Summary of other jet experiments

Non-Invasive profile monitor alternatives

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on behalf of ***BE-BI at CERN***

27 June 2019

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Summary of other jet experiments

Non-Invasive profile monitor alternatives

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Oxygen gas-sheet beam profile monitor for the synchrotron and storage ring, [2004]

- 85mm width by 1.3mm thick, 1x10^{-4} Pa
- Background pressure unaffected and constant at 10^{-8} Pa
- Ionisation used for profile monitoring
- Gas nozzle & skimmers similar to the BGC
- A focusing permanent magnet is used, shown to double density of O2 beam.

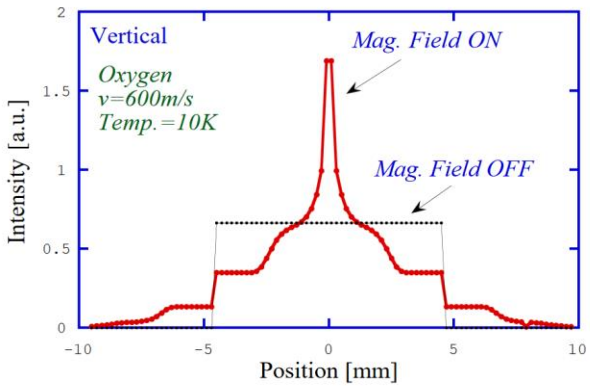
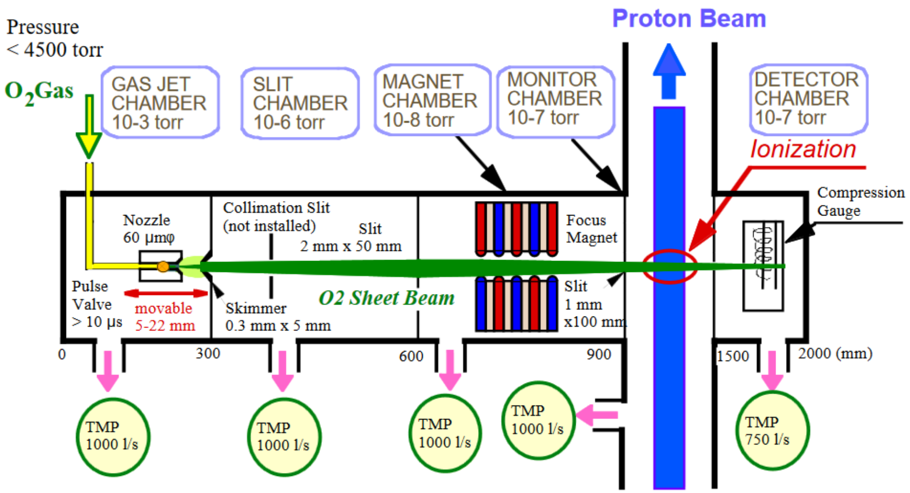


Fig. 3: Calculated Vertical intensity distribution of a molecular oxygen beam.



https://accelconf.web.cern.ch/accelconf/e00/PAPERS/WEP1A12.pdf

Other Gas Jet Experiments

Development of a gas sheet beam profile monitor for IOTA, 2018 [1]

- Nitrogen gas sheet to measure 2.5MeV proton beam in IOTA
- Includes investigation of nozzle types and rectangular capillary tubes for injection
- 70 x 0.2 x 0.2 mm gas sheet, detection is done using ions extracted with electrodes.

Non-destructive 2-D beam profile monitor using gas sheet in J-PARC LINAC, 2018 [2]

- N_2 gas sheet for detection of 400 MeV H^- beam (ionisation, MCP and phosphor screen)
- 1 mm thick gas sheet at 2×10^{-4} Pa, when using 100 Pa inlet pressure
- Gas sheet generator is a rectangular channel instead of a round nozzle, 2018 [3]

PANDA

Cluster Gas Jet targets at PANDA

- Stable target beams demonstrated in COSY setup at Jülich lab, $>10^{15+}$ atoms/cm^2 achieved.
- MIE scattering device used for measurements of cluster mass distributions.
- Preparing CD nozzles with 'similar performance to former CERN nozzles'.
- Cooled CD nozzle is used, clusters can be avoided with higher temperatures.

