# Beam Gas Curtain optimisation for HL-LHC

Genoa, October 2024


Ray Veness on behalf of WP13

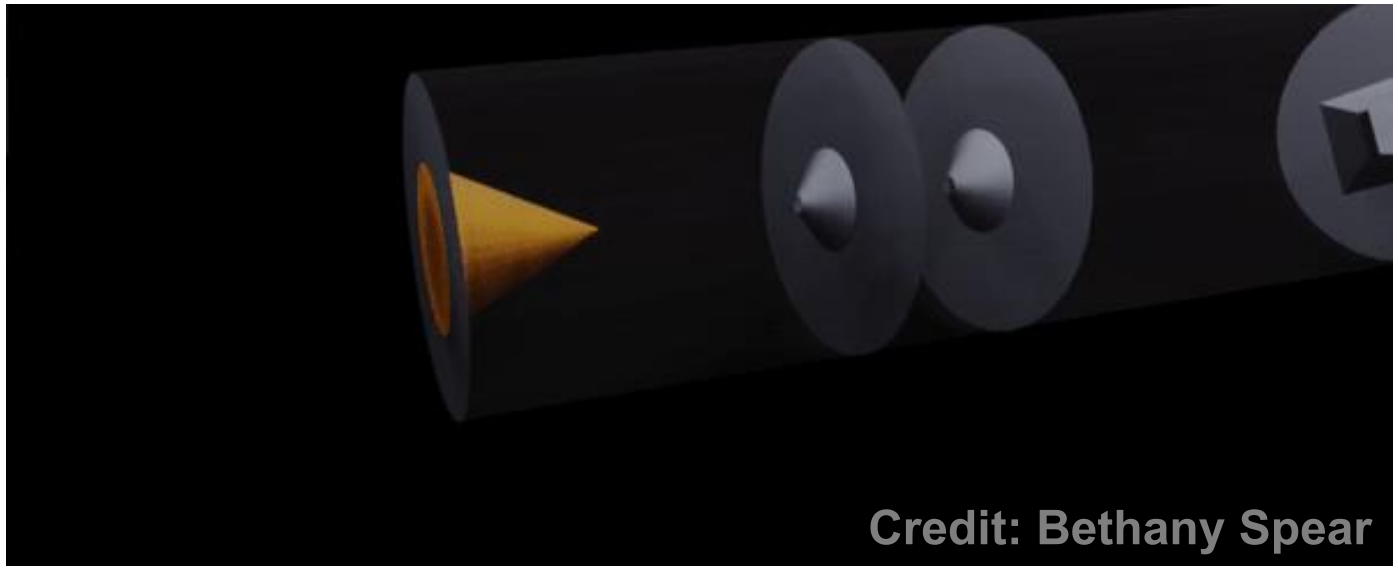
Thanks for material from: Daniele Butti, Gerhard Schneider, Ondrej Sedlacek, Oliver Stringer, Carsten Welch, Hao Zhang,


# Contents

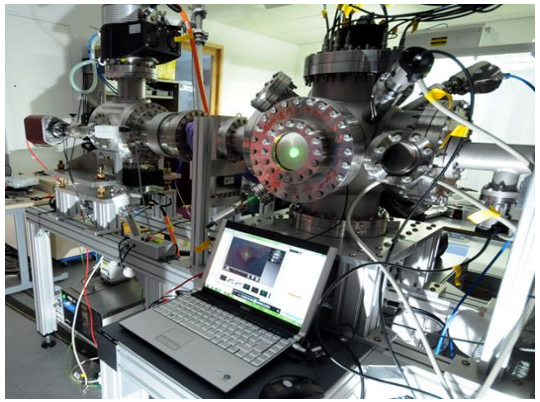
- Background and status
  - The project and collaboration
  - Recent experimental results for electrons and hadrons
- Ongoing activities and plans for HL-LHC
  - Experimental activities upto LS3
  - Baseline for the HL-UK2 deliverables
  - LS3 activities
  - Technical plans
- Summary and conclusions

# Gas Curtain Generation

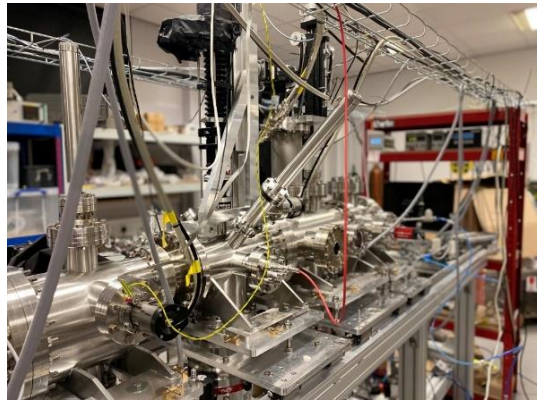
- Accelerate gas to supersonic speeds.
- Collimate the profile using skimmers to a 45 degree thin curtain.
- Observe the beam induced fluorescence with an optical system



