LHC external beam dump block (TDE) works during LS2: new baseline proposition

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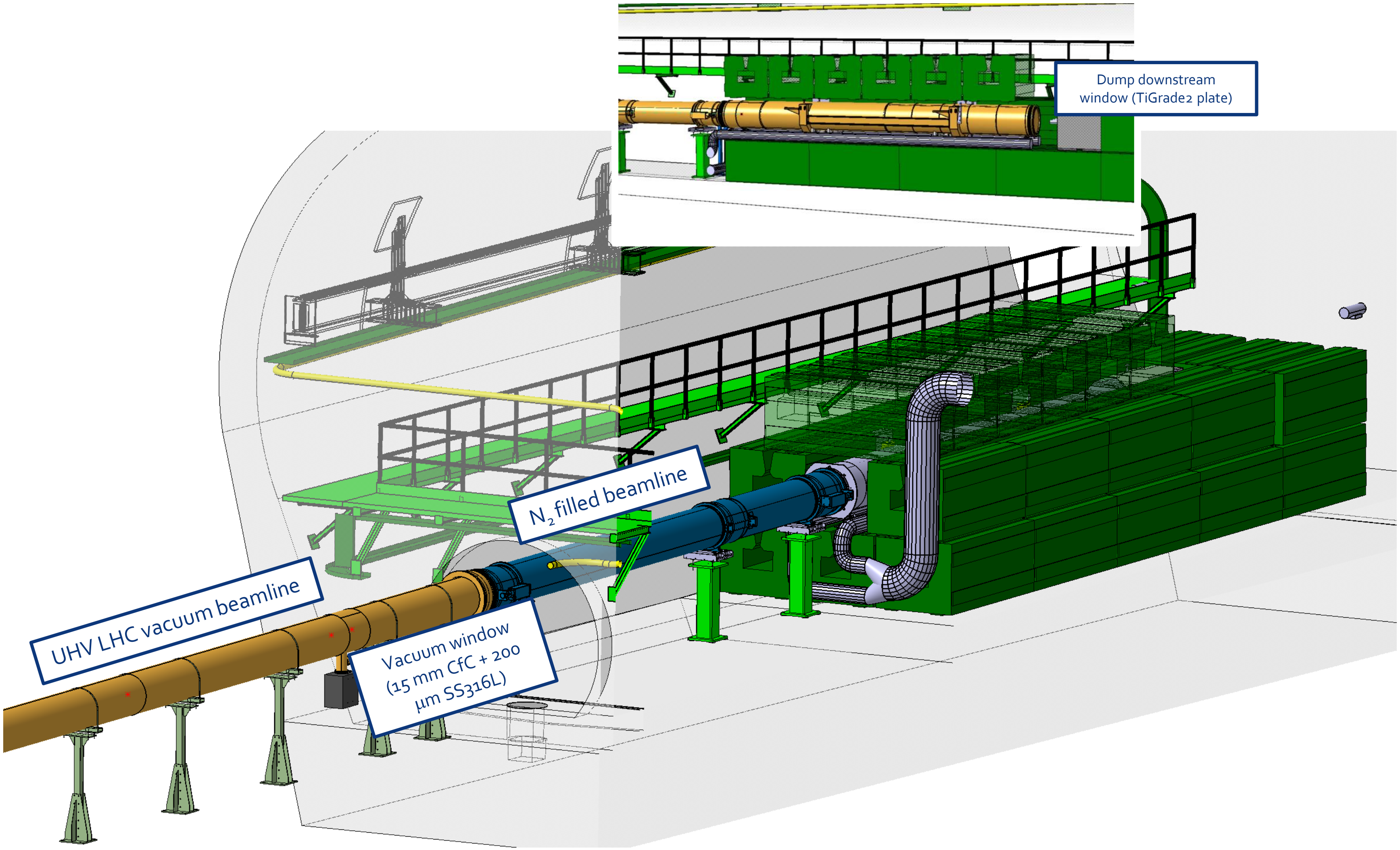
CERN | EN ENGINEERING DEPARTMENT

LMC 387, MPP185

Outline

- Review of Run2 operational challenges
- Pre-LS2 baseline activities
- New findings obtained during 2019
- New proposed baseline for LS2 in view of Run3
- **Interlocking**
- Conclusions

Current configuration of LHC dump block



Run2 challenges and LS2 baseline

- N_2 leaks from the dump assembly starting from end of 2015, regular interventions during TS and (E)YETS
  - Cumulated dose to personnel estimated at ~3 mSv collective
- Damage to helicoflex gaskets throughout the connection line
- Loosening of bolts of the chain clamps
- Following the installation of interferometers, indication of permanent displacement of the dump of up to 7 mm, with a rotation of several degrees

- Baseline for LS2 (see LMC369) :
  - Exchange of downstream window
  - Exchange of N_2 sector gaskets
  - Intervention only on the spare dumps, and swap with operational ones

New findings during 2019

- Energy deposition in the 12 mm thick 318L external vessel containing the graphite core is significant
  - Induced by the showering of the primary beam on the graphite (w/o heat diffusion from the graphite, taking place from minutes after)
  - Adiabatic temperature rise of ~65 $^{\circ}$C in 80 μs

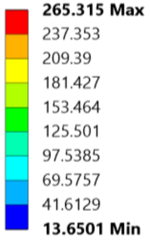
→Excitation of a longitudinal mode of ~6 ms period and 166 Hz

→Vibration and displacement is intensity driven

- Main TDE concerns have always been on the graphite core behavior (due to the 320+ MJ (750 MJ for HL)) deposited energy

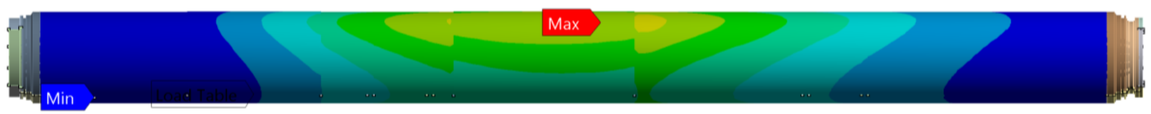
Simulated Energy and temperature evolution in vessel

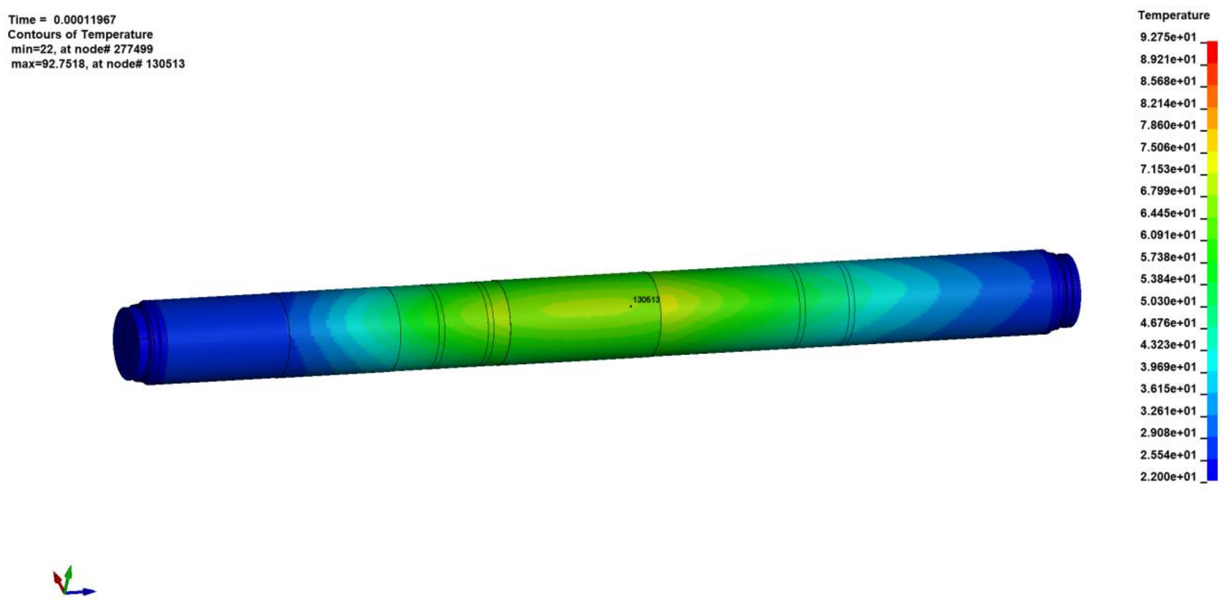
Energy density J/cm3

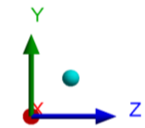


Total energy deposited in the 12 mm 318L shell: **21 MJ/dump**

- Number of bunches 2748
- Intensity : **RUN3 1.8*10¹¹ ppb**
- Standard scenario 6V4H





