Irradiation studies for ATLAS ITk at the Bern Cyclotron

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TIPP 2021 - Online Format

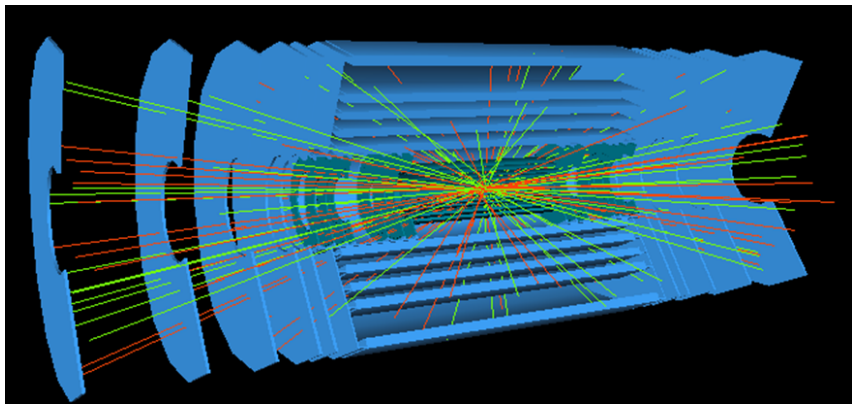
Outlook

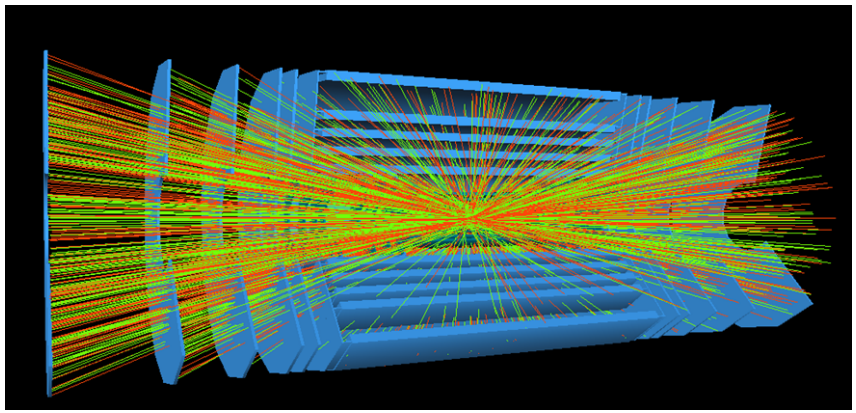
1. High-Luminosity LHC and ATLAS ITk Upgrade
2. Irradiation Facility in Bern
3. Recent Irradiation Campaigns:
   - Optosystem Connectors
   - Cable Shielding Material
   - Twinax Cable
4. Summary & Outlook

HL-LHC

High-Luminosity LHC: at least 10× higher integrated luminosity (3000/fb)

- Study rare processes (e.g. Higgs to muons), search for new particles (SUSY, heavy W' and Z' bosons), and precision measurements





Higher luminosity will increase average number of interactions per beam crossing (pile-up) by factor 4-5!

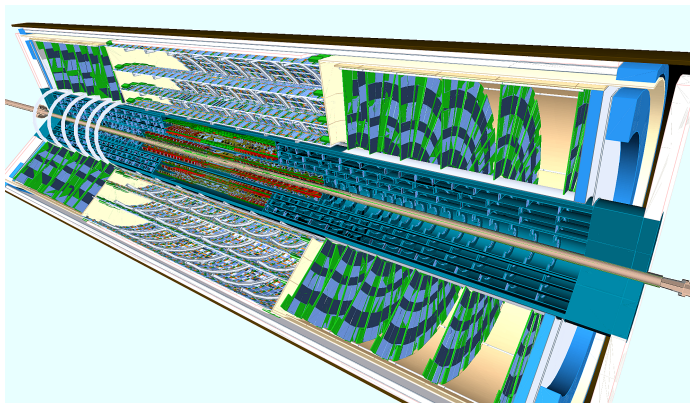
→ **Radiation level increases!**

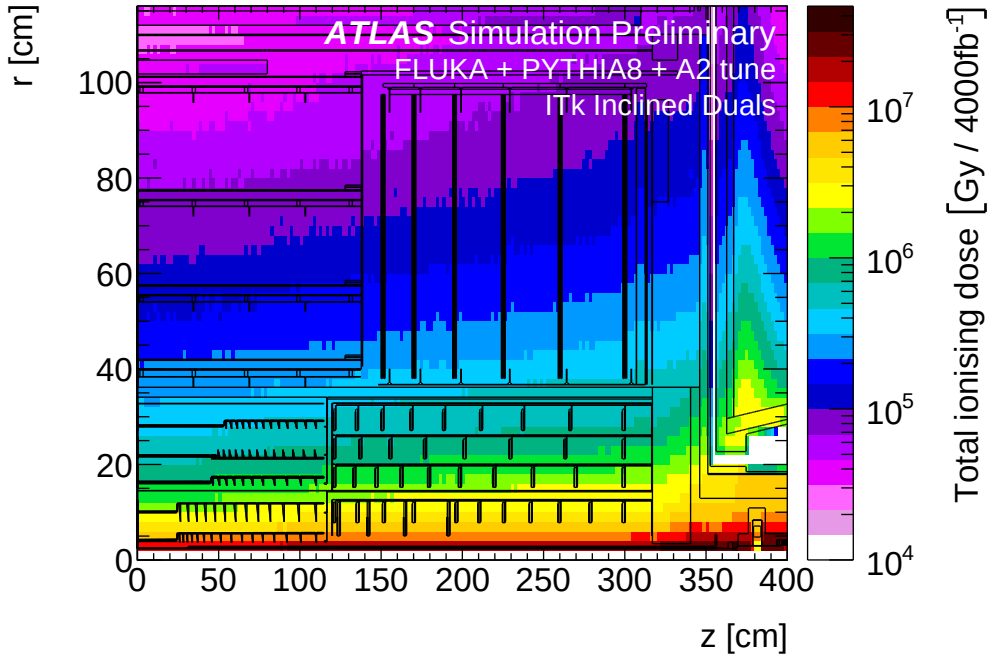
The ATLAS Detector: HL-LHC Upgrade

One of the essential upgrades: the new **Inner Tracker (ITk)**

F. Munoz Sanchez's Talk , K. Krizka's Talk

- All-silicon tracker, with finer **granularity** ($> 10^9$ channels)
- Improved **material budget**
- Capability for increased **data rate** (trigger rate: 1 MHz)
- **Has to withstand high radiation levels**

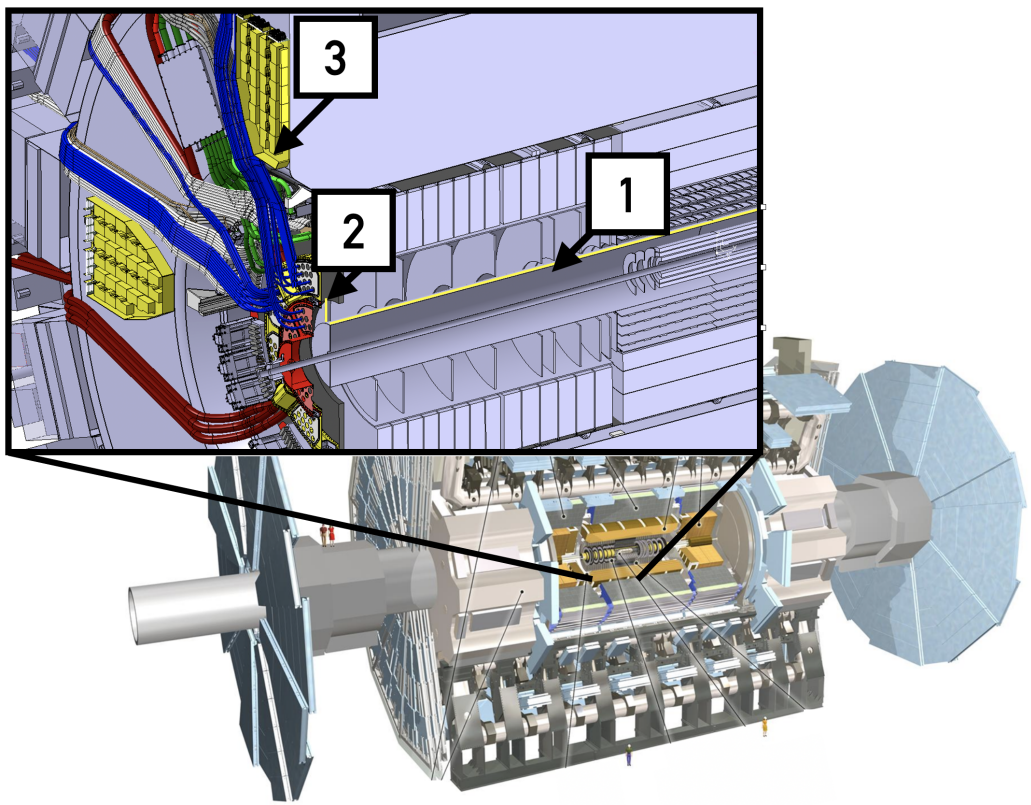




Expected radiation levels:

