This project has received funding from the European Union’s Horizon 2020 Research and Innovation programme under GA No 101004730.

WP8 – Innovative Superconducting Magnets

I.FAST kick off meeting – 4 May 2021 - remote

Lucio Rossi – INFN-Milano –LASA for WP8 collaboration members

iFAST

WP8 Listing (only part of Magnets)

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WP8 duration: from M1 to M48 !!
Scope of our WP8 (Magnet part)

- Here we want to develop technologies supporting the EU Industry that wish to learn about the CCT developed by CERN.
- We aim at something useful for advanced HatronTherapy (SEEIIST)
- → **1 HTS CCT preceeded by 1 NbTi of same dimension as “gauge”**

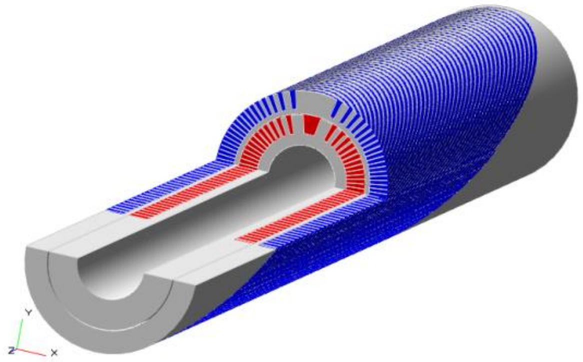
Baseline

Dream

ee ... for ...
)

CCT dipole
4 T operative
5 T target; Ø =60-90 mm;
500mm < L < 1000 mm

- Straight!, since we ... t H already difficult enough!

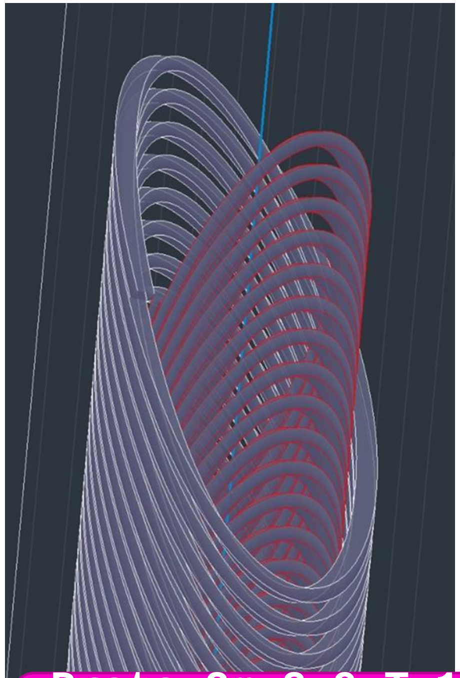


Nb-Ti CCT: p-gantry and HiLumi LHC

LBNL: CCT coil prototype for large acceptance proton gantry ∅ = 400 mm: Successfully tested to 3.5 T; segmented former.

