# CI Experimental results and plan

BGC CI team

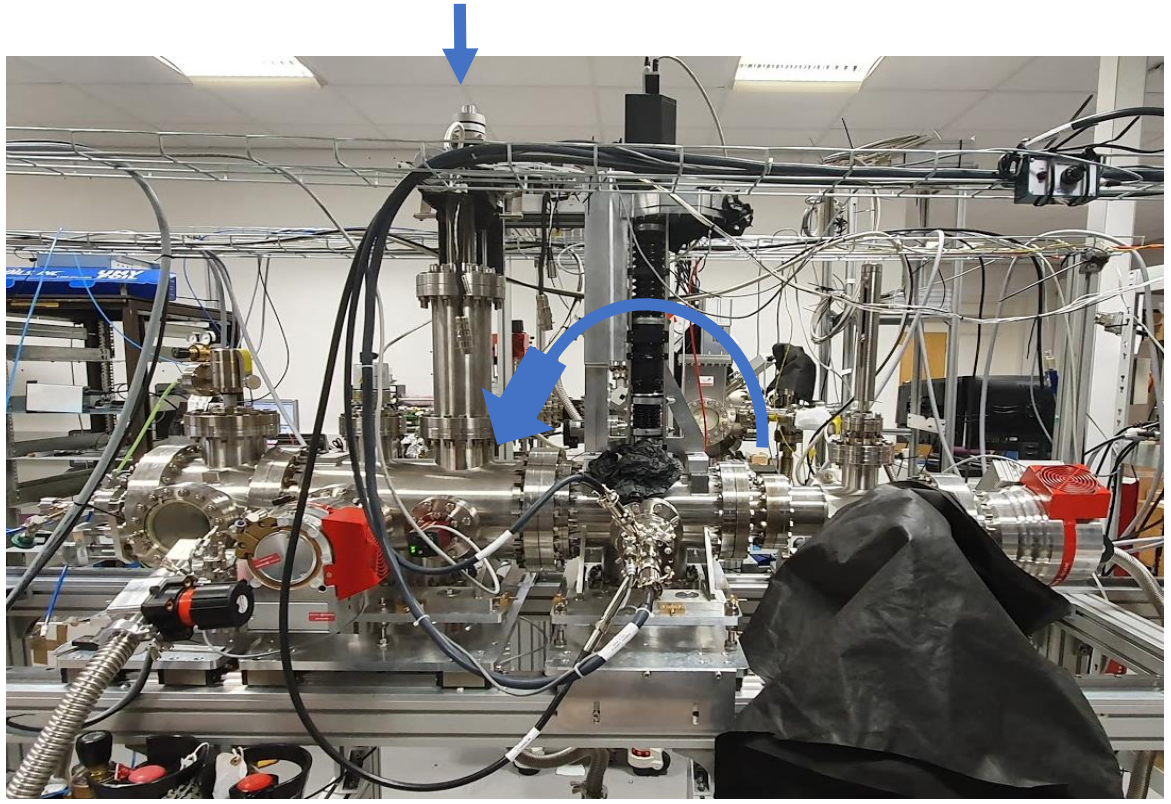
UNIVERSITY OF LIVERPOOL

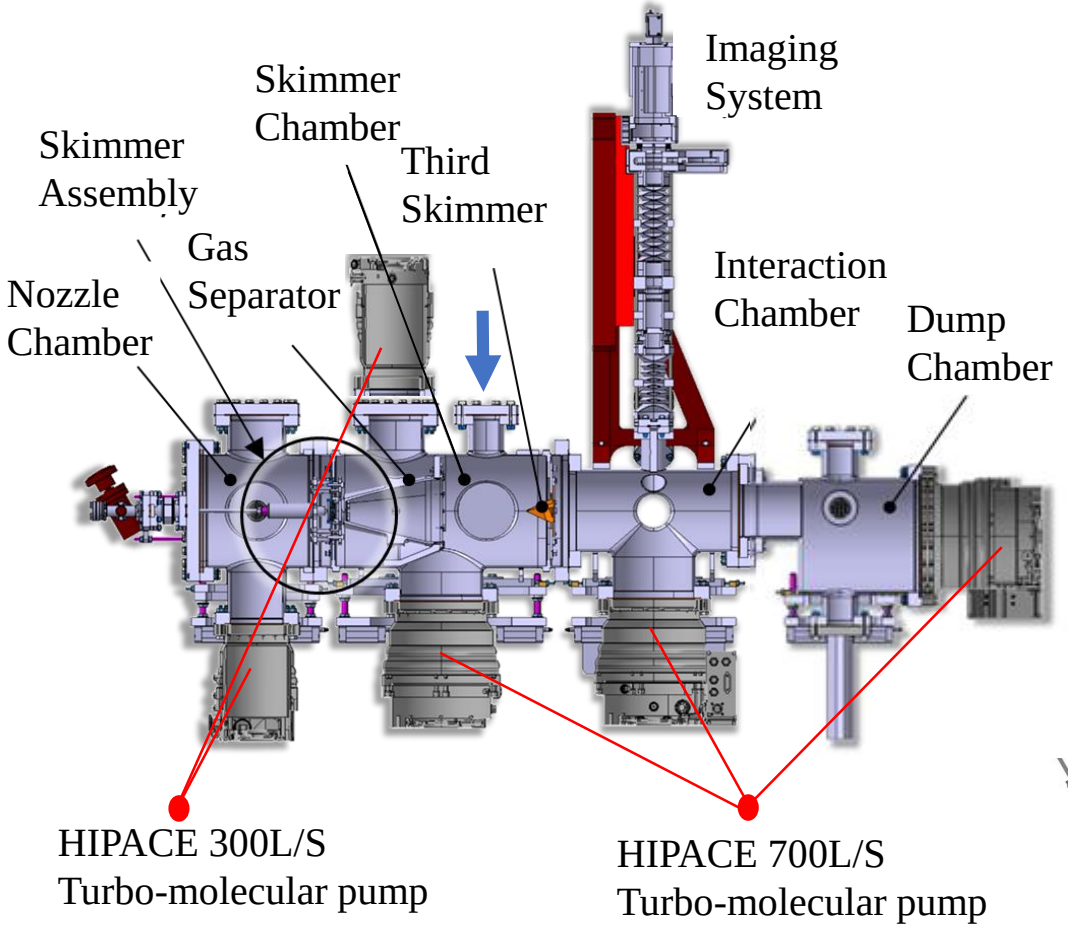
# Section I: Summary from v2 setup

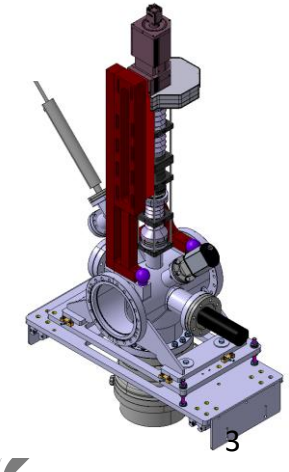
- OTR verification
- Development of a hybrid simulation code
- New configuration for 20 mm long uniform gas jet

# V2 gas jet monitor at the Cockcroft Institute

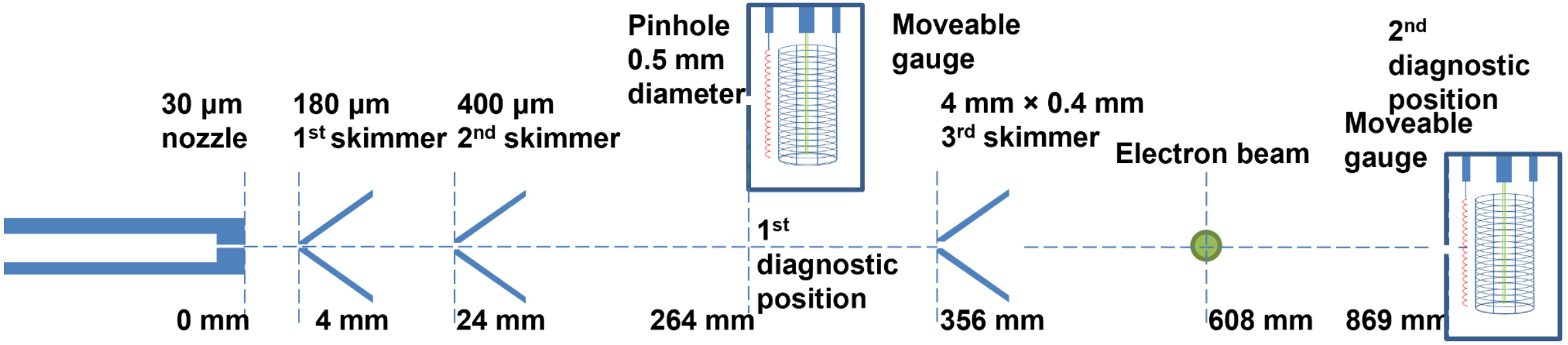
**Moveable gauge 282 mm from nozzle**



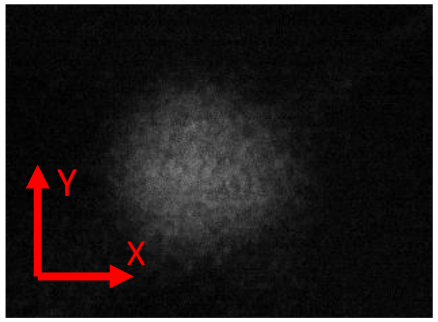


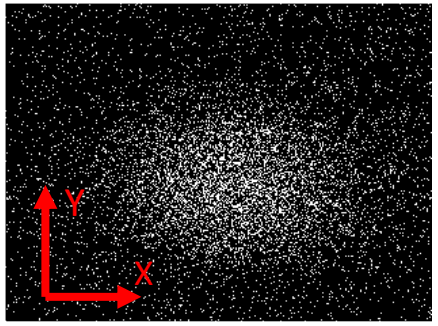



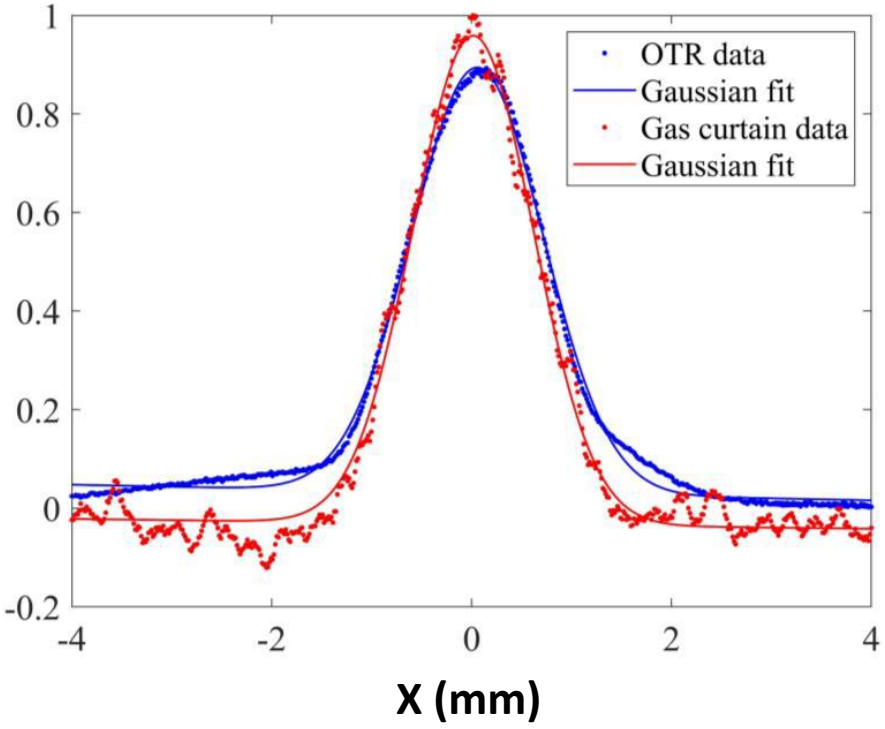
# Geometry used for V2

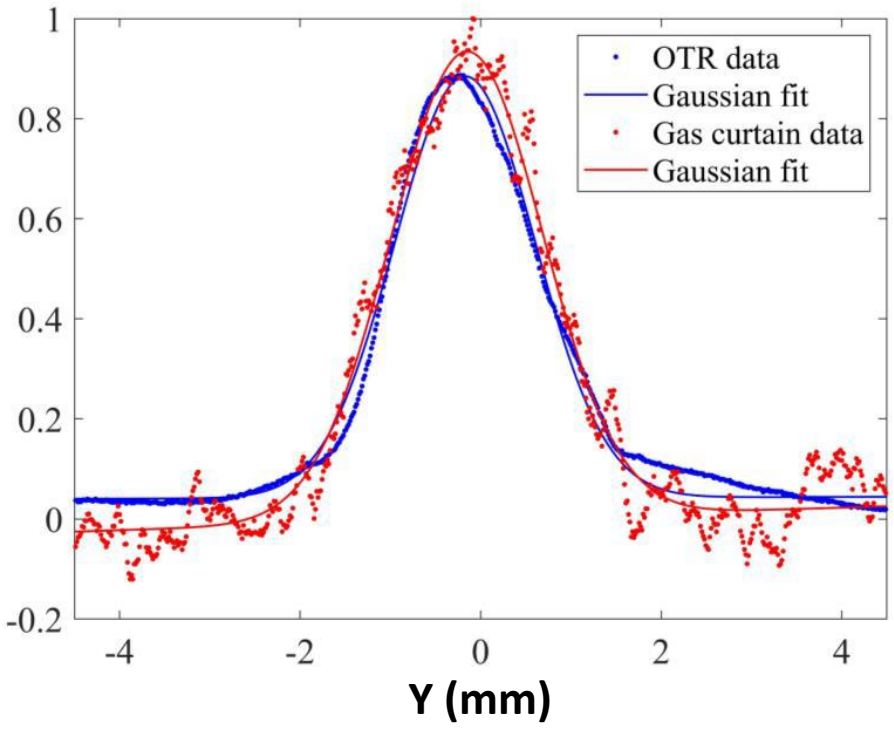


# Gas jet monitor Vs OTR



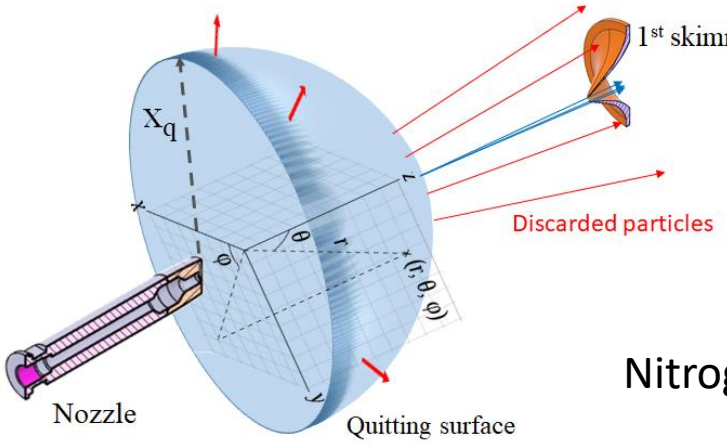



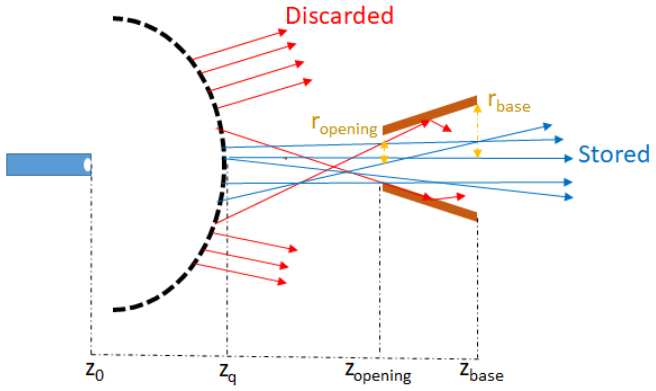



# Hybrid gas jet code from continuous flow to molecular tracking

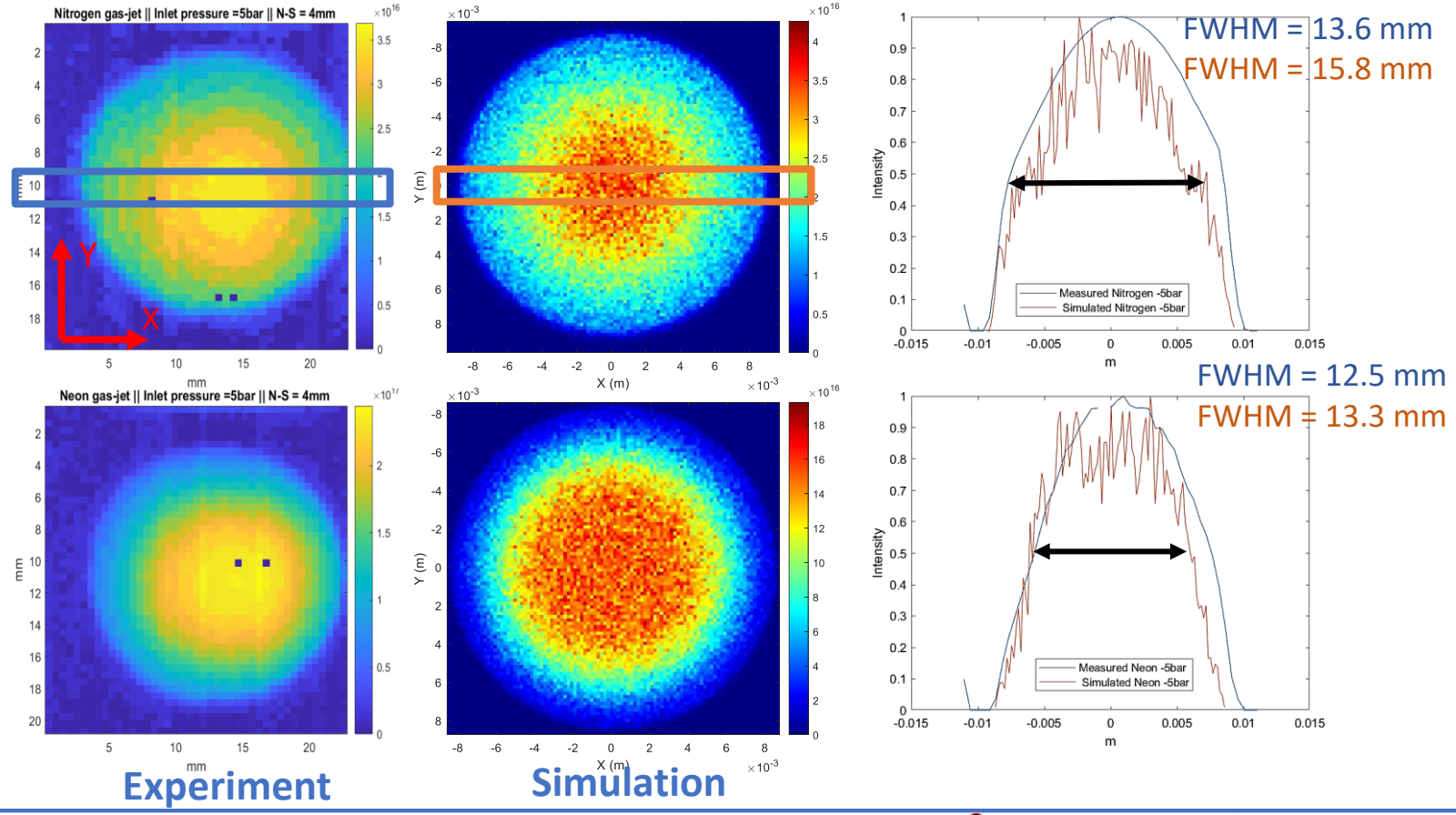
- ***Gas jet density distribution*** verified with old configuration at 264 mm from nozzle:
  - **Nozzle : 30micron; Skimmer I : 180 micron; Skimmer II: 2mm**




