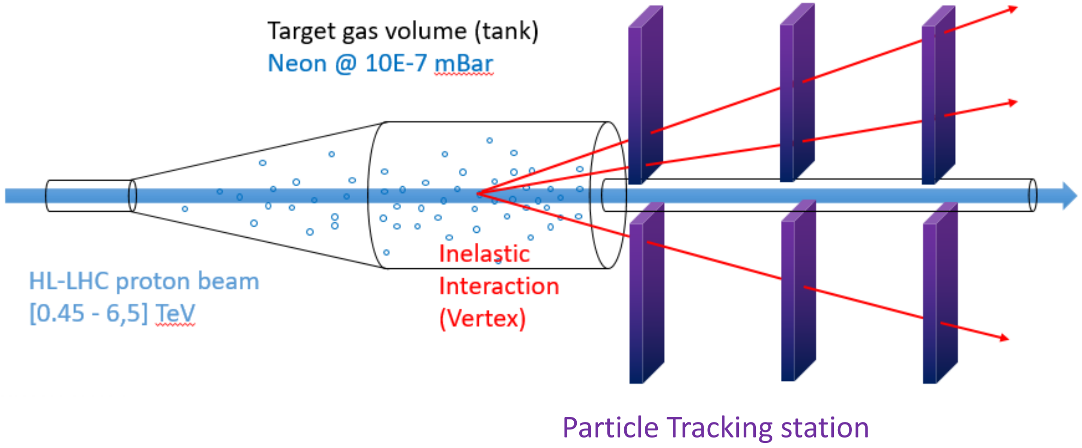
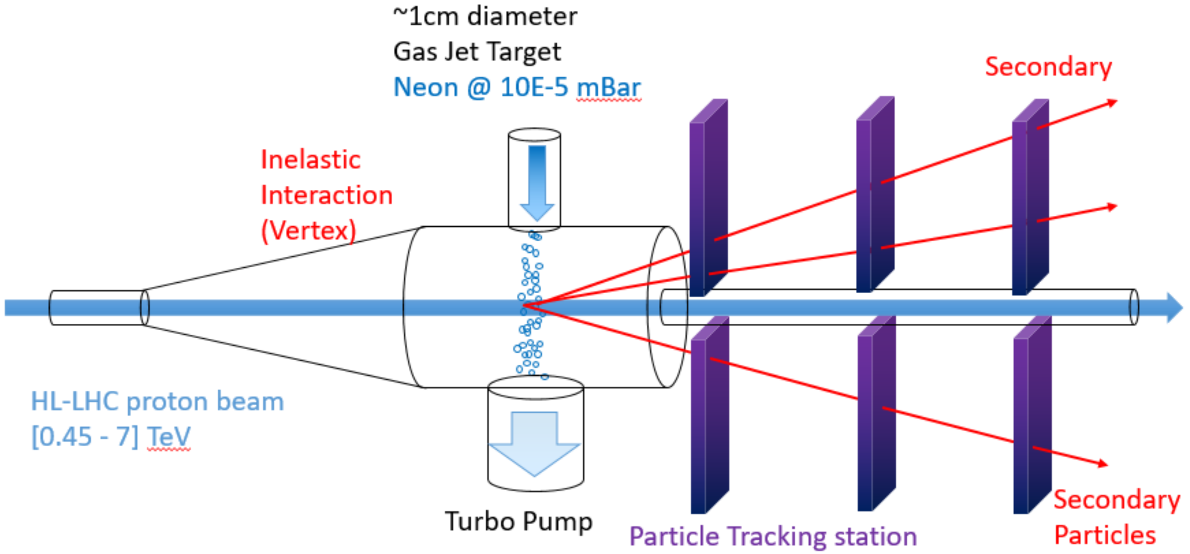
Alternative Gas Jet Creation for the BGV

R. Kersevan, TE-VSC-VSM

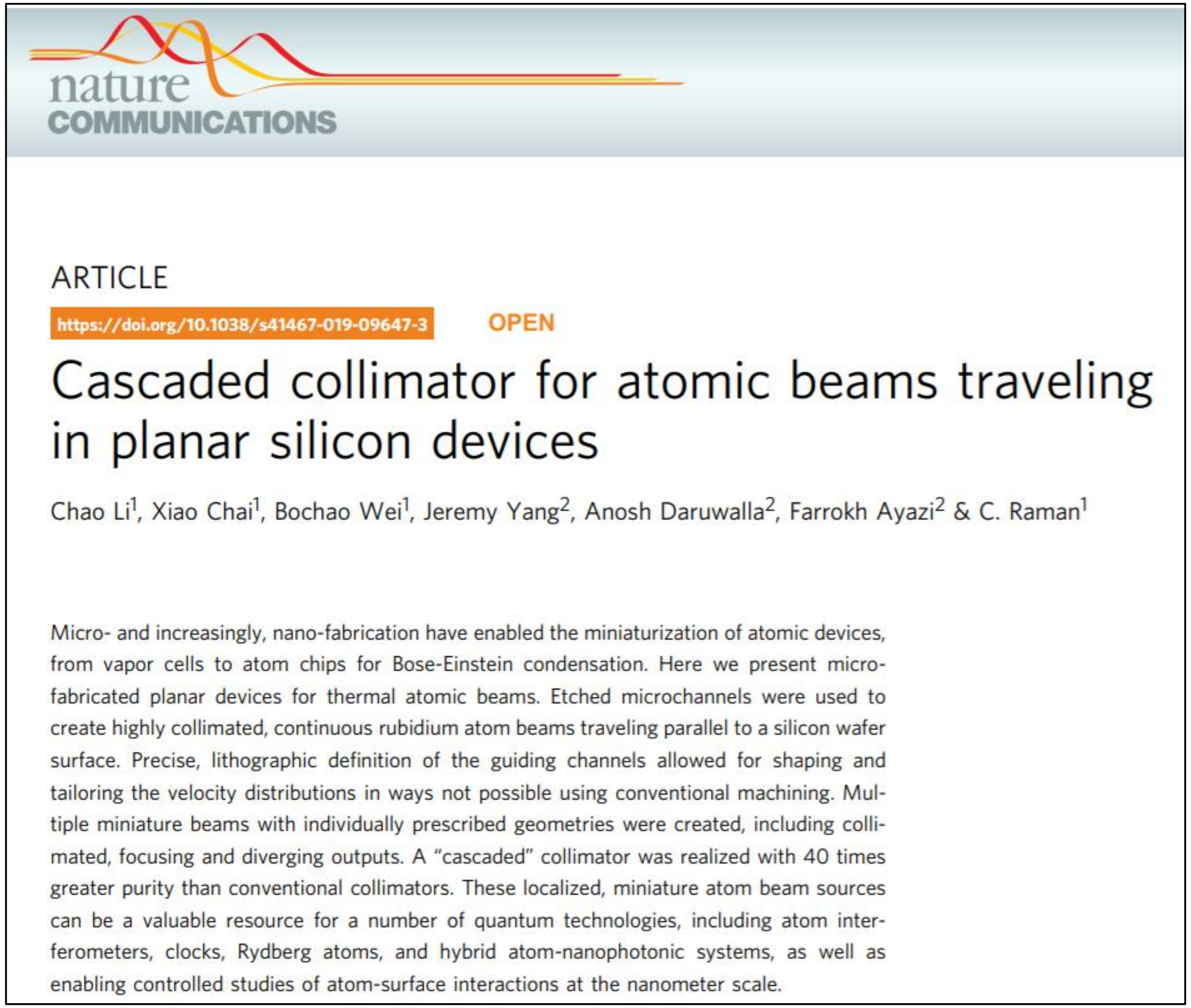
BGC Collaboration Meeting at CERN, Mon May 31st, 2020

- This short presentation gives some details about the ray-tracing montecarlo simulations performed on the existing BGV geometry, and the new one proposed
- Reference is made to the presentation “Beam Gas Vertex instruments for HL-LHC” by **R. Kieffer**, HL-LHC WP13 BI Meeting #3 of 2020, 10/2/2020, https://indico.cern.ch/event/881755/
- The idea is to go from this… → … to this, using a highly collimated **gas jet target**





- In particular it deals with the “optimized” BGV target, which could be obtained applying micro-mechanical manufacturing techniques, as described in https://doi.org/10.1038/s41467-019-09647-3



