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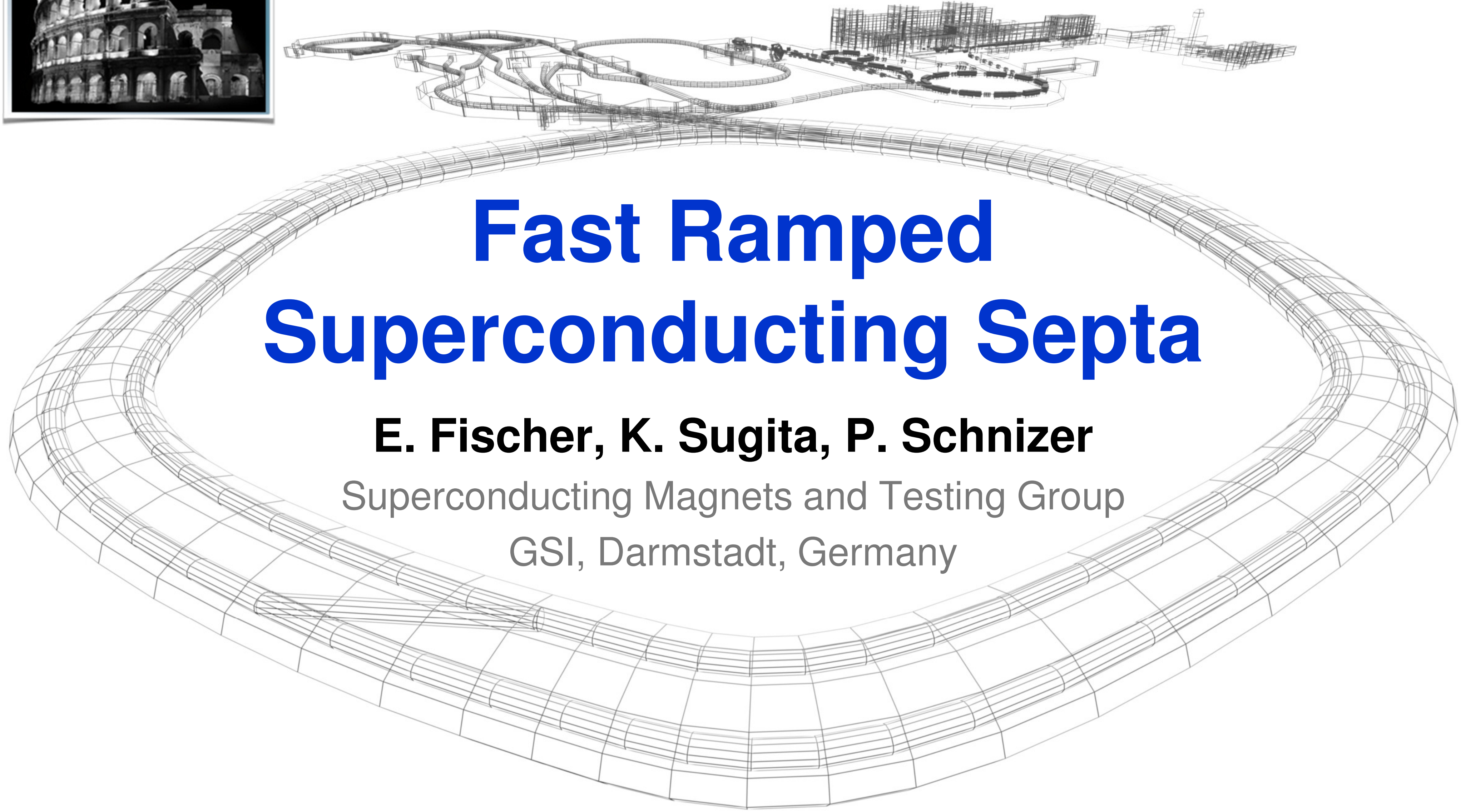

Fast Ramped Superconducting Septa

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Superconducting Magnets and Testing Group

GSI, Darmstadt, Germany

Contents

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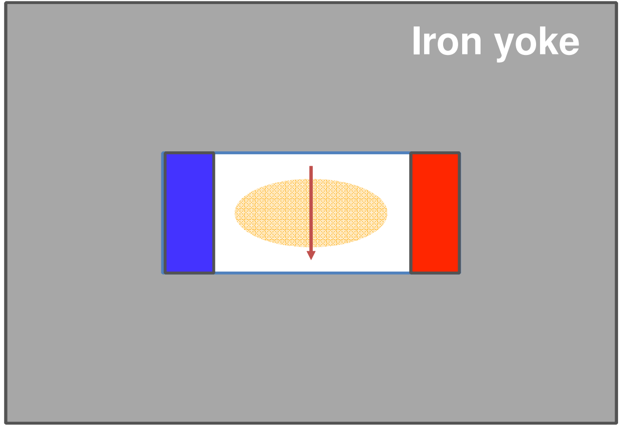
The concept of iron-yoked, truncated cosine-theta septum magnet

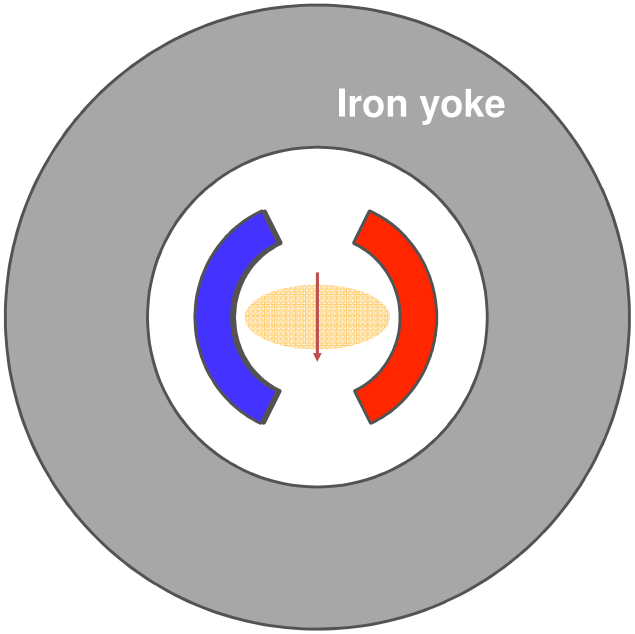
Accelerator dipole magnet

Iron-dominated (Window-frame) Magnet



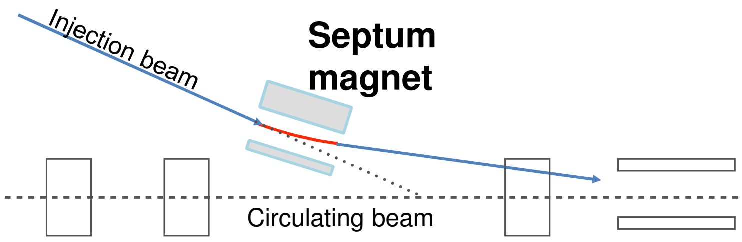
More than
~ 2 Tesla?

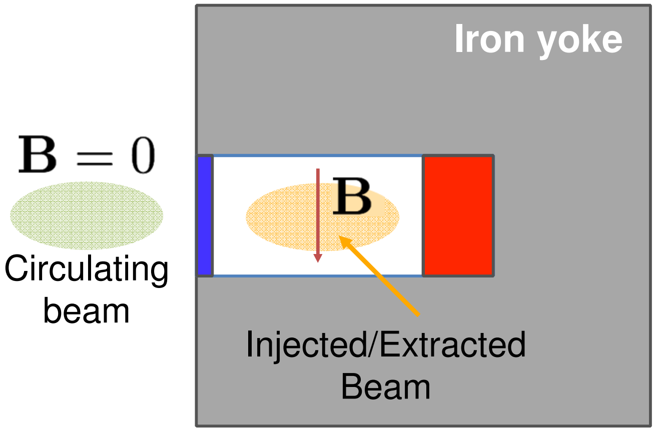
Current dominated, cosine-theta Magnet



Septum magnet

Injection (Extraction) area



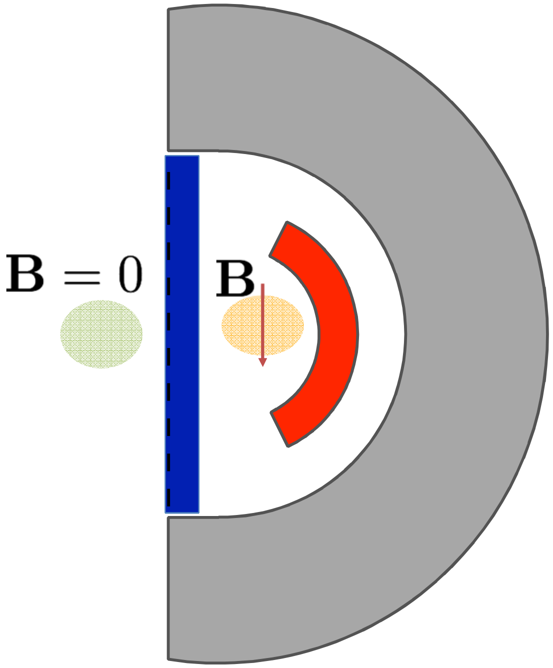


More than
~ 2 Tesla?