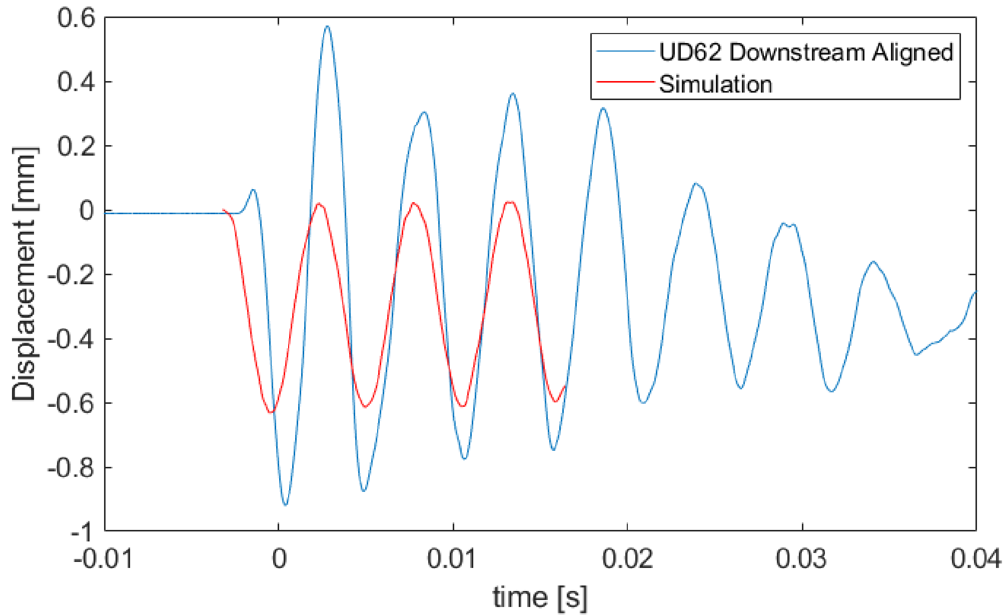


- Adiabatic temperature rise of ~65 °C in 80 µs

Simulated dump movement (I/II)

- Beam impact ~80 μs, dump "breathing" period ~6 ms (~166 Hz)
- Displacement up to 3-4 mm at 166 Hz, up to 3 m/s and ~2000 m/s²

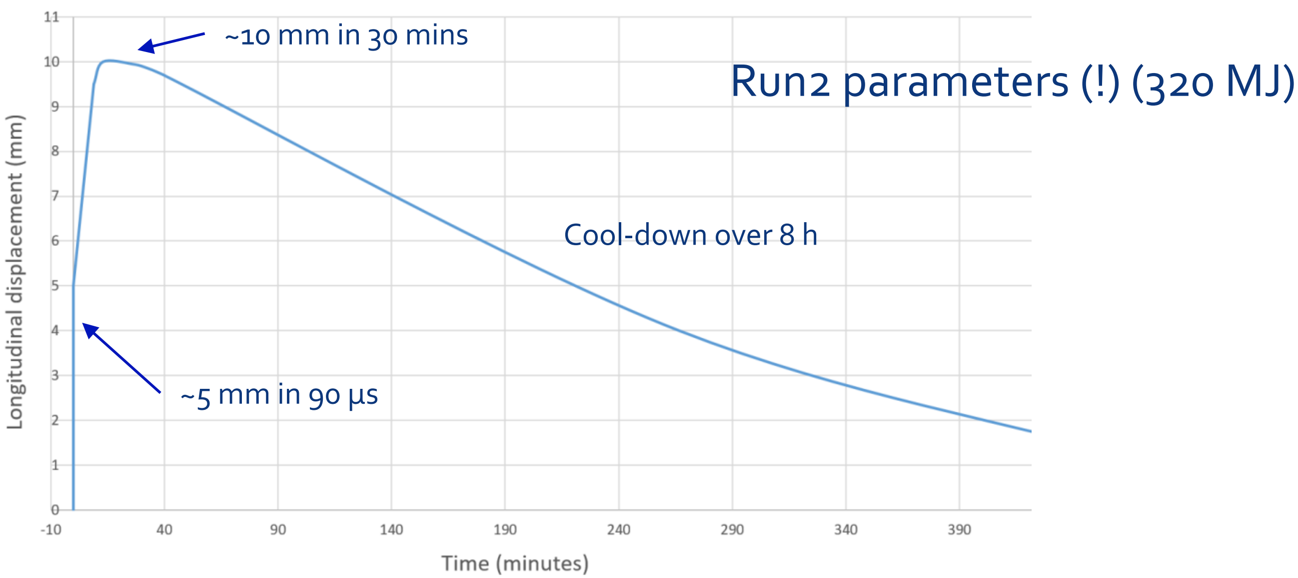
Comparison with Run2 experimental data



- Run2 operational parameters, dump connected to the N2 vessel
- Example from full intensity dump
- Oscillation frequency matching the simulation data (within 5%, **~166 Hz**)
- Amplitude difference due to measurement position on the dump assembly

Dump movement (II/II)

- High frequency vibrations make the dump “jump”, releasing the friction of the non-uniform heating/cool-down displacements and changing the point of contact with the supports
- Dump expansion is not only “dynamic” but also long-term due to significant energy deposition



New proposed baseline for Run3 operation

Objective: increase reliability for Run3

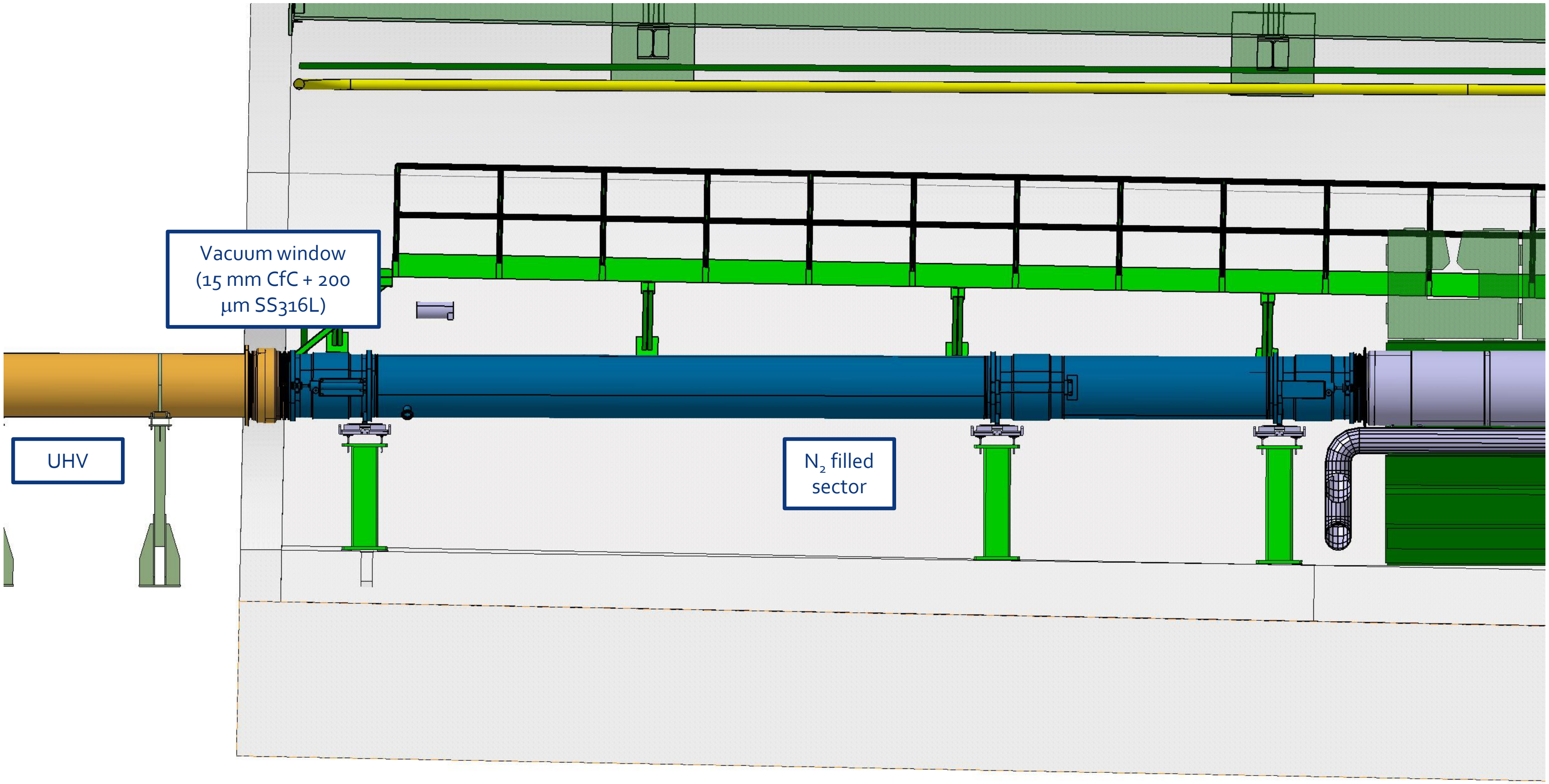
1. **Disconnection of the dump from the UHV vacuum beam line**, to avoid risk of impacting operation in case of increased vibration, by **removal of the upstream N2 connection beam pipe**
2. Installation of a **new TiGr5 window upstream the dump**
3. Change of the **dump supporting system**

