Overview of $\bar{p}$anda

PANDA Russia Workshop, May 26, 2014

Lars Schmitt, FAIR Darmstadt

- Antiprotons at FAIR
- PANDA Overview
- PANDA Systems
- TDR Schedule and Conclusions

FAIR

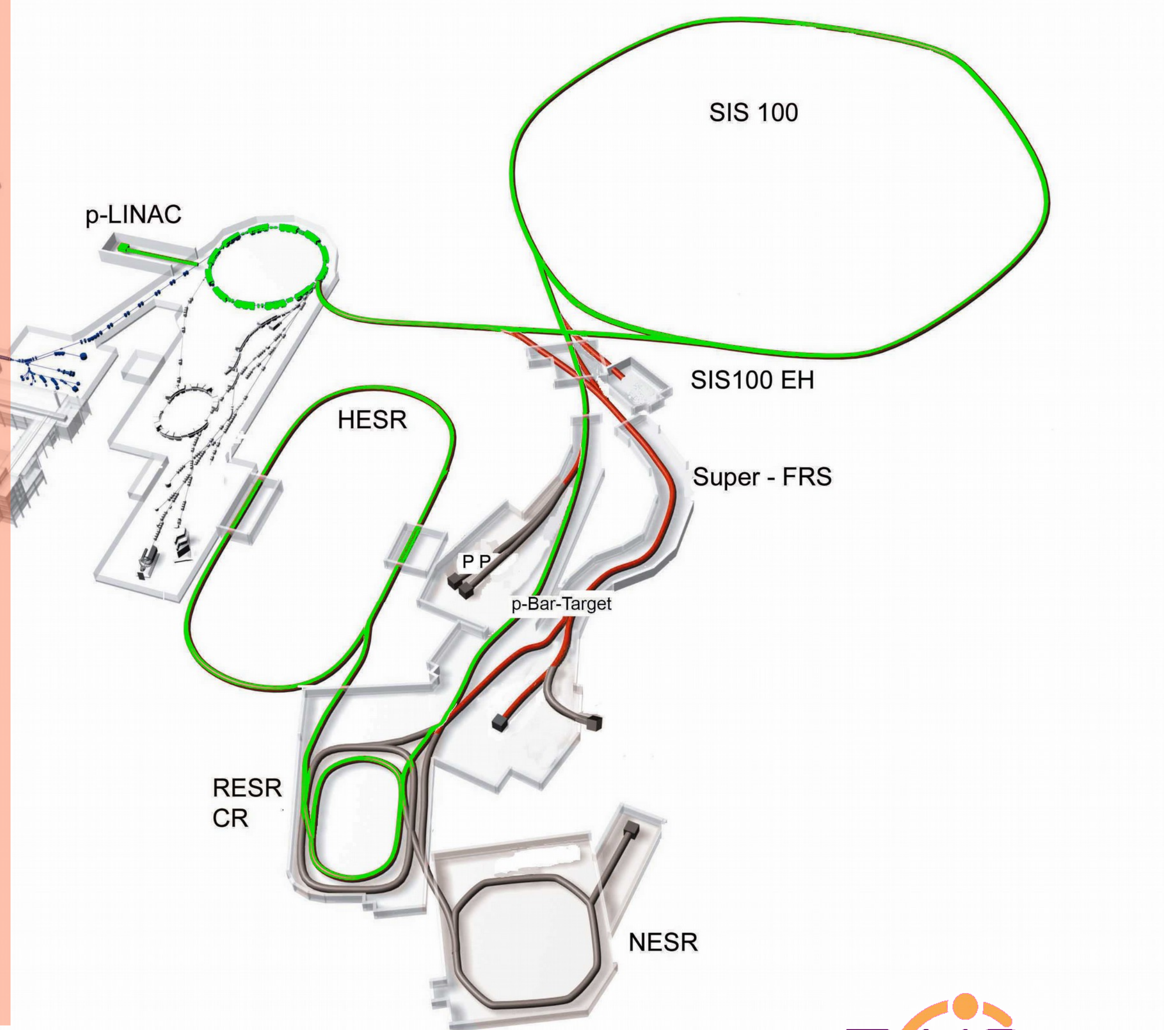
Antiprotons at FAIR

Antiproton production

- Proton Linac 70 MeV
- Accelerate p in SIS18 / 100
- Produce $\bar{p}$ on Cu target
- Collection in CR, fast cooling
- Accumulation in RESR, slow cooling
- Storage in HESR and usage in PANDA

Modularised Start Version

- RESR is postponed (Mod. 4)
- Accumulation in HESR
- 10x lower luminosity



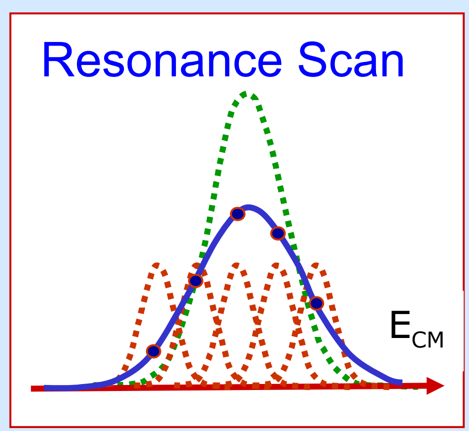
High Energy Storage Ring

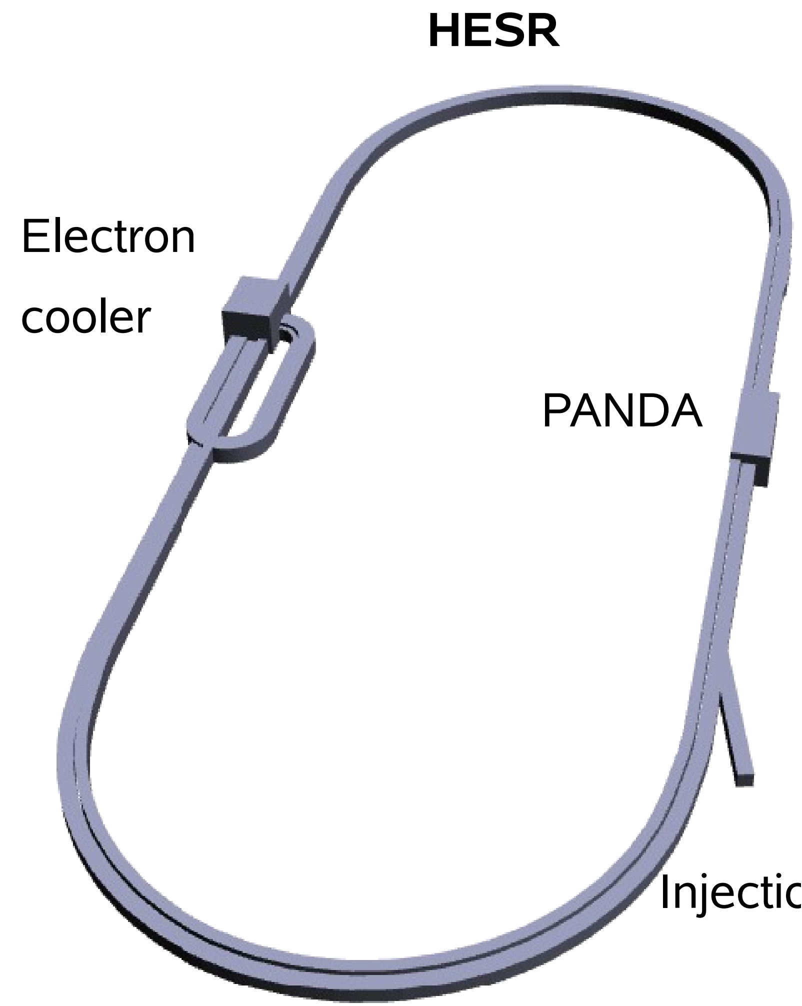
HESR Parameters

- Storage ring for internal target
- Initially also used for accumulation
- Injection of $\bar{p}$ at 3.7 GeV/c
- Slow synchrotron (1.5-15 GeV/c)
- Luminosity up to L~ $2x10^{32}$ $cm^{-2}s^{-1}$

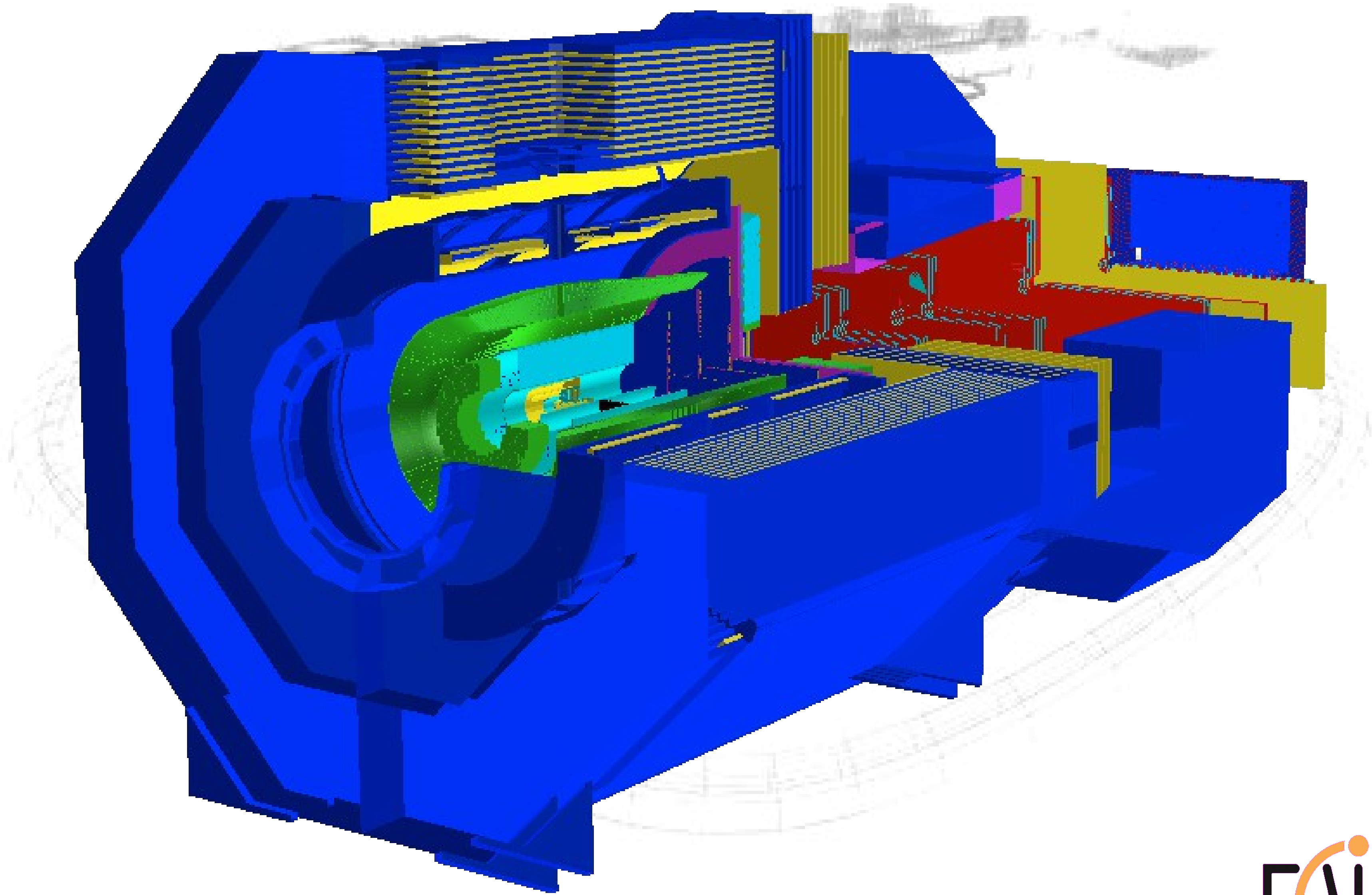
Mode	High luminosity (HL)	High resolution (HR)
$\Delta p/p$	$\sim 10^{-4}$	$\sim 4x10^{-5}$
L ($cm^{-2}s^{-1}$)	$2x10^{32}$	$2x10^{31}$
Stored $\bar{p}$	10^{11}	10^{10}

- Stochastic & electron cooling
- Resolution ~50 keV
- Tune E_{CM} to probe resonance
- Get precise m and Γ





PANDA Overview



Physics Goals of $\overline{\text{P}}$ANDA

Hadron Spectroscopy

Experimental Goals: *mass, width & quantum numbers J^{PC} of resonances*

Charm Hadrons*: charmonia, D-mesons, charm baryons*

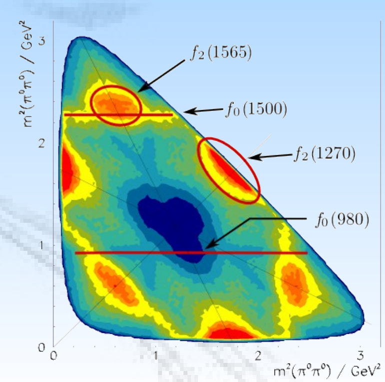
➔ Understand new XYZ states, $D_s(2317)$ and others

Exotic QCD States*: glueballs, hybrids, multi-quarks*

Spectroscopy with Antiprotons:

Production of states of all quantum numbers

Resonance scanning with high resolution



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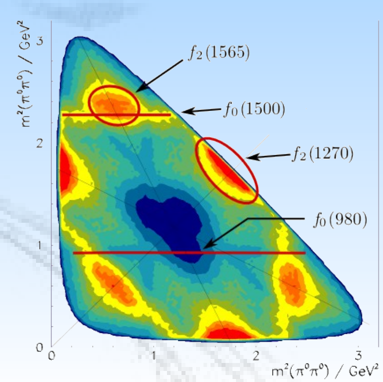

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Exotic QCD States: *glueballs, hybrids, multi-quarks*

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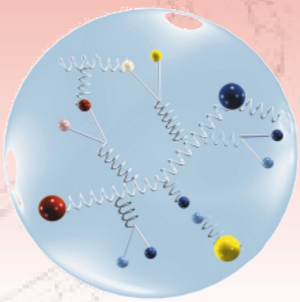
Resonance scanning with high resolution

Hadron Structure

Time-like Nucleon Formfactors



➔ Measurable in annihilation, discrepancy with space-like

Generalized Parton Distributions

Drell-Yan Process

Physics Goals of $\bar{\text{P}}$ANDA

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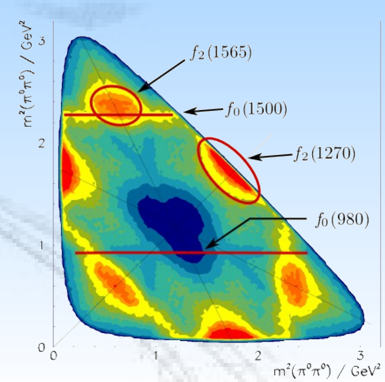

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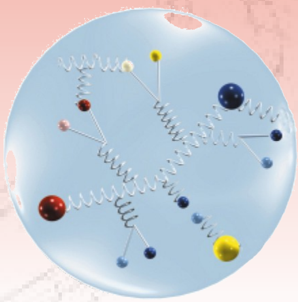


