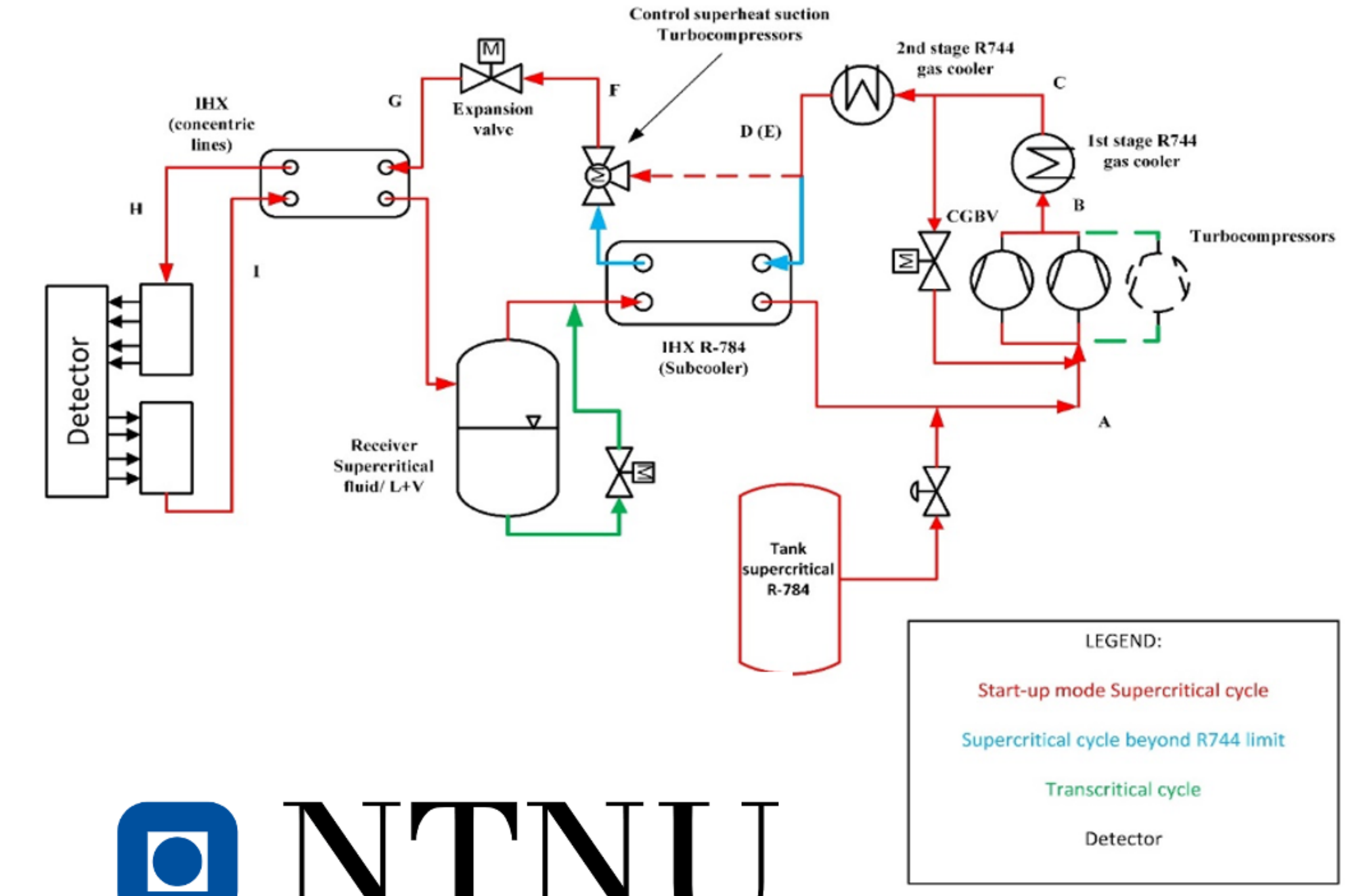
- Higgs Factories
- ALICE, LHCb LS3 pre-TDR, ATLAS & CMS LS4

WP10: Advanced mechanics

Suprecritical refrigerants

A number of candidates considered for a next generation of cooling systems

Krypton seems promising for ranges out of reach for CO2 (-50 to -80C)



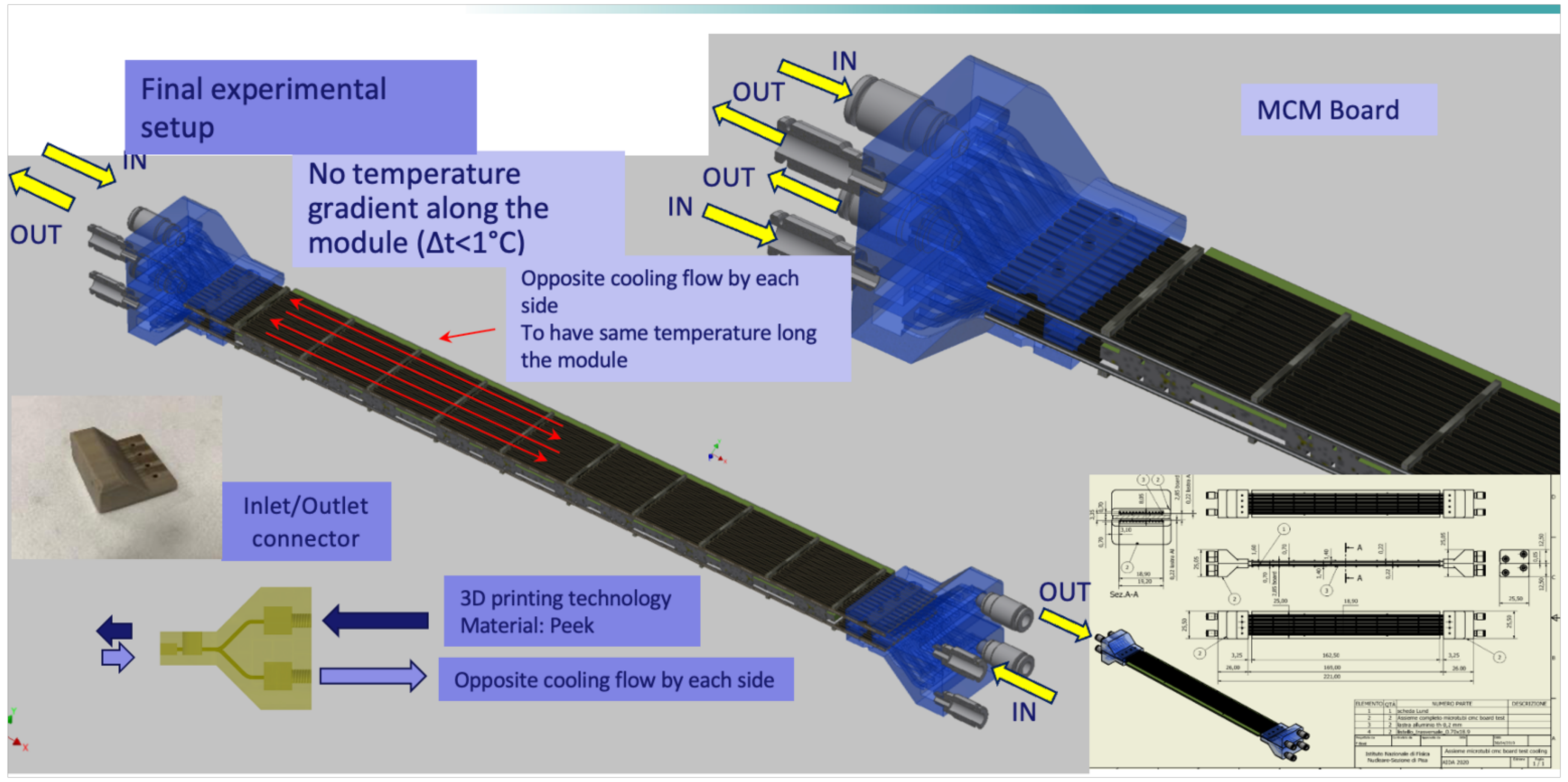
- Oil free machine: **Turbocompressors**
- Heat rejection via **CO_2 gas coolers** (primary CO_2 based chiller)
- **Pressurized tank** with ScKr essential component for the start-up
- **CGBV** to regulate cooling capacity & temperature glide inlet-outlet detector

NTNU

EP-DT
Detector Technologies

Hydraulic interfaces for u-channels

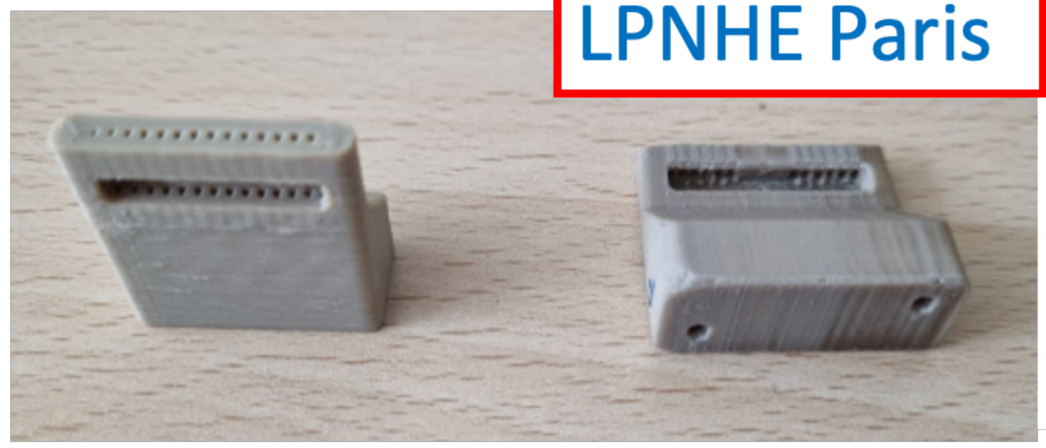
INFN Pisa

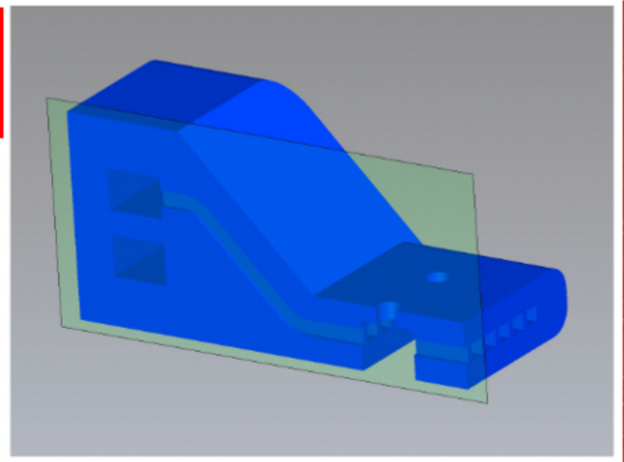


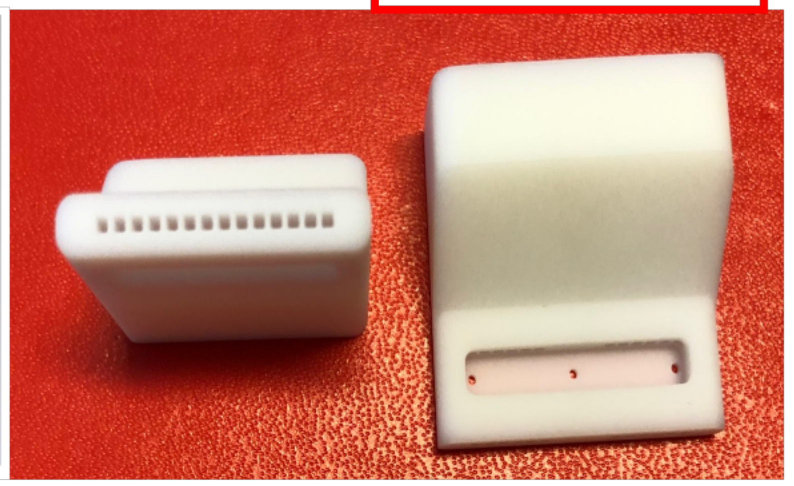
u-tubes in composite with 3D printed interfaces in peek or ceramics