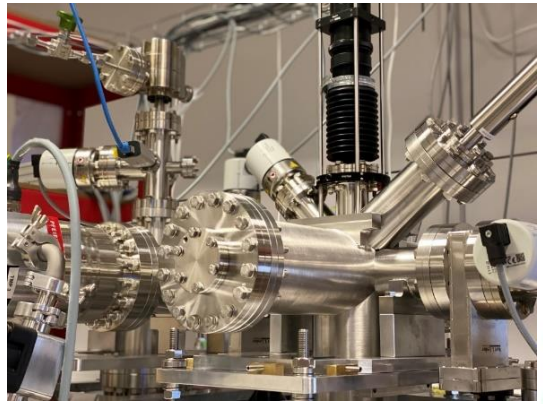

Version 1



Version 2



Version 3



- 17 years of research on gas jet technology and collaboration

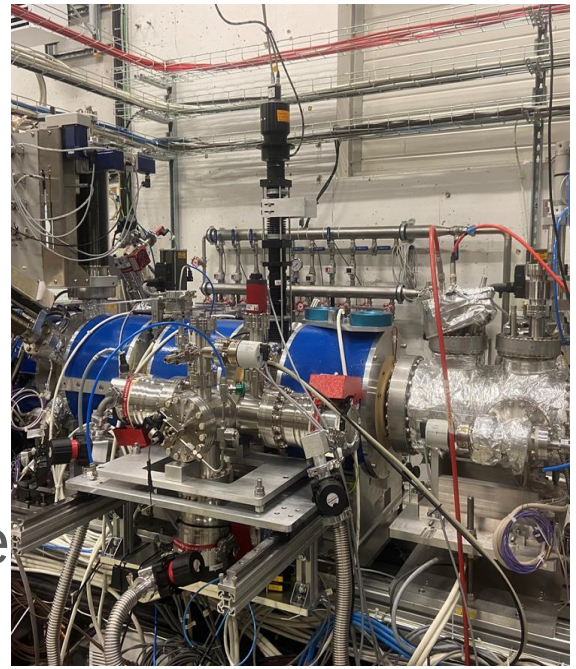
hao.zhang@cockcroft.ac.uk

# Background and project structure

- Originally baselined in HL as an '*overlap*' monitor for the Hollow e-lens (HEL)
  - Overlap = observing image of hollow e-beam overlaid on the centroid of the p+ beam
- Organised as an in-kind instrument as part of HL-UK and HL-UK2 agreements
  - Instruments developed and supplied by Liverpool/Cockcroft with support from CERN and GSI, with LHC integration and services from the HEL project
- HEL was descoped from the HL project following the termination of the Russian collaboration
  - Continued development was supported by the CMAC to allow post-HL reintegration of a HEL
  - Agreed to continue with the HL-UK2 deliverables and their associated test programme with electron and LHC proton beams
  - HL financial support for LHC integration and stand-alone vacuum system
- Instruments
  - One instrument delivered as HL-UK1, optimised as an overlap monitor
    - Installed and tested on the CERN Electron Beam Test Stand (EBTS), briefly in 2022
    - Moved to the LHC IR4L Beam 1 and under test since Run 3 / 2023
  - Two additional instruments are planned for delivery with HL-UK2

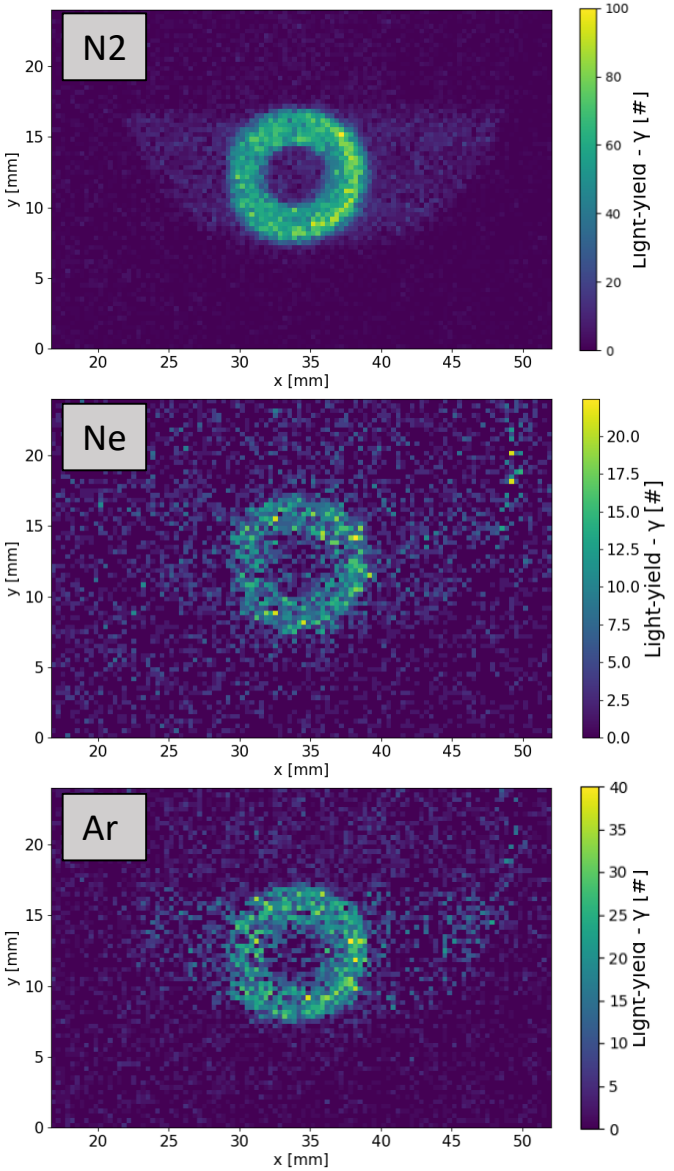
# Experience with HL-UK1 instrument: Electrons

