HFM/LARP Magnet R&D

Giorgio Ambrosio

for the whole HFM group

All Experimenters Meeting 3/6/06

- **High Field Magnet Program (HFM)**
- **LHC Accelerator Research Program (LARP)**

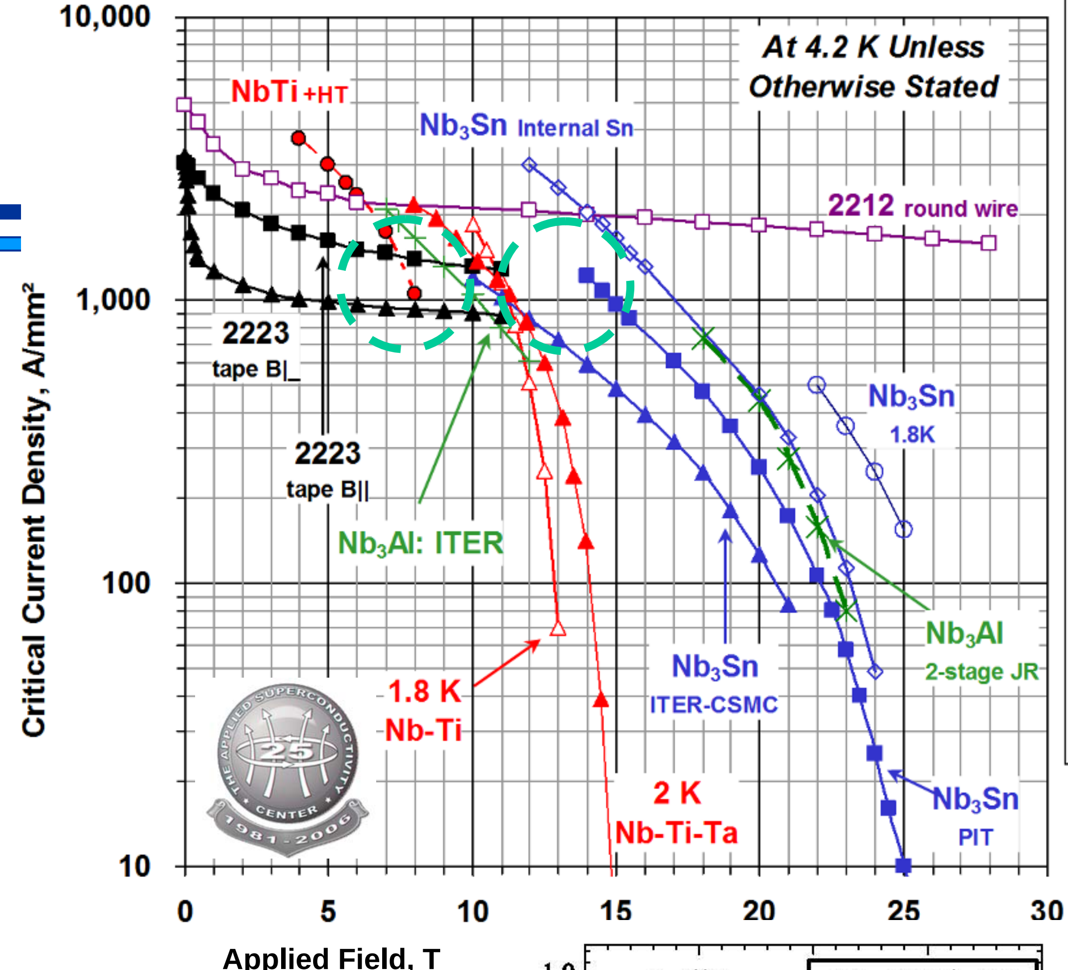
Fermilab has long and successful history of SC accelerator magnet R&D:

Tevatron, Low Beta Quads, SSC dipoles, VLHC superferric transmission-line, LHC IR Quads, HFM dipoles

This is because SC magnets are an enabling technology for HE accelerators

Why Nb_3Sn?