Nitrogen

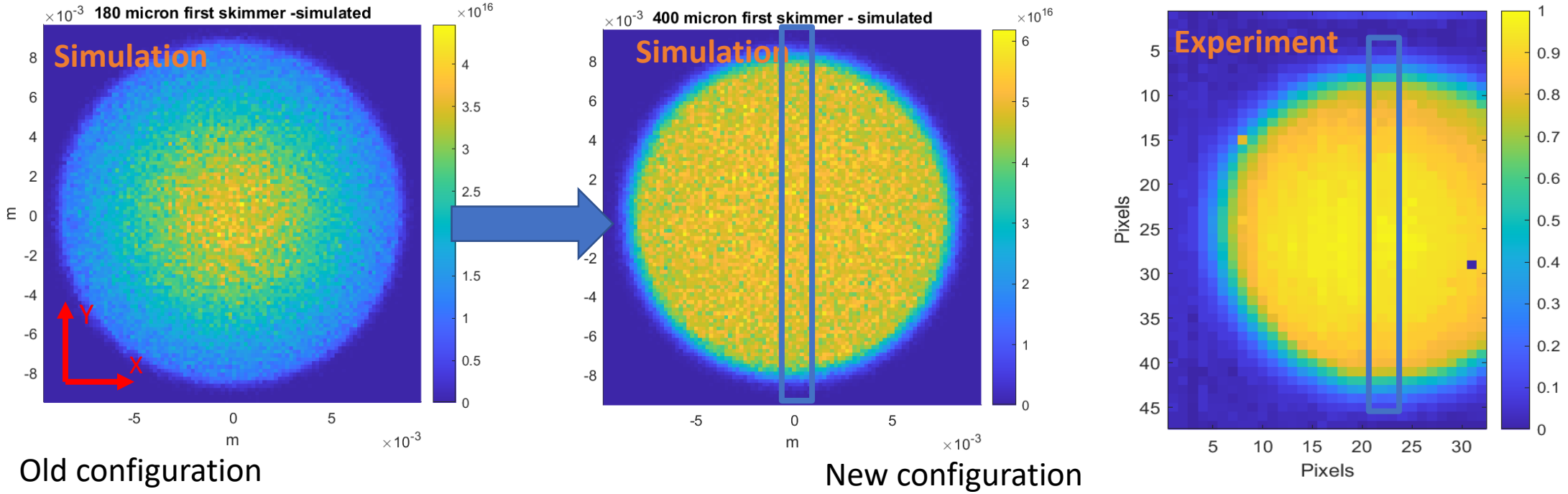
Neon



# Configuration suggested by simulation to generate a uniform distribution gas jet for ~20 mm

- Simulation suggest: uniform distribution after 2nd skimmer at 264 mm from nozzle.
- It is verified by the experiment.

Nitrogen




Old configuration

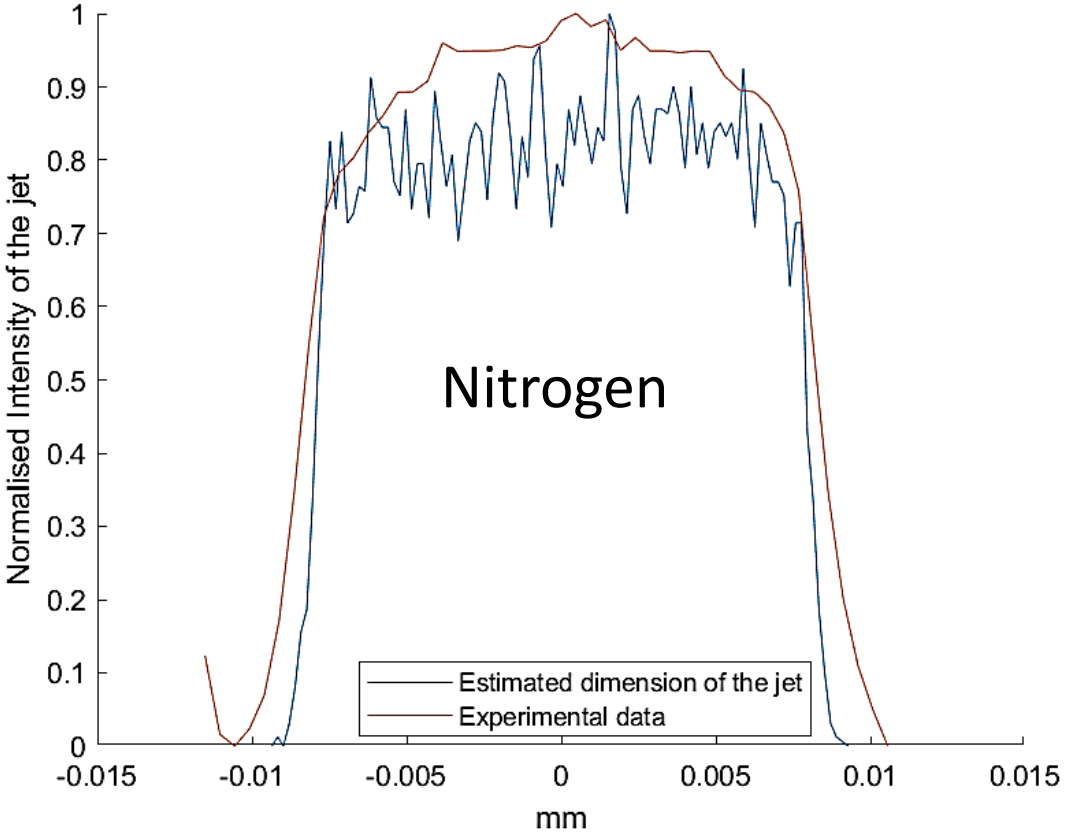
1. 30 micron nozzle
2. **180 micron** first skimmer
3. 2mm second skimmer

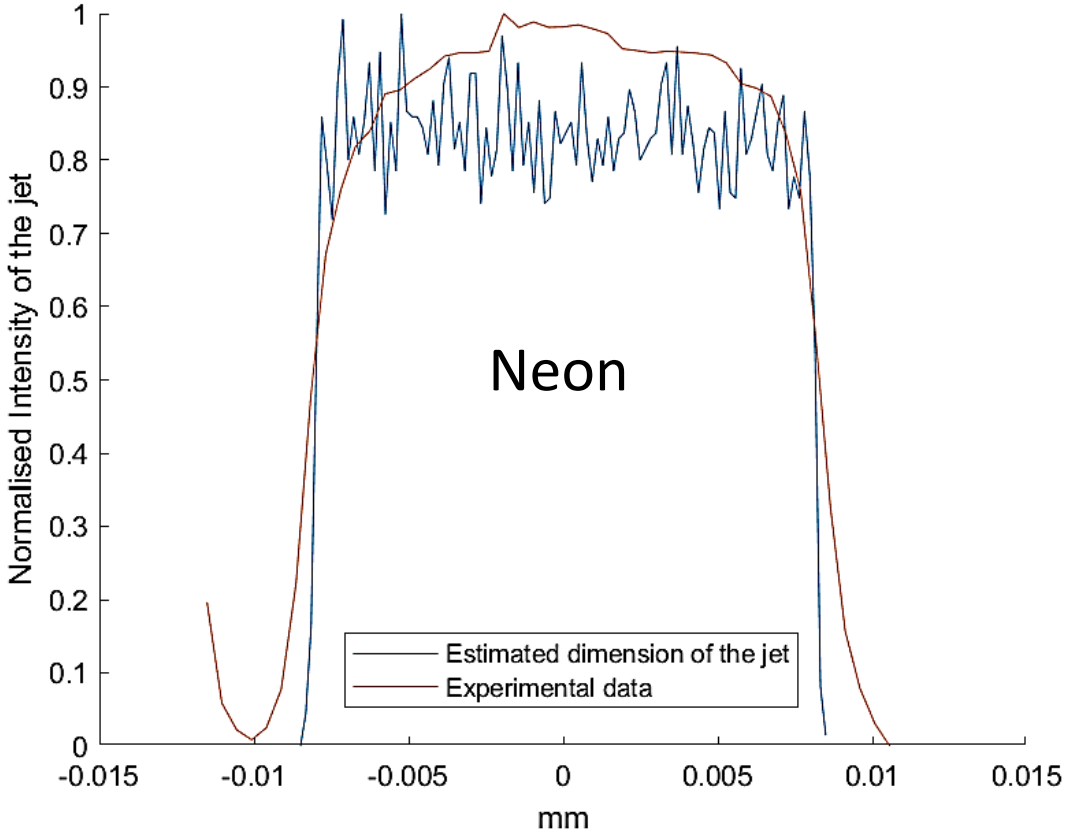
New configuration

1. 30 micron nozzle
2. **400 micron** first skimmer
3. 2mm second skimmer

# Gas jet density with new configuration

- Experiment agree with simulation very well.




**Decision: New configuration will be used for future V3 test.**

# Pressure in each chamber (v3)

| Configuration | Nozzle chamber | Skimmer chamber I | Skimmer chamber II | Interaction chamber |
|---|---|---|---|---|
| Nozzle :30µm<br>1st skimmer: 180µm<br>2nd skimmer: 400µm | 6.03e-3 | 1.69e-05 | 5.33e-07 | <5e-9 |
| Nozzle :30µm<br>1st skimmer: 180µm<br>2nd skimmer: 2mm | 5.9e-3 | 7.91e-6 | 8.03e-7 | <5e-9 |
| Nozzle :30µm<br>1st skimmer: 400µm<br>2nd skimmer: 2mm | 5.56e-3 | 1.13e-5 | 1.52e-6 | <5e-9 |

- Pressure in each chamber given in (mbar) at the specified configuration.
- The last configuration offered the highest gas-curtain density(tested at two locations- before and after third skimmer), as well as a more uniform jet.

# Summary for section I

- Gas jet image was verified with OTR.
- Developed a reliable gas jet density distribution measurement tool.
- Developed a hybrid simulation code can simulate gas jet from continuous flow to molecular flow with a good agreement with experiments.
- Gas jet curtain criteria could be met by new configuration.

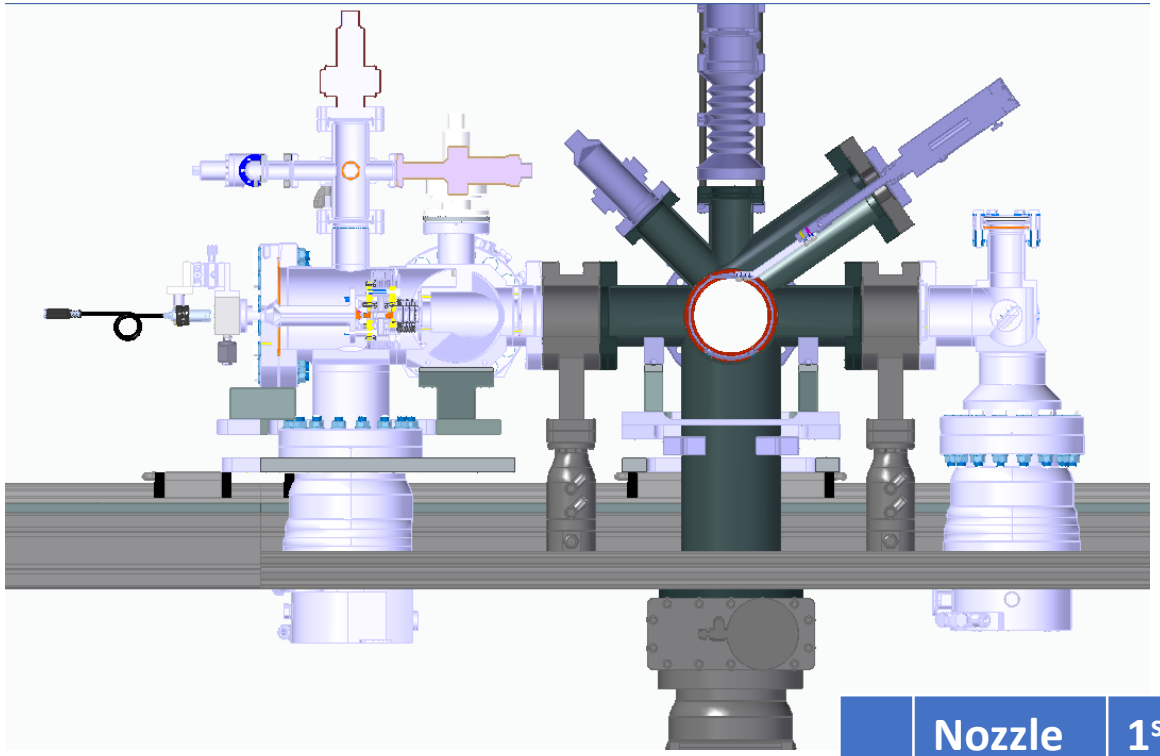
**Table 2: Key performance criteria for v4**

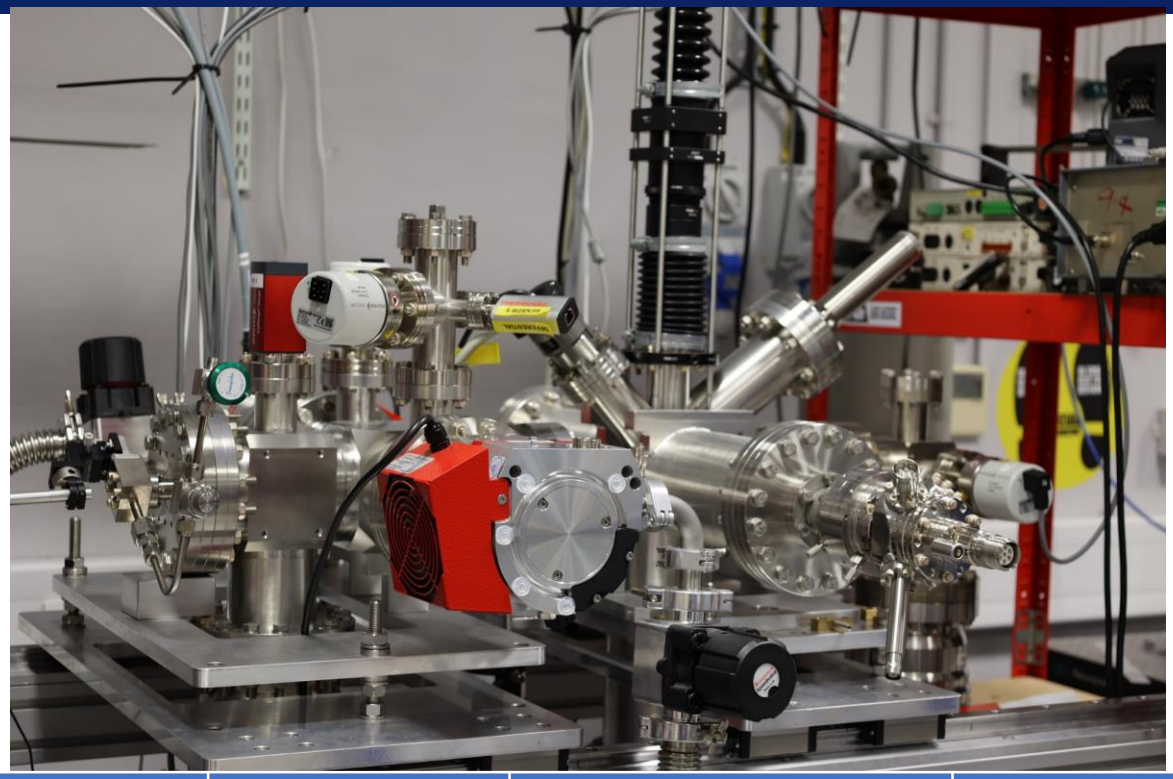
| Criterion | Units | Value |
|---|---|---|
| Minimum gas density in the curtain | $mol.m^{-3}$ | $2x10^{16}$ |
| Minimum transverse curtain dimension | mm | 20 |
| Variation in transverse density over the central 10mm of the gas curtain | % | 20 |
| Maximum deviation from the central transverse density at ± 10mm from the gas curtain centre | % | 50 |
| Maximum through-thickness curtain dimension | mm | 1.5 |
| Maximum residual gas pressure in the interaction chamber, 24h after a 24h bakeout at 250 °C and pumping with nominal system and beam aperture blanked-off. | mbar | $1x10^{-9}$ |
| Signal to noise ratio[2] of the image area corresponding to 0.1 $mm^2$ at the source plane for the highest intensity signal region of a nominal proton beam as measured at the imaging plane in 10 seconds[3]. | Ratio | 10 |

# Commissioning of v3 gas jet monitor

- Setup description
- Gas jet beam profile measurement
- Gas jet density distribution simulation and experiment