- Full prototype instrument delivered in May 2022 and tested at CERN
  - Instrument is an in-kind contribution from the HL-UK1 (Cockcroft Institute/Liverpool Uni) with support from GSI
  - Tested with hollow electron beam on the Electron Beam Test Stand (EBTS) in November 2022 (shown right), before installation in the LHC (next slide)
    - Preliminary performance as an on-line monitor for hollow e- demonstrated with three gas jet species ($N_2$, Ne, Ar)



BGC installed on the EBTS (November 2022- above) with non-destructive images of the hollow electron beam taken with different curtain gases (right)

7 keV, 1.1 A
Beam int. time: 2 s




❑ O.Sedlacek et al. Gas Jet based Fluorescence Profile Monitor for Low Energy Electrons and High Energy Protons at LHC [IBIC 2023]

# Experience with HL-UK1 instrument: Protons and ions

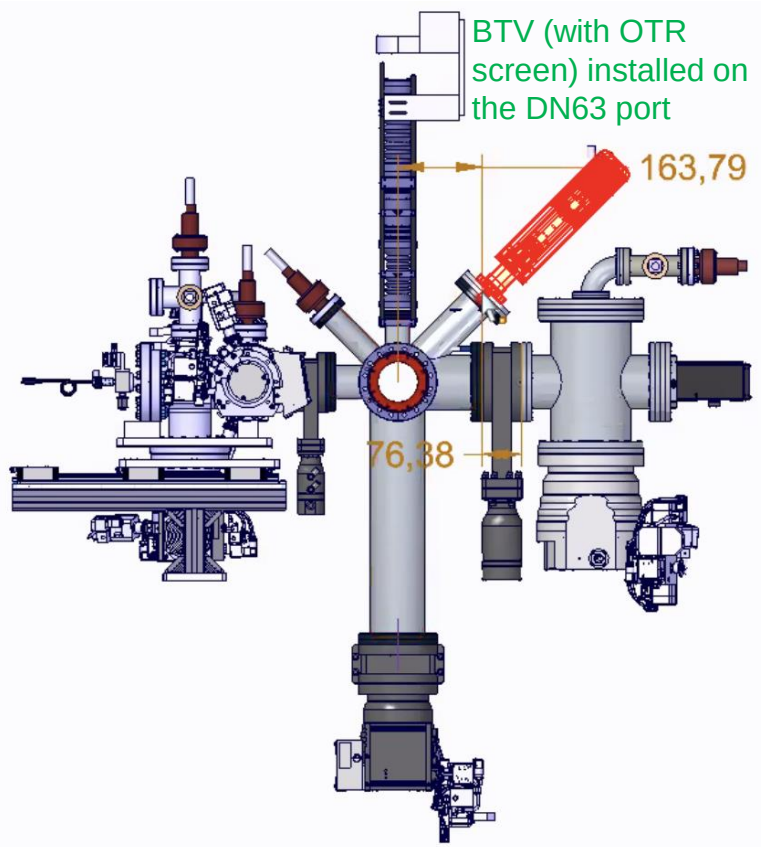
- See Daniele Butti's talk for more details of of recent LHC operations, but…
- Operations in 2023 and 2024 in the LHC have demonstrated
  - Reliable operations with beam and no impact on LHC performance (minimally invasive)
  - Lead ion beam size measurements at injection energies
    - the only instrument able to acquire this data
  - Proton and ion beam size measurement through the acceleration cycle
    - the only instrument able to acquire this data
  - Averaged emittance measurements at all energies
    - Results correlate well with BSRT, BWS and data from experiments
- Recently presented to and supported by the LHC Beam Operation Committee (LBOC)

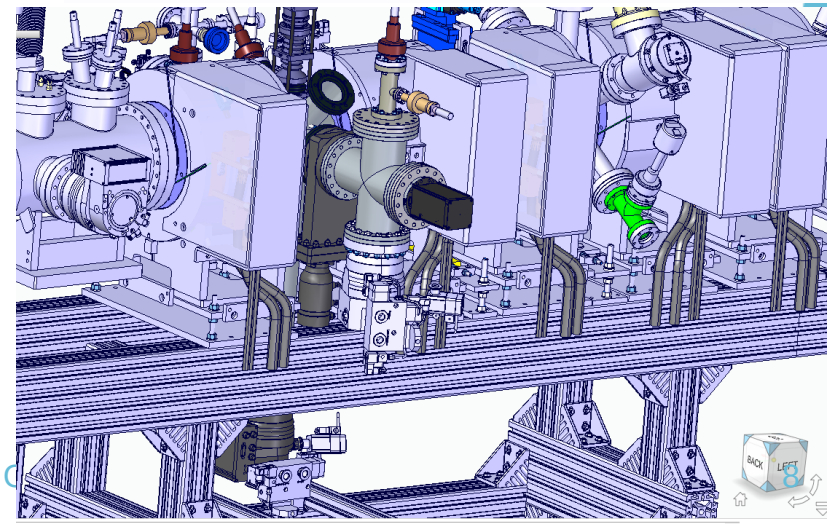

- ❑ D.Butti: Performance of the BGC in the LHC [this meeting]
- ❑ Zhang et al. BGC Monitor: First year of operation at the LHC [IBIC 2024]

# How can we make best use of the HL-UK2 deliverables for HL-LHC?

# Baseline for HL-UK2 deliverables: Electrons

- Aim: Continue validation and use as a monitor for hollow electron beams at CERN
- Design of one instrument has been re-optimized for the Electron Beam Test Stand (EBTS)
  - Larger (60mm) jet width to accommodate full e-beam parameters in the solenoid
  - Interaction chamber adapted to add other diagnostics
- Production in progress as part of HL-UK2
  - One of the two in-kind instruments to be delivered in this collaboration
  - Delivery planned for 2025