Generalized Parton Distributions

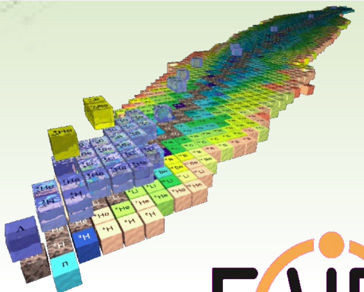
Drell-Yan Process

Nuclear Physics

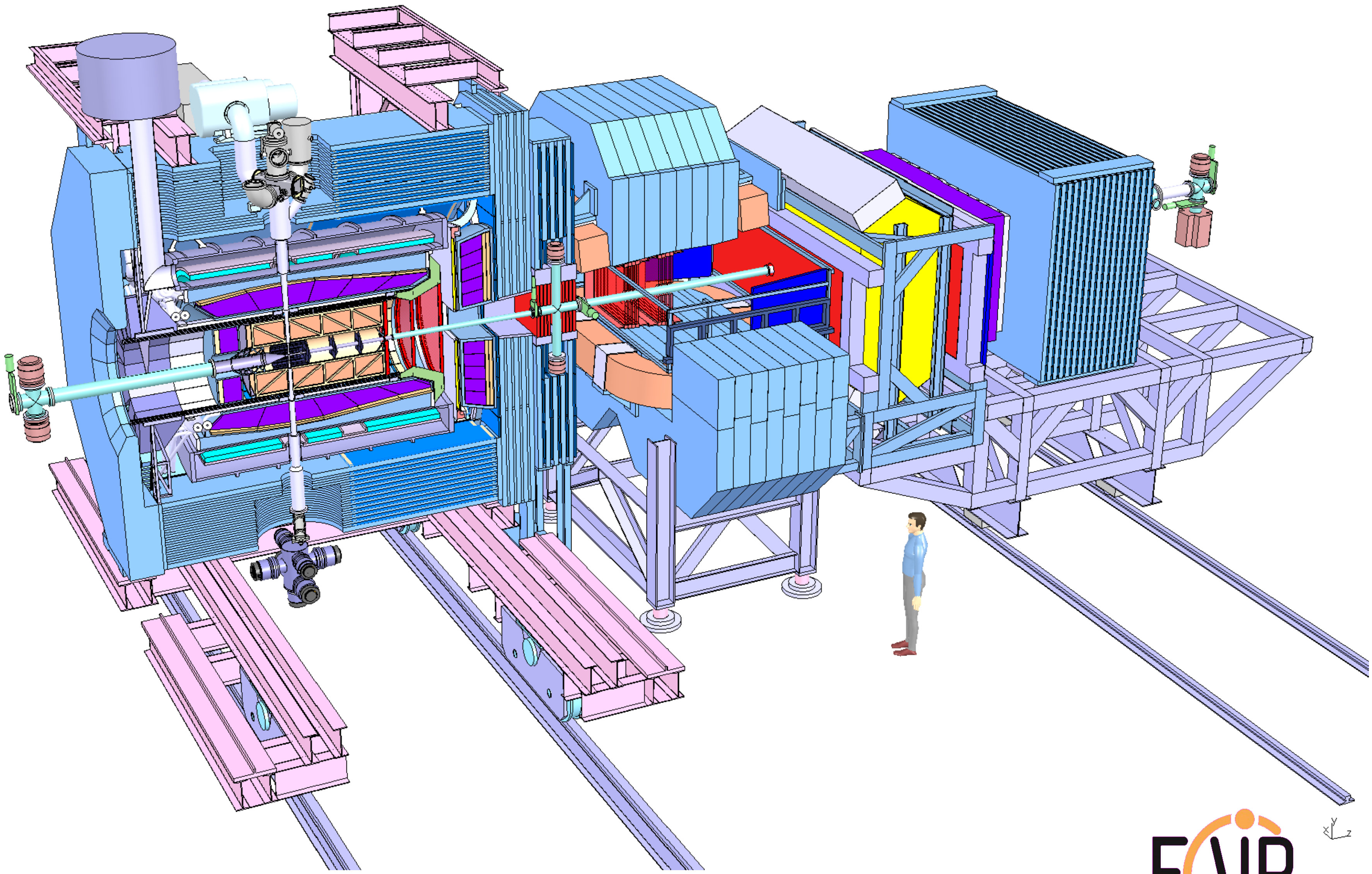
Hypernuclei*:* Production of double Λ-hypernuclei

➔ γ-spectroscopy of hypernuclei, YY interaction

Hadrons in Nuclear Medium



PANDA Spectrometer



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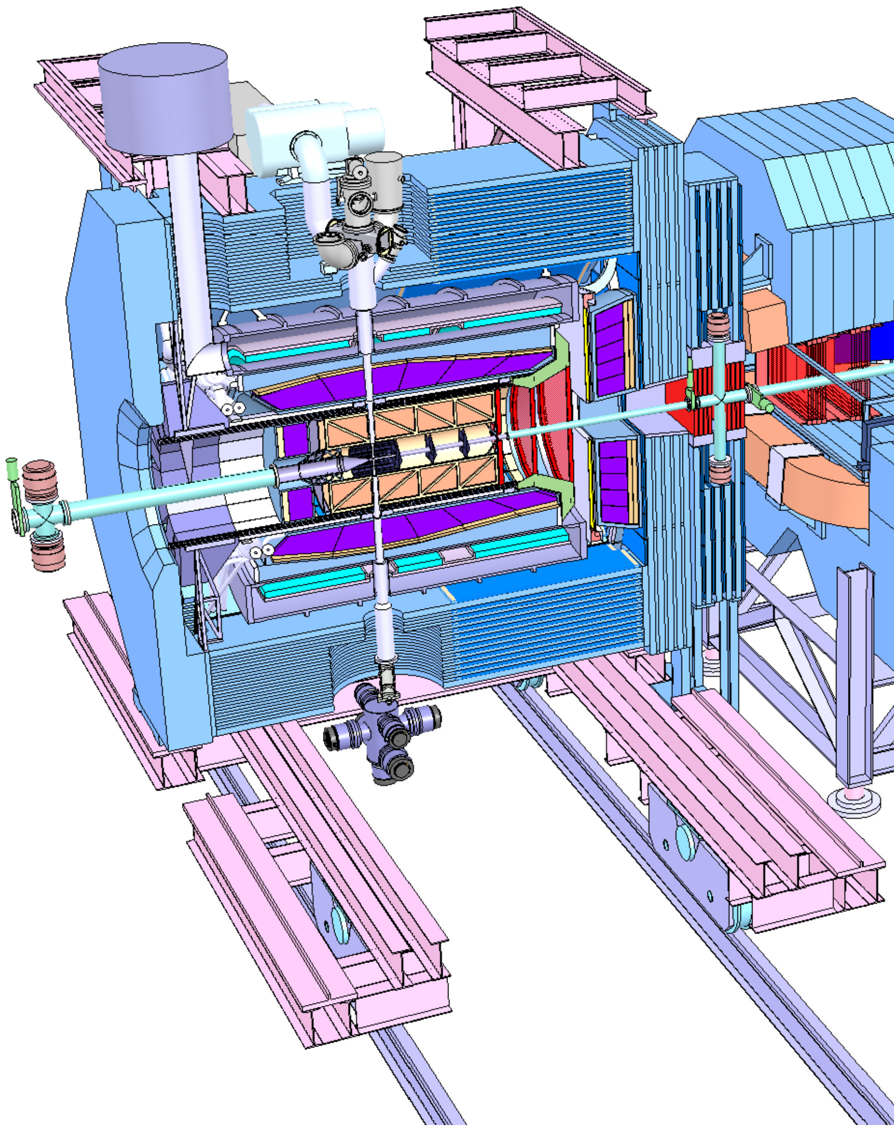
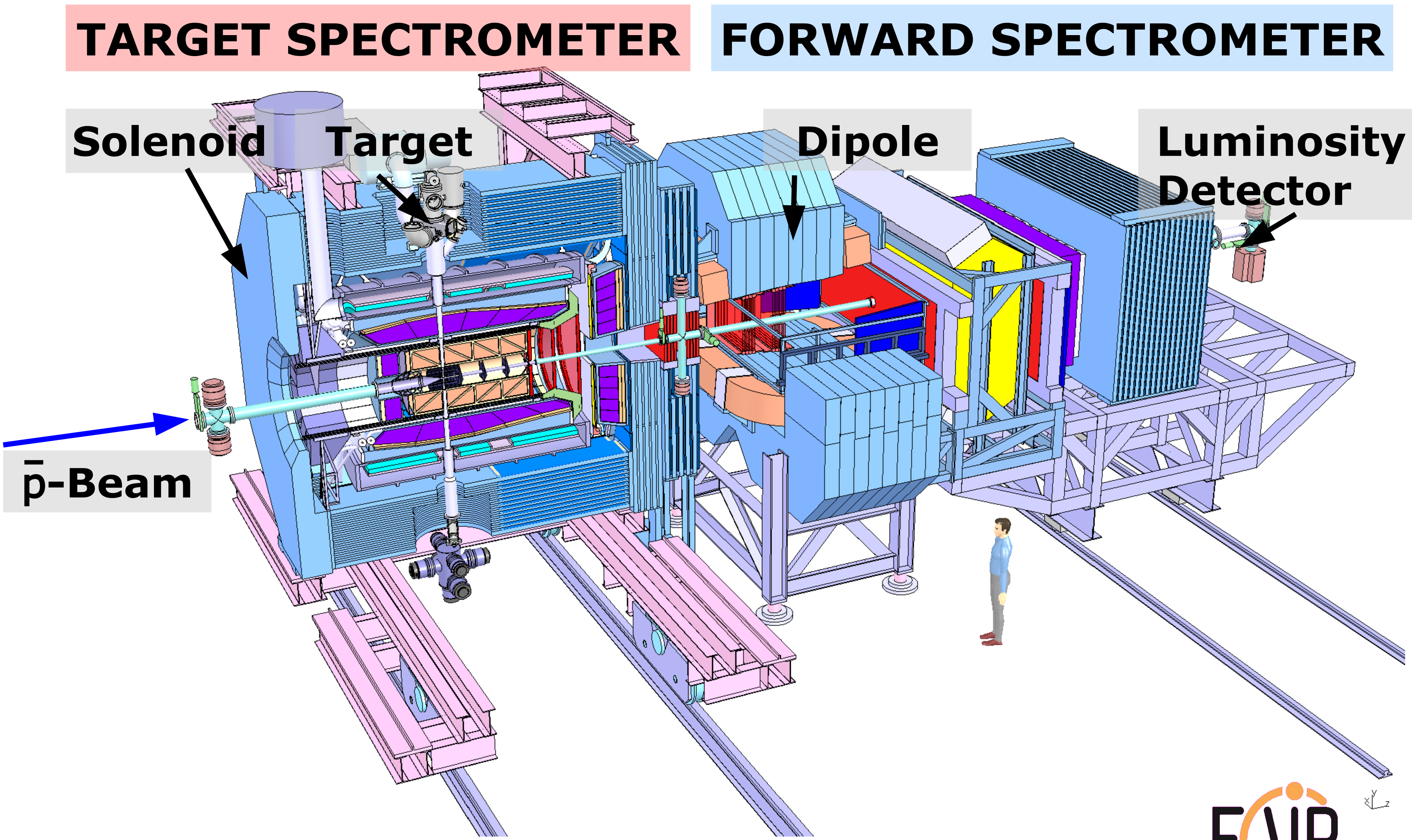


Detector requirements:

- 4π acceptance
- High rate capability: $2\times10^{7}\ s^{-1}$ interactions
- Efficient event selection
- ➔ *Continuous acquisition*
- Momentum resolution ~1%
- Vertex info for D, K^0_S, Y ($c\tau$ = 317 μm for $D^{\pm}$)
- ➔ *Good tracking*
- Good PID (γ, e, μ, π, K, p)
- ➔ *Cherenkov, ToF, dE/dx*
- γ-detection MeV – 15 GeV
- ➔ *Crystal Calorimeter*

PANDA Spectrometer



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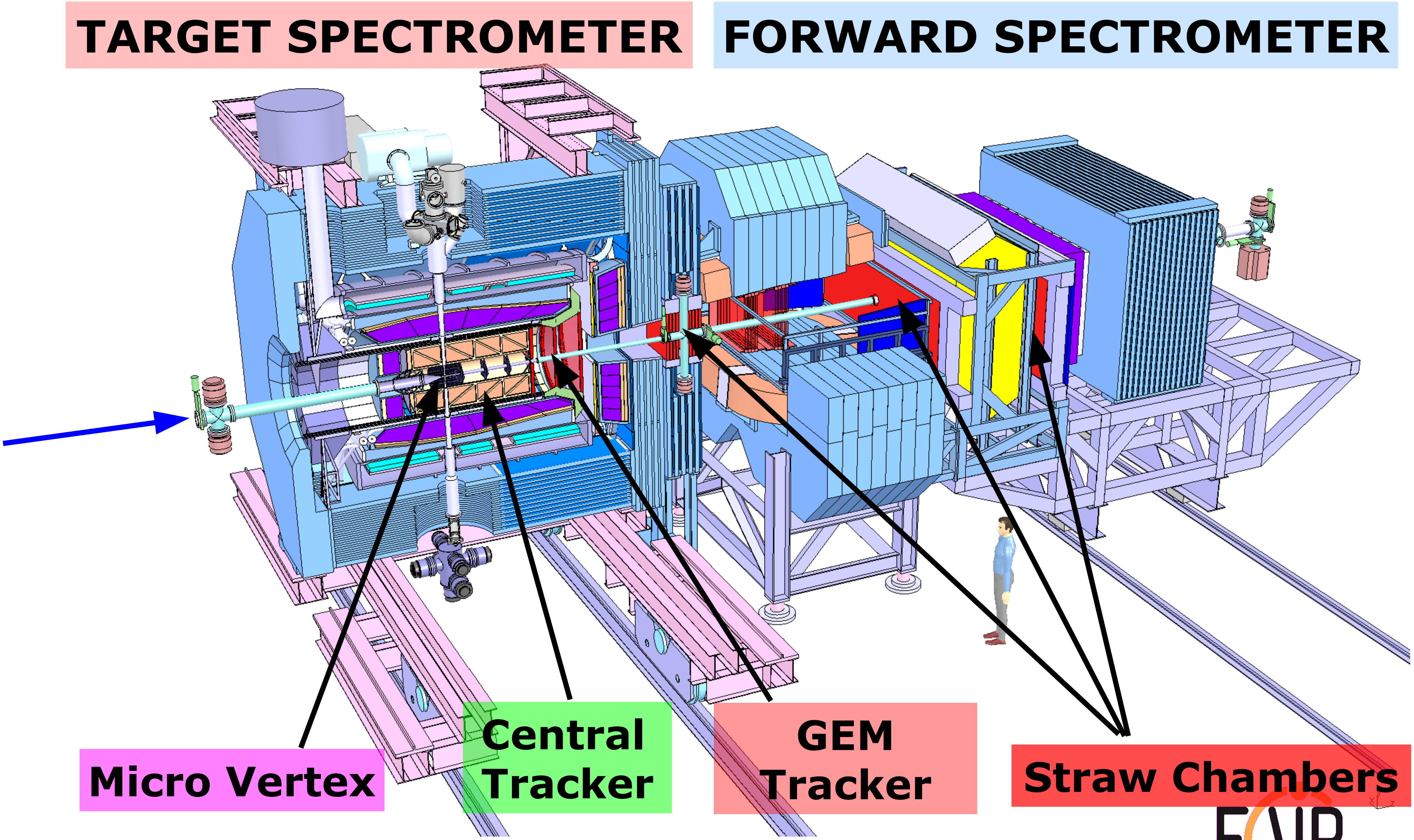