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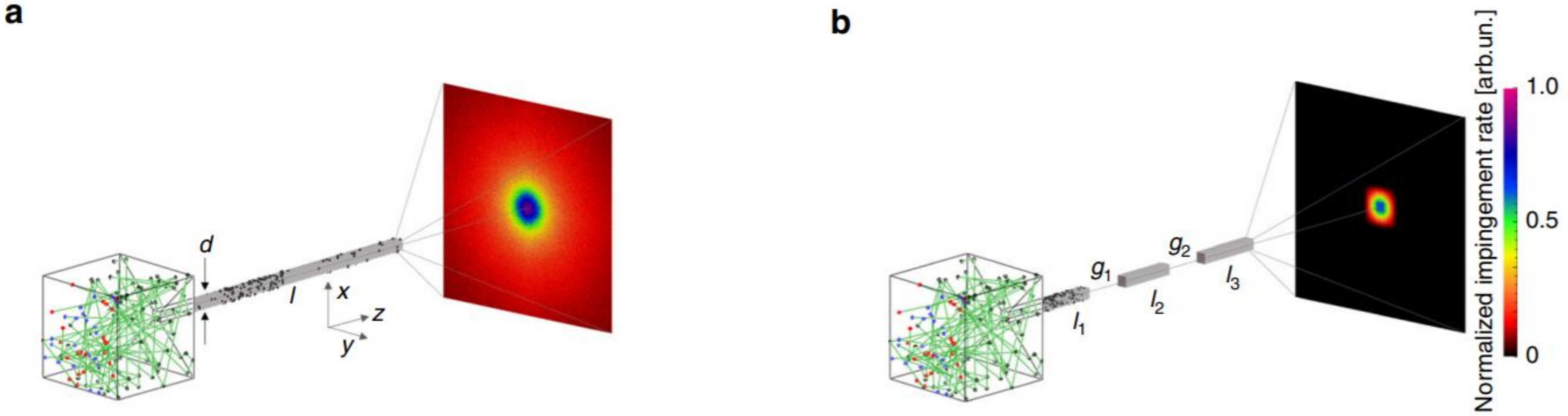
Cascaded collimator for atomic beams traveling in planar silicon devices

Chao Li[1], Xiao Chai[1], Bochao Wei[1], Jeremy Yang[2], Anosh Daruwalla[2], Farrokh Ayazi[2] & C. Raman[1]

Micro- and increasingly, nano-fabrication have enabled the miniaturization of atomic devices, from vapor cells to atom chips for Bose-Einstein condensation. Here we present micro-fabricated planar devices for thermal atomic beams. Etched microchannels were used to create highly collimated, continuous rubidium atom beams traveling parallel to a silicon wafer surface. Precise, lithographic definition of the guiding channels allowed for shaping and tailoring the velocity distributions in ways not possible using conventional machining. Multiple miniature beams with individually prescribed geometries were created, including collimated, focusing and diverging outputs. A “cascaded” collimator was realized with 40 times greater purity than conventional collimators. These localized, miniature atom beam sources can be a valuable resource for a number of quantum technologies, including atom interferometers, clocks, Rydberg atoms, and hybrid atom-nanophotonic systems, as well as enabling controlled studies of atom-surface interactions at the nanometer scale.

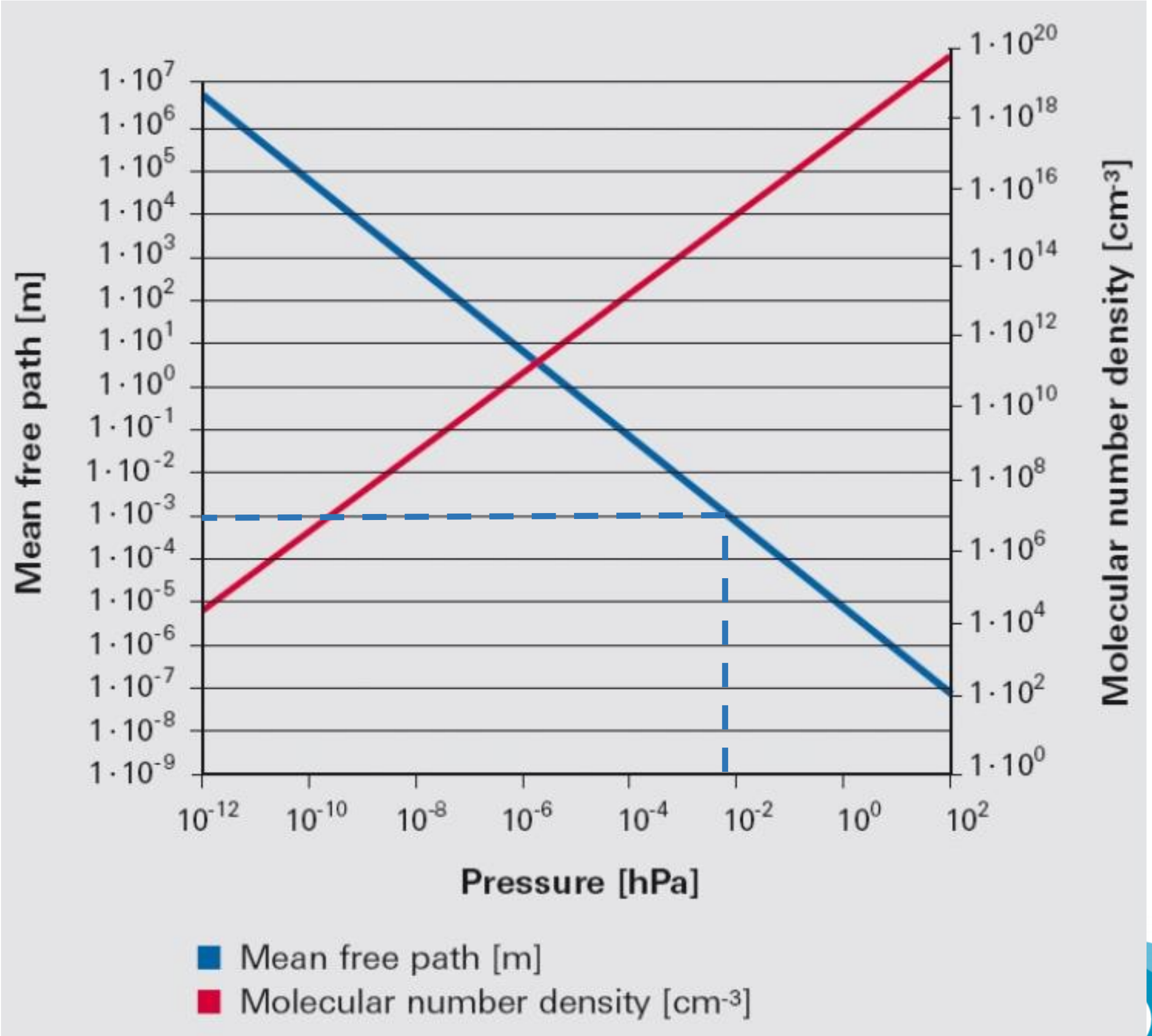
- What is the advantage of such a technology?
- Introduction: one tiny square channel only, with a high-pressure “reservoir” on one side, generates a **highly-directional molecular beam** (a); https://doi.org/10.1038/s41467-019-09647-3



- A similar configuration with 3 shorter channels separated by short “molecular sinks”, g_1 and g_2” (b): only the central part of the collimated (“**beamed**”) molecular flow reaches the exit of the 3rd tube; This configuration, called a “**cascaded collimator**”, helps reducing the background of the molecules effusing at a larger angle; **Even just one g_i may be sufficient**

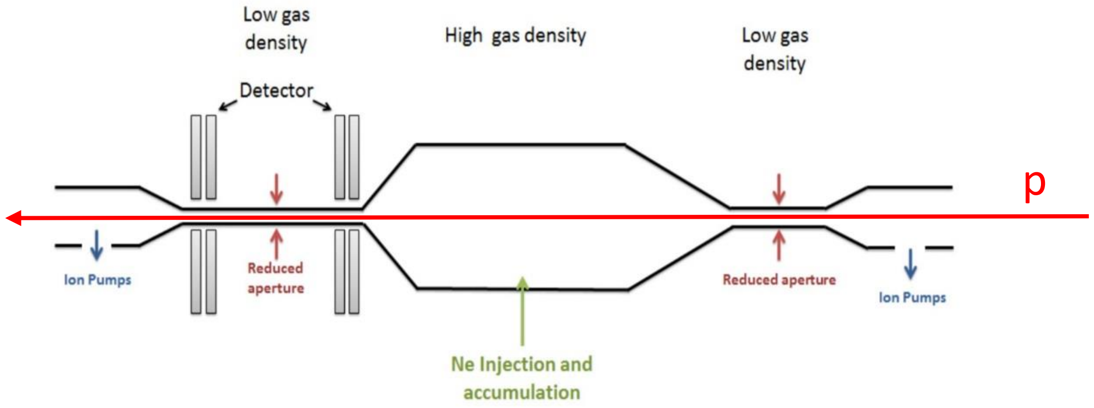
- Typical mean-free path and density variation as a function of pressure (1 hPa = 1 mbar)
- Molecular flow conditions, i.e. ~no inter-molecular collisions, prevail when MFP<< typical vacuum component size (e.g. diameter in a tube)

