Beam-Gas Curtain (BGC) profile monitor: Project Overview and Status

Ray VENESS / CERN

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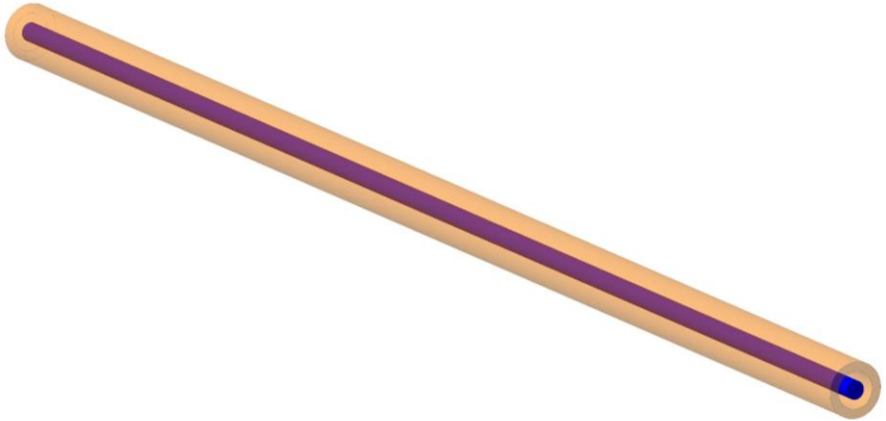
Contents

- Introduction
  - Beam-gas curtain principle and components
  - The potentials for High-Lumi
- Status and work in progress
  - The BGC collaboration
  - Experiments, designs and limitations
- Experimental requirements and plans
- Summary

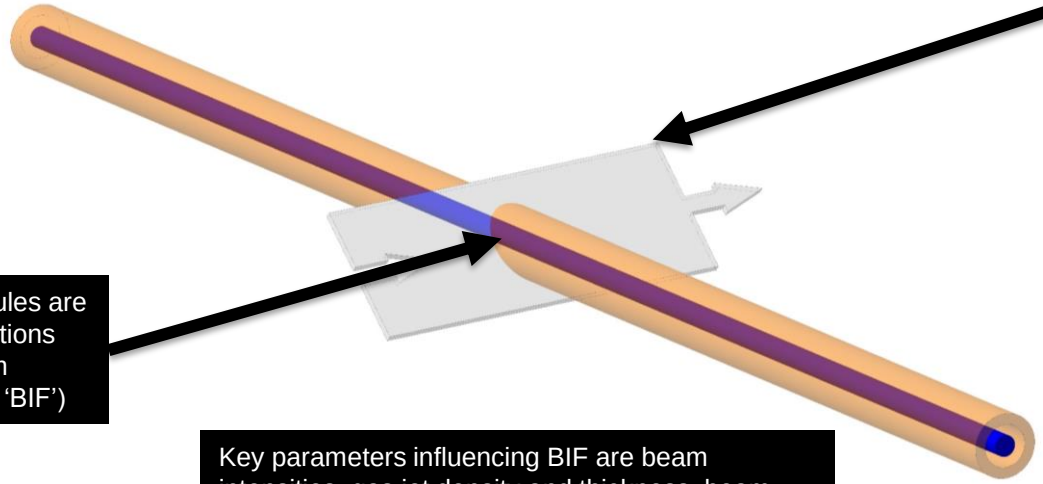
Beam-Gas Curtain: Principles



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

Beam-Gas Curtain: Principles

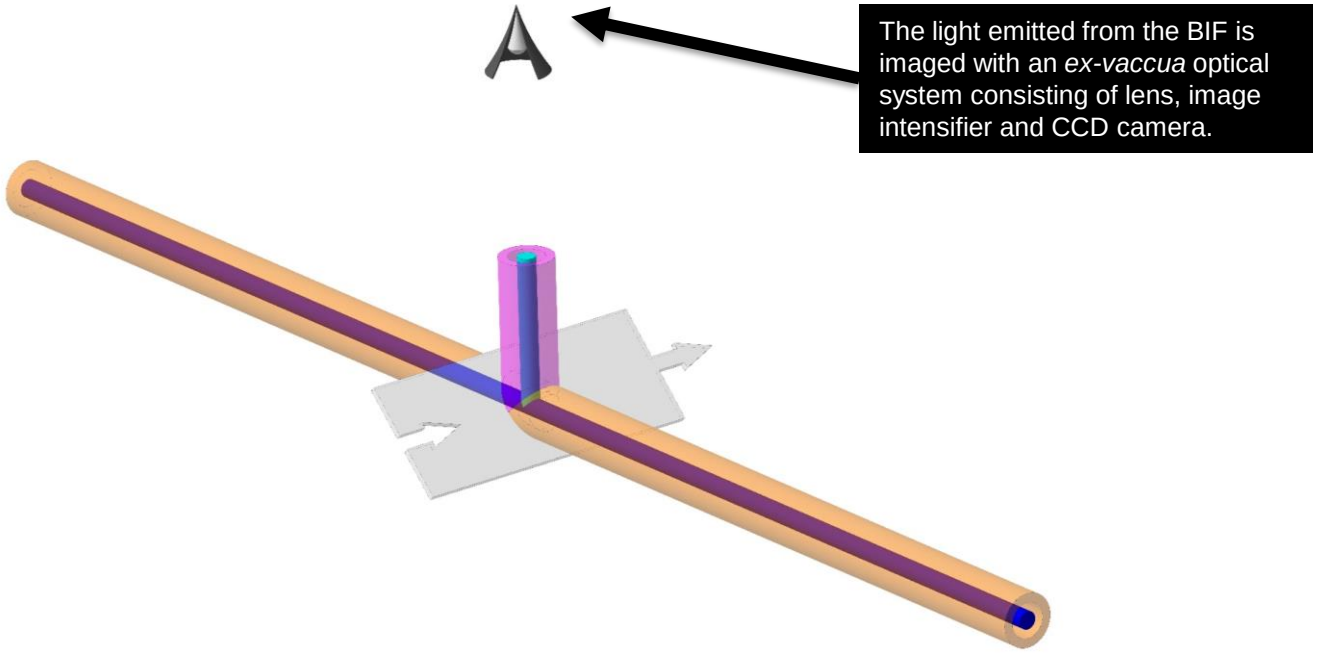
Laminar, supersonic gas ‘curtain’ traverses the beams