# Options for HL-UK2 deliverables: Protons and ions

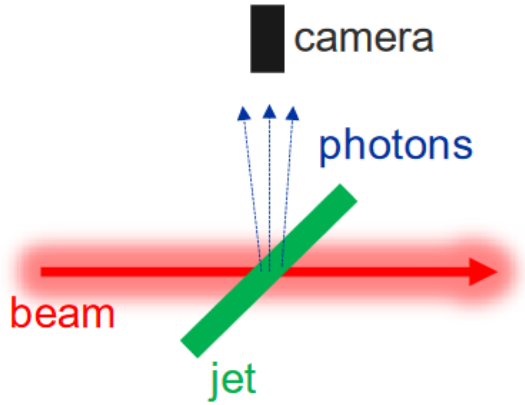
- Current HL-UK1 (v3) design was built as an overlap monitor for the HEL and was installed in the LHC in YETS22-3 with operations since then
  - This implied several significant design constraints, limiting performance
    - Very limited space (200 mm) between HEL solenoids available along the beam axis
    - Wide gas jet required to cover the large e-beam as well as the p+ beam
    - Strong magnetic field of HEL solenoid limits the choice of gas species
- The design can be optimized if we choose to use as a stand-alone profile measurement device for HL-LHC
  - Alternative gas jet species (currently Ne)
    - $N_2$ has a higher fluorescence cross-section and would give more signal (~5x)
  - Smaller gas jet width (just wide enough to reliably observe the p+ beam without an e- beam)
    - Less gas load on LHC and lower beam-gas background
  - Thinner gas sheet
    - Improved vertical profiles (see D.Butti talk) and less gas load on LHC
    - Comes at the cost of a reduced signal intensity, so longer integration times
  - Space for additional vacuum pumps on the beam axis
    - Lower beam-gas background and less gas load on LHC
    - Alternative pumping technologies (NEG, cryo-pumping)
    - More space for integration on the Beam 2 line

# Possible uses as a halo monitor

## Concept

Present BGC conceived as overlap monitor for HEL

→ jet is “gas screen” and detect fluorescence photons

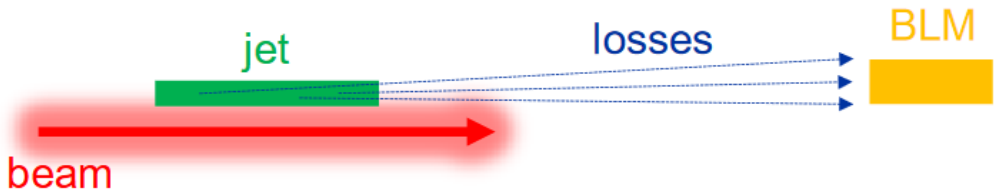



- 2D image very efficient to detect centroid
- info about beam profile (emittance)
- very low fluorescence cross-section, not suitable for halo

Work in-progress: Will be considered by WP13 as part of the halo monitoring review planned for December 2024

