



Beam-Gas Jet profile monitor for the e-lens

Ray VENESS for the BGC team

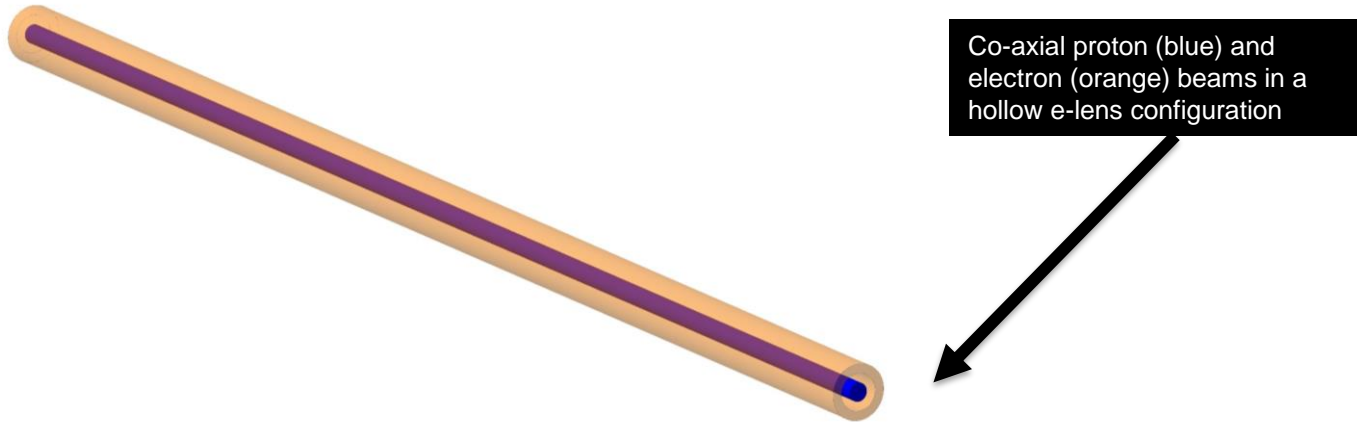


*International Review on the e-lens concept readiness for integration into the HL-LHC Baseline,
21st September 2017*

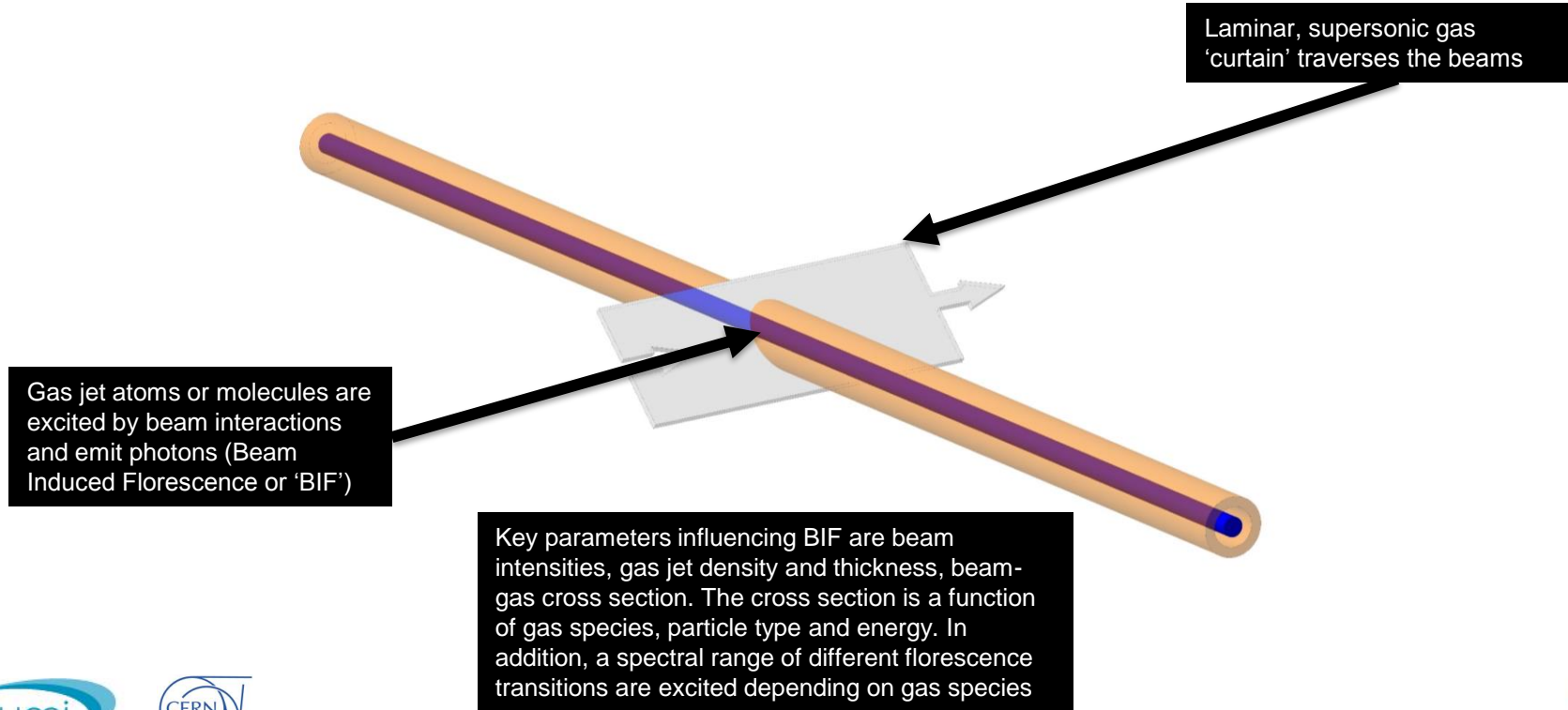
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- Summary

