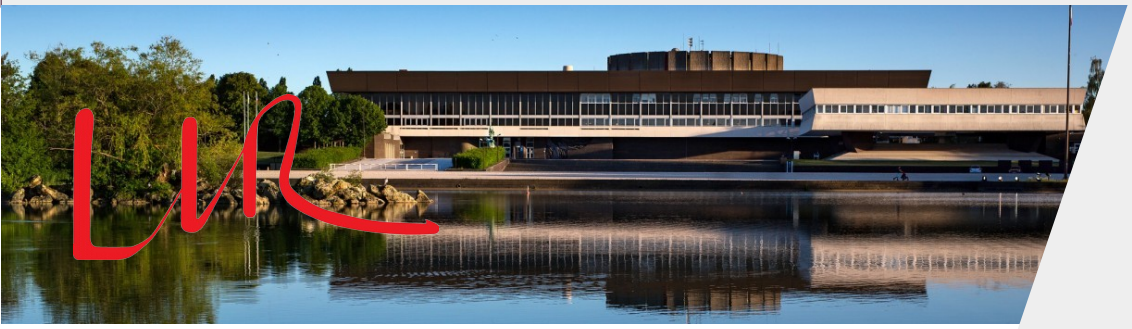
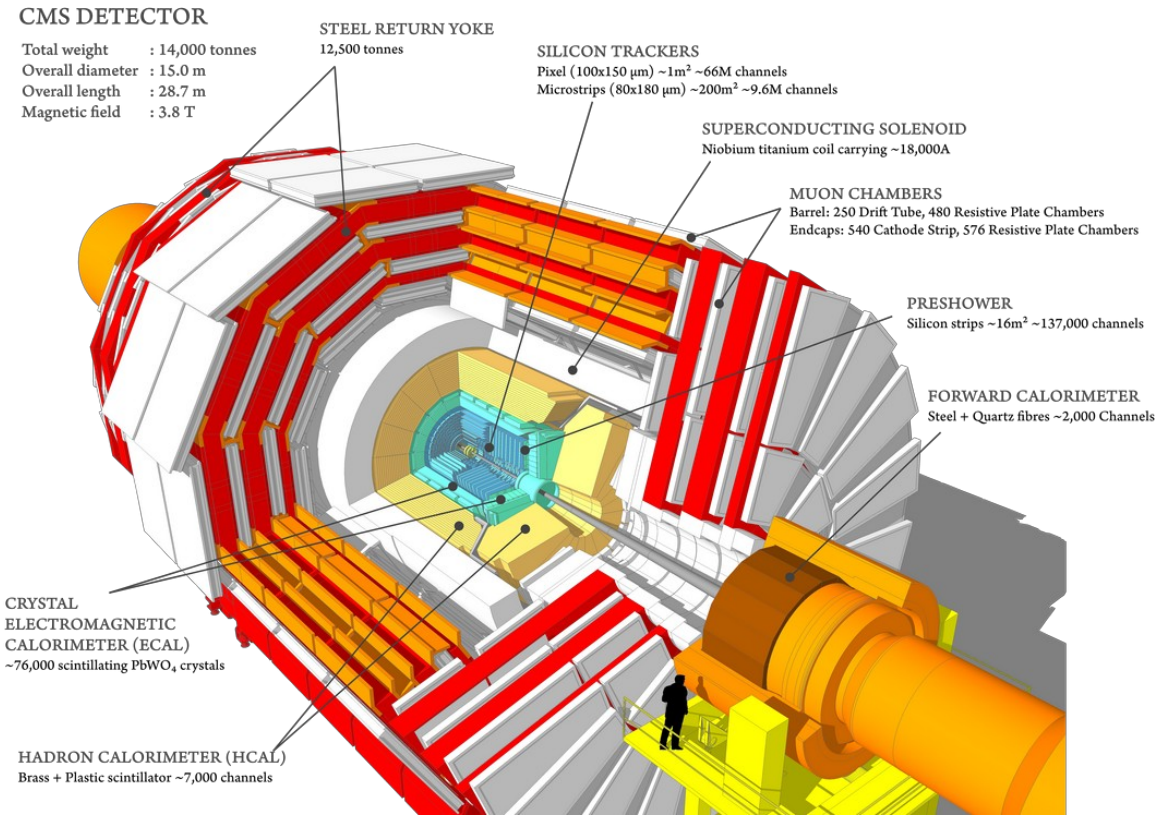
Tourniquet LLR
CMS HL-LHC (HGCAL)

J.-B. Sauvan
LLR CNRS / École Polytechnique

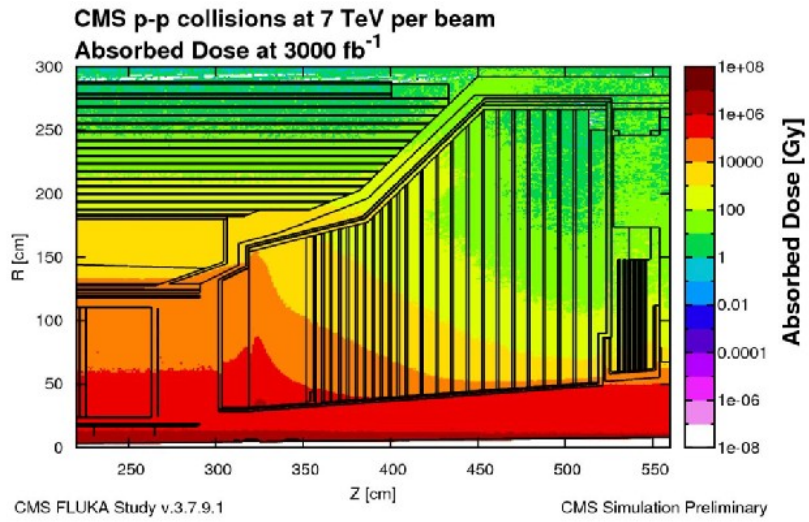


Why the HGCAL?

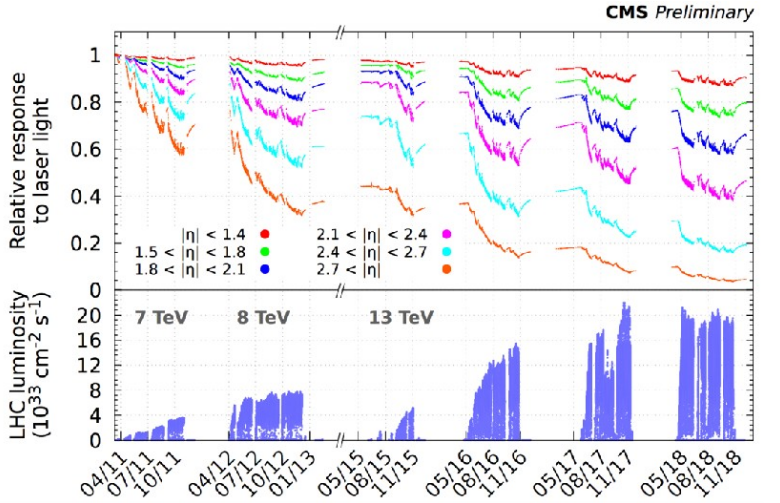
- CMS endcap calorimeters must be replaced
- ☢ ECAL crystals and HCAL scintillators suffer from **irreparable damages** after 500fb^{-1}



Absorbed dose at the end of HL-LHC

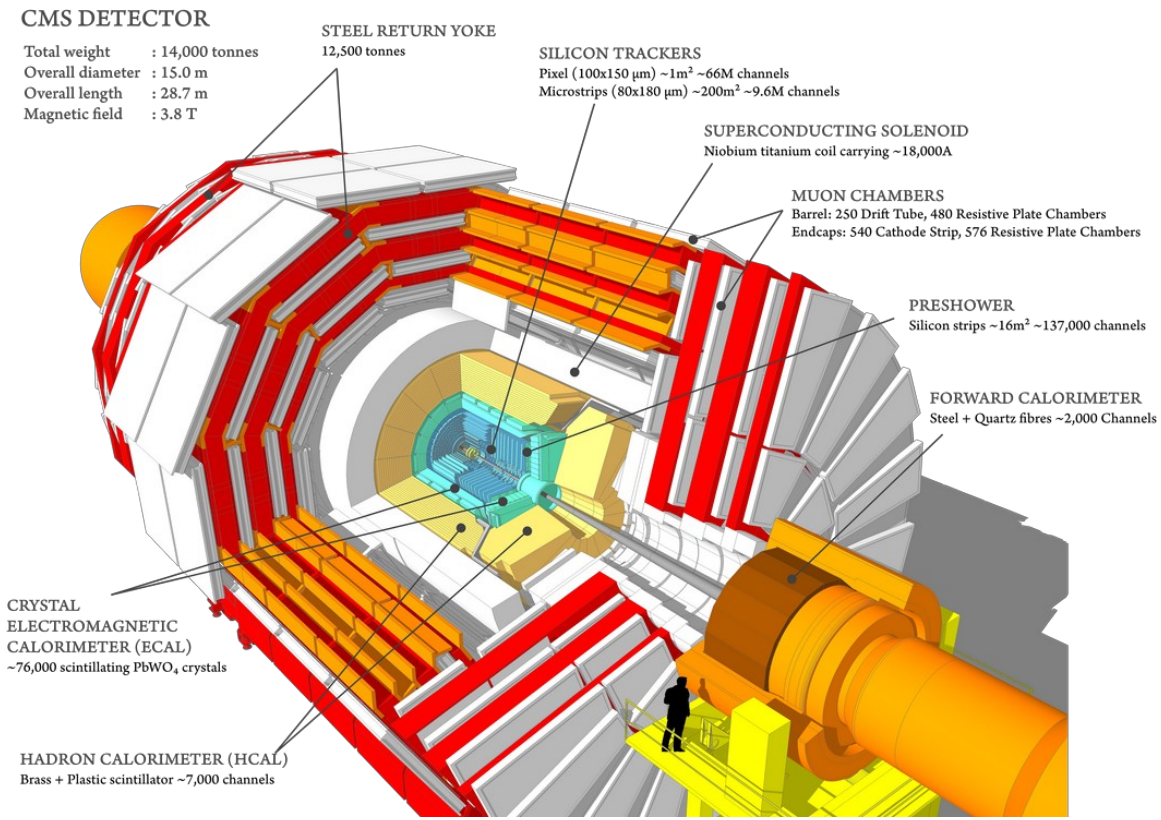


Transparency loss of ECAL crystals

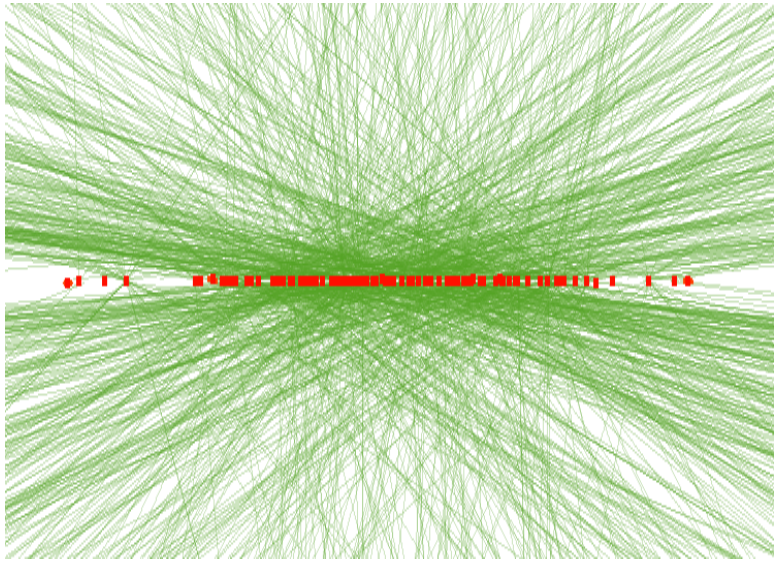


Why the HGCAL?

