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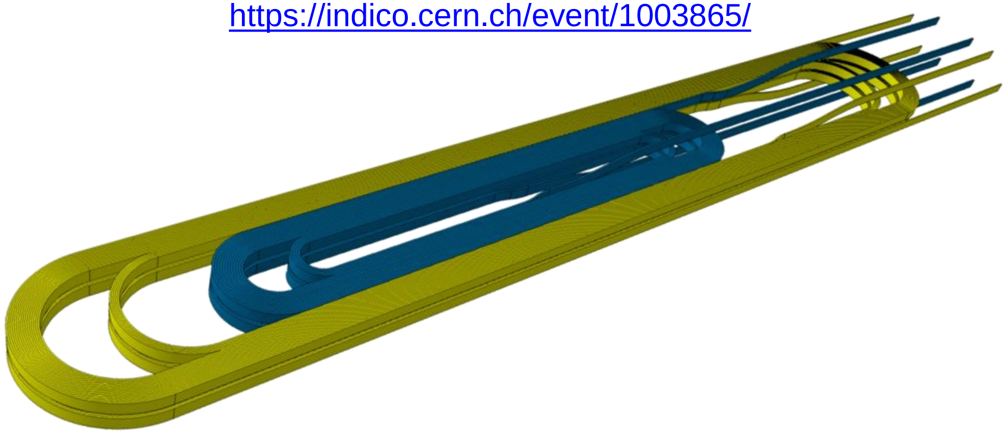
Conceptual Design Review of R2D2
4
- Engineering design -

https://indico.cern.ch/event/1003865/



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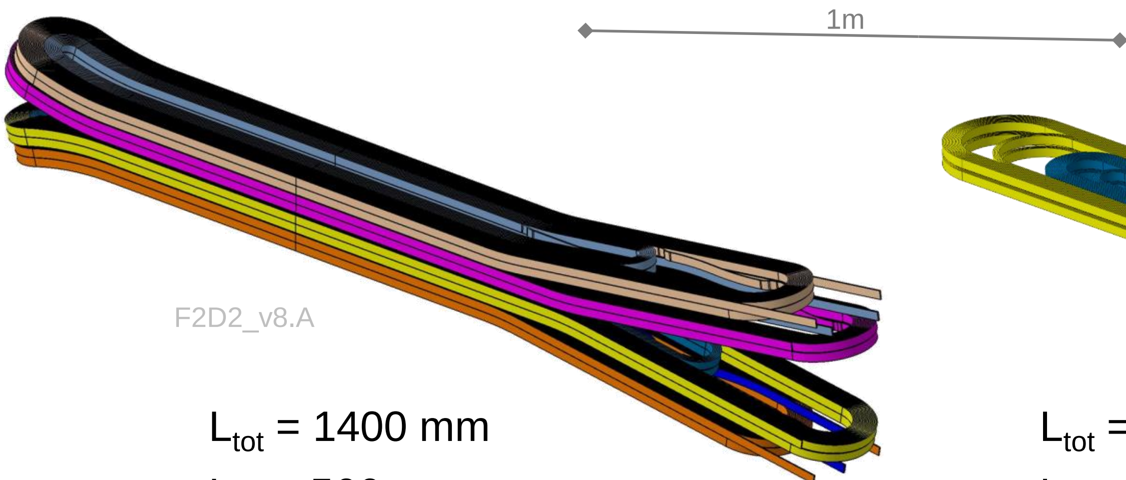
09/03/2021

F2D2 ↔ R2D2

F2D2 dipole



L_{tot} = 1400 mm

L_{ss} = 566 mm

4 coils = 4 graded double-pancakes

8 sub-coils (HF/LF)

Double layer

Flared ends

Layer jump + Exit jumps

External joints

R2D2 dipole

L_{tot} = 1300 mm without leads

L_{ss} = 243 mm

2 coils = 2 graded single layer

4 sub-coils (HF/LF)

Single layer

Racetrack

Exit jumps

External joints

(see **1**, E. Rochepault & **2**, V. Calvelli)

R2D2 ENGINEERING STAKES

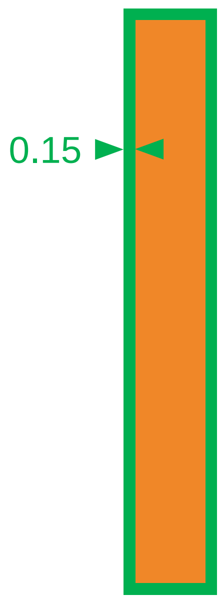
- **How to handle cables in graded coils?**
- **How to ensure longitudinal support?**

→ (Unfortunately) R2D2 is not a 'simplified F2D2' in all matters (see **2**, V. Calvelli)

CABLE DIMENSIONS

Virgin, bare

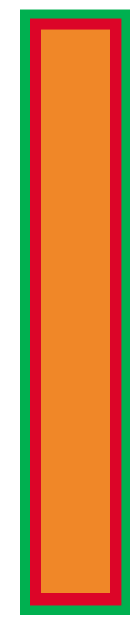
Virgin, insulated



Expansion during reaction :

+ 4.6 % thickness
+ 1.3% width
No changes in insulation

Heat Treated Insulated

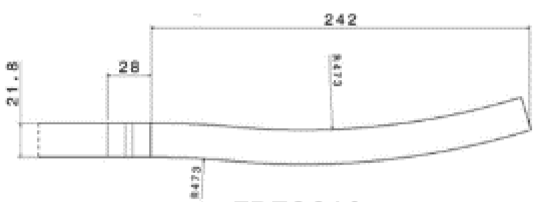


CAD Cable Section
(margin included)

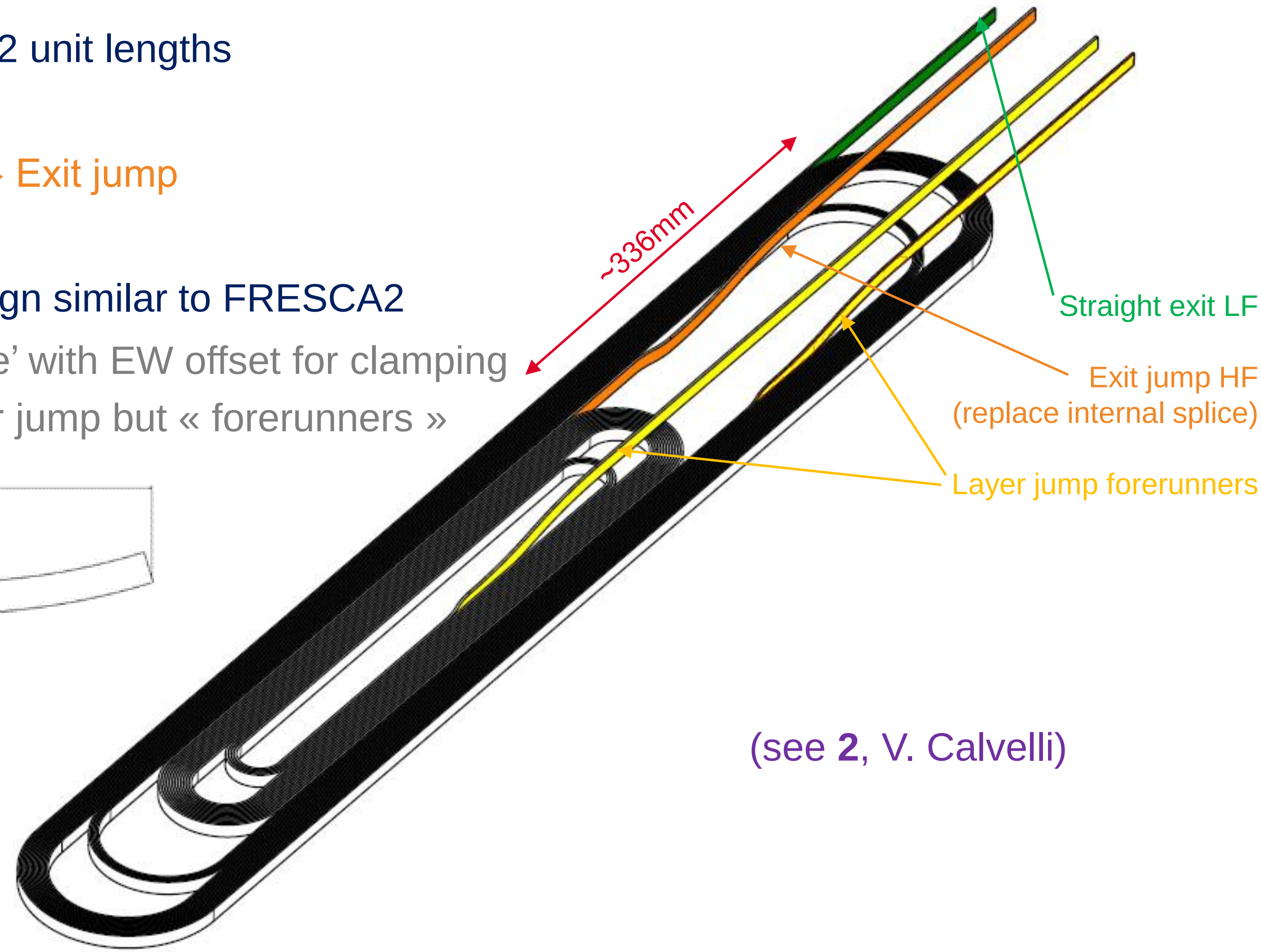
	Virgin, bare	Virgin, insulated	Heat Treated Insulated
HF	12.58 x 1.97	12.88 x 2.27	**13.04 x 2.36**
LF	12.58 x 1.25	12.88 x 1.55	**13.04 x 1.61**

Coil detailed geometry 1/3

- **Each coil** {HF+LF, single-pancake} **is designed and fabricated as one impregnated object**
- 1 coil = 2 sub-coils = 2 unit lengths
- Splicing is external → Exit jump
- F2D2 layer jump design similar to FRESCA2
  - HW-bend 'S-shape' with EW offset for clamping
  - R2D2 has no layer jump but « forerunners »



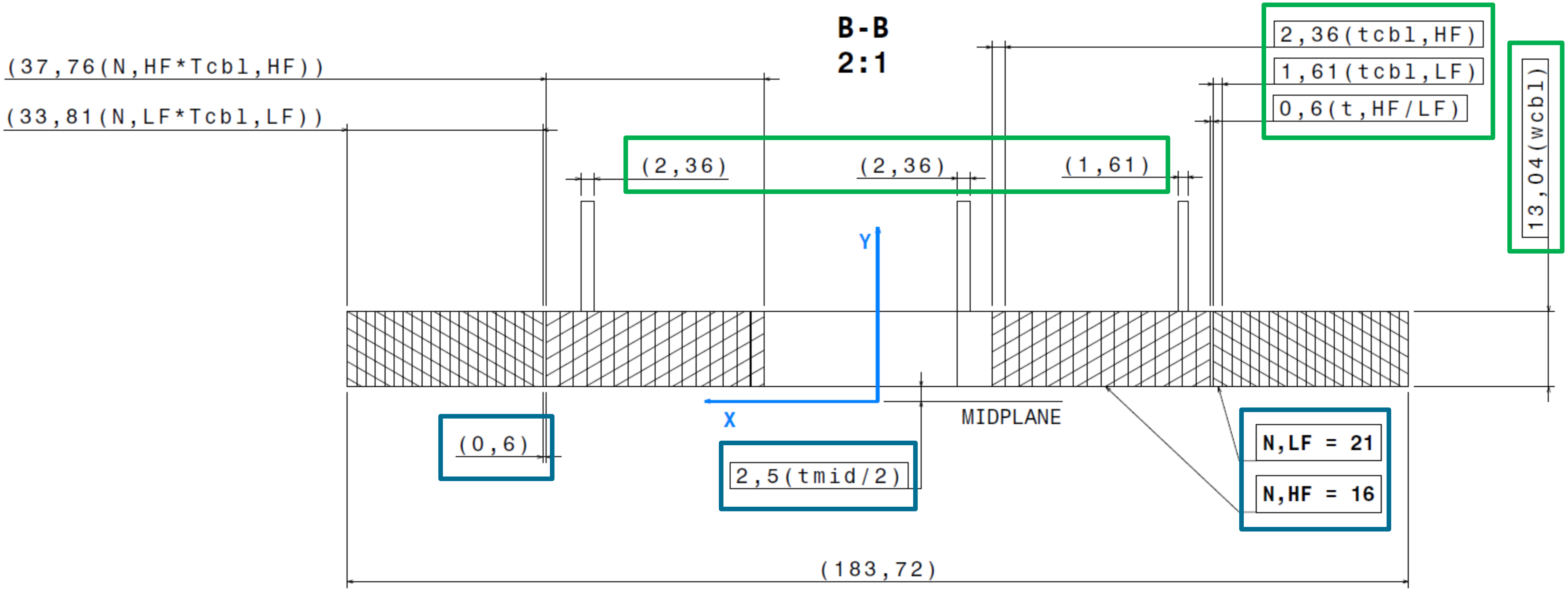
FRESCA2



(see **2**, V. Calvelli)