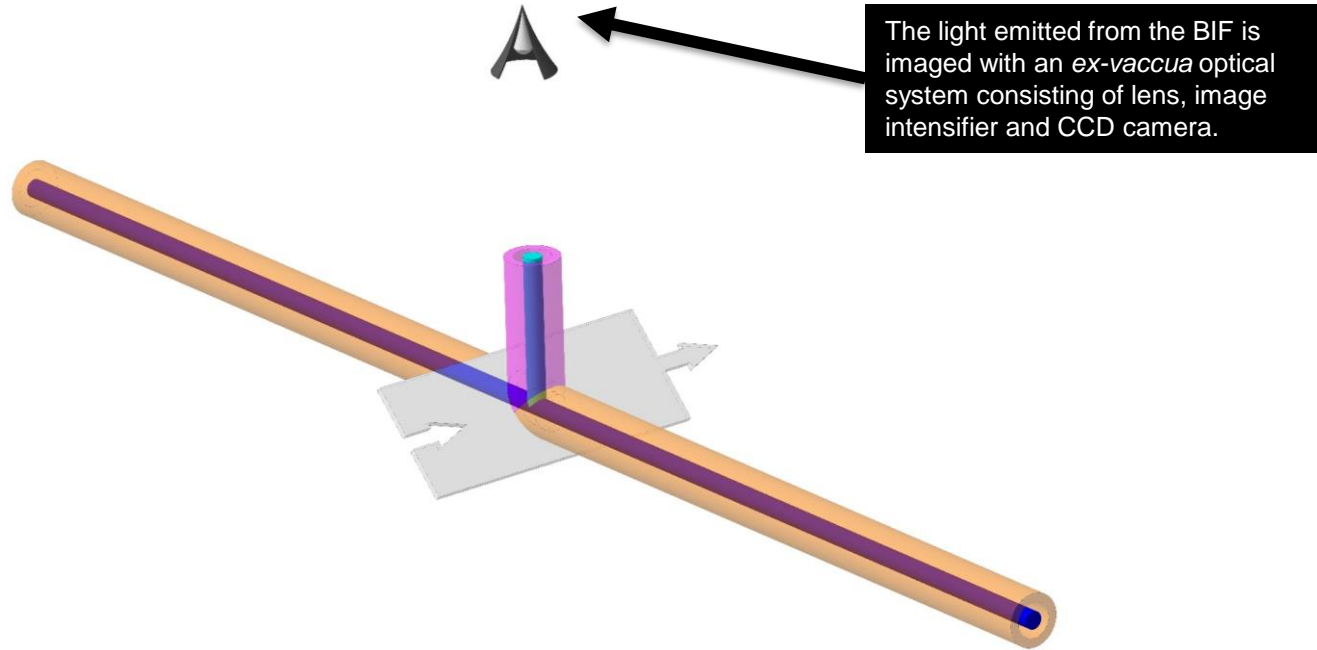
Beam-Gas Curtain: Principles



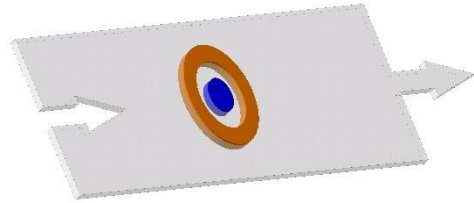
Beam-Gas Curtain: Principles



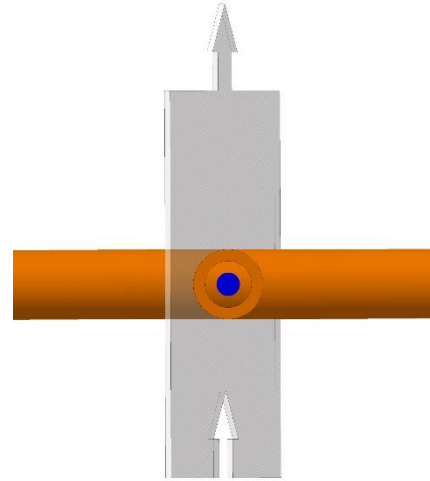
Beam-Gas Curtain: Principles



Beam-Gas Curtain: Principles



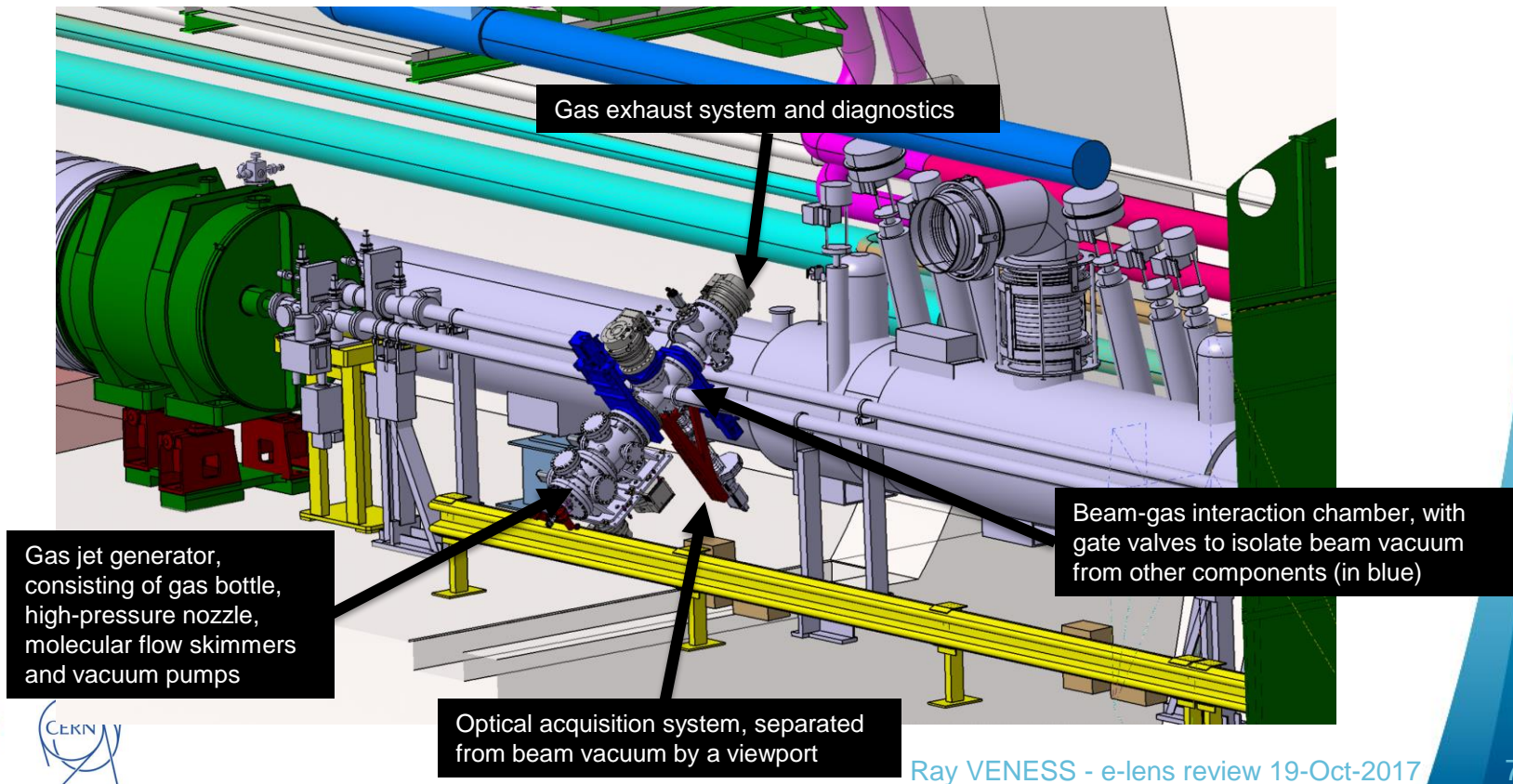
Elliptical image of two beams on the 'virtual screen'



