Progress in EuCARD and plans for EuCARD2

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CERN

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   - Why this dipole and insert ?
   - High field dipole magnet: Fresca2
   - Very high field dipole insert

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   - Conductors
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3. Conclusions

EuCARD HFMs

Why build a 13 T, 100 mm aperture dipole ?

- We need such a magnet for testing high field cables
  - A 13 T 'nominal' field means it should run at 80% of the short sample current: you need to design it for an ultimate current (92%) of 15 T
  - If you do this at 4.2 K you get a 15 T magnet at 86%ss at 1.9 K
  - 13 T to 15 T range is targeted for HL-LHC type conductors
  - It also opens the way to test cables at 1 T or 2 T self field higher than 15 T ➔ the HE-LHC domain
- A 100 mm aperture is very generous for cable tests
  - But opens the way for serving as 15 T outsert for a dipole insert
  - Fresca2 shall be used to test the EuCARD insert to approach 20 T
  - Fresca2 will be used as outsert for the EuCARD2 magnet
- B =13 T with a 100 mm aperture asks for more than a simple scale-up of the LHC dipole type due to the stress on the Nb_3Sn: prepare for HE-LHC magnets

EuCARD HFMs (2)

Why build a 6 T racetrack HTS dipole insert ?

- There is virtually no experience with 20 T dipolar fields
- To get close to 20 T will already gain us a lot of valuable experience
- We need to get experience with using HTS in a magnet
- We need to get experience with high field usage of HTS
- Best strategy: start simple, do things step by step, learn while doing

So:

- Don't try to build a 20 T in one go: but build insert and outsert separately
- Make them mechanically independent
- Start with a racetrack, with a medium current cable, low inductance, short length (we don't want a launcher) ➔ build a racetrack insert

Fresca2, conductor

What strand do we need for Fresca2 ?

- Performance: Jc ≥ 1200 A/mm^2 @15 T, Cu to nonCu ratio 1.25,
- For stability: RRR >150, 1 mm diam.
- High I, low L: 40 strand cable with < 10% cabling degradation

We started from the NED strand of 1.25 mm

- 1.25 mm is risky for stability reasons
- Makes for very stiff cables: hard to wind

Development done with/in industry:

- PIT with Bruker (D)
- RRP with OST (US)

What cable do we need ?

- I >12kA@15T
- 40 strands Rutherford cable
- <10% cabling degradation, RRR>120

Fresca2, conductor (2)

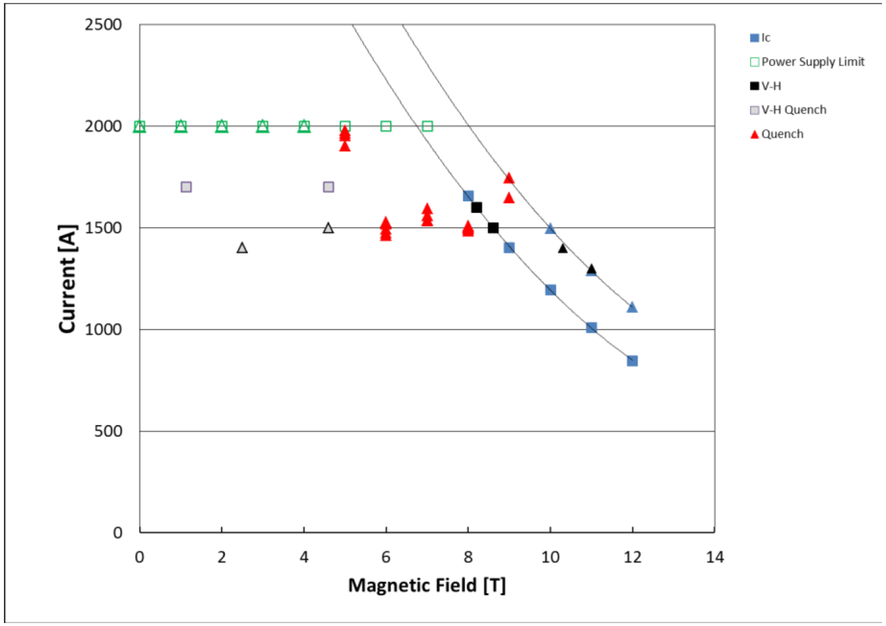
A qualification phase yielded the required performance for both vendors

