SUPERSONIC GAS-JET BEAM PROFILE MONITOR

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Outline

- Gas-jet project review
  - The gas-jet setup in CI
    - Mechanical design
    - Vacuum consideration
    - Beam profile Measurement and resolution
    - Gas dynamics
    - Alignment issue and comments
  - Brief discussion of the on-going BIF mode experiment
    - Preliminary result
    - Possible explanation and solution

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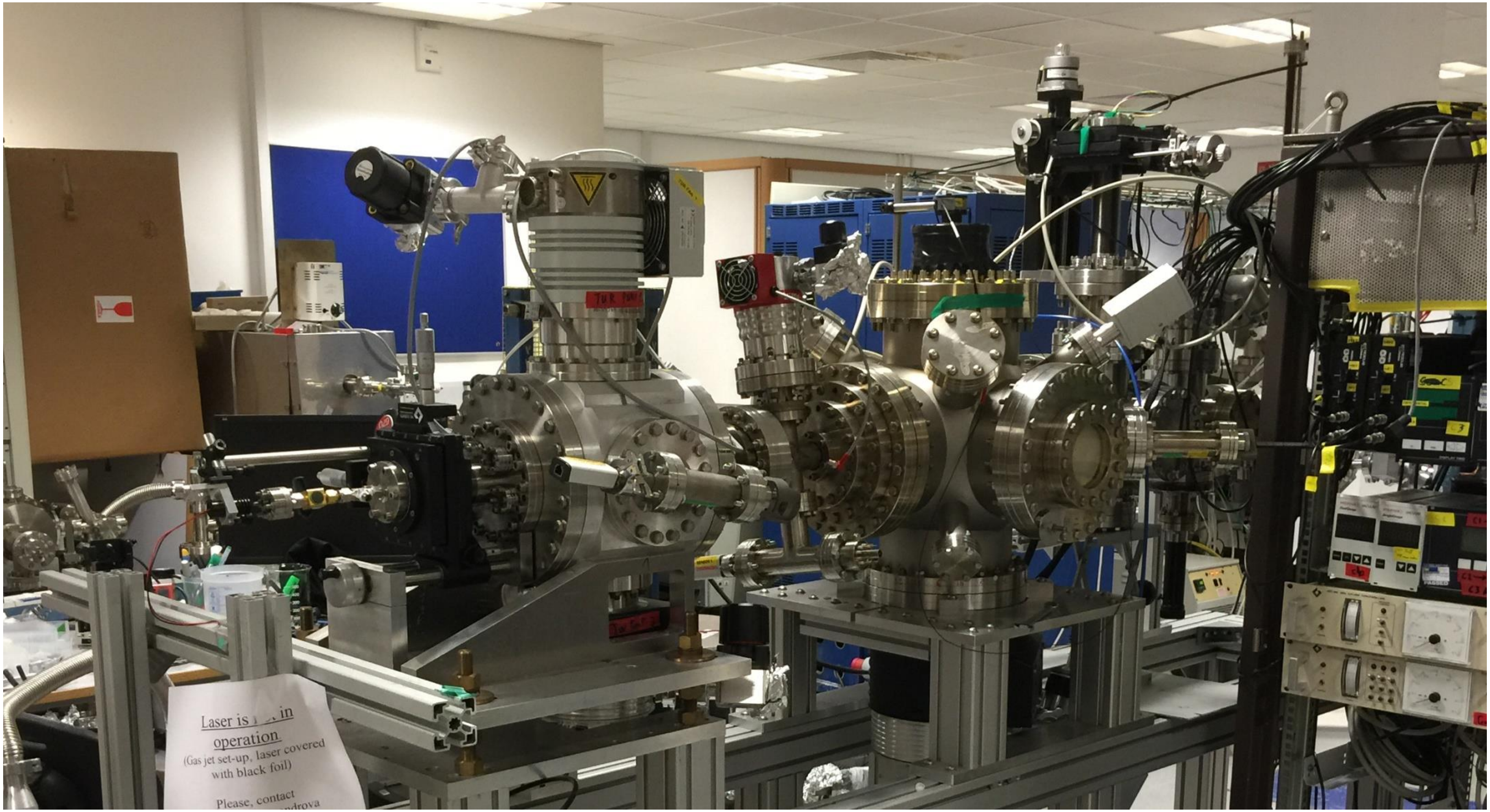
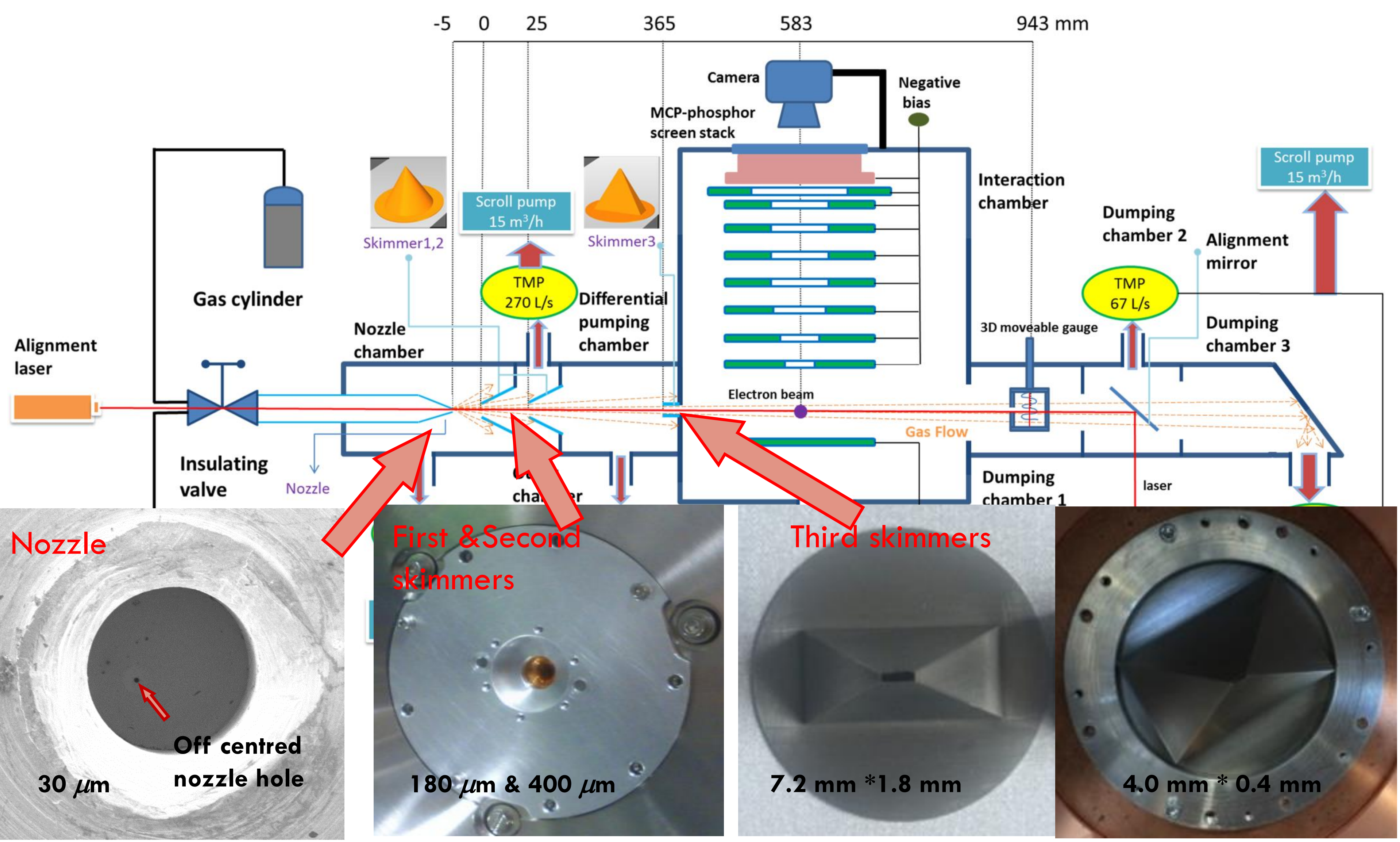
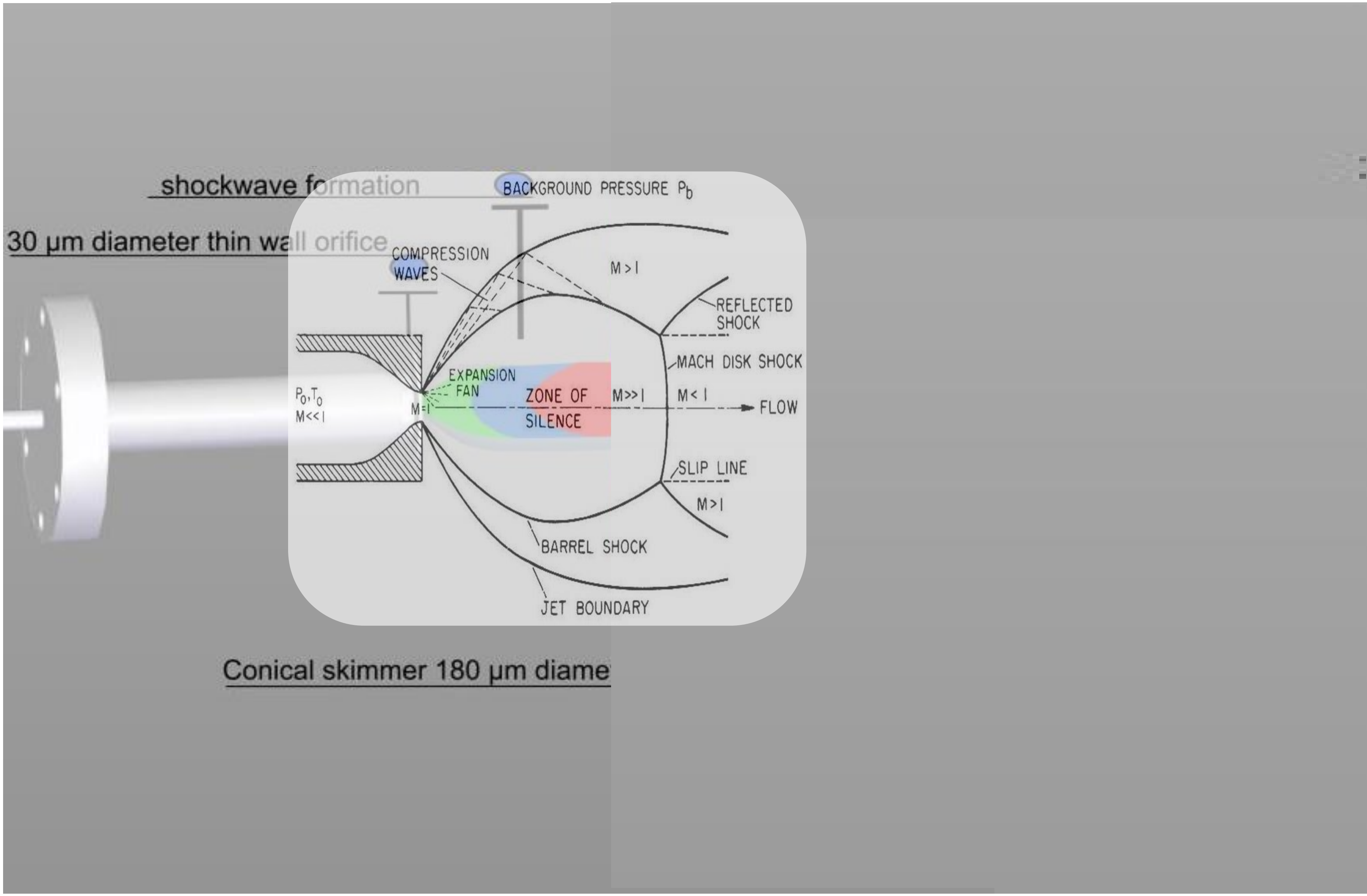
Get-jet Monitor Setup



