Impact of beam screen in field quality MQXF, D1 and D2

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30/06/2020

Introduction

- Recap on previous computations (MQXF)
- Update on expected impact of beam screen in MQXF, D1 and D2

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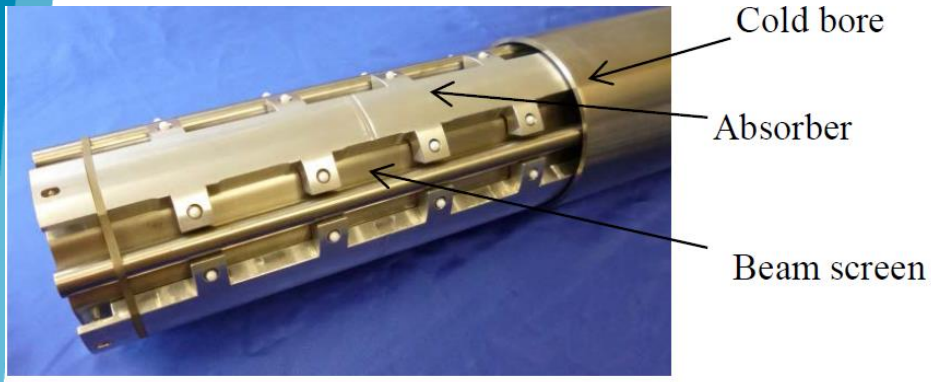
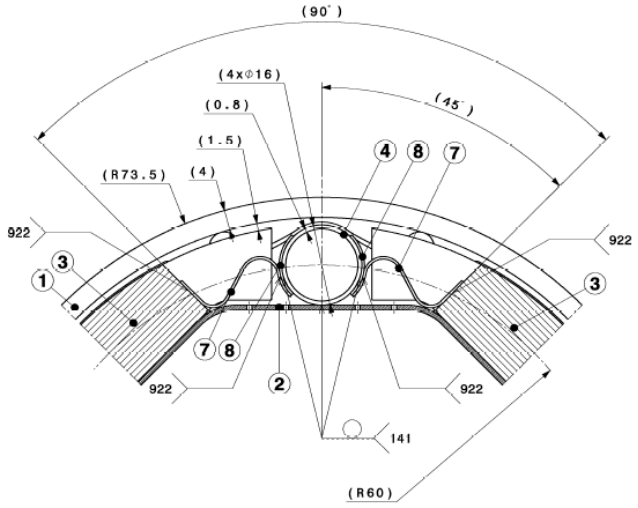
Geometry & Materials (April 2016)





Geometry from lhcvsmpa0009-v0

Materials:

- Beam screen and cooling channels: High-Mn Austenitic Steel (Developed for the LHC beam screen working at 10-20K, must stay non-magnetic down to very low temperatures)
  - Magnetic permeability ~ 1.0025
- Absorber: Tungsten
  - Magnetic permeability ~ 10 times lower than the High-Mn austenitic steel
- Cold bore: Austenitic Steel 316 LN
  - Magnetic permeability ~ 1.01

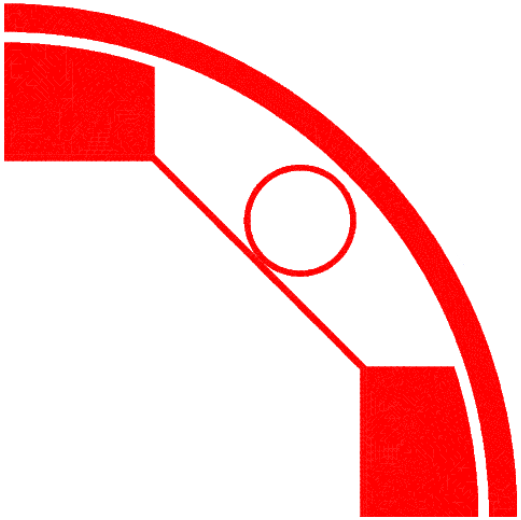
REF: Material characterisation and preliminary mechanical design for the HL-LHC shielded beam screens operating at cryogenic temperatures.
C. Garion, L. Dufay-Chanat, T. Koettig, W. Machiocha, M. Morrone

LARP

ROXIE model & Magnetic Properties (April 2016)

Materials:

- Beam screen and cooling channels: High-Mn Austenitic Steel P506
  - Magnetic permeability = 1.0025
- Absorber: Tungsten
  - Measured data at 4.2 K
- Cold bore: Austenitic Steel 316 LN
  - Magnetic permeability = 1.01



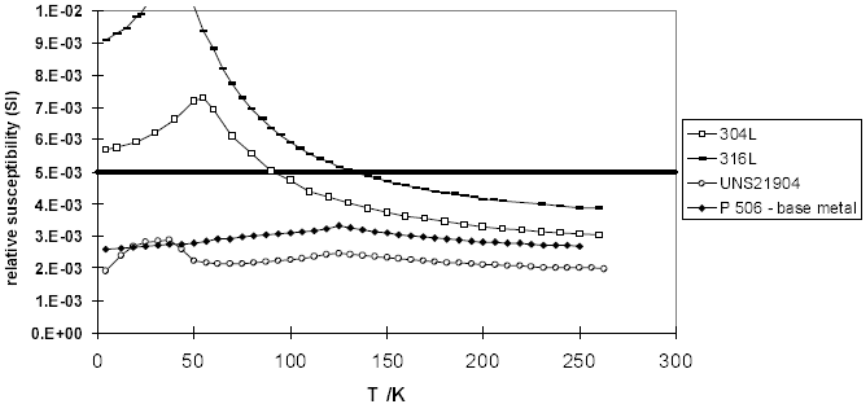
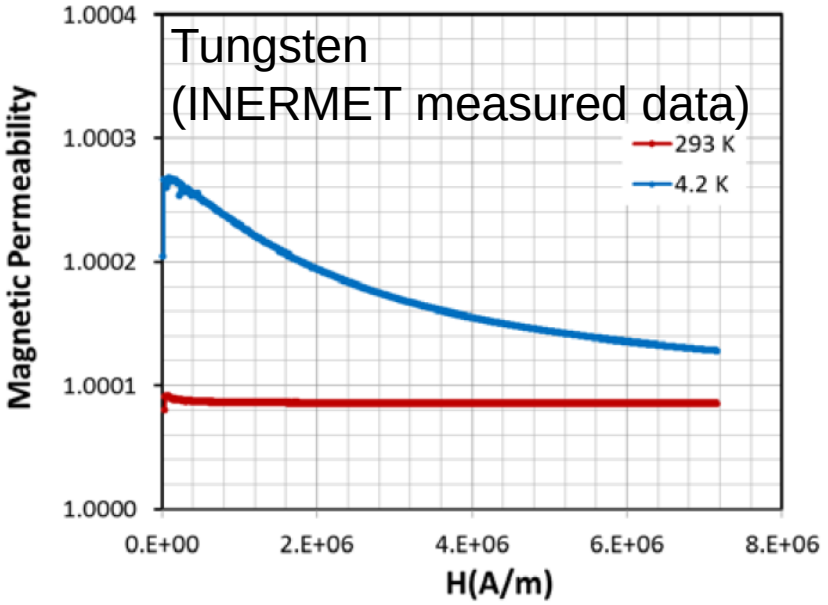


