DUNE Near Detector Superconducting Magnet

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Outline

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Magnet design: Superconducting Coils

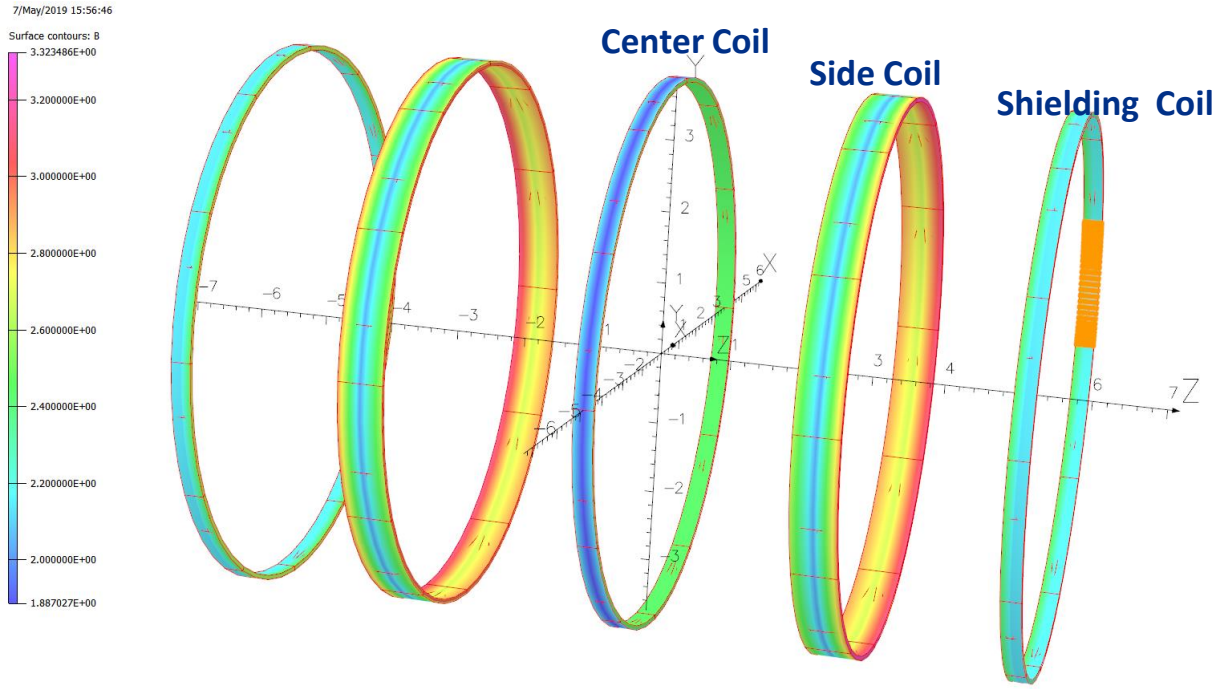
Several variants of magnet system have been investigated:

- **Long Solenoid (expensive, large cryostat and fringe fields).**
- **Solenoid surrounded by an iron yoke (expensive, very heavy iron yoke to effectively shield the field).**
- **Two Helmholz coils, no yoke (poor bore field homogeneity, large fringe field).**
- **Three coils, no yoke (low cost with an acceptable field homogeneity but large fringe field).**
- **Three coils, no yoke with active shielding by two coils (base concept at that time).**