?

Introduction

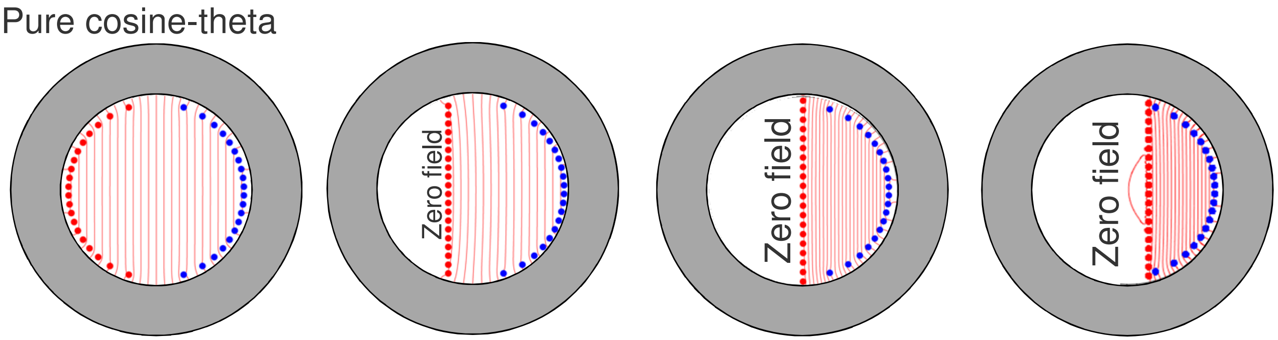
The concept of iron-yoked, truncated cosine-theta septum magnet



Analytical calculations

10 line currents per pole

Iron yoke with infinite permeability (= image current)

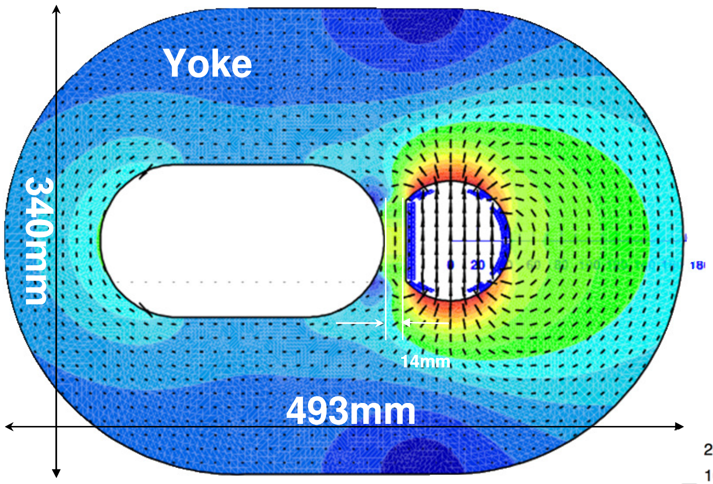


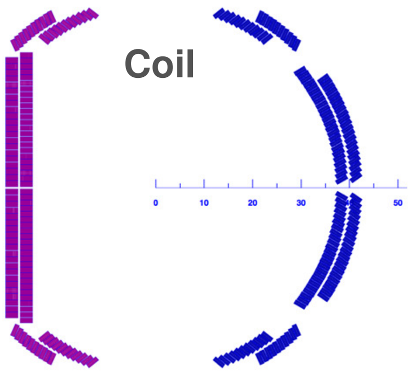
History

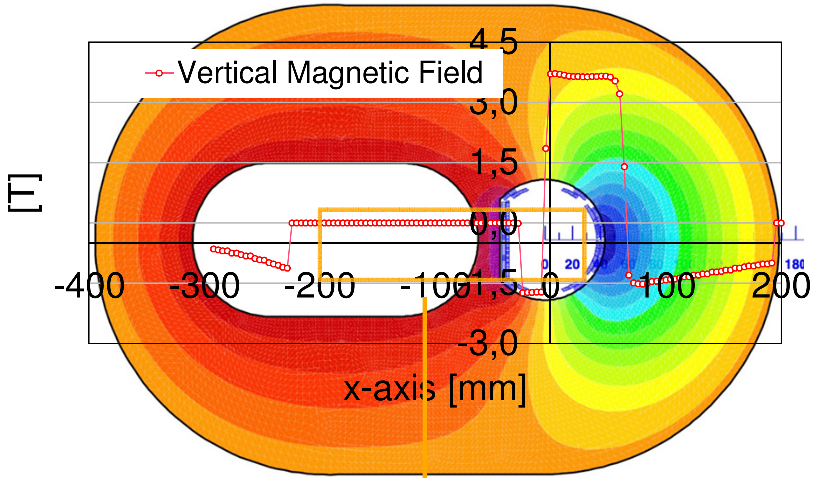
- Invention/International Patent Application (2011)
- International Magnet Technology Conference (2011)
- “Novel Concept of Truncated Iron-Yoked Cosine Theta Magnets and Design Studies for FAIR Septum Magnets”, IEEE Trans. on Appl. Supercond. (2012)
- FCC Week 2015, Session: “Beam Transfer Systems & Instrumentation”
- US Patent: Grant (US9236176, 12 Jan. 2016)

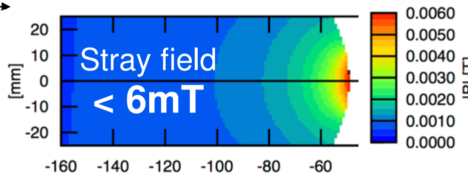
1. Conceptual design studies

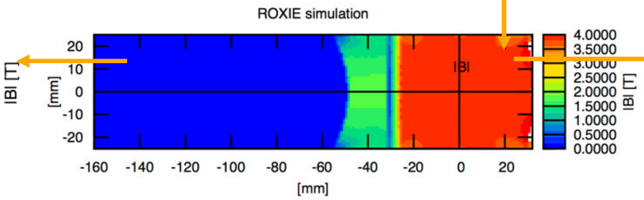
a) 3.5 T Septum Magnet (see FCC Week 2015)

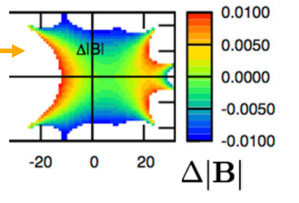








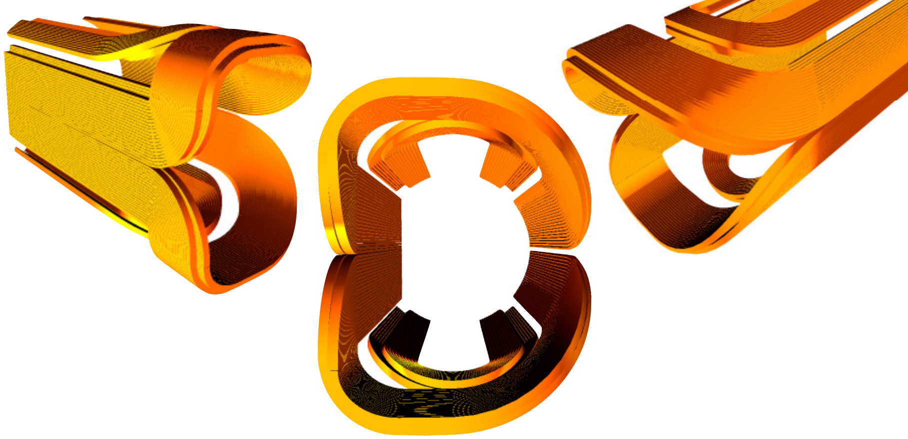




with respect to |B|(0,0)

