https://cds.cern.ch/record/910381

Preparing ATLAS for the future

HANNAH E. HERDE • LUND UNIVERSITY ~ FYSIKDAGARNA 2023

What if we had 10x more data?

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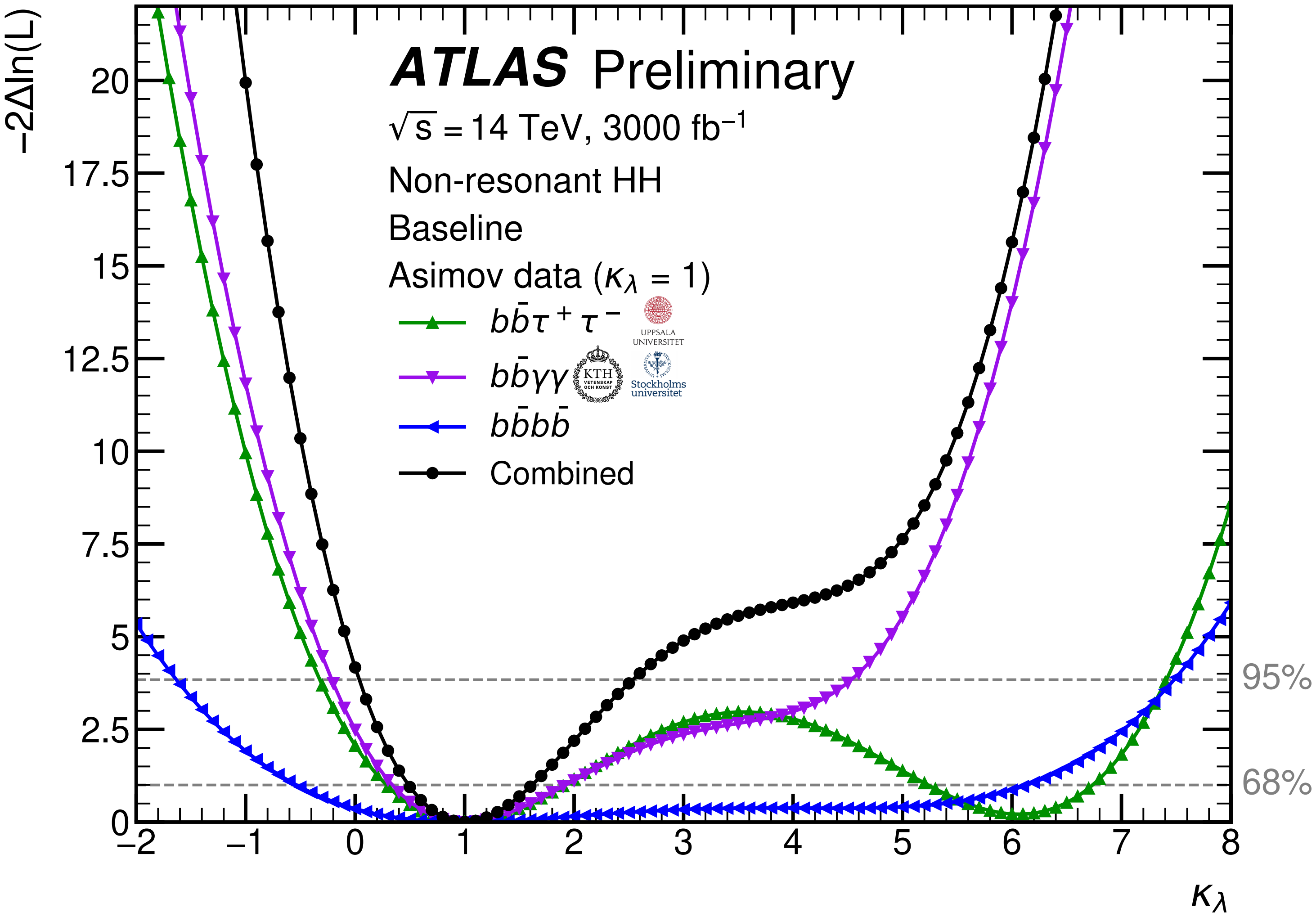
Example projection at 3000 fb^{-1}

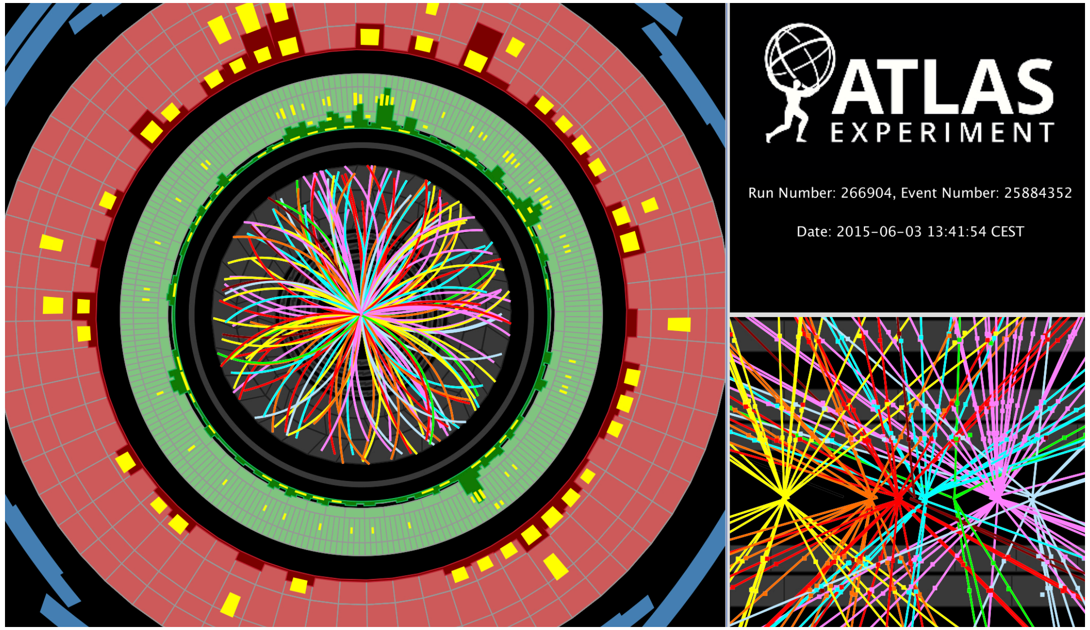


ATL-PHYS-PUB-2022-053

Search for di-Higgs production

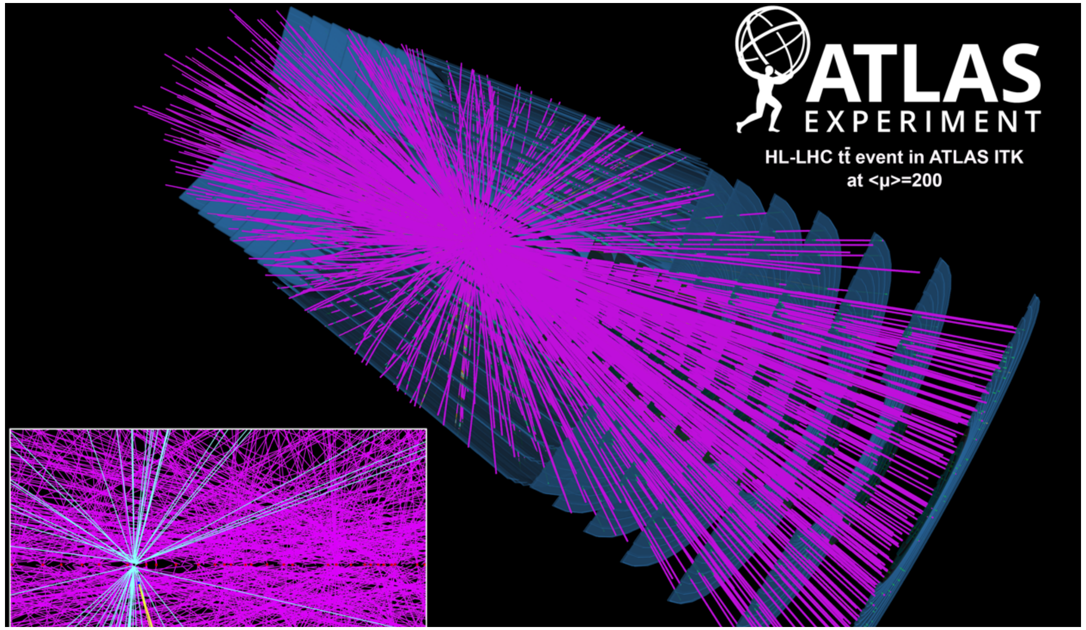
- ★ Di-Higgs production accessible!
  - Assumes performance comparable to Run-2 ATLAS Detector
- ★ **We need to collide even more protons.**

New accelerator coming: We need a new detector.



Large Hadron Collider, LHC

Designed for **~20-30 collisions** per bunch crossing

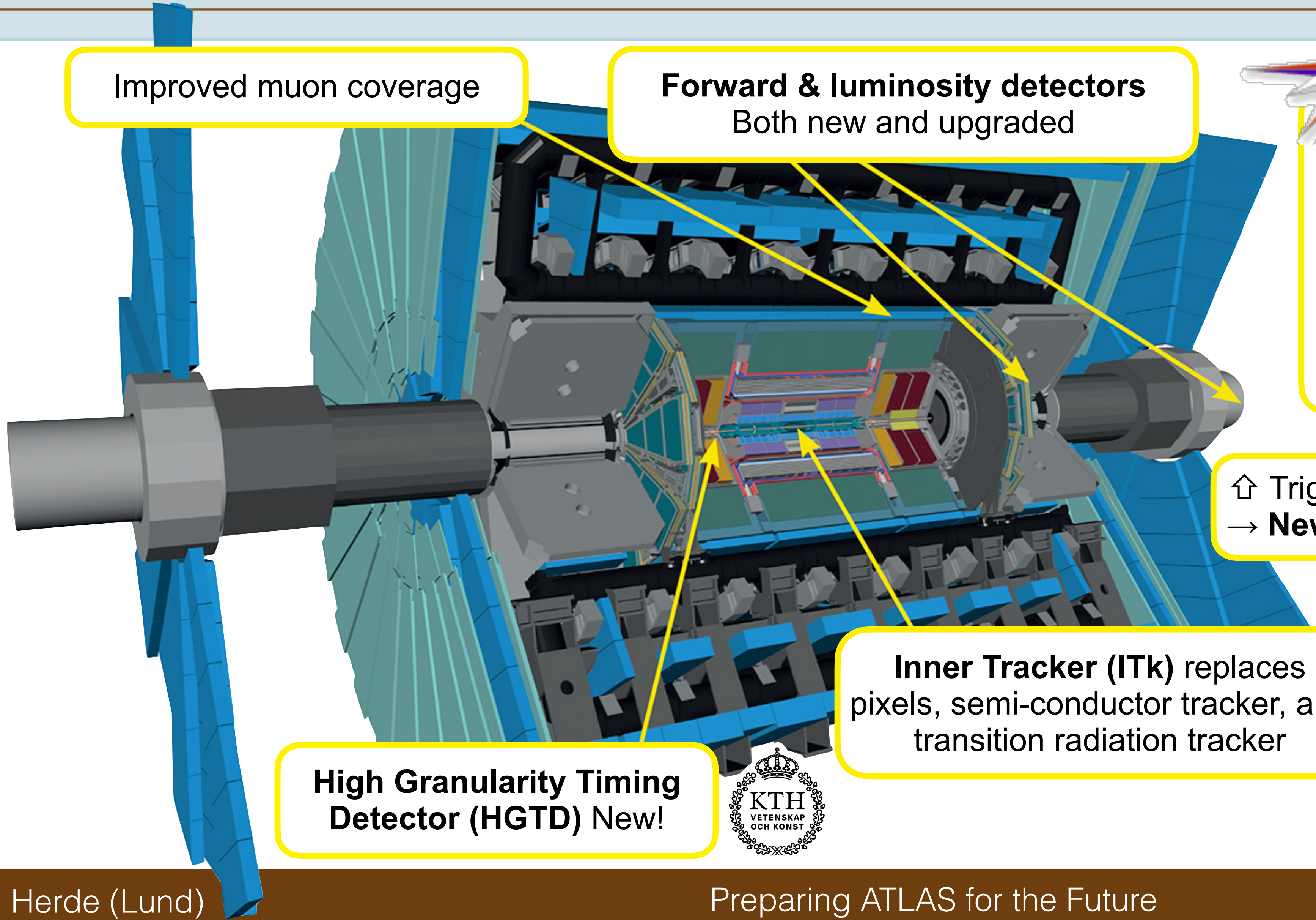


High Luminosity LHC, HL-LHC

Up to **~200 collisions** per bunch crossing

📷 First stable beams at 13 TeV, https://cds.cern.ch/record/2022598; HL-LHC pileup simulation in ATLAS ITk, https://twiki.cern.ch/twiki/pub/AtlasPublic/UpgradeEventDisplays/HL-LHC-tt.png

ATLAS for HL-LHC



Improved muon coverage

Forward & luminosity detectors
Both new and upgraded

NORDUGRID
Grid Solution for Wide Area Computing and Data Handling

Multithreaded computing model

Heterogeneous computing architecture

Significantly increased hardware computing load needs

⇧ Trigger, Data Acquisition rates
→ **New TDAQ system (FELIX)**

Tile Hadronic Calorimeter focused

Stockholms universitet

Inner Tracker (ITk) replaces pixels, semi-conductor tracker, and transition radiation tracker

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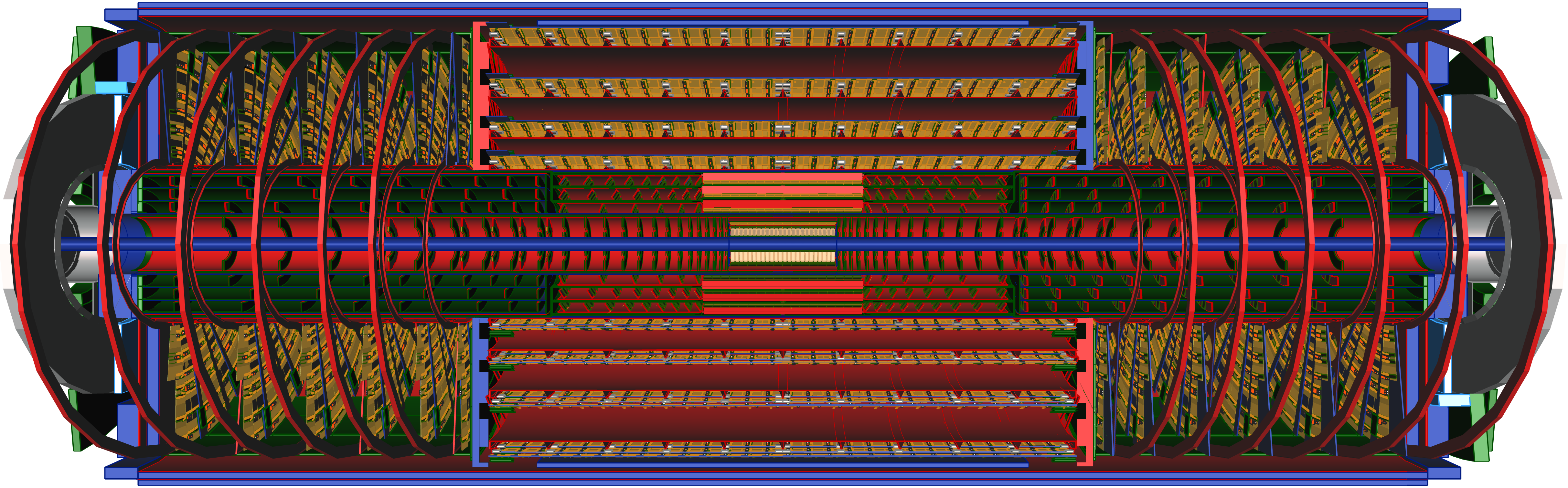
High Granularity Timing Detector (HGTD) New!

