



UNIVERSITY OF
LIVERPOOL



The Cockcroft Institute
of Accelerator Science and Technology



Science and
Technology
Facilities Council



Beam Gas Curtain – Tests with electron beams

Ondrej Sedlacek for BGC Collaboration Team

Ondrej.Sedlacek@cern.ch

Thursday 12:10 Hall XI - *Status of fluorescence tests with protons in the LHC*



12th HL-LHC collaboration meeting 20 09 2022 Uppsala

Content

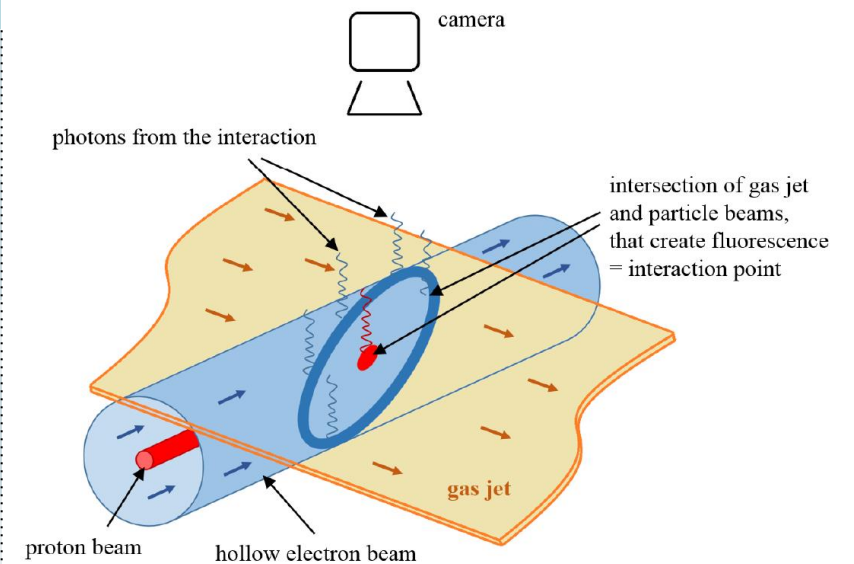
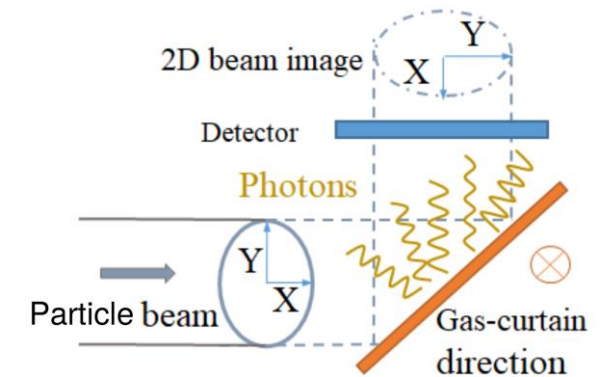
- Introduction to Fluorescence Induced diagnostics
- Experimental results from Beam Gas Curtain at Cockcroft Institute
 - Electron beam profile measurements
 - Gas Curtain measurements and simulations
- Transport to CERN & commissioning
- Summary
- Outlook – goals for BGC at EBTS and LHC

Principle of Beam Induced Fluorescence diagnostics

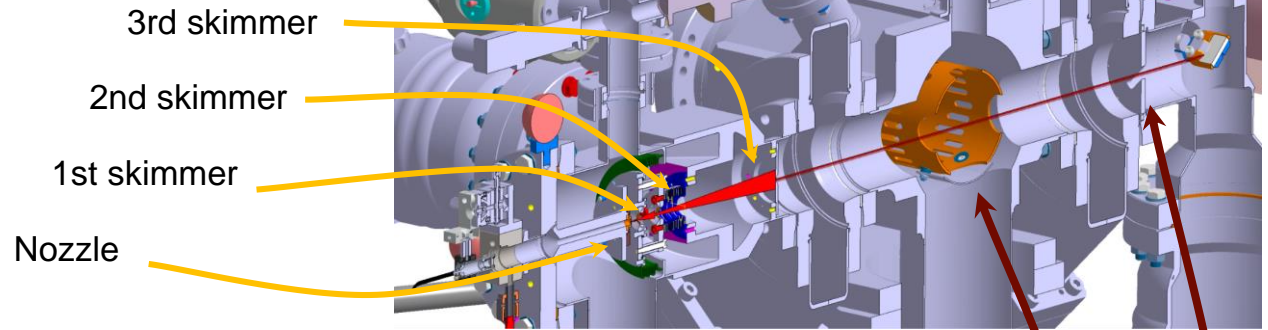
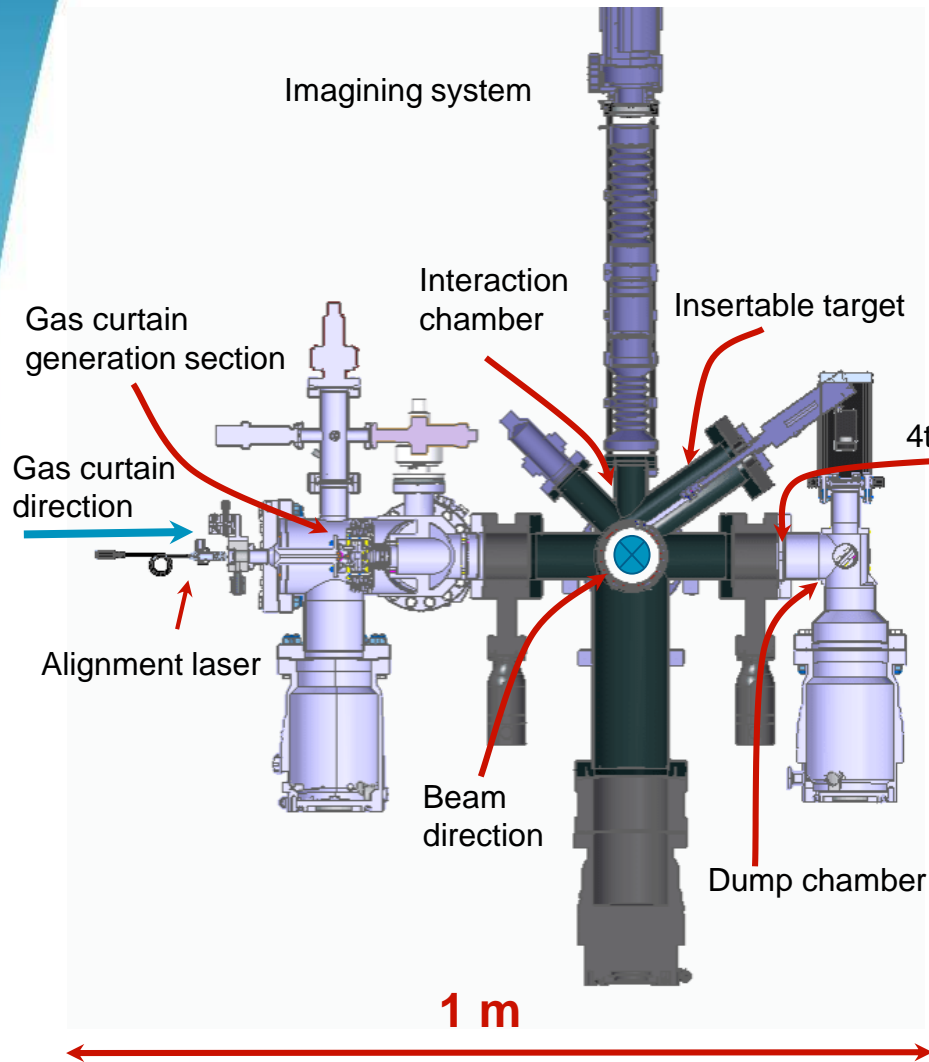
- Particle beam passing through gas gives rise to a fluorescence (among other processes)
- Gas curtain allows:
 - Minimally invasive to particle beam and vacuum level
 - High local gas pressure – higher signal and resolution
 - 2D image with one imaging system
 - Photon yield given by:

$$N = \frac{I}{e} \cdot \sigma \cdot \frac{\Omega}{4\pi} \cdot T \cdot \eta_{pc} \cdot \eta_{MCP} \cdot d \cdot n$$

Parameter	Value
σ	Fluorescence cross-section
Ω	Solid angle
T	Transmittance of the imaging system
I	Beam current
$\eta_{pc} \cdot \eta_{mcp}$	Quantum efficiency of photocathode and MCP
d	Gas curtain thickness
n	Gas curtain density

