Characterization of High-energy and High-intensity Hadron Beams in the LHC using Beam Gas Curtain

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(BGC Collaboration)

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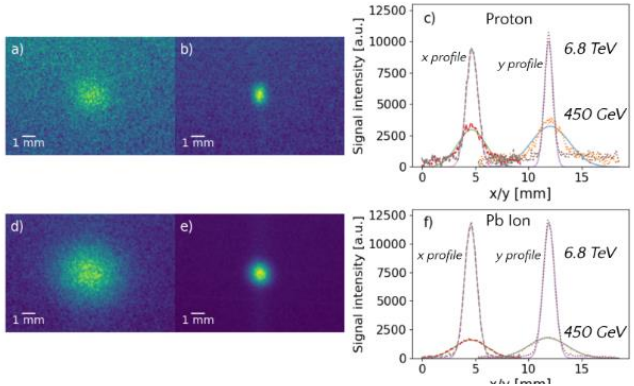
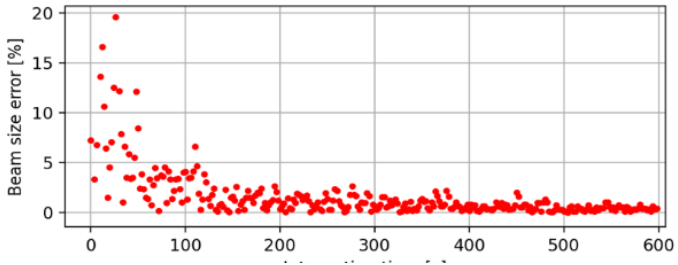
The large energy range and high intensity of current hadron accelerators such as the Large Hadron Collider (LHC) and its planned High Luminosity upgrade pose great challenges on beam measurements. The Beam Gas Curtain (BGC) presents an accurate, minimally invasive profile monitor with large energy range for high intensity beams, by exploiting fluorescence from a supersonic gas jet interacting with the accelerator particle beam. In this letter we report for the first time proton and lead ion beam transverse profile and emittance continuously measured throughout the whole LHC energy range.

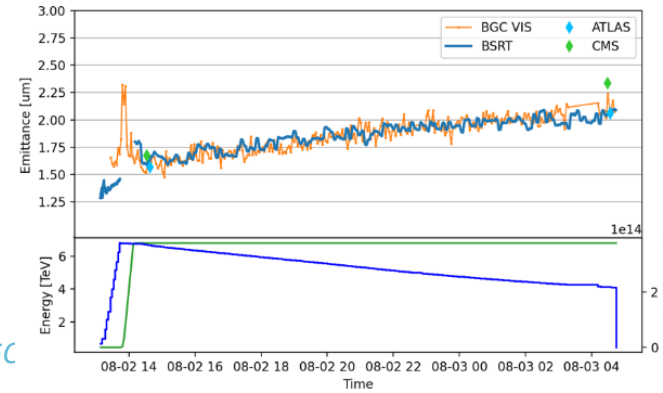
Thank you for comments & suggestions

Contents

- Introduction
  - Different methods of profile & emittance
- Experimental setup
  - Working principle
- Results
  - Sample signals at 450 GeV & 6.8 TeV
  - Systematic beam errors studies
  - Emittance measurements
    - Comparison to BSRT, Experiments & etc
- Summary
  - Where BGC fits (limitations of other installed monitors)







BGC

Remaining comments

- Introduction
  - Citations (also in other sections)
- Experimental setup
  - Figure 1) clarity
- Results
  - Binning
  - Text alterations

