Gas jet based fluorescence profile monitor for low energy electrons and high energy protons at LHC

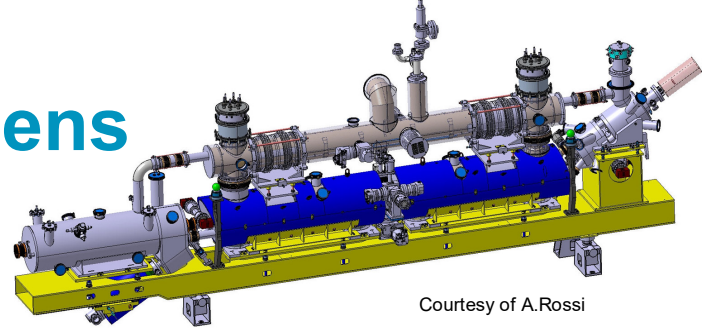
Ondrej Sedlacek

On behalf of Beam Gas Curtain collaboration

Outline

- Introduction to a Gas Jet Monitor
  - Motivation – Hollow Electron Lens
  - Working principle
  - Space-charge & gas thickness broadening
- Gas jet profile measurements
- Results
  - Electron Beam Test Stand
  - Large Hadron Collider
- Summary

Hollow Electron Lens

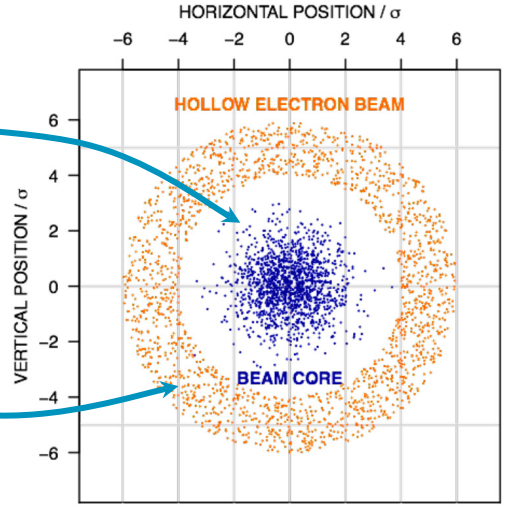


Courtesy of A.Rossi

- Proposed new stage of LHC collimation system
- 10 keV, 5 A hollow electron beam

LHC Beam core – experiences no field

Beam Halo – experiences nonlinear transverse kicks

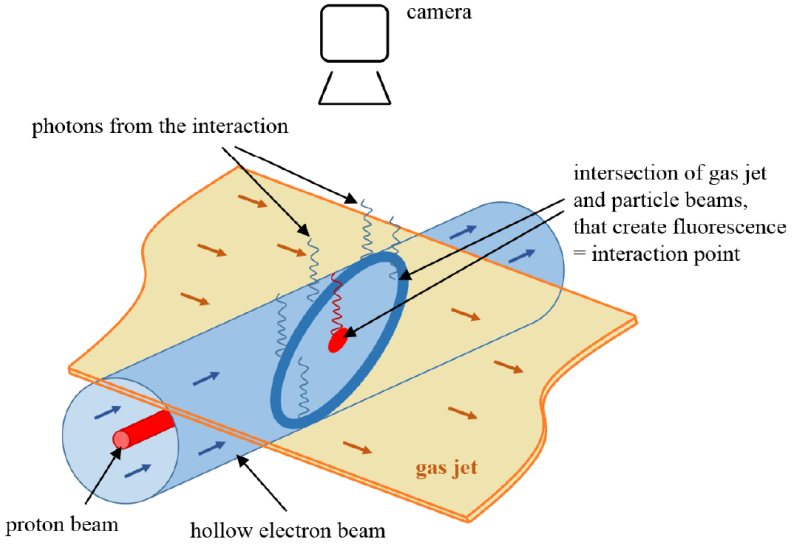


Shiltsev, et al. ;BEAM06,CERN-2007-002 EPAC08

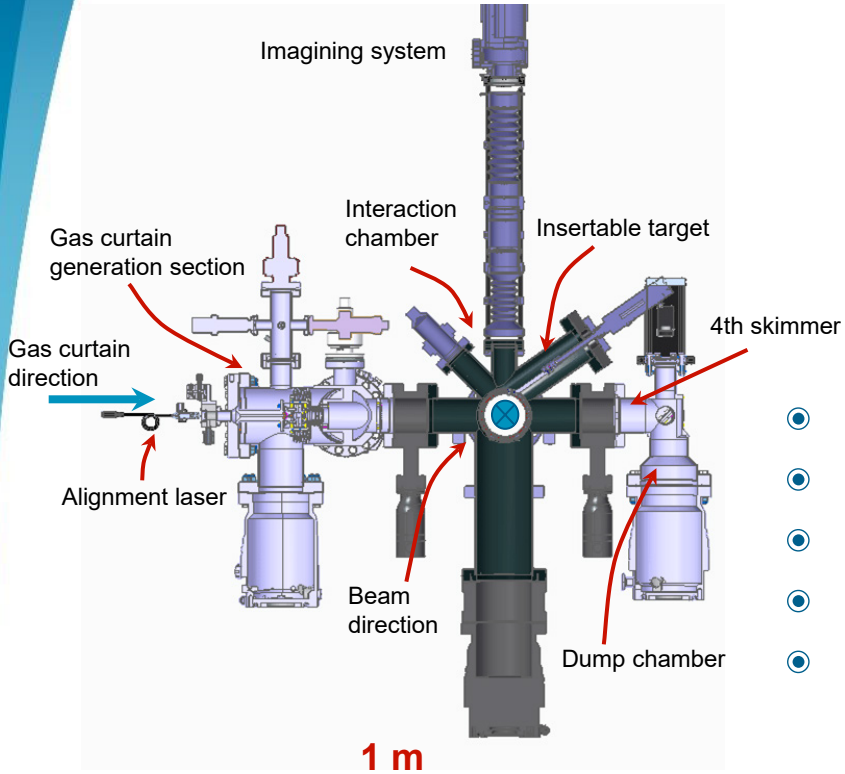
Working principle of Gas Jet Monitor

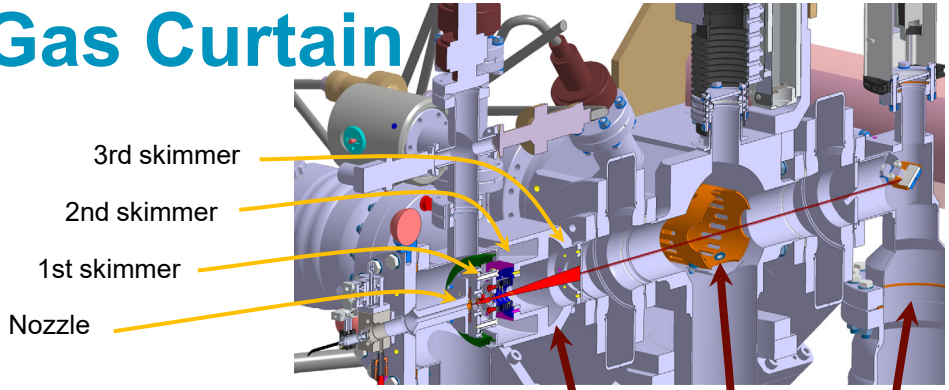
- Particle beam passing through gas -> fluorescence
  - Lower cross section than ionisation
  - Not affected by EM depending on gas species
  - Used in Los Alamos, PSI, GSI, CERN, J-PARC,...
    - D.P. Sandoval et al., BIW'93 p. 273
    - I. Yamada et al., PRAB 24, 042801 (2021)