Magnet Specification

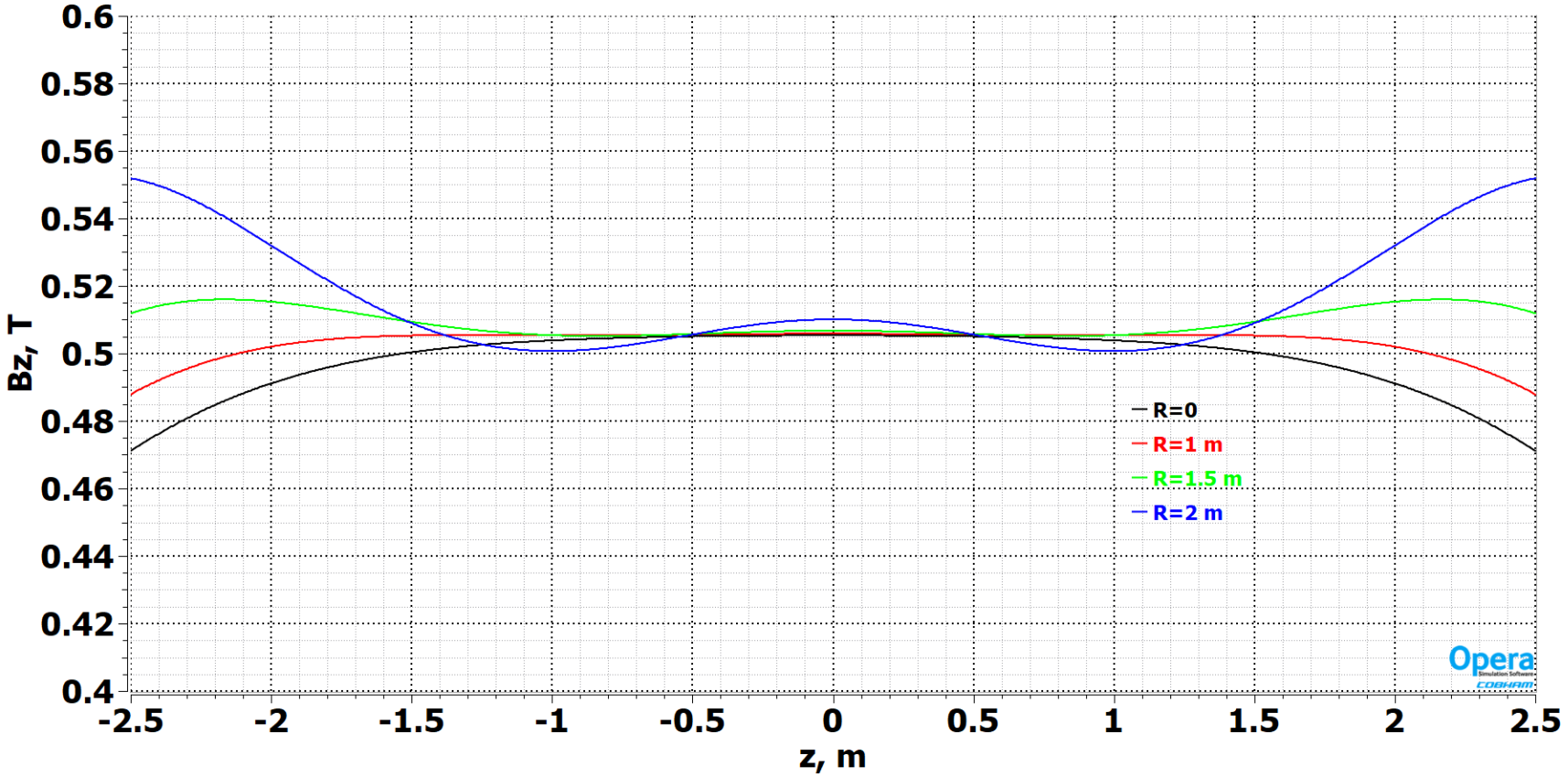
Parameter	Units	Value
Magnetic field configuration		Axial-Symmetric
Center peak field	T	0.5
Good field area diameter/length with the field homogeneity ± 10 %	m	4.0/4.0
The clear bore diameter for TPC	m	7.0
Maximum outer diameter	m	9.0
Maximum length	m	12.0
Superconductor type		NbTi
Preferable material for coils support structure		Aluminum
Superconducting coil operating temperature		≤ 5 K
Minimal distance between coil and strongback, helium piping to the cryostat wall	mm	200
Maximum coil deformation criterion	mm/m	1.7
Maximum vacuum jacket deformation criterion	mm/m	2
Positional Tolerance of the coils	mm	±5
Admissible bucking limit	MPa	120
Cooling source		Cryoplant

