Review of Safe Limits for Injection and Extraction Devices

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EN-STI-TCD

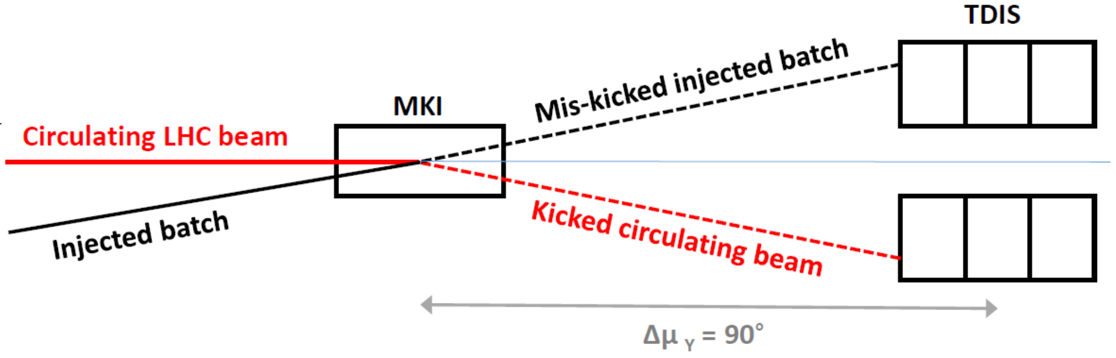
ENGINEERING
DEPARTMENT

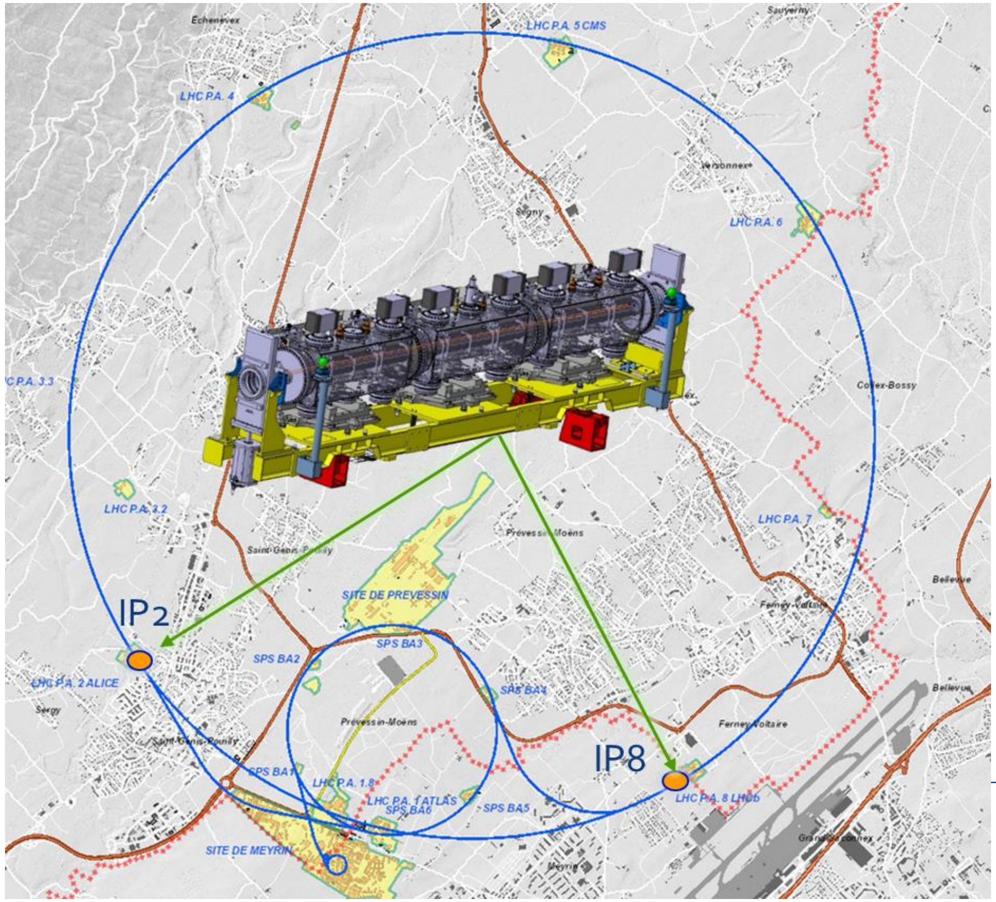
Outline

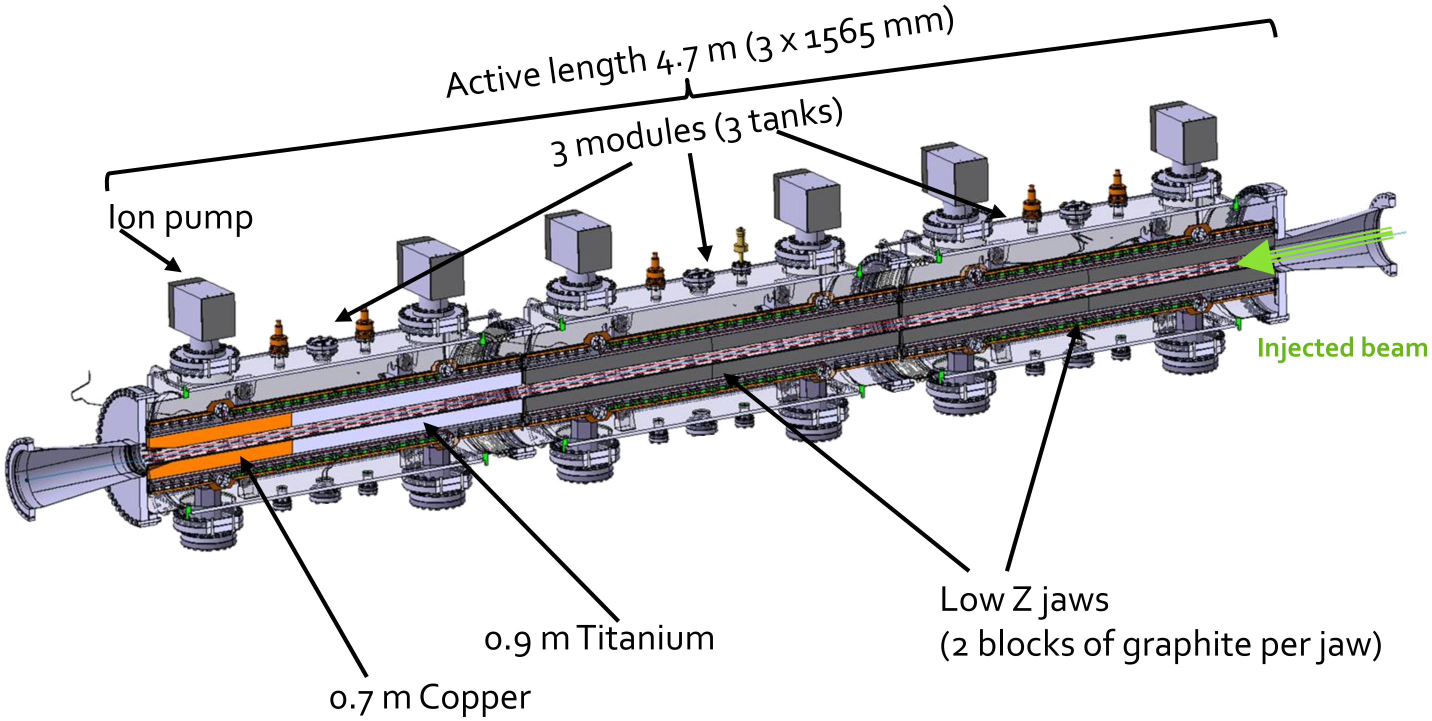
- Injection Protection Absorbers – TDIS
- Static Mask to protect MSD Magnets – TCDS
- Movable Mask to protect Q4 – TCDQ
- LHC Dump – TDE

TDIS

- Machine protection in case of beam mis-steering during LHC filling
- Intercepts beam in case of MKI kickers malfunctions/timing errors





