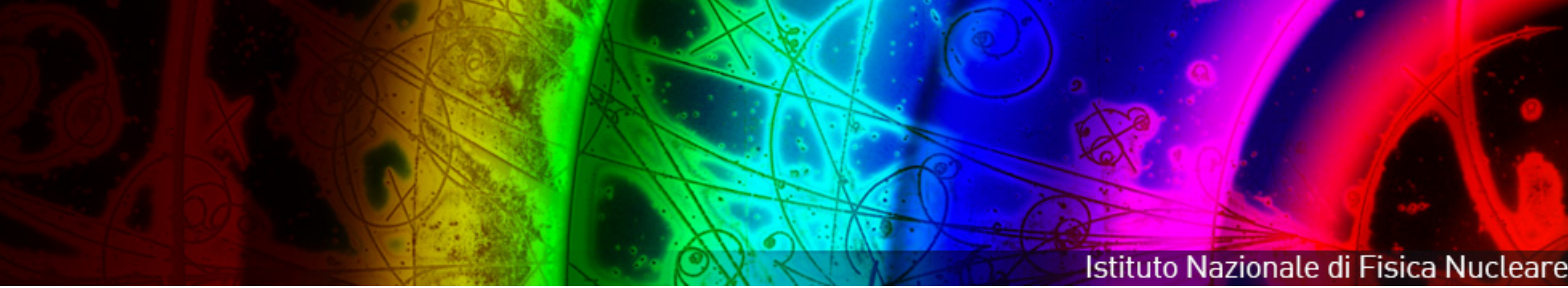


SMOG2 or the SMOG upgrade

Pasquale Di Nezza

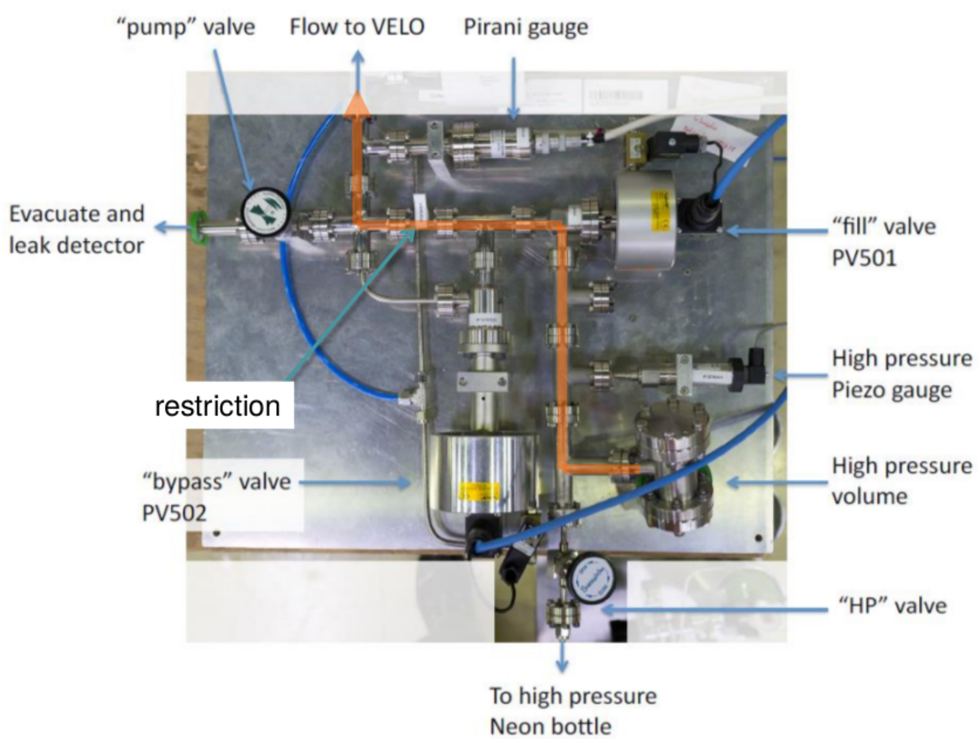
INFN LNF Istituto Nazionale di Fisica Nucleare

LHCb

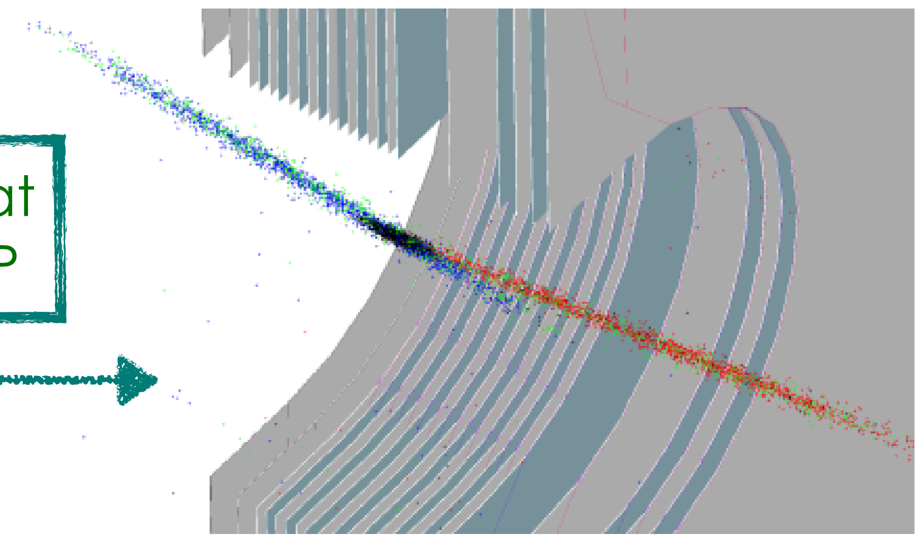
in collaboration with: V.Carassiti, G.Ciullo, P.Lenisa, L.Pappalardo, E.Steffens

SMOG, a successful idea and a pseudo-target

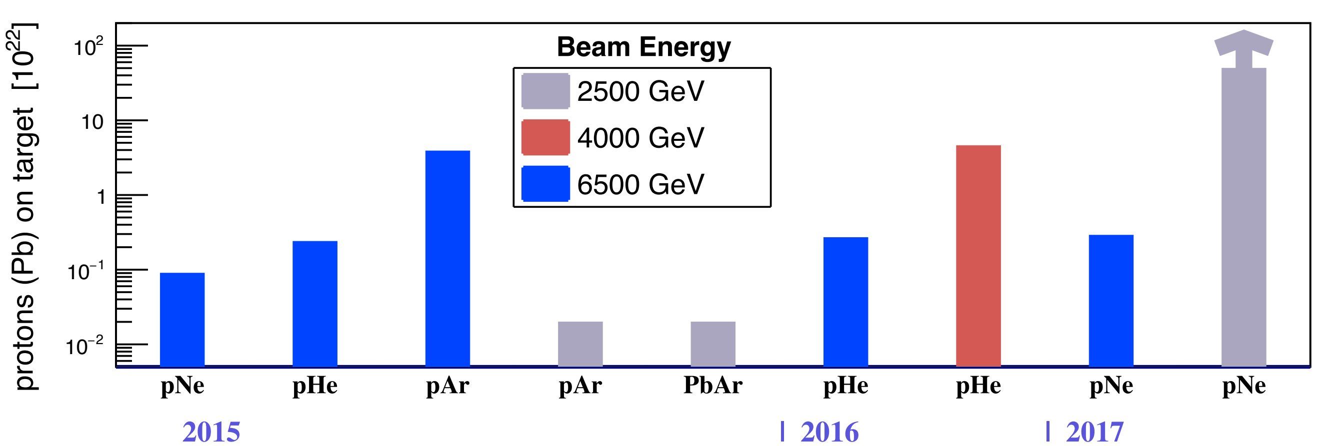
System for Measuring Overlap with Gas (SMOG) has been thought for precise luminosity measurements by beam gas imaging, but then it served as a “pseudo-target” producing interesting results

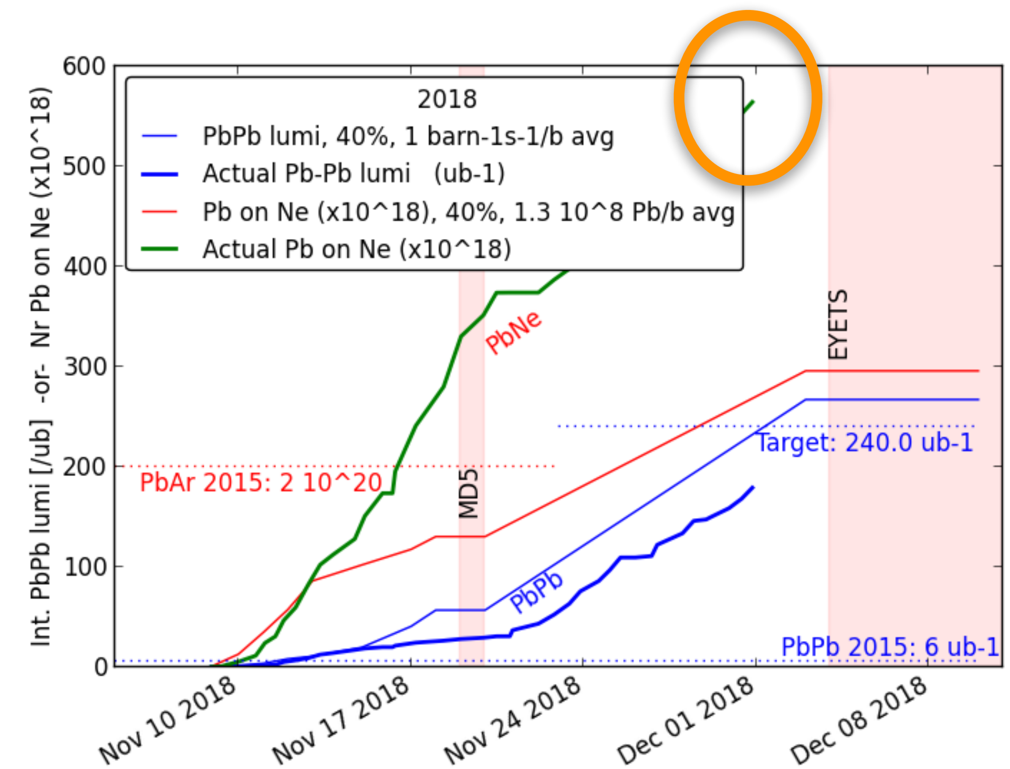


gas injection at the nominal IP



Data taking SMOG 2015-2017





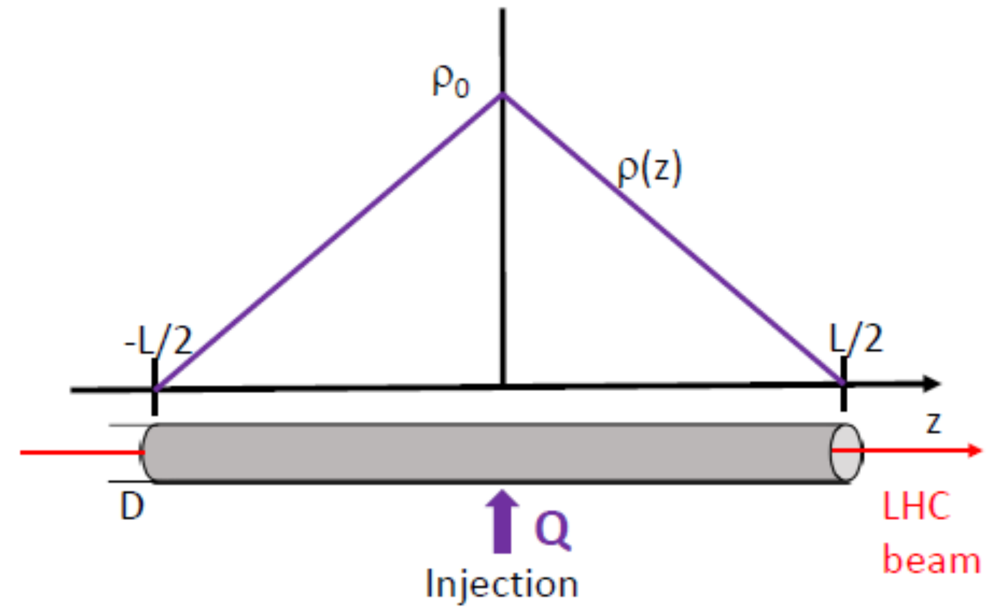
A very successful data taking just concluded

