Conductor and Coil Design of the 2 T Solenoid for the PANDA Detector at FAIR

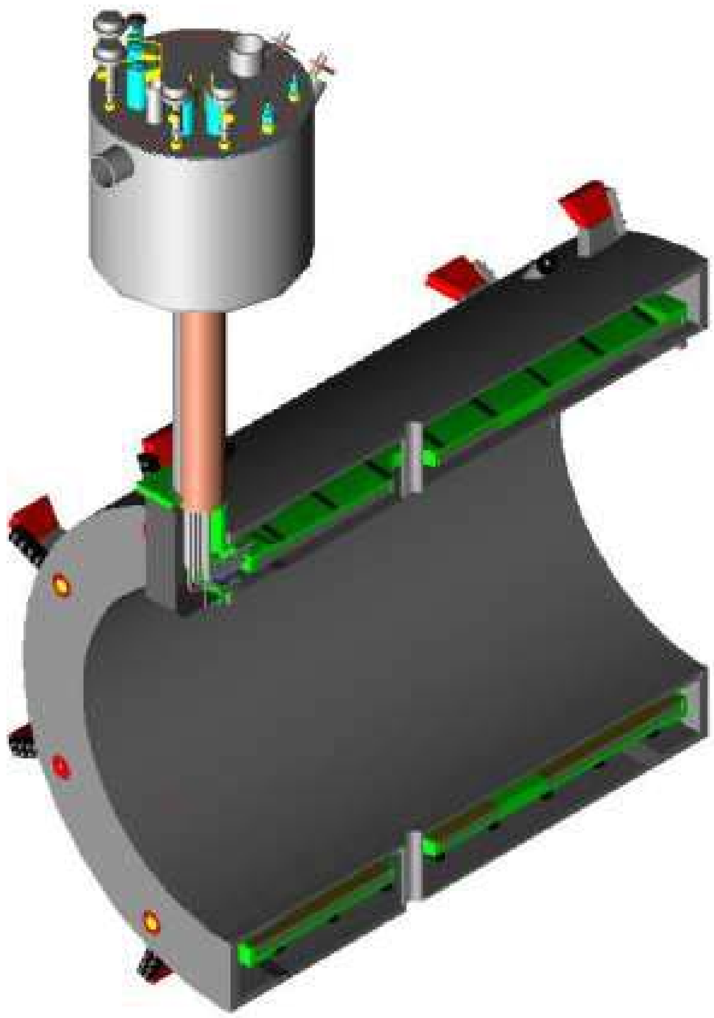
G. Rolando[1], H. H. J. ten Kate[1], A. Dudarev[1]
A. Vodopyanov[2], E. Koshurnikov[2], Y. Lobanov[2], A. Efremov[2], A. Makarov[2]
R. Parodi[3], A. Bersani[3]
J. Luehning[4], H. Orth[4], L. Schmitt[4]