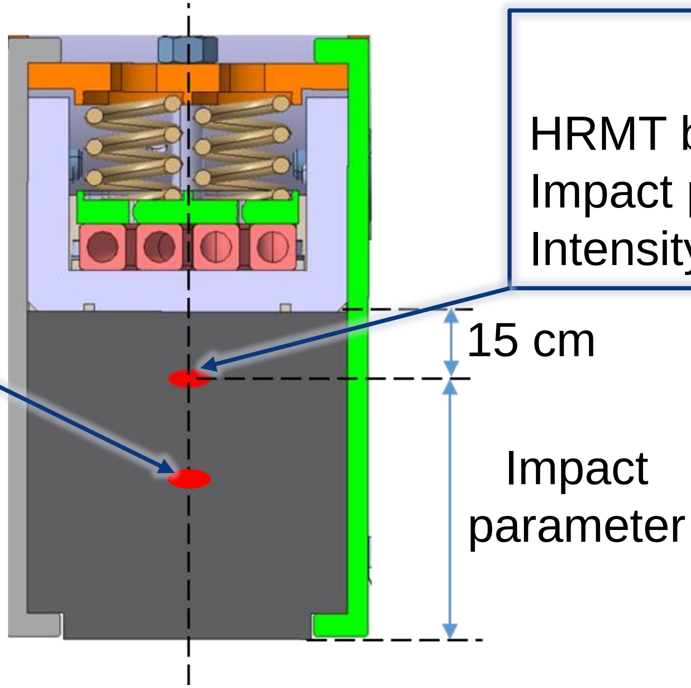


HRMT45 – Integral test

Goal: Integral test of the module under beam.
To reproduce temperatures/stresses in the back-stiffener comparable to HL-LHC 320b beam.

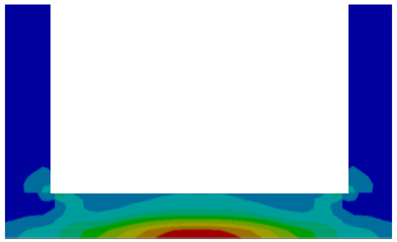
LHC failure scenario (worst-case)

HL-LHC 320b beam
Impact parameter: 38 mm
Intensity: 2.3E11 ppb (320 bunches)

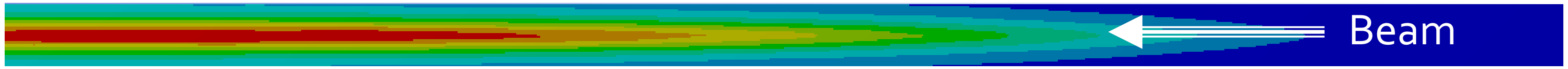


HRMT scenario

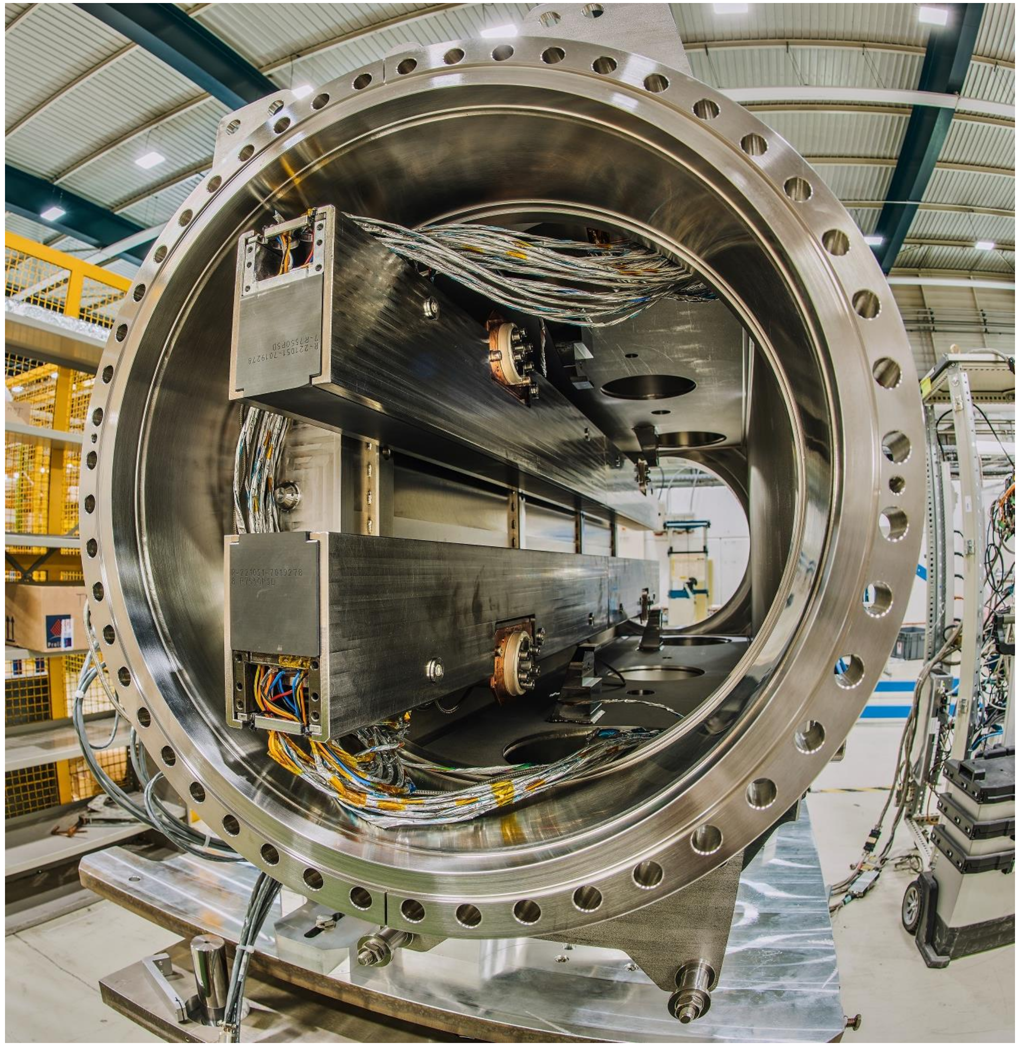
HRMT beam
Impact parameter: 52 mm
Intensity: 1.2E11 ppb (288 bunches)

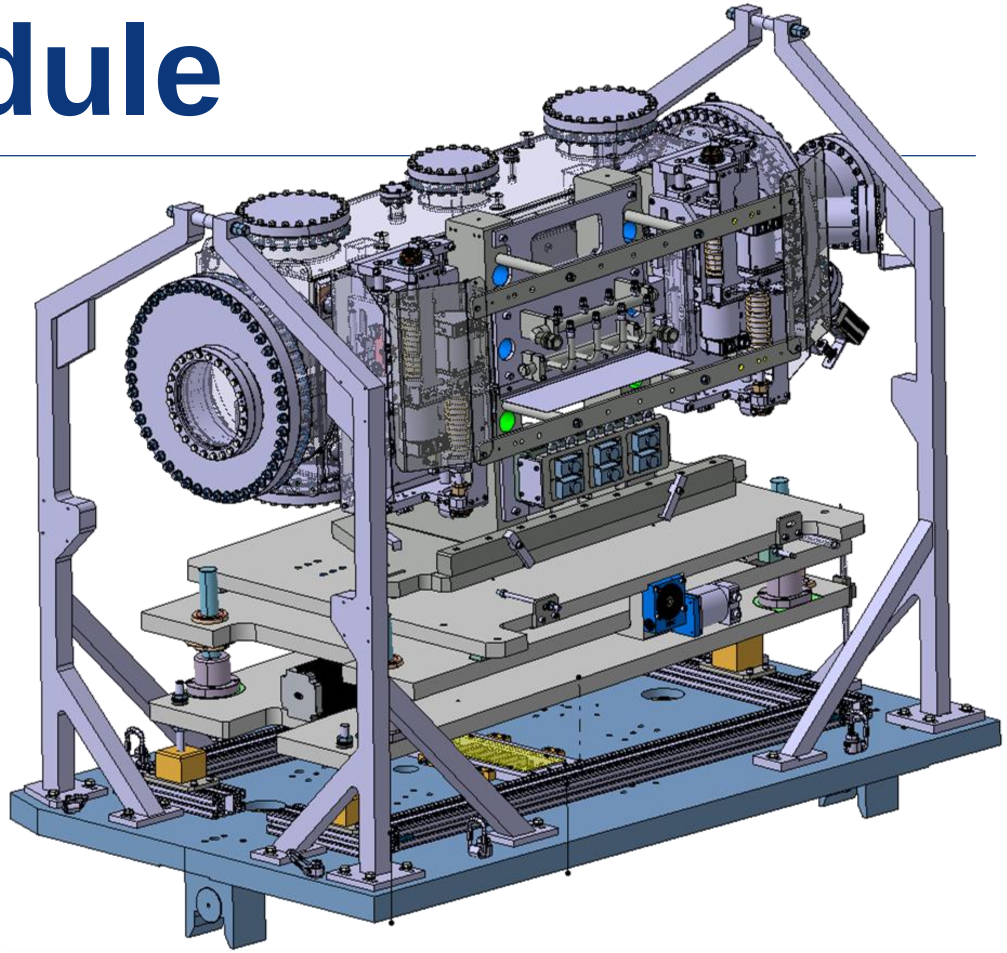


HRMT settings
Max. temp: 235 °C
Max. stress: 460 MPa
(Static tensile strength ≈ 525 MPa)