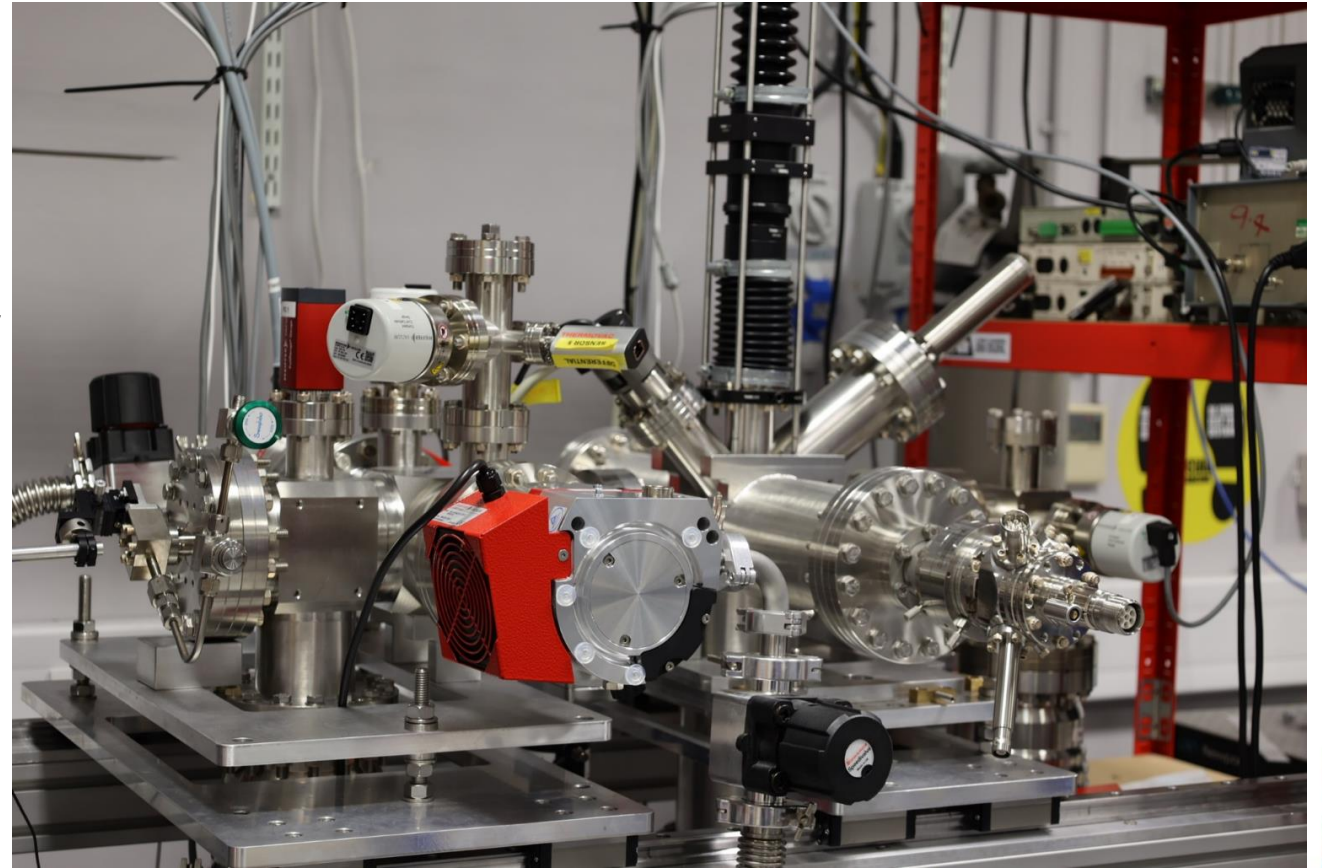
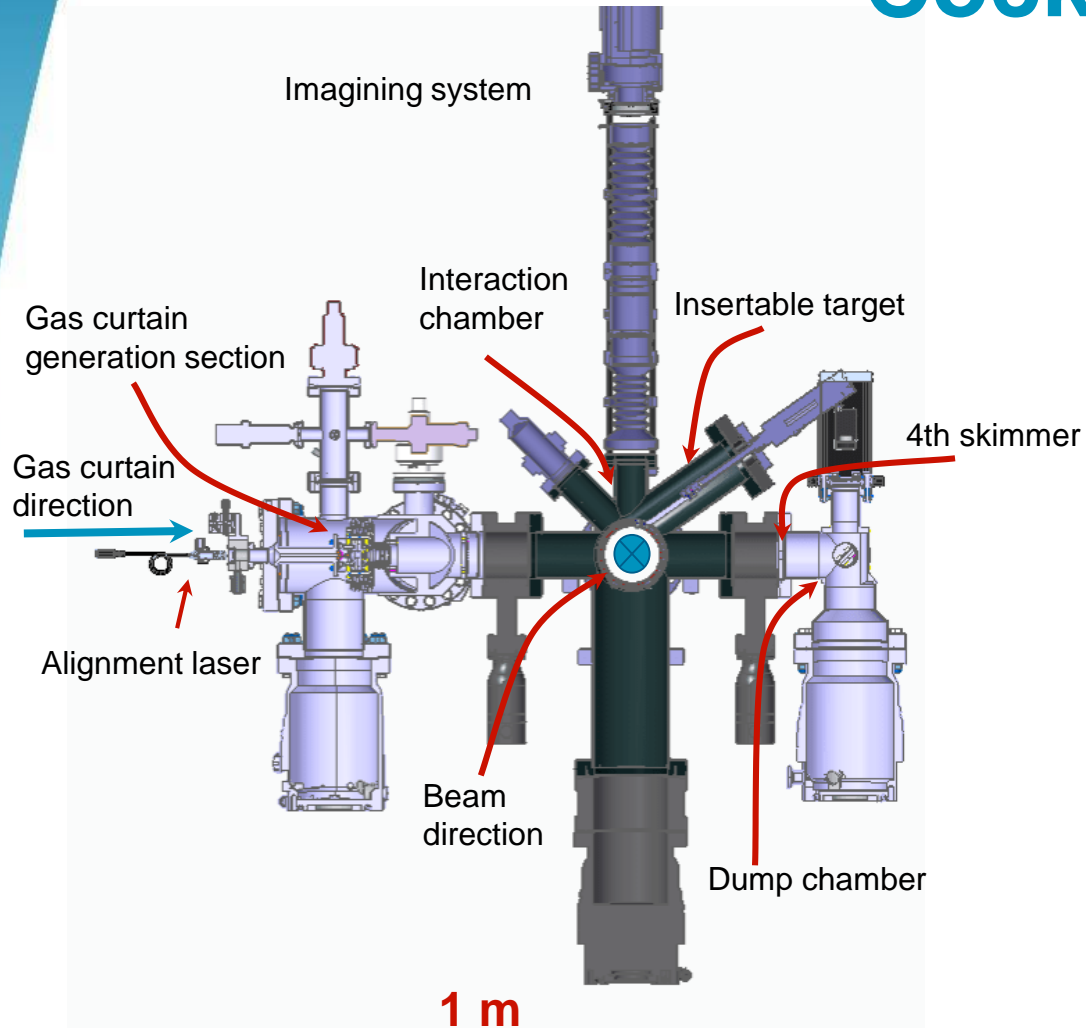


Beam gas curtain Version 3 (V3)

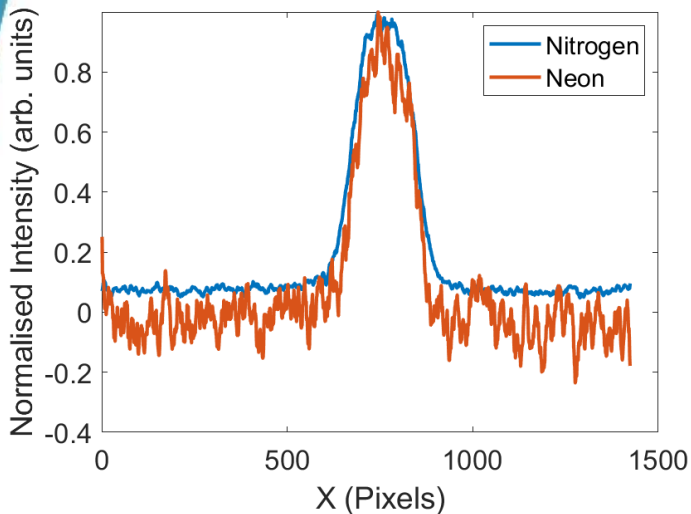


- Compact design while increasing gas curtain density → signal strength
- Special designed contrast plate with multilayer coating
 - Reflectivity of 0.2-0.5 % at wavelength of interest (585.4 nm)
- Fourth skimmer at entrance of dump chamber reducing back-scattering → improving interaction chamber pressure

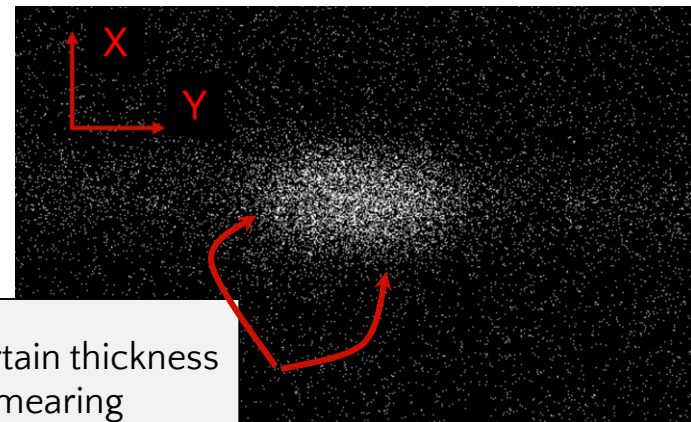
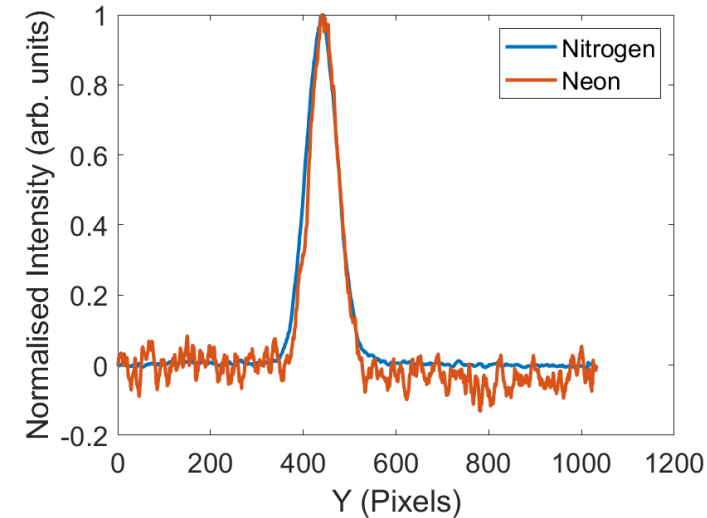
Beam gas curtain monitor Version 3 (V3) at Cockcroft Institute