INFN Pisa

LPNHE Paris





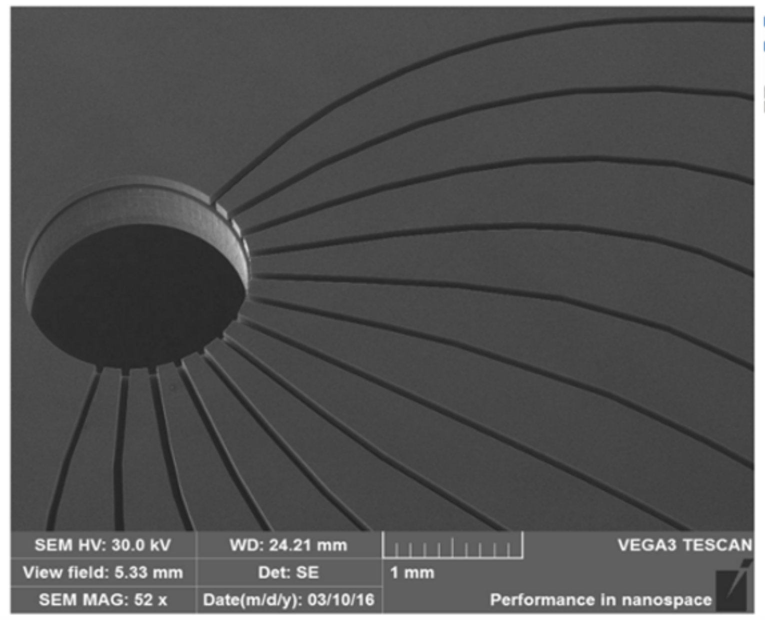


WP10: Advanced mechanics

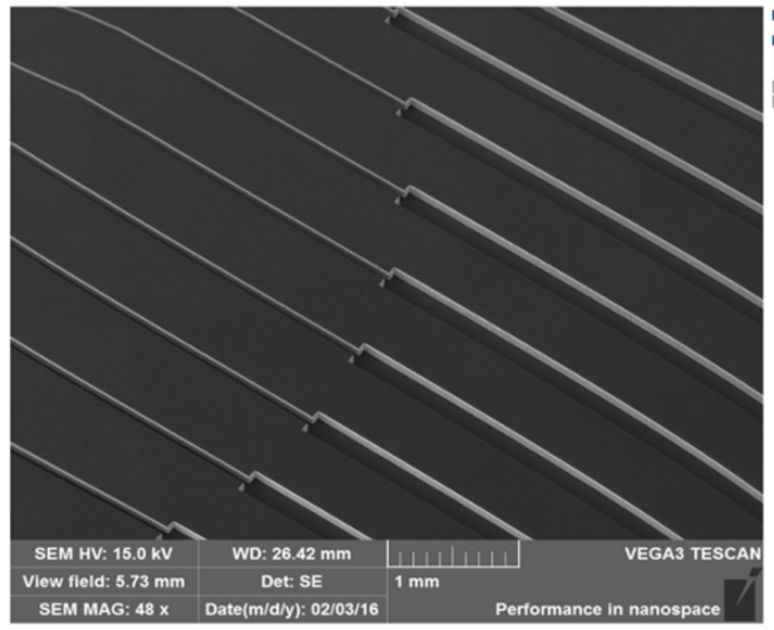
Silicon cooling blocks

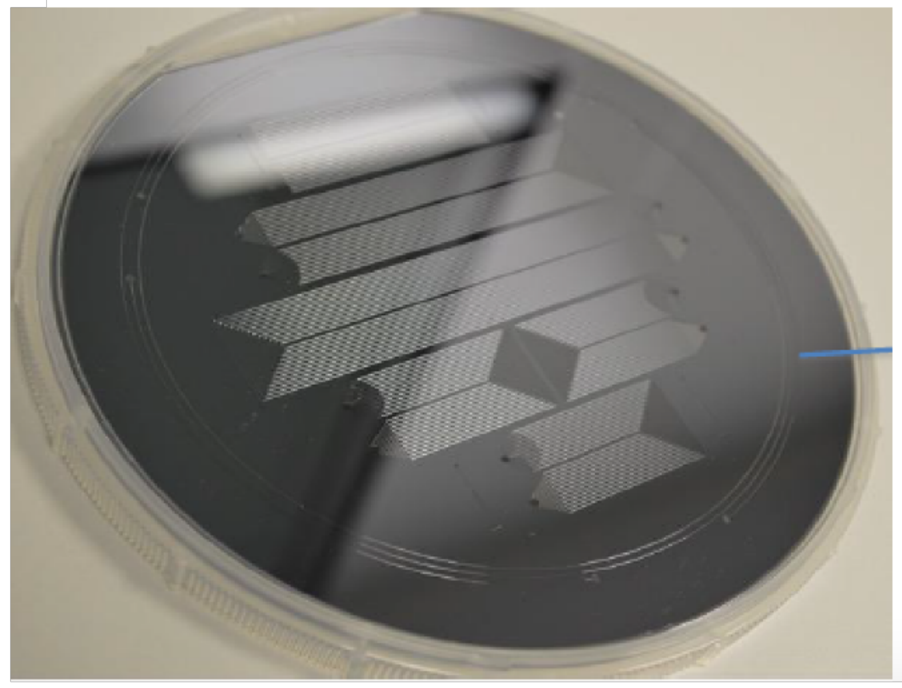
A number of devices produced in AIDA-2020 or independent projects with u-channels in silicon

