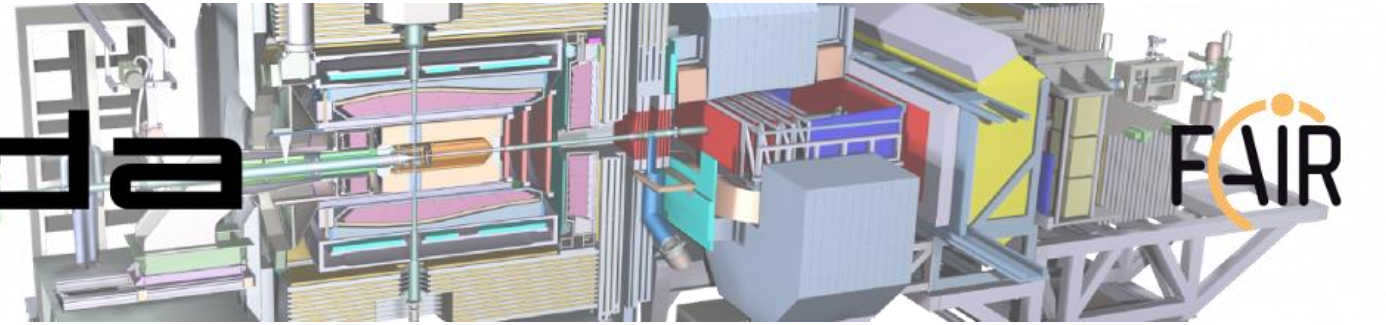
Detector technologies with PANDA



Anastasios Tassos Belias / GSI

JOINT GLUEX-PANDA Workshop 2019

May 3 - 5, 2019 • George Washington University

Detector technologies with PANDA

Antiprotons @ FAIR

PANDA Detector

Schedule & Opportunities

Anastasios Tassos Belias / GSI

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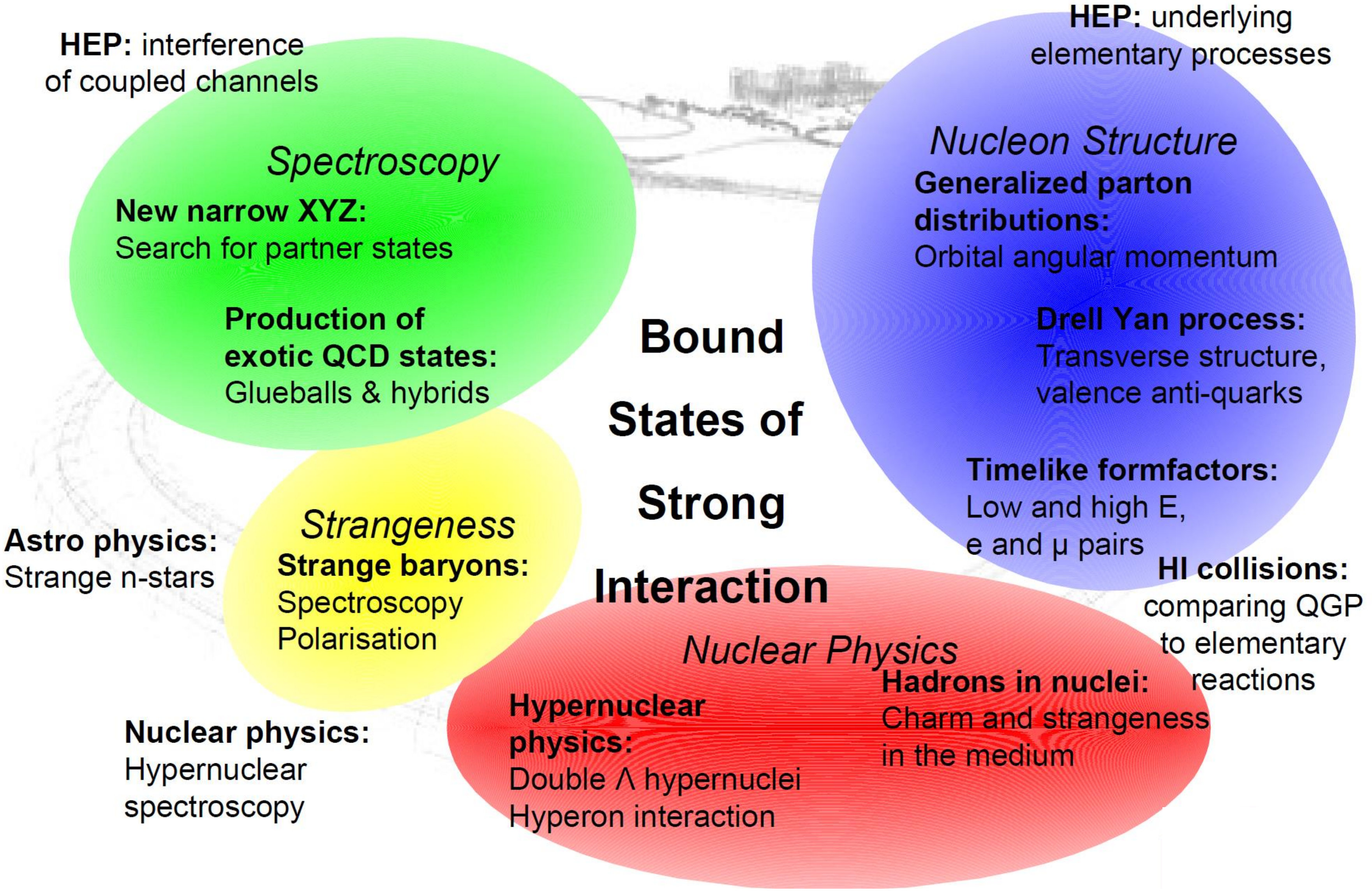
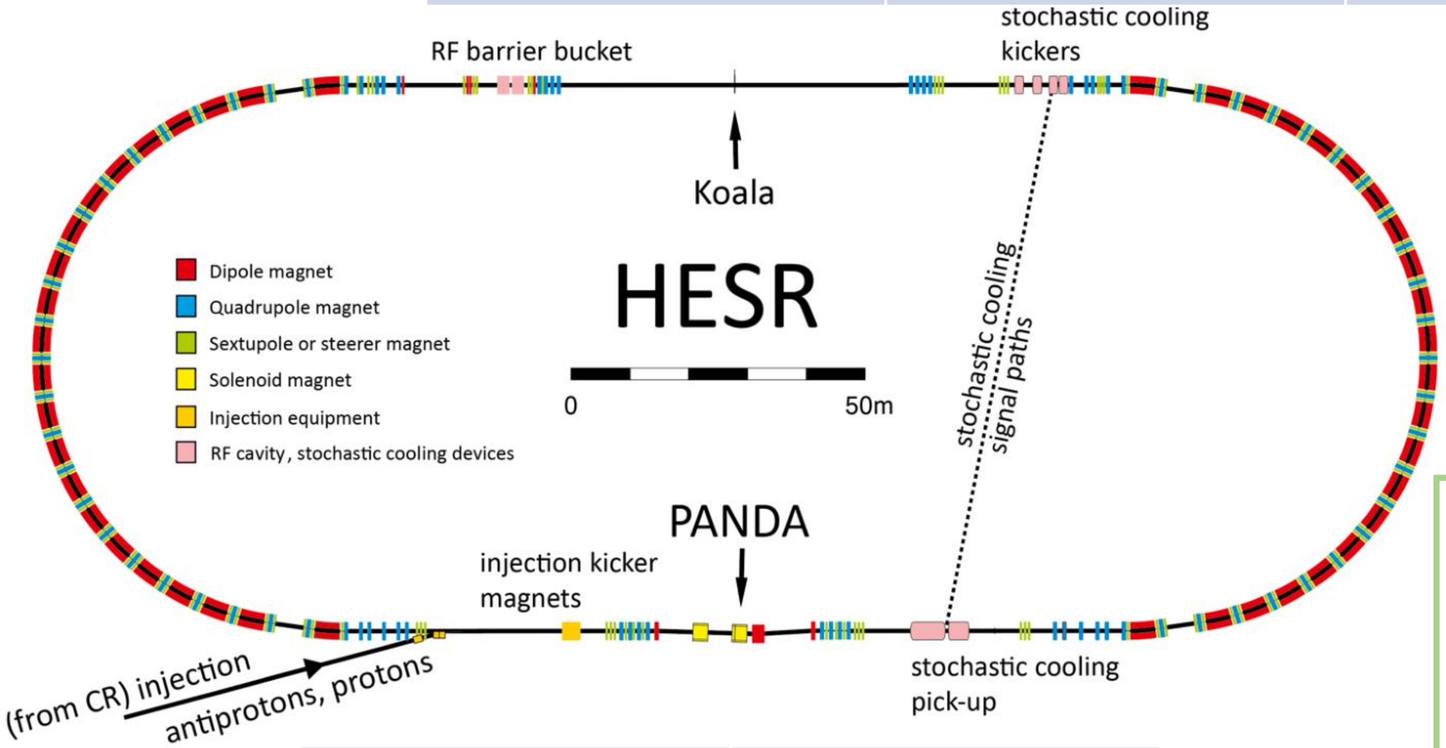
Physics Objectives



HESR - High Energy Storage Ring

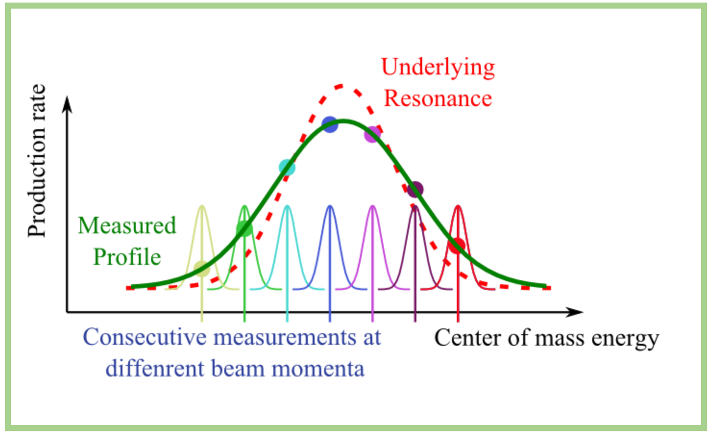
Mode	High luminosity (HL)	High resolution (HR)
Δp/p	~10^{-4}	~$4x10^{-5}$
$L(cm^{-2}s^{-1})$	$2x10^{32}$	$2x10^{31}$
Stored p̄	10^{11}	10^{10}



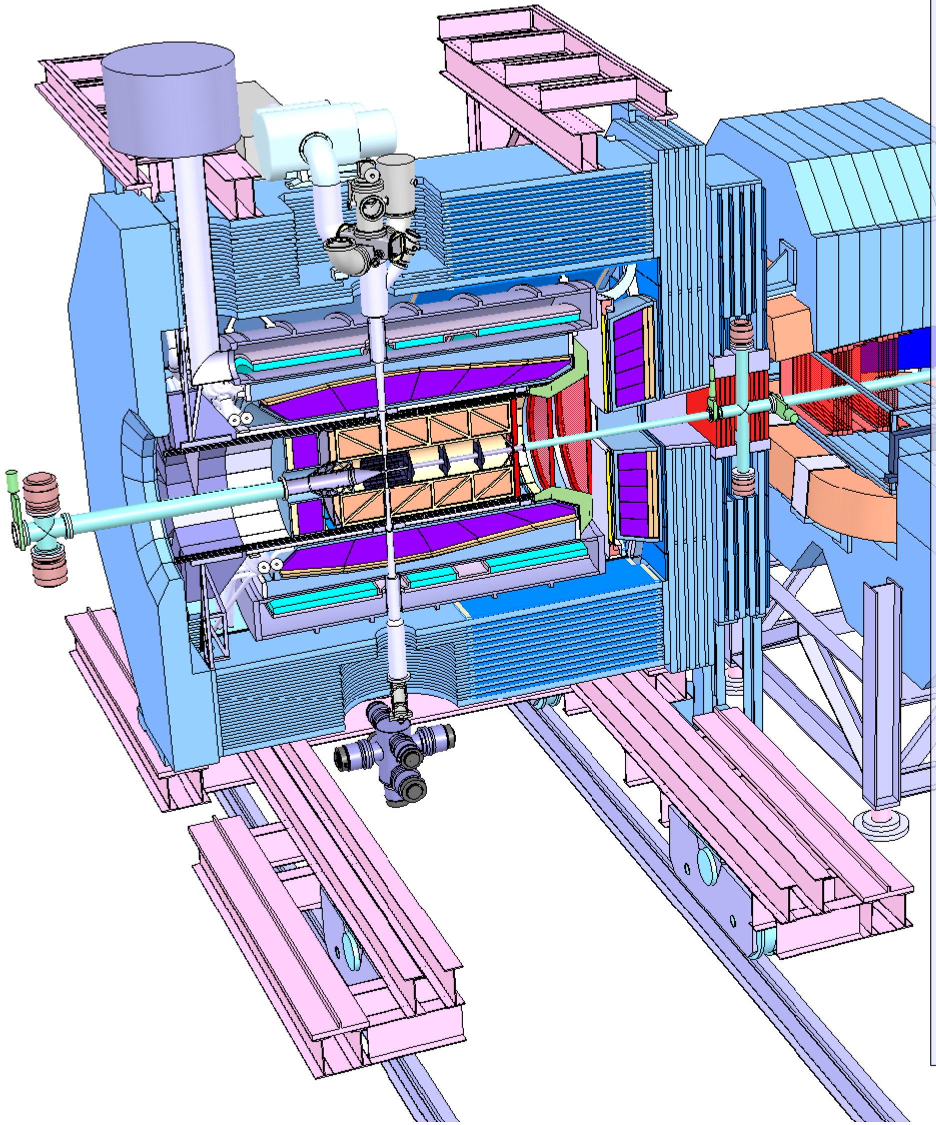
Circumference	575 m
Momentum	1.5 – 15 GeV/c
Stochastic Cooling	Full range

$e^+ e^-$	p p̄
Low hadronic background	High hadronic background
Direct production restricted to 1^{--} states	Direct production of various states

Production experiments



Detector Requirements



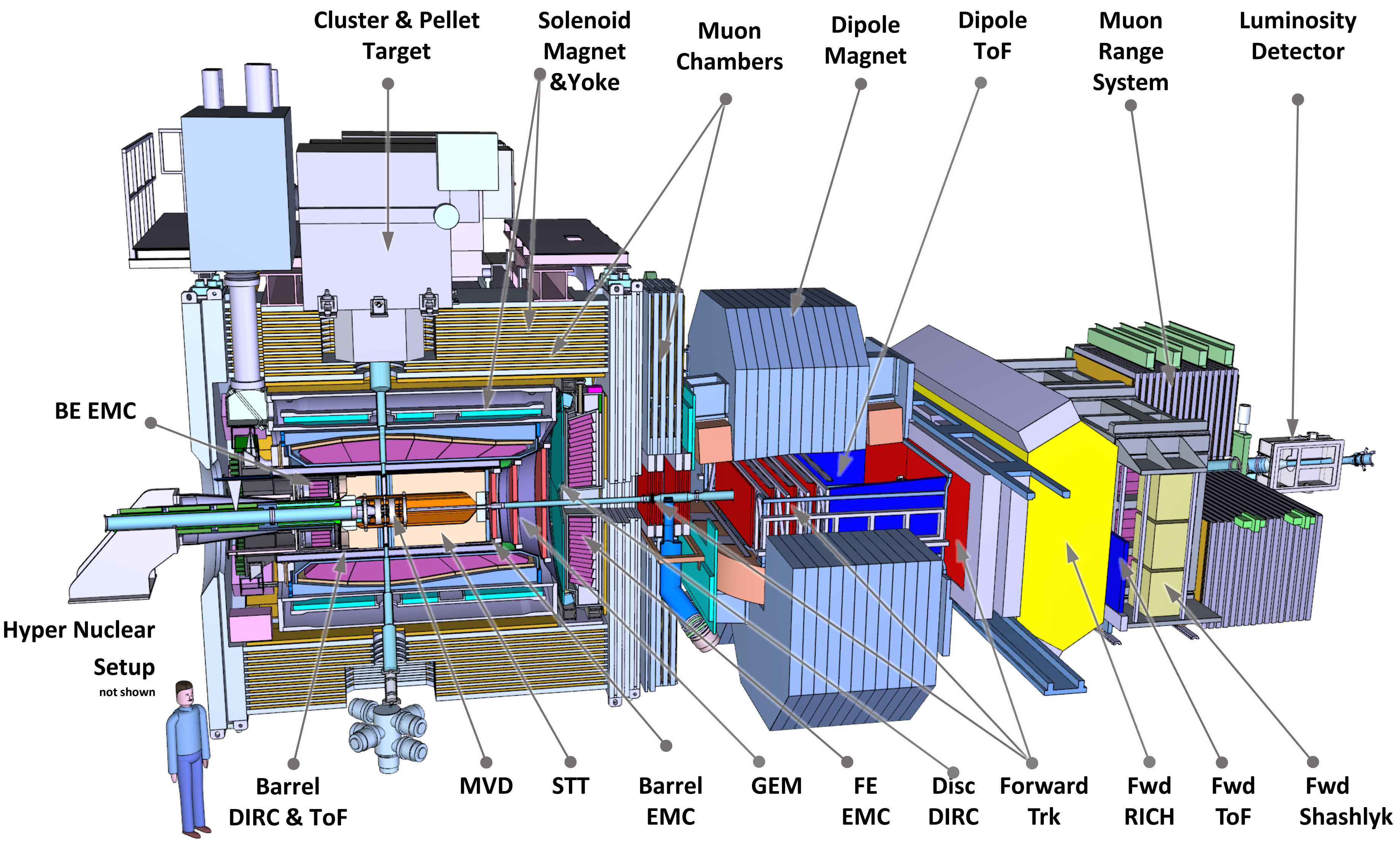
Detector requirements:

- 4π acceptance
- High rate capability: $2\text{x}10^{7}\ s^{-1}$ interactions
- Efficient event selection
- *Continuous acquisition*
- Momentum resolution ~1%
- Vertex info for D, K^0_S, Y (cτ = 317 μm for $D^{\pm}$)
- *Good tracking*
- Good PID (γ, e, μ, π, K, p)
- *Cherenkov, ToF, dE/dx*
- γ-detection 1 MeV – 10 GeV
- *Crystal Calorimeter*

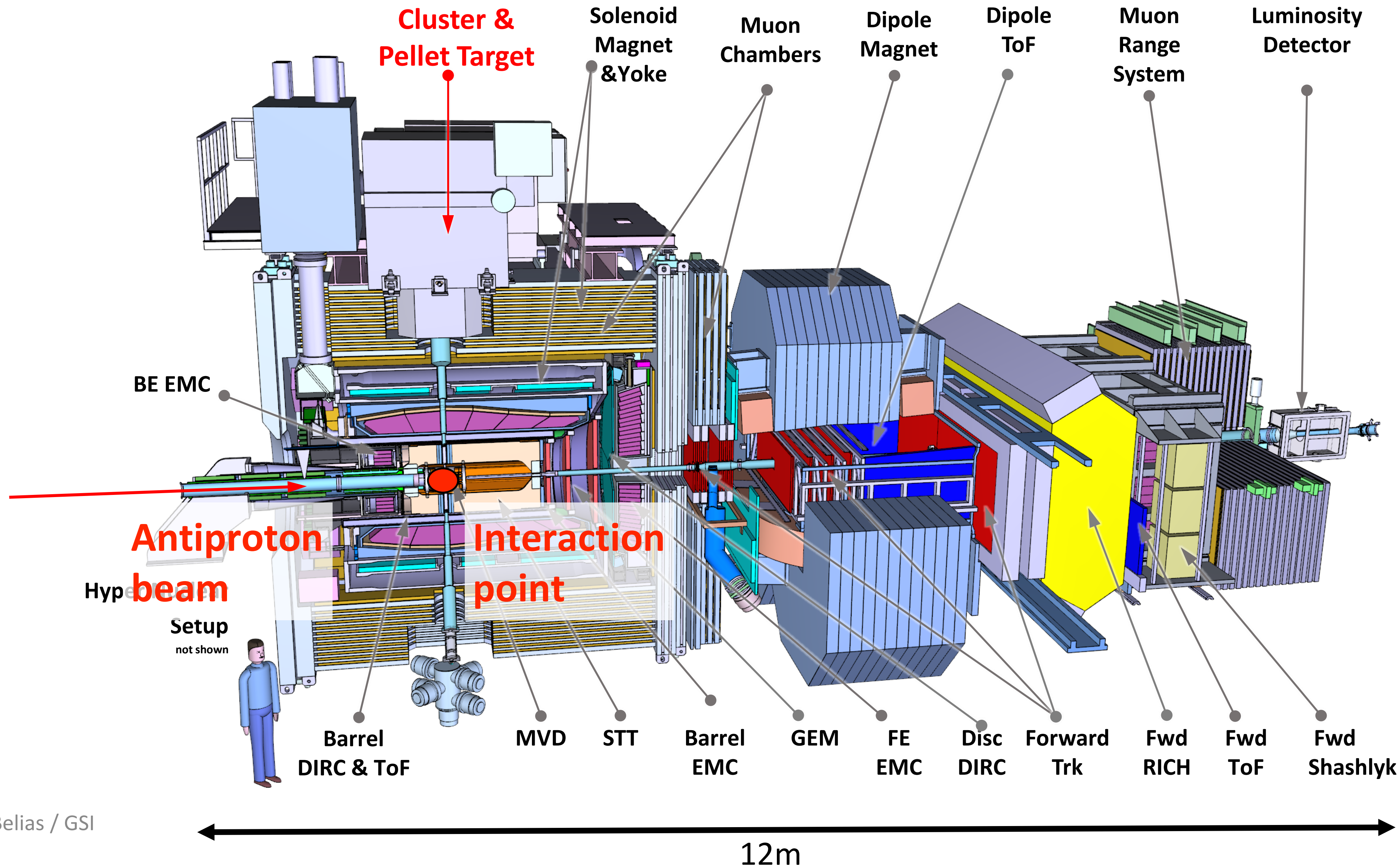
$\bar{\text{P}}$ANDA Detector ...

