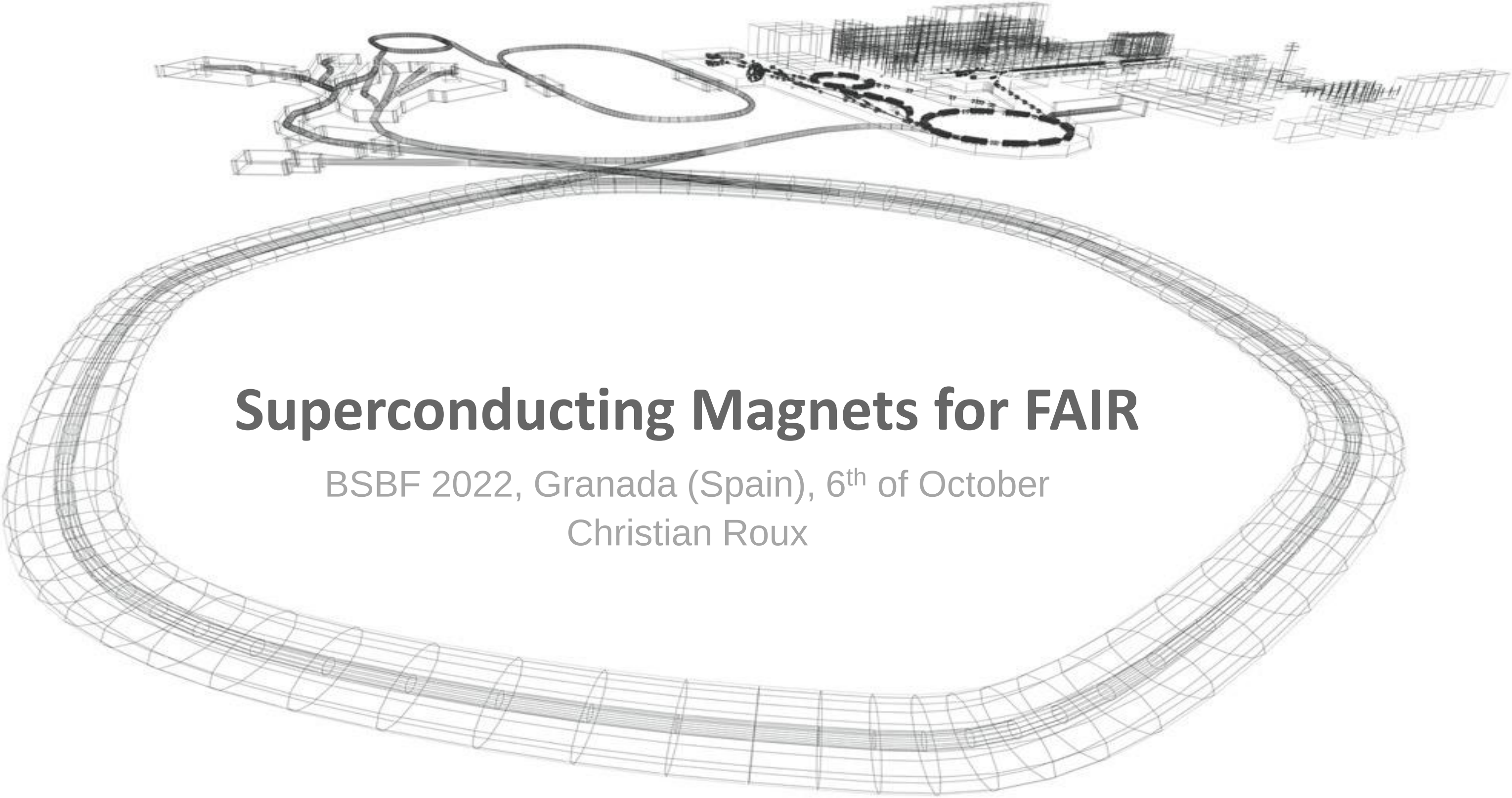
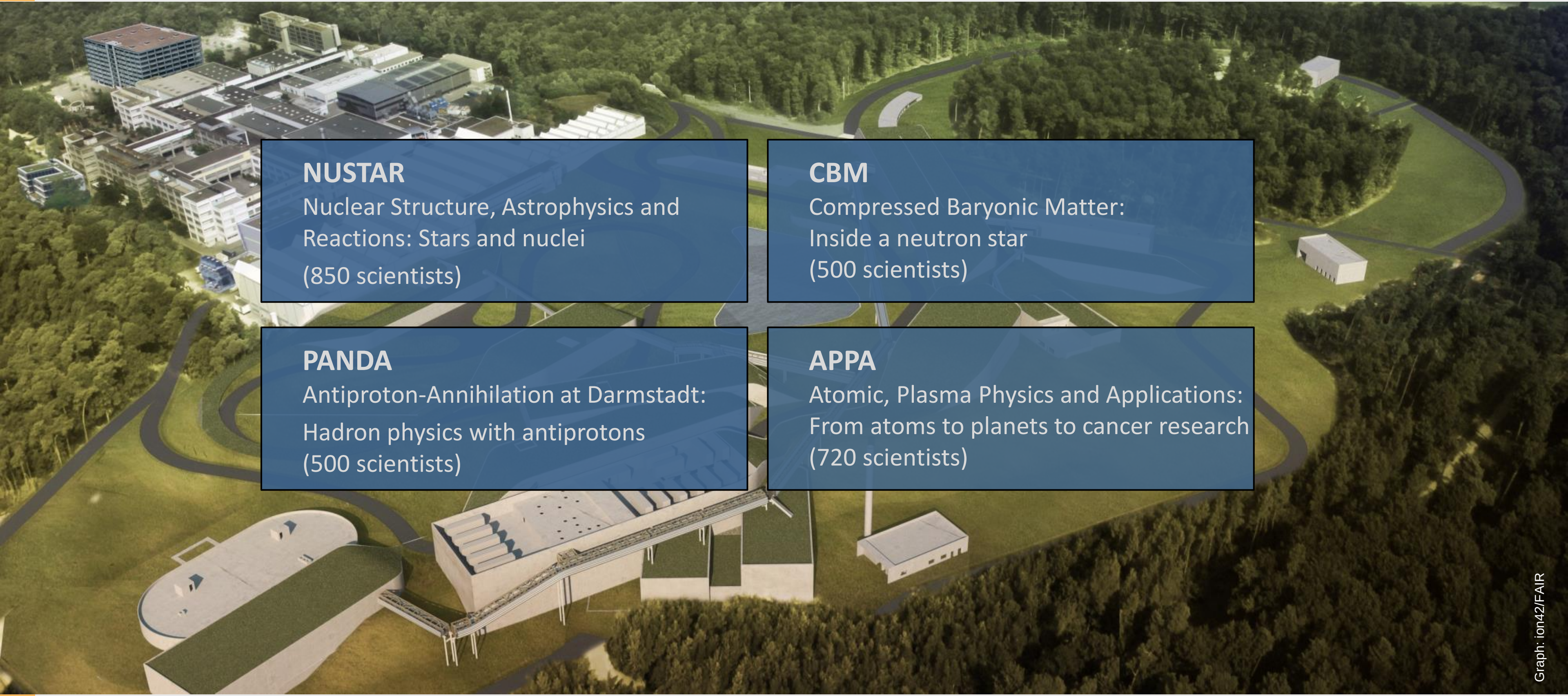


Superconducting Magnets for FAIR

BSBF 2022, Granada (Spain), 6th of October

Christian Roux

FAIR – experimental program



NUSTAR
Nuclear Structure, Astrophysics and Reactions: Stars and nuclei
(850 scientists)

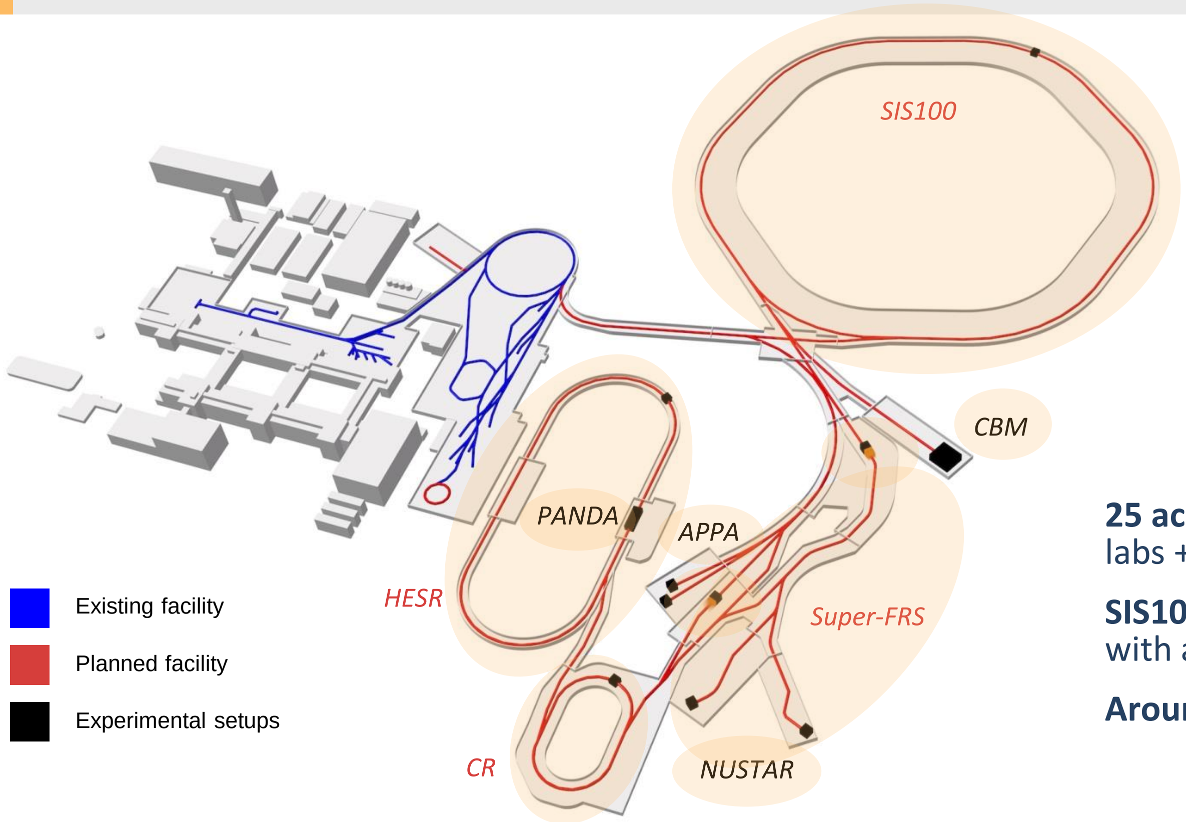
CBM
Compressed Baryonic Matter: Inside a neutron star
(500 scientists)