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

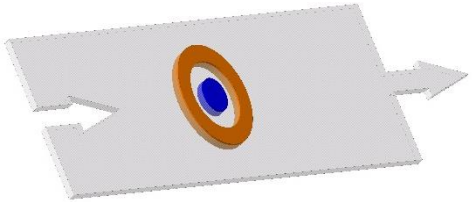
Key parameters influencing BIF are beam intensities, gas jet density and thickness, beam-gas cross section. The cross section is a function of gas species, particle type and energy. In addition, a spectral range of different florescence transitions are excited depending on gas species

Beam-Gas Curtain: Principles

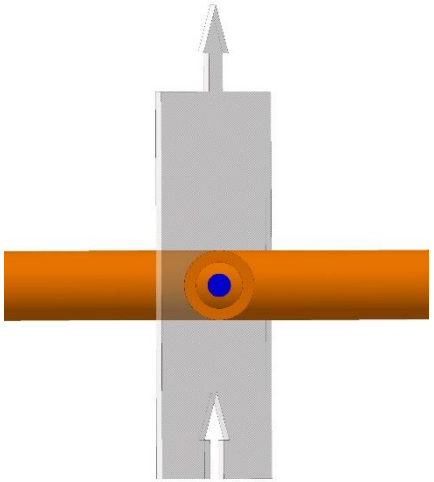


The light emitted from the BIF is imaged with an *ex-vaccua* optical system consisting of lens, image intensifier and CCD camera.

Beam-Gas Curtain: Principles

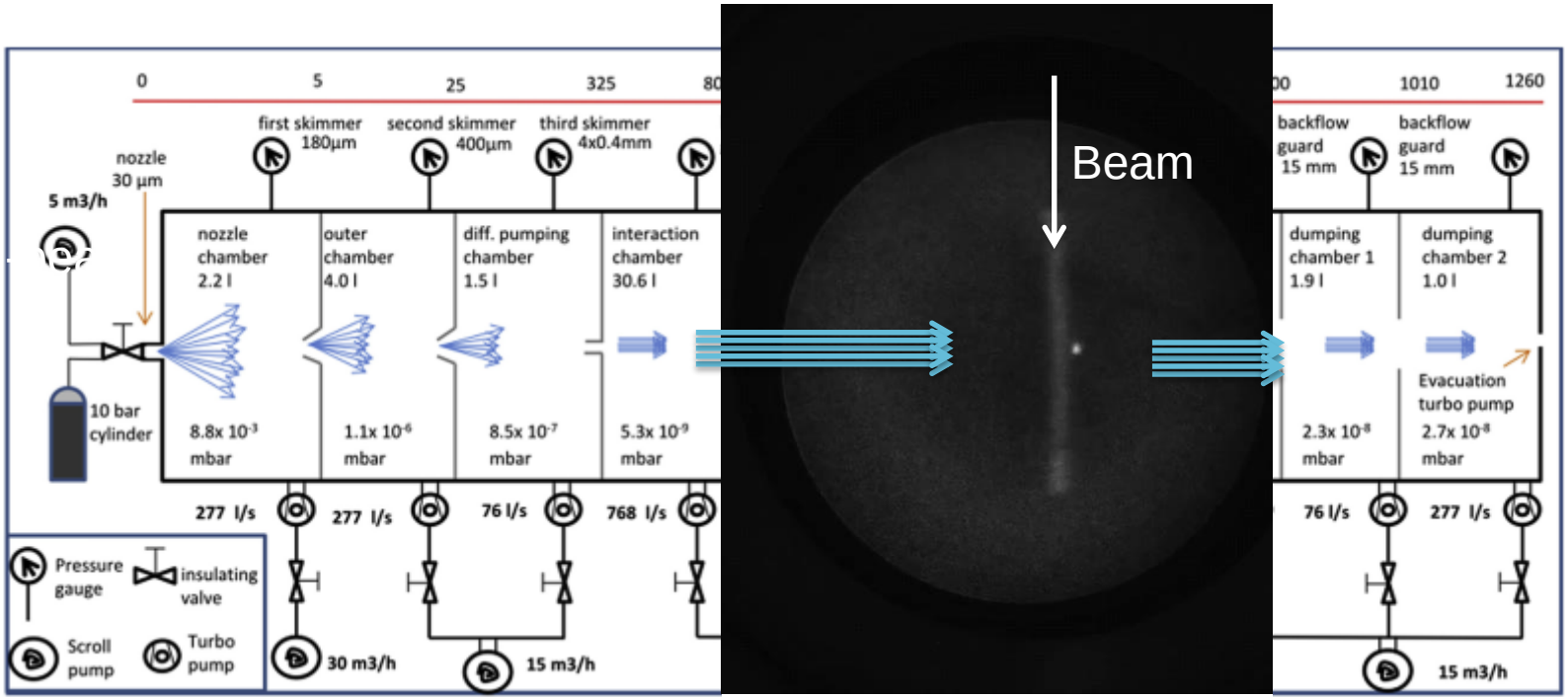


Eliptical image of two beams on the ‘virtual screen’