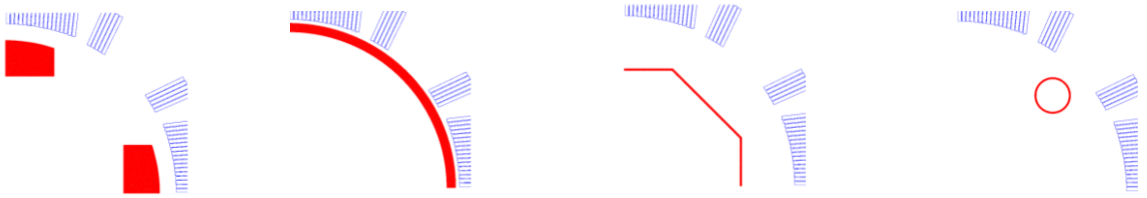
Fig. 3a : Magnetic susceptibility of different steels of the 300 series (Mn content up to 2%), compared to steel P506 (Mn = 12%) and UNS 21904 (Mn = 9 %). Measurements performed at CEN - Grenoble. Results of room temperature DC measurements performed on P506 under a static field of 1000 Oe are consistent with the present results (susceptibility at 293 K : $1.7 \pm 0.3 \cdot 10^{-3}$ SI). Maximum allowed limit is $5 \cdot 10^{-3}$.



Impact on field quality (April 2016)

	Impact of the shielding at 6.5 TeV (beam screen + cooling channels+ absorber + cold bore)		
	Without	With	Δ
b6	-1.53	-2.18	-0.65
b10	-0.11	0.27	0.37
b14	-0.87	-0.95	-0.09
b18	-0.26	-0.16	0.10

Impact of each component:

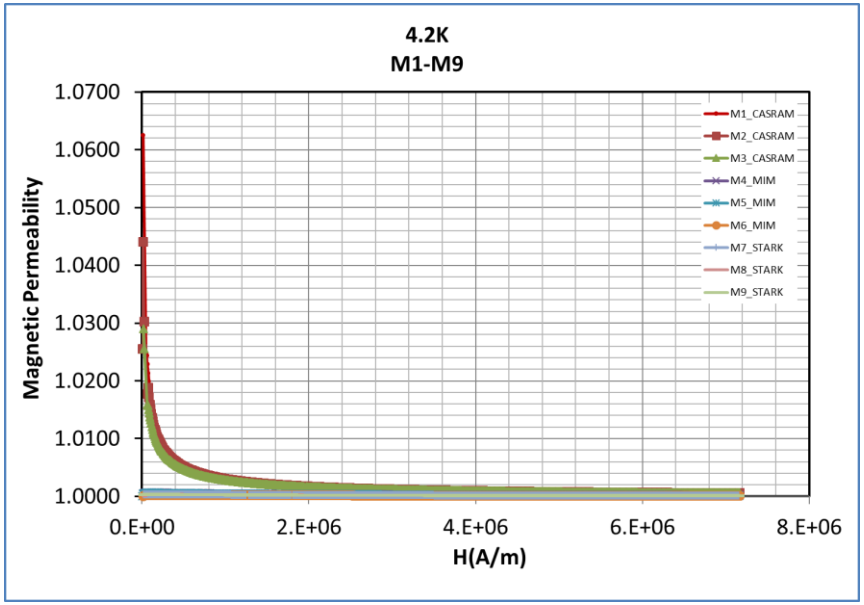


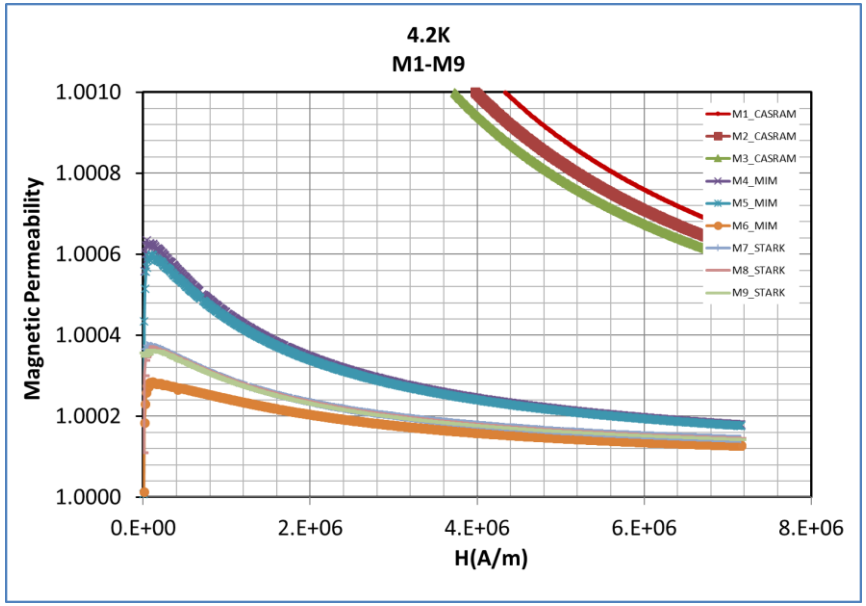
	Absorber	Cold Bore	Beam Screen	Cooling Channels
Δb6	-0.07	0.00	-0.14	-0.44
Δb10	0.05	0.00	0.00	0.32
Δb14	0.02	0.00	0.09	-0.20
Δb18	-0.01	0.00	0.00	0.11