Parameter	
Coil	2 layers
Flat Rutherford cable	1 mm × 2.5 mm
Strand diameter	0.5 mm
Number of strands	10
Turn per pole	66
Current	1.9 kA
Temperature	4.7 K
Min. temp. margin	>1.2 K

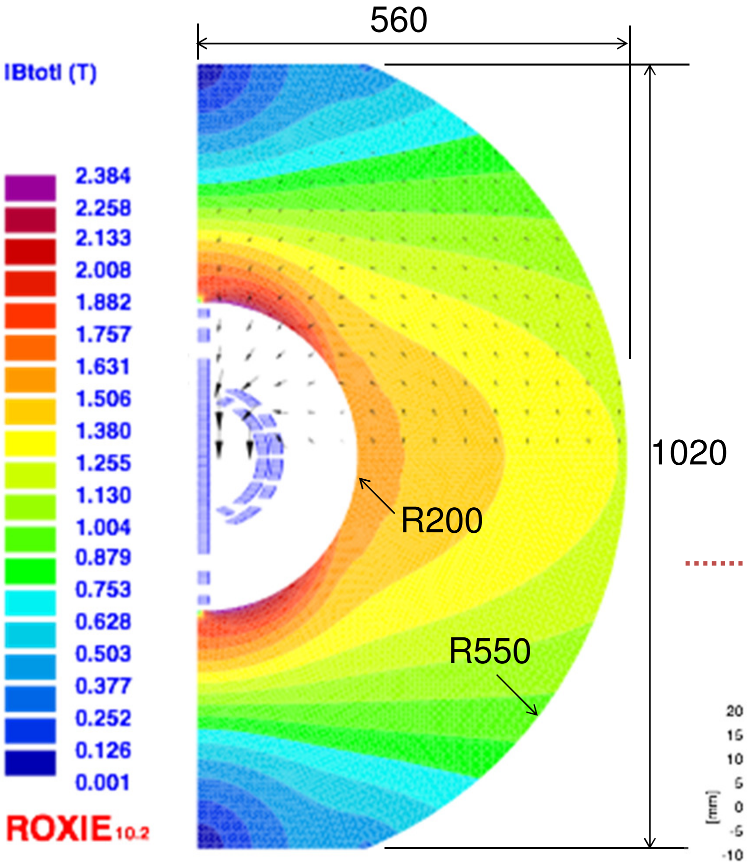
Coil end

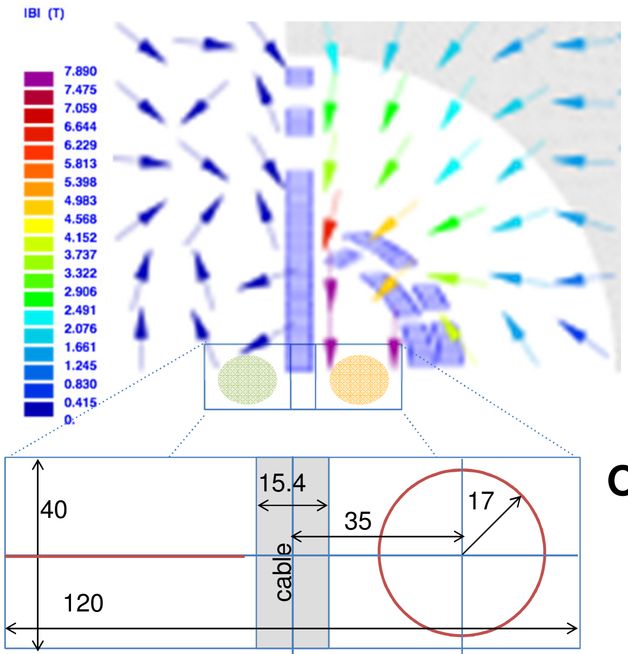


Coil in the yoke

1. Conceptual design studies

b) 8 T Septum Magnet





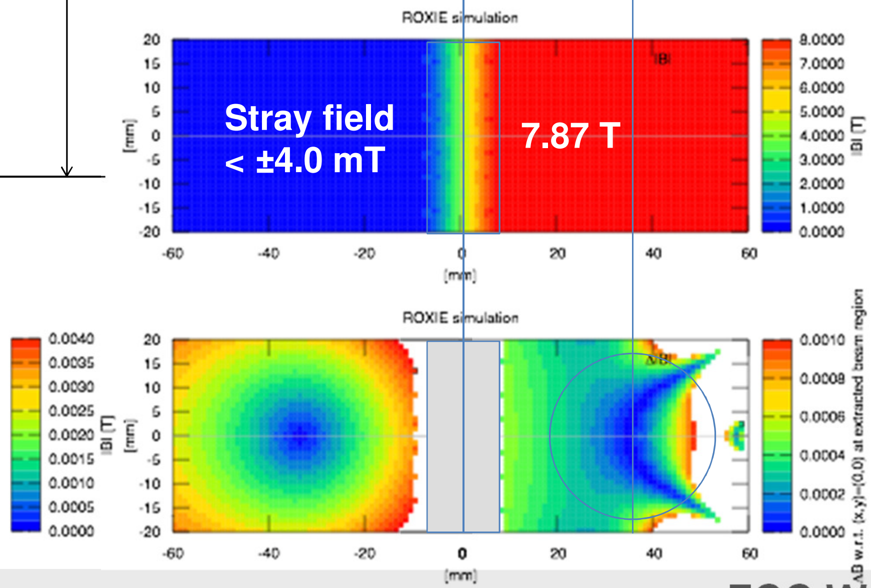
Parameter	
Coil	2 layers / 1 layer
Flat Rutherford cable	15.4 mm × 2.2 mm
Strand diameter	1.605 mm
Number of strands	28
Turn per pole	59
Current	15 kA
Temperature	1.9 K

Optimization (Roxie)

Minimize

Multipole fields at the reference radius

|By| on the x-axis (–210 < x < –10)