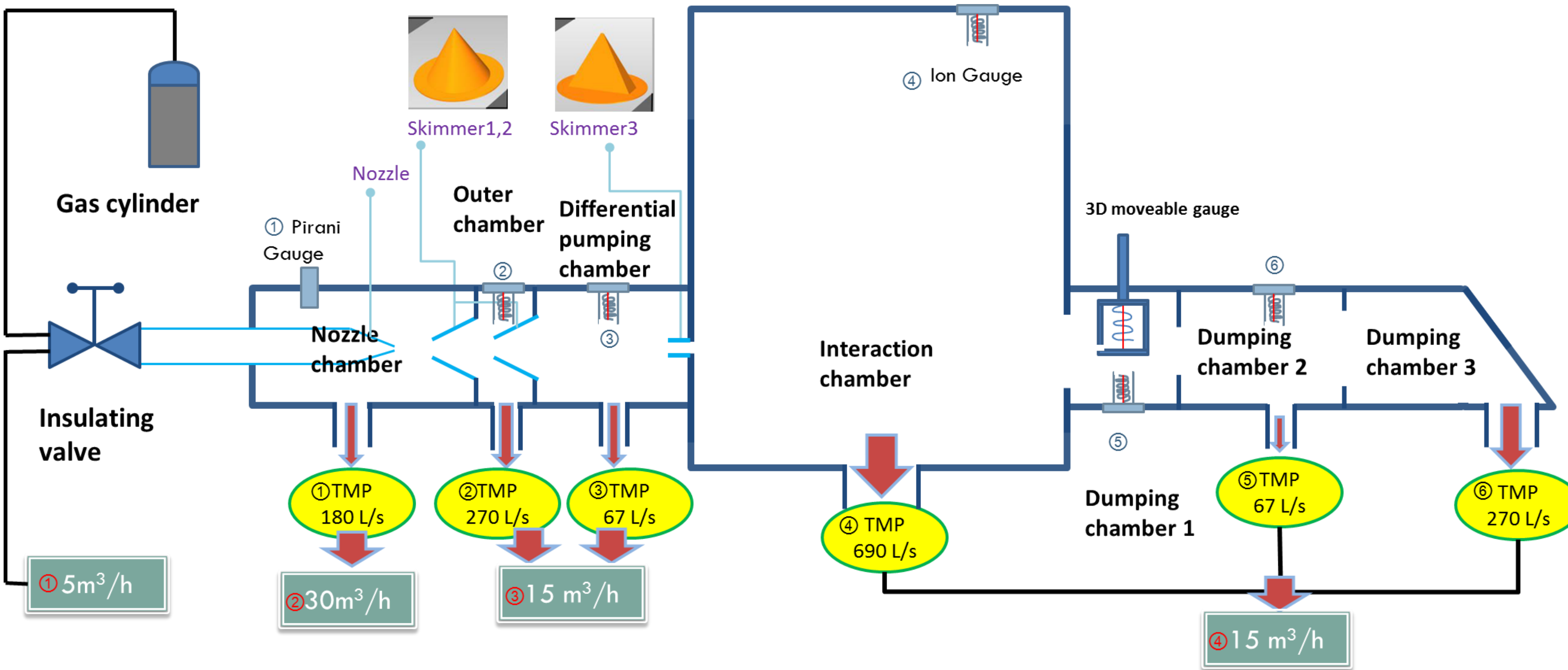
Get-jet Monitor Setup



Generation of supersonic gas jet



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}

Pump and Gauge

Scroll Pump

Number	Brand	Type	Pumping Speed
1	ScrollVAC	SC5D	5 m^3/h
2	ScrollVAC	SD30D	30 m^3/h
3	ScrollVAC	SD15D	15 m^3/h
4	ScrollVAC	SD15D	15 m^3/h

Turbo Pump

	Brand	Type	Pumping Speed*
1	Pfeiffer	TMU200MP	180 L/s
2	Leybold	SL300	270 L/s
3	Pfeiffer	Hipace80	67 L/s
4	Leybold	SL700	690 L/s
5	Pfeiffer	Hipace80	67 L/s
6	Leybold	SL300	270 L/s

*based on N_2 gas.