KTH VETENSKAP OCH KONST

Adapted from https://cds.cern.ch/record/2846341

Inner Tracker (ITk): An all-Silicon tracking system



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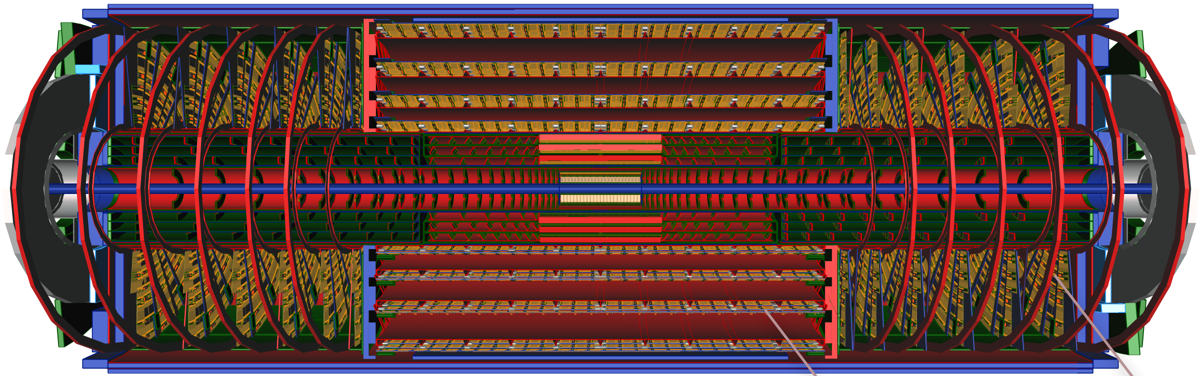
ITk strip system



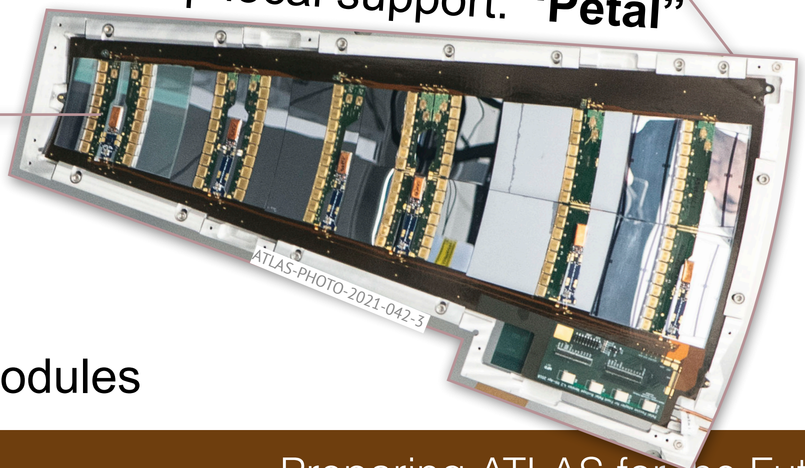
Barrel local support: **“Stave”**


Brookhaven National Laboratory

Individual strip detector unit: **“Module”**

Si sensor mounted with electronics

Endcap local support: **“Petal”**



10 976 barrel + 6 912 endcap modules

10% of endcap modules will be manufactured in Scandinavia

Module assembly

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Wirebonding

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Testing

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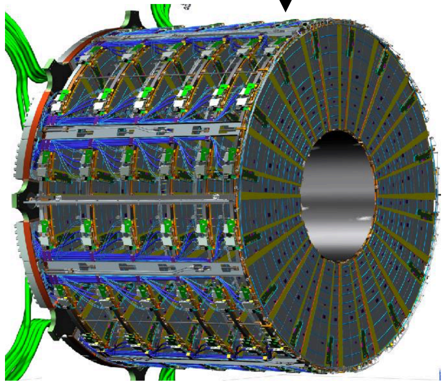
Petal loading

IFIC INSTITUT DE FÍSICA CORPUSCULAR

Endcap integration

Nikhef



Strip modules assembled at Uppsala & NOTE

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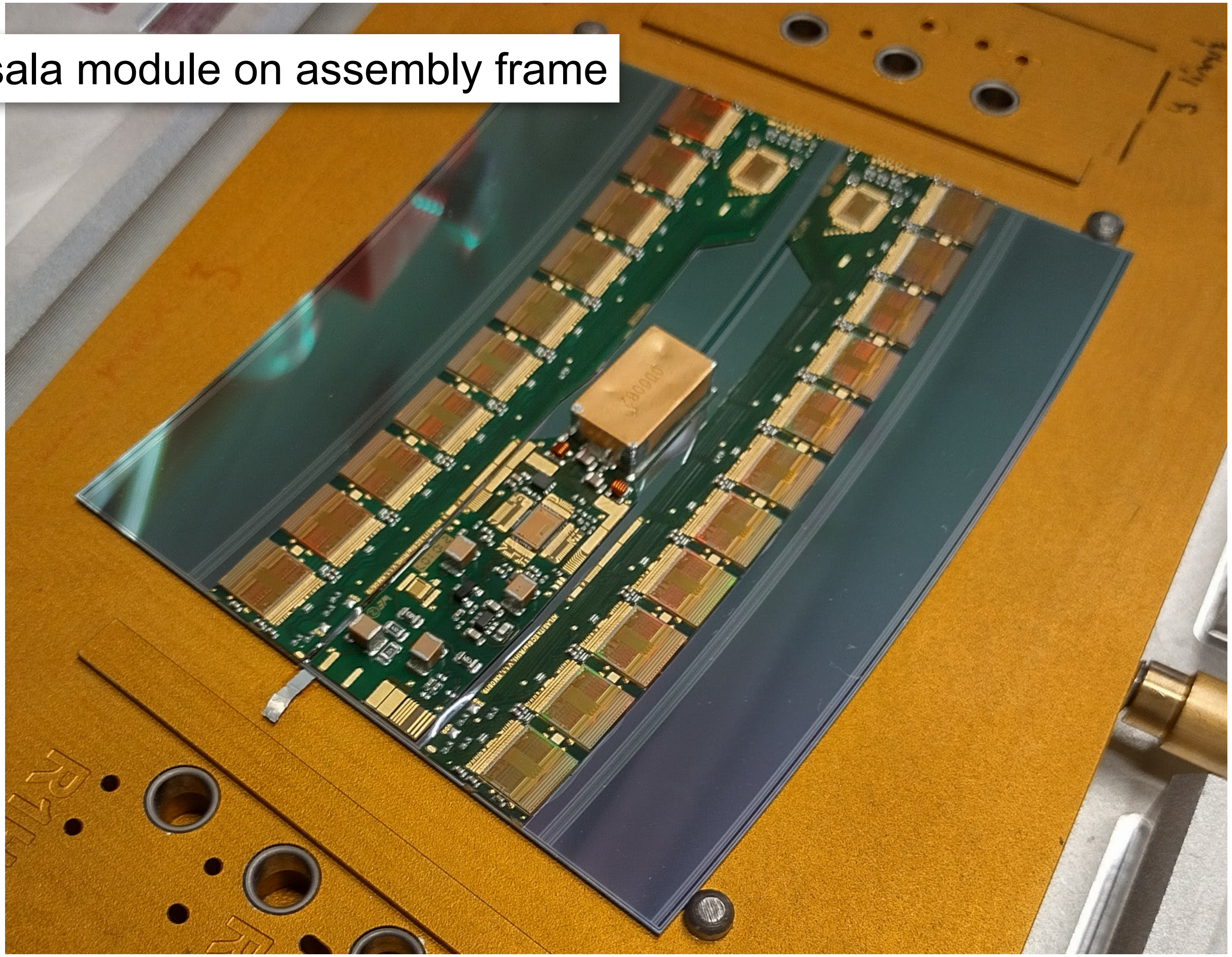
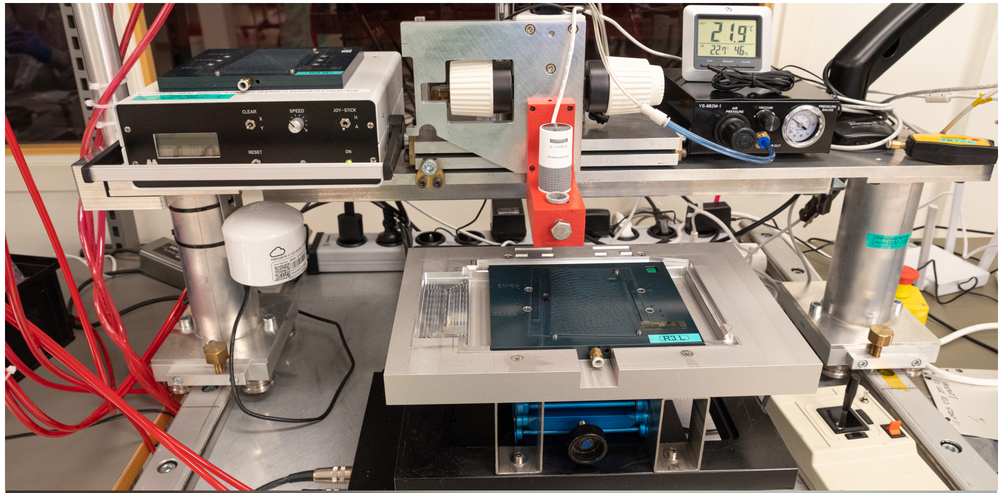
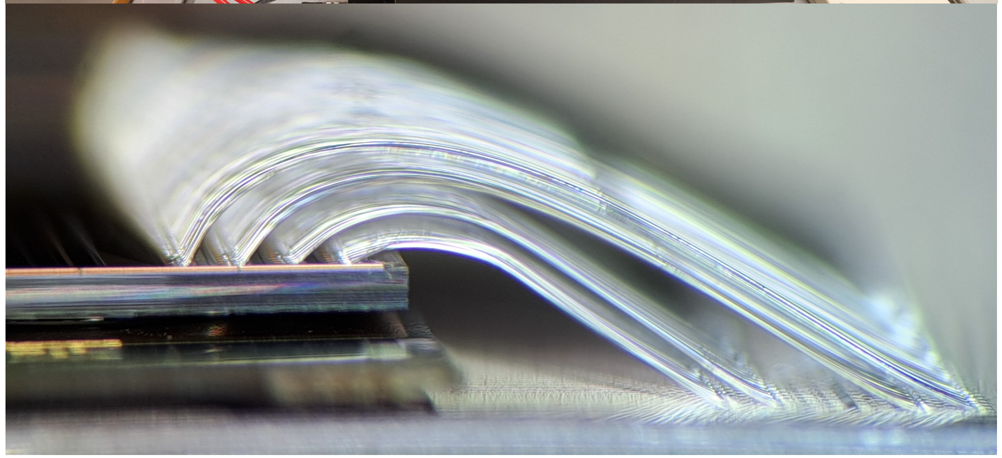
Uppsala module on assembly frame