PANDA
Antiproton-Annihilation at Darmstadt: Hadron physics with antiprotons
(500 scientists)

APPA
Atomic, Plasma Physics and Applications: From atoms to planets to cancer research
(720 scientists)

Graph: ion42/FAIR

FAIR



Experimental Setups
four main pillars

SIS100 heavy-ion synchrotron
high intensity primary beams

Production targets
- exotic nuclei
- anti-protons

25 accelerator and experimental structures,
labs + operation and supply structures

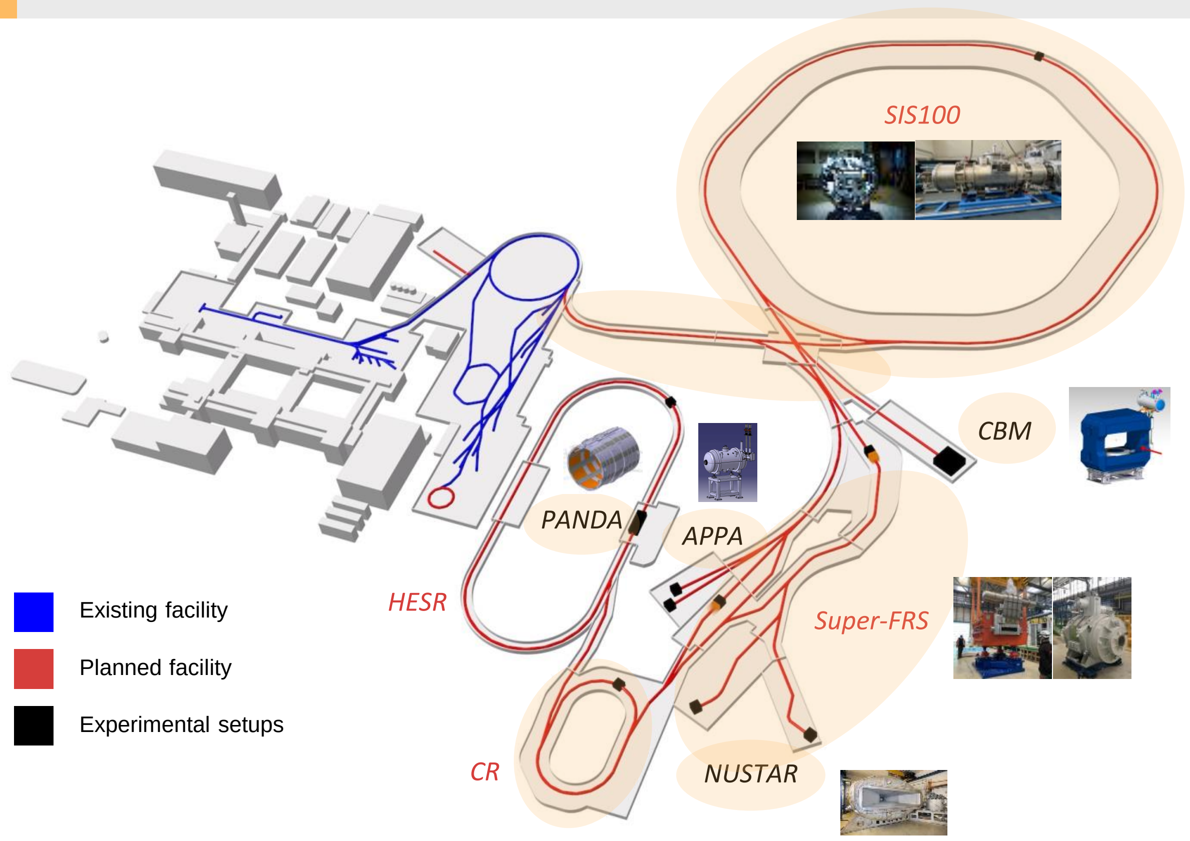
SIS100: underground ring
with a circumference of approx. 1,100 m

Around 150,000 m² of total area

Super Fragment Separator
in-flight separator for exotic nuclei

Rings
collection and storage

FAIR – superconducting magnet‘s point of view



SIS100
- 108 dipoles
- 83 quadrupole doublets

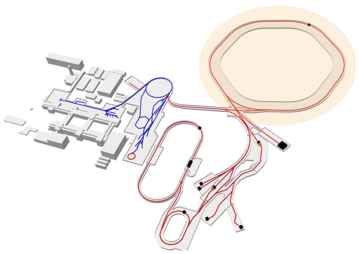
Super-FRS
- 24 dipoles
- 33 multiplets with up to 9 magnets

experimental setups

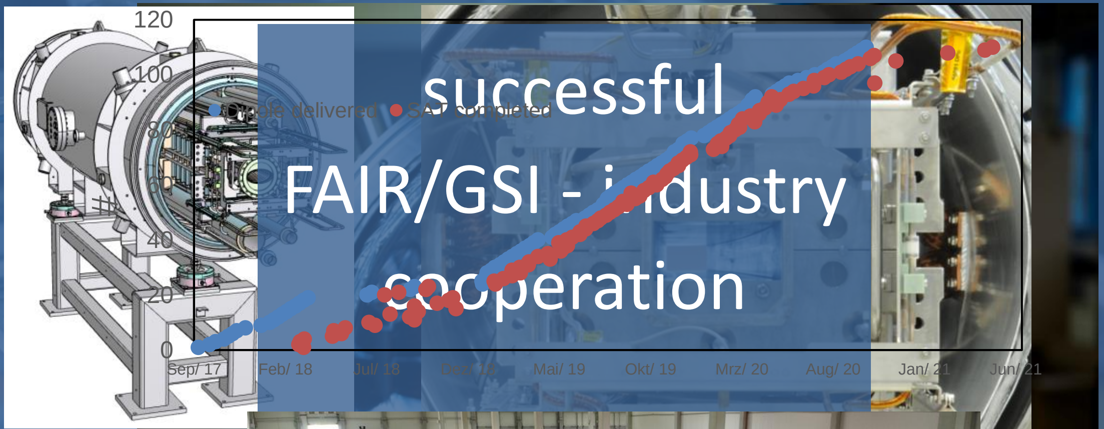
CBM, APPA, PANDA, NUSTAR

under consideration
- collector ring
- beam lines

SIS100 – dipole series



heavy-ion synchrotron



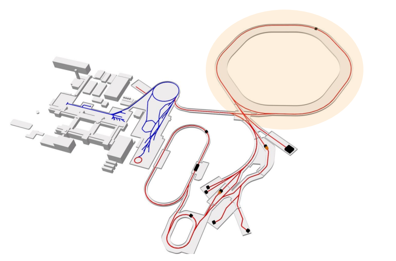
successful FAIR/GSI - industry cooperation

Image: J. H

series completed

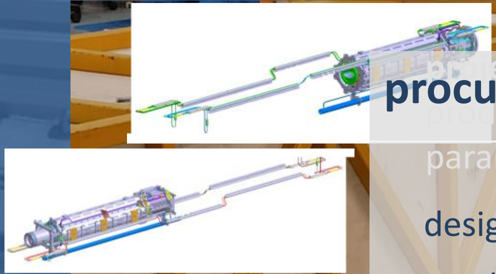
design	• *superferric, Nuclotron cable* • *forced-flow cooling* • *fast ramped*
dimensions	• *aperture: h = 68* mm • *3* t
field	*1.9* T with *4* T/s
current	*13.2* kA

SIS100 – quadrupole units & doublets



heavy-ion synchrotron

design	• *superferric, Nuclotron type cable* • *forced flow cooling* • *fast ramped*
dimensions	• *aperture: d = 100* mm • *units: 1.2* t (without cryostat)
gradient	*28* T/m
current	*10.5* kA



