15 Years Celebration of the SA-CERN Consortium

20-21 January 2025
iThemba Laboratory
Cape Town

An overview of ICPP ATLAS Activities

Rachid Mazini (Wits U.)

On behalf of the Institute for Collider Particle Physics

Scope of Research

Physics through data analysis

Analysis of ATLAS Data
Experimental HEP,
experimental techniques,
Big Data

Artificial Intelligence
Machine Learning,
Data analytics,
Statistics

Particle Physics Phenomenology
HEP Theory,
Connection with SKA
and future facilities

Radiation studies
Nuclear Physics,
Material sciences,
Chemistry, NECSA,
iThemba LABS,
SASOL etc..

Analog and Fast Digital Electronics.
Electrical
engineering,
industry

Theory

Instrumentation

Below is the list of current and past post-doctoral fellows with the starting and end date, with a total of 10.

Name of Post-doc	Starting Date	End date
Y. Hernandez	2019	2022
E. Nkadimeng	2022	2023
S.E. Dahbi	2019	2023
C. Mosomane	2023	2026
S. Bhattacharya	2022	2026
A.K. Swain	2022	2023
R. McKenzie	2024	2026
G. Mokgatitswane	2024	2026
O. Mouane	2023	2025
T. Lagouri	2017	2019

A total of 59 graduate students graduated during the period of 2018-2023 with 11 graduating in 2024, who did their research work in the period of 2018-2023, yielding a total of 70 students.

Out of the total, 27 are Honors, 31 MSc and 12 PhD students.

It is important to note that the vast majority of the students are Black South Africans.

Admittedly, the fraction of females stands at 10%, which is significantly lower than the world average, which stands at around 20%.

The current team

ATLAS students:

- Vongani Chabalala, Thabo Pilusa, Nidhi Tripathi, Kutlwano Makgetha, Vuyolwethu Kakancu, Njokweni Mbuyiswa, Paballo Ndhlovu, Phodiso Maroeshe, Lungisani Phakathi, Sanele Gumede, Kgothatso Ntumbe, Mphumzi Mnyaiza, Thabo Lepota, Donald Ngobeni, Gourav Lall, Cameron Baldwin, Katlego Machethe, Confidence Malatje, Asaad Abdallah, Lunga Mandlazi

ATLAS postdoctoral fellows:

- Ryan Mckenzie, Chuene Misname, Othmane Mouane

Students and Post-doc working with the ATLAS team toward Technology Transfer

- Thuso Mathaha, Nkosiphendule Njara, Raghav Chandra, Manal Karmoude, Brenton Munhungewarwa, Isaiah Chiraira
- Eric Nizeyimana: Post-doc

Postdoctoral Fellows in Phenomenology supporting ATLAS physics analyses

- Srimoy Bhattacharia, Siddhart Maharathy

In conclusion, there are 20+6 students and 3+3 Post-docs for a total od 32 members, not counting the technical support from Wits and iThemba.

Recent Positions of Leadership at ATLAS (I)

Name	Position	Area
Edward Nkadimeng, Ryan McKenzie	Convenors of LVPS working group	Instrumentation
Humphry Tlou	TileCal run coordinator	Instrumentation
Ryan McKenzie	TileCal run coordinator	Instrumentation
Bruce Mellado	Chairperson of the Institutional Board and Deputy Project Leader, Tile Calorimeter	Instrumentation
Bruce Mellado	Level 2 Manager of the TileCal Phase II upgrade	Instrumentation
Xifeng Ruan	Lead contact of analysis group	Data analysis
Gaogalalwe Mokgatitswane	Lead contact of analysis group	Data analysis
Yesenia Hernandez	Lead contact of analysis group	Data analysis
Gaogalalwe Mokgatitswane	TileCal run coordinator	Instrumentation

Recent Positions of Leadership at ATLAS (II)

Name	Position	Area
Mukesh Kumar	Member of TileCal SC, HGTD	Instrumentation
Rachid Mazini	Leading contact for the HGTD project	Instrumentation
Rachid Mazini	Leading Contact for dark photon searches	Data Analysis

Over the period of the ICPP has published:

- 540 publications with the ATLAS collaboration
- 28 non-ATLAS journal publications in particle physics with over 3200 citations and tens of thousands of downloads
- 17 journal publications with Machine Learning for various applications
- 60 conference proceedings

We are leading authors of several publications in the Nature portfolio:

- *Nature* (IF 64.8) volume 607, pages 52–59 (2022) with 305 citations and 34K downloads
- *Nature* (IF 64.8) volume 611, pages 332–345 (2022) with 154 citations and 248K downloads
- *Nature Scientific Reports* (IF 4.6) volume 12, 944 (2022)
- "Anomalies in Particle Physics" accepted for publication in *Nature Reviews Physics* (IF 36.3) in December 2023.

Team members were the co-chief editors of the following papers:

- “The Large Hadron-Electron Collider at the HL-LHC”, J.Phys.G 48 (2021) 11, 110501 with 292 citations and 8.1K downloads

- “Precision Higgs Physics at the CEPC”, Chin.Phys.C 43 (2019) 4, 043002, 153 citations and 4.9K downloads

- “Unveiling hidden physics at the LHC”, Eur.Phys.J.C 82 (2022) 8, 665, with 66 citations and 4.8K downloads.

These papers pertain to large projects where the team has positions of leadership and are pivotal to the future of particle physics:

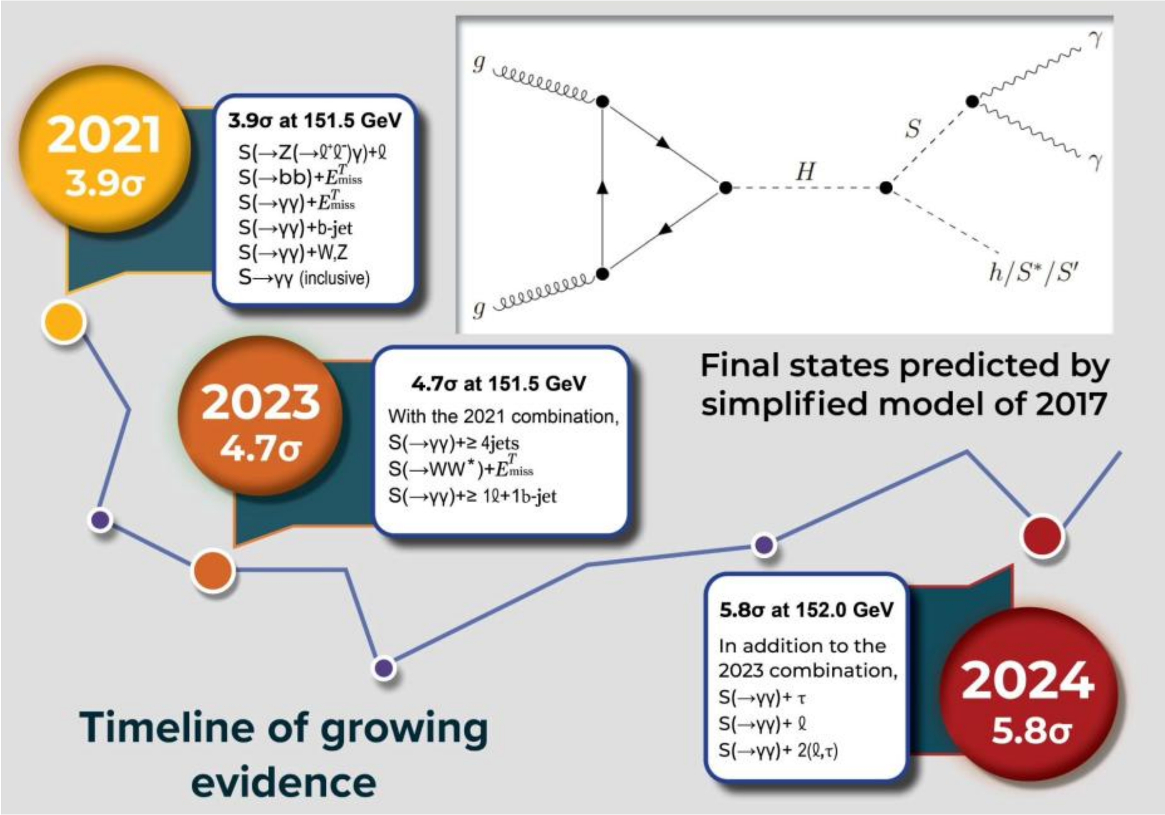
Nature Rev.Phys. (2024), https://www.nature.com/articles/s42254-024-00703-6

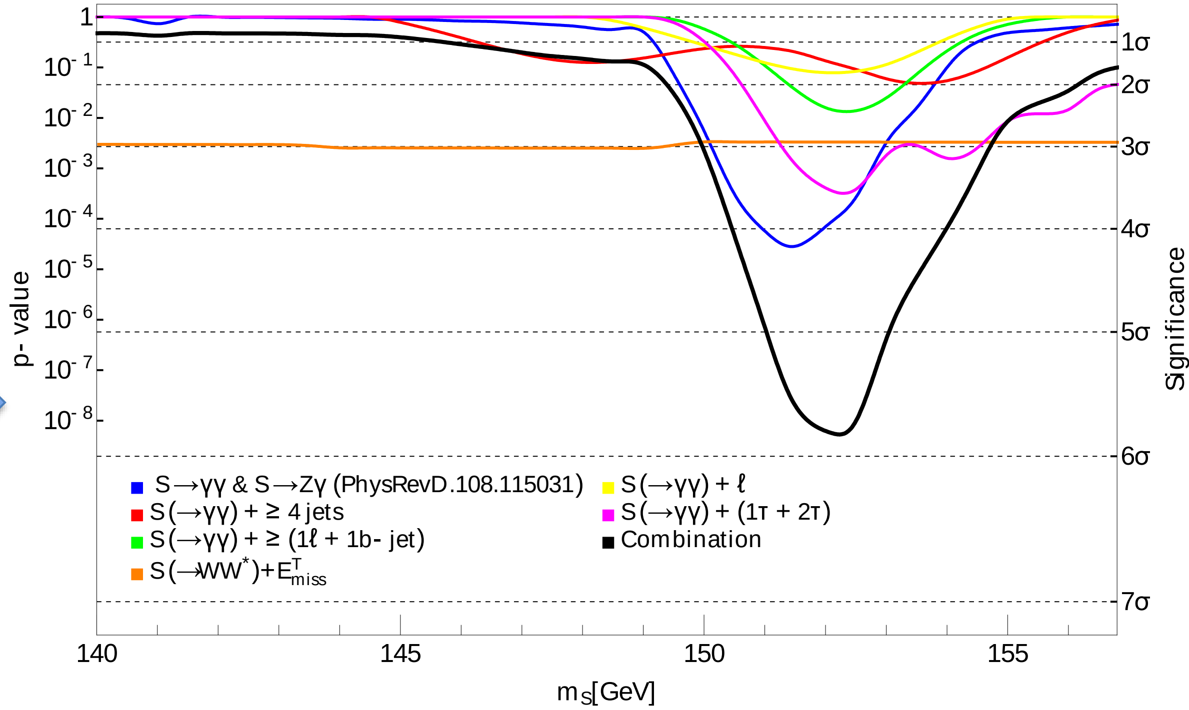
Anatomy of the multi-lepton anomalies (2024)

