Performance of the new PANDA Forward-Endcap PbWOII-EMC measuring neutral pions produced by the COSY beam

Meike Küßner

University Bonn - HISKP

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Federal Ministry of Education and Research

NRW-FAIR Netzwerk

P̄ANDA Physics Program

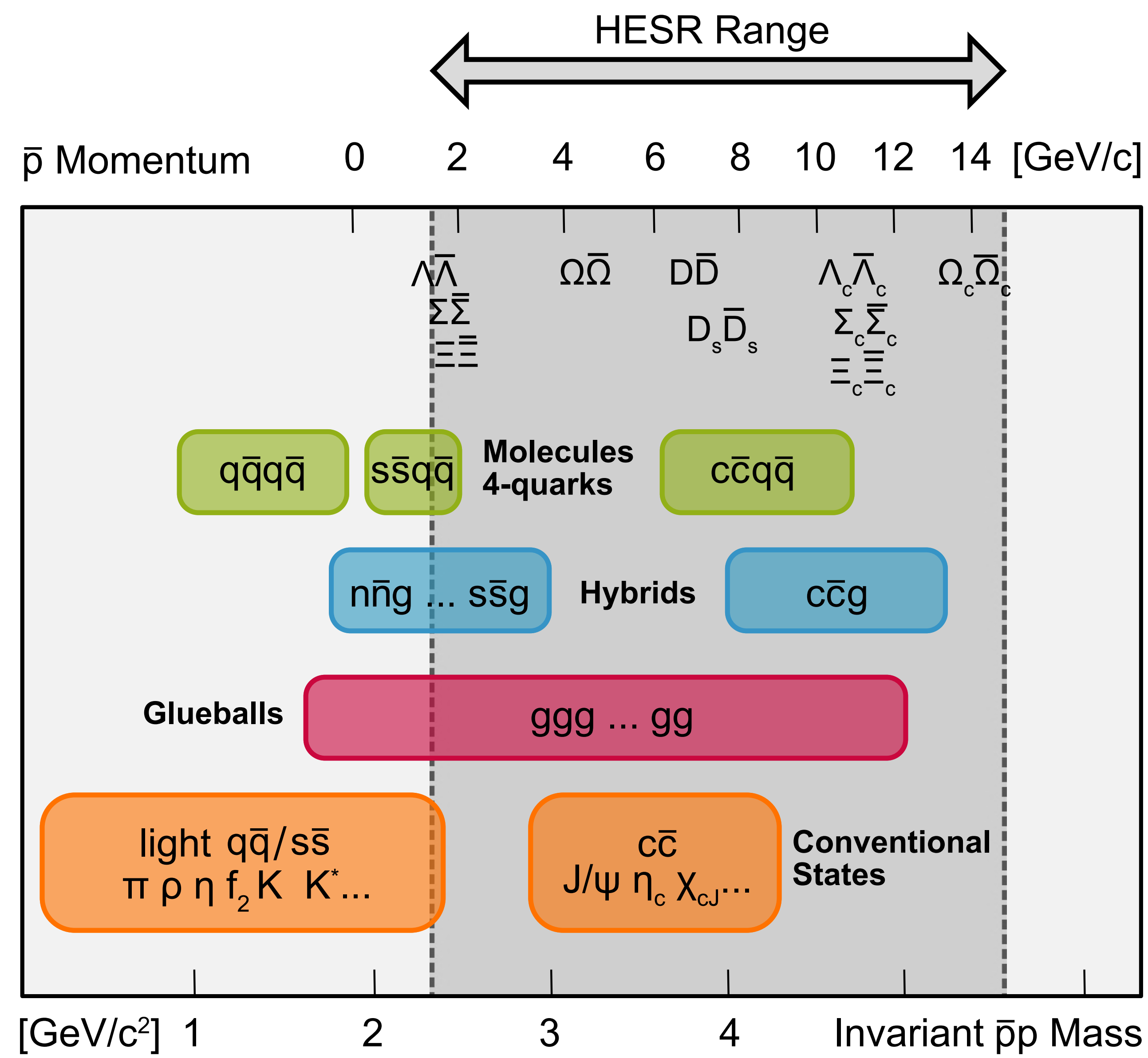
Hadron Spectroscopy

- Light mesons
- Exotic matter (Glueballs, Hybrids etc.)
- Charmonia (including XYZ states)
- Open Charm Physics
- Baryons and Hyperons

Nucleon Structure

- Generalised Parton Distributions (GPD)
- Transition Distribution Amplitudes (TDA)
- Time-like proton form factor
- Transverse Parton Distribution

Physics of Hypernuclei

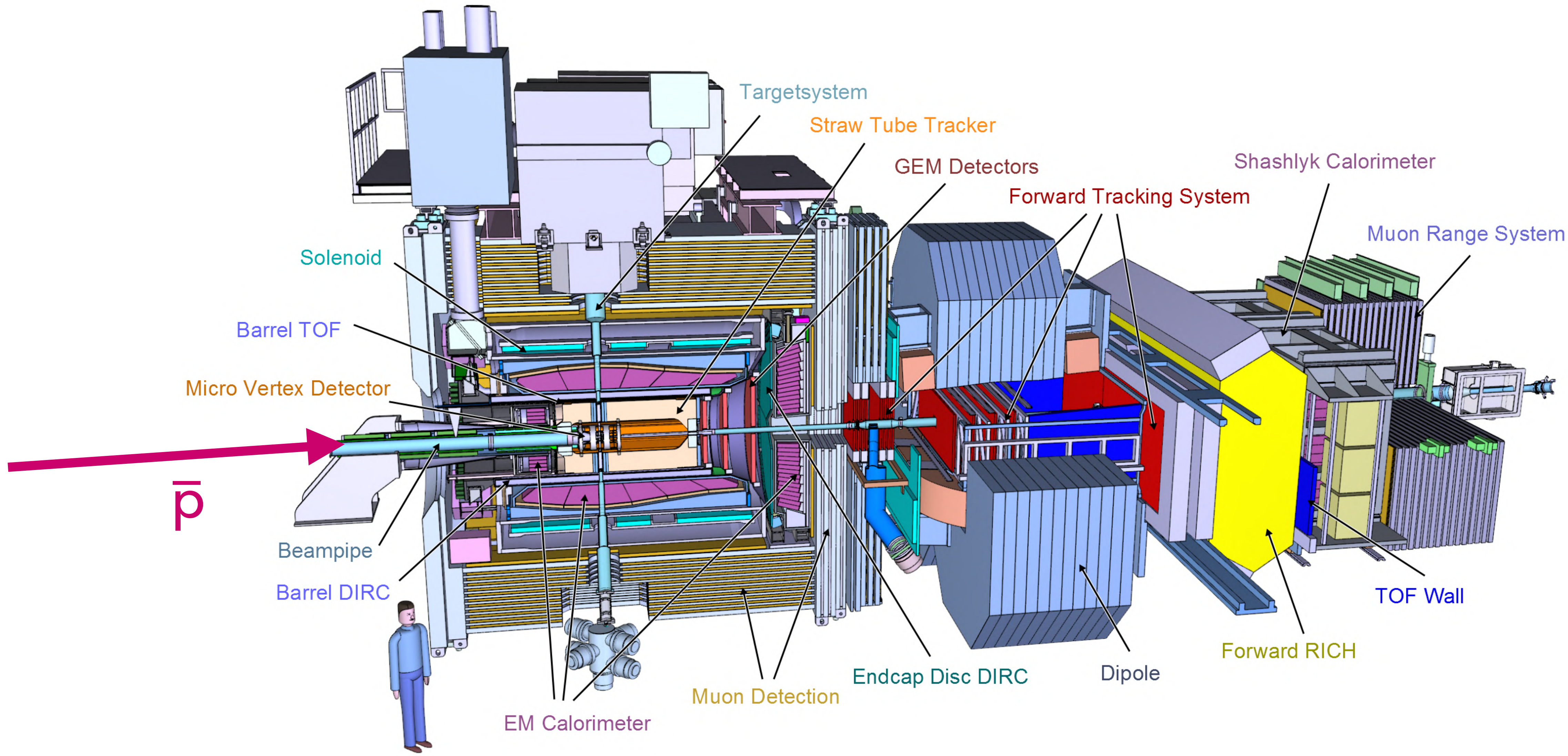


Very broad program

P̄ANDA can contribute to various fields!

The P̄ANDA Experiment

- Fixed target experiment
- Anti-proton beam momentum range: 1.5 -15 GeV/c (max. $\sqrt{s}$ = 5.5 GeV)
- Design luminosity: 10^{31} cm^{-2} s^{-1} - 10^{32} cm^{-2} s^{-1} ➡ High event rates
- Almost full coverage of solid angle due to forward dipole magnet
- Excellent momentum resolution in formation



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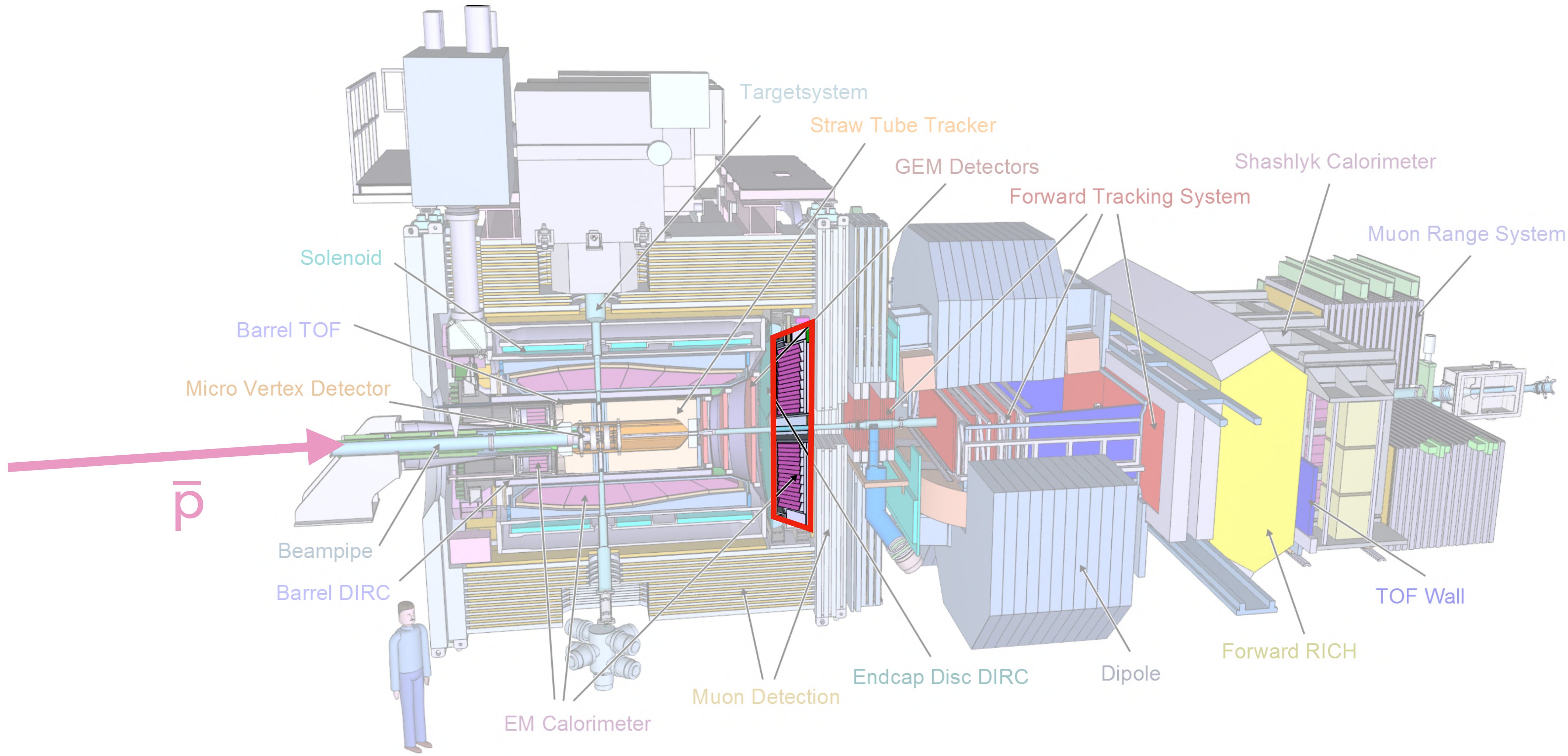
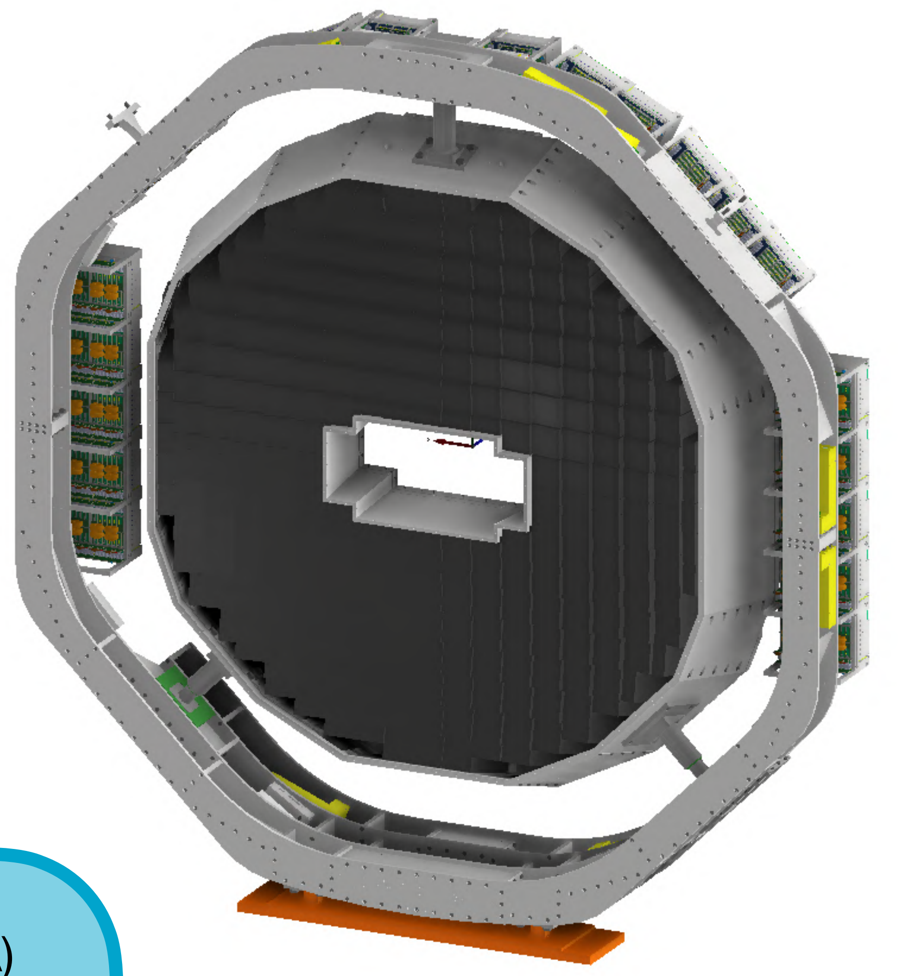


