Warsaw University of Technology

ISE

EUROPEAN SPALLATION SOURCE

WUT Contributions to RF Infrastructure of ESS Beam Diagnostic Systems

Krzysztof Czuba

On behalf of the WUT and ESS BI Teams

SPAS 2026

Kraków, 21.10.2026

WUT Contributions to European Spallation Source

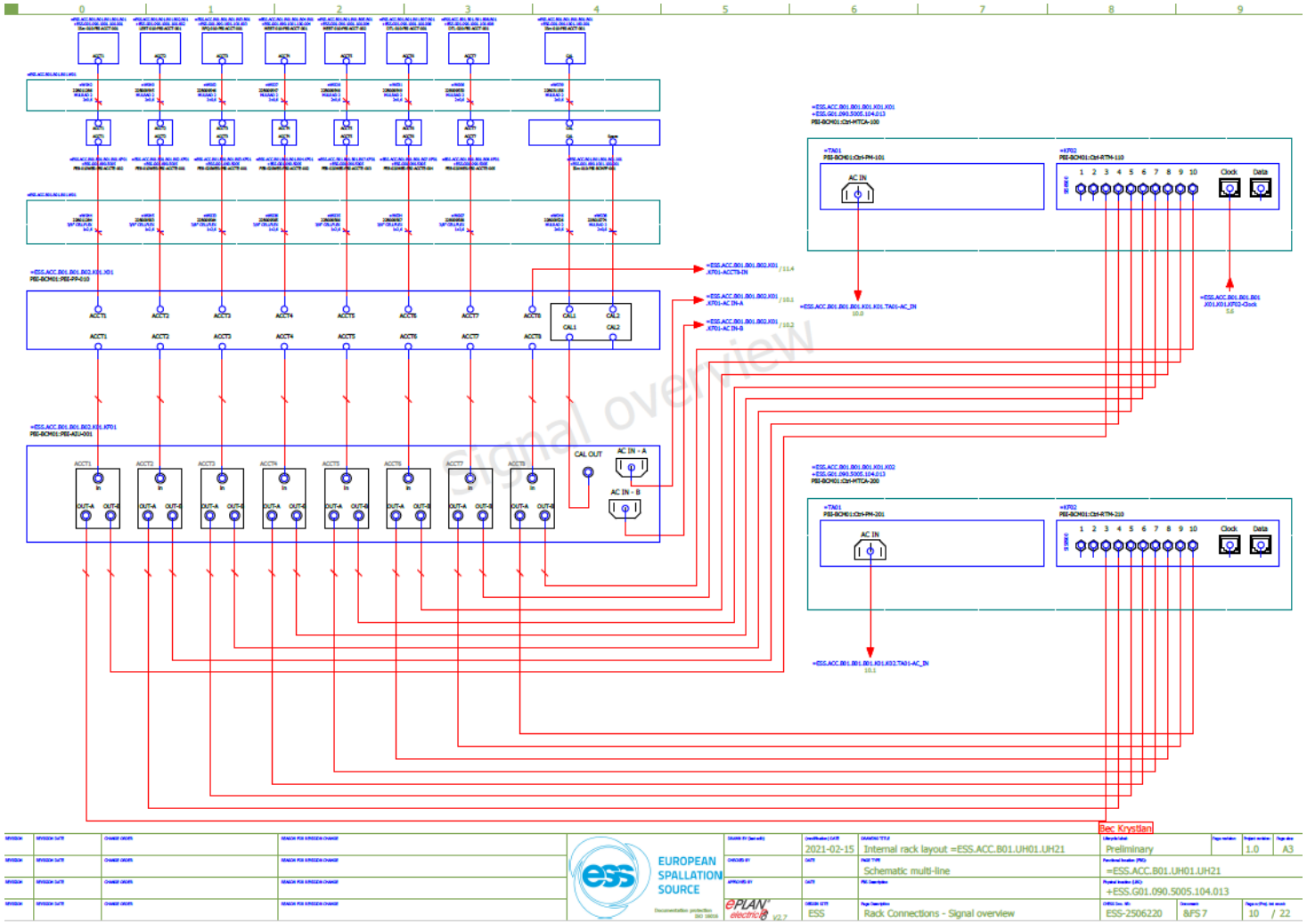
- Phase Reference Line (PRL)[*] - Polish In-Kind
- MTCA. 4 based ESS LLRF control system components[#] (Member of the Polish Electronic Group) - Polish In-Kind
- **RF electronics and cabling design, installation and tests for the Beam Diagnostics** – In-Kind completed, direct collaboration running



[*]Czuba Krzysztof et. al.: *Concept of the Phase Reference Line for the European Spallation Source*, MIKON 2018, Poznań, Poland ISBN 978-83-949421-0-6, ss. 512-514.

[#]J. Szewiński et al., "*Contribution to the ESS LLRF System by Polish Electronic Group*", IPAC2017, Cpenhagen, Denmark.