- TID = 10 MGy
- NIEL = 1.3 $\times 10^{16}$ 1 MeV n_{eq}/cm2

The ATLAS Detector Upgrade: ITk Optosystem

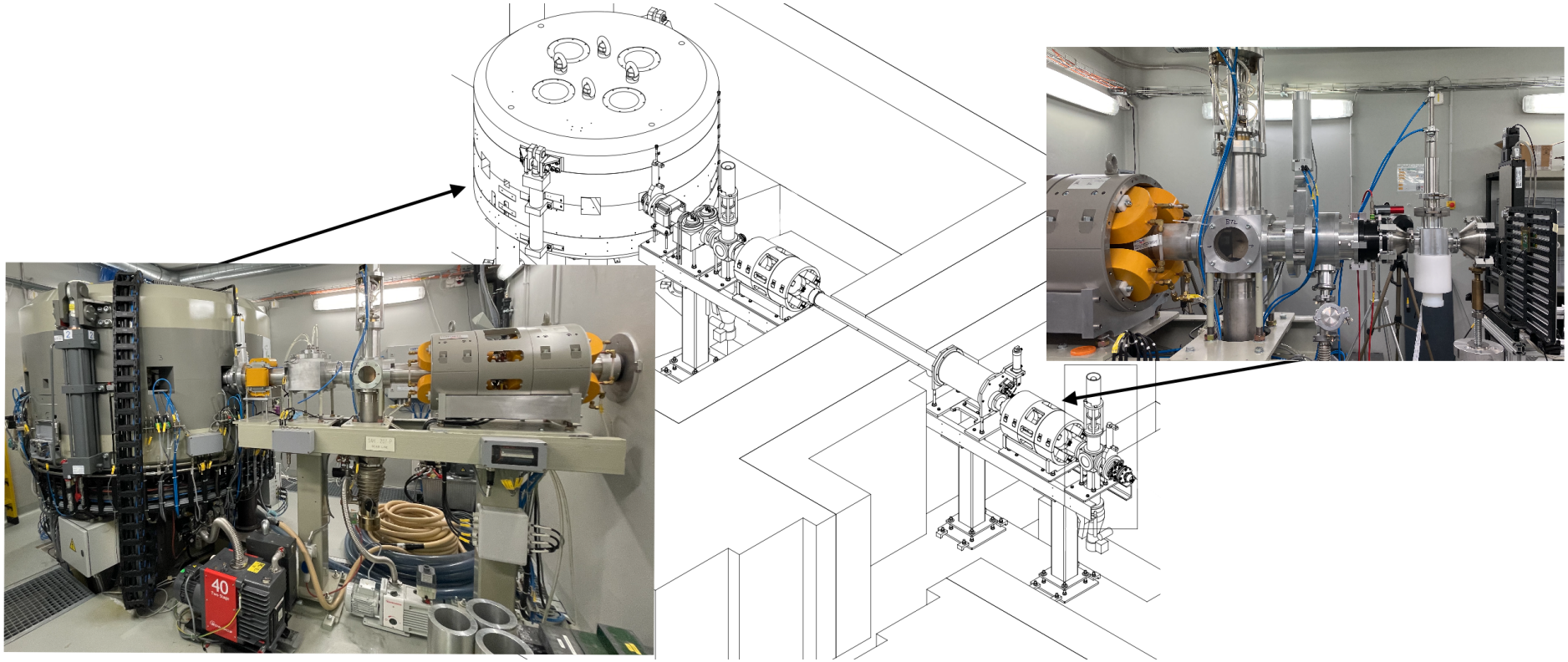


L. Franconi's Poster

- **Twinax cables (1)** transfer electrical signals from the ITk pixel modules
- They are shielded from electromagnetic interference by a **Z-shield (2)**
- The **Optosystem** located on **Optopanels (3)** converts the electrical signals into optical signals
- From here, data is brought to the surface ($\sim$ 100 m)

These components have to be tested for radiation effects,
failing Optosystem = no physics data to analyse!

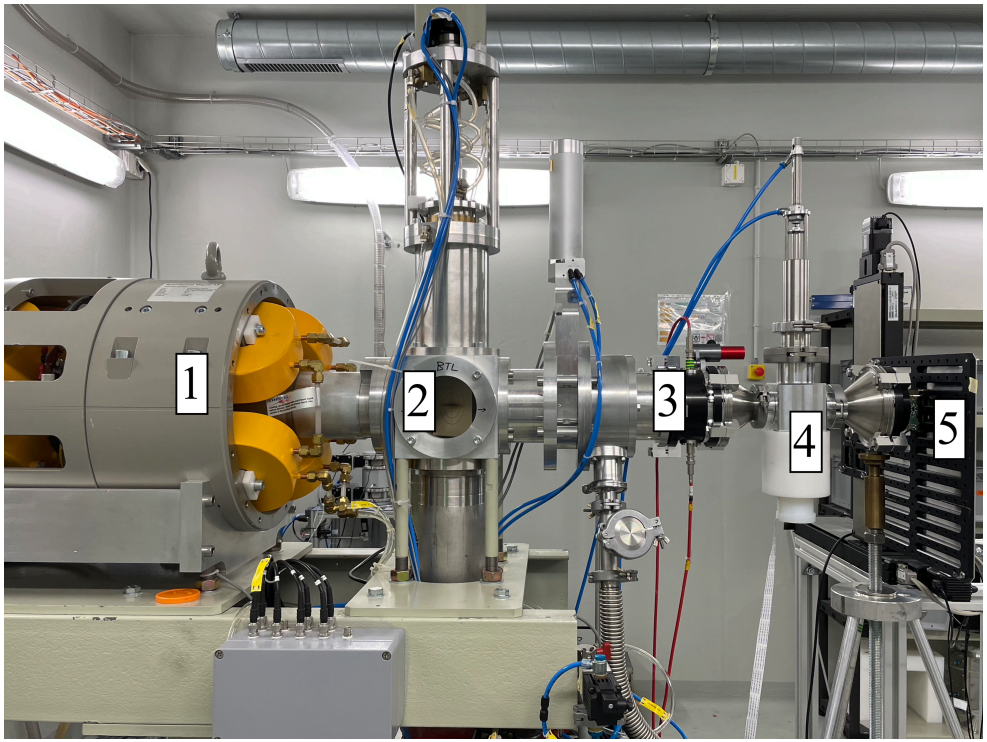
The Irradiation Facility: The Bern Medical Cyclotron



- Bern Medical Cyclotron (18 MeV protons) for F^{18}-isotope production
- Unique infrastructure with Beam Transfer Line (BTL), allowing multi-disciplinary research applications in a separate bunker

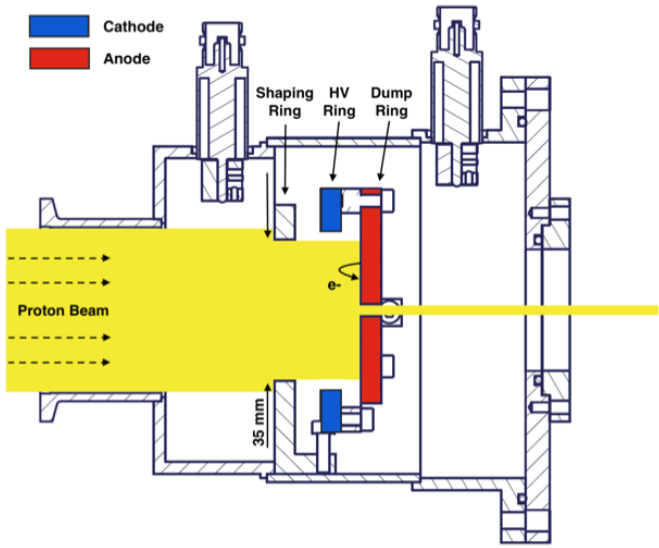
The Irradiation Facility: Irradiation Setup

Flexible irradiation setup in BTL bunker with beam monitoring, dose measurement, and different mounting structures for targets



1: Quadrupole Dublets, 2: Beam Viewer, 3: Collimator,
4: 2D Beam Monitoring Detector (Pi2), 5: 2D Stage

Collimator for dose measurement:



$$\mathrm{TID} = \frac{\phi(\mathrm{E})}{\rho}\frac{\mathrm{dE}}{\mathrm{dx}}$$

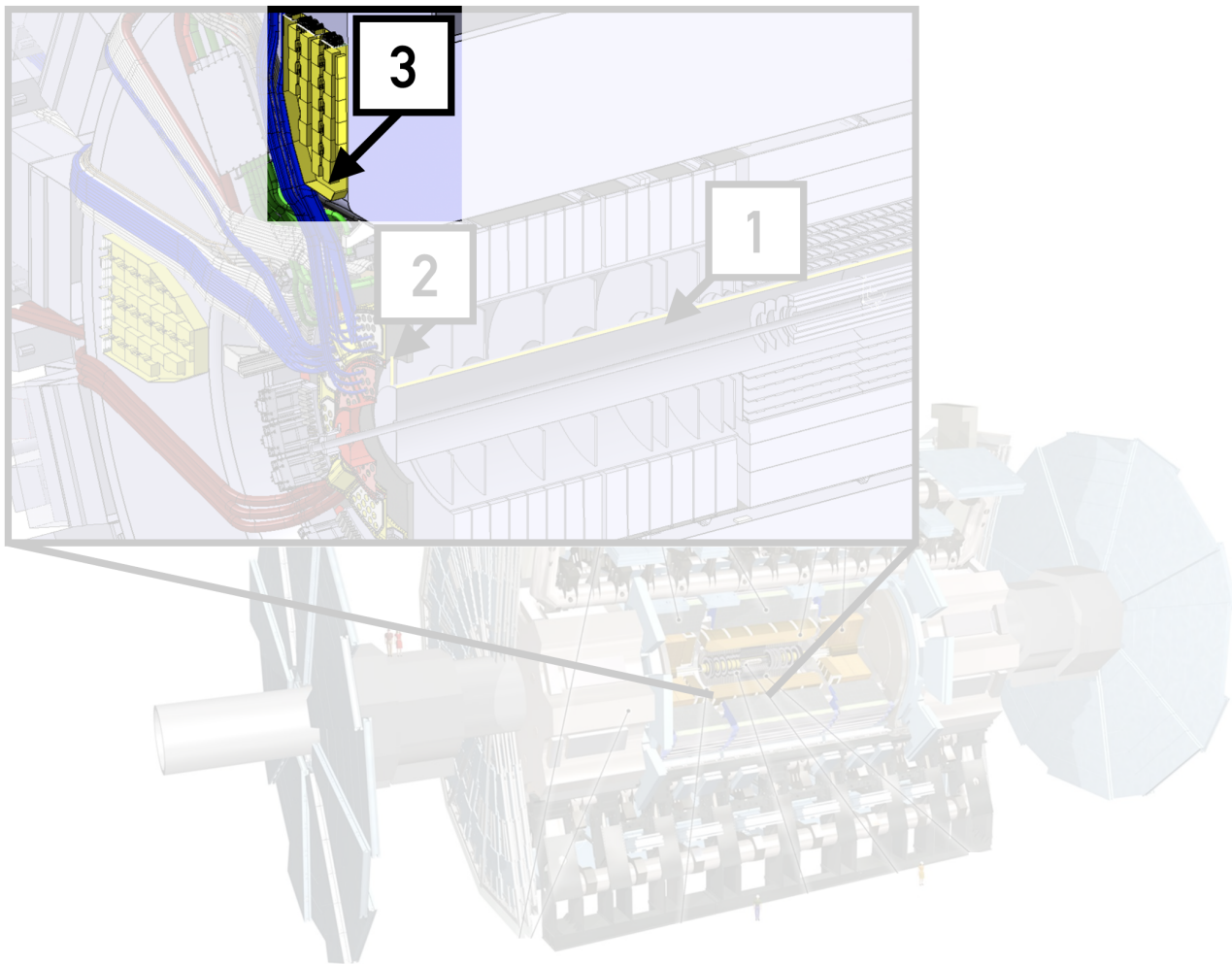
*material dependent

arXiv1803.01939 , I. Mateu's Poster

The Irradiation Campaigns

1. Determine **dose (TID/NIEL)** for sample to be irradiated depending on:
   - Expected dose after 10 years of HL-LHC
   - Energy loss in specific material for 18 MeV protons
2. Design appropriate **adjustment tool/setup** for the irradiation
3. Define **pre- and post-irradiation tests** to verify the effect of the irradiation
4. Perform irradiations