SMOG2 aims at significantly improving the performances of SMOG thanks to the use of a storage cell (extension of the VELO detector). This will allow to greatly expand the physics reach of SMOG paving the way to new and unique measurements

SMOG2 vs SMOG

- Increase of the luminosity by up to 2 orders of magnitude using the same gas load of SMOG
- Injection of $H_2, D_2, He, N_2, O_2, Ne, Ar, (Kr, Xe)$
- Multiple gas reservoirs
- New Gas Feed System. Gas density measured with strongly improved precision
- Well defined interaction region upstream the nominal IP: strong background reduction, no mirror charges effect, possibility to use all the bunches
- First experiment with two separated interaction points having the potentiality to work in parallel

Storage cell concept



A Storage Cell consists of a tube (length L, inner diameter D). Gas is injected at the tube center by means of a capillary from a gas-feed system as a directed flow

Compared with a free beam, the gas atoms are confined by the tube thus forming a target of higher areal density atoms/cm2. The ‘compression factor’ can be as high as 100x depending on the geometry of the storage cell.
The atoms diffuse outwards via the openings in MolFlow mode by performing many wall collisions (≈ 100 or more)

particle intensity (particles/s) of the gas flow

The volume density ρ_0 at the center is given by $$\rho_0 = \frac{I}{C_{tot}}$$

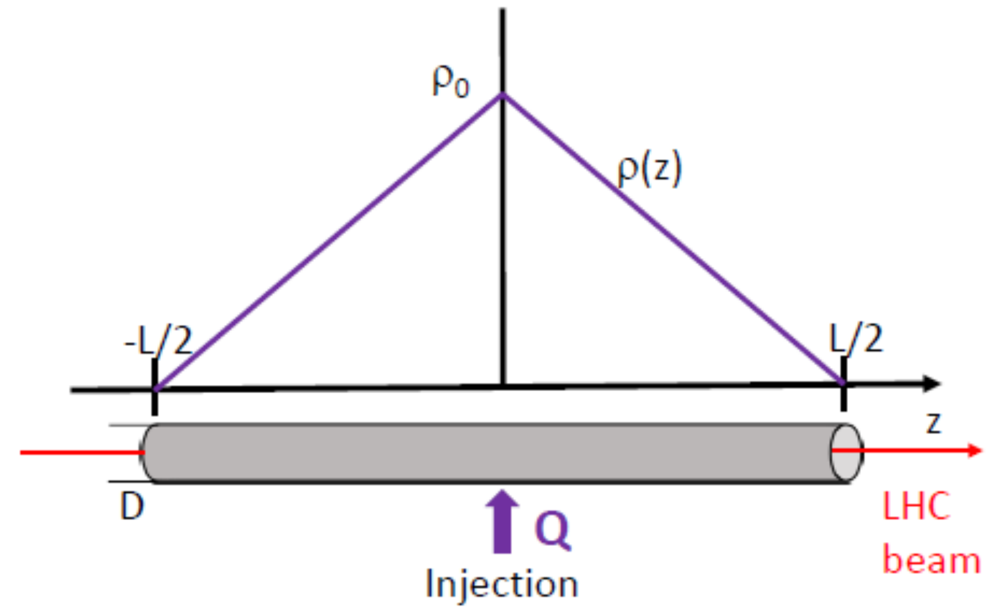
total conductance of the tube

$$C(\mathrm{l/s}) = 3.81\sqrt{T/M}\ \frac{D^3}{L + 1.33\ D}$$

where L, D are expressed in cm, the temperature T in K, and M is the molecular mass number

The areal density is given by: $$\theta = \frac{1}{2}\rho_0 L$$

Storage cell concept



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The atoms diffuse outwards via the openings in MolFlow mode by performing many wall collisions (≈ 100 or more)

For SMOG2 ϱ_0 is typically ~10^{13} atoms/cm^2
with the same gas load of SMOG

This gives a relative beam loss and beam life time reduction of

Beam	Target Gas	σ_{loss} (barn)	τ_{loss} (days)	Relative loss in 10 h
p	H	0.05	2060	0.02 %
p	Ar	1.04	97	0.4 %
Pb	Ar	4.63	22	1.9 %

LHCb-INT-2018-XXX
November 7, 2018
Version 2.0

Presented at the Engineering Design Review on the 15th of November 2018

SMOG2 Technical Proposal

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L. L. Pappalardo[1,2], E. Steffens[4], A. Vasilyev[5]

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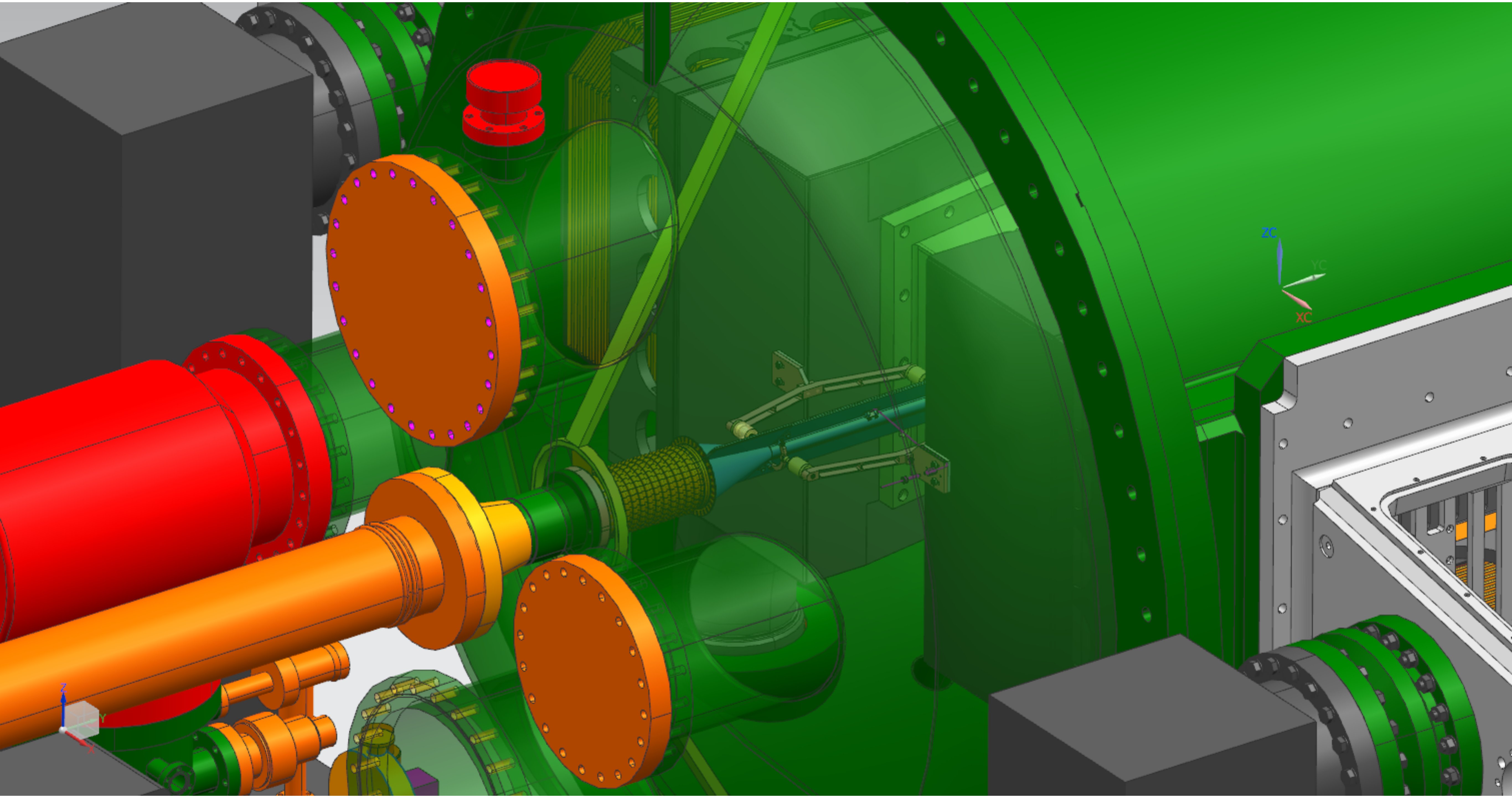
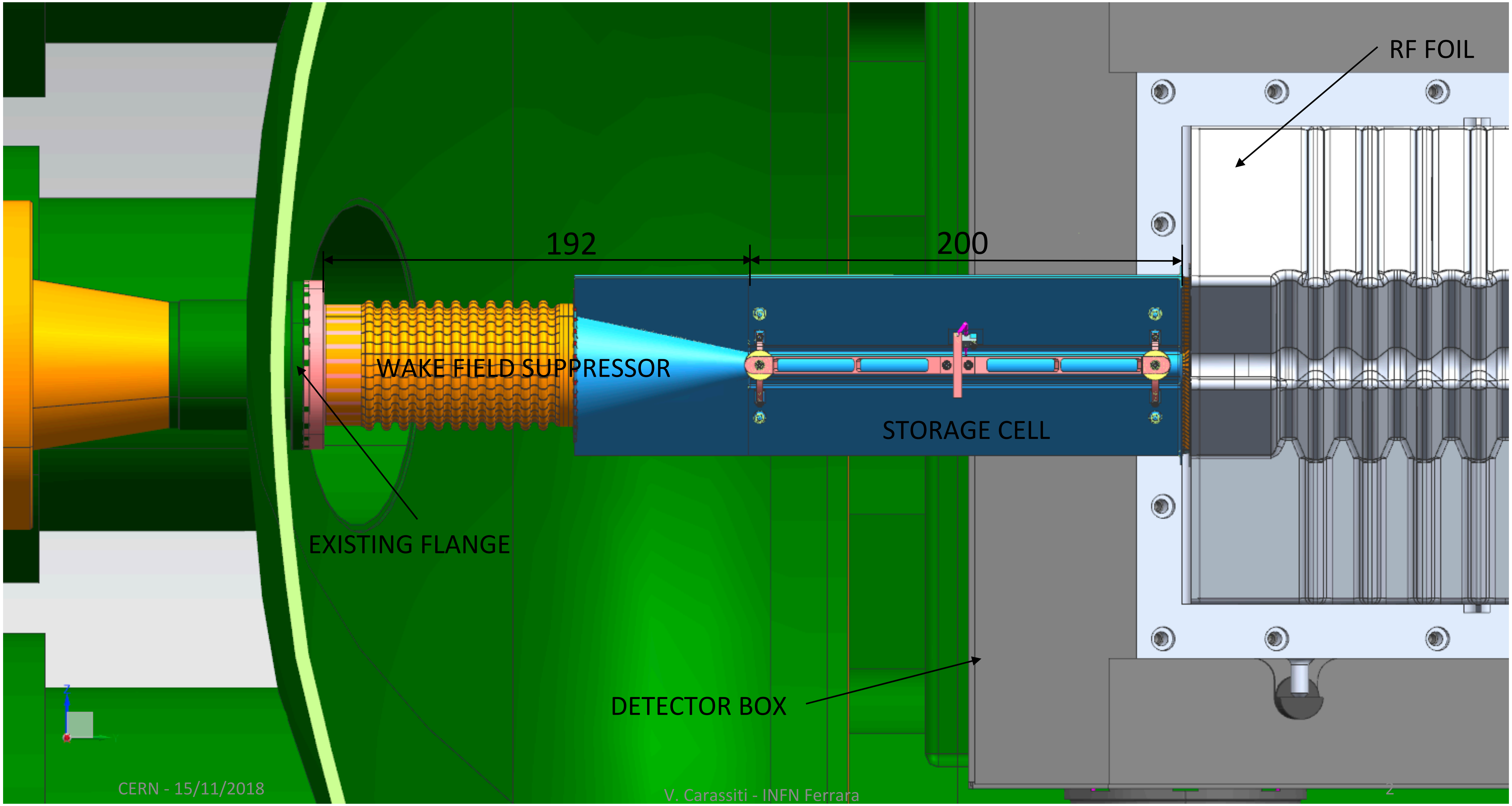
[2]*Dipartimento di Fisica e Scienze della Terra, Università di Ferrara, 44122 Ferrara, Italy*
[3]*Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Frascati, 00044 Frascati, Italy*
[4]*Physikalisches Institut, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany*
[5]*Petersburg Nuclear Physics Institute, Gatchina, Leningrad Oblast,188300, Russia*