Beam Instrumentation Rack Design



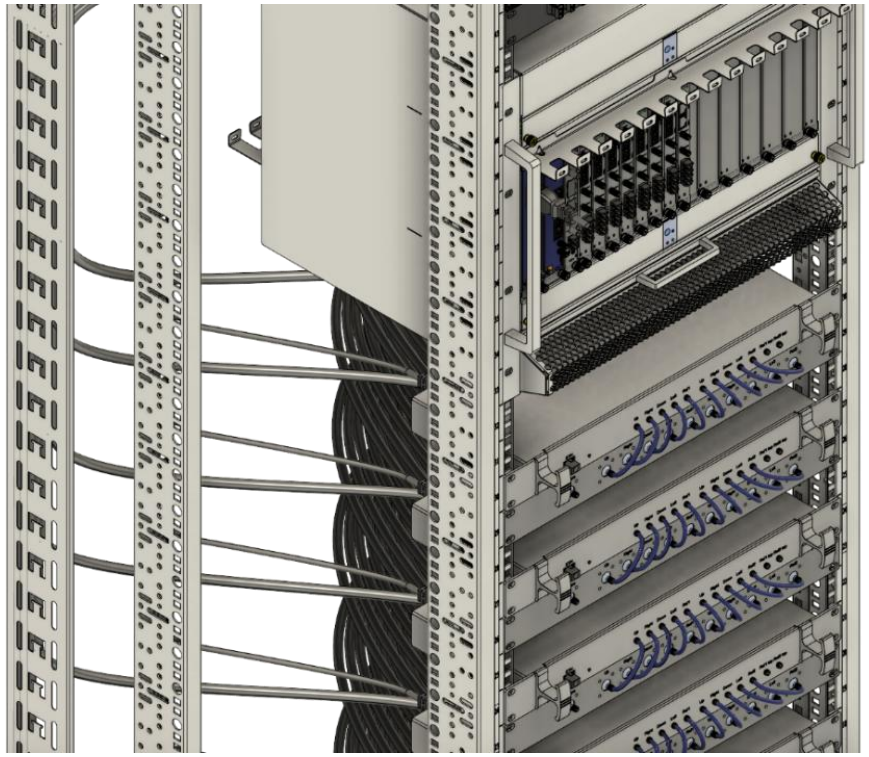
Example of rack schematic: BPM systems

Since 2017 designed over 50:

- rack schematics
- list of cables
- BOMs
- 3D rack models

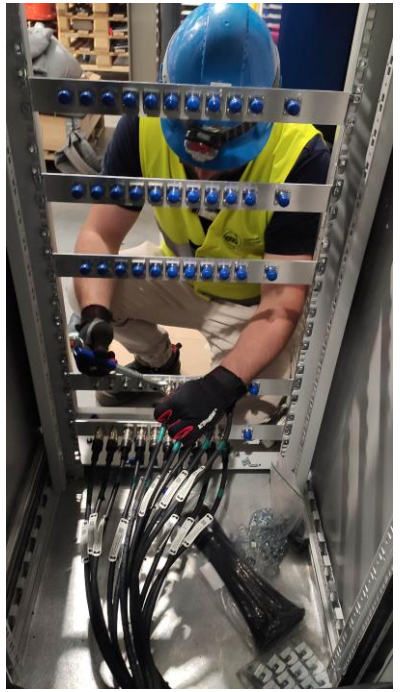
3D Rack Design and Installation

Following the design WUT team prepared and installed almost all BI electronics in racks including cable preparation, length matching and connection testing



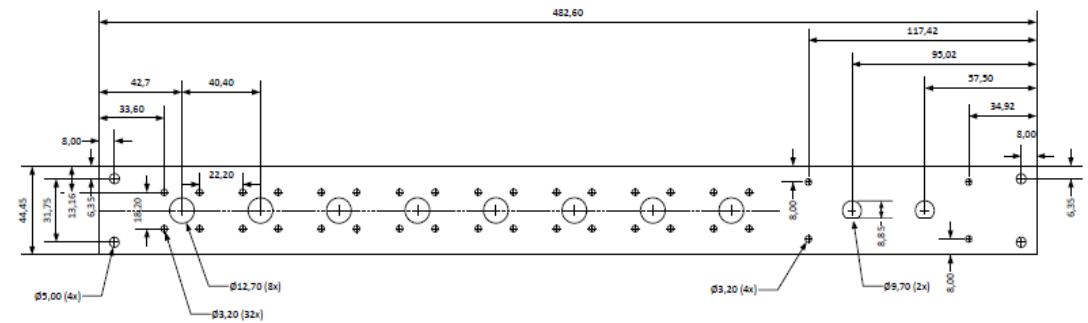


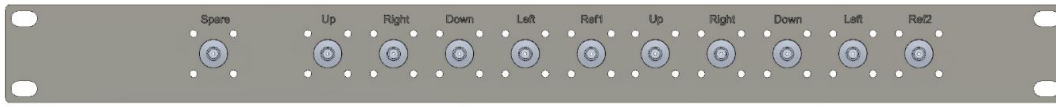




Patch Panel Design and Assembly

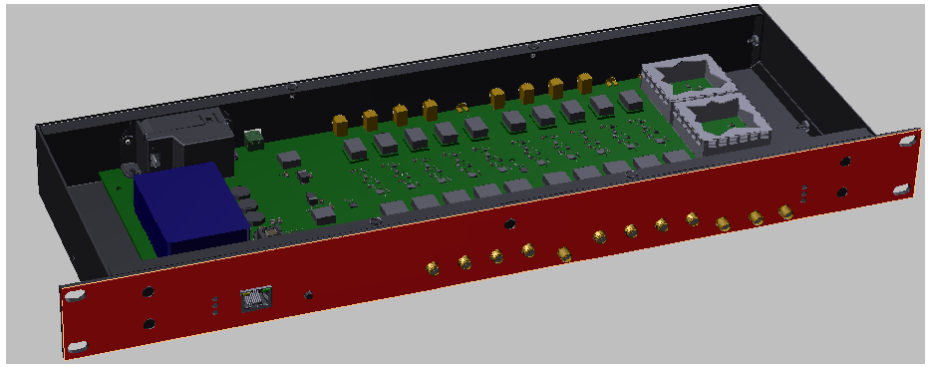
Designed, produced and assembled tens of different patch panels





