# Status of truncated cosine-theta septum magnet study

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- GSI and FAIR project
- Overview of the concept
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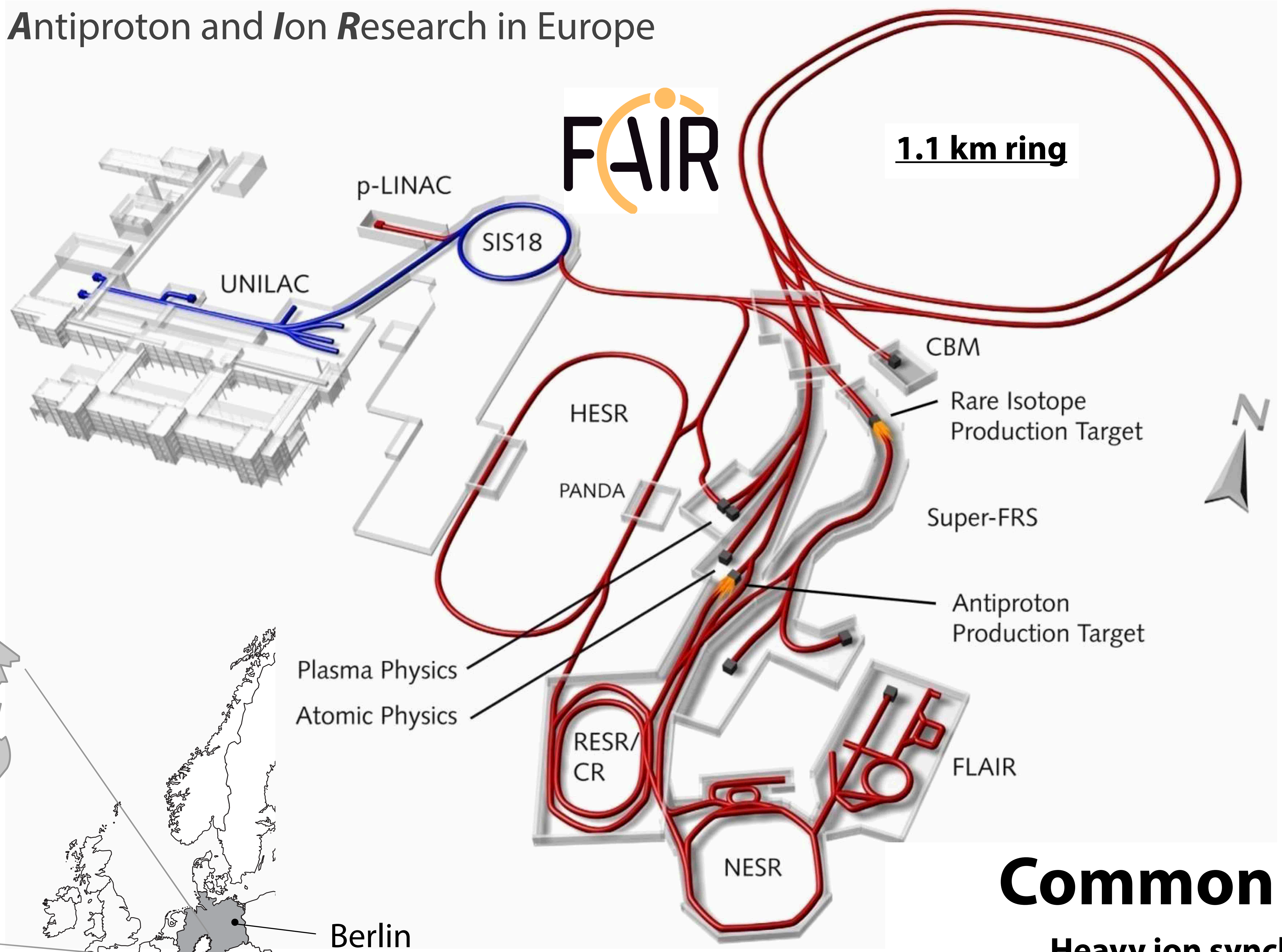
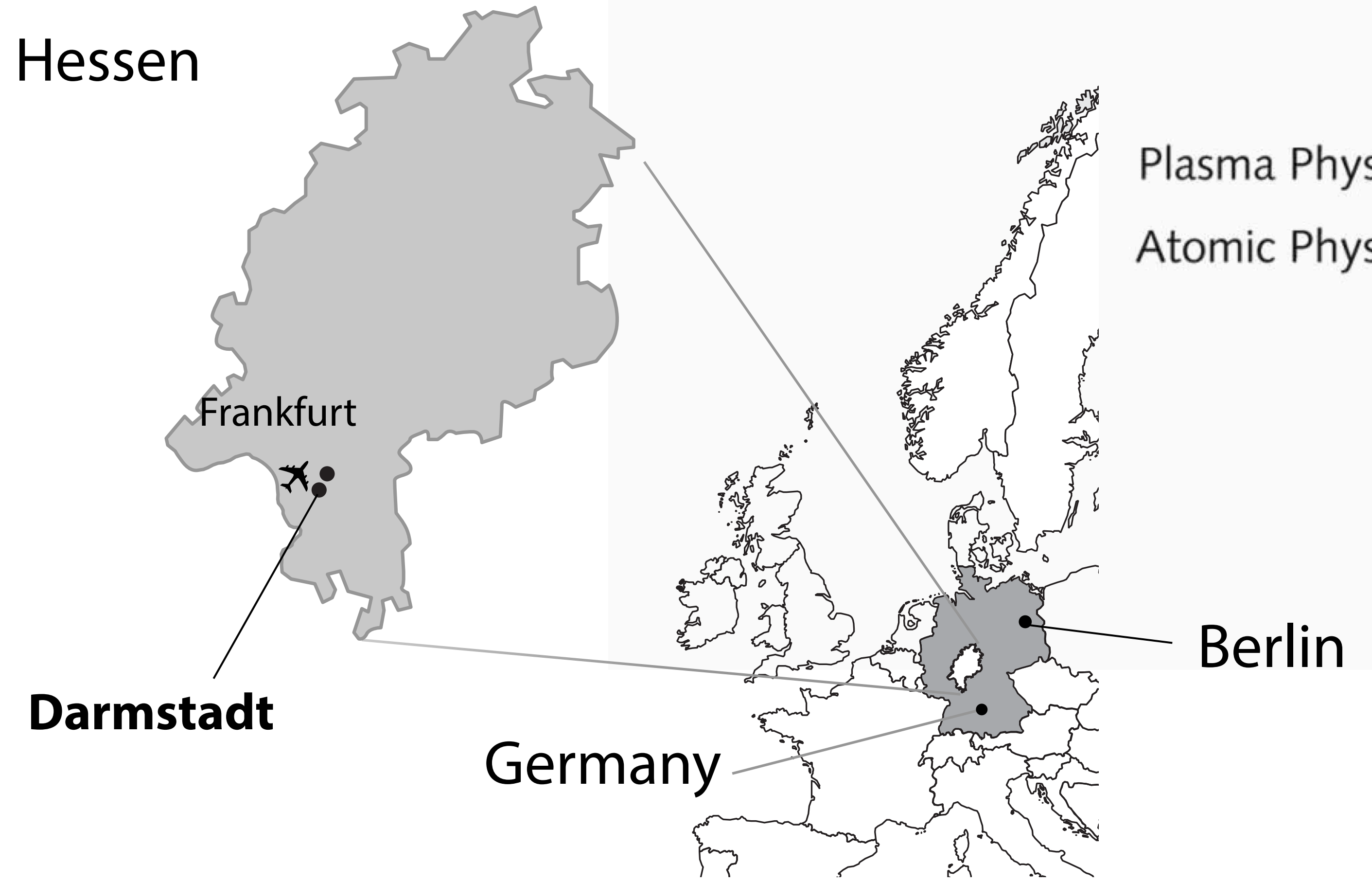
- 2D magnetic design
- 2D engineering design
- 3D coil end design
- Summary and future work

# GSI and FAIR project

- FAIR
  - ***F**acility for **A**ntiproton and **I**on **R**esearch in Europe*




## Superconducting magnets & testing

**Heavy ion synchrotron SIS100**
(Beam rigidity 100 Tm)
**108 Dipoles**
**Series production and testing steadily** ongoing
**166 Quadrupoles + more than 140 correctors**
**First of Series production and testing successfully** done
Preparation of **series production and testing**

**Super Fragment Separator (Super-FRS)**
**24 Dipoles**
Contracted. **Final Design Review** soon.
**76 Quadrupoles + more than 90 correctors**
**First of Series production** ongoing
**Testing** by CERN-GSI collaboration starts soon.

# Common interest on Sc Septum magnet

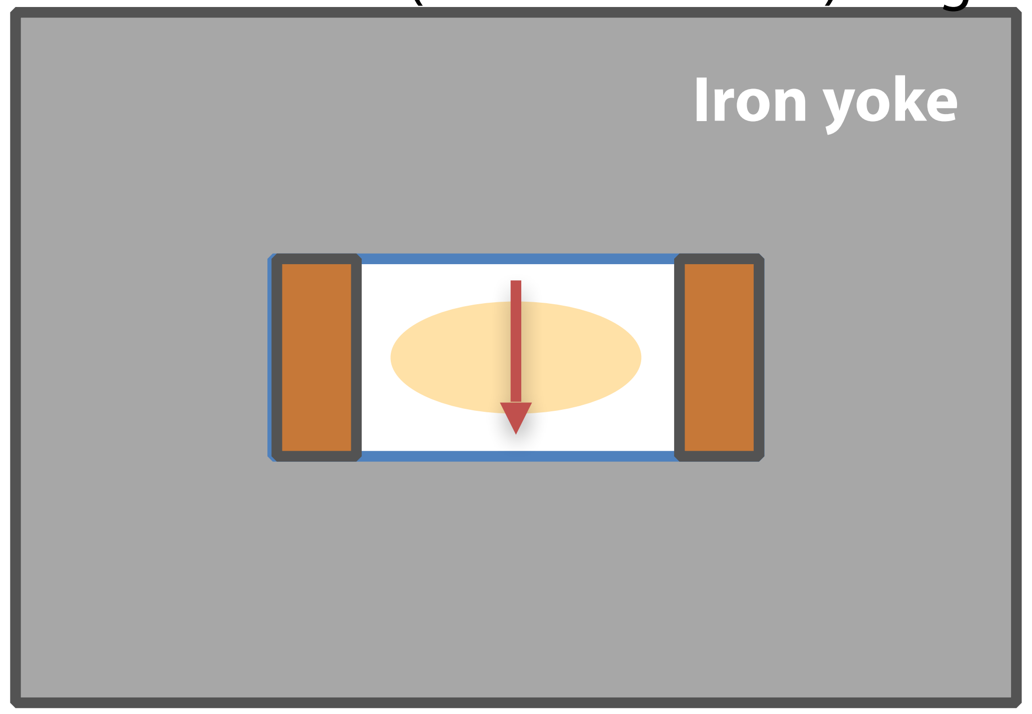
**Heavy ion synchrotron SISx00 (Beam rigidity x00 Tm)**
**Superconducting septum magnet: 3.6 T (x=3), 4.8 T (x=4)**
**Superconducting septum magnet: 4 T**