What we need

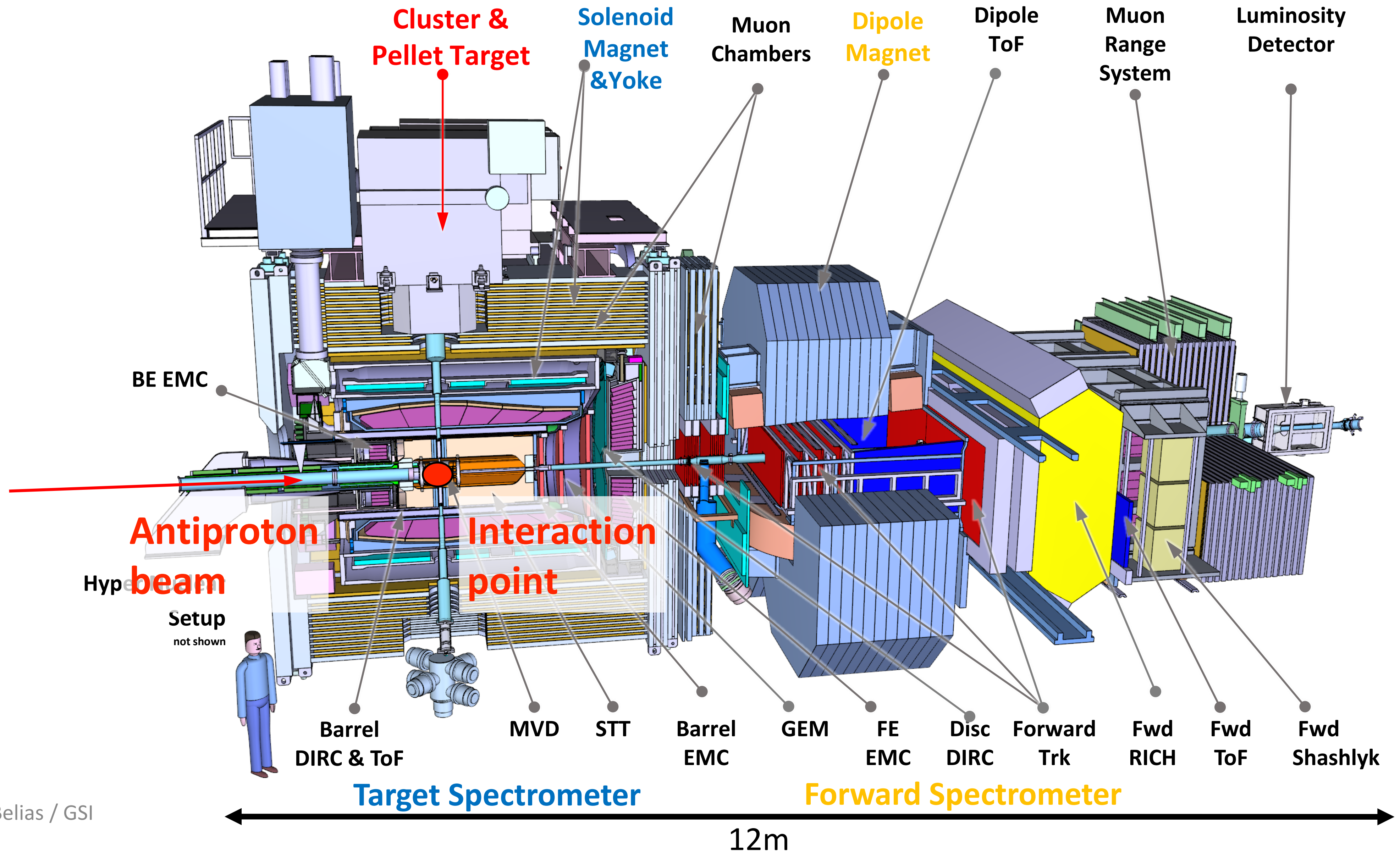
The PANDA Detector



The PANDA Detector



The PANDA Detector



Magnets

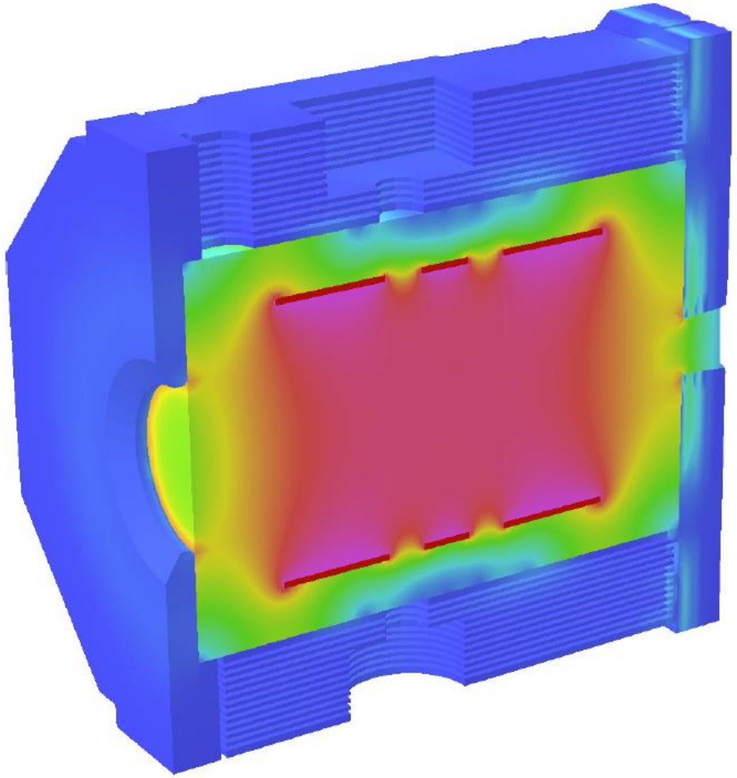
Solenoid Magnet
- Super conducting coil, 2 T central field (B_z)
- Segmented coil for target
- Instrumented iron yoke
- Doors laminated, instrumented, retractable

Status
- Design and production contract with BINP started
- Cooperation with CERN for cold mass
- Conductor production development
  - joint venture, BINP and Russian Inst.
- Yoke production started

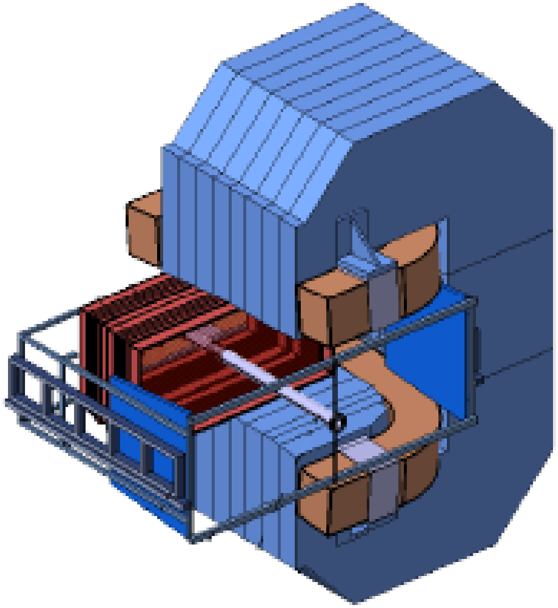
Dipole Magnet
- Normal conducting racetrack design, 2 Tm
- Forward tracking detectors partly integrated
- Dipole also bends the beam

➔ HESR component

Status
- Design contract with BINP started

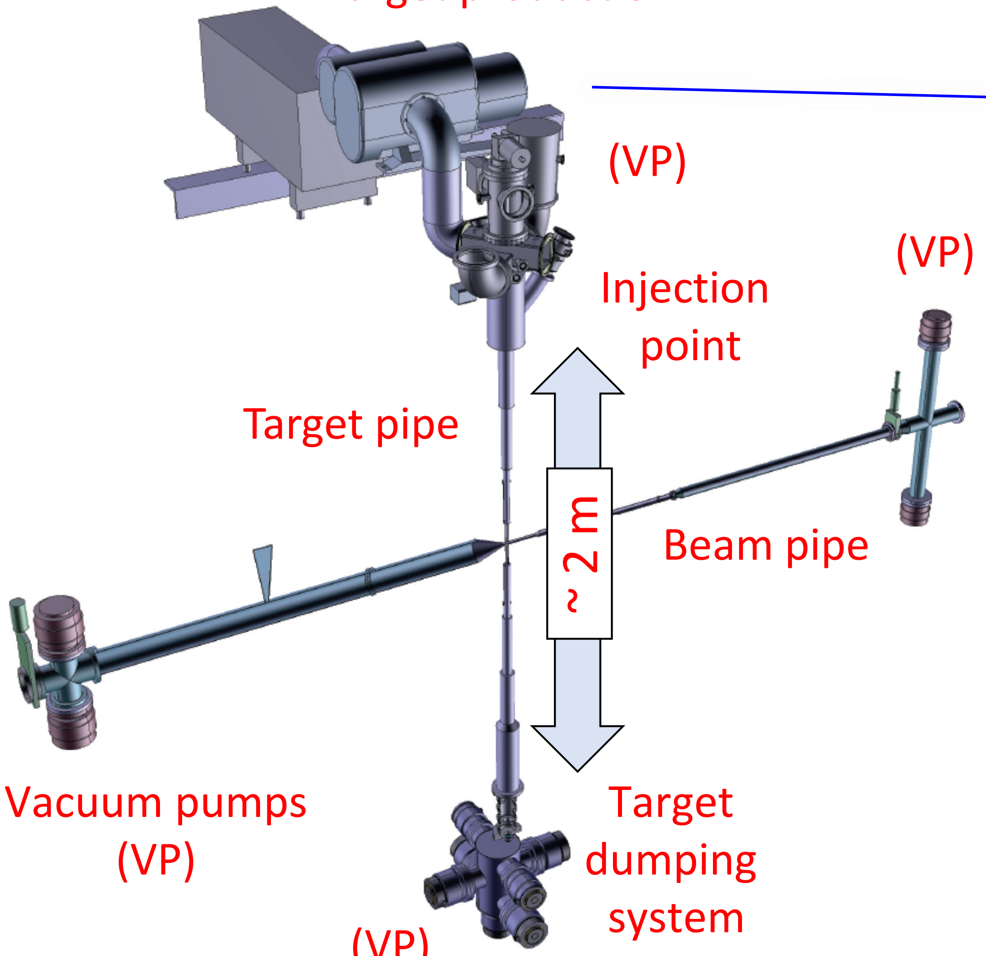


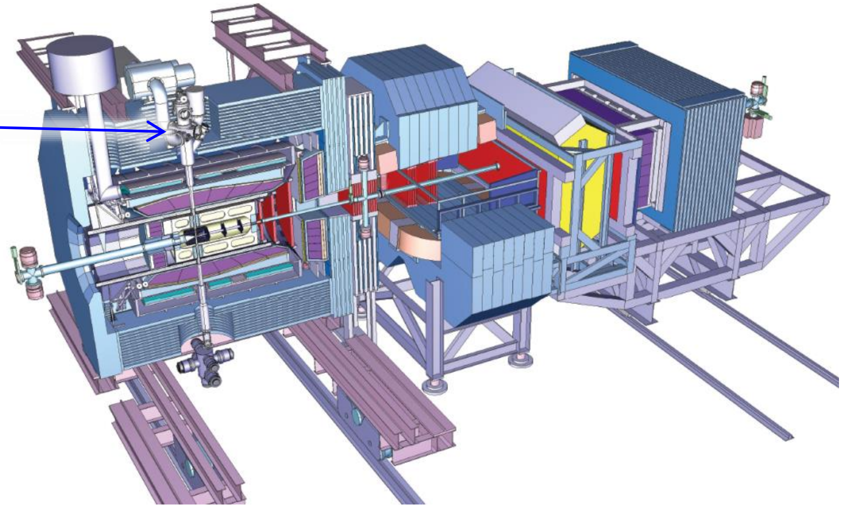
- Inner bore: ∅ 1.9 m /L: 2.7 m
- Outer yoke: ∅ 2.3 m /L: 4.9 m
- Total weight: 300 t



- Vertical acceptance: ± 5°
- Horizontal acceptance: ± 10°
- Total weight: 200 t

Interaction region





- Vacuum system, pumps, shutters
- Beam pipe, target cross, flanges
- Interfaces with detectors, target
- Support for pipe, MVD services
- Mounted on central space frame

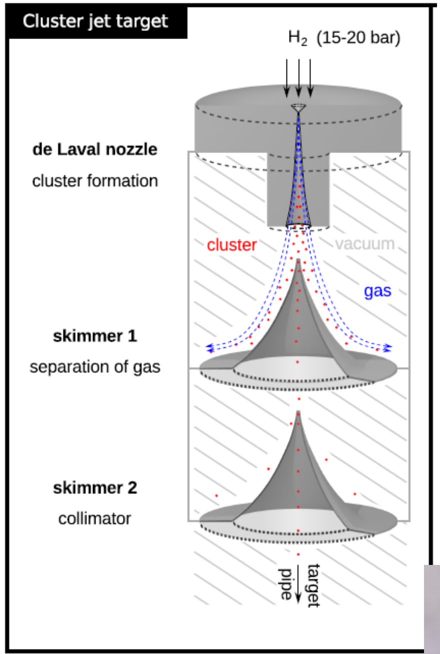
PANDA Targets

Luminosity Considerations

- Goal: $2 \times 10^{32}\ cm^{-2}s^{-1}$ for HL mode
- With 10^{11} p̄ stored and 50 mb cross section:
  → $4 \times 10^{15} cm^{-2}$ target density
- 1 µm gold foil has about $5.9 \times 10^{18} cm^{-2}$

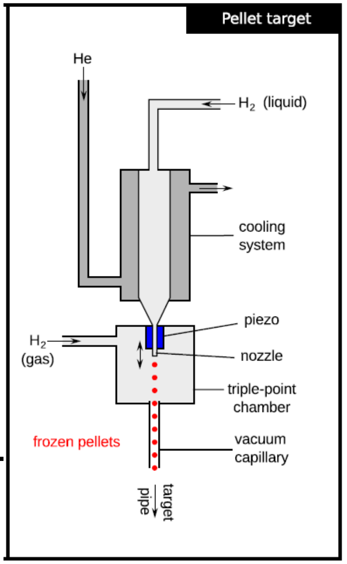
Cluster Jet Target

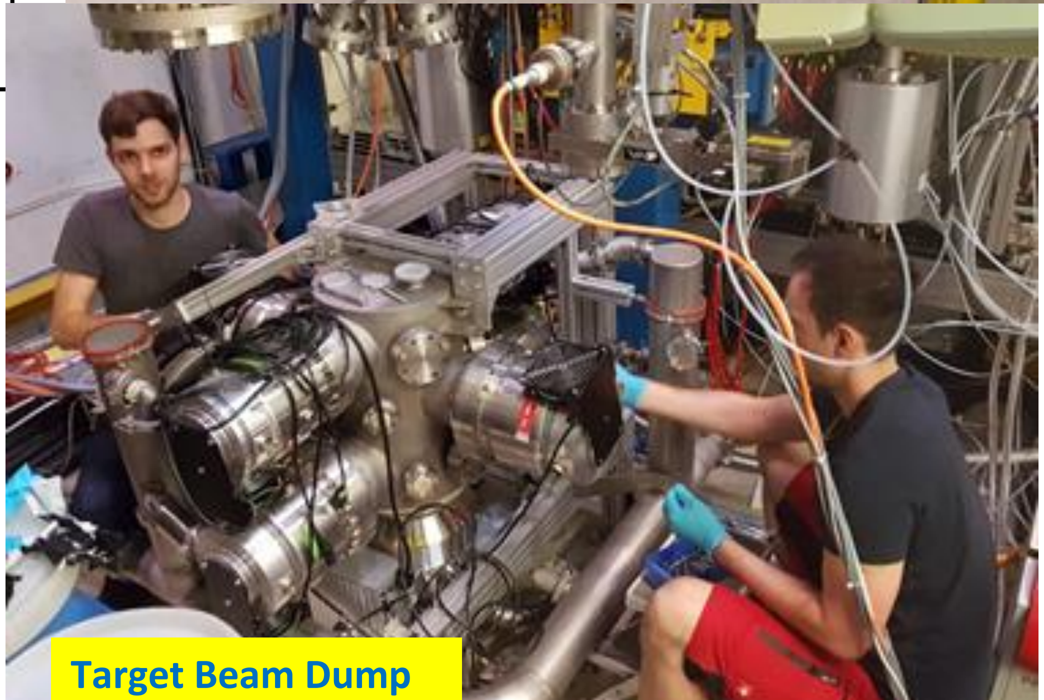
- TDR approved by FAIR ECE
- Record of $2 \times 10^{15} cm^{-2}$ already achieved
- Continuous development
  - Nozzle improvement
  - Better alignment by tilting device