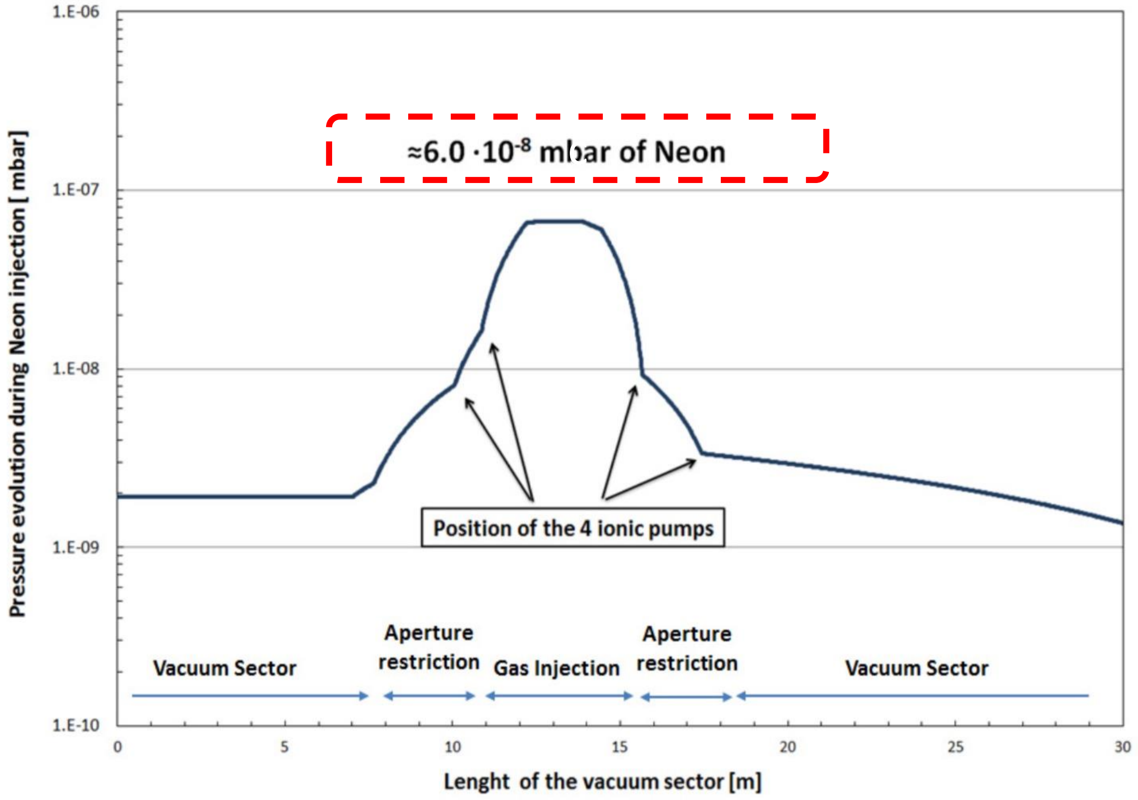
(Ref. “The Vacuum Technology Handbook”, Pfeiffer Vacuum)



- We see that for sub-mm cross-sections molecular flow takes place at pressure in the 10^{-3} mbar range and below

Courtesy R. Kieffer, personal comm.





P = 1E-7 [mBar] = 1E-6 [kg/m^2]

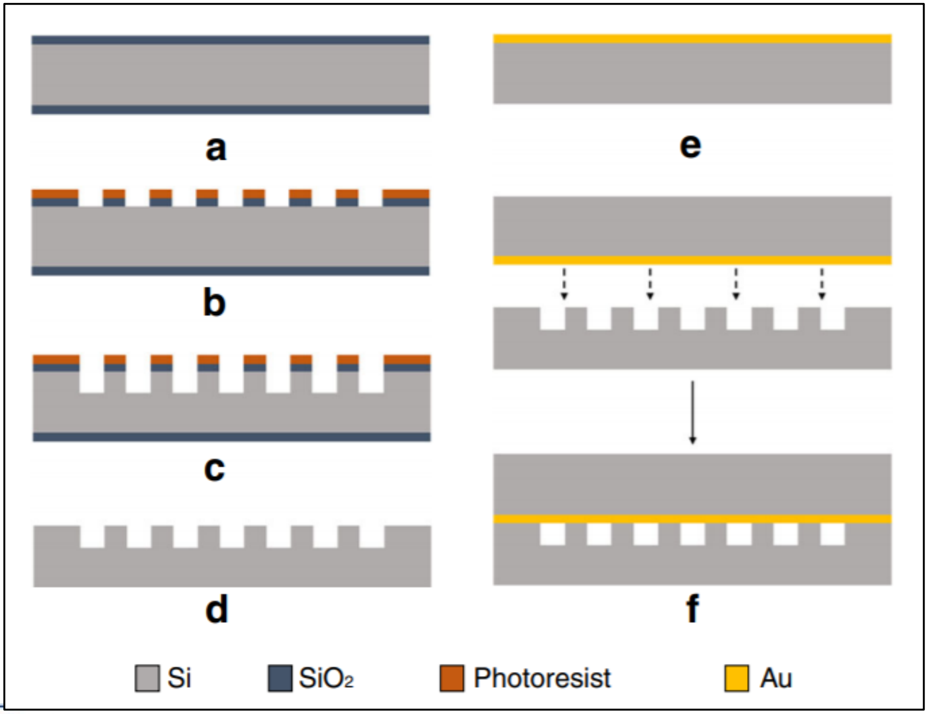
T =293 [K]

K$_b$=1.38E-23 [m^{2}kg . s^{-2} . K^{-1}]

Density = 2.47E15 [Ne/m^3] = 2.47E9 [Ne/cm^3]

Integrated density along the gas target of 200 cm : 4.94E11 [Ne/cm^2]

- Under molecular flow conditions and small channel dimensions, the total gas throughput may not be sufficient to guarantee the necessary **integrated path density** for the BGV; If we want to localize the proton-gas jet interaction along a distance of, say, 1 cm, then we need to have a much higher (~200x) molecular density as compared to the present ~2 m long BGV, so aiming at ~10^{-5} mbar range
- The solution is to be able to fabricate on a single Si substrate, a series of **highly parallel channels**:



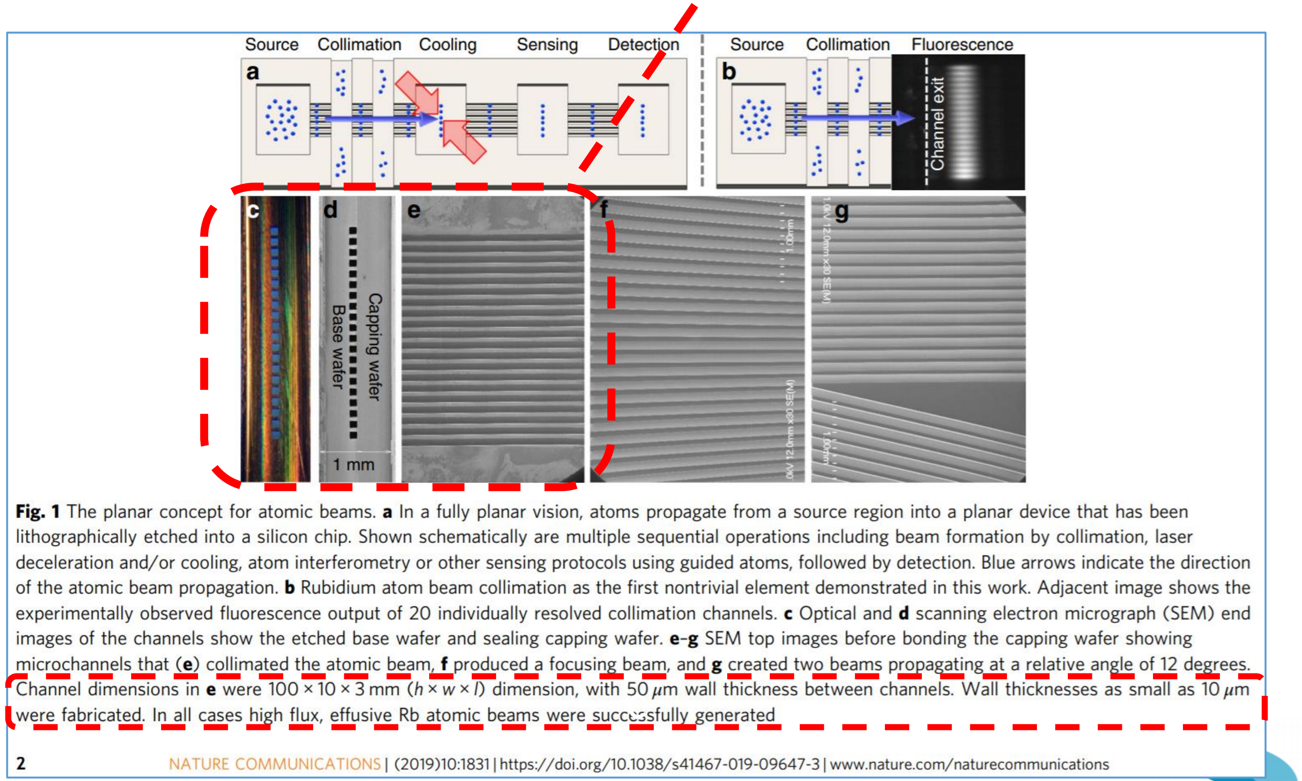


Fig. 1 The planar concept for atomic beams. **a** In a fully planar vision, atoms propagate from a source region into a planar device that has been lithographically etched into a silicon chip. Shown schematically are multiple sequential operations including beam formation by collimation, laser deceleration and/or cooling, atom interferometry or other sensing protocols using guided atoms, followed by detection. Blue arrows indicate the direction of the atomic beam propagation. **b** Rubidium atom beam collimation as the first nontrivial element demonstrated in this work. Adjacent image shows the experimentally observed fluorescence output of 20 individually resolved collimation channels. **c** Optical and **d** scanning electron micrograph (SEM) end images of the channels show the etched base wafer and sealing capping wafer. **e**–**g** SEM top images before bonding the capping wafer showing microchannels that (**e**) collimated the atomic beam, **f** produced a focusing beam, and **g** created two beams propagating at a relative angle of 12 degrees. Channel dimensions in **e** were 100 × 10 × 3 mm ($h \times w \times l$) dimension, with 50 μm wall thickness between channels. Wall thicknesses as small as 10 μm were fabricated. In all cases high flux, effusive Rb atomic beams were successfully generated

2 NATURE COMMUNICATIONS | (2019)10:1831 | https://doi.org/10.1038/s41467-019-09647-3 | www.nature.com/naturecommunications

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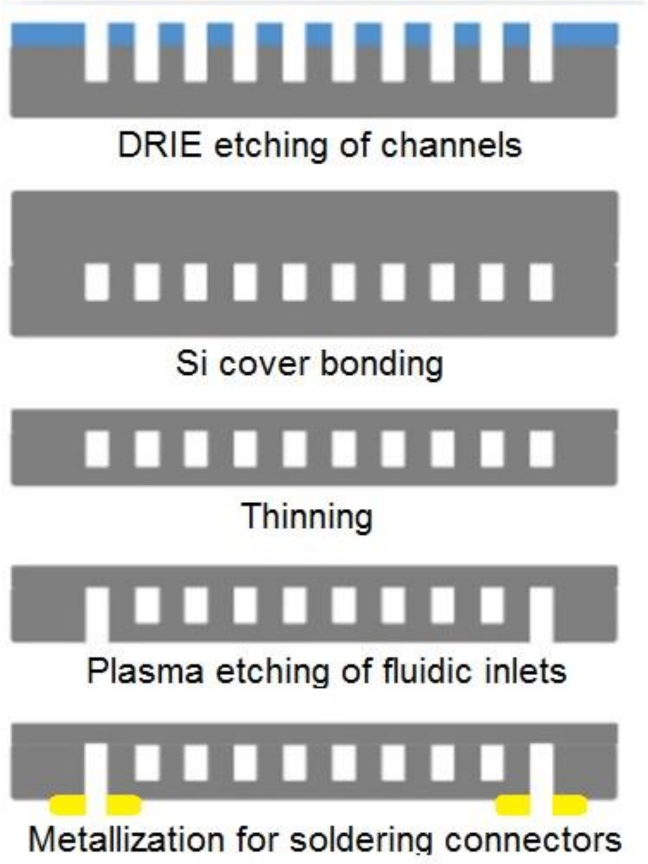
Similar example: microfabrication of cooling plates

(courtesy R. Kieffer, personal comm.)