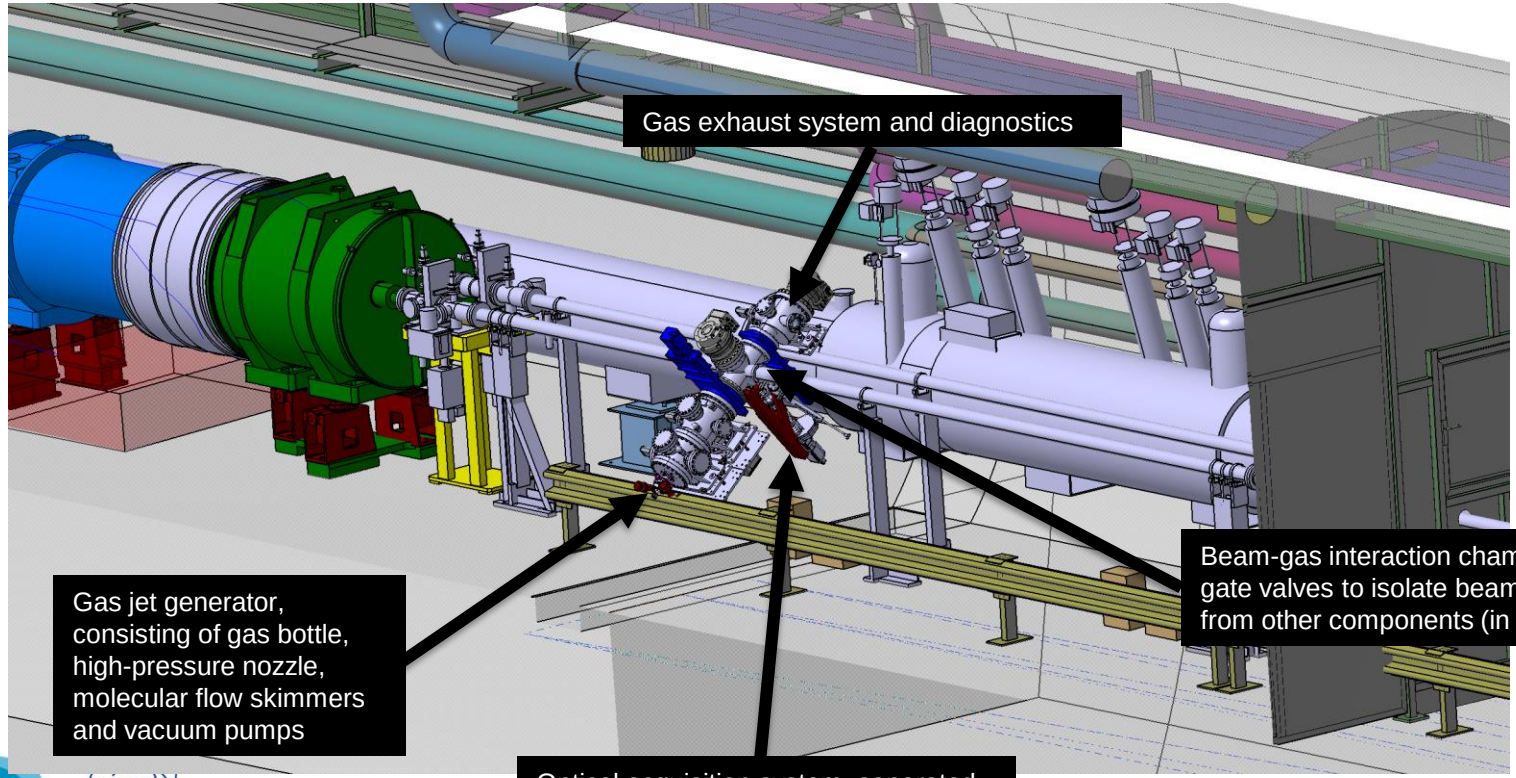
True 2D beam image seen by the camera when viewed at 90° to the beam axis

Beam-gas curtain: Existing (Prototype v1) configuration



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

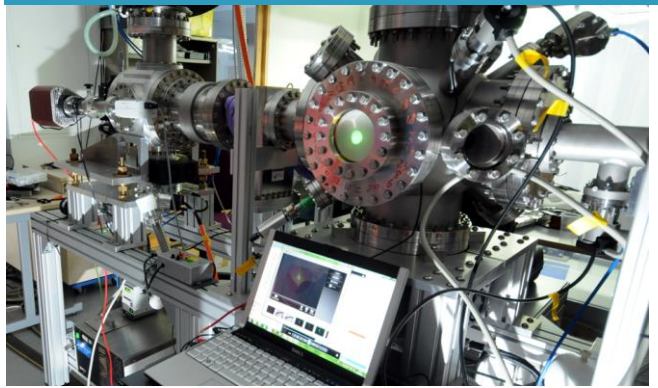
The BGC Collaboration

- 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 beam-induced fluorescence and monitoring
  - Collaboration agreement for the BGC since 2016 funding senior researchers and providing optics for the Cockcroft set-up
- CERN
  - Instrument design, optics and integration expertise (BE-BI)
  - Molecular gas flow simulation expertise (TE-VSC)
  - Mechanical design and specialist production (EN-MME)
- Wroclow University of Science and Technology (PL)
  - Expertise in computational fluid dynamics simulations for supersonic gas jets
  - Collaboration under discussion

Work in Progress: Experimental programme at the Cockcroft Institute

- 2017: Demonstration of beam-induced florescence with a N_2 gas jet [See talk by H.Zhang]
  - 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 N_2 gas curtain and proposed optical system
- 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)

Prototype v1 beam-gas curtain florescence monitor at the Cockcroft Institute



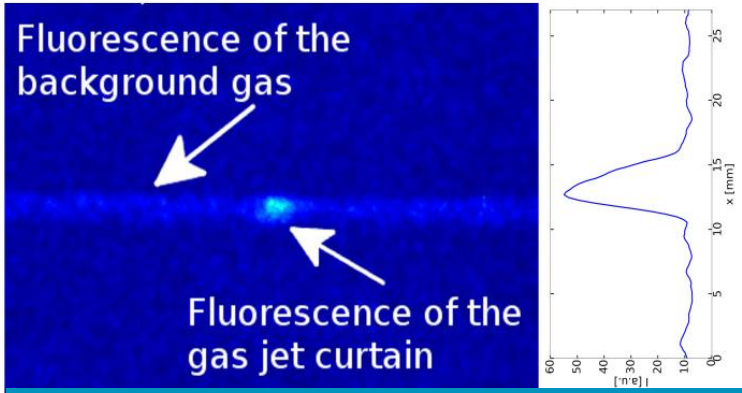
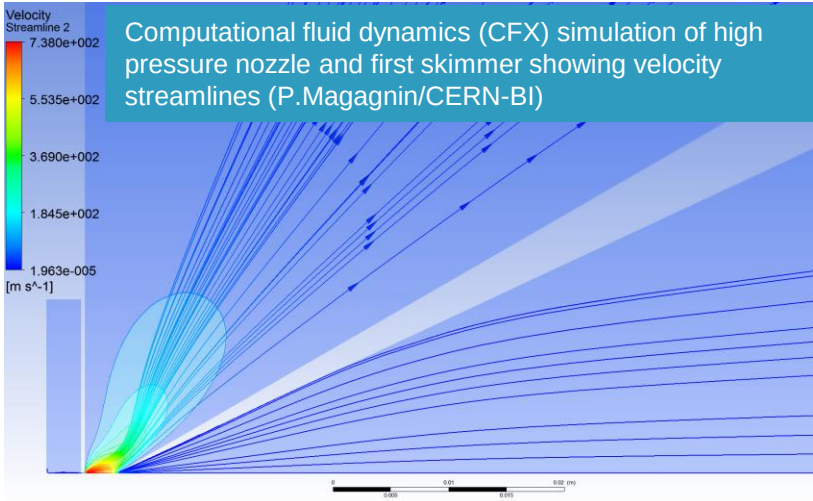