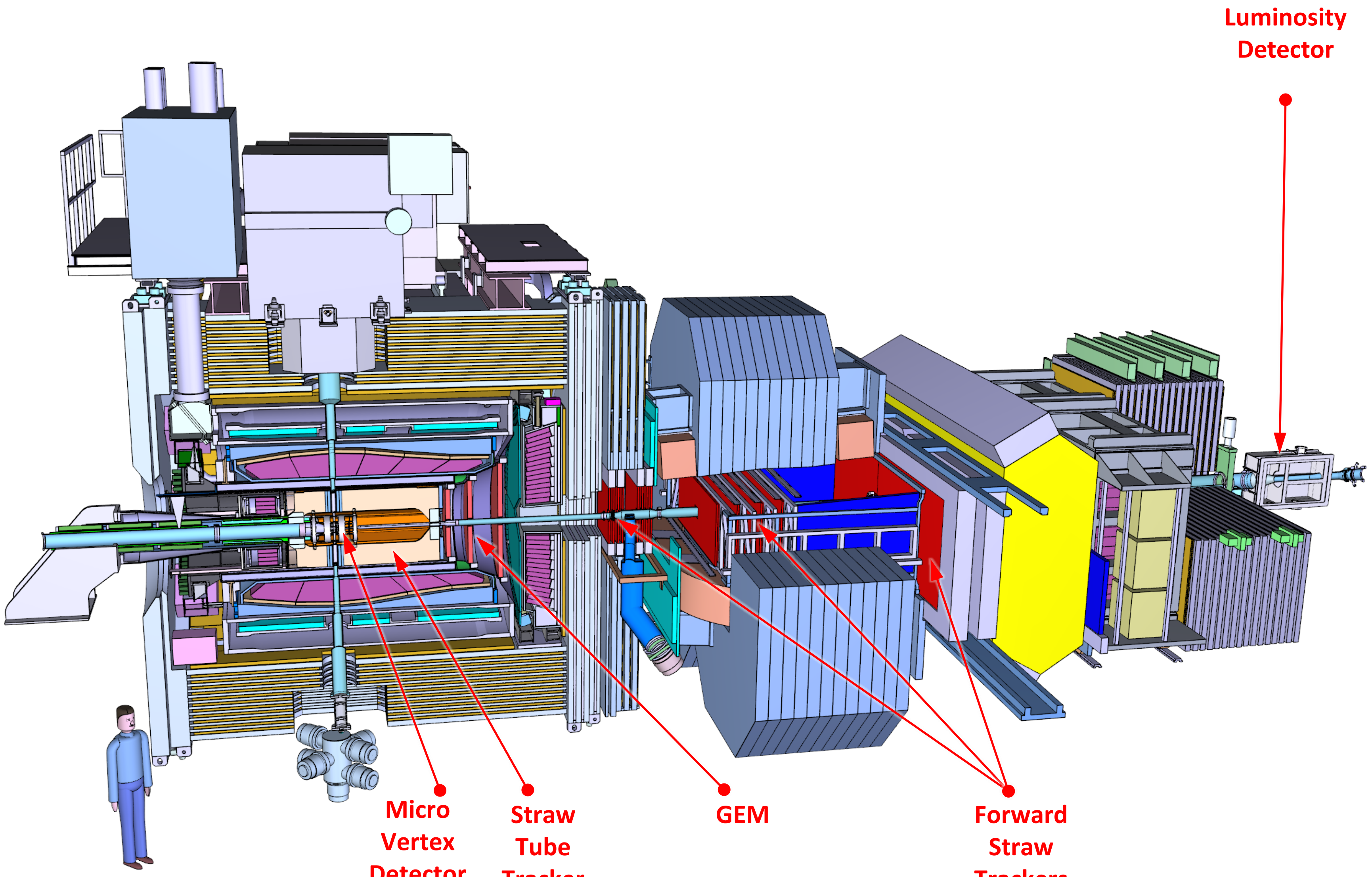
Pellet Target

- $> 4 \times 10^{15} cm^{-2}$ feasible
- Prototype under way
- Pellet tracking prototype
- Towards TDR





The PANDA Detector - Tracking

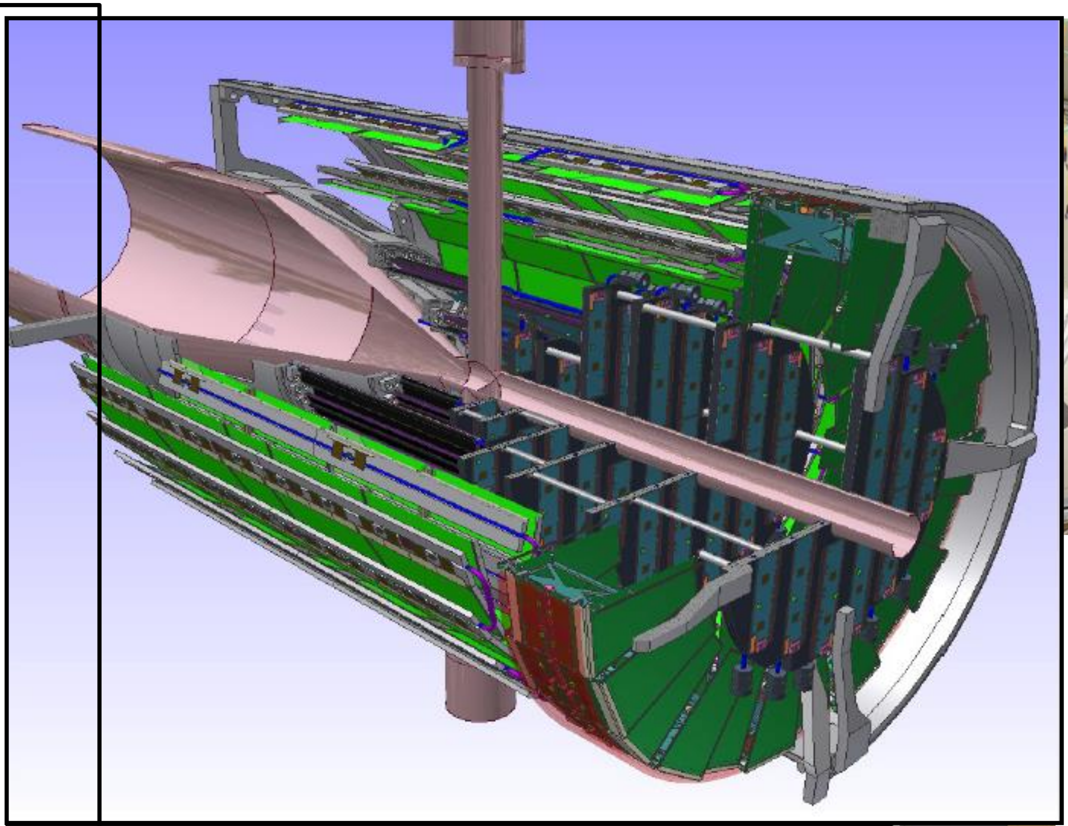


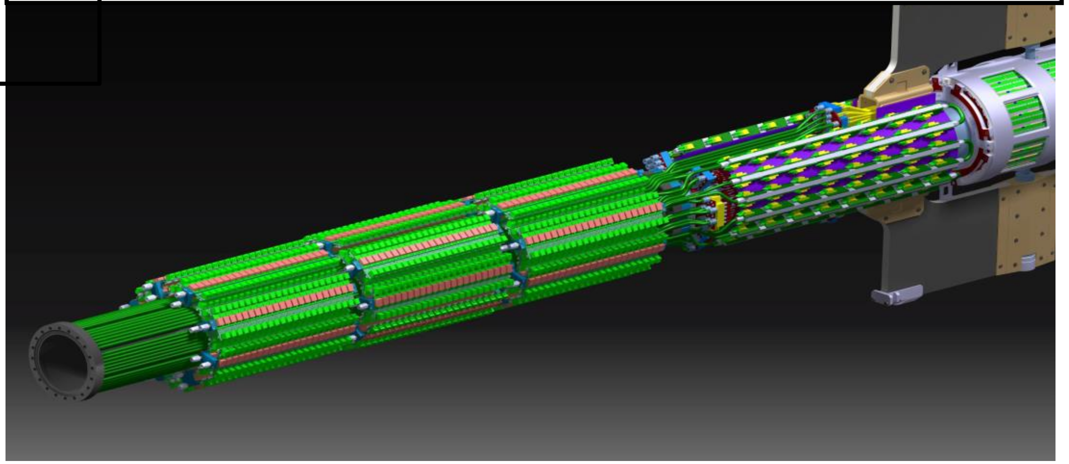
Micro Vertex Detector

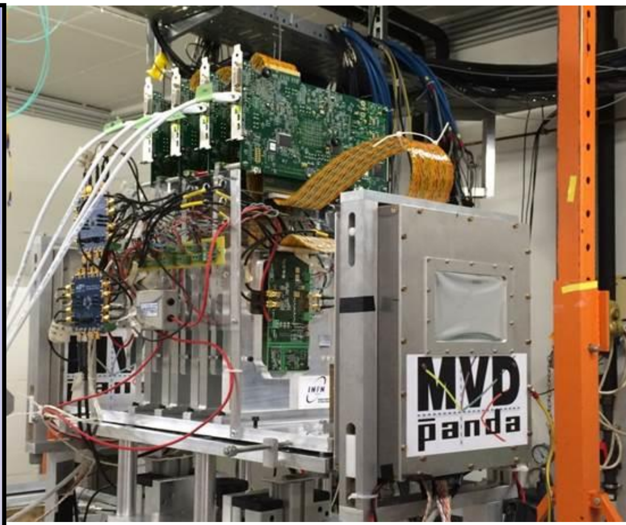
Detector Layout
- Silicon Pixels and Strip detector
- 4 barrels and 6 disks
- Hybrid pixels ($100 \times 100\ \mu m^2$)
  - Radout ASIC ToPiX
  - Thinned sensor wafers
- Double sided strips
  - Rectangles and trapezoids
  - Readout ASIC PASTA
- Mixed forward disks (pixels/strips)
- 50 μm vertex resolution, $\delta p/p \sim 2\%$

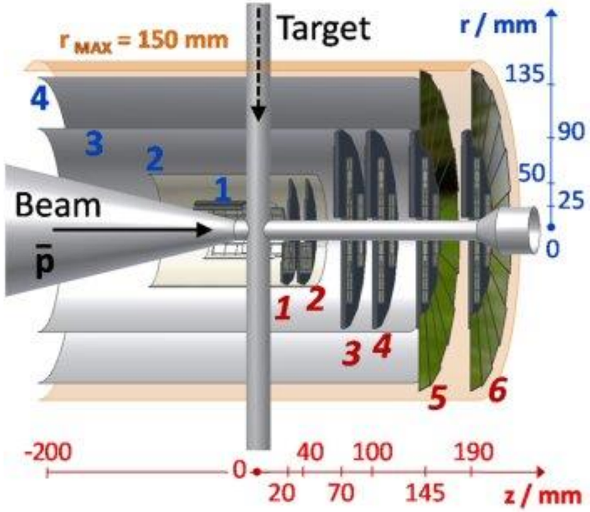
Challenges
- Low mass supports
- Cooling in small volume
- Radiation tolerance $\sim 10^{14} n_{1MeV\ eq} cm^{-2}$

Status
- TDR approved by FAIR ECE
- ASIC prototypes tests & adaptation
- Radiation tolerant links from CERN
  - GBTx, Versatile Link and DC/DC
- Detailed service planning









Straw Tube Tracker

Detector Layout

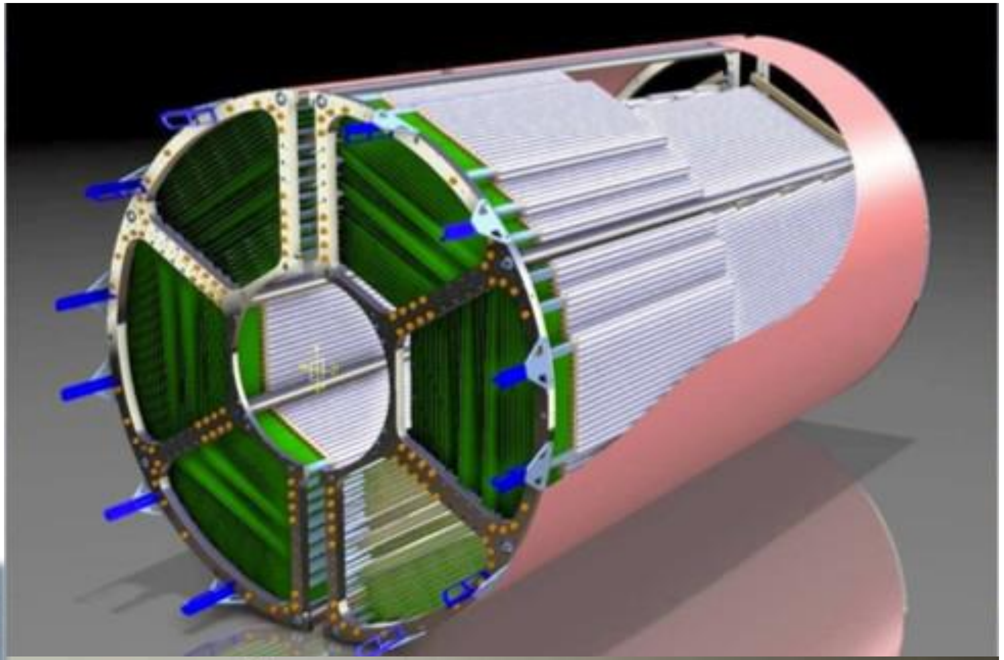
- Layers of drift tubes
- Rin= 150 mm, Rout= 420 mm, l=1500 mm
- Tube made of 27 µm thin Al-mylar, ∅=1cm
- 4600 straws in 21-27 layers, of which 8 layers skewed at 3°
- **Self-supporting straw double layers at ~ 1 bar overpressure (Ar/CO_2) developed at FZ Jülich**
- Resolution: r,ϕ ~150µm, z ~1mm

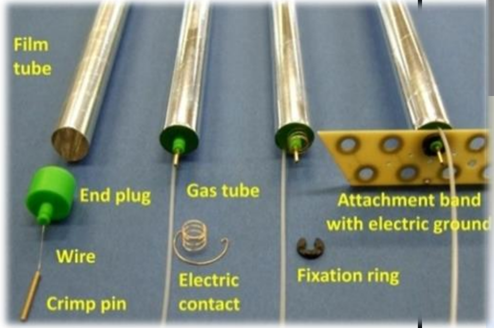
Material Budget

- 0.05% X/X0 per layer
- **Total 1.3% X/X0**

Status

- TDR approved by FAIR ECE
- Readout prototypes & beam tests
- Ageing tests: up to 1.2 C/cm^2
- Straw series production almost completed





Gaseous Electron Multipliers (GEM) Tracker

Forward Tracking inside Solenoid

- Tracking in high occupancy region
- Important for large parts of physics

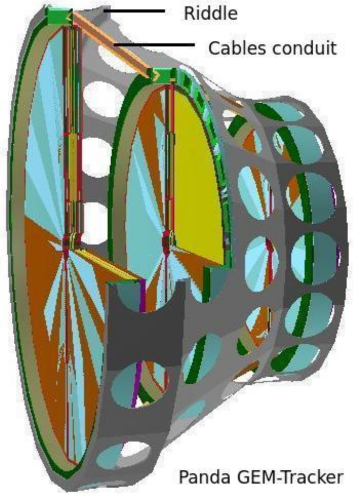
Detector design

- 3 stations with 4 projections each
  - ➔ Radial, concentric, x, y
- Central readout plane for 2 GEM stacks
- Large area GEM foils developed at CERN
  (50μm Kapton, 2-5μm copper coating)
- ADC readout for cluster centroids
  - ➔ Approx. 35000 channels total
- Challenge to minimize material

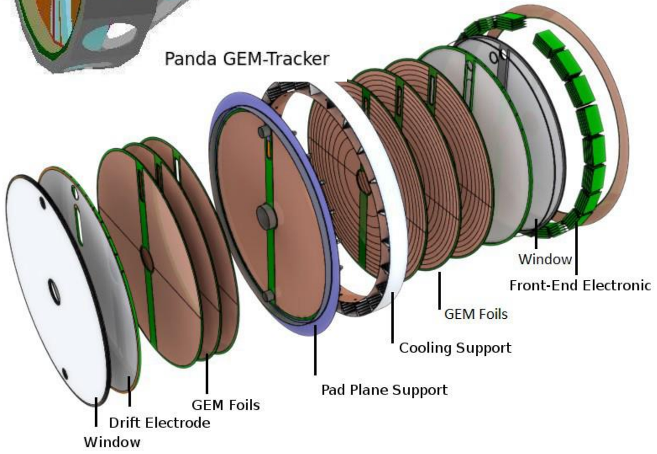
Status

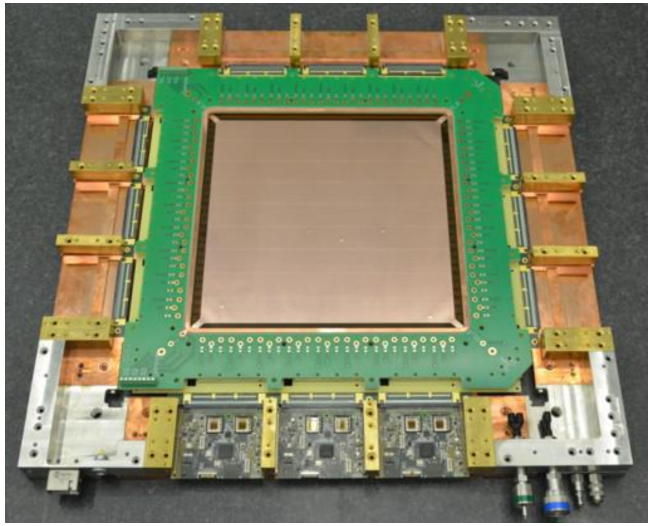
- Advanced mechanical concept
- Demonstrator construction ongoing,
  - GEM foils from TECTRA delays
- Available electronics unstable

➔ **Other readout electronics required**

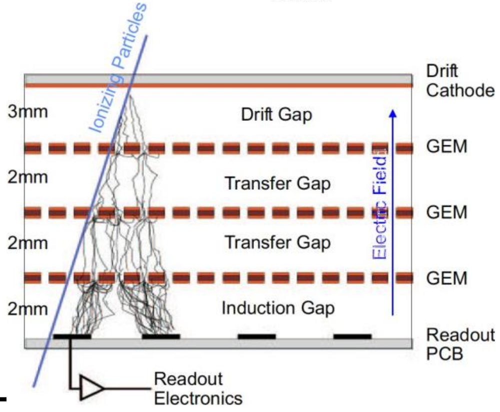


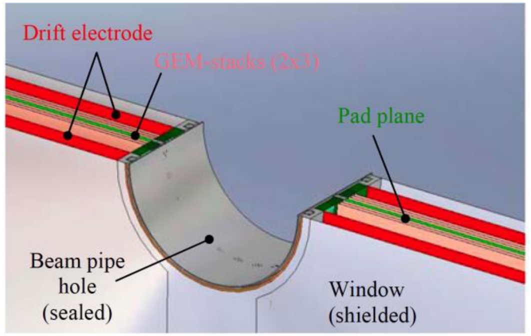
Panda GEM-Tracker





2D Demonstrator





Challenges - Opportunities:

- Completion of demonstrator
- Characterization of GEM foils
- **Readout electronics**
- Full size prototype design
- Lack of manpower
  - → need expert groups

Forward Tracker

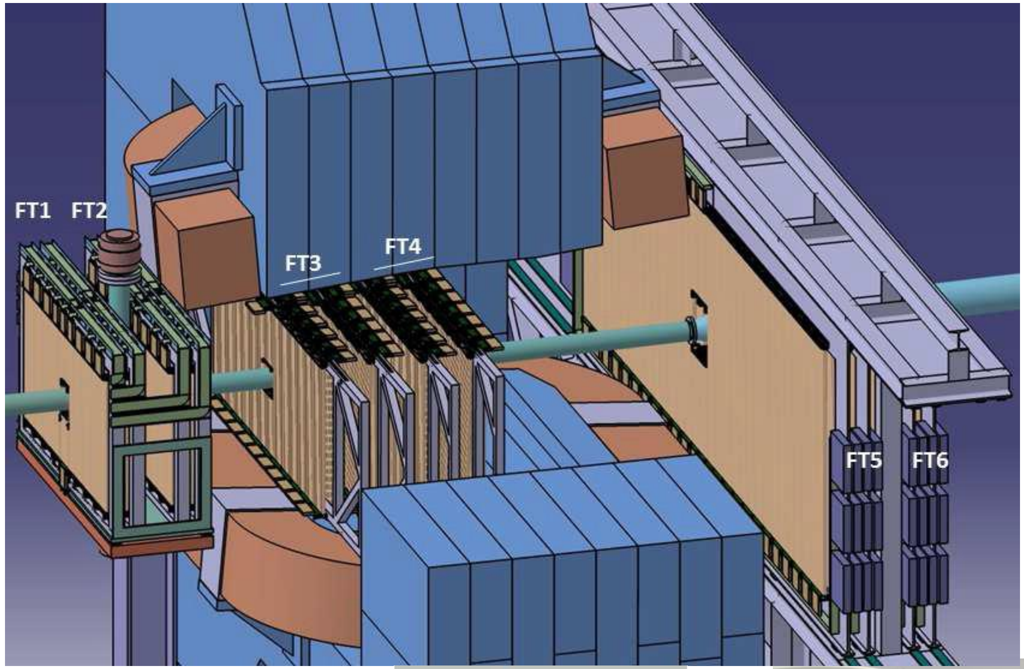
Tracking in Forward Spectrometer

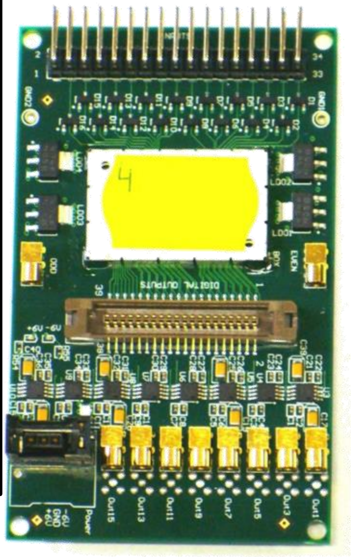
- Straw tubes, same as in STT (Barrel), vertically arranged in double layers
- 3 stations with 2 chambers each
  - FT1&2 : between solenoid and dipole
  - FT3&4 : in the dipole gap
  - FT5&6 : large chambers behind dipole
- 4 projections 0°/ ± 5°/0° per chamber
- Readout ASIC PASTTREC and TDC-FPGA
  - later upgrades for High Luminosity runs

