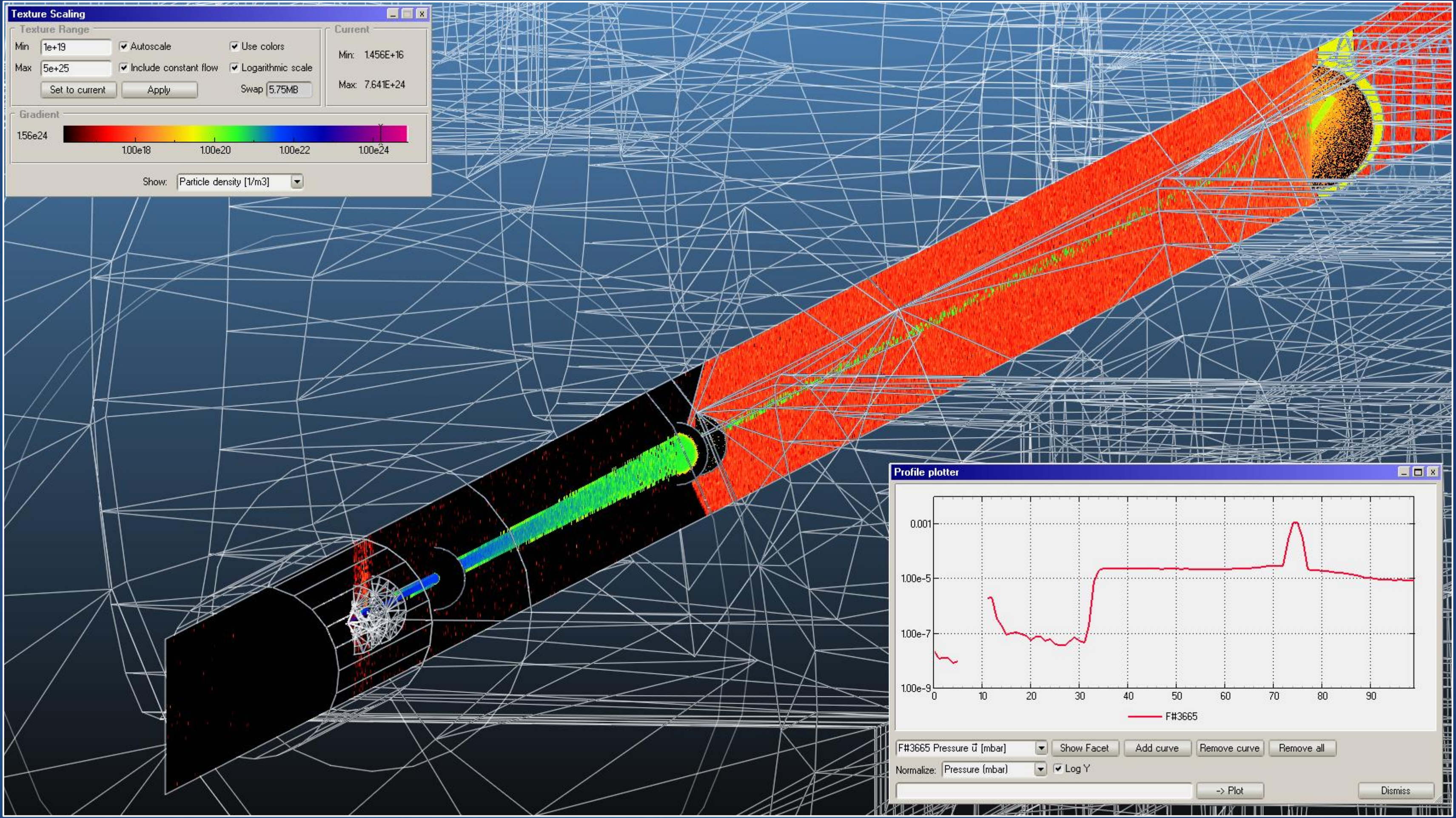
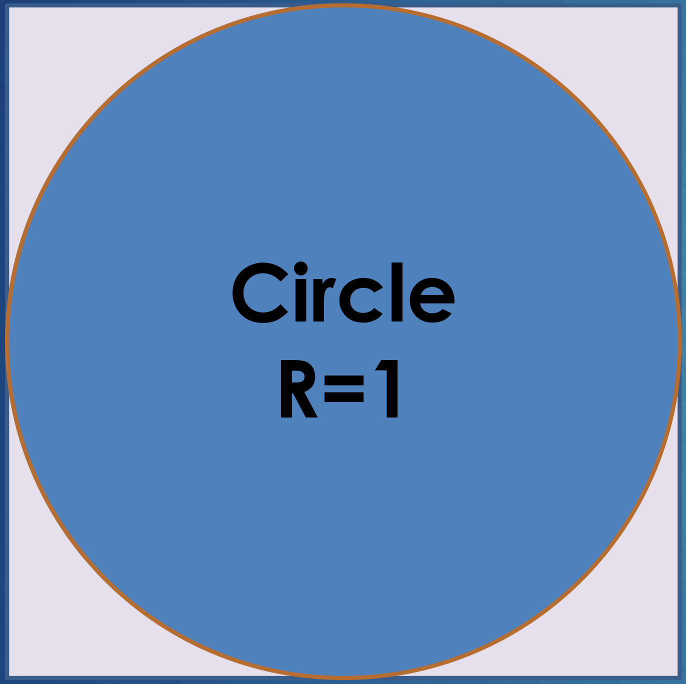
Gas jet simulations



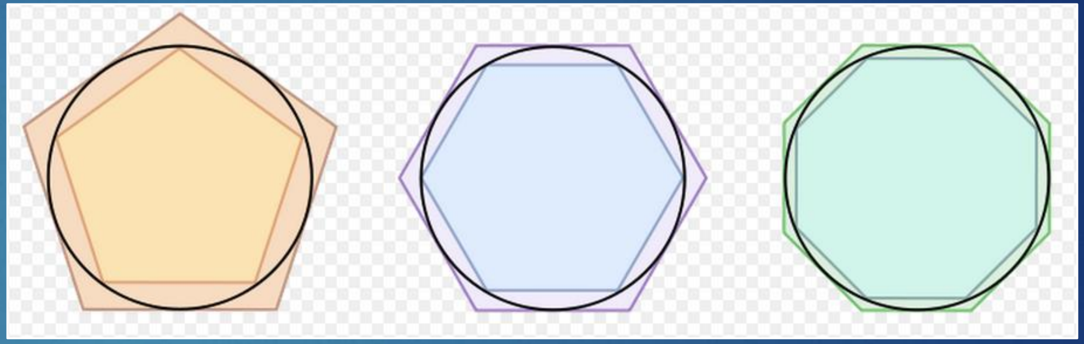
Marton ADY

Cockroft Institute, 27/06/2017

Part 1: Monte Carlo intro



Area=3.14

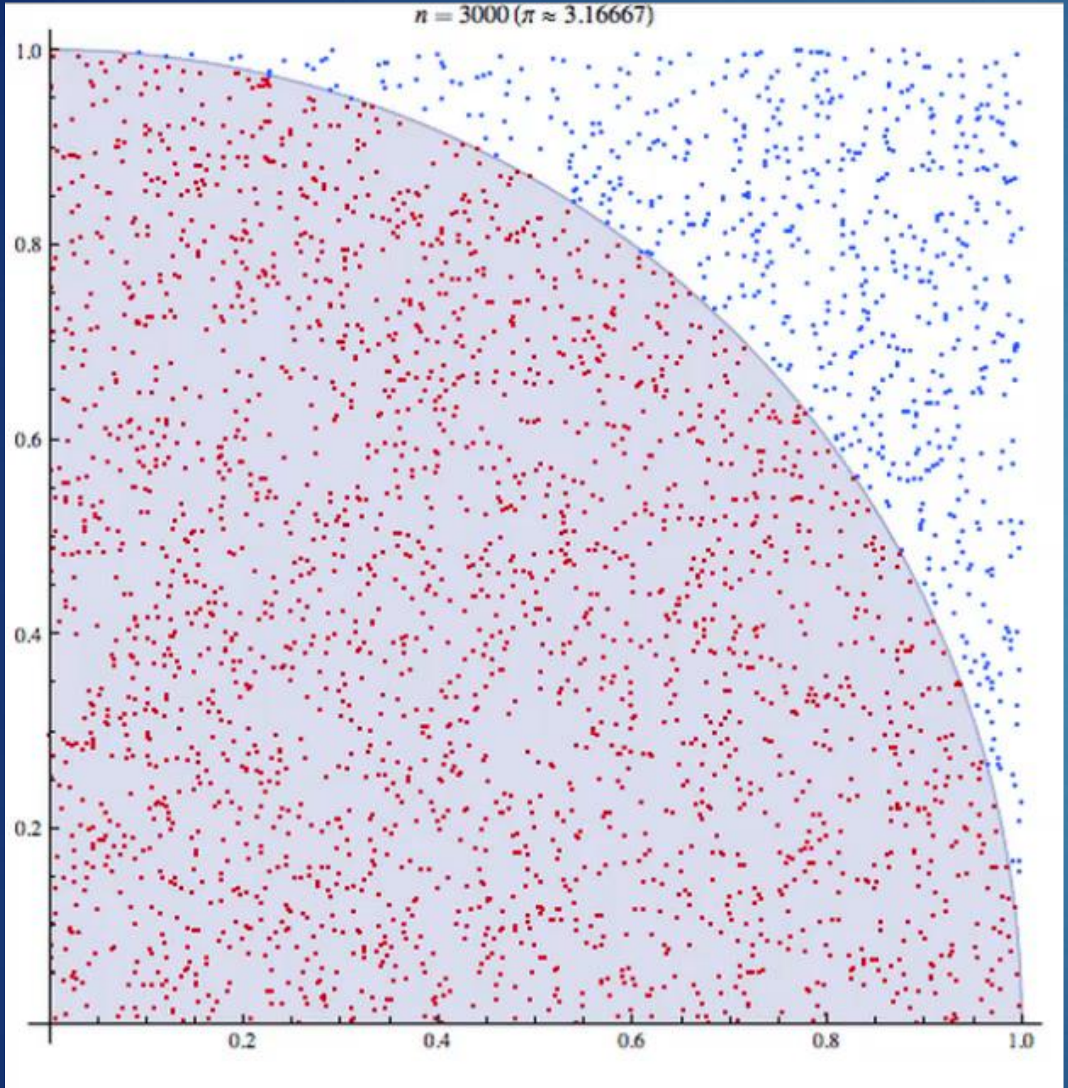


$$\pi = \cfrac{4}{1 + \cfrac{1^2}{2 + \cfrac{3^2}{2 + \cfrac{5^2}{2 + \cfrac{7^2}{2 + \cfrac{9^2}{2 + \ddots}}}}}}$$

$$\frac{1}{\pi} = \frac{2\sqrt{2}}{9801} \sum_{k=0}^{\infty} \frac{(4k)!(1103 + 26390k)}{(k!)^4 396^{4k}}$$

$$\frac{2}{\pi} = \frac{\sqrt{2}}{2} \cdot \frac{\sqrt{2+\sqrt{2}}}{2} \cdot \frac{\sqrt{2+\sqrt{2+\sqrt{2}}}}{2} \cdots$$

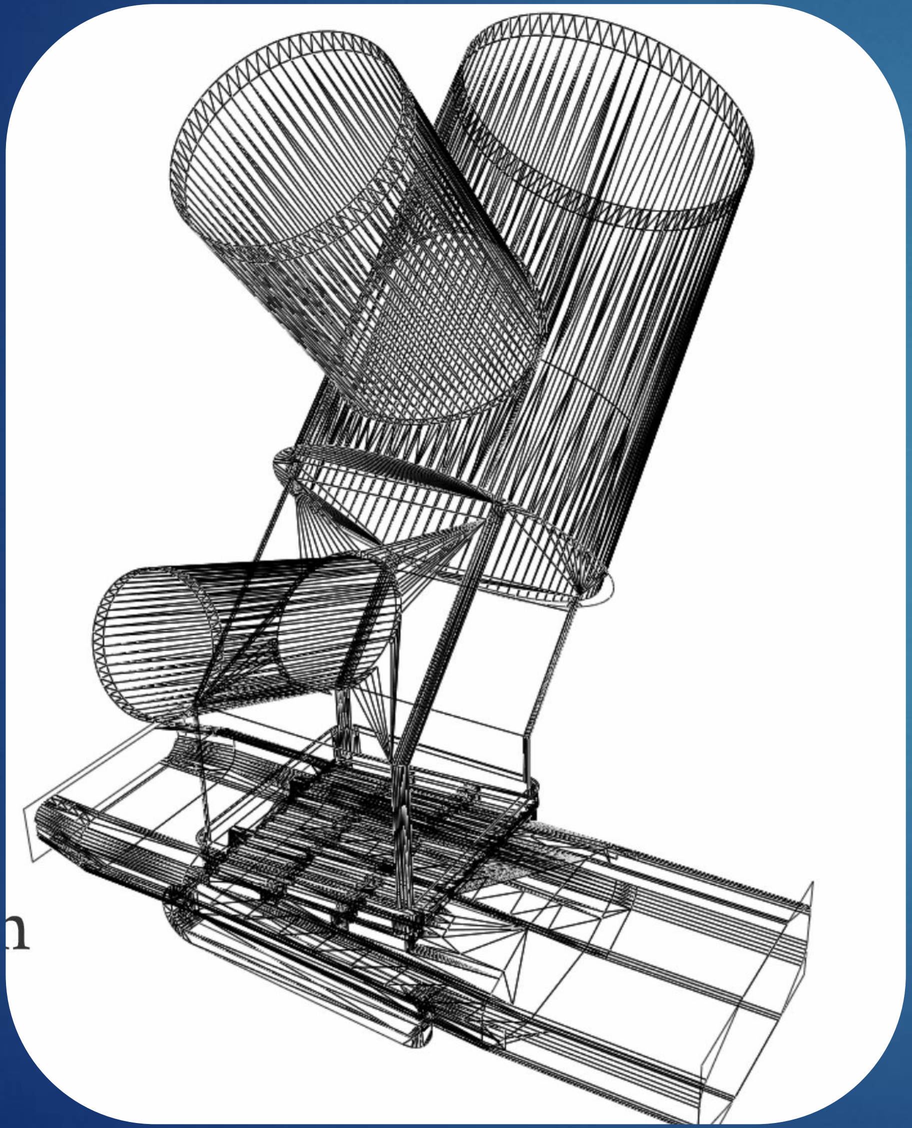
Monte Carlo



$$\frac{\text{points inside}}{\text{all points}} \sim \frac{\text{circle area}}{\text{square area}} = \frac{\pi}{4}$$

Monte Carlo simulations

Geometry: polygons



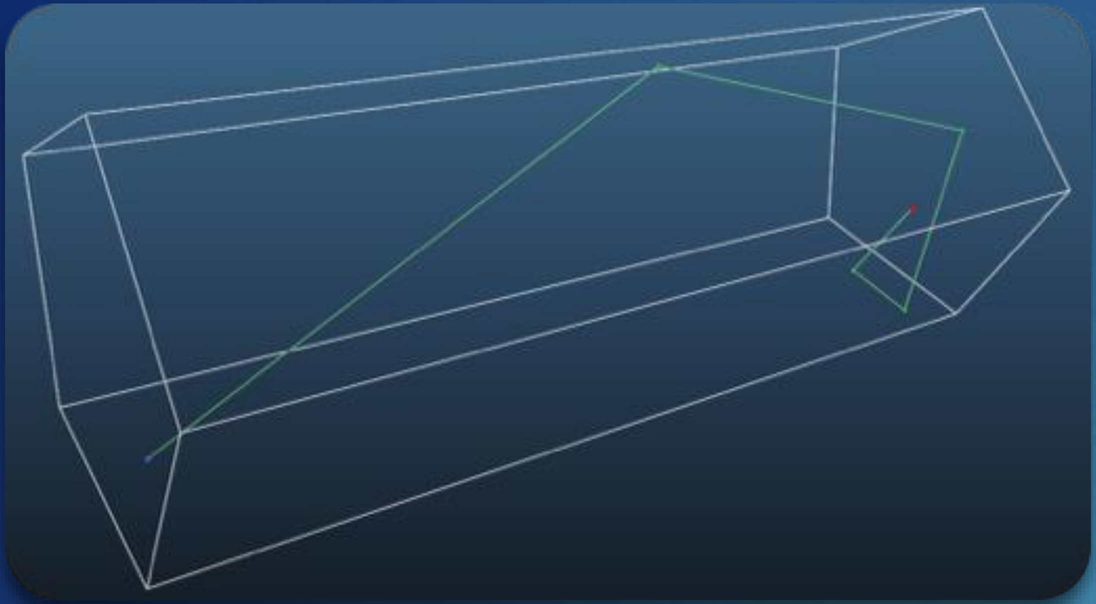
Gas input:

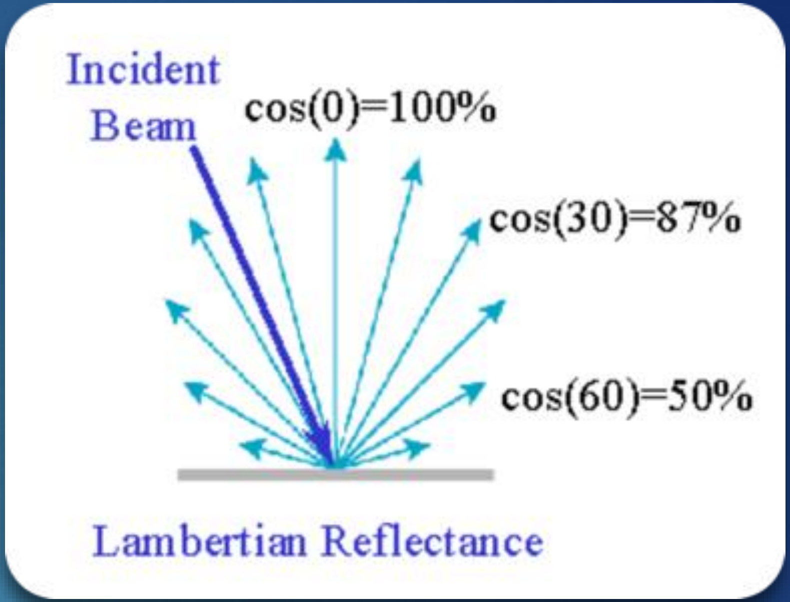
pV=NkT

1 Pa*m^3/s = 2.4*10^{20} molecules/s

Virtual / Physical particle ratio

Reflection

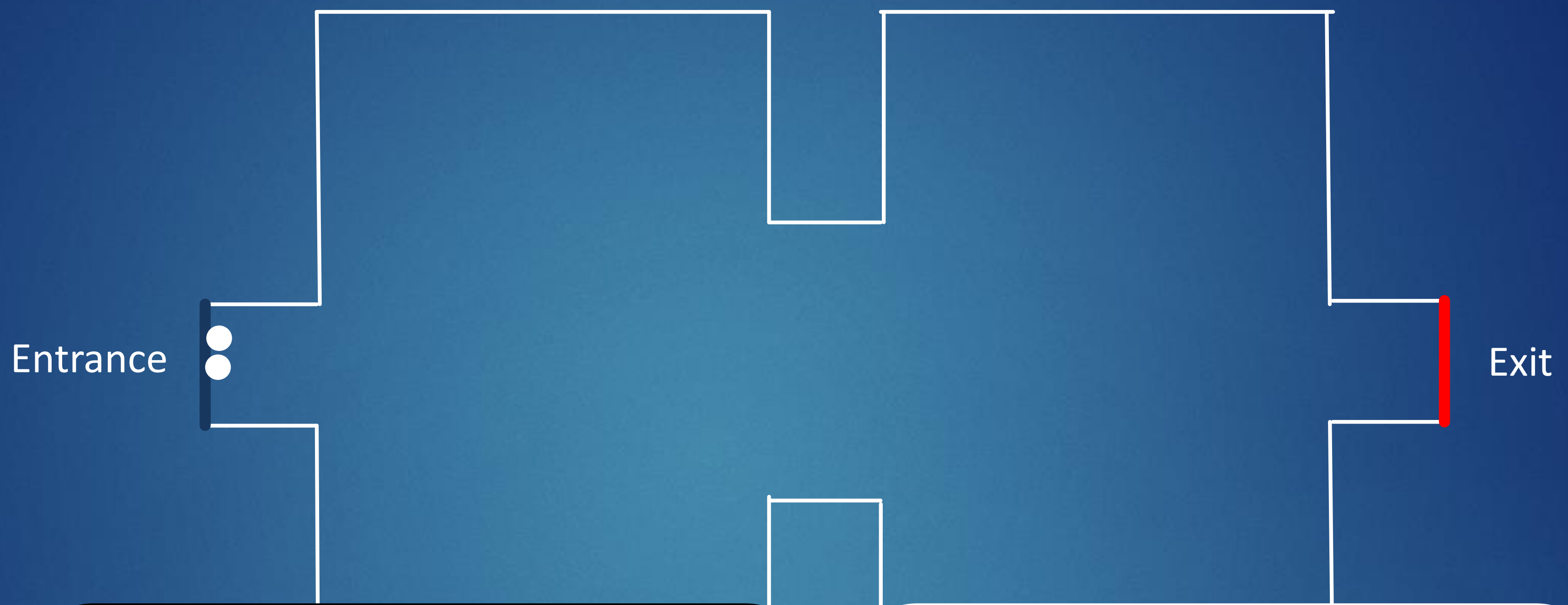


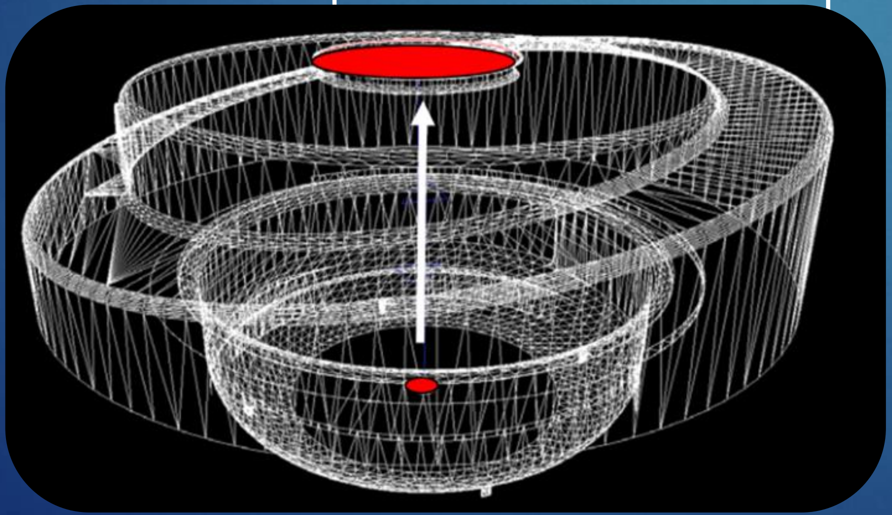


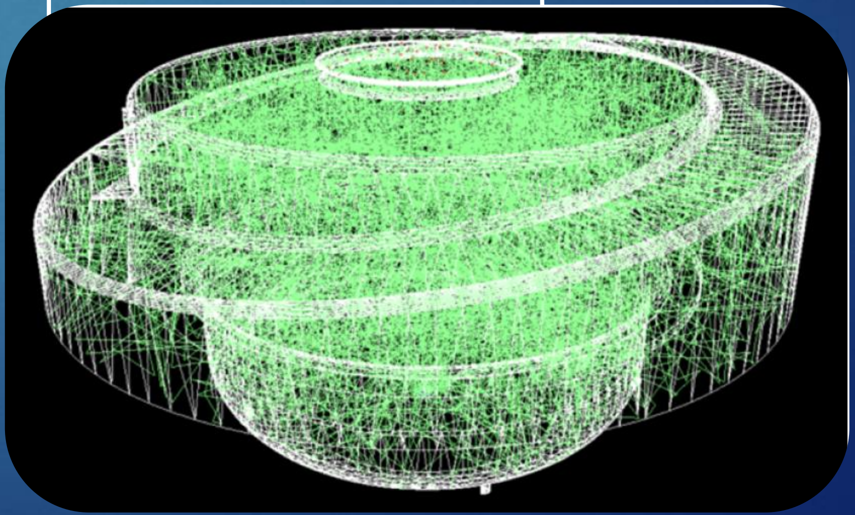
Pumping / absorption

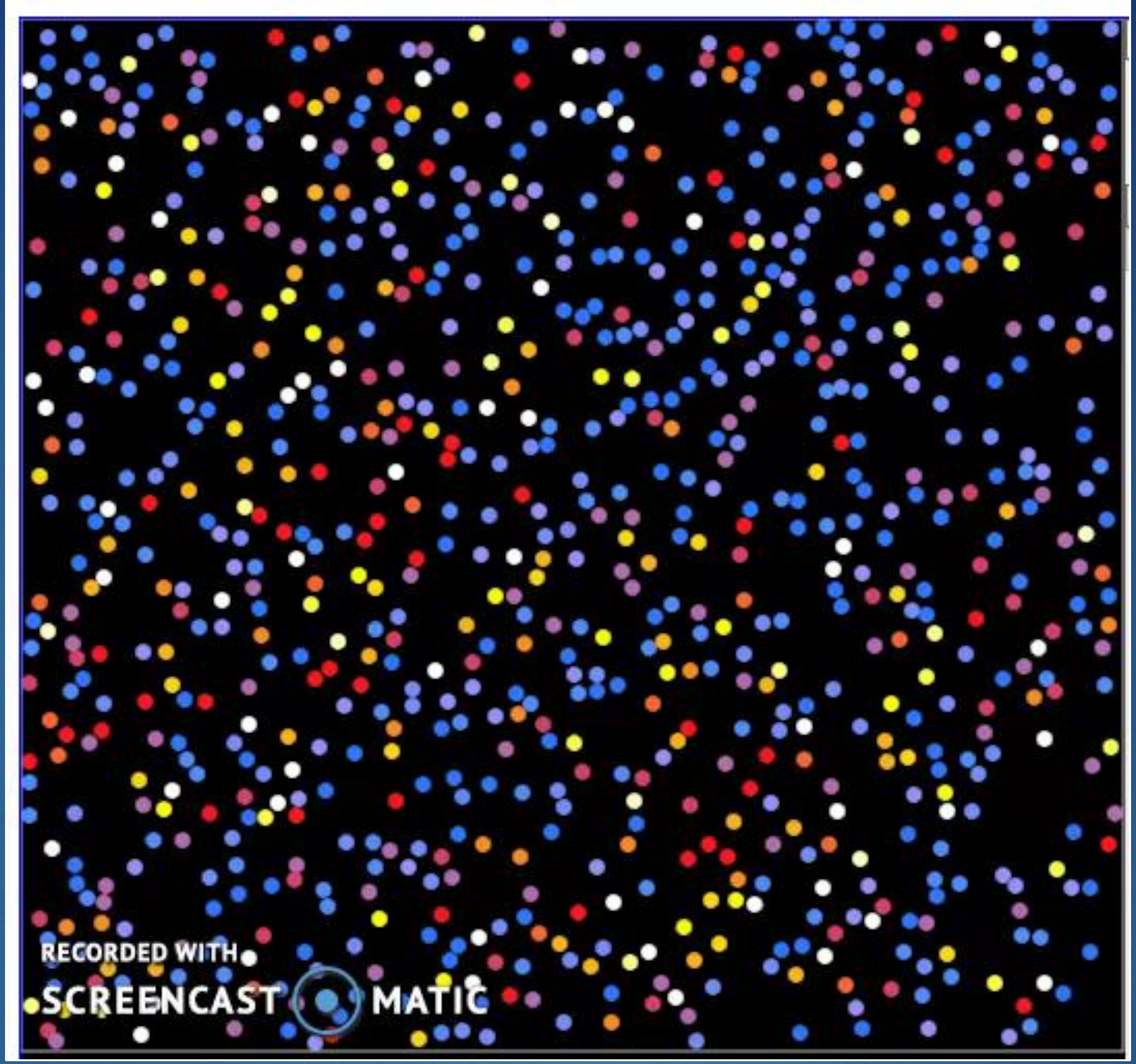
$$S\ [m^3/s] = \text{sticking}\ [0..1] * 1/4 * A\ [m^2] * v_{avg}\ [m/s]$$

Monte Carlo

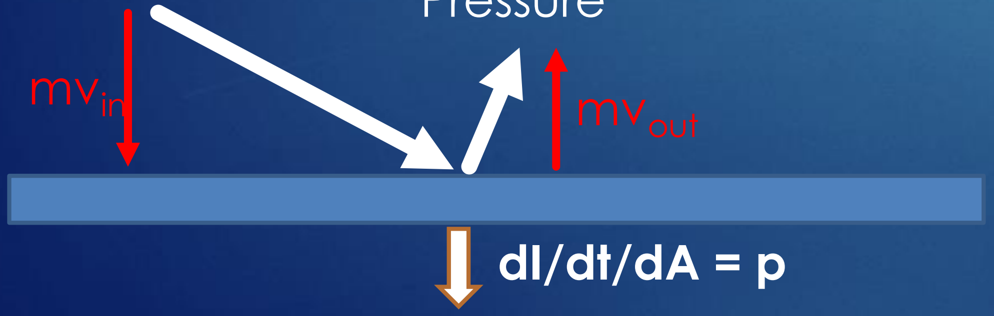




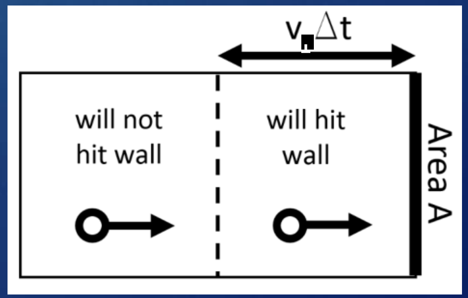


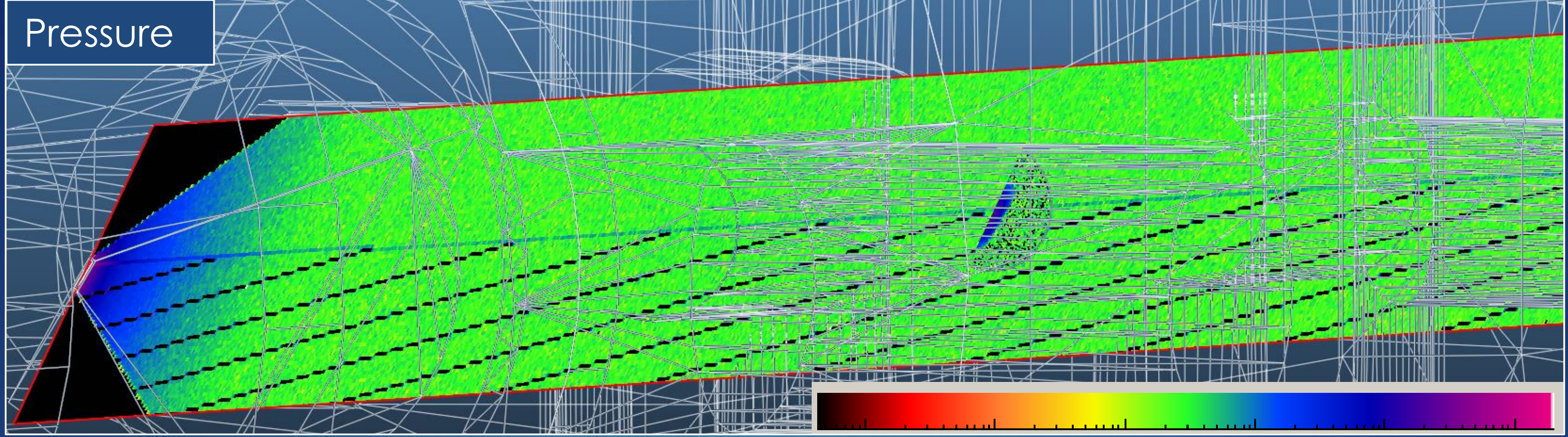
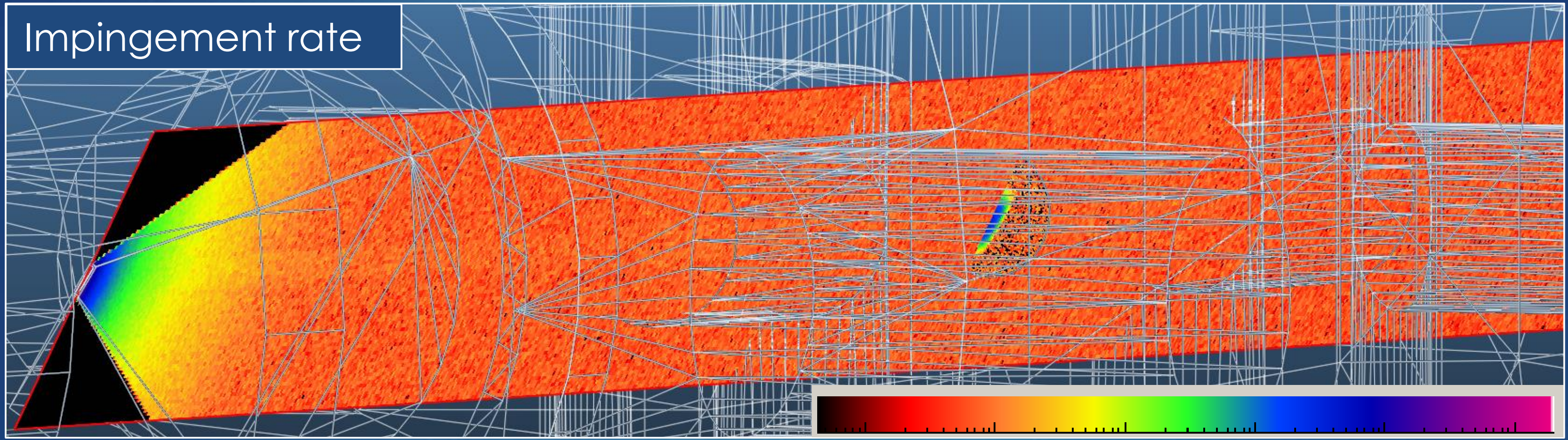
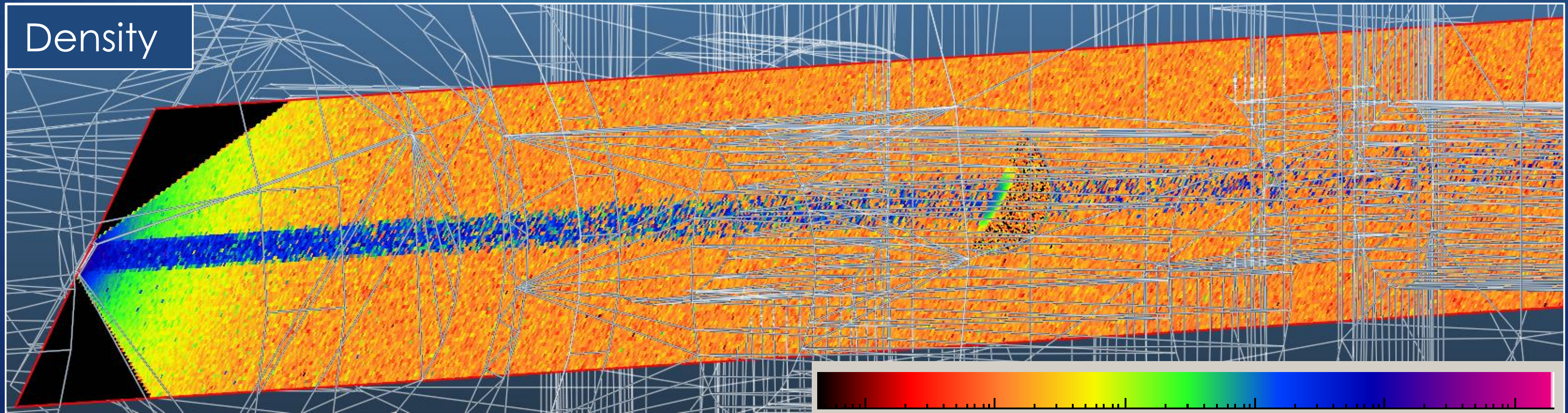


