QXF Design, Fabrication and Irradiation Study

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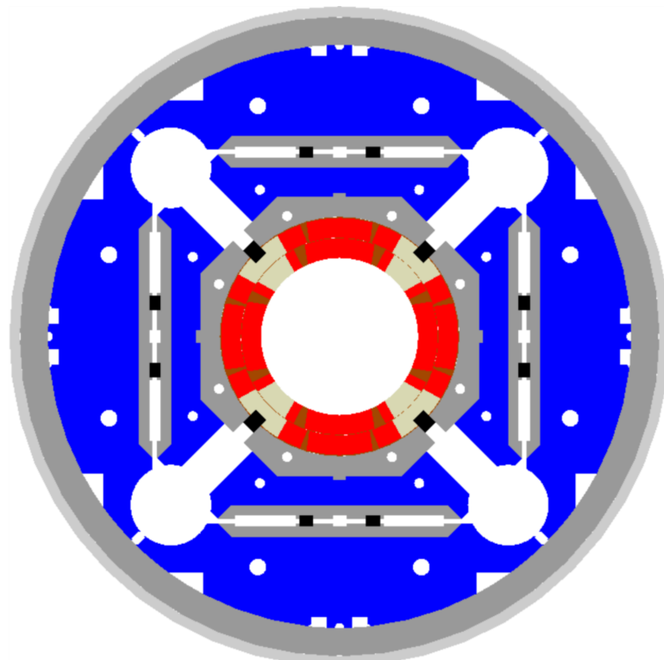
2/17/14

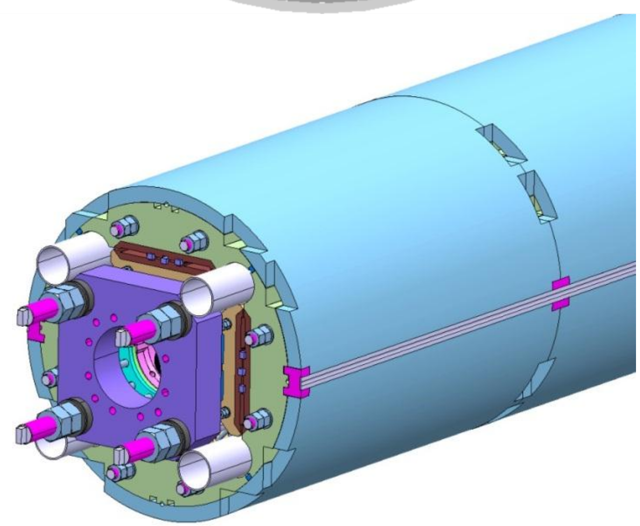
Outline

- Design overview
- Fabrication plans
- Integrated dose & energy deposition

MQXF overview

- 140 T/m in 150 mm coil aperture
- Two-layer coils w/o internal splice
- Al shell structure preloaded with bladders and keys
  - Segmented Al shell
- Axial preload by tie-rods
- Quench protection by active heaters

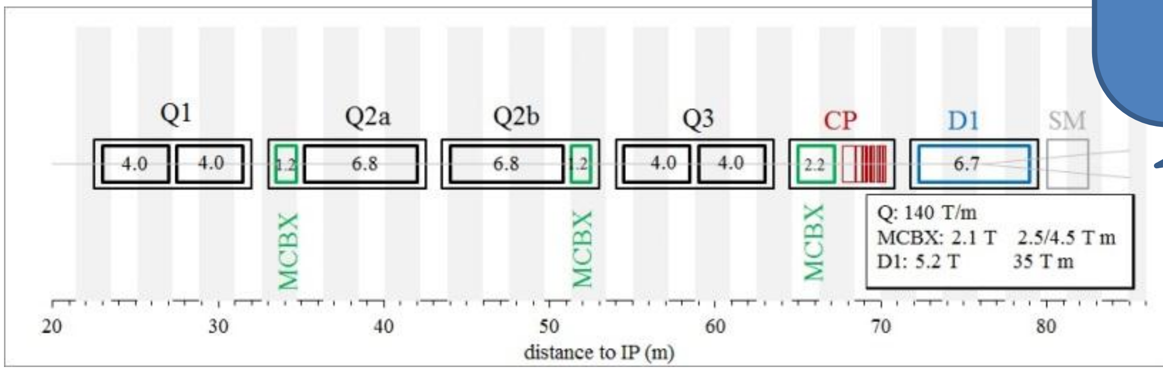


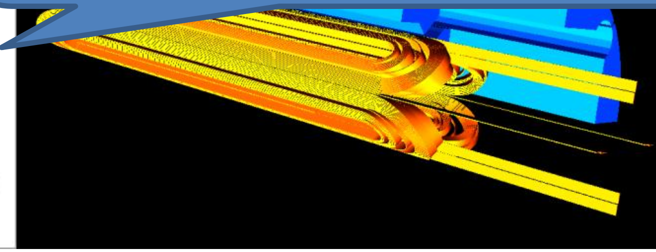


Length

This talk and next ones focus on the “structure” = cold mass w/o He vessel;

Options for deliverable to be presented in Apollinari talk





	Short model	Q1/Q3 (half unit)	Q2
Magnetic length [m]	1.2	4.0	6.8
“Good” field quality [m]	0.5	3.3	6.1
Coil physical length [m]	1.5	4.3	7.1
Cable unit length per coil [m]	150	430	710
Strand per coil [km]	6.5	18	30