# Overview of the concept

- Concept

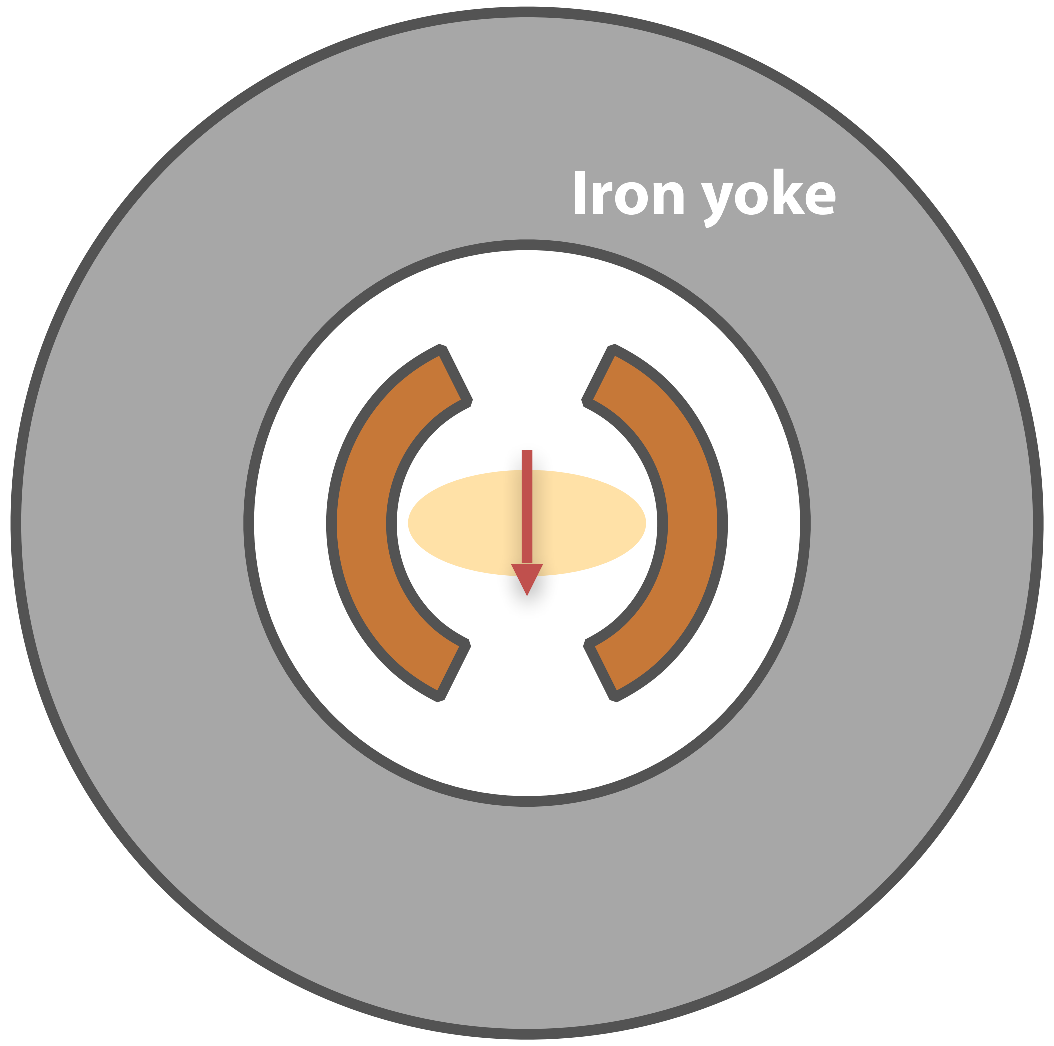
**Dipole magnet**

Iron-dominated (Window-frame) Magnet

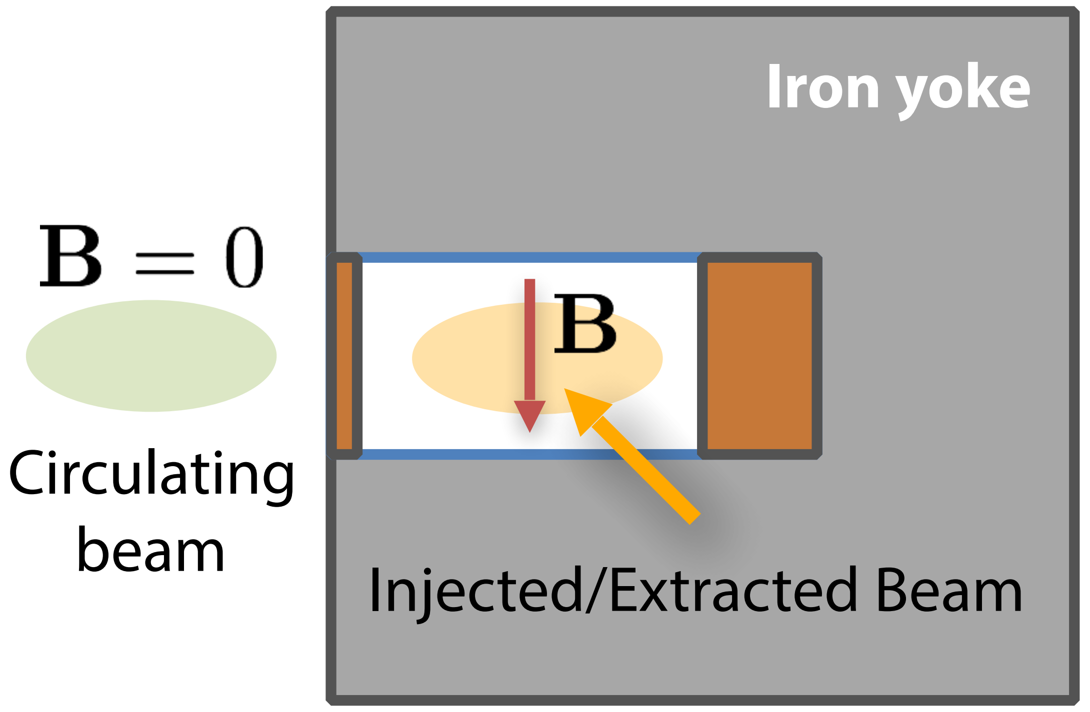



*More than ~ 2 Tesla*

Current dominated, cosine-theta Magnet

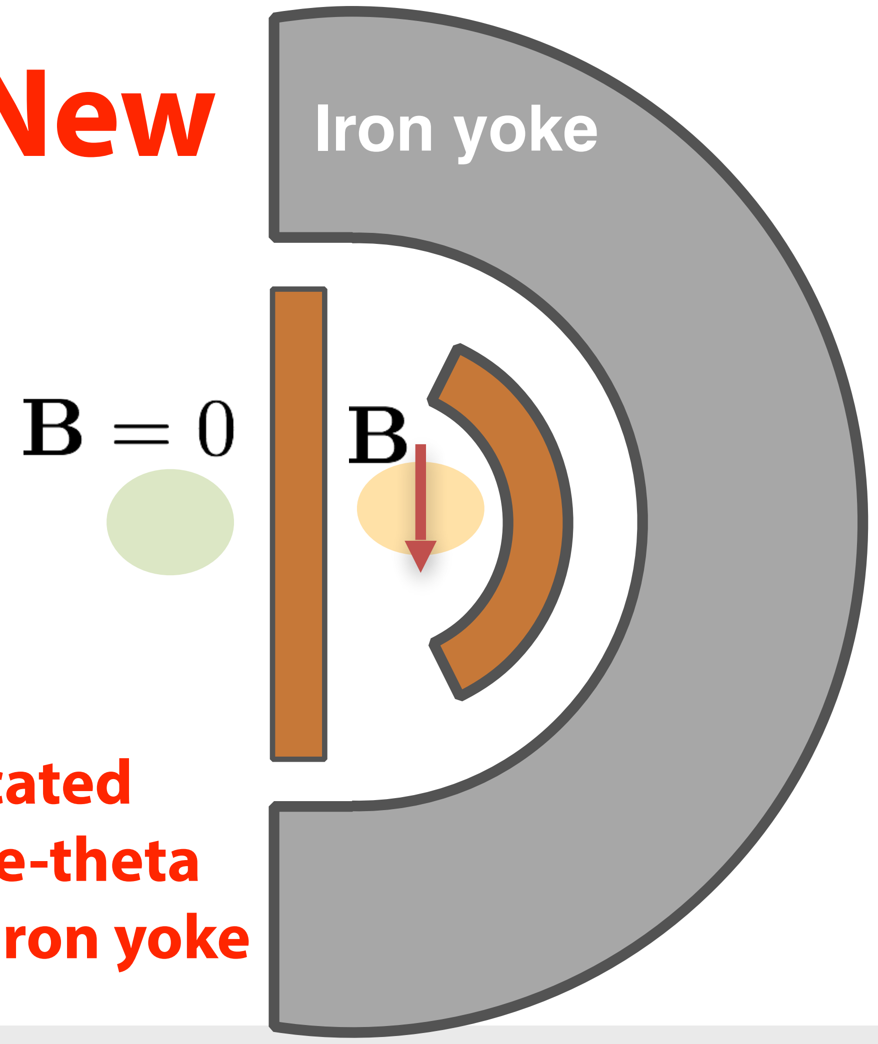



**Septum magnet**




*More than ~ 2 Tesla*

**New**



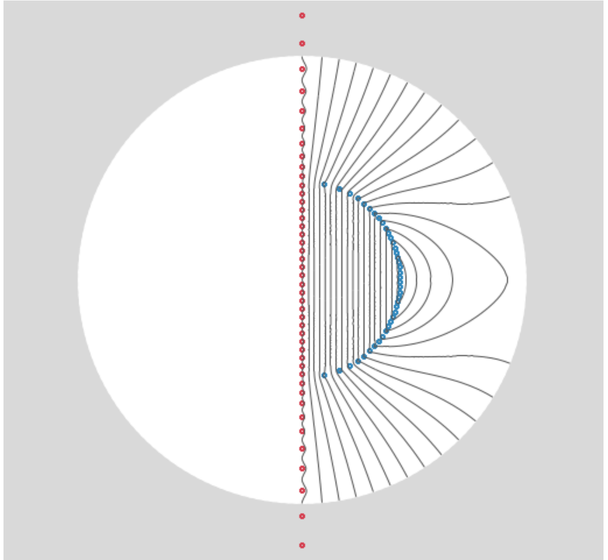

**Truncated cosine-theta with iron yoke**

**Presented in**

***FCC Week 2015***
https://indico.cern.ch/event/340703/contributions/802239/

***FCC Week 2016***
https://indico.cern.ch/event/438866/contributions/1085009/

***FCC Week 2017***
https://indico.cern.ch/event/556692/contributions/2488389/

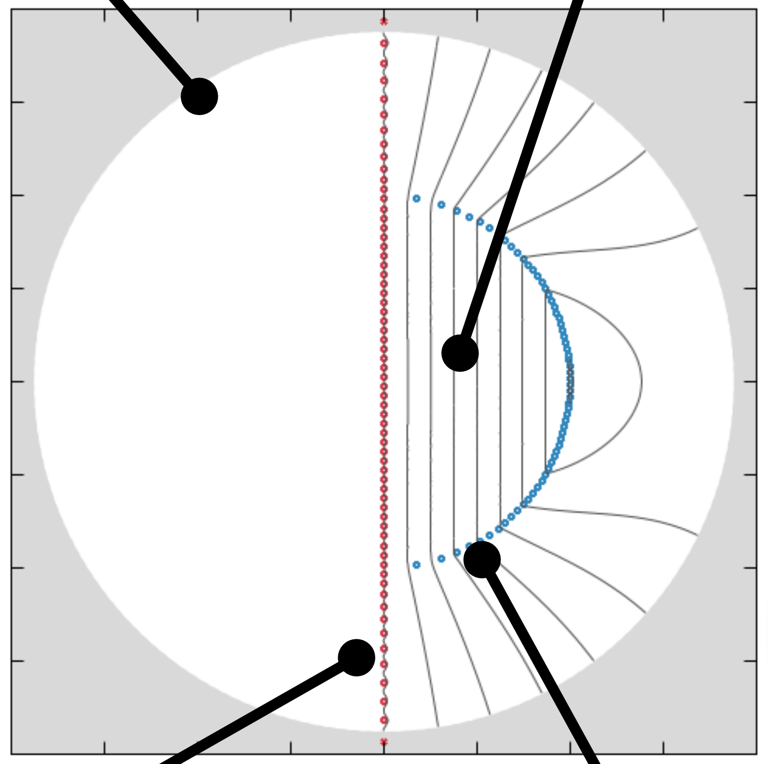


## Analytical design with line currents & image currents

**Parameters**

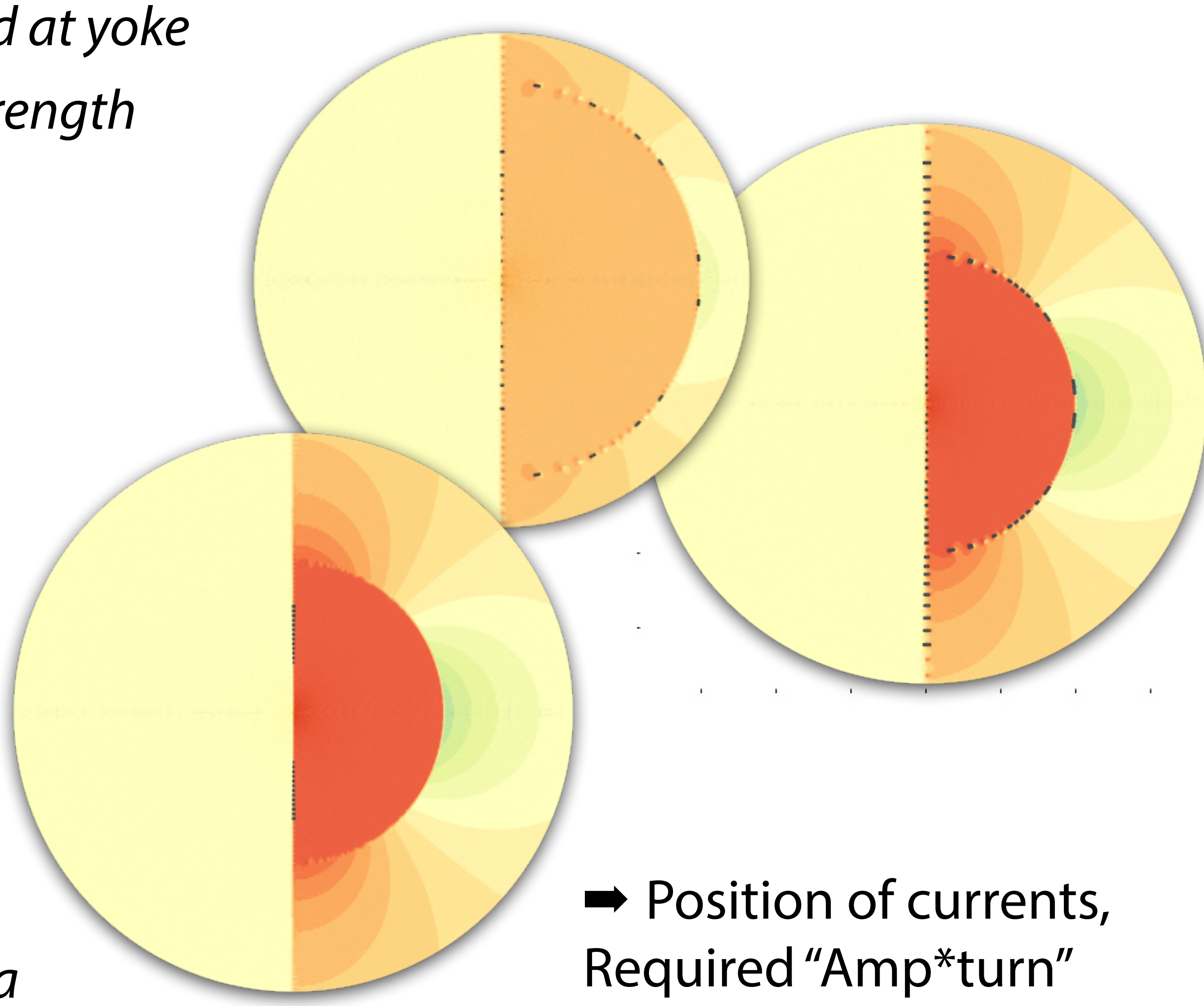
*Iron yoke radius/peak magnetic field at yoke*

*Magnetic field strength*



*Number of turns per pole*

*Coil radius of cosine-theta*

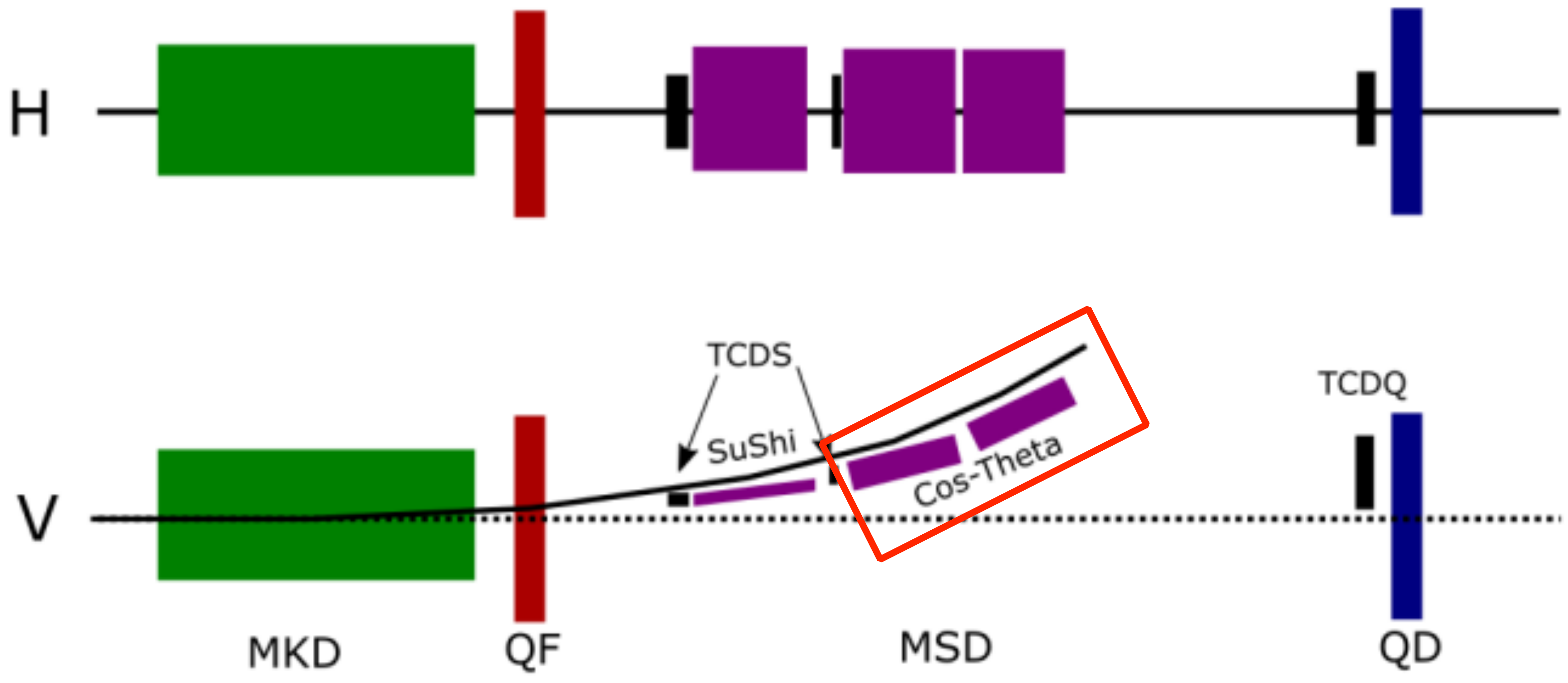


➡ Position of currents, Required "Amp*turn"

