MINIMUM INVASIVE DIAGNOSTICS FOR MEDICAL ACCELERATORS

Contents

- Beam diagnostics in accelerators
- Beam profile measurement
  - Invasive methods
  - Non-invasive methods
  - Gas jet-based monitors
- Possible application for medical accelerator
- Summary

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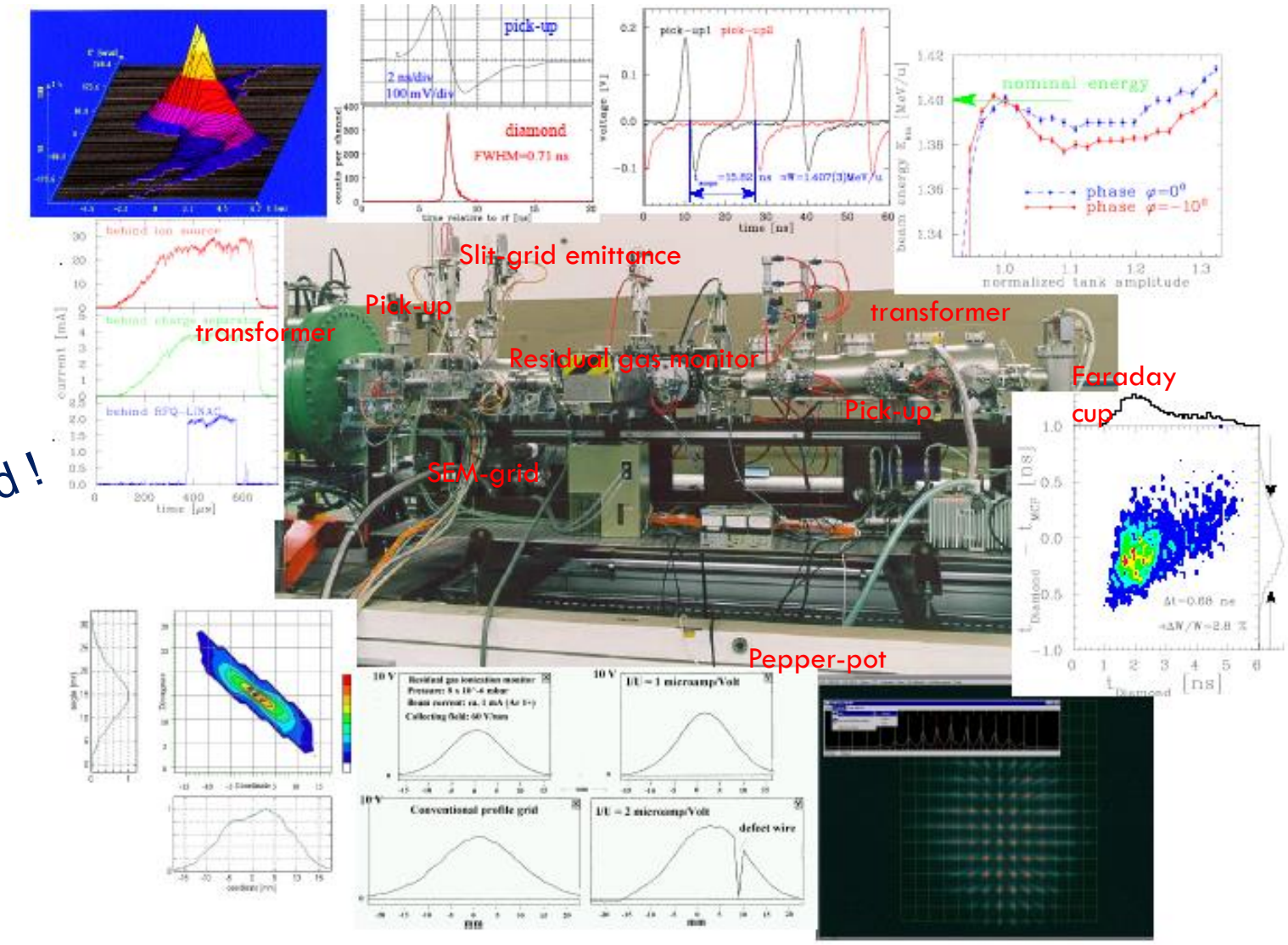
Beam diagnostics in accelerators

- Beam Instrumentation is essential to any accelerators
- Is the 'eyes and ears' of the operators.
- Is important in different stages of a working machine
  - Commissioning
  - Daily maintenance
  - Troubleshooting

A ‘typical’ Accelerator Diagnostics

- Material sciences
- Thermodynamics
- Electro-Magnetism
- Optics
- laser technology
- Mechanics
- Electronics
- Nuclear Physics
- Vacuum science
- …

Multi-disciplinary field !



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Methods for beam diagnostics

- Beam current
  - Faraday cup, Transformer
- Beam position
  - Pick-ups
- Beam energy
  - Pick-ups (TOF), Spectrometer
- Beam profile
- Beam emittance
  - Pepper-pot, quadrupole scan, phase space tomography

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Beam profile measurement method

- Scintillating screen (phosphor, YAG, et al)
- Wire scanner
- Radiation based detection (SR, OTR, ODR)
- Crossed beam monitor
  - Laser wire
  - Ion beam scanner
- Gas-based monitor
  - Ionization monitor
  - florescent monitor

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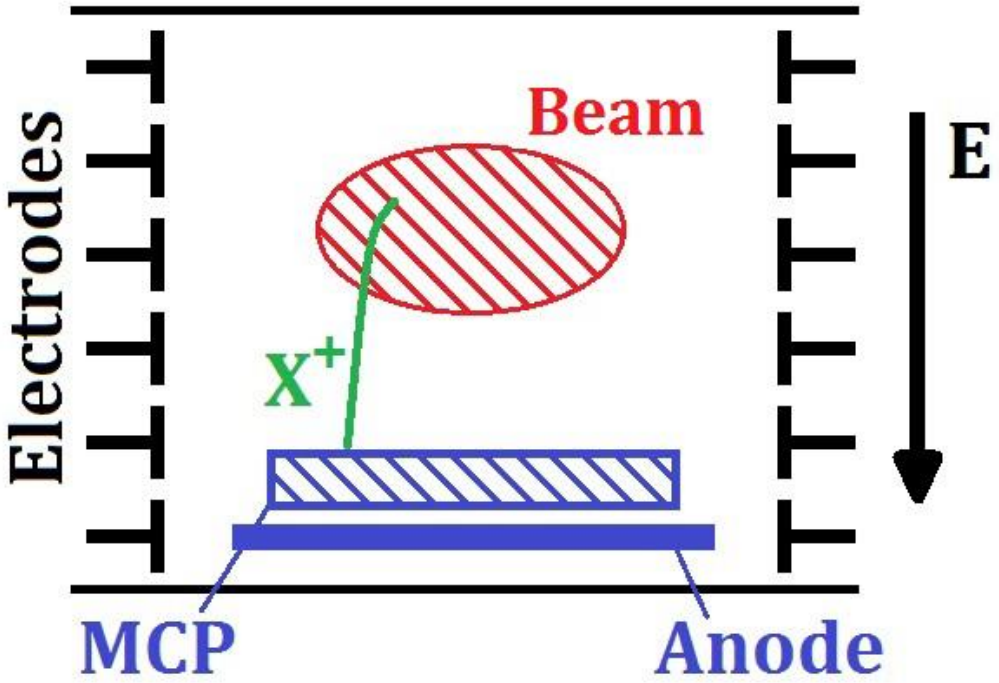
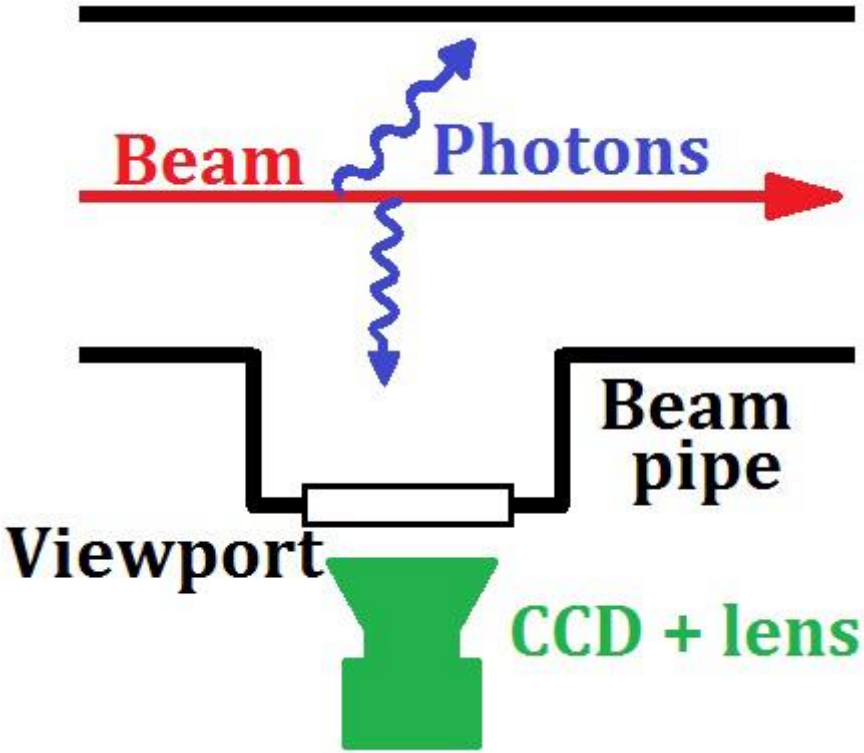
Gas-based monitor

