Next European Dipole (NED) Status Report

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on behalf of the NED Collaboration

CARE General Meeting
DESY
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What is NED?

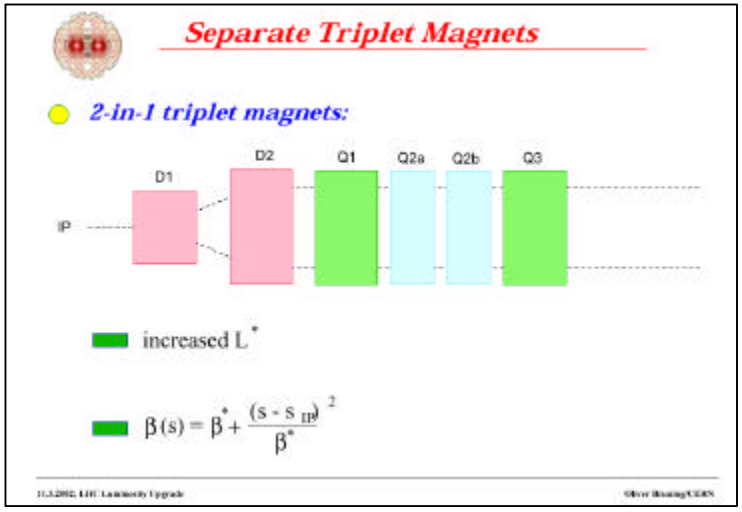
- NED is a Joint Research Activity (JRA) aimed at integrating high-field, superconducting accelerator magnet R&D in Europe so as to get ready for LHC upgrade and beyond.
- It is also meant to bring Nb_3Sn superconductor technology to maturity and to help European laboratory and European industry to bridge the gap with their American counterpart.
- The NED/JRA is tightly connected to the HHH/AMT Work Package.

NED Scientific Goals

- The scientific goals of the initial NED proposal were
  - – to revisit magnetic and mechanical designs of accelerator magnet coils made from brittle materials,
  - – to address coil cooling issues under high beam losses,
  - – to promote high performance Nb_3Sn wire development in collaboration with European industry (aiming at a non-Cu J_C of 1500 A/mm^2 at 4.2 K and 15 T),
  - – to improve mechanical robustness and radiation hardness of Nb_3Sn conductor insulation,
  - – to design, build, and test a large aperture (88 mm), high field (15 T conductor peak field) dipole magnet model that pushes the technology well beyond present LHC limits.

NED Applications

- The proposed magnet model serves two main purposes



— (1) getting ready for LHC IR upgrade, *e.g.*, by studying the feasibility of scenarios where the beam-separation dipole magnets are localized in front of the final-focusing quadrupole magnets,

— (2) upgrade of CERN/FRESCA cable test facility (presently limited to a 10-T background field) to offer unique services to the entire applied superconductivity community.

- Also, it is complementary to the US-LHC Accelerator Research Program (LARP), whose primary focus is on quadrupole magnets.

EU-Led Peer Review

- The peer-reviewers called up by the EU in July 2003 endorsed rather strongly the proposal, wrote very encouraging words in their report and initially recommended a full funding.
- However, in a final round of cuts, they received the wrong information that CERN was already supporting such a program and ended up suggesting to cap the EU contribution at 25% of the requested funding (*i.e.*, ~1 M€ instead of ~4 M€).
- It turns out that the only Nb_3Sn program supported by CERN is a collaboration with Twente University (The Netherlands), that was started in 1998 (with a different and less ambitious objective), and that is suffering from heavy delays (primarily because of lack of resources).

NED Program

- To cope with the dramatic limitation on EU funding, the NED Program was divided into two phases
  - Phase I groups together all the tasks related to Nb_3Sn conductor development and characterization, and includes some limited studies on conductor insulation and magnet design,
  - Phase II groups together all the tasks related to the detailed design, manufacturing and testing of the dipole magnet model.
- Phase I has been approved as part of the CARE project (~13 staff.year over 3 years; total cost: ~2 M€; EU grant: 979 k€).
- The NED collaborators are still struggling to find the funding necessary to carry out Phase II (~22 staff.year, material costs: ~1.2 M€).

NED Collaborators

- At present, eight institutes are collaborating to NED
  - CCLRC/RAL (UK),
  - CEA/DSM/DAPNIA (France),
  - CERN/AT (International),
  - CIEMAT (Spain),
  - INFN/Genova (INFN-Ge) and INFN/Milan (INFN-Mi, Italy),
  - Twente University (TEU, The Netherlands),
  - Wroclaw University of Technology (WUT, Poland).

Steering Committee

- The oversight of the NED/JRA is ensured by a Steering Committee (SC) made up of
  - E. Baynham (CCLRC/RAL),
  - A. Devred, Chairman (CEA & CERN),
  - D. Leroy (CERN),
  - A. den Ouden, Secretary (TEU),
  - J.M. Rifflet (CEA),
  - G. Volpini (INFN-Mi).
- The SC meets every three months, usually at CERN to limit travel costs; the first four meetings were held on 8 January (CERN), 25 March (CERN), 8 July (CERN) and 29 October (CEA/Saclay); the next meeting is scheduled for 20 January 2005 (CERN).