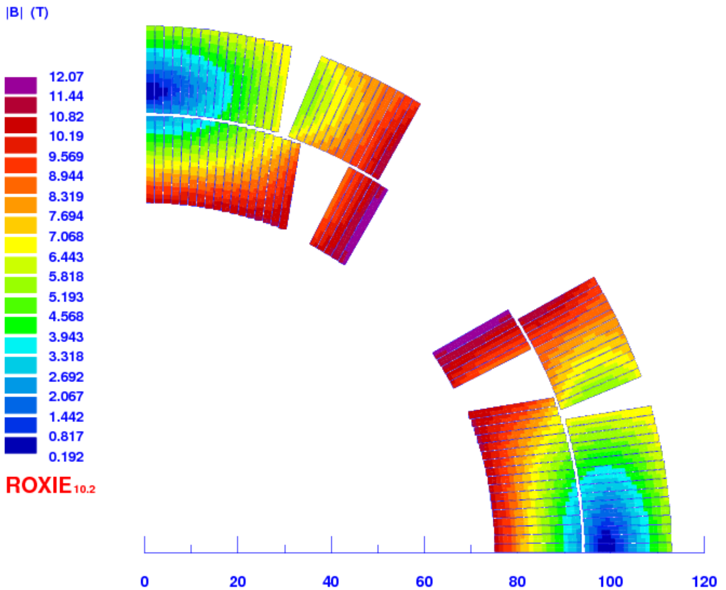
Conductor

- Strand: 0.85 mm diameter
  - Ic > 361 A at 15 T 4.2 K
  - Copper/non_copper > 1.2
  - RRP 132/169; PIT 192
- Cable: 40 strands with stainless steel core
  - 18.15 mm x 1.525 mm
  - 25 um core thickness
- Cable insulation: braided S2-Glass
  - 145 um thick (per side)
  - Silane (933) sizing

Magnetic Design – X-section

Main magnetic parameters of the QXF cross-section at 1.9 K.				
	unit	I_{ss}	I_{max}	I_{nom}
% of Iss†	%	100	90	**82**
Current	kA	21.25	19.12	**17.46**
Gradient	T/m	168	152	**140**
Peak field	T	14.51	13.14	**12.06**
Temperature margin	K	0	2.69	**4.16**
Fx per octant	MN/m	3.85	3.20	**2.75**
Fy per octant	MN/m	-5.69	-4.63	**-3.89**
Energy	MJ/m	1.92	1.56	**1.32**
L_d	mH/m	8.15	-	**8.22**

†Based on Jc = 2450 A/mm^2 at 4.2 K, 12 T (for RRP and PIT)

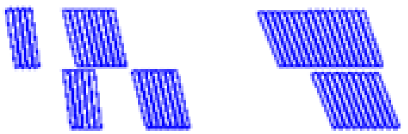


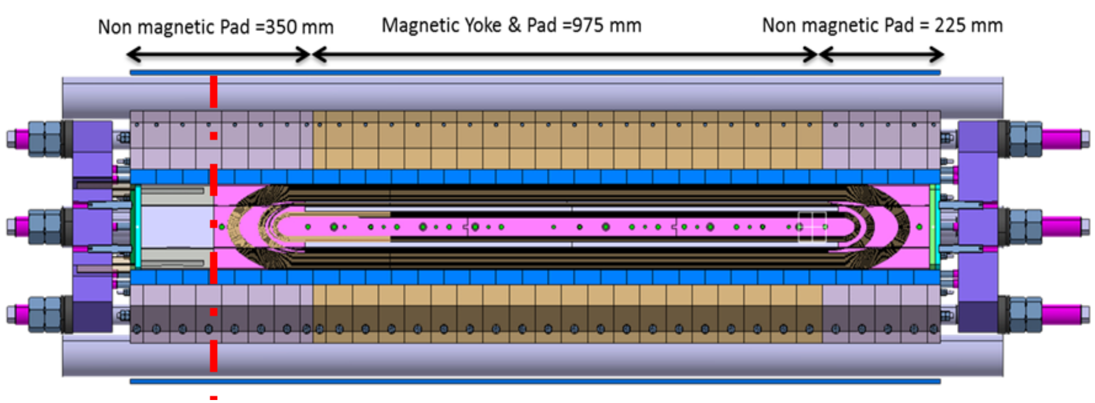
Optimization criteria:

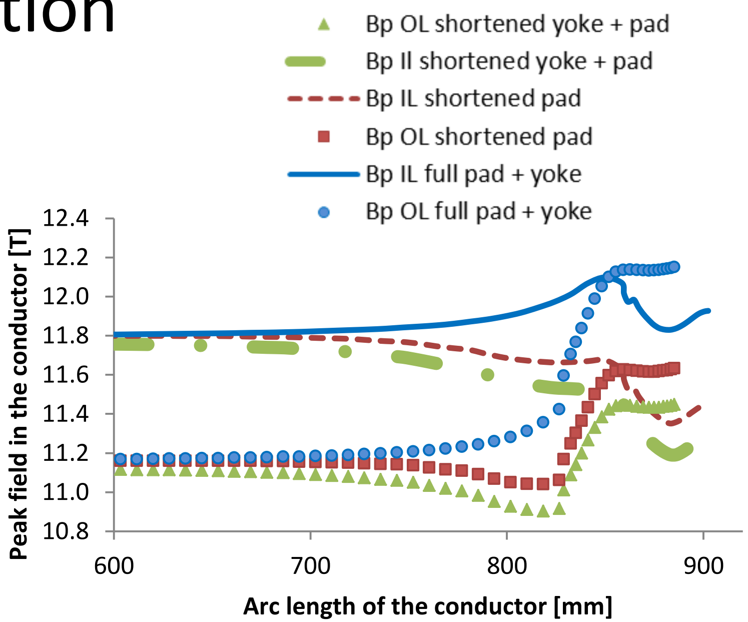
- Geometric harmonics ➔ meets requirements
- Large number of turns (50) ➔ for quench protection
- Even distribution of azimuthal stress in inner and outer layer
- Coil layout similar to HQ ➔ benefit of HQ experience

