- **KEK Spiral Flux Concentrator (SFC) modification**
- **Generation of extremely long pulse magnetic field**

  by Flux Concentrators ~ 1 ms
- **ILC Flux concentrator concept**

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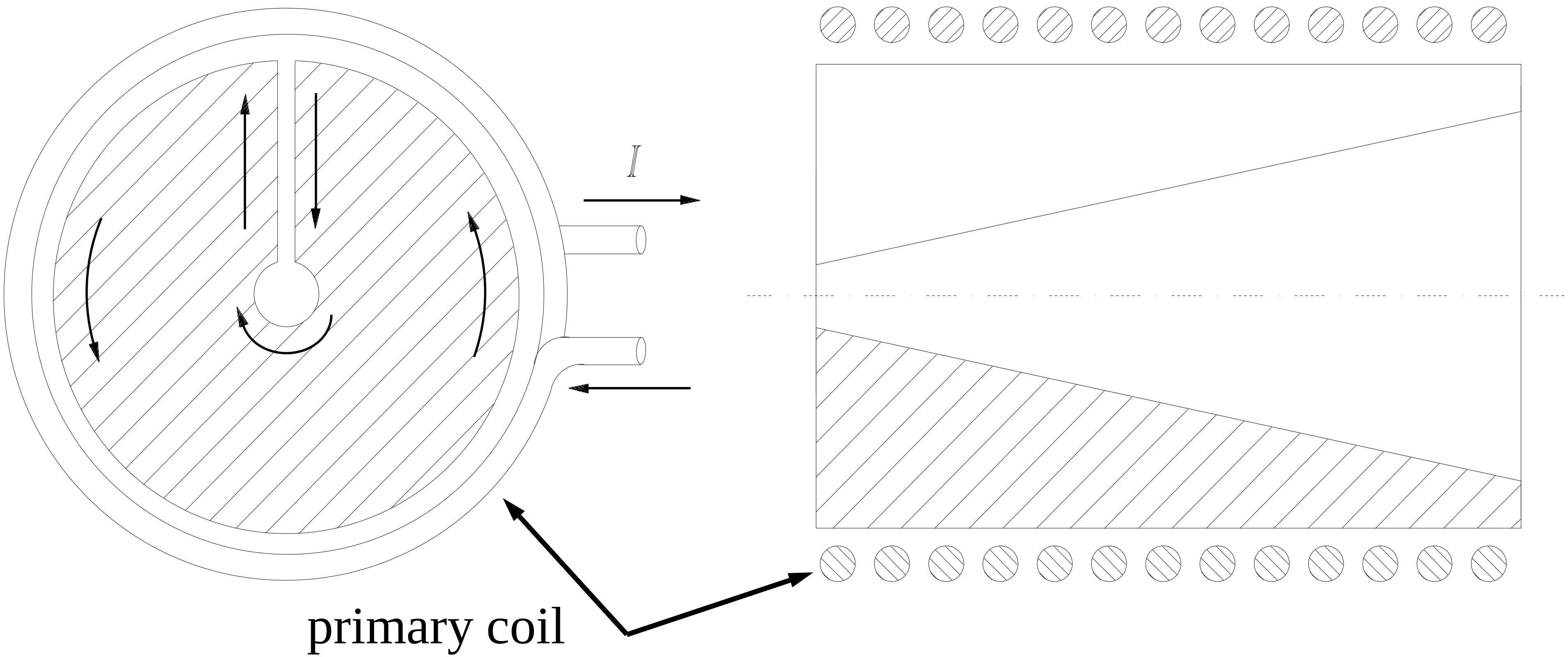
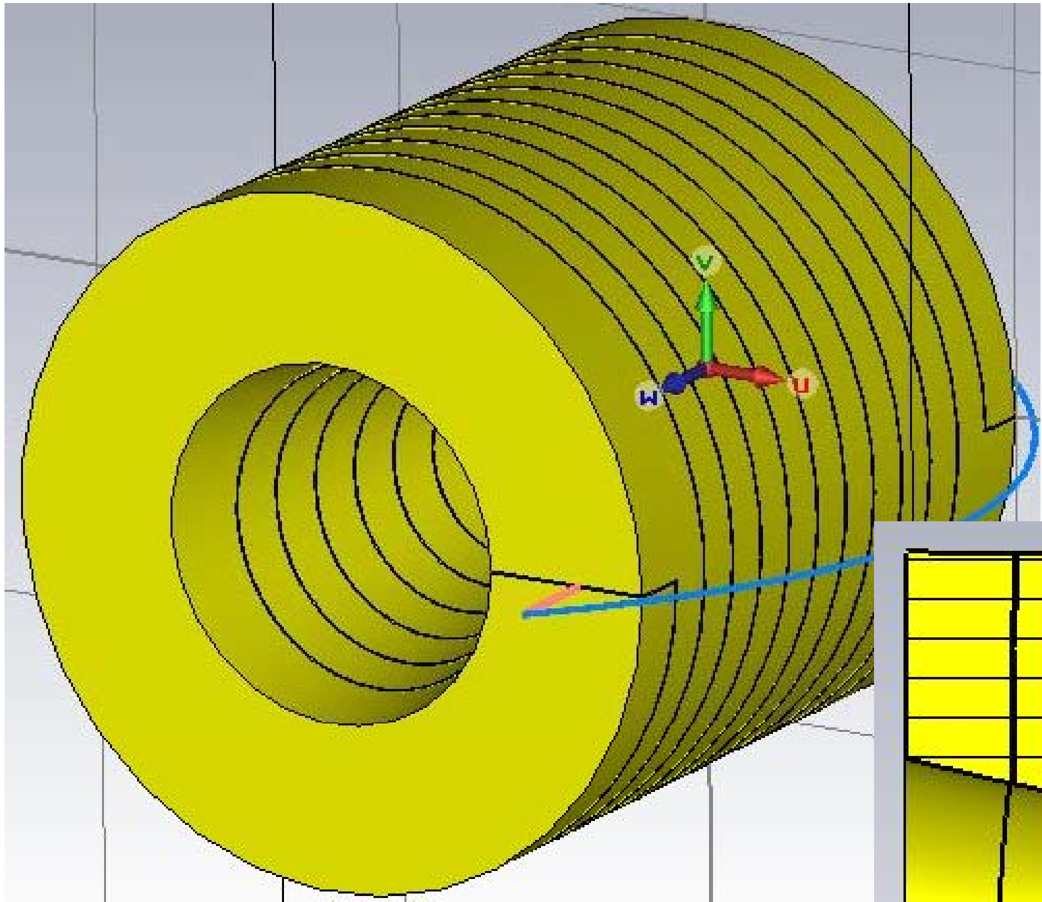
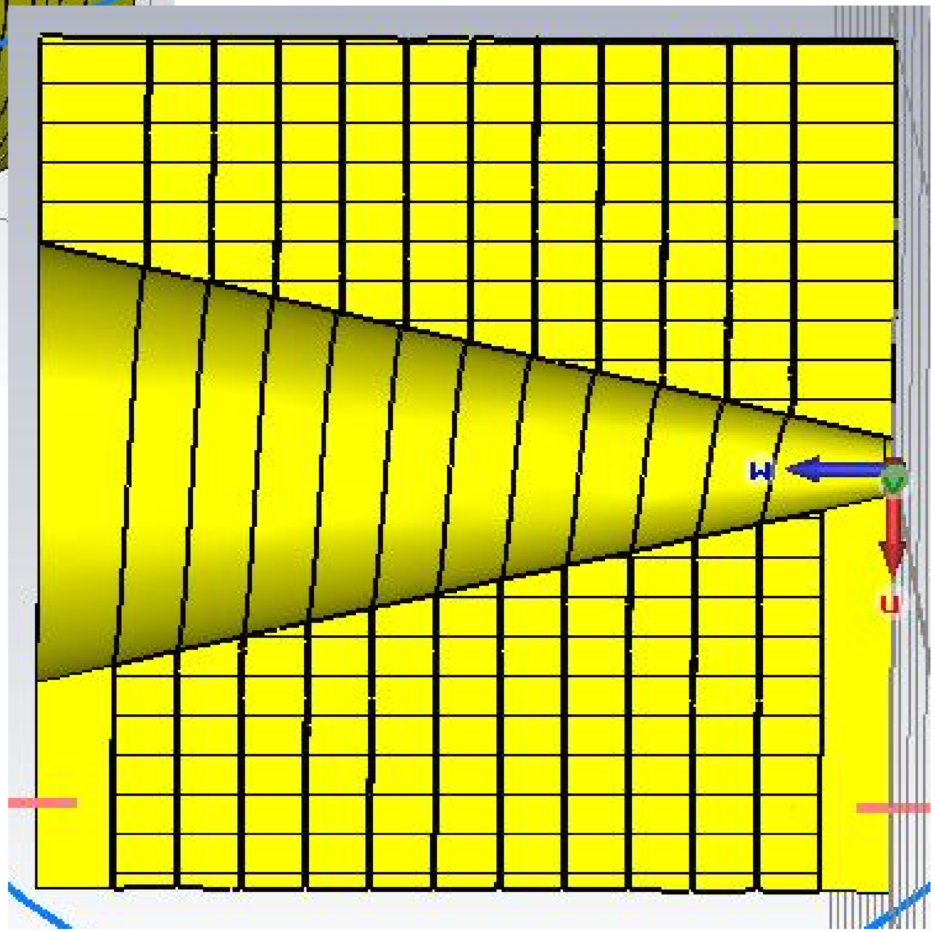
Classical Flux Concentrator



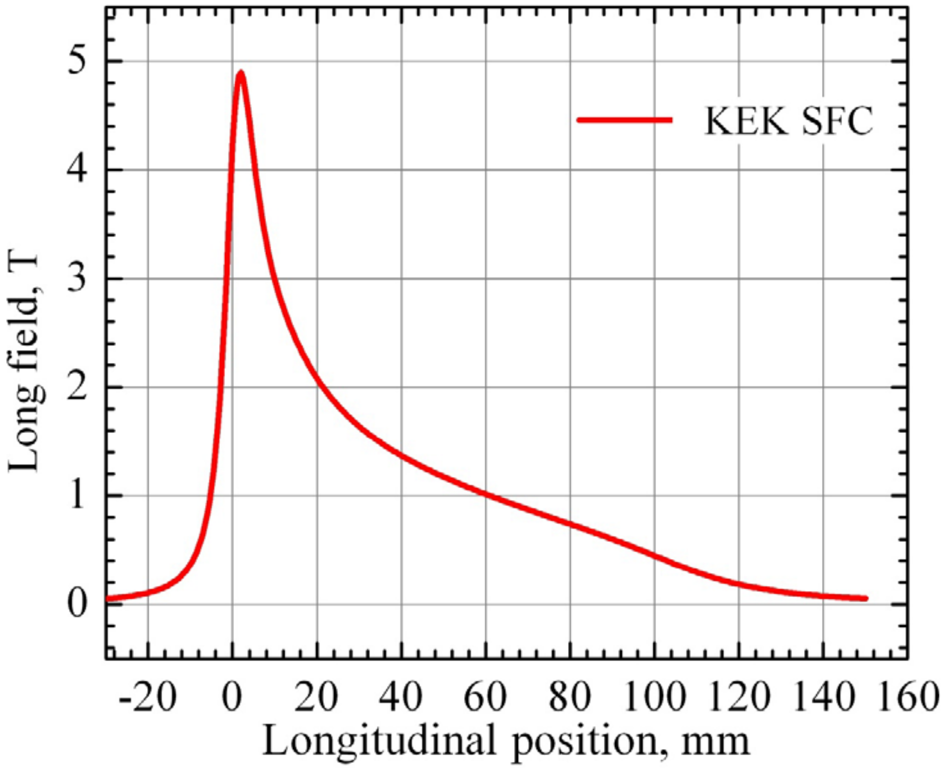
Peak magnetic field and Tapering field parameter are defined by the small hole diameter and the angle of conical cavity.

KEK Spiral Flux Concentrator (SFC) computer model



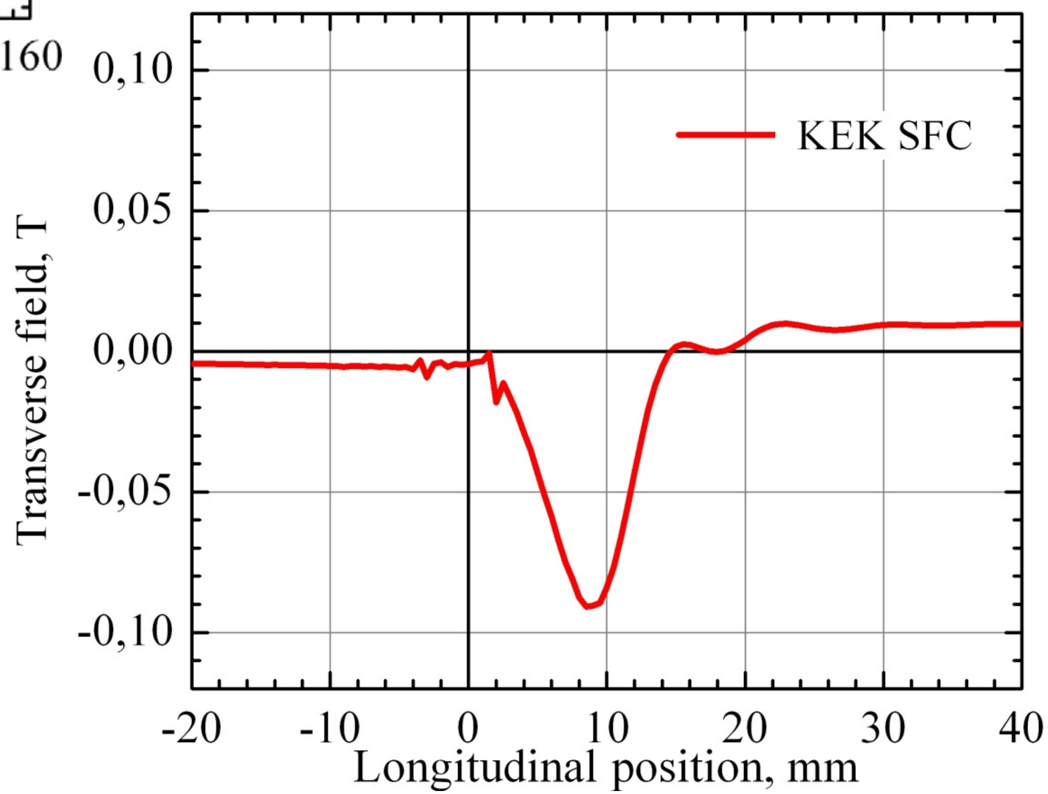


- SFC diameter is 100mm
- SFC length is 100mm
- Min cone diameter is 7mm
- Max cone diameter is 52 mm
- 12 turns
- Current is 12 kA
- Current profile is a half of sine with a pulse length of 6 μs

