NED Status Report

Arnaud Devred
CEA/DSM/DAPNIA/SACM
& CERN/AT/MCS

CARE General Meeting
LNF
17 November 2006

CARE/NED JRA

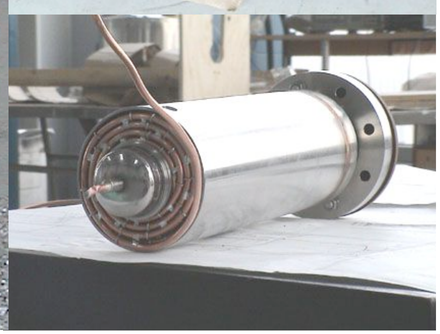
- The NED Activity is articulated around four Work Packages and one Working Group
  1. Management & Communication (M&C),
  2. Thermal Studies and Quench Protection (TSQP),
  3. Conductor Development (CD),
  4. Insulation Development and Implementation (IDI),
  5. Magnet Design and Optimization (MDO) Working Group (extension of scope).
- It involves 7 institutes (8 laboratories)
- Total budget: ~2 M€; EU grant: 979 k€.
- It was launched in January 2004 and was expected to last 3 years.

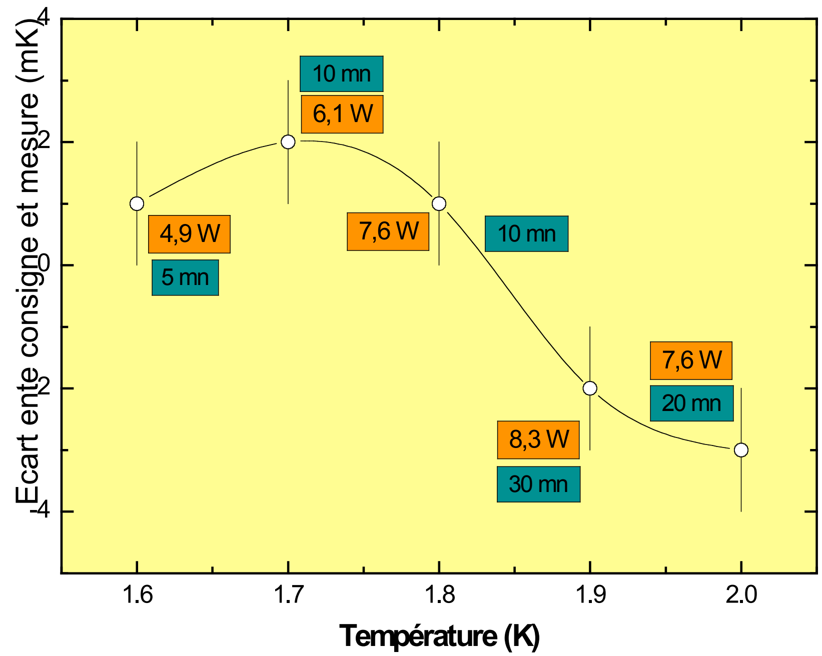
NED/TSQP Work Package

- The TSQ Work Package includes two main Tasks
  - development and operation of a test facility to investigate and measure heat transfer to helium through conductor insulation (CEA and WUT; Task Leader: B. Baudouy, CEA),
  - quench protection computation (INFN-Mi; Task Leader: G. Volpini; completed).
- Two complementary efforts, initiated by NED, are now gaining momentum and starting a life of their own
  - beam loss/energy deposition/temperature margin computations (INFN-MI and CERN; *see F. Broggi's highlight talk),*
  - validation of CEA heat transfer measurements (CERN; leader: D. Richter).

Heat Transfer Measurement Task

- The He-II cryostat manufactured under WUT supervision was successfully commissioned at CEA last month (temperature stability of ~1 mK over 1 hour).
- Facility exploitation to measure heat transfer coefficient can now begin.

