PANDA

Technical Status

L. Schmitt, GSI/FAIR

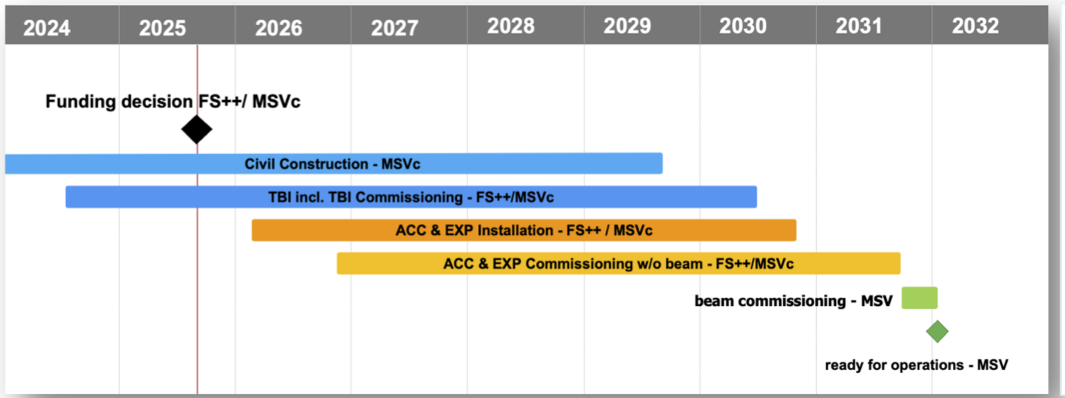
FAIR PANDA RRB
GSI, May 16, 2024

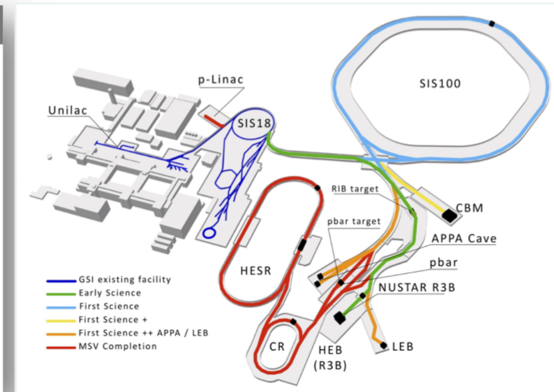
- FAIR News
- PANDA News
- System Status
- Setup Studies

FAIR News

FAIR MSV Completion

Outlook: Steps beyond FS & FS+: FS++ APPA/LEB & MSVc





- Working assumption pending on decisions by the shareholders of FAIR
- Steps beyond FS+ require additional funding, ideally to be in place by Q3 2025 so that the existing FSB Team and contractors are still in place
- CR layout modified according to MAC recommendation

- Decision 2025
- FS++ APPA/LEB ready for operation – 2030
- MSVc ready for operation – 2032

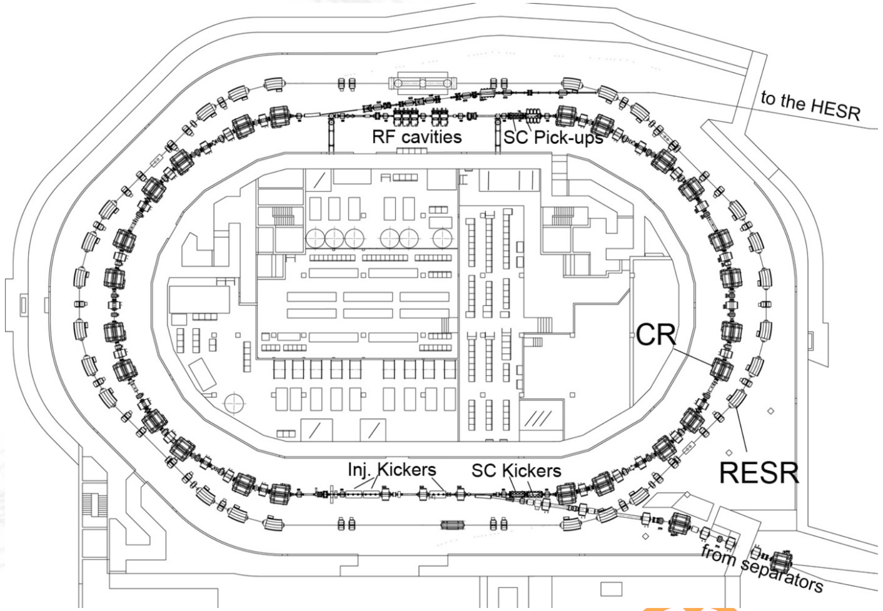
FAIR project time schedule 2023 re-baselining report | 05.07.2023   1

- PANDA Milestones:
  - Decision on the technical choice for the CR: Q4 2025
  - Funding decision for Area West civil construction: Q4 2025
  - Funding allocation: Q2 2026
  - PANDA cave: Q1 2030
  - Start of operation: Q2 2032
- Main risk items:
  - PANDA Solenoid
  - Barrel EMC Crystals
- MSV completion working group

Slide from FAIR Council July 5, 2023 on planning of MSV completion

FAIR MSV Completion

- HESR: Storage in Weiterstadt (90% of components)
  - Activities: documentation, completion of unit assembly, open components
- COSY: planning for orderly dismantling and storage for reuse
  - Implement COSY as accumulator ring replacing RESR
- pLinac: developments at U Frankfurt and GSI
  - Ladder RFQ ready, to be tested
  - CH cavities: prototype in construction, continuation open
  - RF: Klystrons delivered, modulators to be ordered
- pBar separator:
  - Target concept complete, magnetic horn design ready
  - pBar separator planning status advanced, execution linked to CR
- Collector Ring CR / Accumulator RESR
  - MAC recommendations: components of COSY for RESR, of AA for CR
  - Stochastic cooling advanced, some WP still concluded
  - AA availability: only 10 out of 12 dipoles
    → keeping current CR design is still the easiest path
  - Alternative plan for accumulator: use COSY with minimal changes



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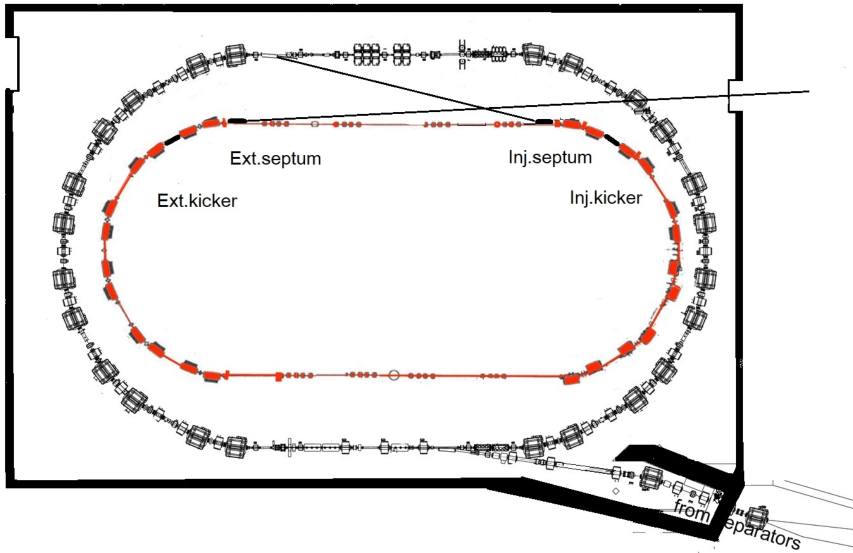
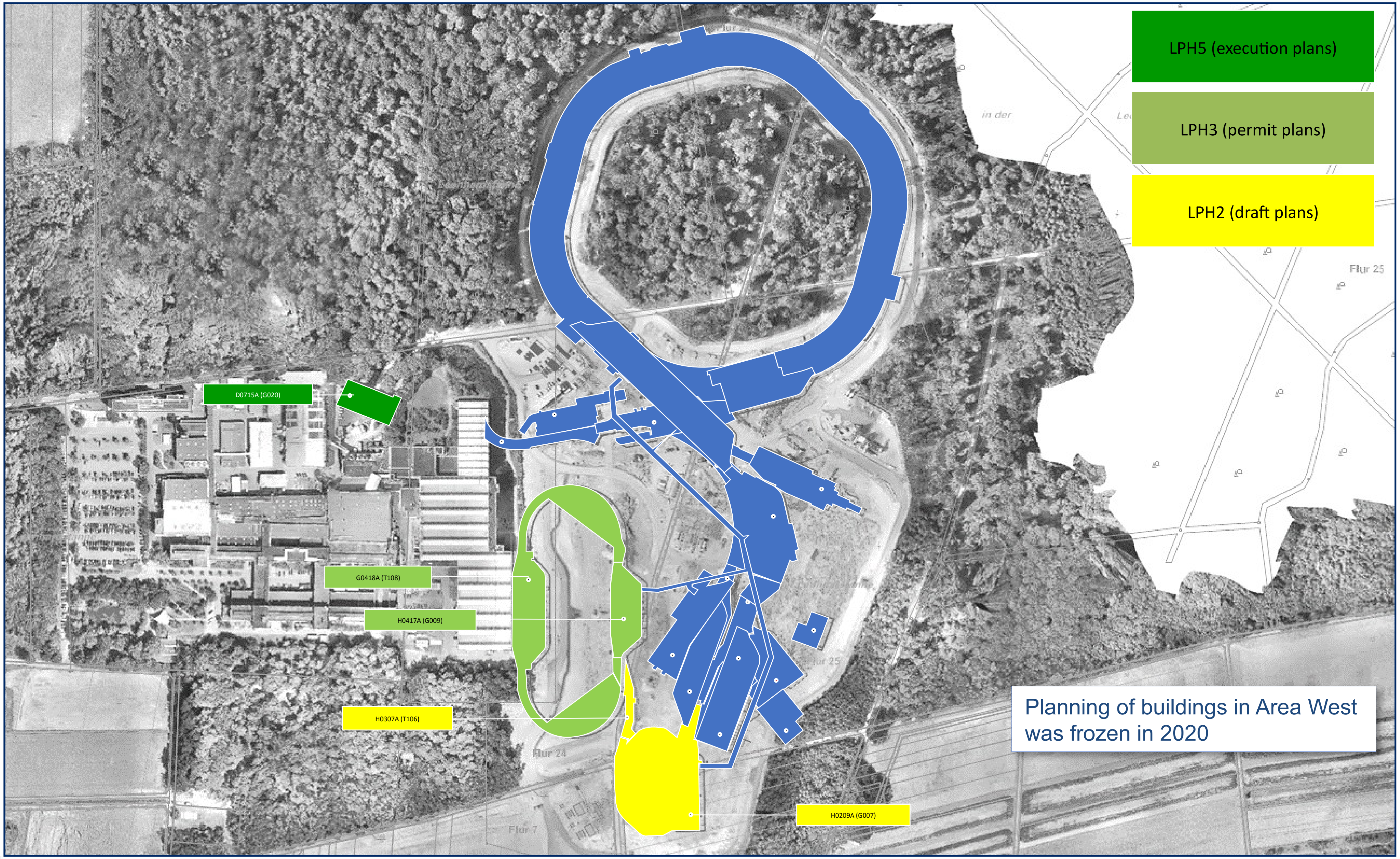


FAIR Area West Planning



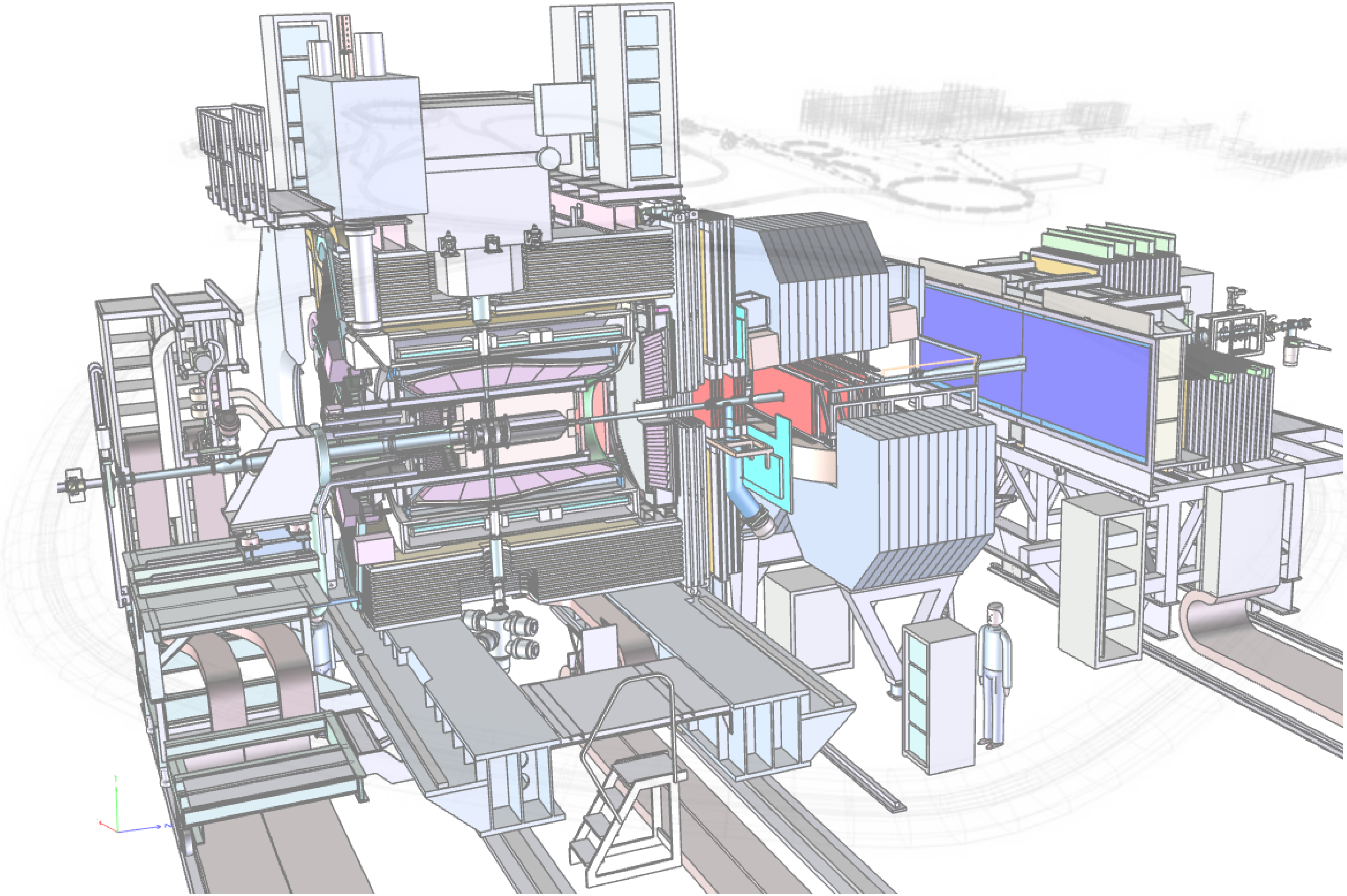
Planning of buildings in Area West was frozen in 2020

FAIR Area West

Activities with FAIR Site & Buildings

- Collection of open Change Requests
  - Check validity of change requests
  - Implement change requests in next planning phase
- Value engineering, next steps:
  - Cost evaluation: new estimate based on FAIR N/S areas
  - Check specifications: machine parameters, radiation protection
  - Align building parameters
  - Consider simpler architecture options:
    - Industrial halls
    - Shielding with mobile blocks
  - Use of COSY as accumulator allows for savings in the CR hall
- Scenario for realization
  - Schedule: Contracts of FSB team till end 2026
  - Prerequisites: Funding approval in 2026