# V3 gas jet monitor at CI

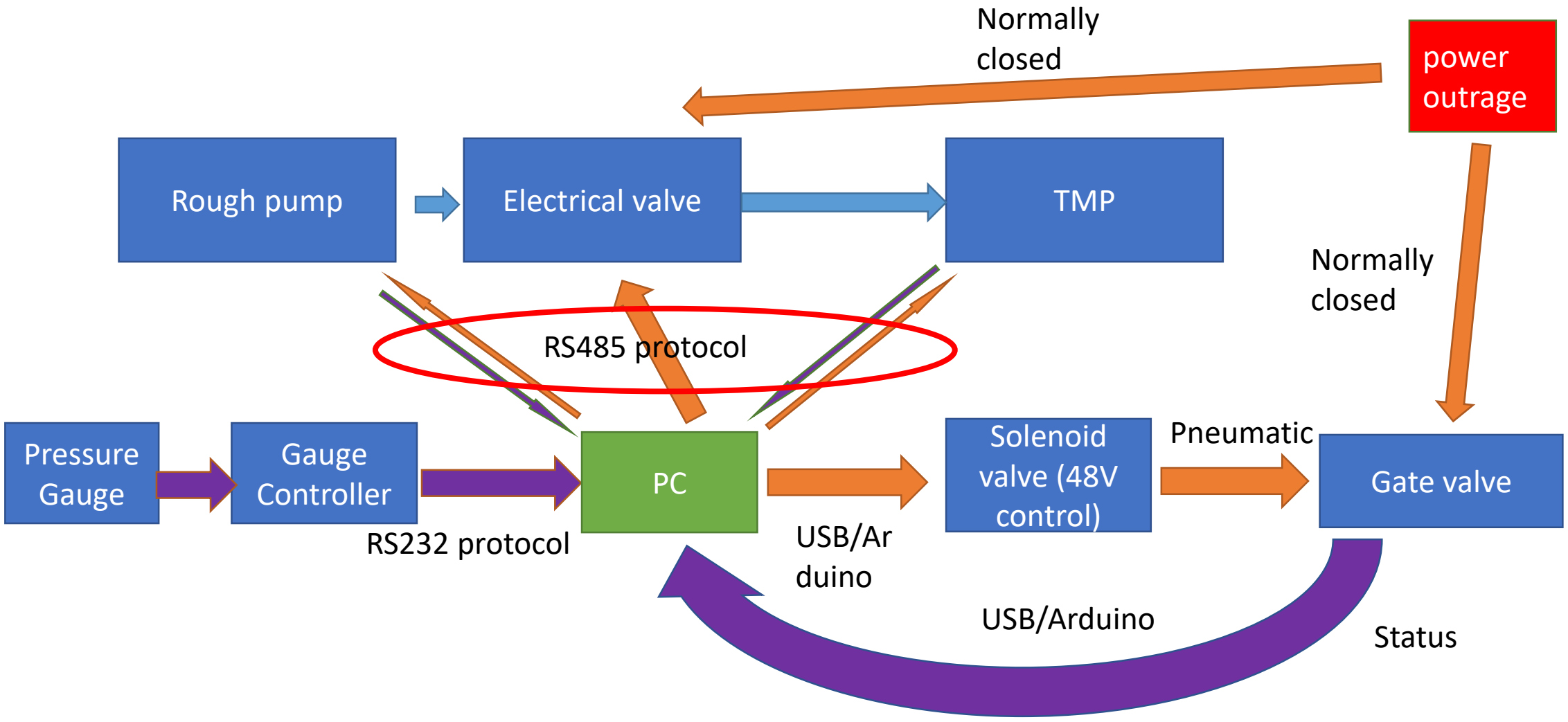




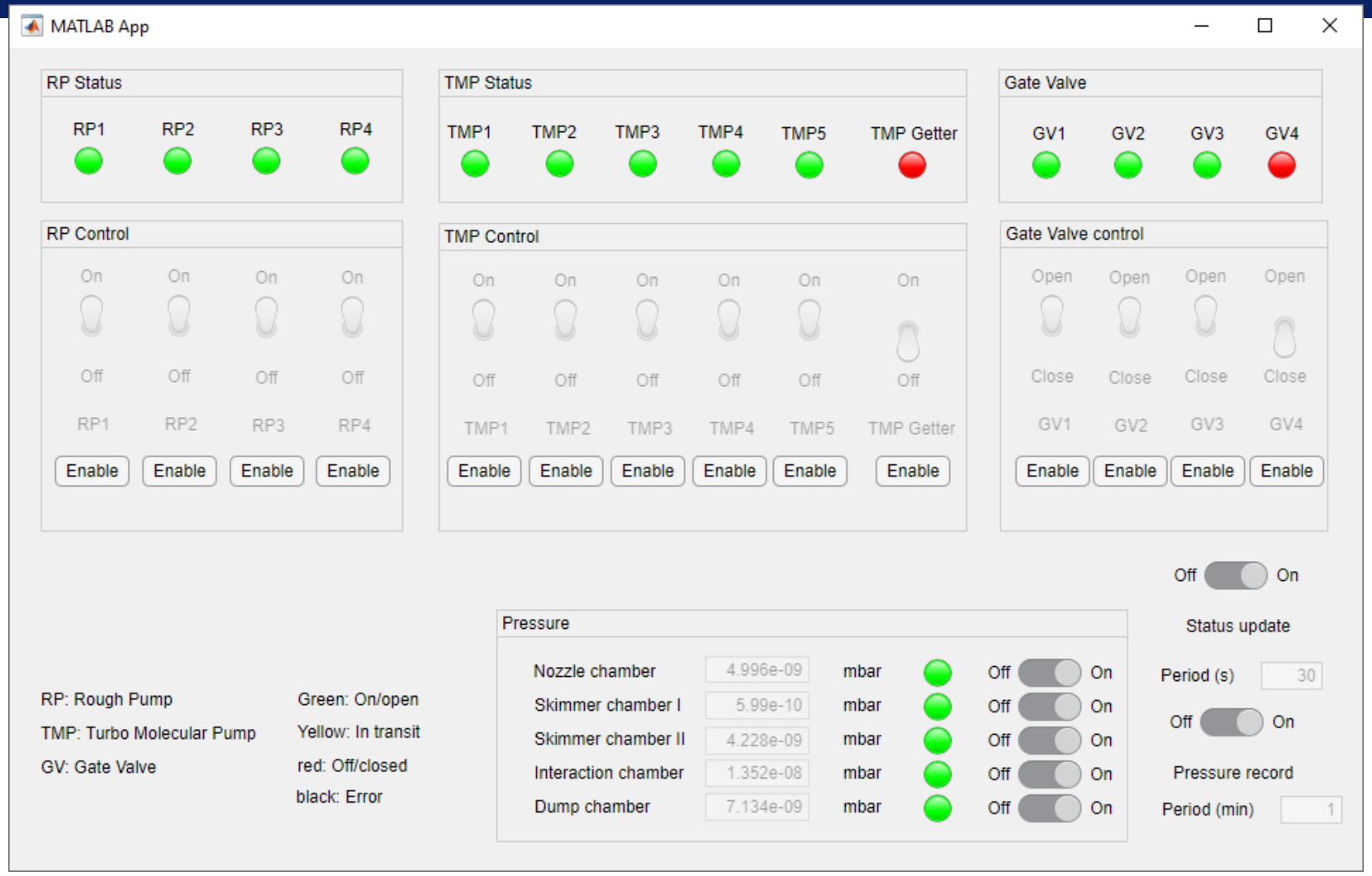
New configuration used

| | Nozzle (0 mm) | 1st skimmer (4.49 mm) | 2nd skimmer (33.59 mm) | 3rd skimmer (168.2mm) | Interaction (393.7 mm) |
|---|---|---|---|---|---|
| 1 | 30 um | 400 um | 2 mm | **0.7** * 9 $mm^2$ or 0.3 * 9 $mm^2$ | |

# Vacuum control system



# Main control GUI



# NEG VS TMP installed in interaction chamber (Nitrogen)

| Condition | CH1 | CH2 | CH3 | CH4 | CH5 |
|---|---|---|---|---|---|
| E-gun & Jet off TMP | 3.8e-7 | 1.2e-8 | 3.1e-8 | 3.2e-8 | 1.3e-8 |
| | | | | | |
| E-gun off Jet on TMP | 4.9e-3 | 1.03E-05 | 1.16E-06 | 3.97E-08 | 1.37E-07 |
| | | | | | |
| E-gun & Jet on TMP | 5.5e-3 | 5.3e-6 | 1.6e-6 | 4.58e-8 | 1.2e-7 |

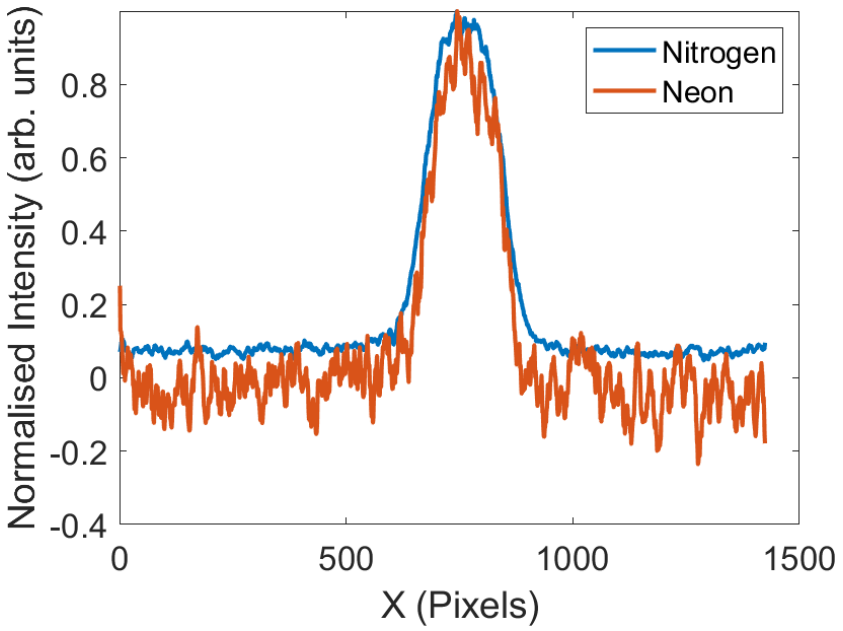
$3^{rd}$ skimmer
0.7 x 9mm

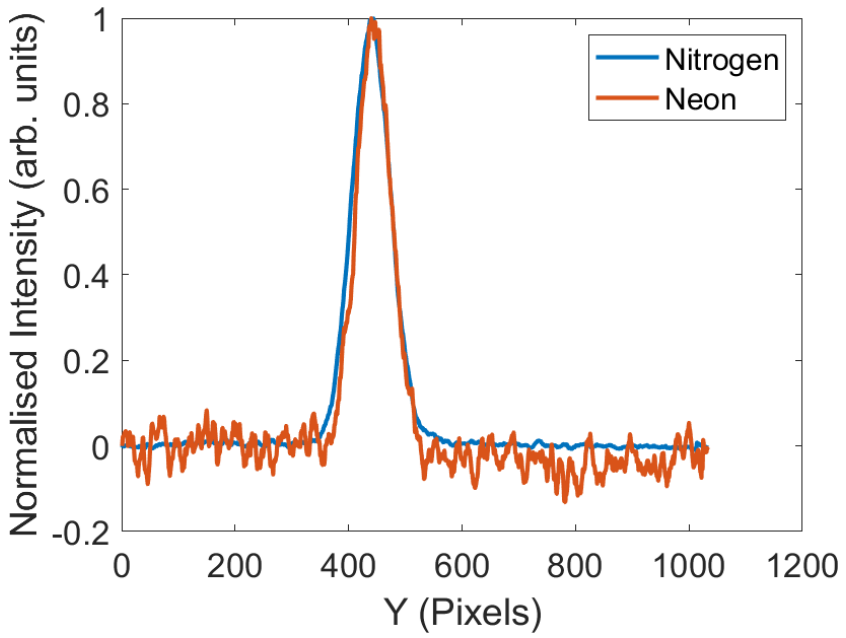
# NEG VS TMP installed in interaction chamber (Nitrogen)

| Condition | CH1 | CH2 | CH3 | CH4 | CH5 |
|---|---|---|---|---|---|
| E-gun & Jet off TMP | 6.90E-09 | 1.90E-10 | 3.70E-09 | 1.66E-09 | 3.20E-09 |
| | | | | | |
| E-gun off Jet on TMP | 5.5e-3 | 1.2e-5 | 1.9e-6 | 1.14e-8 | 3.2e-8 |
| | | | | | |
| E-gun & Jet on TMP | 5.5e-3 | 1.2e-5 | 1.9e-6 | 3.66e-8 | 3.1e-8 |

3rd skimmer
0.3 x 9mm

# Gas jet measured beam profile




Condition:

0.7 mm *9 mm 3rd skimmer

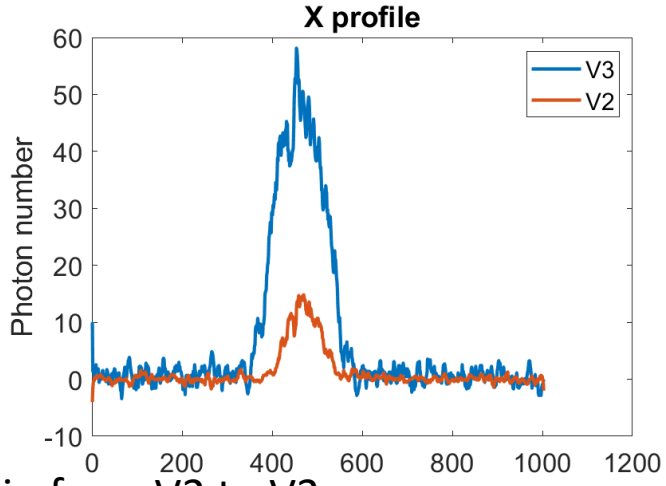
E-beam conditions: 0.63mA at 5keV

Exposure time per picture : 0.1s

Total integration time :

Neon: 2000s

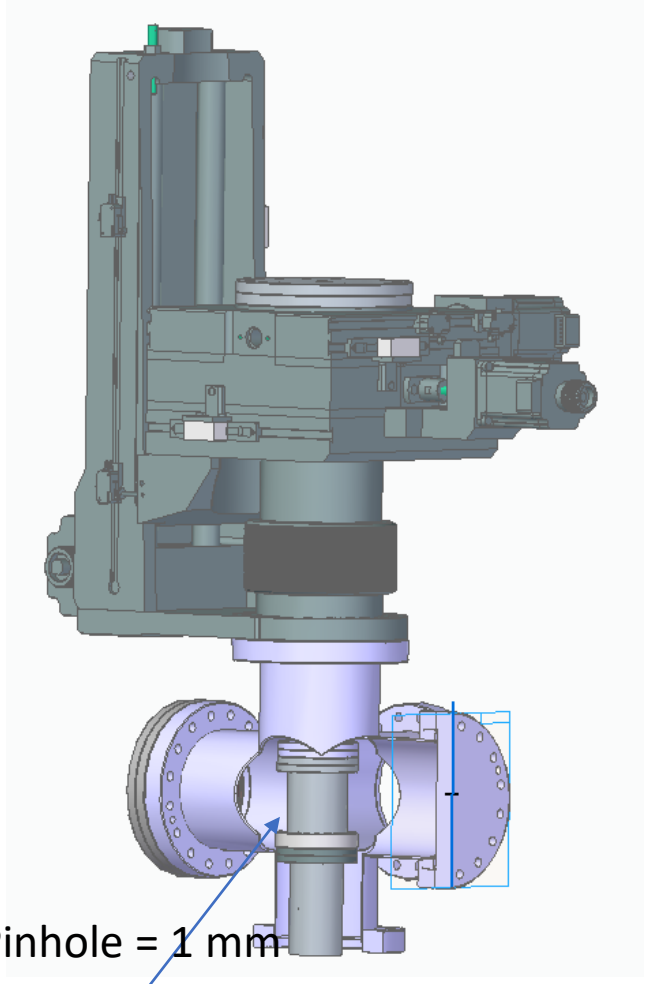
Nitrogen: 200s



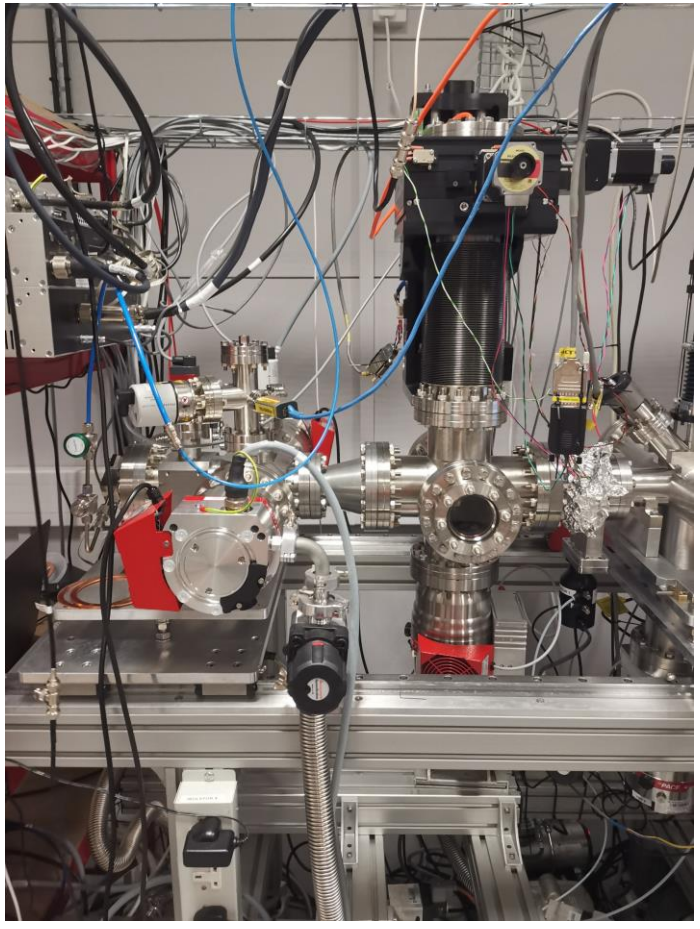

- Photon number per second: Neon: ~22s Nitrogen: ~300s
- The ratio between Nitrogen and Neon signal level consistent with V2, but is at least 5 times higher