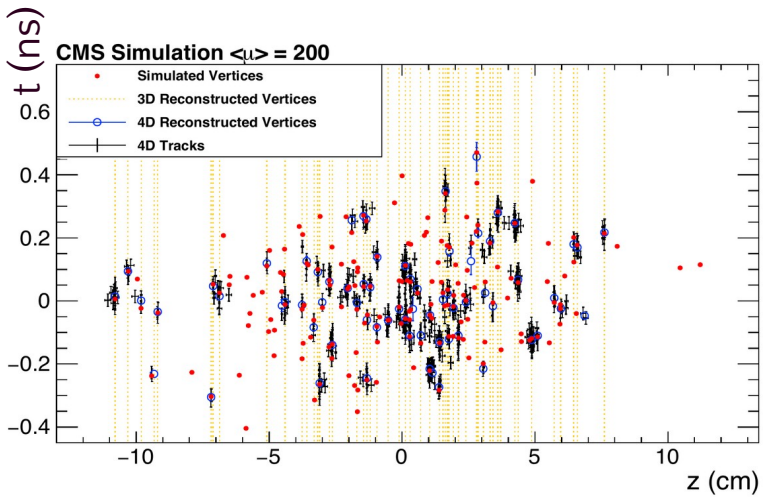
- Ability to disentangle simultaneous collisions
- **High granularity**
- **Precise timing** information