PANDA News



Detector R&D for PANDA

Detector Research and Development collaborations (DRD)

- ECFA DRD Roadmap: https://indico.cern.ch/event/957057/
- Task forces relevant to PANDA:
  Detectors: TF1 (Gaseous det), TF3 (Solid state det), TF5 (PID), TF6 (Calorimetry)
  Cross section topics: TF7 (Electronics), TF8 (Integration)
- R&D collaborations start 1/1/2024
- National initiatives grouping around this, e.g. German Si-D Consortium

PANDA as R&D collaboration/platform

- Attract physics groups to contribute
  - simple detectors
  - online algorithms
- Attract detector expert groups to build new detectors
- Inspire detector groups to repeat their proven designs

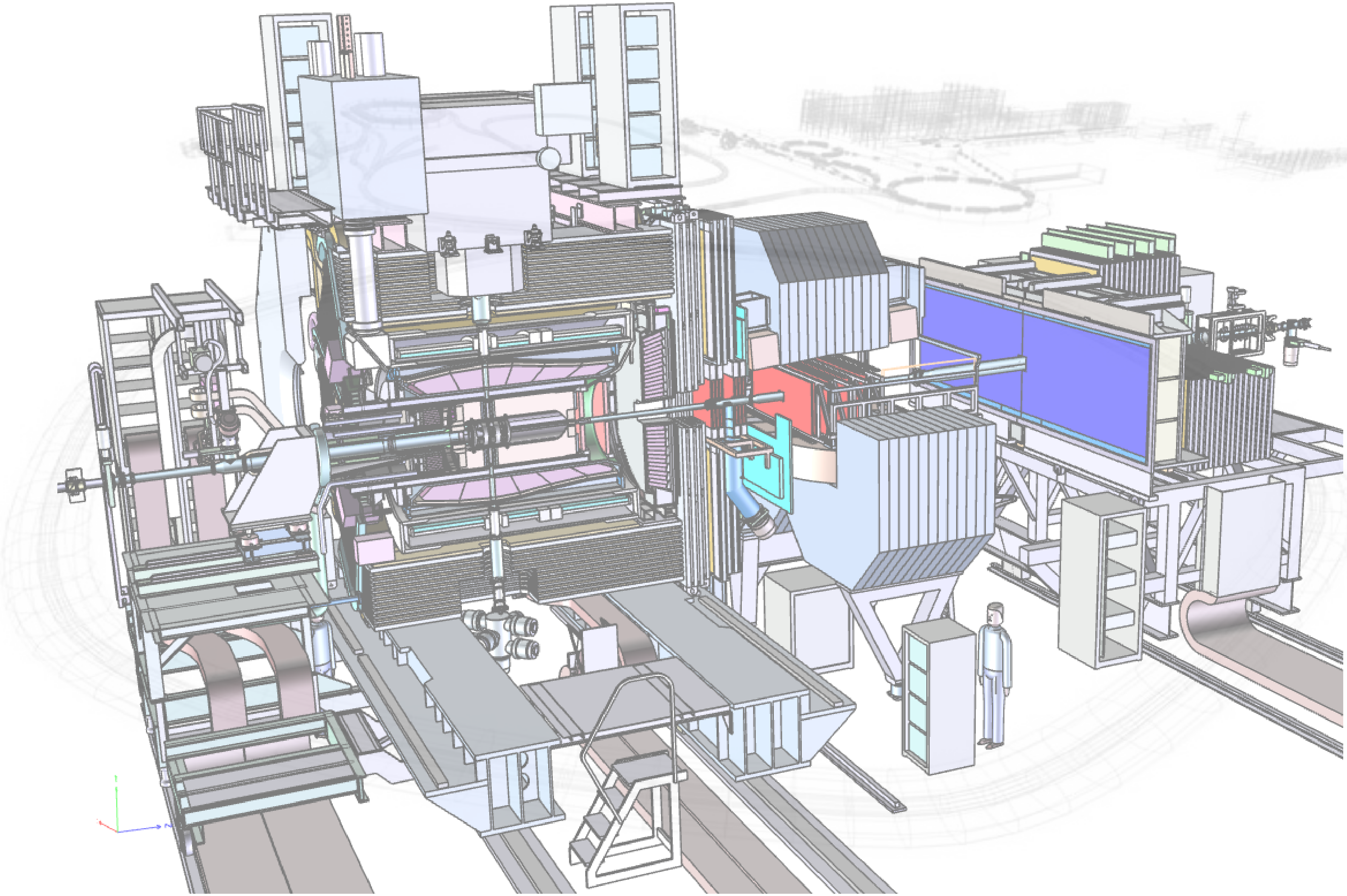
Our needs

- *New devices:* MVD pixels, GEM tracker
- *Replacements:* muon detection, forward calorimetry, TOF, F-RICH

Status of PANDA Systems

- **Cluster Jet Target:**
  - completion in 2024 apart from gas system
  - continue operation with beam to preserve know-how and optimise
- **MVD:** work on strip barrel, ToASt ASIC tested at FZ Jülich, one more iteration
- **STT:** 1 sector in 2024/25, all straws produced, electronics pre-series ready (M8)
- **Barrel DIRC:** Pre-series barbox till end 2025, 35/165 PMTs delivered and accepted
- **Forward Tracker:** FT1/2 ready end 2025, FT3/4 end 2027, 39/180 modules produced, commissioning with sources/cosmics, electronics as for STT, prototype planes at HADES
- **Outer Tracker:** transported to GSI in summer 2023, usage for various applications in discussion
- **Forward Endcap EMC:** partial assembly done at FZJ, COSY beamtime done summer 2023, final assembly and intermediate program planned at ELSA (Bonn)
- **Backward Endcap:** assembly complete spring 2024, beam at MAMI A1 from 2024
- **Barrel EMC:** first slice ready, preparation of readout for characterisation, submodule tests
- **Luminosity Detector:** Final detector till end 2025, tests in KOALA setup planned
- **Orphaned Systems:** MVD Pixels, GEM Tracker, Barrel TOF, Disc DIRC
- **Russian Systems:** Muon System, Forward TOF, FS Calorimeter, Forward RICH

PANDA System Status



Cluster Jet Target

A. Khoukaz, P. Brand, et al. (U Münster)

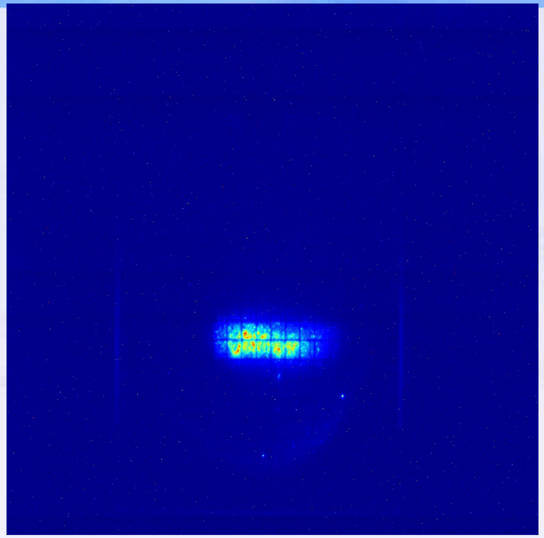
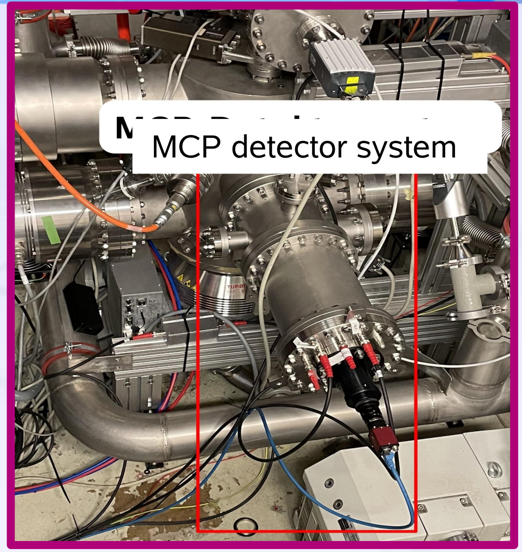
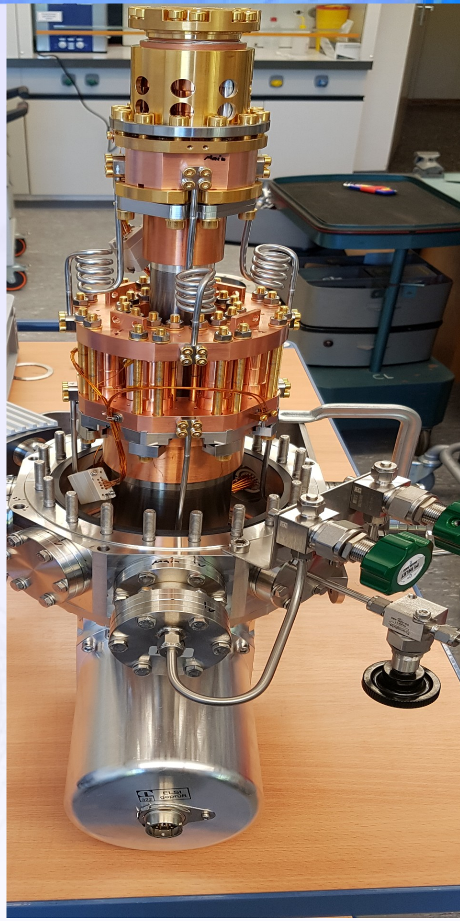


Image taken at COSY
(5e+13 atoms/cm²
2.2e+10 protons)





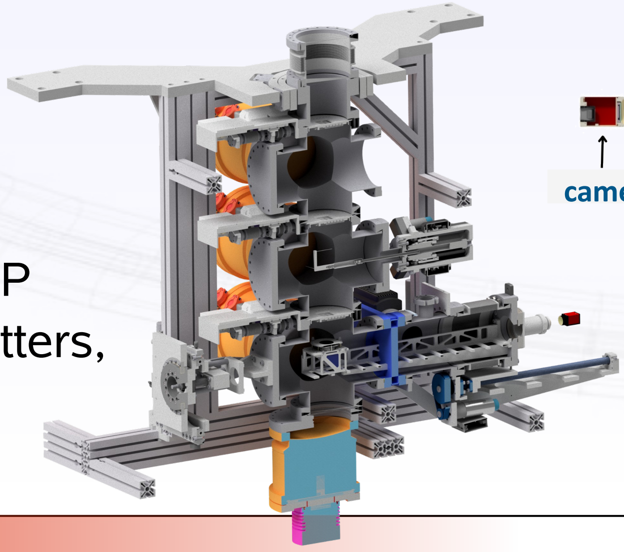
Droplet generator
(as pre-stage for
a pellet target)

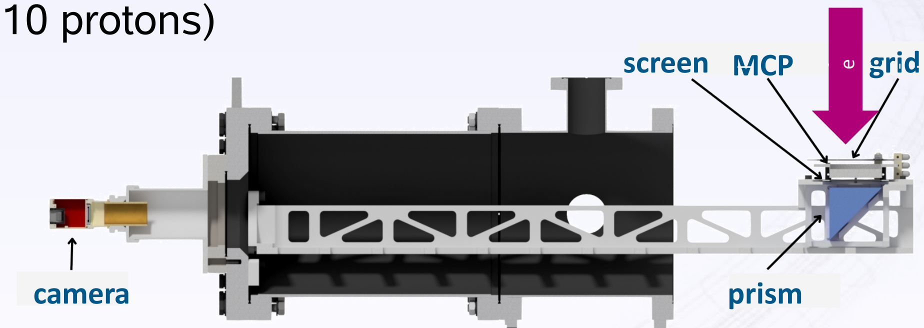
Cluster Generator

- Laval nozzle creates cluster jet
- Collimators define jet beam size
- Tilting apparatus for max. throughput
- Tested at COSY

New Cluster Dump

- 3 pumping stages
- Diagnostics with MCP
- Motor controlled shutters, CANbus, EPICS
- Pump system ready