HRMT45 – Tested Module

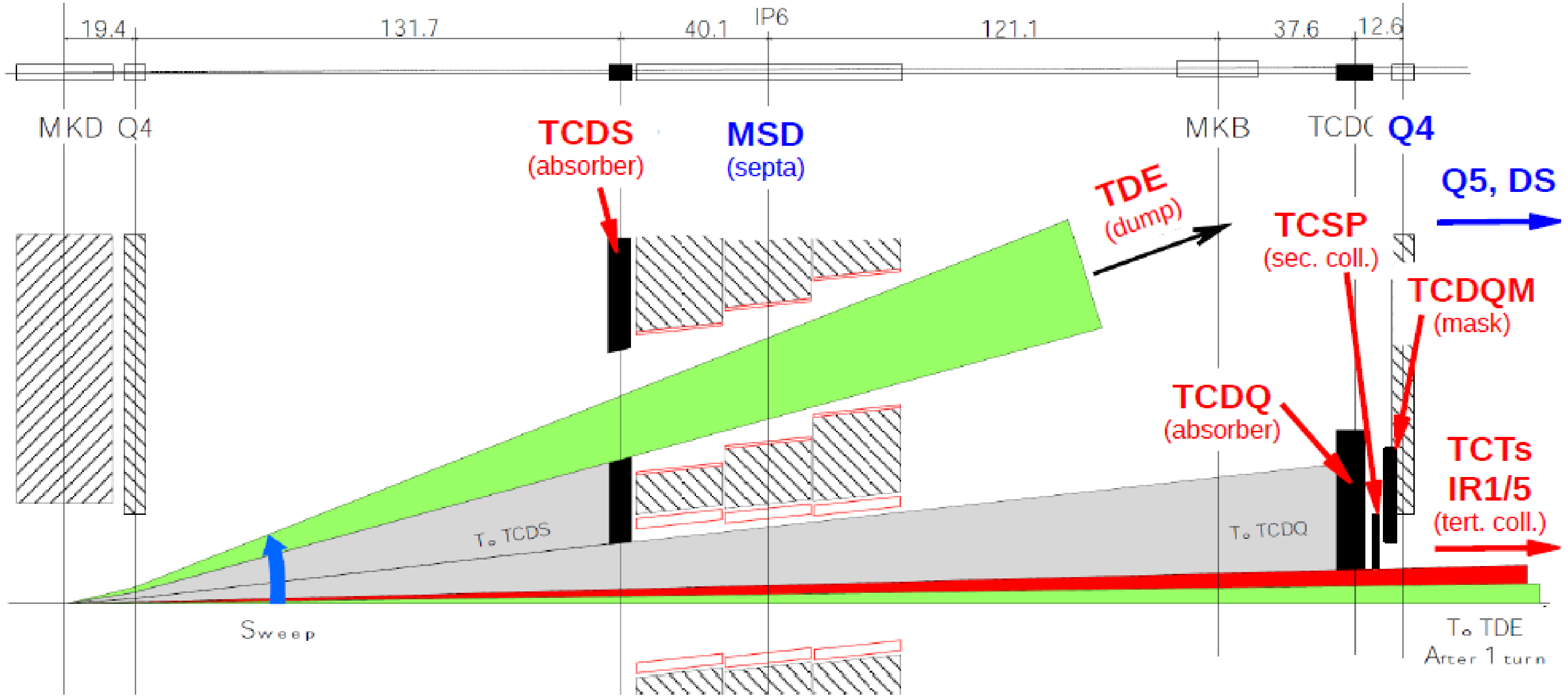




Worst case scenarios calculated and tested.

The TDIS imposes no limitation on HL operation.

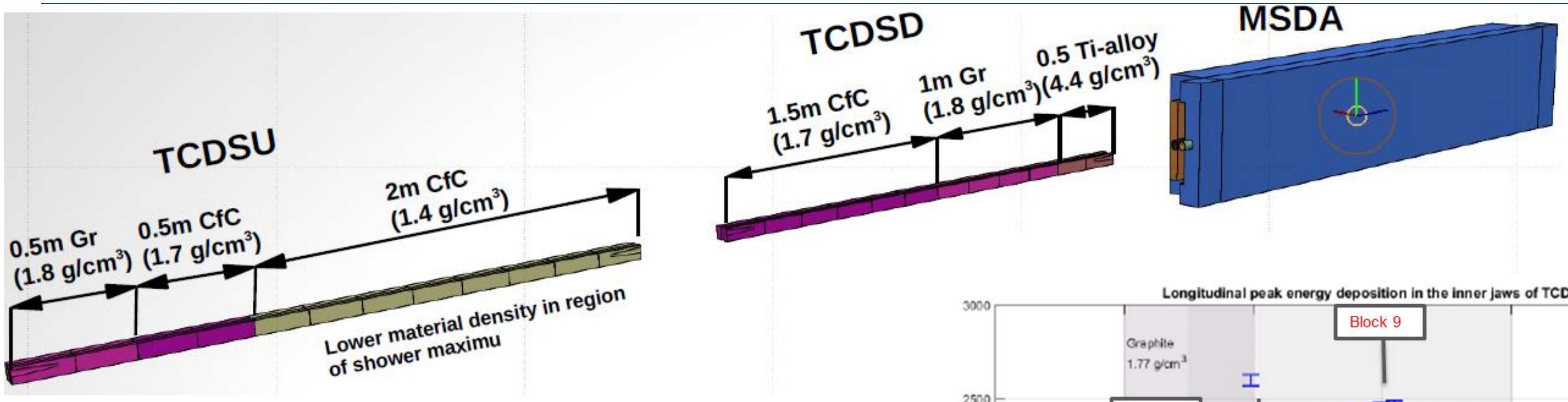
TCDS/TCDQ



TCDS – A fixed diluter block installed immediately upstream of the MSD magnets(IR6)
TCDQ – A mobile diluter block to protect the Q4 magnets, (IR6)

→Asynchronous firing of MKD kickers would cause the beam to sweep over the septum walls