5 Coils Magnet System



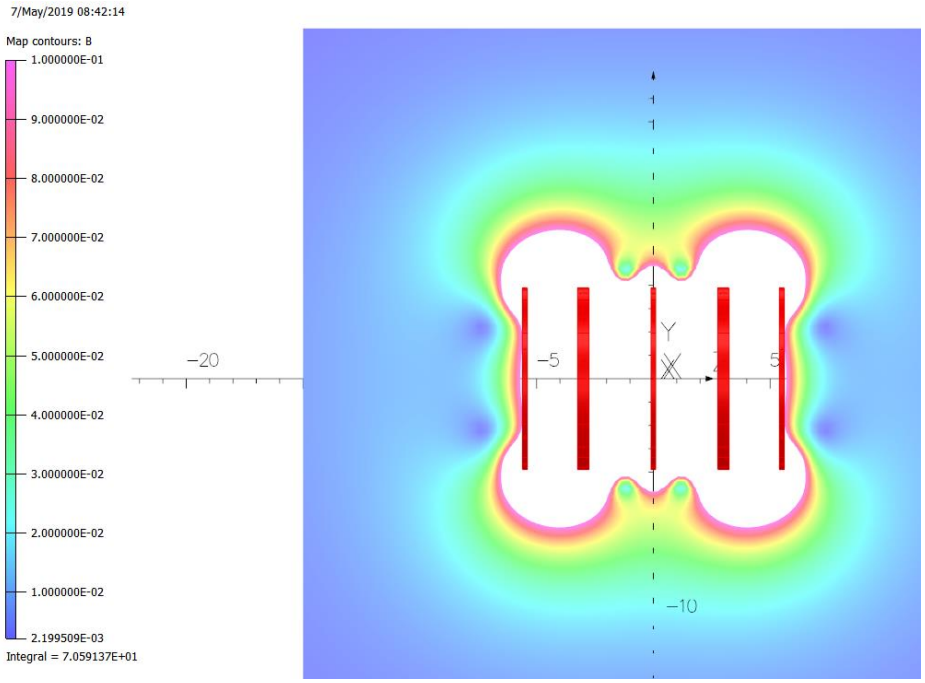
- Peak coil fields: 2.53 T (center), 3.32 T (side) 2.72 T (shield).
- Total stored energy 109 MJ
- Forces Fz : 0.0 (center), - 8.2 MN (side), 4.5 MN (shield).
- Side coils at 3.0 m, shielding coils placed at 5.5 m from the magnet center in Z.
- All coils have the same inner radius 3.8 m and outer radius 3.862 m.
- Center and shielding coils are identical and have the same number of ampere-turns.