LARP

Tungsten Measurements in 2018

- "Good samples": from 1.0006 at low field to 1.0002 at high field
- "Bad samples": from 1.065 at low field to 1.0006 at high field



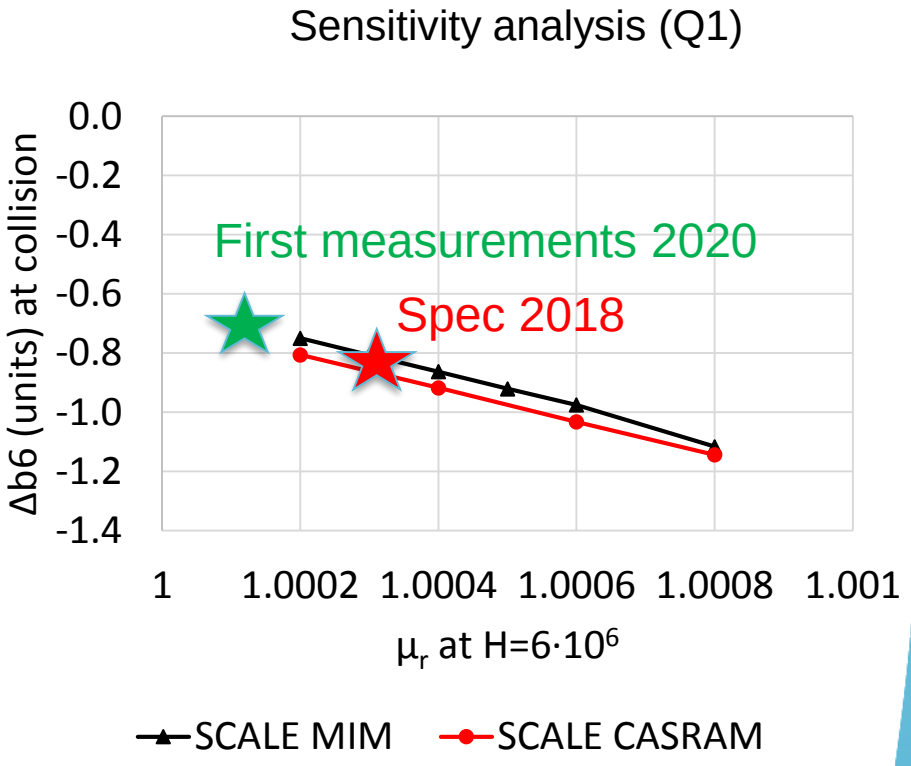


Material qualification EDMS 1973451

Proposal for Tungsten Material Specification

Following a parametric analysis (link here), in 2018, we defined the **material specification** for the tungsten absorber:

- Conservative proposal to assure the tungsten absorber contribution to the field quality in negligible:
  - $\mu_r < 1.0003$ at $H > 6 \cdot 10^6$ A/m
- Permeability at low field is not critical, but we propose
  - $\mu_r < 1.0015$ at $H > 1 \cdot 10^6$ A/m



First pre-series measurements (from Cedric Garion, June 2020) show that the material is significantly **better** than specified: $\mu_r < 1.00011$ (60 K, all field levels)

(M&I Supplier, samples M4/M5 [1] are taken as reference for the next slides)

[1] TungstenAlloy_MagneticCharacterization_III, EDMS 1973451

Introduction

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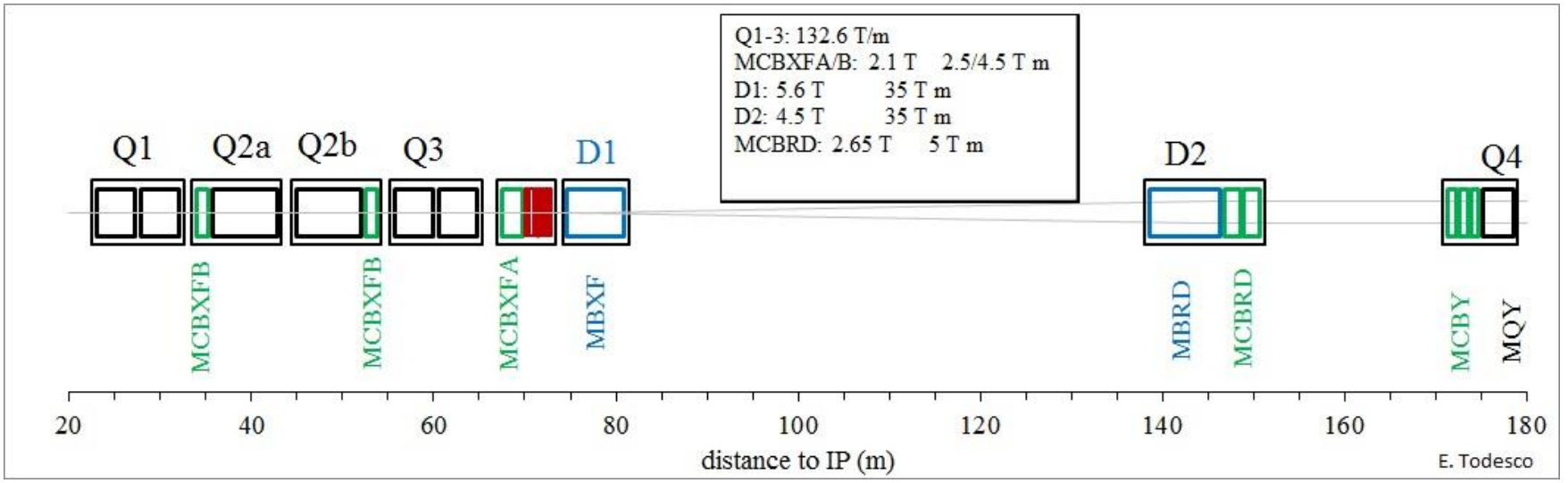
- **Update on expected impact of beam screen in MQXF, D1 and D2**