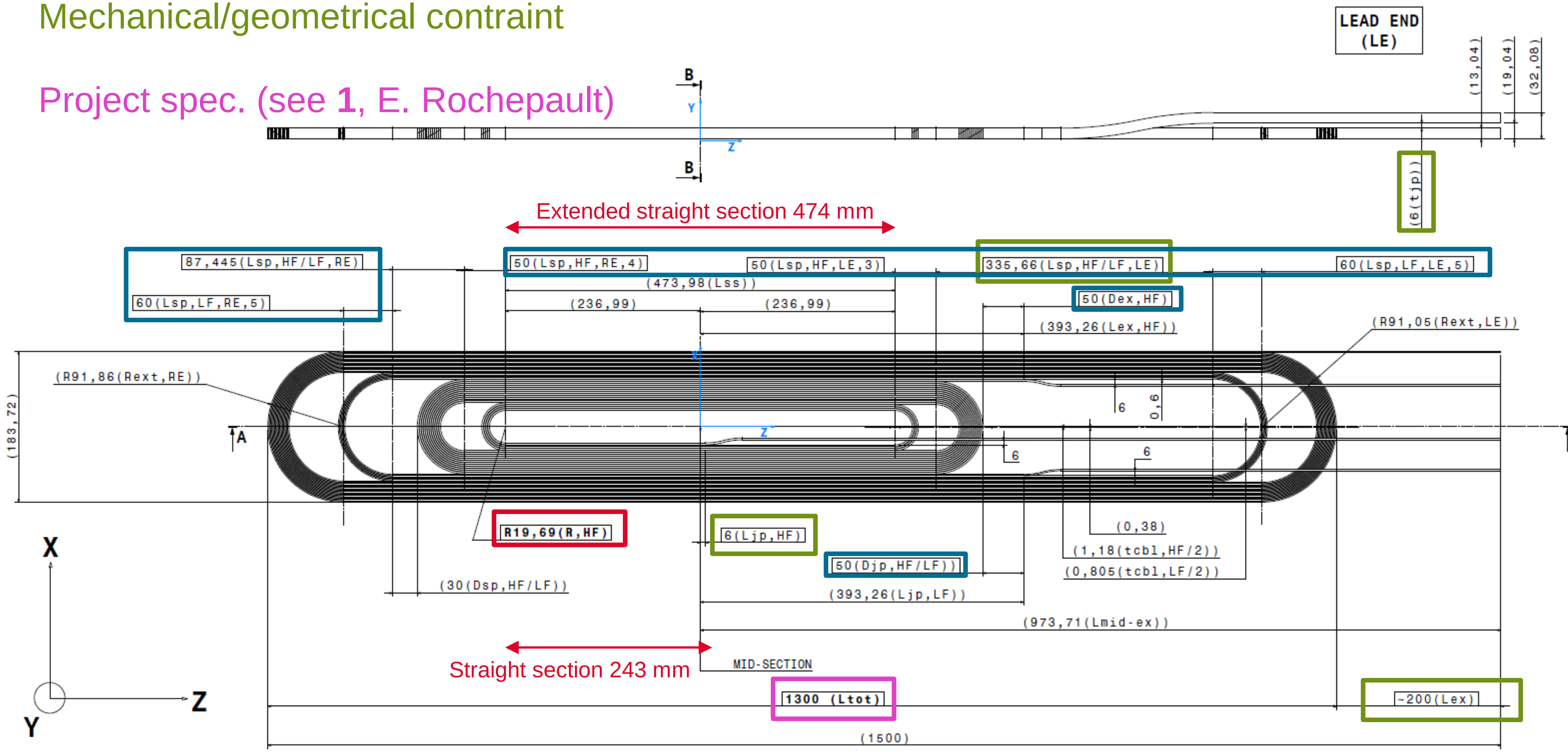
COIL DETAILED GEOMETRY 2/3

- Insulated/reacted cables dimensions (w_{HF} = w_{LF} = =w_{cbl})
- Magnetic design (see **2**, V. Calvelli)



COIL DETAILED GEOMETRY 3/3

- Minimum bending radius : $\frac{R_{HF}}{w_{cbl,bare}} = 10$ (see **5**, M. Durante, for experimental validation)
- Magnetic design (see **2**, V. Calvelli) → long lead ends!
- Mechanical/geometrical contraint
- Project spec. (see **1**, E. Rochepault)



CABLE LENGTHS

- From CAD: for one {HF+LF} coil, **without margins**:

Cable type	Coil cable length (L_{ex} = 200)
HF	22,8 m
LF	55,9 m

- Overall demand including margins and additional lengths:

HF	34 m
LF	67 m

COIL COMPONENTS OVERVIEW

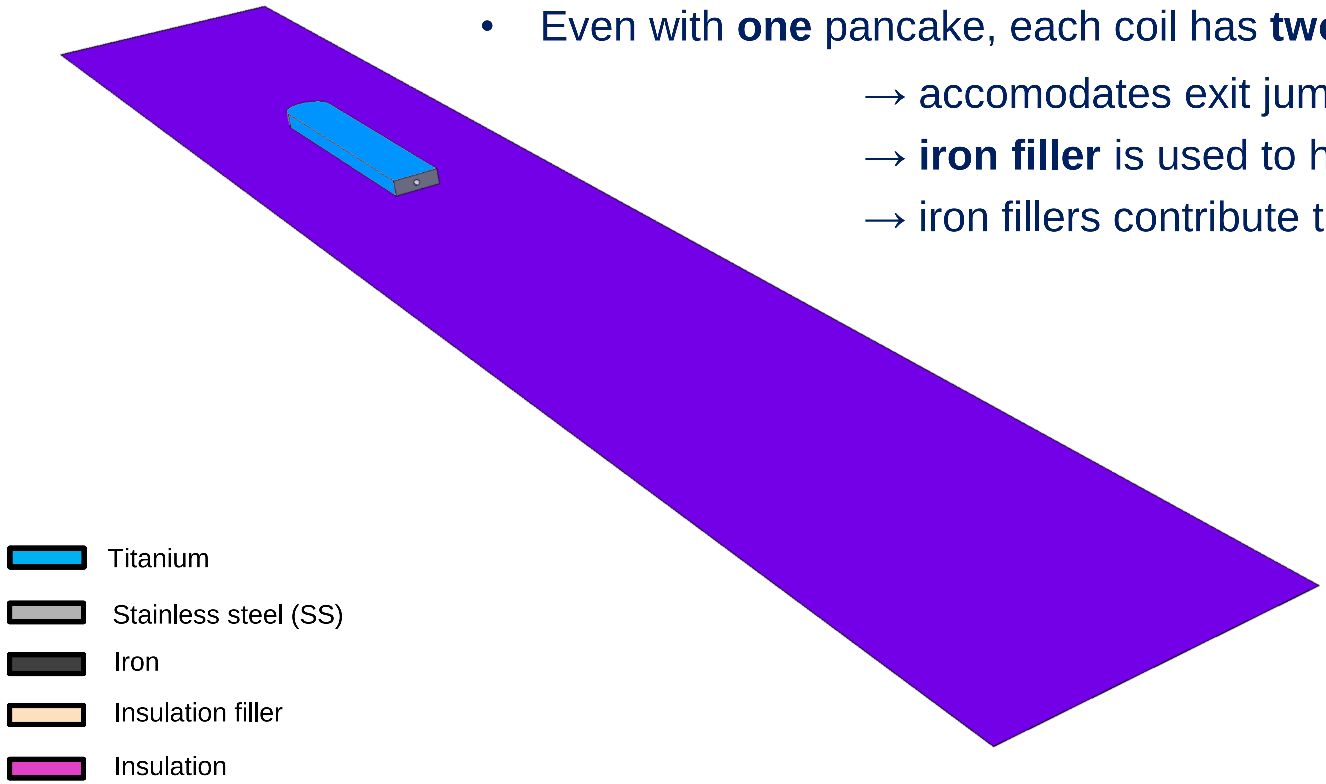
- Preliminary design: details not included

- Even with **one** pancake, each coil has **two** layers

  → accomodates exit jumps

  → **iron filler** is used to have a **flat coil surfa**

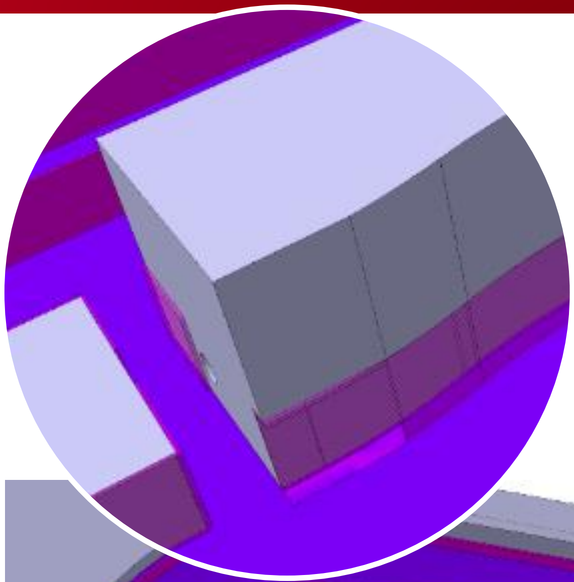
  → iron fillers contribute to magnetic field