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

Beam-Gas Curtain: Instrument Components

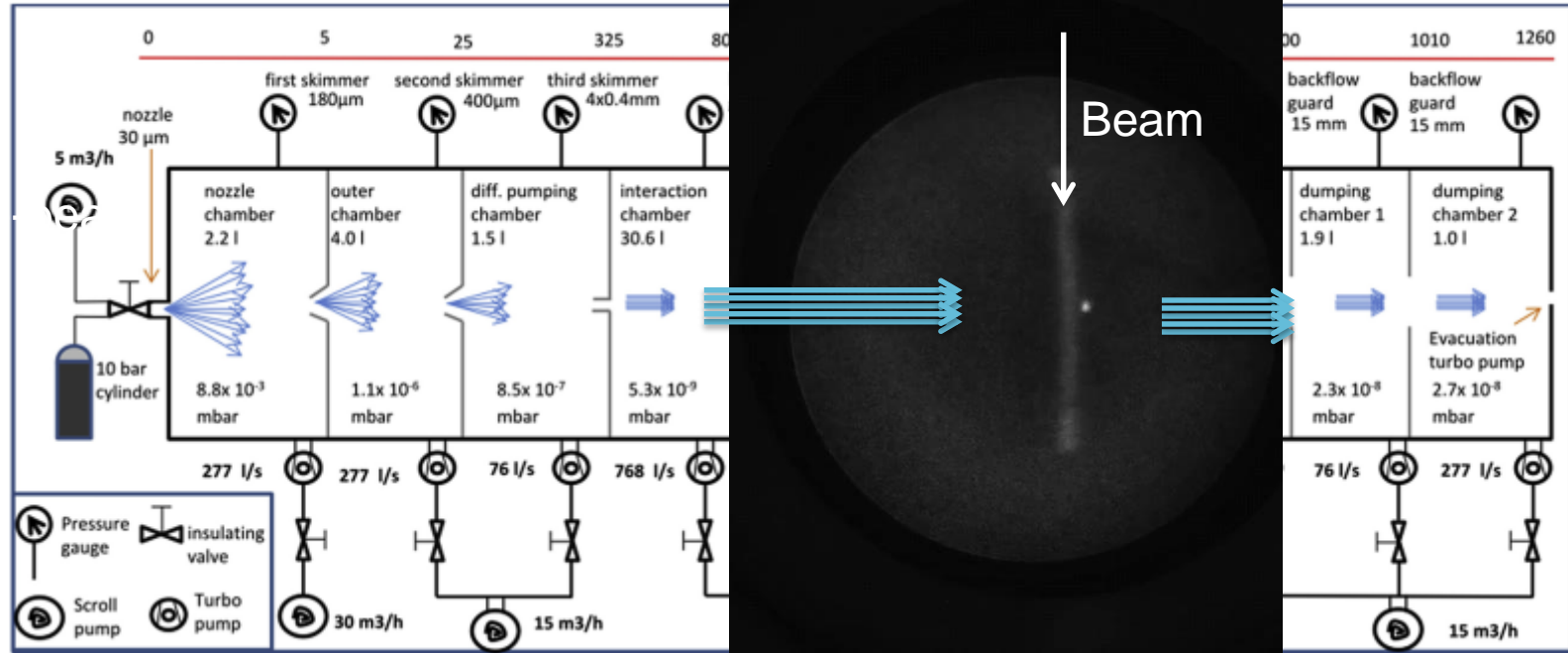
Note: This shows an integration of a laboratory prototype (v2), NOT an instrument designed for the LHC



Beam-Gas Curtain Florescence Monitor as a profile monitor for the e-lens

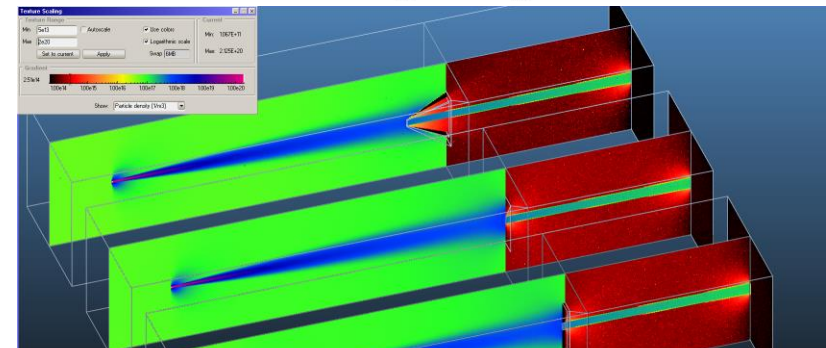
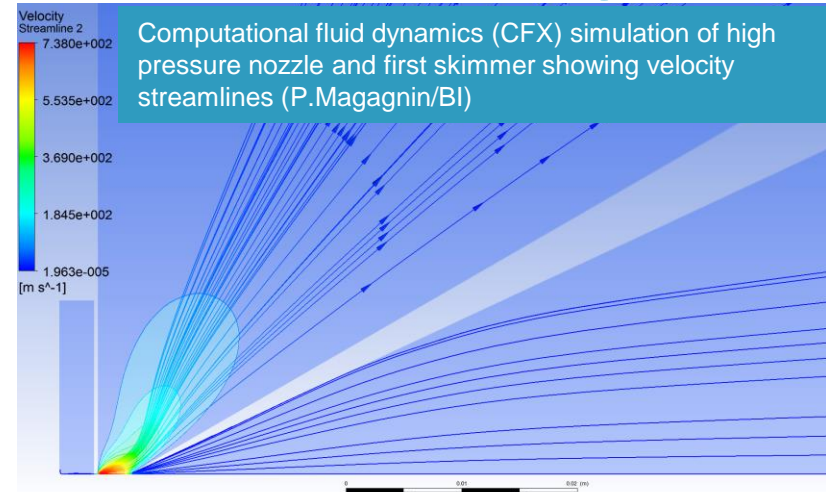
- Full 2D image in real-time* from one instrument without additional image reconstruction or calibration
 - *Limited by image integration time
- Simultaneously image multiple co-axial beams with different energies and species
- Minimally invasive instrument, insensitive to damage by high intensity beams
 - 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

Beam-gas curtain: Existing (Prototype v1) configuration



Optimisation of the gas curtain for the LHC

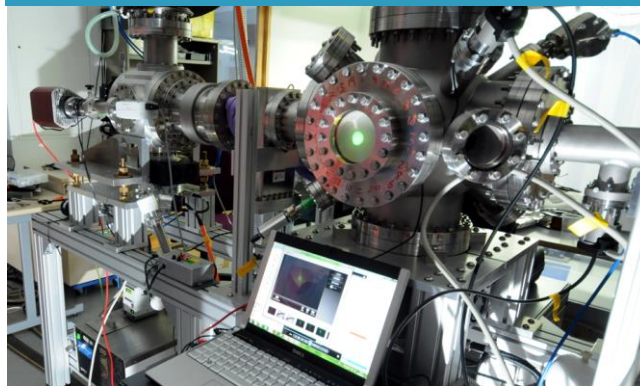
- Gas jet simulations span 13 orders of pressure variation
 - The gas is supplied at 10 bar through a $30\text{ }\mu\text{m}$ nozzle
 - The flow is then progressively 'skimmed' to select molecules with the required trajectory
 - Base pressure in the beam vacuum chamber $\sim 10^{-9}$ mbar with $\sim 10^{-7}$ 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