Abstract

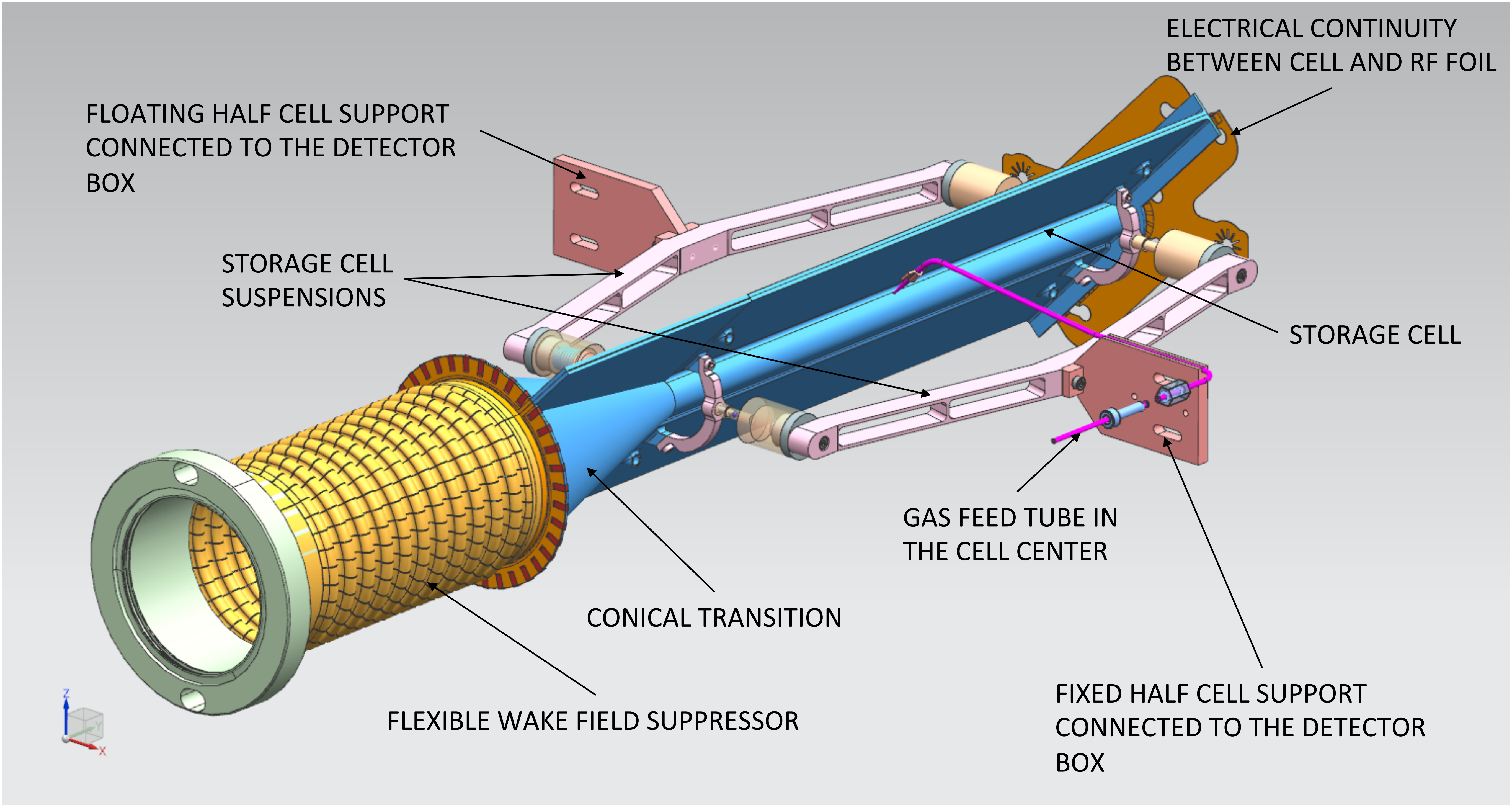
A proposal for an upgraded version of the existing gas injection system for the LHCb experiment (SMOG) is presented. The core idea of the project, called SMOG2, is the use of a storage cell for the injected gas to be installed upstream of the VELO detector. The main advantage of the proposed system is to increase by up to two orders of magnitude the effective target areal density, thus resulting in a significant increase of the luminosity for fixed-target collisions. Other important advantages are the possibility to inject additional gas species, including H_2 and D_2, a better defined interaction region, displaced with respect to the nominal interaction point, and thus possibly compatible with running in parallel to the collider mode (resulting in a further huge increase in luminosity). A technical design of the target system is presented together with a description of the installation procedure. Impedance properties and Electron Cloud effects have been studied for the proposed system, and the possible beam instabilities estimated. The geometry of the system has been integrated into the GEANT4 model of the LHCb detector in order to validate the target design with reliable simulation studies, and to ensure that the near-beam material budget has negligible effects in terms of beam-induced background. The loss in reconstruction efficiency with respect to SMOG for selected physics channels, due to the displaced interaction region with respect to the nominal interaction point, is found to be of the order 10%, thus largely over-compensated by the expected increase in luminosity. The installation of the system is proposed for the LHC Long Shutdown 2. This will open new physics frontiers at LHCb already from the LHC Run-3.

Then approved by the LHCb collaboration

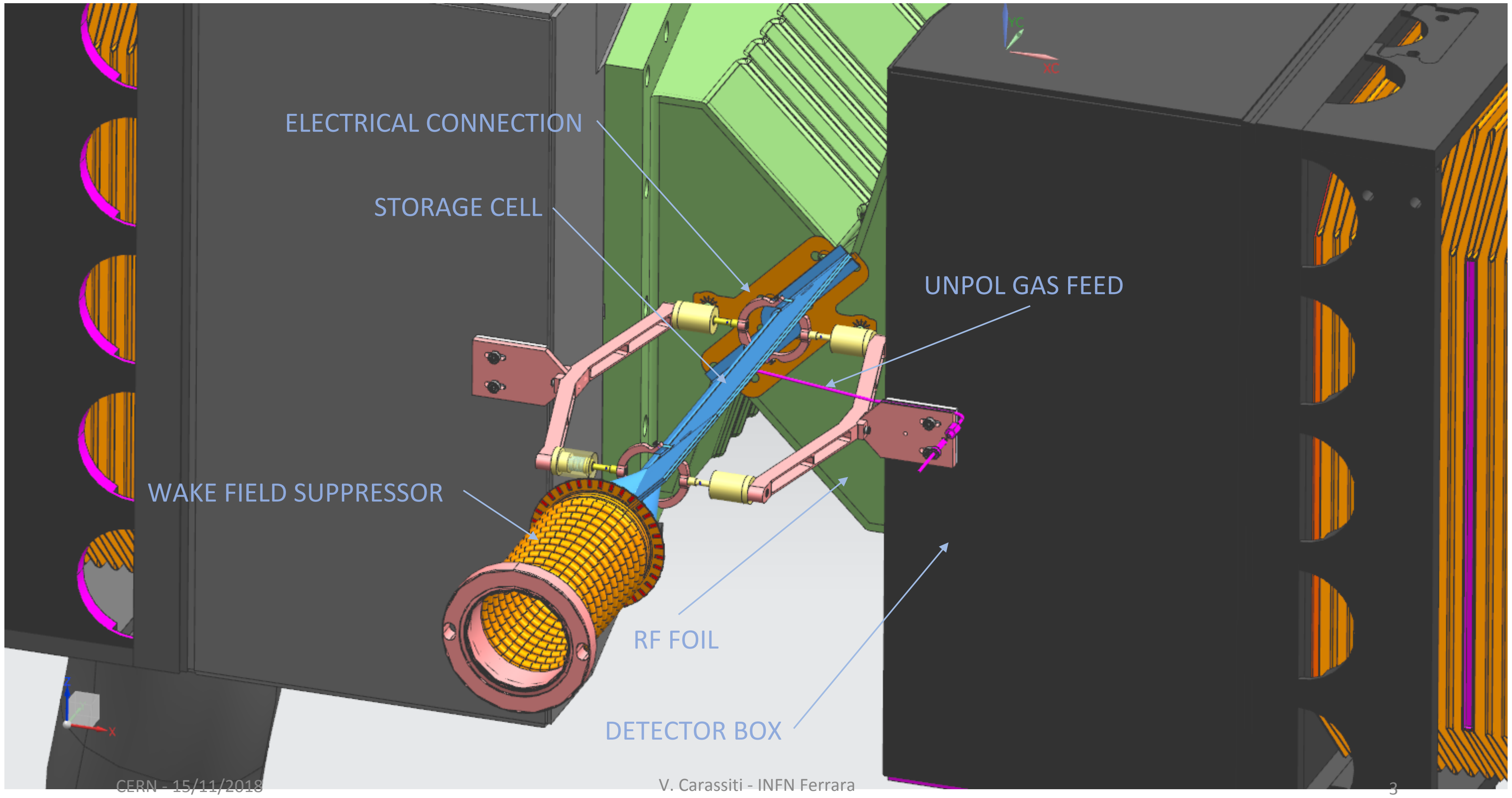

ZC
YC
XC



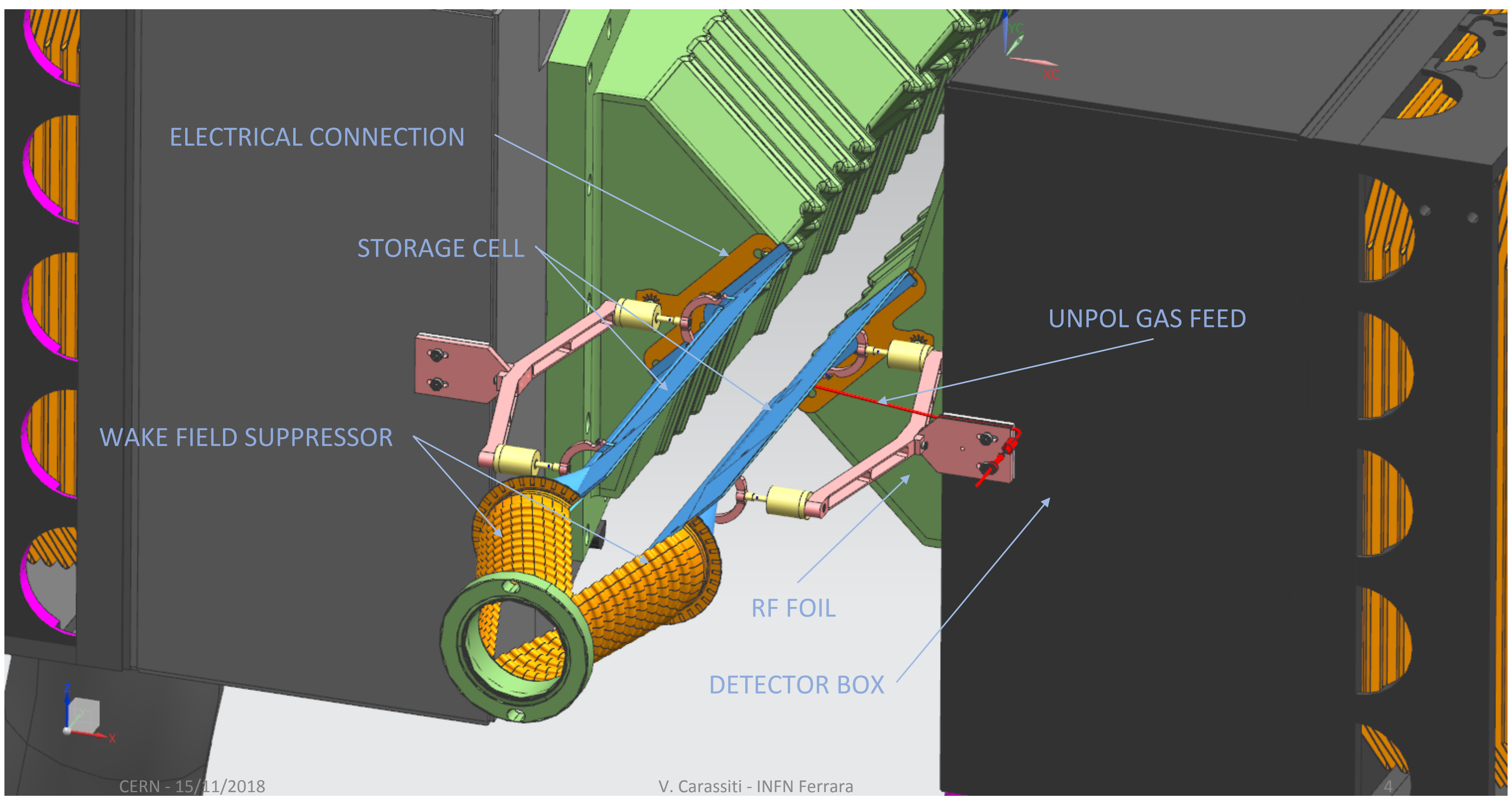
Fits into the space now taken by the upstream WFS


