ECOMAG-05

presented by L. Bottura

CARE-05 General Meeting

CERN, November 23rd-25th, 2005

Overview

- Organization and Aims of the Workshop
- Scope and Magnet Design Parameters
  - Manufacturing issues
  - Pulsed field issues
- R&D Identified
- Networking Results

Venue and Organization

- Workshop jointly hosted and sponsored by ENEA and INFN Frascati
- Organizing committee:
  - L. Bottura (CERN), P. Fabbricatore (INFN), G. Moritz (GSI), W. Scandale (CERN), D. Tommasini (CERN)
- Local organizers:
  - A. Della Corte (ENEA), U. Gambardella (INFN)

Aims

- Define a set of magnet design parameters for the development of pulsed superconducting magnets for accelerators (main objective of HHH-AMT-2)
- Establish the state-of-the-art in present design and manufacturing capability
- Specify the performance requirements of strand, cable, magnet and auxiliaries (i.e. cryogenics, power supplies, instrumentation, protection, measurement systems)
- Define the R&D need to achieve the above specifications

A Workshop !

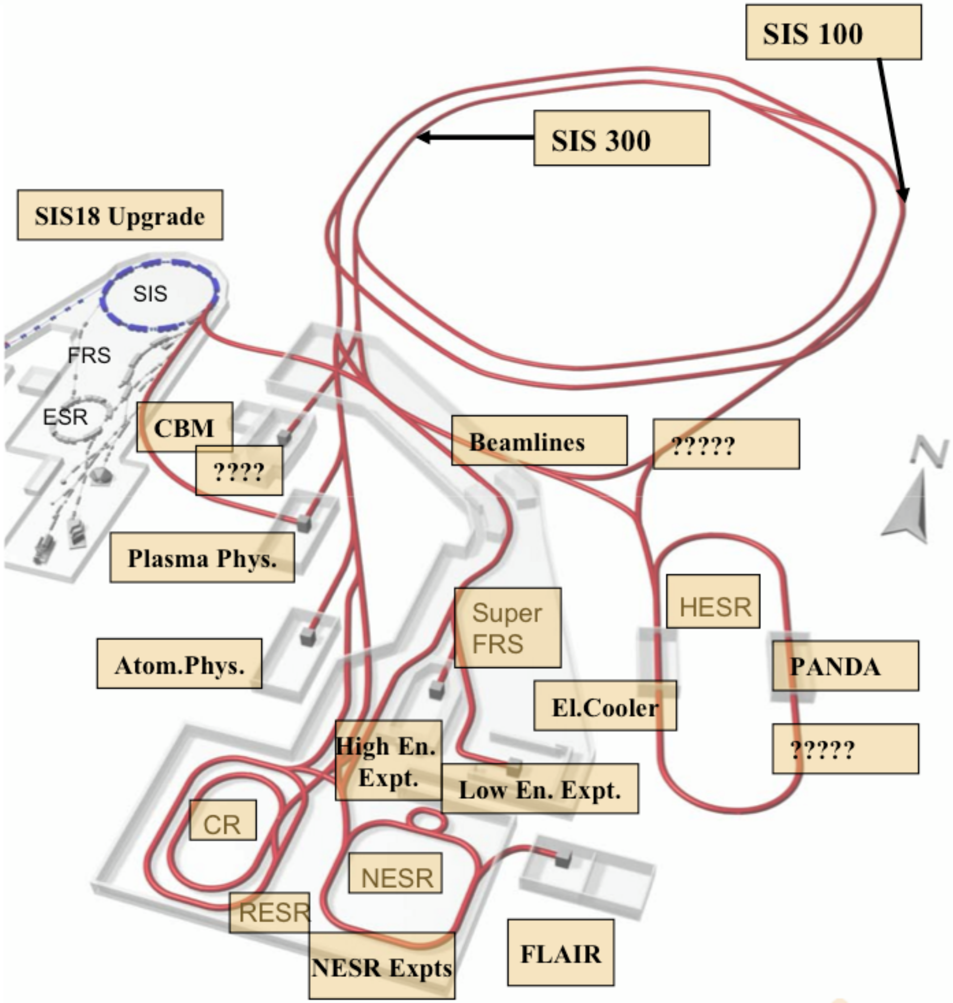
- Three working groups
  - Wires and Cables (WG-1) J. Kaugerts (GSI)
  - Low losses pulsed magnets (WG-2), E. Salpietro (EFDA-CSU)
  - Heat transfer, quench protection and magnetic measurements (WG-3), A. Siemko (CERN)
- Invited talks from specialists in the field
  - D. Leroy (CERN)
  - P. Bruzzone (EPFL-CRPP)
  - J. Minervini (MIT-PFC)
  - B. Baudouy (CEA-Saclay)
- Contributions from industry
- Summary and round table session

Scope

The discussion focused on two large accelerator complexes requiring rapidly pulsed, high duty-cycle synchrotrons:

- the *main rings* of the International Facility for Antiproton and Ion Research (FAIR) at GSI-Darmstadt (Germany):
  - SIS-100 (2 T, 2 s, 200 x 10^6 cycles)
  - SIS-300 (6 T, > 10 s, 1 x 10^6 cycles)
- the LHC injector chain at CERN, aiming at an increase of luminosity and to prepare for an energy upgrade
  - Proton-Synchrotron (PS+) (3 T, 3.6 s, 60 x 10^6 cycles)
  - Super-Proton-Synchrotron (SPS+) (4.5 T, 15 s, 1 x 10^6 cycles)

The FAIR Complex



- SIS-100
  - Heavy ions/protons acceleration
  - Fast extraction to SIS-300
  - Fast extraction to RIB/Antiproton targets
- SIS-300
  - Stretcher ring
  - Accelerates heavy ions
  - Slow extraction

Courtesy of H. Gutbrod, GSI

Magnet Design Parameters for FAIR SIS-100 and SIS-300

	SIS-100	SIS-300
Peak field [T]	**2**	**6**
Good field region [mm]	HxV = 130x60	Φ = 80
Magnet length [m]	2.9	2.9
Number of dipoles	108	108
Field quality [10^{-4}]	**± 6**	**± 2**
dB/dT [T/s]	**3.5**	**1**
Duration of a cycle [seconds]	2	24
Number of cycles (20 years) [-]	**200×10^6**	**1×10^6**
Radiation load [W/m]	1	1
Average refrigeration power [W/m]	**20**	**10**

An Upgrade Scenario for the LHC Injector Chain

- Up to 160 MeV: LINAC 4
- Up to 2.2 GeV(or more): the SPL
  (or a super-BPS)
  (or a RCS)

See CARE-HIPPI

The superconducting way:

- Up to 60 GeV a SC super-PS
- Up to 1 TeV a super SPS
- SC transfer lines to LHC

The normal conducting way:

- Up to 30 GeV a refurbished PS
- Up to 450 GeV a refurbished SPS

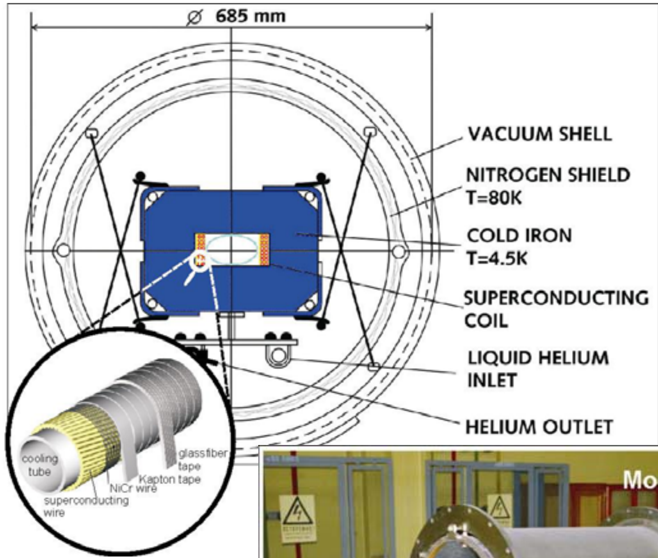
Courtesy of W. Scandale
Proceedings of APD-LUMI-05