System can be adapted to halo measurements

→ use jet as “gas collimator” and detect losses

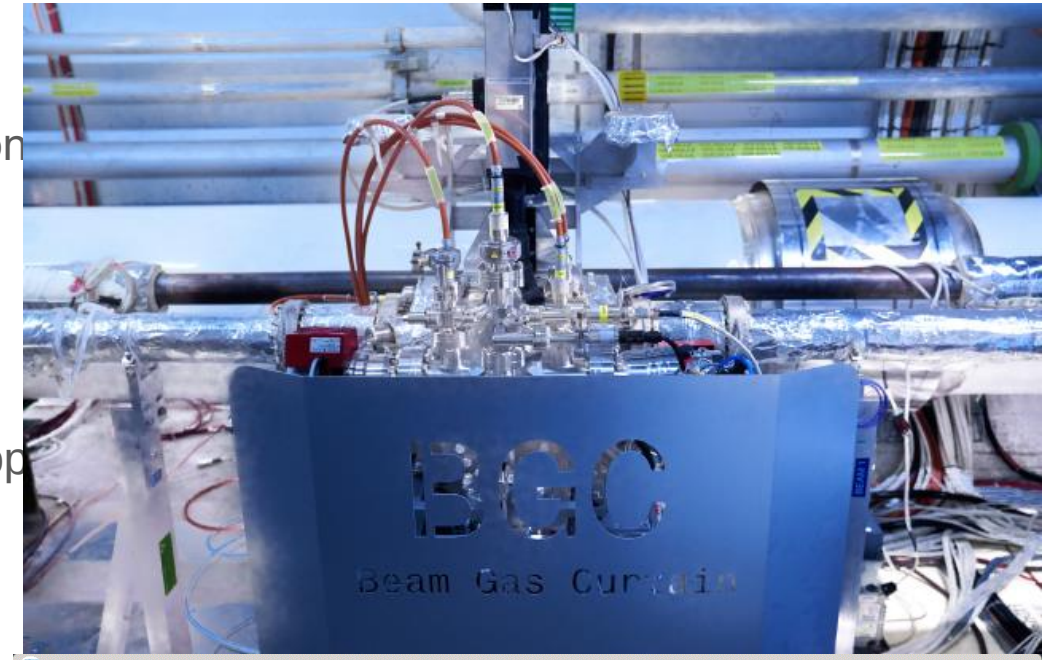


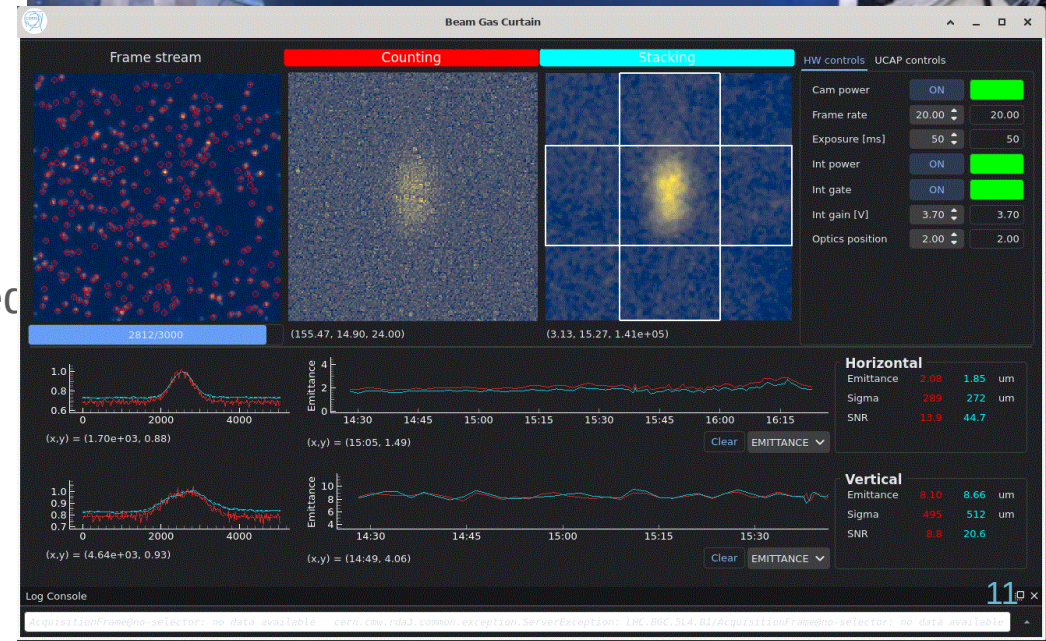

- intrinsically a 1D instrument
- measures integrated halo
- if jet is moved, measures profile (emittance)
- may induce some halo cleaning?

Courtesy: D.Butti

# Proposed next steps in the LHC upto LS3

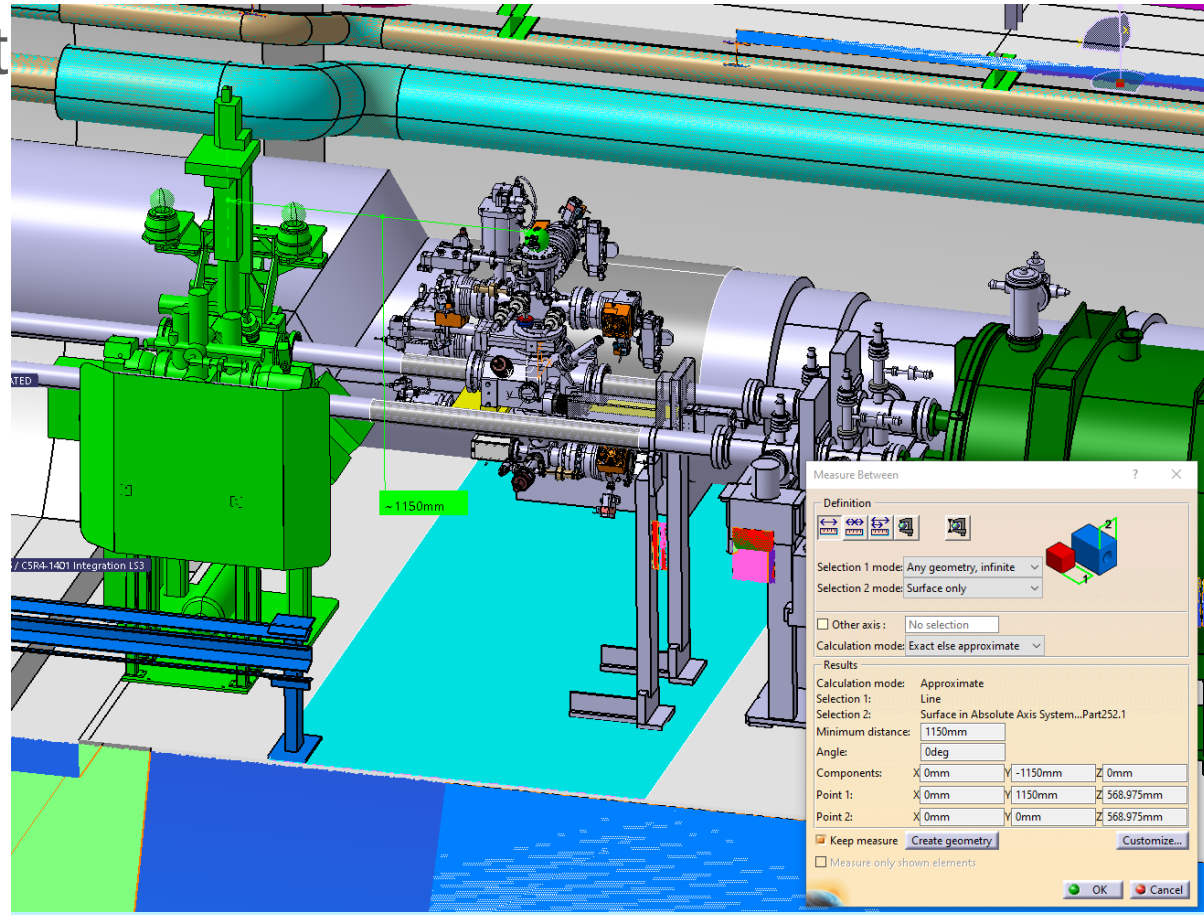
- Run 3 / 2024
  - Continue operation as profile monitor for protons and ions
  - Stress-test as an ‘operational instrument’ for ions in the upcoming ion run
- YETS24-5
  - Installation of new 3rd skimmer, optimized for LHC protons and ions
  - Installation of two new BLMs to allow evaluation of halo signal acquisition
  - Install new nitrogen bottle to allow gas switch during a Technical Stop
  - Automation of gas injection process with TE-VSC and review the operational scenarios
- Run 3 / 2025
  - Continue operation as profile monitor for protons and ions
  - Collect BLM data to understand background for possible halo monitoring
  - Potentially switch to $N_2$ during the year
- YETS25-6
  - Potentially change skimmer configuration to a halo monitor optimised design, plus other improvements
  - Sufficient access time during YETS25-6 is important!
- Run 3 / 2026
  - Potential validation of BGC as a halo monitor