ELECTRICAL CONTINUITY
BETWEEN CELL AND RF FOIL
FLOATING HALF CELL SUPPORT
CONNECTED TO THE DETECTOR
BOX
STORAGE CELL
SUSPENSIONS
STORAGE CELL
GAS FEED TUBE IN
THE CELL CENTER
CONICAL TRANSITION
FLEXIBLE WAKE FIELD SUPPRESSOR
FIXED HALF CELL SUPPORT
CONNECTED TO THE DETECTOR
BOX

Closed position during Lumi Run

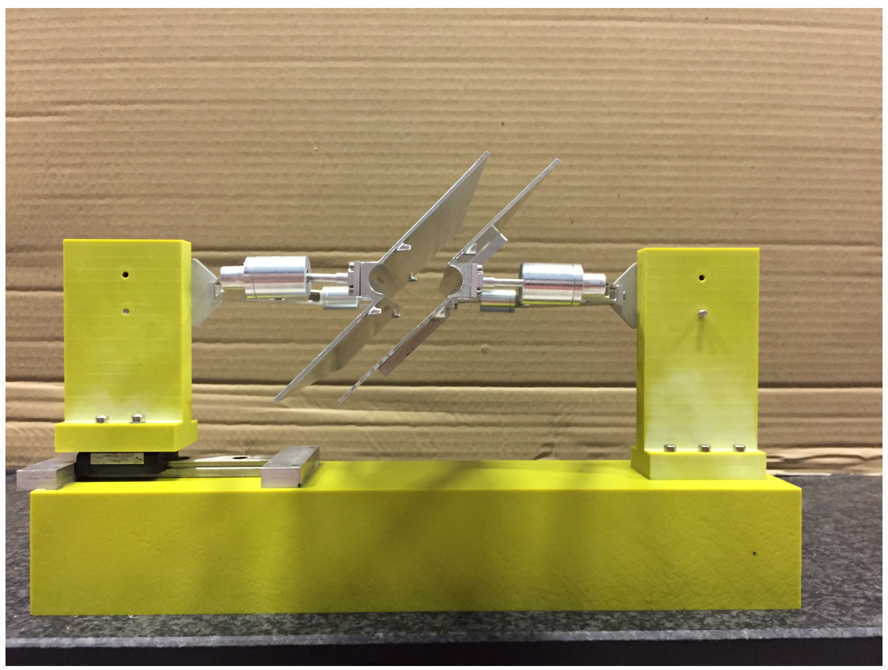


According to the CERN Survey Group the alignment of the system can be done with an accuracy of 50 μm in all the 3D

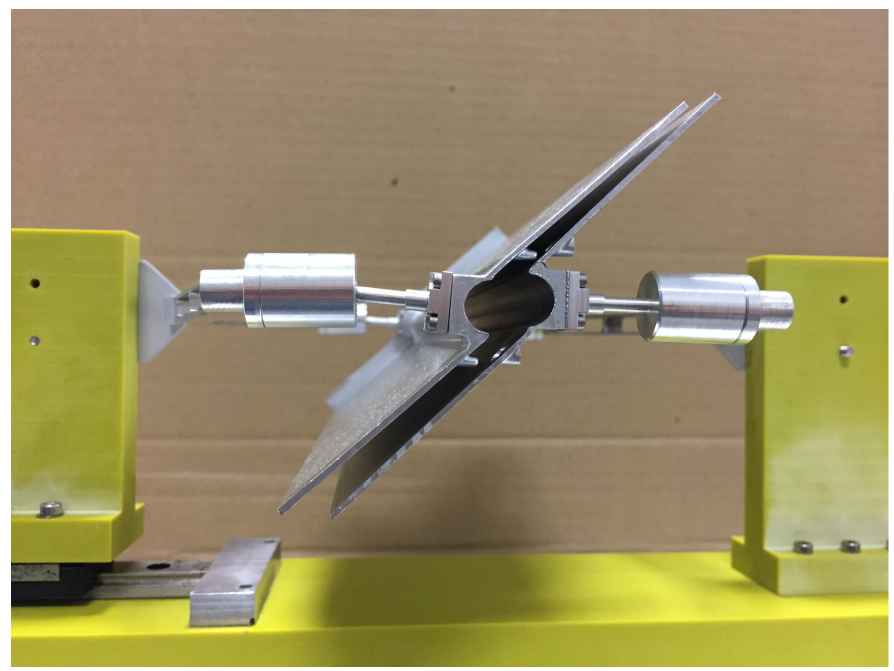


Open position at injection and tuning

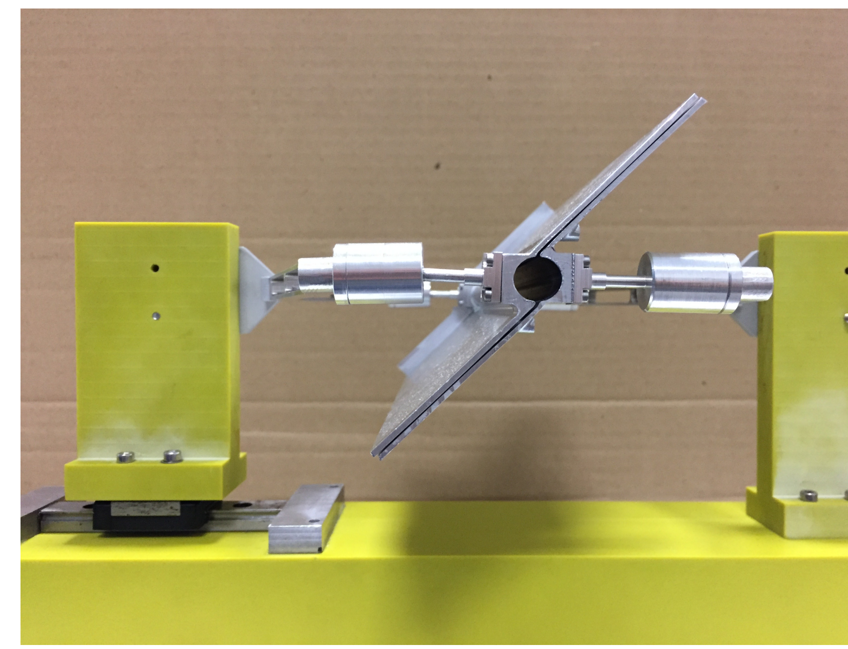
One half of the cell (right) is fixed and used as reference, the other has limited 3D degrees of freedom in order to find always the nominal closed position