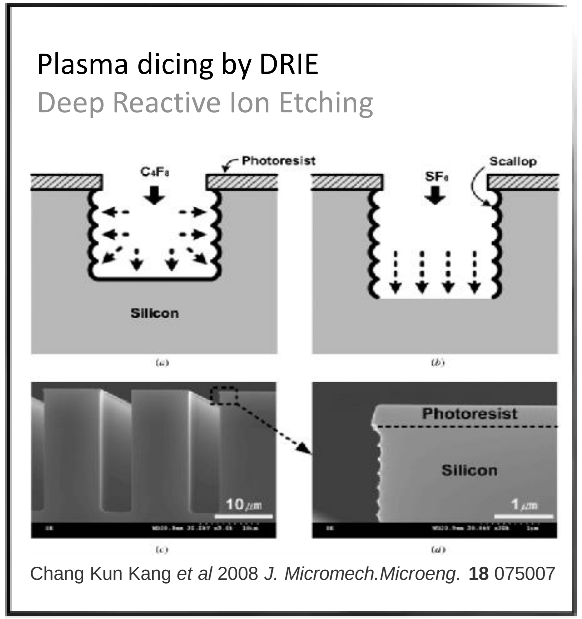
DRIE etching of channels

Si cover bonding

Thinning

Plasma etching of fluidic inlets

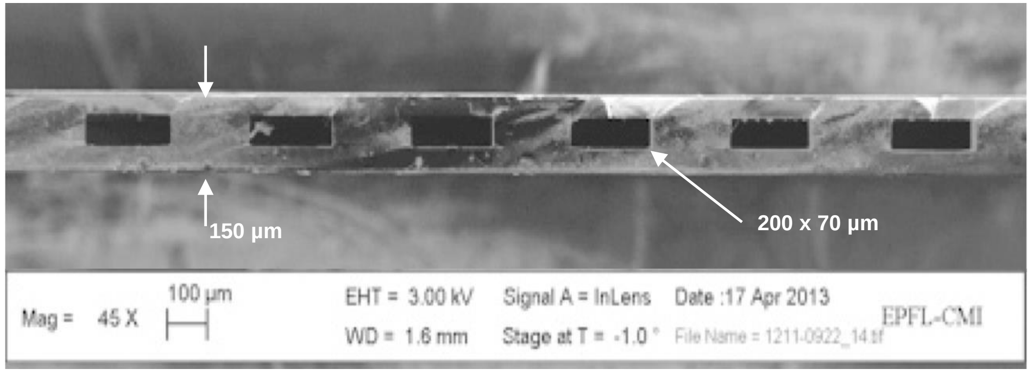
Metallization for soldering connectors

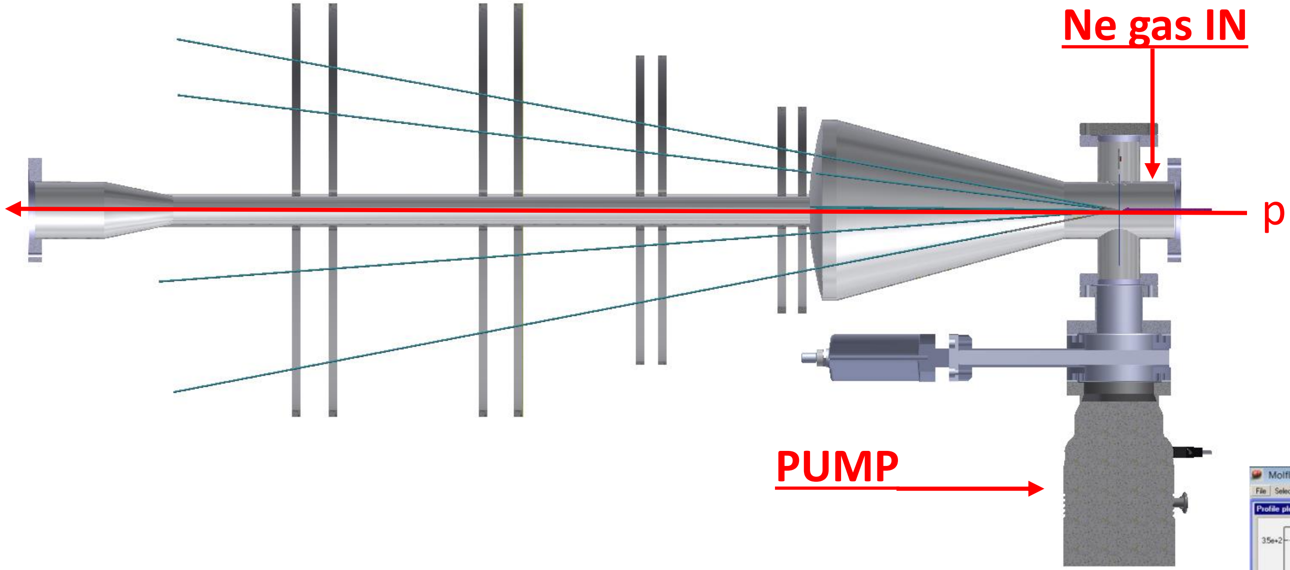


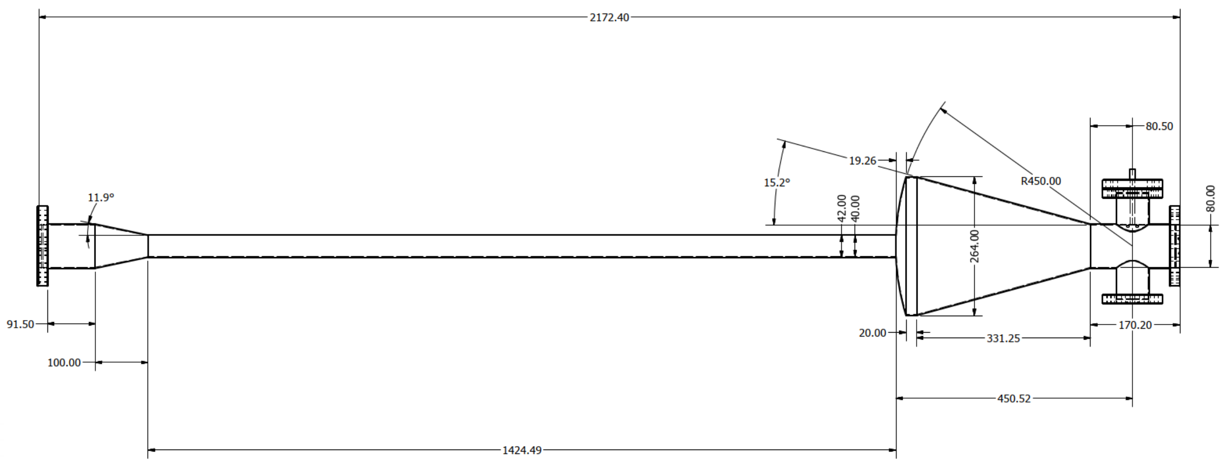
Plasma dicing by DRIE

Deep Reactive Ion Etching

Chang Kun Kang *et al* 2008 *J. Micromech.Microeng.* **18** 075007

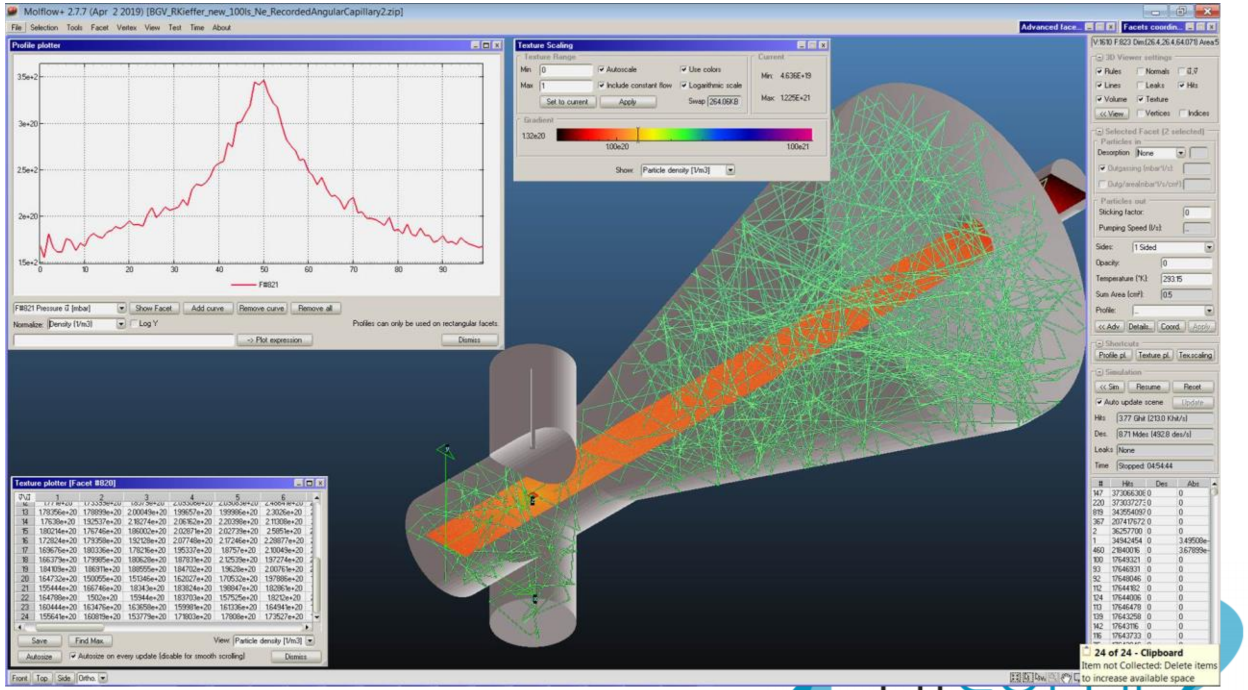




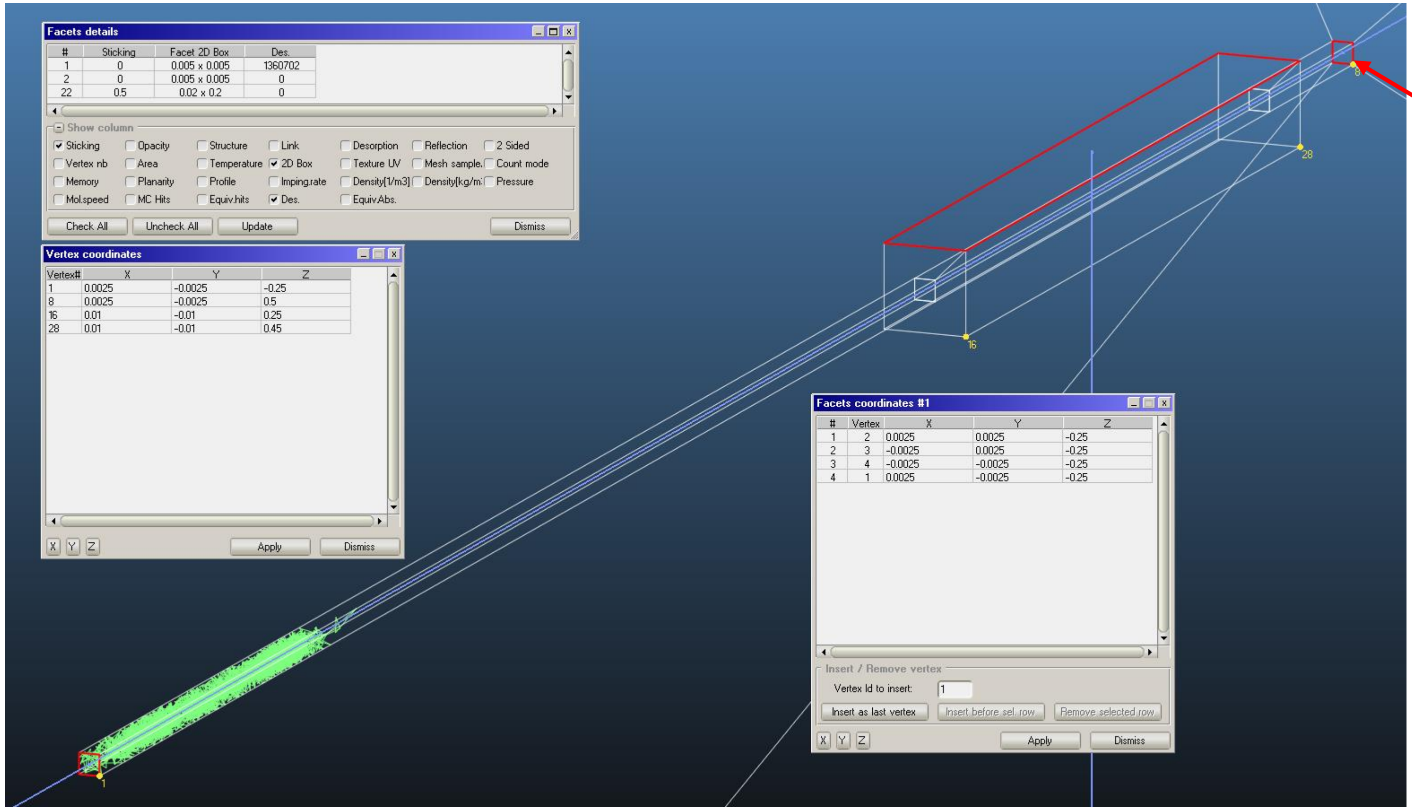


- CAD model and 2D drawing for the “optimized” high-density cascaded collimator gas injection system (left)

- View of one Molflow+ ray-tracing simulation for the same geometry (below); In the inset the well-collimated angular distribution at the beam position