# Plans for the BGC in LS3

- Install the 2nd in-kind deliverable instrument in the LHC
  - Complete the integration on the Beam 2 (QRL-side) line for LSS4
  - Addition of cabling and vacuum equipment
- Reconfigure skimmers and pumping in the existing beam 1 device
  - Options exist for proton, ion and/or halo monitoring options on both beamlines
- New simulation tools for gas jet design
  - Developed by O. Stringer (HL-UK2 Liverpool PhD)
  - Greatly simplifies the design process for gas jet optimisation



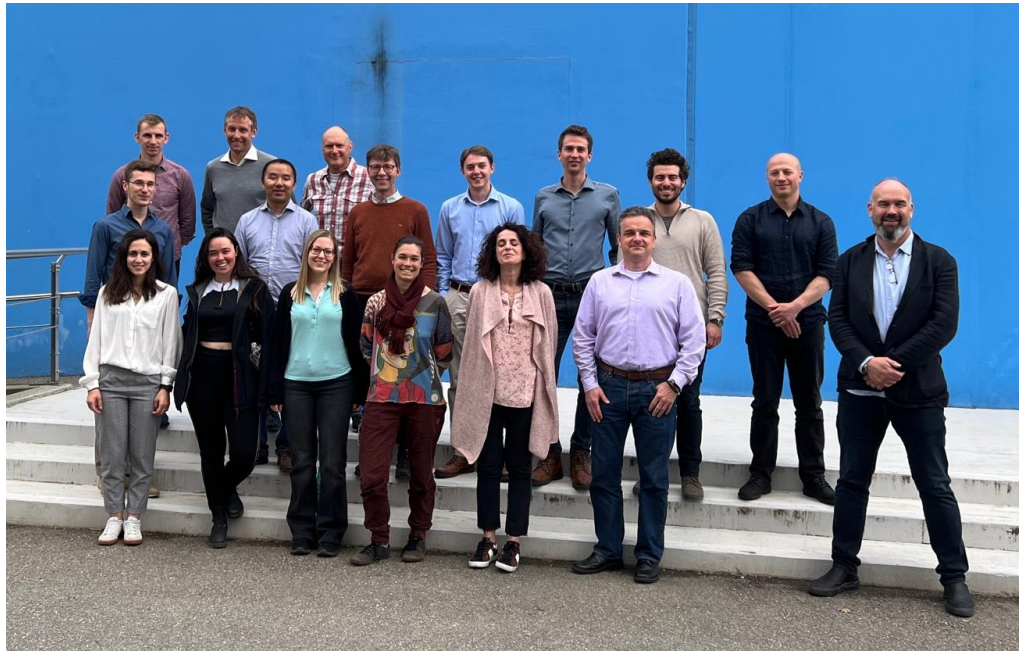

Preliminary integration study for LHC beam 2


- O.Stringer et al. First measurement of the proton beam and lead ion beam in the LHC using beam gas curtain monitor [IPAC 2024]

# Summary and Conclusions

- The HL-UK1 deliverables have been extremely successful
  - Preliminary validation with electrons as an overlap monitor on the EBTS
  - Operating as predicted in the LHC for ions and protons, within the existing constraints as a hollow electron/proton overlap monitor
    - Significant improvement potential as a hadron beam size measurement device have been identified and will be simulated and tested upto LS3
- One of the HL-UK2 deliverables has been re-designed as a monitor for the electron-beam test stand at CERN
  - Complete the validation for the HEL and use as an operating instrument for electron gun testing
- WP13 propose to install the second HL-UK2 in-kind monitor on the LHC beam 2 line and upgrade the existing HL-UK1 instrument
  - Would give coverage on both beams for missing ion injection and through-cycle beam conditions
  - Absolute measurements of integrated beam size at all energies
  - Potential as a halo monitor being evaluated and will form part of the WP13 halo review in December ‘24
  - Take full advantage of LHC operations upto LS3 to decide on optimum configuration
- A HL-UK phase III will be extremely helpful in exploiting this innovative technology for the HL-LHC era

# Thank you for your attention



Many thanks to the whole BGC collaboration for their fantastic innovations and work over the past 10 years.