Experimental System and Results

- 2017: Demonstration of beam-induced fluorescence with a N_2 gas jet
 - 10 μA / 5 keV electron beam
 - Integration times are long due to low e-beam intensity (>1000 s)
 - Estimated $\sim 2.5 \times 10^5$ photons/s for a 5 A electron beam and expected N_2 gas curtain
- Now in progress:
 - Integration of a new electron gun reaching upto 300 μA / 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 fluorescence monitor at the Cockcroft Institute



Fluorescence of the background gas

Fluorescence of the gas jet curtain

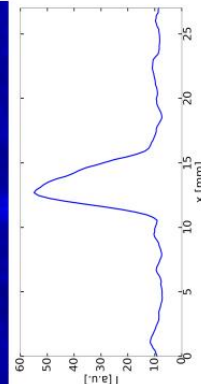
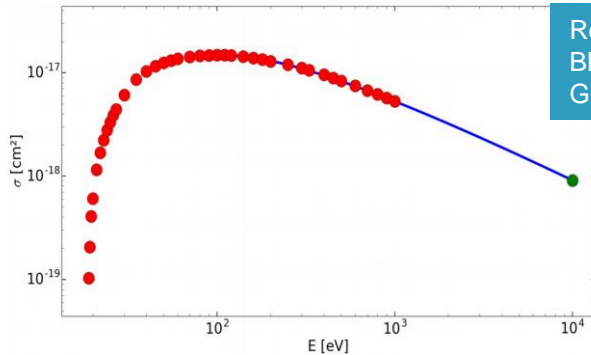


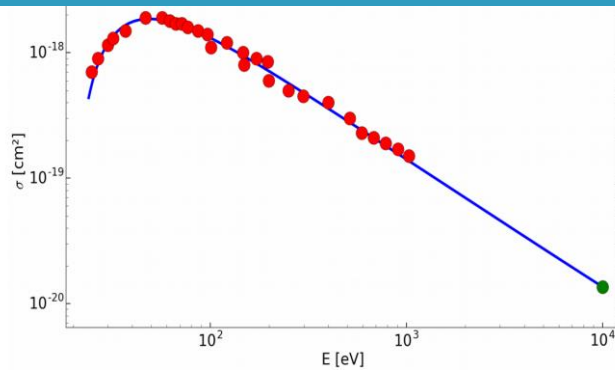
Image of fluorescence from a gas jet curtain interaction with 3.5 keV e- beam at the Cockcroft Institute (S.Udrea et al. IBIC 2017)

Selection of working gas

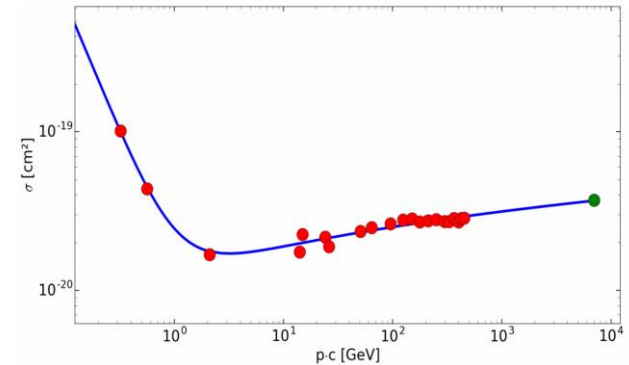
Electron excitation fluorescence cross-section for a specific **N₂** transition, extrapolated to 10 keV



Electron excitation fluorescence cross-section for a specific **Ne** transition, extrapolated to 10 keV



Proton excitation fluorescence cross-section for a specific **N₂** transition, extrapolated to 7 TeV



- Currently evaluating N₂, Ne and possibly Ar for jet gas
- N₂ has a significantly higher cross-section for electrons
- 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

Fluorescence measurement test in the LHC

Which gas to use?

- 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

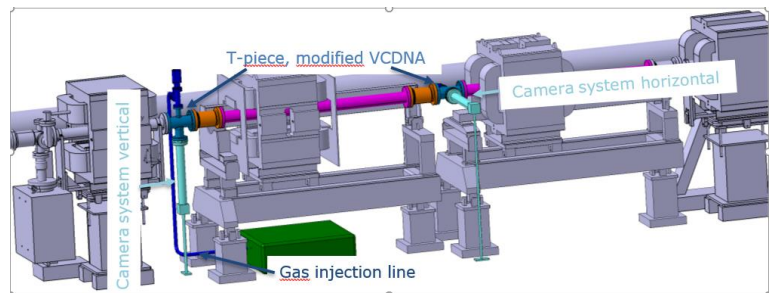
Proposing a direct measurement of Ne cross-section at LHC top energy,

- Using an already-installed and operational neon gas injection line
- Install during the upcoming YETS 17-18 shutdown
- Also measure light background from SR in the LHC vacuum system

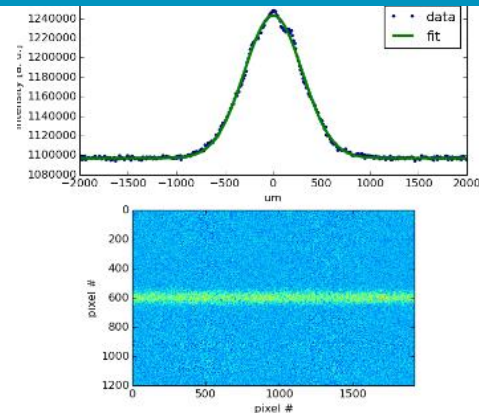
Will give important information for the design of gas jet and optical system that would otherwise not be possible to validate before 2021

- Support from this review for this measurement would be most helpful!