[1] CERN, [2] JINR Dubna, [3] INFN Genoa, [4] GSI

10 Jul 2014

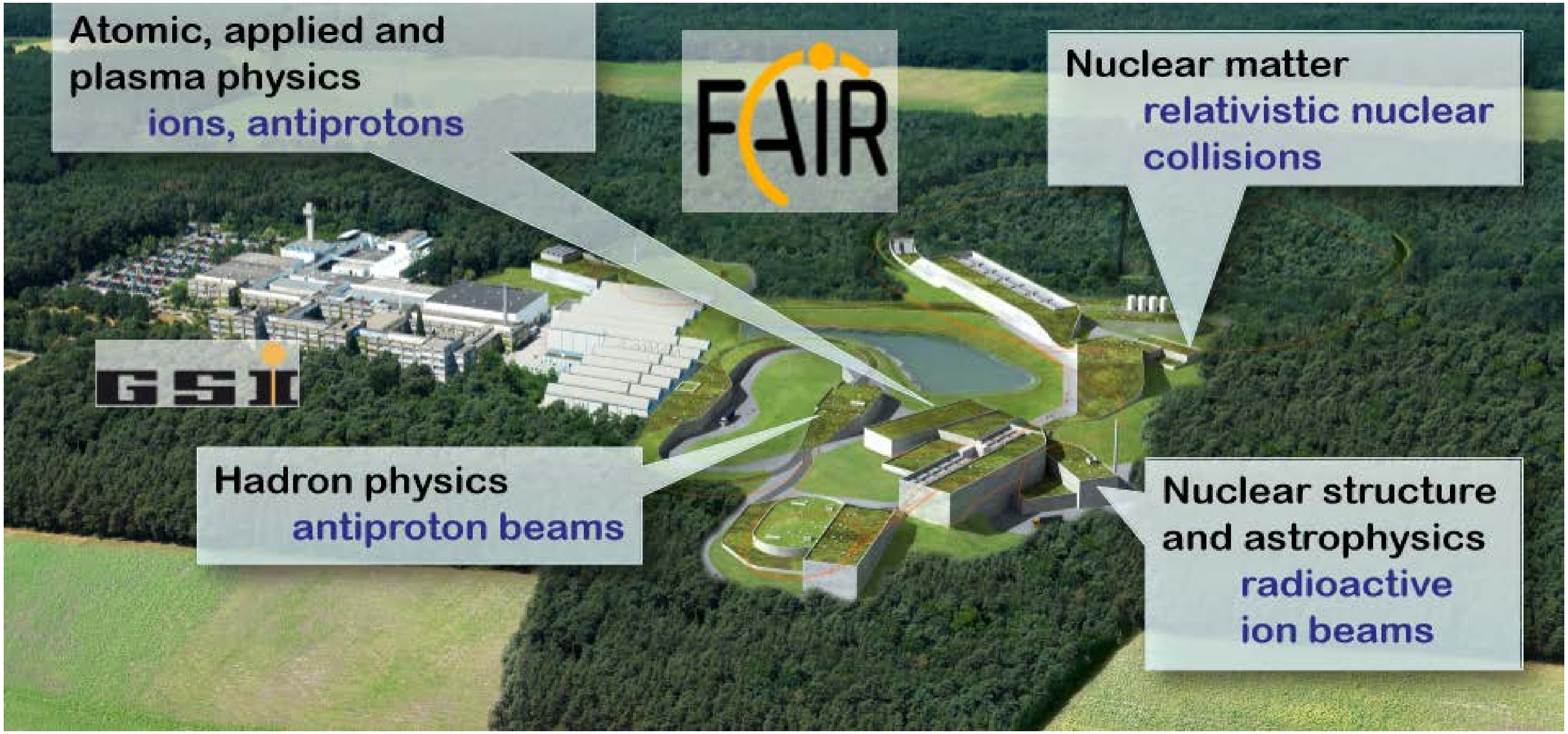
Outline

- ☐ The FAIR facility
- ☐ The PANDA experiment
- ☐ The PANDA detector
- ☐ The Panda solenoid
- ☐ CERN – Panda collaboration
- ☐ Magnet work sharing
- ☐ Time schedule
- ☐ Conductor review
- ☐ Coil design
- ☐ Conclusion and next steps



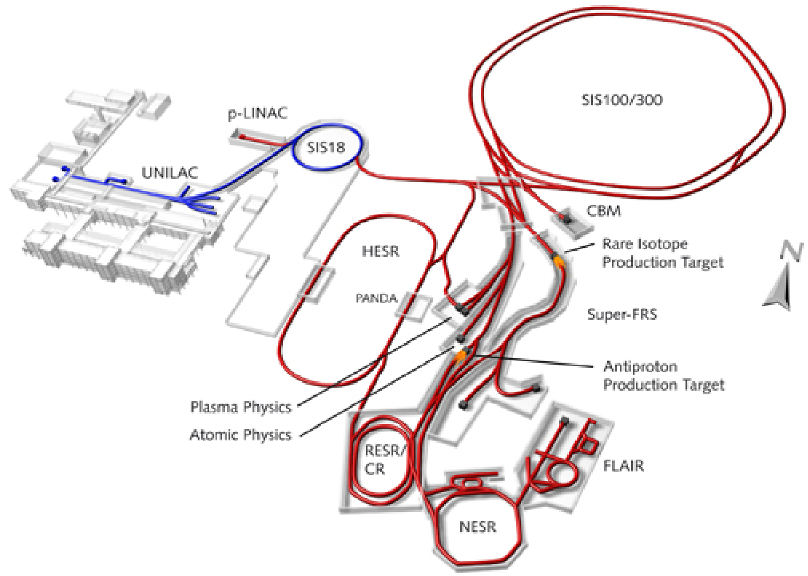
The FAIR Facility

- The Facility for Antiproton and Ion research (**FAIR**) under construction at GSI, Darmstadt (Germany) is one of the largest research project worldwide.
- FAIR will provide antiproton and ion beams with unprecedented intensity and quality do basic research on nuclear, atomic, hadron, plasma physics and astrophysics.



