

II. Physikalisches
Institut

JLU

NEUE WEGE. SEIT 1607.

HFHF
Helmholtz Forschungsakademie Hessen für FAIR

JUSTUS-LIEBIG-
UNIVERSITÄT
GIESSEN

K.-Th. Brinkmann, JLU Gießen & HFHF

Hadronenphysik in der Verbundforschung



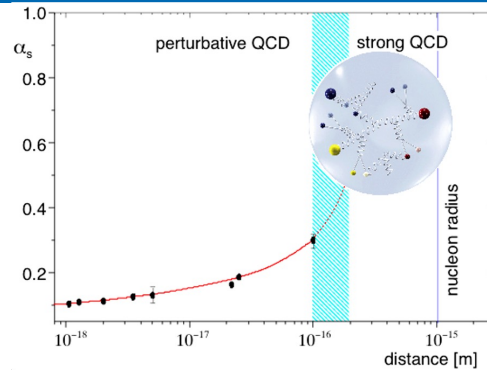
AMBER \bar{P} ANDA

et al.

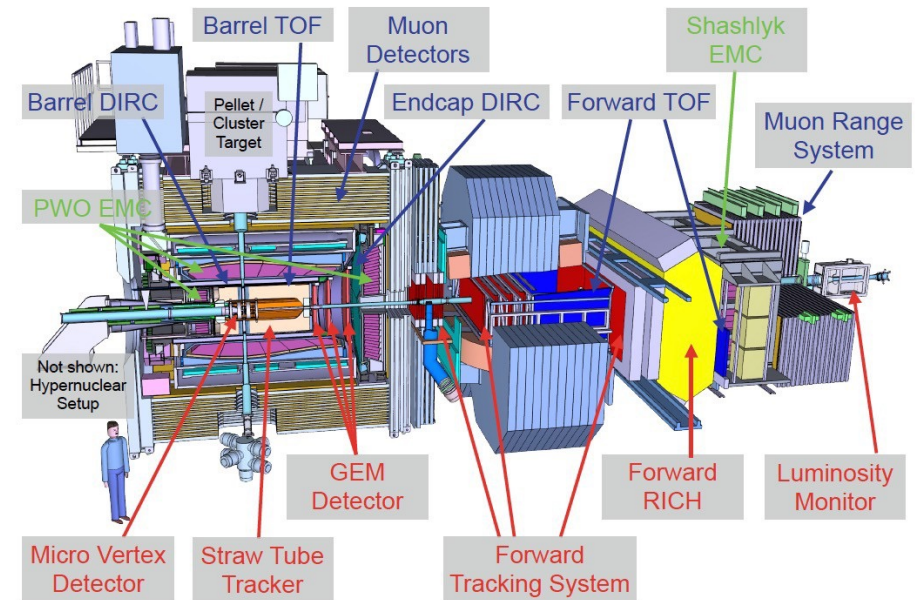
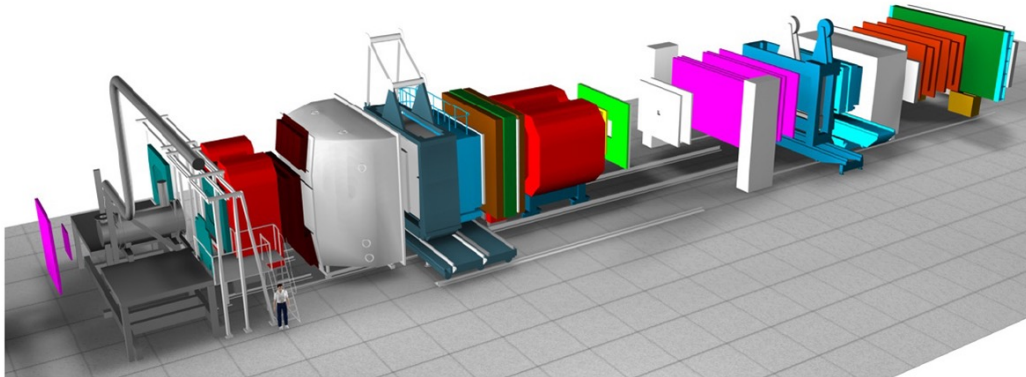


ErUM-FSP T08: \bar{P} ANDA

RFWU Bonn* ALU Freiburg
 JLU Gießen JGU Mainz
 TU München
 GSI



RU Bochum RFWU Bonn
 FAU Erlangen JLU Gießen
 JGU/HIM Mainz U Münster
 KIT FZJ
 FAIR/GSI



Bound States of QCD

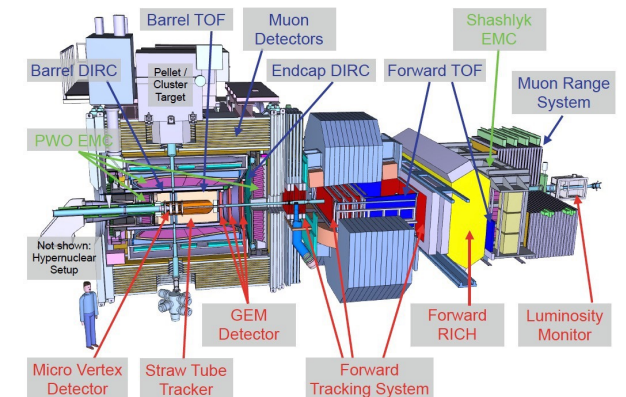
- quark model states and their interaction