Gas curtain e-beam profile measurements



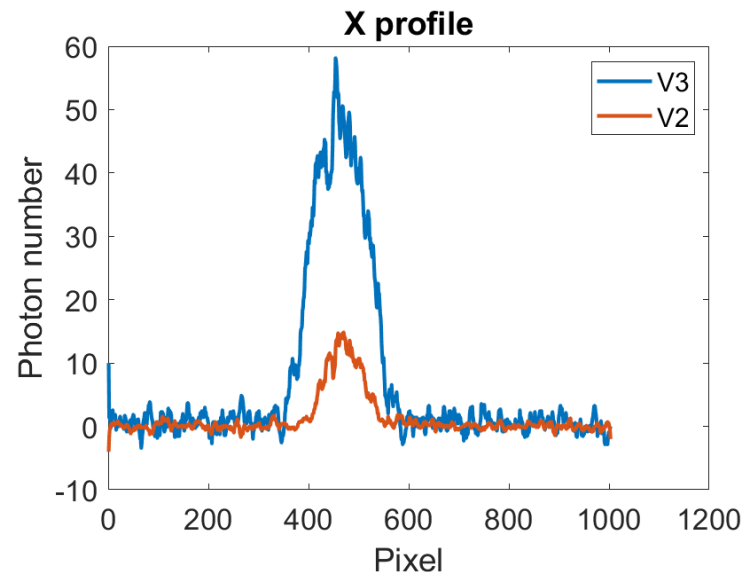
Electron beam imaged using Nitrogen/Neon curtain at 5bar of inlet pressure.
Total integration time set to 200s/2000s



Electron beam at 5 keV imaged using Nitrogen curtain at 5bar of inlet pressure.
Total integration time set to 30s

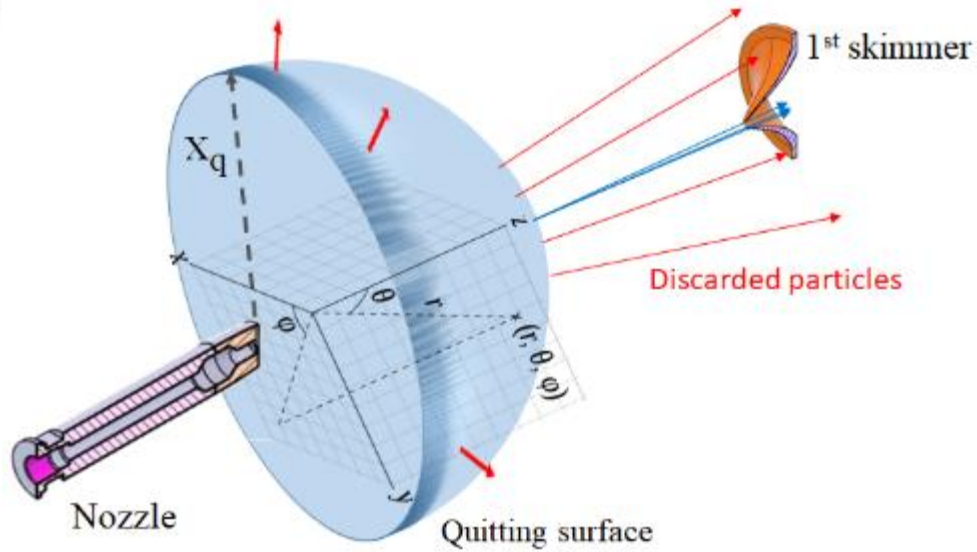
- V3 - Photon rate:
 - Ne - 22 s^{-1}
 - N₂ - 300 s^{-1}
 - N₂/Ne - 5

- Factor of ~20 improvement between V2 and V3
- Due to increase in curtain density

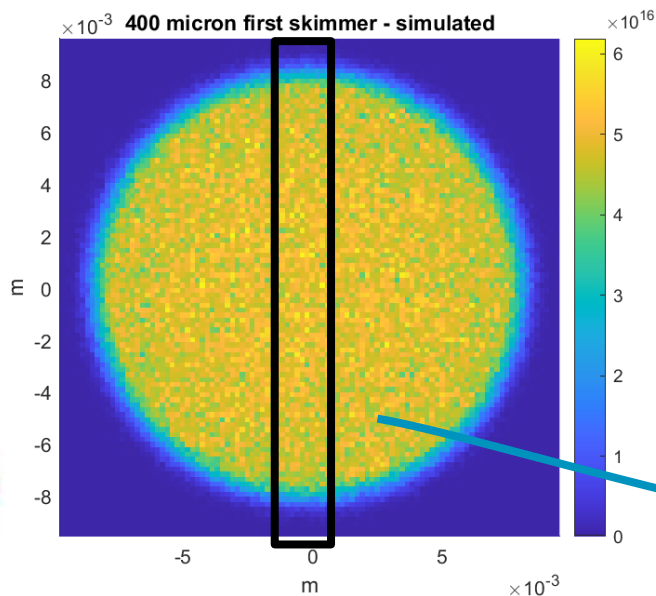


Gas curtain simulation

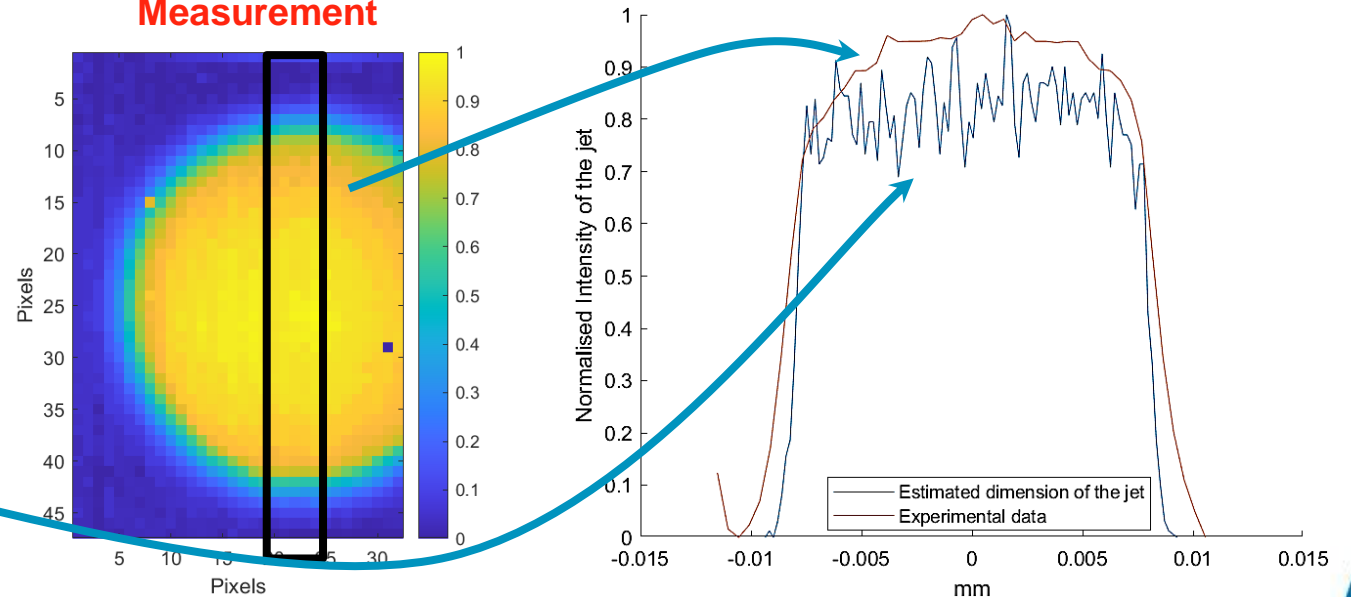
- Optimizing skimmer sizes – many parameters
- Hybrid simulation tool to predict curtain distribution
 - Continuous flow – Analytical
 - Molecular flow – Particle tracking
- Verified with measurements at V2