Residual gas monitor



Beam induced fluorescence monitor



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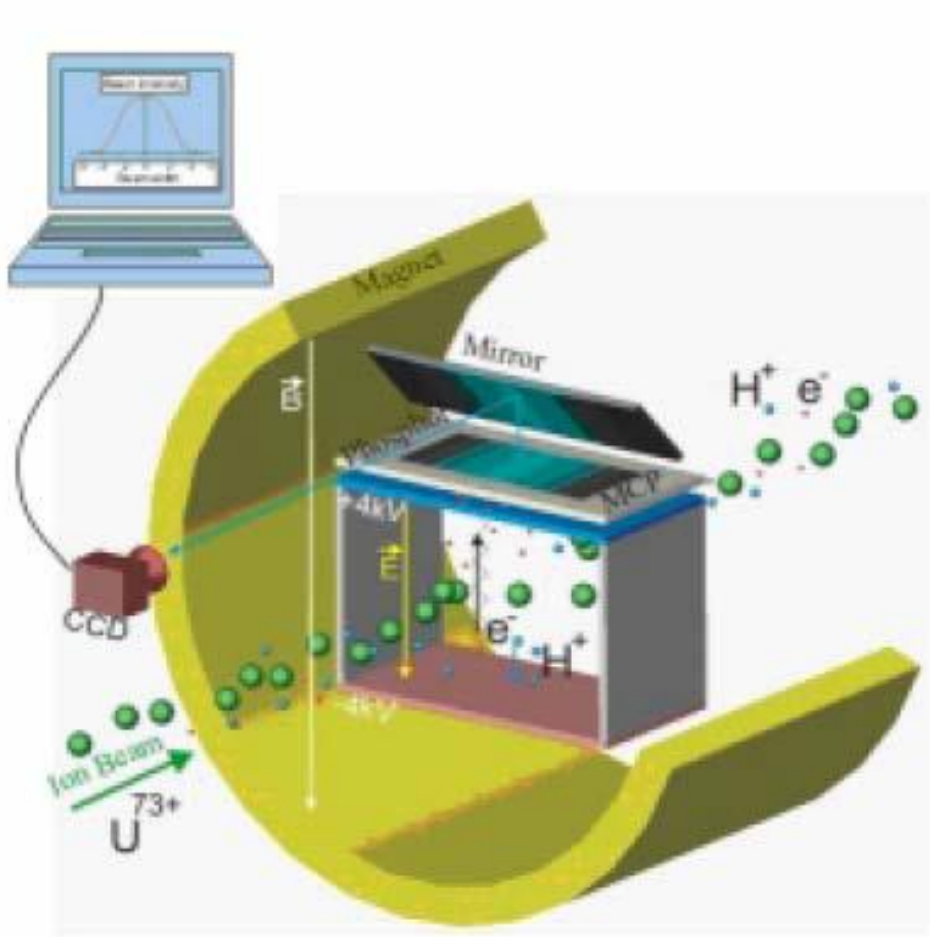
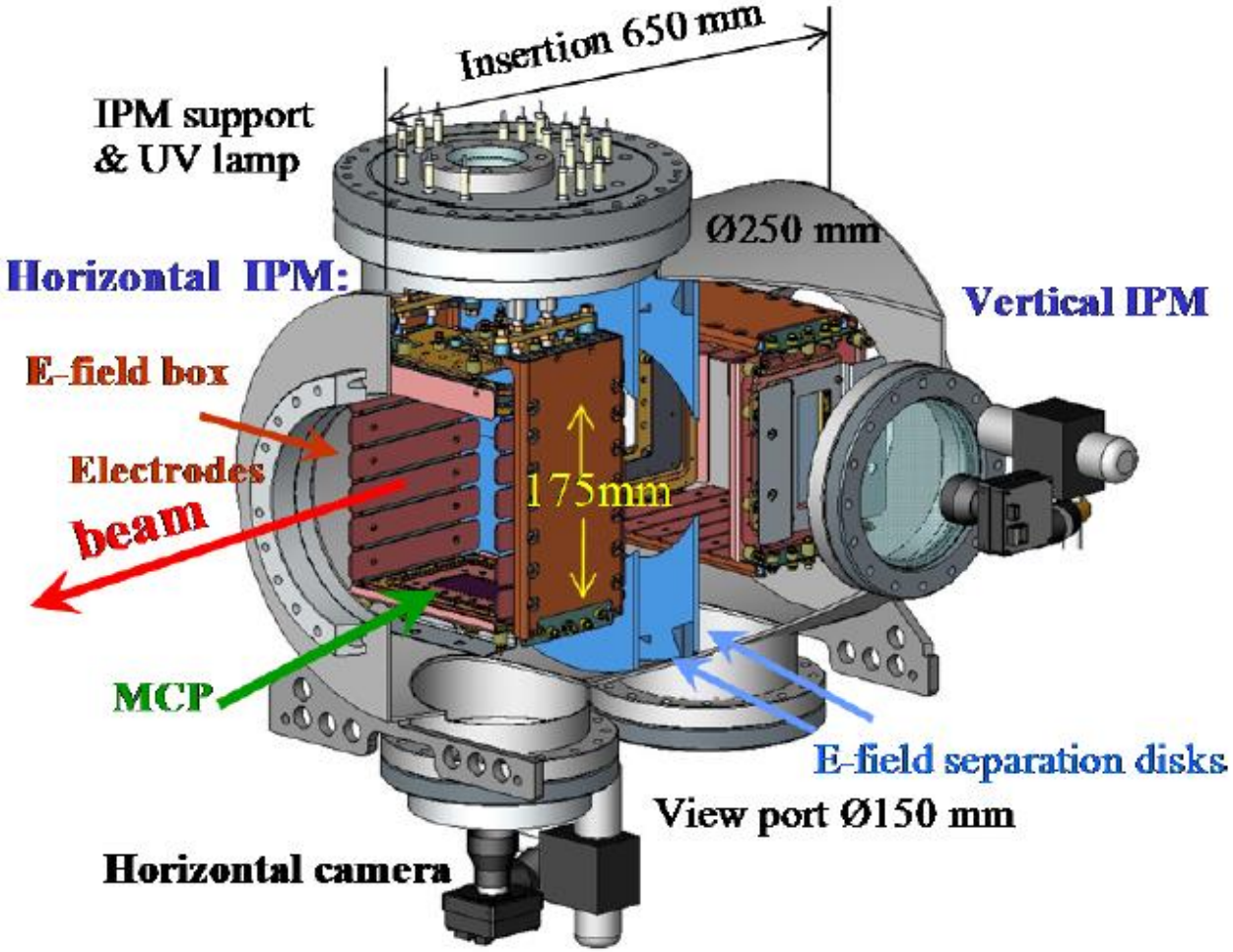
Residual gas based Ionization Profile Monitor