***Useful for estimation, cross check of FEM computations***

## FCC extraction scheme

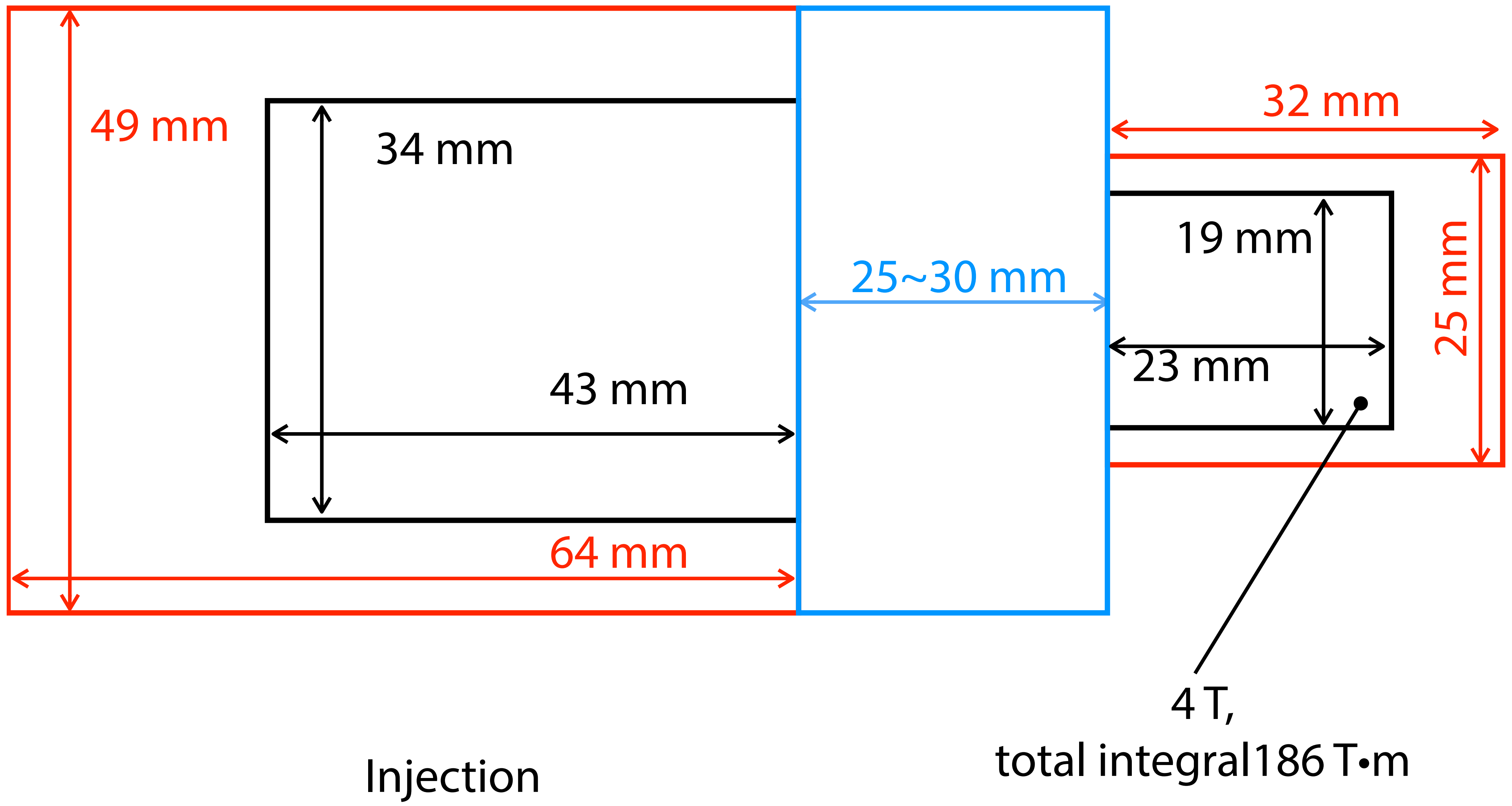
- Configuration




Courtesy of Elisabeth Renner

**FCC Septum Geometry**

*Status : Feb. 2017*

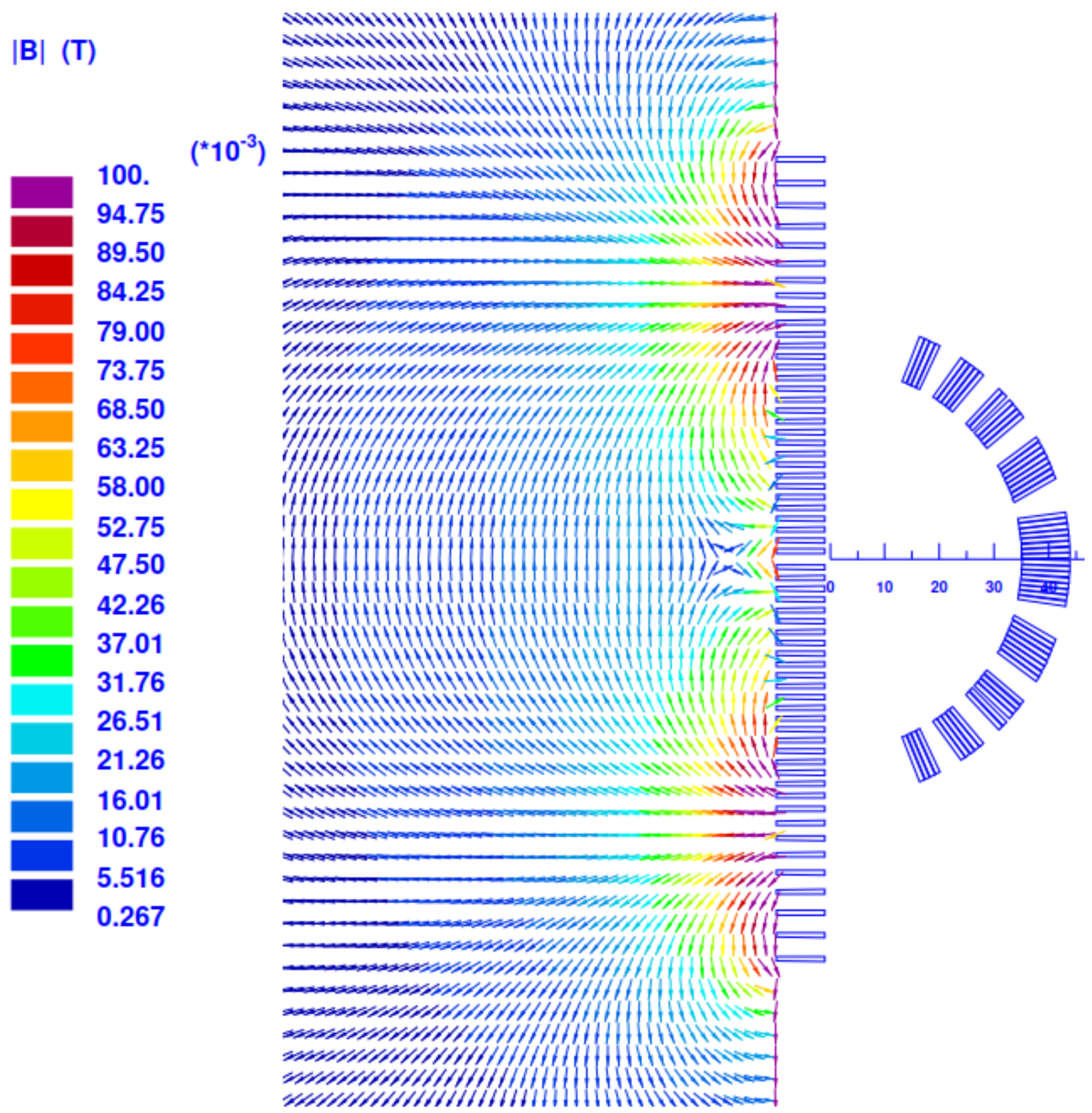



Injection
1.3 TeV 3.3 TeV

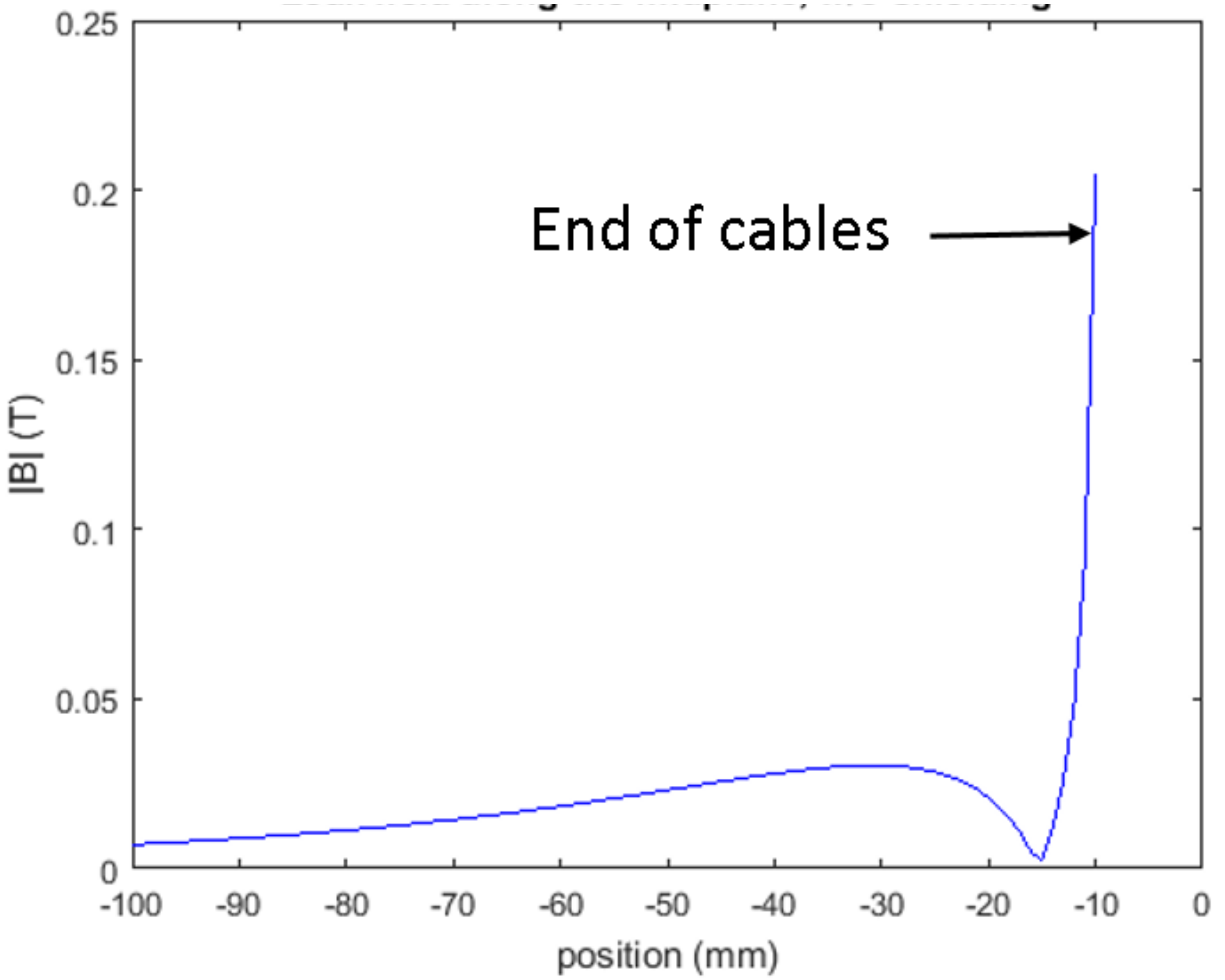
## 2D magnetic design

- Preliminary design

| Magnitude | Value | Unit |
|---|---|---|
| B | 4 | T |
| $B_{leak}$ bare geometry | 20 | mT |
| $B_{leak}$ with magnetic shielding | <0.1 | mT |
| Apparent septum thickness | 30 | mm |
| Cable type | Rutherford (NbTi) | |
| Current | 6284 | A |
| Number of turns/pole | 31 | |
| Magnetic length | 4 | m |




**Leak field along the mid-plane**




Design work done by CERN colleague supervised by GSI

**"Design Knowledge" transfer from GSI to CERN**

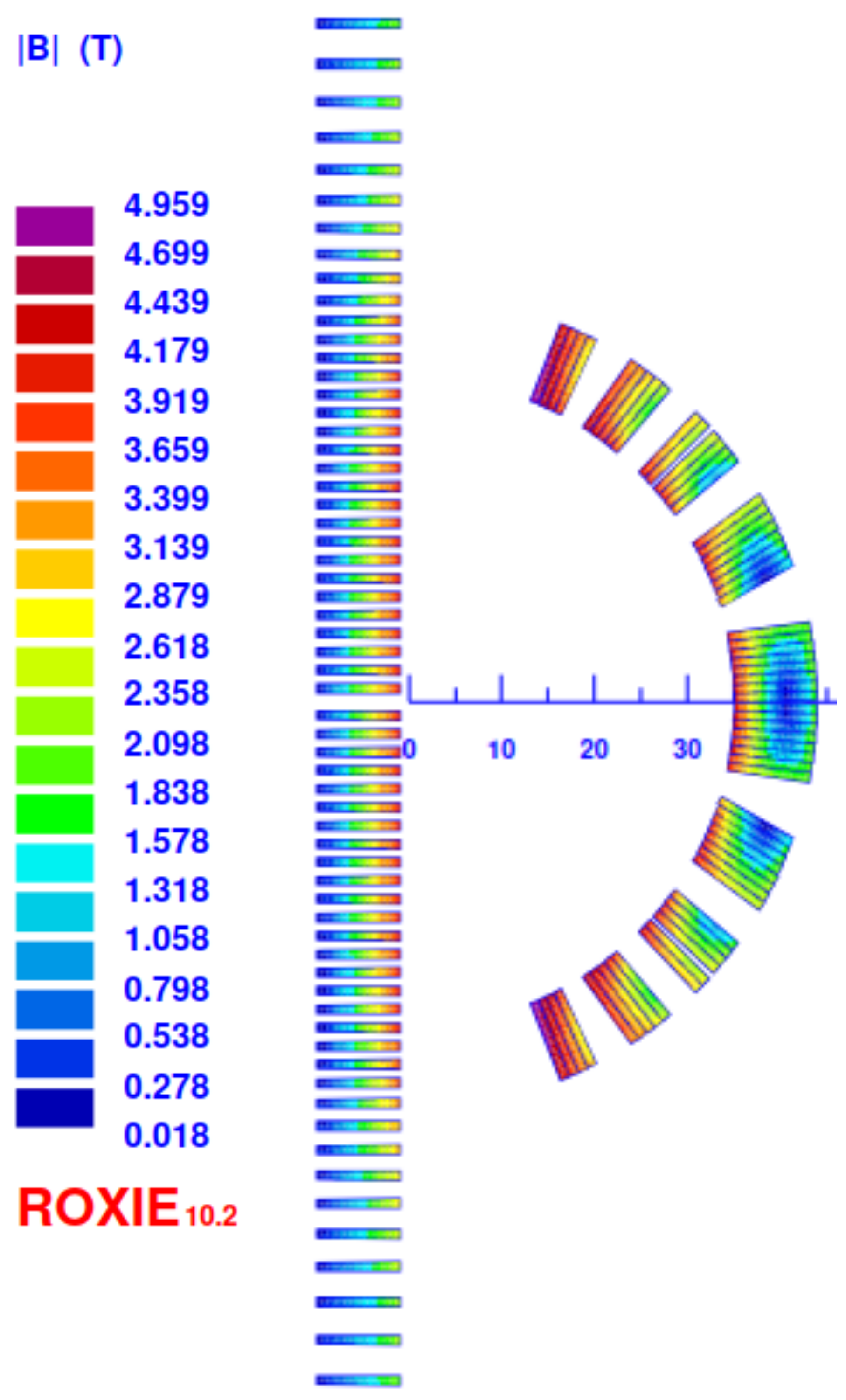
*2D design frozen for further parallel studies:*