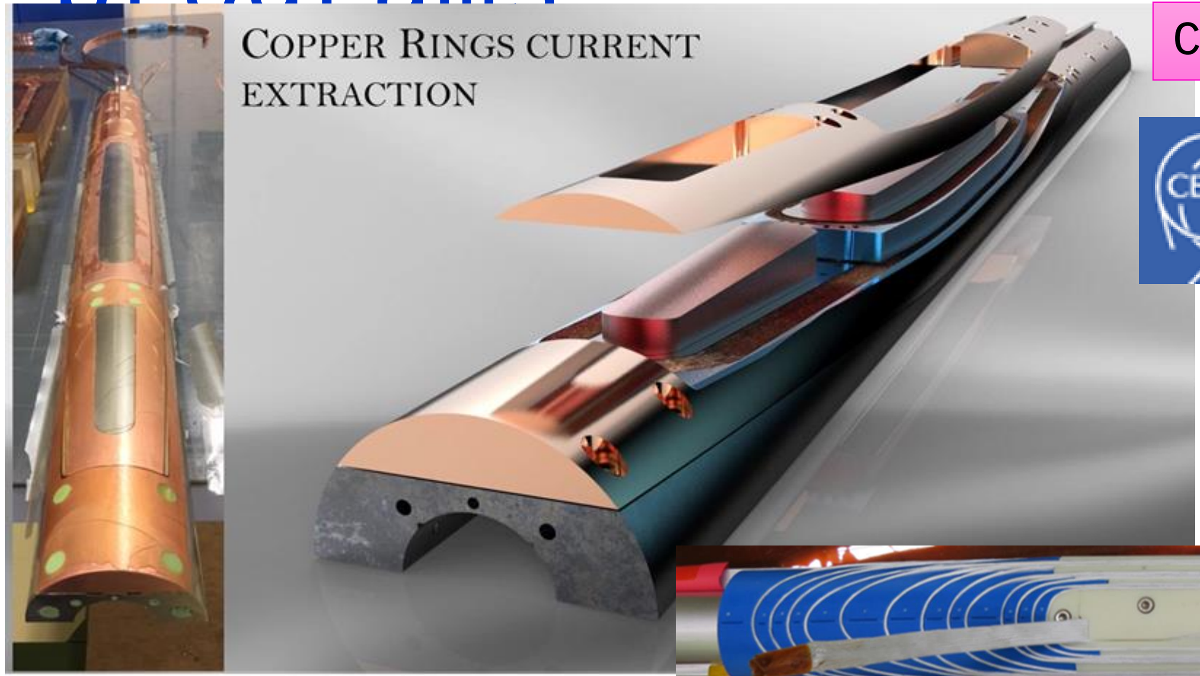
HiLumi LHC: CERN has designed, built and tested a dual 3 T, 2 m long - ∅ = 105 mm, straight CCT. Now IHEP Beijing producing 2x13 units

Short circuit at 3.5T!!

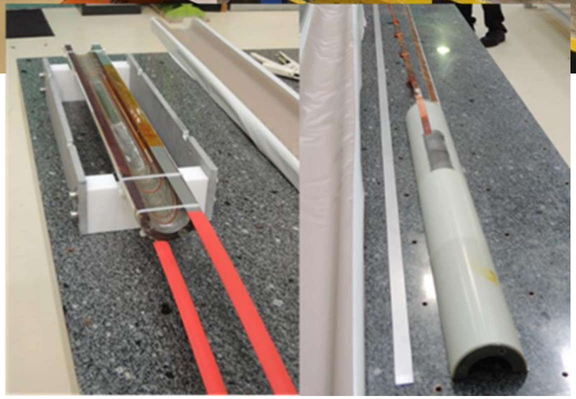


Proto 2m 2.9 T 105 mm very successful at CERN. However, learning and transfer not easy (China…, SE)…