The $\bar{\text{P}}$ANDA Forward Endcap EMC

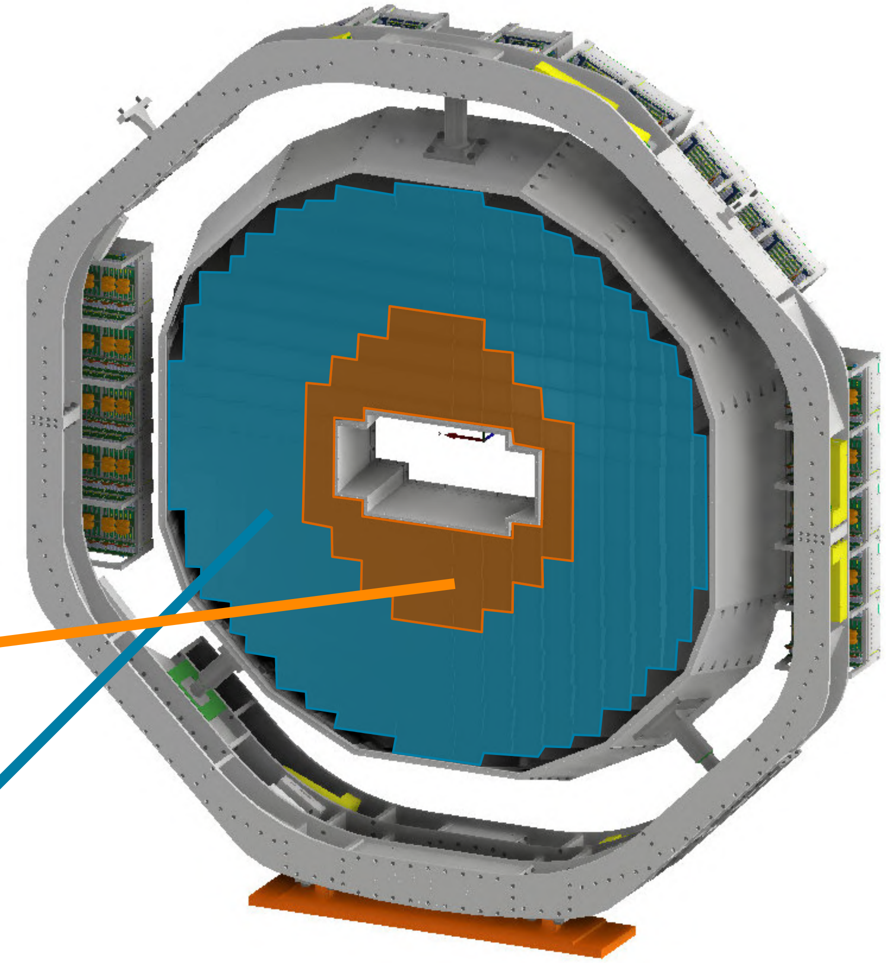
- 3856 $PbWO_4$ crystals
- Angular coverage: $5^\circ < \theta < 23.6^\circ$
- Magnetic field of up to 1.2 T
- Off-pointing geometry
- High dynamic range: 3 MeV – 12 GeV
- Single crystal hit rates up to $10^6\,\mathrm{s}^{-1}$ (full lumi)



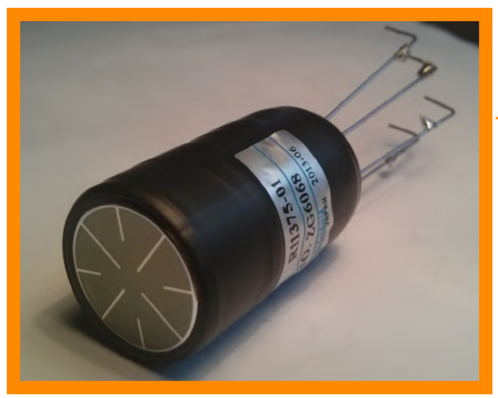
	PWO-I (CMS)	PWO-II (PANDA)
Light yield of a 20cm crystal [phe/MeV]	8-12	17-22
Light yield temperature coefficient	-2.0	-3.0
Ideal working temperature	+18°C	-25°C
statistical term of resolution [%]	2.7	2.0
La, Y concentration [ppm]	100	40

Photodetector Readout

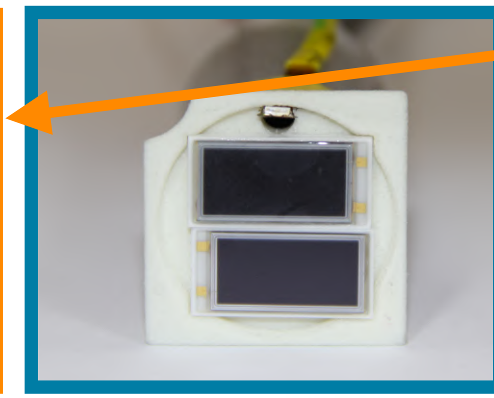
- Crystals are read out by Vacuum Photo Tetrodes (VPTTs) and Avalanche Photo Diodes (APDs)



VPTT (Hamamatsu)



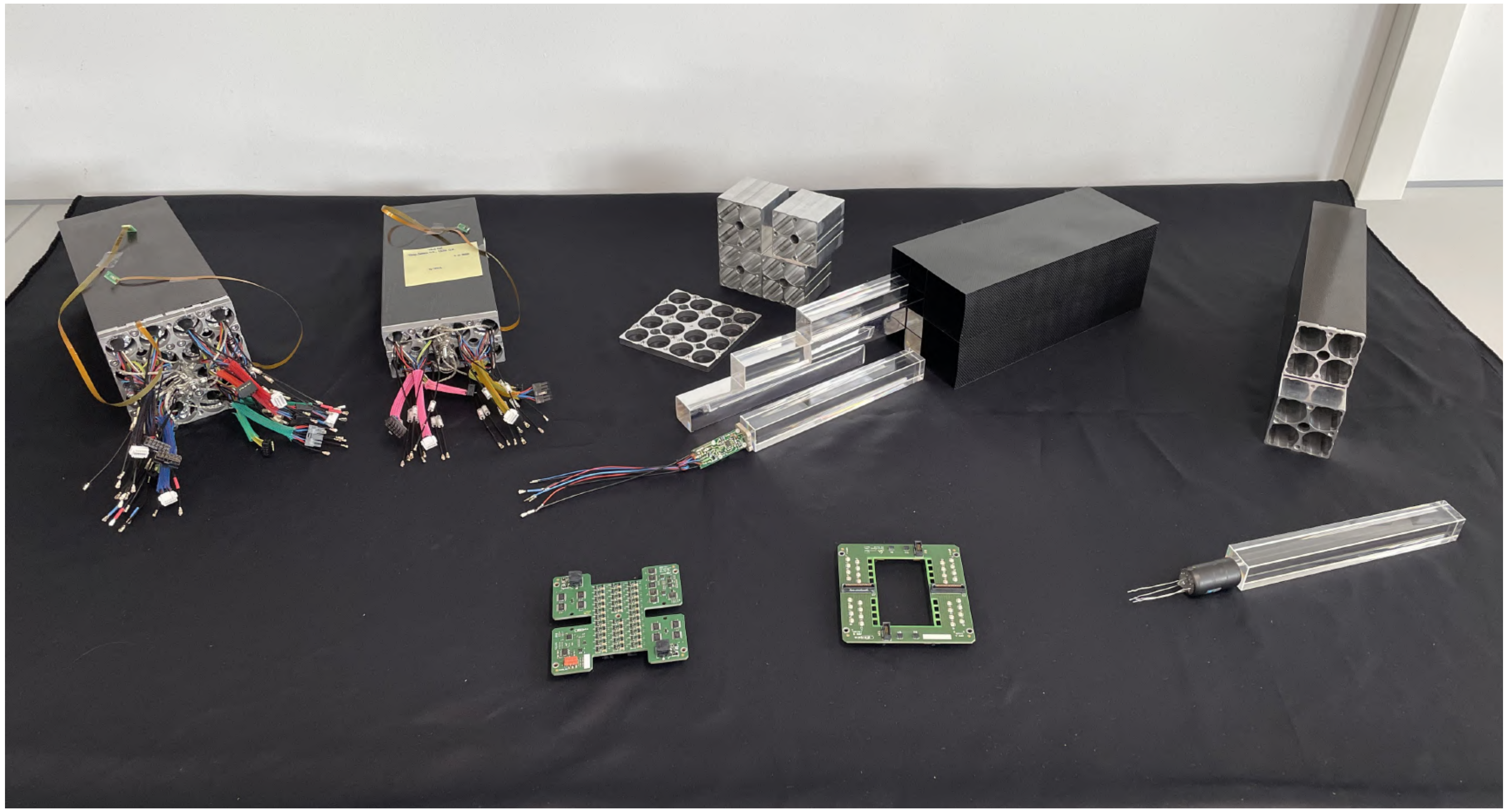
APD (Hamamatsu)