Final state	Characteristic	Dominant SM process	Significance
l^+l^- + jets, b-jets	m_{ll}<100 GeV, dominated by 0b-jet and 1b-jet	tt+Wt	>5σ
l^+l^- + full-jet veto	m_{ll}<100 GeV	WW	~3σ
$l^\pm l^\pm$ & $l^\pm l^\pm l$ + b-jets	Moderate H_T	ttW, 4t, ttZ/tWZ	>3σ
$l^\pm l^\pm$ & $l^\pm l^\pm l$ et al., no b-jets	In association with h	Wh, WWW	4.2σ
Z(->l^+l^-)+l	p_{TZ}<100 GeV	ZW	>3σ

Di-lepton invariant mass in MLA predict a scalar with a mass 150±5 GeV (J.Phys. G45 (2018) no.11, 115003, see also Phys.Rev.D 108 (2023) 11, 115031 and arXiv:2306.17209) in association with leptons and jets.

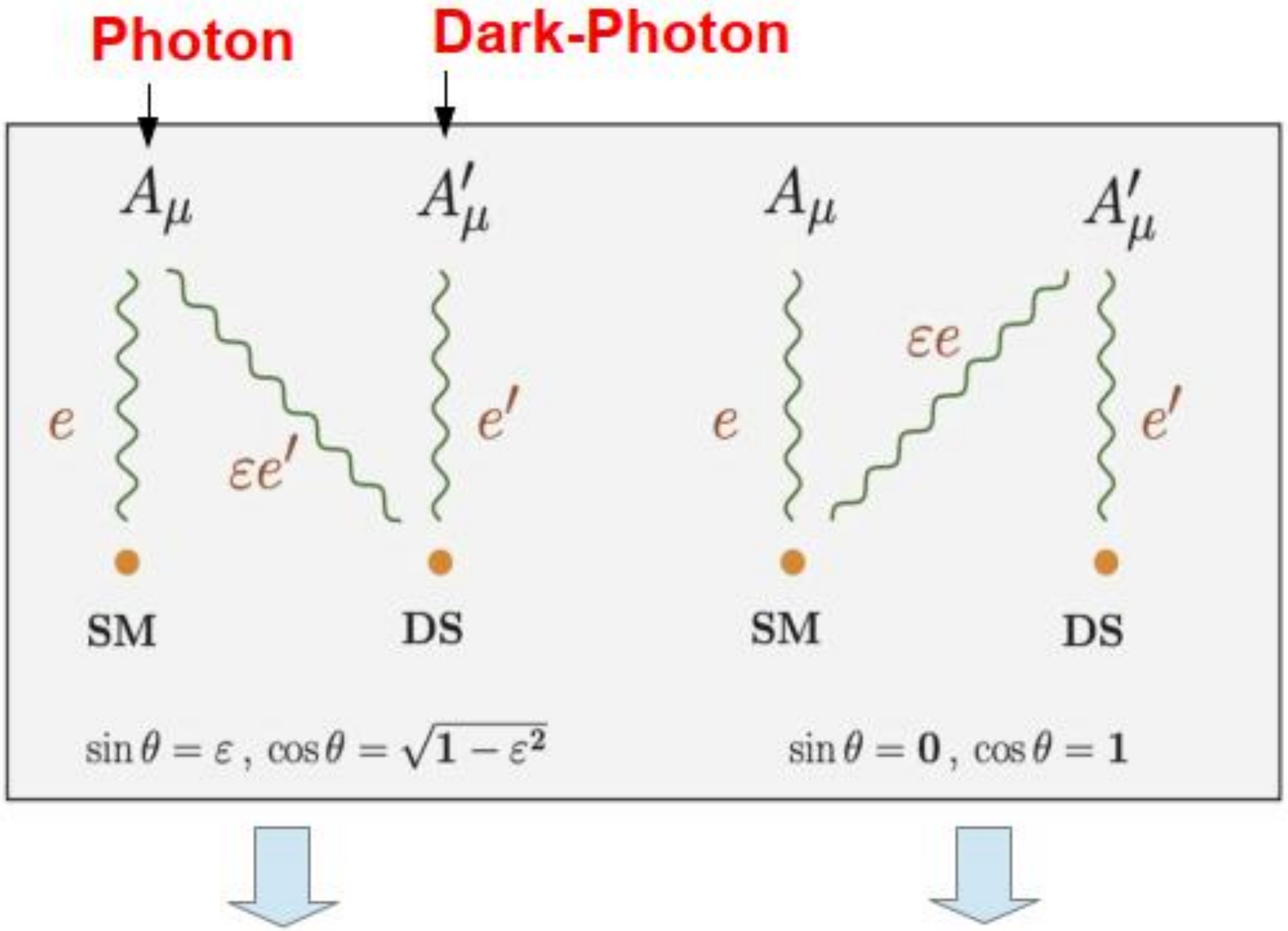
Current status of the combination, based on the Fischer method with 6 n.d.o.f yields largest global significance of a narrow structure beyond the SM at the LHC





Phys.Rev.D 108 (2023) 11, 115031
S.Battacharya, et al. arXiv:2306.17209
S.Battacharya, et al. to appear

Dark photon searches: exploring the SM-DM connection (NEW)



Massless Dark-Photon

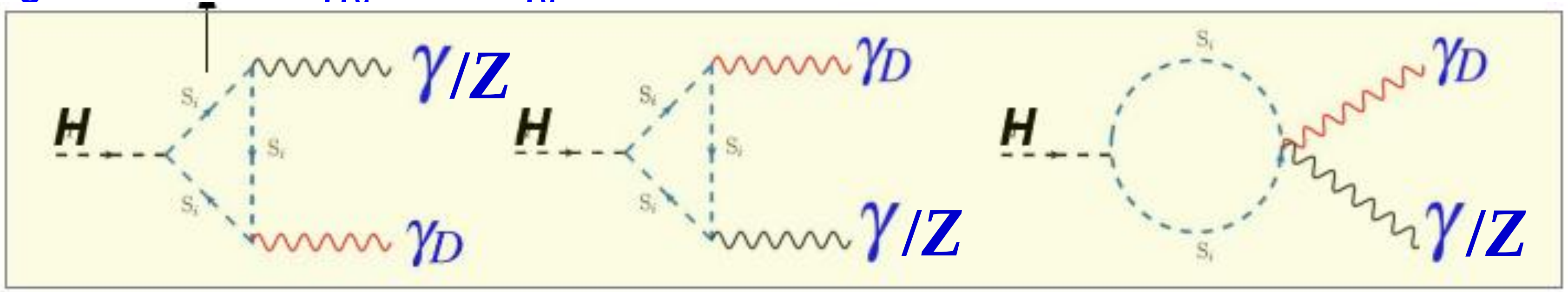
less explored scenario

Massive Dark-Photon

most of experimental searches focus on massive DP scenario (tree-level couplings)

Phenomenology for H → $\gamma\gamma_D$, $Z\gamma_D$

- **Minimal Model, with two scalar messengers with unit charge, allowing to generate both $H\gamma\gamma_d$ and $HZ\gamma_d$ vertices.**



The extension to include $HZ\gamma_d$ vertices leads to:

$$r_{ij} \equiv \frac{\Gamma^{m}_{ij}}{\Gamma^{SM}_{\gamma\gamma}},$$

$$\mathrm{BR}_{\gamma\gamma_D} = \mathrm{BR}^{SM}_{\gamma\gamma}\frac{r_{\gamma\gamma_D}}{1+r_{\gamma_D\gamma_D}\mathrm{BR}^{SM}_{\gamma\gamma}}, \qquad r_{\gamma\gamma_D} = 2X^2\left(\frac{\alpha_D}{\alpha}\right)$$

$$\mathrm{BR}_{Z\gamma_D} = \mathrm{BR}^{SM}_{\gamma\gamma}\frac{r_{Z\gamma_D}}{1+r_{\gamma_D\gamma_D}\mathrm{BR}^{SM}_{\gamma\gamma}}, \qquad r_{Z\gamma_D} = 2X^2R^2_{Z\gamma}\left(\frac{\alpha_D}{\alpha}\right)$$

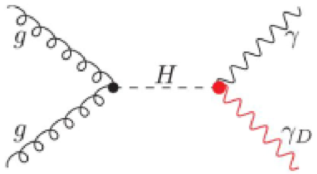
$$\mathrm{BR}_{\gamma_D\gamma_D} = \mathrm{BR}^{SM}_{\gamma\gamma}\frac{r_{\gamma_D\gamma_D}}{1+r_{\gamma_D\gamma_D}\mathrm{BR}^{SM}_{\gamma\gamma}},$$

$$\mathrm{BR}_{\gamma\gamma} = \mathrm{BR}^{SM}_{\gamma\gamma}\frac{\left(1+\chi\sqrt{r_{\gamma\gamma}}\right)^2}{1+r_{\gamma_D\gamma_D}\mathrm{BR}^{SM}_{\gamma\gamma}},$$

