The high-speed opto-electrical conversion system for the readout of the ATLAS ITk Pixel upgrade

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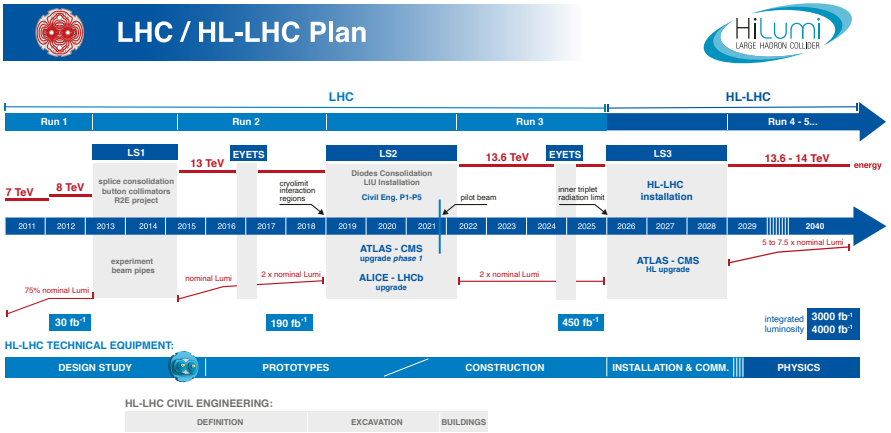
2024-06-20

International School of Subnuclear Physics 2024, Erice

High Luminosity LHC upgrade

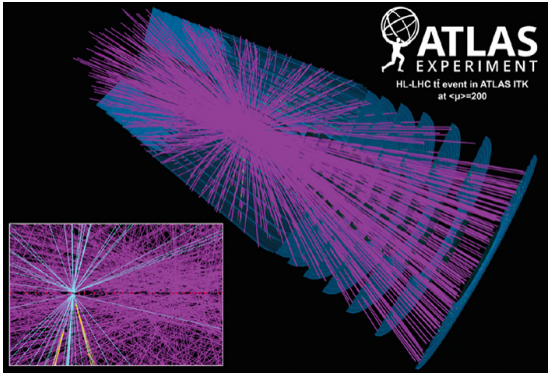
- LHC and LHC experiments are currently running in Run 3
- HL-LHC period will start in 2029 and is supposed to accumulate $\int L dt \approx 4000\,\mathrm{fb}^{-1}$

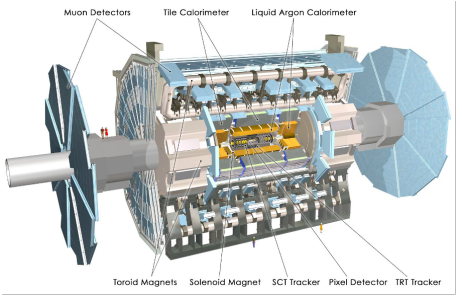


High Luminosity LHC Upgrade

Upgrade to enhance physics reach: higher luminosity (L) and energy (E) $\rightarrow$ HL-LHC

	LHC	HL-LHC (2026)
E	7 - 13.6 TeV	14 TeV
L	2×10^{34} cm^{-2}s^{-1}	7.5×10^{34} cm^{2}s^{-1}
pile-up $< \mu >$	≈ 50	≈ 200





$\Rightarrow$ Replacement of detectors of the ATLAS experiment to

- have higher granularity
- have higher bandwidth
- be $4 - 10\times$ radiation harder

Present Inner Detector pixel technology cannot cope with HL-LHC challenges

High Luminosity LHC Upgrade

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Upgrade to enhance physics reach: higher luminosity (L) and energy (E) → HL-LHC

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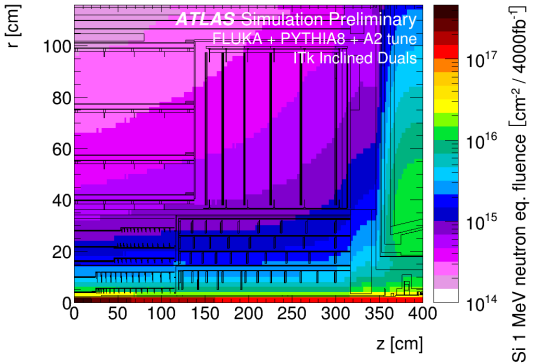