External Scientific Advisory Committee

- The JRA Coordinator is helped by an External Scientific Advisory Committee (ESAC) made up of
  - J.L. Duchateau (CEA; link with ITER Program),
  - H.H.J. ten Kate (CERN & TEU),
  - P. Lebrun (CERN),
  - L. Rossi (CERN; link with HHH/AMT Network Work Package),
  - R.M. Scanlan (retired from LBNL; link with US National Program on Nb_3Sn wire),
  - J.B. Strait, Chairman (FNAL; link with US-LARP Program).
- The ESAC meets once a year; the first meeting was held on 24 March (at the end of HHH/AMT WAMS workshop), and the first report was issued on 29 April; the next meeting will be called in the Fall of 2005.

NED Phase I

- The Phase I of NED is articulated around four Work Packages and a 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.

M&C Work Package

- All information pertinent to NED are posted on a web page mastered by A. den Ouden (TEU; NED representative to the CARE Dissemination Board)
http://lt.tnw.utwente.nl/project.php?projectid=9
- A tree structure has been defined and will be implemented shortly into the CERN Engineering Data Management Service (EDMS); it will be used to approve, circulate, track and store documents.

NED Budget Request

JRA4	Participant (cost model)	Permanent Staff including indirect cost (Euros)	Additional Staff including indirect cost (Euros)	Durable Equipment including indirect cost (Euros)	Consumables and Prototyping including indirect cost (Euros)	Travel including indirect cost (Euros)	Expected costs including indirect cost (Euros)	Direct cost	Subcontract	Indirect cost	Requested funding (Euros)
1	CEA (FC)	358,116	41,667	0	92,500	24,000	516,283	0	0	516,283	45,000
10	INFN (AC)	0	15,000	0	25,750	7,000	47,750	39,792	0	7,958	47,750
11	TEU (FC)	128,887	0	0	37,500	3,000	169,387	108,637	0	60,750	70,785
15	WUT (AC)	0	6,500	0	4,500	2,000	13,000	10,833	0	2,167	13,000
17	CERN (AC)	0	0	0	350,000	0	350,000	350,000	350,000	0	350,000
20	CCLRC (FC)	274,000	0	0	33,300	16,500	323,800	163,967	0	159,833	26,250
	Grand total	**761,003**	**63,167**	**0**	**543,550**	**52,500**	**1,420,220**	**673,229**	**350,000**	**746,991**	**552,785**