- With $X \equiv \frac{\xi^2}{3F(1-\xi^2)}$ and the mixing parameter $\xi = \frac{\Delta}{\bar{m}^2}$ depending on the mass
- difference of the 2 scalars. F from the SM H→$\gamma\gamma$ form factor (6.5). For a pair of mass-degenerate EW messengers, R~0.045
- More constraints could also be derived from H→$\gamma\gamma$ and H→inv BR's limits

$H \to \gamma/Z + \gamma_D$

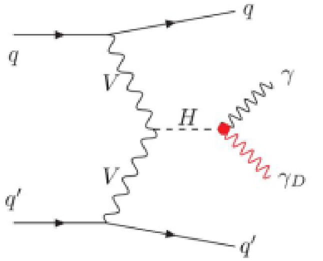
- **DP production mechanisms via $H\gamma\gamma_D$ effective vertex**



gluon-gluon fusion → **gg + VBF analyzed in**
EG, Heikinheimo, Mele, Raidal, PRD 90
Biswas, EG, Heikinheimo, Mele PRD 93

$$pp \to \gamma + \not{E}_T$$

Challenging → large QCD bckg of jets faked as $\not{E}_T$

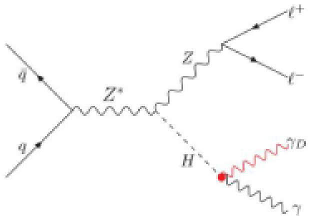


Vector Boson fusion

$$pp \to \gamma + \not{E}_T + jets$$

↗ FB

ATLAS, CMS
run2

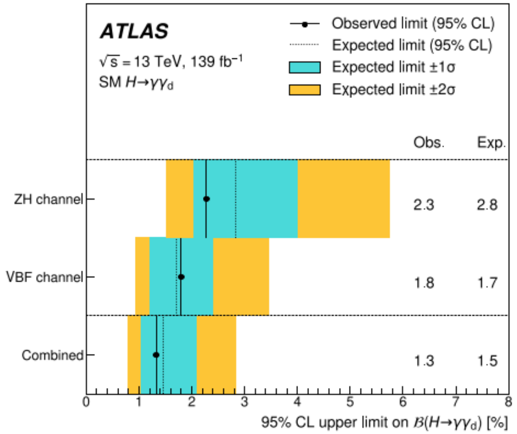


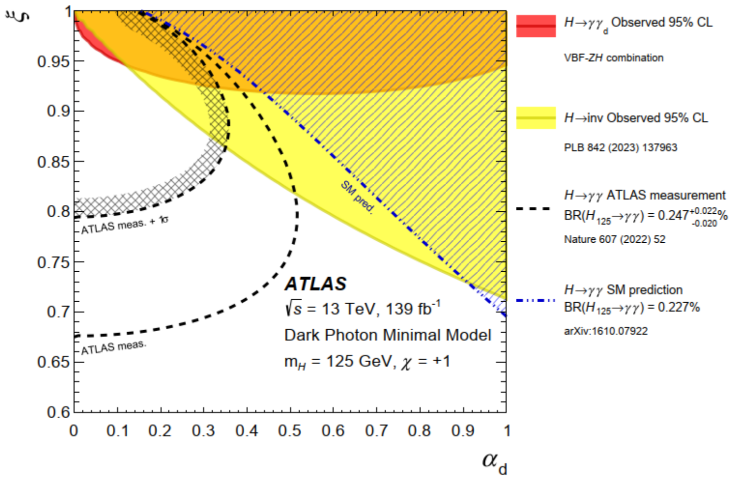
Z associated production

ATLAS, CMS
run2

$$pp \to ZH \to (Z \to \ell^-\ell^+)(H \to \gamma\gamma_D)$$

ATLAS provided unique results for this search





On going analysis @Wits

- $H \to \gamma\,\gamma_D$: Challenging. Run 3 data using custom (γ + MET) trigger
- $H \to Z\,\gamma_D$: First at LHC. Could provide one order of magnitude better limit with Run2 data already.
  - First time at the LHC, ATLAS only
  - Interpretation and combination with other low mass dark photon experiments (FASER,…)

DETECTORS | MEETING REPORT

First TIPP in Africa a roaring success

17 January 2024

6th Conference of Technology and Instrumentation in Particle Physics.

Knowledge-transfer opportunities Cape Town's "City Bowl" as viewed from Lion's Head. Credit: D Delso/Wikimedia Commons

The Conference of Technology and Instrumentation in Particle Physics (TIPP) is the largest conference of its kind. The sixth edition, which took place in Cape Town from 4 to 8 September 2023 and attracted 250 participants, was the first in Africa. More than 200 presentations covered state-of-the-art developments in detector development and instrumentation in particle physics, astroparticle physics and closely related fields.

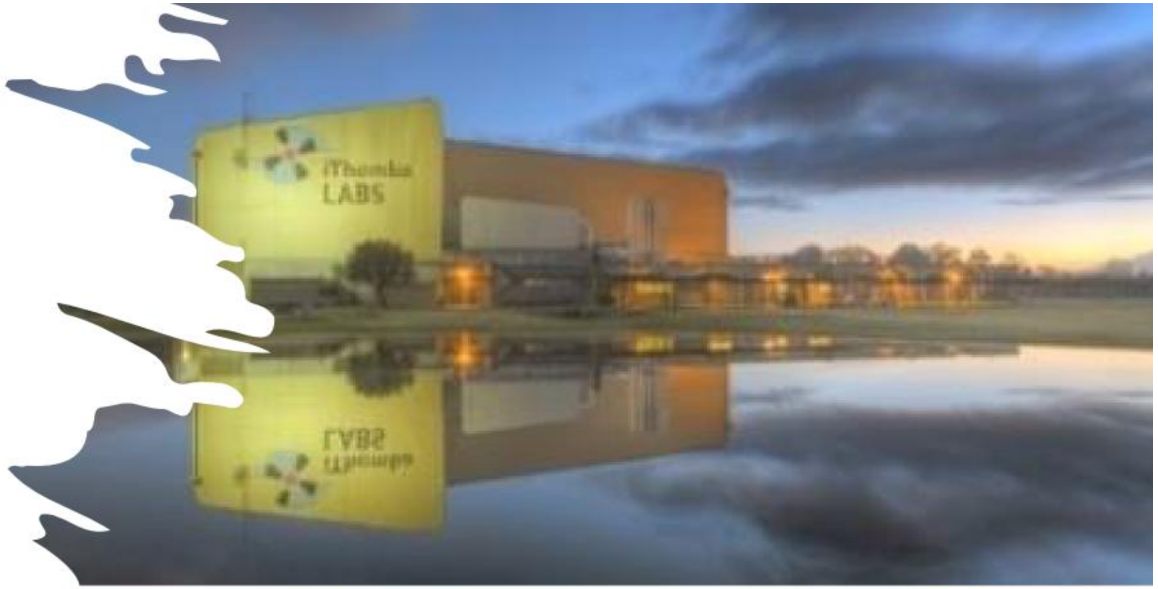
https://cerncourier.com/a/first-tipp-in-africa-a-roaring-success/

SABC NEWS
Independent. Impartial.

Will also host ACHEP2025

Proposal to host the TileCal week outside of CERN in 2025

- at iThemba LABS, located on the old Faure Road, Cape Town, South Africa.
- [29 September – 03 October 2025]



Organizing members

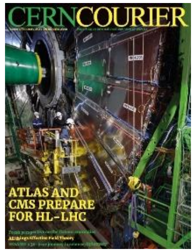
Mukesh Kumar (Chair)
Edward Nkadimeng
Mpho Gift Doctor Gololo
Phumlani Zipho Ngcobo
Ryan Peter Mckenzie

Instrumentation

Maintenance and Operations
Phase-I upgrade: Tile Calorimeter
Phase-II upgrade: Tile Calorimter
HGTD (NEW)

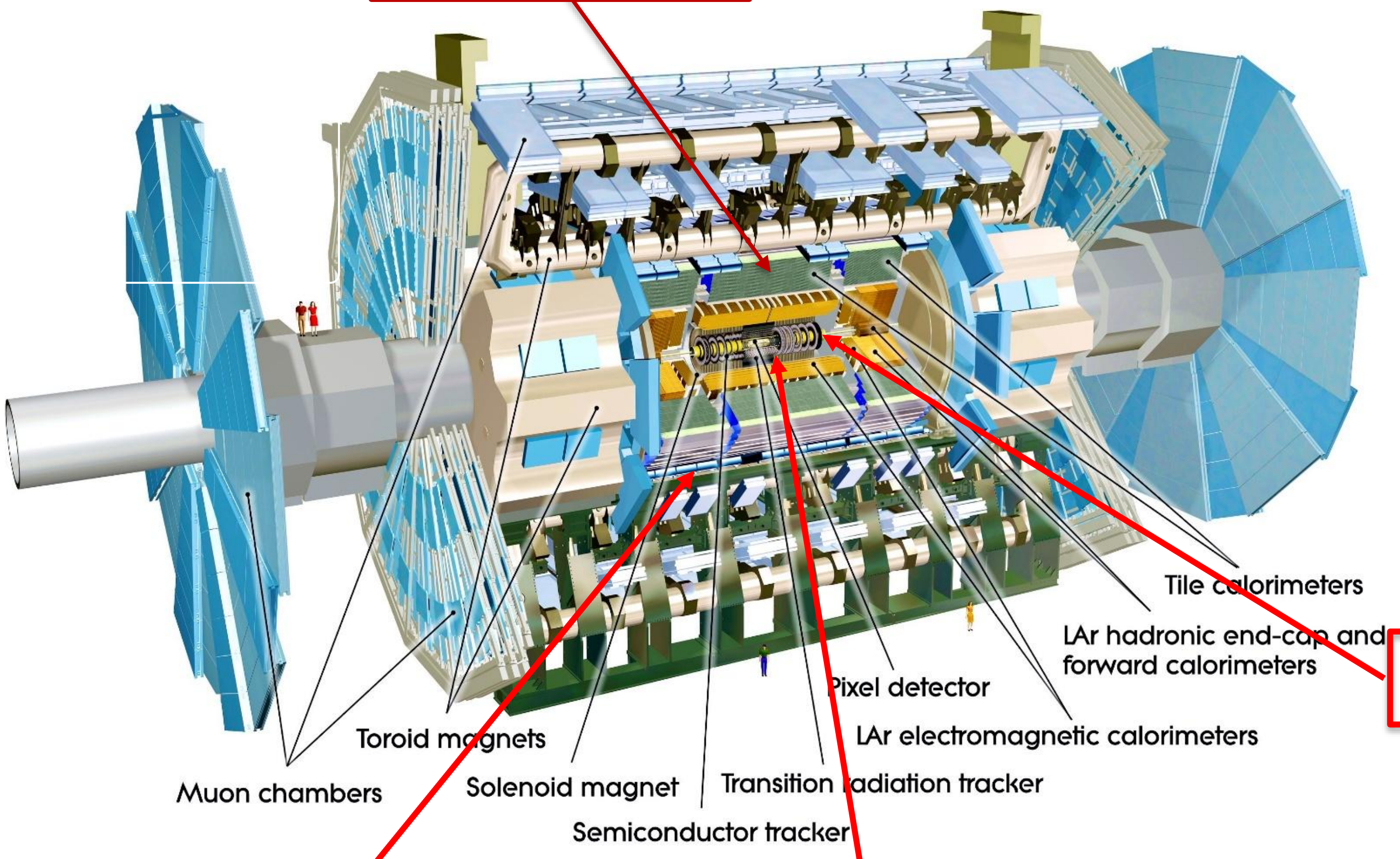
The ATLAS Detector: Phase-I and Phase-II upgrade