The most recent paper includes many numerical calculations of gas flow through CD nozzles and the relevance of temperature

Nm-sized cryogenic hydrogen clusters for a laser-driven proton source

https://aip.scitation.org/doi/10.1063/1.5080011

III. CLUSTER-JET CHARACTERIZATION

The cluster beam was characterized which is required for laser plasma applications. Of special interest is the target volume density at the position of the laser interaction point. Although a direct measurement, in principle, is possible, due to the experimental setup, such a measurement would be accompanied with large systematic uncertainties. Alternatively, a much more reliable method is an estimation using the gas flow through the nozzle. Since the gas flow meter information was designed for higher gas flows at lower temperatures, the gas flow is calculated based on the well known stagnation conditions and the nozzle geometry. The gas volume flow q_v through the nozzle can be calculated using[31]

$$q_v = A^* \frac{p_0}{\sqrt{MT_0}} \frac{T_N}{p_N} \left(\frac{2}{\kappa+1}\right)^{\frac{\kappa+1}{2(\kappa-1)}} \sqrt{\kappa R}, \quad (1)$$

where A^* is the cross section of the narrowest point of the nozzle, p_0 and T_0 are the stagnation conditions of the gas in front of the nozzle, $p_N = 1.01325$ bar and $T_N = 273.15$ K are the normal pressure and temperature, M is the molar mass of the gas, $\kappa = C_p/C_V$ is the heat capacity ratio, and R is the universal gas constant. A calculation of the mass flow $\dot{m}$ with respect to the gas flow q_v

$$\dot{m} = \frac{q_v \cdot M \cdot p_N}{R \cdot T_N} \quad (2)$$

allows for a determination of the target volume density $\rho_{\text{volume}}(x)$ with the cluster beam cross section $A_{\text{beam}}(x)$ at the distance x to the nozzle and the Avogadro constant N_A

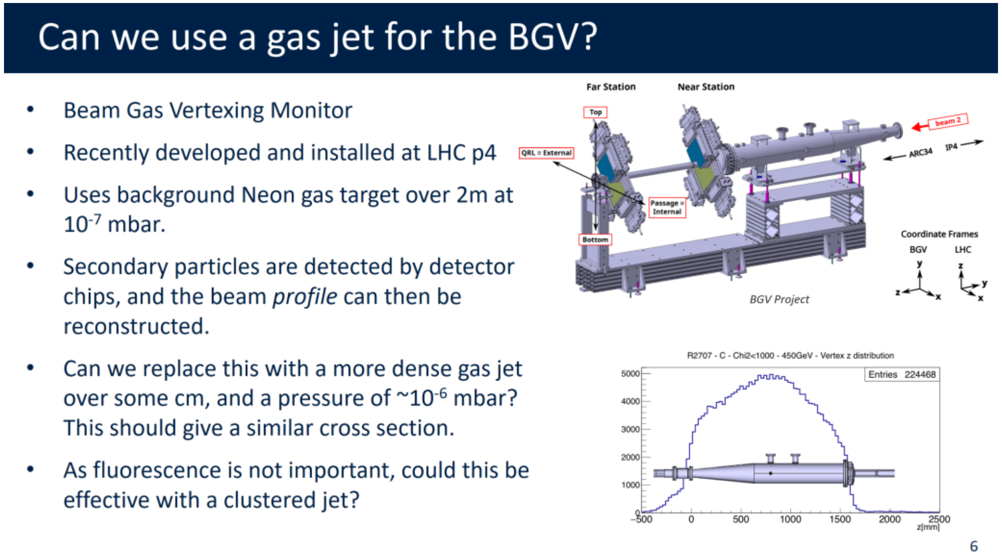
$$\rho_{\text{volume}}(x) = \frac{\dot{m}}{v \cdot A_{\text{beam}}(x)} \cdot \frac{N_A}{M}. \quad (3)$$

For the temperatures used, the mean cluster velocity v can be approximately estimated assuming an ideal gas[27]

$$v = \sqrt{\frac{2\kappa}{\kappa-1} \frac{RT_0}{M}}. \quad (4)$$

In the case of a real gas, the jet velocity might be lower by, e.g., a few percent. Therefore, the estimated target density might be larger by this value. Obviously, the target density depends on the gas used and the stagnation conditions, which can easily be defined

BGV



Looking to apply gas jet technology to other methods of beam instrumentation.