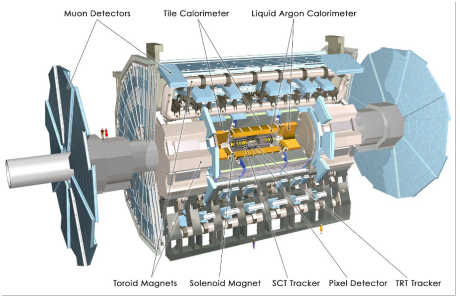

⇒ Replacement of detectors of the ATLAS experiment to

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ATLAS Tracker Upgrade

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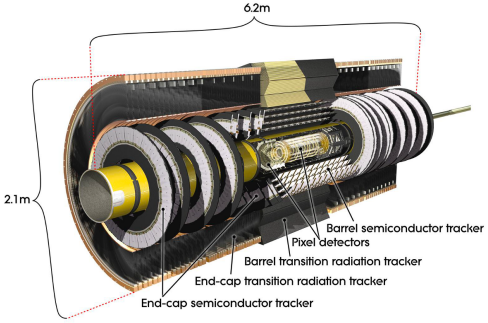
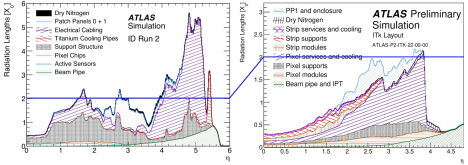
Upgrade of current Inner Detector (ID)





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ATLAS Tracker Upgrade

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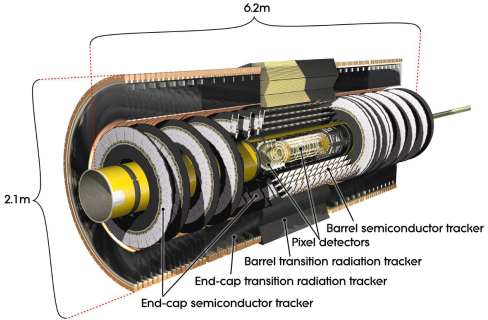

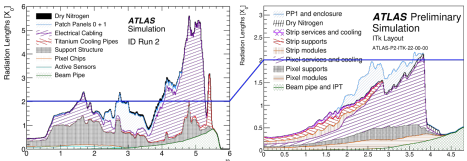

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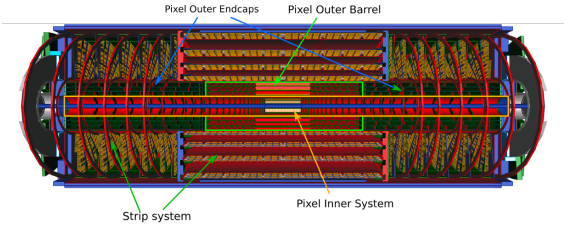
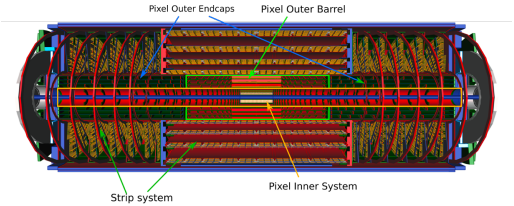
to all-silicon Inner Tracker (ITk) ATL-PHYS-PUB-2021-024



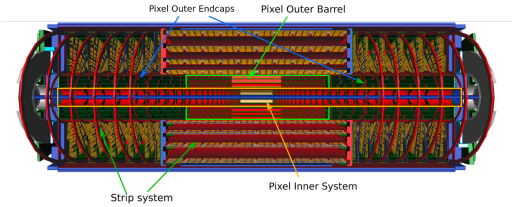
	ID Pixel	ITk Pixel
# pixels	92 M	1.4 G
# modules	≈ 2000	≈ 19400
Active area	1.9 m^2	13 m^2
η	2.5	4.0