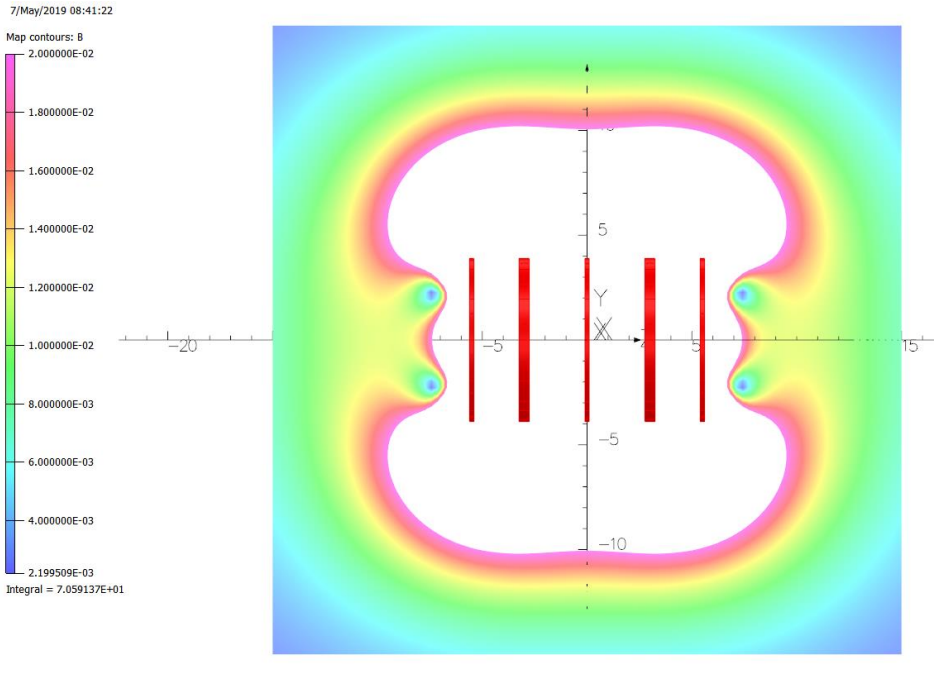
Bz Field in the Magnet Bore



- The center field is 0.5 T at coil total currents:
  1.08 MA (center and shield), 2.46 MA (side).

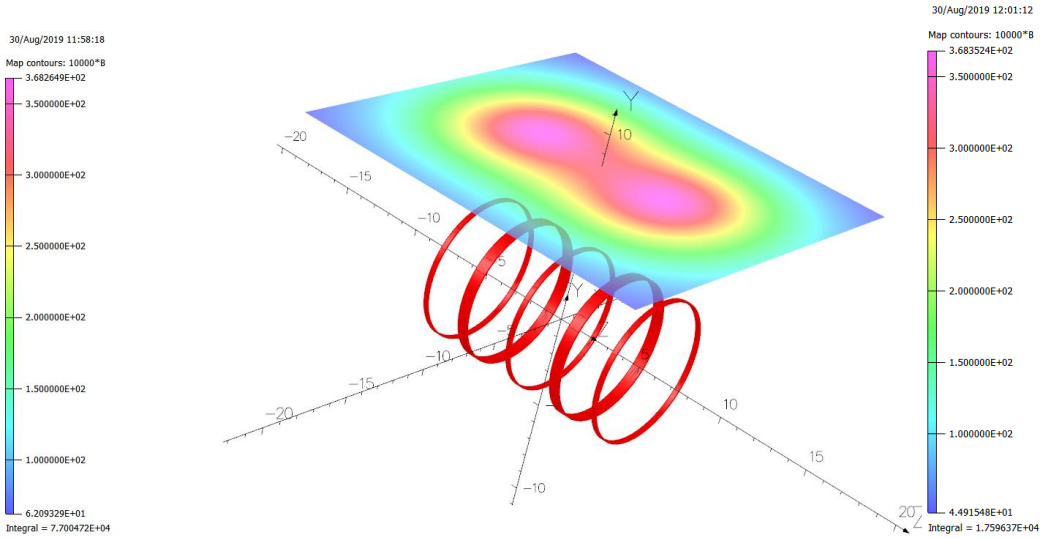
Magnet Fringe Field

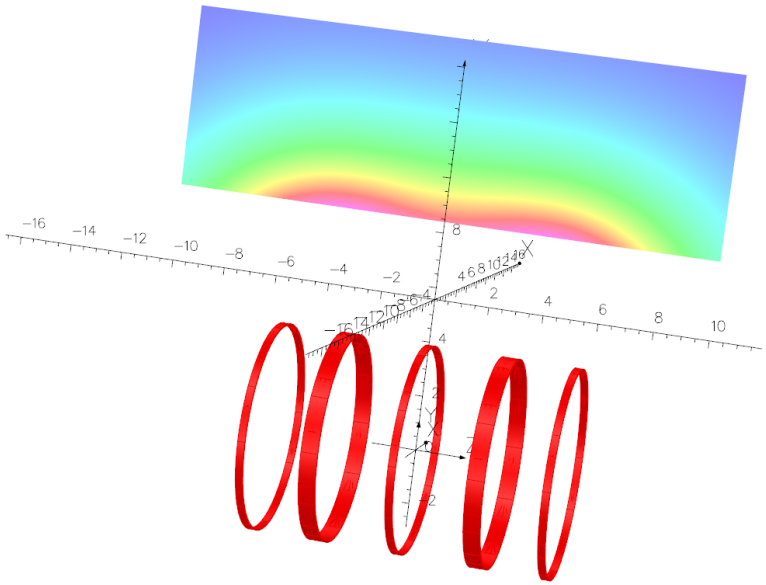




- Fringe fields less than 0.1 T (left) 0.02 T (right) shown as zone maps.