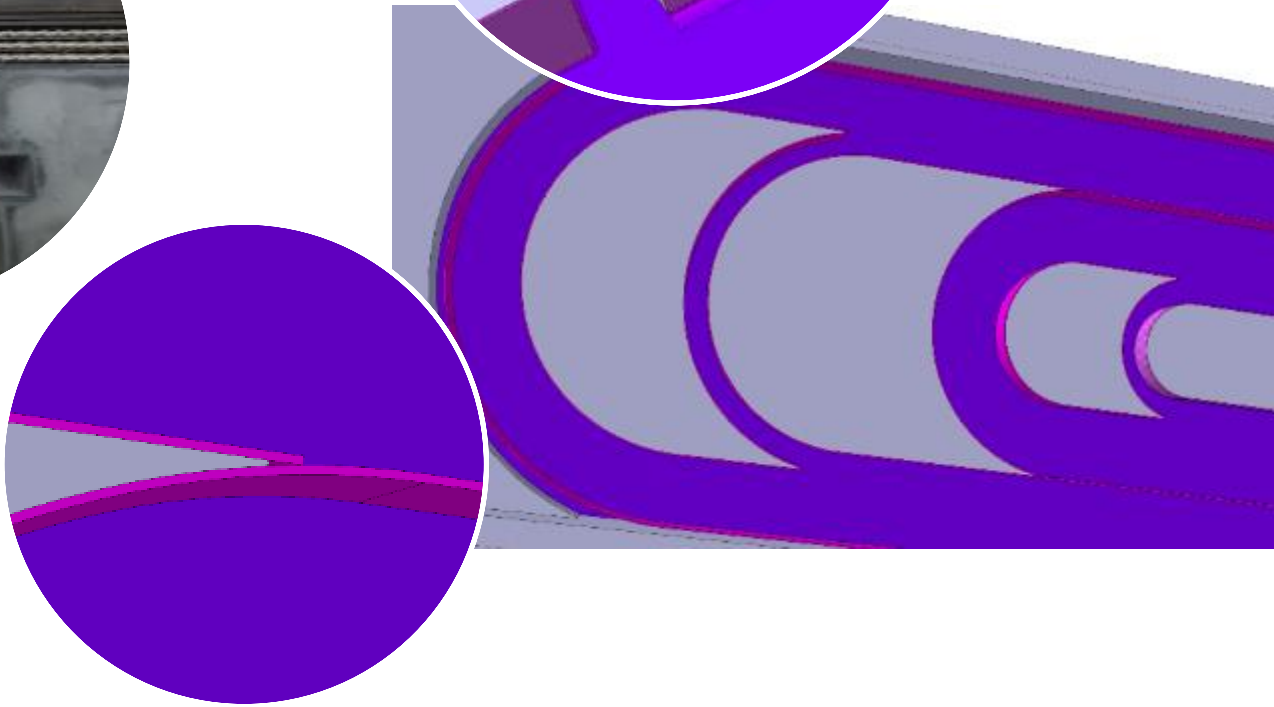
COIL COMPONENTS: CLOSEUP ON DETAILS

- Post:
  - 10mm-split (tbc) for HT contraction
  - Thickness variation to accomodate exits

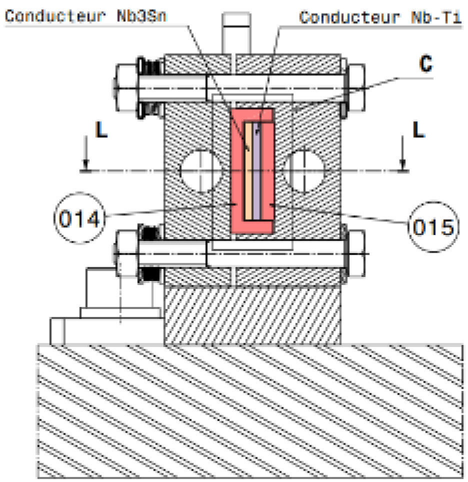
MQXF HT test

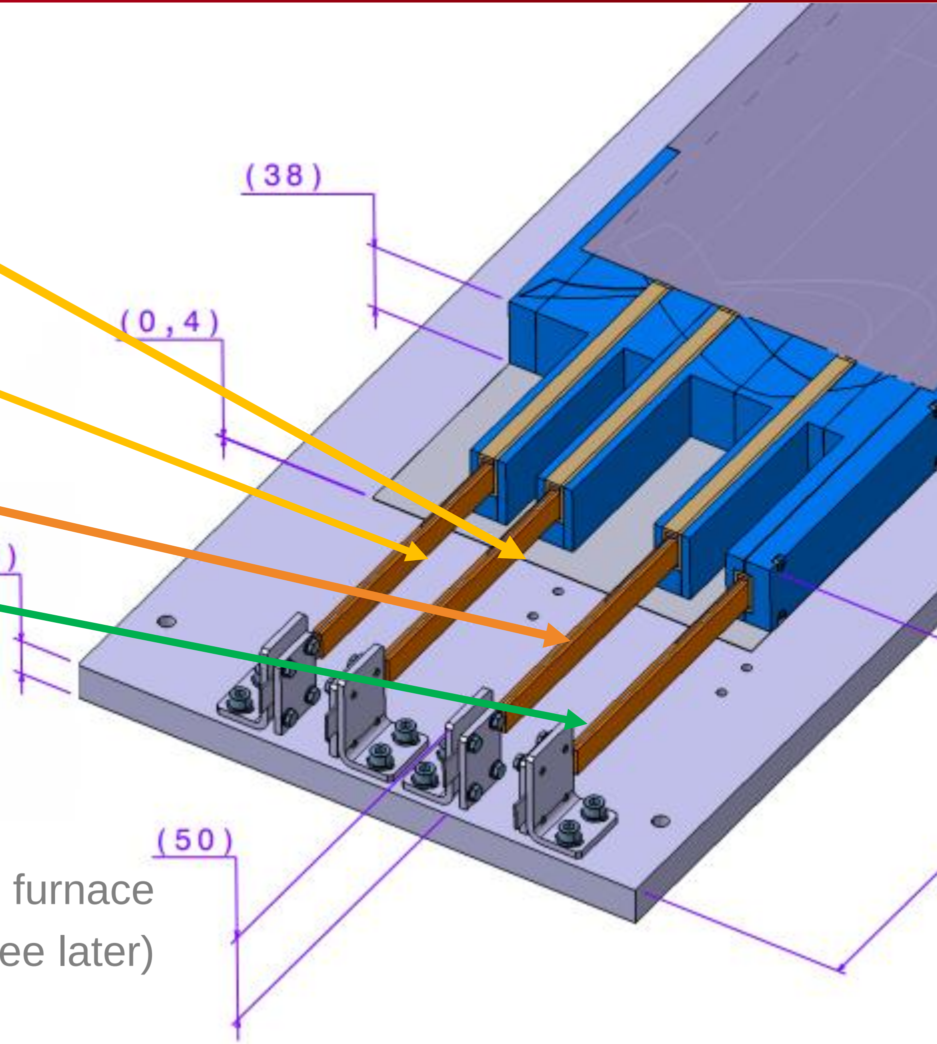


- Components insulation
  - No coating
  - Wrapped insulation



COIL COMPONENTS: SPLICES & JOINTS

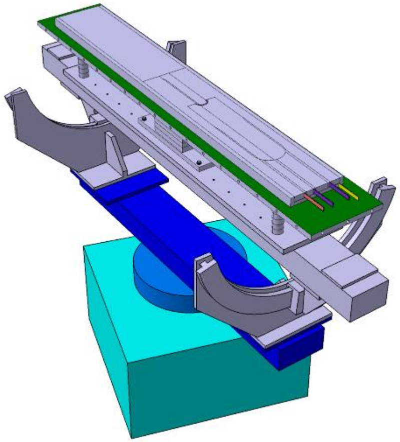




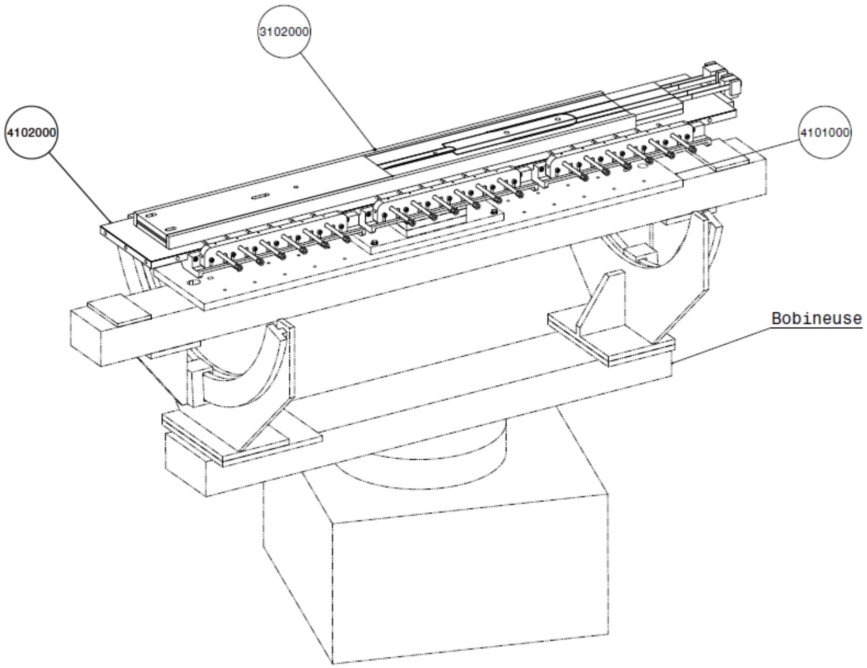
- Splicing procedure similar to FRESCA2's
  - At least 200mm extra length compatible with furnace
  - Option: increasing distance between exits (see later)

(see **5**, M. Durante, for experimental qualification)