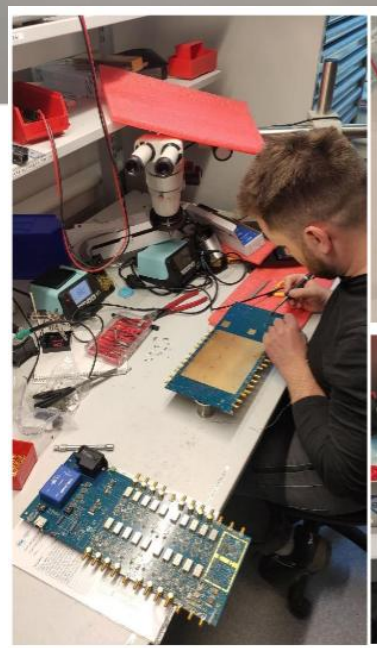


Design, Assembly and Testing of Modules: BPM Frontend











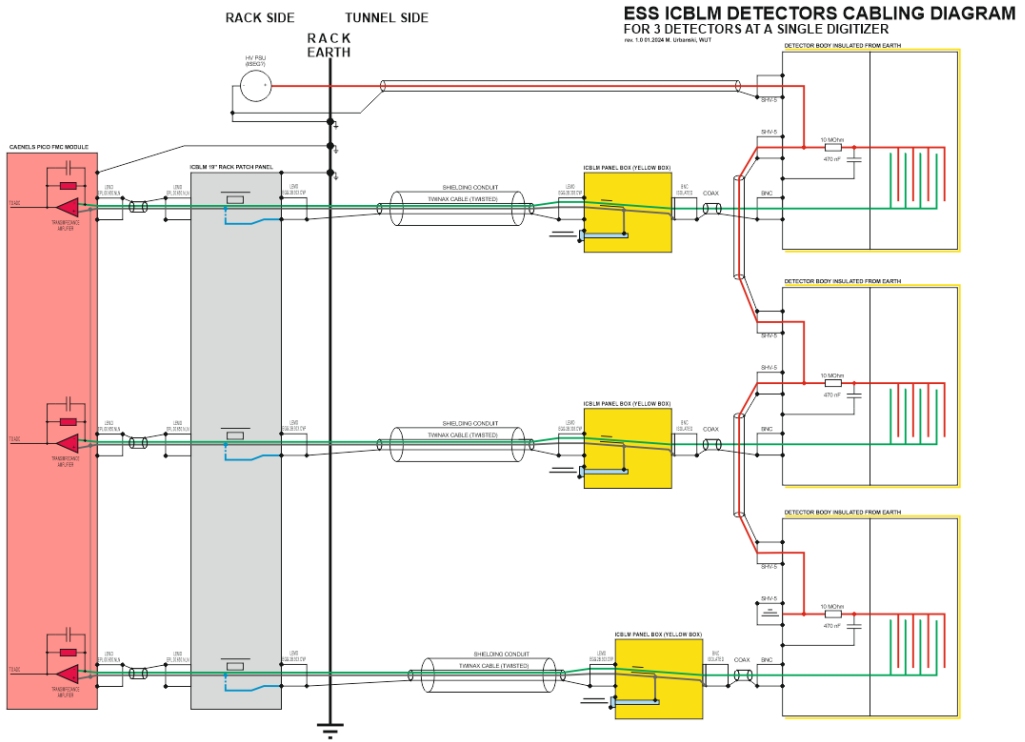


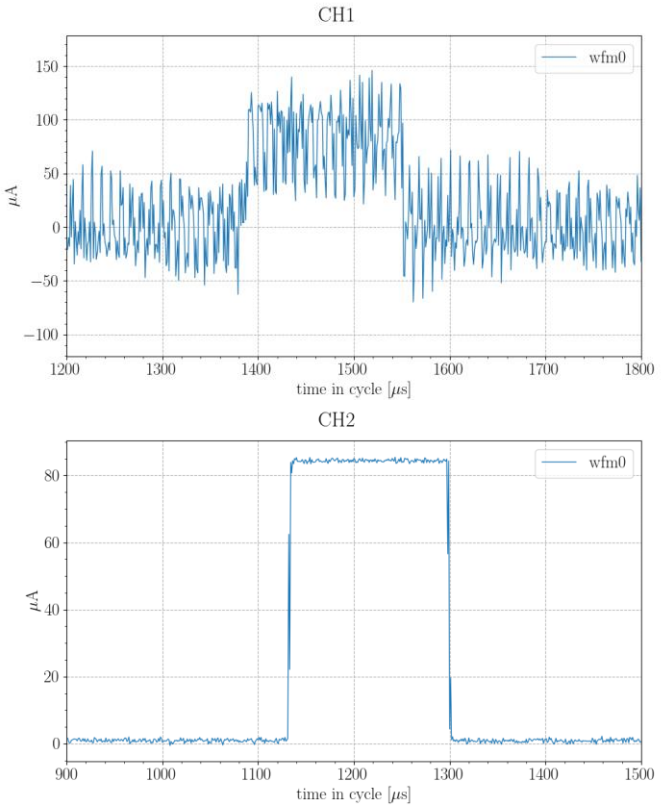
ICBLM Patch Boxes

Produced, installed and connected 312 ICBLM patch boxes

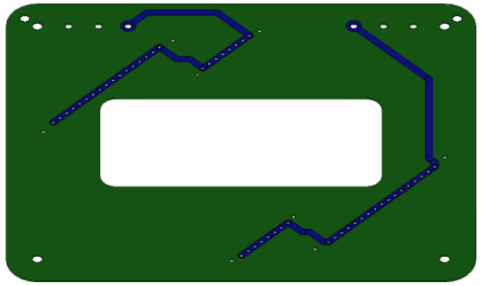
Mitigated EMI problems related to cabling