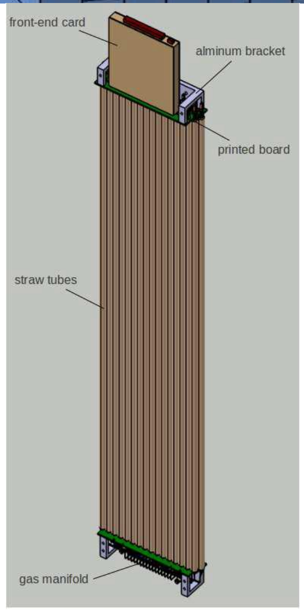
Status

- TDR approved by FAIR ECE
- Testbeam campaigns 2018/2019
- Ongoing stereoscopic scans
- Aging tests: up to 1 C/cm^2

Full Straw Tube Prototypes in HADES at GSI
2019: Installation – 2020: Data Taking







Outer Tracker of LHCb in PANDA

The proposed idea:

- LHCb replaces its outer tracker with scintillating fibres for high intensity
- Short modules 2.4m, 20% of all

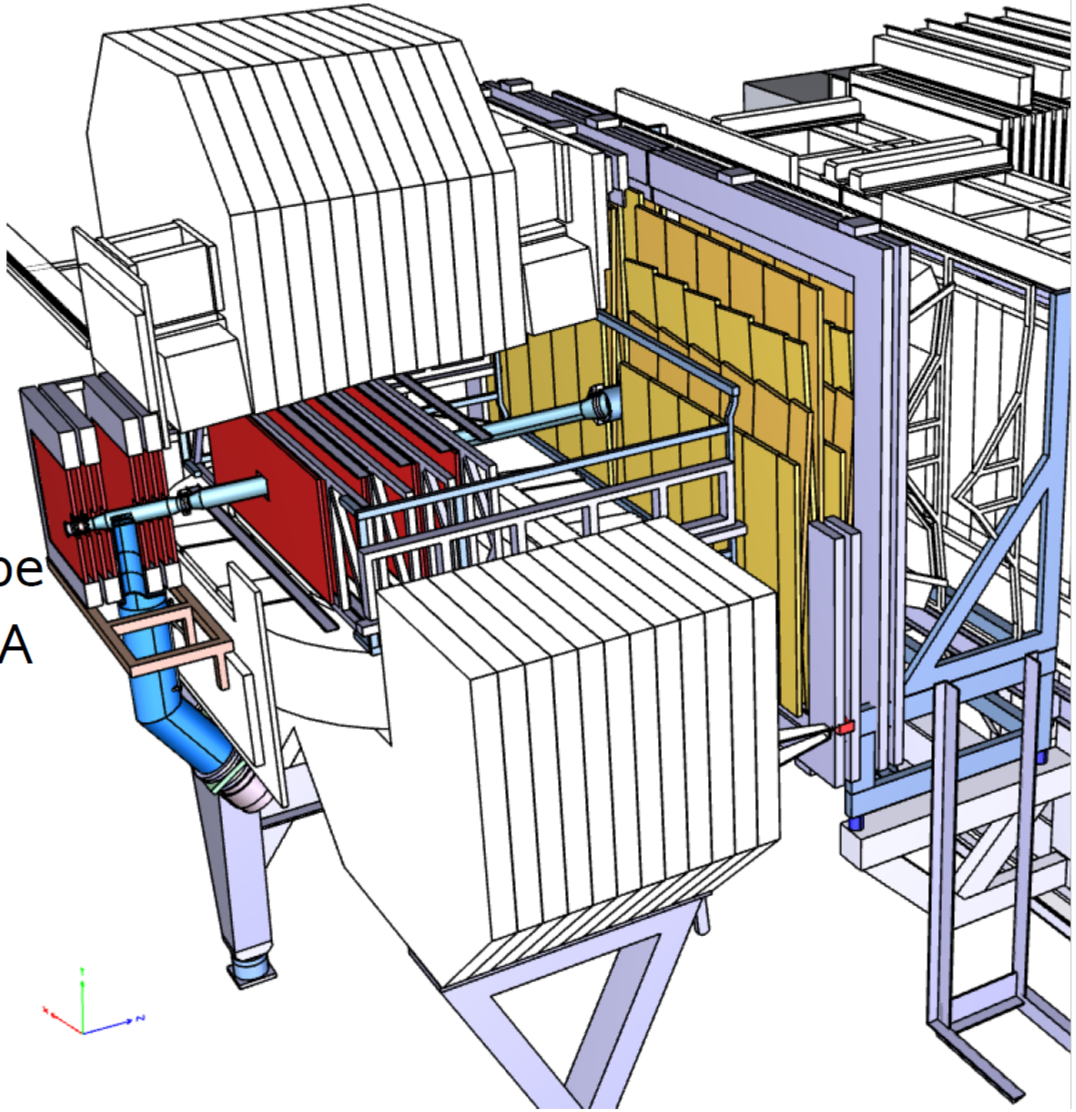
  PANDA could use these modules

Conceptual layout:

- Using all short modules inc. spares: → cover 4m with 2x4 planes
- Somewhat larger hole around beampipe
- Radiation length 2x higher than PANDA

Project assessment status:

- Spares can be delivered to GSI
- Active planes need to cool down
- Electronics: interface to TRB needed
- Mechanics: proposal for Thailand



Luminosity Detector

Elastic scattering:

- Coulomb part calculable
- Scattering of p̄ at low t
- Precision tracking of scattered p̄
- Acceptance 3-8 mrad

Detector layout:

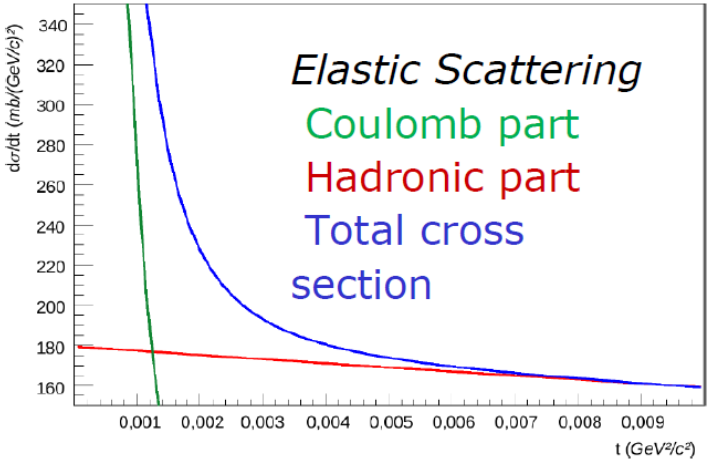
- Roman pot system at z=11 m
- Silicon pixels (80x80 µm2):
  4 layers of HV MAPS (50 µm thick)
- CVD diamond supports (200 µm)
- Retractable half planes in sec. vacuum

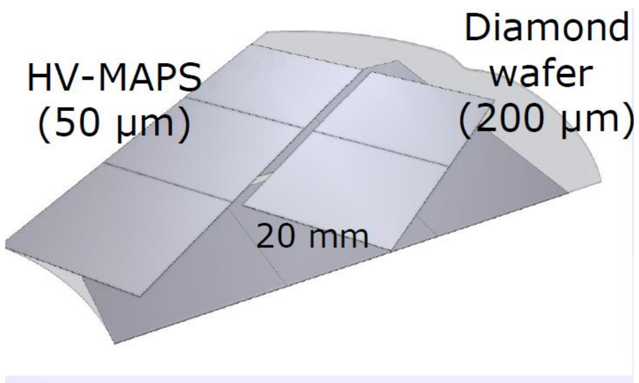
HV MAPS:

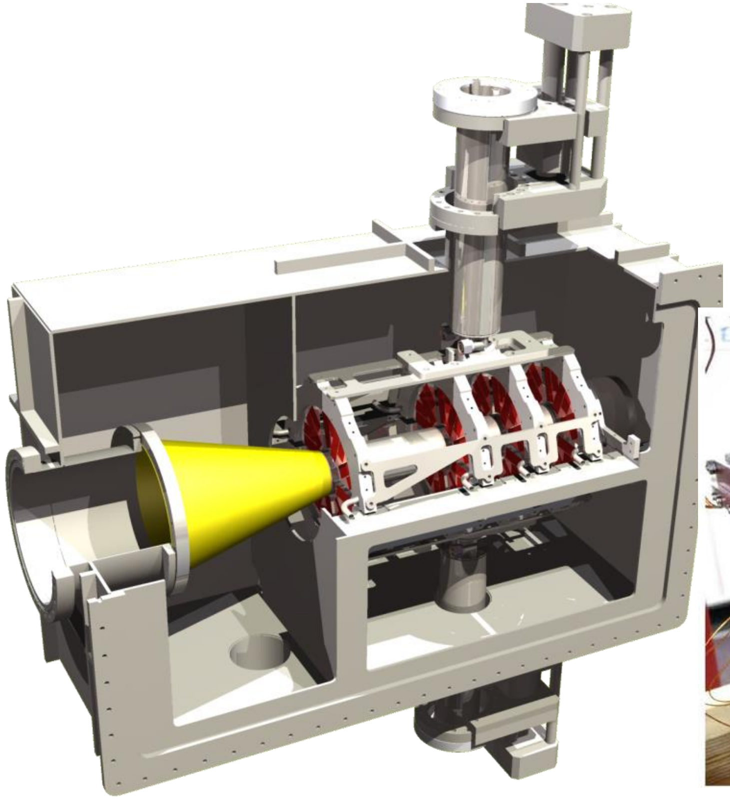
- Development for Mu3e Experiment at PSI
- Active pixel sensor in HV CMOS
  - faster and more rad. hard
- Digital processing on chip

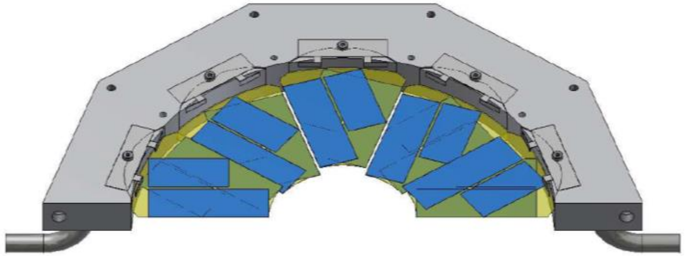
Status:

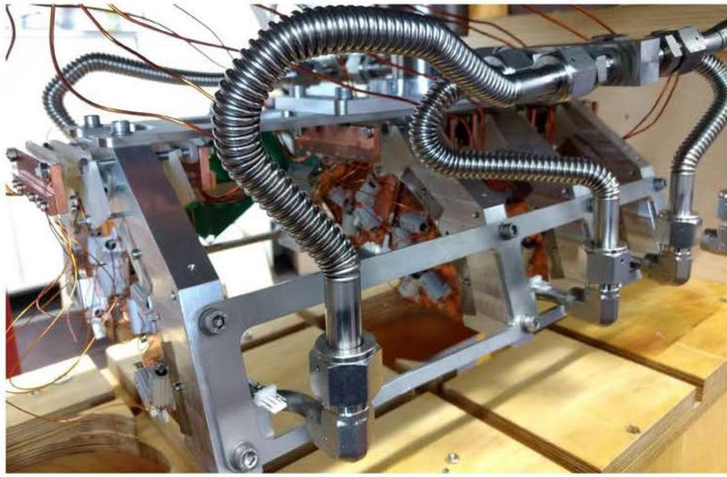
- TDR submitted to FAIR ECE
- Mechanical vessel, cooling, vacuum, design ready
- New MuPix prototype 1x2 cm^2 in test
- FPGA readout tests



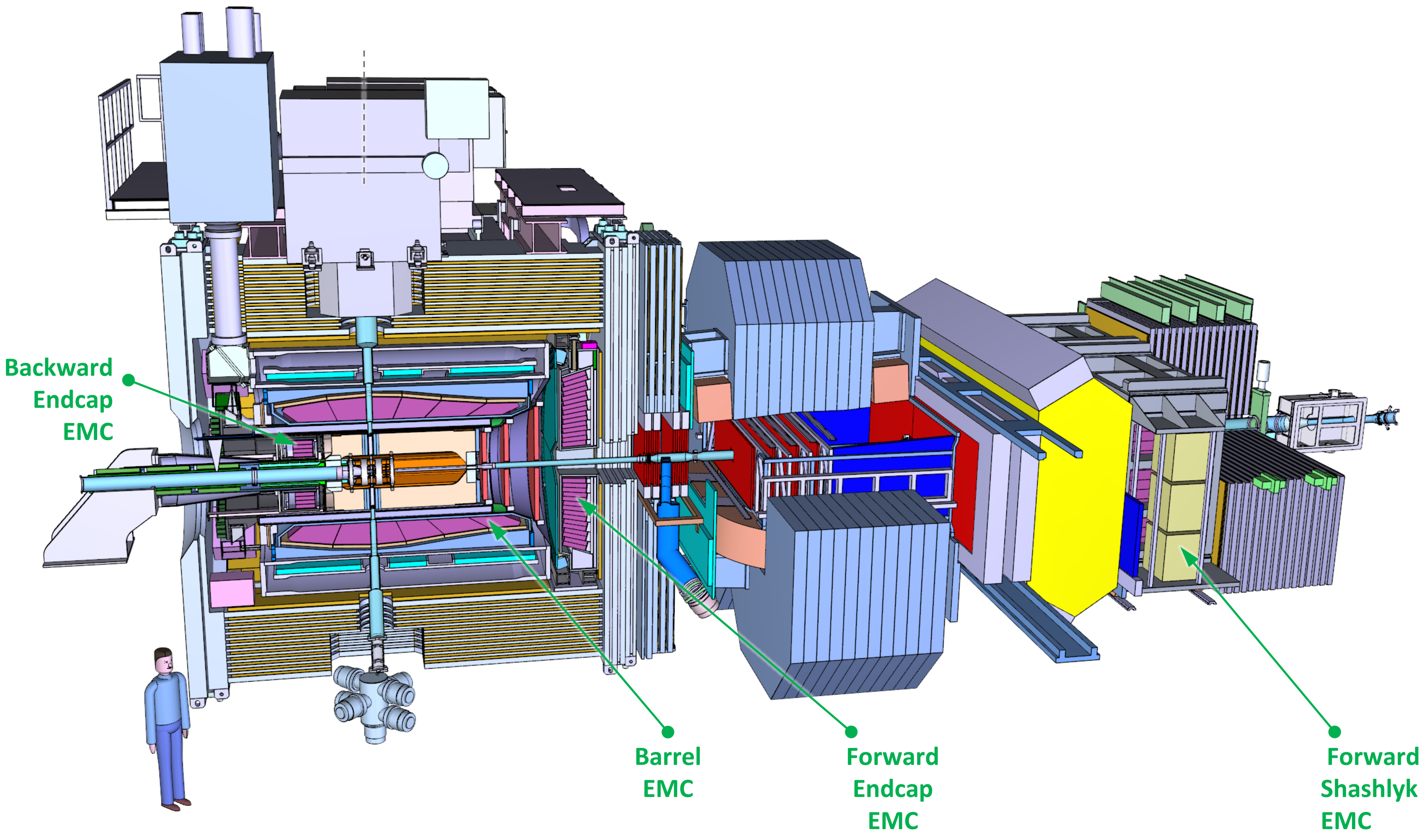








The PANDA Detector - Calorimetry

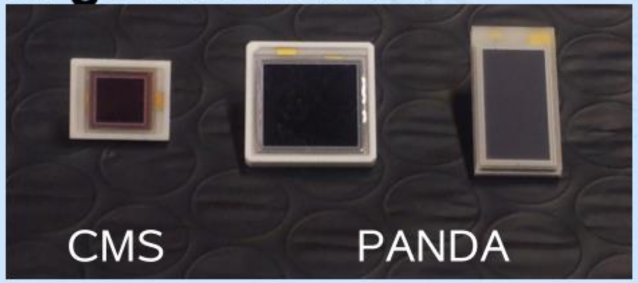


Target Spectrometer EMC

$\overline{\text{P}}$ANDA PWO Crystals

- PWO is dense and fast
- Low γ threshold is a challenge
- 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



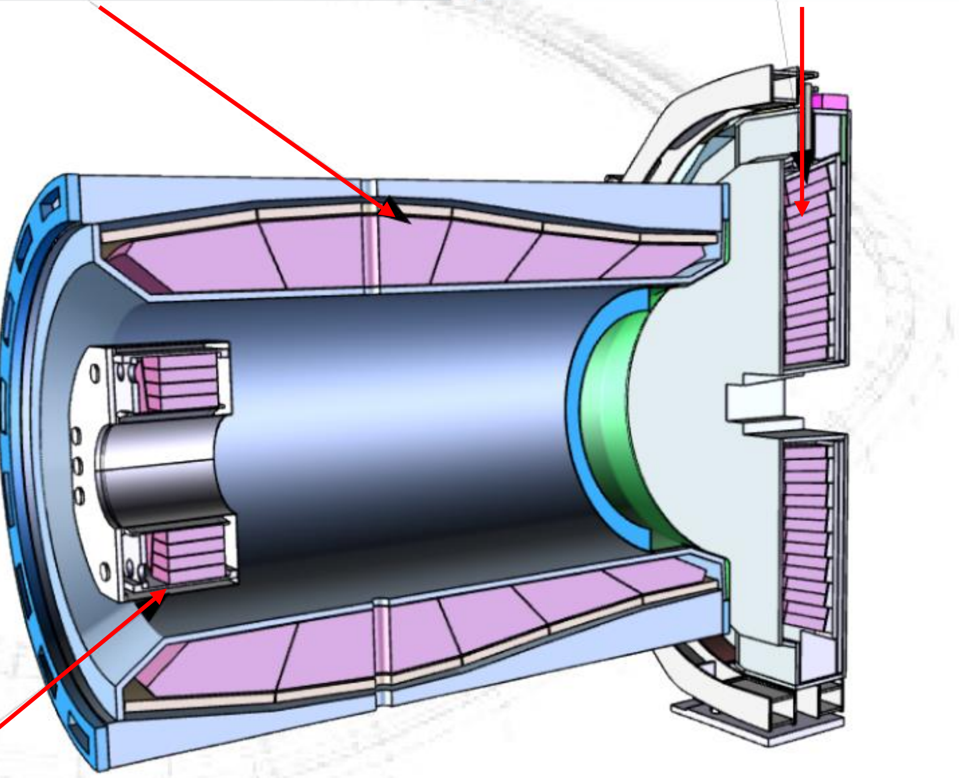
5x5 mm² 10x10 mm² and 7x14 mm²

Barrel Calorimeter

- 11000 PWO Crystals
- LAAPD readout, 2x1cm²
- $\sigma(E)/E \sim 1.5\%/\sqrt{E}$ + const.