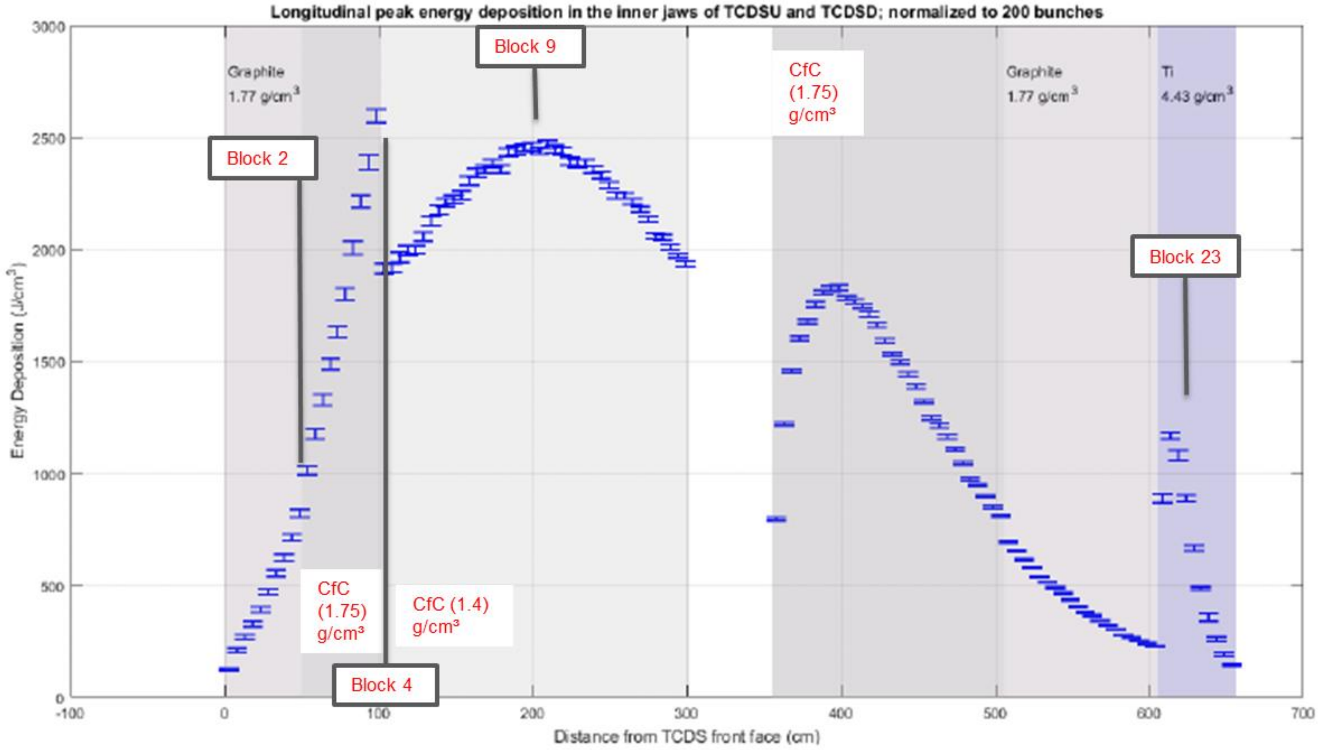
TCDS



2 jaws

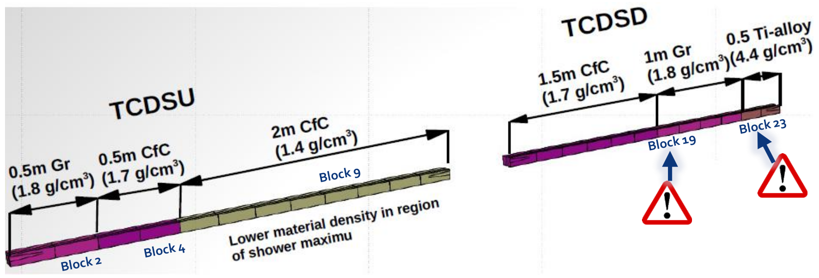
3m long each

Parameters	HL-LHC25ns
Bunch intensity	2.3e11
Number of bunches	65
Total pulse intensity	1.5e13
Beam energy	7 TeV
Pulse length	1.1 μs
Beam emittance	2.1 μm



TCDS Thermal / Structural Simulations

Preliminary results, pending new simulations and material characterisation



TCDS (low Z)				
Material	Graphite C2020 (block 2)	Block **4** C-C 1.7	Block **9** C-C 1.4	Graphite C2020 (block 19)
Max. Temp. [°C]	396	798	1141	402
Max. Comp. Stress. [MPa]	**-20**	**-23**	**-27**	**-33**
Comp. Strength	-35	-70	-70	-35
Max. Tens. Stress. [MPa]	**29**	**18**	**51**	**38**
Tensile Strength	35	61	84	35

For block 9 → **Material properties are not known. Values written are assumptions based on 1.7 g/cc grade**

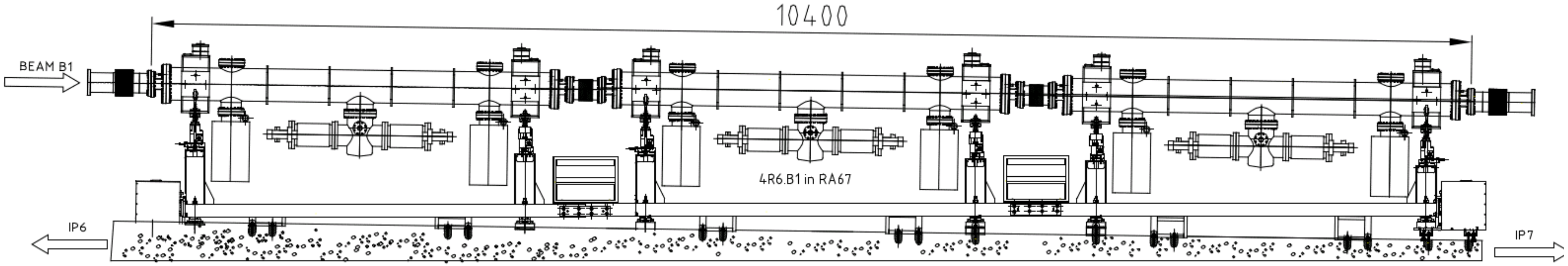
TCDS (Ti6Al4V), block 23	
	Area at Max plastic strain
Temp. [°C]	**255**
Eq. Stress [MPa]	**601**
Yield Strength	529
Tensile Strength	645

The titanium block undergoes plastic deformation (1.2%) on part of the surface.

TCDS – Preliminary Conclusions

- A risk of failure caused by the high stresses and elevated temperature is expected in block 19 (graphite).
- Plastic deformation expected in titanium block. This is to be avoided.
- Material characterisation needed for more reliable simulations.
- Design optimisation recommended
  - Substituting at least blocks 19 and 20 with 2D CFC (1.7 g/cc)
  - Check if titanium is really needed for MSDA protection / or slicing it
  - Replacing titanium with another material

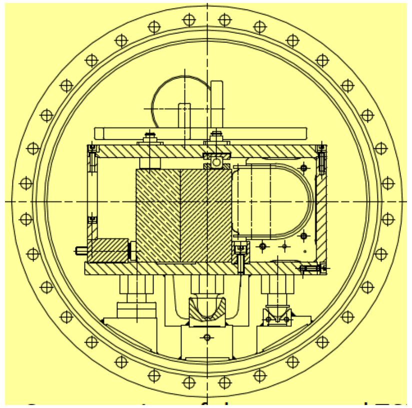
TCDQ



1	2	3	4	5	6	7	8	9	10	11	12		13	14	15	16	17	18	19	20	21	22	23	24		25	26	27	28	29	30	31	32	33	34	35	36
1.75				1.4									1.4								1.75					1.75											

→36 blocks of 250 mm of carbon composite (CFC) with different densities:

- 4 blocks of high density CFC (1.75 g/cm^3)
- 16 blocks of low density CFC (1.4 g/cm^3)
- 16 blocks of high density CFC (1.75 g/cm^3)

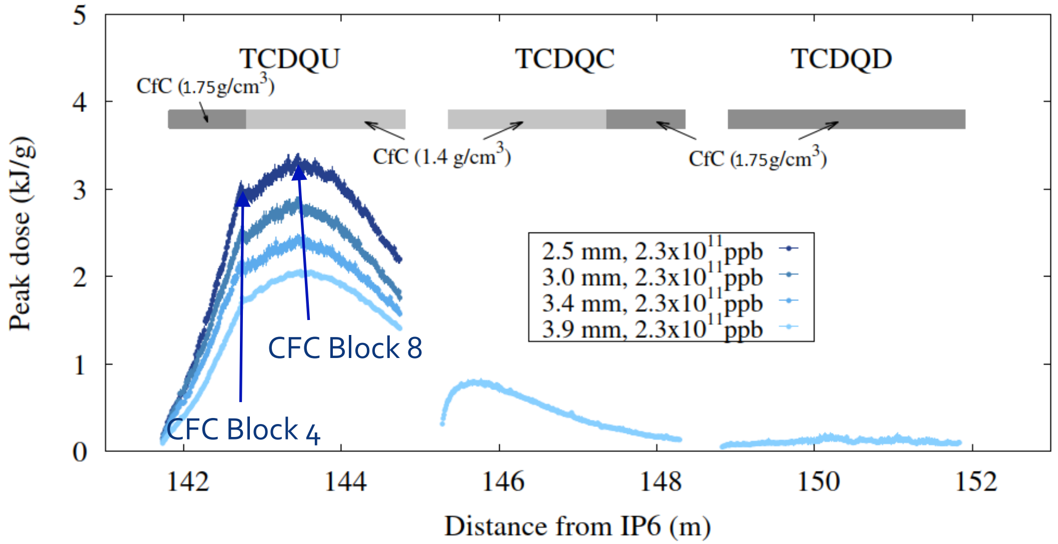


Cross-section of the TCDQ structure showing the graphite (left) and CFC (right) absorber blocks