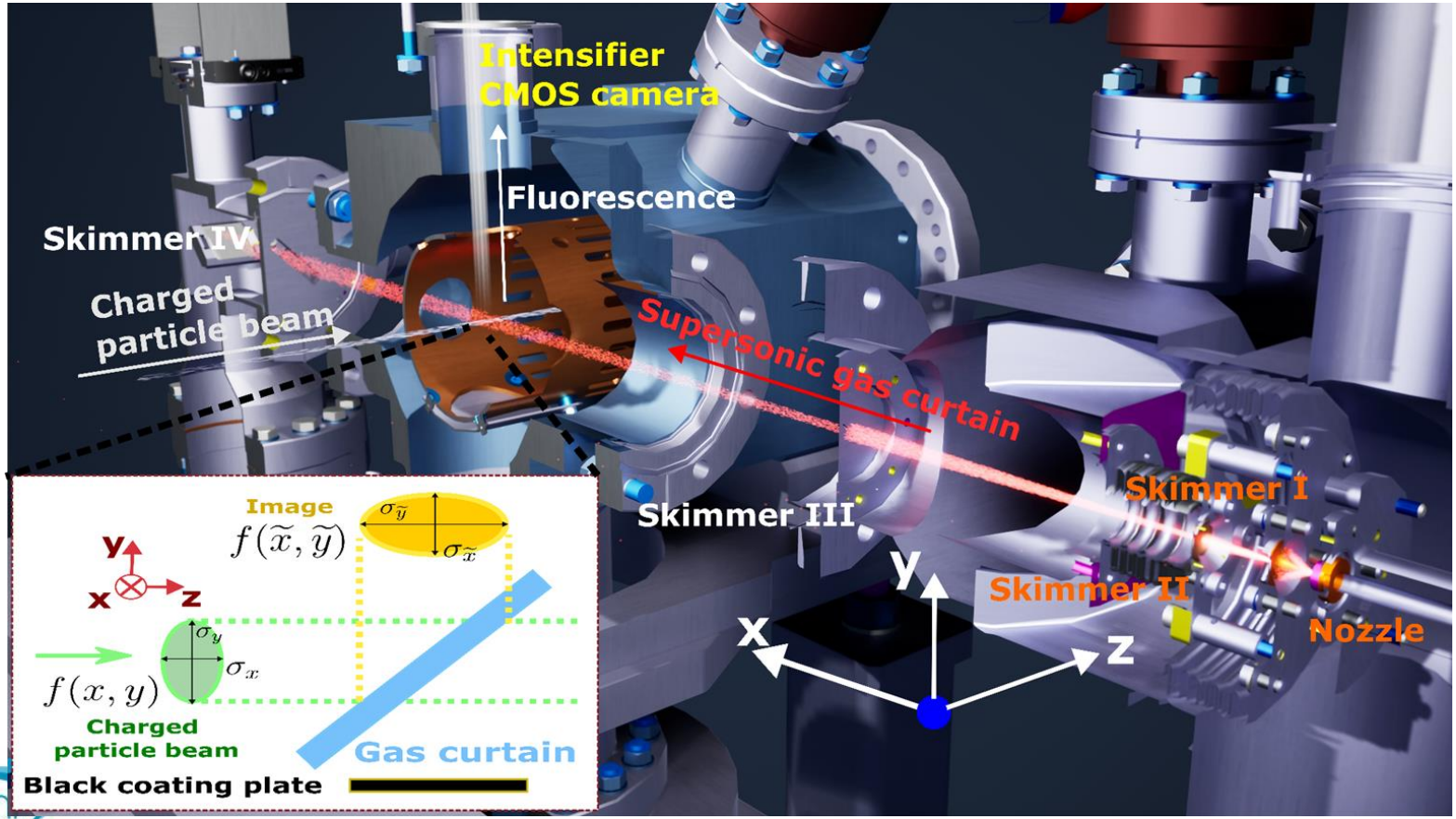
Citations

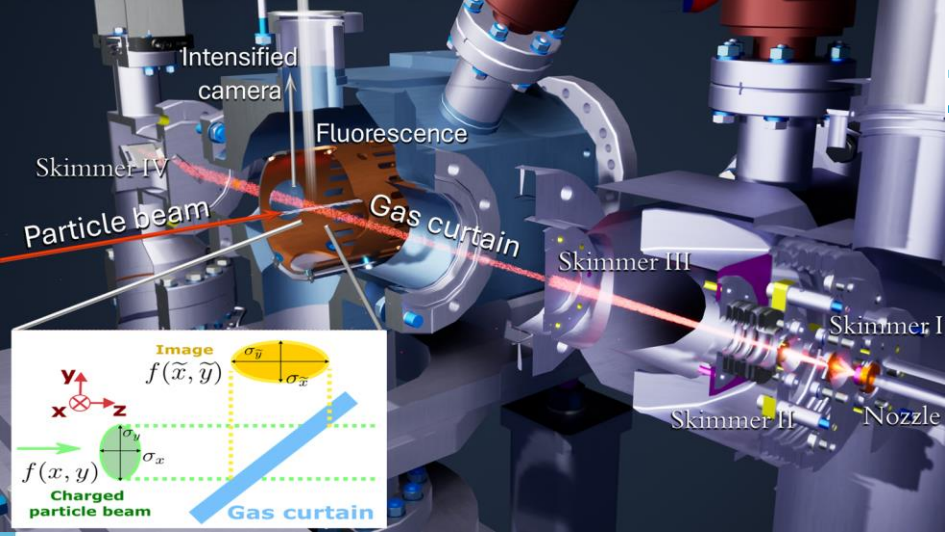
- BSRT
  - Some main paper about the monitor at LHC
  - Paper or proceeding with its PSF mentioned or calculated