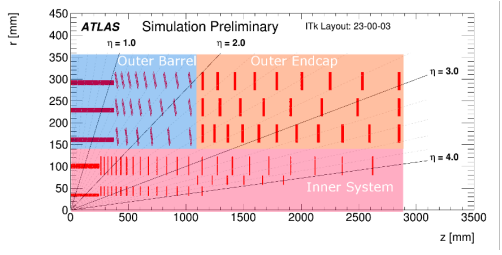
- Increased granularity to maintain occupancy $< 1\%$
- Low mass mechanics, cooling and serial powering
- Increased radiation hardness up to $2 \times 10^{16}\,n/cm^{-2}$

ATLAS ITk Pixel Detector

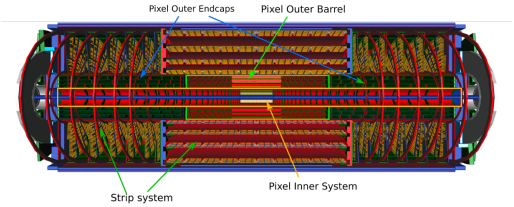


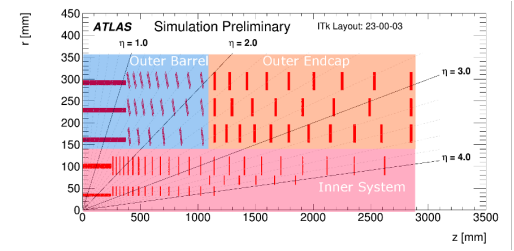
ATLAS ITk Pixel Detector





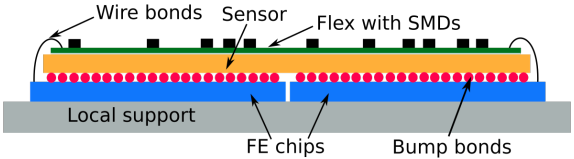
ATLAS ITk Pixel Detector



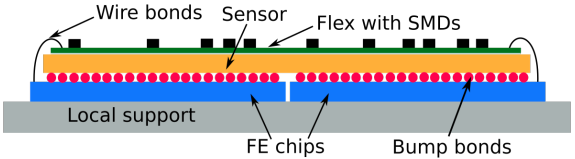


- Outer Barrel:
  - 3 layers of flat staves and inclined rings
  - 4772 quad modules, 6.94 m^2
- Outer End Cap
  - 3 layers of rings
  - 2344 quad modules, 3.64 m^2
- Inner System (Replacable)
  - 2 layers of flat staves and rings
  - Quad and triplet modules
  - 2600 modules, 2.4 m^2

