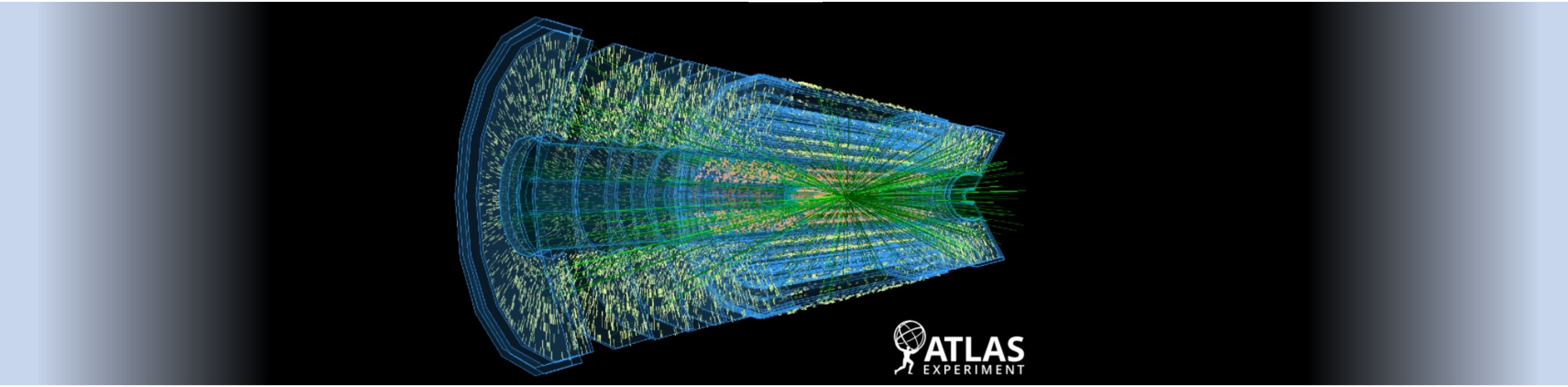
Tests and results of the power components of the ATLAS Inner Tracker detector readout system.



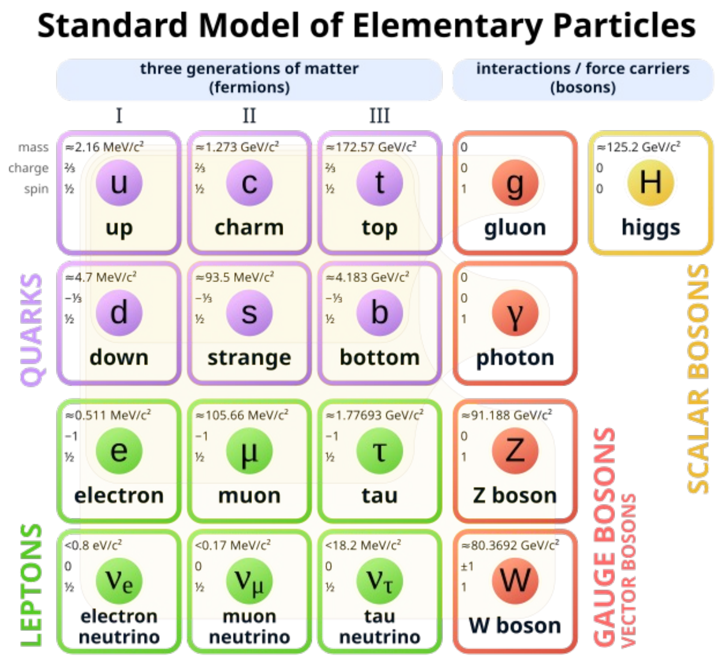
Lucas Mollier

PhD student in LHEP at the University of Bern

SPS 2024 - Zürich

The Large Hadron Collider (LHC) at CERN

- The most powerful hadron collider in the world is in action in Geneva.
- Ring of 27 km of circumference to accelerate protons close to the speed of light (total energy of 14 TeV).
- 4 main collision points and detectors: **ATLAS**, CMS, ALICE and LHCb.
- Used to test the **Standard Model** of particle physics.

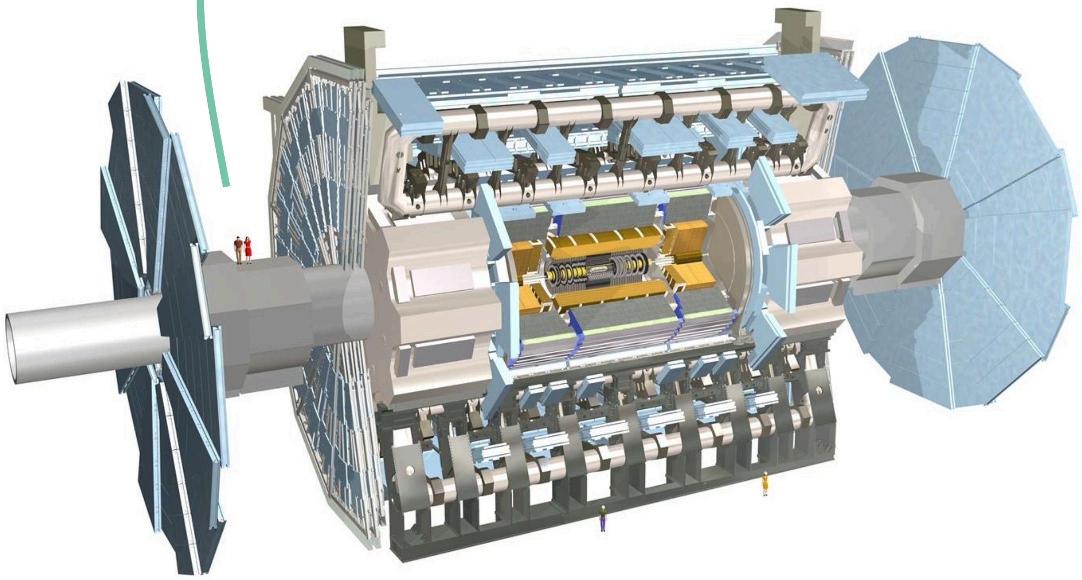


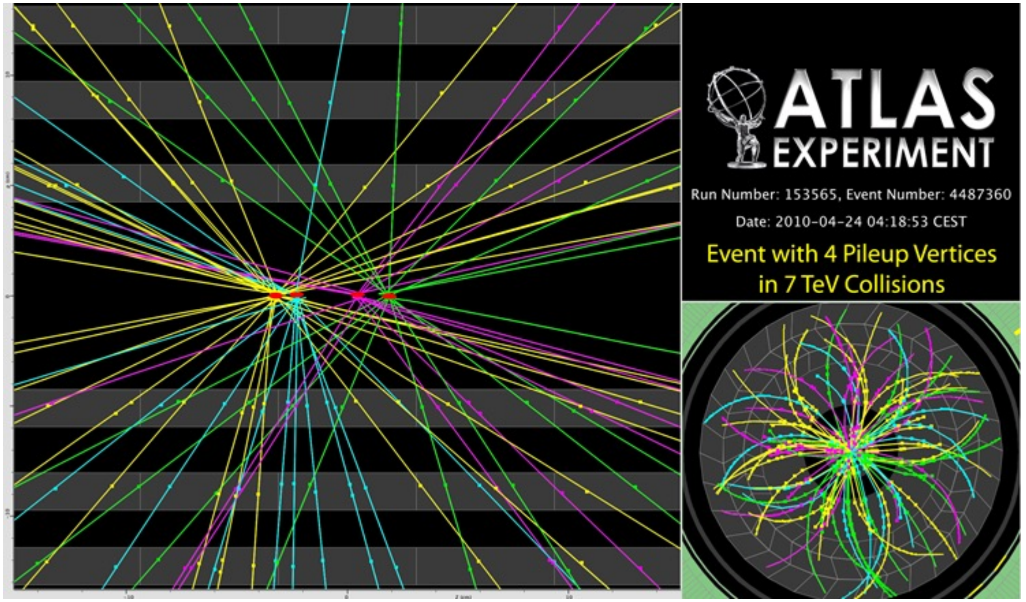
Most famous finding at CERN: **Higgs boson** discovered in 2012 after being postulated 50 years before.