- Gas Jet monitor - Beam Gas Curtain (BGC)
  - Supersonic sheet of gas
  - 45° angle -> 2D transverse distribution
  - Minimally invasive to particle beam
  - High gas curtain density
  - Low background pressures



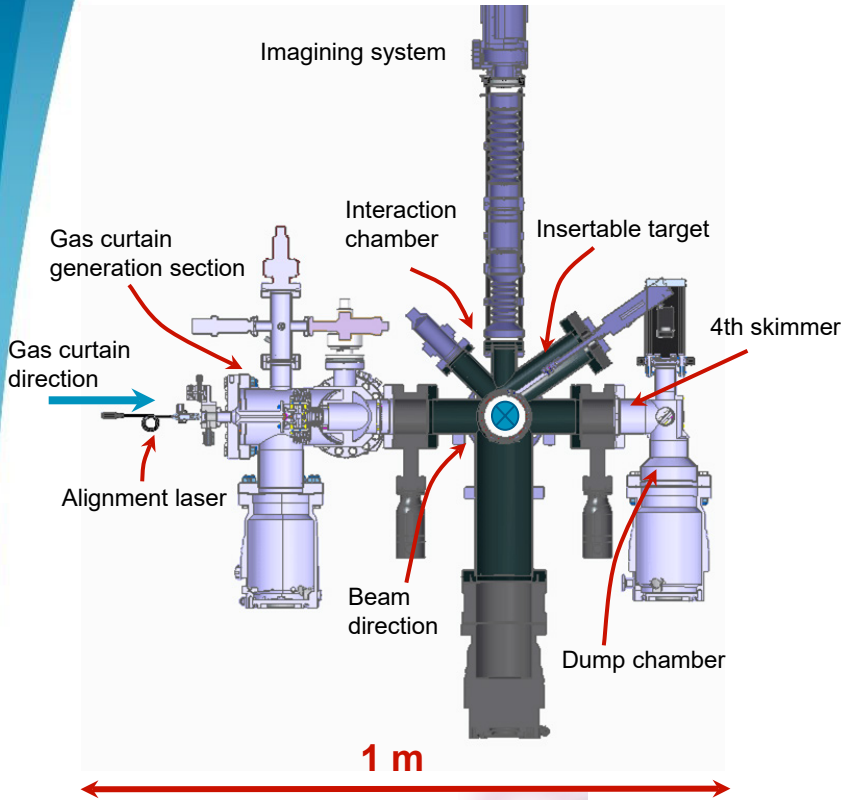
Creating Gas Curtain

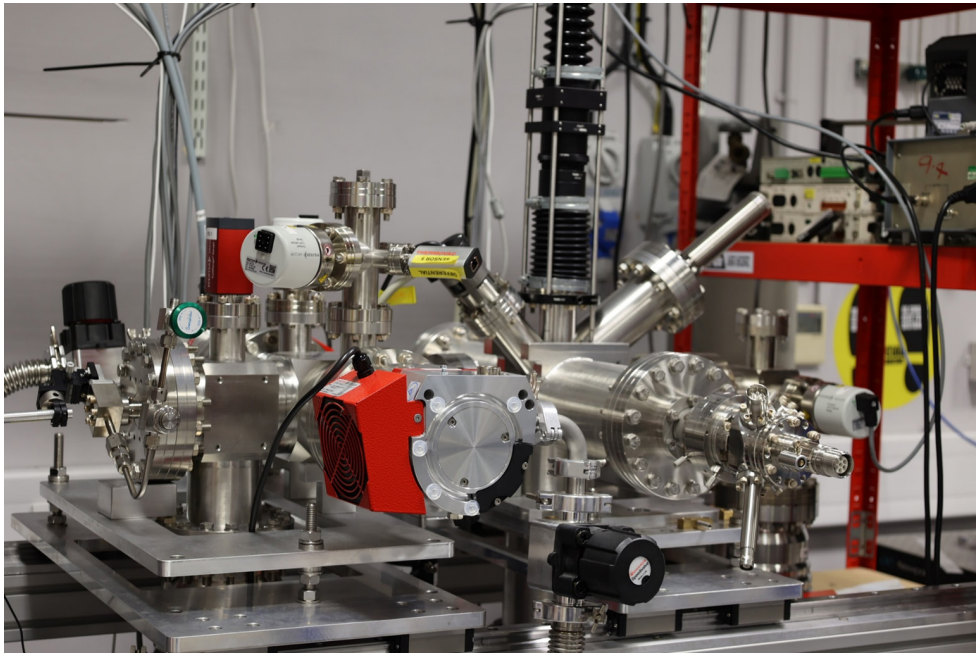




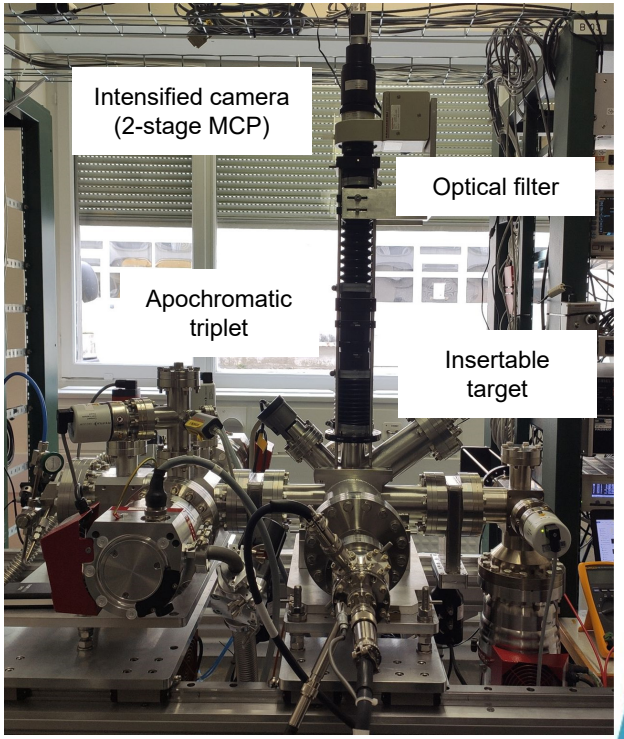
- Gas curtain formed by skimmers
- Passing through beam
- Fluorescence photons
- Pumped out in dump chamber
- Keeping low background pressure