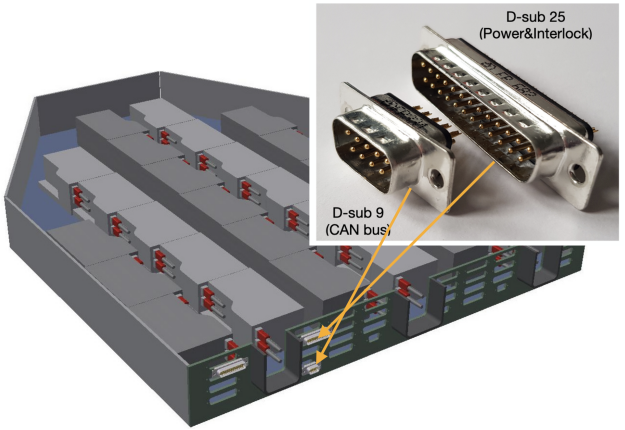
Campaign 1: Optosystem Connectors

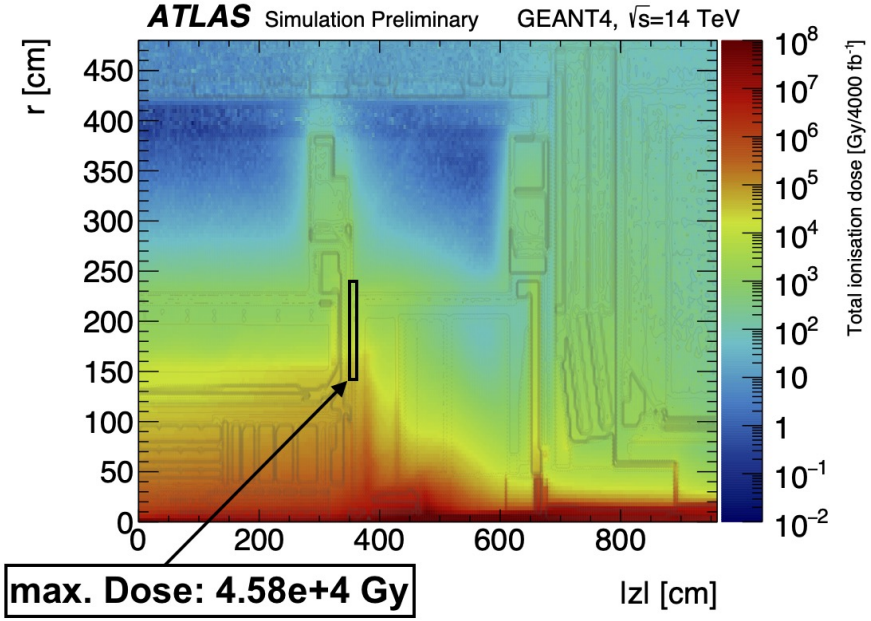


Opto Patch Panel Connectors

- Filtered connectors for power and monitoring lines: 2 types of low-pass filters (330 pF, 6800 pF)

- Irradiation up to **15 Mrad** (incl. SF $>$ 2) TID
- **Pre-/Post irradiation tests:**
  1. Optical inspection
  2. **IV leakage current**
  3. **Current stability**
  4. Cutoff frequency

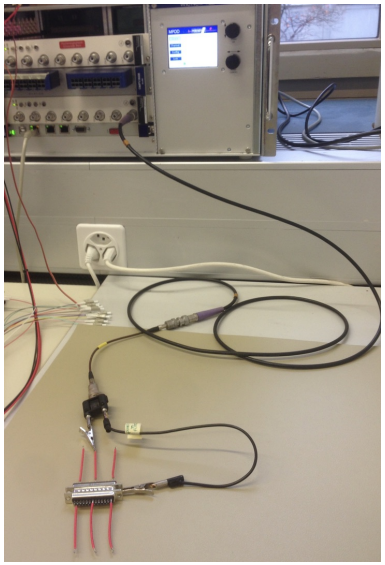


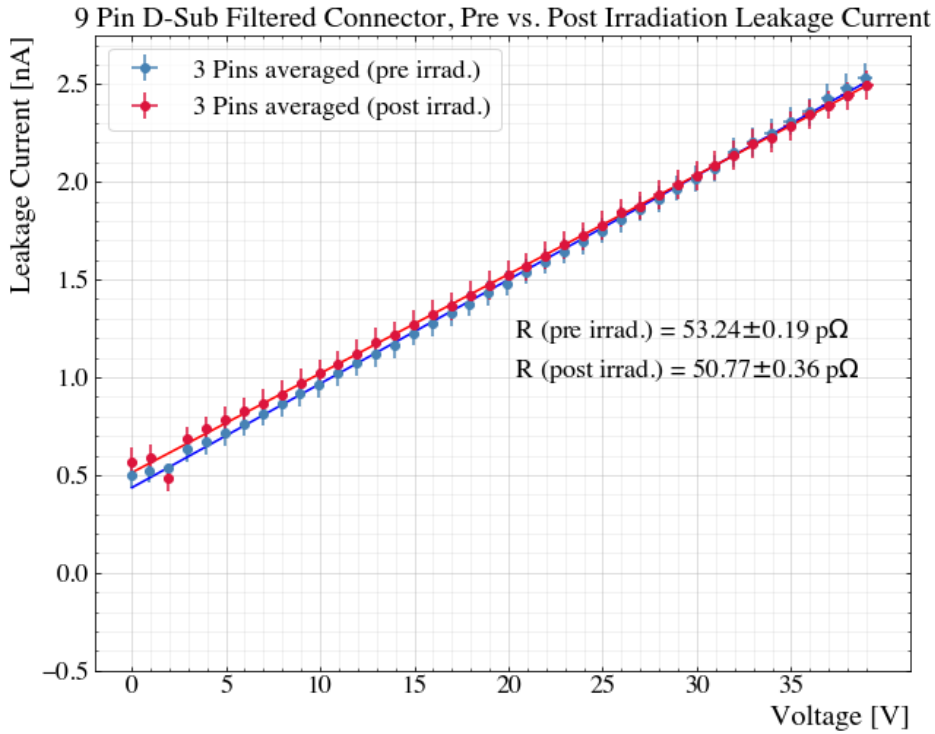


Phase 2 Geometry

Opto Patch Panel Connectors: IV Leakage Current

- IV measurements with M-pod HV module
- At each voltage step:
  60 seconds, 12 measurements, averaged over multiple pins and "runs"

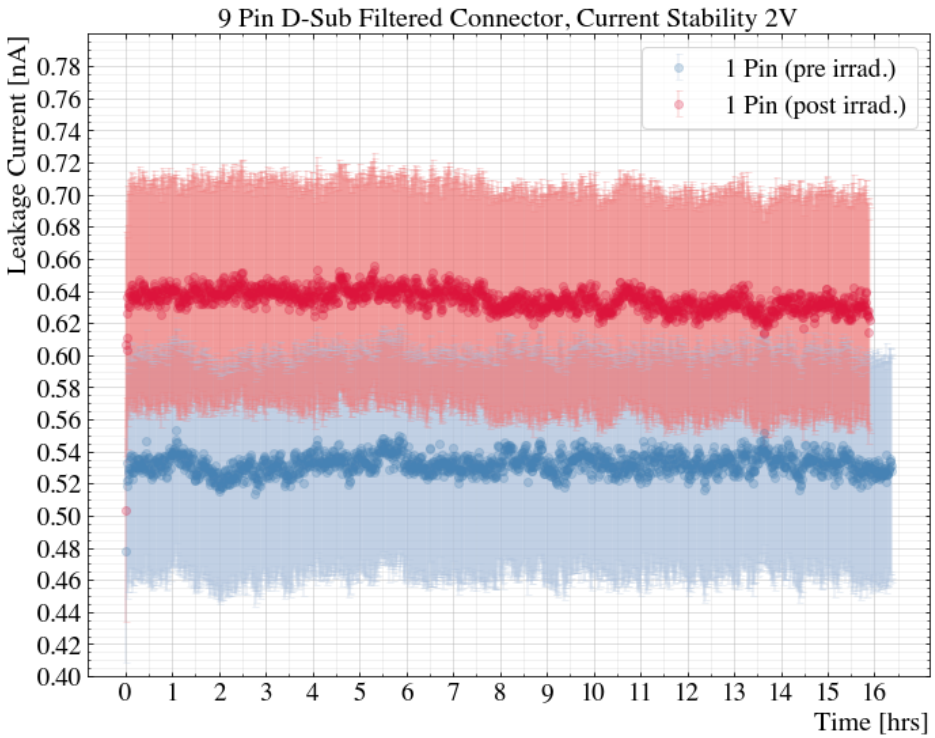


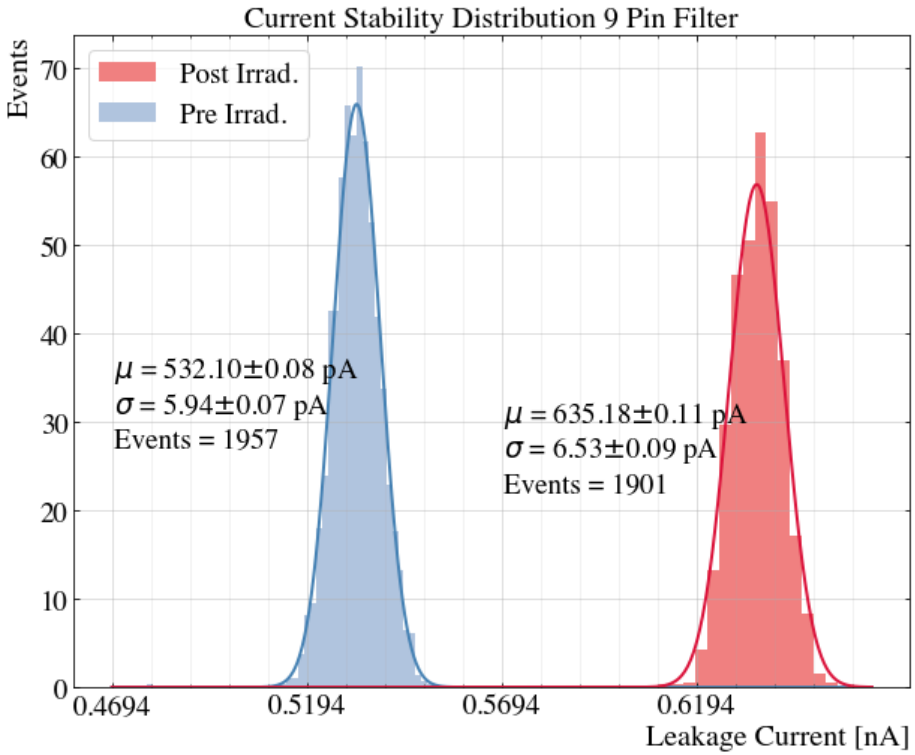


→ Result from 25-pin connector in the Appendix.