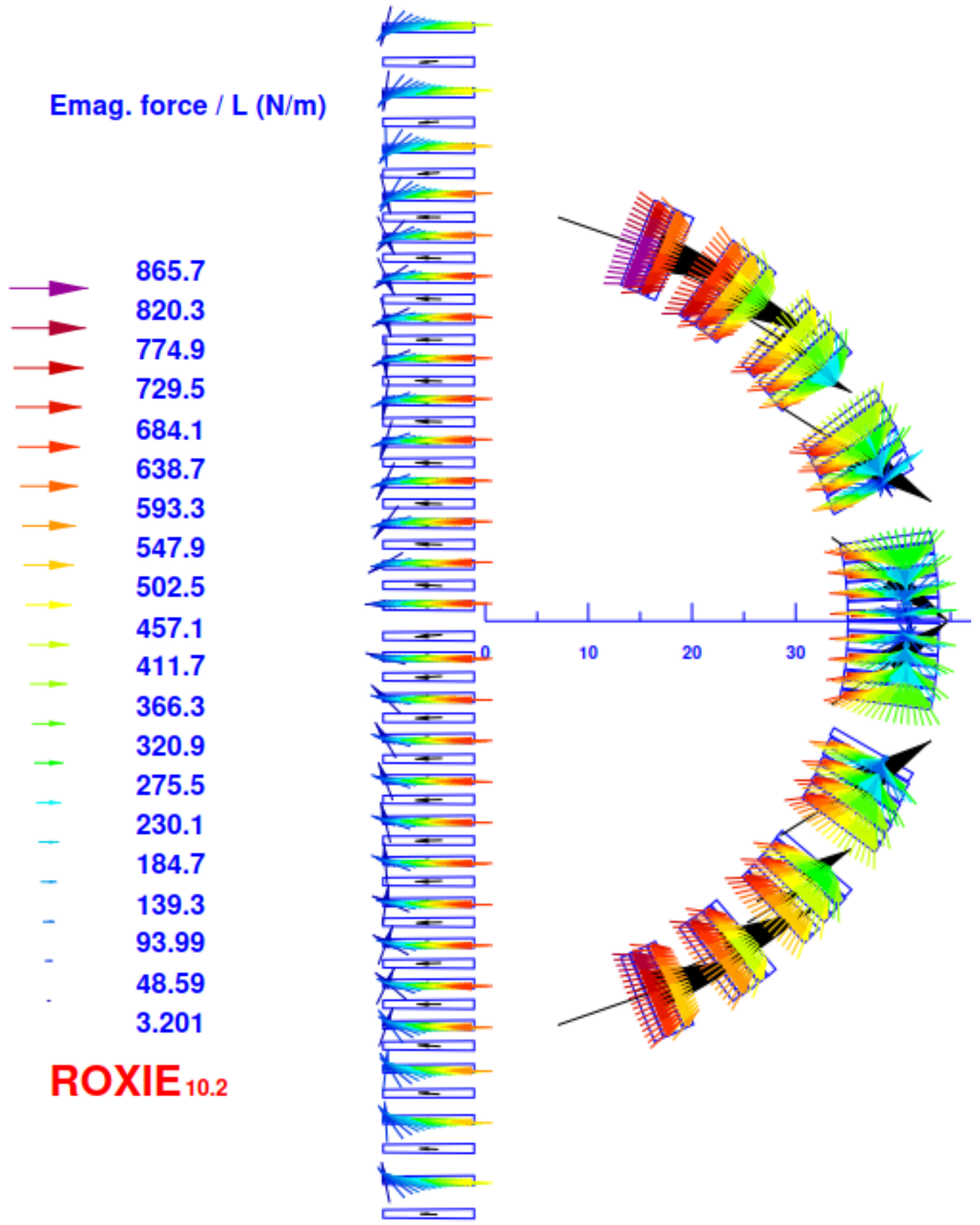
**CERN** mechanical/cooling design

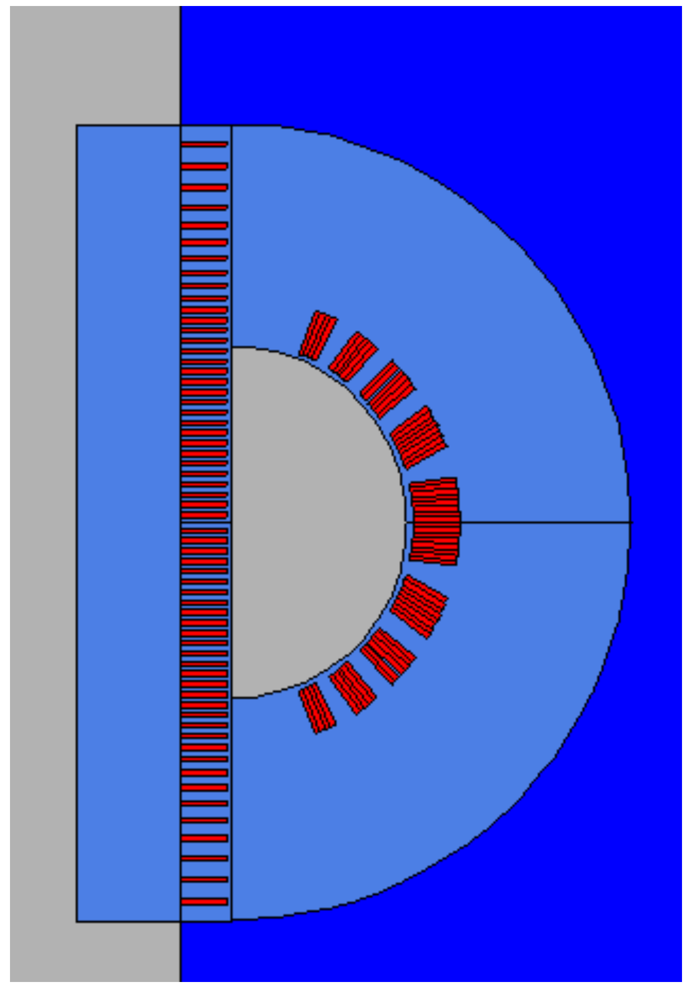
**GSI** 3D coil end design

# 2D engineering design

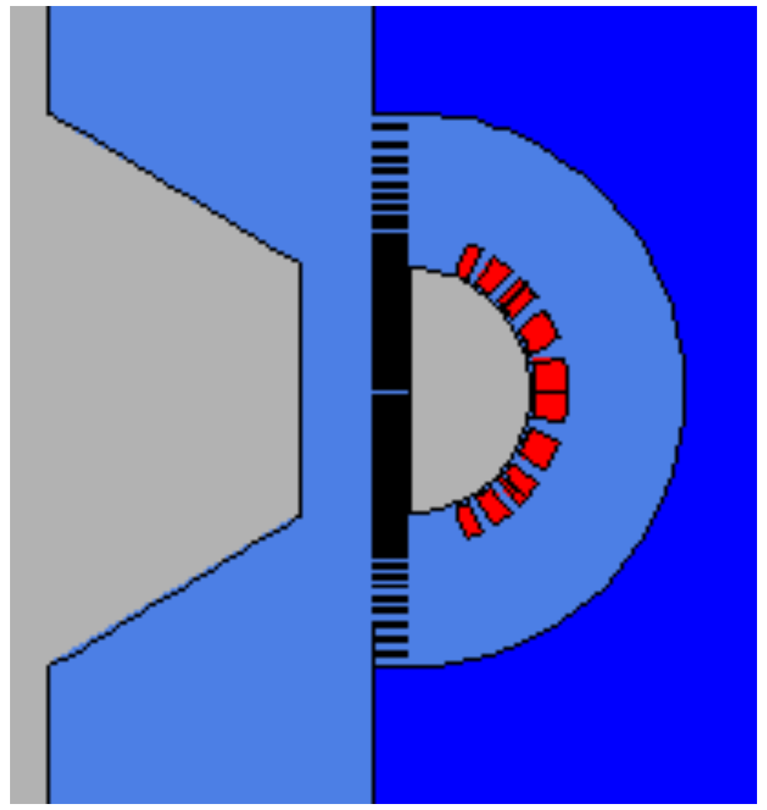
- Mechanical design



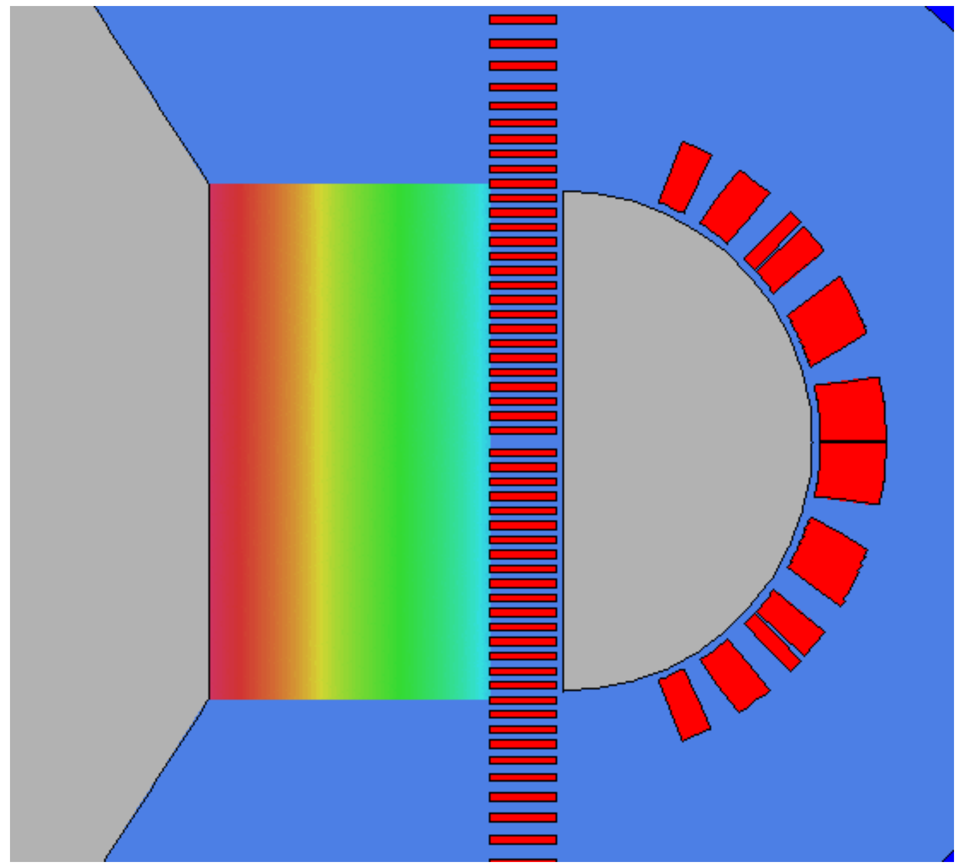



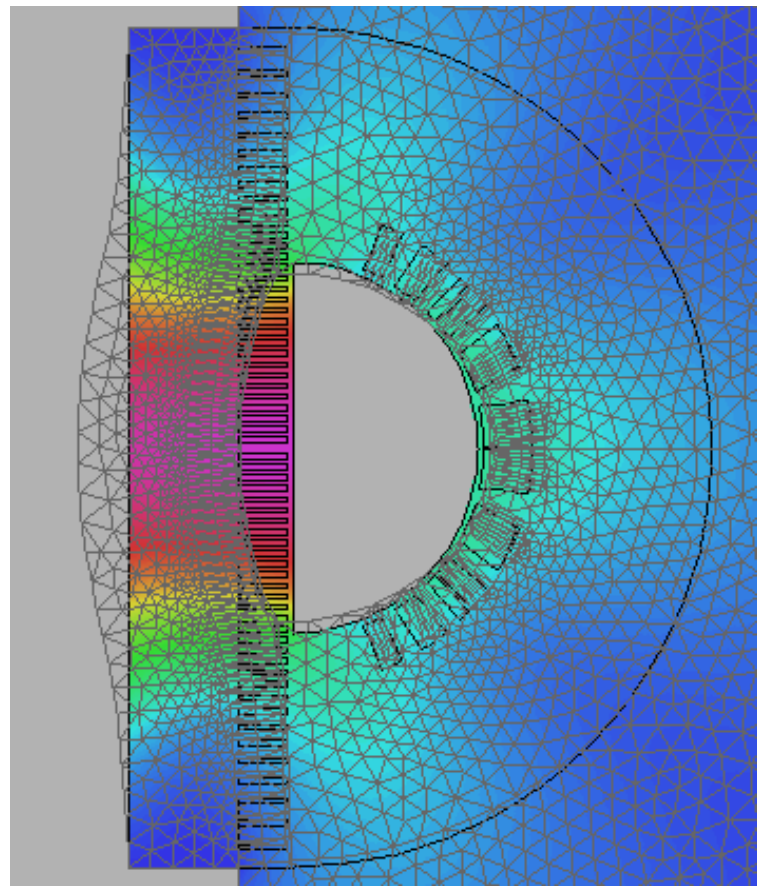
Simple support structure



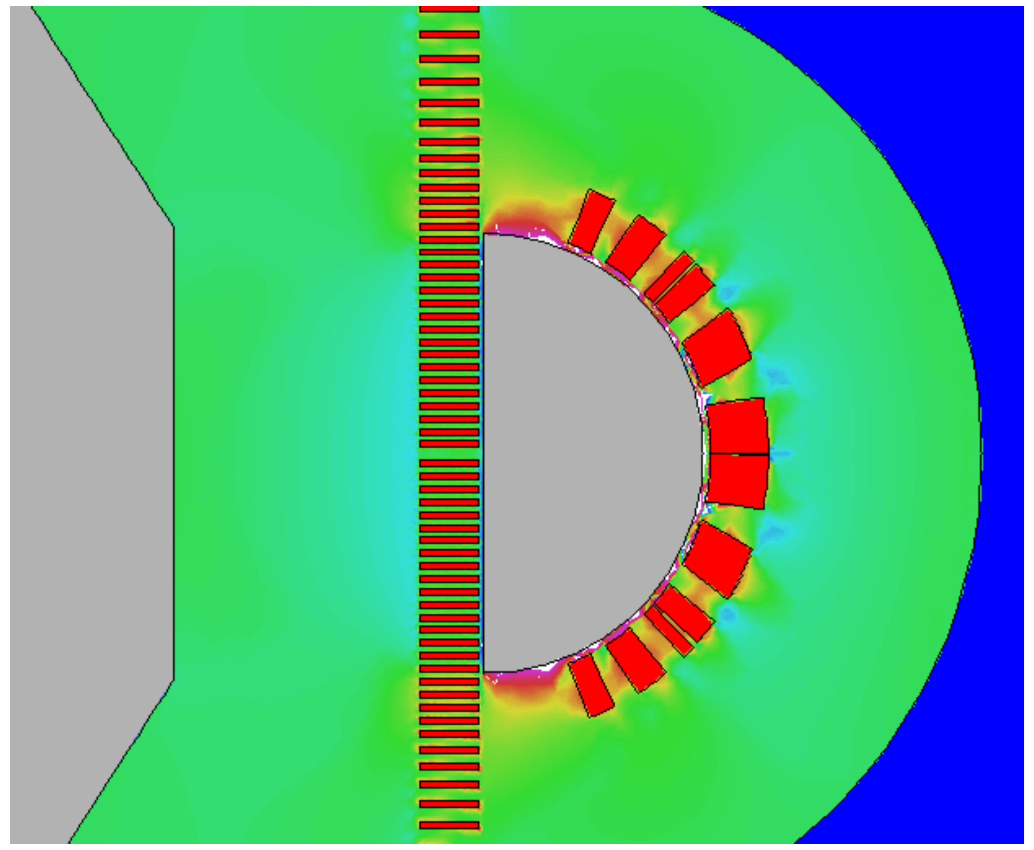
Reinforced support structure



- Maximum displacement in X axis is 0.2 mm.
- Thermal expansion coefficient: some uncertainties (10%).
- Support placement is critical to reduce displacement.

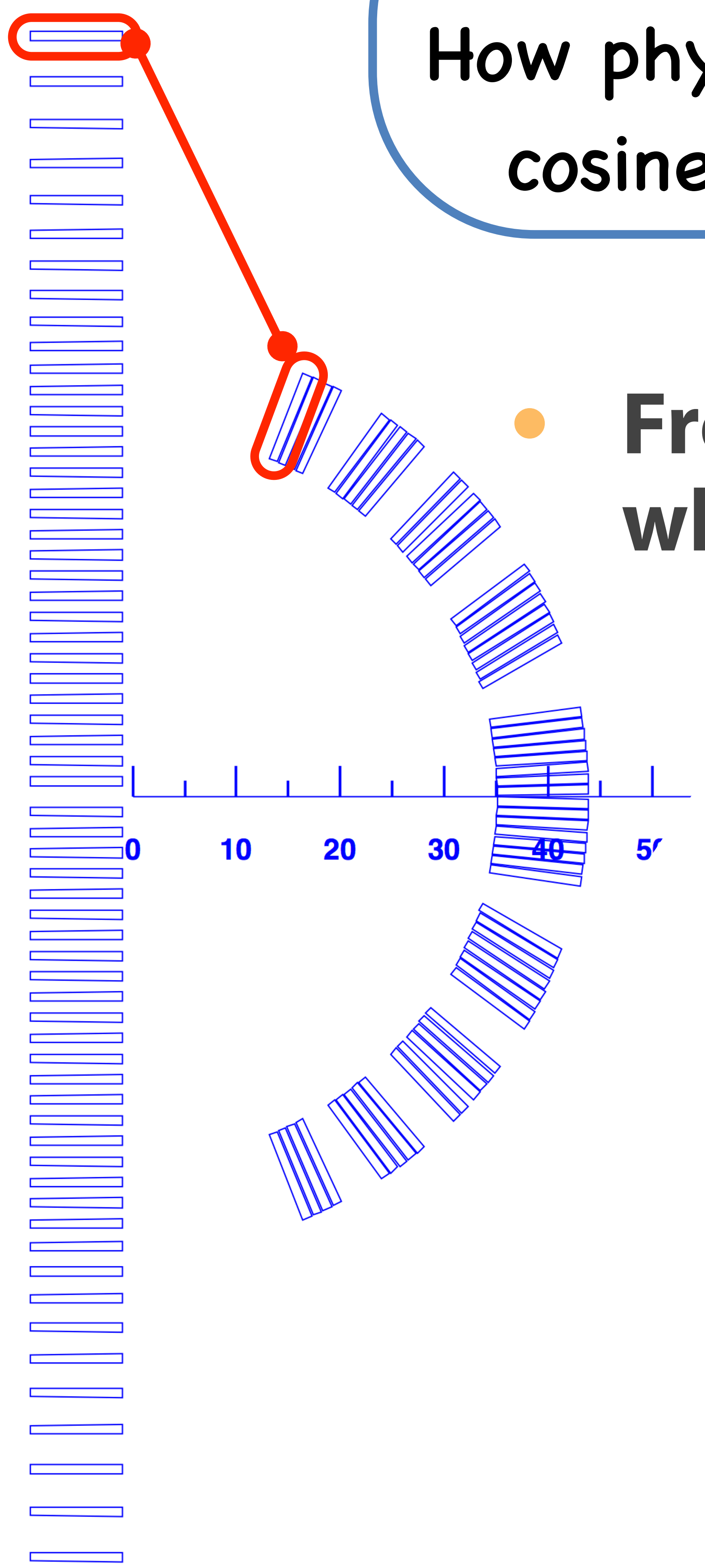


Expected behaviour (qualitative)



- **Pre-compression is necessary.**
- **Most of the material is in the range of 25 to 50 MPa.**

# 3D coil end design

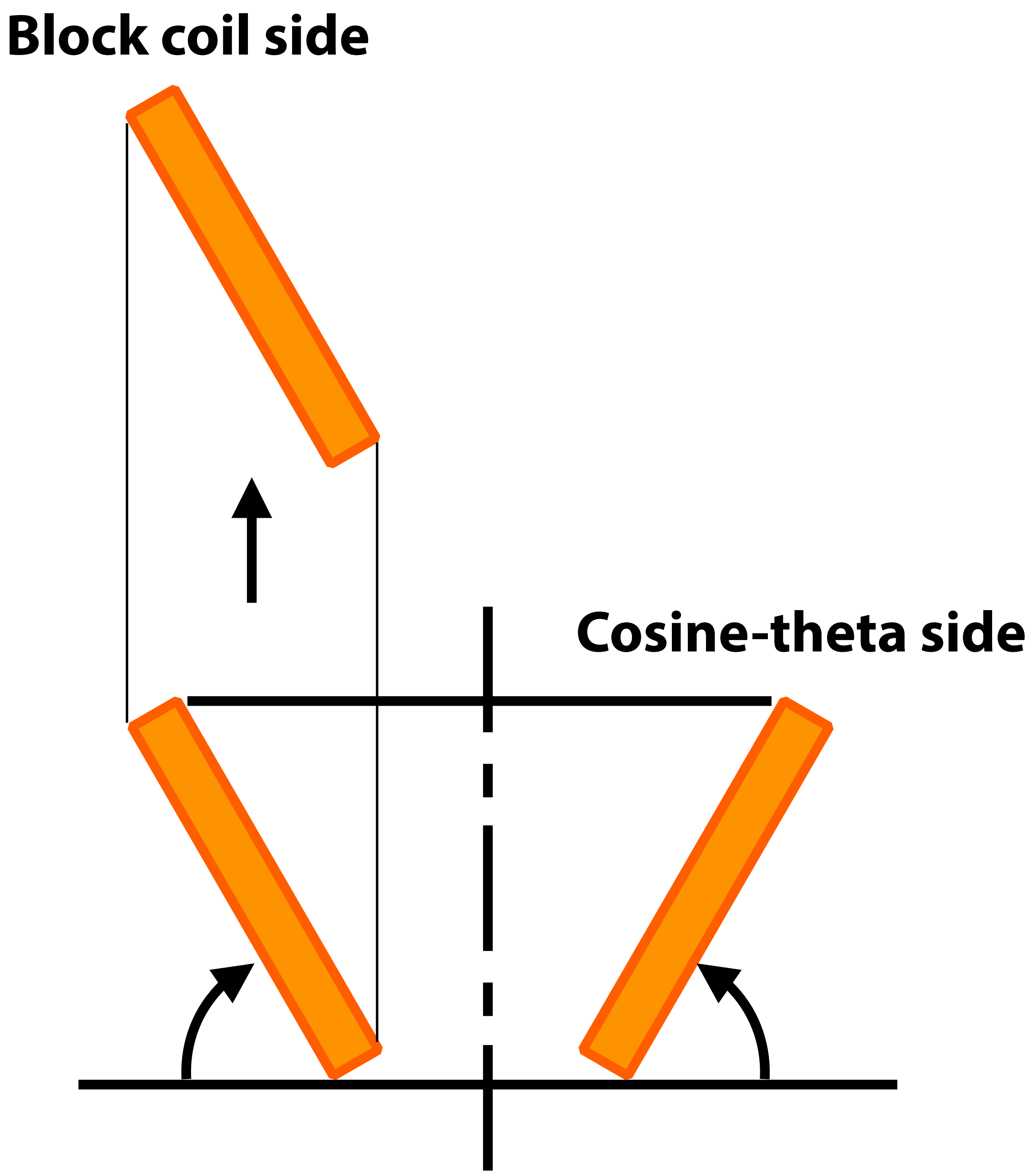



Q. How can we wind the coil?
How physically connect the cable in cosine-theta and block coils?

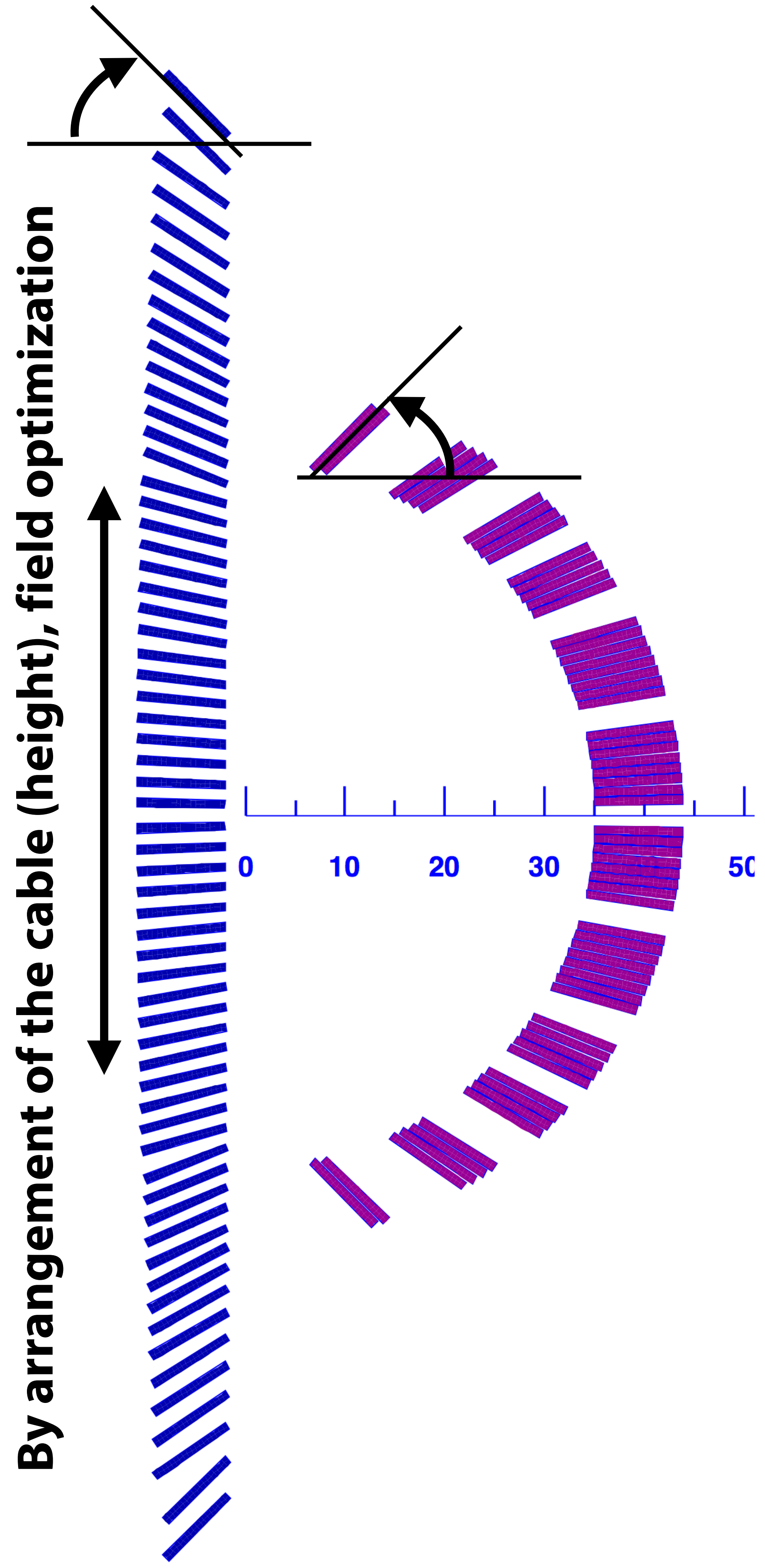
- **From manufacturing point of view, what is possible coil end?**