Better performance at 4.2 K than NbTi at 1.8 K



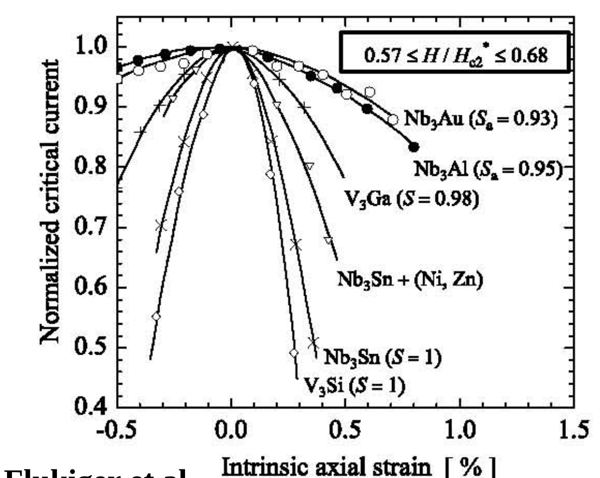
Why not yet?

"Why there aren't Nb_3Sn magnets in any HE accelerator?"

Because Nb_3Sn is a brittle material

➔ Degradation at longitudinal strain > 0.3-0.5%

➔ Degradation at transverse pressure > 120-180 MPa



R. Flukiger et al.,

HFM and LARP goals

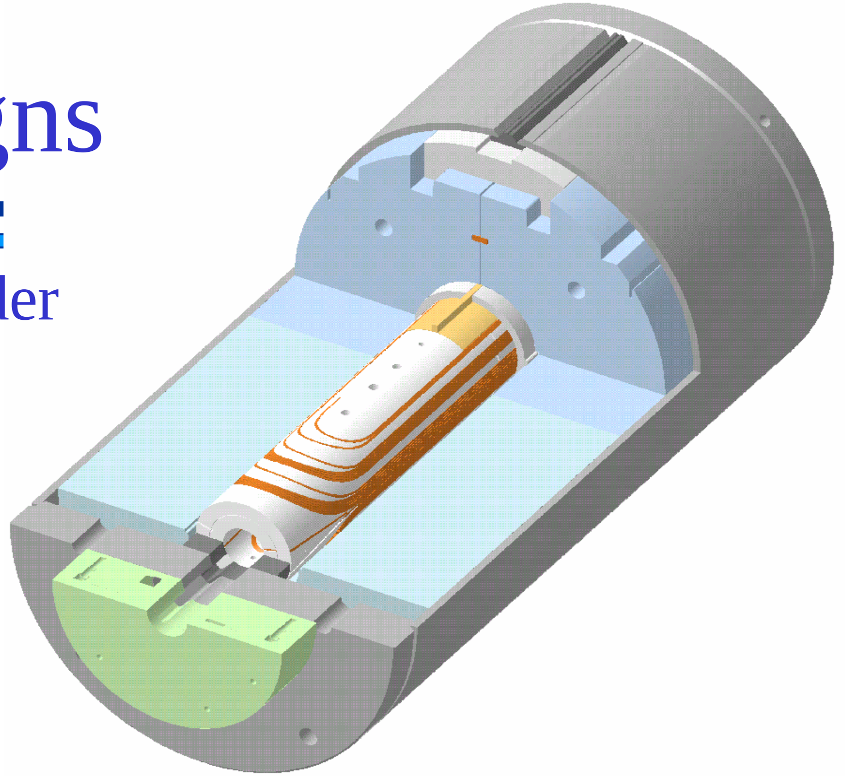
- **HFM program mission: development of <u>next generation SC accelerator magnets</u> with operating fields above 10 T at 4.5 K**
  - ➔ Presently focus on **Nb_3Sn** and **Wind-and-React** technology,
    - React-and-Wind was explored (3 racetrack, 1 Common Coil magnets)
  - ➔ Sufficient aperture, field quality, acceptable dynamic effects
  - ➔ Design and technology compatible with scale-up and industrialization

- **LARP goal: provide options for future upgrades of the LHC IRs**

  1st deadline: **"Demonstrate by 2009 that Nb_3Sn magnets are a viable choice for an LHC IR upgrade"**
  - **Predictable and reproducible performance**
    - SQ and TQ series (1 m, 90 mm aperture, G_{nom} > 200 T/m, B_{coil} > 12 T)
  - **Long magnet fabrication**
    - LR and LQ series (4 m, 90 mm aperture, G_{nom} > 200 T/m, B_{coil} > 12 T)
  - **High gradient in large aperture**
    - HQ series (1 m, 90 mm aperture, G_{nom} > 250 T/m, B_{coil} > 15 T)

HFM magnet designs

- Ceramic Insulation with Ceramic Binder
- No Interlayer Splice
- Spacers instead of Collars
- The yoke gap remains open
- Coil prestress by Al-clamps and skin