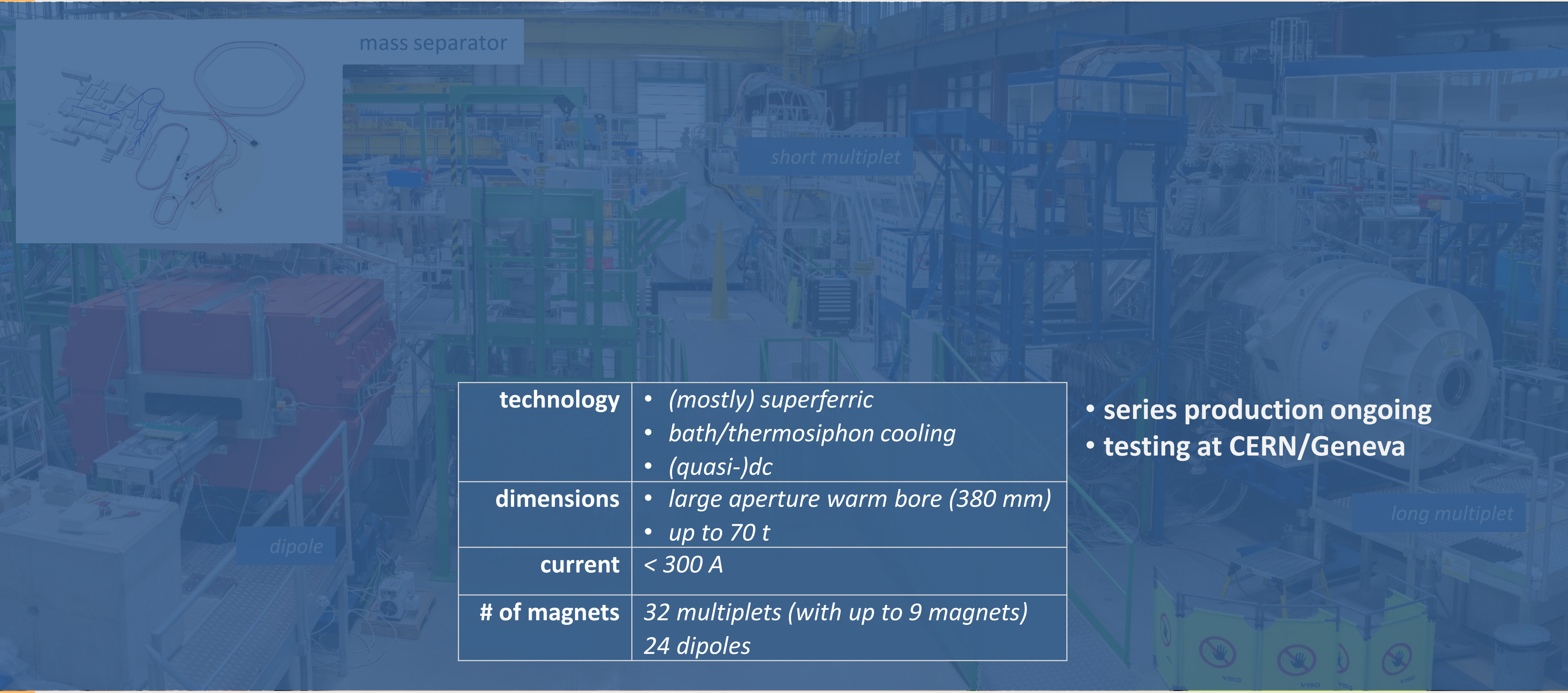
project risk mitigation:
production of prototypes and tooling in parallel to series continuation

procurement figures

scope	3 prototypes
design status	spec in revision
time line	after budget decision

quadrupole doublet module

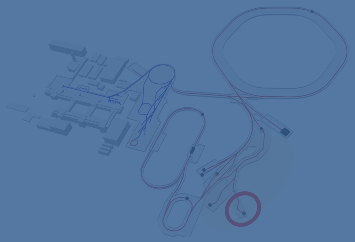
Super-FRS



technology	• *(mostly) superferric* • *bath/thermosiphon cooling* • *(quasi-)dc*
dimensions	• *large aperture warm bore (380 mm)* • *up to 70 t*
current	*< 300 A*
# of magnets	*32 multiplets (with up to 9 magnets)* *24 dipoles*

- **series production ongoing**
- **testing at CERN/Geneva**

Super-FRS – Needs for Energy Buncher Magnets



mass separator

Cu/NbTi wire

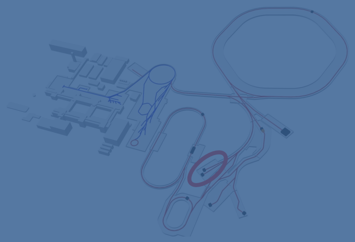
procurement figures

scope	three dipoles
design status	spec by end of 2022
time line	2025 assumed

design	• *superferric, racetrack* • *thermosiphon cooling* • *self protecting*
dimensions	• *large aperture: 500* mm × *140* mm • *75* t
field strength	*1.6* T
current	*< 300* A

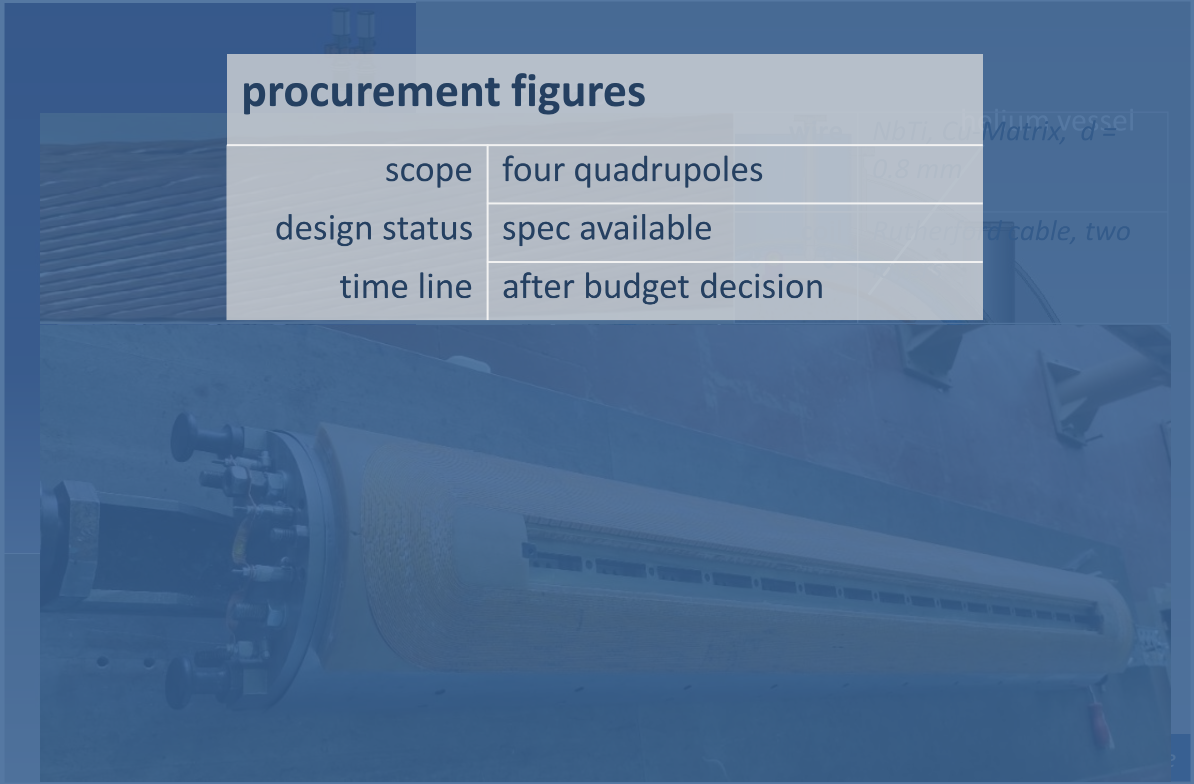
energy buncher dipole

APPA: final focusing quadrupoles



beam focusing for high energy density on target

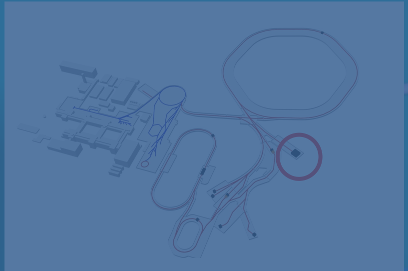
design	• *cos Θ, Rutherford type* • *forced-flow cooling*
dimensions	• *aperture: d = 198* mm • *~ 8* t
gradient	*33* T/m
current	*6* kA



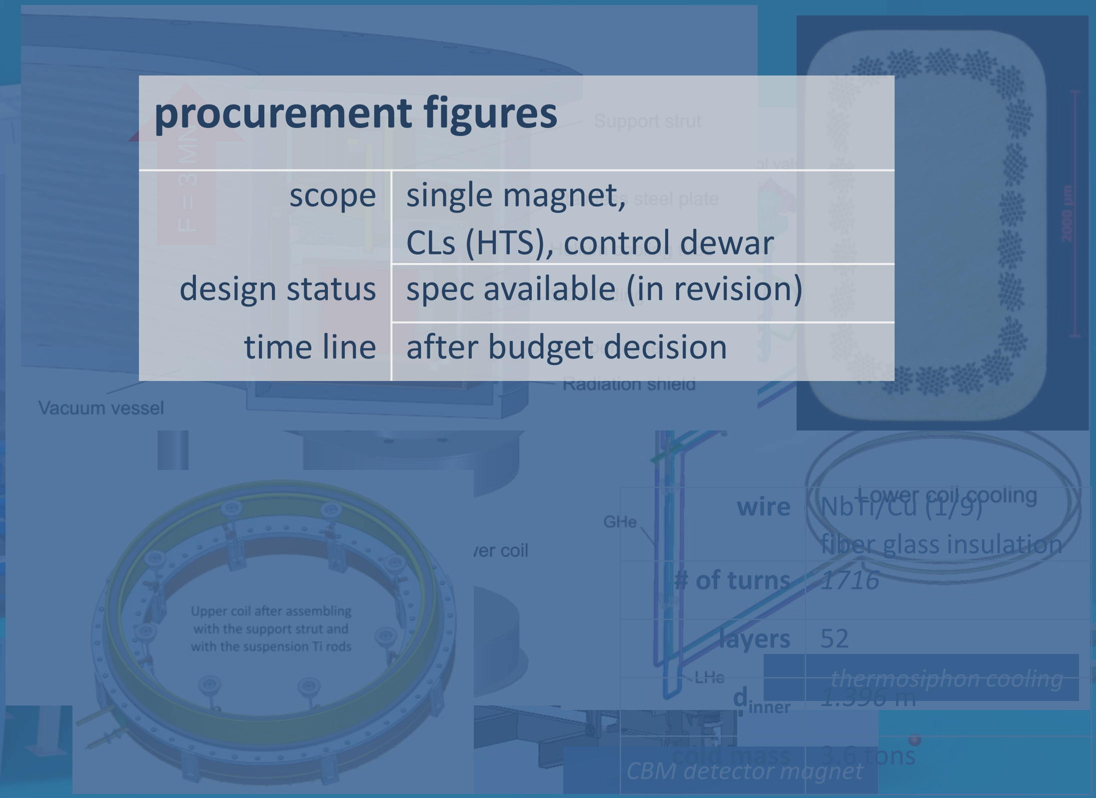
procurement figures

scope	four quadrupoles
design status	spec available
time line	after budget decision