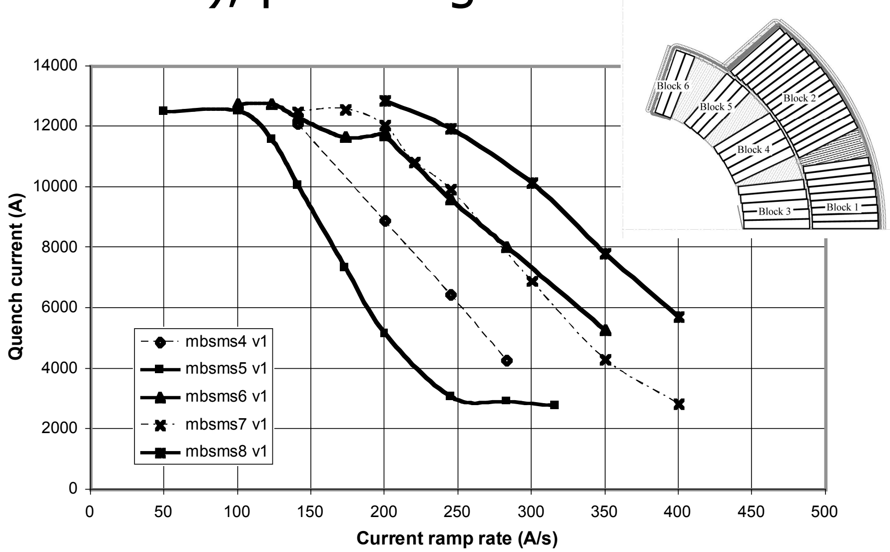


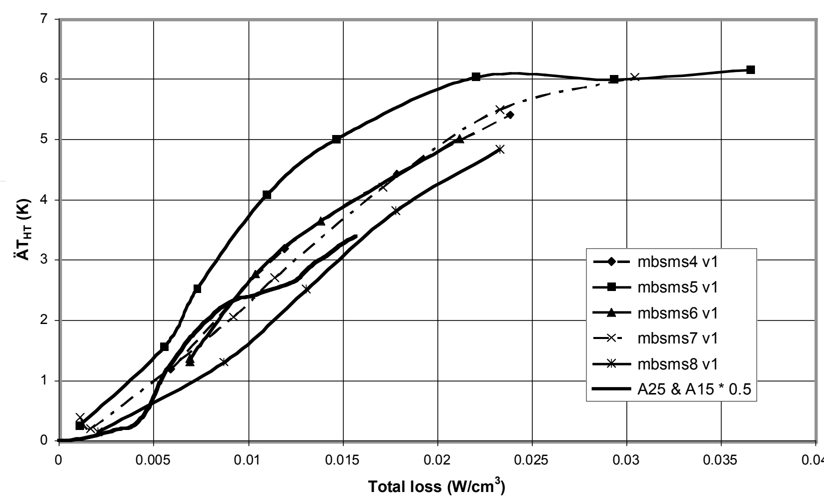


(Courtesy B. Baudouy, CEA)

Validation of CEA HT Measurement (1/2)

- In parallel, D. Richter (CERN) has reanalyzed ramp-rate data from a series of short LHC dipole magnet models to extract an effective heat transfer coefficient from heated coil to superfluid helium.
- The results compare favorably with measurements performed at CEA more than 10 years ago (on samples relying on similar insulation scheme), providing that the heat transfer only occur on one coil side.

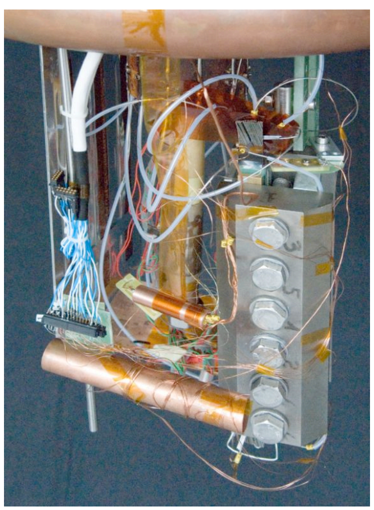


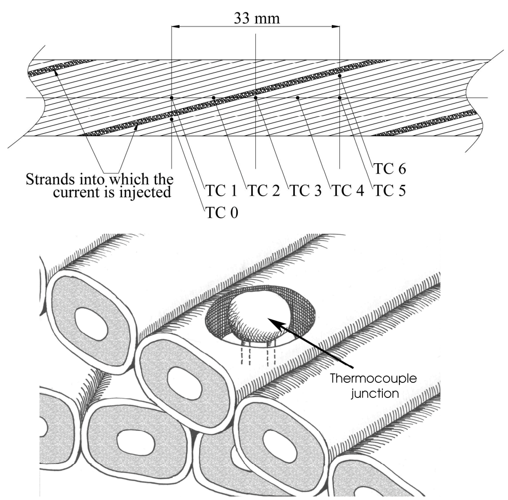


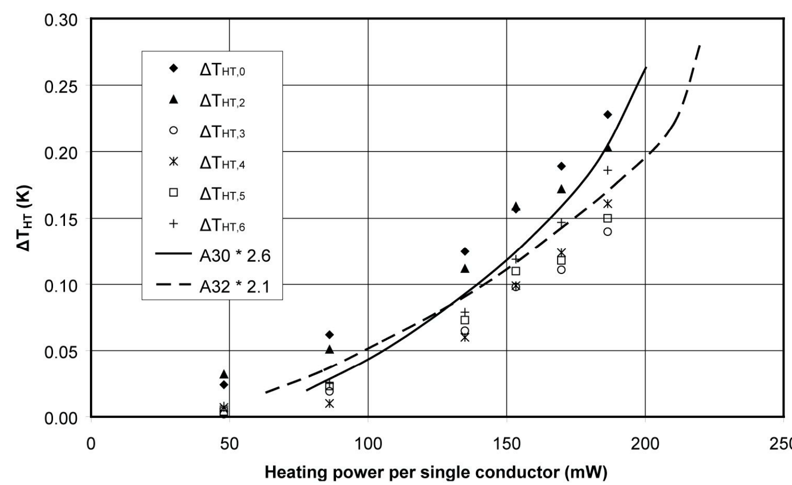
(Courtesy D. Richter, CERN)

Validation of CEA HT Measurement (2/2)

- D. Richter also performed *in situ* measurements on a coil section cut from an LHC dipole magnet coil taken out of production line.
- He relied on interstrand resistances to heat up the conductors and thermo couples to measure their temperatures.
- The measured heat transfer coefficient is 1.4 to 1.7 times higher than the one measured at CEA; more investigations are needed.