open

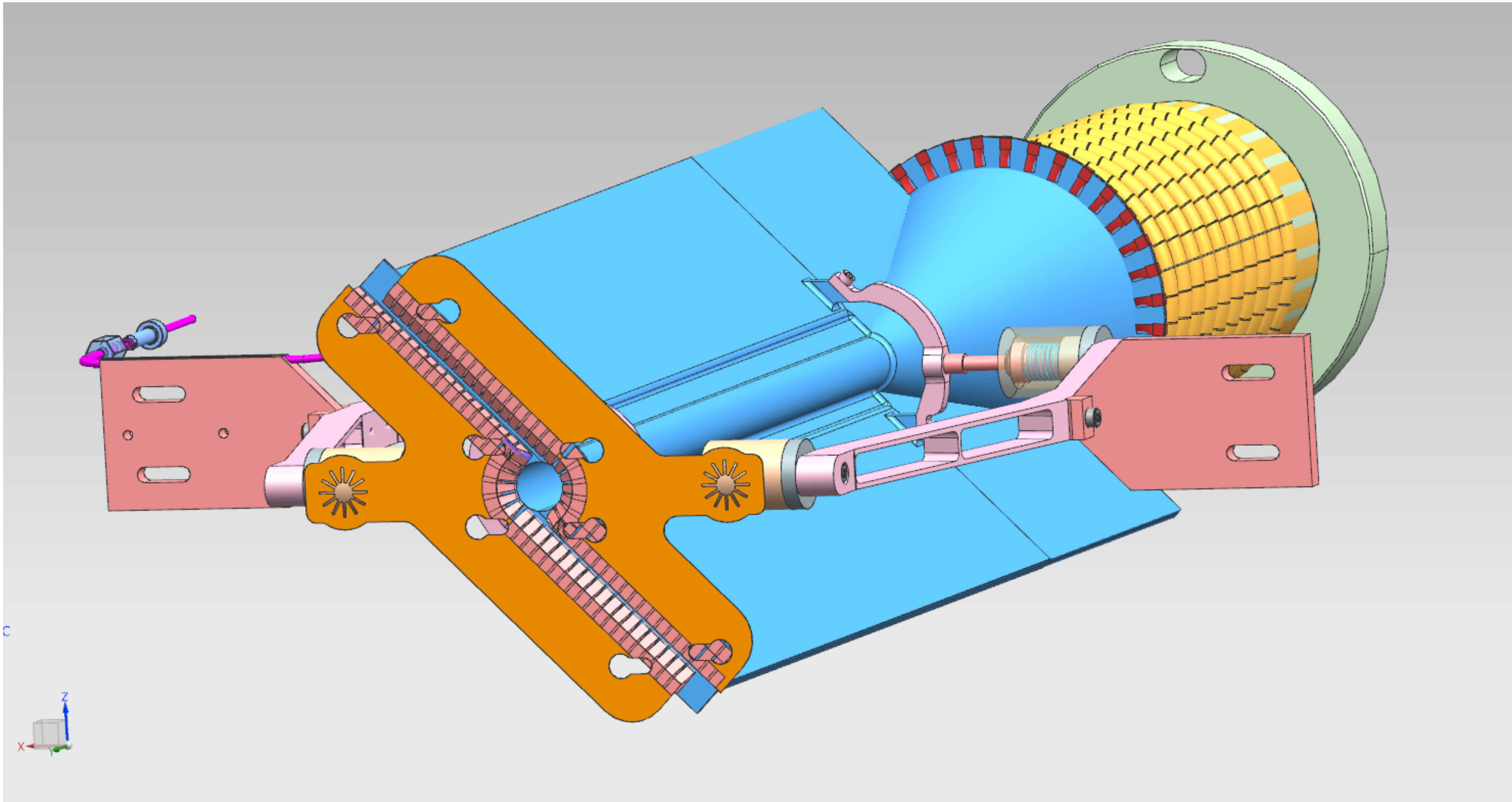


before engaging

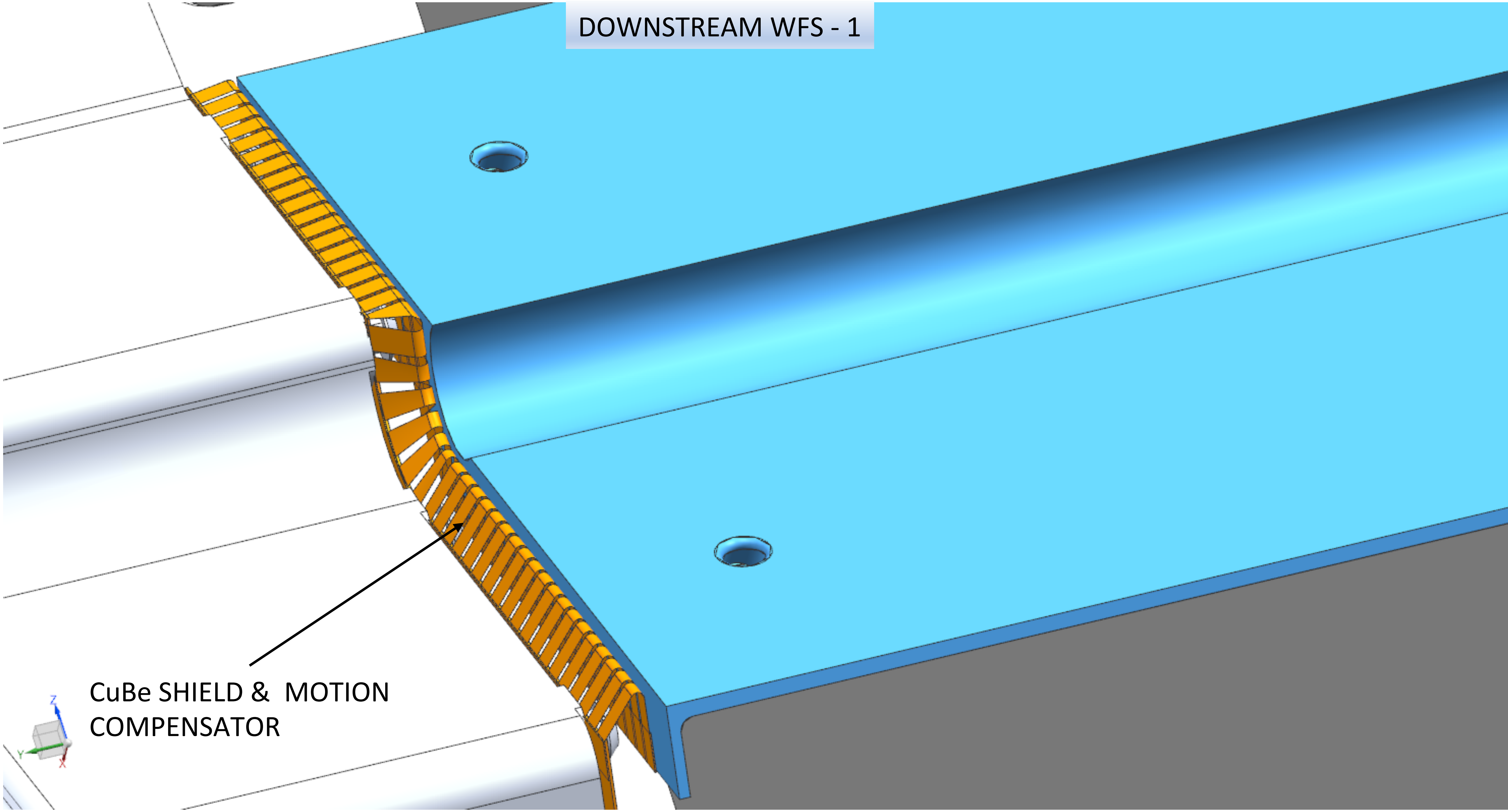


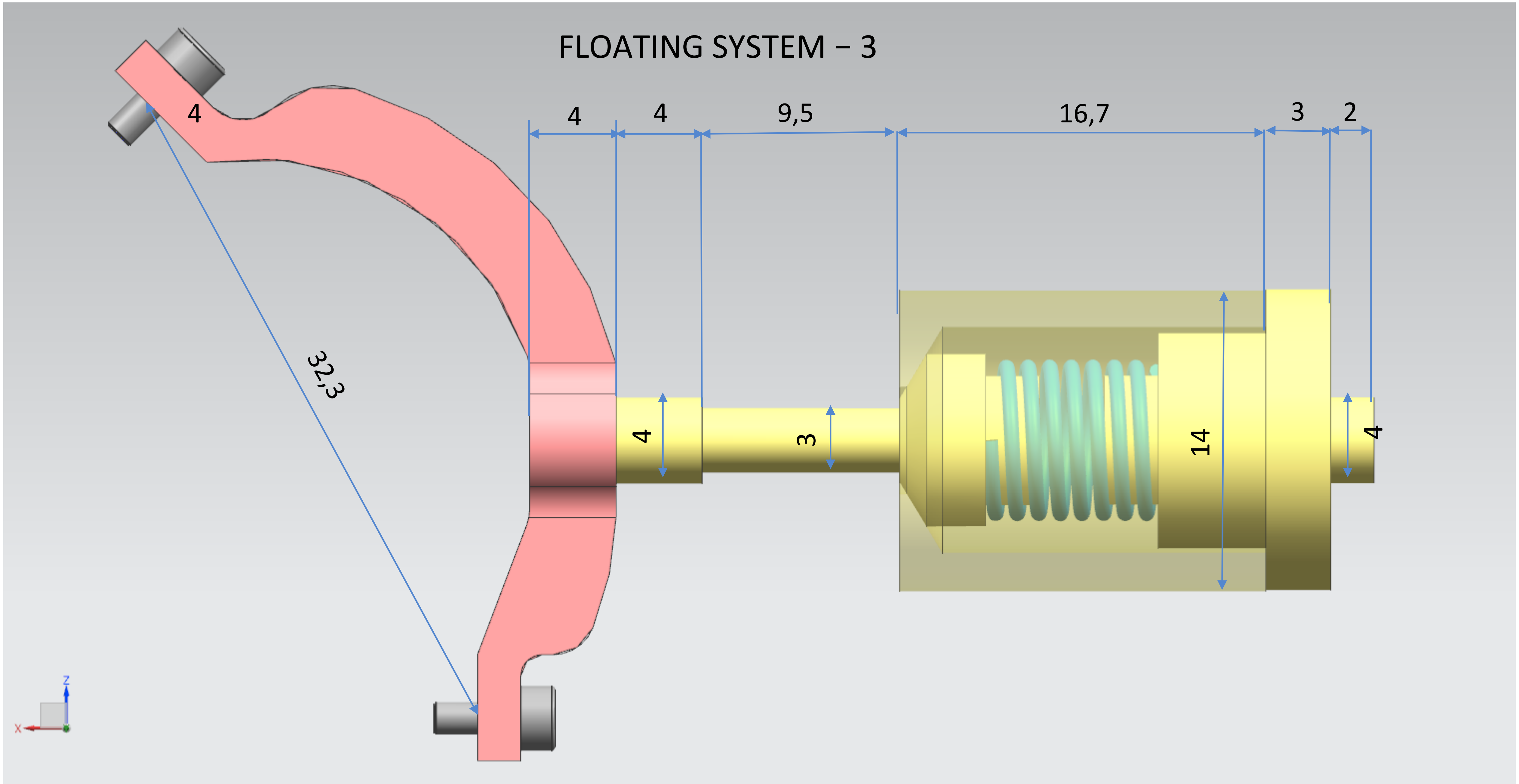
closed

old version prototype

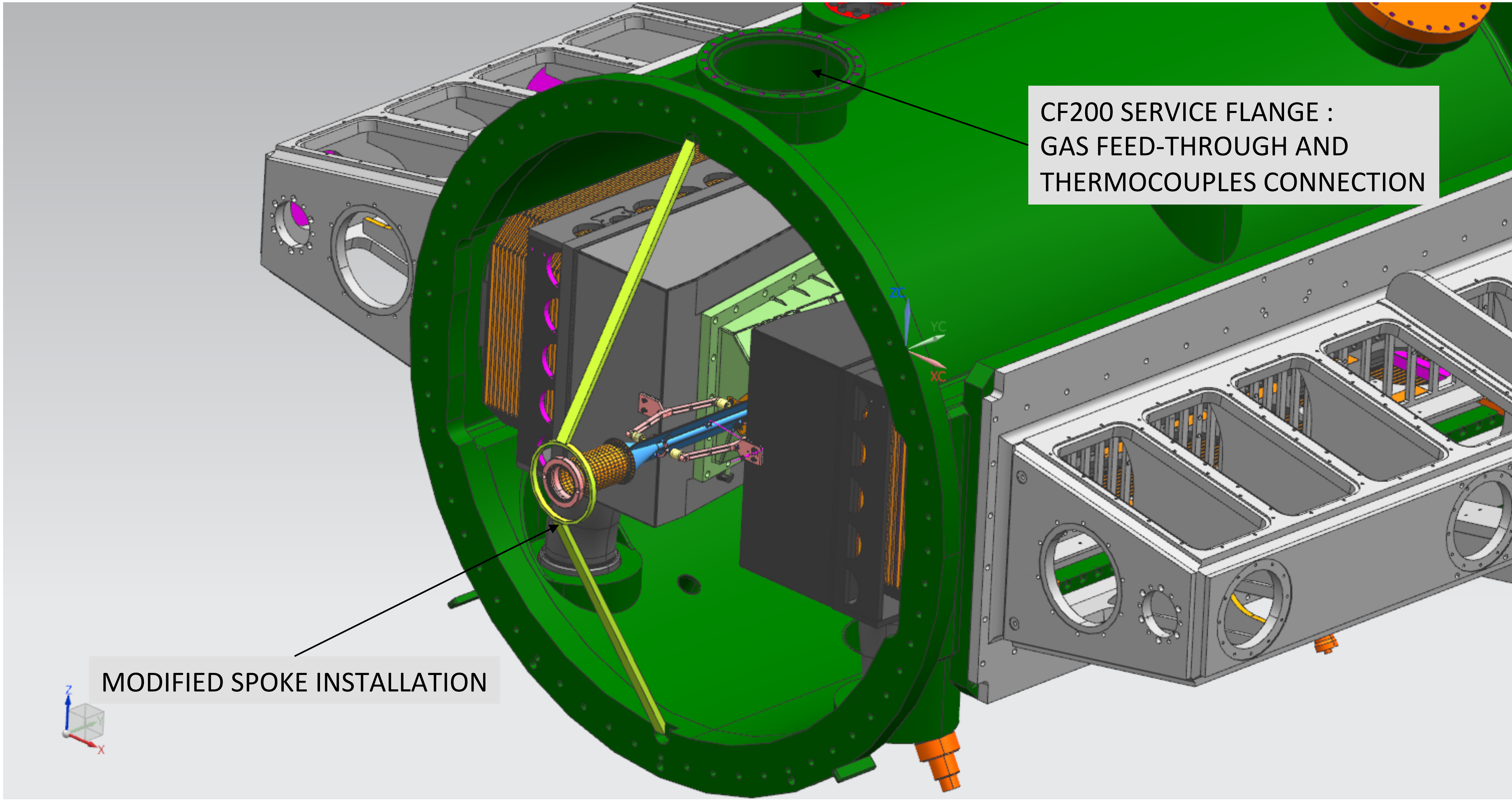


The connections on the back side of the cell uses the pins previously intended to hook the present WFS


DOWNSTREAM WFS - 1
CuBe SHIELD & MOTION
COMPENSATOR



The floating half of the cell allows to close the cell also when the VELO is not completely closed (in a range of 0.5 mm)