Fringe Field in the Cryogenics Area





- Fringe fields less than 370 Gauss shown as zone maps at the distance 8.4 m from the magnet center where the cryogenic equipment might be placed.

Fermilab

Superconductor Choice

- NbTi superconductor is the most economical choice for the large detector magnets;
- From the quench protection view is better to use Al stabilized superconductor if will be available from the industry. Copper stabilized superconductor could be an alternative option.
- Close to needed parameters has Mu2e detector solenoid superconductors with parameters:

- Dimensions 20 mm x 5.25 mm or 20 mm x 7 mm;
- Jc=2750 A/mm^2 at 4.2K, 5T;

- Coils dimensions now based on wider superconductor which has 19.4 kA critical current at 4.2K and 5T. For the coil peak field 3.3T and 10kA operational current there is enough margin.
- The magnet has 109 MJ stored energy, 2.18 H inductance, 10 kA current, and 22 s time constant during discharge on the external dump resistor. These parameters are close to the Mu2e production solenoid: 80 MJ, 1.6 H, 9.2 kA which is very effectively protected.

Magnet Parameters

Coils	N	Iw MA	Bmax T	Rin m	Rou m	Zc m	Width m
Center	1	1.08	2.53	3.8	3.862	0	0.27
Side	2	2.46	3.32	3.8	3.862	3.0	0.616
Shield	2	1.08	2.72	3.8	3.862	5.5	0.27
Total	5	8.16	-				

*Coil dimensions for the 10 kA operating current and without support structure.

N – number of coils;

Iw- coil ampere-turns;

Bmax – peak field on the coil;

Rin, Rou – inner and outer coil radiuses;

Zc – coil center distance;

Width – coil width.

Lorentz Forces

N	Coil	Iw MA	Fz MN	Iw MA	Fz* MN	Iw MA	Fz** MN
1	Shield	1.08	-4.491	0	0	1.08	-0.647
2	Side	-2.46	8.17	-2.46	4.327	0	0
3	Center	-1.08	0	-1.08	-0.404	-1.08	2.908
4	Side	-2.46	-8.17	-2.46	-8.476	-2.46	-6.446
5	Shield	1.08	4.491	1.08	4.552	1.08	4.186

N – coil number;

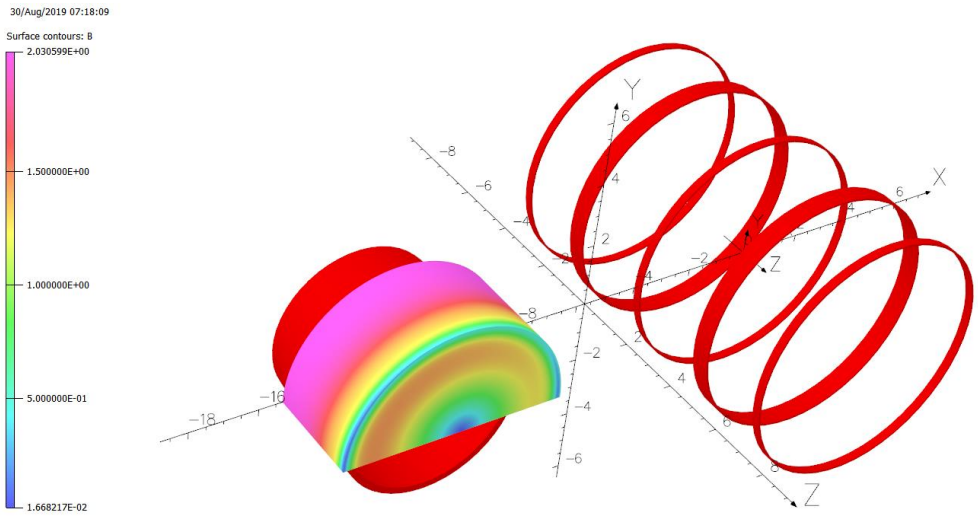
Iw- coil ampere-turns;

Fz – Lorentz force on the coil when all coils powered;

*Fz – Lorentz force on the coil when all coils powered besides one shield coil;

**Fz – Lorentz force on the coil when all coils powered besides one side coil;

ND and KLOE Magnets Interaction



N	Coil	Iw MA	Fz MN	Fx kN
1	Shield	1.08	-4.39	-160
2	Side	-2.46	8.29	14
3	Center	-1.08	0	476
4	Side	-2.46	-8.29	14
5	Shield	1.08	4.39	-160
KLOE	Solenoid	-2.17	0	- 7.1

KLOE iron is saturated up to 2 T at the nominal operational center field 0.6 T.