- exotic states

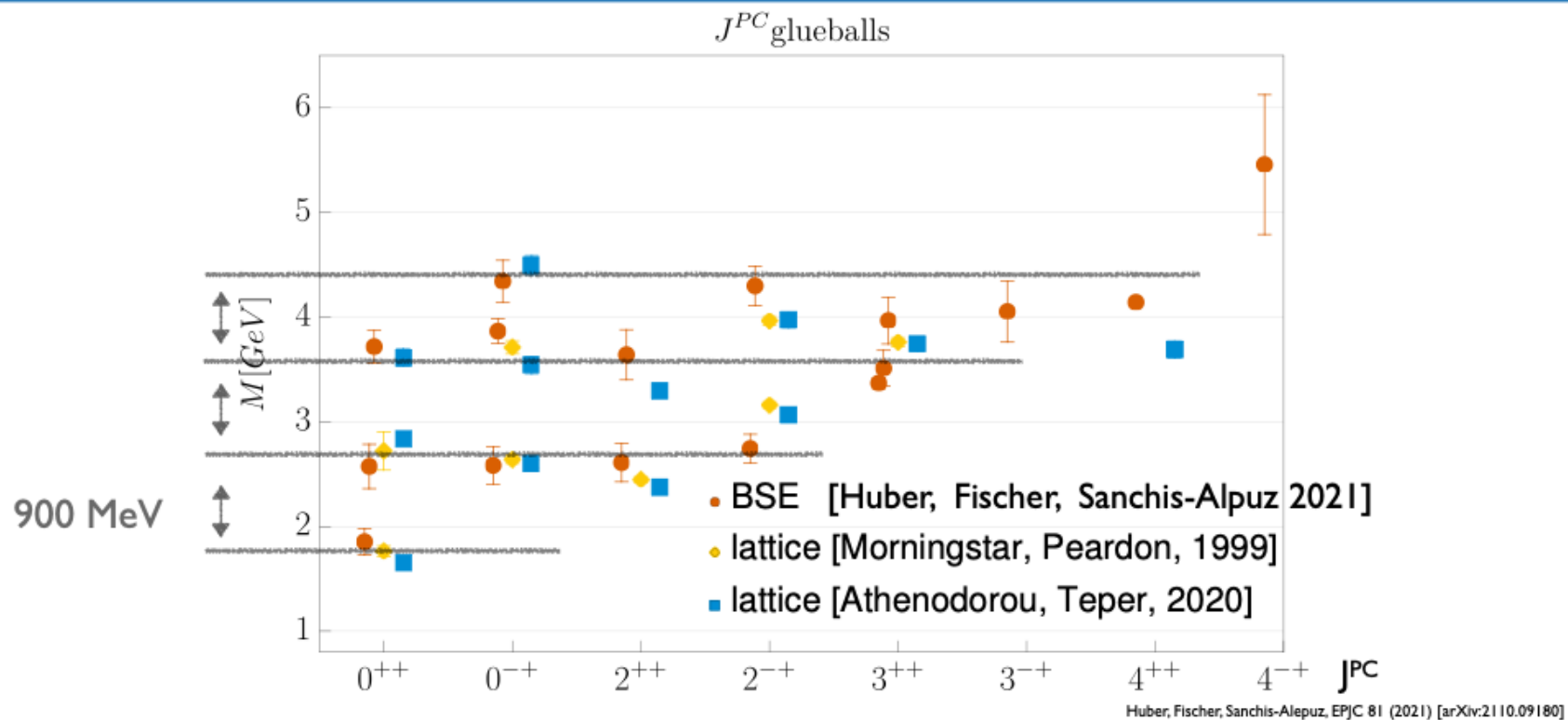
$$\begin{array}{ccccccc}
 \text{J}^{PC} & = & \text{q} \text{q} \bar{\text{q}} & + & \text{q} \text{q} \bar{\text{q}} \bar{\text{q}} & + & \text{q} \bar{\text{q}} \text{g} & + & \text{g} \text{g} & + & \dots \\
 & & (q\bar{q})_0 & & (qq)_8(\bar{q}\bar{q})_8 & & (q\bar{q})_0(q\bar{q})_0 & & (q\bar{q})_8g & & (gg)_0 \\
 & & \text{Tetraquark} & & \text{Molecule} & & \text{Hybrid} & & \text{Glueball} & &
 \end{array}$$

- glueballs

spectroscopy and scattering



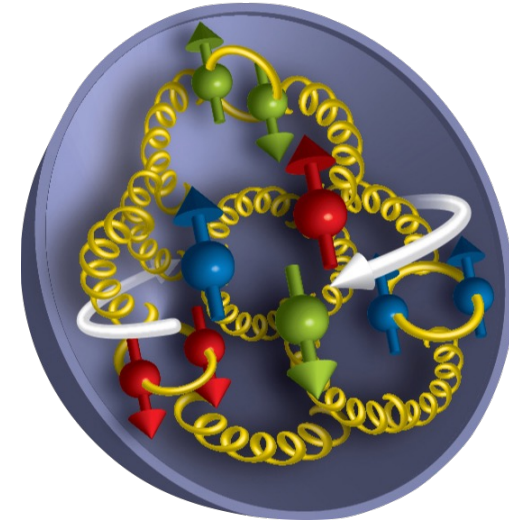
Glueballs: results



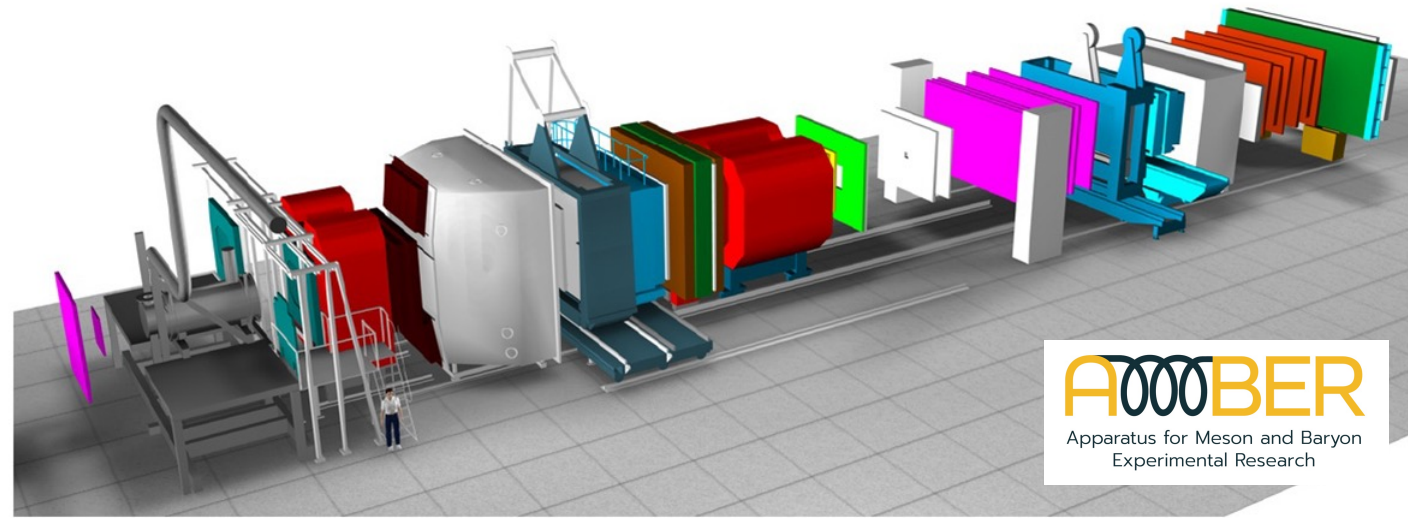
- Experiment: unique opportunity for PANDA at large J
- Theory: very good agreement between Lattice and Continuum QCD
To do: chart mixing of glueballs with conventional meson states...