CBM: detector magnet



nucleus – nucleus collisions

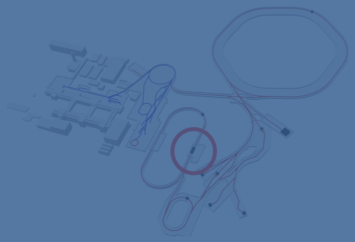


procurement figures

scope	single magnet, CLs (HTS), control dewar
design status	spec available (in revision)
time line	after budget decision

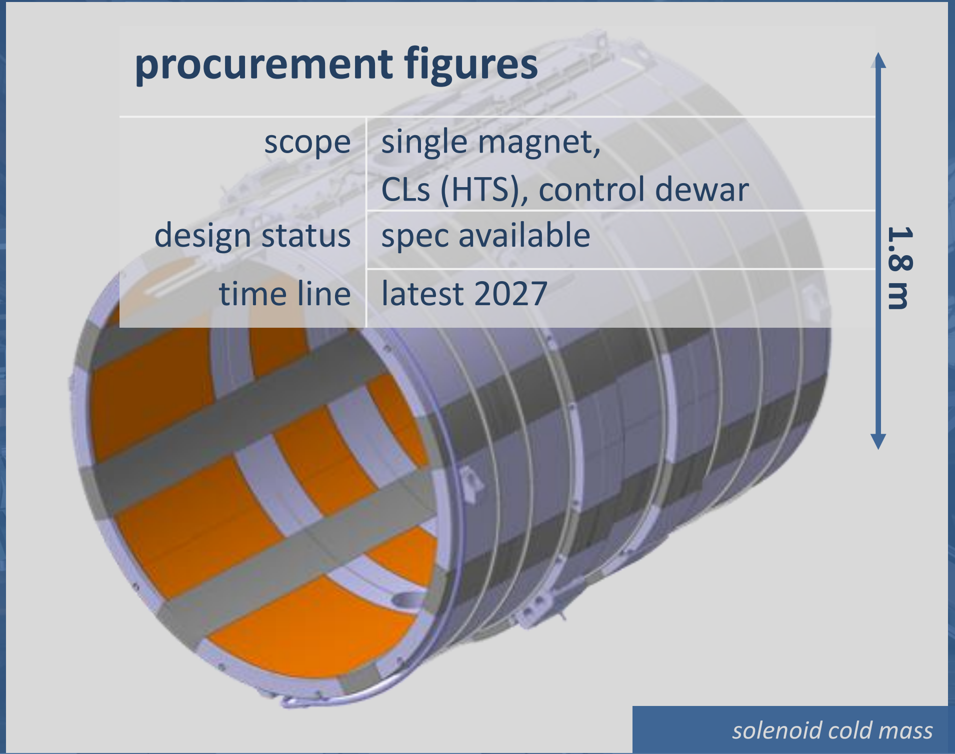
design	• *superferric, racetrack* • *thermosiphon cooling* • *self protecting*
dimensions	• *huge aperture: 1.44* m × *3.0* m • *150* t
field strength	*1* T
current	*666* A

PANDA: detector magnet



antiproton – proton collisions

design	• *instrumented yoke, solenoid* • *thermosiphon* • *(fully) self protecting*
dimensions	• *huge aperture: d = 1.8* m • *~ 360* t
field strength	*2* T
current	*5* kA

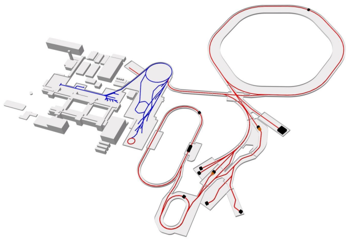


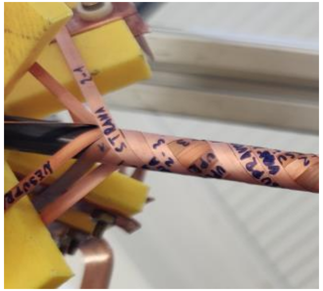
procurement figures

scope	single magnet, CLs (HTS), control dewar
design status	spec available
time line	latest 2027

solenoid cold mass

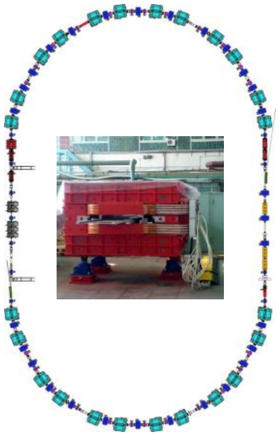
Under consideration / strategic projects





HTS cables
- next-gen accelerator magnet
- power transfer

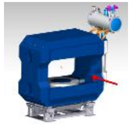
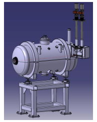
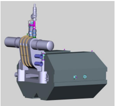
HTS coil replacement
energy saving compared to NC beam line magnets



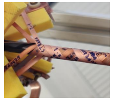
Collector ring
re-consideration of SC design

procurement needs: superconducting magnets for FAIR

	time line	status: model	status: spec	# of magnets
SIS100 units	asap	Q4/22 (in revision)	Q4/22 (in revision)	3
CBM		ok	10/22	1
APPA		ok	ok	4
Super-FRS EB dipoles	2025	Q4/22	Q4/22	3
PANDA	2027	ok	ok	1
Collector Ring	mid-term	concept studies		26 (+ 29)
Beam line upgrade		concept studies		tbd
HTS cable		concept studies		n/a





thank you very much

Our current procurements

Graph: ion42/FAIR

Additional slides

It’s easy to do business with FAIR:

- We buy the vast majority of our needs in open competition
- We have no principle of *juste retour*: the most competitive offer wins, regardless of nationality or EU membership.

Here’s what you need to do:

- Present your portfolio and references to the FAIR/GSI team or send them to our industry contact officer: s.utermann@gsi.de.
- Check our website for upcoming procurements
- Please contact your country’s industry liaison officer. It is their job to advocate for you.
- Reach out to other companies in your country. Consider consortia.
- If you are based in one of our shareholder countries: check the tenders of your country’s shareholder (see the BSBF procurement handbook)

Our current procurements

https://www.gsi.de/en/start/business_industry

How to supply FAIR – shareholder countries

In addition, if you are in a shareholder country,

- Please contact your country‘s industry liaison officer. It is their job to advocate for you.
- Reach out to other companies in your country. Consider consortia.
- Please check the tenders of your country‘s shareholder (see the BSBF procurement handbook):

Country	Shareholder	Tender site
Finland (in consortium with Sweden)	Vetenskapsrådet	www.vr.se
France	CEA and CNRS	www.marches-publics.gouv.fr
Germany	GSI GmbH	www.dtvp.de
India	Bose Institute	www.thetenders.com/all-India-Tenders
Poland	Jagiellonian University	opentender.eu/pl
Romania	Ministry of Research and Innovation	anap.gov.ro
Slovenia	Ministry of Education, Science and Sport	opentender.eu/si
Sweden (in consortium with Finland)	Vetenskapsrådet	www.vr.se

Shareholders worldwide

Shareholders

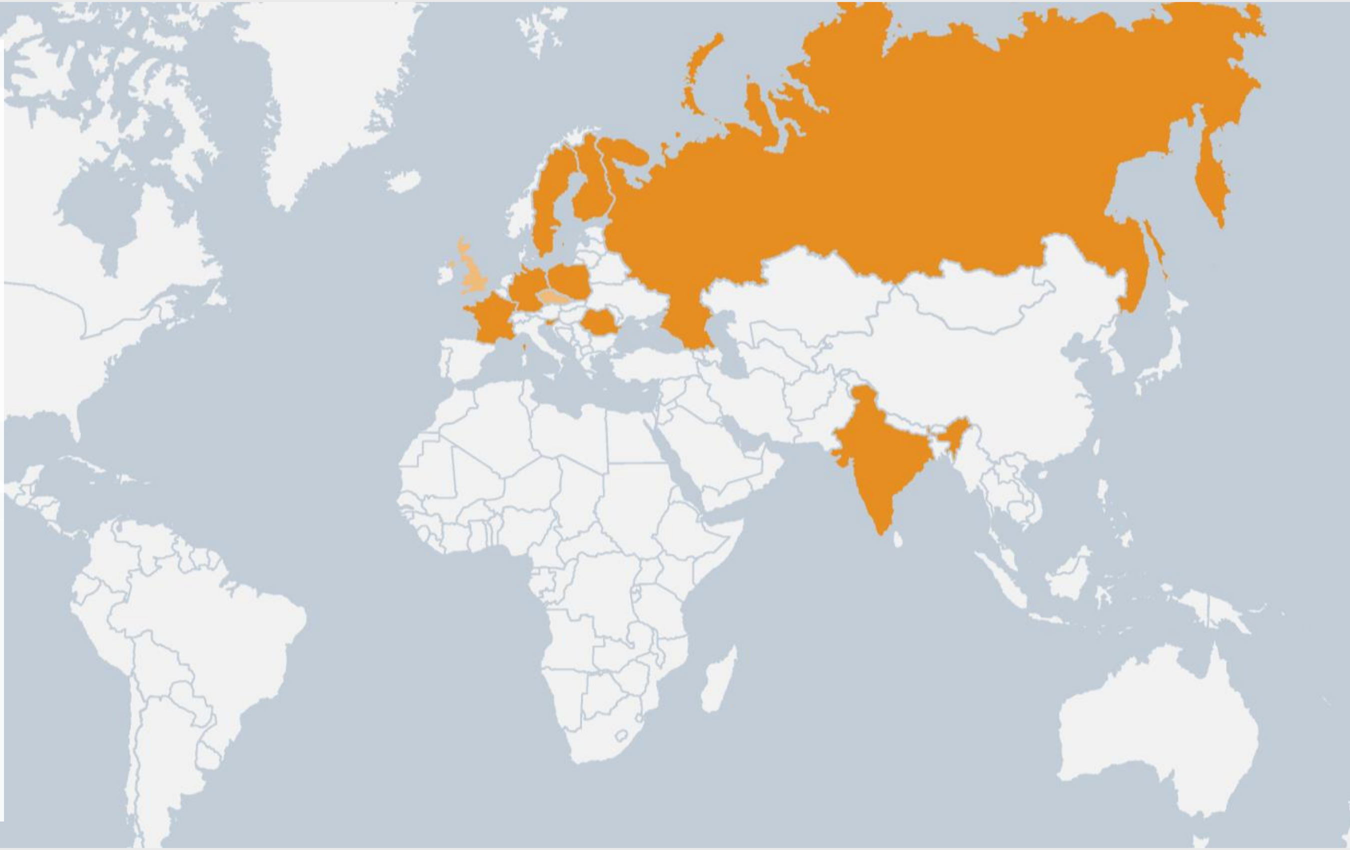
- Finland
- France
- Germany
- India
- Poland
- Romania
- Russia
- Sweden
- Slowenia