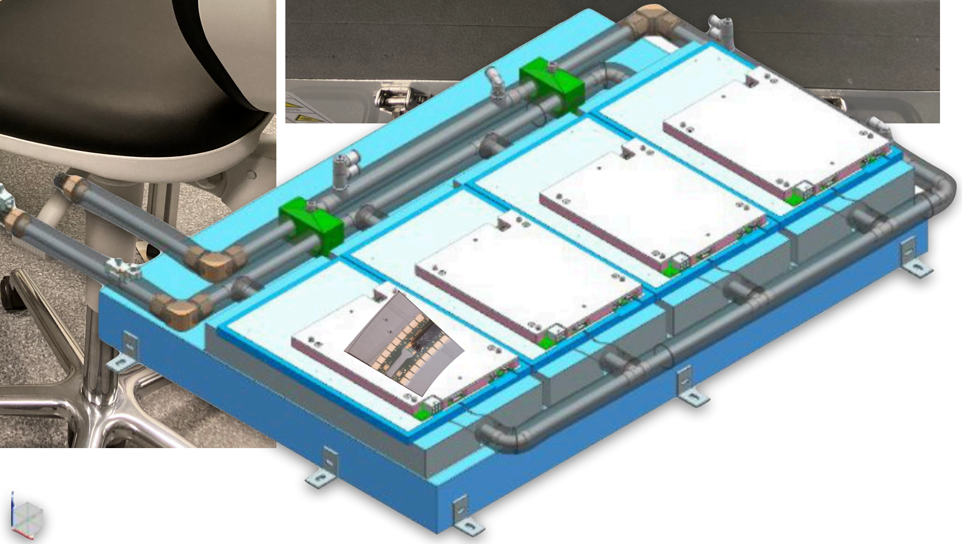


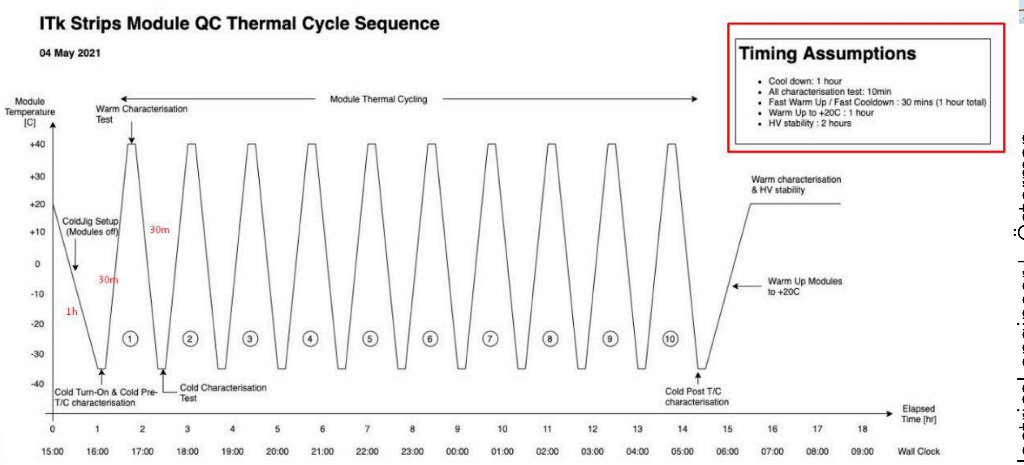


4 layers of 25-µm aluminium wire bonds connect readout & strip

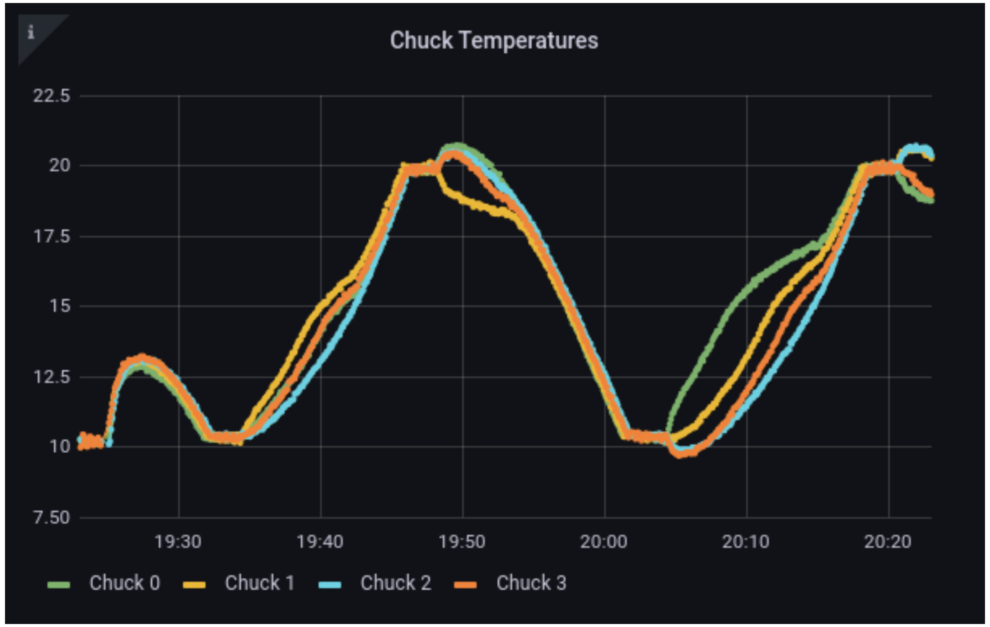
Quality control electrical testing at Lund

Module response to thermal stresses expected during operation



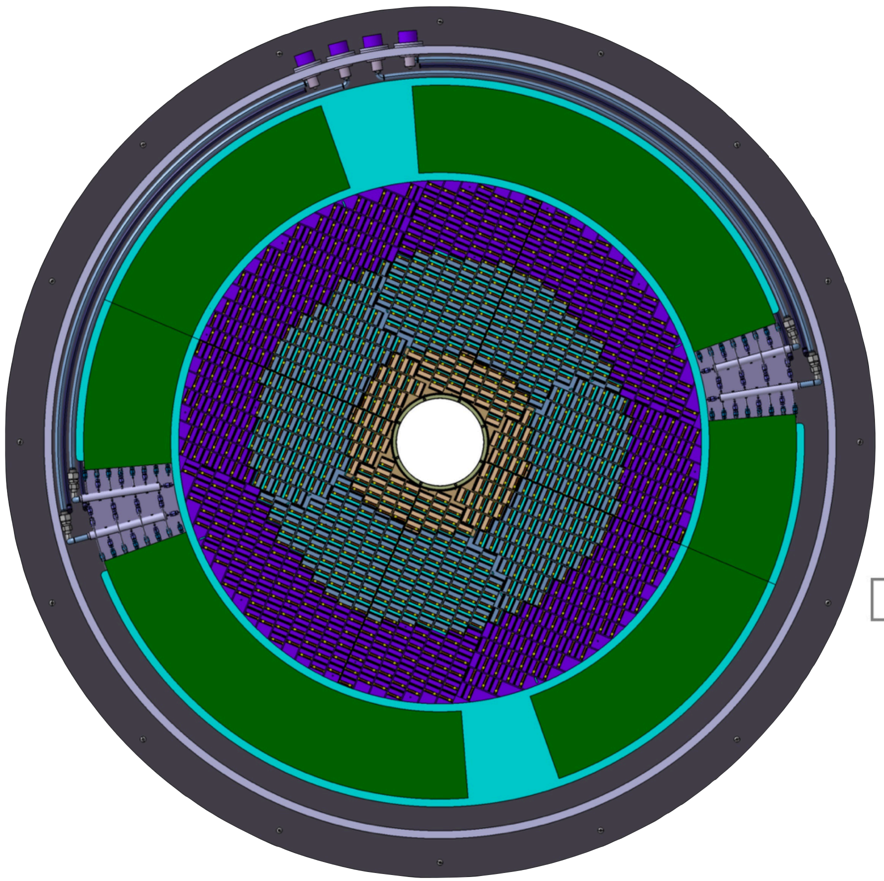


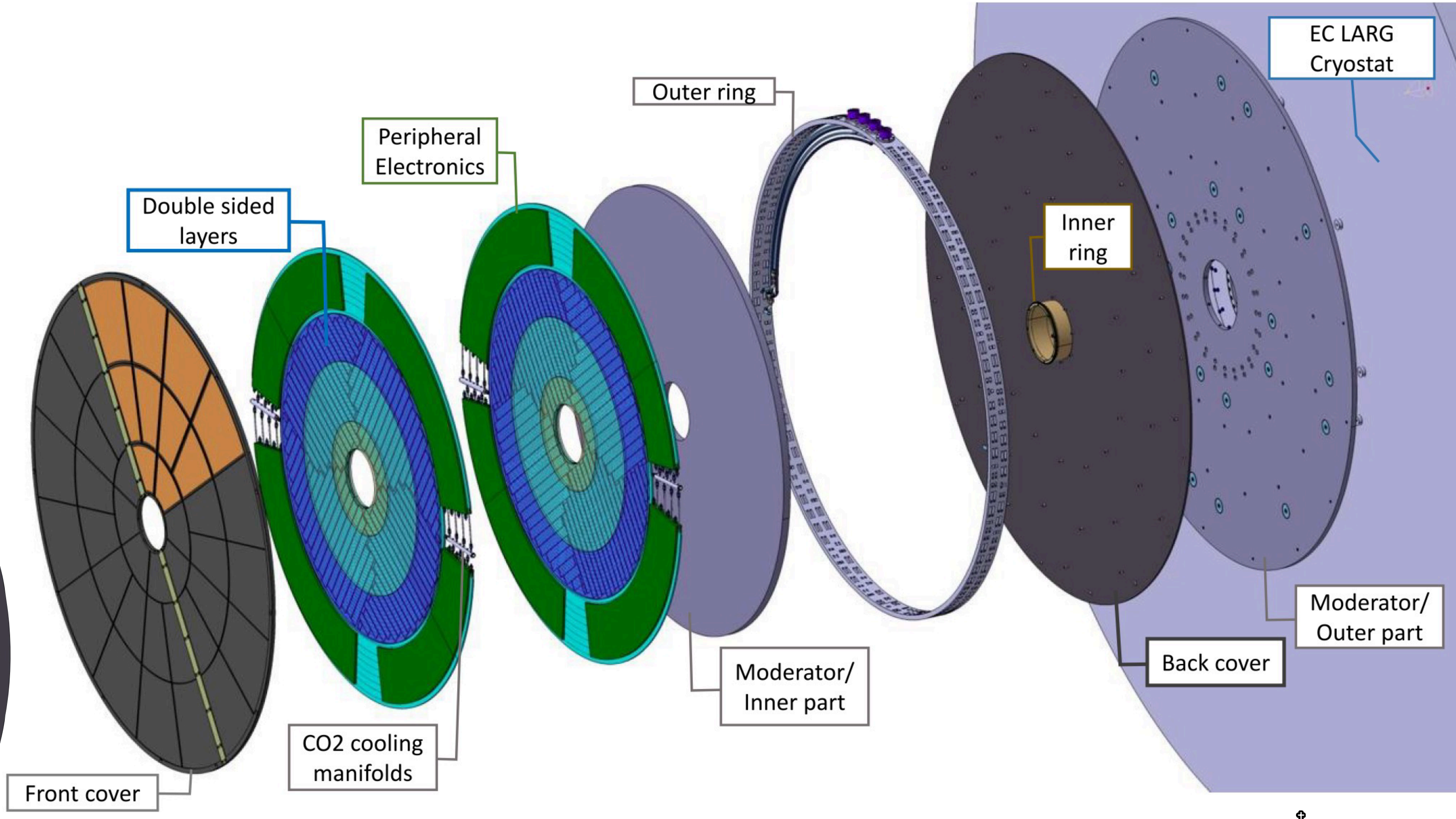
First automated cycle in Lund



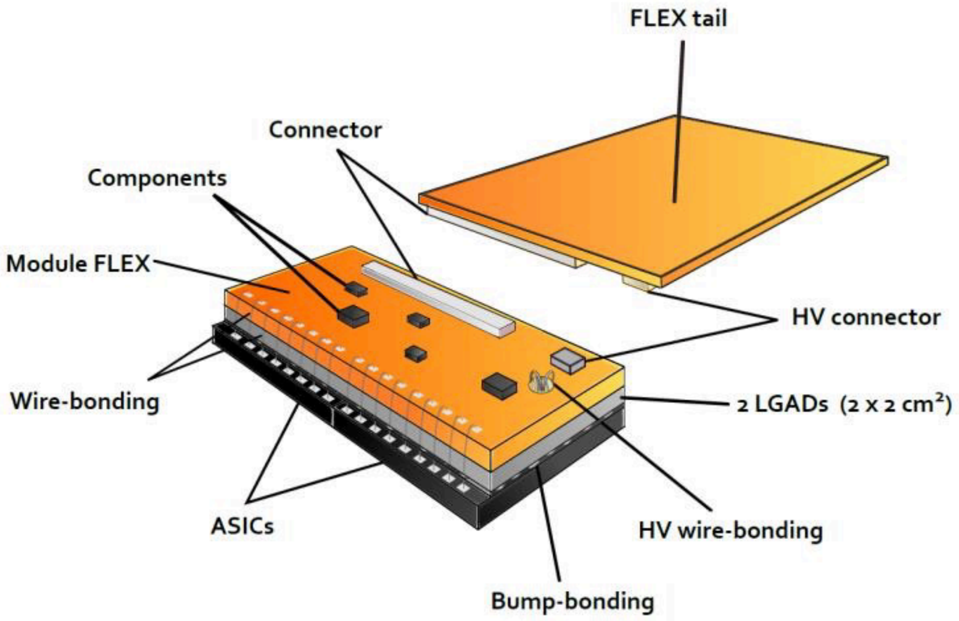
PhD student E. Wallin, masters student E. Torres Reoyo, electrical engineer L. Österman

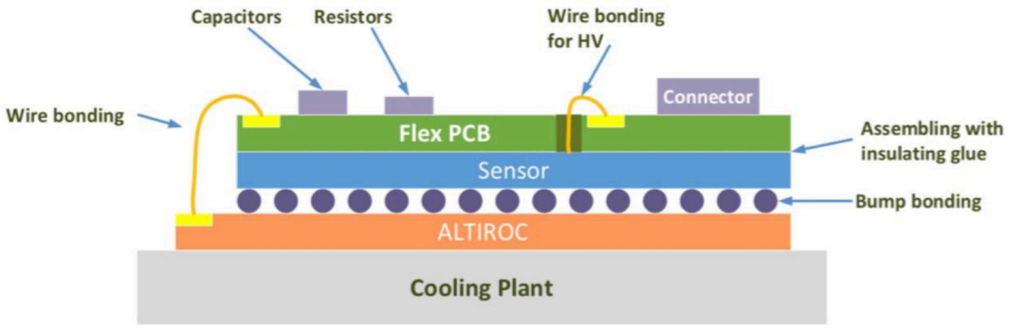
High Granularity Timing Detector (HGTD)





HGTD modules and goals





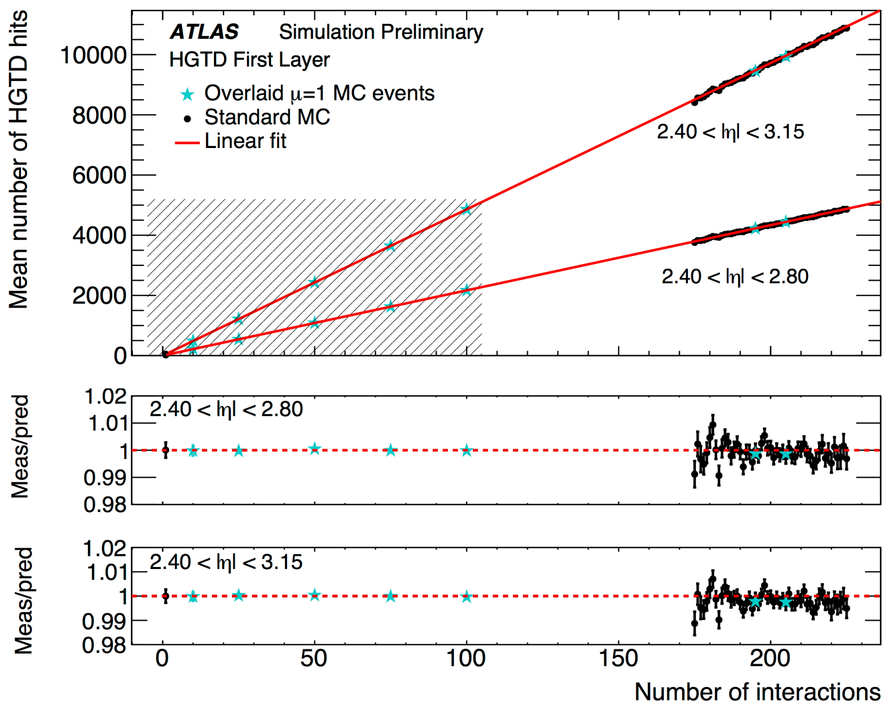
★ Provide accurate **arrival time measurement** for particles in the forward direction (< 50 ps) to **mitigate pile-up**