Partonic Nature of Hadrons

- parton distributions
- generation of mass
- quantum number decomposition

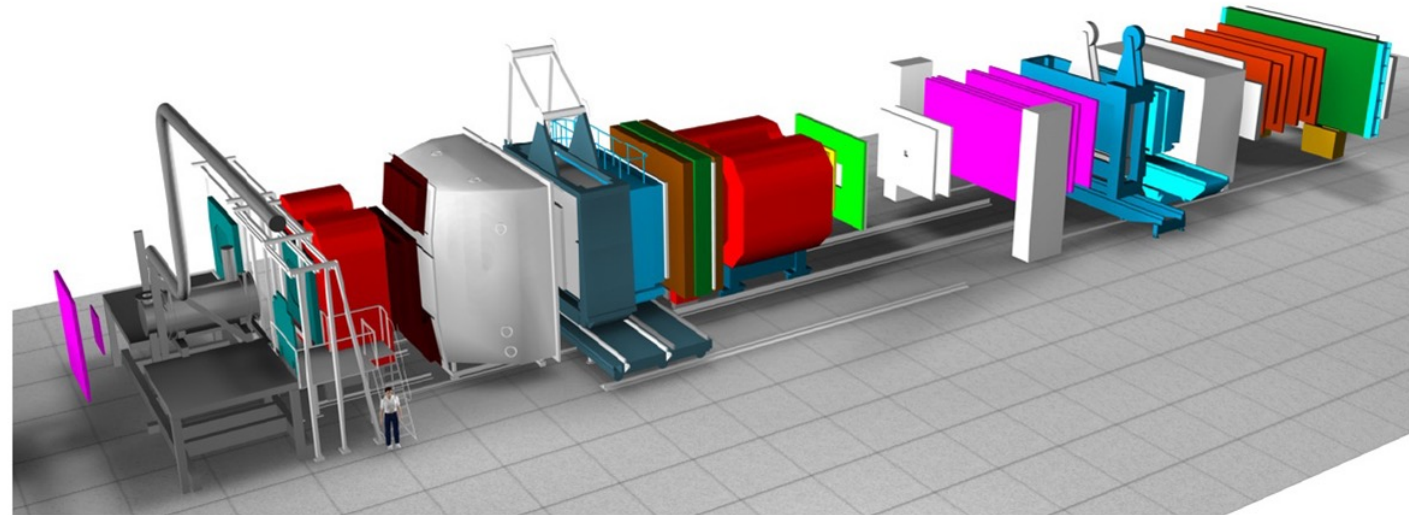


scattering and spectroscopy



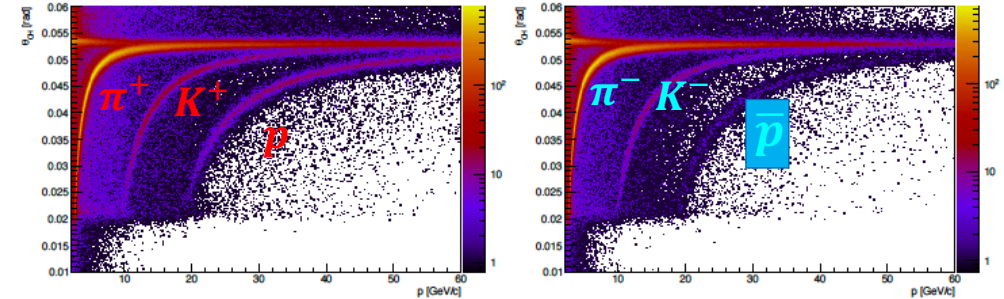
Overview

- AMBER has been **approved** as NA66 experiment **in December 2020**
- the Collaboration consists of ~200 physicists from 34 institutes
 - *two new groups in 2022*
- at the **M2 beamline at SPS muon and hadron beams 60 – 250 GeV**
- AMBER inherited, extended and modernized the **2-stage spectrometer** of the **COMPASS** collaboration
 - **Approved Phase I** physics:
 - \bar{p} production cross-sections
 - proton radius
 - pion/kaon structure functions
 - Intended **Phase II** physics (>LS4):
 - strange-meson spectroscopy
 - kaon polarizability
 - prompt-photon production



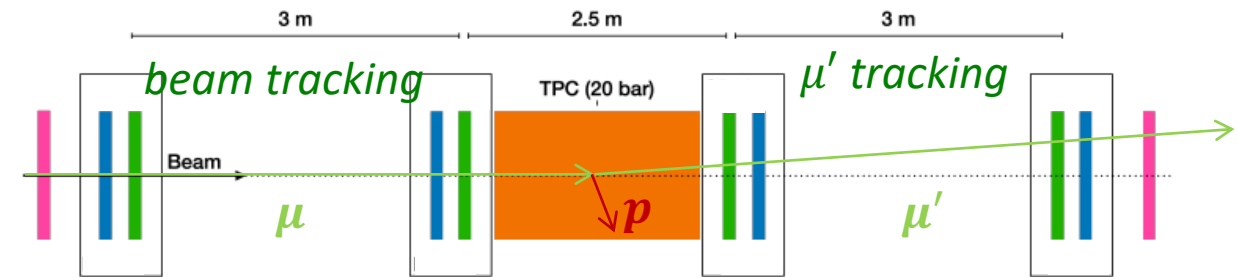
Physics Program

- **Anti-proton production cross sections** in p-He and p-p collisions to constrain cosmic dark-matter search data: unique data sets in unexplored beam momentum range 60-250 GeV/c, successful p-He data taking in 2023

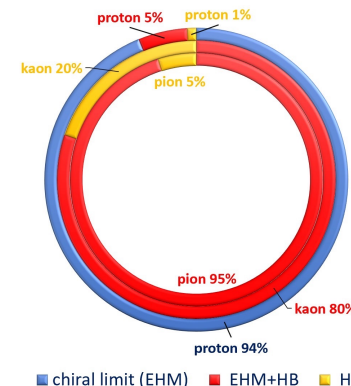
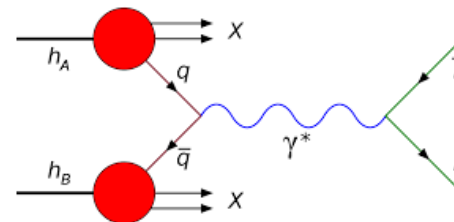


RICH PID: Cerenkov angle vs. momentum

- **Proton radius** via muon-proton scattering, **recoiling proton** and **scattered muon** are measured in coincidence: unique in terms of systematics control



- **Pion and kaon partonic structure** via **Drell-Yan processes**: separate valence and sea contributions in unprecedented precision



Mass budgets: **emergence** of the light-hadron masses is linked to both the QCD partonic structure and to confinement

- *early-career DOE fund for the Los Alamos group (vertex detector)*

The engagement of the German groups focuses on the parts of the program where **long-term expertise is proven**, concerning hardware and analysis (proton radius, in phase 2: meson spectroscopy, low-energy constants, meson radii).

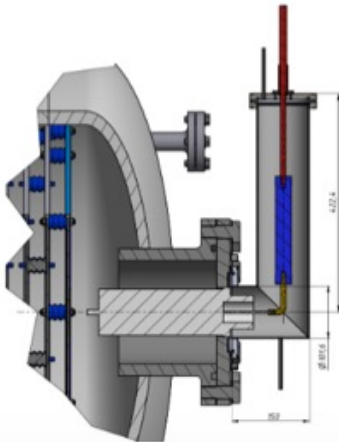
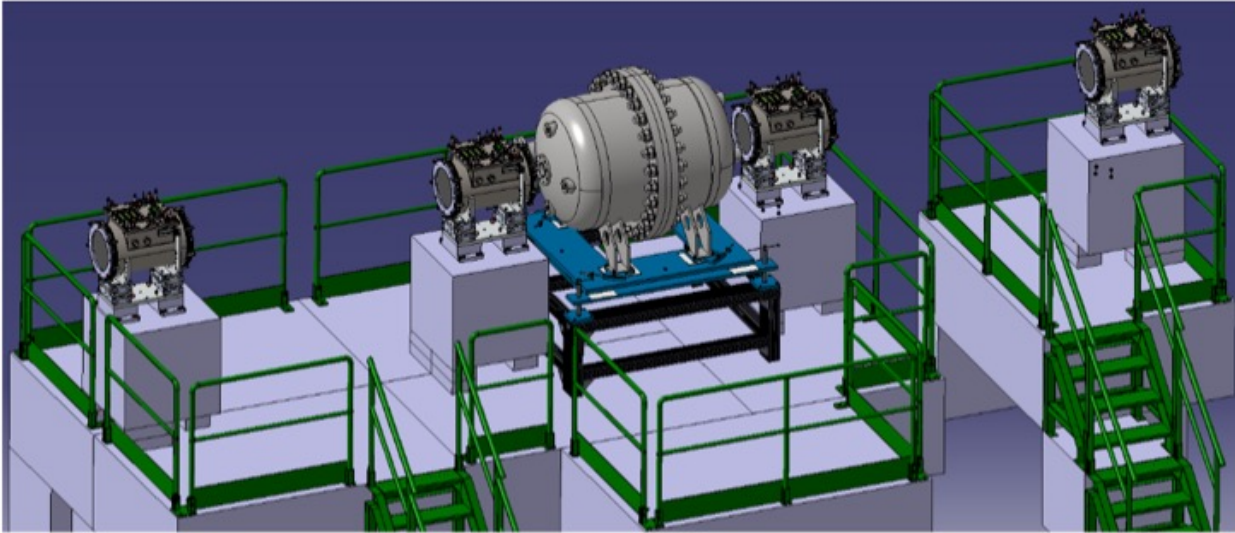
Most **new detector developments** have been **successfully tested as prototypes**.

