Beam-Gas Curtain (BGC) profile monitor tests in the LHC

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HL-TCC meeting, 21st September 2017

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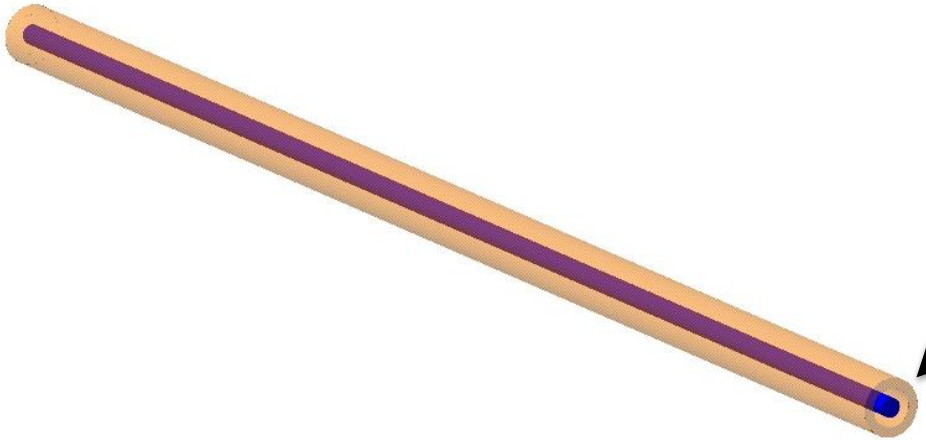
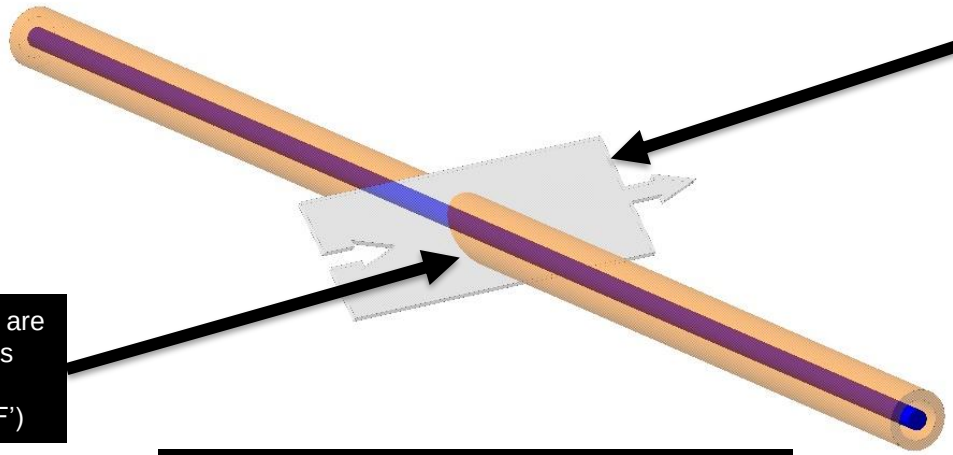
Beam-Gas Curtain: Principles



Co-axial proton (blue) and electron (orange) beams in a hollow e-lens configuration

Beam-Gas Curtain: Principles

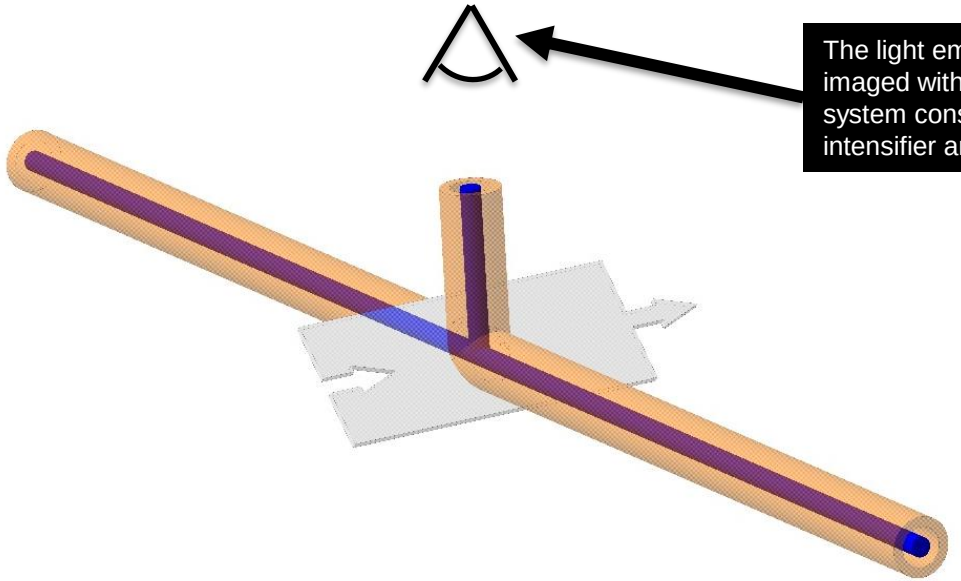


Laminar, supersonic gas ‘curtain’ traverses the beams

Gas jet atoms or molecules are excited by beam interactions and emit photons (Beam Induced Florescence or ‘BIF’)

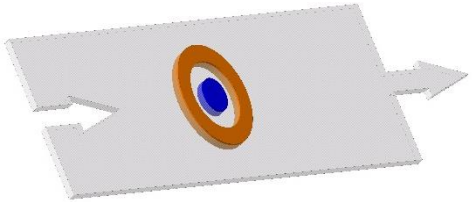
Key parameters influencing BIF are beam intensities, gas jet density and thickness, beam-gas cross section. The cross section is a function of gas species, particle type and energy. In addition, a spectral range of different florescence transitions are excited depending on gas species

Beam-Gas Curtain: Principles

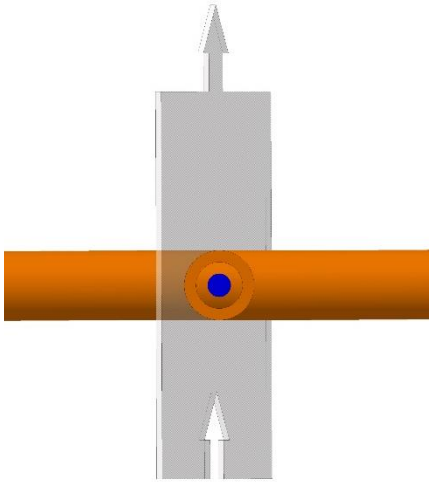


The light emitted from the BIF is imaged with an *ex-vaccua* optical system consisting of lens, image intensifier and CCD camera.