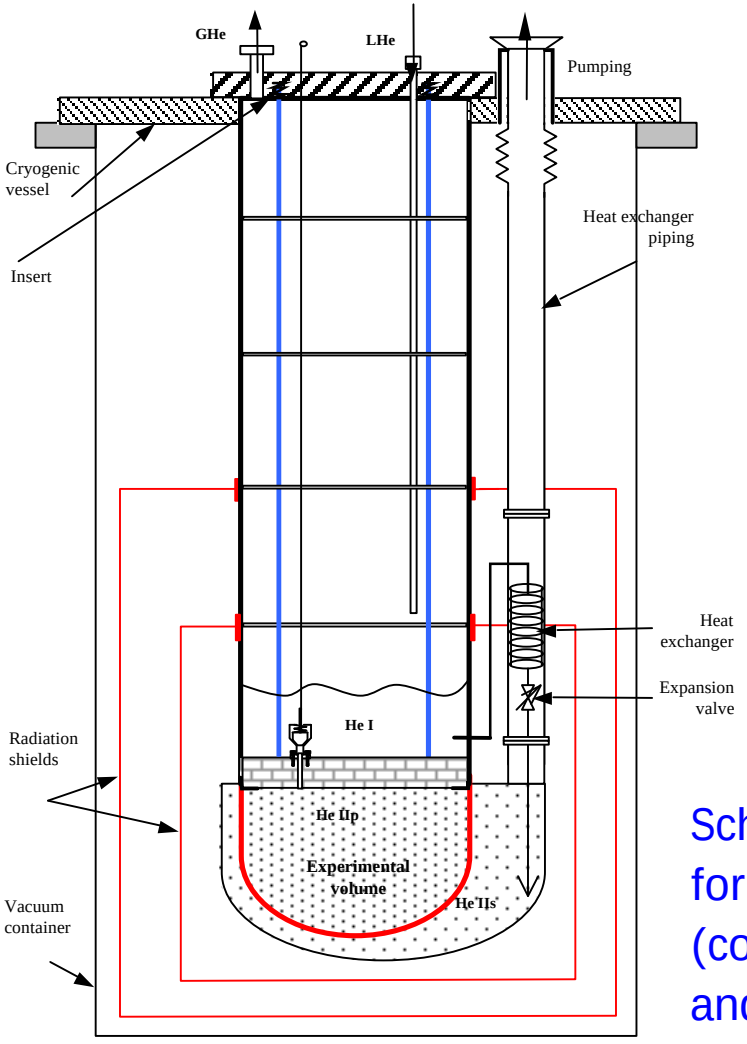
NED Papers

#	CARE document type and number	Title	Author(s) and Lab(s)	Reference	Date
1	N/A	High field accelerator magnets beyond LHC	A. Devred (CEA&CERN)	*Proceedings of the 2003 IEEE Particle Accelerator Conference*, IEEE Catalogue 03CH37423, pp. 146–150, 2003	2003
2	N/A	High field accelerator magnet R&D in Europe	A. Devred (CEA&CERN), D.E. Baynham (CCLRC), L. Bottura (CERN), M. Chorowski (WUT), P. Fabbricatore (INFN-Ge), D. Leroy (CERN), A. den Ouden (TEU), J. M. Rifflet (CEA), L. Rossi, O. Vincent-Viry (CERN), G.Volpini (INFN-Mi)	*IEEE Trans. Appl. Supercond.*, Vol. 14 No. 2, pp. 339-344, 2004	2004
3	Conf-04-005	Performance limits and IR design of a possible LHC luminosity upgrade based on NbTi SC magnet technology	F. Ruggiero, O. BrŸning, R. Ostojic, L. Rossi, W. Scandale, T. Taylor (CERN), A. Devred (CEA&CERN)	*Proceedings of the 2004 European Particle Accelerator Conference*, pp. 608-610, 2004	2004
4	TBD	Status of the Next European Dipole (NED) Activity of the Coordinated Accelerator Research in Europe (CARE) Project	A. Devred (CEA&CERN), B. Baudouy (CEA), D.E. Baynham (CCLRC), T. Boutboul (CERN), S. Canfer (CCLRC), M. Chorowski (WUT), P. Fabbricatore, S. Farinon (INFN-Ge), H. Félice (CEA), P. Fessia (CERN), J. Fydrich (WUT), M. Greco (INFN-Ge), J. Greenhalgh (CCLRC), D. Leroy (CERN), P. Loverige (CCLRC), F. Michel (CEA), L. R. Oberli (CERN), A. den Ouden (TEU), D. Pedrini (INFN-Mi, J. Polinski (WUT), V. Previtali (CERN), L. Quettier, J. M. Rifflet (CEA), J. Rochford (CCLRC), F. Rondeaux (CEA), S. Sanz (CIEMAT), S. Sgobba (CERN), M. Sorbi (INFN-Mi), F. Toral-Fernandez (CIEMAT), R. van Weelderen (CERN), P. Védrine (CEA), O. Vincent-Viry (CERN), G. Volpini (INFN-Mi)	To appear in the Proceedings of the Applied Superconductivity Conference, Jacksonville, FL, October 3–8, 2004	TBD
5	TBD	Future accelerator magnet needs	A. Devred (CEA&CERN), S. Gourlay (LBNL), A. Yamamoto (KEK)	To appear in the Proceedings of the Applied Superconductivity Conference, Jacksonville, FL, October 3–8, 2004	TBD

TSQP Work Package

- The TSQ Work Package includes two main Tasks
  - development and operation of a test facility to measure heat transfer to helium through conductor insulation (CEA and WUT),
  - quench protection computation (INFN-Mi).

Heat-Transfer Measurement Task

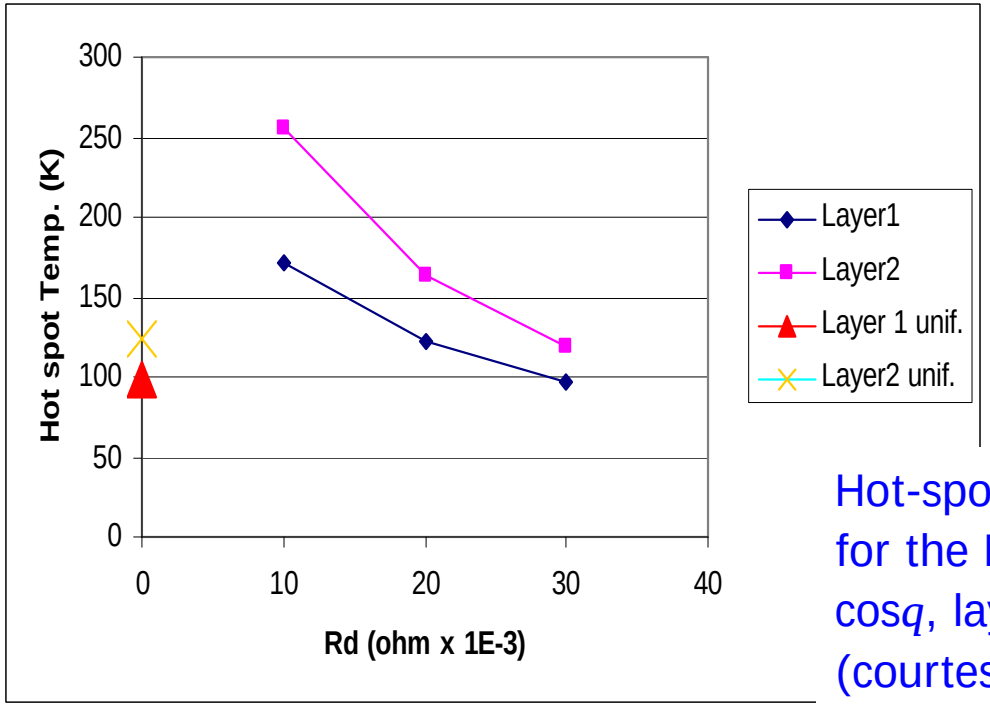


- CEA has designed a new pressurized, He-II, double-bath cryostat.
- The cryostat is being manufactured under WUT supervision and is scheduled for delivery to Saclay in the first quarter of 2005.