Pressure

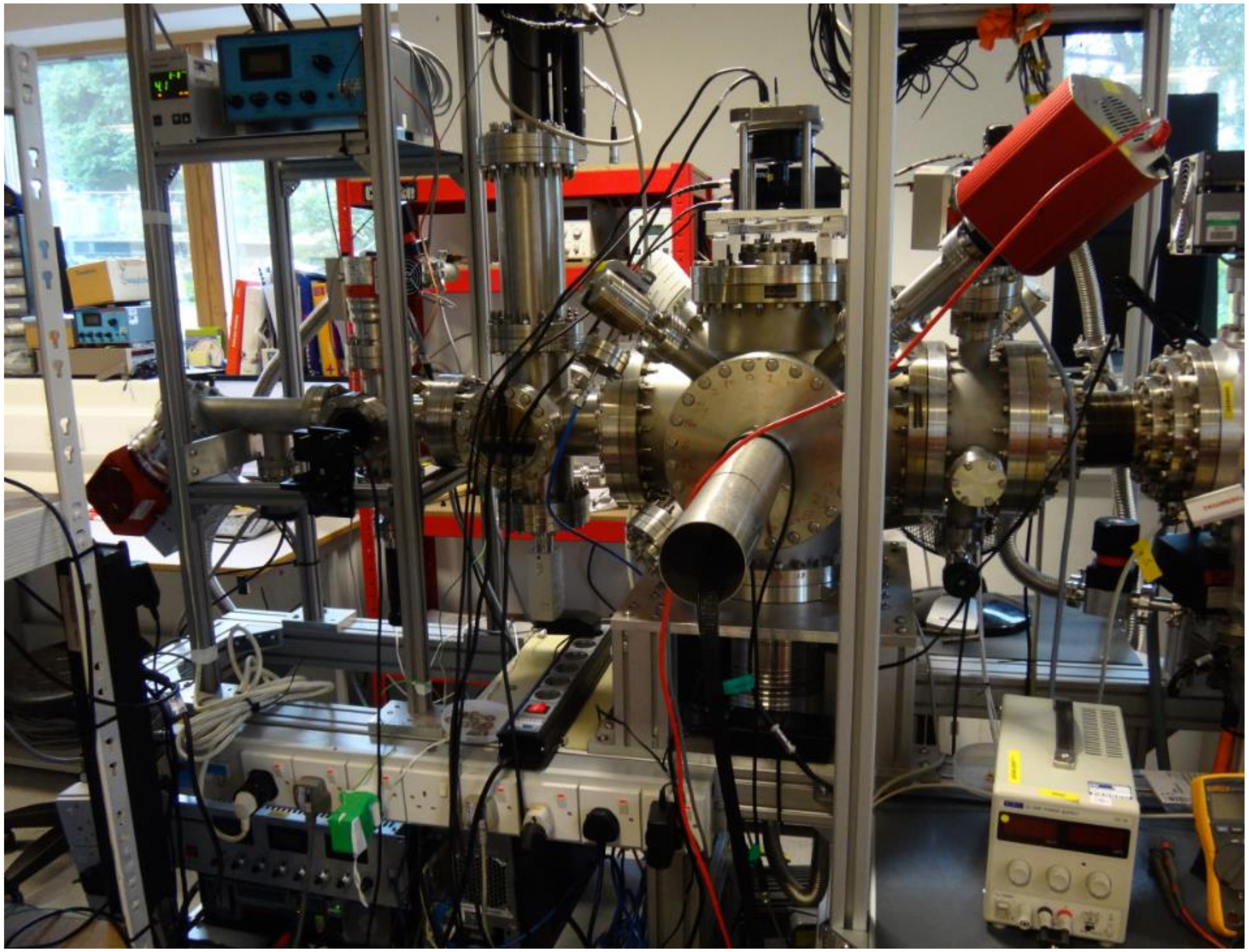


Density

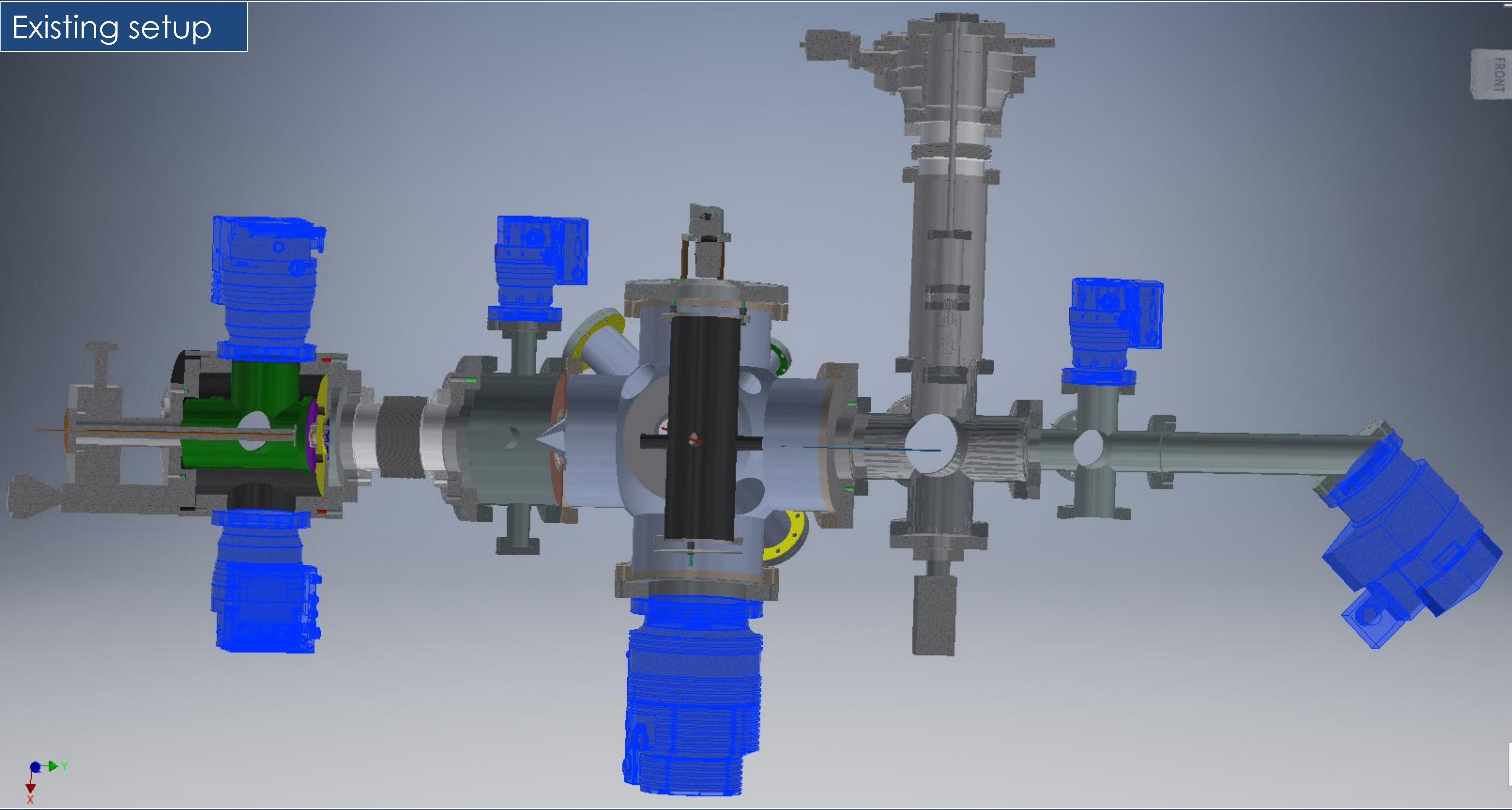



Pressure

Impingement rate

Density

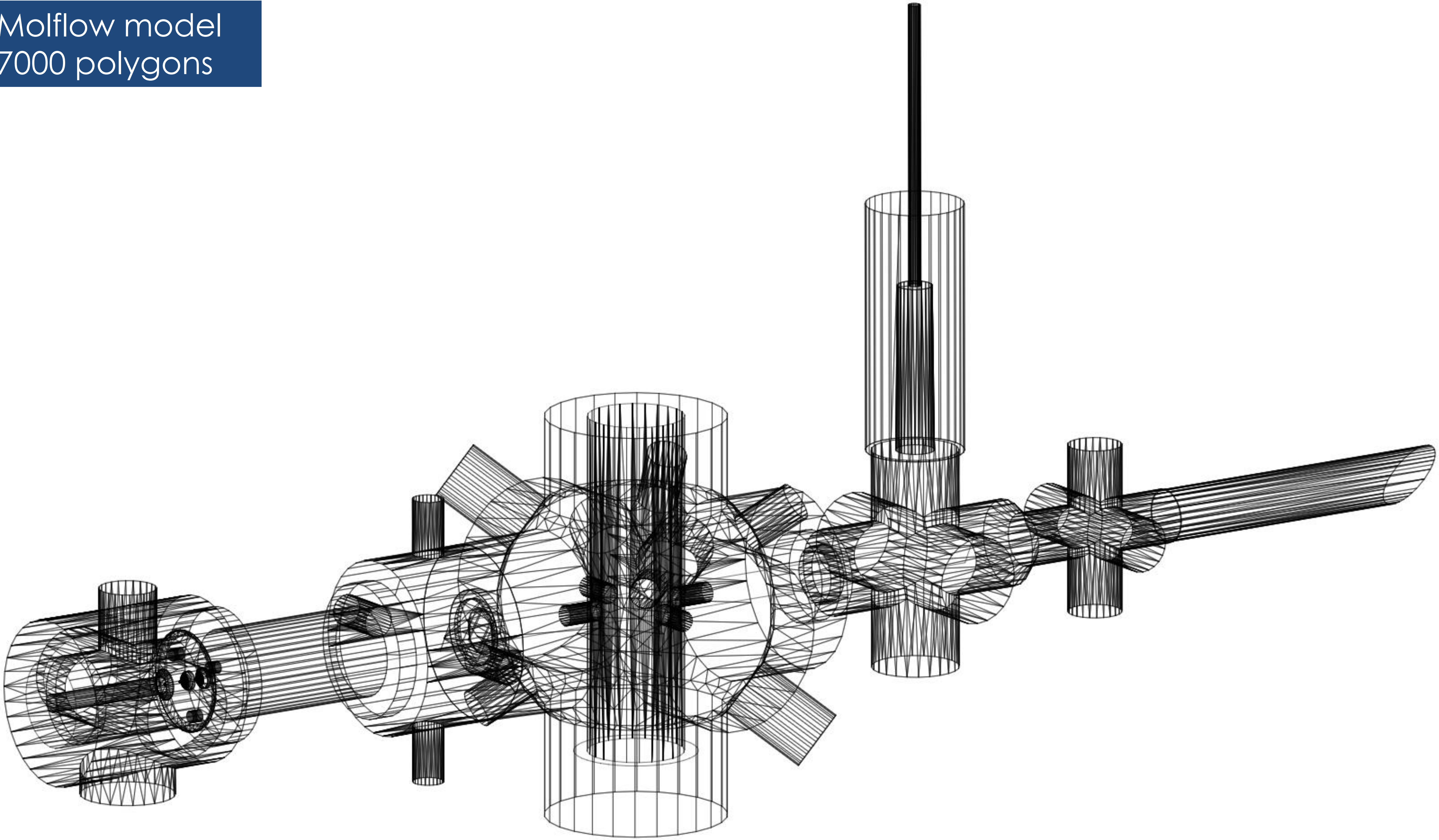
Part 2: First setup

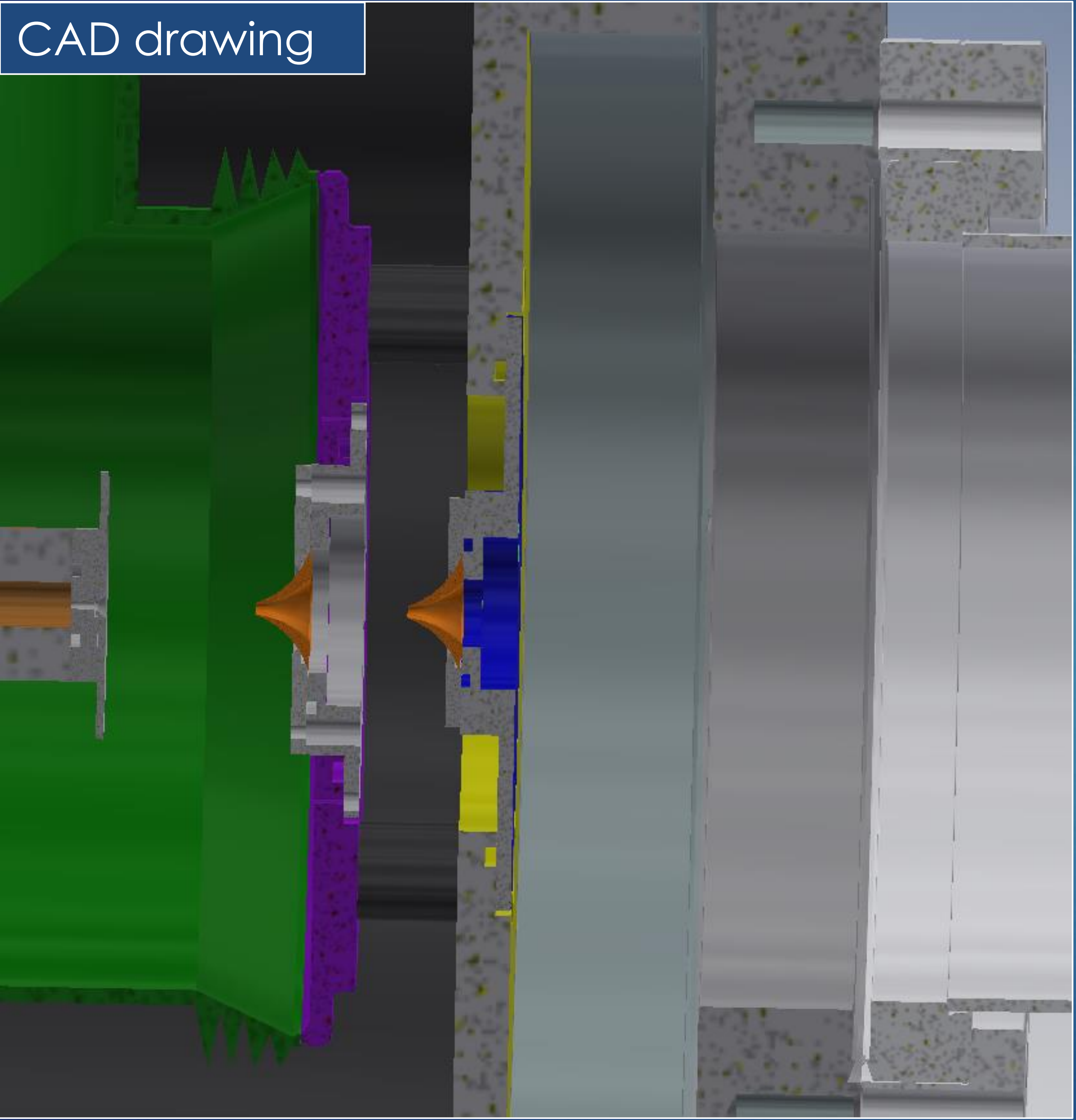


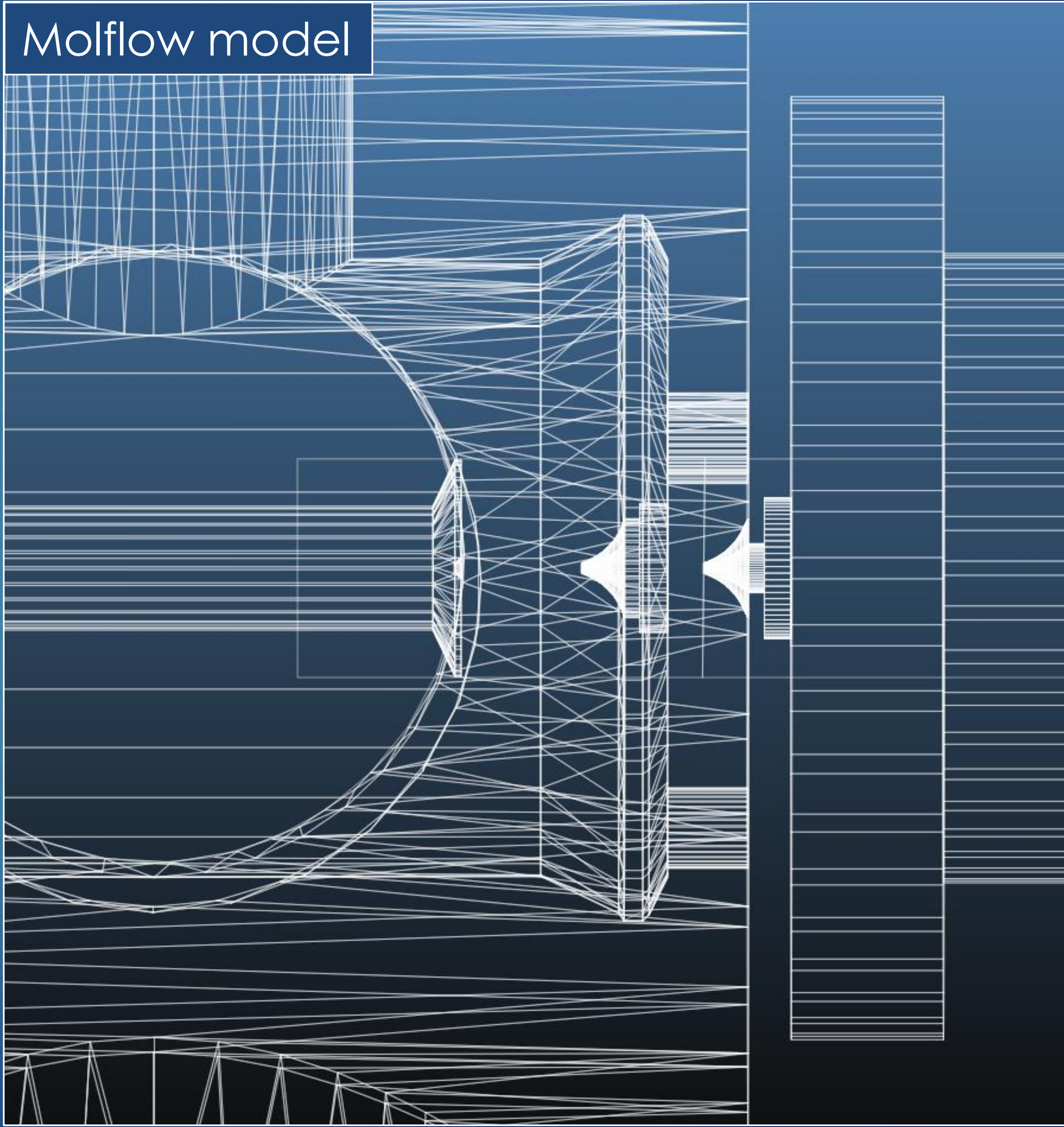
Existing setup

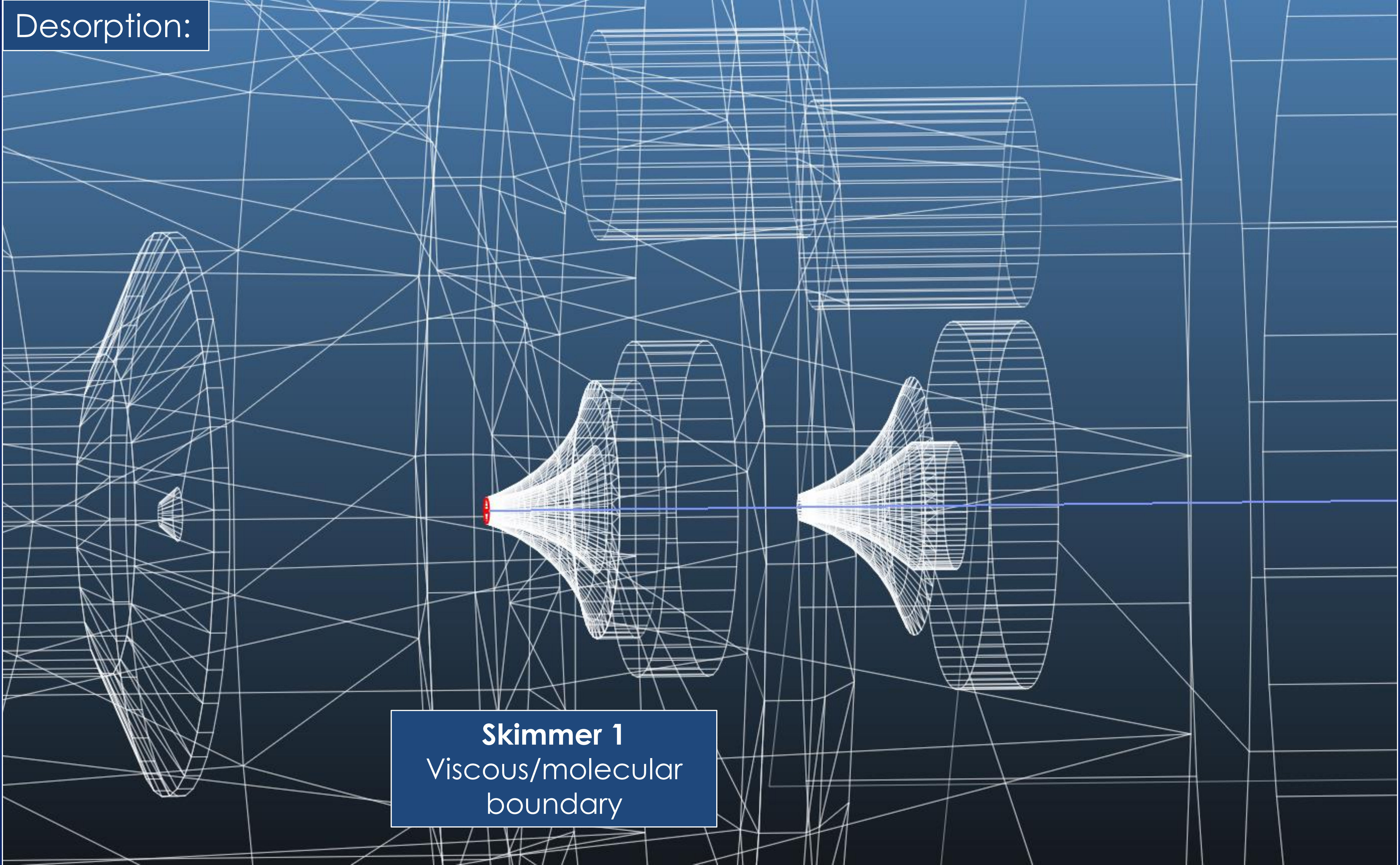


Molflow model
7000 polygons

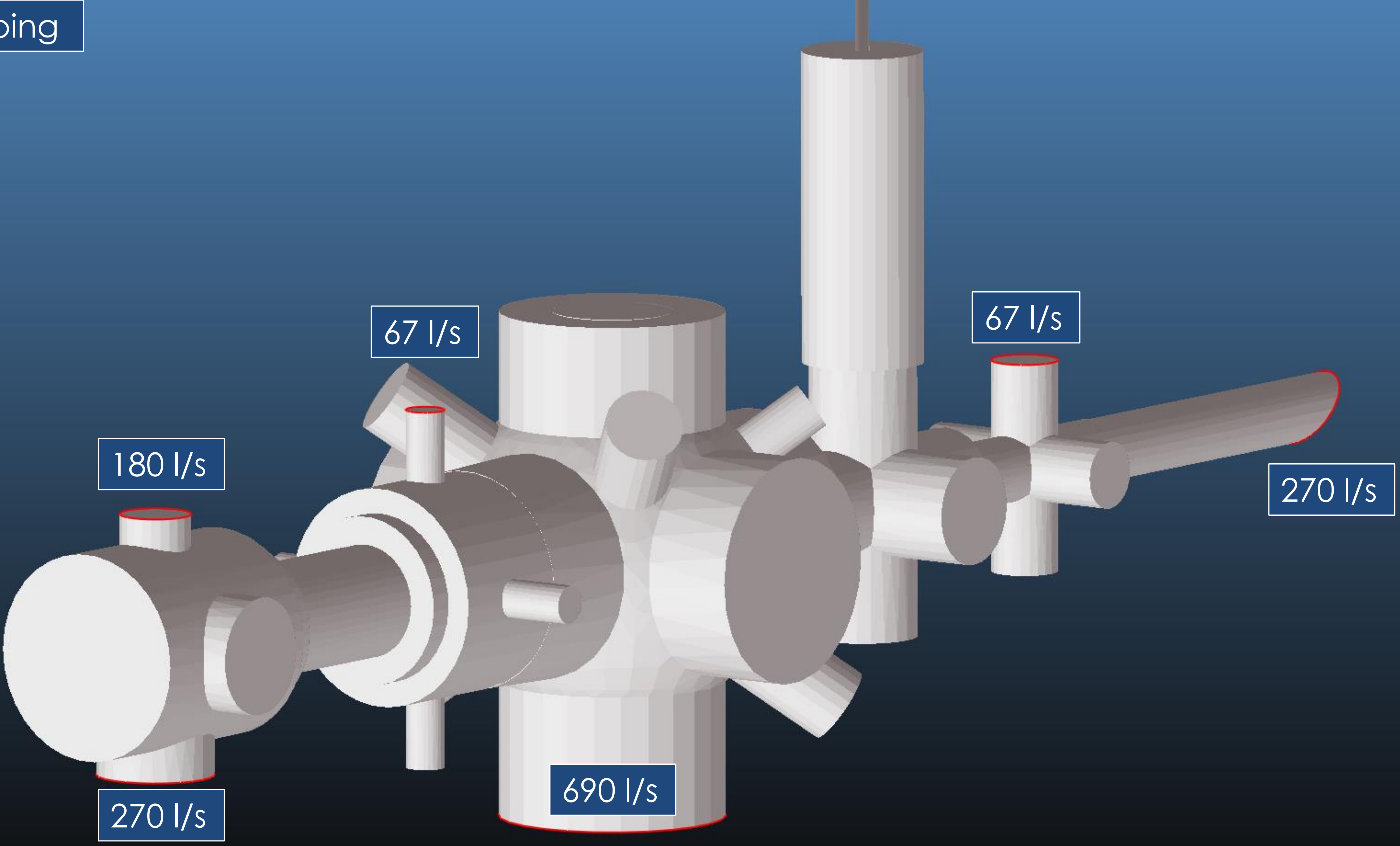



CAD drawing

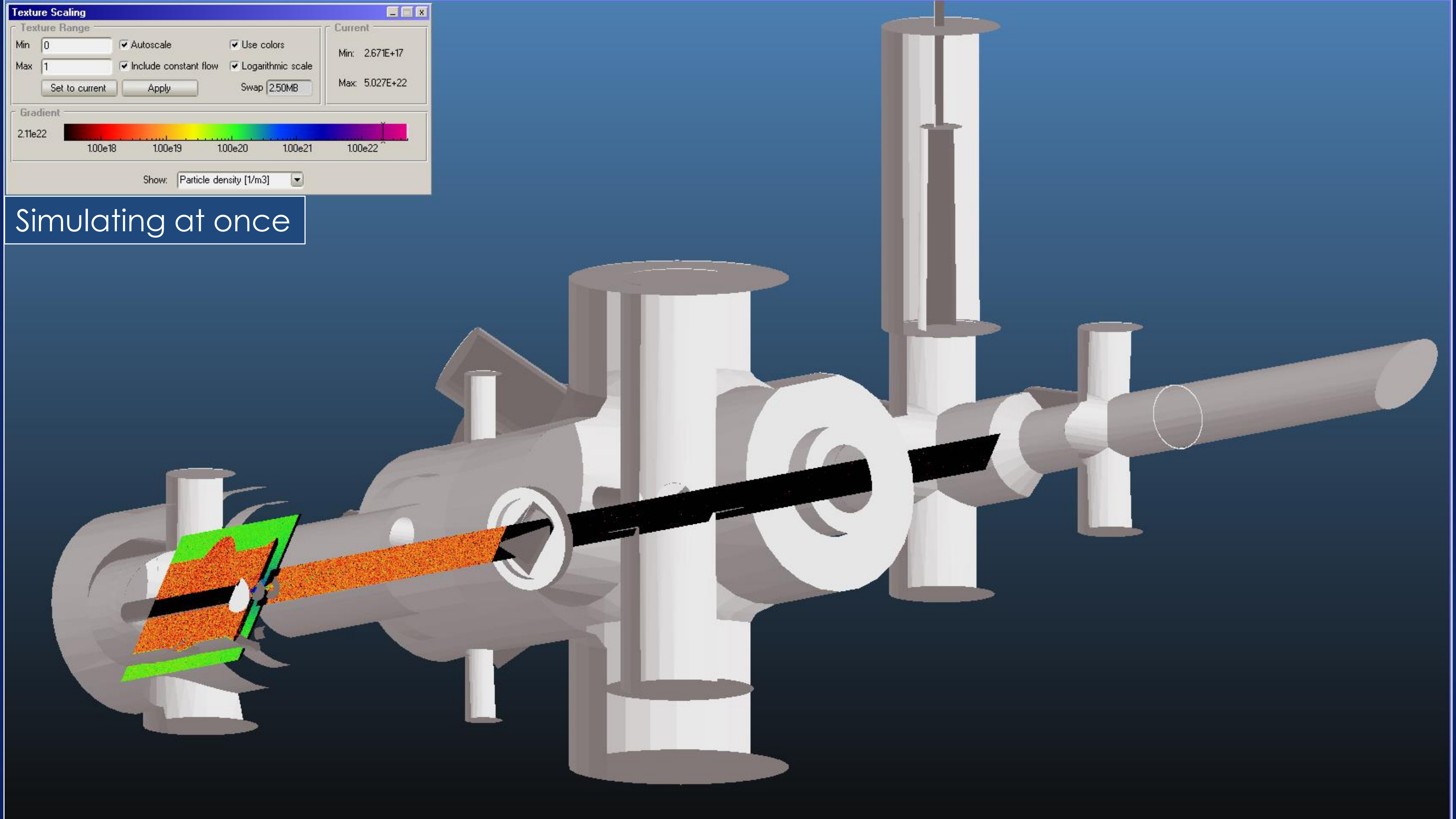

Molflow model


Desorption:
Skimmer 1
Viscous/molecular
boundary

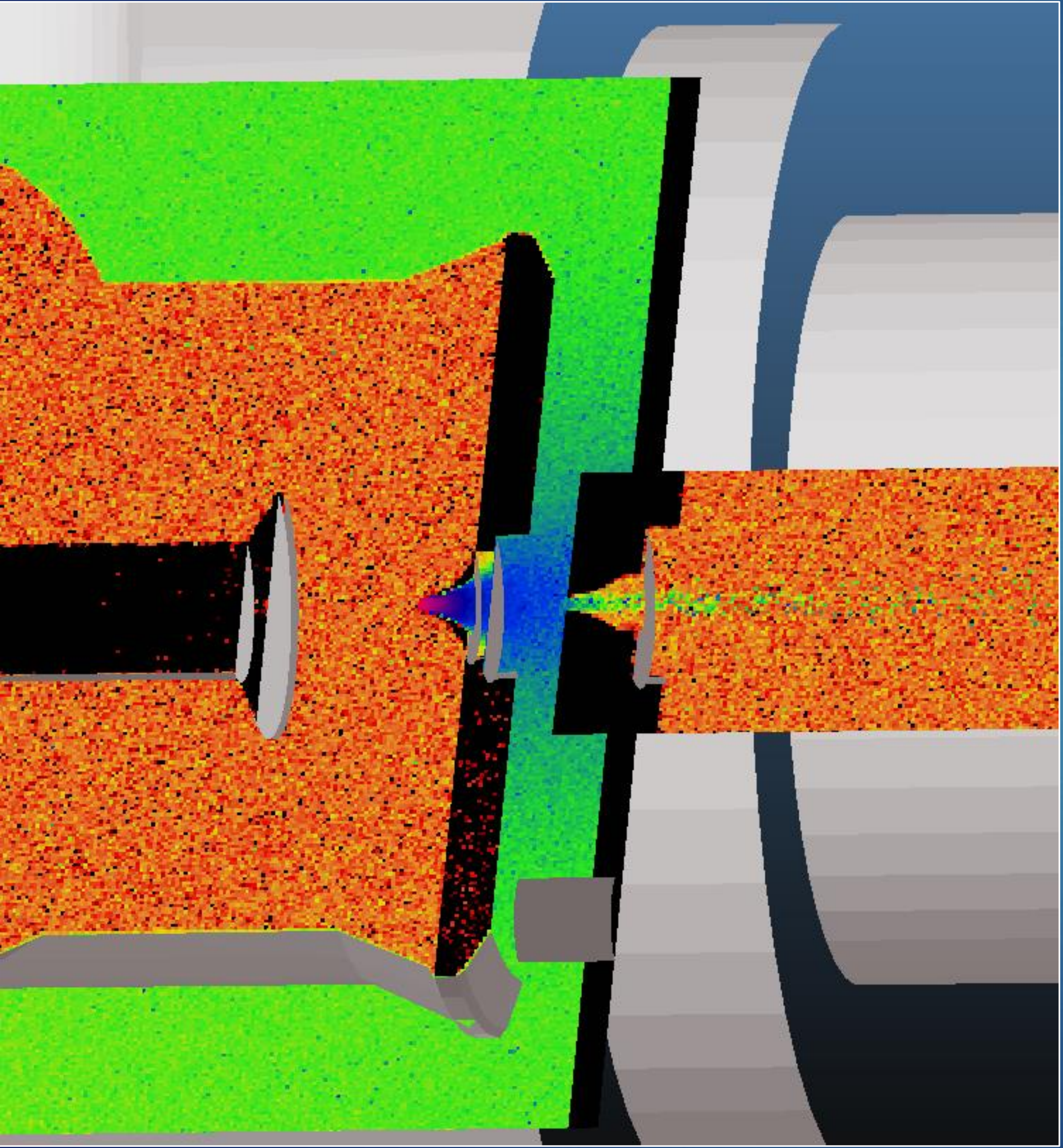
Pumping

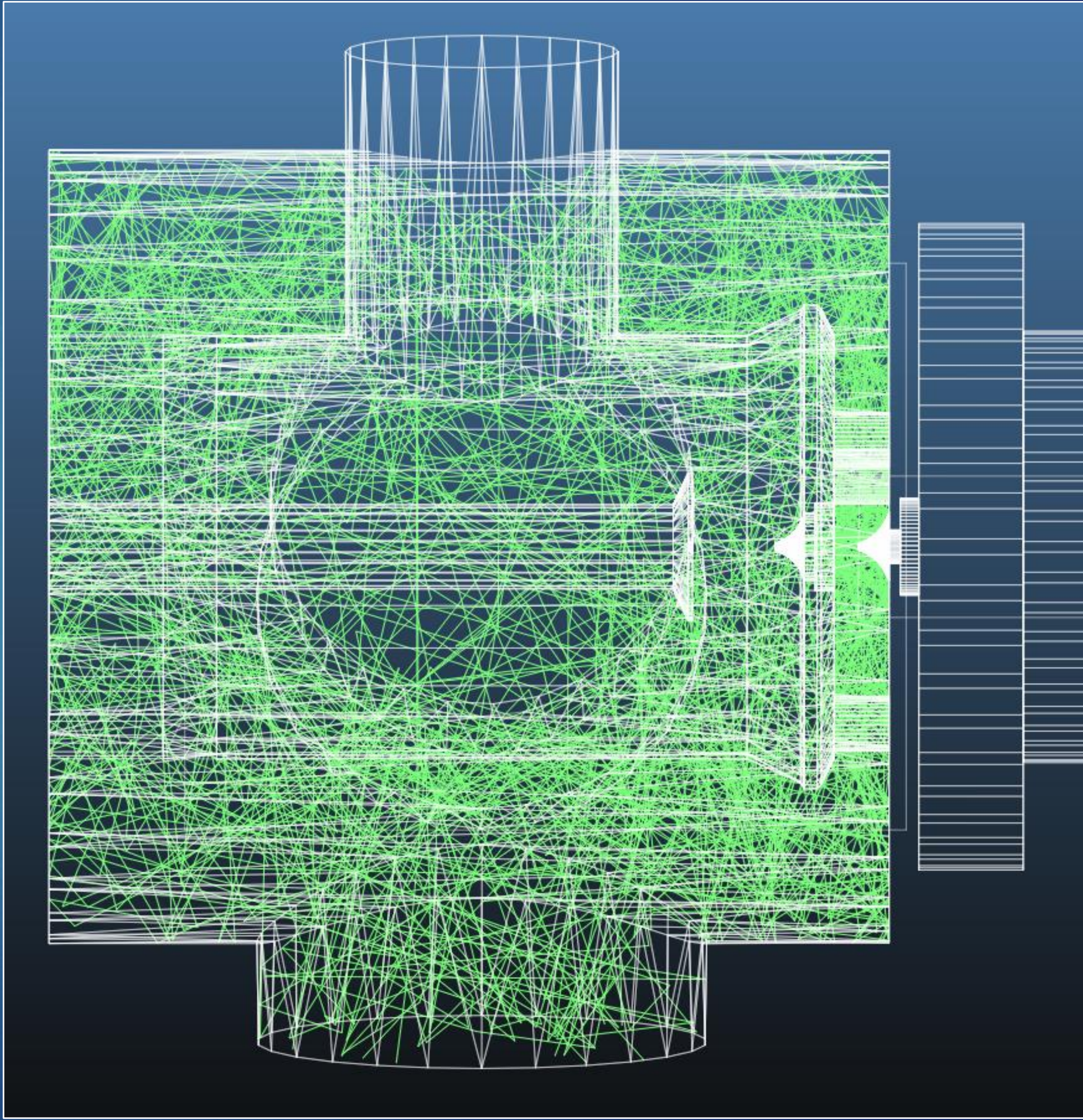


Simulating at once



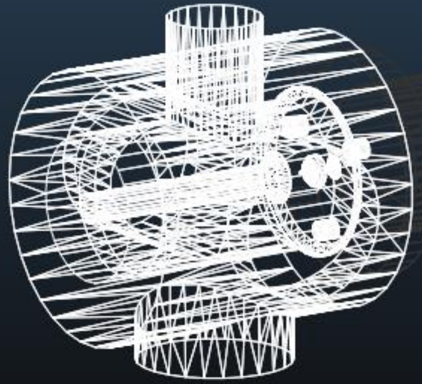
Large density differences: Monte Carlo weakness