CF200 SERVICE FLANGE :
GAS FEED-THROUGH AND
THERMOCOUPLES CONNECTION
MODIFIED SPOKE INSTALLATION

R&D basically completed

R&D basically completed

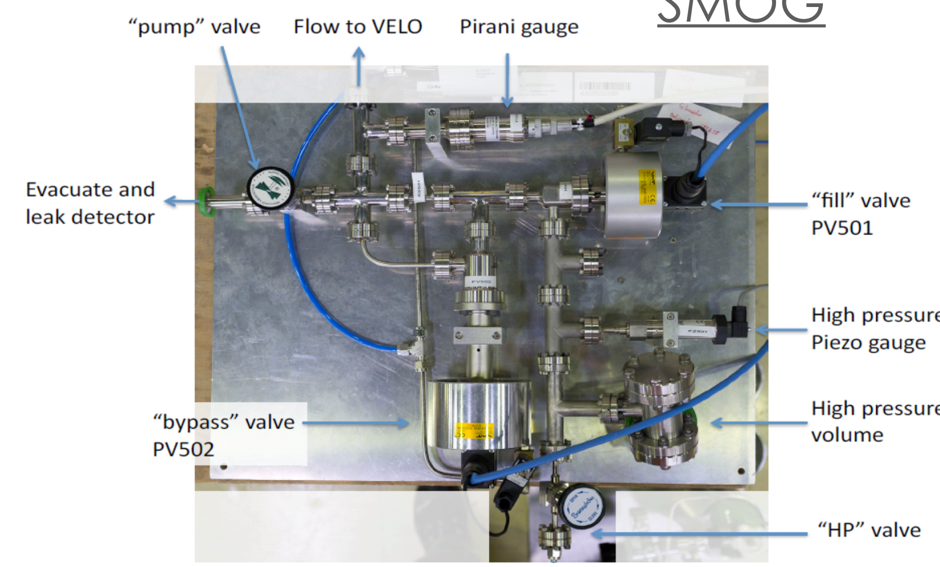
- *Interaction with LHC:*

R&D basically completed

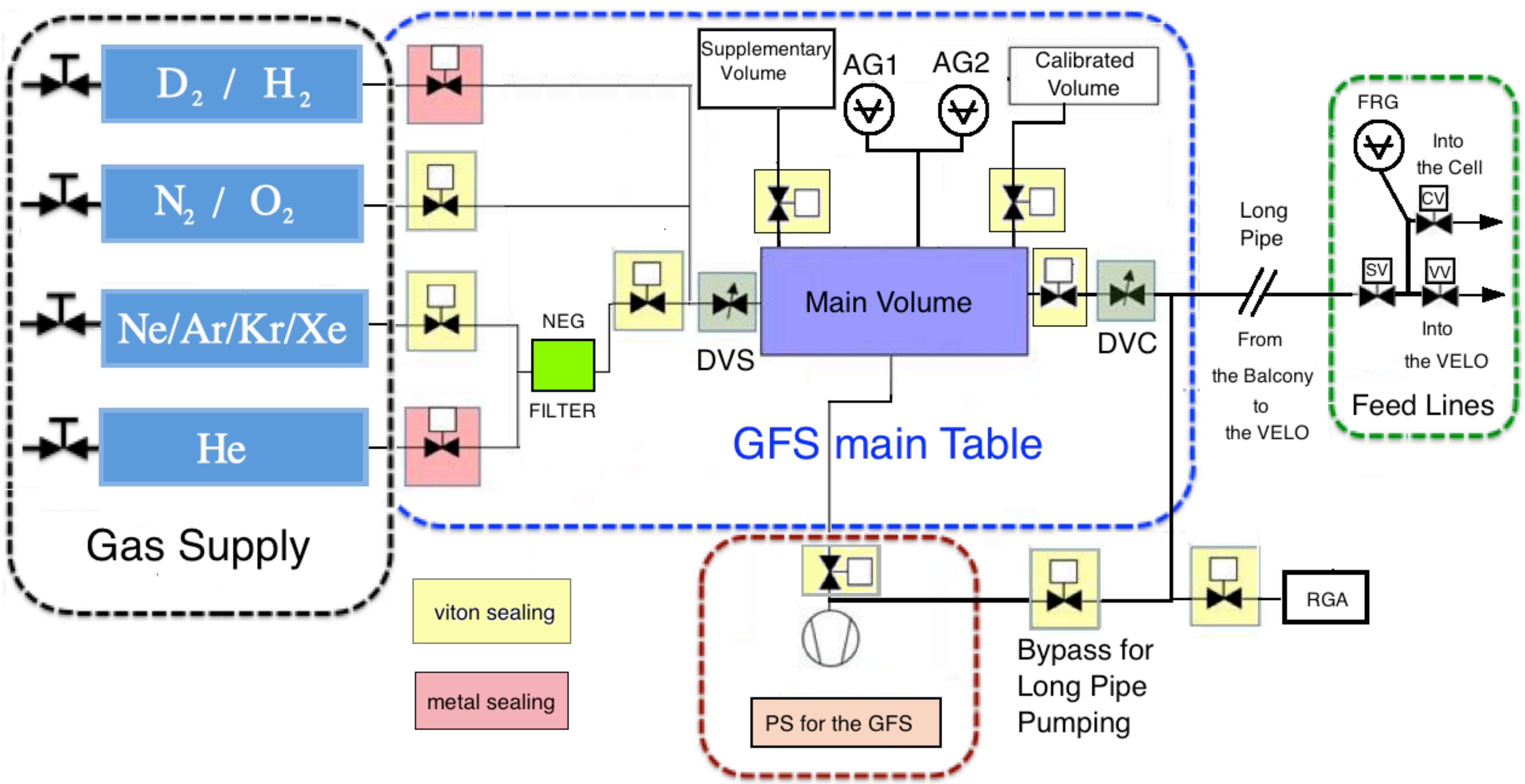
- *Interaction with LHC:*

  -vacuum

  (G. Bregliozzi, P.M. Gebolis, G. Pigny)



The new Gas Feed System to be positioned in a low-radiation area, as close to the IP as possible.



A precise measurement of the flow rate and the temperature of the gas allows for a determination of the luminosity to a couple of %

R&D basically completed

- *Interaction with LHC:*

  -vacuum

  -impedance

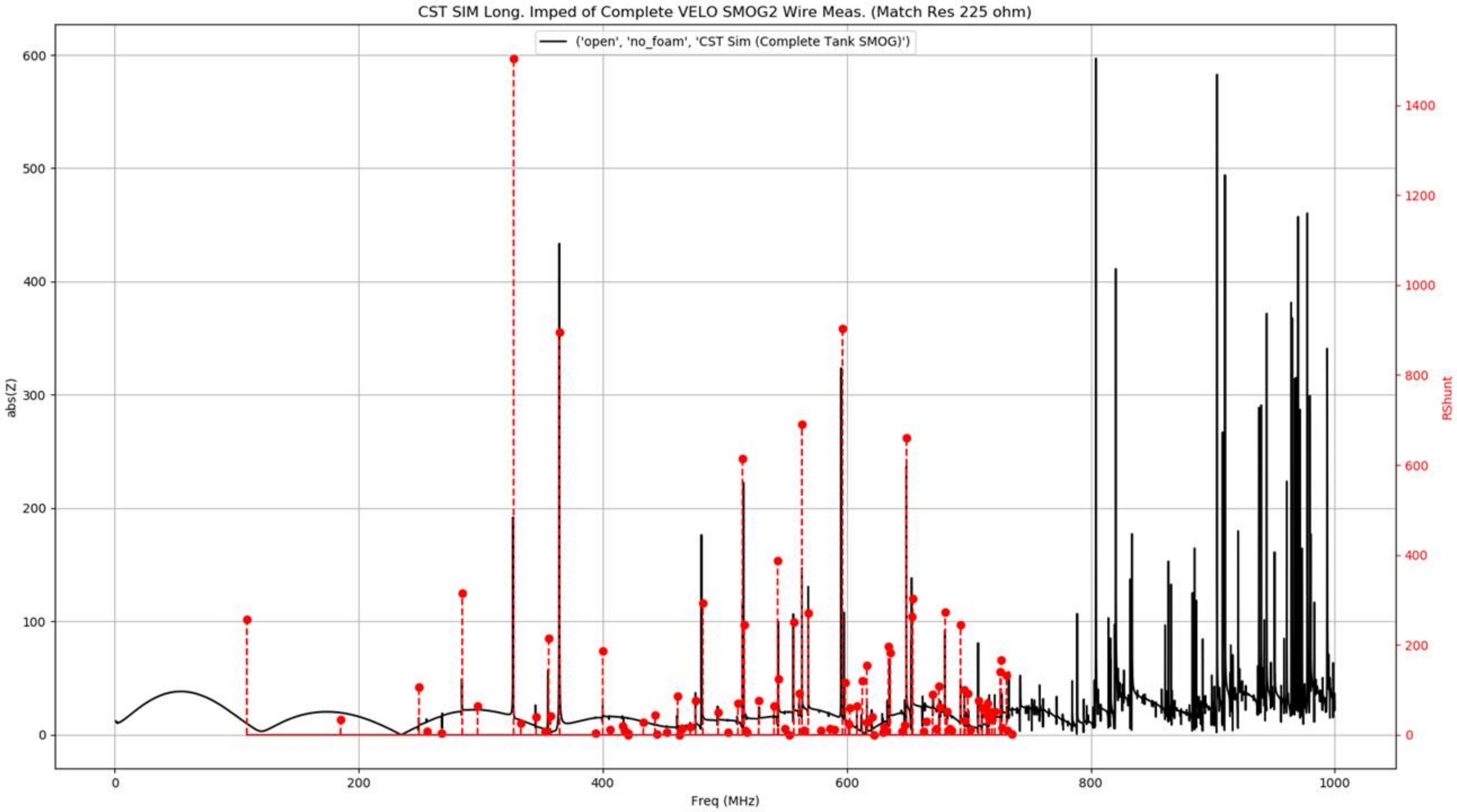
(B.K. Popovic, B. Salvant, C. Vollinger, C. Zannini)

LHC impedance group:

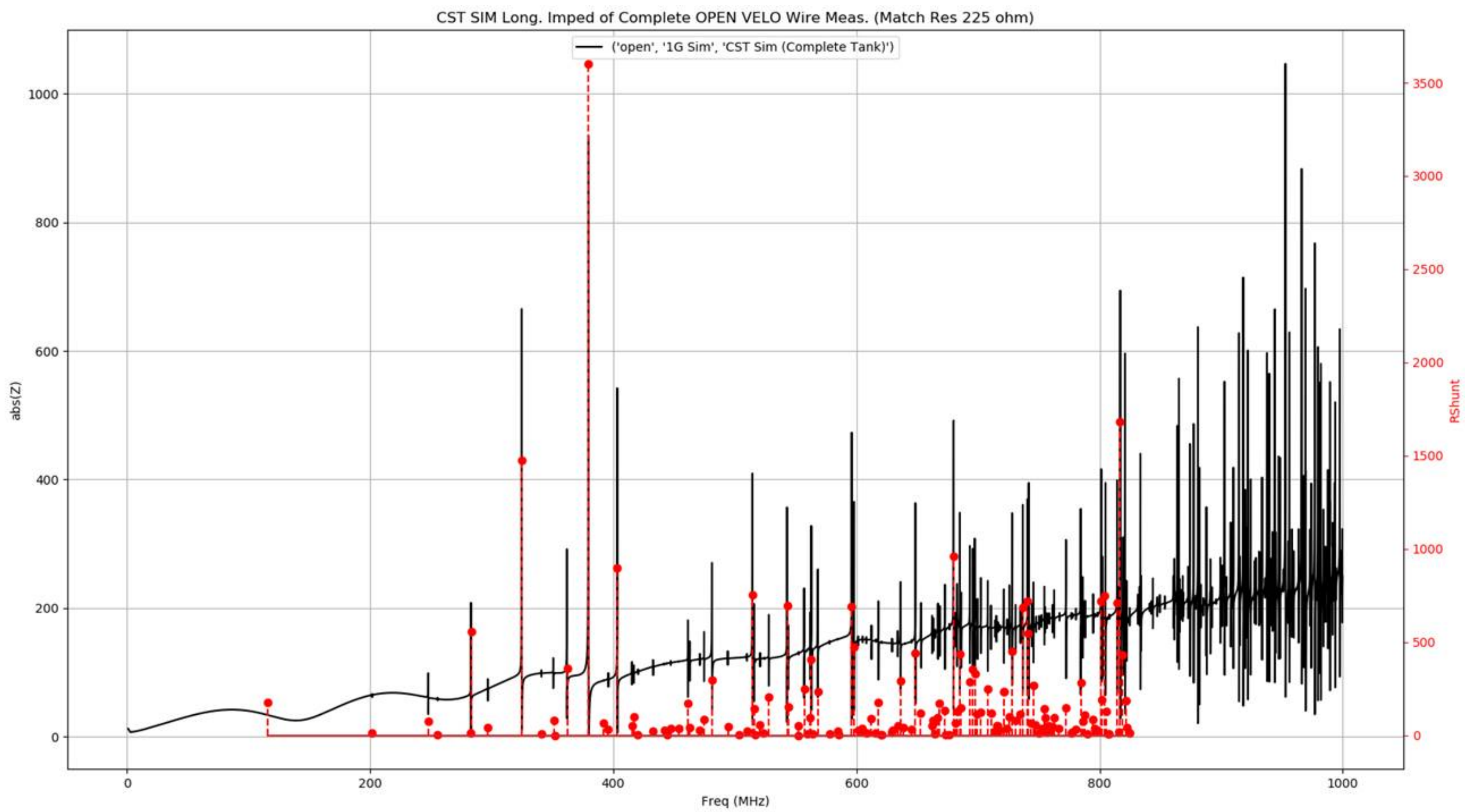
-there is no indication that the replacement of the upstream WFS by the SMOG2 system alters longitudinal and transverse resonant modes significantly in both open and closed positions

-the additional contribution to the low frequency broadband impedance due to the SMOG2 remains small compared to the VELO

-with or without the SMOG2, the expected local power loss can reach up to of the order of 1.5 kW if the worst mode (~380 MHz, Rs ~ 1.5 kOhm) is hit by one the main spectral lines of the HL-LHC beam (2748 bunches with $2.2 \cdot 10^{11}$ p/b). It should be noted that hitting that single line is a possible but statistically unlikely scenario. However hitting one of the large number of modes above this frequency is much more likely, and would yield a power loss of the order of 350 W. The mechanical design of the SMOG2, as for the rest of the VELO, should therefore account for that possibility, and temperature monitoring is recommended.