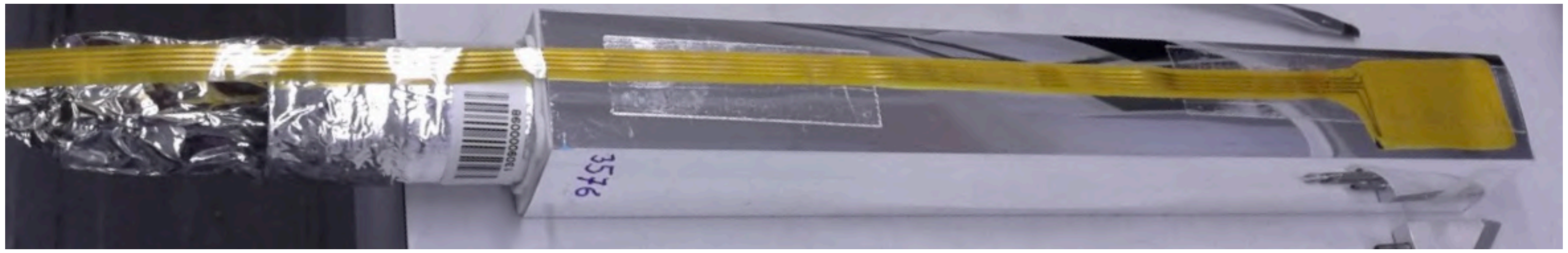


	VPTT	APD
Quantum efficiency	≈20%	≈80%
Active area [cm²]	1	2
Gain	50	200
Dark current	≤1 nA	≈1 pA
Capacitance [pF]	≈22	≈270

Crystal Units and Submodules

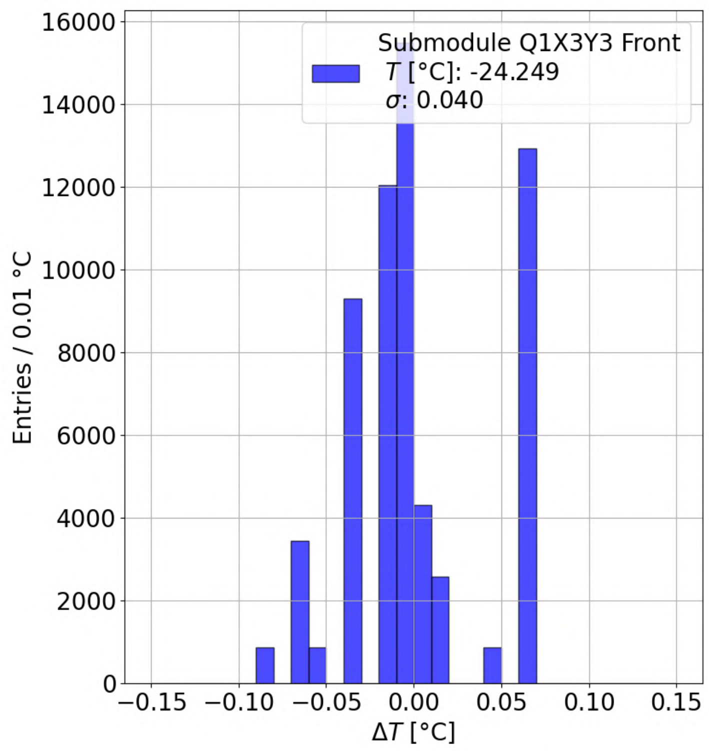
- Crystals are glued to photodetectors which are equipped with pre-amplifier
- Submodules consist of 16 or 8 crystals
- Arranged in carbon fibre alveoles for mechanical support
- Individual orientation angle of module set by interface piece between backplate

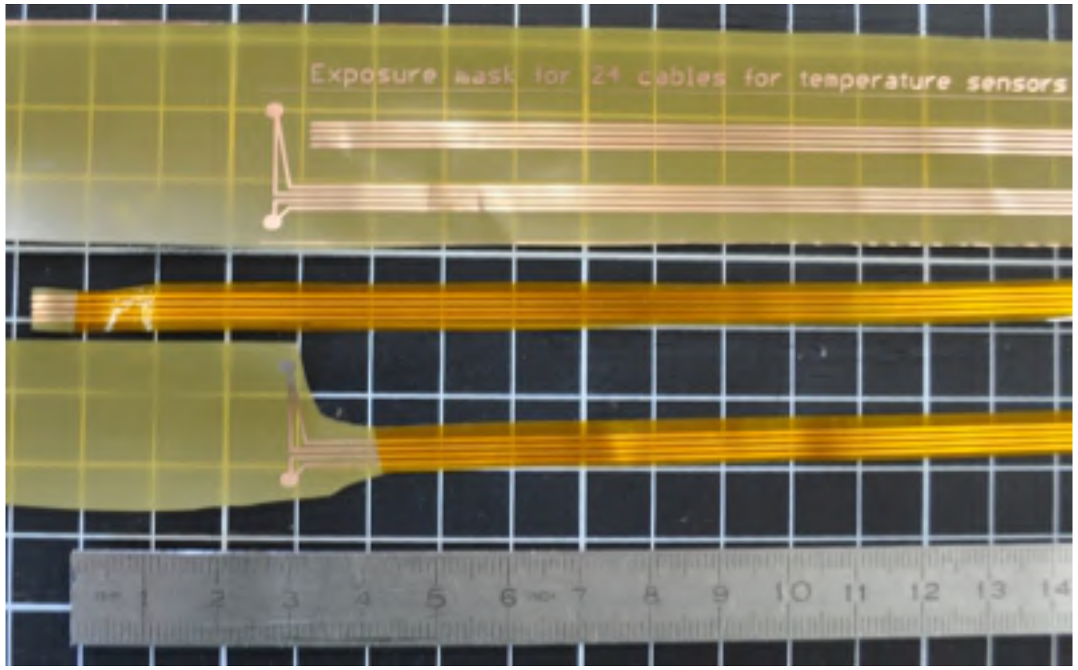


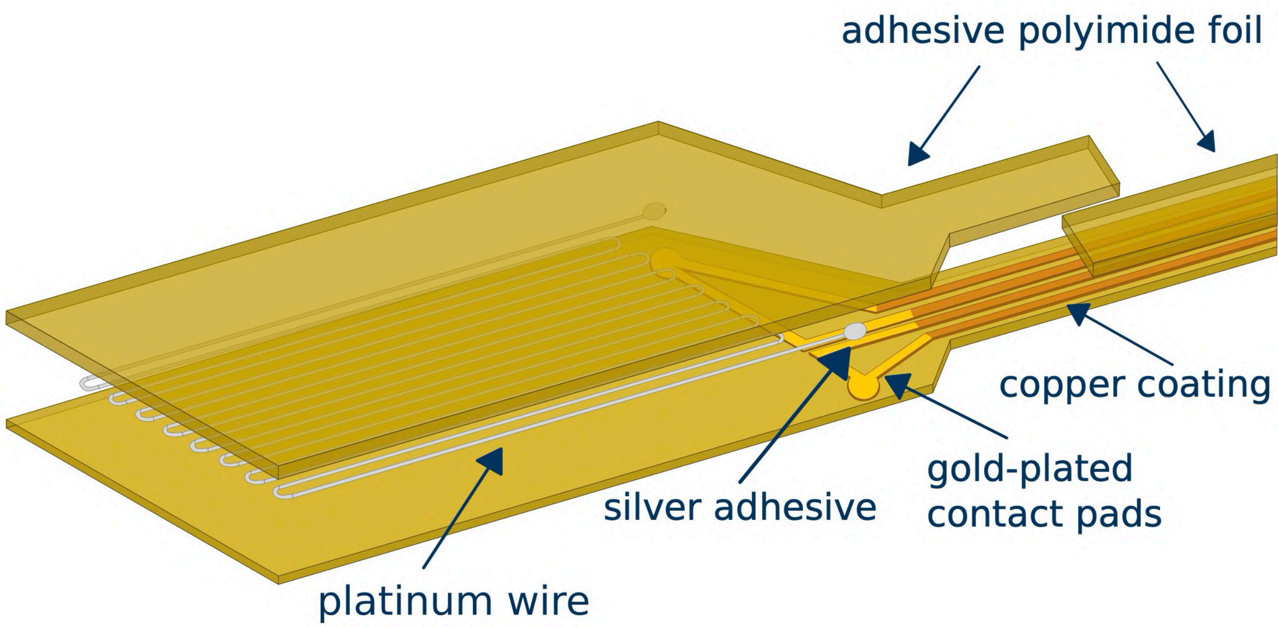


Temperature Monitoring

- Crystal light yield and APD gain temperature dependent
  ➡ High precision control and monitoring of temperature mandatory!
- Temperature monitored directly at crystals, 2 sensors per module
- In house developed thin Pt-sensors (thickness $<$160 µm)
- Sensors's T-R curve measured and individually calibrated
- Design Requirement: ΔT $<$0.1°C, Resolution: $<$0.05°C

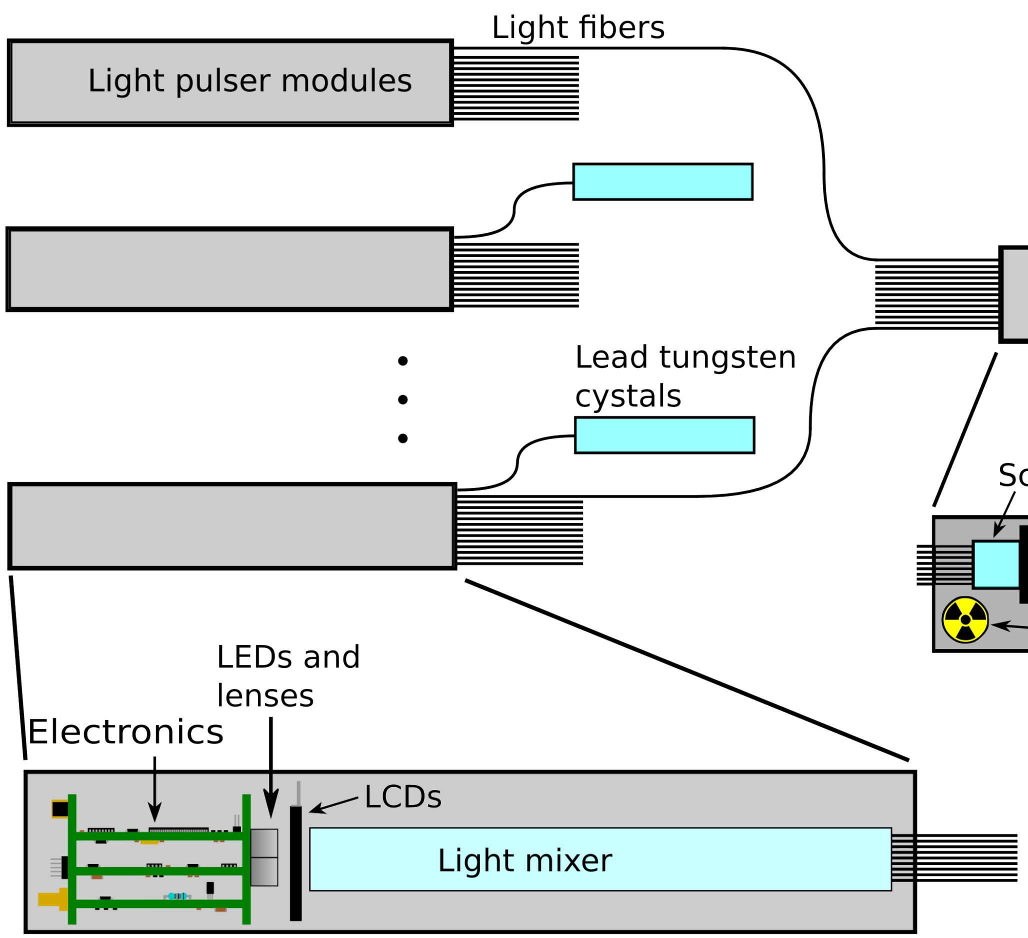






Light Monitoring System - Light Pulser System

- Blue, red, green LED pulses
- Blue LED to detect radiation damage in crystal
- Green/red LED to detect electronic failures
- Attenuation and control using LCD elements
- Light fibres connected to each crystal unit