We build on HTS in Eucard2 – ARIES programs

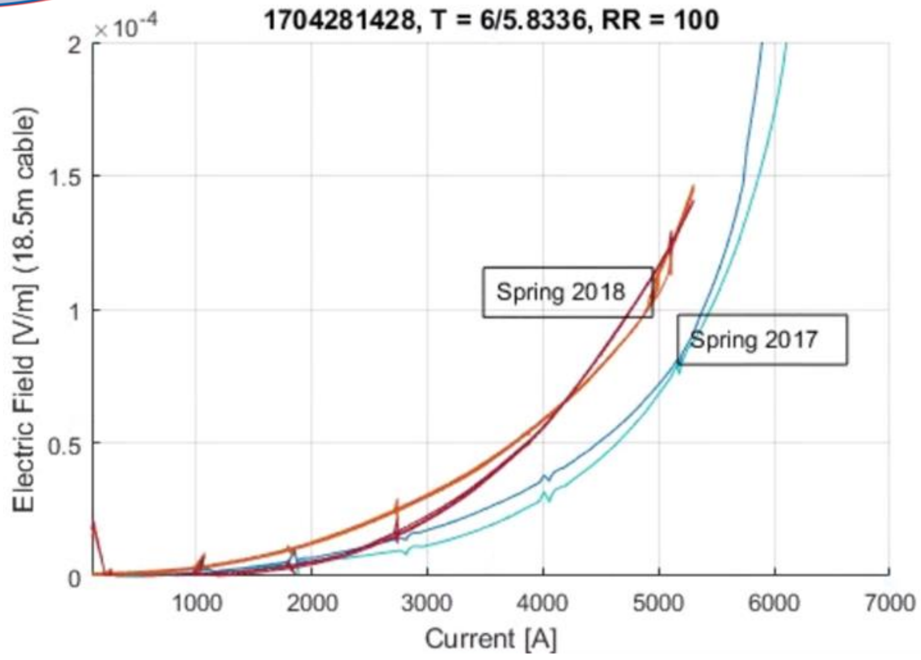


Courtesy of Glyn Kirby

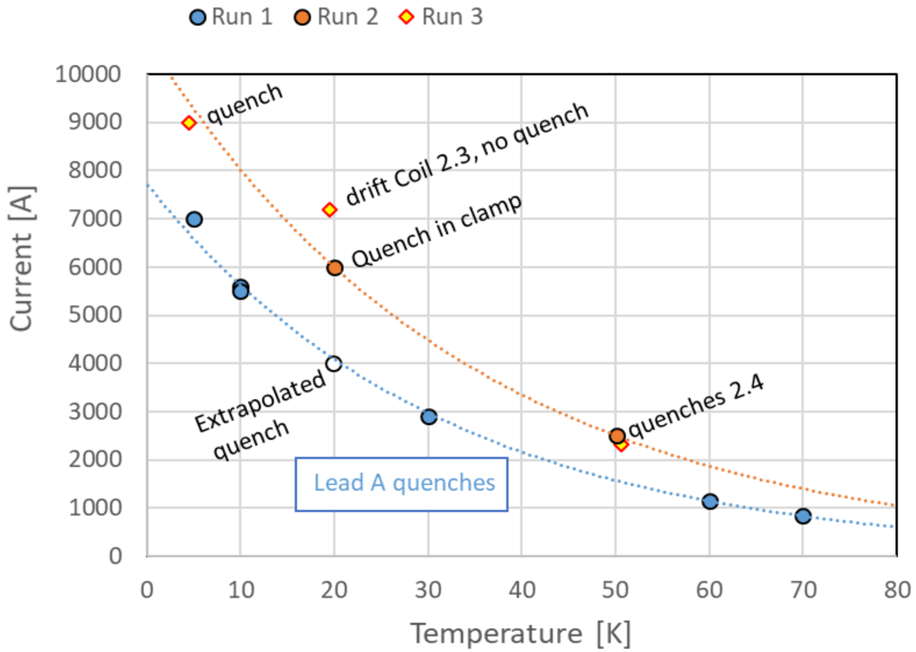


Degradation due to the cycle? Cold down also a little suspicious. But happened other times

G. Willering, CERN



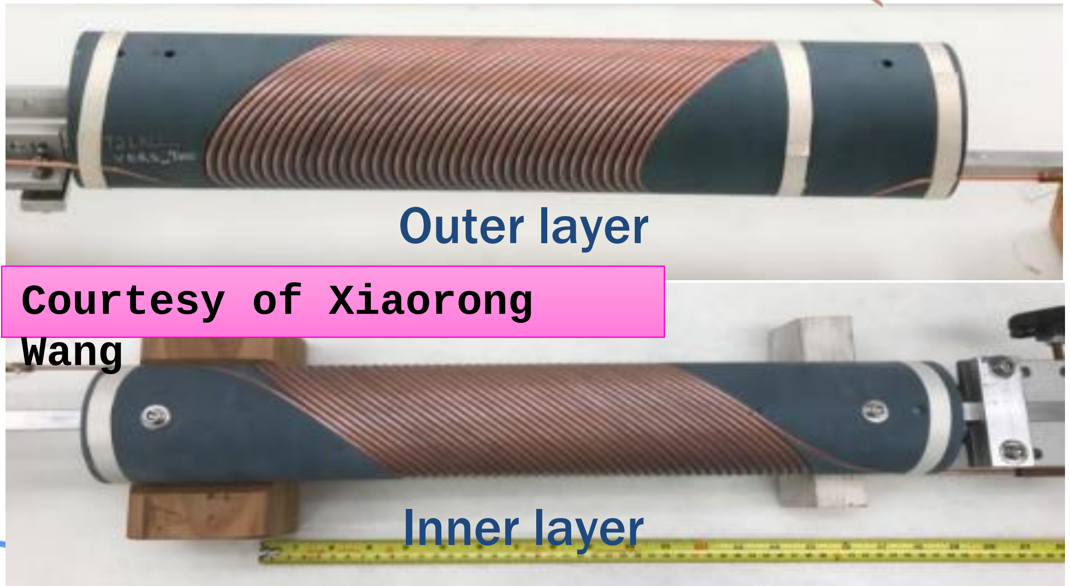
FeatherM2_1-2
3.1 T in ss - 3.5 T in overshooting mode