CST Sim. Long. Impedance (black) **with SMOG2**, VELO and downstream WFS OPEN (red: eigenmode simulation)



CST Sim. Long. Impedance (black) **with two WFS**, VELO OPEN (red: eigenmode simulation)

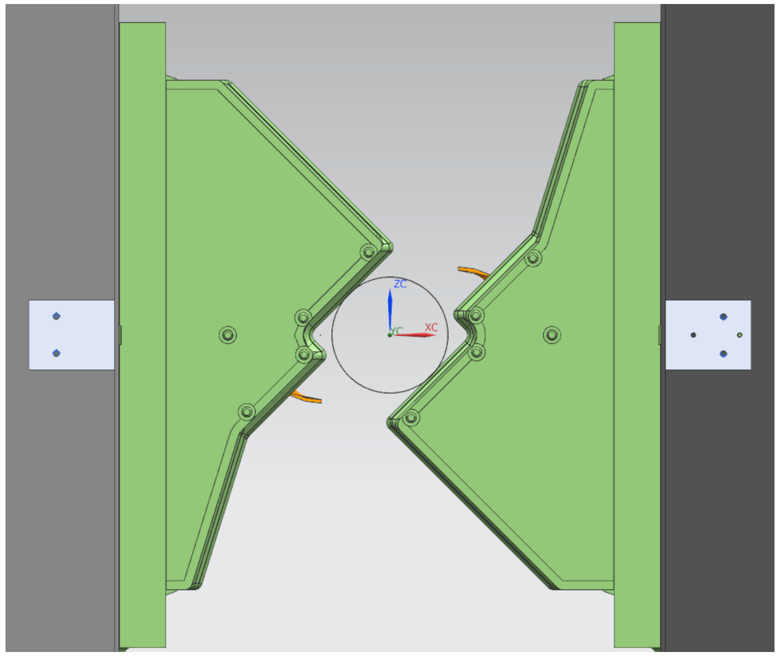
R&D basically completed

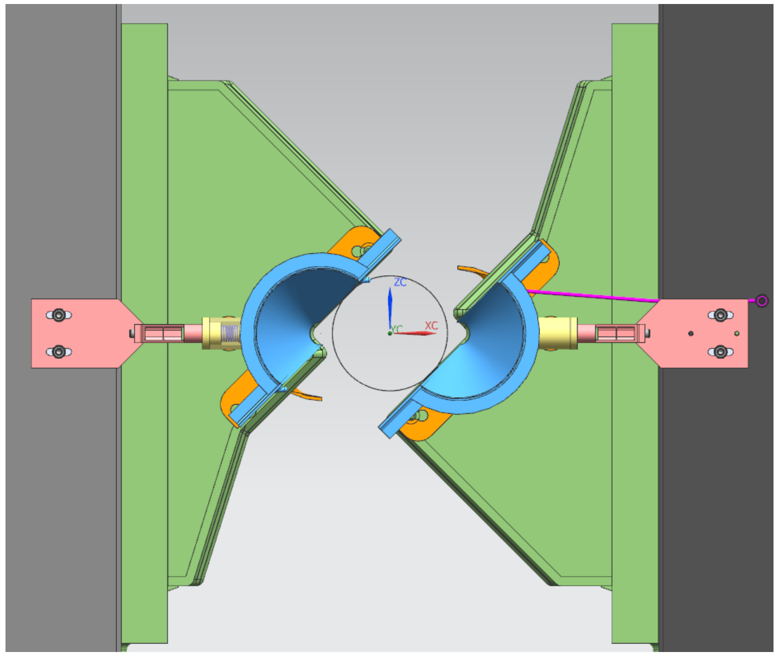
- *Interaction with LHC:*

  -vacuum
  -impedance
  -aperture

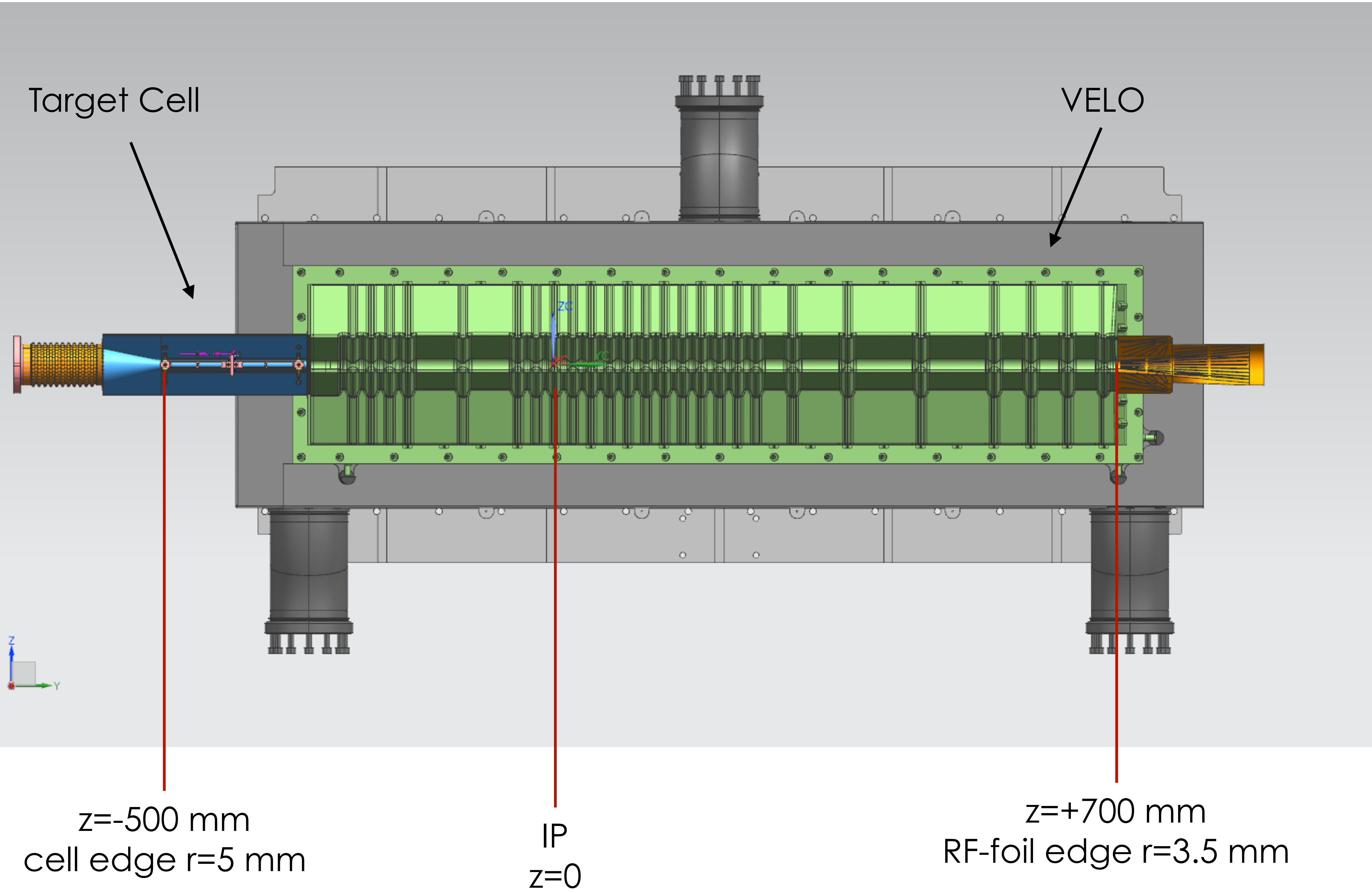
$$r(z) = r_0[1 + (z/\beta^*)^2]$$

By naive approach, the resulting aperture at the upstream end of the target cell (z = –500 mm) is r = 3.19 mm for ß*=1.5 m, so the proposed cell radius of r = 5.00 mm is safely above the minimum aperture requirements



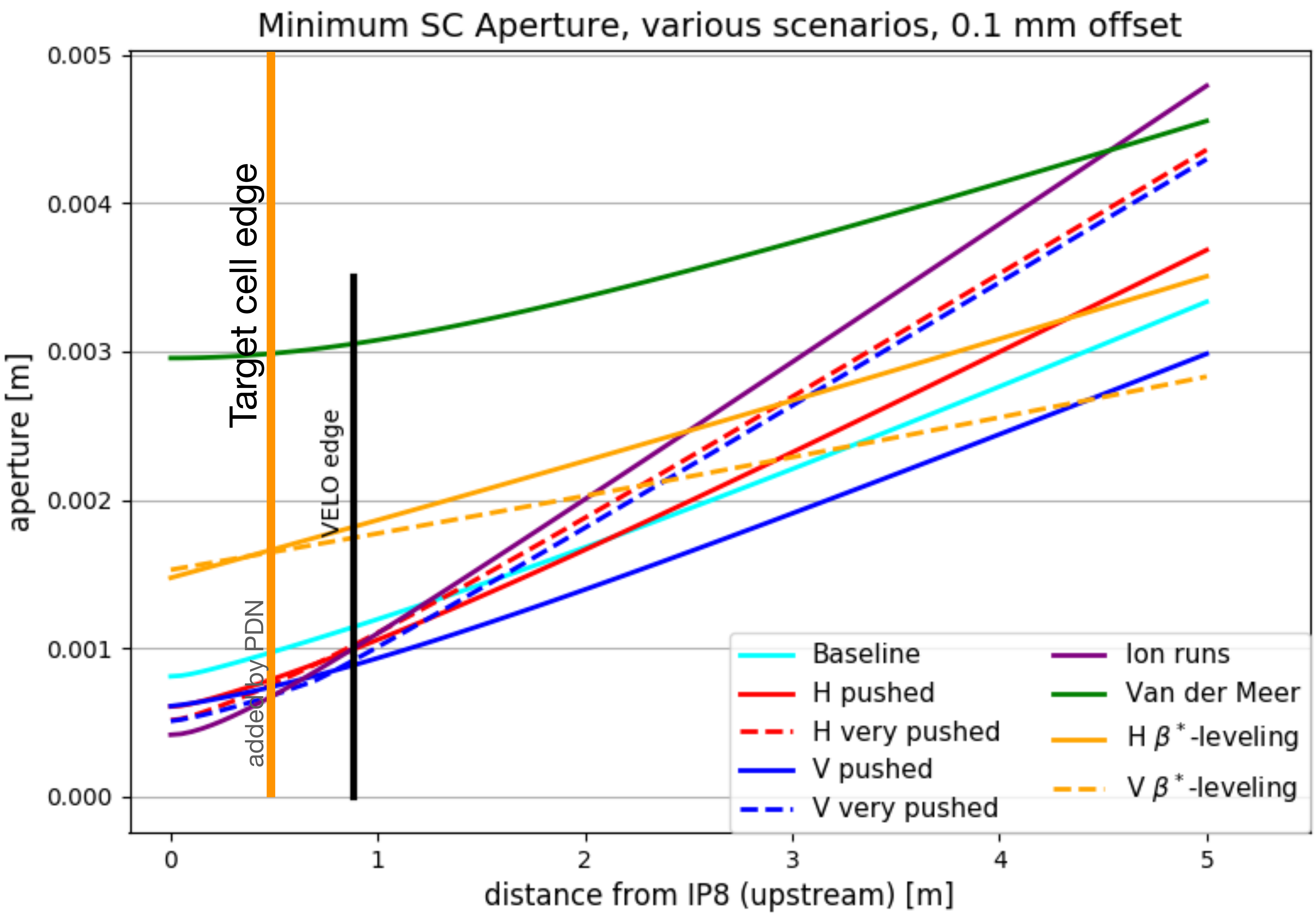


When open, the target walls are away from the beam (50 mm) and do not exceed the VELO minimum distance from the beam


Target Cell
VELO
z=-500 mm
cell edge r=5 mm
IP
z=0
z=+700 mm
RF-foil edge r=3.5 mm

(C. Boscolo Meneguolo, R. Bruce)

Minimum aperture: all scenarios



R&D basically completed

- *Interaction with LHC:*

  -vacuum
  -impedance
  -aperture
  -coating and beam stability (SEY)

  (G. Iadarola, L. Mether)

For the coating the *amorphous carbon* solution has been chosen. This has been already adopted at the SPS and at the vacuum pilot sector of the LHC

<u>LHC Beam Stability Group</u>

The integrated gas densities foreseen for SMOG2 are at least two orders of magnitude lower than in the 16L2 case (where the gas was generated by sublimation of flakes released off the pipe).

The β function at the SMOG2 location is at least one order of magnitude smaller than in the LHC arcs, thus disfavoring the occurrence of fast instabilities.