Many of the BMBF investments into COMPASS in the past two decades will be utilized.

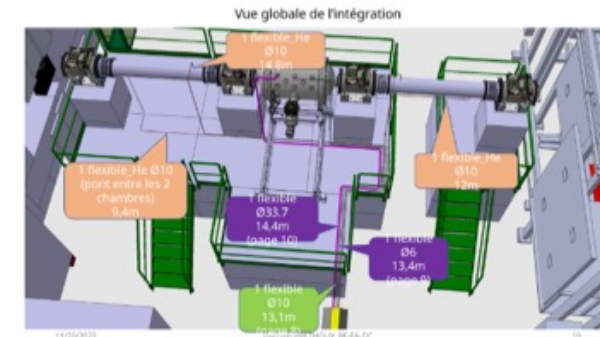
WP's and responsibilities

- Triggerless DAQ and HLT (**Freiburg, Mainz, Munich**, Prague, Warsaw)
- High-pressure hydrogen TPC (**GSI**, PNPI, Glasgow)
- C/W, LH2, LHe target (Lisbon, CERN, Prague, Virginia, Yamagata)
- SciFi/Silicon Pixel tracking stations (**Freiburg, Munich, Giessen**, Torino)
- DY vertex detector (Illinois, Los Alamos, Torino)
- Large-area MPGD detectors with self-triggering readout (**Bonn**, CERN EP-DT, Torino, JINR)
- Self-triggered electronics for ECAL (**Munich, Giessen**, Trieste, Warsaw)
- Upgrade CEDAR electronics for high rates (CERN, Warsaw)

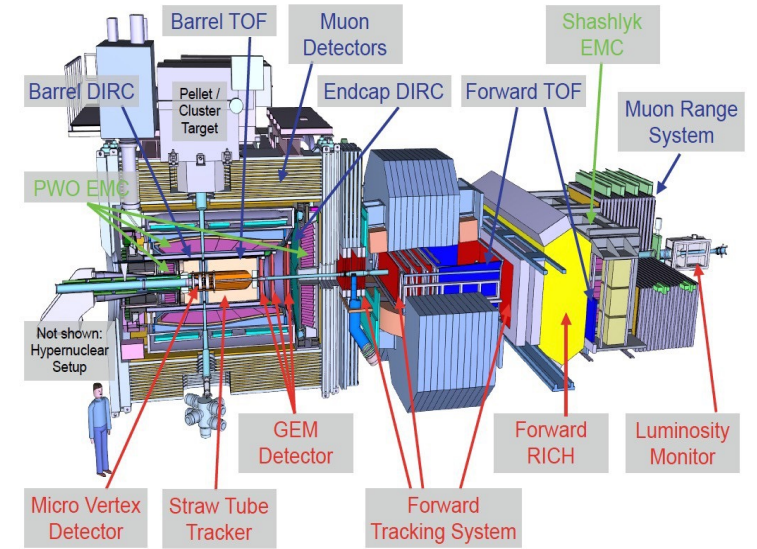
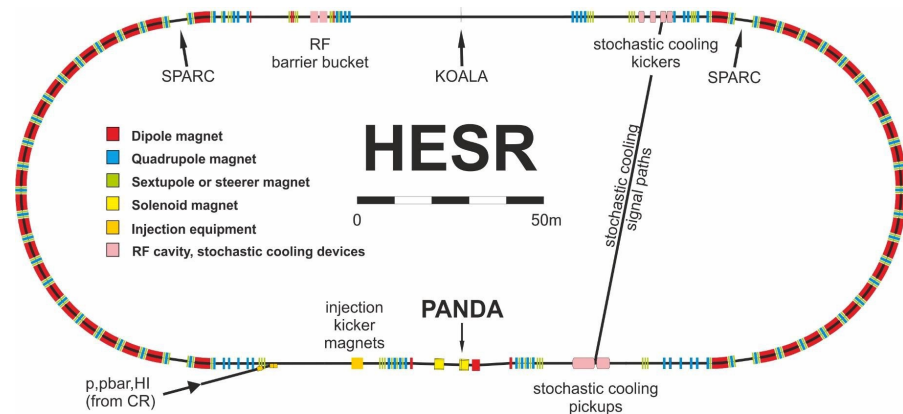
Current Status: TPC

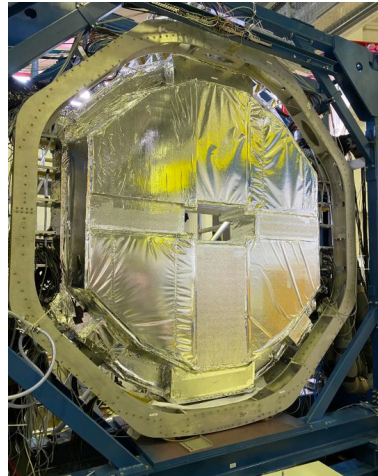
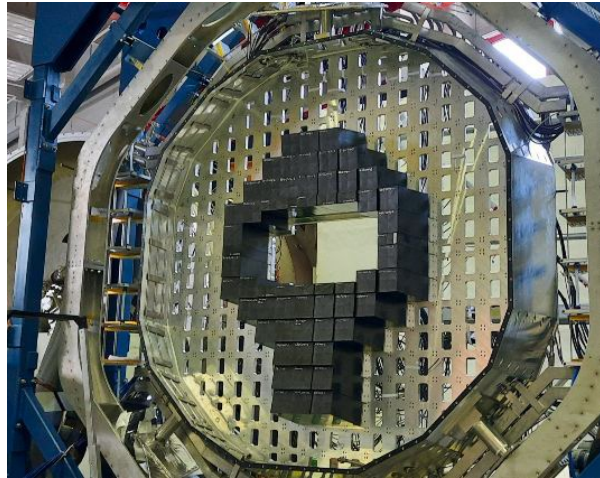


- TPC vessel production finished.
- Middle flange design on-going.
- Installation of H2 pipes on-going.
- Integration studies with BE are on-going.
- Gas system planning is evolving.
- TPC table under HSE review.
- Discussion with safety for HV-feedthrough started.



- Last FAIR review: physics reach and program rated world-class and unique
- Yet, severe impact of FAIR delay and cost hike, world politics etc.
- Detector construction progressing well until recently (large Russian contribution missing!)