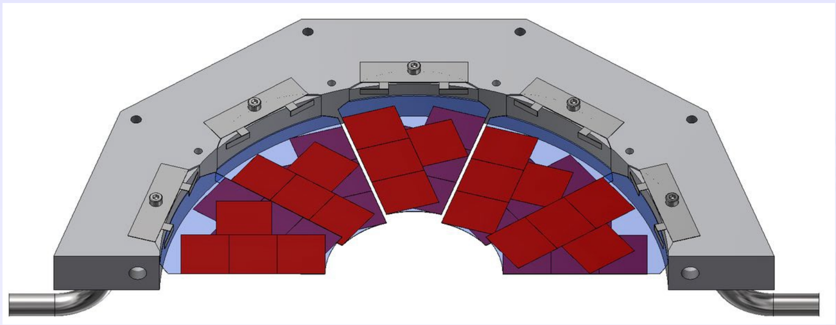


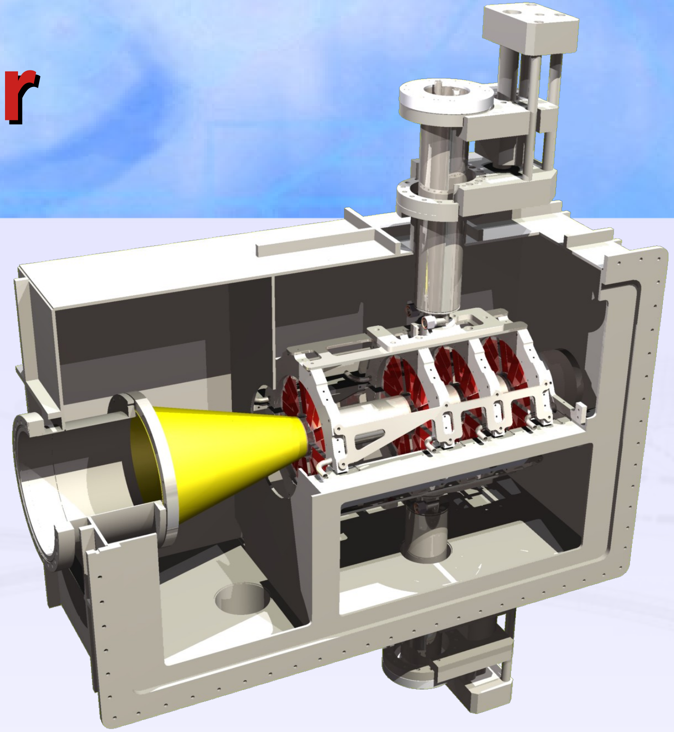


MCP detector system

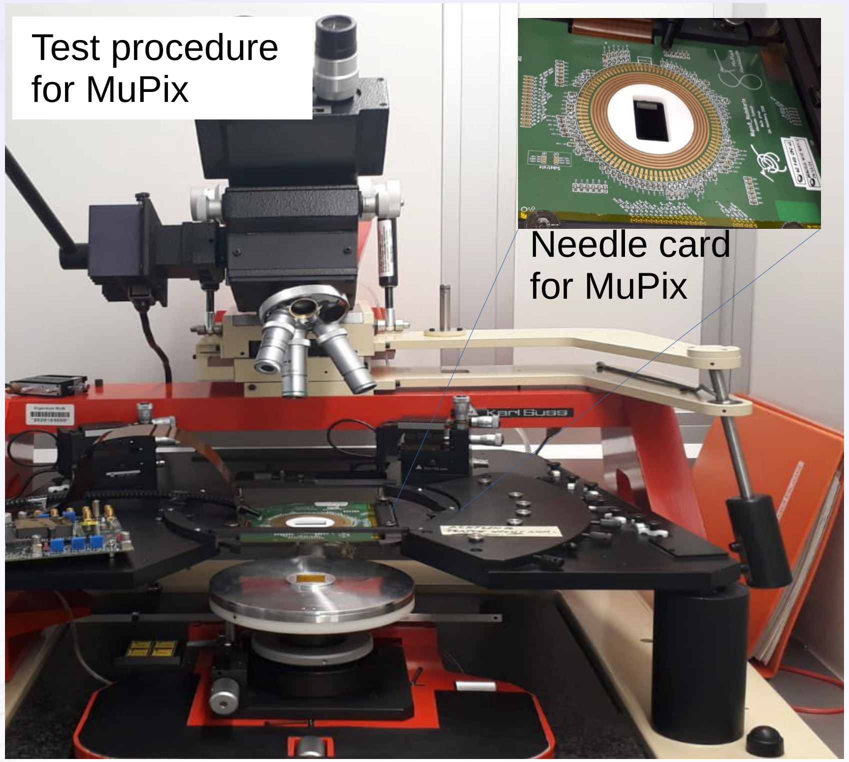
Luminosity Detector

M. Fritsch et al. (RU Bochum)



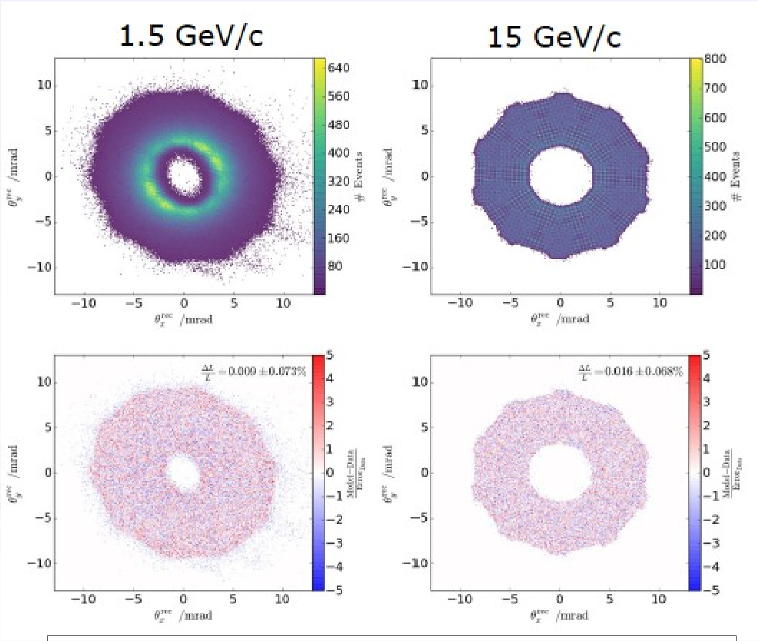


Flexprint cable from LTU, Kharkiv



Detector principle:

- Elastic $p\bar{p}$ scattering:
  calculate coulomb part
- Precise track reconstruction of scattered $\bar{p}$ at z=11 with 4 layers
- Mu3e HV MAPS on CVD in vacuum, 80x80 µm^2 pixels, 50 µm thick



Top: simulated; bottom: difference to fit

Project news:

- MuPix 11 sensors available at RUB
- Flexprint cables delivered by LTU
- Reconstruction of luminosity better than 2%

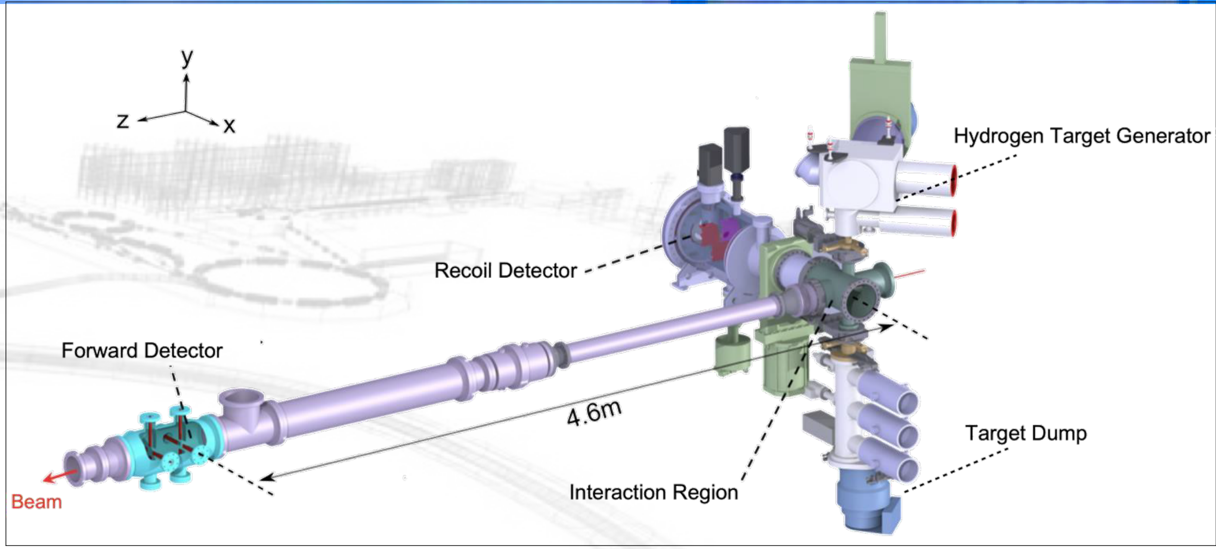
KOALA at GSI Cave C

A. Khoukaz, H. Eick, et al. (U Münster)

KOALA Experiment

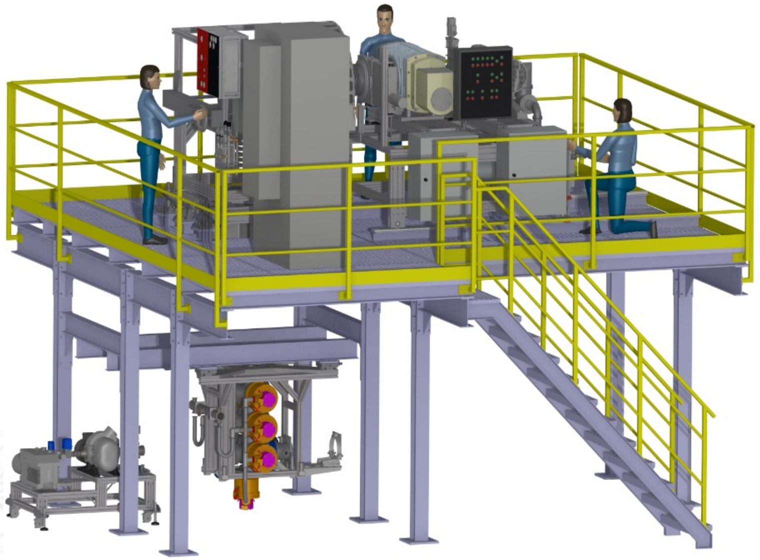
Reference measurement of elastic scattering of pp (COSY, GSI) and $p\bar{p}$ (HESR)

- Setup: LMD prototype, cluster jet target, recoil detector
- First tests at COSY with recoil detector
- Proposal for continuation at GSI Cave C: target optimisation, scattering studies, further detectors



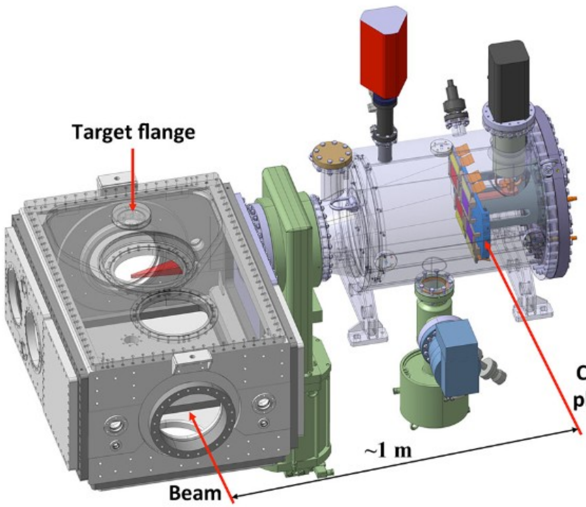
Cluster Targets

- ANKE cluster jet traget: first KOALA run at COSY
- PANDA cluster jet target fully set up at COSY intended move to GSI in 2025/26
- Separate KOALA target at HESR



Detectors

- Luminosity detector:
  - Silicon pixels
  - Roman pot system
- Target recoil at 90°:
  - Silicon strip detectors a
  - Attached to target chamber

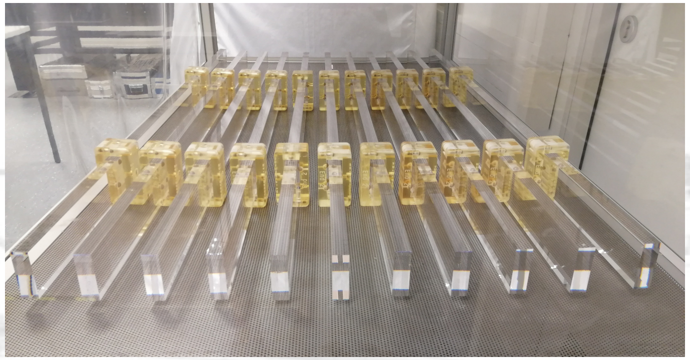


Barrel DIRC: Radiator Bars

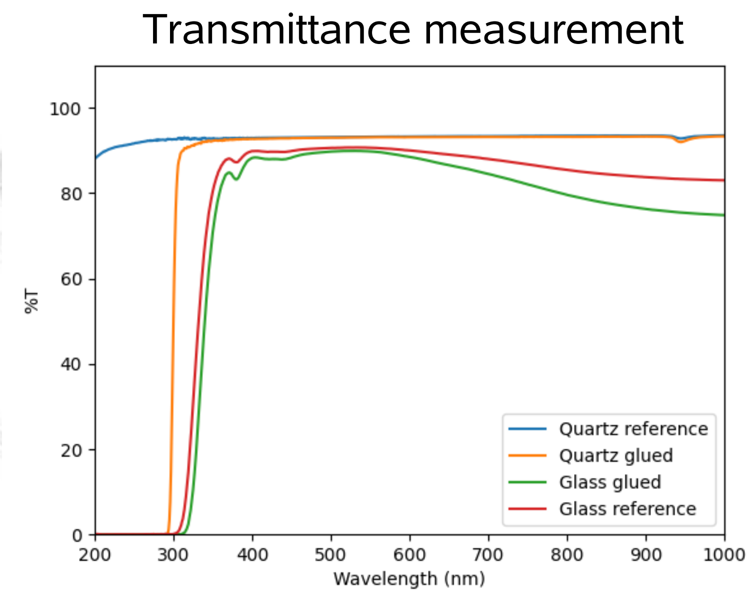
Ahmed Ali, et al. (HI Mainz)

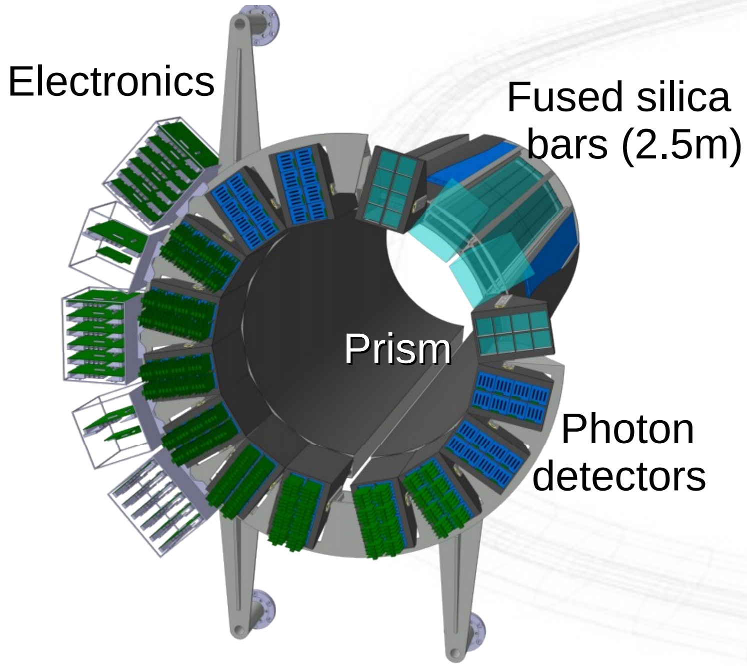
Baseline design based on BaBar

- Fused silica (SiO_2) radiator bars and prisms
- MCP PMT for readout
- Focusing by 3-layer spherical lenses
- Faster readout to suppress background



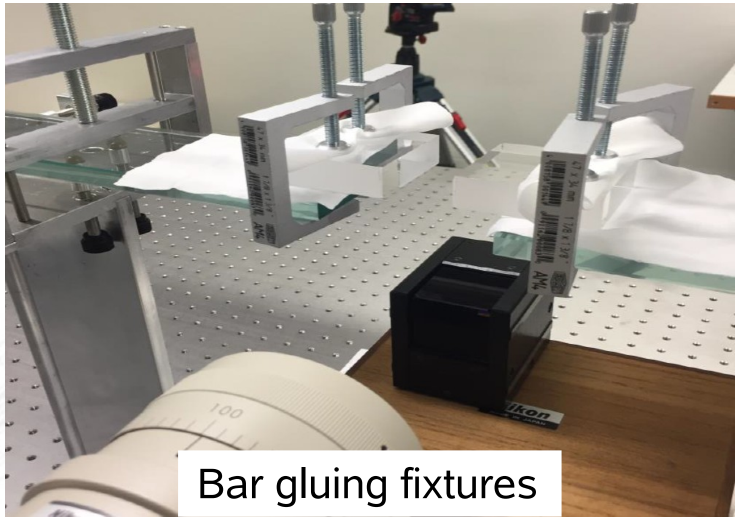
Fused silica radiator bars





Bar Gluing Procedure

- Adapted from BaBar
- EPO-TEK 301 glue
- Cleaning with several steps
- Fixing & alignment (piano wire, auto collimator)
- Glue preparation with precision scale and vacuum pump
- Curing 2-4 days
- Transmittance measurements
- Mechanical tests