Simulation



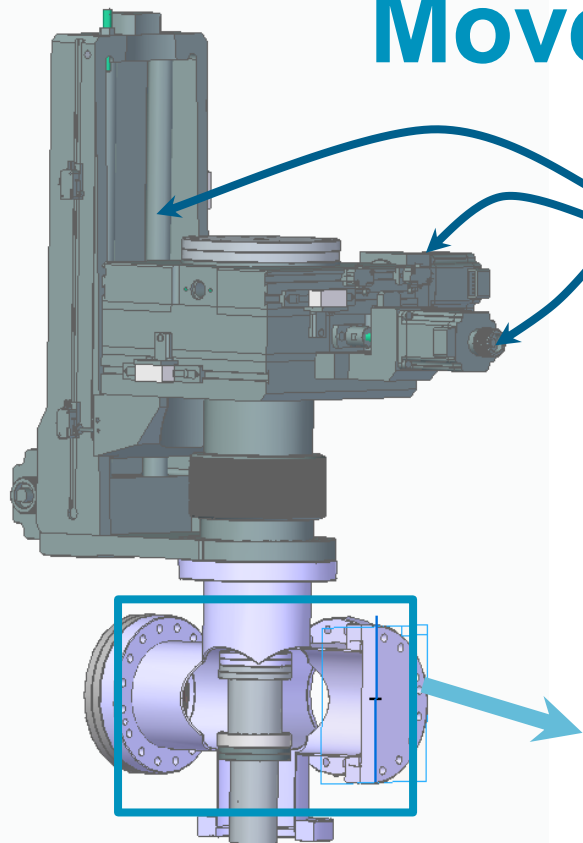
Measurement



Gas curtain simulation and measurement before 3rd skimmer

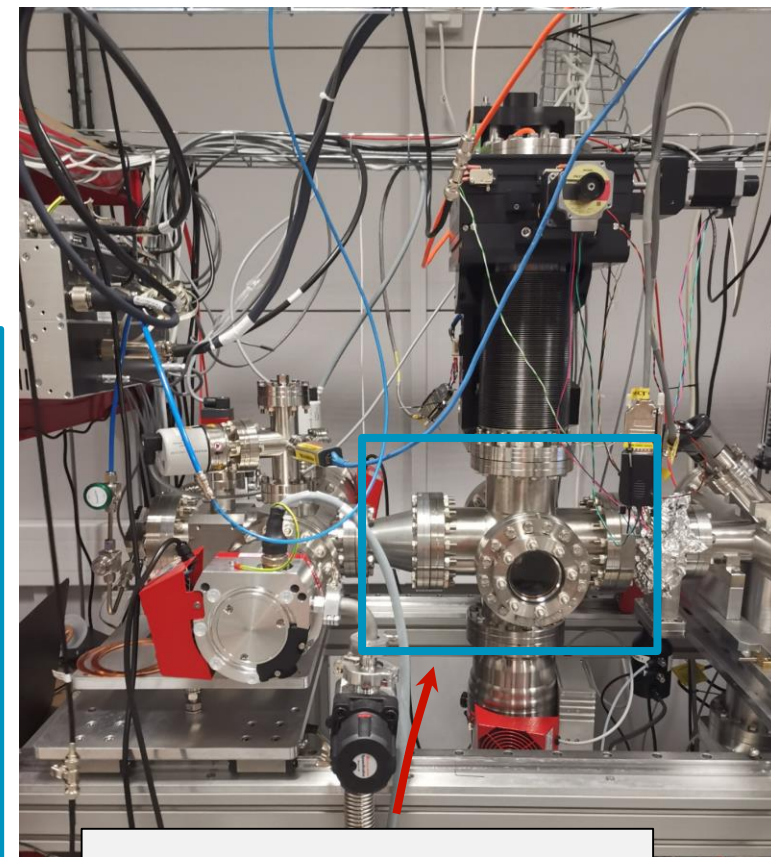
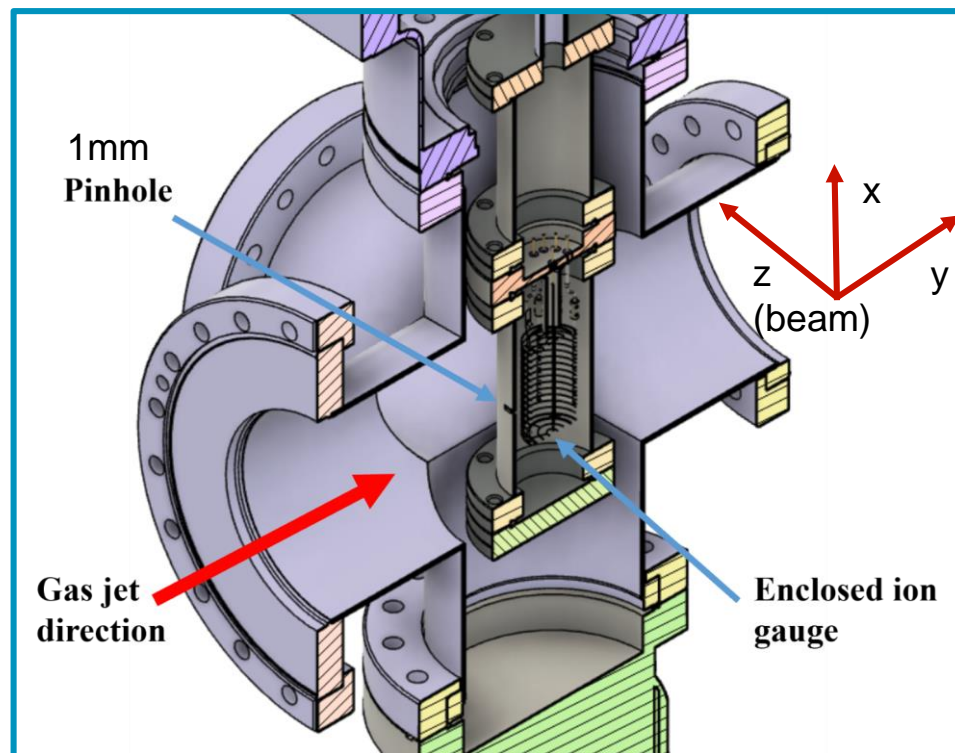
Direct gas curtain profile measurements

Moveable pinhole pressure gauge



Steppermotors in all 3 dimensions

Local gas pressure measurement



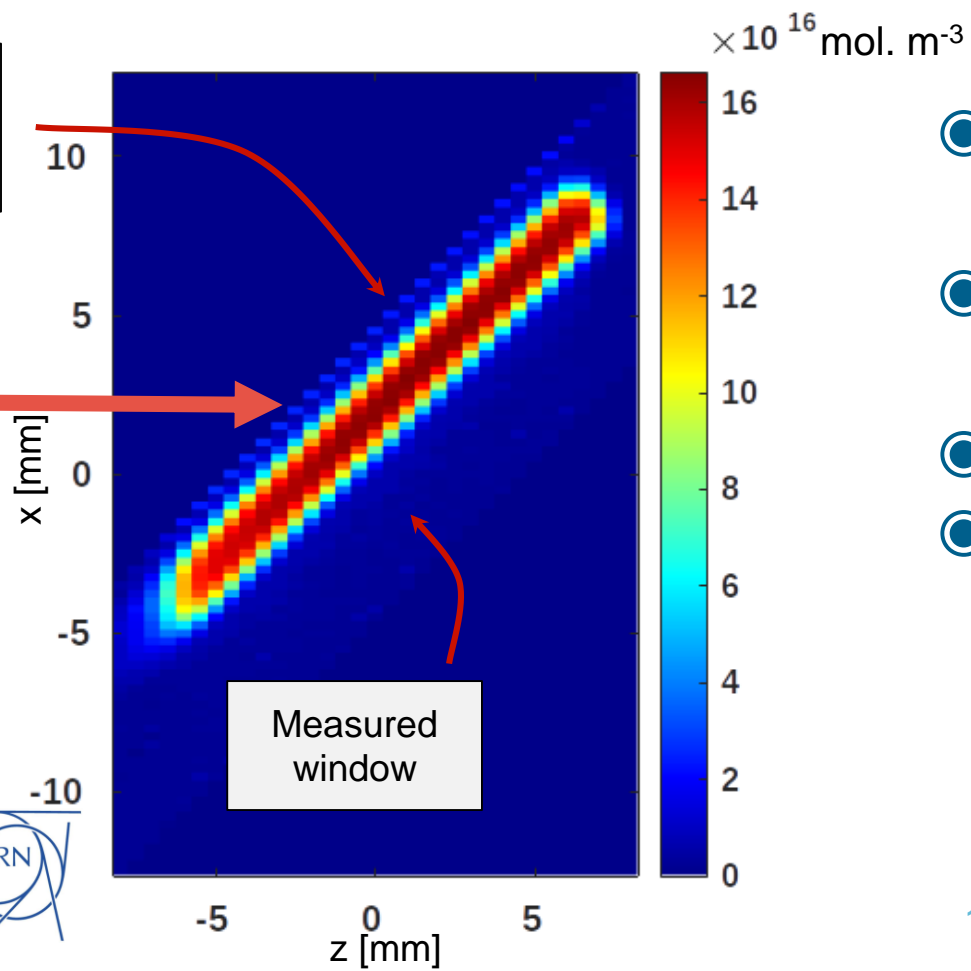
Replaces interaction chamber -> **Measuring Gas curtain profile at interaction point**