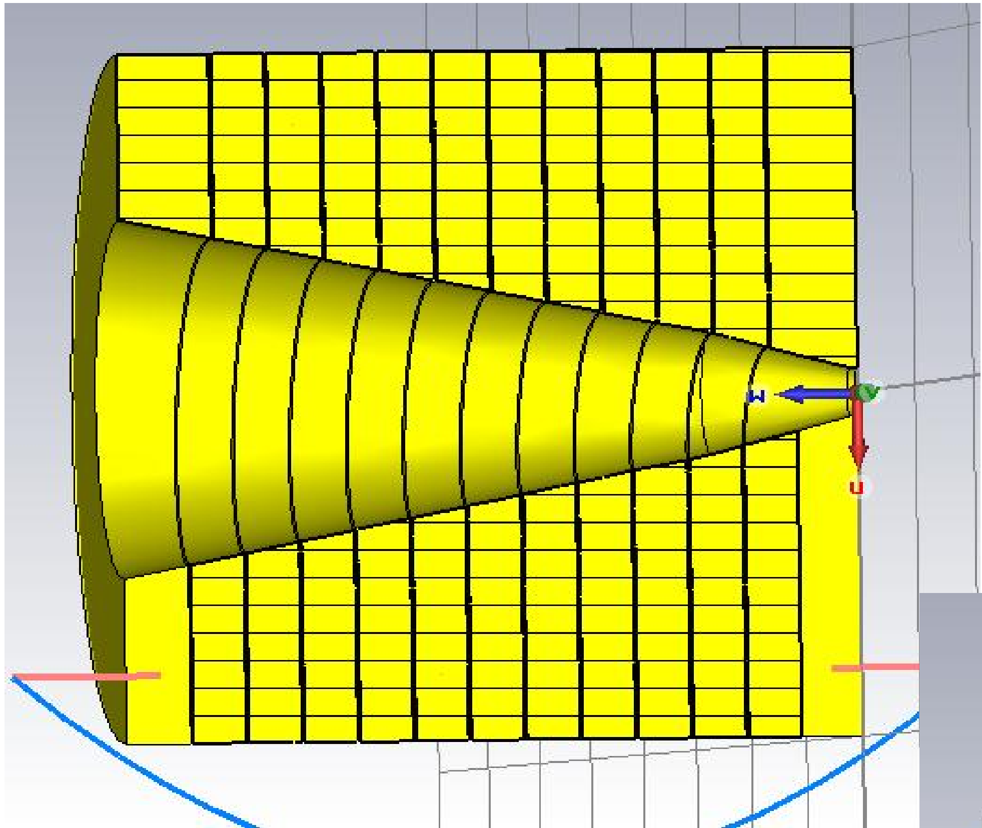


Peak of longitudinal magnetic field is ~ 4.9T

Peak of transverse magnetic field is ~ -0.09T

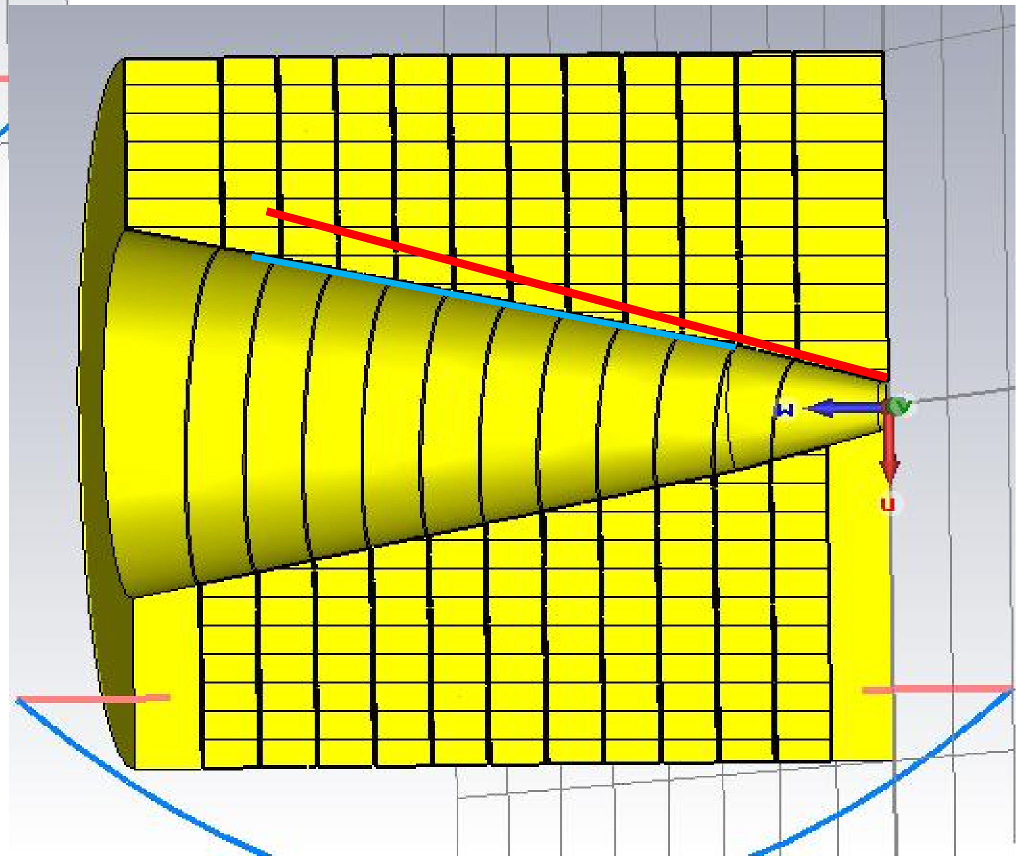


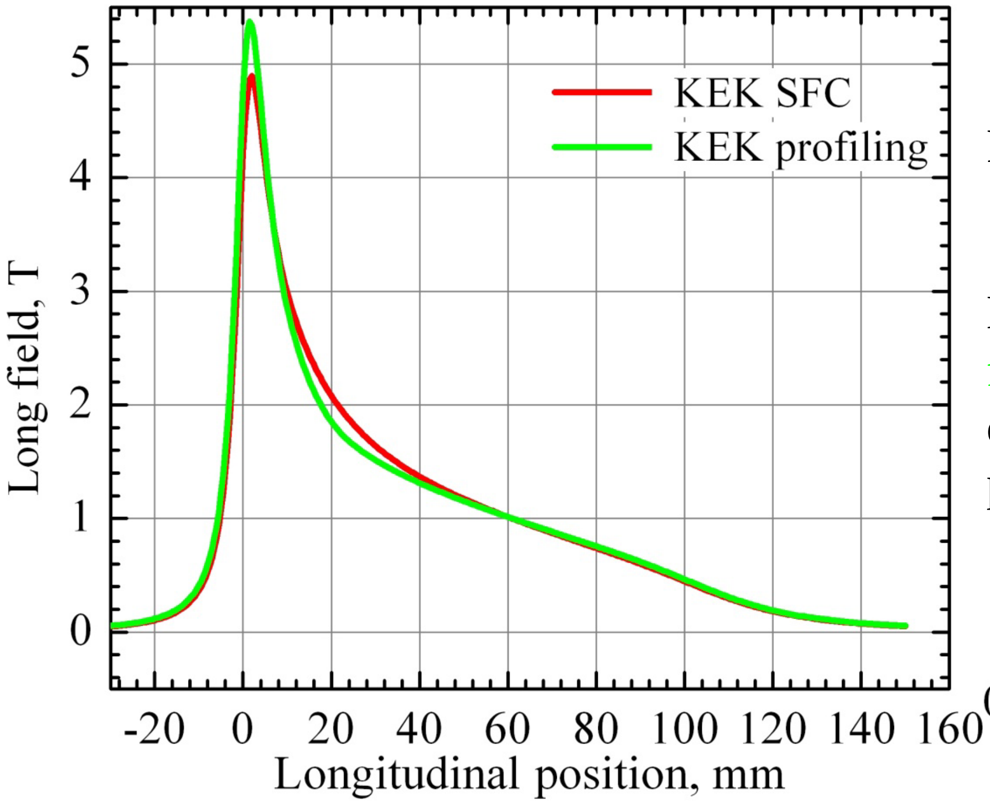
Modification of original KEK SFC design – profiling of conical cavity



Cone angle is increased up to ~ 30˚ (red line) from 0 to 20 mm of longitudinal position

Original cone angle of KEK design is ~ 25˚ (blue line)

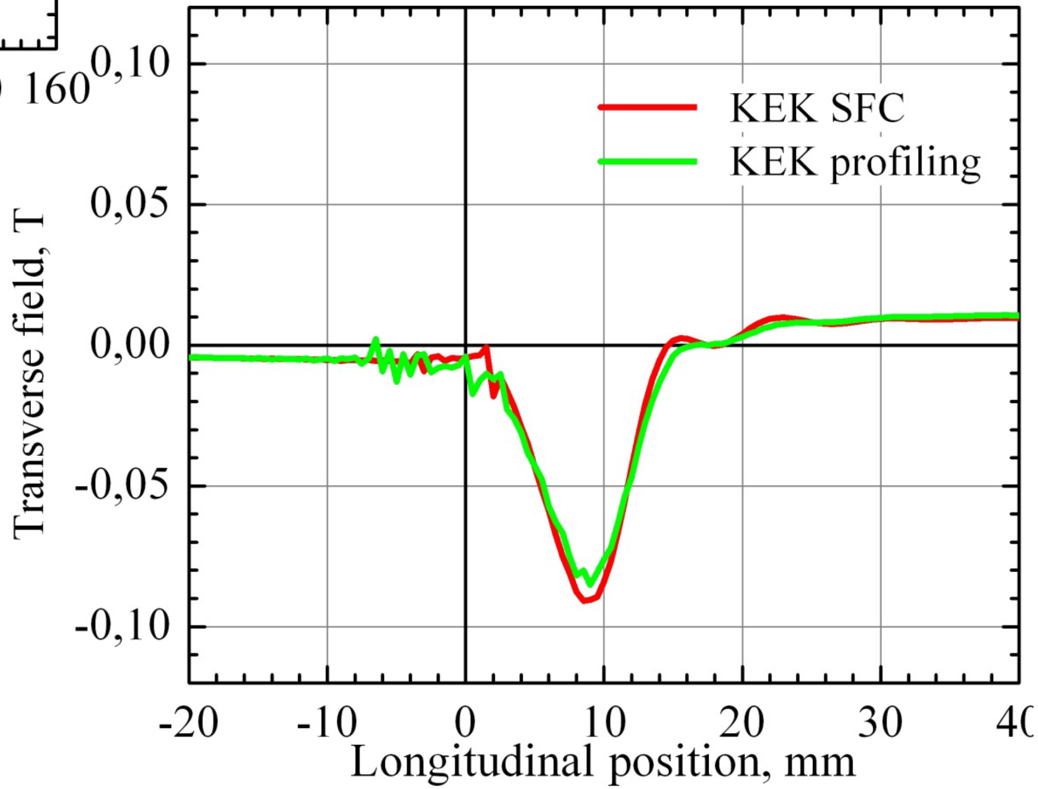


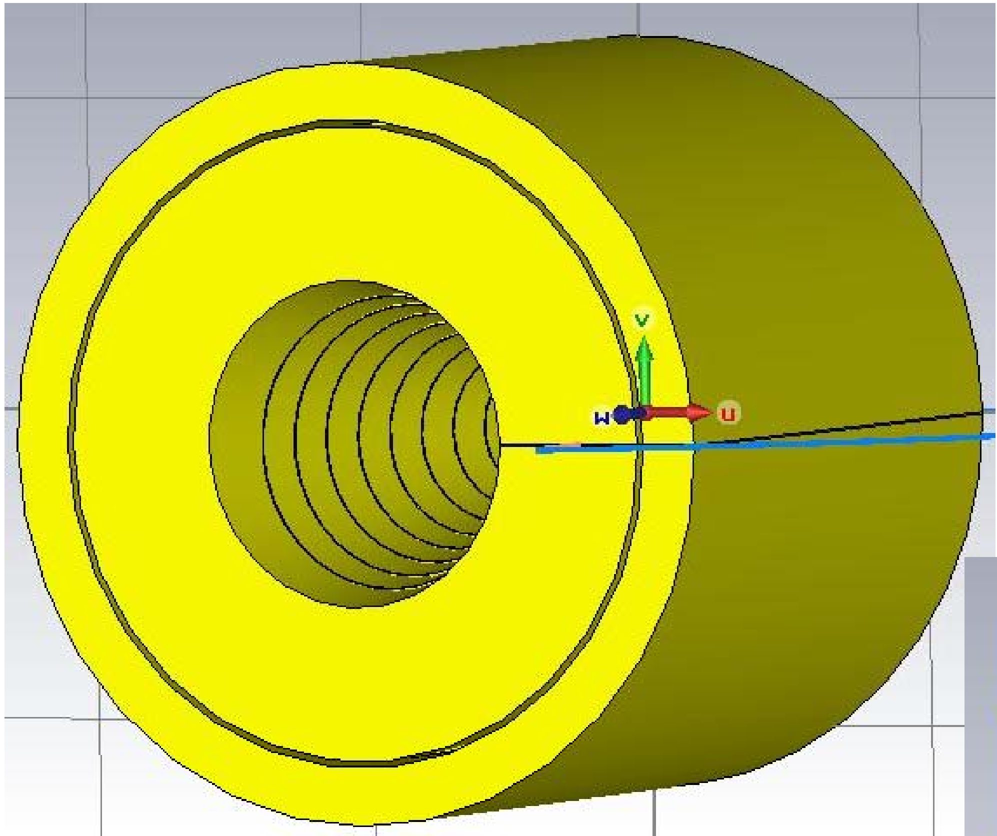


Peak of longitudinal magnetic field is ~ 5.4T

Magnetic field profile is changed (tapering field parameter became less a little) relatively of original design in range of longitudinal position from 10 mm to 50mm.

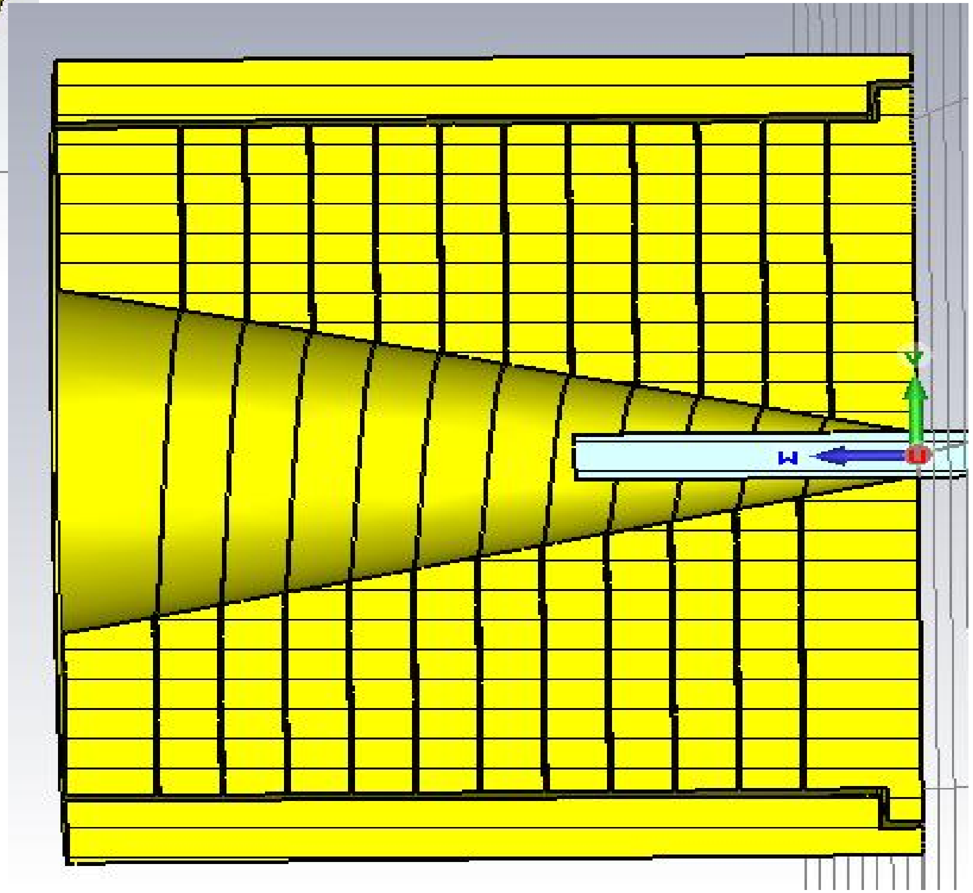
Peak magnetic field became higher due to current density redistribution in first and second turns



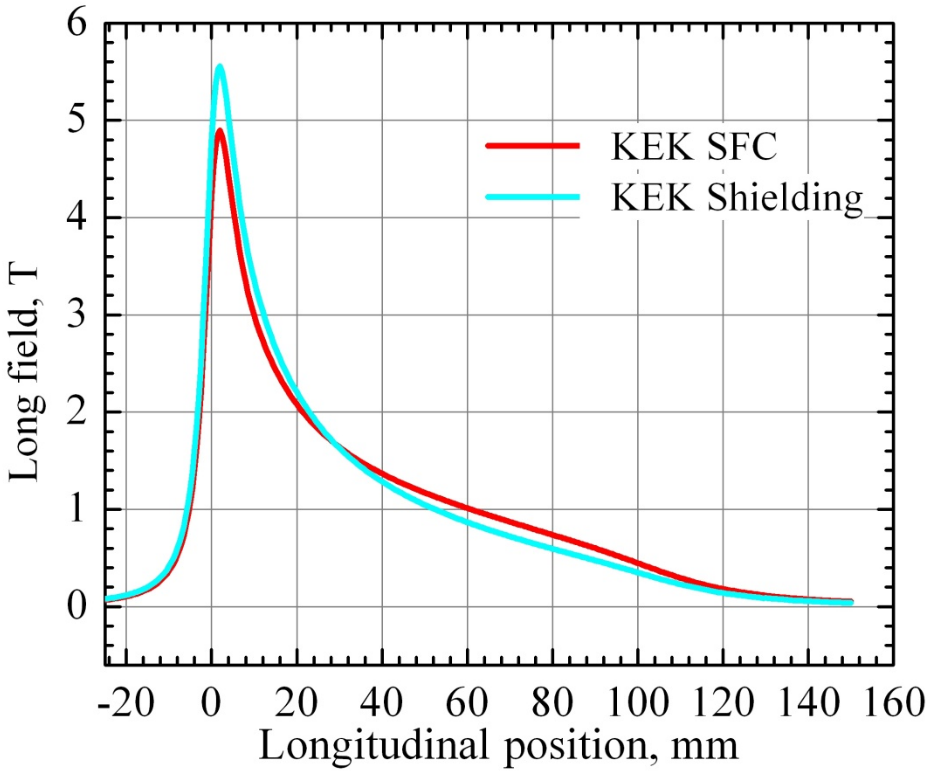


Modification of original KEK SFC design – Shielding of spiral

Shielding of a spiral coil reduces the aside magnetic flux leakage through a spiral gap.
Gap between coil and shield is 1mm



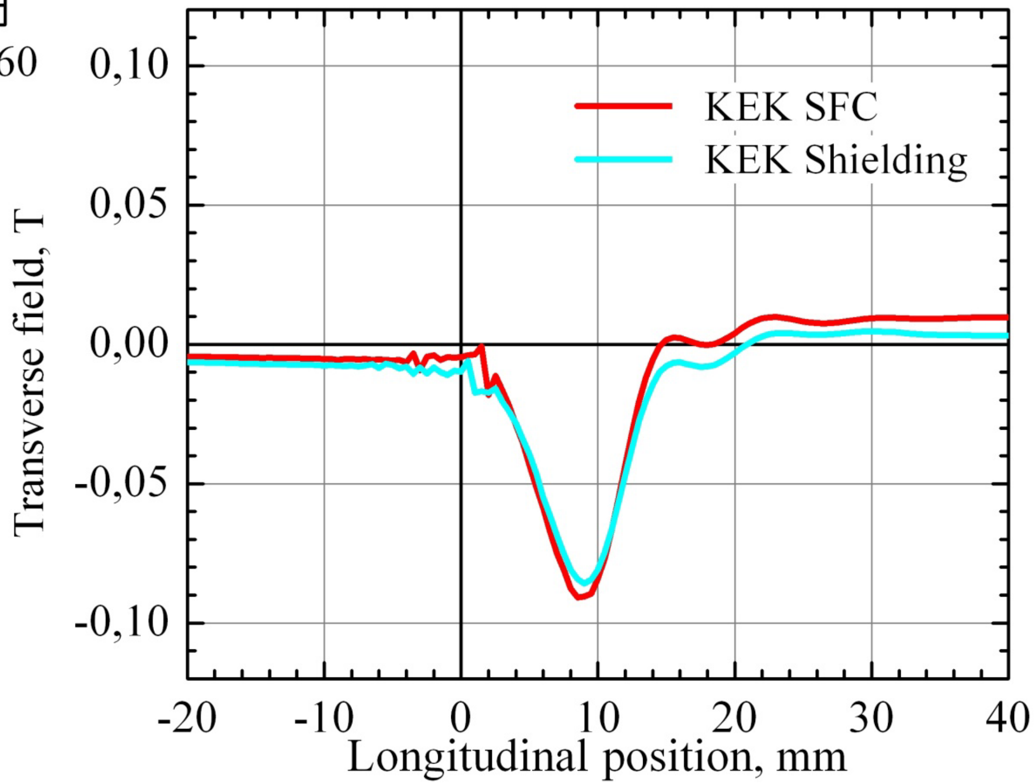
Generally, a peak magnetic field may be increased ~ 30% by shield using (in case of current pulse length should be about 30μs)