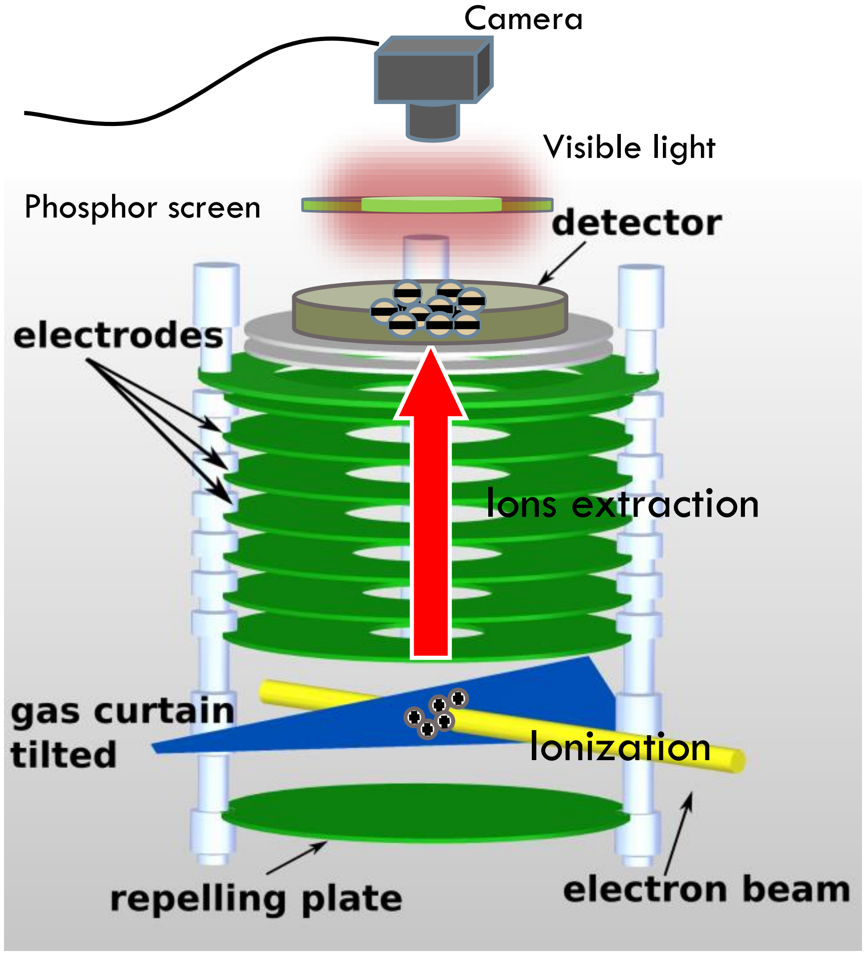
Pirani Gauge

Number	Brand	Type	Min pressure
1	Laybold Thermovac	TTR91 DN16KF	$5*10^{-4}$ mbar

Ion Gauge

Number	Brand	Type	Min pressure
2	Laybold Ionivac	Sensor IE514	$2*10^{-12}$ mbar
3	Laybold Ionivac	Sensor IE514	$2*10^{-12}$ mbar
4	Pfeiffer	PBR260	$5*10^{-10}$ mbar
5	Pfeiffer	PBR260	$5*10^{-10}$ mbar
6	Laybold Ionivac	Sensor IE514	$2*10^{-12}$ mbar

Ionization detection



Estimated integration time = 1 ms

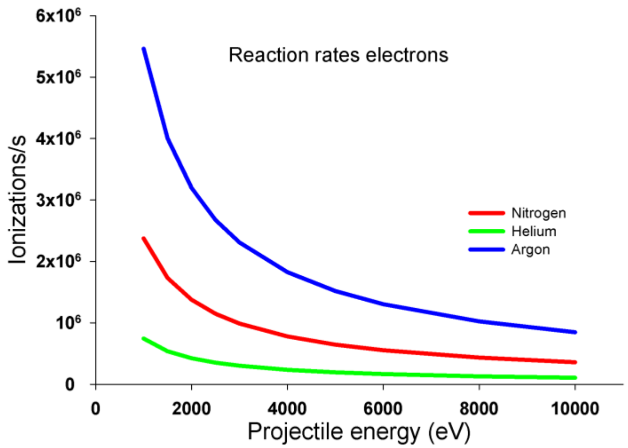
- E-gun

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

- Estimated jet property

Parameter	Value
Density	$2.5*10^{16}$ particle/m^3
Thickness	0.5 mm
Vertical size	5 mm

- Reaction rate



HLLHC Collaboration meeting at CERN 11/10/2016
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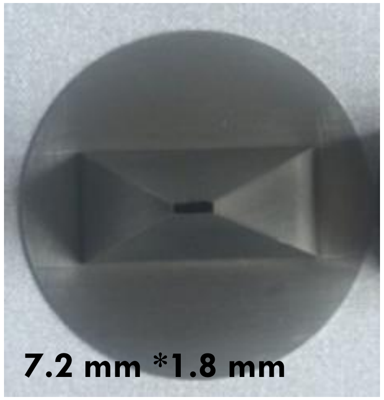
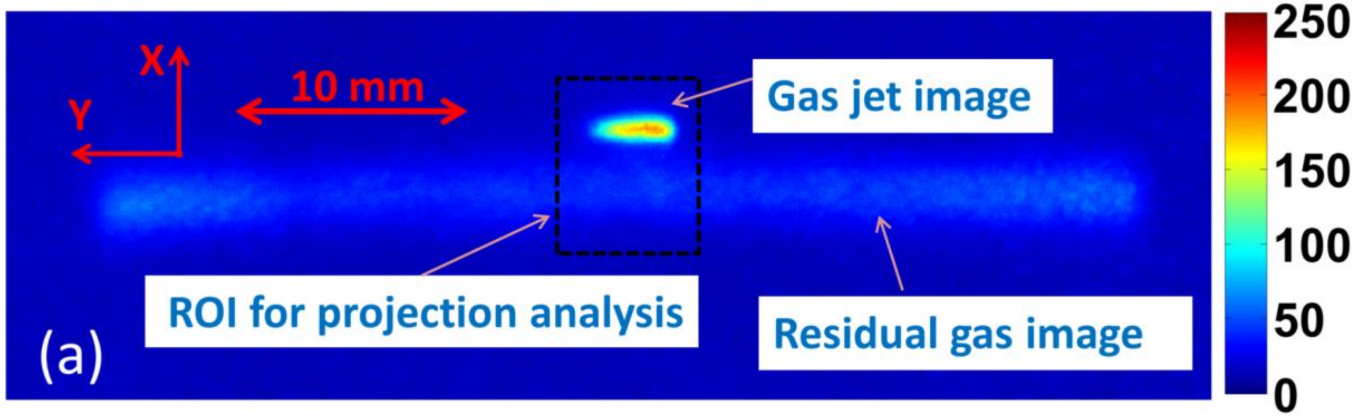
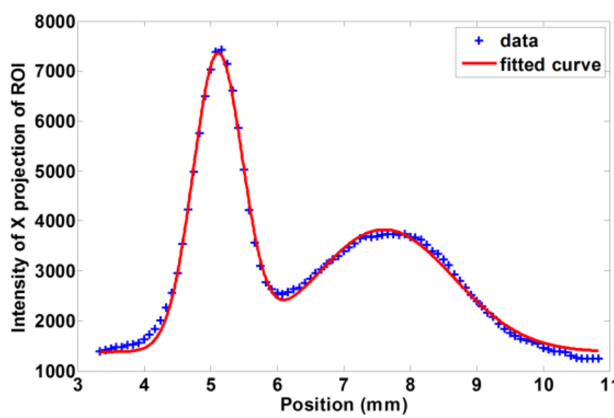
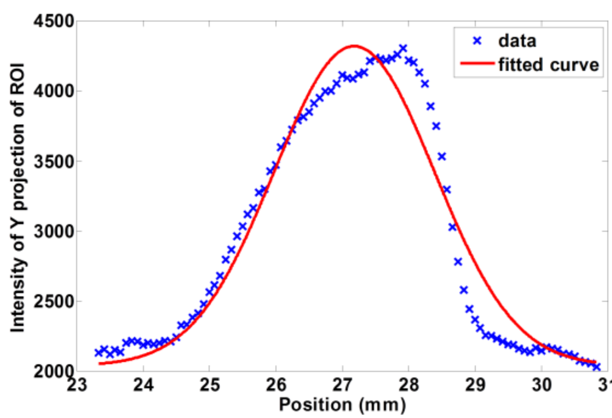
Typical measurement with Large skimmer