Gas curtain profile measurement

Inlet pressure (gas curtain)	Nozzle (30 μm) [mbar]	1st skimmer (400 μm) [mbar]	2nd skimmer (2 mm) [mbar]	3rd skim. (0.7x9 mm) - Interaction chamber [mbar]	Dump chamber [mbar]
Off	$<5.0\text{e-}9$	$1.2\text{e-}9$	$7.3\text{e-}9$	$1.5\text{e-}9$	$2.9\text{e-}9$
5 bar	$5.3\text{e-}3$	$9.2\text{e-}6$	$1.1\text{e-}6$	$8.8\text{e-}9$	$1.3\text{e-}7$

Ne gas curtain profile

Beam direction



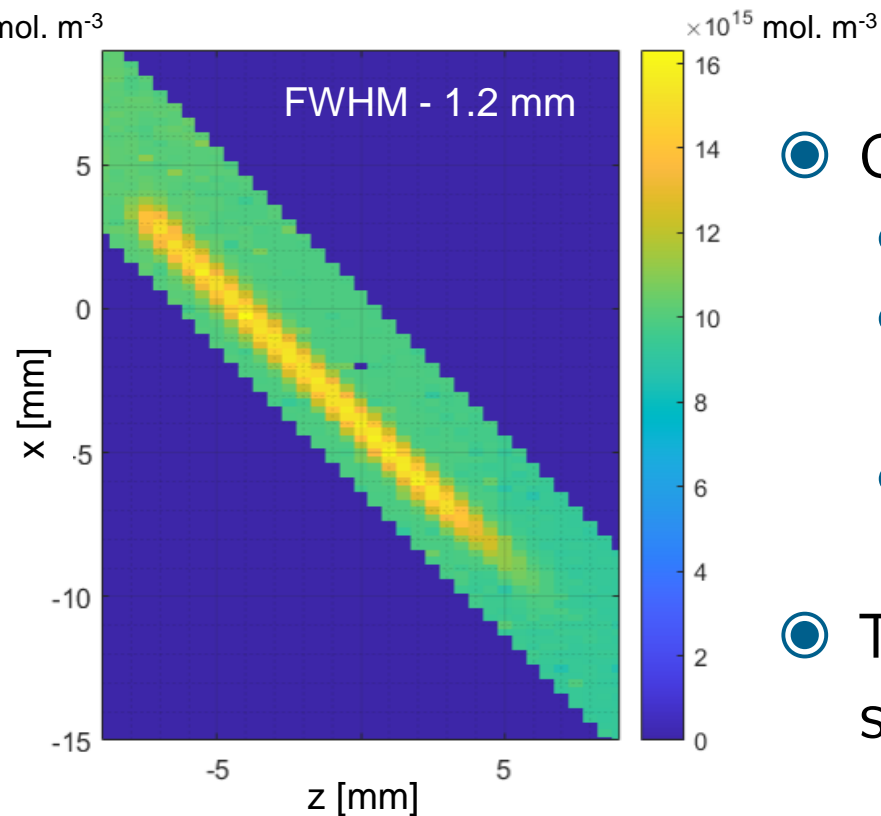
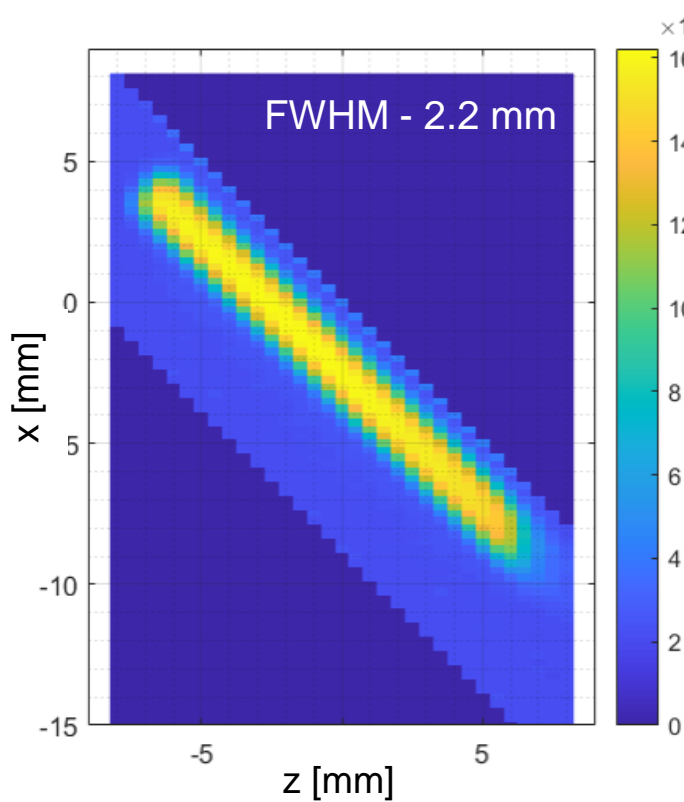
- Each pixel - 1 moveable gauge position
- Curtain Profile stable and homogeneous
- Reaching $\sim 16 \cdot 10^{16} \text{ mol./m}^3$
- Consistent with design prediction by S. Urea and P. Forck, "Milestone 1.6 report" (2018)

Gas curtain thickness tuning

3rd skimmer -
0.7 x 9 mm

N₂ Gas curtain
measurements at
5bar

3rd skimmer -
0.3 x 9 mm



● Changing the 3rd skimmer thickness \rightarrow 0.7 x 9 mm vs 0.3 x 9 mm

- Changes gas curtain thickness
 - Simulation - 2.10 & 1.18 mm
 - Measur. - 2.20 vs 1.17 mm
 - Keeps peak density comparable
- Trade off between signal strength and profile smearing

Integration time estimation

Emitter	σ - Electron beam at 10 keV [cm ²]	σ - Proton beam at 7 TeV [cm ²]	Photon yield - electron beam [s ⁻¹]	Photon yield - proton beam [s ⁻¹]
Ne (585.4nm)	1.4e-20	4.7e-22	2.5e4	1.7e2

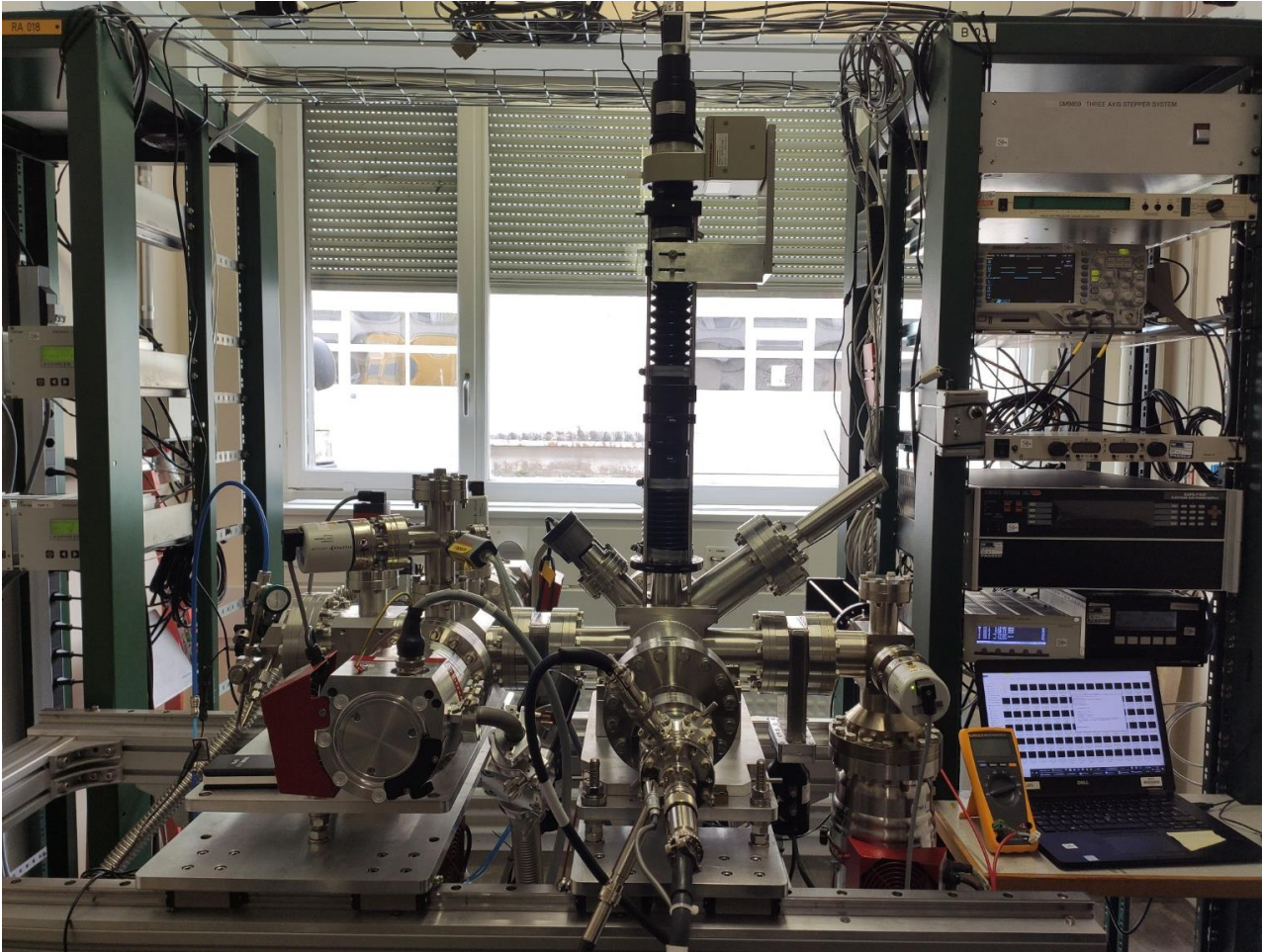
- Based on extrapolated cross sections and measured gas curtain density the integration times should be < 1s for LHC beam
- Exact integration times is subject to:
 - Thickness of gas curtain
 - Exact value of cross-section - Fluorescence tests with protons in the LHC are ongoing → Thursday presentation
- N₂ is considered as a possible working gas due to higher cross-section by a factor of ~ 5, however, is pumped by NEG → a saturation of LHC NEG coating, Ne is therefore, a baseline working gas