Magnetic Design - Ends

- Ends optimization based on:
  - Field in ends lower than in x-section
    - Iron ➔ stainless transition in pads
  - Low integrated field harmonics
  - Minimize cable stress/deformation
  - Compact ends







Design & Fabrication

- Next talks are showing design features and fabrication technology
  - Building upon successfully demonstrated design features and processes

- Design and fabrication responsibilities are distributed according to competencies of each lab for the project

Fabrication Plans

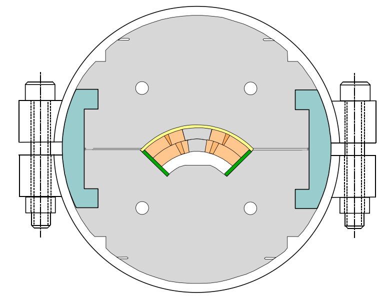
Fabrication plan **at start** is based on LQ, HQ and LHQ plans
at the end demonstrates production readiness:

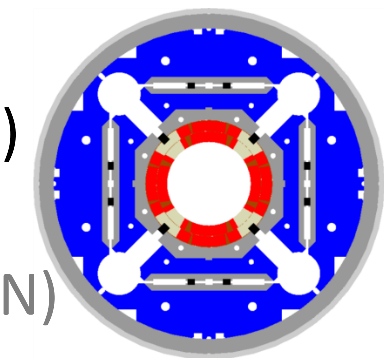
– Cabling: LBNL	LBNL
– Cable insulation: NEWT	NEWT
– Coil W&C: FNAL	→ BNL & FNAL
– Coil R&I: BNL, FNAL, LBNL	→ BNL & FNAL
– Coil traces (protect. heaters): LBNL	LBNL
– Struct. sub-assembly & QA: LBNL	LBNL
– Coil-structure assembly: LBNL	→ BNL & FNAL / LBNL

Plan Overview

More details in last talk

- Short model program: **2014-2016**
  - Program fully integrated between CERN and LARP
  - Fabrication of practice coil is starting this month
    - Earlier than in CollabMtg20 (4/13) schedule
  - First SQXF coil test (Mirror) in Dec. 2014
  - First magnet test (SQXF1) in May 2015
  - 2 (LARP) + 3 (CERN) short models + reassembly (~4)
- Long model program: **2015-2017**
  - Coil winding starts in 2015: Jan. (LARP), Sept. (CERN)
  - First LQXF coil test (Mirror structure) in Dec. 2015
  - First model test in Oct. 2016 (LARP) and July 2017 (CERN)
  - 3 (LARP) + 2 (CERN) models in total
- Series production: **2018-2022**





Test Facilities for S/LQXF

- SQXF models will be tested at FNAL VMTF
- Presently there is no facility in the US for LQXF
- Two options:
  - Upgrade of BNL vertical test facility
    - used for LARP Long Racetrack
  - Upgrade of FNAL horizontal test facility
    - used for present LHC low beta quads
- In the present schedule and budget the upgrade of the BNL test facility is assumed
  - Shorter turn-around time; less expensive upgrade
  - Details have been presented at dedicated workshop and follow-up meetings
    - Workshop: BNL, December 2013

- Design features and fabrication plans in next talks:

Magnet System Session 2
15:05 QXF Conductor and Cable *30'*
15:35 QXF Coil Design and Winding Tests *20'*
15:55 QXF Coil Fabrication and Tooling *20'*
16:15 QXF Support structure design and development *30'*
16:45 QXF Quench protection *20'*
17:05 QXF schedule and preparation for project *20'*

Outline

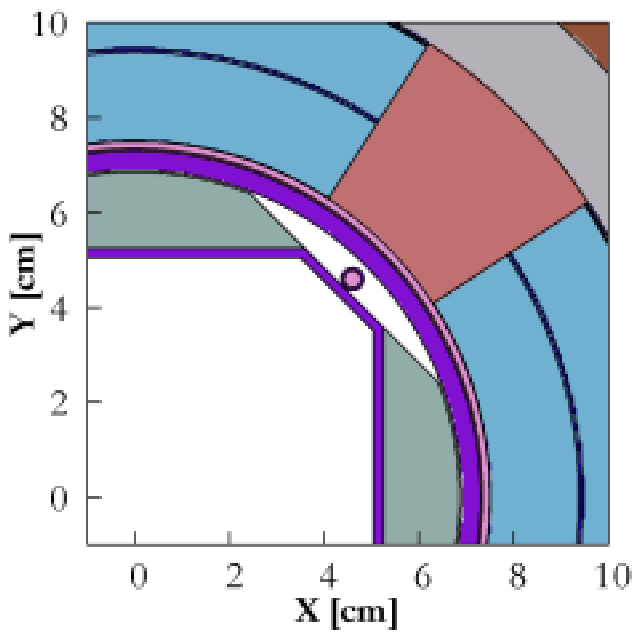
- Design overview
- Fabrication plan
- Integrated dose & energy deposition

The LARP-CERN Strategy

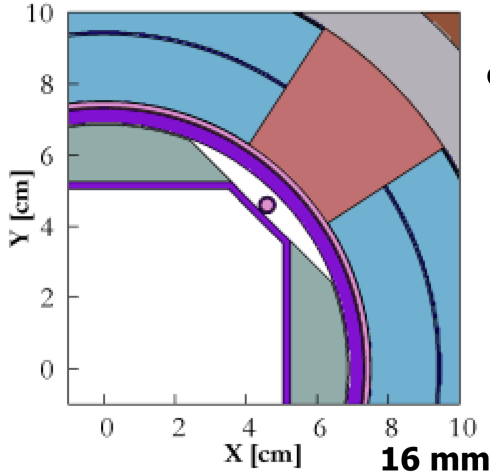
- Simulations
  - MARS and Fluka
- Extensive literature survey, consultation with experts, workshops
  - Fluckiger, Weber
  - WAMSDO 2011, RESMM12/13
    - RESMM14, May 12-15, Wroclaw
- Irradiations and material tests
  - EuCARD program

