High-Field Accelerator Magnet Development

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Magnet Day
CEA/Saclay
3 June 2006

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- Brief History
- What's Next?
- Nb_3Sn Program at CEA and CARE/NED
- Preparing for NED Phase II
- Conclusion

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- **Brief History**
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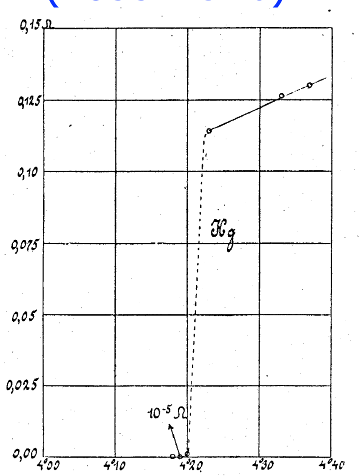
First Discovery

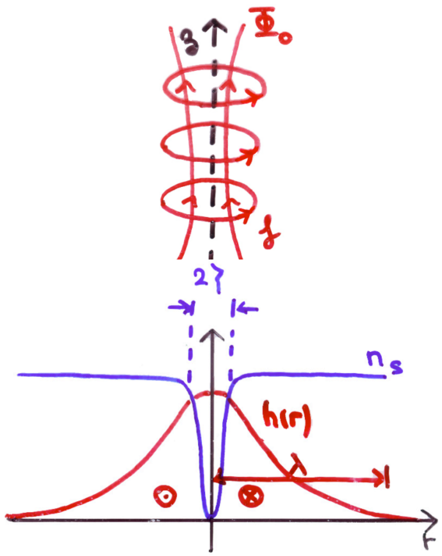
Heike Kammerling-Onnes
(1853–1926)



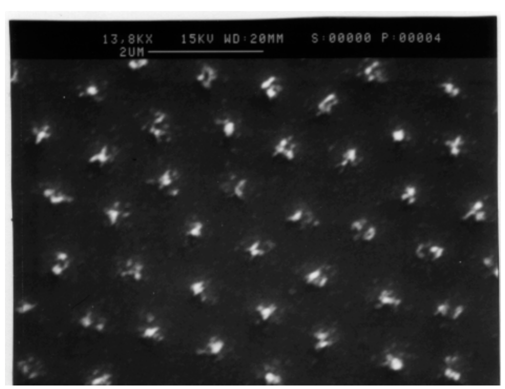
Facsimile of the first observation of superconductivity in a mercury sample

- Superconductivity was discovered in 1911 in a Laboratory of Leiden University, The Netherlands, headed by Heike Kammerling-Onnes.
- Kammerling-Onnes was the first to liquify helium on 10 July 1908 and subsequently used liquid-helium cooling to study the electrical properties of materials at low temperature.
- He was awarded the 1913 Nobel Prize in Physics "for his investigations on the properties of matter at low temperatures, which led, inter alia, to the production of liquid helium."

A Long And Winding Road



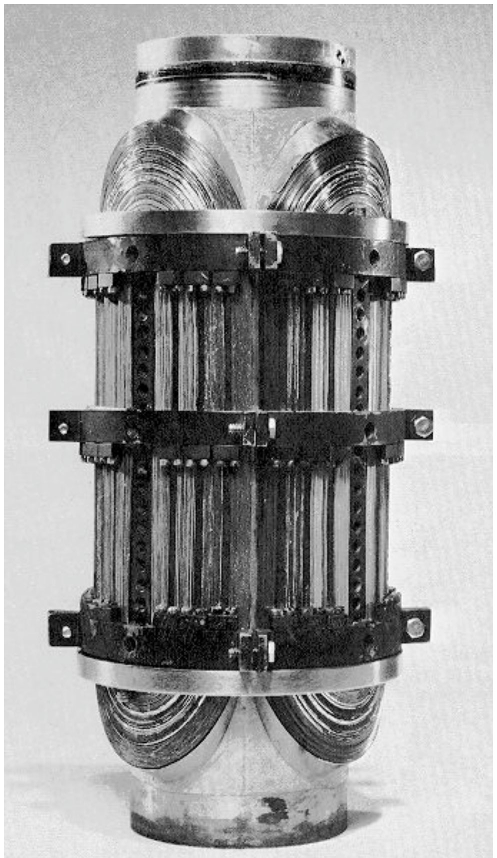
Abrikosov's fluxon



Fluxon lattice
in a type-II superconductor
(Courtesy K. Runge, CRTBT)

- Although discovered at the very beginning of the XXth century, superconductivity remained a laboratory curiosity until the late 1950's.
- At that time, three concomitant events triggered a series of new developments
  - the publication by Bardeen, Cooper and Schrieffer of the first microscopic theory of superconductivity (1972 Nobel Prize),
  - the publication by Abrikosov of the theory of the mixed state of type-II superconductors (2003 Nobel Prize),
  - the finding of materials suitable for high-field, high-current density applications, *e.g.,* Nb_3Sn (1954) and Nb–Ti (circa 1961).

Pioneer Time

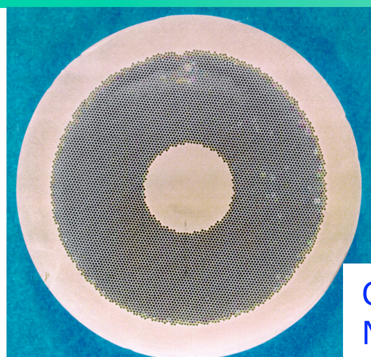


76-mm-aperture, 85-T/m quadrupole magnet model wound from Nb_3Sn ribbons and cold tested at BNL in Jan. 1966 (Courtesy W.B. Sampson)

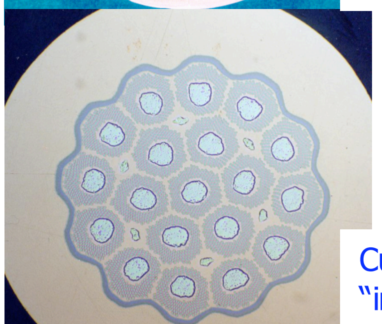
W.B. Sampson, Pioneer of Nb_3Sn and superconducting accelerator magnet technology at BNL

- Soon enough, particle physicists and accelerator scientists realized the potentials of superconductivity for synchrotron magnets.
- The very first superconducting accelerator magnet models were built by W.B. Sampson at BNL in the late 1960's.

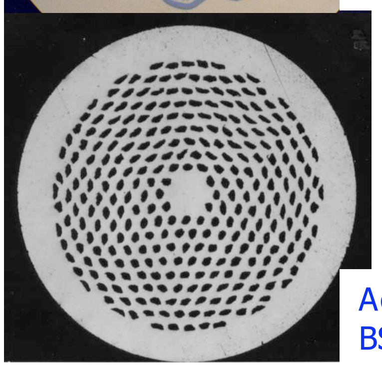
RAL For Ever



Cu-Sabilized
NbTi



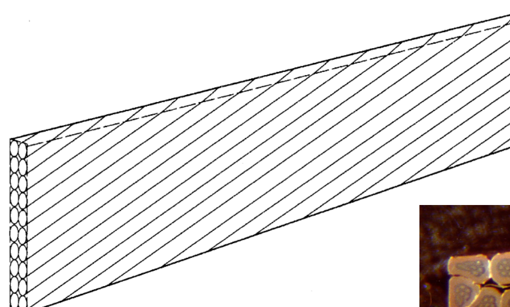
Cu-Sabilized
"internal Sn"



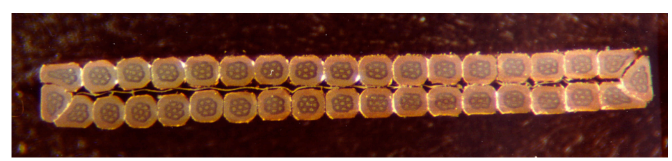
Ag-Sabilized
BSCCO 2212

Examples of superconducting multifilament composite wires

- In the late 1960's–early 1970's, RAL scientists (around M.N. Wilson) understood the importance of subdividing the superconductor into fine filaments twisted together.
- This led to the development of superconducting multifilament composite wires.
- They also produced the first flat, two-layer, rectangular or trapezoidal cables, presently known as "Rutherford-type" cables.



Rutherford-type cable



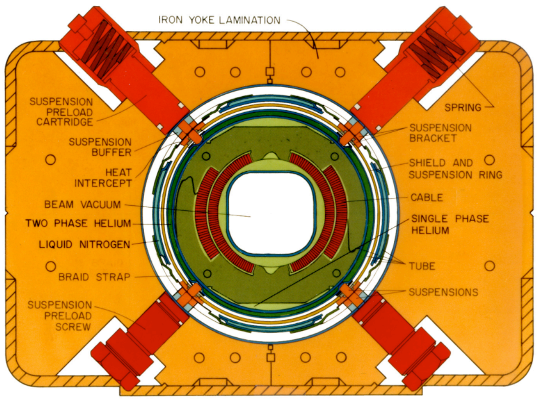
The Tevatron (1/2)

Robert Ratburn Wilson
(1914–2000)

Fermilab High-Rise modeled after Beauvais' cathedral

- In the mid- to late 1970's, Nb–Ti, which is a ductile alloy easy to co-process with copper, emerged as the most suitable material for practical applications.
- Around the same years, Robert Ratburn Wilson, Director of what was then the National Accelerator Laboratory (NAL), had a vision of what Nb–Ti technology could bring to High Energy Physics (HEP) and launched the Energy Doubler (or Energy Saver) Program.
- He imposed his vision and succeeded in building the Tevatron, which was commissioned in 1983 and has been running reliably since then.