Proposed layout of the experiment in the LHC



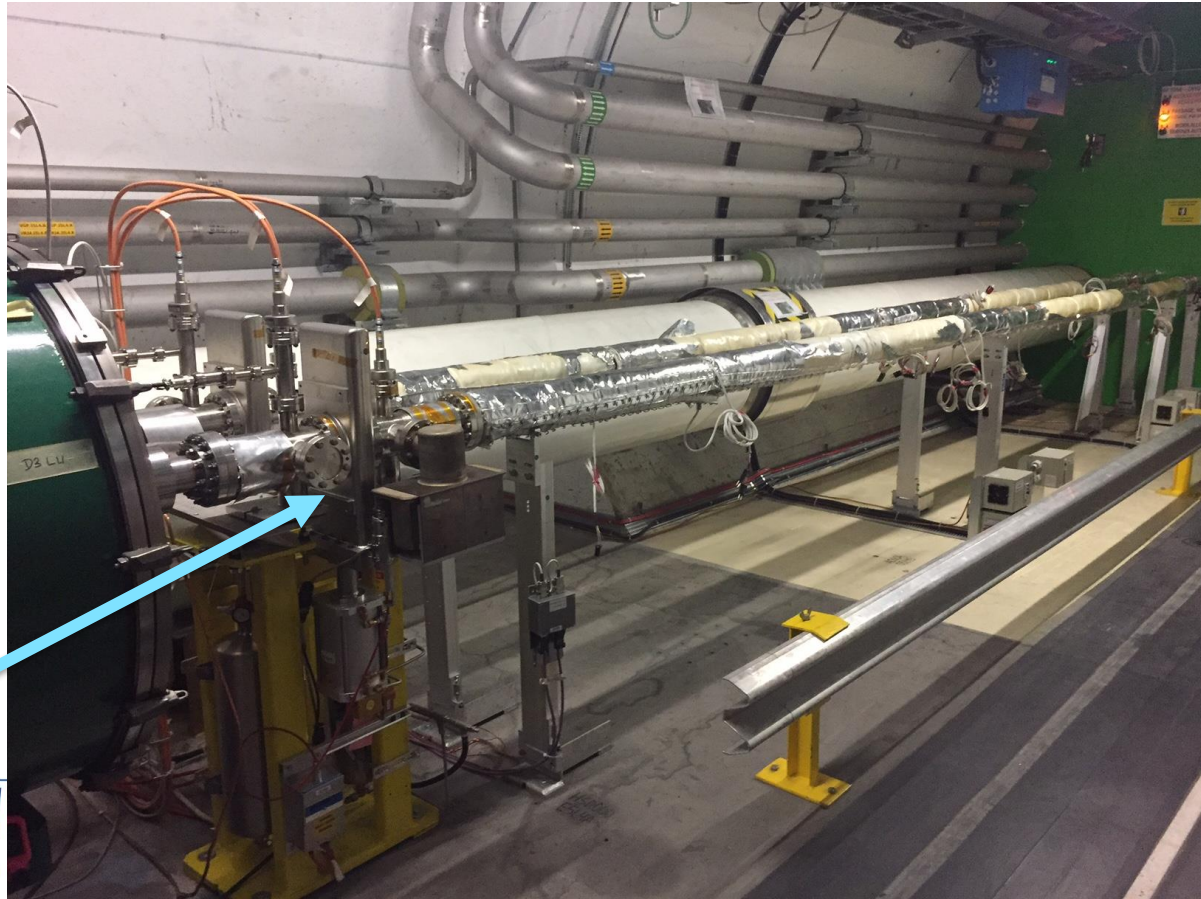
Simulation showing expected fluorescence profile from a test in the LHC (1 s integration time, Ne gas).



Performance expectations for the e-lens

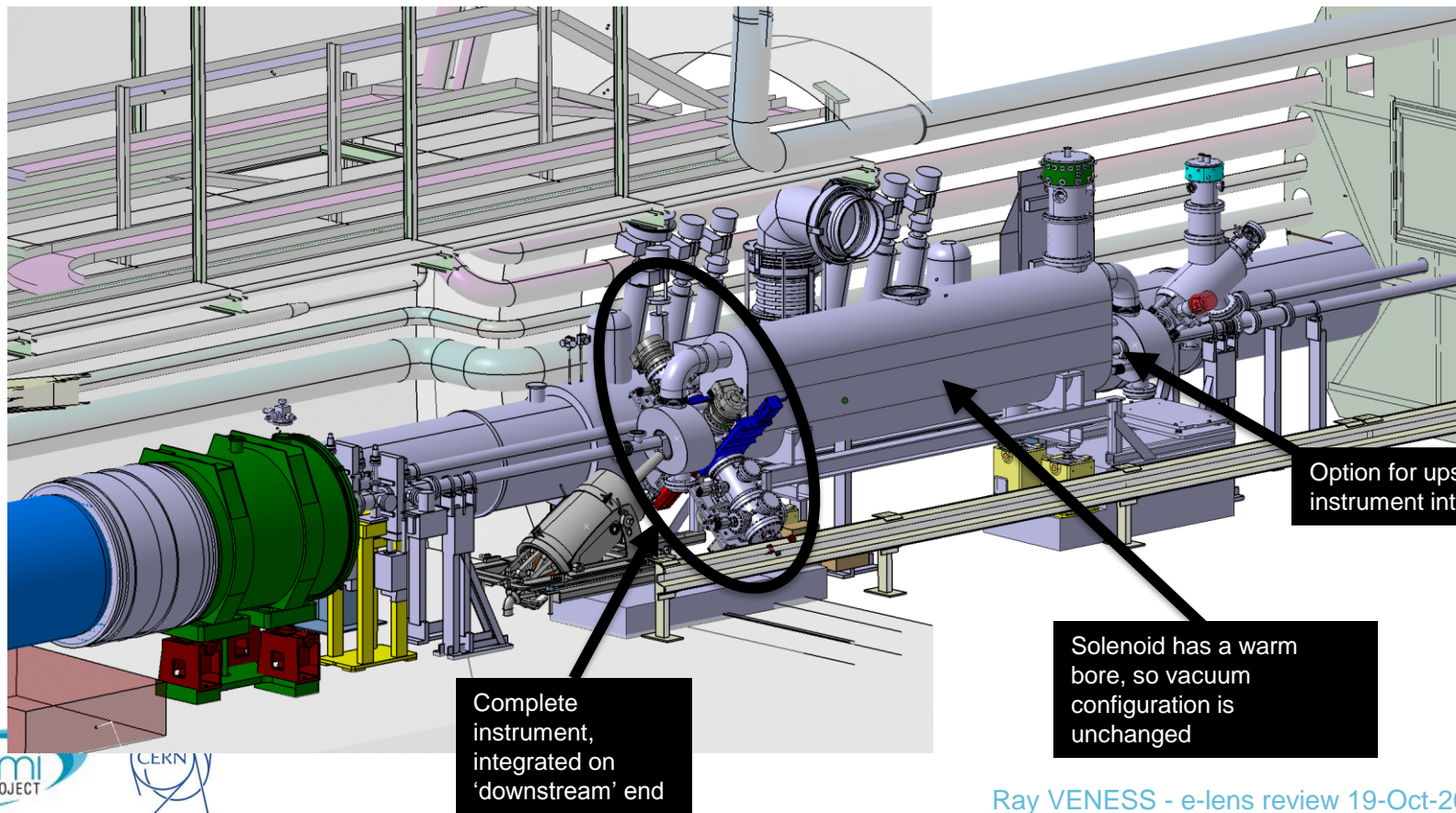
- Considering:
 - nominal parameters for the electron gun and LHC proton beam
 - Extrapolated fluorescence cross-section for Ne at 585.4 nm
 - Based on current prototype technologies
- A signal of $\sim 10^3$ photons/sec from the electron beam is predicted
 - Gives reasonable e-beam profile in 10s of seconds
- Expected signal-per-pixel ratio of electron to proton images of ~ 2.5
 - Both beams should be visible in the same image
- Resolution
 - Expected to be limited by the optical system
 - Existing prototype better than 100 μm resolution

Integration of an e-lens gas-jet profile monitor



Existing vacuum sector
equipment (sector valves,
gauges, pumps)