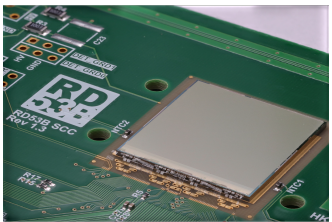
Pixel Detector Modules

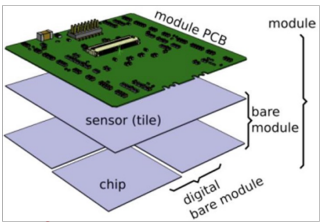


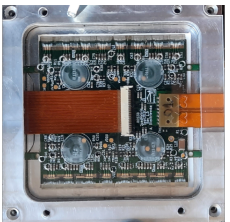
Pixel Detector Modules



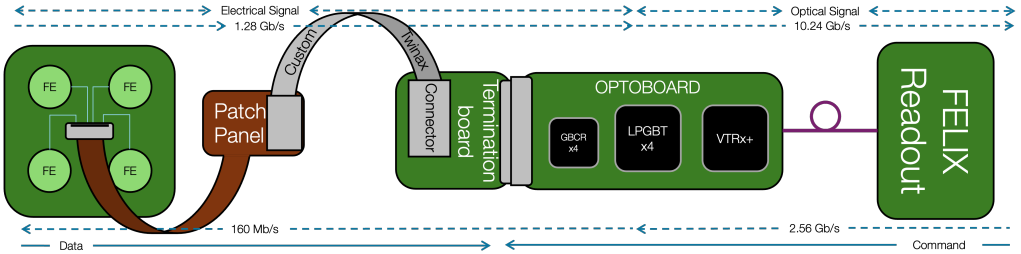
- Hybridisation of FE-chip (readout chip) and sensor → low pitch bump bonding $50 \times 50\,\mu m^2$
- Flex attachment to hybridised module with 100 µm precision
- Large temperature range: operating at $-25\,^{\circ}C$ to $-10\,^{\circ}C$, warmed up to $20\,^{\circ}C$ during maintenance







ITk Pixel Readout System



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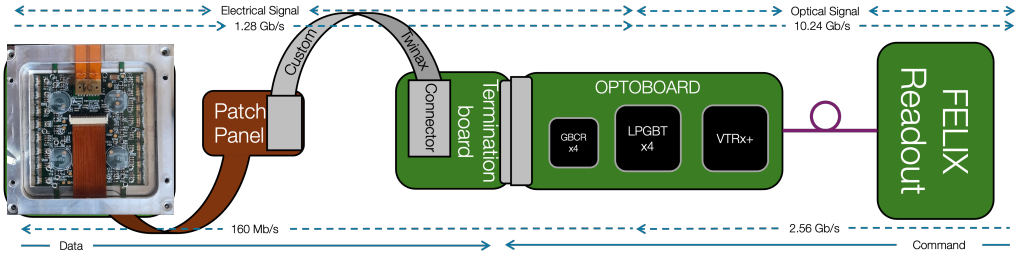

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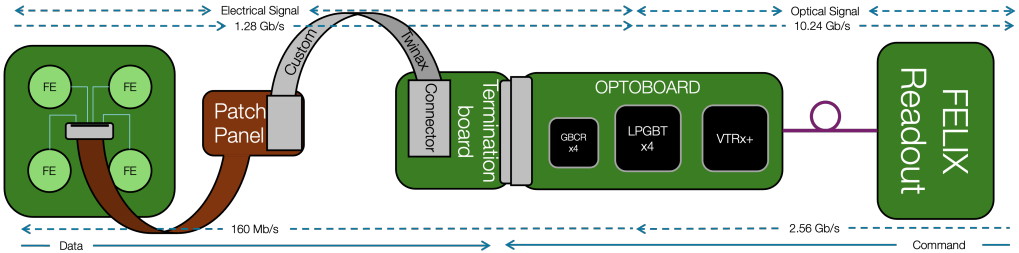
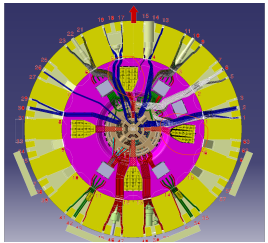
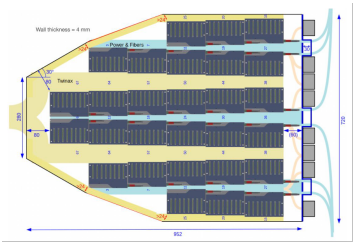
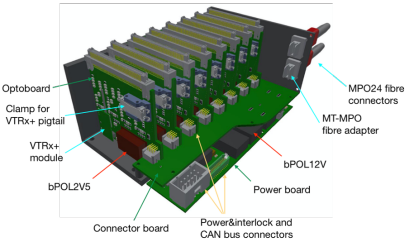
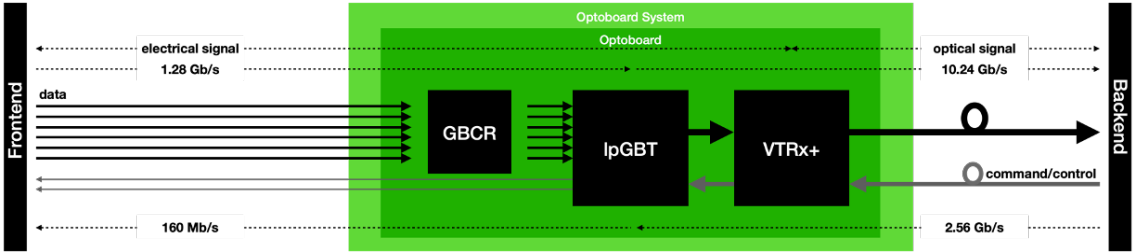