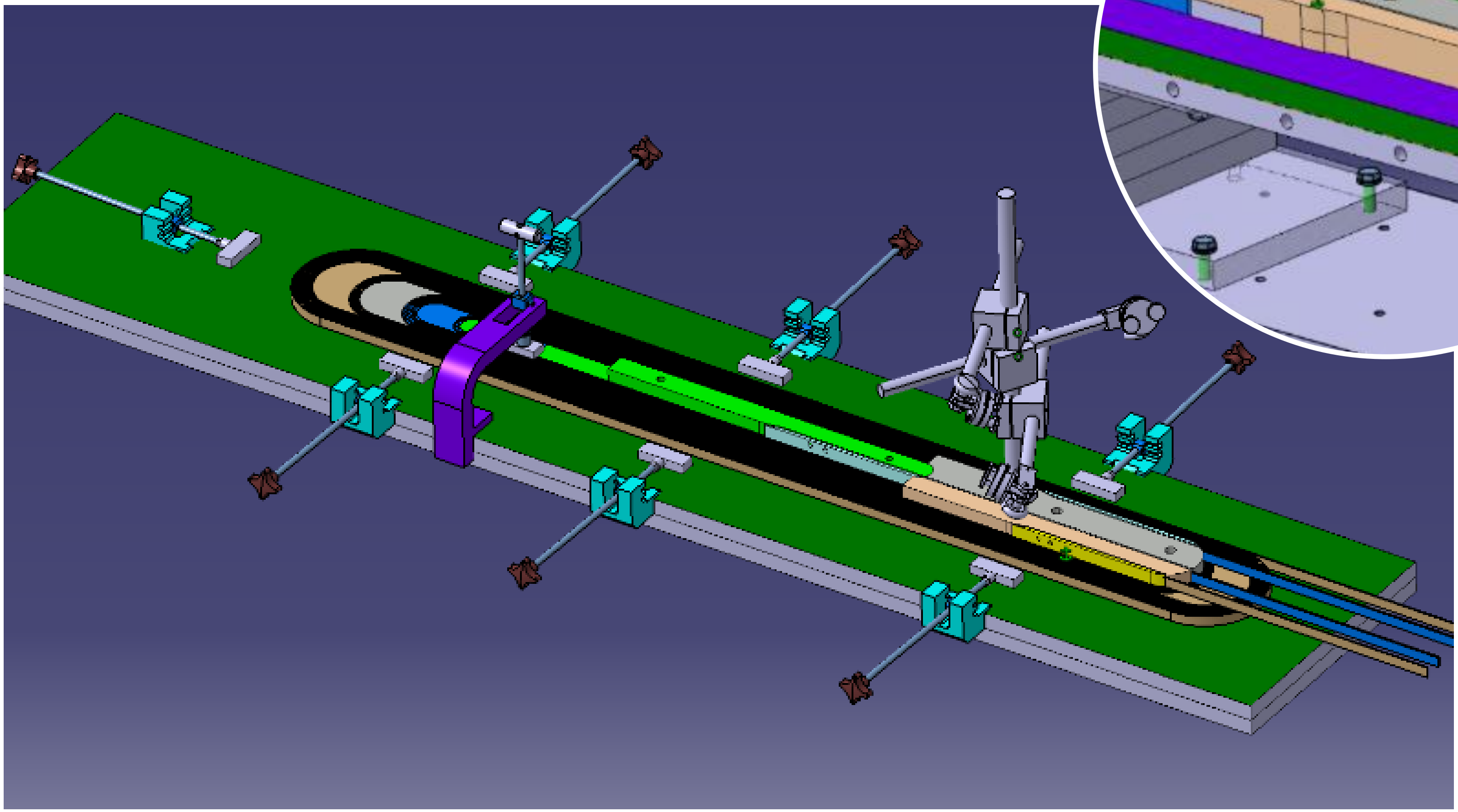
PRELIMINARY WINDING TOOLING 1/3

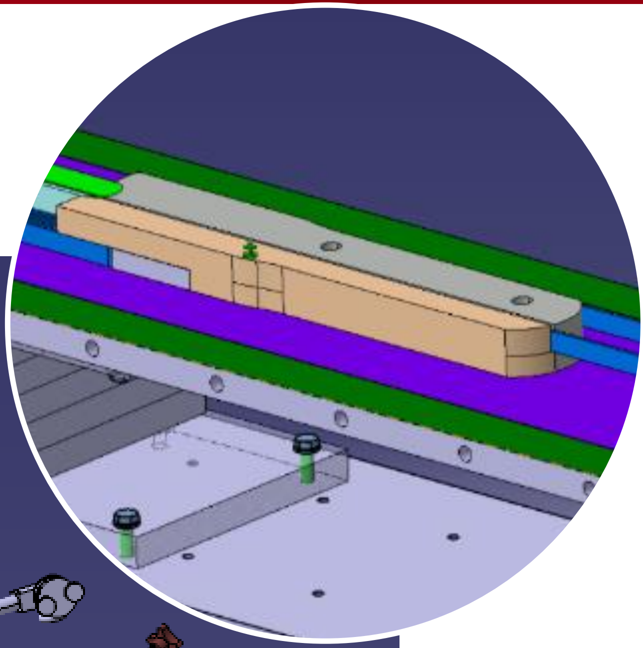


- R2D2 winding will be performed at Saclay
- Fabrication procedure is inspired from SMC and FRESCA2 feedback
- **R2D2 is not strictly a fabrication demonstrator for F2D2!**



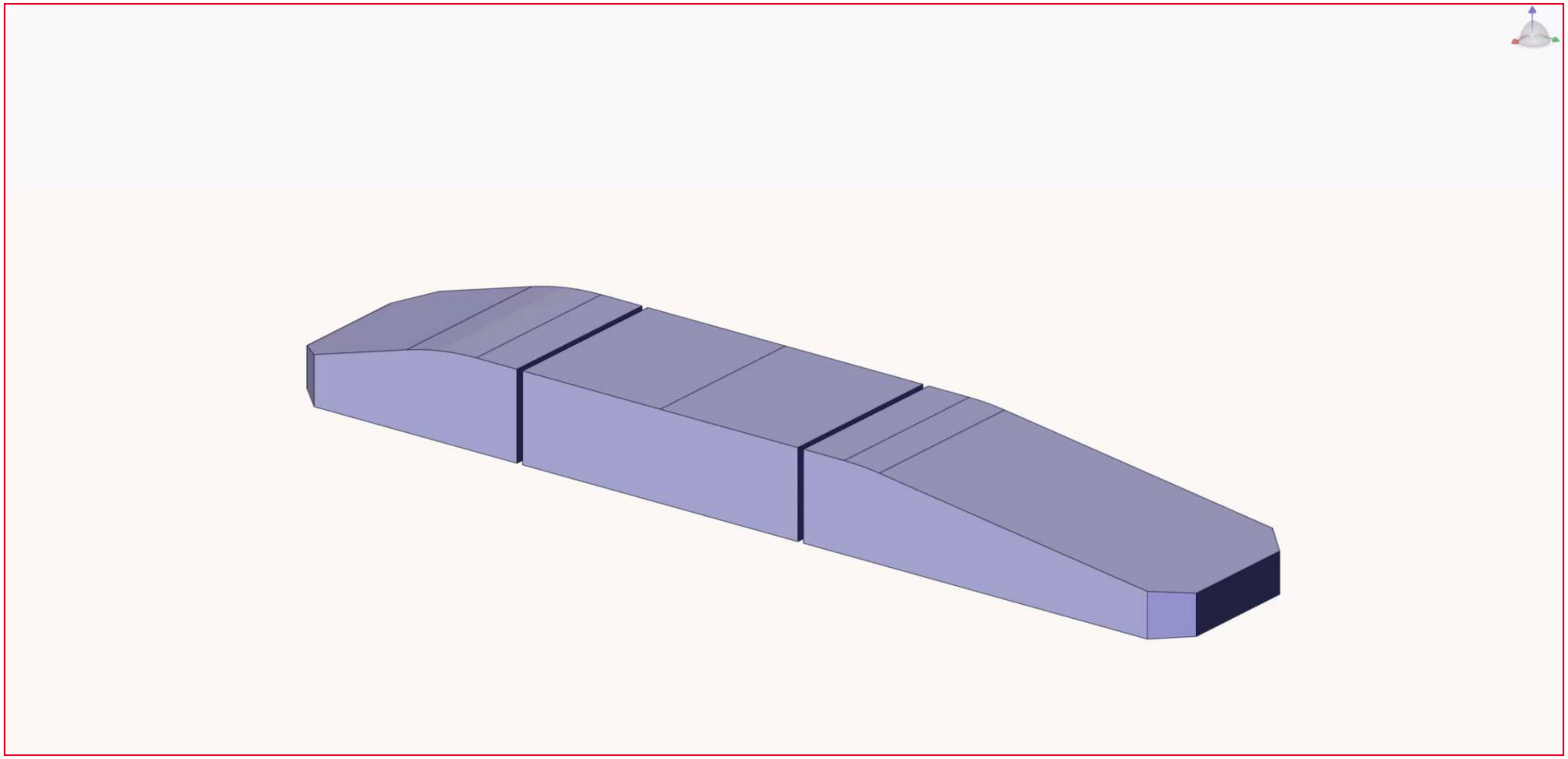
- Winding of each sub-coil starts at the layer jump
- Mica sheets save space for trace (on lower side)





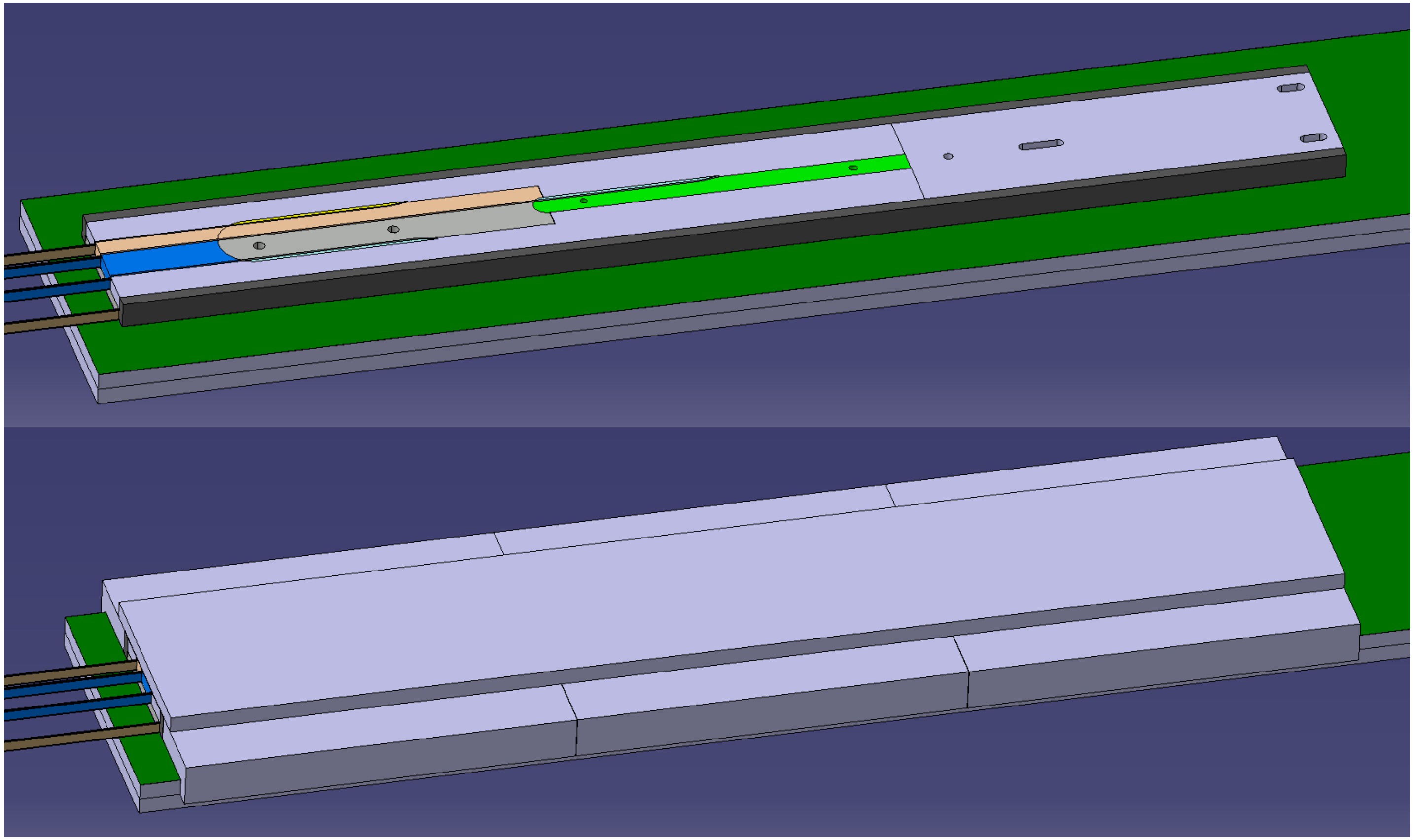
PRELIMINARY WINDING TOOLING 3/3

- Warning: this animation is based on F2D2 design (double-pancake coil)
- Clamping of the jumps/exit will be similar for R2D2

