



**FCC WEEK 2018**

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# **6T Pulsed Dipole for the SPS Upgrade**

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FCC Week, May 28-June 2, 2017, Berlin, Germany

# Outline

- FCC motivated design issues
- The model dipole concept
- Wire, Cable, Magnet Parameters
- Status & Near Future Plan

# FCC motivated design goals



- Increasing the SPS energy up to 1.3 TeV within the same tunnel that require SC magnet system.



- Dipole magnets should operate at 6 T in cycled mode to provide 1.3 TeV proton beam injection into the FCC chain and feed existing areas at 0.45 TeV.



- **SC SPS requires new design (optimization) of all magnet parts aimed at minimization of power losses (wire, cable, yoke etc.)**

# Scope of FCC/JINR collaboration



- focus on bending magnets at the first stage;



- new dipoles should have large dynamic range of operation from injection to top energy and minimal level of the cycling power losses **i.e. a cycled SC machine could be quite advantageous in terms of electrical consumption with respect to the normal conducting SPS).**

The FCC/JINR Addendum was finally approved in December 2017

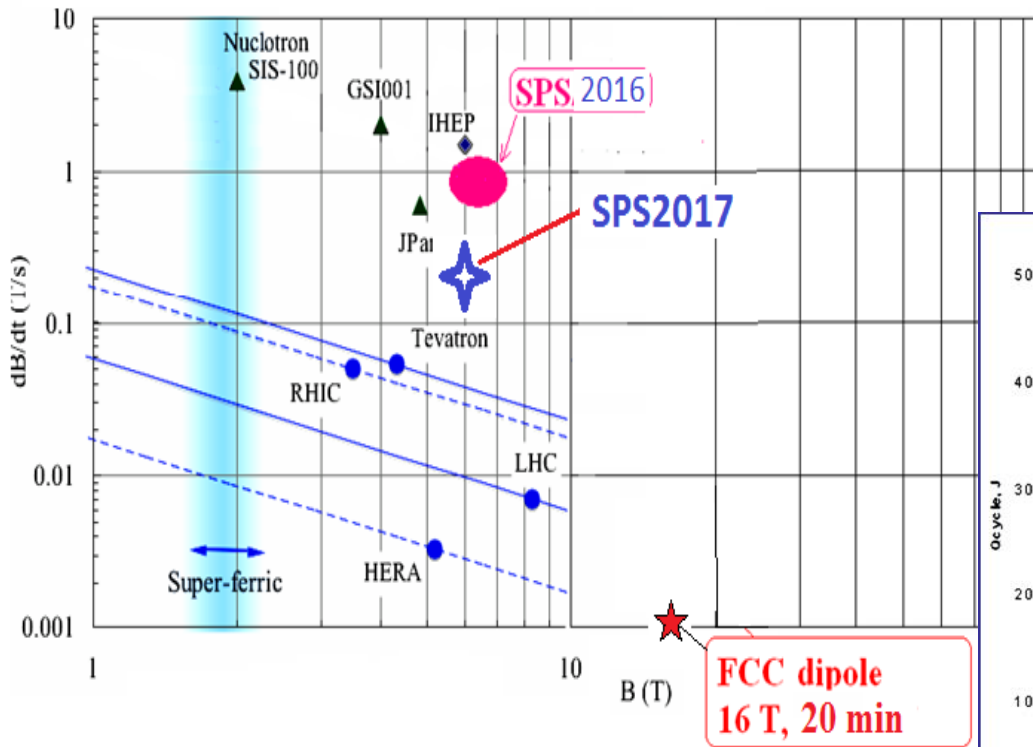
# Model dipole design issues

- The aperture diameter: **80 mm**
- Top/injection field: **6 / 0.12 T**
- Field quality: **adequate to the modes**
- Ramp rate: **0.2 T/s and 0.5 T/s**
- Coil temperature: **1.9 K**
- Iron yoke: **laminated, low losses**

