Data Acquisition System for the PENeLOPE Experiment using the Unified Communication Framework

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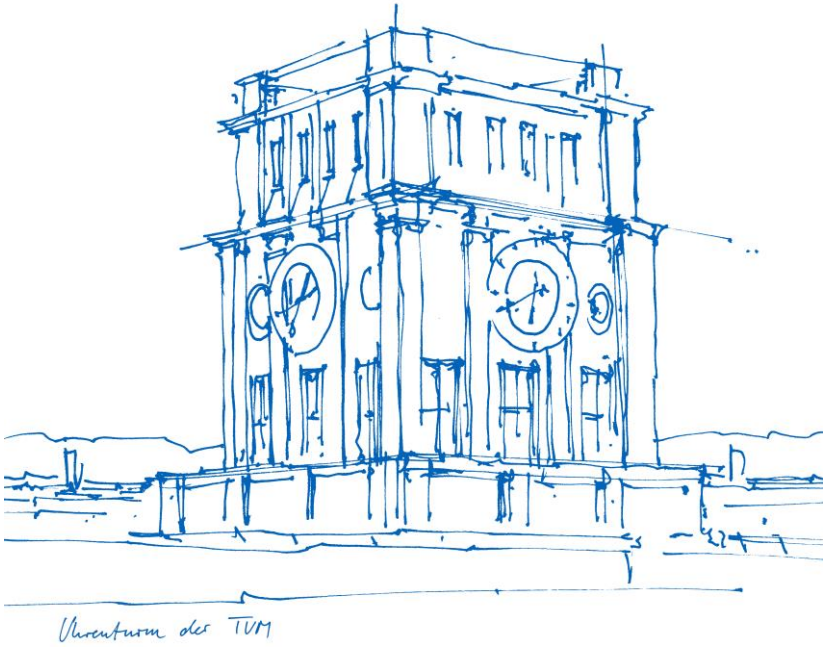
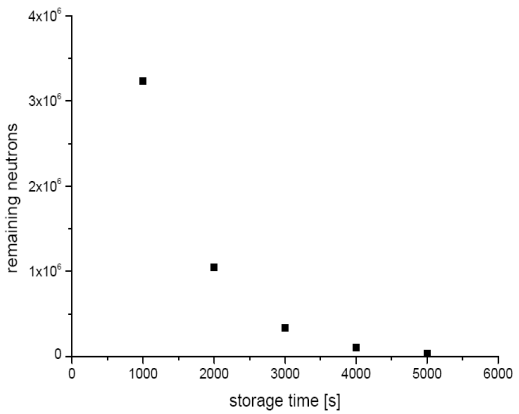
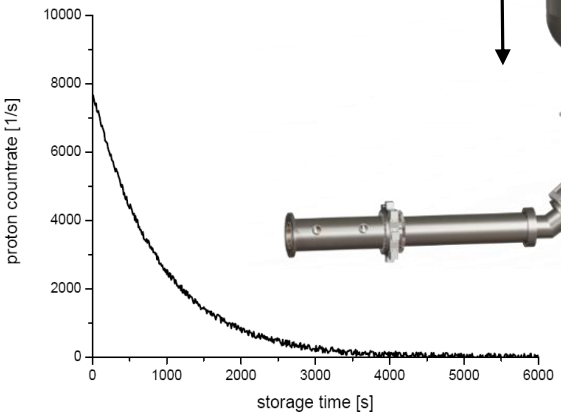
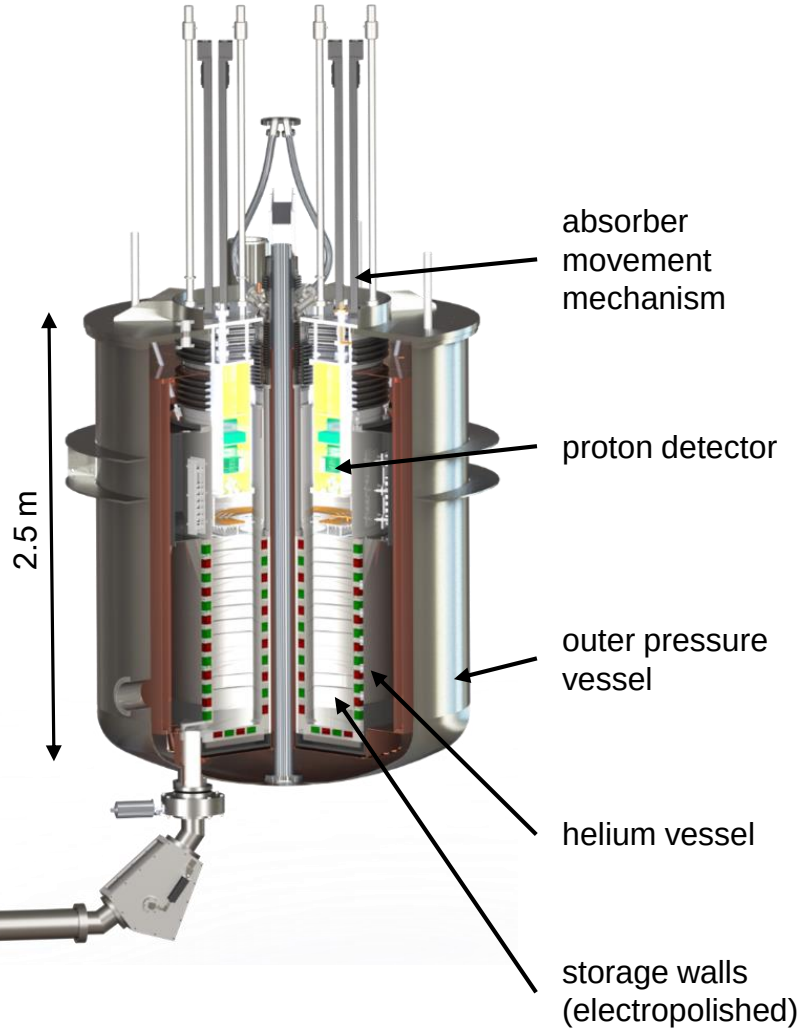