ATLAS (A Toroidal LHC ApparatuS)

- Composed of multiple sub-detectors:
  - **Inner Tracker:** Momentum reconstruction.
  - **Calorimeter:** Energy reconstruction.
  - **Muon spectrometer**: Muon detection.
- 46 meters long, 25 meters of diameter.
- An average of **~60 collisions every 25ns.**

You do feel that tiny when seeing ATLAS

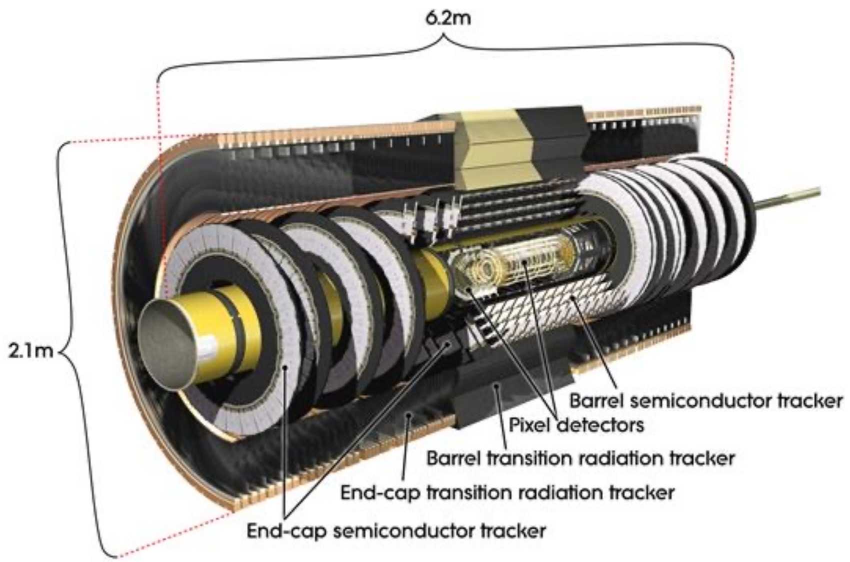




- Up to **40M events/s.**
- Filtered down to 3000 events/s by hardware and software trigger.
- ATLAS records **10,000 TB** of data per year

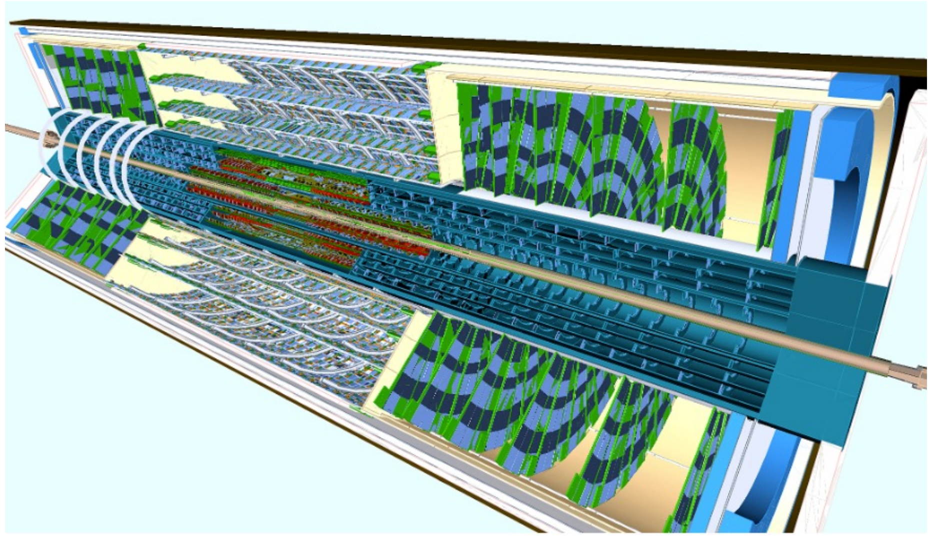
The High-luminosity LHC and the upcoming Inner Tracker (ITk)

- In a couple of years, the LHC will undergo an upgrade to the **"High-Luminosity LHC"** to have more collisions per bunch crossing (from 60 to 200!).
- New requirements for ATLAS and the tracker!



The Inner Detector replaced

by the Inner Tracker!



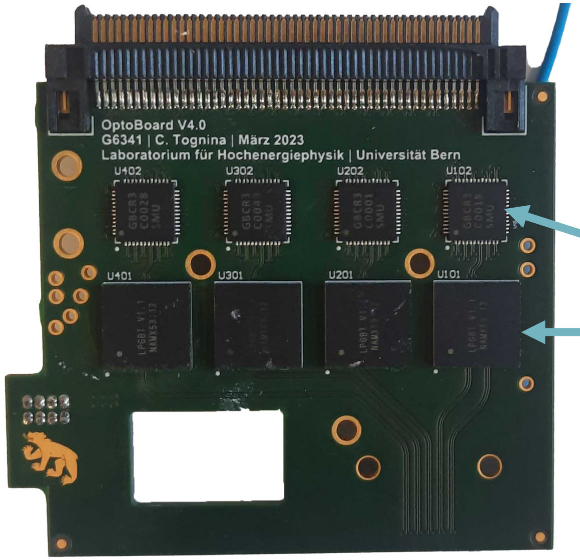
- Made of different technologies
  - Pixel detector
  - Transition radiation tracker
  - Semiconductor tracker
- 10^8 electrical channels

- **All Silicon** based detector.
- Made of pixels and Strips
- **Increased resolution** with $5 \cdot 10^9$ electrical channels
- Radiation hard up to 10 MGy.
- Read-out speed of 1 MHz.

↳ **A new read-out system** needs to be designed!

The Optosystem

- The Optosystem is the central component of the ITk pixel detector **read-out system.**
- Designed to send away data **fast** and **error-free**.
- Placed 6 meters away, where **radiations** are still dangerous for the data.
- It converts the electrical signal from the sensors to optical signal that is send away in the electronics room and vice-versa.

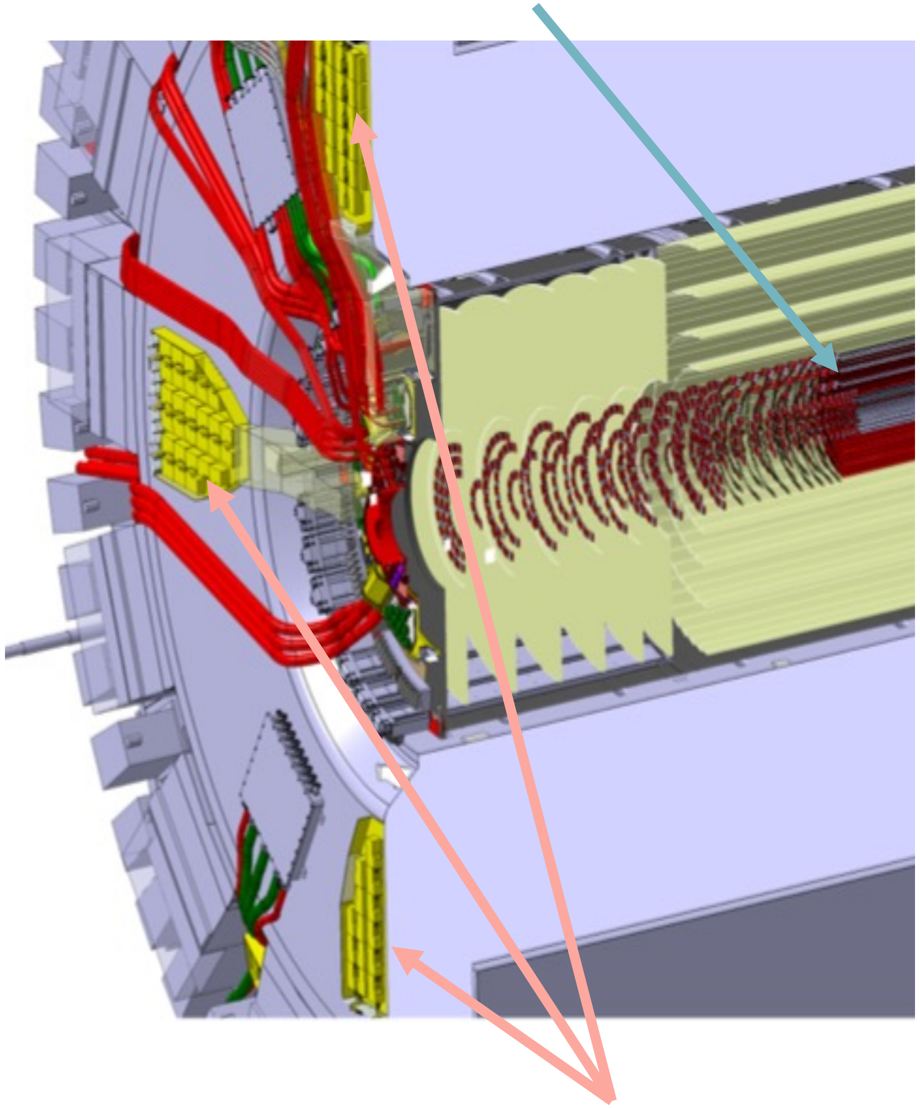


The main electrical component of the Optosystem is the Optoboard which:

equalize the electrical signal (GBCR),

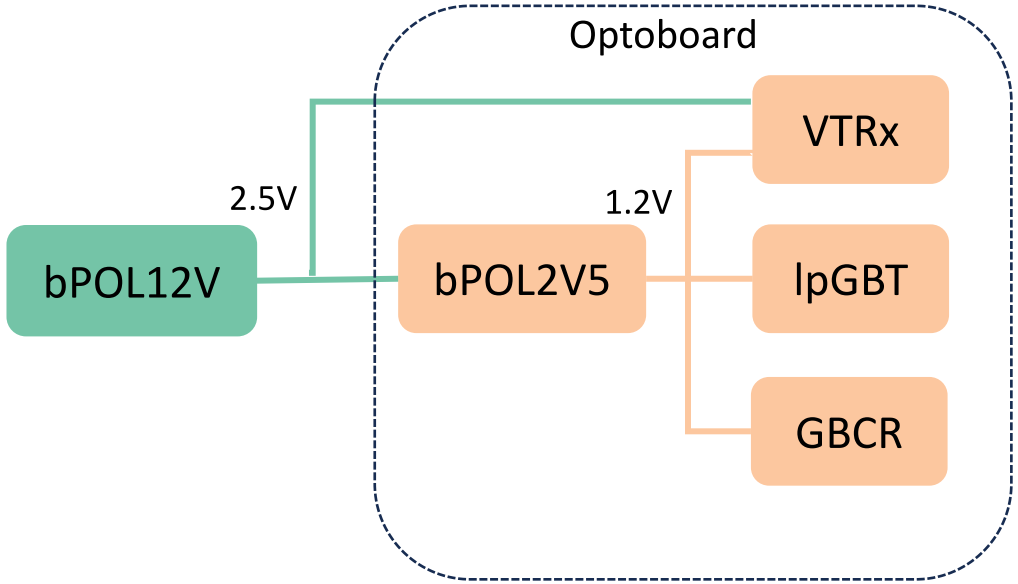
serialize it (LpGBT) .

and do the **opto-electrical conversion** (VTRx+).



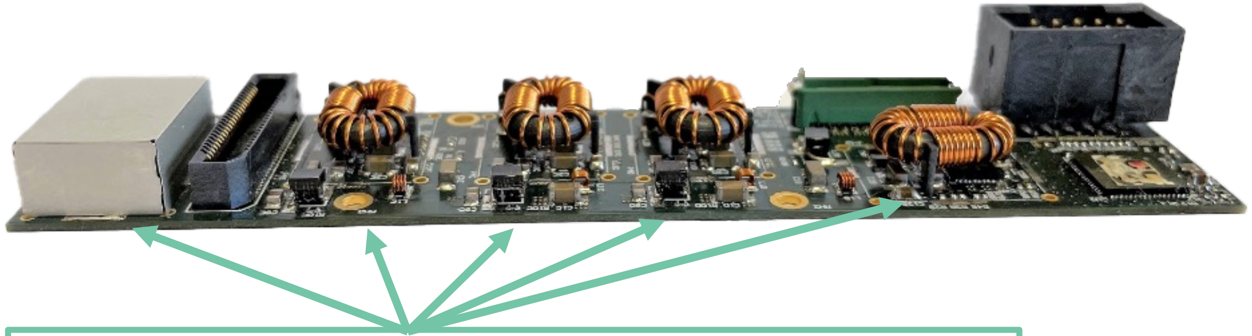
Optosystem position inside ATLAS

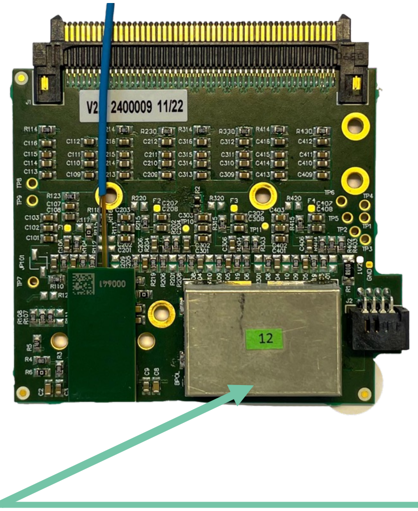
The Powerboard and the bPOLs



- Powerboard designed to power the Optoboards.
- **Transform 9V to 2.5V** for the VTRX+ laser driver.
- Connected to max. 8 Optoboards.

- The Powerboard design needed to be tested and validated.
- Test setup finalised for **Quality Control.**



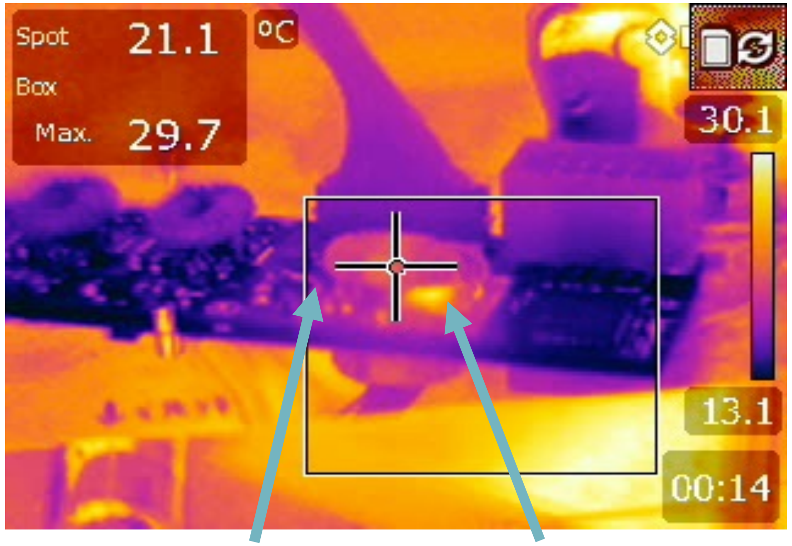


- **5 bPOL12V** DC-DC buck converters to level down the 9V input to 2.5V.
- Up to 3 Optoboards per bPOL12V.
- **1 MOPS** chip to monitor the Optosystem

- **bPOL2V5** placed on the Optoboard to level down 2.5V to 1.2V for the ASICS
- QC test finalised for production

Validation tests

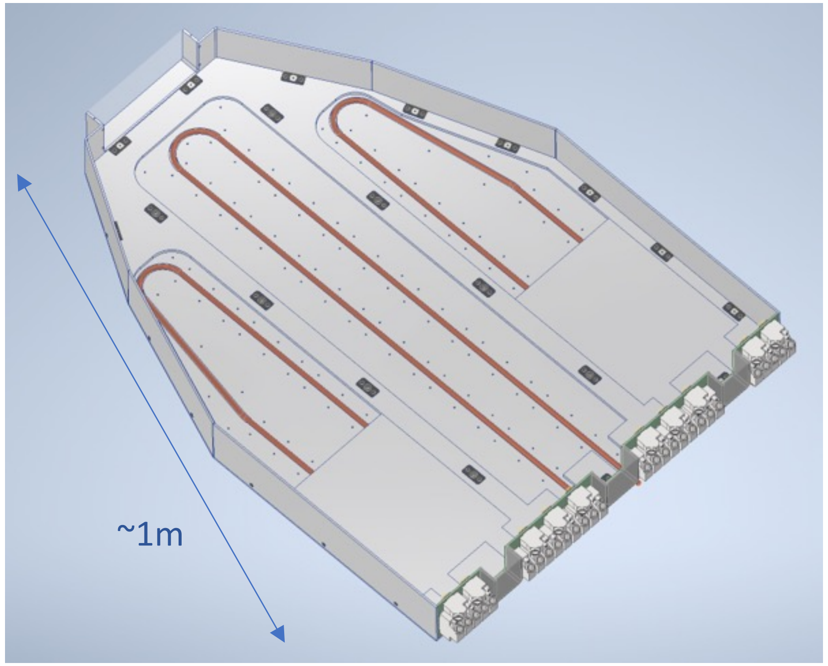
Heat test:
- The bPOL12V must not reach high temperature values (<50°C).
- Using **shield and thermal paste** allows a better cooling of the bPOL12V.
- **Cooling plate** under all Optosystem component