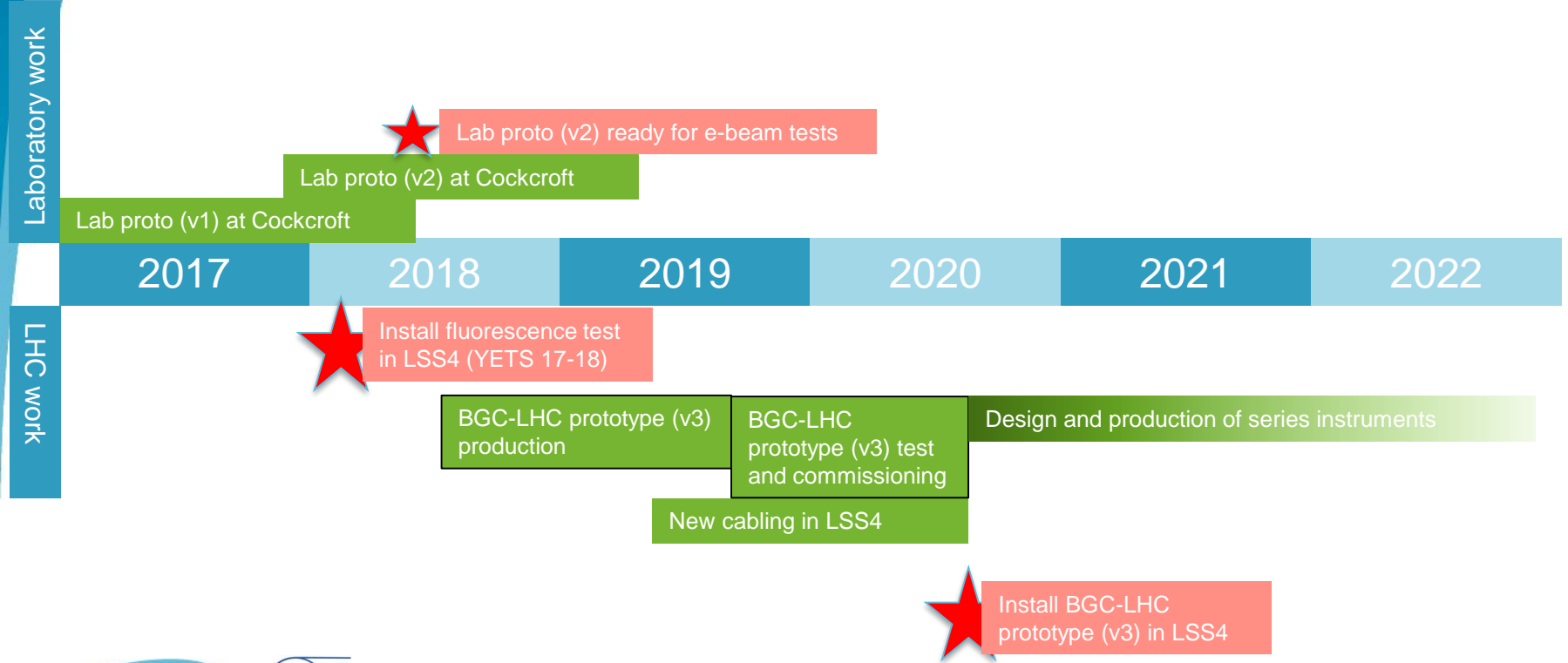
BGC (laboratory, version 2) integrated in LSS4 with a candidate e-lens solenoid



Development and Production

- Development is fully funded as part of UK participation to HL-LHC
 - Collaboration work package 3 / Task 1 (diagnostics) 2016-2020
 - Deliverables:
 - Installation of a gas-jet monitor on an e-beam test stand
 - Design and delivery of a prototype adapted for testing in the LHC
- Immediate development goals
 - Selection of working gas and associated optics to maximise image refresh-rate and resolution whilst remaining LHC vacuum compatible
 - Optimise gas injection and transport to increase jet density and minimize vacuum pump requirements
- Design, production and integration cost for the operational e-lens instrument
 - Estimated at 100 kCHF for one installed system, based on experience with construction of the e-beam test stand prototype

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
- Optimisation of a final instrument for the e-lens will require experimental data and experience with 7 TeV protons
 - Fluorescence cross-section for p+ at 7 TeV
 - Resolution limits with gas jet in the p+ field and with the LHC SR background
- 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 fluorescence measurement in YETS 17-18
- Would expect to have a fully-validated instrument by 2020 with final validation in the LHC from 2021