The FAIR Facility

- At the heart of FAIR is a double ring synchrotron of 1100 m circumference.
- Cooler-storage rings for beam cooling at high energies and experimental halls will be connected to the facility.
- The existing GSI accelerators together with the planned proton-linac will serve as injector for the new facility.
- The double-ring synchrotron provides ion beams of unprecedented intensities and energy and unstable nuclei or antiprotons can be produced.
- A parallel operation four scientific programs can be realized at a time.



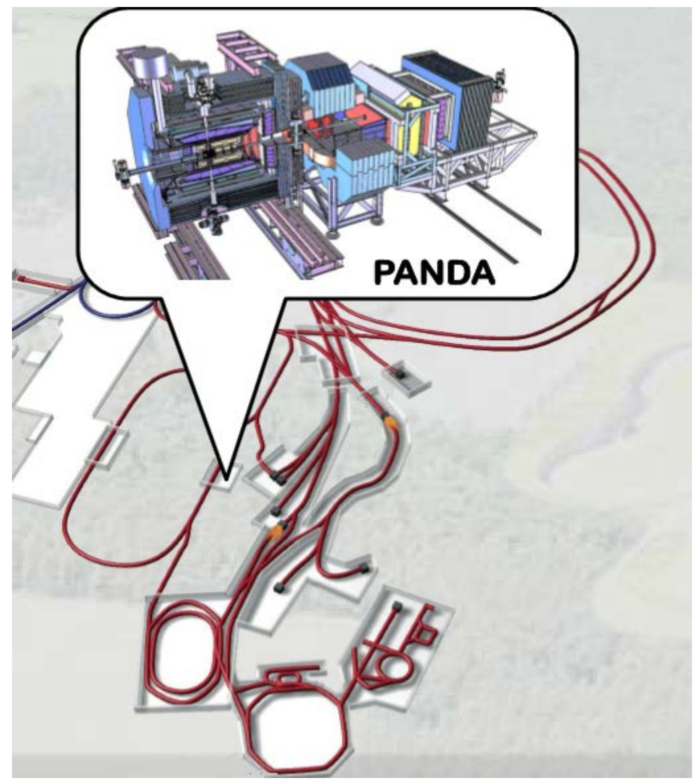
Scheme of the future FAIR facility...

.... and how it looks like now

The PANDA Experiment

- anti-**P**roton **AN**nihilations at **Da**rmstadt.
- The **Panda** collaboration is composed by more than 450 scientists from 17 countries.

- The PANDA experiment intends to do basic research on weak and strong forces, exotic states of matter and the structure of hadrons.
- Antiprotons produced by a primary proton beam is transferred to the High Energy Storage Ring (HESR).
- Antiprotons will collide with the fixed target inside the PANDA Detector.



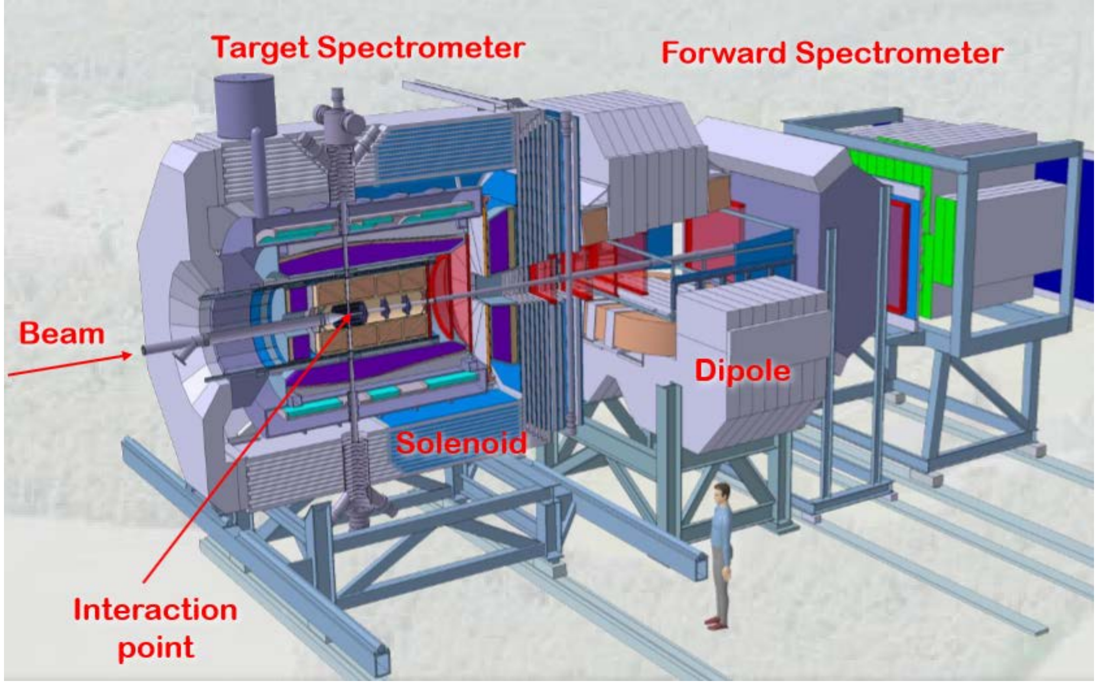
The PANDA Detector

Panda is a **fixed target magnetic spectrometer experiment**.