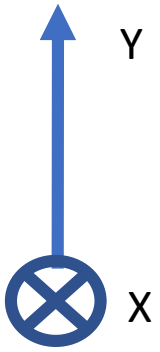
Improvement for S/N ratio from V2 to V3

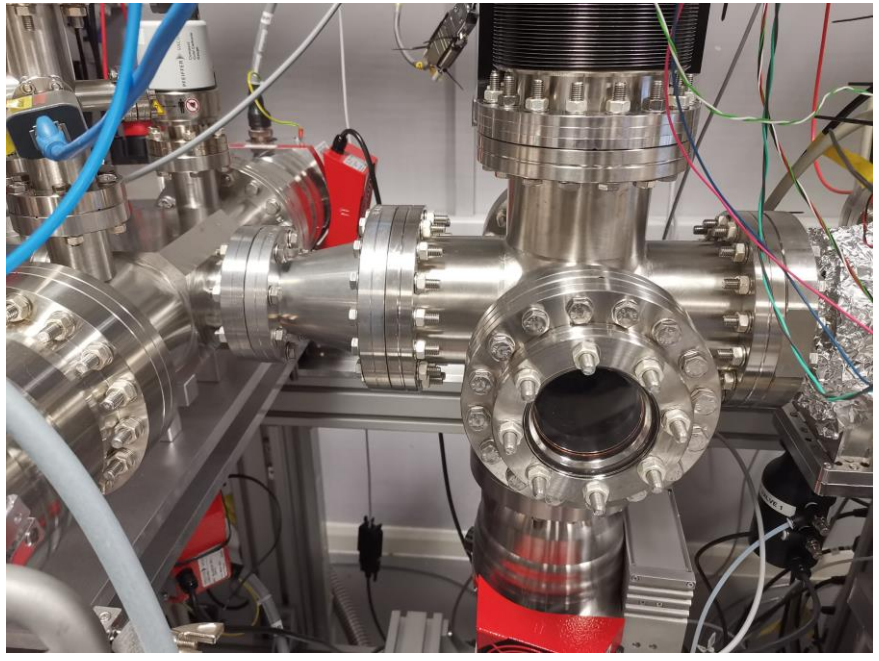
# New Movable gauge system



Pinhole = 1 mm

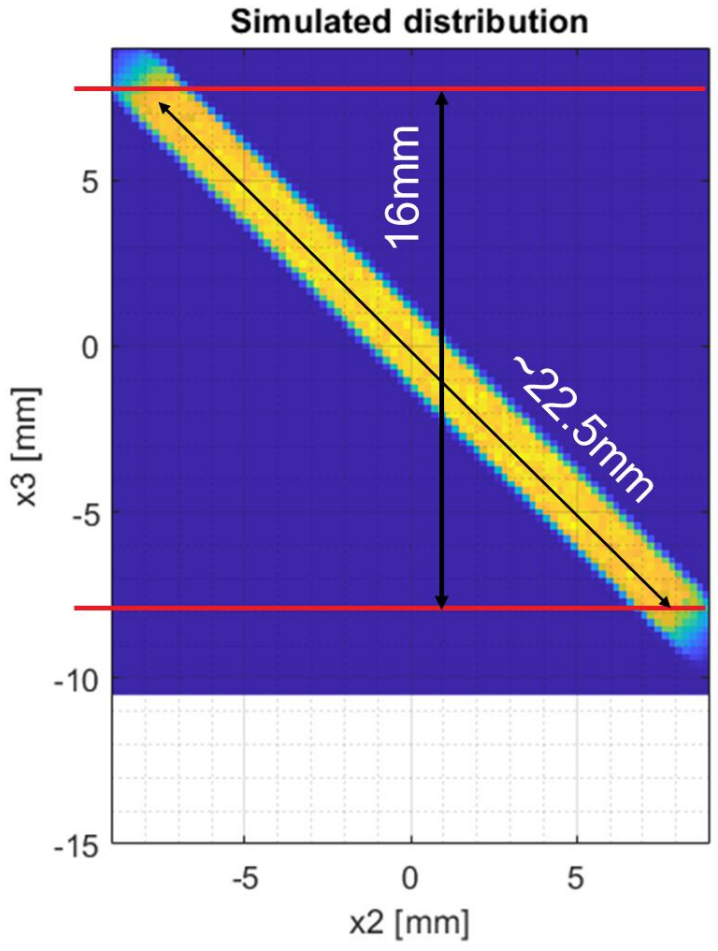


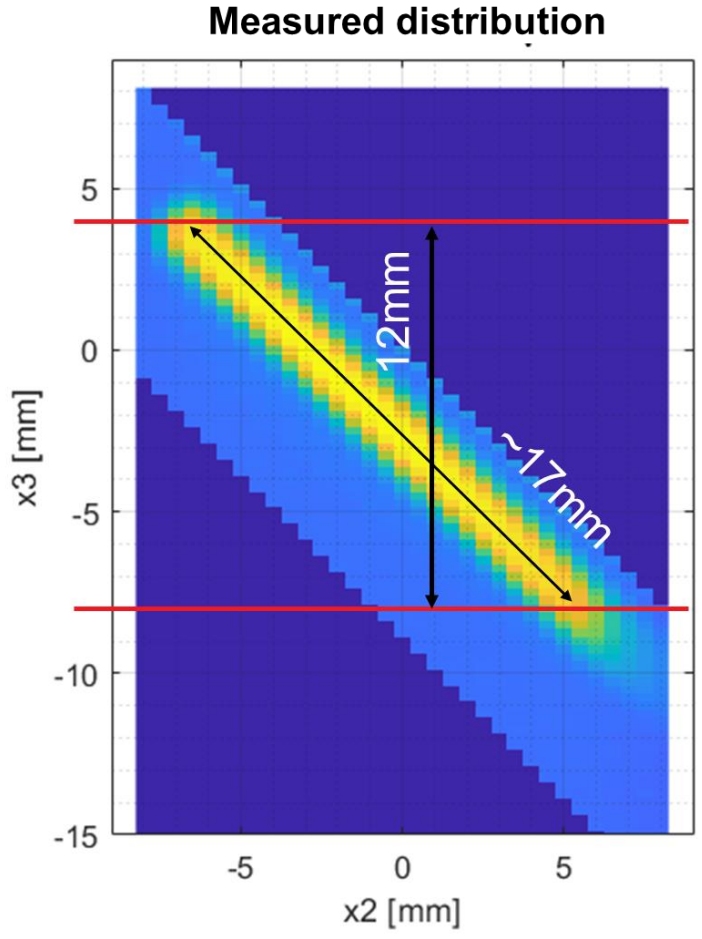


# 3rd skimmer

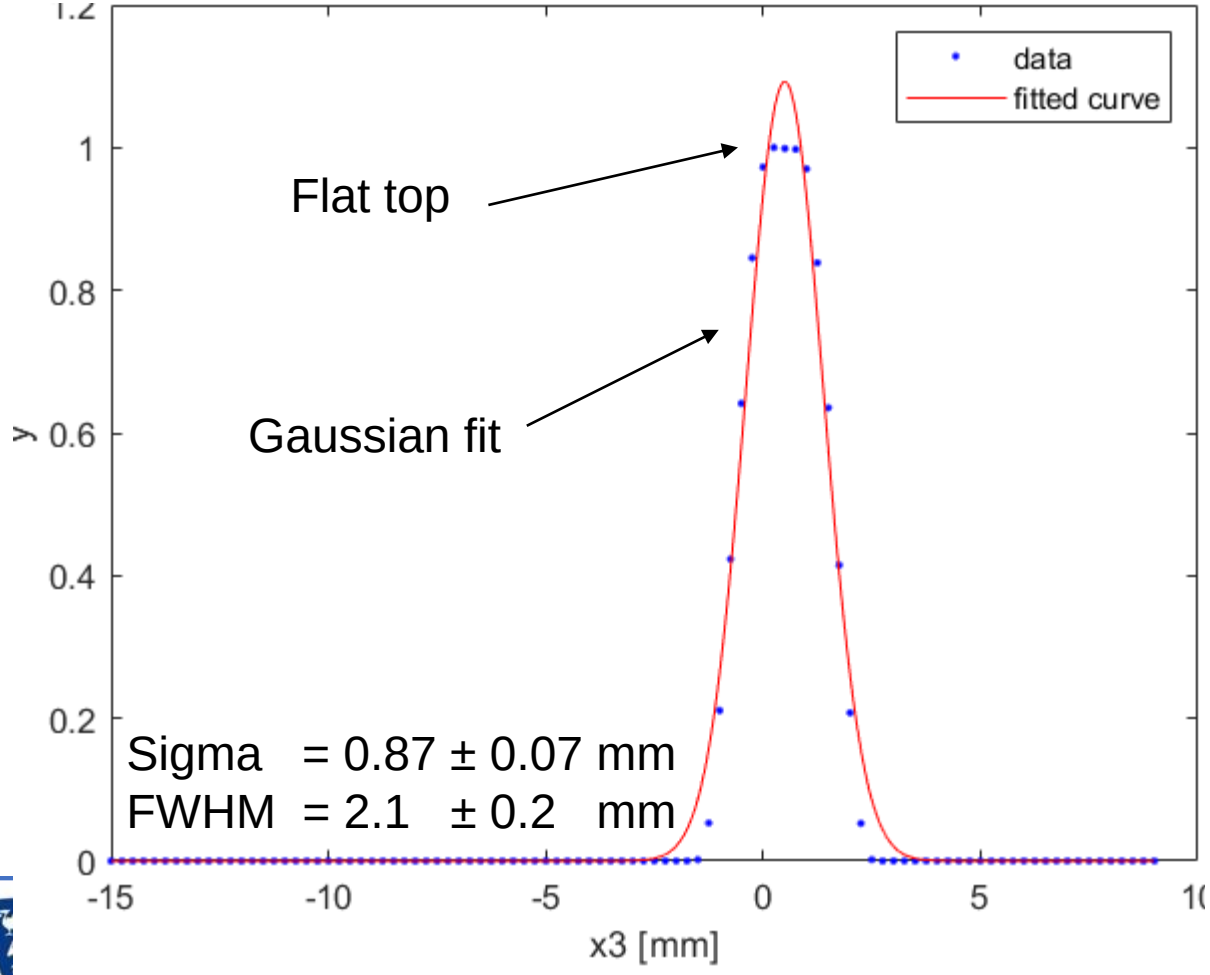
| | Nozzle (0 mm) | 1st skimmer (4.49 mm) | 2nd skimmer (33.59 mm) | 3rd skimmer (168.2mm) | Interaction (393.7 mm) |
|---|---|---|---|---|---|
| 1 | 30 um | 400 um | 2 mm | **0.7**mm*9mm | |