Magnetic field gradient in the coil

7.87T/15.4mm ~ 500 T/m

Multipole coefficient

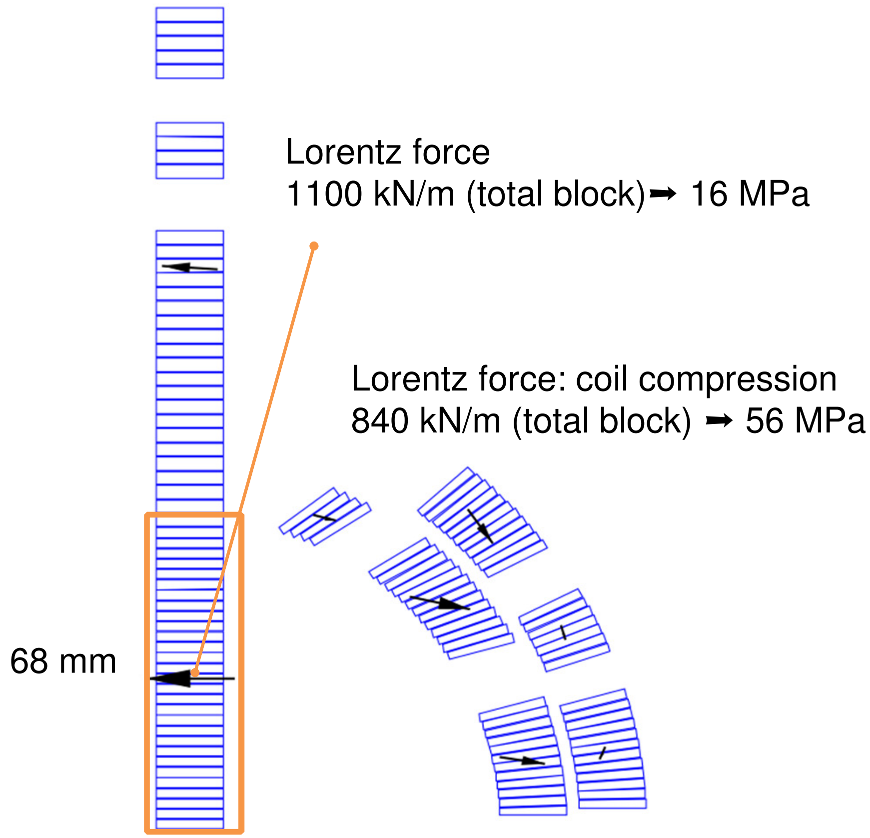
R=17mm, w.r.t B1=1000

b2	b3	b4	b5	b6
6.48	5.29	3.13	-0.12	-1.58

1. Conceptual design studies

b) 8 T Septum Magnet

Lorentz force

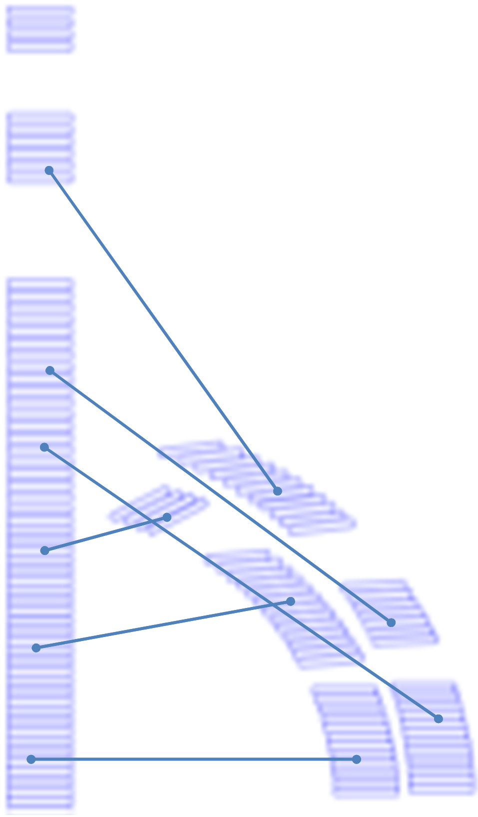


Lorentz force
1100 kN/m (total block)➡ 16 MPa

Lorentz force: coil compression
840 kN/m (total block) ➡ 56 MPa

Asymmetric Lorentz forces have to be maintained by reinforced mechanical structure.

Coil end design



Transition of two-layer to one-layer coil requires complexity of the end design.

2. Design Versions with NTC

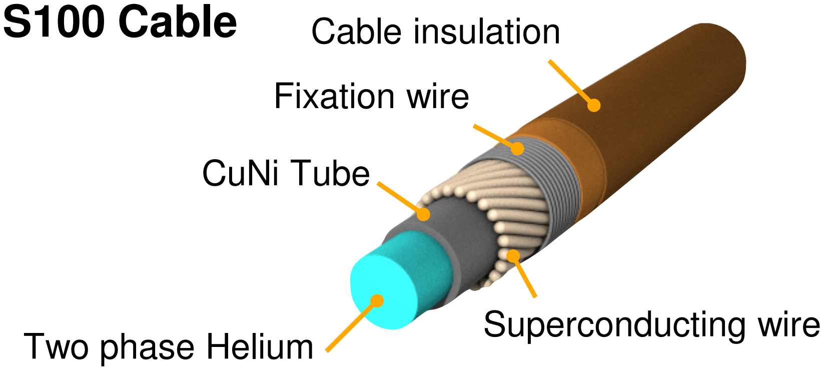
a) Fast ramped superconducting magnets of the FAIR and NICA projects