PENeLOPE

- **P**recision **E**xperiment on **Ne**utron **L**ifetime **O**perating with **P**roton **E**xtraction
- Will be located at the Forschungs-Neutronenquelle Heinz Maier-Leibnitz (FRM II)
- Magneto-gravitational trap for ultra-cold neutrons
- Aiming for a precision of ± 0.1 s
- Measuring protons and neutrons

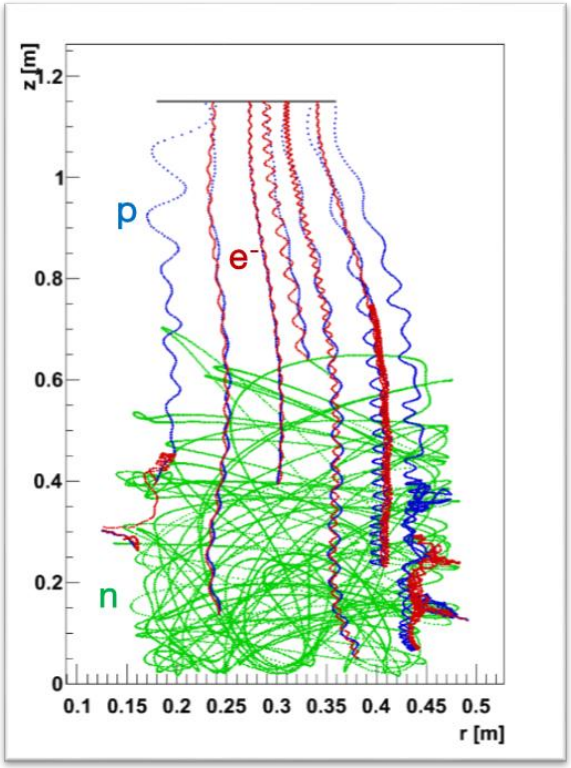






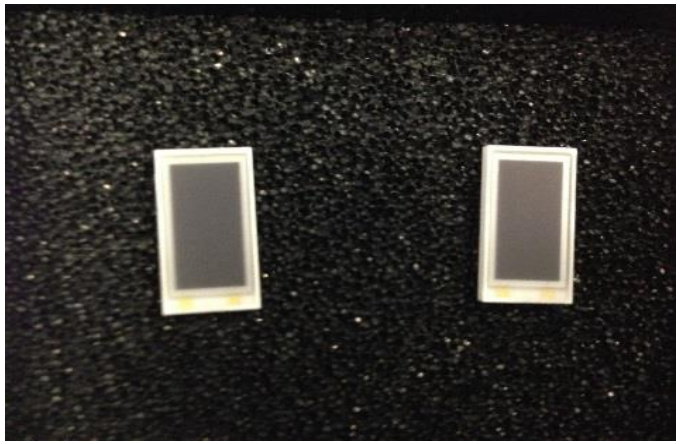
PENeLOPE - Proton Detector Requirements

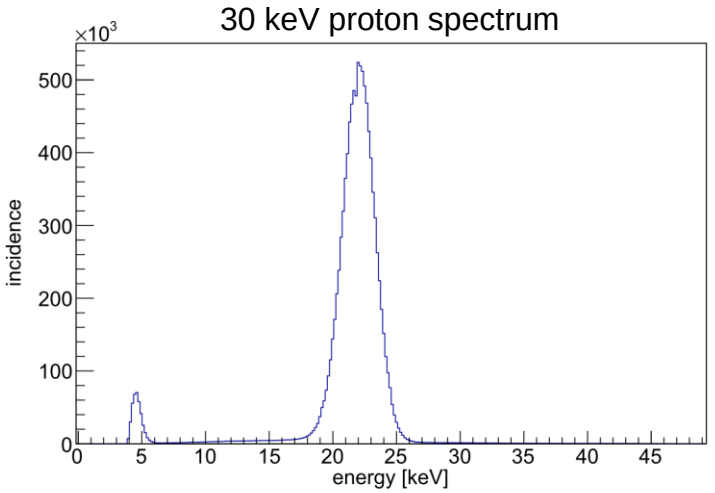
- Protons are guided via magnetic and accelerated by electrical field
- Complete detector and electronics on -30 kV
- Detector at 77 K
- Electronics at 300 K
- Active area of 0.23 m^2
- Peak event rate including margin:
  130.000 events/s + bg ≈ data rate: 500 Mbit/s
- Background is < 1/Ch/s