Jan/Feb 2023 CERN Courier [link]



Ongoing ICPP Contribution

Tile Calorimeter



Upgraded Trigger and Data Acquisition system

Level-0 Trigger at 1 MHz

Improved High-Level Trigger (150 kHz full-scan tracking)

Electronics Upgrades

LAr Calorimeter

Tile Calorimeter

Muon system

High Granularity Timing Detector (HGTD)

New ICPP Contribution

Forward region ($2.4 < |\eta| < 4.0$)

Low-Gain Avalanche Detectors (LGAD) with 30 ps track resolution

Additional small upgrades

Luminosity detectors (1% precision goal)

HL-ZDC

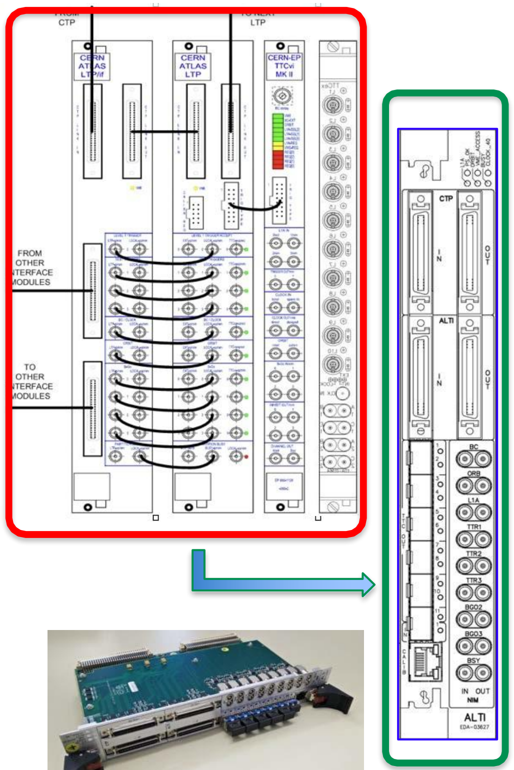
New Inner Tracking Detector (ITk)

All silicon, up to $|\eta| = 4$

New Muon Chambers

Inner barrel region with new RPC and sMDT detectors

Phase-I upgrade



ATLAS Local Trigger Interface (ALTI)

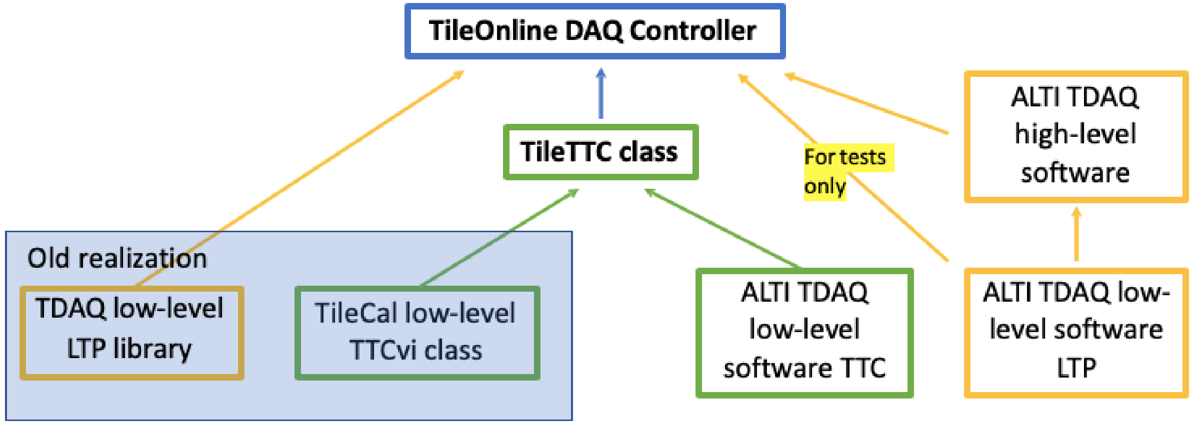
Set of local trigger processor boards (LTPi, LTP, TTCvi, TTCex) replaced by a single ALTI board

- ❑ Aging legacy modules, spares (obsolete components)
- ❑ New sub-systems in Run-3 need new TTC modules

TileCal Online software now incorporates new TileTTC class functionalities, compatible with the ALTI and TTCvi systems

- ❑ Tested and installed in P1 in July 2021

CERN test bench



Phase-I Upgrade activities: Assembly, quality checks and installation of the gap scintillator counters on the ATLAS detector

During Run-2 (2015-2018) data-taking period of the LHC, Crack and MBTS scintillators were degraded by radiation and had to be replaced with more radiation-hard scintillators as part of the phase-I upgrade.

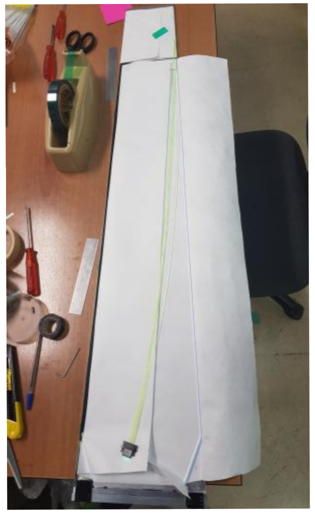
Upgrade activities consisted:

- Re-design of the crack and MBTS counters
- Assembly of detector modules
- Qualification and characterization using radioactive sources (Strontium-90 and Cesium-137)
- Installation on the ATLAS detector

ASSEMBLY (Crack and MBTS)