TCDQ Energy Deposition

Table 1. Beam parameter

Beam Parameters	HL-LHC25ns
Bunch Intensity	2.3E11
Number of bunches	50
Beam energy	7 TeV
Pulse length	950ns
Beam emittance	2.1 μm



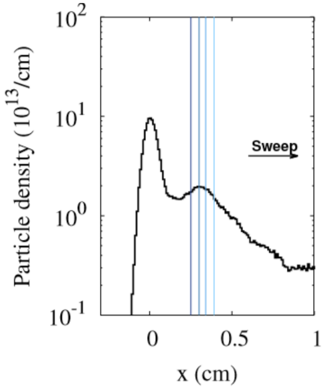


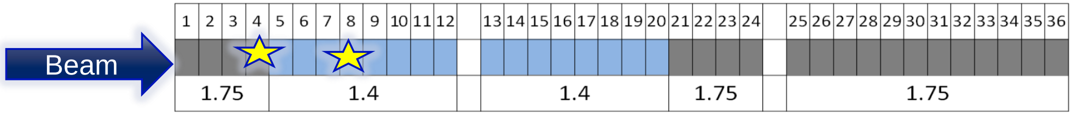
Fig. 1. Energy deposition distribution [2]. Courtesy of M. I Frankl.

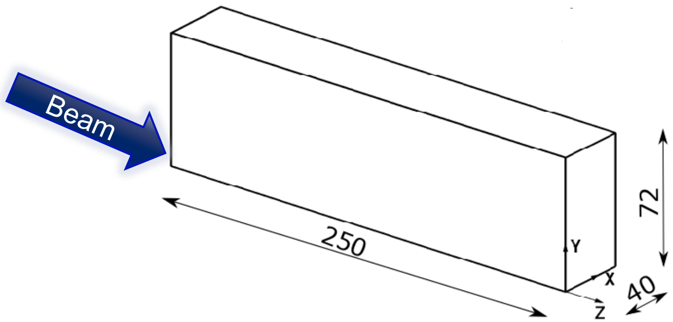
- The TCDQ gap affects the energy deposition.
- From the mechanical point of view, the 4th and 8th blocks (high and low density CFC blocks, respectively) are the most affected.

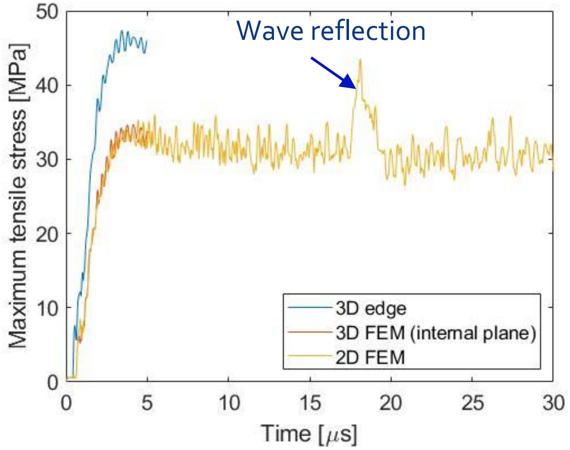
	1.4×10^{11}	1.7×10^{11}	2.0×10^{11}	2.3×10^{11}
2.5 mm	2.0 kJ/g (1300°C)	2.4 kJ/g (1500°C)	2.8 kJ/g (1700°C)	3.3 kJ/g (1900°C)
3.0 mm	1.7 kJ/g (1100°C)	2.0 kJ/g (1300°C)	2.4 kJ/g (1500°C)	2.7 kJ/g (1600°C)
3.4 mm	1.5 kJ/g (1000°C)	1.8 kJ/g (1200°C)	2.1 kJ/g (1300°C)	2.4 kJ/g (1500°C)
3.9 mm	1.3 kJ/g (900°C)	1.5 kJ/g (1000°C)	1.8 kJ/g (1200°C)	2.1 kJ/g (1300°C)

Table 2. Peak doses as function of the gap and beam intensity [2]

Stresses in TCDQ







	Bunch intensity 1.7e11		Bunch intensity 2.3e11	
	CFC 4th block	CFC 8th block	CFC 4th block	CFC 8th block
	2D FEM			
Max. Temp [°C]	1401	1534	1837	2018 ⚠
Max. Princp. Stress [Mpa]	31/33(wave refl.) Y-dir	35/43(wave refl.) Y-dir	41/44(wave refl.) Y-dir	42 / 58 (wave reflection), Y-dir
Min. Princp. Stress [Mpa]	-29 Y-dir	-39 Y-dir	-38 Y-dir	-48 Y-dir
Compressive strength [Mpa]	-69.6 (X-dir) -88.6 (Y-dir) -82.4 (Z-dir)	Not known	-69.6 (X-dir) -88.6 (Y-dir) -82.4 (Z-dir)	Not known
Tensile strength [Mpa]	? (X-dir) 84 (Y-dir) 61 (Z-dir)	Not known	? (X-dir) 84 (Y-dir) 61 (Z-dir)	Not known
Safety factor (based on stress)	**2.5**	**2.4***	**1.90** ⚠	**1.45*** ⚠

*Considering strength of 1.75 g/cc grade

Results highly dependent on the CTE

TCDQ - Conclusions

- Simulations for:
  - 2.0×10^{11} ppb / 2.0 mm gap
  - 1.7×10^{11} ppb / 2.5 mm gap

  → Targets integrity expected to be kept, but impossible to commit due to lack of material data.

- Simulations for 2.3×10^{11} ppb / 2.5 mm gap

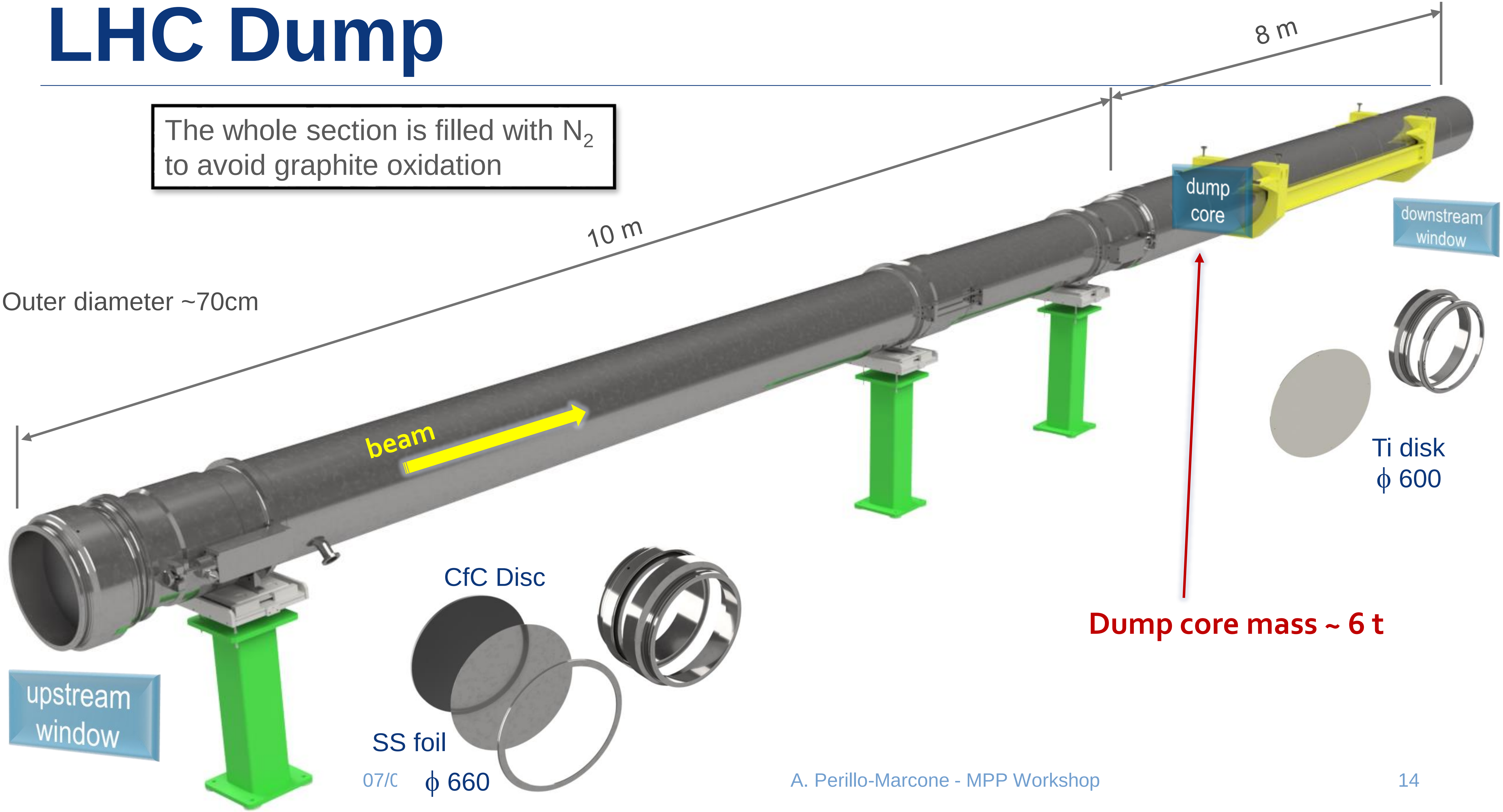
  → High temperature and high strain may lead to material failure.