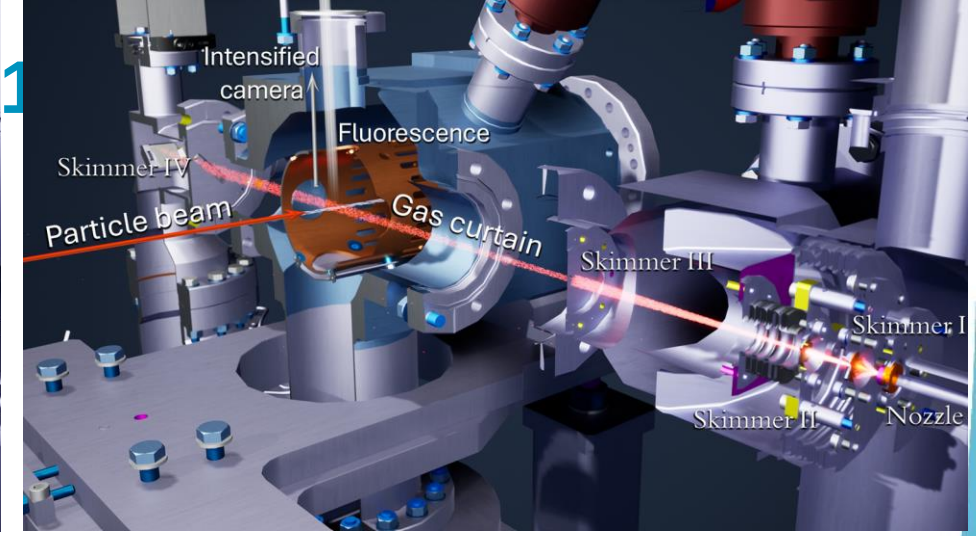
- LHC Wire scanner
  - Some main paper about the monitor at LHC

- BGI at LHC - Beam heating?
  - Is there paper or proceeding about BGI at LHC with the beam heating?
- Emittance scans at ATLAS and CMS

Figure 1 clarity




Intensified camera
Fluorescence
Skimmer IV
Particle beam
Gas curtain
Skimmer III
Skimmer I
Skimmer II
Nozzle
Image
$f(\tilde{x},\tilde{y})$
$\sigma_{\tilde{y}}$
$\sigma_{\tilde{x}}$
y
x
z
σ_y
σ_x
$f(x,y)$
Charged particle beam
Gas curtain


Intensified camera
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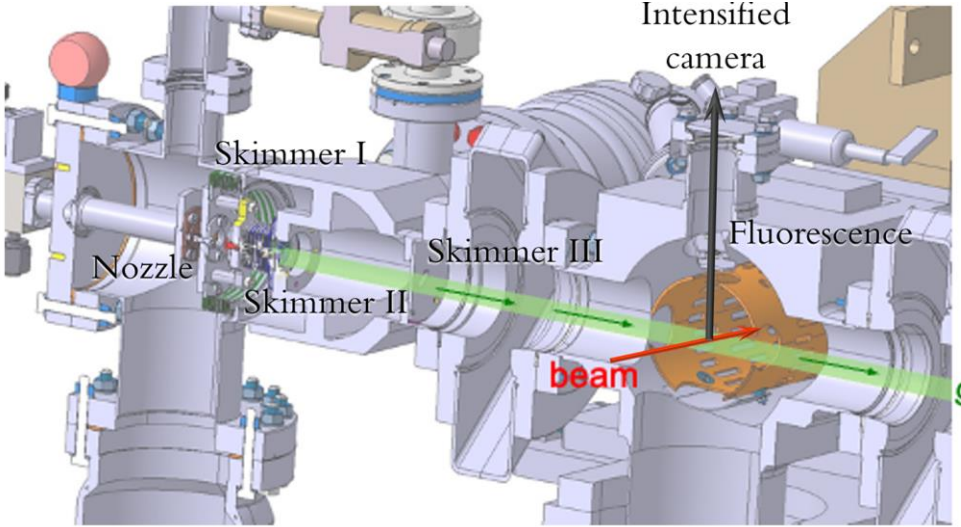
(1)


Intensified camera
Skimmer I
Nozzle
Skimmer III
Skimmer II
Fluorescence
beam
gas jet

(2)

(3)

Binning

size error. In comparison, the full intensity LHC lead ion beam with 1.32×10^{13} charges requires only about 5 seconds of integration time to reach a beam size error of approximately 3.5% at a collision energy of 6.8 TeV/Z, due to its higher signal-to-noise ratio. At an injection energy of 450 GeV/Z, the lead ion beam requires 20-30 seconds of integration time to reach $\leq$5% error, due to its larger transverse beam size.