Optosystem

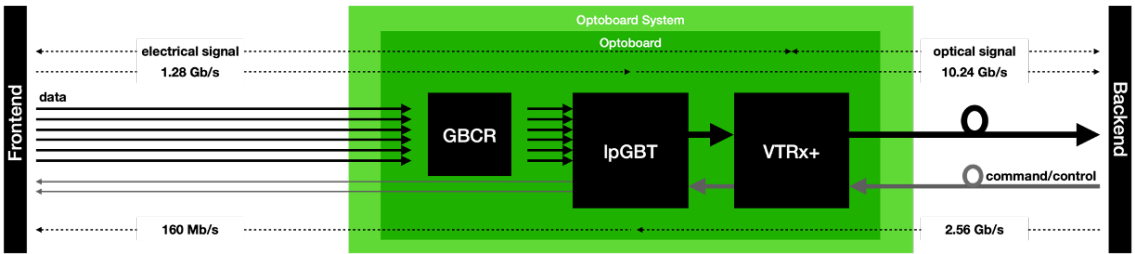


Losses need to be below 20 dB from FE-chip to GBCR including connectors, flexes and cable:

- Electrical signal recovery on Optoboard in Optobox by GBCR
- Serialisation of electrical signals by lpGBT
- Opto-electrical conversion by VTRx+

Data Transmission

- Readout of FE-chip at 1.28 Gb/s with up to 4 links per chip depending on position in system
- Uplink sharing on module used on all layers to reduce material, sharing of downlinks
- Up to 6 data links per lpGBT from 1-6 modules sharing one 10.24 Gb/s fibre, downlink 2.56 Gb/s per lpGBT
- Optical fibres to readout PCs with FELIX readout boards



Validation of the Optosystem

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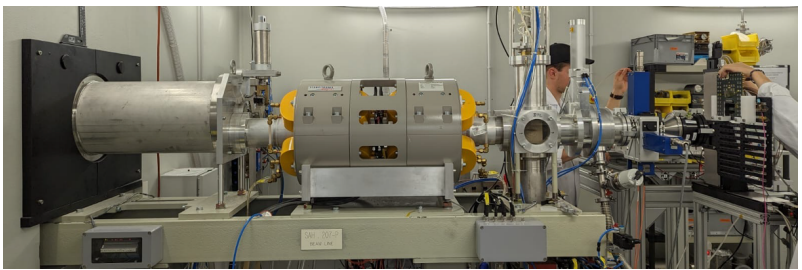
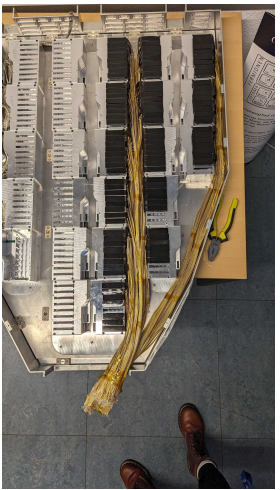
Tests performed in the past

- Tests of the first prototypes of the optoboards
- Different data transmission chains: from FELIX card to readout chip with different cables and connectors
- Irradiation of components of the data transmission chain
- Experimental verification of the mechanical concept
- Tests and simulation of the thermal management