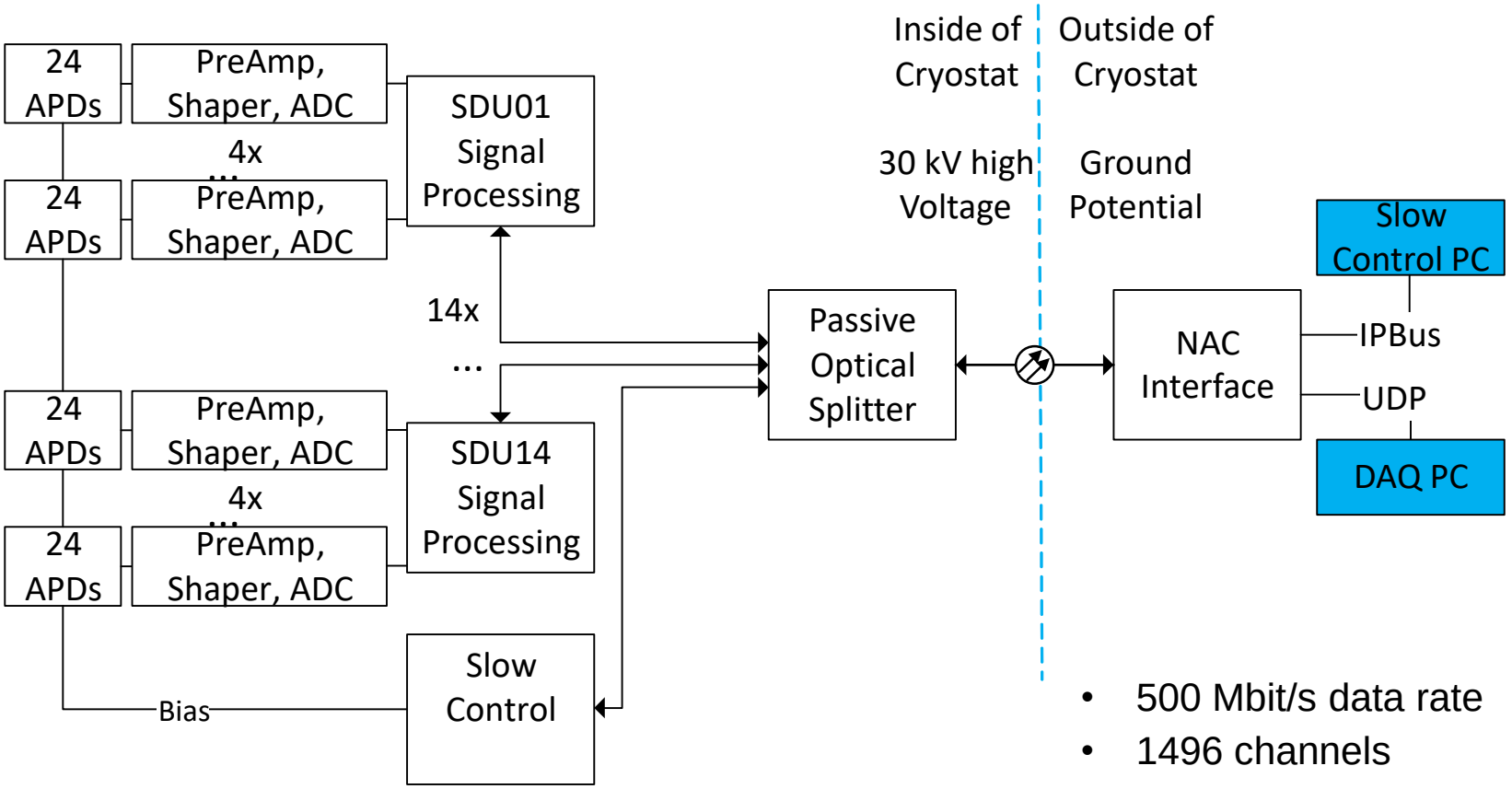
PENeLOPE - Hamamatsu S11048 APD

- 6.8x14 mm^2 active area
- 18x9 mm^2 size
- 4.4 %/V gain sensitivity to voltage at a gain of 100
- Operational voltage of 365 V to 440 V
- No epoxy window since low energy protons would be absorbed
- Commissioning tests with samples done
- Beam test with final detector mid of 2017