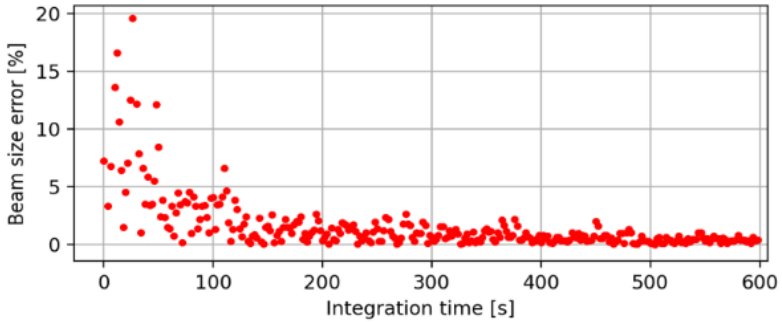


FIG. 3. Systematic studies of the BGC relative beam size error dependency on integration time, based on measurements of an LHC proton beam at full intensity (6.8 TeV/Z). An integration time of 60-120 seconds is sufficient for normal operation, yielding a beam size error of approximately 5%.

- No binning used in the studies
  - Might simply remove last sentence
  - Or mention expected lower light-yield
- Bethe-Bloch expects lower light-yield
  - ~2.7x lower at 450 GeV than 6.8 TeV
- Might benefit in future by binning

Limitations of other instruments

These achievements make the monitor a significant advancement in high-intensity beam profile measurements, addressing limitations present in the currently installed systems. Existing systems include the BSRT, a synchrotron radiation-based monitor a main bunch-by-bunch emittance monitor at LHC; emittance scans at the ATLAS and CMS experiments; and wire scanners. The BSRT is intrinsically limited in resolution due to diffraction of the observed spectrum and requires regular calibrations with wire scanners. Additionally, it can only measure lead ion beams at collision energy due to insufficient signal at lower energies. For proton beams, the BSRT must switch sources from an undulator to a dipole during the energy ramp, which renders it inoperable during this phase. Wire scanners, meanwhile, can only handle a limited number of bunches at a time to avoid wire breakage. Emittance scans at the experiments can operate at varying energies and higher intensities, however, the measurements couple the sizes of both beams and have other resolution and accuracy limitations. A Beam Gas Ionization monitor, previously installed at the LHC, suffered from beam heating issues originated by beam coupling impedance and was eventually decommissioned.

- No citations
  - Probably hard to find papers mentioning limitations?
- No quantification
  - Would require probably more extensive comparison (e.g. BSRT limited resolution)

Thank you for your attention!
Questions?

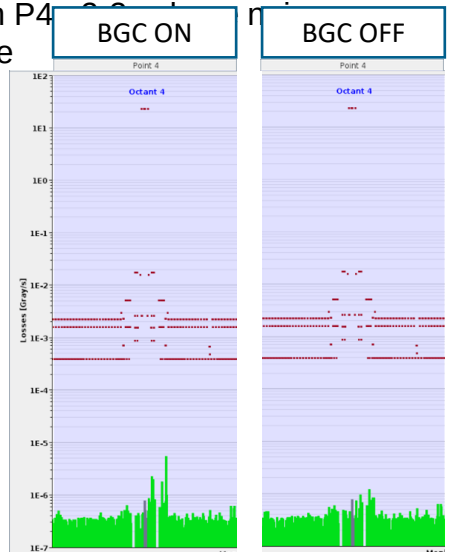
Working conditions

P4: 5L4
Beam 1

- BGC operated and validated on standard full intensity (Injection->Ramp->Stable Beams) for proton and ion beam