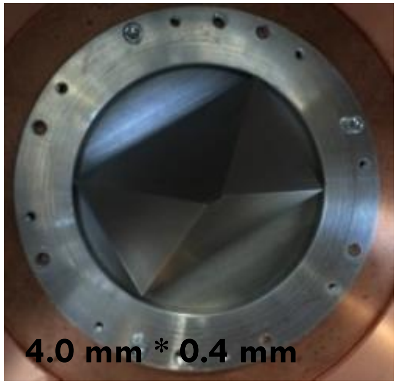


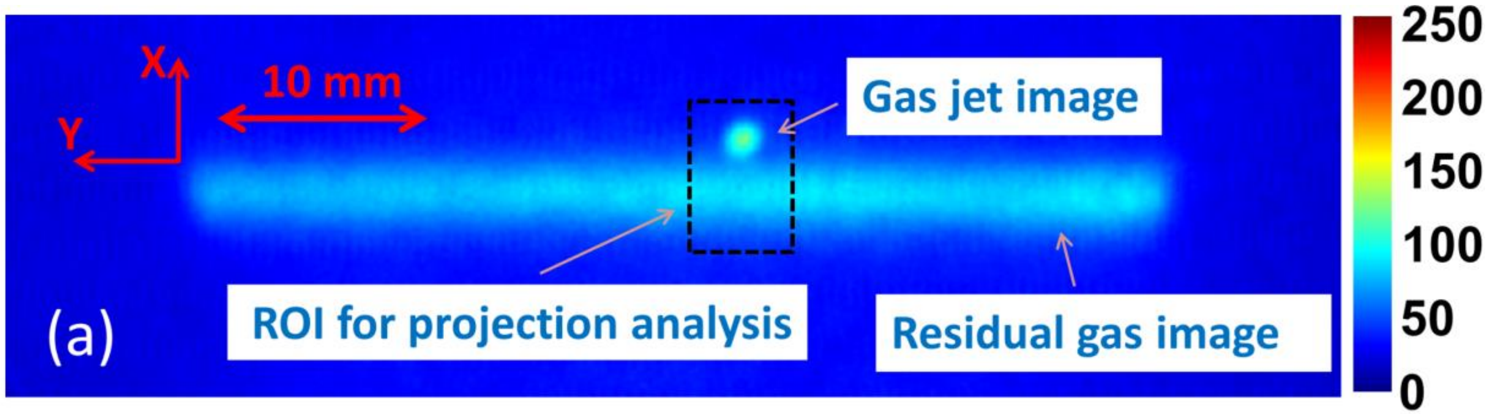


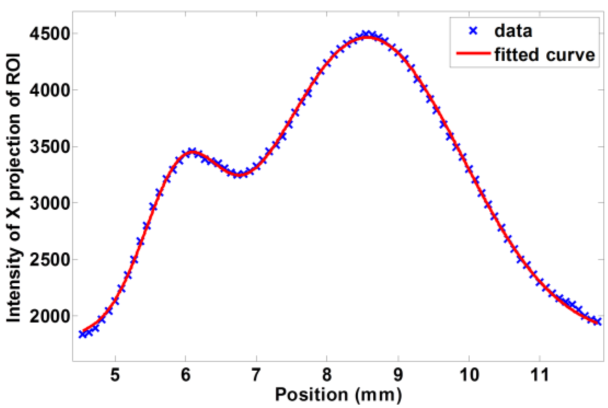
Setting	Value
Energy	3.75 keV
Current	~5.0 μA
External field	7.5 kV/m
Exposure	70 ms

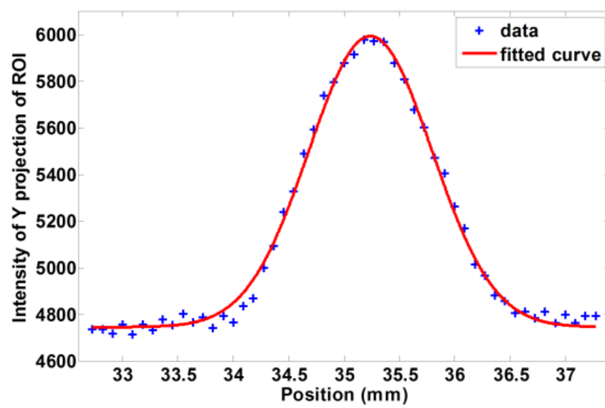
size	Value
Xrms	0.37
Yrms	1.21
Xrms from residual	1.05

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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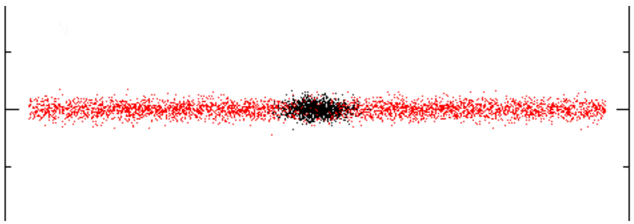
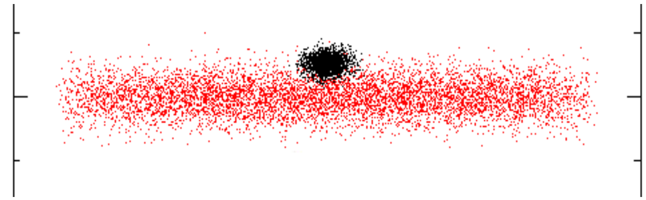
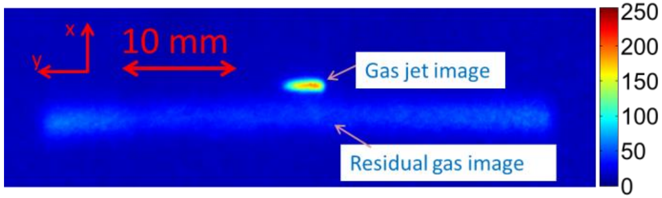
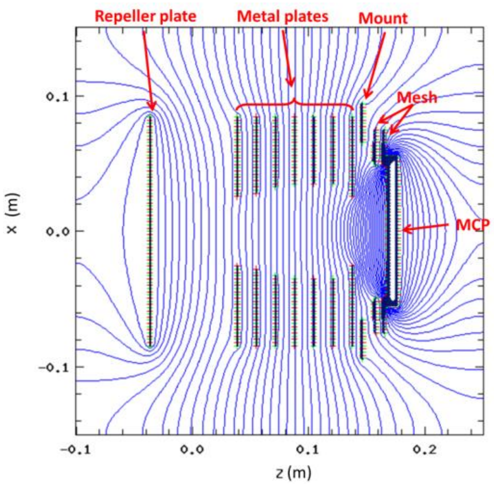
Resolution

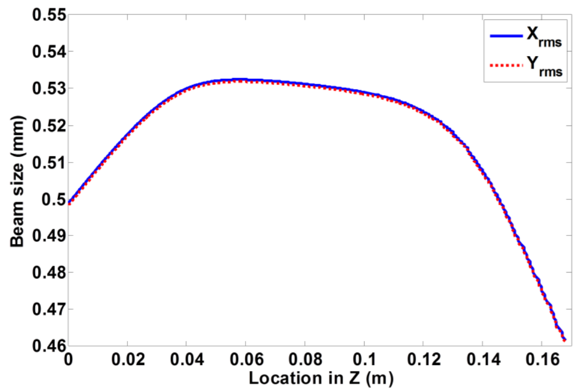
Image broadening because of thermal drift and magnification of external fields