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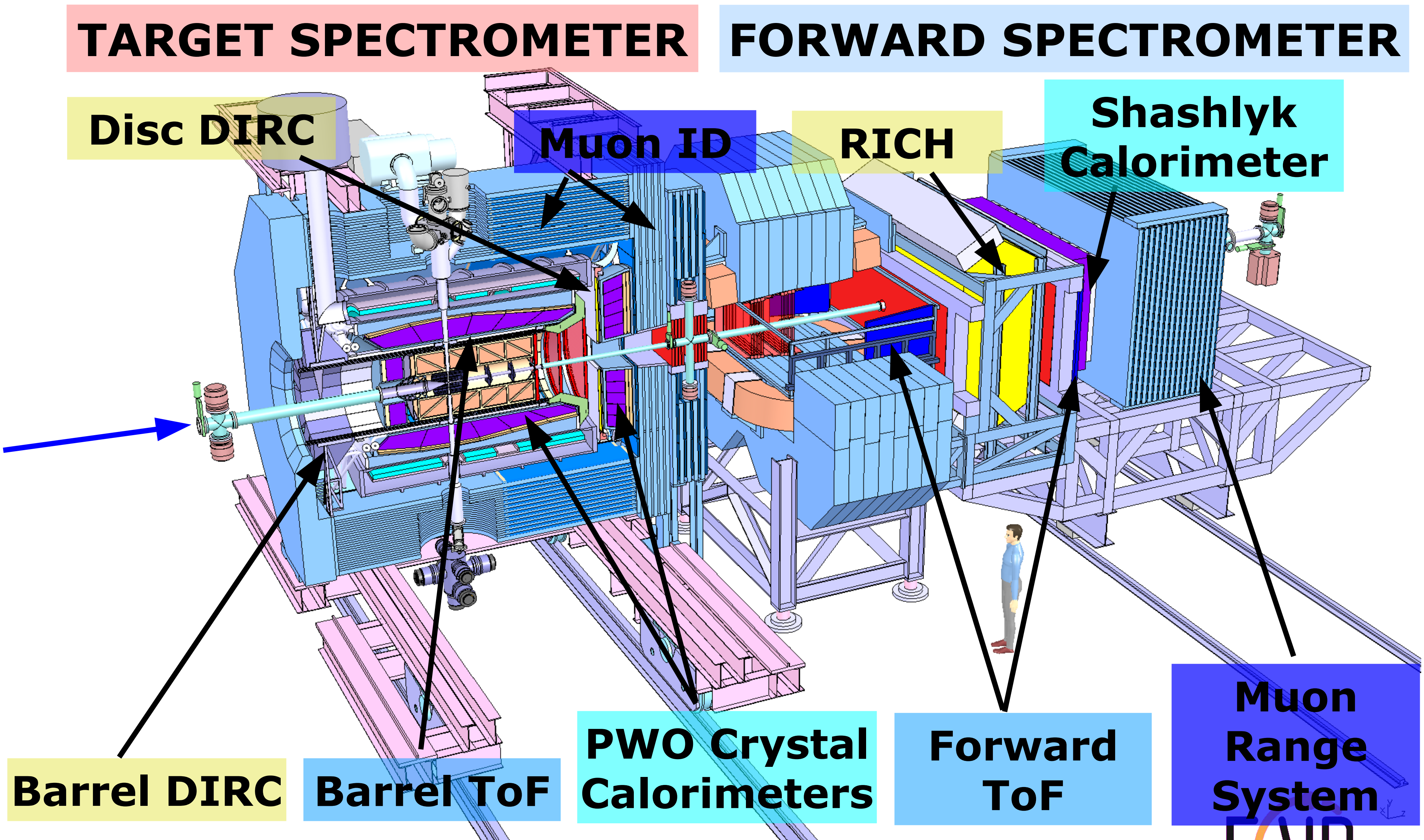
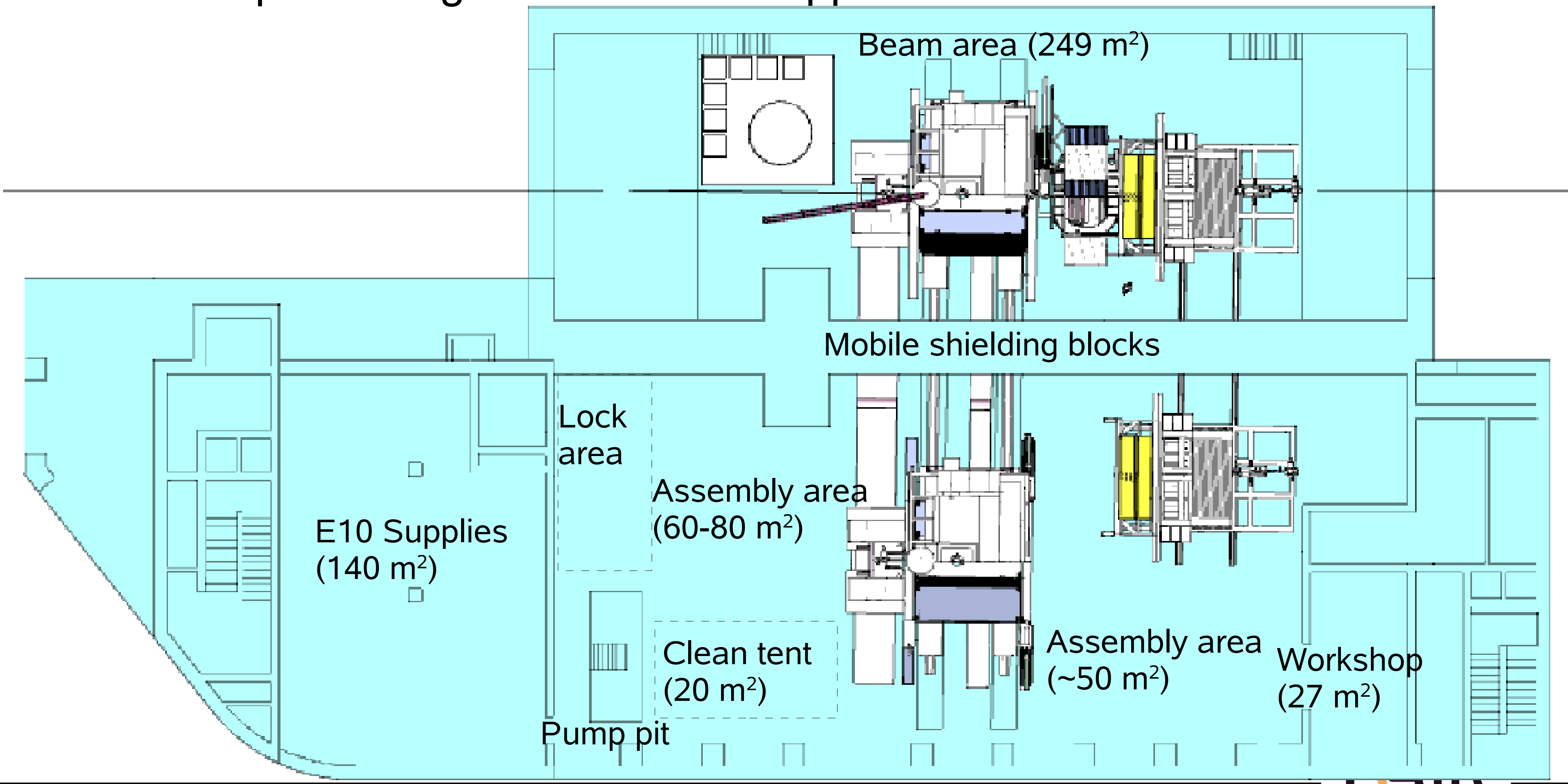


The PANDA Hall

- Architects approaching execution planning
- Detailed layout of infrastructure, shielding, services
- Next steps: routing of cables and supplies



PANDA Construction Schedule

Subsystem		2015				2016				2017				2018				2019				2020			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Dipole								M7/8																	
Forward TOF						M4/7																			
Forward Shashlyk Calorimeter							M7/8																		
Forward Range System																									
Luminosity Detector																									
Supports																									
Supplies																									
Controls																									
Computing																									
DAQ																									
Solenoid					Conductor production								M8/9												
Cluster Jet Target																									
TS Barrel Muon Detectors																									
TS Endcap Muon Detectors																									
Muon Filter																									
Forward Tracking							M4/7																		
Barrel EMC							Crystal production																		
Pellet Target											M8/10														
Barrel DIRC							8																		
Barrel Time of Flight (TOF)																									
Interaction Region																									
Micro Vertex Detector (MVD)									M4/8																
Straw Tube Tracker (STT)																									
Backward Endcap EMC	M3/7																								
Planar GEM Trackers																									
Forward Endcap EMC	M3/8							M9/10																	
Endcap Disc DIRC																									
Hypernuclei Primary Target																									
Hypernuclei Germanium Detector																									
Hypernuclei Secondary Active Target																									
Silicon Lambda Disks																									
Forward RICH																									

R&D, **M3:** TDR approved
Tendering, Contract Preparation, **M4:** Contracts signed
Construction design, **M7:** Planning completed
Prototype/Pre-series construction, **M8:** Prototype/Pre-series testing complete, production readiness
Component construction & testing, Module assembly & testing, **M9:** Acceptance test completed
Pre-assembly, off-site testing, Transport to FAIR, site-acceptance tests, **M10:** Ready for installation

Subject to change due to funding and civil construction

PANDA Installation Schedule

Subsystem	20XX				20XX+1			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Dipole								
Forward TOF								
Forward Shashlyk Calorimeter								
Forward Range System								
Luminosity Detector								
Supports								
Supplies								
Controls								
Computing								
DAQ								
Solenoid								
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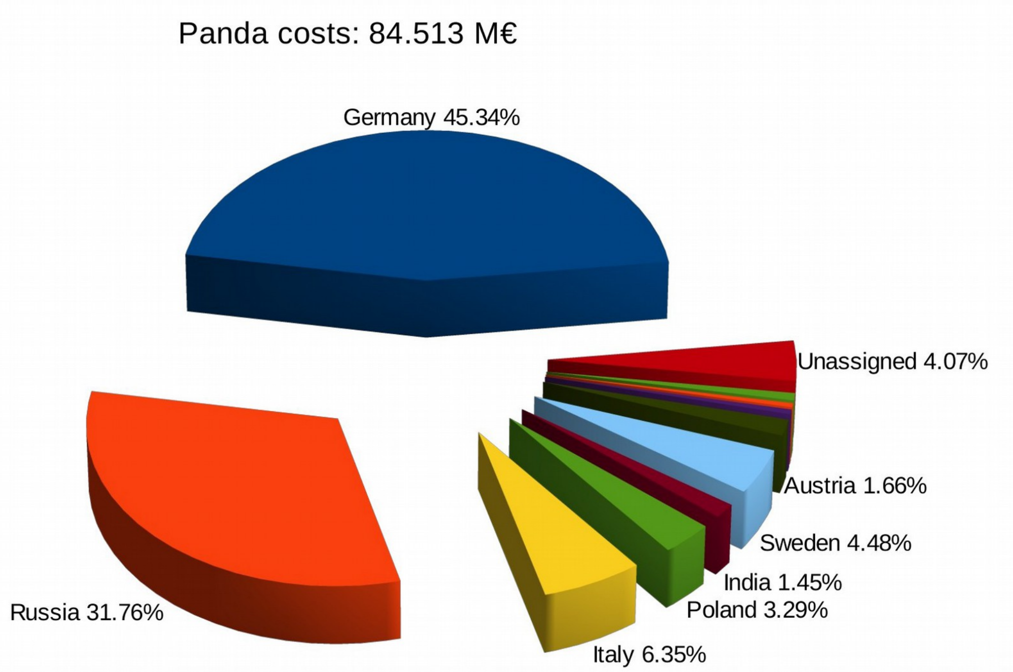
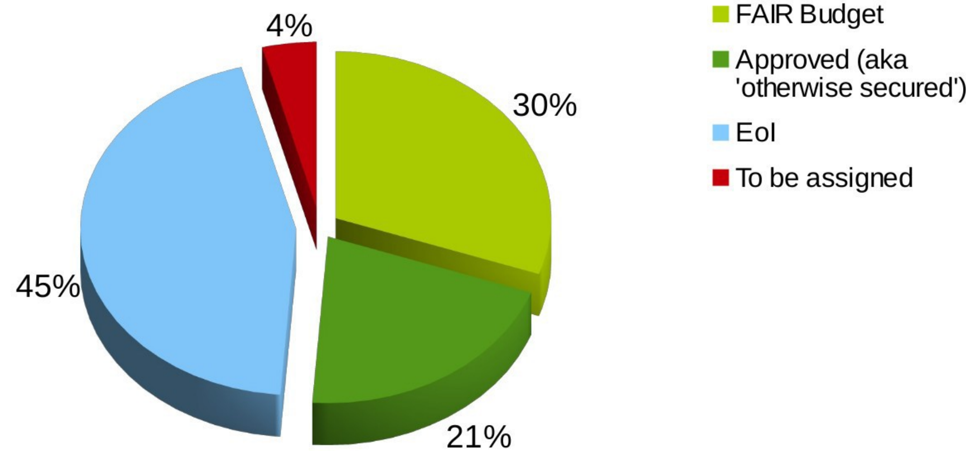
Hypernuclei Secondary Active Target								
Silicon Lambda Disks								
Forward RICH								

Pre-assembly, off-site testing, Transport to FAIR, site-acceptance tests, **M10:** Approval for installation
Installation at FAIR, commissioning without beam, **M11:** Ready for beam
Commissioning with beam, **M12:** Ready for operations
Magnet field mapping

Subject to change due to funding and civil construction

PANDA Funding





PANDA Systems

Subsystem		2014				2015				2016				2017				2018				2019				2020			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Pellet Target									M3						0				M11										
Cluster Jet Target	M3							M8						M10		M11													
Micro Vertex Detector (MVD)										M7			M4/8								M9/10	M11	M12						
Straw Tube Tracker (STT)										M8								M9	M10	M11	M12								
Planar GEM Trackers										M8								M10			M11								
Silicon Lambda Disks																													
Barrel DIRC																						M10		M11	M12				
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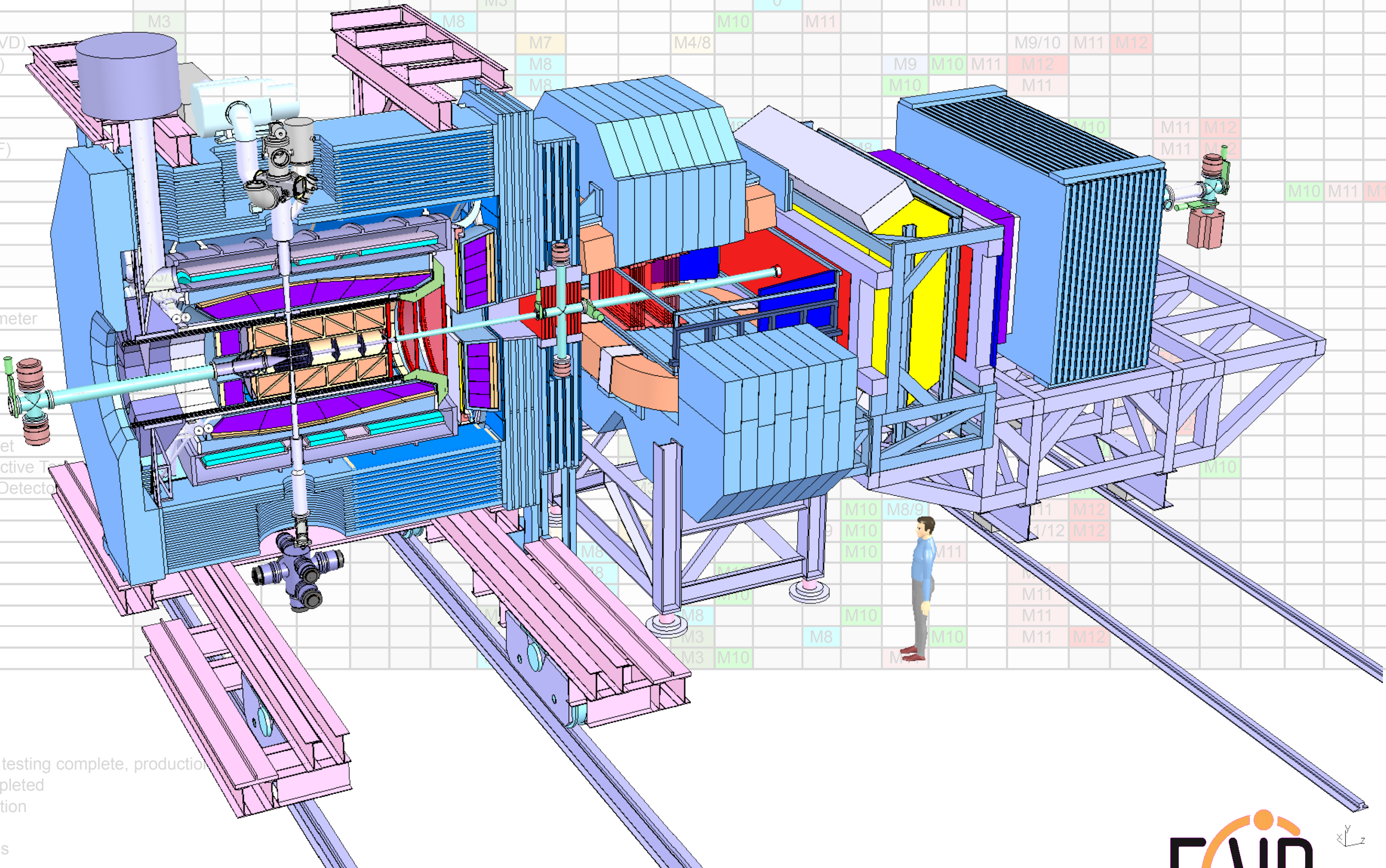