Horizontal force between magnets (on ND coils) is 183 kN.

Horizontal force on KLOE solenoid is – 7.1 kN.

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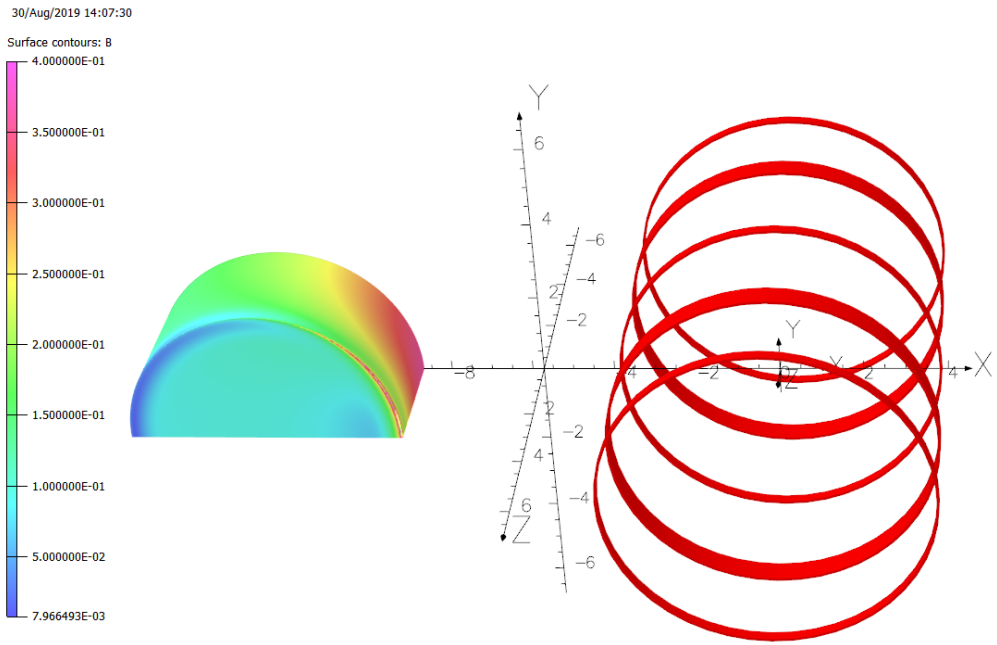
ND and KLOE Magnets Interaction



N	Coil	Iw MA	Fz MN	Fx kN
1	Shield	1.08	-4.38	-164
2	Side	-2.46	8.28	23
3	Center	-1.08	0	485
4	Side	-2.46	-8.28	23
5	Shield	1.08	4.38	-164
KLOE	Solenoid	0	0	0

KLOE iron max field from ND is 0.4 T at zero current in KLOE solenoid.

Horizontal force between magnets (on ND coils) is 202 kN.

Horizontal force on KLOE solenoid is zero.

Summary

✓ The magnetic design was updated to the new specification:

- Increased the distance between side coils from 5 m to 6 m;
- Increased the distance between shielding coils from 10 m to 11m;
- Increased all coils inner radius from 3.5 m to 3.8 m;
- For Al stabilized conductor increased coils outer radius to 3.8 m.

✓ Because of that:

-Total magnet ampere-turns increases from 6.72 MA to 8.16 MA.

- Coil peak field decreases from 4.9 T to 3.32 T (wider side coils).
- Peak coil force increases from 5.9 MN to 8.17 MN.
- Fringe field at z=10 m is 112 Gauss.

✓ Because of fields coupling there is Lorentz force on ND coils 183 kN, on KLOE solenoid -7.1 kN.