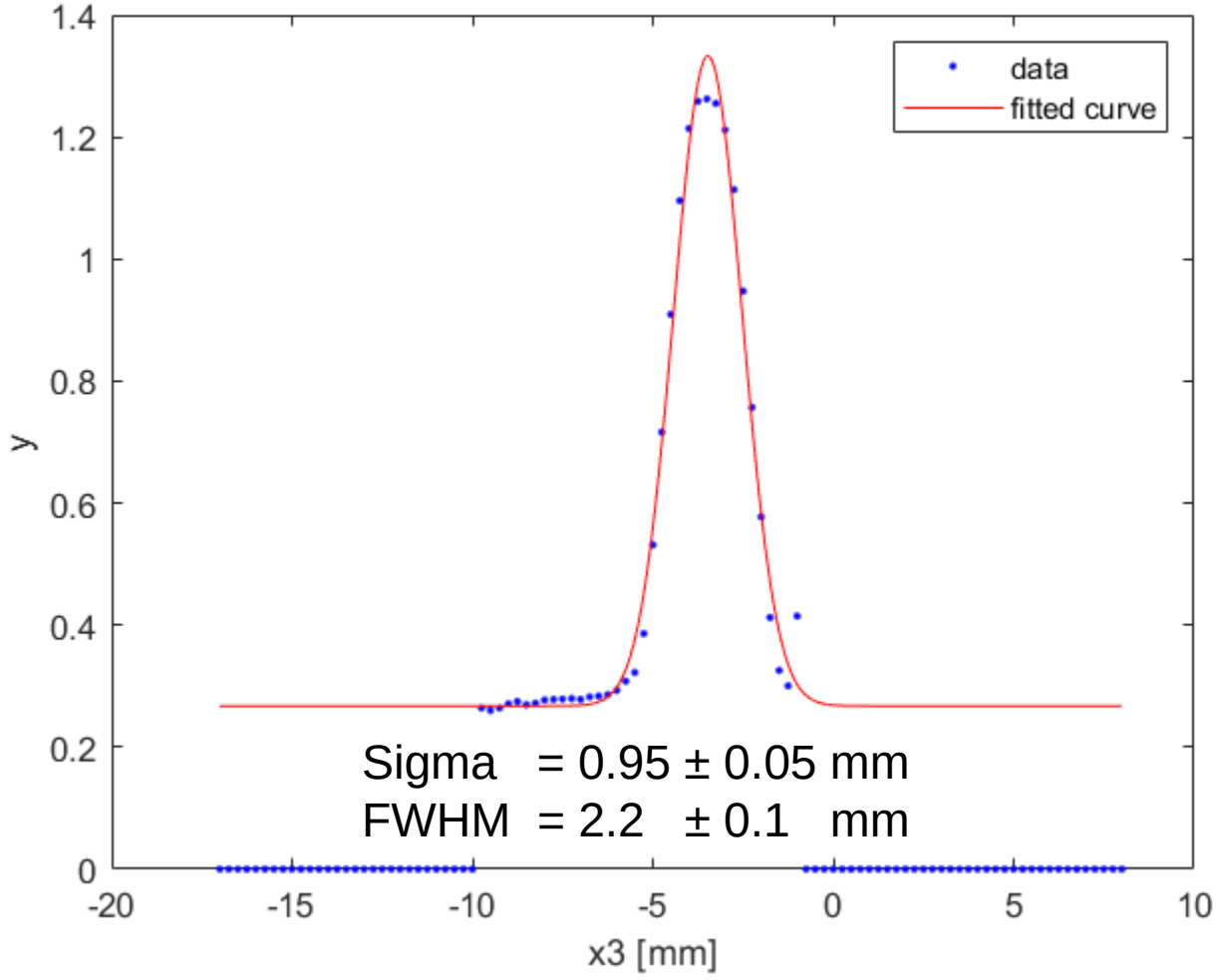



# Convoluting simulation with pinhole Vs Measurement (large skimmer)

## Simulation (convoluted)

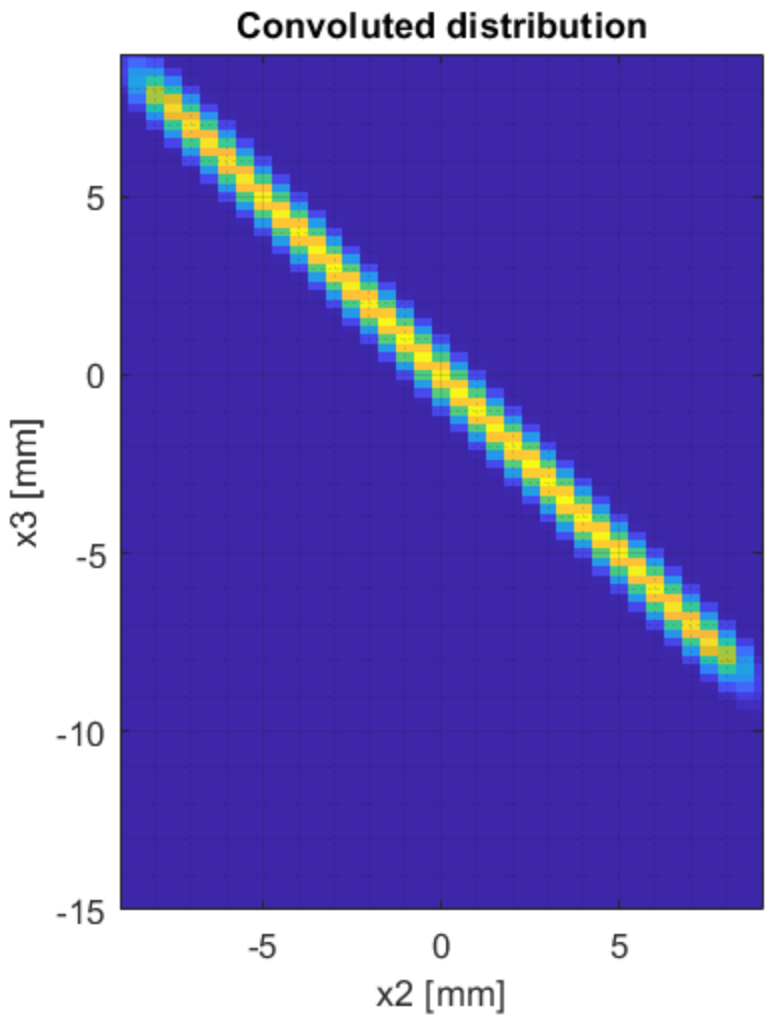


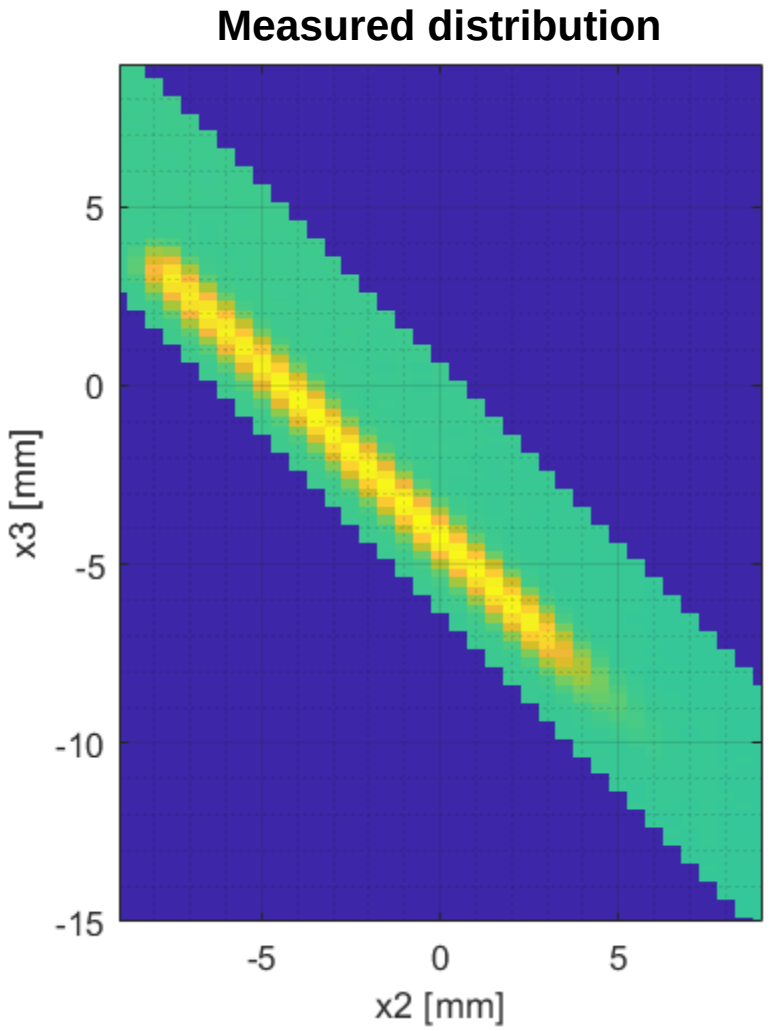

## Measurement



# 3rd skimmmer

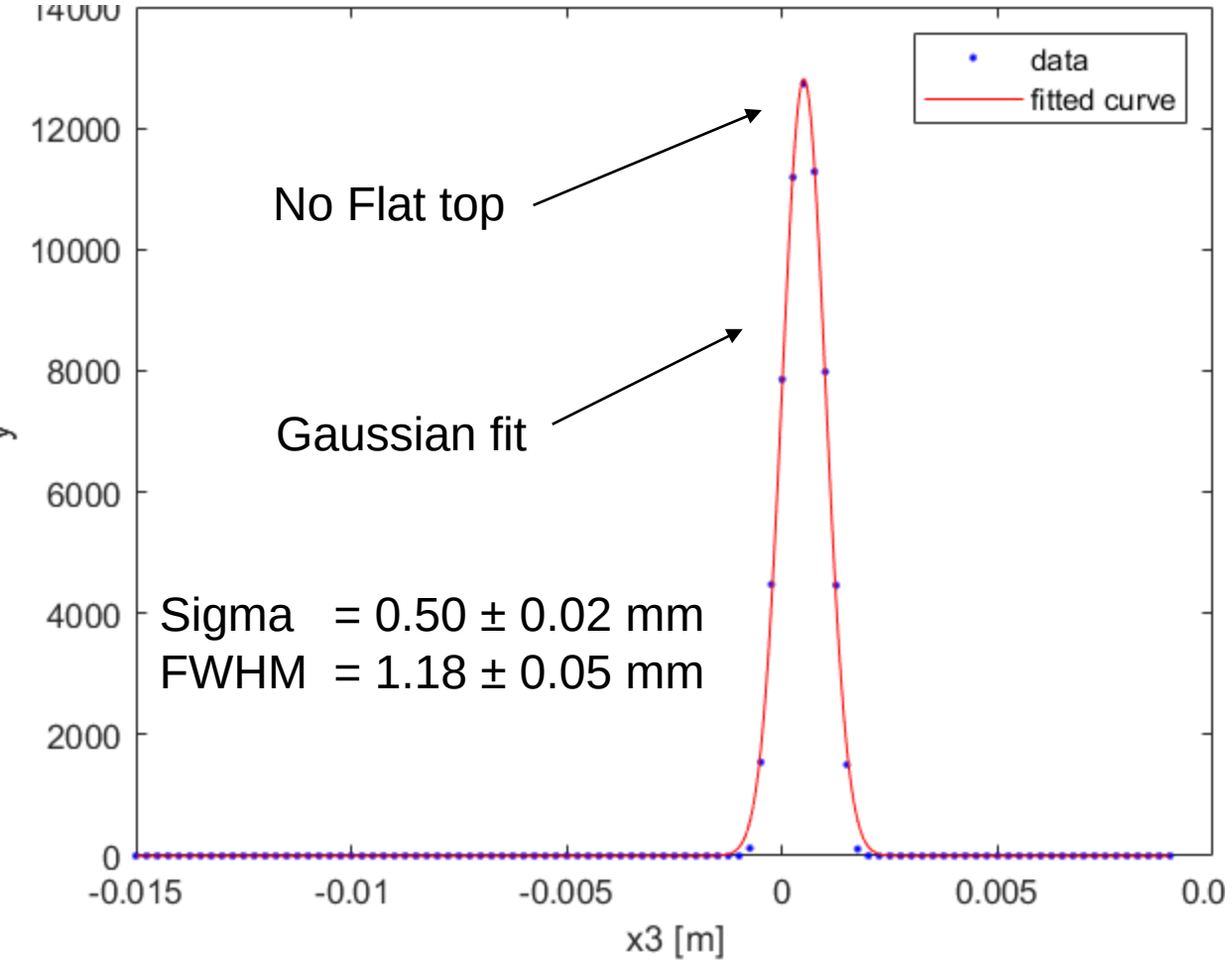
| | Nozzle (0 mm) | 1st skimmer (4.49 mm) | 2nd skimmer (33.59 mm) | 3rd skimmer (168.2mm) | Interaction (393.7 mm) |
|---|---|---|---|---|---|
| 1 | 30 um | 400 um | 2 mm | **0.3**mm*9mm | |



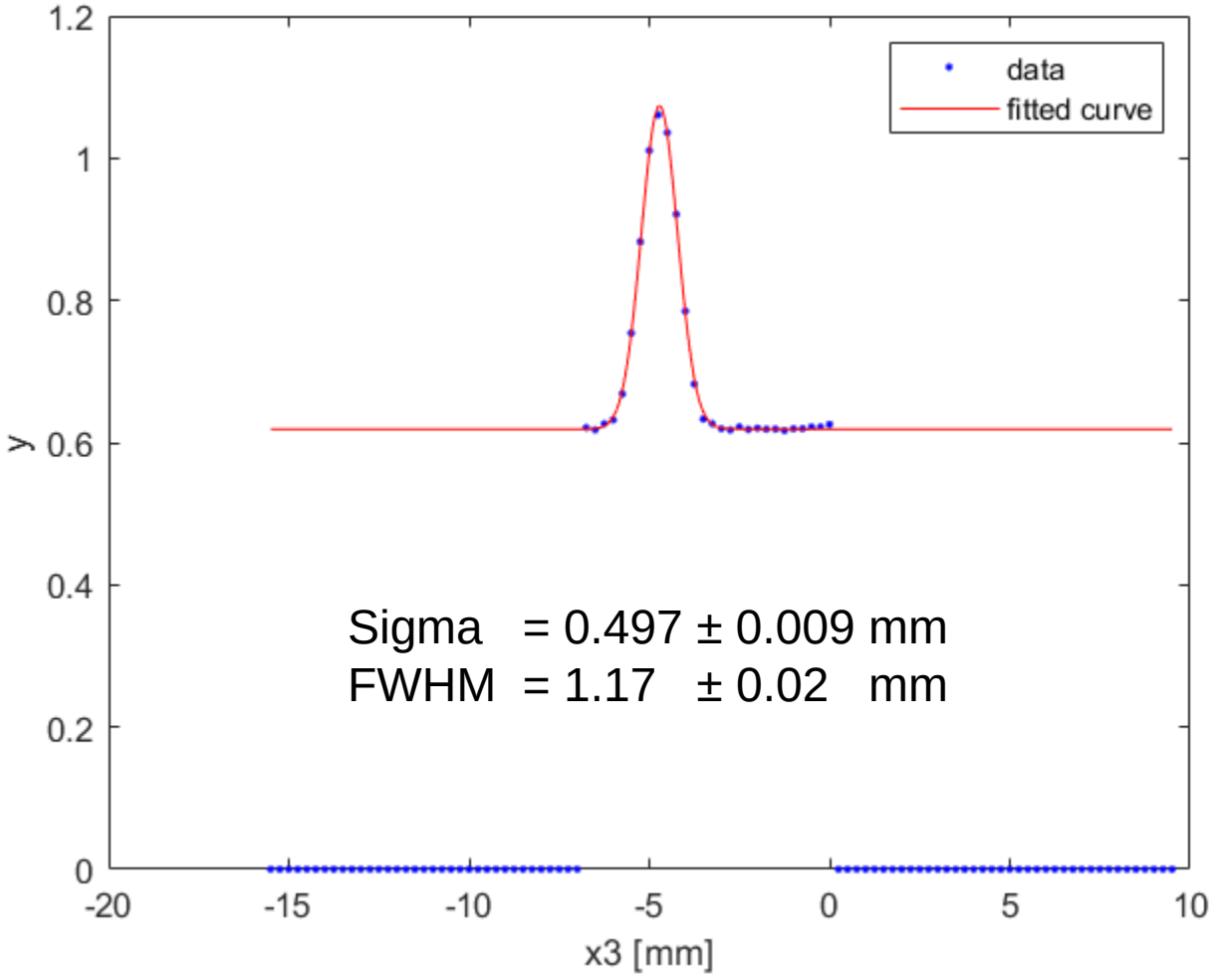



# Convoluting simulation with pinhole Vs Measurement

## Simulation (convoluted)

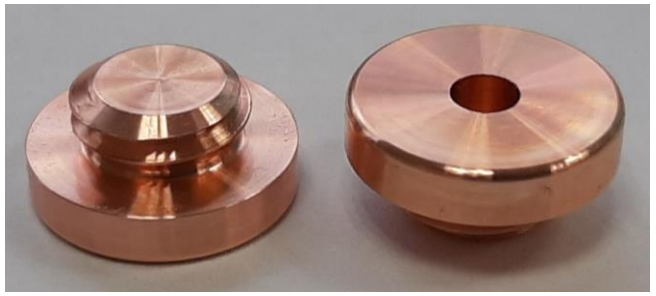


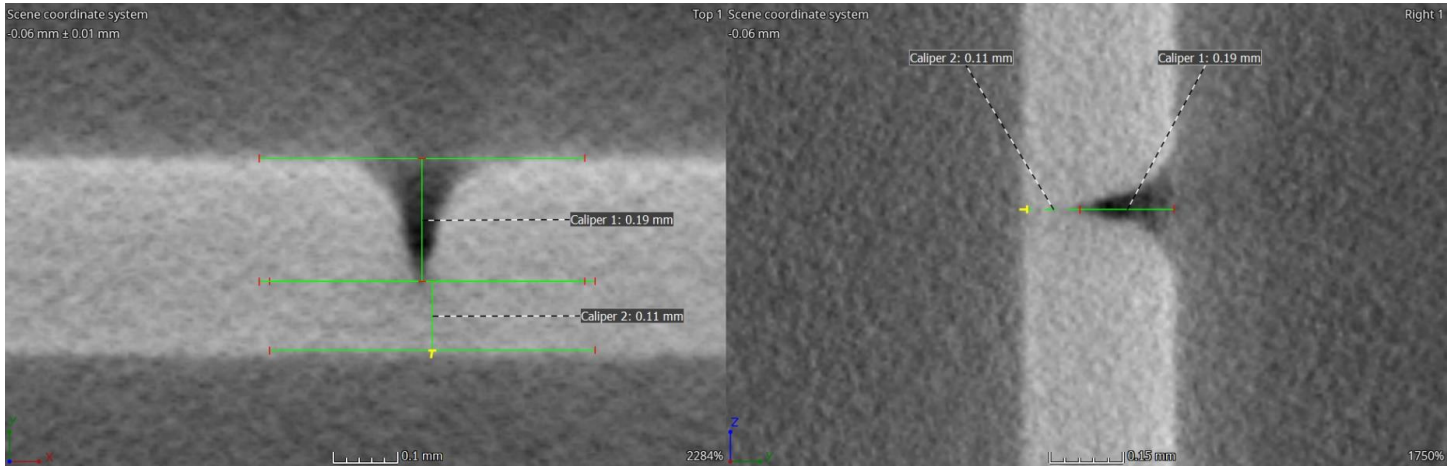

## Measurement

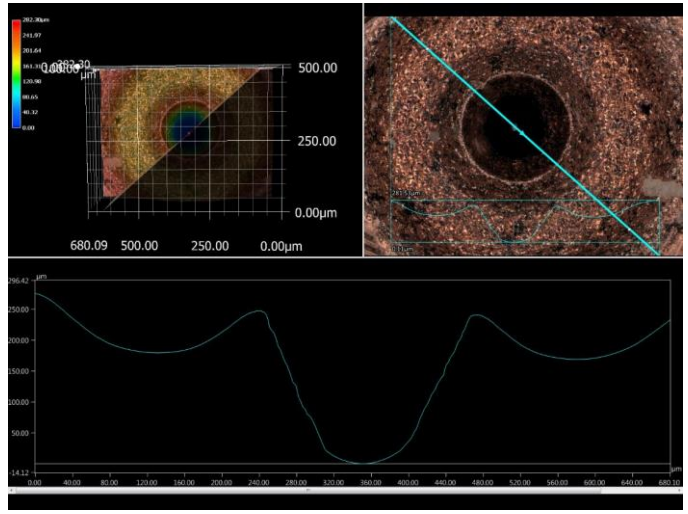


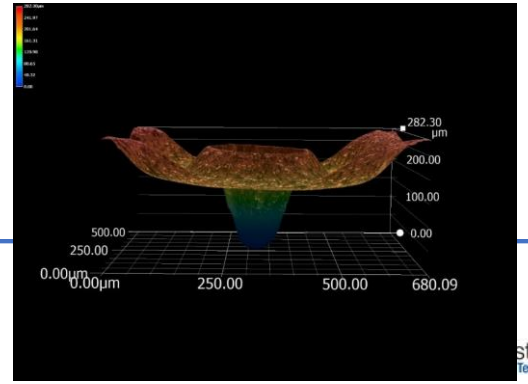
# Convergent-Divergent (CD) Nozzles

- CERN workshop EDM and Focused Ion Beam (FIB) divergent nozzle development
- FIB nozzle now with Cockcroft institute for tests



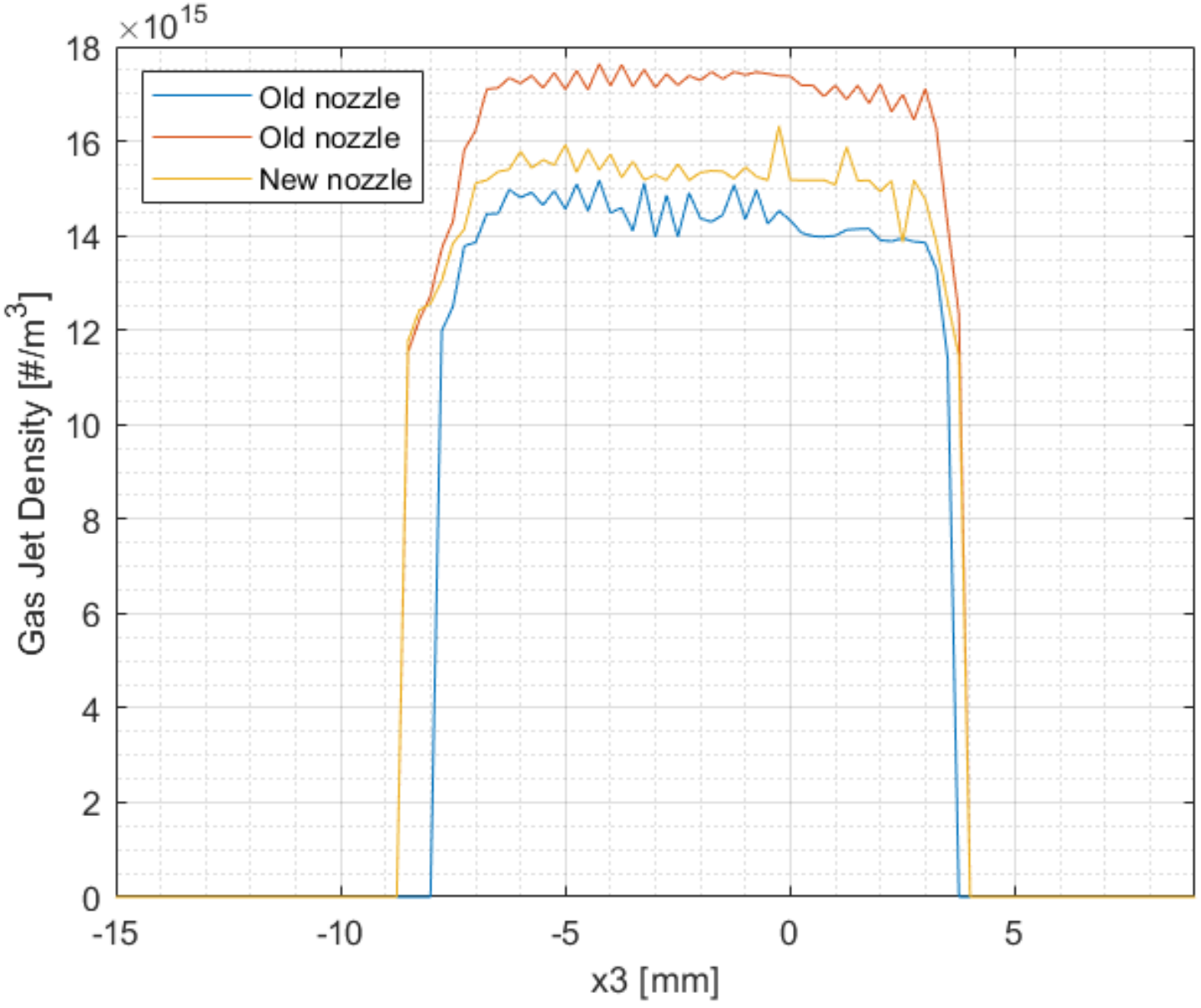


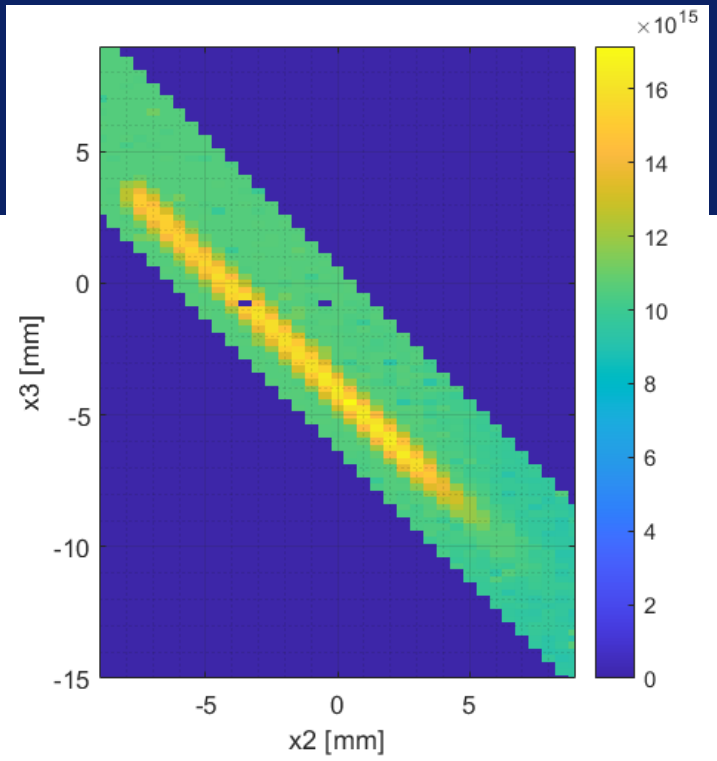



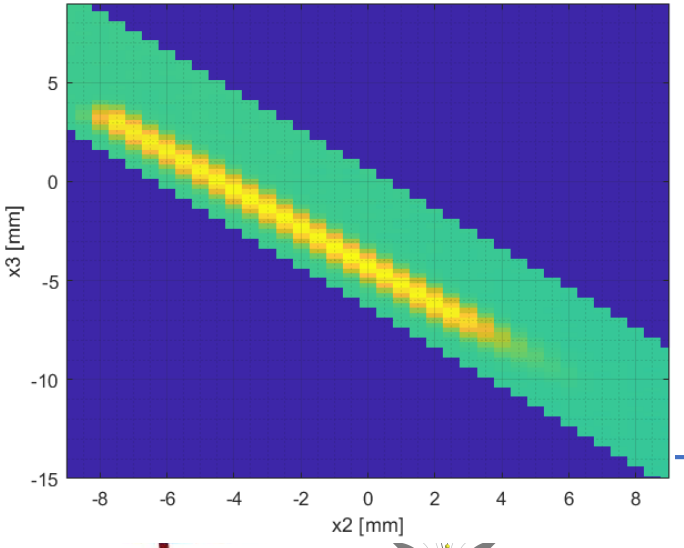




Pictures Courtesy A. Cherif

# Old vs New nozzle




The Cockcroft Institute
of Accelerator Science and Technology

# Summary for section II

- Design, procurement and commissioning of V3 gas jet monitor
- Demonstrated a beam profile measurement with much higher SNR than v2.
- New configuration of nozzle-skimmer assembly shows a good gas jet property and easy of alignment.
- The difference of CD nozzle and flat nozzle shows little difference.