- Molflow+ simulation: 1st step is to generate angular distribution at exit of one 50x50 μm^2 tube, made up of one initial section of 0.5 mm-long, then one bigger pumping space (pumping prob.= 50%) 0.2 mm-long, and then finally o short square tube 0.05 mm-long (left);


Facets details

#	Sticking	Facet 2D Box	Des.
1	0	0.005 x 0.005	1360702
2	0	0.005 x 0.005	0
22	0.5	0.02 x 0.2	0

Show column

☑ Sticking	☐ Opacity	☐ Structure	☐ Link	☐ Desorption	☐ Reflection	☐ 2 Sided
☐ Vertex nb	☐ Area	☐ Temperature	☑ 2D Box	☐ Texture UV	☐ Mesh sample.	☐ Count mode
☐ Memory	☐ Planarity	☐ Profile	☐ Imping.rate	☐ Density[1/m3]	☐ Density[kg/m	☐ Pressure
☐ Mol.speed	☐ MC Hits	☐ Equiv.hits	☑ Des.	☐ Equiv.Abs.		

Vertex coordinates

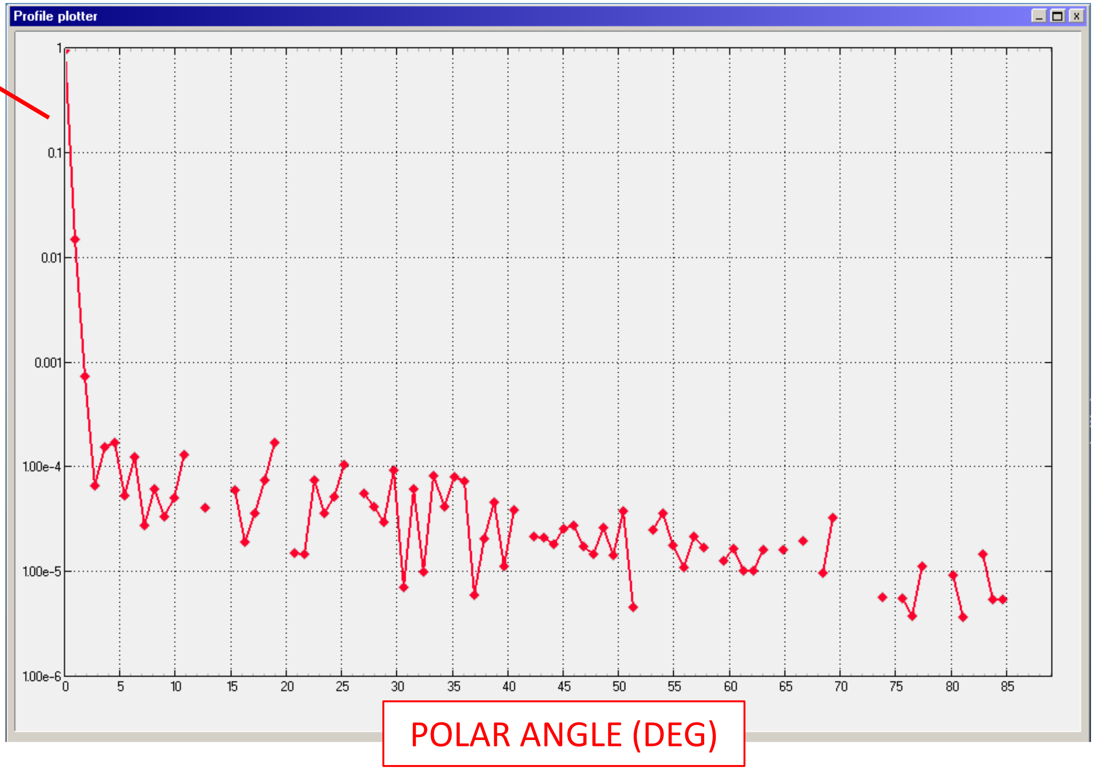
Vertex#	X	Y	Z
1	0.0025	-0.0025	-0.25
8	0.0025	-0.0025	0.5
16	0.01	-0.01	0.25
28	0.01	-0.01	0.45