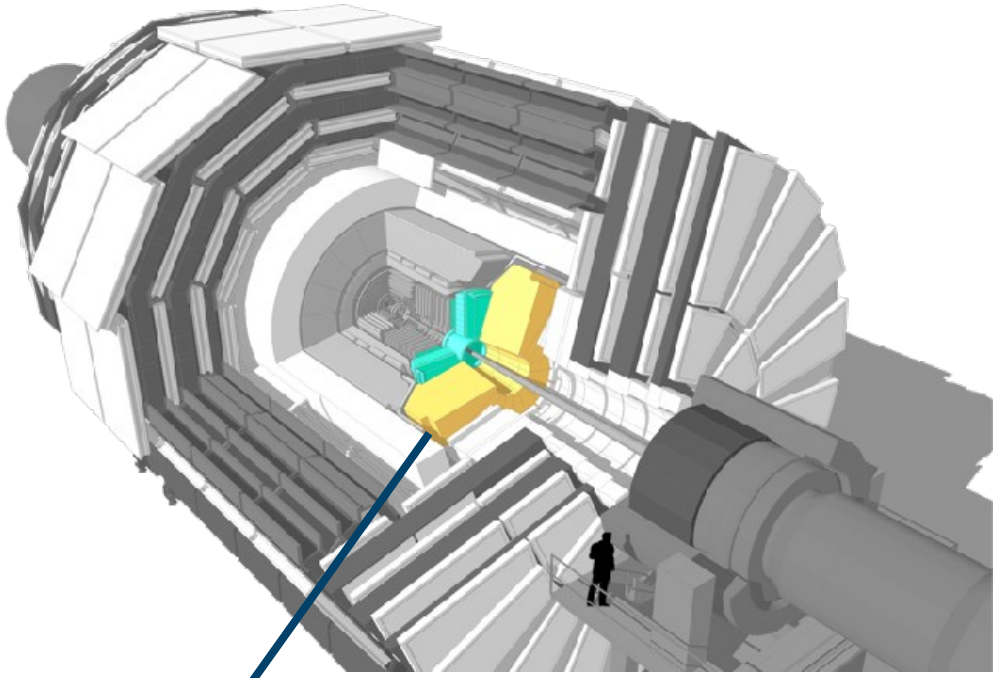
140 PU interactions event

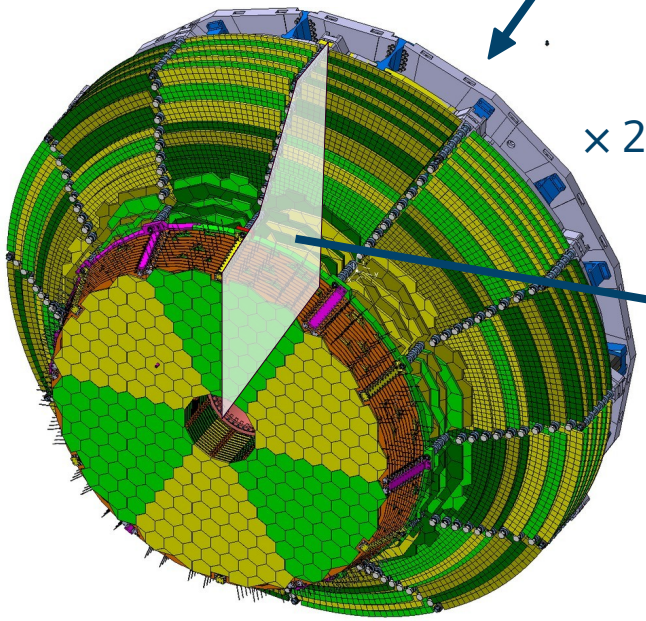


Space-time view of interaction vertices

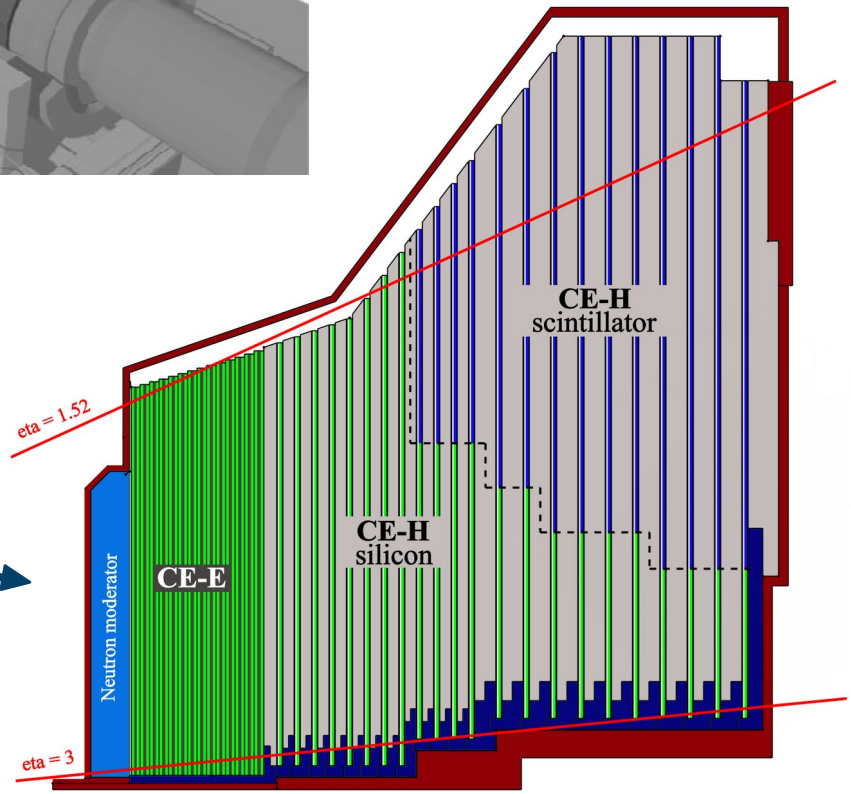


The High Granularity CALorimeter

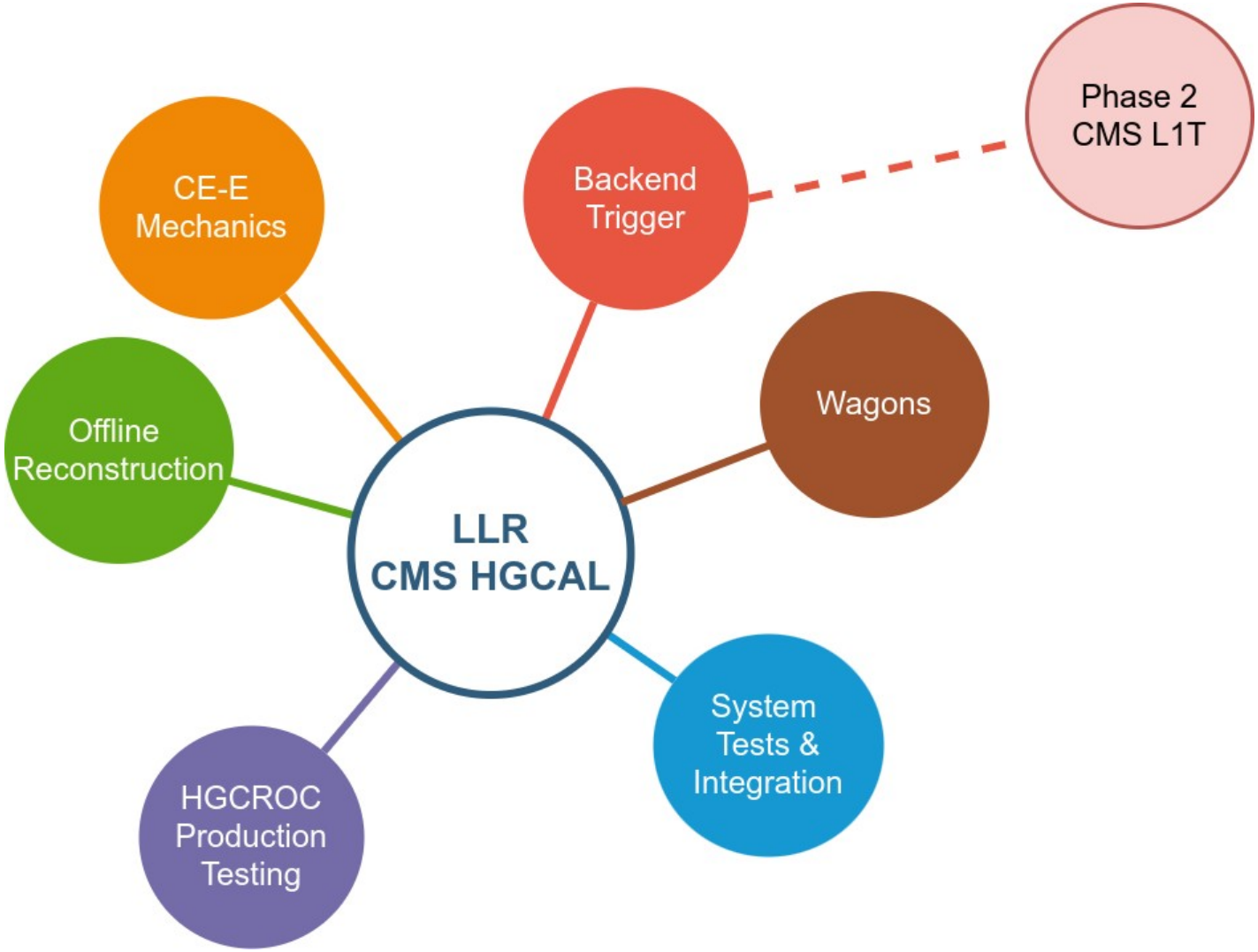




× 2

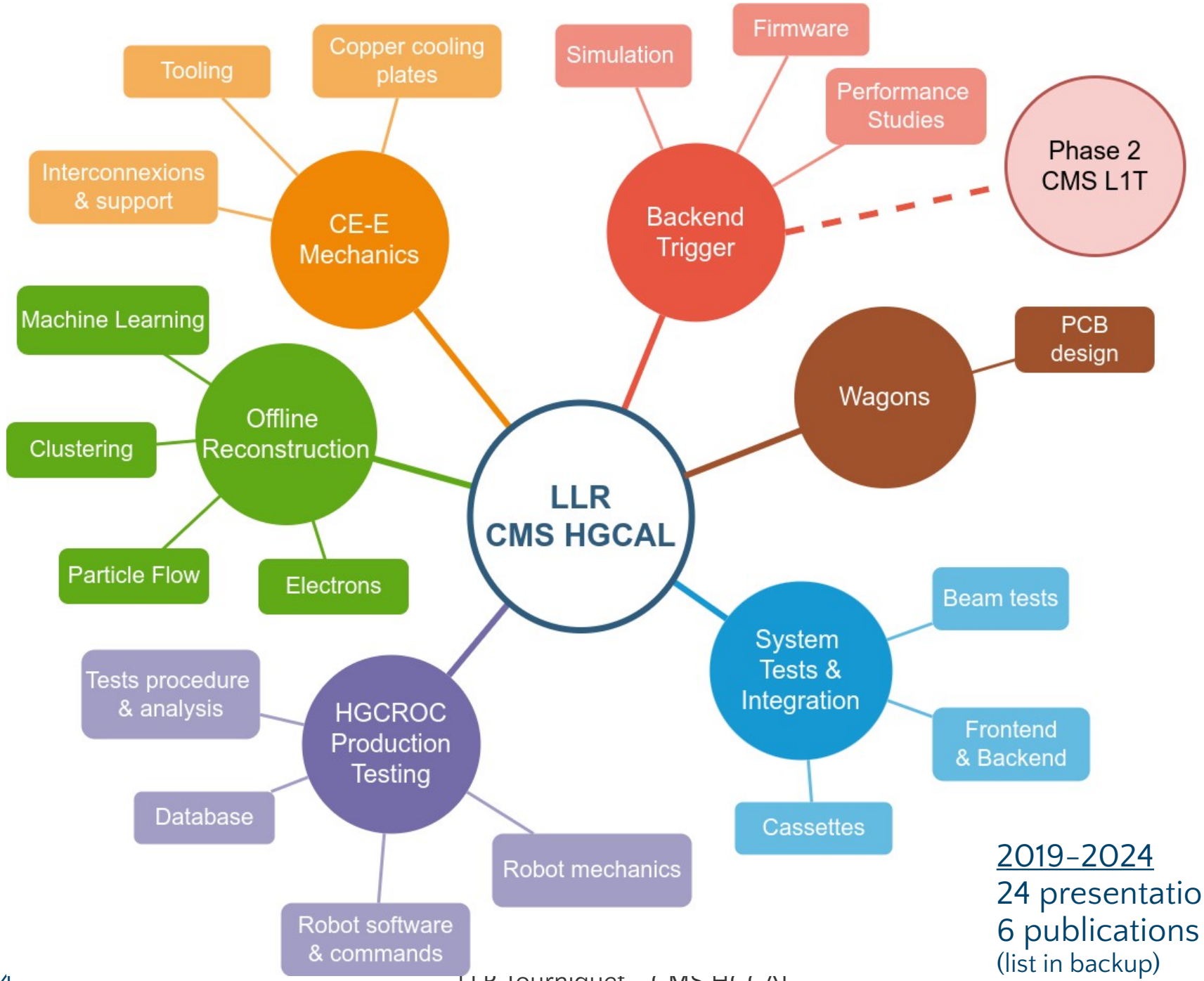


The HGCAL @LLR



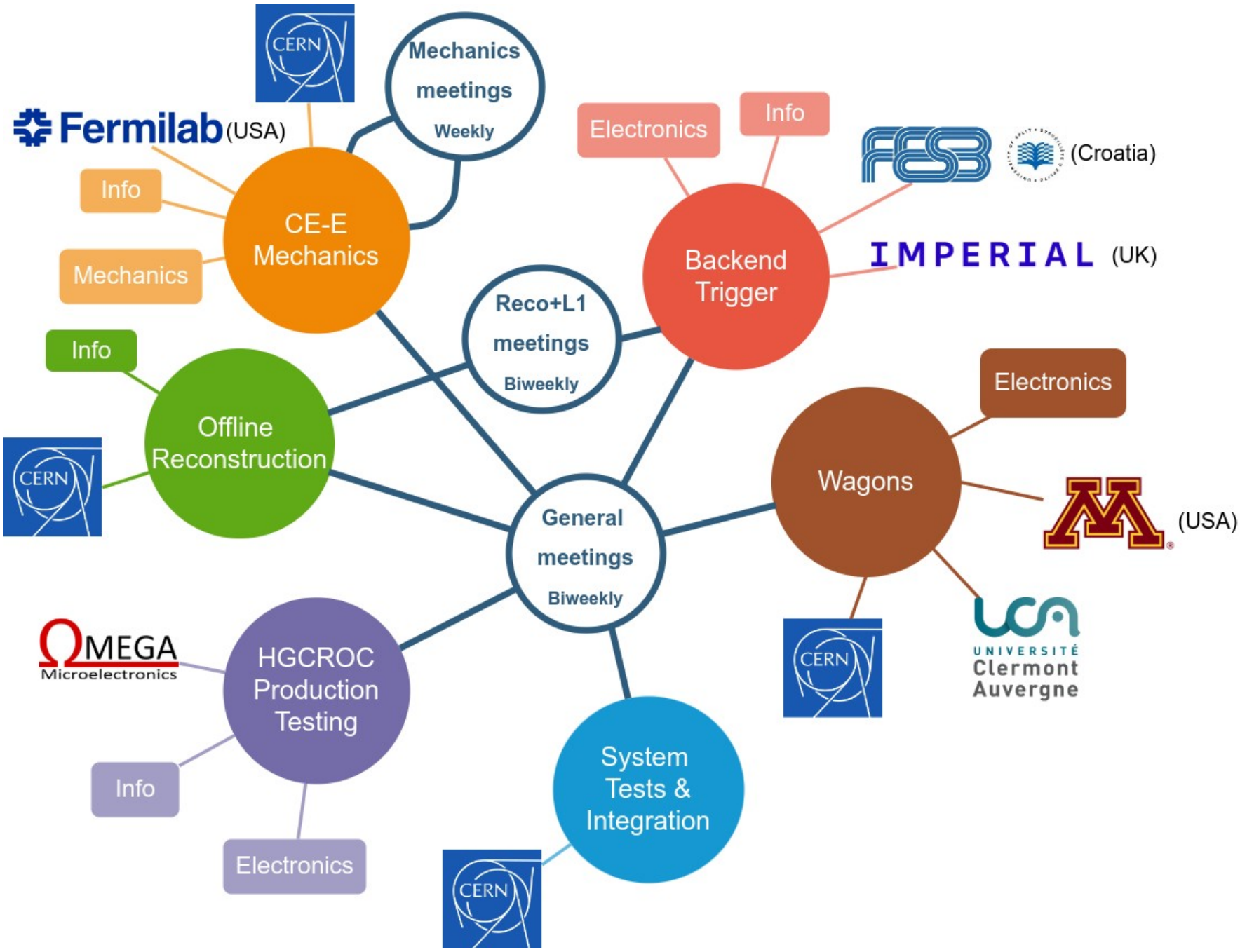
2019–2024
24 presentations in conf.
6 publications
(list in backup)

The HGCAL @LLR



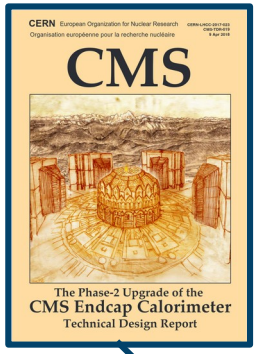
2019-2024
24 presentations in conf.
6 publications
(list in backup)

Connections, Meetings and Collaborations



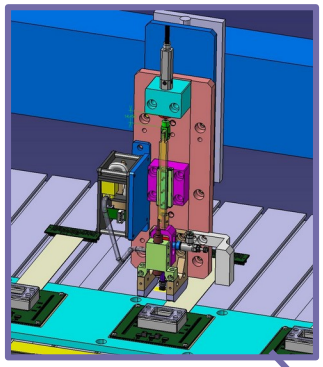
Some milestones

HGCAL TDR

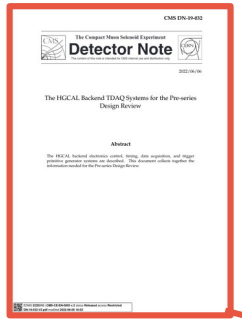


Tourniquet

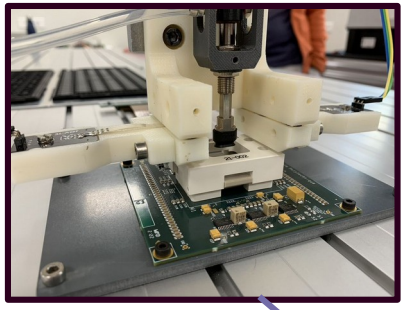
Starting HGCROC testing robot design



Backend Pre-Series Design Review

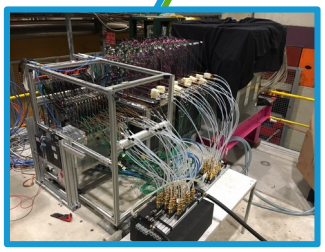


Two HGCROC robots finalized

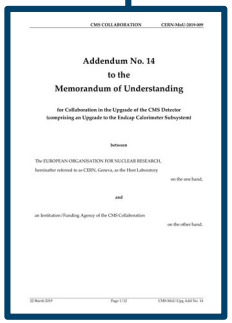


Beam tests with Backend

18 19 20 21 22 23 24



Beam tests 2018



Signature MoU

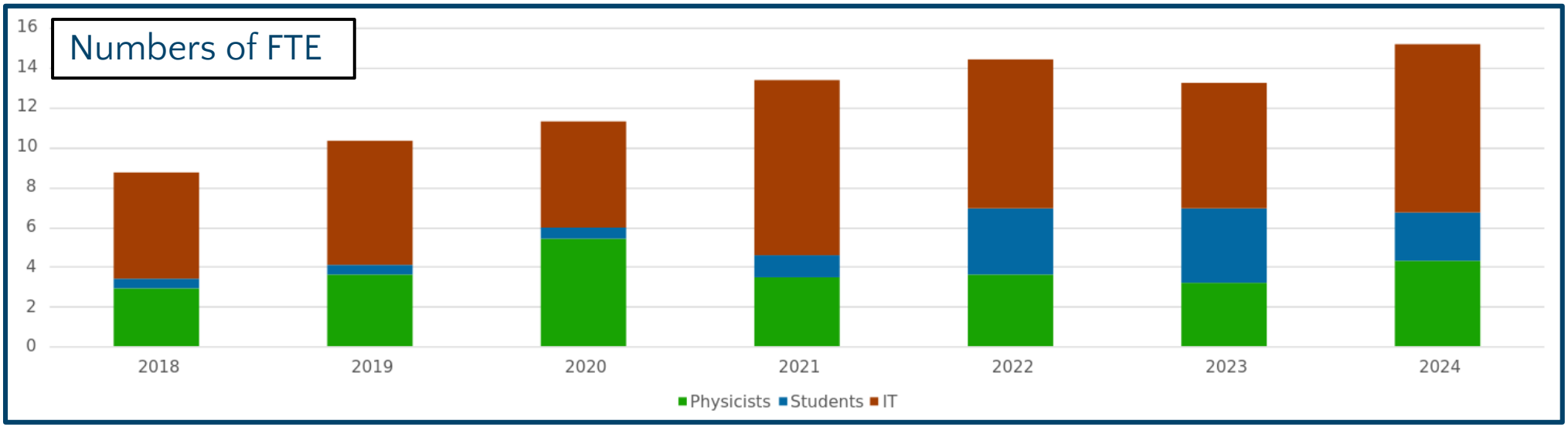
Reorganization mechanics workshop

1st CE-E cooling plate produced at LLR

1st HD wagon prototype

Copper procurement contract signed

Human resources



P2IO HIGHTEC

ANR HiGranTS

LLR-IC PhD

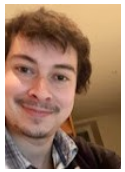
18 19 20 21 22 23 24

PhD students with HGCAL contributions


M. Prvan


C. Martin Perez


M. Bonanomi


A. Hakimi

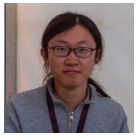

A. Buchot Perraguin


A. Tarabini


J. Motta

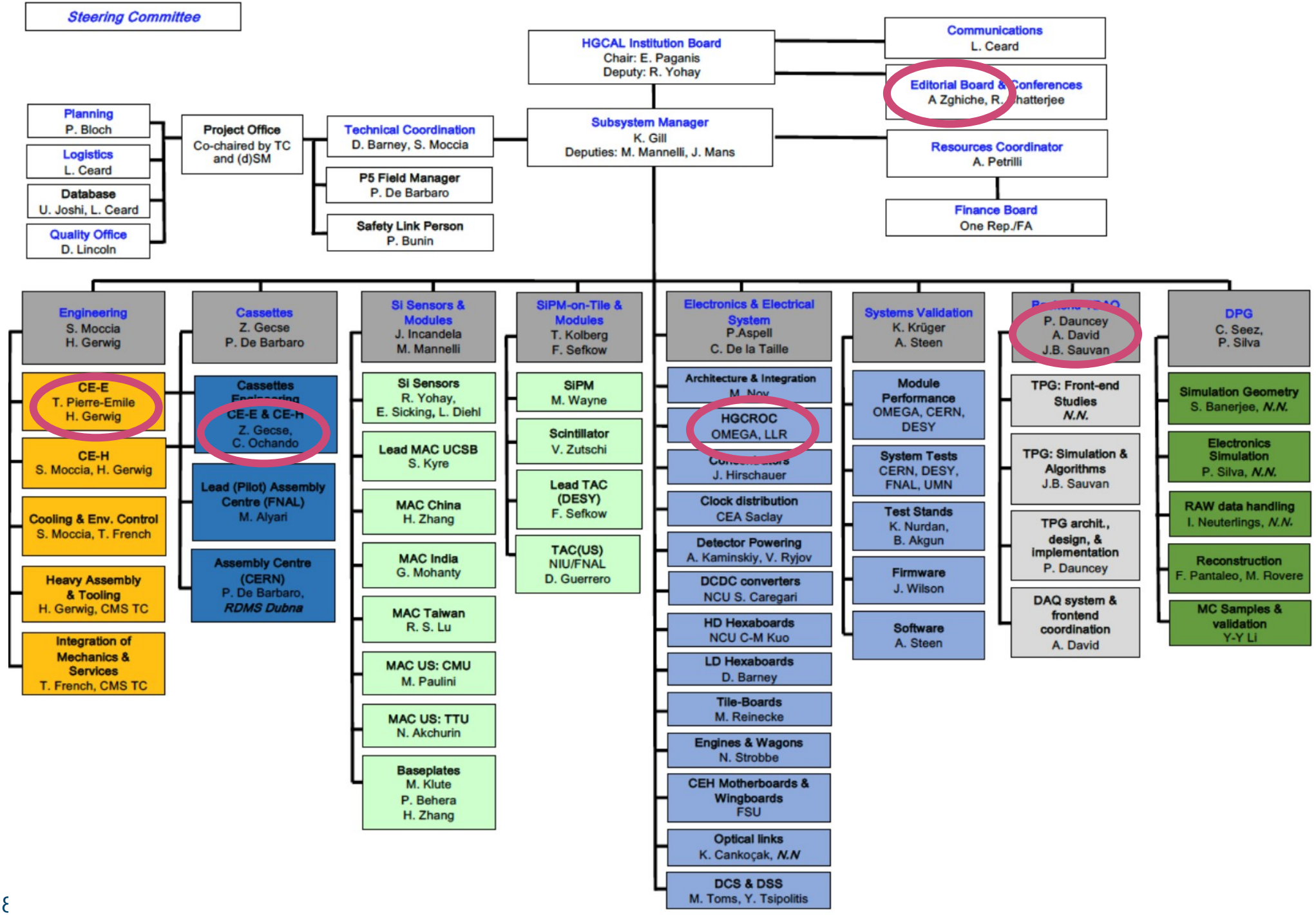

E. Vernazza


B. Alves


G. Liu

Since several years, all our PhD students as well as postdocs contribute significantly to HGCAL

HGCAL Organigramme



CE-E Mechanics

Physicists


F. Beaudette

RS


C. Ochando


Y. Sirois

IT


A. Bonnemaison


A. Cauchois


A. Chiron

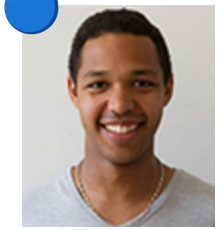

V. Davouloury


G. Le Barbu


A. Mahjoub


C. Massa

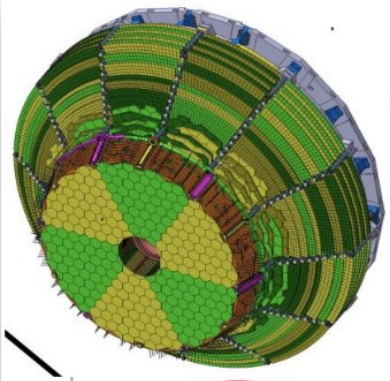
RT


T. Pierre-Emile


F. Saadi


M. Sidibé

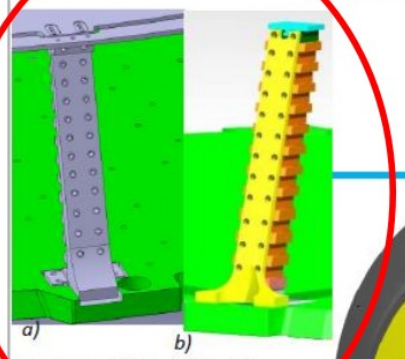

E. Wanlin



CE-E Mechanics / Cassette: Involvement at LLR

CE-E Cassettes (Cu plate+Si modules+electronics) stacked horizontally, with Pb sheets in between, starting from SS back-plate,