**Typical cosine-theta coil end (one cable)**

**Cosine-theta coil end**
**+**
**Soft < "Medium" < Hard bend**

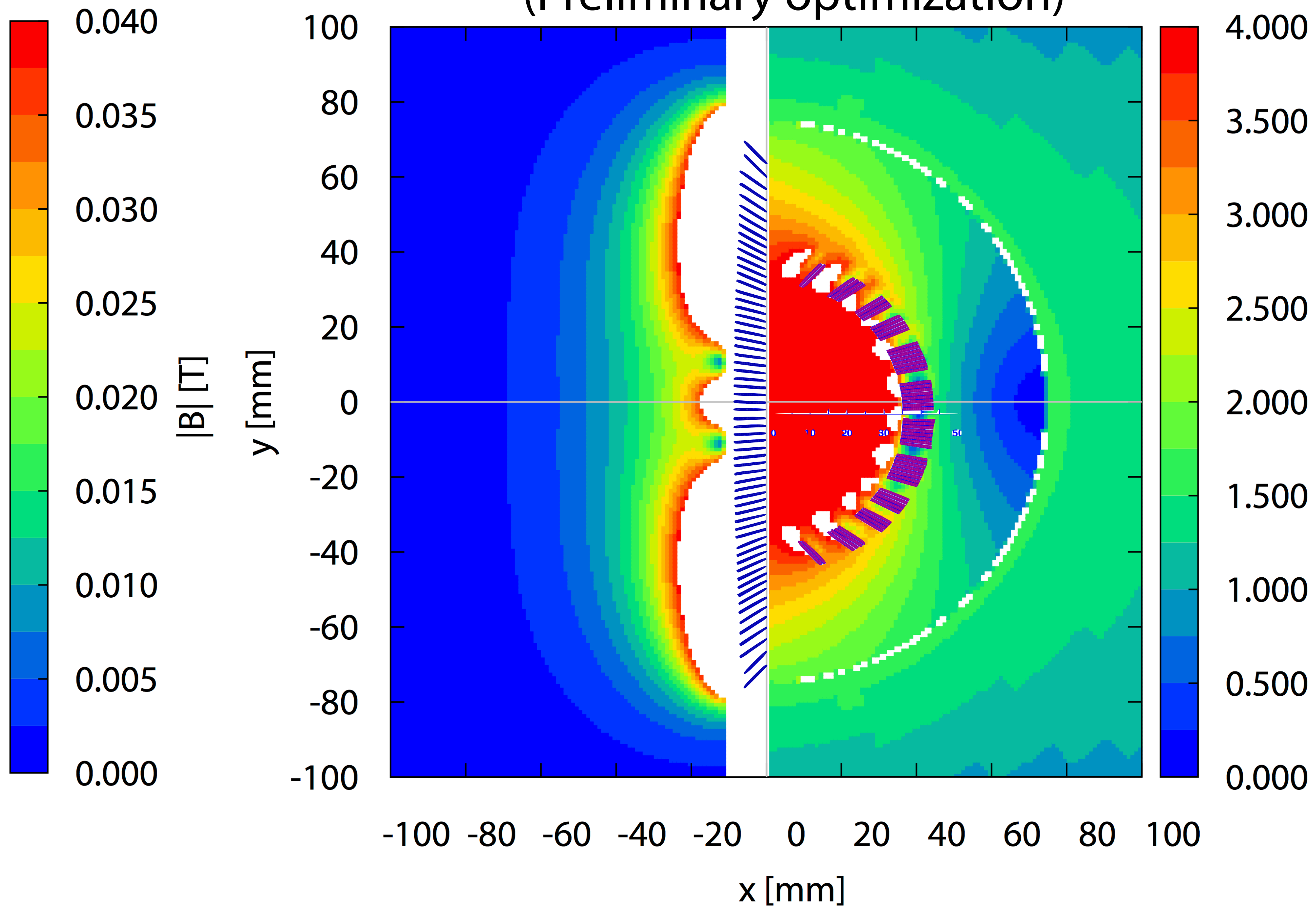



**Each turns: symmetric cable angle**



# 3D coil end design

**Stray field / Main field**
(Preliminary optimization)

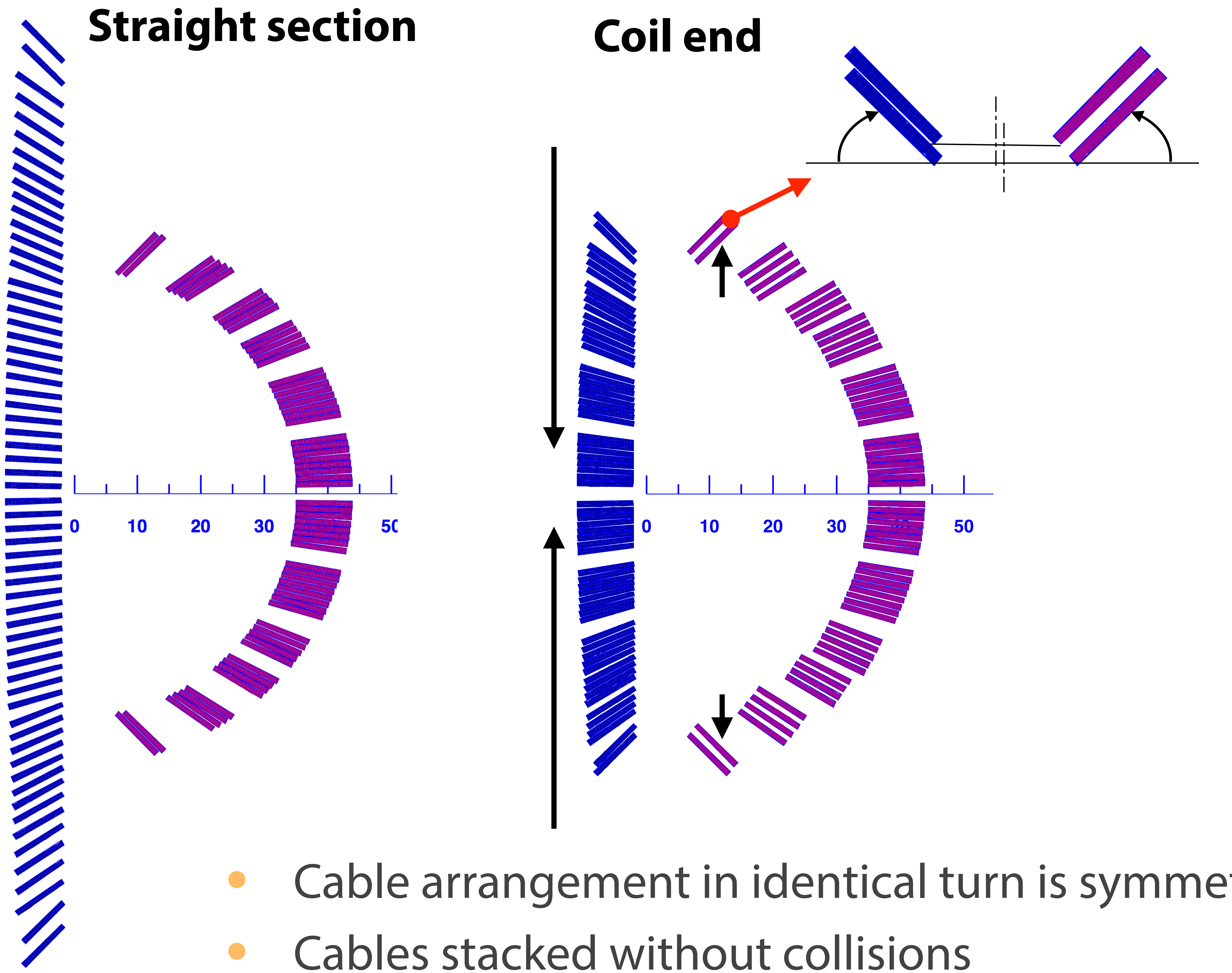



- Straight section (2D) would be ok.
- Further optimization on

  Field quality in the aperture

  Leak field at the circulating beam area

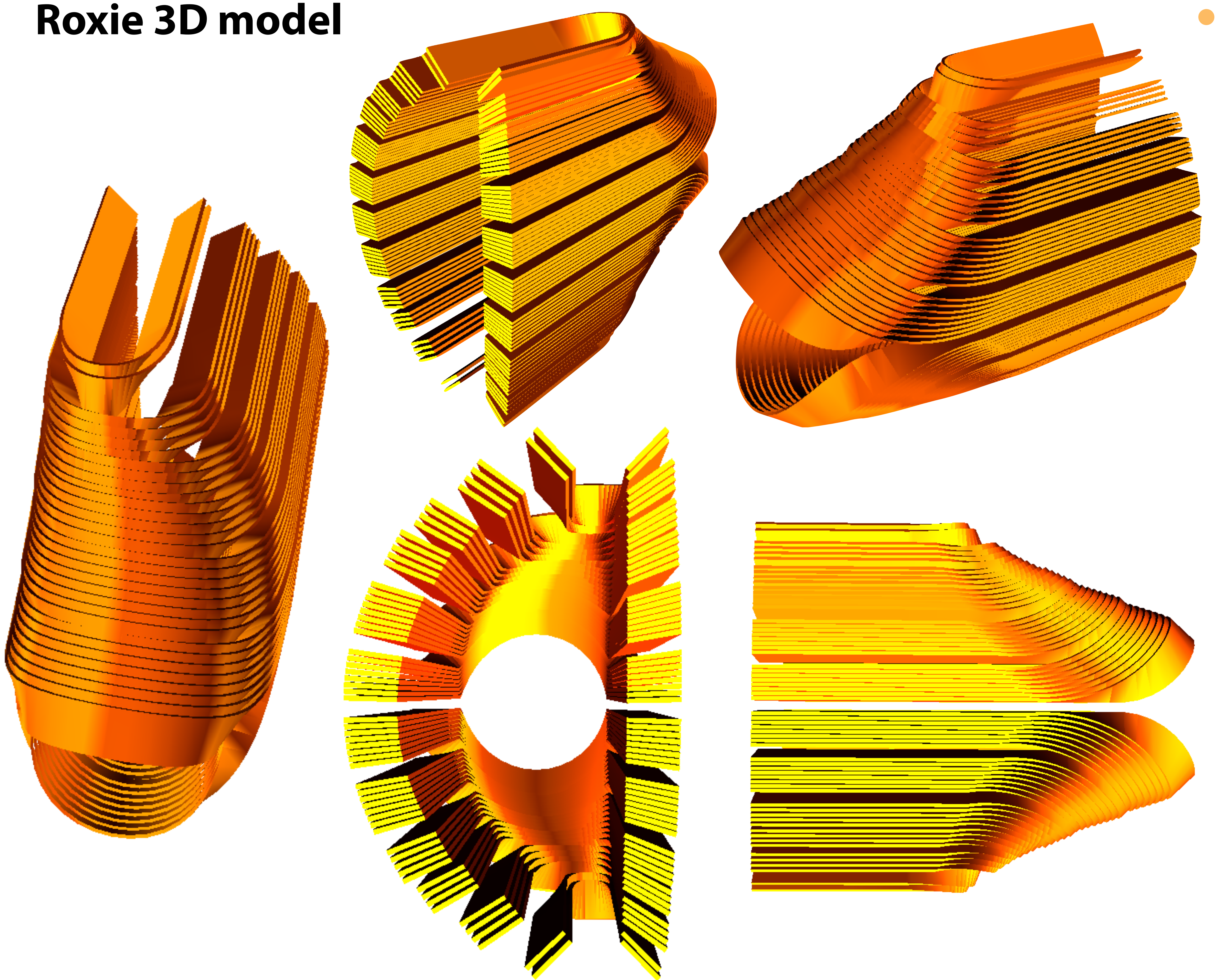
is possible.



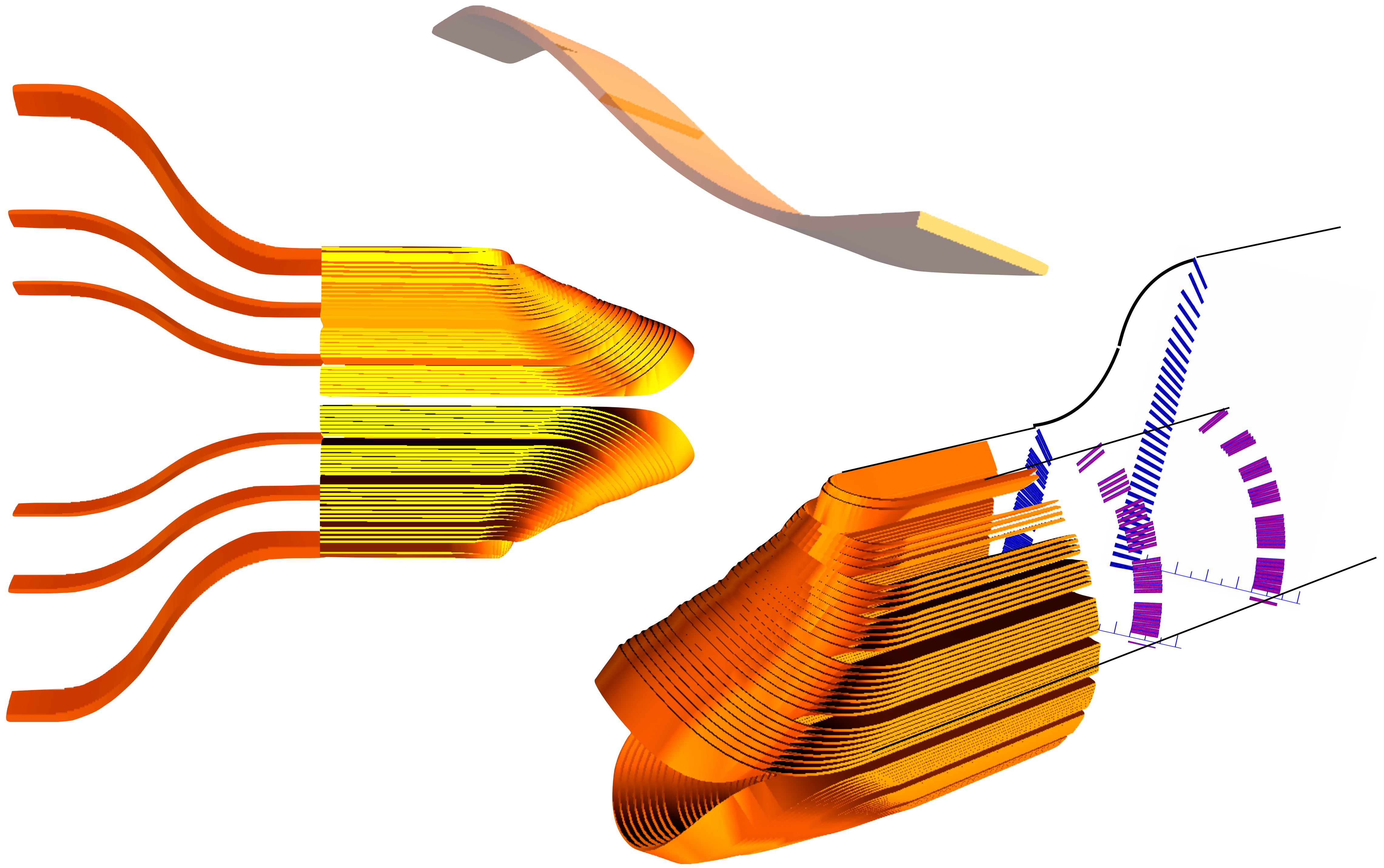

- Cable arrangement in identical turn is symmetric
- Cables stacked without collisions

# 3D coil end design

**Roxie 3D model**



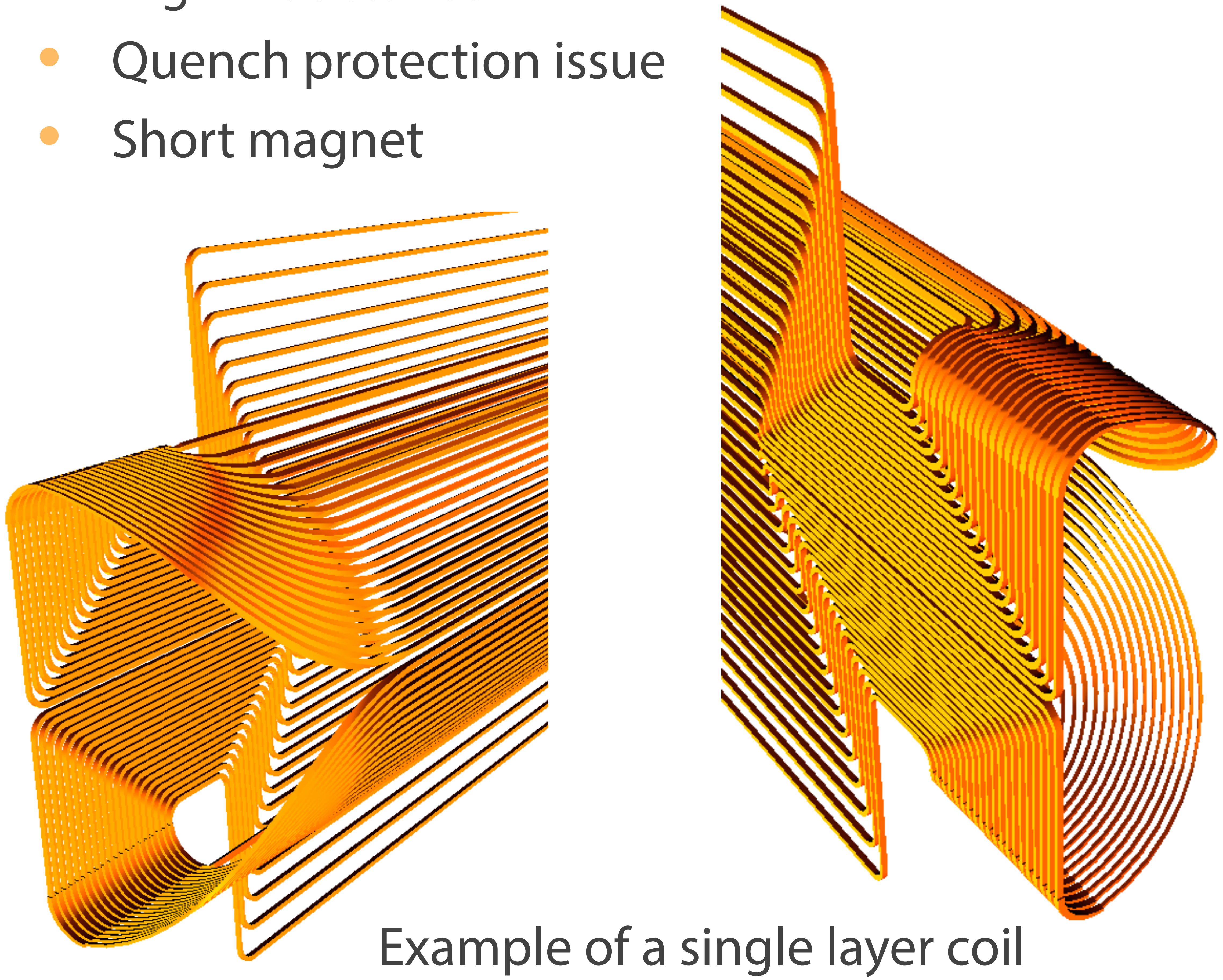
- Still "Medium" bend joints are missing