Opto Patch Panel Connectors: Current Stability

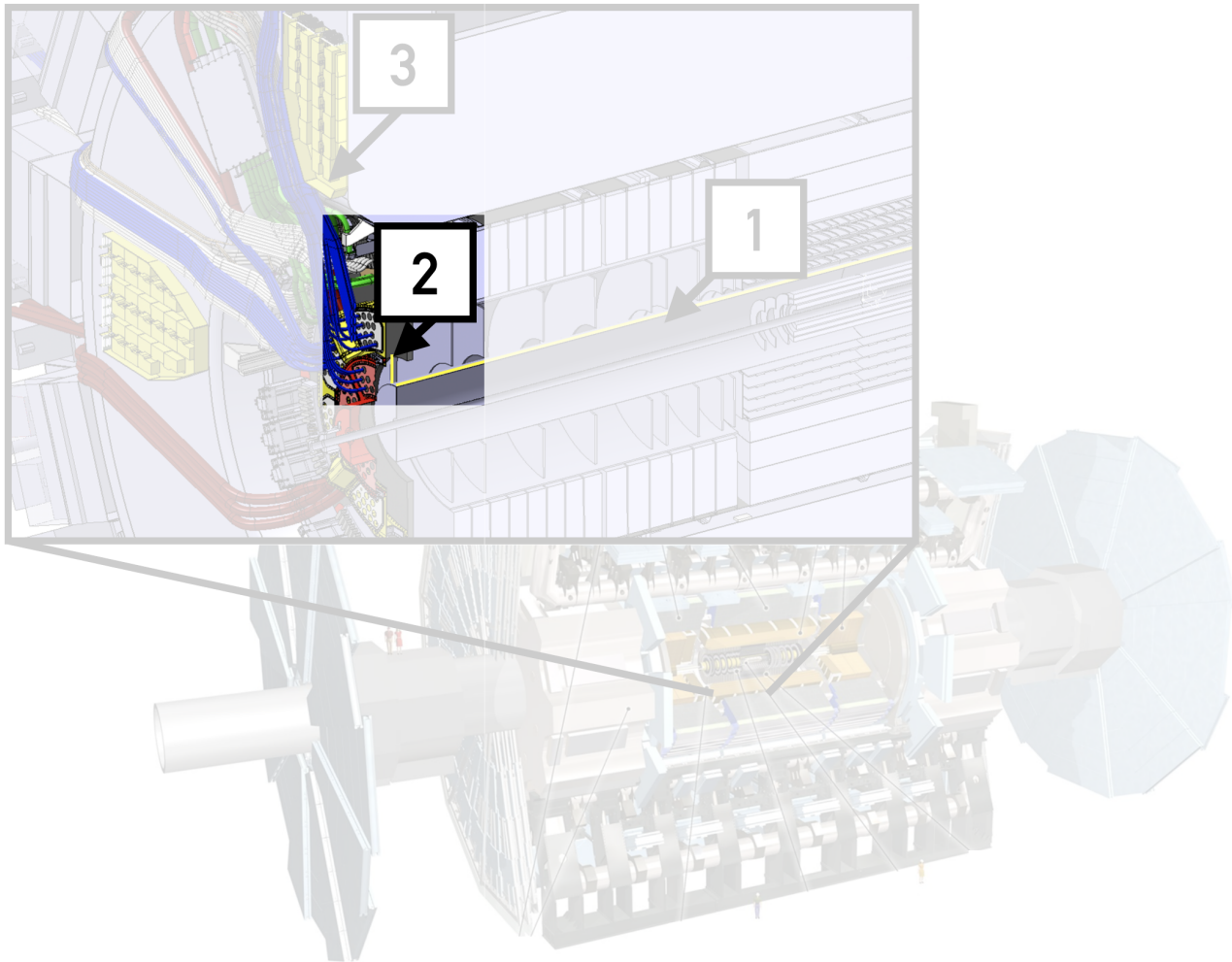
- Same setup as for the IV leakage current measurement
- Applied 2 V for 15+ hours to qualify the current stability





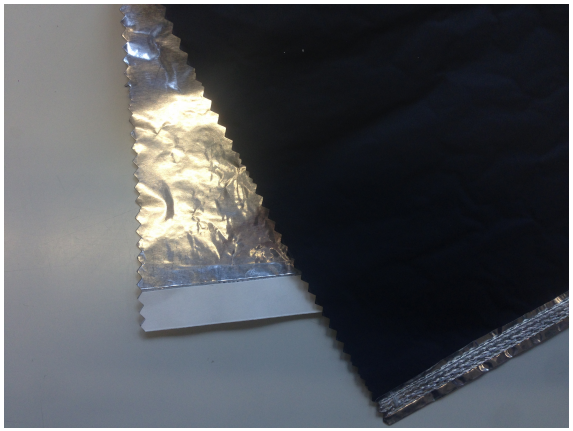
→ Result from 25-pin connector in the Appendix.

Campaign 2: Cable Shielding Material

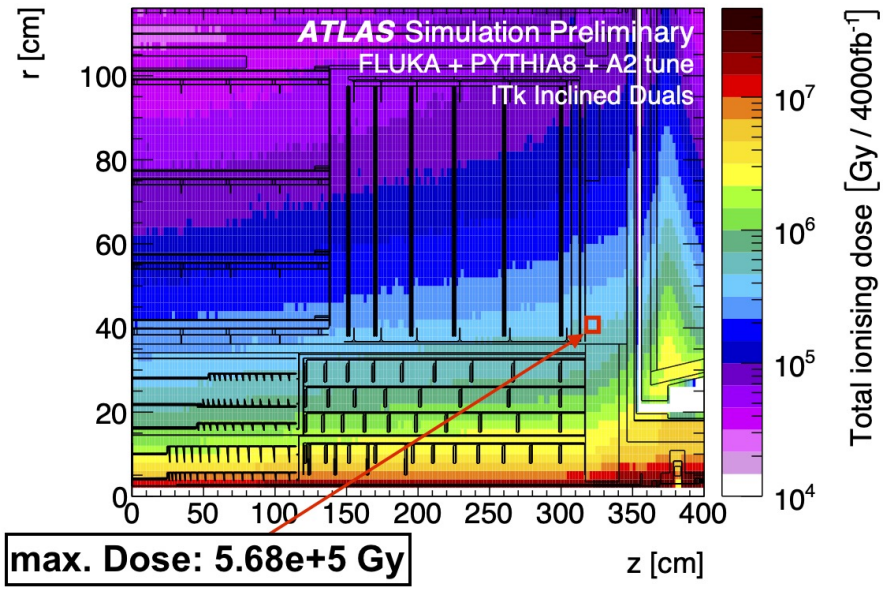


Z-Shield

- Shielding material (foil) for cables to avoid electromagnetic interference

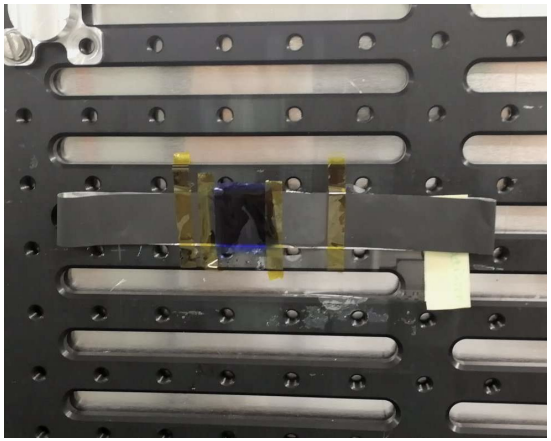


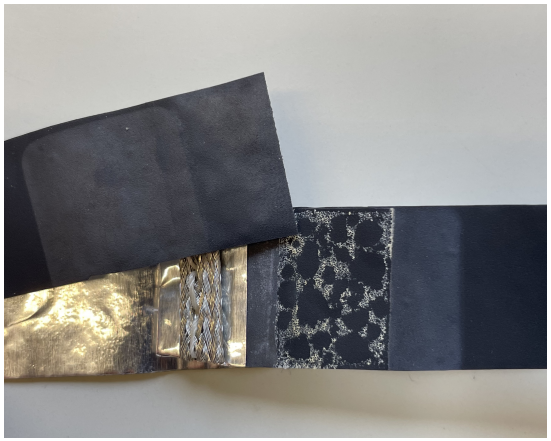
- Irradiation up to **120 Mrad** (incl. SF > 2) TID
- Irradiation of 2-cm-wide "rings"
- **Pre-/Post irradiation tests:**
  1. **Optical inspection**
  2. **Pull tests along the adhesive**
  3. Electrical conductivity



Z-Shield: Optical Inspection & Pull Tests

1. Optical Inspection





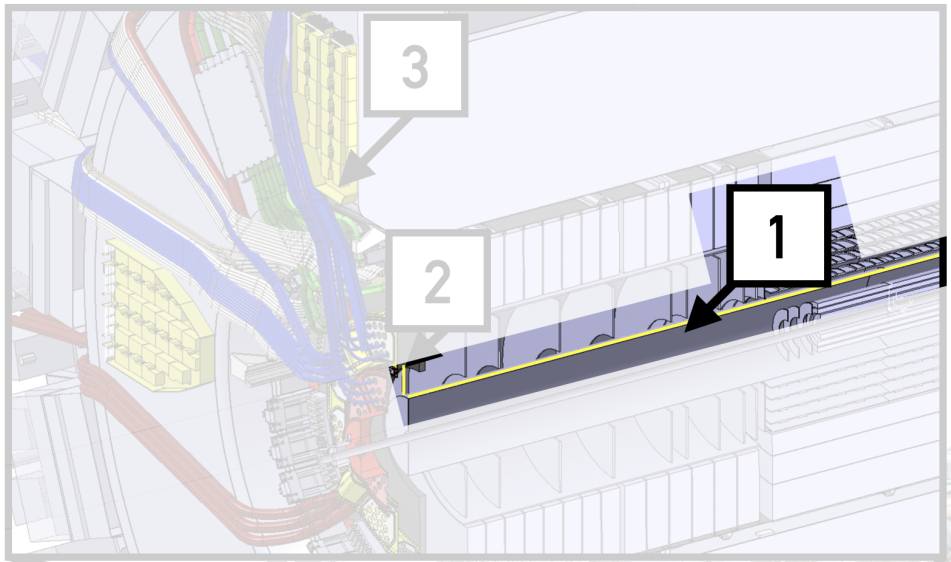
Irradiation caused change of color and "bubbles" on surface.