Forward Endcap

- 4000 PWO crystals
- High occupancy in center
- LA APD and VPTT



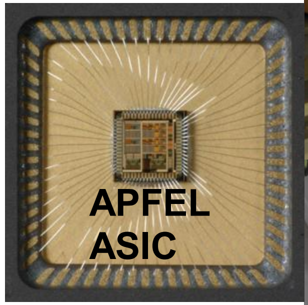
Backward Endcap for hermeticity, 530 PWO crystals

Target Spectrometer EMC – Status (1)

Barrel EMC

PWO Crystal Production

- New producer CRYTUR (CZ)
  - High quality crystals received
- EoI to fund remaining crystals



APD Screening

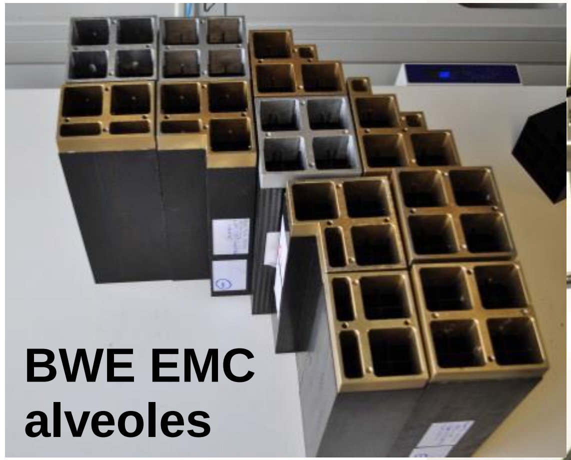
- Screening of 30000 APDs
- Facility in full shift operation

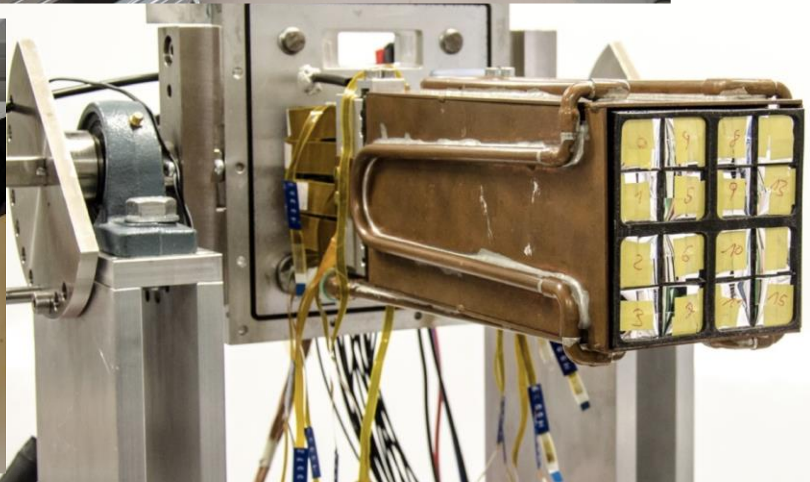
- All alveoles produced
- APD readout APFEL ASIC produced
- **First slice (of 16) assembled**

Backward Endcap EMC

- Submodule design ready
- Prepare series production
- Readout new ASIC tests successful

Activities at MAMI - BWE EMC data taking with A1 spectrometer for high-resolution electron scattering in coincidence with hadrons





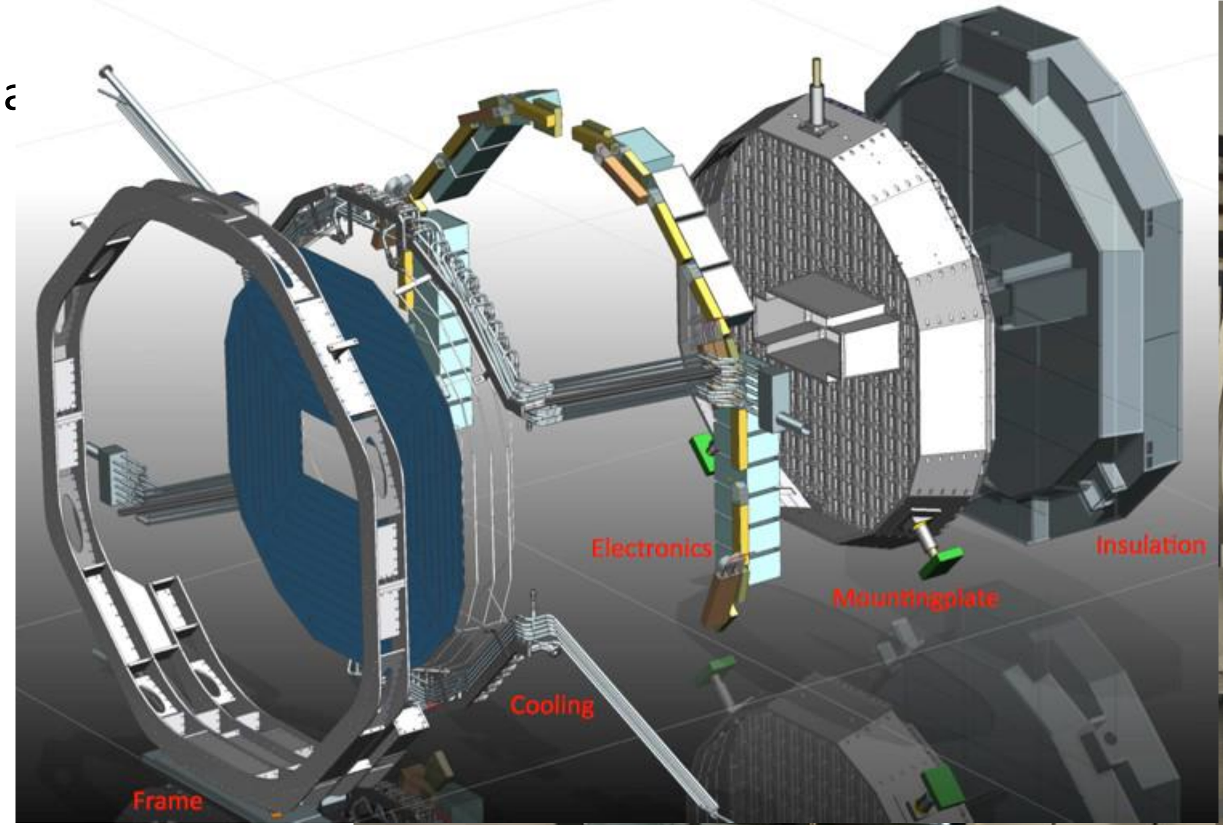
Target Spectrometer EMC – Status (2)

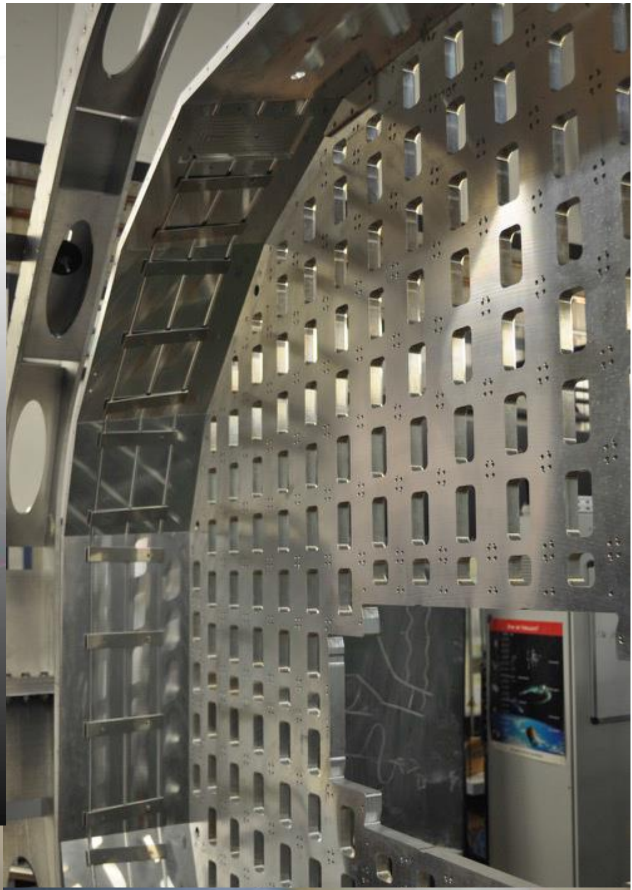
Forward Endcap EMC Status

- Production & Assembly well a
- All crystals are produced

- VPTT all characterized
  - Modules production done
- APD screening progress
  - Modules assembly started

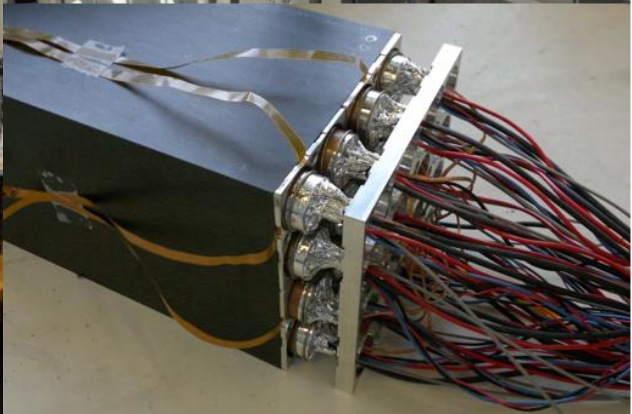
- FADCs for digitization
  - SADC board (+Vers. Link) in production





- Test stand for Module calibration with cosmics
- Cooling system available, controls tests
- Pre-assembly support prepared

- **First detector system to be fully assembled**



Forward Spectrometer Calorimeter

Forward electromagnetic calorimeter

- Interleaved scintillator and absorber layers
  - 0.3 mm lead and 1.5 mm scintillator
  - total depth 680 mm (380 layers)
  - transverse size 55x55 mm^2
- WLS fibers for light collection
- PMTs for photon readout
- FADCs for digitization
- Active area size 297x154 cm^2

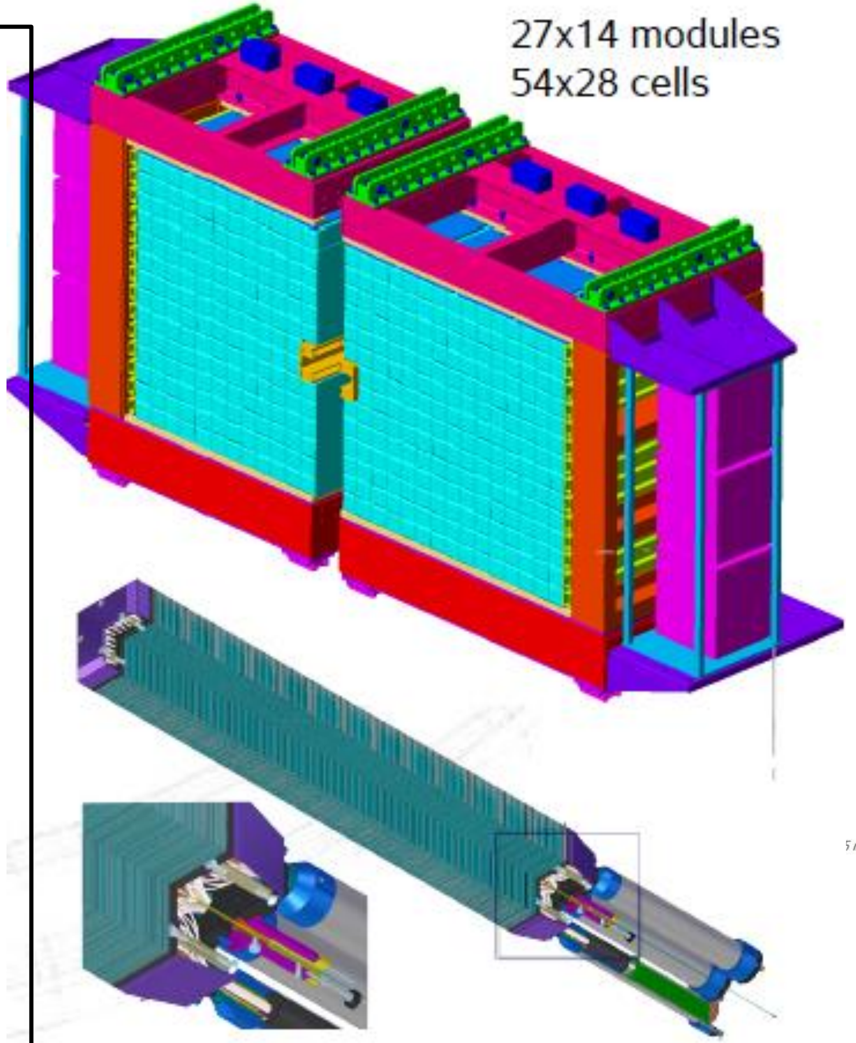
Status

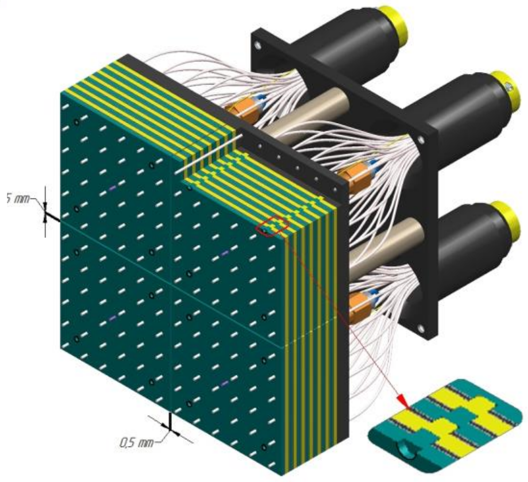
- TDR approved by FAIR ECE
- SADC readout board in production
- Module design 2 x 2 cells of 5.5 x 5.5 cm^2 verified
- Tests with electrons and tagged photons:

→ **Energy resolution**

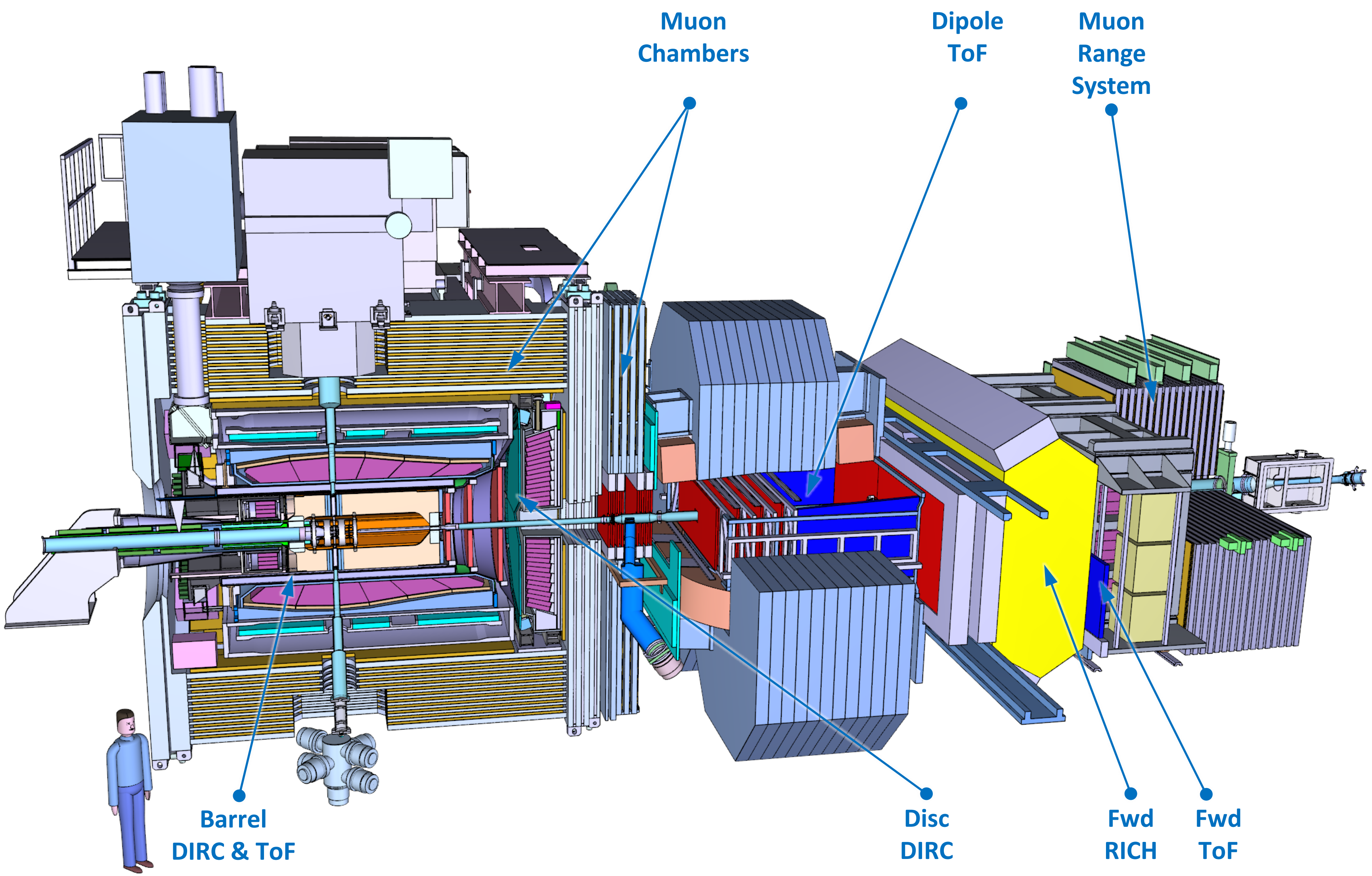
- $\frac{\sigma_E}{E} = 5.6/E \oplus 2.4/\sqrt{\mathrm{E[GeV]}} \oplus 1.3$ [%] (1-19 GeV e^-)
- $\frac{\sigma_E}{E} = 3.7/\sqrt{\mathrm{E[GeV]}} \oplus 4.3$ [%] (50-400 MeV γ)

→ **Time resolution** 100 ps/$\sqrt{\mathrm{E[GeV]}}$





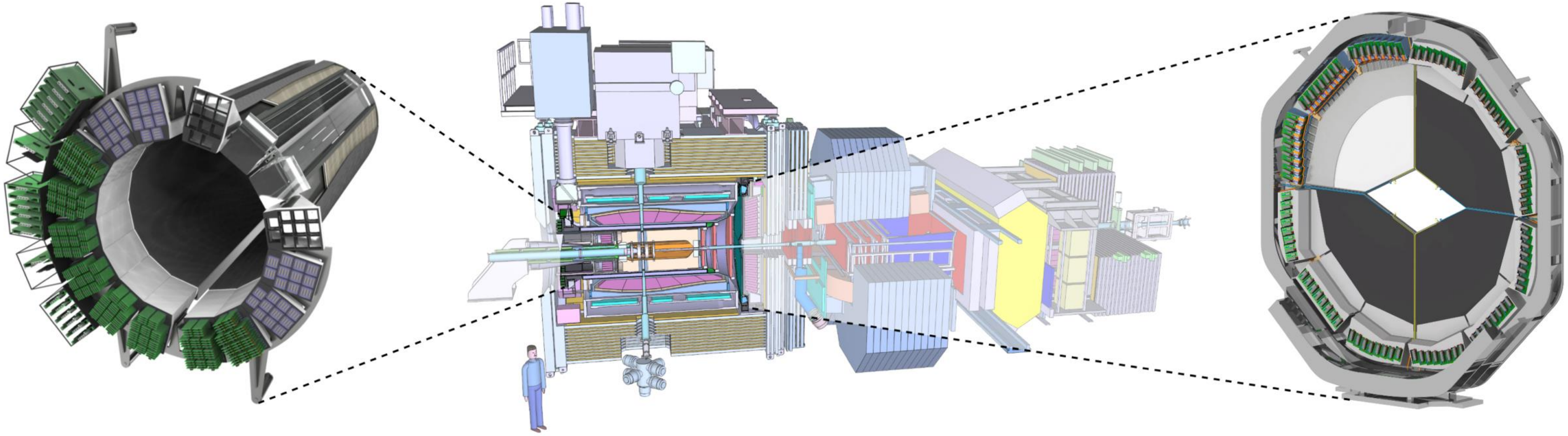
The PANDA Detector – Partcile ID



Target Spectrometer – DIRC Counters

Detection of Internally Reflected Cherenkov light pioneered bv BaBar

- Cherenkov detector with SiO_2 radiator
- Detected patterns give β of particles



Barrel DIRC

- Design similar to BaBar DIRC
- Polar angle coverage:
  $22° < \theta < 140°$
- PID goal:
  3σ π/K separation up to 3.5 GeV/c
- *Barrel DIRC Leader: J. Schwiening (GSI)*