FeatherM2_3-4
(Eucard2 cable) **4.5 T**

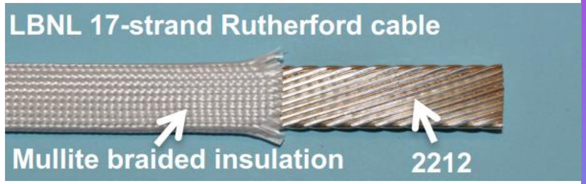
LBNL effort on HTS accelerator magnets

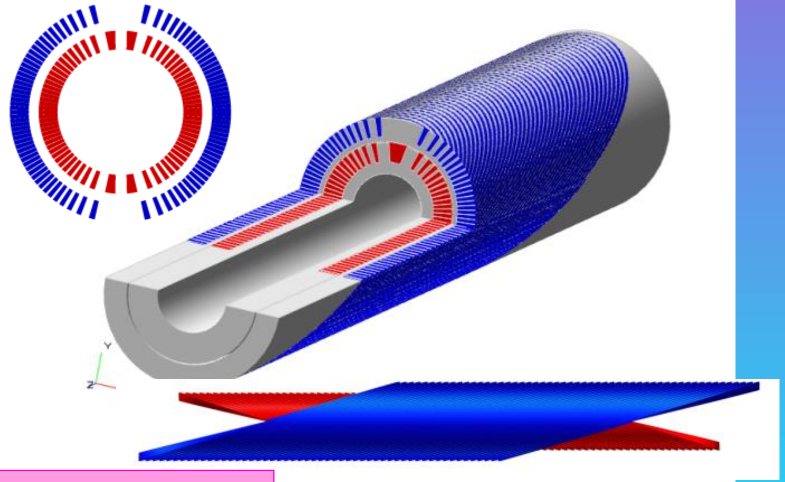
Program based on CORC and CCT layout led by X. Wang & S. Prestemon



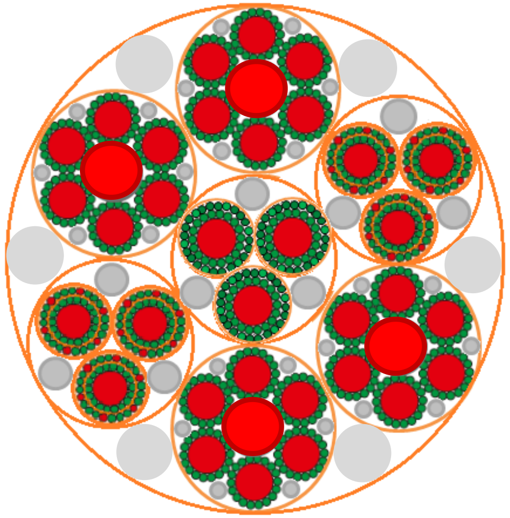
Courtesy of Xiaorong Wang

Program on use of Bi-2212 Rutherford cable with race track and CCT layout led by T. Shen and S. Prestemon





Courtesy of Tengming Shen



MgB_2 cable from HiLumi LHC – WP6 – Courtesy A.

MgB_2, instead? It maybe convenient for 3 T

Maybe using MgB_2 instead of the first NbTi…

If we can afford the conductor - depending on CERN mainly and on Ic degradation vs curvature radius, we can get some field (3T) with MgB_2?

Alternative : explore low losses Nb_3Sn, like the one for ITER, as possible alternative to Nb-Ti. Probably it works but is also expensive… Depending also on our Industry partner.