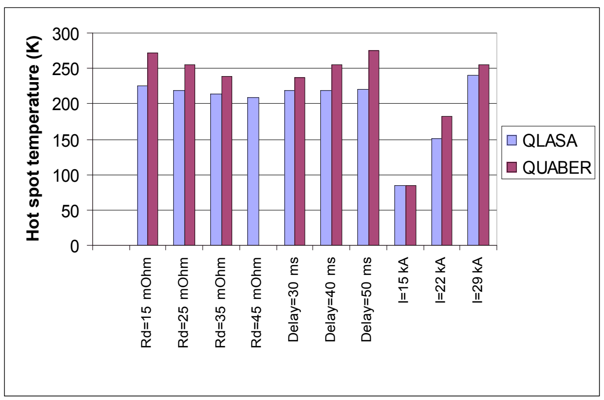


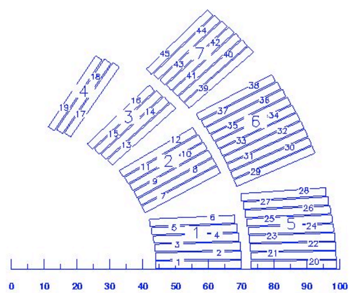


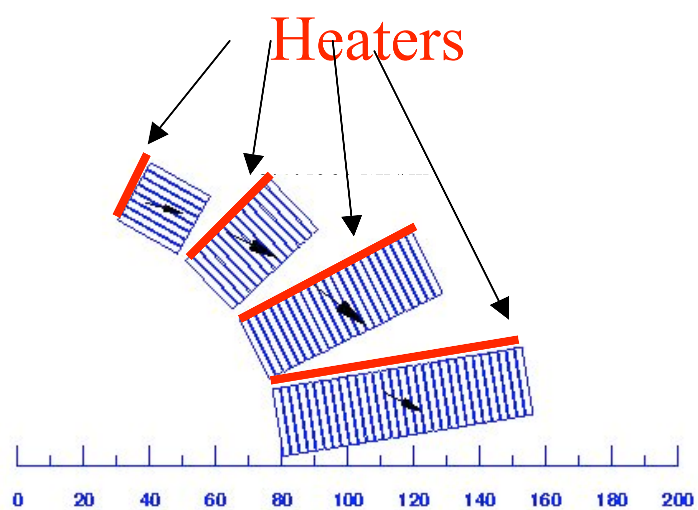
(Courtesy D. Richter, CERN)

NED Quench Computation Task

- Task was completed in early 2006 and a final report has been issued.
- Computations have been carried out for 1-m, 5-m, and 10-m long, 88-mm-aperture cosθ, layer design and 5-m-long, 160-mm-aperture, cosθ, slot design.







Simulation results for 10-m-long model
(Courtesy M. Sorbi, INFN-Mi)

- Both designs can be protected, using active quench protection heaters.

NED/CD Work Package

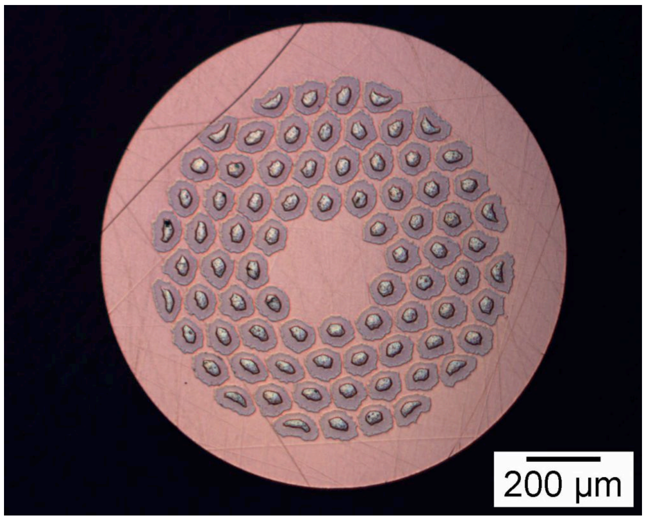
- The CD Work Package includes two main Tasks
  - – conductor development
    (two industrial contracts under CERN supervision: Alstom/MSA, France and SMI, The Netherlands; Task Leader: L. Oberli),
  - – conductor characterization
    (CEA, INFN-Ge, INFN-Mi, and TEU; Task Leader: A. den Ouden, TEU),
- It is the core of the Program and absorbs ~70% of the EU funding.
- It has been complemented by INFN-Ge and CERN through the development a FE wire model to simulate cabling effects *(see S. Farinon's highlight talk).*

NED/CD Work Package

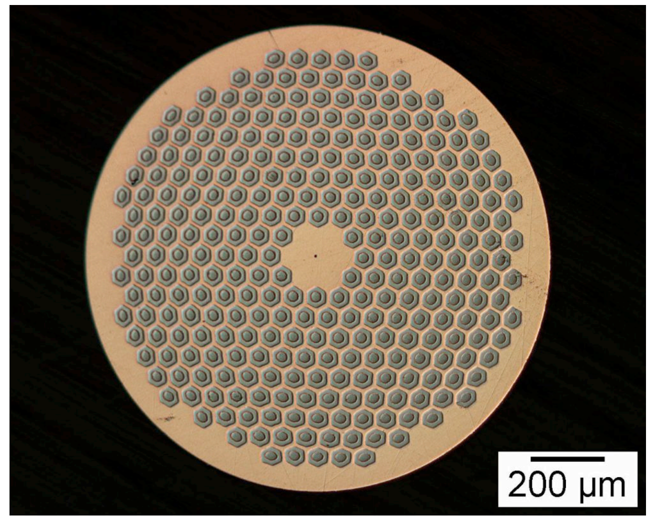
- The CD Work Package includes two main Tasks
  - conductor development
    (two industrial contracts under CERN supervision: Alstom/MSA, France and SMI, The Netherlands; Task Leader: L. Oberli),
  - conductor characterization
    (CEA, INFN-Ge, INFN-Mi, and TEU; Task Leader: A. den Ouden, TEU),
- It is the core of the Program and absorbs ~70% of the EU funding.
- It has been complemented by INFN-Ge and CERN through the development a FE wire model to simulate cabling effects *(see S. Farinon's highlight talk).*