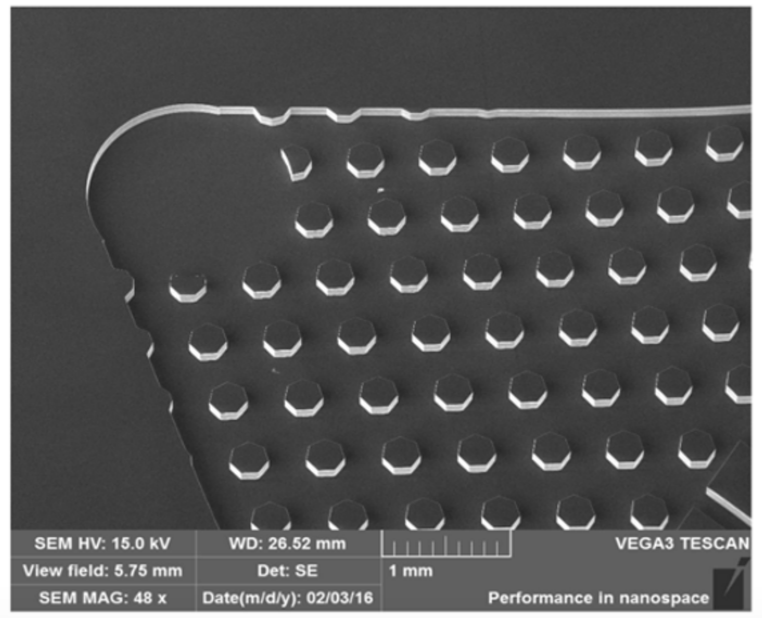
Inlet fanout



Channel size modulation to control CO2 boiling



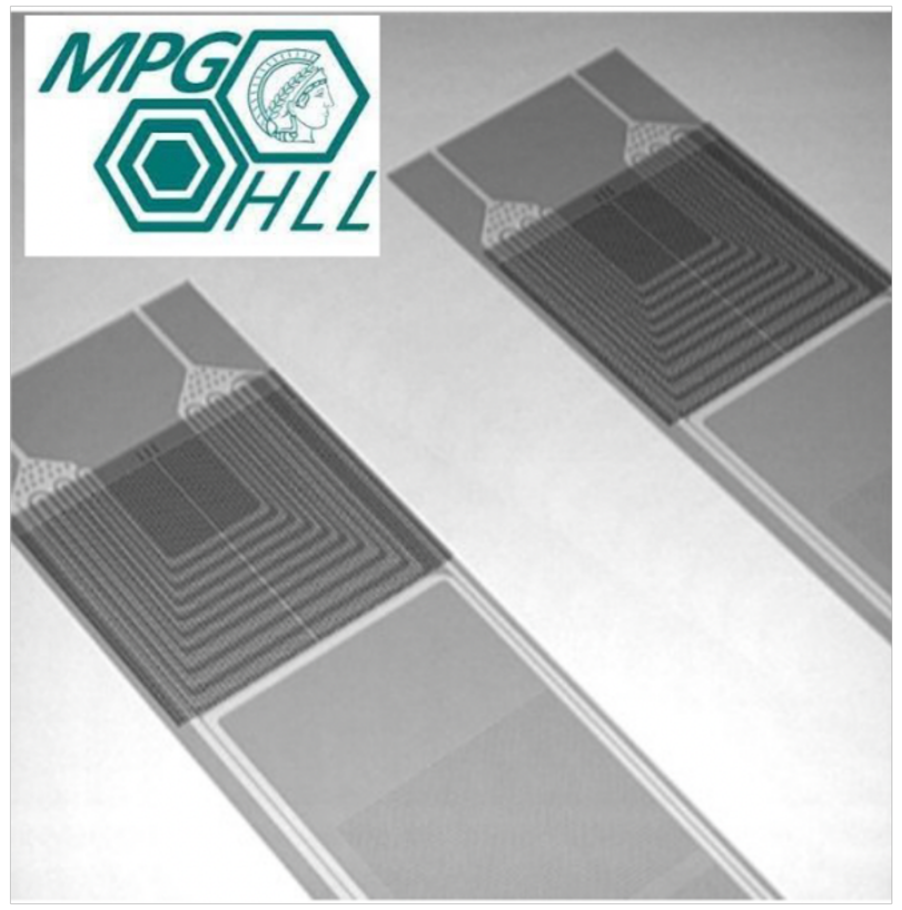




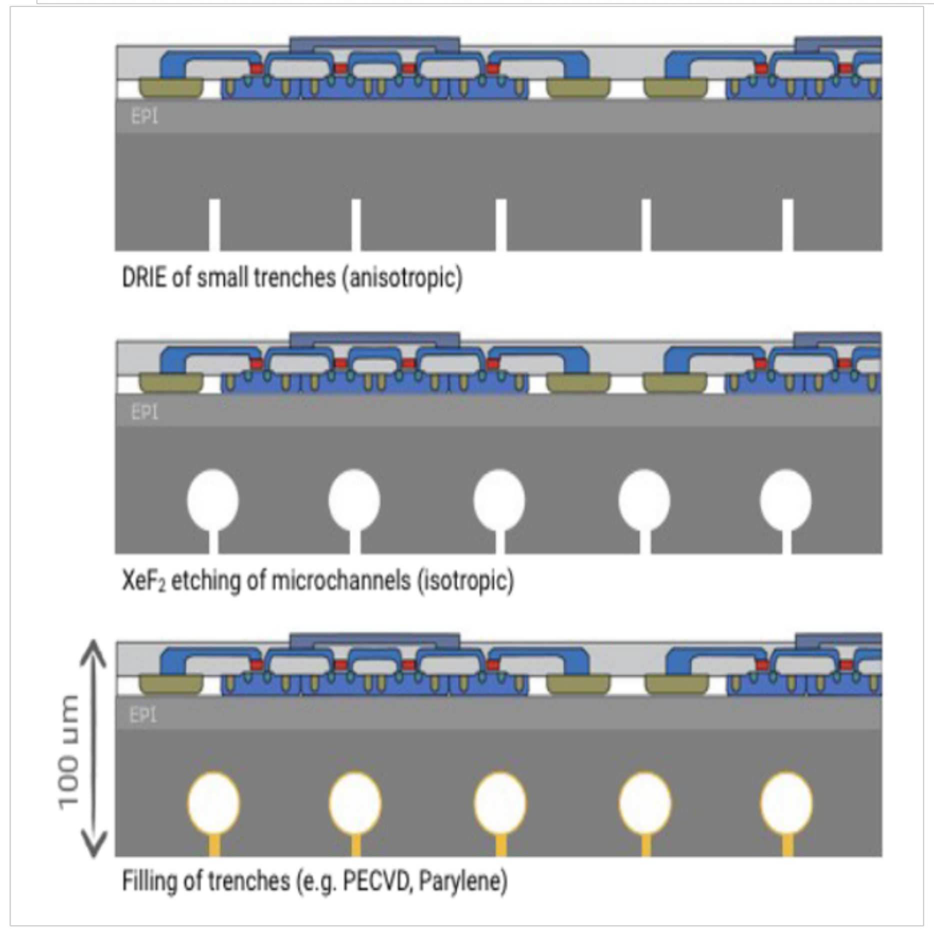
LPNHE Paris

Financed by AIDA-2020 WP9 and French technology-innovation calls

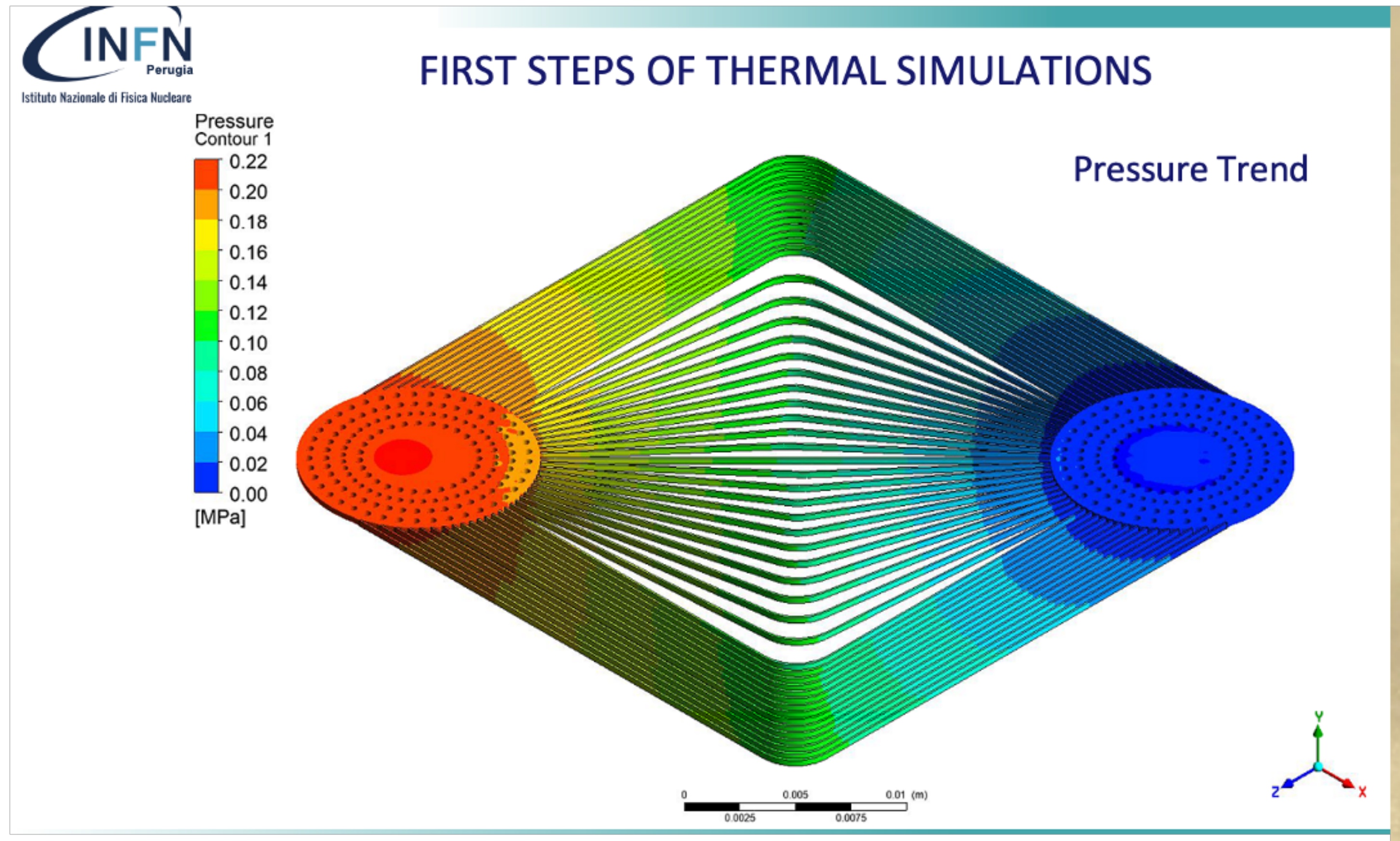
Most of these objects are still in the pipeline for being tested

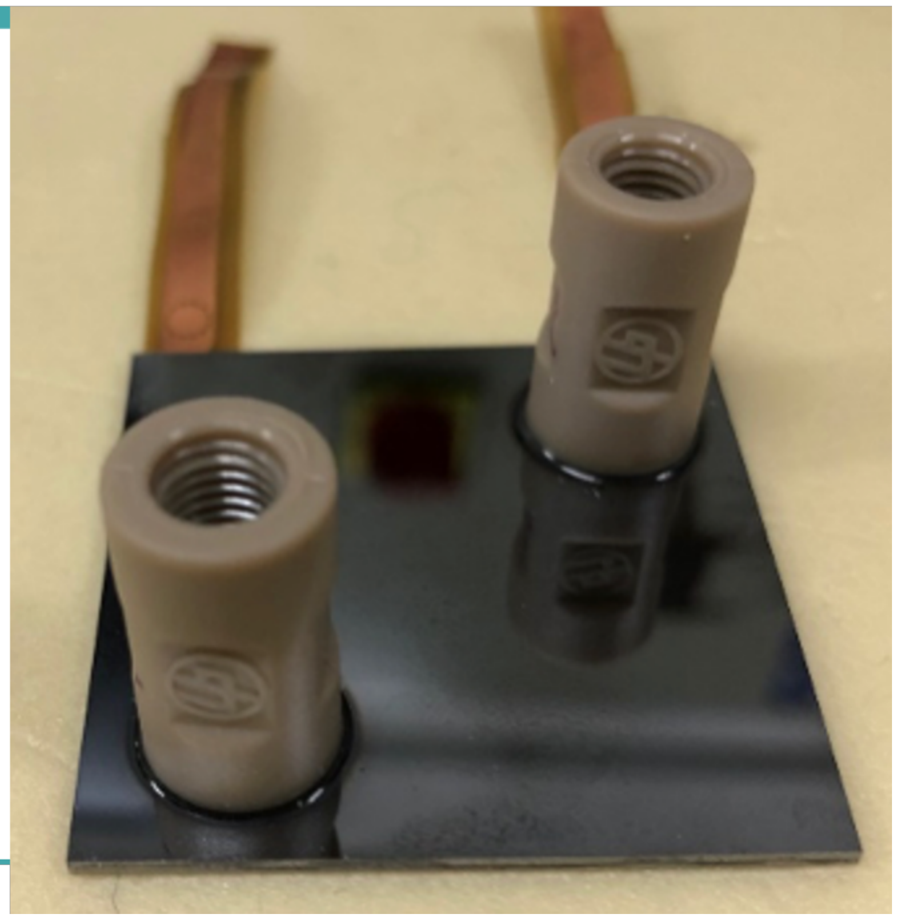


2019: Buried micro-channels in working MALTA CMOS sensor (CERN, EPFL)