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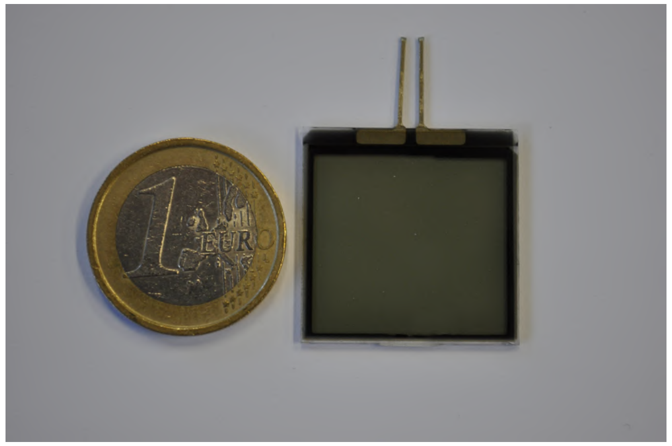
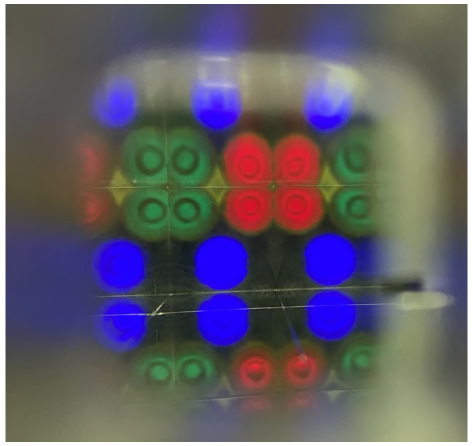
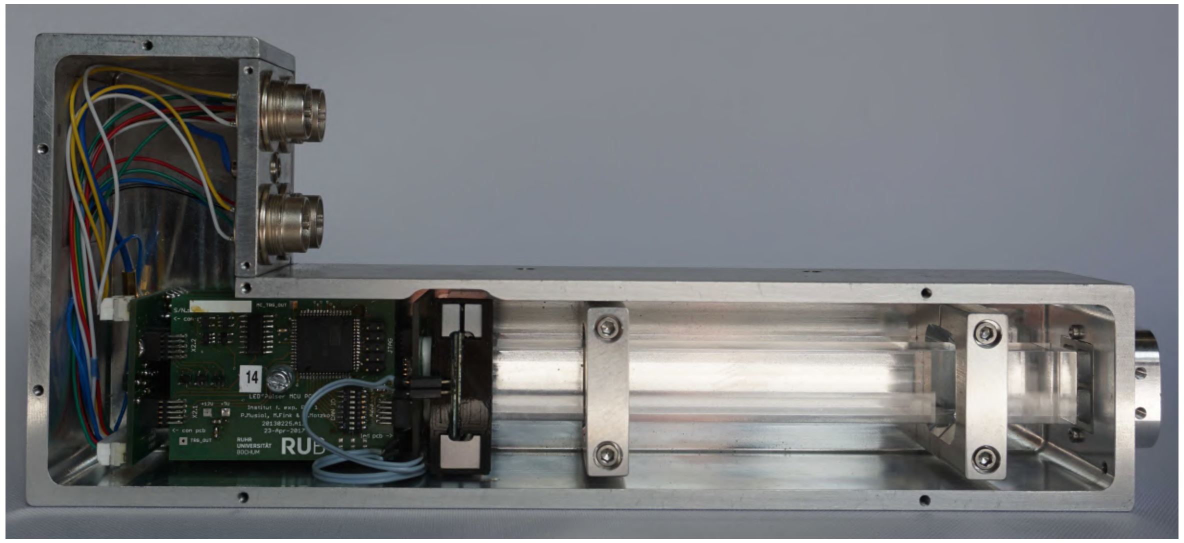
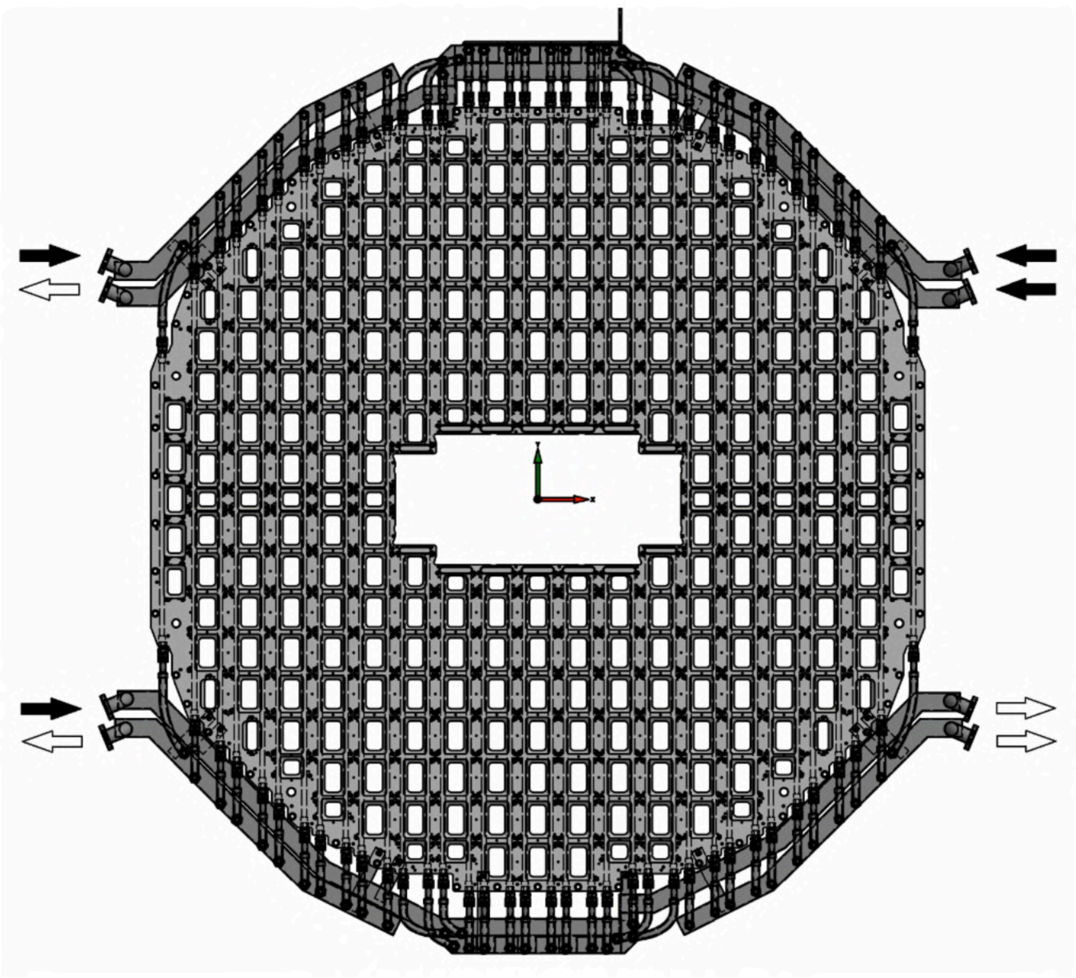