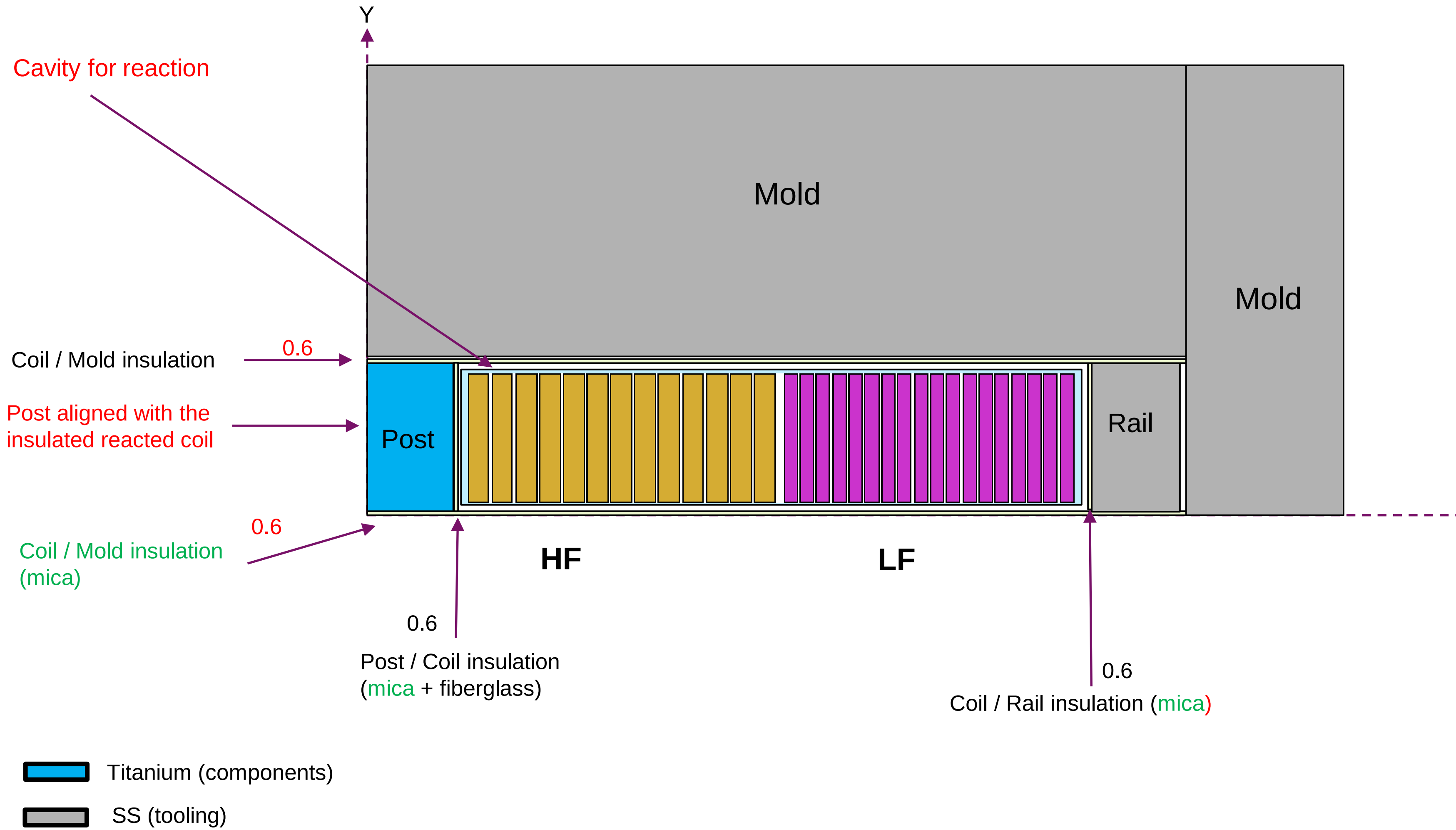


HEAT TREATMENT TOOLING CONCEPTS

- Reaction performed at Saclay
- Coil should be able to slide as much as possible sliding
  - Mica sheets all around
  - Minimal guiding features, one fix point (LE)

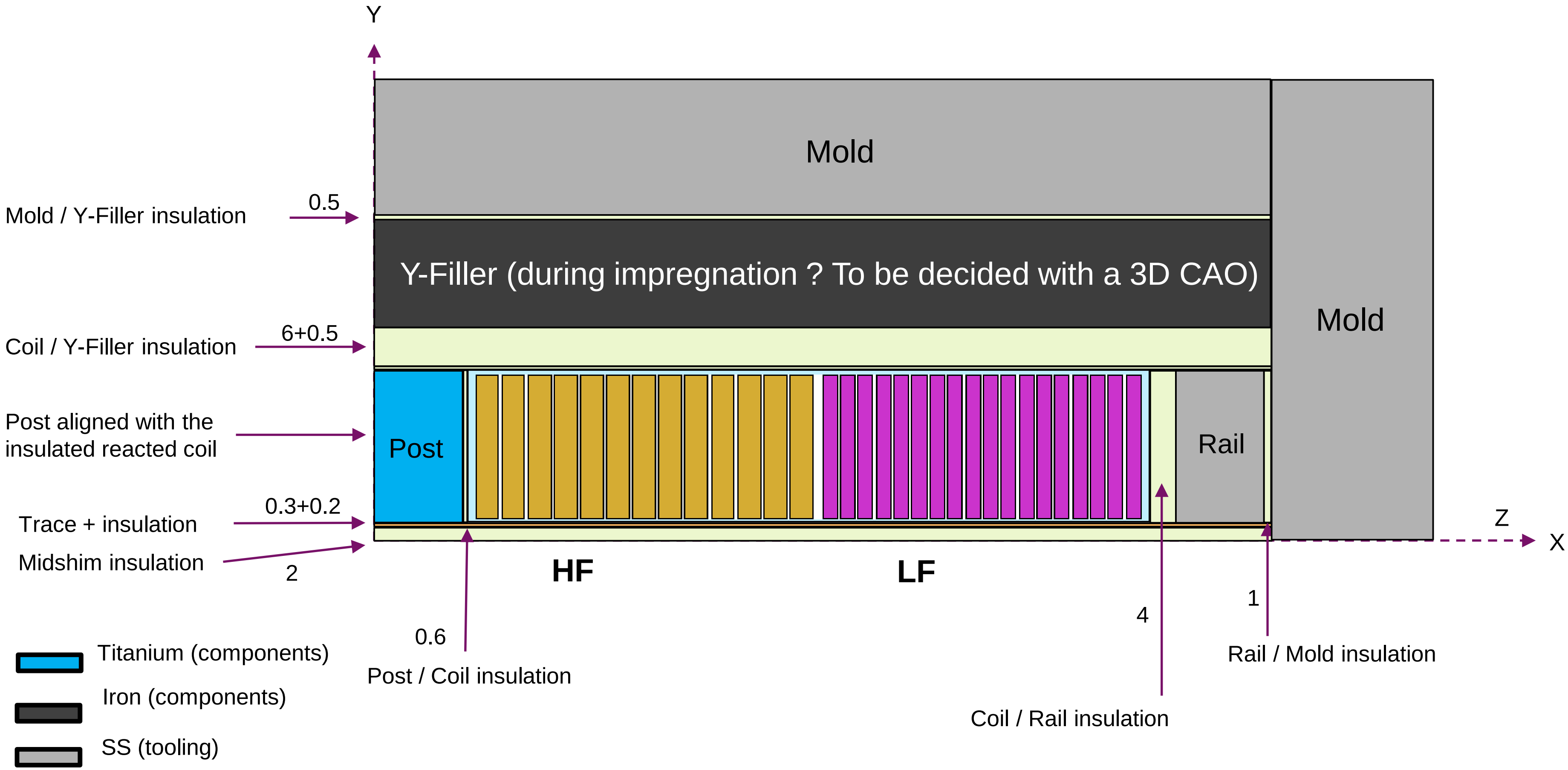


R2D2 REACTION CONFIGURATION

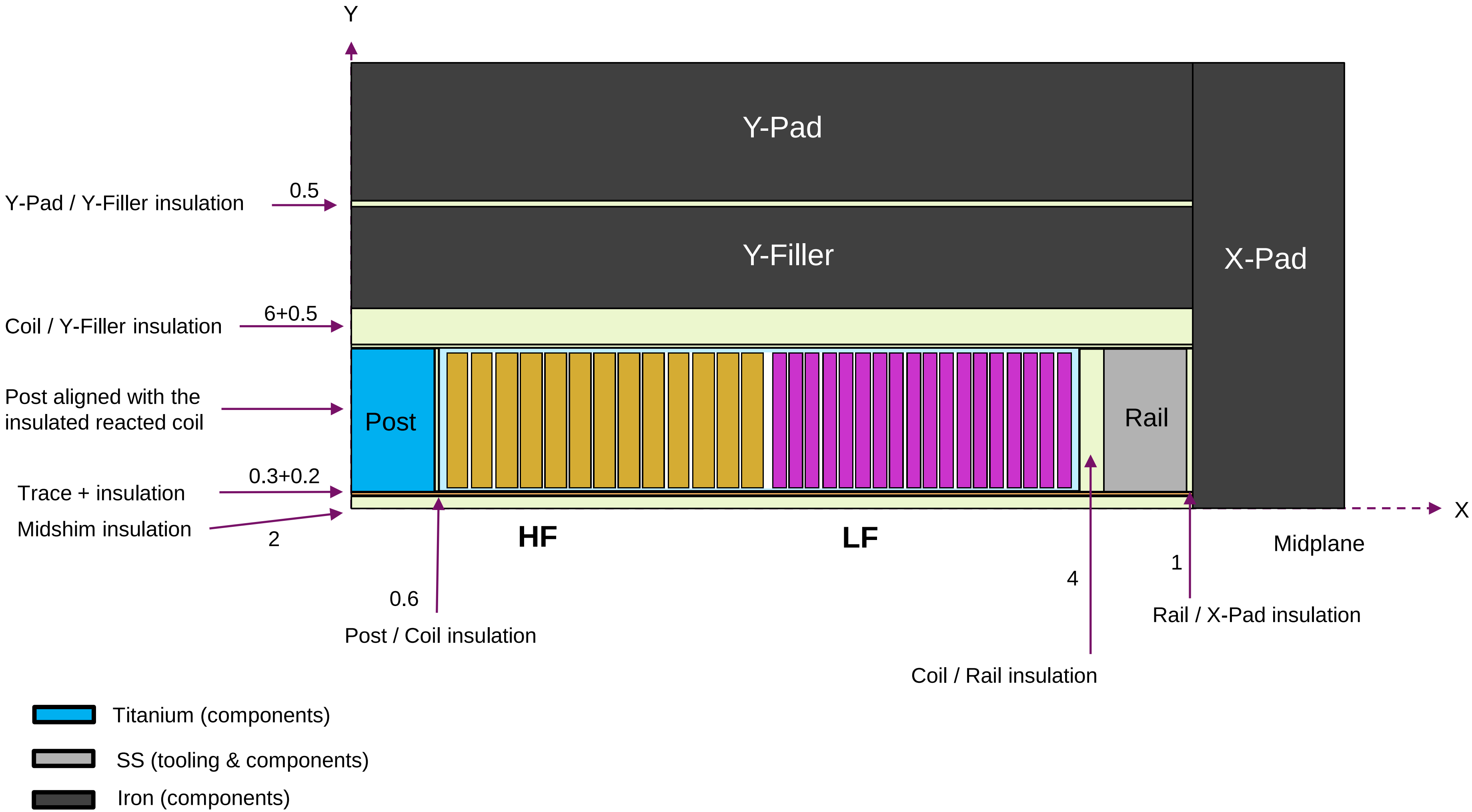


R2D2 IMPREGNATION CONFIGURATION

- Impregnation performed at Saclay
  - 2-layers coil pack integrates SS rails and iron filler that contribute to magnetic field
- Impregnation process should be demonstrated on SMC