To achieve full coverage of the solid angle together with good particle identification and high energy and angular resolutions, the detector is **subdivided in two magnetic spectrometers**:

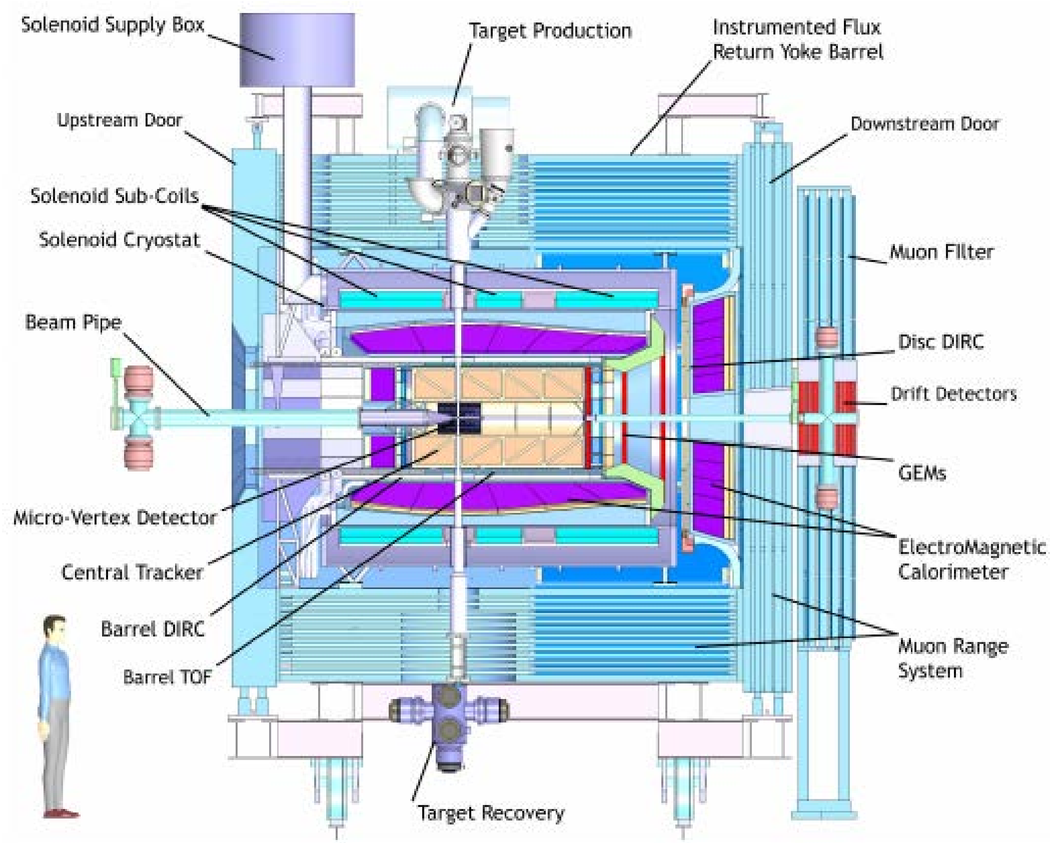
- ☐ **Target Spectrometer** based on a superconducting solenoid around the interaction point for large angles tracks.

- ☐ **Forward Spectrometer** equipped with a dipole magnet for small angle tracks.

