QXF
Preliminary Mechanical Analysis and Plans

2nd Joint HiLumi LHC – LARP Annual Meeting

INFN Frascati – November 14th to 16th 2012

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Context and Outline

- A support structure developed jointly by CERN and LARP
  - $\Rightarrow$ 1 short version for SQXF -CERN
  - $\Rightarrow$ 1 long version for LQXF – LARP

  The two support structures should be identical
  Joint mechanical analysis effort

- **Outline**
  - Status report: comparison of several cross-sections in the same structure
  - Future work
    - List of criteria
    - List of tasks and critical inputs from other working groups

Cross-sections comparison

- At the level of the design study: criteria allowing comparison between various coil and structure cross-sections

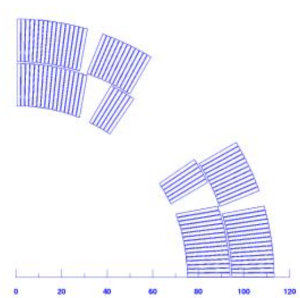
  - ✓ Operating point: 140 T/m - ~ 80 % of Iss
  - ✓ Pole turn compression of at least -2 MPa in both layers

- Demonstrate that the support structure has margin to preload the coil up to 155 T/m ~ 90 %

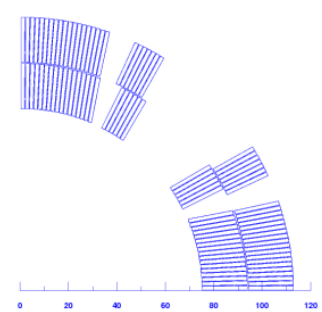
- Cross-section considered in this study

MQXFi-V0: presented on Sept 07th
MQXFi-v1: presented on Oct 23rd - interlayer
MQXFi-v2: with conductor aligned on OD to be presented

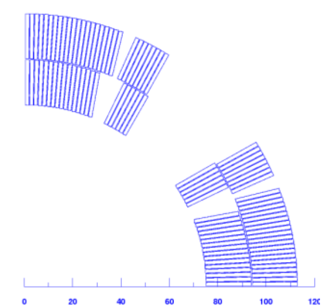
CERN



MQXF1-v0



MQXF3-v0



U.S. LARP

Cross-sections v0

High Luminosity LHC

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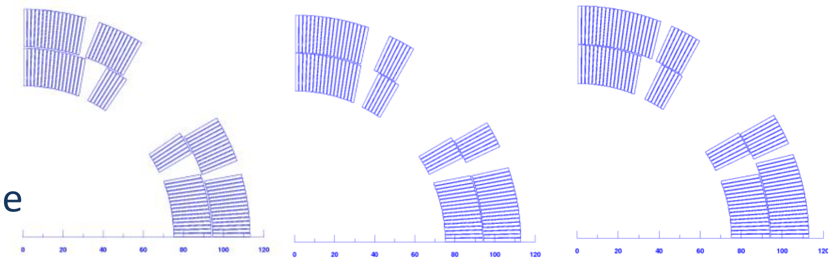
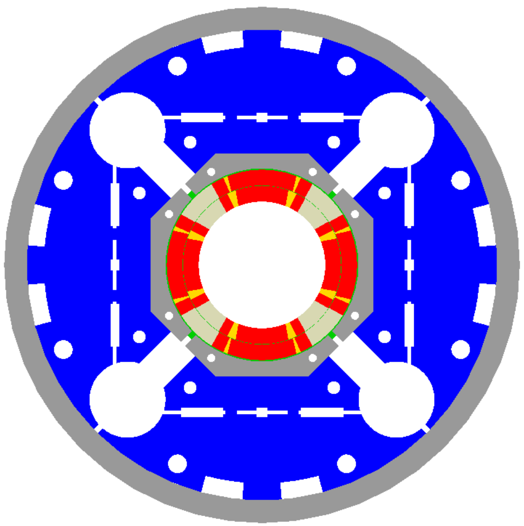
MQXFi-v1: presented on Oct 23rd - interlayer
MQXFi-v2: with conductor aligned on OD to be presented