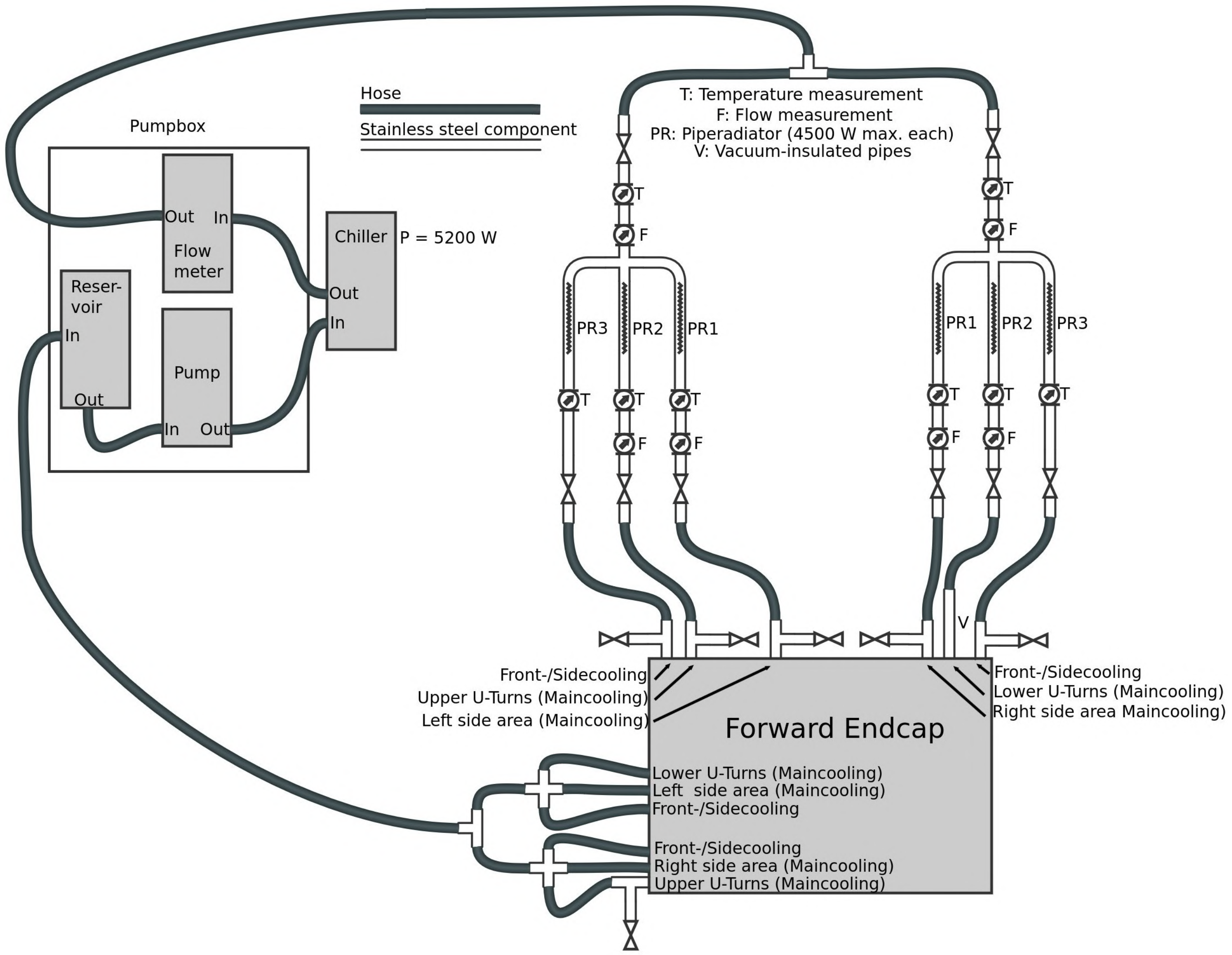




Cooling System

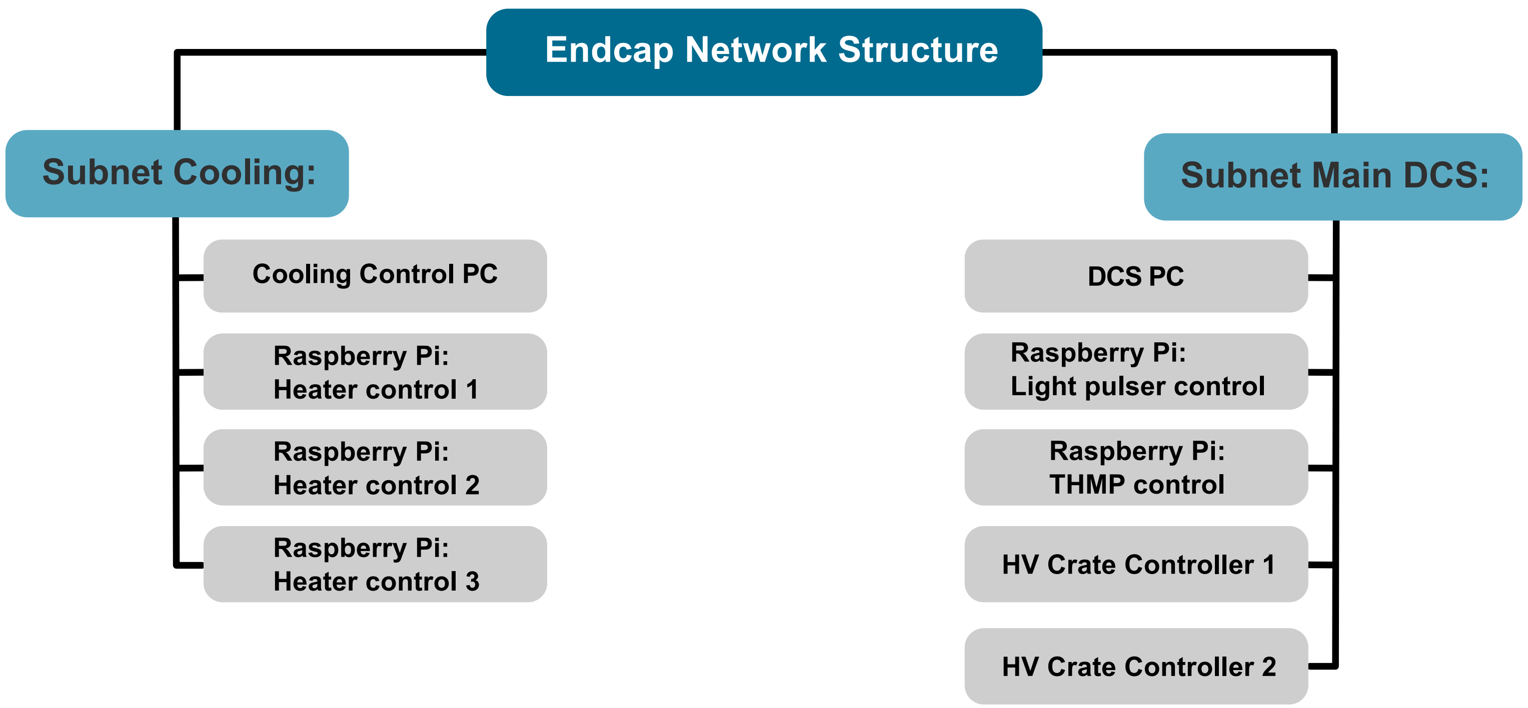
- Main cooling lines are drilled through backplate
- In addition front and side cooling lines
- Main chiller has a power of 5.2 kW
- Heater pipes are needed to keep coolant temperature stable when cooler sets in
- Dry air/nitrogen flow for cooling and dehydration in cold volume
- Thermal insulation using two layers vacuum insulation panels
  - Very low thermal conductivity, custom made, expensive, susceptible





Detector Control System Setup

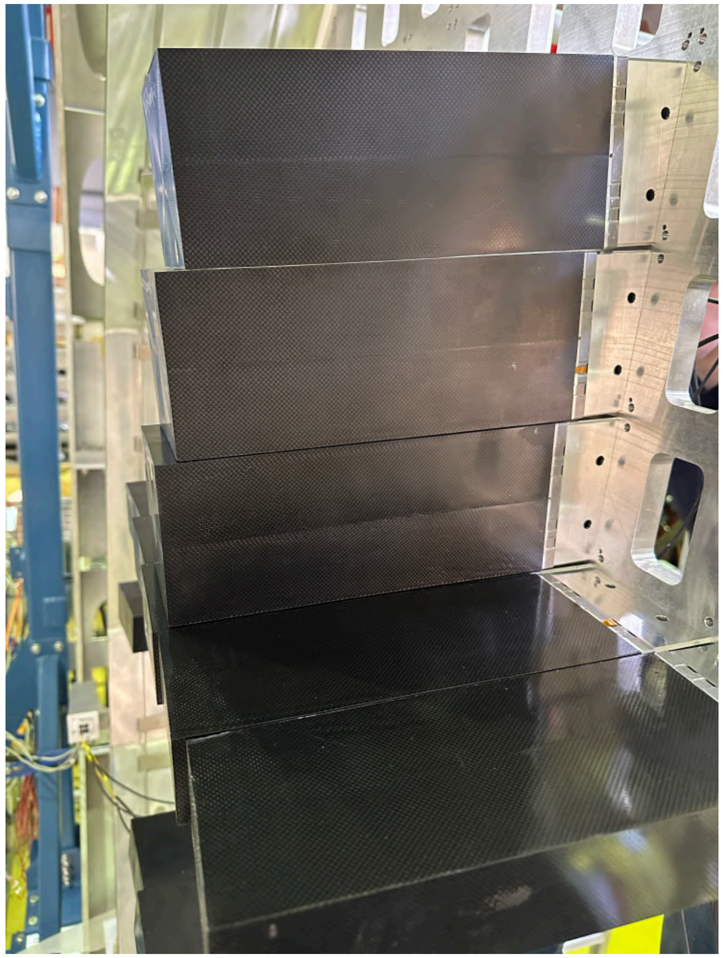
- Everything controlled using Epics as planned for the later configuration for full PANDA:
  - 2 iseg HV crates (216 channels in total used)
  - 4 Wiener PL500 LV (each 16 channels)
  - 4 light pulsers and 4 THMPs operated
- EPICS for subsystems and Archiver running in Docker containers
- Setup is ready to be easily extended to the full setup



- Everything worked stable over the two beam times!

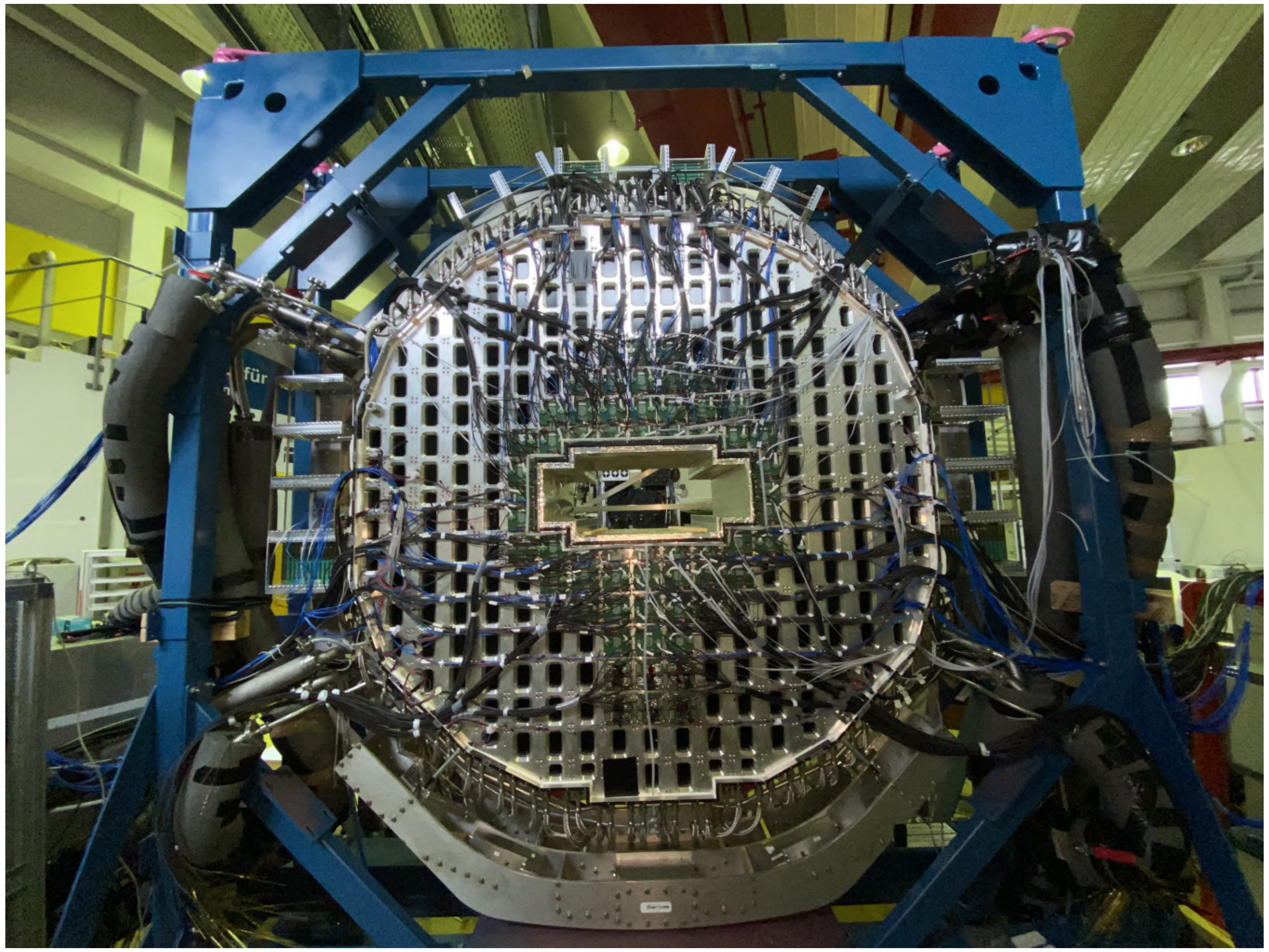
Module Mounting

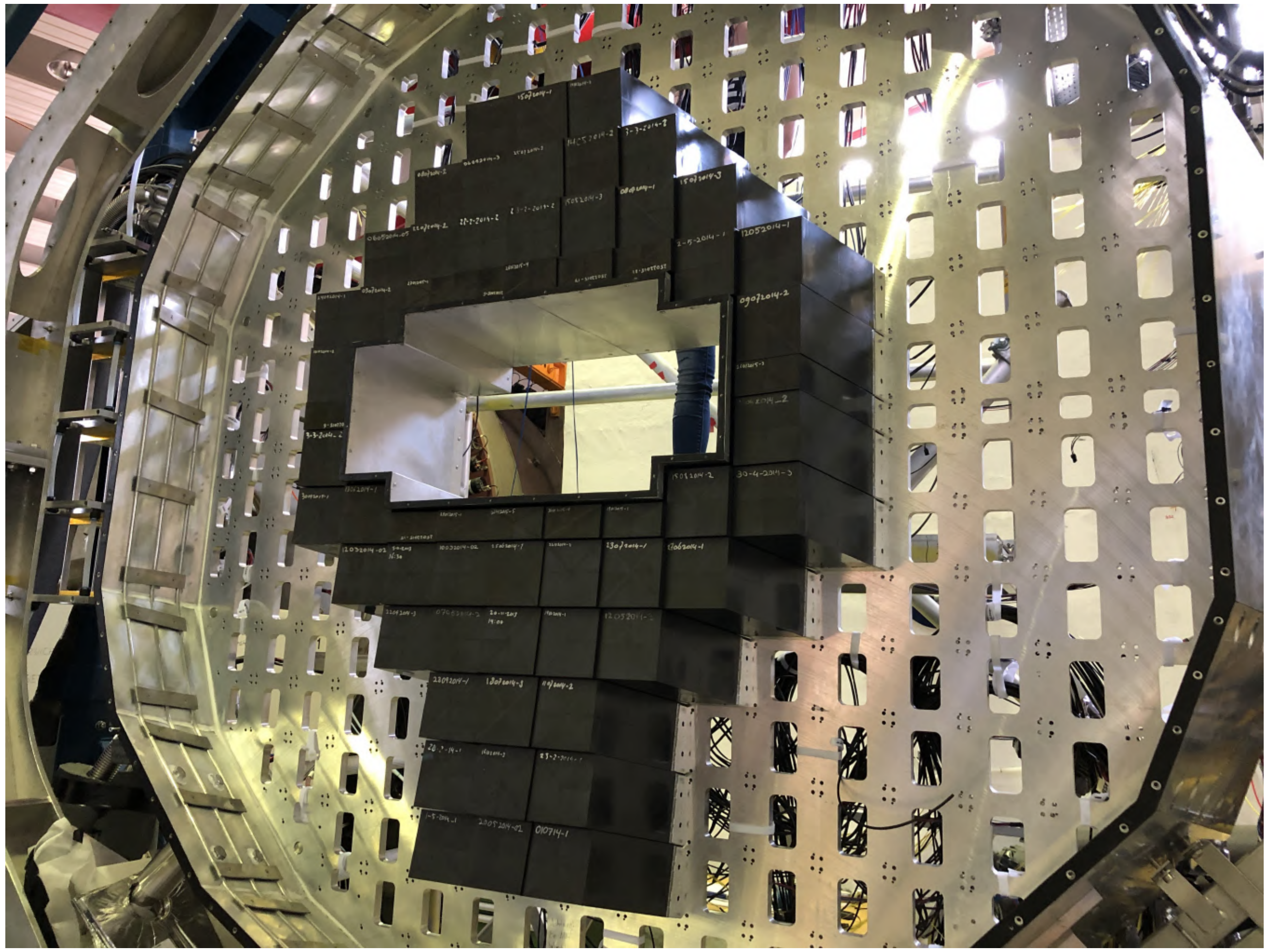
- All submodules tested and pre-calibrated with cosmics measurements at -25°C
- Precise determination of external dimensions
- Carbon fibre alveole then glued to aluminum inserts
- Module mounted to backplate using a hydraulic arm
- Module position and backplate deformation precisely measured using a laser measurement system