Beam-Gas Curtain: Principles



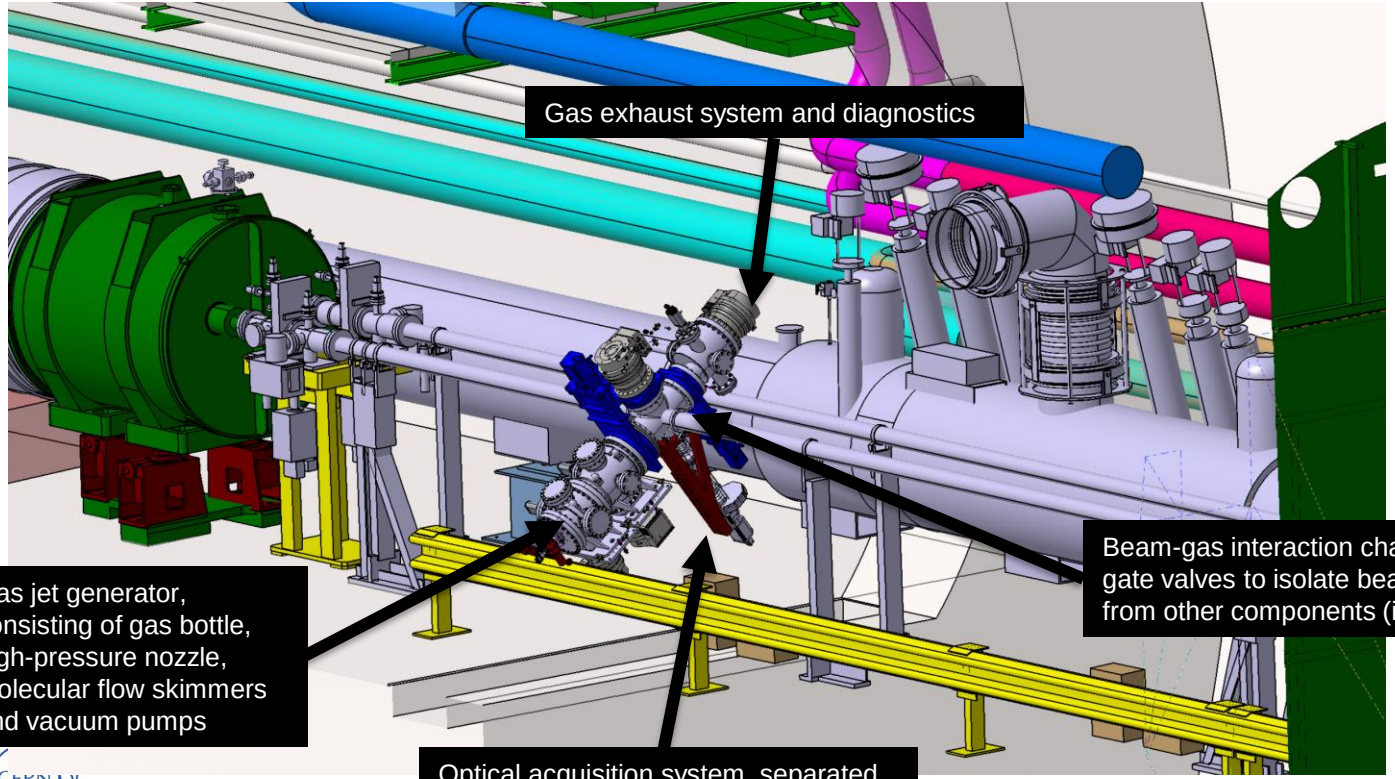
Eliptical image of two beams on the ‘virtual screen’



True 2D beam image seen by the camera when viewed at 90° to the beam axis

Beam-Gas Curtain: Instrument Components

Note: This shows an integration of a laboratory prototype (v2), NOT an instrument designed for the LHC



Beam-Gas Curtain Florescence Monitor: The potential for Hi-Lumi

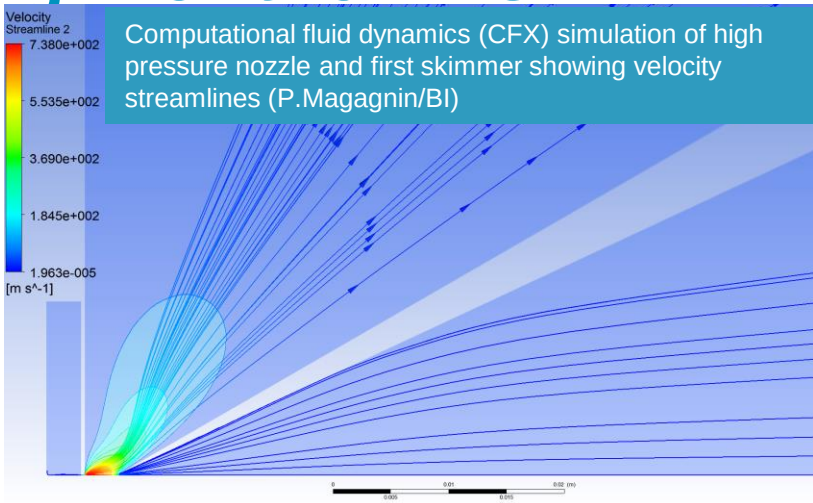
- Full 2D image in real-time* from one instrument without additional image reconstruction or calibration
  - *Limited by image integration time
- Simultaneously image multiple co-axial or parallel beams with different energies and species
- Minimally invasive instrument, insensitive to damage by high intensity beams
  - Suitable for any LHC operating scenarios
- Imaging light: Independent of local magnetic fields*
  - *to a first order, some drift of ionized particles during florescence emission, depending on gas species
- Initial motivation was to develop a profile measurement system for high-current electron beams confined in solenoids
  - An ideal on-line profile monitoring instrument for e-lens or e-BBLR systems in the LHC

The BGC Collaboration

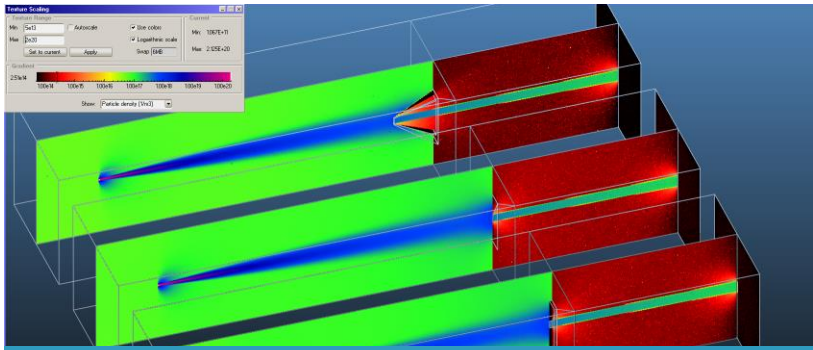
- The Cockcroft Institute (UK)
  - Experience and experimental equipment for beam-gas curtains
  - Part of the High-Lumi/UK framework collaboration (WP3-Beam diagnostics) which includes co-funding for researchers, an experimental programme and construction of 2 prototypes, including one adapted for testing in the LHC
- GSI (DE)
  - Expertise in luminescence monitoring
  - Collaboration agreement upto end 2017
- CERN
  - Instrument design, optics and integration expertise (BE-BI)
  - Molecular gas flow simulation expertise (TE-VSC)
- Wroclow University of Science and Technology (PL)
  - Expertise in computational fluid dynamics simulations for supersonic gas jets
  - Collaboration under discussion