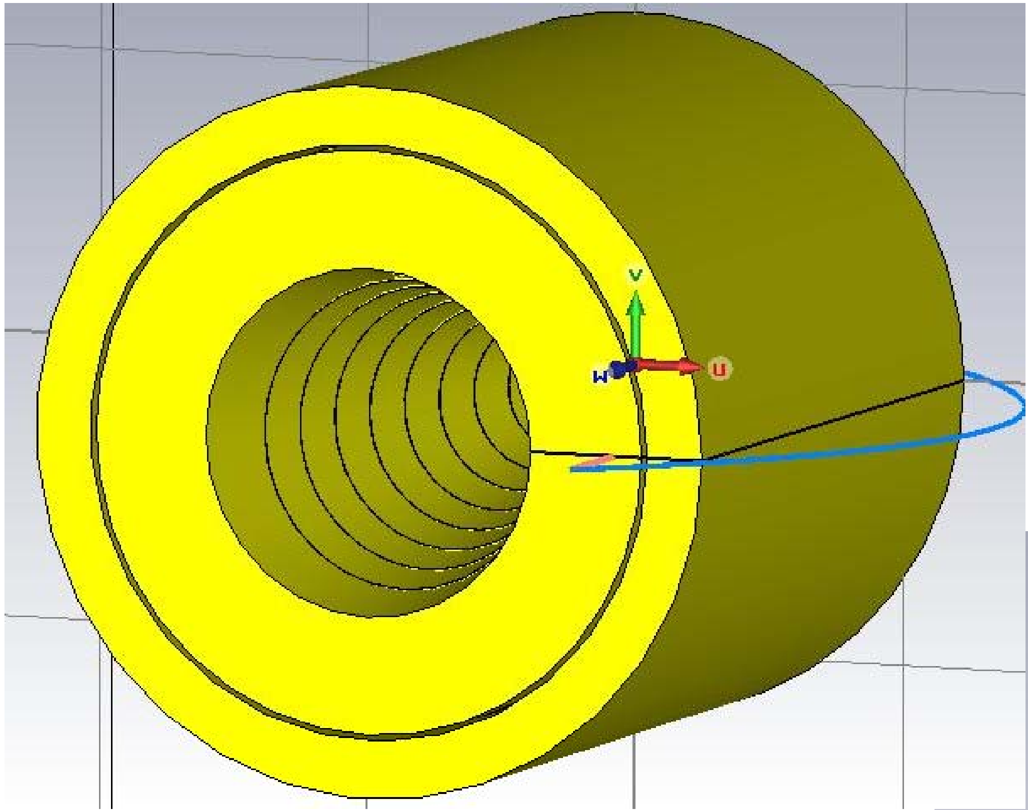


Peak of longitudinal magnetic field is ~ 5.6 T

Shielding increases peak magnetic field only 13% (expectation was about 30% and maybe higher)

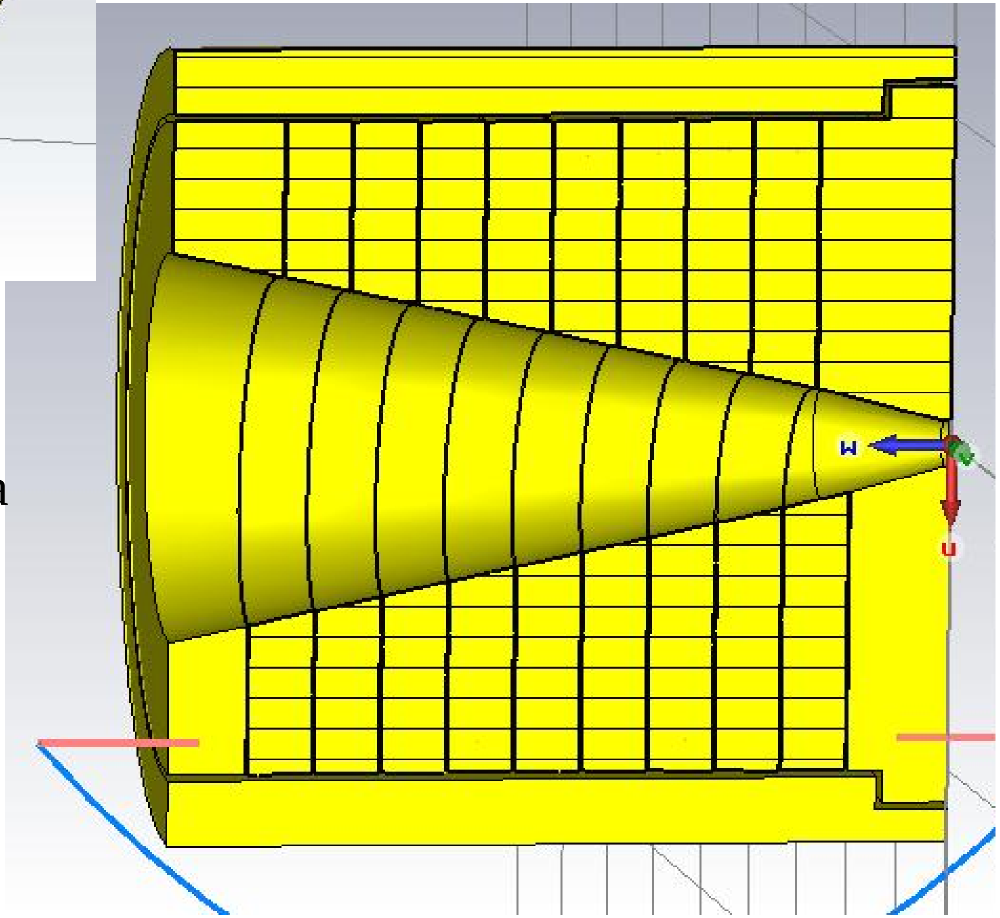
Difference between computed and expected field increase can be explain by a different skin layer depth. Effective turn gap (from magnetic flux point of view) is estimated as sum of geometrical and twice of skin layer depth (left and right from gap). The aside magnetic flux leakage at list 2 time less in case of 6μs pulse length. It is a reason why a shielding rises peak field not so high as expected.



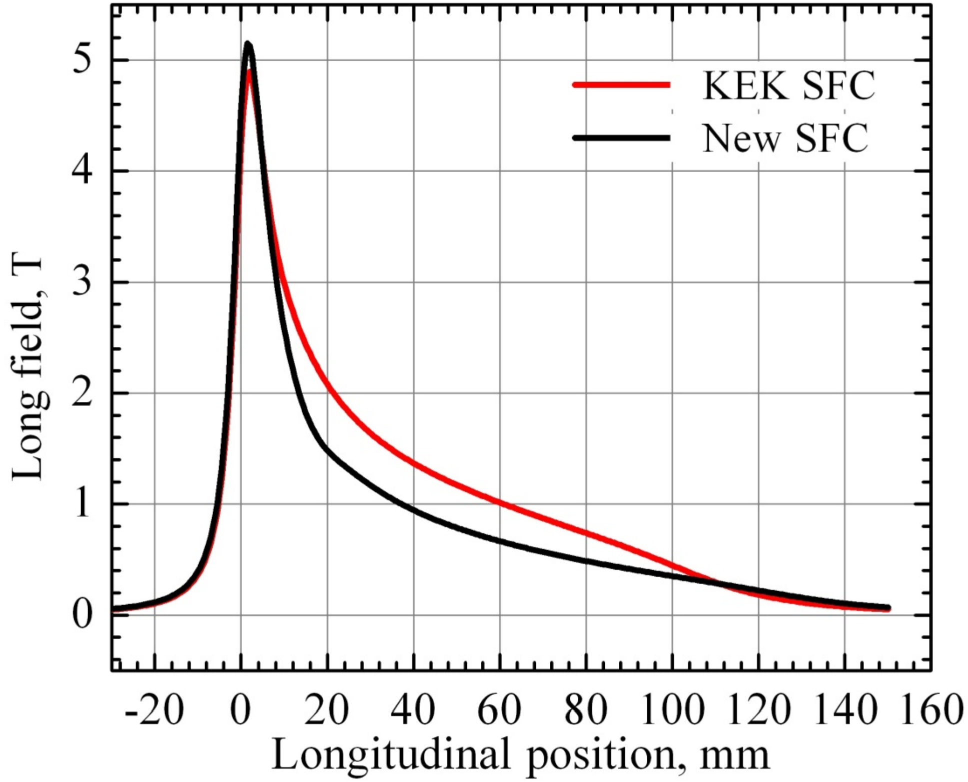


New SFC with changed geometry of turns with profiling and shielding

- SFC spiral diameter is 100mm
- SFC length is 120mm
- Min cone diameter is 7mm
- Max cone diameter is 52 mm



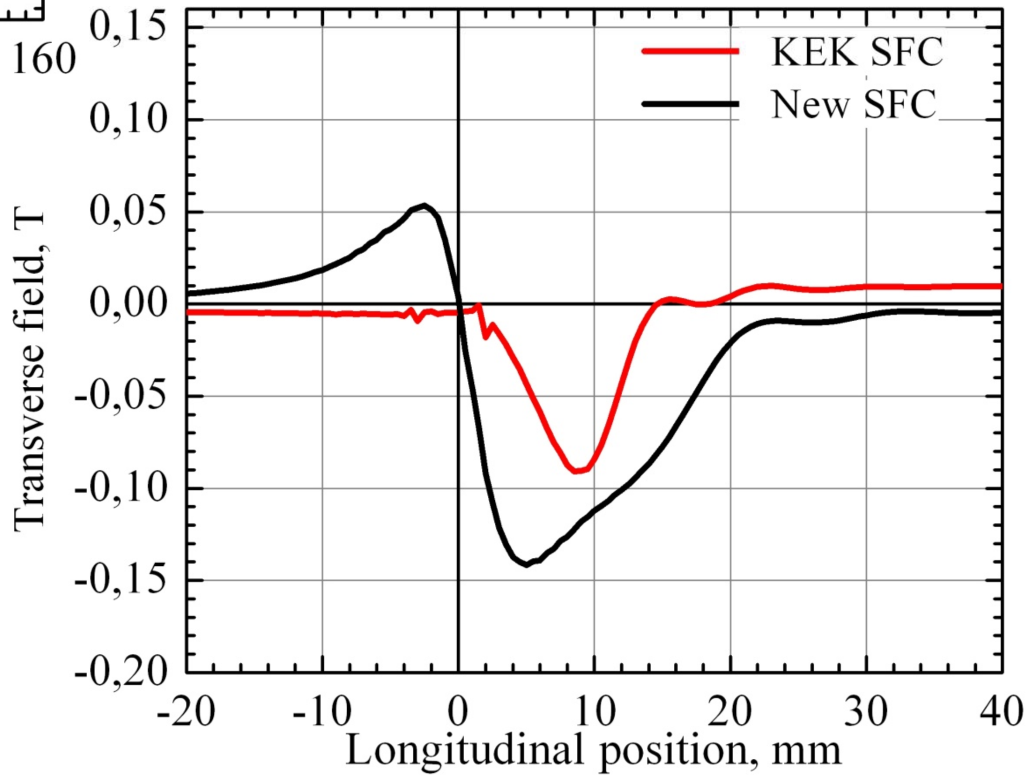
- **Coil has10 turns**
- Current is 12 kA
- Current profile is a half of sine with a pulse length of 6 μs
- Gap between turns is 0.3mm
- Gap between coil and shield is 1 mm
- **Gap between spiral and shield is 1mm**
- **Width of first turn is 15.4 mm**
- **Turns width is 11.4 mm**



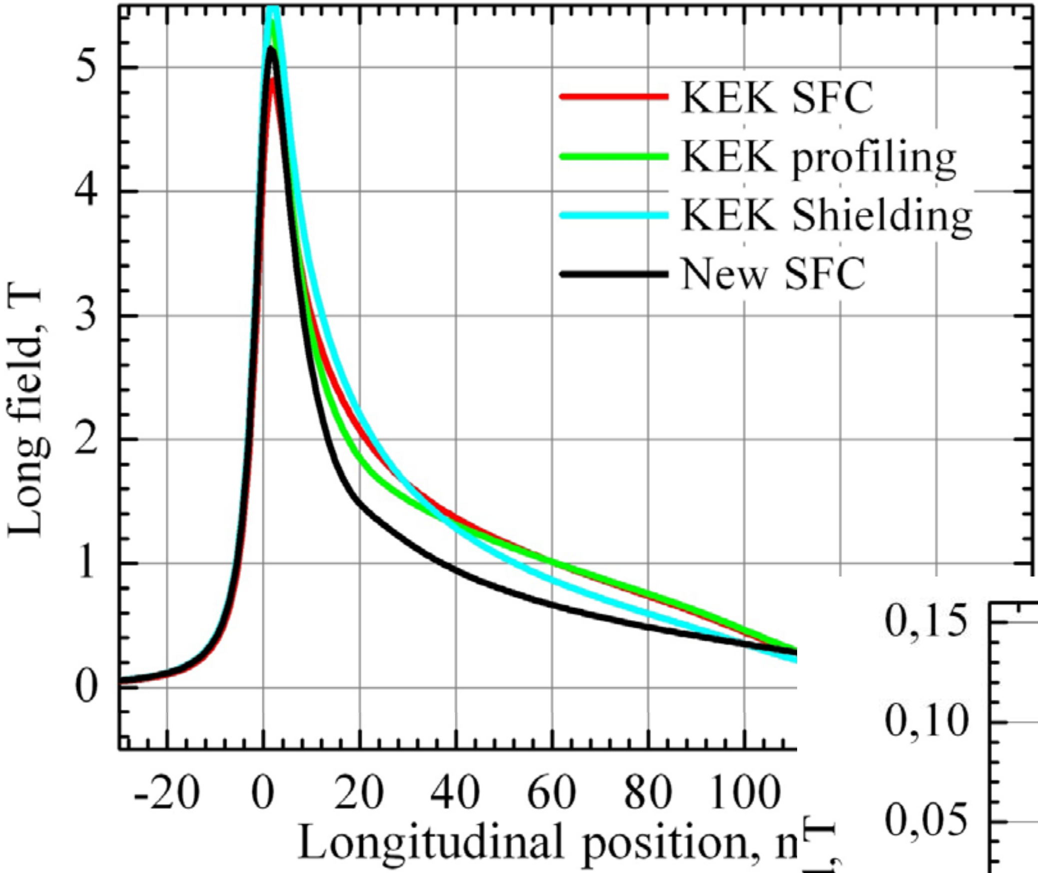
Peak of longitudinal magnetic field is ~ 5.2T

- Tapering parameter of magnetic field became bigger

Peak of transverse magnetic field is ~ -0.14 T

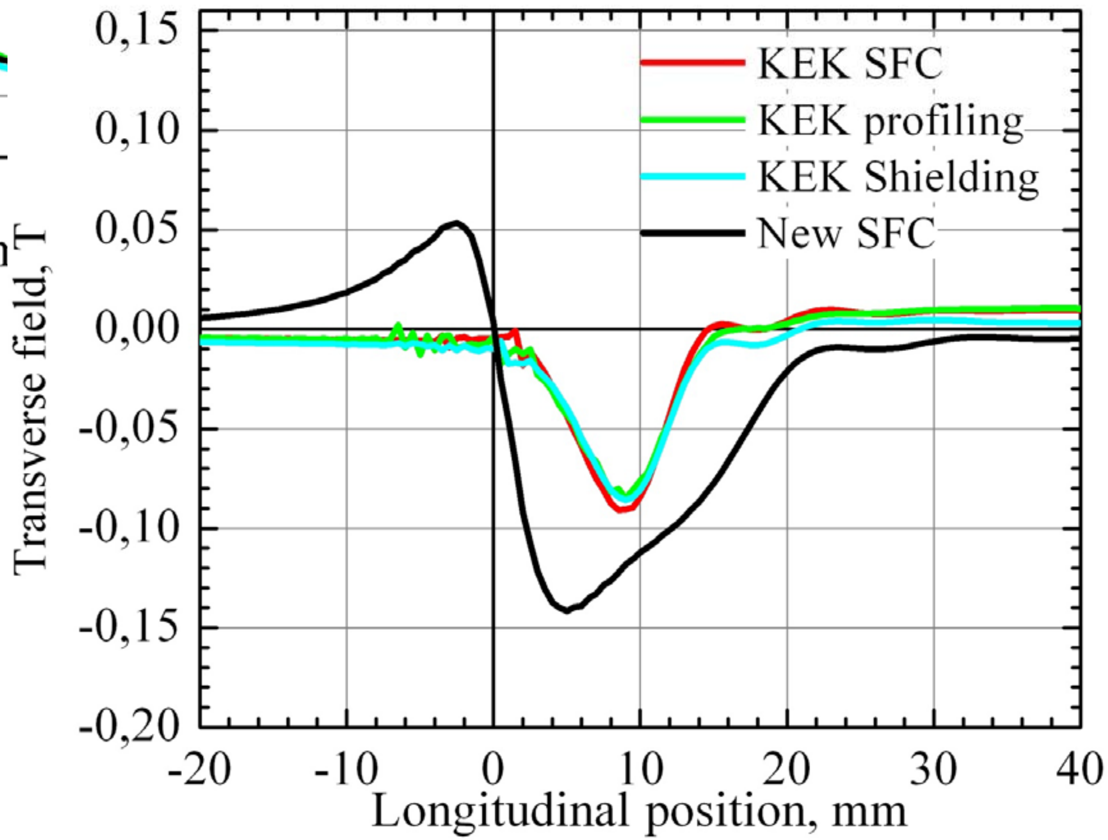


- **Transverse component of magnetic field became approximately 1.5 times higher (peak value) and twice longer due to width of first turn was approximately twice enlarged.**