(plus the following actions from previous baseline)

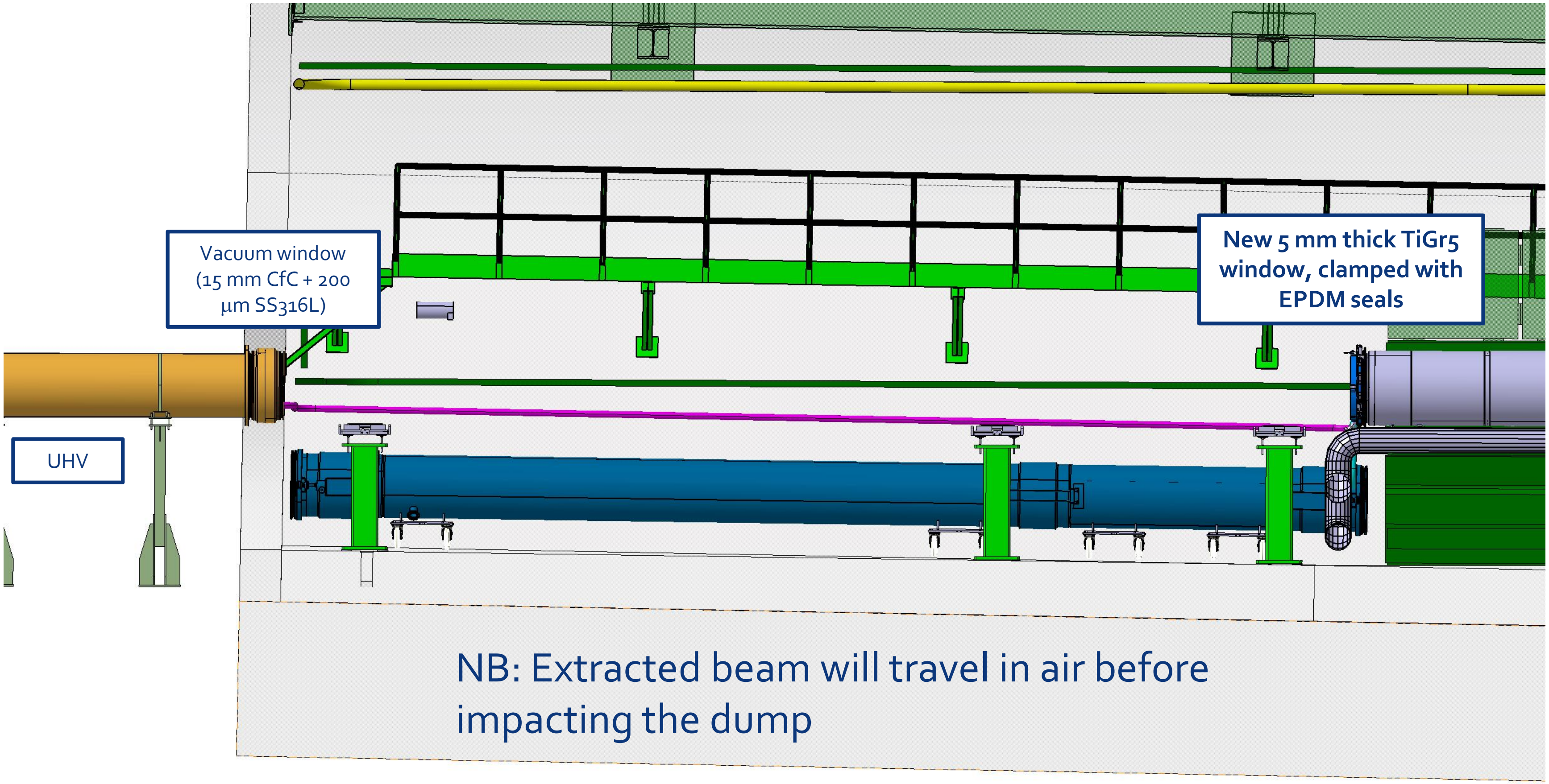
- Exchange the **downstream TiGr2 window for a CF TiGr5**
- Dump **instrumentation**