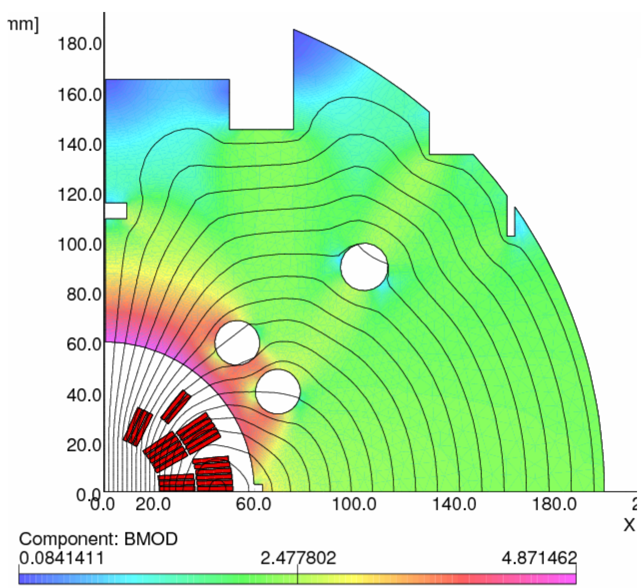
DIPOLE magnet:

- Magnet bore diameter = 43.5 mm
- Number of turns = 48
- Cable: 28 1-mm strands
- B_{max} = 12 T @ J_c = 2000 A/mm^2
- I_{max} = 21.2 kA
- Insulation thickness = 250 μm

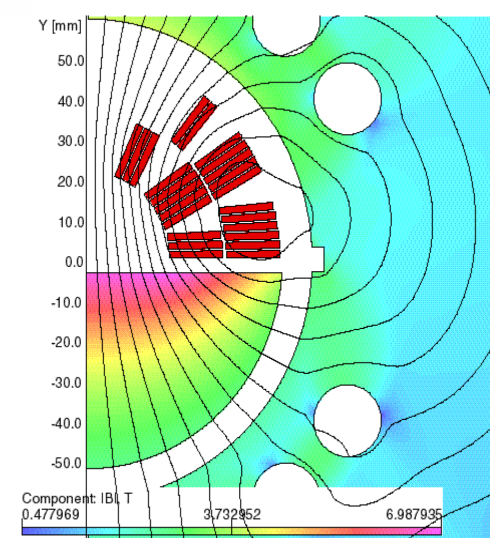
MIRROR magnet

- Number of turns = 24
- Same cable as in dipole magnet
- B_{max} = 8.4 T @ J_c = 2000 A/mm^2
- B_{peak} = 11.2 T @ J_c = 2000 A/mm^2
- I_{max} = 25 kA

DIPOLE magnet

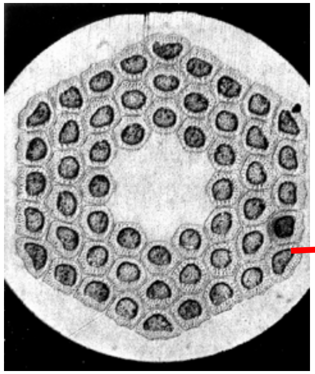


MIRROR magnet

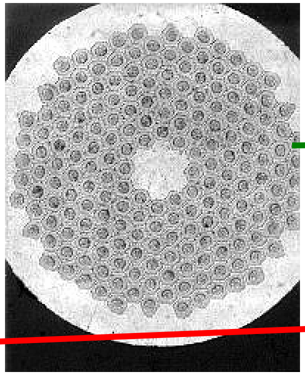


HFM results - I

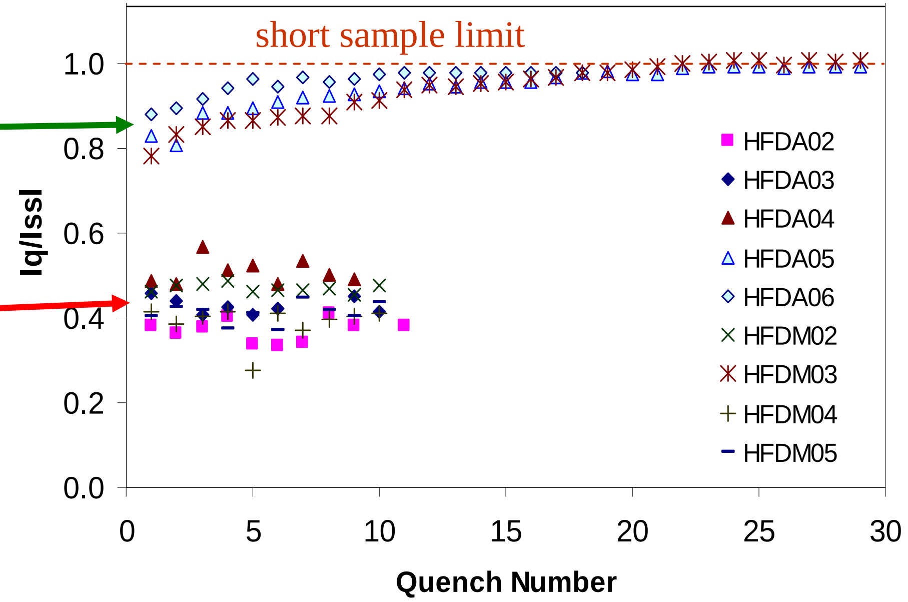
- **Found limitation of present high-current-density Nb_3Sn conductors, understood cause, presented problem to community, and successfully implemented solution**