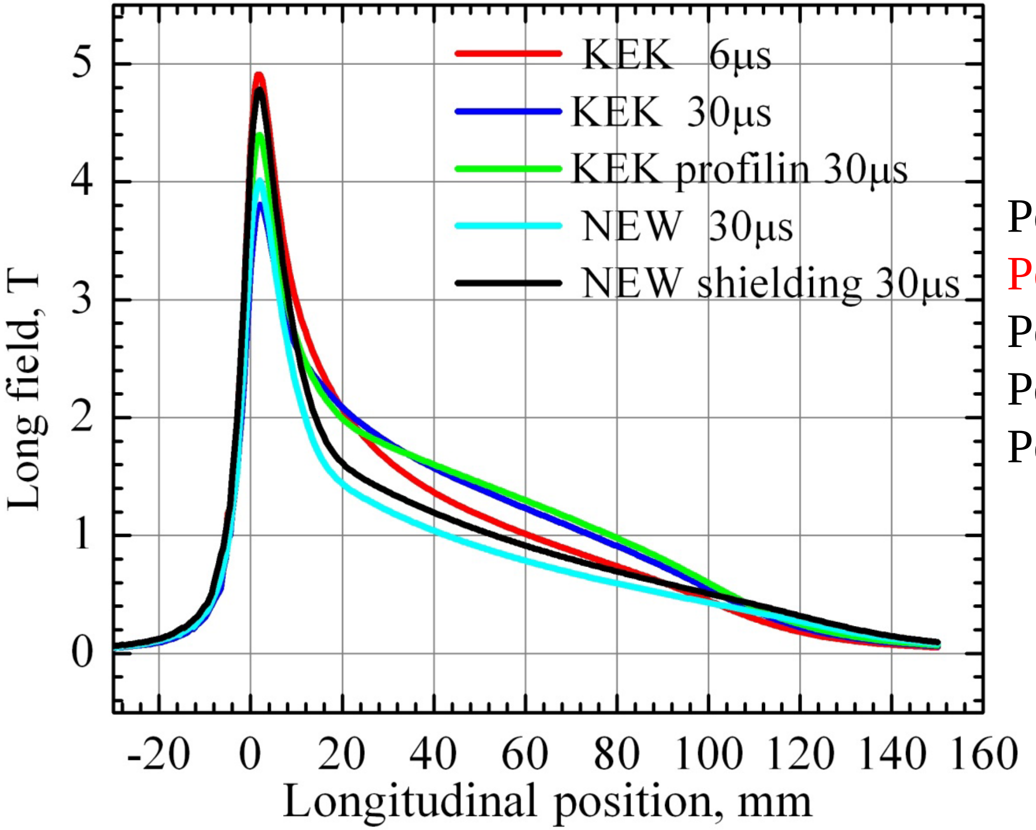


Longitudinal component s:

Peak field of KEK SFC is ~4.9T
Peak field of KEK profiling is ~5.4T (increasing of 10%)
Peak field of KEK Shielding is ~5 .6T (increasing of 13%)
Peak field of New SFC design is ~5.2T



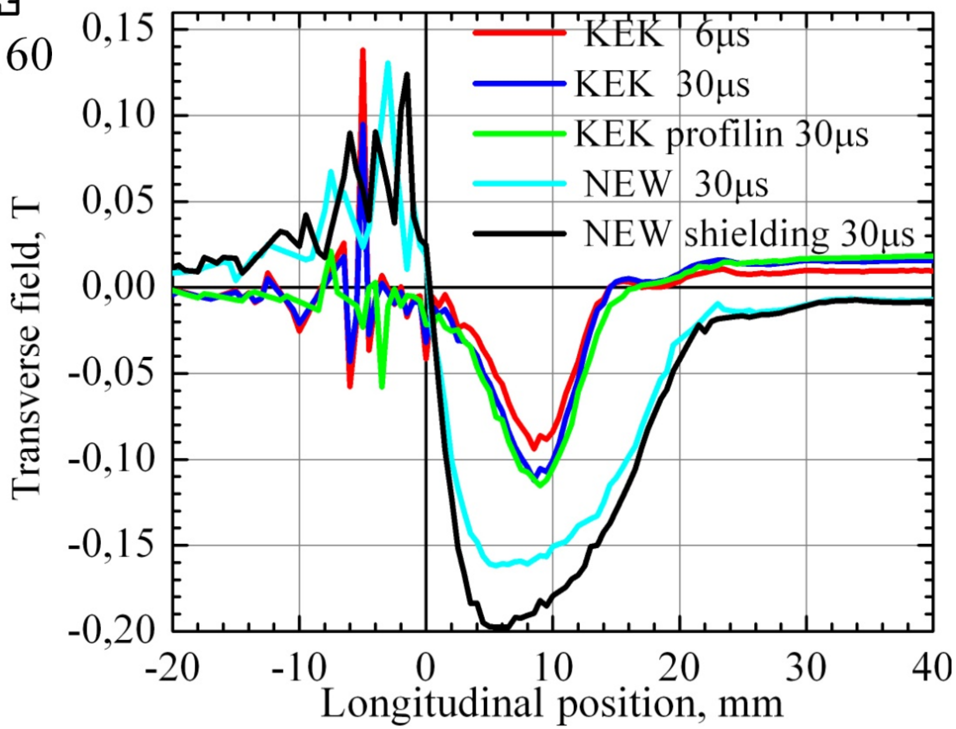
- Profiling and shielding increase peak field and change a little longitudinal profile.
- Transverse component profile practically is not changed for all KEK SFC variation.
- **Enlarged first turn changes transverse profile and peak field strong.**



Longitudinal component s:

Peak field of KEK SFC (6μs) is ~4.9 T
Peak field of KEK SFC (30μs) is ~3.8 T
Peak field of KEK profiling (30μs) is ~4.4 T
Peak field of New (30μs) is ~4.0 T
Peak field of New shielding (30μs) is ~4.8 T

- Longest pulse generates lower peak field (KEK SFC).
- Profiling (KEK SFC) increases peak field up to 4.4 Tesla.
- Additional shielding may increase peak field at list 1.2 times more up to 5.3 Tesla.
- **Transverse component of field becomes higher and longer with enlarging of a first FC turn.**



Summary
of KEK SFC parameters variation

Variation of SFC geometrical parameters with short pulse length of **6 μs is not so effective** as for example with a pulse length of 25÷30 μs. Peak magnetic field increasing is only :

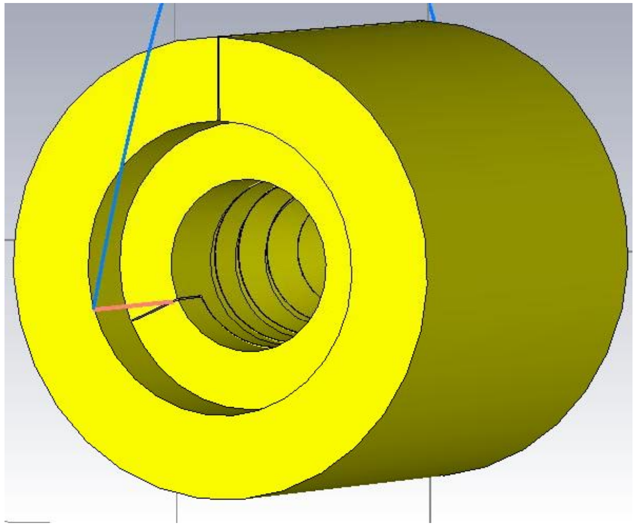
- 10% for the cone profiling (tapering parameter of magnetic field becomes larger)
- 13% for the shielding (insteed of 30%÷40% with 25÷30 μs)

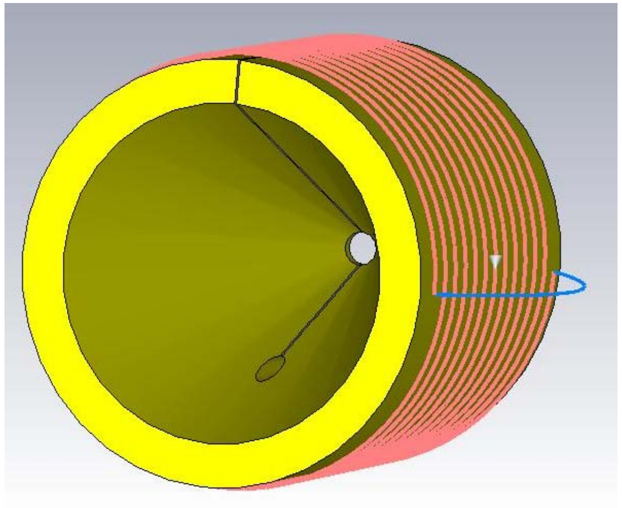
Shielding of KEK SFC **doesn't look attractive with peak operation voltage ~12kV**, because, probability of breakdown between shield and spiral coil becomes very high.

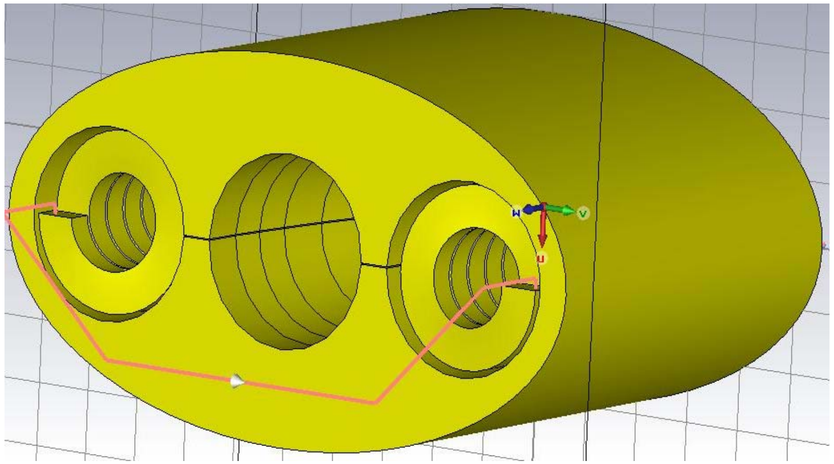
The enlarged width of a first turn leads to rising of field transverse component on the SFC axis in **~1,5 times and profile becomes longer more then 2 times**.

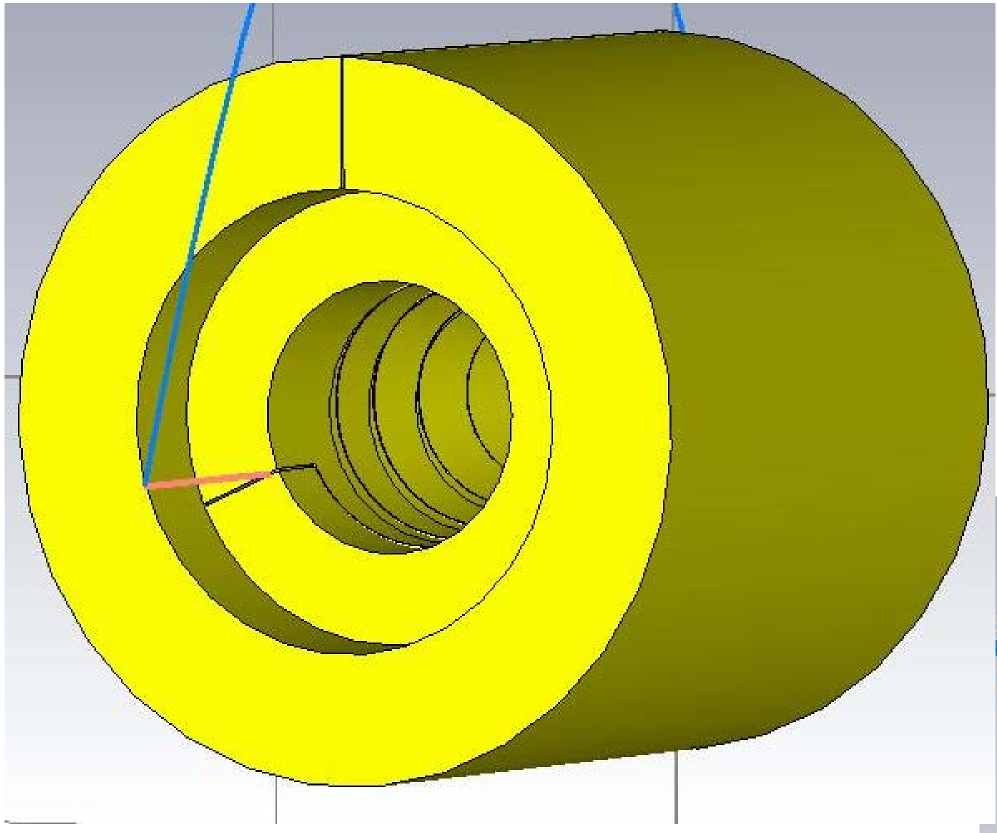
Profiling of simple internal conical shape is rather preferable way to optimize the existed KEK SFC to increase a peak magnetic field or to reduce a peak current.

Flux Concentrators
With Extremely Long Pulse 500÷900μs



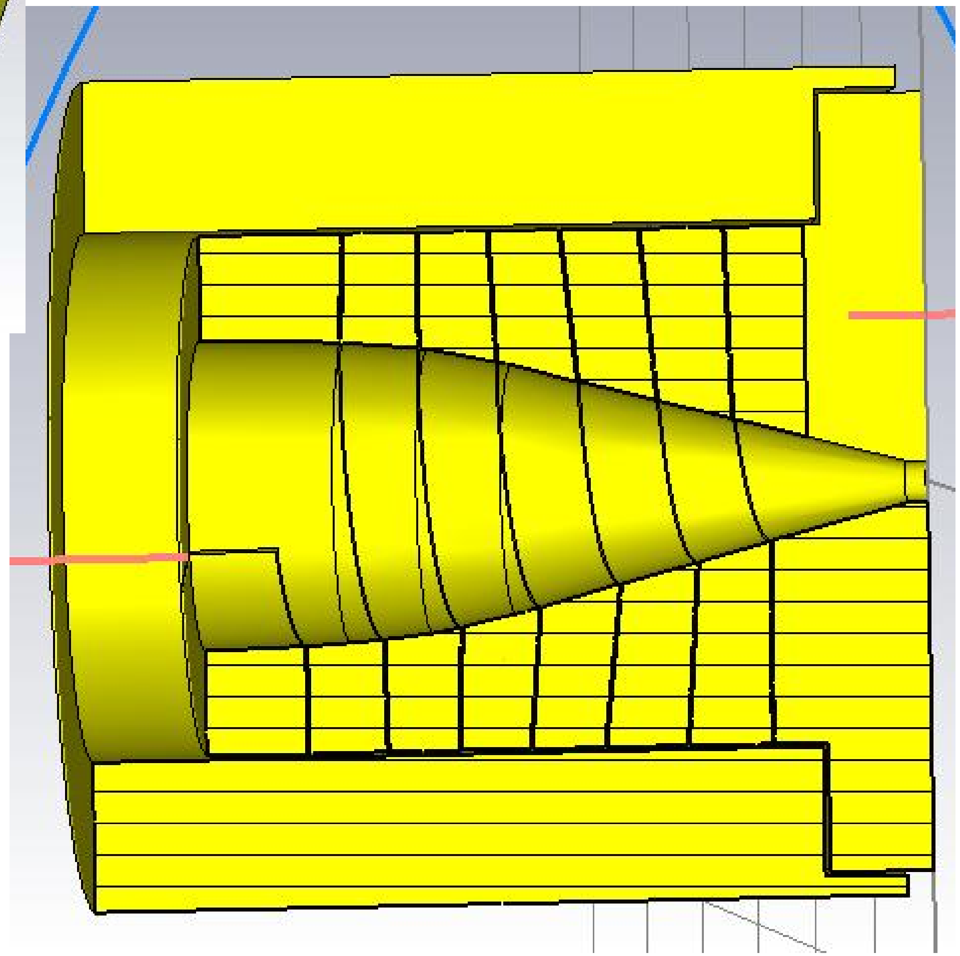




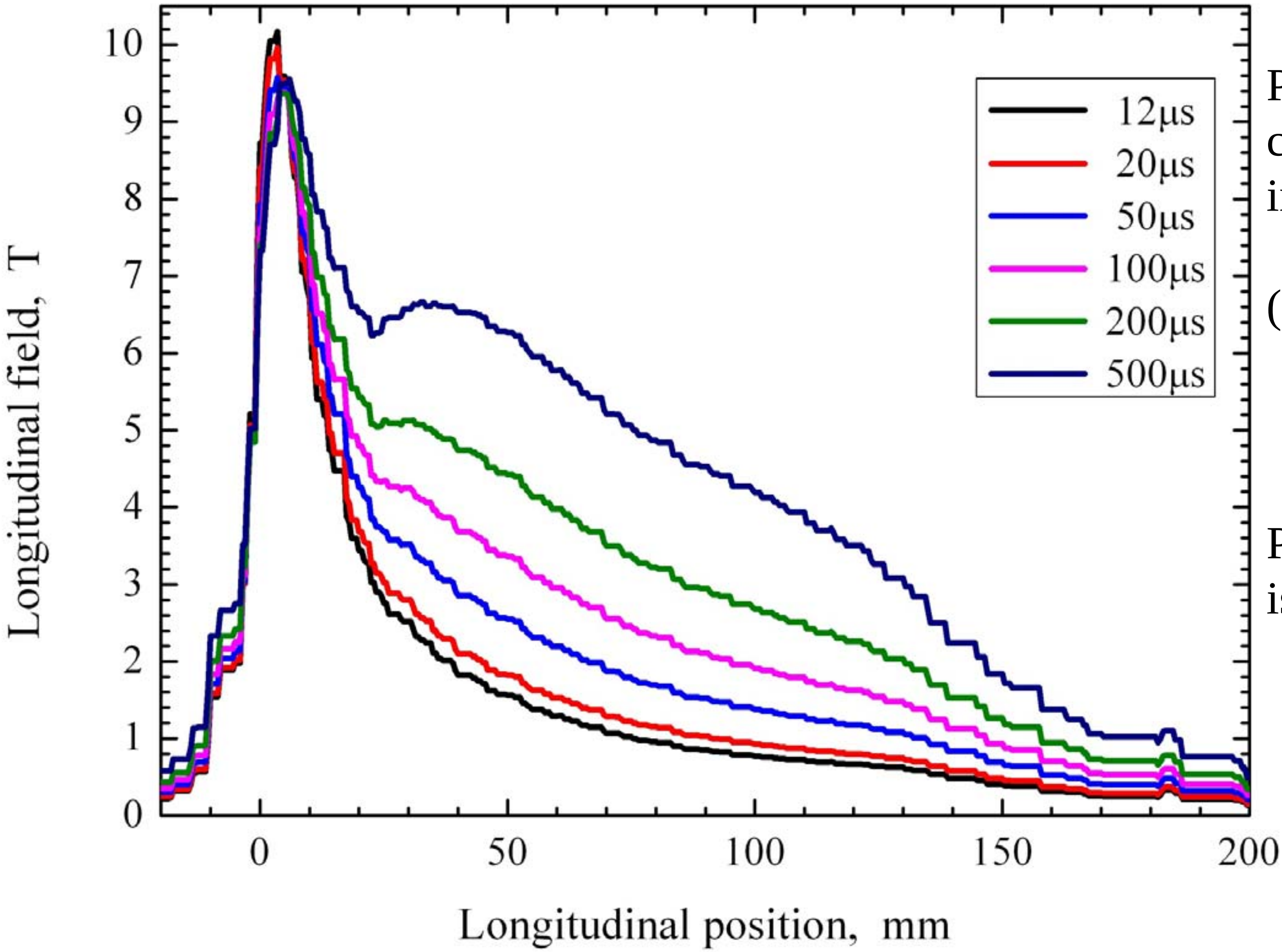


BINP SFC type with shielding

- Length of spiral is140 mm
- External coil diameter is 120 mm
- Min coil diameter is 8mm
- Max coil diameter is 60mm