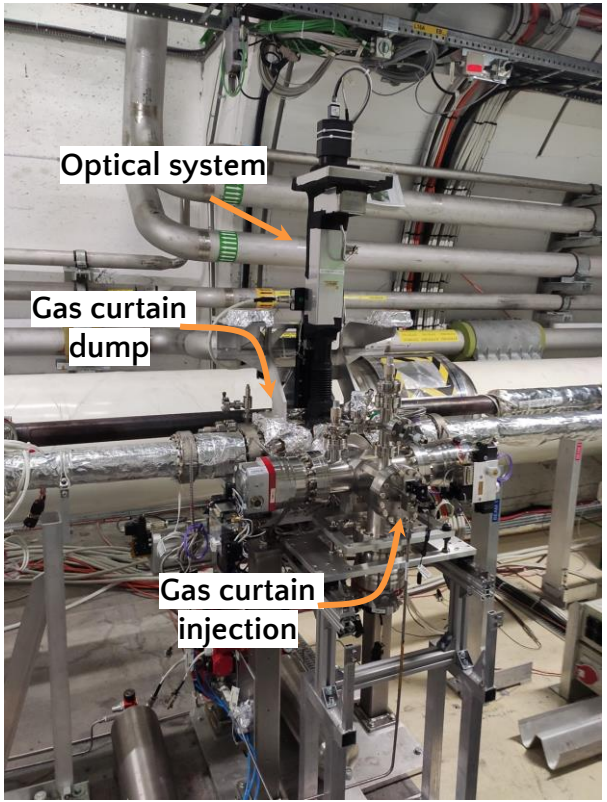
Interaction chamber (VGP.4a.5L4.BGC)	Pressure [mbar]
Gas Jet OFF	2.0e-10
Gas Jet On	4.00e-8

- Beam losses
  - Beam Injection - no losses above noise in Fixed display
  - Stable beams - local increase in P4
  - No observed effect on emittance



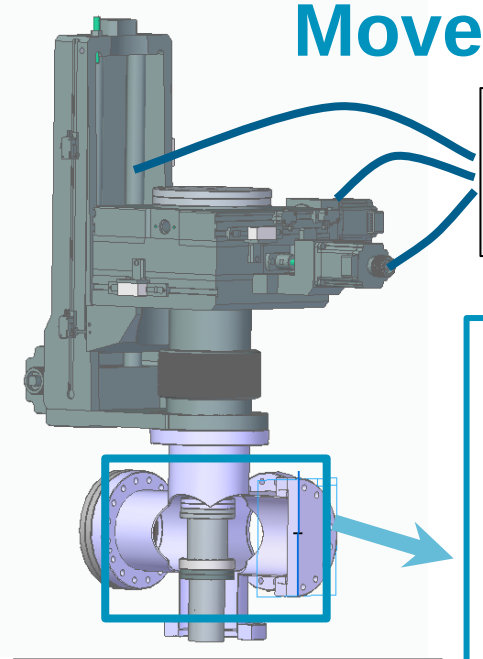
- BGC in 2023 on LHC p-beam ~10h
  - Validation - ok
  - Systematic studies needed

- BGC in 2023 on LHC Pb-beam >70h
  - Validation - ok
  - Systematic studies done
    - Being analysed