BGV could use similar gas jet generation technology, with a different data collection method.

More info to follow from Robert Kieffer

Focusing Gas

Techniques investigated:

Electrical/ Magnetic focusing

Magnetic hexapole lens focusing of metastable helium atomic beam, 2006

Focusing Mirrors

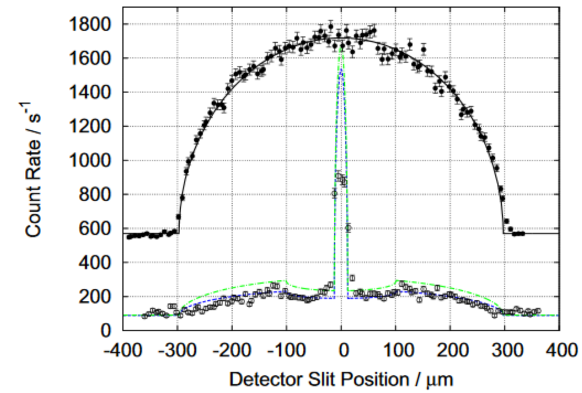
Focusing a helium atom beam using a quantum-reflection mirror, 2009

Fresnel Zone plates - University of Bergen, Norway

Atom sieve for nanometre resolution neutral helium microscopy, 2017

Focusing of a neutral helium beam with a photon-sieve structure, 2015

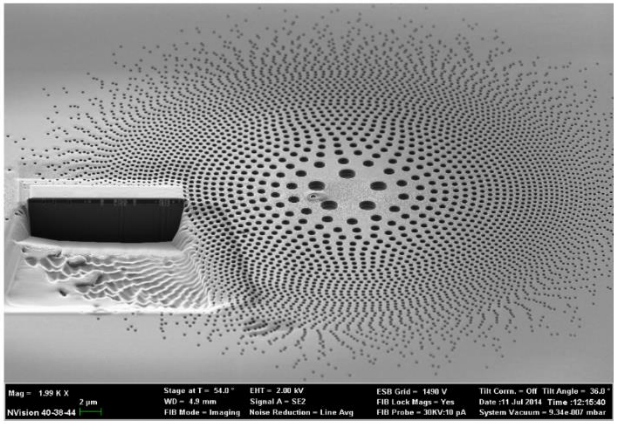
Focusing of a neutral helium beam below one micron, 2012



Potential next steps:

- Simulation of zone plates using McStats, a MonteCarlo ray-tracing program for neutron scattering experiments. This could be used to investigate focusing effect by simulating quantum behaviour of helium gas.

- Could the Cockcroft Zone plate be used in BGC v1?



Cockcroft Zoneplate

Ion Probe Beam

Transverse profile monitor using ion probe beams, 2001

Low intensity and energy ion beam probe demonstrated on the SPS at CERN.

Heavy ions, up to Xenon, used instead of electrons due to lower speed & lower deviation angle. Ion beam current is about 1 nA.

Ion beam is scanned across the proton beam, deflected by electric field.