Air coil

bPOL12V chip

Cooling circuit of the Optosystem:
- Passing under 28 Optobox (composed of 8 Optoboards and 1 Powerboard)



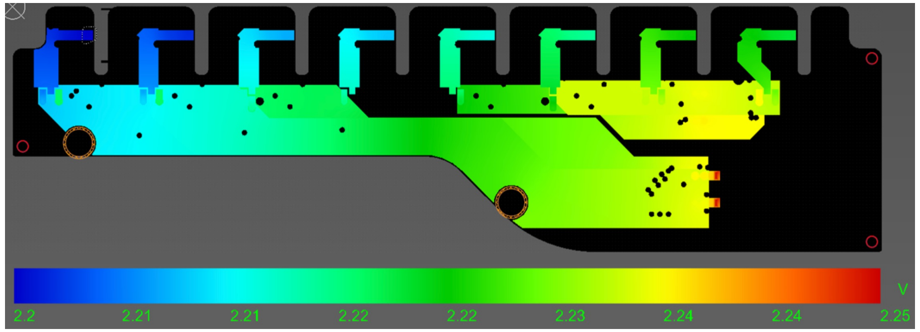
Other validation tests

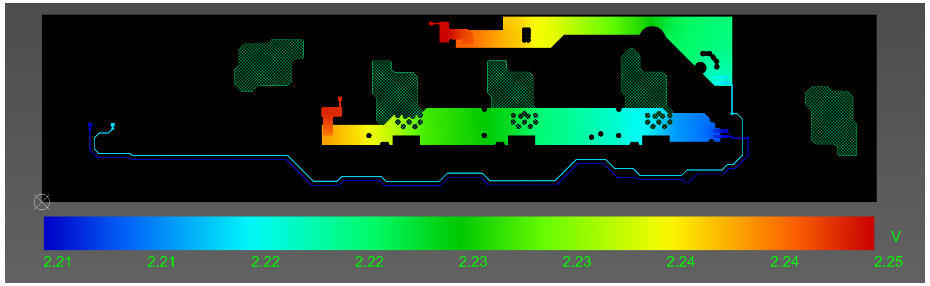
Voltage drop characterization:

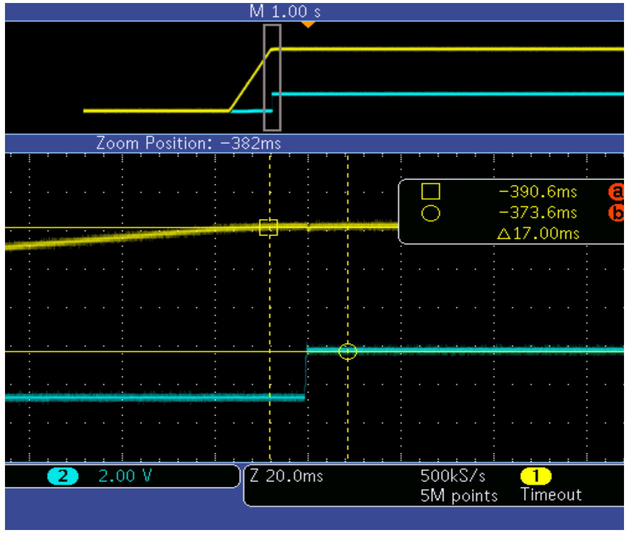
- From the bPOL12V output to the Optoboard chips input voltage.
- Simulation and physical measurement

Ramp-up test and interferences:

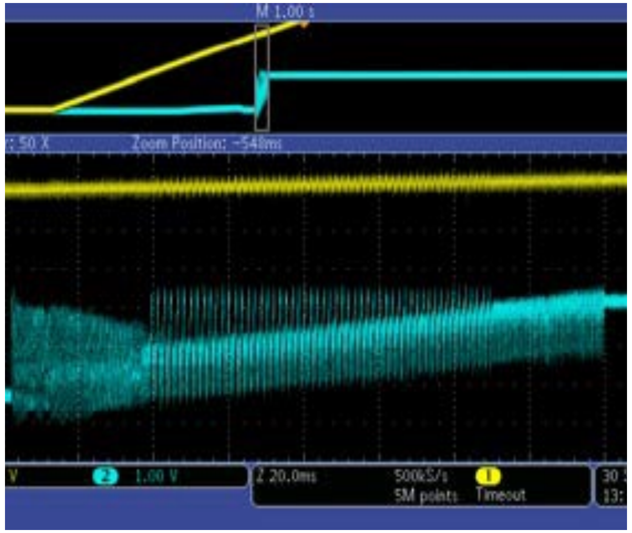
- If the ramp-up speed is too slow, it could damage the system by turning on and off the bPOL.
- No interference were found between the bPOLs.







Speed of 20V/s

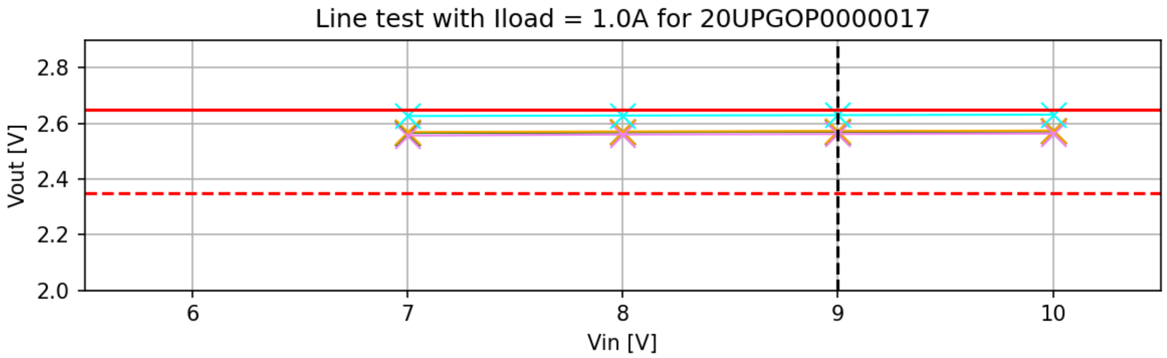


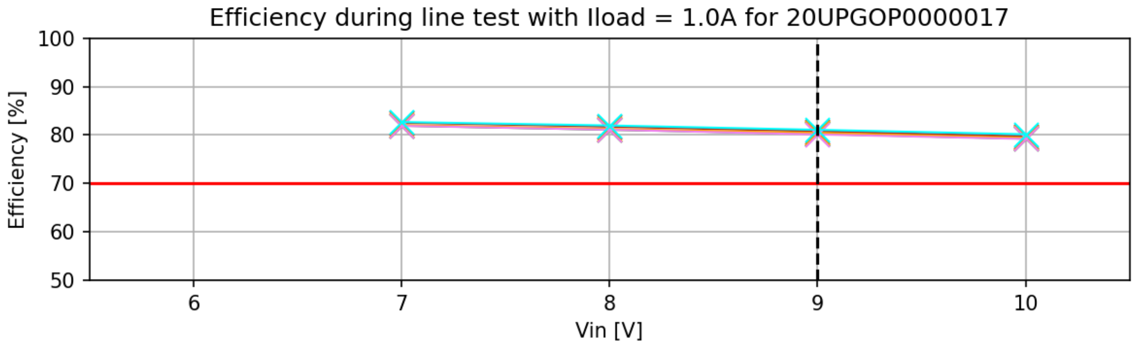
Speed of 2V/s

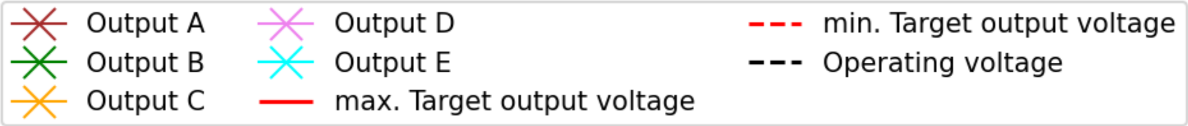
All the tests were performed before and after irradiating a Powerboard. Irradiation performed with the Bern Insel Spital cyclotron facility with a dose of 150 Mgy (safety factor of 3).