Program in short

Task 8.1: Coordination and High-Temperature Superconductor (HTS) Strategy Group M1 – M48
• Coordinate the WP activities, especially between CCT design and the fast cycling.
• Form a permanent European Strategy Group, open to worldwide partners, to discuss the European strategy for HTS magnets for accelerators, and to improve Industry involvement in this technology.

Task 8.2: Preliminary Engineering design of curved Canted Cosine Theta (CCT) magnet M1 – M34
• Define some options for the magnet structure and magnetic design at conceptual level for a CCT scaled demonstrator with new integrated curved coil geometry, in Nb-Ti and/or Nb3Sn.
• Provide a preliminary engineering design of a scaled prototype.
• Procure the superconductor for the construction of the demonstrator, in Nb-Ti and/or Nb3Sn.

Task 8.3: Preliminary Engineering design of HTS CCT M1 – M36
• Define the best option for the magnet structure and magnetic design at conceptual level for the HTS CCT scaled demonstrator.
• Provide technological tests (small coils) and a preliminary engineering design of a scaled prototype.
• Procure and qualify the HTS superconductor for the construction of the demonstrator.

Program in short – cont.

Task 8.4: Construction of curved CCT magnet demonstrator M10 – M48

- Magnet demonstrator design and construction of coil former and assembly parts.
- Winding and magnet assembly, magnet test and validation.

Task 8.5: Construction of the HTS CCT magnet demonstrator M12 – M48

- Magnet demonstrator construction design and construction of coil former and assembly parts.
- Winding and magnet assembly, magnet test and validation.

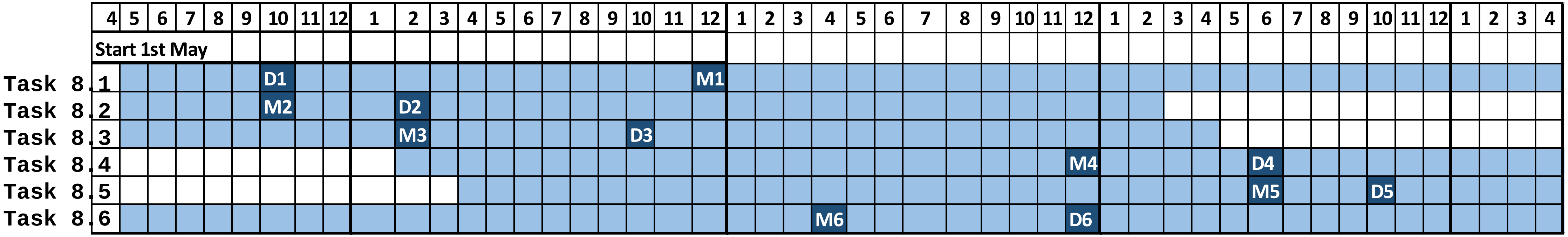
Task 8.6: Development of ReBCO HTS Nuclotron cable M1 – M48

- Choice of ReBCO tape material to be used in a Nuclotron cable for fast-cycling magnets.
- Manufacture a cable prototype and evaluation of its performance.

talk by
Timeo

Timeline

IFAST WP8: Innovative Superconducting Magnets
Task 8.1 - Coordination and High-Temperature Superconductor (HTS) Strategy Group
Task 8.2 - Preliminary Engineering design of curved Canted Cosine Theta (CCT) magnet
Task 8.3 - Preliminary Engineering design of HTS CCT
Task 8.4 - Construction of curved CCT magnet demonstrator
Task 8.5 - Construction of the HTS CCT magnet demonstrator
Task 8.6 - Development of ReBCO HTS nuclotron cable



IFAST Deliverables

	Task	Resp.	Type	Del. In Months	Name	Description
D1	8.1	CERN	Report	6	HTS European Strategy Group	Set up of the ESG and kick off meeting with approval of program, scope, and modus operandi.
D2	8.2	INFN	Report	10	Conceptual Design of curved CCT in LTS	Report with complete list of parameters motivating the choice for the design.
D3	8.3	CEA	Report	18	First Engineering design of HTS demonstrator	Report with a set of coherent parameters of the near-to-final design
D4	8.4	BNG	Demo	38	Construction of curved CCT demonstrator	Magnet demonstrator complete with electrical termination and transport constrains
D5	8.5	Ellytt	Demo	42	Construction of HTS CCT demonstrator	Magnet Demonstrator with electrical terminations and transport constrains.
D6	8.6	GSI	Report	32	Fast-cycling Nuclotron HTS cable design	Design parameters of the HTS Nuclotron cable aiming at 6 T magnetic field cooled by two phase forced flow Helium, AC loss measurements.