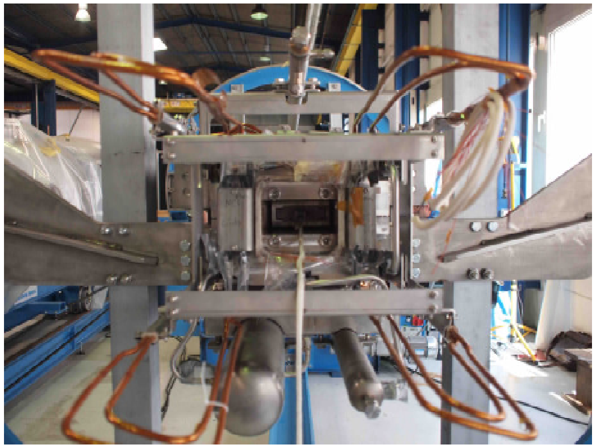
Nuclotron Cable Technology

Advantage: Cooling ➡ Fast ramped magnet

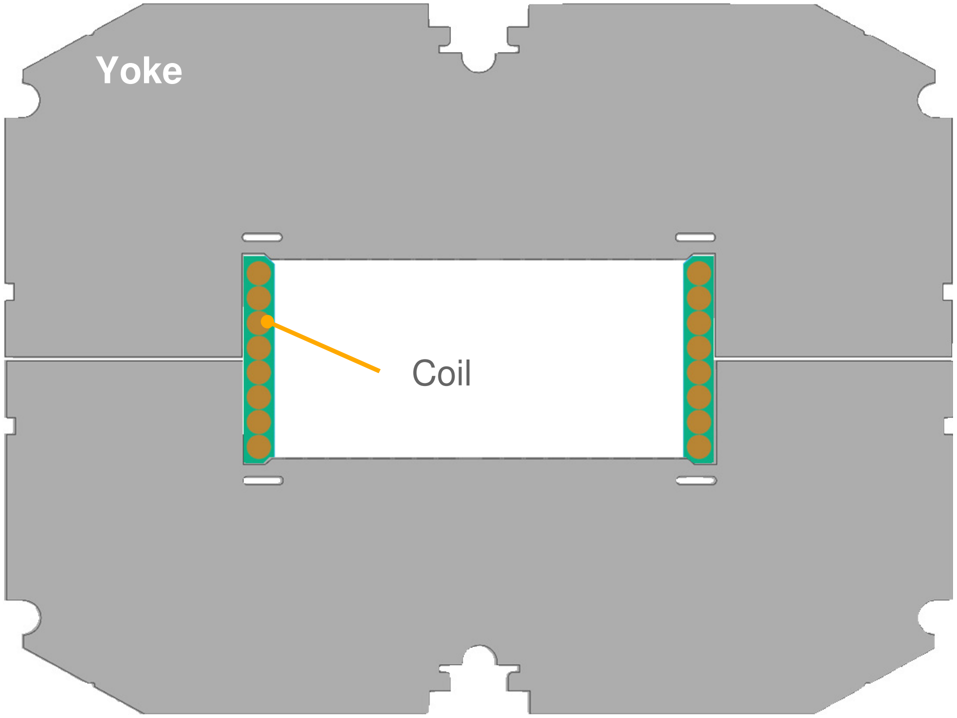
Nuclotron, SIS100, NICA

SIS100 Cable





SIS100 Dipole Cross Section



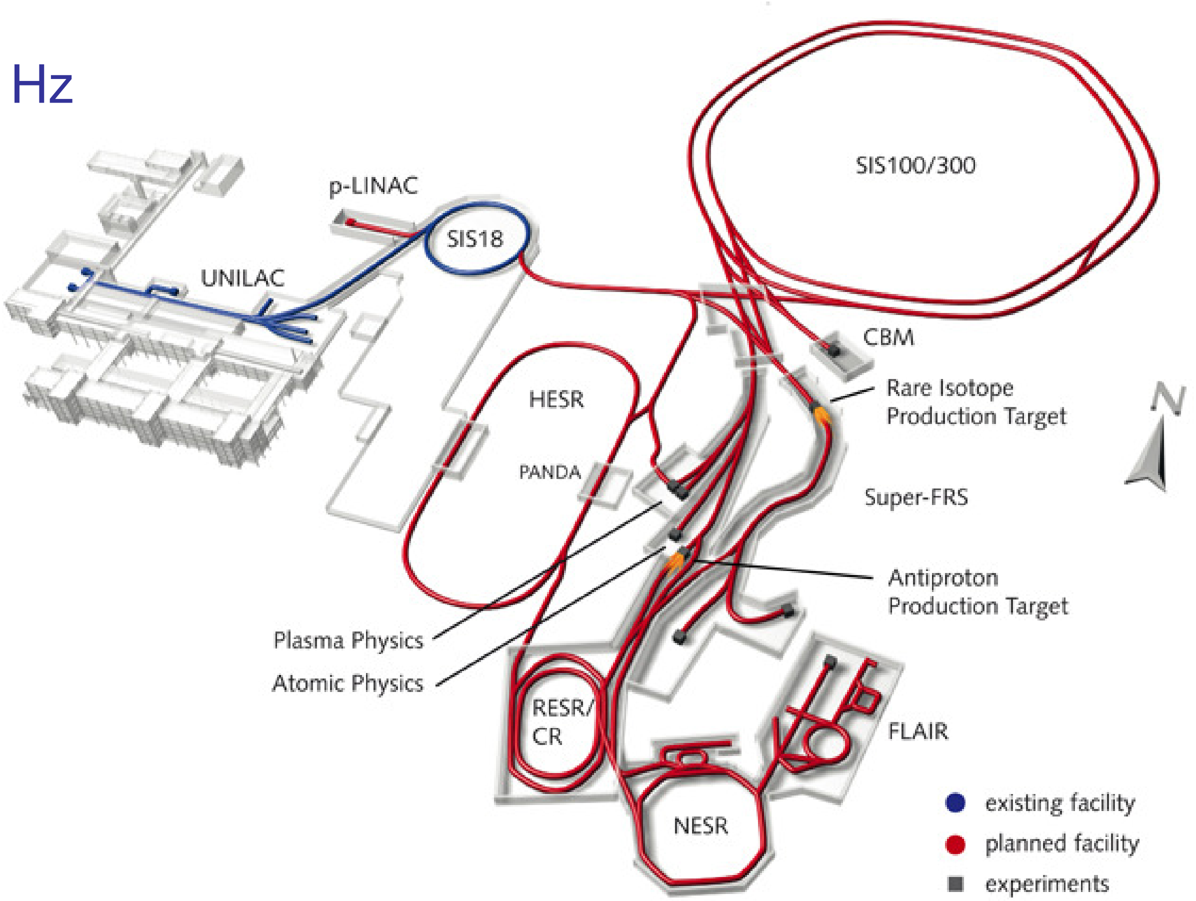
Parameter	
Field strength	1.9 T
Current	13.1 kA
Ramp rate	4 T/sec. ➡ 27.6 kA/sec.

2. Design Versions with NTC

a) Fast ramped superconducting magnets of the FAIR and NICA projects

- **Heavy Ion Synchrotrons with superconducting magnets**
- **SIS100 – the core component of FAIR**

- 100 Tm rigidity
- B_{max} = 1,9 T, $^{dB}/_{dt}$ = 4 T/s, f_{cycle} = Hz
- 1100 m circumference
- sc dipoles
- sc quadrupoles
- sc correctors
- cold beam pipe:
  vacuum quality critical for beam life time: < 10^{-12} mbar

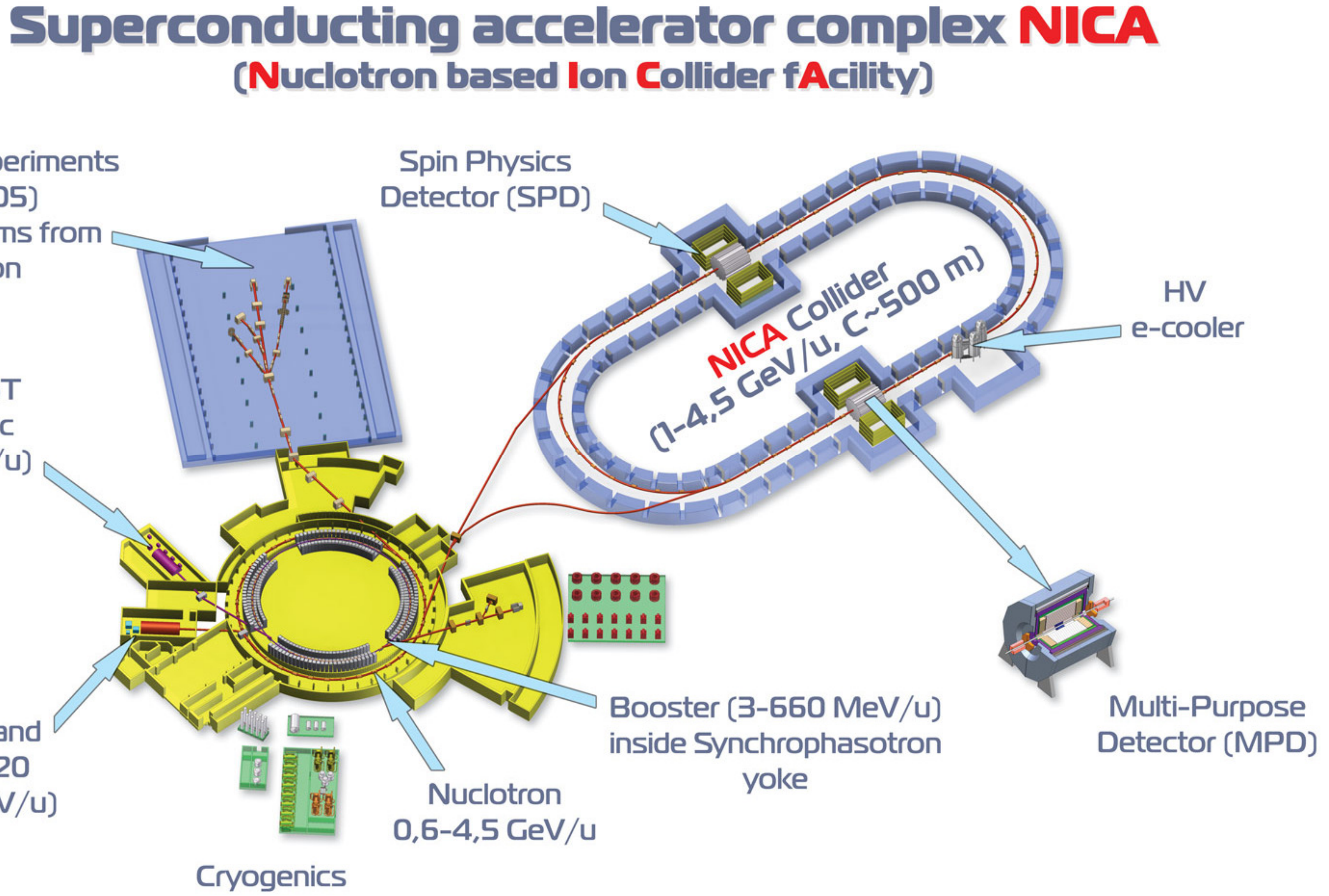


- **SIS300 – project phase B**

- 300 Tm rigidity
- B_{max} = 4,5 T, $^{\mathbf{dB}}/_{\mathbf{dt}}$ **= 1 T/s**
- sc dipoles
- sc quadrupoles
- sc correctors

2. Design Versions with NTC

a) Fast ramped superconducting magnets of the FAIR and NICA projects



Superconducting accelerator complex NICA

(Nuclotron based Ion Collider fAcility)

Fixed target experiments area (b.205) Extracted beams from Nuclotron

Spin Physics Detector (SPD)

HV e-cooler

KRION-6T and HILac (3,5 MeV/u)

SPP and LU-20 (5 MeV/u)

Cryogenics

Nuclotron 0,6-4,5 GeV/u

Booster (3-660 MeV/u) inside Synchrophasotron yoke

Multi-Purpose Detector (MPD)

2. Design Versions with NTC

a) Fast ramped superconductiong magnets of the FAIR and NICA projects

Comparison of the Main Dipoles	GSI	NICA	NICA	
	SIS100	*Booster*	*Collider*	
cable				
tube inner diameter	4.7	3	3	mm
number of strands	21	18	16	
critical current (at 2.5 T and 4.5 K)	19.8	14.2	16.8	kA
dipole				
field strength	1.9	1.8	1.8	T
→ field ramp rate	4	1.2	≤ 0.5	T/s
pole gap height	68	64	70	mm
→ magnet length	3.1	2.2	1.94	m
curvature radius	52.625	14.090		m
operation current	13.1	9.68	10.4	kA
inductance	0.55	0.63	0.45	mH
→ maximum AC loss	100	8.4	8	W