D_{eff}: 110 μm
RRR ~ 10



D_{eff}: 54 μm
RRR ~ 100



"The tremendous accomplishments of these last two years confirm the strength of the group"

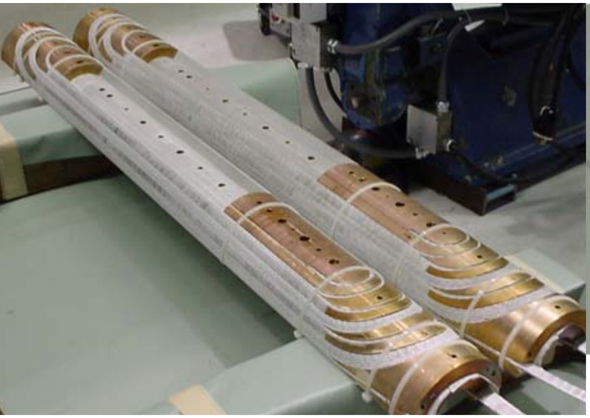
"The expertise developed in these years and the infrastructure that exists or is under procurement, constitutes a vital asset for LARP"

Jan 06 HFM review closeout (L. Rossi, chair)

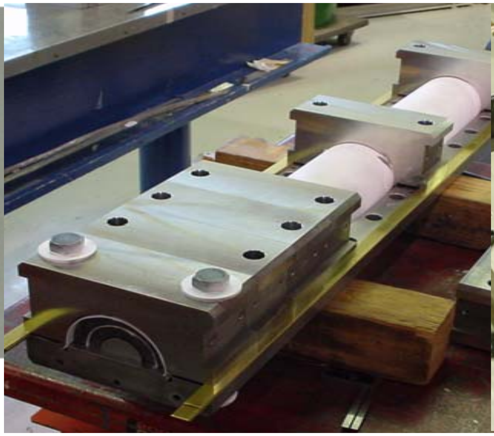
HFM Results - II

- **Developed a <u>robust Nb_3Sn coil fabrication technology</u> with several new features suited for length scale-up and industrialization ➔** All adopted for LARP quadrupoles

  Ceramic binder for insulation, water-jet technology for end-parts, reaction procedure with azimuthal and pole gaps, segmented tooling with "gentle-transfer" procedure, splice design and procedure,



Water Jet Machined Part



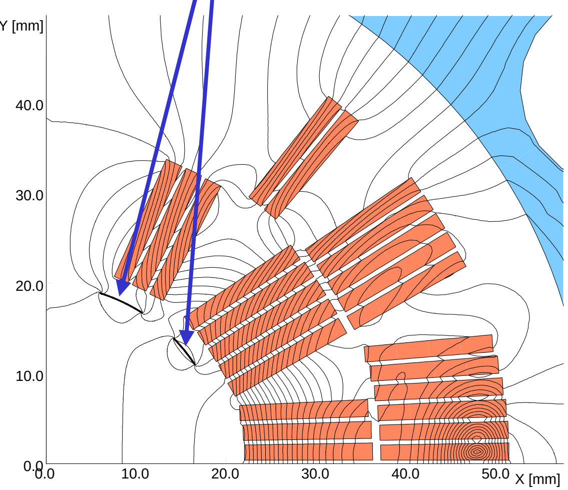
- **Developed Nb_3Sn magnet design and assembly technology allowing significant <u>reduction in cost and assembly time</u>, and easily <u>scaleable to full length</u> accelerator magnets**
  - 4 ½ months for dipole magnet test, 3 months for dipole coil test