Transport of BGC Version 3 to CERN

17th May 2022

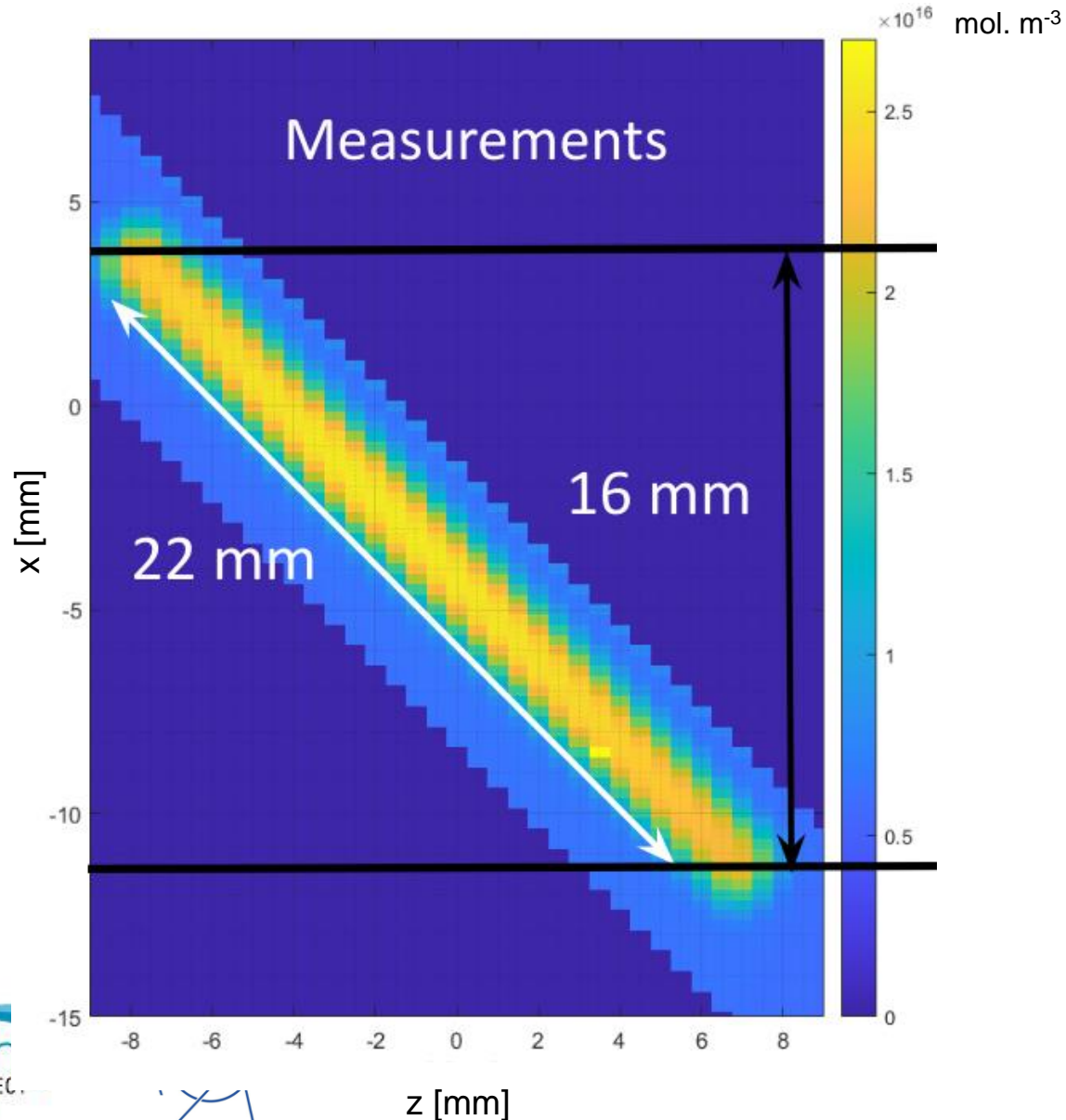


BGC Version 3 to CERN - Commissioning



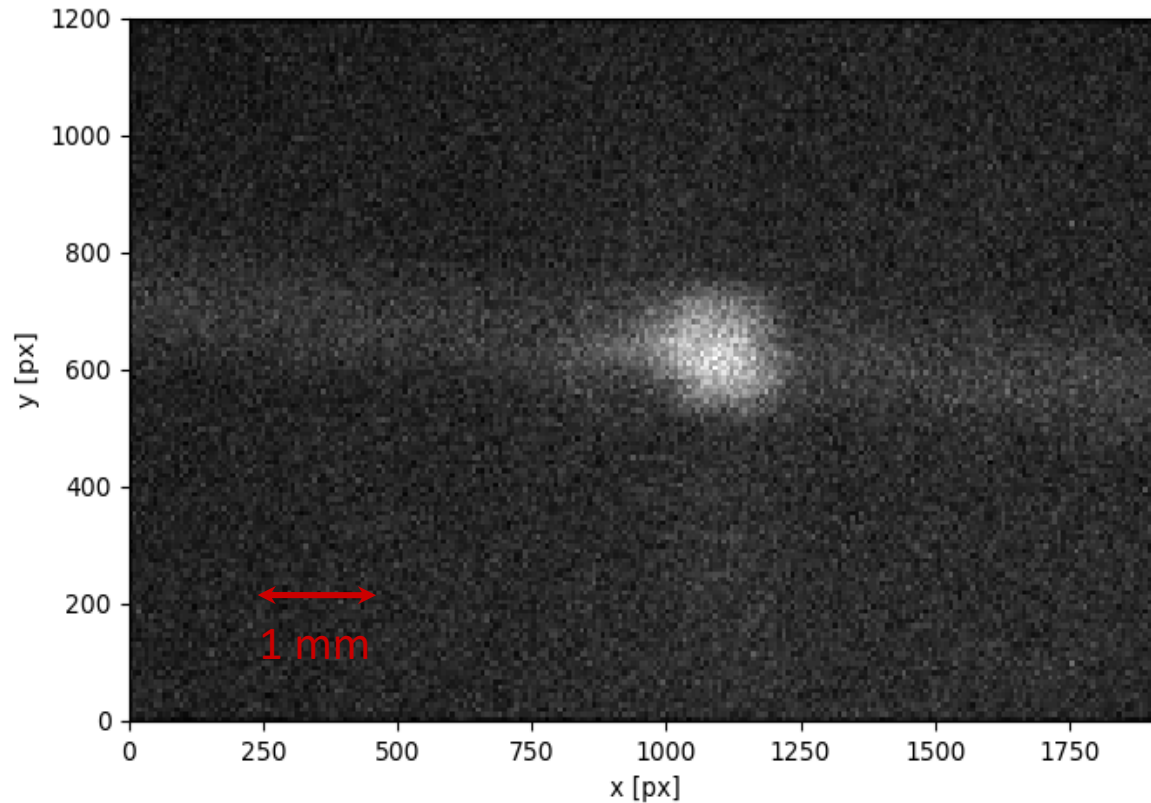
- Full assembly in one week
 - Including vacuum pump down tests - Successful
- Alignment of nozzle-skimmer assembly - Successful
 - Including building alignment setup at CERN

BGC Version 3 to CERN - Commissioning



- Full assembly in one week
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- Alignment of nozzle-skimmer assembly - Successful
 - Including building alignment setup at CERN
- Moveable pressure gauge installed & Gas curtain profile measured - Successful
 - Great agreement with simulations