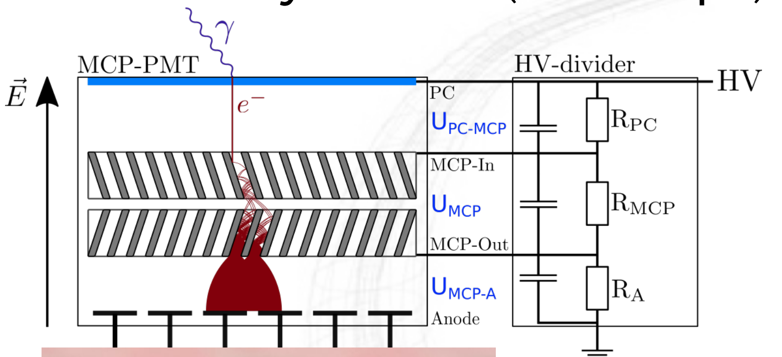
Bar gluing fixtures

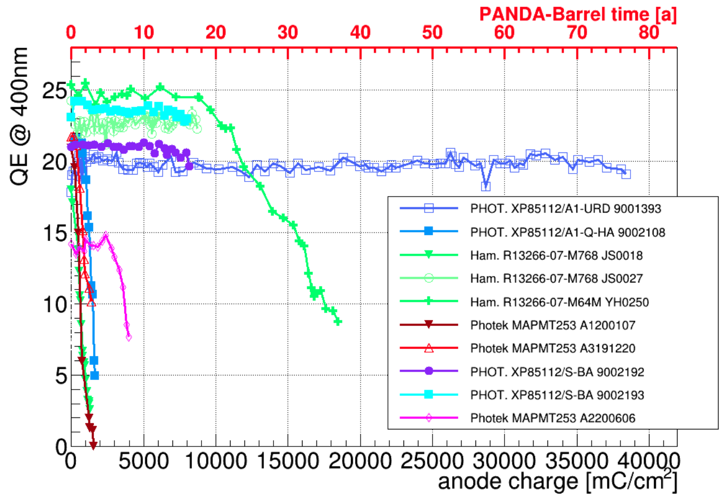
Barrel DIRC: MCP PMT QA

A. Lehmann, S. Krauss et al. (U Erlangen)

MCP PMT

- Insensitive to mag. field
- 8 PMT per bar box
- 2 ALD layers enhance lifetime
- QA setup at U Erlangen
- Delivery started (20/155 pc)



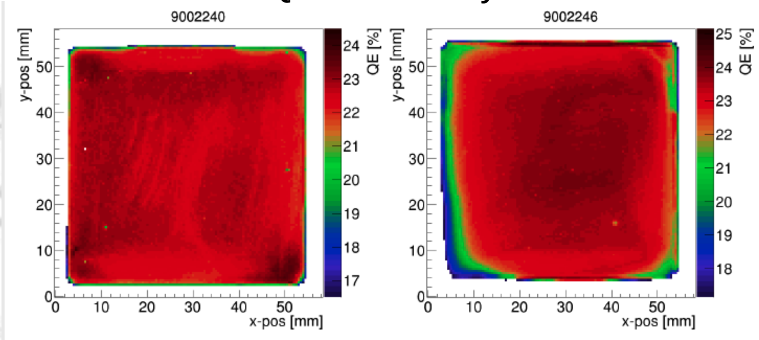


Longterm lifetime measurements (longest: 75 PANDA y)

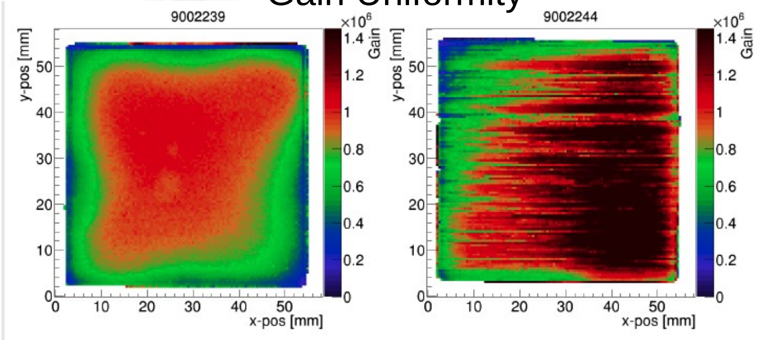
QA Parameters

- Lifetime (few samples)
- Gain vs voltage
- Uniformity of QE and gain
- Collection efficiency
- Rate capability
- Time resolution
- Dark count rate, afterpulse fraction, time resolution
- MCP-PMT efficiency

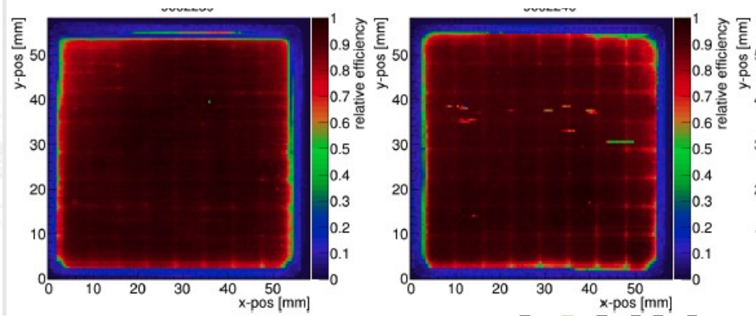
QE Uniformity



Gain Uniformity

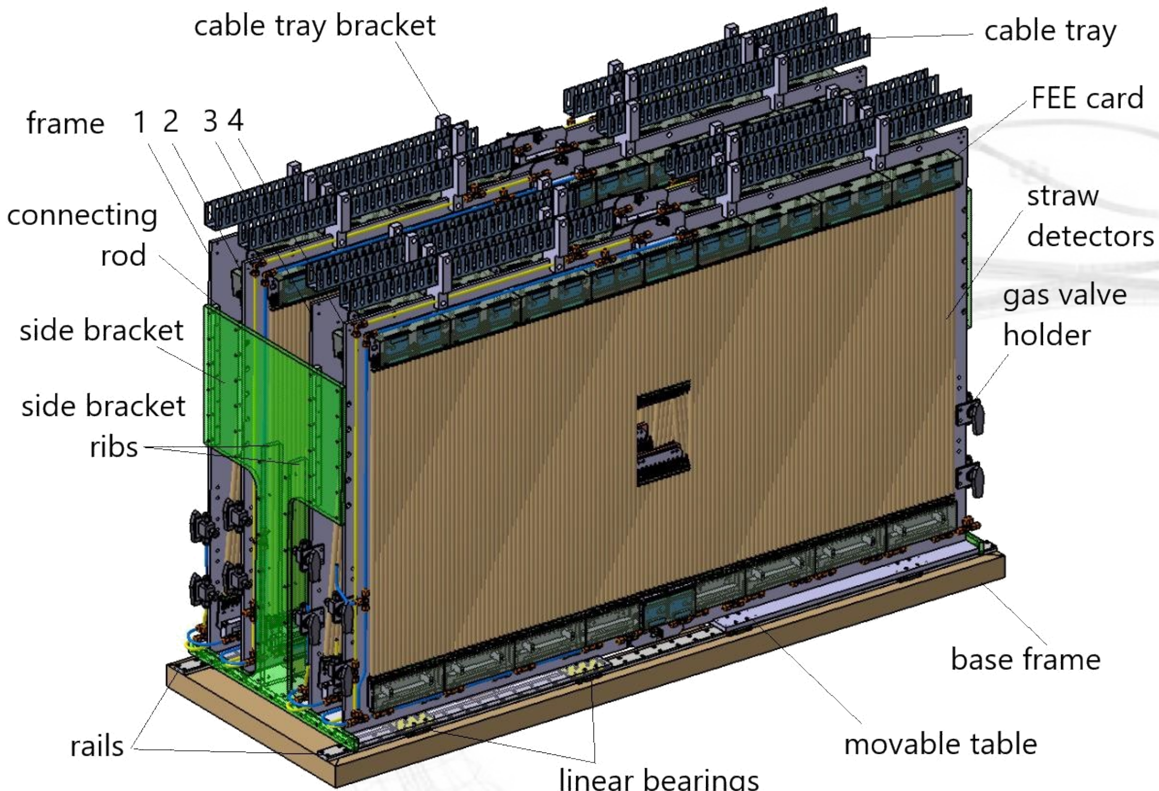


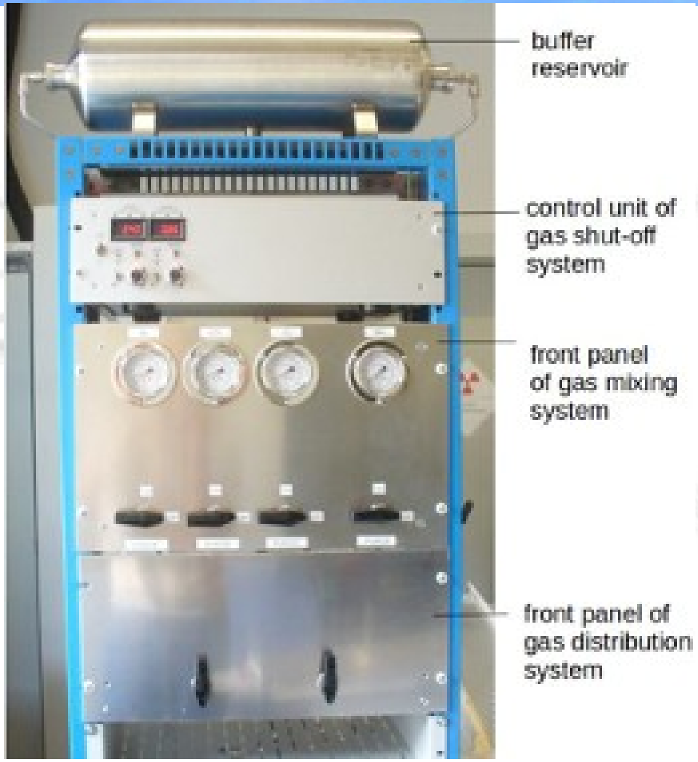
Efficiency

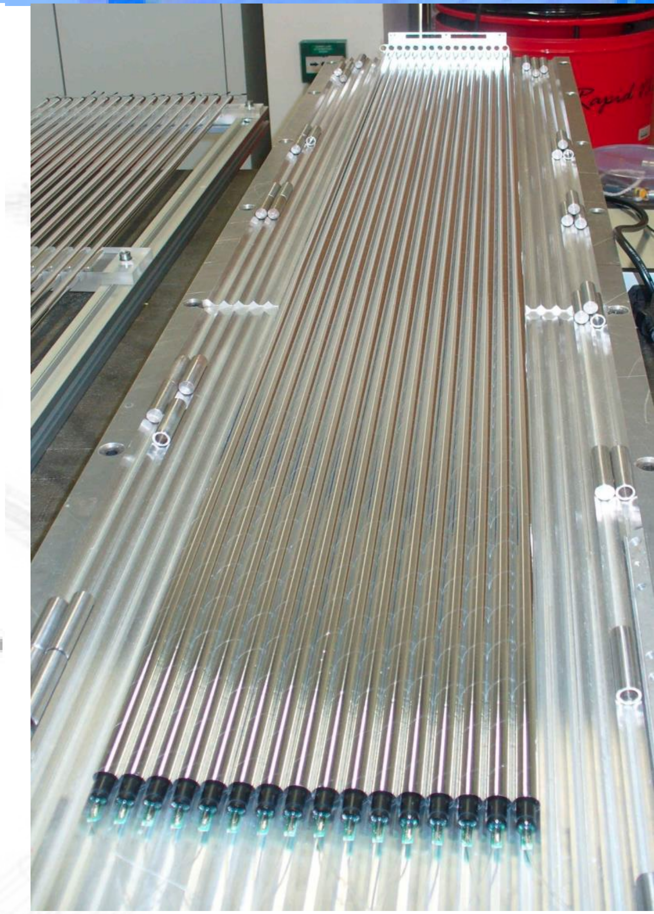


Forward Tracker Progress

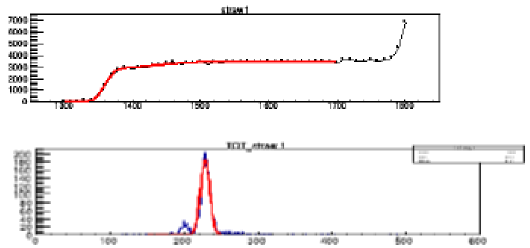
J. Smyrski, JU Krakow







- In-kind contract with JU Krakow
- Frames for FT1/2 ready, for FT3/4 in production
- Module production started, 39/184 modules done
- Tender for HV system and gas flow regulators
- Prototype purified gas system used for tests



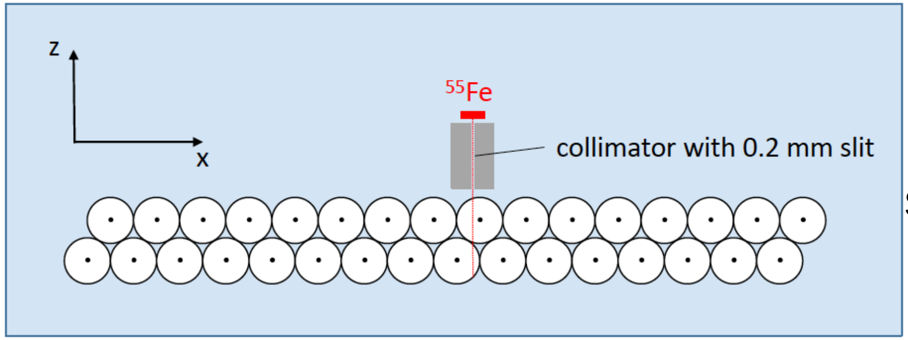
QA plots:
- HV plateau
- ToT

Forward Tracker QA

J. Smyrski, JU Krakow

Automatised FT QA Tests

- Gas tightness
- Dark current and noise level
- High voltage counting rate plateau with ^{55}Fe
- High voltage counting rate plateau with ^{90}Sr
- Time over Threshold spectra with ^{55}Fe
- Drift time spectra with ^{90}Sr
- Scan of straw tube positions
- Scan of wire positions
- Check of module planarity



Inspection of straw positions

FEE card

32 straw module

Scintillator

^{55}Fe and ^{90}Sr

Laser sensor

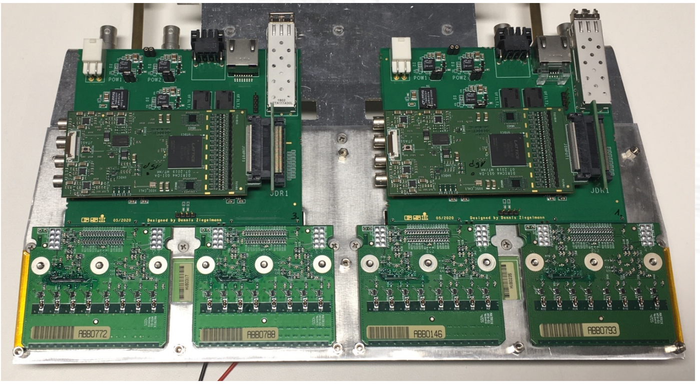
Slit collimator

Motorised xy

LHCb Outer Tracker: Journey to GSI

LHCb Outer Tracker
- Donation from CERN
- Transported from CERN to GSI

PANDA Implementation:
- Interface PCB to connect LHCb FEE to GSI DIRICH readout
- Mechanics design with SLRI, Thailand
- Usage as tracker in FS and in Forward Muon Range System

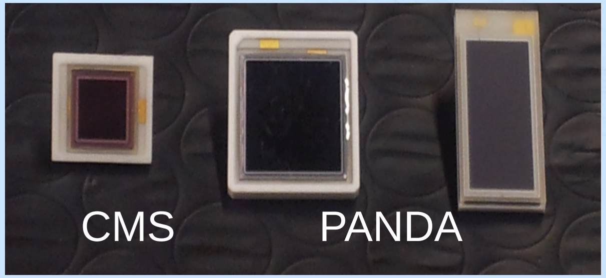


Top row: ready at CERN, unloading from the boat at Gernsheim
Bottom row: Interface board at GSI, arrived at GSI, parking with the robo-tug
(Photos from LHCb and GSI)

PANDA EMC

P̄ANDA PWO Crystals
- PWO is dense and fast
- Low energy threshold
- Increase light yield:
  - improved PWO II (2xCMS)
  - operation at -25°C (4xCMS)
- Challenges:
  - temperature stable to 0.1°C
  - control radiation damage
  - low noise electronics
- New producer CRYTUR