Credit: P. Fork, GSI

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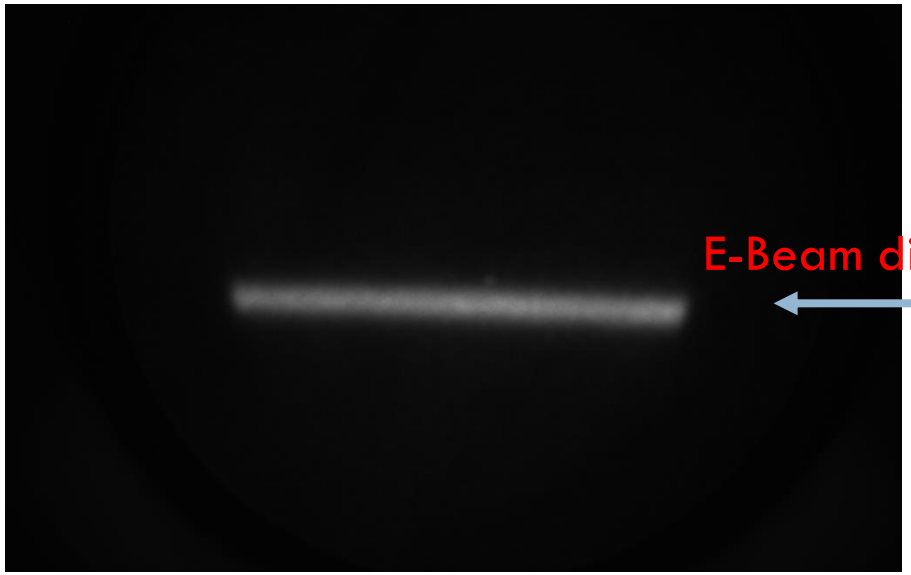
Residual gas image of a electron beam



Give you a one dimensional profile!

- Secondary ions or electrons are collected.
- Magnetic field are used to compensate the profile distortion by self space charge force or wake fields.
- Secondary particles are collected by electronics or optical (scintillator plus MCP)

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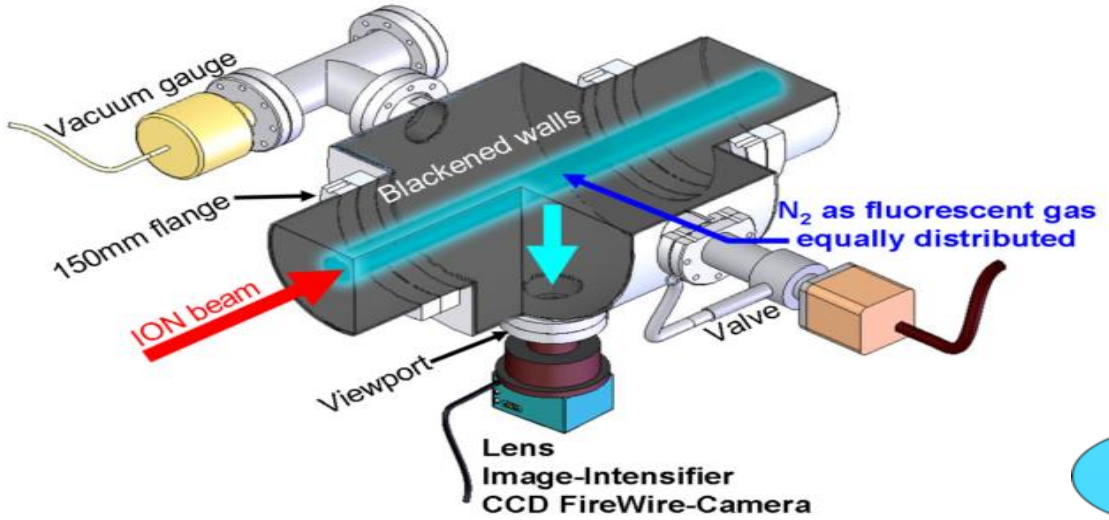
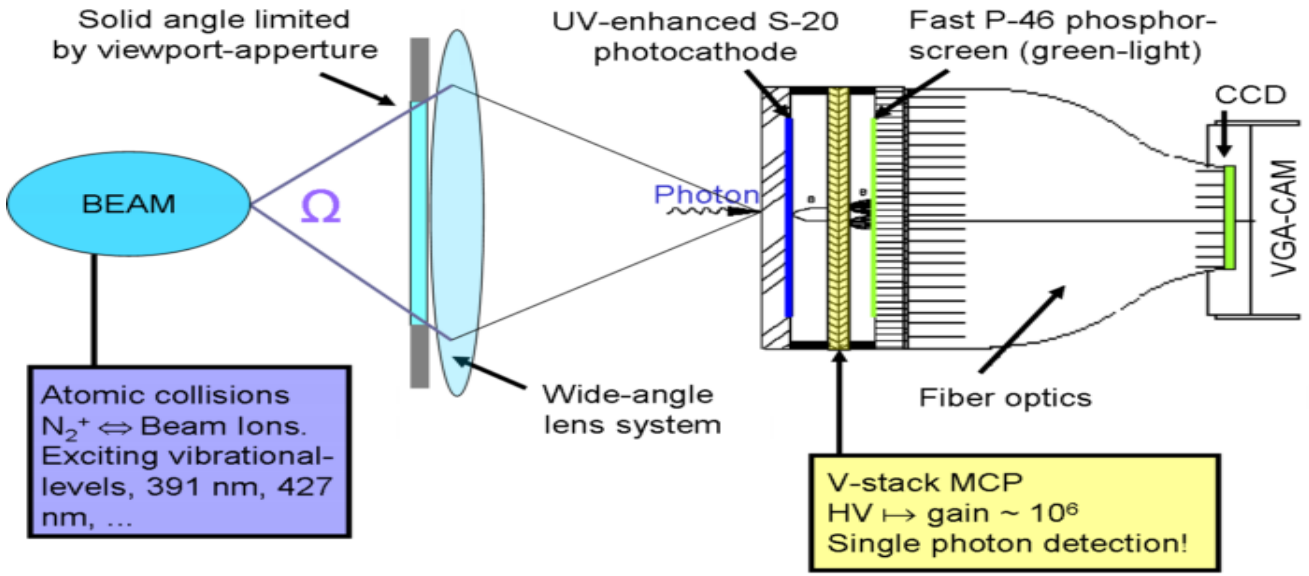
Beam induced fluorescence (BIF)



Schematic drawing of the BIF-monitor as installed at GSI UNILAC. *



BIF detection principle - How the beam induced fluorescence light is imaged, intensified and detected.*

*Credit: GSI, http://www-bd.gsi.de/dokuwiki/doku.php

IPM and BIF

- The cross section for impact ionization and fluorescence dependent on the beam energy, residual gas species, and certain fluorescent wavelength.
- BIF has longer integration time due to lower cross section and viewed at certain solid angle.
- Might need gas injection using a leaking valve to increase the local pressure.
- Normally N_2 is used for its easy access, other gases such as Ne, Ar has also been used.

Using Supersonic gas jet !