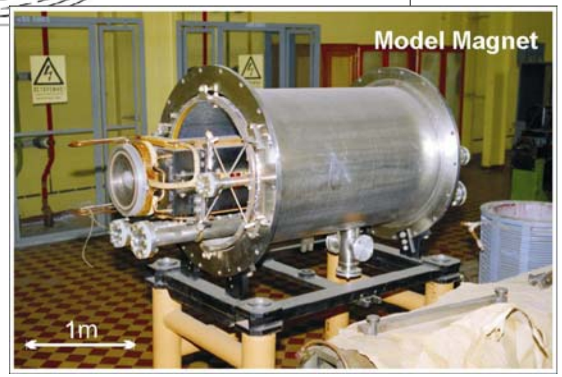
Magnet Design Parameters for the Upgrade of LHC Injectors

	PS^+	SPS^+
Peak field [T]	**3**	**4.5**
Good field region [mm]	HxV = 130x80	Φ = 80
Magnet length [m]	4	6
Number of dipoles	100	750
Field quality [10^{-4}]	**± 4**	**± 2**
dB/dT [T/s]	**3.5**	**1.5**
Duration of a cycle [seconds]	3.6	12
Number of cycles (20 years) [-]	**60×10^6**	**1×10^6**
Radiation load [W/m]	10	10
Average refrigeration power [W/m]	**20**	**10**