- Further modification of UHV upstream window being discussed with TE/VSC

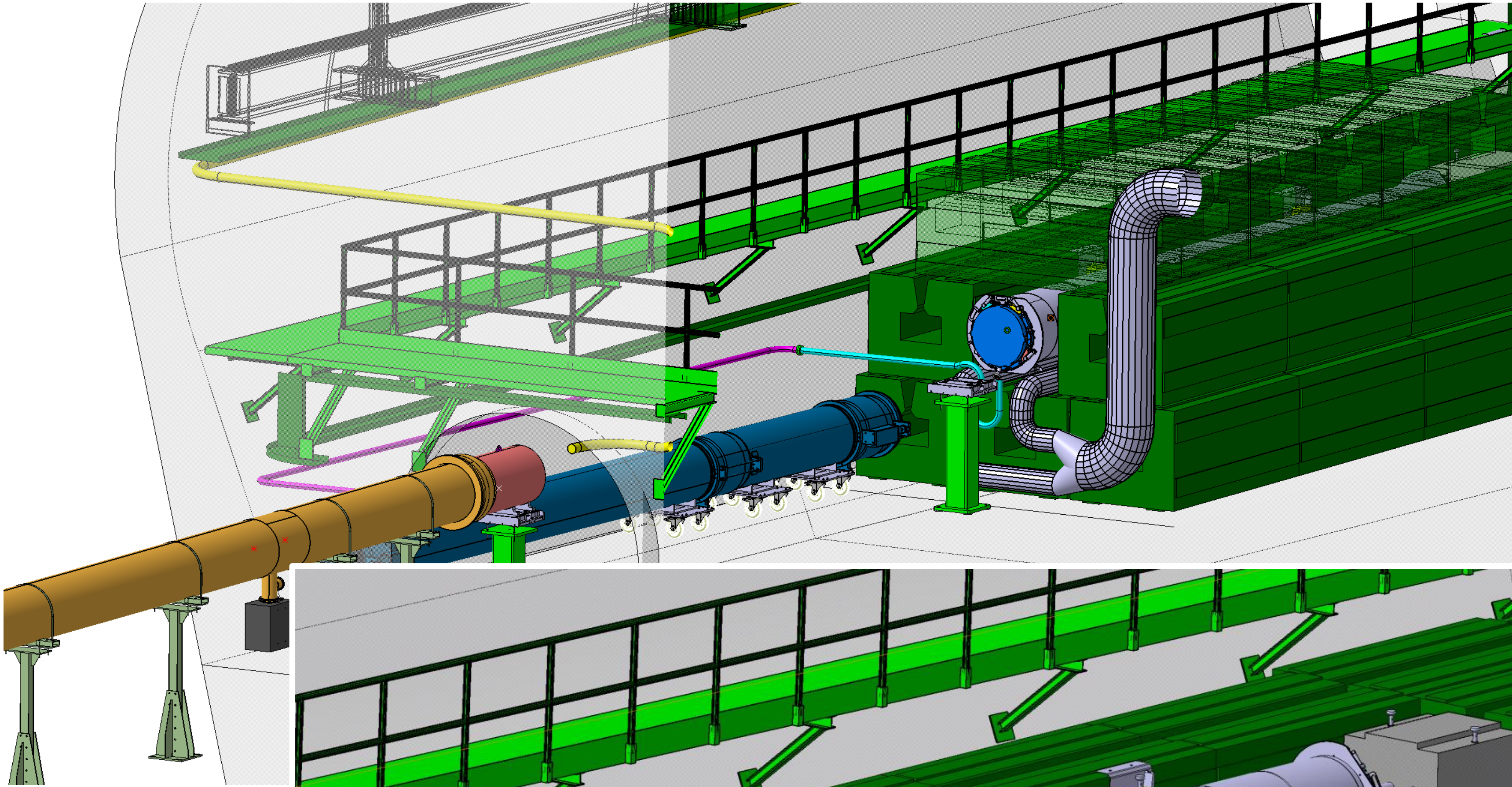
Pre-LS2 configuration

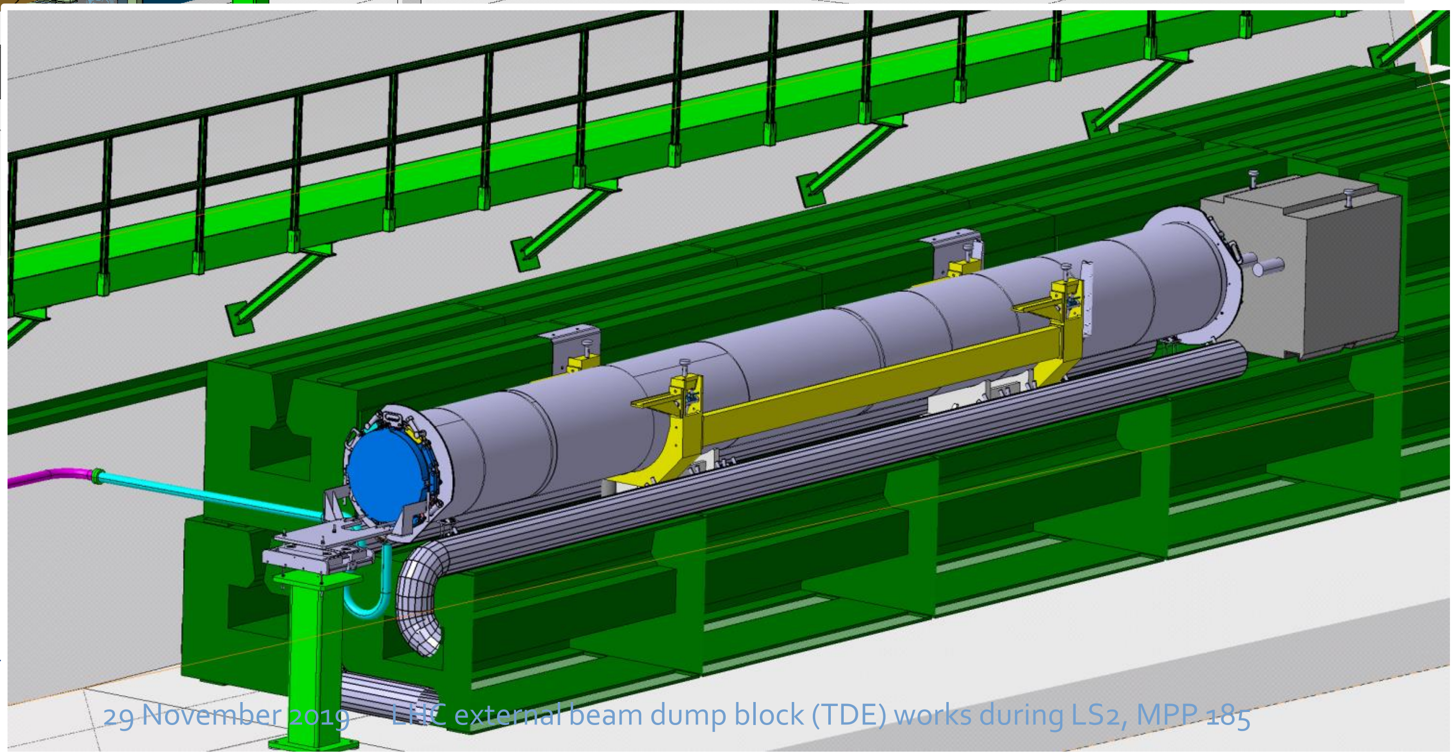


Proposed post-LS2 configuration



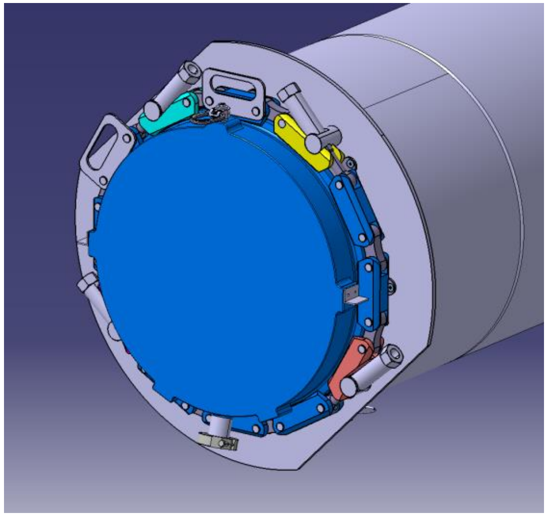
NB: Extracted beam will travel in air before impacting the dump