The Tevatron (2/2)

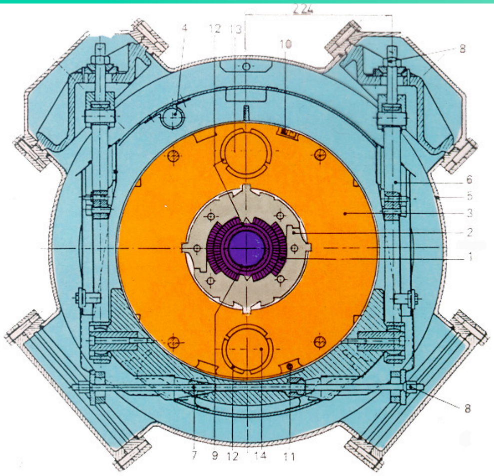


76.2-mm-aperture, 4-T Tevatron dipole magnet

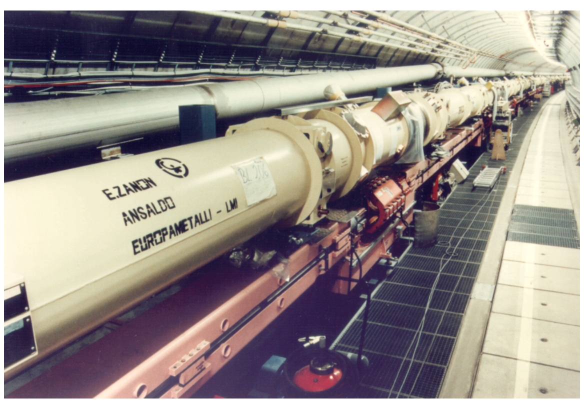
6.3-km circumference Tevatron magnet ring (bottom)

- The Tevatron designers, and foremost among them, A. Tollestrup, pioneered the concepts that made the success of superconducting accelerator magnets (saddle-shape coils wound from Nb–Ti, Rutherford-type cables, collar support structure, laminated tooling…).
- The Tevatron was instrumental in demonstrating the feasibility and reliability of large superconducting magnet systems and paved the way to their commercial applications, such as MRI systems.
- Also, it was the first act in a long and fruitful relationship between applied superconductivity and High Energy Physics.

HERA-p (1/2)



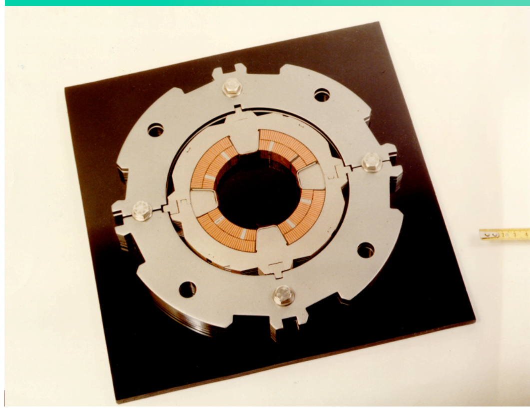
75-mm-aperture, 5.23-T HERA-p Dipole Magnet



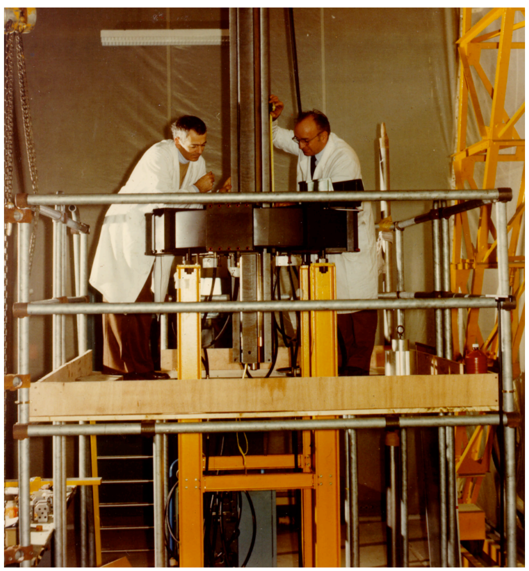
Superconducting HERA-p magnet ring on top of resistive HERA-e magnet ring

- The second act was the HERA-proton (HERA-p) ring at DESY.
- The superconducting magnets for HERA-p are a cautious extrapolation of Tevatron magnets, relying on NbTi, Rutherford-type cables and a collar support structure, but with two improvements
  - the iron yoke is included in the magnet cold mass,
  - the magnets were mass-produced in industry.
- HERA was commissioned in 1990 and has also been running reliably since then.

HERA-p (2/2)



75-mm-aperture, ~100 T/m
HERA-p Quadrupole Magnet



Vertical collaring at CEA

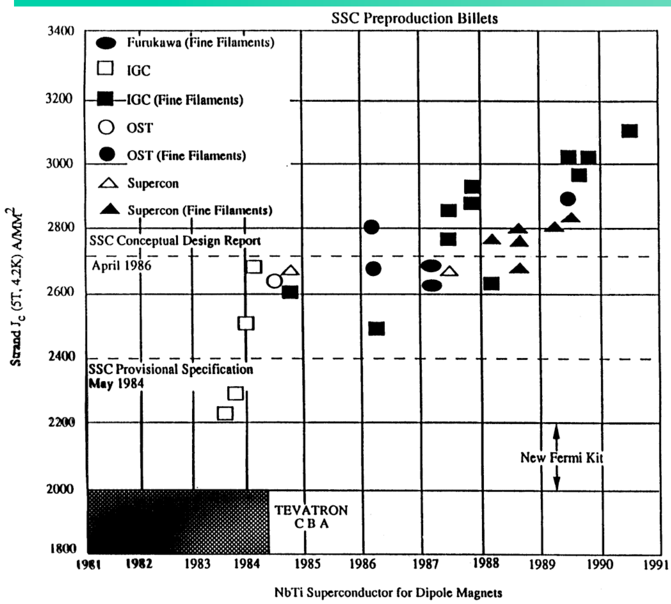
- DPhPE/STIPE was responsible for the design, manufacturing and industrial follow-up of the ~225 arc quadrupole magnets.
- This design, developed by J. Pérot, was inspired by the Tevatron quadrupole magnet design and is an engineering treat.
- It includes features that now embody the "CEA touch," *e.g.*
  - self-supported collared-coil assembly,
  - free coil ends,
  - precisely machined inertia tube,
  - vertical assembly.
- It earned J. Pérot the 1989 CEA prize.

J. Pérot's Road to Success

- The HERA quadrupole magnets are the culmination of over 10 years of trials and errors and model magnet R&D that enabled J. Pérot to achieve maturity; the projects he carried out are
  - 1972-1973: MOBY, within the framework of GESYN (CEA, CERN, Karlsruhe, RAL; NbTi, flattened, rope-type cable),
  - 1975: ALEC, designed by J. Pérot, manufactured by CGE and Alsthom,
  - 1978-84: CESR (2 x 150-mm-aperture, 3-m-long. 4.5-T, beam-transport, dipole magnets), CEA/CERN collaboration (NbTi monolith),
  - ~1980: several, Tevatron-like, short, NbTi dipole models for UNK (NbTi, Rutherford-type cable),
  - 1982: one Nb_3Sn dipole model for UNK,
  - 1983: four, short, NbTi "block" dipole magnet models for UNK,
  - early 1980's: HERA quadrupole magnet prototypes,

  (– early 1990's: first series of LHC quadrupole magnet prototypes).

SSC



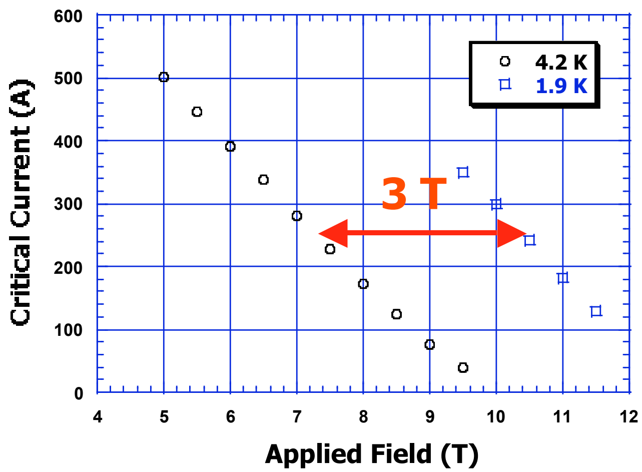
Progress in SSC wires

Optimized Nb–Ti microstructure

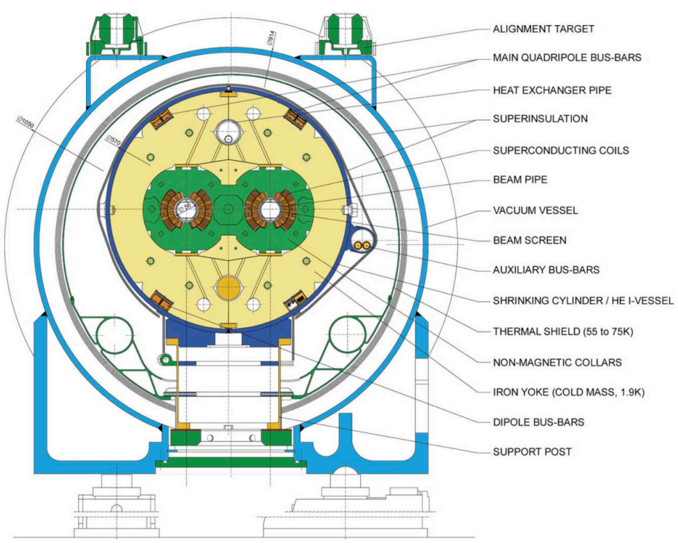
- Albeit a dramatic termination on 21 October 1993, the SSC invested serious money into Nb–Ti wire and cable development, enabling tremendous progress in performances, production yields and costs (whose beneficiaries included Alstom/MSA).

- The progress in Nb–Ti J_C is mostly due to the team of D. Labarlestier at the University of Wisconsin at Madison, who understood the role played by α-Ti precipitates in fluxon pinning and learned how to engineer them at a nanometric scale during wire production.

LHC (1/2)



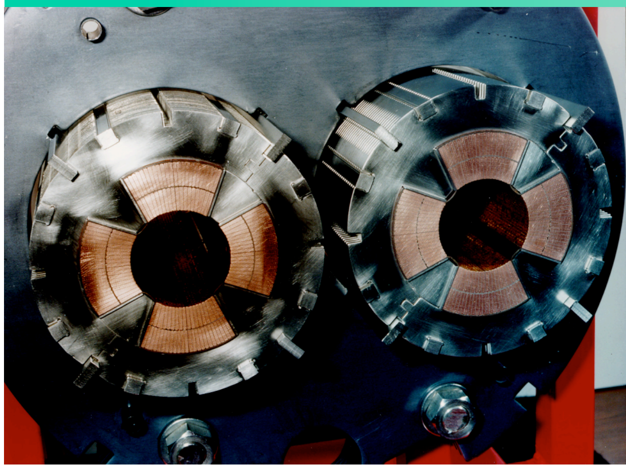
NbTi critical current enhancement from 4.2 to 1.9 K



LHC arc dipole magnet

- The LHC is the next step on the Tevatron-HERA-SSC continuum and builds upon the success of Tore Supra operation with superfluid helium.
- The LHC magnets rely on optimized NbTi wires and cables, cooled-down to 1.9 K to benefit from a ~3-T field enhancement.
- They also rely on a 2-in-1 structure to save space.
- Compare to the Tevatron, the operating field is more than twice as large (8.33 T compared to 4 T), and the Lorenz forces in the coils are ~4 times higher.