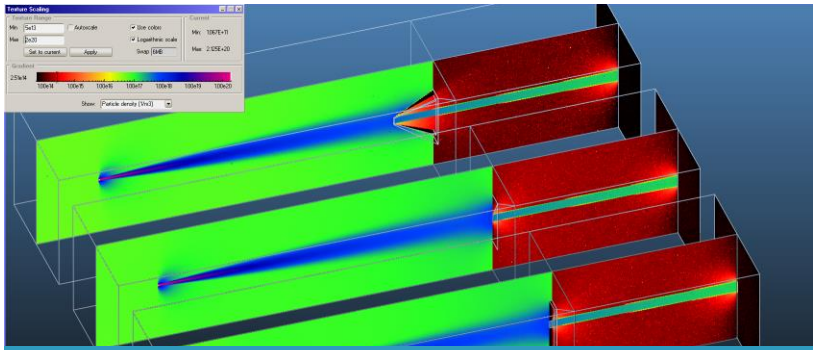
Image of fluorescence from a gas jet curtain interaction with 3.5 keV e- beam at the Cockcroft Institute (S.Udrea et al. IBIC 2017)

Work in progress: Gas jet simulations

- Gas jet simulations span 13 orders of pressure variation
  - 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
  - Base pressure in the beam vacuum chamber ~10^{-9} mbar with ~1x10^{-6} mbar locally in the gas jet
- 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
  - Incorporate experience from gas jet targets to improve the nozzle geometry



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

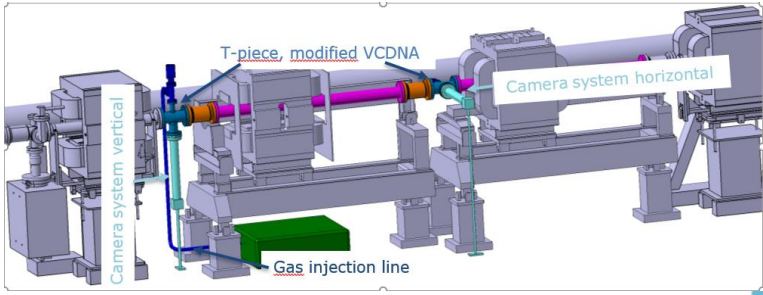


Molecular flow (MOFLOW) simulation through second and third skimmers showing gas density in interaction chamber (M.Ady/CERN-VSC)

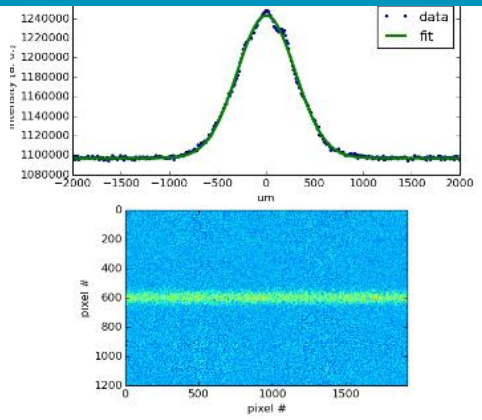
Fluorescence measurement test in the LHC

- Which gas to use? [See talk by P.Forck]
  - Signal integration time scales with fluorescence cross-section, which varies greatly for different gases and at different energies
  - Nitrogen has a higher cross-section, but neon has a number of other advantages for the LHC
  - Fluorescence cross-section data not available above 450 GeV
- Proposing a direct measurement of Ne cross-section at LHC top energy,
  - Using an already-installed and operational neon gas injection line, producing a small gas background 'bump' of $3x10^{-8}$mbar
  - Could install during the upcoming YETS 17-18 shutdown
  - Also measure light background from SR in the LHC vacuum system
- Will give important information for the design of gas jet and optical system that would otherwise not be possible to validate before 2021

Proposed layout of the experiment in the LHC



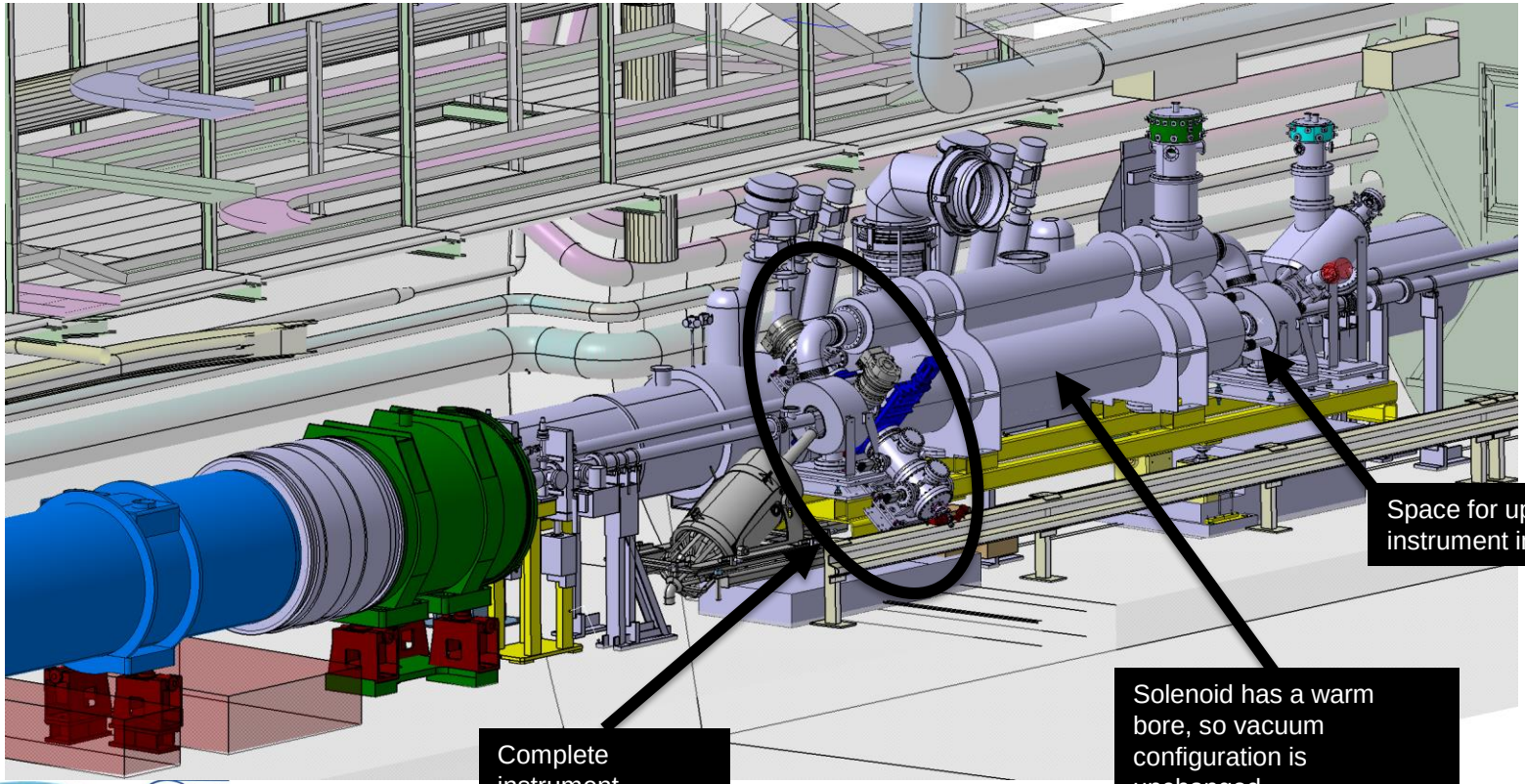
Simulation showing expected fluorescence profile from a test in the LHC (1 s integration time, Ne gas).