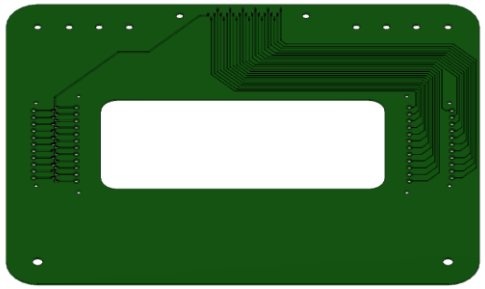




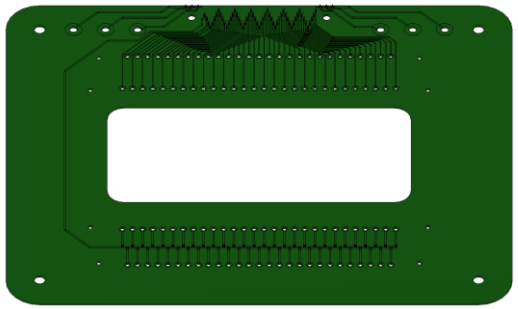
Proton Beam Instrumentation Plug (PBIP) Grid



Bias board



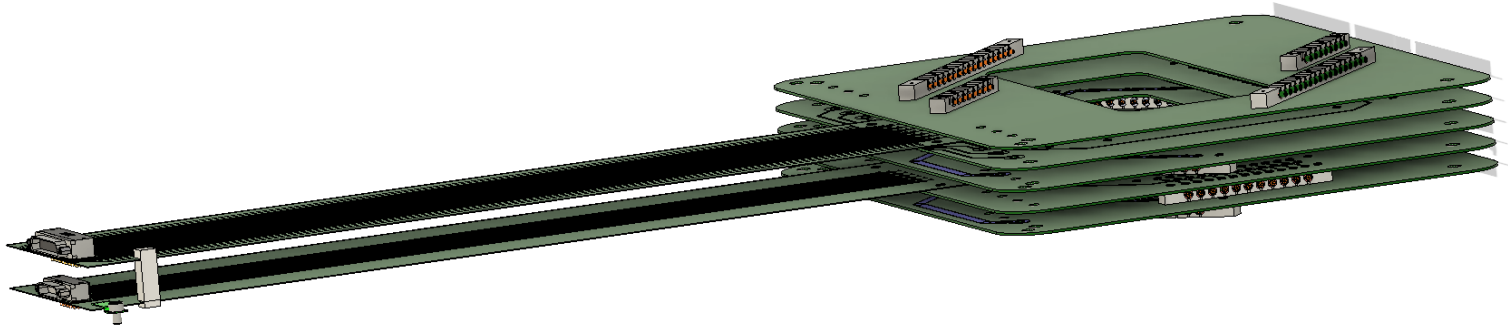
Vertical grid board

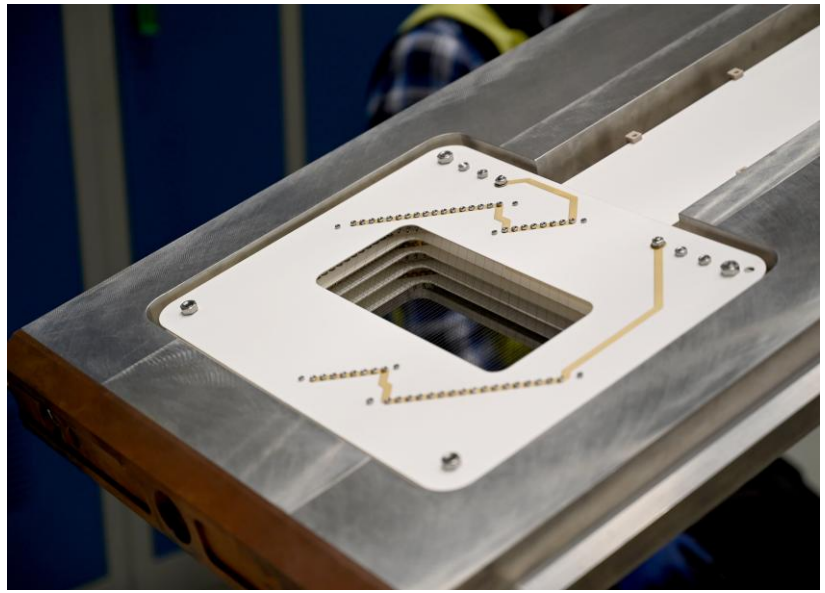


Horizontal grid board



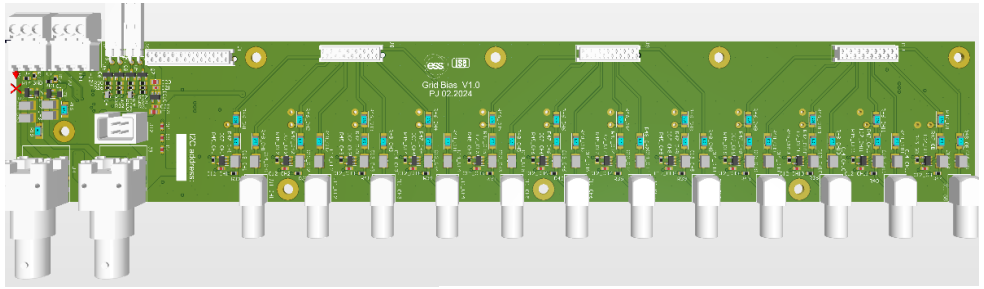