Associated

- United Kingdom

Aspirant

- Czech Republic



Graph: GSI/FAIR

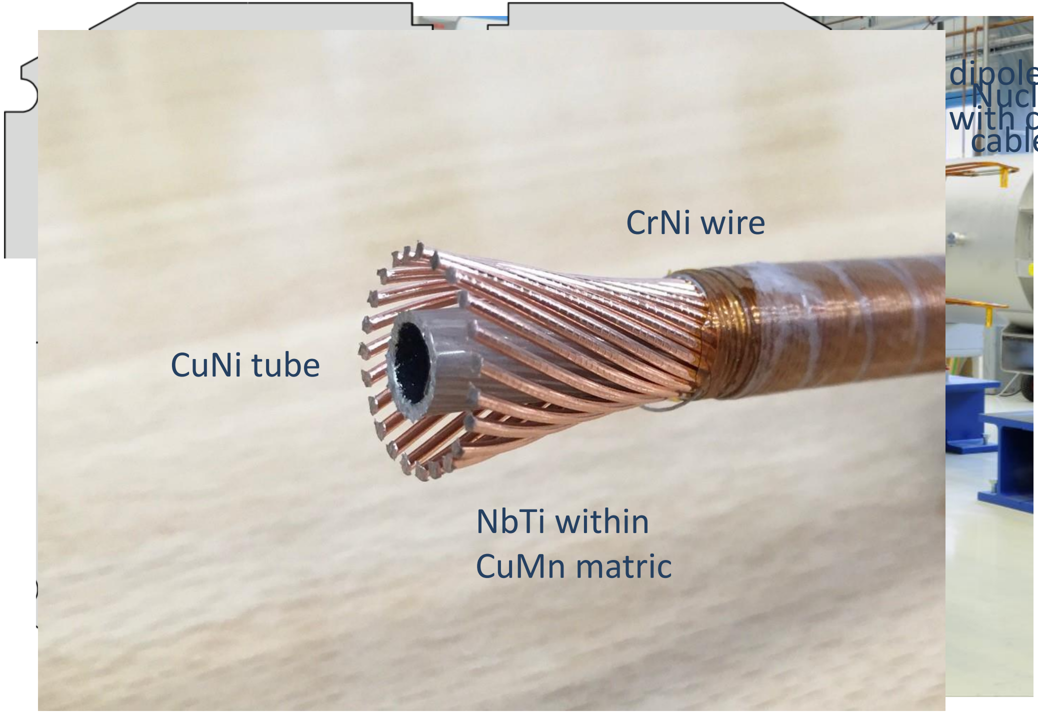
SIS100

type and specs

iron dominated – window frame

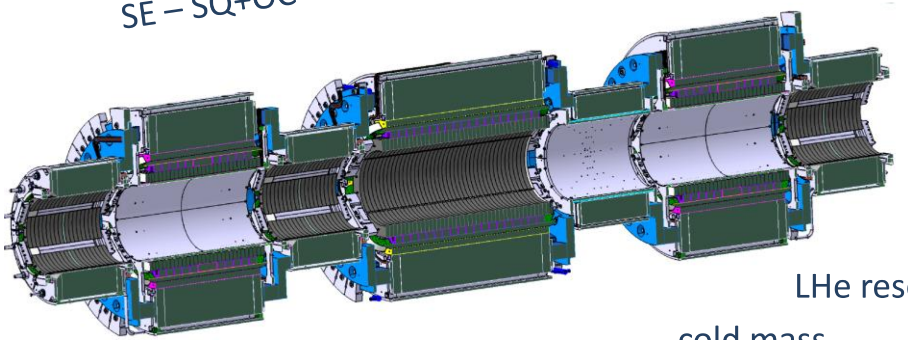
Nuclotron NbTi cable

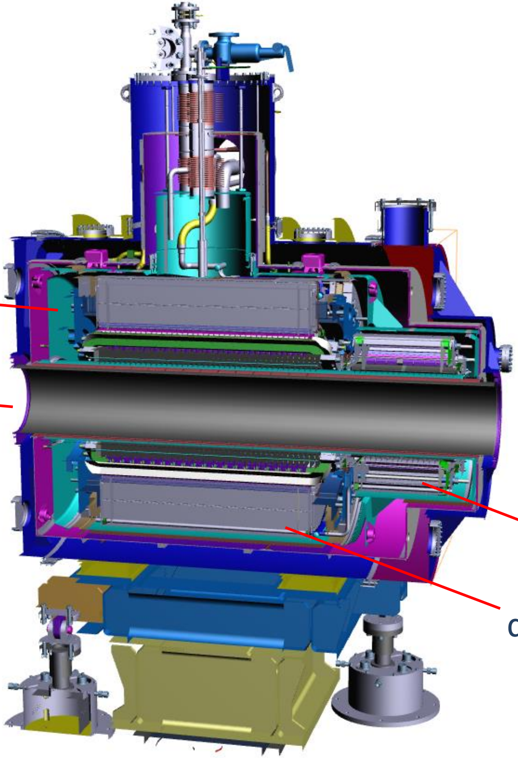
forced flow two-phase He



SUPER-FRS

SE – SQ+OC – SE – LQ – ST – SQ+OC – SE





Multiplets

short multiplets (8 pcs)

pre separator

standard: quadrupole + sextupole

2.5 m, 25 tons

multiplets – common specs

(cold) iron dominated

common helium bath

warm beam pipe (d = 380 mm)

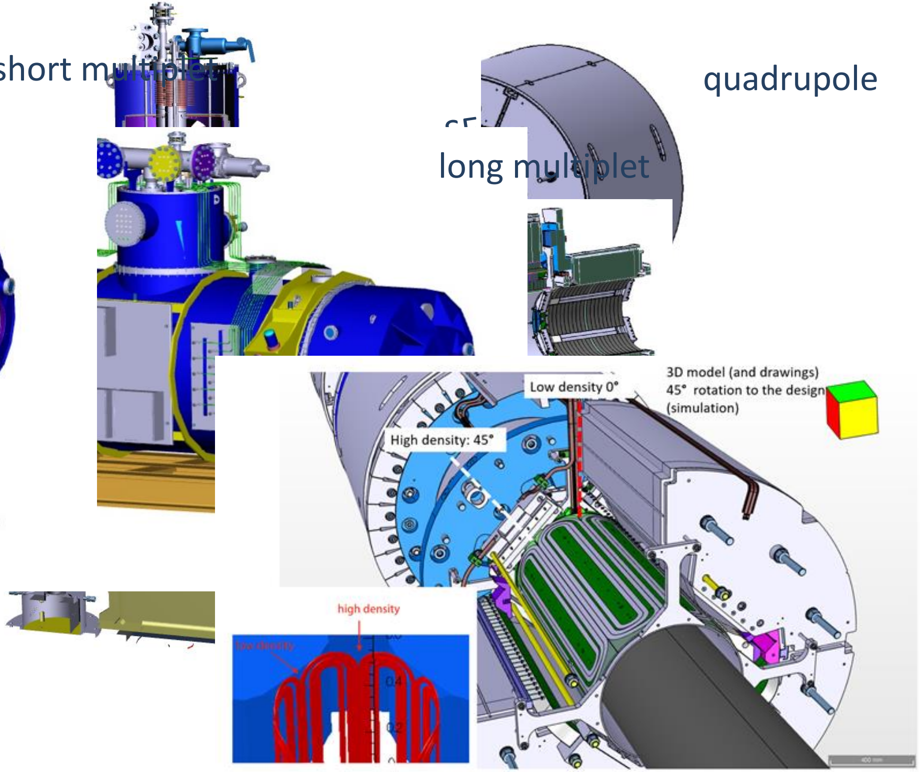
individual powering (I < 300 A)

long multiplets (25 pcs)