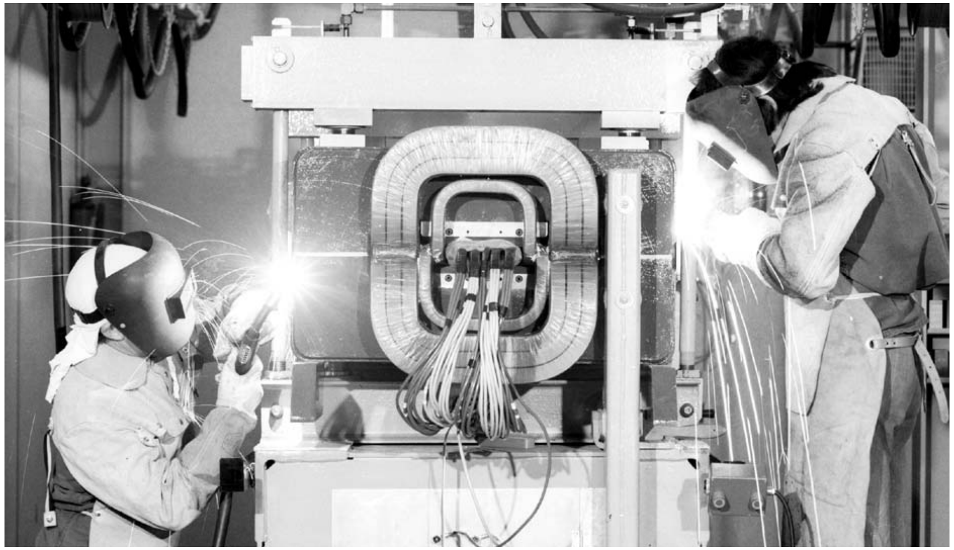
Magnet Design Options:
Up to 2 T

Superconducting option





Resistive option

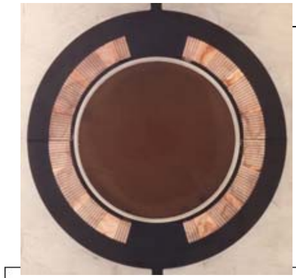


SPS dipole

Nuclotron (SIS-100) dipole

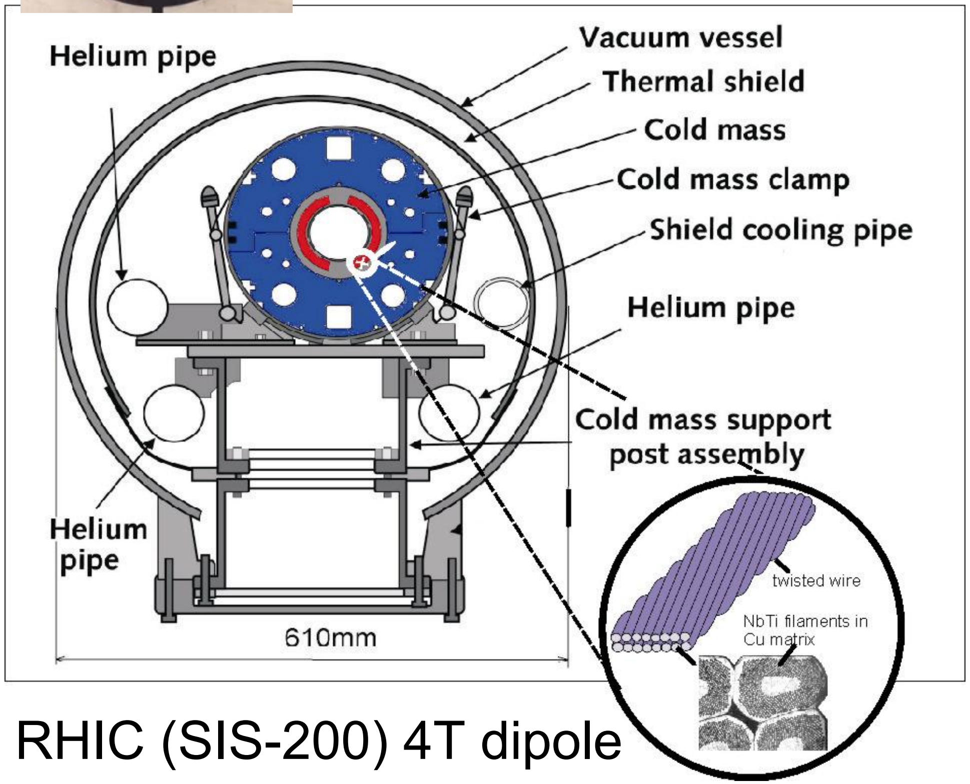
Courtesy of G. Moritz, GSI

Magnet Design Options:
Up to 4 T

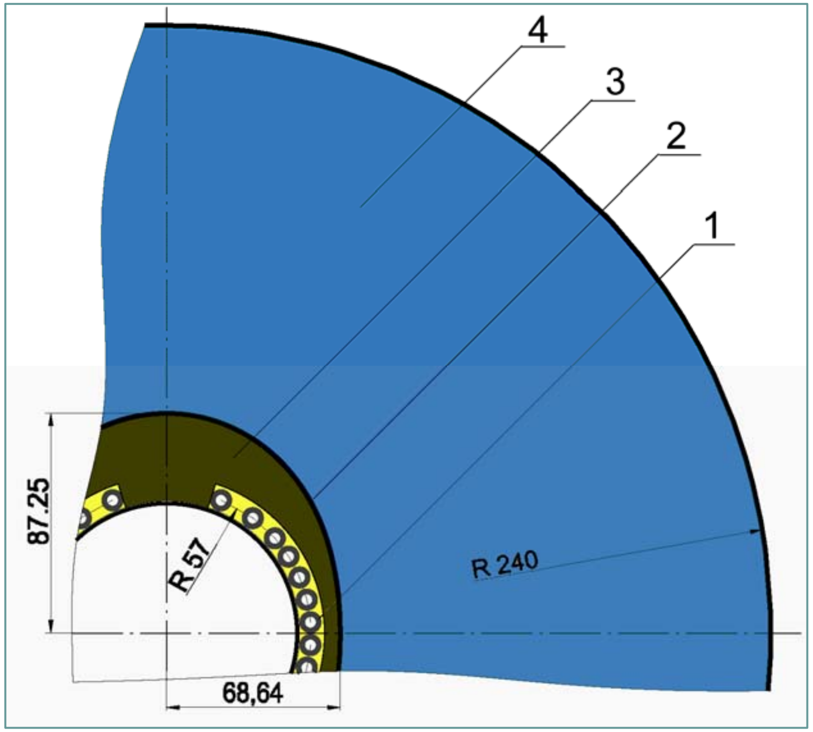


Cos-θ design

Internally cooled cables



RHIC (SIS-200) 4T dipole



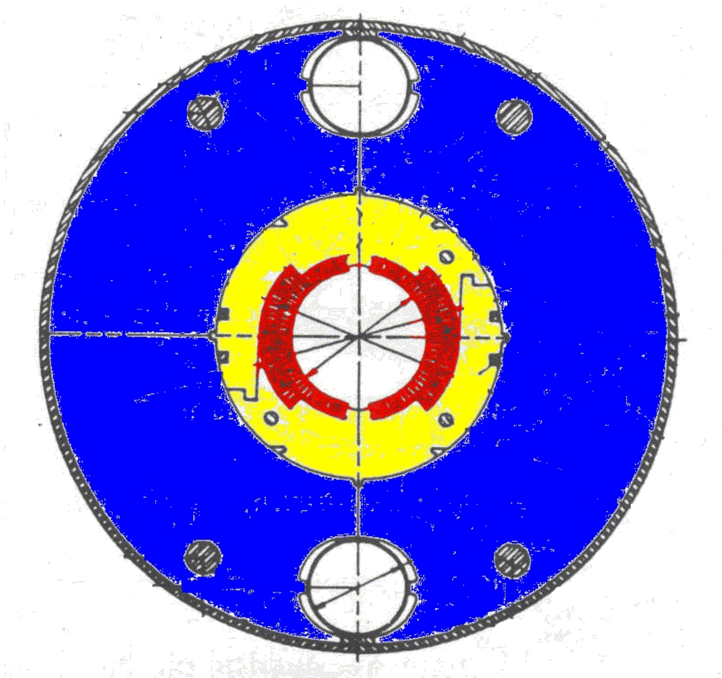
3T dipole

Courtesy of G. Moritz, GSI

Courtesy of A. Kovalenko, JINR

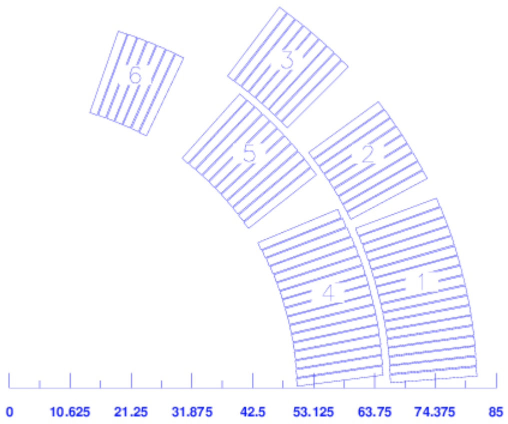
Magnet Design Options: Beyond 4 T

Cos-θ design

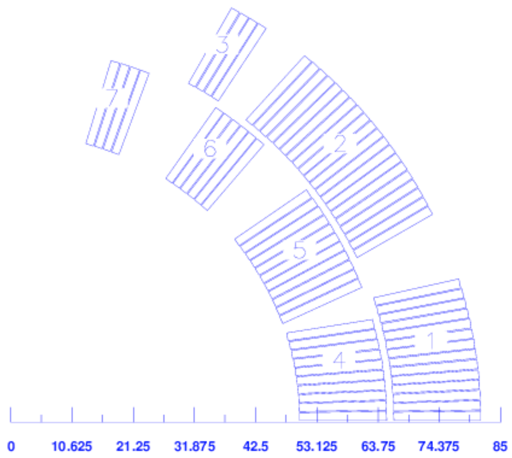


UNK (SIS-300) 6T dipole

Coil optimization



V6 (IHEP)



V7 (CERN)

Courtesy of G. Moritz, GSI

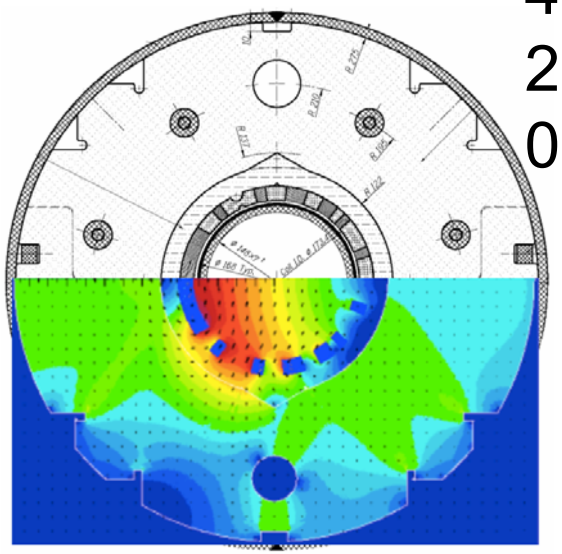
Comments on the Magnet Design Options

- All magnet families have difficulties and challenges
  - Balance of conductor margins, losses, heat removal
  - Field quality in ramped conditions
  - Large dynamic range (a factor 30 in energy for the PS^{+})
  - Magnet protection during quench
  - Pulsed SC joints
  - Fatigue (several 1…100 MCycles)
  - Radiation (1…10 MGy)
  - Measurement and test issues
- All factors can be addressed and seem to be in reach of present technology, possibly with optimized industrial process (strand, cable)

Can we build and measure these magnets ? YES

Design and Optimization Issues *for CERN injectors* - 1

- Combined functions or FODO
  - Examine the lattice options
  - Summarize available lengths
  - Optimize the use of space
- Magnetic length vs. magnet sagitta vs. longitudinal filling factor
  - See the *discussion* on the effect of an increase of magnetic length in the dipoles for SIS-300