Endcap Disc DIRC

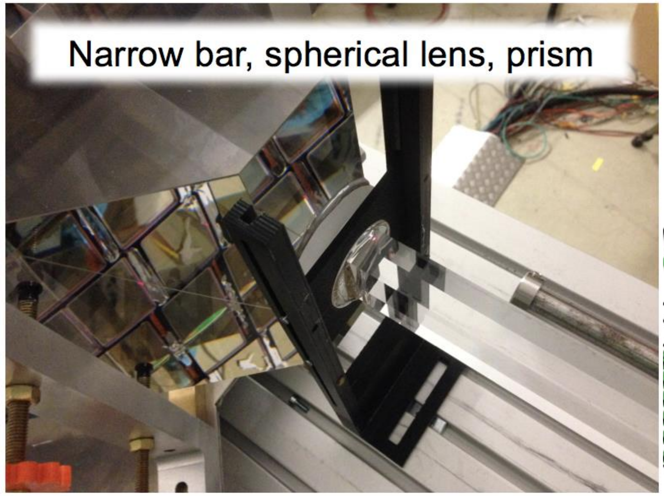
- Novel type of DIRC
- Polar angle coverage:
  $5° < \theta < 22°$
- PID goal:
  3σ π/K separation up to 4 GeV/c

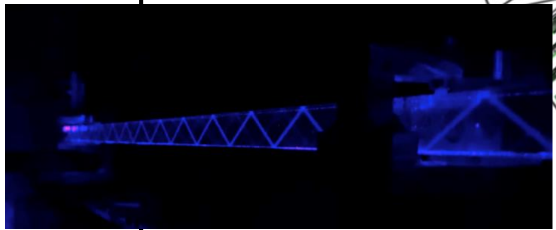
Barrel DIRC

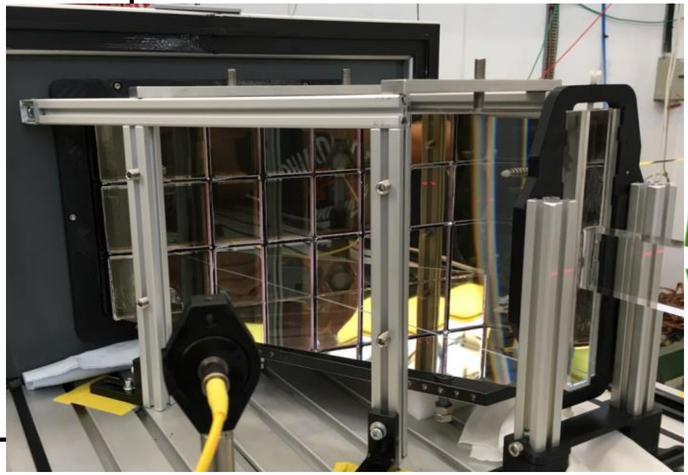
Optimization and challenges
- Barrel ∅: 1 m, L: 2.5 m
- Focusing by lenses/mirrors
- More compact design
- Magnetic field → MCP PMT
- Fast readout to suppress BG

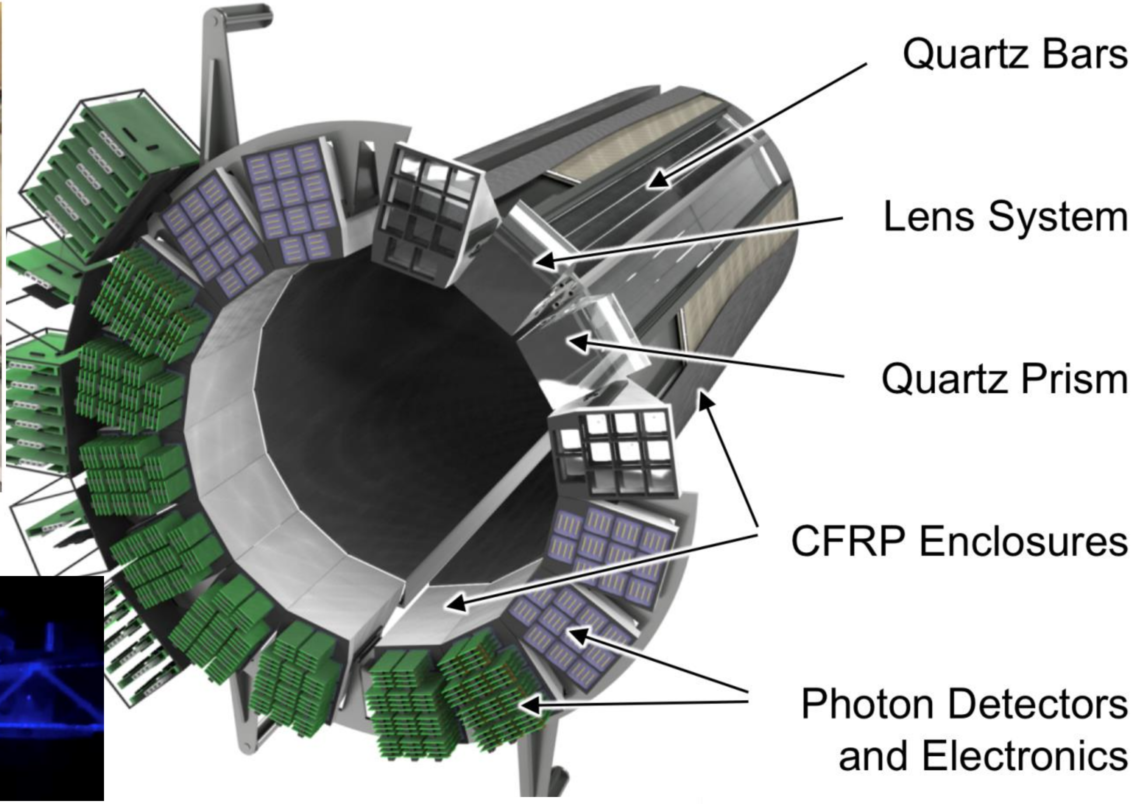
Testbeams at CERN
- Several campaigns with improved prototypes
- Measurements agree well with simulation
- Developments of reconstruction methods
- Optimization of readout options
- π/K separation of 4.3 σ reached

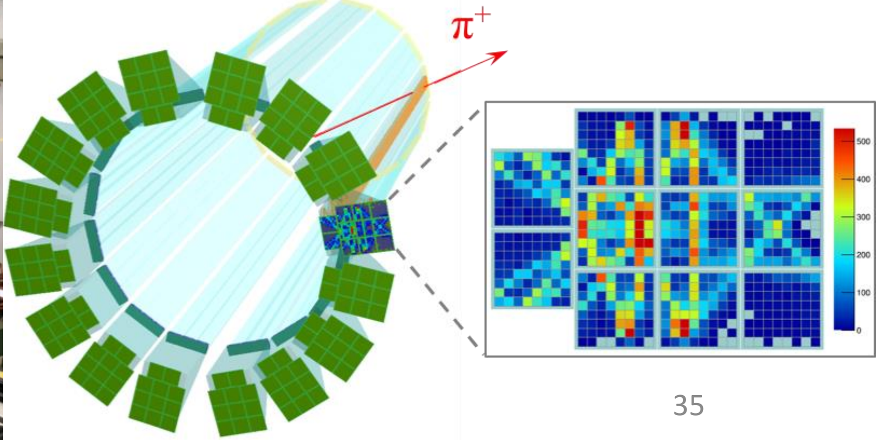
Status
- TDR approved by FAIR ECE
- In-kind contract signed, tendering started
- Mechanics and optics production design
- QA of optics and MCP PMT developed
- Readout with PaDiWA / TDC (DiRICH, GSI)



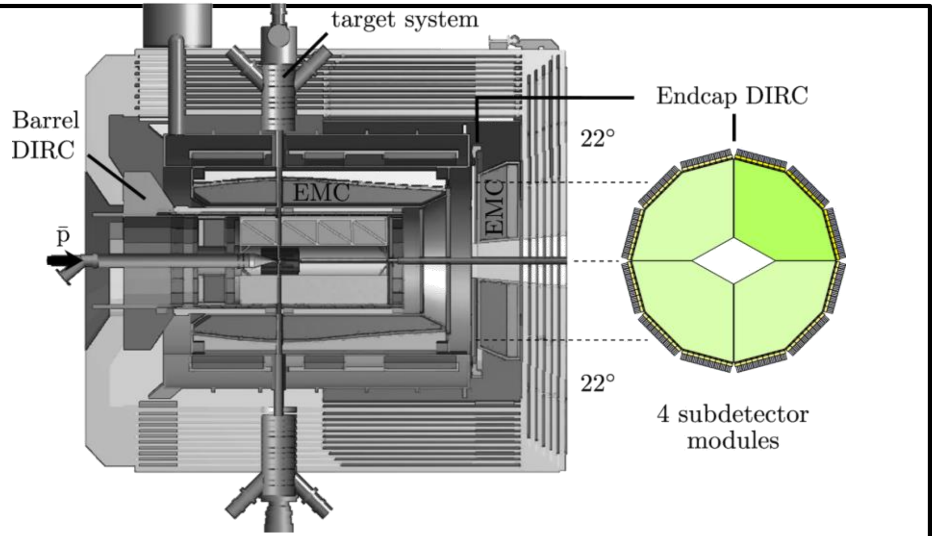








Endcap Disc DIRC

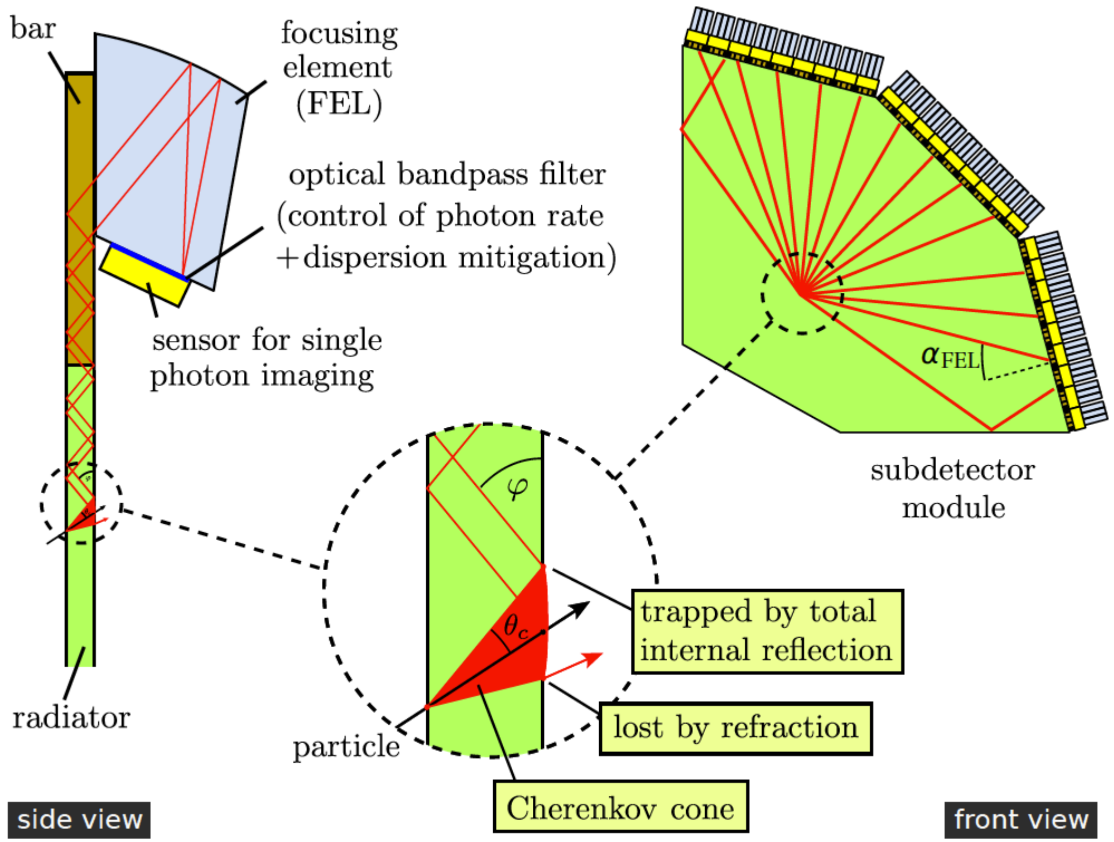


Novel concept for forward PID

- Based on DIRC principle
- Disc shaped radiator
- Readout at the disc rim

Status

- Advanced design
- Several testbeams at CERN
- TDR submitted to FAIR ECE
- Goal: Full quarter disc prototype



Basic components

- SiO2 radiator disc - 4 quadrants
- Focusing elements
- Optical bandpass filter
- MCP PMT for photon readout in magnetic field
- Readout of MCP PMT with ToFPET ASIC

Barrel Time of Flight

Target Spectrometer

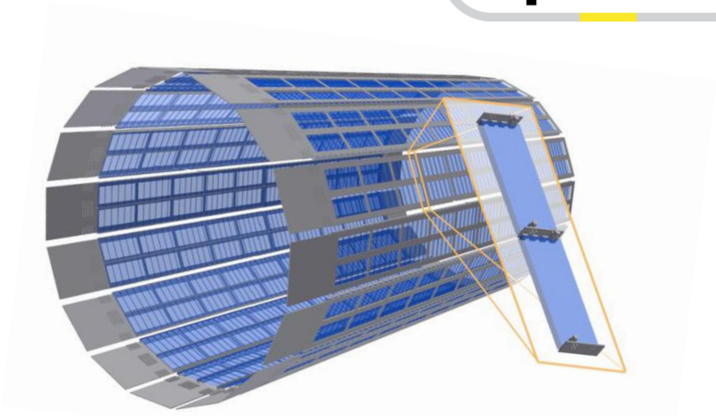
ToF in-between Barrel DIRC and Barrel EMC

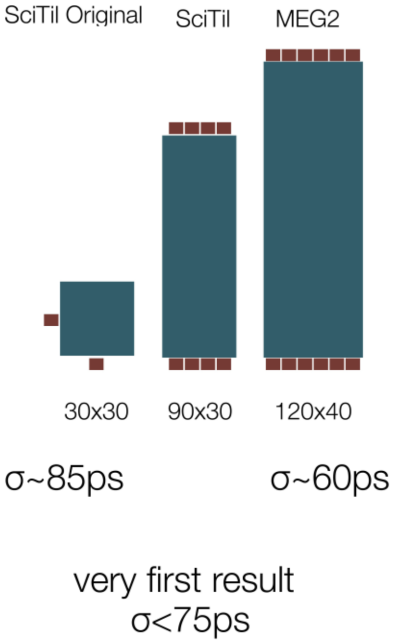
Scintillator Tile Hodoscope

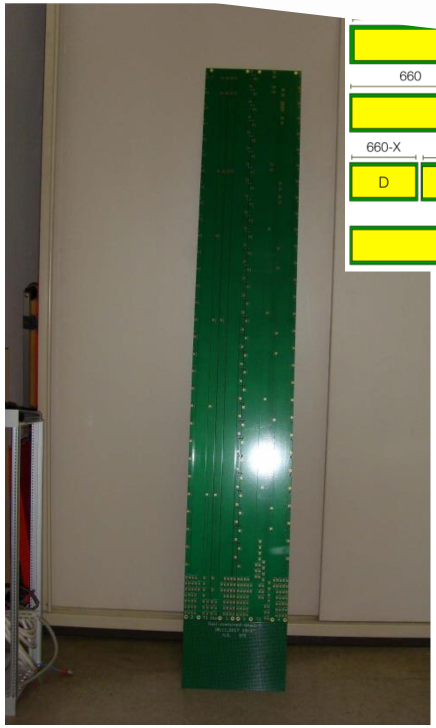
- Scintillator tiles 5 mm thick
- Photon readout with SiPMs (3x3 mm2)
  - High PDE, time resolution, rate capability
  - Work in B-fields, small, robust, low bias
- System time resolution: <100 ps achieved
- ASIC ToFPET for SiPM readout – Co-development
- Layout: long multilayer PCB for transmission ("railboard")

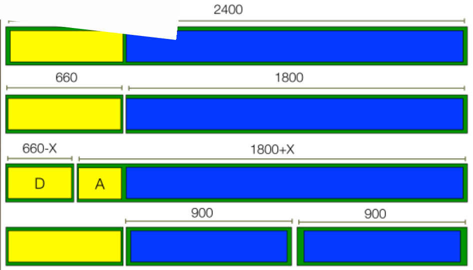
Status

- TDR approved by FAIR ECE
- Study of scintillator thickness (3-6 mm):
  - 5mm thickness confirmed as optimal
- SiPM radiation hardness studies planned
- Full Prototype readout "railboard" required
- QA of SiPM required









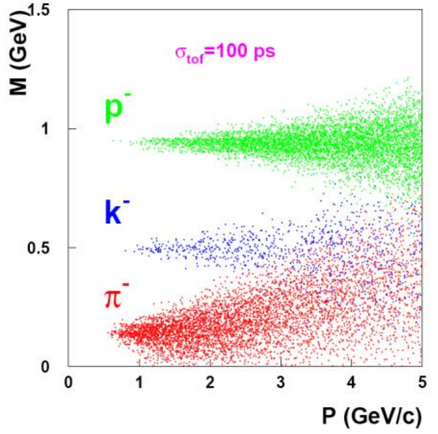
Prototype readout "railboard" 1m long!