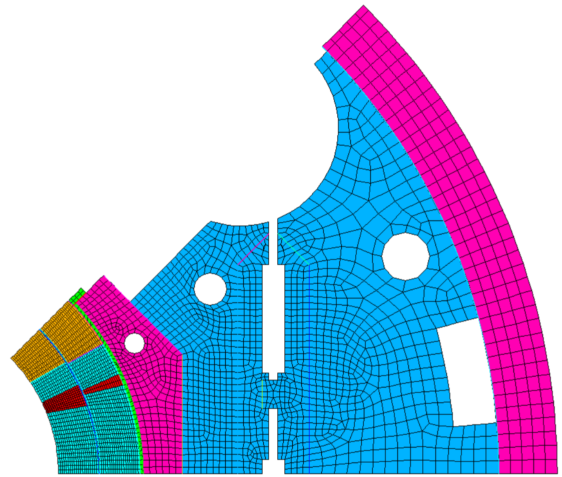


	Units	CERN	MQXF1	MQXF3
Gradient	T/m	140	140	140
Nominal Current	kA	17.310	17.388	16.986
Fraction of Iss	%	81.10	80.63	80.47
Temp. Margin	K	4.410	4.492	4.516
Peak Field @ In	T	12.1778	12.0668	12.1276
Stored energy @ In	MJ/m	1.312	1.284	1.319
Diff. inductance	mH/m	8.27	8.01	8.63
Nb turn/coil	-	50	49	51

2D ANSYS Model

- Presently a pure scale up of the HQ cross-section





Model includes:

- Friction 0.2
- Coil layers are glued

OD: 610 mm

Shell thickness: from 25 mm (HQ) to 27 mm

Collar: from 22.6 mm (HQ) to 17 mm

Cooling channels: 90 mm => a concern for the rods and “bolting” procedure

Bus bar: 20 x 50 mm2

Bladders width: 50 mm

Figure of merits of this analysis

From the magnetic analysis

- Lorentz stresses in each layer (from F_θ accumulation on the mid-plane)

From the mechanical analysis

- **Coil**
  - ✓ Peak stress in the coil at each stage
    - Bladder pressurized
    - Shimming
    - Cool-down
    - 140 T/m
  - ✓ Compression of the pole turn at 140 T/m for both layers
  - ✓ Interference and corresponding bladder pressure
  - ✓ Mid-plane radial displacement

- **Structure**
  - ✓ Yoke, pad and masters maximum first principal stress
  - ✓ Shell maximum azimuthal stress

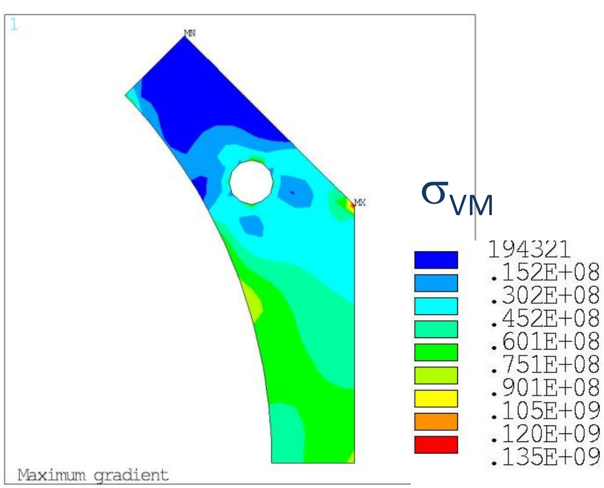
Coil Comparison – 140 T/m

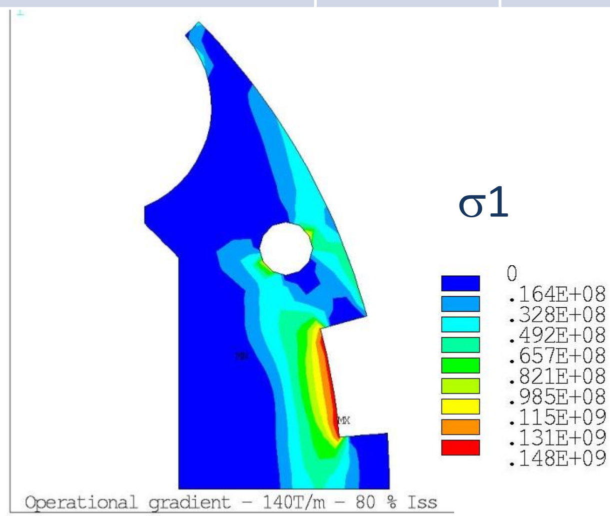
	Units	CERN	MQXF1	MQXF3
Lorentz stress (L1/L2)	MPa	-110/-125	-116/-113	-107/-128
Peak Azimuthal stress / VM stress				
Bladder pressurized	MPa	-65 / 65	-72	-68
Preloaded	MPa	-50 / 49	-58 / 57	-54
At 4.2 K	MPa	-150 / 150	-151 / 150	-149
At 140 T/m	MPa	-134/134	-132 / 136	-131
Compression at the pole (L1/L2)	MPa	-2.3/-8.8	-2.5 / -19	-2.5/-5.4
Shimming	μm	360	420	370
Bladder pressure allowing 100 μm clearance	MPa	31	34	32
Radial displacement from 0 to 140 T/m	μm	67	70	71