Beam gas curtain monitor at Cockcroft Institute

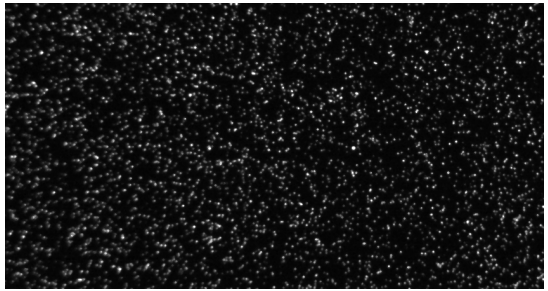




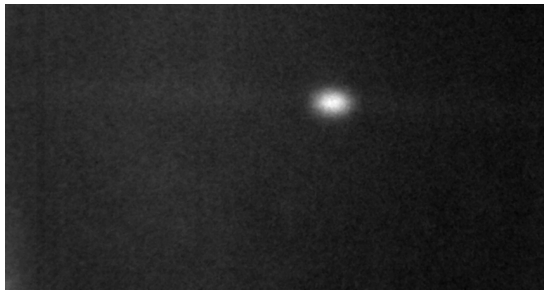
Optical system

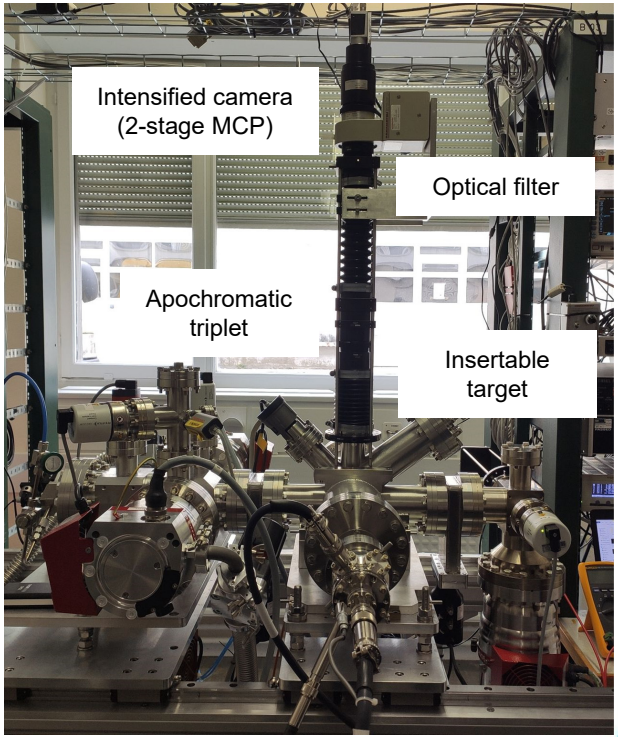


Optical system



Photon counting or Averaging

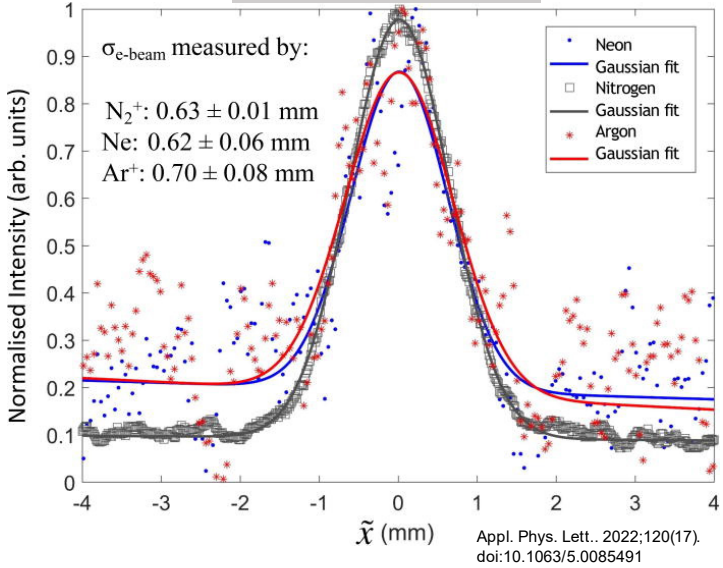




Working gases

	Neon	Nitrogen
λ [nm]	585.4	391.4
10 keV e^- σ [cm^2]	1.4e-20	9.1e-19
6.8 TeV p σ [cm^2]	4.7e-22	3.7e-20

electron beam
5 keV, 0.66 mA



Appl. Phys. Lett.. 2022;120(17).
doi:10.1063/5.0085491

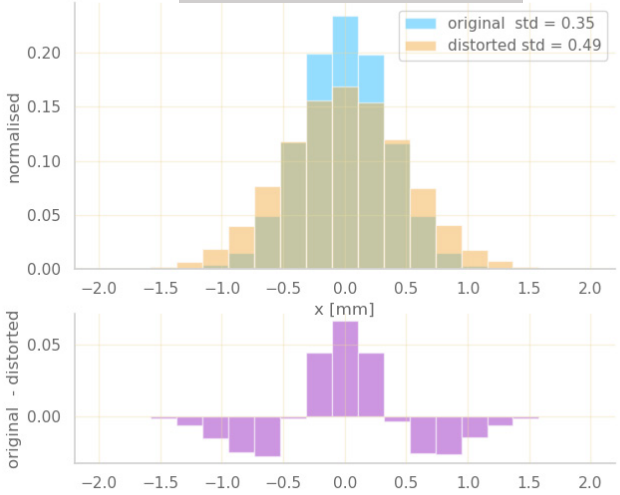
$$Ne + p/e^- \longrightarrow Ne^\star + p/e^- \longrightarrow Ne + \gamma + p/e^-$$

$$N_2 + p/e^- \longrightarrow \left(N_2^+\right)^\star + e^- + p/e^- \longrightarrow N_2^+ + \gamma + e^- + p/e^-$$

Space-Charge effect

	Neon	Nitrogen
λ [nm]	585.4	391.4
10 keV e^- σ [cm^2]	1.4e-20	9.1e-19
6.8 TeV p σ [cm^2]	4.7e-22	3.7e-20
Transition	Neutral	Charged
τ [ns]	16	60

Virtual-IPM Simulations
LHC bunch
Space-charge effect
N_2 curtain



$$Ne + p/e^- \longrightarrow Ne^\star + p/e^- \longrightarrow Ne + \gamma + p/e^-$$

$$N_2 + p/e^- \longrightarrow \left(N_2^+\right)^\star + e^- + p/e^- \longrightarrow N_2^+ + \gamma + e^- + p/e^-$$