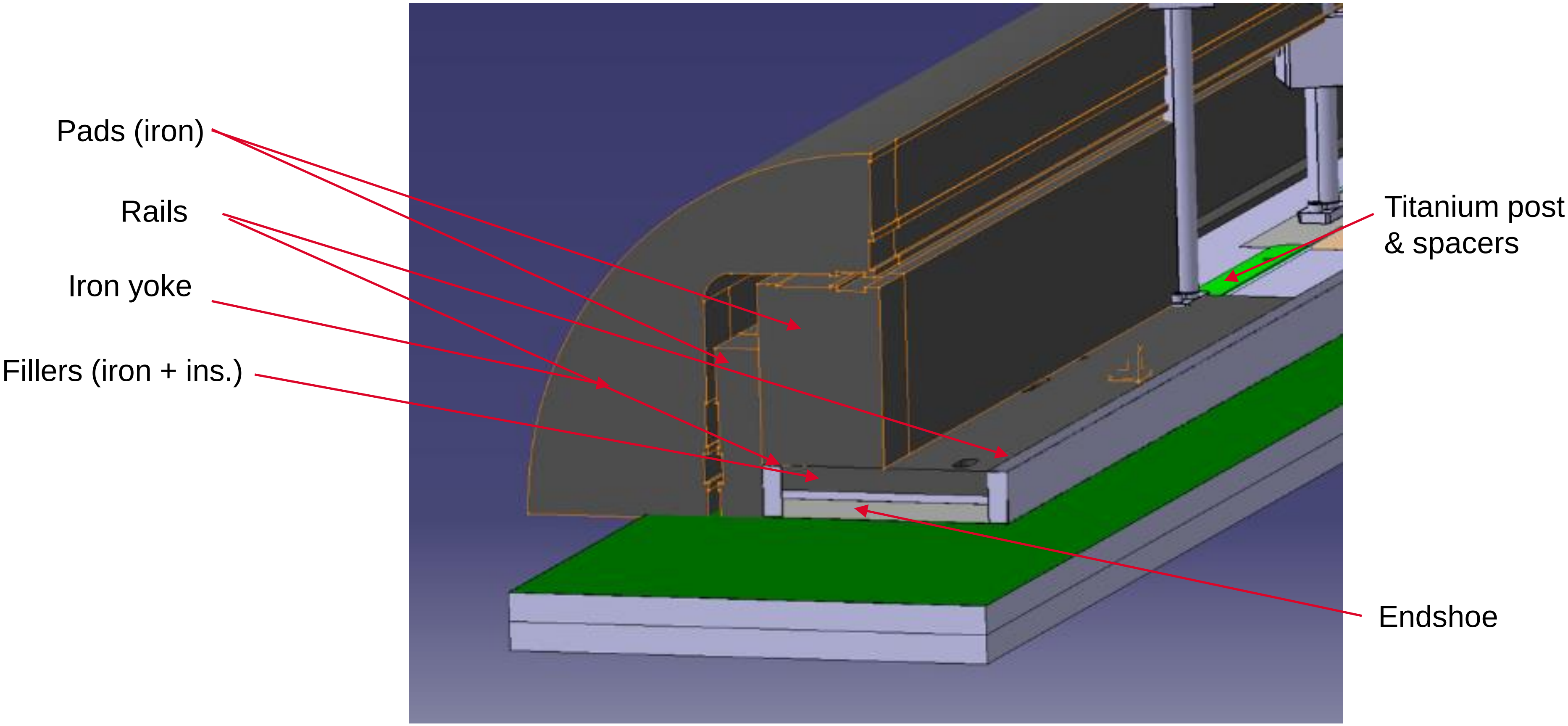


R2D2 FINAL CONFIGURATION



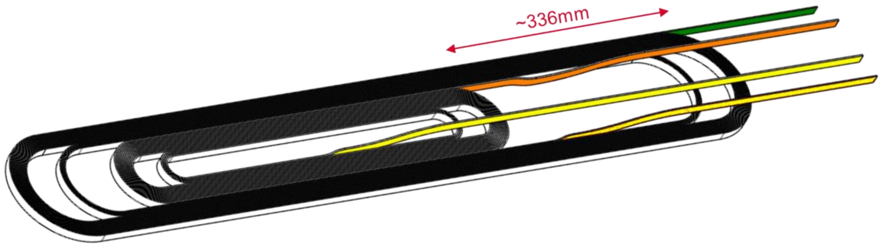
COIL INTERFACE WITH STRUCTURE

- Coil pack integrates iron filler that contribute to magnetic field



Break for questions?

R2D2: LONGITUDINAL SUPPORT CONCEPTS

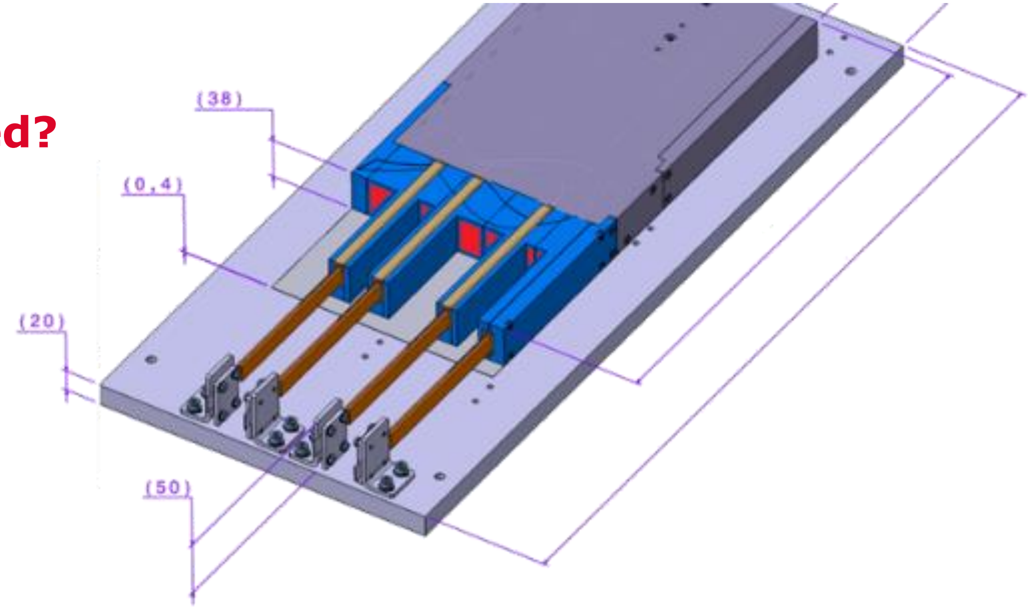


- Goals of the longitudinal support:
  - No separation in coil-ends
  - Safe stress zone (<200 MPa)
- External joint → small support area (red surfaces)
- Long spacers → difficult to reach coil-pole contact*

« Anything you do to reduce the tails will reduce the risk » (this review, yesterday session)

→ Is longitudinal support required?

→ New concept ?



→ Three approaches

1. Conventional
2. Rigid wall support
3. Internal pre-load

OPTION 1: CONVENTIONAL [1/2]

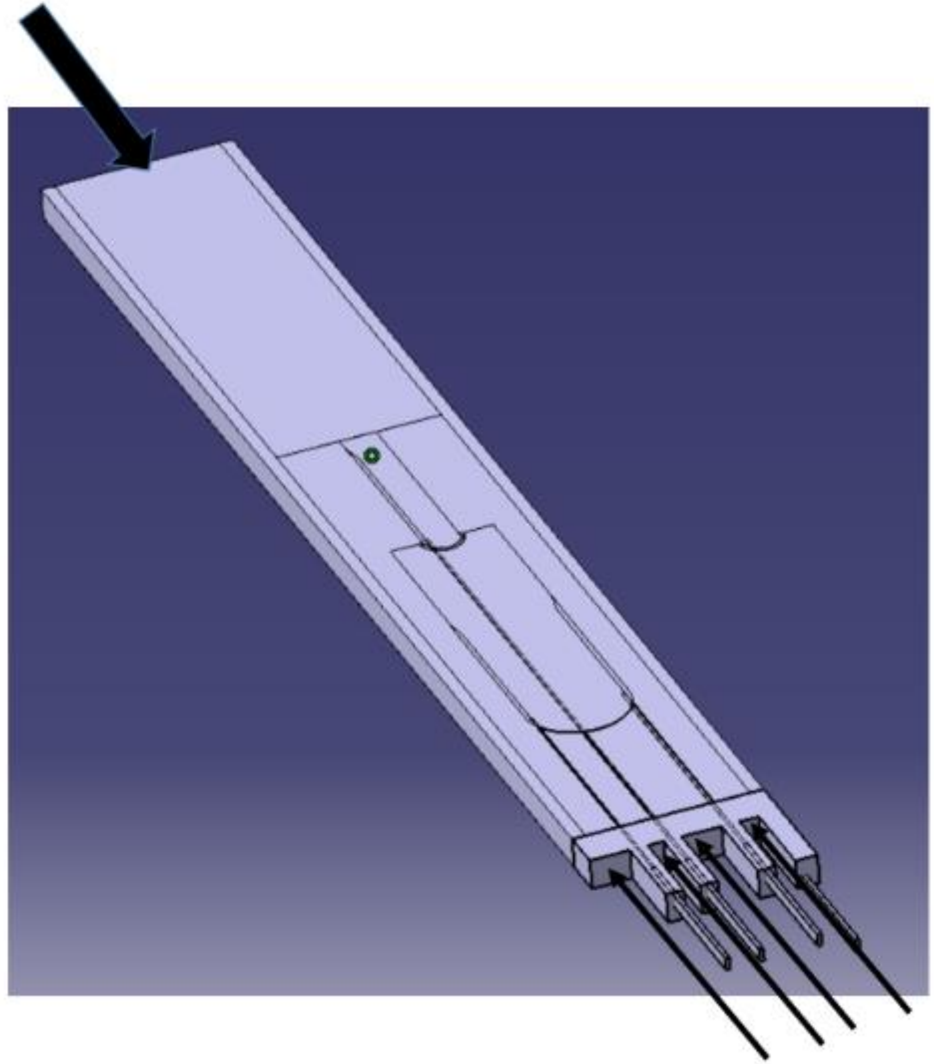
a) Rods + Endplates (baseline: FRESCA2c)

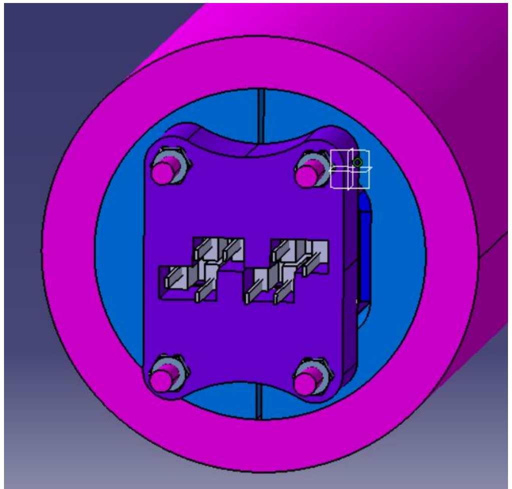
Pros:

- Well-known

Cons:

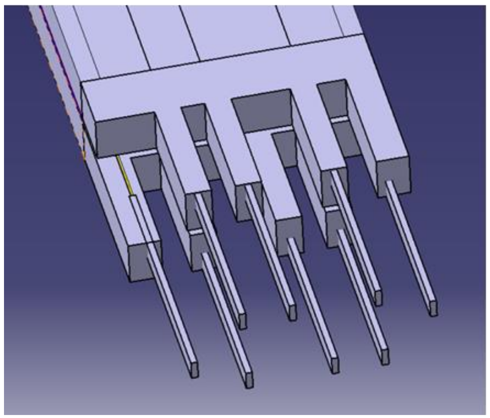
- High forces in Rods
- **Coil-pole separation** at ultimate current
- Lead end needs redesign
- Asymmetric configuration of exits