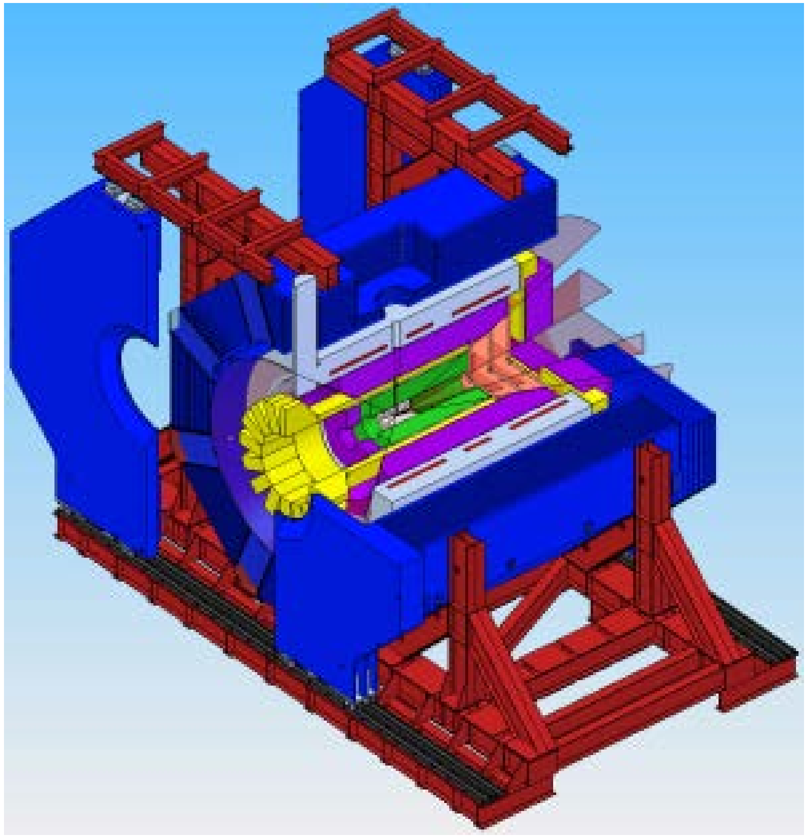


The PANDA solenoid - coils

- The Target Spectrometer is the core of the PANDA detector.
- The **Solenoid** features a warm bore of 1.9 m diameter around the interaction point with 4 m free length.
- The interaction point is located at 1/3 of the length of the coil. The solenoid is at this point and the cryostat exhibits a warm bore of 100 mm.
- For balancing forces and the required field homogeneity the coil is split in 3 parts.



The PANDA Solenoid - structure and yoke

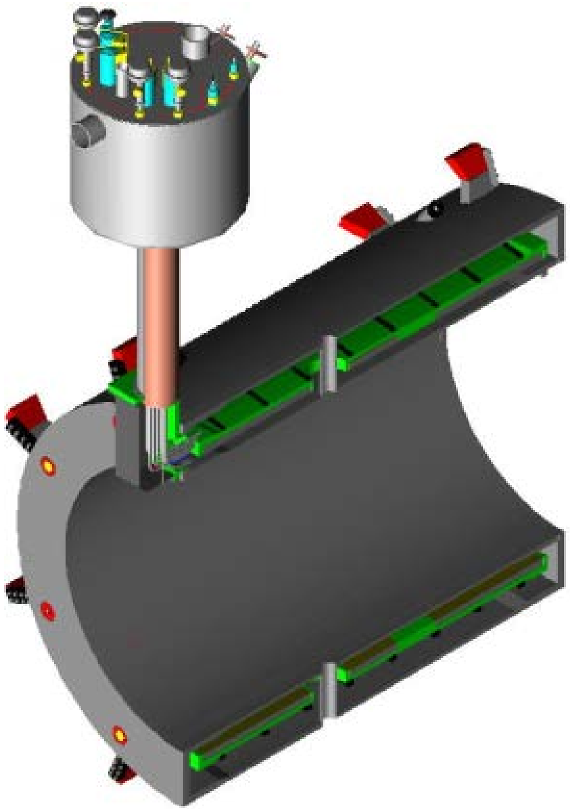


- The Solenoid is indirectly cooled.
- The cryostat surrounds all detectors and serves as mounting structure.
- The flux-return yoke is made of 13 layers of iron and incorporates mini-drift tubes for muons detection.
- Both ends of the return are fabricated as opening doors, and is also part of the muon system.
- The entire set up of more than 300 t is retractable and can go into a parking position outside the beam, for commissioning and maintenance.

The PANDA solenoid - summary

Cold mass parameters	
Free bore	1.9 m
Length	2.7 m
Mass	4.5 t
Stored Energy	21 MJ
Yoke parameters	
Length	4.9 m
Outer radius	2.3 m
Iron layers	13
Mass	300 t

Central field	2 T ± 2%
Radial field integral $Int(r, z_0) = \int_{-0.4\,m}^{z_0} \frac{B_r(r,z)}{B_z(r,z)} dz$	< 2mm



- **Challenges**:
  - field homogeneity
  - intersection of a warm target feed pipe
  - detector access and movement system.