Gas jet profile

- Moveable pinhole
  - Jet pressure sampling

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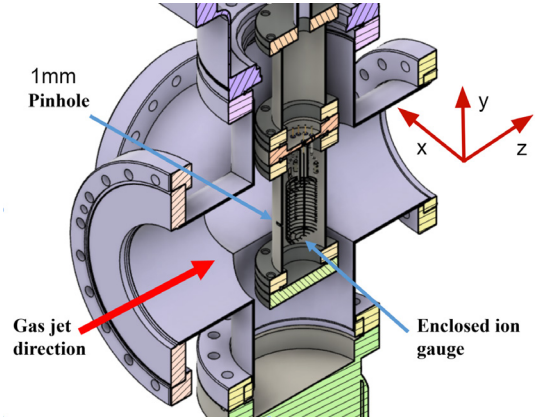
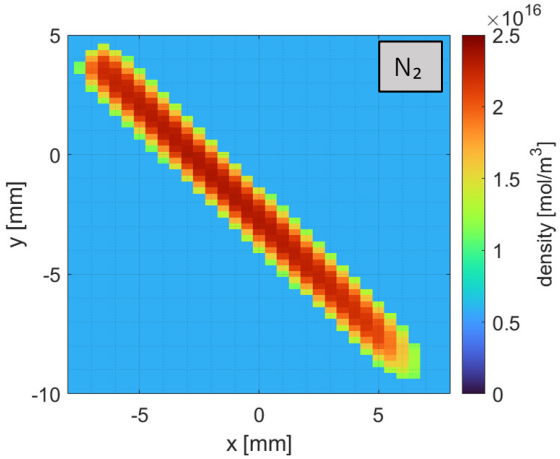
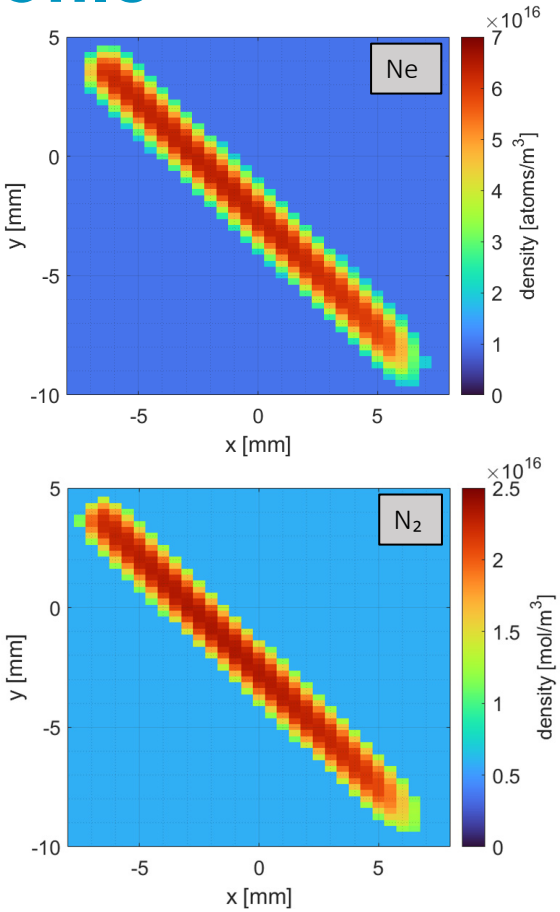




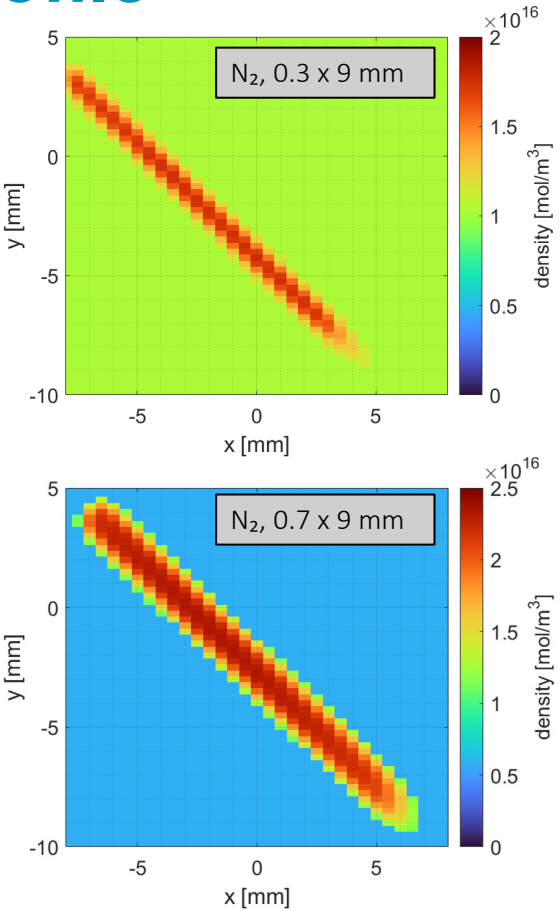
Gas jet profile

- Moveable pinhole
  - Jet pressure sampling
- Ne/N_2 shape – constant
- Ne/N_2 density ≈ 2.9

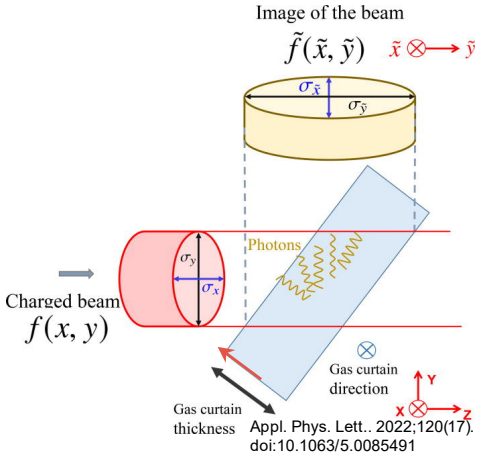


Gas jet profile

- Moveable pinhole
  - Jet pressure sampling
- Ne/N_2 shape – constant
- Ne/N_2 density ≈ 2.9
- 3rd skimmer – thickness, density
  - Signal amplitude
  - Vacuum background
  - Thickness broadening



Thickness broadening

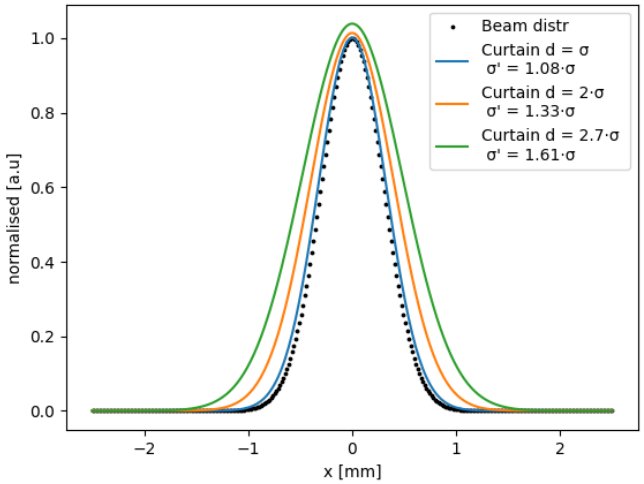


$$\widetilde{f_x} = f_x$$

$$\widetilde{f_y} = \int_{-d/2}^{d/2} \rho(\xi) \cdot f_y\left(\xi \cdot 2/\sqrt{2} - y\right) d\xi$$