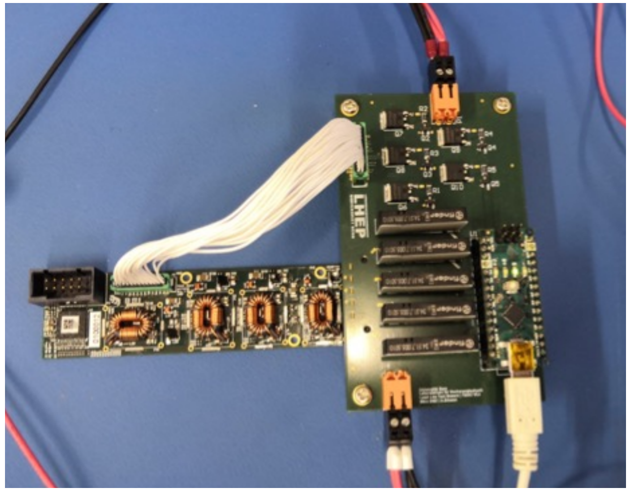
Load Line tests for Quality Control of bPOL12V

- Design of the powerboard was validated and the output voltage has been defined. For full Optosystem, **200+ Powerboards** will be tested.
- 10% of the full batch has been received and 40 Powerboards are currently under test.





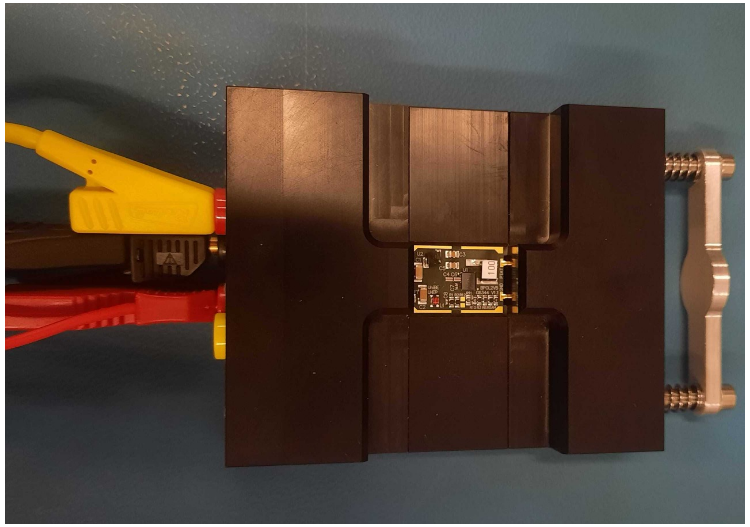


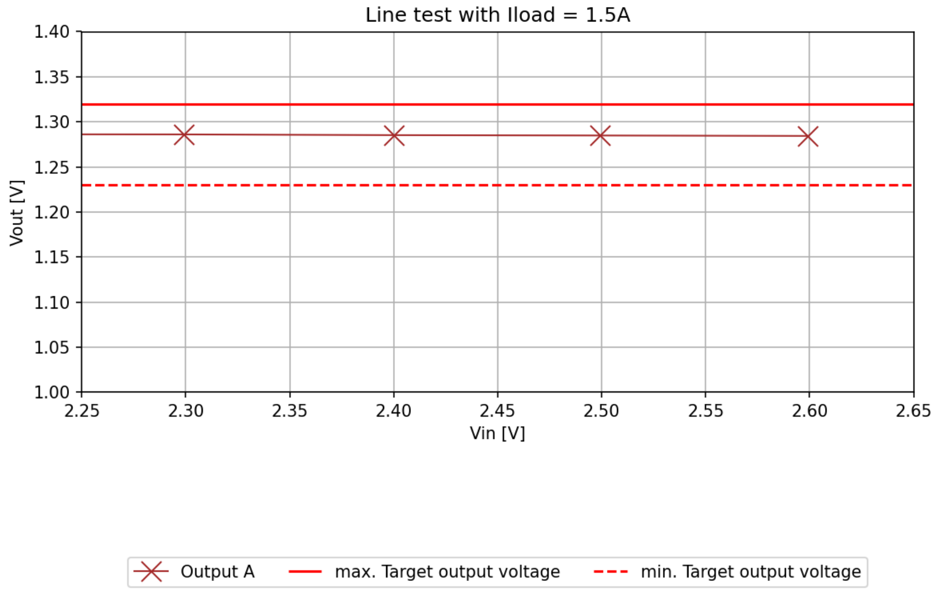


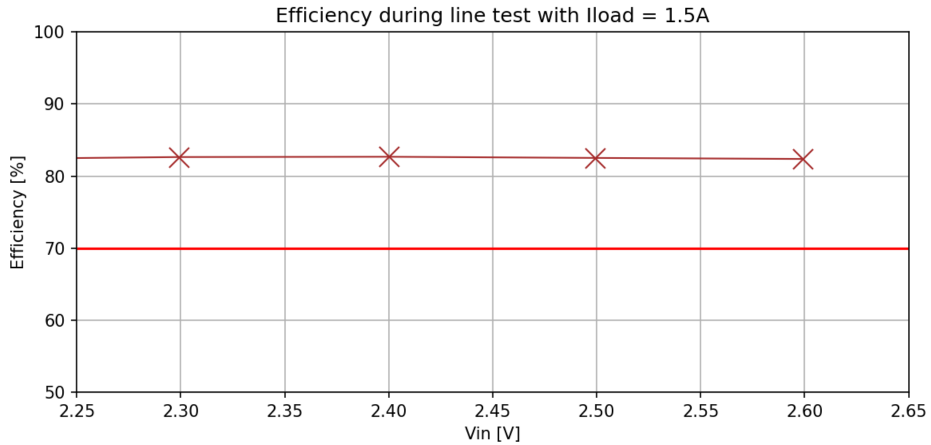
- A test setup was designed to measure the output voltage of the bPOL12V **under different input voltage and load.**
- The output voltage must be in between 2.35 and 2.65 V.
- The efficiency must be above 70%.

Load Line tests for Quality Control of bPOL2V5

- For full Optosystem, **1500+ bPOL2V5** will be tested.
- A test setup was designed to measure the output voltage of the bPOL2V5 **under different input voltage and load.**
- The output voltage must be in between 1.23 and 1.32 V.
- The efficiency must be above 70%.







Conclusion

- The LHC will undergo an **upgrade** to get more collisions per bunch crossings.
- Implies new requirement for ATLAS and design of a **new tracker (ITk).**

- The **Optosystem** is the key component of the pixel read-out chain.
- The Powerboard is the component to power all the Optosystem and transform 9V to 2.5V with the **bPOL12V.**
- **bPOL2V5** is used to level down 2.5V to 1.2V.

- The final design was validated in spring 2024 after being tested.
- **10% of final components** received for Quality Control.

More information on the Optosystem next with

- **Marianna Glazewska** on the Optoboard performance:

  Performance tests of the ATLAS Inner Tracker Pixel detector opto-electrical conversion system.

- **Una Alberti** on the impedance measurement of the Optosystem with TDR:

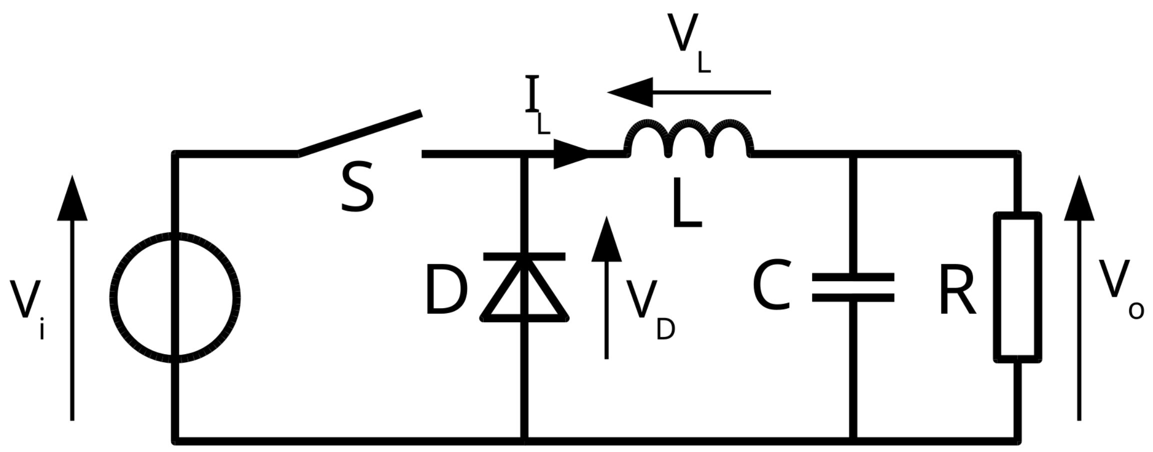
  Time-domain Reflectometer Measurements of the Optosystem Data Transmission Chain