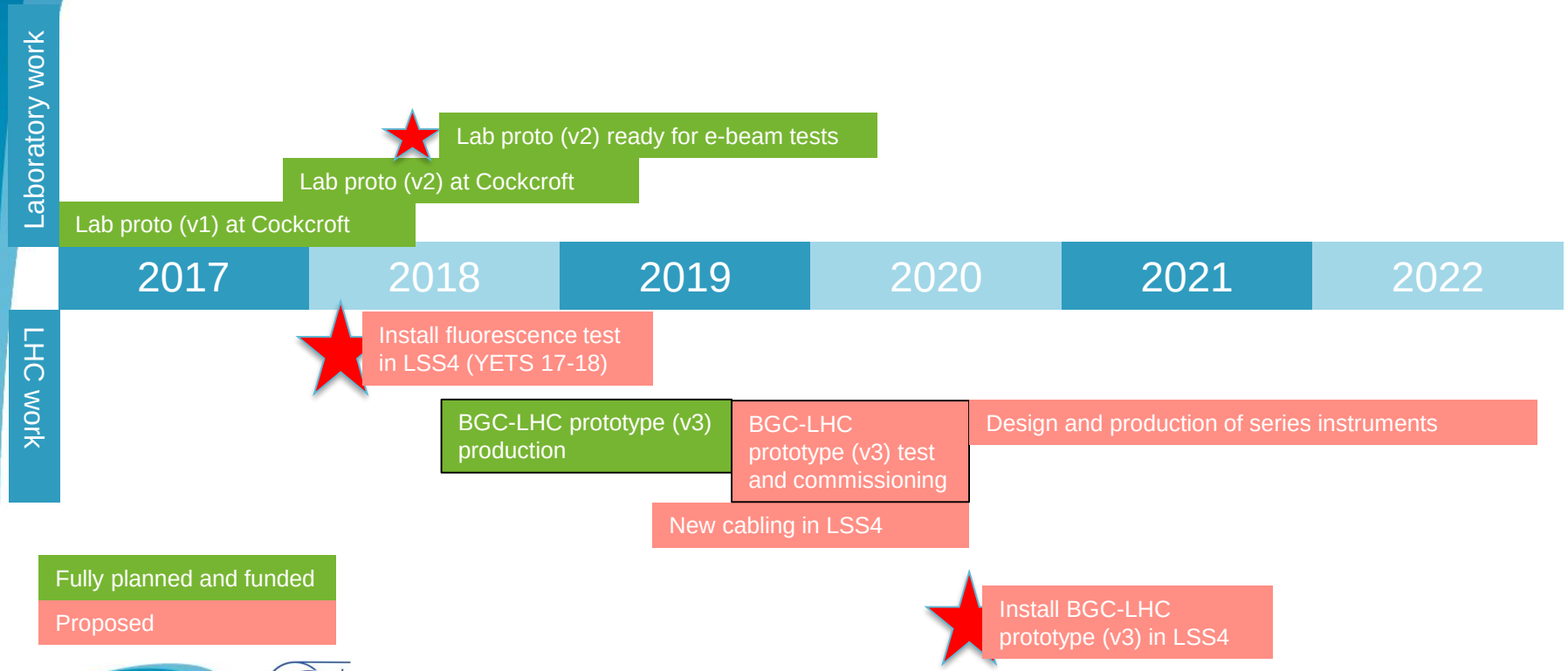
Next steps

- Development is fully funded as part of UK participation to HL-LHC
  - UK-HLLHC Collaboration package 3 / Task 1 (diagnostics) 2016-2020
  - Design and production of 2 prototypes:
    - ‘Laboratory prototype’ for with potential for installation of a full gas-jet monitor on an e-beam test stand
    - Design and delivery of a prototype adapted for testing in the LHC
- Immediate development goals
  - Continue to gain operational experience with measurements on the Cockcroft installations with and upgraded set-up operational in early 2018 [See talk by H.Zhang]
  - Selection of working gas and associated optics to maximise image refresh-rate and resolution whilst remaining LHC vacuum compatible [See talk by P.Forck]
  - Optimise gas injection and transport to increase jet density and minimize vacuum pump requirements [See talk by H.Zhang]
- Design and integration of an instrument for the LHC
  - Risk analysis for a full gas jet installation in the LHC
  - Development of LHC-compatible UHV pumping solutions
  - Evaluation of impedance and beam-induced heating
  - Integration studies with the HL integration team

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



Global schedule



Summary

- A new profile measurement instrument is under development for High-Lumi
  - Designed to provide a full 2D image of both e- and p+ beams in real-time,
  - Part of the WP13 (Beam Instrumentation) technical design study for high-current electron lenses for use in long-range beam-beam compensation
  - Active international collaboration with a fully-funded deliverable for an LHC-compatible prototype in 2019
  - CERN baseline instrument for on-line overlap and e- beam profile measurement for a HL-LHC hollow e-lens system
- 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
  - Background gas measurements of fluorescence cross-section for p^+ at 7 TeV and SR background in the LHC, potentially in 2018
  - Prototype v3 installed in the LSS4 of the LHC, potentially during LS2,
- Would expect to have a fully-validated instrument by 2020 with potential for final validation in the LHC from 2021