Optimisation of the design for the LHC

- Gas jet simulations require two specialist analysis codes
  - The gas is supplied at 10 bar through a 30 μm nozzle
  - The flow is then progressively ‘skimmed’ to select molecules with the required trajectory
- Gaining predictive power to produce a design optimized for the LHC
  - Maximise the gas density in the curtain at the interaction
  - Minimise the mass flow into the vacuum system



Computational fluid dynamics (CFX) simulation of high pressure nozzle and first skimmer showing velocity streamlines (P.Magagnin/BI)

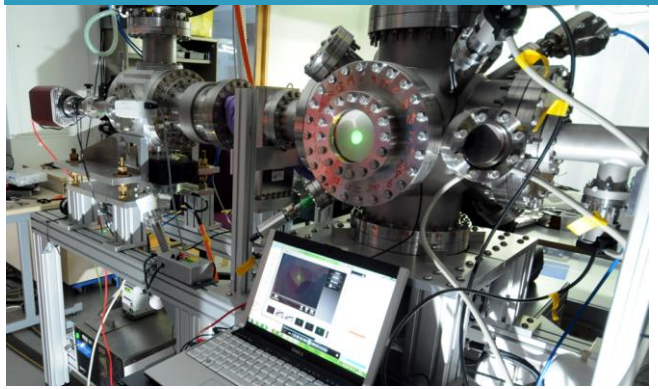


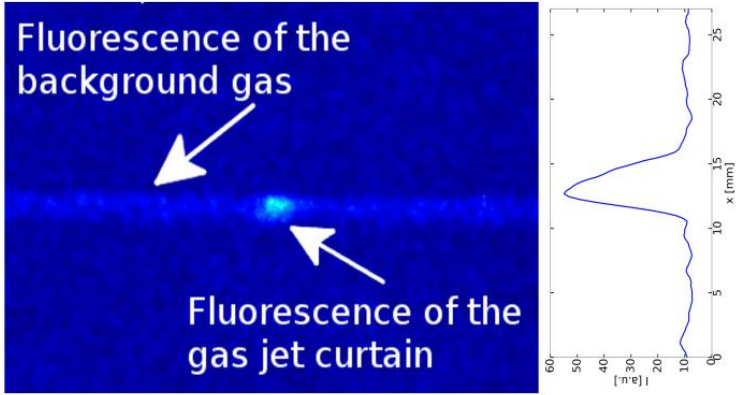
Molecular flow (MOFLOW) simulation through second and third skimmers showing gas density in interaction chamber (M.Ady/VSC)

Experimental System and Results

- 2017: Demonstration of beam-induced florescence with a N_2 gas jet
  - 10 uA / 5 keV electron beam
  - Integration times are long due to low e-beam intensity (>1000 s)
    - Estimated ~2.5×10^5 photons/s for a 5 A electron beam and expected gas curtain
- Now in progress:
  - Integration of a new electron gun reaching upto 300 uA / 10 keV
  - Tests with a Ne gas jet with a new, optimized optical system
  - Production of second gas jet prototype (Version 2)

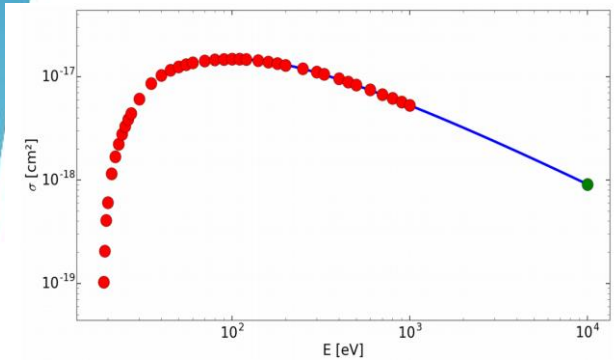
Experimental beam-gas curtain florescence momitor at the Cockcroft Institute



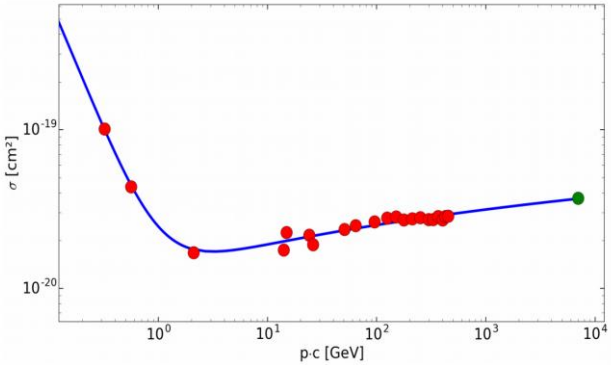


Florescence cross-sections

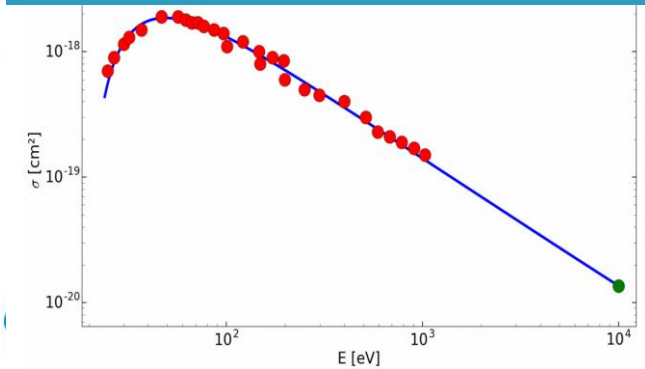
Electron excitation florescence cross-section for a specific N2 transition, extrapolated to 10 keV (green dot)



Proton excitation florescence cross-section for a specific N2 transition, extrapolated to 7 TeV (green dot)



Electron excitation florescence cross-section for a specific Ne transition, extrapolated to 10 keV (green dot)