INFN Pisa

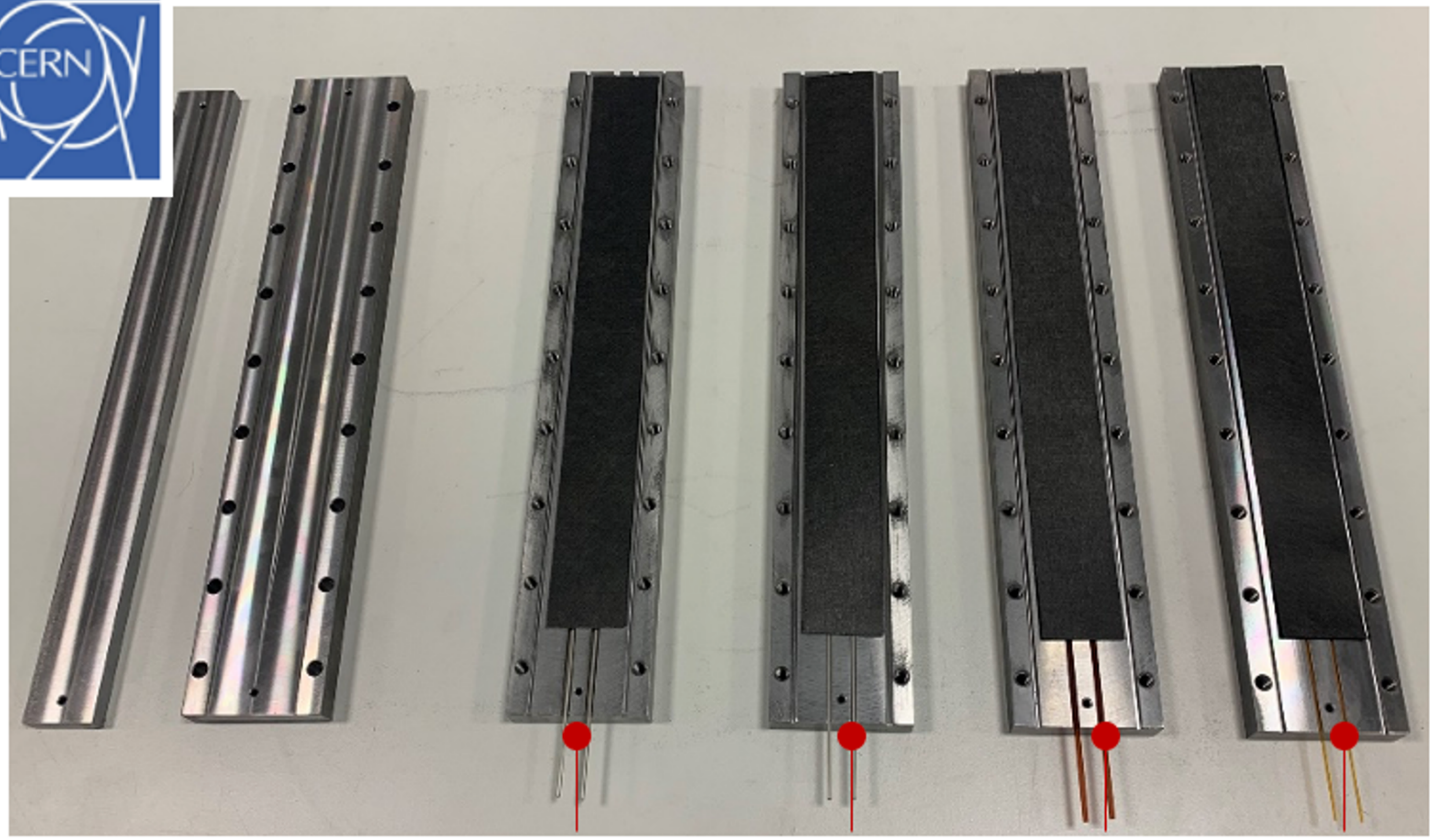




WP10: Advanced mechanics

Ultra light structures

- **Carbon Cold Plate (CP) with embedded Kapton pipes**

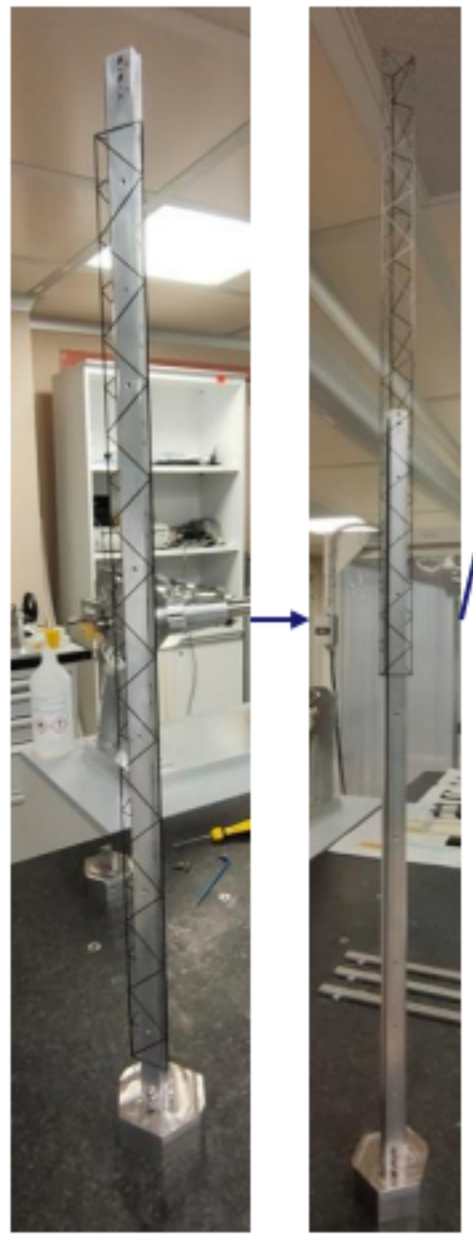


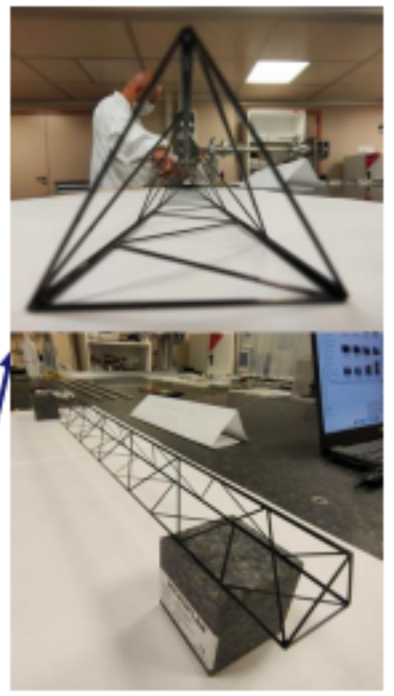
704 mm length truss for Belle 2 VTX upgrade
Total weight 5.8g, max sag 3-400um

INFN Pisa

WP10: ultralight CF ladders

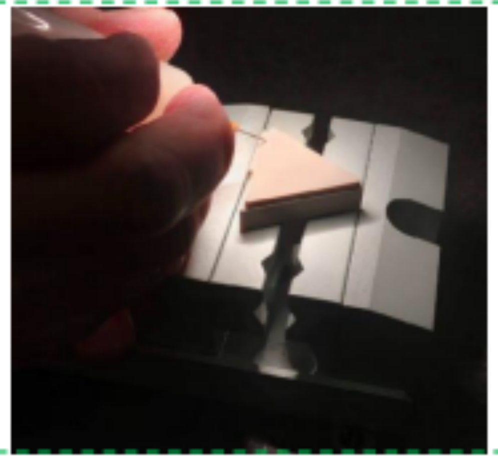
INFN PISA





The total weight of the **704 mm** length carbon fiber truss is about 5.8 g.

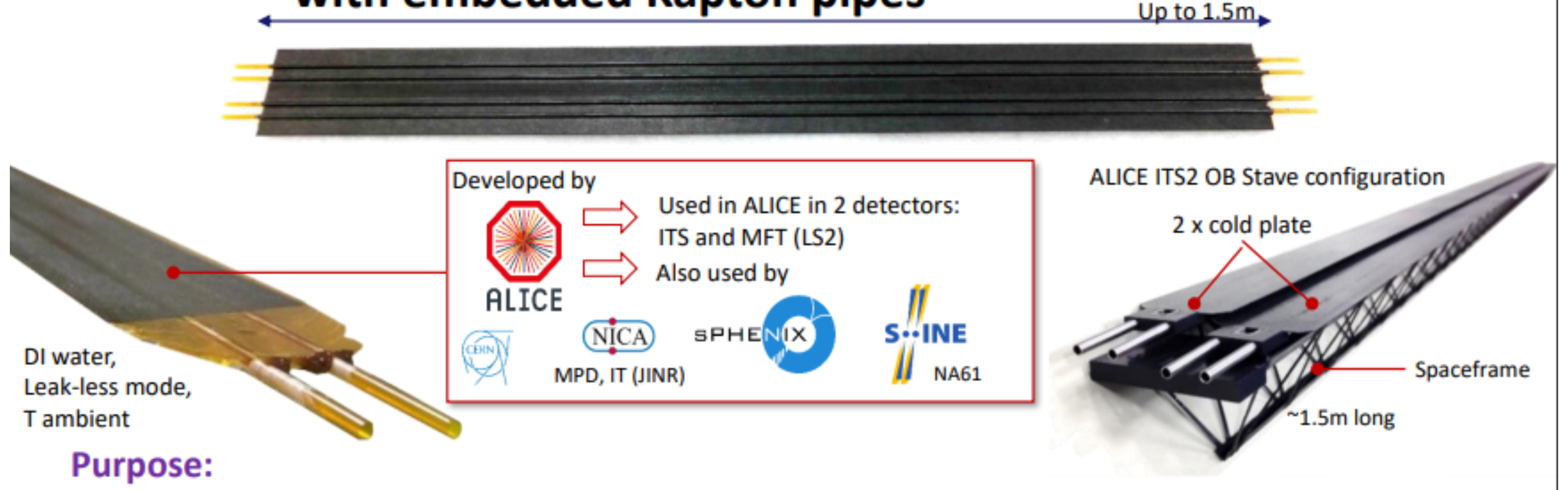
The glue accounts for 0.36 g (~6 %).