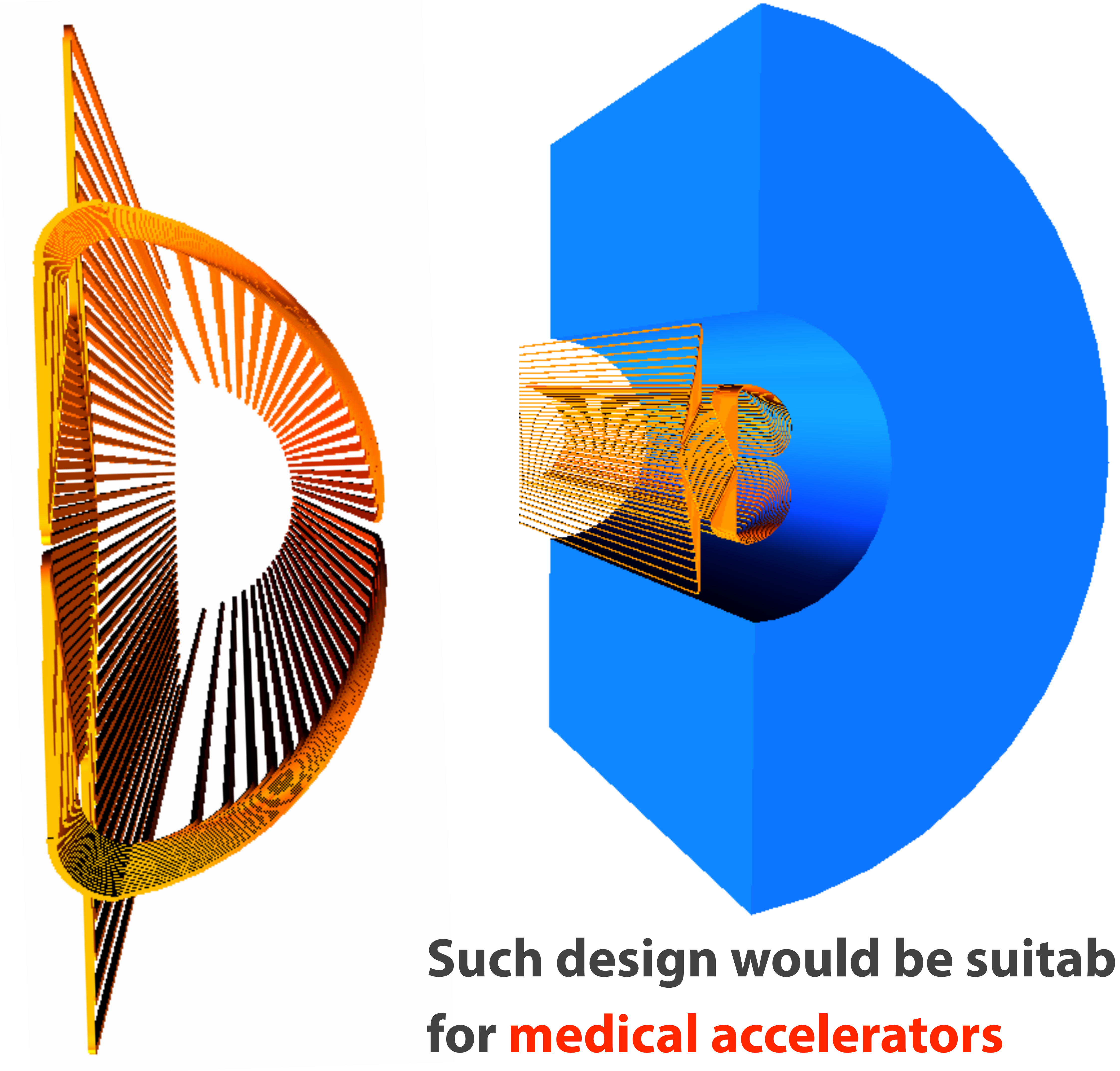
- Cable bending for single cables looks fine.
- Devoted winding mandrel, support structure, tooling might be necessary.

# 3D coil end design (single strand coil)

- Alternative: **Single strand winding**
  - Low current, many turns/layers
  - High inductance
  - Quench protection issue
  - Short magnet



Example of a single layer coil



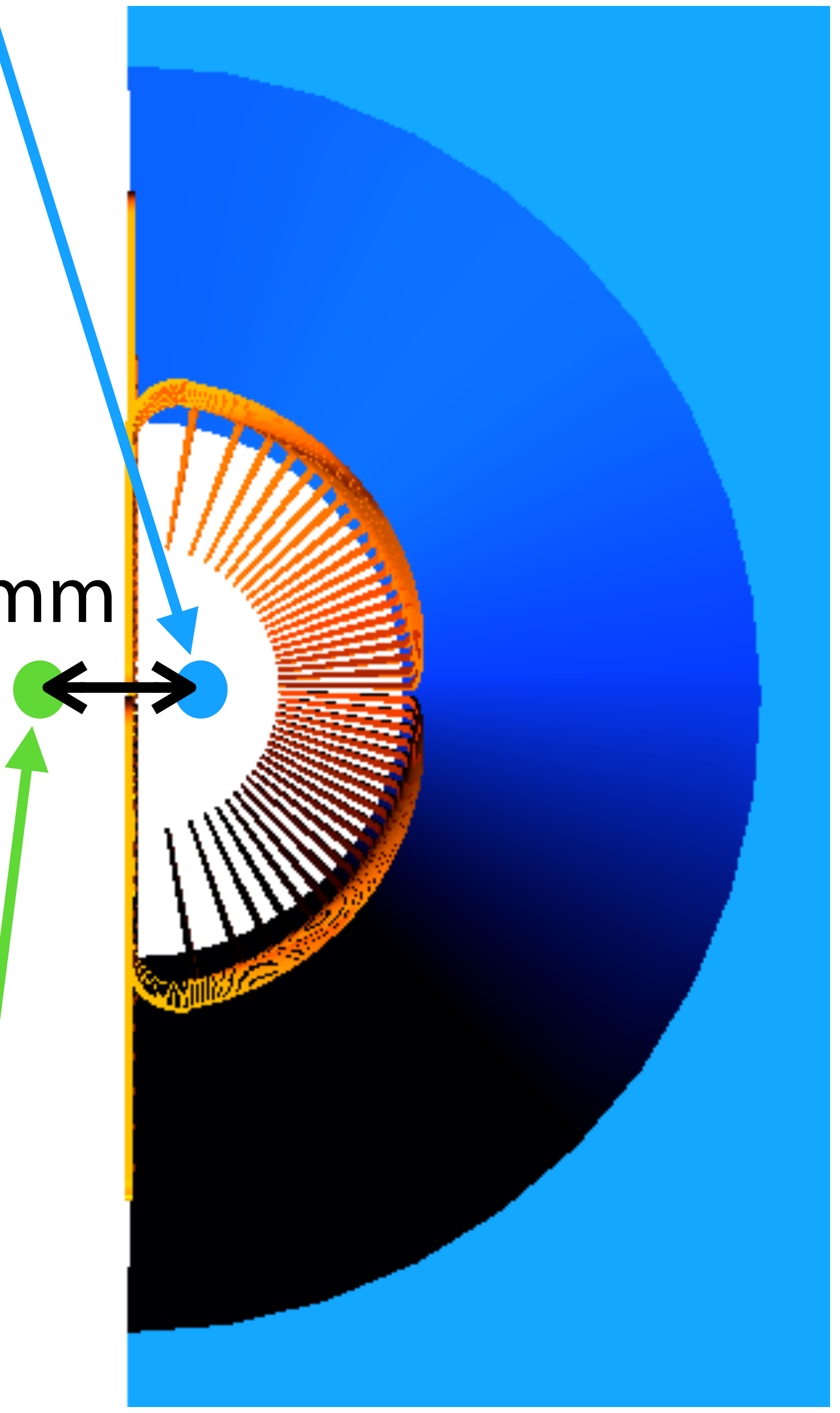
**Such design would be suitable for medical accelerators**

# 3D coil end design (single strand coil)

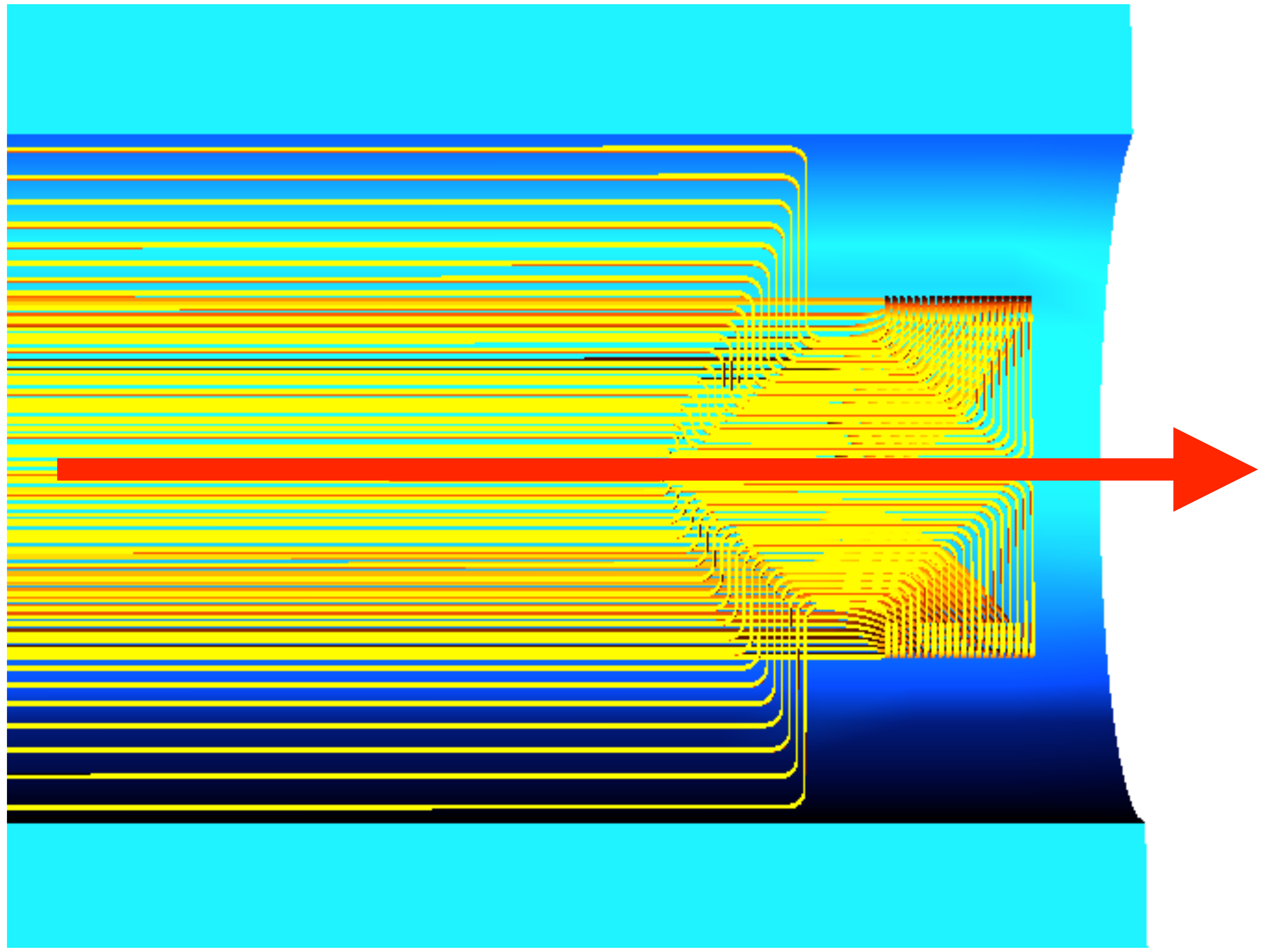
- Field at the coil end

B_in relative

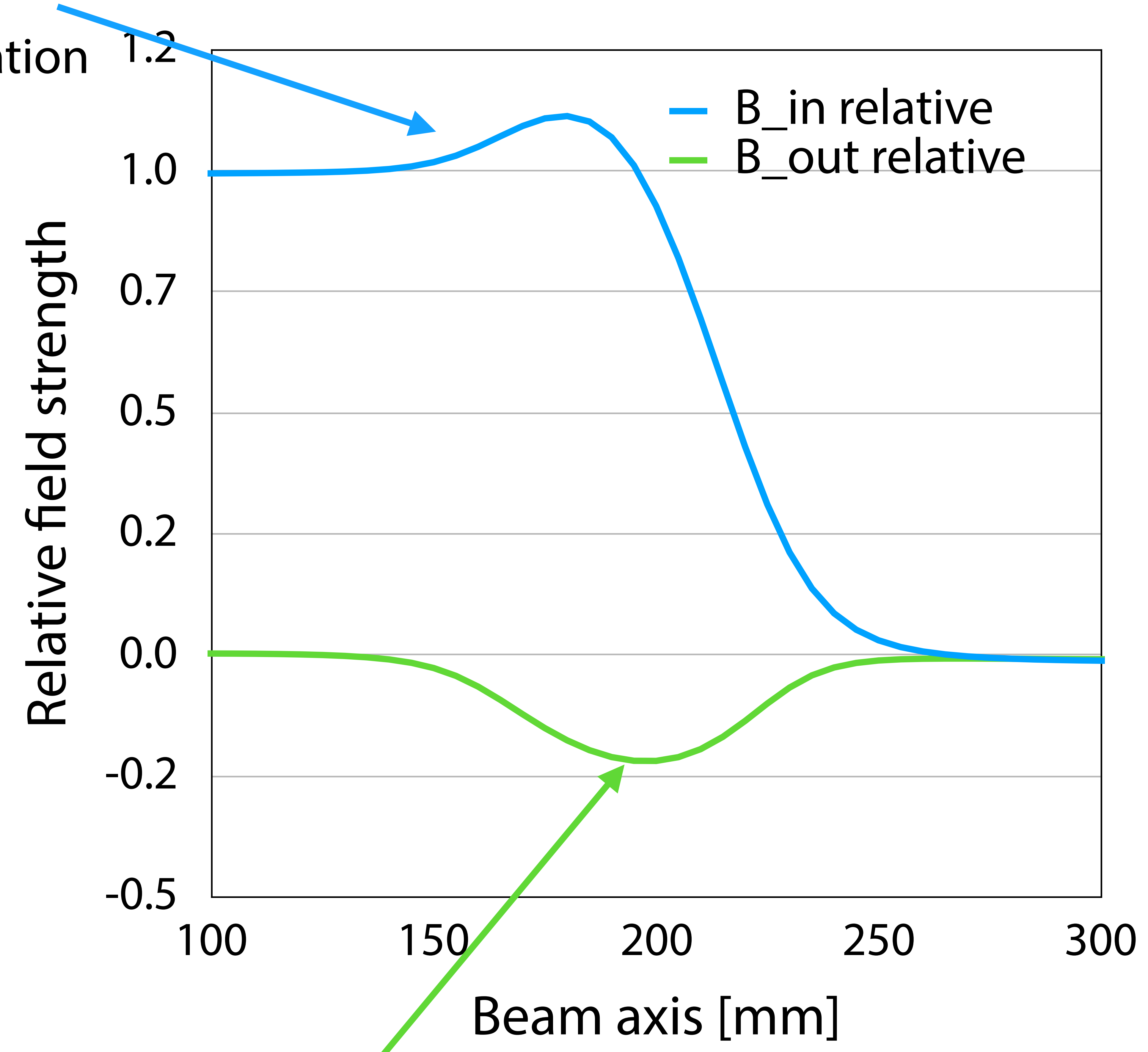
37mm



B_out relative



10% higher field
➡Quench calculation




20% leak field (w.r.t. nominal field in the aperture)
➡ Proper shield might be necessary

## Summary

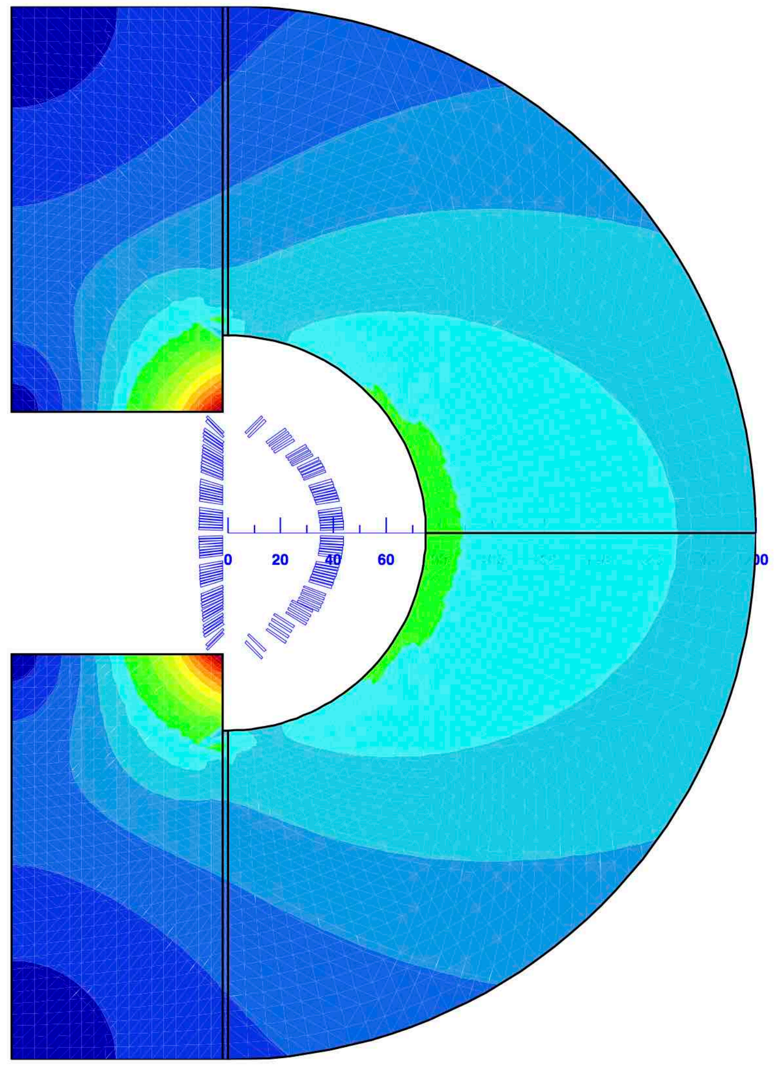
- **GSI and CERN started developing conceptual design for the FCC superconducting septum magnet.**
- A 4 T with a 30 mm septum thickness is presented based on NbTi Rutherford cable.
- **No showstopper has been identified.**
- **Mechanical design is ongoing**
  - Proper support design for the block coil is necessary.
  - Mechanical stresses in coil are well within material limits.
- **Cold end design concepts are developed.**
  - Rutherford cable can be applicable.
  - Single strand coil would be alternative.
- **Very promising innovative septum topology**