Forward Time of Flight

Forward Spectrometer PID
- Time of Flight essential
- No start detector
- Relative timing to Barrel ToF

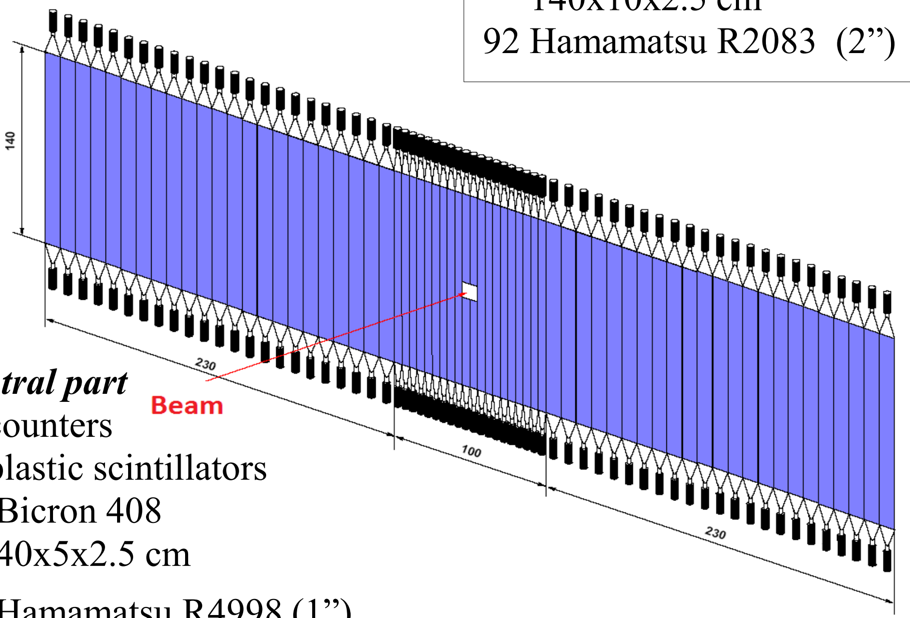
Detector layout
- Scintillator wall at z=7.5m made of 140 cm long slabs
- Bicron 408 scintillator
- PMT readout on both ends
- 10 cm slabs on the sides, 5 cm slabs in the center
- Readout FPGA

Status
- TDR approved by FAIR ECE
- Readout optimization ongoing
- Design laser calibration system



Goal: Time-of-flight with σ(t) better than 100 ps

Side parts
2x23 counters
46 plastic scintillators
Bicron 408
140x10x2.5 cm
92 Hamamatsu R2083 (2")



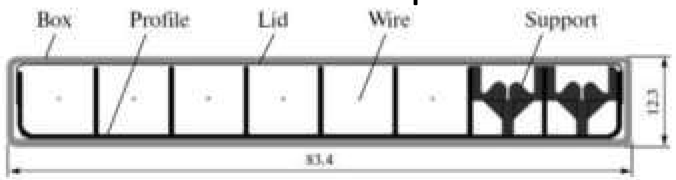
Central part
20 counters
20 plastic scintillators
Bicron 408
140x5x2.5 cm

40 Hamamatsu R4998 (1")

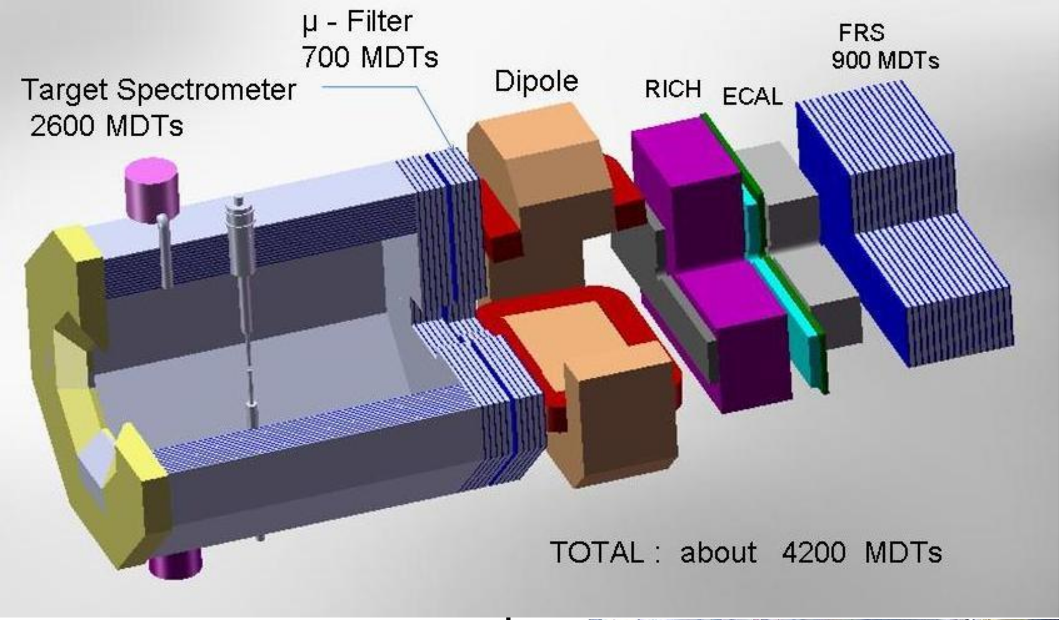
Muon Detector System

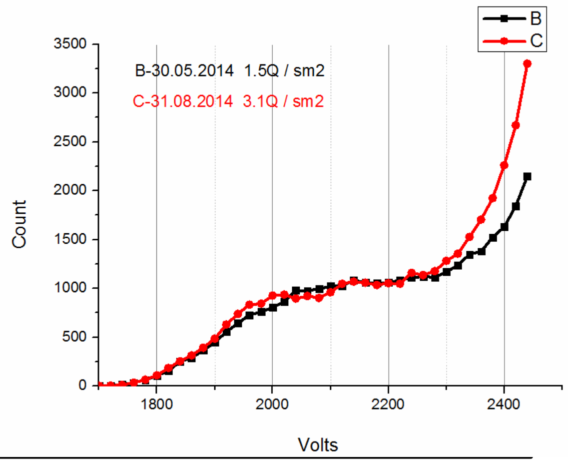
Muon system rationale
- Low momenta, high BG of pions
➔ Multi-layer range system

Muon system layout
- *Barrel*: 12+2 layers in yoke
- *Endcap*: 5+2 layers
- *Muon Filter*: 4 layers
- *Fw Range System*: 16+2 layers
- *Detectors:* Drift tubes with wire & cathode strip readout

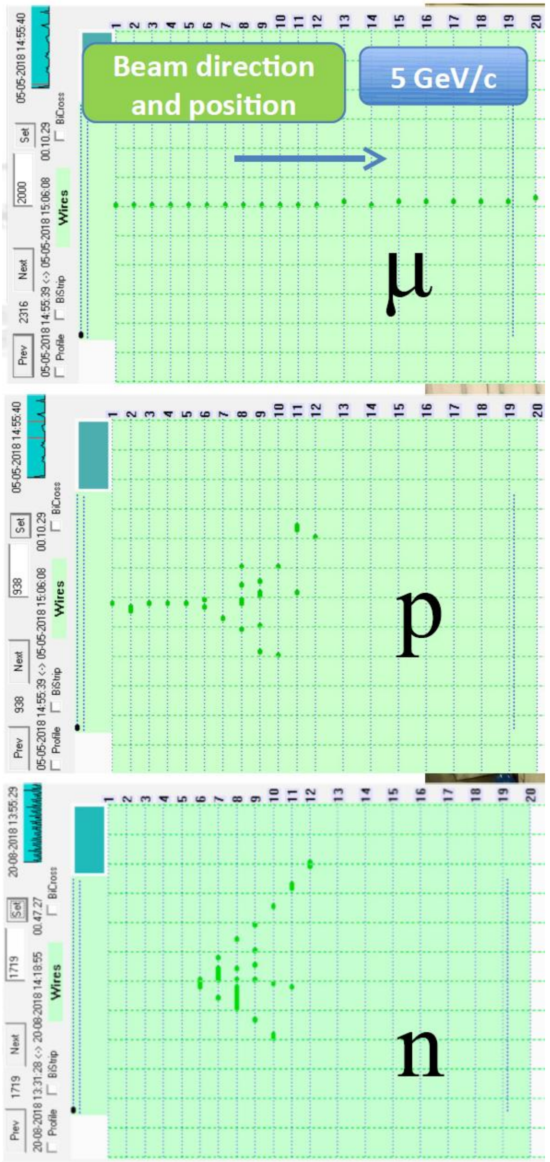


Status
- TDR approved by FAIR ECE
- Testbeams at CERN, aging, cosmics
- Aging tests up to 3C/cm2
- Digital FEE (Artix-7) development
- Production designs starting



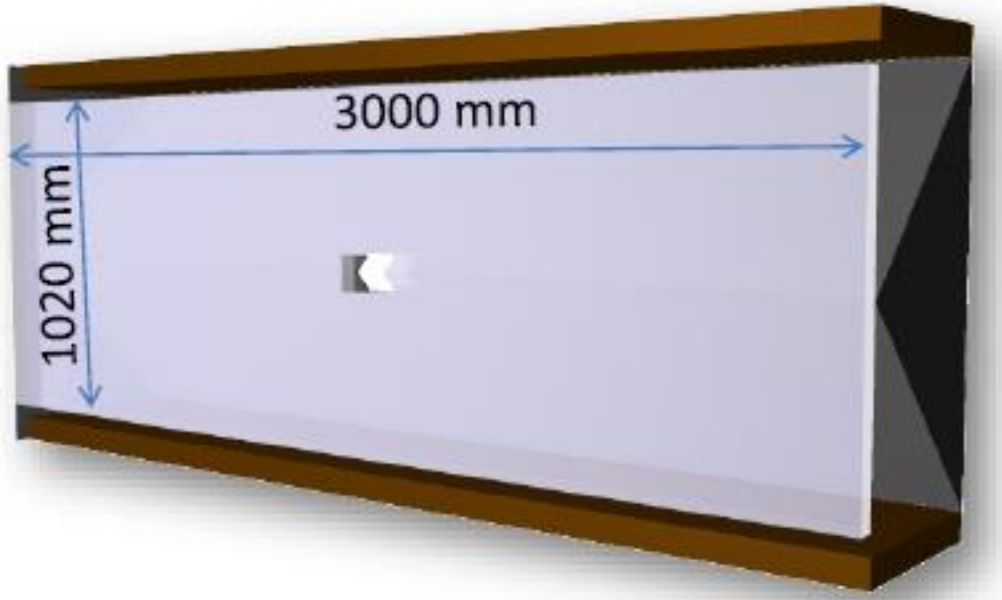


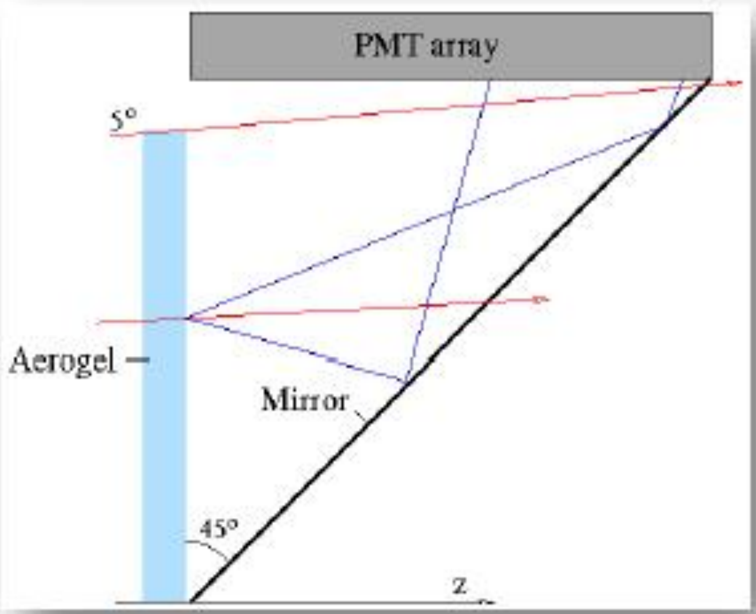
Testbeam results:
- μ, p and n easily resolved



A. Belias / GSI

Forward RICH





Hamamatsu H8500 MaPMT

- flat panel,
- 8x8 anode pixels of 6mm size
- 89% active area ratio
- Bialkali photocathode
- Gain: $1.5 \cdot 10^6$
- Relatively cheap (≈€1800 / unit)
- Robust
- Long lifetime

- 2-layer aerogel n_1=1.050, n_2=1.047 (no gas)
- Flat mirrors only
- MaPMT readout
- MC simulated PID performance:
  - π/K up to P = 10 GeV/c
  - μ/π up to P = 2 GeV/c

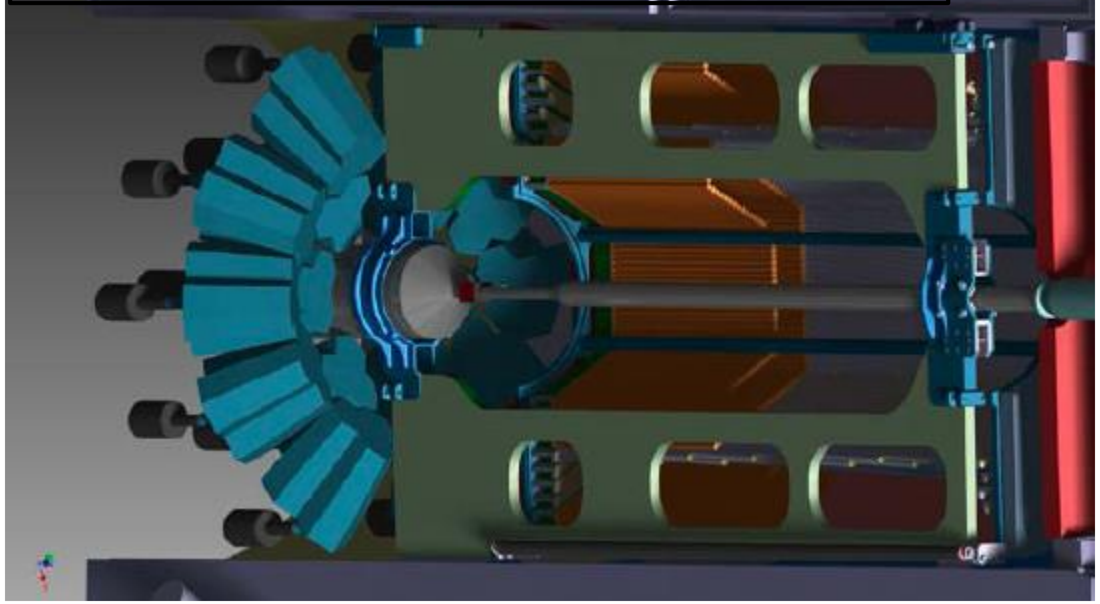
Hypernuclear Setup

Principle:

- Produce hypernuclei from captured Ξ

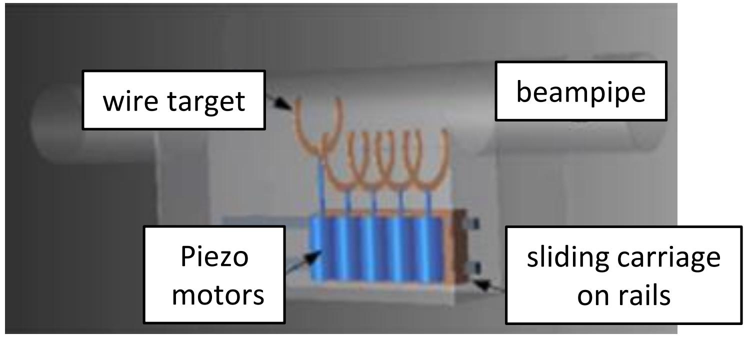
Modified Setup:

- Primary retractable wire/foil target
- Secondary active target to capture Ξ and track
  products with Si strips
- HP Ge detector for γ-spectroscopy



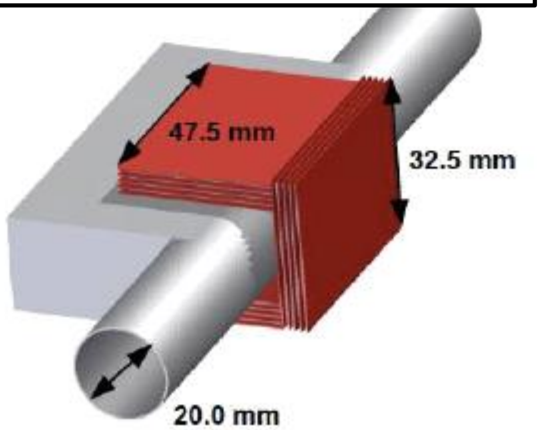
Priamary target:

- Diamond wire
- Piezo motored wire holder



Active secondary target:

- Silicon microstrips
- Absorbers



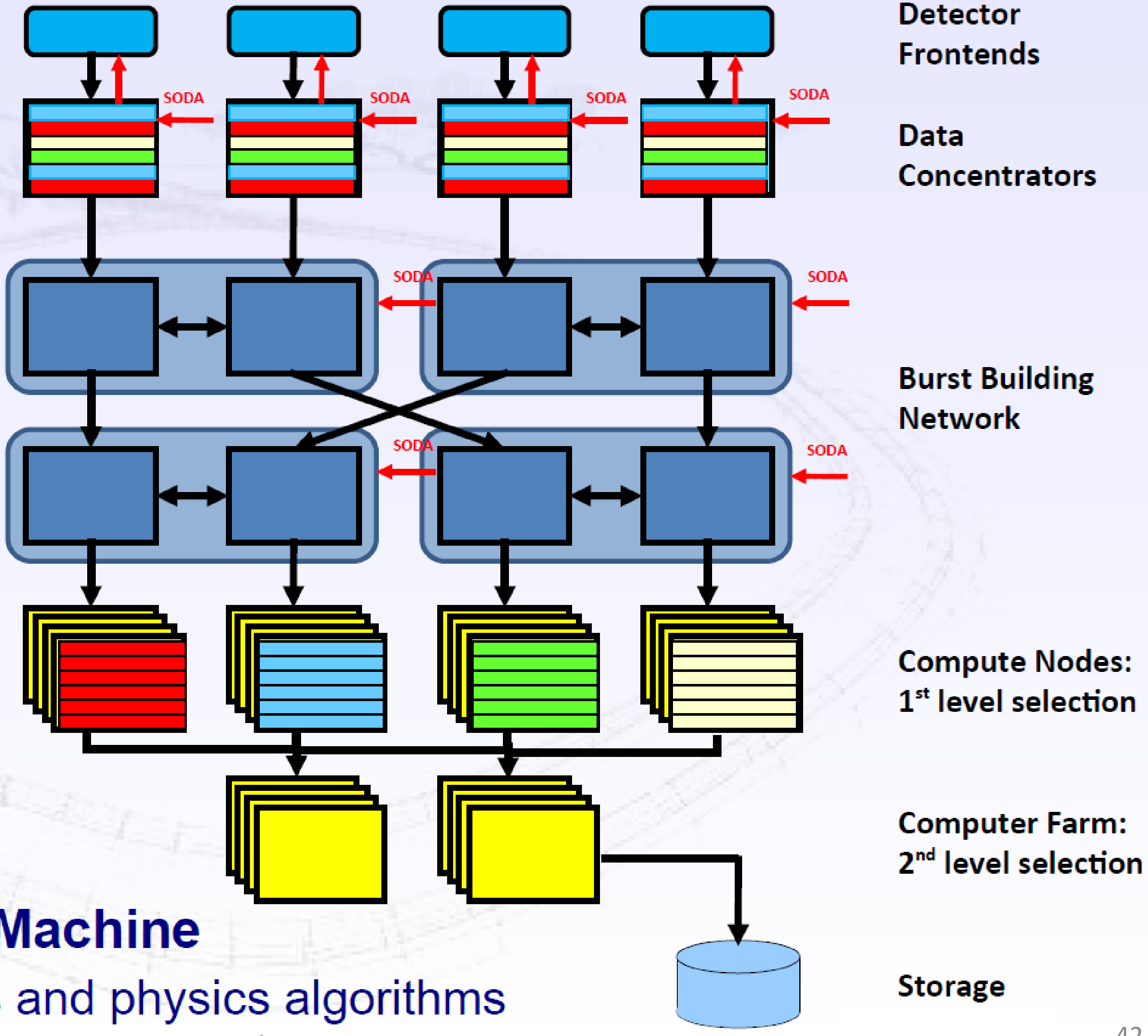
Data Acquisition System (DAQ)

Continuous Acquisition

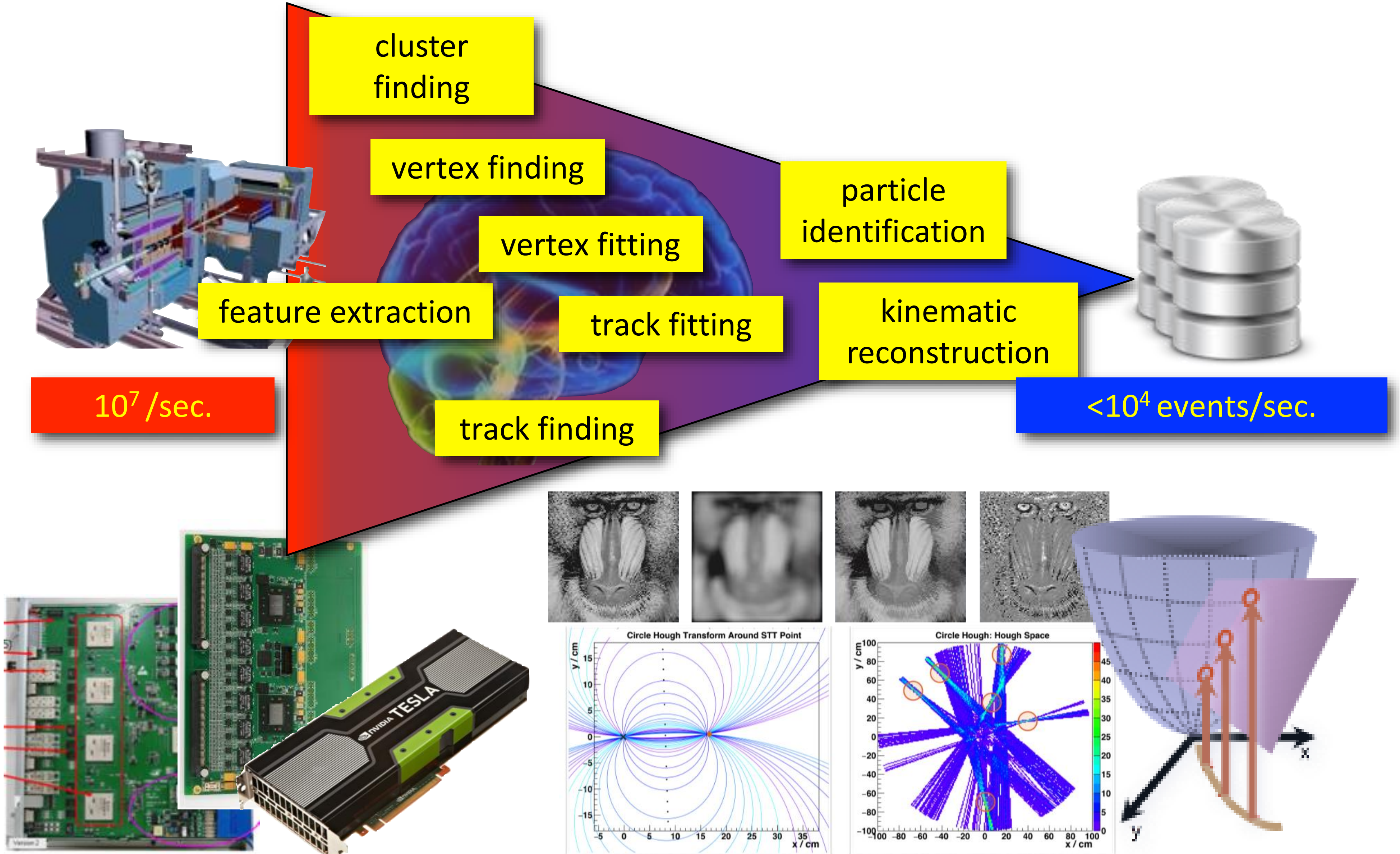
- Components:
  - Time distribution: SODA
  - Intelligent frontends
  - Powerful compute nodes
  - High speed network
- Data Flow:
  - Data reduction
  - Local feature extraction
  - Data burst building
  - Event selection
  - Data logging after online reconstruction