Schematic of double-bath cryostat for heat-transfer measurements (courtesy F. Michel, B. Baudouy and B. Hervieu, CEA)

Quench Protection Task

- INFN-Mi has completed a survey of thermal properties and is now undertaking systematic quench protection studies, starting from the 88-mm-aperture, cos$q$, layer design chosen as reference for NED.



Hot-spot temperature computations for the NED, 88-mm-aperture, cos$q$, layer baseline design (courtesy G. Volponi and M. Sorbi, INFN-Mi)

TSQP Planning

WBS #	Title	Original begin date (Annex 1)	Original end date (Annex 1)	Estimated Status	Revised end date
2.1	TSQP WP Coordination				
2.2	Heat Transfer Measurements				
2.2.1	Specifications	1 January 2004	31 March 2004	Completed	8 June 2004
2.2.2	Cryostat design and manufacturing	1 April 2004	31 Dec. 2004	Ongoing	On time
2.2.3	Heat exchanger manufacturing	1 April 2004	31 Dec. 2004	Ongoing	On time
2.2.4	Facility integration and commissioning	1 January 2005	31 March 2005	Not started	On time
2.2.5	Measurements and data analysis	1 April 2005	31 Dec. 2006	Not started	On time
2.3	Quench protection computation	1 April 2004	30 June 2005	Ongoing	On time

- Collaboration between CEA and WUT is off to a good start -enthusiasm of team compensates lack of human resources.
- All tasks are on time!

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TSQP Milestones and Deliverables

WBS #	Title	Responsible Lab(s)	Due date in Annex 1	Status	Revised delivery date
2.2.4	Report on test facility commissioning (deliverable)	CEA and WUT	1 April 2005	Not started	On time
2.2.5	Interim report on measurements (milestone)	CEA	31 December 2005	Not started	On time
2.2.5	Final report on measurements (deliverable)	CEA	31 December 2006	Not started	On time
2.3	Interim report on quench protection computation (milestone)	INFN-Mi	31 December 2004	Ongoing	On time
2.3	Final report on quench protection computation (deliverable)	INFN-Mi	30 June 2005	Not started	On time

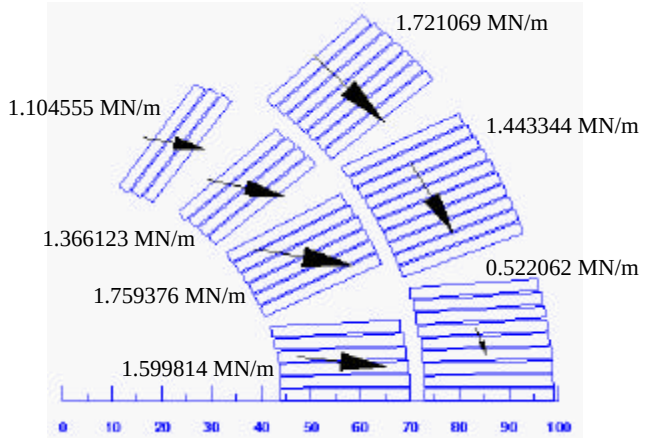
CD Work Package

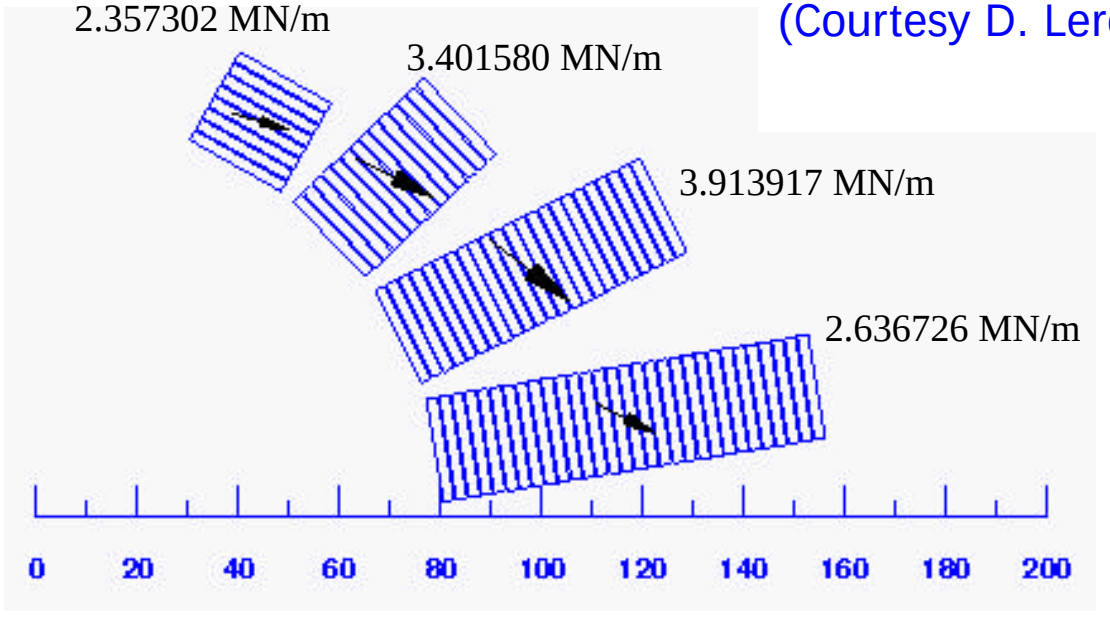
- The CD Work Package includes four main Tasks
  - – preliminary magnet design aimed at deriving meaningful conductor specifications (CERN),
  - – wire and cable development (under CERN supervision; through two industrial sub-contracts, investigating two different manufacturing processes: Enhanced Internal Tin and Powder in Tube),
  - – wire and cable characterization (CEA, INFN-Mi and INFN-Ge, TEU),
  - – mechanical FE analysis of cabling effects (INFN-Ge).