2. Pull tests with Newtonmeter:

- Before Irrad.: 55 N (after re-gluing: 48 N)
- After Irrad.: 46 N (re-gluing **not possible!**)

Qualification status under discussion.

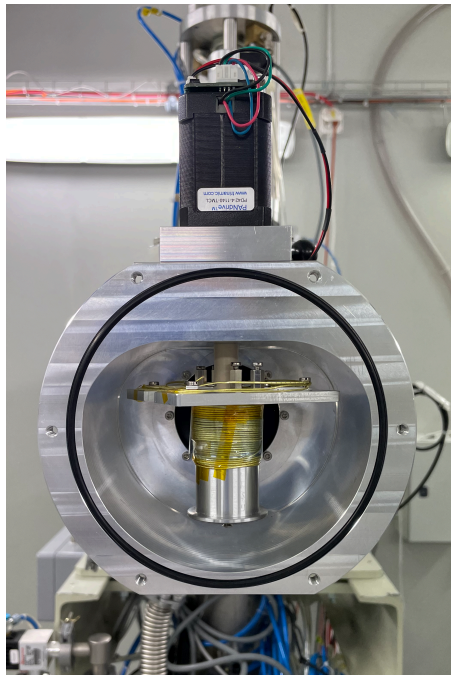
Campaign 3: Twinax Cable



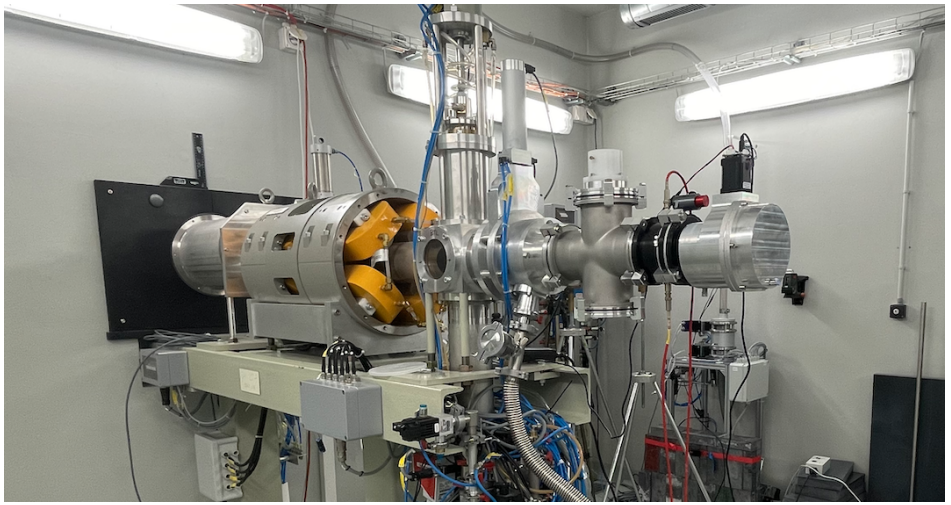
Irradiation Studies: Twinax Cable

- 6 m differential cable for electrical signals coming from the individual silicon modules to the Optosystem

- Irradiation of Twinax cables up to **500 Mrad!**
- Twinax cable mounted on a spool in two layers to maximise irradiated length in minimal time span
- **Pre-/Post- irradiation tests**:
  1. Bit error rate
  2. **Signal loss**

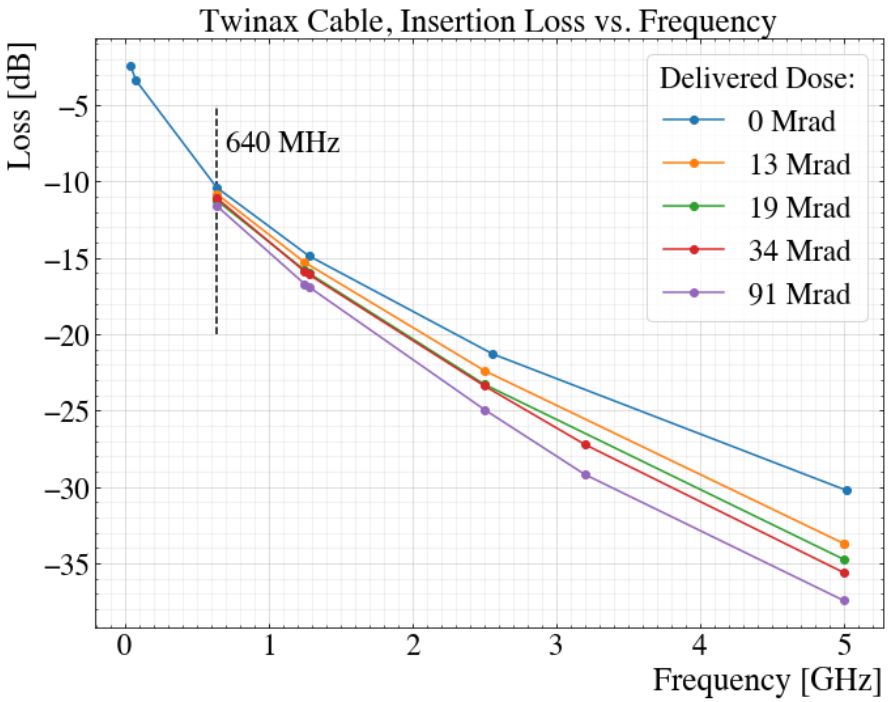


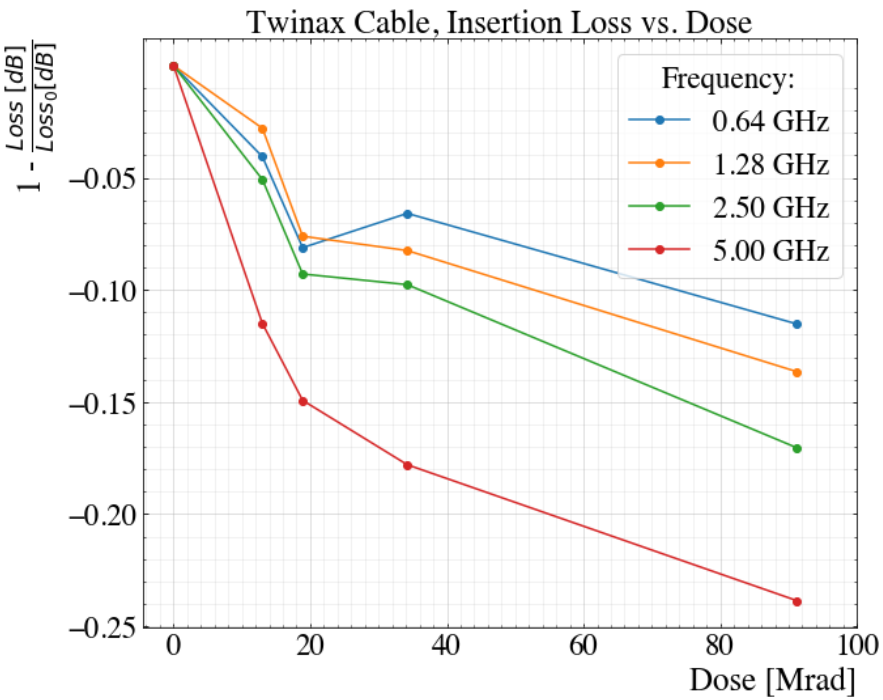
Irradiation setup
for Twinax cable



Irradiation Studies: Twinax Cable

- Preliminary irradiation campaign in 2019 went up until 92 Mrad
- New campaign with two cables is about to start!





Irradiation with highest dose to be delivered → dedicated "cyclotron setup" to test and validate the cable at the irradiation facility

Summary & Outlook

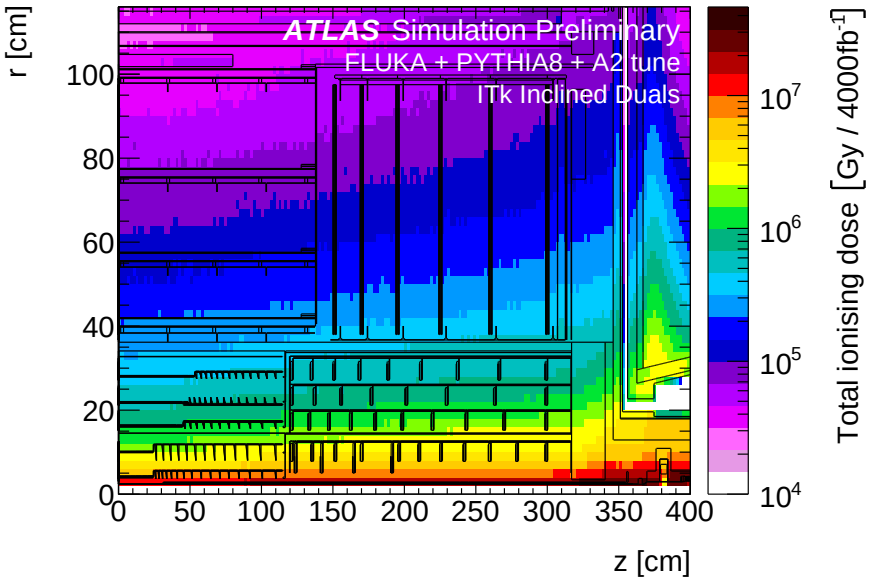
- Recent irradiation campaigns for ATLAS ITk Optosystem show that the tested components satisfy radiation related requirements so far
- Upcoming tests related to ITk Optosystem:
  1. 2 Twinax cables in multiple steps up to 500 Mrad
  2. More components of the Optosystem, as soon as availability allows