E3 Scintillator slab

Slab wrapping

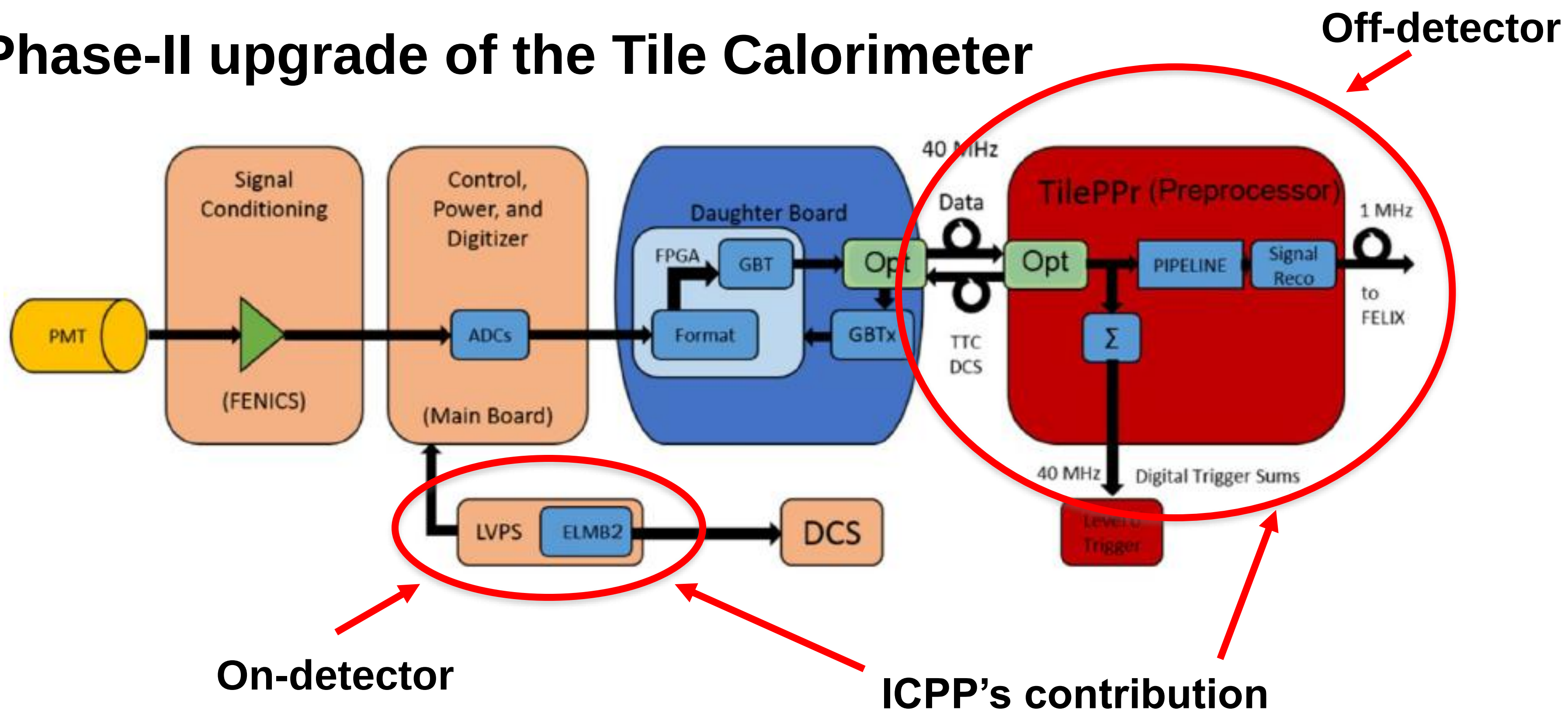


Fibre placement

Encapsulation with Al

Assembled modules

Phase-II upgrade of the Tile Calorimeter



South Africa's contribution to the TileCal Phase-II Upgrade is

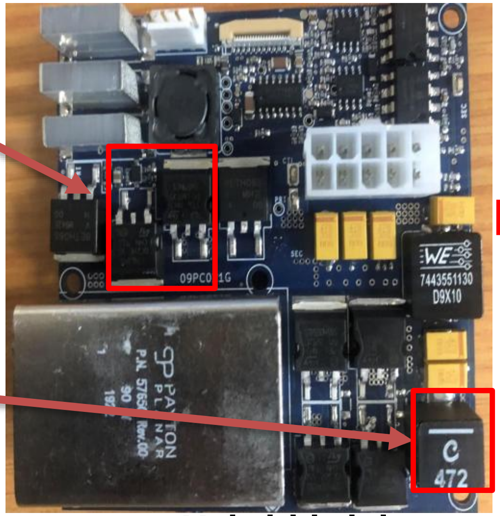
1. 50% of the production of the Low Voltage Power Supplies (LVPS)
   - Fully manufactured in South Africa
   - Fully tested in South Africa
2. 24% of the production of the Tile Preprocessor (PPr)
   - Two of the boards within the PPr fully manufactured in SA
   - Contribute to fare-share share of FPGAs and Back-ends

Brick production in South Africa

- ❑ Latest round of eight (8) bricks were populated in May 2021
- ❑ All 8 of these bricks were shipped to CERN to be used in several vertical slice tests
- ❑ Test performed on all bricks showed expected behaviour as per specification requirements
- ❑ Changes made on for the hybrid to the latest high efficiency bricks shown on labels

MOSFETS: STB57N65M5

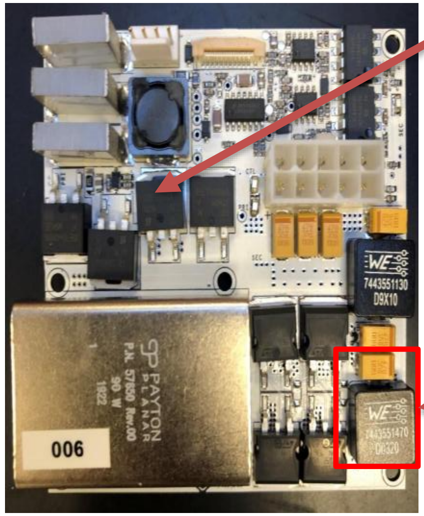
Inductor: XAL1010-472MEB



Hybrid brick

MOSFETS: IRFS9N60APBF

Inductor: 7443551470



High Efficiency brick

Burn-in station - Final integration

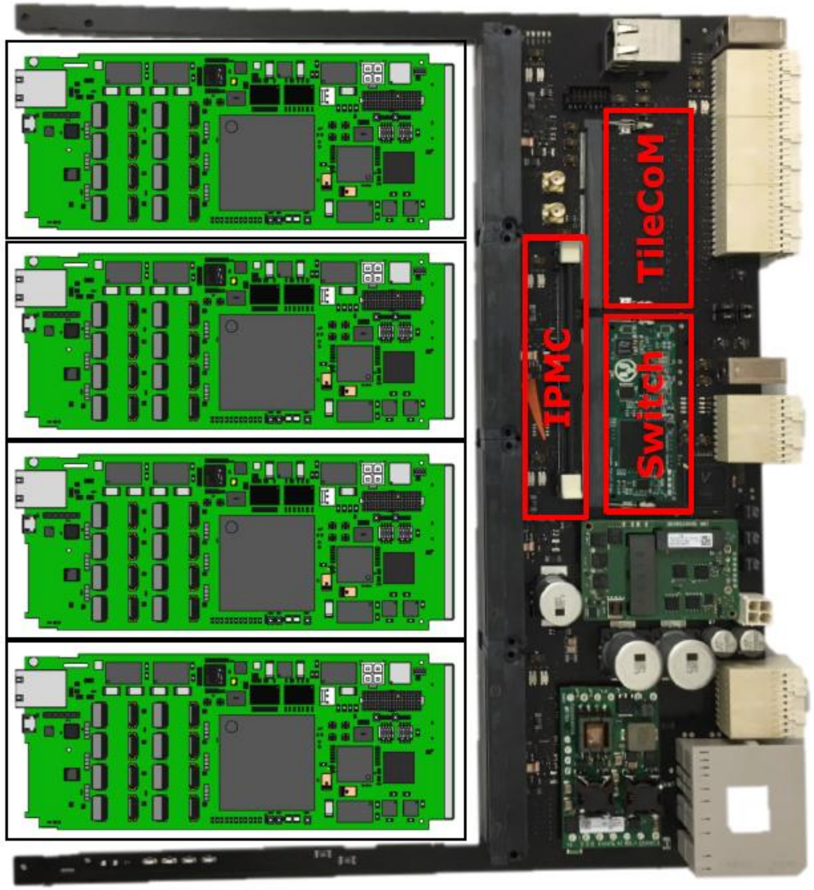
The Cooling plate mounting brackets are being designed and manufactured.

The custom made Wiring is being produced.

The perspex lid and top panel are to be produced in the coming month.

The TilePPr for Tile Phase II upgrades

- S.A Contributes 24 % of the Tile PPr
  - Production of boards in S.A.
  - Current production focus on the TileCoM and the Tile GbE Switch
- Developments and testing
  - TileCoM standalone developments
  - Testing of the boards after production
  - Integration of boards produced in S.A with Tile-PPr boards

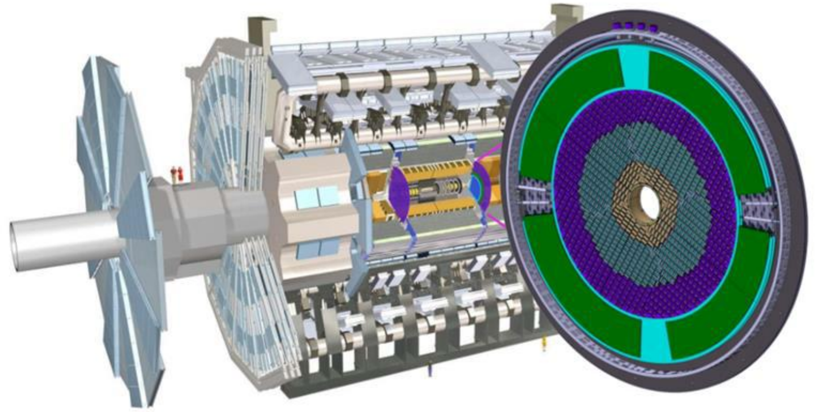


The TilePPr boards produced in SA

- First **PPr demonstrator** board produced in South Africa (**Similar to CPM**)
  - Successfully tested in the demonstrator project
  - Currently used for data acquisition in the Tile Cal Phase II upgrade electronic system
- Tile GbE Switch produced in South Africa
  - Successfully tested with the TileCoM firmware and software developments
- The next board to be produced by South African companies is the TileCoM
  - Production of this board will start soon
  - This board will host all the developments developed by University of the Witwatersrand

Phase-II upgrade: The High Granularity Timing Detector (NEW)

ATLAS EXPERIMENT

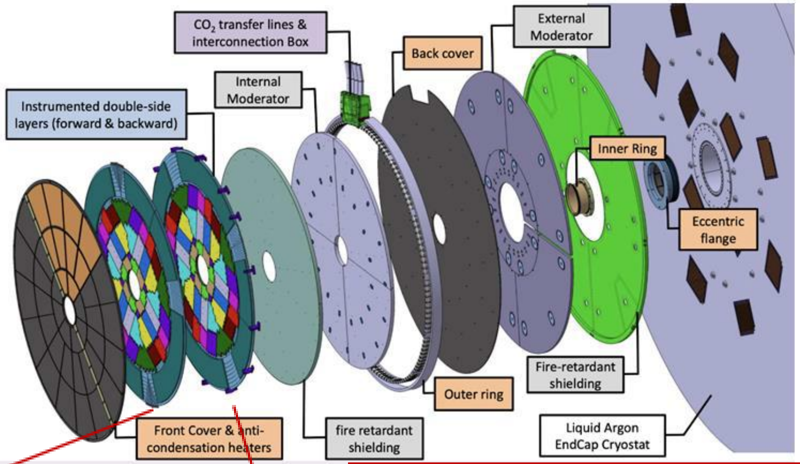


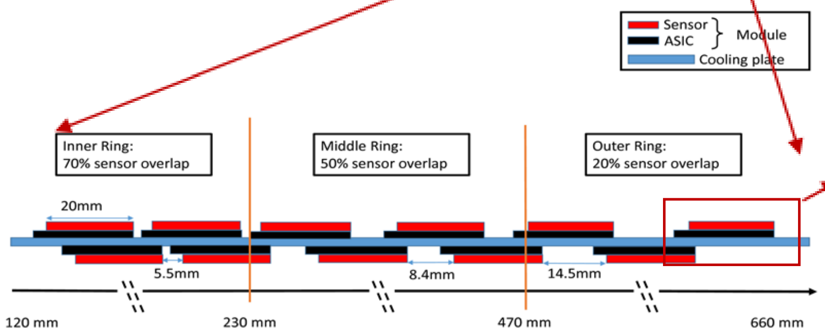
The HGTD is designed to provide timing information for ATLAS at the HL-LHC