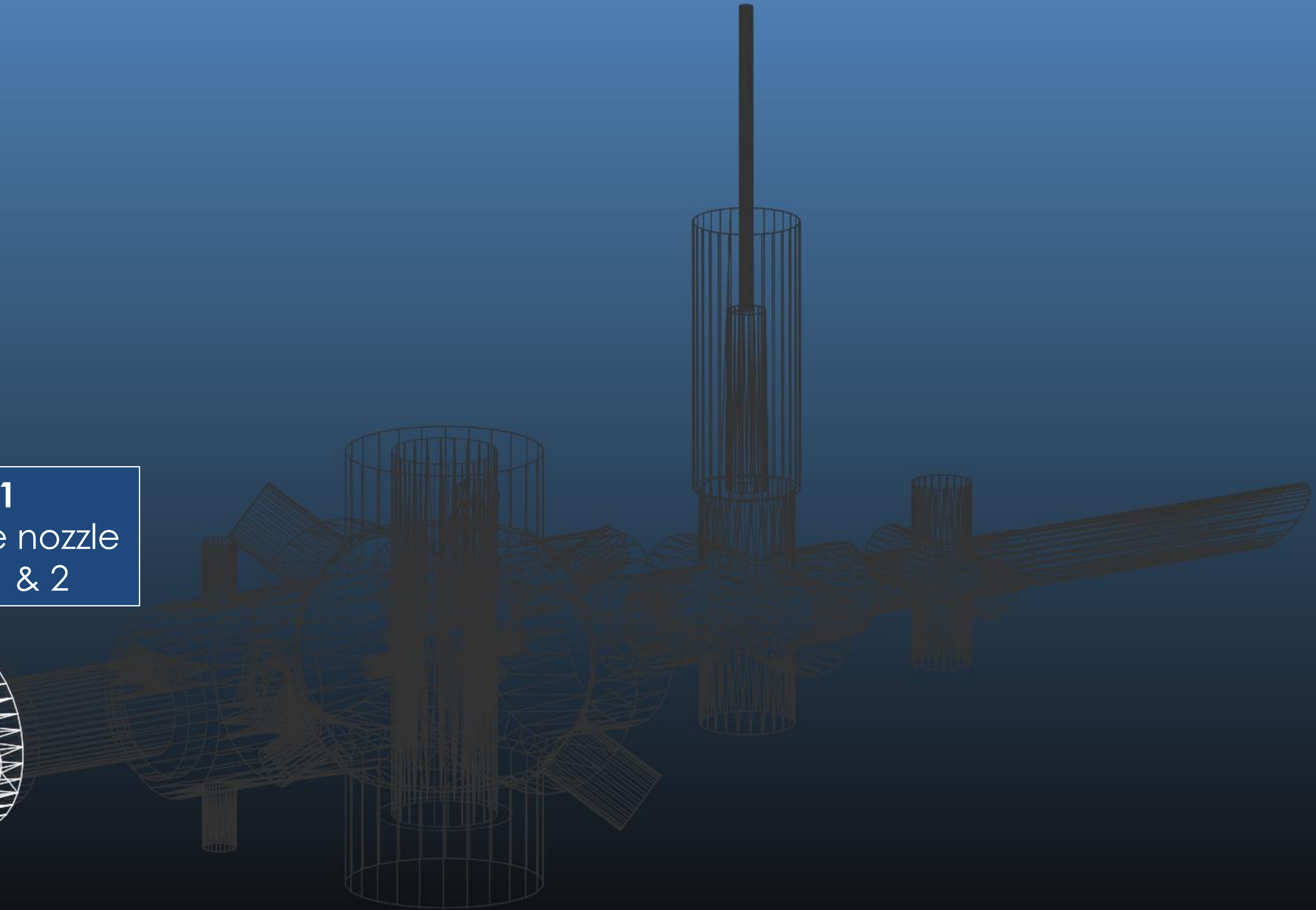




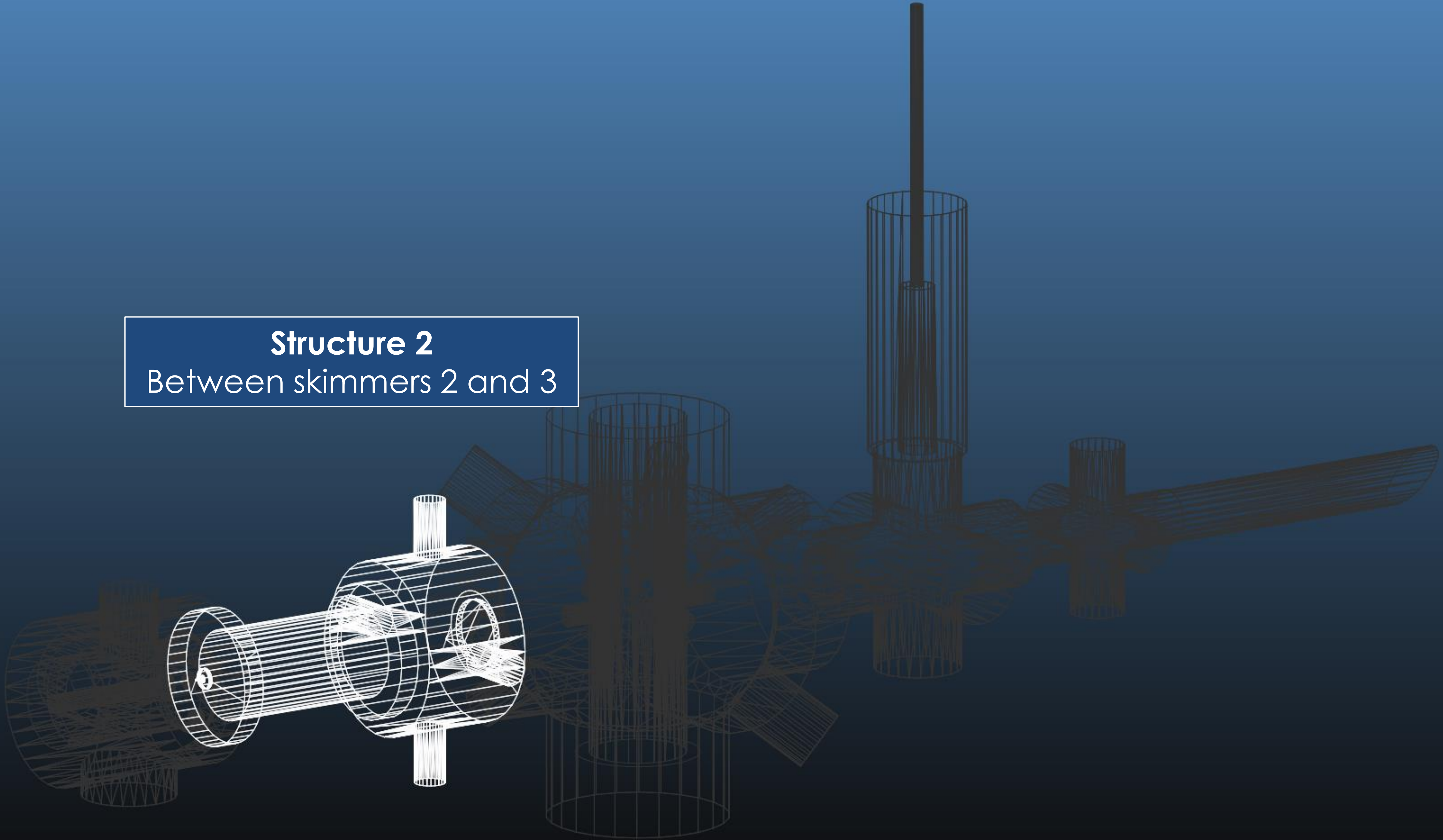
Structure 1

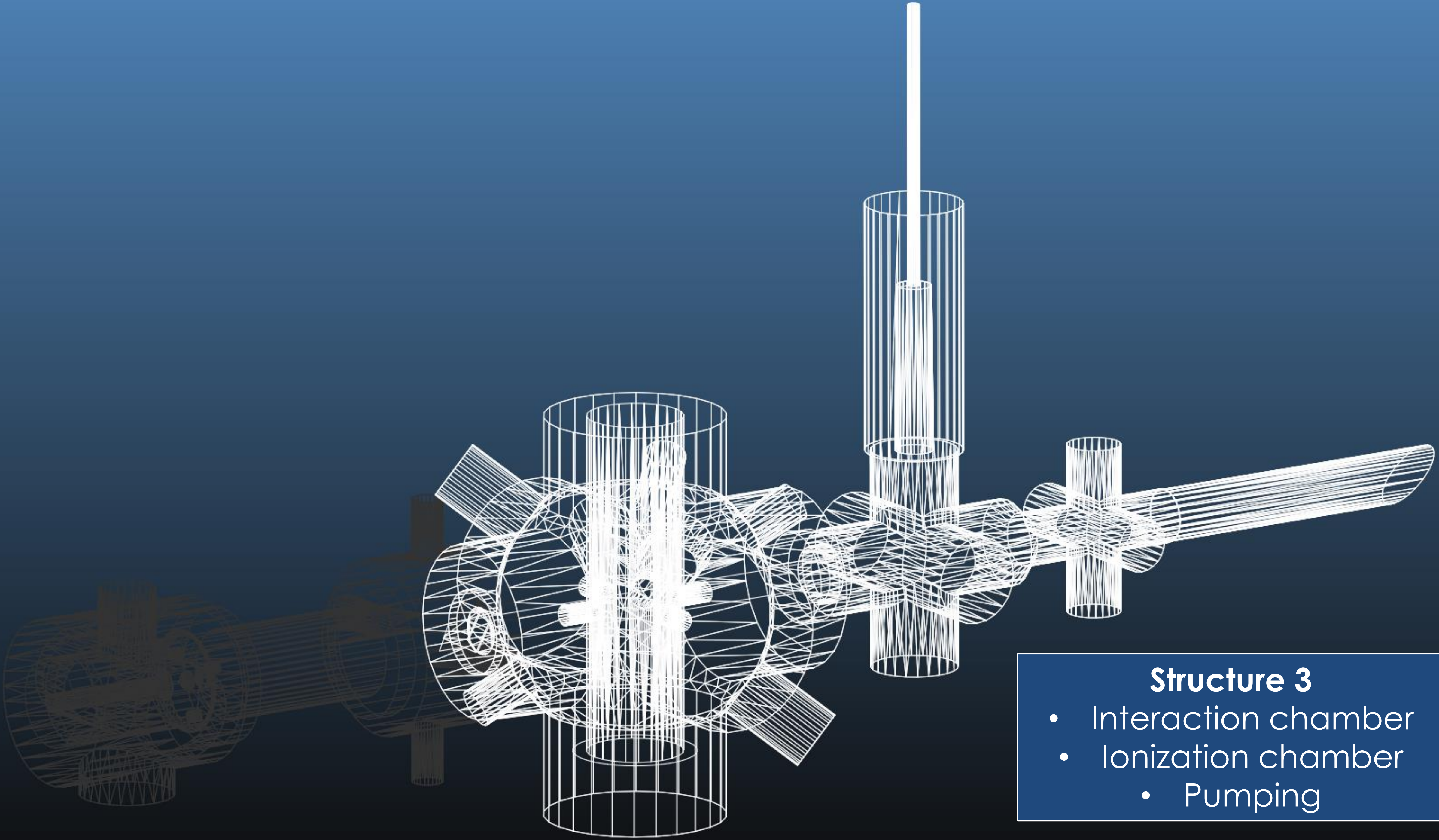
- High pressure nozzle
- Skimmer 1 & 2





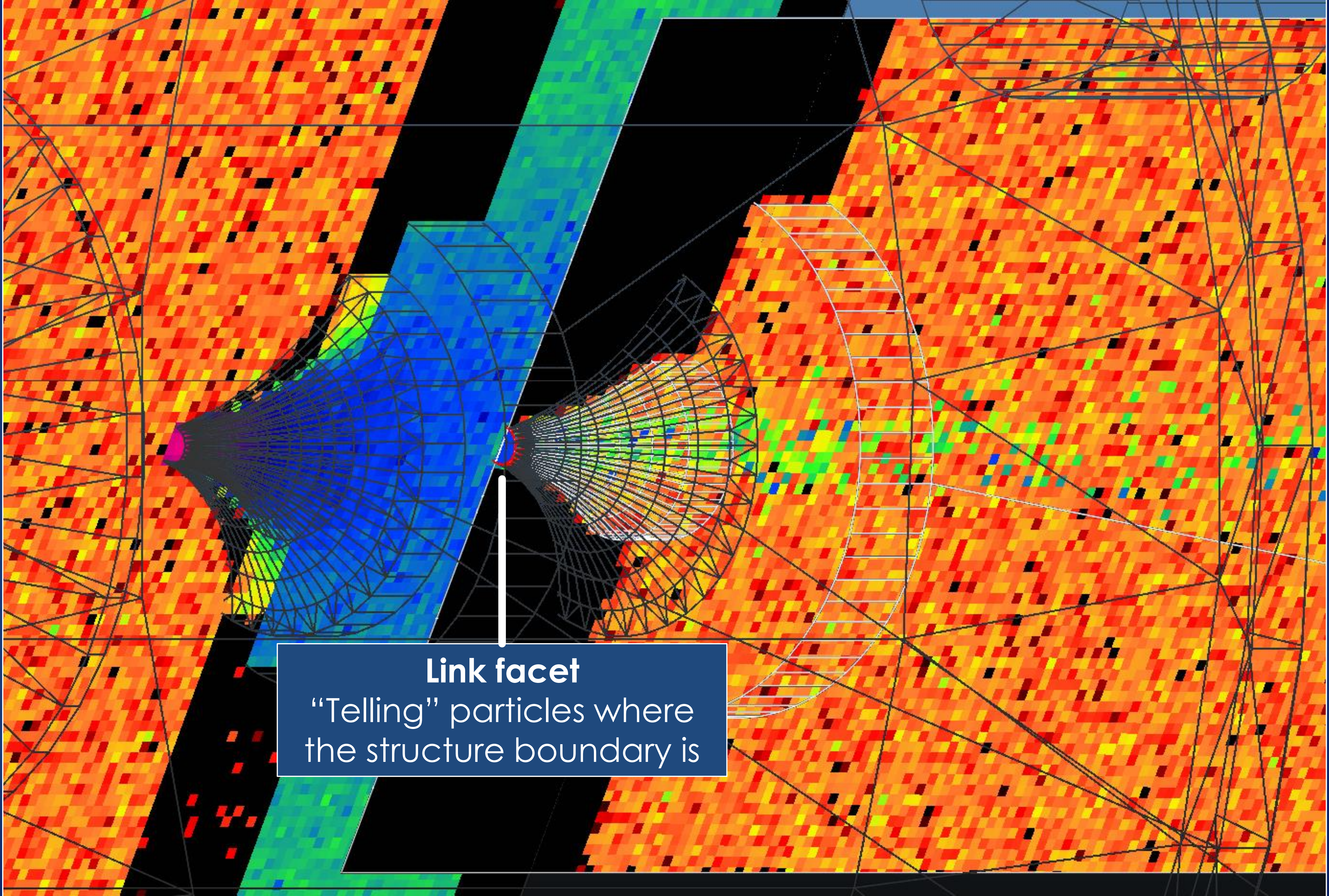
Structure 2
Between skimmers 2 and 3



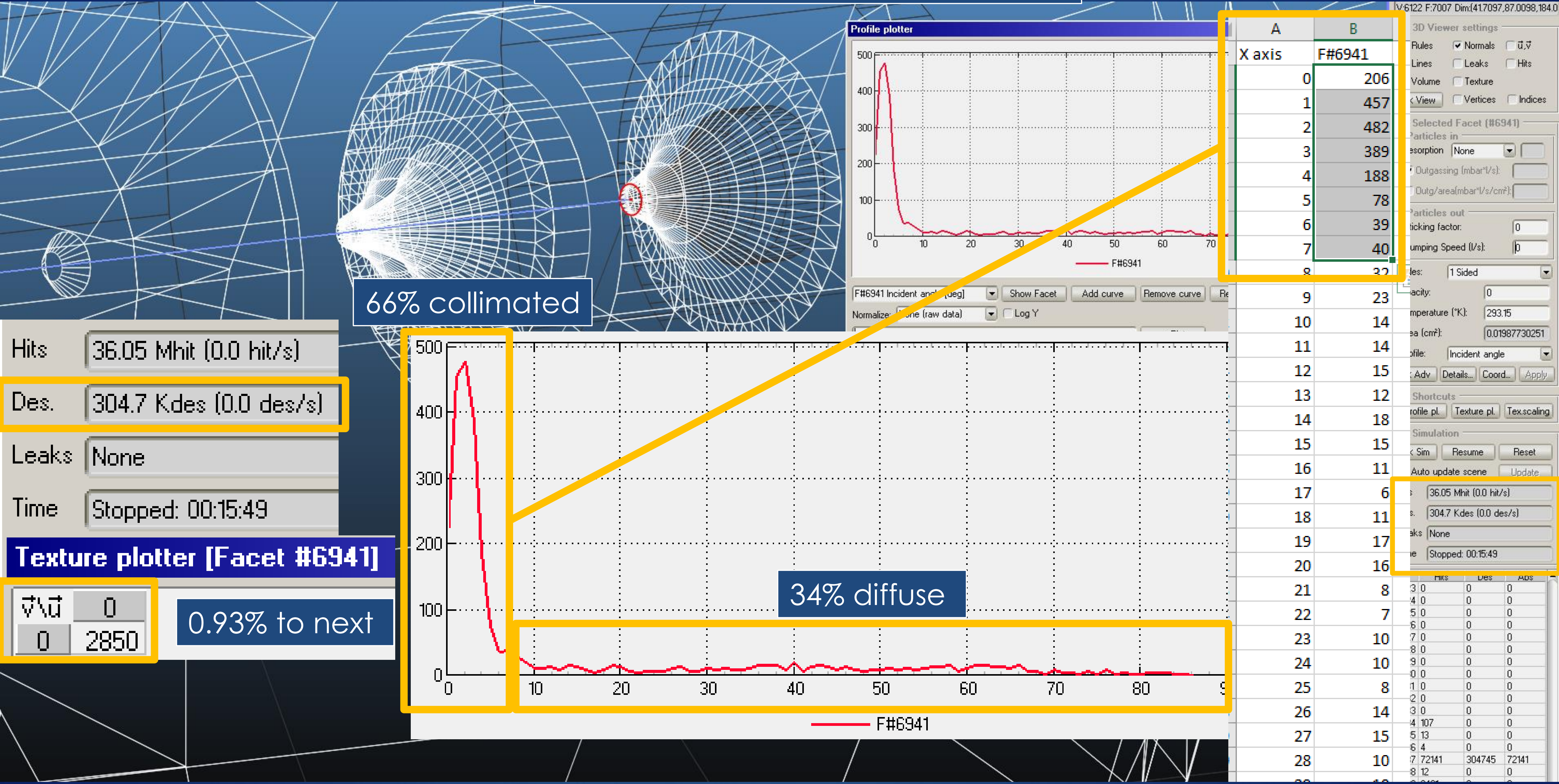


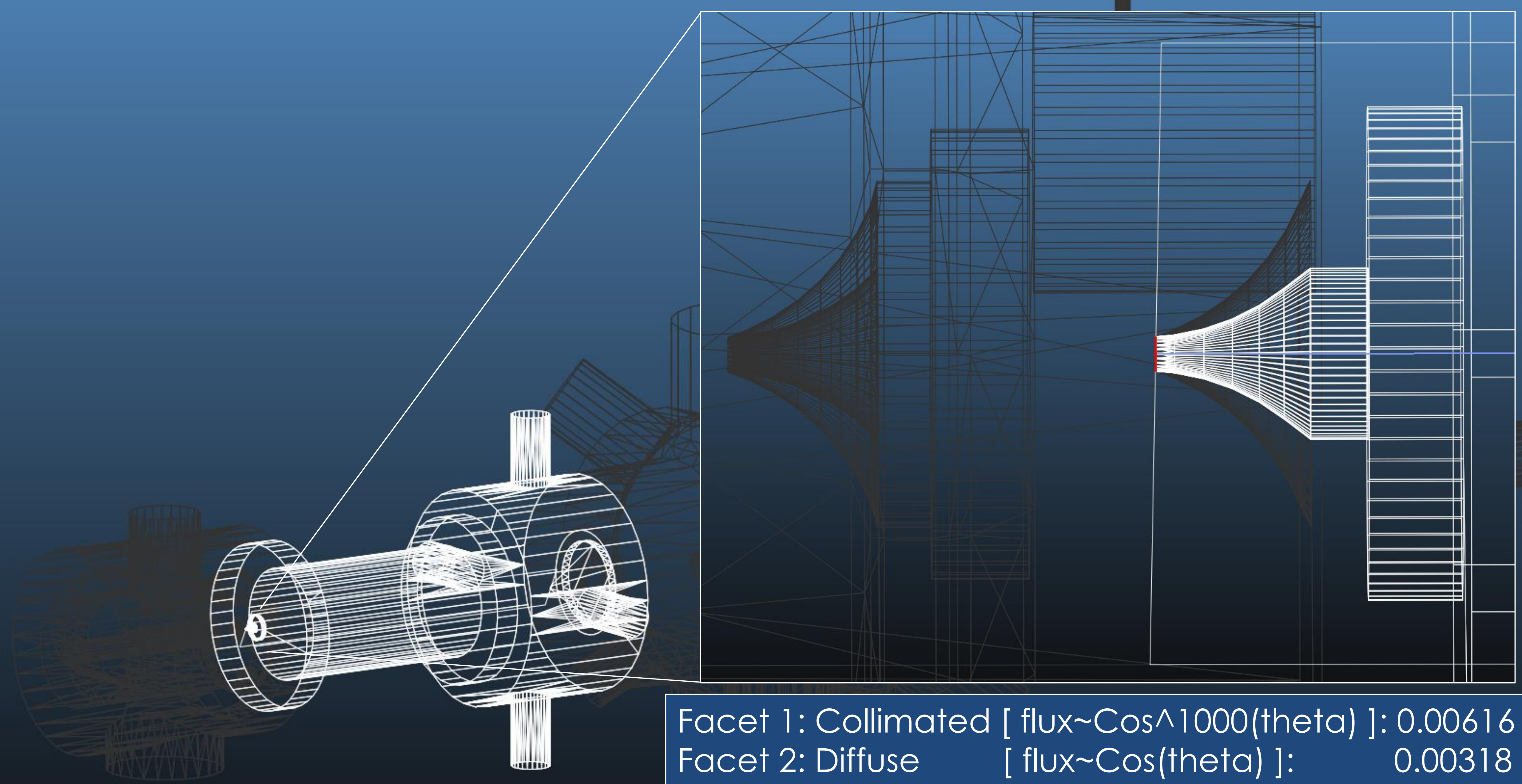
Structure 3

- Interaction chamber
- Ionization chamber
- Pumping


Link facet
“Telling” particles where
the structure boundary is