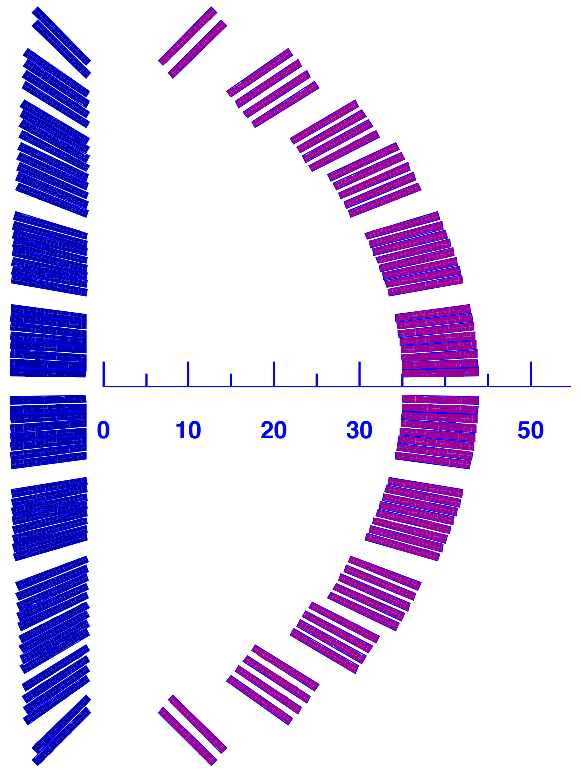
## Future work

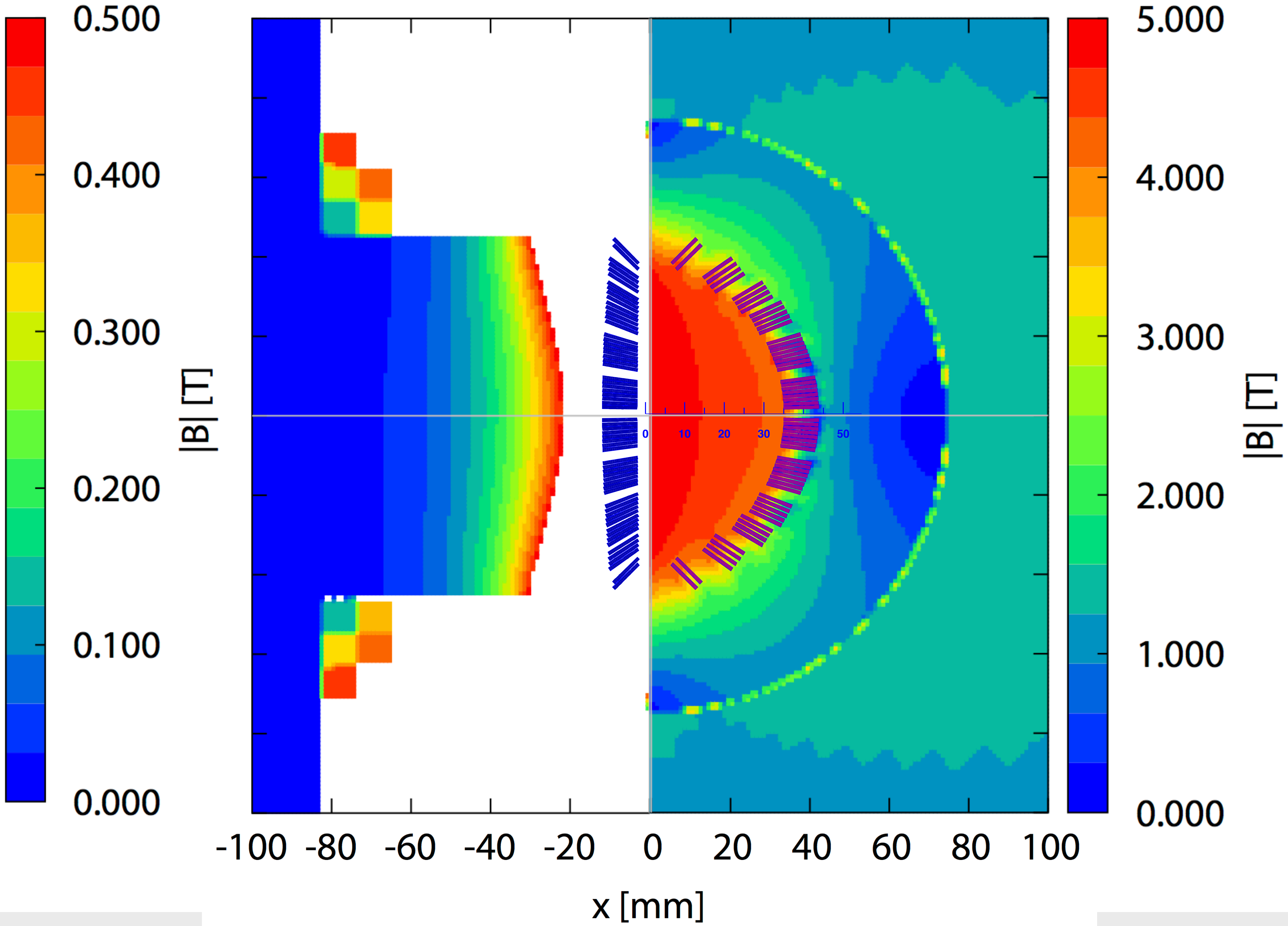
- Iteration of  magnetic design and engineering design is to be continued.
- In general,
  - Extracted beam exposed in the field only one time.
  - Field quality is not so demanding in comparison with magnets in the ring.
  - More freedom for the engineering design, but other specific restrictions.
  - Leak magnetic field in the circulating beam area, especially at the magnet end, must be controlled.
- Cooling design study will be done.