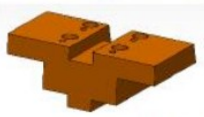
LLR



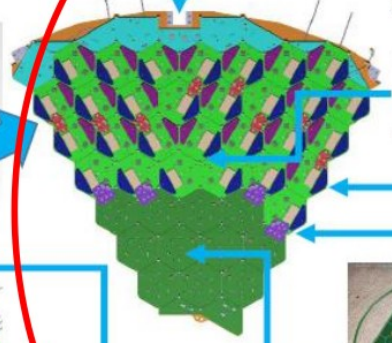
2 types of Z bars (x 12)
a) : Interconnecting Zbar (x6)
b) : Central Zbar (x6)

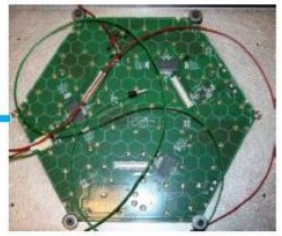
LLR

Central bracket (x 78)

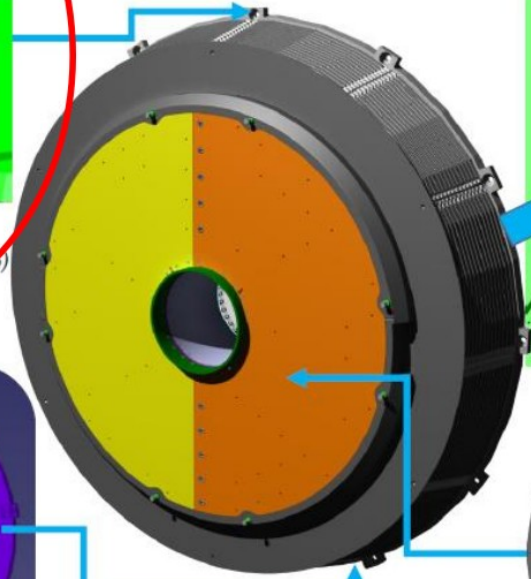


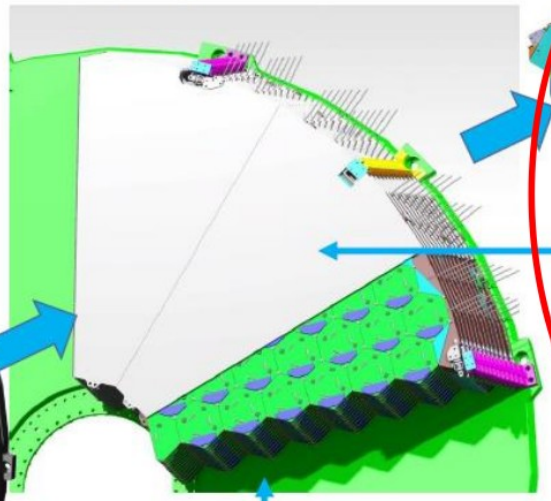
3 major types of Spacers



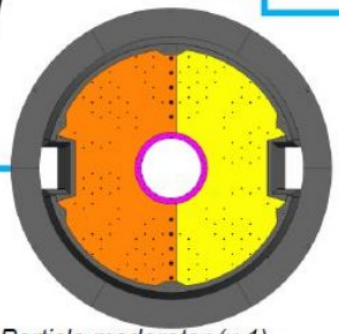


Several module types (**)



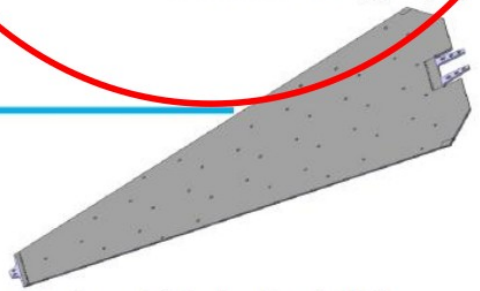


CE-E back plate (x 1)



Particle moderator (x 1)

Central support structure (x 1)



Lead sandwich absorber (x 156)

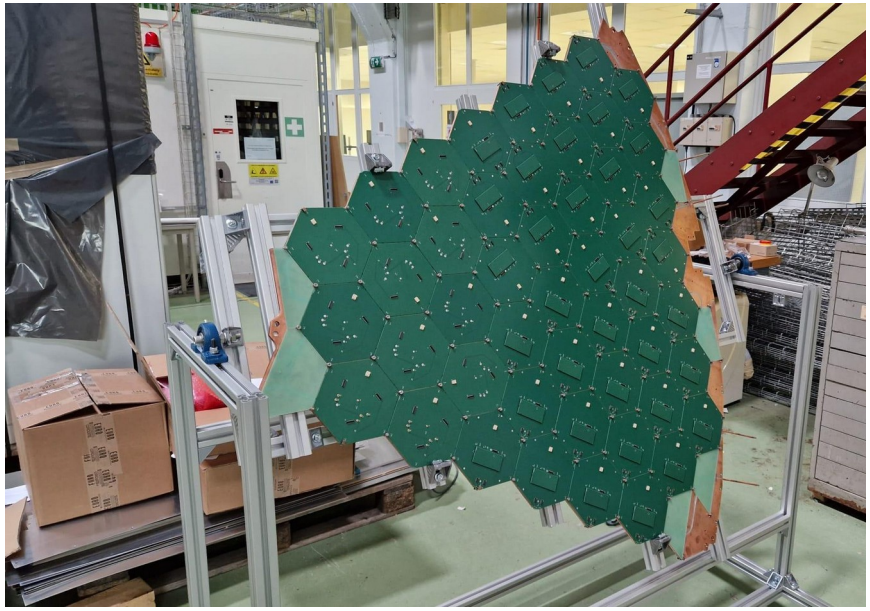
LLR : general design of CE-E (with CERN)
+ responsibility: Cu cooling plate, interconnexions (“Z-bars”), module fixation