- **Material characterisation needed**

LHC Dump

The whole section is filled with N_2 to avoid graphite oxidation

Outer diameter ~70cm



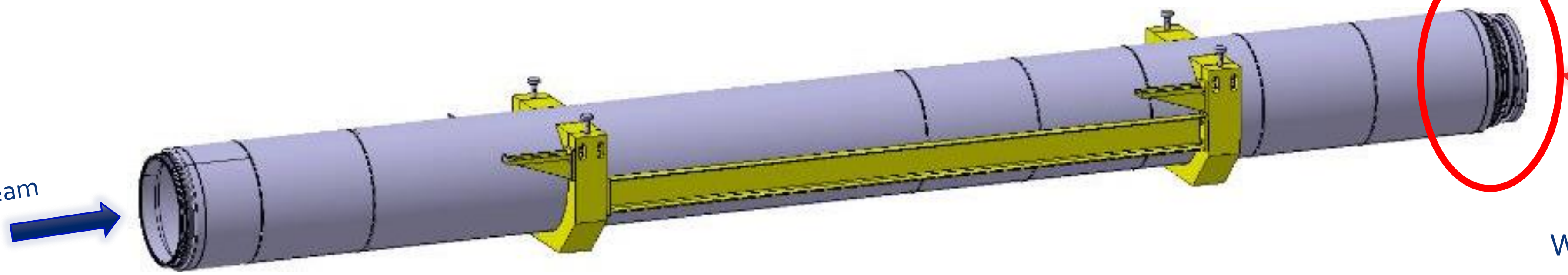
Upgrades for LS2

- Downstream window
- Mechanical Connections
- Upstream window (to be done during YETS 21/22)
- Restraining of dump movement
- Instrumentation