CERN - PANDA collaboration

- At CERN, magnets for detectors are handled by a magnet team within the Physics Department.
- The team and its mission:
  - Primarily operate, maintain, upgrade the ATLAS magnet system.
  - Develop new technologies for detector magnets.
  - Support on request other detectors with design, constructions, repair, etc…
  - 2 engineers and 3 technicians, 3 fellows, 1 PhD + few students.
  - On-call support for magnet services by 2-3 engineers and 5-10 technicians and operators.

ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

COLLABORATION AGREEMENT

No. KR2345/PH

between

THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
(CERN)

and

Forschungszentrum Julich as a member of the PANDA Collaboration
(FZJ)

concerning

Phase I of the Design and Realization of the Superconducting Solenoid
for the PANDA Particle Detector

Following PANDA's request CERN is supporting the solenoid construction and a collaboration agreement has been signed.

Work sharing

The construction of the Panda Solenoid is split between CERN and JINR-Dubna.

CERN tasks:

- ☐ Construction of Solenoid cold mass (conductor, coil winding and cold mass assembly)
- ☐ Integration of the cold mass into the cryostat
- ☐ Power and controls
- ☐ Test and commissioning.

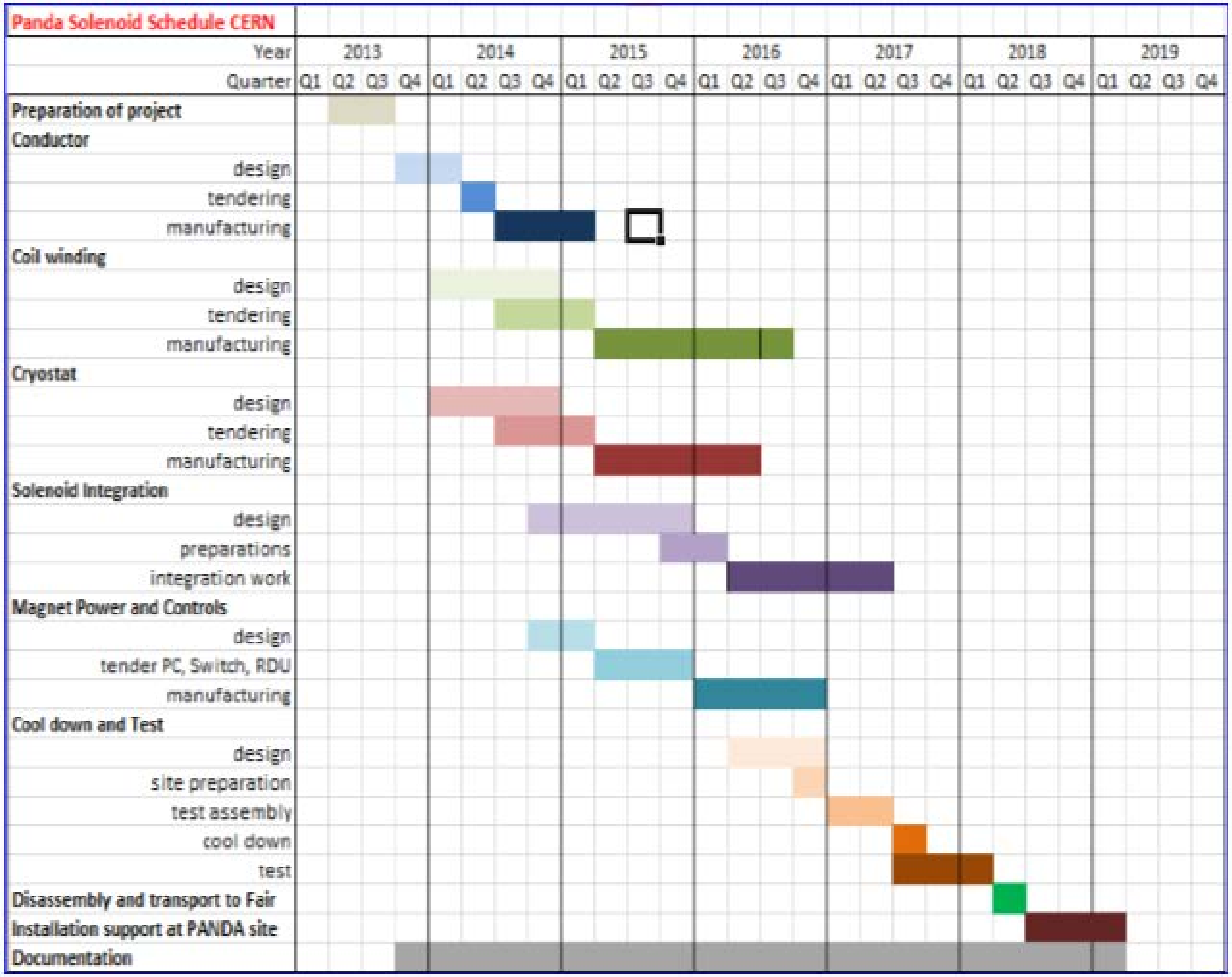
JINR-Dubna tasks:

- ☐ Construction of the cryostat

When ready, the system is shipped to PANDA site at GSI.