LHC (2/2)



LHC arc quadrupole magnet

Vertical yoking at CEA

- The LHC arc quadrupole magnet design developed by DAPNIA/SACM is the natural heir to the HERA quadrupole magnet design, save for
  - the 2-in-1 structure (which is not a complication since each collared-coil assembly is self-supported),
  - the superfluid helium operation (which imposes drastic requirements on leak tightness, *e.g.*, the "bouchons").

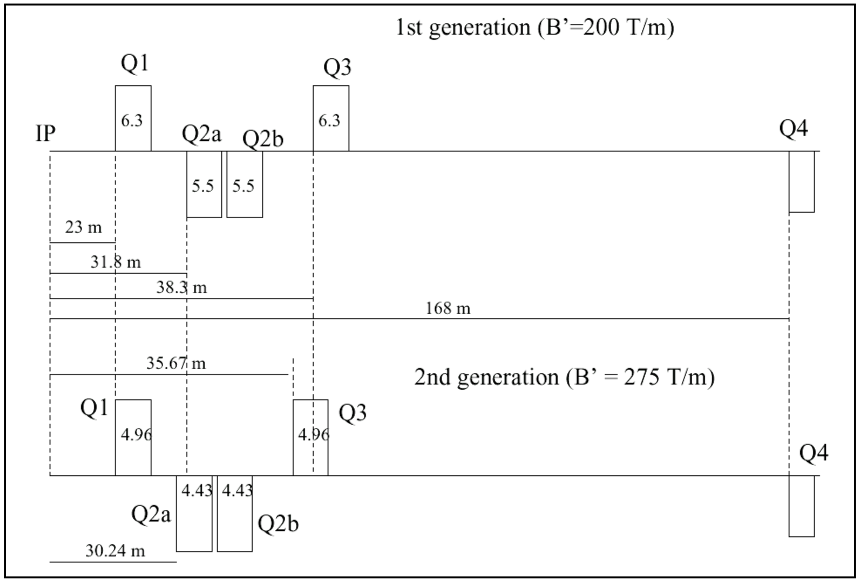
Contents

LHC and ILC IR's

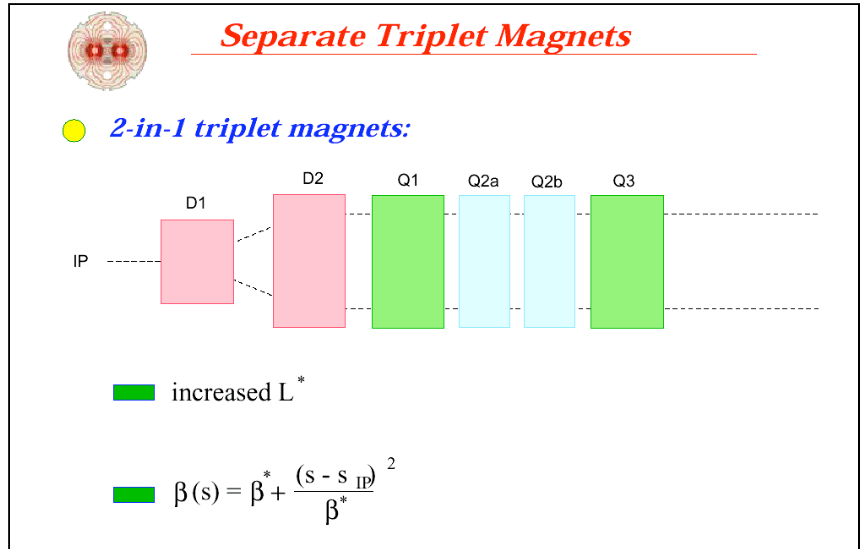
- Due to the high radiation doses to which they will be submitted, the life expectancy of the present (US and Japan-contributed) LHC Interaction Region (IR) magnets is estimated ~7 years.
- Also, after 7 years of operation, LHC physicists are likely to be craving for more integrated luminosity.
- Hence, the LHC IR magnets will have to be replaced ~2015 and this replacement will offer an opportunity to upgrade LHC IR optics and boost luminosity.
- Mid-2010's is also the earliest time frame when one can expect to need final-focusing quadrupole magnets for the International Linear Collider (ILC).

Magnets for LHC IR Upgrade

- Several LHC IR upgrade scenarios are presently being considered, *e.g.*



Same layout as present, but with larger-aperture and stronger final-focusing quadrupole magnets (Courtesy T. Sen)

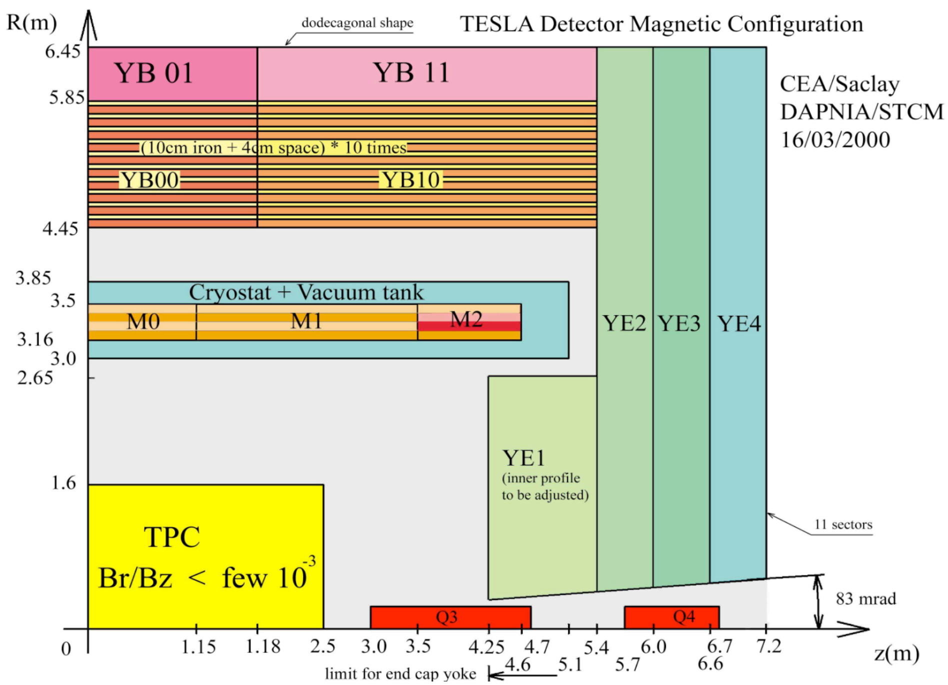


New layout where beam-separation dipoles are positioned in front of final-focusing quadrupole magnets (Courtesy O. Brüning)

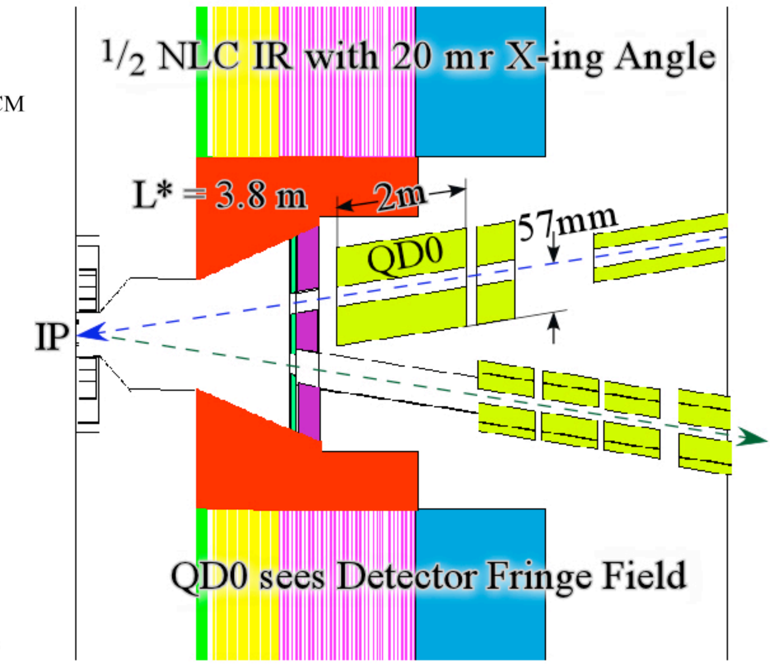
- All scenarios enabling a significant luminosity increase call for the development of large-aperture, high-field or high-field-gradient magnets (with peak fields in the 13-to-15-T range).