Connector boards



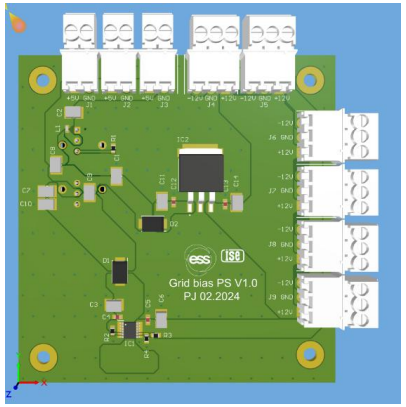


https://ess.eu/article/2025/10/10/all-hardware-ess-target-now-place

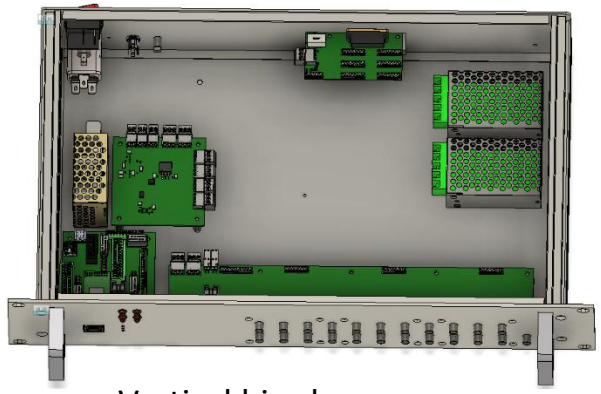
PBIP Grid Frontend Modules



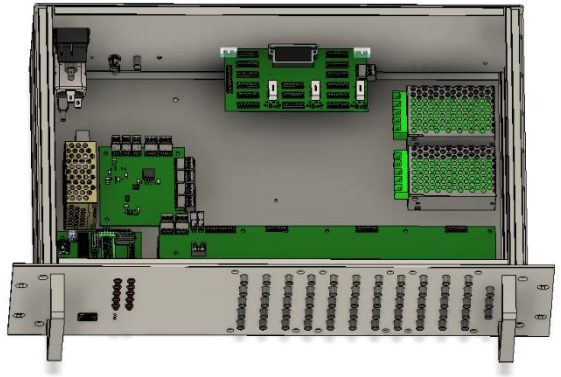
Grid polarization boar



Power distribution board

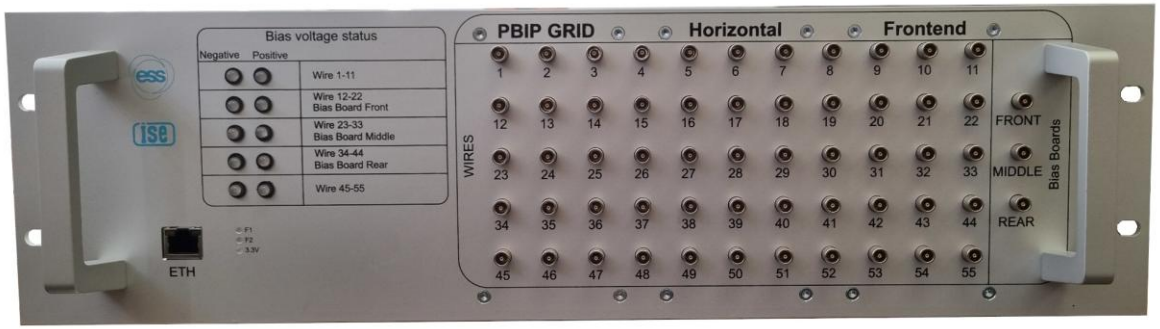