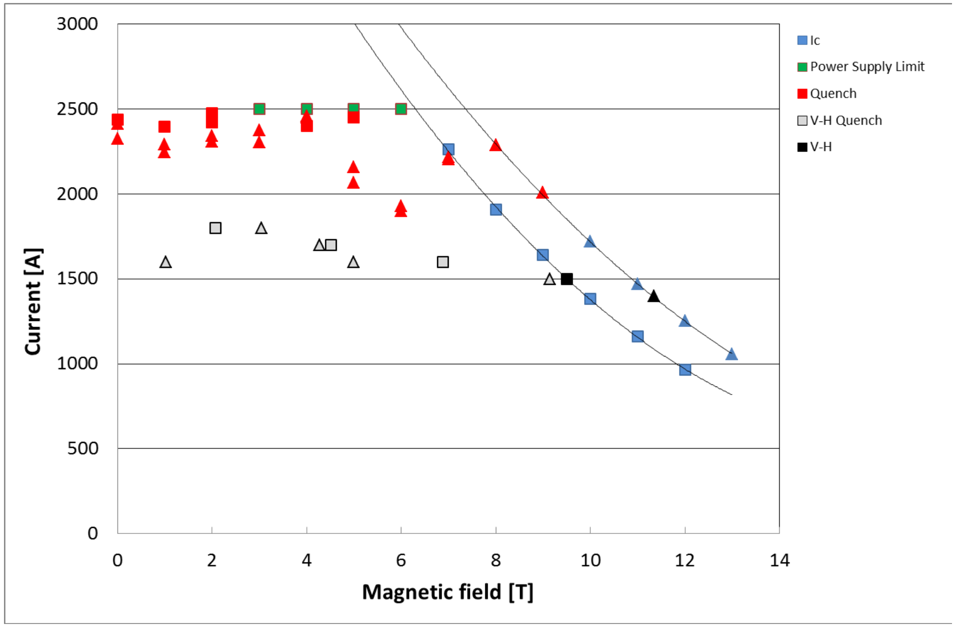
		FRESCA2 specification	PIT	RRP
Strand diameter	(mm)	**1.00**	**1.00**	**1.00**
Strand layout	-		192 filaments	132/169 stack
Sub-element diameter	(μm)	< 50	~ 48	~ 57
Copper to non-Copper volume ratio	-	1.25 +/- 0.1	1.28 (σ = 0.02)	1.28 (σ = 0.02)
J_C(12 T, 4.2 K)	(A/mm^2)	2500	**2497**	**2842**
J_C(15 T, 4.2 K)	(A/mm^2)	**1250**	**1425**	**1623**
n-value @15 T and 4.2 K	-	> 30	~ 44 (σ = 8)	~ 50 (σ = 10)
RRR (after full reaction)	-	> 150	**192 (average)**	**260 (average)**
ΔM at 3 T and 1.9 K	mT	-	173	323
Effective filament diameter	(μm)	-	44	64
Piece length	-		**7% below 1 km**	**40 % below 1 km**

Fresca2, conductor (3)

Stability of the strand was an initial worry: 1 mm strand performs ok for both PIT and RRP

Stability margin at low field is > factor 2



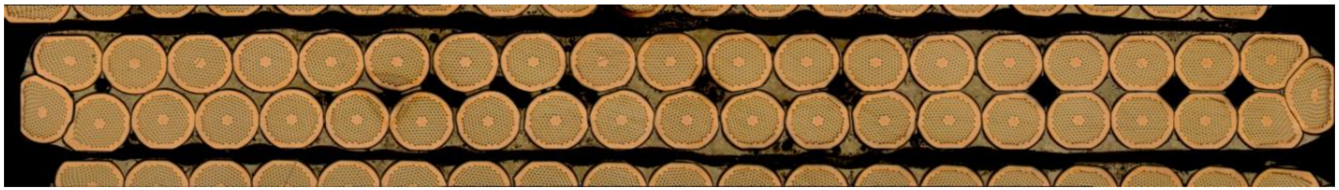


L. Oberli

Fresca2, conductor (4)