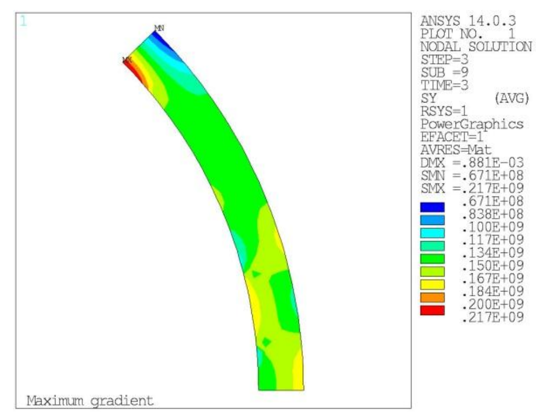
Support structure – 140 T/m

The structure is the same for all cross-sections:

At 140 T/m	Units	
Collar σ_{VM}	MPa	135
Pad $\sigma 1$	MPa	83
Master pad side / yoke side $\sigma 1$	MPa	108 / 142
Yoke $\sigma 1$	MPa	148
Shell σ_{VM}	MPa	217





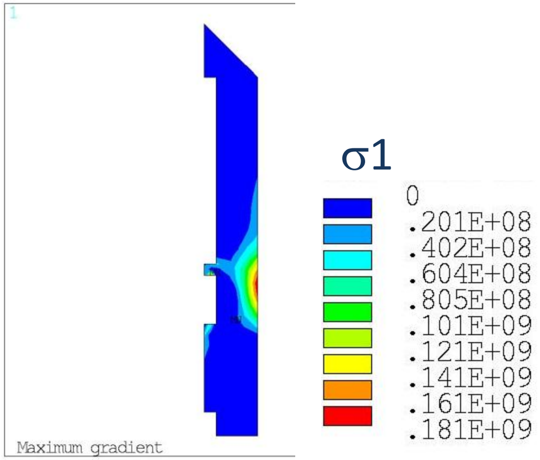


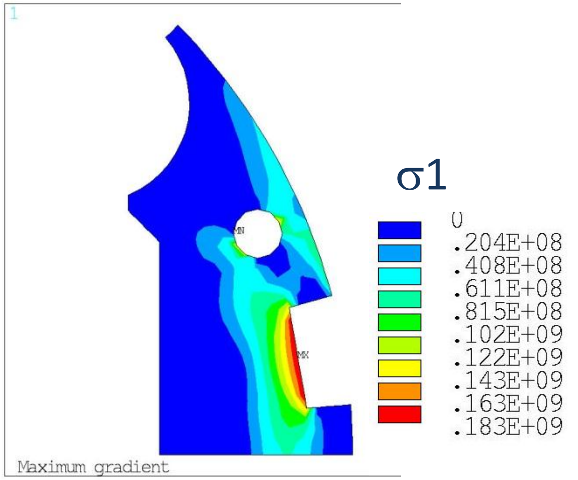
155 T/m – 90 % Iss
Coil stress

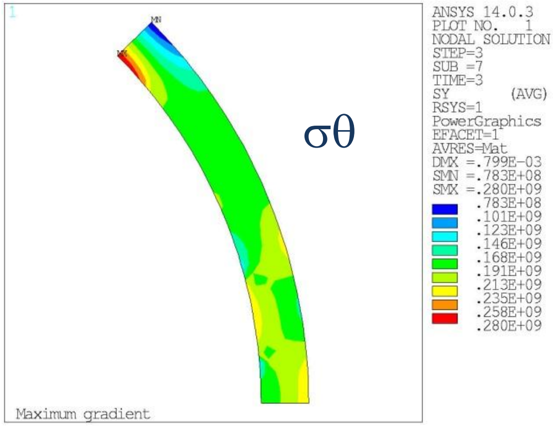
	Units	CERN 155 T/m	CERN 140 T/m
Lorentz stress (L1/L2)	MPa	-136/-155	-107/-128
Peak Azimuthal stress / VM stress			
Bladder pressurized	MPa	-96 / 96	-65 / 65
Preloaded	MPa	-81 / 79	-50 / 49
At 4.2 K	MPa	-177 / 176	-150 / 150
At 155 T/m	MPa	-163 / 163	-134/134
Compression at the pole (L1/L2)	MPa	-2.1/-9.4	-2.3/-8.8
Shimming	μm	585	360
Bladder pressure allowing 100 μm clearance	MPa	46	31
Radial displacement from 0 to 155 T/m	μm	78	67

155 T/m – 90 % Iss
Structure

	Units	140 T/m	155 T/m
Collar σ_{VM}	MPa	135	165
Pad $\sigma 1$		83	102
Master pad side / yoke side $\sigma 1$	MPa	108 / 142	134 / 181
Yoke $\sigma 1$	MPa	148	183
Shell σ_{VM}	MPa	217	280







Design Criteria
Work in progress

- Pole-coil contact at 155 T/m (90% of I_s),

  p_{cont} ≥ 2 MPa in midpoint

- Max bladder pressure