HFM results - III & Work in Progress

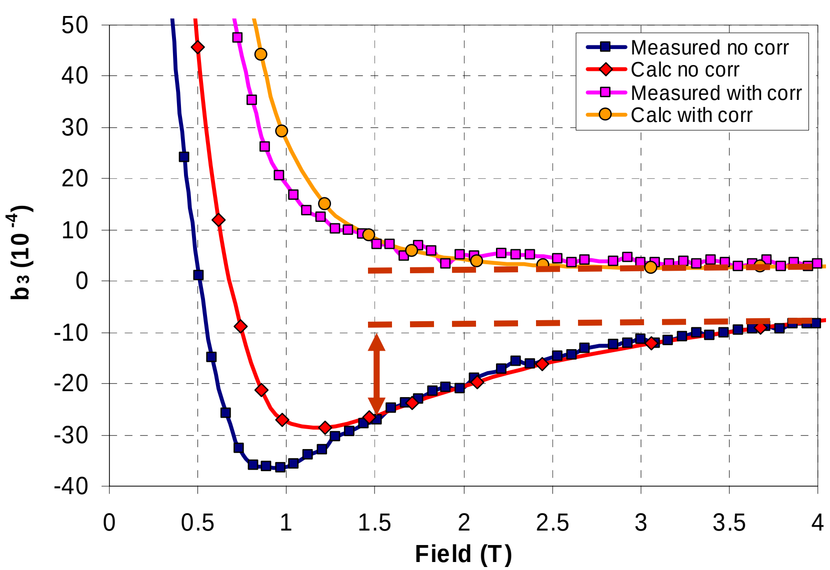
- **Demonstrated field quality reproducibility in Nb_3Sn accelerator magnets, developed simple and effective passive correction of coil magnetization effect, and are studying dynamic effects**
  - Measured field quality in 5 Nb_3Sn cos-theta dipoles (unprecedented)
  - and their dynamic effects (unprecedented) – Work in progress

➔ understanding and reducing largest deviations (by feedback into coil fabrication and assembly technology) – Work in progress

Iron strips



Passive correction effectiveness



The passive correction has reduced the sextupole variation in the field range of 1.5-4 T during the field up-ramp from $19 \cdot 10^{-4}$ to $4 \cdot 10^{-4}$ (R_{ref} = 10 mm)

HFM short-term plan

GOAL: to develop fabrication technology for long Nb_3Sn coils

➔ fabricate and test 2m and 4m long Nb_3Sn dipole coils

- TD Industrial Building 3 (IB3) has been upgraded to allow the fabrication of Nb_3Sn coils and cold masses up to 6m

Front view of mirror magnet

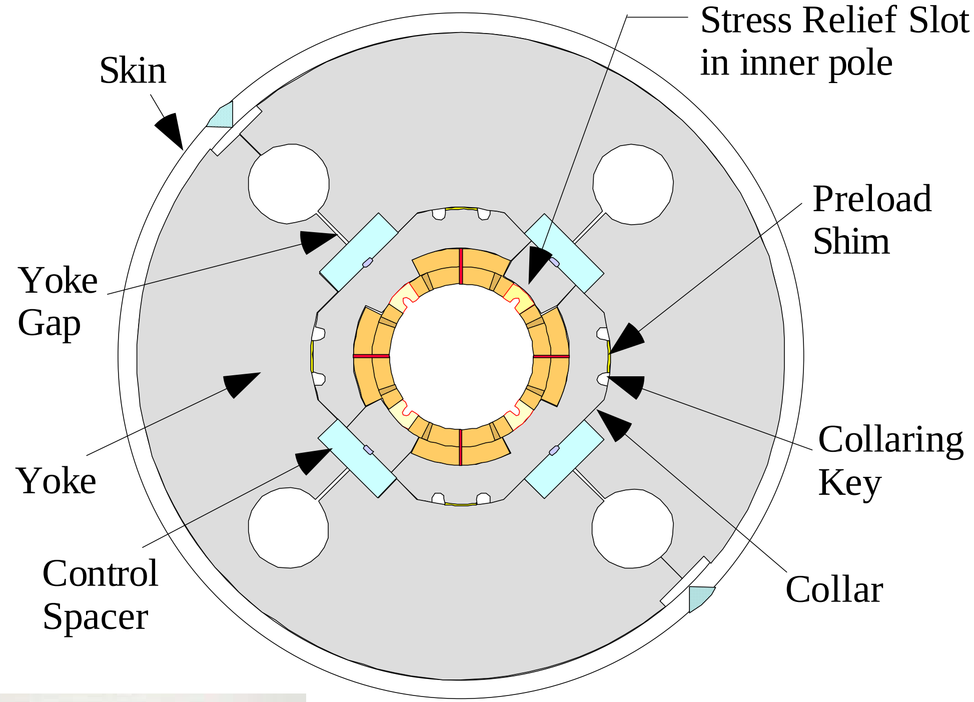
LHC-Quad tooling from ICB to IB3

New 6m furnace for Nb_3Sn

LARP @ FNAL - I

Technological Quadrupoles using collars (TQC)