This work was supported by the HL-LHC-UK phase II project funded by STFC under Grant Ref: ST/T001925/1 and the STFC Cockcroft Institute core grant No. ST/V001612/1.

UNIVERSITY OF LIVERPOOL

The Cockcroft Institute of Accelerator Science and Technology

QUASAR GROUP

GSI

CERN

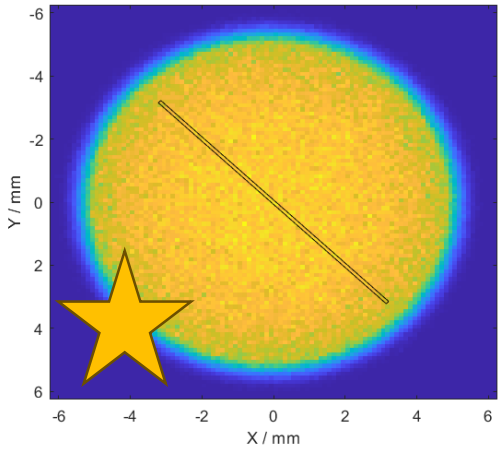
UKRI Science and Technology Facilities Council

SCAN

# BACKUP

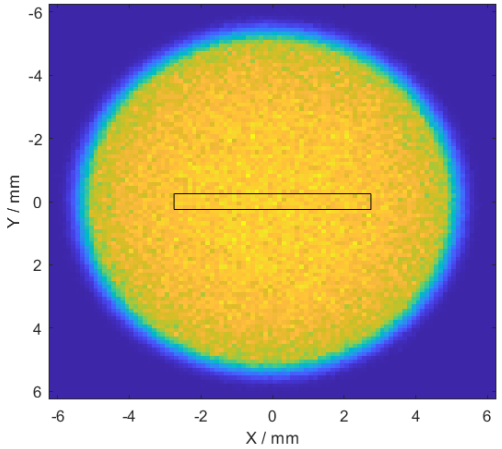
# Skimmer Options

See .docx file for summary document of concepts



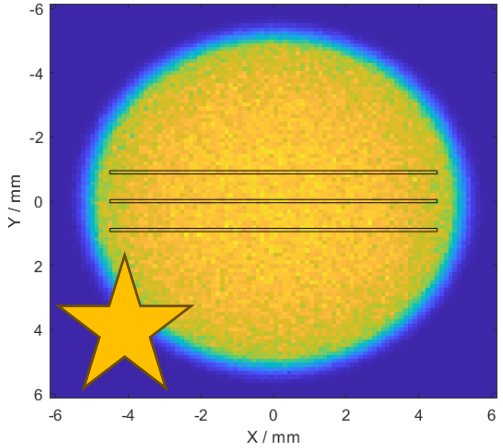

1.1 – Thin Curtain

Reduce thickness smearing for 2D profile



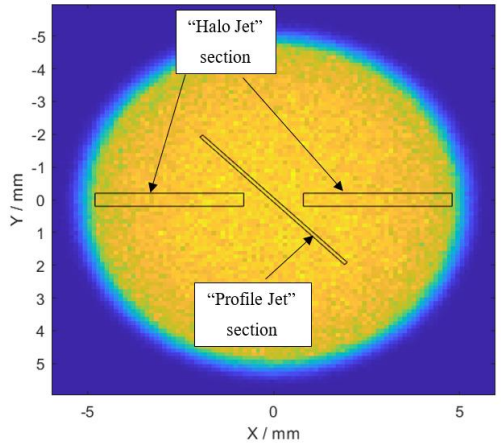

1.2 – Halo Single

Maximise losses for halo detection




1.3 – Halo Multi

Same as 1.2, but reduced chance of misalignment

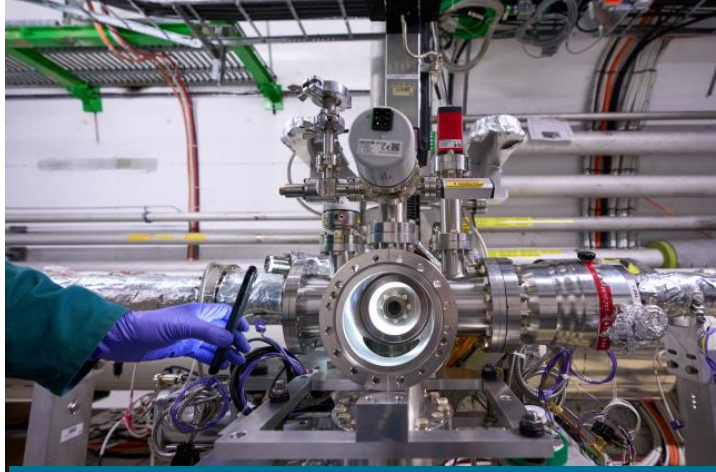



1.4 – Profile & Halo

Combination of 1.1 and 1.2 (shared positives and negatives)

# Task 13.2: BGC in the LHC

- Installed in the LHC, p4 during YETS22-3
  - Commissioned, then very successful (but preliminary) non-invasive tests measuring LHC proton beams during run 2023
  - Plans for future tests with ions then protons in 2024