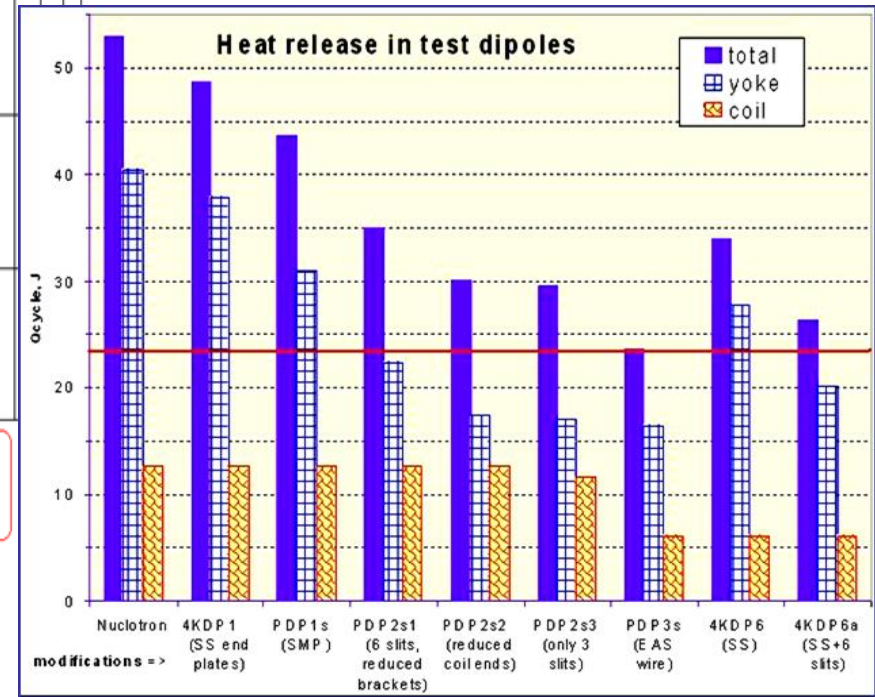


**Total thermal losses should be limited to:**  
**tentatively  $< 2 \text{ W/m}$  at  $4.2 \text{ K}$  equivalent at ramping.**

# SC Magnets Design Scope



JINR/GSI: SIS100: 2T, 4T/s, 1Hz,  
Apert. 120x56 mm, length – 1.4 m.



A.Kovalenko, A.Milanese. FCC  
Week2017, Berlin, June, 2017

A lot of tests were performed on the power loss minimization of 2T fast cycled dipole by the JINR/GSI Collaboration for the FAIR program

# Experience on 6 T Pulsed Dipole Design



Fig.1. Design I: 1 – coil; 2 – collars; 3 – key; 4 – iron yoke; 5 – outer shell; 6 – staple.



Fig.2. Design II: 1 – coil; 2 – collars; 3 – key; 4 – iron yoke; 5 – outer shell; 6 – staple; 7 – C-clamp.

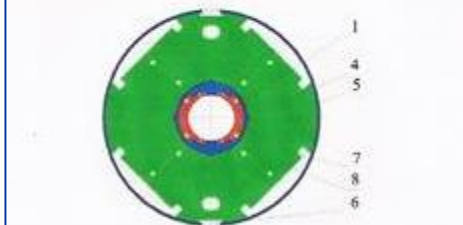


Fig.3. Design III: 1 – coil; 4 – iron yoke; 5 – outer shell; 6 – staple; 7 – C-clamp; 8 – spacer.

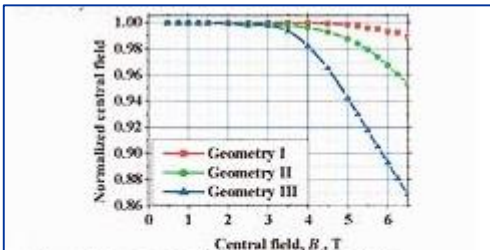
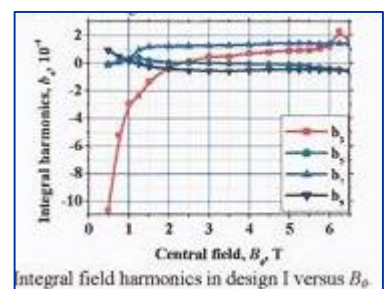