Thank you for your attention

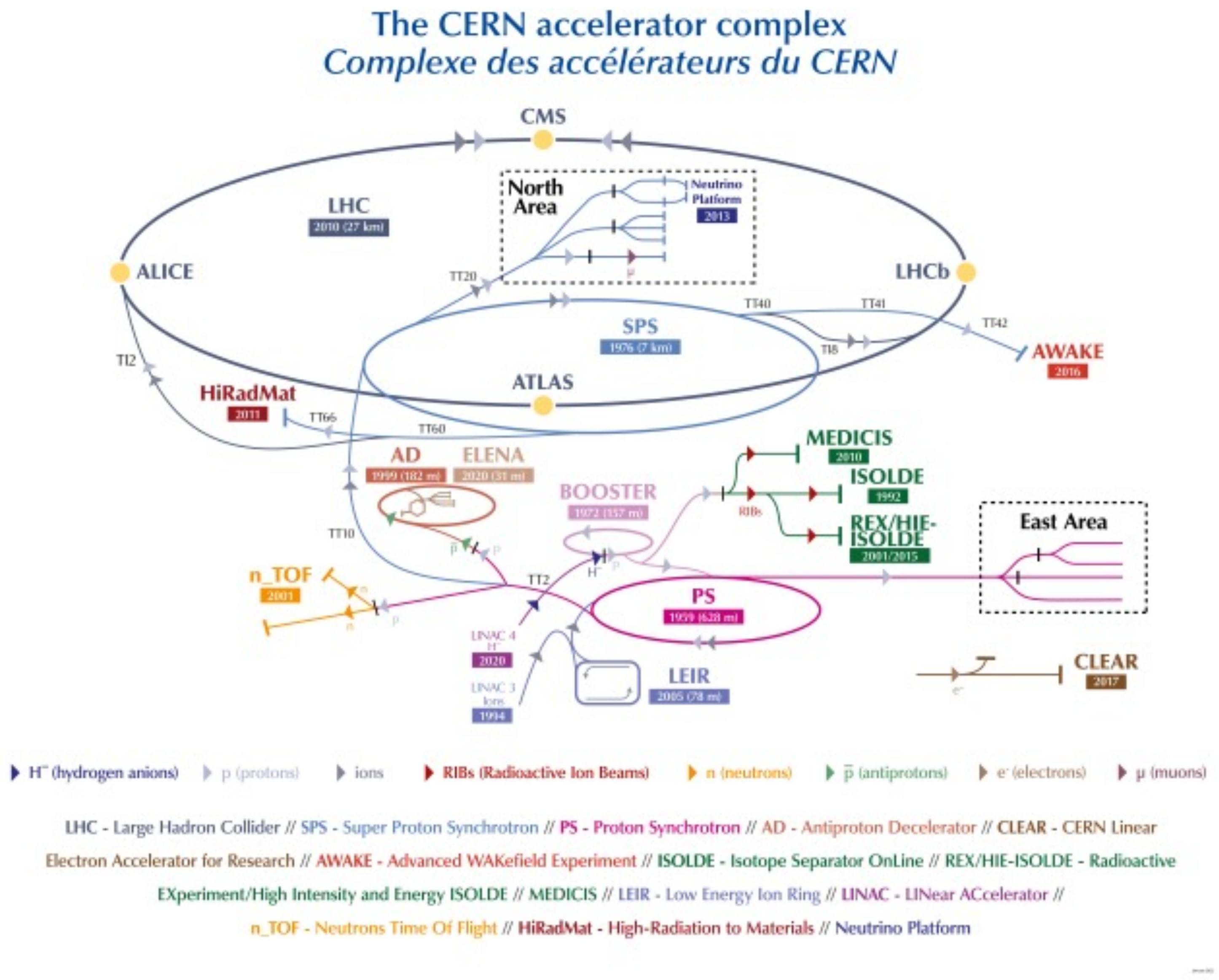
References

- ATLAS Collaboration 2008 *The ATLAS Experiment at the CERN Large Hadron Collider JINST* **3** S08003
- ATLAS Collaboration *Technical Design Report for the ATLAS Inner Tracker Pixel Detector* CERNLHCC-2017021; ATLASTDR030
- Laura Franconi and on behalf of ATLAS Itk 2022. *The Opto-electrical conversion system for the data transmission chain of the ATLAS ITk Pixel detector upgrade for the HL-LHC* . J. Phys.: Conf. Ser. 2374 012105
- ATLAS Collaboration 2012 *Observation of a New Particle in the Search for the Standard Model Higgs Boson with the ATLAS Detector at the LHC* . Phys.Lett. B716 (2012) 1-29
- A. Xiang et al., *A Versatile Link for High-Speed, Radiation Resistant Optical Transmission in LHC Upgrades*, Phys. Procedia 37 (2012) 1750.
- R. Ahmad, *The Monitoring of Pixel System (MOPS) chip for the Detector Control System of the ATLAS ITk Pixel Detector*, J. Phys. Conf. Ser. 2374 (2022) 012094.
- L. Zhang et al., *The design and test results of A Giga-Bit Cable Receiver (GBCR) for the ATLAS Inner Tracker Pixel Detector*, 2023 JINST 18 C03005 [arXiv:2301.13399].
- N. Guettouche et al., *The lpGBT production testing system*, 2022 JINST 17 C03040.