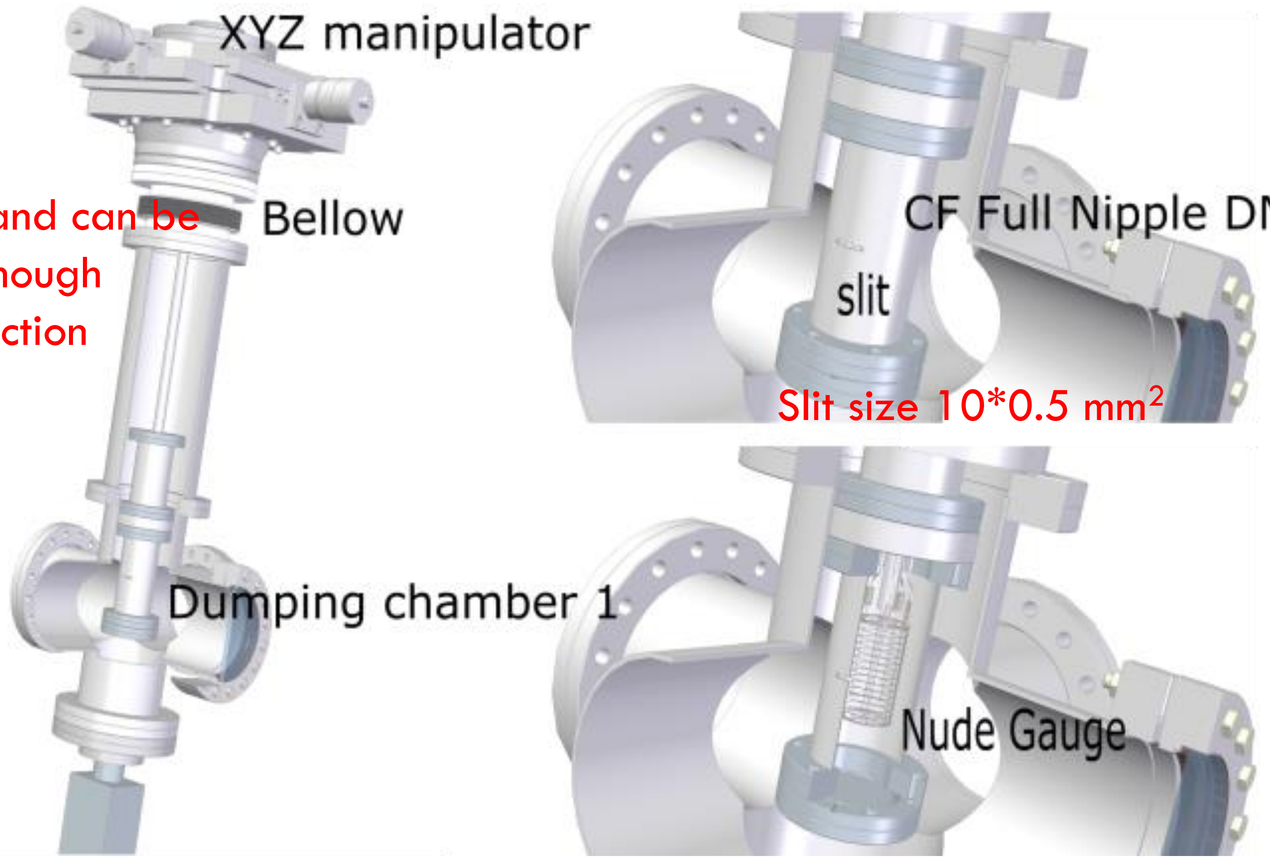
$$\sigma_{measured} = \sqrt{M^2({\sigma_{real}}^2+{\sigma_{jet}}^2)+{\sigma_{thermal}}^2 + {\sigma_{sc}}^2 + {\sigma_{MCP}}^2 + {\sigma_{CCD}}^2}$$

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

Movable gauge

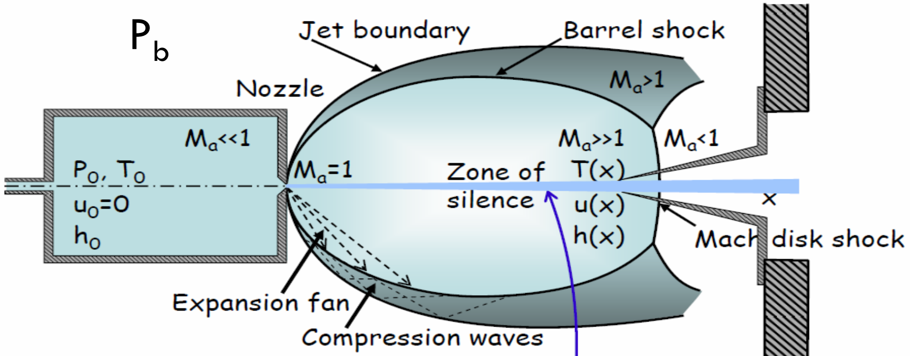
Motorized and can be controlled though serial connection



Gauge signal is amplified by pico-ampere meter and record by scope.

Nozzle skimmer distance study

Free Jet Expansion



complicated, viscous, heat conducting, nonisentropic

Zone of silence: isentropic, $M_a>>1$, properties independent of $P_b \Rightarrow$ molecular beam extracted

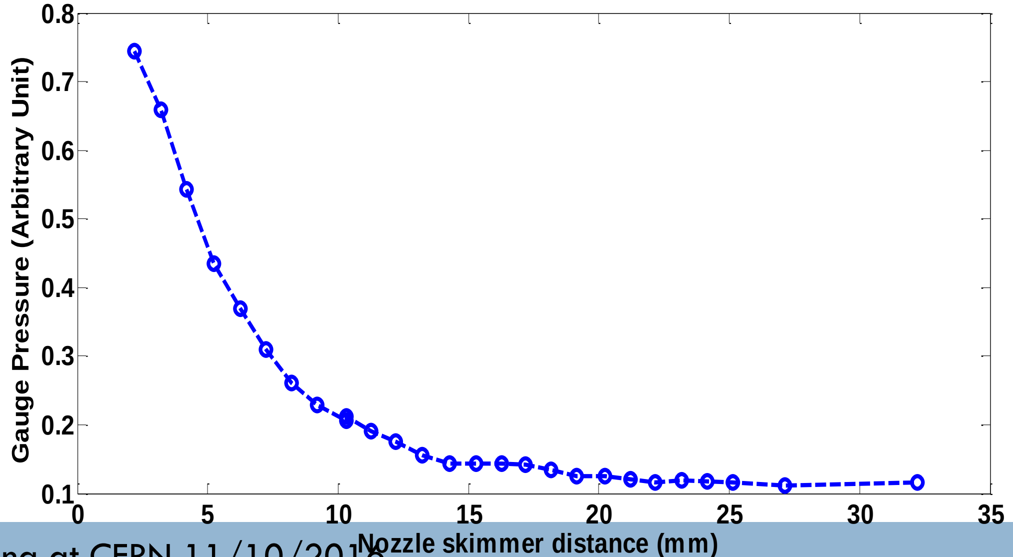
Mach disk location **(x_M/d) = 0.67 $(P_0/P_b)^{1/2}$** (γ independent)

Mach diameter ~$0.5x_M$; Barrel shock width ~$0.75x_M$ (γ, P_0/P_b dependent)

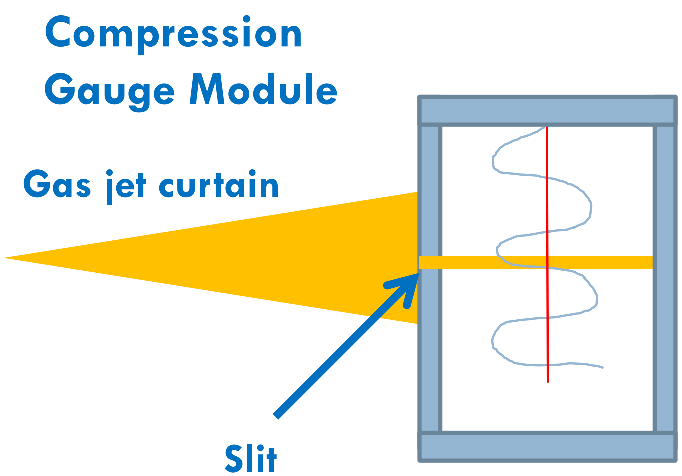
For our case, P_0 = 5 bar,
P_b ~ 1.0e-3 mbar
=> x_M/d = 1500;

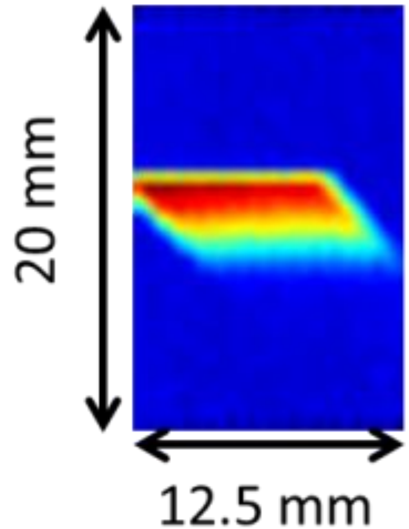
d =30μm=> x_M = 45 mm

This curve give a Mach disk about 25 mm, which is in the same order of magnitude with the calculation.