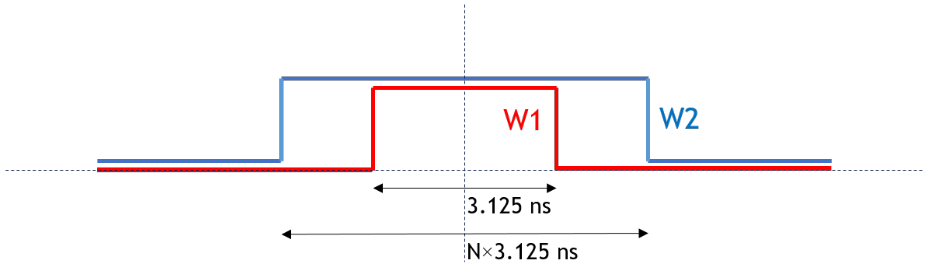
★ Send information of the total number of hits for every bunch crossing, used to estimate the luminosity of the LHC. **[KTH responsibility]**

- KTH: Firmware, software for luminosity data stream, all analysis for extracting luminosity measurement

CERN-LHCC-2020-007

HGTD as a luminosity detector





HGTD designed for low occupancy & fast signals

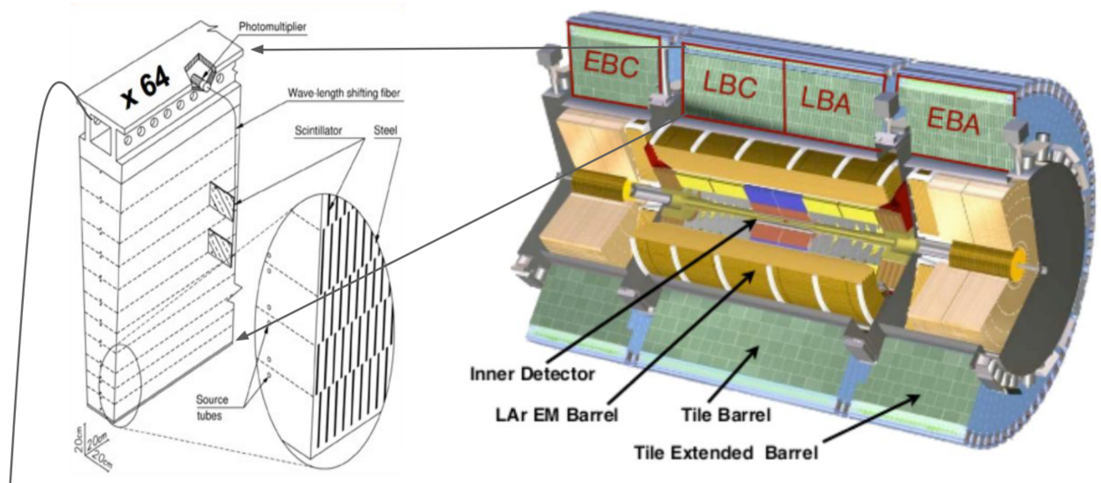
★ Average number of hits ∝ luminosity

- Low occupancy → linearity over the full range of μ

★ Compensate for 2 Si detector limitations: ALTIROC chips report:

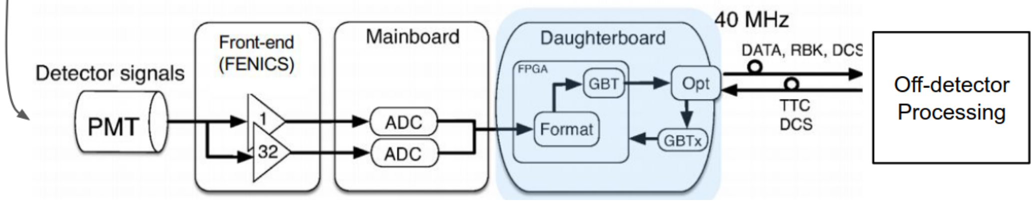
- Total number of hits in that sensor for every bunch crossing in a dedicated data stream
- Number of hits in a sideband time window for every bunch crossing → in-situ measurement of afterglow background levels

Trigger & Data Acquisition: Tile Calorimeter readout electronics



Daughterboard: Tile readout-out link

- Control & readout interface for the upgraded TileCal front end systems



ATLAS trigger rates

LHC Run 3	HL-LHC
100 kHz	1 MHz

\+ harsher radiation environment
→ new TileCal readout electronics

★ Digitised data will be sent off-detector for every LHC bunch-crossing (40 Tb/s over 6000 optical fibres)

★ On-detector electronics must sustain high radiation doses

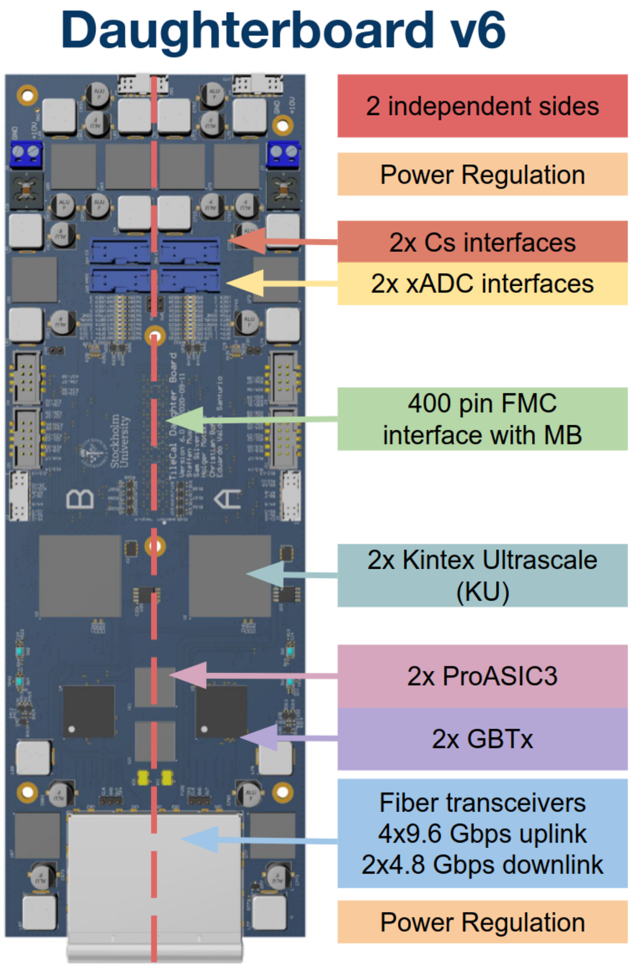
★ Design, production, and testing of all **1085** daughterboards done by Stockholm University

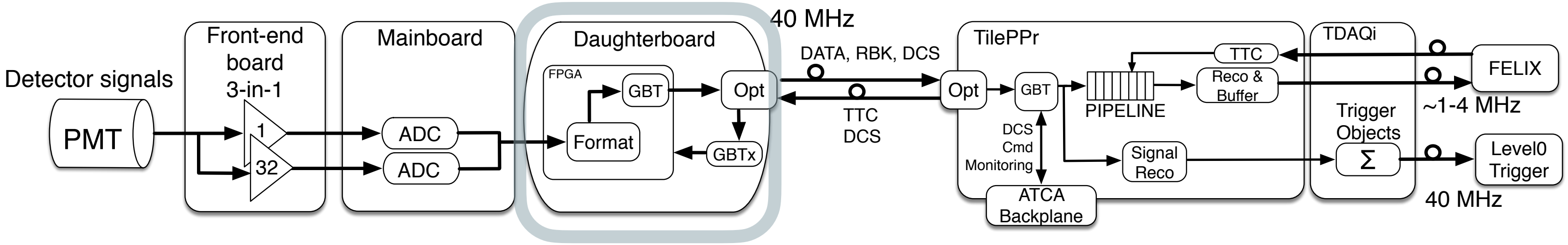
Stockholms universitet

https://cds.cern.ch/record/1095927

Daughter board

High-speed interface with off-detector electronics via redundant links





★ Collects digitised data from the MainBoard

★ Interfaces to off-detector electronics through optical links

★ Clock and commands recovery and distribution

★ Design and radiation testing close to complete (Final design review in fall 2023)

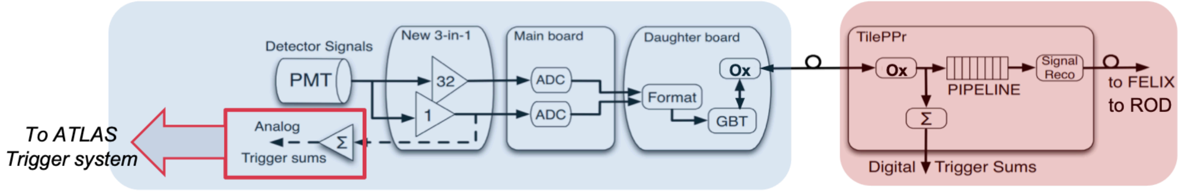
Stockholm University production lab:

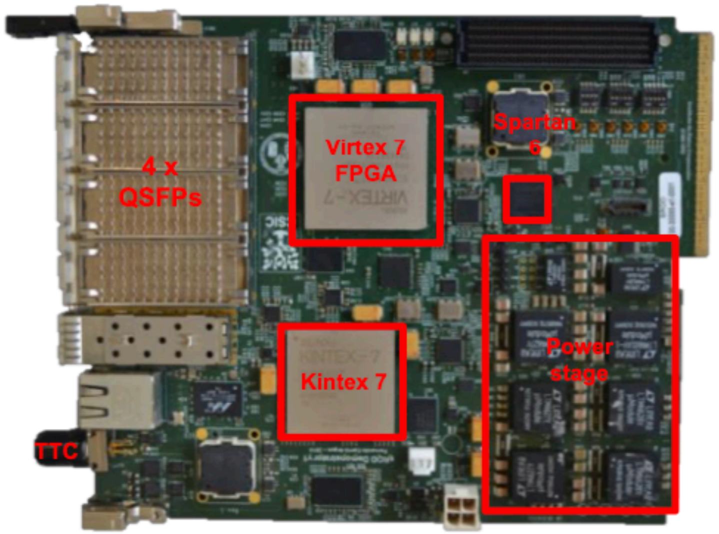
- 2 test benches for production testing and debugging
- Burn-in oven for up to 40 daughter boards, with temperatures up to 85°C

Delivery to ATLAS by end-2026

ATL-TILECAL-PROC-2022-017

Demonstrator module





TilePPr Demonstrator

DaughterBoard v6

Running in ATLAS Run 3

- ★ TileCal prototype electronics for HL-HLC installed in ATLAS readout **right now**
  - Fully integrated with detector control and trigger/data acquisition software
- ★ Good performance
  - Low noise levels wrt legacy modules
- ★ Depends on Stockholm's daughter board

ATLAS for HL-LHC: Key takeaways

★ Extensive programme touching every part of ATLAS to cope with massive increase in data rate

★ Swedish contributions to ITk, HGTD, TileCal trigger & data acquisition, and software & computing

Next two talks: Focus talks on specific analyses with Avik Banerjee and Olga Sunneborn Gudnadottir

More ATLAS at the poster session!

★ Eduardo Torres Reoyo (Lund): ITk module thermal cycling chamber commissioning

★ XU Xiangyu (Lund): ITk module metrology

★ Lara Čalić (Lund): Tracking with A Common Tracking Software (ACTS)

★ Alexander Ekman (Lund), Axel Gallén (Uppsala): Machine learning based compression for scientific data

