The Optosystem: validation and testing of the high-speed optical-to-electrical conversion system for the readout of the ATLAS ITk Pixel upgrade

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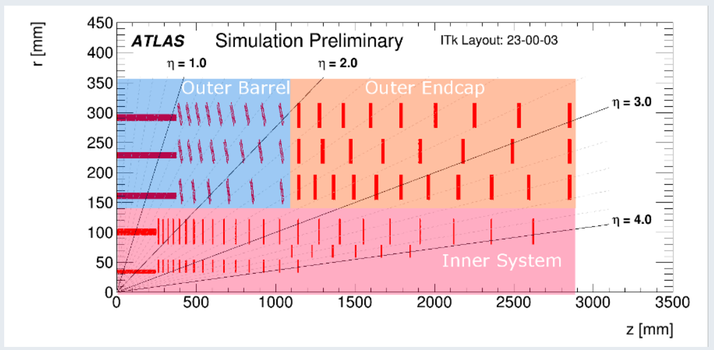
Why ATLAS needs a new tracking detector and implications for the readout system

LHC:

- *pp* collider at the energy frontier
- 40 MHz collision rate
- Upgrade to enhance physics reach

	LHC	**HL-LHC** (2028)
Energy	7-14 TeV	14 TeV
Luminosity	$2\times10^{34}\,\mathrm{cm^2/s}$	$7.5\times10^{34}\,\mathrm{cm^2/s}$
Pile-up	≈ 55	≈ 200
Highest fluence	$5\times10^{15}\,\frac{n_{eq}}{cm^2}$	$1.3\times10^{16}\,\frac{n_{eq}}{cm^2}$

⇒ Upgrade of ATLAS inner detector (ID) to all-silicon new inner tracking detector (ITk)

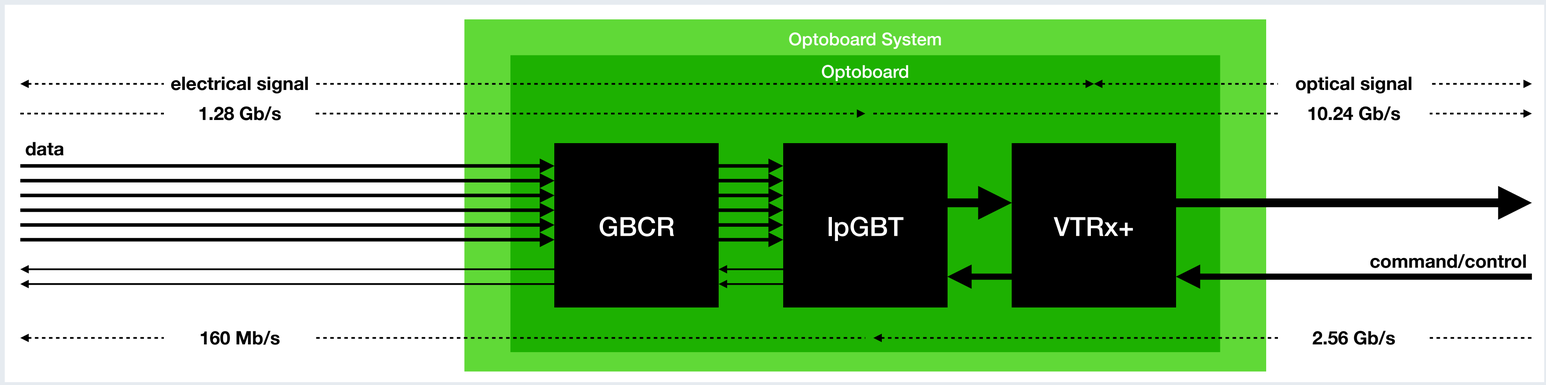


ITk requirements:

- Higher granularity tracking
  ⇒ from $\sim 10^8$ (ID) to $5\cdot10^9$ electrical channels
- Readout speed of 1 MHz
  ⇒ corresponds to $\sim$ 25 Tbps
- Radiation hardness
  ⇒ foreseen maximum integrated dose is $\sim$ 10 MGy.