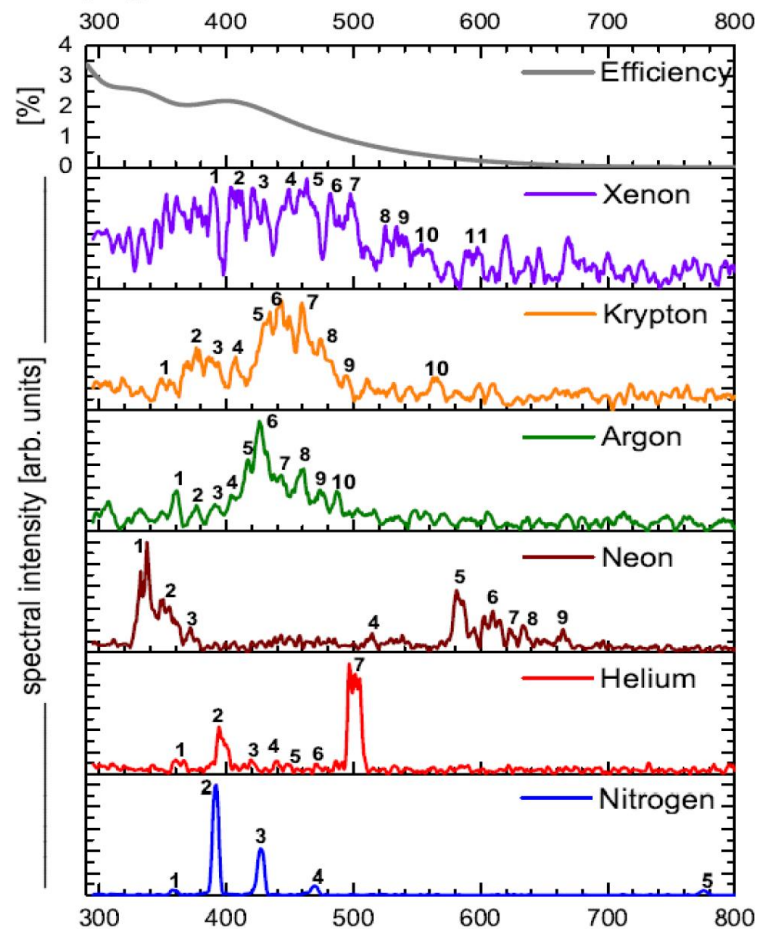
Thanks for your attention

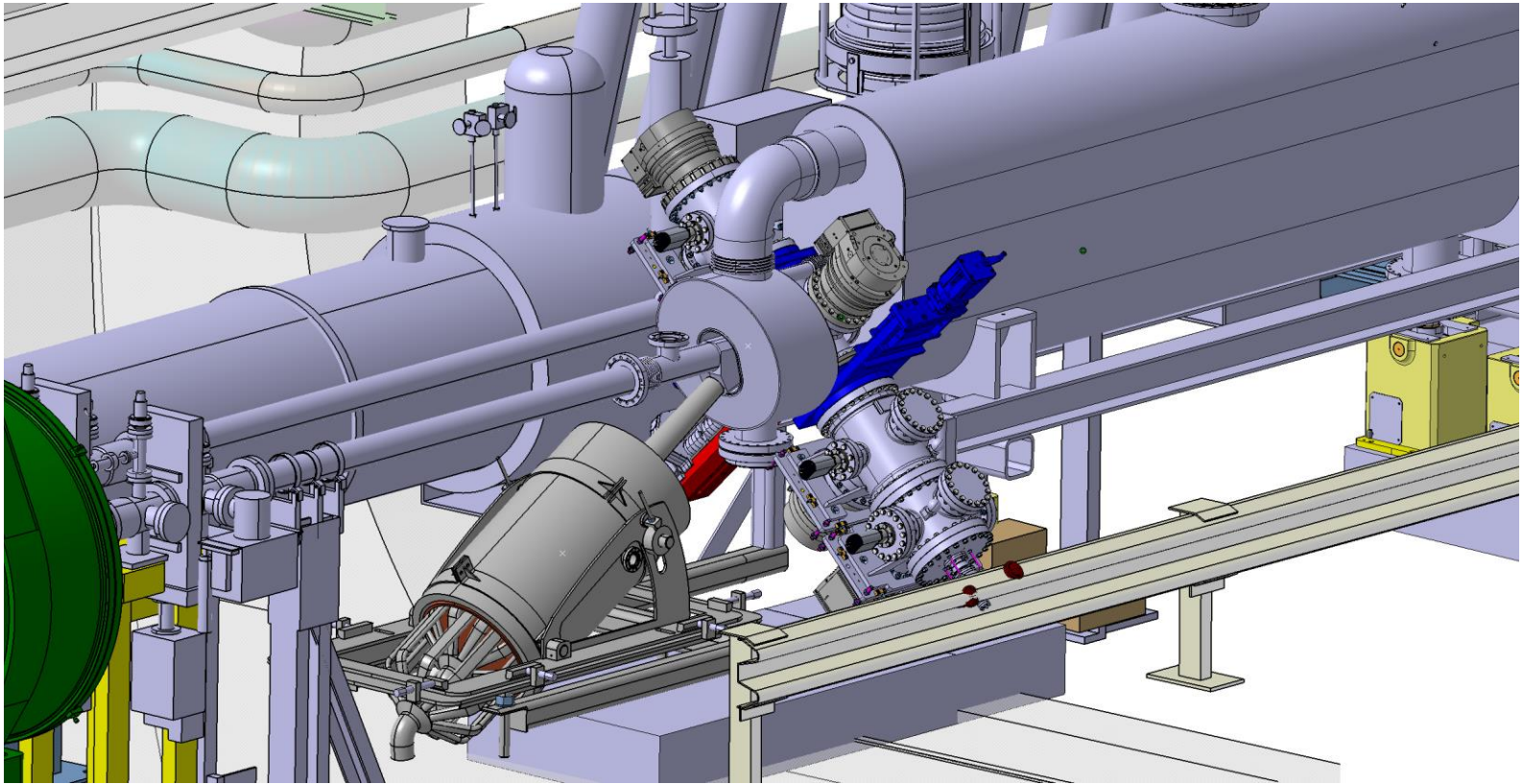


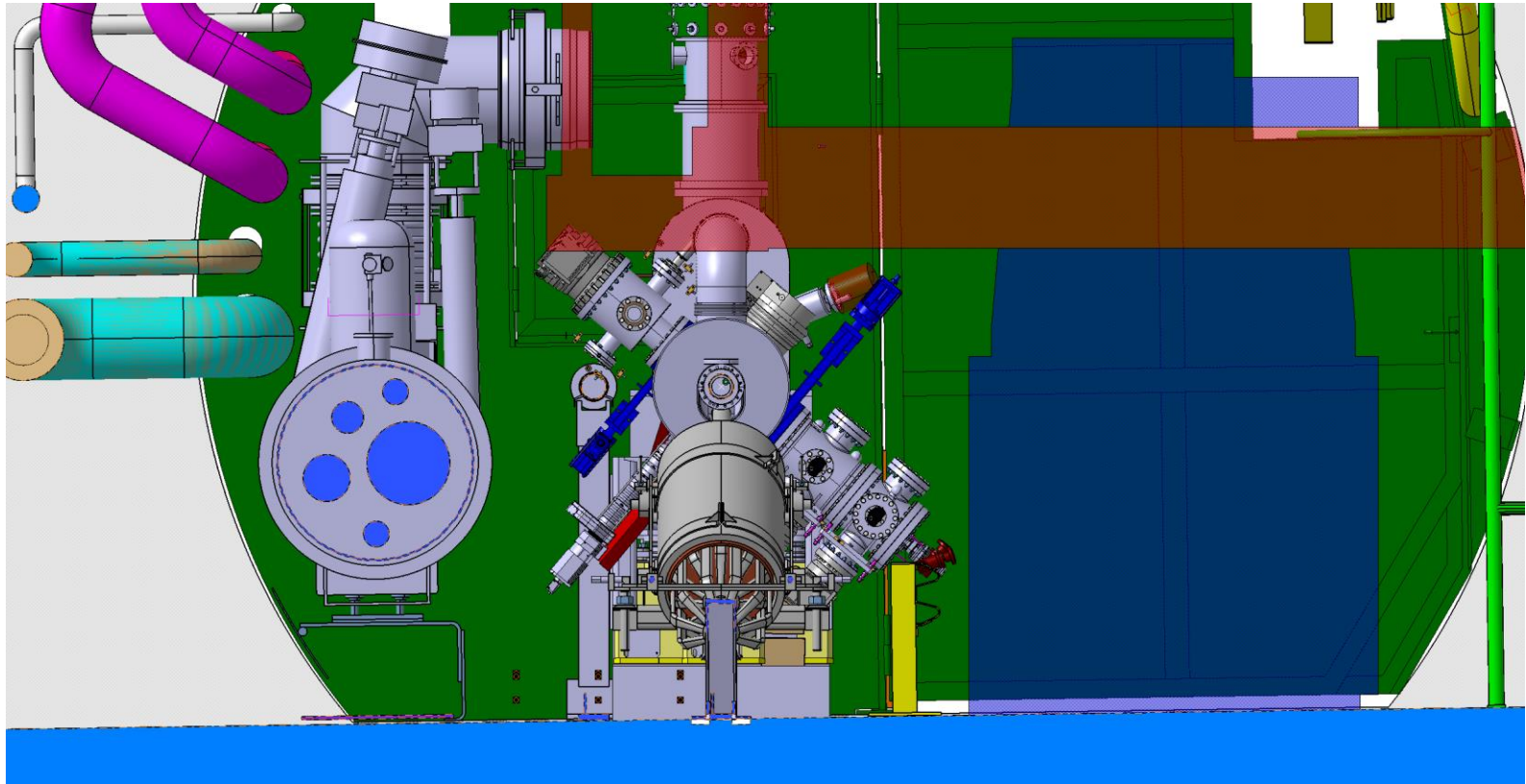
The BGC Team

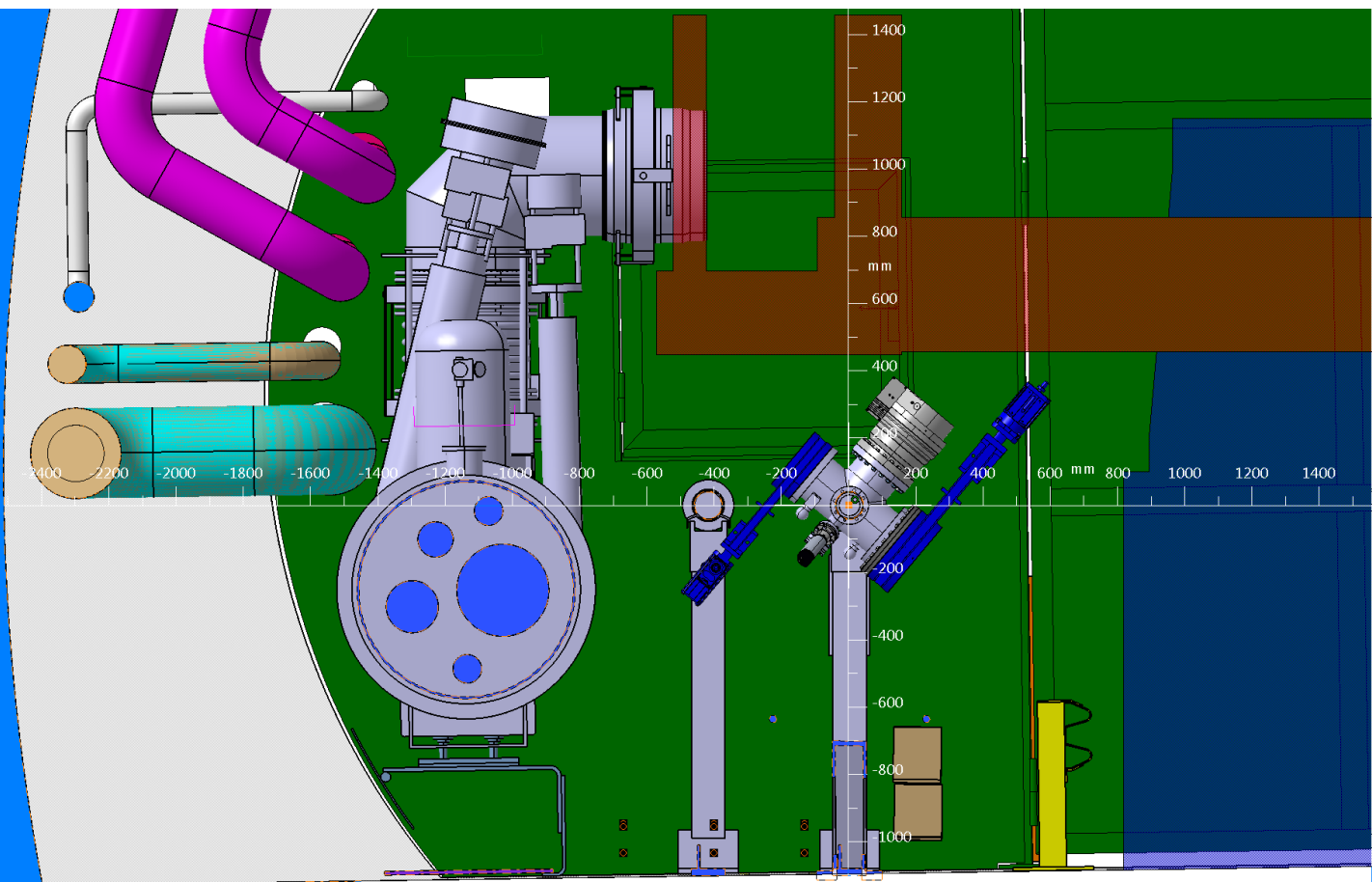
- The Cockcroft Institute (UK)
 - Experience and experimental equipment for beam-gas curtains (**C.Welsch, H.Zhang**)
 - Part of the High-Lumi/UK framework collaboration (WP3-Beam diagnostics) which includes co-funding for researchers, an experimental programme and construction of 2 prototypes
- GSI (DE)
 - Expertise in luminescence monitoring (**P.Forck, S.Udrea**)
 - Collaboration agreement upto end 2017
- CERN
 - Instrument design, optics and integration expertise (BE-BI) (**E.Bravin, T.Dodington, S.Mazzoni, R.Jones, G.Schneider, R.Veness**)