★ Eva Mayer (Uppsala): Boosted decision trees for searches for dark mesons

Additional material

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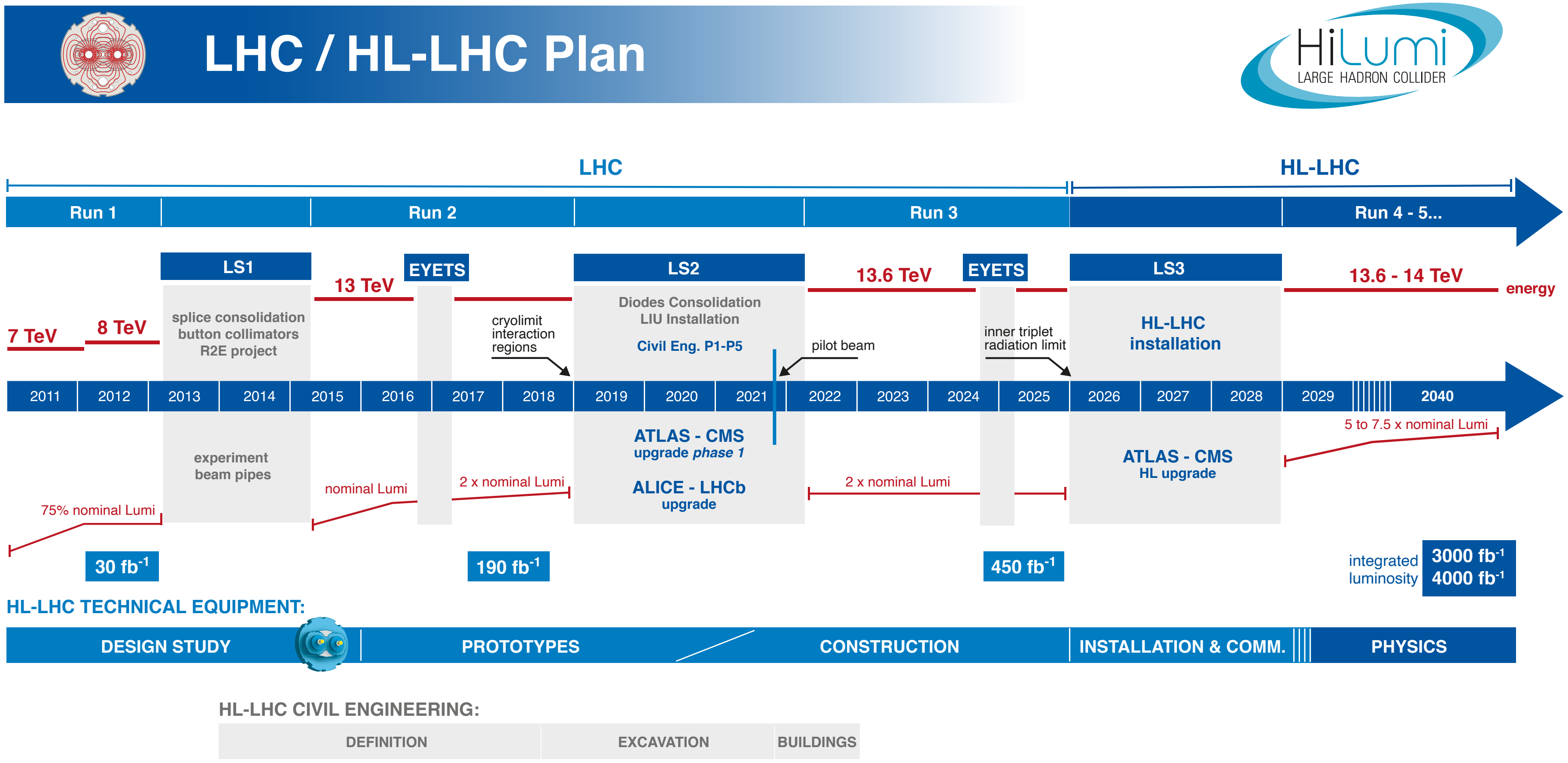
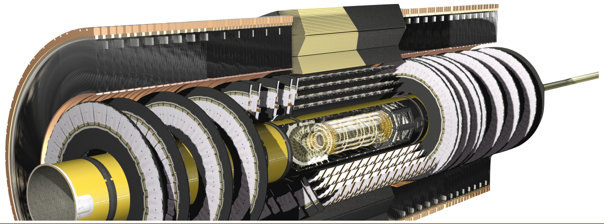
LHC/HL-LHC Schedule

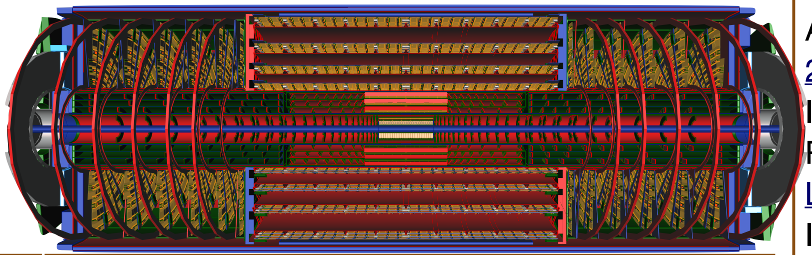
Updated January 2022



How much of an “upgrade” *really* is ITk?

Comparing ATLAS’ current Inner Detector and future Inner Tracker

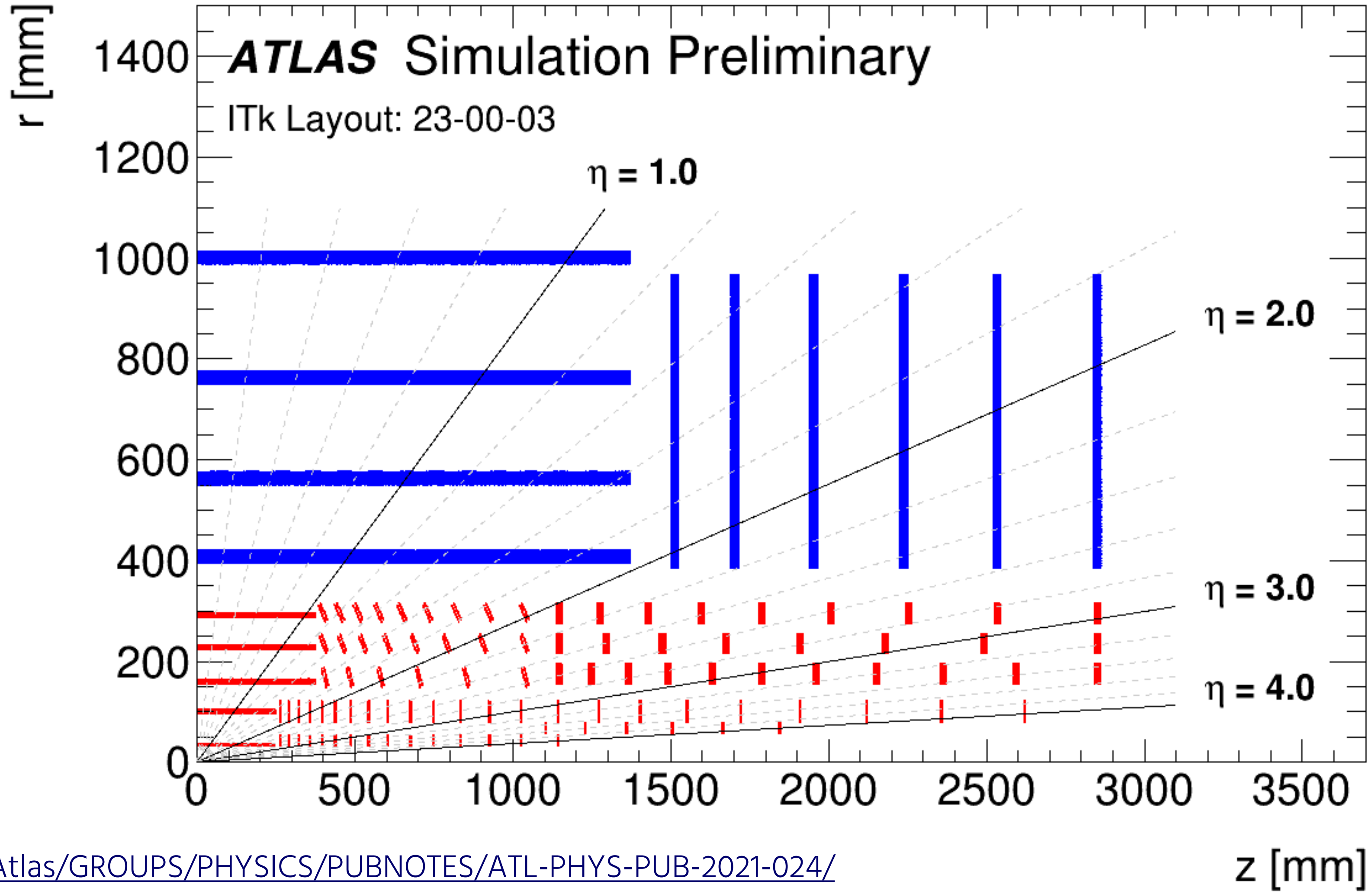




	Inner Detector (ID)	Inner Tracker (ITk)	
Detector layers	Si (pixels, strips) & gas trackers	Si trackers (pixels, strips)	
Coverage, $\|\eta\|$	<2.5 (pixels & strips), <2.0 (TRT)	<4.0 (pixels), <2.7 (strips)	
Trigger rate	100 kHz	1 MHz	x10
	Pixel detector	ITk Pixels	
№ of Pixels	92 million (80M Pixel + 12M IBL)	5 billion	x55
Pixels silicon area	1.9 m^2	12.98 m^2	x6.5
Pixel size	50x250 μm (IBL), 50x400 μm, 50x600 μm	50x50 μm, 25x100 μm	Smaller
	SCT	ITk Strips	
№ of Strips	6.2 M	59.9 M	x10
Strips silicon area	61 m^2	165 m^2	x10
Pitch	80 μm	75.5 μm	Strips smaller and closer together
Strip length	12.8 cm	2.4-4.8 cm	

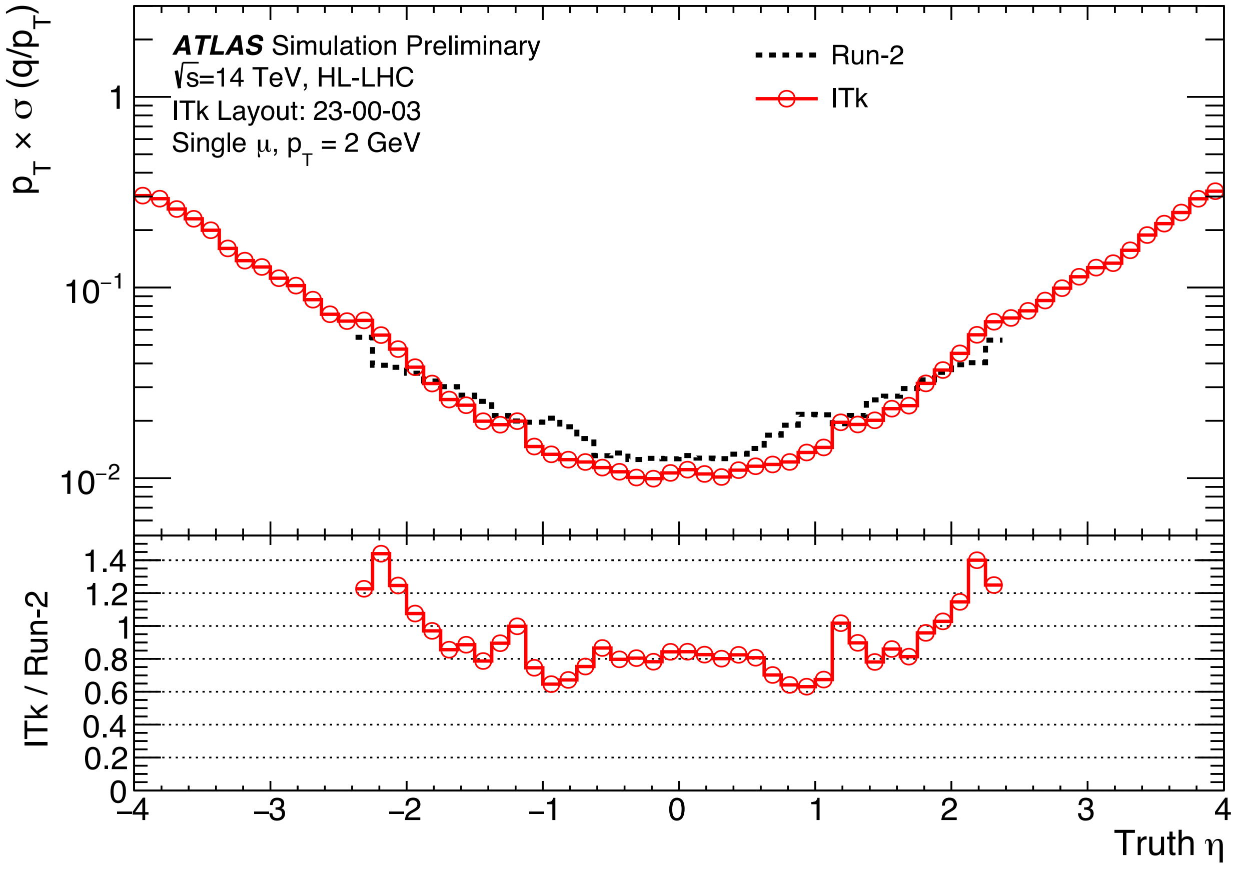
Learn more:
ATLAS Detector: 2008 JINST 3 S08003
IBL Technical Design Report (TDR): CERN-LHCC-2010-013
ITk Pixels TDR: CERN-LHCC-2017-021
ITk Strips TDR: CERN-LHCC-2017-005