Magnets for ILC IR's

- Magnet requirements are IR-design dependent, *e.g.*



TESLA-type IR requiring LHC-type quadrupole magnets to be operated in a 4-T solenoidal background field (Courtesy F. Kircher)



NLC-type IR with large crossing angle requiring strong but very compact quadrupole magnets to clear the way for crossing beam (Courtesy B. Parker)

High-Field Accelerator Magnet Roadmap

- A reasonable roadmap for high-field accelerator magnet development appears to be

  – to get ready for LHC IR upgrade in 2015
  (large-aperture, high-performance dipole and/or quadrupole magnets with 13-to-15-T peak field range; cost is not the primary issue),

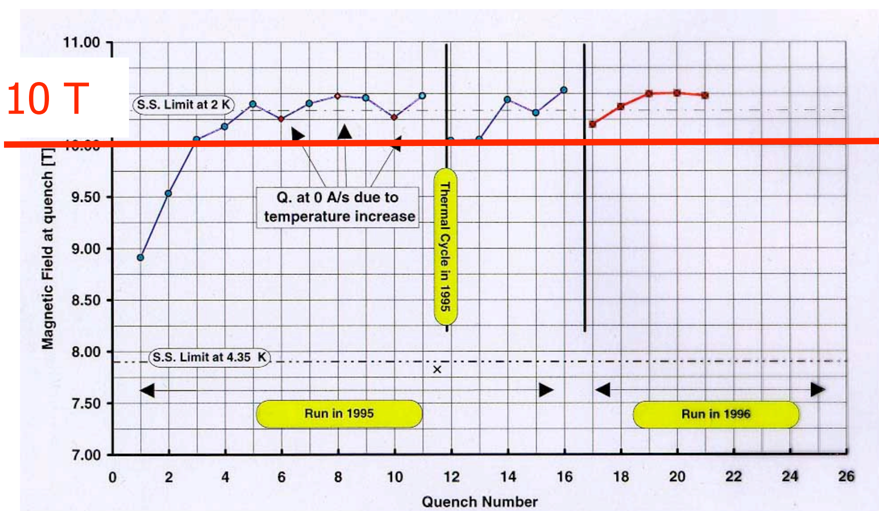
  – to develop final-focusing quadrupole magnets for ILC IR in the mid-2010's
  (LHC-type quadrupole magnets in a solenoidal background field operating beyond 10-T peak field, or compact quadrupole magnets; cost is not the primary issue),

  – to promote generic magnet R&D aimed at LHC energy upgrade or a super LHC in the 2020's
  (high-performance, low-cost dipole and quadrupole magnets).

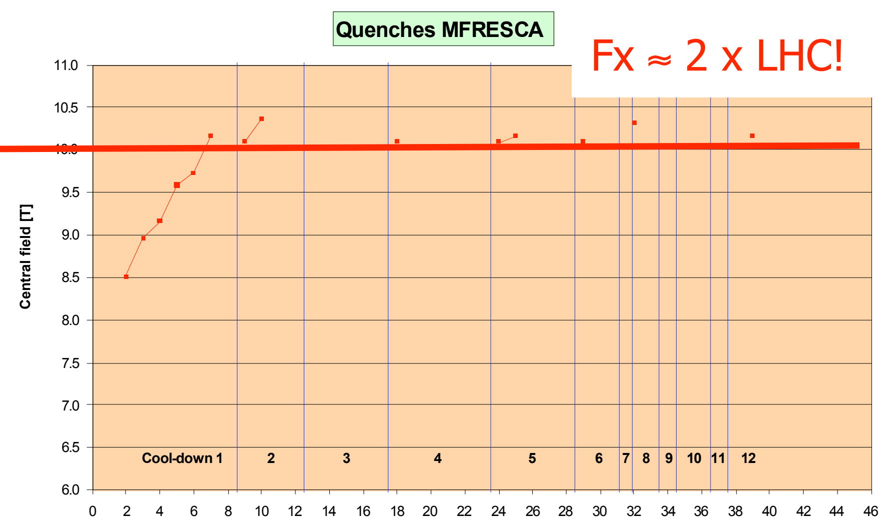
State of the Art: LHC & NbTi (1/2)

- At present and thanks to HEP, the most widely used superconductor is Nb–Ti (world production: ~1500 t/year; LHC uses 1200 t).
- The best performing Nb–Ti dipole magnets are the 50-mm-twin-aperture MFISC and the 88-mm-single-aperture MFRESCA (both designed and manufactured by a team led by D. Leroy, CERN/AT), which plateau at quench fields in the 10-10.5-T range at 1.9 K.

10 T



MFISC Training (Courtesy A. Siemko, 1996)

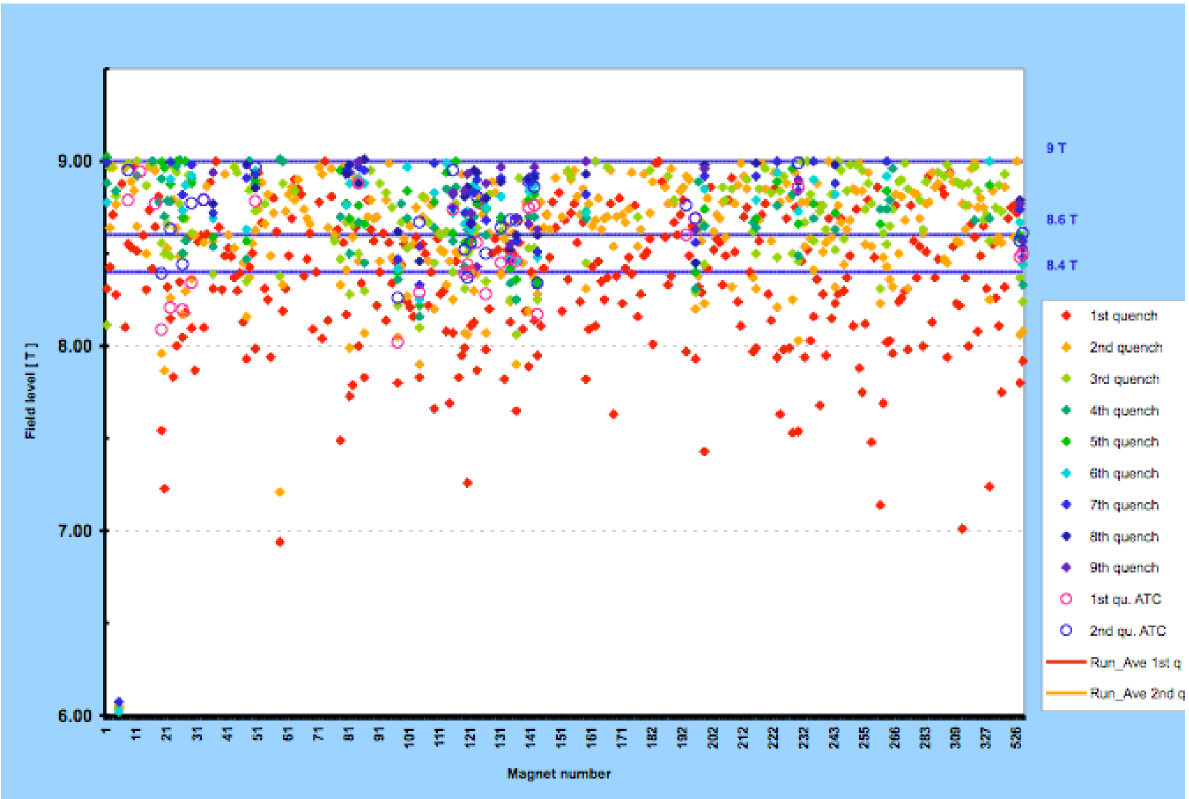


Fx ≈ 2 x LHC!

MFRESCA Training (Courtesy A. Verweij)

State of the Art: LHC & NbTi (2/2)

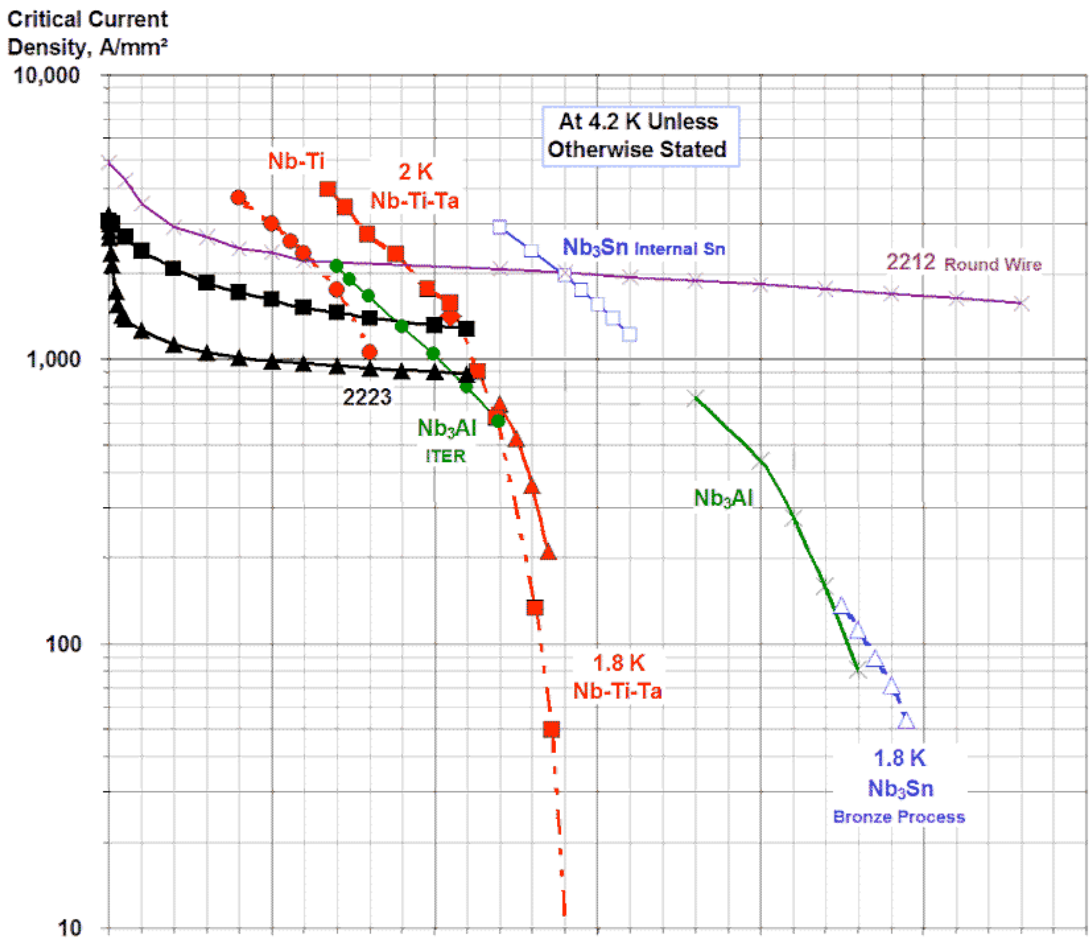
- The LHC dipole magnet production shows that, in practice, the limit of Nb–Ti dipole magnets is in the 8.5-9-T range at 1.9 K.



Quench performance of industrially-produced
LHC dipole magnets (Firm 1; courtesy M. Pojer, CERN)

- Hence, to go beyond the 10-T threshold, it is necessary to change the superconducting material.