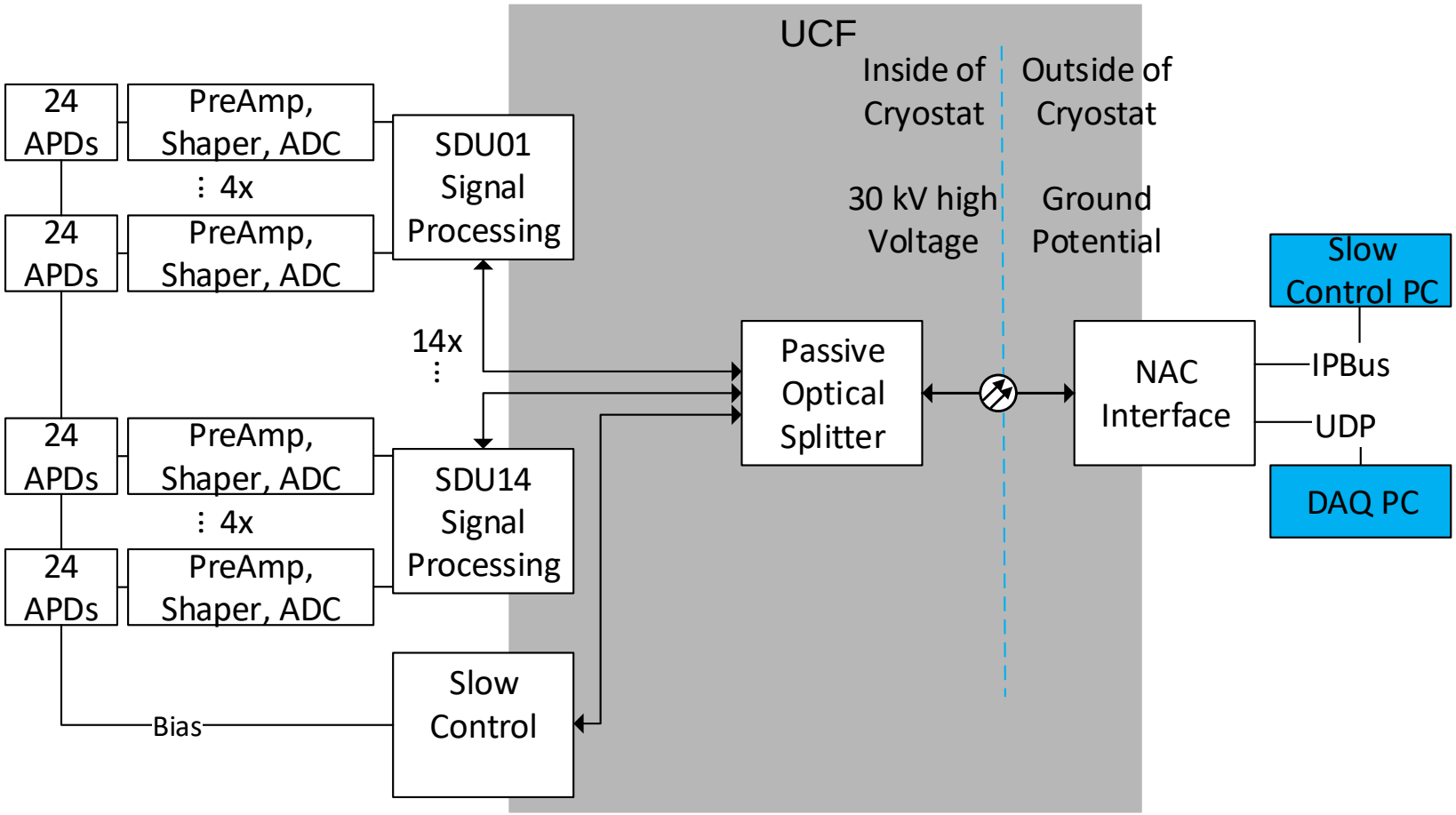


PENeLOPE - Proton Detector Readout Concept



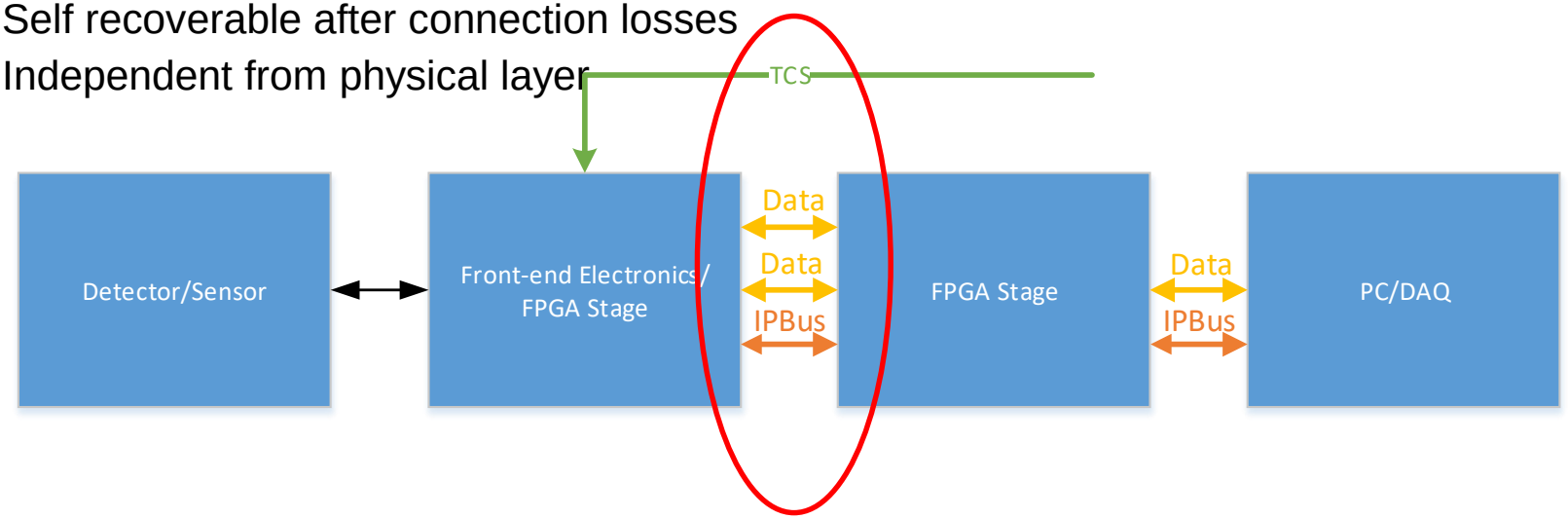
- 500 Mbit/s data rate
- 1496 channels

PENeLOPE - Proton Detector Readout Concept



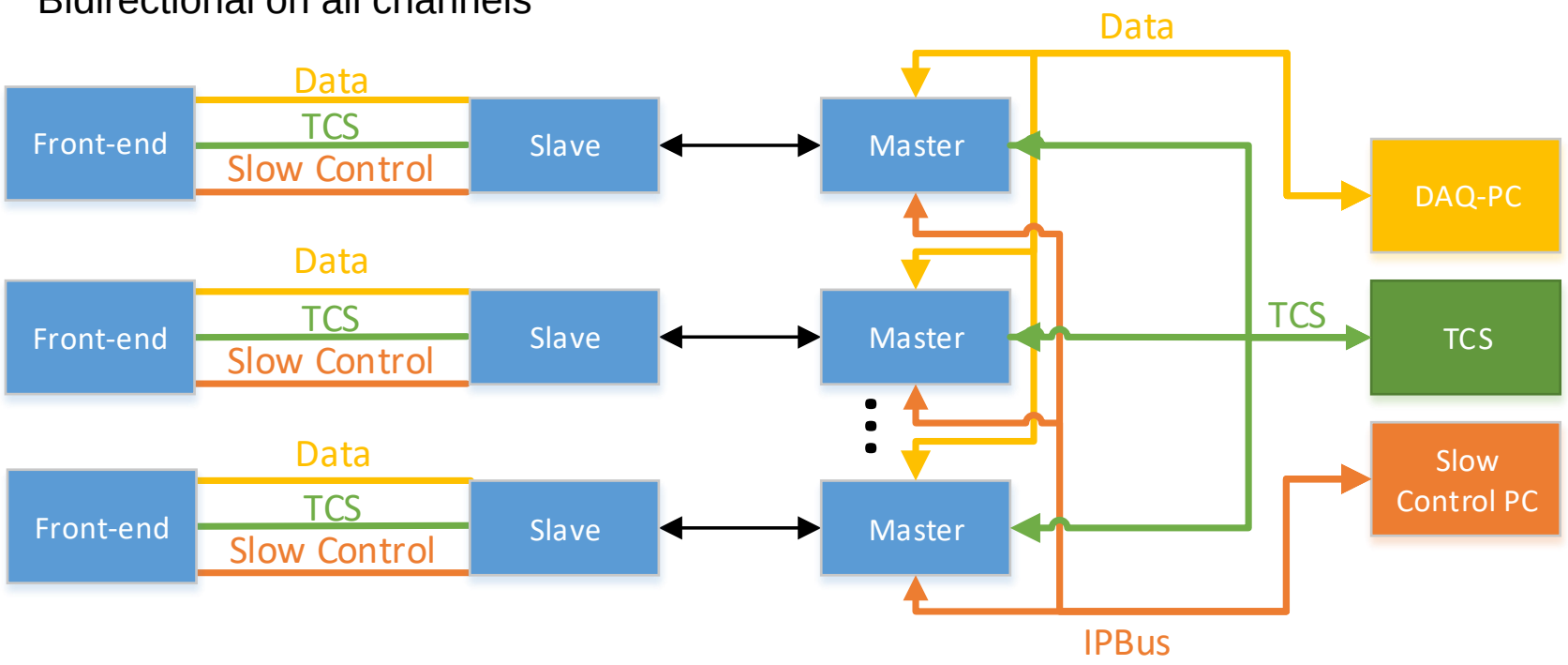
Unified Communication Framework (UCF)

- Originates from the SODA time distribution system developed for the PANDA experiment
- Single high-speed serial link for data, slow control, trigger, and timing information implemented on FPGAs
- Up to 64 different communication channels (e.g. timing, slow control, Data, JTAG, I2C, SPI, TCP, UDP…)
- Fixed latency for one channel
- Priority handling for all channels
- Self recoverable after connection losses
- Independent from physical layer