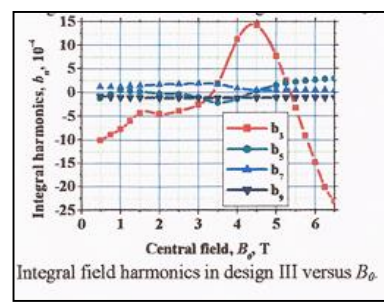
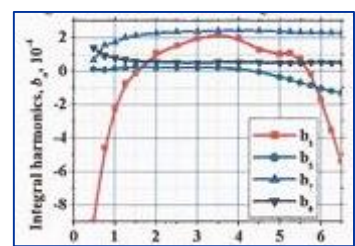
Fig.4. Normalised field versus central field  $B_p$ . The next three Figures demonstrate behaviour of lower integral field harmonics versus central field. The effects of superconductor magnetization were taken into account.

Geometry	I	II	III
Collar thickness, mm	45	30	10
Strand number in cable	38	35	30
Bare cable width, mm	12.80	11.70	9.91
Cable thickness with insulation, mm	1.264	1.273	1.289
Total turn number	91	90	89
Operating current, kA	4.98	4.78	4.48
Inner iron radius, mm	121.4	104.2	80.6
Iron thickness, mm	158	138	140
Coil length, mm	2750	2750	2750
Iron length, mm	2410	2434	2464

## SIS300: IHEP/GSI



Integral field harmonics in design I versus  $B_p$



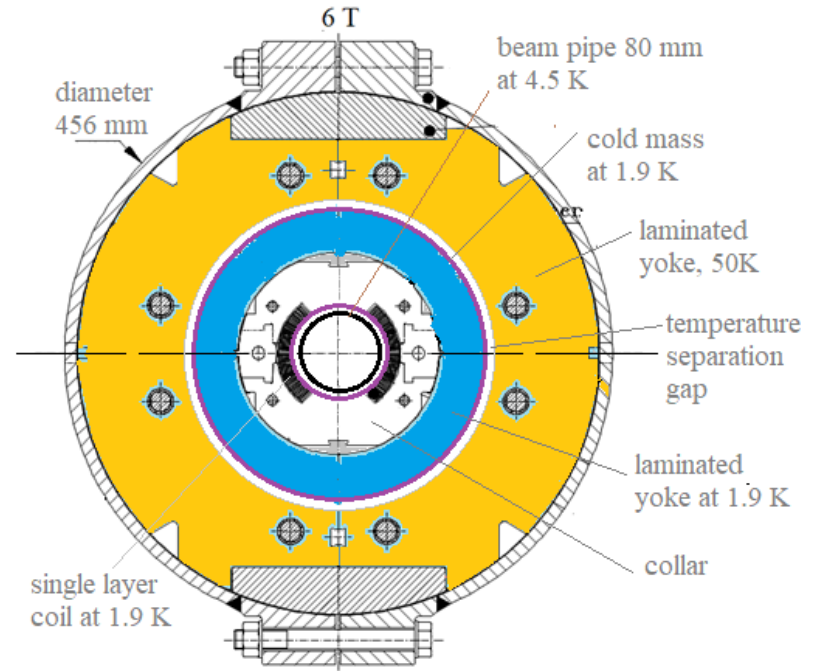
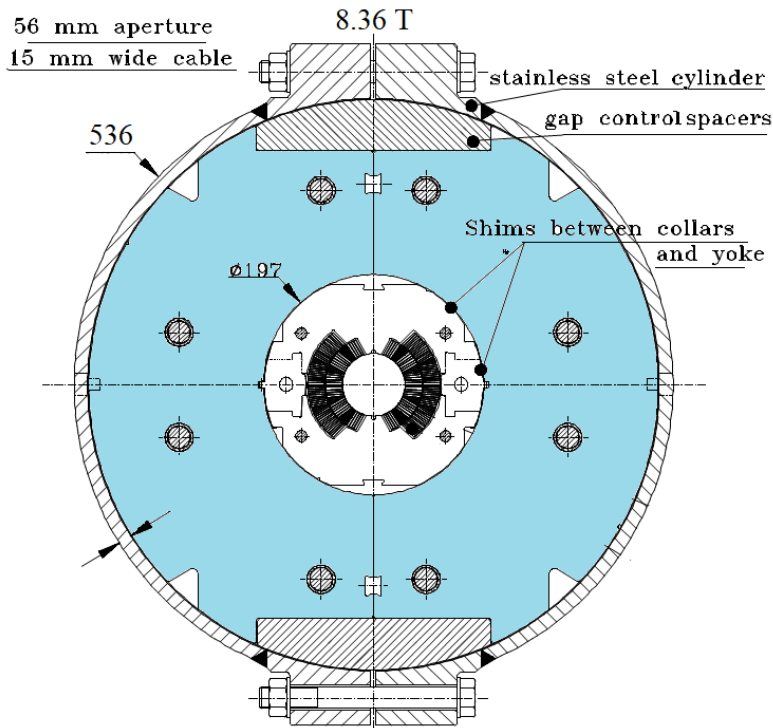
Integral field harmonics in design III versus  $B_p$