main separator

14 configs

max: 9 magnets, 7 m, 60 tons

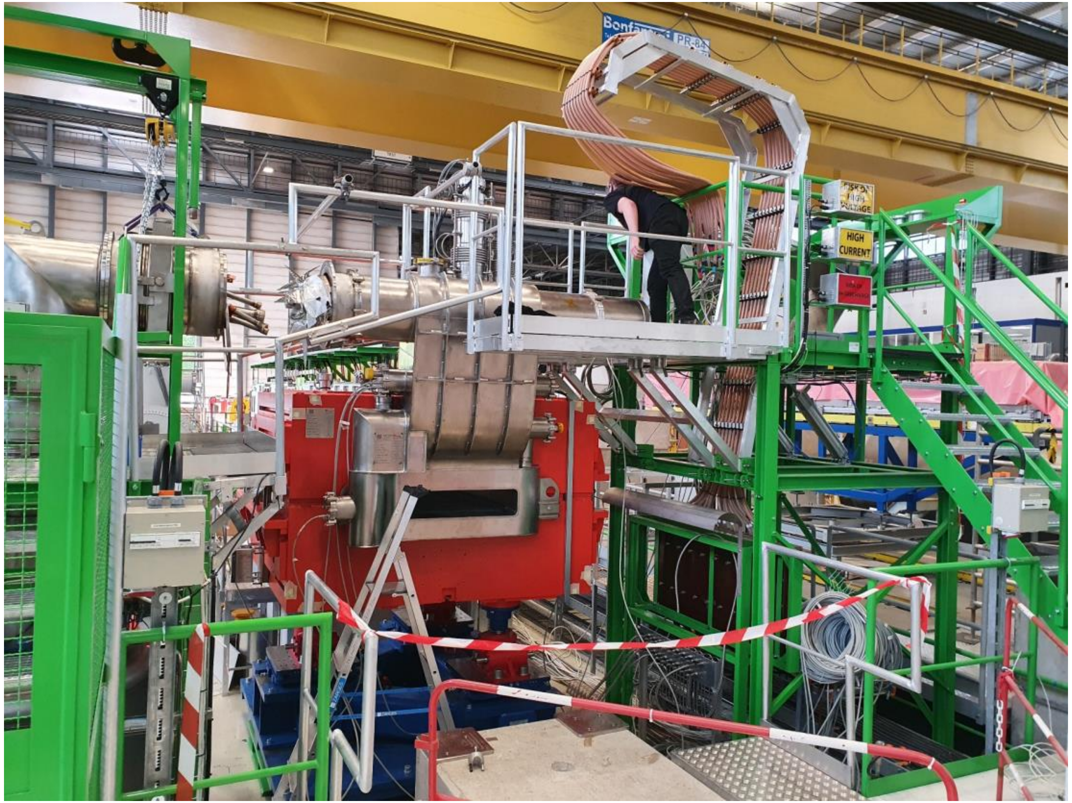


Multiplets

FoS LM (front)

FoS SM (back)

dipole



Thermosiphon

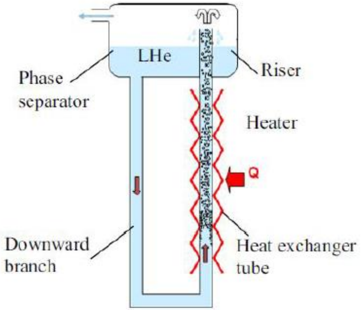


Figure 10: schematic of a helium 2-phase circulation open loop

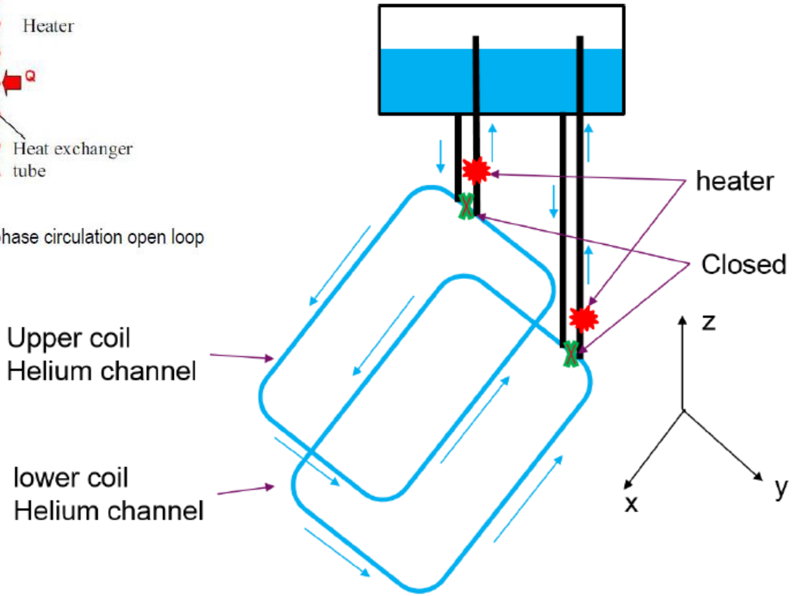
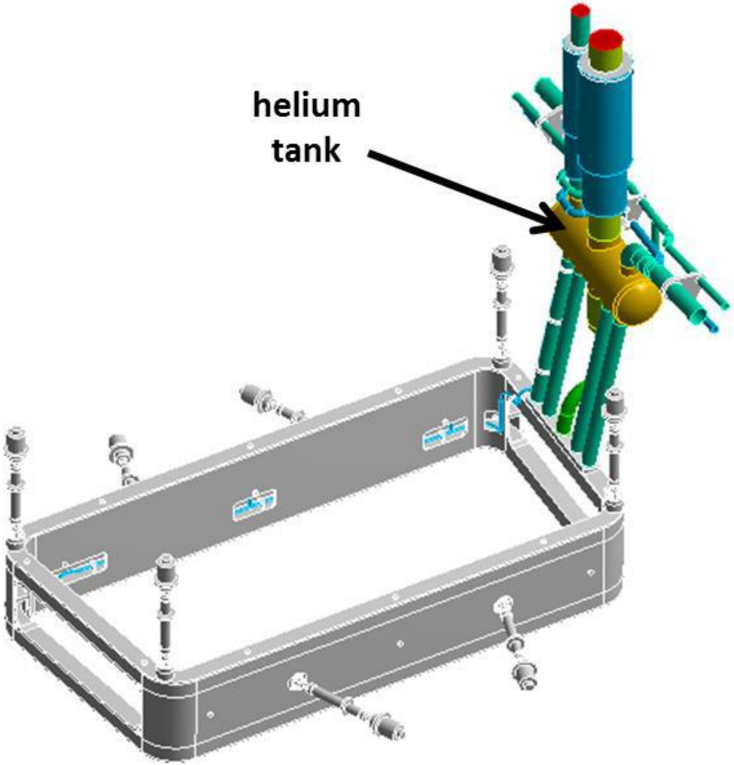


Figure 11: schematic of Super FRS thermosiphon loops

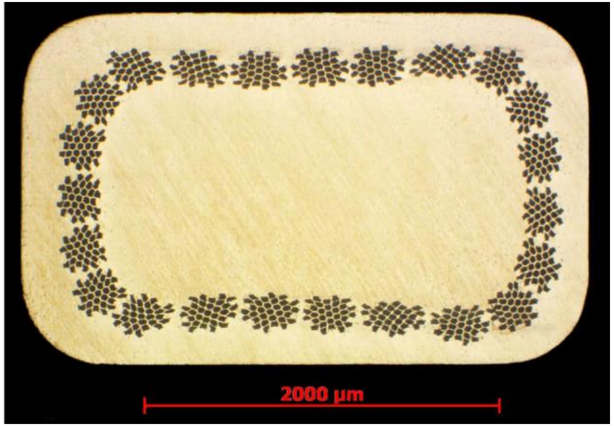


CBM

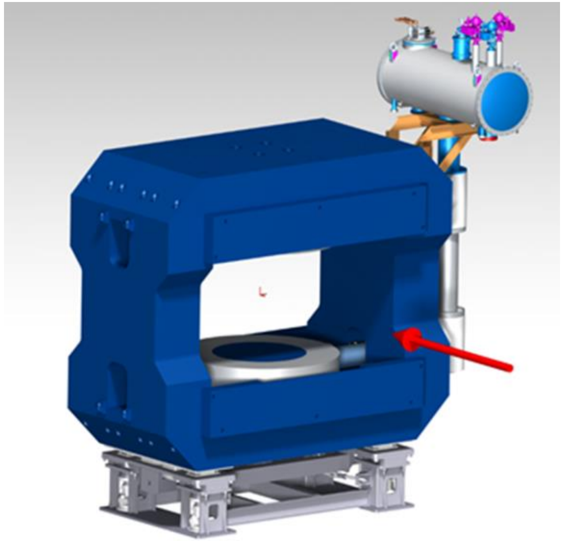
Wire

Table 2. The main parameters of the manufactured SC wires

Cable #	Length, km	Height Width, mm	Cu/nonCu	Critical current at 8 T, A	RRR	Number of filaments	Diameter of filaments, um	Yield strength, MPa	Twist pitch, mm
1-c3-37-2-18	5.2	2.02 3.25	6.994	>764	217	713	38	115	39
1-c3-37-3-18	5.4	2.02 3.25	6.610	>820	223	713	39	145	39
1-c3-37-4-18	5.5	2.02 3.25	6.825	>786	214	713	38	122	38
1-c3-37-5-18	5.4	2.02 3.25	6.704	>800	209	713	38	138	38
1-c3-37-6-18	5.5	2.02 3.25	6.987	>779	200	713	38	122	38
1-c3-37-7-18	5.5	2.02 3.25	6.705	>799	208	713	38	123	38



Wire

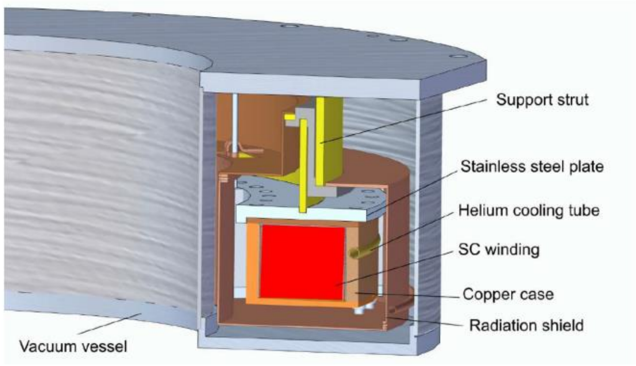


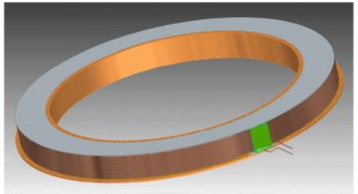
Main parameters of the CBM magnet	
Magnetic field integral along 1 m about the center, T*m	1.02
Maximal magnetic field on the coils, T	3.6
Inner diameter of the SC winding, m	1.396
Vertical distance between the poles, m	1.47
Operating current, A	666
Number of turns per coil	1716
Total current, MA	1.143
Number of layers	52
Stored energy at test current, MJ	5.0
Coils cold mass, kg	3600
Operating temperature, K	4.5
Inductance at operating current, H	21
Vertical force acting on the coils toward the iron yoke, MN*	3.0
Total weight of the yoke, kg	150