Beyond NbTi: Nb_3Sn

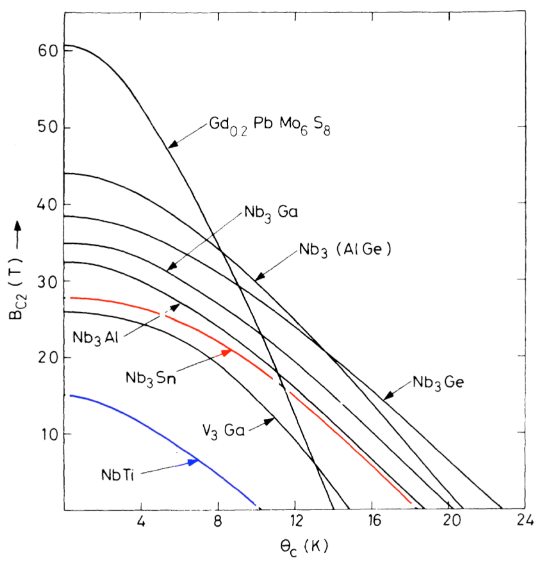


- At present, the only serious candidate to succeed to NbTi is good old Nb_3Sn (world production: ~15 t/year; ITER will require 500 t).

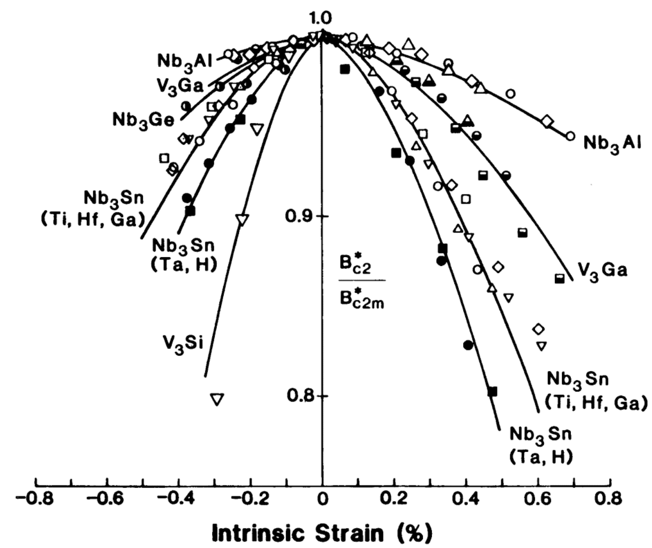
(Critical current density on >100-m-long conductor samples; courtesy P.J. Lee, University of Wisconsin at Madison)

Pros and Cons of Nb_3Sn

- Nb_3Sn has a critical temperature (θ_C) and an upper critical magnetic flux density (B_{C2}) that are about twice those of NbTi, but once formed, it becomes brittle and its θ_C, B_{C2} and J_C are strain-sensitive.
- The brittleness and strain sensitivity of Nb_3Sn require a rethinking of all manufacturing processes and, so far, have limited its use of to specific niche applications (such as high-field NMR magnet systems).



(Courtesy M.N. Wilson, 2002)

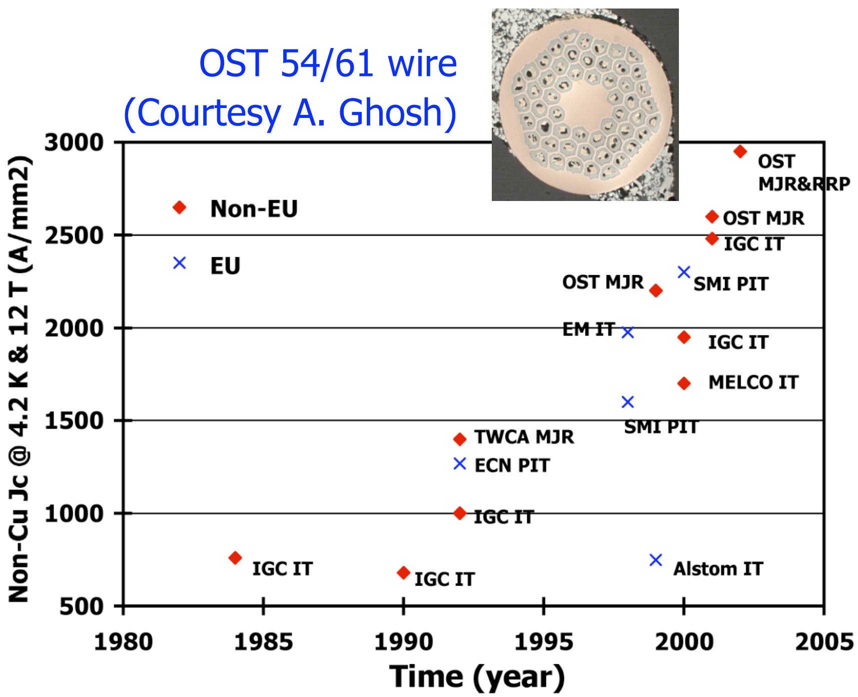


(Courtesy J.W. Ekin, 1983)

US Efforts

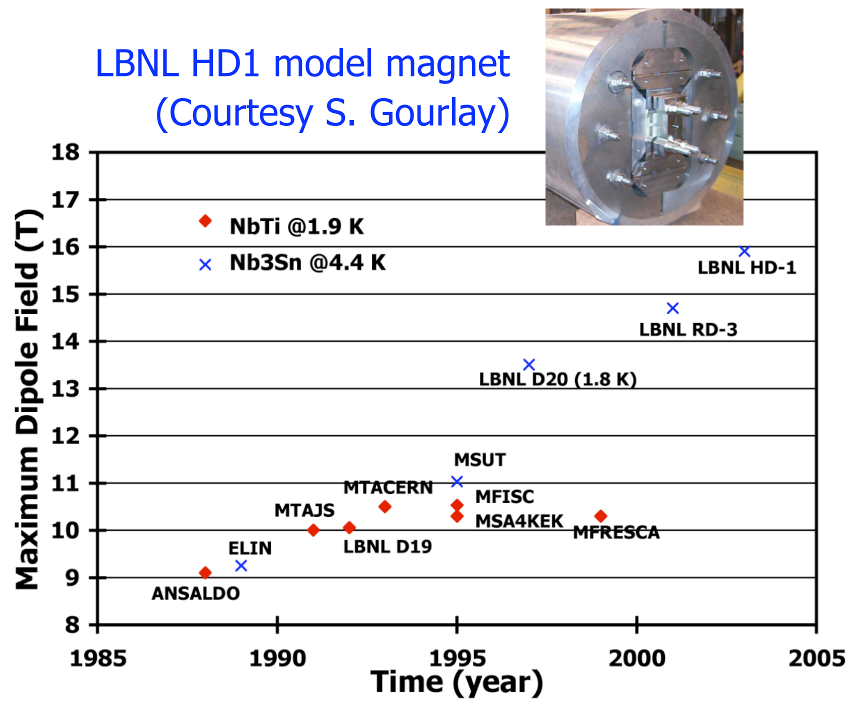
- However, over the last decade, significant progress has been achieved on Nb_3Sn, thanks to ITER/EDA and to vigorous efforts promoted by the US/DOE High-Energy Physics Office (~$ 2.5 M/year for conductor development).

OST 54/61 wire
(Courtesy A. Ghosh)



Progress on non-Cu J_C (at 4.2 K and 12 T) of Nb_3Sn wires

LBNL HD1 model magnet
(Courtesy S. Gourlay)



Progress on maximum quench field of dipole magnet models

US-LARP (1/3)

LARP

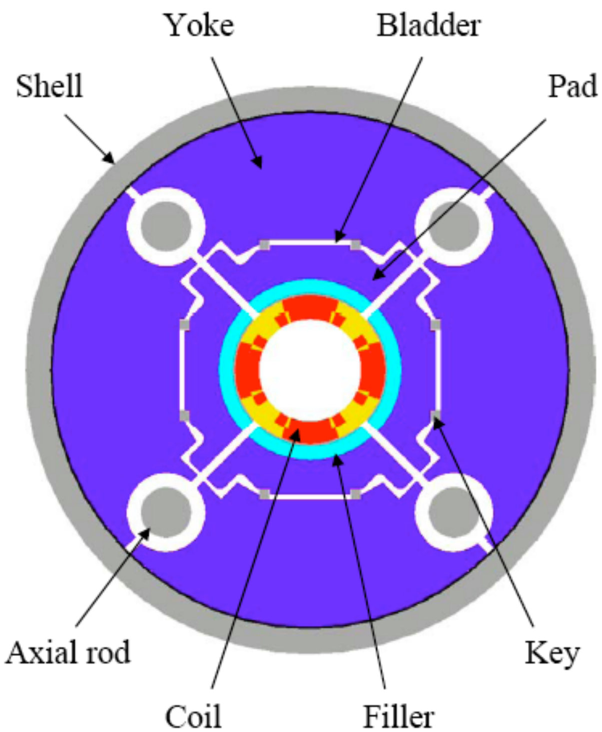
- The Department of Energy has now agreed to fund the US-LHC Accelerator Research Program (LARP).
- LARP is aimed at supporting US efforts in LHC commissioning and at designing and developing equipment for LHC upgrade (such as advanced beam instrumentation and Nb_3Sn magnets).
- It is carried out by a collaboration made up of BNL, Fermilab, LBNL and SLAC.
- Serious things have started in FY06, with a budget of 11 M$ (5.7 for magnets, 4.0 for accelerator-related R&D and 1.3 for management).
- This budget is expected to be maintained at a constant level for a few years (till FY09?).