Optosystem for ITk Pixel detector readout:

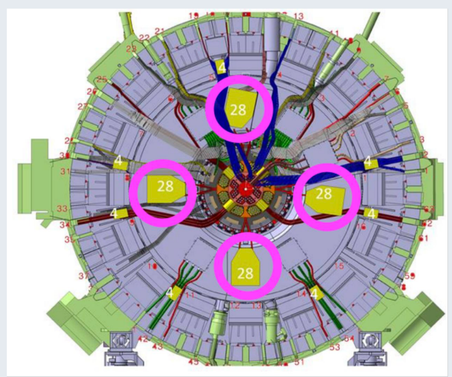
- $\sim$ 1600 Optoboards
  - Signal recovery/equalisation of the signal (GBCR)
  - Multiplexing (serialisation) of the independent sensor signals (lpGBT)
  - Opto-electrical conversion (VTRx+)
  - Radiation hardness (estimated dose: 150 kGy)
- More than 4000 optical fibres
  - Downlink: Command and triggers from off-detector readout system ($\sim$ 190 FELIX cards) to front-end chips in detector modules
  - Uplink: Opto-electrical conversion of detectors signals coming from front-end chips and transmitted to FELIX cards



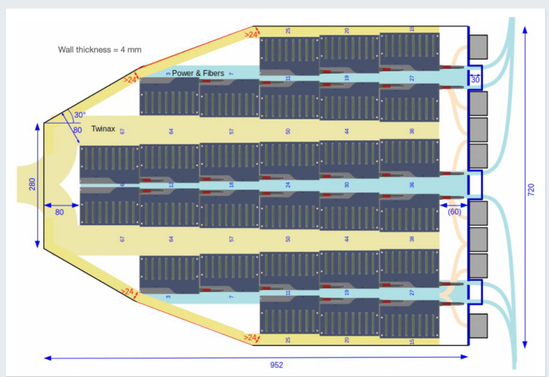
Data transmission scheme with the Optoboard System.

ITk Pixel Optosystem - from the panel to the Optoboards

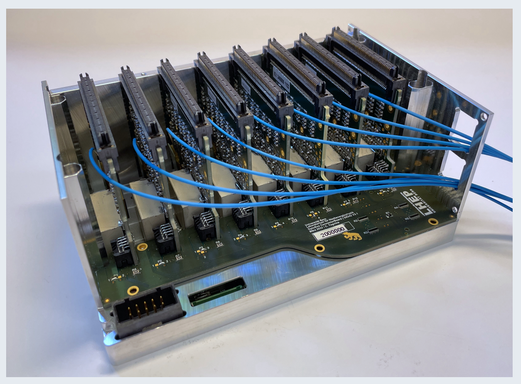
- 9 V powering to the Optosystem from the ATLAS service caverns
- 8 Optopanels for the ITk detector, housing 28 Optoboxes each:
  - Faraday cage shielding
  - Cooling system for the Optoboxes ($\sim$ 25 W per box)
- Power conversion with bPOLs On the Optoboxes and Optoboards
- Up to 8 Optoboards in an Optobox.



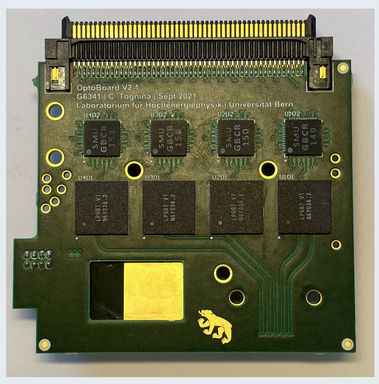
Optopanel position in ATLAS.



Optopanel with Optoboxes.



Fully populated Optobox.



Optoboard v2.1 backside.

Data Transmission Tests

Bit error ratio tests (BERT) to evaluate the signal transmission:

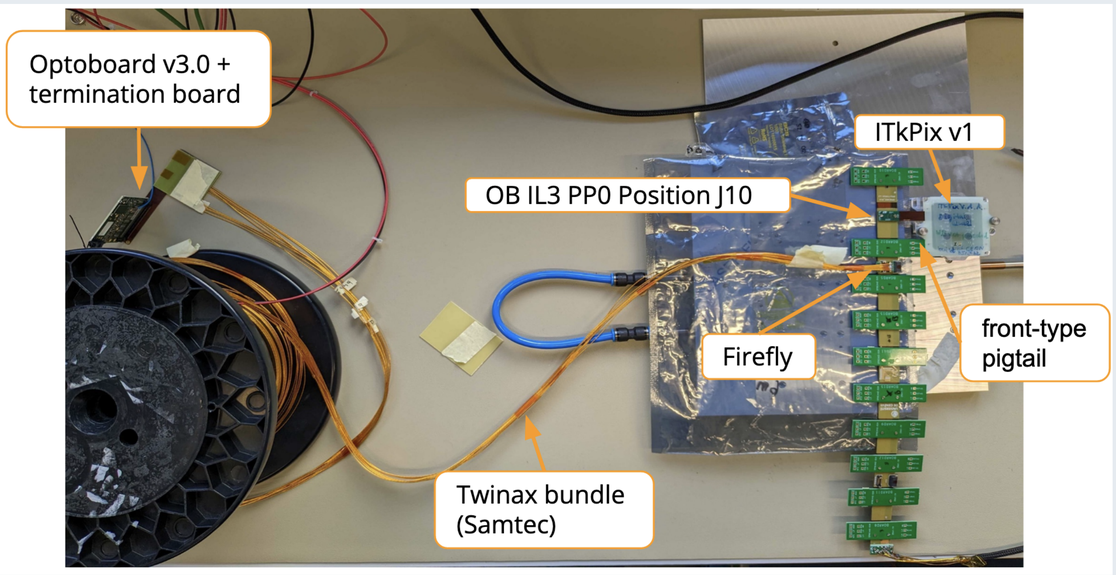
- Verification of different Optoboard versions
- Twinax cable vendor validation (Samtec or Molex)
- Assurance of proper function of data transmission chain detector components (patch panels and connectors)