- Currently evaluating N2 and Ne for jet gas
- Ne has advantages for LHC
  - Observed transition is neutral excitation (not ionization), so no beam charge movement effects
  - Shorter excitation decay time (~15 ns), so improved spatial resolution
  - Not pumped by NEG coatings, so preferred by vacuum
- Data for proton cross-sections only available upto 450 GeV (SPS) for N2 and 1 MeV for Ne

Data courtesy S.Udrea/GSI

Key next steps in the project

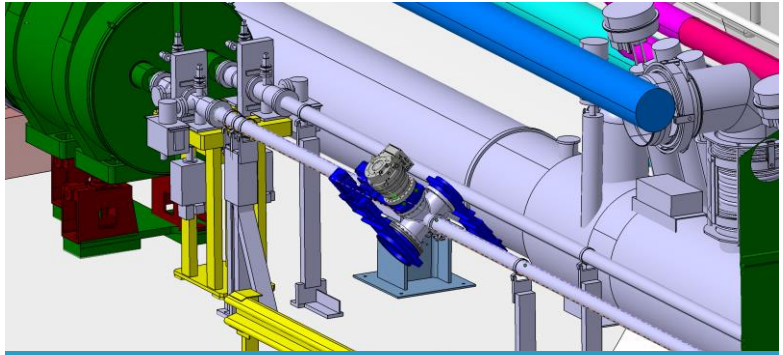
- Which gas do we use for the curtain, N_2, Ne, (Ar?)
  - Need experimental data for florescence cross-sections to validate the integration time for the measurement:
    - 10 keV electrons – some data should come from the new electron gun, then from a future e-beam test stand
    - 7 TeV protons – can only come from the LHC
  - Instrument resolution limitations due to:
    - Movement of ionized gas in magnetic fields
    - Movement of ionized gas due to space charge effects
    - Inhomogeneity of gas curtain

LHC experimental programme proposal

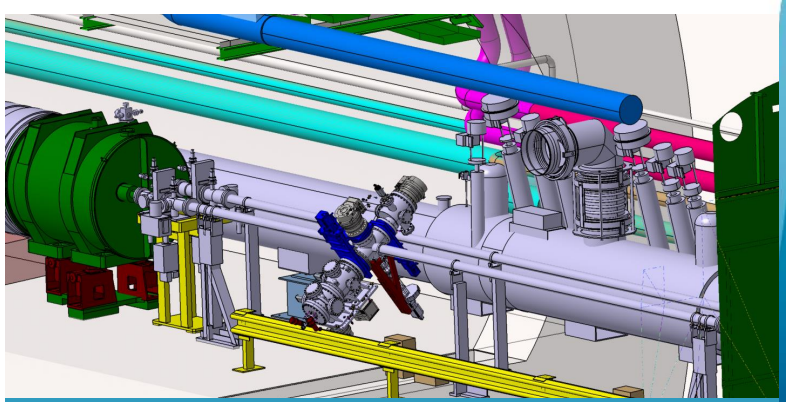
- Preliminary measurements of florescence
  - Make an installation in YETS 17-18
  - Use existing gas injection infrastructure and cabling from the BGI in LSS4
    - Pending LMC decision to confirm BGI removal during this YETS
  - Add a camera to make preliminary measurements of beam-gas florescence with high energy protons
  - Data will be limited by the low ‘background gas’ density available
  - ECR in progress, discussions well advanced with VSC, impedance calculations in progress
- Measurements with the BGC prototype in the LHC
  - Prepare the new sector for the e-lens during LS2
  - Install the LHC BGC prototype (already a deliverable in the current High-Lumi/UK beam diagnostics collaboration)
  - Validate simulations for:
    - Florescence cross-sections for protons at 7 TeV – measure the integration time for a p^+ beam profile
    - Gas dispersion due to beam-gas electro-magnetic effects
    - Optical resolution limits due to gas curtain geometry in the LHC proton beam
  - Gain operational experience before operations with an e-lens system

Phased installation during LS2 in the LHC

- Phased installation:
  - Maintains the LHC in full operating condition after each phase
  - Used successfully for the BGV installation during LS1
- Phase I:
  - Install the new vacuum sector valves and instruments, pull cables
- Phase II
  - Add the new BGC interaction vacuum chamber with valves on the gas jet and exhaust ports and viewport for the optics
- Phase III
  - Add the main BGC elements (gas jet, exhaust, optical system)