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Motivation to use gas jet

- Working in ultrahigh vacuum environment
- Non-invasive or minimum-invasive
- Minimized scattering
- Not dependent on beam species, energy and intensity
- No damage threshold

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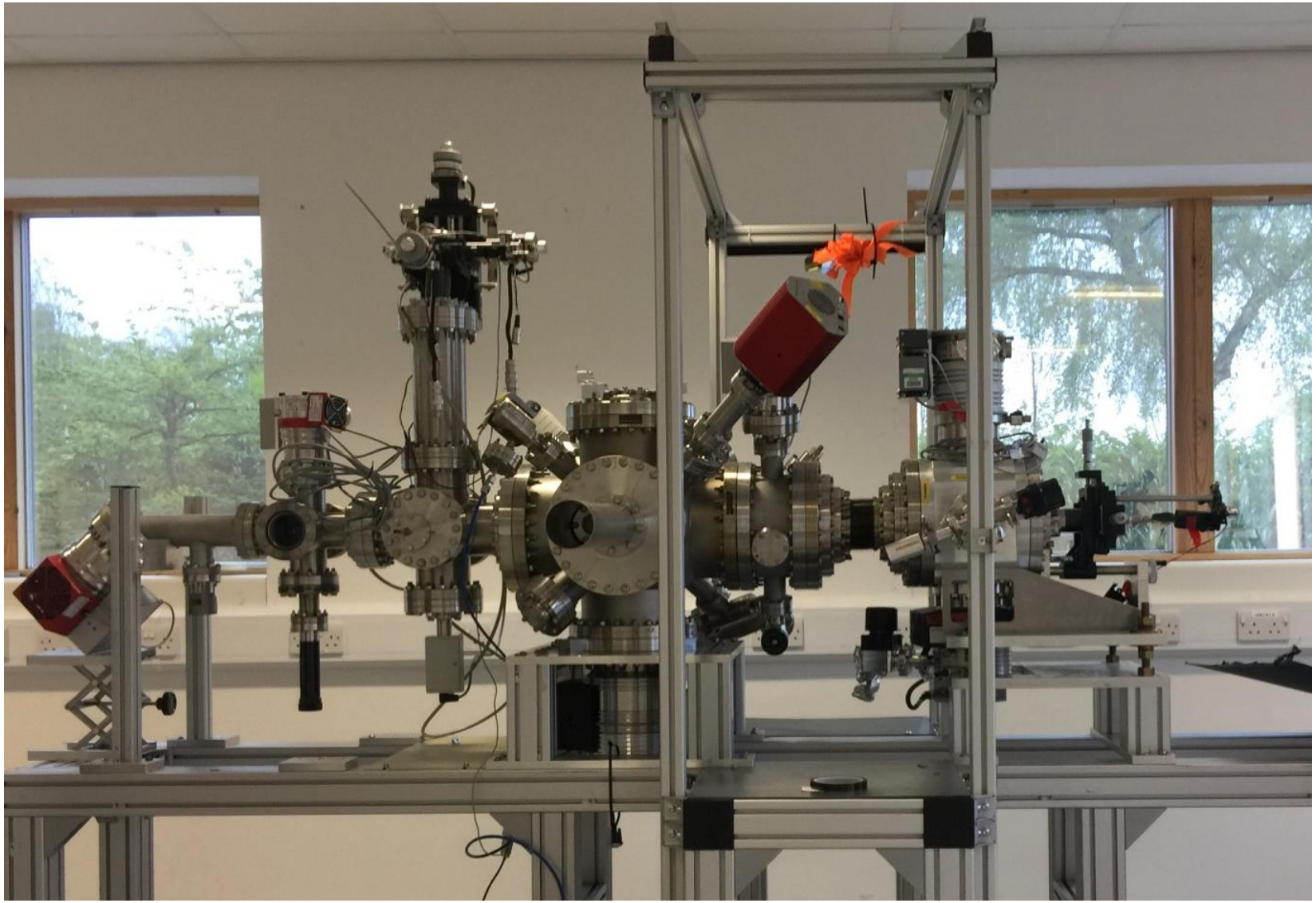
Get-jet Monitor Setup



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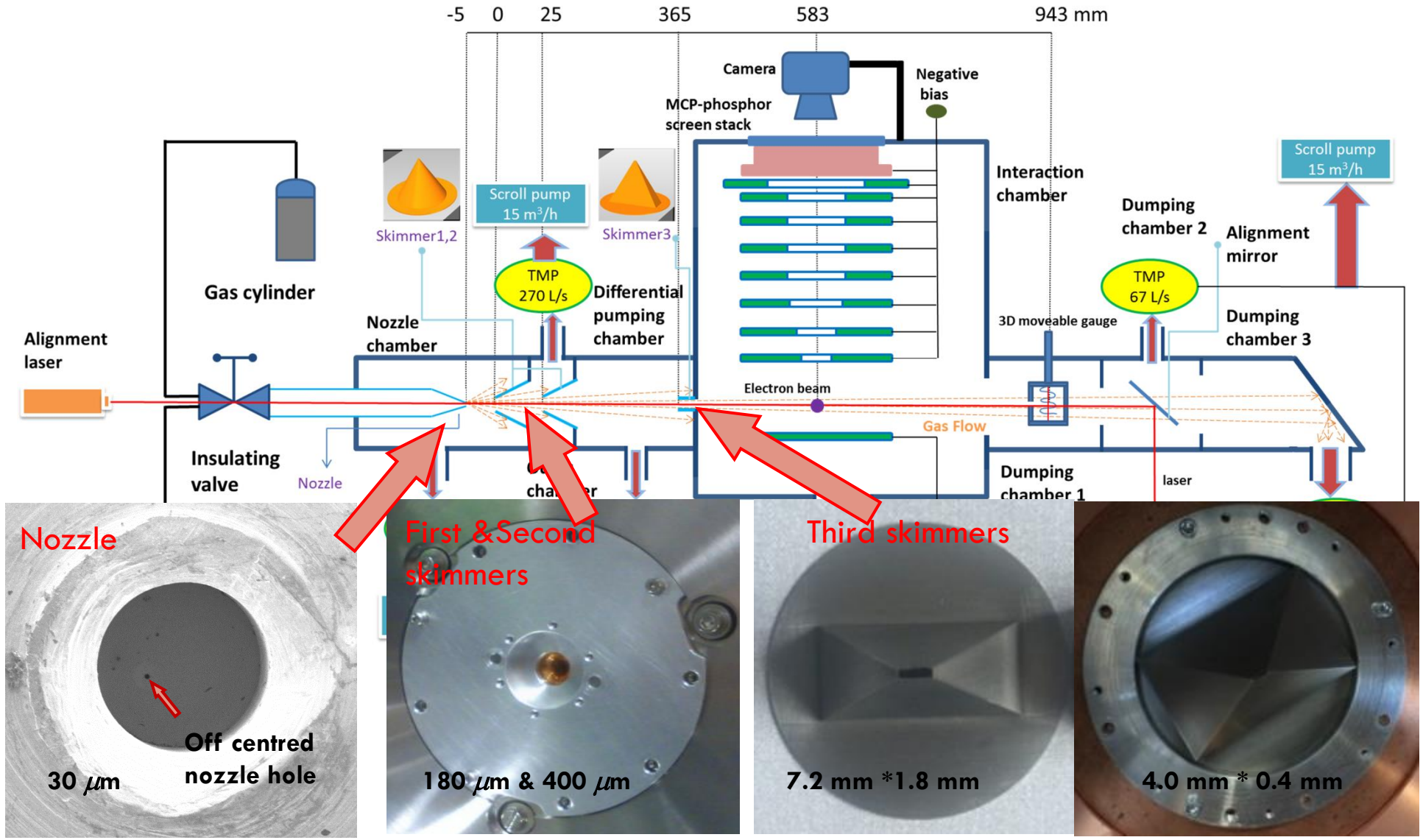
Get-jet Monitor Setup