Thanks for your attention

Thanks to :

P.Forck, S.Udrea (GSI)

V.Tsoganis, C.Welsch, H.Zhang (Cockcroft Institute)

Slawomir Pietrowicz, Przemysław Smakulski (Wroclow University)

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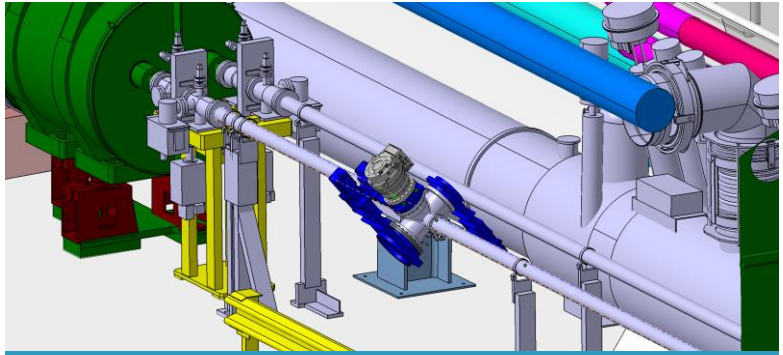
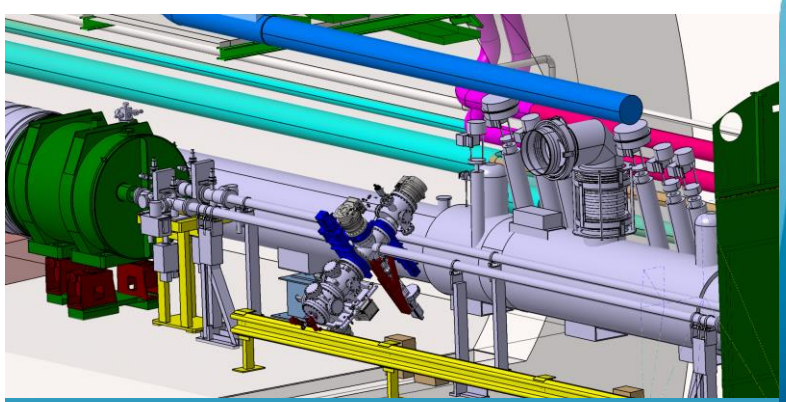
Phased installation during LS2 in the LHC

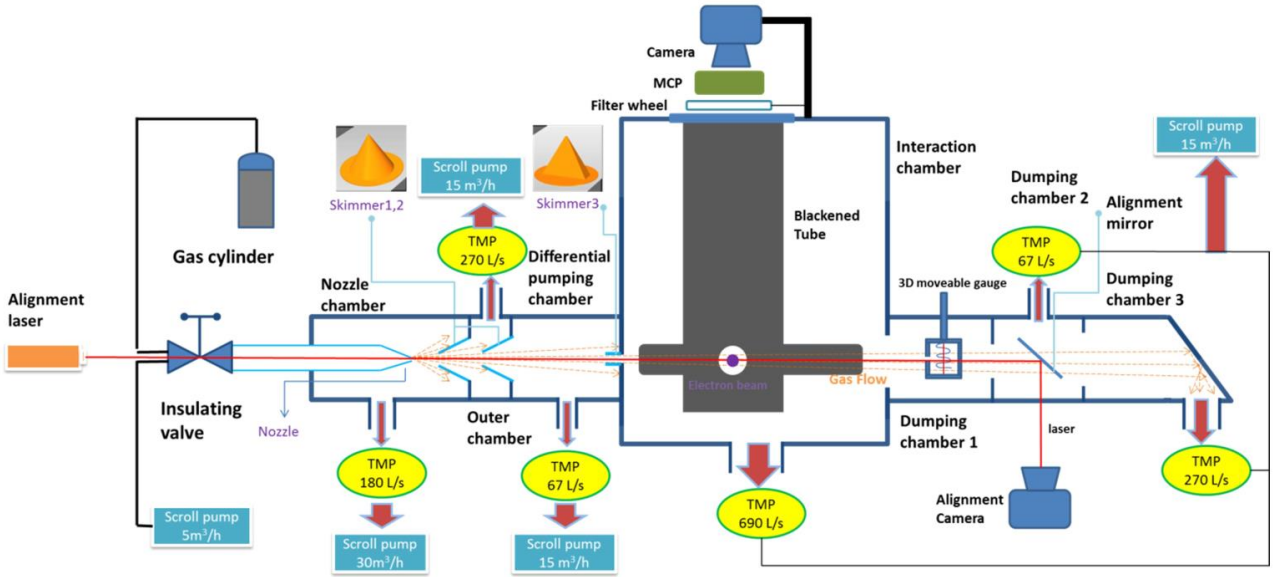
- Phased installation:
  - Maintains the LHC in full operating condition after each phase
  - Used successfully for the BGV installation during LS1
- Phase I:
  - Install the new vacuum sector valves and instruments, pull cables
- Phase II
  - Add the new BGC interaction vacuum chamber with valves on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