Beam Time Setup

- Beam time setup:
  - All VPTT modules mounted + 6 APD submodules
  - ➡ 864/3088 crystals mounted
  - 2.3 GeV proton beam ~ 10^8 protons/s on plastic target in 2 m distance from detector





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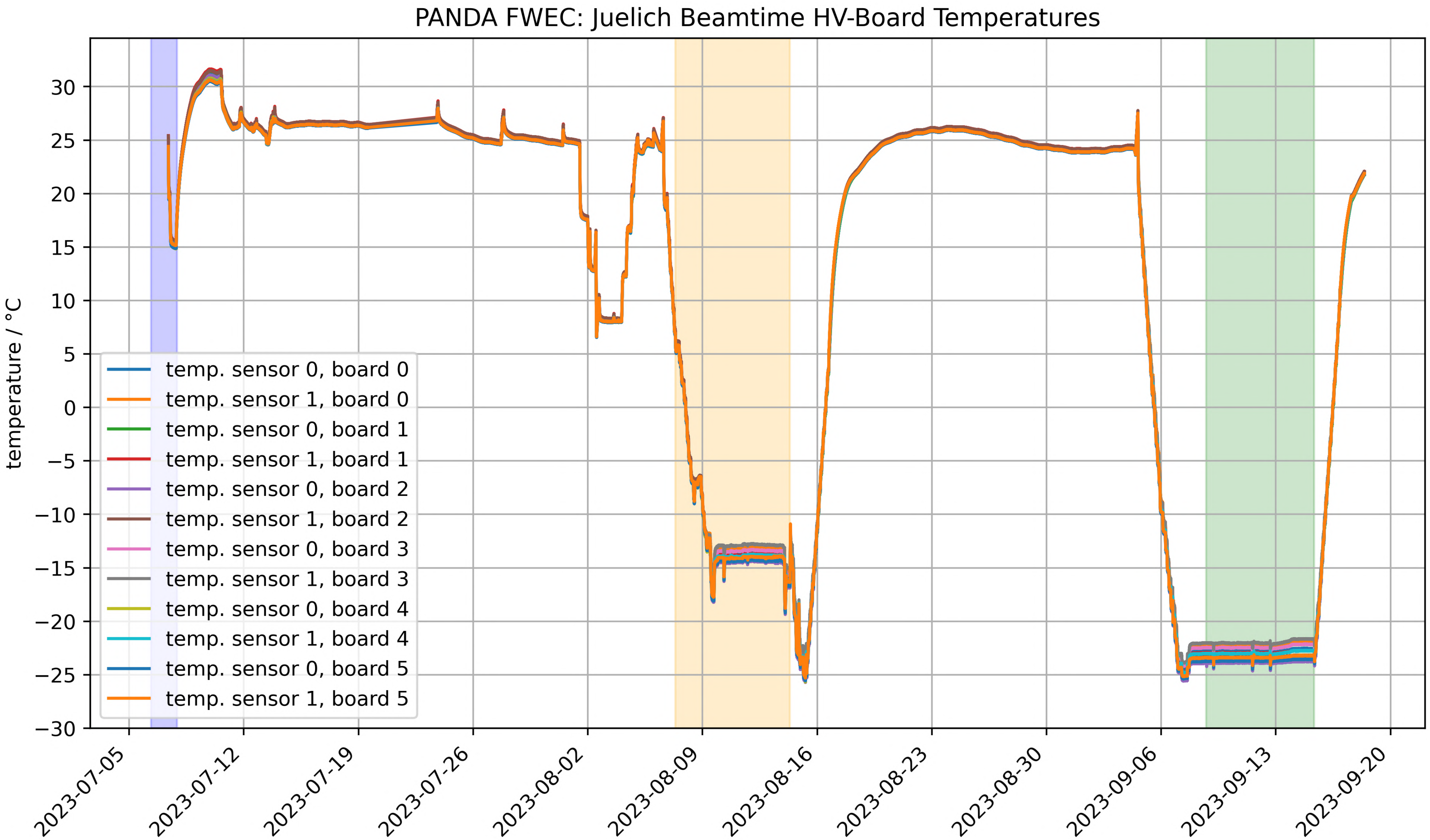
Beam Time Setup

- 2 days of DAQ and hardware tests in July 2023
- 2 weeks of test beam in August and September 2023, 4 days for cool/heat down/up
- Cosmic runs in beam down-times



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- **1st Beamtime:**
  - 1 week data taking
  - Reached temperature of -15°C
    - ➡ useful for light yield studies
- **2nd Beamtime:**
  - Design operation temperature of -25°C reached !!!
  - Higher rates due to waveform suppression
    - ➡ useful for pion-calibration and energy resolution studies

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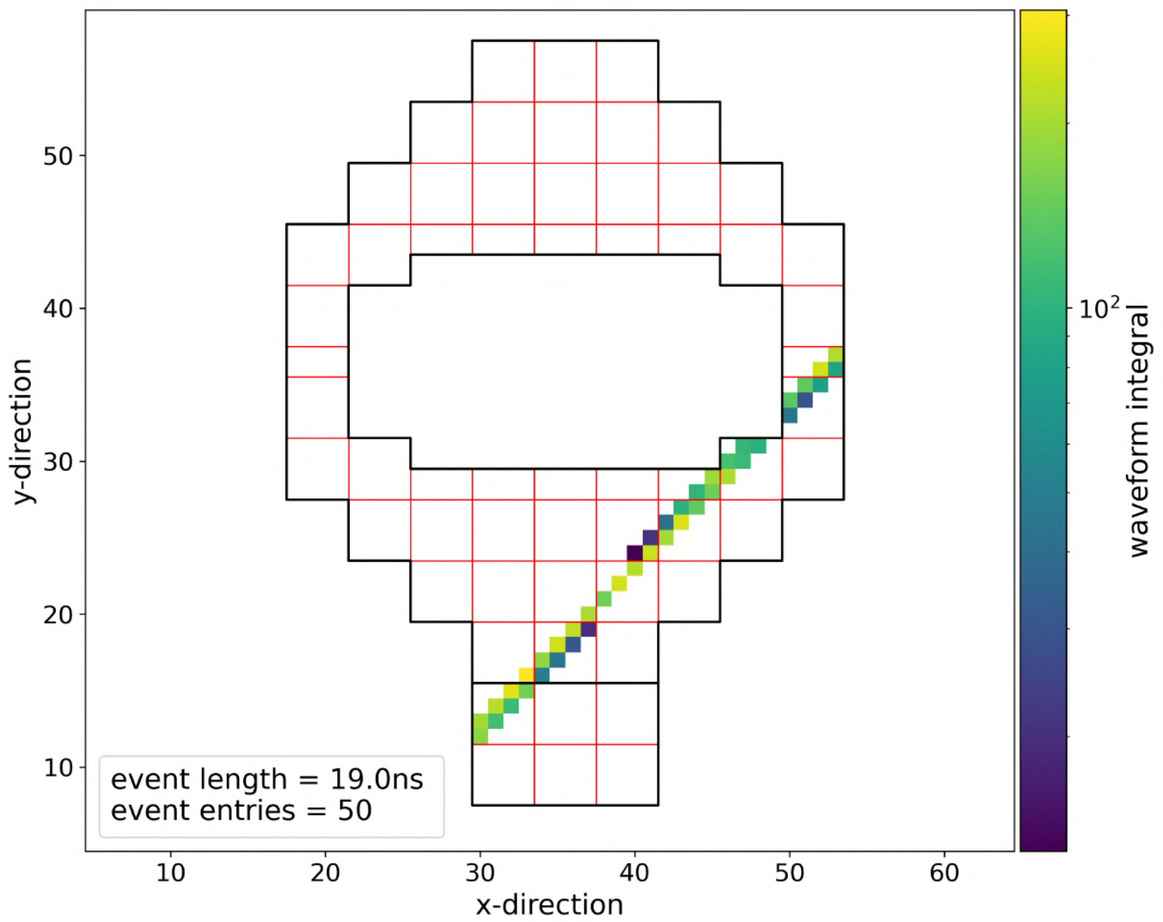
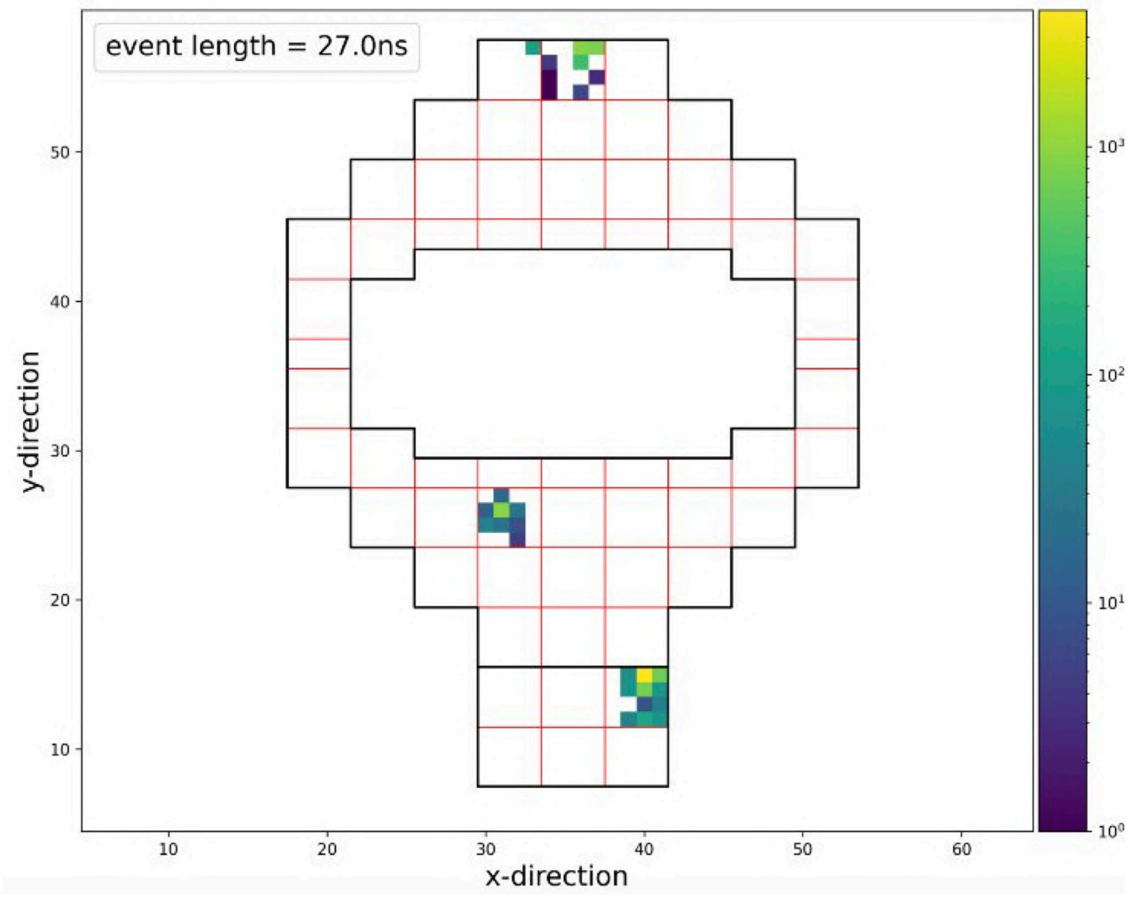
- Cosmic runs in beam down-times