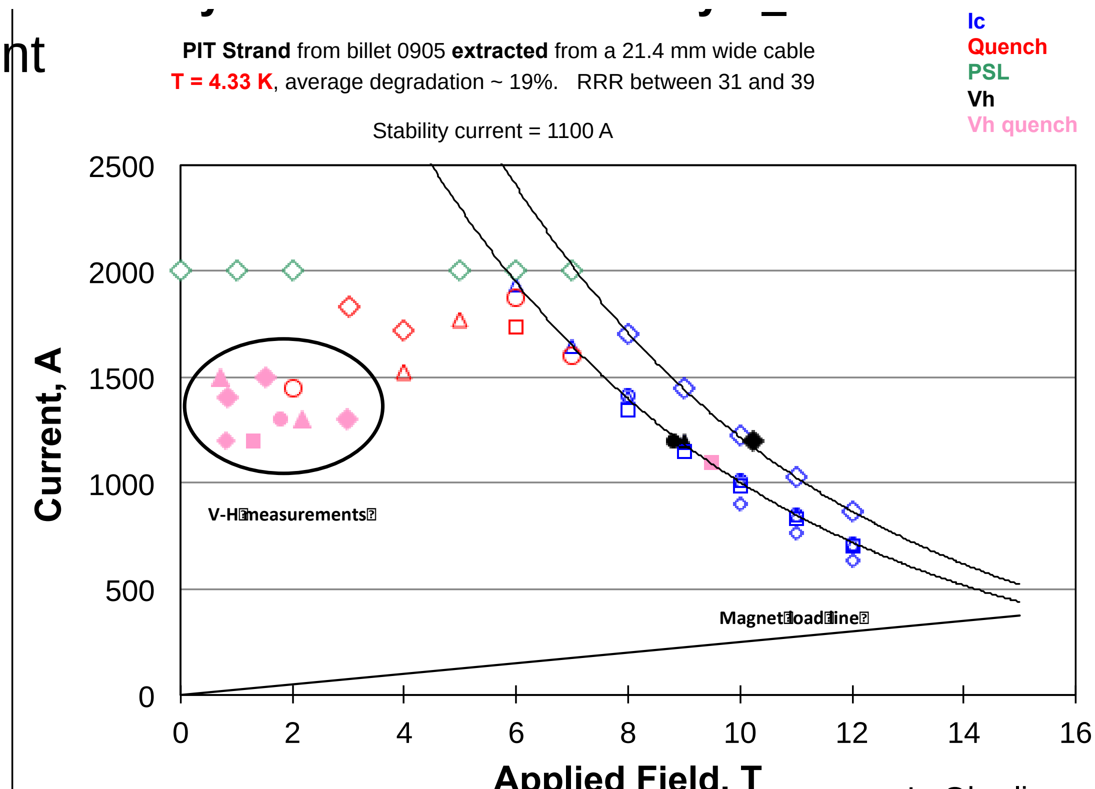
Fresac2 cable:

40 strands, 20.9 mm wide, 1.82 mm thick, rectangular, pitch 120 mm



After one year of development cabling degradation is now reliably ≤5%

The good stability is maintained for the cables.



L. Oberli

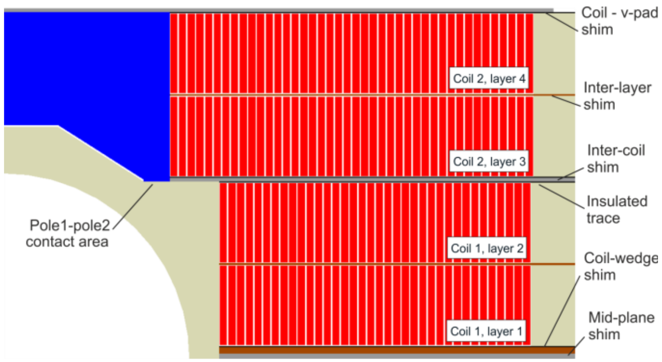
Fresac2 magnet (1), design

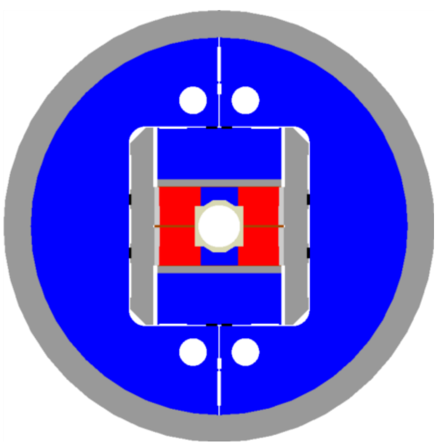
13T nominal field at 4.2K, max length 1.6m , diameter 1.03m