The weight of the peek end pieces is around **9.7 g each**

oVTX L5 Mechanical structure prototype

- **Carbon Cold Plate (CP) with embedded Kapton pipes**

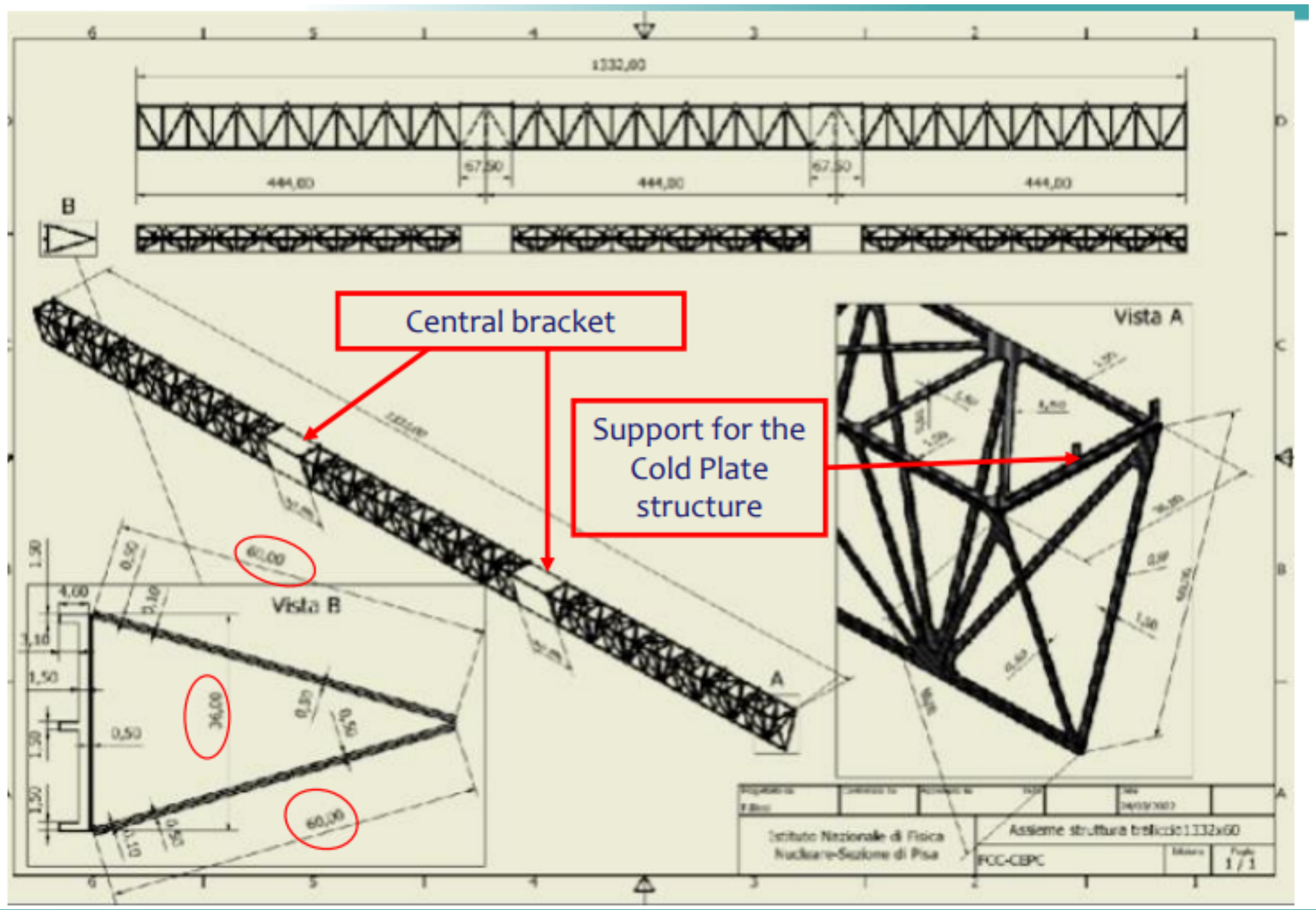


Purpose:

- Compatible with **high-pressure liquid coolants**: **Two-phase CO_2** refrigerant and new coolants (Krypton,...).
- Produce extended Carbon CP to **cover large surfaces**: understand their potentialities and limitations (considering minimum bending radius, pressure drop and pressure resistance limitations).

Collaboration between CERN and Workshape (composite company).

Long Stave realized gluing together the three 3single structures realized on the long gluing mask



WP11

- **Task 11.2. Exploratory study of advanced CMOS (28 nm)**
  - AGH: propose to study ADCs and PLLs and participate to next LPGBT
  - CPPM: test vehicles for SEU/SET and TID studies (Expected submission Q3 2022)
  - Ubonn: study FPGA implementation for next generation chips and digital blocks
  - INFN PV: work started with FALAPHEL INFN project, propose to further study analog front-ends and IP blocks (Expected submission Summer 2022)

Urgent need of 3-way NDA with TSMC and CERN

Indispensable to share expertise and blocks

- **Task 11.3. Networking and ASICs for other WPs (65/130 nm)**
- AGH: FLAME/FLAXE readout ASIC for LUMICAL, TDC developments (10 ps)
- CNRS IP2I: plan to do cryogenic tests on low dropout regulator prototype
- CNRS OMEGA: AC LGADs timing chip readout in 130 nm submitted
- DESY/Heidelberg: study of SiPM tilebaords with KLAUS5/6 readout
- INFN BA/PV: MPGD 32ch readout ASIC in 130n 12b ADC + 100ps TDC, dual polarity, variable peaking time.
- INFN BO/LNF/TO: uRwell readout chip, based on TIGER chip. Test uRwell chambers with APV and TIGER. Design dedicated chip in 130n end 2022.
- INFN TO: engineering run in UMC110n for timing detectors
- WEEROC: SiPM readout/LIROC timing results.

Propose to share an engineering run (end 2022) to get larger quantities of chips and equip detectors

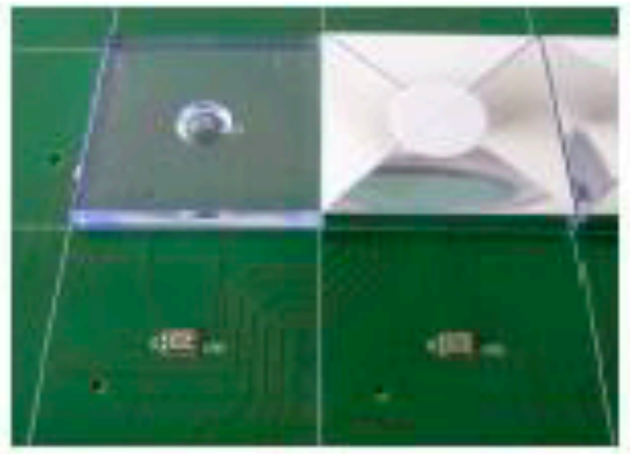
Still open to additional detector requests…

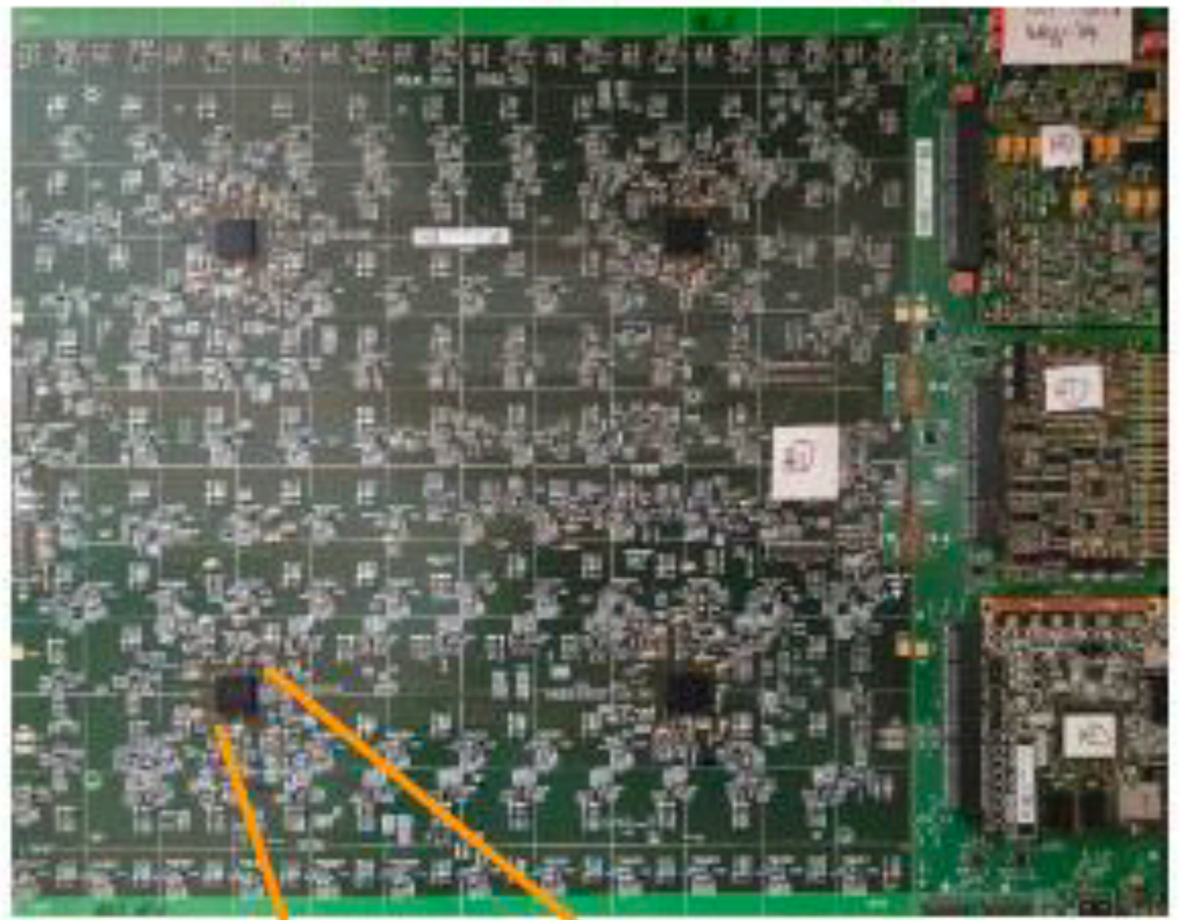
WP11:

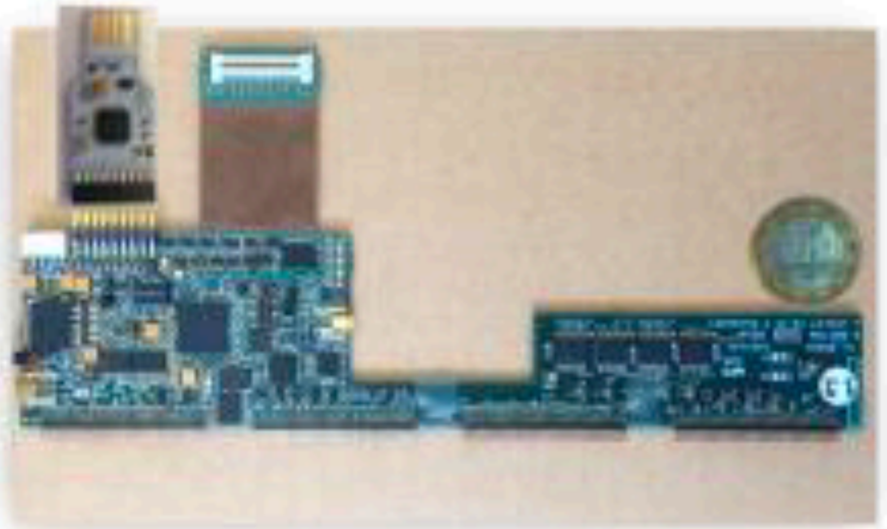
DESY in WP11 (and WP8)

- Development of a highly granular SiPM-on-tile calorimeter
  - Originally for the hadron calorimeter of a detector at a linear electron-positron collider
  - baseline or option for a detector at any future - linear or circular - Higgs factory
  - Technology has been adopted for the CMS calorimeter endcap upgrade (HGCAL)
  - Technology is under discussion for ECAL of DUNE Near Detector

- Future R&D in AIDAinnova:
  - Improved timing: readout electronics for KLauS ASICs
    - First version in AIDA2020 for KLauS5
  - Homogenized readout electronics with ECAL for pulsed and continuous operation (WP8)