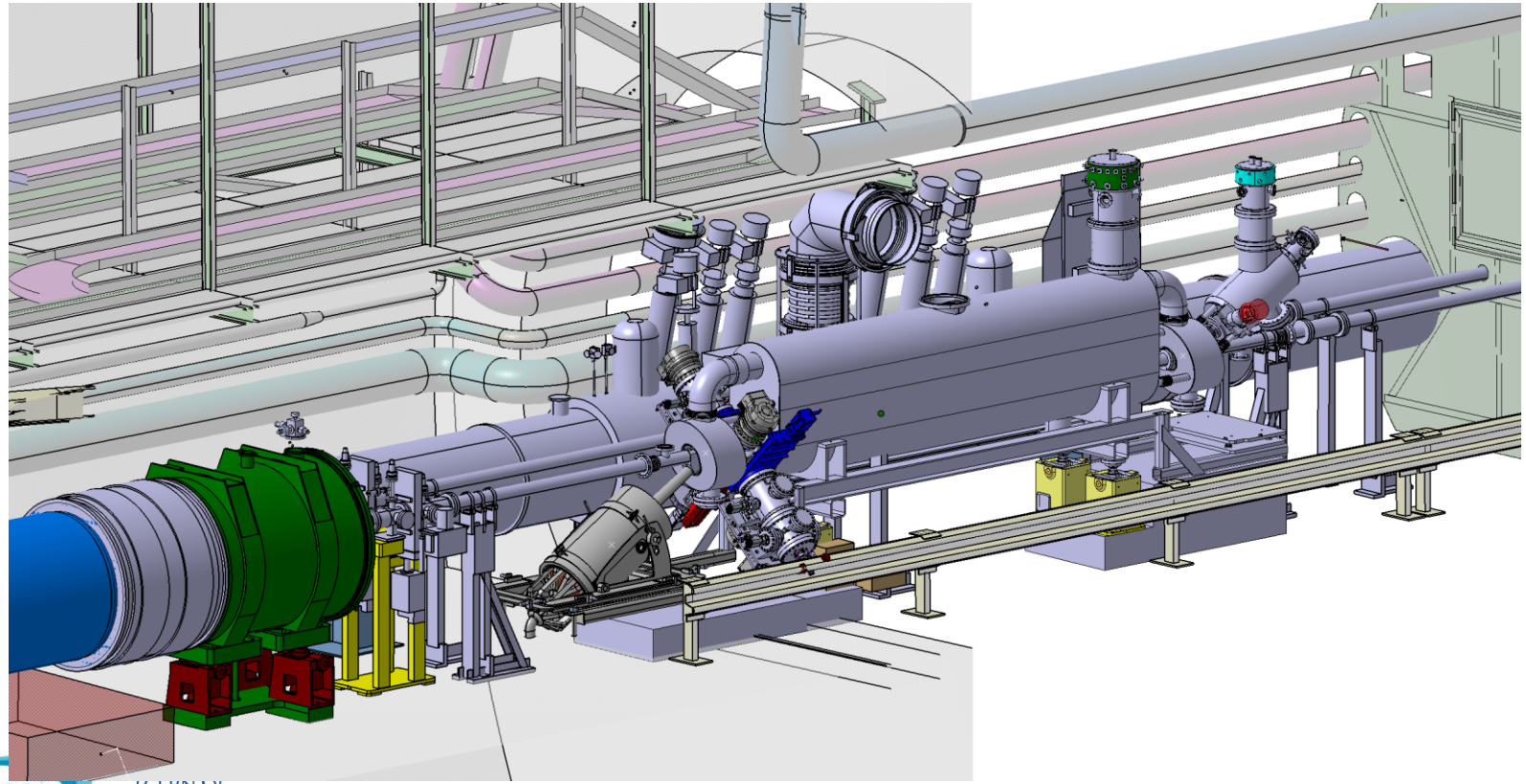


LHC sector after Phase 2 of the installation



LHC sector after Phase 3 of the installation

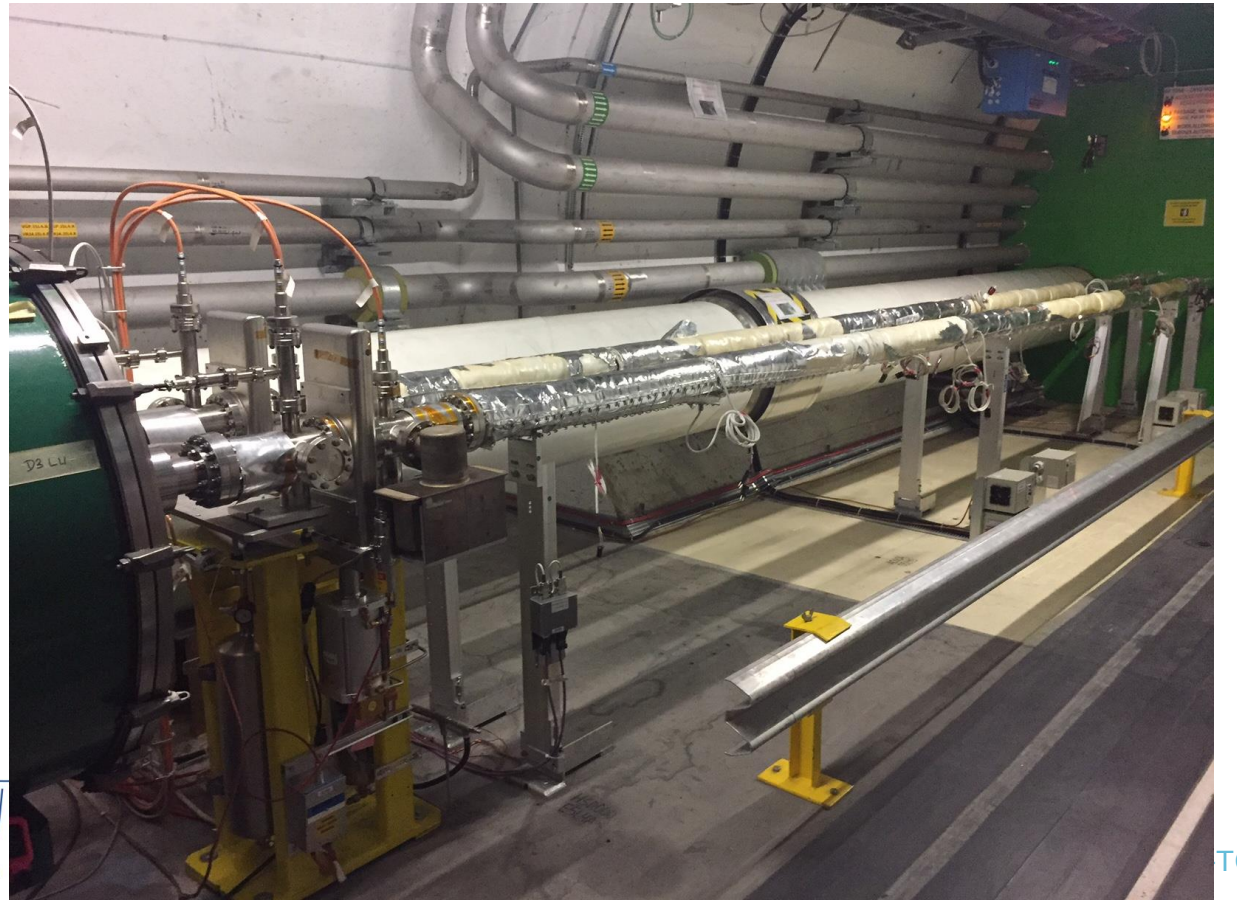
BGC (laboratory, version 2) integrated in LSS4 with a candidate e-lens solenoid