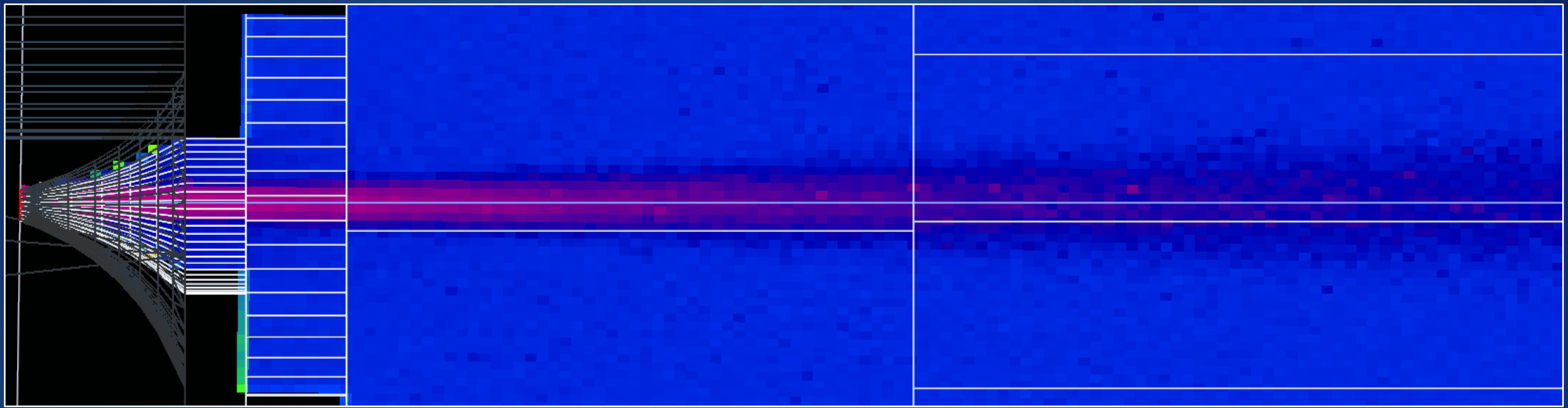
Sequential simulation basic steps





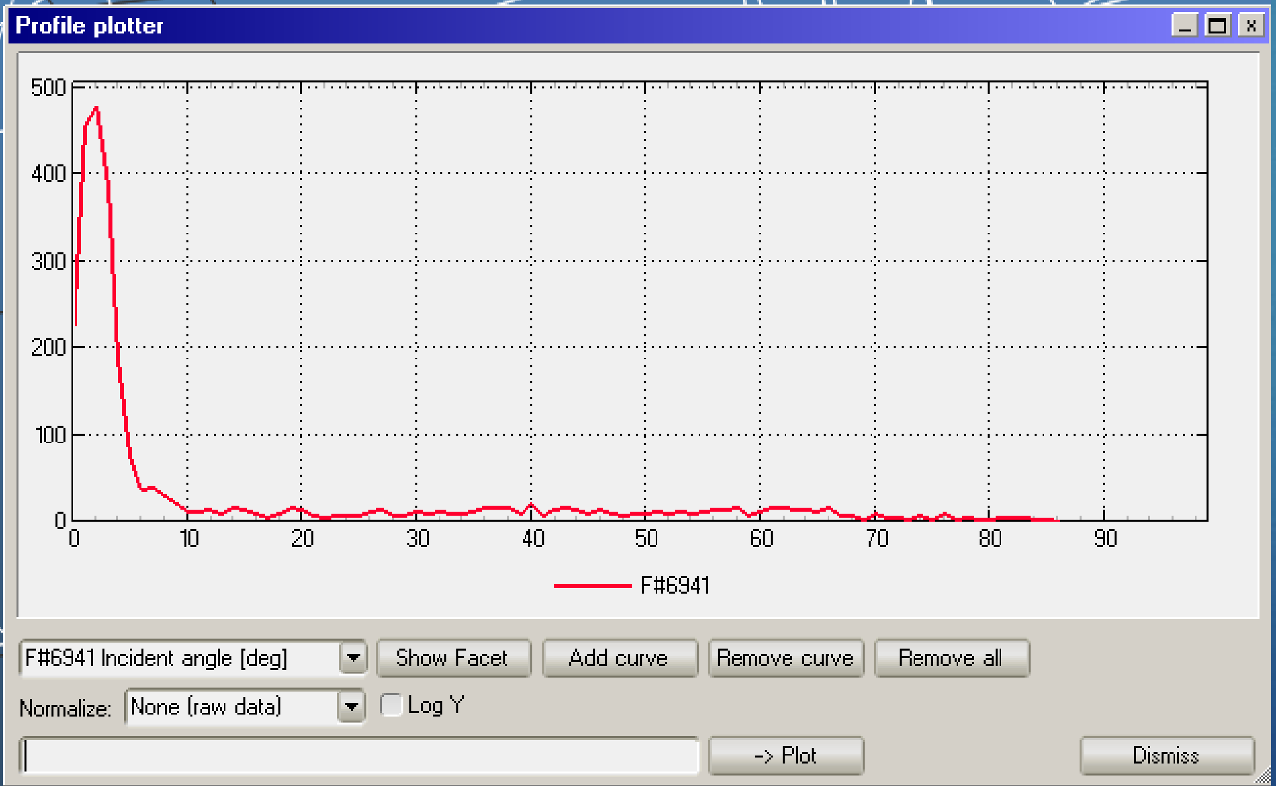
Facet 1: Collimated [flux~Cos^1000(theta)]: 0.00616
Facet 2: Diffuse [flux~Cos(theta)]: 0.00318

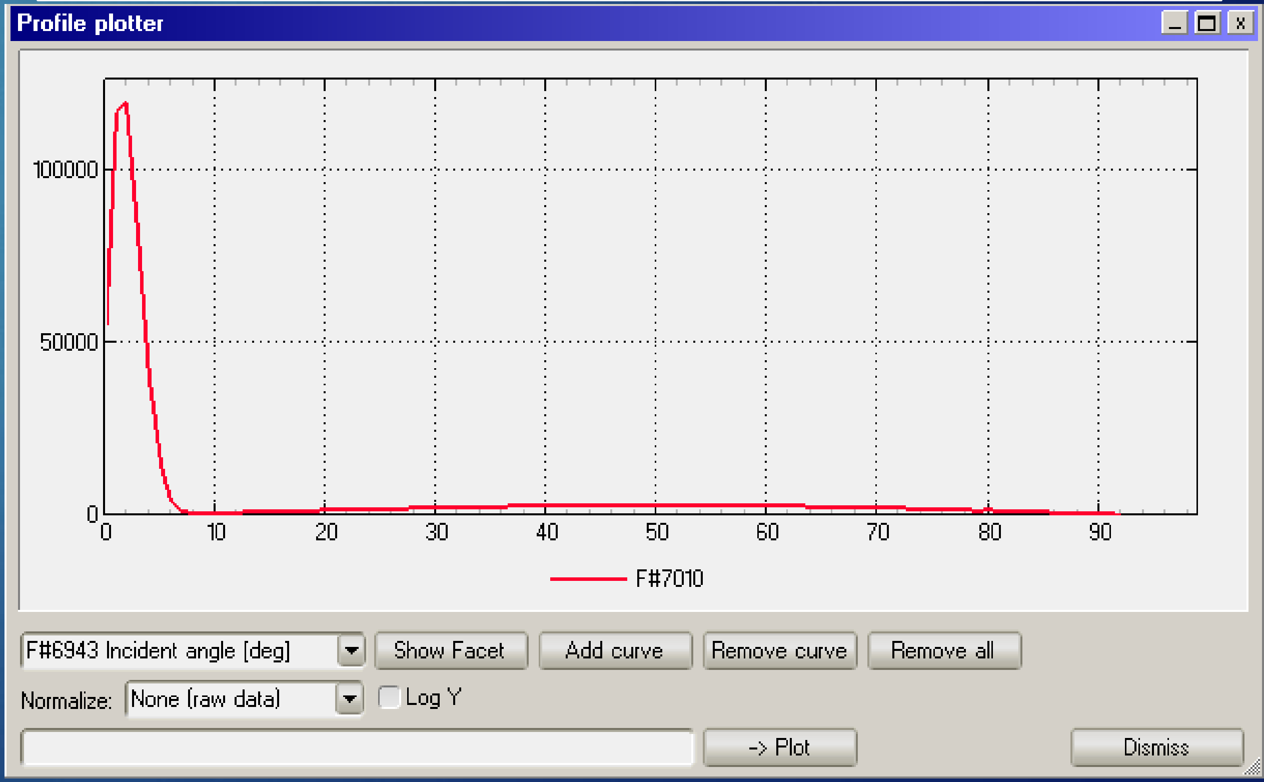
Sum: 0.93%

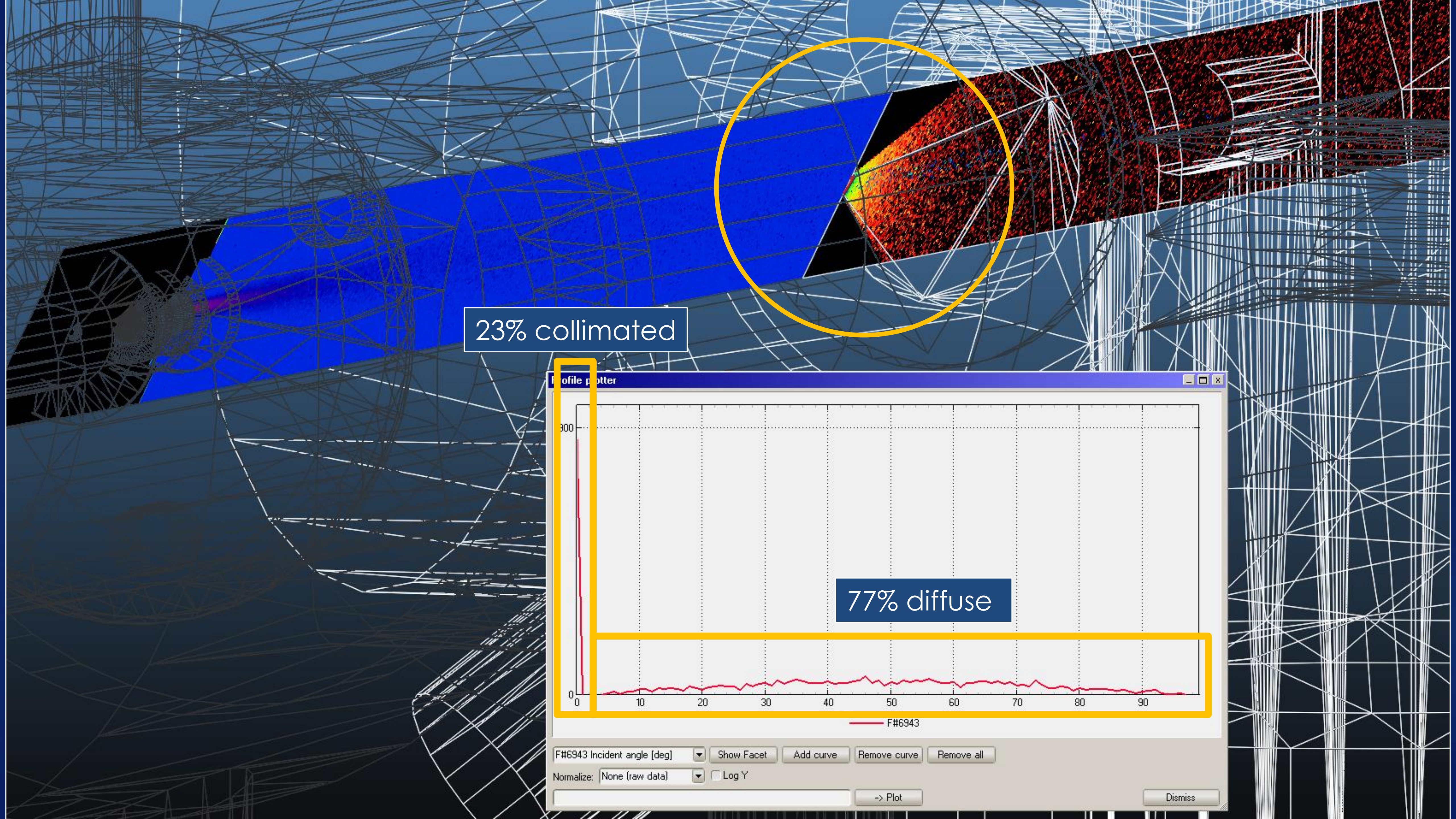


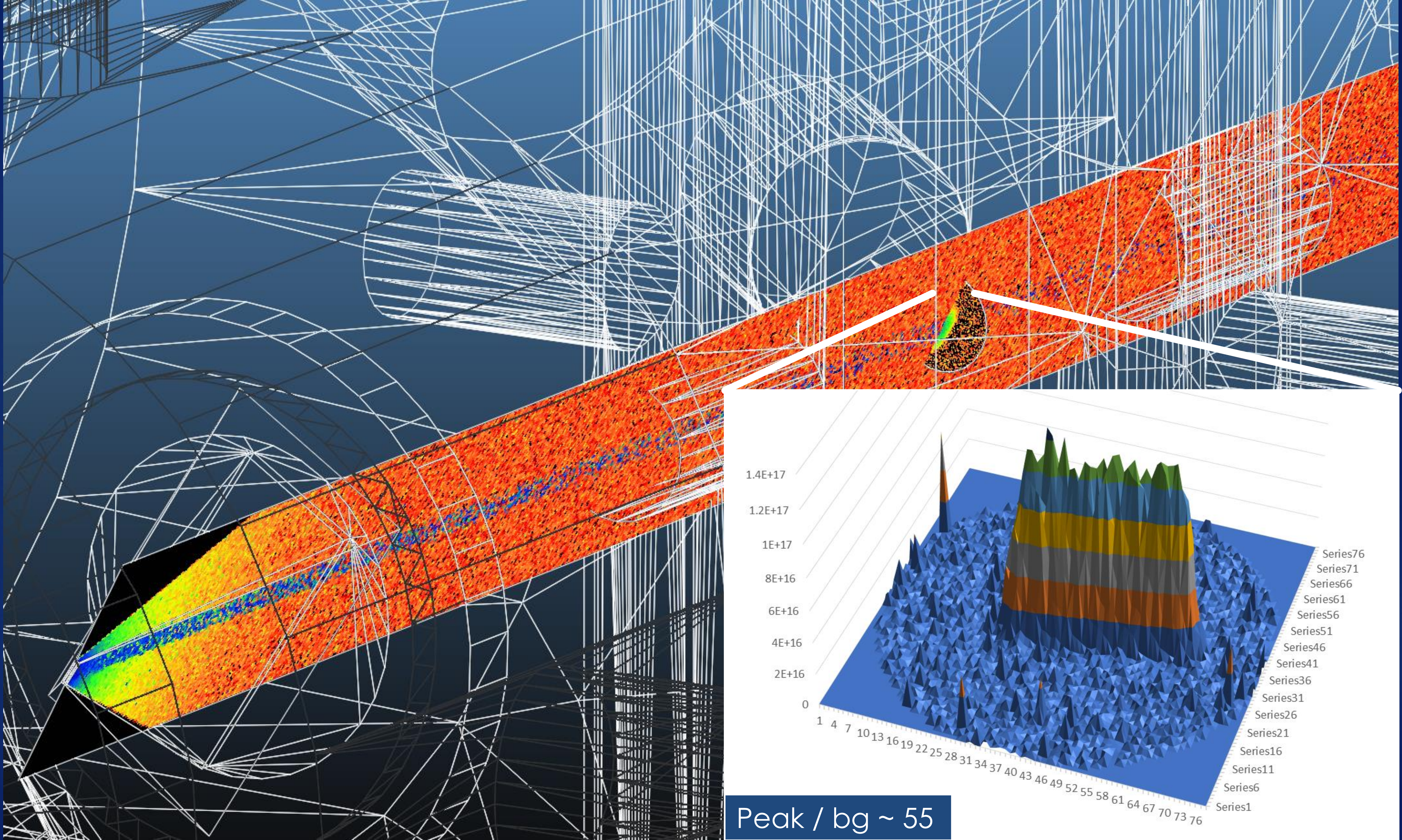
Original distribution
as sampled

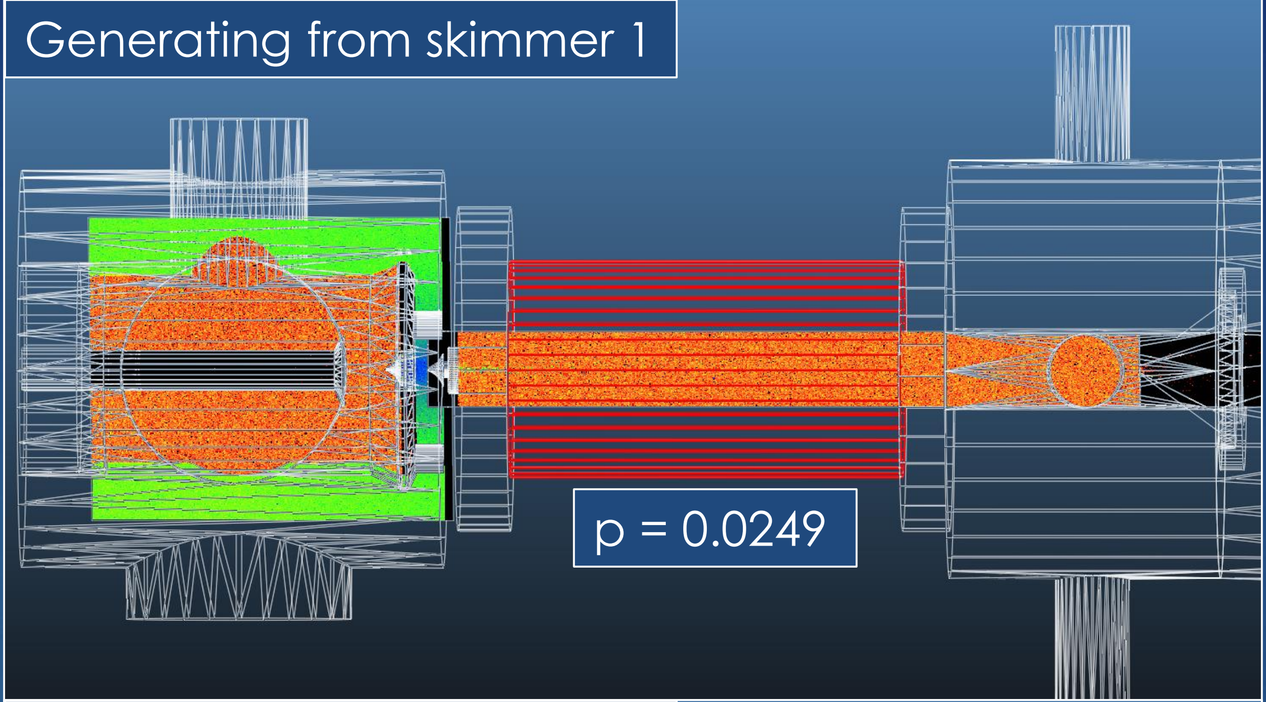
Sum of collimated and diffuse distributions
as generated