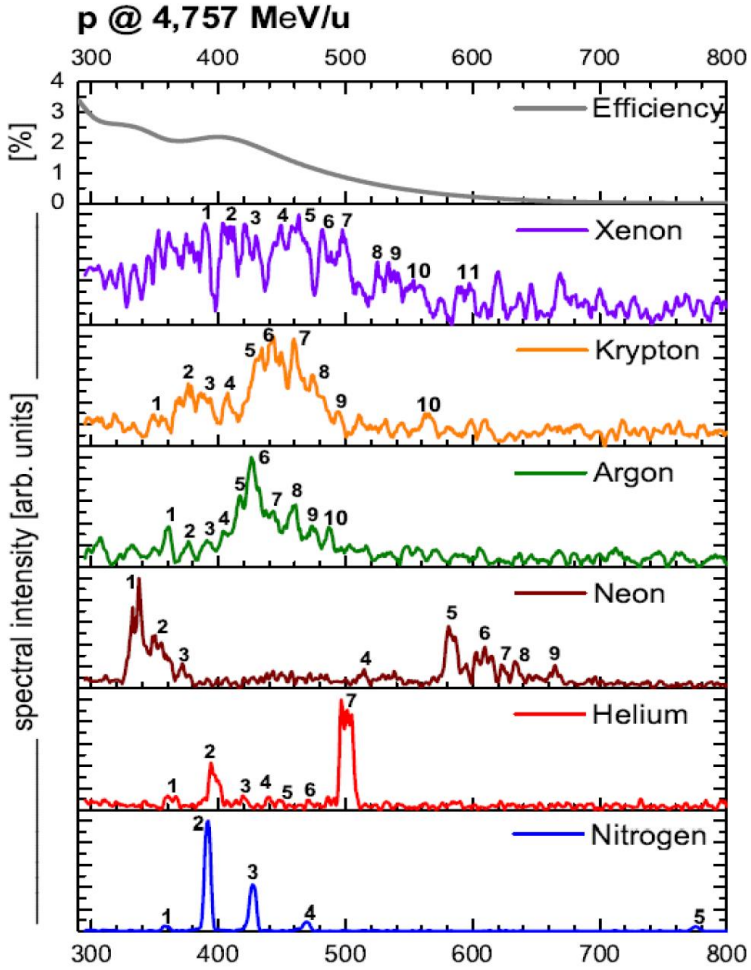


LHC sector after Phase 2 of the installation



LHC sector after Phase 3 of the installation


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
Alignment laser
Nozzle chamber
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
Scroll pump 5m³/h
Scroll pump 30m³/h
Scroll pump 15 m³/h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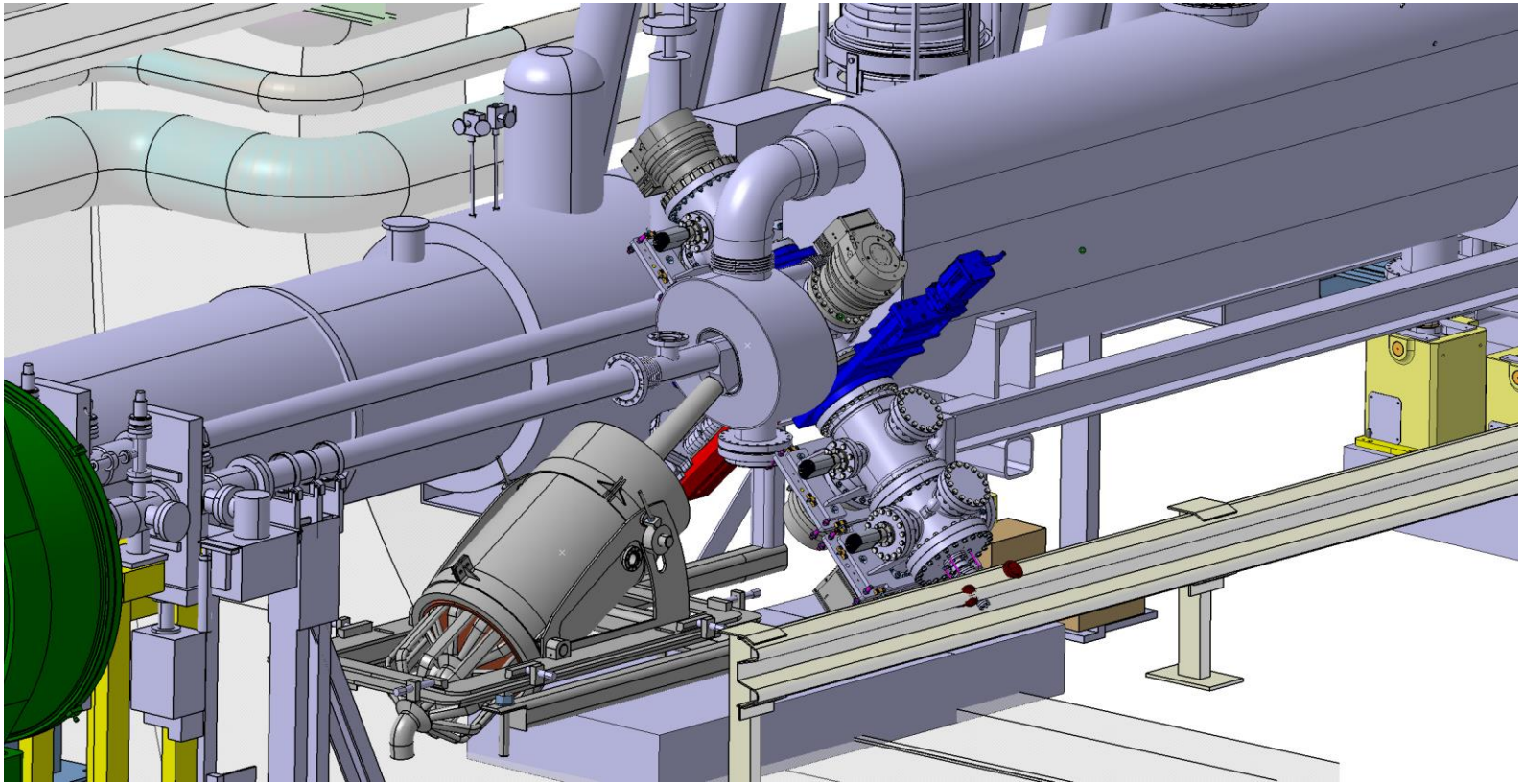