Preliminary Design Task (1/3)

- In order to derive meaningful conductor specifications, CERN has investigated two types of cos$q$, dipole magnet designs: a layer-type and a slot-type.
- The investigation was carried out for three apertures: 88 mm, 130 mm and 160 mm and aimed at a 13-to-15-T bore field.

Preliminary Design Task (2/3)





Examples of cos*q*, dipole magnet designs investigated by CERN: 88-mm-aperture, layer-type (top) and 160-mm-aperture, slot-type (bottom) (Courtesy D. Leroy and O. Vincent-Viry)

Preliminary Design Task (3/3)

- The preliminary design study led to define a strand of 1.25 mm diameter, with a non-Cu J_C of 1500 A/mm^2 at 4.2 K and 15 T, and a Cu-to-non-Cu ratio of 1.25 to 1 as the most suitable for NED.
- At 4.2 K, the study shows that the bore field stays around 14 T with a quench field of ~15 T on the conductor.
- Hence, the magnet should be operated at 1.9 K to reach bore fields higher than 15 T (note that the He-II operation may also be required to improve cooling under high beam losses).
- The 88-mm-aperture, cos$q$, layer design is chosen as the reference design.

NED Strand Characteristics

- The main NED strand characteristics are
  - diameter 1.250 mm,
  - effective filament diameter < 50 μm,
  - Cu-to-non-Cu ratio 1.25 ± 0.10,
  - filament twist pitch 30 mm,
  - non-Cu J_C 1500 A/mm^2 at 4.2 K and 15 T,
  - minimum critical current 1636 A at 12 T,
    818 A at 15 T,
  - *N*-value > 30 at 4.2 K and 15 T,
  - RRR (after heat treatment) > 200.
- It is also requested that the billet weight be higher than 50 kg.

NED Cable Characteristics

- Although the final cable dimensions will only be decided later on, the main cable parameters used in the reference, 88-mm-aperture, cos$q$ layer design are

– width	26 mm,
– mid-thickness	2.275 mm at 50 MPa,
– keystone angle	0.22 degrees,
– number of strands	40,
– minimum critical current	58880 A at 4.2 K and 12 T,
(with field normal to broad face)	29440 A at 4.2 K and 15 T,
– RRR (after heat treatment)	> 120,
– minimal cable unit length	> 145 m.

- The cable critical currents assume a cabling degradation of 10%.

Conductor Development Task (1/2)

- Following a market survey and a call for tender under CERN rules, two contracts for the production of a few hundred meters of cables have been awarded late September to
  - Alstom/MSA, France (Enhanced-Internal-Tin process),
  - SMI, the Netherlands (Powder-In-Tube process), with EAS, Germany as subcontractor.
- The contracts will be monitored by CERN and extend over a 2-year period.
- Discussions are are ongoing with OAS, who may join the program without receiving EU-funding.

Conductor Development Task (2/2)