Vertical bias box



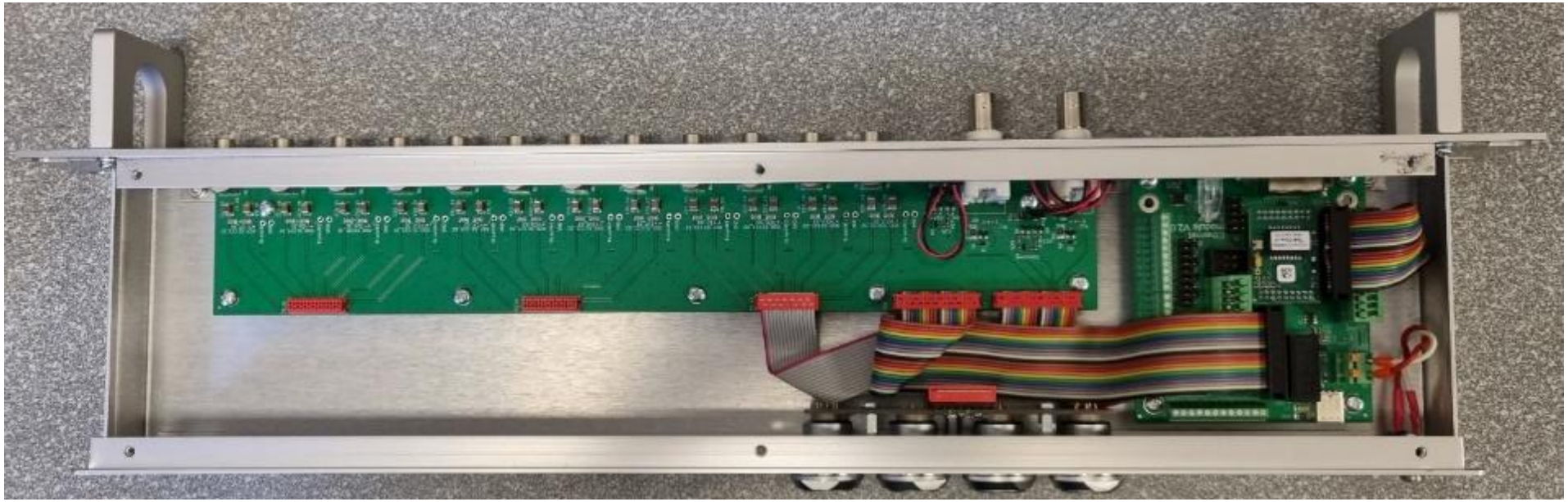
Horizontal bias box





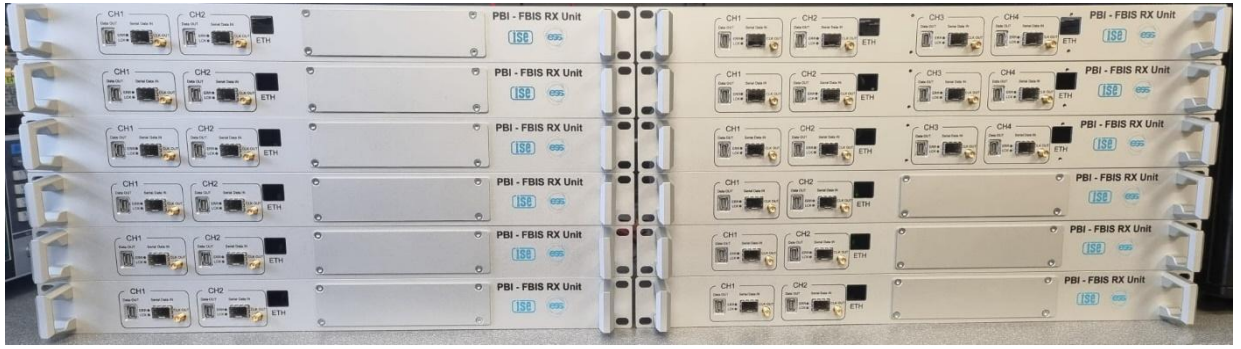
Aperture Monitor (APTM) Interface Modules





Fast Beam Interlock System (FBIS)

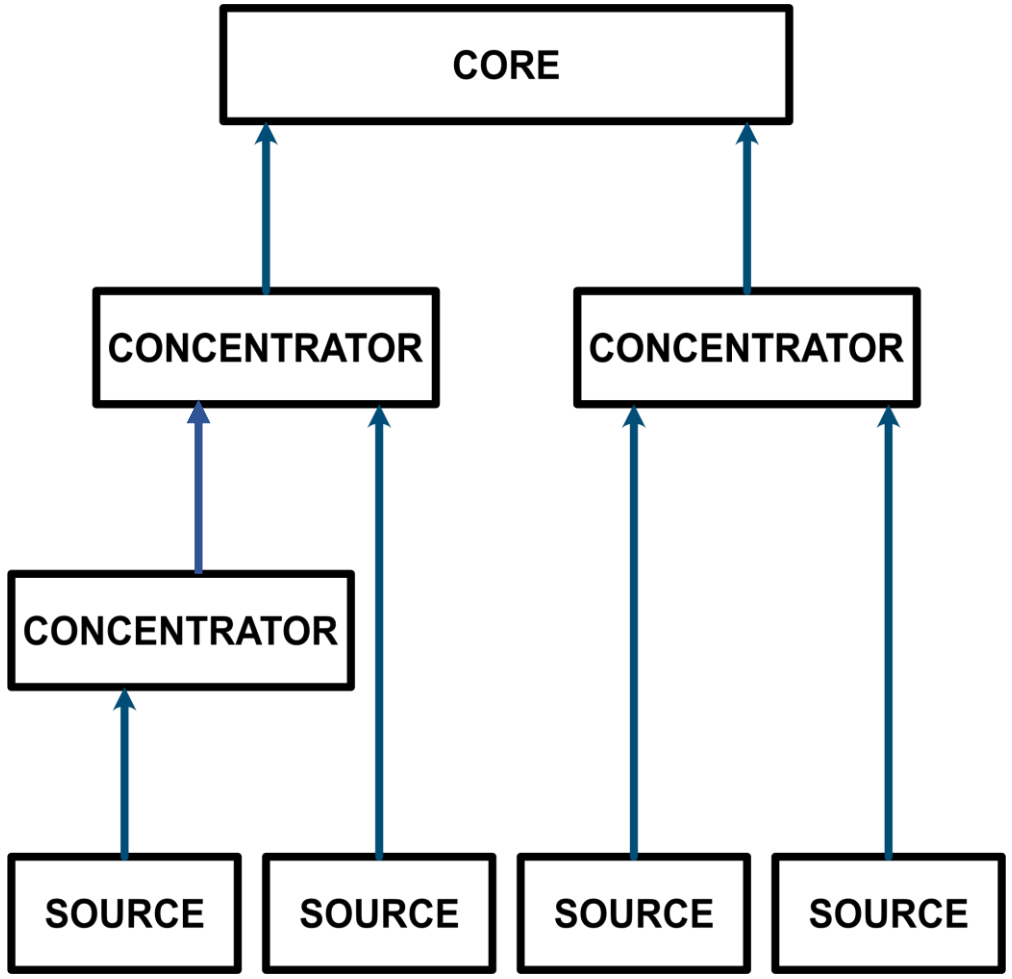






Minimum-Latency Optical Data Acquisition Link (MODAL)