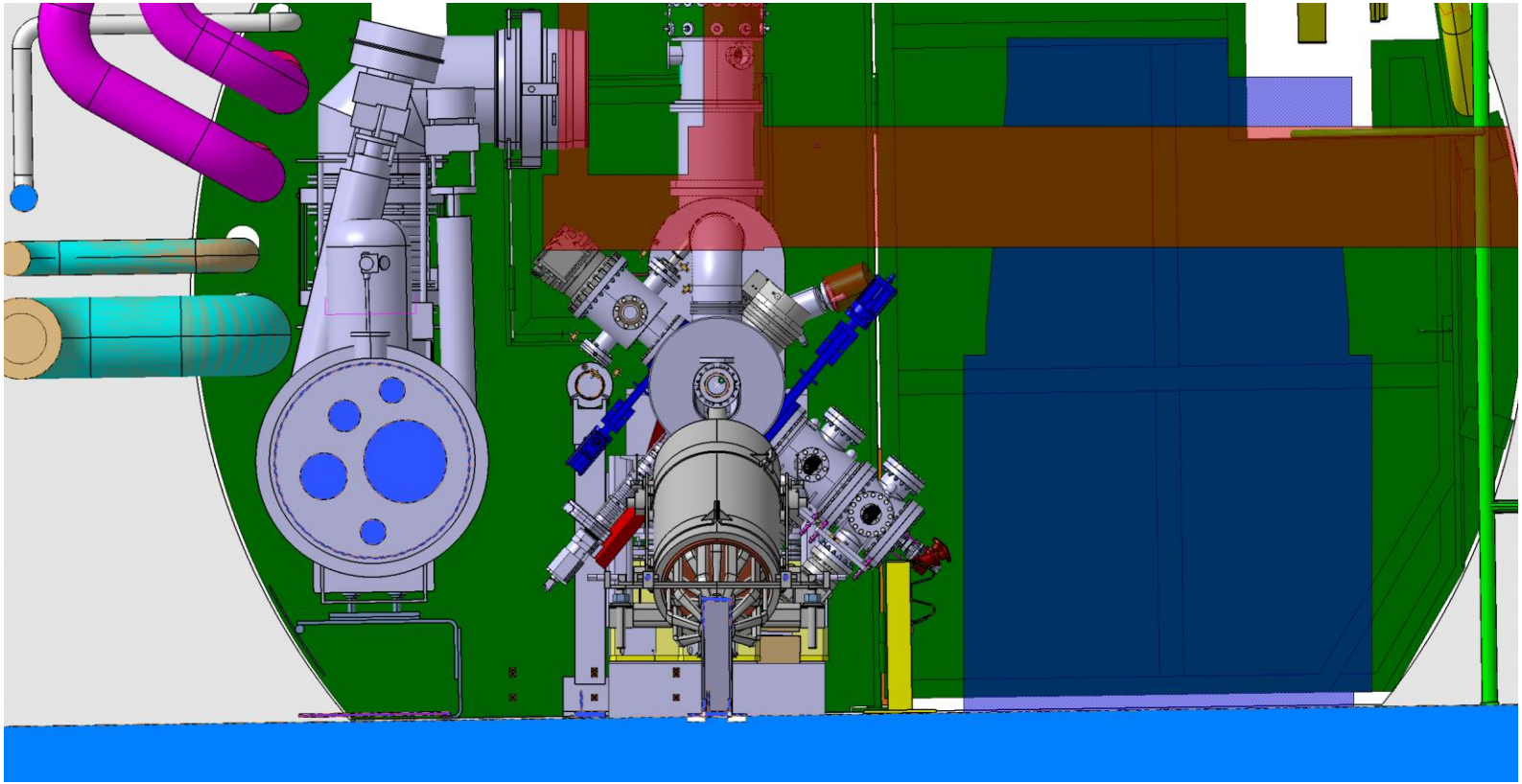

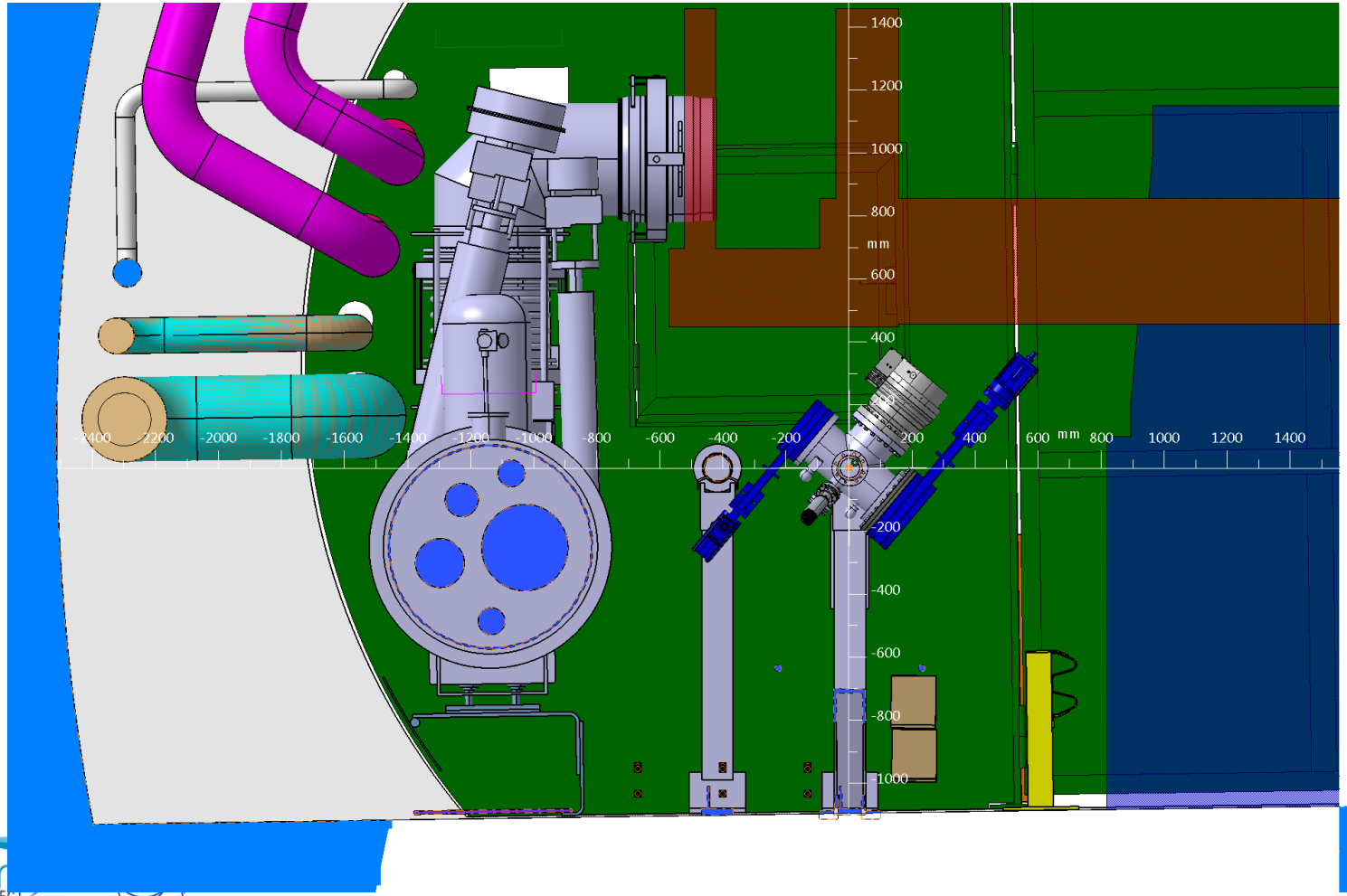
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