Introducing TAXI.

A Transportable Array for eXtremely large area Instrumentation studies

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HELMHOLTZ | ASSOCIATION
Alliance for Astroparticle Physics

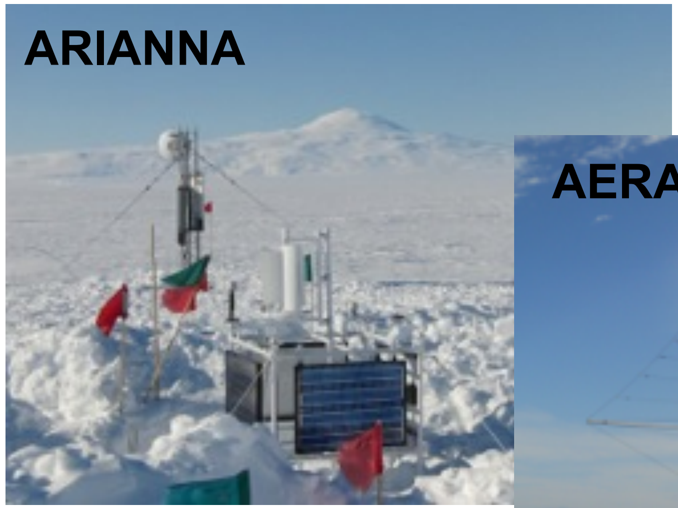
Karlsruhe Institute of Technology

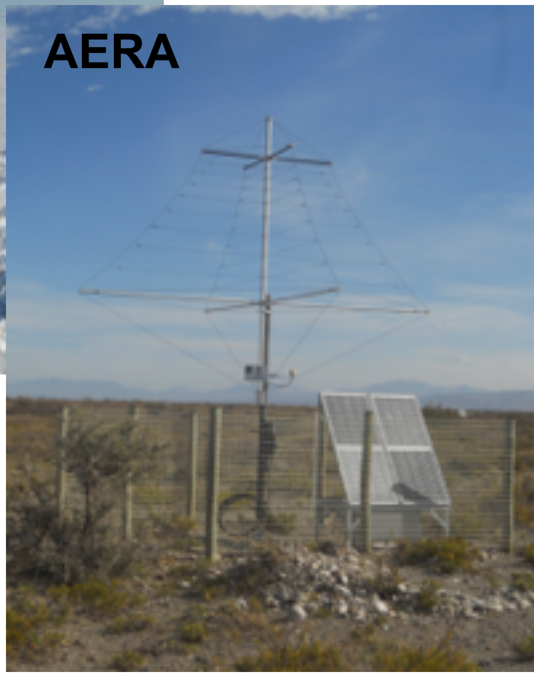
DESY

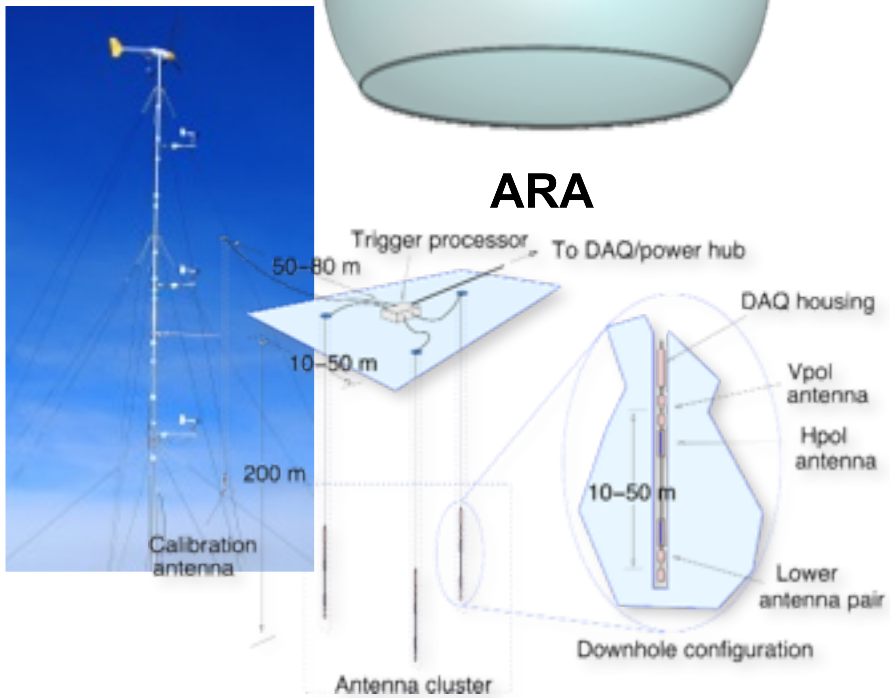
The Concept

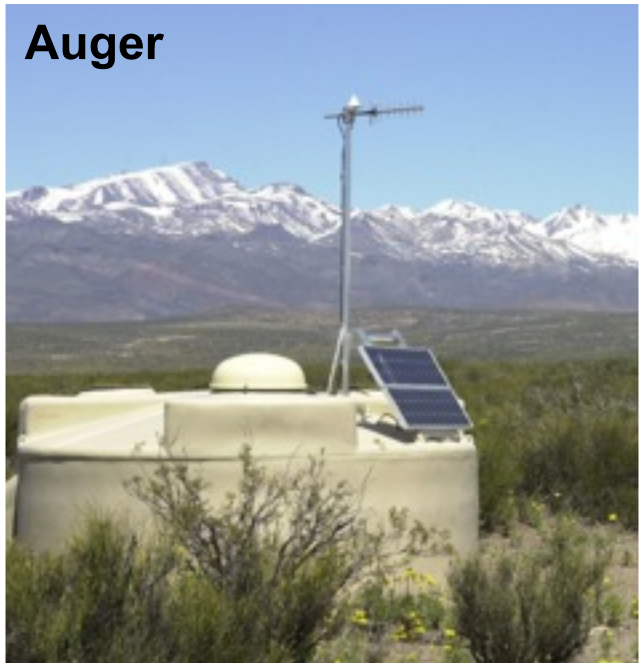
The Idea

- Common "feature" of many astroparticle projects at the highest energies: (UHECR, neutrinos, (non-imaging) gamma astronomy)
  - Small signal fluxes:
    - Large detection areas required
  - Very similar infrastructure:
    - capture of an analogue signal
    - trigger for distributed stations
    - communications
    - power distribution
    - clock distribution









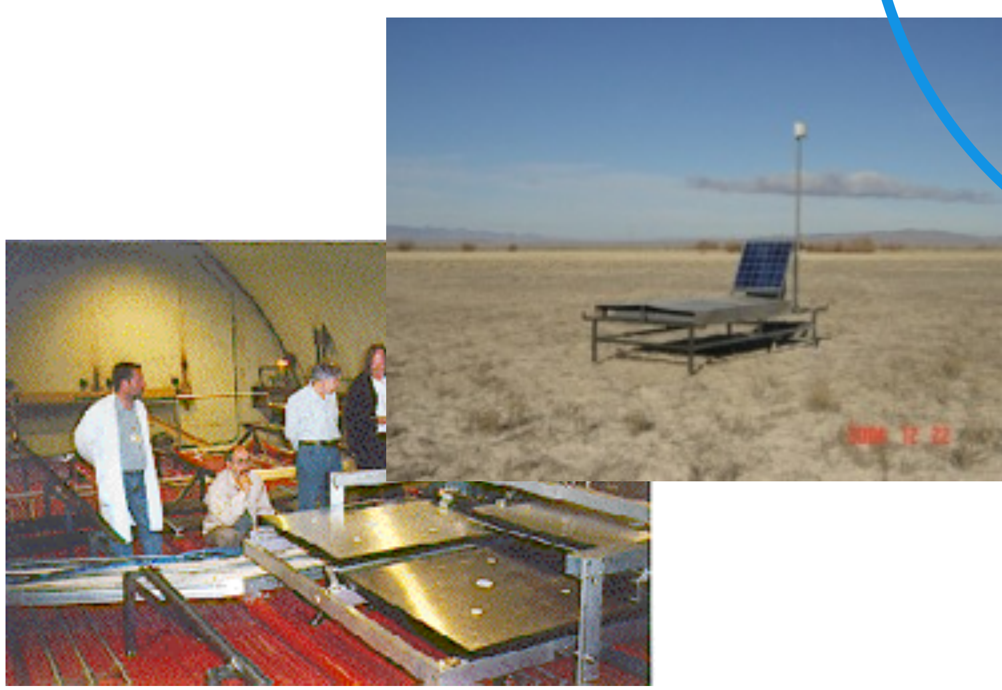
- **Develop a R&D system for testing different aspects of large area detectors**

Sensors

Communication

TAXI

Reference Detector

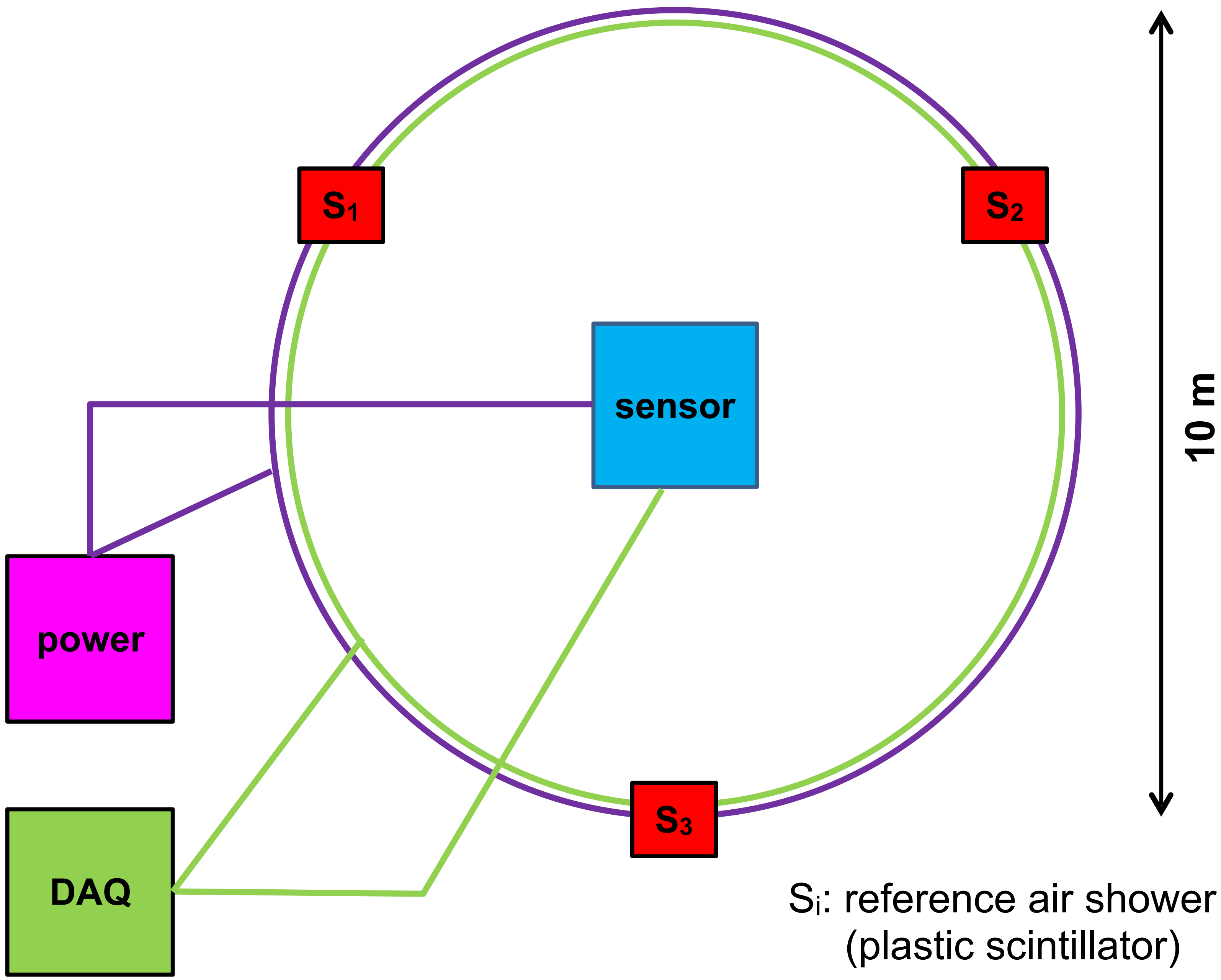


Power Source

First Step: Single Station

Sensor R&D

Idea: Use a simple reference air shower detector for trigger and coarse reconstruction



S_i: reference air shower detectors (plastic scintillator)