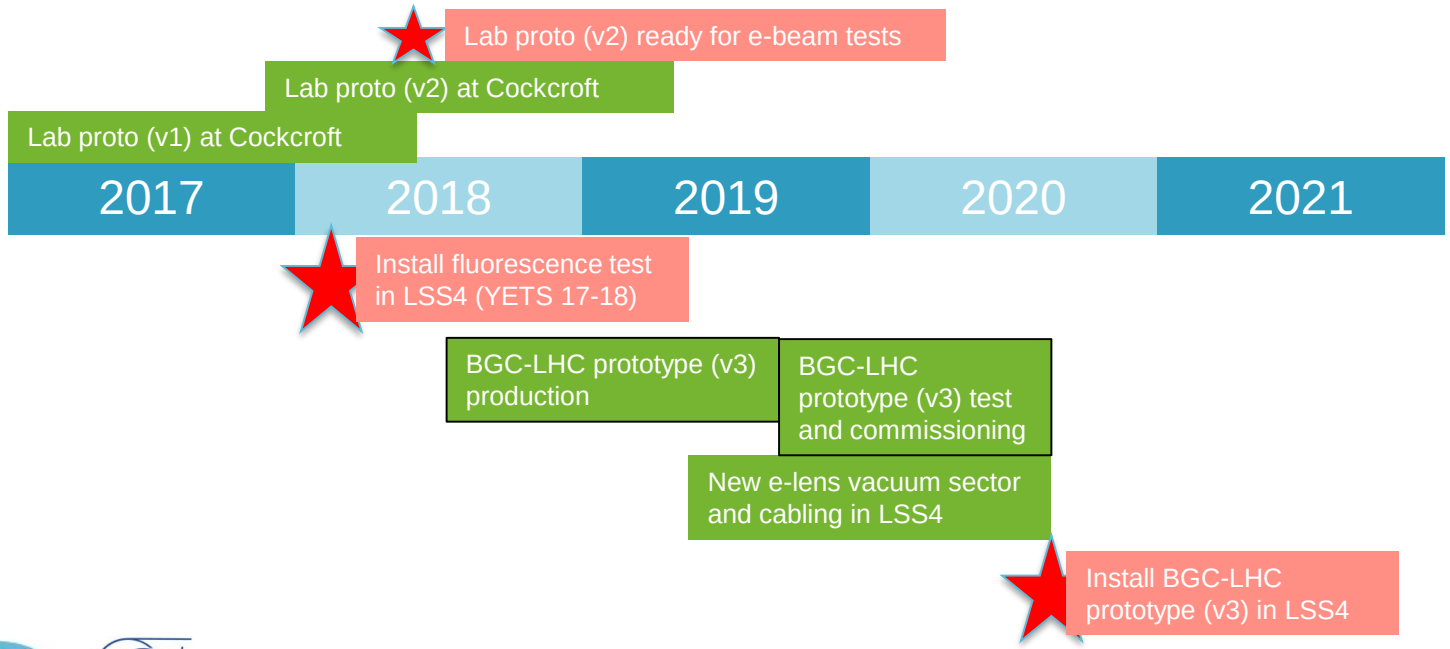
HiLumi HL-LHC PROJECT

CERN

LSS4 Sector as of yesterday



Global schedule



Summary

- A new profile measurement instrument is under development for High-Lumi
  - Ideally suited for on-line e^-/p^+ measurements in the hollow e-lens or e-BBLR
  - Active international collaboration with a High-Lumi funded deliverable for an LHC-compatible prototype in 2019
- Optimisation of a final instrument for High-Lumi will require experimental data and experience with 7 TeV protons
  - Florescence cross-section for p^+ at 7 TeV
  - Resolution limits with gas jet in the p^+ field
- An experimental programme is planned at the Cockcroft Institute, on a future e-beam test stand and in the LHC
  - Prototypes v1, v2, v3 tested at Cockcroft
  - Prototype v2, (v3) on an e-beam test stand
  - Prototype v3 installed in the LSS4 of the LHC during LS2, with a preliminary florescence measurement in YETS 17-18
- We request endorsement for the test programme in the LHC machine by the HL-TCC