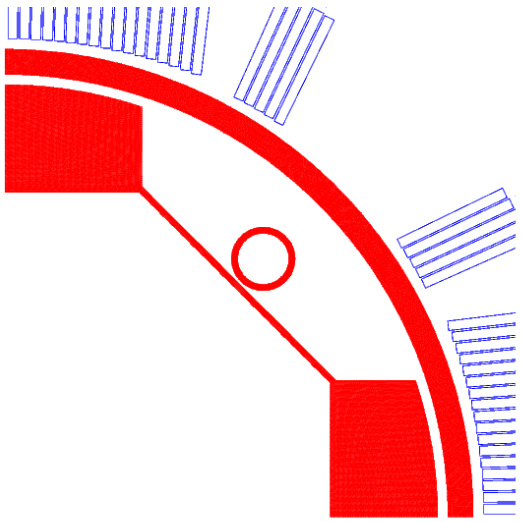
Magnetic models

- ROXIE 2D Magnetic models, provided by the collaborations, available in ROXIE HiLumi Magnet Repository:

  http://roxie-lhc-magnets.web.cern.ch/roxie-LHC-magnets/HiLumi/

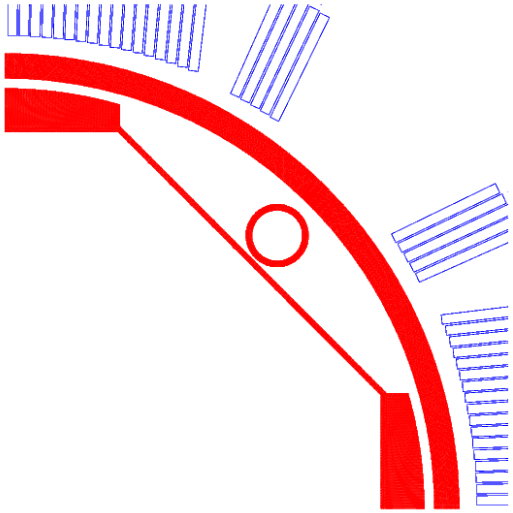
- Two different beam screen geometries:

'Thick Tungsten" Q1



LHCVSMSH0011

'Thin Tungsten" Q2,Q3,D1



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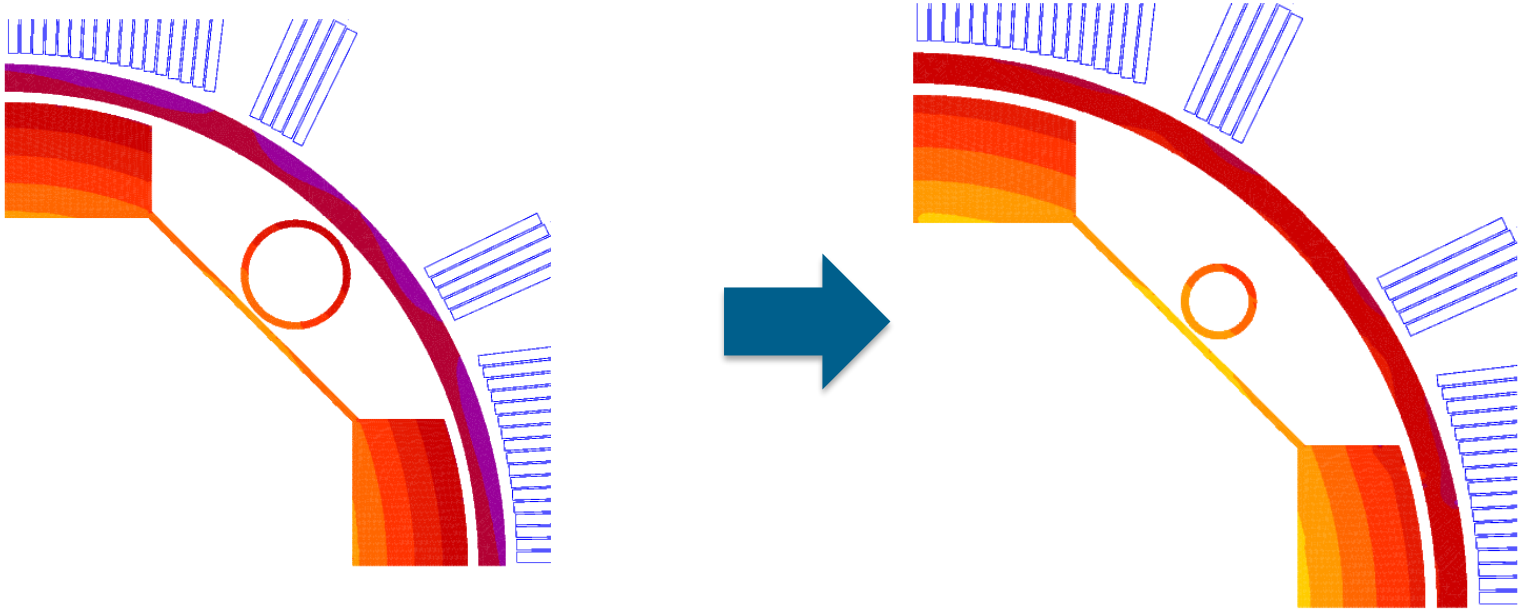
Beam screen geometry