Magnet aperture – 100 mm, Operating temperature – 4.2 K.

**The magnet was constructed and tested.**

Magnet aperture – 100 mm, Operating temperature – 4.2 K.

# One layer coil 6 T Pulsed Dipole Concept



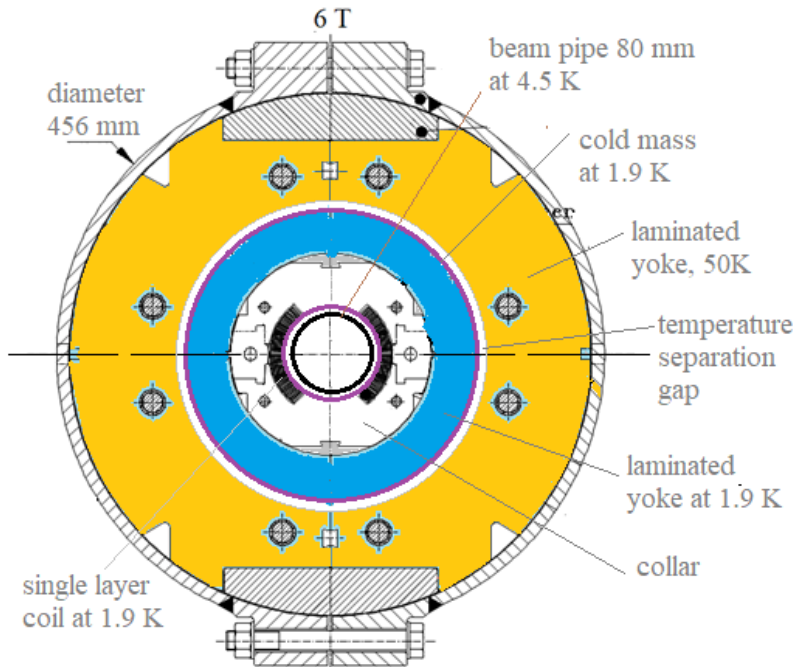
## THE 1m LONG SINGLE APERTURE DIPOLE COIL TEST PROGRAM FOR LHC

N. Andreev, K. Artoos, L. Bottura, G. Kirby, D. Leroy,  
L. Oberli, J. Osner, D. Perini, A. Poncet, F. Rodriguez-Mateos,  
S. Russenschuck, T. Siambanis, N. Siegel, A. Siemko,  
D. Tommasini, G. Trinquart, I. Vanenkov, R. Veness,  
L. Walckiers, W. Weterings, CERN, Geneva, Switzerland

**Start version of 6 T pulsed model dipole for SC SPS**



# One layer coil 6 T Pulsed Dipole Concept



## What is the profit:

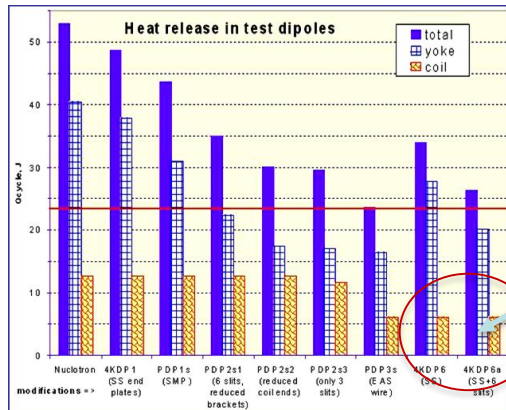
- Minimal power losses in the coil at 1.9 K;
- Better heat transfer from the winding