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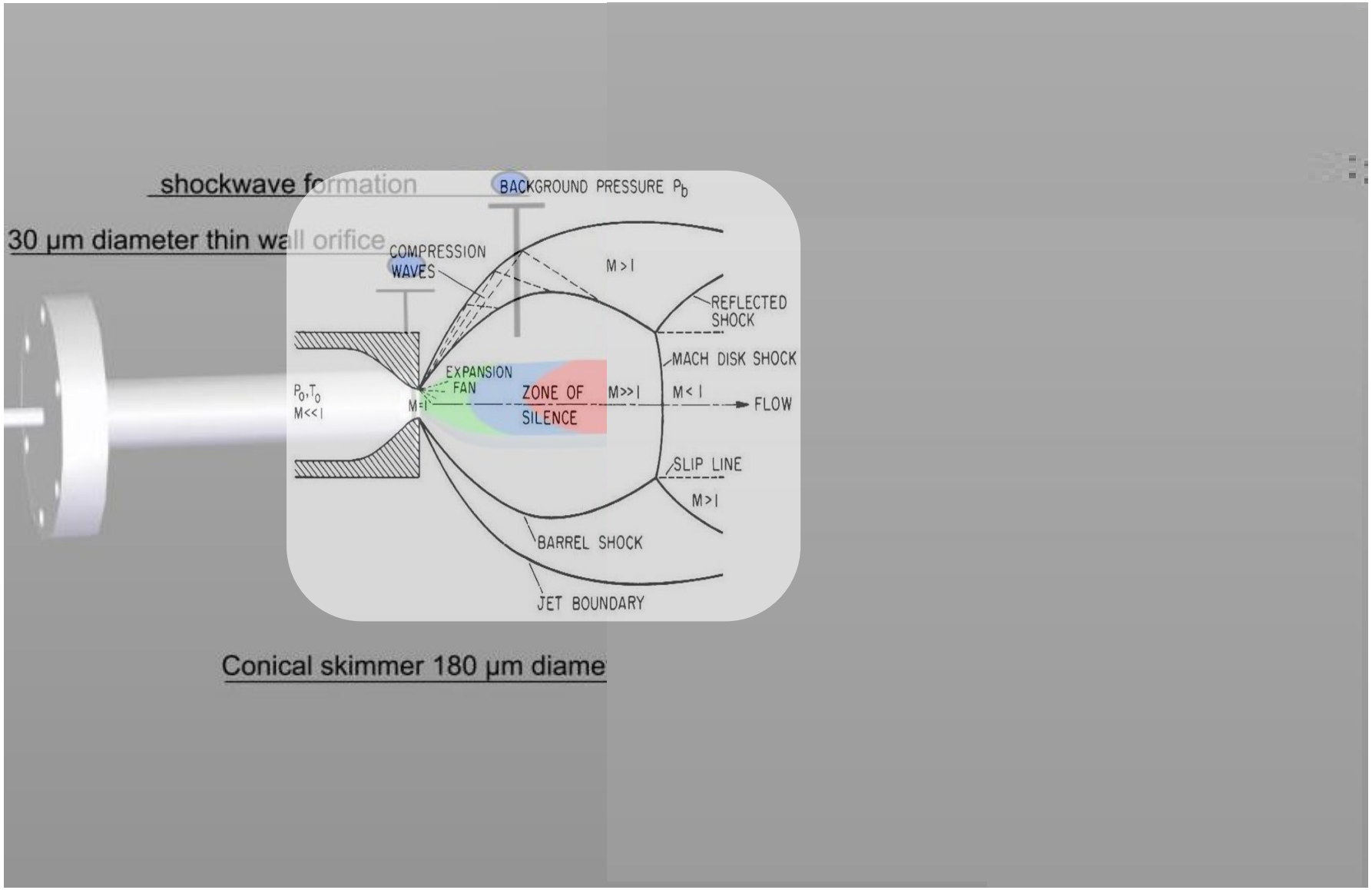
Generation of supersonic gas jet



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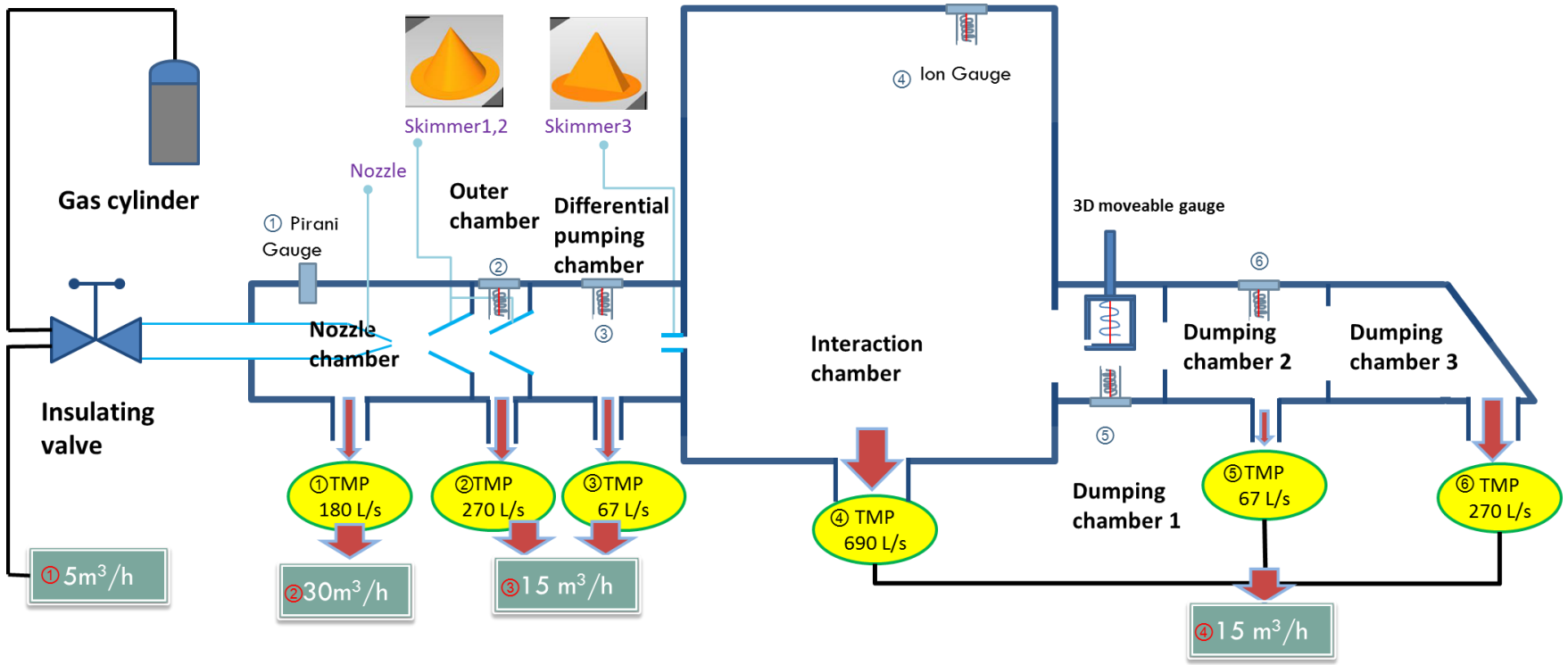
Vacuum consideration



Number	1	2	3	4	6
Jet off (mbar)	$<5.0*10^{-4}$	$2.1*10^{-6}$	$9.7*10^{-8}$	$1.8*10^{-8}$	$5.36*10^{-10}$
Jet on (mbar)	$1.19*10^{-3}$	$6.9*10^{-5}$	$4.8*10^{-6}$	$2.3*10^{-8}$	$1.21*10^{-9}$

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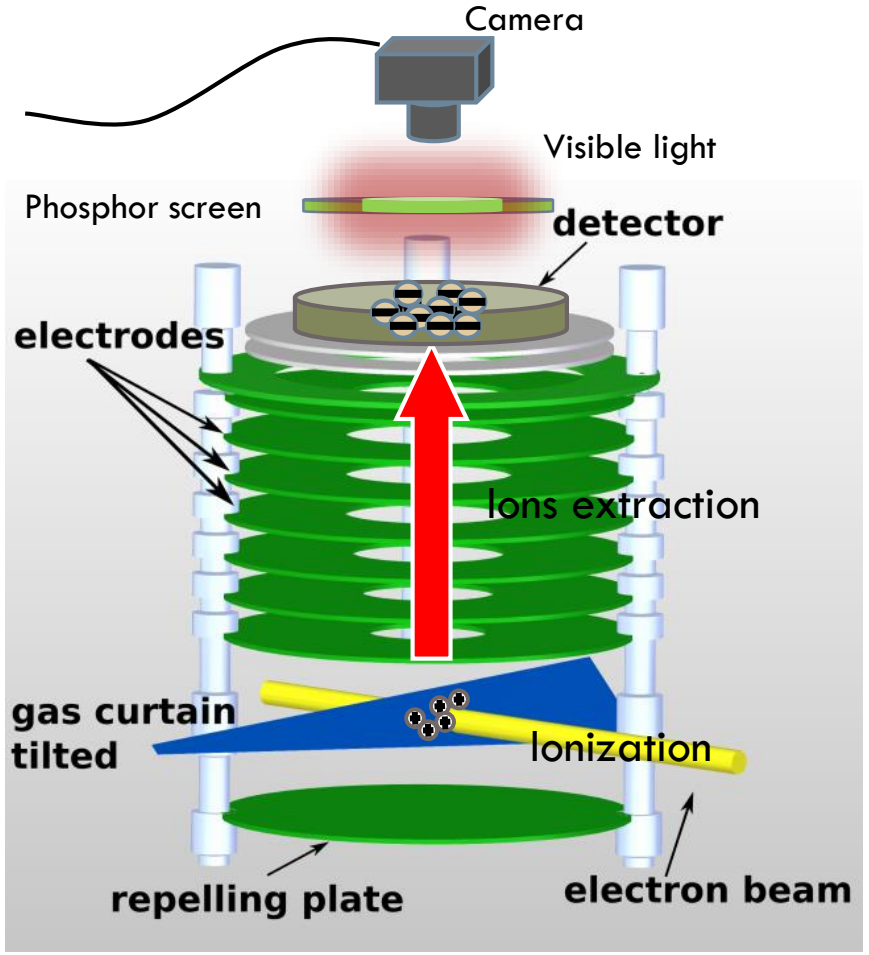
Ionization detection