Conductor Development Task

- The two industrial subcontractors developing NED conductors have achieved significant milestones *(see L. Oberli's highlight talk).*



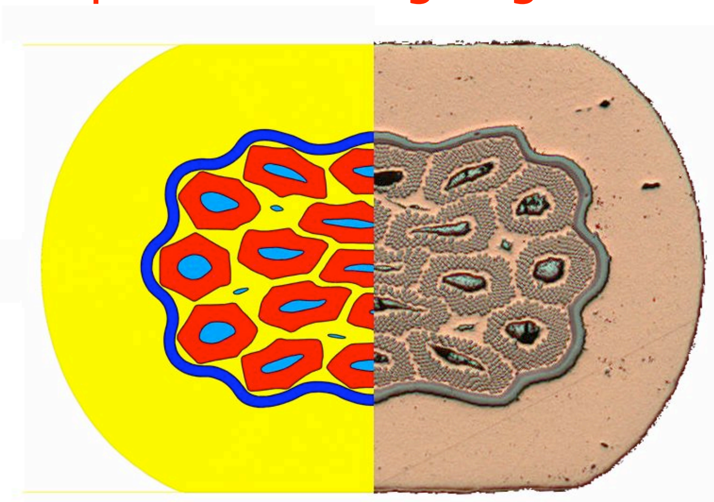
Alstom/NED
(workability program milestone)
1.25 mm ; 78x85 μm sub-element
740 A (~1500 A/mm^2)
@4.2 K & 12T
(measured at CERN & INFN-Mi)

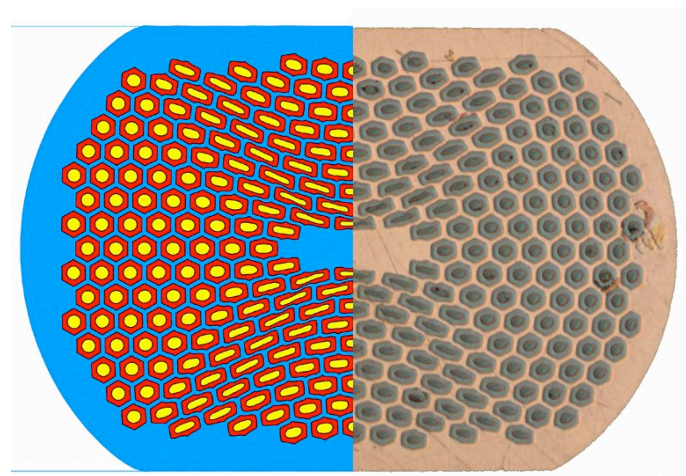


SMI/NED
(step II iteration)
1.26 mm ; 288 x 50 μm tube
1400 A (~2500 A/mm^2)
@4.2 K & 12T
(measured at TEU & INFN-Mi)

FE Wire Model

- Stefania Farinon (INFN-Ge) has developed an (ANSYS®-based) mechanical model to compute (and, thereby, predict) the sensitivity of un-reacted, NED-type wires to transverse loading.
- This provides a unique tool to compare and optimize billet layouts with respect to cabling degradation.





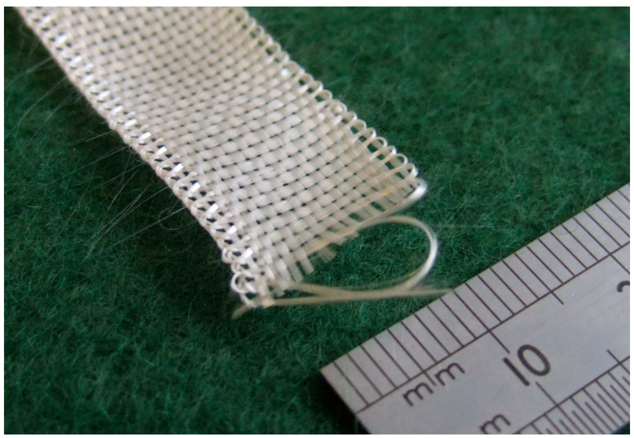
Side-by-side comparisons of computed and observed deformations of un-reacted "internal tin" (left) and "PIT" (right) wires (Courtesy S. Farinon, INFN-Ge)

NED/IDI Work Package

- The IDI Work Package includes two main Tasks
  - studies on “conventional” insulation systems relying on ceramic or glass fiber tape and vacuum-impregnation by resin (CCLRC/RAL; Task Leader: S. Canfer),
  - studies on “innovative” insulation systems relying on pre-impregnated fiber tapes and eliminating the need for a vacuum impregnation
    (CEA; Task Leader: F. Rondeaux).

Conventional Insulation Task

- RAL has received 1 km of polyimide-sized S2 glass fiber tape from JPS, NC and is presently carrying out final qualification tests.