# Backup

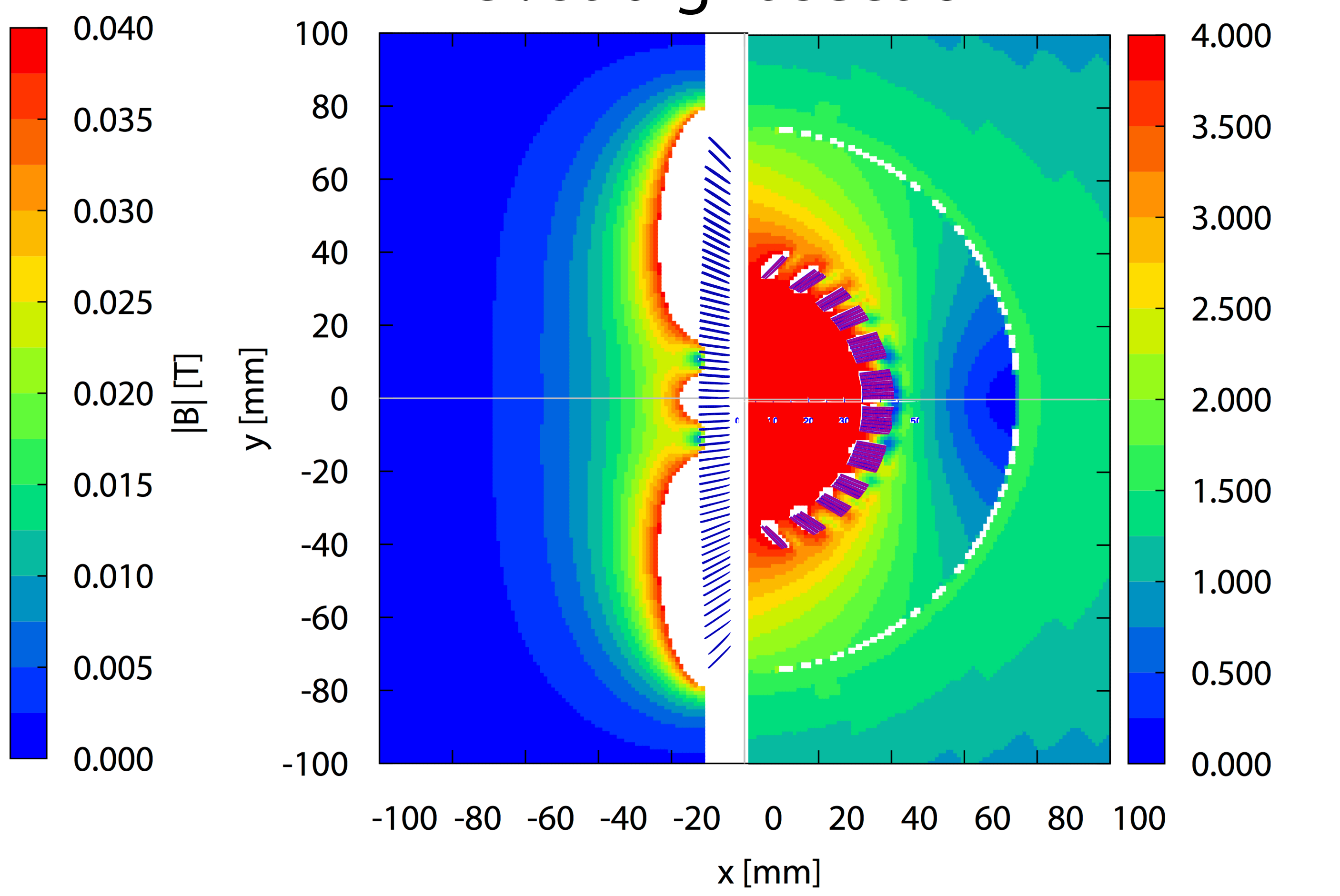
## Rutherford Coil End





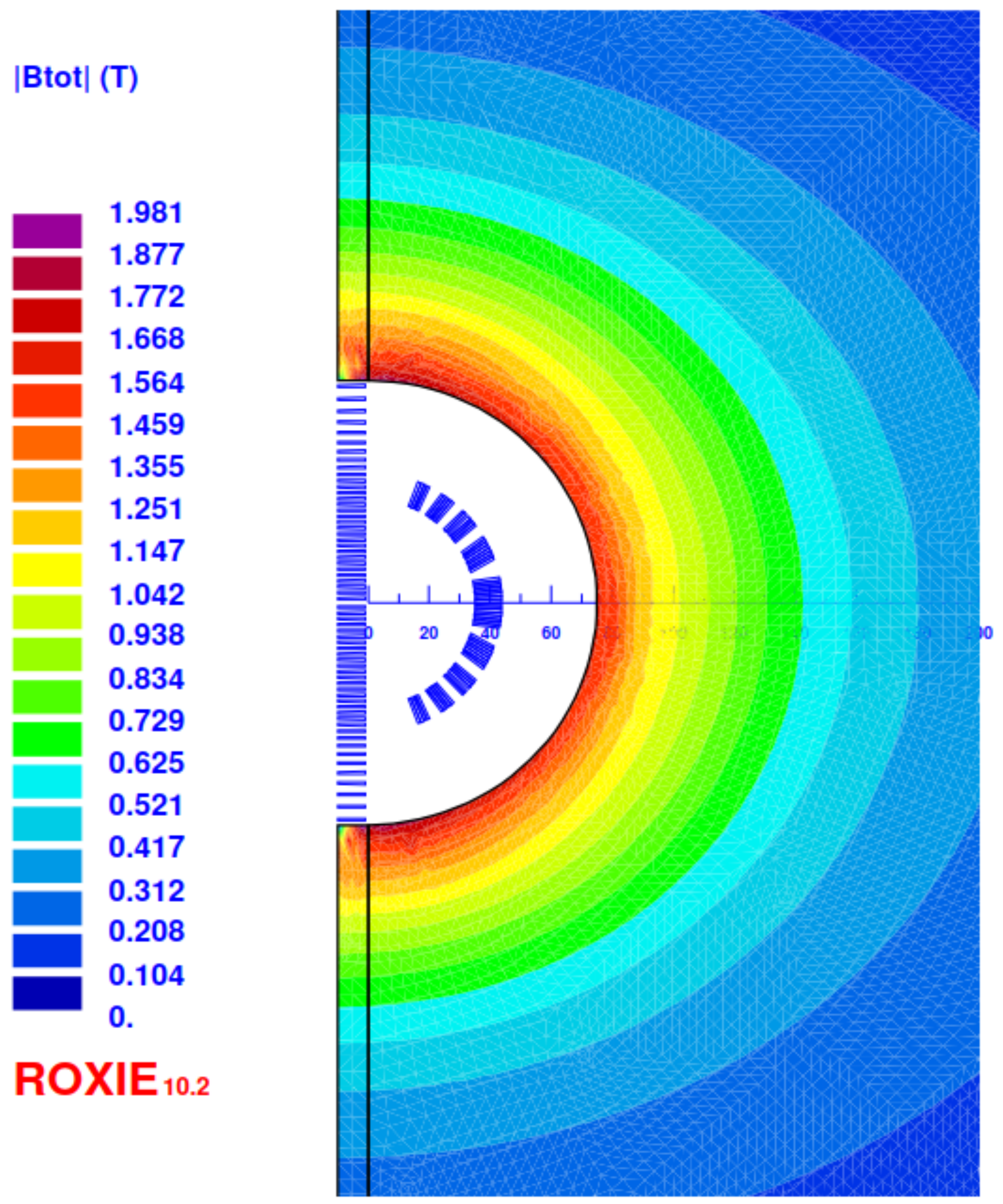




cf. straight section

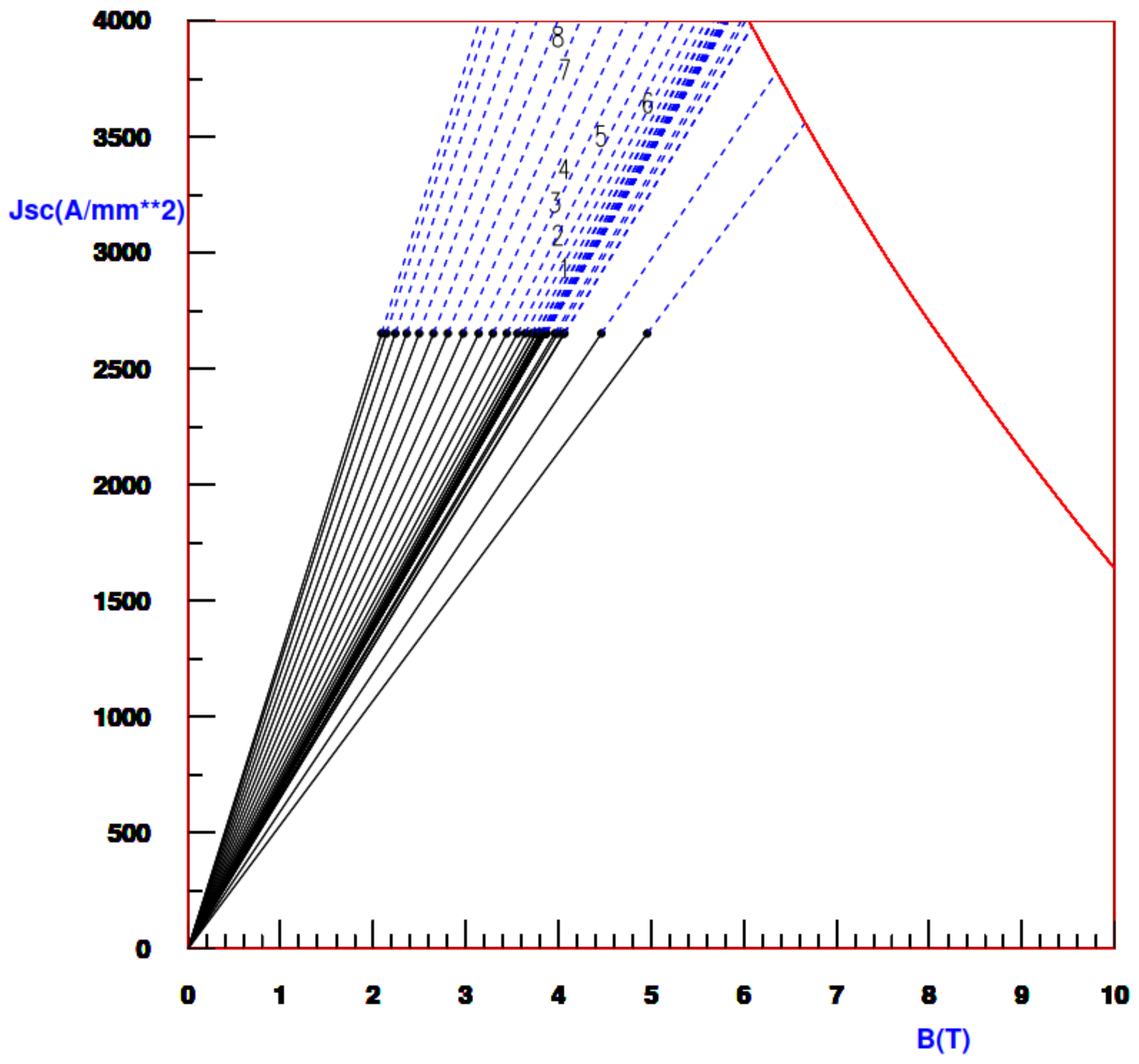


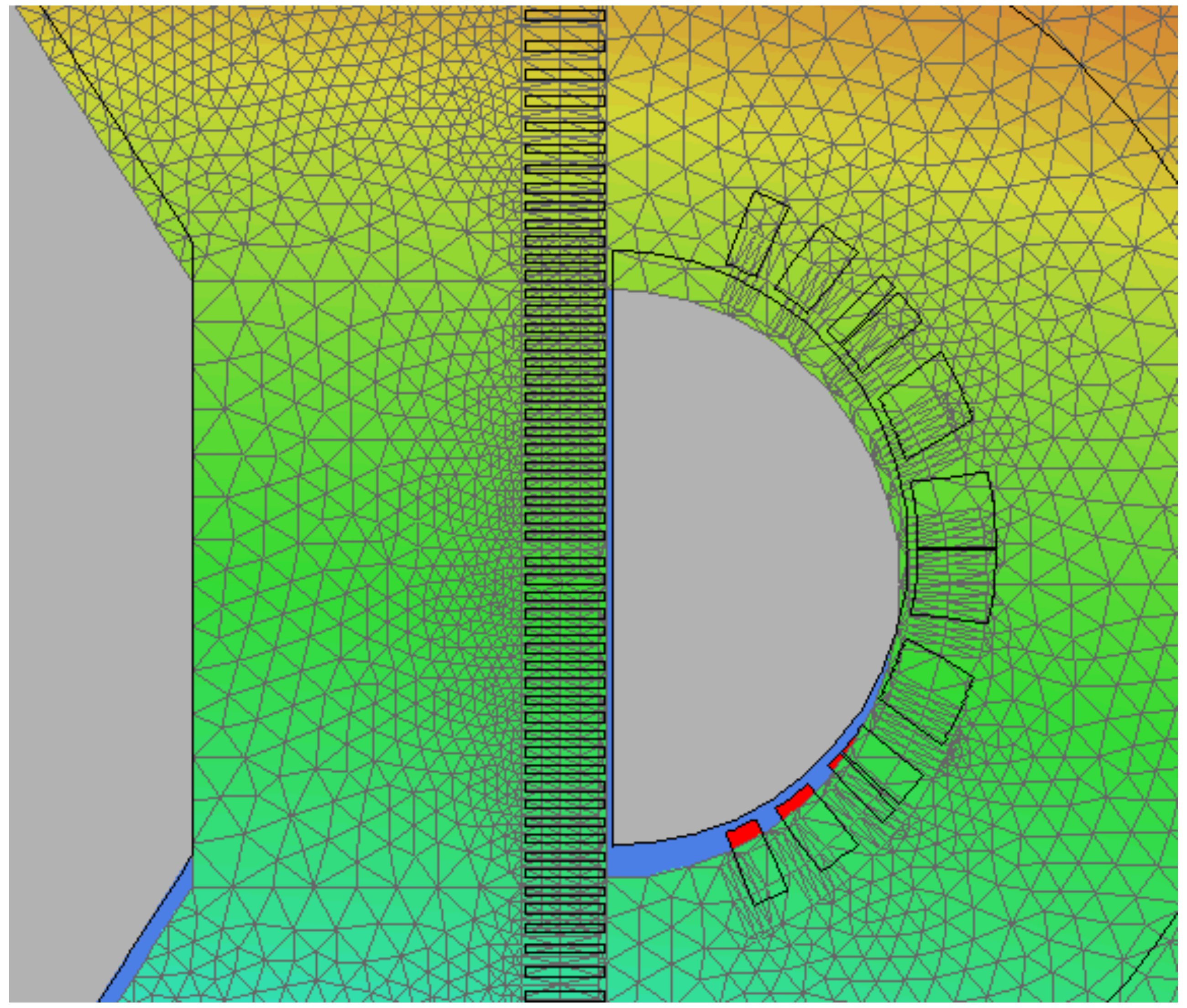
- CERN

Non saturated yoke is essential to performance




Worst case: 30% margin (corner)

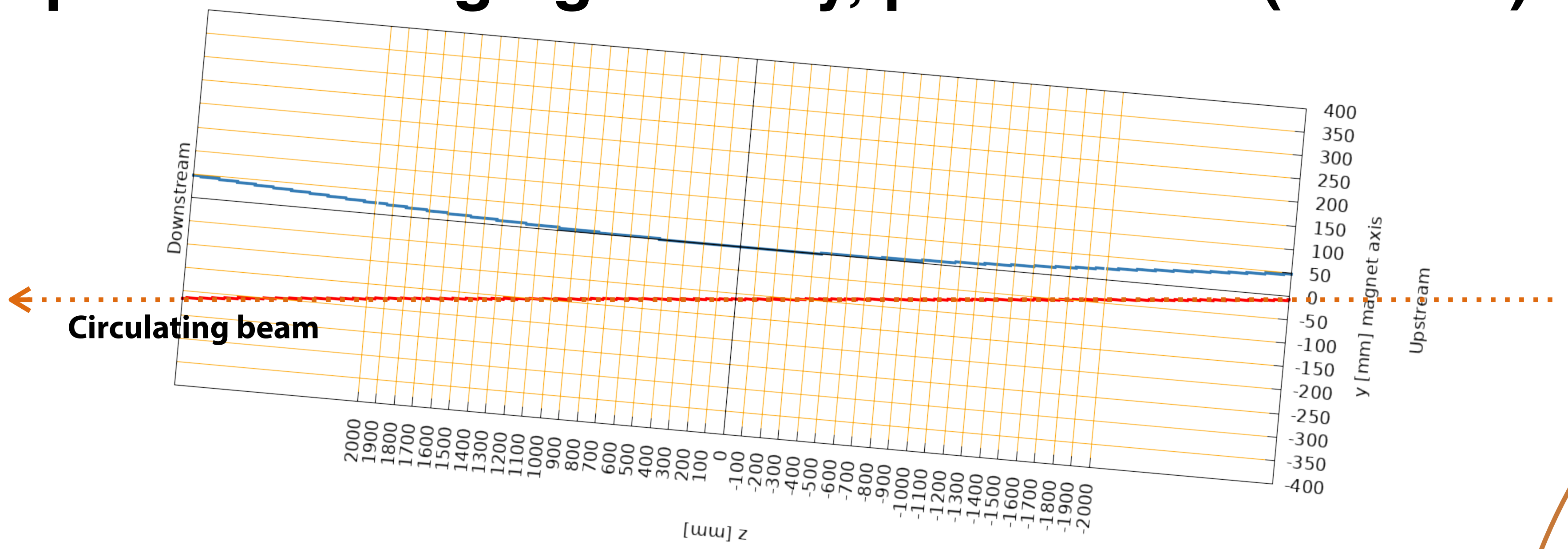


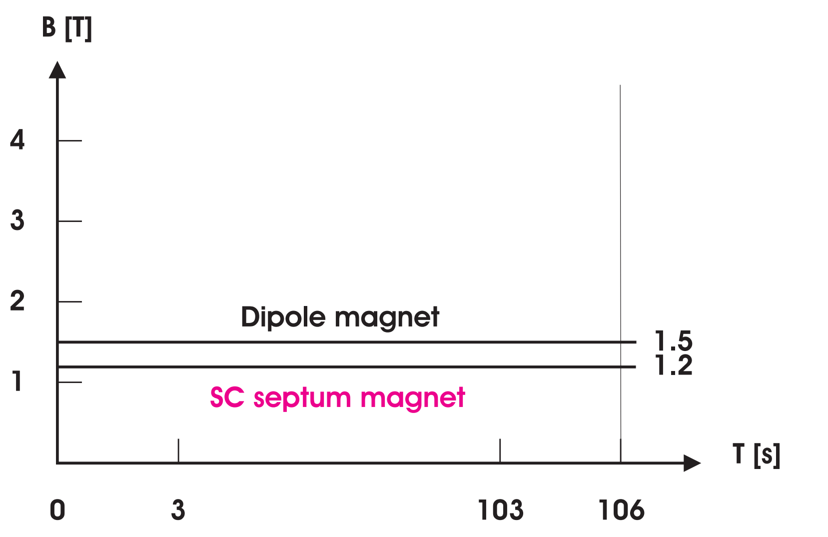



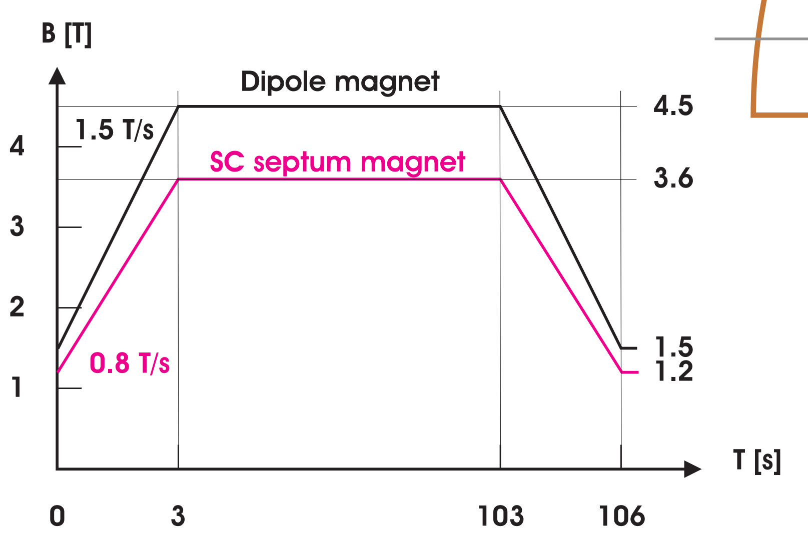
Biggest contribution is DISPY, fixed at the bottom (-1.5,-1) mm

# Geometry 2017

## Update of design geometry, parameters (300 Tm)



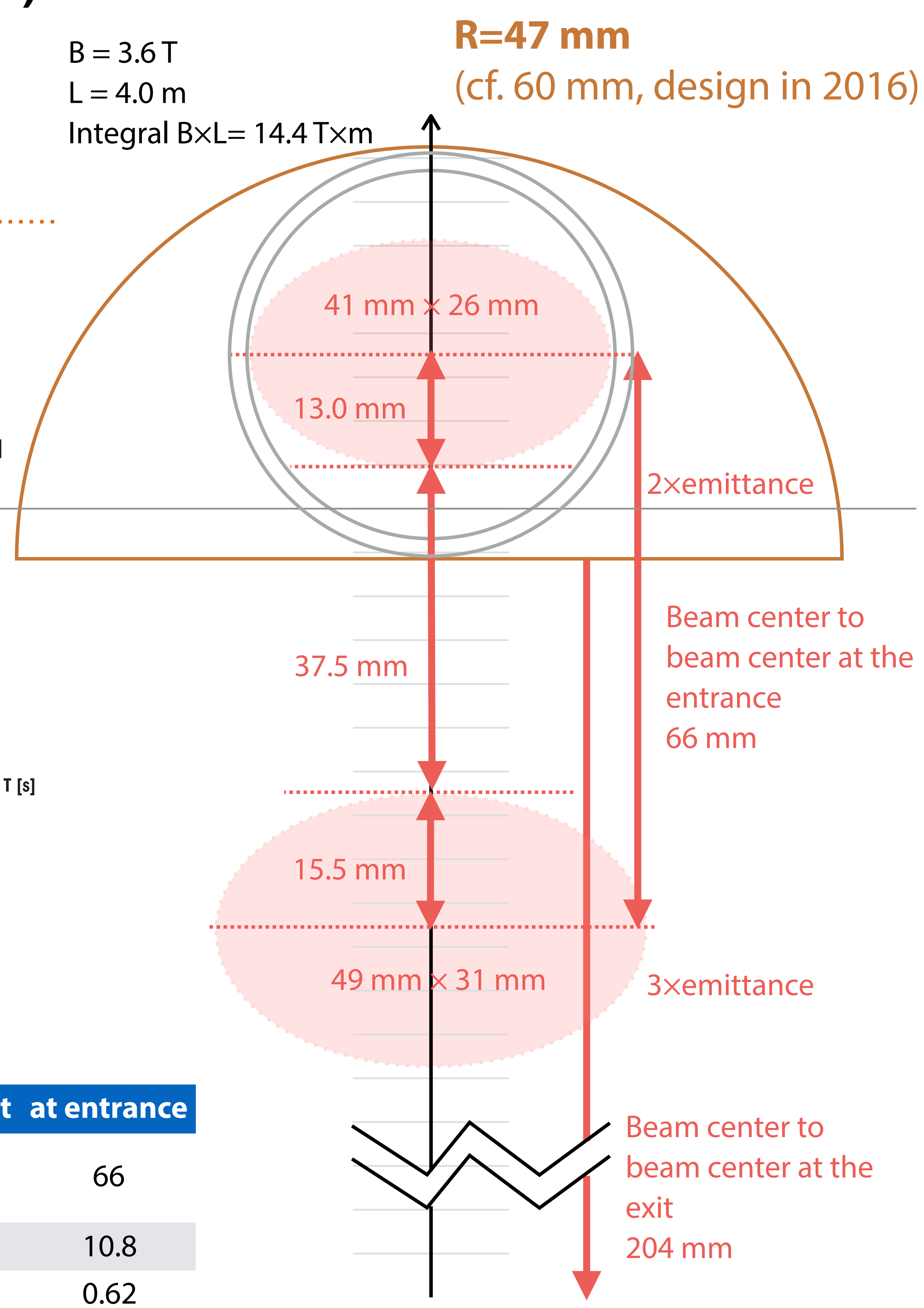




| | | magnet |
|---|---|---|
| Bending angle | mili-rad | 47.4 |
| | degree | 2.71 |
| Bending radius | m | 83.33 |
| Field strength | T | 3.6 |
| Effective length | m | 4 |
| Beam rigidity | Tm | 300.00 |
| Sagitta of orbit | mm | **23.38** |
| Alignment angle | mili-rad | 34.49 |
| | degree | 1.98 |

B_min = 1.2 T
B_max = 3.6 T
dB/dt = 0.8 T/s

| | | at exit | at entrance |
|---|---|---|---|
| Distance between beam centers | mm | 204 | 66 |
| Angle | mili-rad | 58.2 | 10.8 |
| | degree | 3.33 | 0.62 |

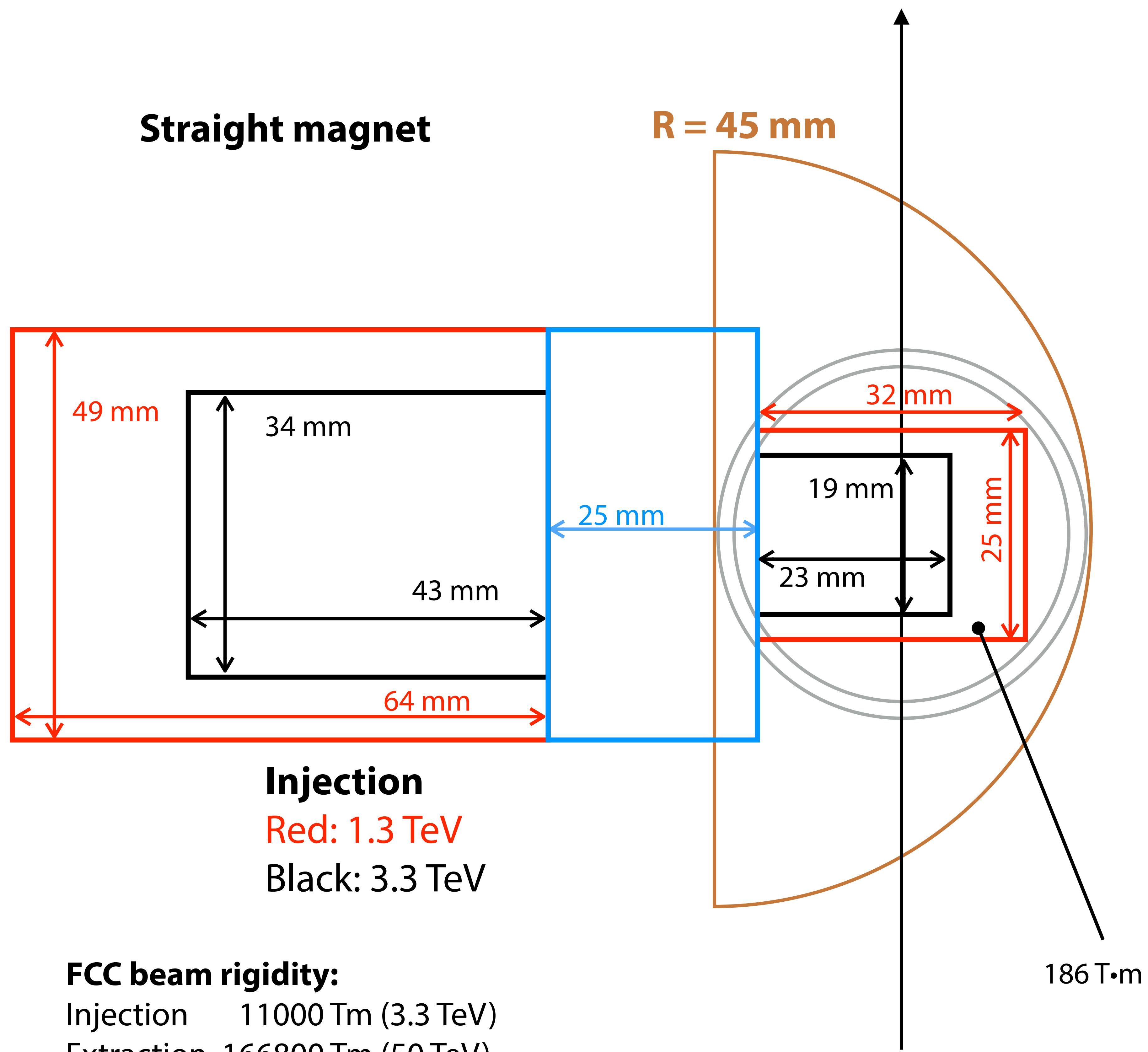
B = 3.6 T
L = 4.0 m
Integral B×L= 14.4 T×m




**SISx00 septum should be designed as a curved magnet.**

## FCC Septum Geometry

*Courtesy of J. Borburgh, CERN, Feb. 2017*




**Injection**
Red: 1.3 TeV
Black: 3.3 TeV

**FCC beam rigidity:**

| | |
|---|---|
| Injection | 11000 Tm (3.3 TeV) |
| Extraction | 166800 Tm (50 TeV) |
| cf. | |
| LHC | 23400 Tm |
| SIS300 | 300 Tm |