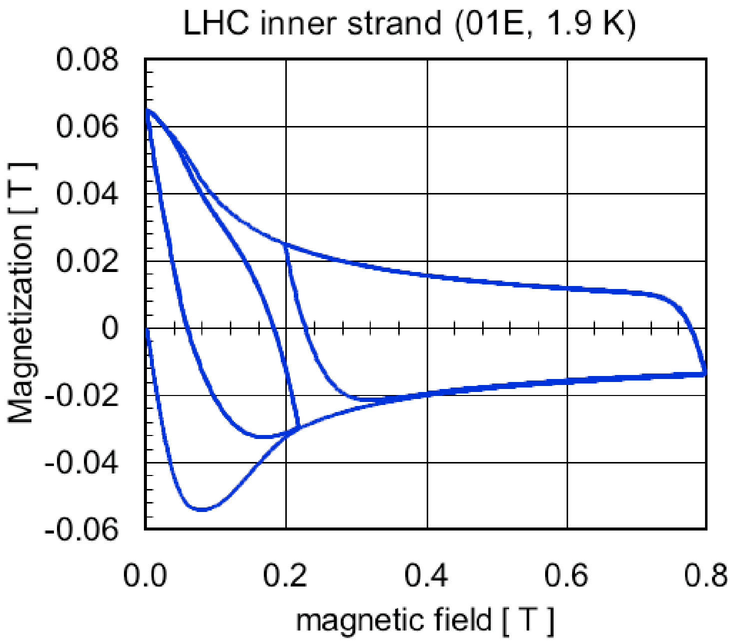


4.6 T B_{peak}
2.5 T B_{dipole}
0.7 T/s

Courtesy of A. Yamamoto, KEK

We need to be clear on the requirements on optics/field/magnet design

Design and Optimization Issues *for CERN injectors* - 2



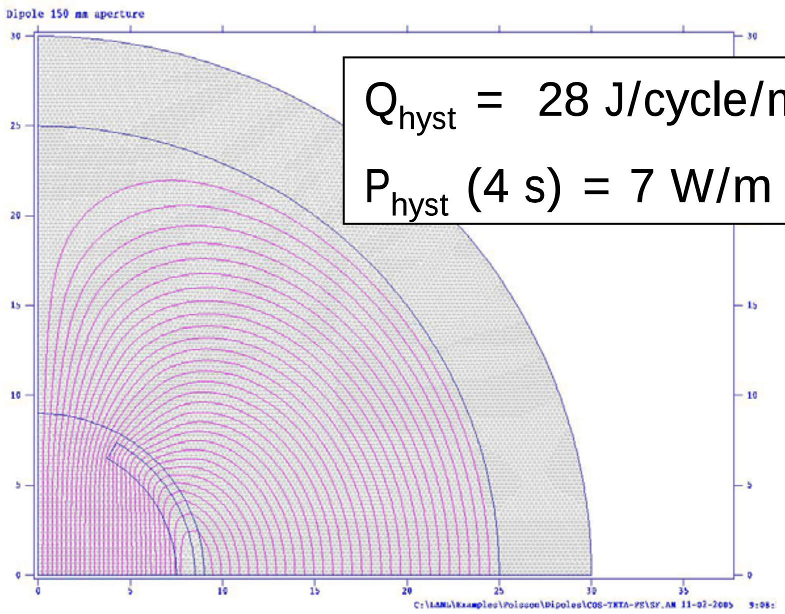
Courtesy of S. Le Naour, CERN

- Large dynamic range
  - 30 for PS^+, 10 for SPS^+,
- Low injection field in the coil
  - $PS^+ \approx 0.1$ T, $SPS^+ \approx 0.4$ T
- SC filament magnetization may have a very strong effect on field quality (at the $10^{-3} \ldots 10^{-2}$ level)
- An iron-dominated magnet reduces the influence of SC magnetization, but has a large saturation and require complex design of lamination, shims (and compensation coils, if needed)

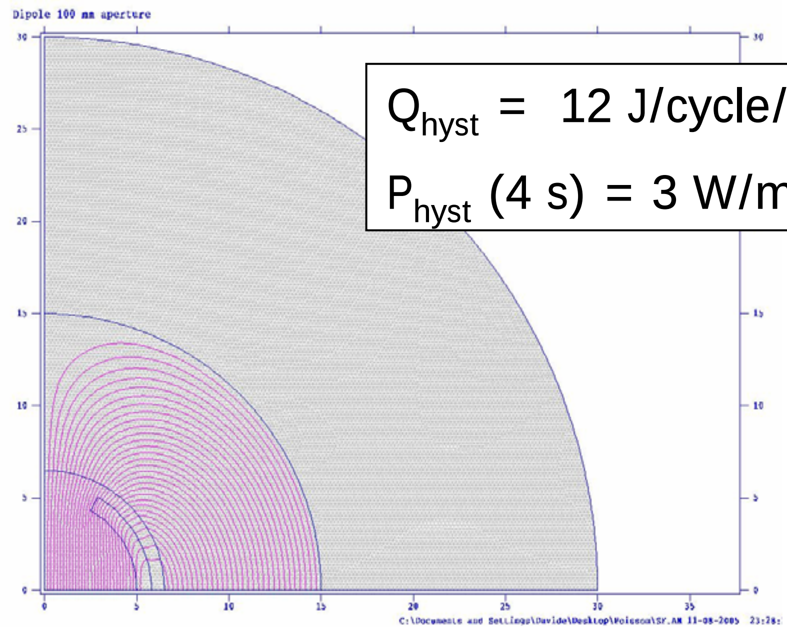
We need to examine concepts and *home-in* on the best design for the required performance

Design and Optimization Issues *for CERN injectors* - 3

150 mm aperture, 3.5 T



100 mm aperture, 3.0 T

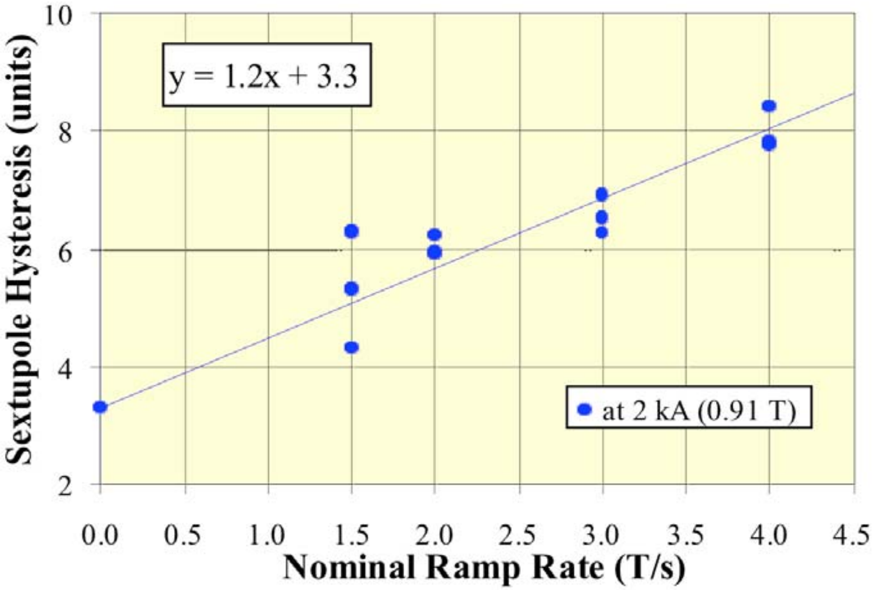


Courtesy of D. Tommasini

Magnet specifications, design options and performance limits are closely inter-related

Design and Optimization Issues - 4

- The effect of eddy currents on the field (lag/advance) and field quality becomes an issue at a ramp-rate of 1…4 T/s