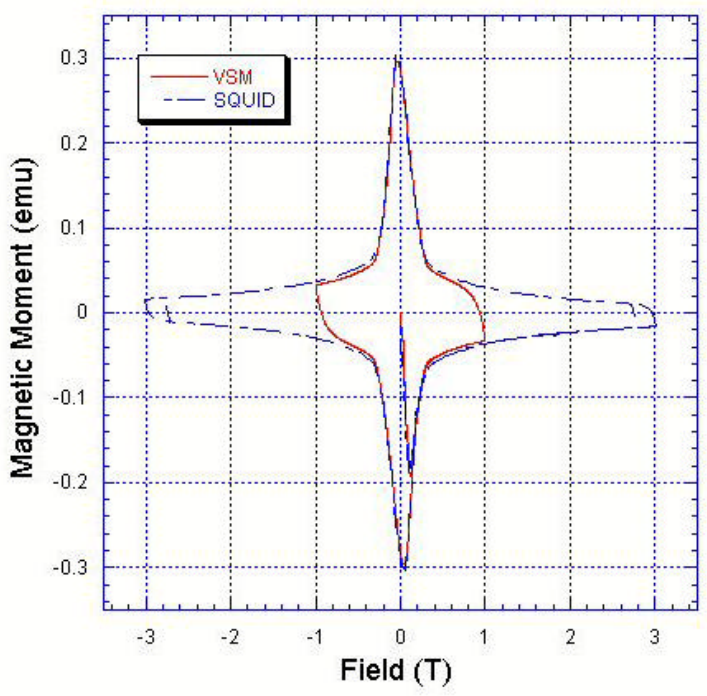
- We are somewhat disappointed that SMI and EAS have not formed a joint venture as they intended to in 2003.
- CERN has imposed two safeguards on the SMI contract
  - the R&D phase includes a 50 kg billet to demonstrate the ability of scaling up the process to a near-industrial production,
  - the financial loss in case of failure is capped to 30% of the total amount of the contract.
- In spite of the commercial risks, we are fully convinced that the potentials of the Powder-In-Tube process needs to be investigated further and weighted against the more conventional Internal-Tin process promoted by Alstom/MSA.

Conductor Characterization Task (1/2)

- Representatives of interested parties (CEA, CERN, INFN-Ge, INFN-Mi and TEU) have set up a Working Group on Conductor Characterization (WGCC), under the supervision of TEU.
- The WGCC is charged with the definition and development of standardized procedures to measure the critical current, magnetization and RRR of virgin, deformed and extracted strands and has the responsibility for certification of the measured data.
- Following the example of the VAMAS program, the WGCC has initiated a cross-calibration program of critical current test facilities, whose conclusions are due in June 2005.

Conductor Characterization Task (2/2)

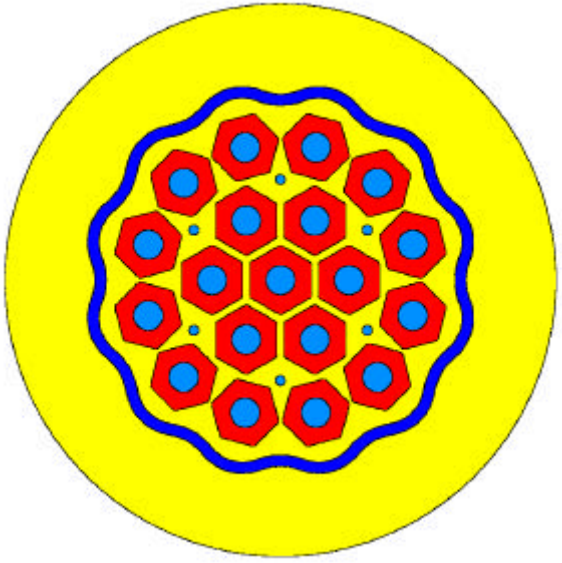
- Magnetization measurements will be performed under the supervision of INFN-Ge using a SQUID magnetometer and a Vibrating Sample Magnetometer (VSM).

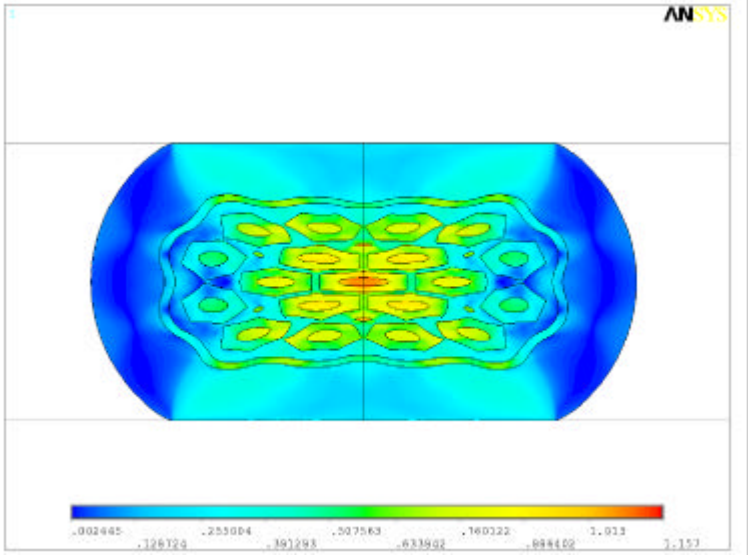


Exploratory magnetization measurements on a 5-mm-long Nb_3Sn wire sample exposed to a transverse field cycle (SQUID measurements are courtesy of C. Ferdeghini, INFM/Genova; VSM measurements are courtesy of U. Gambardella, INFN/Frascati)

Mechanical FE Analysis Task

- INFN-Gen is developing a mechanical FE model to simulate the effects of cabling on un-reacted, Nb-Sn wires and optimize their design.