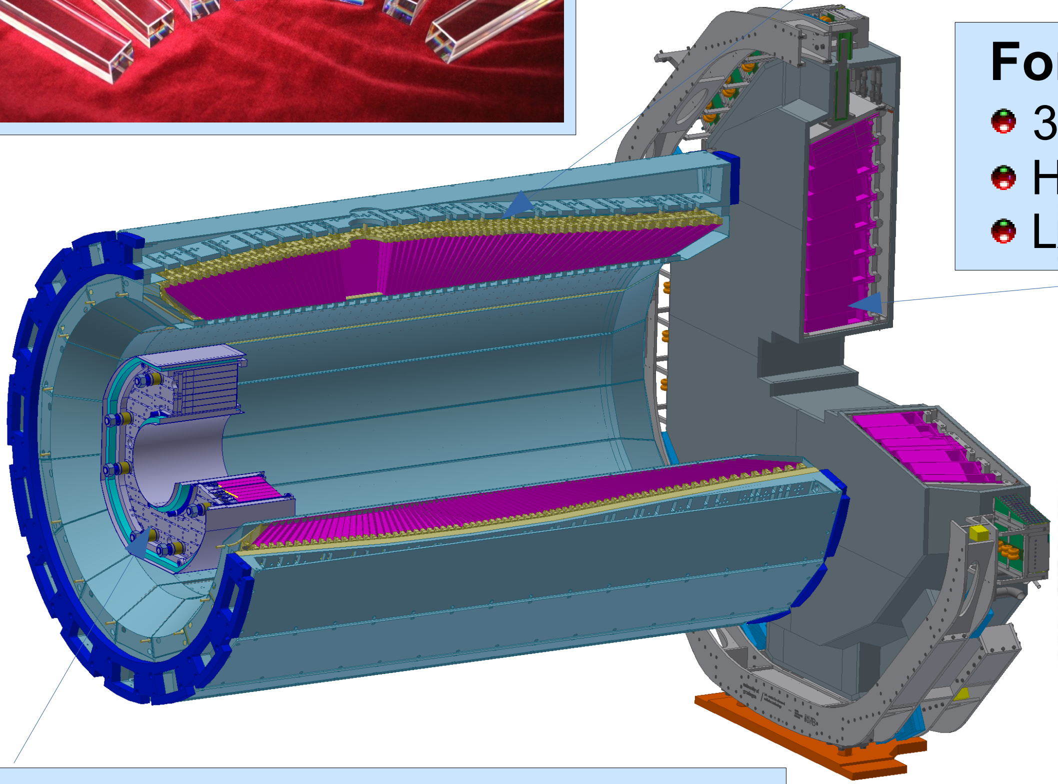
Large Area APDs



5x5 mm^2 10x10 mm^2 and 7x14 mm^2

Barrel Calorimeter
- 11360 PWO Crystals
- LAAPD readout, 2x1cm^2
- $\sigma(E)/E \sim 1.5\%/\sqrt{E}$ + const.

Forward Endcap
- 3856 PWO crystals
- High occupancy in center
- LA APD and VPTT



Backward Endcap for hermeticity,
524 PWO crystals

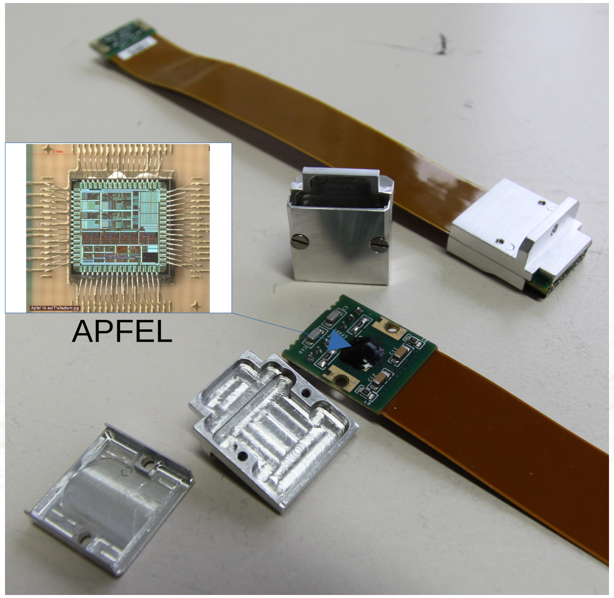
Barrel EMC

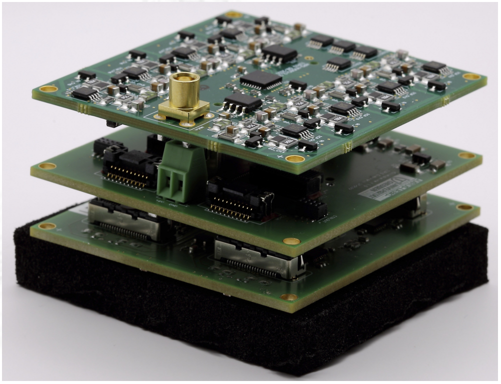
Mechanics
- All alveoles produced
- First slice fully assembled, cooling implemented
- Production of next slice in preparation

Crystals
- Producer Crytur in Czech Republic
- 6100 crystals for complete setup needed, 129 needed for 3rd slice, 402 for 4th slice
- All raw material available

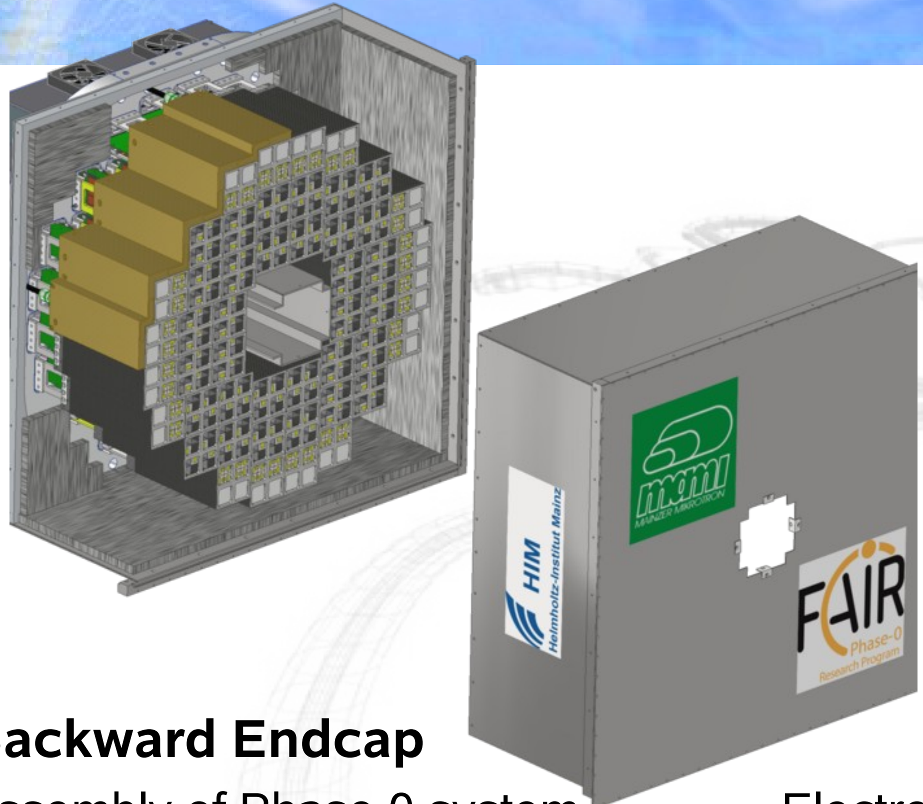
Readout
- APFEL ASIC, all available, flex PCBs delivered
- Hit Detection ASIC: ATR16 prototype delivered
- Backplane stack with HV regulation board, design verified, preparing series production

Services
- Light pulser monitoring
- Stimulated recovery with blue LED





Backward Endcap EMC



Backward Endcap

Assembly of Phase 0 system
(640 ch instead of 524 for PANDA)

- All modules assembled and calibrated
- Pre-tests done
- Calibration in Coldbox starting
- Beamtimes at MAMI in 2024 ff

Electronics

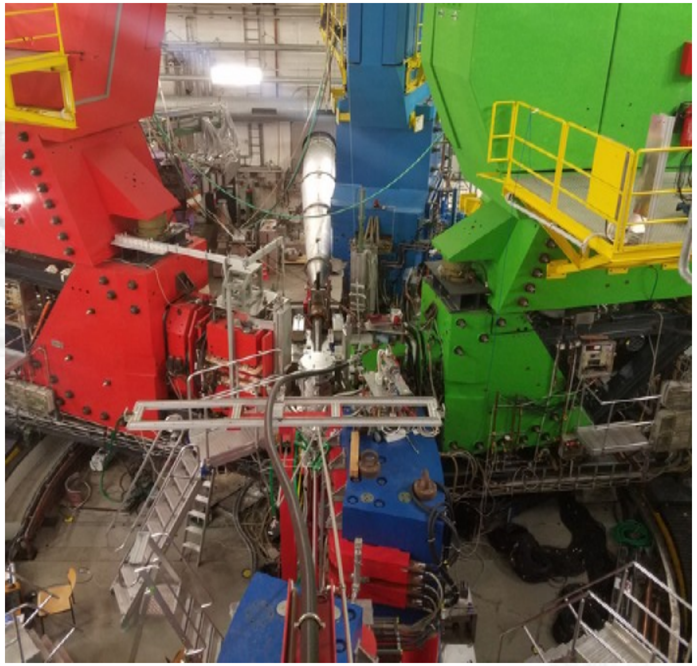
- HV boards series production, calibration in progress
- Lightpulser system: fibrebundles produced, PCB boards in production
- Arduino Apfel&HV control: tested and working

Backward Endcap at MAMI

L. Capozza et al., HI Mainz

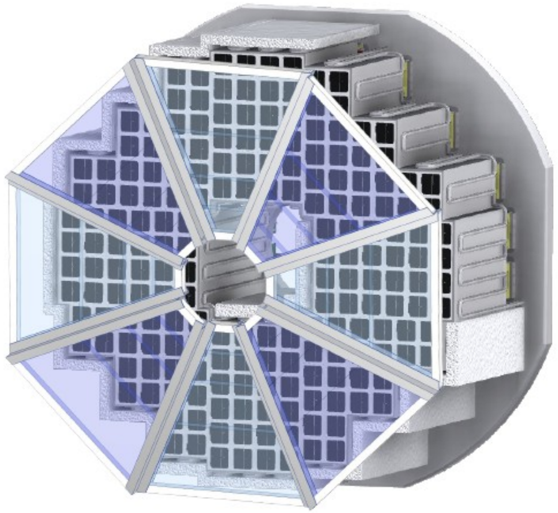
Physics program with PANDA Endcap at MAMI

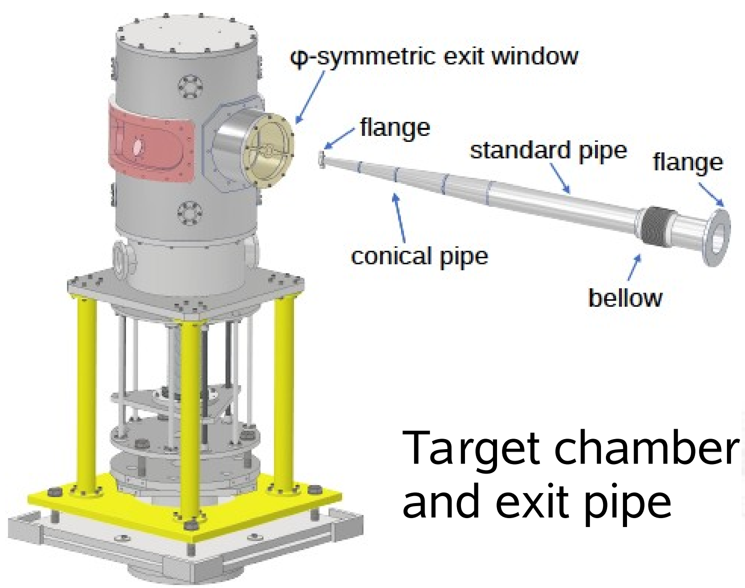
- π^0 to $\gamma\gamma$ transition form factor (TFF)
- Primakoff π^0 electroproduction
- Setup: endcap calorimeter around beam pipe
- Measurement at MAMI: CW e-beam, up to 1.5 GeV



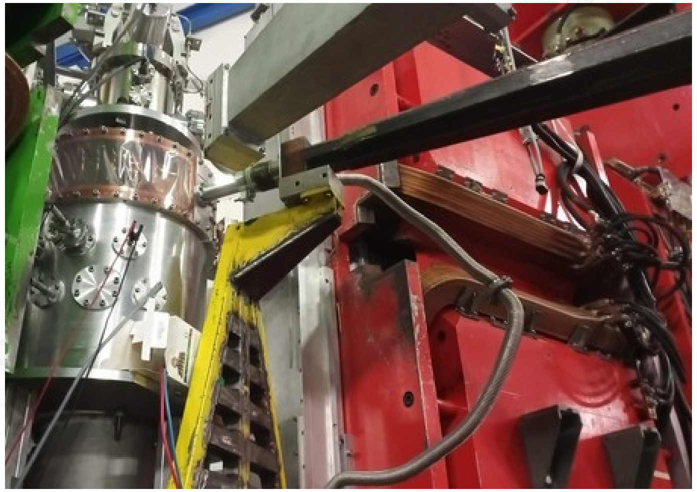
MAMI A1
3 spectrometer setup

PANDA Endcap with
Scintillator for e-detection





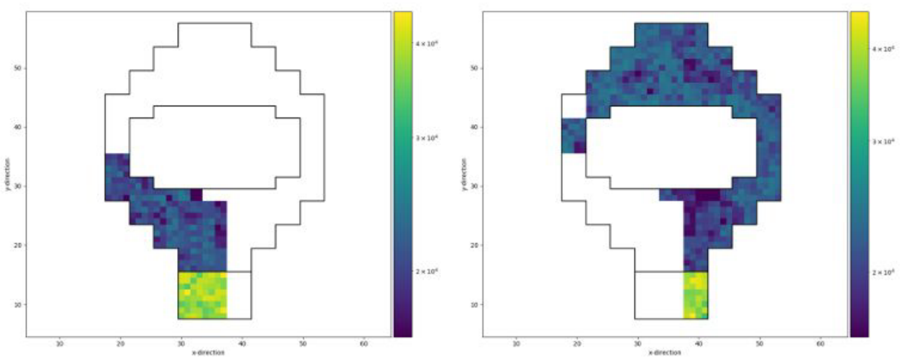
Target chamber
and exit pipe



FWE EMC Beam Test at COSY

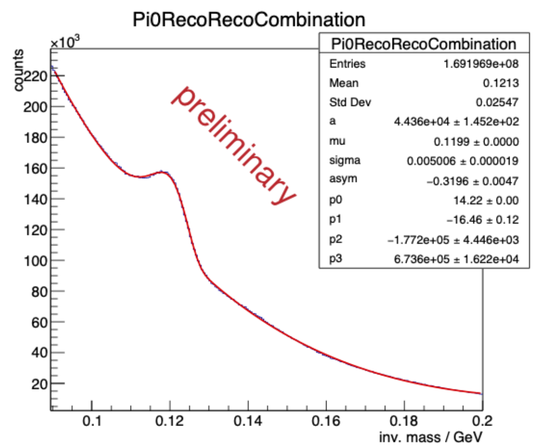
Forward Endcap Status

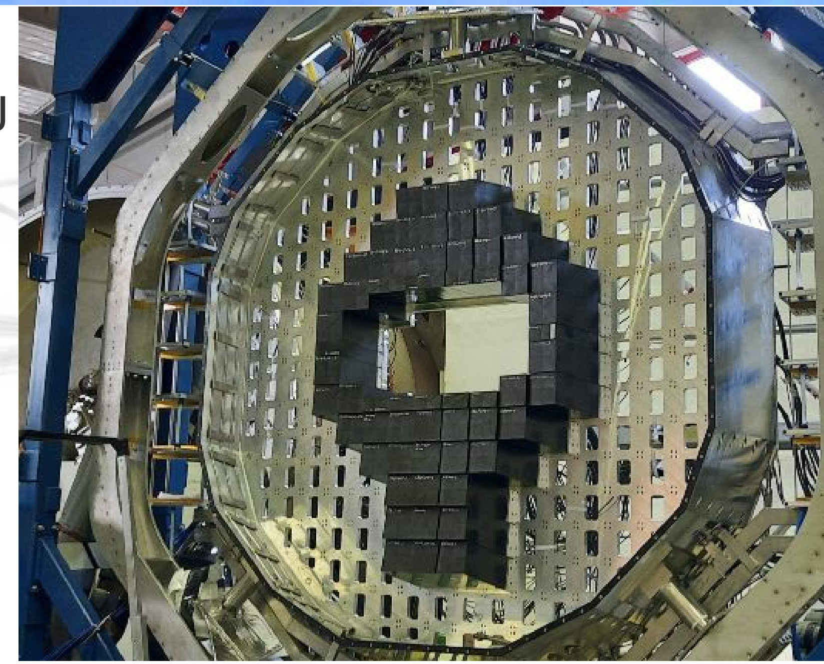
- All VPTT + 6 APD modules installed at FZJ
- Cabling and insulation optimisation
- SADC readout with CBarrel DAQ
- 3 beam periods at COSY (Jul-Sep) final T of -25°C reached