2. Design Versions with NTC

a) Fast ramped superconductiong magnets of the FAIR and NICA projects

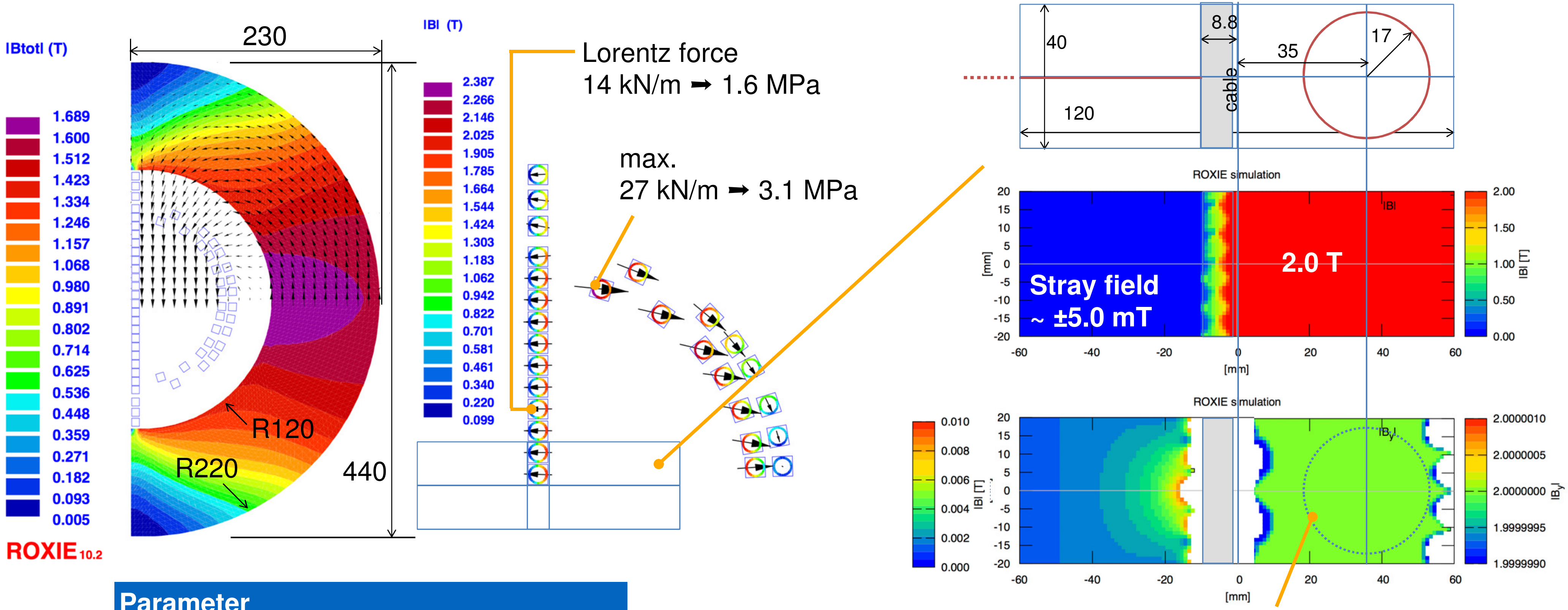
Basic Topics and Design Aspects:

- ✓ Superconducting → high current density
- ✓ Accelerator Magnets → high magnetic field quality
- ✓ Fast ramped → sc cable quench stability
- ✓ High repetition frequency → Cooling conditions
  → stable high heat removal ,
  → mechanical stability of the coil
- ✓ Nucloton type cables and corresponding cooling principles are effective for fast ramped superconducting accelerator magnets. They can be applied in a wide range of critical fields, operation cycles and magnets designs.

  (► see also next presentation in this session)

2. Design Versions with NTC

b) Design of a 2 T septum magnet with Nuclotron Type Cable



Lorentz force
14 kN/m ➡ 1.6 MPa

max.
27 kN/m ➡ 3.1 MPa

2.0 T

Stray field
~ ±5.0 mT

Roxie optimization works very well!

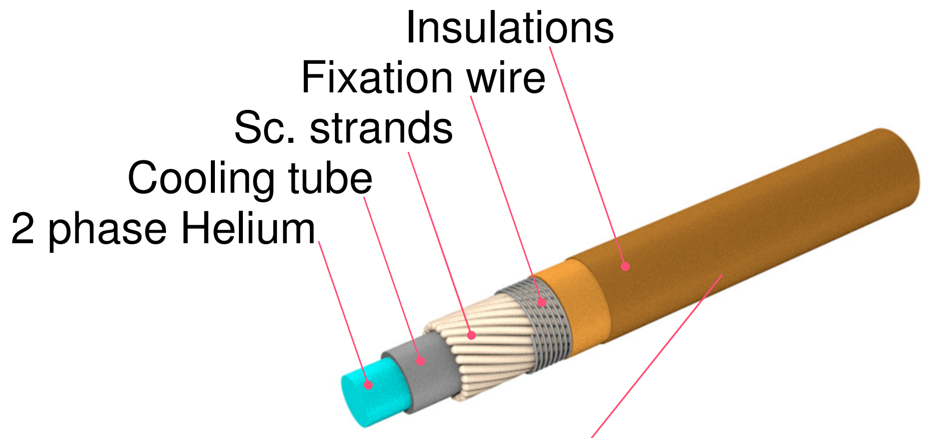
b2	b3	b4	b5	b6
-0.048	-0.082	0.021	-0.831	-0.480

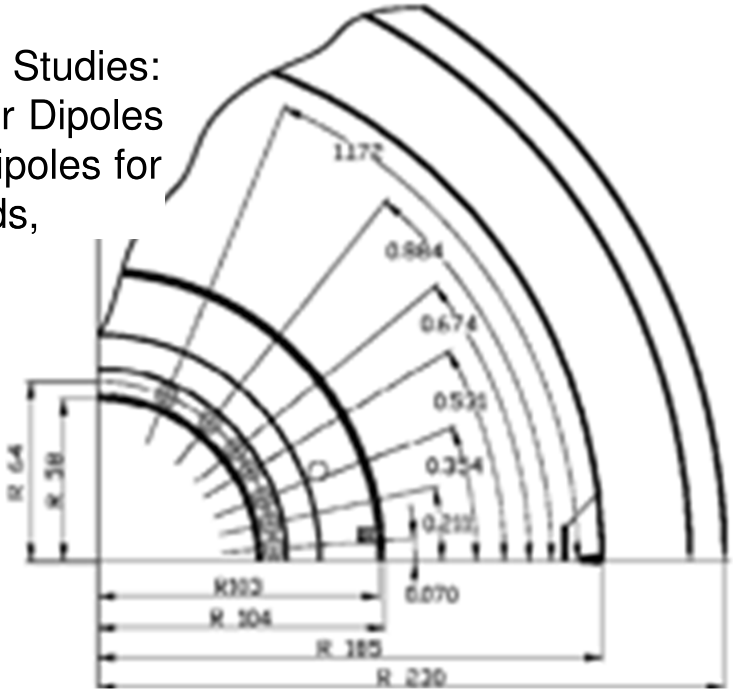
Parameter	
Coil	2 layers / 1 layer
Nuclotron cable	SIS100 cable
Strand diameter	0.8 mm
Number of strands	23
Turn per pole	14
Current	13.3 kA
Temperature	4.7 K

Since the peak field is higher than SIS100 dipole (1.7 ➡ 2.4 T),
4 T/sec. may not possible (due to high AC Loss).
Further studies (incl. hydraulic calculations) are necessary.