  < 50 MPa (better 40 MPa?)

- Bladder should open the interf=$interf_{nom}$ + 100µm

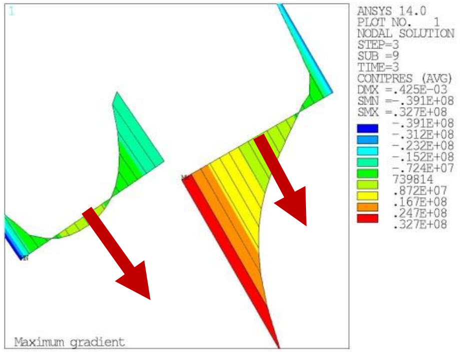
- $\sigma_{eq\ coil\ max}$ **≤ 150-200 MPa** at 4.3K and 155 T/m

  ≤ 100 MPa at 293K

- All components **$\sigma \leq R_{p\ 0.2}$**

- For iron at 4.3K (brittle)

  $\sigma_I \leq$ ~200 MPa



Material	$R_{p\ 0.2}$ [MPa]	
	293 K	4.3 K
Al 7075	480	690
SS 316 LN	350	1050
NITRONIC 40	353	1240
MAGNETIL	180	723
Ti 6Al 4V	827	1654

Material properties

Material	E [GPa]		$R_{p\ 0.2}$ [MPa]	
	293 K	4.3 K	293 K	4.3 K
Al 7075	70	79	480	690
SS 316 LN	195	208	350	1050
NITRONIC 40	211	225	353	1240
MAGNETIL	205	215	180	723
Ti 6Al 4V	110	130	827	1654

- Thermal contraction
- Safety factor
- … Under discussion

Criteria applied to the coil

- Pole-coil contact at 155 T/m (90% of I_s) **p_{cont} ≥ 2 MPa** in midpoint
- $\sigma_{eq\ coil\ max}$ **≤ 150-200 MPa** at 4.3K and 155 T/m
  ≤ 100 MPa at 293K

	Units	CERN 155 T/m	CERN 140 T/m
Lorentz stress (L1/L2)	MPa	-136/-155	-107/-128
Peak Azimuthal stress / VM stress			
Bladder pressurized	MPa	-96 / 96	-65 /
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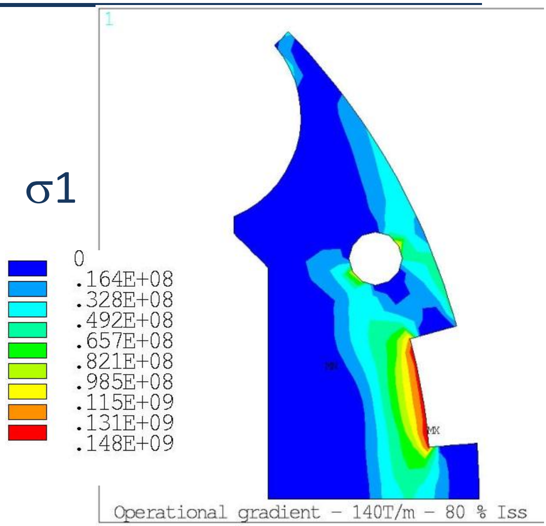
Radial displacement from 0 to 155 T/m	µm	78	67