Plan: 3+ by the end of FY07



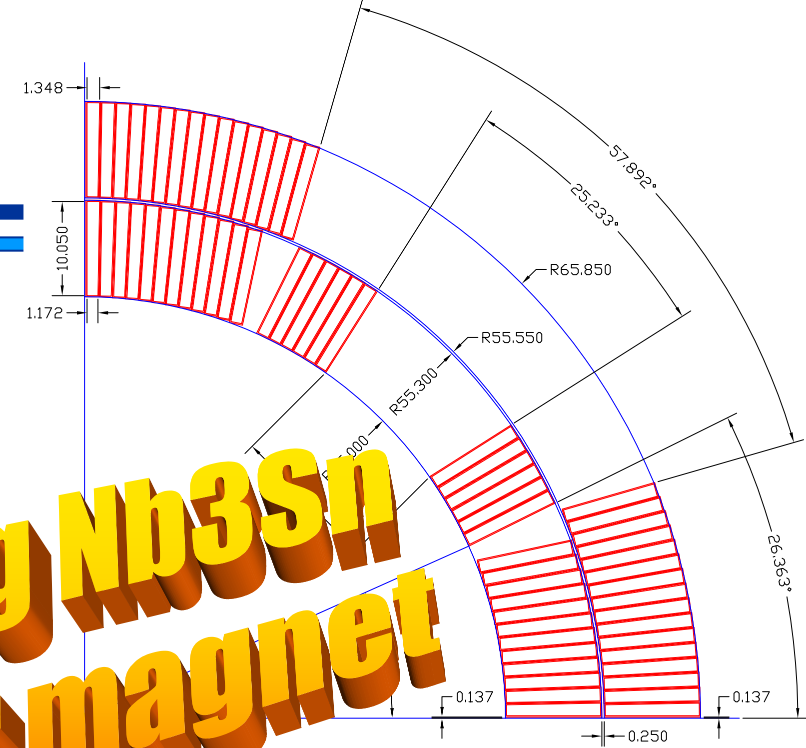
- Magnet bore diameter = 90 mm
- Number of turns = 136
- Strand: Nb_3Sn, ϕ 0.7 mm,
- Cable: N=27, Keystone Angle = 1
- J_c = 2000 A/mm^2 @ 4.2K 12T
- G_{max} = 216/233 T/m @ 4.2/1.9 K
- I_{max} = 12.9/14.1 kA @ 4.2/1.9 K
- Insulation thickness = 125 μm

TQC collar lamination →

LHC_Quad collar lamination →

Can use collars, yoke, skin, tooling and infrastructure developed for the LHC-IR Quads

LARP @ FNAL - II



LONG QUADRUPOLES

- **Gradient > 200 T/m**
- **Aperture 90 mm**
- **Length 4 m**

The 1st long Nb3Sn accelerator magnet

- **Coil design based o[illegible] LARP-TQ[illegible]**
  - 2 layers with 10 mm wi[illegible] [illegible]layer splice
- **Two mechanica[illegible] [illegible]der investigation (TQs):**
  - collars (TQC)
  - Al-shell based structure (preloaded by bladders & keys)
- **Length related issues under investigation by LARP LQ Design Study, by LARP Long Racetrack (4m), and by FNAL Long Mirror magnets**
- **Two Long Quad models tested by end of FY 2009**

Long-term Plans

- **LARP Second phase (2010-2012)**
  - New IR design and **full-size (6m) IR quadrupole prototype**
- **LHC IR upgrade project (~2013-2015)**
  - **fabrication and test of IR quads** for the LHC high luminosity upgrade
- **Magnets for future accelerators:** ***(Muon collider/SR, future hadron colliders, …)***
  - Nb_3Sn: Wind-and-React vs. React-and-Wind

    ➔ cost estimate and industrialization
  - new HFM technologies based on alternative/complementary superconducting materials (HTS, MgB_2, …)