Examples of mechanical FE model for an old “internal-tin” wire design and of Von Mises strain due to a diameter reduction of about 40% (courtesy S. Farinon, INFN-Ge)

CD Planning

WBS #	Title	Original begin date (Annex 1)	Original end date (Annex 1)	Estimated Status	Revised end date
3.1	CD WP Coordination				
3.2	Preliminary design	1 January 2004	31 Dec. 2004	90% complete	On time
3.3	Conductor specifications	1 April 2004	30 June 2004	Completed	On time
3.4	Wire development	1 July 2004	30 June 2006	Started	30 September 2006
3.5	Wire characterization	1 July 2004	30 June 2006	Ongoing	
3.5.1	Definition of procedures	1 January 2005	30 June 2005	Ongoing	On time
3.5.2	Ic measurements at CEA	1 July 2005	30 June 2006	Started	31 October 2006
3.5.3	Ic measurements at INFN/Mi	1 July 2005	30 June 2006	Started	31 October 2006
3.5.4	Ic measurements at TEU	1 July 2005	30 June 2006	Started	31 October 2006
3.5.5	Magnetization measurements at INFN/Ge	1 July 2005	30 June 2006	Started	31 October 2006
3.6	Cable development and manufacturing	1 July 2005	31 Dec. 2006	Not started	15 December 2006
3.7	Cable characterization	1 October 2005	31 Dec. 2006	Not started	On time

- Start date of 3.4 delayed by 3 months due to longer contract negotiations than anticipated.
- End date of 3.4 delayed accordingly.
- End date of 3.5 delayed to match that of 3.4.
- End dates of 3.6 and 3.5 not moved due to some built-in slack in initial program.

CD Milestones and Deliverables

WBS #	Title	Responsible Lab(s)	Due date in Annex 1	Status	Revised delivery date
3.2	Report on preliminary design (deliverable)	CERN	31 December 2004	Ongoing	On time
3.5	Conductor specifications (deliverable)	CERN	30 June 2004	Completed	On time
3.4	Progress report on wire development (milestone)	CERN	30 June 2005	Not started	31 December 2004 31 December 2005
3.4	Wire unit lengths (deliverable)	CERN	30 June 2006	Not started	30 September 2006
3.5	Interim report on wire characterization (milestone)	CEA, INFN/Ge, INFN/Mi, TEU	31 December 2005	Started	On time
3.5	Final report on wire characterization (deliverable)	CEA, INFN/Ge, INFN/Mi, TEU	30 June 2006	Not started	31 October 2006
3.6	Cable unit lengths (deliverable)	CERN	31 December 2006	Not started	15 December 2006
3.7	Report on cable characterization (deliverable)	TEU	31 December 2006	Not started	On time

- Same comments as above.

IDI Work Package

- The IDI Work Package includes three main Tasks
  - redaction of an engineering specification and definition of characterization tests (CCLRC),
  - studies on “conventional” insulation systems relying on ceramic or glass fiber tape and vacuum-impregnation by epoxy resin (CCLRC),
  - studies on “innovative” insulation systems relying on pre-impregnated fiber tapes and eliminating the need for a vacuum impregnation (CEA).

Insulation Specification

- A basic engineering specification for the conductor insulation of a 15-T dipole magnet has been developed under CCLRC supervision.
- The main parameters are
  - thickness 0.2 mm per conductor face,
  - dielectric strength 1 kV inter-turn in He at 300 K,
  - compressive strength > 200 MPa at 300 K and 4 K,
  - short-beam shear strength > 50 MPa at 4 K,
  - transverse tensile strength > 25 MPa at 4 K,
  - thermal contraction 0.3-0.4% between 300 & 4 K,
  - thermal conductivity > 20 mW/K at 4 K,
  - thermal cycle > 10,
  - running cycle > 100.

Insulation Development Tasks

- CCLRC is undertaking a test program for conventional insulation that will address
  - glass fiber sizing issues,
  - radiation-hard resin alternatives, such as cyanate esters,
  - improved filler materials, such as nanoclays or dendritic powders.
- CEA will pursue its ongoing development on innovative, ceramic-based insulation, concentrating more specifically on
  - optimization of nature and weaving of the fiber tape pre-impregnated with ceramic precursors,
  - characterization of mechanical properties after heat treatment.

IDI Planning

WBS #	Title	Original begin date (Annex 1)	Original end date (Annex 1)	Estimated Status	Revised end date
4.1	IDI WP Coordination				
4.2	Specification drafting	1 April 2004	30 June 2004	Completed	22 July 2004
4.3	Conventional Insulation				
4.3.1	Literature survey	1 July 2004	30 Sept. 2004	Completed	On time
4.3.2	Tooling preparation	1 October 2004	30 October 2004	Ongoing	On time
4.3.3	Component supply	1 October 2004	31 Dec. 2004	Ongoing	On time
4.3.4	Iterative tests	1 January 2005	30 Sept. 2005	Not started	31 Dec. 2005
4.3.5	Irradiation tests	1 July 2005	30 June 2006	Not started	30 June 2006
4.4	Innovative Insulation				
4.4.1	Tape weaving trial	1 July 2004	31 Dec. 2004	Not started	31 Dec. 2005
4.4.2	Characterization tests	1 July 2004	30 June 2005	Not started	30 June 2006

- Scope of Task 4.3.5 has been increased to include radiation tests and the end date has been moved to 30 June 2006.
- Start date of 4.4 delayed until 1 January 2005 due to lack of human resources at CEA (technician).
- End date of 4.4 delayed accordingly.