- Signal vs Broadening tradeoff
- Thickness d = 830(20) µm

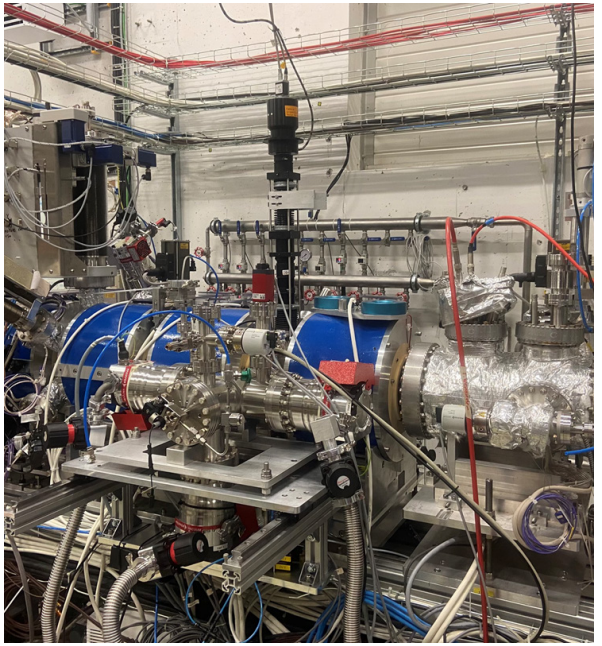
Uniform gas curtain
Gaussian beam



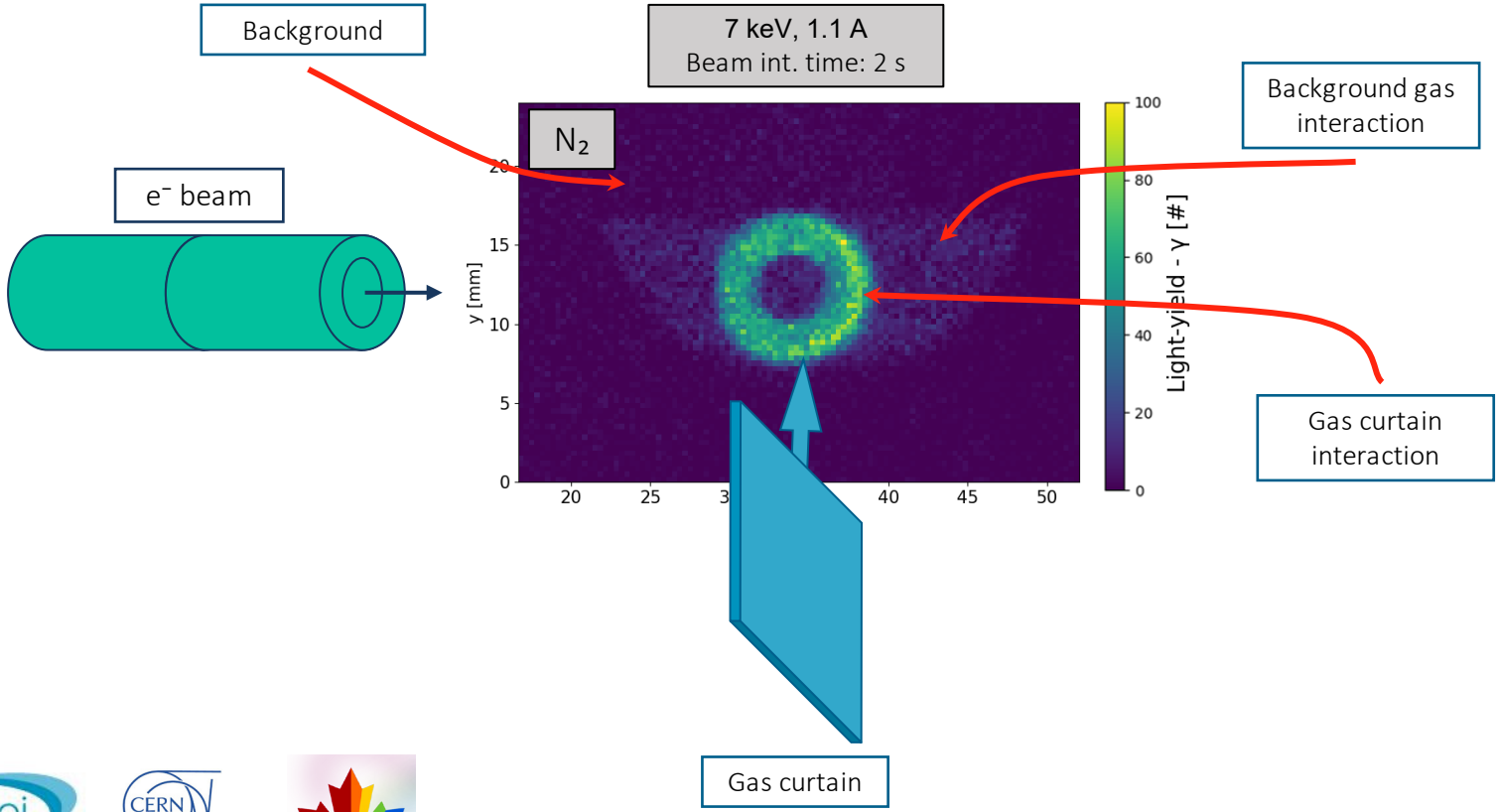
Electron Beam Test Stand (EBTS)

- Development of Hollow electron beam
- Typically: 7 keV, 1.1 A, 25 μs pulse, 10 Hz repetition rate

Interaction chamber	Pressure [mbar]
Gas Jet OFF	4.71e-8
0.7 x 9 mm 3rd skimmer	2.04e-7
0.3 x 9 mm 3rd skimmer	8.63e-8



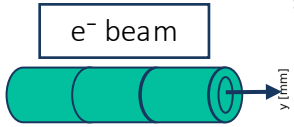
EBTS: Profile measurements

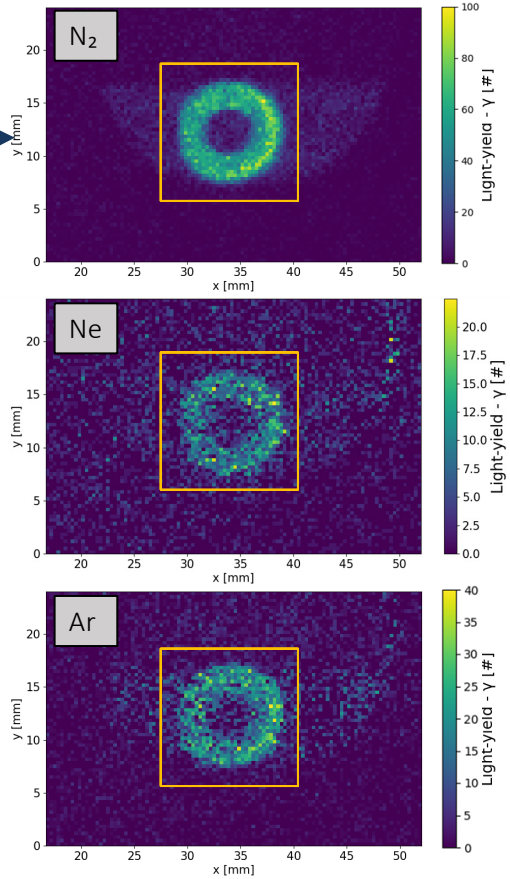


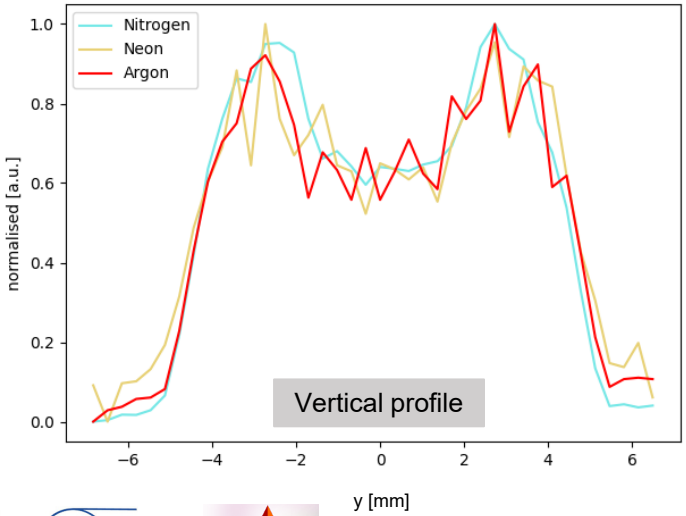
EBTS: Gas species

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

- Distribution shape – Constant
  - Low charge density – negligible space-charge effect for N_2
- Centre of Mass – Constant
- N_2 – Best resolution