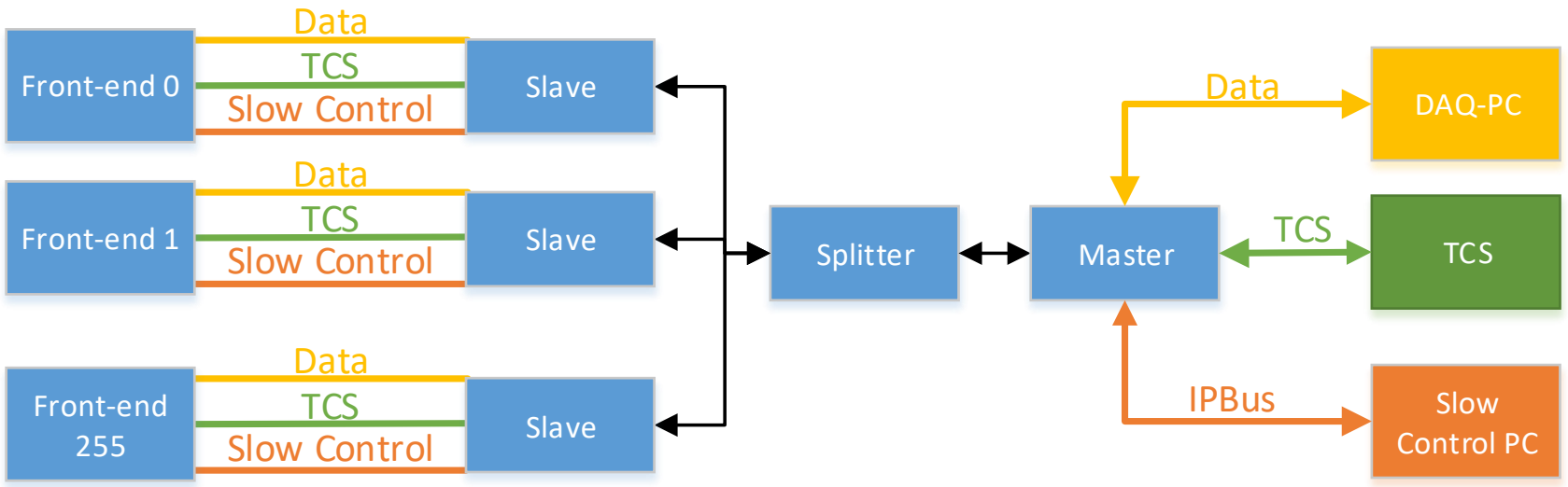
UCF – Example Topologies

- Point-to-Point topology:
  - Multiple or single 1:1 connections
  - Experiments with high data rates, …
  - Bidirectional on all channels



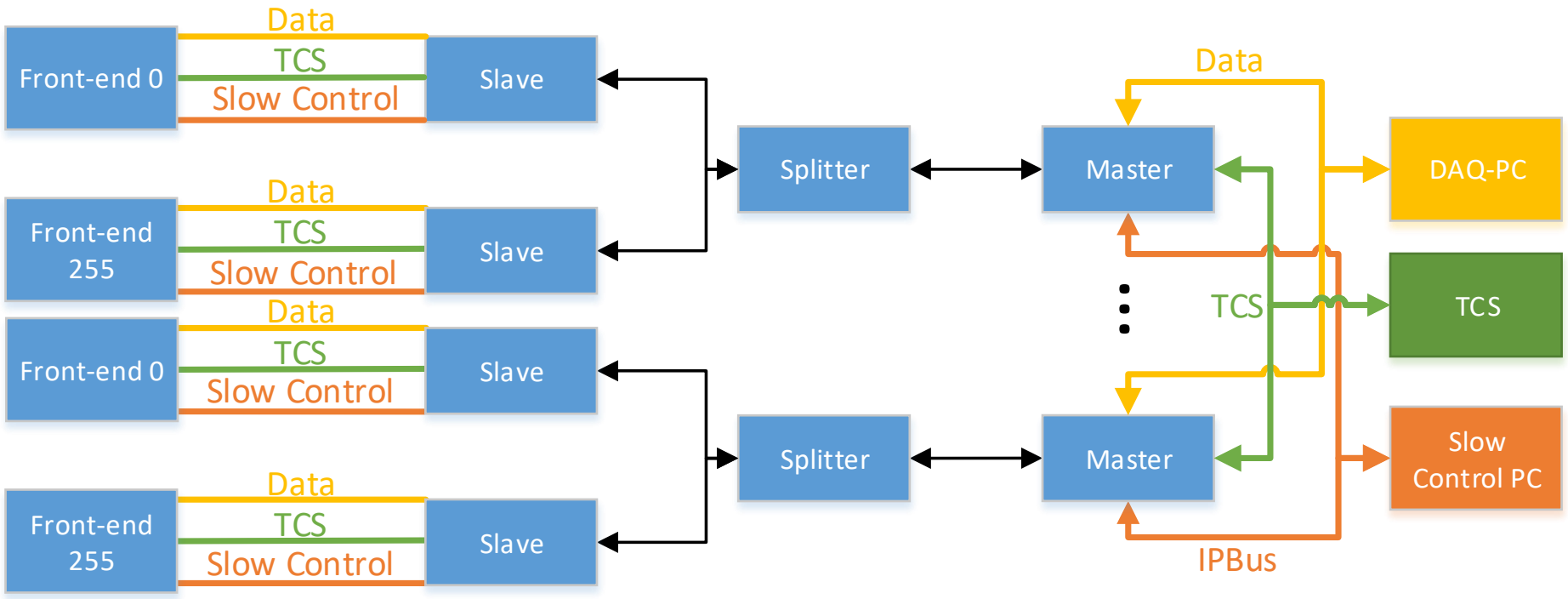
UCF – Example Topologies

- Star-like topology:
  - Single 1:n connections
  - Experiments with low data rates, time distribution systems …
  - Slaves share link in time division manner
  - Bidirectional on all channels



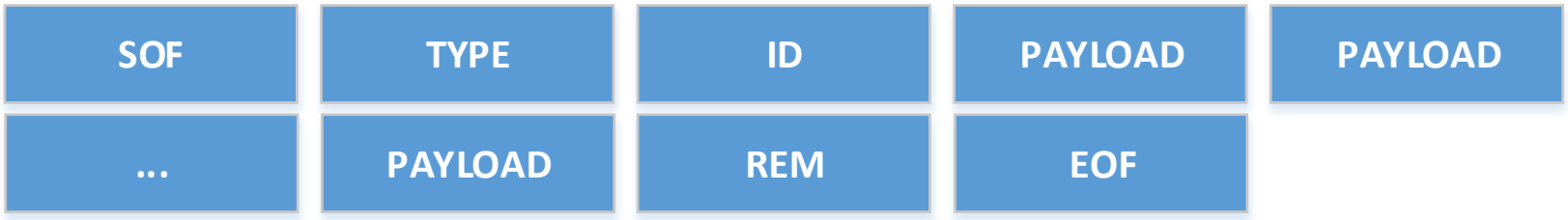
UCF – Example Topologies

- Hybrid topology:
  - Combination of point-to-point and star-like topologies
  - Bidirectional on all channels