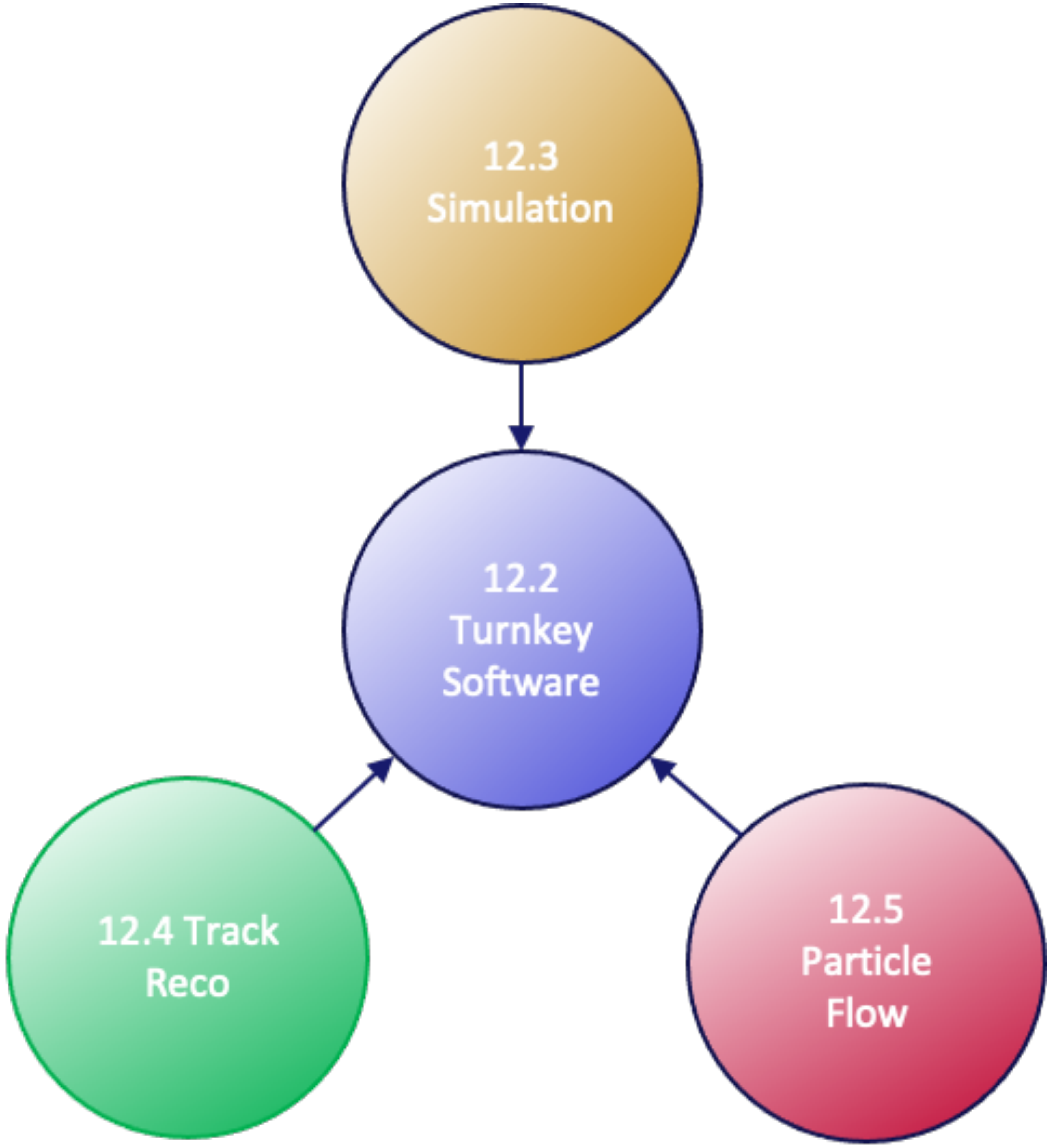






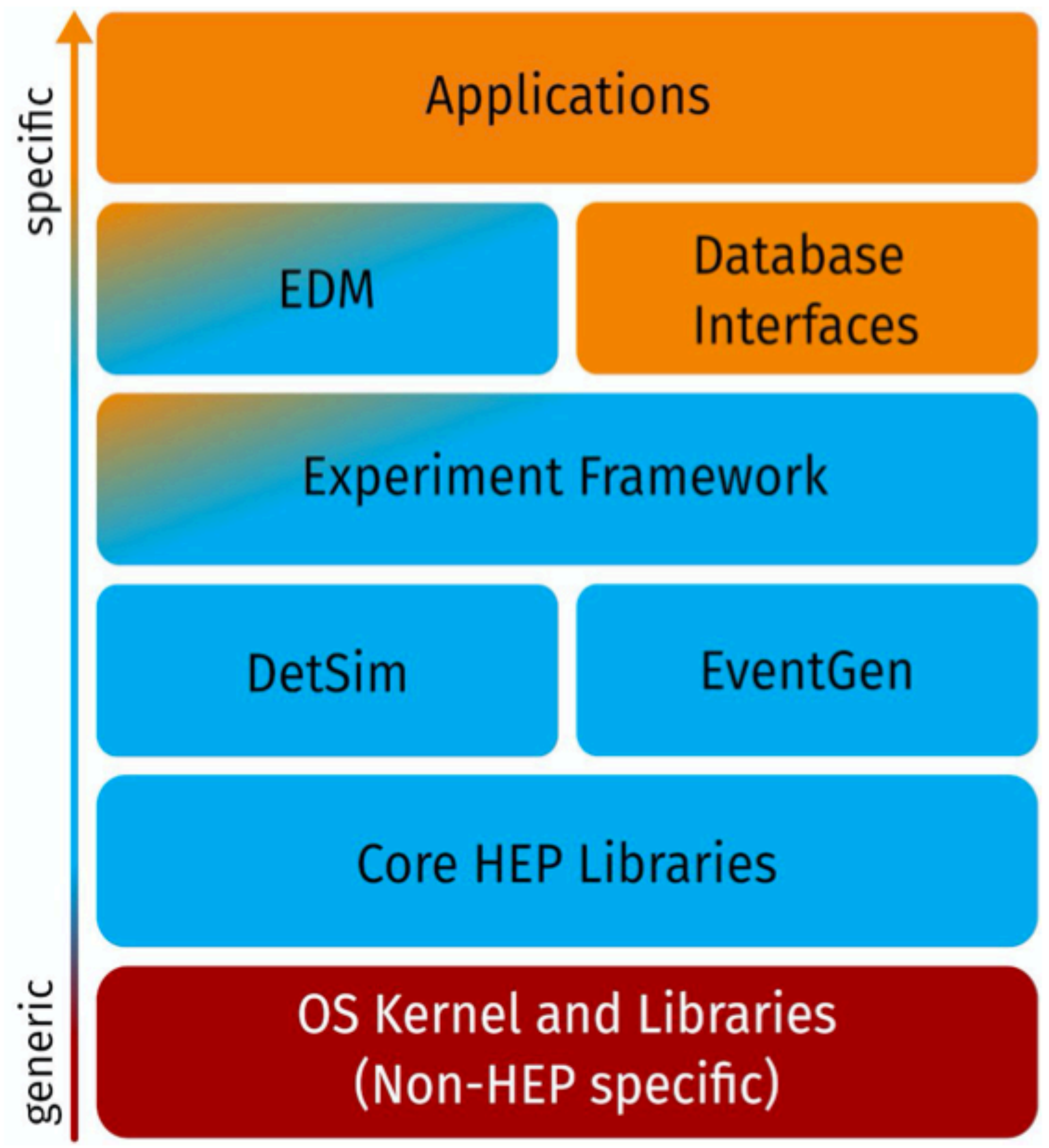
WP12: structure

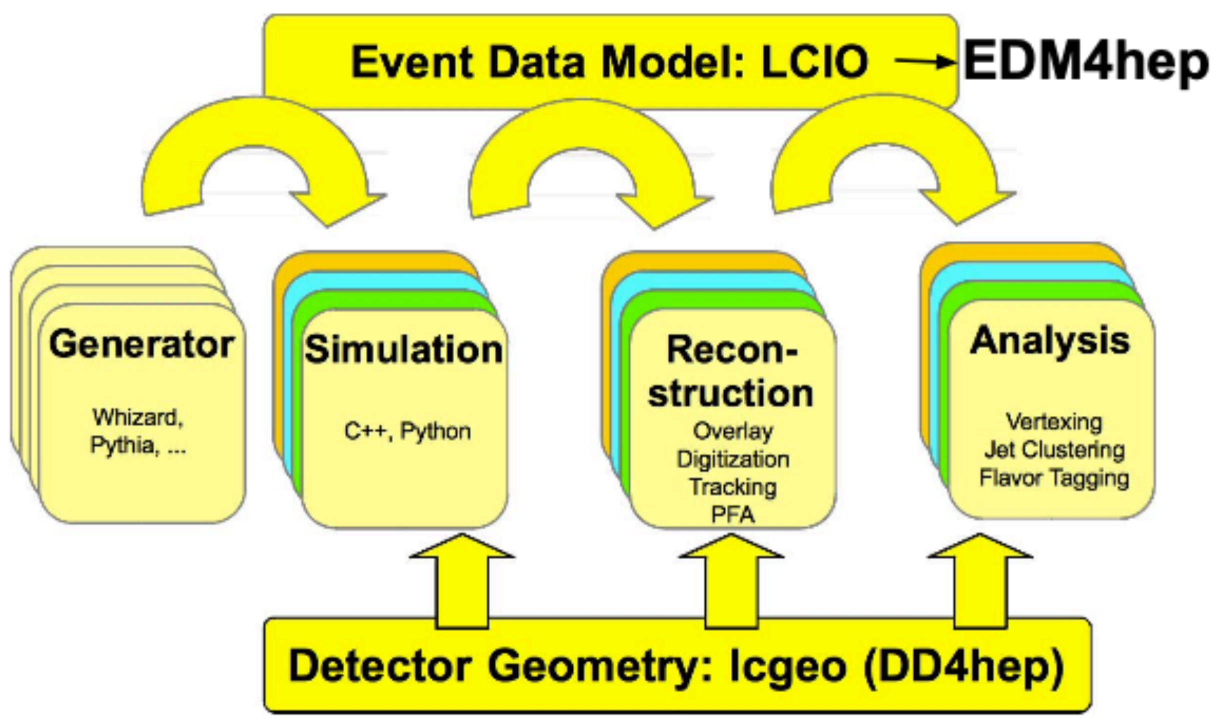
- Simulation
  - Fast simulation of calorimeters
  - Adopt and develop the latest techniques in parametric and machine learning approaches
- Track Reconstruction
  - Advanced tracking tools for speed and physics performance, ACTS
  - ML based track reconstruction toolkit for triple-GEM and u-RWELL detectors
- Particle Flow
  - Continue to develop state of the art algorithms for neutrino and linear colliders: PandoraPFA, APRIL
  - Develop PF for dual readout calorimeters
- Turnkey Software
  - Integrate software into a working and validated stack
  - Flexibility to rapidly prototype different detector options
  - Management of heterogeneous resources