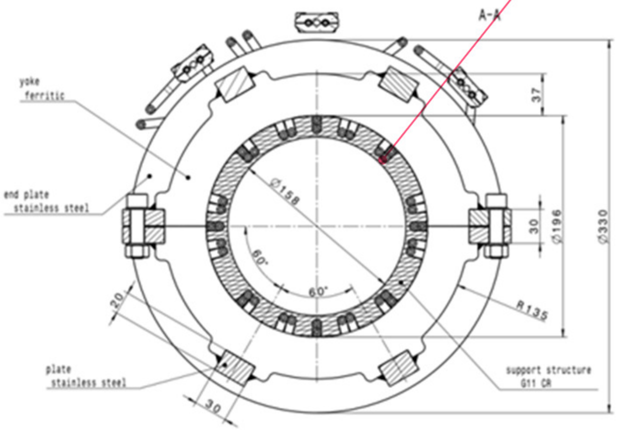
2. Design Versions with NTC

c) Further Options with Nuclotron type cables



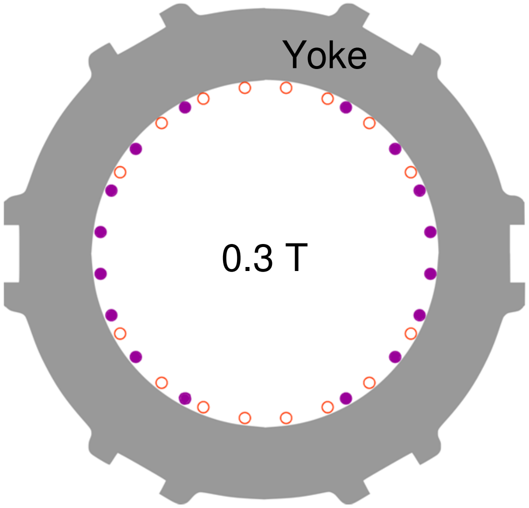


GSI-JINR Design Studies:
4.0 T Single Layer Dipoles
and Two layer Dipoles for
higher fields,

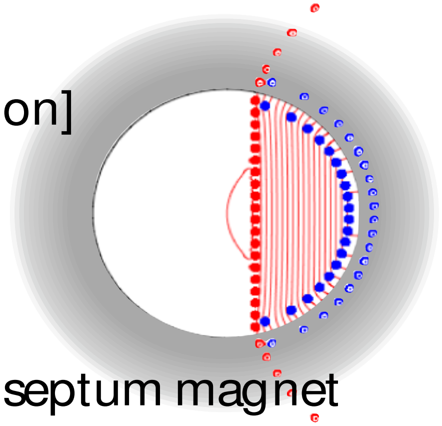


Yoke

SIS100 Multipole corrector
Cosine-theta type (nested)



SIS100 Steering Magnet
Cosine-theta type (H/V nested)



[Design Option]

Fast-Ramp,
Truncated,
Iron-yoked,
cosine-theta septum magnet

2. Design Versions with NTC

c) Further Options for high field magnets

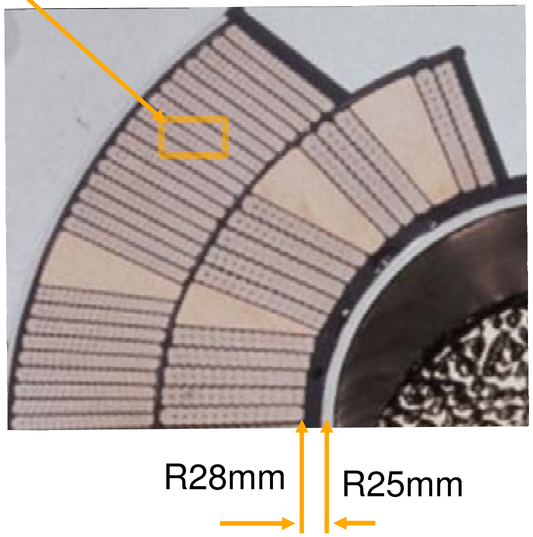
Application for high field magnets

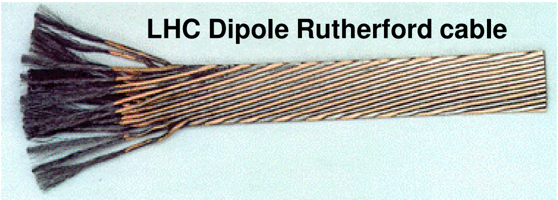
Disadvantage: Low engineering current density

…Really?

Here? Yes.

Cross section of LHC Dipole

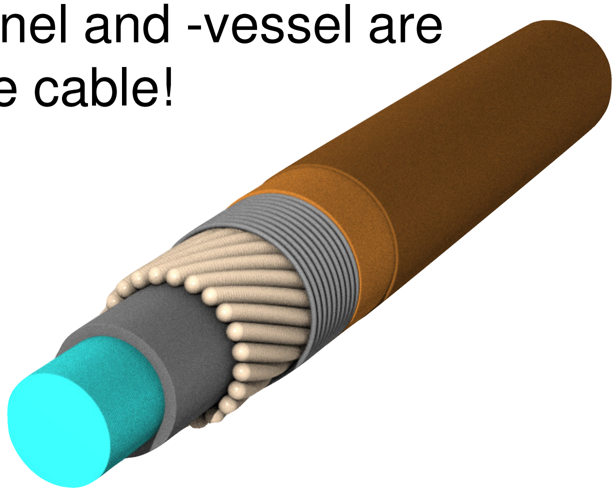



LHC Dipole Rutherford cable

Necessary for the helium channel and vacuum vessel

Nuclotron cable

Helium-channel and -vessel are already in the cable!



2. Design Versions with NTC

c) Further Options for high field magnets

Application for high field magnets

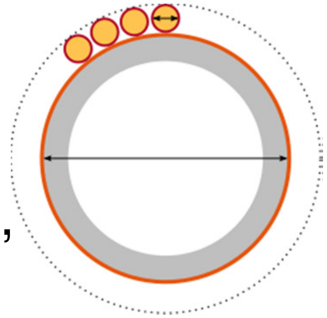
Disadvantage: Low engineering current density

In case of “High field” but “DC magnet”

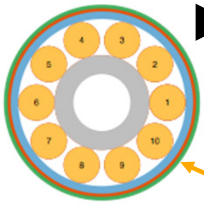
➡ Low AC losses ➡ Smaller helium channel ➡ High engineering current density

Engineering current density defined by cable geometry

Mainly outer diameter of the cooling tube and strand diameter.



10 strands
Cooling tube diameter: 2.5 mm
Strand diameter: 0.95 mm
Strand transposition pitch: 50 mm
Cable diameter: 5.16 mm

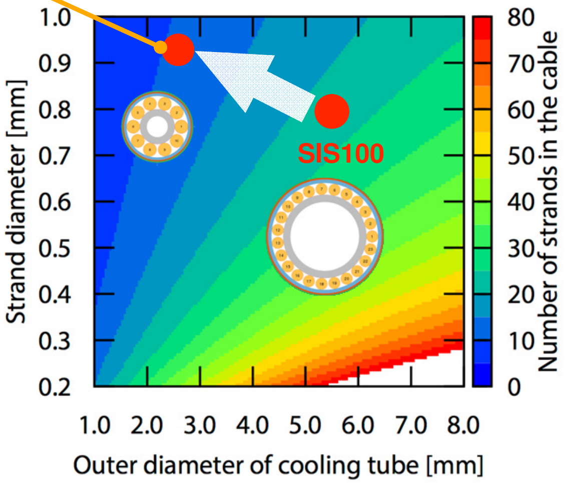


► or even key stoned strands, with/without inner tube!

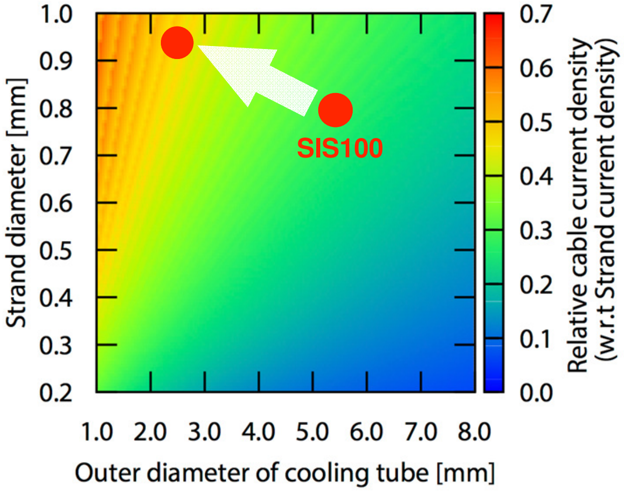
Relative engineering current density ~0.5
(cf. SIS100 Cable 0.27, Strand 1.0)

Competitive!