	Task	Type	Deliv. In Months	Name
M1	8.1	Review Report	20	Construction readiness of curved CCT demonstrator
M2	8.2	Measurement Report	6	Charac. of the first length of superconductor for low losses
M3	8.3	Design Report	10	Conceptual design of HTS magnet
M4	8.4	Rep. Conformity Cert.	32	Construction of the curved formers for CCT winding
M5	8.5	Rep. Test and Ass.	38	Test of mock up coils with dummy cable
M6	8.6	Lab. Test of Sample	24	HTS Nuclotron cable produced

WP8 Risk & Mitigation Actions

Risk number	Description of risk	WP Number	Proposed risk-mitigation measures
1	Withdrawal or default of beneficiary (ies) [Likelihood: Medium]	WP1, WP10, WP11, WP12, WP13, WP2, WP3, WP4, WP5, WP6, WP7, WP8, WP9	Reassignment of work
8	Difficulty in designing the curved CCT magnet at reasonable price [Likelihood: Medium]	WP8	Design with larger aperture, segmented magnets, returning to lumped functions lattice (task 8.2)
9	Controlled-Insulation technology not suitable for HTS ramped magnets of accelerator quality [Likelihood: High]	WP8	Design with classical insulation and develop quench detection system of new temperature-based generation (task 8.3)
10	Difficulty to get good field quality winding in curved CCT [Likelihood: Medium]	WP8	Explore technique like wet-winding or corrector magnet scheme (task 8.4)
11	Amount of HTS much larger, or HTS tapes much more expensive, than anticipated [Likelihood: Medium]	WP8	Explore low-cost HTS from China or Russia and compensate for lower current density by lowering field (task 8.3, task 8.5)
12	Not enough high quality HTS tape material available [Likelihood: Medium]	WP8	Manufacture shorter-length sample of HTS Nuclotron cable and shorten test programme (task 8.6)

talk by
Timeo

I.FAST WP8 Innovative SC Magnet. Budget for the program.

Members	Person-months	EC funding	Institute matching funds	TOTAL Funds
CEA	10	42,188	76,705	118,892
CERN	11	190,153	345,732	535,884
Wigner RCP	24	24,638	44,795	69,433
INFN	14	112,613	204,750	317,363
CIEMAT	12	26,438	48,068	74,506
UU	5	31,500	57,273	88,773
PSI	6	28,688	52,159	80,847
BNG	17.5	121,200	94,300	215,500
Scanditronix	10	59,938	108,977	168,915
Elytt	22.5	115,600	89,900	205,500
~~Sigmaphi~~	~~15~~	~~59,938~~	~~108,977~~	~~168,915~~
Grand Total	**132**	**700,340**	**1,273,345**	**1,973,685**

CERN is Project Coordinator
INFN is the WP8 – Magnet Coordinator
(CEA is the deputy) START: 1 May 2021

The amount of personnel paid by EC must be complemented by the matching resources by Institutes.

We MUST MEET Deliverables!!

Participation per Partner

Partner number and short name	WP8 effort
1 - CERN	6.00
6 - CEA	5.50
10 - BNG	7.40
13 - GSI	1.00
16 - ILK	8.90
20 - Wigner RCP	16.00
24 - INFN	14.00
29 - UT	7.00
32 - IEE	6.50
34 - CIEMAT	5.50
36 - ELYTT	10.50
39 - Scanditronix	5.50
40 - UU	3.50
41 - PSI	2.50
Total	99.80

HITR+ WP8 (Magnet Design) and I.FAST WP8 (Innovative Magnets) will work closely together …

Thanks!