DC-DC buck converters

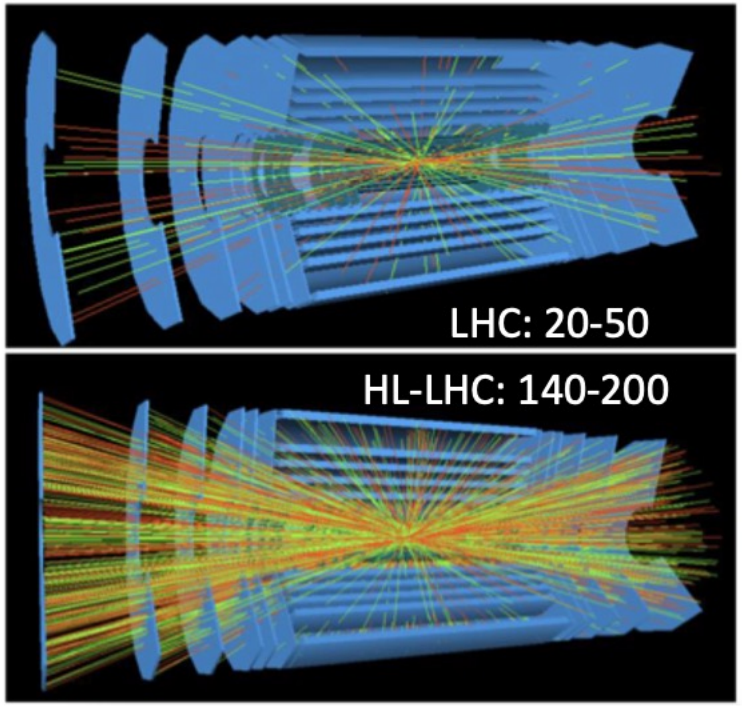


CERN

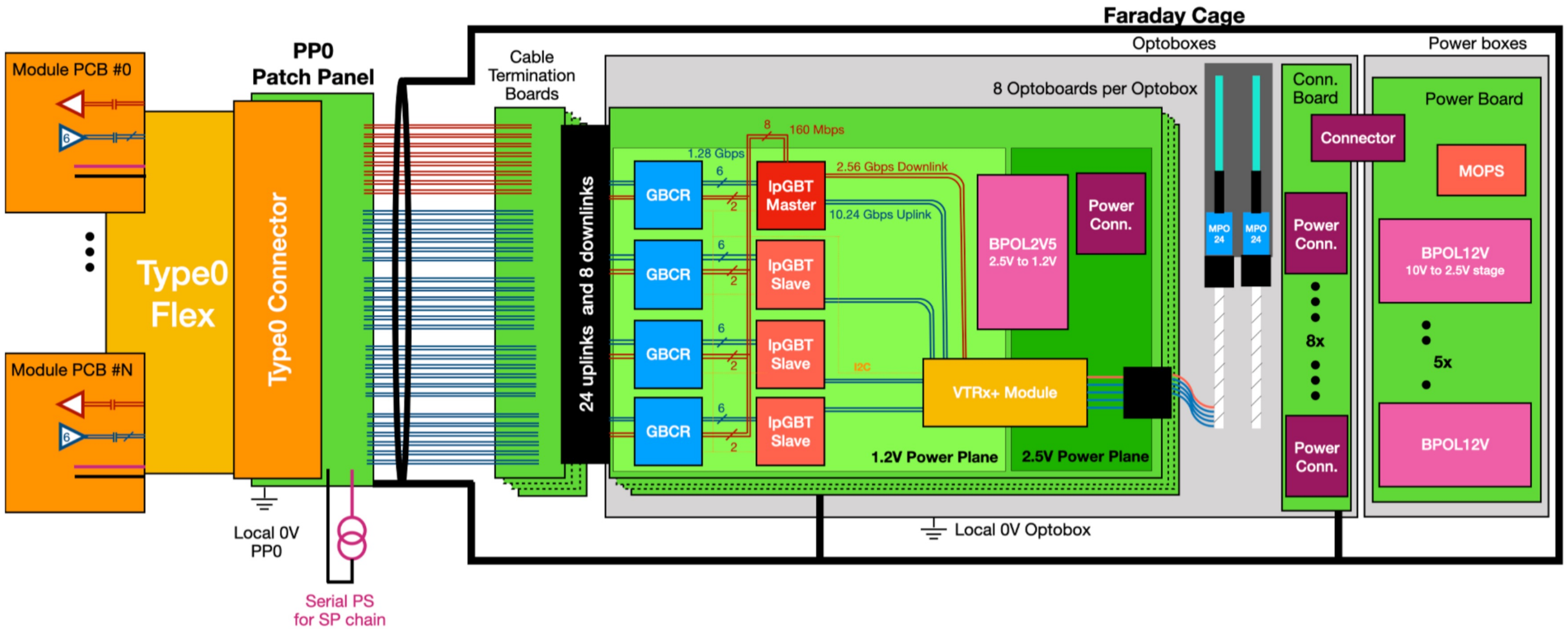


The CERN accelerator complex
Complexe des accélérateurs du CERN
CMS
North Area
Neutrino Platform
2013
LHC
2010 (27 km)
ALICE
LHCb
TT20
TT40
TT41
TT42
AWAKE
2016
SPS
1976 (7 km)
TI8
TI2
ATLAS
HiRadMat
2011
TT66
TT60
AD
1999 (182 m)
ELENA
2020 (31 m)
BOOSTER
1972 (157 m)
MEDICIS
2010
ISOLDE
1992
RIBs
REX/HIE-ISOLDE
2001/2015
East Area
TT10
n_TOF
2001
TT2
PS
1959 (628 m)
LINAC 4
2020
LINAC 3
Ions
1994
LEIR
2005 (78 m)
CLEAR
2017
H⁻ (hydrogen anions)
p (protons)
ions
RIBs (Radioactive Ion Beams)
n (neutrons)
p̄ (antiprotons)
e⁻ (electrons)
μ (muons)
LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKefield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE-ISOLDE - Radioactive EXperiment/High Intensity and Energy ISOLDE // MEDICIS // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator // n_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials // Neutrino Platform