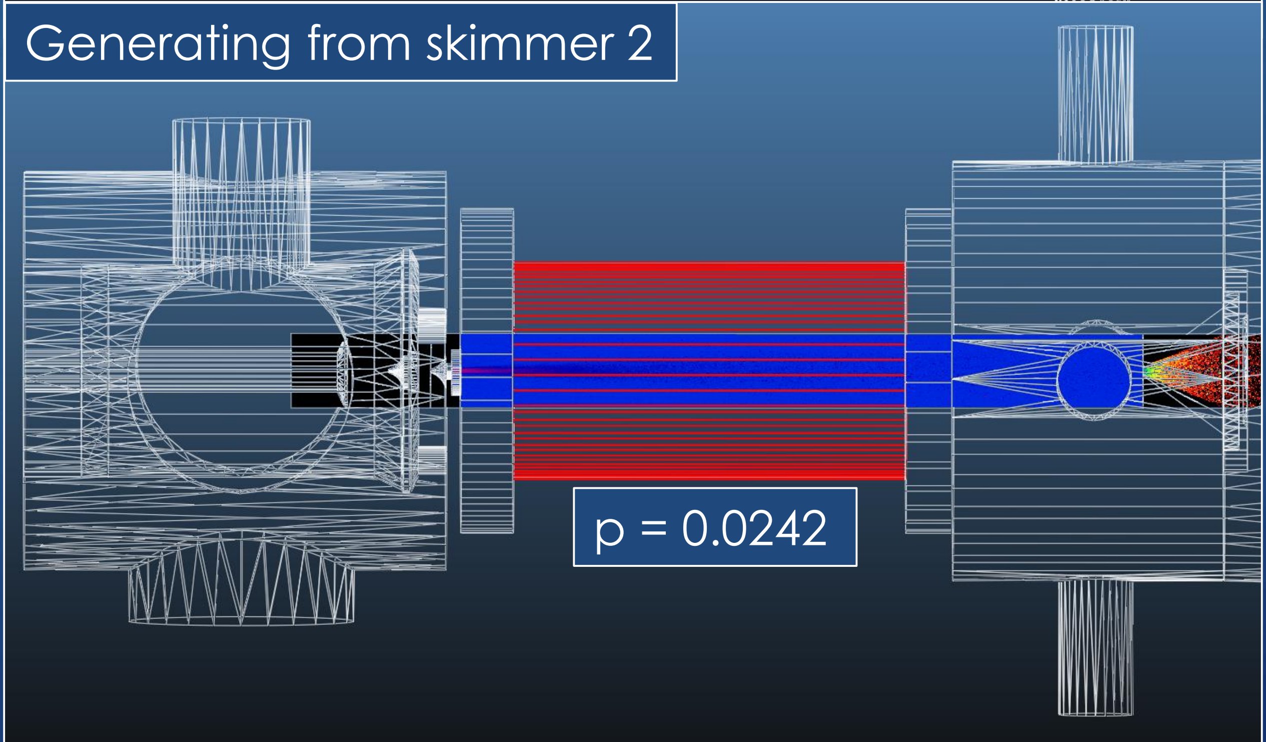


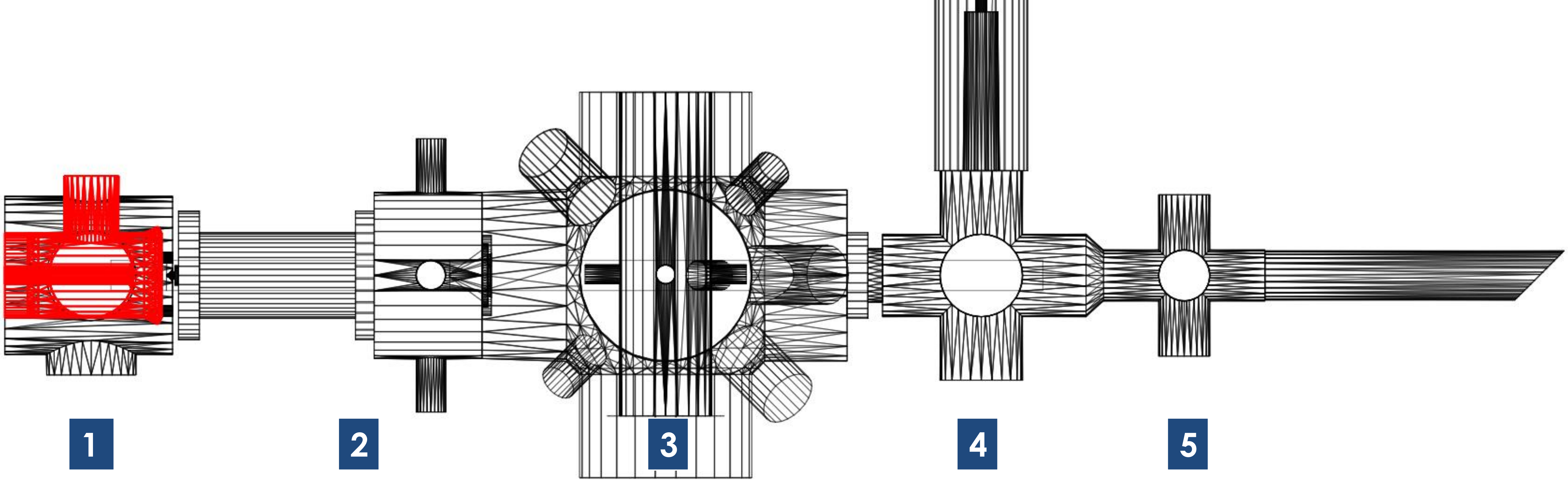



23% collimated
77% diffuse
ofile p tter
300
0
0
10
20
30
40
50
60
70
80
90
F#6943
F#6943 Incident angle [deg]
Show Facet
Add curve
Remove curve
Remove all
Normalize:
None (raw data)
Log Y
-> Plot
Dismiss

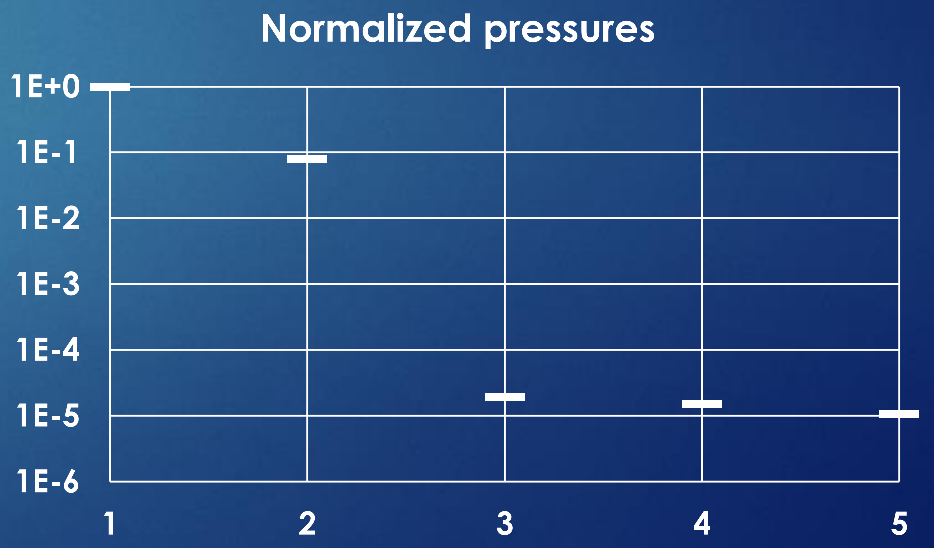

1.4E+17
1.2E+17
1E+17
8E+16
6E+16
4E+16
2E+16
0
1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76
Series76
Series71
Series66
Series61
Series56
Series51
Series46
Series41
Series36
Series31
Series26
Series21
Series16
Series11
Series6
Series1
Peak / bg ~ 55


Generating from skimmer 1
p = 0.0249

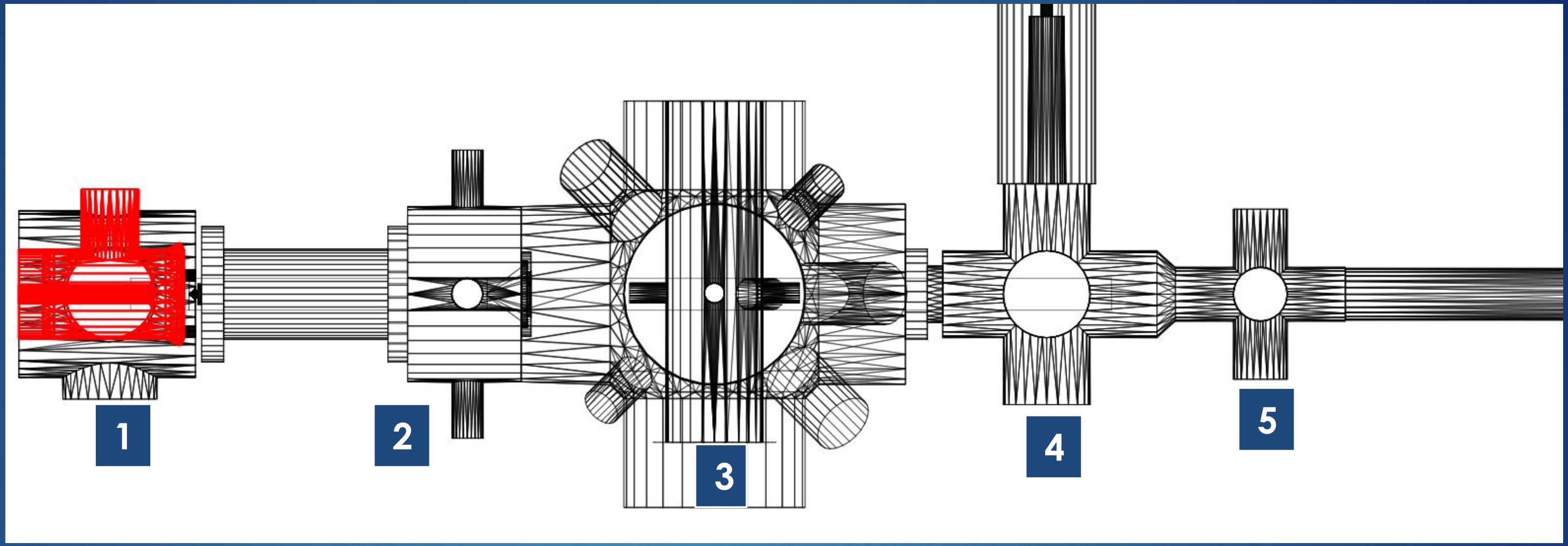

Generating from skimmer 2
p = 0.0242



		Norm.density and pressure
1	Between skimmers 1 - 2	1.00E+00
2	Between skimmers 2 - 3	7.80E-02
3	Interaction chamber	1.89E-05
4	Ionization chamber	1.51E-05
5	Last pump	1.04E-05

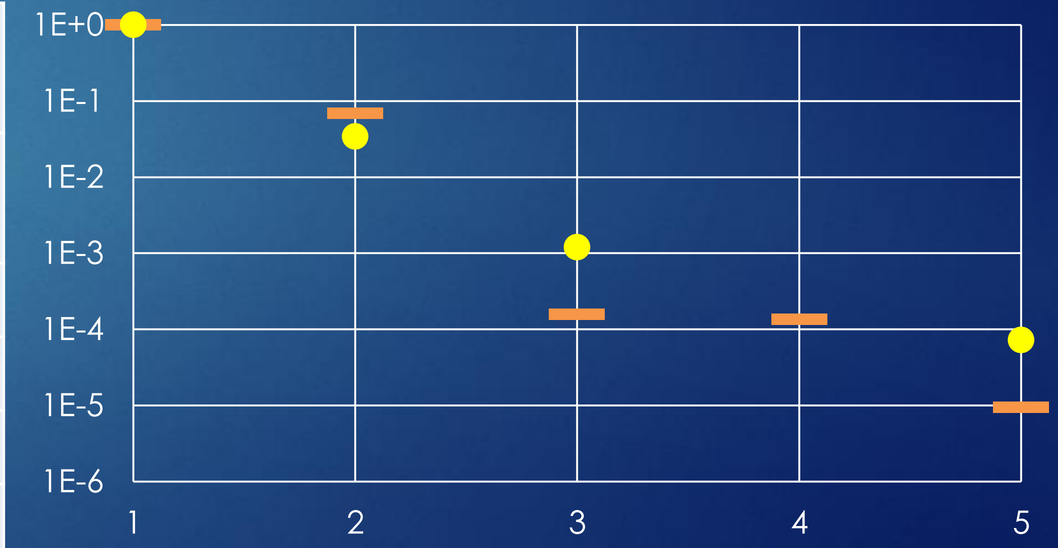


Morning update

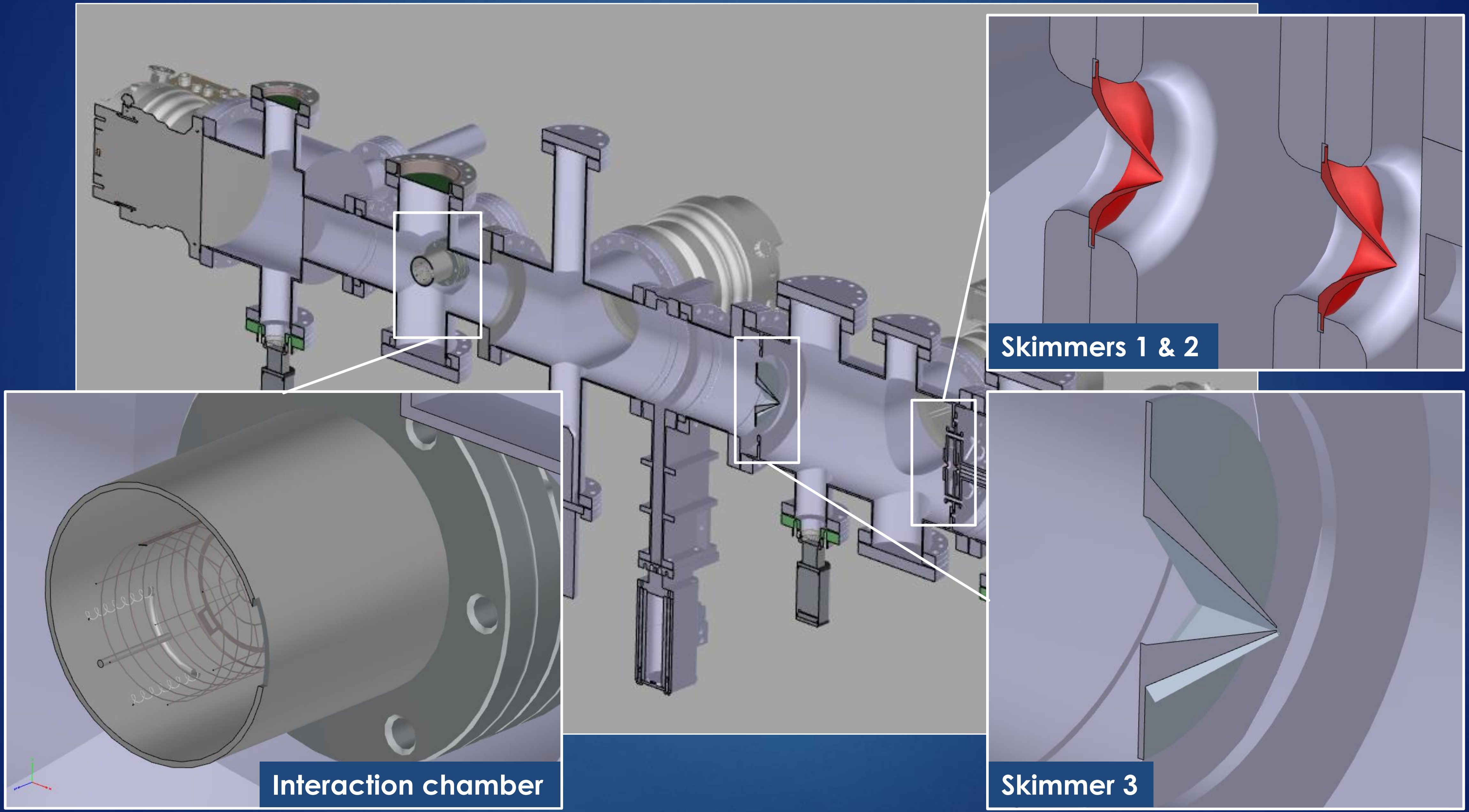


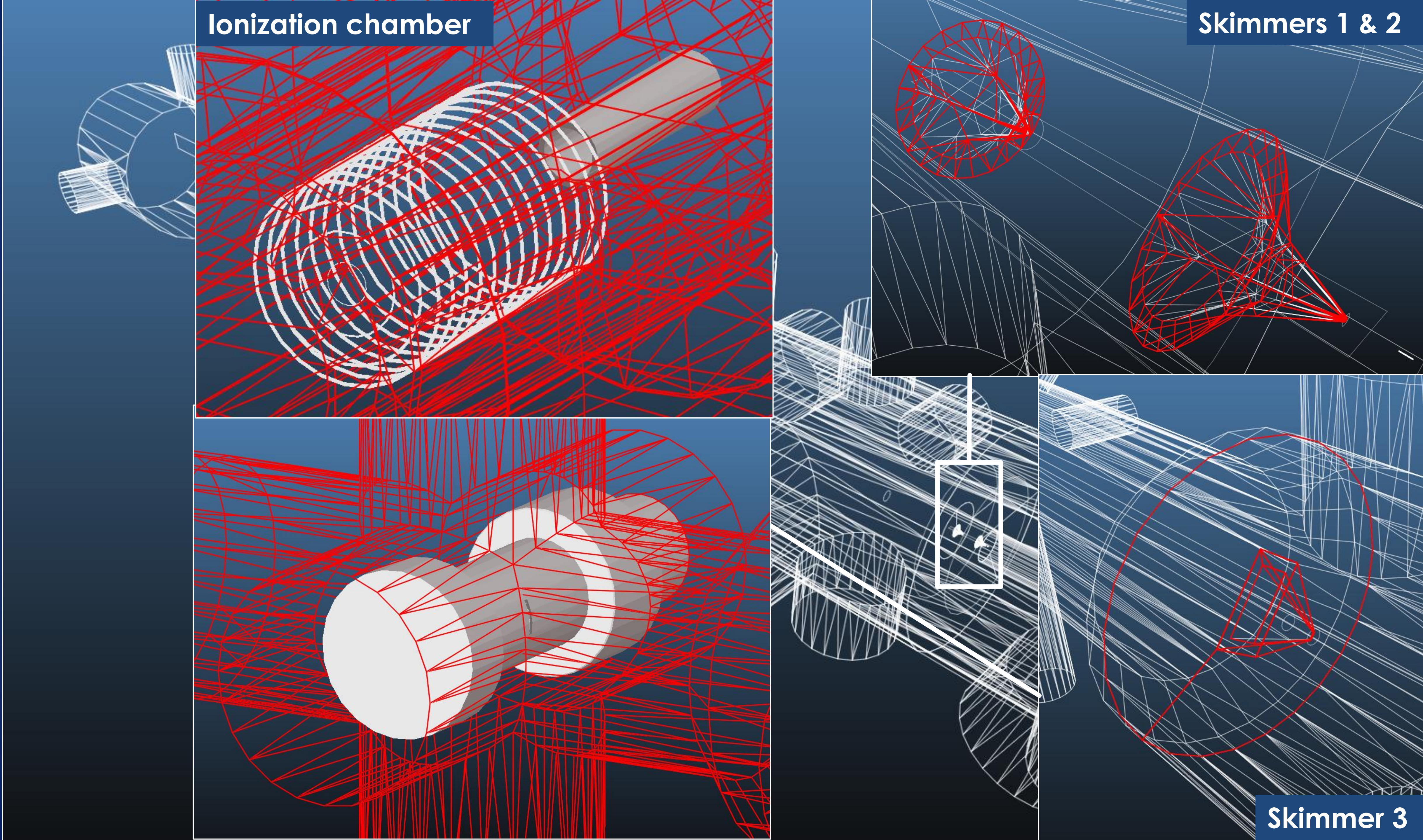
		Norm.density and pressure	Pressure	On	Off	Diff	Norm diff
1	Between skimmers 1 - 2	**1.0E+00**	**3.2E-03**	**6.5E-06**	**1.5E-06**	**5.0E-06**	**1.0E+00**
2	Between skimmers 2 - 3	**6.9E-02**	**2.2E-04**	**2.1E-07**	**4.0E-08**	**1.7E-07**	**3.4E-02**
3	Interaction chamber	**1.6E-04**	**5.0E-07**	**2.8E-08**	**2.2E-08**	**6.0E-09**	**1.2E-03**
4	Ionization chamber	**1.3E-04**	**4.3E-07**				
5	Last pump	**9.4E-06**	**3.0E-08**	**1.3E-09**	**9.4E-10**	**3.6E-10**	**7.2E-05**

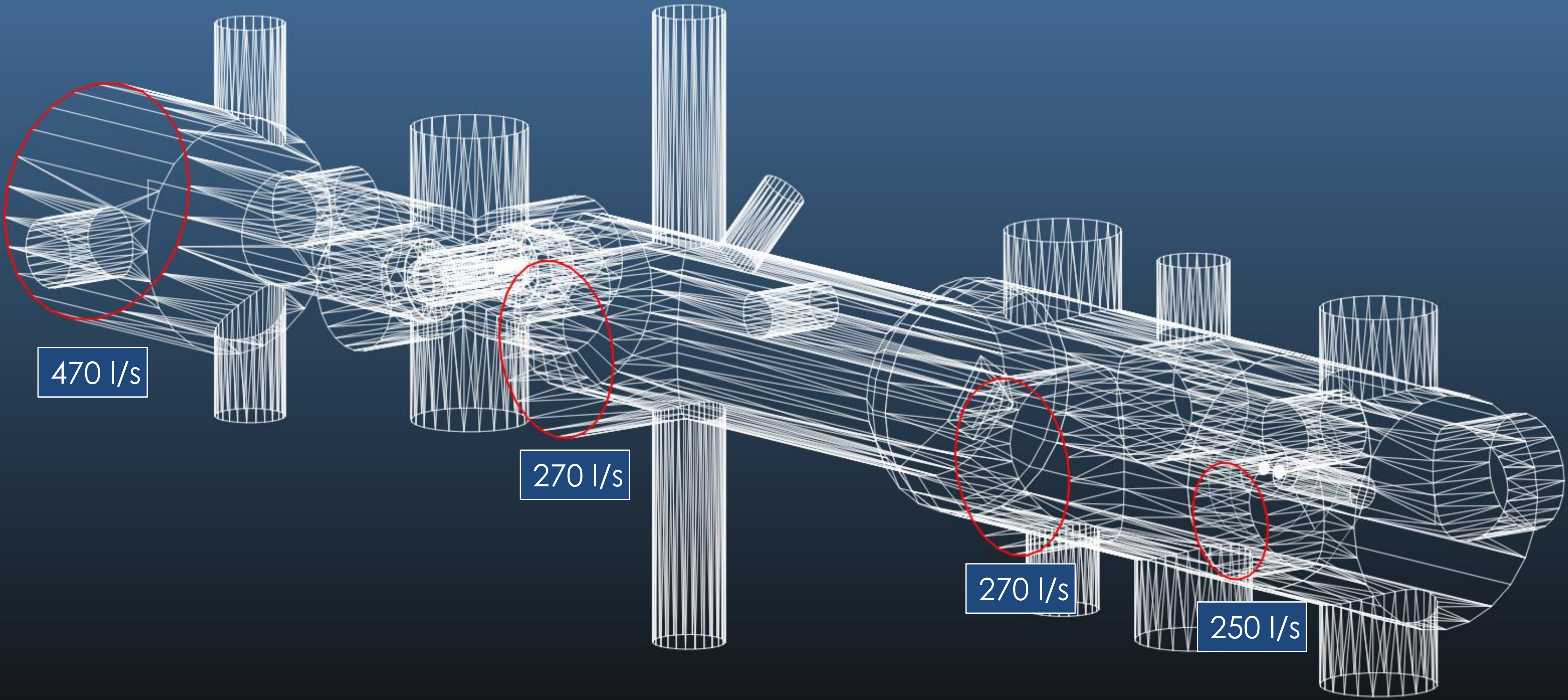
Normalized pressures



Part 3: Improved setup



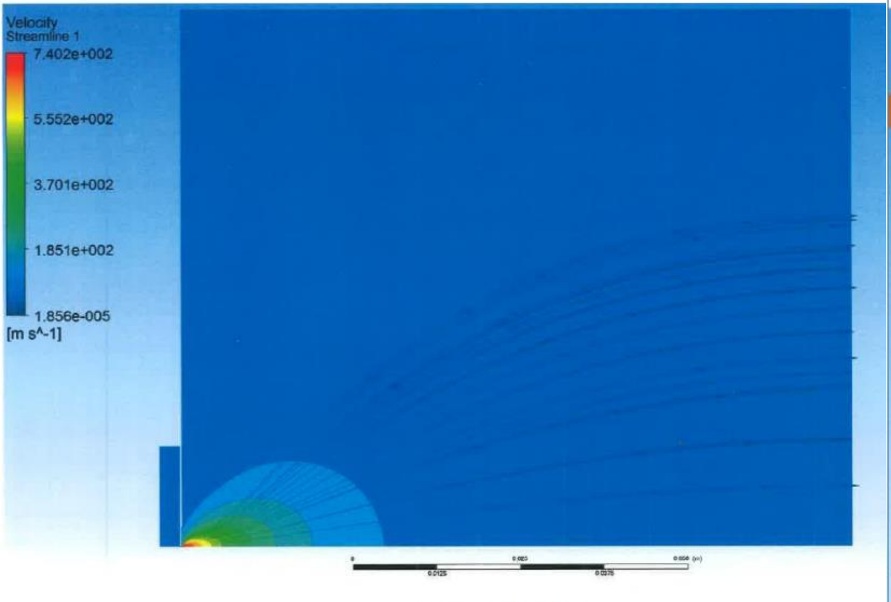

Ionization chamber
Skimmers 1 & 2
Skimmer 3



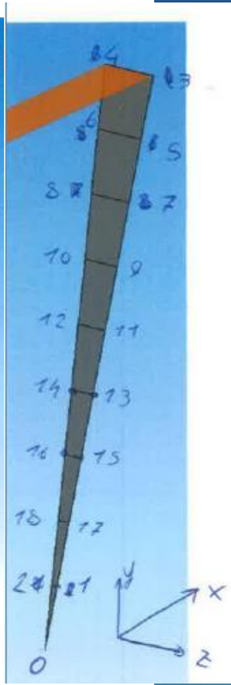
470 l/s
270 l/s
270 l/s
250 l/s

Input parameters:

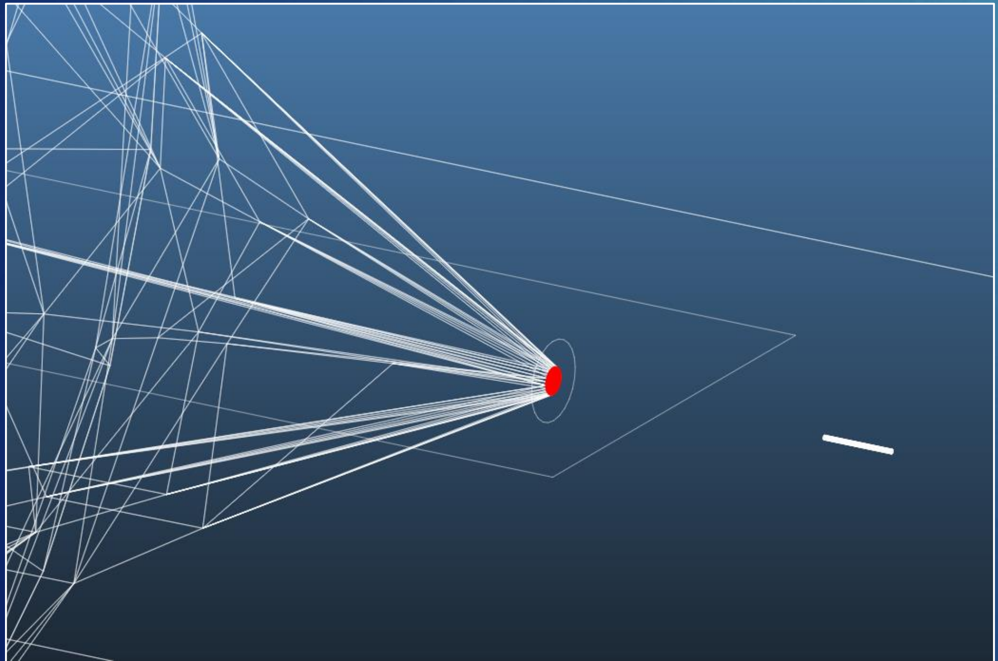
2. Viscous-flow regime input (P. Magagnin, personal communication, July 2016);

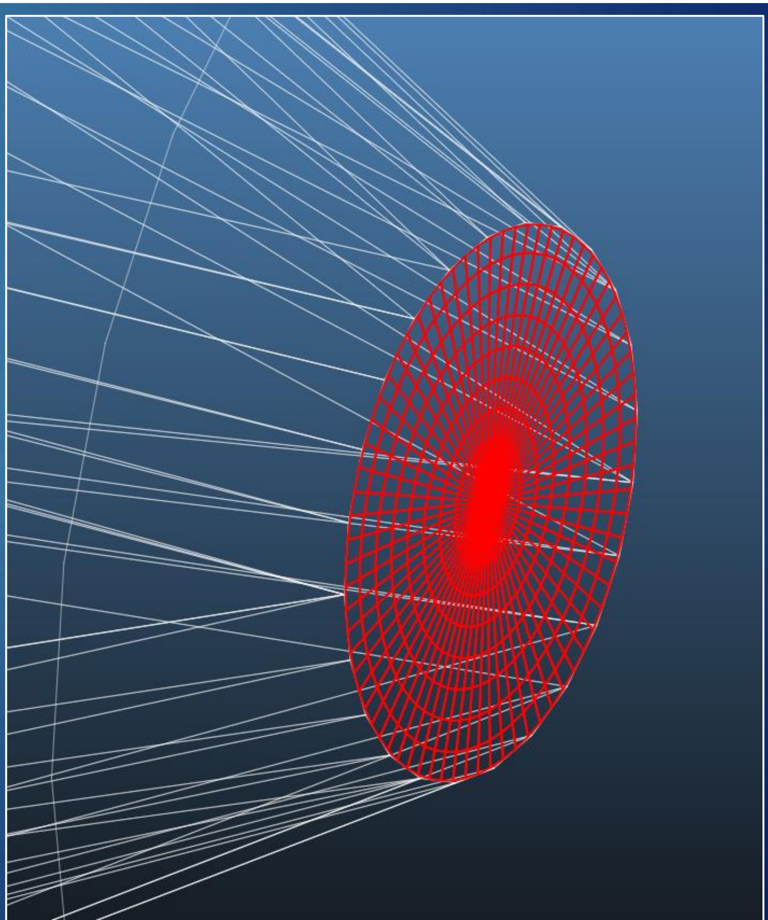


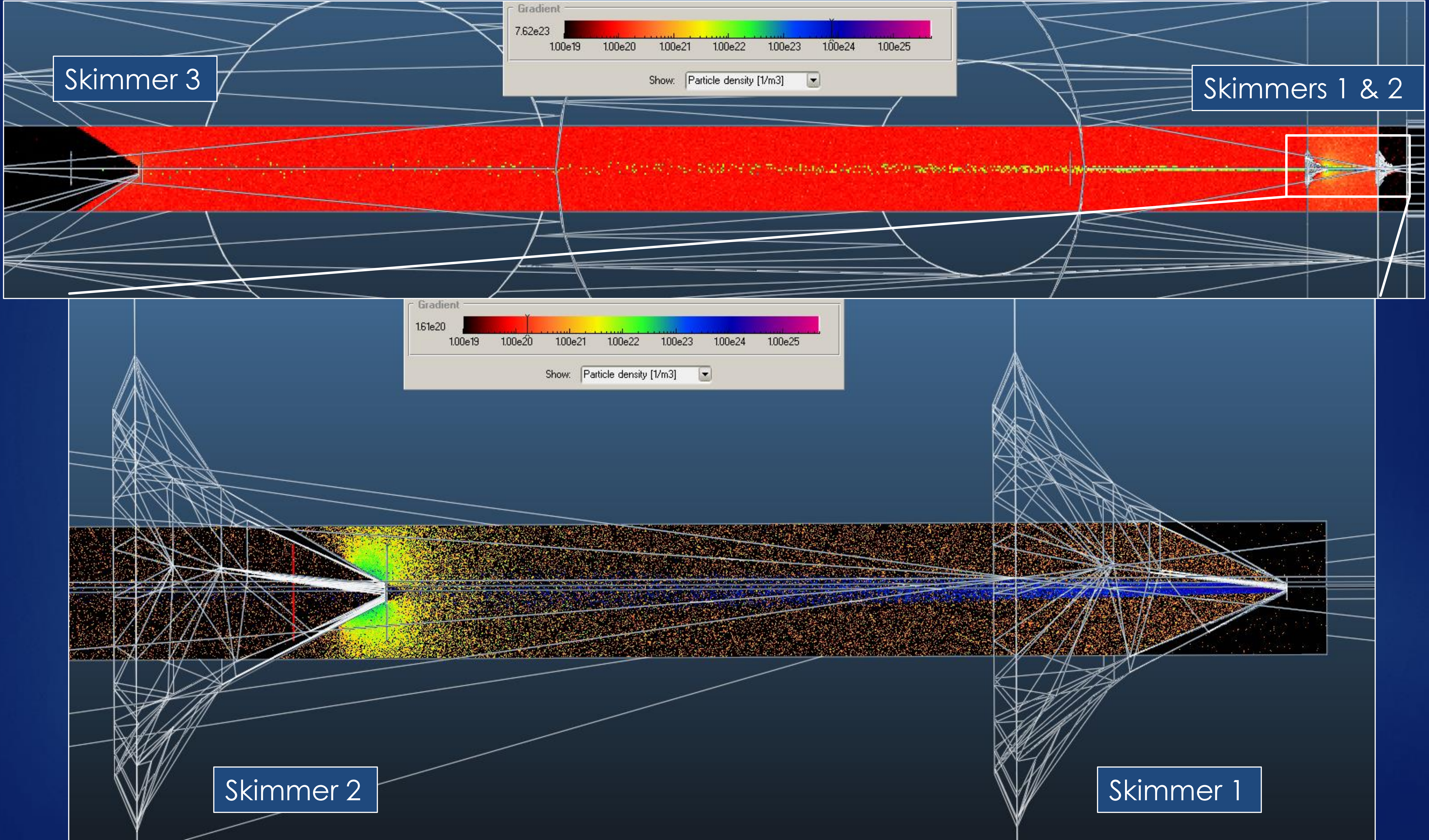
Horz. Scale: 50 mm



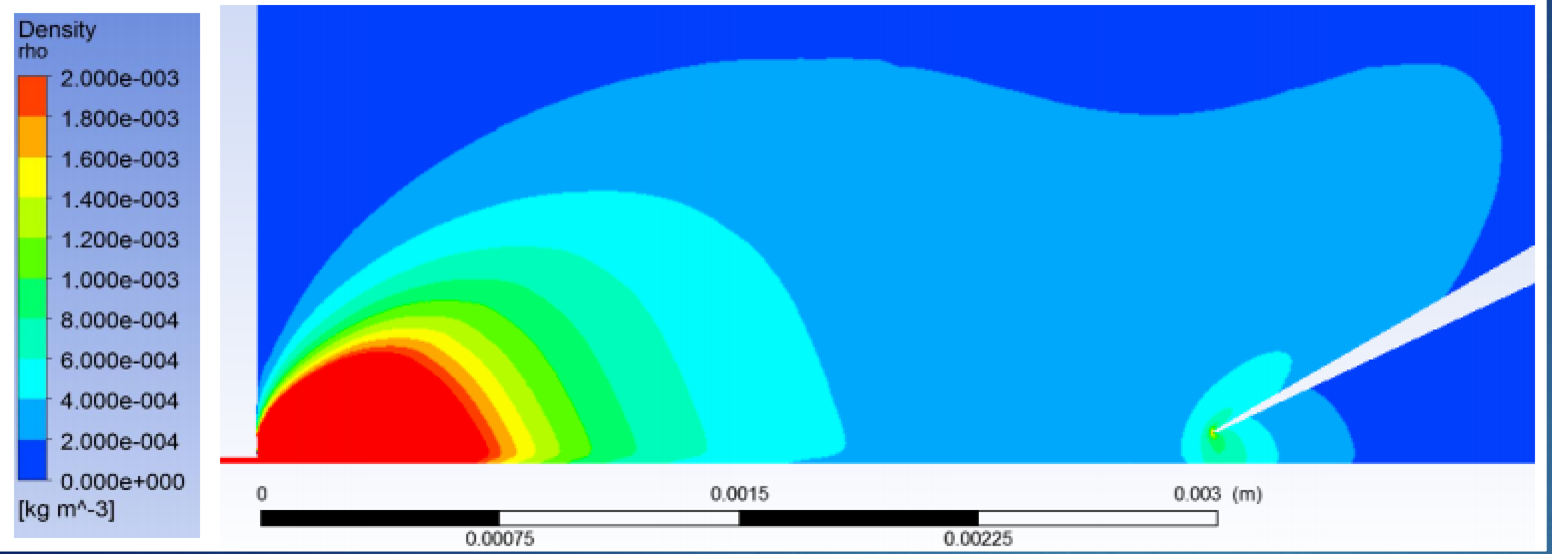
	A	B	C	D	E	F	G	H	I	J	K
1		X[m)	Y[m]	Z[m)	vel	vel u	vel v	vel w	angle	diffRAD	diffDEG
2	0	2.99E-03	0.00E+00	0.00E+00	5.9094E+02	5.9094E+02	0.00E+00	0.00E+00	0		
3	2	2.99E-03	1.00E-05	0.00E+00	5.9088E+02	5.9088E+02	1.53E+00	0.00E+00	0.002586	0.002586	0.148174
4	17	2.99E-03	2.00E-05	0.00E+00	5.9086E+02	5.9085E+02	2.93E+00	0.00E+00	0.004966	0.00238	0.136355
5	16	2.99E-03	3.00E-05	0.00E+00	5.9084E+02	5.9082E+02	4.45E+00	0.00E+00	0.007534	0.002568	0.14713
6	14	2.99E-03	4.00E-05	0.00E+00	5.9080E+02	5.9077E+02	6.00E+00	0.00E+00	0.01016	0.002626	0.150453
7	11	2.99E-03	5.00E-05	0.00E+00	5.9074E+02	5.9069E+02	7.56E+00	0.00E+00	0.0128	0.00264	0.15128
8	9	2.99E-03	6.00E-05	0.00E+00	5.9066E+02	5.9059E+02	9.12E+00	0.00E+00	0.015447	0.002647	0.151646
9	8	2.99E-03	7.00E-05	0.00E+00	5.9057E+02	5.9048E+02	1.07E+01	0.00E+00	0.0181	0.002653	0.152016
10	5	2.99E-03	8.00E-05	0.00E+00	5.9047E+02	5.9034E+02	1.23E+01	0.00E+00	0.02077	0.00267	0.152995
11	4	2.99E-03	9.00E-05	0.00E+00	5.9034E+02	5.9018E+02	1.39E+01	0.00E+00	0.023483	0.002713	0.155452

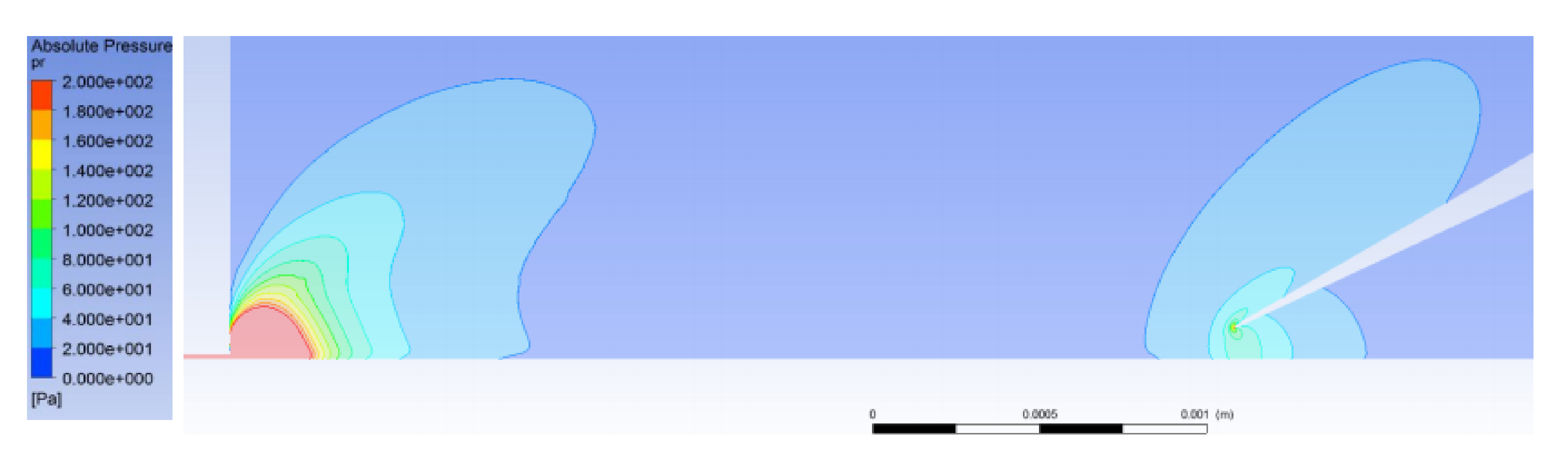






Skimmer 3
Skimmers 1 & 2
Gradient
7.62e23
1.00e19
1.00e20
1.00e21
1.00e22
1.00e23
1.00e24
1.00e25
Show:
Particle density [1/m3]
Gradient
1.61e20
1.00e19
1.00e20
1.00e21
1.00e22
1.00e23
1.00e24
1.00e25
Show:
Particle density [1/m3]
Skimmer 2
Skimmer 1





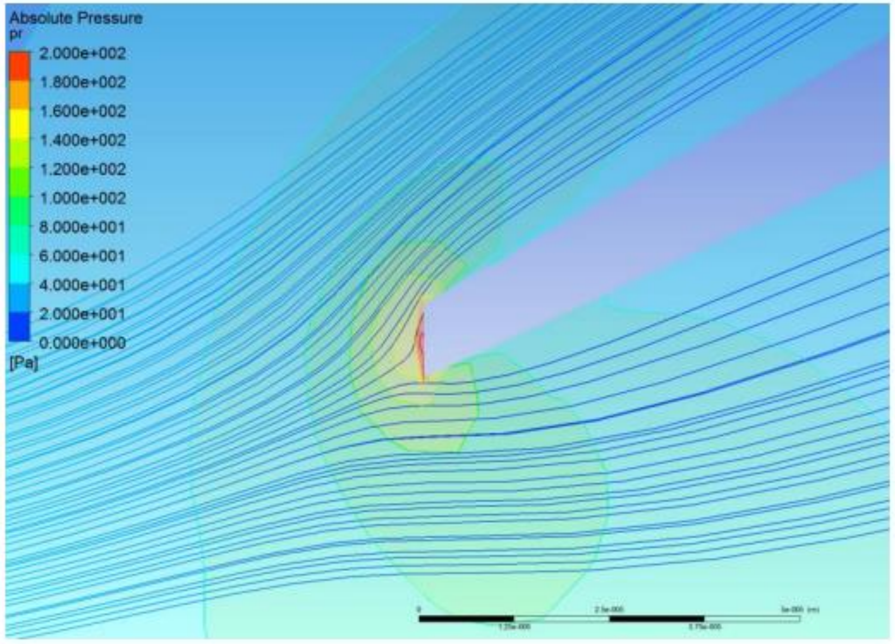
For pressure P_0 = 0.52517275 mmHg = 0.02067522 inHg = 0.07 kPa

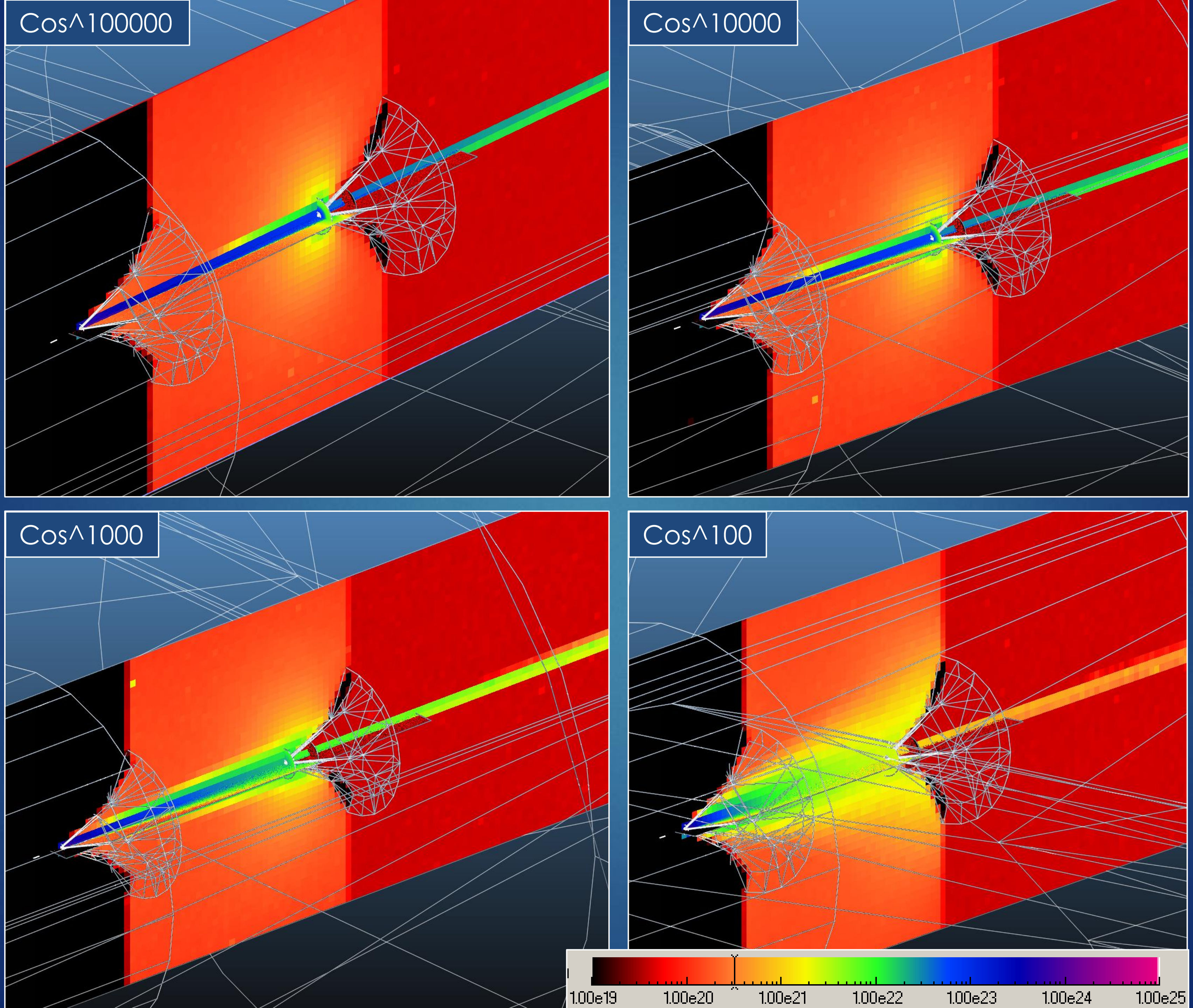
and temperature **T**= 300 K = 26.8500000 C = 80.3300000 F,

Molecules of diameter 3.64 x 10^{-10} meters (angstroms)