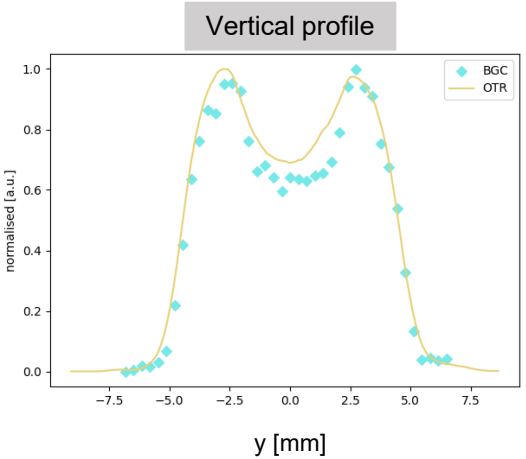


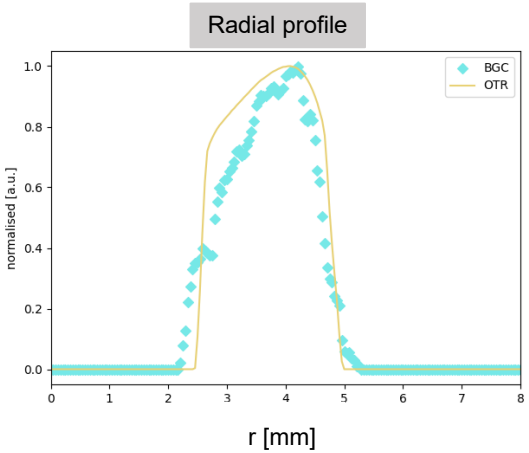


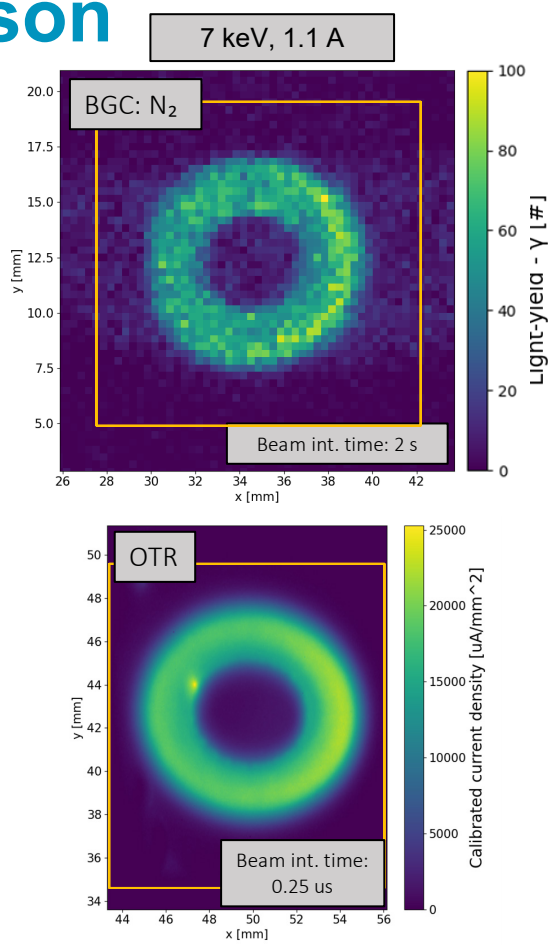


EBTS: OTR comparison

- OTR – Glassy carbon screen
- Distribution shape – Compares
- Outer radii – Agree within 1%
- Inner radii – Agree within 5-10%