Facets coordinates #1

#	Vertex	X	Y	Z
1	2	0.0025	0.0025	-0.25
2	3	-0.0025	0.0025	-0.25
3	4	-0.0025	-0.0025	-0.25
4	1	0.0025	-0.0025	-0.25

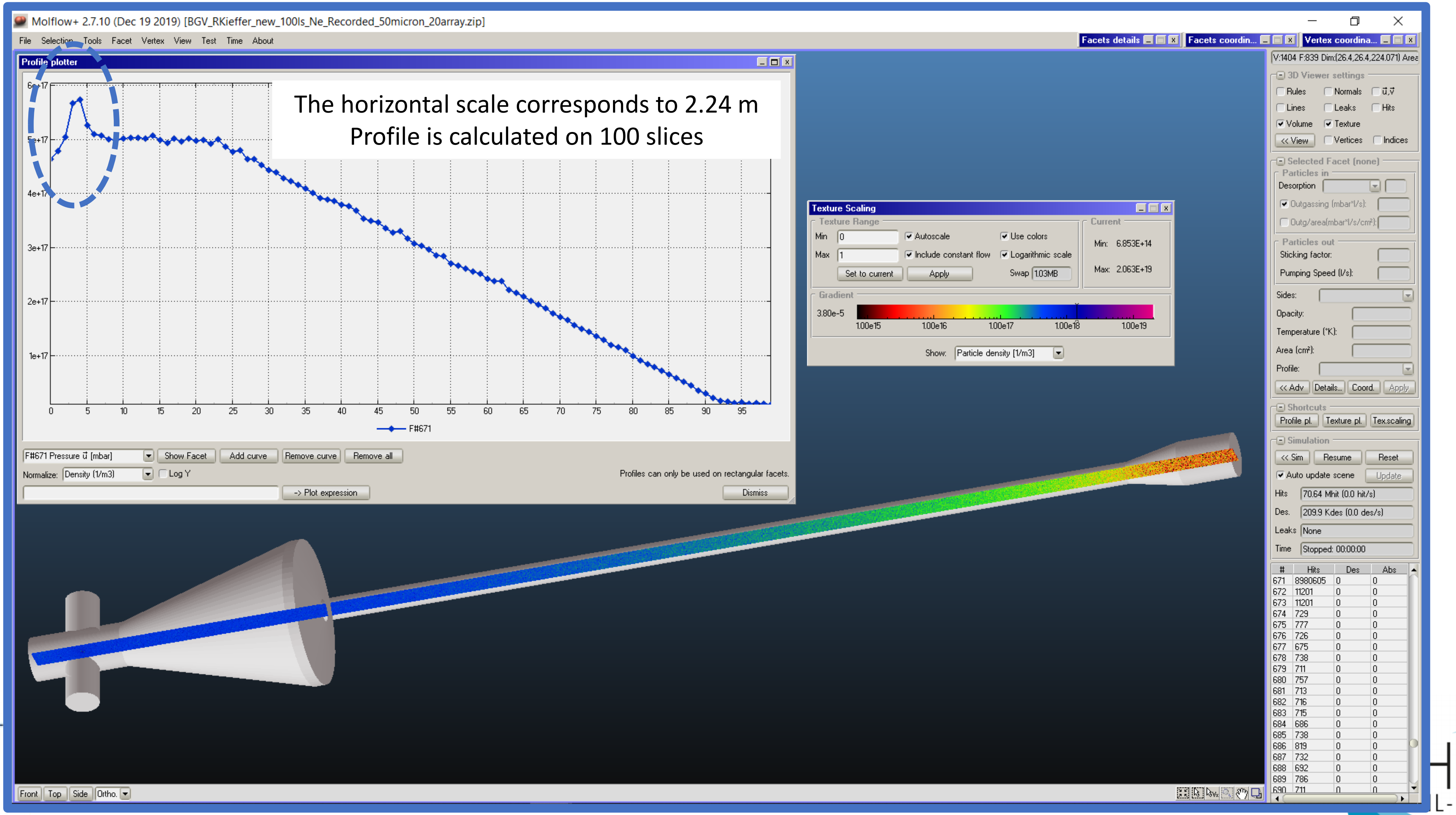
Insert / Remove vertex

Vertex Id to insert: 1



- The angular plot at the exit (right) shows that the molecular beam is contained within +/-2°
- 2° angular divergence corresponds to ~2.9 mm across the 80 mm tube, towards the pump

- The peak in front of the 20-channel gas injection array is underestimated in this plot, since the bin size (224/100=2.24 cm) is far too big compared to the axial width of the injected Ne, which is only ~ +/- 0.1 mm FWHM (see next slide)



The horizontal scale corresponds to 2.24 m
Profile is calculated on 100 slices

Molflow+ 2.7.10 (Dec 19 2019) [BGV_RKieffer_new_100ls_Ne_Recorded_50micron_20array.zip]

V:1404 F:839 Dim:(26.4,26.4,224.071) Area

3D Viewer settings: ☐ Rules ☐ Normals ☐ $\vec{u},\vec{v}$ ☐ Lines ☐ Leaks ☐ Hits ☑ Volume ☑ Texture ☐ Vertices ☐ Indices

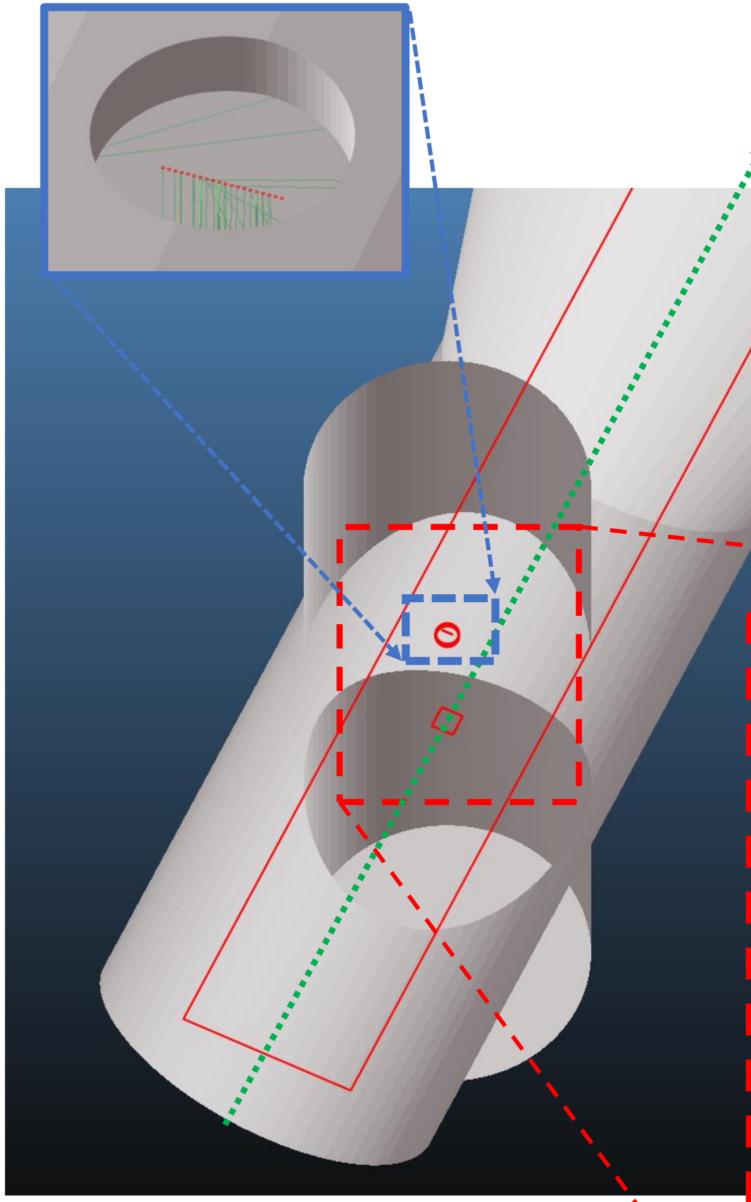
Selected Facet (none)
☑ Outgassing (mbar*l/s):
☐ Outg/area(mbar*l/s/cm²):

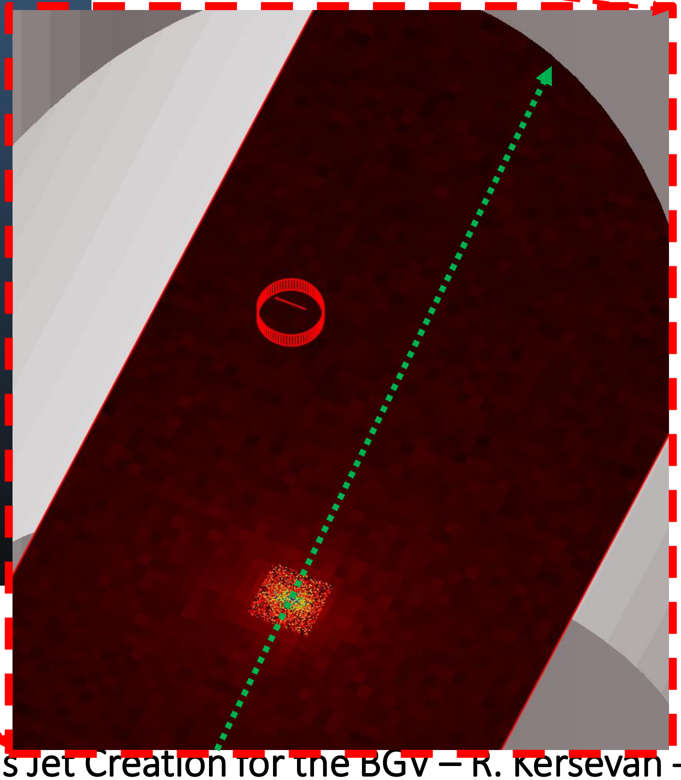
Simulation: ☑ Auto update scene
Hits: 70.64 Mhit (0.0 hit/s)
Des.: 209.9 Kdes (0.0 des/s)
Leaks: None
Time: Stopped: 00:00:00

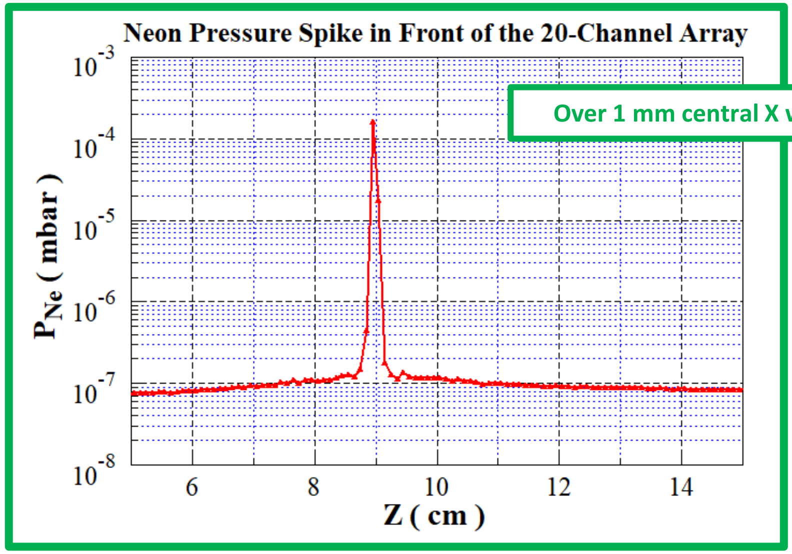
#	Hits	Des	Abs
671	8980605	0	0
672	11201	0	0
673	11201	0	0
674	729	0	0
675	777	0	0
676	726	0	0
677	675	0	0
678	738	0	0
679	711	0	0
680	757	0	0
681	713	0	0
682	716	0	0
683	715	0	0
684	686	0	0
685	738	0	0
686	819	0	0
687	732	0	0
688	692	0	0
689	786	0	0
690	711	0	0