IDI Milestones and Deliverables

WBS #	Title	Responsible Lab(s)	Due date in Annex 1	Status	Revised delivery date
4.2	Engineering specifications (milestone)	CCLRC	30 June 2004	Completed	22 July 2004
4.3&4.4	Test Programme definition (milestone)	CCLRC&CEA	31 July 2004	Completed	August 2004
4.3	Report on conventional insulation (deliverable)	CCLRC	31 December 2005	Not started	30 June 2006
4.4	Report on innovative insulation (deliverable)	CEA	30 June 2005	Not started	30 June 2006

- Same comment as above.

MDO Working Group (1/3)

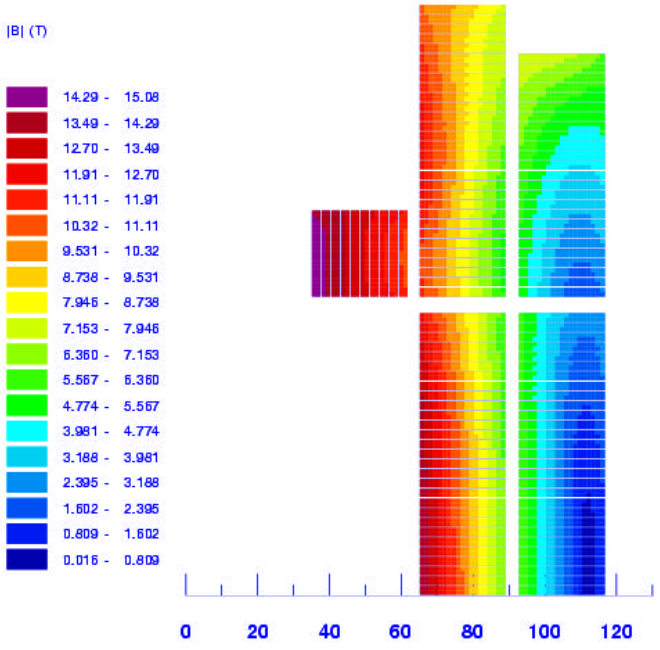
- The MDO Working Group is made up of representatives from CCLRC, CEA, CERN and CIEMAT.
- Its main charge is to address the following questions
  - How far can we push the conventional, cos$q$, layer design in the aperture-central-field parameter space (especially when relying on strain-sensitive conductors)?
  - What are the most efficient alternatives, in terms of performance, manufacturability and cost?

MDO Working Group (2/3)

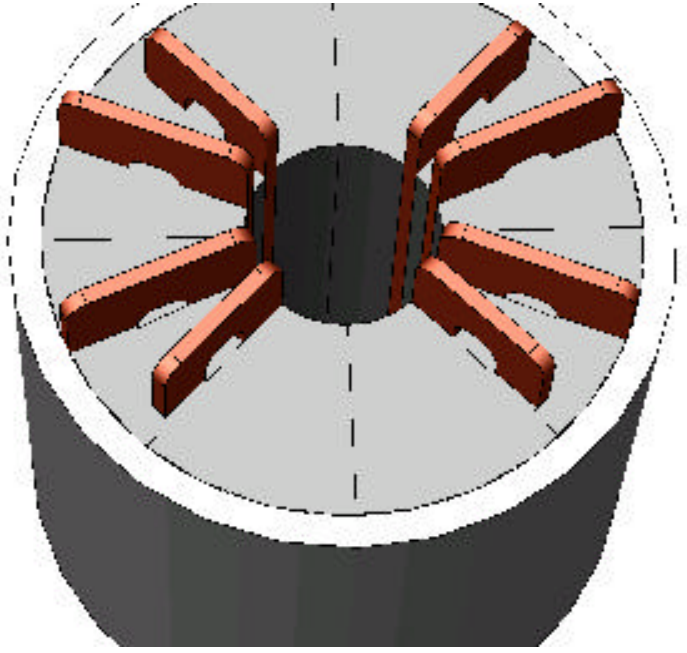
- The MDO WG has selected
  - a number of magnetic configurations to be studied,
  - ranges of design parameters,
  - terms of comparison between solutions.
- Each Institute participating to the WG will completely study one or two configurations.
- Results of the comparative study are expected by December 2005.

MDO Working Group (3/3)

- Examples of alternative dipole magnet configurations to be optimized and compared



Window-frame design
proposed by CEA
(courtesy H. Felice and P. Védrine)



Motor-type design
proposed by CIEMAT
(courtesy S. Sanz and F. Toral)

Conclusion

- All the tasks of the CARE/NED JRA have been launched and are well under way (in particular, the conductor subcontracts were signed at the end of September).
- The program is initiating the desired synergies among the various European partners involved.
- The NED collaborators are still struggling to find the necessary funding to carry out the model magnet manufacturing and test at the 2008 horizon as initially foreseen.