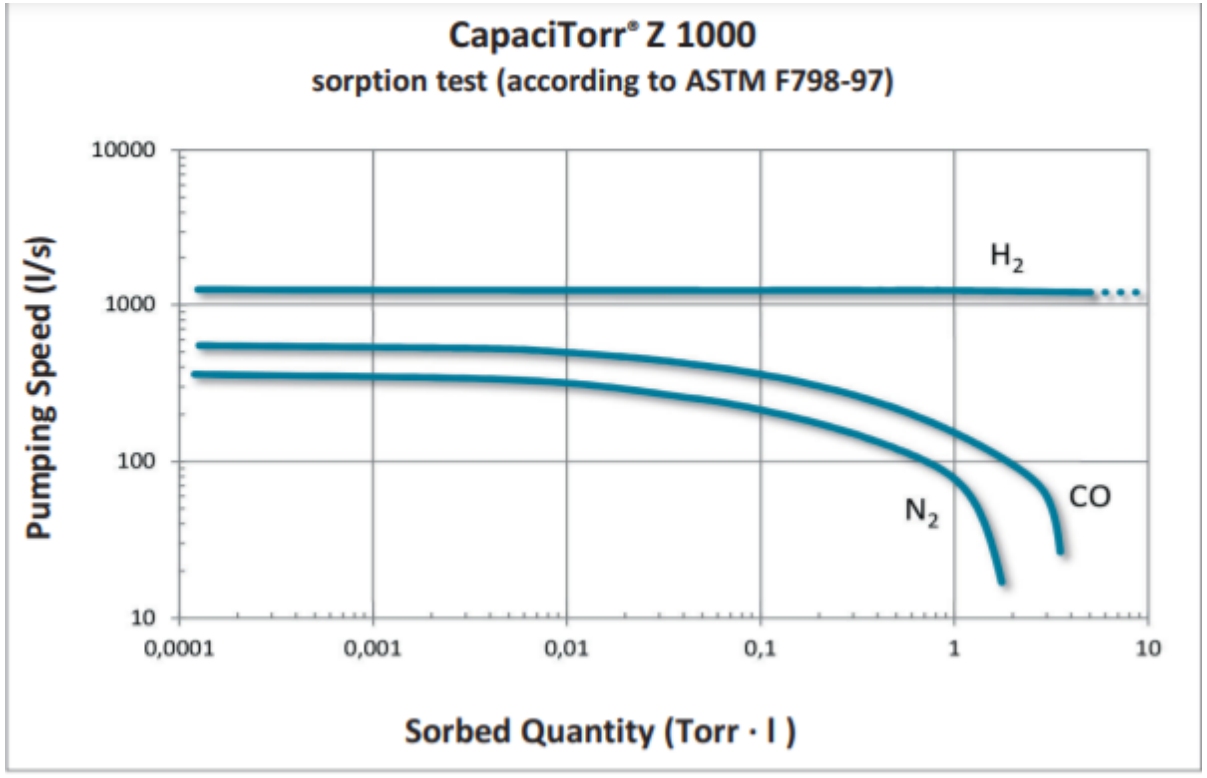
# Section III: NEG Experiments

# NEG Pump Introduction

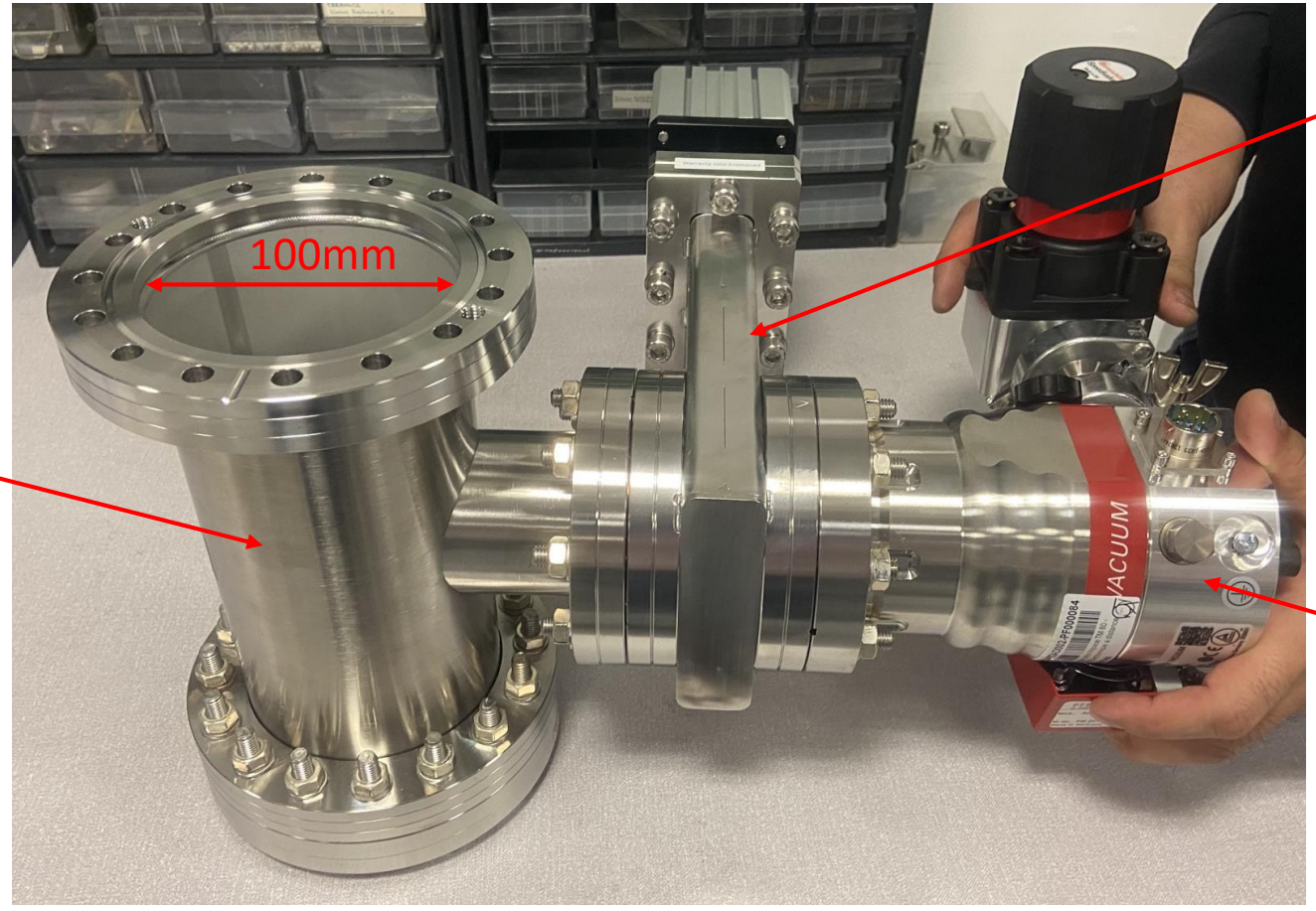
CapaciTorr Z1000 installed in the Dump chamber and later re-located to the Interaction chamber, replacing the TMP's installed in each chamber.

Once activated, the NEG pumps at 360L/s but slows as the getter material becomes coated with the sorbed molecules. Once fully saturated, all pumping will stop.

When reactivated, sorbed molecules are released or diffused into the bulk of the getter.



# NEG Subsystem

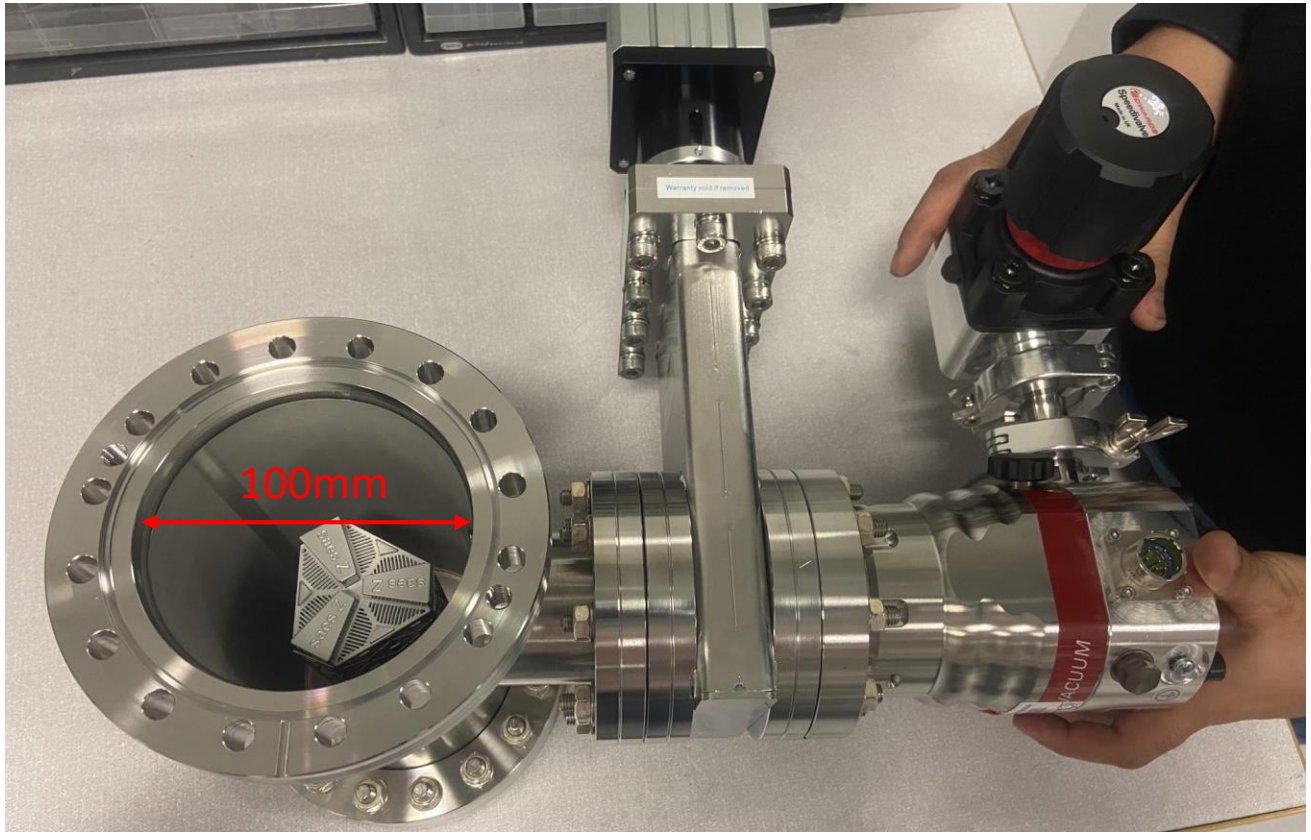



NEG inside DN100 pipe

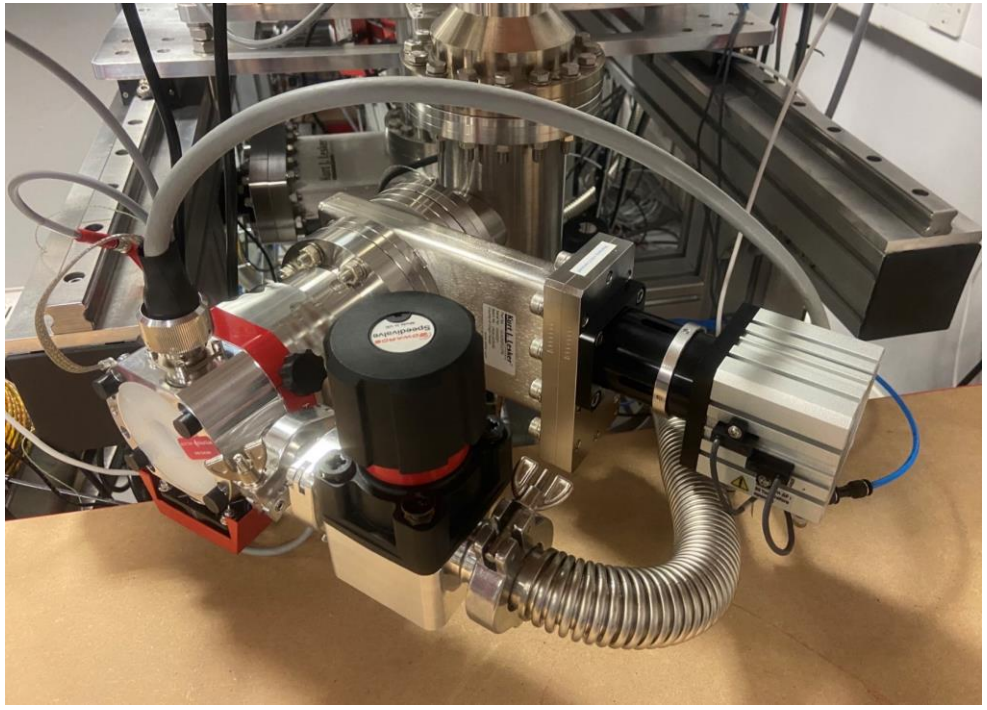
Gate valve to isolate TMP from NEG during normal operation

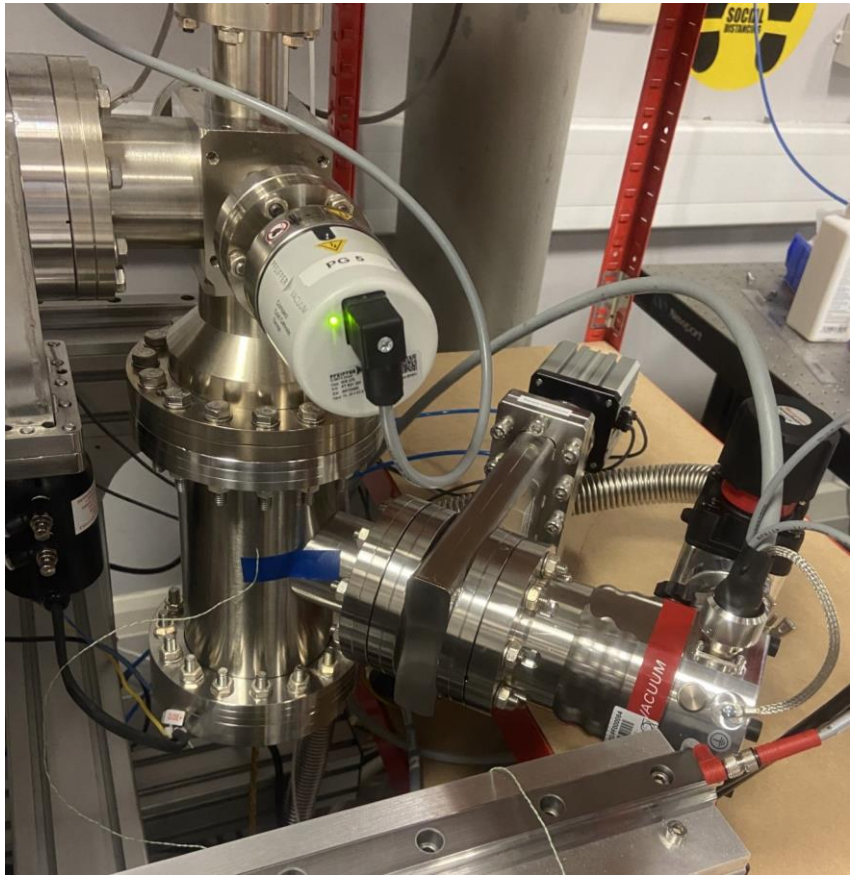
TMP used to reach activation pressure and pump released molecules during activation.