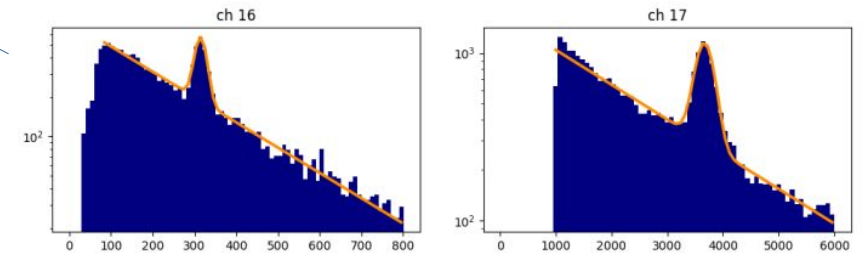
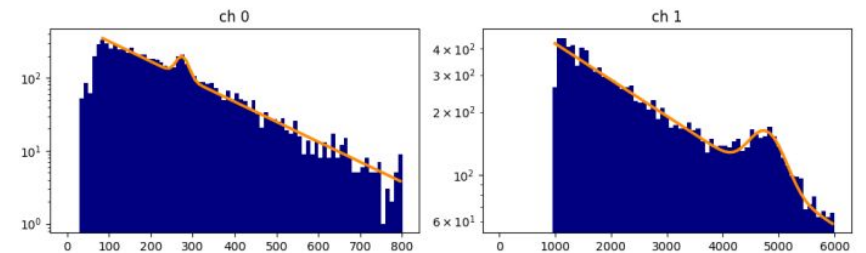
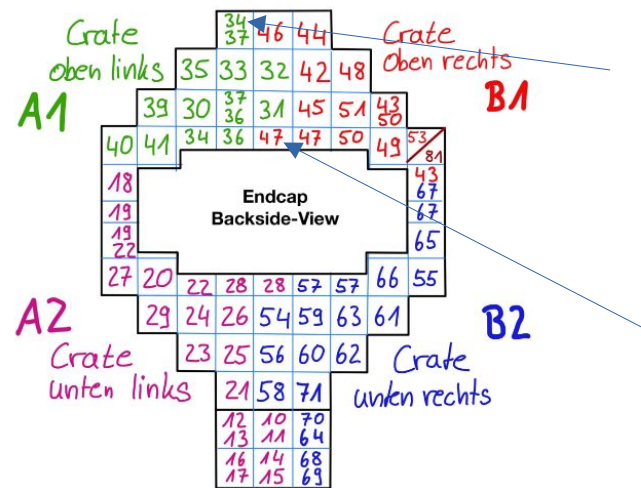


Beamtimes - 2740 MeV/c protons (Aug 7 – 11, Sep 11 – 15, 2023)

Energy calibration

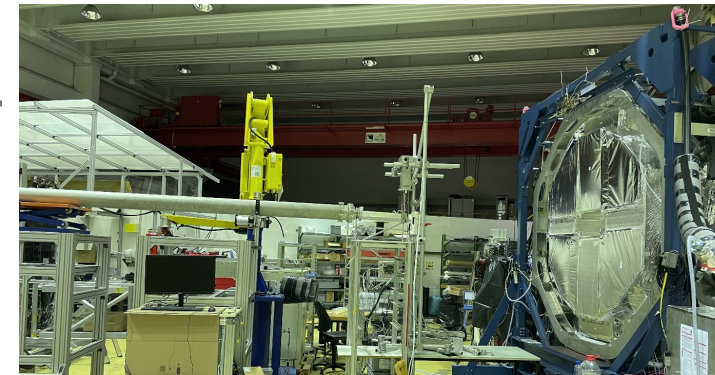
Calibration can be done via cosmic tracks or via minimum ionizing particles from beam data.

Examples for single crystal cluster energy distribution

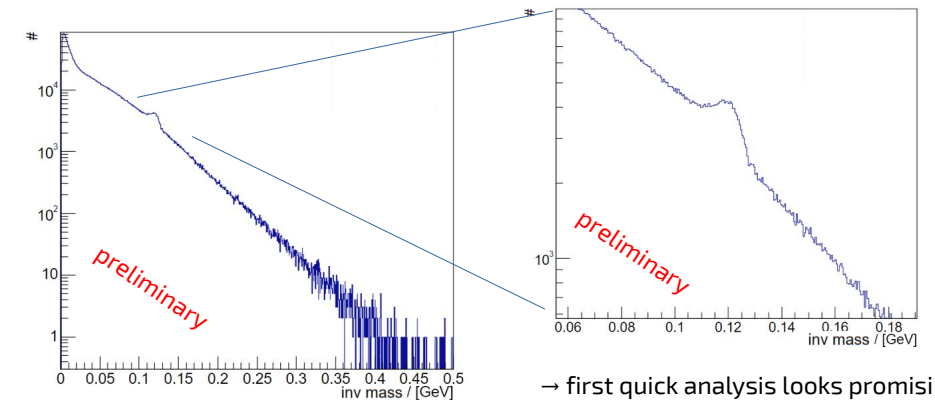
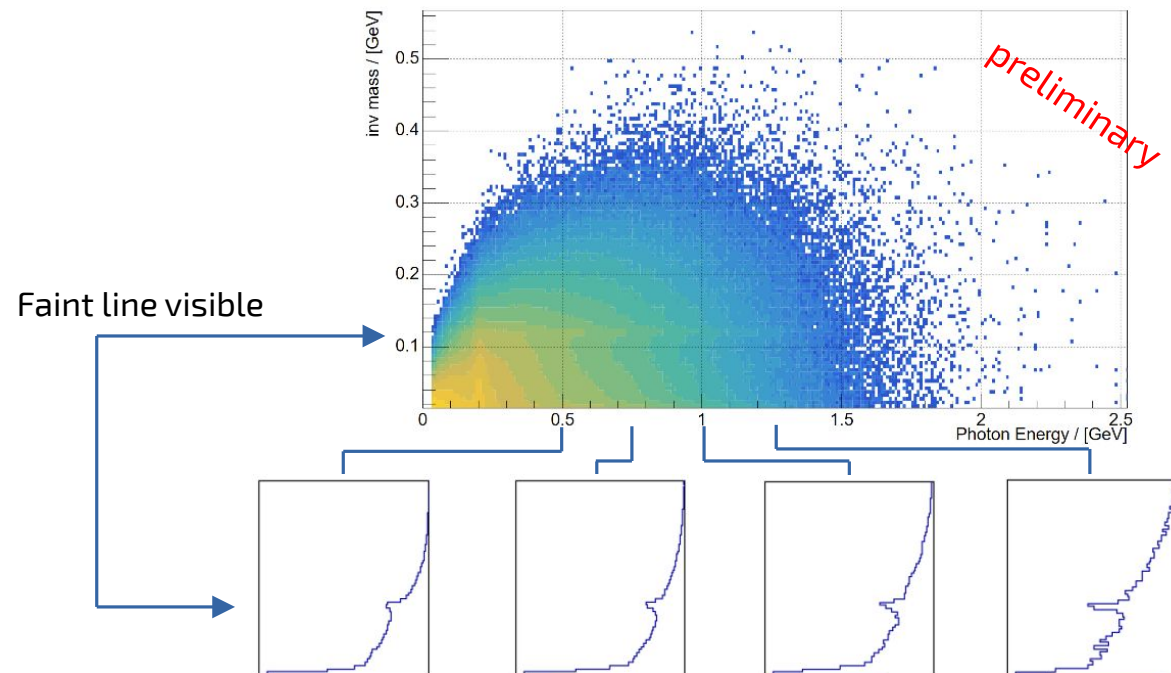


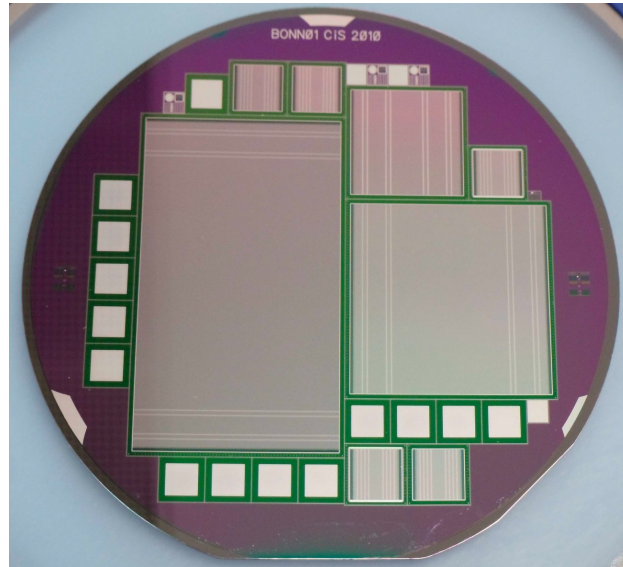
Beamtimes - 2740 MeV/c protons (Aug 7 – 11, Sep 11 – 15, 2023)