First Step: Single Station

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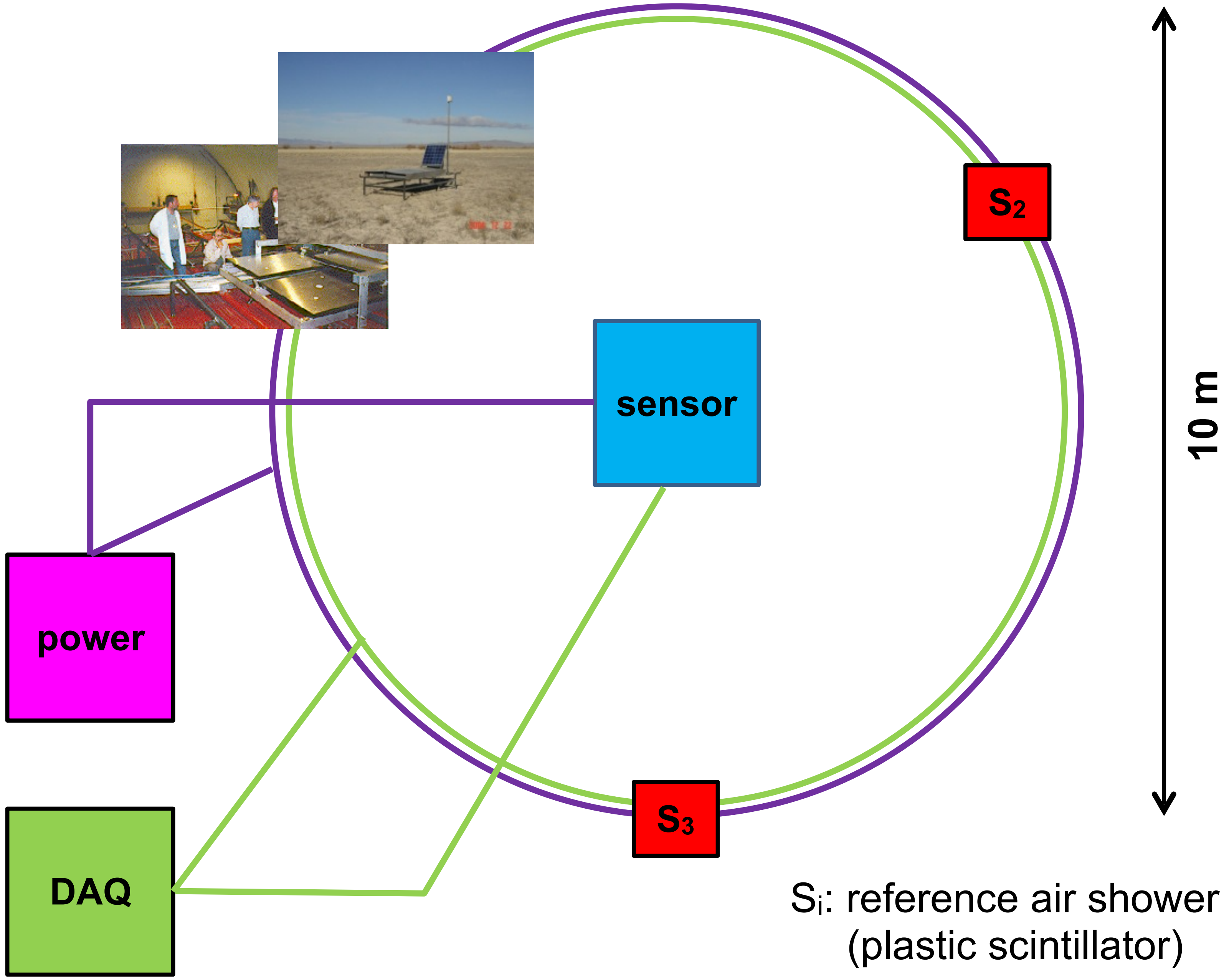
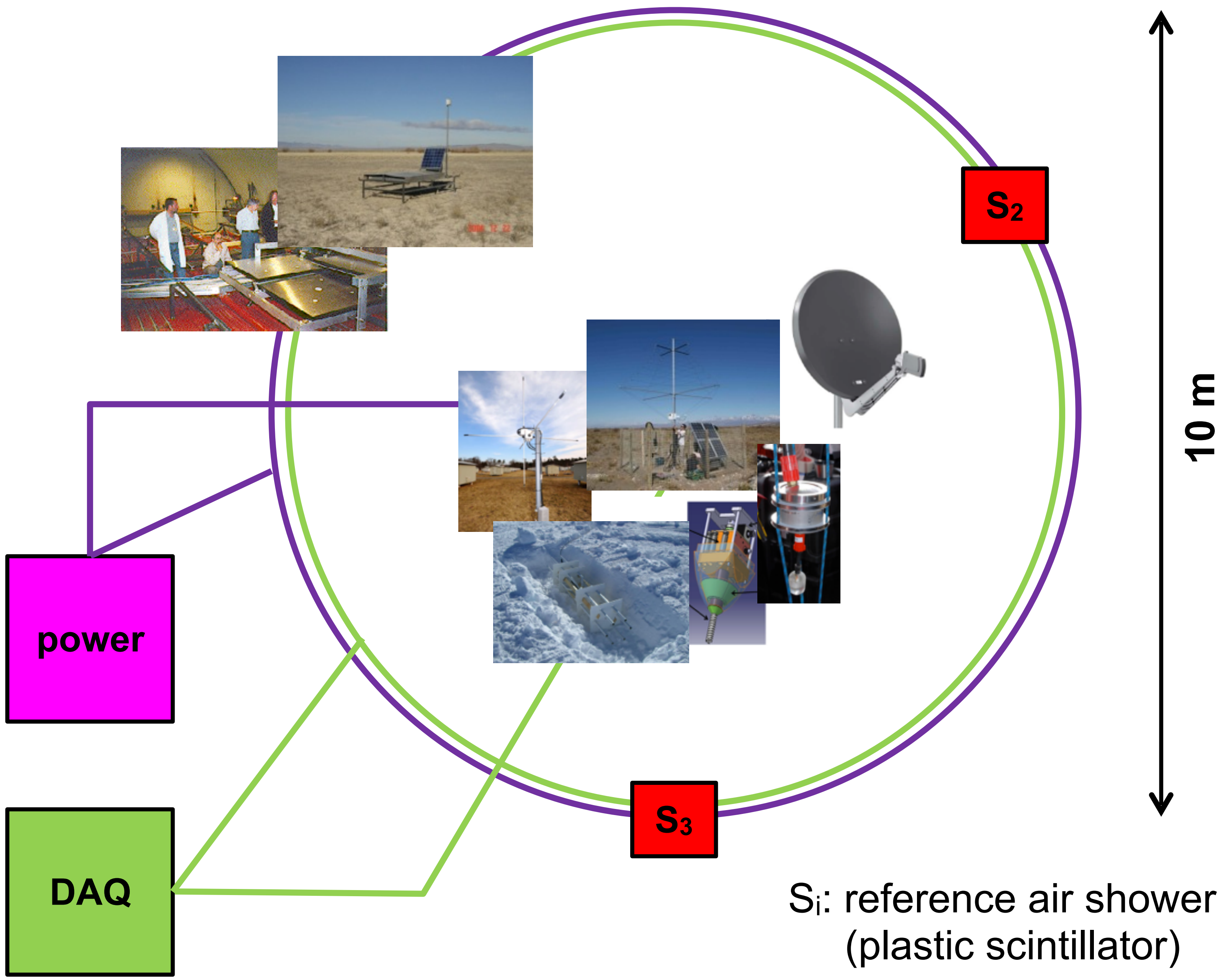


S_i: reference air shower detectors (plastic scintillator)

First Step: Single Station

Sensor
R&D

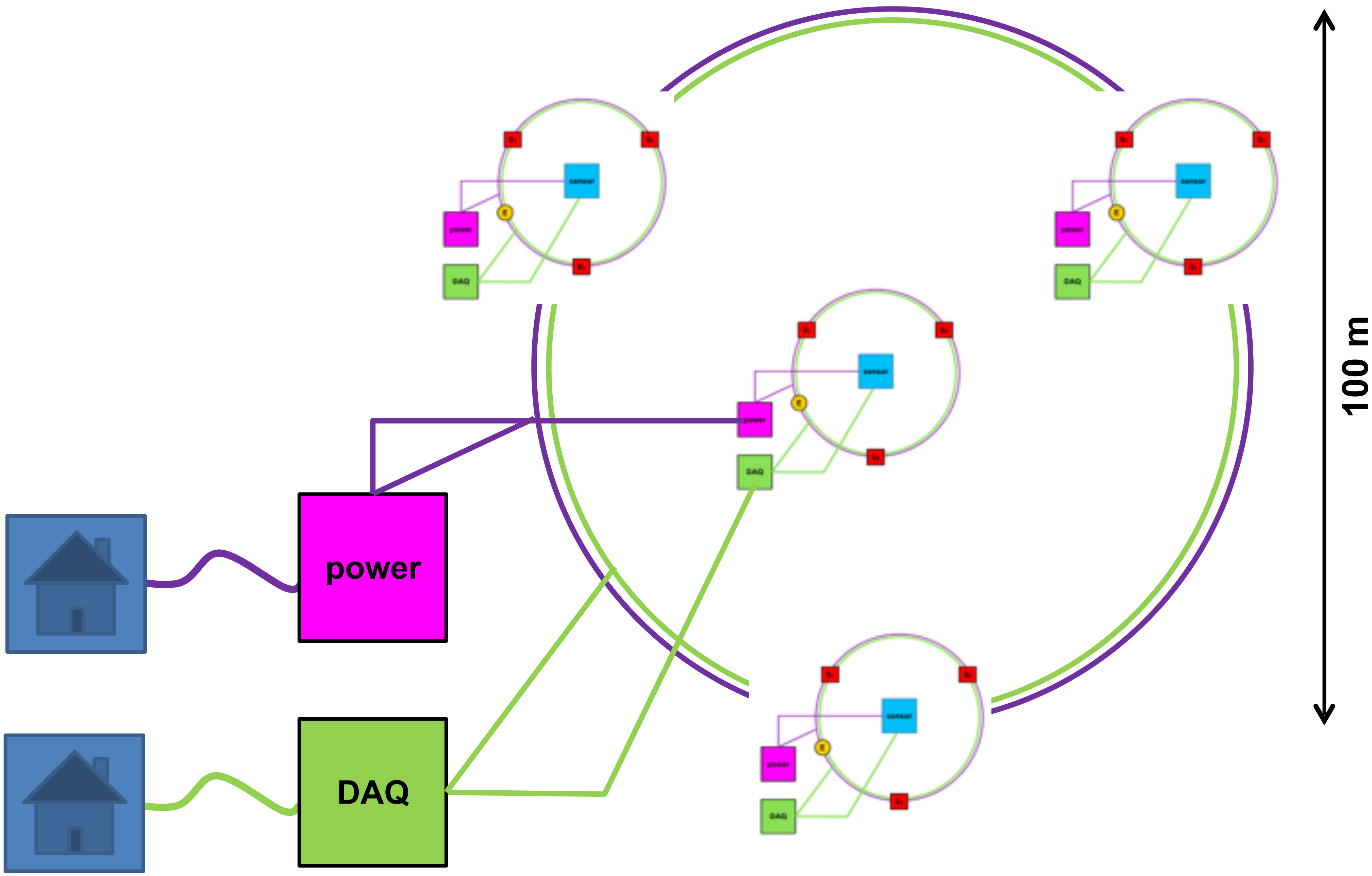
Idea: Use a simple reference air shower detector for trigger and coarse reconstruction



S_i: reference air shower detectors
(plastic scintillator)

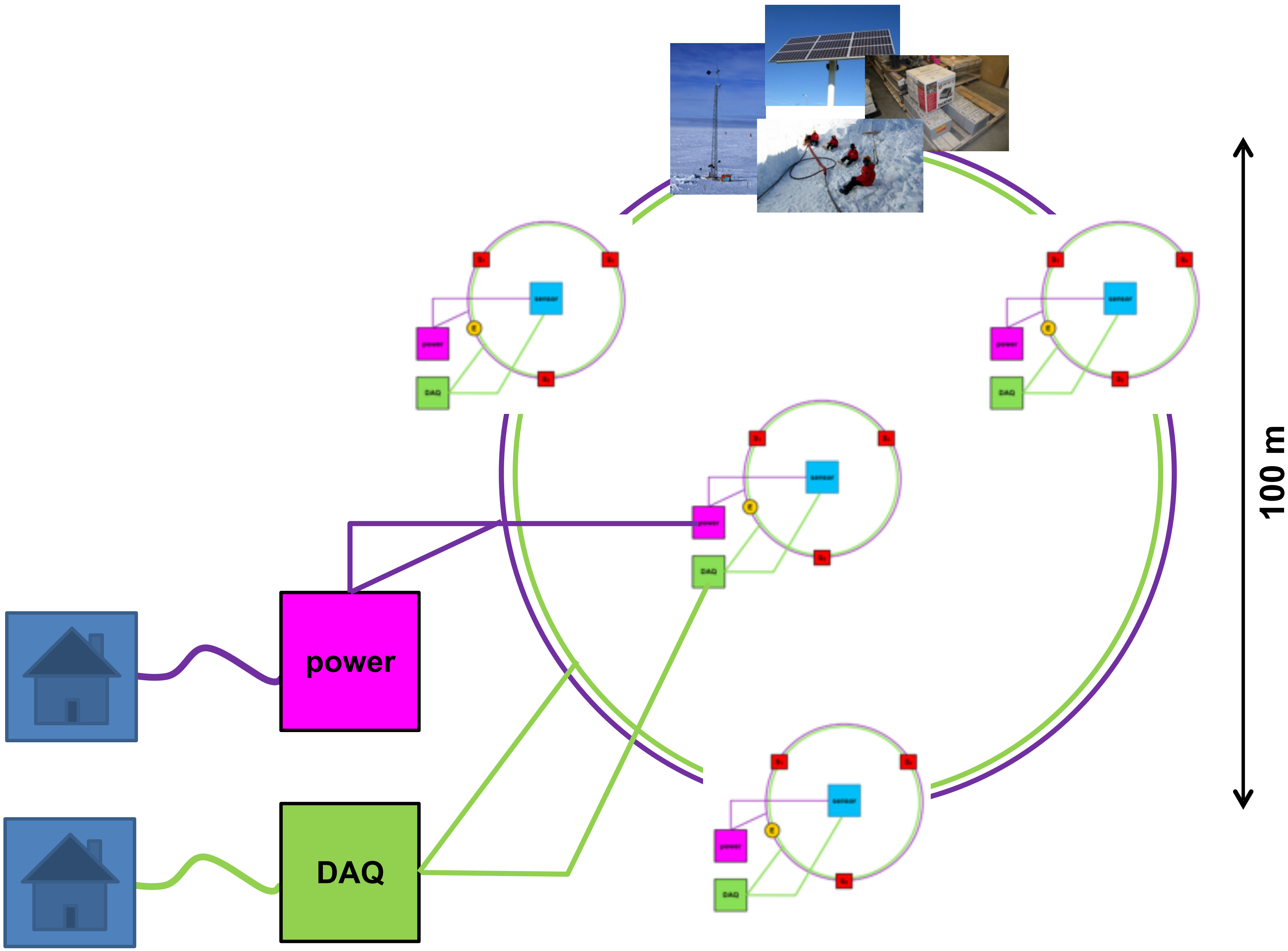
Second Step: Cluster (4 Stations)