- Turn width is 14 mm
- Number of turns is 8
- Gap between turns is 0.35÷0.4 mm
- Peak current is 35 kA (10 Tesla)
- Pulse length is about 24μs



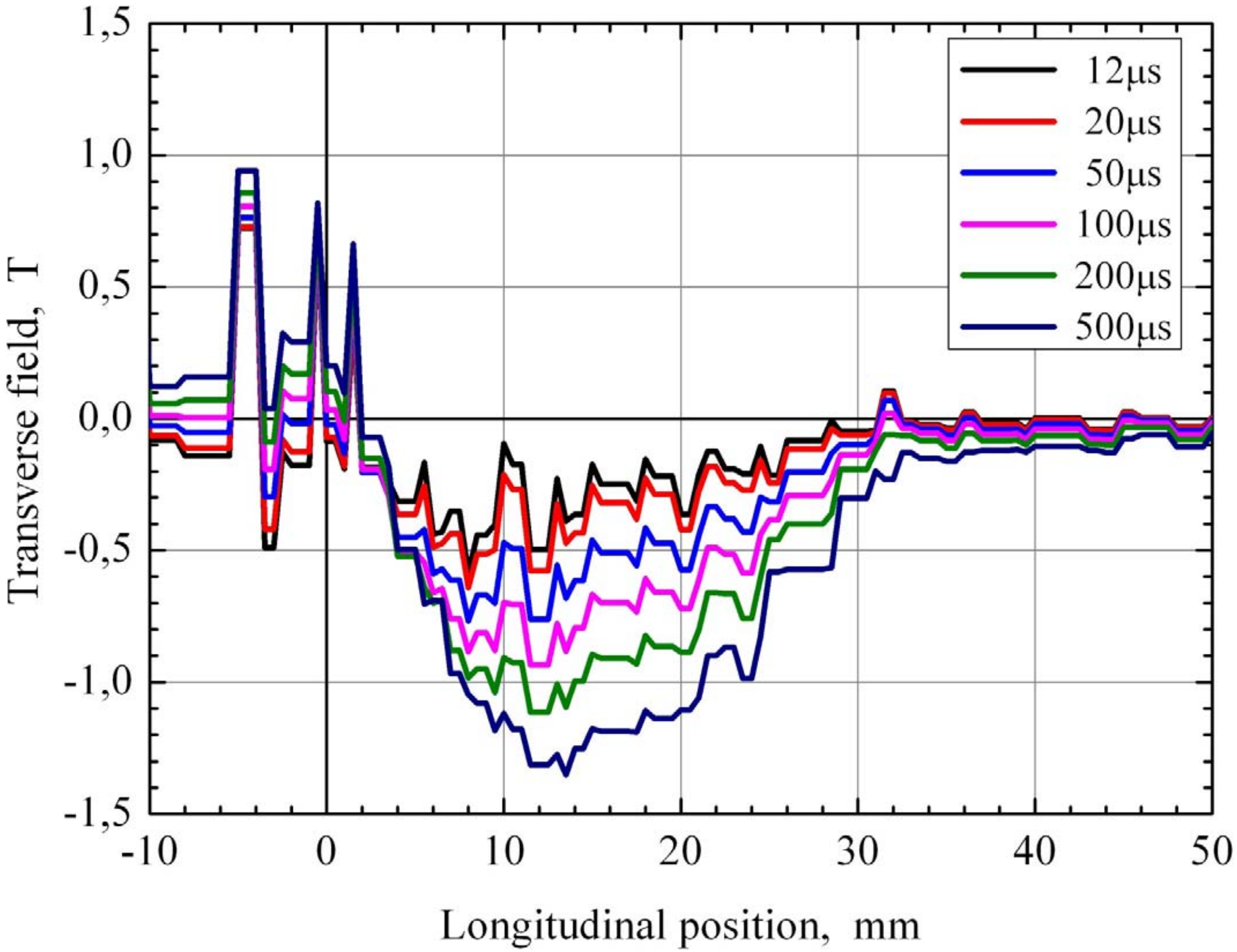
Profile of longitudinal field component at different instants of time .

(1-st order of approximation)

Peak field value fluctuation is from 9.5Tesla to 10.1 Tesla

A skin layer depth becomes deeper in time and as result a magnetic flux through copper conductors also redistributes. These leads to longitudinal field profile deformation through a pulse time. Big profile deformation is observed starting from 100µs pulse time.

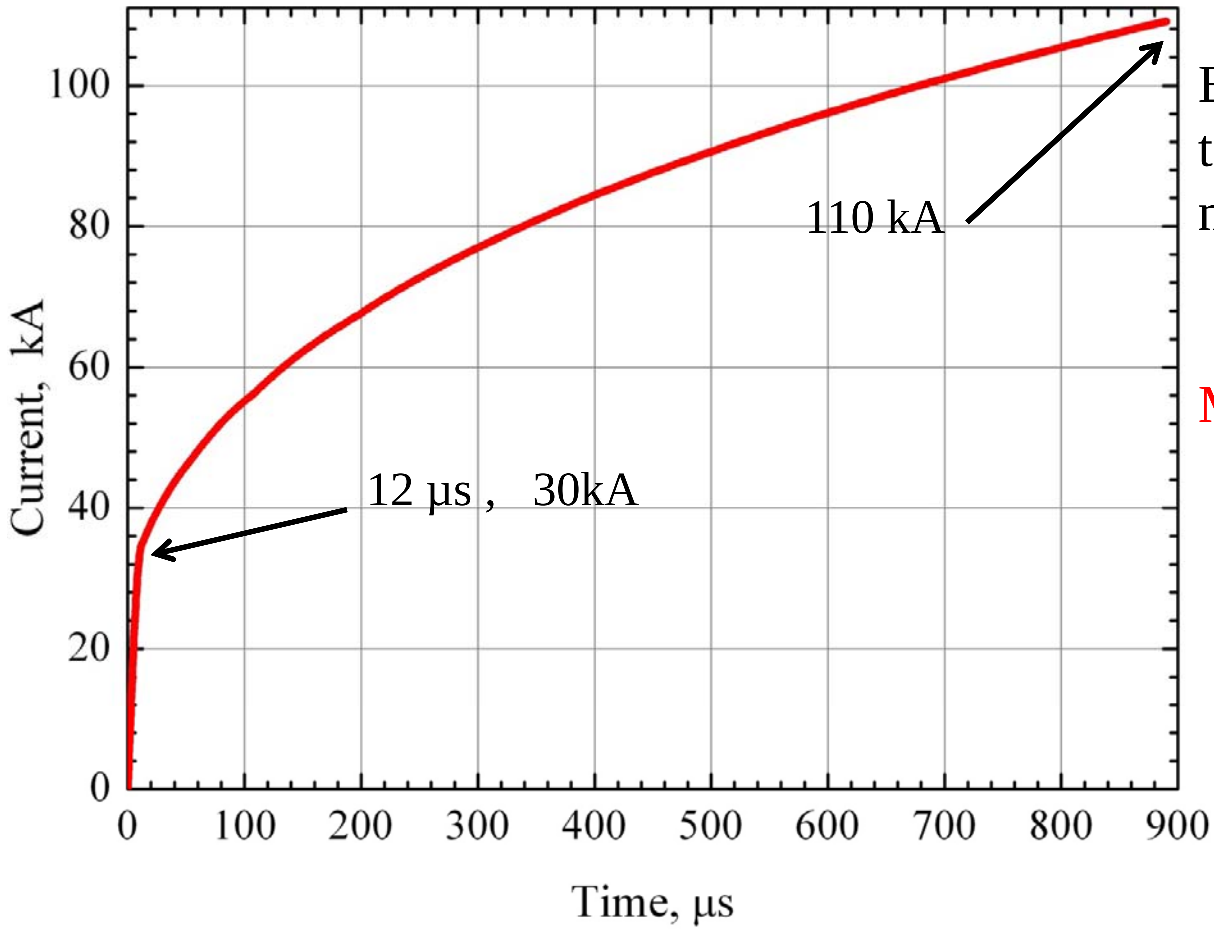
Profiles should be recomputed with 2-nd order of approximation to confirm deformation in time



Profile of transverse field component on the geometrical axis SFC at different instants of time.

(1-st order of approximation)

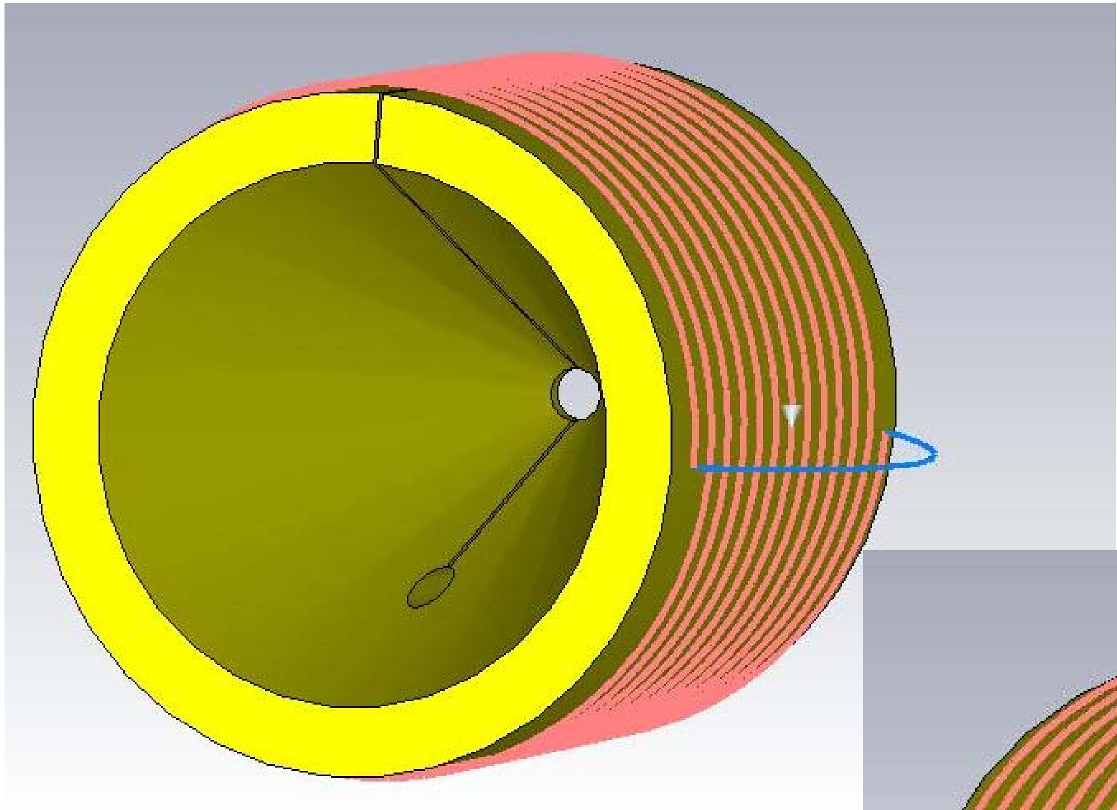
Increase of transverse component of magnetic field also is observed in time. Peak field value of transverse component about 0.35 Tesla (red line) should be taken as a limit value.



Excitation current profile vs time to have the flat peak magnetic field value.

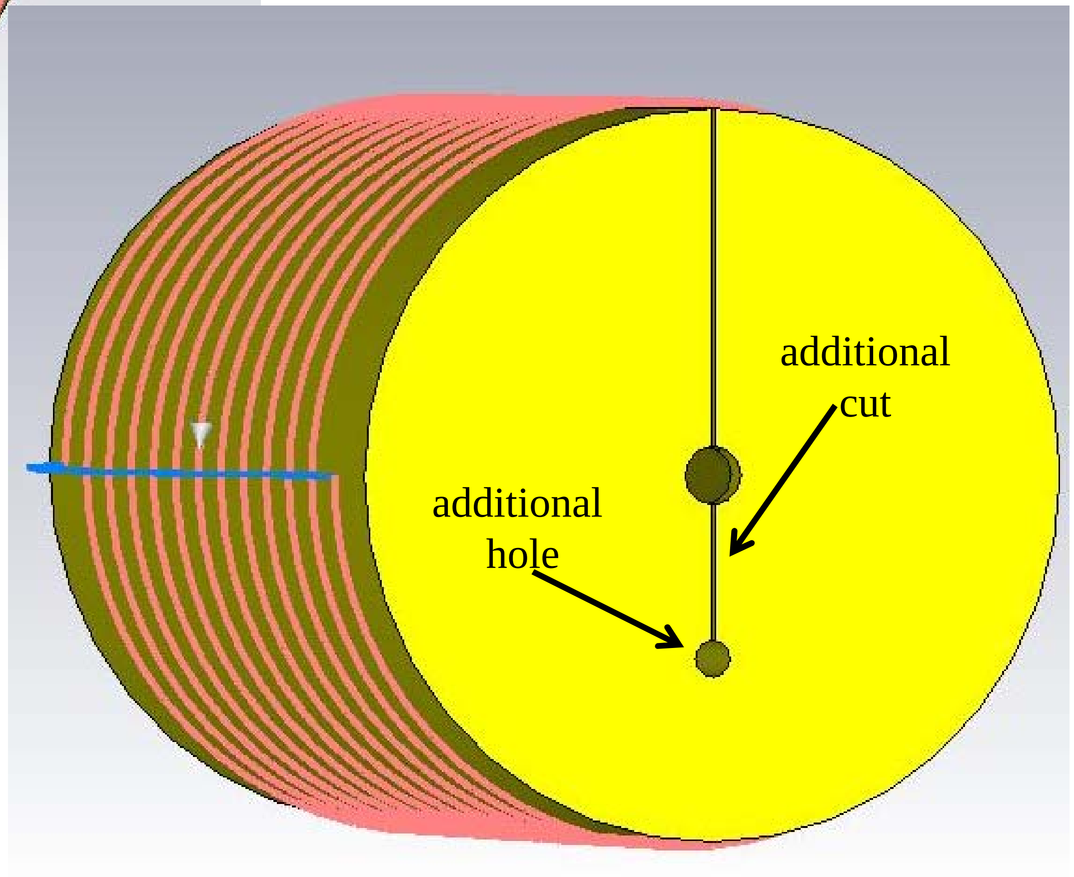
Max current ~110kA (900μs)

To generate a flat peak field during of all pulse time a excitation current should have special profiling in time.