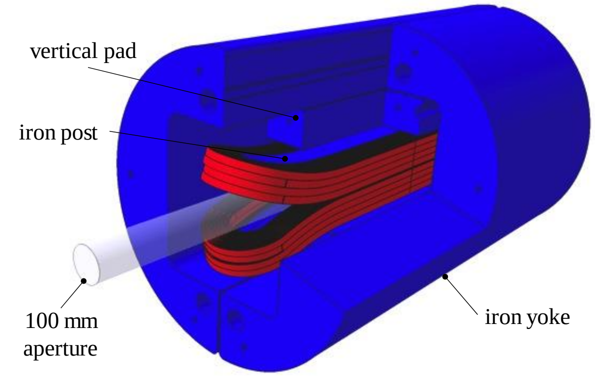
Very systematic design effort: 3D models, FE models, all details addressed

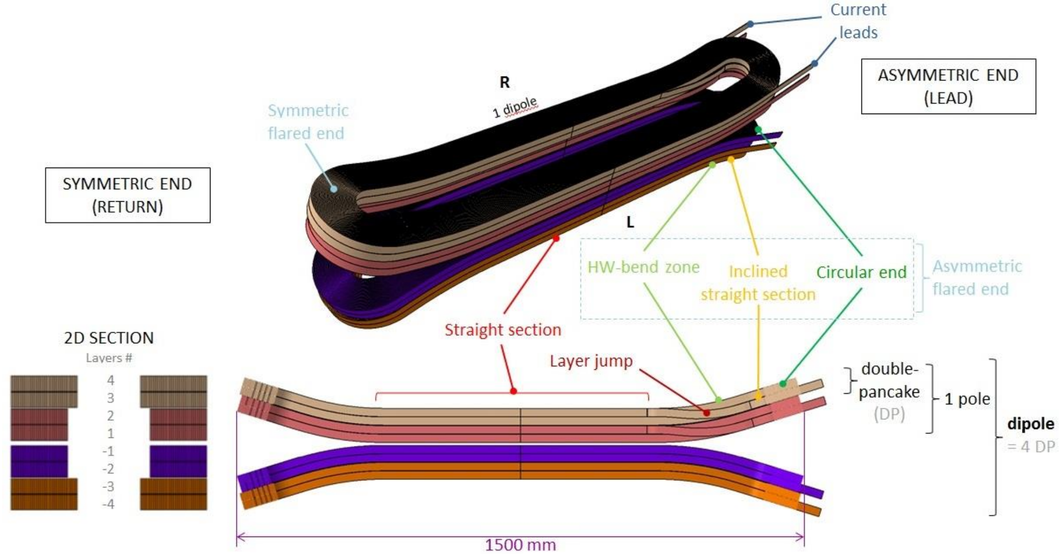
After an ‘intense’ conceptual design phase a layout was chosen with:

- Block coil with flared ends (LBNL style)
- Shell, bladder and keys structure







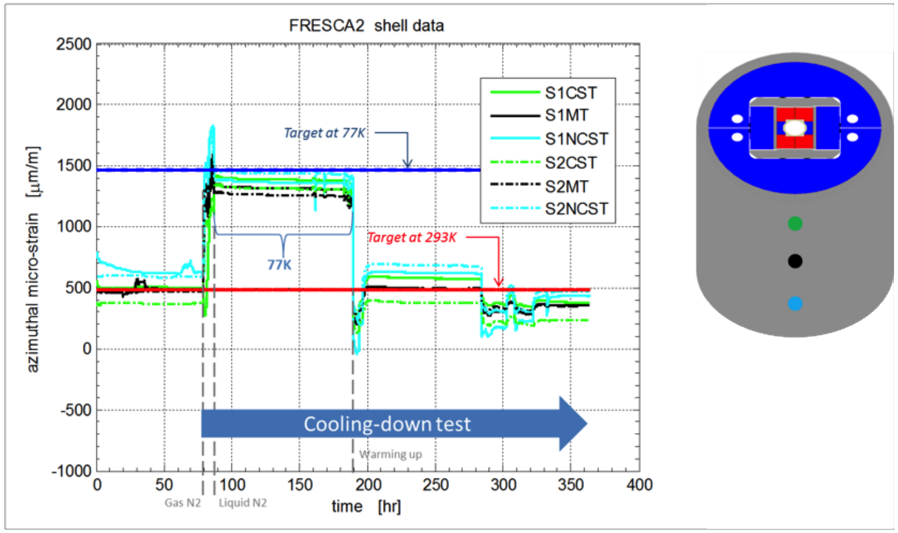


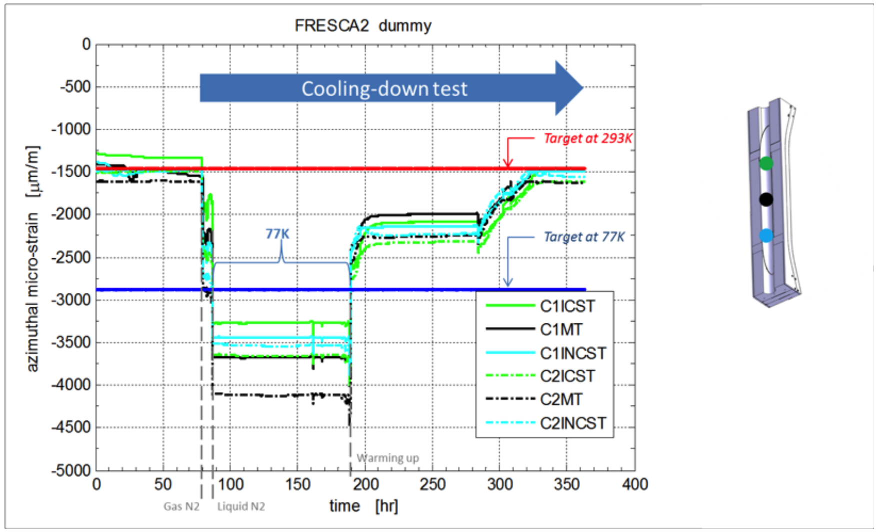
A. Milanese, P. Manil, P. Ferracin, + the whole collaboration

Fresac2 magnet (2), Structure

Structure is completed

- Tested at CERN at 77K in the LN2 cryostat using Al dummy coils
- Preliminary results show a good correspondence with the FE model: permits us to fine-tune the models and to aim for a precisely calibrate pre-stress on the coils



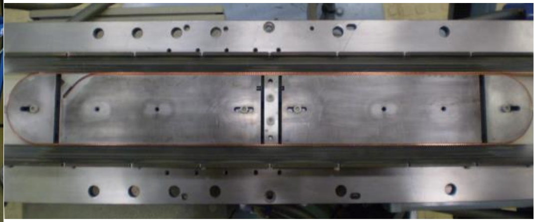


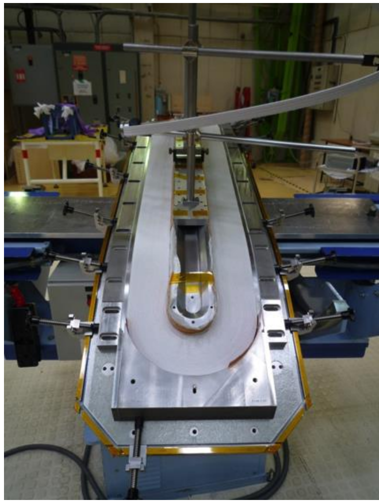
J. Munoz, P. Ferracin, J-C. Perez + the whole collaboration

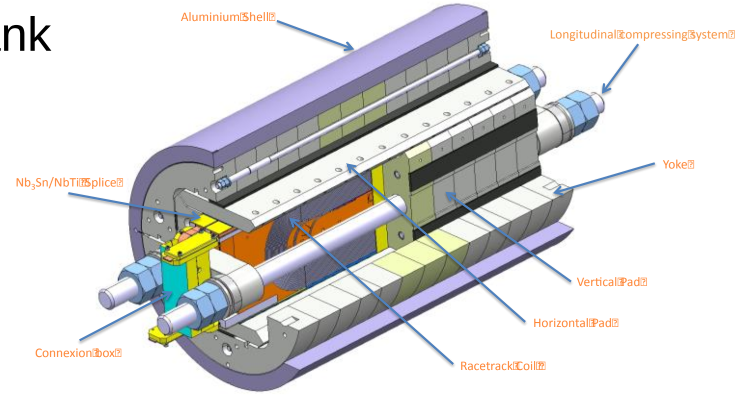
Fresac2 magnet (3), coil manufacturing

Do a stepwise approach, testing a maximum of intermediate steps, we addressed a large number of outstanding issues