## Basic features:

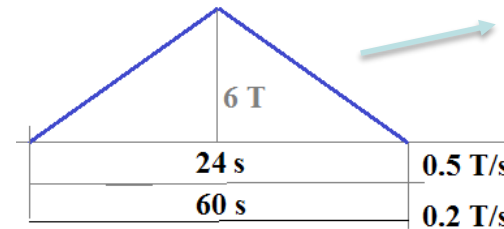
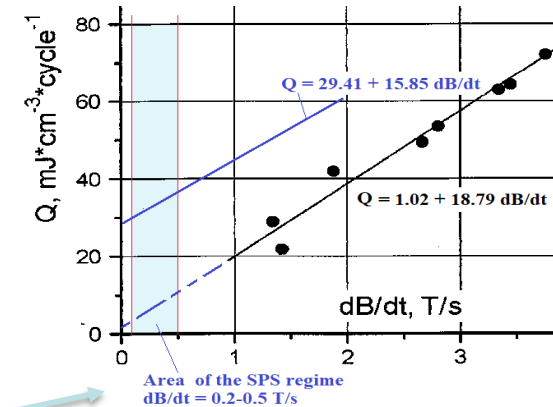
- reduced NbTi amount (higher  $I_c$  @1.9 K)
- adequate filament size and twist pitch;
- optimal number of coil turns ( $I_m \sim 13$  kA);
- separated yoke: min. at 1.9 / rest – 50 K;
- some other possibilities...

# Remarks on Power Losses

Total thermal losses should be limited to: **< 2 W/m at 4.2 K** equivalent at ramping.



**Coil loss – 3.5 W/m, 4 T/s,  
2 T, 1 Hz, apert. 55x120 mm<sup>2</sup>.  
4.2 μm filament, 0.5 mm wire,  
31 wire, twist pitch of ~12 mm**



**SPS/Nucl cycle: – k1 = 3, k2 = 0.05 – 0.125,  
k3 = 1/24; 1/60 Hz.  
k1,k2,k3 – field, the field ramp, pulse  
repetition rate respectively**

<b>Coil losses:</b>	
<b>magnetization</b>	$P_h \sim df \cdot B_m \cdot f$
<b>matrix</b>	$P_e \sim (B_m \cdot f \cdot l_p)^2$
<b>Yoke losses:</b>	
<b>magnetization</b>	$P_y \sim B_m \cdot f$
<b>eddy current</b>	$P_e \sim (B_m \cdot f \cdot \delta)^2$

# Wire and Cable

n	Wire model	Filament diameter, $\mu\text{m}$	Twist pitch, mm	$J_c$ A/mm <sup>2</sup> (5T, 4.2 K)
1	0.24 mm, 3132 fil. Single stacking	3.4	No	2804
			7	2626
			4	2553
			2	1950
2	0.825 mm Design 1 (379x84)	2.9	11	2548
			8	2552
			6	2561
3	0.79 mm, Design 1 (379x84)	2.8	8	2307
4	0.825 mm, Design 2 (3132x5)	4.2	12	2450
5	0.79 mm, Design 2 (3132x5)	4.1	8	2373
6	0.5 mm, Design 1 modified. (379x84)	3.1	8	2631