From a coil stress point of view, the criteria are met

Criteria applied to the structure

- Max bladder pressure **< 50 MPa** (better 40 MPa?)
- All components **$\sigma \leq R_{p\,0.2}$**
- For iron at 4.3K (brittle) **$\sigma_I \leq$ ~200 MPa**

σ1



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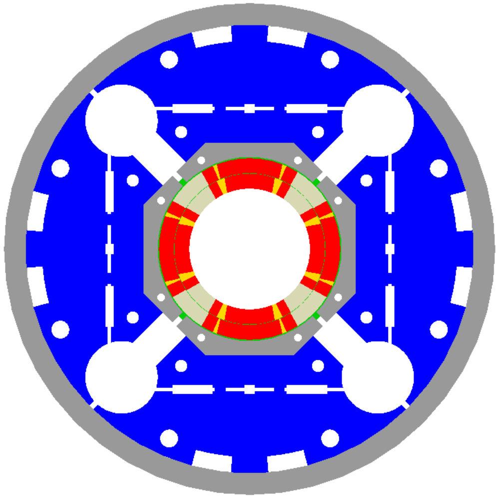
Pad σ1	MPa	83	102
Master pad side / yoke side σ1	MPa	108 / 142	134 / 181
Yoke σ1	MPa	148	183
Shell σ_{VM}	MPa	217	280
Bladder pressure		31	46

Material	$R_{p\,0.2}$ [MPa]	
	293 K	4.3 K
Al 7075	480	690
SS 316 LN	350	1050
NITRONIC 40	353	1240
MAGNETIL	180	723
Ti 6Al 4V	827	1654

From the structure point of view, criteria are met

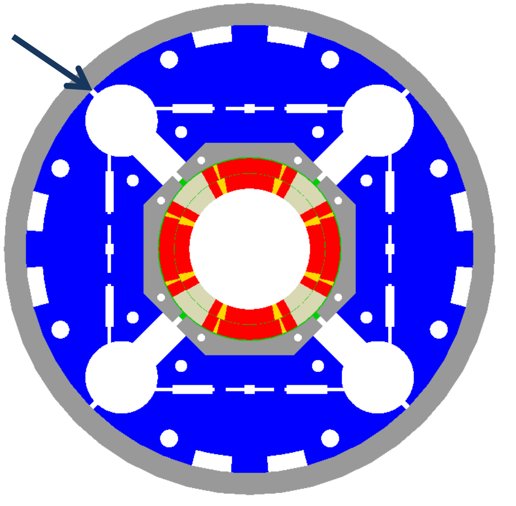
Degrees of freedom for optimization

- Key vertical location
  - ✓ For stress distribution optimization
- Collar shape
  - ✓ For alignment
  - ✓ Preload optimization
- Bladder size
  - ✓ Optimization of bladder size to minimize risk of bladder failure and improve reliability
  - ✓ Potential limitation due to the size of the cooling holes
- Material of some components
  - ✓ Master could be stainless steel
- But we need critical inputs…



List of critical inputs

- To complete our list of criteria
- To finalize some design choices
  - ✓ Cooling holes
    - Impact on bladder size
    - Impact on yoke keys
    - Potential impact on axial rods
    - Could we consider 4?
  - ✓ LHe containment
  - ✓ Bus bar location
    - Impact on yoke stress
    - Potential impact on assembly procedure
    - What about external bus bar?
  - ✓ Alignment criteria
    - From coil to structure
    - From cold mass to cryostat
    - What is requested?



Summary and next steps

- The cross-section with lower Lorentz stress in the inner layer seems to allow even unloading of both layers during excitation
- Some optimization is required on the structure design with input from other work packages

- Next steps
  - ✓ Review of HQ/LQ concept and identification of possible show-stoppers or issues
  - ✓ Finalize list of criteria for structure and cross-sections comparison
  - ✓ 2D
    - Finalize cooling holes, bus-bar slots and LHe vessel dimensions
    - Optimize collar shape and key position to minimize peak stress
    - Tolerance analysis
  - ✓ 3D
    - Modelling: transfer coil geometry from Bend/Roxie to ANSYS/Opera
    - Determine segment length
    - Check axial rods dimensions and material