Gas density measurement





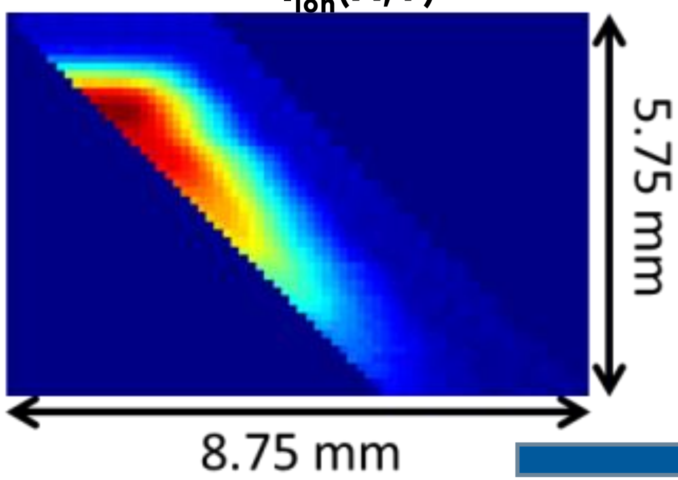
Current reading I_{ion} from ion gauge

By 41*26 pixel (pixel size is 0.5 mm)

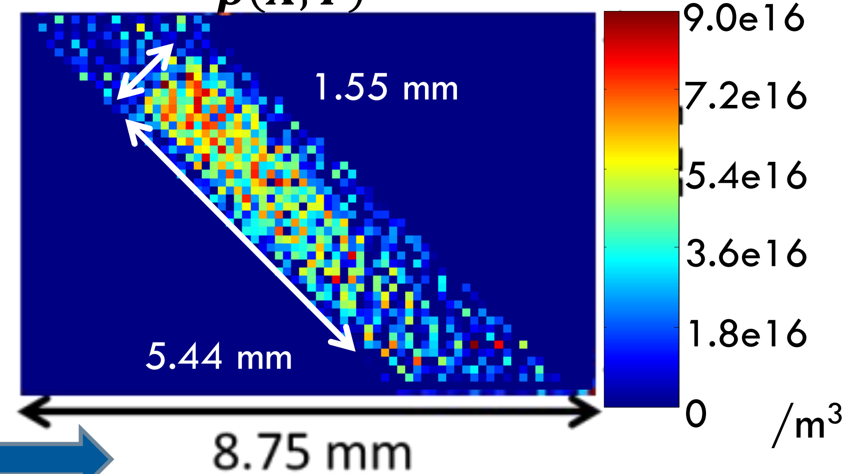
$$\rho(X,Y) = -\frac{1}{I_e S v L_y}\frac{V}{k_B T}\frac{d}{dX}\frac{dI_{ion}}{dt}(X,Y)$$

46*25 edge pixel (pixel size is 0.125 mm)

$I_{ion}(X,Y)$



$\rho(X,Y)$



Differentiate the data in horizontal axis

Jet size in interaction point is estimated as : 4.66 mm *0.92 mm

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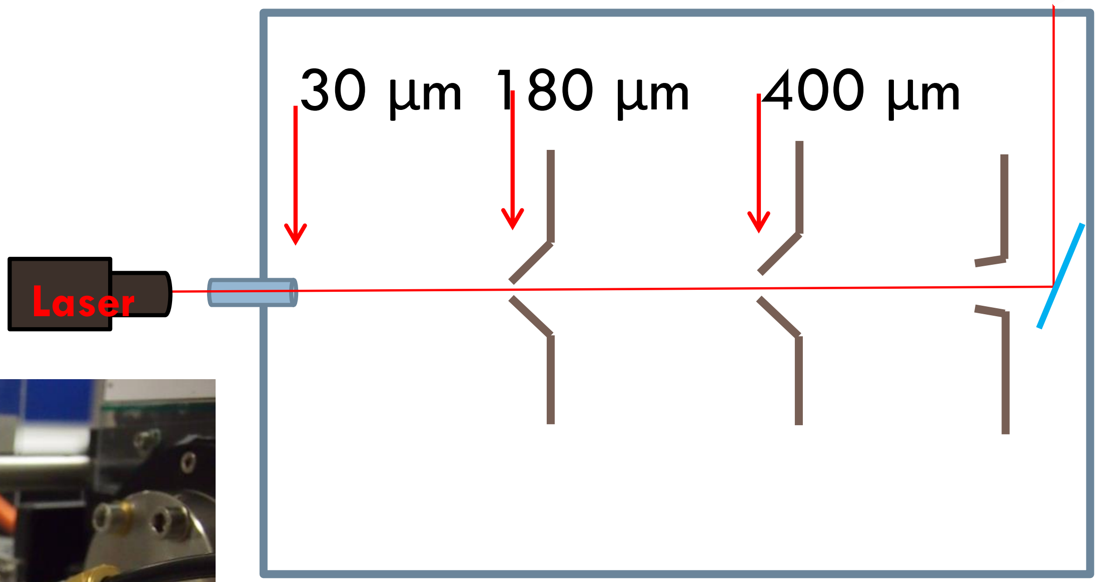
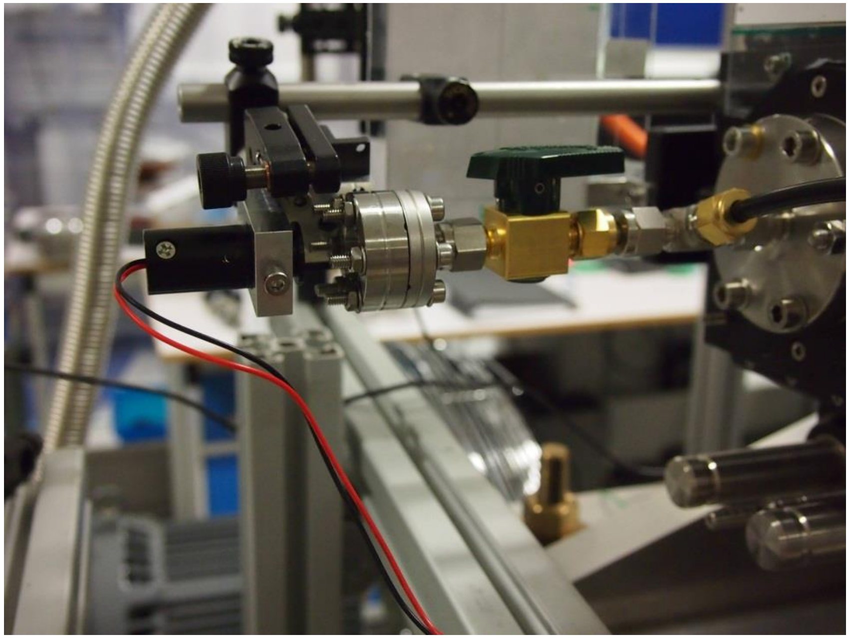
Alignment of nozzle & skimmers