PANDA Solenoid: sharing of work			CERN						Panda/JINR				
Work package for CERN	Main item	Sub items	Design	Spec for tender	Follow-up	Materials supply	Work at CERN	Interface	Design	Tender	Follow-up	Materials	Work
1	Cold mass	Conductor	x	x	x								
		Cylinder+winding+cooling circuits	x	x	x								
		Instrumentation	x			x	x						
		Internal cables	x			x	x						
		Bus connections	x			x	x						
		Current Leads	x			x	x	x					
	Cryostat	Cold Mass Supports						x	x			x	
		Thermal Shield							x	x	x		
		Cooling Circuits							x	x	x		
		MLI							x			x	x
		Vacuum Vessel+turrets							x	x	x		
		Turrets interior						x	x			x	x
		Cryo-connection							x			x	x
		Vacuum pump, valves, gages							x			x	x
2	Cryostat Integration	Site preparation	x				x						
		Coldmass in Vessel	x				x						
		Turrets assembly	x				x	x					
		Instrumentation	x				x						
		Current Connections	x				x						
		Helium Connections					x						
3	Power and Controls	Solenoid controls (final)	x			x	x						
		Vacuum controls (final)	x			x	x						
		Current supply +Switch+RDU (final)	x	x	x		x						
4	Test at CERN	Site preparation	x			x	x						
		Helium supply (temporary)	x			x	x						
		Test of solenoid	x			x	x						x
5	Transport to PANDA site	Consultancy and on-site support					x	x	x	x	x	x	x
6	Documentation	of CERN works					x						
	Yoke								x	x	x		x
	Supports/Feet								x			x	x
	Helium Plant+controls								x	x	x		
	Proximity Cryogenics								x	x			x
	Integration with Detector Controls								x			x	x
	Installation at FAIR/GSI								x			x	x

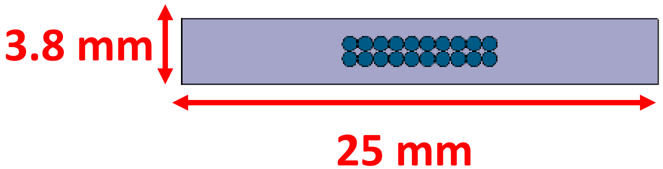
Time schedule



Project started in Dec 2013, delivery to PANDA site at FAIR projected in 2019.

Conductor review

Parameter	*Value*
Conductor type	NbTi Pure Al-stabilized Co-extruded
Al RRR	> 500
SC cable	Rutherford type
Dimensions Rutherford	1.15 x 8 mm^2
d_{strand}	0.80 mm
No. of strands	20
Cu/non Cu ratio	1.5
$d_{filament}$	20 µm
Insulation type	Fiberglass type
Ins. thickness	0.4 mm



- Review of the conductor design from Technical Design Report (2009) by INFN Genoa.
- Increase the temperature margin

  $\Delta T = 1.7$ K → $\Delta T > 2.4$ K

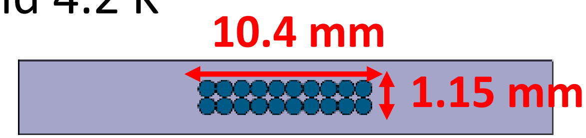
- In the TDR $I_{c_{cable}}$ = 10 kA @ 3 T and 4.5 K
- Thus $I_{c_{strand}}$ = 500 A @ 3 T and 4.5 K

  $J_{c_{strand}}$ ~ 2100 A/mm^2 @ 5 T and 4.2 K

- The Ic_{strand} is low compared to achievable NbTi strand performance nowadays.
- The Cu/nonCu ratio is high for a Al-stabilized conductor.