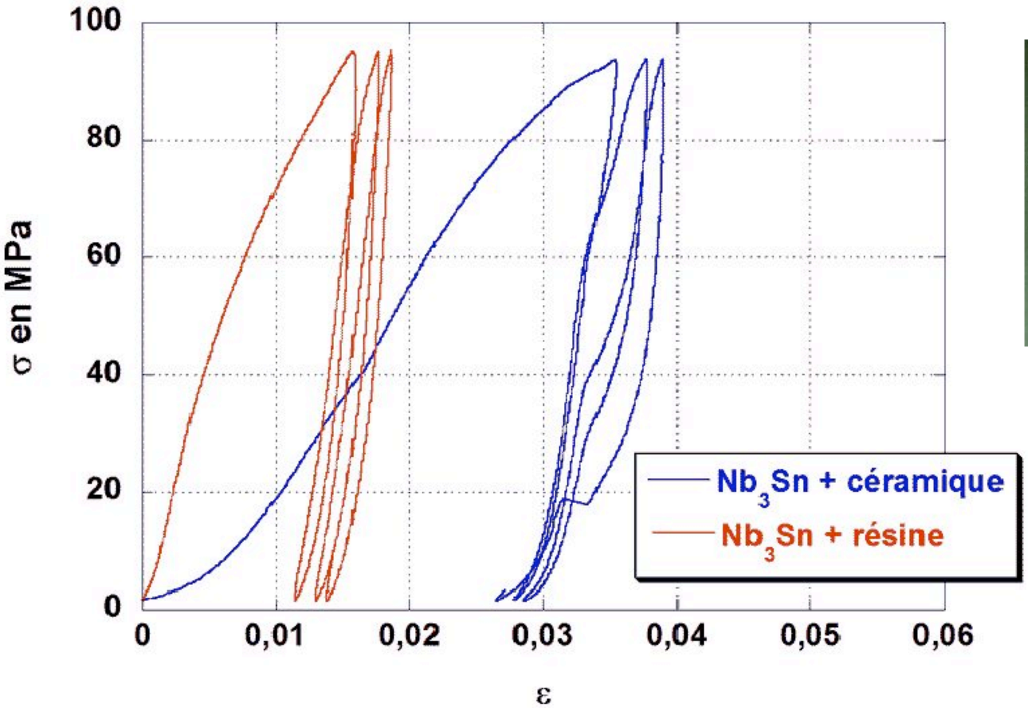


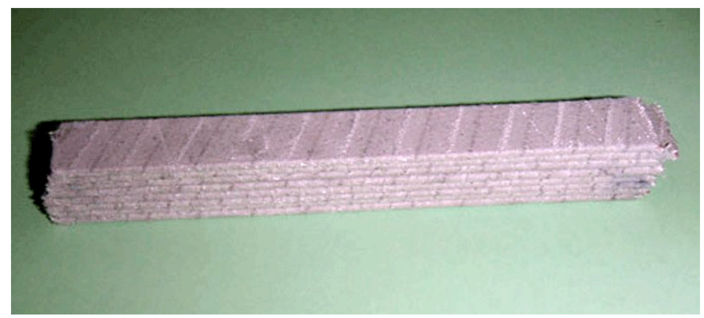
Polyimide-sized S2 glass fiber tape
(Courtesy S. Canfer, CCLRC/RAL)

- It has started investigations on radiation-hard cyanate esters to replace epoxy resin for vacuum impregnation.
- It is developing an experimental set up to characterize turn-to-turn bonding in magnet coils.

Innovative Insulation Task

- CEA has launched a campaign to study the influence of the application of a pre-compression during heat treatment, so as to increase ceramic density and reduce insulation thickness.
- It should also help to eliminate large deformation measured on virgin conductor stack upon first loading and improve mechanical robustness.



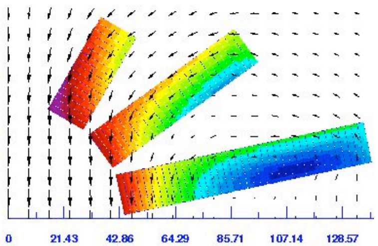


Stress-strain curve measured on conductor stack (Courtesy F. Rondeaux & P. Fourcade, CEA)

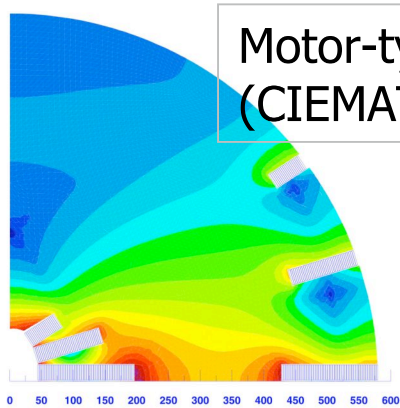
NED/MDO Working Group

- The Magnet Design and Optimization (MDO) Working Group is made up of representatives from CCLRC, CEA, CERN and CIEMAT (Chairman: F. Toral, CIEMAT).
- The Working Group has completed its comparison of selected 2D magnetic configurations.
- In parallel, CERN has completed its optimization of 2D 88-mm-aperture, cosθ, layer magnetic design (Reference Design V2) and CCLRC/RAL has undertaken a 2D mechanical design.

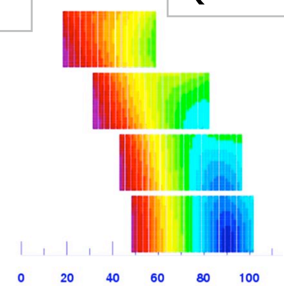
2D Magnetic Design Comparison (1/2)



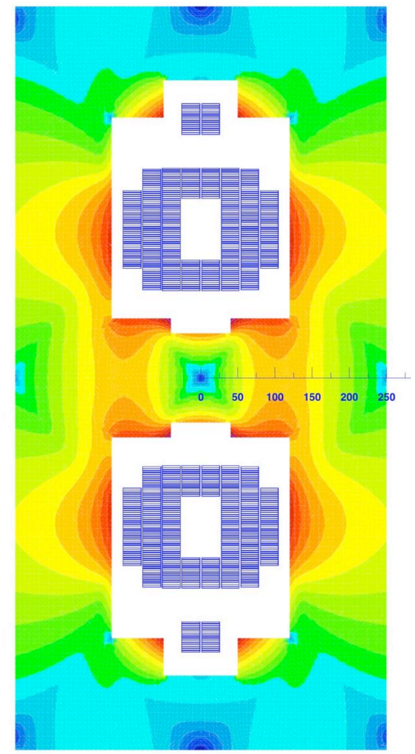
Cosθ slot
(CERN)