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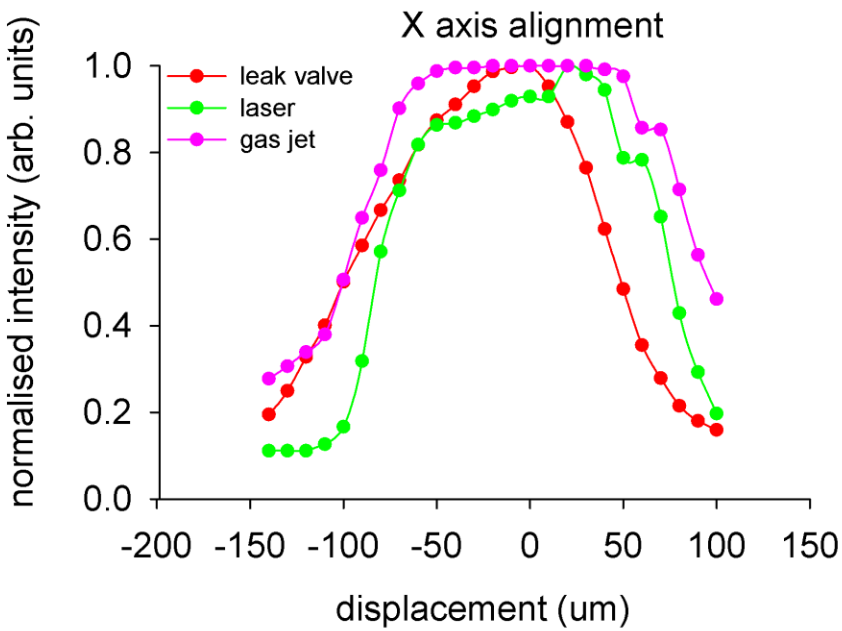
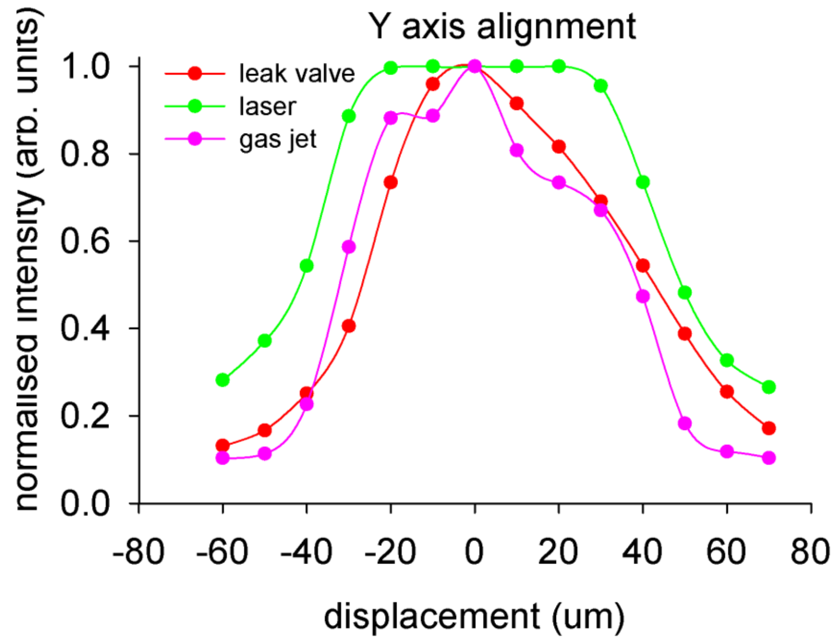
Alignment issue and comments

- Small acceptance region



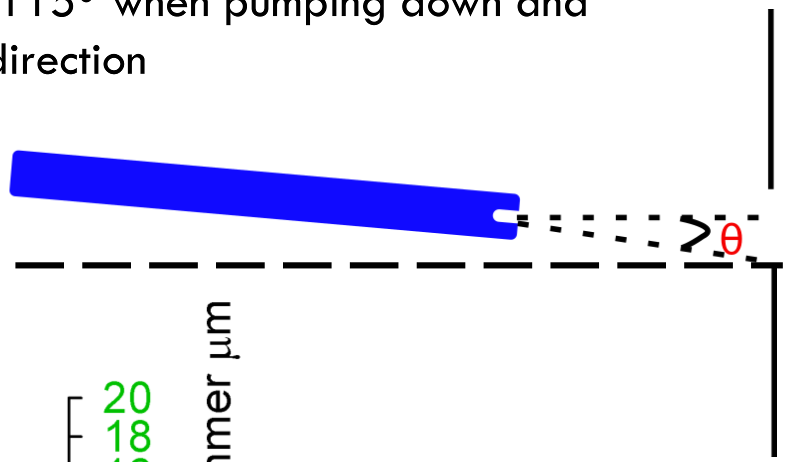


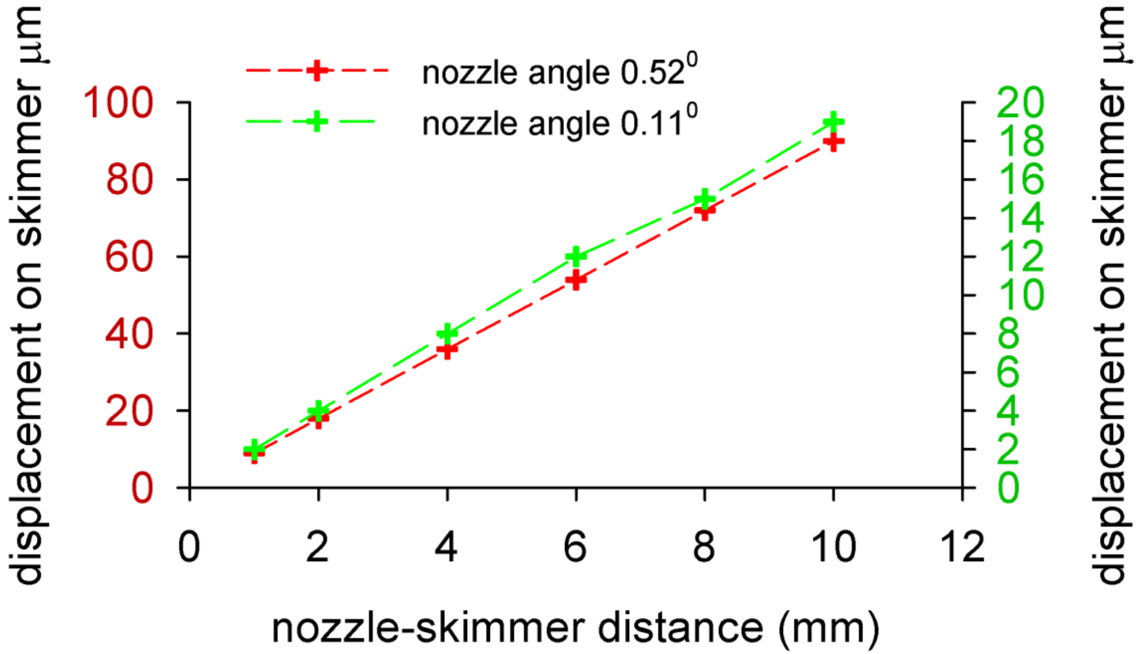
Alignment issue and comments

Resent measurement shows Nozzle is tilted by 0.115^0 when pumping down and translated by 1.8 mm towards the downstream direction