(reserve slides follow)

Description of work and role of partners

WP8 - Innovative superconducting magnets [Months: 1-48]
INFN, CERN, CEA, BNG, GSI, ILK, Wigner RCP, UT, IEE, CIEMAT, ELYTT, Scanditronix, UU, PSI
Task 8.1: Coordination and HTS Strategy Group (INFN, CEA, CERN, CIEMAT, PSI, UU, Wigner RCP)

The Task will coordinate work-package activities and organise reviews, collecting the input of Industry, to make sure that the designs are suitable for practical fabrication and that the demonstrators can be extrapolated to real full-size magnets, for ion therapy and/or synchrotrons for HEP or Nuclear Physics. It will maintain a close liaison with other possible EC projects having synergies with this WP and make an inventory of possible future accelerator projects that may need HTS magnets and cables, like FCC, FAIR upgrade, CERN fixed targets beamlines, beam lines in other EU laboratories, etc.

A permanent European Strategy Group (ESG) will be formed, open to worldwide partners, to discuss the European strategy for HTS magnets for accelerators, and to improve industry involvement. Two or more events with Laboratories and Industry will be organised to foster common developments. The ESG group will meet at least once a year, more frequently if needed, and will write a document for promoting the use of HTS in a realistic way in the accelerator domain. The document will be the base for a formal contribution document to the next update of the European strategy on Particle Physics.

INFN will lead the task. CERN will be in charge of the ESG and workshop organization, with the support of INFN. All Institutes will participate to the ESG. CEA and INFN will organize the technical reviews. Wigner and CERN will provide the general feedback based on experience in testing their CCT magnets.

Task 8.2:Preliminary Engineering design of curved CCT magnet (INFN, CERN, CIEMAT, UU, Wigner)

The partners will carry out conceptual design and preliminary engineering design of a CCT scaled demonstrator with new integrated curved coil geometry. Various options, with different structural and superconducting layout will be examined to approach an achromatic beam transport: nested dipole and quadrupole, co-wind of dipole and quadrupole in the same winding, series winding of dipoles and quadrupoles in the same layout. The design will consider for winding, as a first baseline, the use of LTS as Nb-Ti with fine filaments for low losses or low-cost Nb3Sn of fusion specifications, and evaluate advantages and disadvantages. The team will decide in M12 the best solution and then will implement a realistic engineering design for a demonstrator of a length of 0.5-1 m. The figures of merit for the optimization are: total cost, mechanical structure, field quality, easy of assembly, coil ends, quench and protection, low-cost powering by limiting the operational current. The SC and thermal design will take into account that the final lay-out must be a "dry magnet", i.e. cooled either by gas or by solid conduction from a cryo-cooler.

The partners will share the design job and, for each important aspect like field quality and protection, there will be an independent verification. The superconductor, either low-loss Nb-Ti or high-stability (higher Tc) Nb3Sn, will be procured, in sufficient quantity for a complete demonstrator, and characterized in operative conditions. Particular care will be devoted, in case of choice, to the characterization vs. temperature of the Nb3Sn wire. We aim at wires of 0.7-0.8 mm diameter stabilized with cupro-alloy in order to reduce losses allowing the use of sweeping fields at a critical current density about 400 A/mm2 in operative conditions.

INFN will procure the wire; CERN, will provide inputs for the design and assure the SC wire qualification; Wigner RCP will carry out computations with CERN, CIEMAT and INFN, and will produce part of the of the engineering drawings with CIEMAT; CIEMAT will provide global integration of the design and contribute to engineering drawings; UU will consider aspects of the design interfering with testing.

Task 8.3: Preliminary Engineering design of HTS CCT (CEA, INFN, CERN, CIEMAT, PSI)
The partners will carry out conceptual design and then preliminary engineering design of a HTS CCT scaled demonstrator with new Controlled Insulation (CI) technology. First, the team will select the type of HTS among the various types (REBCO tapes, Bi-2213 or Bi-2223, IBS). If the MgB2 would enable operation also at 15-20 K with sufficient current density of 400 A/mm in the conductor, MgB2 could also be considered as "low temperature" HTS options. Then, all grades of CI (from no insulation, to classical infinite insulation) will be examined and evaluated with respect to the use. The team will study and select the insulation type and will choose the type of conductor (single tape versus multi-strand cable in different shapes). The chosen solution will be assessed and validated with small experimental tests, in the most convenient shape (CCT or simple circular or race-track coils). The partners will share the design job and, for each important aspect, like field quality and protection, there will be an independent verification. Task 8.3 will also consider how the medical-applications design can be used, with minor modifications, for nuclear and high energy physics applications, in synchrotrons or beamlines for experimental areas.
CEA will provide basic design inputs and carry out the insulation/non-insulation test on HTS tapes or small coils, with the support of CERN that will provide the conductor. CEA and CIEMAT will be in charge of the engineering drawings, with the support of INFN and PSI. INFN and PSI will carried out the engineering checks.