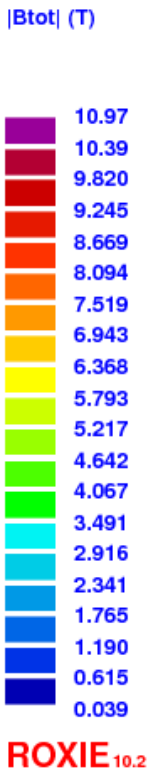
- The main dimension of the beam screen did not change significantly in the last couple of years
  - Only the diameter of the cooling channel in Q1 (D(old) = 16 mm; D (2020) = 10 mm)



LHCVSMPA0009
2018

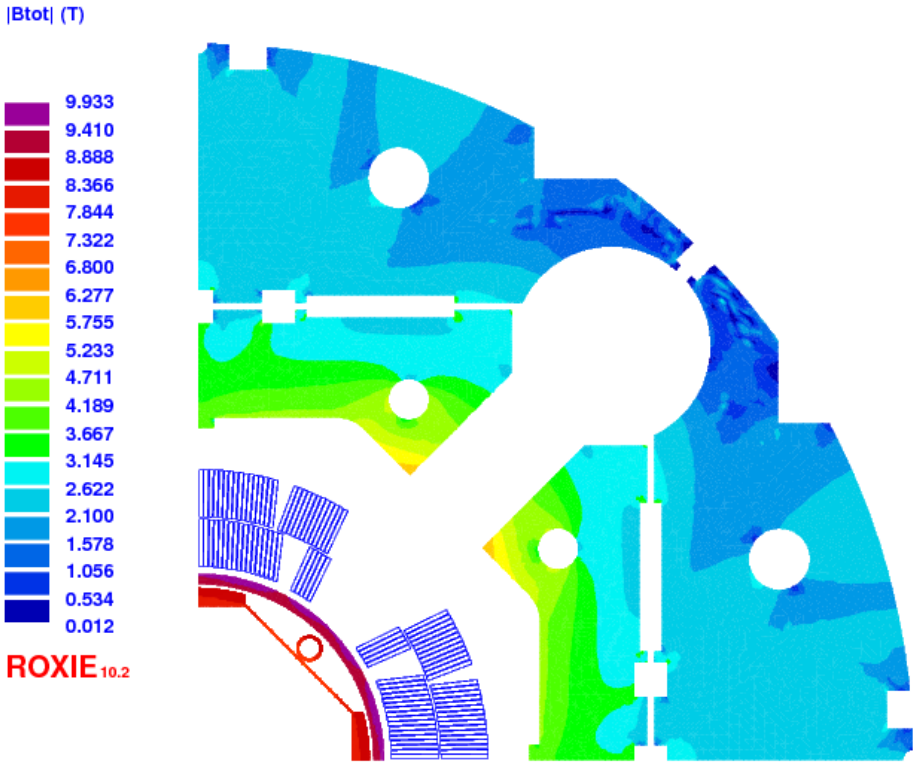
LHCVSMSH0011
2020

Q1 case



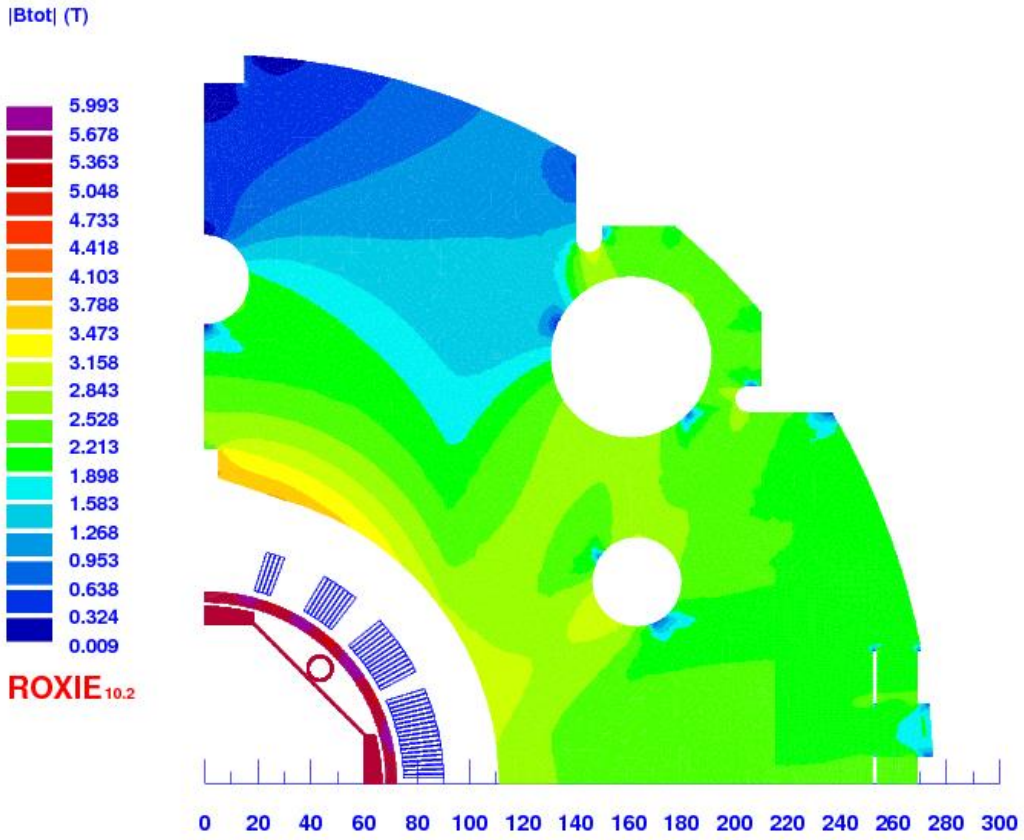
	Δ @ Inj.	Δ @ 7 TeV
	(beam screen + cooling channels+ absorber)	
b_6	-0.88	-0.70
b_{10}	0.64	0.50
b_{14}	-0.16	-0.22
b_{18}	0.19	0.23