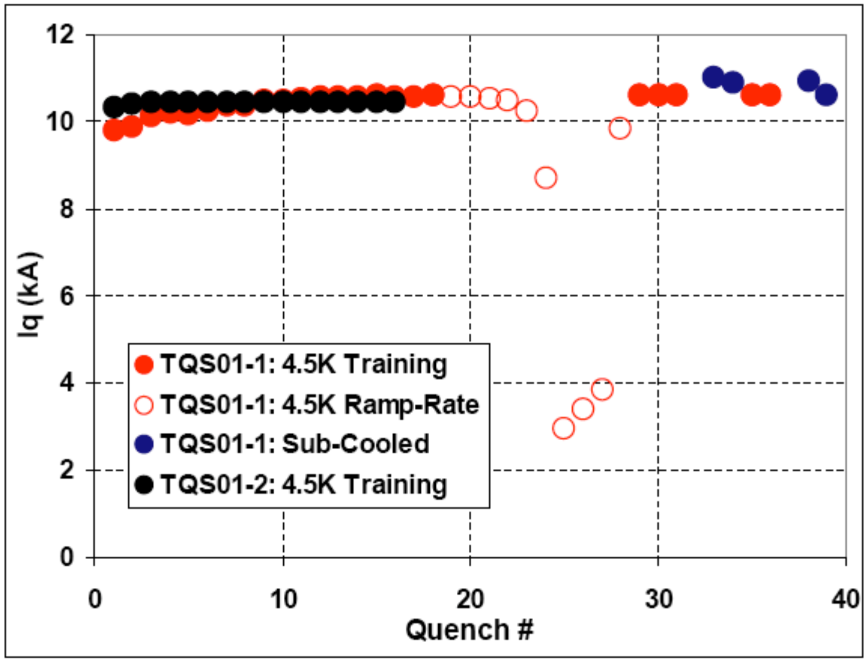
US-LARP (2/3)

- The magnet part of LARP is aimed at building by 2009 2x4-m-long, 90-mm-aperture, >200-T/m (10-to-12-T conductor peak field) quadrupole magnet prototypes, so as to demonstrate the feasibility of "long," accelerator-class Nb_3Sn magnets.
- It includes
  - building a cable inventory (1 100 kg of OST 54/61 wire over 3 years),
  - manufacturing of several short and 2x4-m-long racetrack-type coils (to investigate scaling up issues),
  - manufacturing of 5x1-m-long and 2x4-m-long quadrupole magnet models and prototypes.
- If resources are available, it is also foreseen to manufacture two additional 1-m-long, 90-mm-aperture, 300-T/m (~15-T conductor peak field) quadrupole magnet models.

US-LARP (3/3)

- The first, LBNL-style, 1-m-long quadrupole magnet model (TQS01) was tested in May; it achieved ~195 T/m (~10 T conductor peak field) at 4.5 K (87% of expected short sample limit; "old" MJR wires).



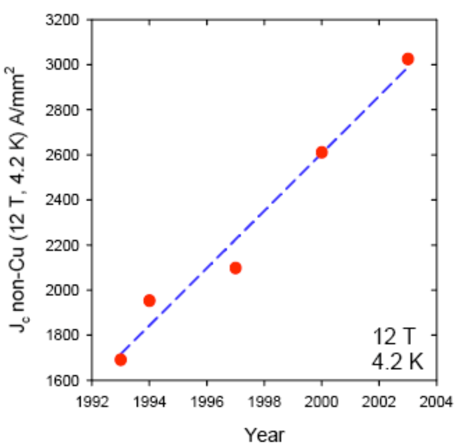


Cross-sectional view and training performance
of US-LARP TQS01 quadrupole magnet model (Courtesy G. Sabbi, LBNL)

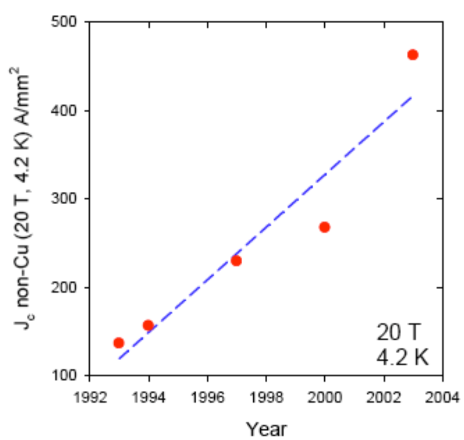
High-Field NMR

- The progress made by OST on Nb_3Sn critical current density is also significant at very high fields (> 20 T), enabling the manufacture of 950 MHz (~22.3 T) NMR systems; 1 GHz (~23.5 T) is at hand.
- This is an HEP spin-off equivalent to MRI for the Tevatron; there may also be a market for ISEULT-type applications.

Doubled @ 12 T



Tripled @ 20 T



(Courtesy Seung Hong, OST,
winner of the 2006 Superconductor Industry
Lifetime Achievement Award)

European Efforts

- Because they have been busy building the LHC, European laboratories and European Industry are lagging the US efforts on Nb_3Sn.
- At present, there are 4 European programs on high-field, Nb_3Sn accelerator magnet R&D
  - Nb_3Sn R&D Program at CEA/DSM/DAPNIA (approved in 1995 and launched in 1996),
  - Collaboration Twente University (TEU)/CERN on 88-mm-aperture, 10-T dipole model (signed in 1998; on hold since 2002 due to lack of resources),
  - EU-FP6 CARE/NED JRA (approved with a reduced scope in 2003 and launched in January 2004),
  - CANDIA program at INFN (to complement NED conductor development at Italian manufacturer; approved in November 2004 and launched in September 2005).

High-Field Magnet Road Map

Technology	Machine	Application	Conductor Peak Field	Year
Cu (resistive)	LEP, ESRF Soleil, Diamond	Misc.	up to 2 T	1970’s
NbTi, 4,2 K	Tevatron	HEP	~4 T	1983
NbTi, 1,9 K	Tore Supra	Fusion	9 T	1988
NbTi, 1,9 K	LHC	HEP	8.7 T	Easter 2008
NbTi, 1,9 K	*NEUROSPIN/ISEULT*	*Medical*	*>11.75 T*	*2008-2009?*
Nb_3Sn, 5 K	ITER/EDA - TFMC/CSMC *ITER*	Fusion	12/13 T	1995-2001 *>2015?*
Nb_3Sn	US LARP, EU CARE/NED *LHC IR upgrade & ILC* *LHC doubler*	HEP	15 T	2009? *2015?* *>2020?*
Nb_3Sn, 1,9 K	*1-GHz RMN*	*Misc.*	*>23.5 T*	*2006-2007?*
HTS	*LHC tripler*	*HEP*	*24-25 T*	*>2030?*

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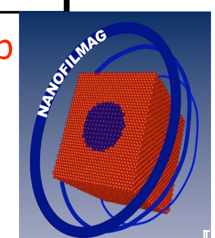
- What's Next?
- **Nb_3Sn Program at CEA and CARE/NED**
- Preparing for NED Phase II
- Conclusion

CEA Program Overview

- The CEA Nb_3Sn R&D program was initiated by J. Pérot and J. Haïssinski in the Fall of 1995 and includes 3 Tasks
  - – Conductor R&D
    (in collaboration with Alstom/MSA),
  - – Insulation R&D
    (in collaboration with Laboratoire de Céramique et Matériaux Avancés of CEA/DAM and Institut Européen des Membranes, Montpellier),
  - – Magnet R&D
    (in collaboration with
    Alstom/MSA: Phase I "quadrupole magnet model",
    LBNL: Phase II "short model coil studies").
- Each Task is or has been supported by 1 or 2 graduate students.

CEA Program Articulation

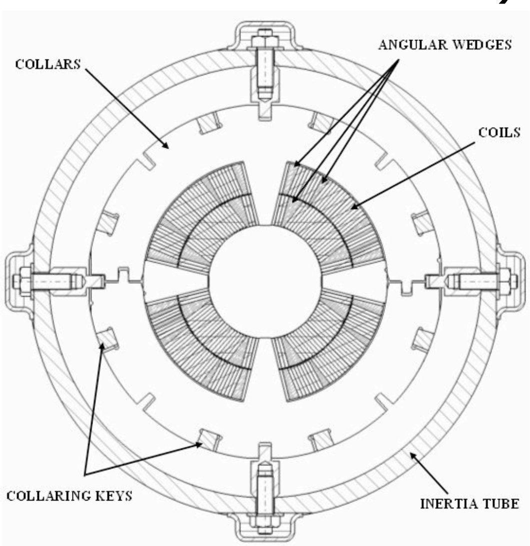
	Phase I (catching up with existing technologies)	Phase II (improving performances, reliability and costs)	Phase III (breaking new grounds)
Conductor[a]	750 A/mm^2 (completed)	Tesla: 2000 A/mm^2 NED: 3000 A/mm^2 (ongoing)	NANOFILMAG[b] (not started) 
Insulation	Quartz (completed)	Ceramic (led by F. Rondeaux; pursued within NED)	Demonstrator (short model coil; not started)
Magnet	Quadrupole (led by M. Durante; ongoing)	Short Model Coils (ongoing)	NED manufacture? (not started)

[a]Non-Cu critical current density at 4.2 K and 12 T.
[b]ANR/RNMP proposal submitted by Alstom/MSA, LNCMP, LMP, LITEN, DAPNIA.

Quadrupole Magnet Model (1/3)

dapnia cea saclay

- The core of the Program is the manufacturing of a 1-m-long quadrupole magnet model, based on the conception of the LHC arc quadrupole magnets, but where the NbTi coils have been replaced by Nb_3Sn coils (wound from the conductor developed by Alstom/MSA in Phase I of Conductor Task).



Cross-sectional view of CEA Nb_3Sn quadrupole magnet model (Courtesy A. Acker)

- The magnet model is not expected to break any records, but is meant as a technology demonstrator.

Gradient	222 T/m
Current	12 500 A
Peak field	6.8 T

(at 4.2 K)

Quadrupole Magnet Model (2/3)

- The project has suffered from heavy delays due to lack of resources and priority, but was "revived" by P. Debu in 2002.

Alstom/MSA tech helping out the CEA crew

Nb_3Sn coil winding (Courtesy M. Segréti)

Nb_3Sn coil heat treatment (Courtesy M. Durante)

- Even with P. Debu's support, it was still short of manpower, until January 2006 when Alstom/MSA agreed to send for six months one of its best "technicien d'atelier" to help finish the work and ensure a direct technology transfer.
- Cold test in an horizontal cryostat is scheduled for early 2007.

EU-CARE/NED

- The CEA Nb_3Sn efforts are complemented and extended by the EU-funded Next European Dipole (NED) Joint Research Activity (JRA) that was launched in January 2004.
- NED is part of the Coordinated Accelerator Research in Europe (CARE) project, with a total budget of ~2 M€ and an EU grant of 979 k€ (over 3 years).
- In spite of the limited funding, NED is supported by an active and enthusiastic collaboration of 8 institutes, coordinated by CEA

NED Program (1/2)

- The initial goal of the NED proposal was the design, manufacture and test of a large-aperture (88 mm), high-field (~15-T conductor peak field) accelerator-class, dipole magnet model.
- The proposed magnet model served two main purposes
  - to get ready for LHC IR upgrade,
  - to enable the upgrade of the FRESCA cable test facility at CERN (presently limited to 10 T).