Array
R&D



Second Step: Cluster (4 Stations)

Array R&D



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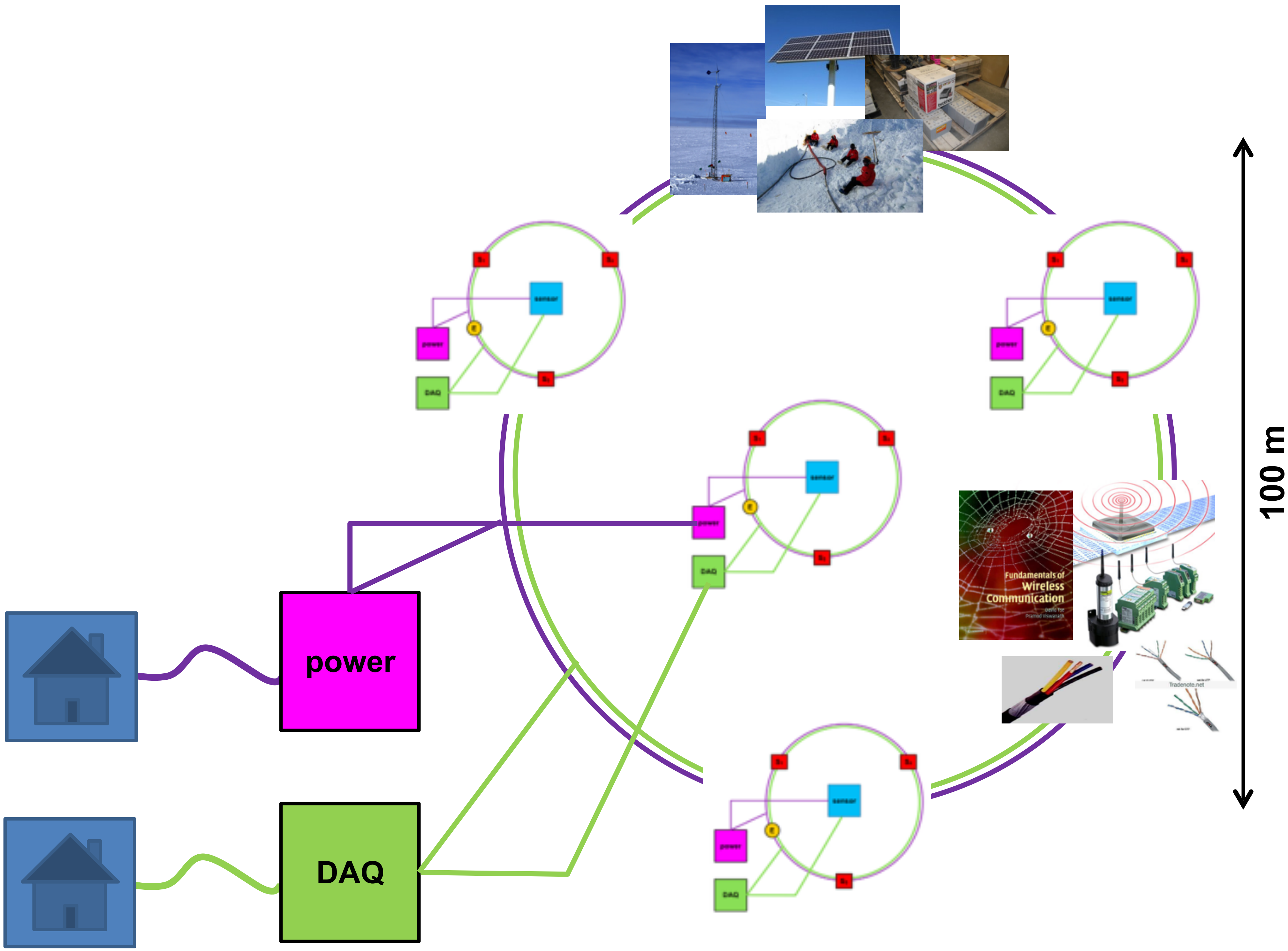

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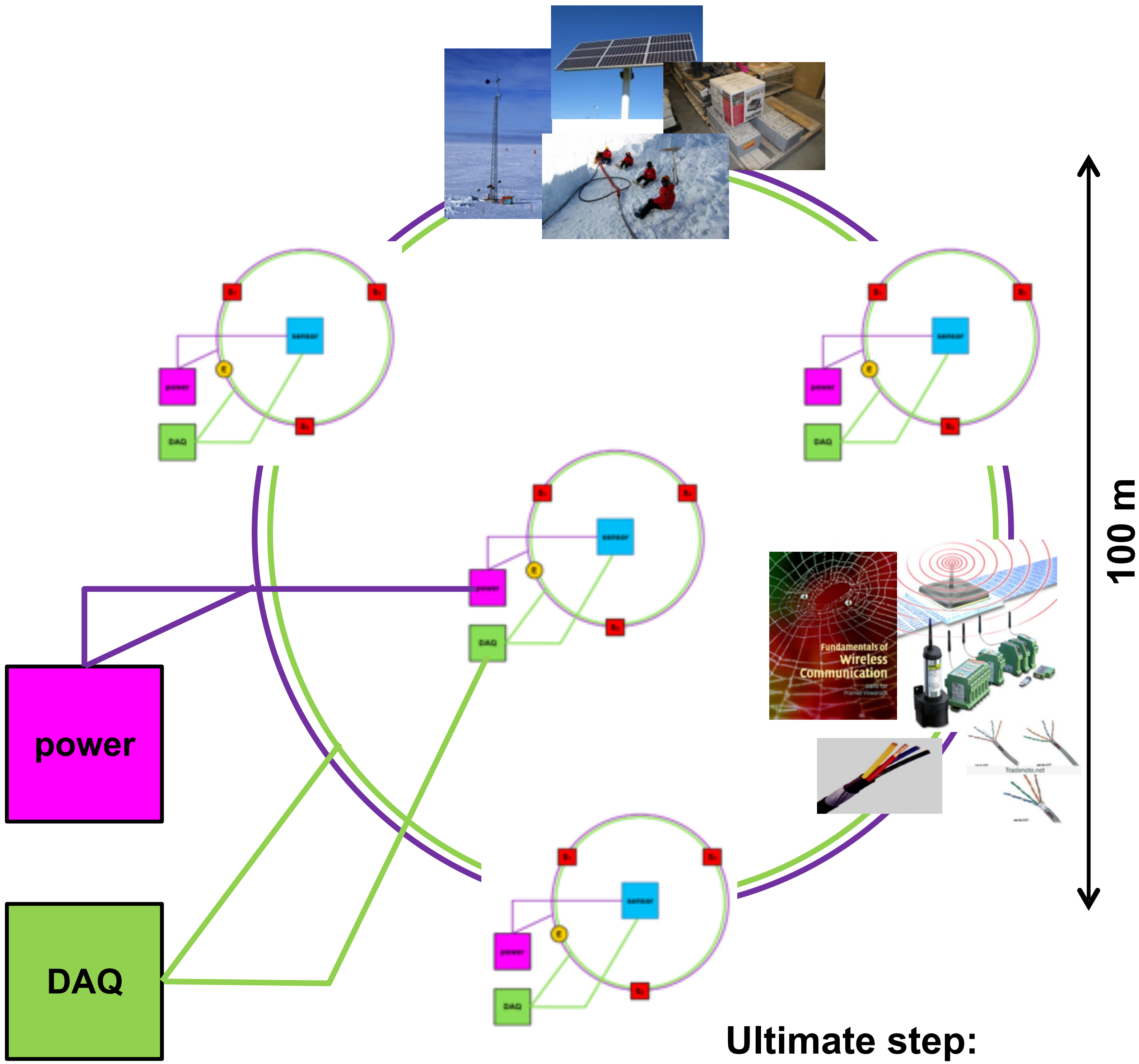


Ultimate step:
self-sustaining power and DAQ

Requirements

> Highly modular system that allows easy interchange of components
  - R&D environment for different system components with well defined interfaces

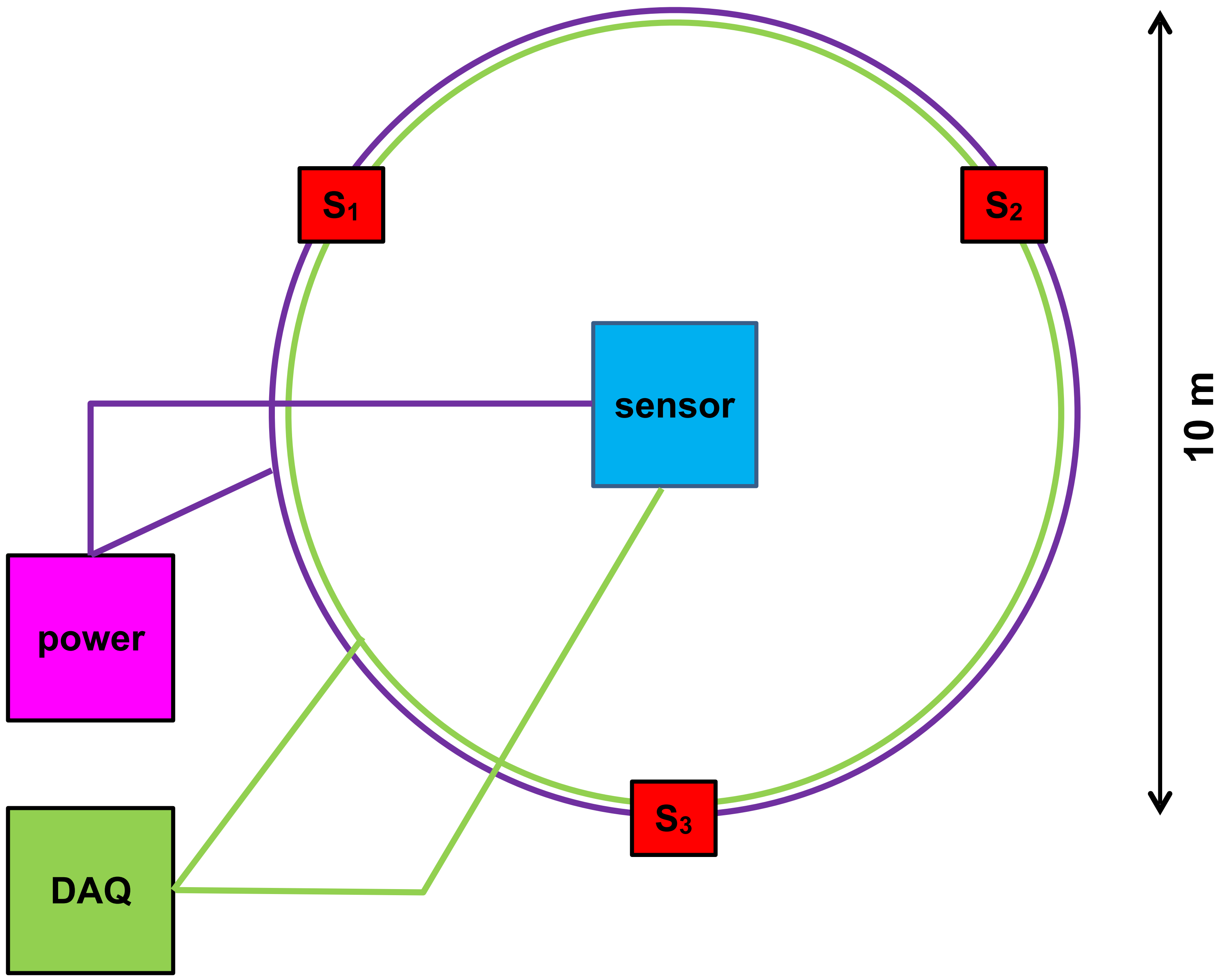
> Easy transport and setup: site studies for future projects
  - long term background measurement and monitoring
  - signal propagation studies (signal speed, attenuation, refraction, …)