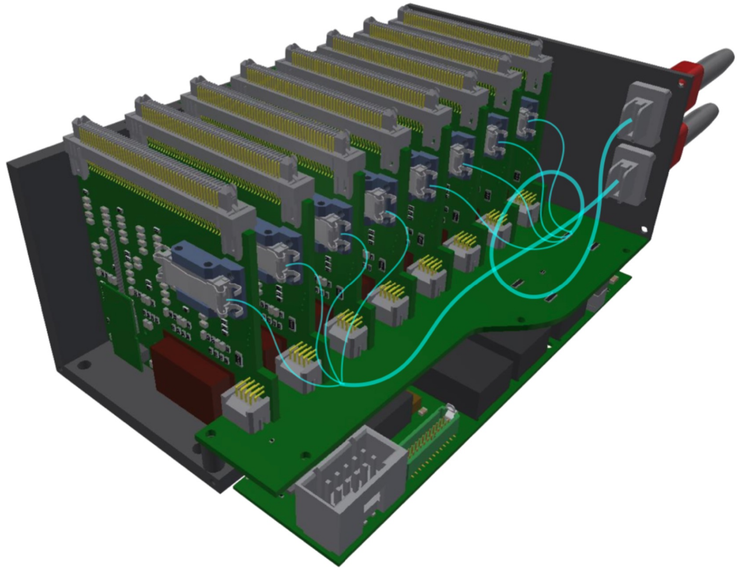
PILE-UP and HL-LHC

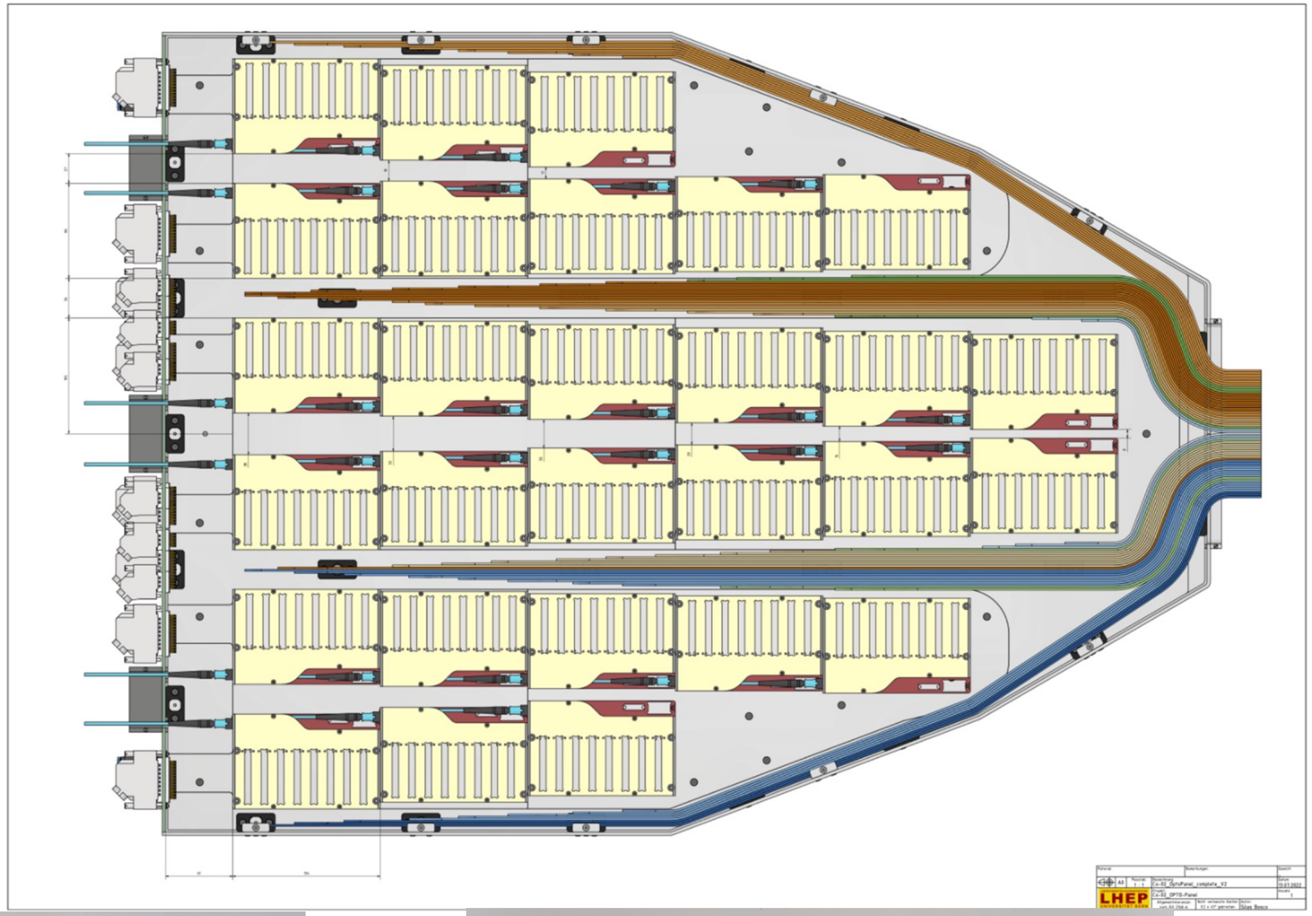


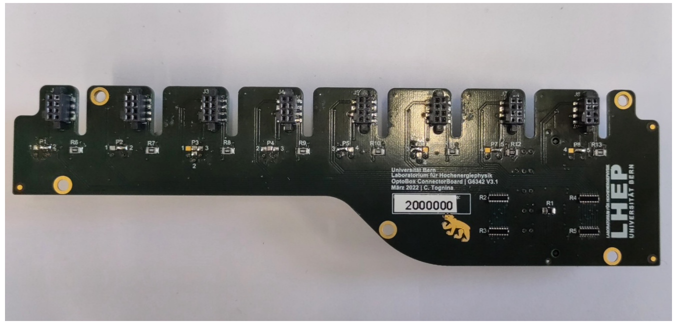
Data Transmission Chain

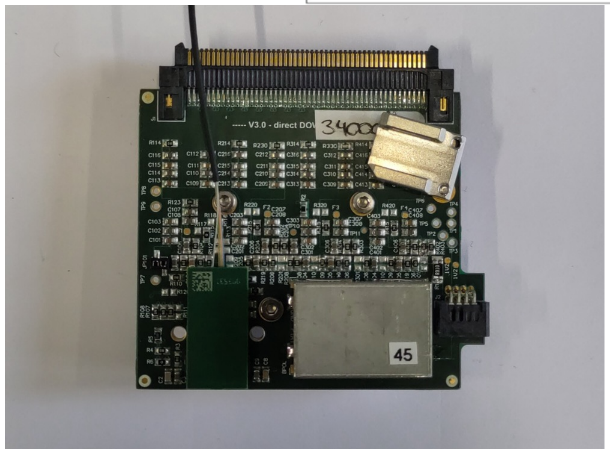


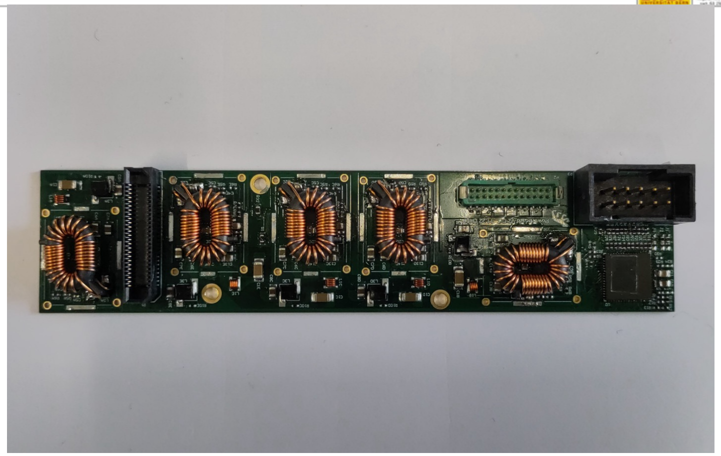
Optosystem



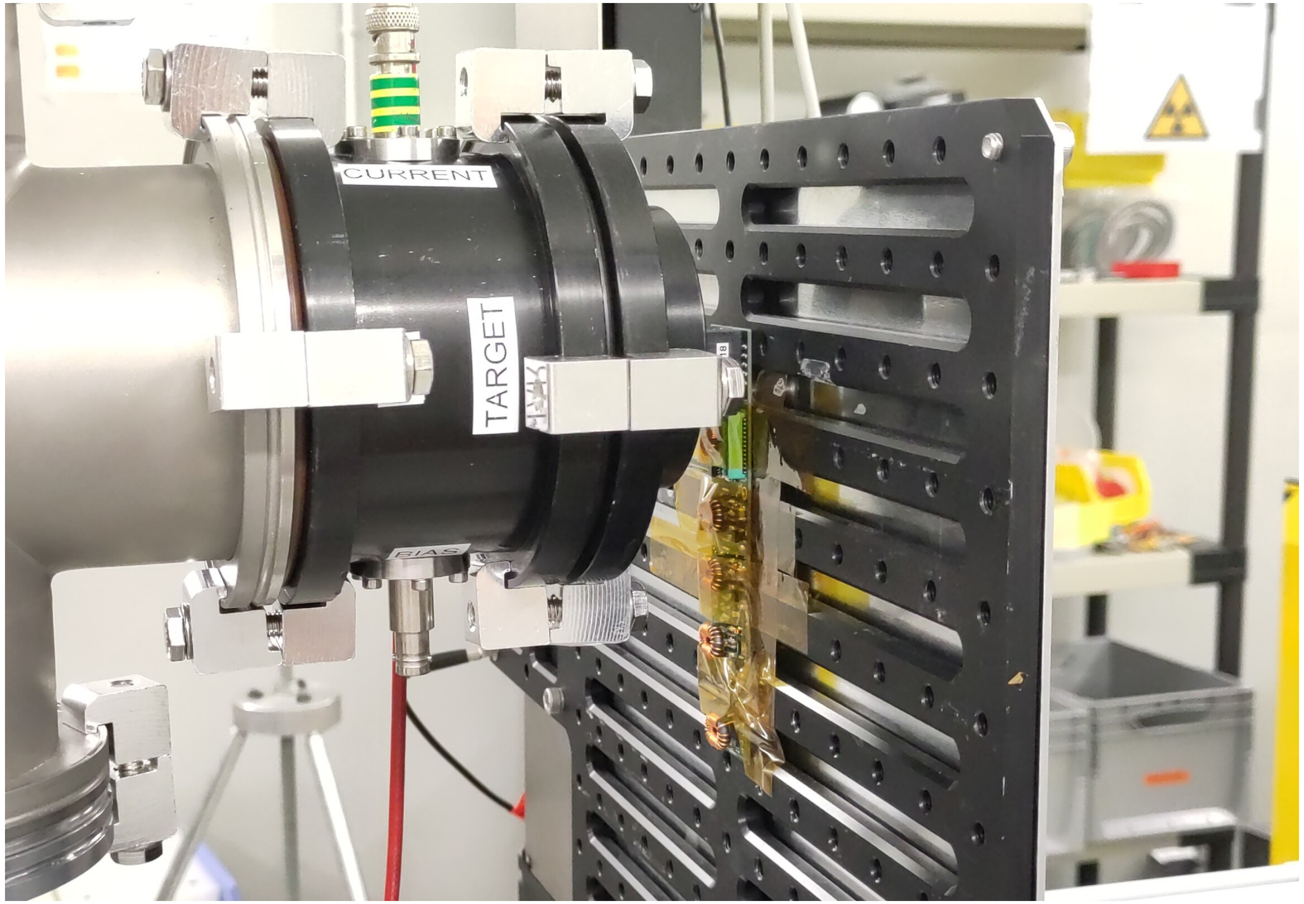


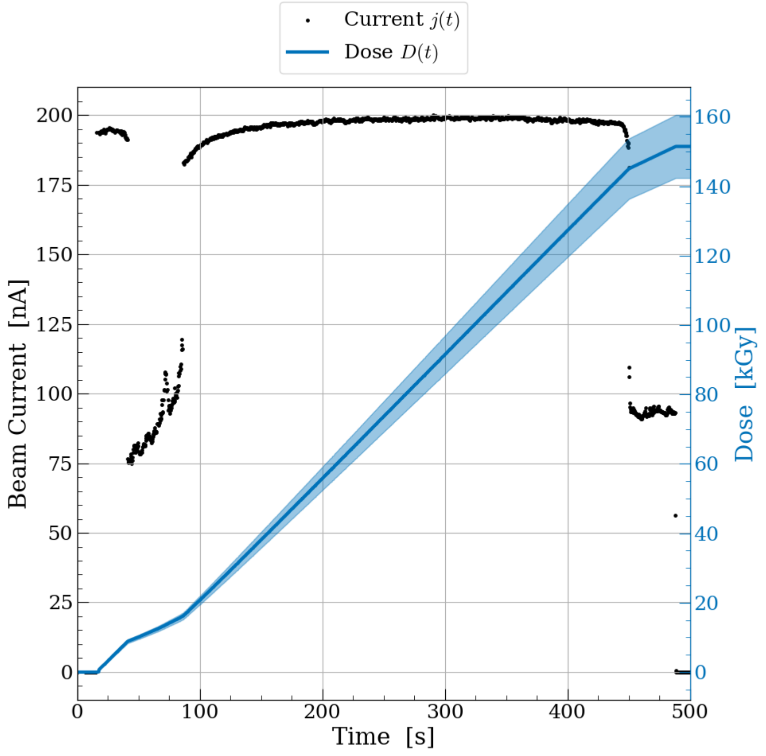






Irradiations





Irradiations