# NEG Subsystem



# NEG Pump Installed in the Dump Chamber



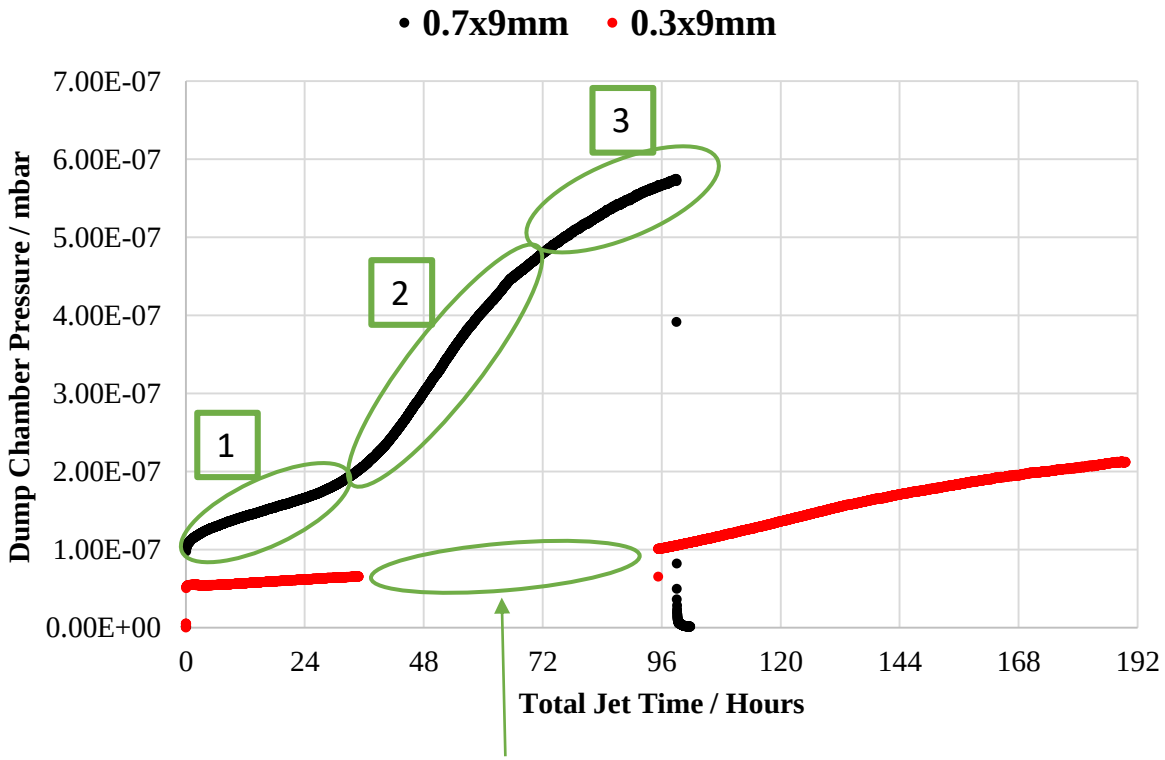


All Jet tests use N2 at 5 bar

# Dump Chamber Pressure

- 0.7x9mm skimmer saturates much quicker than 0.3x9mm skimmer due to increased volumetric flowrate to dump chamber.
  1. NEG pumping at max 360L/s
  2. NEG pumping speed reduced as getter surface becomes coated
  3. Pumping tends towards an equilibrium as NEG saturates and pumping is provided from diffusion effect through the 4$^{th}$ skimmer.

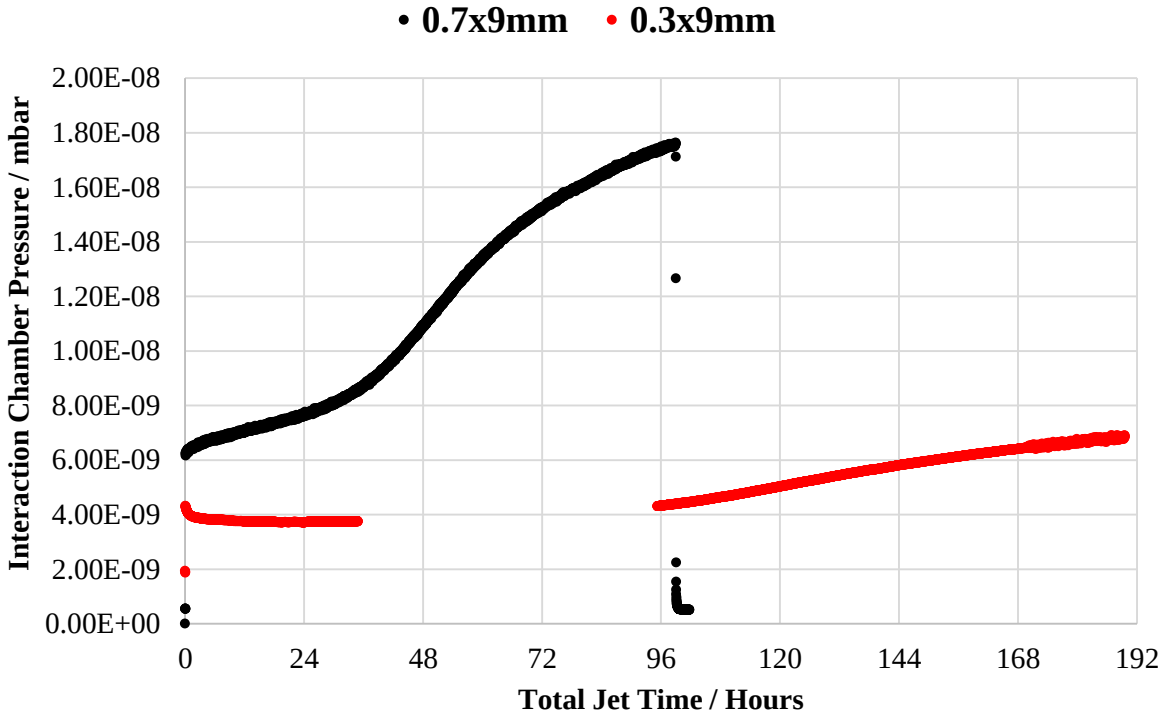
- Using the saturation curve from the larger skimmer, It is predicted that the smaller skimmer will reach an equivalent saturation after 13 days of continuous jet.



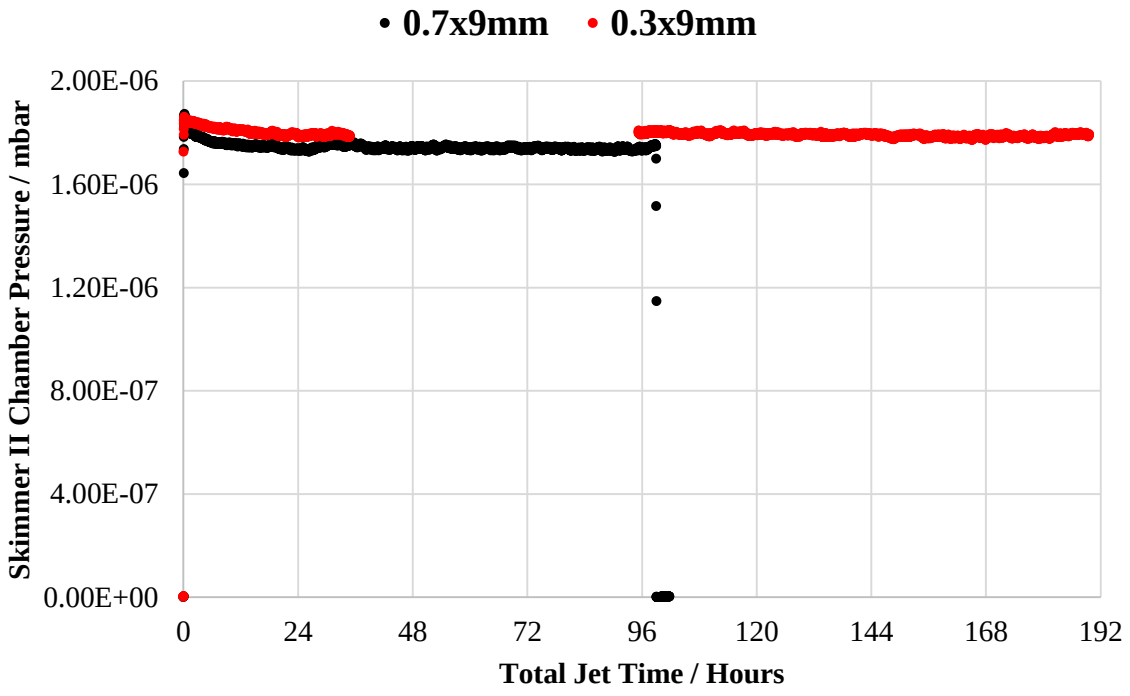

Data failed to save over weekend. Problem fixed.

# Interaction Chamber Pressure

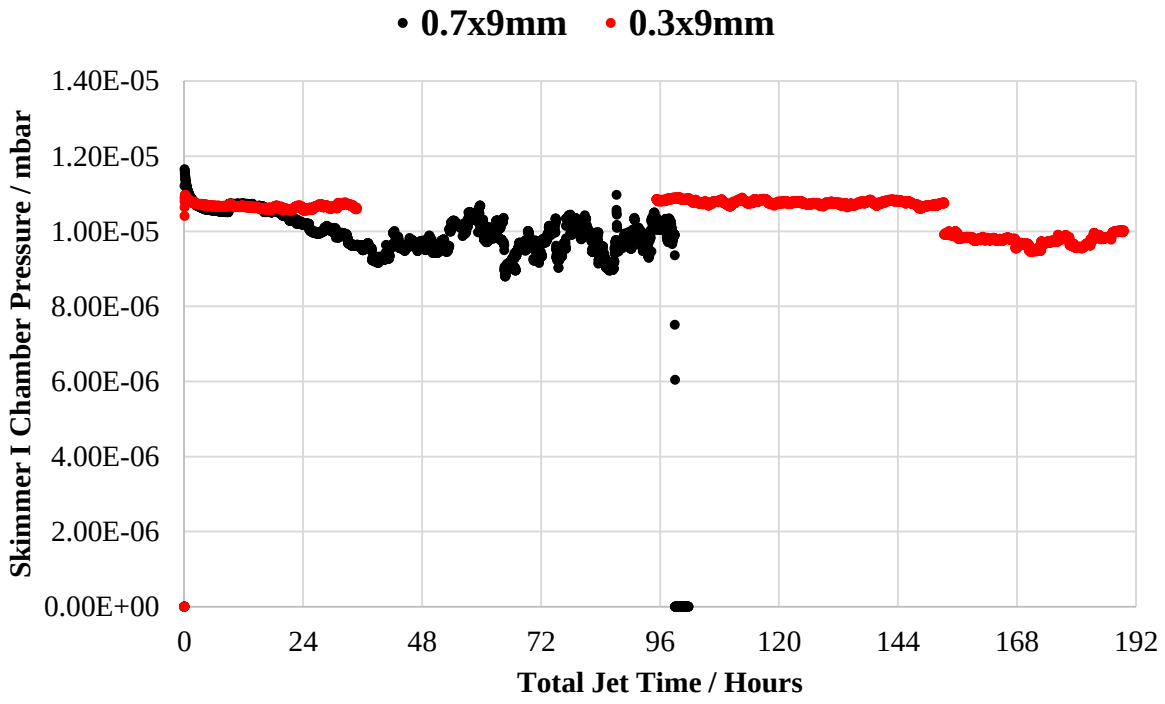
- Interaction chamber follows a similar pressure curve to the Dump chamber.
- There is a clear dependency between the interaction and dump chambers as a result of the diffusion effects through the 4th skimmer.
- A maximum pressure of 1.75E-8 mbar is seen compared to the dump chamber maximum pressure of 5.73E-7 mbar.



# Skimmer Chambers I and II Pressure




Near constant skimmer II chamber suggests NEG effects are independent of pressure data from nozzle to skimmer II chamber.




The skimmer I chamber is also near-constant with an increase in noise experienced.

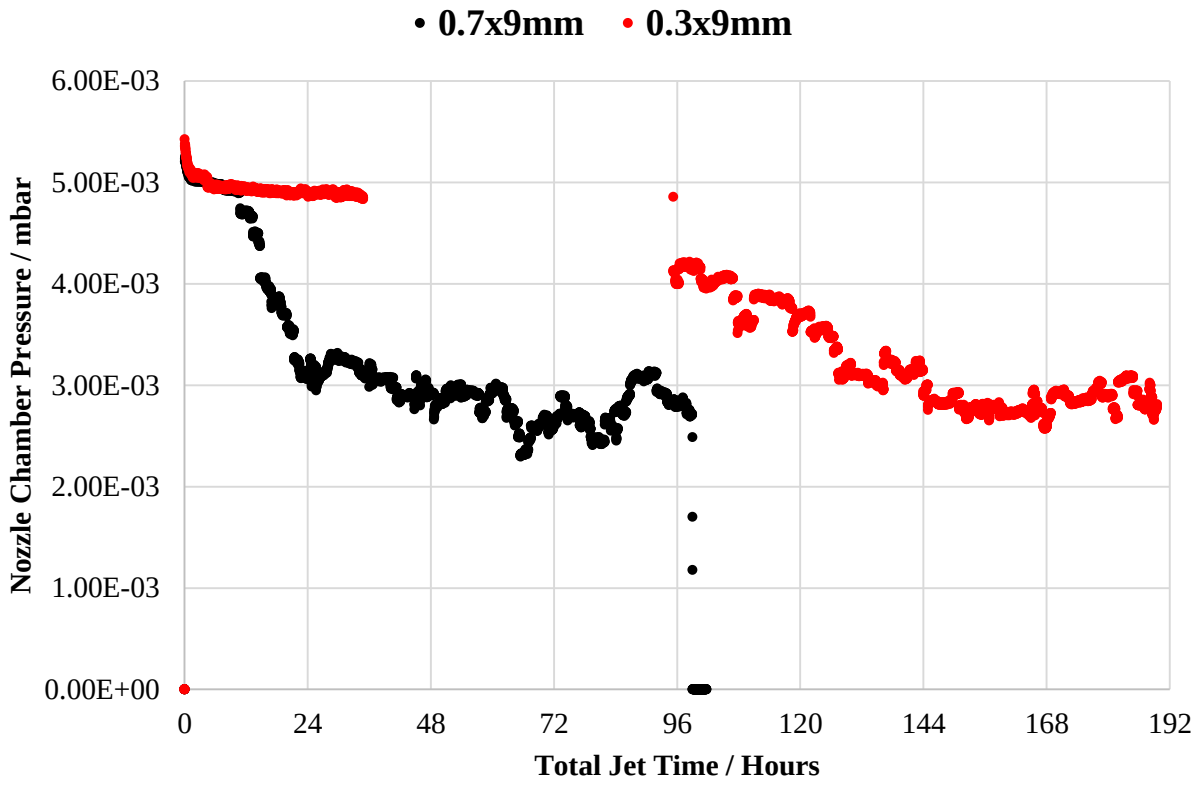
# Nozzle Chamber Pressure

Drop in nozzle chamber pressure of approximately 50% from initial jet.

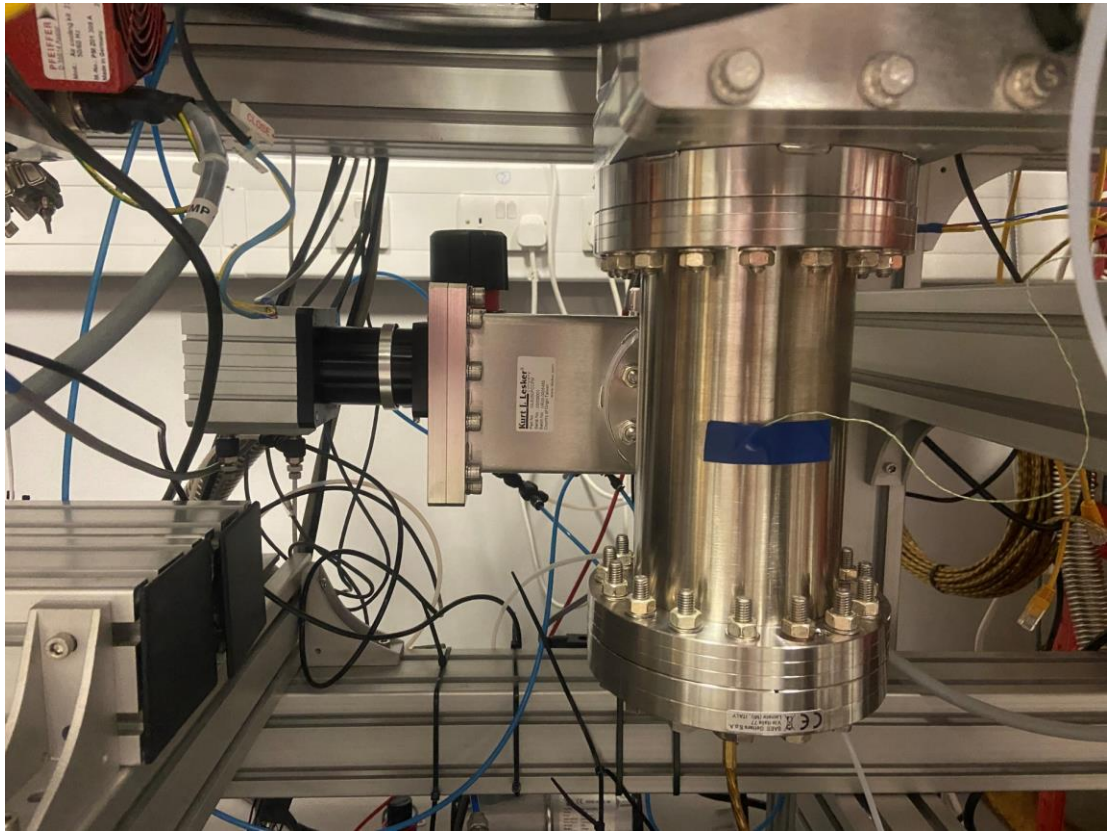
Anticipated not a function of NEG saturation as nozzle chamber should be fully independent from NEG located in the dump chamber.