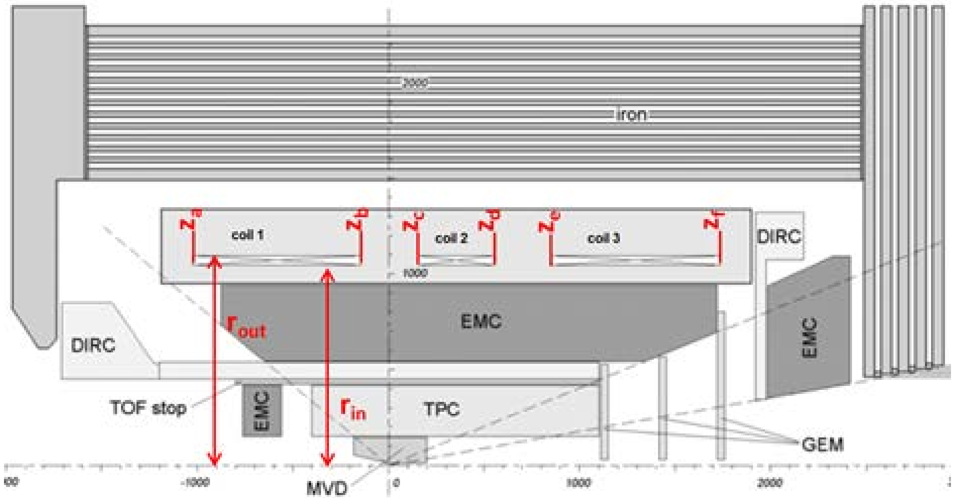
Conductor review

- Increase the temperature margin by upgrading the original conductor design:
  - State-of-the-art NbTi strands can provide J_c = 2800 A/mm^2 @ 5 T and 4.2 K
  - Considering degradation (5% for cabling, 10-15% for co-extrusion)
  - This leads to J_c (effective) = 2300 A/mm^2 @ 5 T and 4.2 K
- **For ΔT = 2.4 K we need 26 strands**



Conductor	Cu/noCu	J_c @ 5T/4.2 K [A/mm^2]	No. of strands	d_{strand} [mm]	ΔT [K]
TDR	1.50	2104	20	0.8	1.71
upgraded – 1	1.20	2300	20	0.8	2.06
upgraded – 2	1.20	2300	24	0.8	2.27
upgraded – 3	1.20	2300	26	0.8	**2.38**
upgraded – 4	1.20	2300	20	0.81	2.09
upgraded – 5	1.20	2300	20	0.83	2.16
upgraded – 6	1.20	2300	20	0.85	2.22

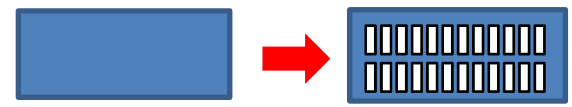
Coil design



Parameter		Value
Radius	Inner Outer	1045 mm 1095 mm
Length	Coils 1+3 Coil 2	881.6 mm 395.2 mm
Turns/layer	Coils 1+3 Coil 2	232 104
Turn layers		2

☐ **Peak field on the conductor**

To better asses B_{peak}, and hence the temperature margin, a model of the coils detailed down to the Rutherford cable is used.



Model	B_{peak} [T]	ΔT [K]
Uniform J (conductor)	2.7	1.78
Uniform J (Rutherford)	3.04	1.71

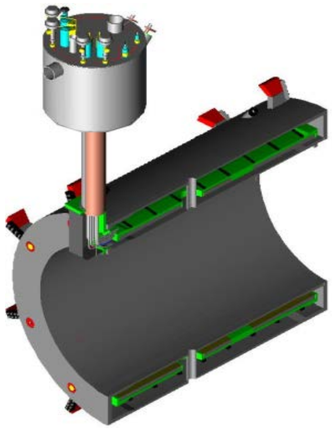
☐ **Peak adiabatic temperature**

Worst case: stored energy is dumped in the smallest (center) coil, with no external resistor $T_{peak} \approx 160$ K (still safe)

Normal case: $R_{dump} = 0.1\ \Omega$ and $\tau = 17$ s

$T_{peak} \approx 40$ K

Conclusion and next steps



- ☐ CERN supports Panda in engineering, construction and test of the solenoid and a sharing of work between CERN and PANDA/JINR has been established.
- ☐ Conductor design was reviewed for increasing the temperature margin ΔT to 2.4 K.
- ☐ Conductor specification is ready, order is placed in the coming months.
- ☐ Design review and engineering continues with the cold mass, winding and support cylinder specifications, coil winding technology and cryogenics.
- ☐ ….. Stress analysis in windings and support cylinder, Thermal load analysis, Cooling modes, Quench analysis, Instrumentation, Controls & Powering.
- ☐ Coil and Cryostat production are in 2015-16, integration and test in 2017-18.
- ☐ The schedule is challenging for delivery in 2019.