M3: TDR approved
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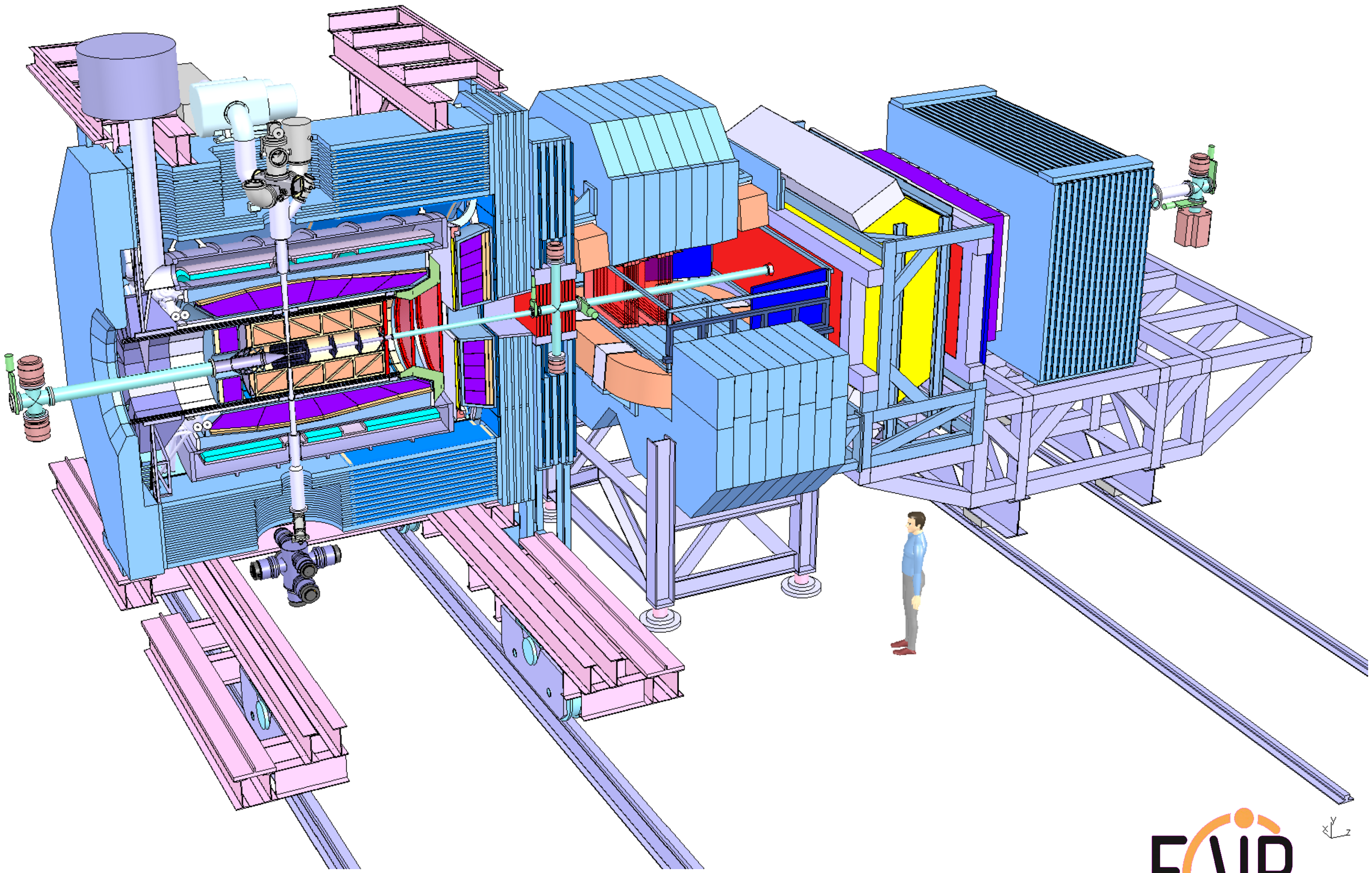
Approved Systems

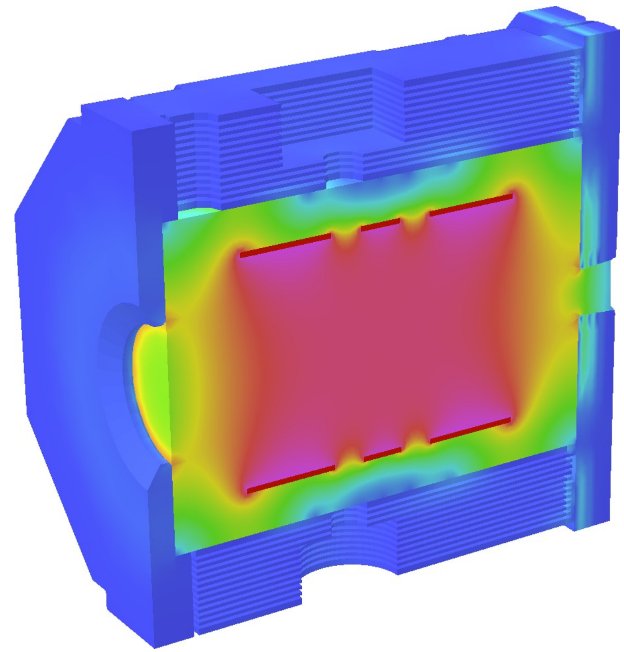


Magnets

Solenoid Magnet

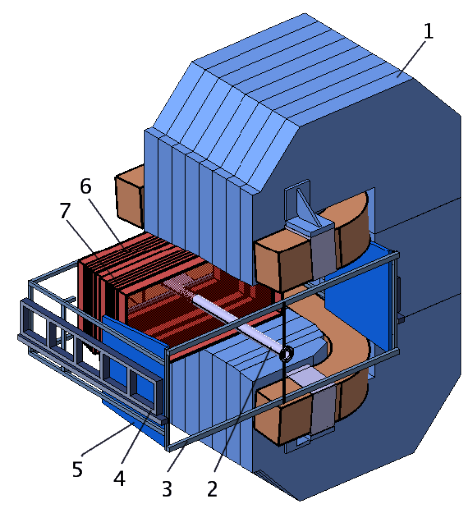
- Super conducting coil
- 2 T central field
- Segmented coil for target
- Instrumented iron yoke
- Doors for installation and maintenance
- ***Status:***

  - Cooperation with CERN for cold mass
  - Conductor optimized, close to tender
  - Yoke design complete
- Time critical !



Dipole Magnet

- Normal conducting racetrack design
- Dipole also bends the beam
- Segmented yoke for ramping



PANDA Target

Luminosity Considerations

- Goal: 2×10^{32} cm^{-2}s^{-1} (HL mode)
- With 10^{11} stored $\bar{p}$ and 50 mb: 4×10^{15} cm^{-2} target density

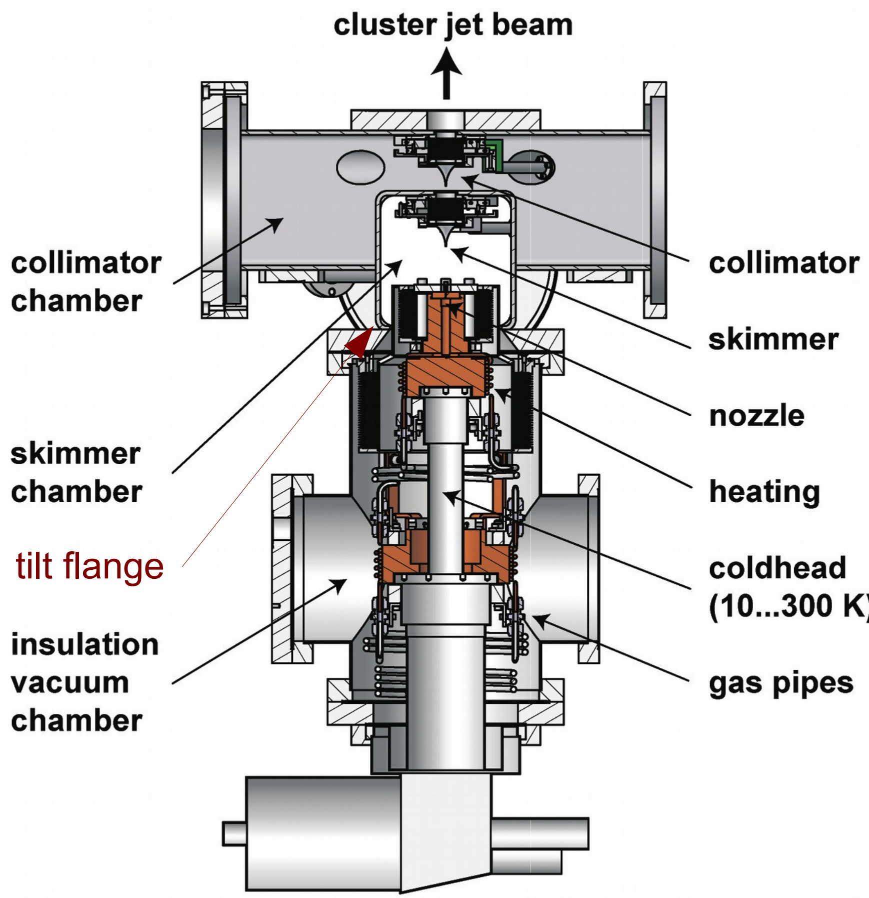
Cluster Jet Target

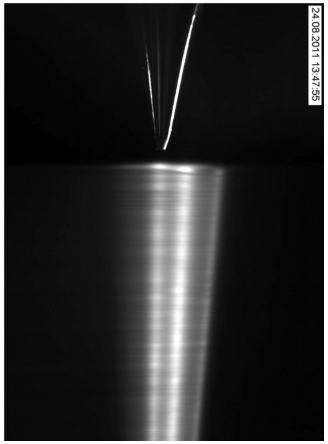
- Continuous development
  - Nozzle improvement
  - Better alignment by tilt device
  - Record 2×10^{15} cm^{-2} reached
- TDR approved

Pellet Target

- $>4 \times 10^{15}$ cm^{-2} feasible
- Prototype under way
- Pellet tracking prototype
- Second TDR part 2015/16

Latest version of the cluster jet target

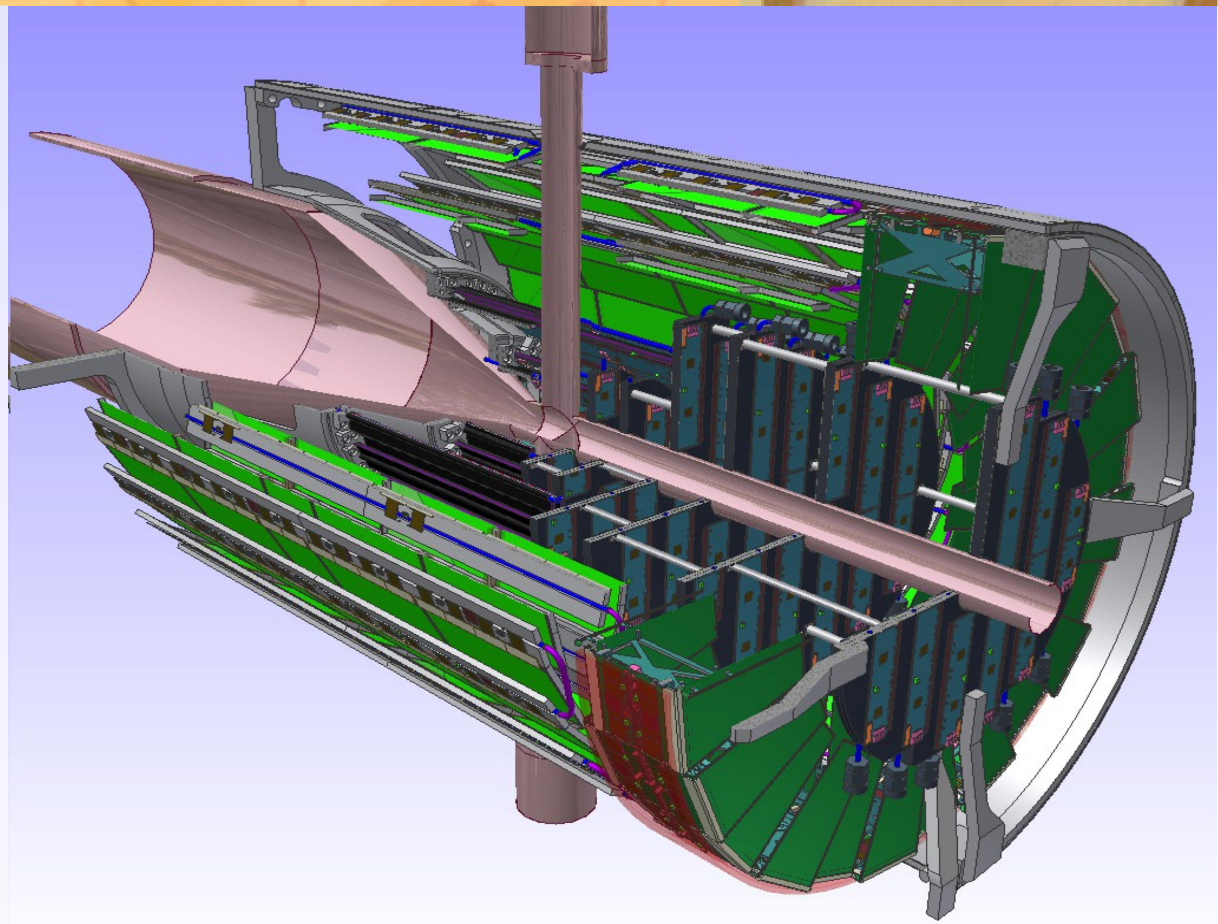




Micro Vertex Detector

Design of the MVD

- 4 barrels and 6 disks
- Continuous readout
- *Inner layers*: hybrid pixels (100x100 μm^2)
  - *ToPiX* chip, 0.13μm CMOS
  - Thinned sensor wafers
- *Outer layers*: double sided strips
  - Rectangles & trapezoids
  - 64 ch ASIC *PASTA*
- Mixed forward disks (pixel/strips)