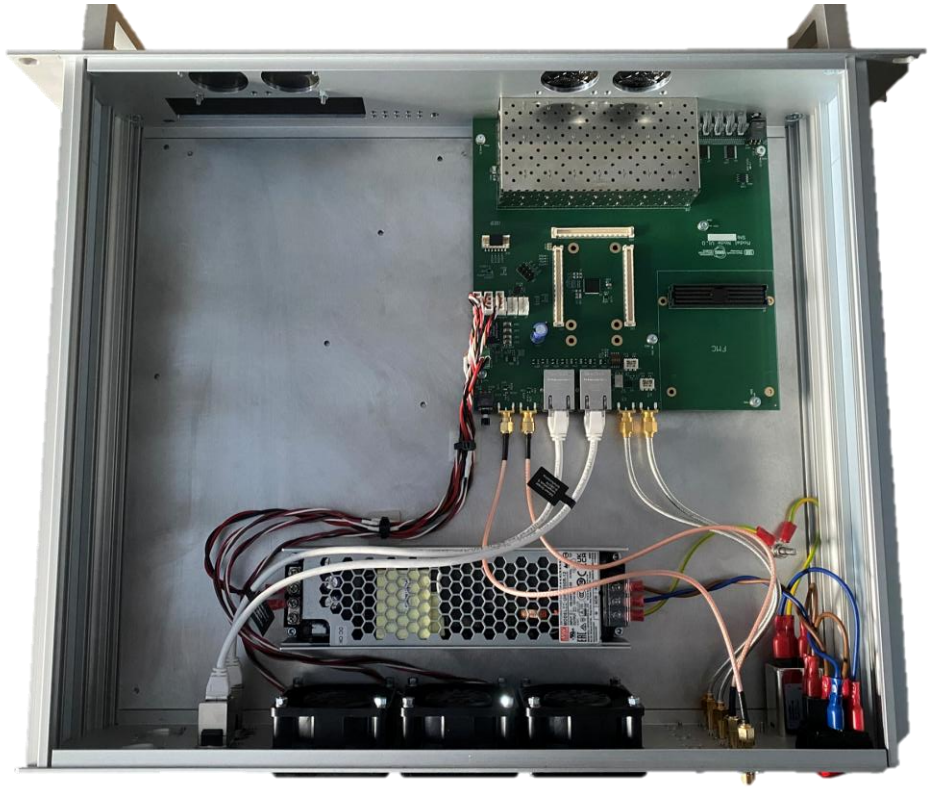
- Designed to collect data from all BI Systems
- **Tree architecture**, where data from local subsystems is transmitted to a central processing unit
- **Enables synchronized analysis of multiple systems at once**
- Advanced ML/AI-based tools can then support diagnostics, fault detection, and accelerator performance optimization.

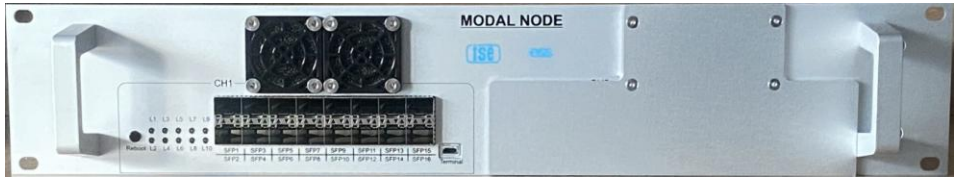


"The project is co-financed by the Polish Ministry of Education and Science under the program entitled 'Co-financed International Projects'."

MODAL Hardware - Node

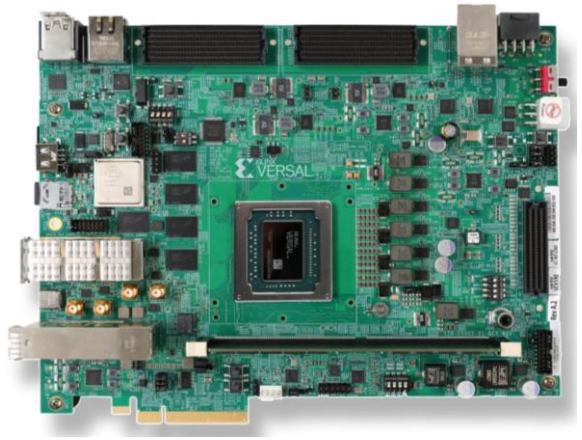
- The MODAL Node gathers data from BI subsystems
- Based on the Enclustra XU8+ module with the AMD Zynq UltraScale+ SoC
- The system includes:
  - 16 Multi-Gigabit Transceivers (MGTs) for uplink and downlink communication, **12.5 Gbps each**
  - 2 Gigabit Ethernet ports for configuration and diagnostics
  - FMC connectors for future upgrades
  - Internal clock distribution with external clock I/O and synchronization I/O
- Two MODAL Nodes can be integrated into a single enclosure

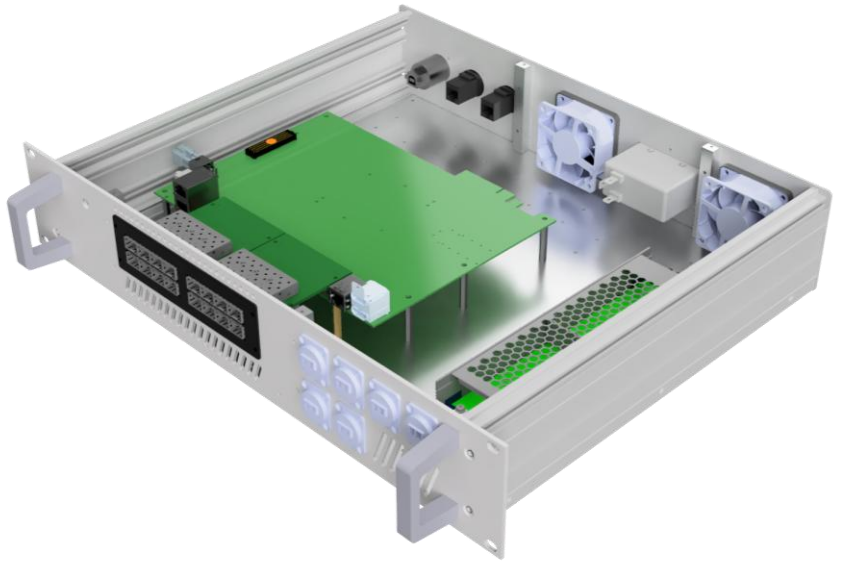




MODAL Hardware - Core

- The MODAL Core is responsible for gathering and processing data from all connected systems.
- Based on the Xilinx VCK190 board featuring the Versal AI Core SoC for advanced processing capabilities.
- Includes 30 Multi-Gigabit Transceivers (MGTs) for high-speed communication with MODAL Nodes:
  - 2 MGTs through SFP28 connectors
  - 4 MGTs through QSFP connectors
  - 24 MGTs (2 x 12) through FMC+, with plans to use an FMC+ to QSFP mezzanine card