BGC installed in the LHC during YETS22-3

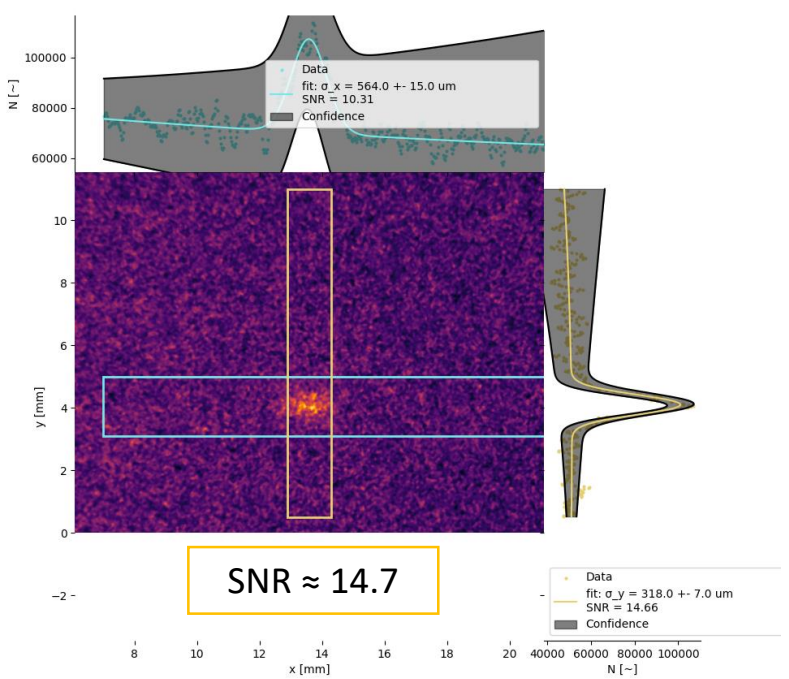
Centroid measurements

Profile measurements

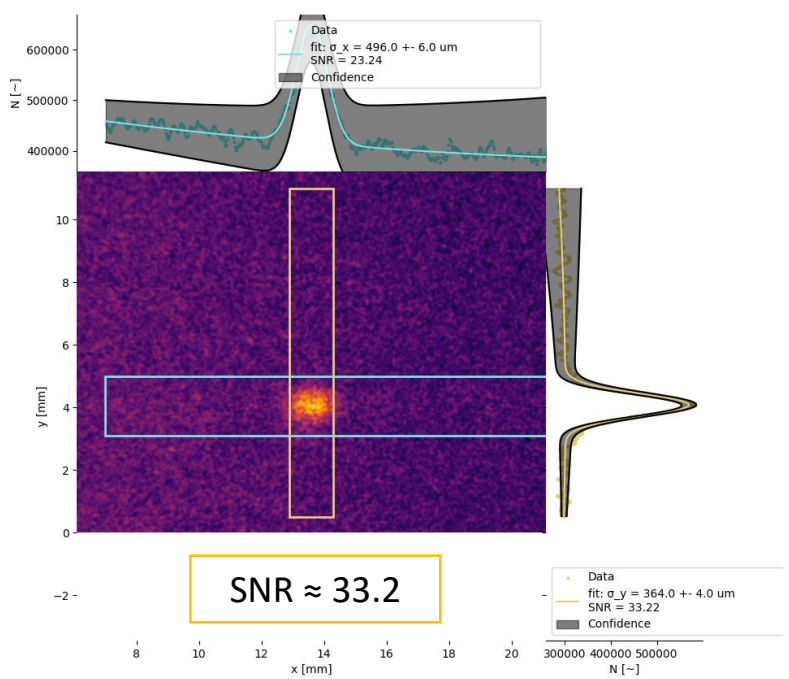
10s

1min

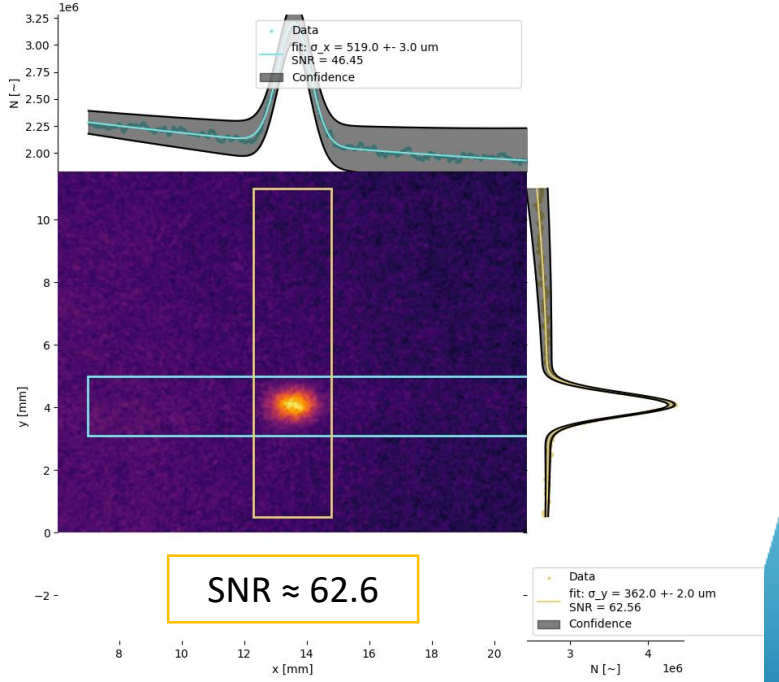
5min




SNR ≈ 14.7




SNR ≈ 33.2




SNR ≈ 62.6

https://videos.cern.ch/record/2297523