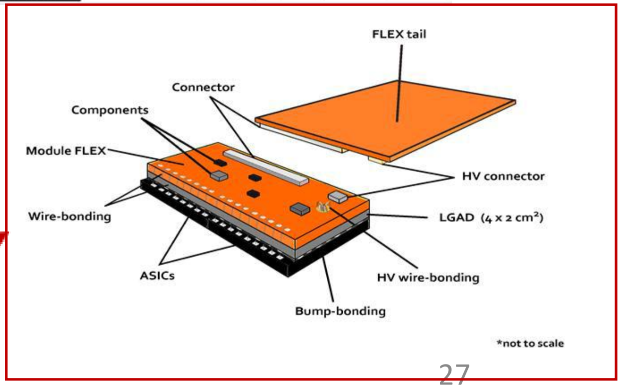
- 6.4 m^2 silicon detector and about 3.6×10^6 channels,
- Based on the low-gain-avalanche-detector senor, 1.3 mm × 1.3 mm, able to work in the ATLAS detector environment,
- Design time resolution: 30 – 50 ps/track (start to end-of-life),
- Provide luminosity measurement,
  - Count number of hits at 40 MHz (bunch-by-bunch),
  - Goal for HL-LHC: 1% luminosity Uncertainty.

The two detectors are located between the barrel and the endcap calorimeters

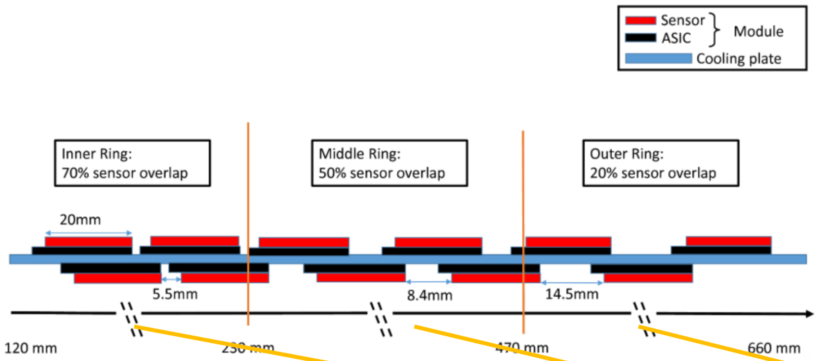
- Each detector (end) has two disks with sensors mounted on both sides,
- Located at ±3.5 m from the interaction point,
- Active area coverage: 2.4 < |η| < 4,
- Radius: 120 mm < r < 640 mm.



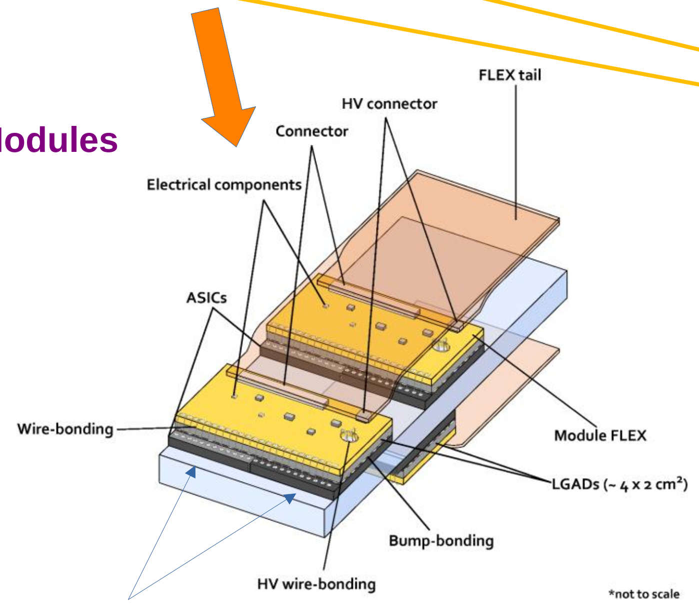




HGTD: The Instrumented disk

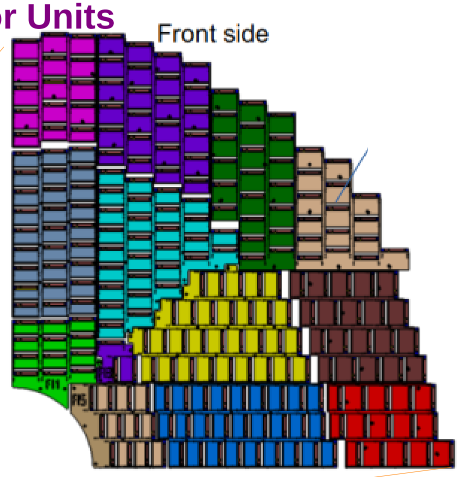


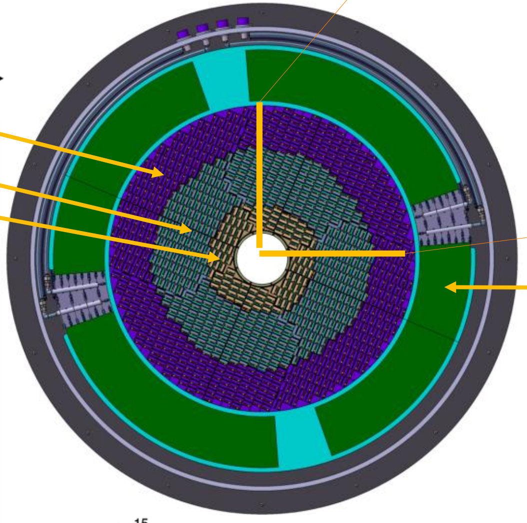
Modules



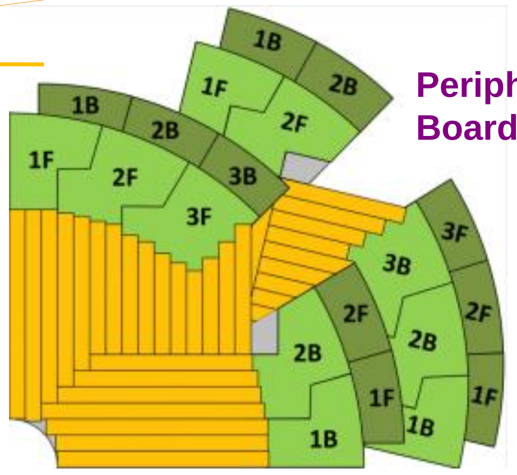
Hybrid = ASIC (ALTIROC) + sensor (LGAD)
Module = 2 hybrids + flex PCB

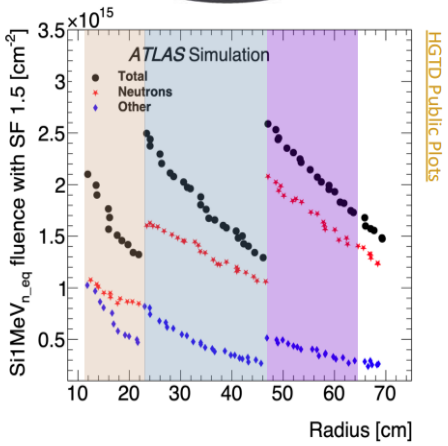
Detector Units





Peripheral Electronics Boards (PEB)



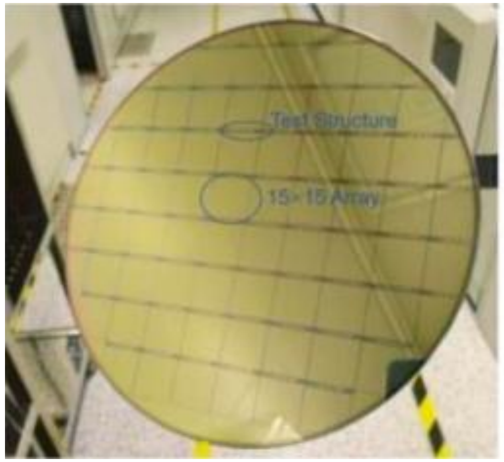


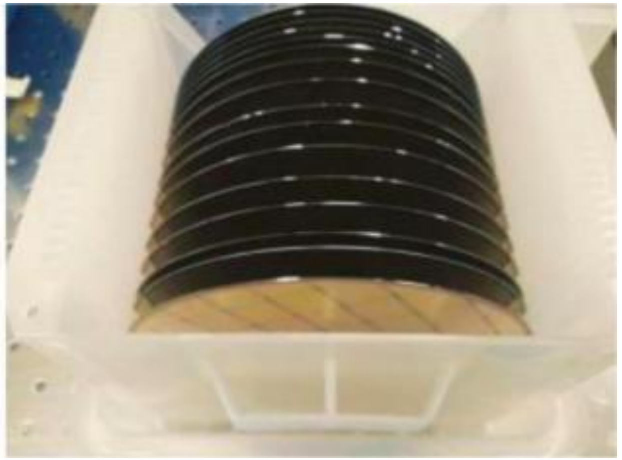
Maximum fluence **2.5 x10^{15} n$_{eq}$/cm^2** and **2 MGy** at the end of HL-LHC (after 4000 fb^{-1})