Copper cooling plate

2019
1st copper plate 1:1 scale
Produced by external company

2023
1st copper plate prototype produced @LLR

Including cooling pipe soldering
Assembly of dummy modules @CERN



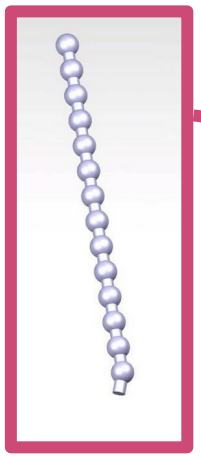
Interconnecting and supporting elements

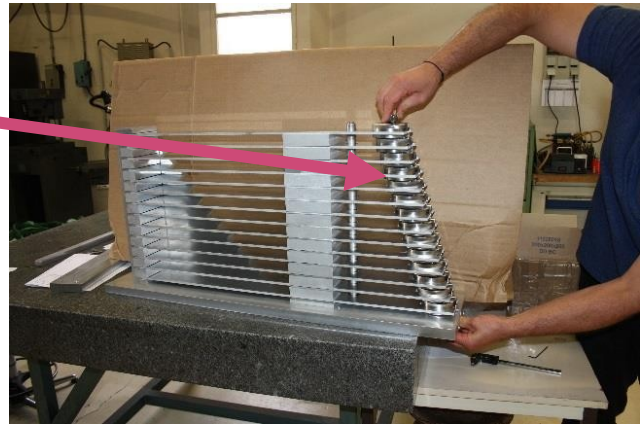
2019: First prototypes

Modules spacers

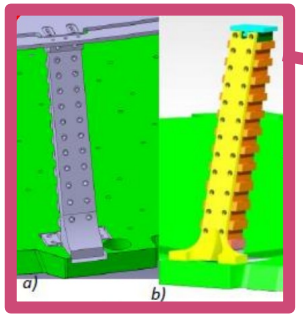
ϕ interconnection

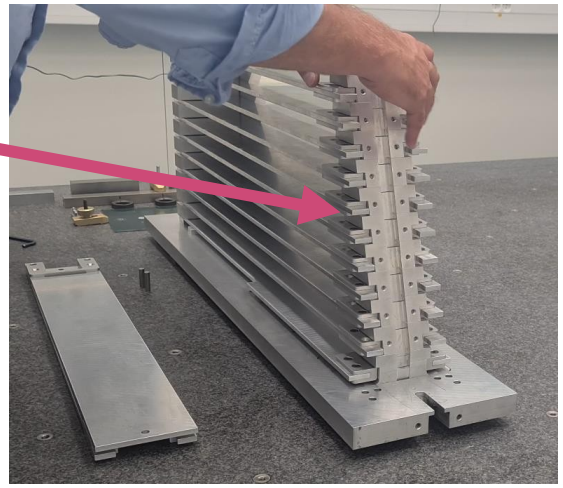
Interconnection z-bar

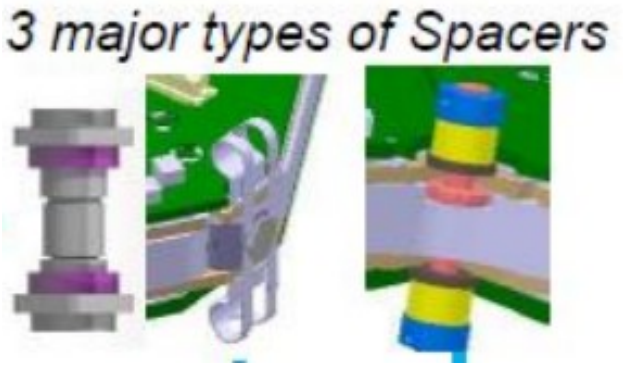




2021: Final prototypes

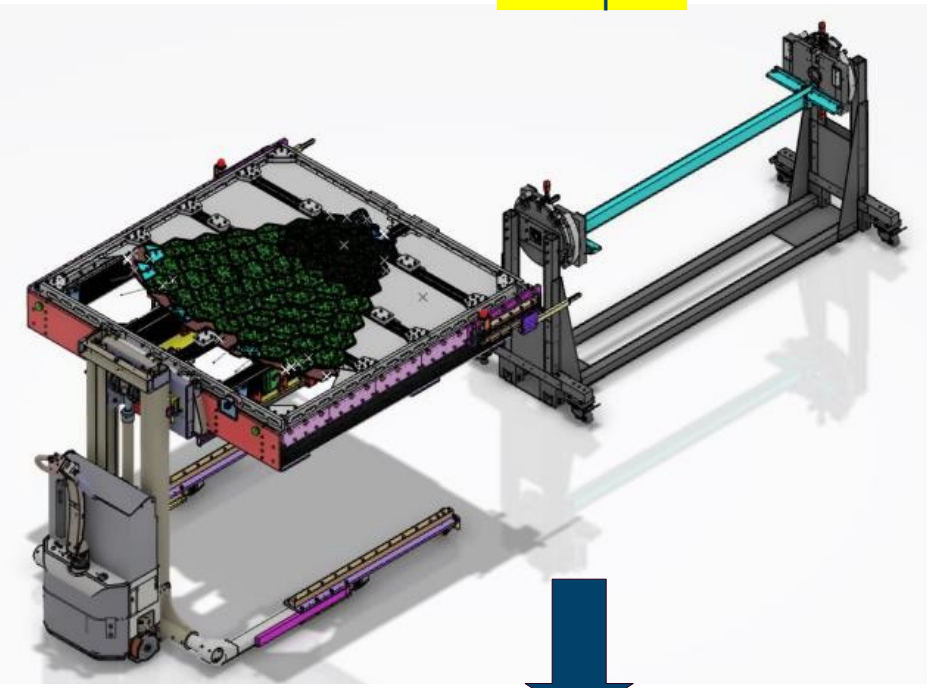




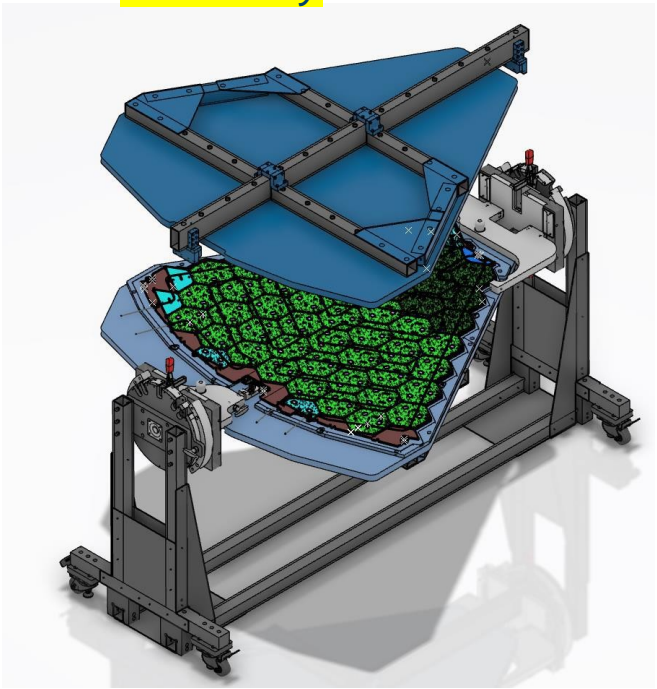


Handling tools for Cassette Assembly Center

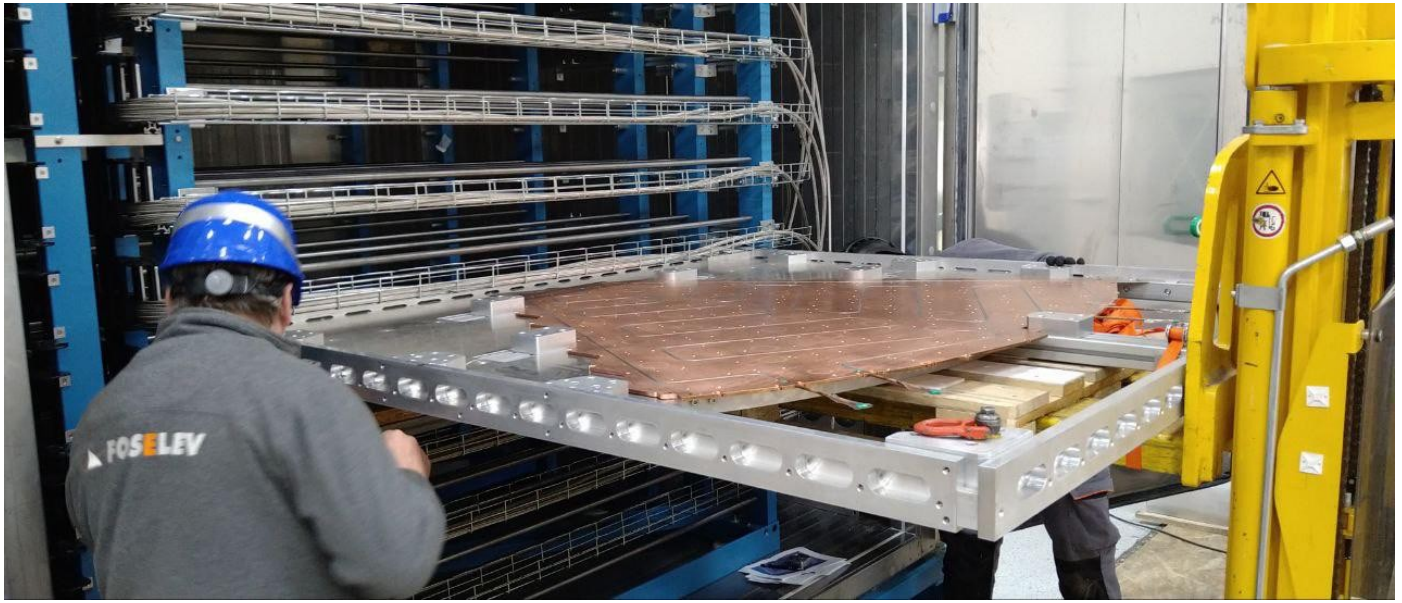
Forklift and cassette transport frame



Assembly table



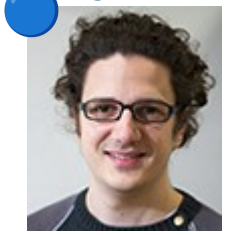
Cassette frame prototype insertion inside cassette testing coldbox



HGCROC production tests

Physicists

RS



O. Davignon

S. Obraztsov

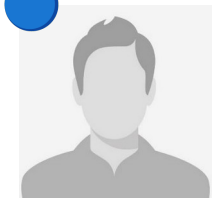
PhD Students

L. Kalipoliti

IT

A. Mahjoub

RT

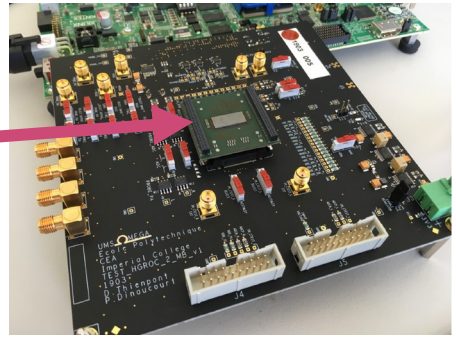


L. Eychenne

Testing automation

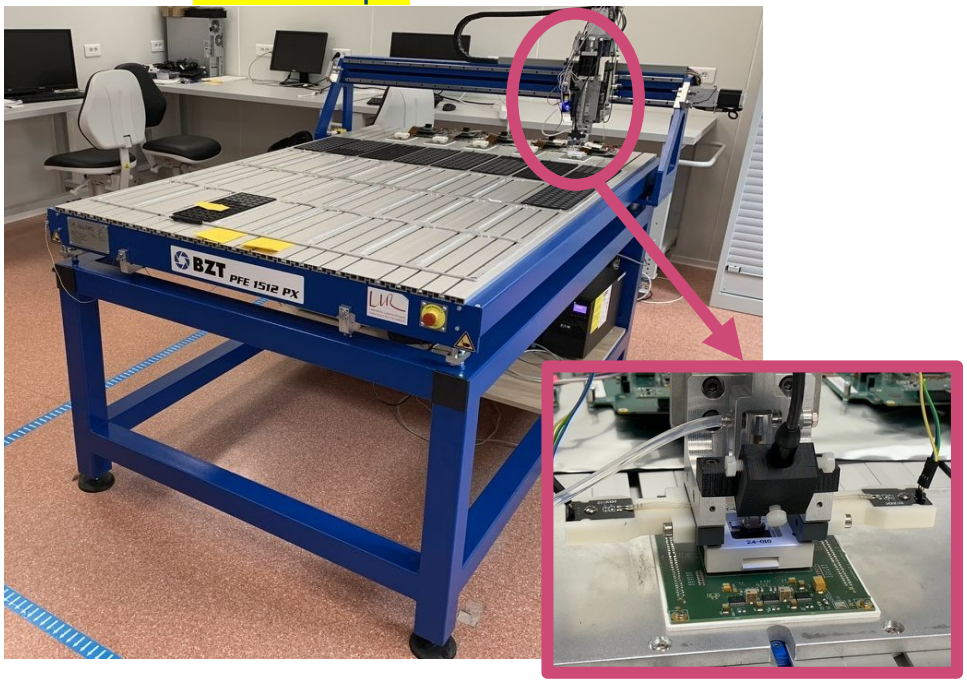
Low Density (LD) and High Density (HD) HGCROC chips

≤ **2021**: Testing of several 100's HGCROCs manually



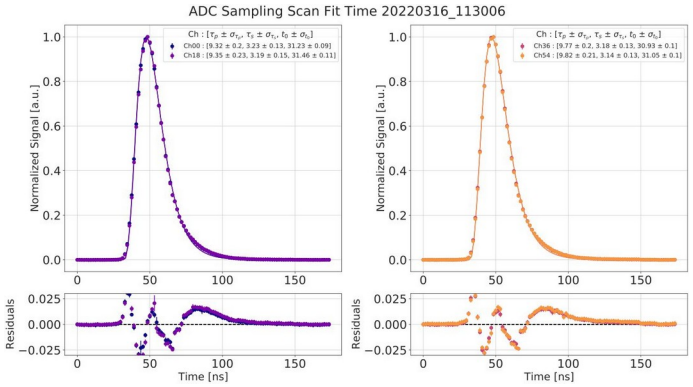
≥ **2022**: Batch testing with robots at LLR and then Omega
Experience gained and improvements towards production
150k chips to be tested

The robots we were looking for for the production testing



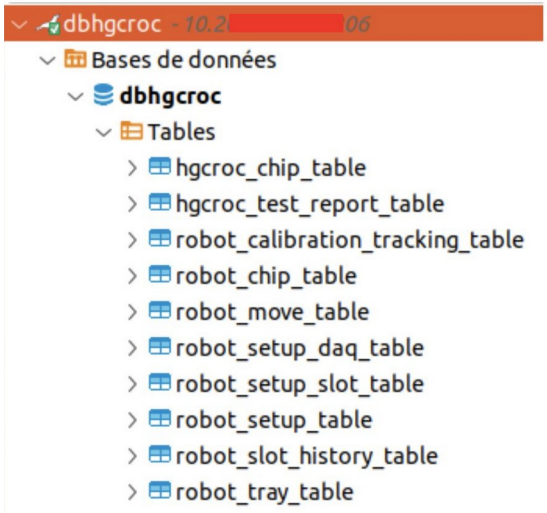
Robots are cool, but there's more than that

Detailed characterization of the different versions of the chip
Including irradiated chips

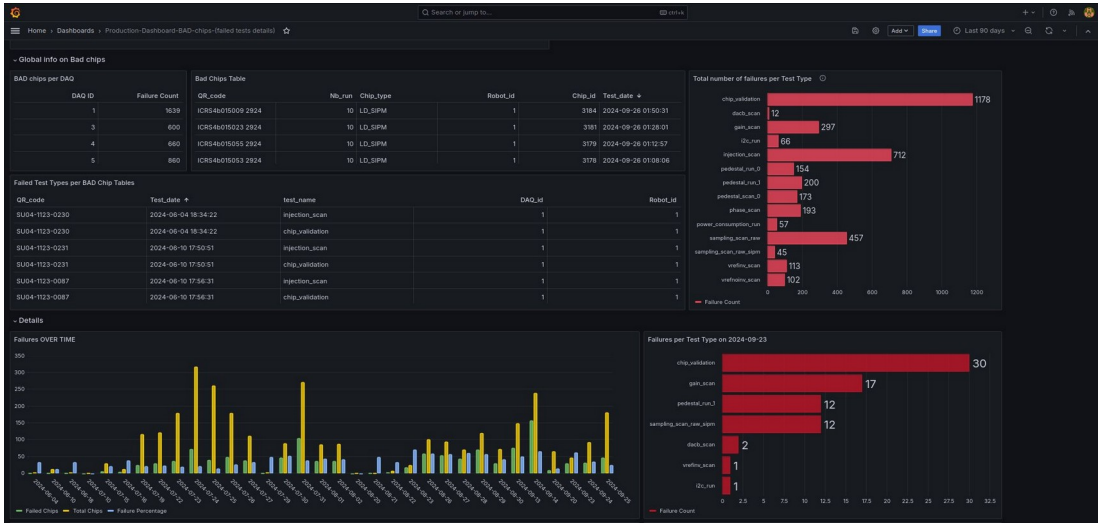


CMS Award to Elena Vernazza for her contributions on the HGCROC characterization

Database developments towards the production



Development of monitoring and visualization tools



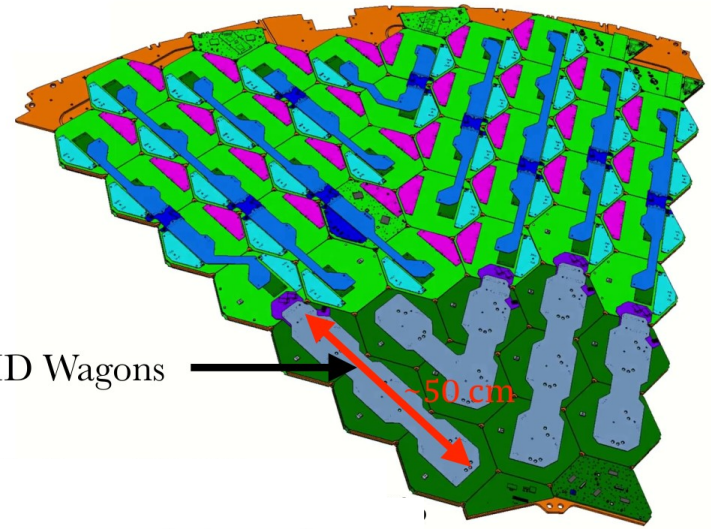
HD Wagons design

RT

O. Le Dortz

IT

with LPC Particules pLasmas Univers applicationS Laboratoire de Physique de Clermont



2023

Help asked by HGCAL management

Design of the HD wagons PCBs

Long PCBs (35-50 cm) with ~10 variants

	Name	Code	N (full detector)	Engine Type	Image w/ index	Module Index	Module Type	T1	T2	T3	T4	D1	D2	Notes
1	LLR					1	Full	3		2		2		
						2	Full	4		3		2	1	
						3	Full		7		4	3	2	
✓	LLR	WH30B1 1000F4000F5000F50	264	Half		1	Full	2	2			1		
						2	Full	2	3			2		
						3	Full	3	2			2		
	UMN	WH30C1 1000F6000F7040F60	48	Full		1	Full	3		3		2		
						2	Full		7			3		
						3	Full	3		3		2		
✓	UMN	WH30D1 1000F4000F5040F50	348	Full		1	Full	2	2			2		
						2	Full	3	2			3		
						3	Full	2	3			2		
✓	CERN	WH31A1 1000F5000F7000F9005d70	312	Full		1	Full	2		3		1	1	
						2	Full		3		4	2	1	
						3	Full	5		4		2	3	
						4	Semi L/R		4		3	2	1	
	CERN	WH31B1 1000F5000F5000a4040F50	84	Full		1	Full	5				2		
						2	Full		5			2		
						3	Top Half	2	2			1	1	
						4	Full			5		2		
	LLR	WH20A1 1000F5000F50	84	Half		1	Full	3	2			1		
						2	Full	4	1			2		
✓	CERN	WH21A1 1000F6000F9000g80	156	Full		1	Full	3		3		2	1	
						2	Full		7		2	2	2	
						3	Chop Two	4		4		3	2	
✓	UMN	WH21B1 1000F0000F0000g00	156	Half		1	Full		1 DAQ			1		No trigger links are required (used only in even layers). One lpGBT that would normally be a trigger lpGBT will serve instead as a second DAQ lpGBT
						2	Full		2 DAQ			2		
						3	Chop Two		2 DAQ			2		