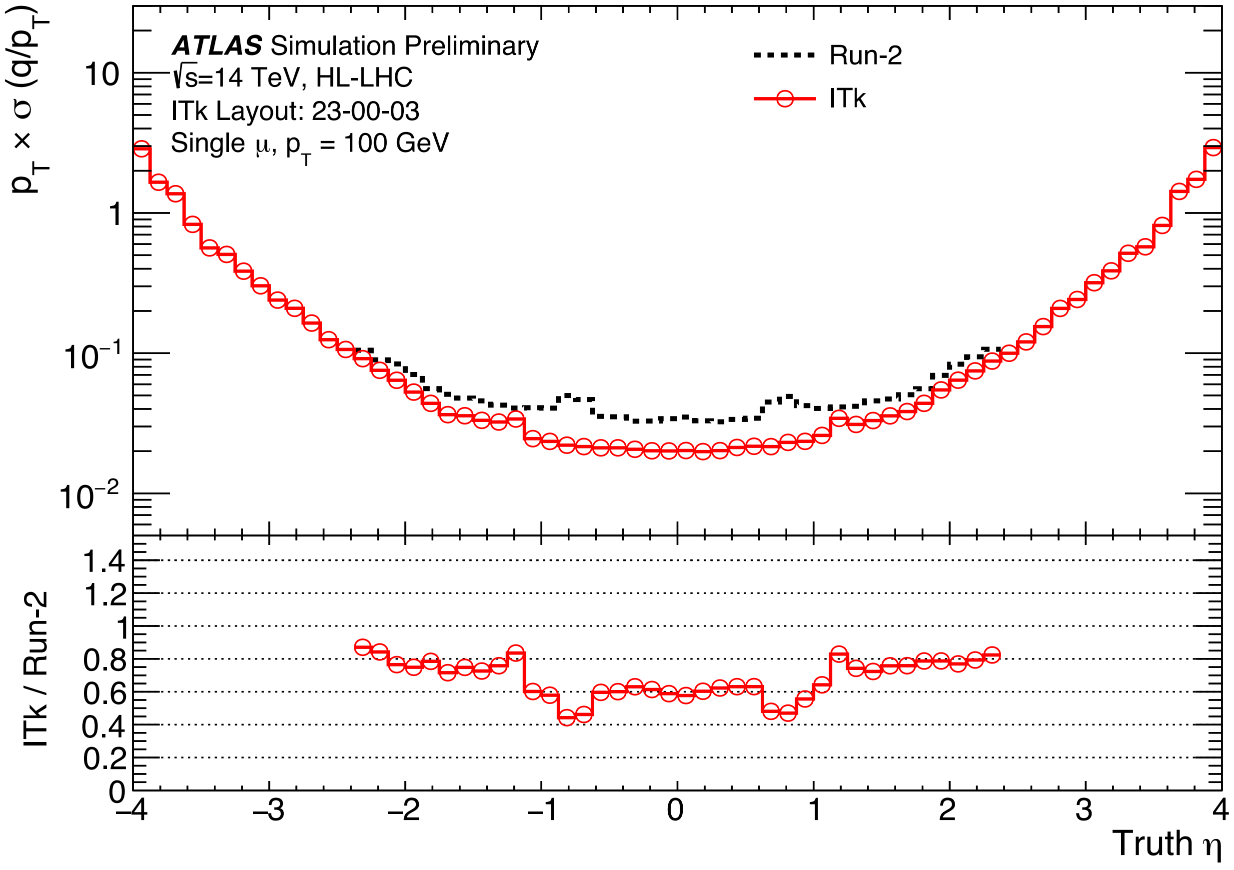
ITk layout



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2021-024/

ITk expected resolution



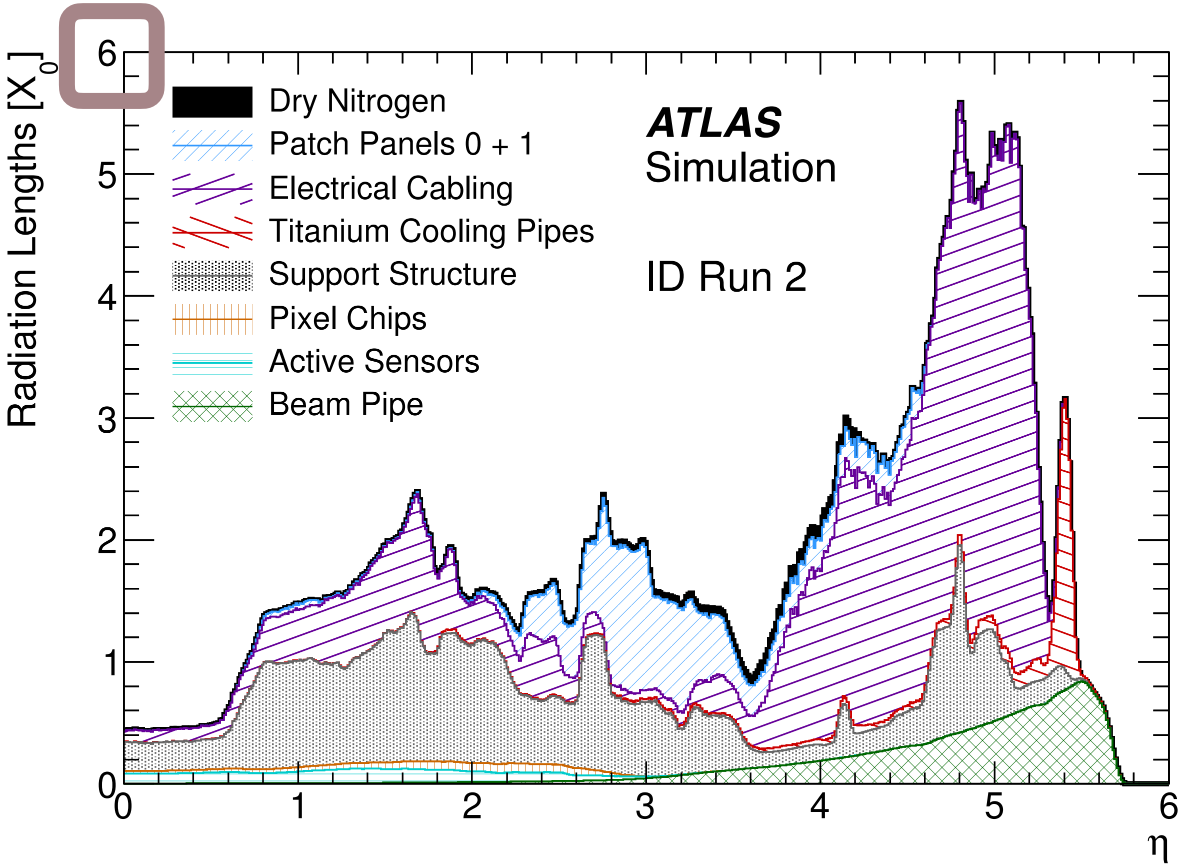


p_T^μ = 2 GeV

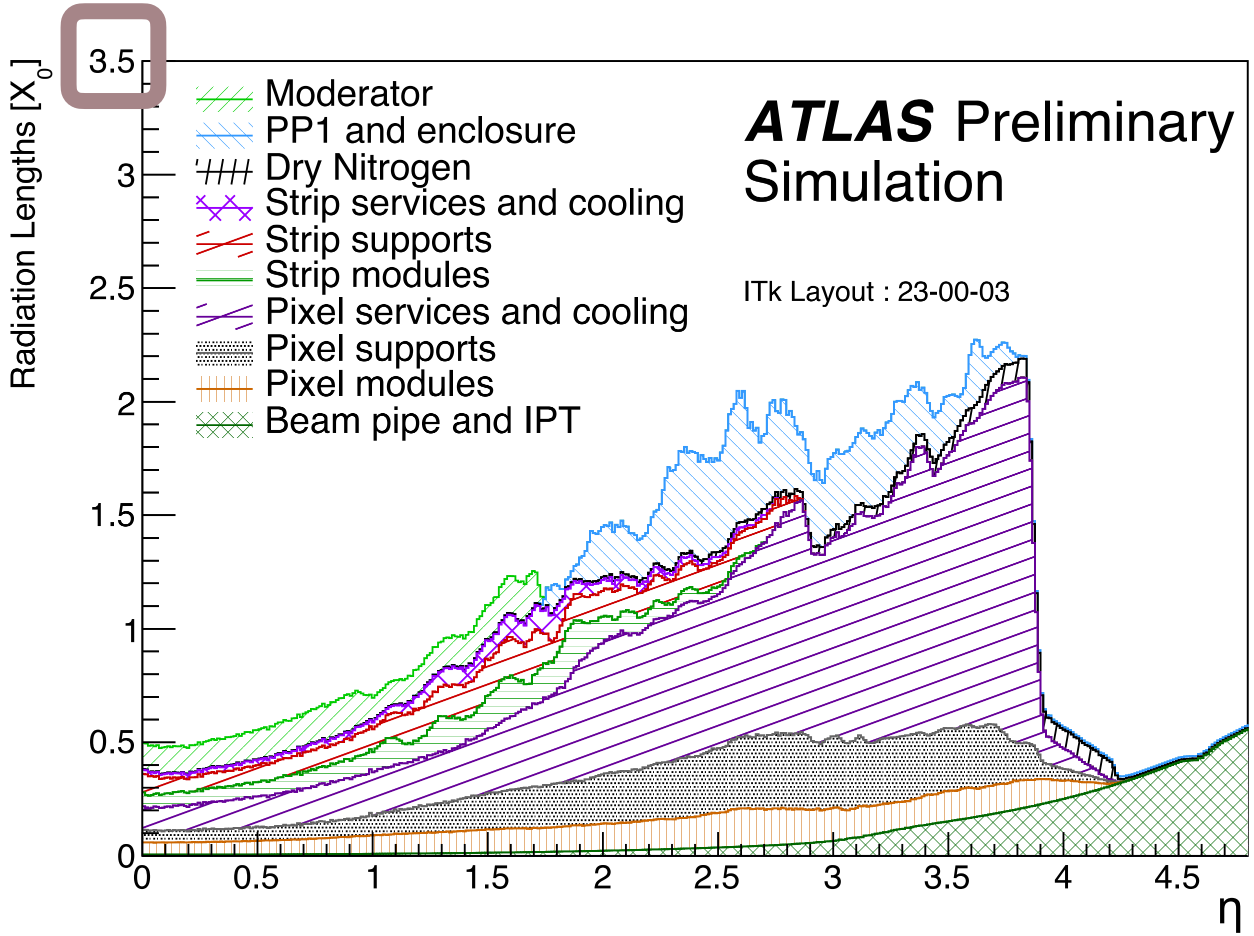
p_T^μ = 100 GeV

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2021-024/

More active area for less material



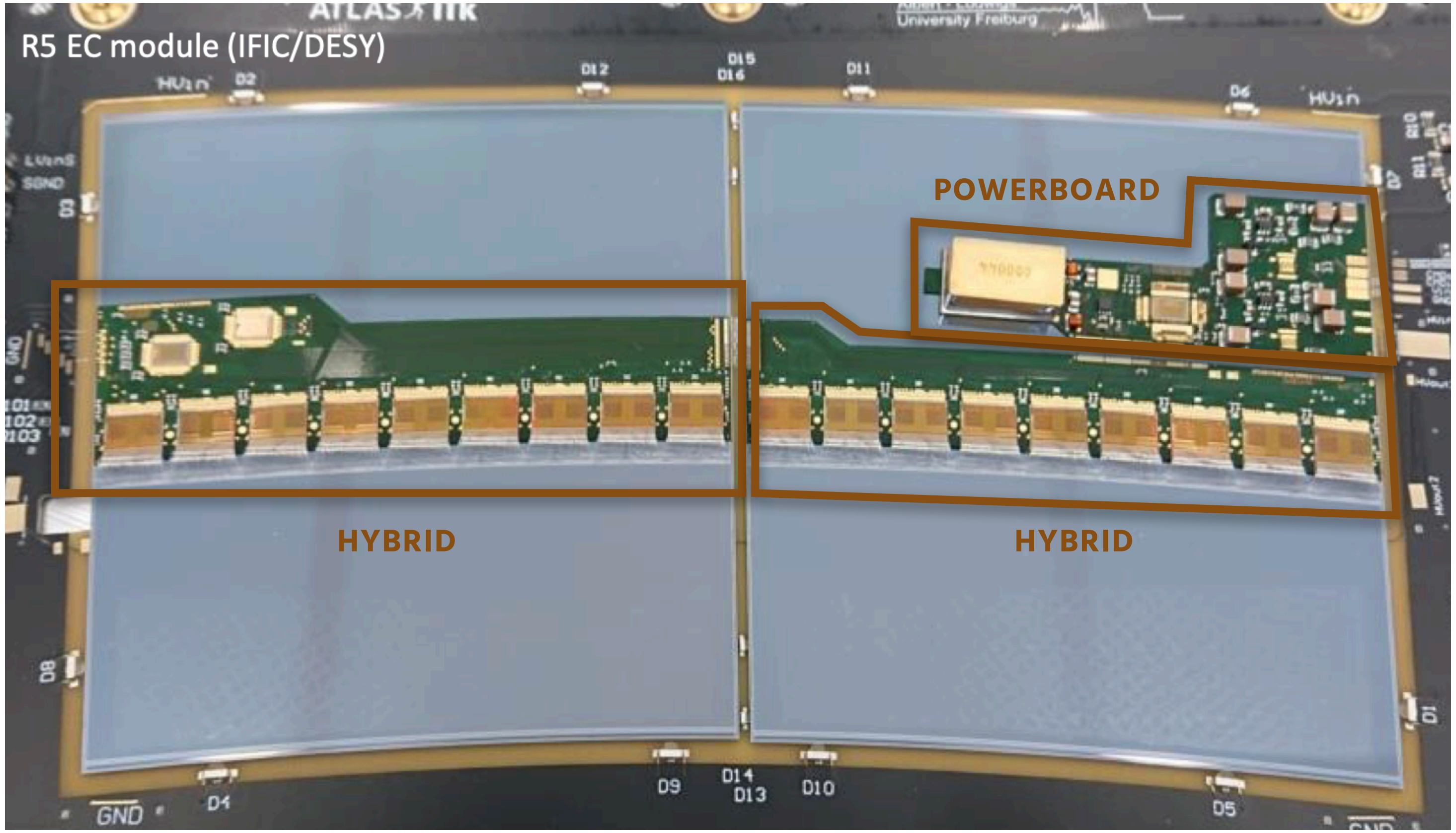
Inner Detector (current)

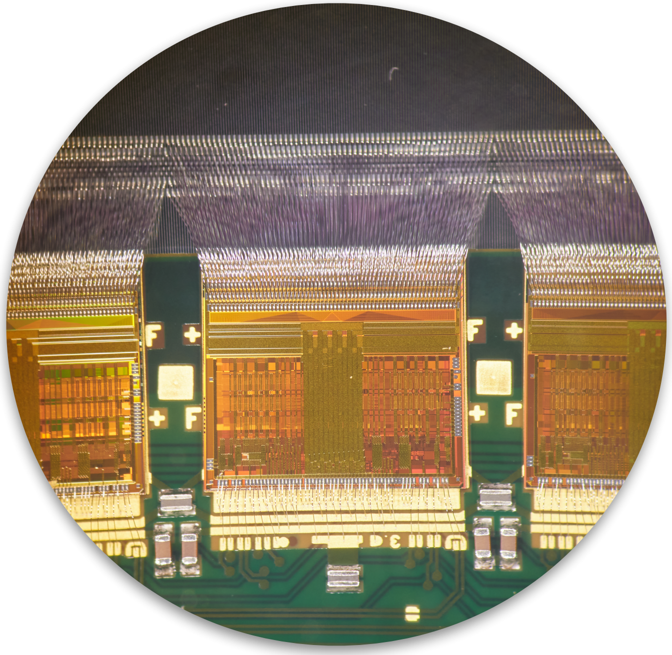


Inner Tracker (HL-LHC)

📷 ID material budget, fig. 9 https://cds.cern.ch/record/2257755; ITk material budget, fig. 4 https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2021-024/