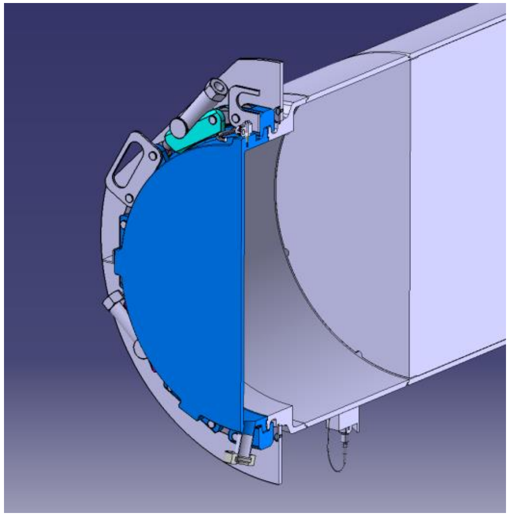




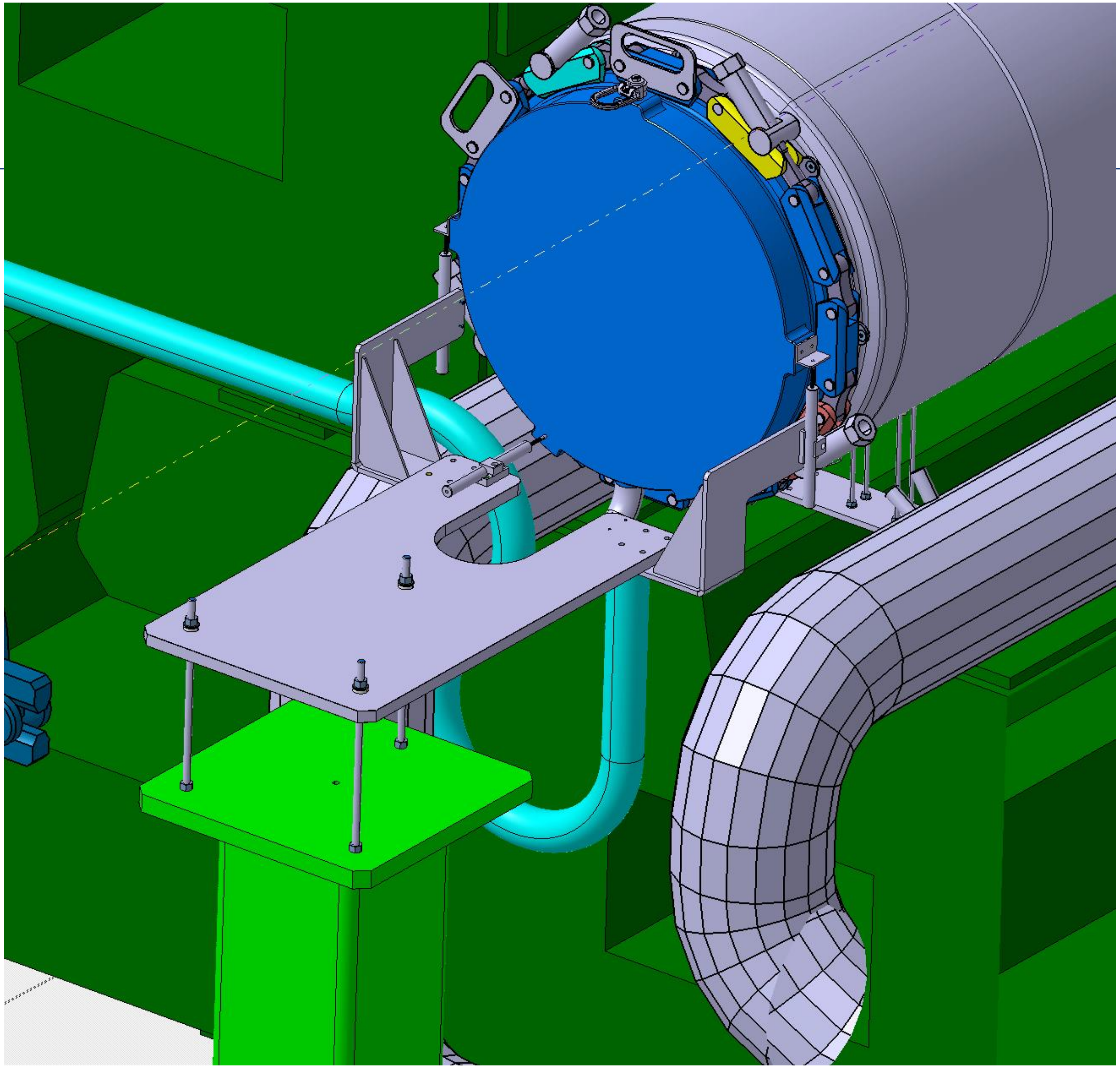
New dump upstream window

- TiGr5 window with EPDM seals, chain clamp and vacuum/N_2 connection port to feed the dump block
- Chain clamp and seals have been analyzed considering dynamical effects
- Vacuum / N2 connection design *needs* to consider dynamical effects



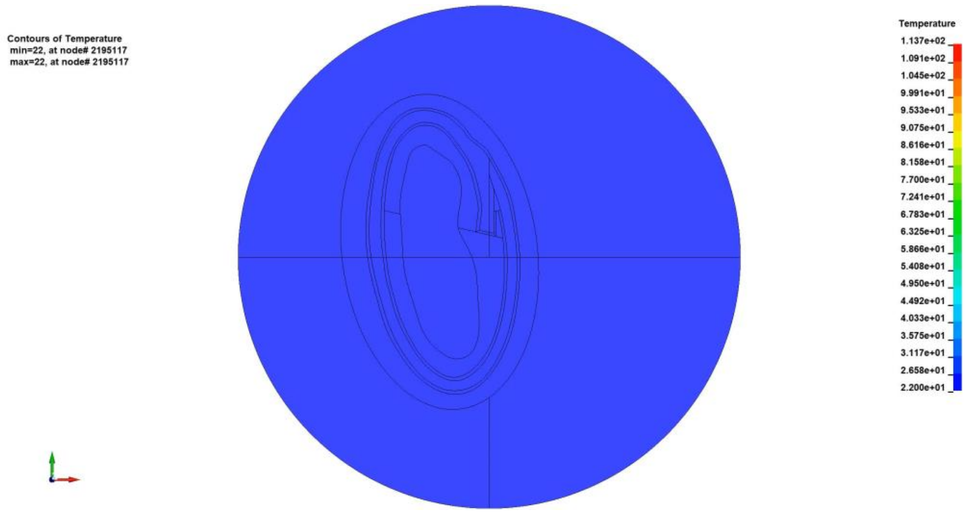


- Window has to withstand 3 types of loads:
  - Thermo-mechanical loads induced by the beam
  - Static vacuum/N2 overpressure load
  - Dynamic load due to the 166 Hz vibration of the dump
- **Proposed thickness 10 mm**