BGC Version 3 to CERN - Commissioning

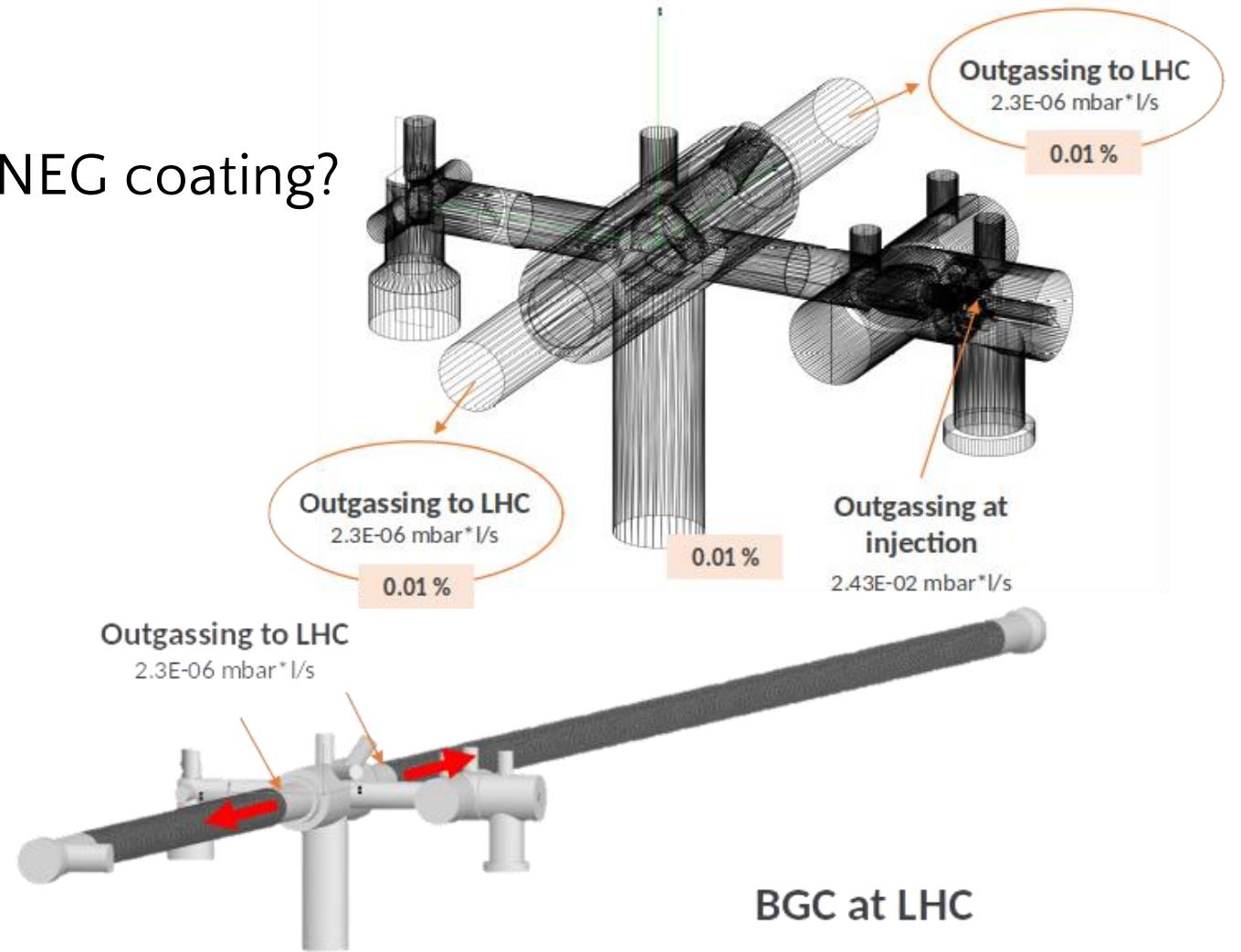
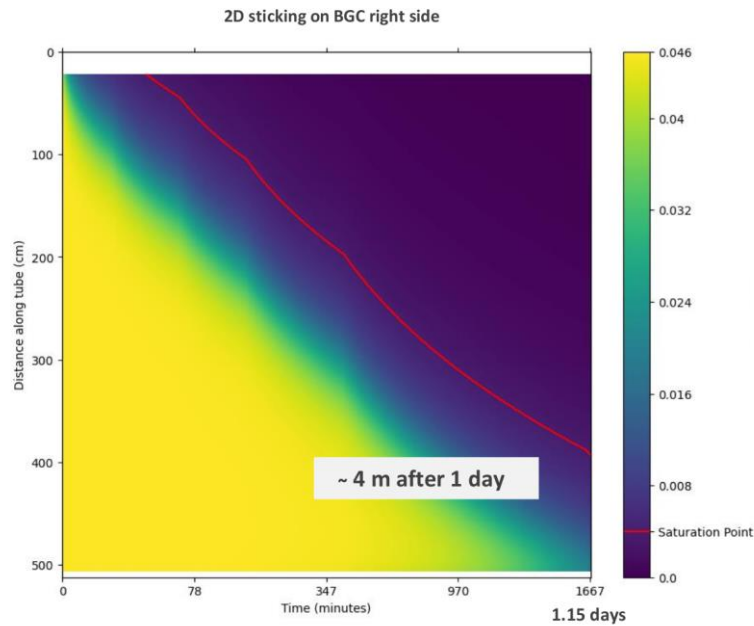


N_2 Gas curtain
measurements of a 1
mA electron beam at 5
keV and 100s int. time

- Full assembly in one week
 - Including vacuum pump down tests - Successful
- Alignment of nozzle-skimmer assembly - Successful
 - Including building alignment setup at CERN
- Moveable pressure gauge installed & Gas curtain profile measured - Successful
 - Great agreement with simulations
- E-beam profile measured - Successful

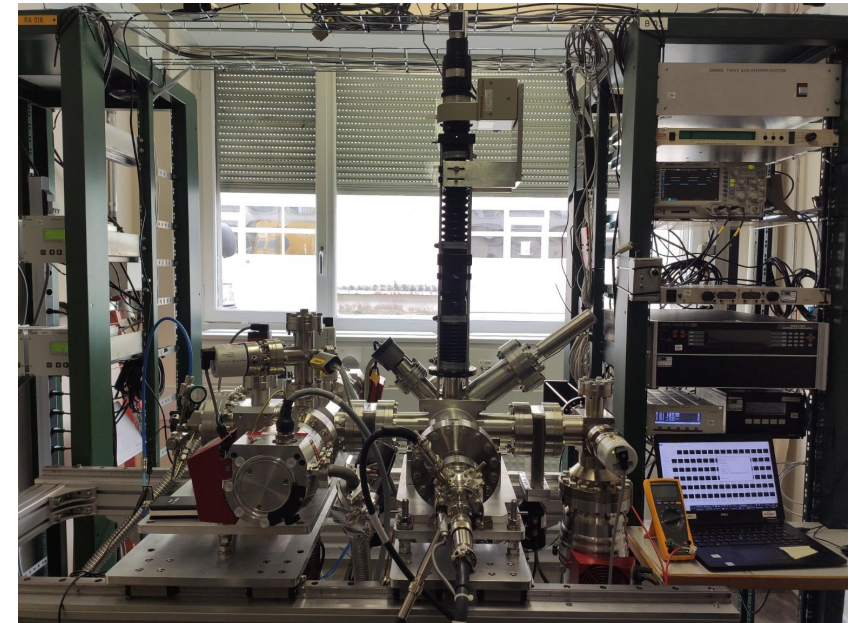
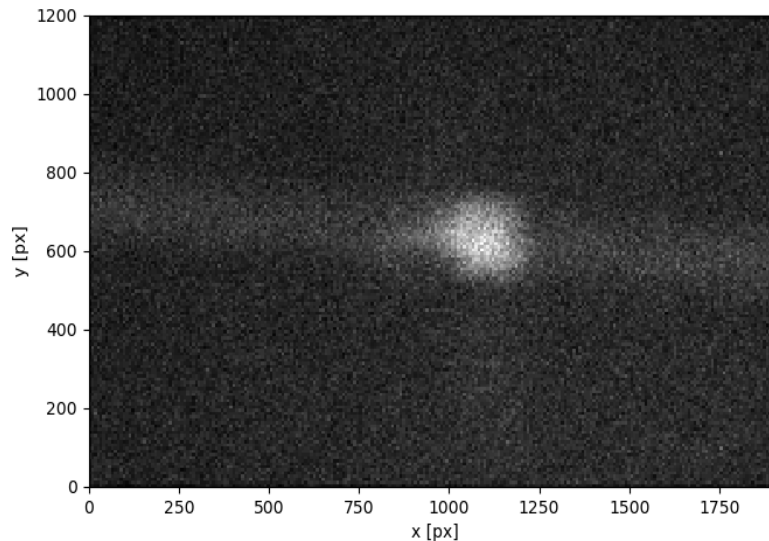
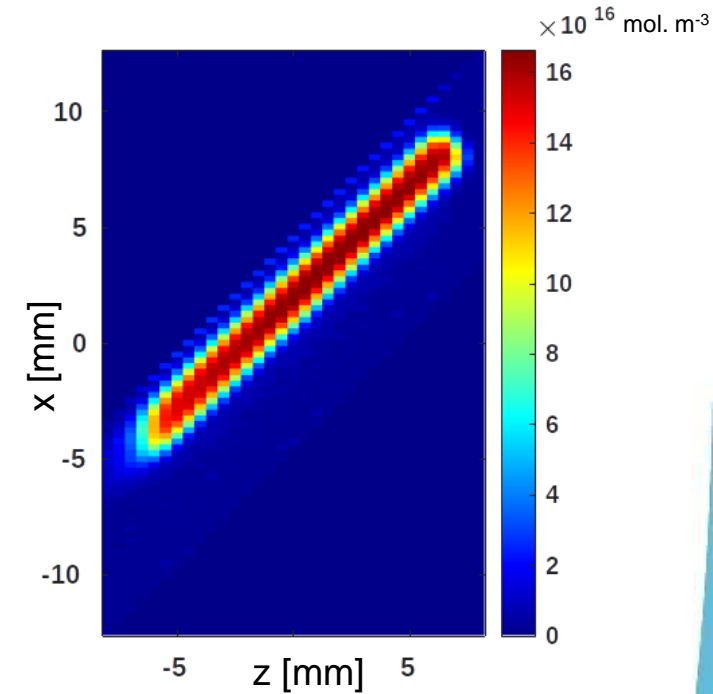
LHC Vacuum and LHC NEG coating saturation

- BGC Version 3 – Pump down curves being characterized to simulate effect on LHC vacuum
 - Bakeout needed ?
 - If N₂ jet – saturation of NEG coating?