WP12: turnkey software

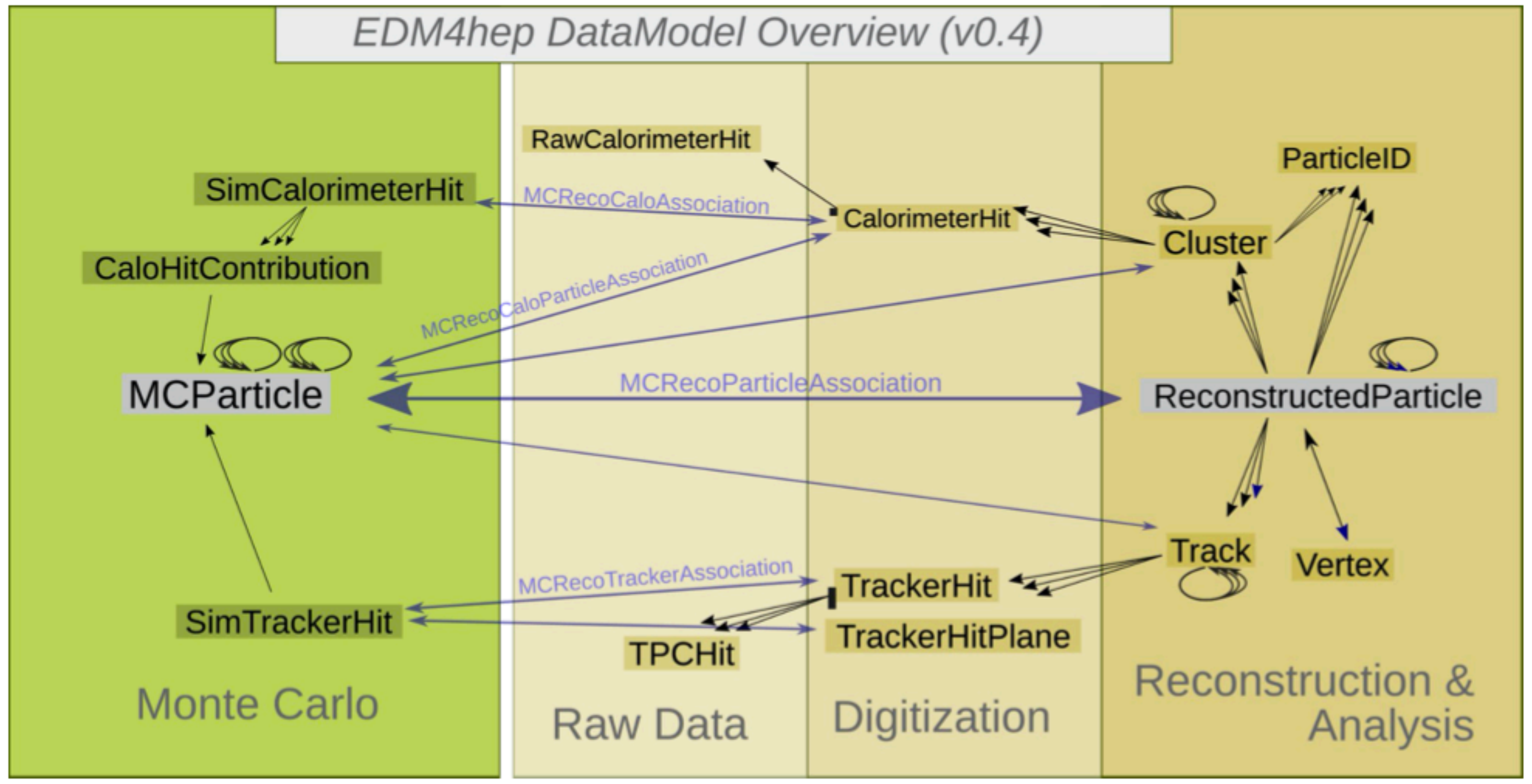
- **Key4HEP**: turnkey software stack for all future collider projects
- Take existing tools where possible
  - A lot of existing software from the shared **iLCSoft** developed by ILC and CLIC
- All major players involved: CEPC, CLIC, FCC, ILC, EIC
- Provide a complete data processing framework
  - Shared components reduce overhead for all users
- Supported by HSF, CERN EP R&D and AIDAinnova

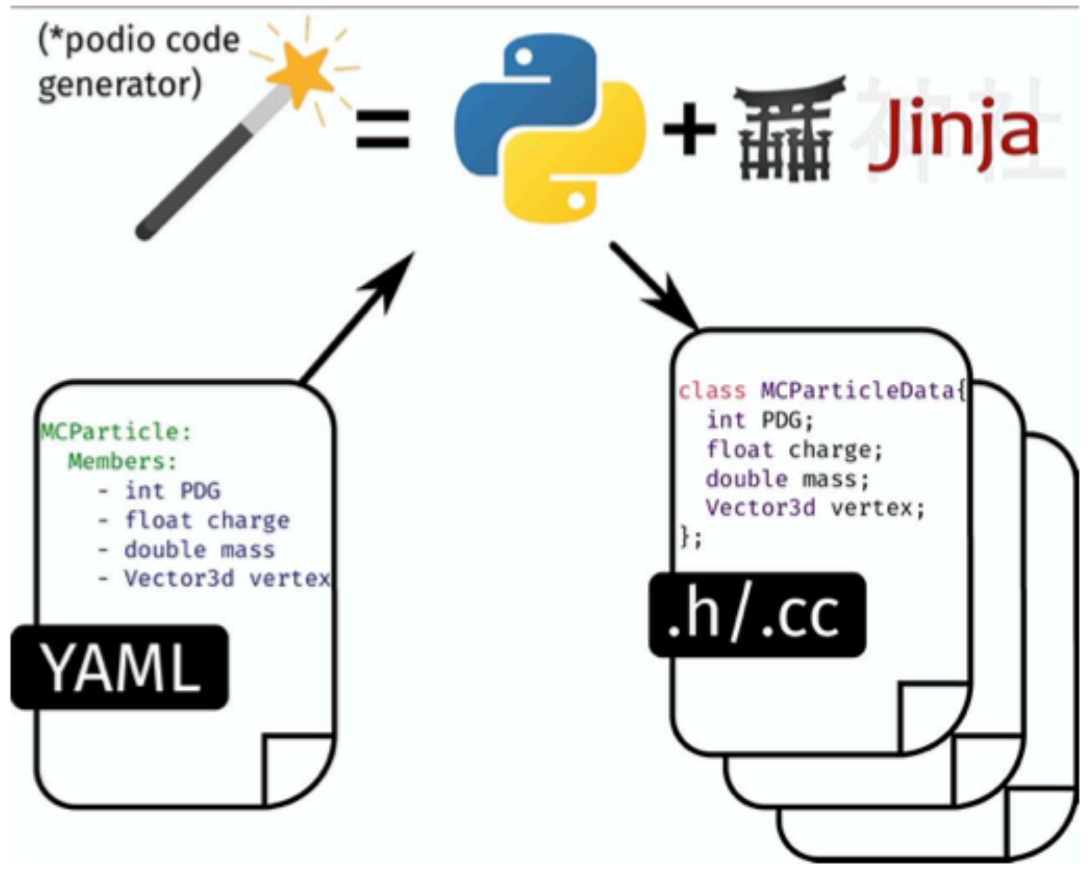


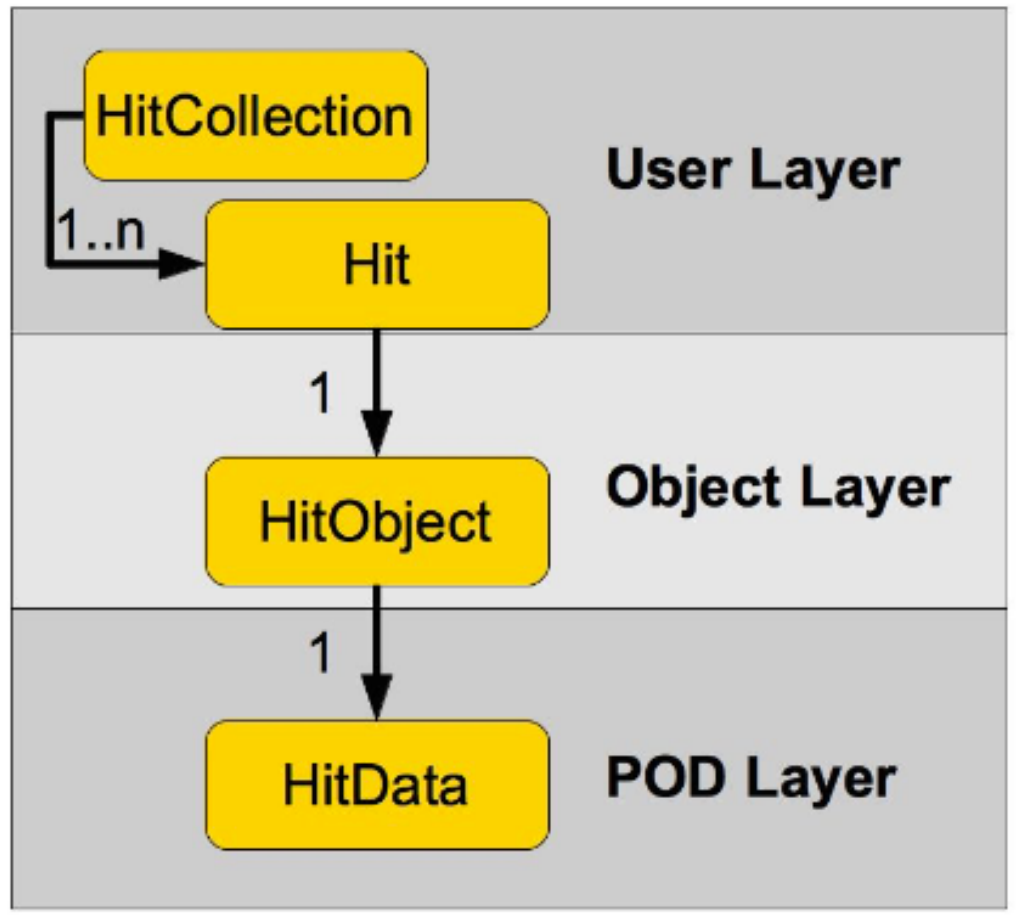


WP12: turnkey software

- **EDM4hep** defines the common language for all **Key4hep** components to communicate
  - Heavily inspired by **LCIO** successfully shared by ILC and CLIC
  - Additional novel ideas from fcc-edm
- Generated by the **PODIO** EDM toolkit
  - *Main functionality exists*
  - *Aiming for prod. Release v1.0*
  - *Need schema evolution, event frames and thread safety ....*







WP13 Prospective and Technology-driven Detector R&D

Prospective and Technology-driven Detector R&D: → support blue-sky research

Call for proposals in 2021: 550 kEUR in total (+25% overheads), 2-4 projects, 3-year projects, small consortia, require modest matching funds.