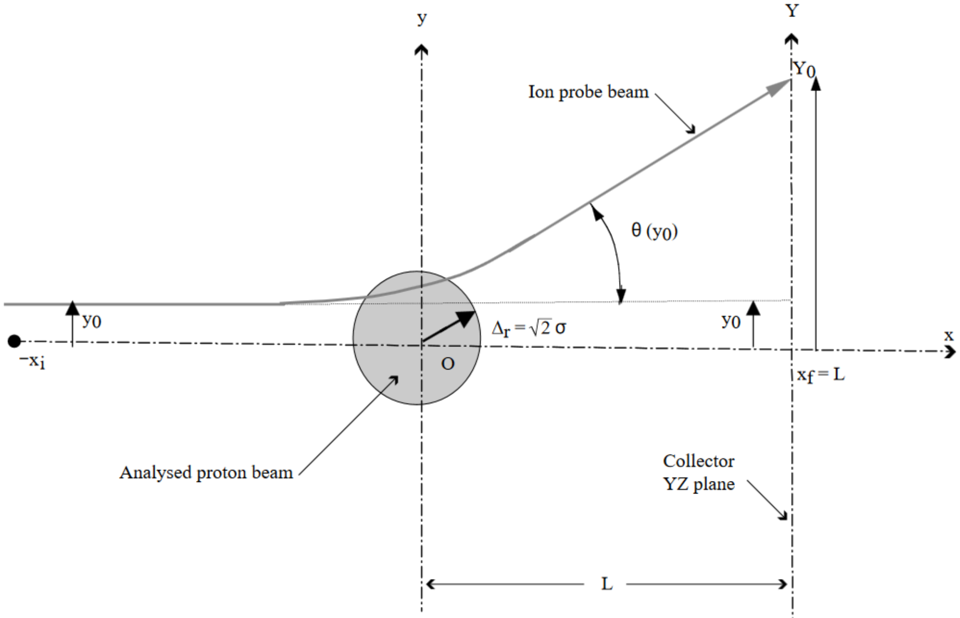
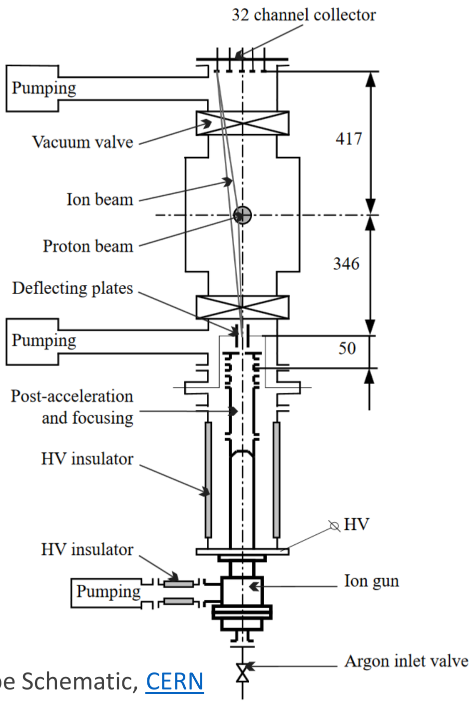


Fig. 1. (a) System of coordinates. (b) Principle of the ion pencil-beam 'profilometer'.



SPS Ion Probe Schematic, CERN

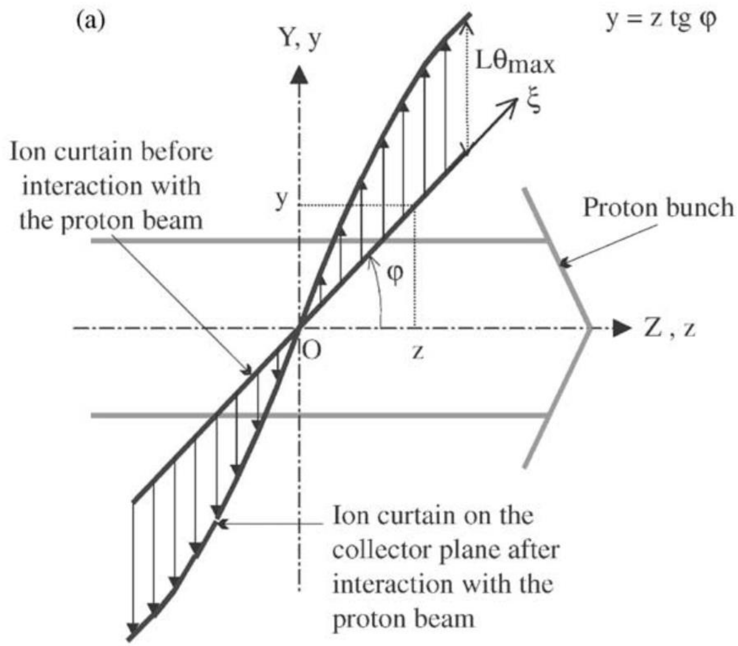
Ion Probe Beam

3 collectors used to measure the deflection

- 1.5mm spaced microstrips
- Resistive plate
- Luminescent screen

Different Ion beam structures used:

- Pencil beam
- Ion Curtain
- Shadowing technique



Principle for the Ion Curtain Profilometer, [CERN]

Reasons given for ending research was required improvements of ion source quality, electronics and processing time. 18 years on now…

Focused Ion Beams

The problem

Higher energy machines need non-invasive solutions

- intercepting devices (screens, wires etc.) will be destroyed.

The challenge

Can we replace a wire scanner with an scanning ion beam?