> Operation at isolated sites
  - low power, self-sustained power supply
  - environmental range from Antarctica to hot climate

> Scalability

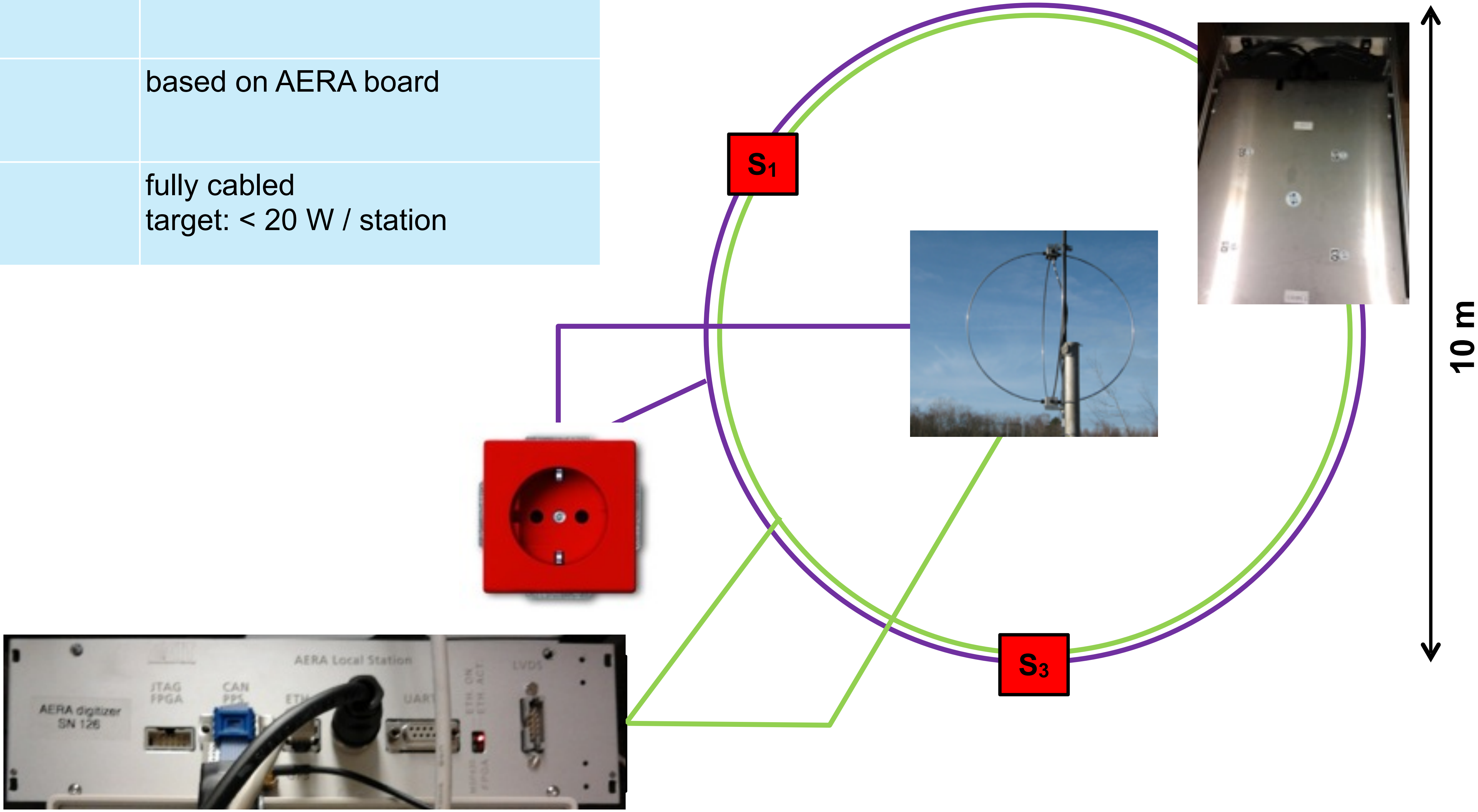
Current Status

Station 1 Operational @ DESY



Station 1 Operational @ DESY

Sensor:	radio antenna (MHz air shower detection)
Ref. Detector:	plastic scintillator
DAQ:	based on AERA board
Power:	fully cabled target: < 20 W / station



Station 1 Operational @ DESY

SALLA antenna
(courtesy of Tunka-Rex)

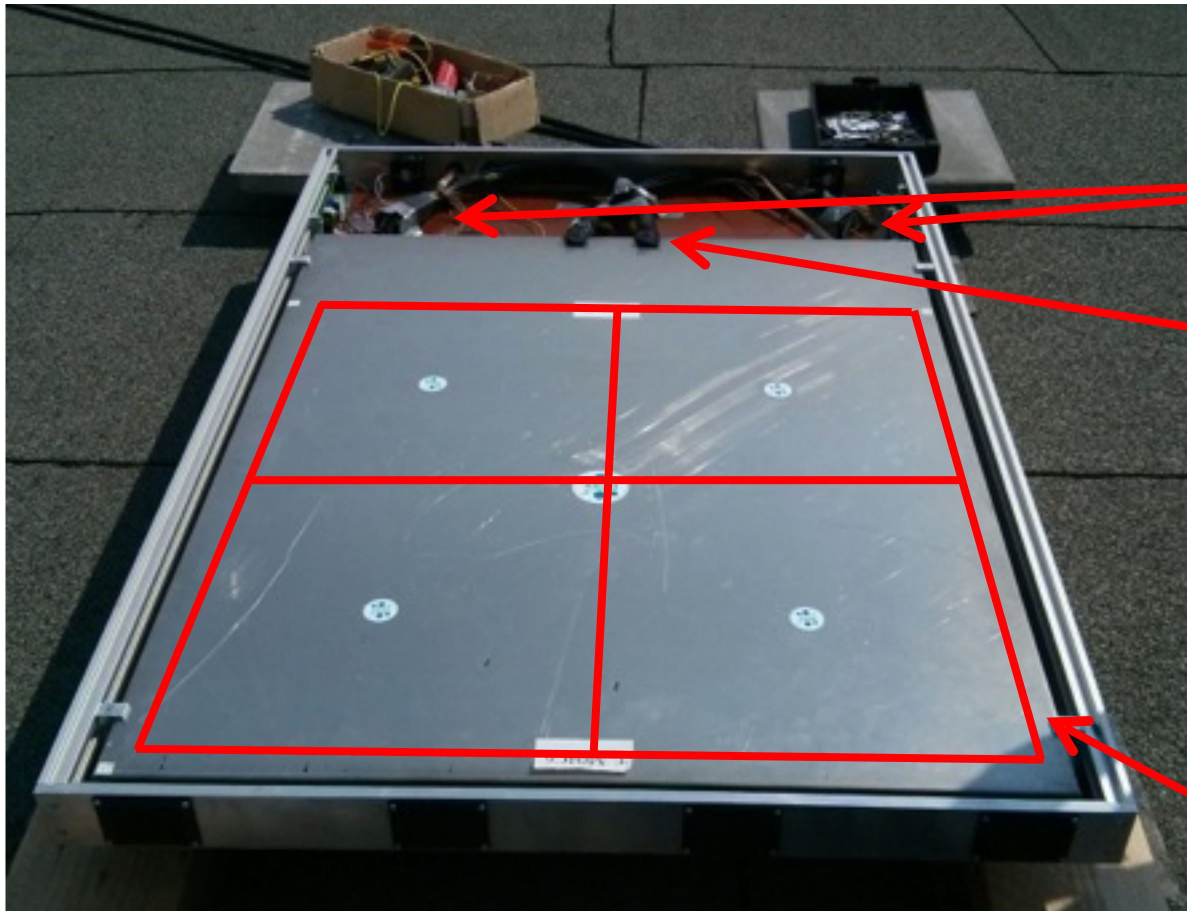
Scintillator 3

Scintillator 2

Scintillator 1

DESY Zeuthen,
Mechanical Workshop

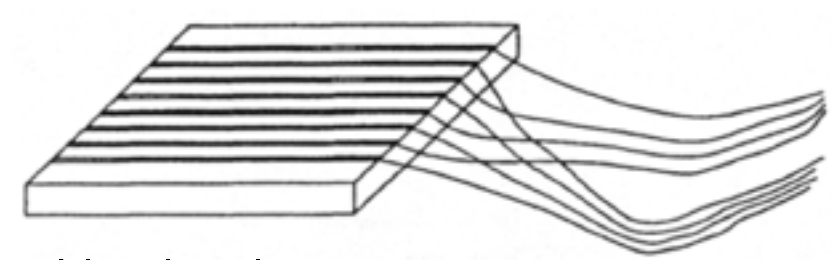
Scintillation Detector



Hamamatsu R 5900-3-M4
2 × 2 multi-anode PMT

optical fibers
each tile read out by 2 sets of fibers

1 m^2 tiled plastic scintillator
16 tiles, 25 × 25 cm each



combined to 4 segments
of 50 × 50 cm for readout

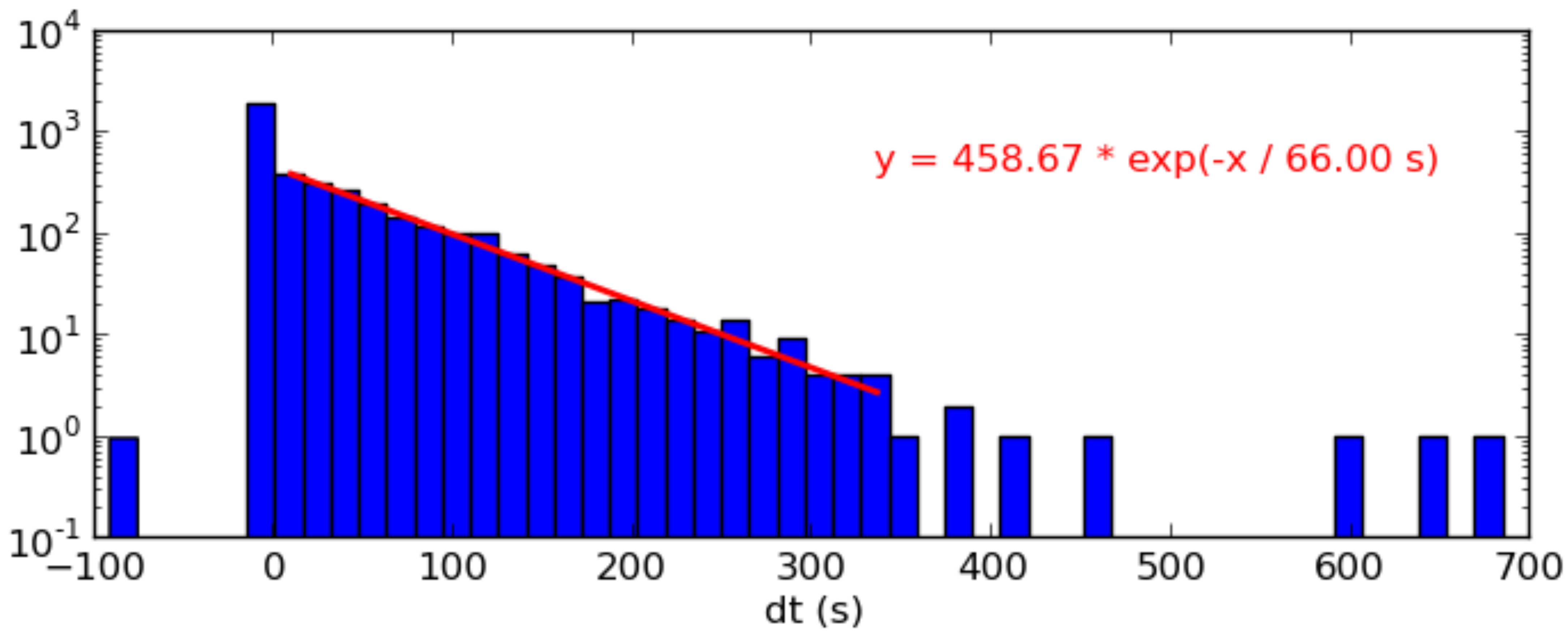
- Input: ± 12 V
- Output: differential,
  analog PMT signal (8 channels)