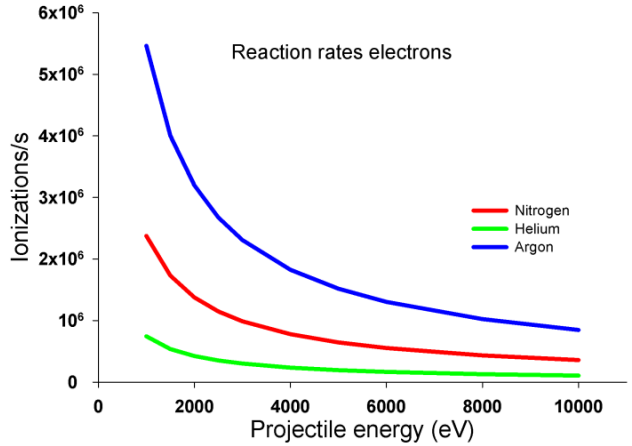
- E-gun

Parameter	Value
Energy	1 – 5 keV
Current	0.1 – 7.0 μA

- Estimated jet property

Parameter	Value
Density	$2.5*10^{10}$ particle/cm^3
Thickness	0.5 mm
Vertical size	5 mm

- Reaction rate



Estimated integration time = 1 ms

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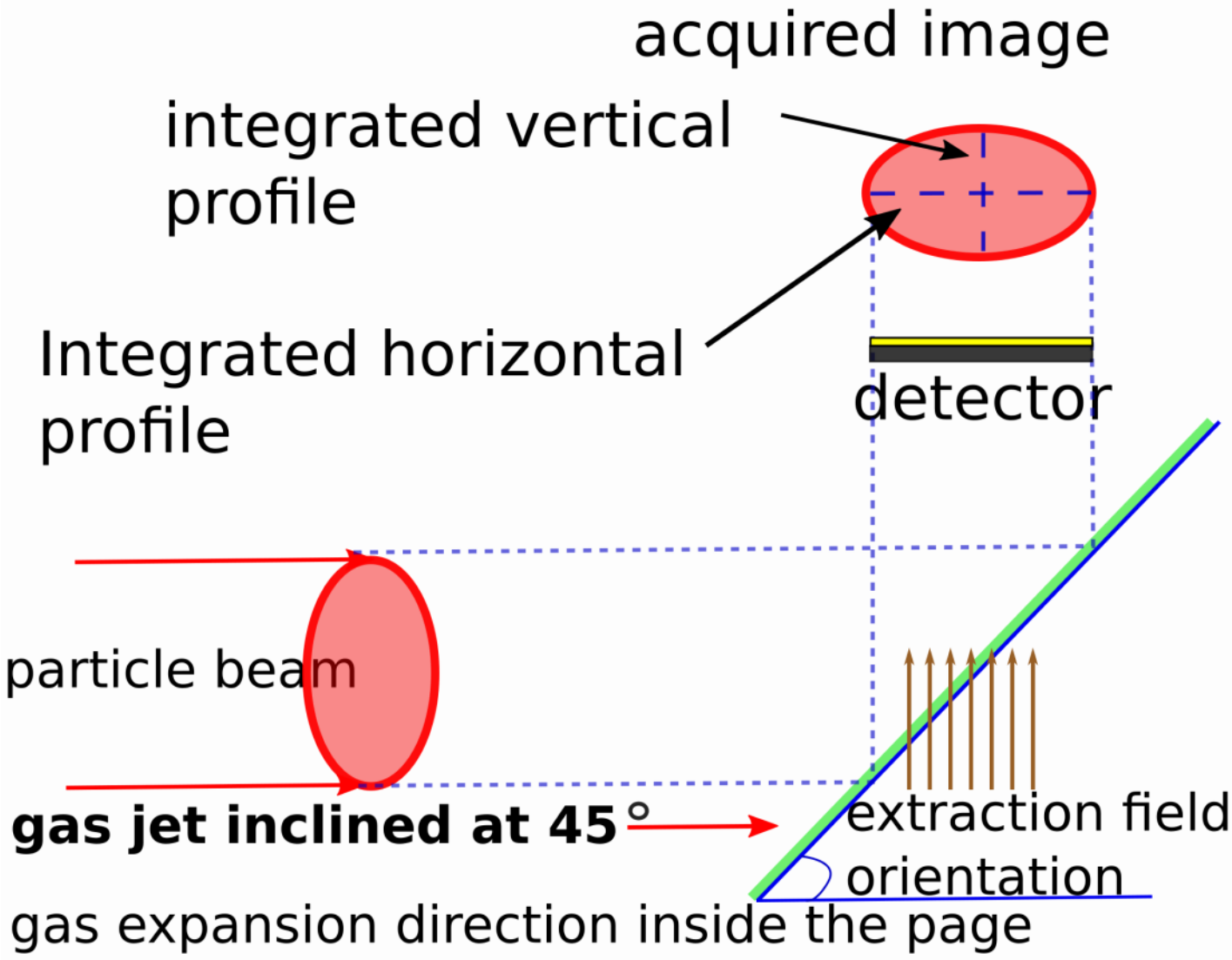
2D imaging realization



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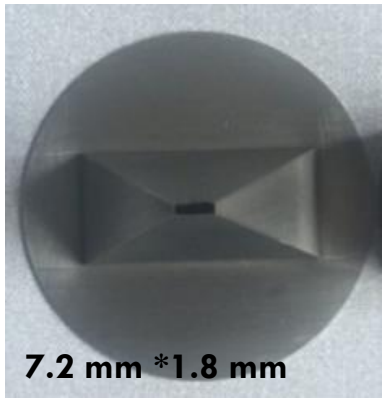
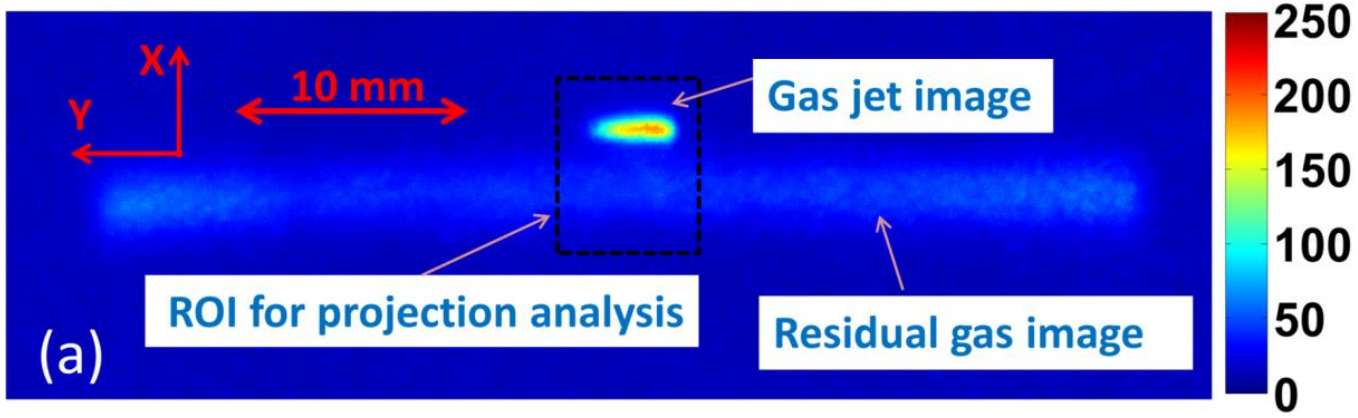
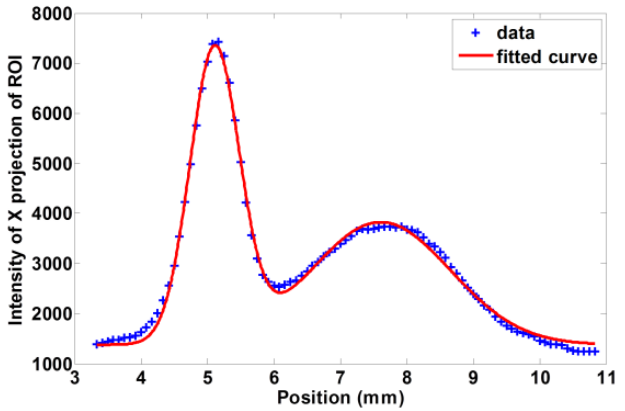
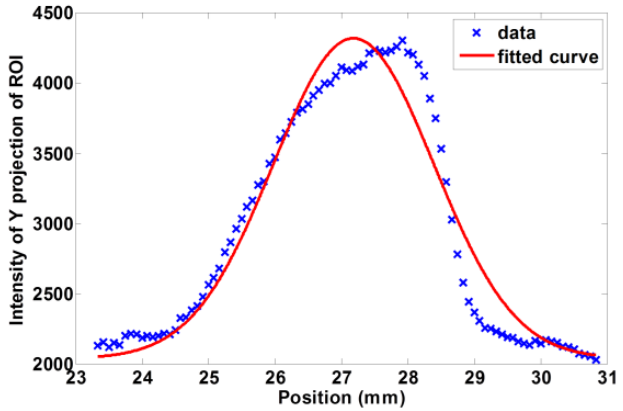
Typical measurement with Large skimmer