HGTD: LGAD sensors preproduction

IHEP-IME

52 sensors/wafer

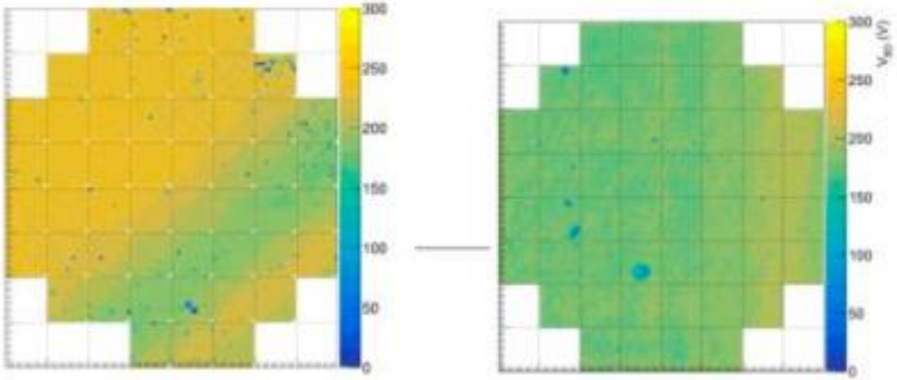




115 wafers processed (90 already fabricated)

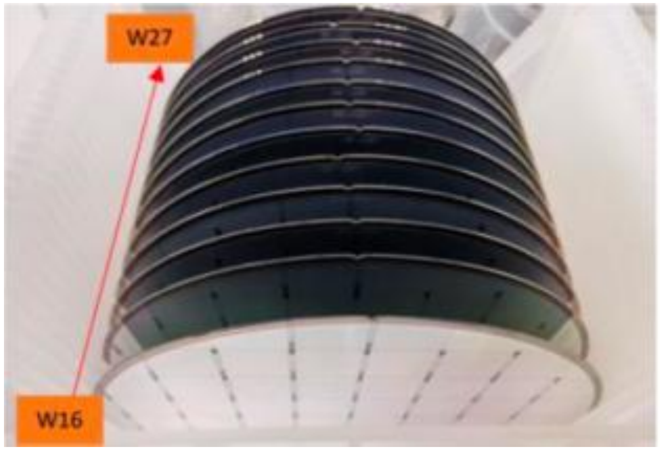
- Considering min. 35% yield → 2093 sensors
- Required: 200 (in-kind) +580 (CERN) sensors

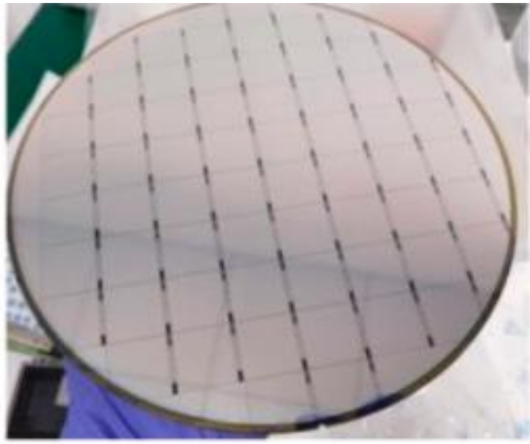
Satisfy Requirements



USTC-IME

52 sensors/wafer

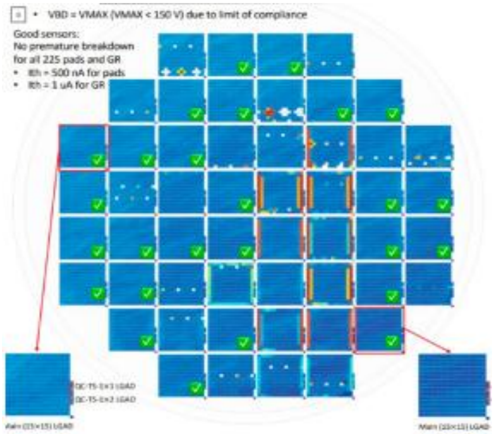




27 wafers fabricated

- Considering min. 35% yield → 590 sensors
- Required: < 200 (in-kind)

Satisfy Requirements

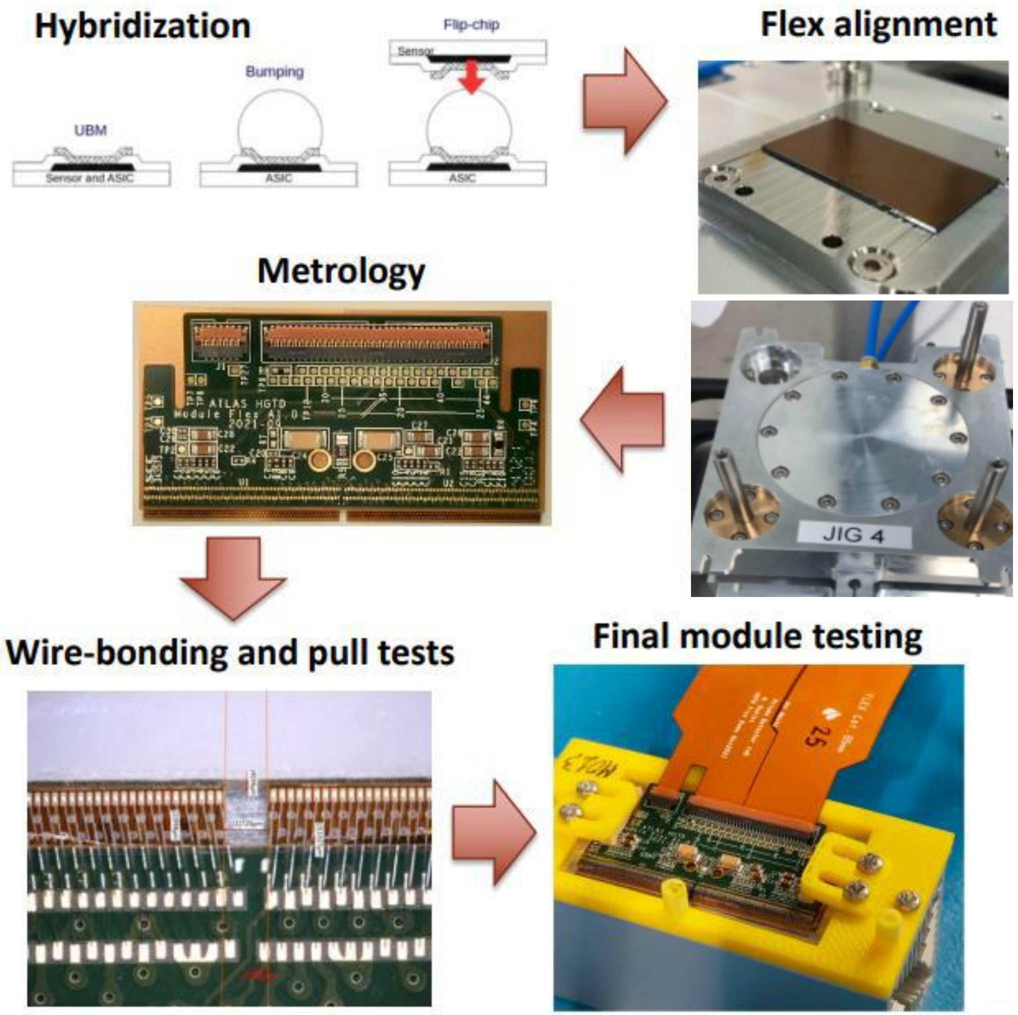


9 wafers passed all the requirements

HGTD: Module Assembly

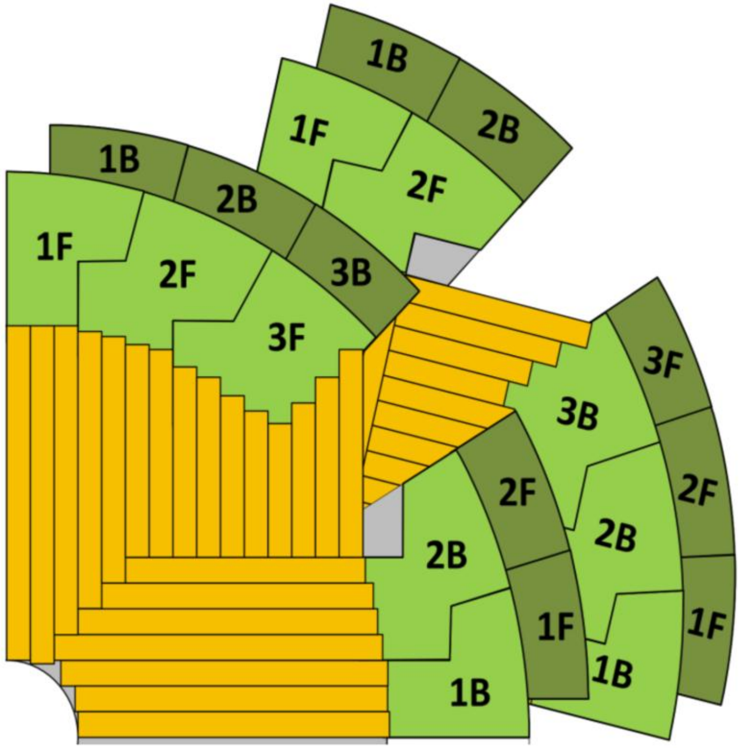
Module
- Hybridization
- Hybrids/Flex Gluing
- Metrology
- Wire Bonding
- Module testing

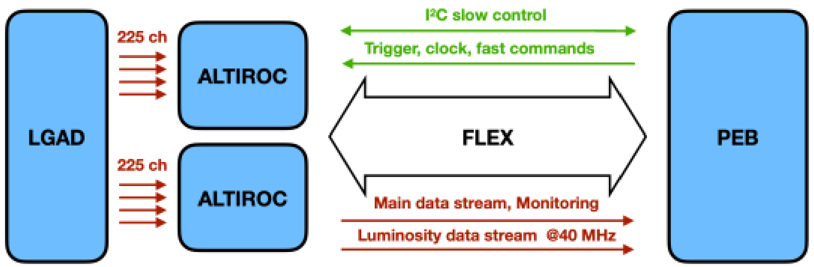
Detector Unit
- Vaccum plate positioning
- Height measurement
- Support Unit Gluing
- Move to transport plate
- Pack & ship



HGTD: Peripheral Electronics Boards (PEB)

- The front-end modules are connected to the PEB (660 < r < 920 mm) via flex tails
- Six types of PEBs to be designed (1F, 2F, 3F, 1B, 2B, 3B)