The Solution

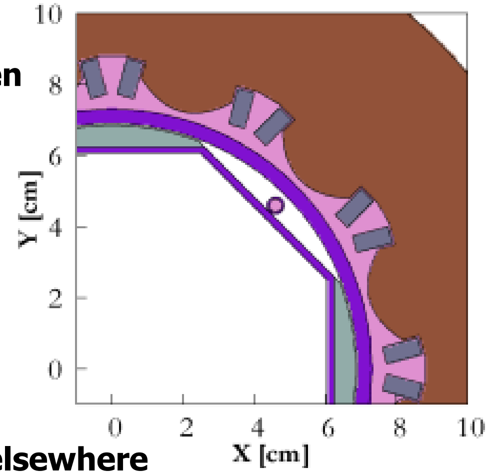
- Tungsten shielding on coil mid-planes inside aperture
  - First proposed by N. Mokhov for 120 mm aperture



SHIELDING THE NEW TRIPLET – CP – D1 [II]

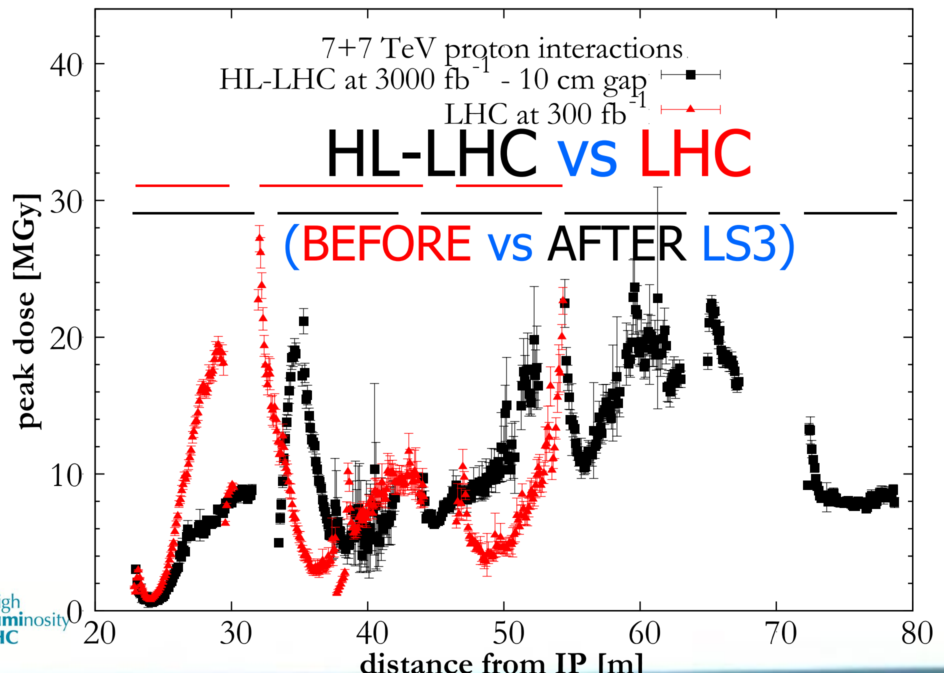


tungsten inserts
on the beam screen



16 mm in Q1 and 6 mm elsewhere

peak dose longitudinal profile



larger values for increasing crossing angle

beam screen gap in the interconnects is critical