Setting	Value
Energy	3.75 keV
Current	~5.0 μA
External field	7.5 kV/m
Exposure	70 ms

size	Value
Xrms	0.37
Yrms	1.21
Xrms from residual	1.05

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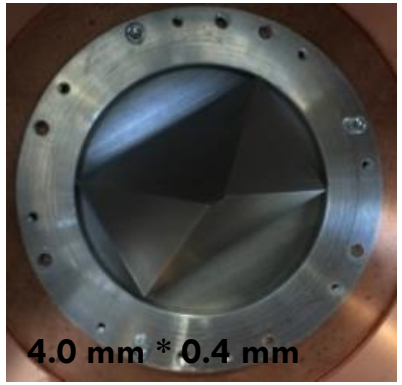
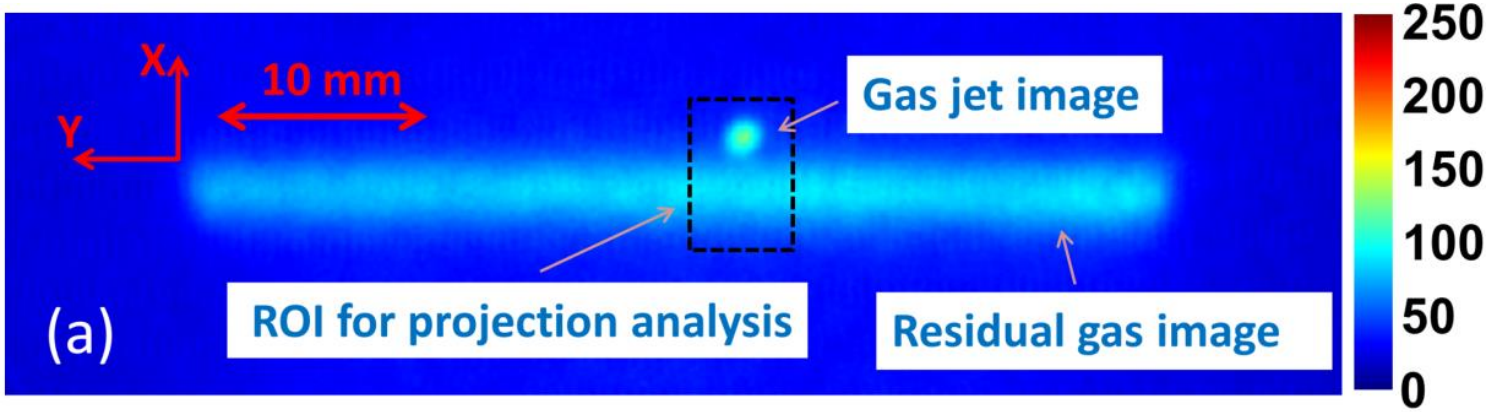
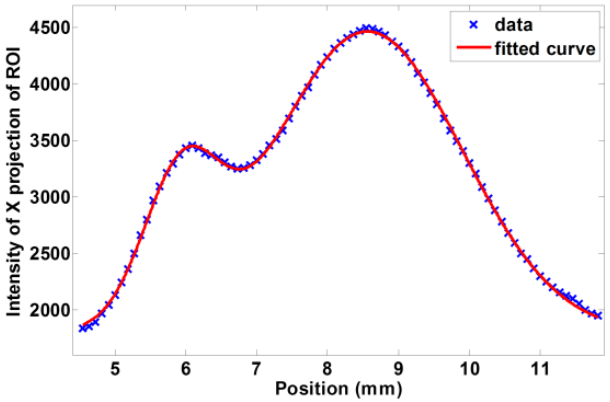
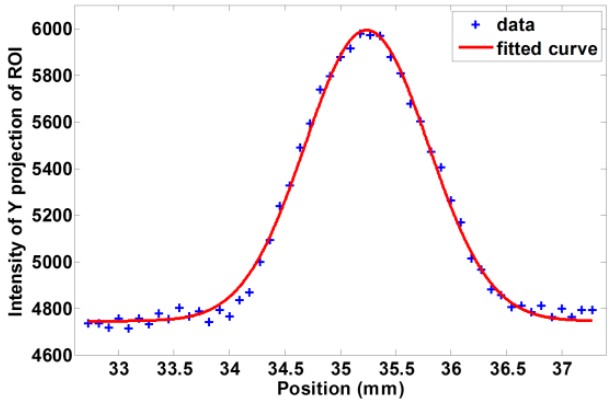
Small skimmer









Setting	Value
Energy	3.5 keV
Current	~7.0 μA
External field	8.0 kV/m
Exposure	120 ms

size	Value
Xrms	0.54
Yrms	0.56
Xrms from residual	1.34

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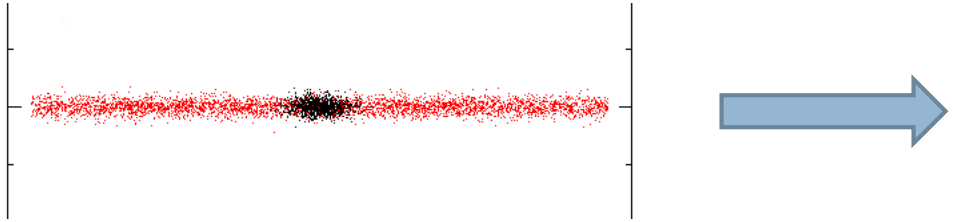
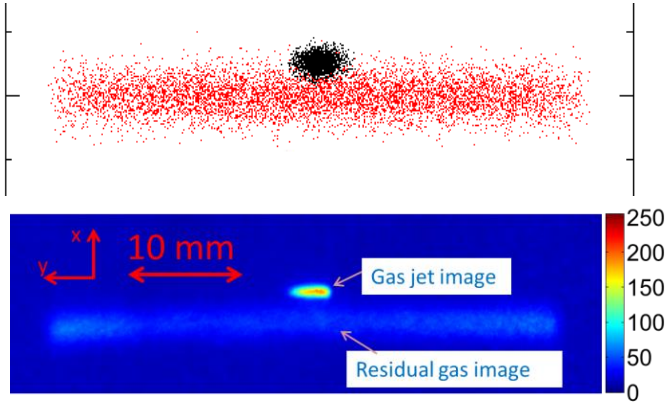
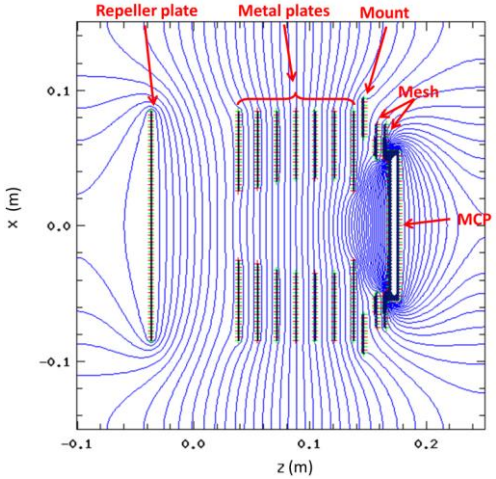
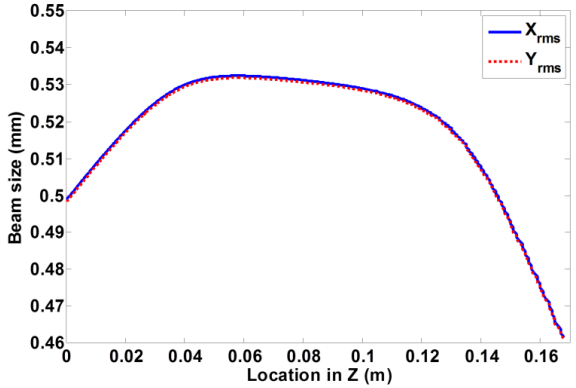
Resolution