Task 8.4: Construction of curved CCT magnet demonstrator (BNG, Scanditronix; CERN, INFN, UU, Wigner RPC)
Industry will take the preliminary conceptual design developed with the academic partners and will transform it into a construction project for an operating magnet demonstrator. The construction design will include drawings, description of the construction process, design and construction of the tooling and magnet components, especially the winding cylinder. The fabrication of a curved slim cylinder for CCT will be an important novelty and the decision on the technology will be taken by the Industry in agreement with the Institutes. The demonstrator is of reduced size (0.5-1 m) but will be manufactured with technologies that are scalable to full size magnets. After procuring the main components, the industrial partners will carry out winding of the two layers, impregnation, assembly of the magnet demonstrator, and testing to verify quality.
BNG and Scanditronix will manufacture the demonstrator at their premises; Wigner RCP will check the drawings and contribute to supervision, with support from CERN and UU. Finally, the demonstrator will be tested and qualified in close to operational conditions at CERN or UU.

Task 8.5: Construction of HTS CCT magnet demonstrator (Elytt, BNG, CERN, CEA, INFN, PSI)
In this Task, the industrial partners will realise a magnet demonstrator in HTS. The procedure will be the same as in Task 8.4, but involving two different industrial partners. They will take the preliminary conceptual design of the scientific partners and transform it into a construction project for a real operating magnet demonstrator including drawings, description of the construction process, design and construction of the tooling and magnet components. Again, the fabrication of a cylinder for CCT with CI technology will also be a novelty and the decision of the technology for CI will be the critical point to be implemented by Industry in agreement with the partners. The demonstrator is of reduced size (0.5-1 m) and straight but will be manufactured with technologies that are scalable to full size magnets (2-3 meters).
After procurement of the main components, Industry will carry out winding tests with a dummy cable, and produce mock-up coils that can be tested by the laboratory to qualify the effect of CI. Then, the winding of the two layers, impregnation and finally the magnet demonstrator will be assembled. Once assembled, the industrial partners will carry out tests to qualify the winding.
Elytt and BNG will manufacture the demonstrator at their premises; CEA will check the drawings and will contribute to the supervision, with support from CERN and PSI. Finally, the demonstrator will be tested and qualified in conditions near to the operative ones by cold test at CERN or UU or INFN.

Last task led by GSI – see next talk!

Task 8.6: Development of ReBCO HTS Nuclotron cable (GSI, UT, IEE, ILK)
This Task will design and assemble a HTS superconducting cable based on the Nuclotron cable technology already used at GSI. Its main purpose is the application in a fast-cycling accelerator magnet with a magnetic field of 6 T required for, e.g., a future 2nd stage of the heavy ion synchrotron for the FAIR project at GSI. The cable design requirements will meet the LTS Nuclotron design. To overcome the limitations of LTS, a HTS ReBCO superconductor will be used. In the envisaged design, multiple HTS tapes will be wound around a central cooling channel in order to obtain a high-current cable. Present design specifications call for a current level of 30 kA.
IEE will lead the tape choice based on magnet design parameters given by GSI. After a successful selection of the tape, tape procurement for cable manufacturing will be done by IEE/ILK. Cable manufacturing will be done by IEE, building on previous experience. After successful cable winding IEE will perform cryogenic testing on the cable at 77 K, while UT will characterize the cable at 4.2 K together with cable modelling to predict and understand the AC loss characteristics. ILK and GSI will perform forced flow testing of the produced cable to evaluate its thermal performance.