Readout electronics: Brain of a module



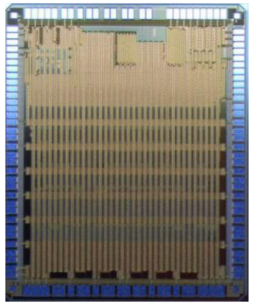


ATLAS binary readout chip

S. Diéz, ICHEP2022

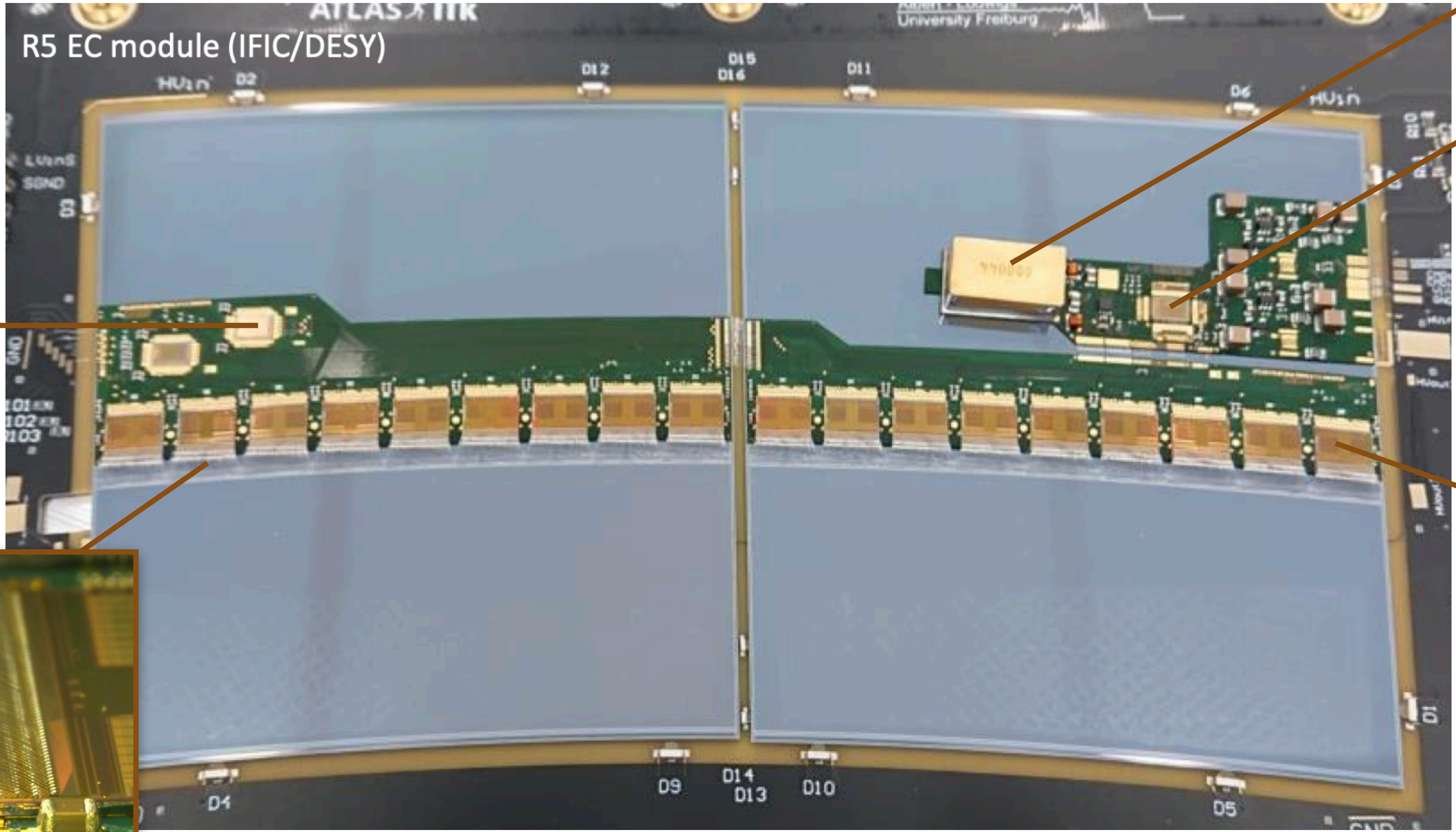
Readout electronics: Brain of a module

Common chipset across all module flavours • 130-nm CMOS chipset



HYBRID CONTROLLER CHIP (HCC)

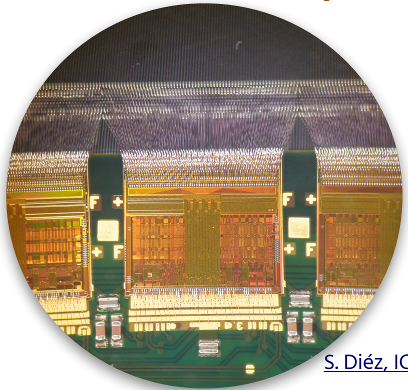
DIGITAL INTERFACE



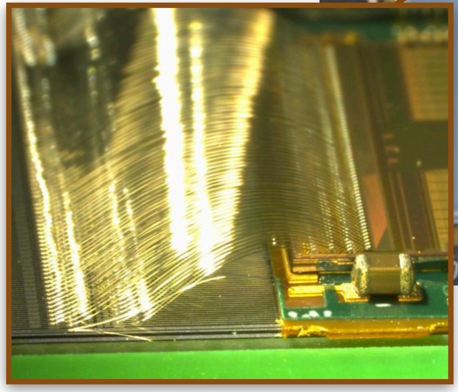
DC-DC CONVERTER

AUTONOMOUS MONITORING & CONTROL CHIP (AMAC)

FRONT-END: ATLAS BINARY CHIP (ABCSTAR)



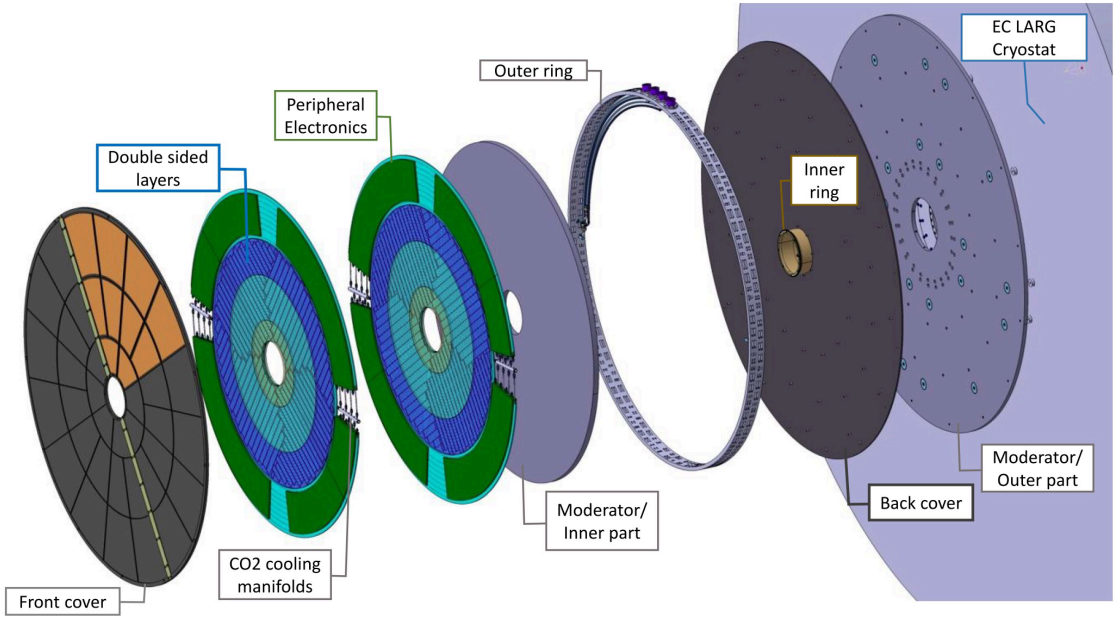
FRONT-END WIREBONDS



S. Diéz, ICHEP2022

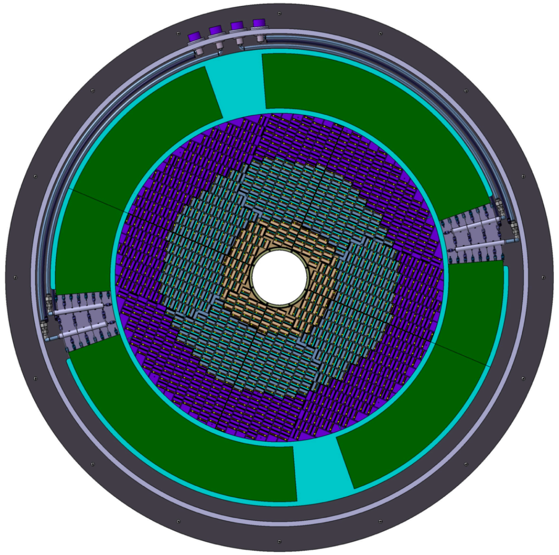
The High Granularity Timing Detector (HGTD)

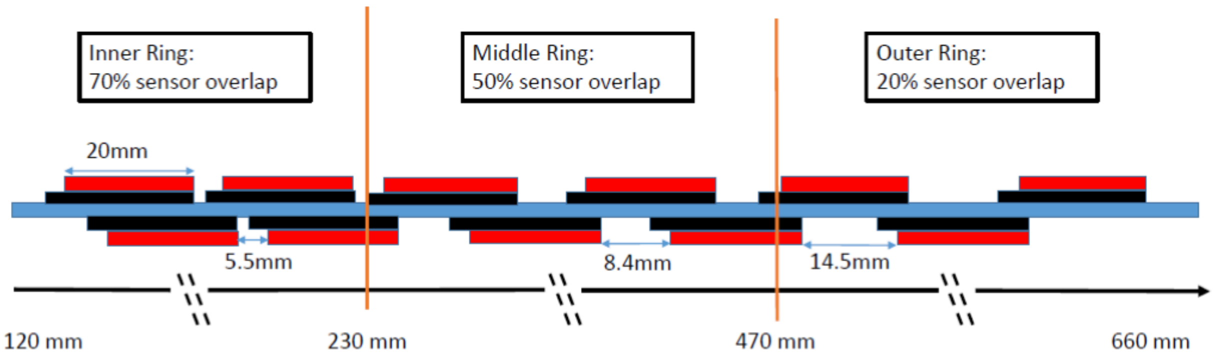
- Two main functionalities for HGTD:
  - Provide accurate measurement of the arrival time for particles in the forward direction (< 50 ps) to mitigate pile-up.
  - Send information of the total number of hits for every bunch crossing, used to estimate the luminosity of the LHC. [KTH idea and responsibility]
- Two detector vessels, mounted to the front walls of the end-cap calorimeters, in the space currently used for the MBTS detector.
  - Located at position z = ±3.5 m from IP.
  - 11 < r < 110 cm.
  - Thickness 12.5 cm, including moderator.

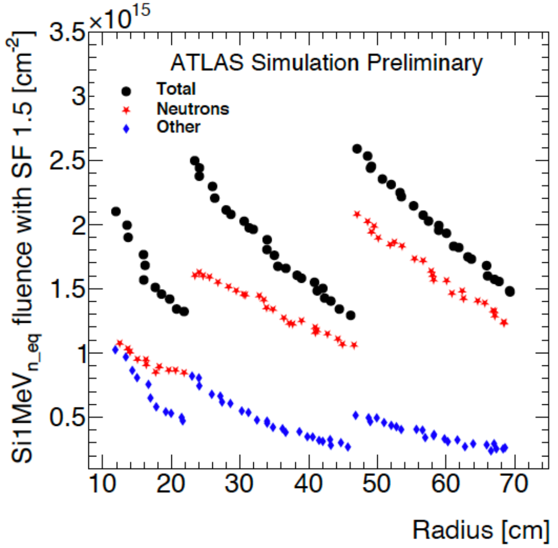


HGTD Ring Layout

- The active detector is defined by three rings of modules, covers $2.4 < |\eta| < 4.0$.
  - Inner ring replaced every 1000 fb^{-1}.
  - Middle ring replaced every 2000 fb^{-1}.
  - Outer ring never replaced.
- Surrounded by the Peripheral Electronics Boards (PEB).
- Modules between $2.4 < |\eta| < 2.8$ are used for luminosity determination.
  - At highest radius, lowest occupancy.