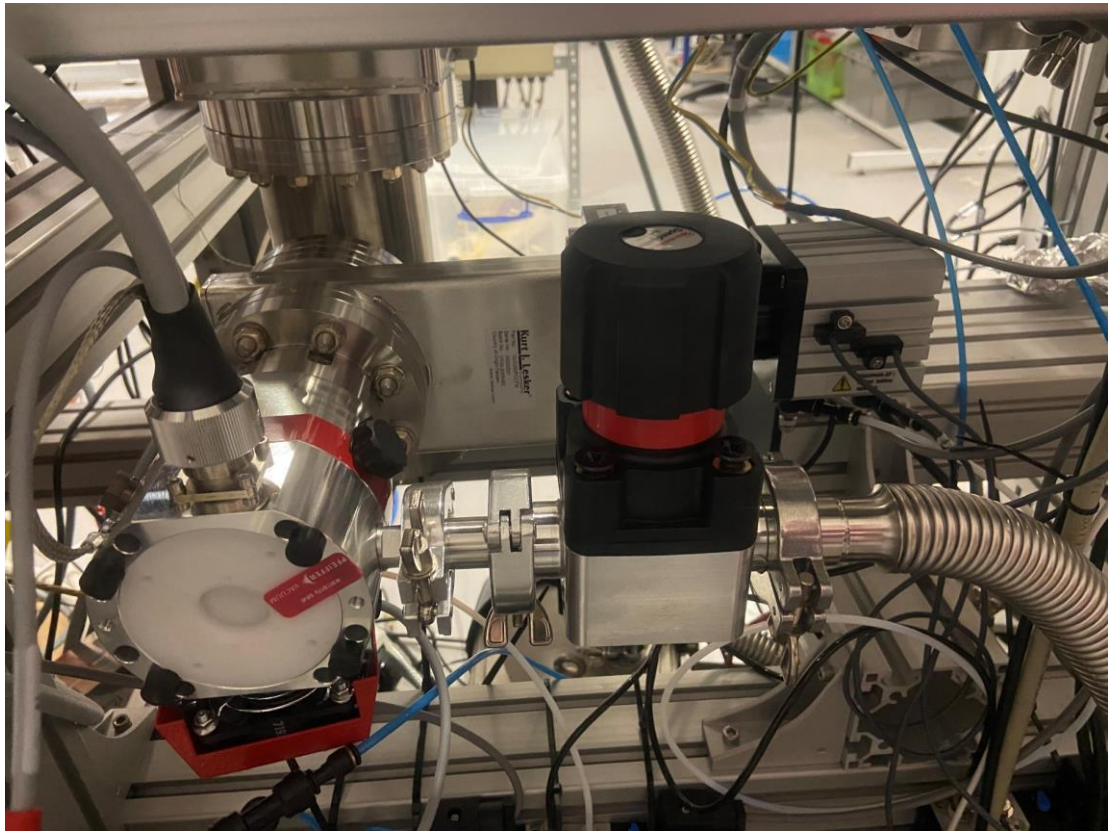
Likewise, pressure decrease between different 3rd skimmers should be relatively similar in the nozzle chamber. However, we see a discrepancy of 5 days.

Further testing required.



# NEG Pump Installed in Interaction Chamber



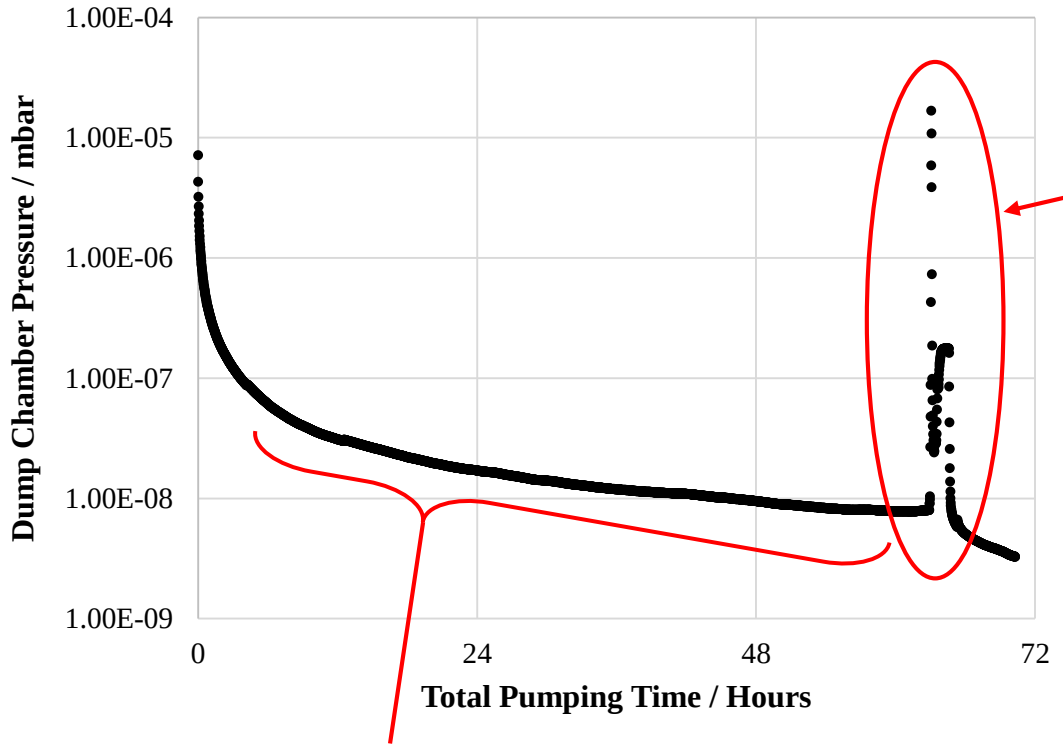


# Pump Down Pressure Data

E-7 mbar reached within 15 minutes of gauge on.

Full activation and NEG cooldown takes 3 hours and reaches E-9 mbar.

Anticipated minimum pump down from 1 bar & NEG activation should take 4 hours total to reach E-9 mbar.




NEG activation and TMP gate valve closed.

Left pumping over weekend. Maximum pressure required to activate NEG is E-4 mbar.

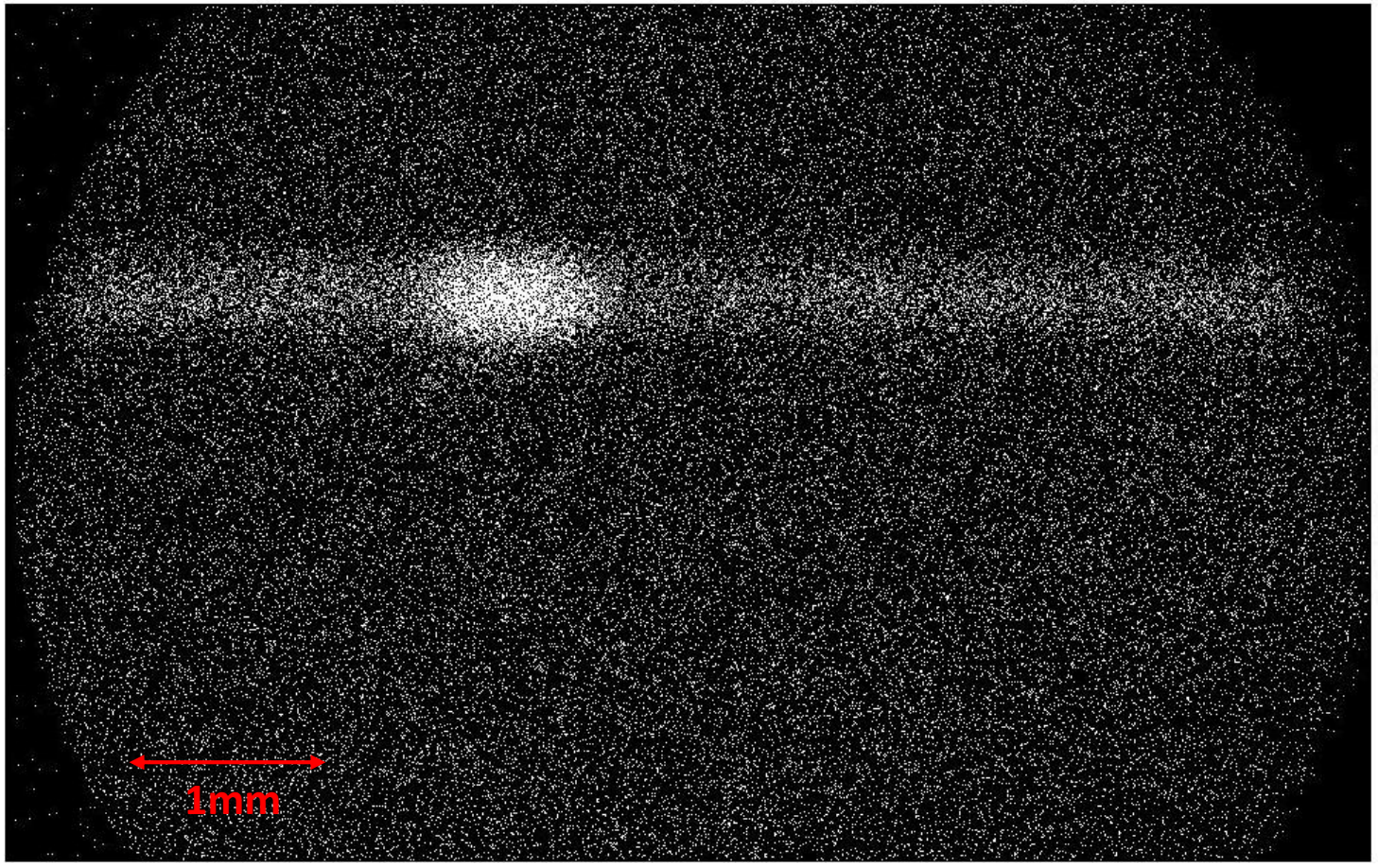
# NEG Initial Results

0.7x9mm 3rd skimmer

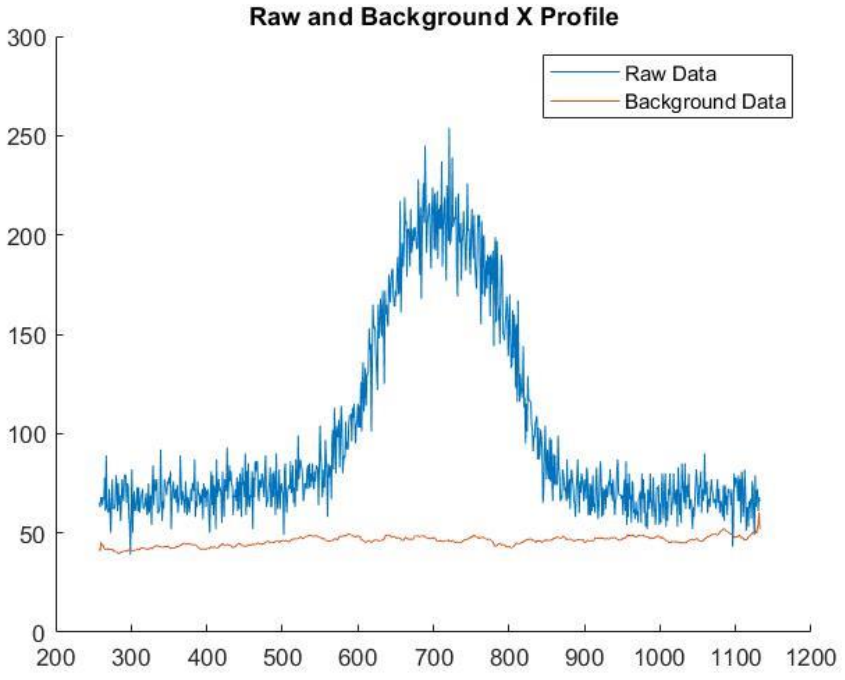
100s integration time

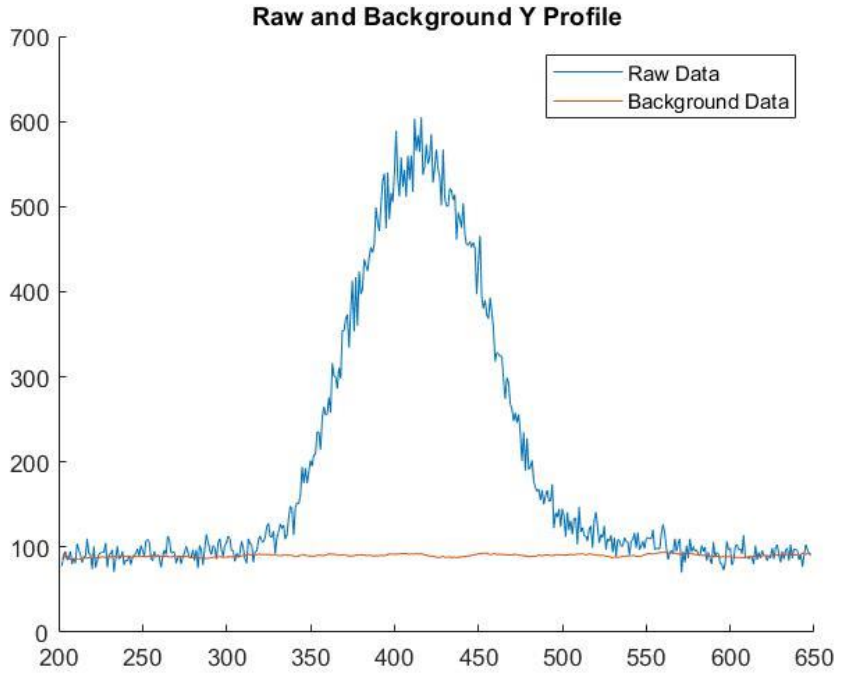
0.60mA E-gun Emission

N2 @ 5bar



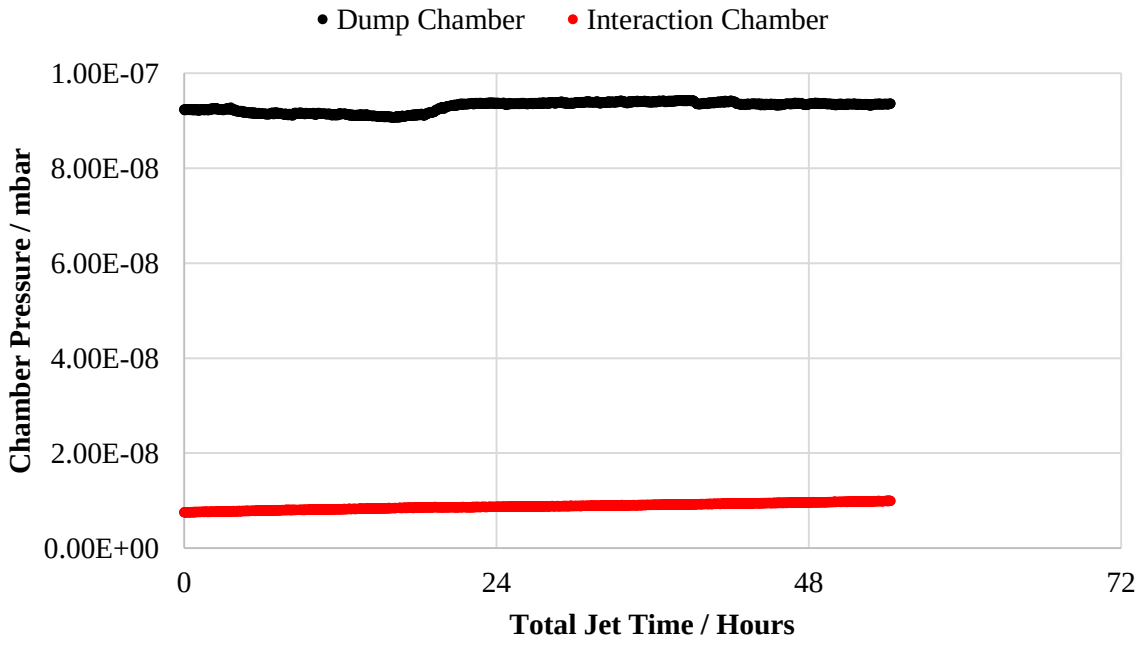
# NEG Beam Measurement

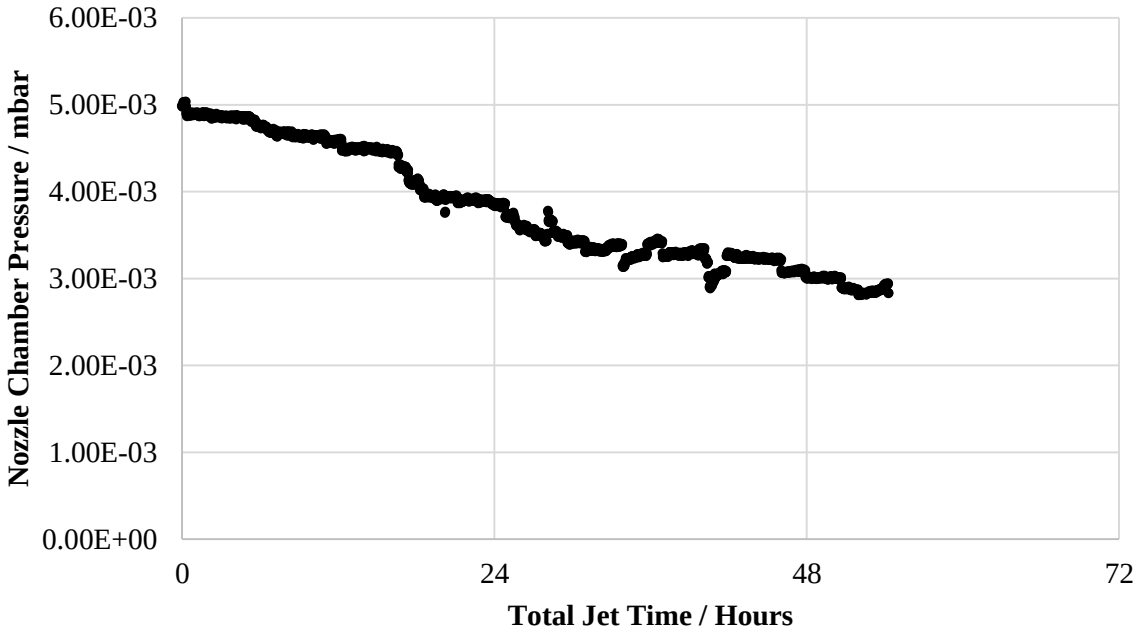



| | NEG | TMP |
|---|---|---|
| Photon Rate / $s^{-1}$ | 290 | ~300 |

# Dump, Interaction and Nozzle Chamber Pressures




Only 54 Hour Jet Time due to shipping time constraints.

Little to no noticeable change in Interaction and Dump chamber pressures over such a small time.

As with previous measurements, the Nozzle chamber appears to reduce again. Further evidence of a NEG independent trend.

# Future Pressure Tests

- Jet will be ran until pressure reaches a steady state and NEG can clearly be defined as saturated.
- More pressure data collected for NEG located in the interaction chamber.
- Pressure will be recorded with Jet for exclusively TMP pumping to observe nozzle chamber without a NEG installed.