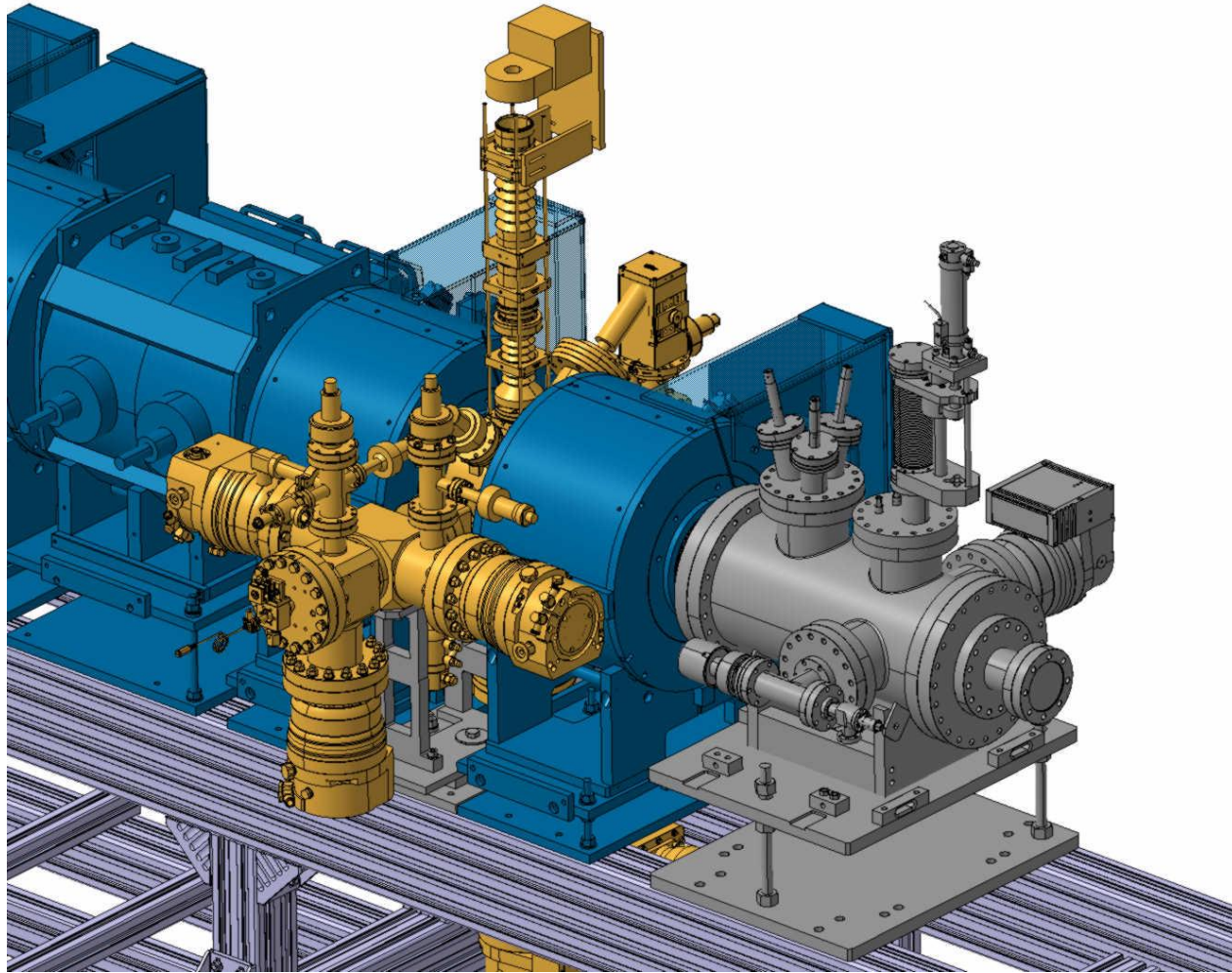


Summary

- Beam Gas Curtain monitor Version 3 assembled, tested, and optimized at Cockcroft Institute
 - Including direct gas curtain profile measurements
- Ne gas as a baseline working gas for LHC
- BGC Version 3 sent to CERN from Cockcroft Institute
 - Successfully assembled and tested

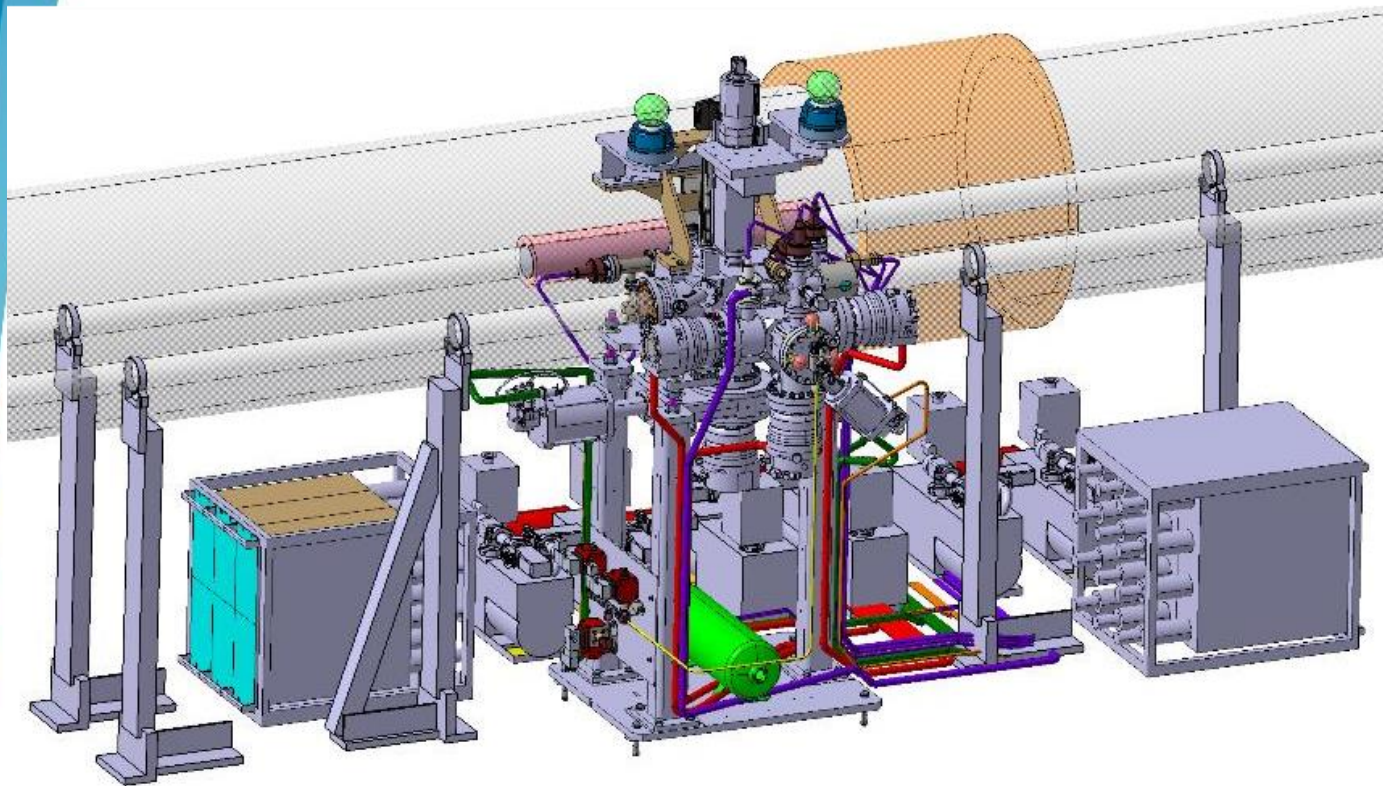


Outlook - goals of BGC at EBTS



- Installation on Electron Beam test stand - November 2022
- Measuring intense hollow electron beam profile
- Measure cross-section 10 keV
- Test electron trapping
- Test different working gasses:
 - Ne - LHC baseline
 - N₂ , Ar

Outlook - goals of BGC at LHC



- Installation in LHC - YETS 2022/23 - if possible
- Validating BGC with LHC beams
- Measuring 6.8 TeV proton beam with gas curtain for first time!
- Measure proton LHC beam transverse 2D profile



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Thank you for your attention!

Questions?

Ondrej.Sedlacek@cern.ch

Work presented on behalf of the BGC collaboration:

O. Sedlacek^{1,2}, M. Ady², A. R. Churchman², P. Forck³, T. Lefevre², S. Mazzone², M. Sameed², O. Stringer¹, A. Rossi², G. Schneider², C. Castro Sequeiro², K. Sidorowski², S. Udrea³, R. Veness², C. P. Welsch¹, H. D. Zhang¹,

¹ Cockcroft Institute and University of Liverpool, UK ² CERN, Geneva, Switzerland ³ GSI, Darmstadt, Germany



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