PRBS7 signal of module:

- Pattern checker on lpGBT can execute a BERT
- Result is read out via optical fibre to FELIX

64b/66b ITkPix idle signal of module:

- Test on realistic data stream = Soft Error Test
- Checking of the frame with FELIX

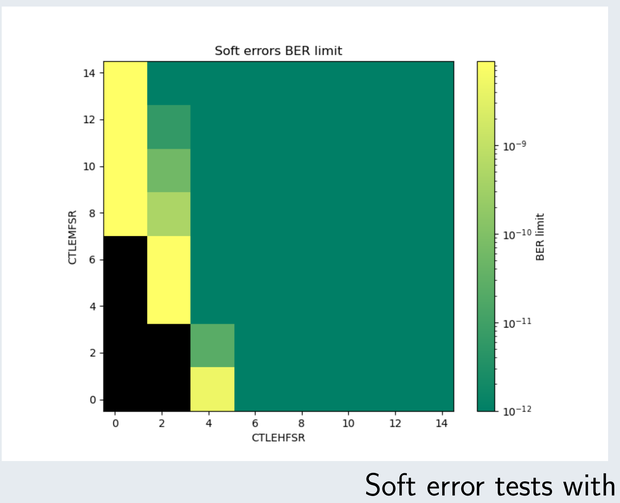


QC setup for the data transmission tests of Optoboards.

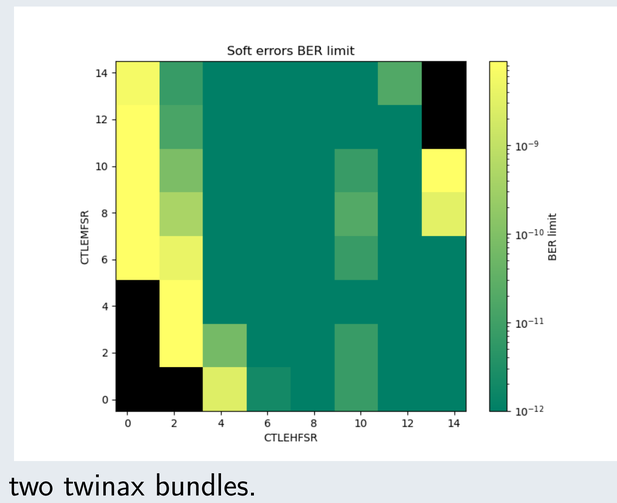
Soft Error BER Tests

Soft error tests with 95% CL on BER limit $< 2.7\cdot10^{-12}$ (Optoboard v3)
⇒ Multiple soft error tests are performed, changing the parameters of the equaliser of the GBCR

Molex bundle



Samtec bundle



Soft error tests with two twinax bundles.

Complementary tests

- Irradiation tests with Bern cyclotron (18 MeV protons)
  - Irradiation of components of the data transmission chain ⇒ subsequent evaluation of performance
  - Operation of an Optoboard during irradiation
- Verification of the powering scheme concept
- Optopanel cooling tests with heat pads
- Readout of a module during a testbeam with an Optoboard

Conclusion and Outlook

- Almost final data transmission chain working within required BERT limits
- Finalizing irradiation tests on all components
- Extensive tests of final read-out already during ITk detector integration

System Tests and Integration

- 11 sites have been appointed to build and test sections of the ITk detector
- Sites from all subsystems will integrate their test setups in one large setup
  - User-friendly software for configuration of Optoboards
  - Custom Optopanel with 1-4 Optoboxes for conceptual tests