Thanks for your attention

Thanks to the BGC collaboration:
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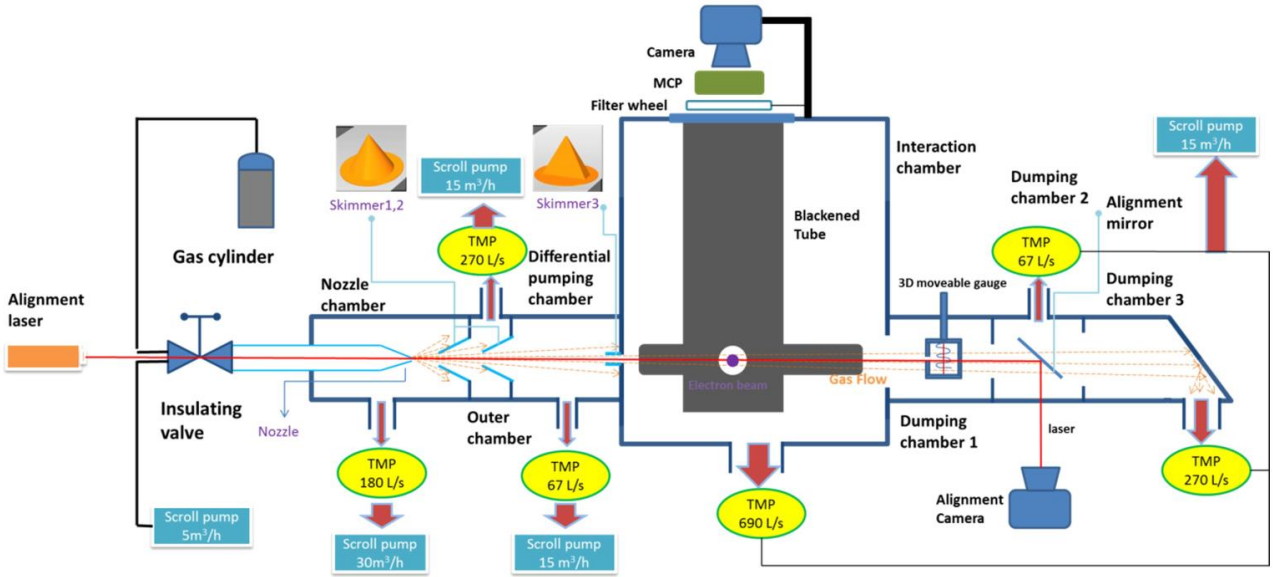
Camera
MCP
Filter wheel
Interaction chamber
Scroll pump 15 m³/h
Dumping chamber 2
Alignment mirror
Skimmer1,2
Scroll pump 15 m³/h
Skimmer3
Blackened Tube
TMP 67 L/s
Gas cylinder
TMP 270 L/s
Differential pumping chamber
3D moveable gauge
Dumping chamber 3
Nozzle chamber
Alignment laser
Electron beam
Gas Flow
Insulating valve
Nozzle
Outer chamber
Dumping chamber 1
laser
TMP 180 L/s
TMP 67 L/s
TMP 690 L/s
TMP 270 L/s
Alignment Camera
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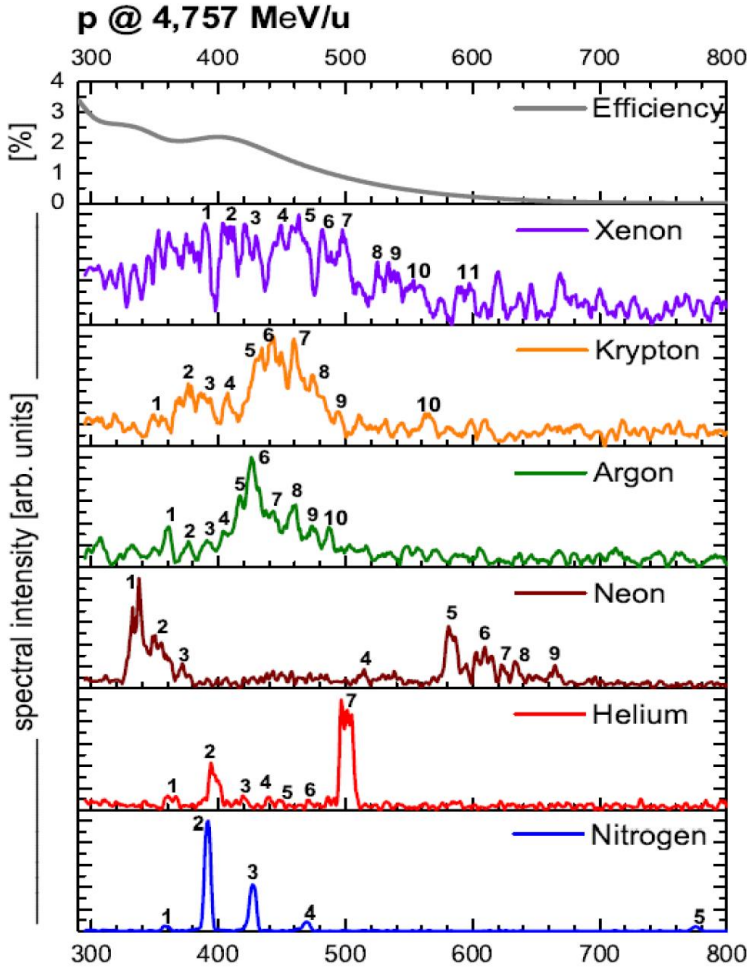
Scroll pump 30m³/h
Scroll pump 15 m³/h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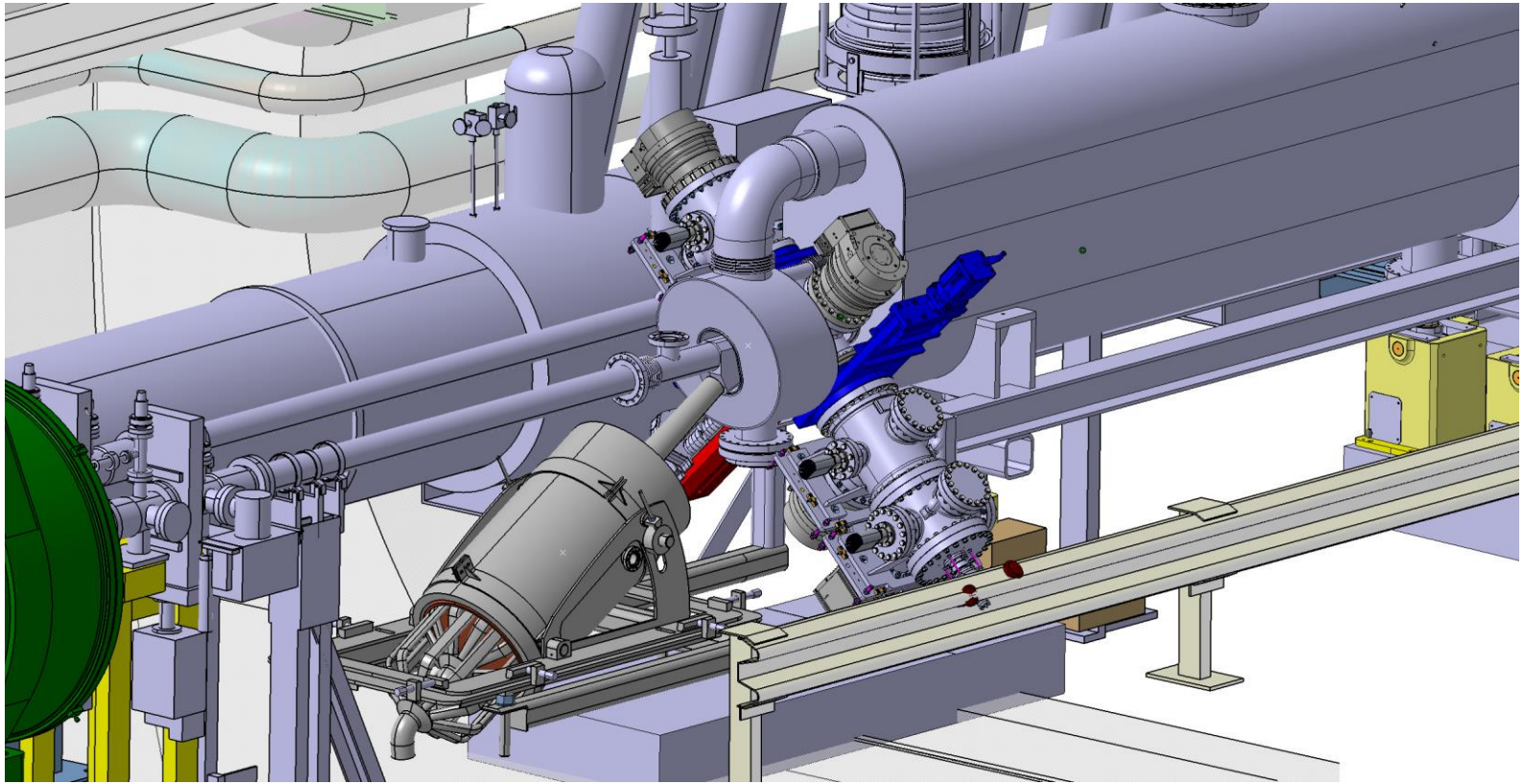