Downstream window upgrade

In collaboration with **EN/MME**

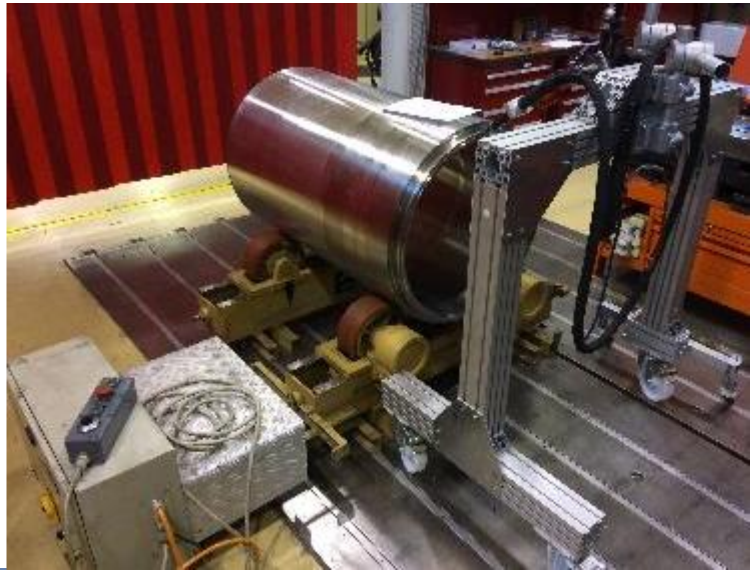
Beam



Ti window

Welding procedure ready

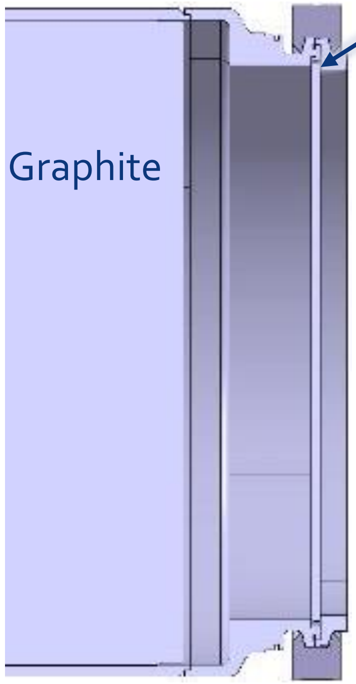
To be done in UX65 during LS2



Current design

SS 318L

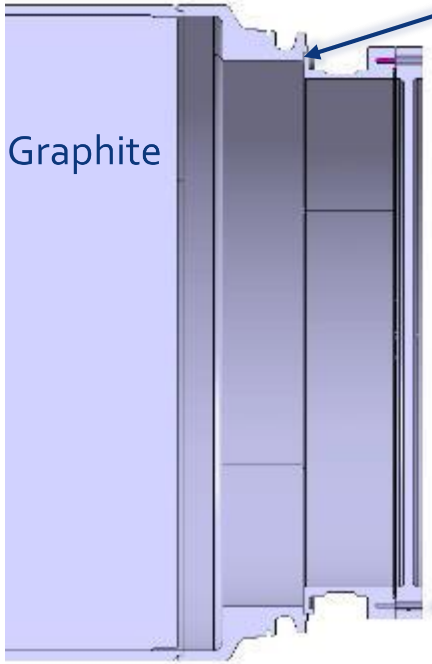
Helicoflex gasket



Ti Gr2 window

Proposed design

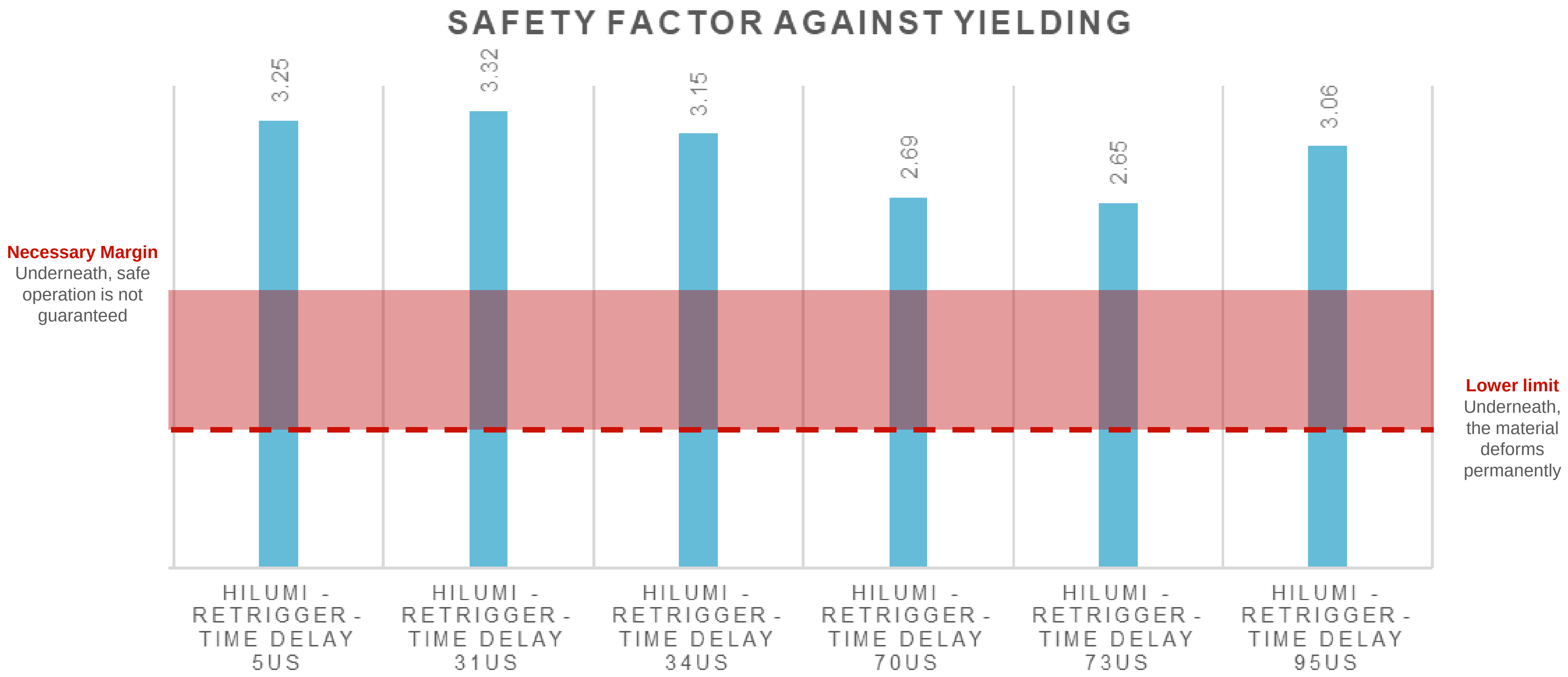
Weld on current flange



Ti Gr5 window

CF flanges

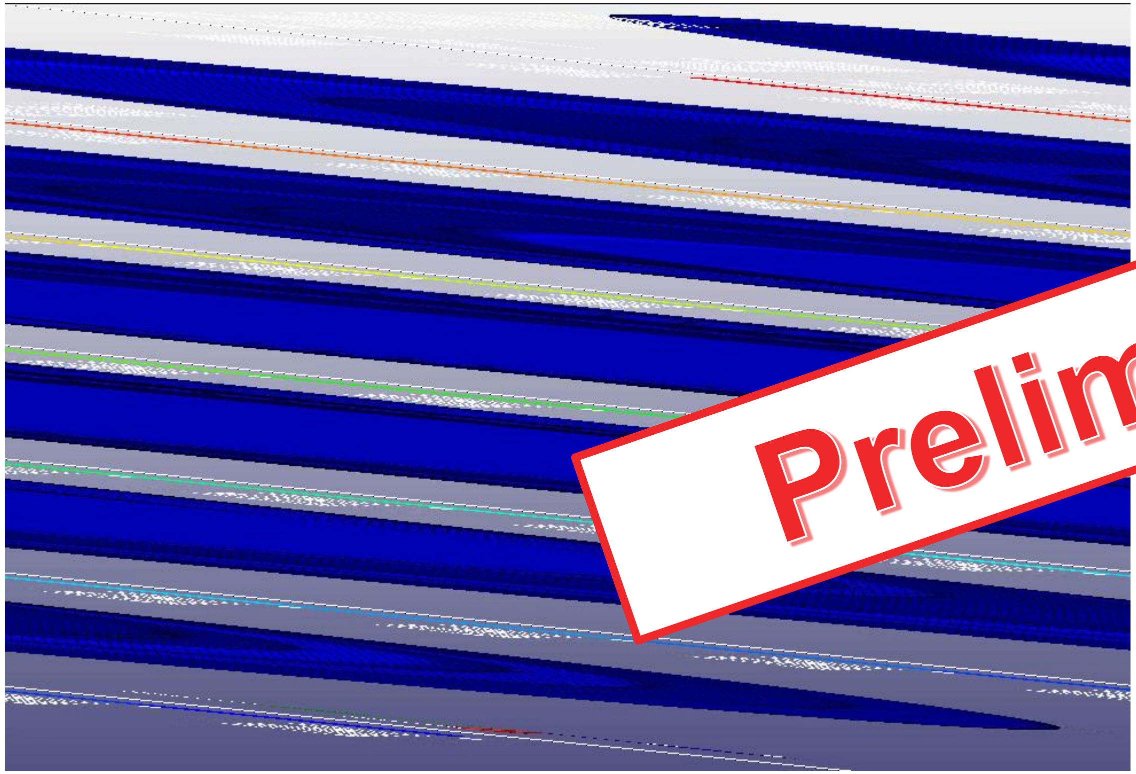
Stresses in Downstream Window



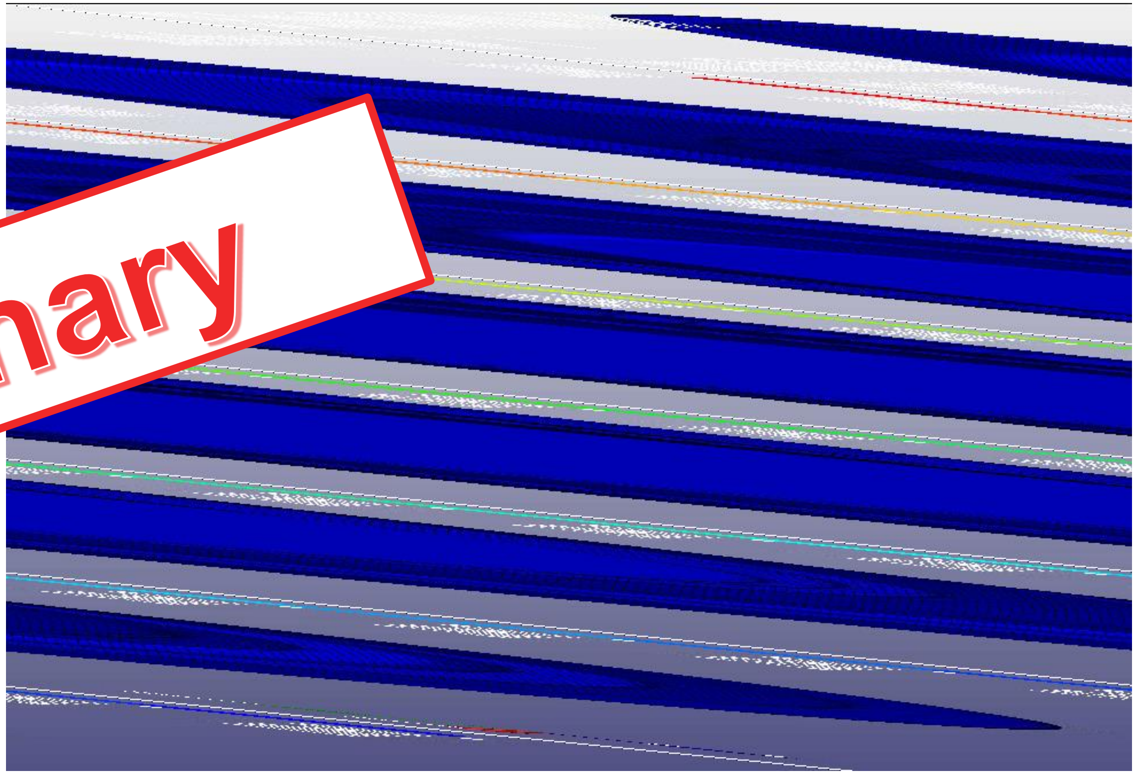
The expected stresses for the upgraded window are safely within the limits

Loads in housing

Temperature °C



Von Mises Stresses (MPa)