First quick analysis - pandaroot

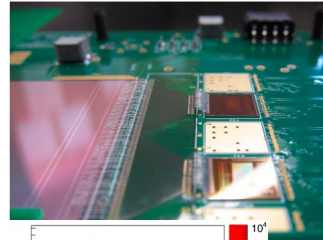


Invariant mass of 2 particles vs photon energy (one run of 2nd beamtime ~20min):

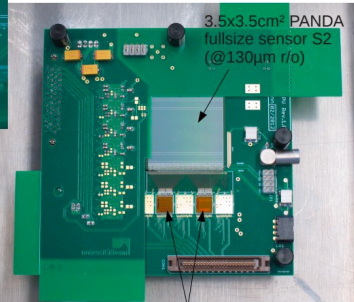




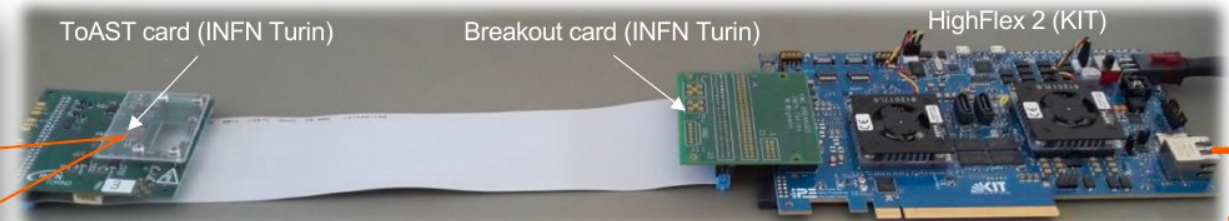
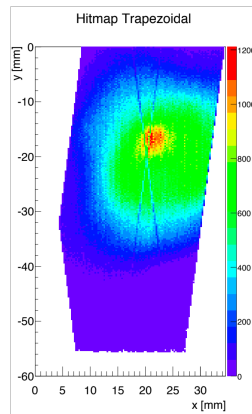
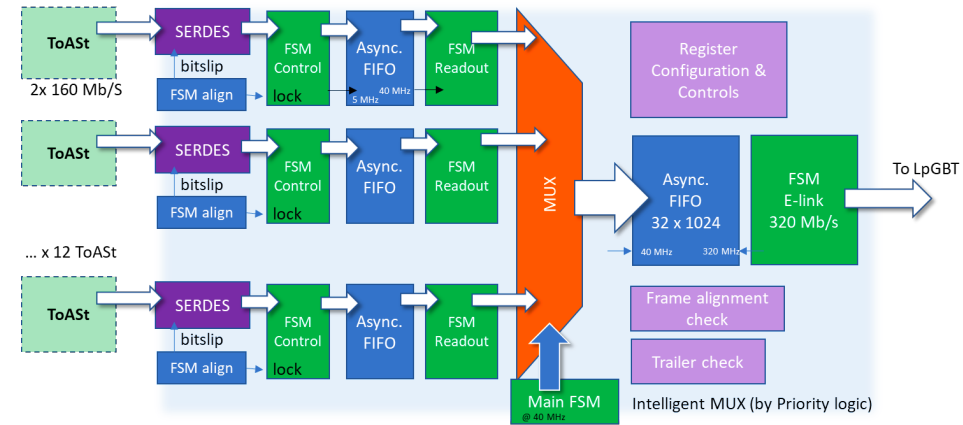
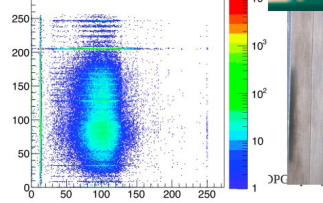
Prototypes



Flex-PA and squared sensor assembled on a test board and successfully tested at SPS, CERN (September 2012)

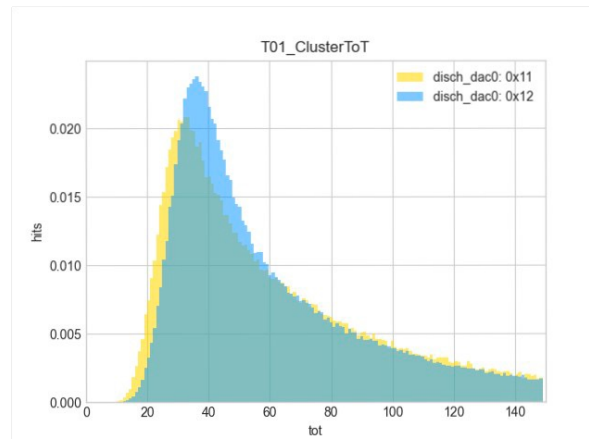
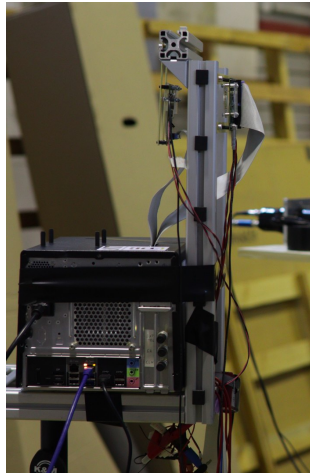
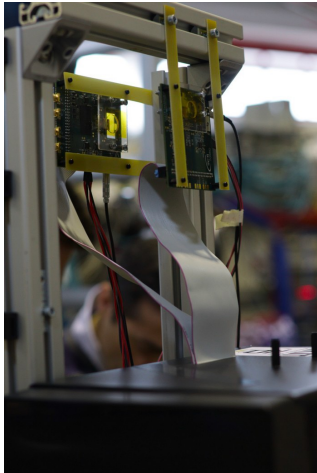


APV25 Front-ends



MDC implemented on FPGA (beam test setup)

Readout and control by ETH



In parallel:

Successful test of hardware and readout for the luminosity detector (based on HV-Maps, Bochum, Mainz)

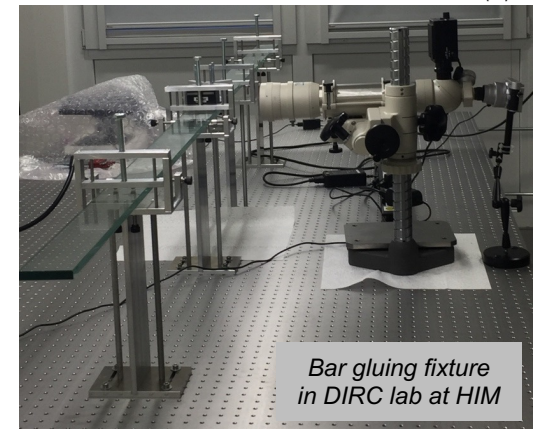
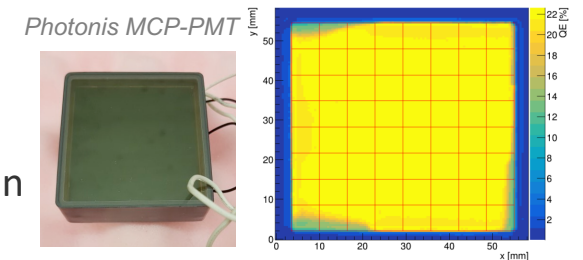
PANDA Barrel DIRC