Strand internal structure, resistive matrix and twist pitch

Cables and inter-strand resistance control

Iron (ends !) and iron packs

Effect of conducting components

The basic understanding is there, but…

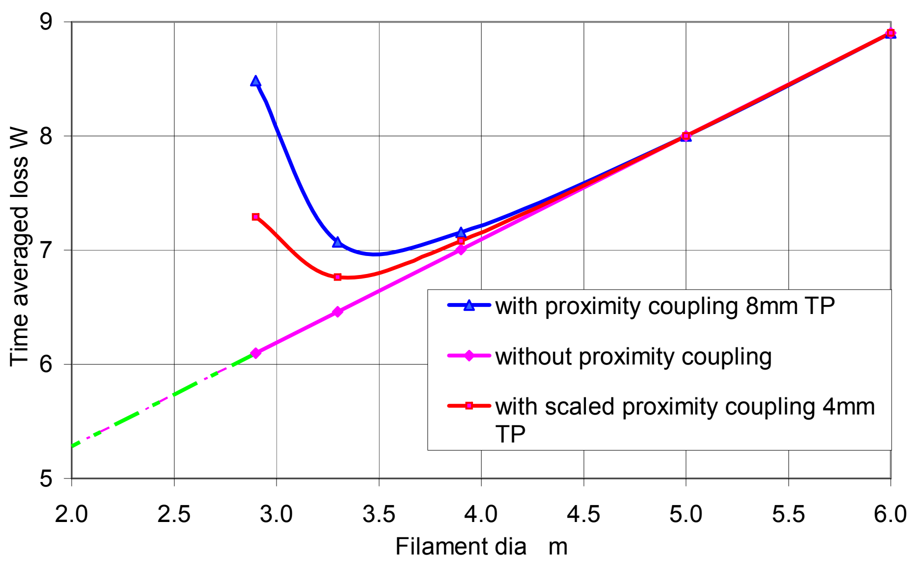
can we predict/optimize as well as we think ?

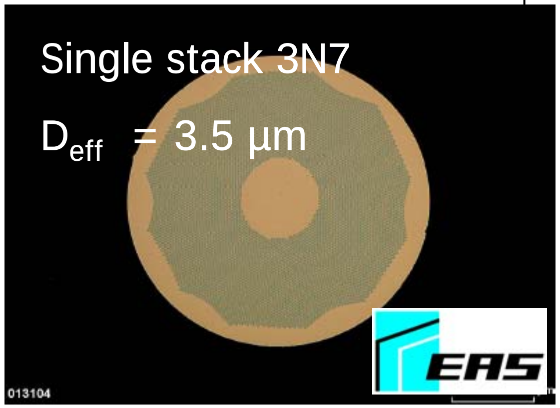
On the Strand

- Present strand technology is sufficient for the demands of FAIR
- The requirements for an efficient upgrade of the CERN injector chain may demand further reduction of AC loss (factor 3…5)
- The plan is to industrialize the baseline strand for SIS-300 through the production of several billets to achieve consistent and continuous performance
- Set clear targets for improved performance of FAIR magnets and economic CERN injector upgrade and assist manufacturers in this development

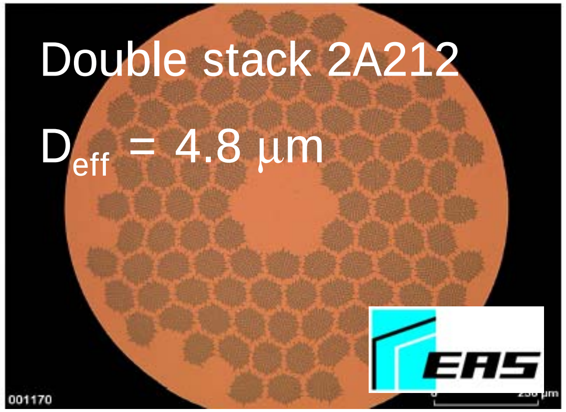
Small Filament R&D - 1

- About 50 % of the loss is generated by hysteresis in the filaments
- Simply reducing the filament size does not work



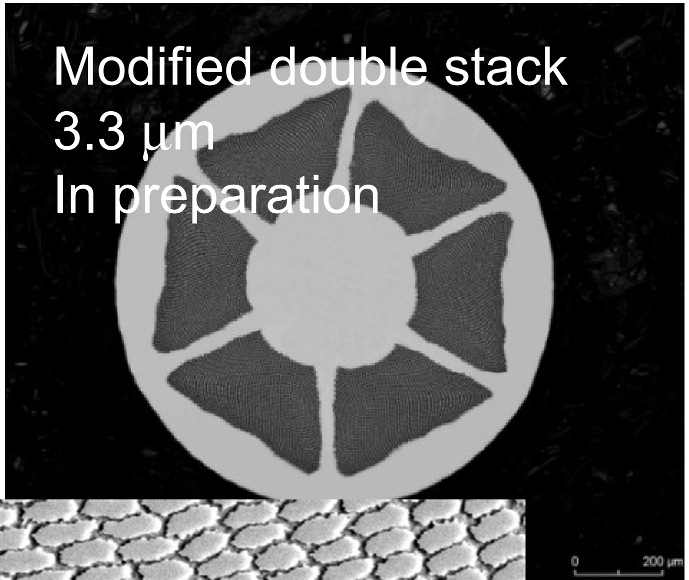


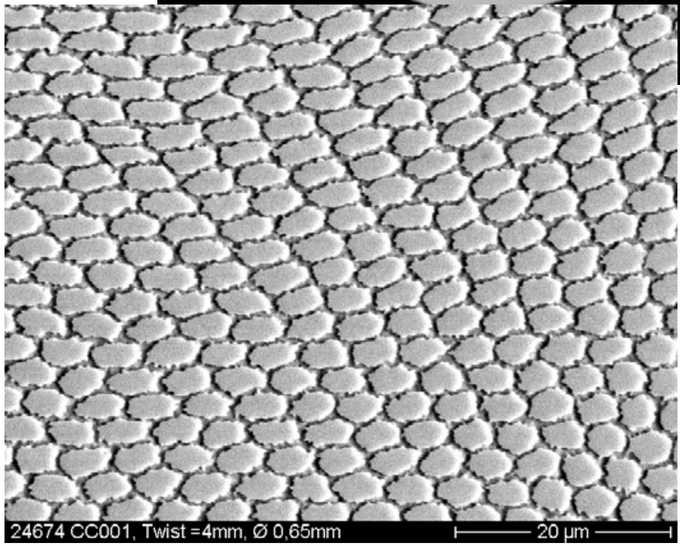
12000 monocores (1.5 mm wide)!

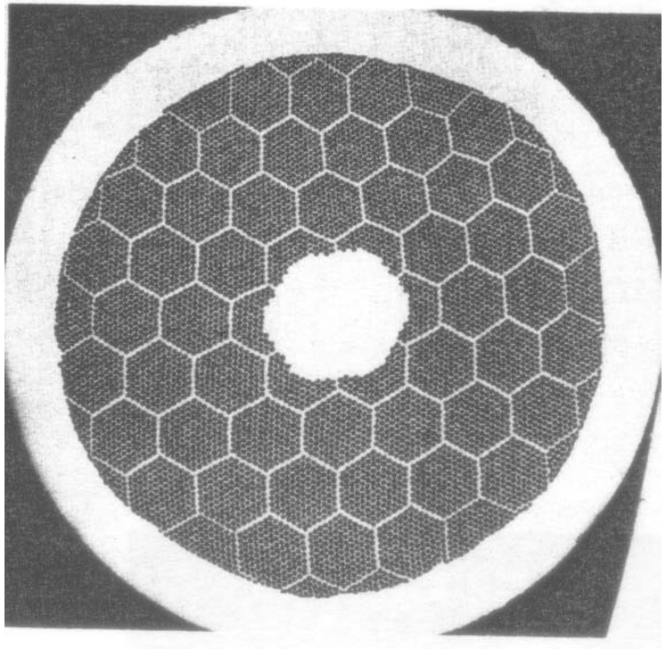


filament distortion near the copper !