 - Molecular gas flow simulation expertise (TE-VSC) (**M.Ady, R.Kersavan**)
 - Integration into LHC vacuum (TE-VSC) (**V.Baglin, G.Bregliozzi**)
 - LHC Impedance studies (BE-ABP) (**G.Mazzacano, B.Salvant**)
 - Mechanical design (EN-MME) (**N.Chritin**)
- Wroclaw University of Science and Technology (PL)
 - Expertise in computational fluid dynamics simulations for supersonic gas jets (**S.Pietrowicz, P.Smakulski**)
 - Collaboration under preparation

p @ 4,757 MeV/u



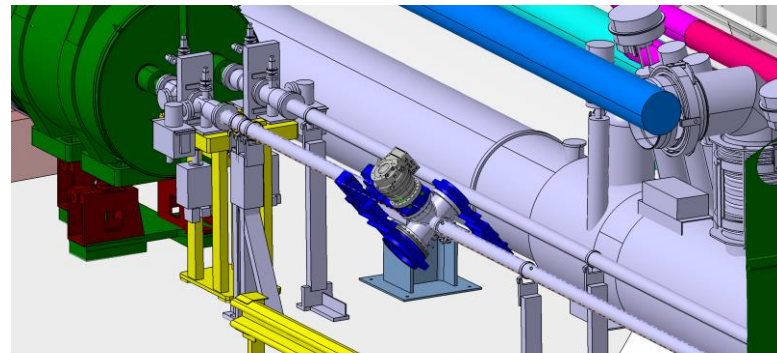




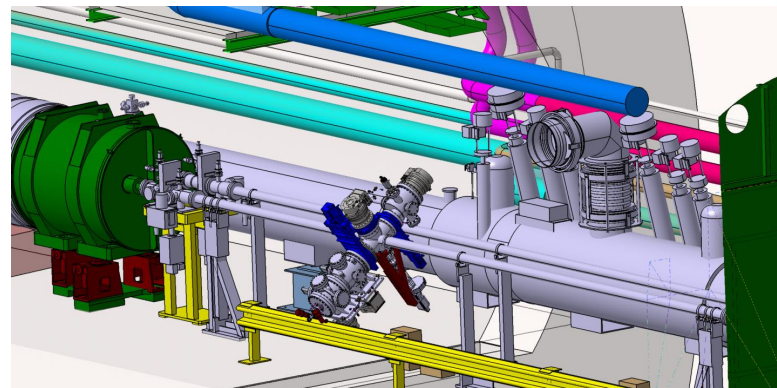


Phased installation during LS2 in the LHC

- 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