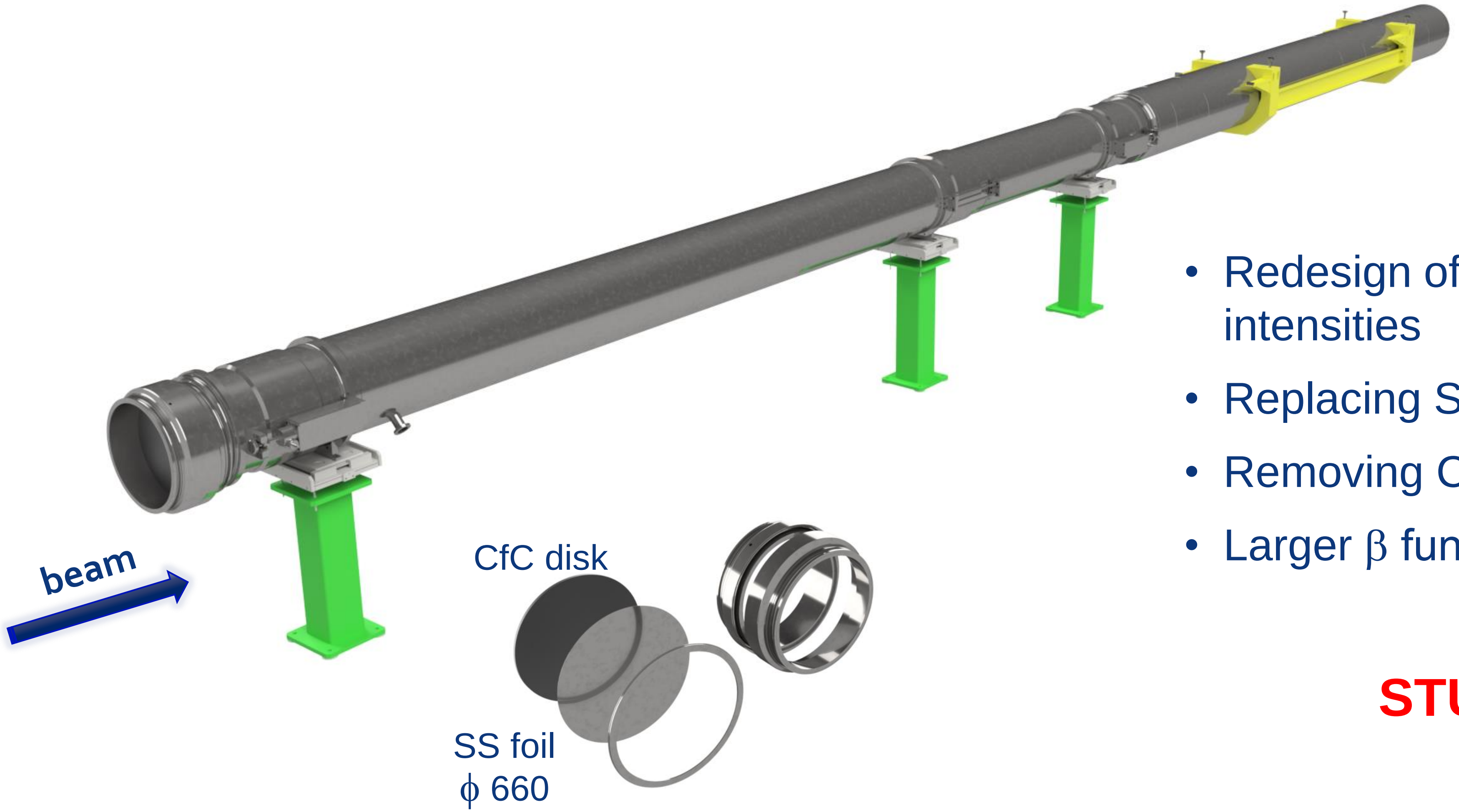


Max T = 156 °C

Max VMS = 256 MPa

Safety Factor = 1.2 !

Upstream window – YETS after LS2



- Redesign of window to cope with higher intensities
- Replacing SS with Ti-Gr5
- Removing CfC disk (5-10 mm Ti-Gr5 disk)
- Larger β function → Lower loads

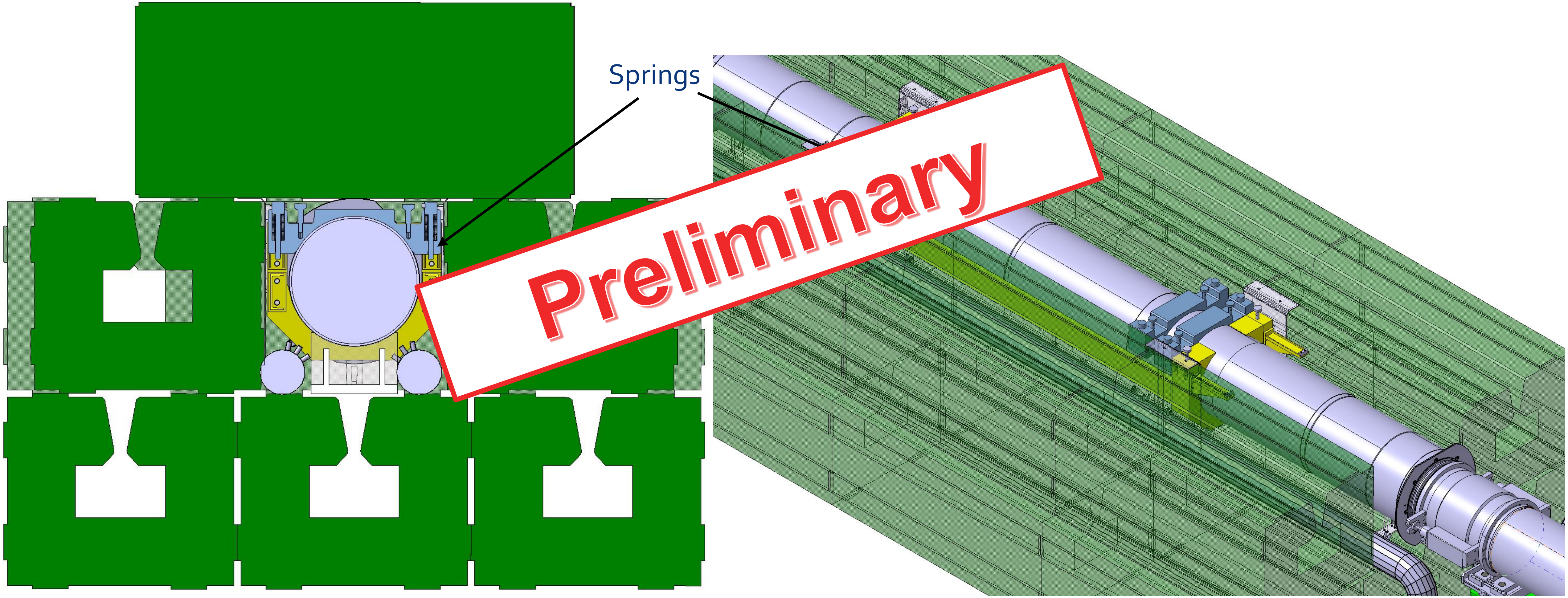
STUDIES UNDER WAY

Connection Upgrade

Goal : Reduce risks of N_2 leaks after high-intensity dumps

- **Helicoflex seal replacement with EPDM seal**
- **Shifting of existing clamping chain ring to allow tightening of all four nuts**
- **Removal of bellow compression jacks during operation**
- **New clamping ring design**

Restraining Dump Displacements



Instrumentation upgrade

- New interferometers, better suited for expected regimes
- Temperature sensors on the core housing
- Strain gauges on the core housing
- LVDTs

Vital to better understand the behavior of the dump, in view of producing a more robust design

Under discussion with EN/SMM…

TDE – Conclusions

Run 3: Assuming 1.8E11 ppb and 1.8 um

- Fewer interventions expected (more robust connections)
- DS window in Ti-Gr5 compatible
- US window in should be OK (Ti-Gr5 or larger β)
- Better understanding of dump dynamics
- Large displacements still possible – to be monitored closely
- In case of dilution failure, graphite core may be at the limit (even more critical for HL operation)
- Core material characterisation required !

Thank you for your attention.