Performance

> Air shower trigger from scintillators: 3-out-of-3 condition

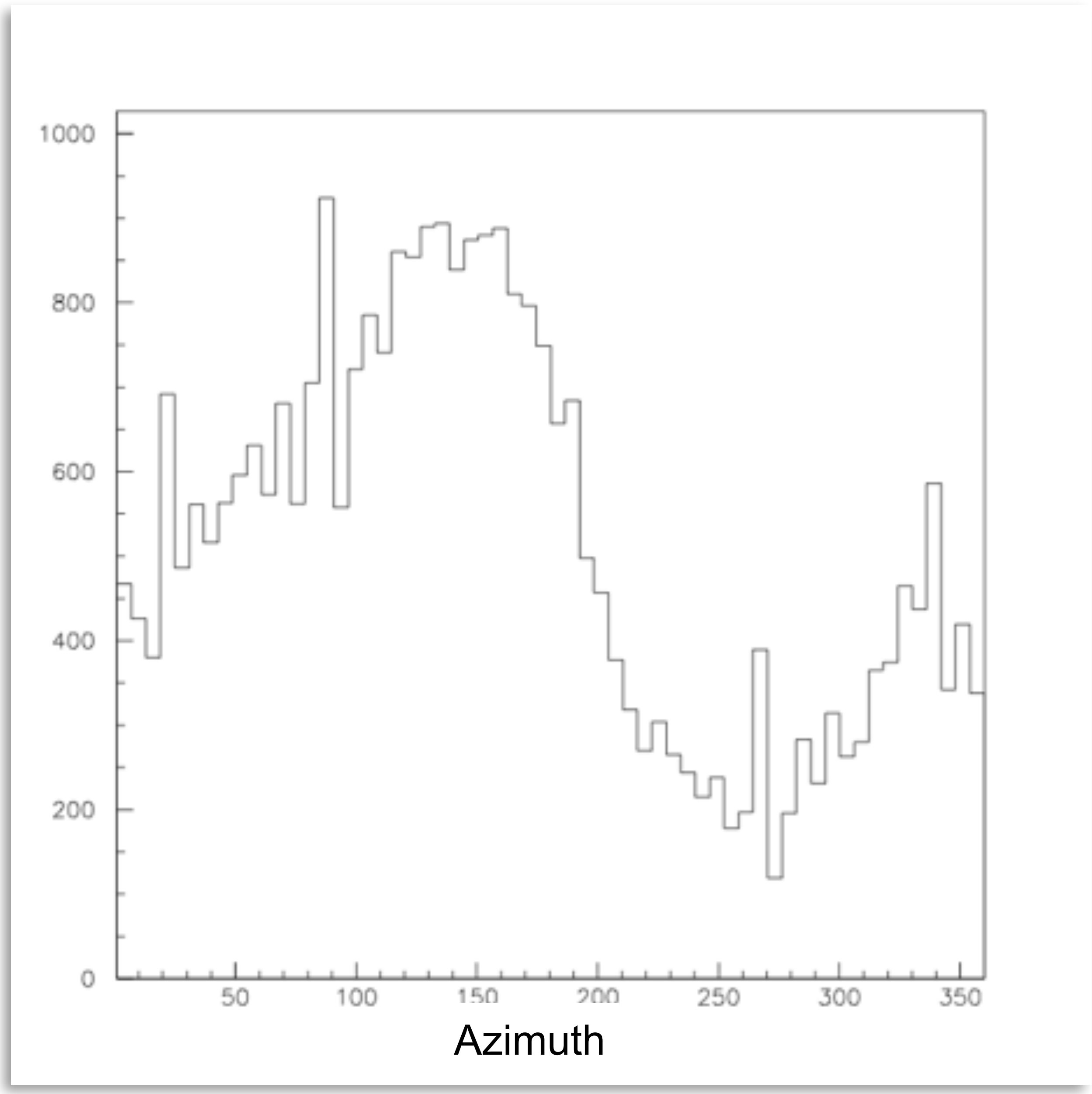
- PMT pulses from scintillators read out by QDC and TDC
  (12 channels: 3 scintillator plates with 4 channels each)
- Trigger from scintillators used to trigger read out of radio signal

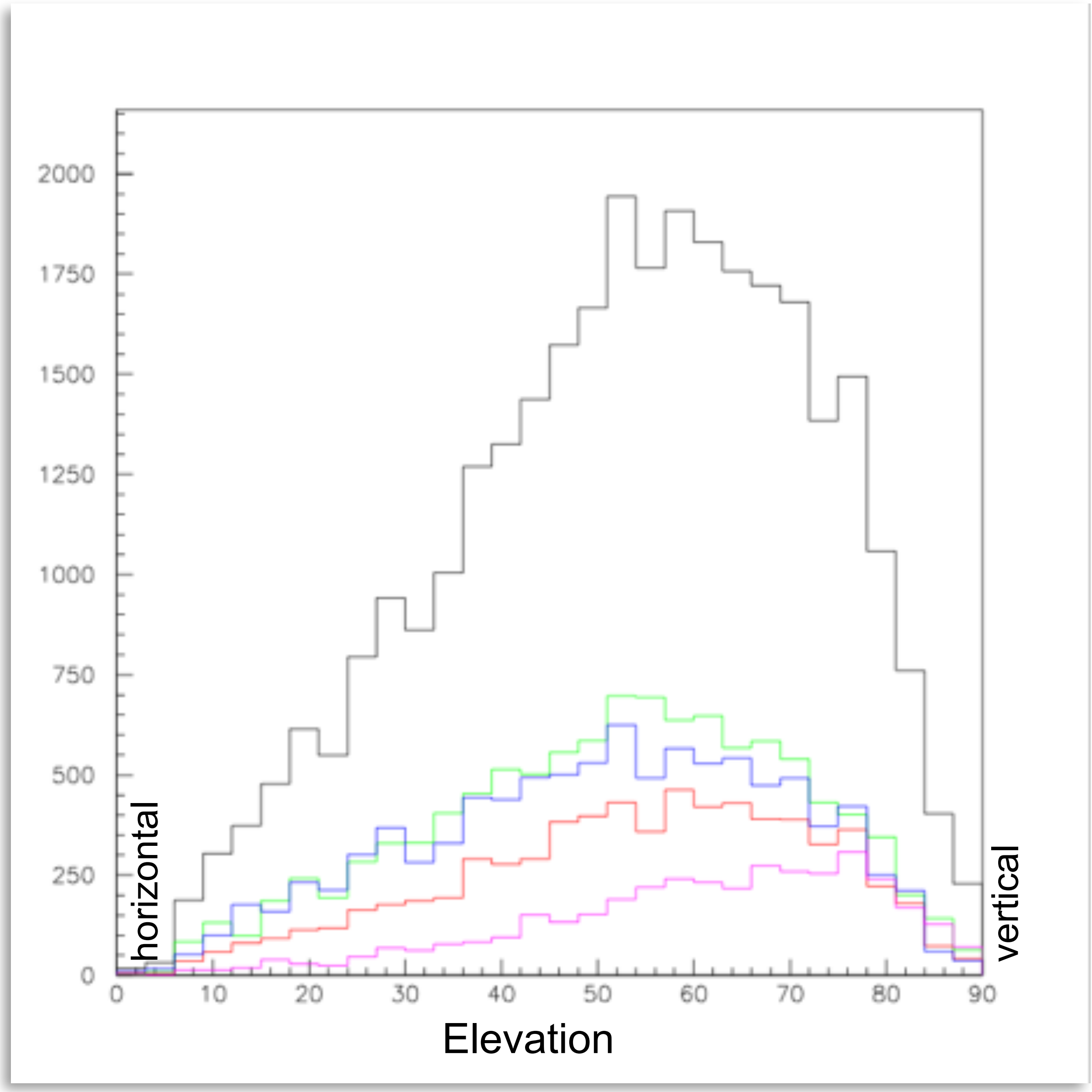
> Rate: ≈ 1 min-1



Reconstructed Directions

Direction of air shower reconstructed from arrival time differences





(35 days of data)

Reconstructed Directions

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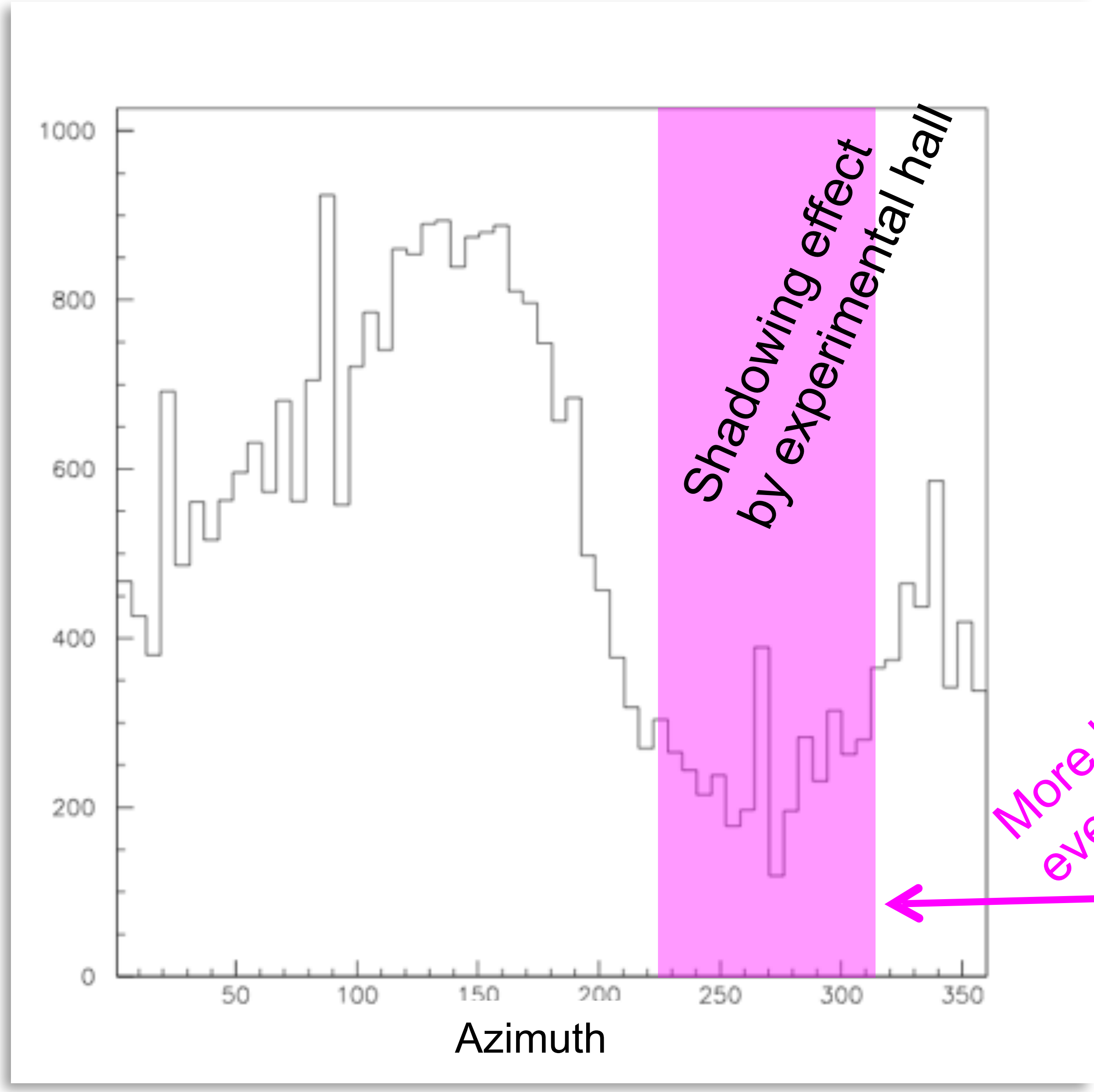
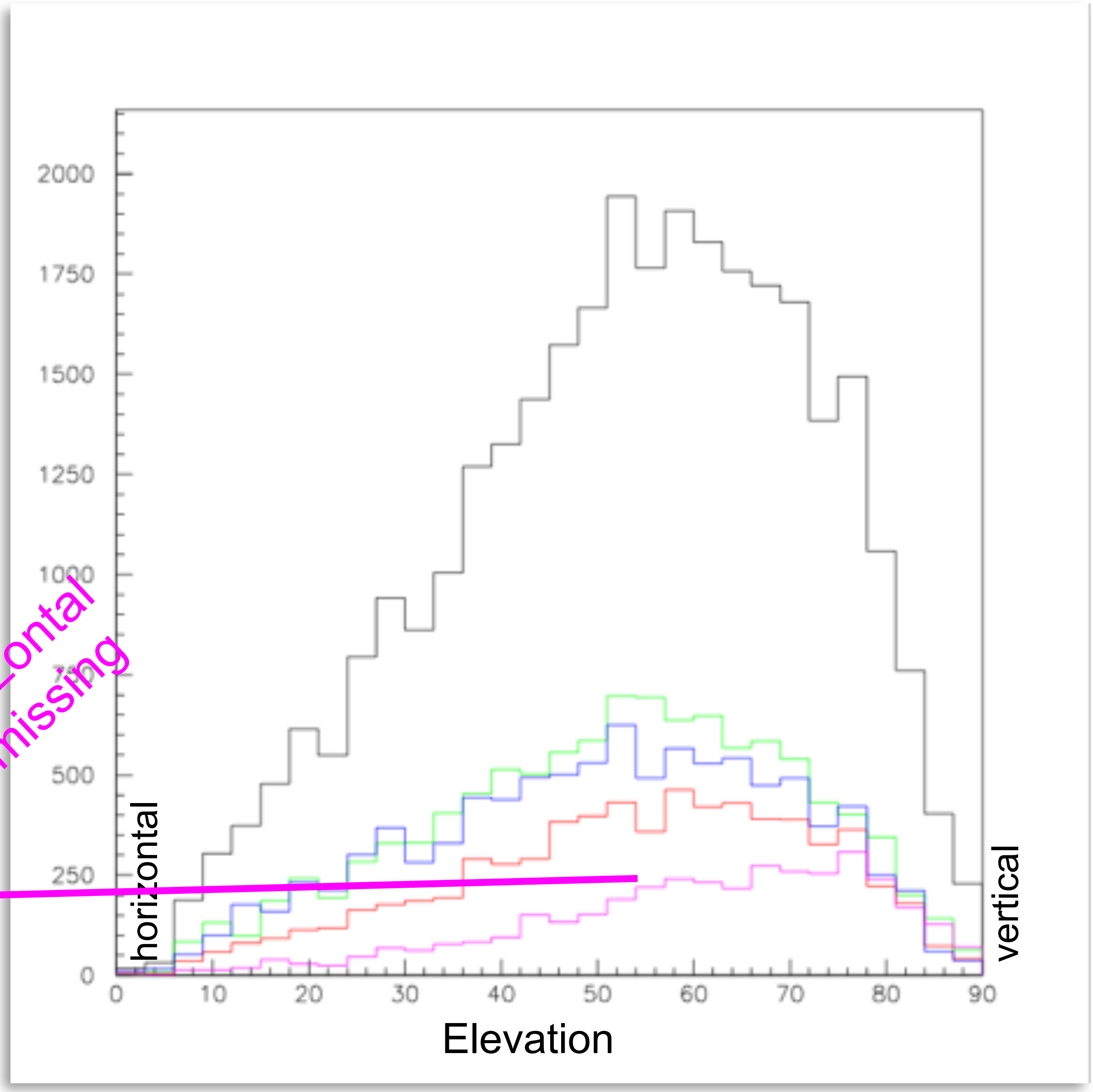
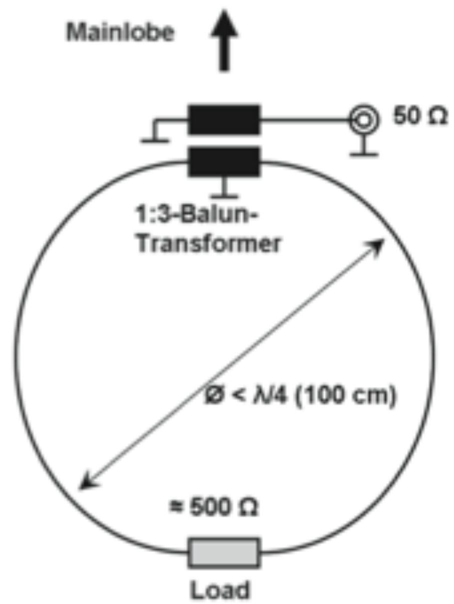