**Market of a low loss NbTi wires is exist . Main problem to keep it alive for the future.**

**The problem is to reduce a cable loss and cooling efficiency of Rutherford type cable.**

**Known solutions:**

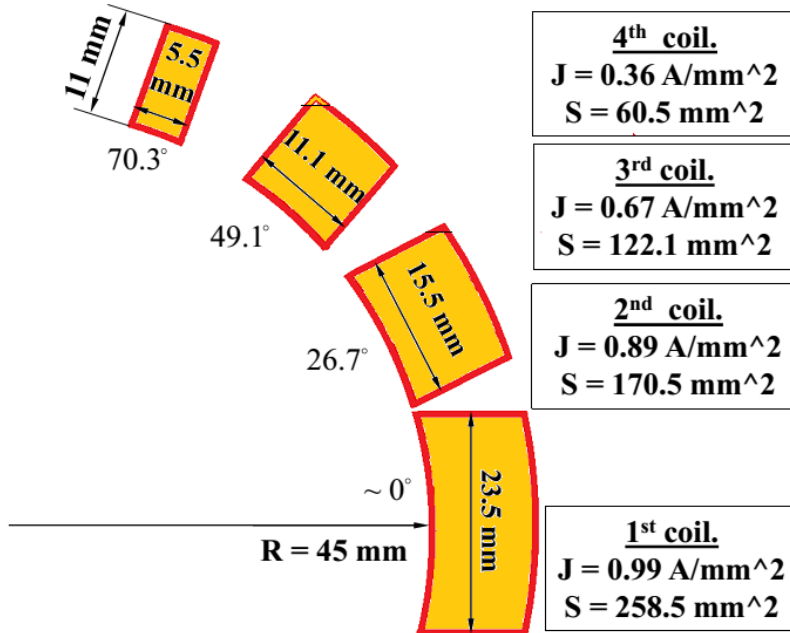
- no soldering wires;
- corded cable;
- wire with resistive barrier;

**Other idea? Need to test.**

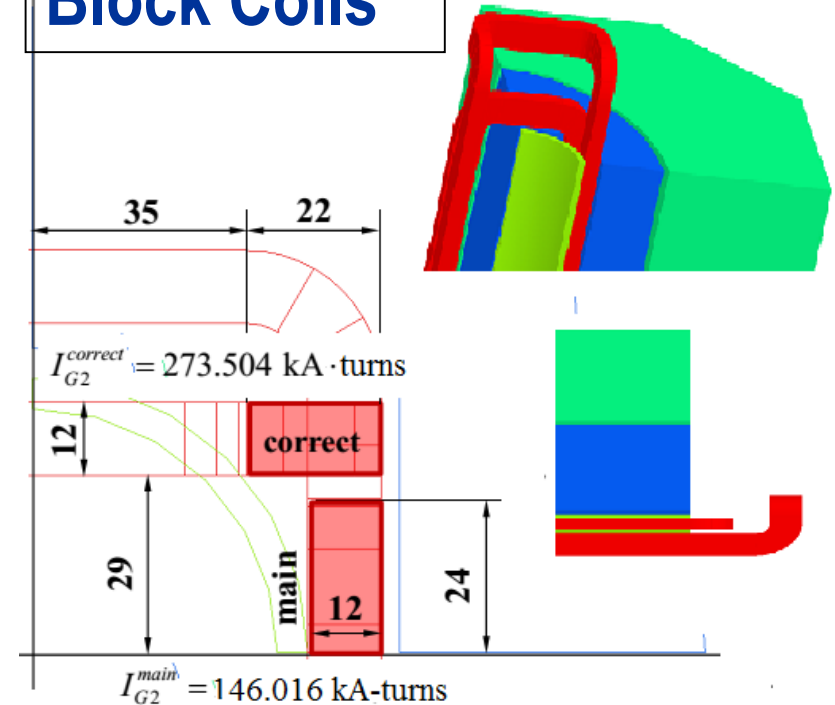
L. Potanina, V. Pansyrny, A. Shikov, N. Salunin, I. Gubkin, V. Korpusov, H. Khodzhbagiyani, A. Kovalenko, E. Fischer, H. Mueller, and G. Moritz. Experimental Results on the Development of Superconducting NbTi/Cu-Mn/Cu Wires for Magnet Systems of SIS100 and SIS300 Synchrotrons of FAIR. IEEE Trans. on Appl. Superconductivity, Vol.20, No.30, June 2010 pp. 1395-1398.

# Coil Design Approach

## «COS(θ)» - approximation



## Block Coils



Magnetic field calculations with Opera-3D were performed for two coil configurations, i.e. “Cos(theta)” and “block coil”. Work is in progress.

# Summary & Outlook

- R&D work on 6 T pulsed dipole is in progress;
- Some options of SC magnets were considered;
- The solution for a single layer dipole is analyzing;
- We are planning to start technical design of the first test model in June this year.

**THANK YOU  
FOR YOUR ATTENTION**