2024

First prototype designed by LLR and LPC

Backend trigger

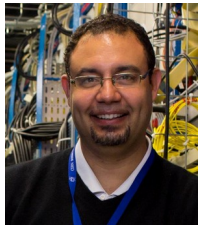
Physicists


A. De Wit


A. Gilbert

RS

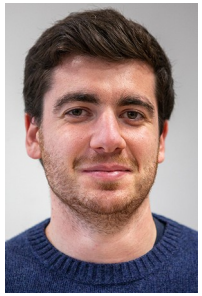

J.-B. Sauvan


A. Zabi


A. Zghiche

PhD Students


R. Amella Ranz


M. Chiusi


T. Debnath


M. Manoni

IT

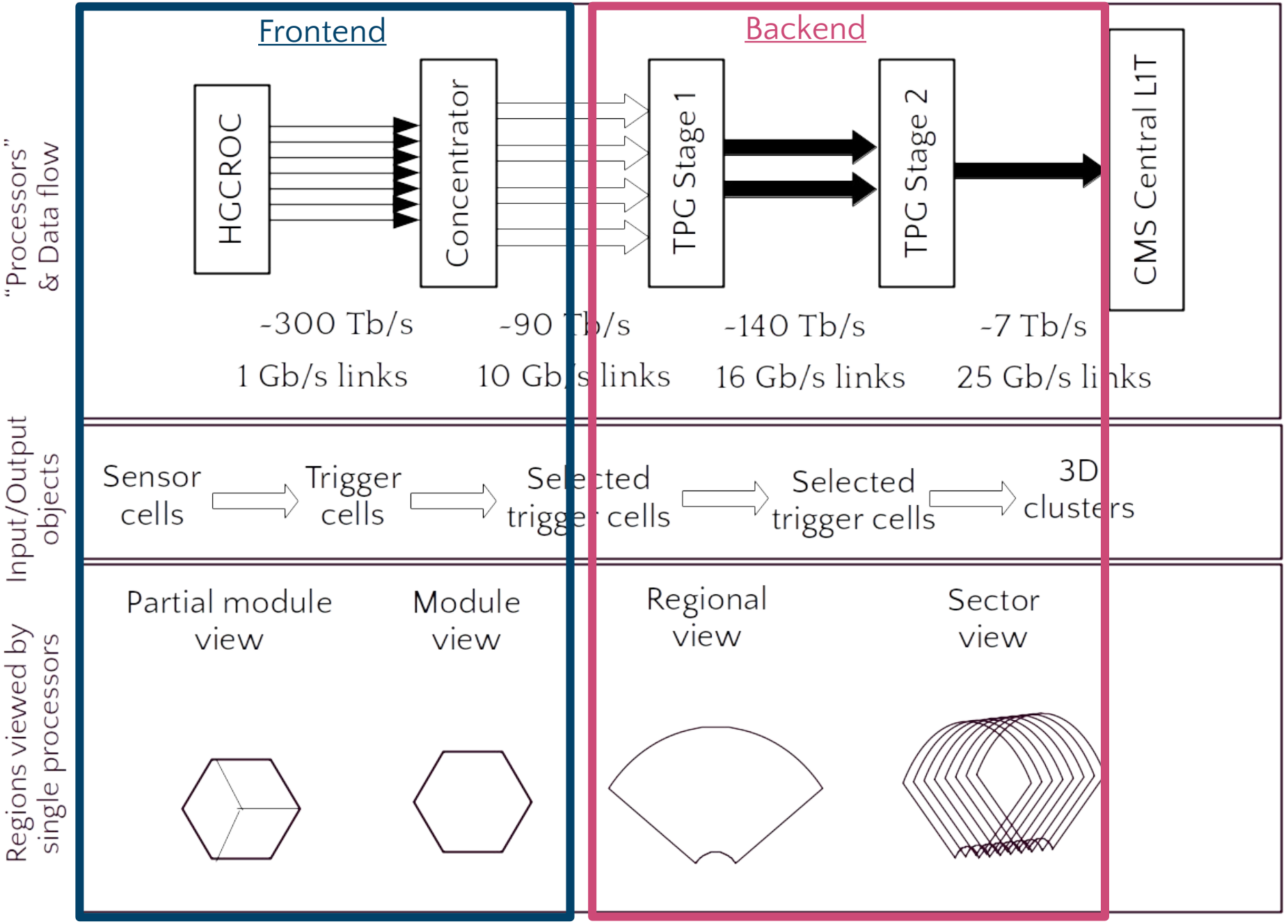
RT


F. Beaujean

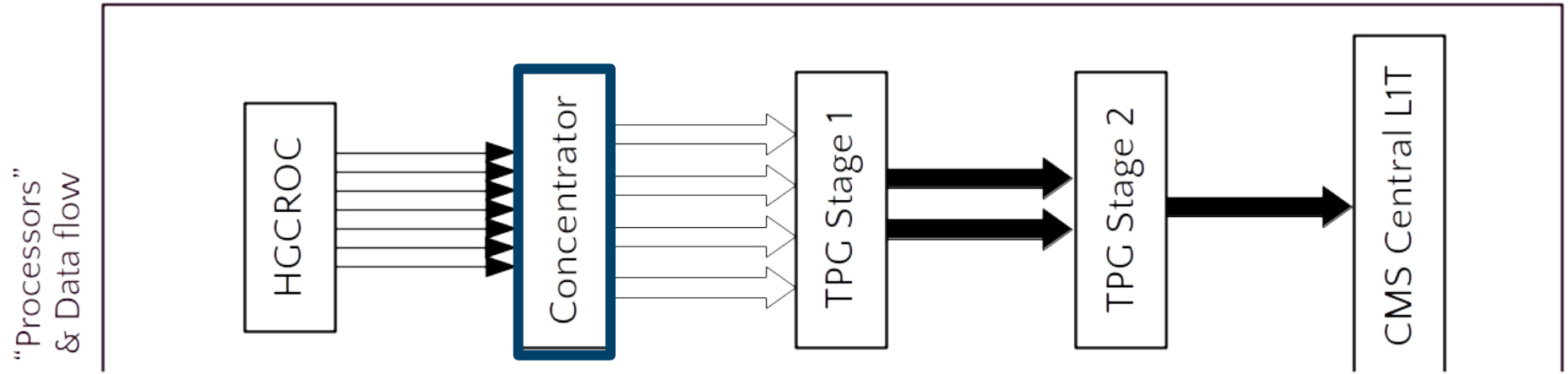

E. Becheva

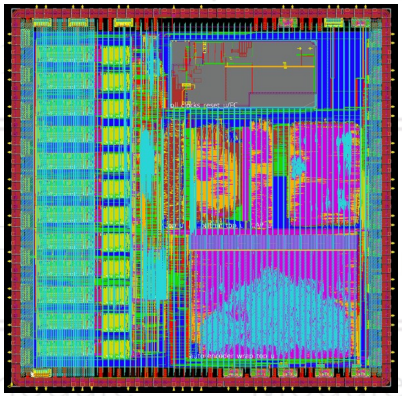

O. Le Dortz

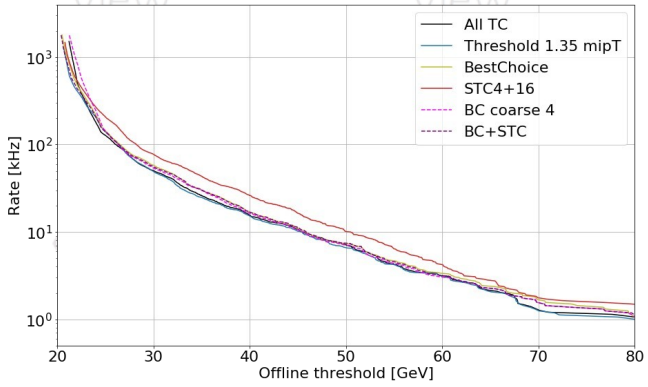
Data flow overview



ECON-T data reduction





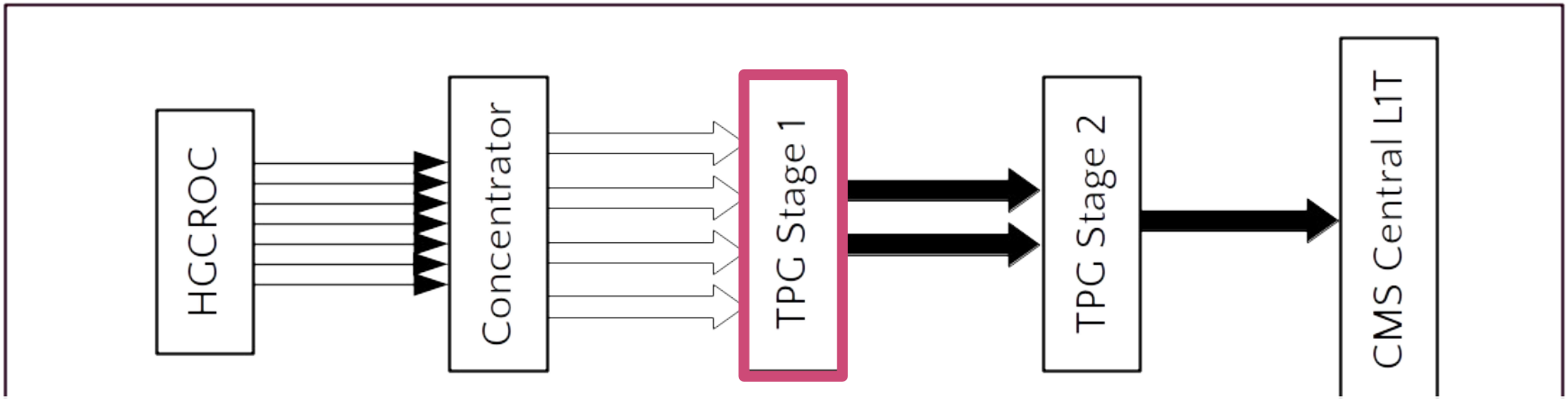


2019-2020

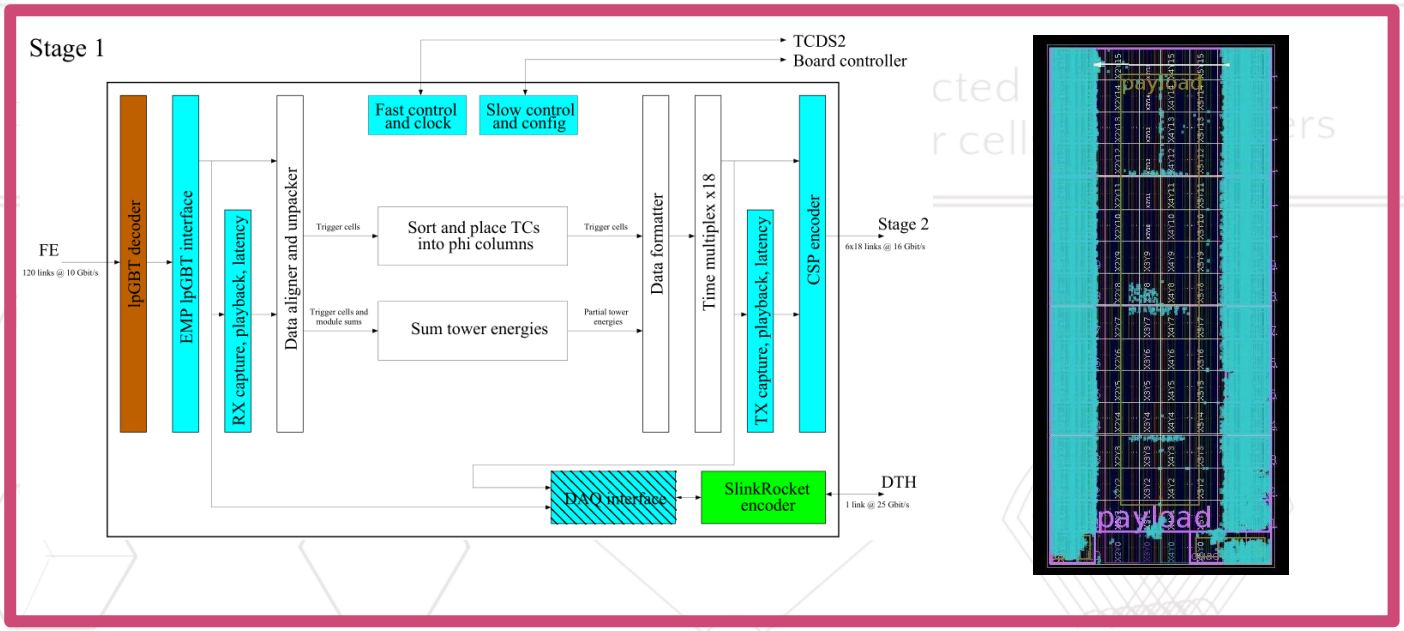
Design of 1 among 4 data reduction algorithms