Texture Scaling
Texture Range: Min 0, Max 1, ☑ Autoscale ☑ Include constant flow ☑ Use colors ☑ Logarithmic scale, Swap 1.03MB
Current: Min: 6.853E+14, Max: 2.063E+19
Gradient: 3.80e-5
Show: Particle density [1/m3]

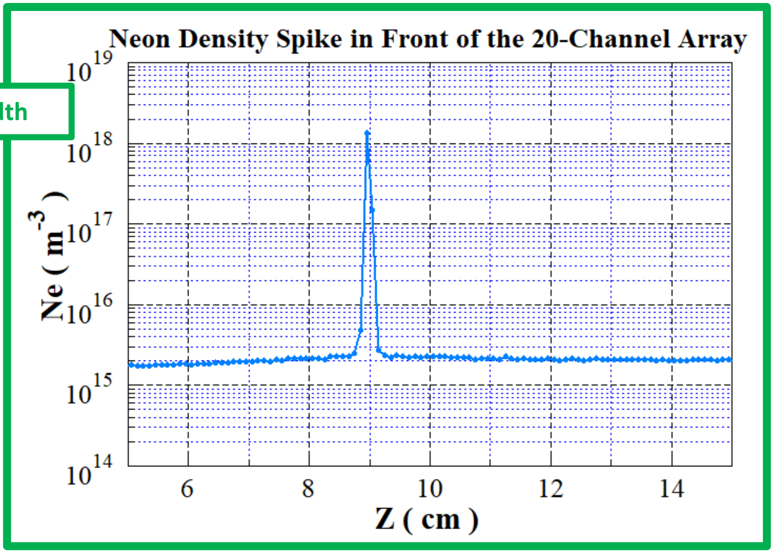
Profile plotter: F#671 Pressure $\vec{u}$ [mbar], Normalize: Density (1/m3), ☐ Log Y
Profiles can only be used on rectangular facets.

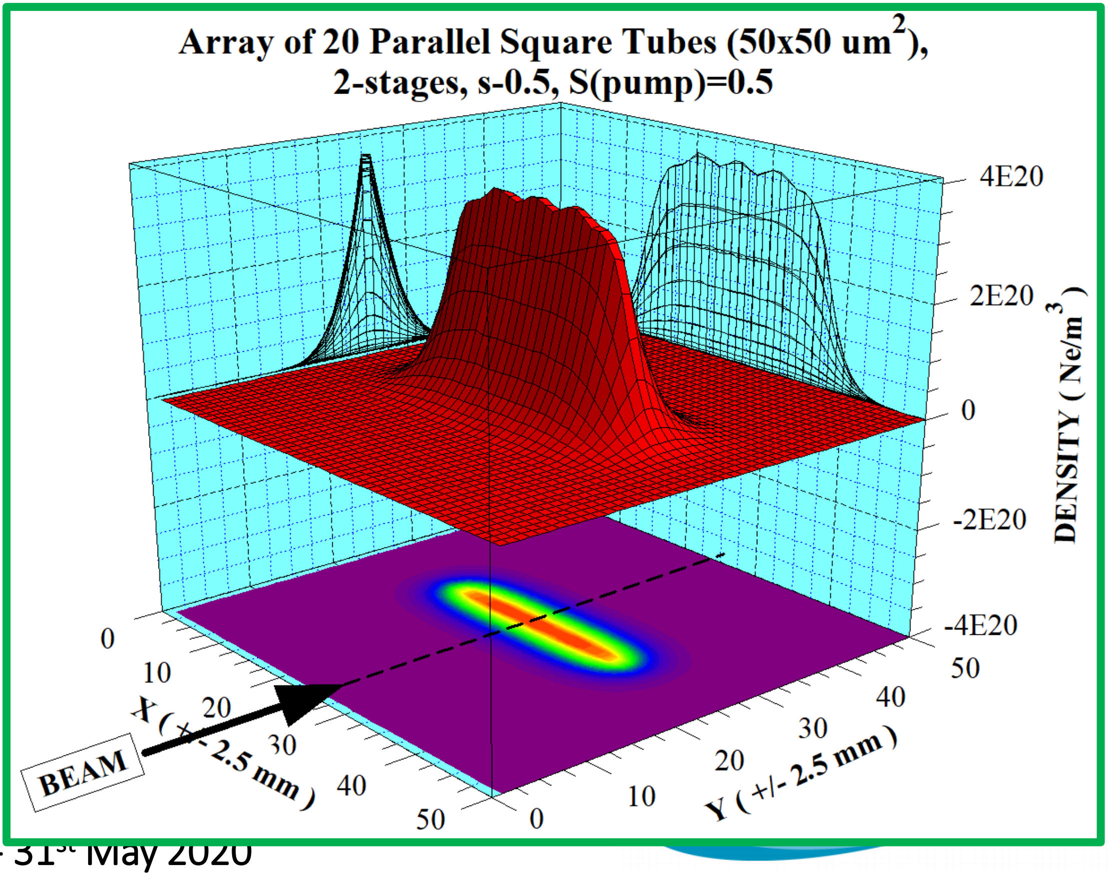






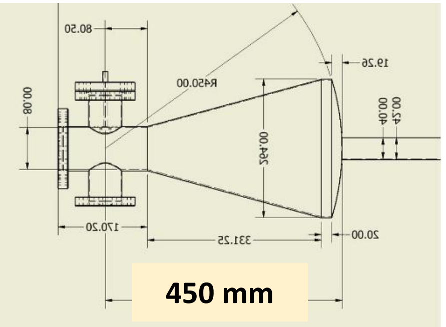
Over 1 mm central X width

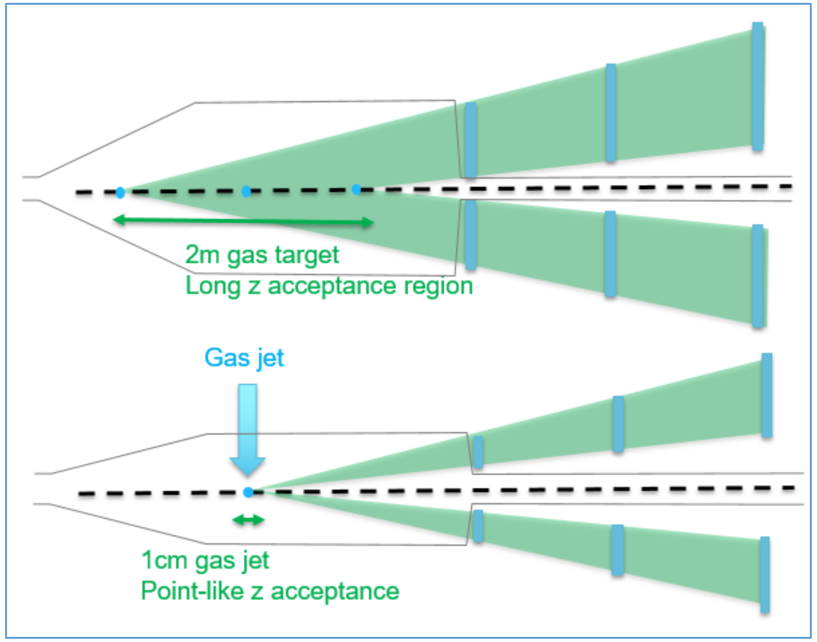




Summary and future developments

- A new model, with a very collimated cascaded capillary array has been proposed
- It has been shown, via ray-tracing MC simulations, that such a configuration has the advantage of allowing the creation of a ~3 orders of magnitude localized density spike, which in turn would allow a better vertex localization, with a thinner exit window





- Further modelling needs to be carried out in order to evaluate the contribution of the p-Ne interactions along the 450 mm-long conical plenum
- A collaboration with a laboratory where the silicon array can be manufactured needs to be established (as far as I know it was EPFL when R. Kieffer was on the project)