Small Filament R&D - 2



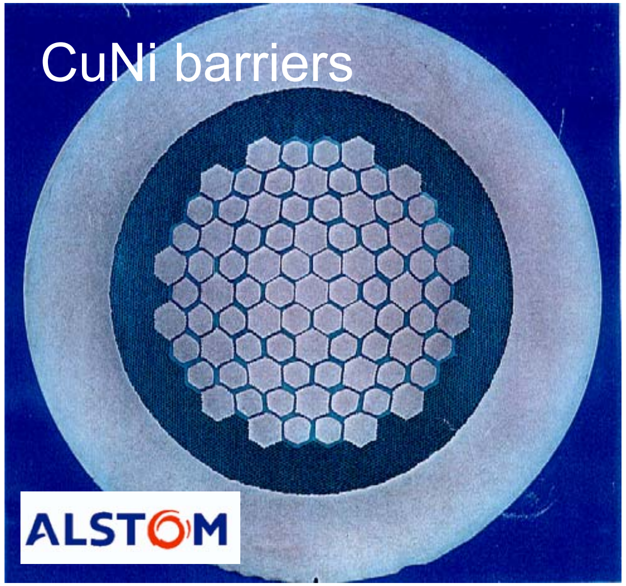


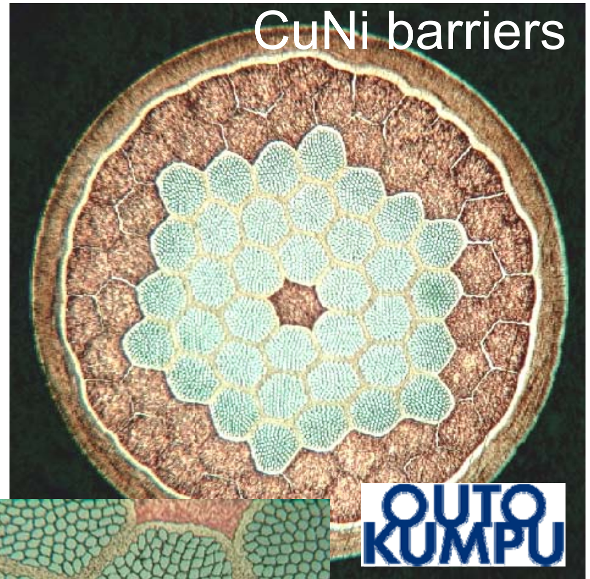


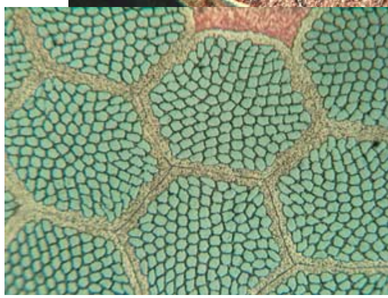
Hex single stack

Better geometry control

Small Filament R&D - 3



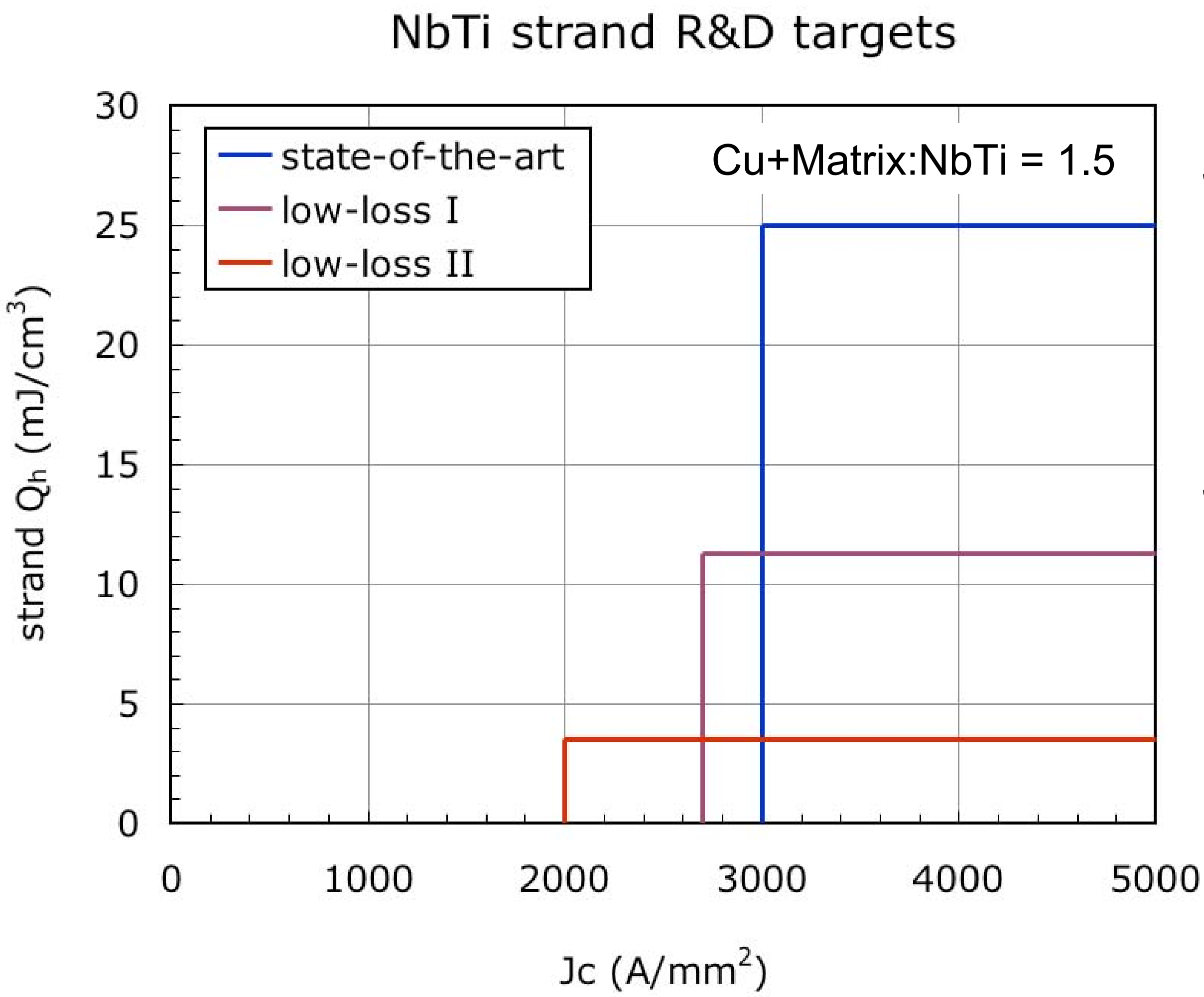




CuNi to reduce coupling

CuMn to reduce proximity

Strand R&D Targets



D = 0.5 … 0.8 mm
J_c > 2500 … 3300 A/mm^2
D_{eff} = 3.5 … 5 µm

D = 0.8 mm
J_c > 2700 A/mm^2
D_{eff} = 2.5 µm

D = 0.5 … 0.8 mm
J_c > 2000 A/mm^2
D_{eff} = 1 µm

On the Cable

- Open issues remain on basic understanding of collective thermal and electromagnetic behaviors
  - Heat transfer experiments (as proposed)
  - Stability experiments and simulations (as proposed)
    - **What is the optimum resistance ?**
  - Perform AC loss measurements (program ?)