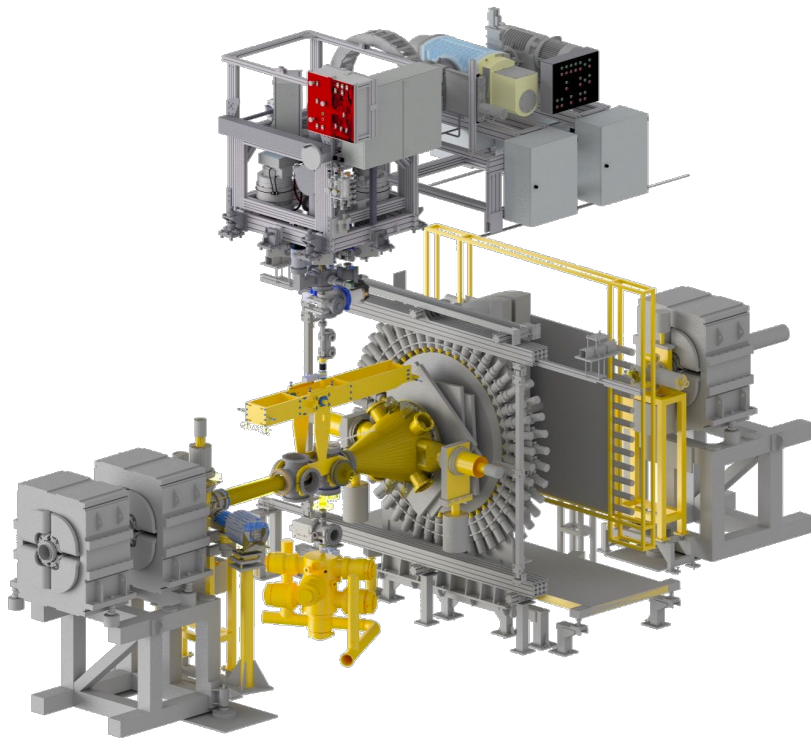
- German In-Kind contribution, 100% project funding for construction via GSI
Close cooperation between GSI, FAU Erlangen, GU Frankfurt, JGU Mainz, HI Mainz
- Key component of the PANDA PID system, innovative design
- Series production of MCP-PMT DIRC photon sensors underway (Photonis Netherlands BV), QA measurements performed at FAU Erlangen (A. Lehmann et al., supported by BMBF and GSI)
- Preparation of fused silica DIRC bar assembly at HI Mainz near completion, tooling and gluing procedure documented, review pending
- Long-term study of impact of material candidates considered for construction of DIRC bar boxes on bar surface reflectivity started at GSI
- Preparation of first-item vertical slice “sector #0” for detector tests starting in 2026



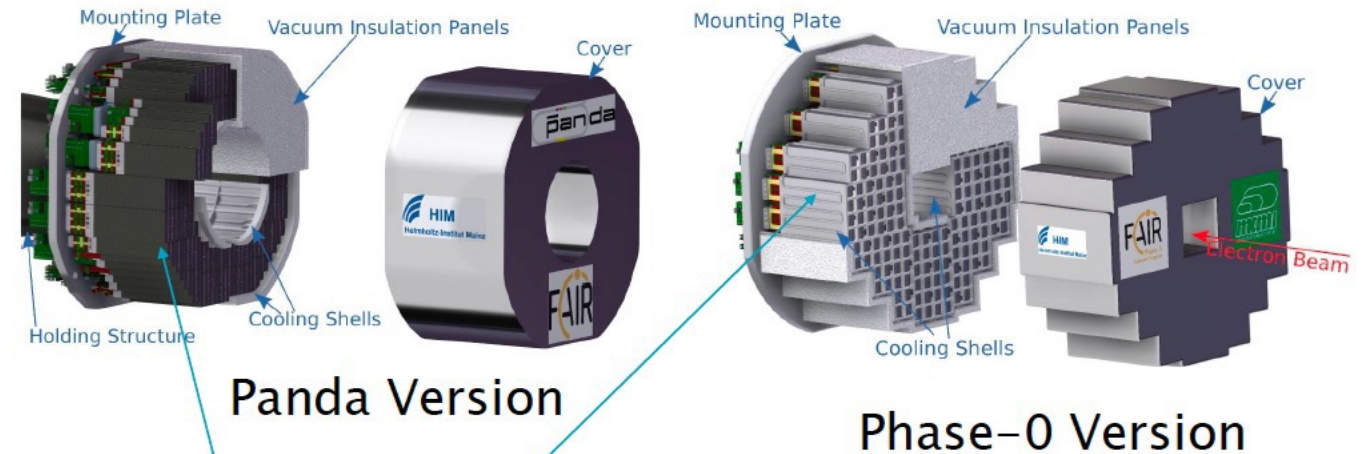
2D quantum efficiency scan at FAU Erlangen



Cluster jet target (Münster)



Backward EMC (Mainz)

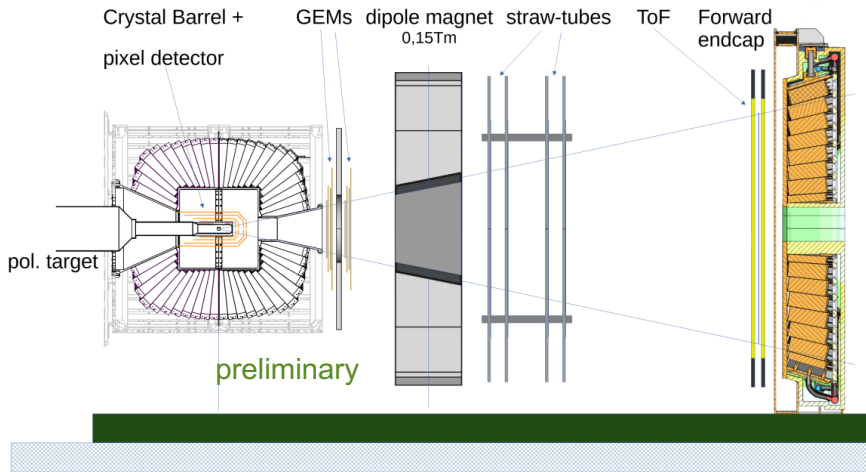


Panda Version

Phase-0 Version

Measurement of the electromagnetic transition form factor of the π^0 in the space-like region via Primakoff electroproduction at MAMI in the A1 experimental hall

Commissioning of and Physics with the PANDA-FW-EMC at ELSA



4 π measurement of photons and detection of charged particles

$$\sqrt{s_{\max}} = 2.6 \text{ GeV}$$

+ polarisation measurements

Non-strange baryon spectroscopy:

Gain a complete picture of the light-quark N^* , Δ^* - baryon spectrum:

- **Polarized photoproduction off the polarized proton and neutron!**

⇔ unambiguous PWA not possible without the measurement of polarization observables

- **Multi-meson photoproduction**

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

More states expected than in the u, d-sector but much less states found so far!