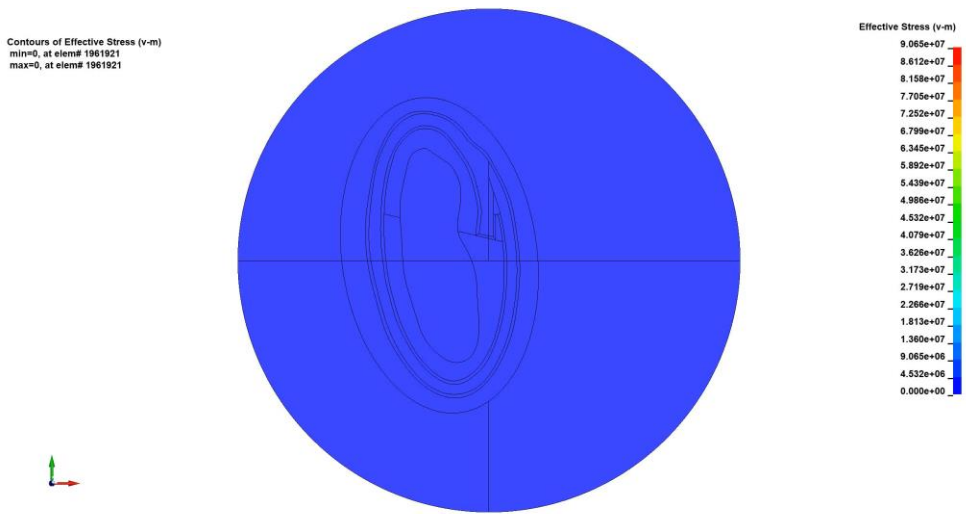


Dump upstream window analyses

Temperature



Von Mises Stress



Beam scenario: **Flashover**

Time scale: 150 µs

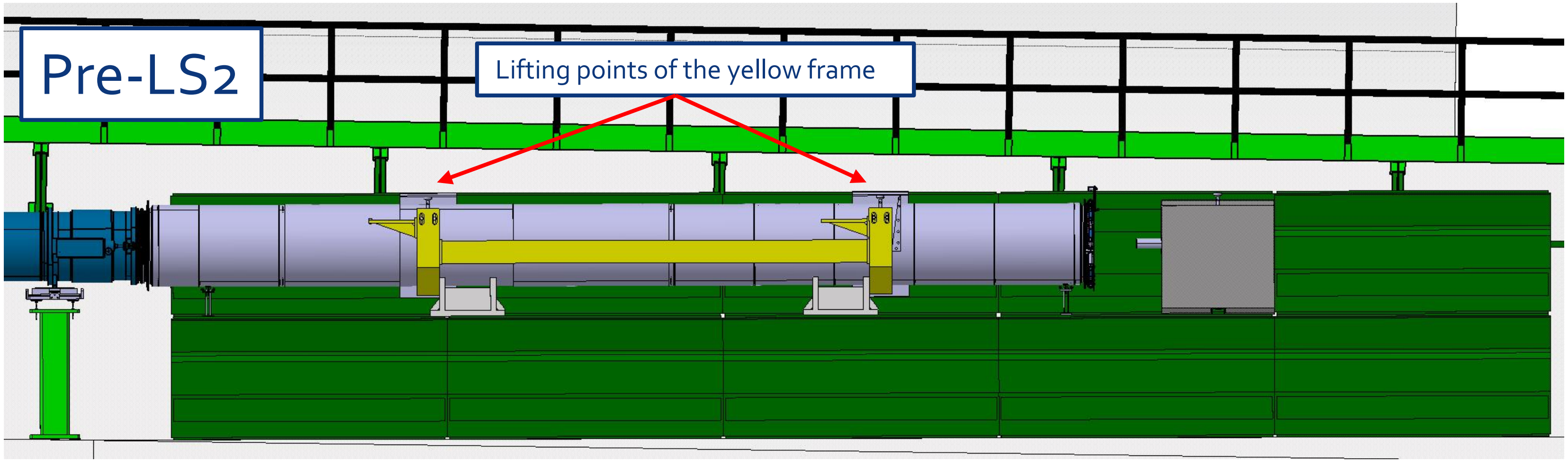
Thickness= 10 mm

Max T= 113.7 °C
Max VM= 90.6 MPa

Yield Strength TiGr5 at 100 °C = 870 MPa

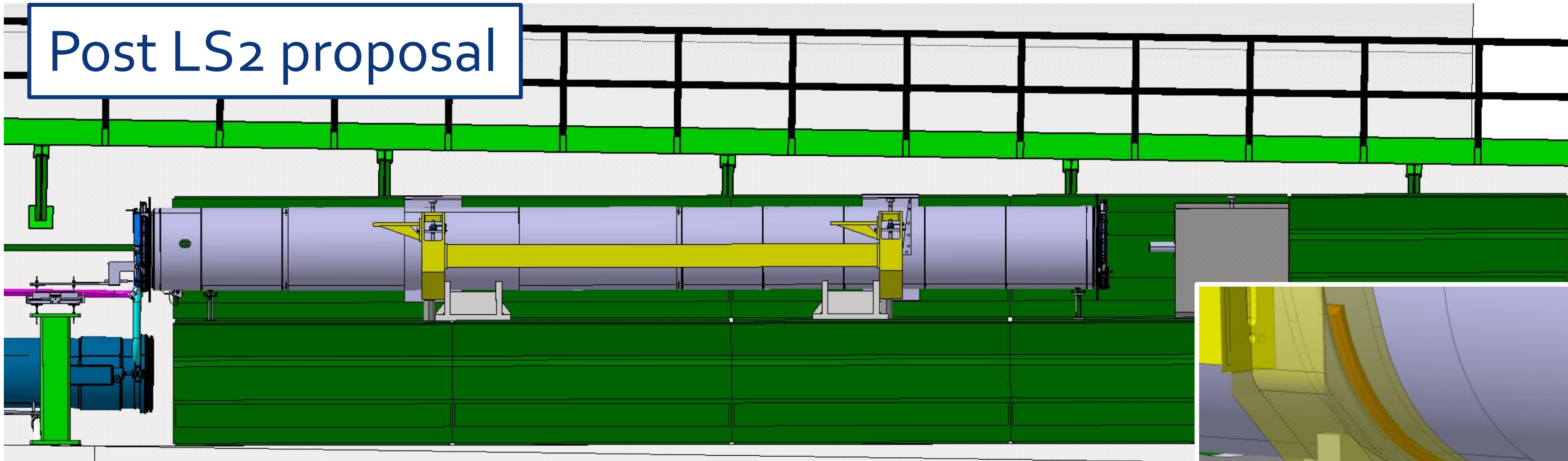
Dump supports and displacement (I/II)

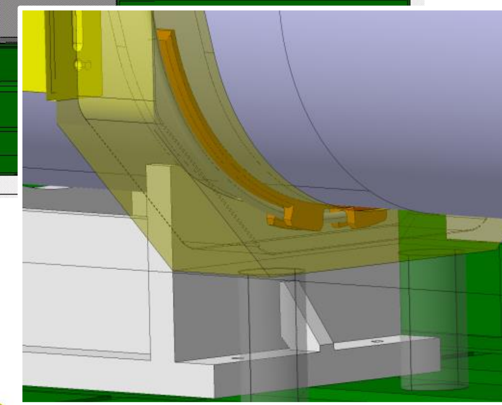
- Cannot restrain the dump to stop it moving due to rapid thermal expansion
- **Dump should not move** with each dump cycle as this moves centre of gravity in its lifting frame.
- We are investigating a preferred solution to stop migration of dump



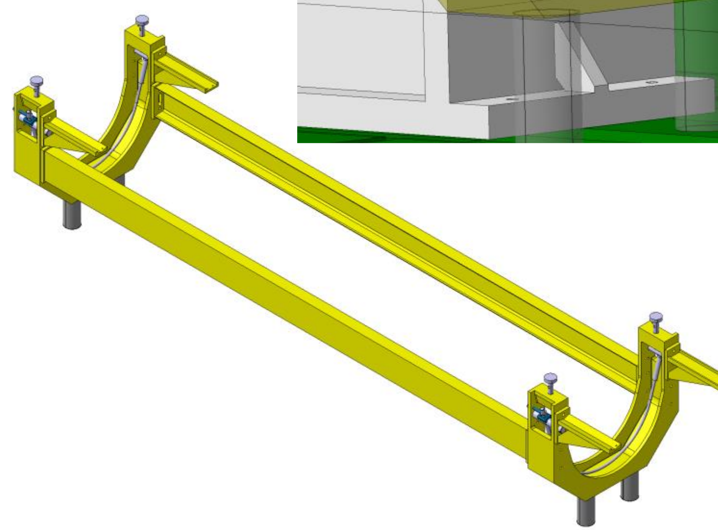
In operating conditions, the yellow lifting frame is hanging from the dump. It can't move longitudinally, because of the grey supports. If the dump moves, it will slide inside the yellow frame, so the dump's centre of gravity will not be centered between the lifting points of the yellow frame.

Dump supports and displacement (II/II)





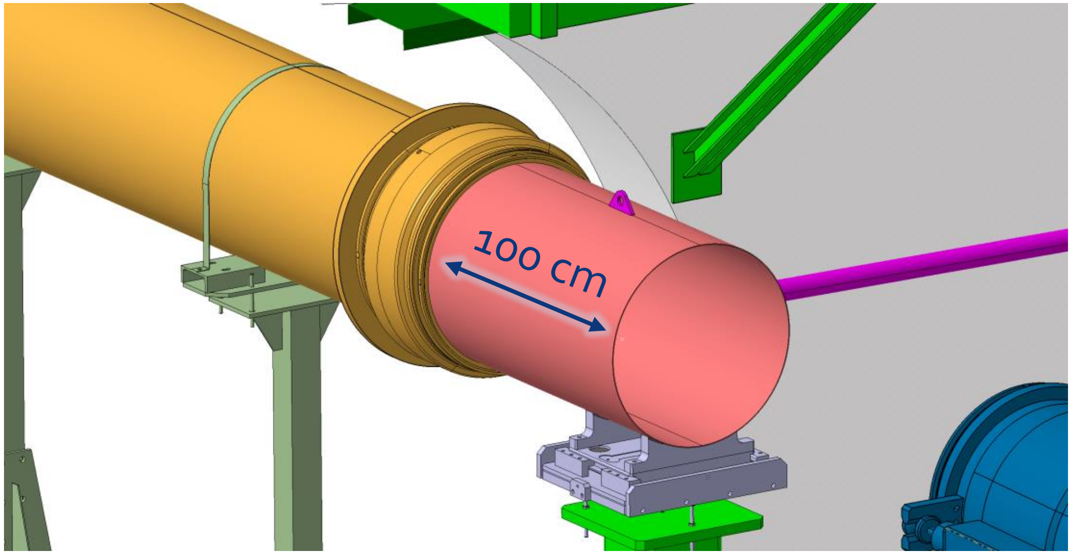
- Modification of existing support frame so the dump is suspended from steel cable loops (a few mm above existing supports)
- The yellow frame will be supported on feet (instead of hanging from the dump)
- Small blocks welded on bottom of dump to stop slipping between cables and dump during rapid expansion
- Dump can expand freely and gravity will bring it back to original position



Discussions ongoing for design finalization, thanks to EN/MME

HSE feedback (RP+OHS)

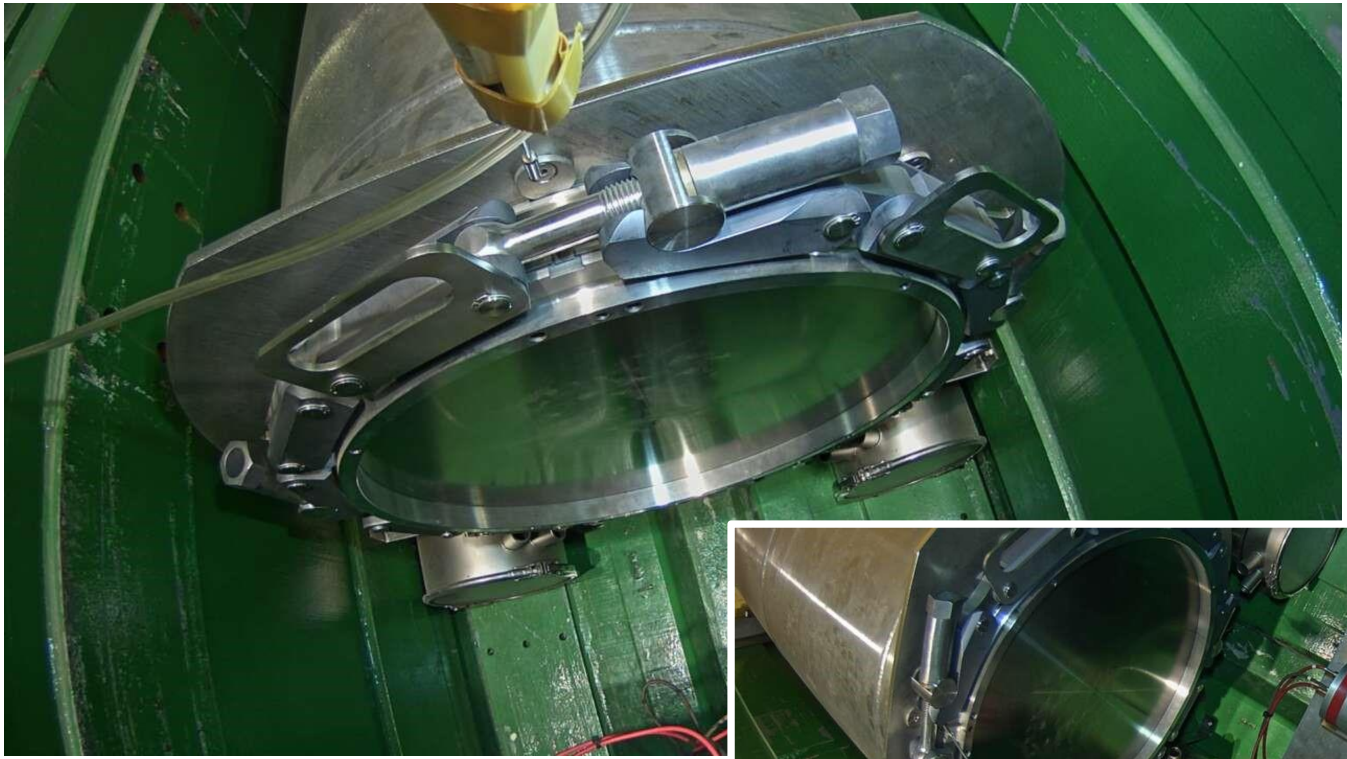
- Removal of the connection line & new TiGr5 window
  - Preliminary discussions with HSE-RP shown a priori no significant radiological impact increase (beam travelling in air rather than closed N_2)
  - Discussions with HSE-OHS also positive if supported by an external protection of the UHV window (~1 meter long independent protection)
- OHS will also support in the design and construction/validation of the cradle