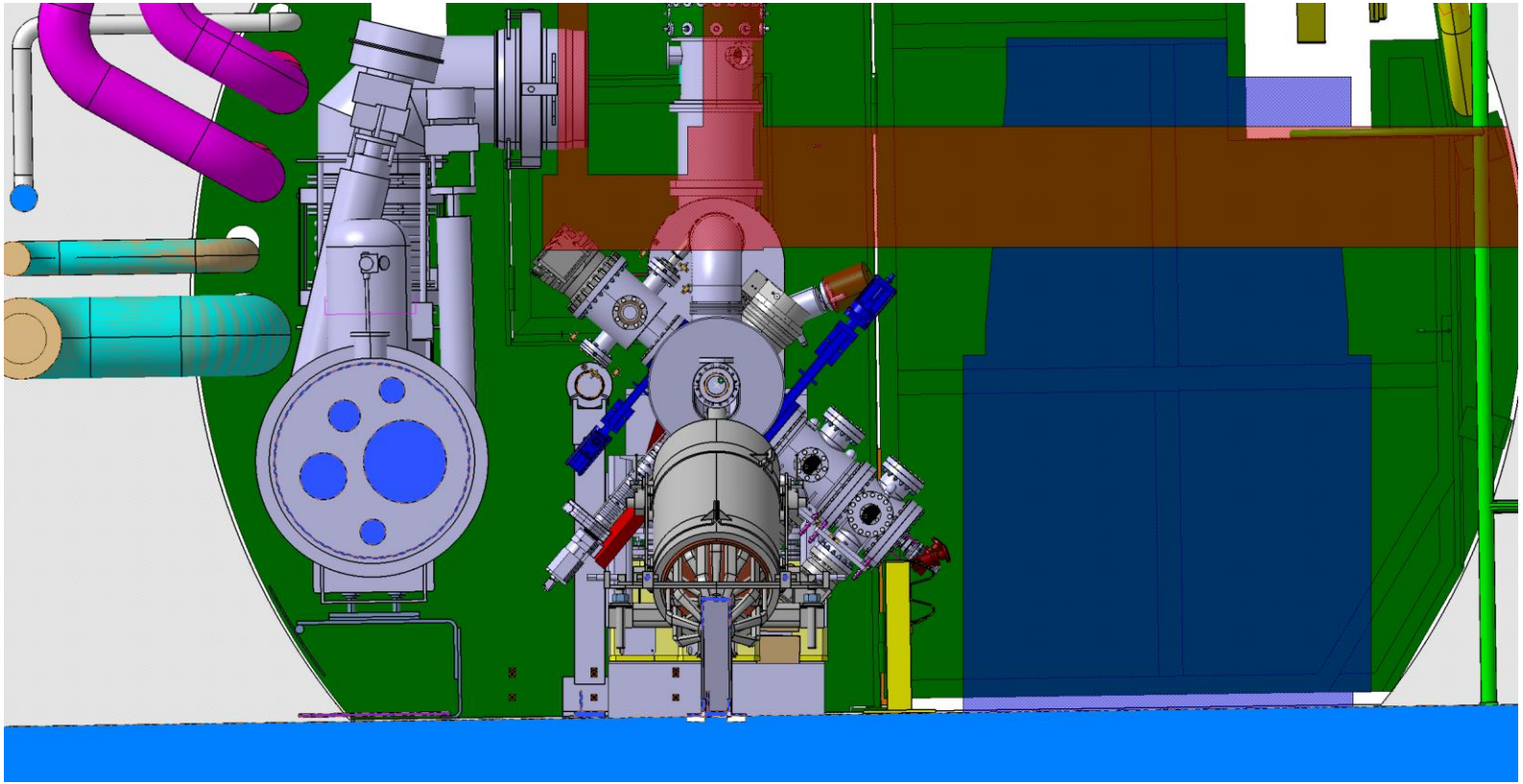

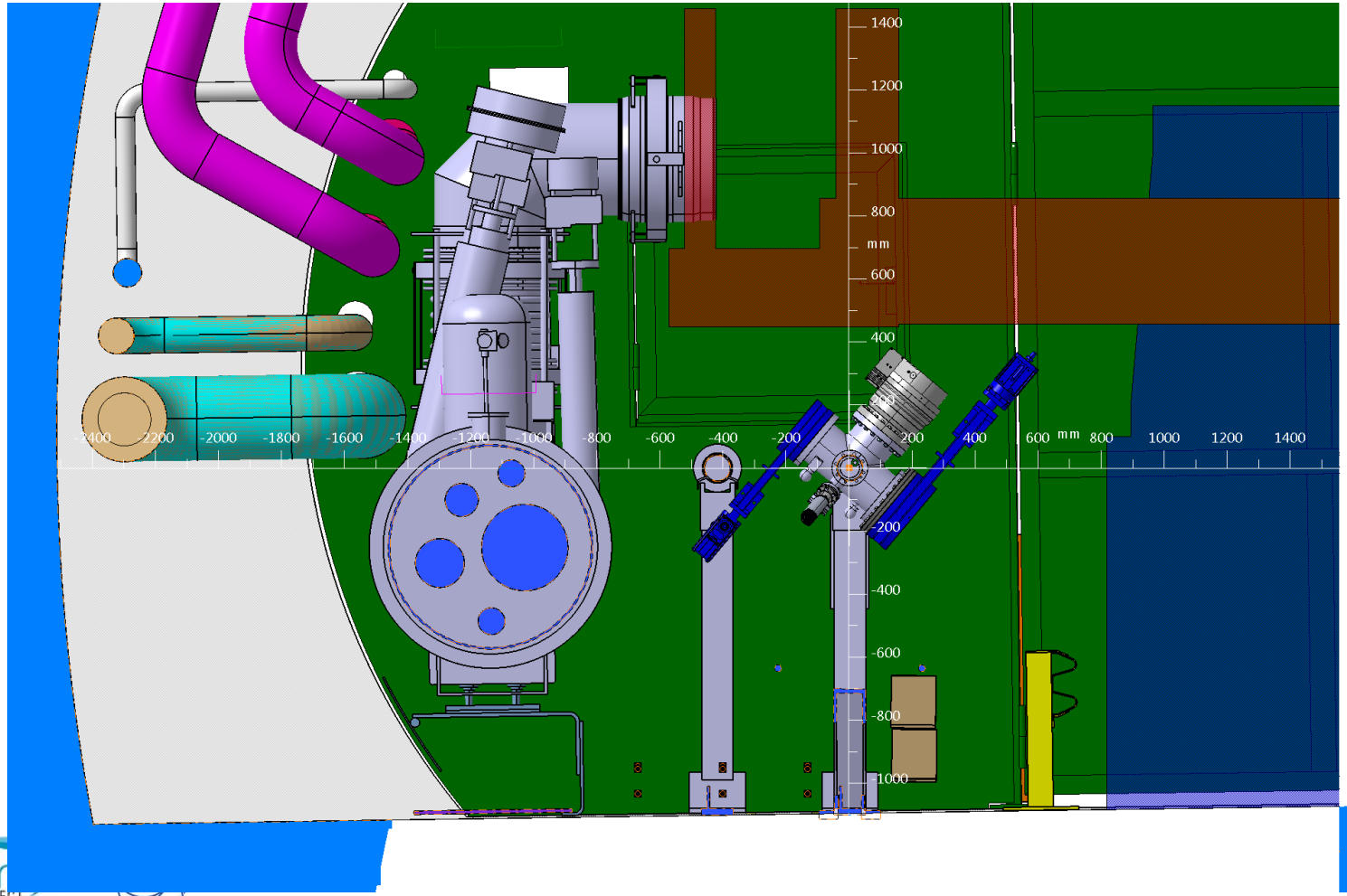
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