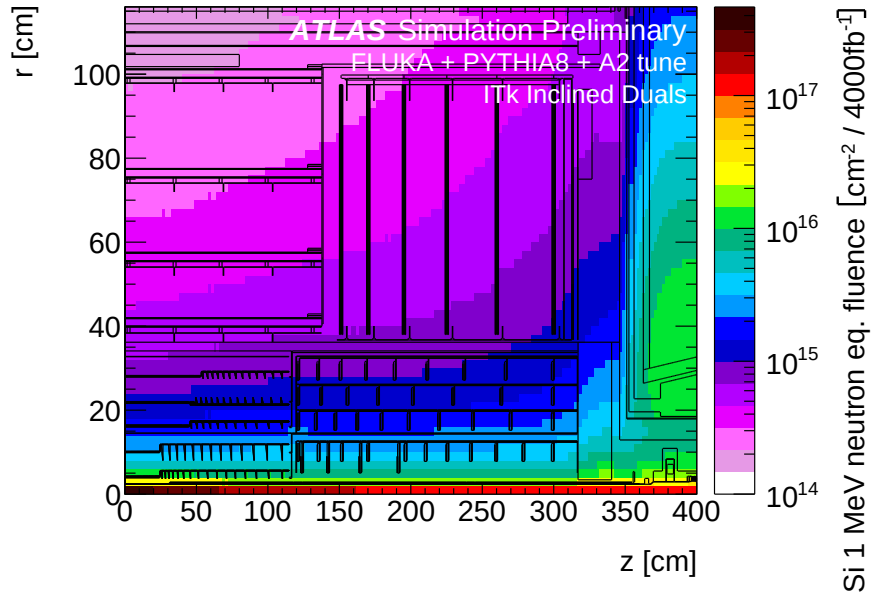
- Bern medical cyclotron can be utilised as a flexible facility for various irradiation campaigns
- Not only for the ATLAS ITk irradiation studies, but also other samples (e.g. CMS silicon sensors, ESA space mission) have been irradiated and more to come!

Thank you for your attention!
Questions?

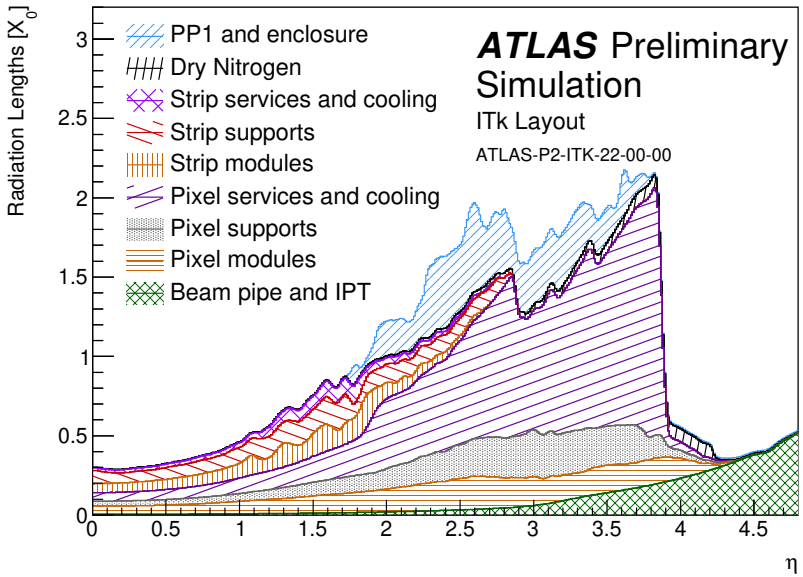
Backup Slides

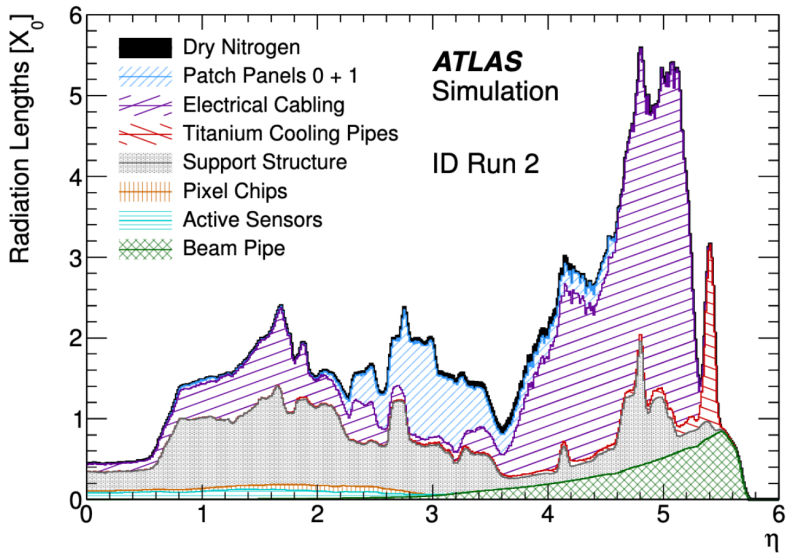
ATLAS ITk Radiation Levels





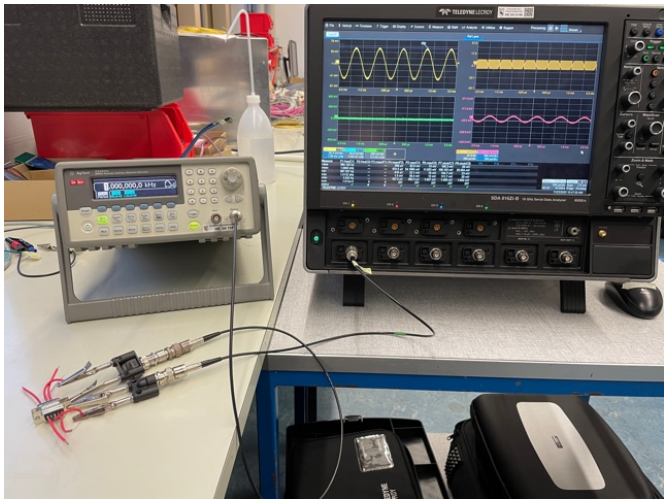
ATLAS ITk vs. ATLAS ID Material Budget

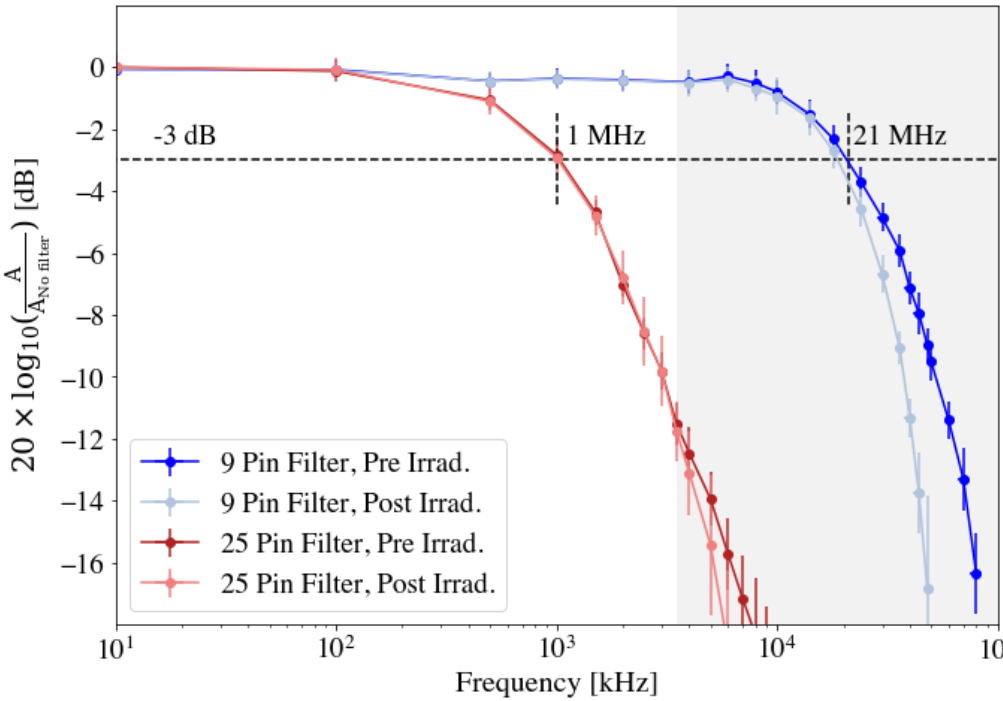




Opto Patch Panel Connectors: Cutoff Frequency

- Cutoff frequency as descriptive property of filter: $f_c = \frac{1}{2\pi RC}$
- Measurement with Agilent 80 MHz Pulse Generator and SDA 816Zi-B 16 GHz Serial Data Analyzer





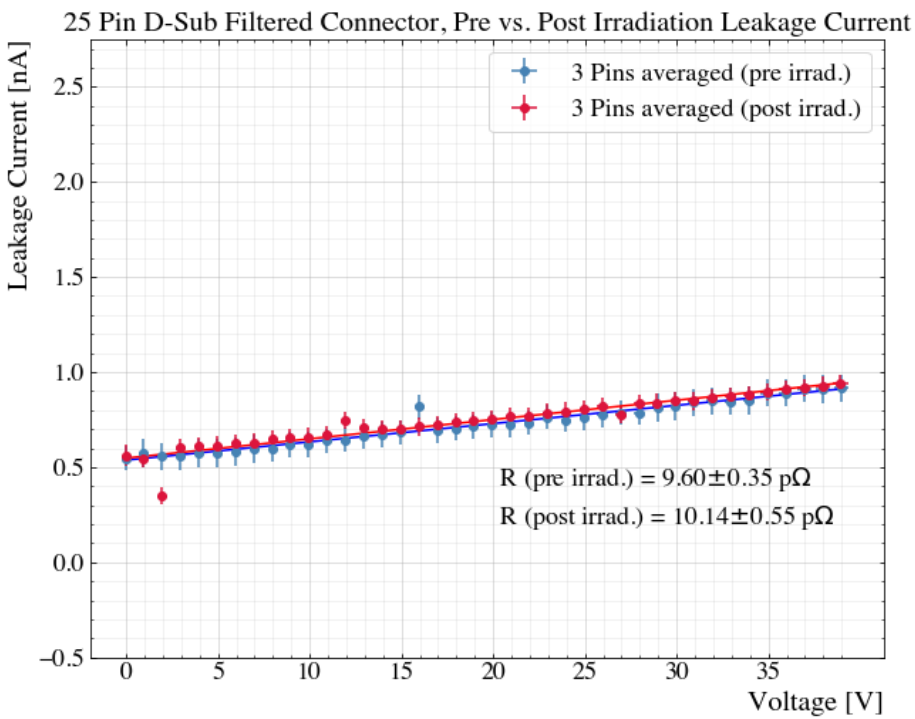
Expected cutoff frequencies:

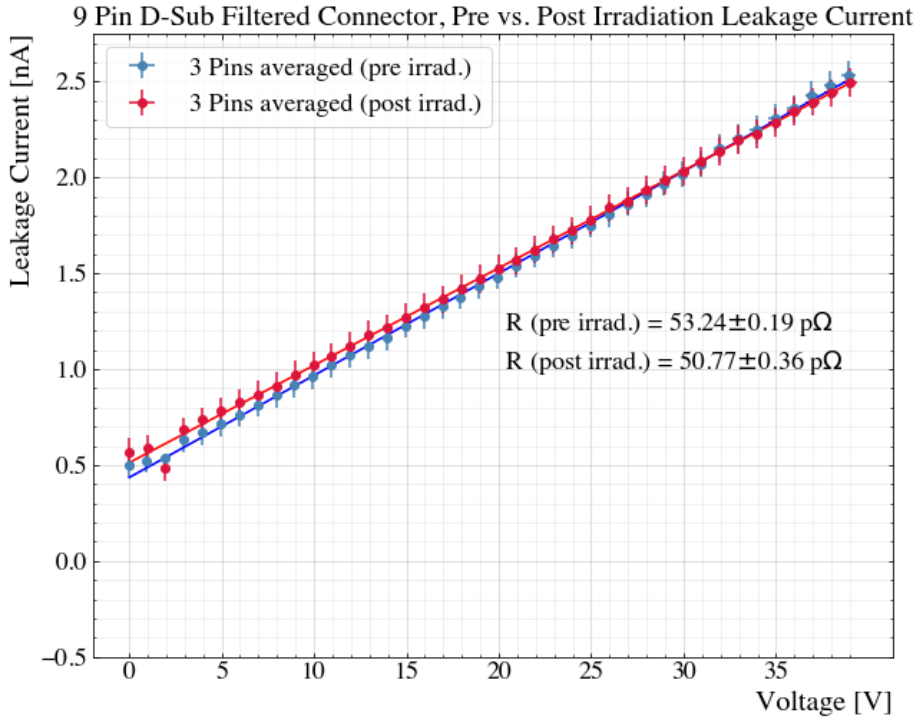
$f_{C,25} \cong 1.02$ MHz

$f_{C,9} \cong 20.96$ MHz

Opto Patch-Panel Connector Results

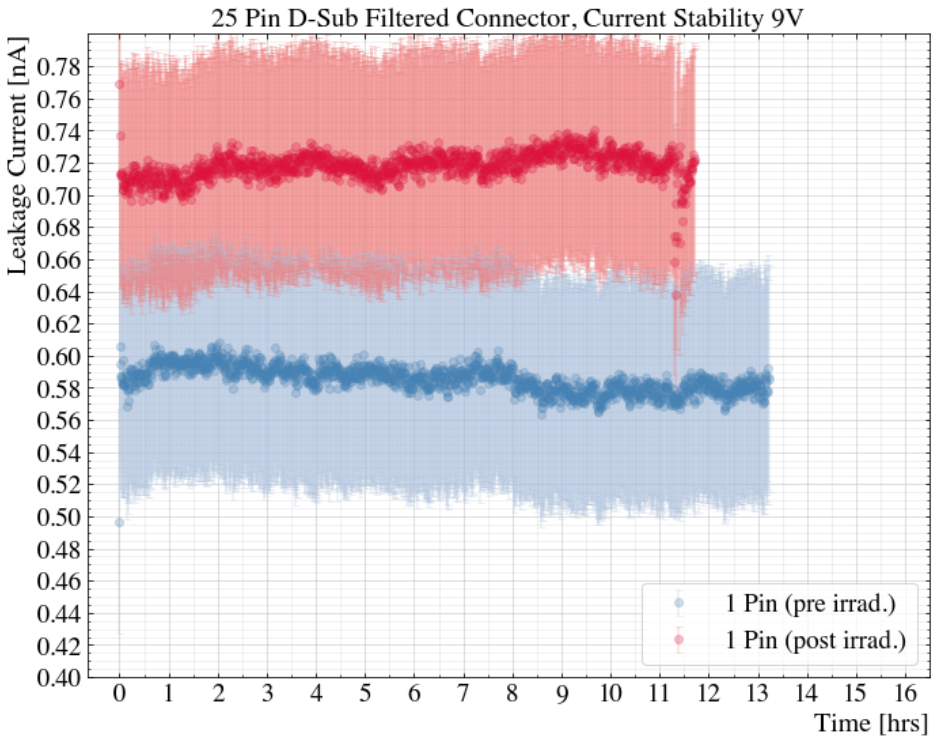
1. IV Leakage Current: 25-pin & 9-pin Connector

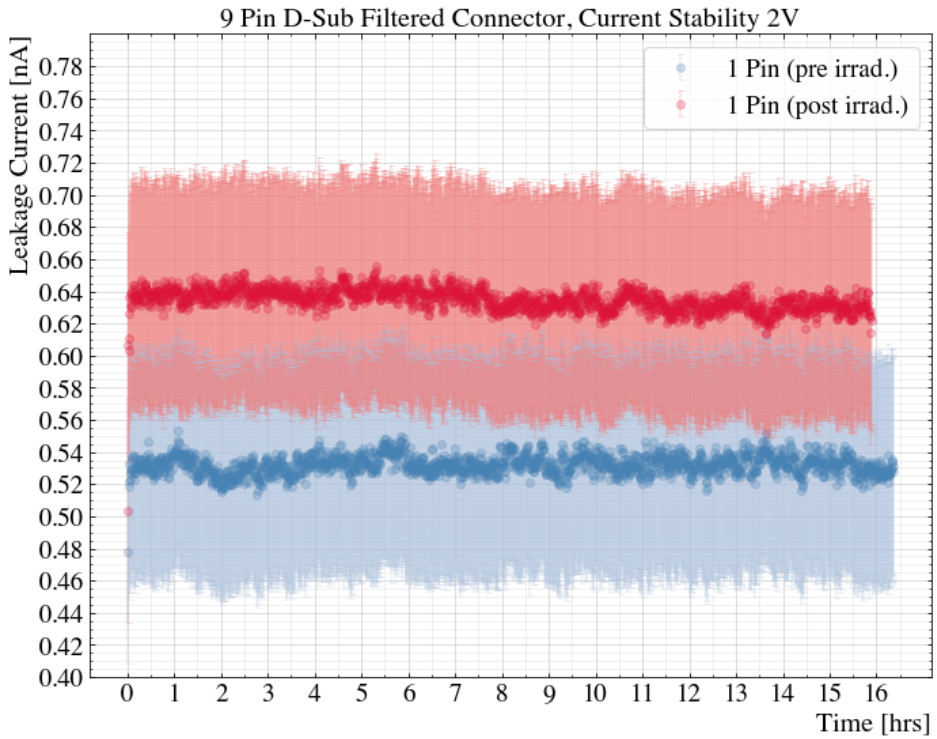




Opto Patch-Panel Connector Results

2. Current Stability: 25-pin & 9-pin Connector





Opto Patch-Panel Connector Results

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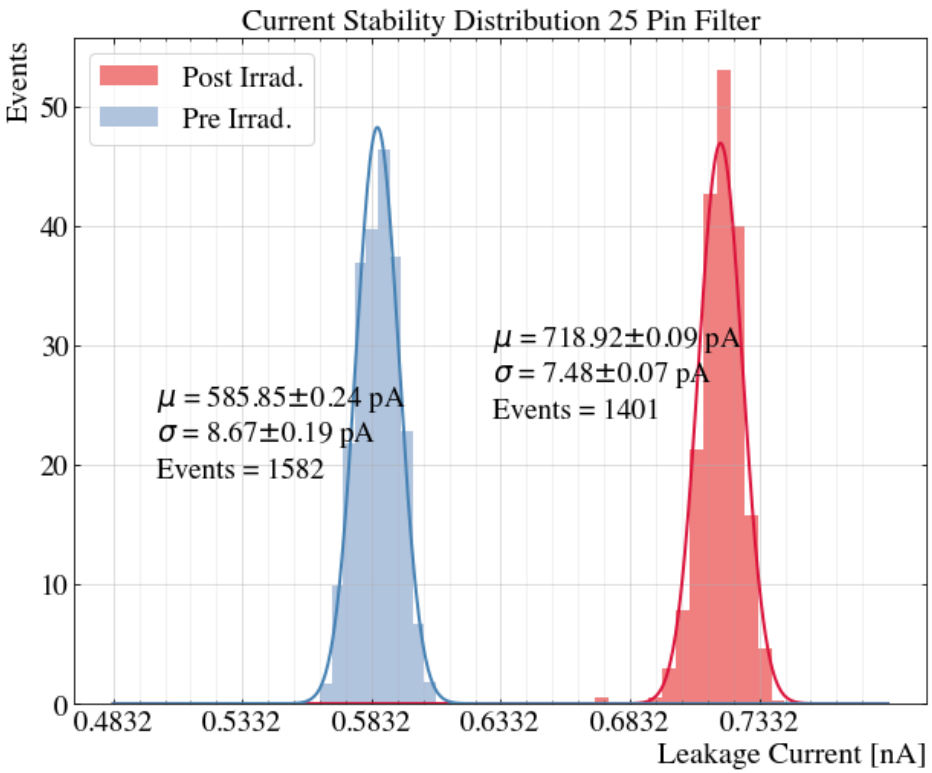
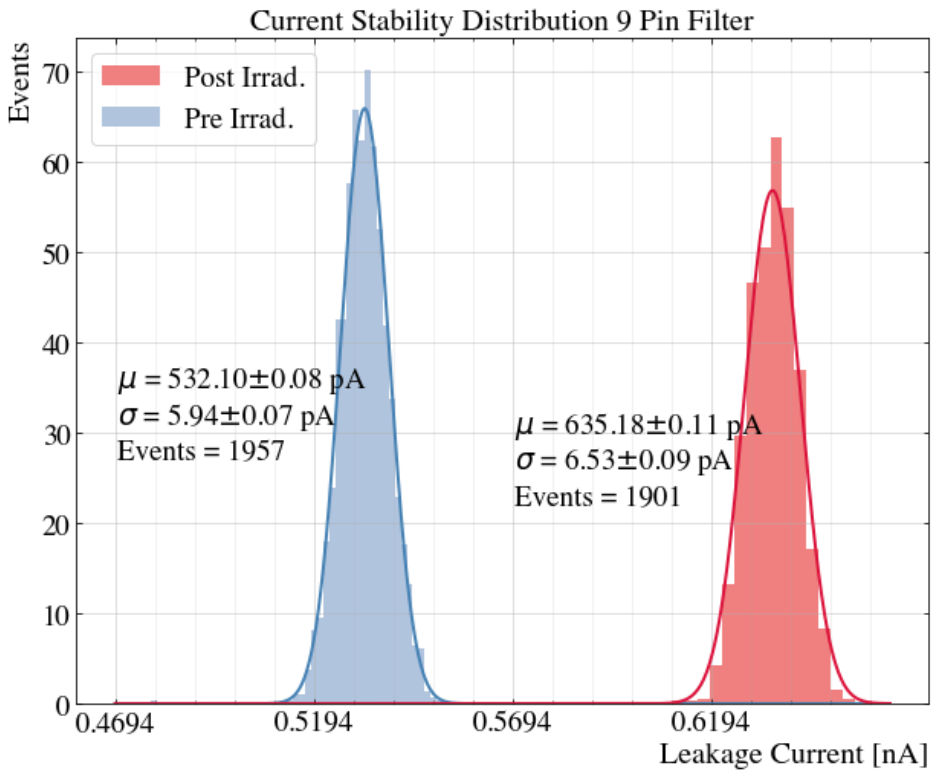
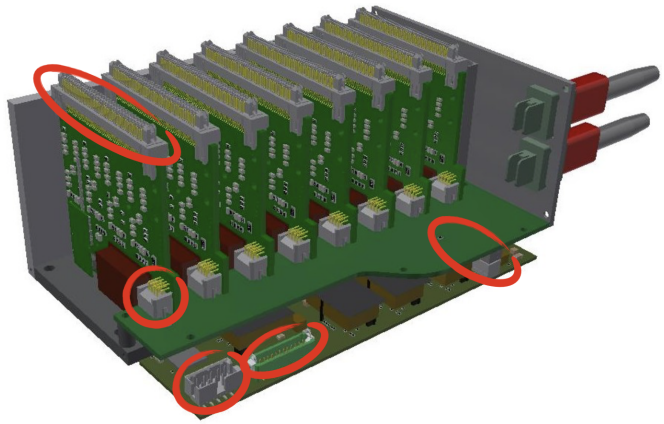
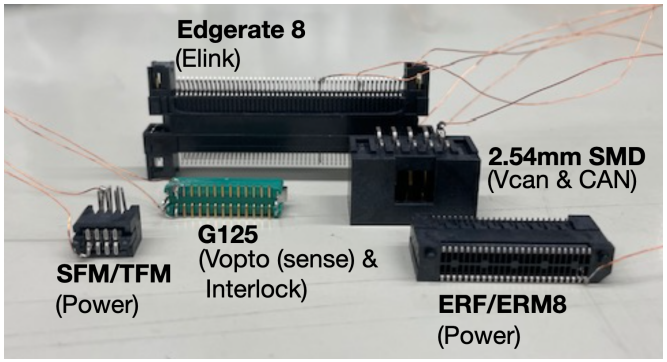