→ tungsten in the BPM's

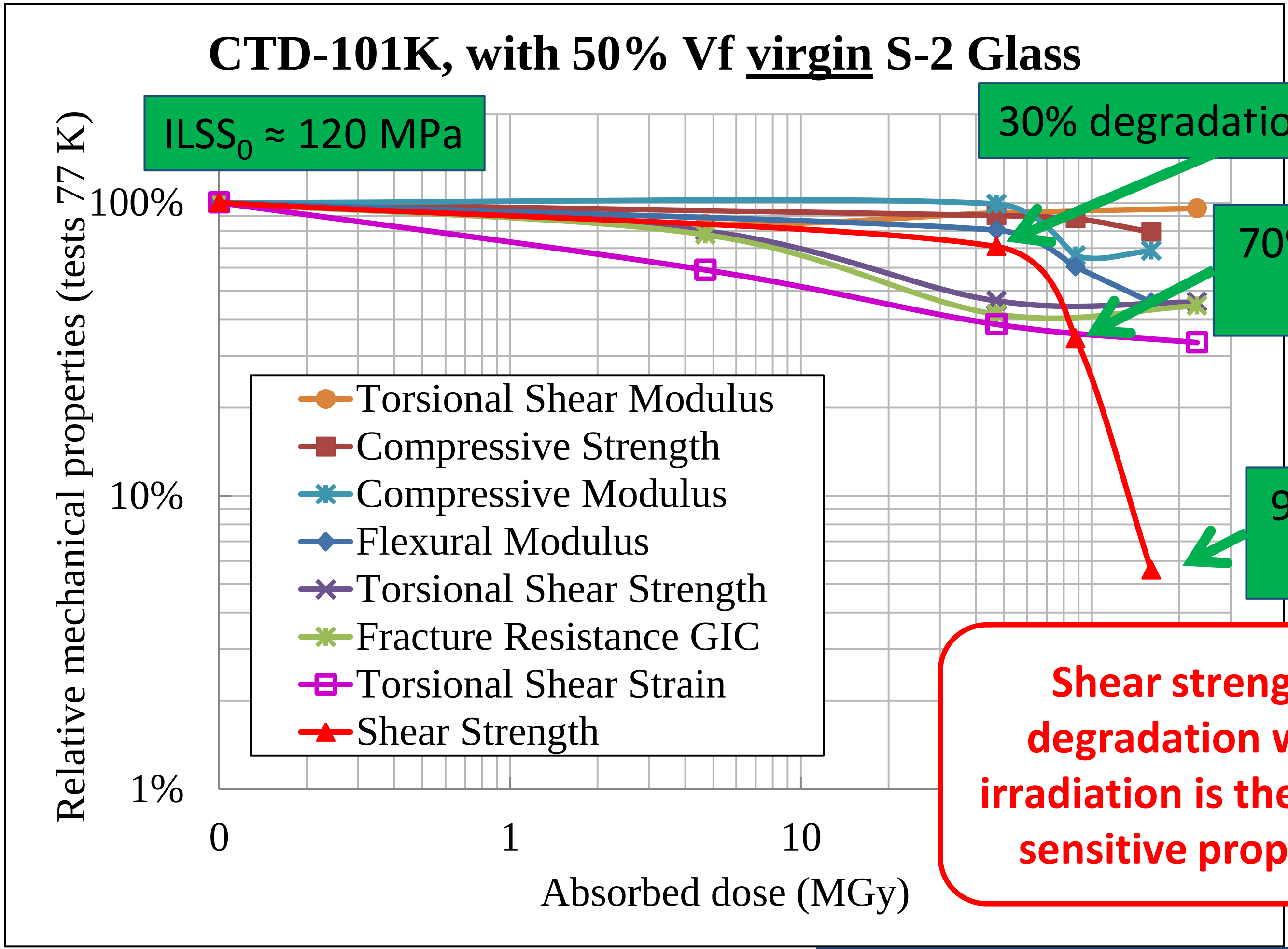
more than **600 W** in the cold masses

as well as in the beam screen

(i.e. 1.2-1.3 kW in total)

Relative mechanical properties for CTD-101K

Note: 41 references!

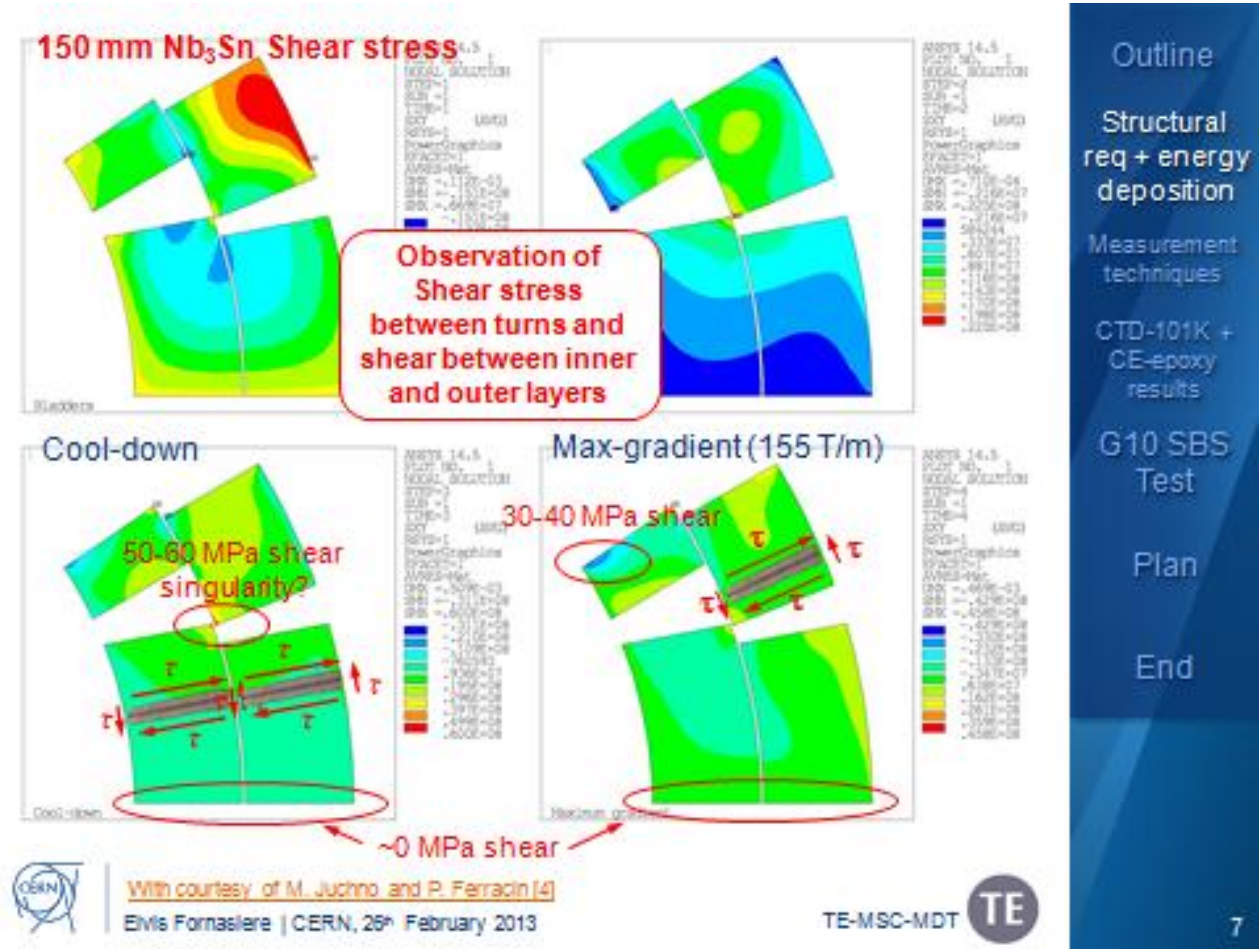


UTS: 35% reduction at 180 Mgy from UTS_0 ~ 1050 MPa
Compressive strength = 1080 MPa at 160 Mgy (Loss 20%)
Fracture Resistance G_{IC}: 66% reduction at 230 MGy