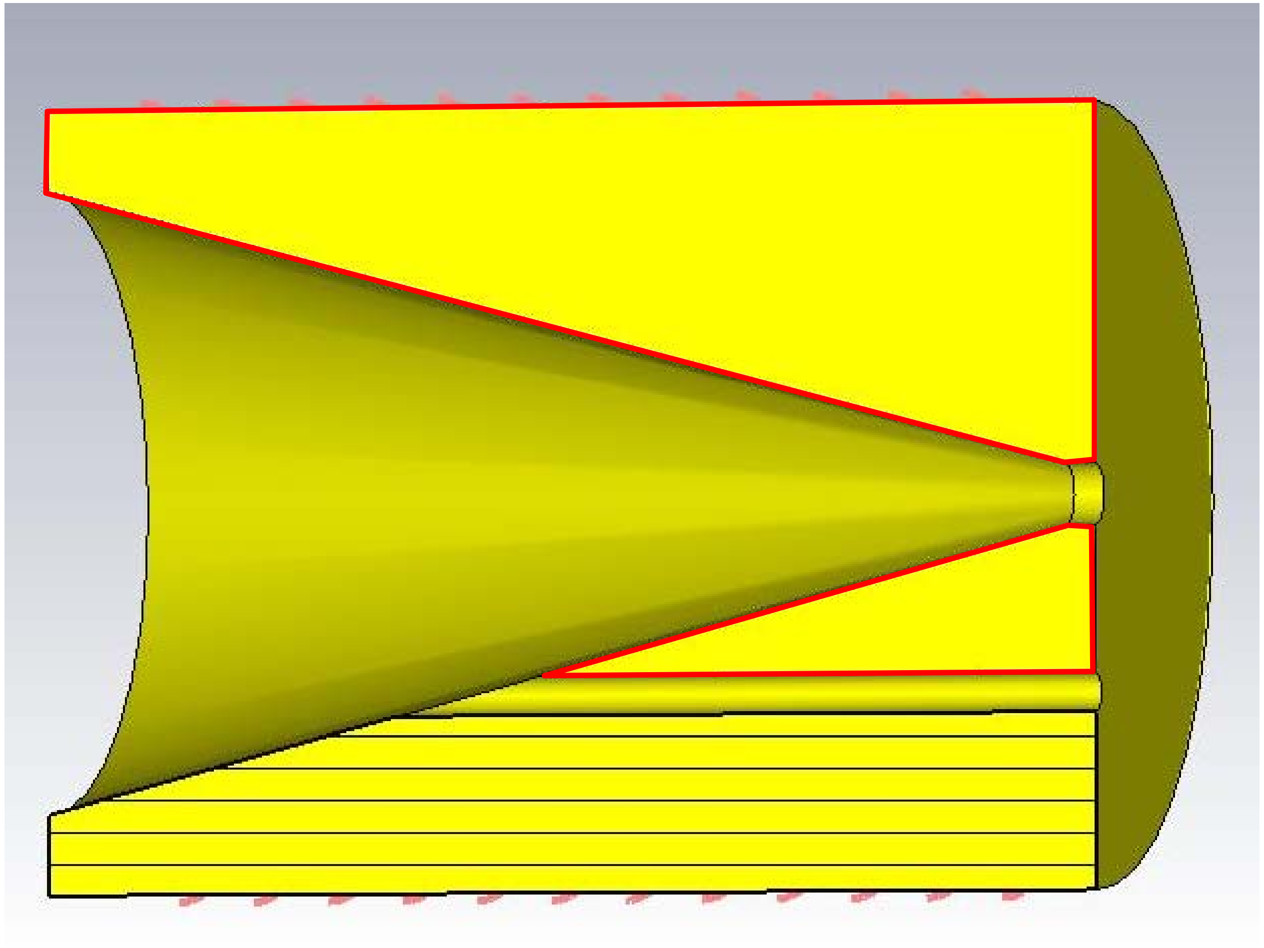


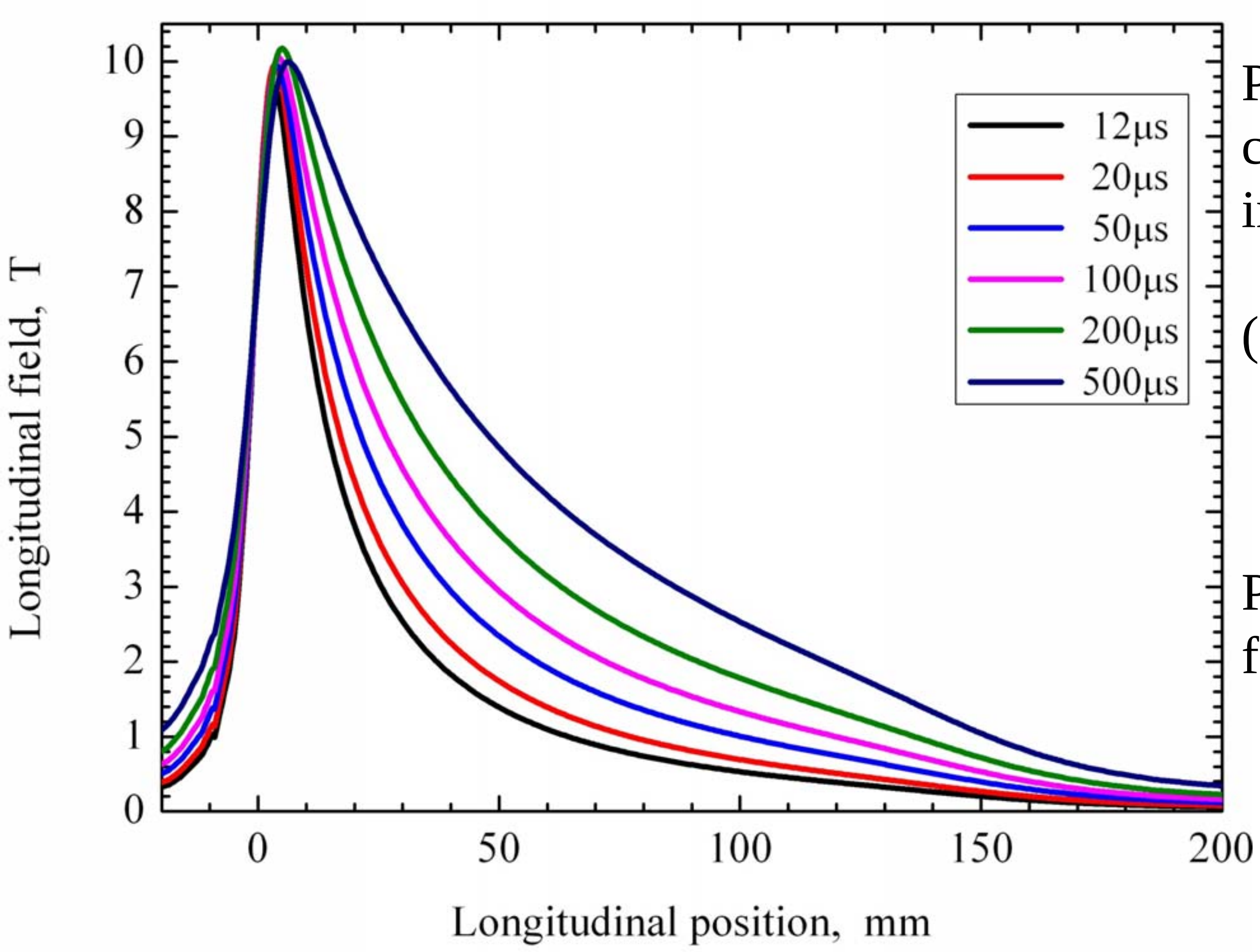
Classical FC with additional body cut and hole **to compensate transverse component of magnetic field** on the geometrical axis.

- Length FC is 140 m
- Min cone diameter is 8 mm
- Max cone diameter is 80 mm
- Diameter of additional hole is 4 mm
- 12 pseudo- turns of primary winding



Cross section of classical FC with additional body cut and small hole in plate of body cuts

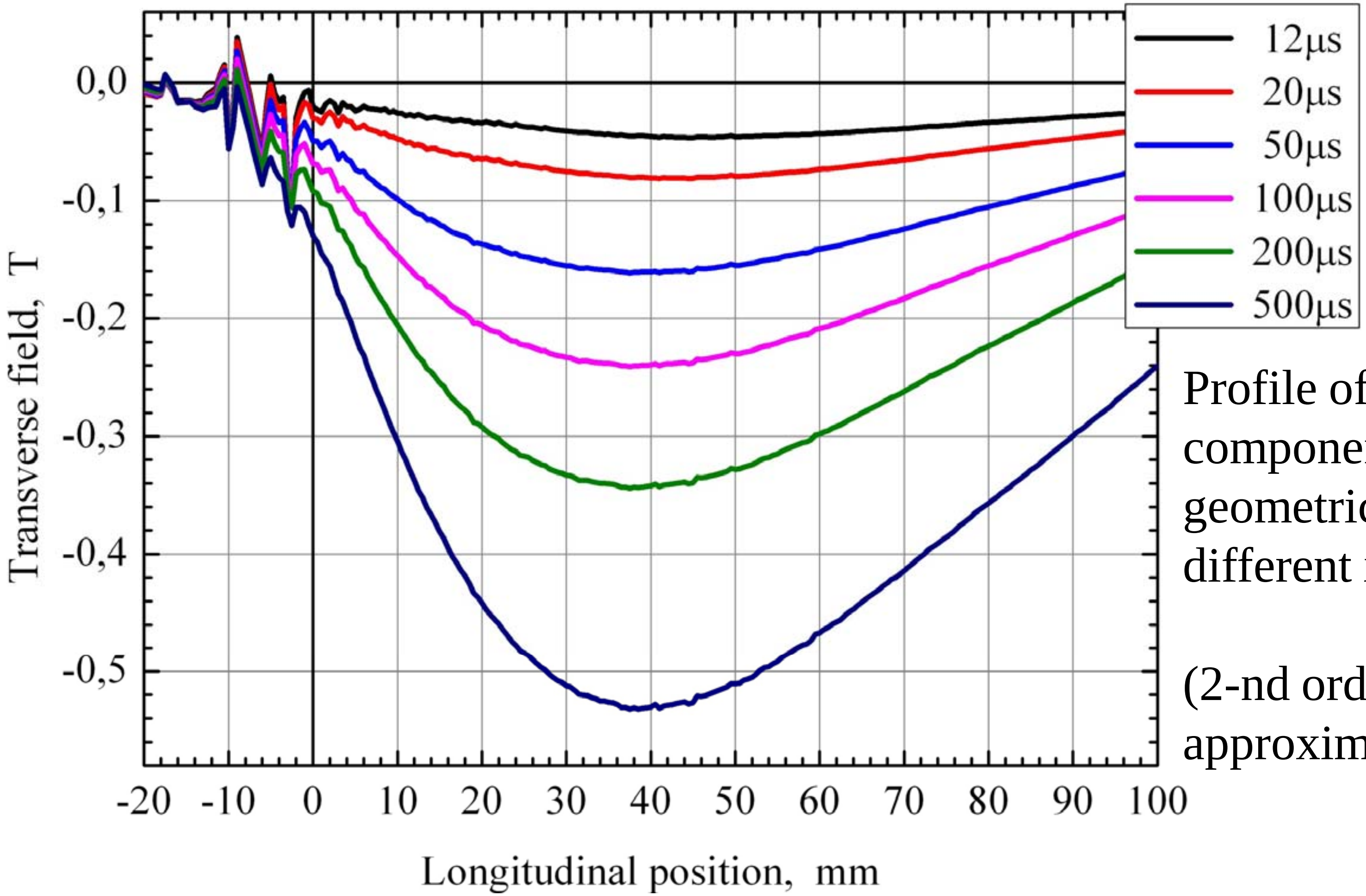




Profile of longitudinal field component at different instants of time

(2-nd order of approximation)

Peak field value fluctuation is from 9.5Tesla to 10.1 Tesla



Profile of transverse field component on the geometrical axis FC at different instants of time .

(2-nd order of approximation)

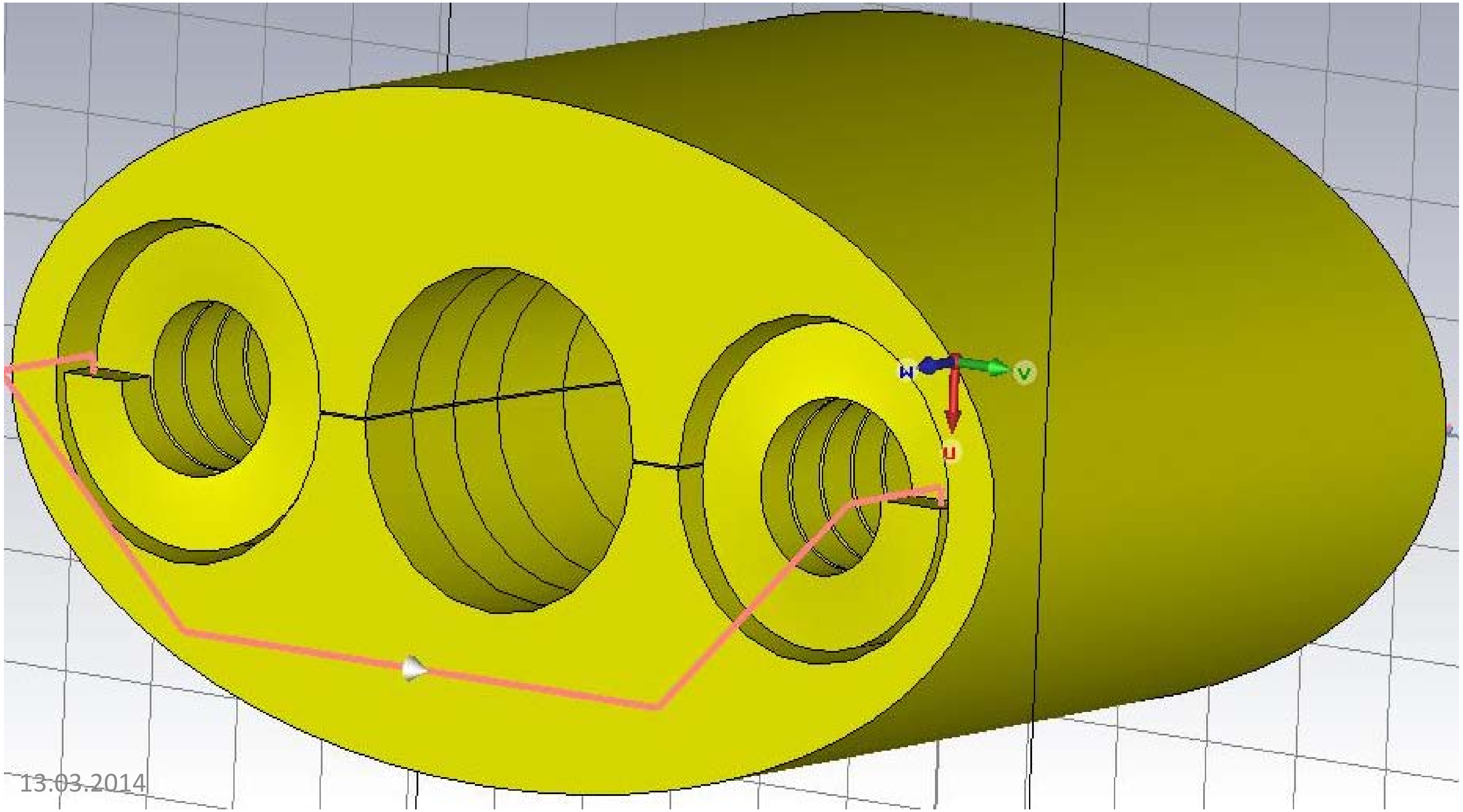
Increase of transverse component of magnetic field also is observed in time as for BINP SFC. All profiles are extremely long (through all FC length).

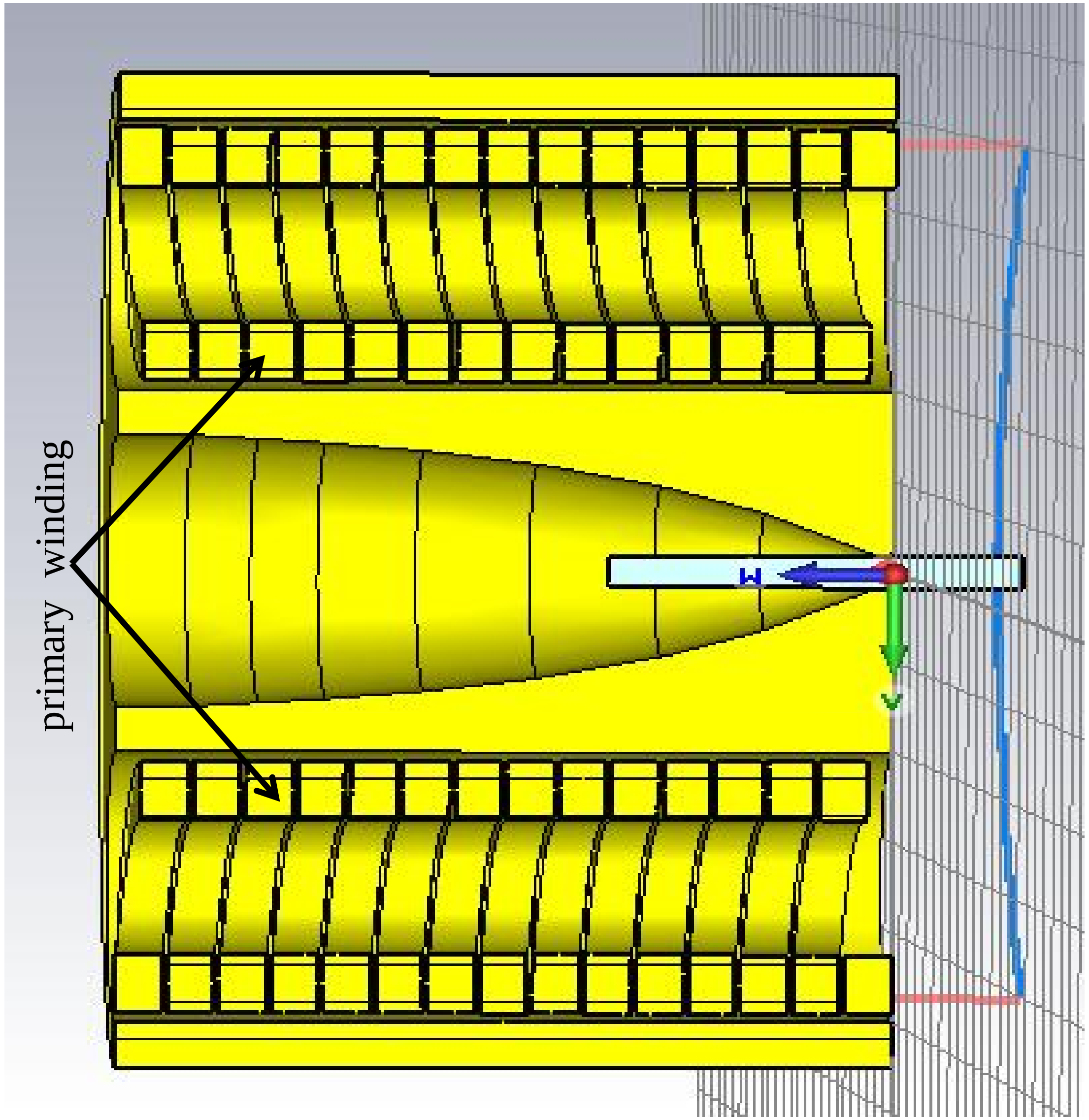
Peak field value of transverse component became 0.08 Tesla (red line) . **Profile became at list 3 times longer. Compensation of transverse component is not enough.**

Compensation of a transverse magnetic field component on the geometrical axis

Computation of transverse component profiles on the axis shows (BINP SFC and CFC) rising of component through a pulse time due to the diffusion of current and magnetic field into copper conductors.