Received 15 proposals (novel semiconductor detectors - 6, rad hard silicon – 3, gaseous detectors – 2, light detection ar scintillators - 3, DAQ - 1)

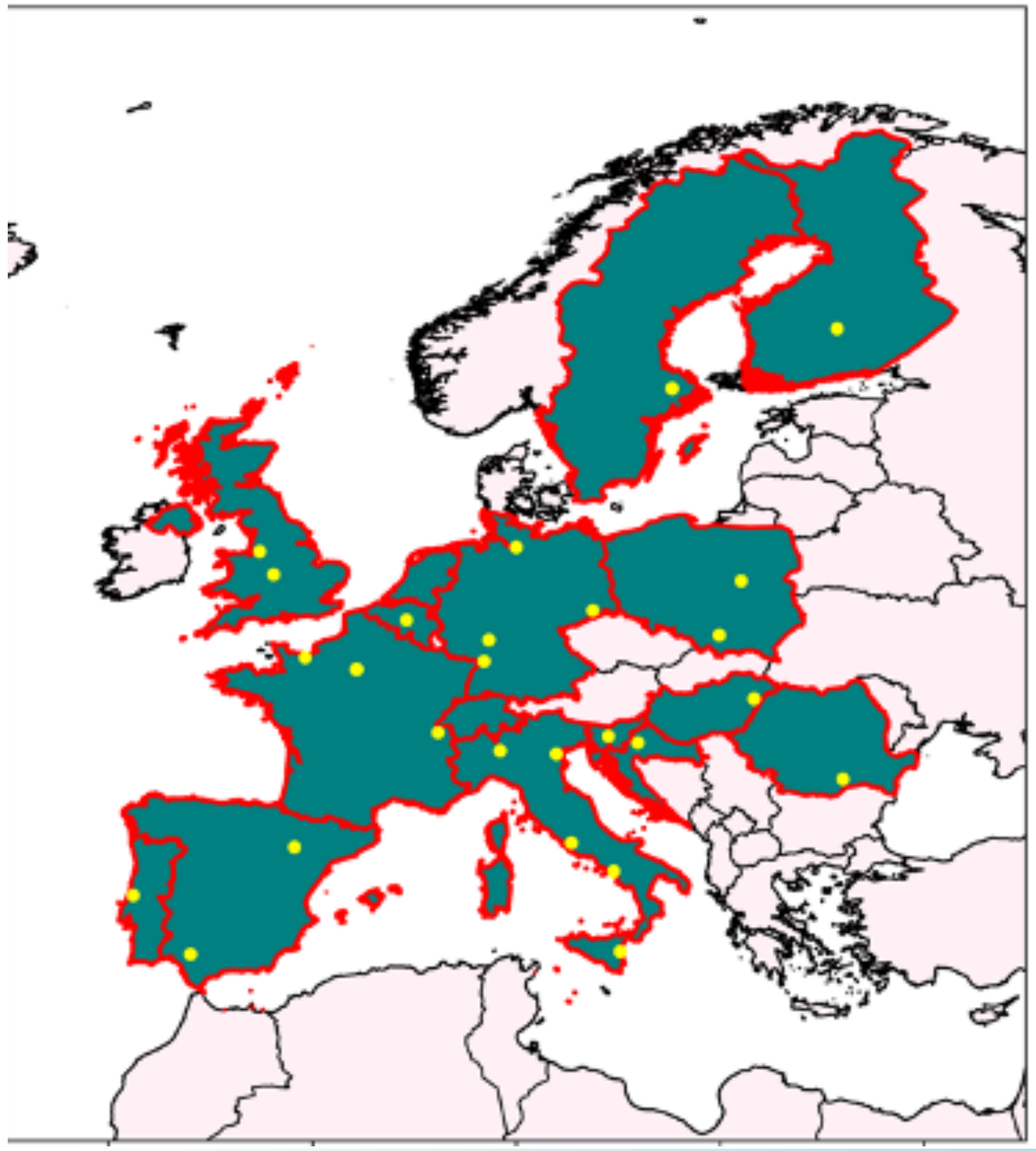
Selection: committee a combination of WP conveners and external experts: Felix Sefkow, Daniela Bortoletto, Paolo Giacomelli, Peter Križan, Christophe de la Taille, Christian Joram, Kevin Einsweiler, Niko Neufeld, Bernhard Ketzer. Two phases, second phase with interviews.

Selected 4 projects

- Thin Silicon Sensors for Extreme Fluences
- The Silicon Electron Multiplier, a new approach to charge multiplication in solid state detectors
- Development of fine-sampling calorimeters with nanocomposite scintillating materials
- Wireless Data Transfer for High-Energy Physics Applications

AIDAinnova associated EU projects

EURO-LABS
EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES



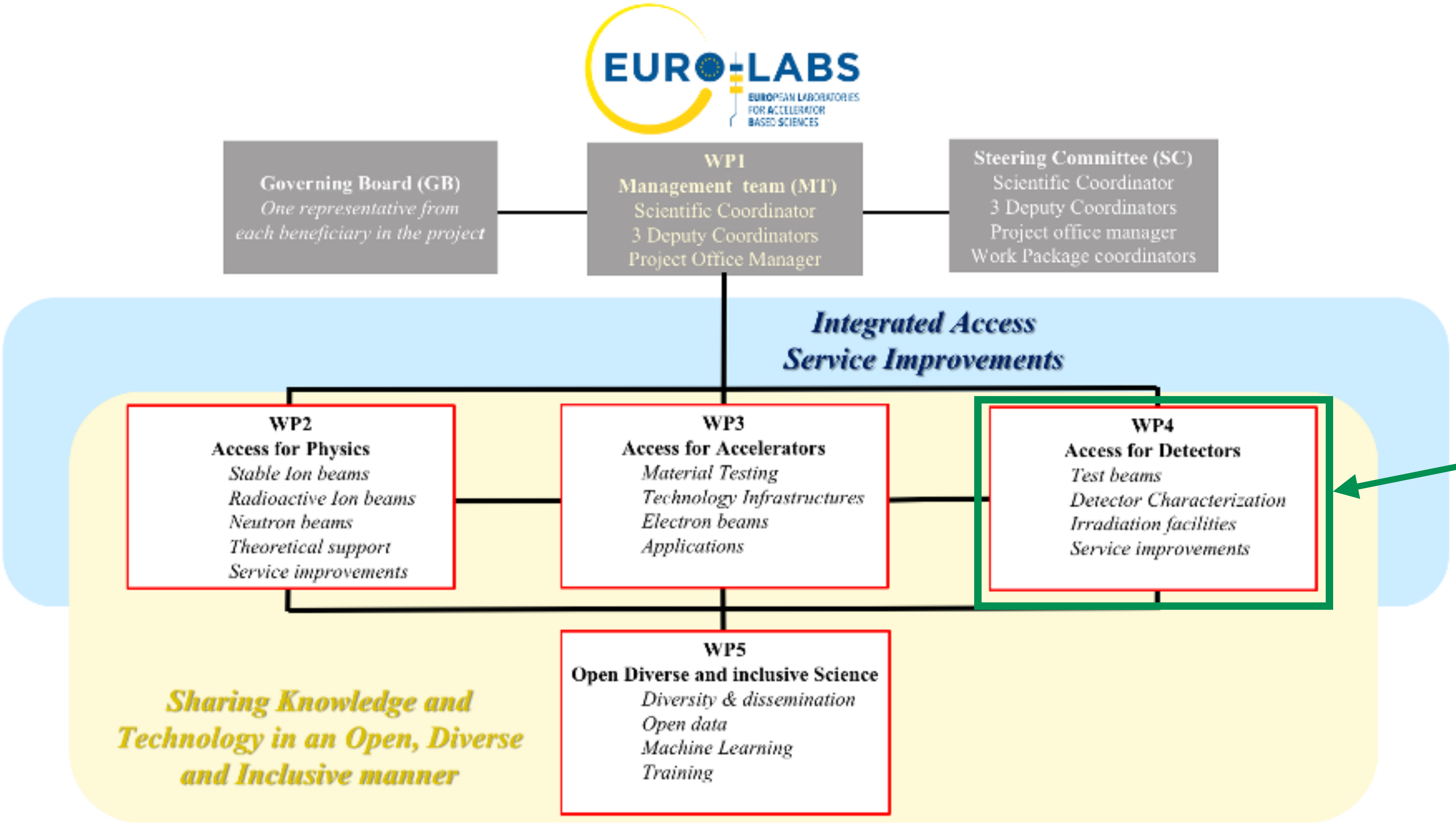
Horizon Europe call for Research Infrastructure (RI) services
HORIZON-INFRA-2021-SERV-01-07

EURO-LABS is a consortium of thirty-nine Research Infrastructures (RIs) from twelve countries in Europe

Finland in the north and Italy to south to Romania in the east and Portugal in the west

- **First joint EU proposal between Nuclear Physics, HEP accelerators and HEP detectors!**

EURO-LABS structure



EURO-LABS is a project that mostly provides funding for Transnational Access (TA) to Research Infrastructures (RI). For us this means test beams and irradiation facilities.

Total EURO-LABS EU funding: **14.5 M€**

WP4: Access for detectors

- **CERN**
  - **PS, SPS, IRRAD, GIF++**
- **DESY**
  - **Testbeam**
- **PSI**
  - **PiM1, UCN**
- **RBI**
  - **RBI-AF**
- **ITAINNOVA**
  - **EMC-Lab**
- **JSI**
  - **Triga**
- **IFJ PAN**
  - **AIC-144**
- **UCL**
  - **HIF-LIF-NIF**
- **UoB**
  - **MC40**

INFN is the coordinating institute of EURO-LABS.

The Project Office (PO) of EURO-LABS will be at INFN Bologna.

P.G. is the Project coordinator and Project Office manager.

Marko Mikuz is the WP4 coordinator.

EURO-LABS timeline

- **Deadline of the call: 23/09/2021**
- **Results of the evaluation: 18/01/2022**
- **Grant agreement: 31/03/2022?**
- **Beginning of the Project: 01/09/2022**
- **Duration: 01/09/2022 - 31/08/2026**

Budget for WP4: ~2.8 M€ (+25% overheads)

Conclusions

- AIDAinnova is the largest EU program on R&D for HEP detectors
  - Lots of activity ongoing
  - Many areas of interest to FCC-ee
  - Roughly 30% of AIDAinnova's budget is for R&D for Higgs factories
  - AIDAinnova aims at improving the connections and synergies with other existing detector R&D programs
    - CERN's EP R&D program, national programs, etc.
- A new EU project, Euro-Labs, that will fund Transnational Access to Test beams and irradiation facilities will start in September of this year.
- FCC-ee should continue to collaborate closely with AIDAinnova and profit of Euro-Labs when it becomes available