[29]+[30]+[31]

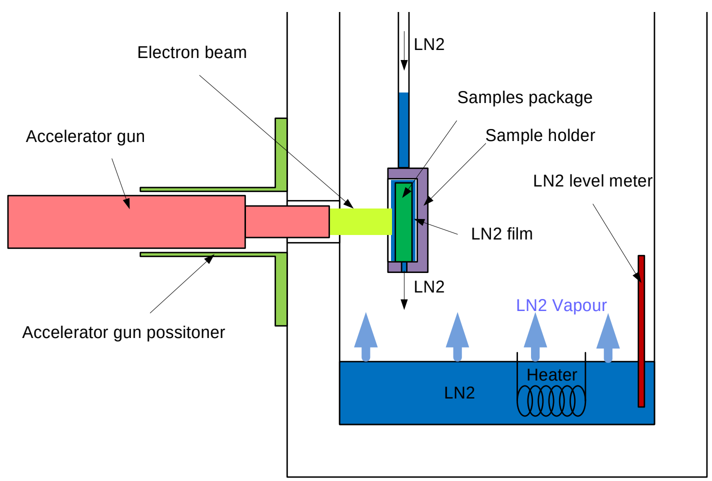
Shear Strength Requirements

- Very low on midplane
- 40 MPa on pole turn



Irradiation & Test

- Irradiation and test campaign on four candidate materials for the impregnation of Nb_3Sn coils
- by EuCARD



https://edms.cern.ch/file/1001894/1/EuCARD-Del-D7-2-1_final-1.pdf

Grant Agreement No: 227579

EuCARD

European Coordination for Accelerator Research and Development

Seventh Framework Programme, Capacities Specific Programme, Research Infrastructures, Combination of Collaborative Project and Coordination and Support Action

DELIVERABLE REPORT

CERTIFICATION OF THE RADIATION RESISTANCE OF COIL INSULATION MATERIAL

DELIVERABLE: D7.2.1

Document identifier:	EuCARD-Del-D7-2-1-final-1
Due date of deliverable:	End of Month 42 (September 2012)
Report release date:	31/07/13
Work package:	WP7: HFM
Lead beneficiary:	PWR
Document status:	Final

Abstract:

The goal of the WP 7.2.1 sub-task of the EuCARD program has been to determine the Nb_3Sn based accelerator magnet coil electrical insulation resistance against irradiation, which will occur in future accelerators. The scope of the certification covers determination of mechanical, electrical and thermal properties changes due to irradiation. The report presents a selection of the insulation material candidates for future accelerator magnets as well as the definition of the radiation certification methodology with respect of radiation type, energy, doses and irradiation conditions. The test methods and results of the electrical and mechanical insulation materials properties degradation due to irradiation are presented. Thermal conductivity and Kapitza resistance at temperature range from 1.5 K to 2.0 K (superfluid helium conditions) are given.

Report Executive Summary

Within the WP 7.2.1 sub-task of the EuCARD program the radiation resistance of the potential materials for future Nb_3Sn accelerator magnets electrical insulation has been accomplished. S-glass fibre reinforced DGEBA epoxy (RAL Mix71), TGPAP epoxy (RAL Mix 237), cyanate ester-epoxy mixes (CE-Epoxy) and CTD101 ceramic epoxy (LARP) laminates have been certified with respect to the requirements resulting from the radiation conditions estimated for future accelerators. The materials have been irradiated with 50 MGy, 4 MeV electron beam at 77 K conditions. Electrical, mechanical and thermal properties tests of the materials before and after irradiation have been performed in cryogenic conditions (LN2 environment).

The electrical strength of 0.5 mm thick insulation samples at 77 K tests shows strong degradation of the insulation properties due to the irradiation. Nevertheless, electrical strength of each irradiated material is a few times higher than the required 5 kV/mm.

Mechanical ultimate tensile strength tests at 77 K also show strong degradation of the materials due to the irradiation. The strength of RAL Mix 71 after irradiation has decreased almost to 0 MPa, which disqualifies this material for use in the accelerator magnets.

Thermal properties of the materials have, due to program time limit, been determined for unirradiated samples only. Nevertheless, the obtained results can be very useful in Nb_3Sn magnets thermal design. The thermal measurements of the irradiated samples are in progress.

Summary Table

Table 9.1. Summary of the electrical insulation materials certification program (properties after irradiation).

Material	Electrical properties	Mechanical properties	Thermal properties (non-irradiated / irradiated)		Applicability for accelerator magnets
Mix 71	Good	Very bad	Very good	TBD	Non applicable
Mix 237	Good	TBD	Good	TBD	TBD
LARP	Very good	Satisfactory	Good	TBD	Applicable
CE Epoxy	Very good	TBD	Satisfactory	TBD	TBD

TBD – to be defined

- The LARP insulation & impregnation scheme meets all requirements tested so far
- To be tested:
  - Thermal properties after irradiation
  - Impact of swelling (15% at 50 MGy)
  - Impact of HT with binder + irradiation on mech. properties

Effect on Critical Current

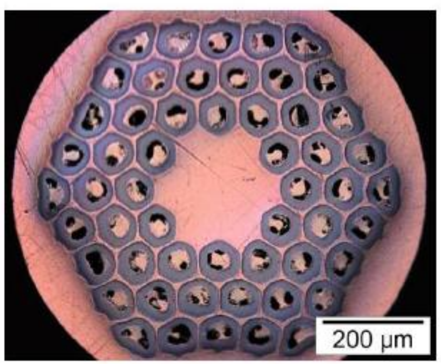
- Jc of high-Jc strands increases with irradiation