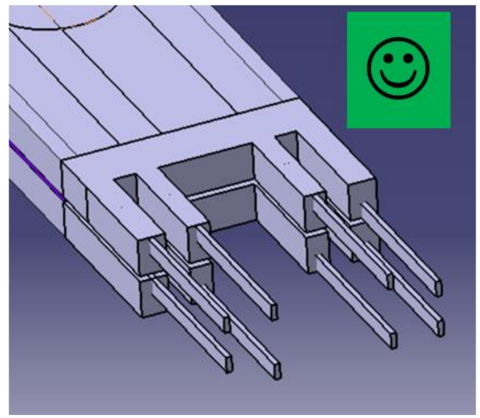


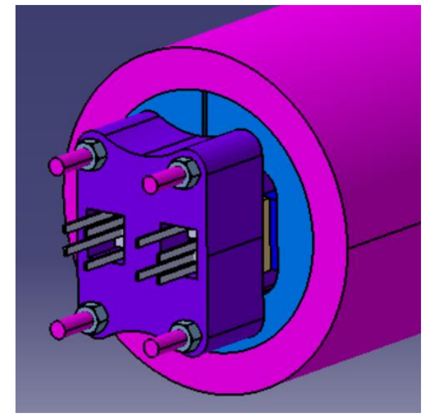


OPTION 1: CONVENTIONAL 2/2

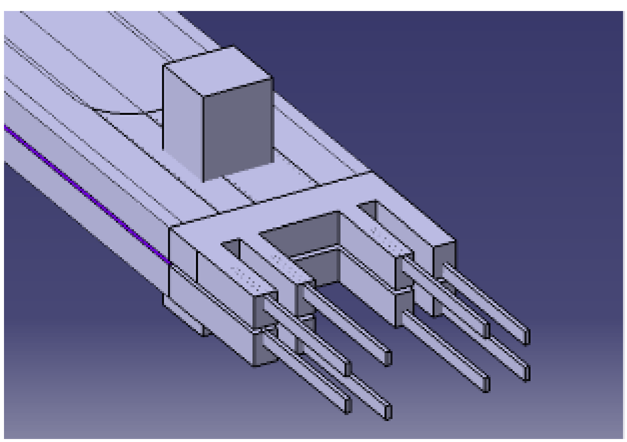
- b) Exit cables can be moved outwards to allow more space for Endplate contact and symmetry

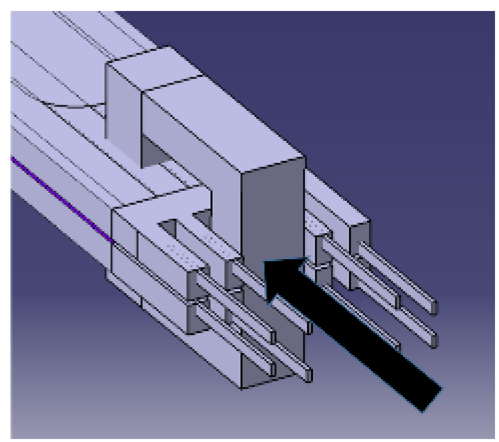






- c) Rods pressure is applied directly to the Horseshoe (mechanical bypass or sliding interfaces)





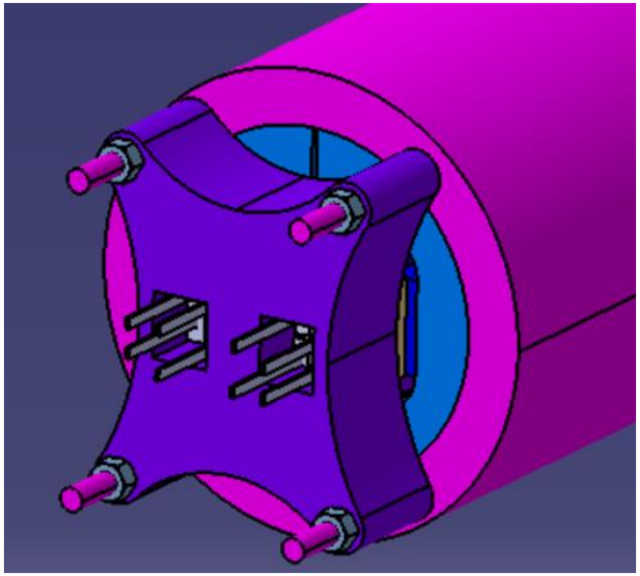
OPTION 2: HARD WALL SUPPORT

Pros:

- Simple and compact
- Can benefit from Al structure contraction
- No longitudinal pre-stress

Cons:

- Little pre-stress at warm, only via bullets
- Coil-pole separation



OPTION 3: INTERNAL PRE-LOAD

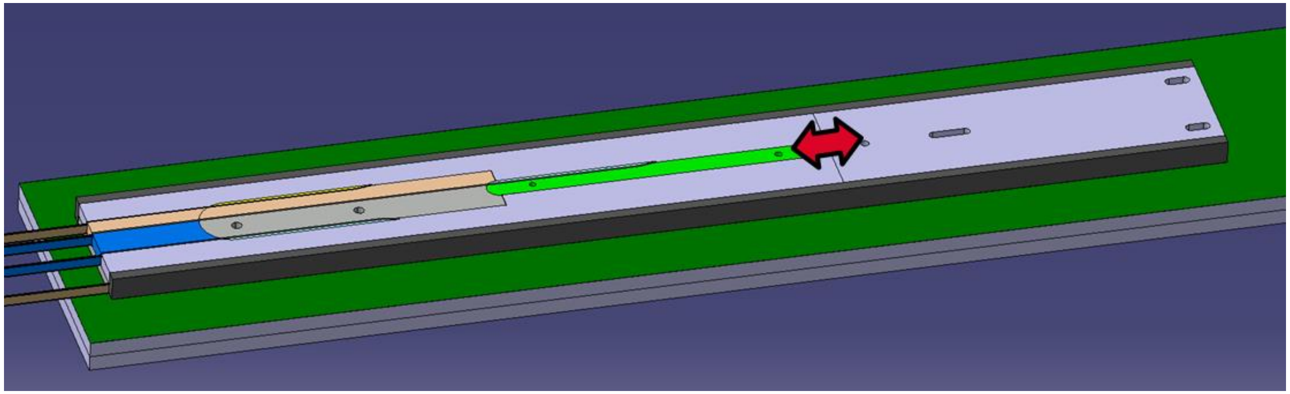
Benefits from split Post

Pros:

- « internal » pre-load, via the pole
- No coil-pole separation (potentially), no overload of the conductor
- Scalable

Cons:

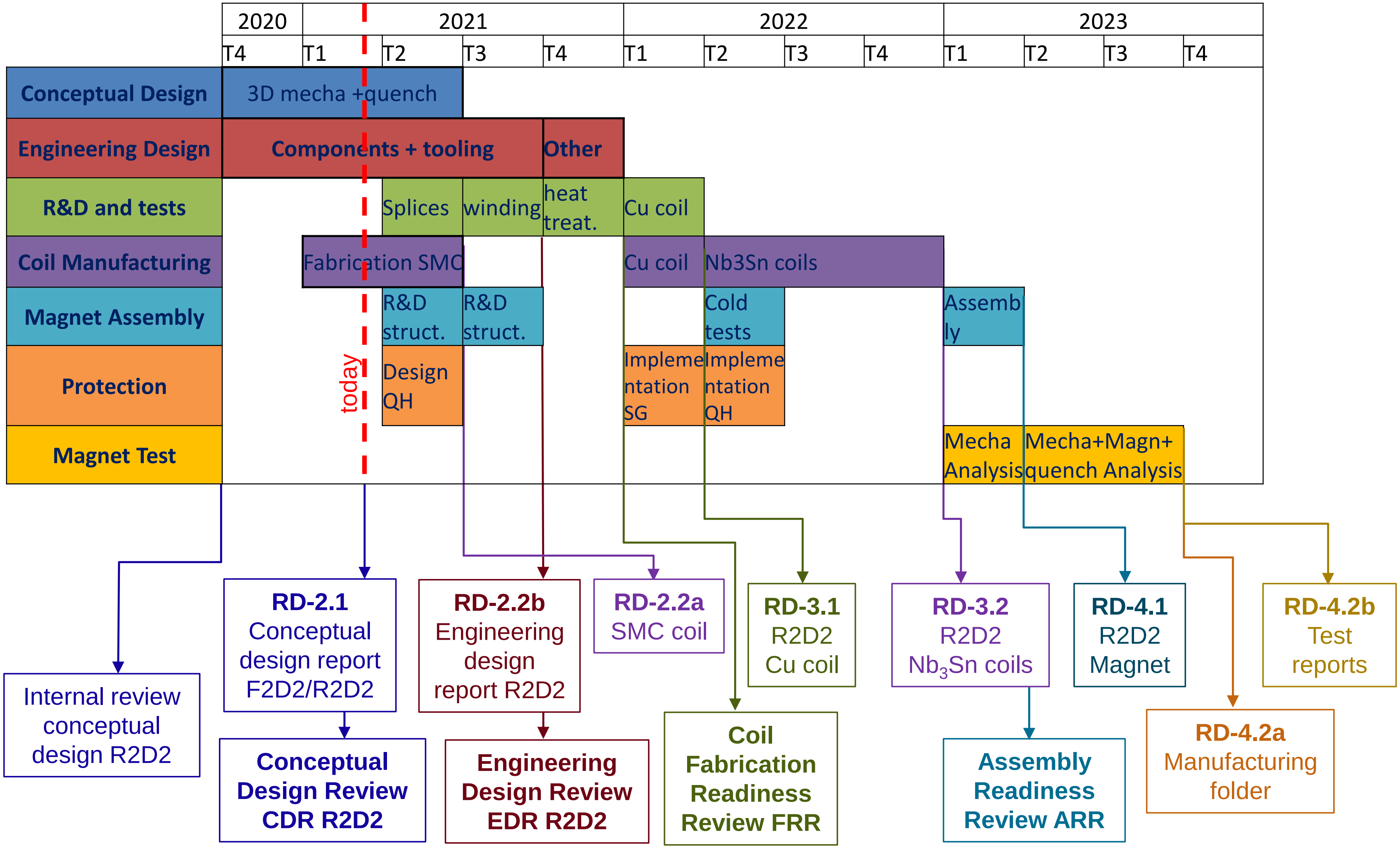
- Still requires an external structure to counter-act the force
- Need for a detailed engineering study (split Rods)
- Need for R&D
- Risks for the project



Other open questions

- Cable glued on components?
- Split post value?
- Insulation detailed configuration
- Need for additional preliminary tests? (see **5**, M. Durante)

R2D2 Simplified Schedule



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Thank you

References

- HD1: P. Ferracin, IEEE TAS, 2005
- SQ: P. Ferracin, IEEE TAS, 2007+2008
- SD: H. Felice, IEEE TAS, 2007
- SMC: E. Fornasiere, IEEE TAS, 2013 + other SMC ref
- RMC: J.C. Perez, IEEE TAS, 2016 + CERN conv.
- MQXF: E. Takala, IEEE TAS, 2021 + other MQXF ref + G. Vallone priv. conv.
- FRESCA2: E. Rochepault, IEEE TAS, 2018 + G. Willering, IEEE TAS, 2019
- ERMC: M. Garcia, IEEE TAS, 2020
- More info: US MDP-FCC 05