Challenges

- Low mass supports
- Cooling in a small volume
- Radiation tolerance

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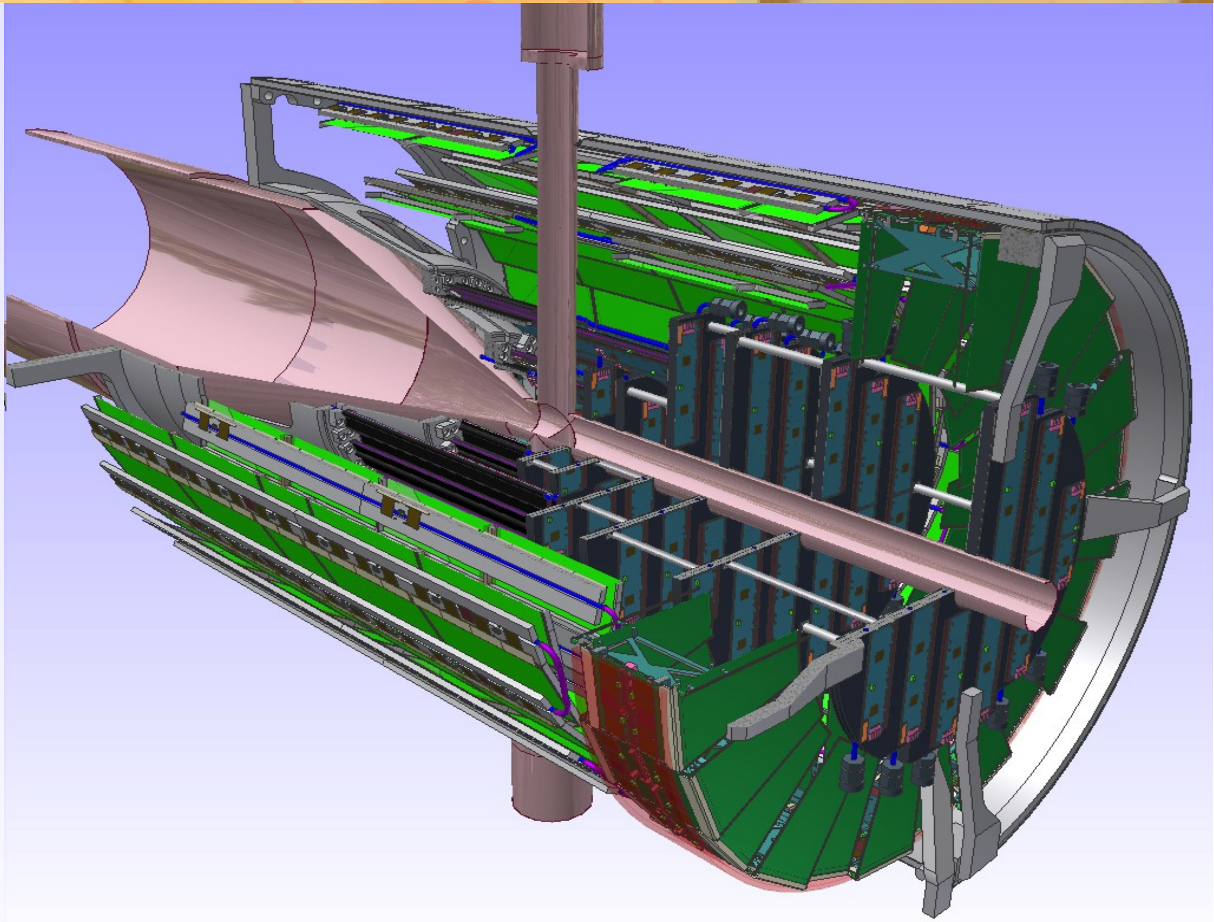


- ToPiX full version in 2015
- PASTA ASIC in 2015
- Detailed service planning

The Straw Tube Tracker

Detector Layout

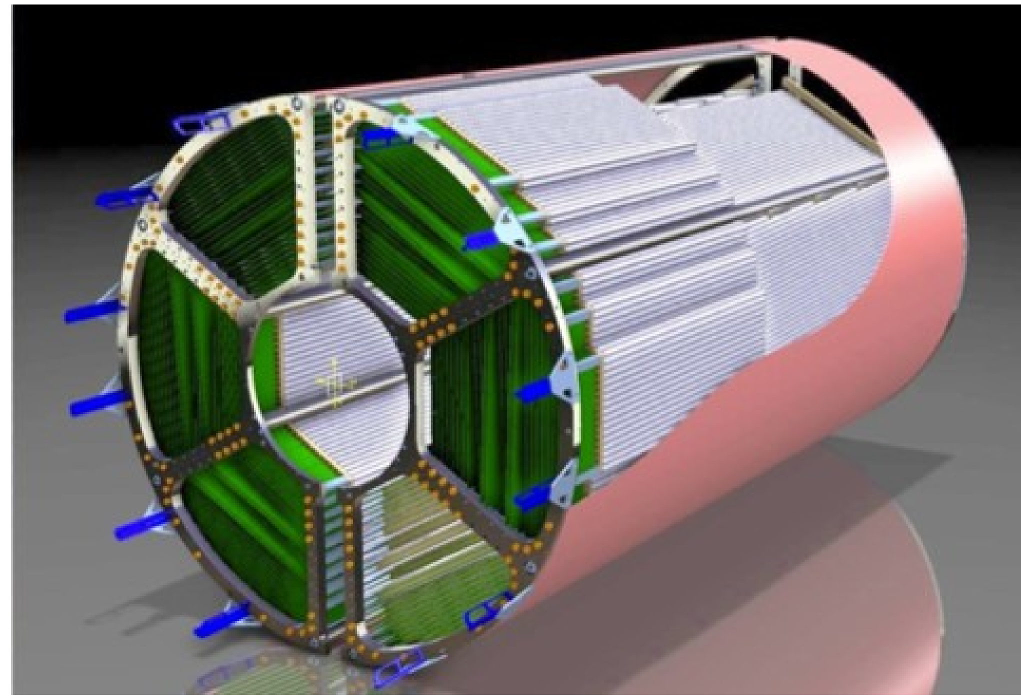
- 4600 straws in 21-27 layers, of which 8 layers skewed at ~3°
- Tube made of 27 µm thin Al-mylar, Ø=1cm
- R_{in}= 150 mm, R_{out}= 420 mm, l=1500 mm
- Self-supporting straw double layers at ~1 bar overpressure (Ar/CO_2)
- Readout with ASIC+TDC or FADC

Material Budget

- Max. 26 layers,
- 0.05 % X/X_0 per layer
- Total 1.3% X/X_0

Project Status

- Prototype construction & beam tests
- Aging tests: up to 1.2 C/cm^2
- Straw series production started



Electromagnetic Calorimeters

$\overline{\text{P}}$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
- Delivery of crystals 54%

Large Area APDs

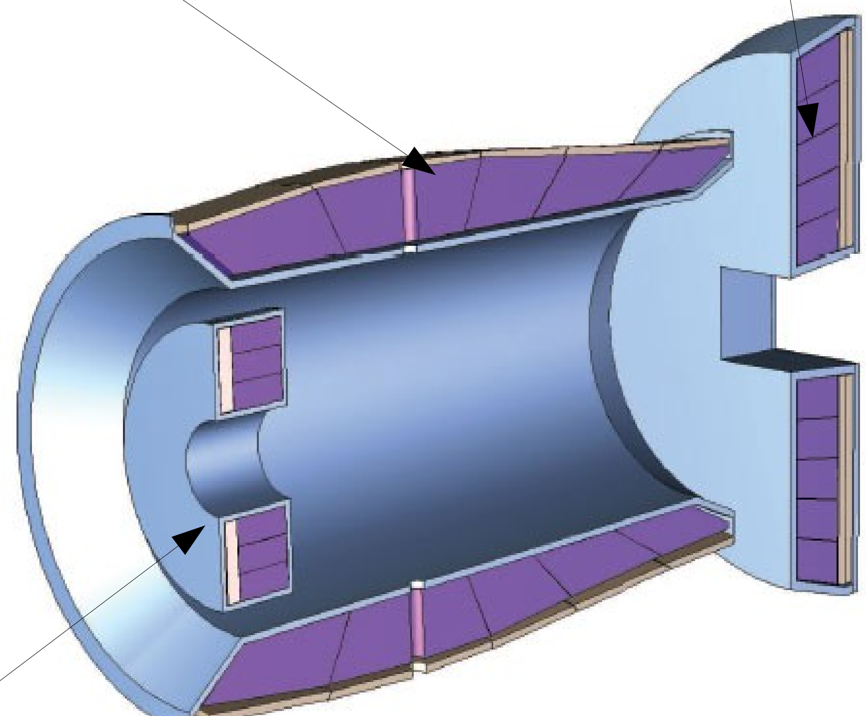
5x5 mm² 10x10 mm² and 7x14 mm²

Barrel Calorimeter

- 11000 PWO Crystals
- LAAPD readout, 2x1cm²
- σ(E)/E~1.5%/√E + const.

Forward Endcap

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



Backward Endcap for hermeticity, 530 PWO crystals

Electromagnetic Calorimeters

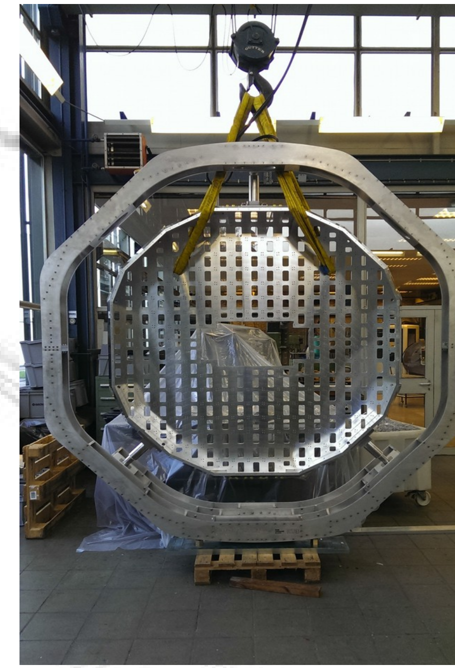
PWO Crystal Production
- 2 new producers: SICCAS & Crytur
- 54% of crystals produced
- EoI to fund remaining crystals

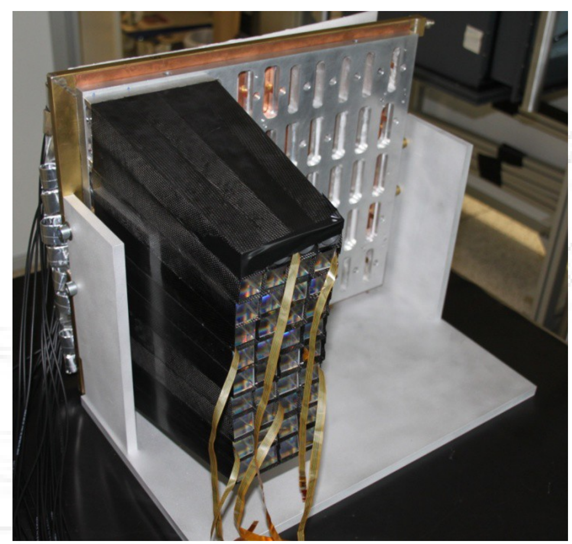
APD Screening
- Screening of 30000 APDs at GSI
- Facility started shift operation

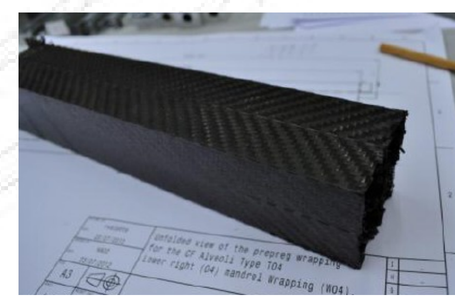
Barrel
- Mechanics design being finalised
- APD readout ASIC characterisation

Backward Endcap
- Prototyping advanced
- Mech design being finalised

Forward Endcap
- Support frame done
- Module production commencing







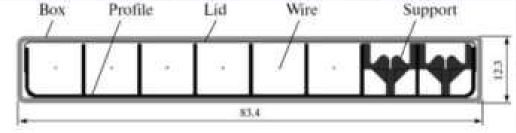
Muon Detector System

Muon system rationale:

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

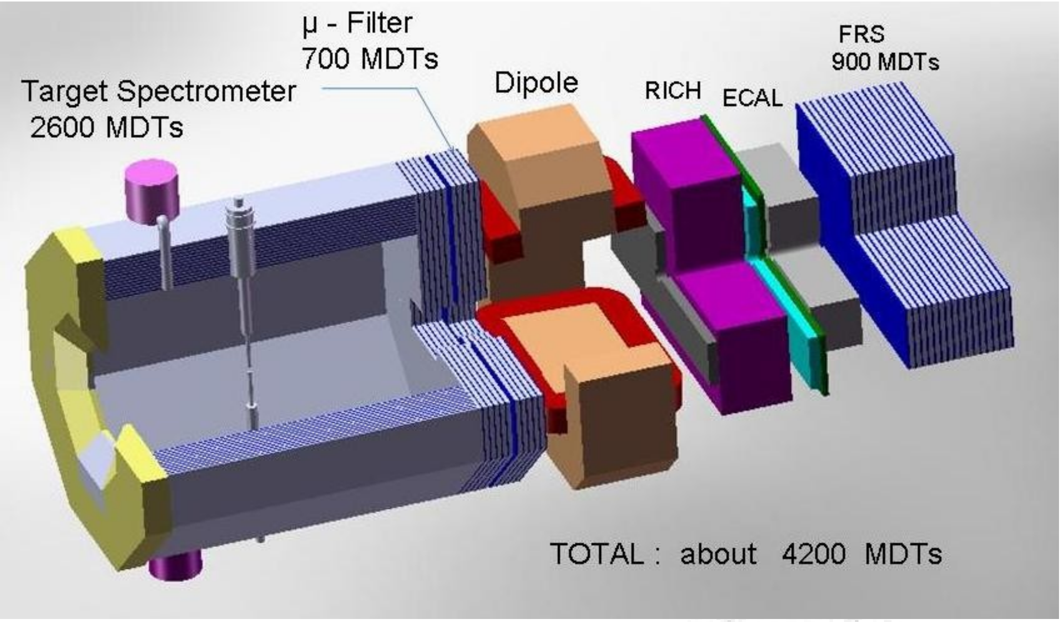
Muon system layout:

- *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

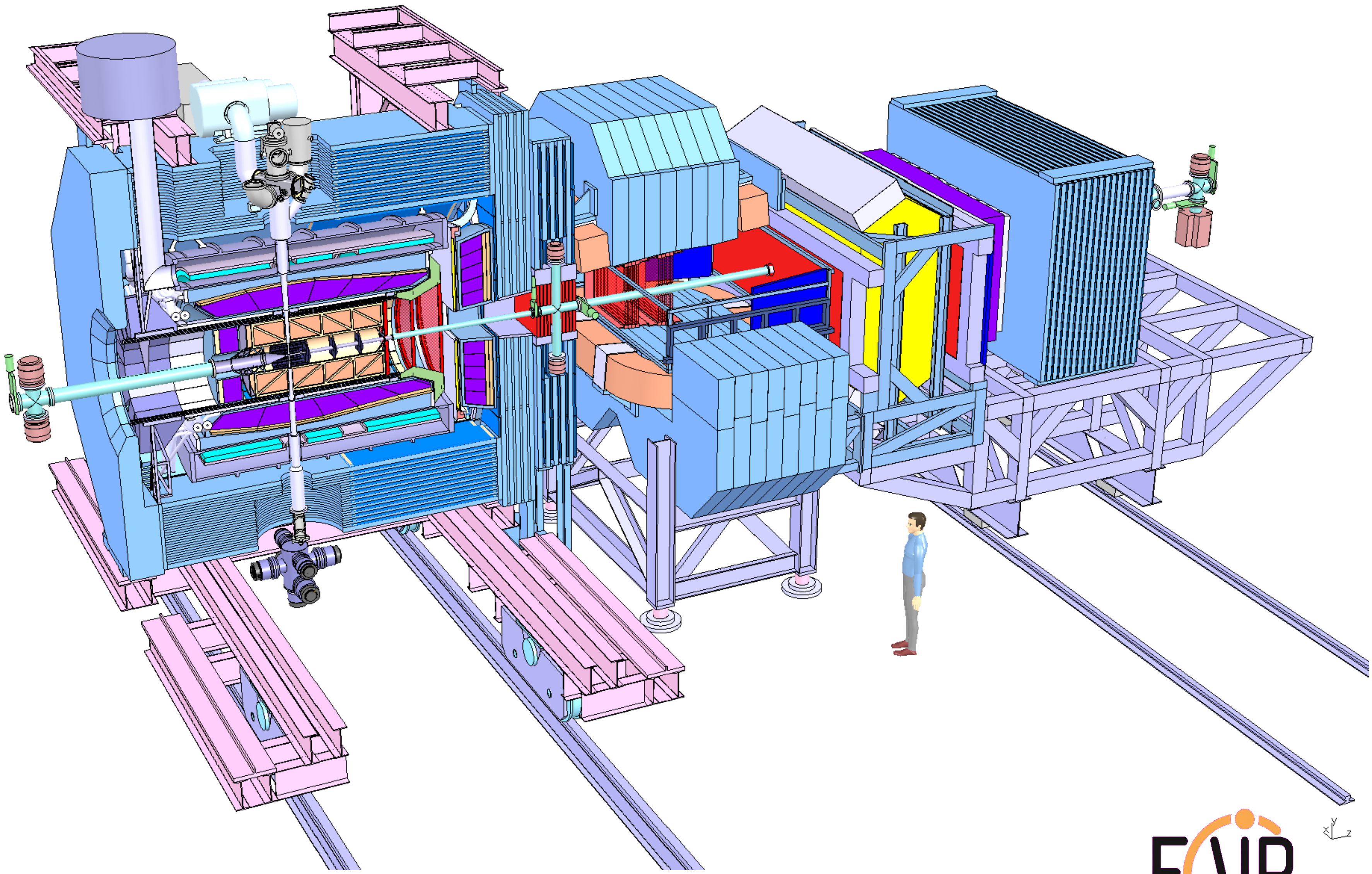


System status

- TDR approved Sep 2014
- Range system tests at CERN



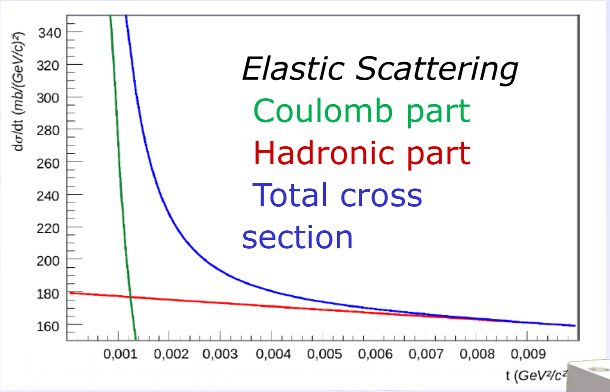
Imminent TDRs: 2015



Luminosity Detector

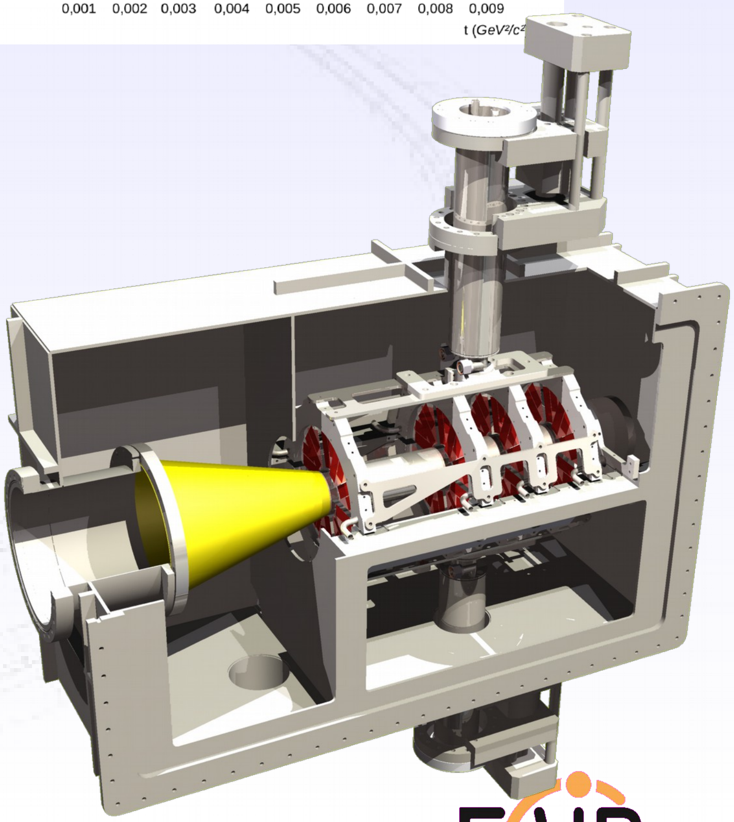
Elastic scattering:

- Coulomb part calculable
- Scattering of $\bar{p}$ at low t
- Precision tracking of scattered $\bar{p}$
- Acceptance 3-8 mrad

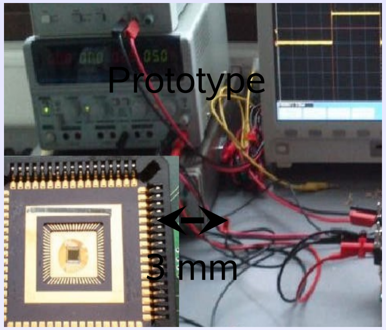


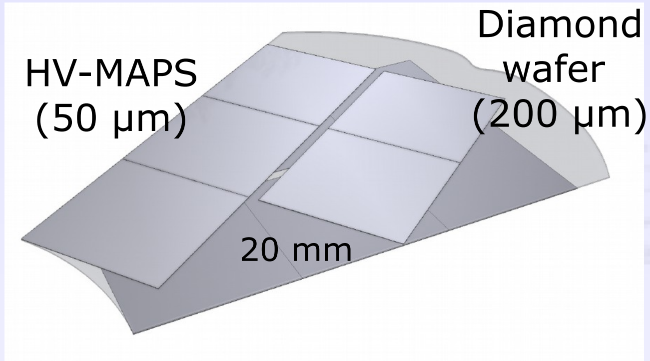
Detector layout:

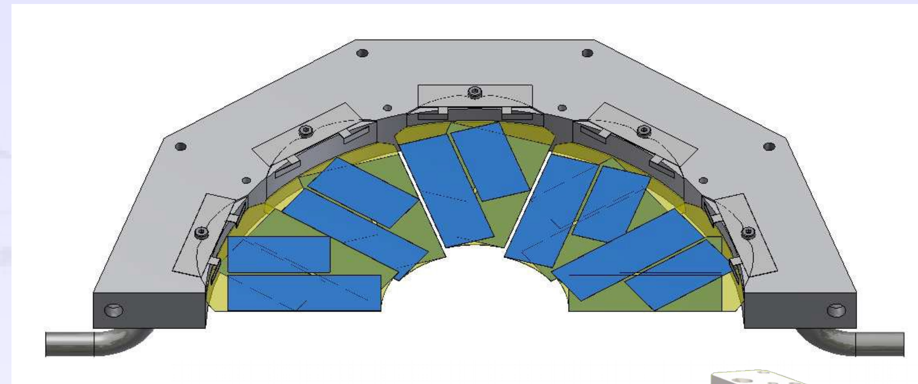
- Roman pot system at z=11 m
- Silicon pixel detector:
  - 4 layers of HV MAPS (50 μm thick)
  - pixels 80x80 μm^2
- CVD diamond supports (200 μm)
- Retractable half planes in secondary vacuum



Luminosity Detector

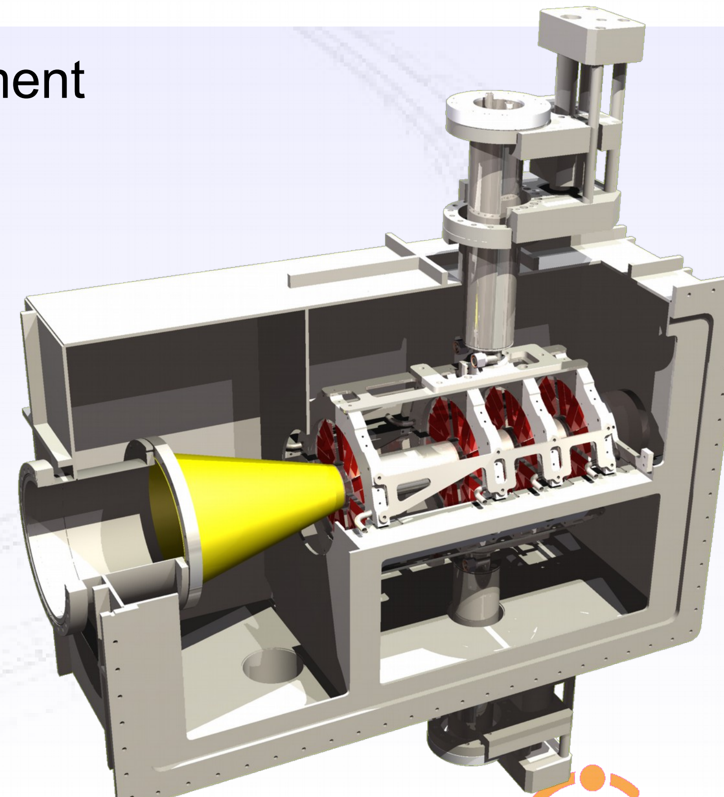






HV MAPS:

- Development at U Heidelberg for Mu2e Experiment
- Active pixel sensor in HV CMOS
- Digital processing on chip
- Testbeam results: S/N ~ 20, Efficiency ~99.5%



Project status:

- Cooling system prototype tested
- Mechanical vessel and vacuum system prototype tested
- CVD diamond supports available
- TDR in final stage

Forward Shashlyk Calorimeter

Forward electromagnetic calorimeter:

- Interleaved scintillator and absorber
- WLS fibres for light collection
- PMTs for photon readout
- FADCs for digitization
- Active area size 297x154 cm^2

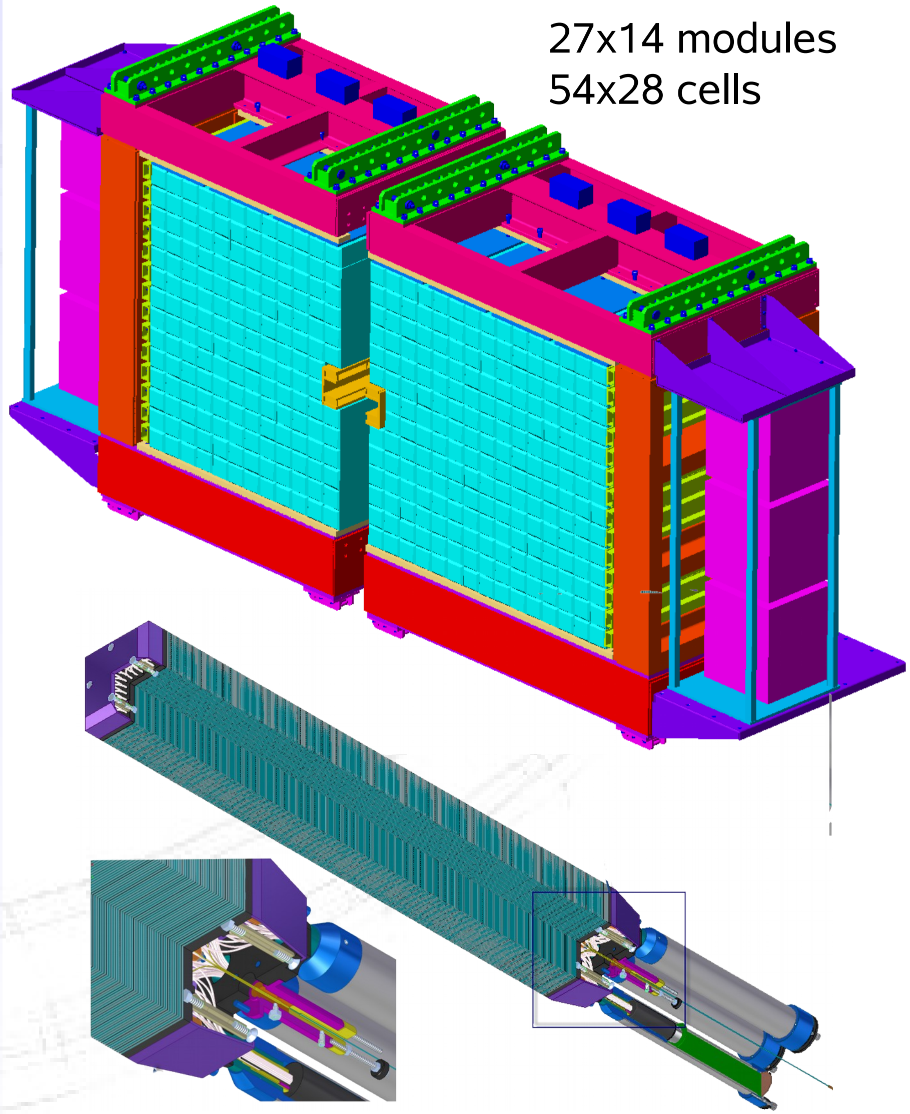
System status:

- Module design 2x2 cells of 5.5x5.5 cm^2 verified
- Tests with electrons and tagged photons:
- ➔ **Energy resolution:**

  $\sigma_E / E = 5.6/E \oplus 2.4/\sqrt{E}\ [GeV] \oplus 1.3\ [\%]$
  (1-19 GeV e-)

  $\sigma_E / E = 3.7/\sqrt{E}\ [GeV] \oplus 4.3\ [\%]$
  (50-400 MeV ph)

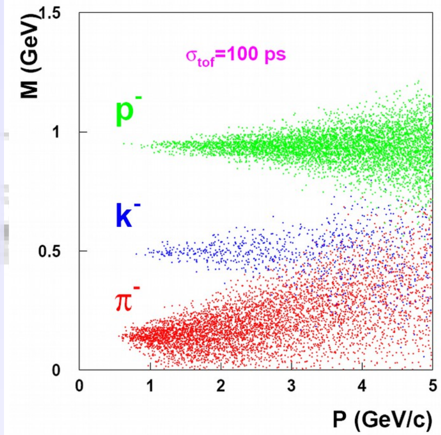
- **Time resolution:** 100 ps/$\sqrt{E}$ [GeV]



Forward Time of Flight

Forward Spectrometer PID

- Time-of-Flight essential
- No start detector
- Relative timing to Barrel

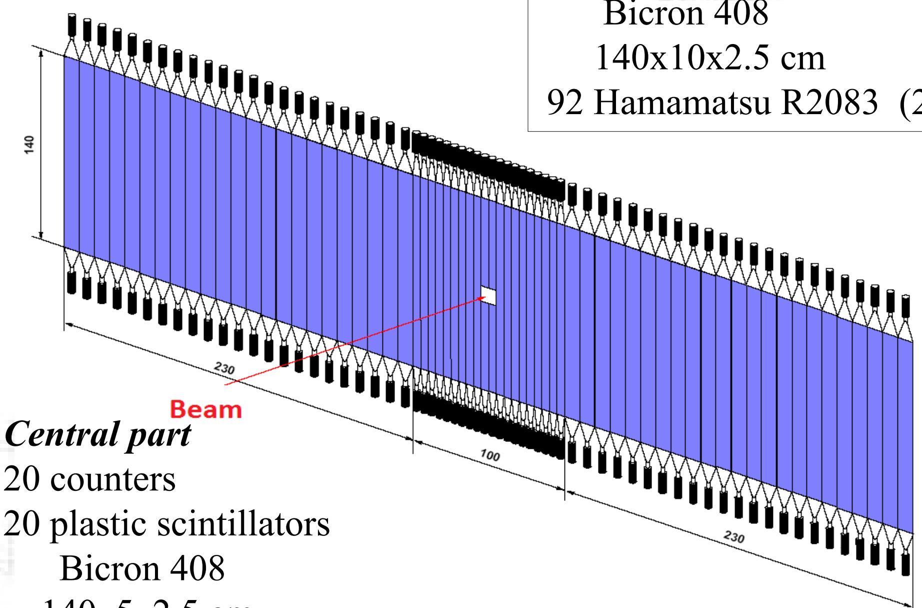


Goal: Time-of-flight with σ(t) better than 100 ps

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
- TDC readout
- **Additionally:** Side walls inside dipole for low momentum tracks

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



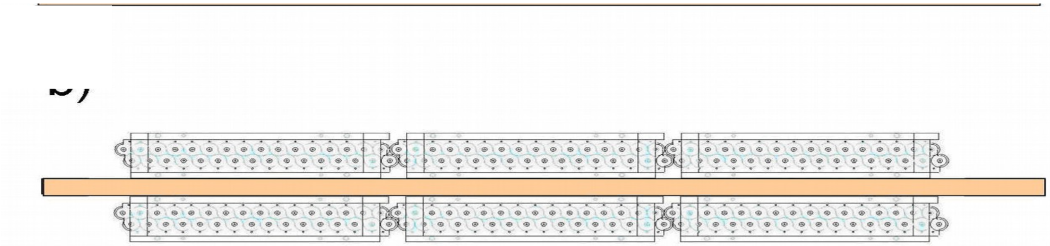
Central part
20 counters
20 plastic scintillators
Bicron 408
140x5x2.5 cm
40 Hamamatsu R4998 (1")