CERN FRESCA cable test facility

- Furthermore, the NED proposal was complementary to US-LARP, which is mainly focused on quadrupole magnet development.
- Unfortunately, the EU capped its funding at 25% of the requested budget, and, after re-scoping, the model magnet was left out of CARE.

NED Program (2/2)

- In addition to Management & Communication (M&C), the NED Activity is presently articulated around three technical Work Packages (WP) and one Working Group (WG) that cover the main design studies needed to develop such a magnet

  WP 2: Thermal Studies and Quench Protection (TSQP),

  WP 3: Conductor Development (CD),

  WP 4: Insulation Development and Implementation (IDI),

  WG on Magnet Design and Optimization (MDO) Working.

NED Conductor Development (1/3)

- As in most superconducting magnet R&D program, the Conductor Development Work Package is the core of the NED Activity and absorbs about 70% of the EU-allocated funding.
- It includes three main Tasks
  - wire development

    (two industrial contracts under CERN supervision:

    Alstom/MSA, France and SMI, The Netherlands;

    Task Leader: L. Oberli, CERN),
  - wire characterization

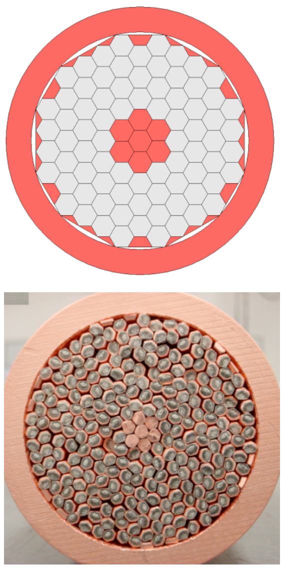
    (CEA, INFN-Ge, INFN-Mi, and TEU;

    Task Leader: A. den Ouden, TEU),
  - cabling studies

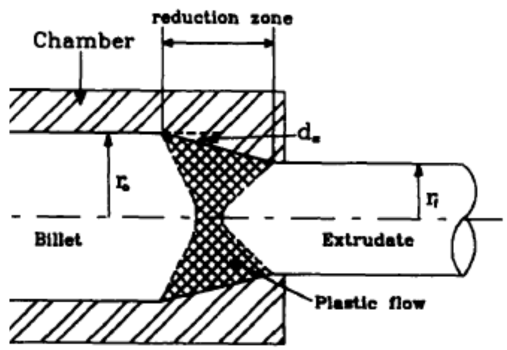
    (CERN and INFN-Mi; Task Leader: S. Farinon, INFN-Mi).

NED Conductor Development (2/3)

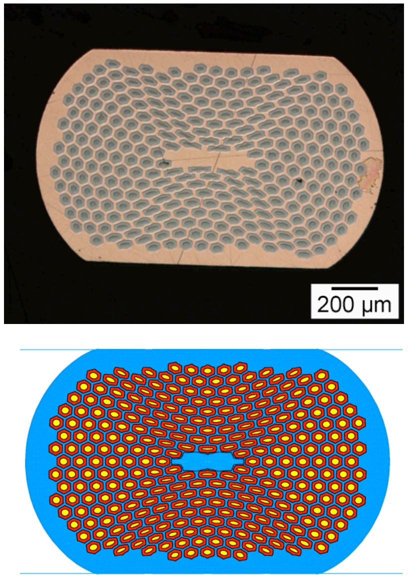
- The NED conductor specifications are very ambitious and require special R&D skills, *e.g.*



Billet design & assembly (Courtesy C. Verwaerde, Alstom/MSA)



Optimization of extrusion and drawing parameters (Courtesy F. Lecouturier, LNCMP)

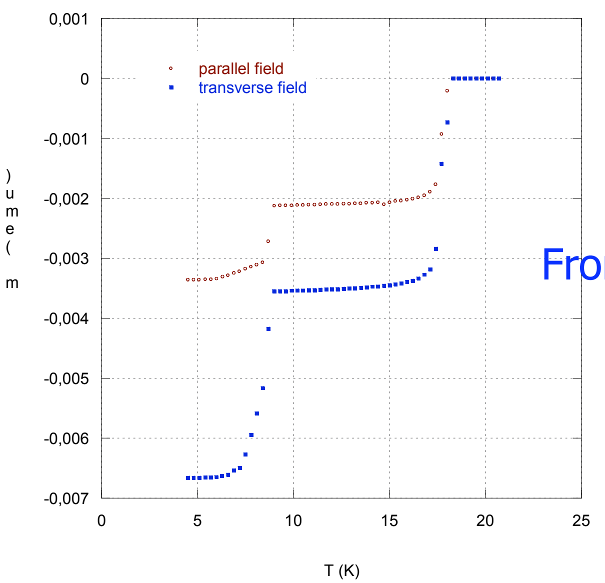


Cabling modelling (Courtesy L. Oberli, CERN and S. Farinon, INFN-Ge)

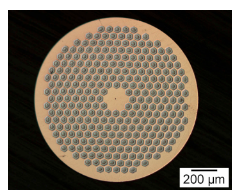
- DAPNIA/SACM was never really strong in this area; the NANOFILMAG project may enable the creation of a French Pole of Excellency.

NED Conductor Development (3/3)

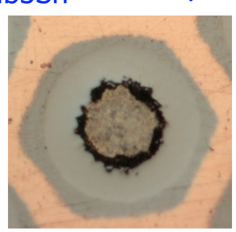
- The NED conductor characterization also represents a real challenge, especially in terms of critical current measurements (target value of ~1600 A at 4.2 K and 12 T on a 1.25-mm-Ø wire, to be compared with the ~200 A presently achieved on 0.8-mm-Ø ITER wires).
- This led us to share the risks among 3 partners (CEA, INFN & TEU), which prove to be a smart move (at least to meet NED objectives).



(Courtesy M. Greco, INFN-Ge)



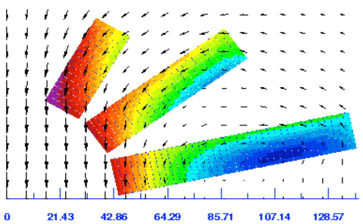
From shielded volumes
$Ø_{Nb}$ = 55 µm
$Ø_{Nb3Sn}$ = 44 µm



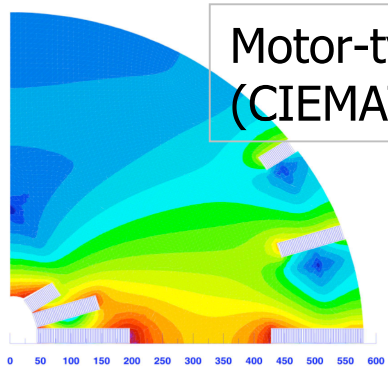
- Note the excellent work carried out by INFN-Ge with magnetization measurements, turning them into a powerful tool to probe the internal structure of Nb_3Sn wires and the origin of flux jumps.

NED Design & Optimization (1/2)

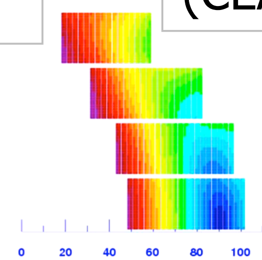
- Thanks to powerful tools such as ROXIE, the electromagnetic design of NED-like magnets has become the "easy" part and a land of many opportunities, *e.g.*



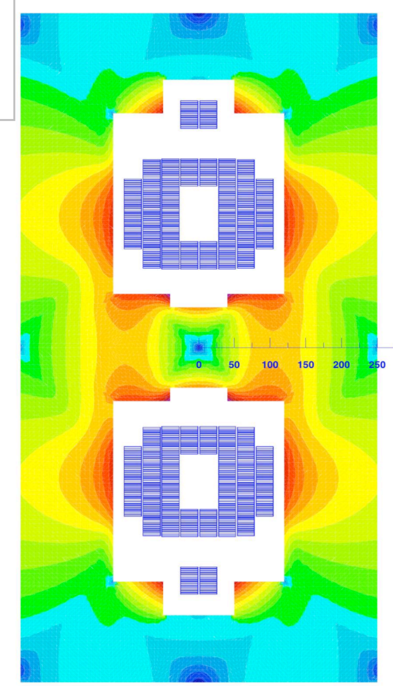
Cosθ slot (CERN)



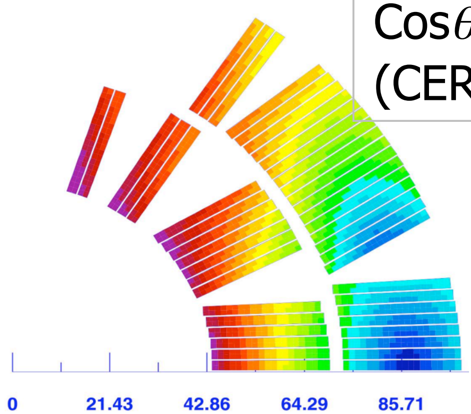
Motor-type (CIEMAT)



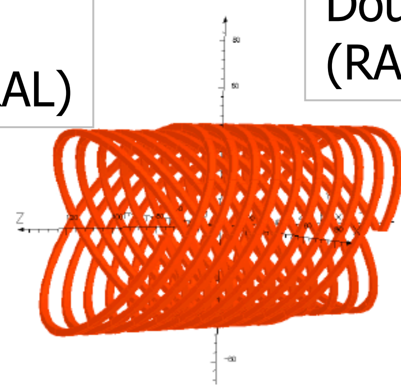
Ellipse-type (CEA/Saclay)



Common coil (CIEMAT)



Cosθ layer (CERN & RAL)