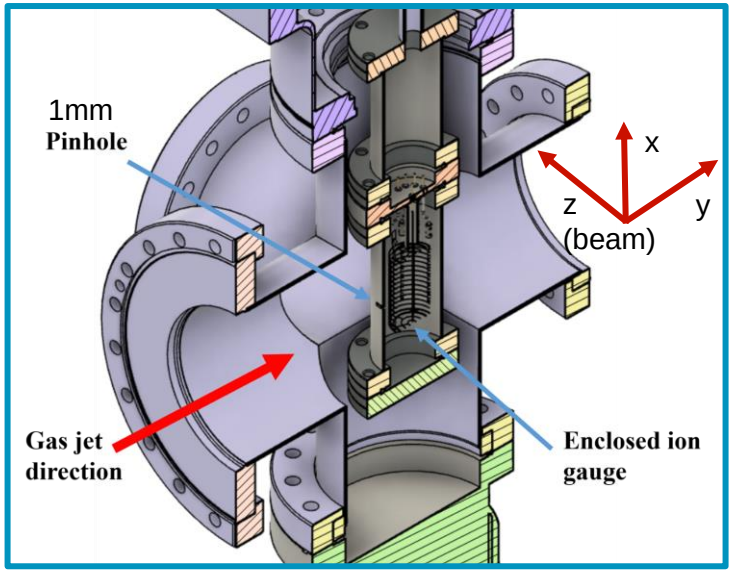


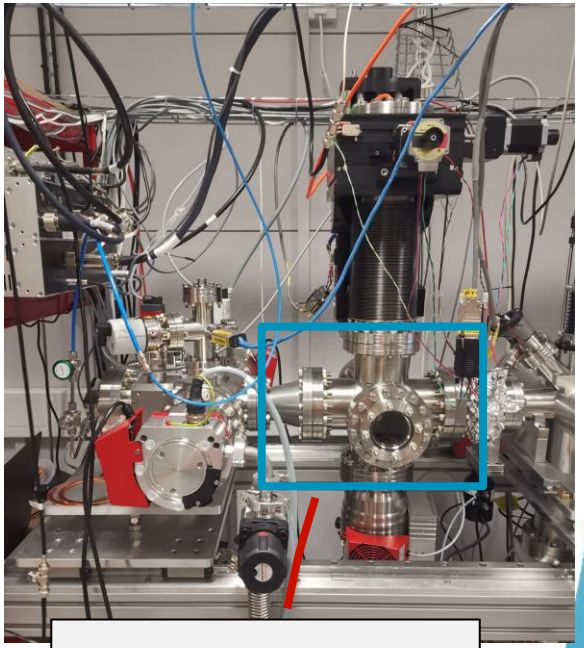
Radiation levels during 2022 Distributed gas experiments - D. Prelipcean, G. Lerner; BGC collaboration meeting

Direct gas curtain profile measurements
Moveable pinhole pressure gauge



Stepmotors in all 3 dimensions

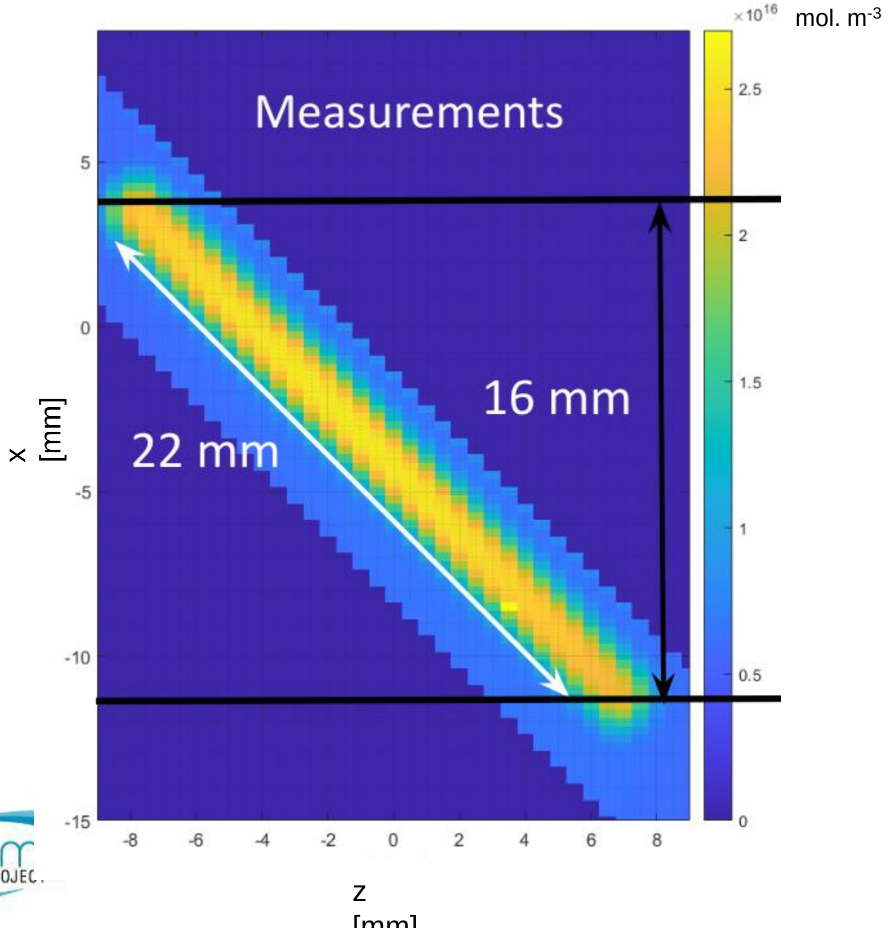




Local gas pressure measurement

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

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
- Moveable pressure gauge installed & Gas curtain profile measured - Successful
  - Great agreement with simulations