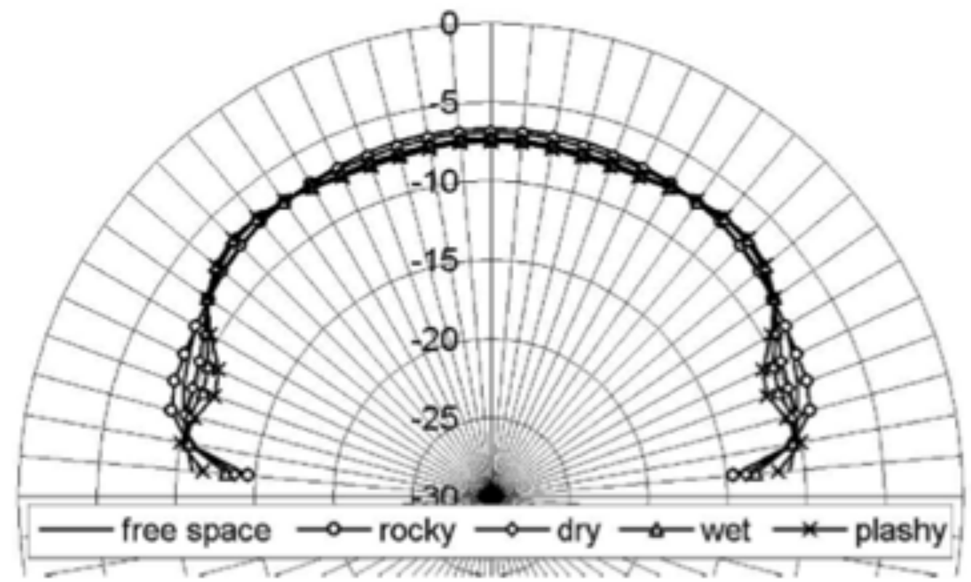


(35 days of data)

View in the Direction of 270°

Radio Antenna

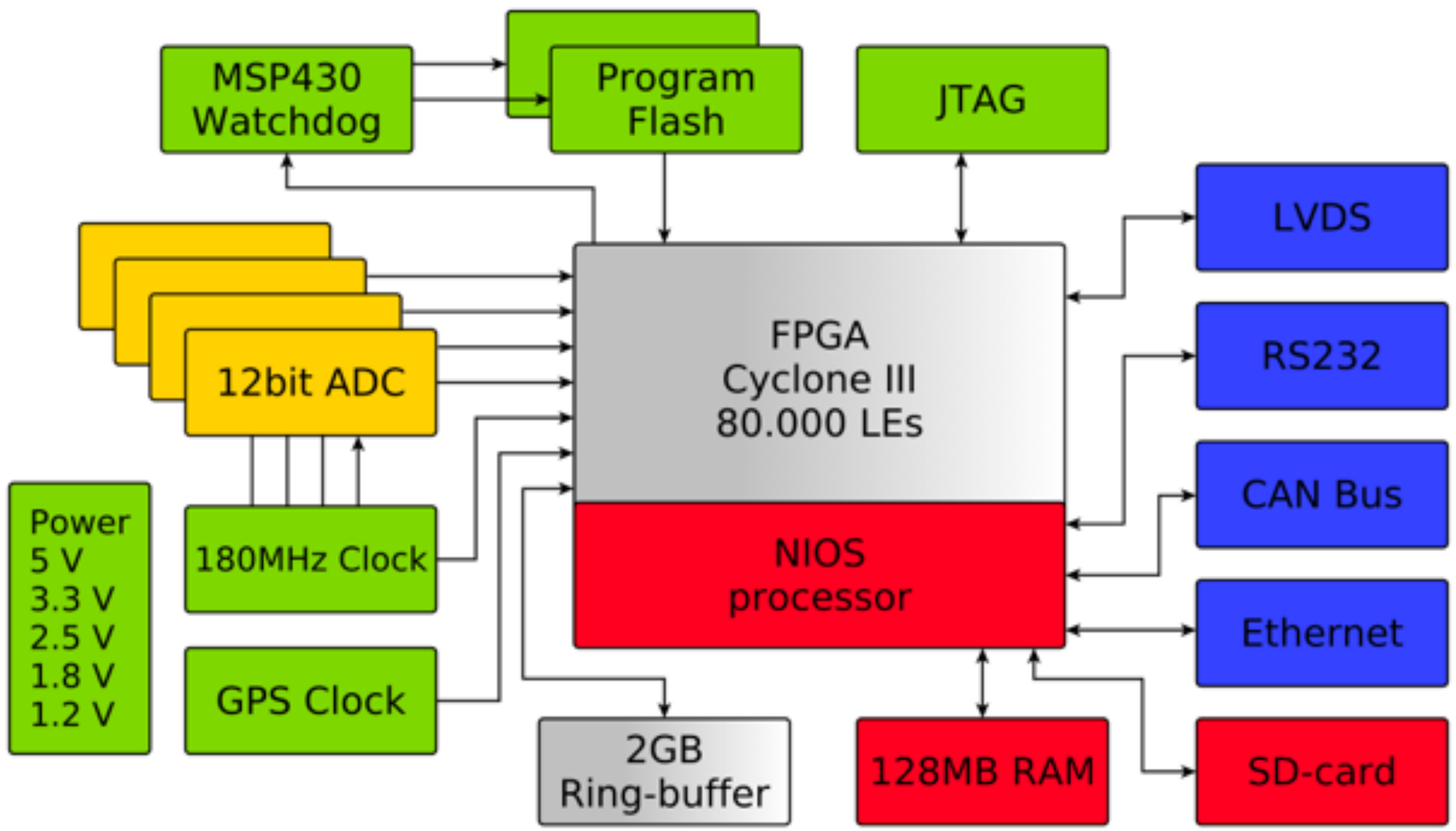




LOPES Collaboration, 31st ICRC, Łódź, 2009

- SALLA: Short Aperiodic Loaded Loop Antenna
- Used in Tunka-Rex
- Flat gain over wide frequency range from ~30 MHz to > 80 MHz
- Very low dispersion (< 5 ns)
- Insensitive to ground properties

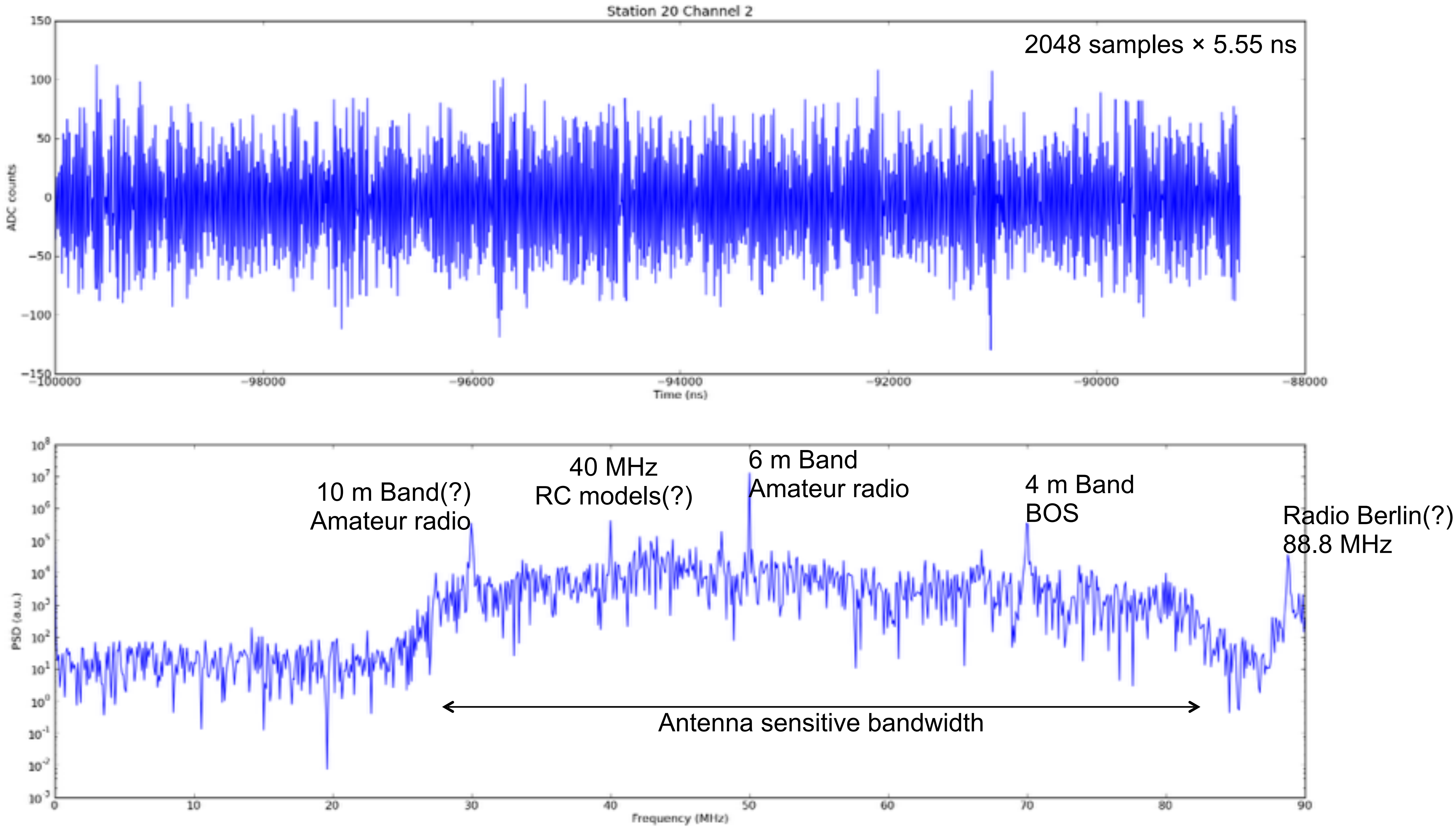
Radio Waveform Readout



Block diagram:
A. Schmidt, PhD Thesis, KIT (2012)