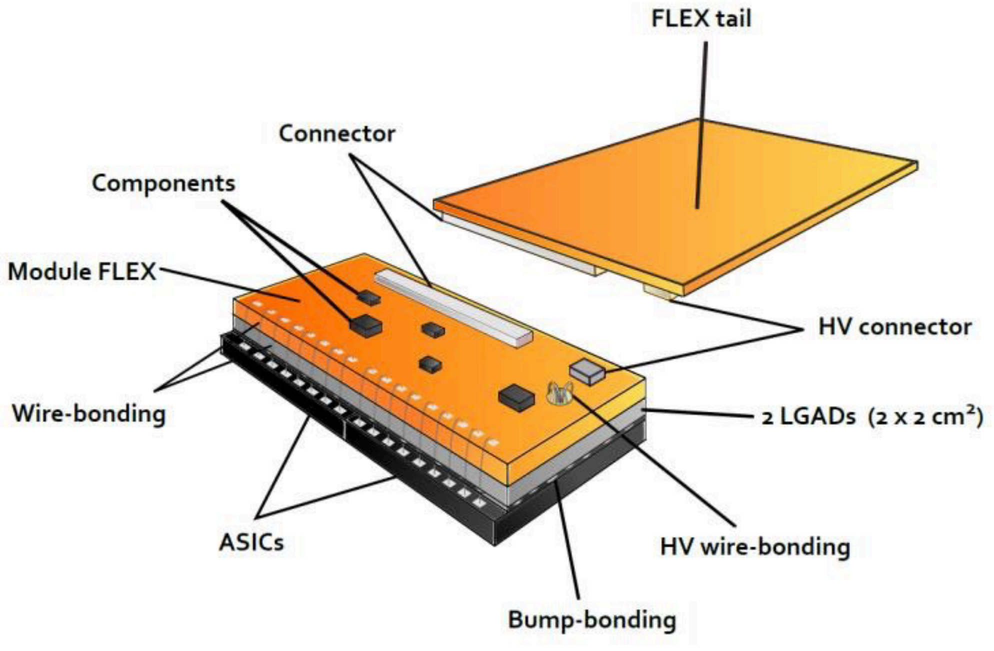


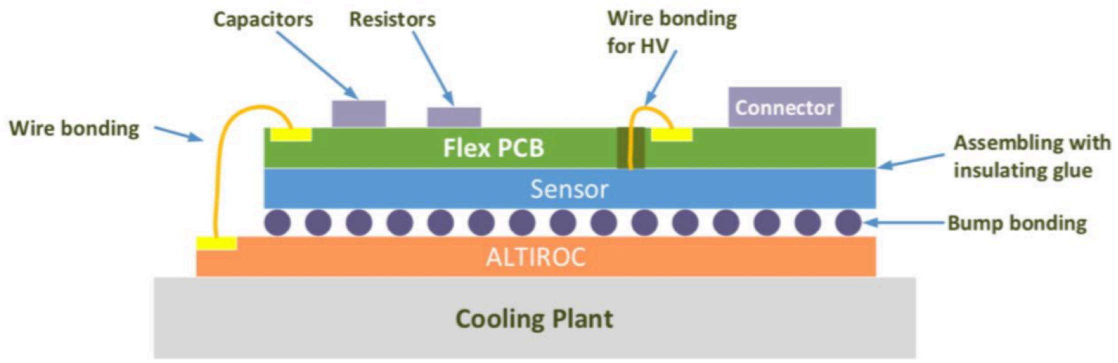




HGTD Detector Modules

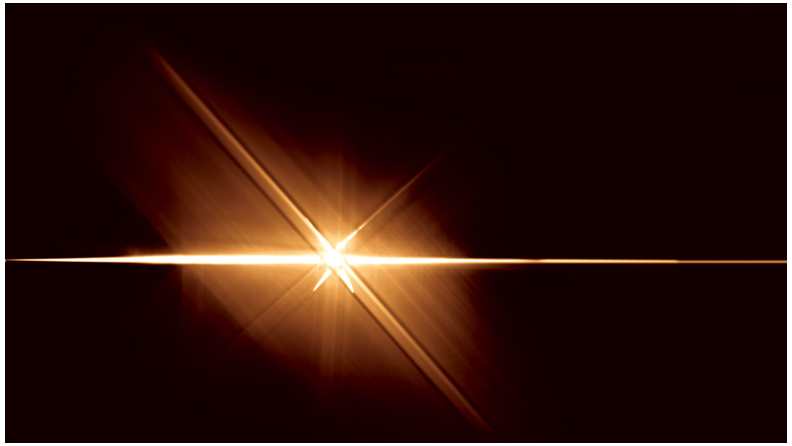
- One module, which is 2x4 cm^2, consist of:
  - 2 LGAD sensors.
  - 2 ALTIROC ASICs, bump-bonded to the sensors.
  - Module FLEX.
- Connect to the PEB via the FLEX tail.
  - Arranged in rows.
- Each ALTIROC as 15x15 readout channels (covering the 2x2 cm^2 sensor area).





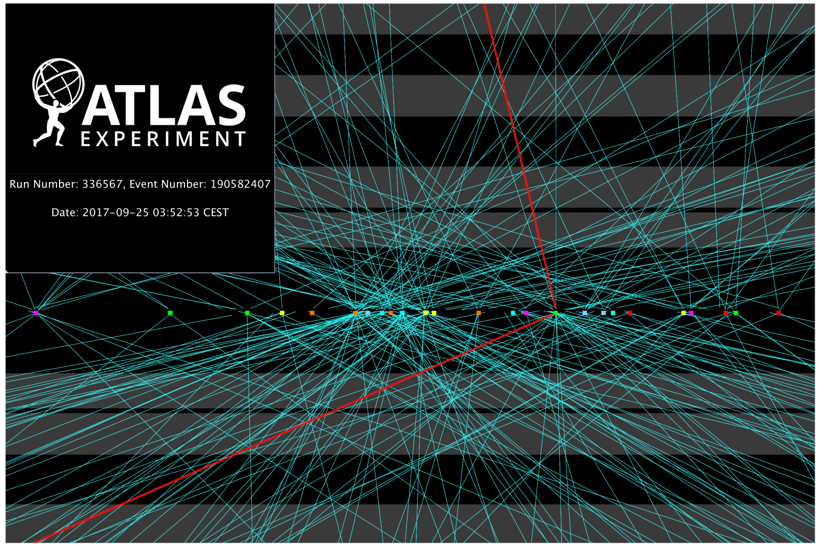
Measuring Luminosity at Hadron Colliders

- The luminosity is a measure of the rate of p-p interactions.
  - Integrated over time it is an estimate of the total number of interactions in a dataset.
- Needs to be known precisely for most physics analyses, will be increasingly important for high-precision analyses at HL-LHC.
- Detectors are calibrated in van der Meer runs, with special beam conditions and $10^{-5} < \mu < 1$, where μ is the average number of collisions per bunch crossing.
  - Physics at HL-LHC will be at $\mu \sim 200$, luminosity detectors need dynamic range of 7 orders of magnitude.



- Monitor something which is proportional (linear) to the luminosity, e.g.:
  - Hits in the PMTs of the LUCID detector.
  - Current drawn by LAr.
  - Hits in the BCM diamonds.

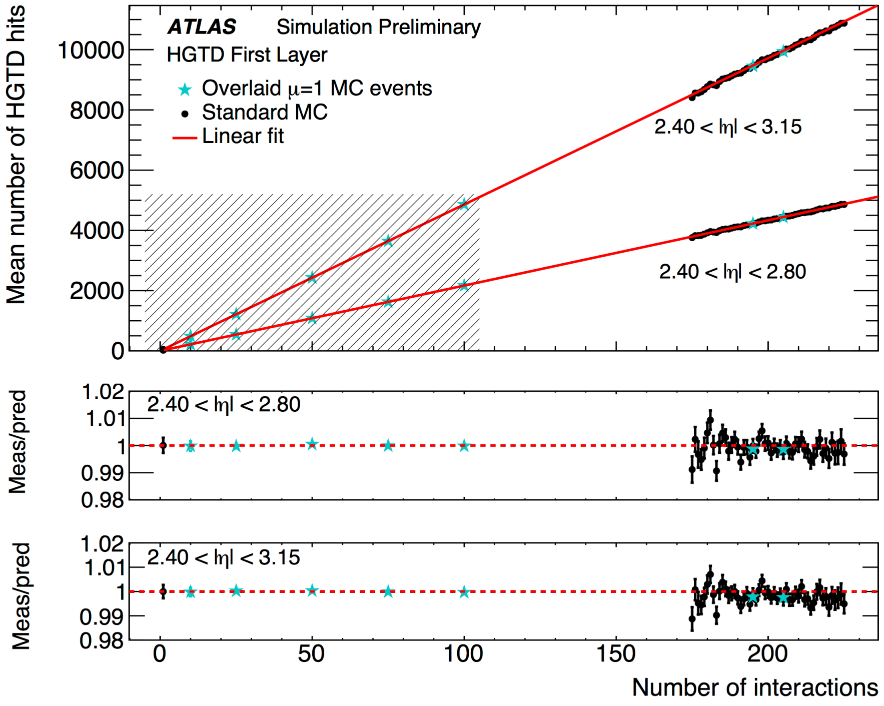
Measuring Luminosity at the HL-LHC

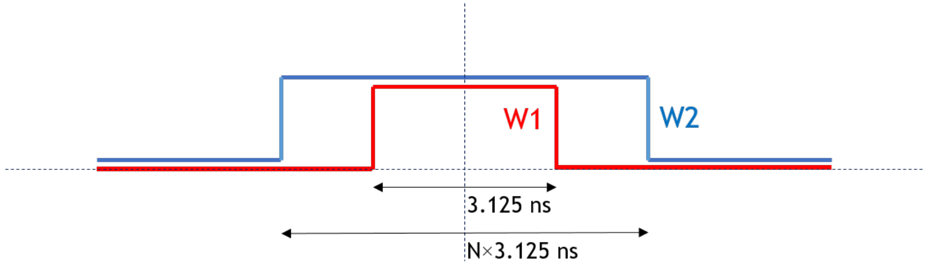


- At the HL-LHC, the uncertainty on the luminosity measurement can be the leading uncertainty on the Higgs boson measurements, for example.
  - At the 2016 Aix-Les-Bain workshop theorist Gavin Salam said: *"Experimental progress on luminosity determination may be the keystone for precision physics at the LHC. Are there hardware changes to HL-LHC that could help with lumi determination?"*
- Silicon detectors have been widely used already for measuring luminosity, by counting hits or counting tracks in the detector.
- Silicon detectors have traditionally had two major shortcomings:
  - They are not able to read out the detector for every bunch crossing, only for the triggered events. Since the trigger introduce a bias on the lumi measurement, a dedicated "random" trigger is needed to collect the data.
  - They can suffer from "afterglow background", hits in the detector which are not directly coming from the primary proton-proton collisions.

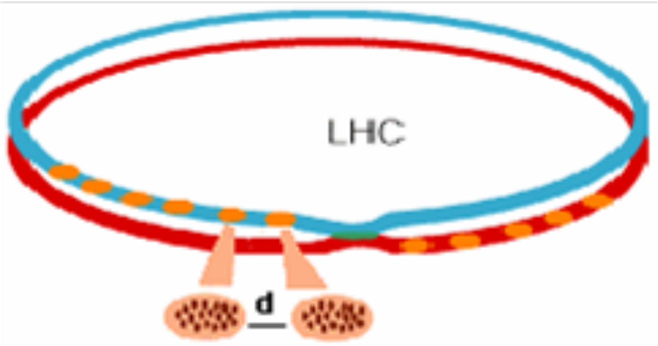
HGTD as a Luminosity Detector

- HGTD, with its low occupancy and fast signals, can be used as a luminosity detector. The average number of hits will be proportional to the luminosity.
  - The low occupancy ensures linearity over the full range of μ.
- It is also trying to overcome the two main limitations of silicon detectors:
  - The ALTIROC chips will also report just the *total number of hits* in that sensor *for every bunch crossing* in a dedicated data stream.
  - It will also report the number of hits in a *sideband time window* for every bunch crossing, in order to get an in-situ measurement of the afterglow background levels.



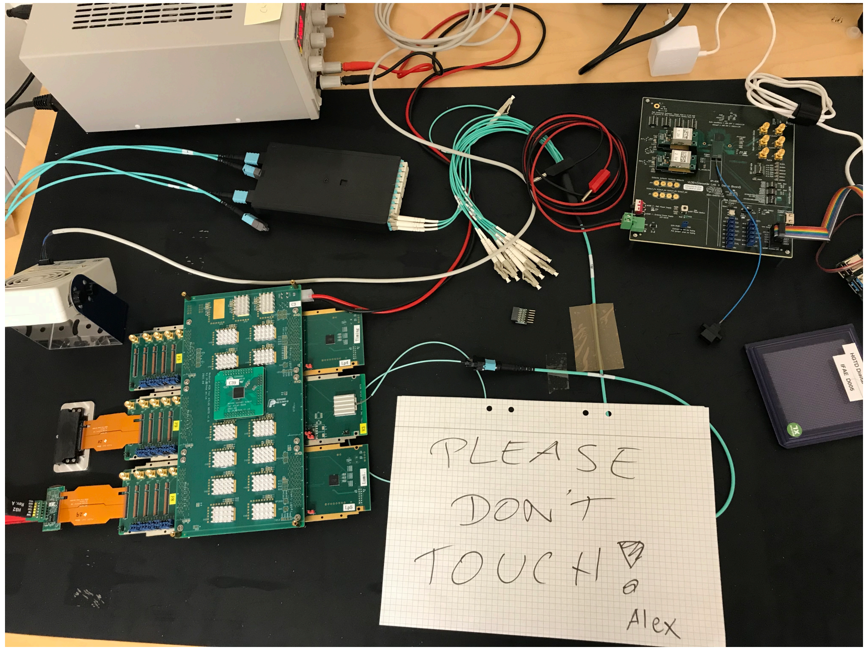


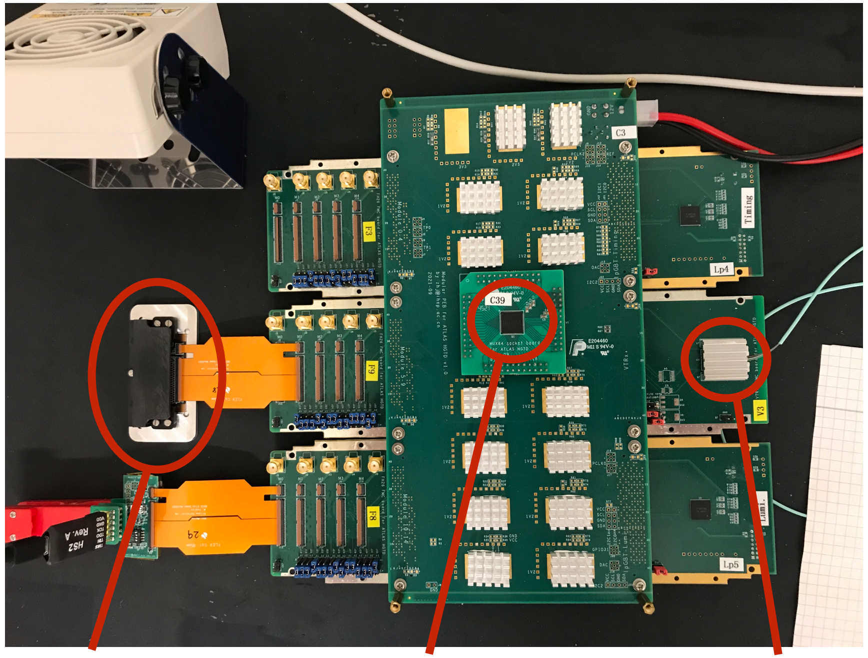
Luminosity of the LHC



- Protons in the LHC are accelerated in bunches. There are 3,564 nominal positions which can be filled with bunches, labelled by BCIDs.
  - In practice a sub-set of these are actually filled with protons, according to the LHC filling scheme. The maximum number of bunches are around 2,800 per beam.
- There can be variations in the number of protons per bunch, or the sizes of the bunches.
  - Therefore the luminosity needs to be determined for every pair of colliding bunches separately.
- So in essence we want to calculate the average number of hits for each ALTIROC, in each of the two time windows and for each BCID, separately using the luminosity data stream.

HGTD Luminosity Developments at KTH





- KTH responsible for developing the firmware and software for the luminosity data stream, and all the steps that turns this into a luminosity measurement.
- Passed a specification review for the luminosity in January 2023, now developing initial firmware in collaboration with the Trigger and Data Acquisition group in ATLAS.
- Need a complete version in time for the surface integration of HGTD which will start in 2024/2025.