Q2-Q3 case



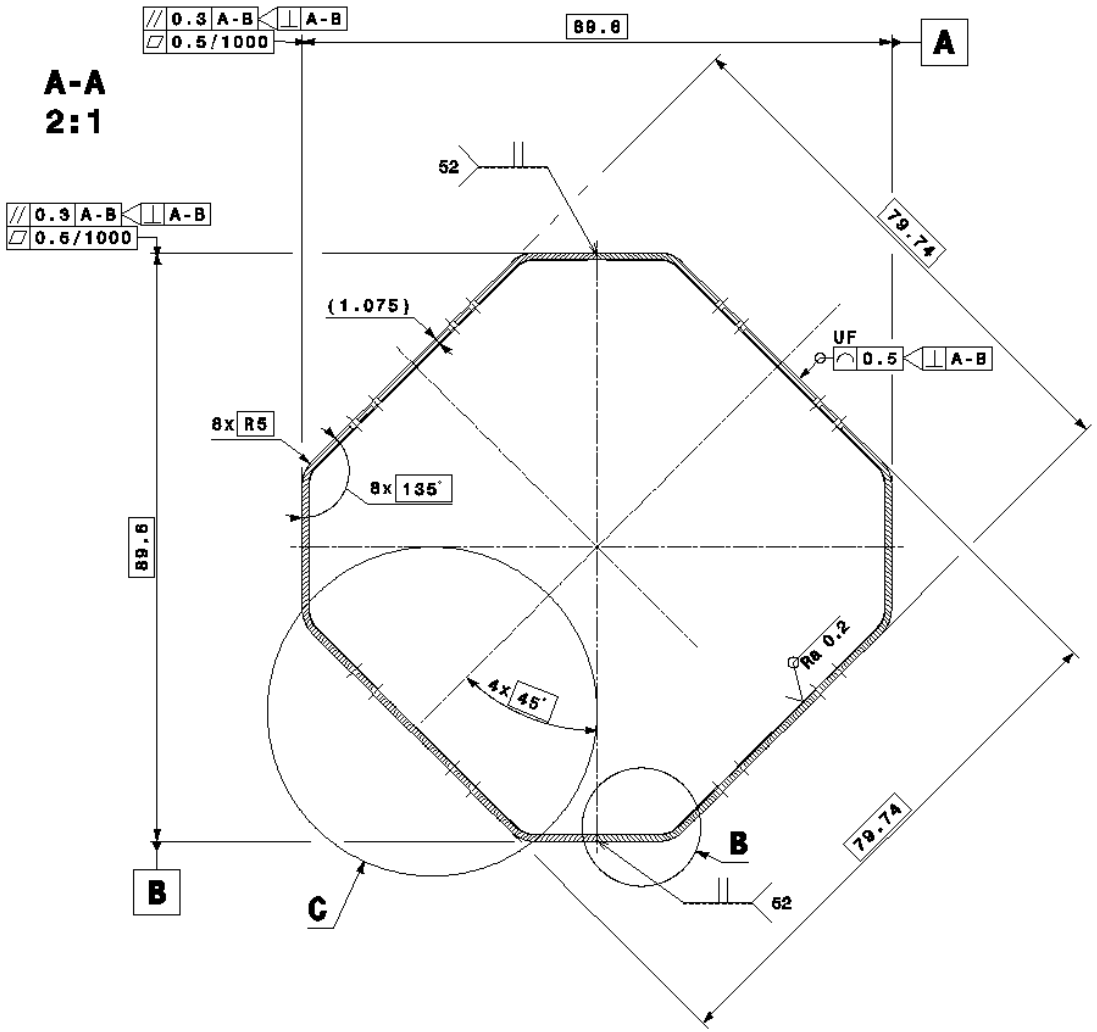
	Δ @ Inj.	Δ @ 7 TeV
	(beam screen + cooling channels+ absorber)	
b_6	-0.50	-0.42
b_{10}	0.17	0.18
b_{14}	-0.11	-0.12
b_{18}	0.08	0.08

D1 case



	Δ @ 7 TeV (beam screen + cooling channels+ absorber)
b_3	0.16
b_5	-0.02
b_7	-0.36
b_9	0.00
b_{11}	0.14

D2 case



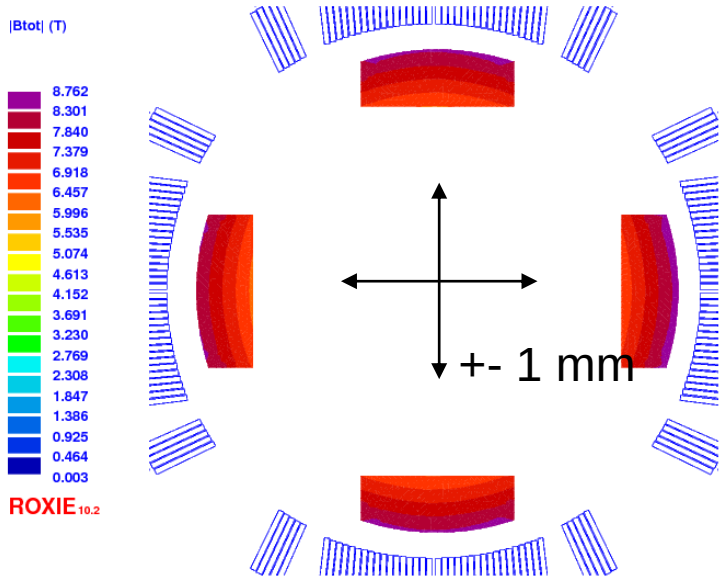
- Design of the beam screen still in discussion with the aperture team.
  - Impact on field quality will be estimated once design is finalized.