Gas jet profile

- Moveable pinhole
  - Jet pressure sampling

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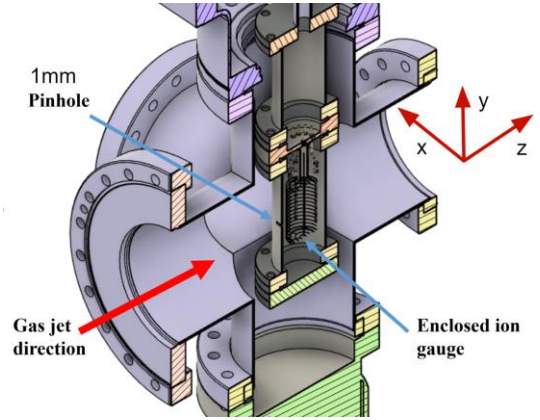
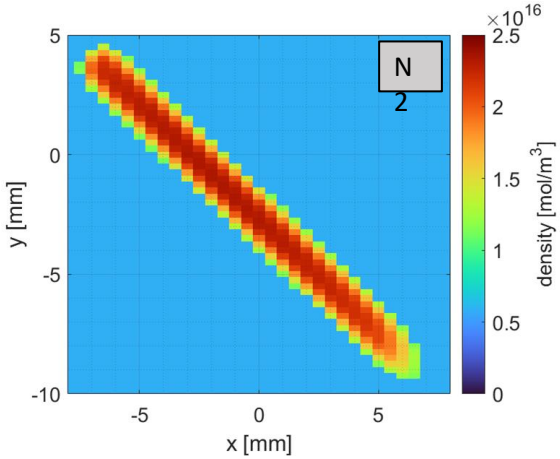
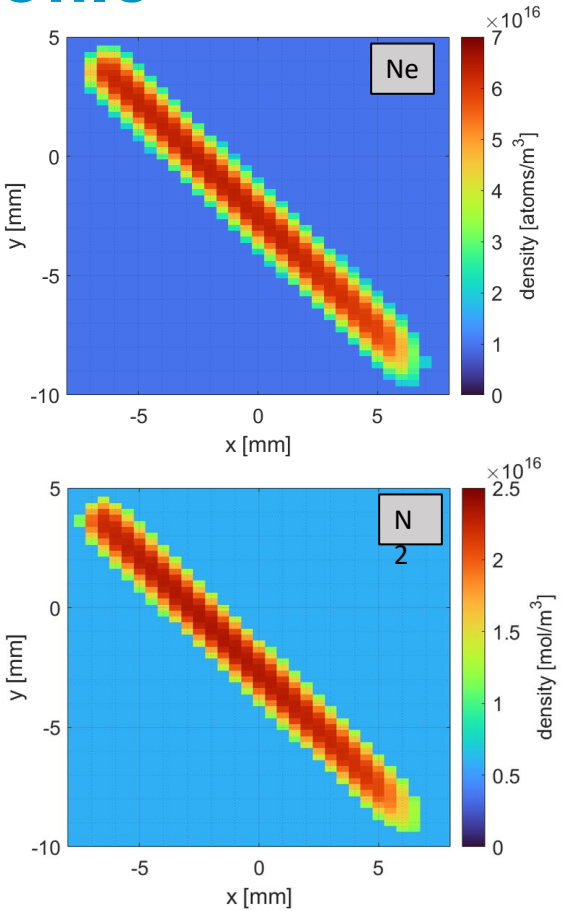