How many strands in the cable?



Relative engineering current density

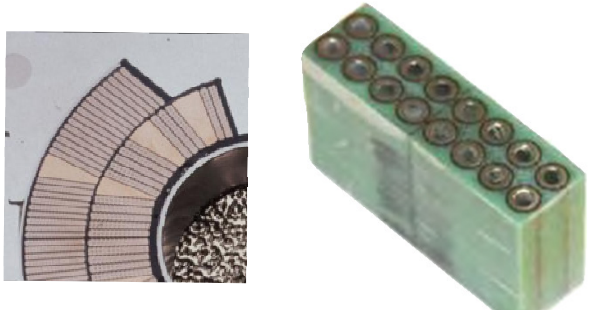


2. Design Versions with NTC

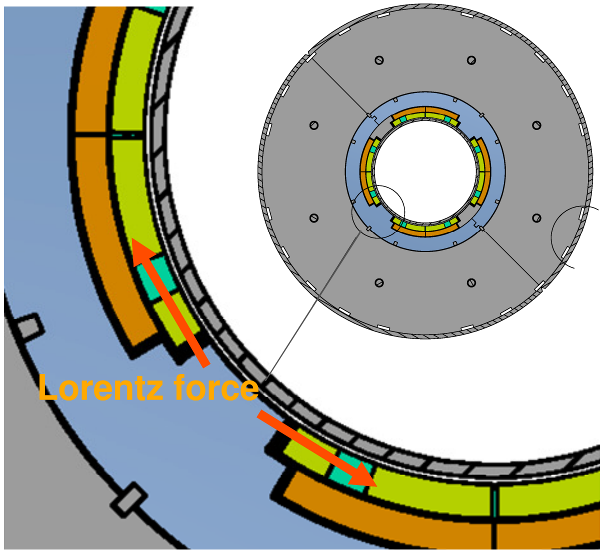
c) Further Options for high field magnets

Advantage compare with Rutherford cable, **especially for large aperture magnets** (incl. septa)

Mechanical stability



Youngs modulus:	5-10 GPa	~50 GPa
Thermal contraction coefficients:	0.005	0.002



Final focusing quadrupole for the High Energy Density Matter Generated by Heavy Ion Beams (HEDgeHOB) at FAIR

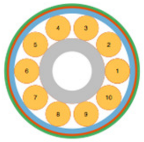
Without additional Helium channel und -vessel

Less Helium,-material, weight

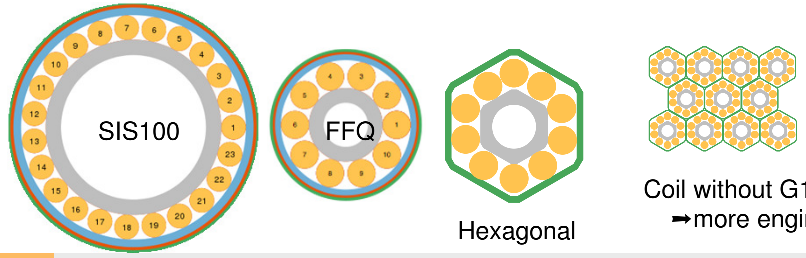
➡**Cost effective!**

Transport, cool-down/warm-up time…

Alternative design with Nuclotron cable

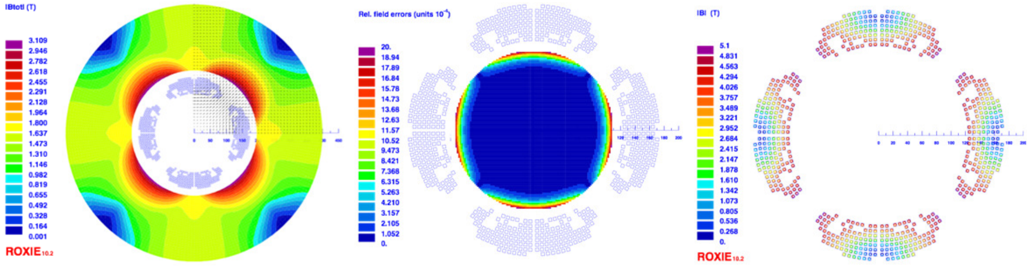


Further cable R&D is necessary…



Hexagonal

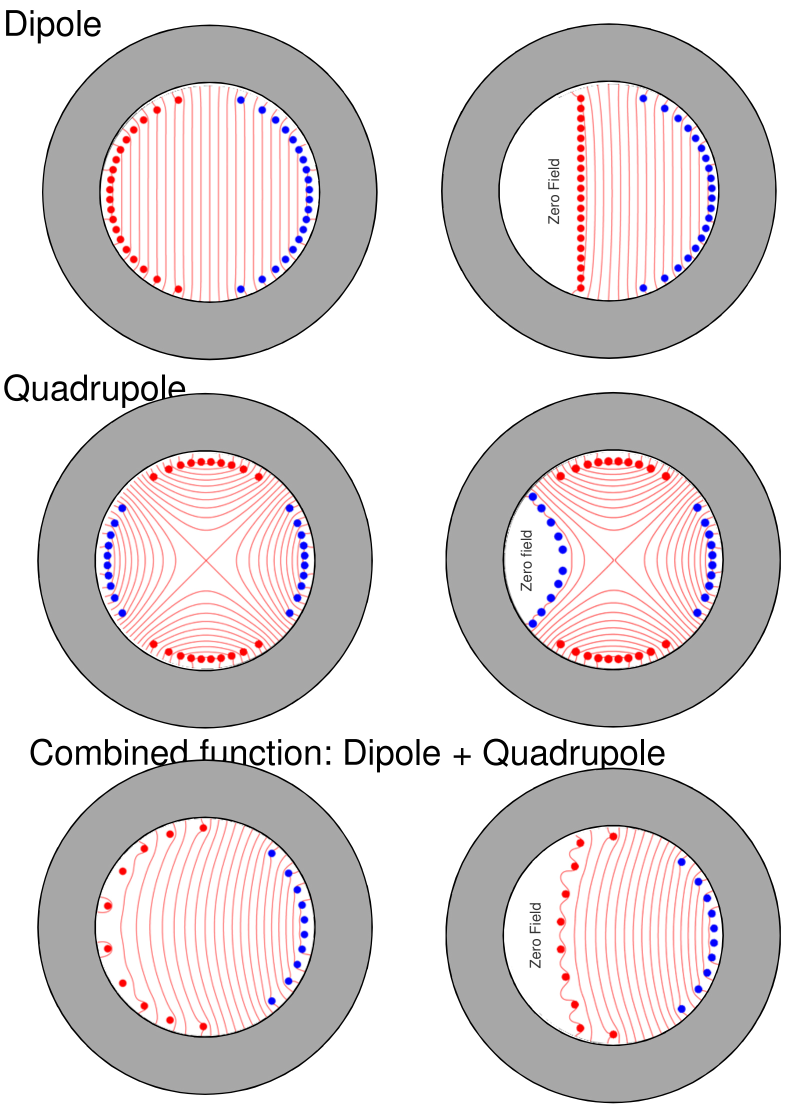
Coil without G11 structure
➡more engineering current density



2. Further Design Options

Quadrupole, Combined function septum magnet

Quadrupole, higher multipole,
and combined function septa are possible.



Not only for superconducting magnets
but also for conventional normal-conducting magnets!

Summary

- Design studies on SC septa with iron-yoked, truncated cosine-theta concept is ongoing.
- 8 T, 2D design study shows the feasibility.
- For fast ramped SC septa, a Nuclotron cable has advantage for the cooling and will be suitable candidate.
- Coil end has inevitably complicated 3D structure.
    - Rutherford cable: bending direction “hard-way” and “soft-way”.
    - Nuclotron cable: no difference of bend direction

Summary

Next tasks:

- Detailed design study
  - 3D coil end design
  - Mechanical structure design and the analysis
    - Assembly, cool-down, powering (Lorentz forces)
- Cable design study and R&D
  - Nuclotron cable for high field magnets
  - Test cabling, prototype coil winding
- Prototype magnet assembly and testing

Target parameters, physical boundary conditions (available space, coolant, powering system…) are to be definded for further studies.