RRP (OST): $(NbTa)_3Sn$

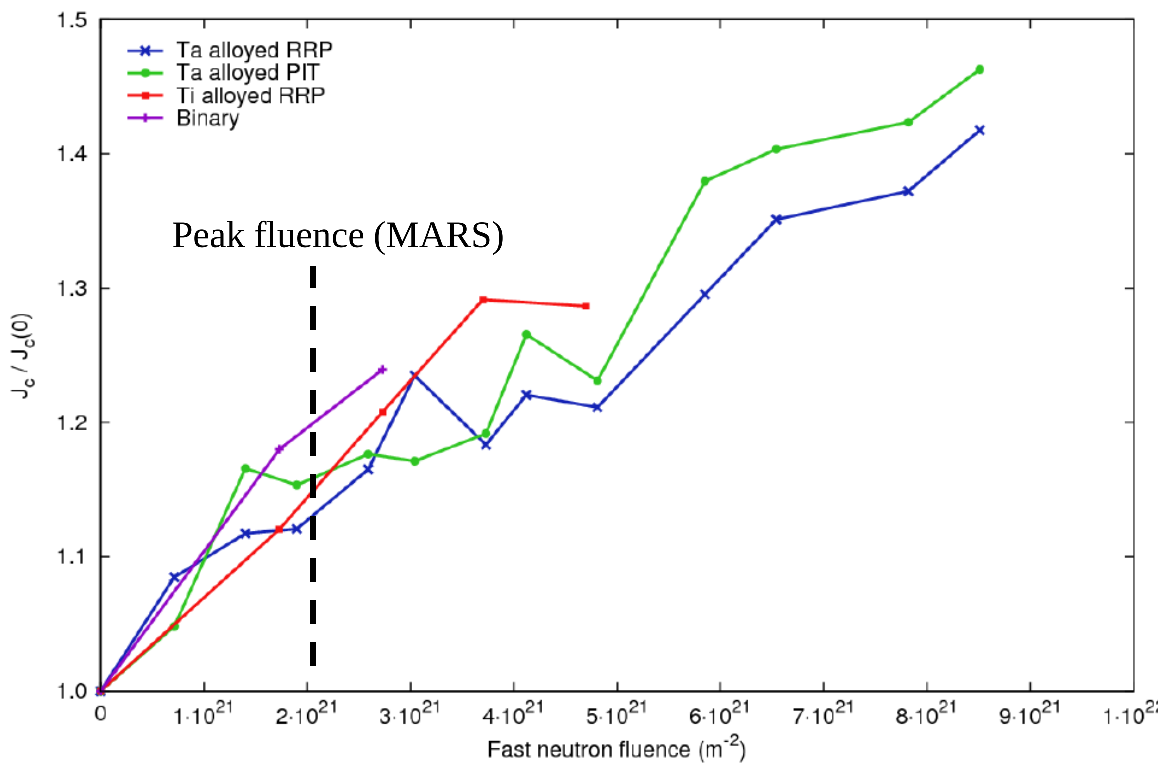
RRP (OST): $(NbTi)_3Sn$

PIT (Bruker EAS): (NbT

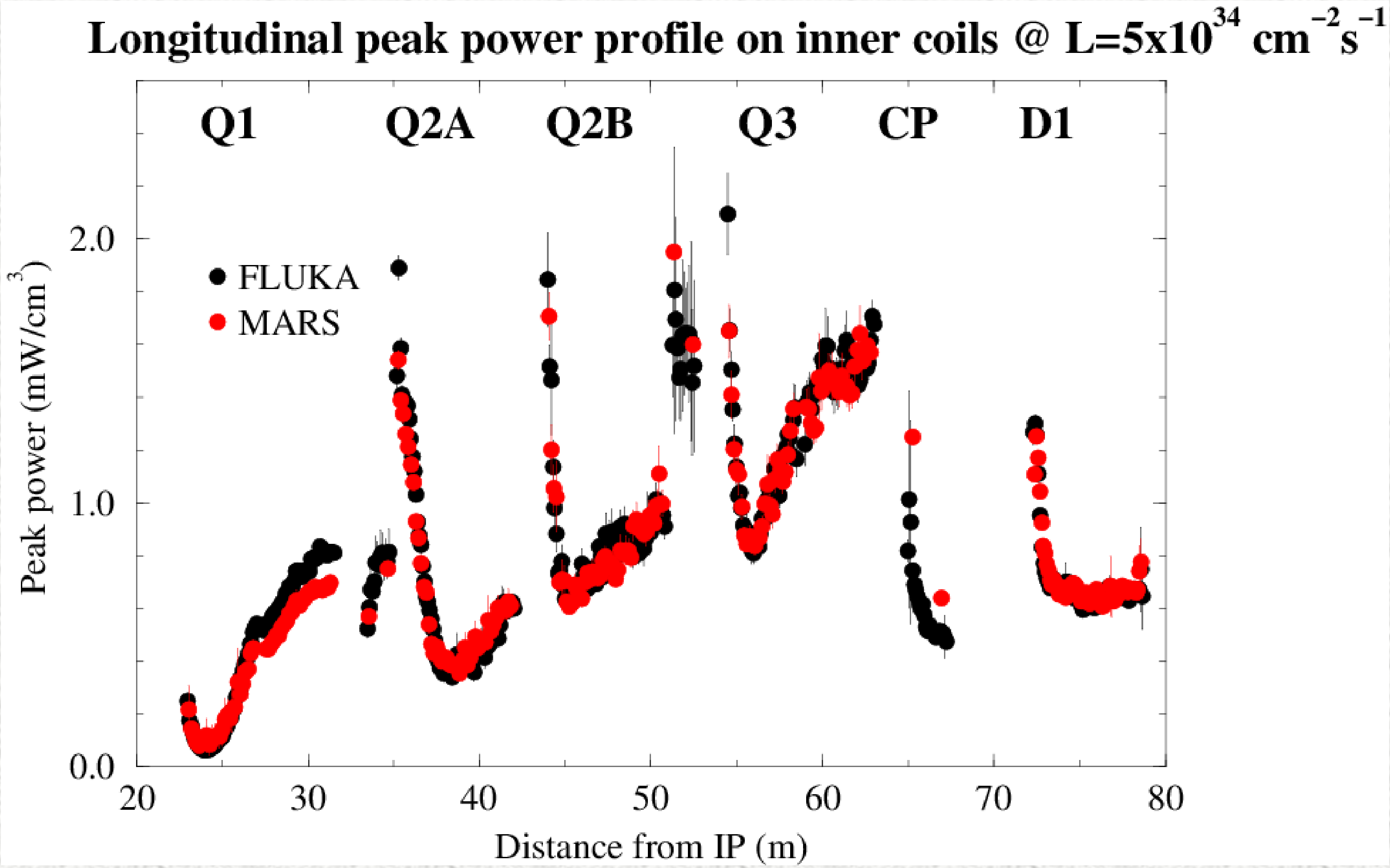
(OST): Nb_3Sn



T = 4.2 K, 6 T



Peak Power Density Longitudinal Profile



Peak power density is averaged over the ***full cable width***; ***50 cm*** beam screen interruption in the interconnects

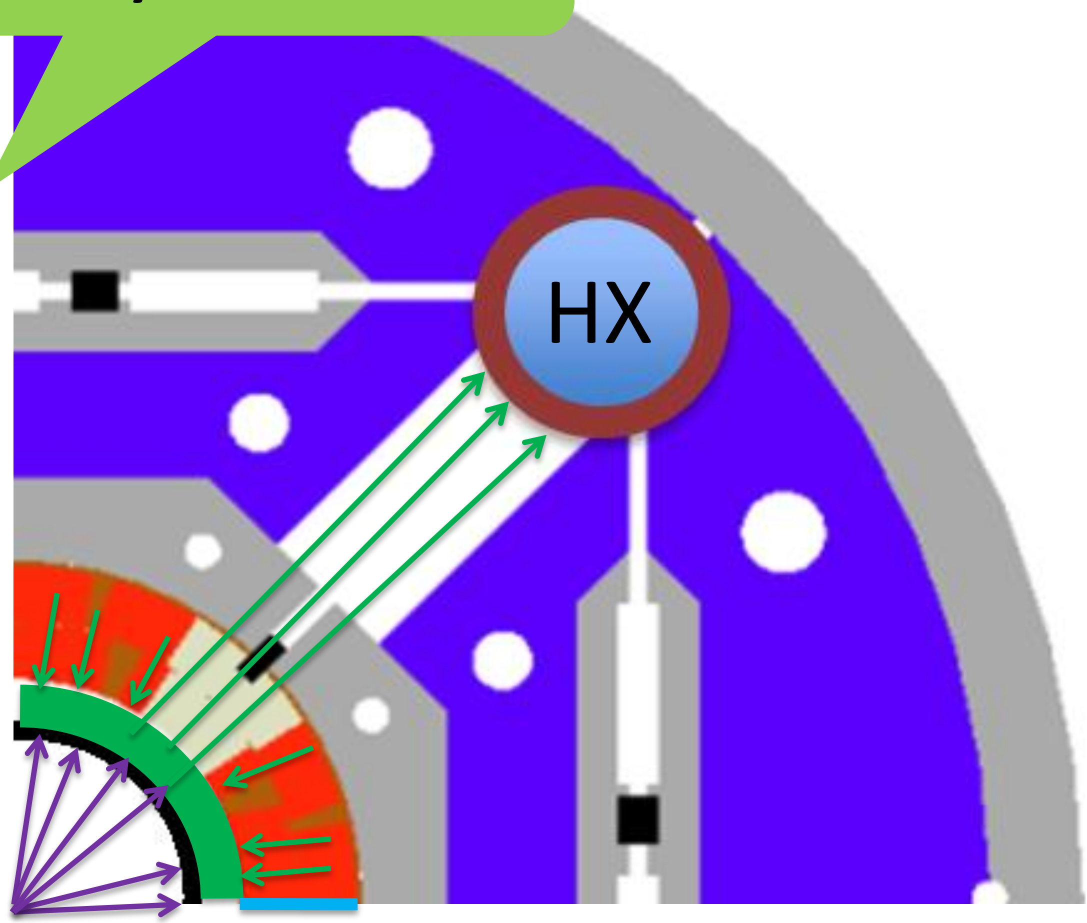
Coil cooling principle

- Heat from the coil area (green) and heat from the beam pipe (purple) combine in the annular space between beam pipe and coil and escape radially through the magnet "pole" towards the cold source → *"pole, collar and yoke" need to be "open" :*
Calculations show that > 80 % of the heat is evacuated via the pole piece!

- Heat Conduction mechanism in the coil packs principally via the solids

- Longitudinal extraction via the annular space is in superfluid helium, with T close to T_λ and with magnets up to 7 m long not reliable → *"pole, collar and yoke" need to be "open"*

With 50 mm spacing
Safety factor = ~8



≥ 1.5 mm annular space

Conclusions

➔ The LARP technology meets all dose/energy related requirements tested so far.

- We have high confidence that it will meet all requirements, and there is work in progress for demonstrating it:
  - Understand impact of gas evolution, and RRR degradation for possible “warm-up requirements”
  - Thermal conductivity after irradiation
  - Map max dose on all components/materials
    - HL LHC WP10 effort