Simulation study of the impact of these algorithms

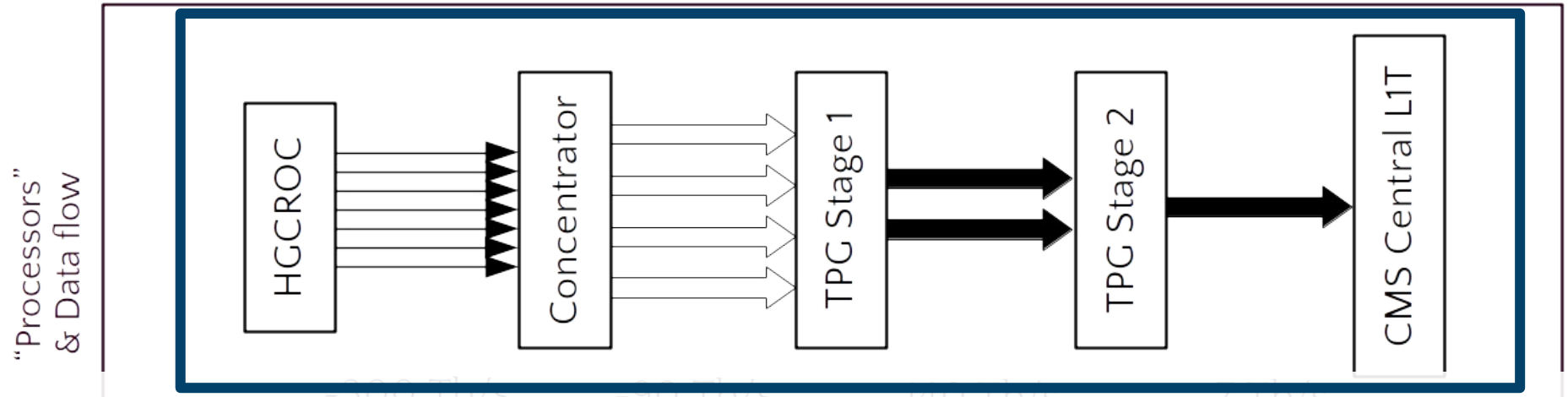
Backend Stage 1



≥ **2021**: Contributions to the design of the Backend Stage 1 firmware

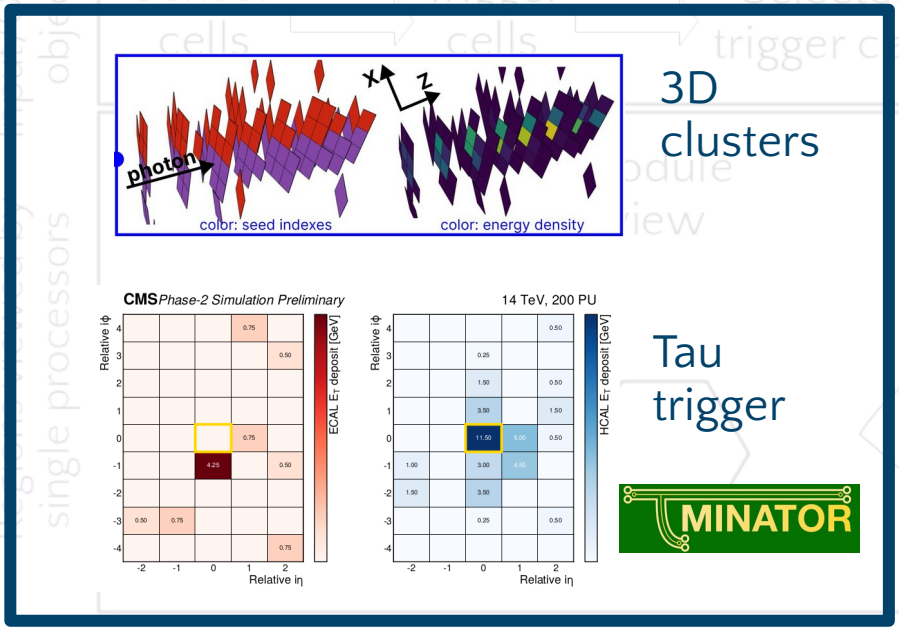


Simulation & Performance



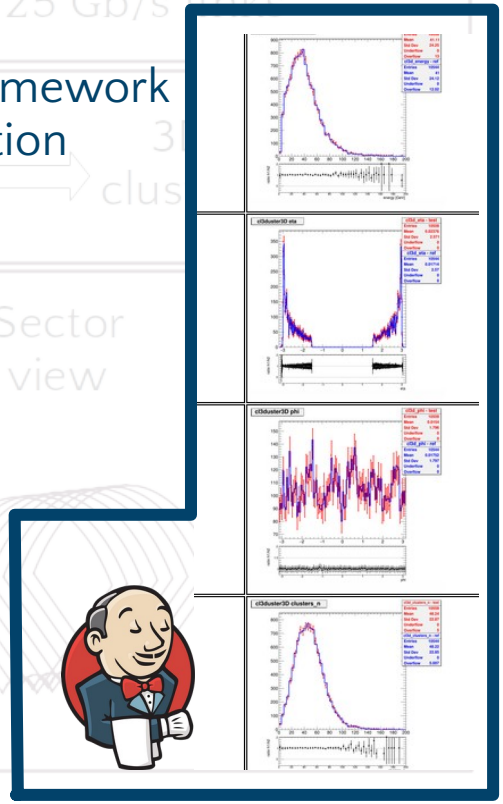
≥ 2016

Simulation and performance study of the full trigger reconstruction chain



≥ 2019

Validation framework of the simulation



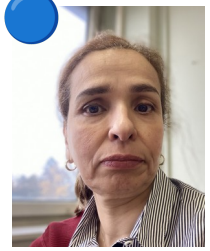
System tests & Integration

Physicists

L. Urda

A. Zabi

RS



A. Zghiche

PhD Students

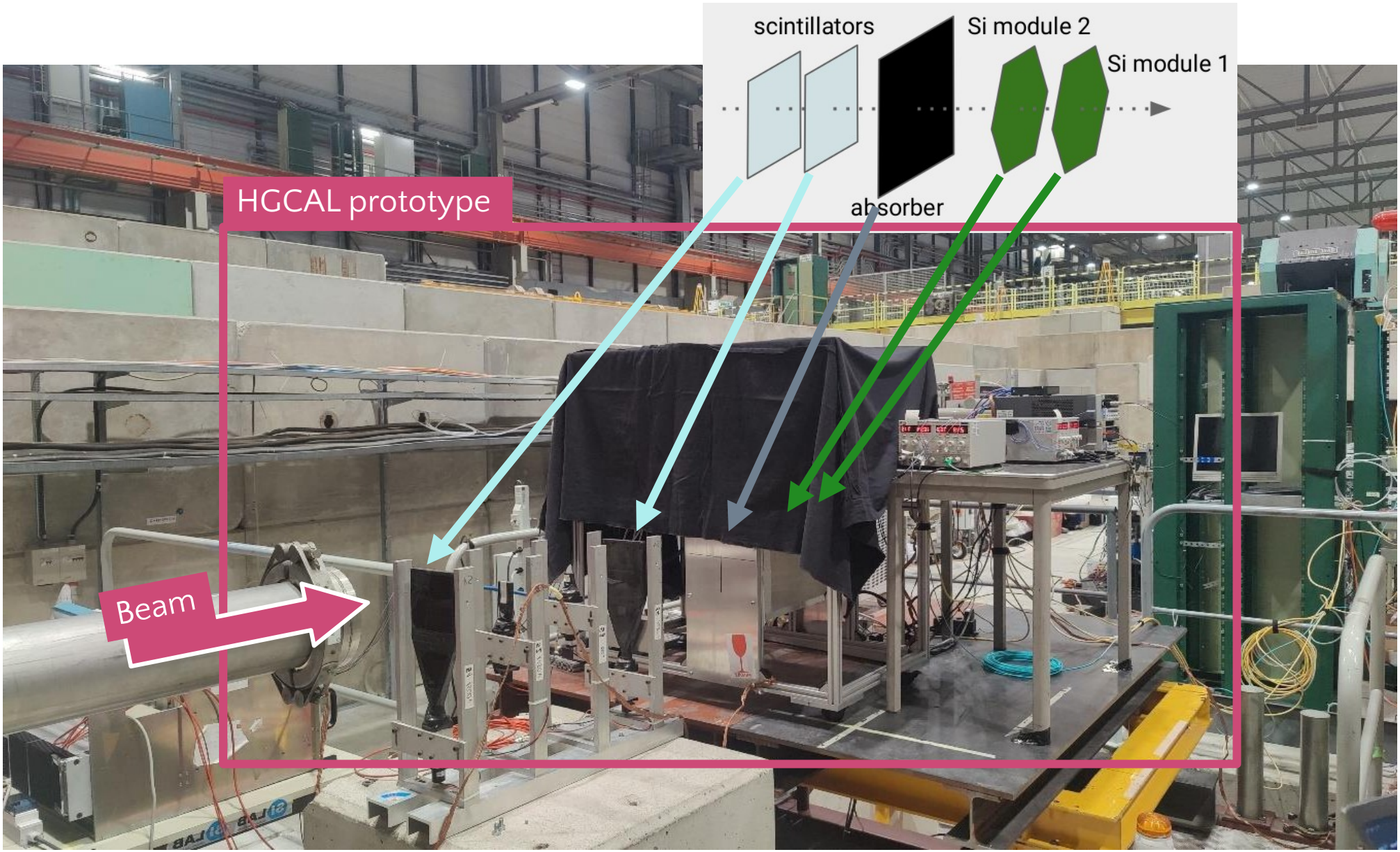
M. Chiusi

M. Manoni

Testing the full readout chain – 2023 Test Beam

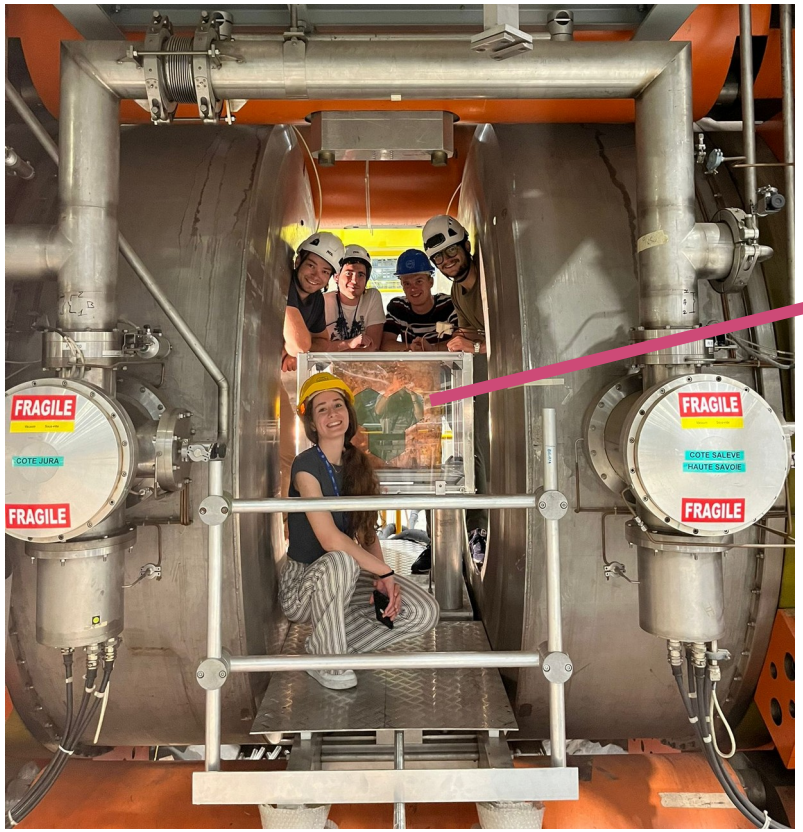
CERN SPS-H4 beam line: pions, muons, electrons

Testing the full readout chain – 2023 Test Beam

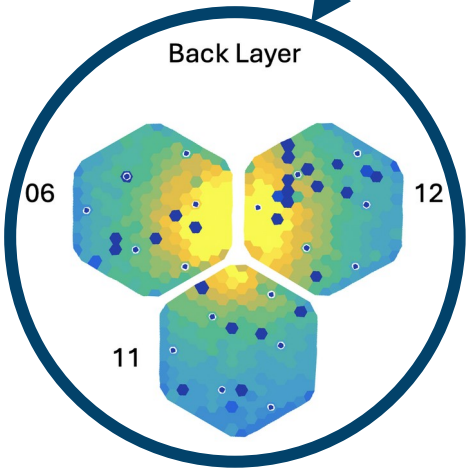


2024 test beam campaign

August 2024
LLR students (and former LLR students) around the HGCAL prototype



Larger prototype tested compared to last year
Readout includes part of the Backend Stage 1 firmware

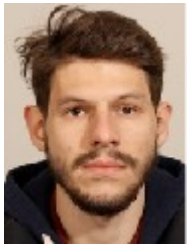


Offline reconstruction

Physicists

RS

F. Beaudette



G. Boldrini

G. Sokmen

PhD Students

T. Cuisset

K. Biriukov

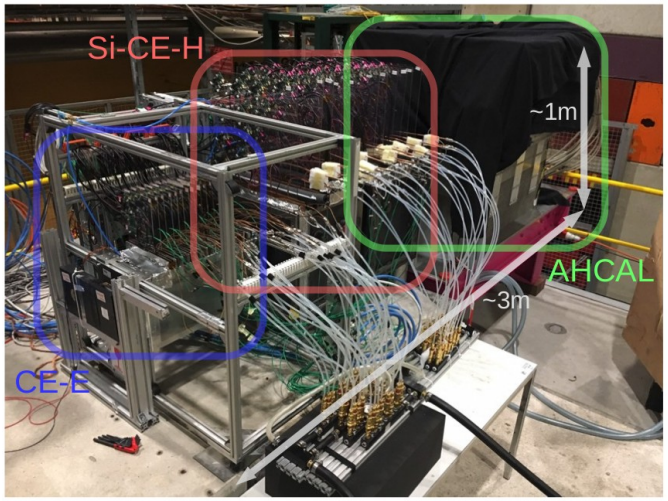
IT

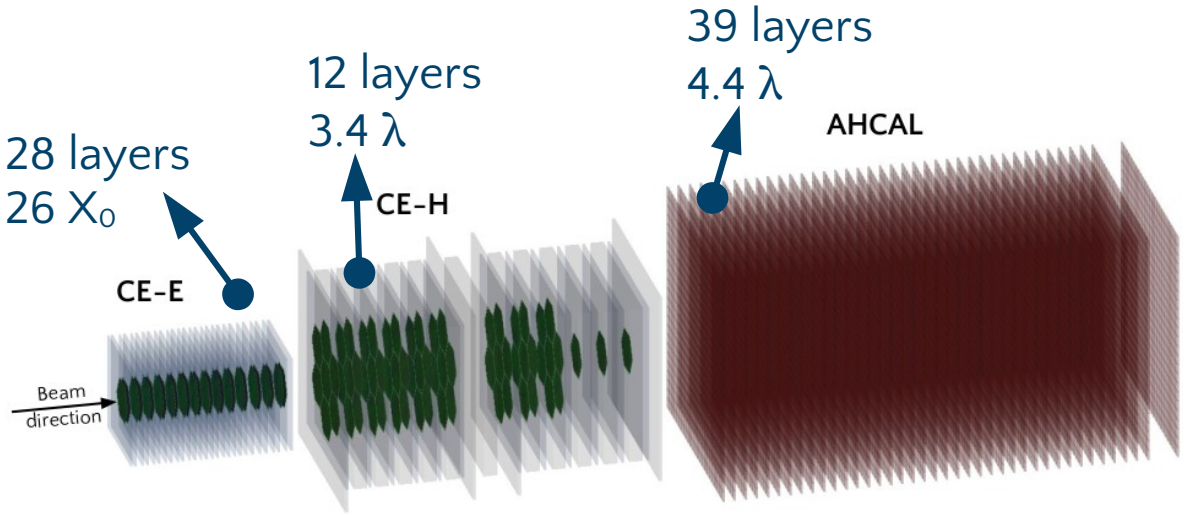
A. Chiron

RT

S. Ghosh

2018 test beam data analysis





5 papers published by HGCAL between 2021 and 2024 (including engineers as authors)