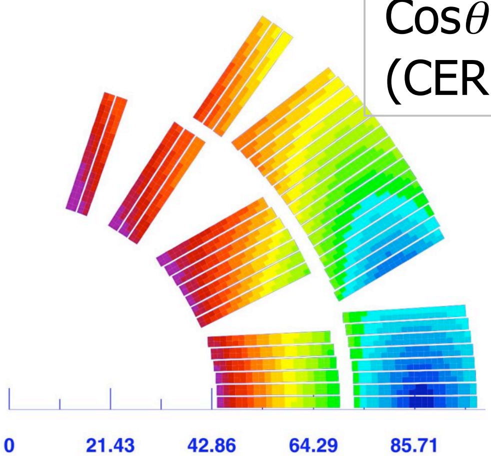
Motor-type
(CIEMAT)



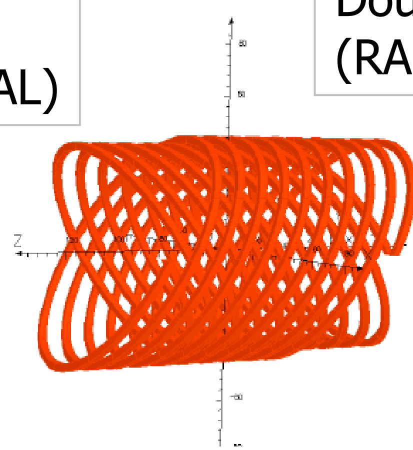
Ellipse-type
(CEA/Saclay)



Common coil
(CIEMAT)



Cosθ layer
(CERN & RAL)



Double helix
(RAL)

NED Magnet Zoo
(Courtesy F. Toral, CIEMAT)

2D Magnetic Design Comparison (2/2)

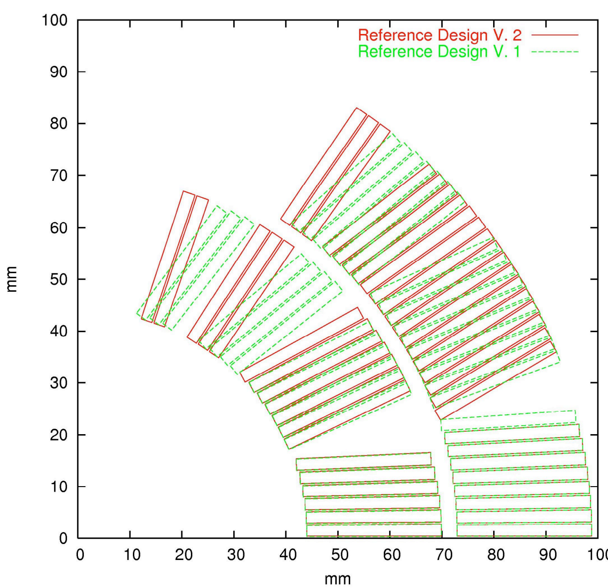
- For a 88-mm aperture, the comparison supports the choice made earlier of the cosθ, layer design as a baseline.