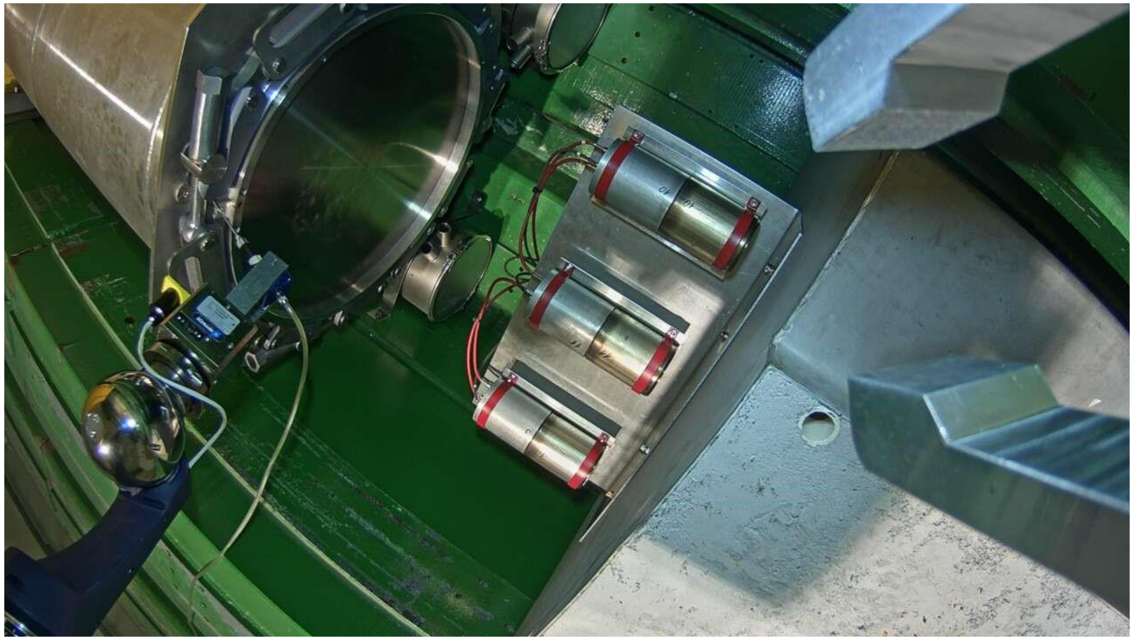


Operational aspects

- In collaboration with TE/ABT, determine any operational constraint during Run3
  - Analyzing if any limit on number of consecutive dumps or minimum time between consecutive dumps
  - Dump core and new windows compatible with Run3 beam parameters
- In collaboration with MPP/OP/ABT need to decide if we update/relax the interlocking strategy as an outcome of the proposed improvements and the resulting operational envelope/constraints (*see next slide*)
- With TE/VSC:
  - Confirm no issue related to possible oxidation of Ti windows due to temperature increase in case of dilution kicker failure
    - Temperatures seems to be sufficiently low even in this case
    - Observation on DS windows indicate no damage
    - AD target external vessel made of Ti show no traces of oxidation despite larger operational temperature estimated for dump windows
  - Current UHV window (15 mm CfC + 200 μm 316L) not compatible with $1.8*10^{11}$ ppb: further interventions being discussed