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Spare

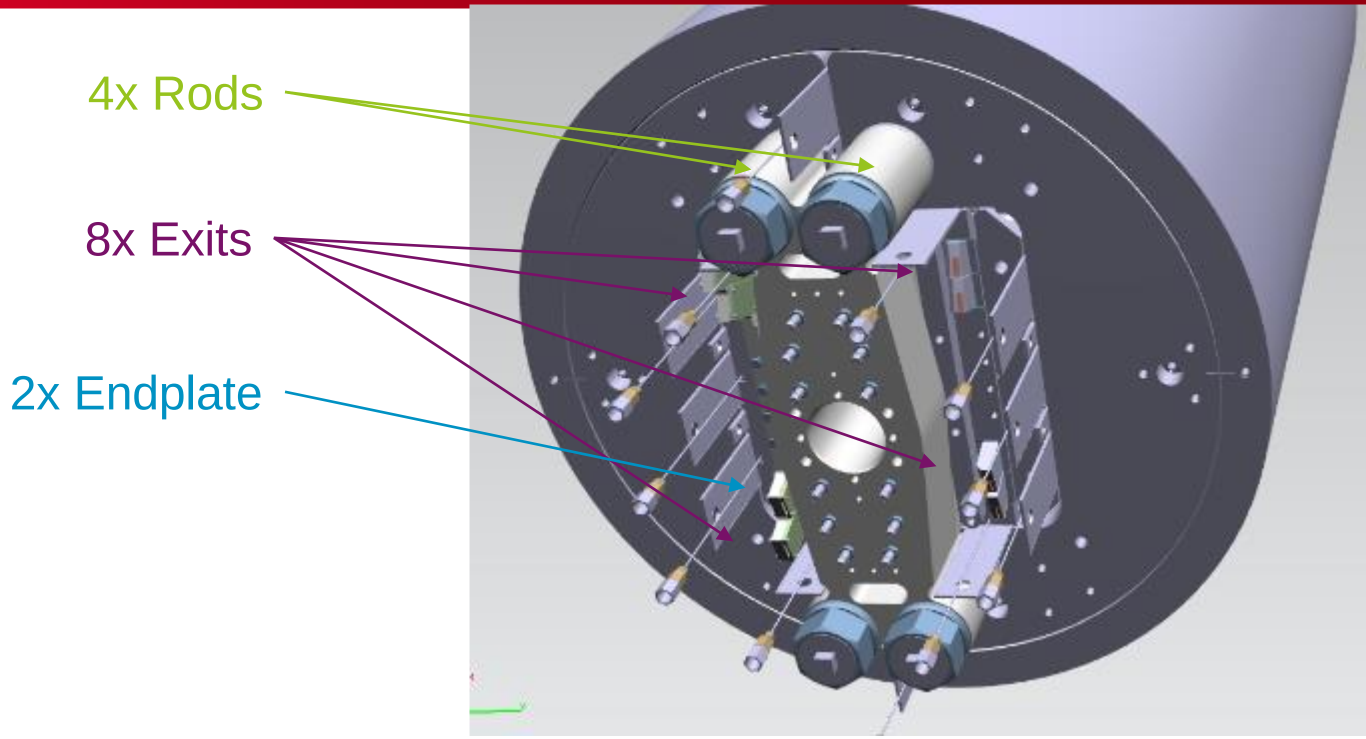
CABLE DIMENSIONS: SPARE

- Cable does not exist yet

- ECC Baseline + Uncertainties management → F2D2/R2D2 Cable Baseline

PARAMETER	Unit	Proposed				
		HF		LF		Reason of uncertainty
		Value	Uncertainty	Value	Uncertainty	
Strand diameter	mm	1.1	0	0.7	0	-
Number of strands	-	21	+/-1	34	+/-1	Cabling stability
Unreacted width	mm	12.446	+/-0.030	12.446	+/-0.030	Cabling stability +Ic degradation
Unreacted thickness	mm	1.969	+/-0.030	1.253	+/-0.020	
Bare cable compaction	%	10.5	+/-1.5	10.5	+/-2.5	
Packing factor	%	84.9	?	87.5	?	
Pitch angle	°	16.5	+/-1	16.5	+/-1	
Transposition pitch	mm	84.0	+/-5	84.0	+/-5	
Width Reaction expansion	%	1.0	+0.5/-1.0	1.0	+0.5/-1.0	Conductor properties
Thickness Reaction expansion	%	3.0	+/-0.5	3.0	+/-0.5	
Reacted width	mm	12.570	+0.090 -0.150	12.570	+0.090 -0.150	Cabling+Ic degr.+Conductor
Reacted thickness	mm	2.028	+/-0.040	1.291	+/-0.030	
Insulation thickness	mm	0.15	+/-0.01	0.15	+/-0.01	Braiding

CONCEPTS FOR LONGITUDINAL SUPPORT



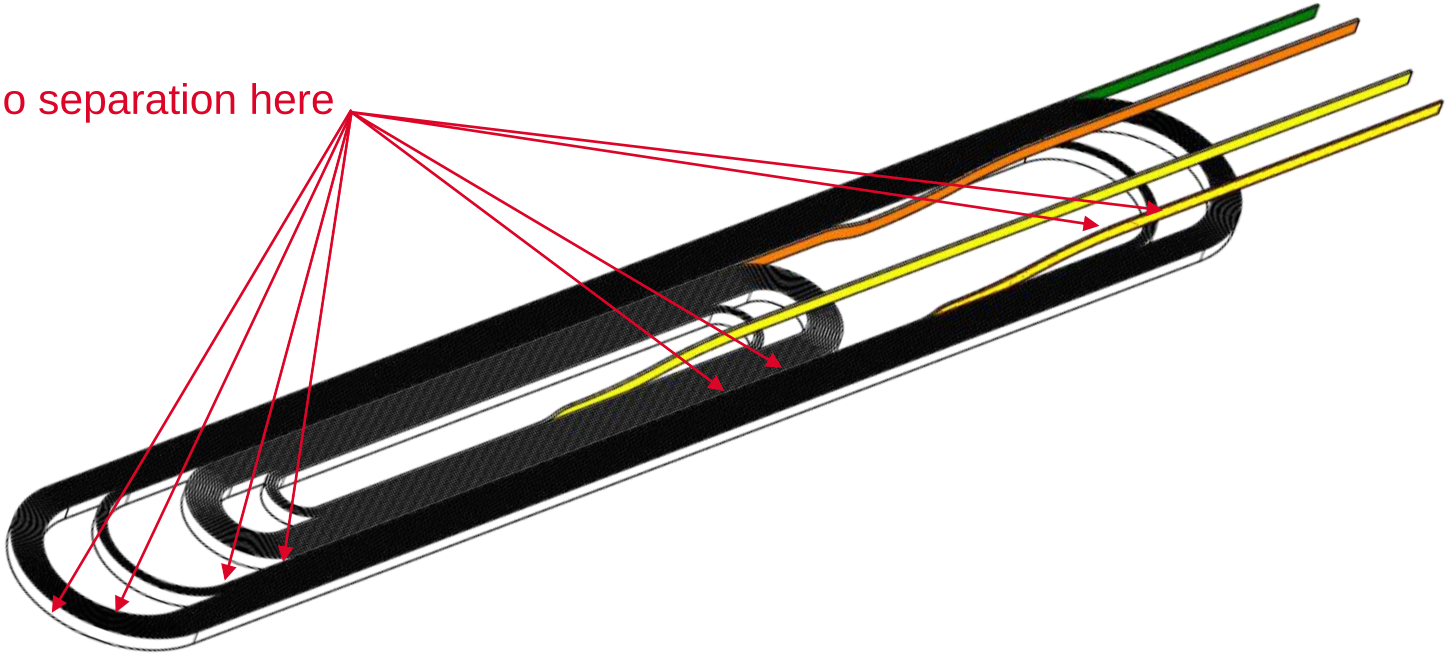
- FRESCAc could serve as baseline: « conventional approach » = 4 Rods + 2 Endplates
- FRESCA2c RT load applied by <u>symmetric Endplates</u> on Horseshoes = 40% $F_{z,mag}$
- FRESCA2c resulting load at CD = **68%** $F_{z,mag}$

LONGITUDINAL SUPPORT: BENCHMARK

Magnet	% EMF, RT	% EMF, cold	Coil-pole	Quench behavior in ends
HD1a	260 Mpa	?	85 µm	Quenches in coil-ends
HD1b	300 MPa	?	35 µm	improved
SQ02a	40 %	70 %		Improvement of Iss
SQ02b	80 %	115%		
SQ02c	0	0		Detraining
SD01a	180 MPa	?		Detraining
SD01b	0	0		
SMC	Usually low			Quenches in coil-ends
RMC-FR2	5 %	32 %	-25 MPa	Quenches in coil-ends
RMC-QXF	24 %	52 %	0 MPa	Quenches in coil-ends
MQXFS1a/b, 3a		50 %	-10 MPa	No clear impact
MQXFS1c, 3b/c, 4, 5		93 %	10 MPa	
FRESCA2a,b	28 %	68 %	75 µm	**No quench in the ends**
FRESCA2c	**40 %**	**68 %**	**160 µm**	
ERMC	64 % tbc	89 % tbc		No quench in the ends

Goal of the longitudinal support

- No separation here



- While keeping the conductor in its safe stresse zone (<200 MPa)

R2D2: EXPECTED EFFECT OF LONGITUDINAL PRELOAD

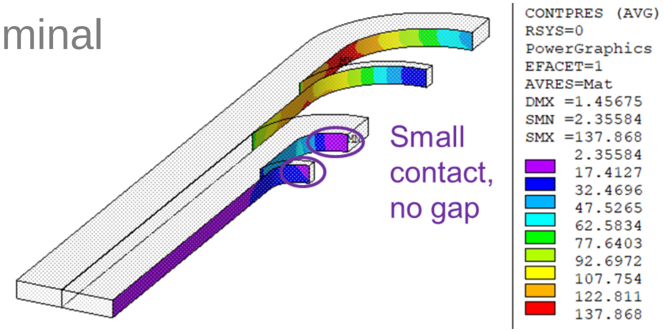
- Von Mises stresses < 150 MPa at nominal; < 200 MPa at ultimate (high stresses in ends)

Parameter	Unit	NOM 4.2 K	NOM 1.9 K	UWP 4.2K	UWP 1.9K
Current	A	13772	15055	**16500**	**16500**
B (0,0)	T	10.42	11.15	**11.98**	**11.98**
Max. Von Mises stress in coil	MPa	141	155	195	195

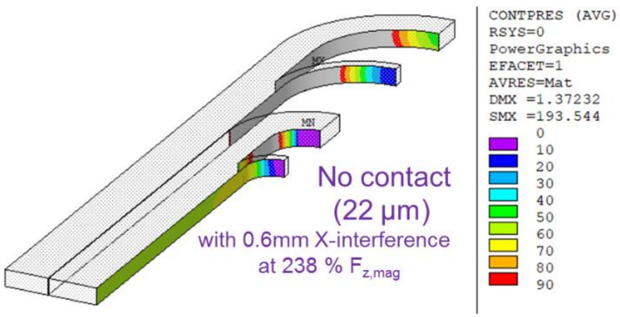
(see **3**, E. Rochepault)

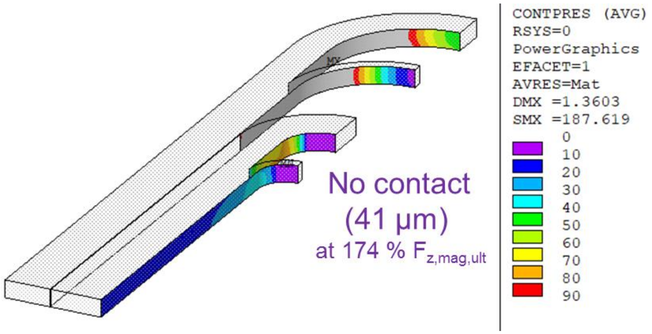
- No separation at nominal

  (183 % $F_{z,mag}$)



- but separation occurs with higher X pre-stress… …or at ultimate





→ Even 174% $F_{z,mag}$ at CD doesn't guarantee contact criterion at ultimate