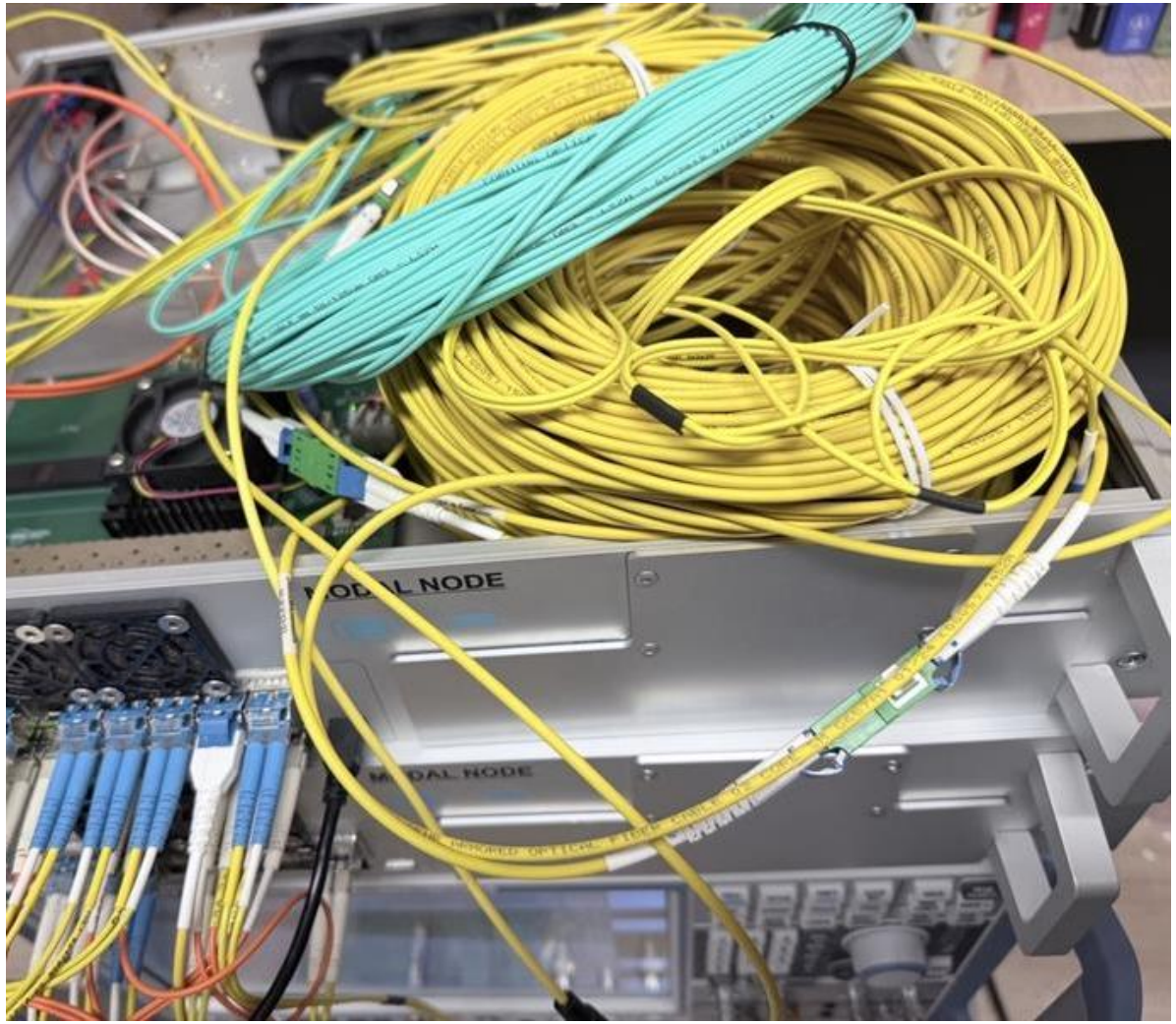




Possible Applications

- Machine learning models for real-time diagnostics, anomaly detection, and prediction to support machine protection systems
- Differential current measurements between Beam Current Monitors (BCMs), Faraday Cups, and related sensors for improved beam diagnostics
- Correlation of beam loss and beam position data for better understanding of accelerator behavior and fault detection
- Centralized analysis of multiple Beam Instrumentation systems to improve performance optimization and operational reliability

The system can also support new accelerator applications, and we are open to implement new ideas



Summary

- Very fruitful collaboration ~10 years now
- Designed dozens of system
- Delivered and tested hundreds of modules
- Installed most of the BI electronic infrastructure in the Klystron Gallery and the Tunnel

Thank you for attention!

Thanks to all contributors to the system design and installations!

Slava Grishin, Johan Norin, Cyrille Thomas, Edvard Bergman, Rafael Baron, Tom Shea, Hooman Hassanzadegan, Krystian Bęc, Łukasz Czuba, Paweł Jatczak, Maciej Grzegrzółka, Maciej Urbański