PEB	Front side	Back side
1F	54 modules	55 modules
2F	52 modules	56 modules
3F	39 modules	-
3B	-	39 modules
2B	52 modules	48 modules
1B	54 modules	53 modules

- 80 PEBs per HGTD vessel, thus 160 PEBs in total

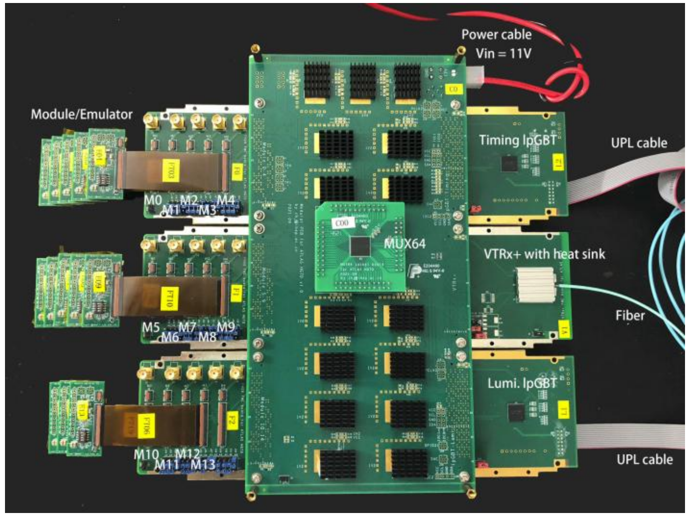
Shape	1F	2F	3F	3B	2B	1B
Requirements	32	32	16	16	32	32

- Very complex PCB design (22 layers)

- Basic functions of PEB
  - Data transmission (timing + Lumi)
  - Control (fast + slow)
  - Monitoring
  - Power supply distribution (HV + LV)
  - Temperature sensor routing for interlock system

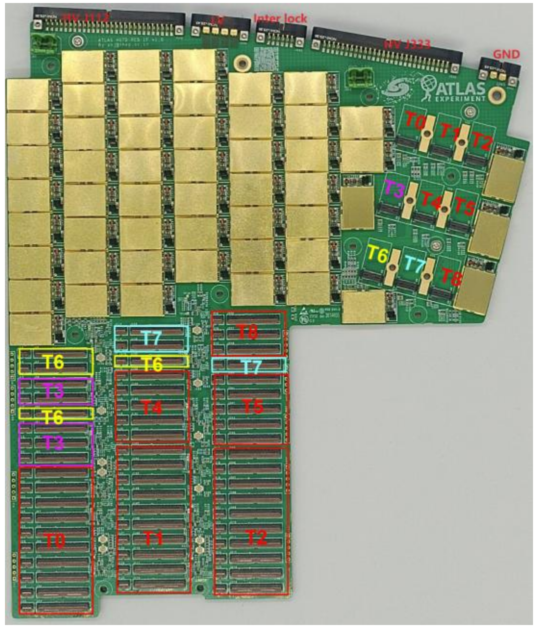
PEB: Hardware status

Peripheral board	Modules	lpGBT	bPOL12v	MUX	VTRx+
1F	55	9+3	52	9	9



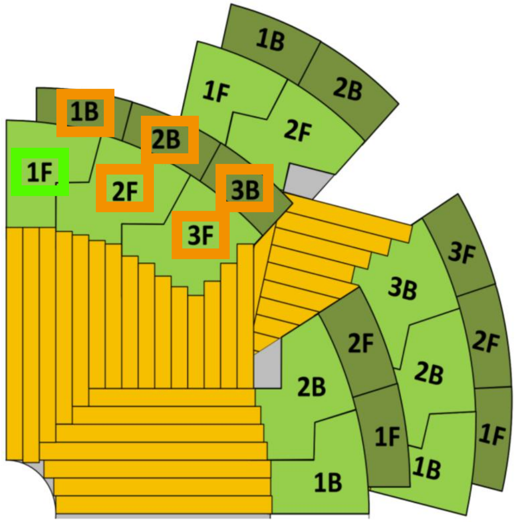
Modular PEB (1/9 of PEB 1F)

- Individual test boards (front-end modules, MUX64, bPOL12V, lpGBT and VTRx+)
- Achieve basic functions of PEB
- Validated by collaborators



PEB 1F

- Most complex one among the 6 types of PEBs, 22-layer PCB
- Up to 12 lpGBTs are used



Other 5 PEB types (ongoing)

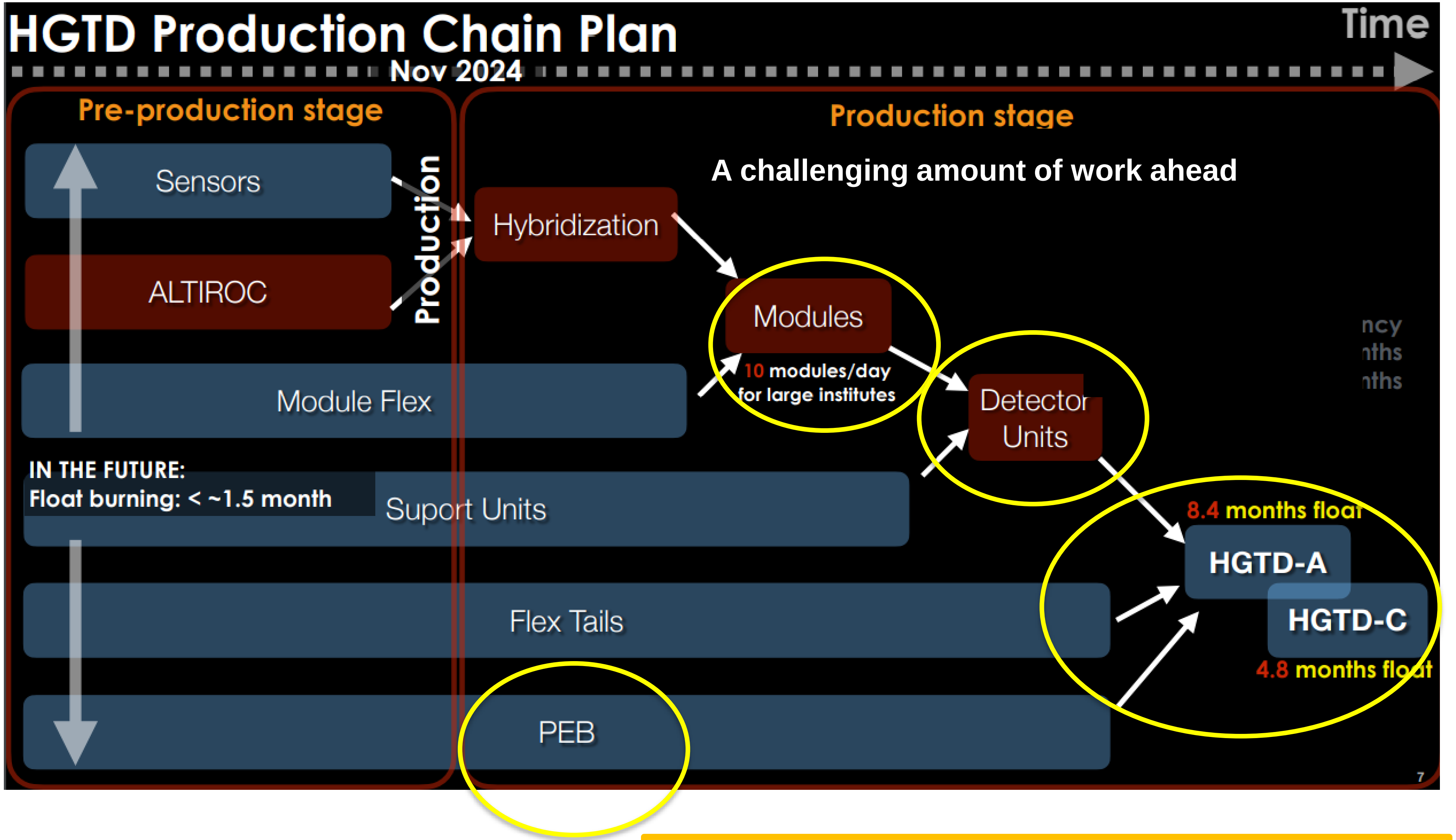
- Derived from PEB 1F, sharing library files, PCB stack-up and design specifications

	CERN	IHEP	NJU	Nikhef	KTH	Clermont
Modular PEB			1	1	1	1
PEB 1F	1	1				
Task	Demonstrator, System test	QA/QC, Responsibility	Training	DAQ	Lumi.	Timing

Planned ICPP/Wits Contributions to the HGTD

- Ongoing discussion to formalize our contributions to the HGTD project
- Wits HGTD group would be involved in the following:
  - Extensive test and validation of PEBs prototype (Thabo Lepota and Katlego Machethe first students to join this year)
  - Module assembly at CERN and full chain demonstrator
  - Assembly and Integration of Module-0 + beam-tests
  - Assembly, Integration and commissioning of the full HGTD (longer term plans)
- Roadmap to acquire expertise in the early stage (2025) of the ongoing work as a preparation towards the full installation.
  - Planned continuous presence at CERN (students, Postdoc?, Technical support)
- Potential technical support from iThemba Lab (under discussion)
  - Design of “some” PEBs?
  - Support to the assembly and integration effort when needed.
- Further contributions in performances studies and software development via qualification tasks (QT).

Production Plan



ICPP planned involvement in HGTD production

Summary

- ICPP has a strong and dedicated ATLAS team involved in numerous and diverse activities
  - Tile Calorimeter (operations, phase-I,II upgrades), HGTD (phase-II)
  - Detector Performance studies
  - Physics analyses: New searches, Anomaly detection, Dark Matter….
  - New Analysis techniques: ML, AI in HEP

- All these projects provide a unique training to SA students in high-end technology, Software tools, MC, HEP phenomenology…

- ATLAS/LHC future planning offers even many possibilities for further ICPP involvement and development
  - HL-LHC Run4,5… "New ATLAS detector", operations, handling of extremely large data, New techniques in physics analysis, New theoretical models…
  - Looking forward to contributing even more to ATLAS activities. ☺