Forward Tracking

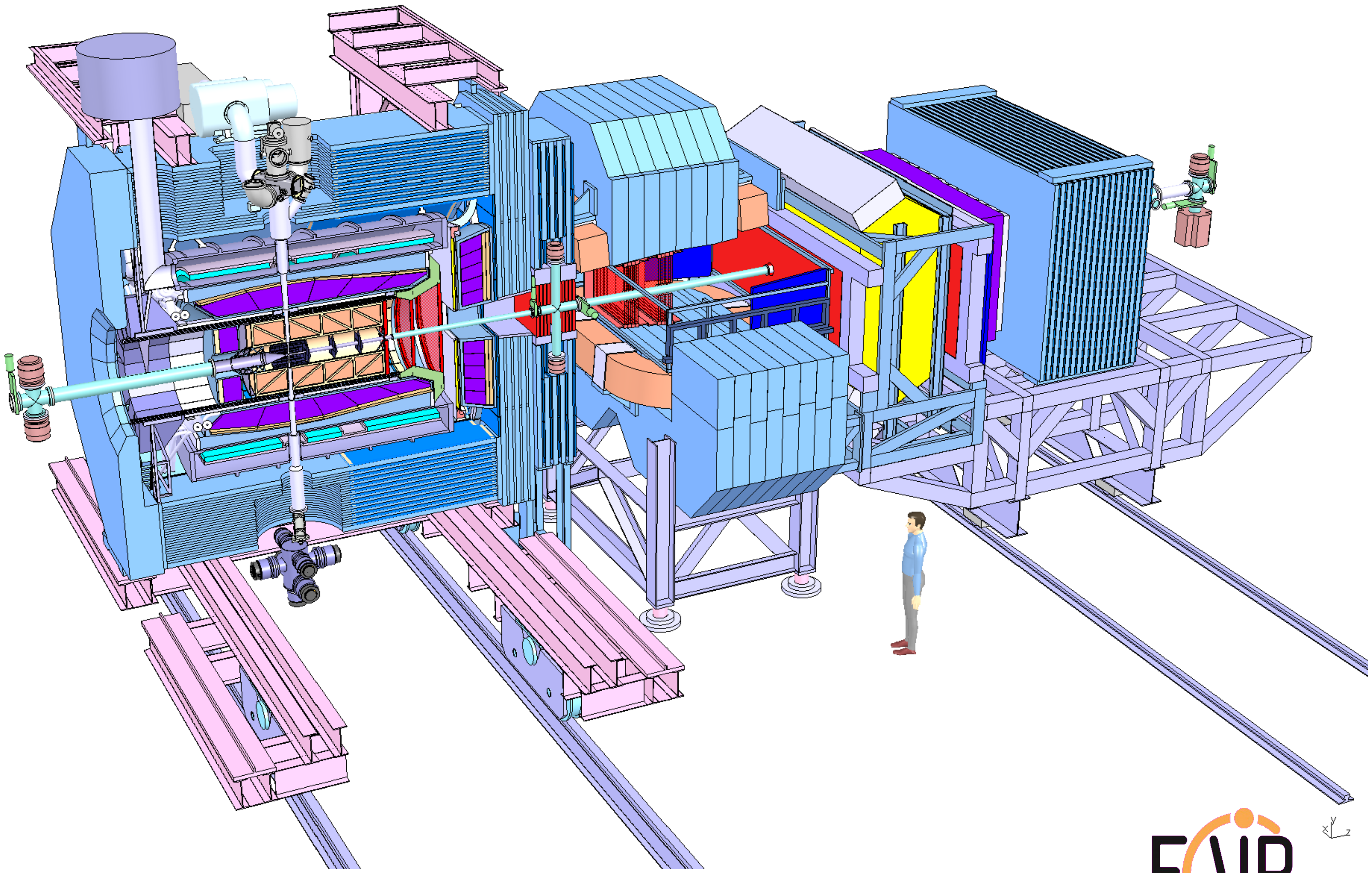
Tracking in Forward Spectrometer

- 3 stations with 2 chambers each
  - FT1&2 : between solenoid and dipole
  - FT3&4 : in the dipole gap
  - FT5&6 : largest chambers behind dipole
- Straw tubes arranged in double layers
  - 27 μm thin mylar tubes, 1 cm Ø
  - Stability by 1 bar overpressure
- 3 projections per chamber (0°, ±5°)

Modular layout of straws



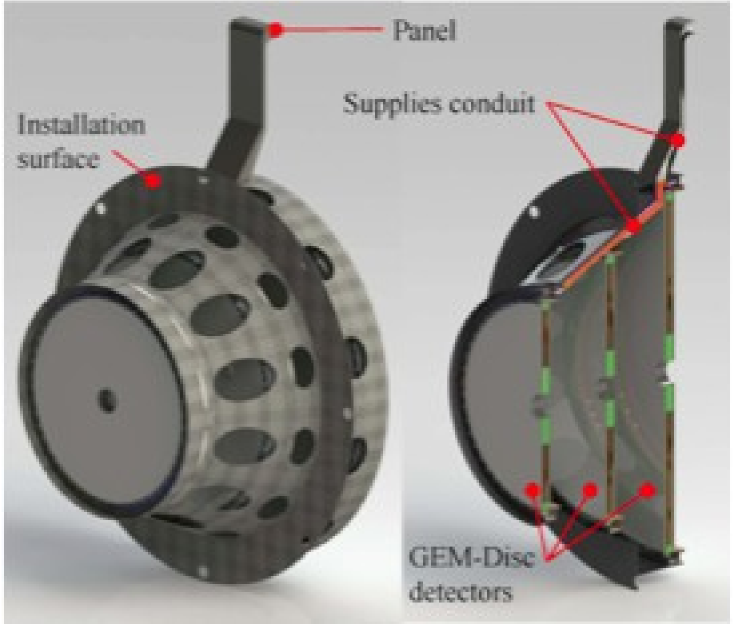
Further Systems: 2016+

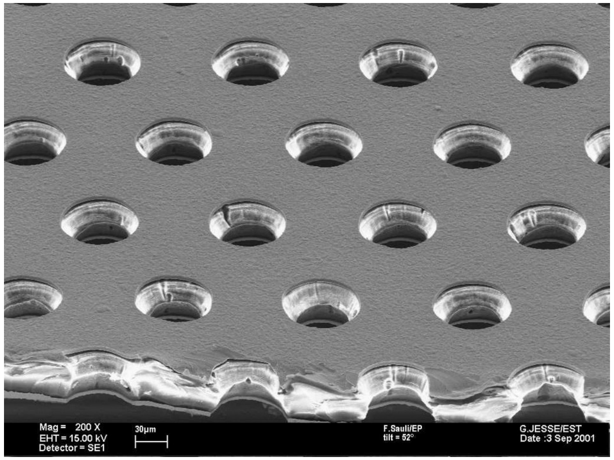


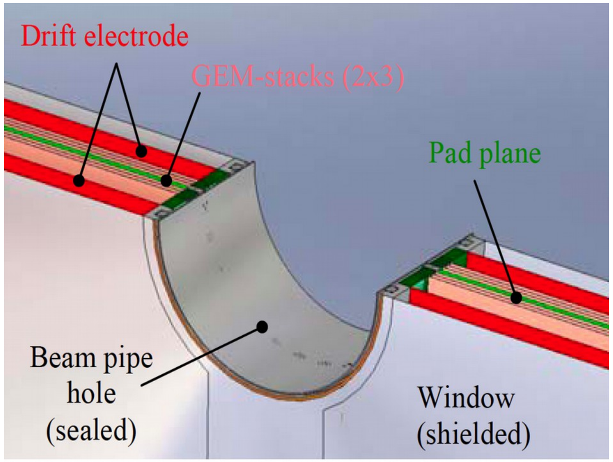
Forward GEM Tracker

Forward Tracking inside Solenoid

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







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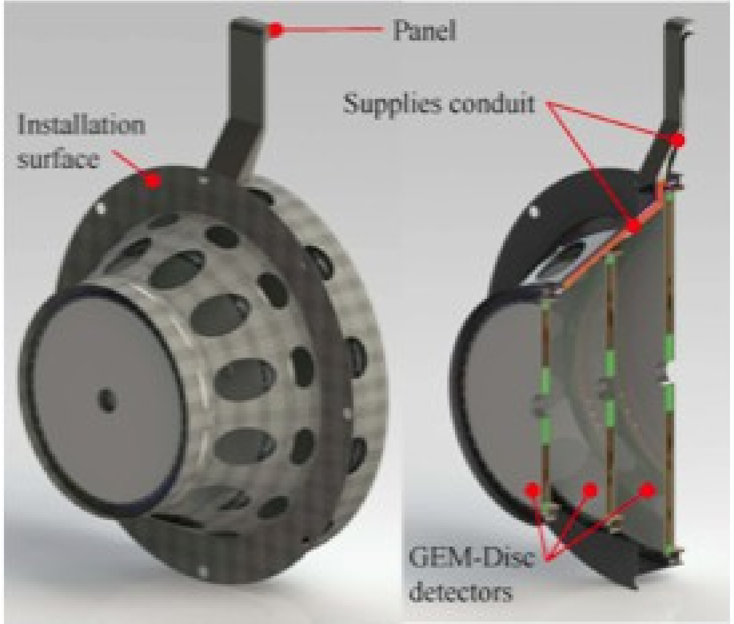
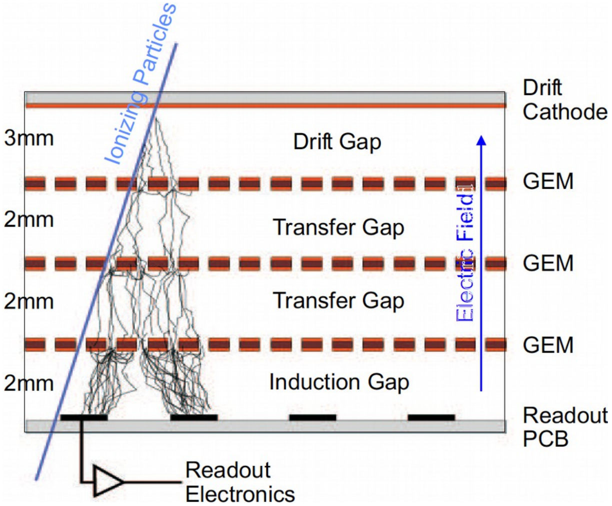
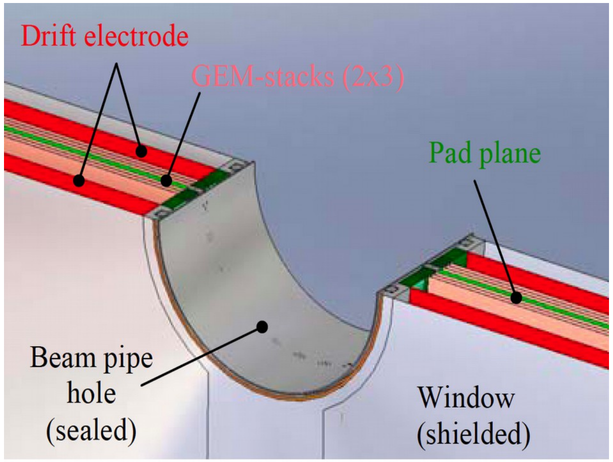






PANDA Barrel DIRC

Baseline design

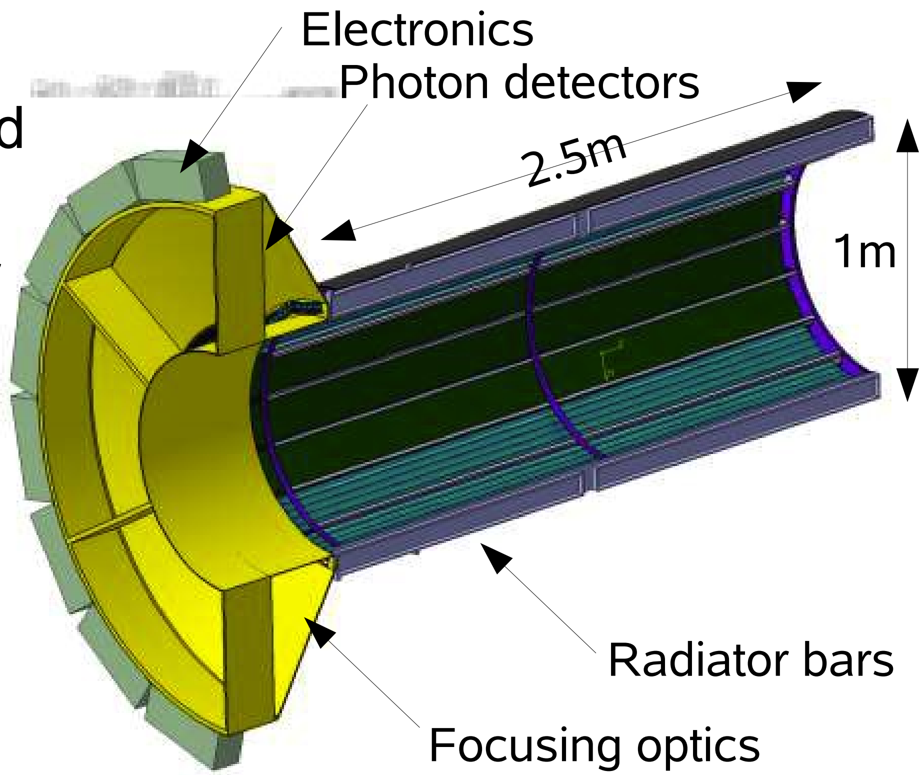
- DIRC: Detection of Internally Reflected Cherenkov light pioneered by BaBar
- Cherenkov detector with SiO_2 radiator
- Detected patterns give β of particles

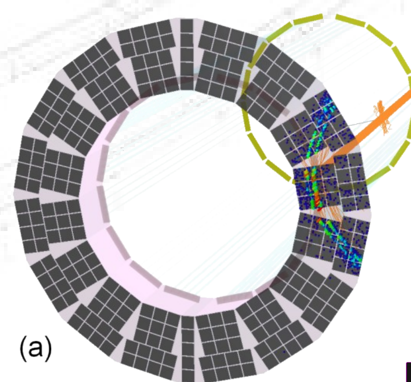
Optimization and challenges

- Focusing by lenses/mirrors
- More compact design
- Magnetic field → MCP PMT
- Fast readout to suppress BG
- Plates as more economic radiator