- Make racetrack coils with small cable (SMC)
- Winding tests
- Layer jump tests
- Cable reaction tests
- Insulation development
- Make racetrack coils with Fresca2 cable (RMC)
- Furnace and impregnation tank
- Design the coil in all details
- Design de manufacturing procedure and tooling
- Make Cu coils
- Make final coils







Results: we claim to know how to make the coils: Very useful feedback to the other Nb_3Sn projects

Fresca2 magnet (4)

Fresca2 results dd June2013:

- We have a conductor design for which measurements have shown it is in specification
- We have 2 conductor suppliers, and strand for 1 magnet in-house
- We have a tested structure
- We have the coil manufacturing infrastructure
- We know how to make the coils
- We have the tooling for half of the coils in house
- We know from scaled-down models that the technology can work
- We are manufacturing coils now

So we are learning how to build a 15 T large aperture magnet: this looks very much a HE-LHC outsert magnet. It also points to how to build a 15 T accelerator dipole with small aperture

EuCARD Insert, Conductor

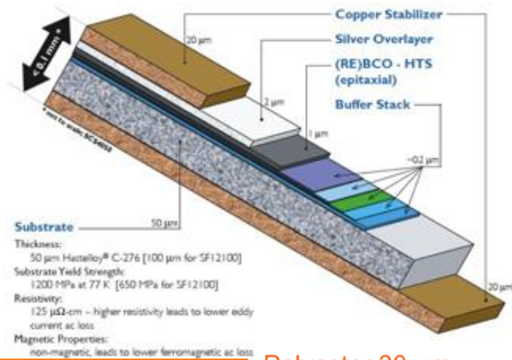
YBCO conductor

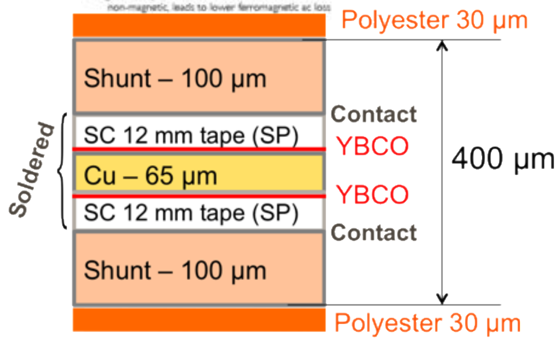
Special cable for I_{eng}=2800A@20T

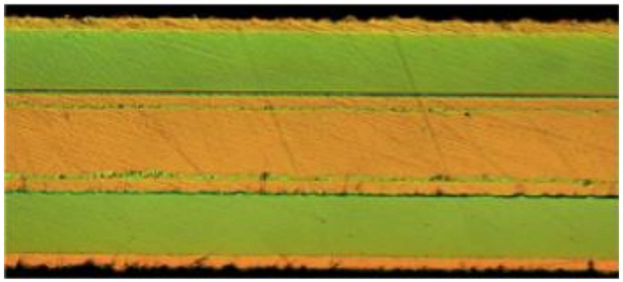
Will get the experience with YBCO tape despite the fact that the cable is not the final one

We are gaining experience on

- Long length tapes
- Angular field I_{eng} dependence
- Splicing connection
- Stress sensitivity
- ‘windability’
- Conductor current and mechanical stability
- Quench development







P. Tixador at al.

EuCARD Insert, design

At the start in 2009 the WP did not have an idea how to do it. So, they went into uncharted territory.

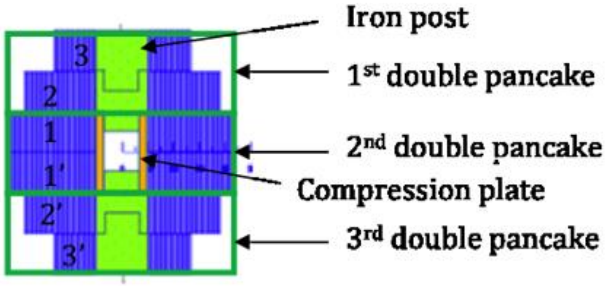
Simplifications introduced:

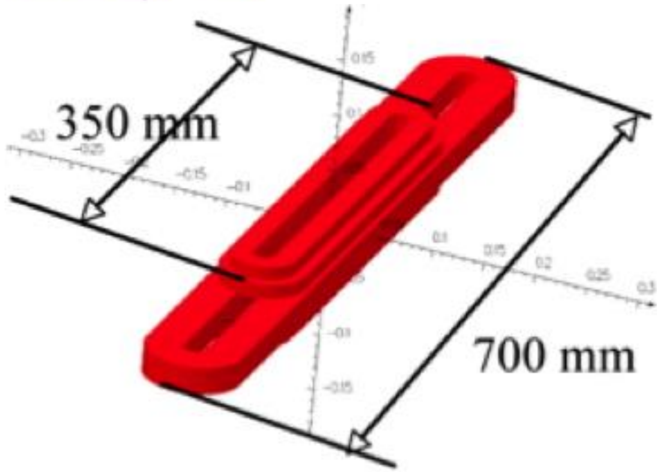
- Racetrack coils, no free bore
- 3 double pancake coils, 700 total length but 2 are shorter
- Should fit in the central homogeneous field region to avoid axial forces (no launcher)
- 2x2 tape cable: 2 core conductors of 2 tapes soldered together face to face
- Reinforcement of core conductor with CuBe strips
- Insert to be mechanically independent of the outsert
- Dry operation for coil and T > $T\lambda$ (2.17 K) to avoid He infiltration

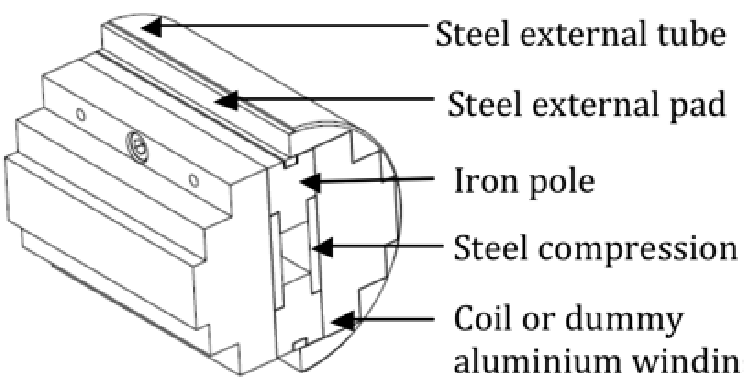
EuCARD Insert, design

Results:

- Mechanical structure designed
  - Steel pads
  - Shrinking cylinder
- New connection scheme designed
  - Transpose poles
  - Splices of double core conductors
- Insulation scheme
  - 0.03 mm polyester tape