Well compensation may be provided only by an absolutely symmetrical geometry.

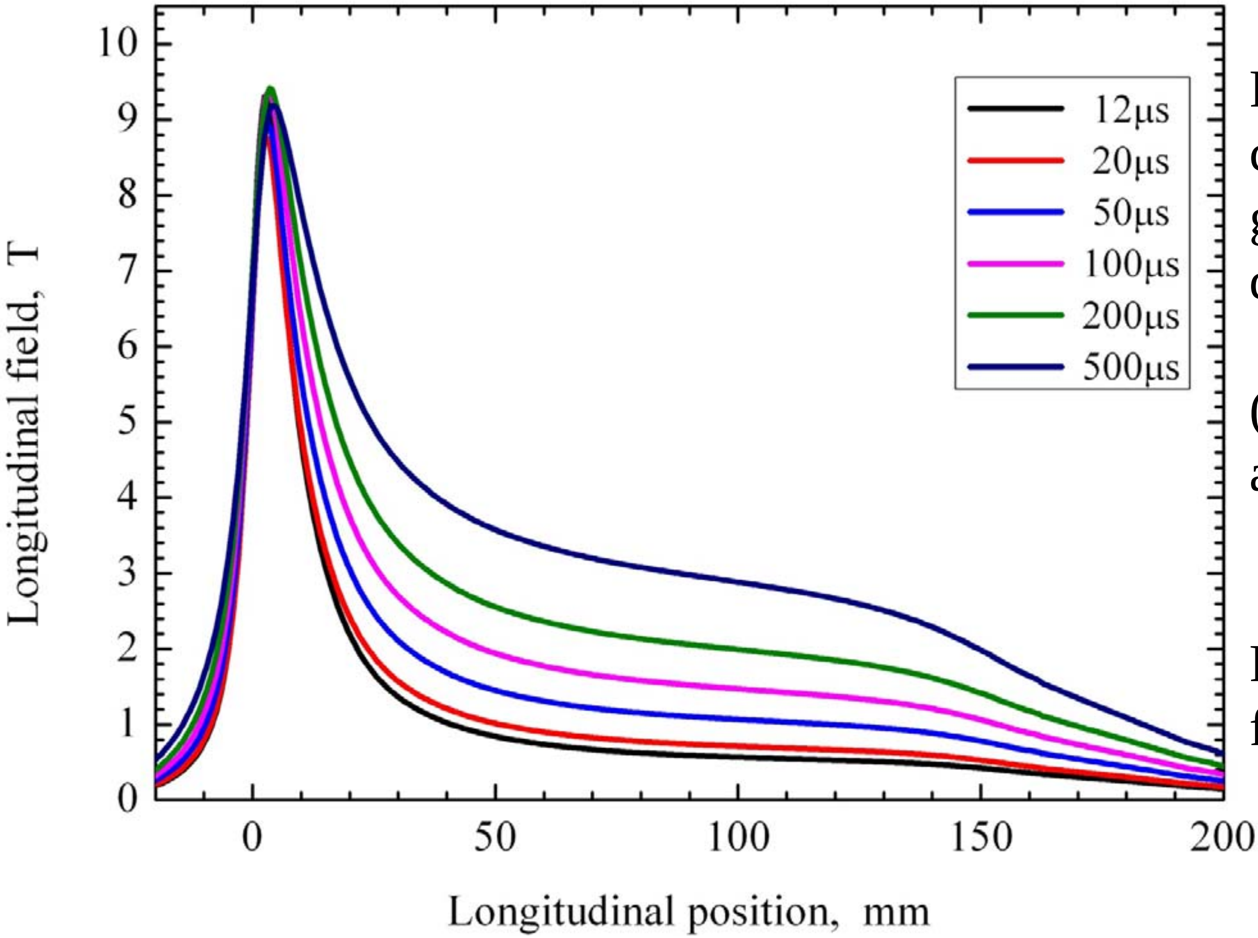




- FC spirals diameter is 28 mm
- FC length is 150 mm
- Min cone diameter is 7 mm
- Max cone diameter is 30 mm

- 2 primary windings (coils)
- Coils have 14 turns
- Gap between turns is ~1 mm
- Gap between spiral and body is 1mm
- Turn width is ~9 mm

- Coils connection is series

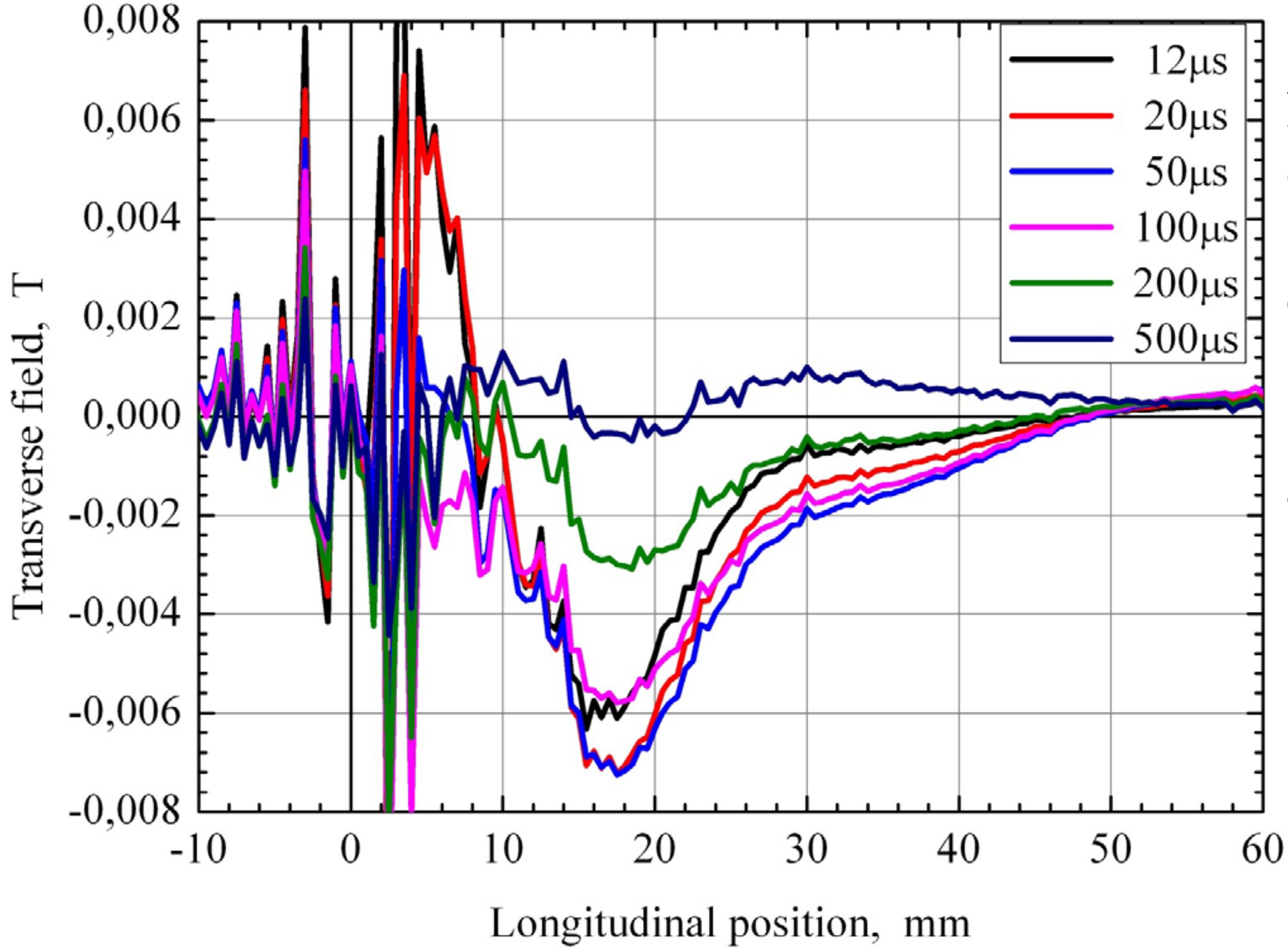


Profile of transverse field component on the geometrical axis SFC at different instant of time .

(2-nd order of approximation)

Peak field value fluctuation is from 9.5Tesla to 10.1 Tesla

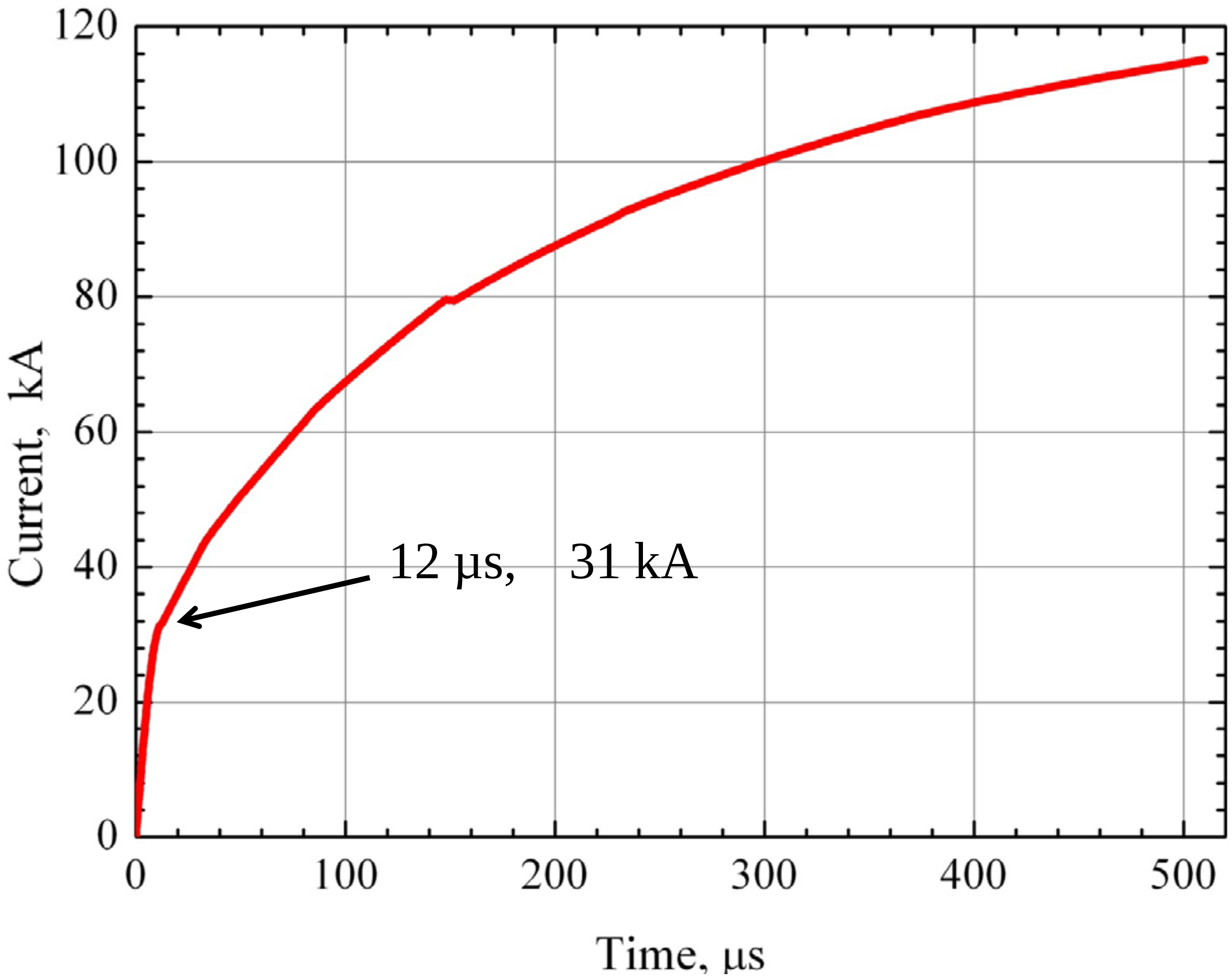
Tapering parameter of longitudinal field profile is bigger of spiral FC



Profile of transverse field component on the geometrical axis FC at different instants of a time .

(2-nd order of approximation)

Transverse component of field is practically compensated at any time of pulse



Excitation current profile vs time to have the flat peak magnetic field.

Max current ~115 kA (900µs)

Peak current value is extremely high

May be there is opportunity to compensate high peak current by increasing of primary winding turns

ILC Flux concentrator concept

- **All well known types of FC are not well suitable** to generate high magnetic field with extremely long pulse as it required by ILC positron source parameters following to different reasons.

- Computer simulation of ILC FC should take into consideration the **unsteady-state diffusion of magnetic field and flux in the FC body** and profile variation in pulse time.
- Magnetic field computation of particular FC design **should include obligatory a transverse component profile and its variation during of pulse time**. The peak value of a transverse magnetic field component and profile are very important parameters of any FC applied as a positron matching device and mainly define a positron yield.

- The life time of any positron source FC should be enough long. **The number of pulses accumulated by FC , for example, during one year of continuously operation with 5 pps should be about $160 \cdot 10^6$, with 50 pps about $1.6 \cdot 10^9$** . All mechanical parameters of metals have the tendency to degrade accumulating huge number of pulses.

- Vibration of FC parts is proportional to the square of peak magnetic field and square pulse duration. **FC device should have enough mechanical strength to operate in long pulse duration mode**. Thickness of FC turns, bolt connection of FC parts should be enough and extremely strong to provide long time reliability.

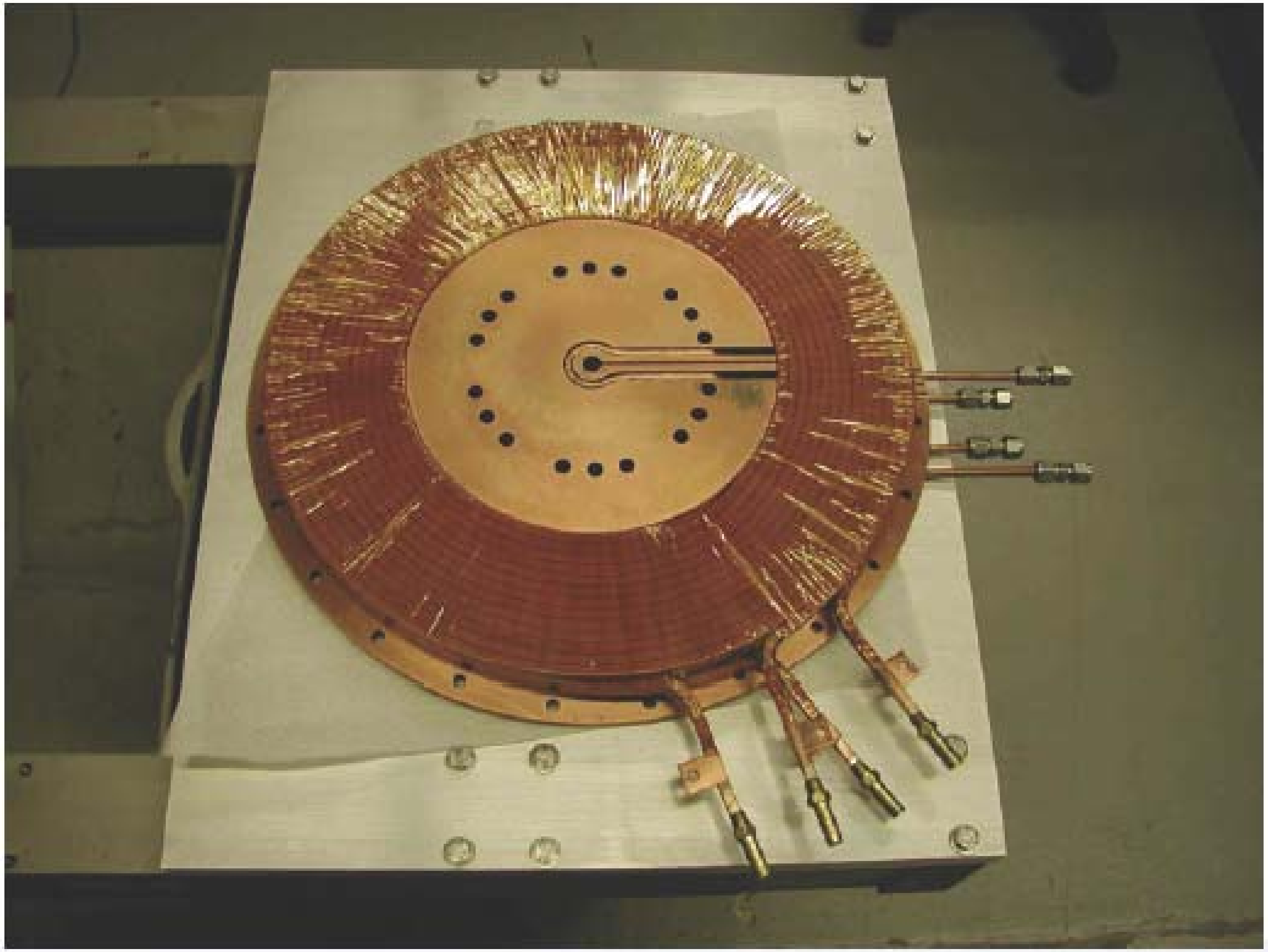
- **Fast degradation of primary winding insulation is very big problem** for any types of FC, which have a separated primaries from a main body. Reliable mounting of excitation coil with FC body is now yet solved problem. The reason of these problem is vibration of all parts of FC due to a pulse mode operation. **Most reliable devices with long life time have ceramic or vacuum insulation only**.