Inspired by P. Bruzzone, PERITVS DELINEANDI OPTIMORUM DVCTORVM

On the Magnets

- Responsibles (design coordinators) identified for the four magnet families
  - SIS-100 G. Moritz (GSI)
  - PS^{+} D. Tommasini (CERN)
  - SPS^{+} G. Kirby (CERN)
  - SIS-300 P. Fabbricatore (INFN)
- Workplan for the design coordinators:
  - Examine magnet concepts, question the conductor selection, identify main R&D issues, quantify work (prototypes, how many, by when ?)

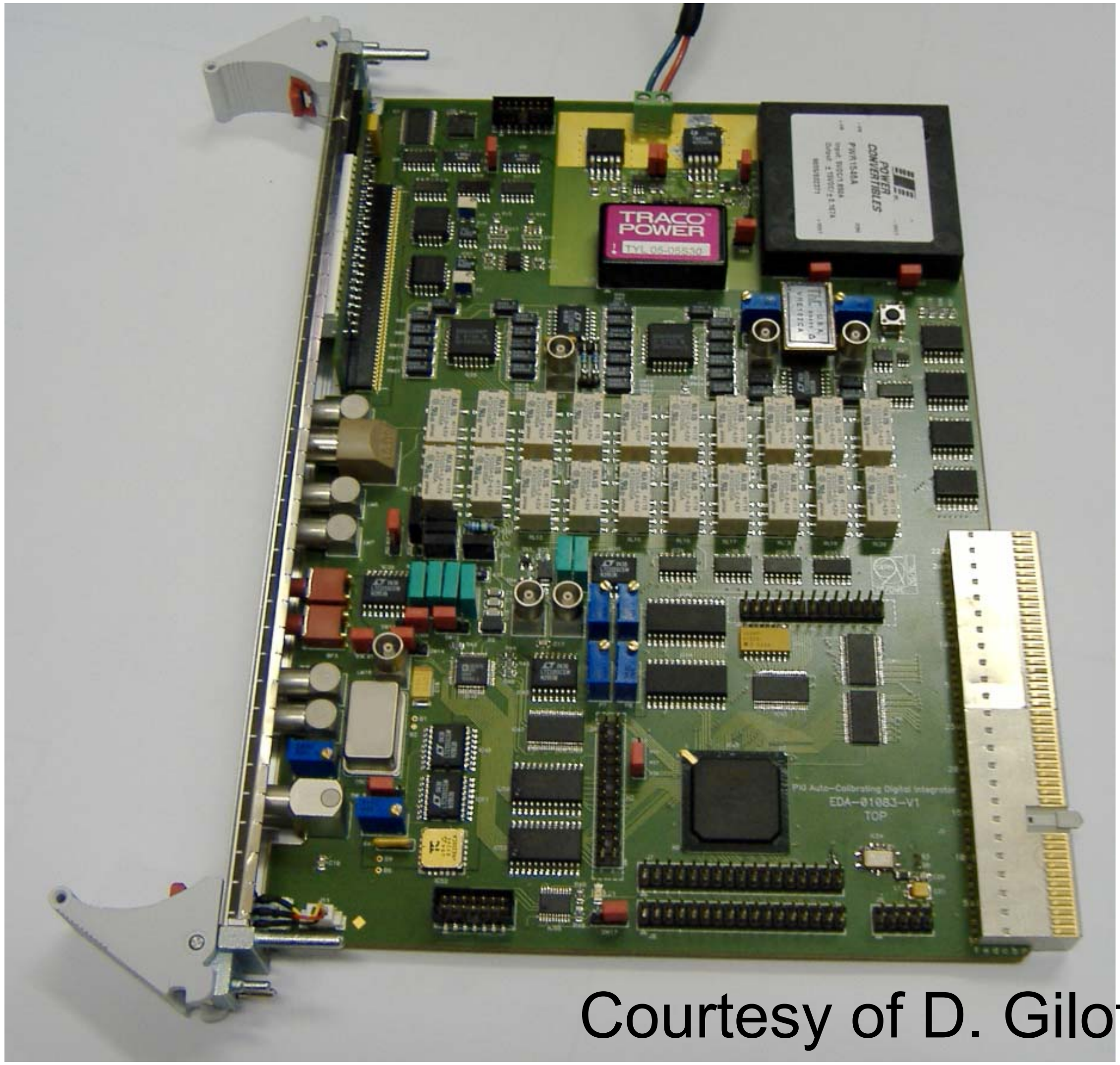
The final answer will only come from magnet test
we need prototypes !

Measurement Issues - 1

- Present capability is well assorted but scattered
  - Fast Digital Integrators and fast rotating coil systems (CERN-AT)
    - Speed, resolution, and accuracy to be proven
  - SPS and CNAO (curved) flux-meters (CERN-AT)
    - Good for main field and homogeneity to few 10^{-4}, no harmonics
  - Harmonic, fixed coils (BNL)
    - Technique in development, low order harmonics at 10^{-4}
  - Harmonic analysis in space of repeated cycles in time
    - *Old* method, promising but relies on powering cycle reproducibility
- No *off-the-shelf* method is available today for the measurement of 3…5 T, 1…4 T/s at 10^{-4}

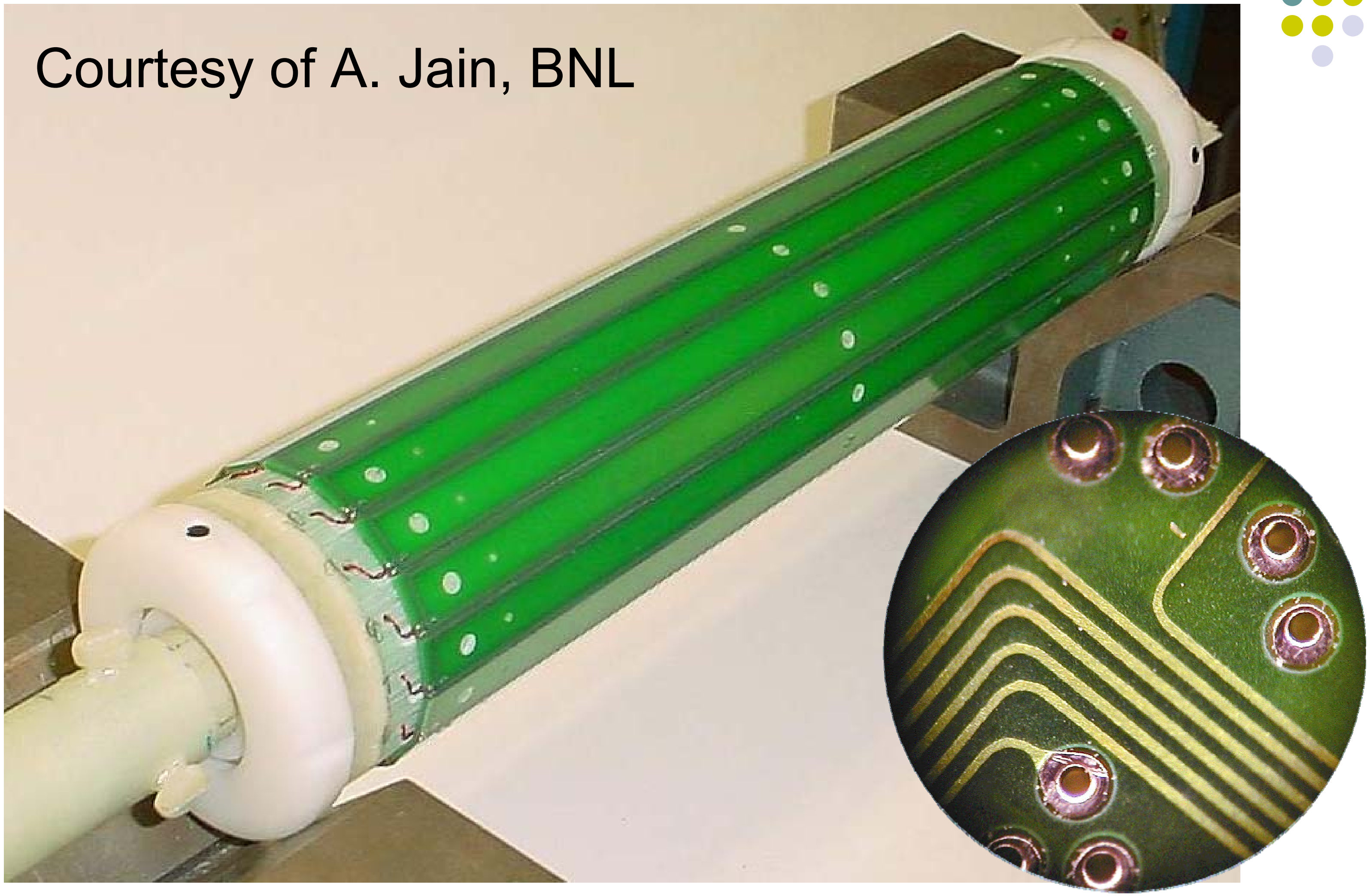
The R&D should be adapted to the new requirements