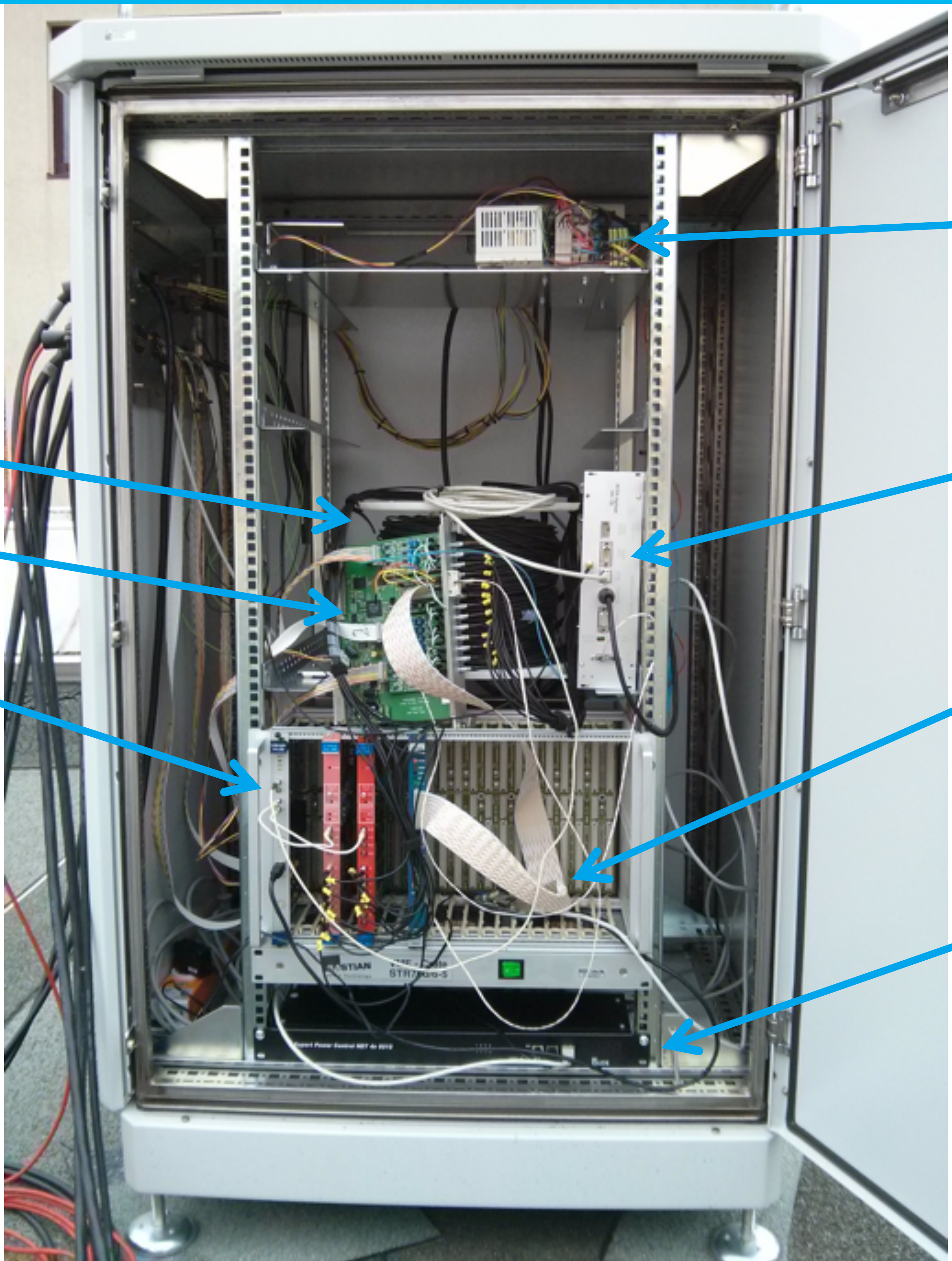
- Developed at KIT (IPE, IKP) for the Auger Engineering Radio Array (AERA)
- Four digitizers (180 MHz, 12 bit; can be interlaced to 2 × 360 MHz)
- Deep ring buffer (7 seconds for 2 channels @ 180 MHz)
- Powerful FPGA for real-time signal processing
- External trigger from scintillation detector
- Power: < 10 W (including LNAs for radio antenna)

Ext. Triggered Event: Radio Background in Zeuthen



Next Steps and Timeline

Coming Soon: Low Power Single-Board DAQ



Power supply

Cable delay for QDC

AERA board

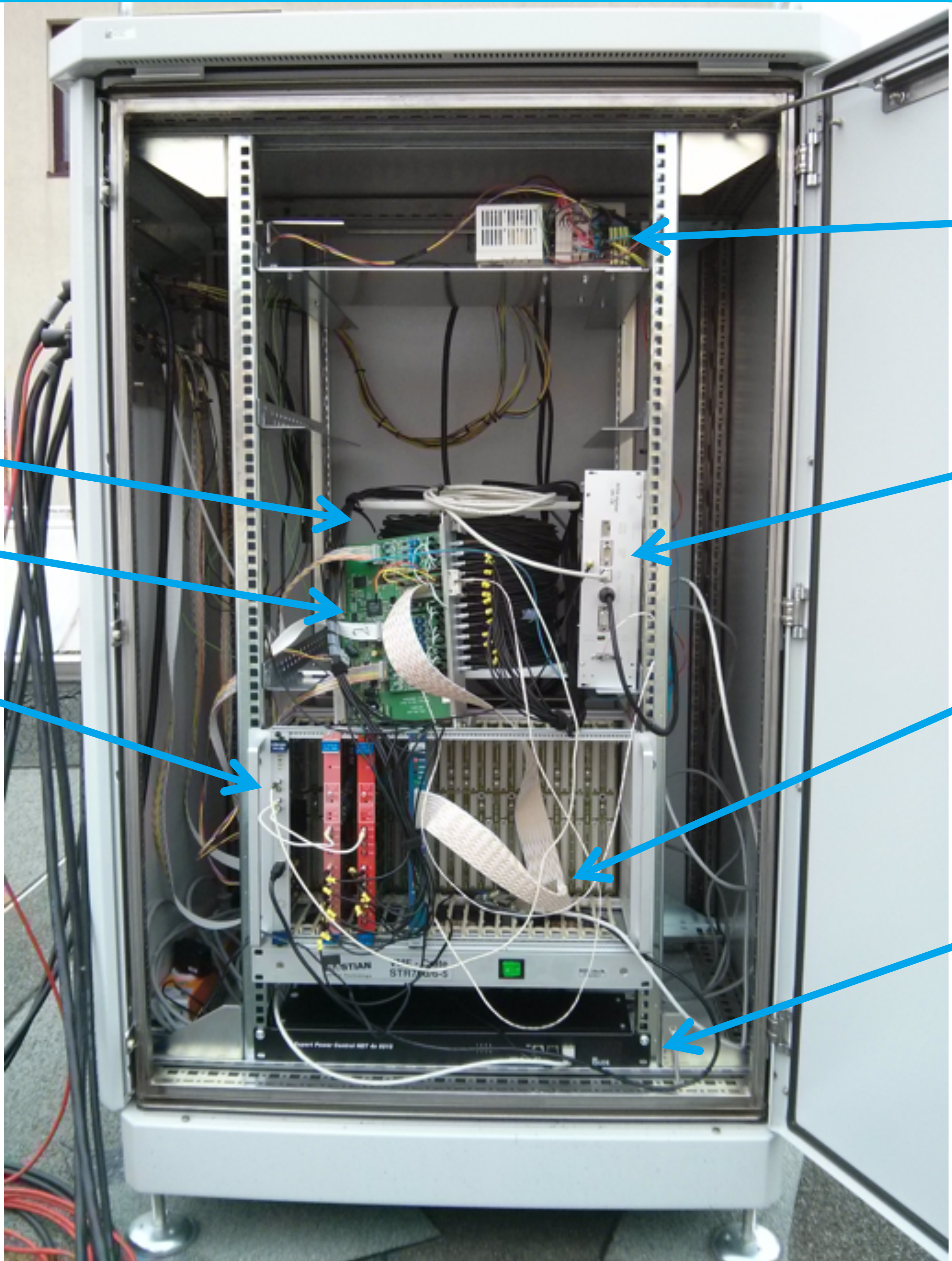
Trigger board

VME DAQ f. Scintillators (QDC + TDC)

VME readout: Raspberry Pi

Power control via Ethernet

Coming Soon: Low Power Single-Board DAQ



~~Power supply~~

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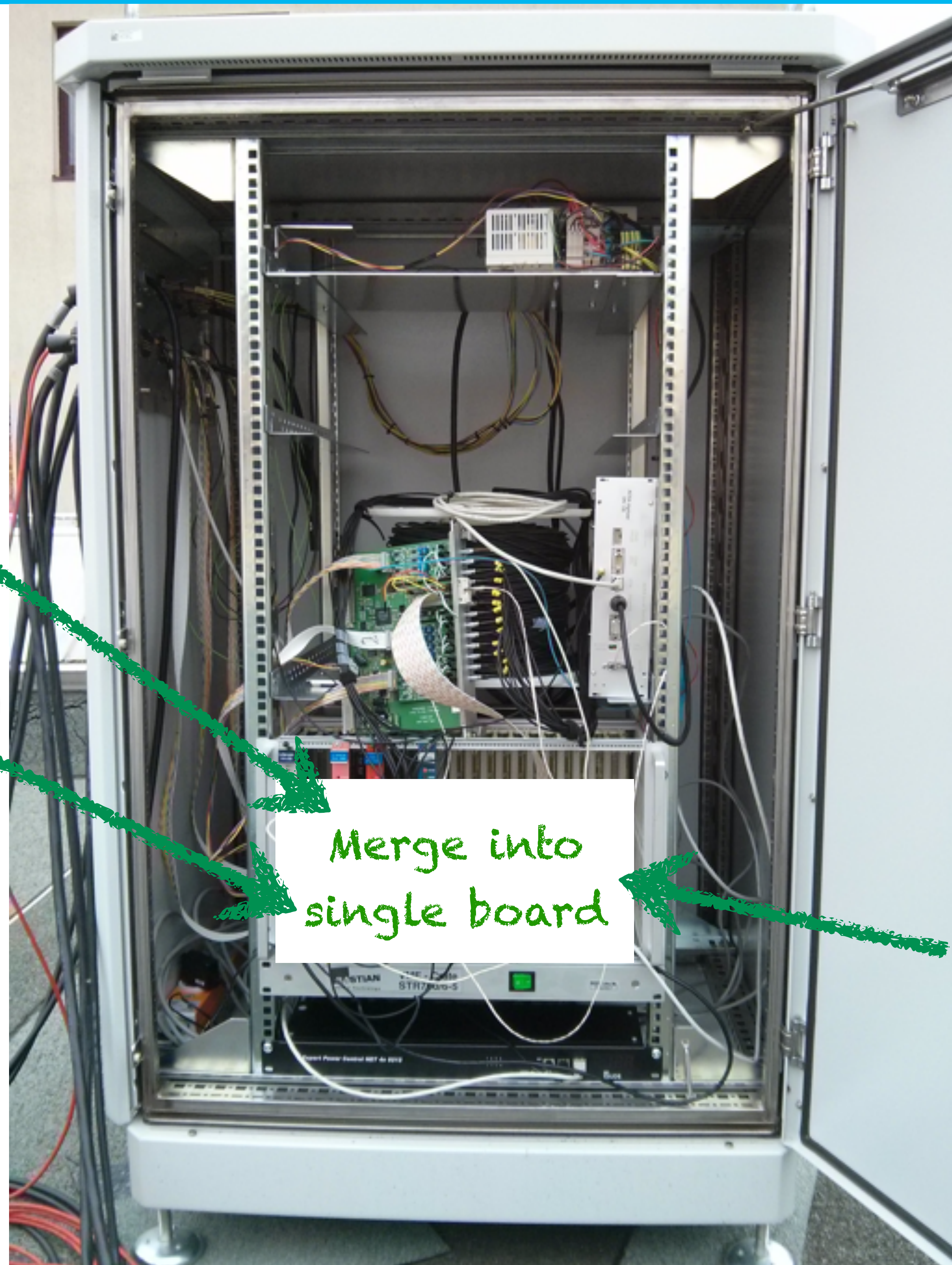