Status of downstream window early 2018

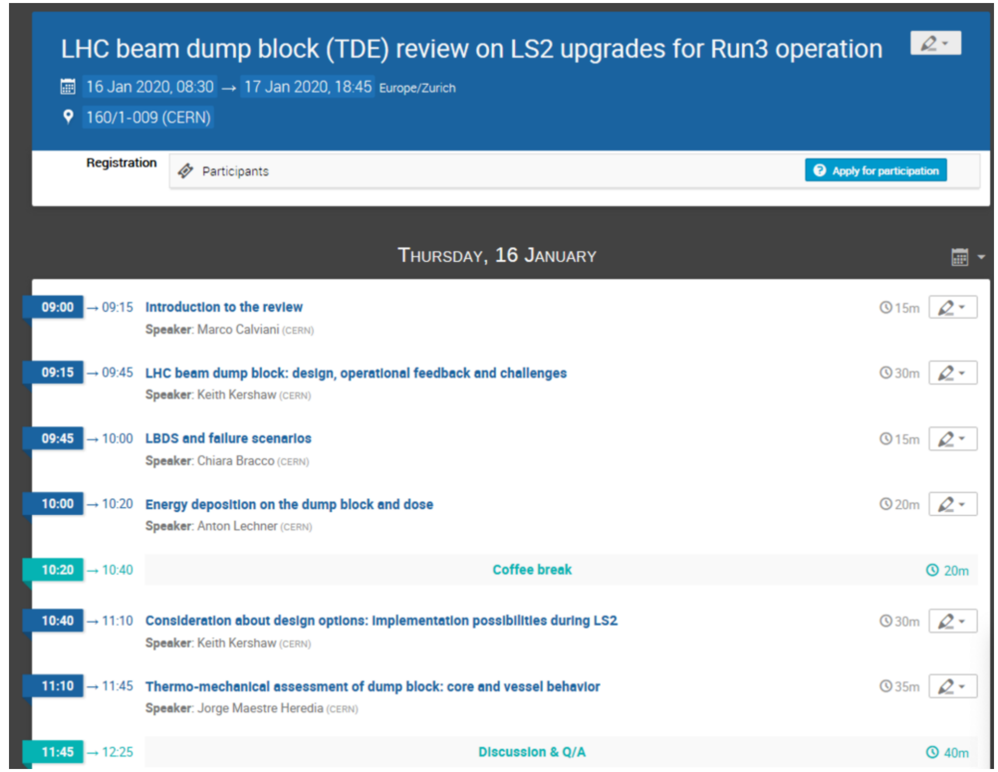




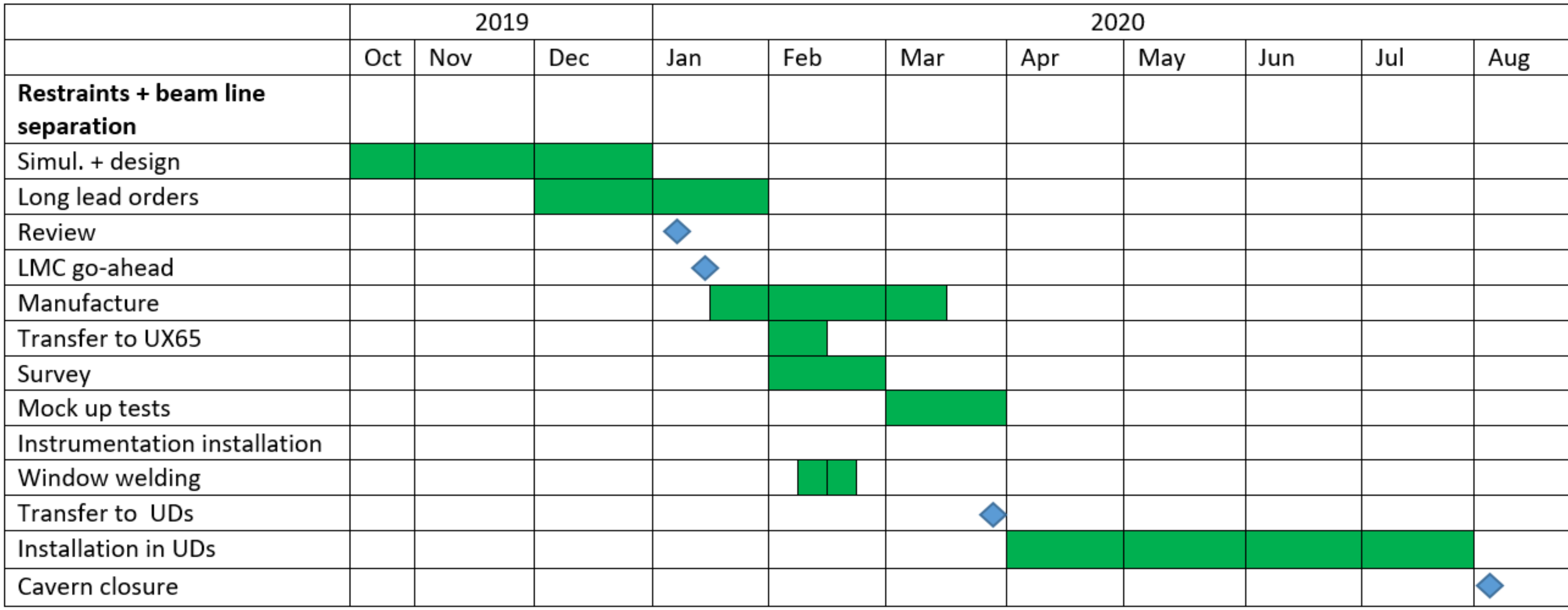
Credits: EN-SMM

TDE review 16-17 January 2020

- Review organized 16-17 January 2020, **with internal and external reviewers**, in order to present in detail the plans, review assumptions and calculations and receive recommendations
- Mandate being drafted
- Following the recommendations, presentation at LMC end of January 2020 in order to allow for the start of the work in early February



Planning and scheduling

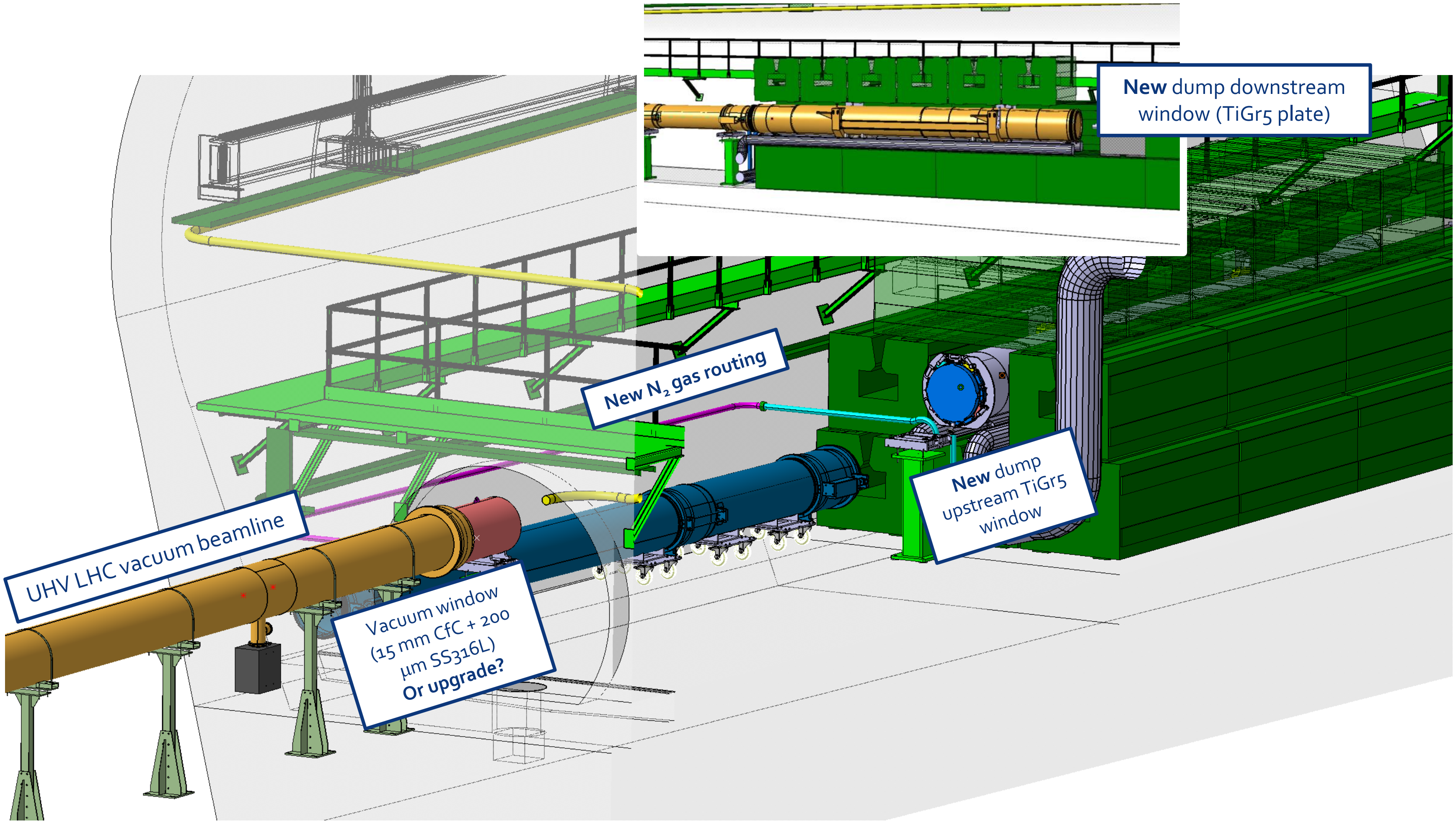


Planning compatible with LHC Masterplan, as discussed at LS2 Days
Procurement of the TiGr5 under discussions with Central Store
Machining of TiGr5 and production of new cradle under discussion with EN-MME

Dump instrumentation

- Ongoing discussions with EN/SMM and EN/MME to instrument the dump while interventions are ongoing in the UX65
- Focus on:
  - PT100 to measure dump temperature evolution
  - LVDTs to measure permanent dump displacement over time
  - (*under study*) inertial accelerometers to measure dump accelerations at different locations
  - (*under study*) measurement of strains (electrical or optical fiber-based) along the dump assembly & windows to identify dump deformations
- Will be finalized and decided before end of 2019
- Instrumentation fundamental for:
  - Monitoring dump also to assess any operational constraint (large movements and/or large vessel temperature)
  - Better understanding of dump behavior in preparation of HL new design

New proposed TDE configuration post LS2



Interlocking possibilities

- Caveat: too early to finalize decisions – still we can brainstorm

1. **Pressure (old)**: nitrogen inside dump assembly
2. PT100 (new): external temperature of the external vessel
   1. Protection of the dump in case of continuous dumping (if requested) - considering that the dump is not efficiently cooled
   2. Limits could be set during the first weeks of operation (likely ~200 °C)
3. LDVT (new): permanent displacement
   1. Expected displacements due to thermal expansion in the order of 10-15 mm
   2. Permanent deformation warning – need to put a “grace period” to compensate for “quick” expansion (1-2 hours)

- Caveat2: we cannot guarantee that instruments will be capable of working for all Run3 – some instruments could stop working due to the huge acceleration (~2000g)
- Lessons to be learnt for the design & operation of the HL-LHC dump

Conclusions

- Baseline for interventions on TDE decided in February 2019 is proposed modification by the advancement in the understanding of the reasons of dump movement achieved during 2019
- **New baseline activities being proposed – to be reviewed in a dedicated review 16th January 2020, followed by a new LMC presentation by end of January 2020**
  - **Further discussions also in an upcoming MPP meeting**
- **Assessment of any operational constraint for Run3 ongoing**
- A big thanks to all supporting teams:
  - TE/VSC, TE/ABT, TE/MPE, EN/MME, EN/SMM, EN/HE, EN/EA, EN/EL, HSE/RP, HSE/OHS, BE/OP and many others