Coil

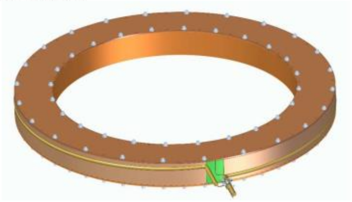
Table 1 Superconducting coil parameters

Coils parameters	Values
Inner cold diameter of the winding, mm	1396
Cross section cold sizes of the winding:	
height, mm	132
radial thickness, mm	157
Number of turns in one coil (33x52)	1716
Number of layers in one coil	52
Interlayer insulation, mm	0.3
Operating current Io, A	666[2]
Test current, Io*1.05, A	700
Magnetic field on the coil Bmax, T	3.6
Io/Ic ratio along the load line, %	~50
Io/Ic at fixed B, %	20
Helium temperature, K	4.5
Temperature of current sharing, K	6.8
Stored energy of the magnet, MJ	4.9
Cold mass of one coil, kg	~ 1800
Cold mass of one coil SC winding, kg	800
Inductance of the magnet at operating current, H	~22.1
E/M ratio for two windings, kJ/kg	3.1
Mutual inductance between the coils, H	0.21
Vertical force on one coil toward the yoke, MN	3.0



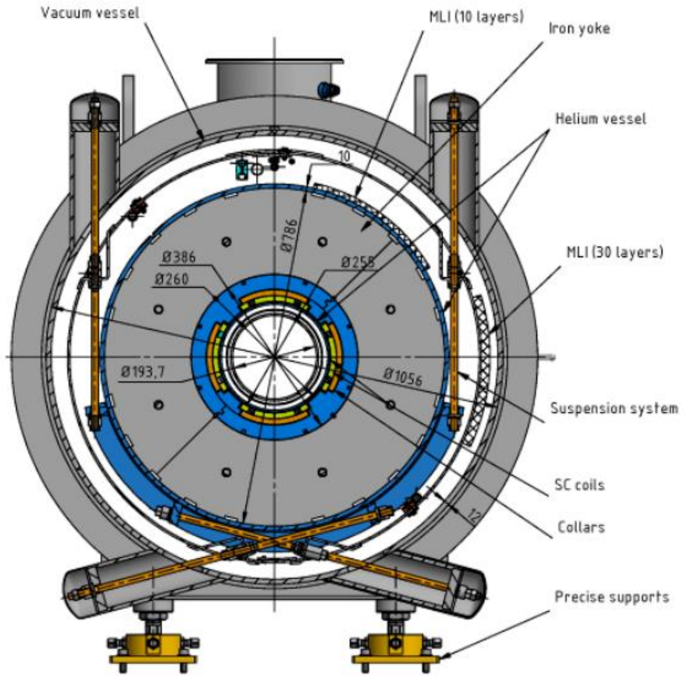


ig. 8. The superconducting coil after the first impregnation with epoxy resin. The green part is an nsertion of G-10 material.



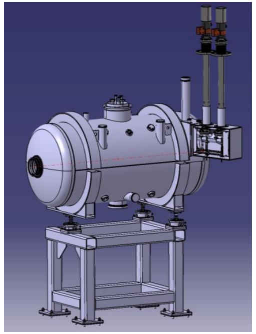
APPA

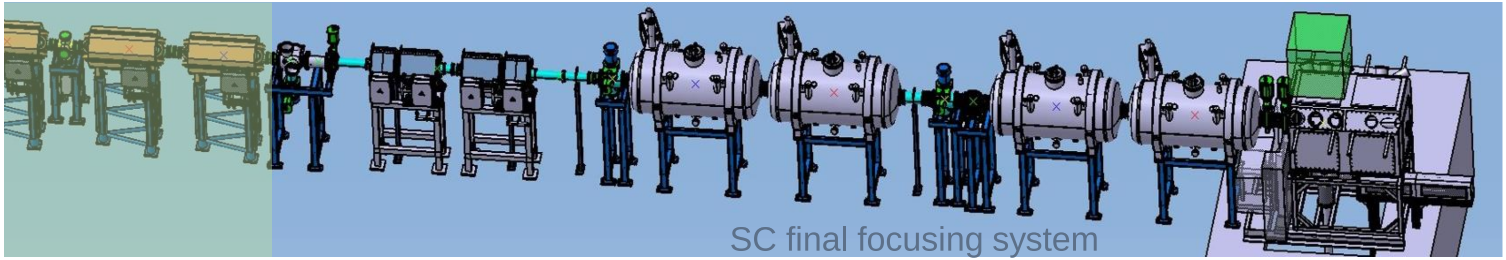
Quadrupole Specs



Name of magnet		**FFS super-conducting quadrupoles for HED@FAIR**
Design		Cos-θ type quadrupole Rutherford-type sc cable
operating mode		DC, no ramping
Quantity of magnets		4
coil inner diameter	mm	260
distance between quadrupole centres of two nearby quadrupoles	m	2,5
Effect. (magn.) length	m	2
integral of field gradient	T	66
central gradient (G0)	T/m	33
region of a good field quality (r0)	mm	110
lowest harmonics (6-th and 10-th), 6-th integral field harmonics		$< \pm 2\times 10^{-4}$
operating temperature	K	4,4
temperature margin	K	< 1
compatible with a warm ion beam pipe		
Beam pipe interface		CF 200 rotable flange

Overview





4 large-aperture (inner diameter: 260 mm) high-gradient (integral field gradient: 66T) superconducting cosθ quadrupoles

1280 m Rutherford type sc cable winded in 2-layer coils

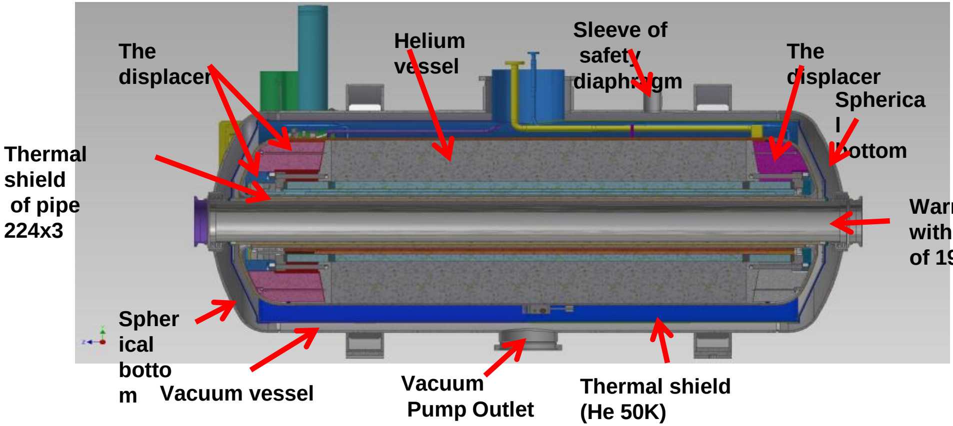
Collars and iron yoke (approx. 8 t), liquid He cooled

Pressure vessel according AD2000

Thermal shield and cryostat

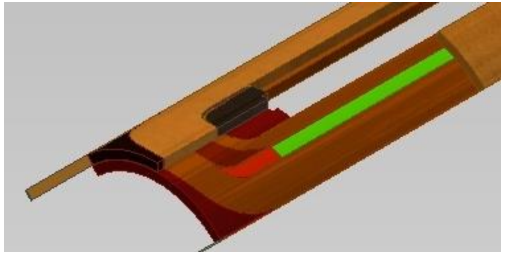
Incl. alignment feed and stand

Existing design and construction drawings



Cable

Superconducting alloy	NbTi
Titanium percentage, %	50 ± 4
Matrix material	copper
Wire diameter, mm	0.85+0.03
Filament diameter, µm	6
Filling factor	0.42+-0.02
Twist pitch, mm	10+-2
Residual Resistance Ratio (RRR) of matrix	≥70
Critical current at B = 5 T, T = 4.23 K, A	600 ± 50
Critical current density at B = 5 T, T = 4.23 K, kA/mm2	2.5 ± 0.1



Polyimide film (3x0,025mm)