~~Power supply~~

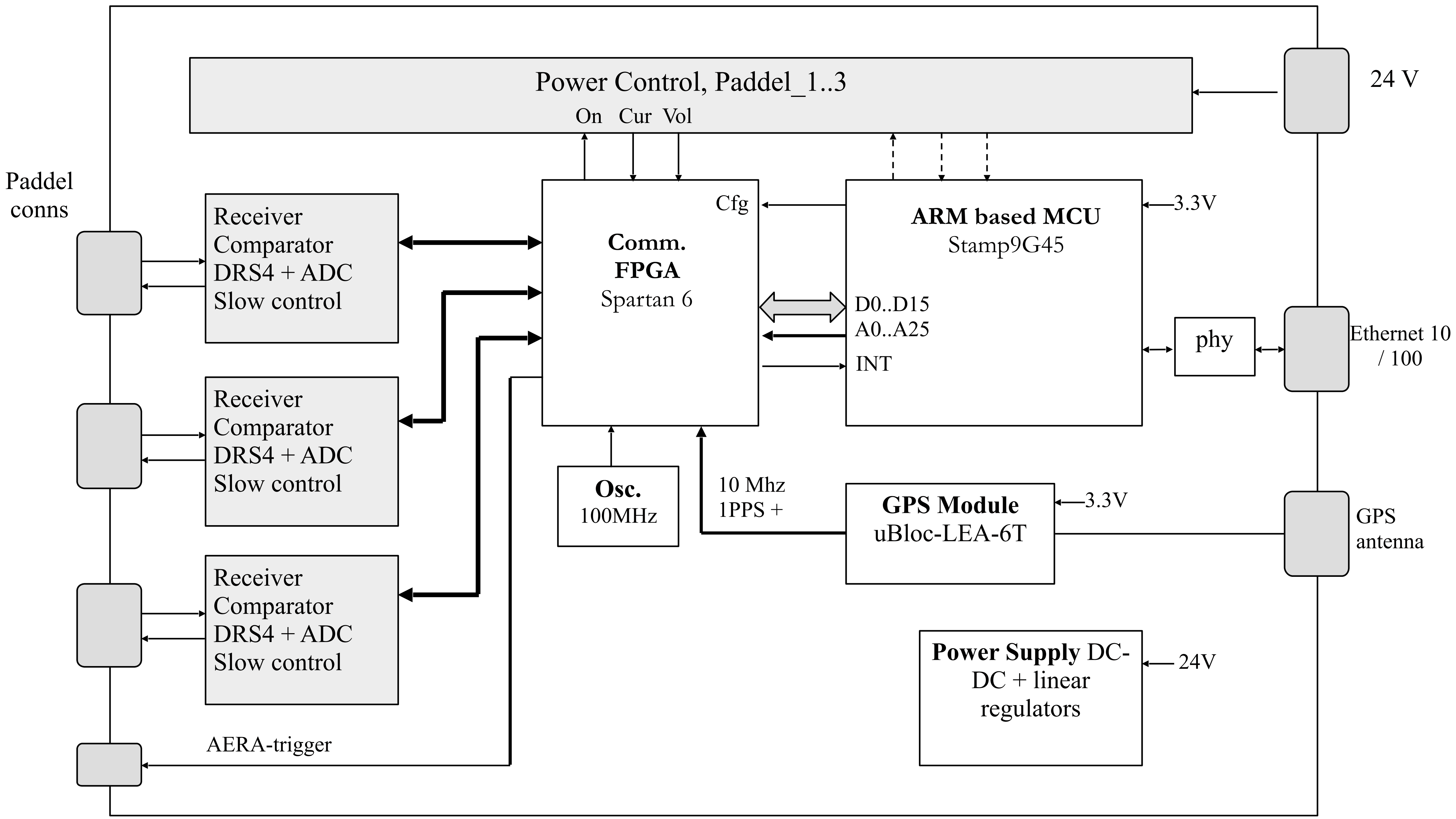
24 V input

AERA board

~~VME readout: Raspberry Pi~~

Power control via Ethernet

TAXI Station



courtesy K.-H. Sulanke

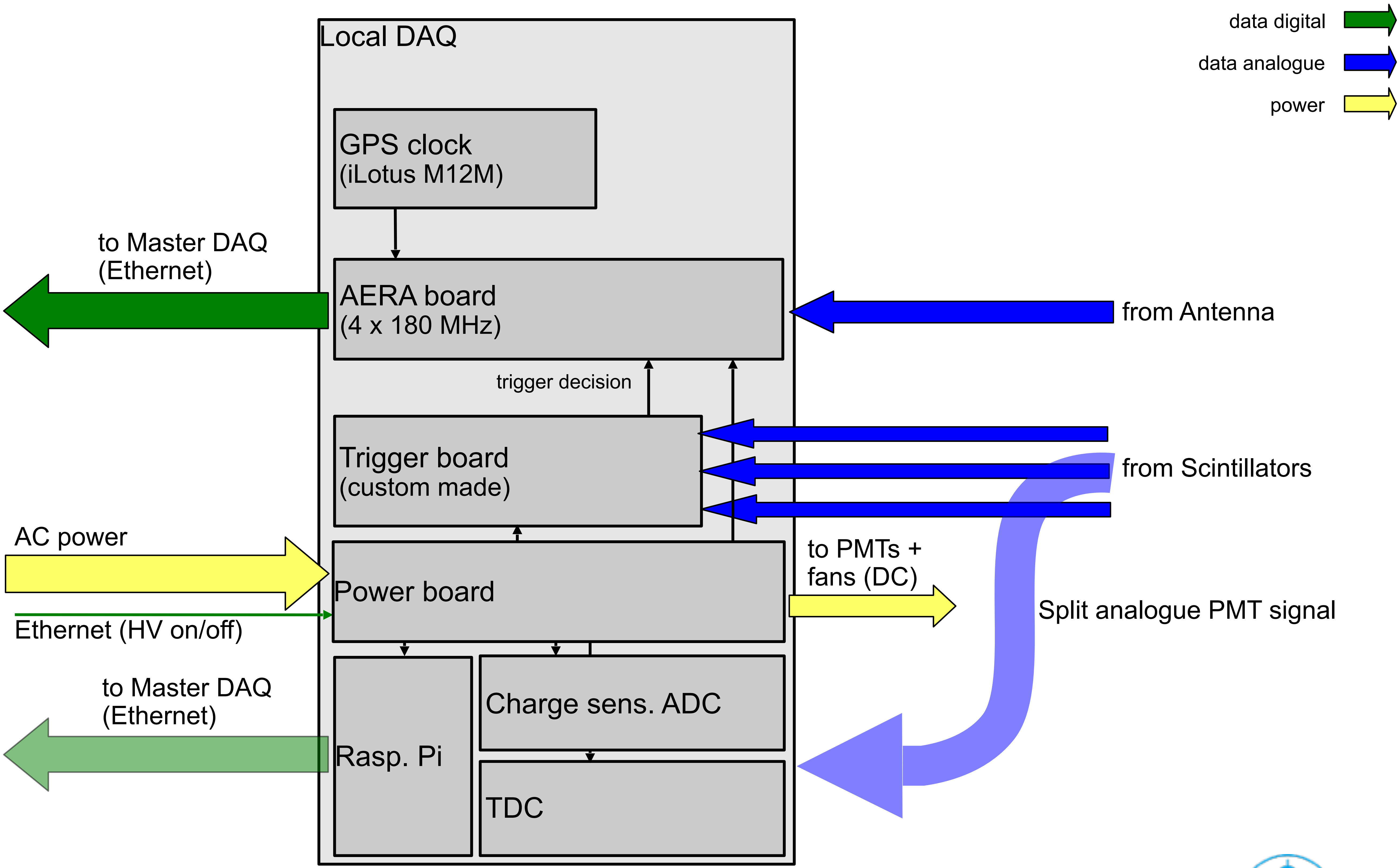
Summary and Outlook

- TAXI is a R&D system for large area instrumentation
  - Modular: Develop and test different components under realistic conditions:
    Power supply and distribution, communication, triggering, clock synchronization, …
  - Transportable: Perform short- and long-term site studies for prospective experiments
- One prototype station constructed and successfully taking data

- Mid 2014:
  Reach target power budget of < 20 W / station by replacing
  VME read-out for scintillators
- End 2014:
  Finish four station array in Zeuthen with generic interfaces
  for power and communications

Backup Slides

Station 1 Data Flow



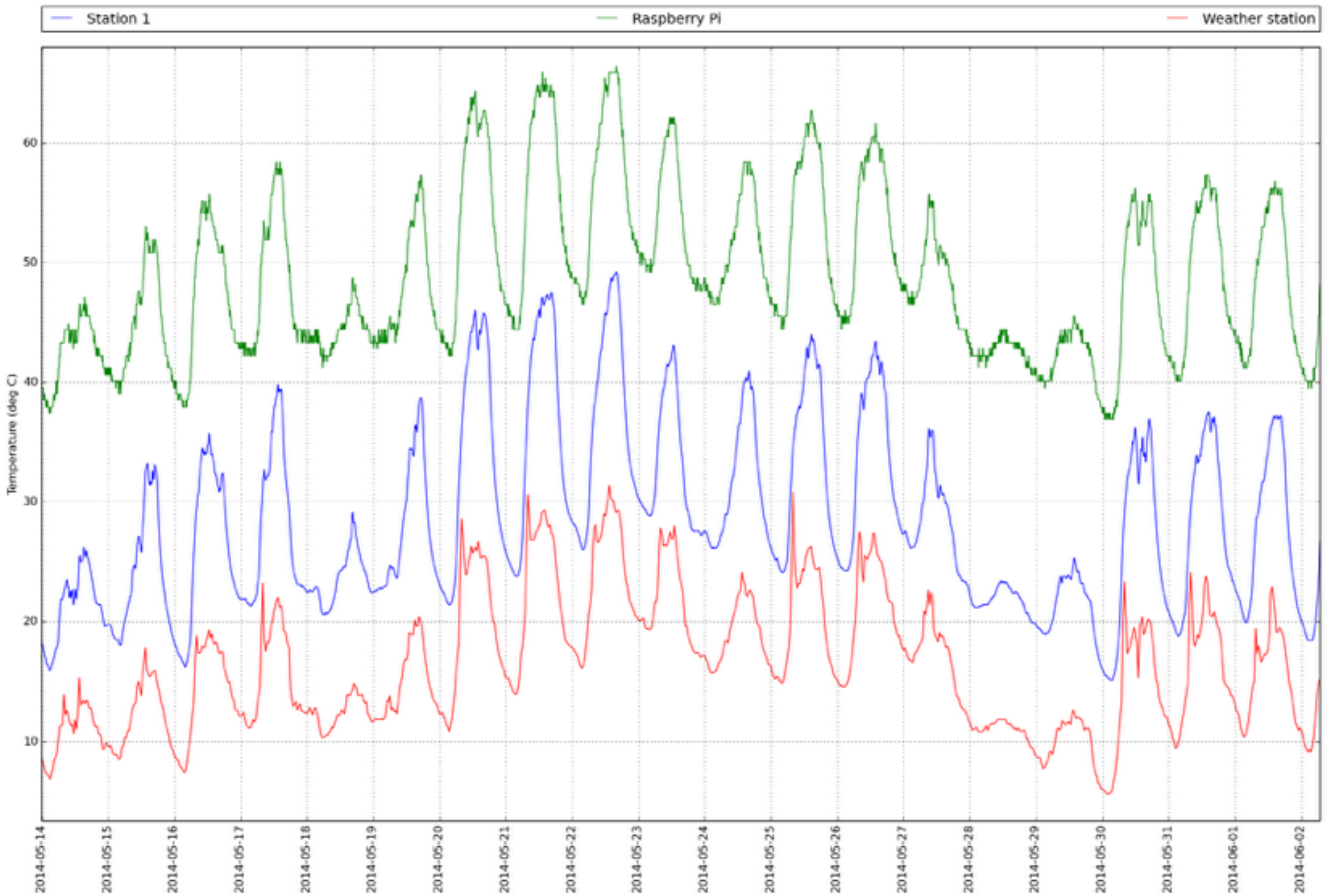
Trigger Board

- Custom made: DESY Zeuthen
- Trigger decision made in FPGA ⇒ flexible trigger logic
- Implemented as stand-alone board
- Inputs:
  - 24 differential, analog signals (3 scintillation detectors × 4 segments × 2 PMTs)
  - Differential receivers and discriminators on three mezzanine boards (1 per scintillation detector)
  - 24 digital signals from discriminators routed into FPGA
- Logic:
  - 1st step: require logical AND between the two signals from one scintillator segment (suppress PMT noise)
  - 2nd step: require at least one segment per scintillation detector in 400 ns
- Outputs:
  - global trigger (to AERA board, VME DAQ, TDC stop)
  - 12× analog signal (analog sum of 2 PMTs / segment)
  - 12× TDC start

Current Mode of Operation

- Unsupervised operation
  - Automatic run transitions every 4 hours
- Readout scheme
  - Scintillation detector triggers AERA board
  - AERA board transmits time stamp to central DAQ PC (in lab)
  - Central DAQ PC requests waveforms from AERA board
  - Can be easily extended to a trigger between several TAXI stations
- Currently, scintillation detector data and AERA board data written to separate streams and merged offline
  - Online data merging in progress
- Trigger rate ≈ 1 min-1

Station 1 Temperature



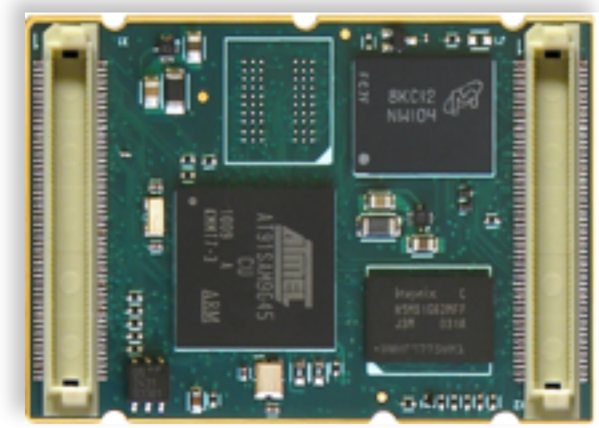
TAXI Station, Design Goal

- Single board design, power consumption < 10 W (w/o ADC)
- Communication via ethernet 10/100
- Single low cost Xilinx FPGA, Spartan 6
- 24 analog channel with differential input
- 24 discriminators with programmable threshold
  - minimum detectable signal: 1mV pk
- TDC functionality, time diff. measurements with 0.5 ns accuracy
- Time stamping
- Optional 24 ADC channel, 1024 samples per channel
  - Sampling rate 200 MSPS … 6 GSPS (DRS4)
  - Dead time: TBD

courtesy K.-H. Sulanke

Ethernet to FPGA Bridge

- ARM based MCU unit (100 €), primarily as ethernet to comm. FPGA bridge
  - Stamp9G45's PCB is only 53.6x38x6.0 mm
  - AT91SAM9G45 runs at 400 MHz with a memory bus frequency of 132 MHz
  - 10/100 Mbit Ethernet, USB, UARTs, …
  - 128 MB NAND flash memory (optional up to 1GB)
  - 128 MB LPDDR-SDRAM (optional up to 512 MB)
  - 16-Bit parallel CPU-Bus (fast FPGA conn.)
  - Memory mapping, DMA, …
  - See also http://www.taskit.de/home.html
  - Comes with real time linux development system
  - Widely used at DESY Zeuthen
  - 400 MHz ARM core can do more than just moving data
  - Might be replaced later
    - e.g by adding the interface part to the Xilinx FPGA



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