Nozzle-slimmer distance is 1-10 mm

Skimmer diameter is 180 µm

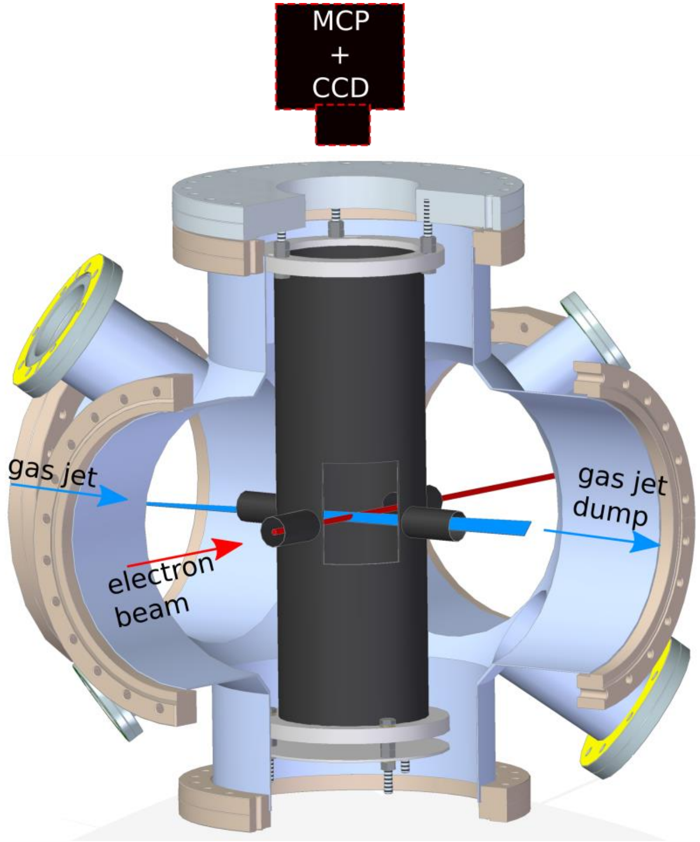




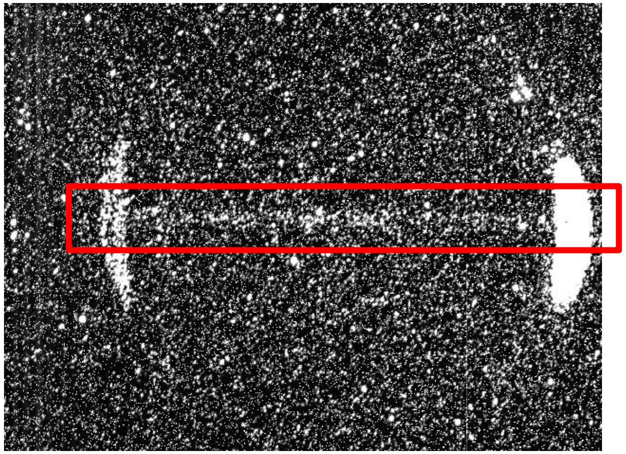
This will cause a reduced density as we see from the images when we change the skimmer.

Beam induced Fluorescent (BIF) detection

What is new



Setting	Value
Inlet pressure	5 bar
Energy	4.5 keV
Current	~7.0 μA
Exposure	1.1 s
Jet on time	2 s
Jet off time	2 s
Frame	2000
Total integration time	2200 s



Some basics for integration time

Cross section:

$$\sigma_p \approx 2.8\cdot 10^{-20}\ \mathrm{cm}^2$$

Based on 7 TeV Proton

Based on 10keV electron

$$\sigma^e_{391} \approx 9.2\cdot 10^{-19}\ \mathrm{cm}^2$$

$$\sigma^e_{337} \approx 1.48\cdot 10^{-23}\ \mathrm{cm}^2$$

Number of Photon detected :

$$N_\gamma = \sigma\cdot\frac{I\cdot\Delta t}{e}\cdot n\cdot d\cdot\frac{\Omega}{4\pi}\cdot T\cdot T_f\cdot\eta_{pc}\cdot\eta_{MCP}$$

$$N_\gamma \approx 1.5\cdot 10^{21}\cdot\sigma\cdot\Delta t$$

Proton detection: 24 ms/photon

Electron detection: 0.7 ms/photon

I (electron current)	10A
n (gas jet density)	2.5e10 cm^{-3}
d (jet thickness)	0.5 mm
Ω(acceptance solid angle)	$4\pi\cdot$10e-5 sr
η_{pc}(MCP photocathode efficiency)	0.2
η_{MCP}(MCP detection efficiency)	0.5
T(Transmittance of optics)	0.65
T_f(Transmittance of band pass filter)	0.3

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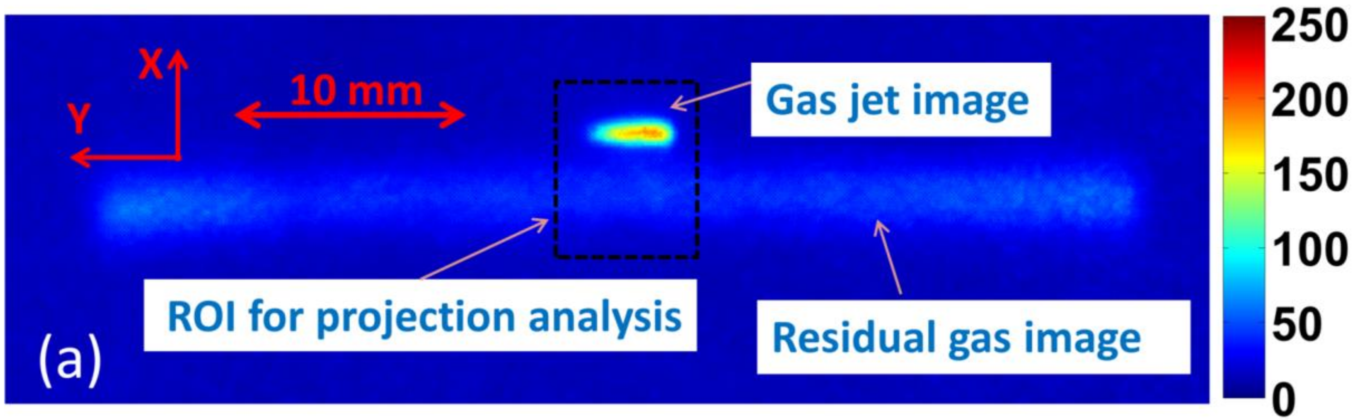
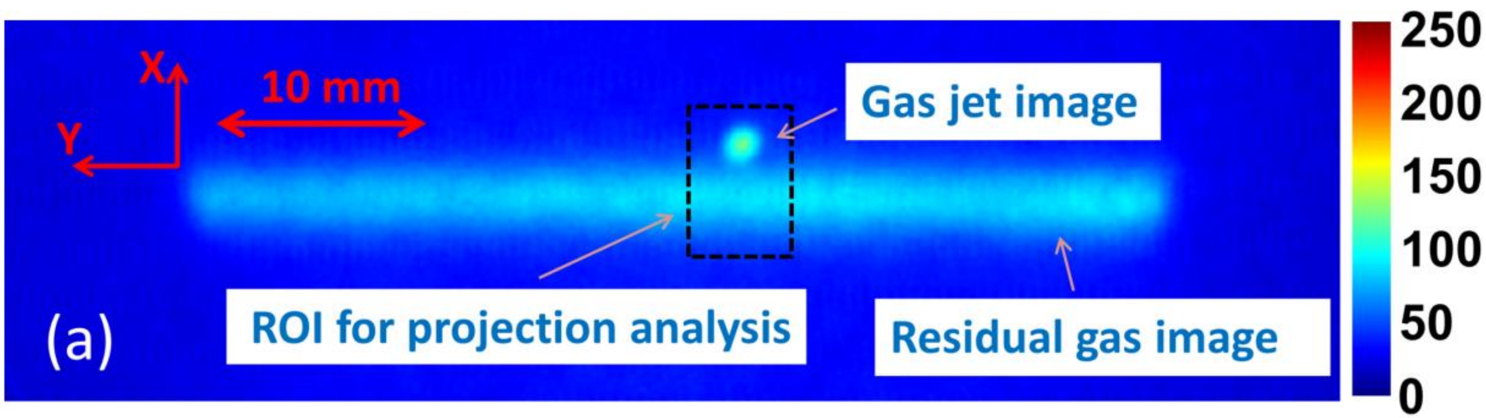
Possible explanation and possible solution

- Jet and e-beam does not meet each other.
  - Scan the e-beam vertically until they meet.
    - We did try but We don't know how much we move the electron beam. Previously we removed phosphor screen in the back to prevent the light contamination from phosphor but we lose the sense of location of the electrons.
    - Fix: we will redo the scan but with the screen re-installed with a gated valve
- Reaction rate is low

  Long integration time, each data point need 2 hour, and each scan will take 20 data point.
  - Increase the gas jet density (which might give us a factor of 5)
    - Tilted nozzle problem.
    - Large 3rd skimmer has a large acceptance angle and thus have a larger density. See next slide.
    - Fix: we get the skimmer installed recently.
  - Lower the E-beam energy
    - 1keV E-beam has a larger cross section. (about a factor of 2)
  - Higher current electron gun (Very expensive, about $30k)
    - Increase current from ~7uA to 1 mA (give us a factor about 200)


X
Y
10 mm
Gas jet image
ROI for projection analysis
Residual gas image
(a)
250
200
150
100
50
0


X
Y
10 mm
Gas jet image
ROI for projection analysis
Residual gas image
(a)
250
200
150
100
50
0

Conclusion

- Summary
  - We successfully use the supersonic gas jet to monitor beam profile in ionization mode.
  - We have a tool to measure the jet density which can be used to benchmark the simulation.
  - Still make progress on the BIF mode.