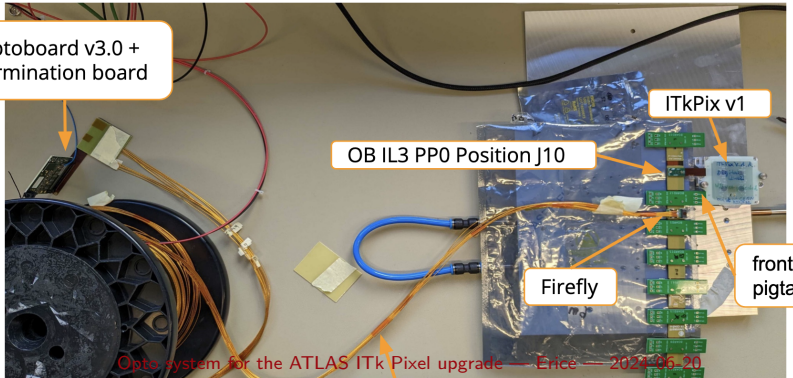


Validation of Data Transmission Chain

Bit Error Ratio (BER) tests on data transmission chain with final components:

- Using pseudorandom signal
  - Pattern checker on the lpGBT can execute a BERT
  - Result is sent via optical fiber to FELIX
- Using 64b/66b FE-chip idle signal → test on realistic data stream

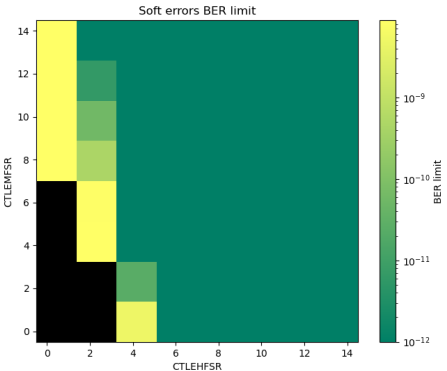
  ⇒ Multiple BERTs are performed, changing the parameters of the equalizer of the GBCR



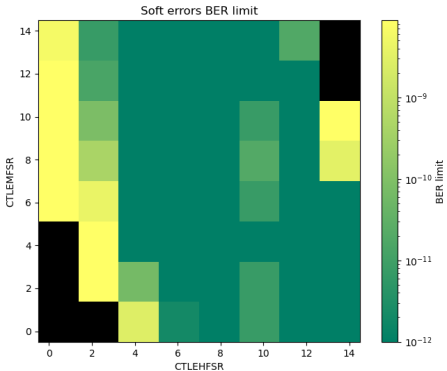
Optoboard Results

BER tests with 95% CL: BER limit $< 10^{-12}$, for several configurations, using FE-chip idle signal

Cable type I bundle

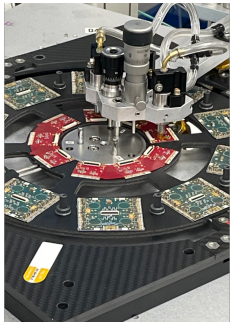


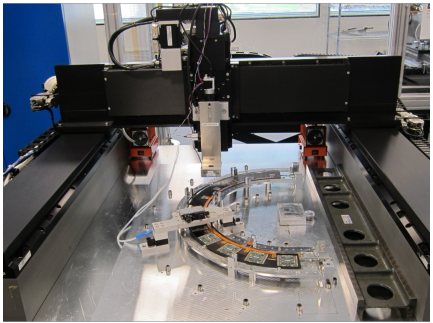
Cable type II bundle

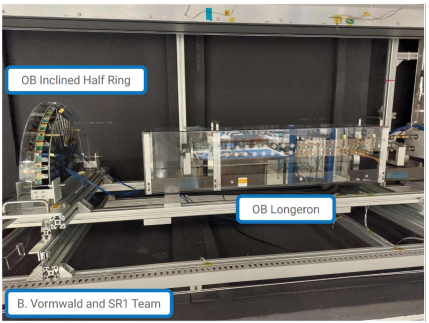


System Test Setups

- Multiple System Test Setups at different institutes
- Each testing site gets one detector support structure with modules and an Optobox







Summary and Outlook

- Data transmission chain working within required BER limits
- Large batch of Optoboards to arrive soon in Bern for testing
- Final system test planning is under way

Thank you for your attention!