Focused Ion beams

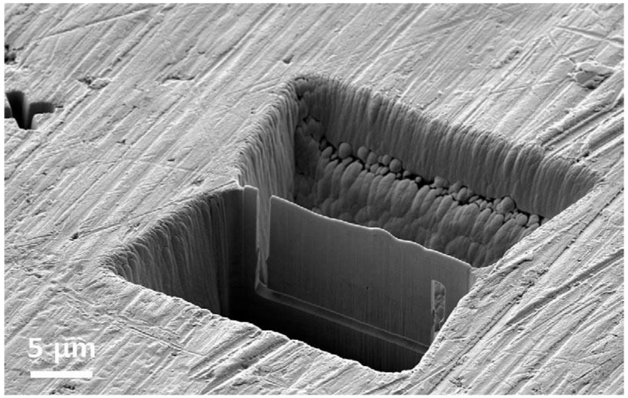
Commercially used in semiconductor industry and microscopy

Increasingly higher currents allow ion machining

High electric field used for ionisation of the source

Acceleration to 1-50keV

Focusing using electrostatic lenses



NanoFabrication with a FIB, [ZEISS]

Focused Ion Beams

Characterising the BGC Jet

Target FIB density >> 3 $A.m^{-2}$

Smaller diameter allows high precision and scanning.

Wire scanner is diameter is 20 um

Speed:	750 $m.s^{-1}$
Density: Optimistic (Serban)	2.5E16 m^{-3}
Realistic / Measured	4E15 m^{-3}
Flow rate:	1.88E19 atoms m^{-2} s^{-1} (flux)
CSA, 2mm diameter	3.14E-6 m^2
Flow	5.90E13 atoms s^{-1}
Current density, q = 1.6E-19 C	3.0 $A.m^{-2}$ (for Ne^+)
Current, I = q.ϱ.V.A	9.4E-6 A

BGC Characteristics

Zeiss and Tescan produce commercial FIBs, huge range of options.

Xe^+ by Tescan seems best: **Flow rate** 9.95E+23 ions $m^{-2}s^{-1}$ & **Ionic density** 1.50E+19 m^{-3}

Next Steps:

- Investigate Space-charge effect
- Detection techniques
- Cross-sections & detection limit

	Resolution	Energy	Current	Current density	Density (m^{-3})
Helium	0.5 nm @ 30 kV	10-30 kV	0.1 - 100 pA		
Zeiss	*Ø 3 nm*	*30 kV*	*100 pA*	14,147,106 $A.m^{-2}$	1.81E20
Neon	1.9 nm @ 25 kV	10-25 kV	0.1 - 50 pA		
Zeiss	*Ø 3 nm*	25 kV	*50 pA*	7,073,553 $A.m^{-2}$	9.05E19
Gallium	3 nm @ 30 kV	1-30 kV	1pA – 100 nA		
Zeiss &	*Ø 3 nm*	*30kV*	*1 pA*	141,471 $A.m^{-2}$	1.65E18
Tescan	*Ø 4 um*	*30kV*	*100 nA*	7957 $A.m^{-2}$	1.02E14
Xenon	25nm @ 30kV	3-30kV	1pA – 2 µA		
Tescan	*Ø 4 um*	*30kV*	*2µA*	159,154 $A.m^{-2}$	4.74E18
	Ø 50 nm	*30kV*			

Summary of commercial FIBs

Additional Gas Jet Papers

- Development of a Beam Profile Monitor Using an Oxygen Gas Sheet, 2000
- Development of a Non-Destructive Beam Profile Monitor Using a Gas Sheet, 2001
- Development of a Gas-Sheet Beam Profile Monitor, 2001
- Oxygen gas-sheet beam profile monitor for the synchrotron and storage ring, 2004
- Development of a Non-destructive Beam Profile Monitor Using a Sheeted Nitrogen-Molecular Beam, 2010
- Development of a Beam Profile Monitor using Nitrogen-Molecular Jet for intense beams, 2012
- A Non-Destructive Profile Monitor Using a Gas Sheet, 2016
- Development of a Gas Sheet Beam Profile Monitor for IOTA, 2018 [1]
- Non-Destructive 2-d beam profile monitor using gas sheet in J-Parc LINAC, 2018 [2]
- A Non-Destructive 2D Profile Monitor Using a Gas Sheet, 2018 [3], slides