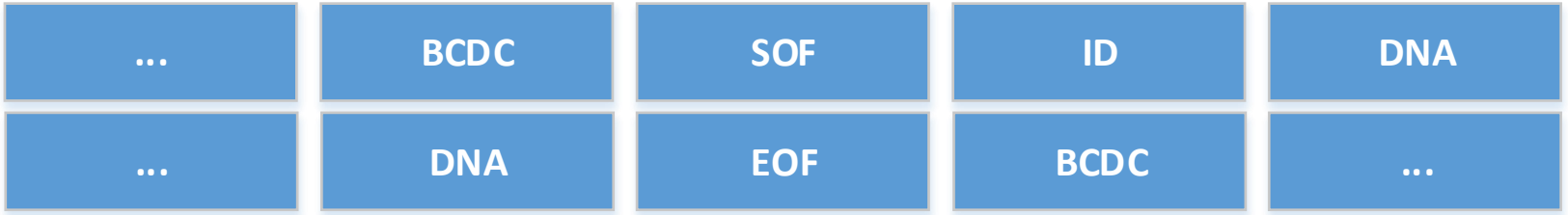
UCF – Low Layer Protocol

- Backbone of UCF
- Handles communication and initialization
- 8b/10b encoding scheme
- 10b K-characters for control and synchronization
- Protocol frames consist always of several character sequence:
  - Start of frame
  - Type of the message (either specific destination or broadcast)
  - Protocol identifier
  - Payload
  - Remainder defining the valid bytes in the last transmission
  - End of frame



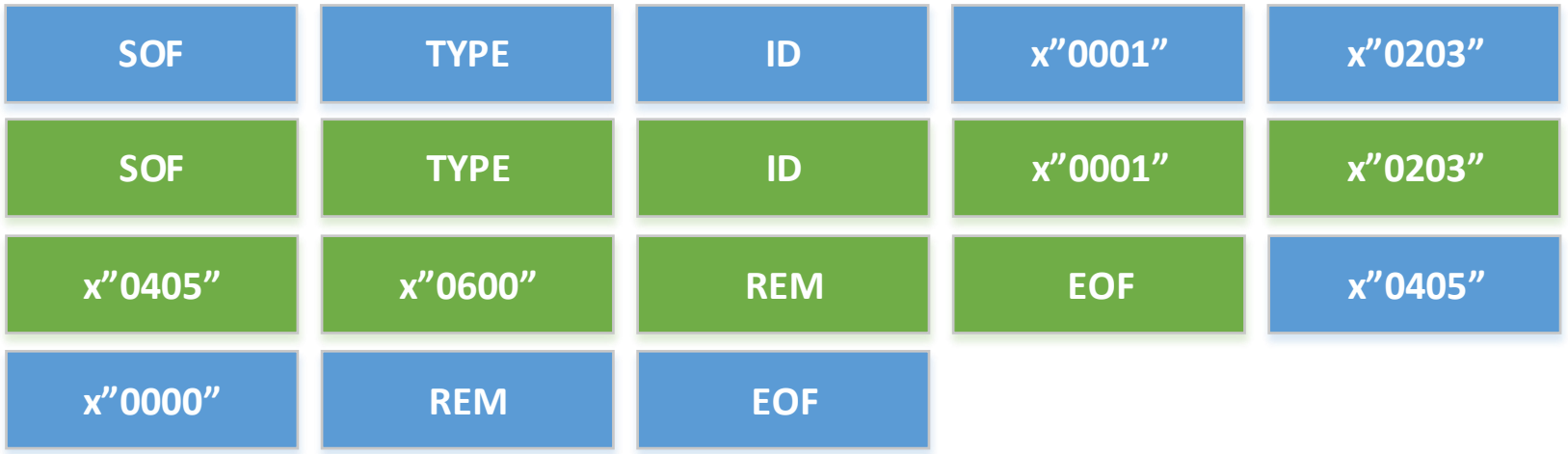
UCF – Initialization

- Fixed phase synchronization by sequence of two defined K-characters (x”BCDC”)
- Synchronization character will be send for specific time to let the slaves synchronize
- Attached parties are scanned by sending an initialization frame containing different DNAs and waiting for response
- DNA can be taken as the serial number of an FPGA
- Unique ID and IP assignment for all connection parties



UCF – Priority Handling

- All 64 communication channels have different priorities
- Protocol 0 has the highest and then it cascades down to the protocol 63 which has the lowest priority
- Frames with higher priority can always interrupt lower priority frames
- Maintains fixed latency for the timing channel