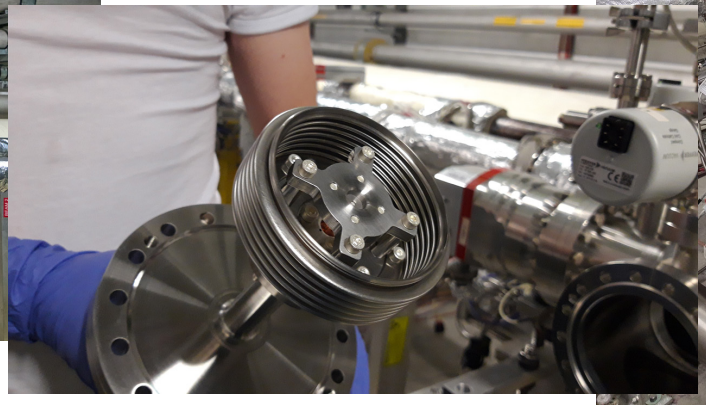


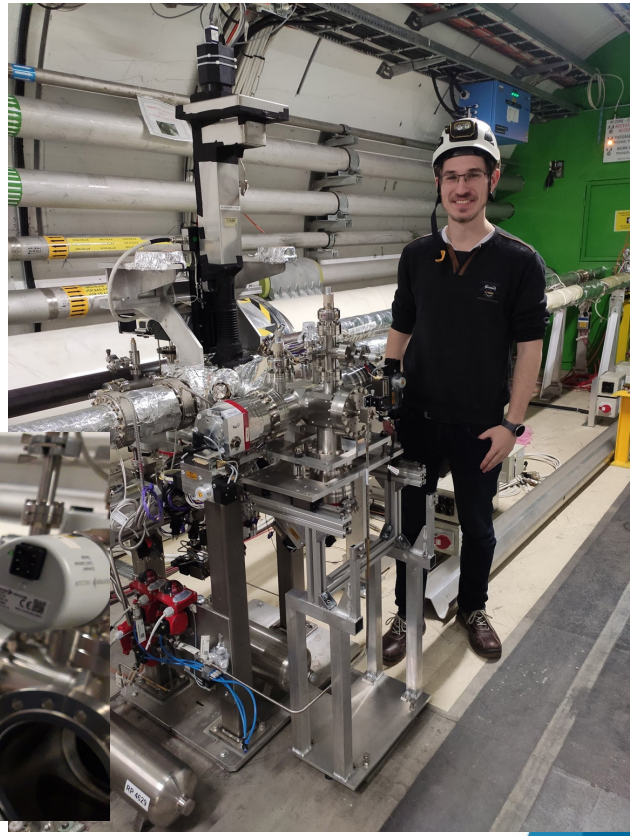




Gas jet installation at LHC

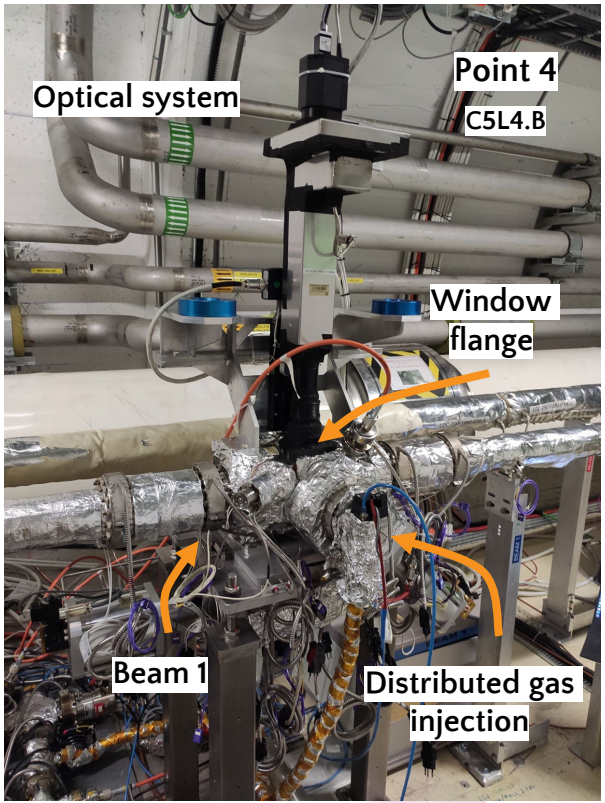
- Gas jet monitor successfully installed at LHC in January of 2023!!
- Huge effort and success for the whole collaboration





Gas jet monitor at LHC

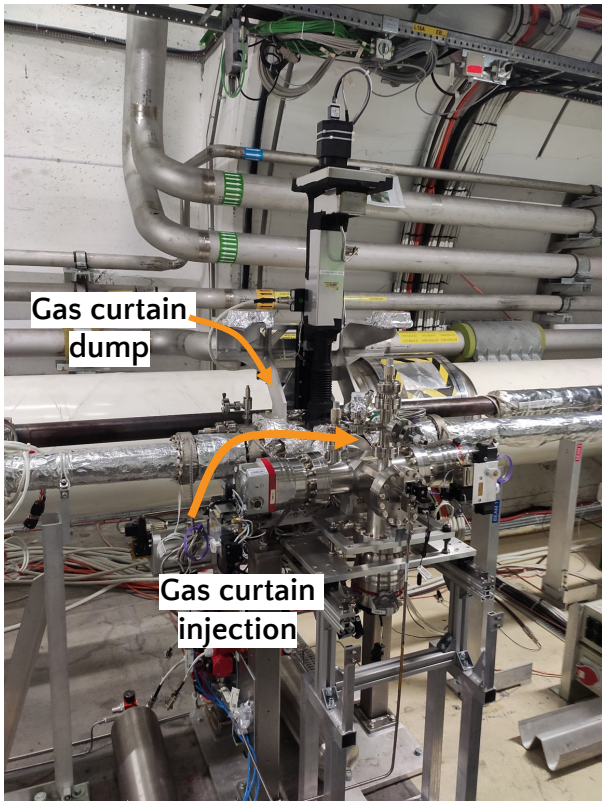
2022



Interaction chamber	Pressure [mbar]
Gas Jet OFF	2.0e-10
Gas Jet On	4.00e-8
Gas jet pressure eq.	≈3.30e-6

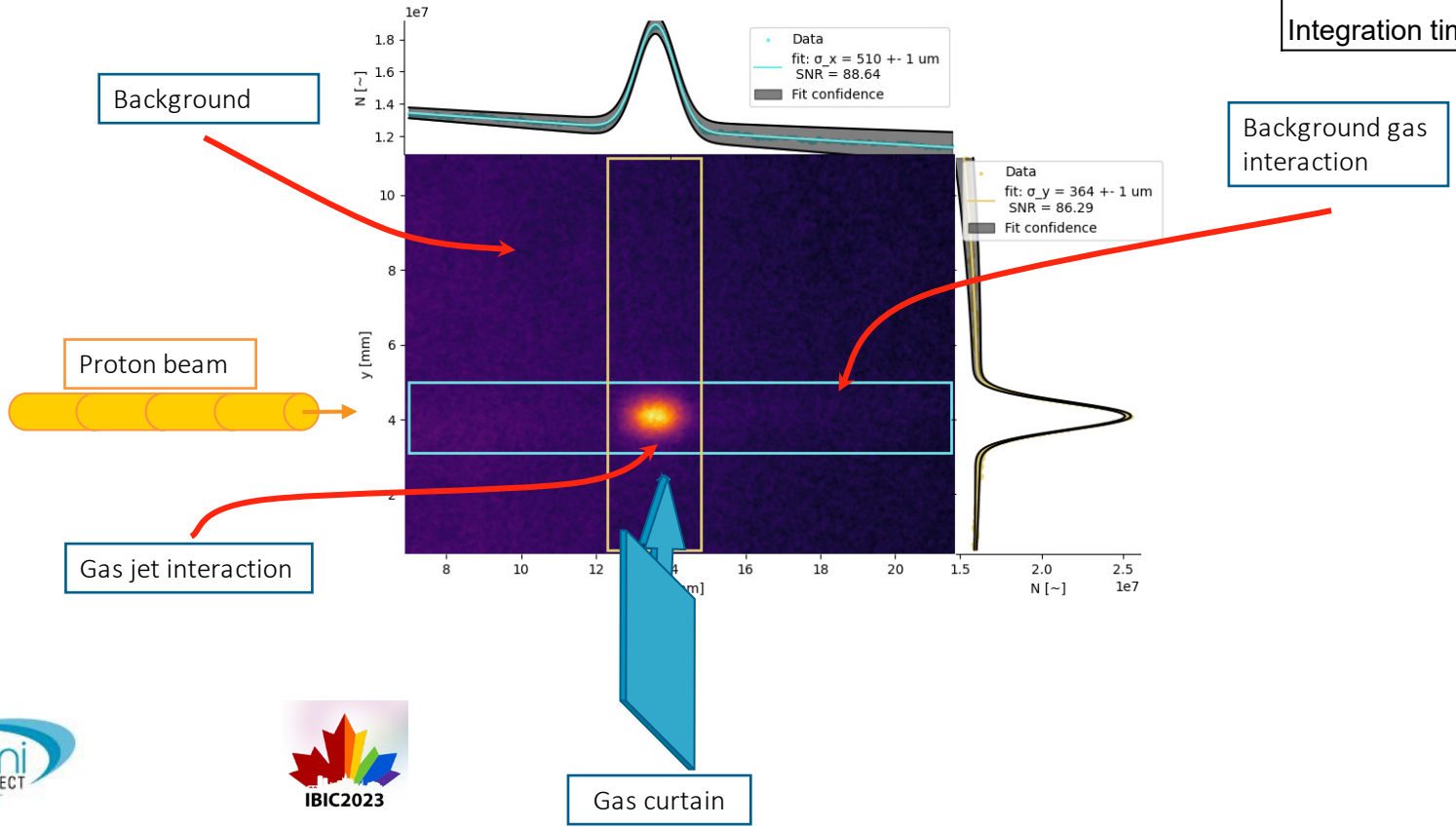
- Validated transparent for standard LHC beam

2023



First Gas Jet fluorescence measurements at LHC at 6.8 TeV

Parameters	
Beam Energy [TeV]	6.8
Beam intensity [p]	2.2e14
Gas jet	Ne
Integration time [s]	1659