Fast Digital Integrator

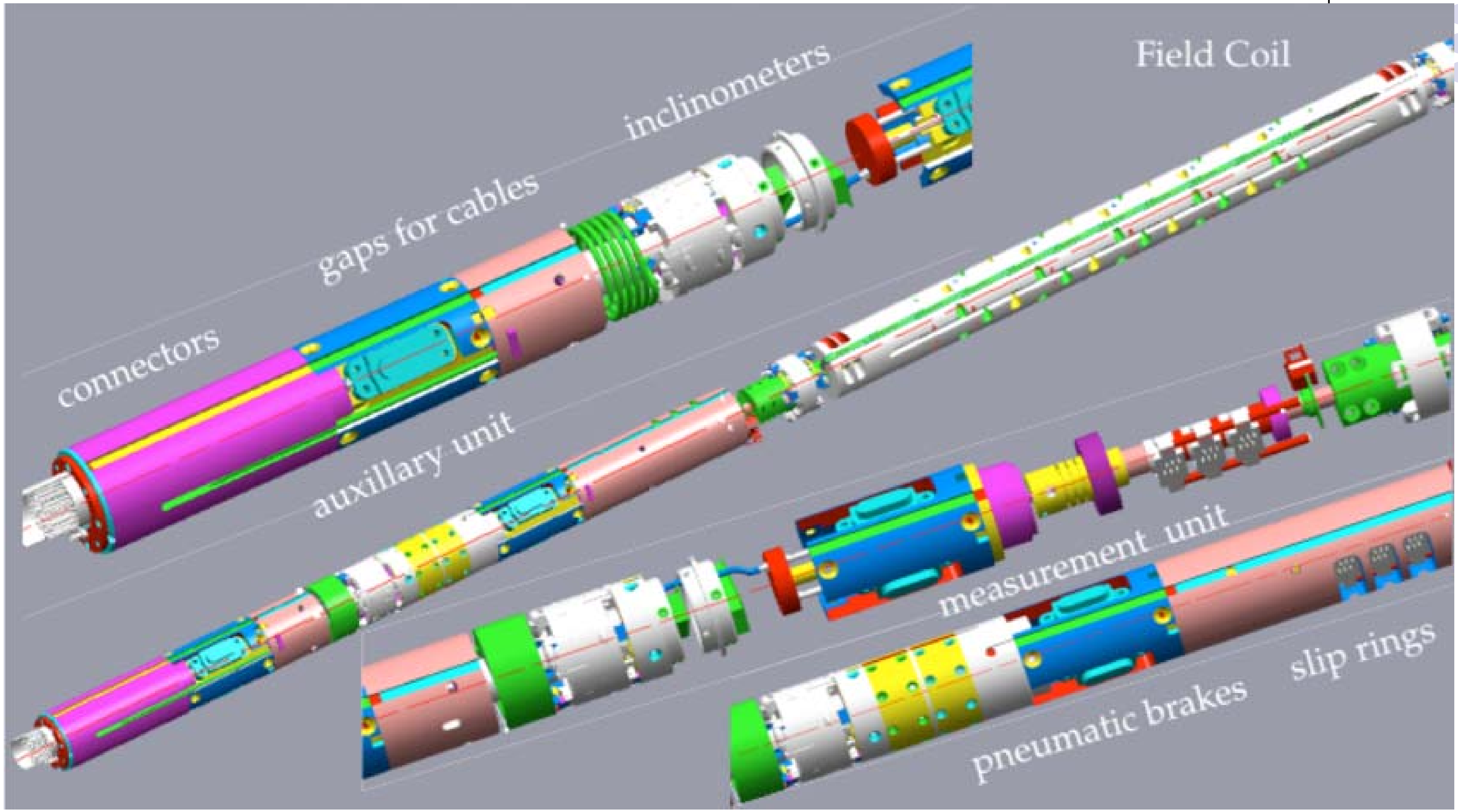


Courtesy of D. Giloteaux, CERN

BNL Harmonic Coil Array



The *do-it-all* Mole



Courtesy of P. Schnizer, GSI

Measurement Issues - 2

- Good pulsed magnets must have low loss
  - 10 W/m to 20 W/m of magnet length, on average
  - 50 to 100 W per magnet
- The reactive power necessary to pulse the magnet is large
  - Typically 100 kVA *per magnet* (20 V, 5 kA)
- The measurement of resistive losses of 10^{-3} of the reactive power is a difficult task (requires a rejection at 10^{-4})

We should demonstrate the feasibility and accuracy of this measurement

Power Control Issues

- A good pulsed magnetic field requires an excellent control of pulsed current
- Large dynamic range (e.g. 30 for PS$^+$) and large controlled voltage (e.g. 1 kV voltage withstand) may pose a challenge for precise control
  - 10^{-4} at injection is 3 ppm at flat-top

Early interaction on the PC design is important for the selection of the magnet concept

Networking Results - 1

- More than 70 participants (initial plan on 30 to 50)
- 17 among laboratories and universities
  - Bochvar Institute, CEA, CERN, **CIEMAT(*)**, **EFDA-CSU(*)**, **ENEA(*)**, **EPFL-CRPP(*)**, **FzK(*)**, GSI, IHEP, INFN-Frascati, INFN-Genova, INFN-Milano, JINR, KEK, **MIT(*)**, Ohio State

    (*) fusion/energy laboratories
- 7 major European industries:

Networking Results - 2

- Cross-breeding among laboratories (HEP and Fusion research in particular) on the topic of pulsed magnets
- Industry involved from the start of the brainstorming, bringing focused and relevant experience in this technology
- Very positive response !

We have identified a general interest in the community of *clients* and *producers*

Follow-up

- The material discussed is collected and will be posted on the www site of the Workshop
- The design coordinators will maintain momentum on the issues identified
- Reconvene in 6 months to verify progress

Special session at **WAMDO**
April 3-7 2006
CERN (Archamps)