Cosmic event example



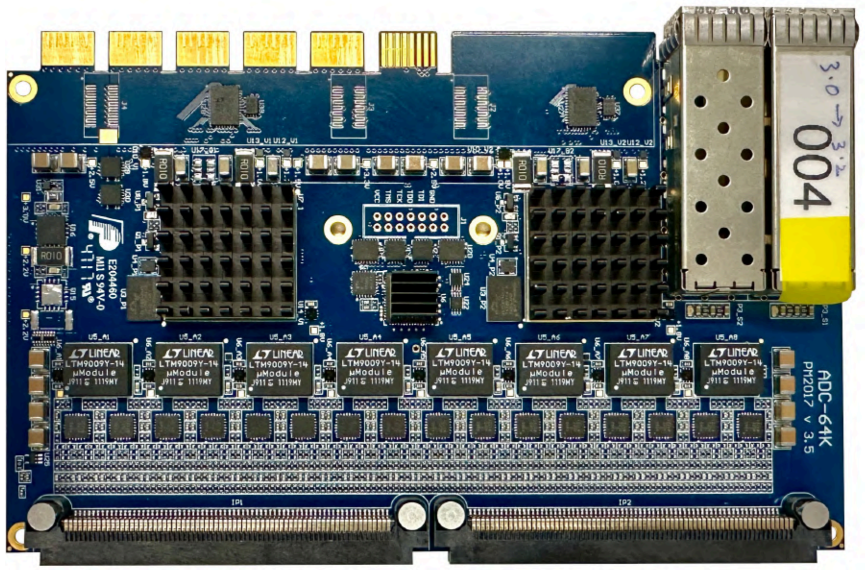
Proton event example



Read-Out and Digitization

- 2 Kintex-7 FPGAs, online feature extraction
- 2 optical interfaces (SFP, 2 Gbit/s)
- Dedicated cooling crates located directly in support frame
- In total about 220 boards used
- 64 channel Sampling ADC boards
- 80 MS/s, 14 bit resolution
- Analog shaping stages
- High/low gain splitting

PANDA SADC



Data Acquisition

- Forward endcap in its final setup used for the first time:
  - ➡ feature extraction not tested to the last detail in full setup
- To be on the save side:
- To maintain all infos ➡ store waveforms
- Very large amount of data, 512 x 16bit ➡ 1kB per channel
  - ➡ Reduce network data transfer by
  - ➡ suppress empty channels
  - ➡ compression of waveforms (factor of about 3)

First Energy Calibration Using MIP events

- MIP-peak position is a measure of the light yield and therefore temperature!
- Mean HV-board temp. for each run
- Expect ~3%/°C
- Measured with VPTT-equipped channels (no temperature dependant APD gain change involved)

➡ Result to be taken only as a first estimate

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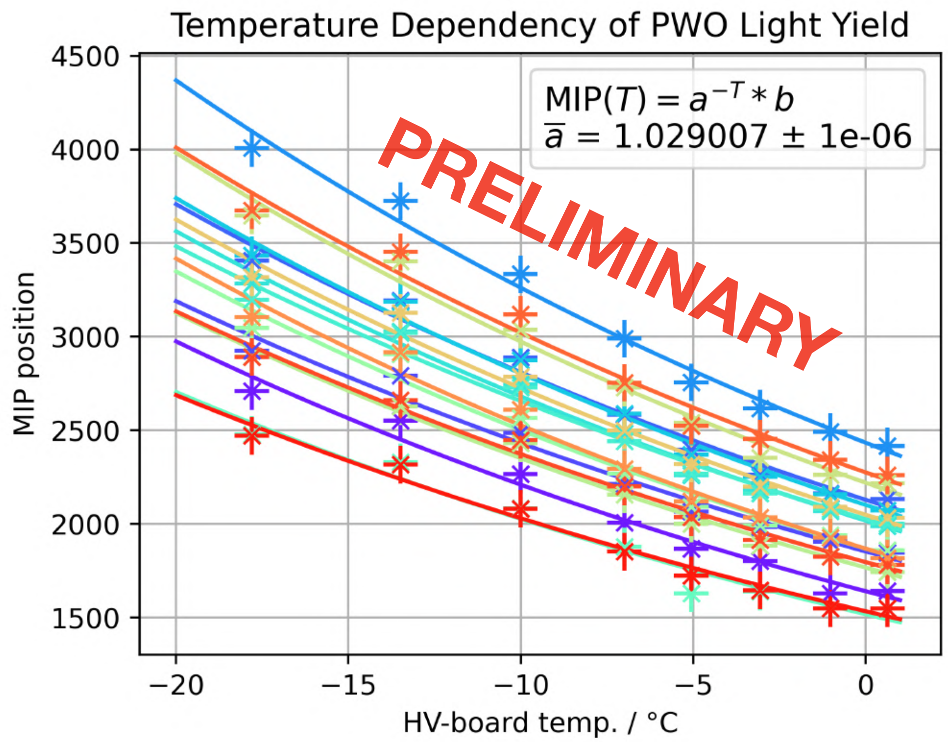

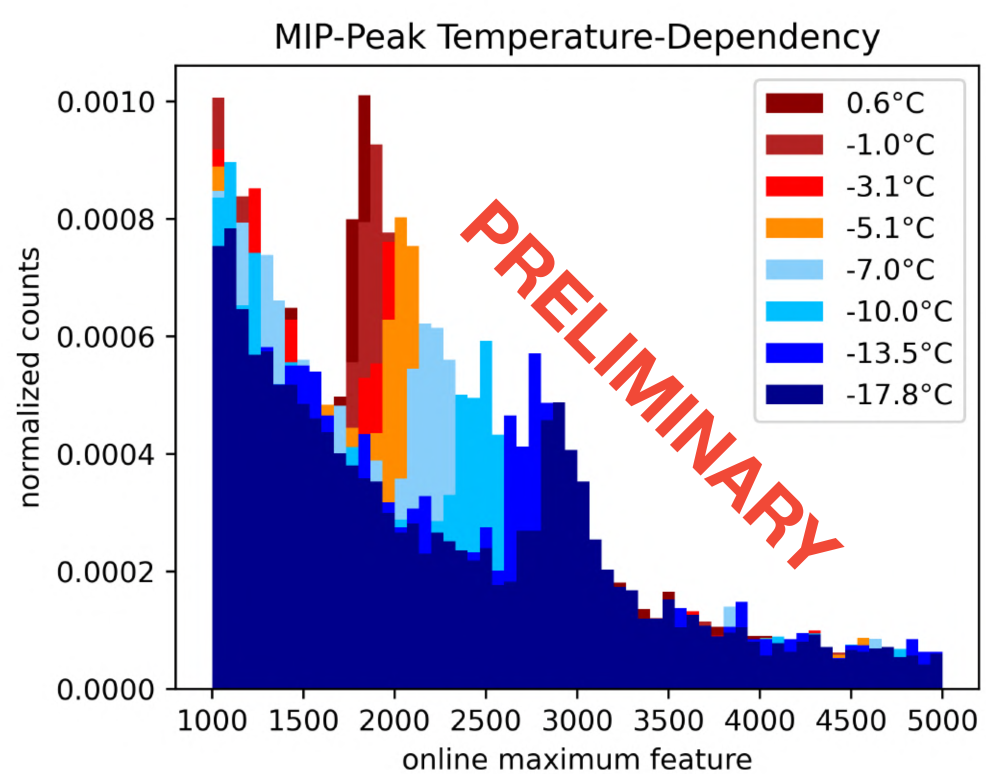

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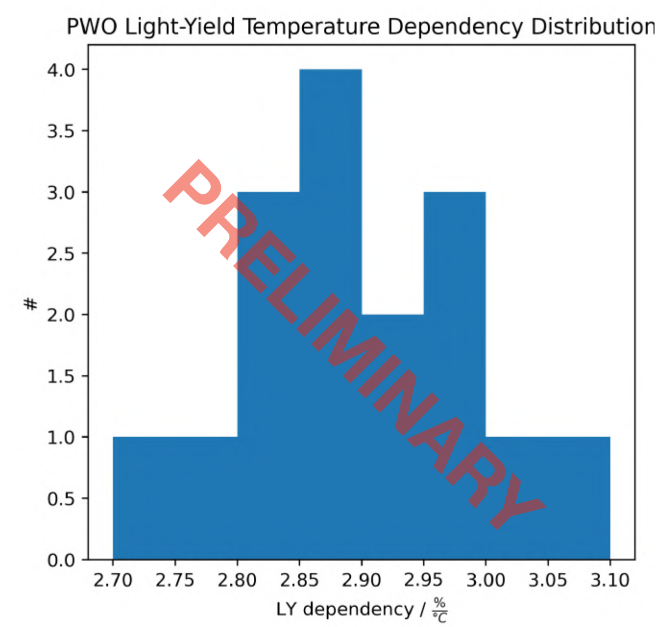
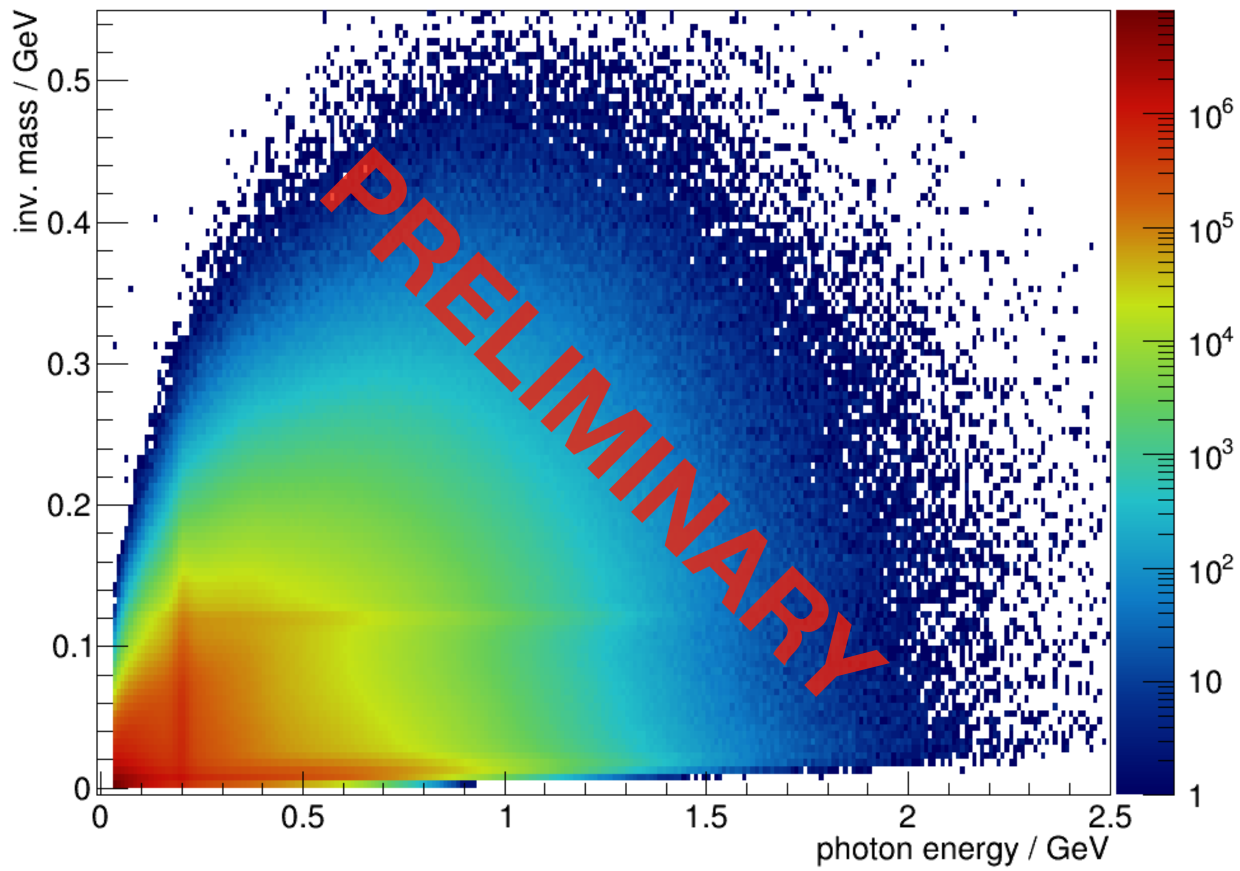


First Results on π^0 Callibration



- Only ~10% of the data analysed so far!
- Clear MIP-peak at 200 MeV
- Expected to be due to $\pi^{\pm}$, due to cluster shapes
- Band structure at invariant mass of ~120 MeV, slightly lower energy due to lacking ECF