Optobox Connectors

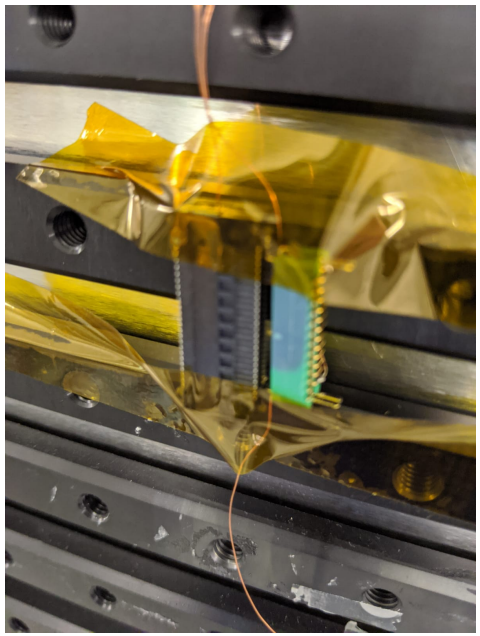


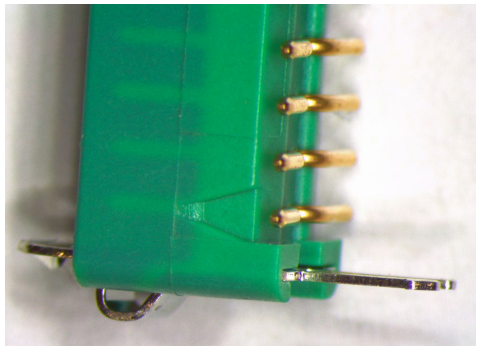


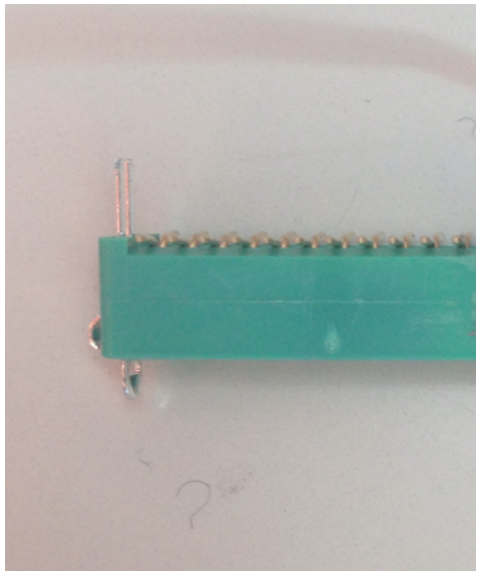
- 5 different connectors located within the Optoboxes: Edgerate 8, SFM/TFM, ERM/ERF 8, G125, 2.54mm SMD

- Irradiation up to **15 Mrad** (incl. SF $>$ 2) TID
- **Pre-/Post irradiation tests:**
  1. Optical Inspection
  2. Resistance of different pins

Optobox Connectors: Optical Inspection

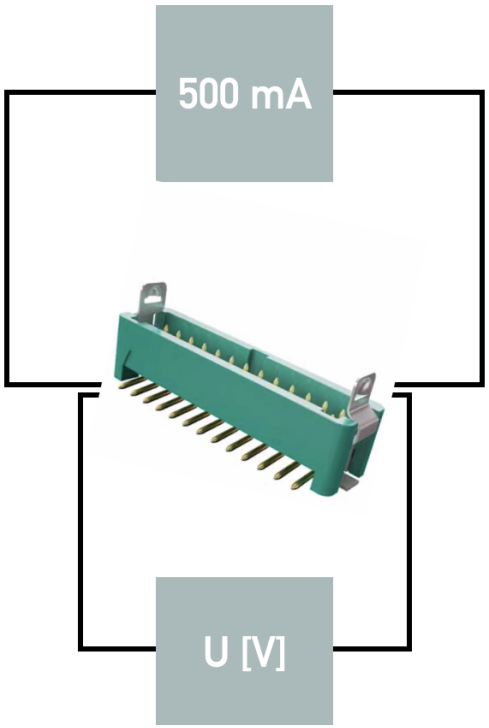




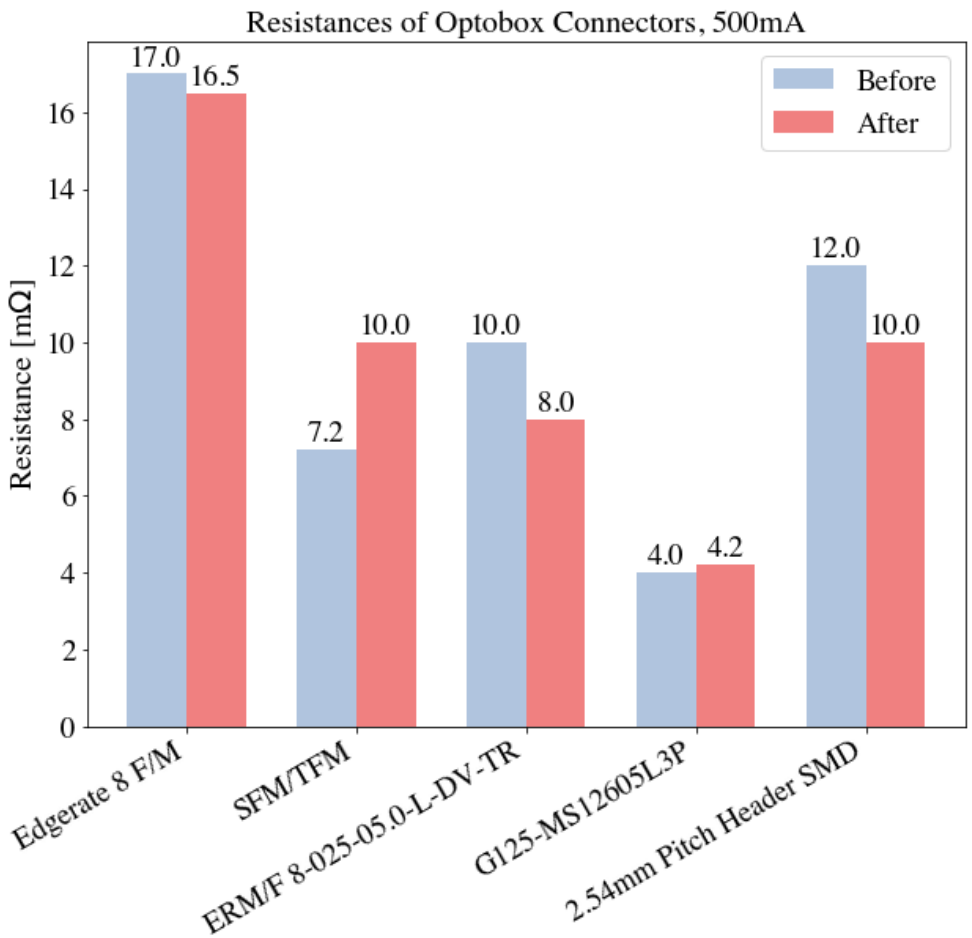


No further surface damages detected (also w. microscope)!

Optoboard Connectors: Resistance



- Apply 500 mA current with Agilent E3649A, measure voltage with Keysight 34461A $6_{1/2}$ Digit Multimeter



Further References

[1] HL-LHC Industry, https://project-hl-lhc-industry.web.cern.ch/content/project-schedule, last called: 04/05/21

[2] ATLAS Upgrade for the HL-LHC: meeting the challenges of a five-foldincrease in collision rate. Peter Vankov. url

[3] Technical Design Report for the ATLAS Inner Tracker Pixel Detector. The ATLAS Colaboration. url

[4] Report on the Physics at the HL-LHCand Perspectives for the HE-LHC. The ATLAS and CMS Collaboration. url

[5] ATLAS Public Results: RadiationSimulationPublicResults. url