Fiberglass with an adhesive layer of 0,1 mm

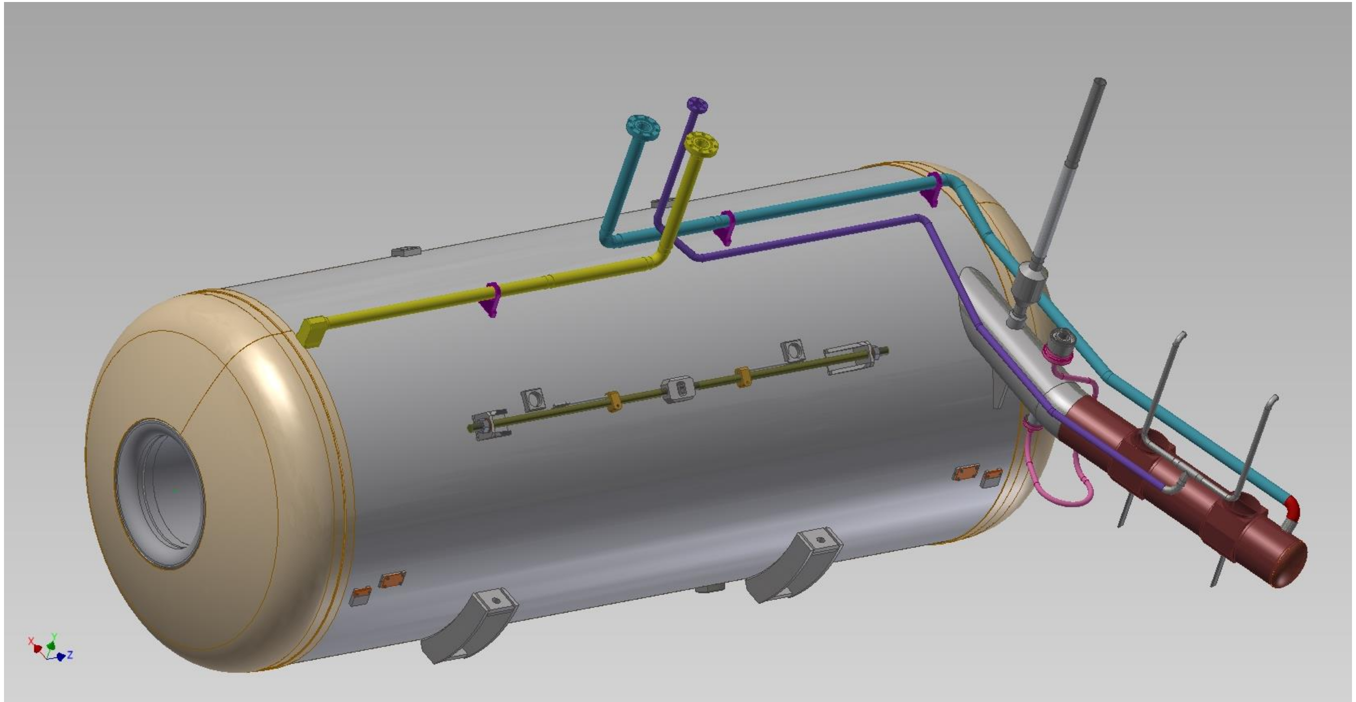
Application

Function

4 super conducting (33 T/m) large aperture (260 mm) quadrupoles

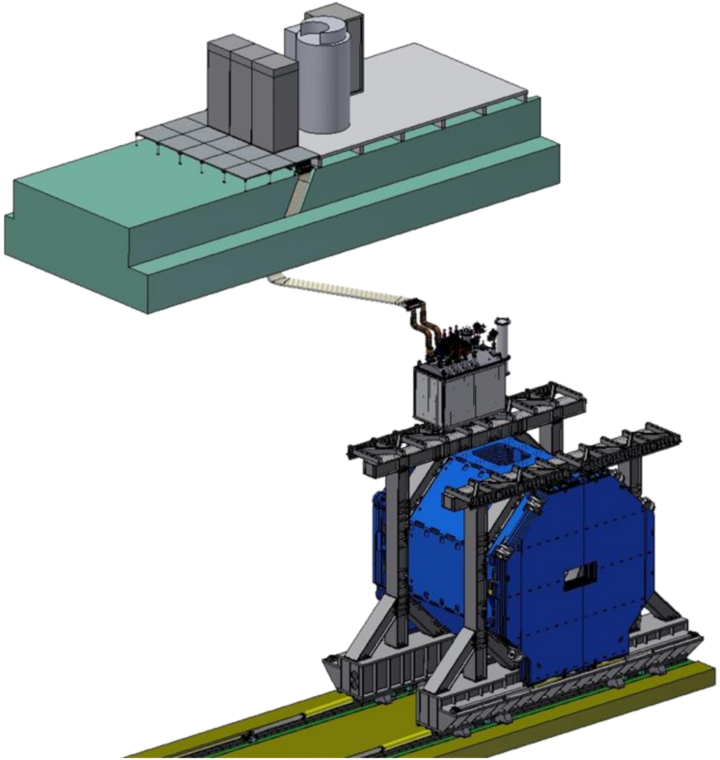
Key component for the HIHEX and LAPLAS experiments. The energy that can be deposited in the target with the ion beam is a key parameter for HED experiments and therefore the achievable ion beam intensity and focal spot size are of utmost importance. In order to maximize the energy deposition, it is necessary to use a heavy ion beam with a low charge state and very high intensity, which in turn requires focussing magnets with a very strong magnetic field together with large apertures for focusing the beam to a spot size of about 1 mm in diameter.

cryo supply and current leads connection

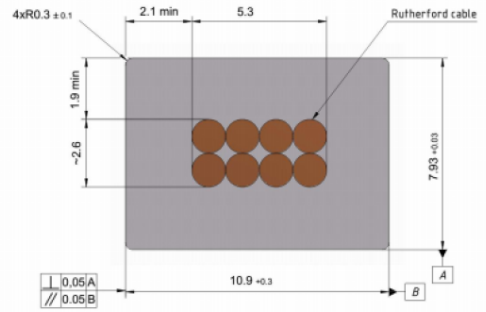


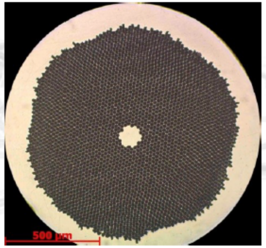
PANDA

Overview

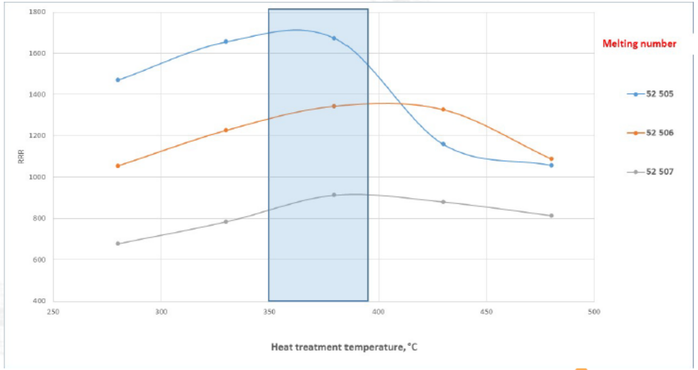


Panda Cable





Parameter	Unit	Certified		1-C2-1P-1-21/1 > 1400 m
		Value	Tolerance	
Diameter filament	μm	< 20	-	
Diameter strand	mm	1.400	± 0.005	
Cu/SC ratio	-	.50/.50	± 0.05	/0.5187
Critical current (at 4.2 K, 5 T)	A	> 2160	-	2220
n-value (at 4.2 K, 5 T)	-	> 30	-	71*
Conductor RRR	-	> 100	-	196
Twist direction	-	left	-	left
Twist pitch	mm	25	± 5	22



Status of Production

- SC strand production started at VNIINM Bochvar
- Extrusion tests at SARKO, tools and heater from BINP
- Contract for Rutherford cable with VNIIKP
- Pure Aluminum available, production of 9 mm wire with VNIINM Bochvar
- Production was to be completed in 2022

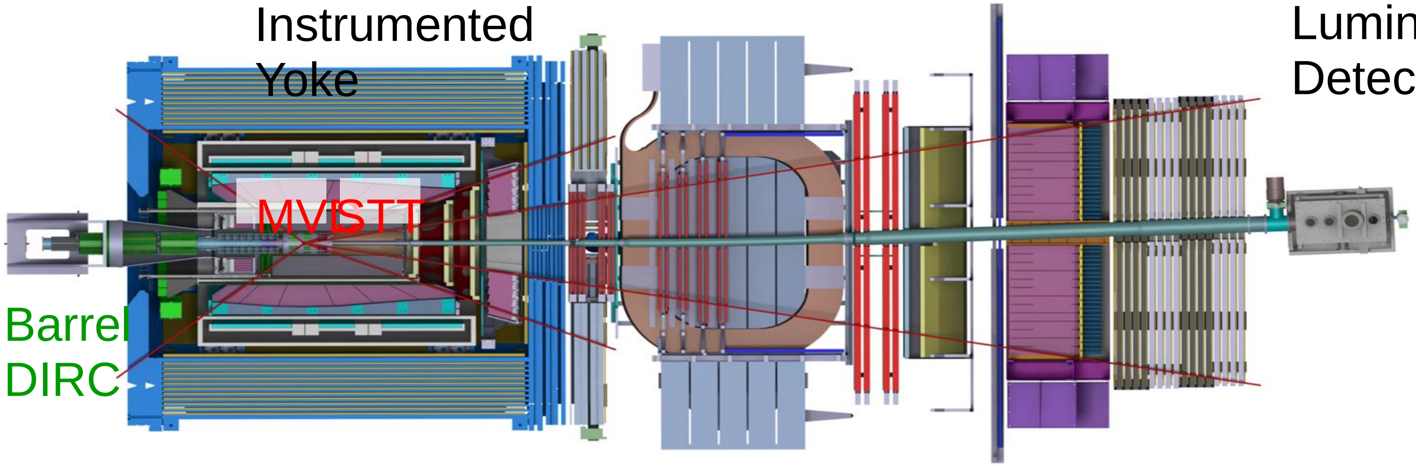
SC Strands

- 1600m sample tested
- All parameters to specs
- High quality of conductor shown by x2 RRR and n

Aluminum Extrusion

- Wire production optimal at 350 – 380°C: RRR>10^3
- First 1000m A95 Cu cable
- SC 80m sample A995
- PANDA conductor 8km

View from top



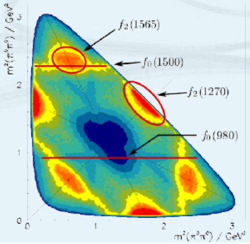
Panda objectives

Bound States of Strong Interaction

Spectroscopy

- New narrow XYZ:
  - *Search for partners*
  - *Measure lineshapes*
- Production of exotic QCD states:

  Glueballs & hybrids of all quantum numbers

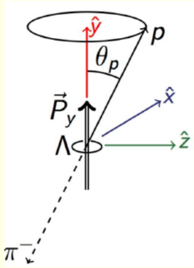


Strangeness

- Hyperon spectroscopy:

  excited states largely unknown
- Hyperon polarisation:

  accessible by weak decay, parity and CP observables



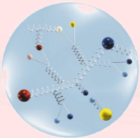
Nucleon Structure

- Generalized parton distributions:

  Orbital angular momentum
- Drell Yan: *Transverse structure, valence anti-quarks*
- Time-like form factors:

  Low and high E, e^+e^- and $\mu^+\mu^-$

  Unphysical region: $e^+e^-\pi^0$



Nuclear Hadron Physics

- Hypernuclear physics:
  - *Hyperatoms*
  - *Double Λ hypernuclei*
  - *YN and YY interactions*
- Hadrons in nuclei:

  Charm and strangeness in the medium