R&D basically completed

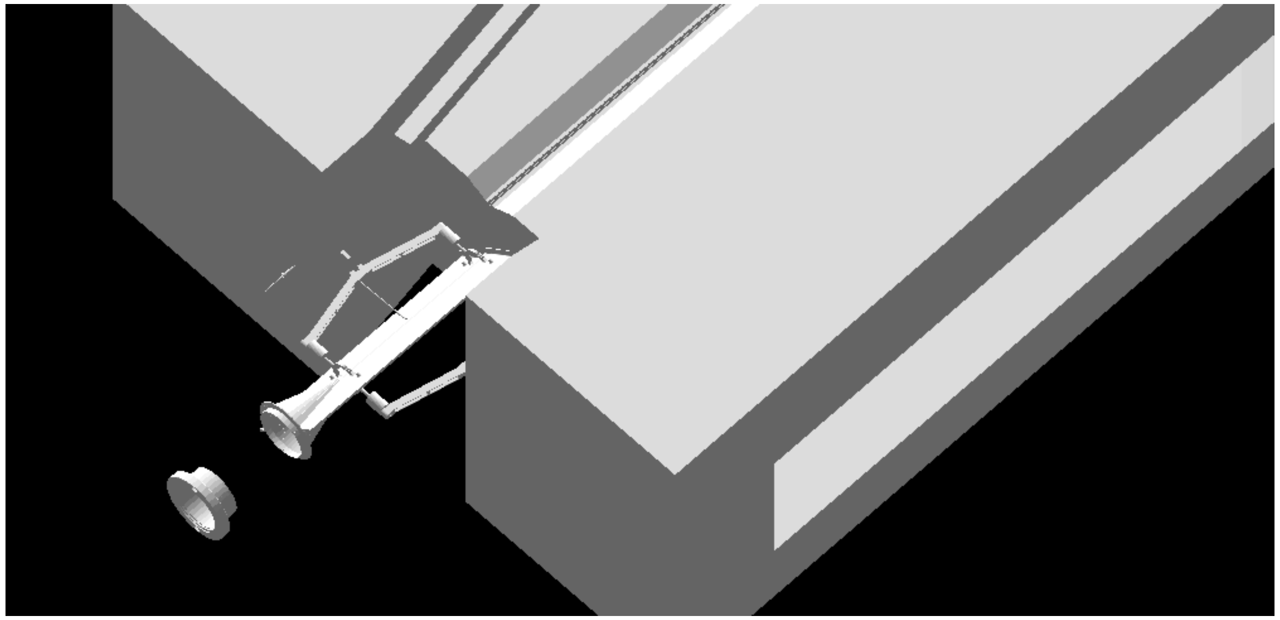
- *Interaction with LHC:*
  -vacuum
  -impedance
  -aperture
  -coating and beam stability (SEY)
- *Target prototypes and tests*
- *Induced heating and bake-out stress*
- *WFS prototypes and stress test (15.000 cycles)*

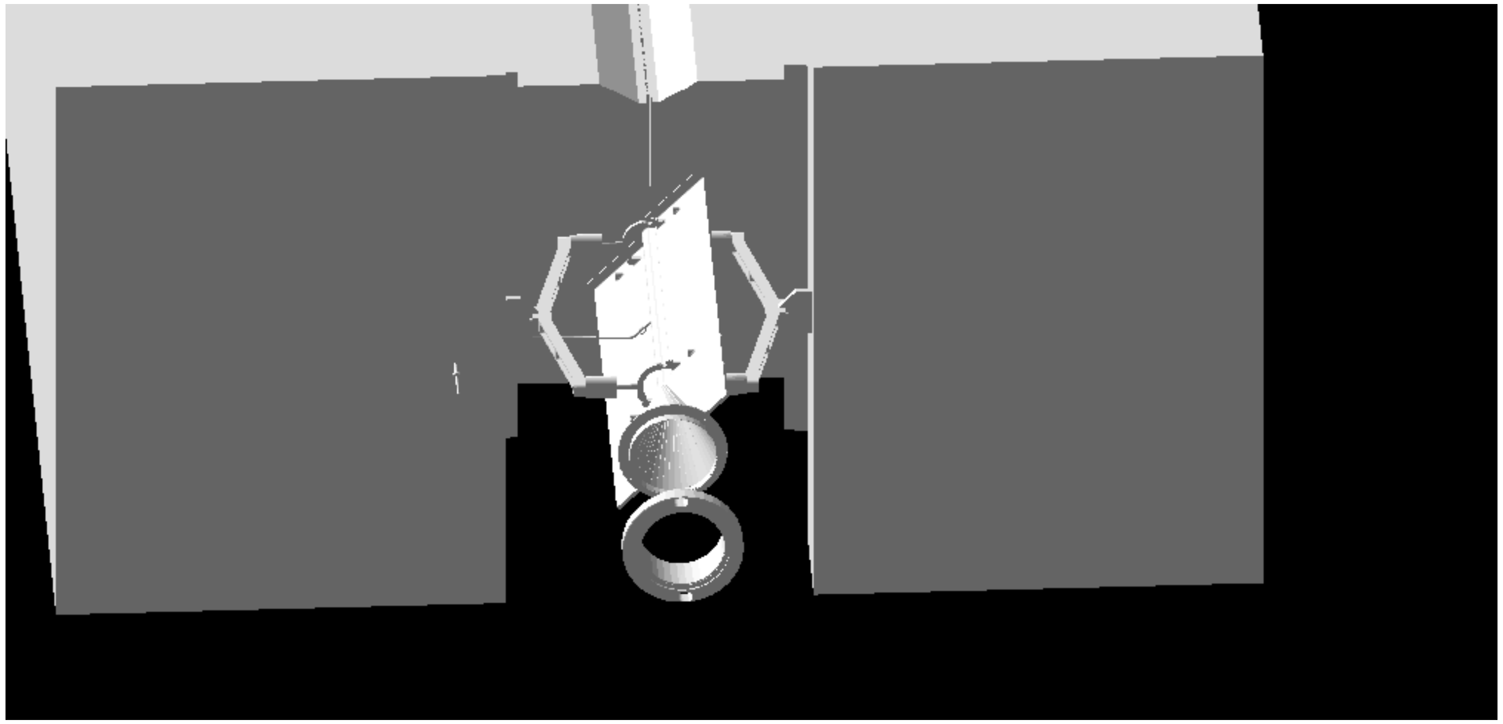
R&D basically completed

- *Interaction with LHC:*
  - *-vacuum*
  - *-impedance*
  - *-aperture*
  - *-coating and beam stability (SEY)*
- *Target prototypes and tests*
- *Induced heating and bake-out stress*
- *WFS prototypes and stress test (15.000 cycles)*
- *Material budget and Machine Background Induced on LHCb*

Implementation into GEANT4

The CAD step files have been transformed in GDML (tassellated) format:





GEANT4 visualization

Machine Induced background … in the LHCb spectrometer

The installation of the gas target in the upstream section of the LHCb spectrometer adds material budget that can, in principle, increase the background seen by the sub-detectors

This has been carefully calculated following the same, consolidated, method used at the beginning of the data taking and checking with/without target:
-pp collisions
-Beam-gas interactions in Long Straight Section (LSS) leading up to the experiment
-Interactions with the Tertiary Collimators (TCT) located upstream on both sides of the beam pipe.

	Average VELO clusters per event						
Config.	MIB-TCT (μ=0.0238)	MIB-LSS (μ=0.0019)	pp	pp + μ MIB	$\Delta^{MIB-TCT}$	$\Delta^{MIB-LSS}$	$\Delta^{pp+\mu MIB}$
no target	75	481	443	446	–	–	–
target	87	506	442	445	+16.0 %	+5.2 %	0

- This is un upper limit because the pileup has not been considered.
- Adding the SMOG2 material budget in front of the LHCb detector does not change the number of VELO clusters per event in the pp collisions.
- The MIB alone has a maximal variation of +16%.
- When the MIB is properly scaled and embedded into the pp collisions, **the effect of SMOG2 is completely negligible.**

Conclusions

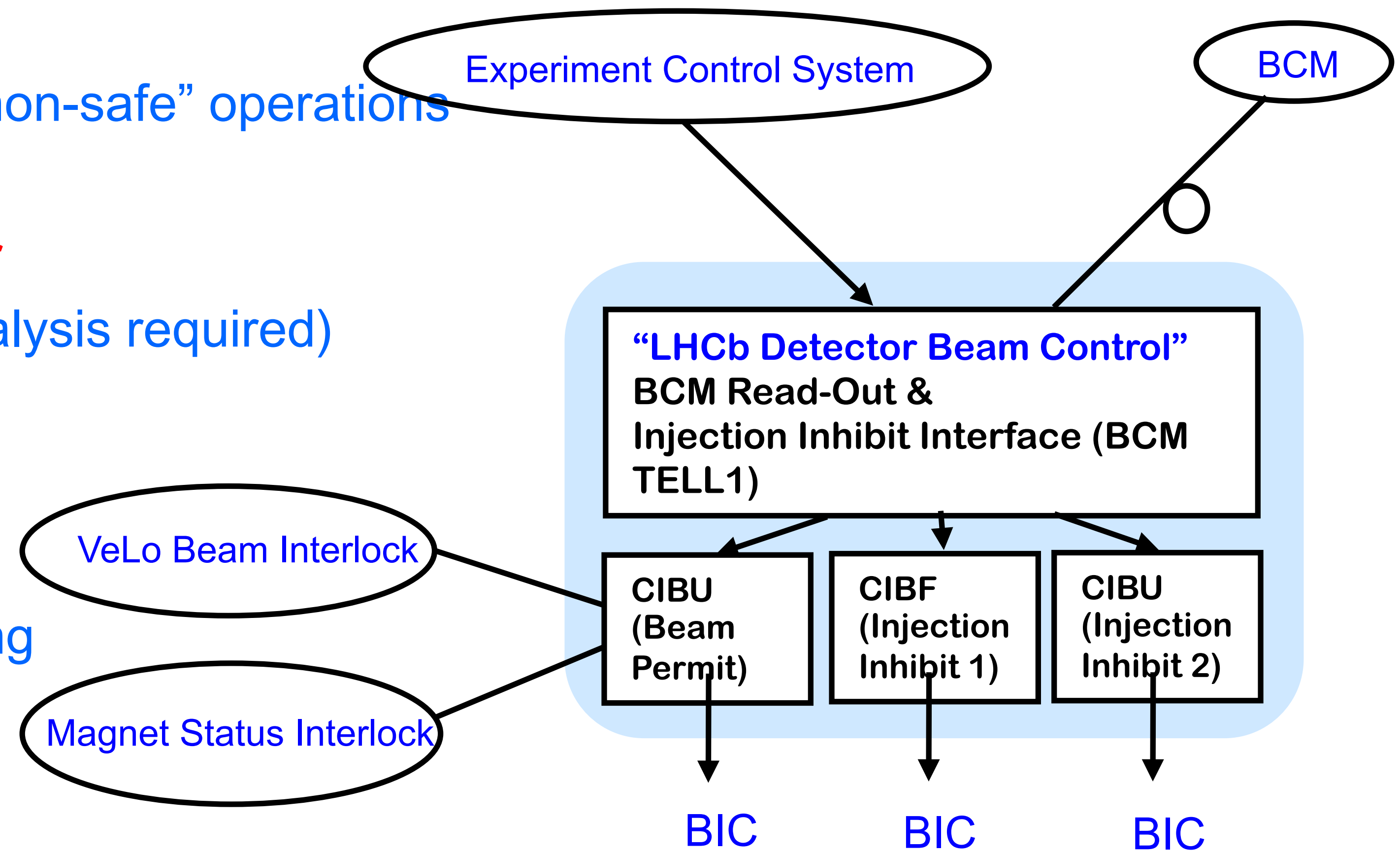
- We believe the project is mature and sound enough to go for construction
- LHCb approved the upgrade through an internal evaluation panel (FITPAN)
- We will keep a close contact and cooperation with LHC experts (impedance, vacuum, machine protection, aperture) during the SMOG2 fabrication and validation process all the way up to installation

Fixed target collisions at LHCb offer a unique opportunity for *a laboratory for QCD* and astroparticle in unexplored kinematic regions … in a short but realistic time schedule

LHCb defense & safety

Inhibit injection or dump the beam

1. Vertex Locator out of garage position in “non-safe” operations
2. LHCb spectrometer magnet NOT OK
3. Diamond-based **Beam Conditions Monitor**
   - BCM dumped the beam (human analysis required)
   - Master of Injection Inhibit



“Safe Beam Flags” for Mode dependence

→ Distributed via the General Machine Timing

→ Beam declared “safe”

Handshakes

→ between machine and experiment to allow moving from a “safe”mode to an “unsafe” machine mode (INJECTION, ADJUST during physics and controlled DUMP state)