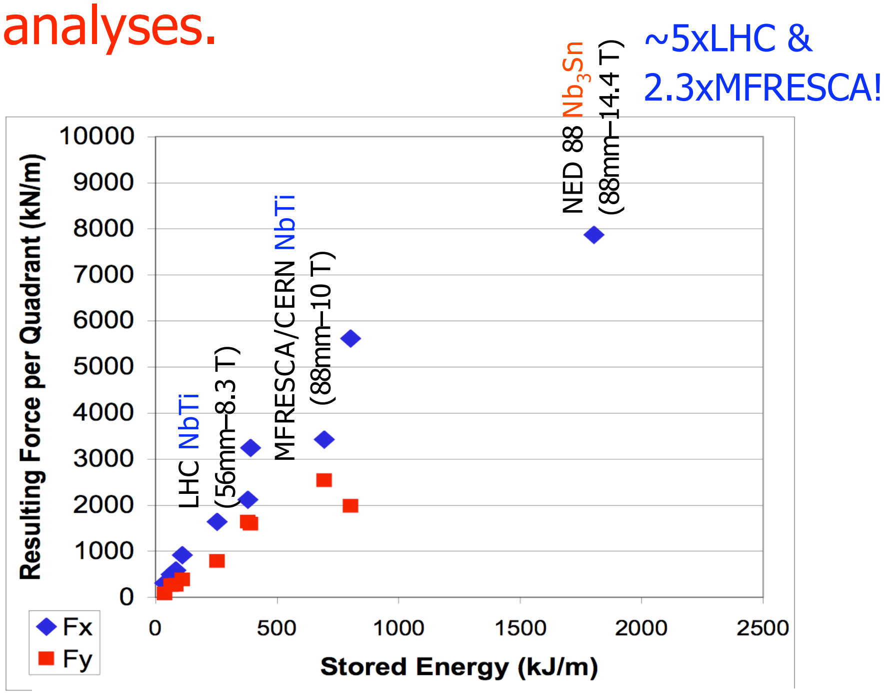


Double helix (RAL)

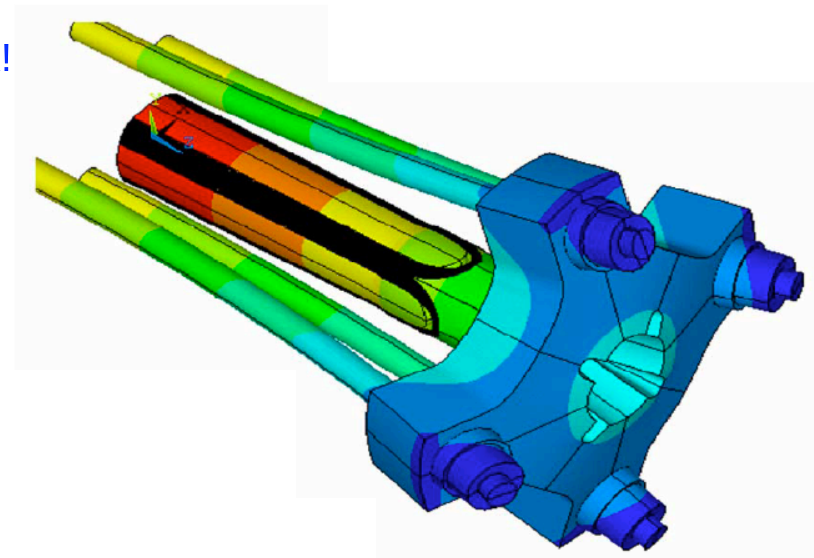
(Courtesy F. Toral, CIEMAT)

NED Design & Optimization (2/2)

- The tricky part is the mechanical design, which now calls for sophisticated 3-D models, with coupled electro-thermo-mechanical analyses.



Lorentz forces in cosθ dipole magnets



3-D model of US-LARP TQS01 at full energization (Courtesy S. CASPI, LBNL)

- DAPNIA/SIS possesses such skills and should be encouraged to use and develop them.

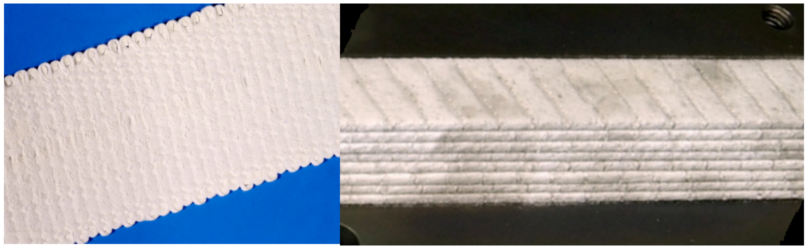
NED Heat-Transfer Studies

- Wherever they are implemented, NED-like magnets are likely to be subjected to high-beam losses, resulting in large energy depositions onto the magnet coils and significant temperature margin reductions.
- Hence, it is of critical importance to compute the beam losses and the the ensuing energy deposition (with codes like GEANT, MARS or FLUKA), to develop detailed thermal models of the magnet coils (to enable temperature margin estimation) and of the magnet cooling system (to ensure proper energy extraction).
- The NED activity includes or sponsors a number of Tasks covering these various aspects; one of them is the study of heat transfer through conductor insulation (which is at the heart of the coil thermal models).

⇒ See B. Baudouy's Talk.

NED Insulation Studies

- Another critical issue is the fact that the conductor insulation must sustain the high-temperature heat treatment (up to 700 ºC for several tens of hours) required for Nb_3Sn phase precipitation.
- The heat treatment is applied to the whole coil upon winding completion, once the most potentially-damageable mechanical deformations have been applied to the conductor ("wind & react" process).
- CCLRC/RAL has identified a polyimide-sized, S2 glass fiber tape that seems a promising candidate for the "conventional" insulation system.
- CEA is pursuing its development on the ceramic-based, "innovative" insulation system that could be used for future applications.



Innovative insulation development at CEA (Courtesy F. Rondeaux)

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Next Step

- The present NED Activity is expected to end during the first semester of 2007.
- By then, we should have: 4 Alstom/MSA and 2 SMI cable unit lengths, a conventional insulation system and a conceptual design.
- The next natural step would be to build one or two magnet models.
- However, it now appears that the FP7 money for CARE-like proposals will not be available before 2009, thereby leaving a 2-year gap!

European Strategy

15 March 2006

A Strategy
for European Superconducting Accelerator Magnet R&D
aimed at LHC Luminosity Upgrade

Dr. Arnaud Devred
CEA/DSM/DAPNIA/SACM (France) & CERN/AT/MAS (International),
CARE/NED JRA Coordinator
Dr. D. Elwyn Baynham
CCLRC/RAL (UK)
Head of Engineering Department
Pr. Maciej Chorowski
Wroclaw University of Technology (Poland)
Dean of the Faculty of Mechanical and Power Engineering
Dr. Pasquale Fabbricatore
INFN-Genova (Italy)
Dr. Eng. Luis Garcia-Tabares
CIEMAT-CEDEX (Spain)
Head of Applied Superconductivity Group
Dr. Stephen Gourlay
LBNL/AFRD (USA)
Leader of US-LARP/Superconducting Magnets
Ir. Andries den Ouden
Twente University (The Netherlands)
Faculty of Science and Technology
Dr. Stephen Peggs
BNL/SMD & FNAL/TD (USA)
Leader of US-LARP
Pr. Lucio Rossi
CERN/AT (International)
Head of Magnets And Superconductors Group
Mr. Laurent Tavian
CERN/AT (International)
Head of Cryogenics for Accelerators Group
Dr. Giovanni Volpini
INFN-Milano/LASA (Italy)
Mr. Louis Walckiers
CERN/AT (International)
Head of Magnet Test and Measurements Group

1/5

- In March 2006, the NED+US-LARP partners have co-signed a document outlining "a strategy for European accelerator magnet R&D aimed at LHC luminosity upgrade."
- Among others, this document recommends the manufacturing of NED in a time frame compatible with the design choices for LHC IR upgrade (end of 2009-beginning of 2010).

Aymar's Strategy

Conclusions

CERN is ready to make its contributions to the further development of high energy physics in the coming decades,

→first of all by **providing the LHC, to be optimally exploited** by the ATLAS, CMS, LHCb and ALICE collaborations;

→by endeavoring into a **challenging R&D programme within large collaborations,** in order to provide the community with results allowing timely choices around 2010 on:

- CLIC technology and LC design;
- High field Nb_3Sn magnets (~15T)
- Pulse field NbTi magnets (3.5T, 4T/sec)
- Advanced proton accelerator design (SPL; fast cycling SC synchr.);
- neutrino factory design study

→provided the community can convince the member states to adequately **bridge the funding gap in CERN budgets from 2007 - 2011**

R. Aymar, Zeuthen Workshop, May 2, 2006

Preparing for NED Phase II

- Following up on the Zeuthen meeting, ESGARD met on 19 May 2006 and has recommended that NED partners put together a collaboration to carry out the manufacturing and test of NED on internal funding.
- A proposal should be submitted to ESGARD by mid-September 2006.
- A similar exercise was carried out in the Spring of 2005 for a EU-NEST proposal (EUROMAG) that was not accepted; EUROMAG can be used as a basis for the new collaboration.

Proposed NED Phase II WBS

- The proposed NED Phase II organization is
  - WP1: Central Design & Integration (all; activity coordination, technical document centralization and interface management),
  - WP 2: Supporting R&D & Demonstrators **(CIEMAT;** R&D on critical components and tooling + LBNL-type short model coils; possible collaboration with US-LARP),
  - WP 3: Coil Manufacturing **(CEA**+CCLRC for insulation; 4 dummy poles + at least 6 final poles),
  - WP 4: Collaring & Cold Mass Assembly **(INFN**+CERN support; 2 model magnets, one for CERN and one for CEA?),
  - WP 5: Cold Test **(CERN).**
- Institutes may team up with industrial partners, but given the level of risks and complexity, they should be sole responsible.

Planning for NED Phase II Proposal

- The following planning is proposed
  - June 2006: round table and brainstorming

    (so far, I have had contacts with

    J.A. Rubio, CIEMAT,

    L. Rossi, L. Walckiers and P. Lebrun, CERN,

    G. Volpini, INFN,

    B. Mansoulié, A. Dael, J.M. Rifflet, P.Y. Chaffard, J.M. Baze, CEA,

    and I am meeting J. Womersley, CCLRC/RAL, on 5 July).
  - July 2006: proposal update.
  - August 2006: proposal write up.
  - September 2006: presentation to ESGARD.
  - November 2006: review by NED/External Scientific Advisory Committee.

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Conclusion

- Nb_3Sn technology may be at hand for the next generation of accelerator magnets needed for LHC upgrade and beyond, but still requires very substantial R&D efforts.
- NED phase II seems a good vehicle to promote this type of R&D in Europe, while being complementary to US programs.