Different integration times

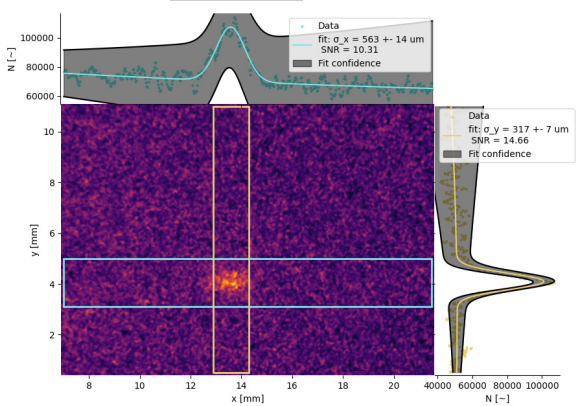
Centroid measurements

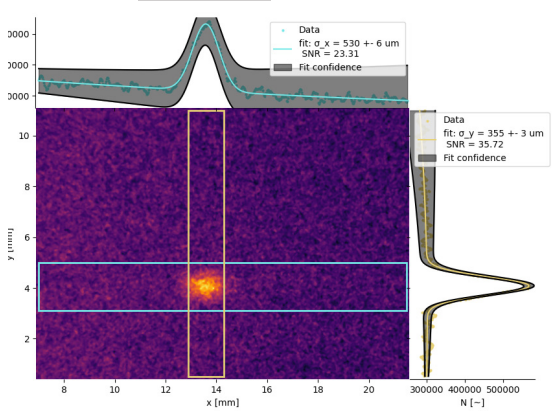
Profile measurements

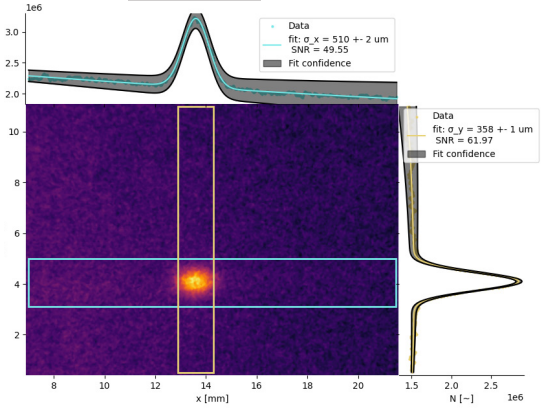
10s

1min

5min







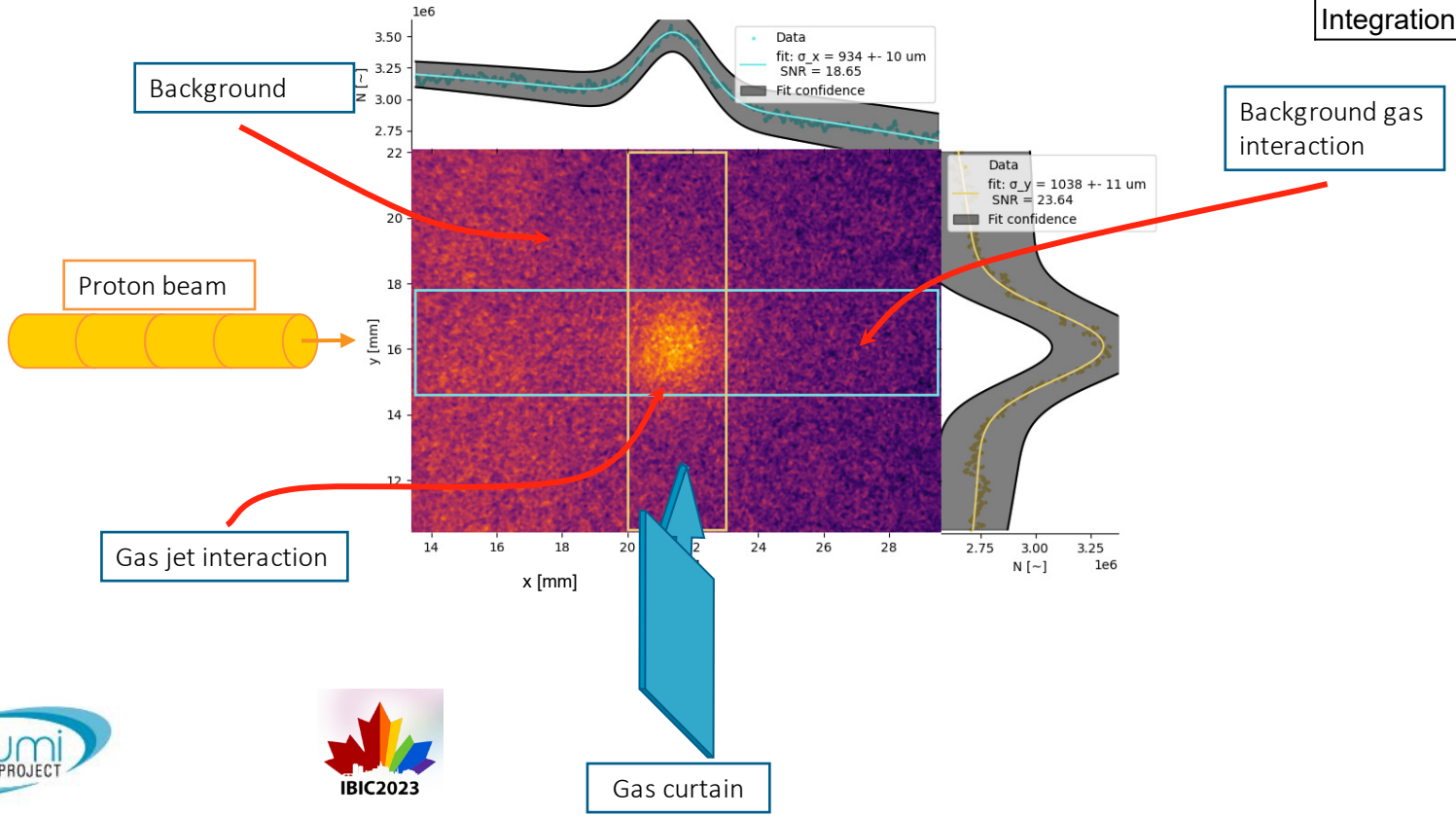
SNR ≈ 14.7

SNR ≈ 35.7

SNR ≈ 62.0

First Gas Jet fluorescence measurements at LHC at 450 GeV

Parameters	
Beam Energy [GeV]	450
Beam intensity [p]	3.7e14
Gas jet	Ne
Integration time [s]	239



Summary

- Beam Gas Curtain monitor, a 2D profile monitor utilizing fluorescence of supersonic gas jet
- Gas curtain density profile shows good transverse uniformity for Neon and Nitrogen curtain
- Varying 3rd skimmer lowers background and resolution significantly
- BGC monitor measured a hollow electron beam on Electron Beam Test Stand
  - Beam profile and centroid using N2, Ne, and Ar gas curtain in agreement
- BGC monitor measured installed and validated at LHC
  - First gas jet measurements of 6.8 TeV proton beam!
  - Further systematic studies will be performed in near future and published accordingly

Thank you for your attention!

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Work presented on behalf of the BGC collaboration:

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