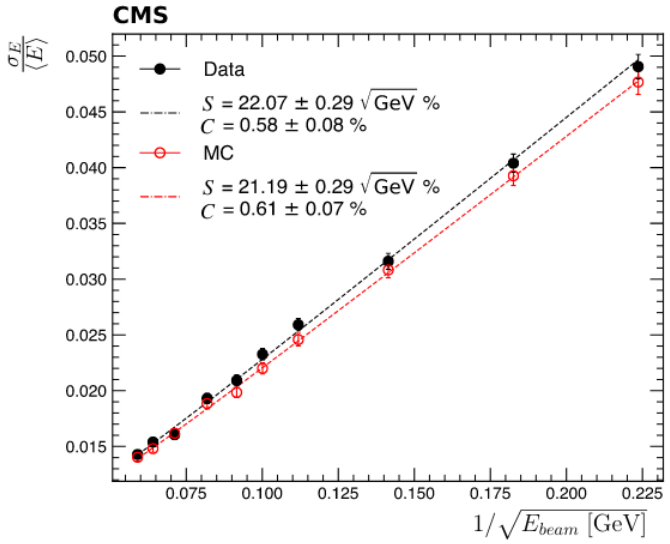
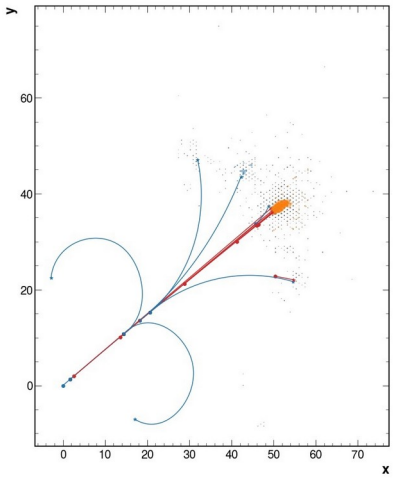


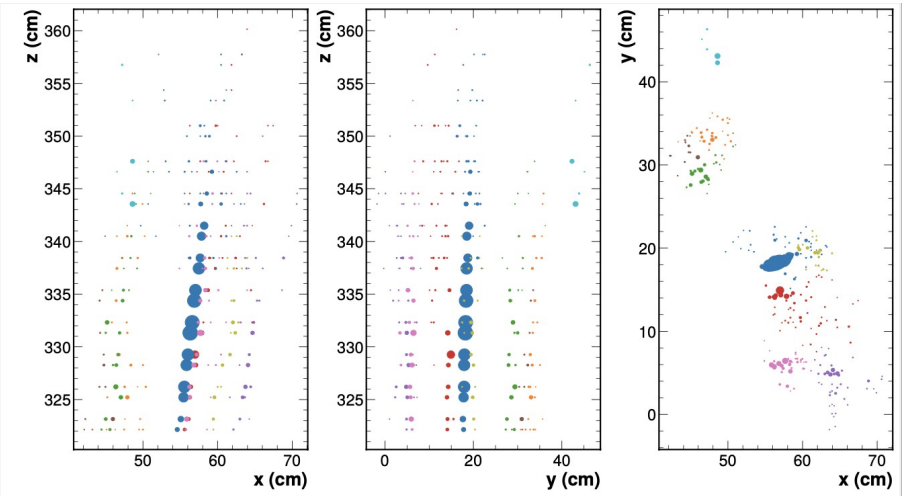
Figure 7: Measured energy resolution for data and simulation.

Electron reconstruction and identification

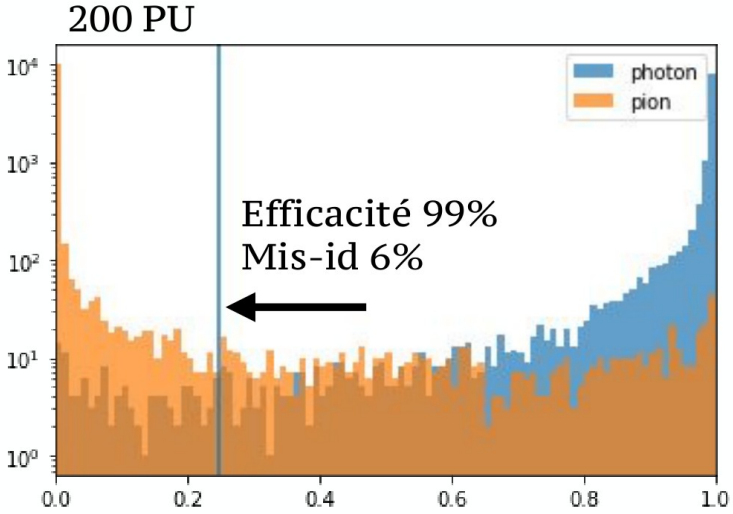
Complete rewriting of the reconstruction in HGCAL post-TDR
Centered on a Particle Flow strategy



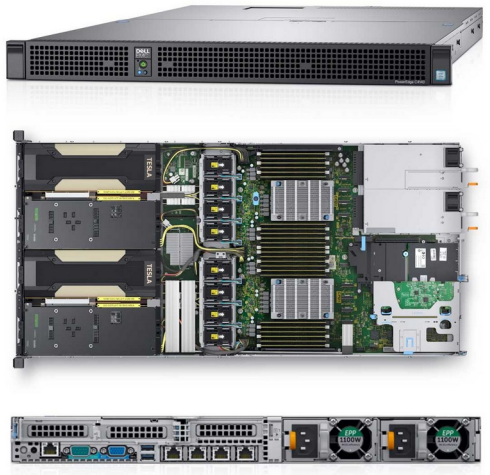
End 2020: LLR embarked in this activity:
Identification, noise reduction, super-clustering



Using Machine Learning as much as possible
In particular Graph Neural Networks

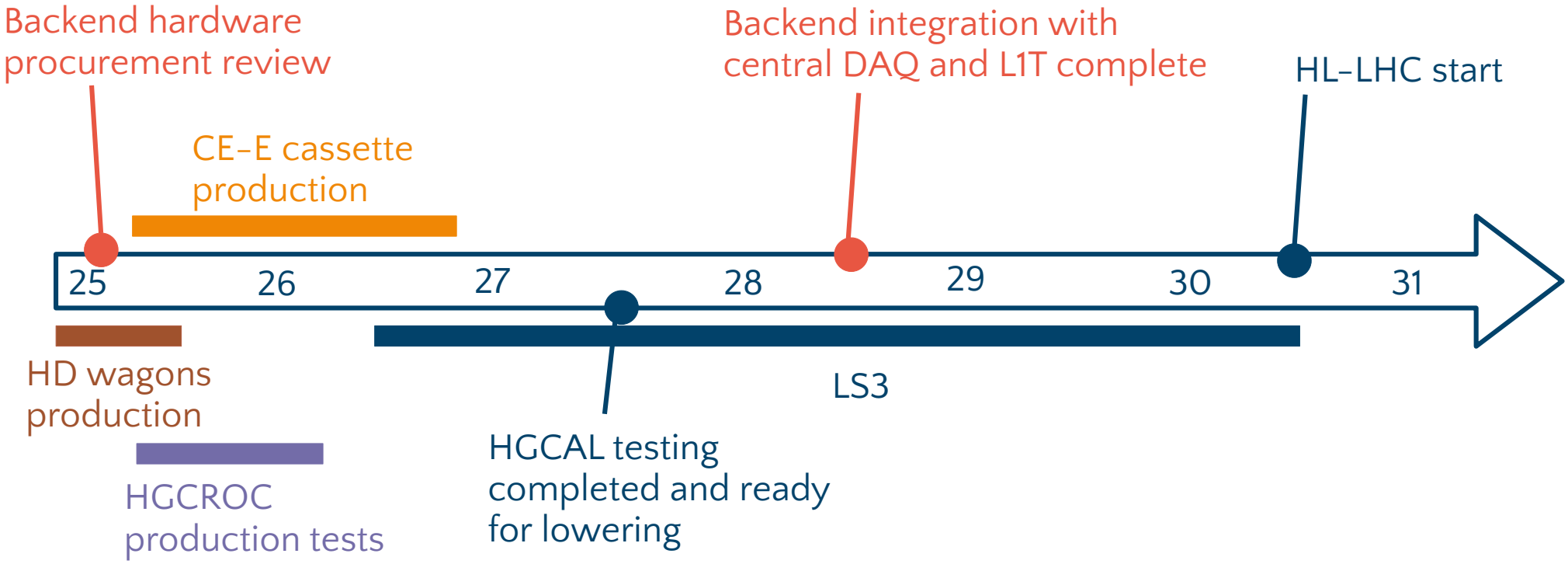


Purchase in 2020 of a powerful GPU server
Game changer for heavy NN training



Dell PowerEdge C4140

Future & challenges



- Entering critical production, assembly and commissioning period
- Challenges in ensuring the required level of human resources
  - Both Physicists and IT, in particular at CERN
- Very difficult to hire, in particular AI and Technicians
- People retiring are rarely replaced in time → expertise disappearing

Additional material

Presentations in conferences

2019

- CLIC: Towards the construction of the CMS High Granularity Calorimeter, A. Lobanov (PA)
- CHEP: A deep neural network method for analyzing the CMS HGCal events, G. Grasseau (PL)
- CHEF: Precision timing calorimetry with the CMS High Granularity Calorimeter, A. Lobanov (PL)
- CHEF: Performance of CMS high granularity calorimeter prototypes in testbeam experiments, A. Lobanov (PL)
- CHEF: Concepts and design of the CMS High Granularity Calorimeter Level 1 Trigger, S. Ahuja (PL)

2020

- ICHEP: The CMS Trigger system for the HL-LHC, A. Zabi (PA)
- PyHEP: High Granularity Calorimeter (HGCAL) test beam analysis using jupyter notebooks, M. Bonanomi (PL)
- ACES: HGCAL Architecture and TPG, A. Lobanov (IN)

Presentations in conferences

2021

- TWEPP: Automated firmware generation and continuous testing for the CMS HGCAL trigger primitive generator, JB Sauvan (PA)
- TIPP: System Design and Prototyping for the CMS Level-1 Trigger at the High-Luminosity LHC, A. Zabi (PA)
- BTTB9: Electromagnetic performance of CMS High Granularity Calorimeter (HGCAL) in beam tests , M. Bonanomi (PL)

2022

- IEEE-NSS: Irradiation tests of HGCROC, the front-end readout ASIC for the CMS HGCAL , Elena Vernazza (PA)
- LHC Days: New detector technologies , A. Zabi (IN)
- CALOR: Level-1 Triggering on High-Granularity Calorimeter information at the HL-LHC, L. Portales (PL)
- IML: Multi-objective optimization for the CMS High Granularity Calorimeter Level 1 trigger, A. Hakimi (PL)
- LP: Challenges and novel reconstruction techniques for the CMS High Granularity Calorimeter for HL-LHC, S. Ghosh (PA)

Presentations in conferences

2023

- PyHEP: Standalone framework for the emulation of HGCAL firmware trigger primitives in the CMS online trigger system , B. Alves, M. Chiusi (PL)
- IPRD: Design of the CMS High Granularity Calorimeter trigger primitive generator system, Isaac Ehle (PO → PL)
- EPS-HEP: Overview of the HL-LHC Upgrade for the CMS Level-1 Trigger, J. Motta (PA)
- CHEP: Cluster reconstruction in the HGCAL at the Level 1 trigger, B. Alves (PA)
- IEEE-NSS-MIC: A Trigger Primitive Generation system for the High-Granularity Calorimeter (HGCAL) of the CMS Phase-2 detector upgrade, M. Chiusi (PA)

2024

- LHC Days: CMS HGCAL project , JB Sauvan (IN)
- BTTB: Summary of HGCAL beam tests in 2023 , G. Liu (PL)
- ML4Jets: ML assisted Event Reconstruction in the CMS Phase-2 High Granularity Calorimeter Endcap, T. Cuisset (PA)

Publications

- 2020: The Phase-2 Upgrade of the CMS Level-1 Trigger, TDR CERN-LHCC-2020-004
- 2021: Construction and commissioning of CMS CE prototype silicon modules, 2021 JINST 16 T04002
- 2021: The DAQ system of the 12,000 channel CMS high granularity calorimeter prototype, JINST 16 (2021) 04, T04001
- 2022: Response of a CMS HGCAL silicon-pad electromagnetic calorimeter prototype to 20-300 GeV positrons', JINST 17 (2022) P05022 14
- 2023: Performance of CMS High Granularity Calorimeter prototype to charged pion beams of 20-300 GeV /c, JINST 18 (2023) 18 P08014
- 2024: Timing Performance of the CMS High Granularity Calorimeter Prototype. JINST 19 P04015