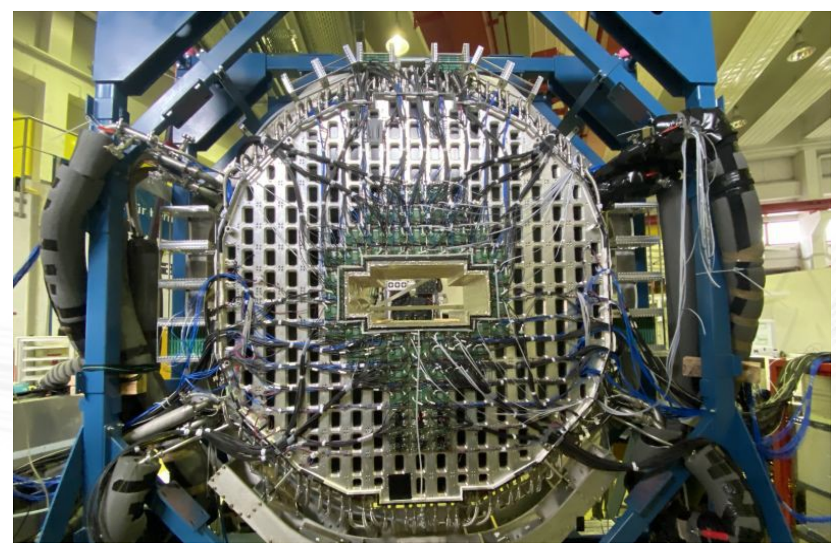


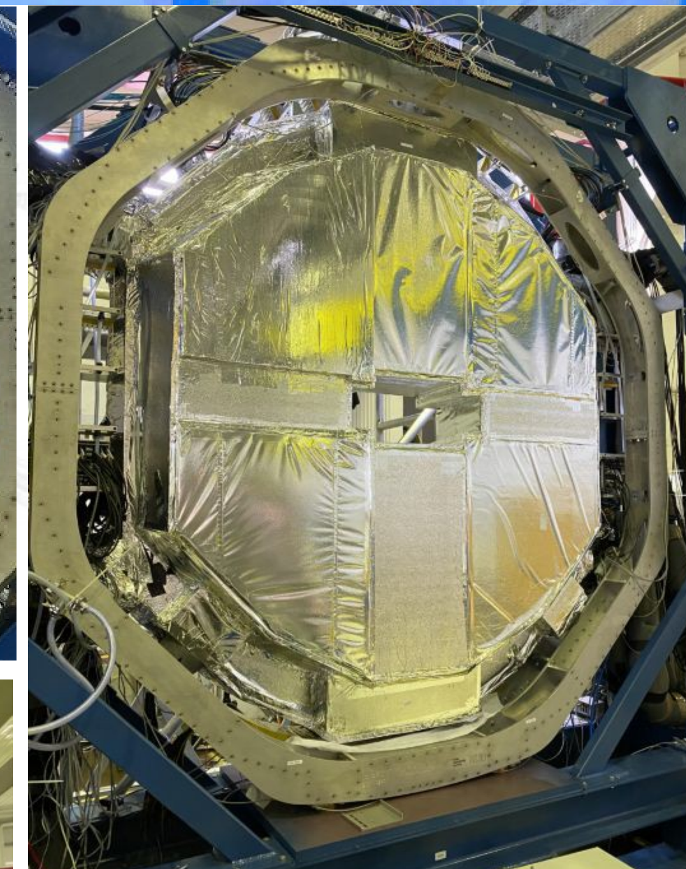
Top: Synchronisation

Right: First π^0 peak approx. 5MeV width





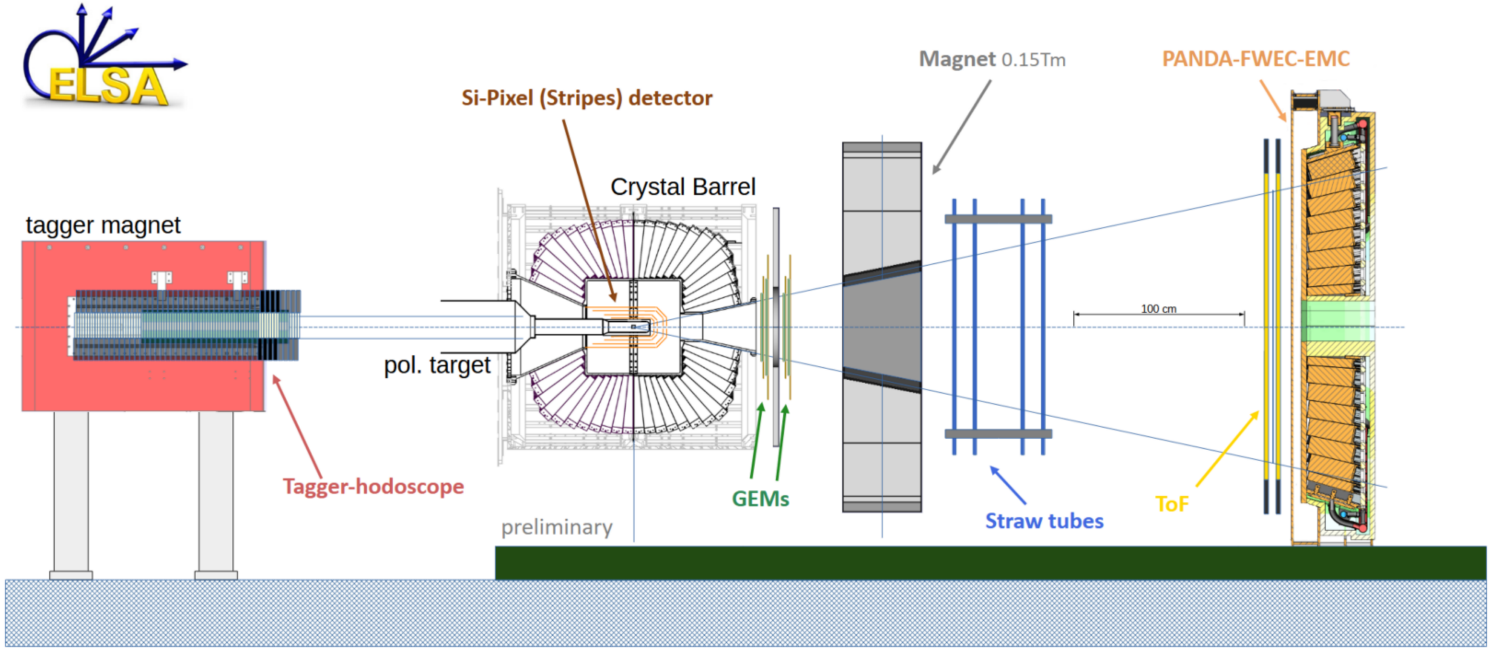


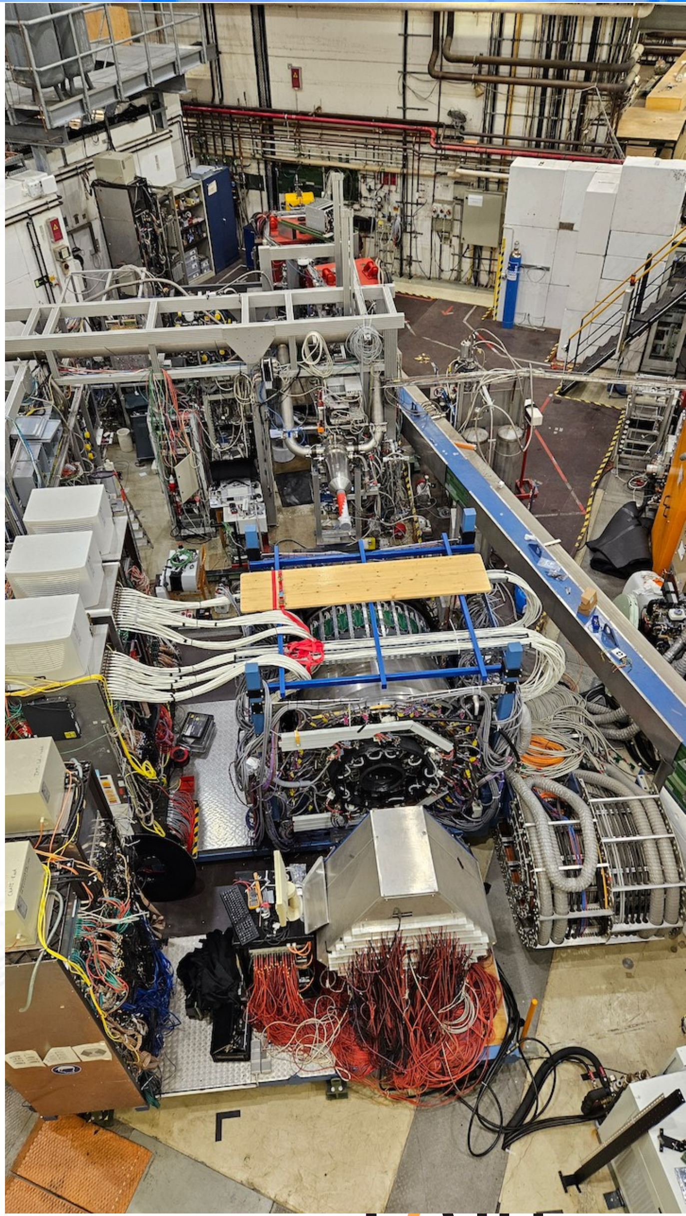


C. Frenkel, C.Schmidt et al. (U Bonn),
F.H. Heinsius, T. Held et al. (RU Bochum)

PANDA FWE EMC at ELSA

U. Thoma et al., U Bonn





New Setup of CB ELSA

- PANDA FWE replaces TAPS
- GEMs and straws for tracking
- Forward dipole magnet
- Physics goals:
  - Strange baryon spectroscopy
  - Baryon spectroscopy with polarisation observables

Schedule of FWE at ELSA

- Assembly at FTD lab till mid 2025, <10 mod / wk
- Possible integration for beam test at end 2025
- ELSA shutdown end 2025 – mid 2027
- Start of physics mid 2027

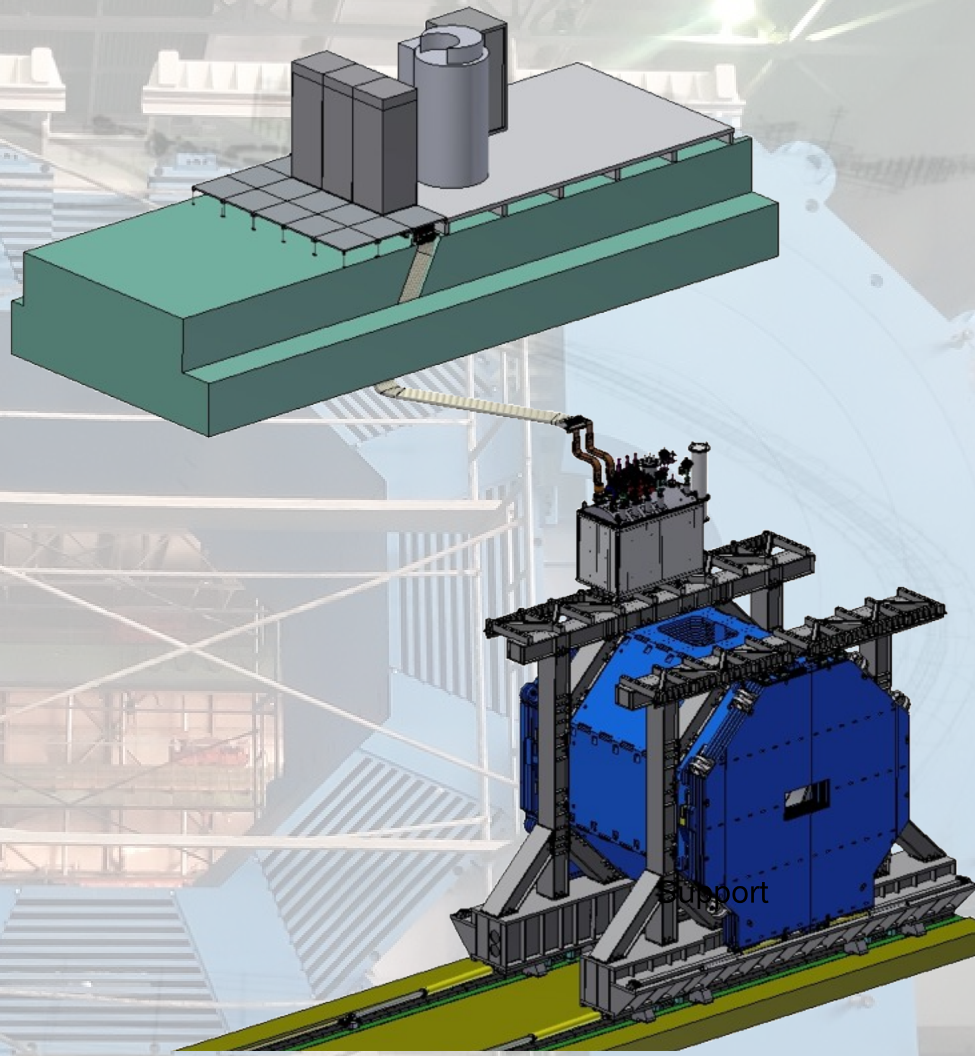
Solenoid Magnet Overview

Specifications:

- 2 T field, 1% homogeneity
- Bore of 95 cm radius
- Target pipe orthogonal to axis
- 3 sub-coils for target gap
- Cryostat l=3m, Ø 1.9-2.7m
- Segmented yoke l=5m,Ø 2.3m, weight 340 t incl. support beams