→ **Programmable Physics Machine**

Online selection schemes and physics algorithms are a key for successful measurements



Intelligent *in-situ* data processing



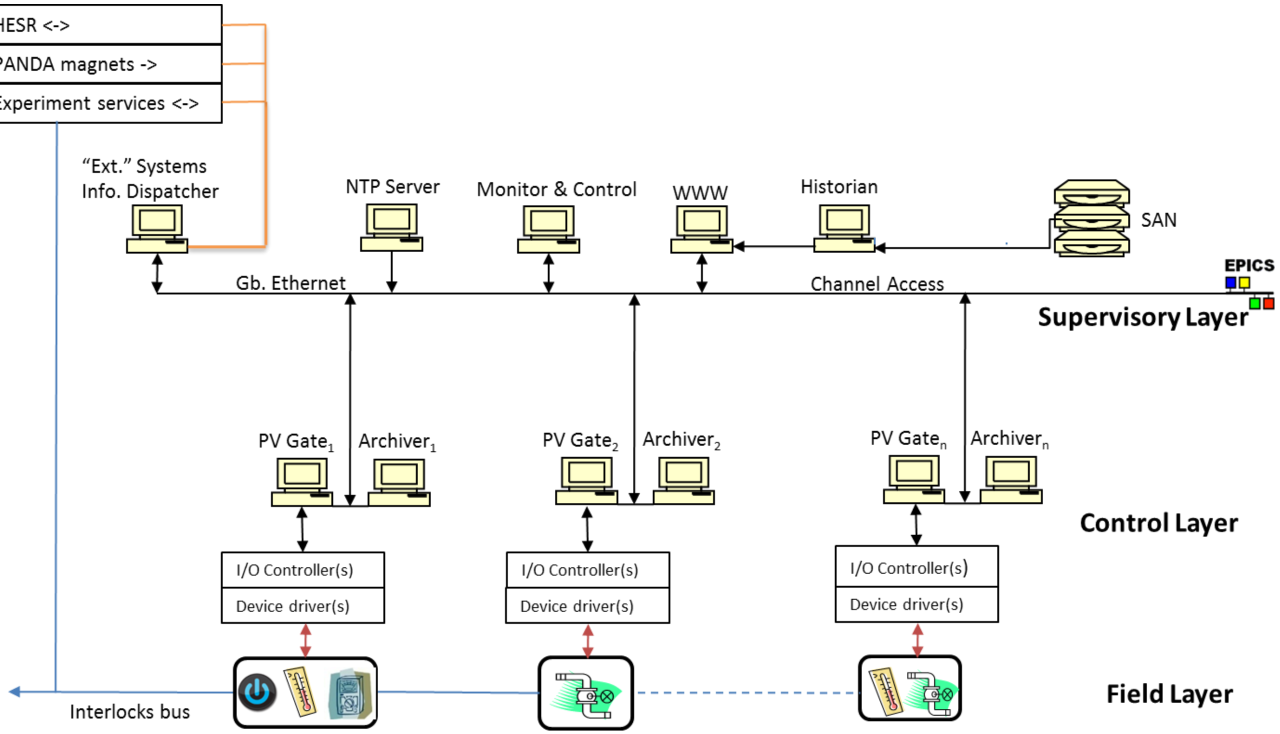
Detector Control System (DCS)

Operations parameters:
- HV, LV, currents,
- Gas-flow, cooling

Environmental parameters:
- Temp., Hum.

Interface to HESR, Magnets

Detector Safety



Supervisory Layer
Controls GUI interface
Databases & configurations
Interface: HESR, DAQ

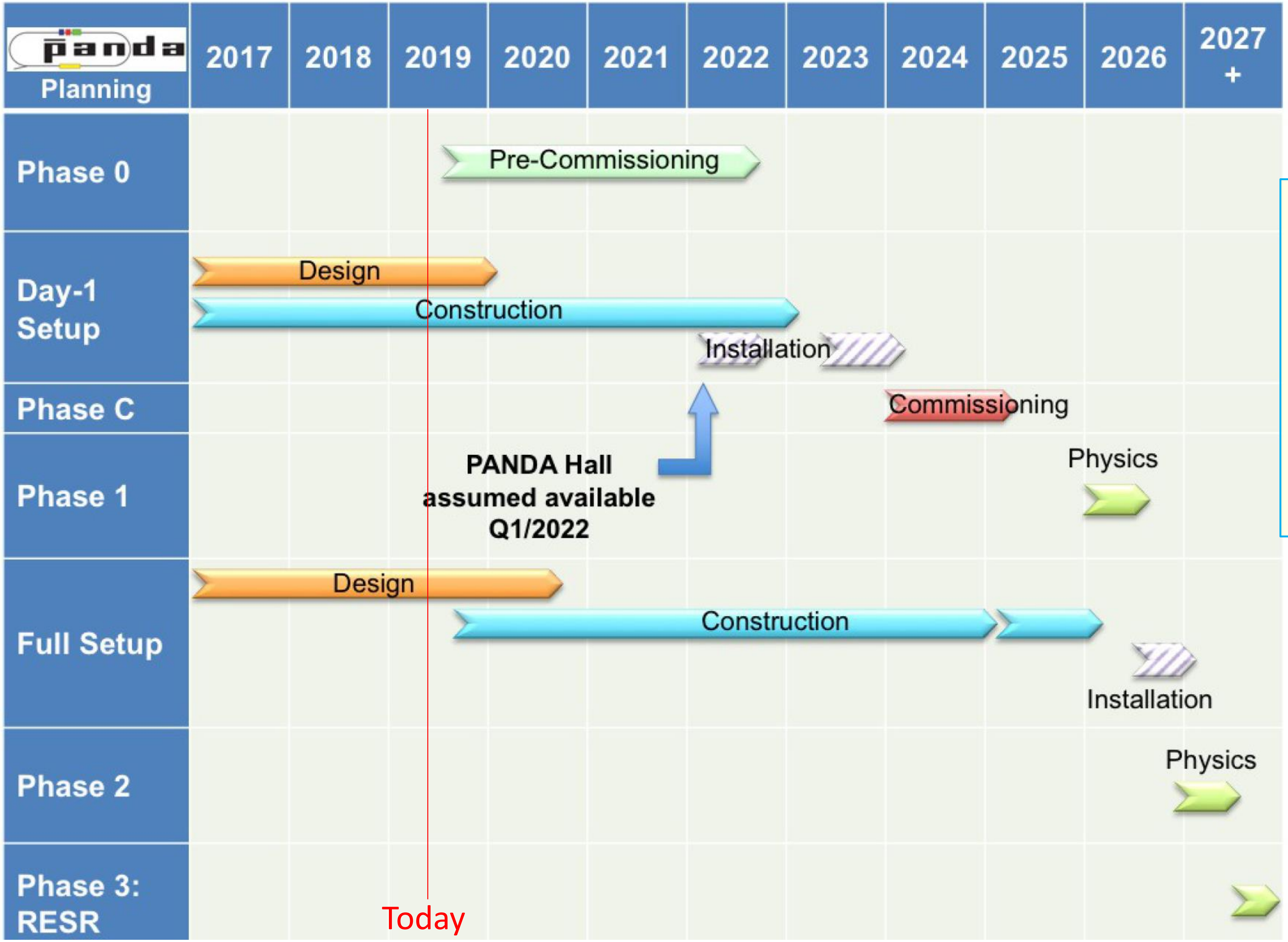
Control Layer
I/O controllers
Device Drivers
Archiving sub-system

Field Layer
PANDA sub-systems specific
Interface: Detector Safety System

EPICS - **E**xperimental **P**hysics and **I**ndustrial **C**ontrol **S**ystem

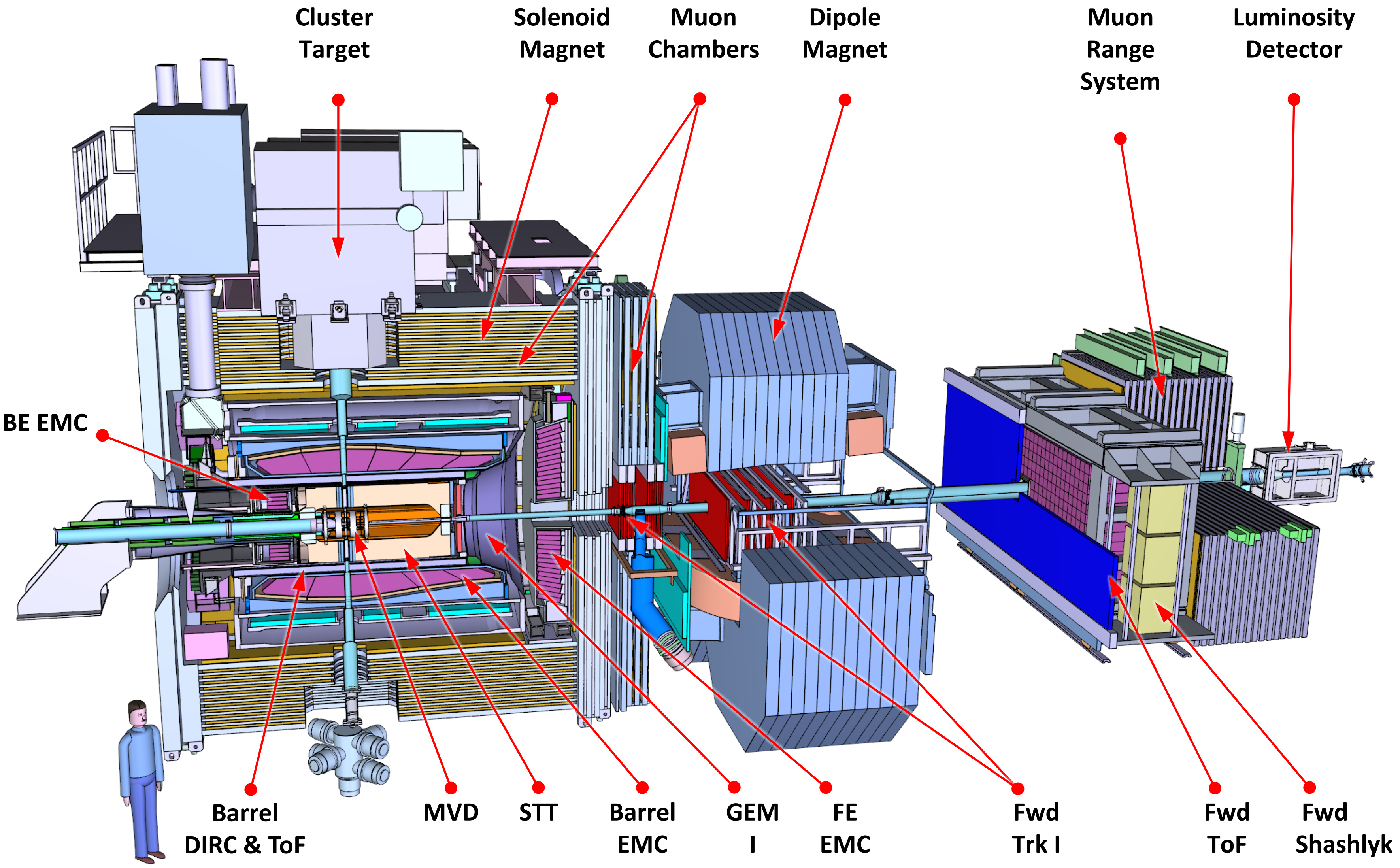
- ❑ Decentralized architecture
- ❑ Freely scalable
- ❑ Allows "partitioning"

Schedule

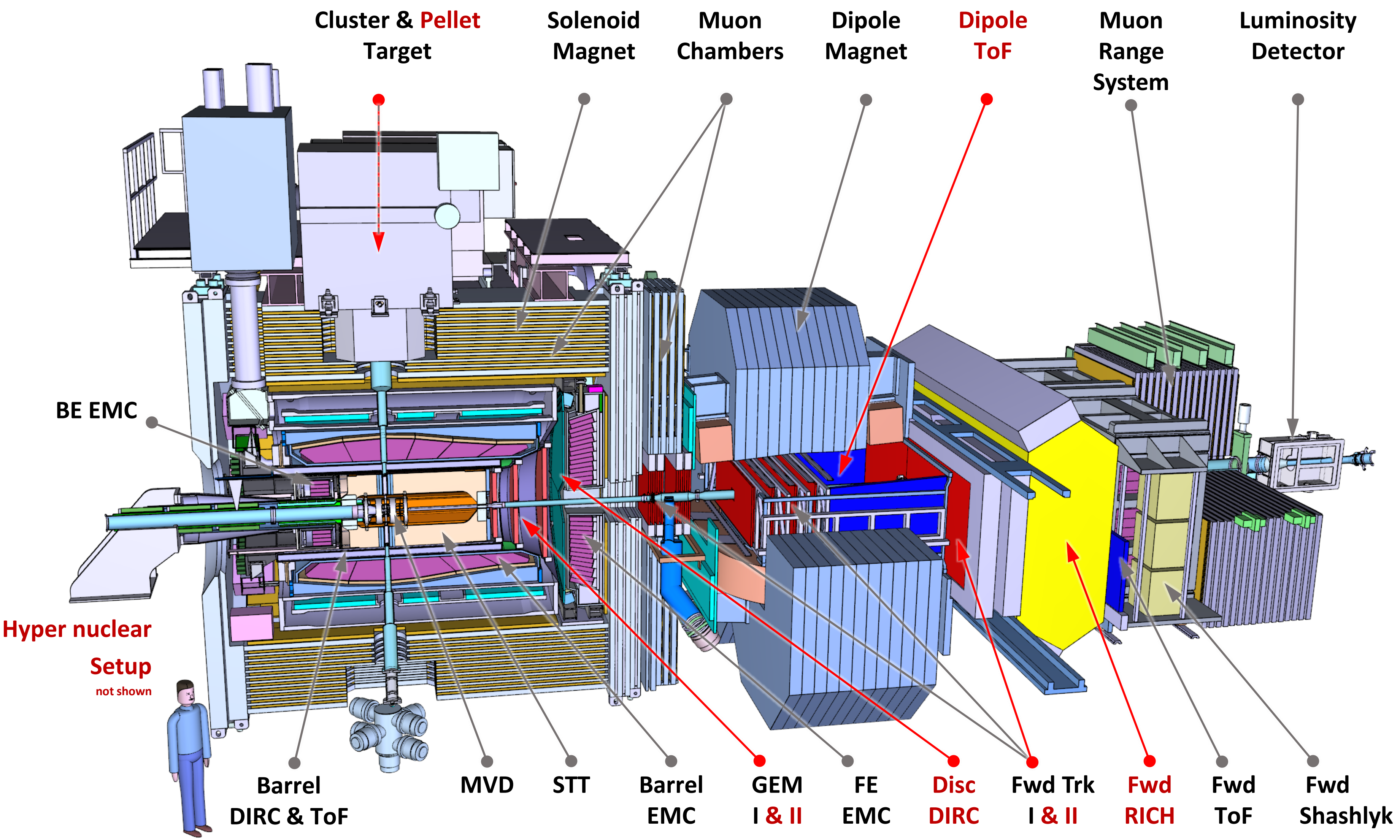


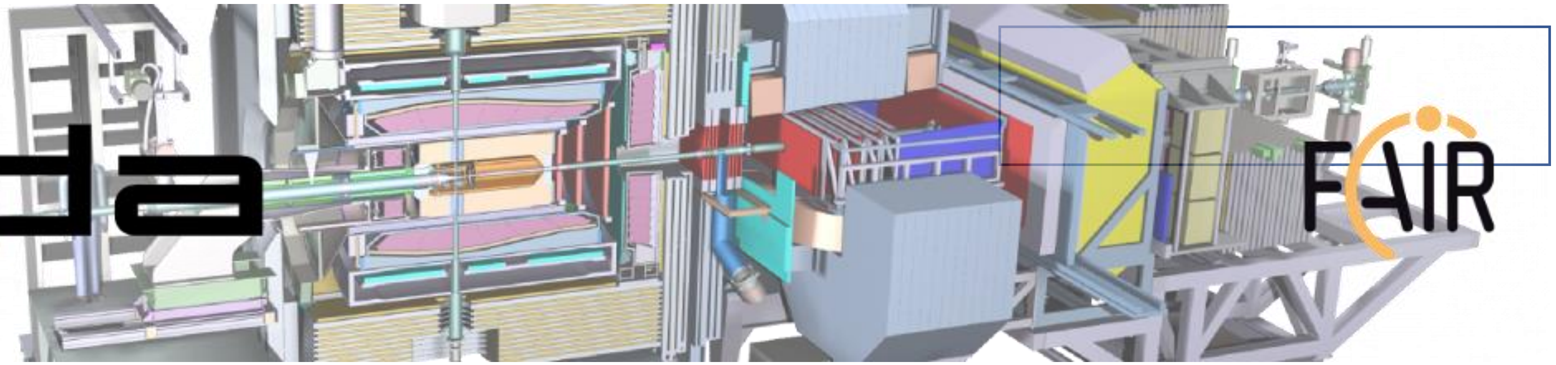
- Construction of Phase 1 systems
- Installation periods
  1. Solenoid, Dipole, Supports
  2. All Detectors
- Commissioning with beam (protons / antiprotons)
- Physics with antiprotons

Start Setup (Phase 1)



Full Setup (Phase 2)





Present Status of PANDA

- Most Phase 1 detector TDRs complete
- Preparation for Construction MoUs ongoing
- Sharpened physics focus and detector start sequence

Timeline for PANDA Construction

- Construction of detector systems has started
- Pre-assembly of first components has started
- Installation at FAIR planning 2022 - 2023
- Commissioning with beam 2024 - 2025

PANDA physics with antiproton beam 2026

- Versatile physics machine with full detection capabilities
- PANDA will shed light on many of today's QCD puzzles

Opportunities for significant contributions in PANDA

Opportunities – Aspects of Contributions

- Scope for R&D
  - Phased schedule allows for R&D
  - Detectors Phase 1 - TDR process
  - Detectors Phase 2
  - Upgrades Higher Luminosity

- Prototype tests & developments
  - Readout electronics
    - analog / digital
  - DAQ algorithms FPGA, GPU
  - Detector Controls software

- First of Series
  - Detector module integration
  - Mechanical interfaces
  - Complete module operations

- Production
  - QA/QC processes
  - Construction, mechanics, supports
  - Detector module assembly
  - Overall detector integration

➔ Explore Opportunities & Synergies GLUEX - PANDA