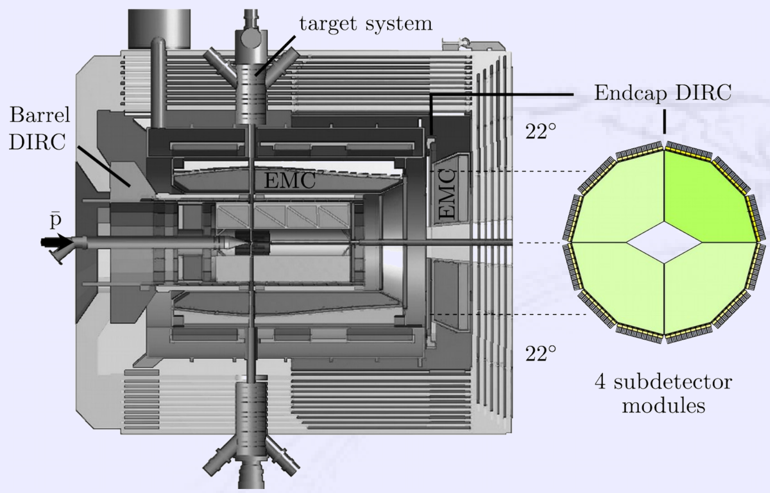
Project status

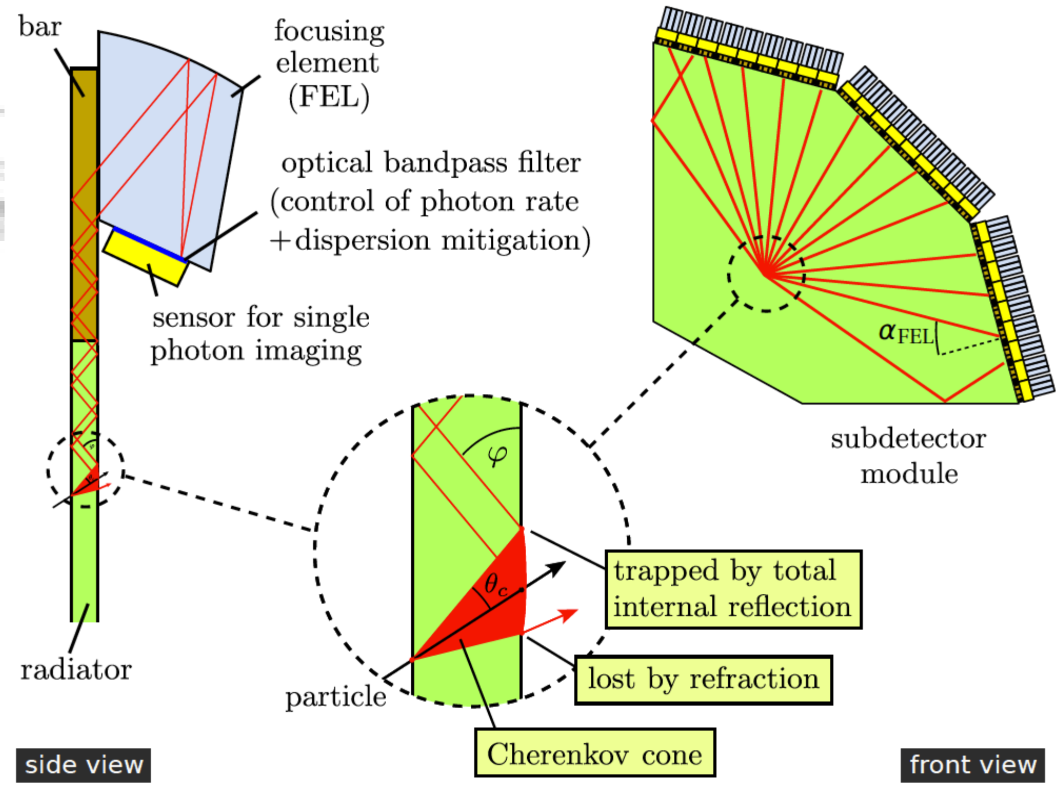
- Baseline design verified
- Qualification of final design in 2015





$\overline{\mathrm{P}}$ANDA Disc DIRC





Novel concept for forward PID

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

Project status:

- Advanced design, first tests
- Review with external experts
- Next: full quarter disc prototype

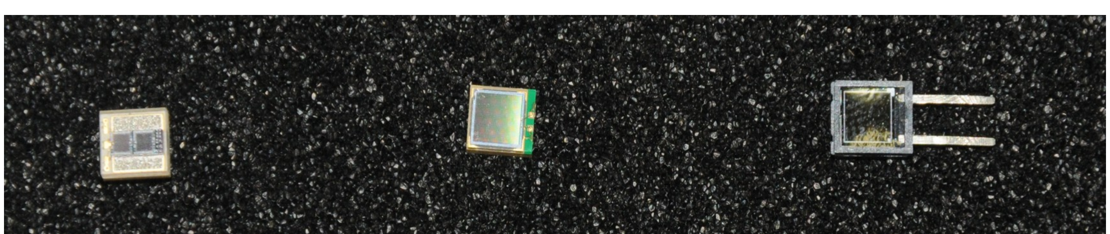
Basic components:

- SiO_2 radiator disc
- Focusing element
- Optical bandpass filter
- MCP PMT for photon readout in magnetic field
- ASIC for electronic readout

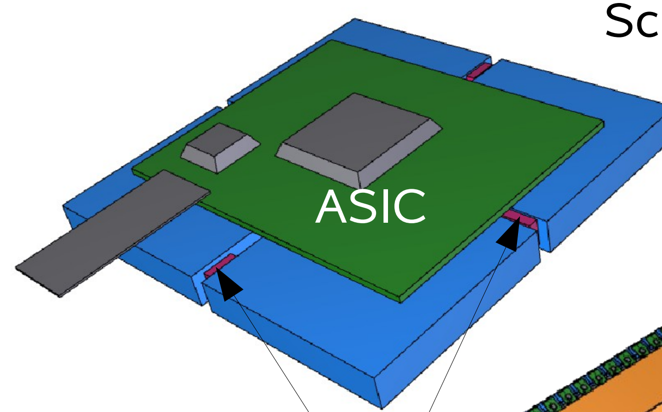
Scintillator Tile Hodoscope

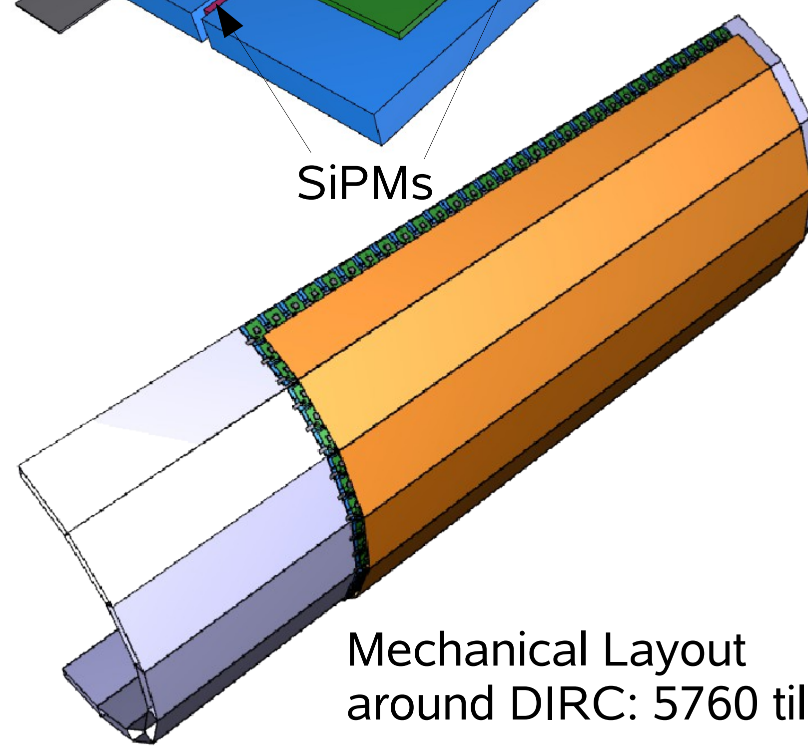
Detector for ToF and event timing

- Scintillator tiles 3x3x0.5 cm^3
  - BC404, BC408 or BC420
  - Space points with precision timing
  - Lowest possible material budget
- Photon readout with 2 SiPMs (3x3 mm^2)
  - High PDE, time resolution, rate capability
  - Work in B-fields, small, robust, low bias
  - *High intrinsic noise*
  - *Temperature dependence*
- Goal for time resolution: 100 ps
- ASIC for SiPM readout



Quad Module



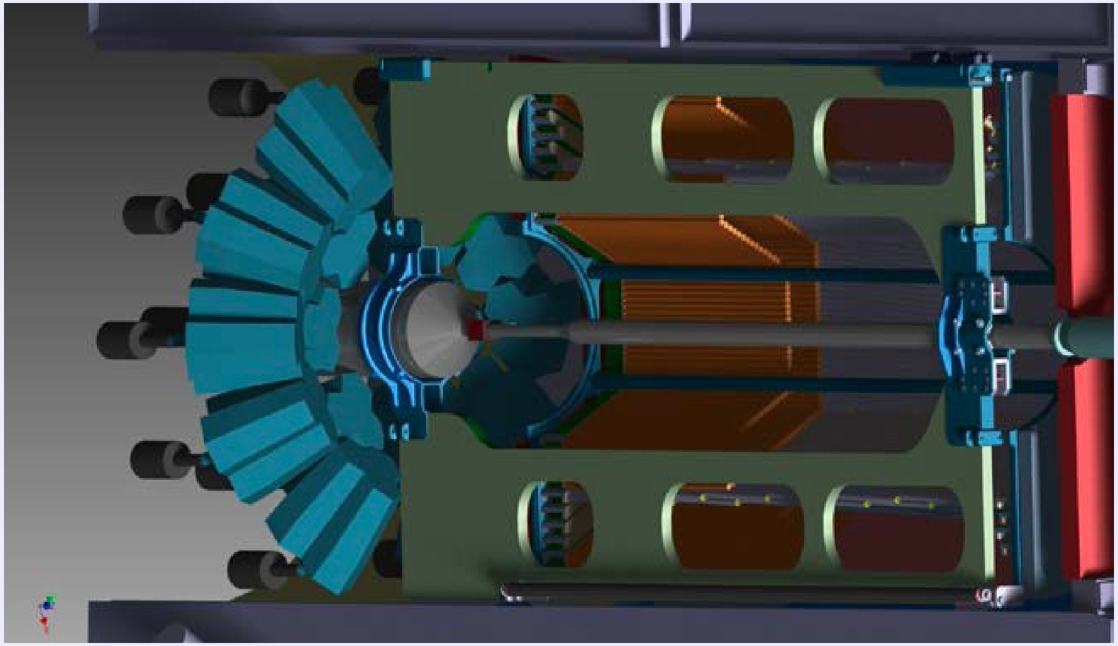


Mechanical Layout around DIRC: 5760 tiles

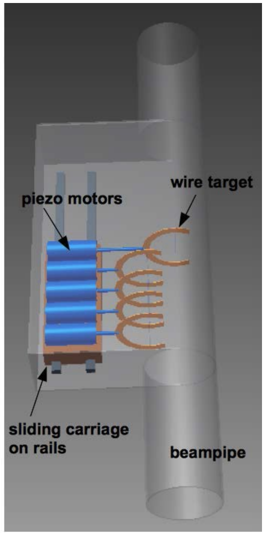
Hypernuclear Setup

Principle:
- Produce hypernuclei from captured Ξ

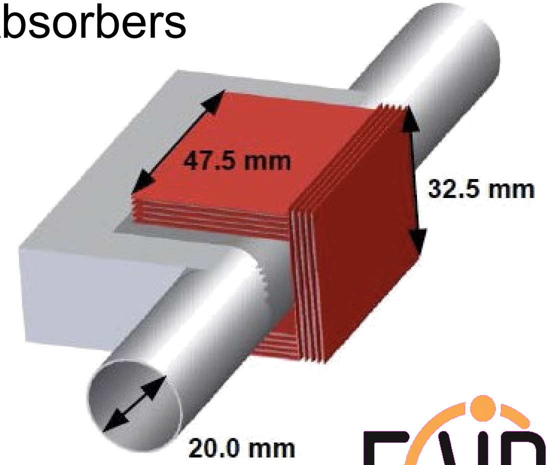
Modified Setup:
- Primary retractable wire/foil target
- Secondary active target to capture Ξ and track products with Si strips
- HP Ge detector for γ-spectroscopy



Primary Target:
- Diamond wire
- Piezo motored wire holder



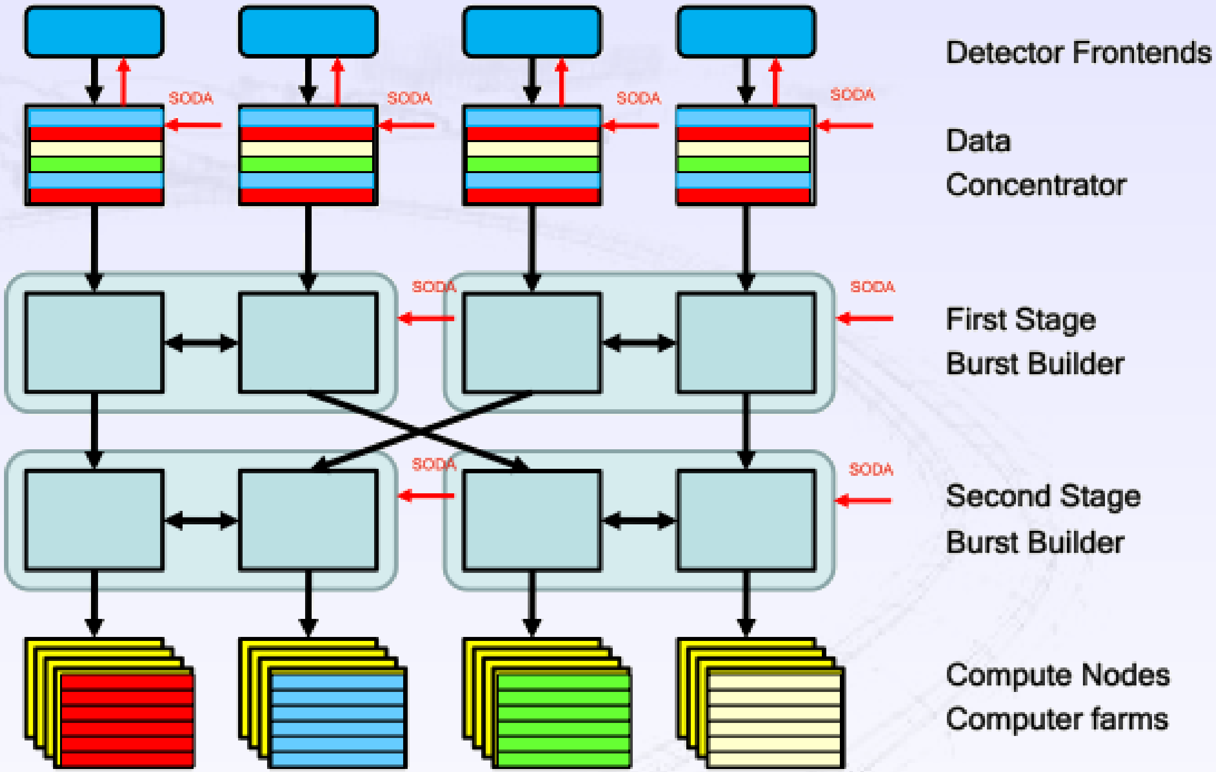
Active Secondary Target:
- Silicon microstrips
- Absorbers



P̄ANDA Data Acquisition

Self triggered readout

- Components:
  - Time distribution system
  - 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**

PANDA TDR Schedule

Submission 2015:

- Q3: Luminosity Detector
- Q3: Forward Shashlyk
- Q3: Forward Time of Flight
- Q4: Forward Tracking
- Q4: Pellet Target Addendum

Submission early 2016:

- GEM Tracker
- Detector Controls

Submission 2016/17:

- Barrel DIRC
- Hypernuclear Setup
- SciTil / Barrel ToF
- DAQ and Computing
- Disc DIRC

Summary

Present Status of PANDA

- Several systems head for TDR submission
- Preparation for Construction MoU
- Physics and detector topics

Timeline of PANDA

- Most TDRs to complete by end 2016
- Start of construction in 2014 for some systems
- Start of possible preassembly at Jülich in 2015
- Ready for mounting at FAIR in 2018/19

PANDA & FAIR start in hadron physics from 2020+

- Versatile physics machine with full detection capabilities
- PANDA will shed light on many of today's QCD puzzles
- Beyond PANDA further plans for spin physics at FAIR exist

The $\overline{\text{P}}$ANDA Collaboration

More than 520 physicists from 68 institutions in 18 countries

Aligarh Muslim University
U Basel
IHEP Beijing
U Bochum
Magadh U, Bodh Gaya
BARC Mumbai
IIT Bombay
U Bonn
IFIN-HH Bucharest
U & INFN Brescia
U & INFN Catania
NIT, Chandigarh
AGH UST Cracow
JU Cracow
U Cracow
IFJ PAN Cracow
GSI Darmstadt

Karnatak U, Dharwad
TU Dresden
JINR Dubna
U Edinburgh
U Erlangen
NWU Evanston
U & INFN Ferrara
FIAS Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Glasgow
U Gießen
Birla IT&S, Goa
KVI Groningen
Sadar Patel U, Gujart
Gauhati U, Guwahati
IIT Guwahati

IIT Indore
Jülich CHP
Saha INP, Kolkata
U Katowice
IMP Lanzhou
INFN Legnaro
U Lund
U Mainz
U Minsk
ITEP Moscow
MPEI Moscow
TU München
U Münster
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TSL Uppsala
U Uppsala
U Valencia
SMI Vienna
SINS Warsaw
TU Warsaw