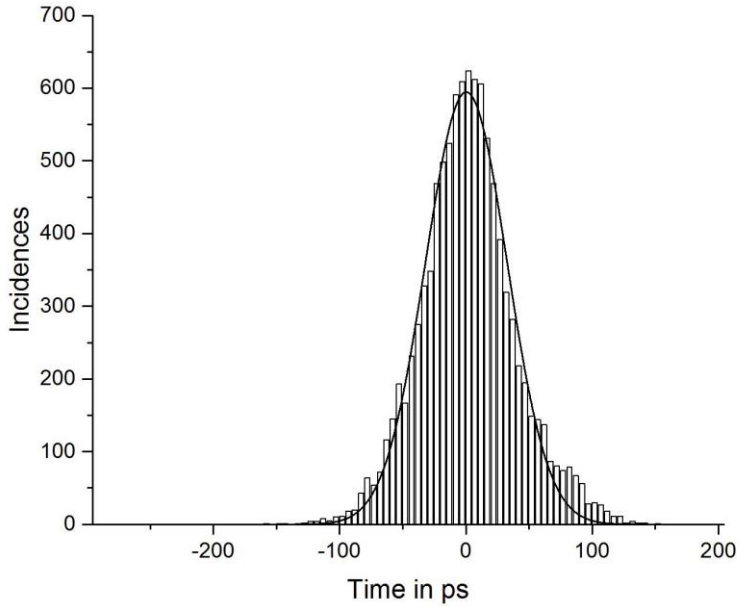


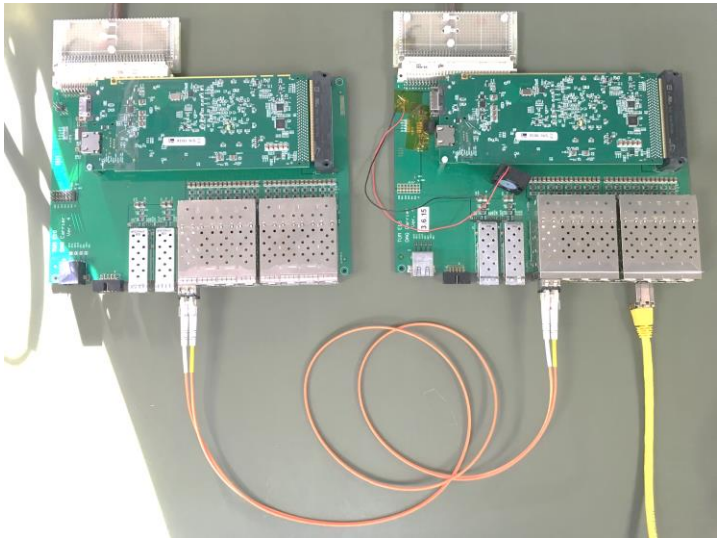
UCF – User Interface and Configuration

- All channels are addressed via the standardized ARM AMBA AXI4 Stream interface
- Leads to easy interfacing with other IP-Cores
- Configuration of all parameters with a generic directly in the top module instantiation:
  - Link speed
  - Topology
  - Device type (Spartan6, Virtex6, Artix7)
  - ….

UCF – Tests and Measurements

- Point-to-Point topology with 1 slave and 1 master
- 2.5 Gbit/s link speed
- Virtex 6 as slave and master
- Recovered clock jitter (σ) of 23 ps
- Long term test with 4 different protocols and link utilization of 99 % over two weeks

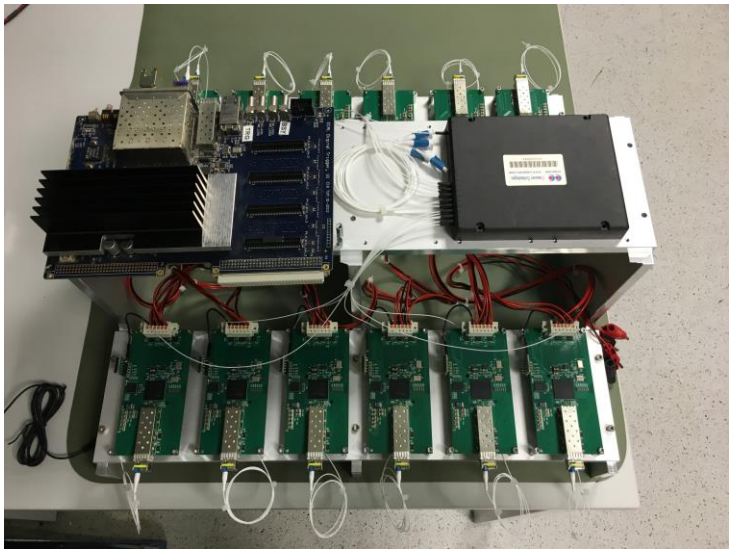




UCF – Tests and Measurements

- Star-like topology with 12 slaves and 1 master
- 1.25 Gbit/s link speed
- Spartan 6 FPGA as slave and Virtex 6 as master
- Switching time of 16 µs (includes character transmission and synchronization)
- Long term stability test with 99 % link utilization over two weeks
- JTAG over UCF
- IPBus over UCF

Transmission Time [µs]	Efficiency [%]
25000	99,93
10000	99,84
1000	98,42
500	96,90
100	86,20



Conclusion

- Developed IP-Core providing unified communication of up to 64 channels via a single optical link
- Fixed latency for one channel (23 ps clock jitter)
- Standardized ARM AMBA AXI4 Stream interface for user
- Multiple 1:n and 1:1 connections possible
- Typically 98 to 99 % link utilization efficiency for star-like topologies (16 µs switching time)
- JTAG over UCF
- IPBus over UCF

Thank you for your attention