Image broadening because of thermal drift and magnification of external fields









$$\sigma_{measured} = \sqrt{M^2(\sigma_{real}{}^2+\sigma_{jet}{}^2)+\sigma_{thermal}{}^2+\sigma_{sc}{}^2+\sigma_{MCP}{}^2+\sigma_{CCD}{}^2}$$

Summary of the image broadening terms for the experiment

Error term	Value
Magnification	External field dependent
σ_{jet}	0.28 mm
$\sigma_{thermal}$	0.17 mm
σ_{sc}	0
σ_{MCP}	0.08 mm
σ_{CCD}	0.08 mm

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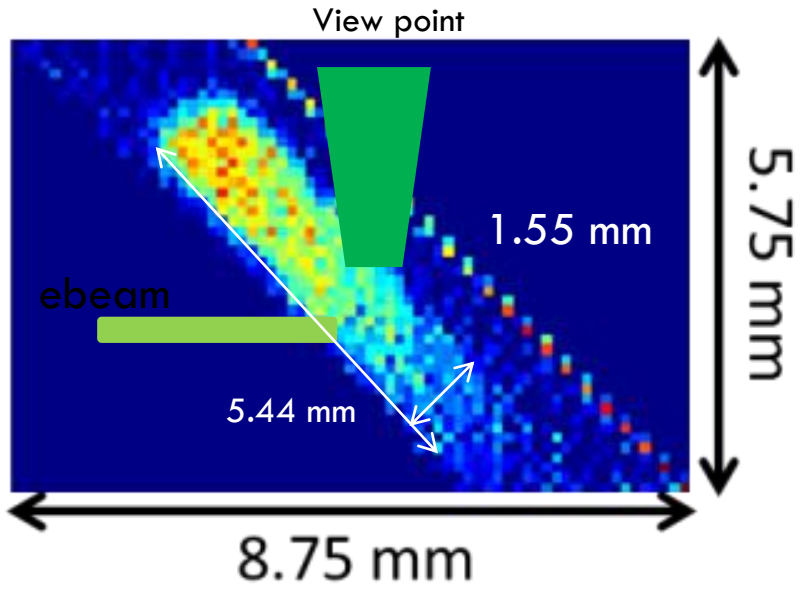
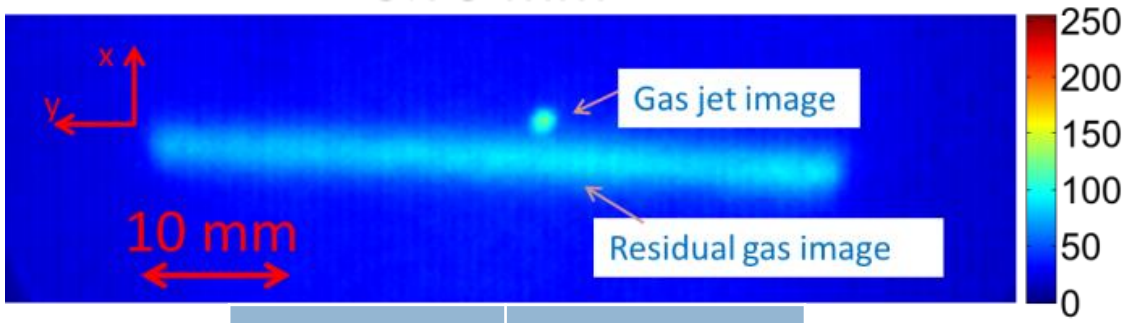
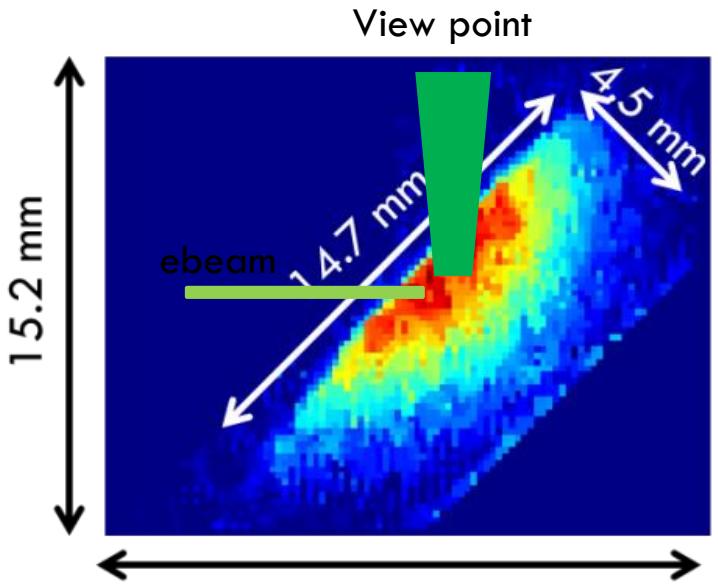
Beam enlarged by jet thickness

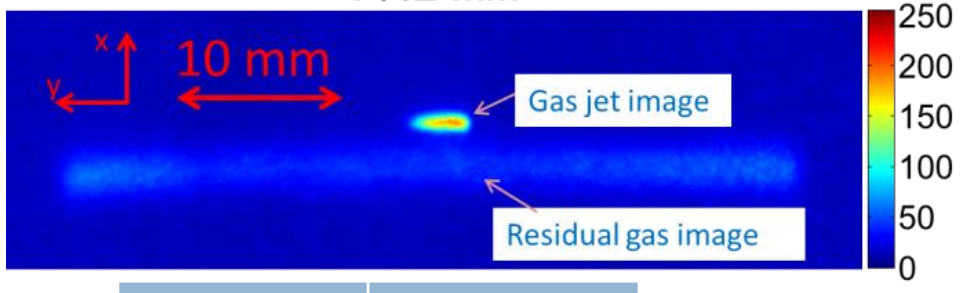




Beam size	mm
σ_x (Gas jet)	0.5 ± 0.2
σ_y (Gas jet)	0.5 ± 0.2

σ_{jet} = 0.29 mm





Beam size	mm
σ_x (Gas jet)	0.4 ± 0.2
σ_y (Gas jet)	1.2 ± 0.2

σ_{jet} = 0.99 mm

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Comparison

IPM	BIF	Gas jet-based IPM	Gas jet-based BIF
low pressure	Moderate pressure	Ultralow pressure	Ultralow pressure
Moderate cost	low cost	High cost	High cost
1d beam profile	1d beam profile	2d beam profile	2d beam profile
moderate integration time	long integration time	Low integration time	moderate integration time

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- Need more compact design
- Tailored arrangement nozzle and skimmers set to meet the vacuum requirement and gas jet density (integration time)
- Scattering effect needs to be studied.

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Summary

- Gas based beam profile monitor could potentially be used for medical accelerator as a minimum invasive diagnostics.
- Tailored design needed if gas jet is used.
- Economically, it takes up accelerator space and cost money.

Thank you for your attention

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