Project Status for PANDA:

- Contract with BINP canceled in 2022
- Yoke built, design revision needed
- Cold mass and cryostat design usable
- Local cryogenics design not complete
- *Superconductor from Russia unavailable*



Power Converter
with dump resistor (BINP),
LHe plant (FAIR)

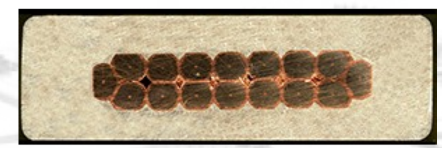
Current leads /
busbars (BINP),
Transfer line (FAIR)

Control dewar
(local cryogenics)
with 300l LHe reservoir
(BINP)

Yoke with platform,
cryostat and cold mass
(BINP),
Rails and rollers (FAIR)

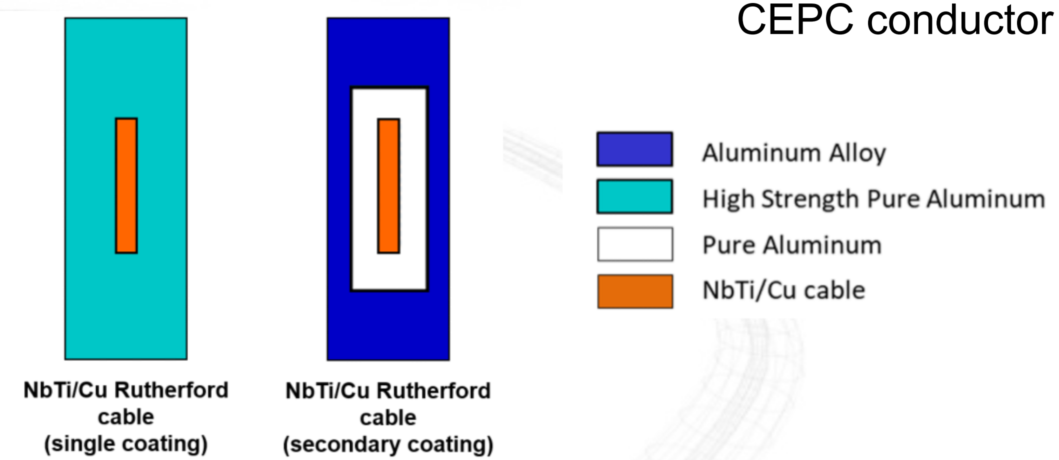
Superconductors for Detector Magnets

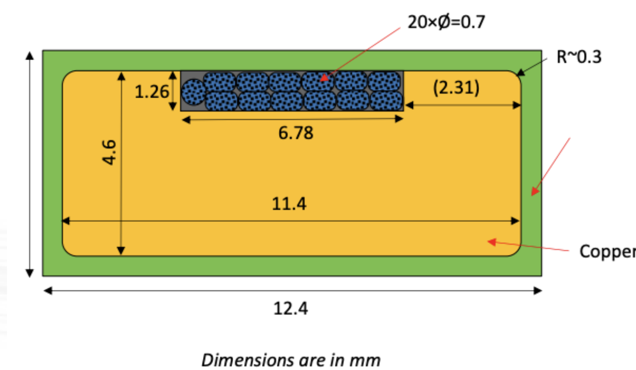
- Conductors for Detector Magnets
  - Al stabilised conductors are still state-of-art for safe operation
  - Currently no commercial producer
  - Chinese company Wuxi Toly Electrical develops cable for CEPC
- Follow superconductor developments
  - Development at CERN:
    Tendering for <1 km test cable
  - Prototype from Wuxi Toly (China) for EMuS
  - Cu stabilized conductor: ePIC
    Strong repercussions on quench protection
- ZEUS magnet
  - Planned visit to DESY
    - State of cryostat and coil
    - Availability of power supply
  - Power test to detect shorts
  - ATLAS current leads available



Wuxi Toly (China) Prototype

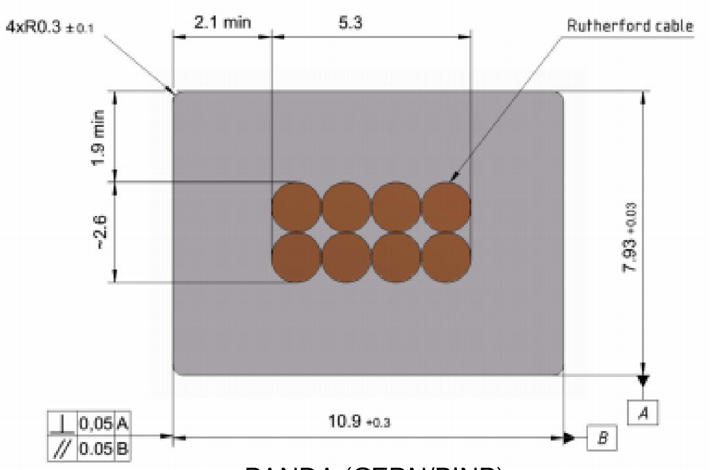
CEPC conductor



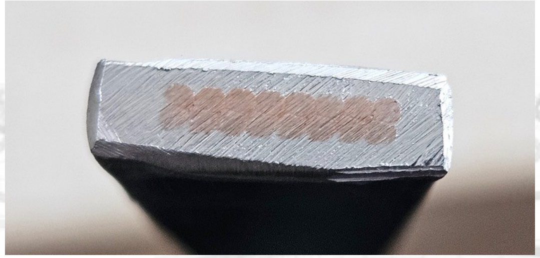


ePIC conductor (Luvata)

PANDA Superconductor



PANDA (CERN/BINP)
11 mm x 8 mm



Wuxi Toly 15 mm x 4.7 mm

	PANDA conductors	
	CERN/BINP, Detailed Specs	Wuxi-Toly
Warm dimensions Without insulation	10.95×7.93 (86.8mm²)	15×4.7 (70,5mm²)
Cold cross section with 0.2mm Insulation	11.3×8.3 (93.8mm²)	15.34×5.08 (77.9mm²)
Strands	8 × Ø1.4mm	16× Ø1.2mm
Strand crit. curr. (at 4.2K, 5T)	>2160A	1690A
Cable crit. curr. (at 4.2K, 5T)	>14690A	27000A
Quench criteria	Nominal current 4.96kA, 30% of critical current (at 4.5K, 3T). Temperature margin for quench well above 2.0K	?
Al 0.2% yield Strength at 4.2K	>40MPa	158MPa (?)
Al/Cu/NbTi ratio	10.5/1/1	4.4/1/1 (?)

Superconductor from Wuxi Toly

- Al stabilised conductor, 16 strands
- Will be used for EMuS project, China
- Core for CEPC Solenoid conductor
- Samples donated to GSI from IHEP Beijing

European Test Facilities for Superconductors:

- SuperACT foundation at U Twente (NL)
- CEA LEAS, Saclay, (F)
- SULTAN facility, EPFL/PSI (CH)

Planned Tests:

– Microscopy study of cross section, strand and bonding
– Extract strand and check for shape and broken filaments
– Critical current versus B in range 3-5 T
– Residual Resistance Ratio

Main question: stability and safety margin

ZEUS Magnet Option for PANDA

- ZEUS solenoid with cryostat from DESY
  - Build new yoke with ~150 t mass
  - ZEUS yoke was 3600 t, ECAL outside magnet
- Integrate central TS detectors
- Make mechanics compatible with PANDA

ZEUS magnet available at DESY

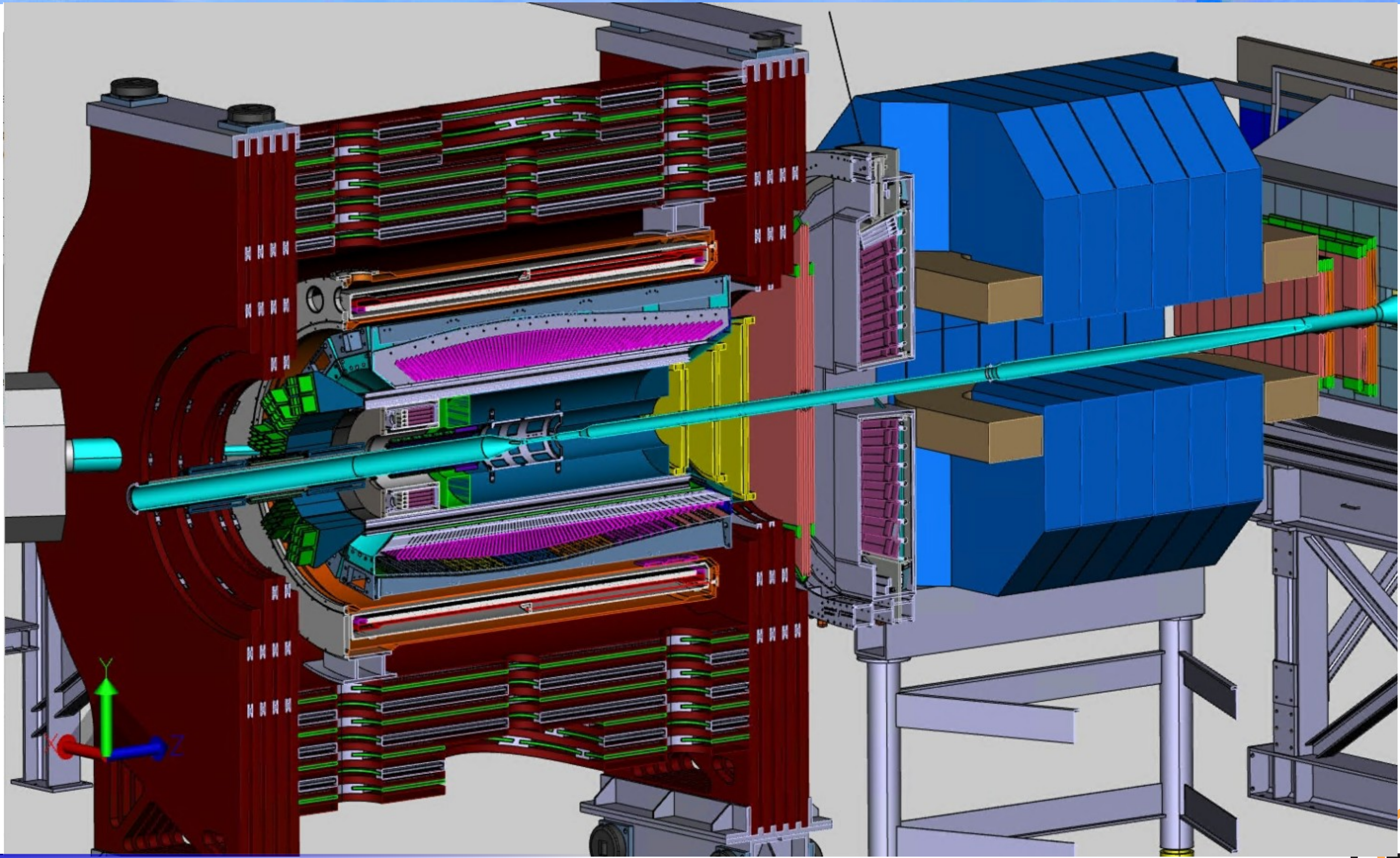
- Dimensions of Coil and Cryostat:

Cryostat		
	Inner radius	$860^{-0.0}_{+1.0}$ mm
	Outer radius	$1110^{-0.0}_{+1.0}$ mm
	Length	$2800^{-1.0}_{+1.0}$ mm
	Forward length (z^+)	$1450^{-0.5}_{+0.5}$ mm
	Backward length (z^-)	$-1350^{-0.5}_{+0.5}$ mm
Coil		
	Inner diameter	1850 mm
	Outer diameter	1914.2 ± 0.1 mm
	Length	2.46 m
	Forward coil limit (z^+)	1.3 m
	Backward coil limit (z^-)	-1.2 m

- Comparison to PANDA Solenoid:

Dimensions of	radius / mm	axial length / mm	zmin / mm	zmax / mm
C_i	950	3090	-1190	1900
C_o	1340	3090	-1190	1900
Y_i	1490	4070	-1585	2485
Y_o	2300	4875	-1970	2905

Setup Studies



Early PANDA Setup

- PANDA Solenoid Magnet Perspectives
  - Magnet construction needs SC cable development
  - Unlikely to complete before 2025
  - No group and no funding
- Construction of PANDA detectors continues
- ZEUS magnet for detector integration
- Antiprotons in 2032: PANDA needs to be ready

Main challenges of ZEUS option:

- How to implement a target in ZEUS?
- How to implement a smaller Barrel EMC?

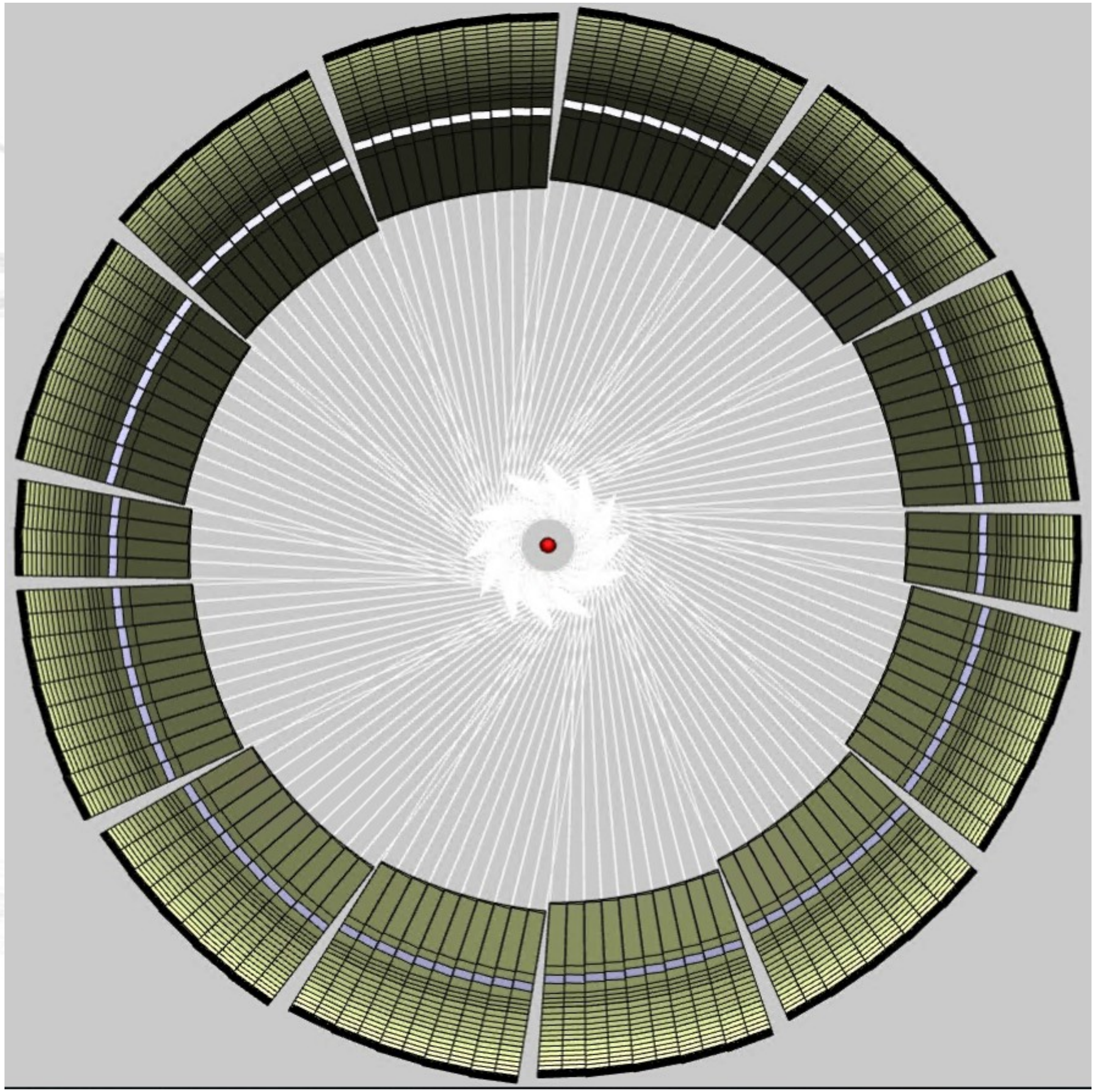
Barrel EMC: Reduced Radius

Barrel EMC with 12+2 slices
r=432 mm: 12x10 crystals
+2x4 crystals in ϕ

12 original slices with 710 crystals
2 special slices with 284 crystals

Simulation studies started at U Bonn
with PANDAroot (B. Salisbury)
to evaluate losses:

- Photon gun at various energies
- $\eta\pi^0\pi^0 \rightarrow 6\gamma$



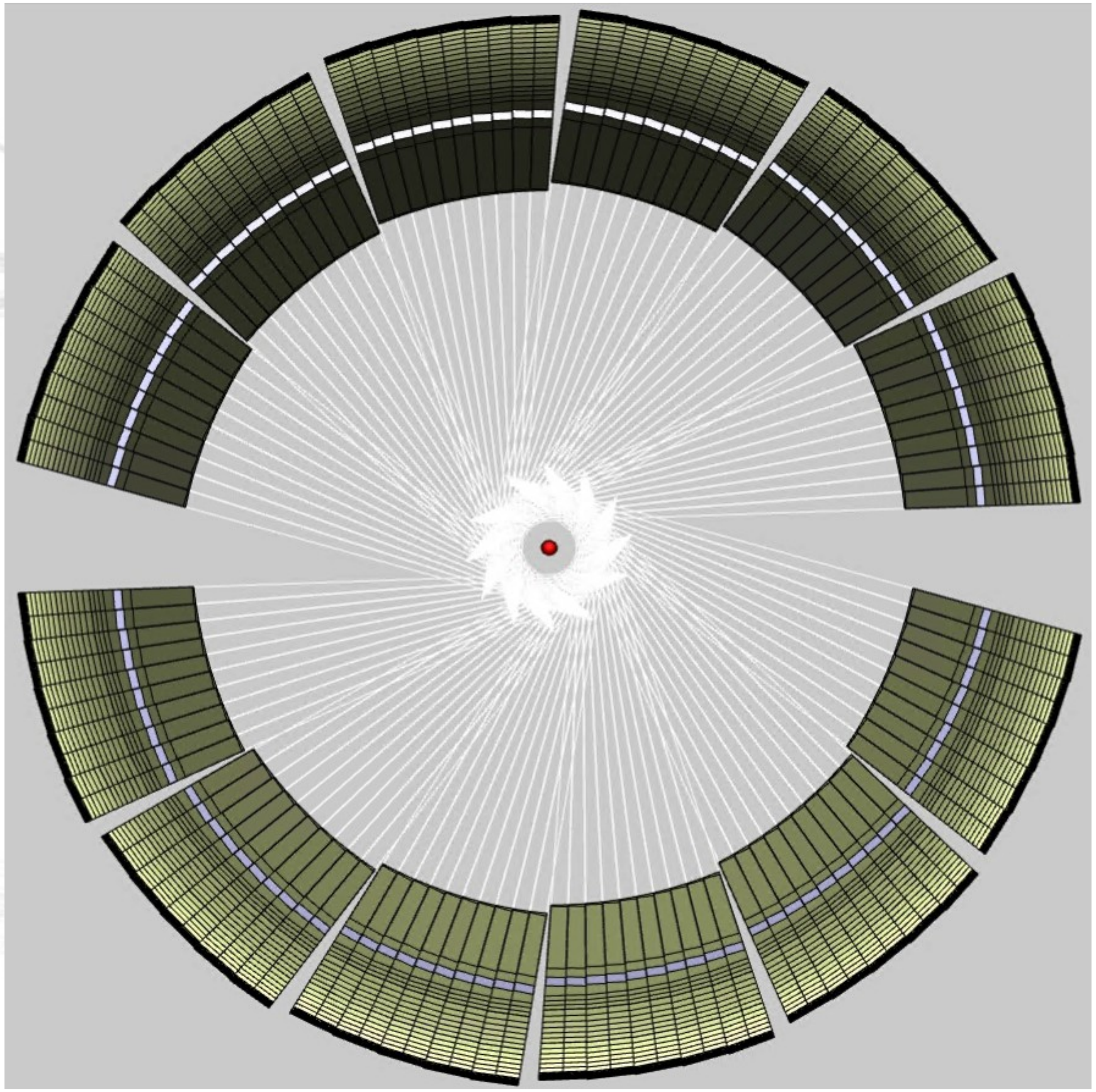
Barrel EMC: Reduced Radius

Barrel EMC with 12+2 slices
r=432 mm: 12x10 crystals

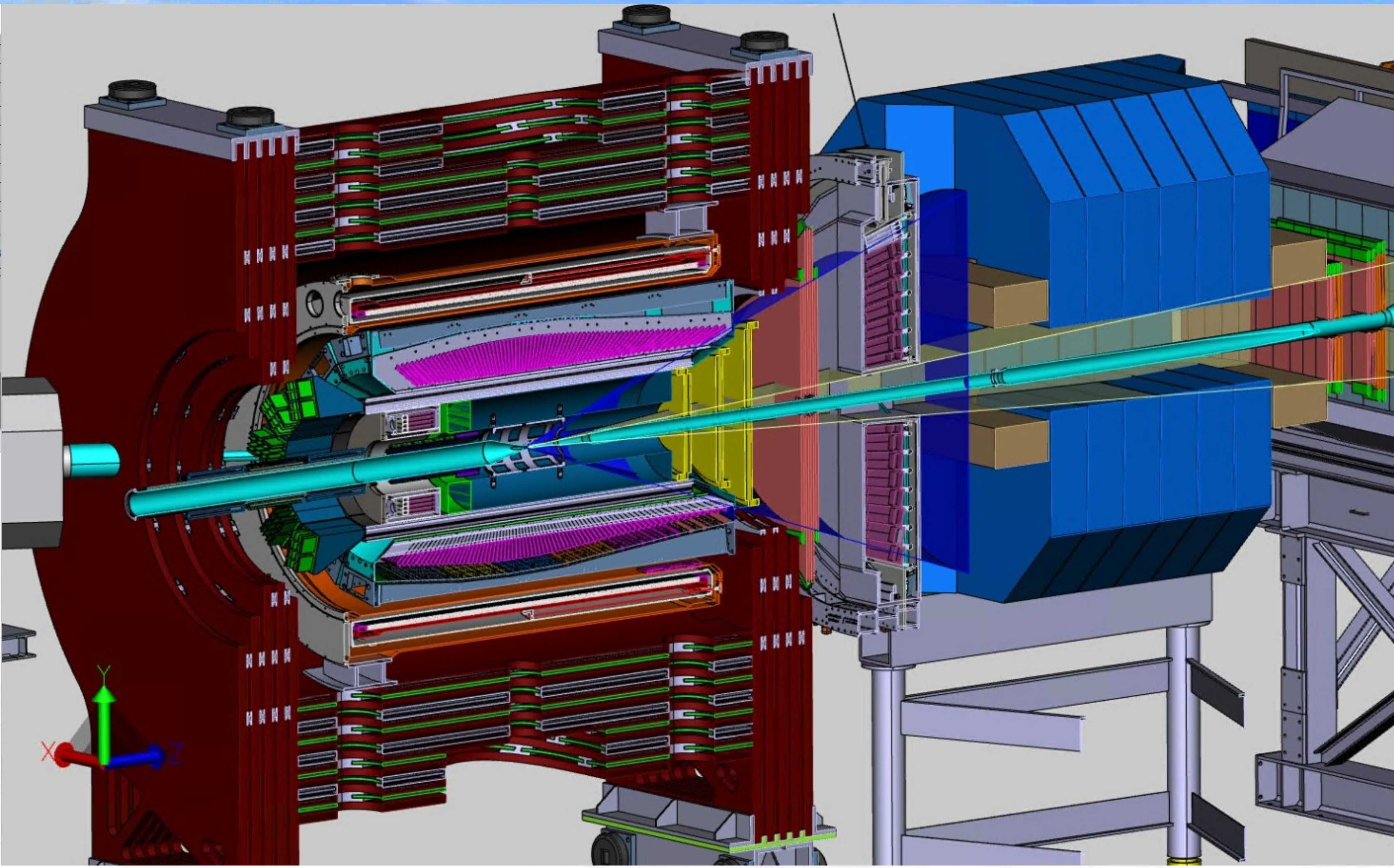
12 original slices with 710 crystals
2 special slices left out for
diagonal target pipe

Simulation studies started at U Bonn
with PANDAroot (B. Salisbury)
to evaluate losses:

- Photon gun at various energies
- $\eta\pi^0\pi^0 \to 6\gamma$



Compact Setup



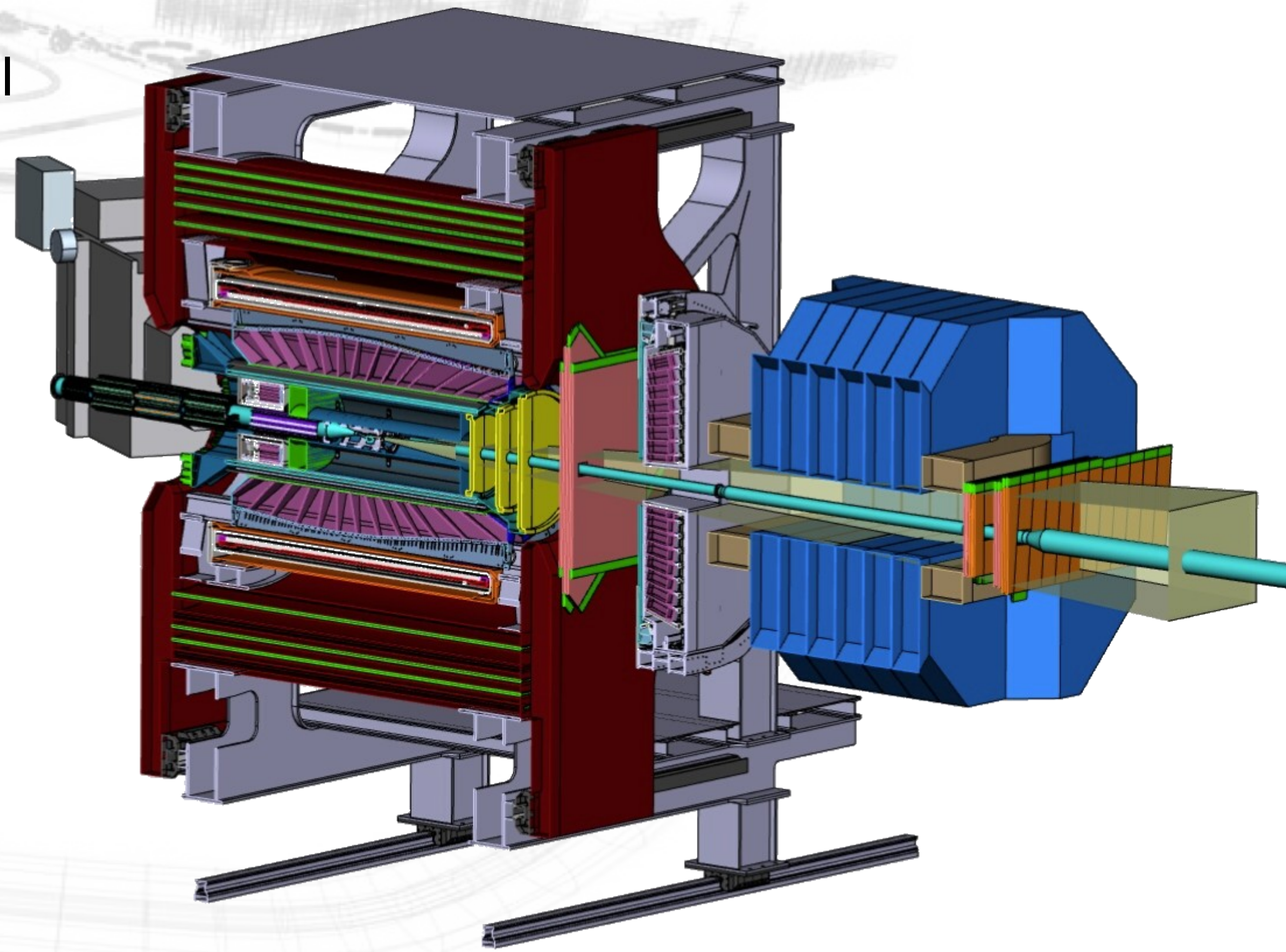
Goal: Ready for $\bar{p}$ in 2032

- Horizontal Cluster Jet Target
- Adapt position of FWE EMC:
  Outside Solenoid!
- More compact Solenoid yoke
  (*Recess for vertical cluster jet target already foreseen)*
- Advantages:
  - Implement all components
  - Much reduced cost
  - Easier access to FWE EMC and target
- Drawbacks:
  - Lower granularity
  - Worse magnetic field
  - Smaller BWE

Compact Setup: Forward Spectrometer

Observation: Smaller Acceptance for Forward Spectrometer

- Adapted FWE Position outside Solenoid
- Angular range ±6.5° horizontal and ±3° vertical
- More compact dipole!
  - Smaller yoke mass: 140 t instead of 240 t
  - Smaller gap: 50 cm instead of 1 m
  - Lower power: 150 kW instead of 400 kW
- Tracking with rearranged FT1-4 modules
- Advantages:
  - Implement all components
  - Much reduced cost of FS
  - Smaller FS PID detectors
- Drawbacks:
  - Verify acceptance, resolution and physics



ECE Recommendations on PANDA

- Important to get a clear perspective and plan: urgently needed to retain collaboration members and attract new parties.
  - Consider to secure COSY ring (and store it). This would send a positive sign and could save costs with respect to RESR ring.
  - Estimate (approximately) the loss of physics impact by using the ZEUS magnet, including the horizontal operation of the cluster target.
  - Continue with vigour the option of available superconductivity cables and implication of building a magnet with the geometry to operate a vertical target injection.
  - The committee is concerned with remaining risk items: Magnet, Barrel Crystals, orphaned systems

- Reiteration of former recommendations
  - Implement the “compact” geometry and baseline assumptions for detector technologies/designs in MC and estimate precision/reach for a couple of “golden channels” for the first 5 years of beam
  - Create a strawman detector completion timeline with milestones.

Conclusions

Strategy of PANDA

- Usage of ready detectors for physics: FWE EMC, BWE EMC, straws
- Completion of detectors in construction
- Integration of all TS detectors in construction
- Testing with beam at GSI Cave C: Koala at SIS18

Magnet

- Long term: SC cable development, CERN or CEPC
- Alternative: ZEUS magnet for start program
- **ECE observation:** investigate “compact” setup
- Evaluate savings vs. physics

PANDA with Antiprotons

- Development of missing systems in parallel
- **Gateway of decision in 2026:**
  - *PANDA Hall until 2030:* start with PANDA based on ZEUS
  - *PANDA Hall after 2034:* alternative programs