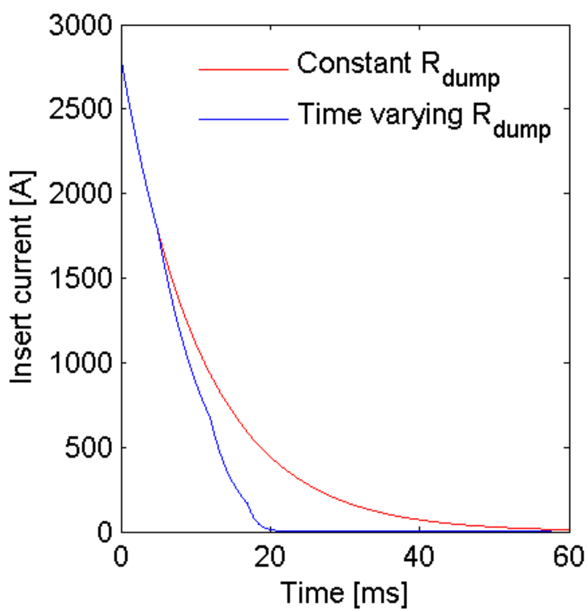


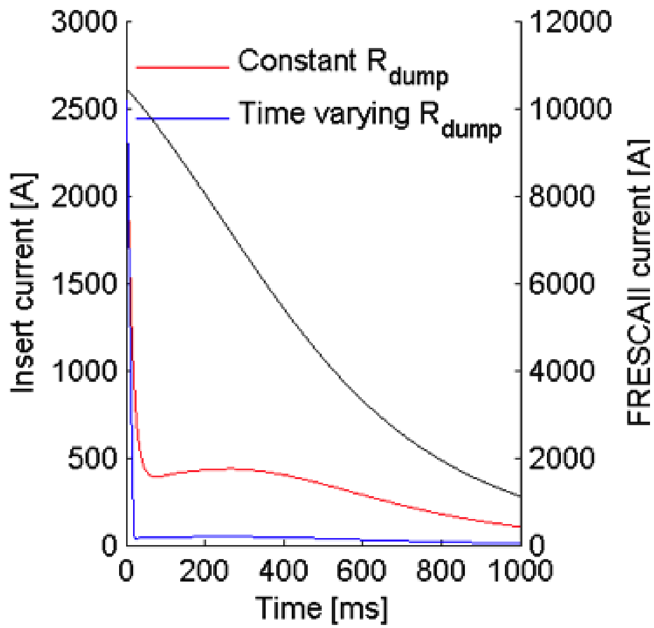
EuCARD Insert, quench

"In 2009 HTS coils would mostly burn out at the first quench"

Results of EuCARD:

- Model software made for HTS coils
- Models compared to small coil tests
- Feasible quenching scheme for stand alone developed
- Feasible quenching scheme for insert in outsert





EuCARD Insert, conclusions

- Many of the completely open issues in the beginning have been addressed
- The stand alone test will tell us already what some of the remaining issues are
- The final test in an outsert (Fresca2 ?) will be crucial for continuing with 20 T projects

EuCARD2 : the next step

What is the next step ?

Build a accelerator compatible 5 T dipole with HTS conductor

What is accelerator compatibility (with the HE-LHC in mind) ?

- Field quality (b_n < few units 10^{-4})
- Free aperture of 40 mm
- Be able to ramp up in a few minutes
- Cable with > 10kA@20T (less turns, less inductance)
- Compatible with high mechanical stresses
- Quenchable
- Dynamic field quality

EuCARD2 : the conductor

There are 2 types of conductors available:

YBCO

- Tape, cable concepts to be proven (Roebel, Cork, or ?)
- Mechanically strong (700 MPa in tension)
- High current density I_{eng} >250A/mm^2 @20T (dream 750A/mm^2)
- Some known problems with tape stability (delamination)

Bi-2212

- Round wire, can be cabled into a Rutherford cable
- Mechanically fragile (ceramic in a silver matrix)
- Need to react the coil at 850° with a 1° precision in a O_2 atmosphere under pressure
- Insulation needs to withstand the treatment

EuCARD2 : the conductor (2)

Program for EuCARD2

- Develop with industry strand for both Bi-2212 and YBCO going towards 750 A/mm^2 @20T
- Develop YBCO cable for >10kA@20T
- Develop Bi-2212 cable for >10kA@20T
- Test and characterize the cables

These cables can then be directly used for an HTS dipole (2 versions).

Effort shared by 2 geographical poles Europe and US

This will be a “fly or bust” effort: if we cannot make a viable cable out of HTS we will probably have a hard time getting a 20T HE-LHC

EuCARD2 : the magnet

The EuCARD 2 magnet program:

Construct 5 T HTS magnets

- Using a Bi-2212 cable (probably in the USA)
- Using a YBCO cable (probably in Europe)

Pull all experience from NED, EuCARD, LARP, LBNL, FNAL, BNL, etc together and build the 2 magnets.

Test the magnets in stand-alone: The YBCO magnet is to be tested at LASA (the USA has >3 stations available)

This will be a “fly or bust” effort: if we cannot make a viable dipole magnet out of HTS we will probably have a hard time getting a 20T HE-LHC.

Once the magnet works in standalone mode other accelerator applications will immediately be attracted to this type of magnet.

EuCARD2 : the magnet as an insert

The successful magnet(s) will be modified into a smaller structure (no yoke) to be tested as an insert in a high field large aperture magnet (the outsert).

The possible candidate outserts are:

- Fresca2 at CERN 13 T – 15 T in a 100 mm bore (under construction)
- LD1 at LBNL 15 T in a 150 mm x 100 mm bore (planned)
- EDIPO (PSI-CCRP) 12.5 T in a 140 mm x 91 mm bore (operational)

This test should bring us to a real 20 T range dipole

conclusions

The NED, EuCARD and EuCARD2 HFM projects are a logical chain of projects leading from 8T Nb-Ti magnets to 15 T Nb_3Sn magnets and after that to 20 T HTS-Nb_3Sn magnets.

We have to watch out not to try and jump stages as history has shown us that SC magnet development is a road full of holes and bumps.

The EuCARD2 stage will tell us whether we got close or we still have to interject additional development stages.

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