- Current profile and especially **peak value can be critical point** of long flat peak field generation.

- Mean ohmic-losses power is estimated about 40|kW . Problem of heat transfer from FC becomes very serious. Large number of cooling hole in FC body makes device mechanically weak.

- Positron production target should rotate with speed not less of 150m/s (maybe even faster) in high magnetic field. In result, the mean ohmic-heating power of target is about 10 kW.

- Positron production target rotating with high speed has got a strike by high FS magnetic field . Peak value of target vibration is open question. **Rotation a target with very high speed and simultaneous vibration can be VERY DANGEROUSE for the target survival**.



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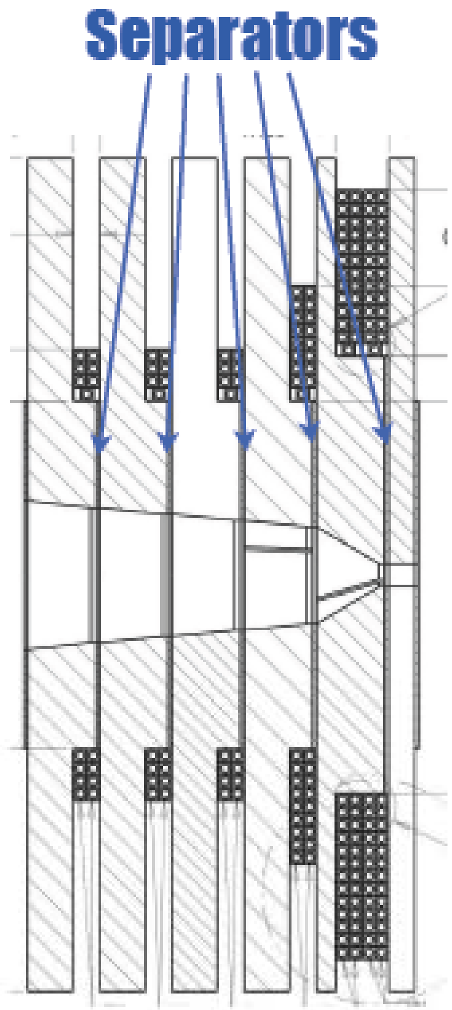

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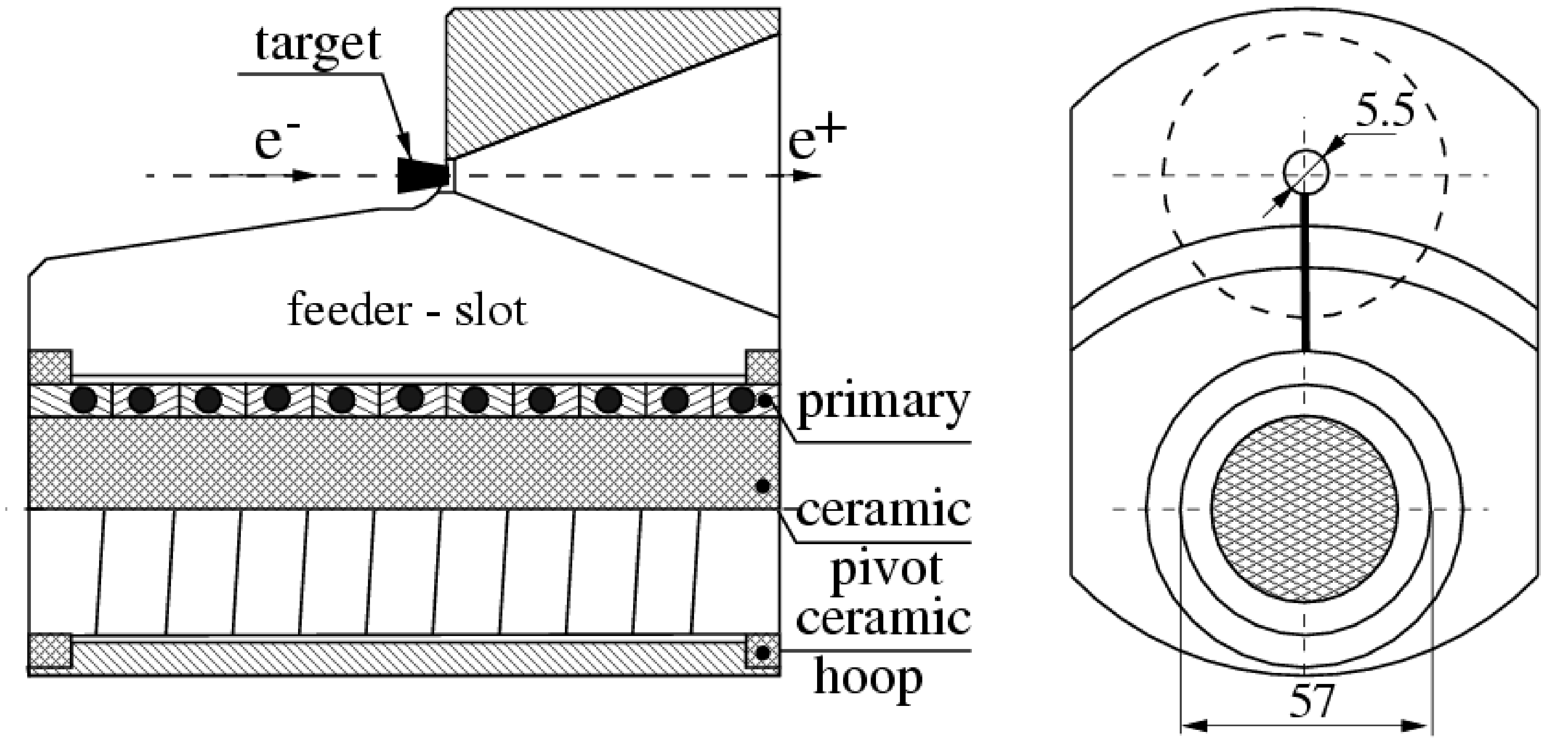
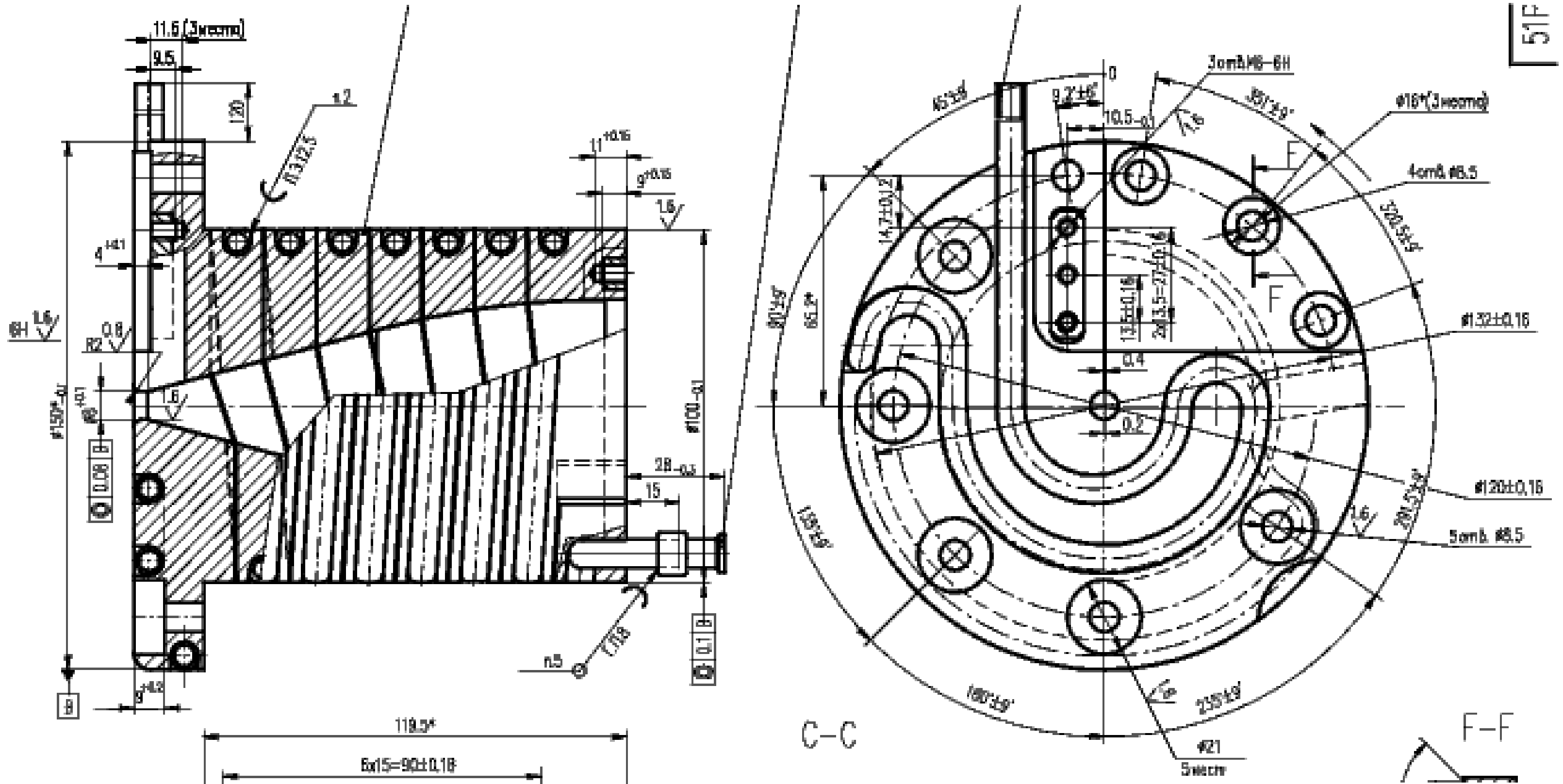
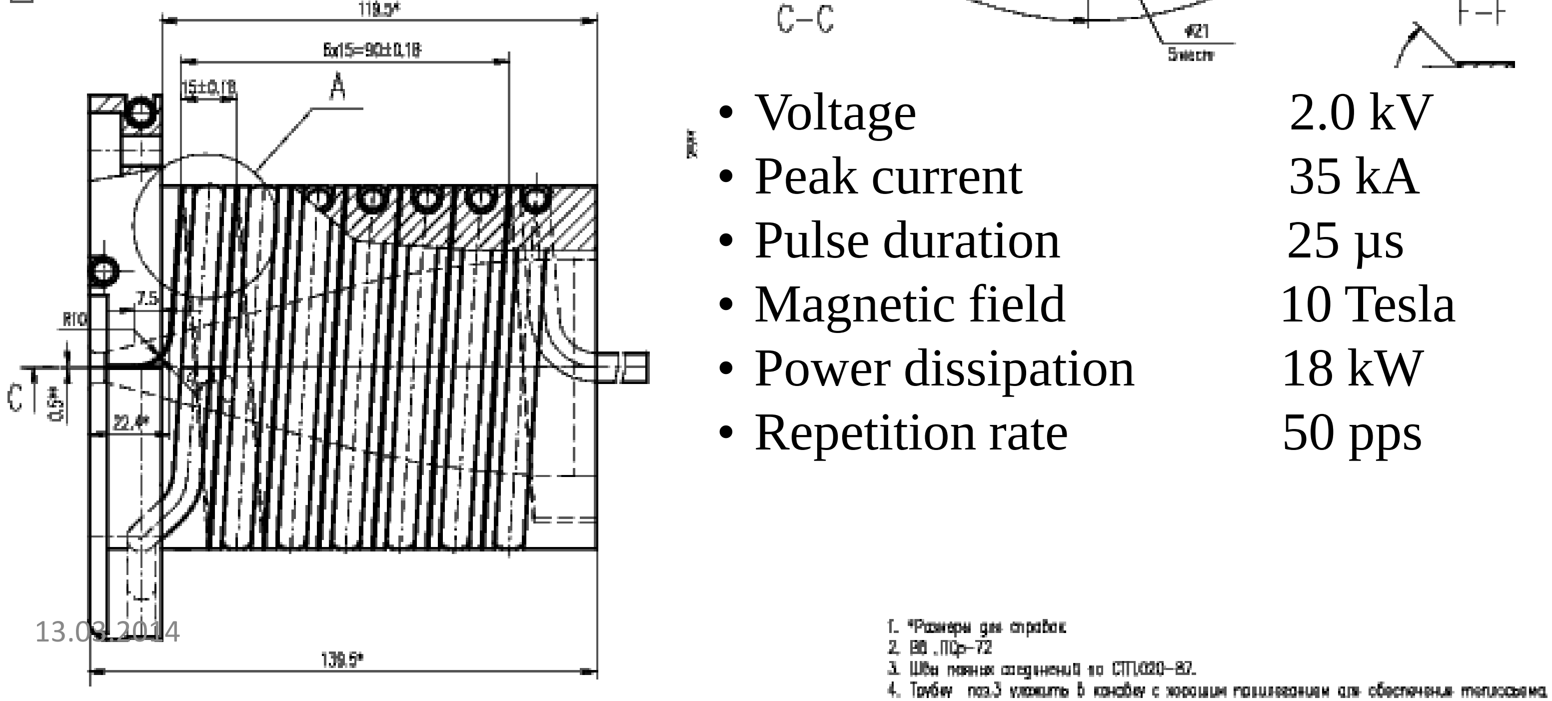
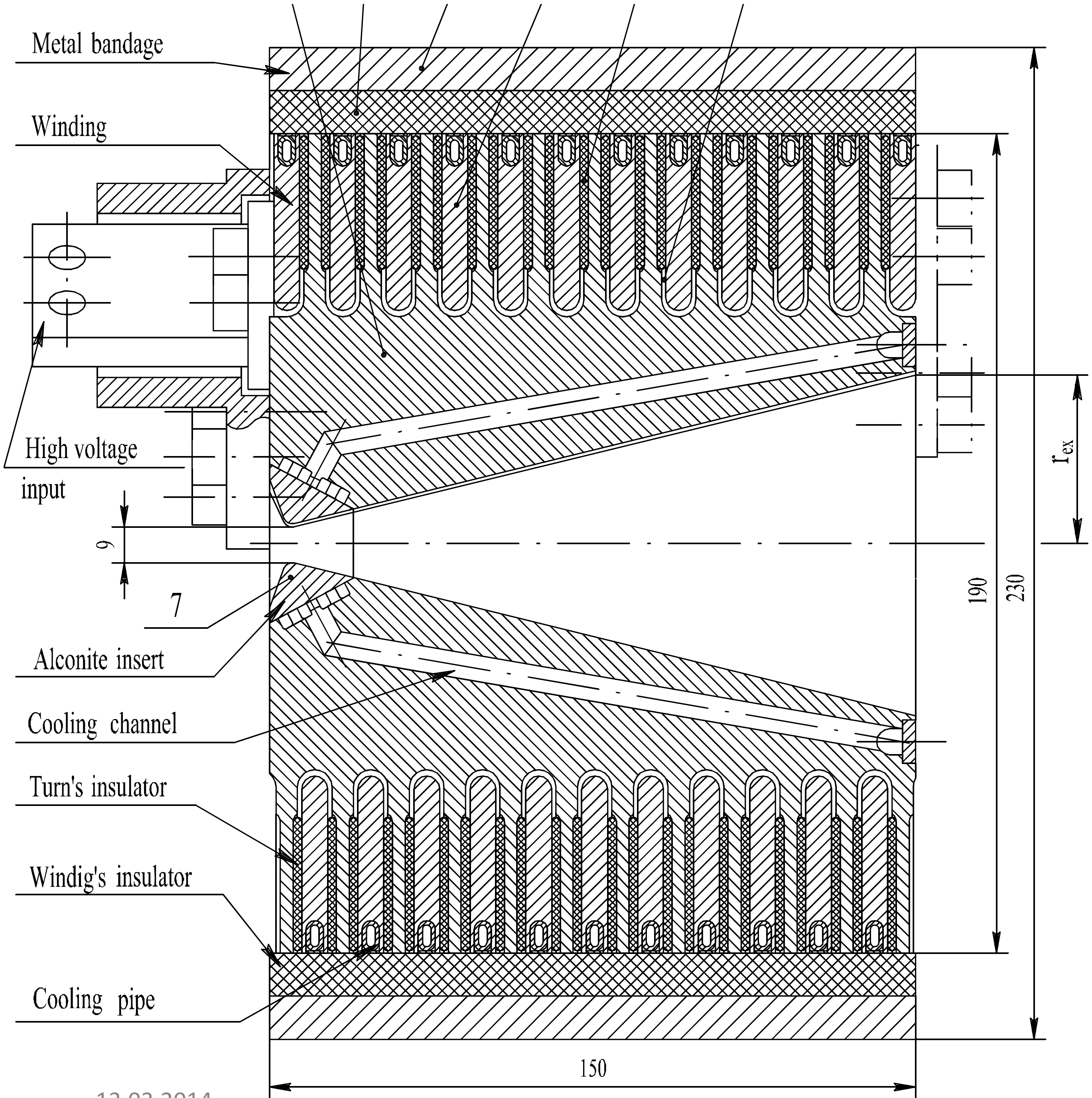
VEPP-5 forinjector matching device





- Voltage 2.0 kV
- Peak current 35 kA
- Pulse duration 25 µs
- Magnetic field 10 Tesla
- Power dissipation 18 kW
- Repetition rate 50 pps




Metal bandage
Winding
High voltage input
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Alconite insert
Cooling channel
Turn's insulator
Windig's insulator
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