LHCVSCS_0001

Additional slides

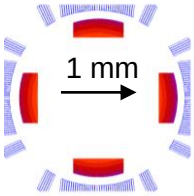
Tolerance analysis

- If STARK or MIM are the chosen materials for the beam screen, the contribution of the Tungsten to the field quality is negligible with respect to the impact of the cooling channels and beam screen.
- If CASRAM is the chosen material, the absorber has a significant contribution (0.5 units of b_6), so a more detailed analysis on the geometrical tolerances is needed.
- Preliminary numbers given by Vacuum:
  - 2 degrees of rotation
  - +- 1 mm of shift



Tolerance analysis

- Analysis on going
  - A shift of all blocks has small effect



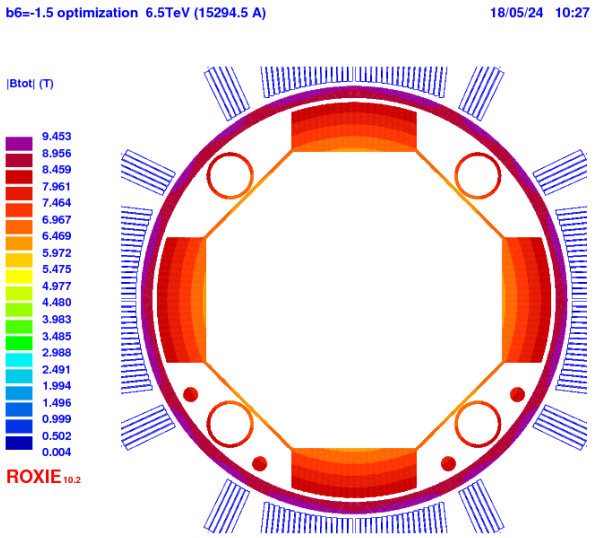
CASRAM, only Tunstgen	Impact of the shielding at 6.5 TeV (units at Rref = 50 mm) (beam screen + cooling channels+ absorber + cold bore)							
	Without	With						
		Nominal	dx = 1 mm, all blocks	dx =dy= 1 mm, all blocks	dx = 1 mm, one block	dx =dy= 1 mm, one blocks	rot = 2 deg, all blocks	rot = 2 deg, one block
Iron file		vs55	vs55	To be done				
b3	0.00	0.00	-0.04					
b4	0.00	0.00	-0.02					
b5	0.00	0.00	0.04					
b6	-1.53	-1.97	-1.97					
b10	-0.11	0.14	0.14					
b14	-0.87	-0.84	-0.84					
b18	-0.26	-0.27	-0.28					
a3	0.00	0.00	0.07					
a4	0.00	0.00	0.01					
a5	0.00	0.00	0.00					

First quick check

LHCVSMPA0009 iron vs57

	Impact of the shielding at 6.5 TeV (units at Rref = 50 mm) (beam screen + cooling channels+ absorber + cold bore)				
	Without	With beam screen		Δ (units)	
		Only tungsten	Tungsten + Ti supports	Only tungsten	Ti supports
b3	0.00	0.00	0.06	0.00	0.06
a3	0.00	0.00	0.12	0.00	0.12
b4	0.00	0.00	0.00	0.00	0.00
a4	0.00	0.00	0.00	0.00	0.00
b5	0.00	0.00	0.01	0.00	0.01
a5	0.00	0.00	-0.06	0.00	-0.06
b6	-1.53	-2.28	-2.12	-0.75	0.16
b10	-0.11	0.33	0.15	0.44	-0.18
b14	-0.87	-0.98	-0.94	-0.12	0.05
b18	-0.26	-0.15	-0.13	0.11	0.02

Remember this is only in a very specific longitudinal location, should be diluted by a factor 0.05-0.01



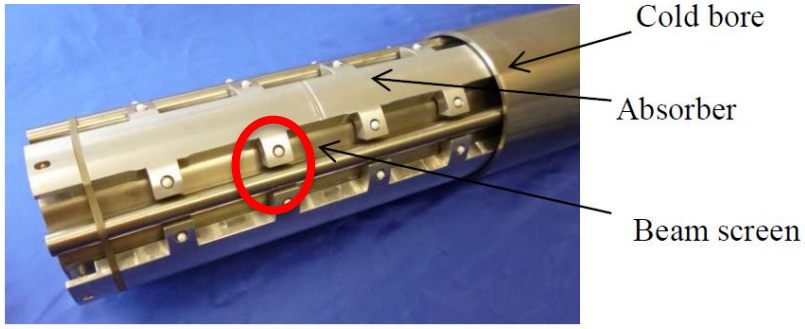
Drawings

- The drawings of the beam screens are the following:
  - LHCVSMSL0038: Q2
  - LHCVSMSL0039: Q3
  - LHCVSMSL0041: CP
  - LHCVSMSL0048: D1
  - LHCVSMSH0022: Q1

Conclusions for Tungsten

- If the material from STARK or MIM is chosen, the impact on field of the Tungsten absorber is negligible at collision energy.
- The use of CASRAM material contributes with 0.4 units of b_6 at collision energy, which is comparable to the contribution of the cooling channels.

If CASRAM is selected as material for the beam screen, we should further check the impact of assembly tolerances (probably not critical) and 3D effects (20 % of the beam screen has different Tungsten geometry)