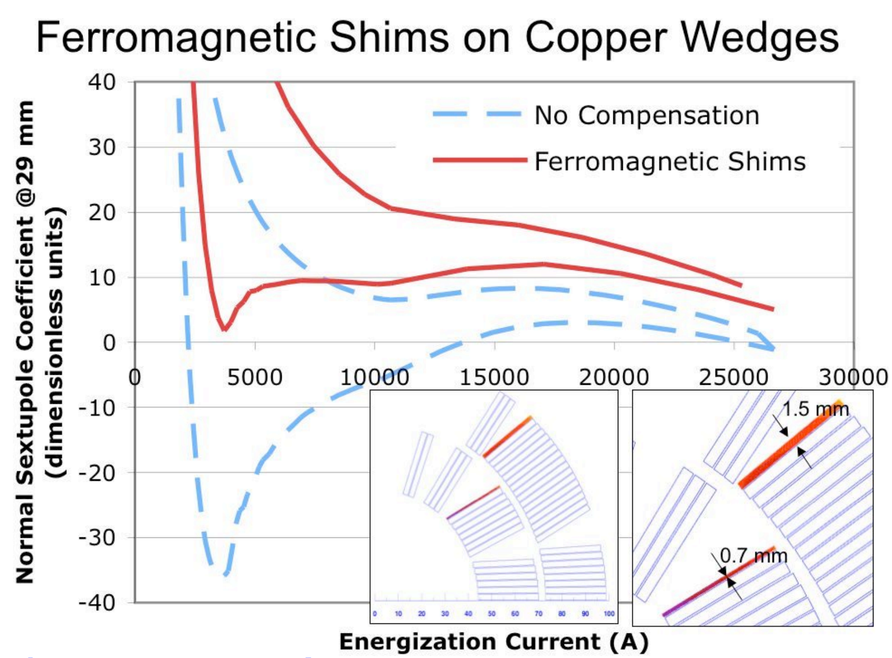
Magnet type	Layered cos -θ	Ellipse	Slotted motor	Slotted cos -θ	Common coil	Toroidal motor -type	
Area of bare conductors/aperture	10647	16761	10190	8596	11762	31668	mm^2
Area of insulated conductors/aperture	12711	20165	12283	10333	14140	38069	mm^2
Number of strands per aperture	7200	11856	7208	6080	8320	22400	
Outer iron yoke radius	475	500	450	450	500/250	450	mm
Current	25939	20243	23550	28950	27300	26700	A
Margin on load line	9.44	10	9.978	10.060	10.073	9.994	%
Bore field	13.05	13.54	12.928	12.743	12.596	12.707	T
Peak field	13.46	13.974	13.394	13.266	13.414	13.465	T
Peak field /bore field	1.031	1.032	1.036	1.041	1.065	1.060	
Peak field for 0% on load line	15.01	15.49	14.879	14.749	14.917	14.960	T
Magnetic field quality							
b3	0.004	0.136	-0.018	-0.099	0.020	-1.931	10^{-4} units
b5	-0.022	0.2635	-0.012	-0.009	-0.181	-0.045	10^{-4} units
b7	0.024	0.661	-0.007	-0.378	8.895	0.072	10^{-4} units
b9 -- *a2* (common coil)	0.871	0.247	-3.857	-7.572	-0.448	-3.785	10^{-4} units
b11 -- *a4* (common coil)	2.354	-0.007	-3.001	-0.499	2.714	-1.694	10^{-4} units
Engineering current density	371.02	313.2	406.472	425.860	401.589	392.760	A/mm^2
Self inductance /aperture /unit length	4.373	10.71	5.869	3.112	5.662	8.380	mH/m
Stored energy /aperture / unit length	1.471	2.19	1.628	1.304	2.111	2.987	MJ/m
Stray magnetic field							
- at 50 mm of the outer iron radius	0.03	0.06	0.096	0.034	0.908	1.781	T
- at 1 m away from the magnet center	0.006	0.015	0.018	0.006	0.072	0.133	T
Lorentz forces							
- *Fx* per side of aperture	13.37	19	13.894	12.072	13.049	11.198	MN/m
- *Fy* per quadrant	-3.233	-3.54	-3.062	-2.846	-0.210	-3.004	MN/m
- Maximum accumulated membrane stress perpendicular to the broad side of the cable	125.2	107	118.691	39.606	71.764	89.373	MPa
- Maximum accumulated membrane stress parallel to the broad side of the cable	101.62	65	126.390	111.984	110.281	115.231	MPa

(Courtesy F. Toral, CIEMAT)

Reference Design V2

- CERN has completed its 2D electromagnetic optimization of baseline, 88-mm-aperture, cosθ layer design with respect to
  - – conductor geometry,
  - – iron shape (to reduce saturation effects),
  - – ferromagnetic shims (to compensate magnetization effects).

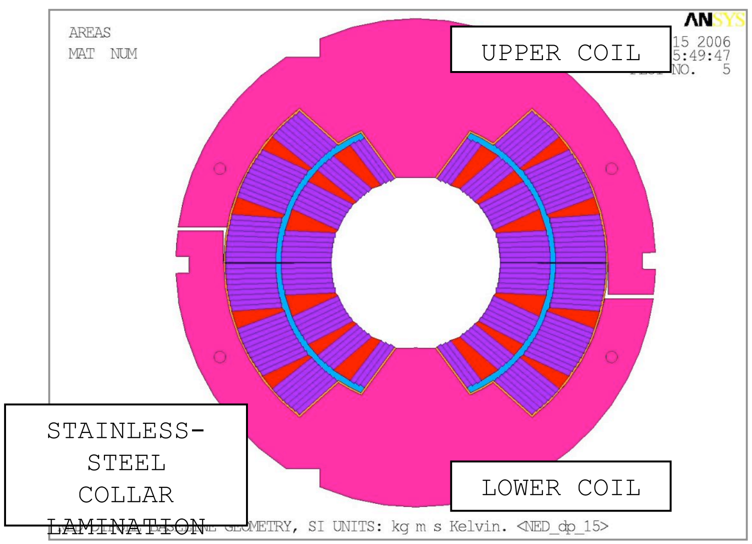


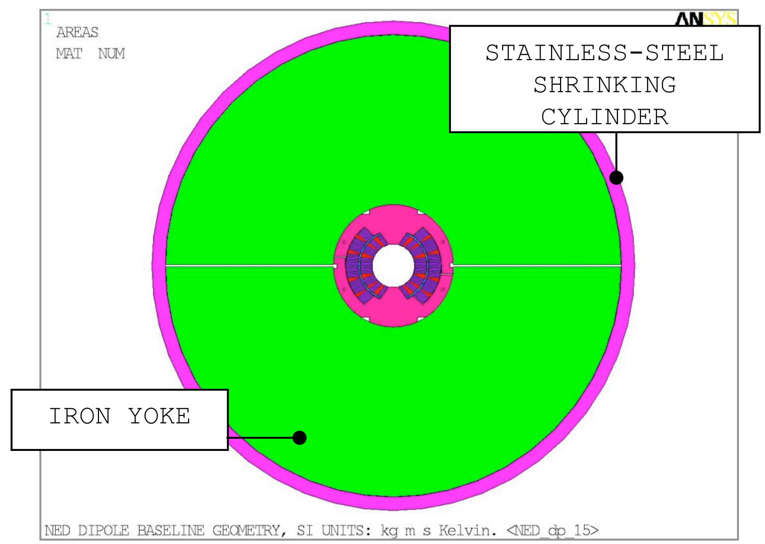


(Courtesy N. Schwerg, CERN)

2D Mechanical Design

- CCLRC/RAL is pursuing its development of a comprehensive (ANSYS®-based) mechanical model of baseline, 88-mm-aperture, cosθ layer design throughout the various steps of manufacturing, cooldown and energization.