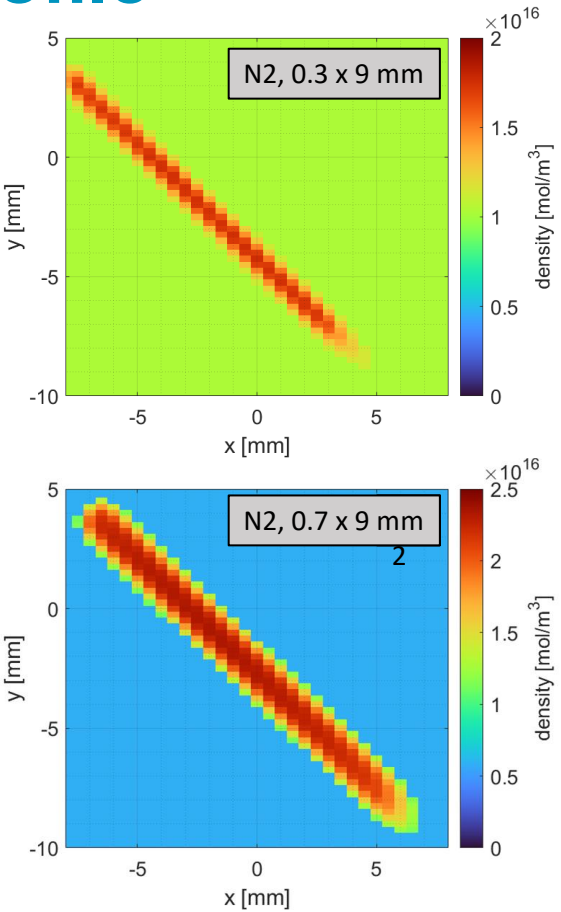
Gas jet profile

- Moveable pinhole
  - Jet pressure sampling
- Gass shape - constant
  - $Ne/N_2 \approx 2.9$



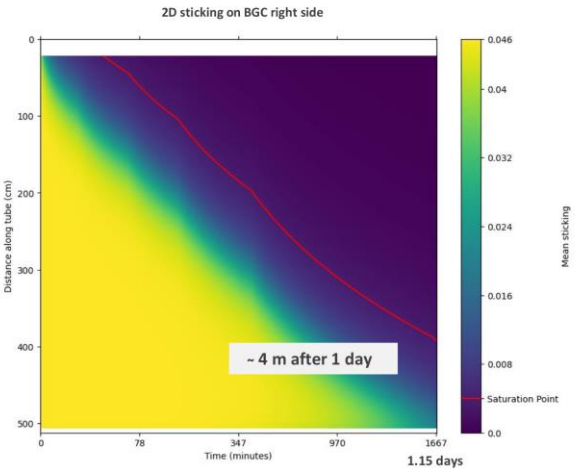
Gas jet profile

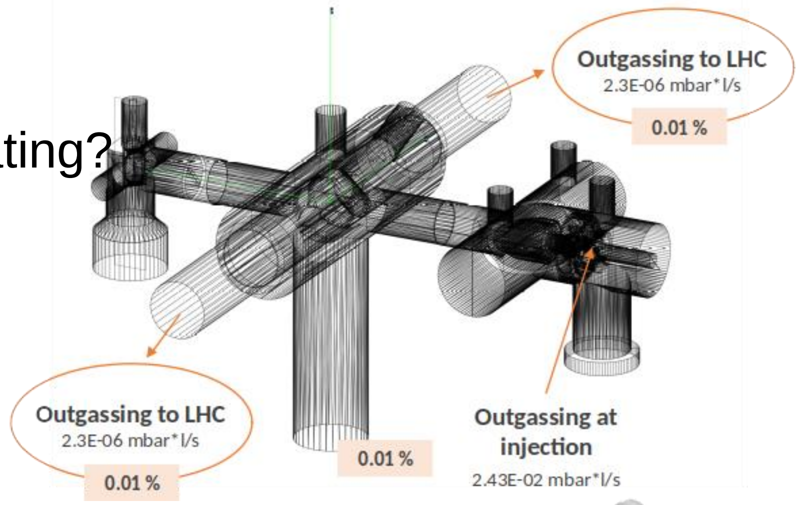
- Moveable pinhole
  - Jet pressure sampling
- Gass shape - constant
  - $Ne/N_2 \approx 2.9$
- 3rd skimmer - thickness, density
  - Signal vs vacuum

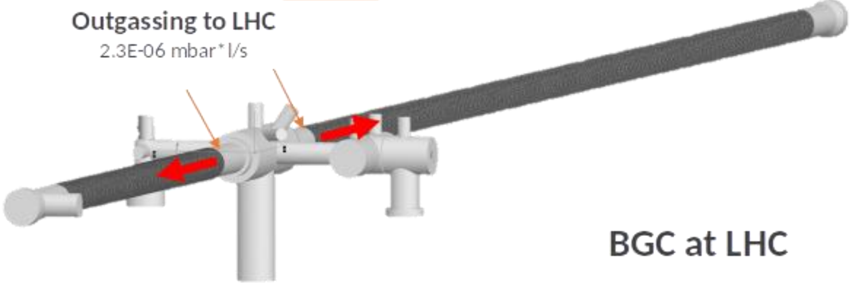


LHC Vacuum and LHC NEG coating saturation

- BGC Version 3 - Pump down curves being characterized to simulate effect on LHC vacuum
  - Bakeout needed ?
  - If N_2 jet - saturation of NEG coating?







BGC at LHC

Courtesy of Cristina Castro Sequeiro TE-VSC