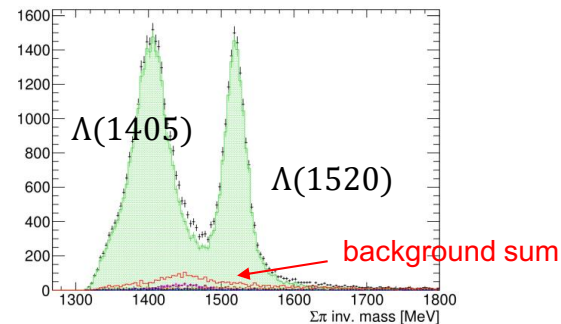
⇔ **Do they exist ?**

⇔ **Are they consistent with SU(6)xO(3)- symmetry?**

⇔ **Nature of the observed states=?**

e.g. $\Lambda(1405)$, 2-pole structures / multiquark-states?

PDG'2022: “.., the field is starved for data”



Use of $\bar{\text{P}}\text{ANDA}$ equipment and know-how in co-operations:

BWEMC: MAMI, Mainz

MAPS: Mainz

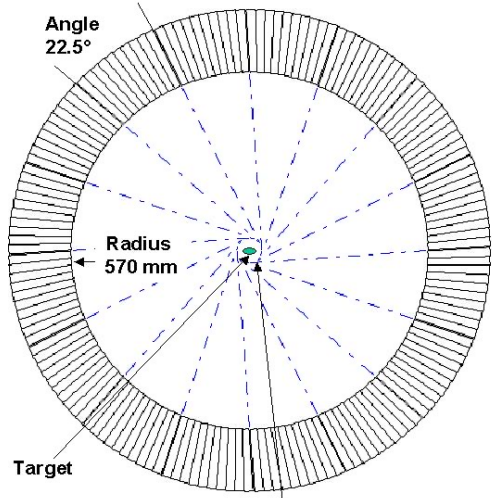
Tracking (Straw detectors):

HADES

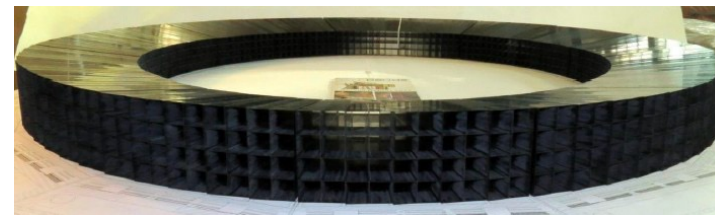
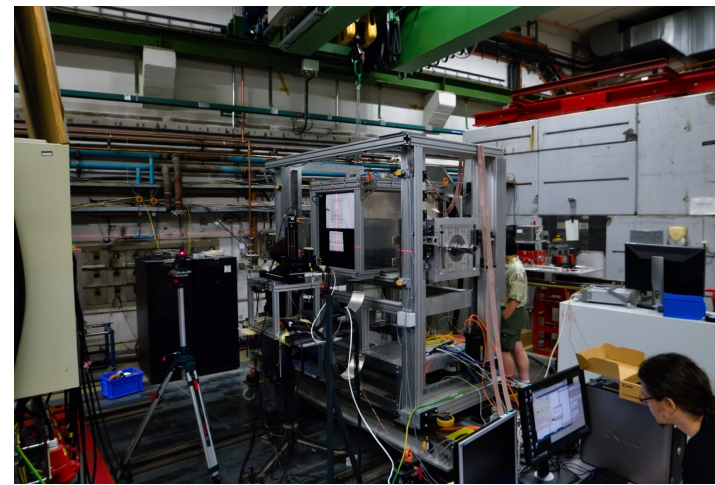
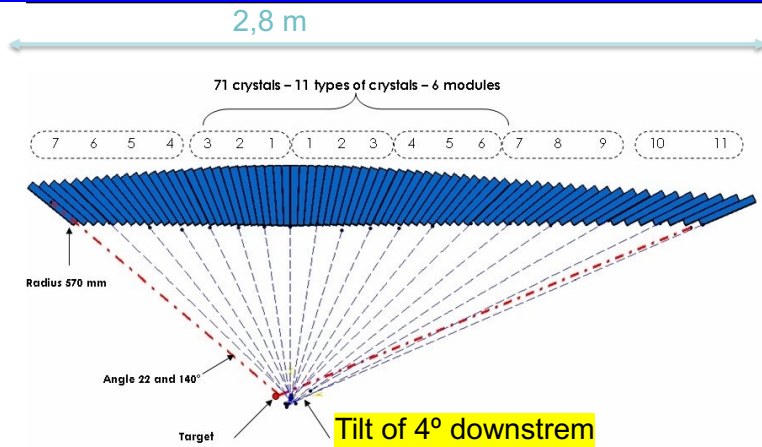
FWEMC: ELSA

Barrel EMC ?

Barrel EMC

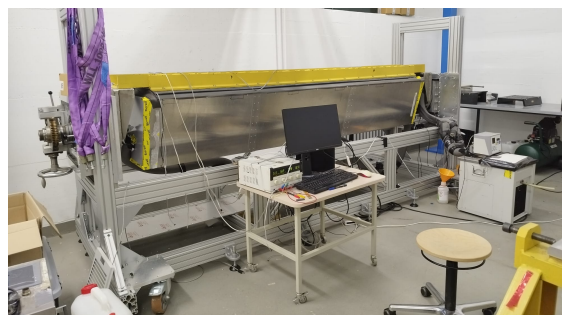


Tilt of 4°



1st slice of 16

cooling tests
@Giessen

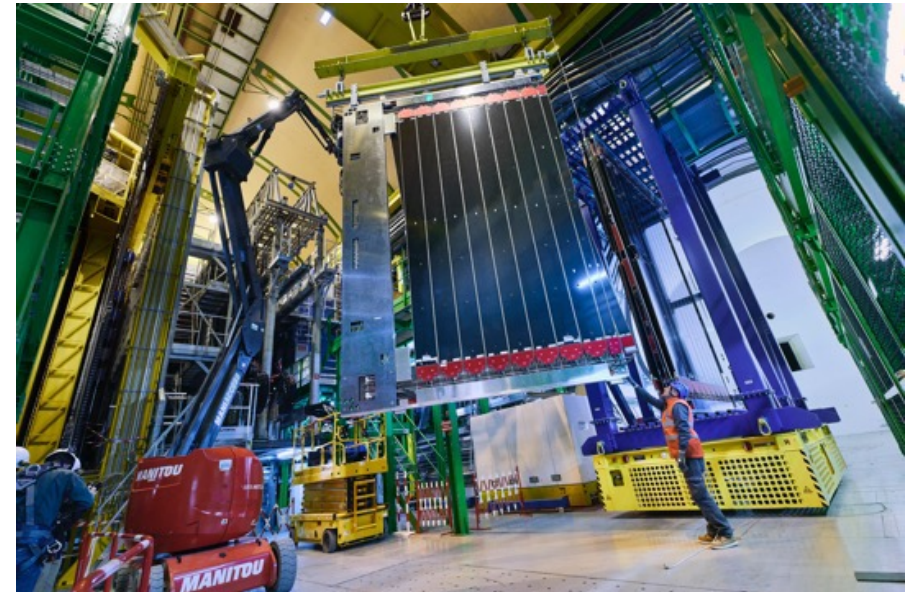




Status

PANDA is outcropping into hadron physics in a variety of settings, contributing equipment and expert know-how.

PANDA is exploring options and scenarios in discussions and simulations, e.g. usage of available equipment, ramp-up scenarios with reduced set-ups.



Summary

- German hadron physics is very much alive.
- New exciting developments.
- AMBER is taking data and gearing up for more.
- \bar{P} ANDA is commissioning and using equipment for physics even without antiprotons, while preparing for FAIR operation.