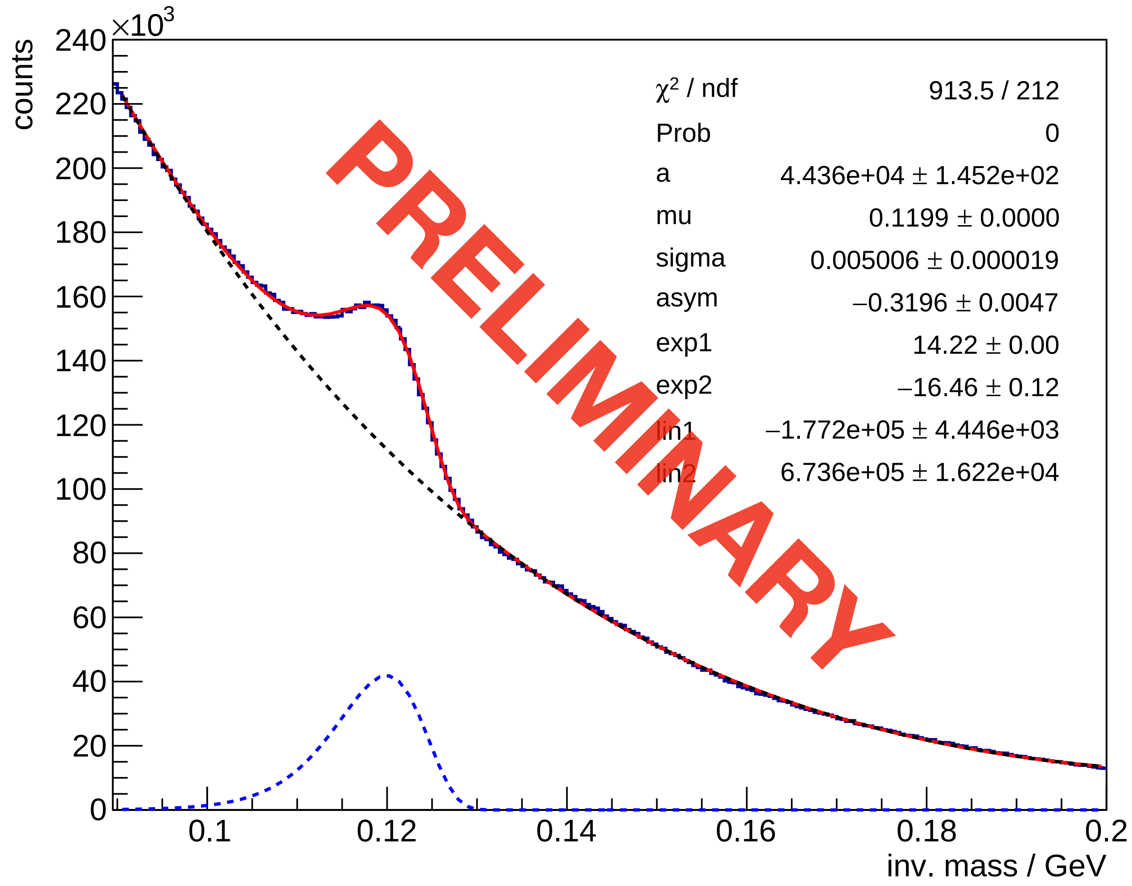
➡ Still visible after MIPs cut away ➡ cannot be caused by MIP

➡ Also visible over wide ϕ and θ ranges ➡ cannot be accidentally correlated noise

➡ **This is the π^0!**

First Results on π^0 Calibration

- fit. background (exp. + pol1) + Novosibirsk



- **Width σ of π^0 5MeV!**
- **“World leading“ resolution even without energy calibration!**

Summary

- PANDA forward endcap calorimeter built up at COSY@Jülich
- Beam time in 2023 was a big success!
- First operation of the final system at -25°C
  - ➡ All systems worked in the end as planned
- 220 TB of compressed waveforms recorded
  - ➡ Analyses are still ongoing (especially π^0 energy calibration)
- First results show outstanding performance!

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Outlook

- In the meantime successful transport to ELSA in Bonn!
- Completion (mounting all submodules) and
- First long term physics operation at CB@ELSA before used at PANDA!

@ELSA INSIGHT
Investigation of the strong interaction in the light flavor sector

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INSIGHT @ELSA
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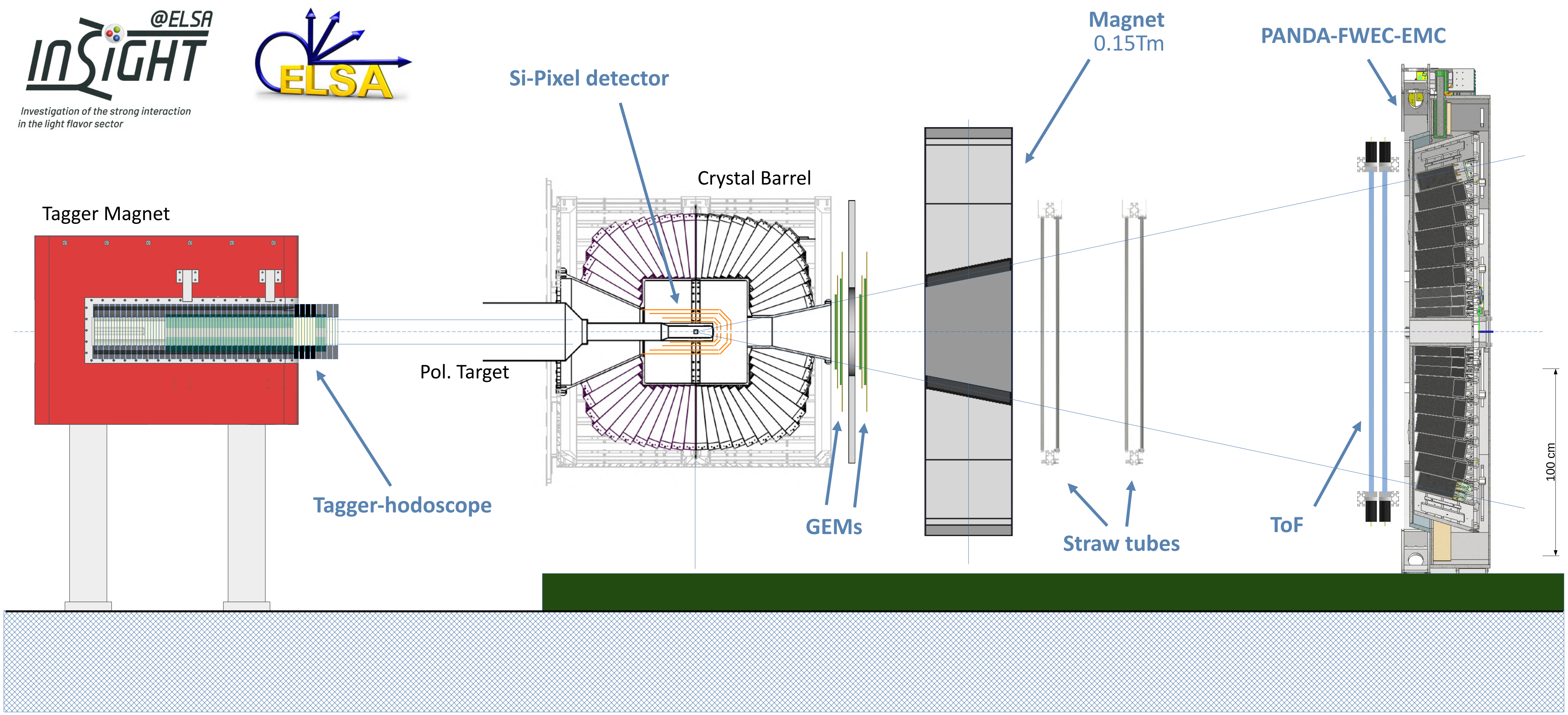

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- 4π detection of photons and charged particles for $\sqrt{s} \leq 2.6\,\mathrm{GeV}$
- Measurements with polarised target **and** beam

INSIGHT @ELSA
Investigation of the strong interaction in the light flavor sector

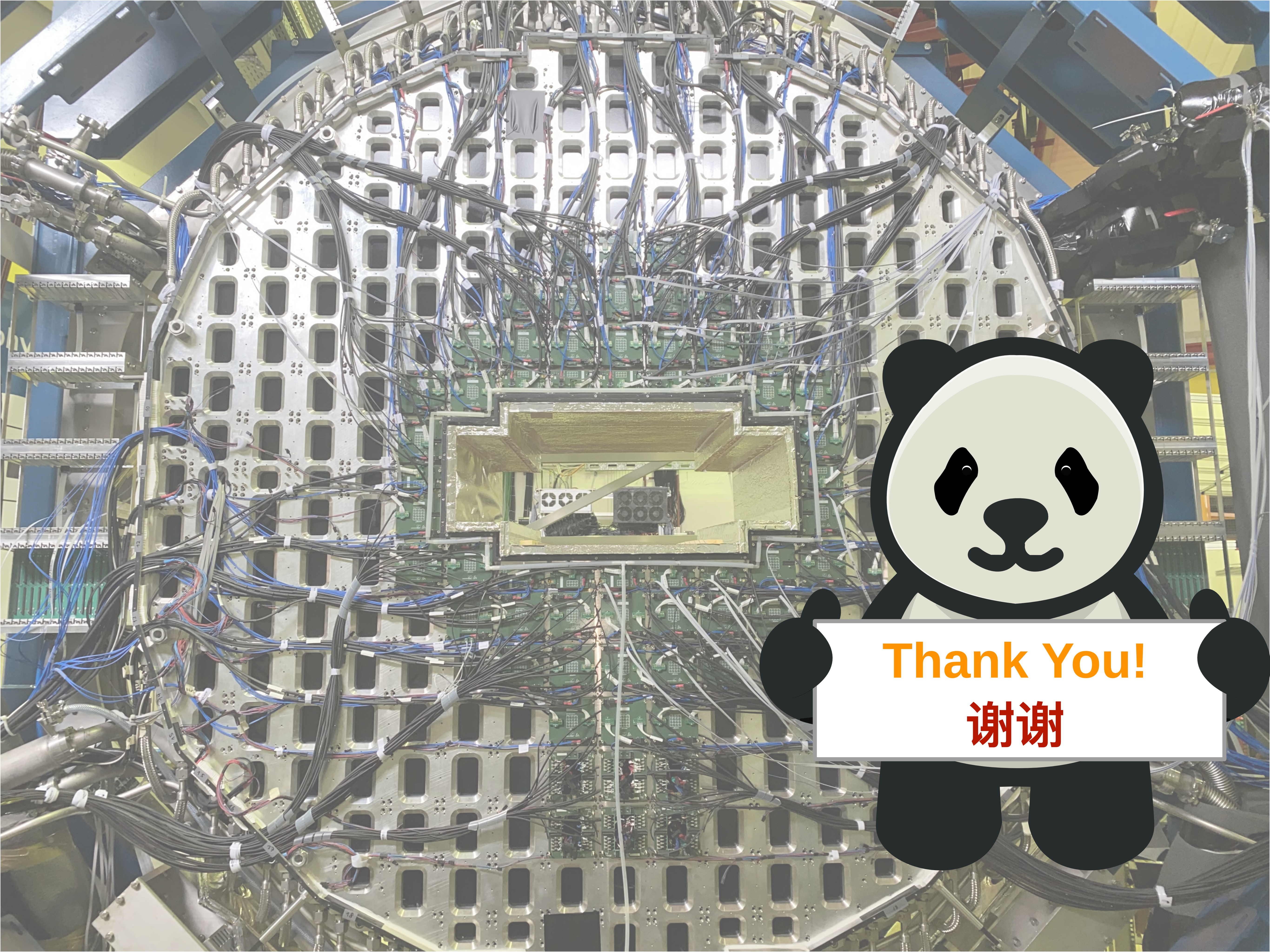
Physics goals:

Strange baryon spectroscopy (Λ^*, Σ^*):

- More states expected than in the u, d-sector but much less states found so far
- Do they exist and what is their nature?
- Are they consistent with SU(6)xO(3)-symmetry?
- *"..., the field is starved for data"* [PDG 2022]

Non-strange baryon spectroscopy (N^*, Δ^*):

- Gain a complete picture of the spectrum!
- Unambiguous PWA only possible with measurement of polarization observables
  - ➡ Polarized photoproduction off the polarized proton and neutron possible!


Thank You!
谢谢