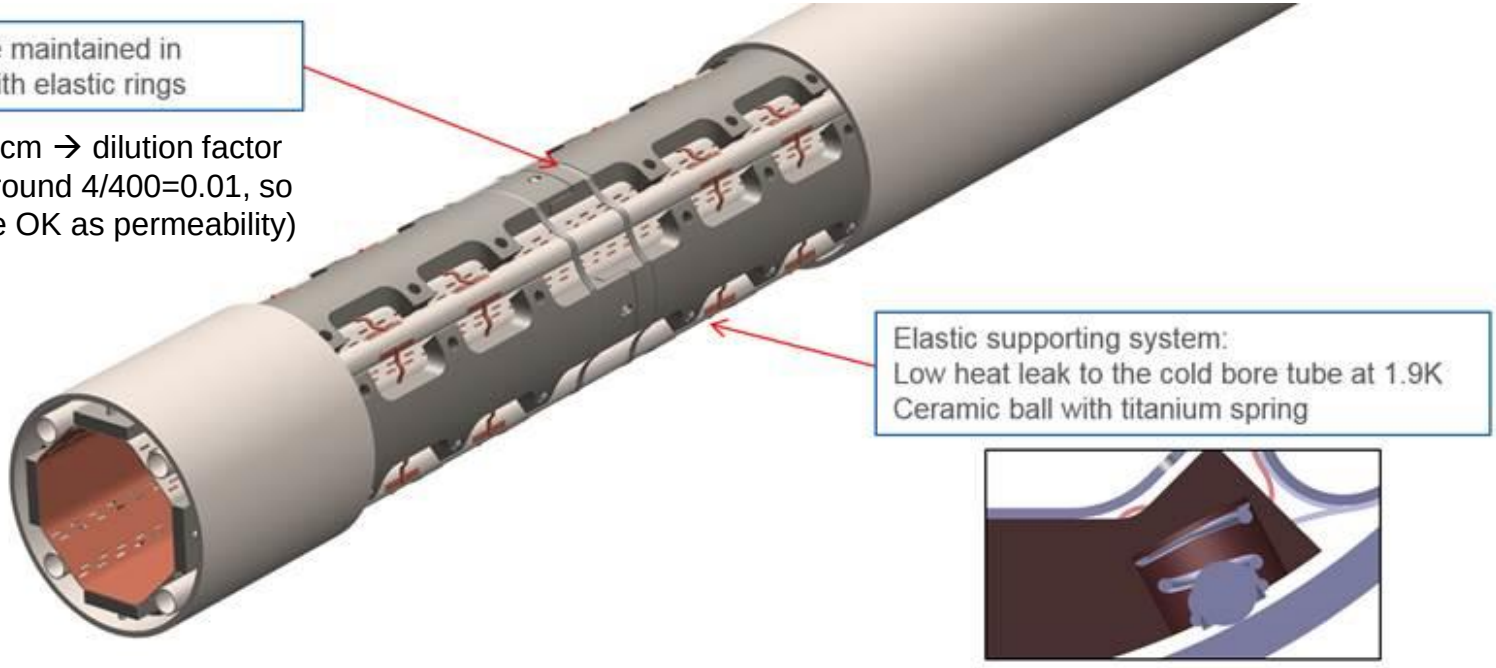


- In order to guarantee that the tungsten contribution to the field quality is negligible, we propose to set as specification:

  - $\mu_r < 1.0003$ at $H > 6 \cdot 10^6$ A/m
  - $\mu_r < 1.0015$ at $H > 1 \cdot 10^6$ A/m

Titanium rings for support

- Magnetic permeability for spec < 1.005



(once every 40 cm → dilution factor longitudinally around 4/400=0.01, so 1.005 should be OK as permeability)

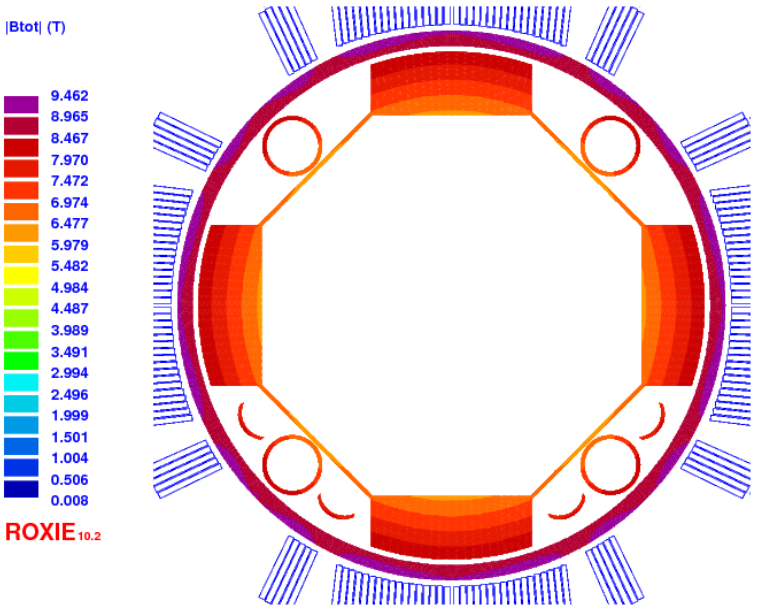
(in 4 longitudinal sections, 4 in between each 40 cm section. Only in the 4 lower ceramic ball supports (to support against gravity))

A quick check

- Since the supports are not symmetric (top bottom), quick check to verify if the asymmetry was creating un-allowed harmonics
- Remember this is only in a very specific longitudinal location, should be diluted by a factor 0.05-0.01

LHCVSMPA0009 iron vs58

	Impact of the shielding at 6.5 TeV (units at Rref = 50 mm) (beam screen + cooling channels+ absorber + cold bore)				
	Without	With beam screen		Δ (units)	
		Only tungsten	Tungsten + Ti supports	Only tungsten	Ti supports
b3	0.00	0.00	-0.09	0.00	-0.09
a3	0.00	0.00	0.02	0.00	0.02
b4	0.00	0.00	0.05	0.00	0.05
a4	0.00	0.00	0.00	0.00	0.00
b5	0.00	0.00	0.00	0.00	0.00
a5	0.00	0.00	-0.05	0.00	-0.05
b6	-1.53	-2.28	-2.18	-0.75	0.10
b10	-0.11	0.33	0.23	0.44	-0.10
b14	-0.87	-0.98	-0.96	-0.12	0.02
b18	-0.26	-0.15	-0.14	0.11	0.01



Titanium rings are OK!

Conclusions

- The contribution of titanium rings and washers for support is negligible in terms of field quality → Magnetic permeability for spec < 1.005 is OK
- For the Tungsten absorber, our proposal is
  - $\mu_r < 1.0003$ at $H > 6 \cdot 10^6$ A/m
  - $\mu_r < 1.0015$ at $H > 1 \cdot 10^6$ A/m