(Courtesy P. Loveridge, CCLRC/RAL)

Preparing for NED Phase II

- Most Tasks of the present NED Activity are expected to be completed during the first semester of 2007.
- By then (next Summer?), we should have: 4 Alstom/MSA and 2 SMI cable UL's, a conventional insulation system and a conceptual design.
- The next step would naturally be to build a couple of magnet models.
- Following the recommendation issued by ESGARD last May, the NED partners have investigated the possibility of maintaining the collaboration so as to carry out the detailed design, manufacture and test of NED magnets on internal funding.
- This led to the elaboration of a tentative Program and a preliminary cost estimate, that was reported to ESGARD in September.

Tentative NED Phase II Program

- The proposed NED Phase II Program is to build by 2009 one dipole magnet model with Alstom/MSA cable and one with SMI cable, relying on the cosθ, layer design and the conventional insulation system.
- The NED Phase II proposal is articulated around 3 main Work Packages

  WP1: Design and Integration (01/07-12/09),

  WP2: Supporting R&D and Demonstrators (01/07-06/08),

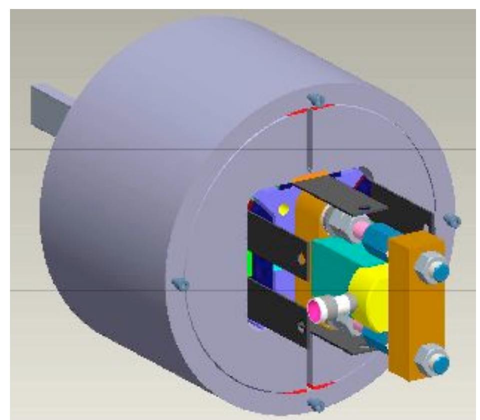
  WP3: Model Magnet Manufacturing and Test (07/07-12/09).
- WP1&2 call for paper studies and small-scale models that only requires limited investments; they need to be be launched right away.
- WP3 calls for significant material costs and human resources and its launching may be differed by 6 to 9 months.

NED Demonstrators

- The goal of WP2 is to build and test pairs of short Racetrack-type coils to validate, with a fast turnaround time, cable design, insulation choice and optimize various mechanical features.
- It is inspired from the successful "Short Model Coil" program carried out at LBNL and will be developed in collaboration with US-LARP.
- First results are expected by the end of 2007.

30 cm

(Courtesy P. Ferracin, LBNL)



(Courtesy H. Félice, CEA)

NED Manufacturing and Test

- WP3 is articulated around 3 main Tasks
  - 3.1: Pole manufacturing

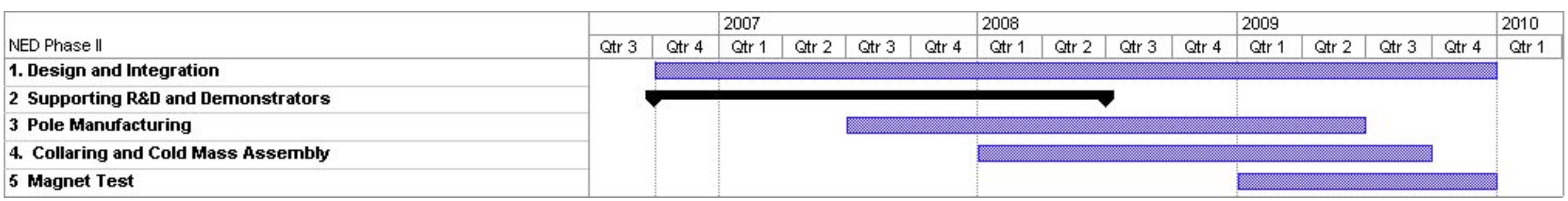
    detailed design and manufacturing of 10 poles (4 dummy, 4 Alstom/MSA, 2 SMI + possible extension to 4 Luvata)
  - 3.2 Collaring and cold mass assembly

    manufacture and test of 2 collaring and 1 yoking/shell welding model, collaring and yoking/shell welding of 2 NED magnets (1 Alstom and 1 SMI + possible extension to 1 Luvata)
  - 3.3: magnet test

    adaptation of CERN FRESCA facility to high current (29 kA at 4.2 K, 32 ka at 1.9 K), large stored energy (2.3 MJ) and heavy load (7.5 t) operations and test of 2 to 3 NED magnets.

NED Phase II Budget & Schedule

Work Package/Task	k€	Staff.month
WP1: Design and Integration	n/a	72
WP2: Supporting R&D and Demonstrators	350*	72
WP3.1: Pole manufacturing (x10)	550	164
WP3.2: Collaring & Cold Mass Assembly (x2)	450	72
WP3.3: Magnet Test (x2)	150	30
Total	1500	410



Conclusion

- Significant progress have been achieved for most Tasks, and we can prepare the Activity landing.
- Foreseen end dates of various Tasks are
  - Task 2.2 (Heat Transfer Measurements): 31 September 2007
  - Task 2.3 (Quench Computation): completed
  - Task 3.2 (Preliminary Design): completed
  - Task 3.3 (Conductor Specifications): completed
  - Task 3.4&5 (Wire Development & Characterization): 30 June 2007
  - Task 3.6&7 (Cable Development & Characterization): 30 June 2007
  - Task 4.2 (Insulation Specifications): completed
  - Task 4.3 (Conventional Insulation): 31 December 2006
  - Task 4.4 (Innovative Insulation): 31 March 2007
- Preparation is ongoing for NED Phase II.