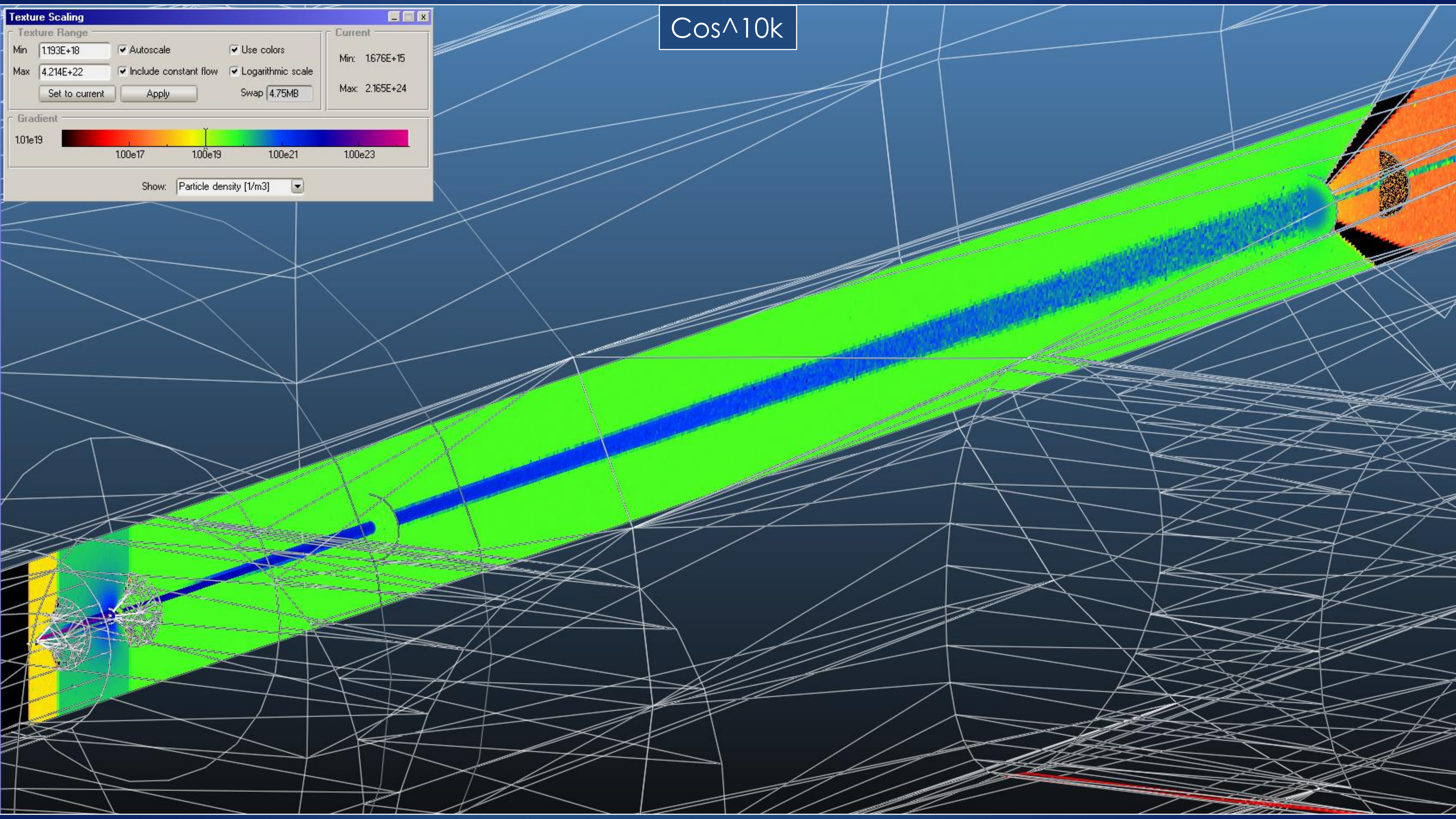
should have a mean free path of $\lambda = \dfrac{RT}{\sqrt{2}\pi d^2 N_A P}$ = 1.0051748 x 10^ -4 m

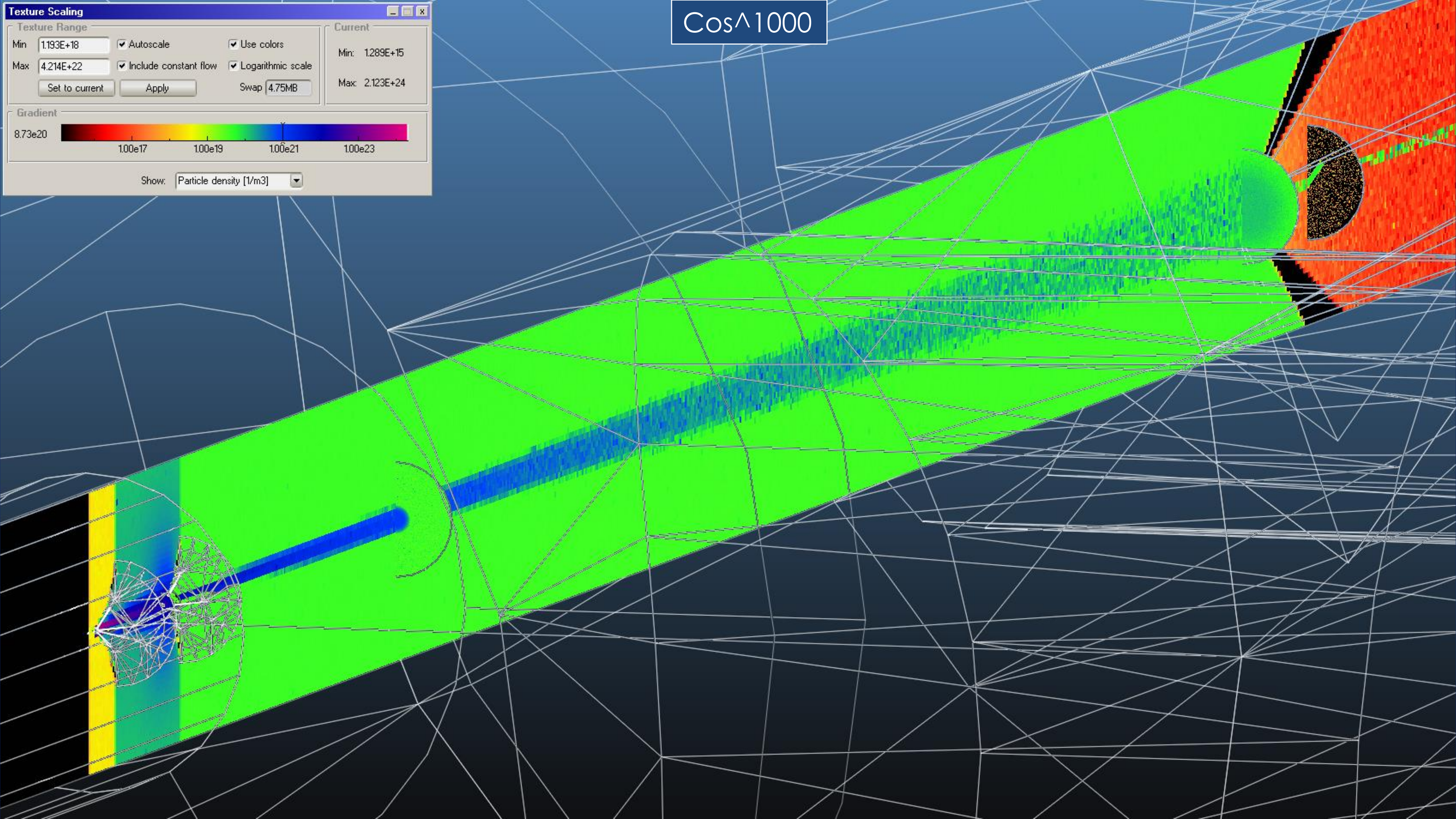
- Streamlines and absolute pressure on background

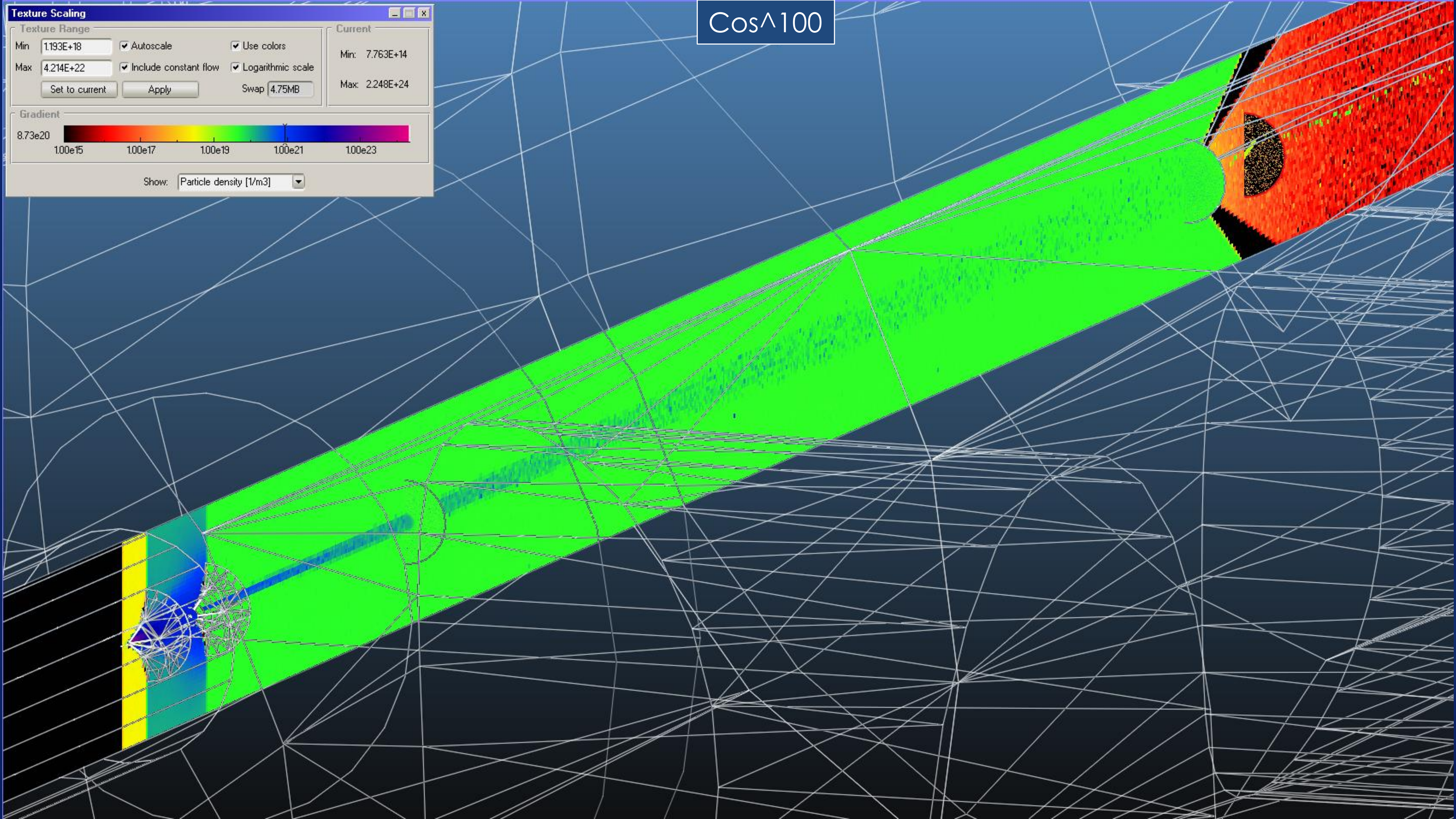


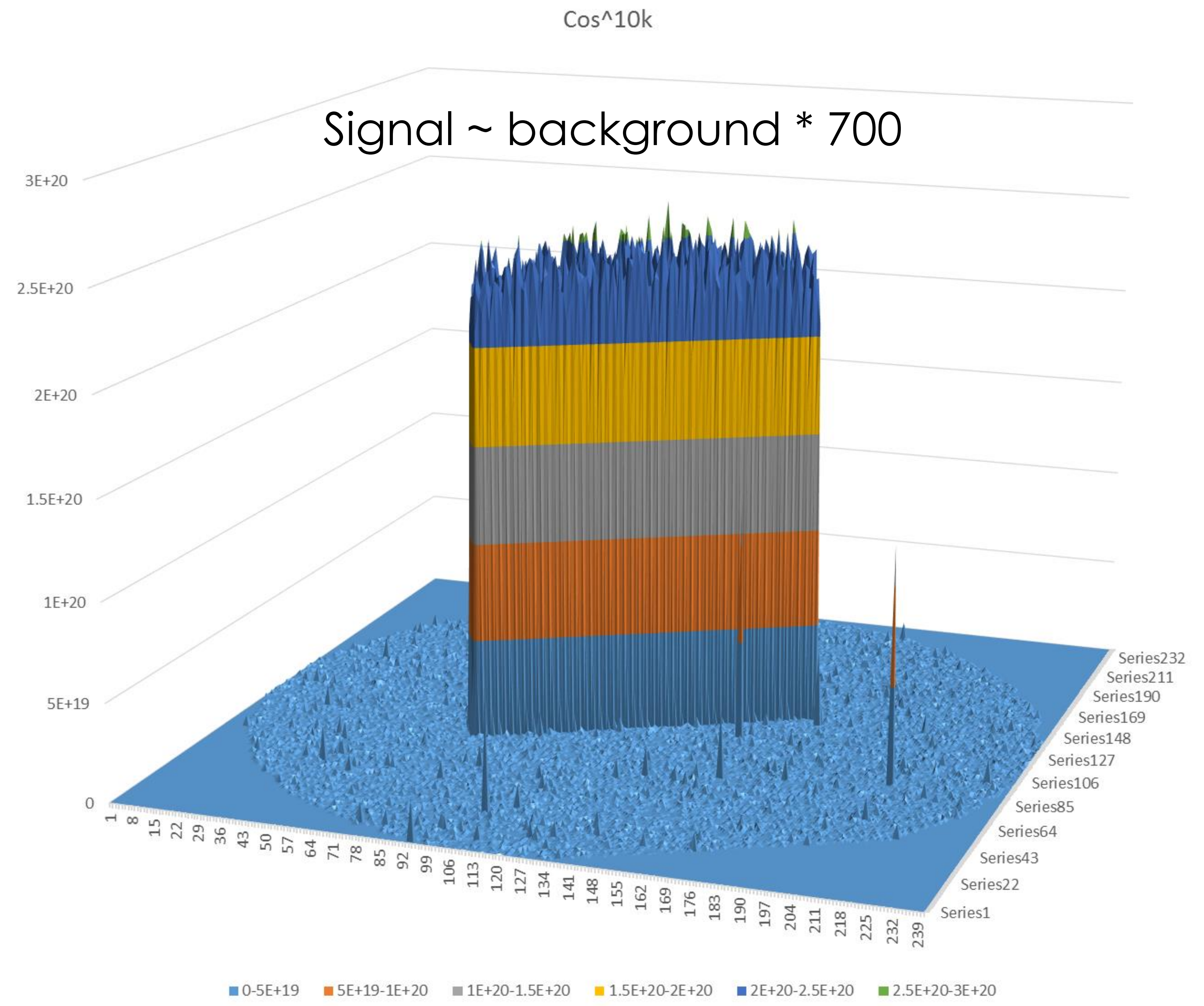

Cos^100000
Cos^10000
Cos^1000
Cos^100
1.00e19
1.00e20
1.00e21
1.00e22
1.00e23
1.00e24
1.00e25

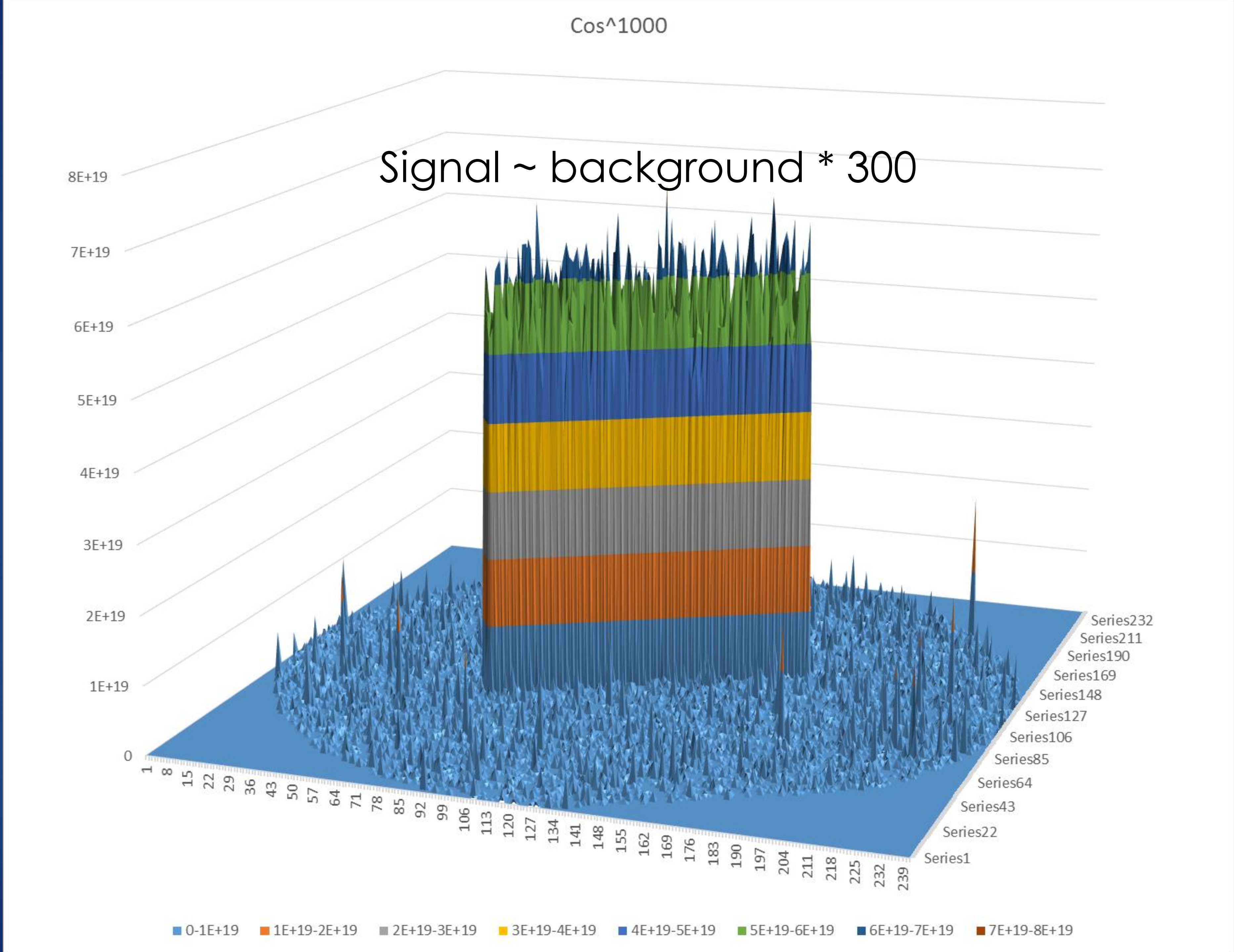
Cos^10k


Texture Scaling
Texture Range
Min 1.193E+18
Max 4.214E+22
Autoscale
Include constant flow
Use colors
Logarithmic scale
Set to current
Apply
Swap 4.75MB
Current
Min: 1.676E+15
Max: 2.165E+24
Gradient
1.01e19
1.00e17
1.00e19
1.00e21
1.00e23
Show: Particle density [1/m3]

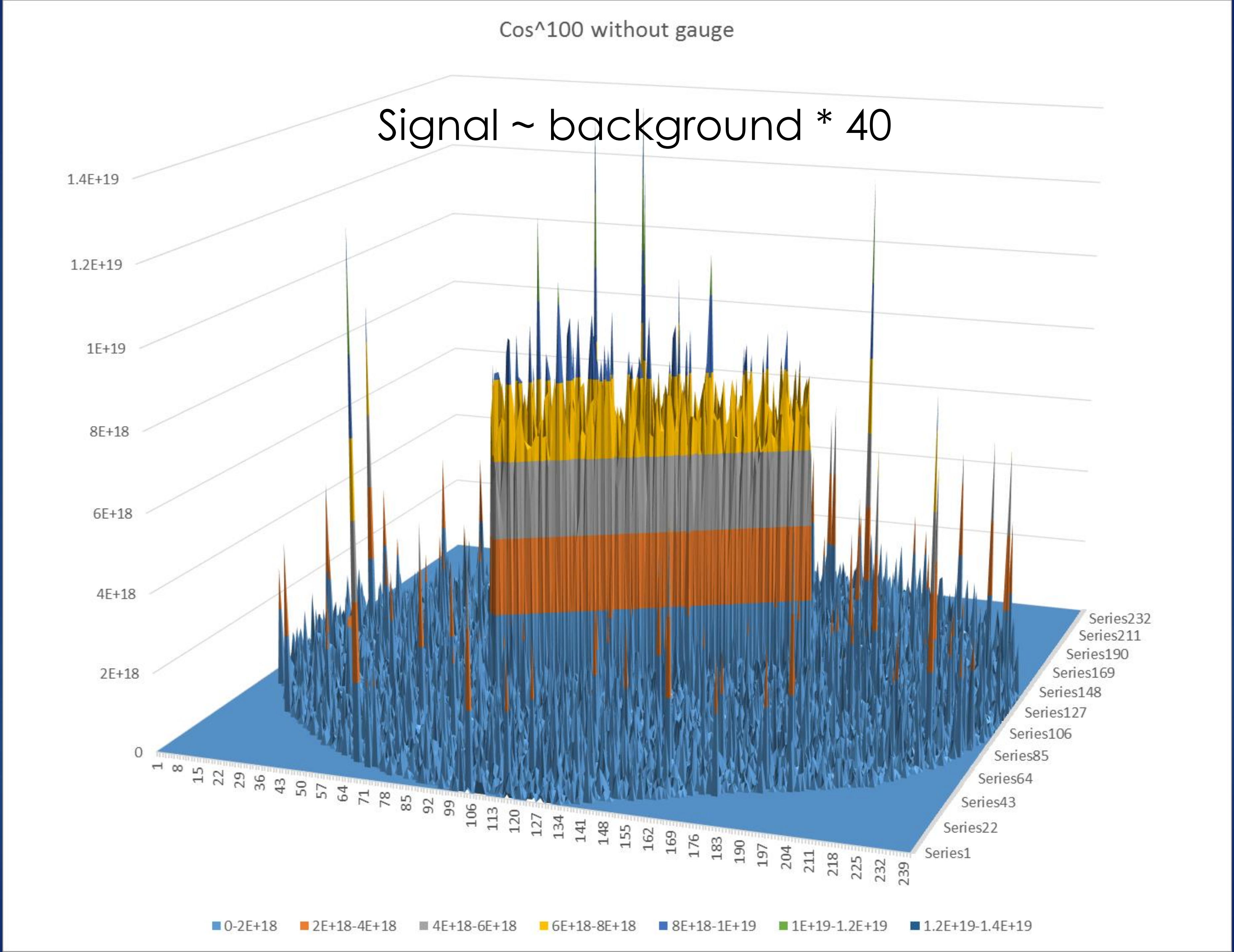

Cos^1000
Texture Scaling
Texture Range
Min 1.193E+18
Max 4.214E+22
Autoscale
Include constant flow
Use colors
Logarithmic scale
Set to current
Apply
Swap 4.75MB
Current
Min: 1.289E+15
Max: 2.123E+24
Gradient
8.73e20
1.00e17
1.00e19
1.00e21
1.00e23
Show: Particle density [1/m3]

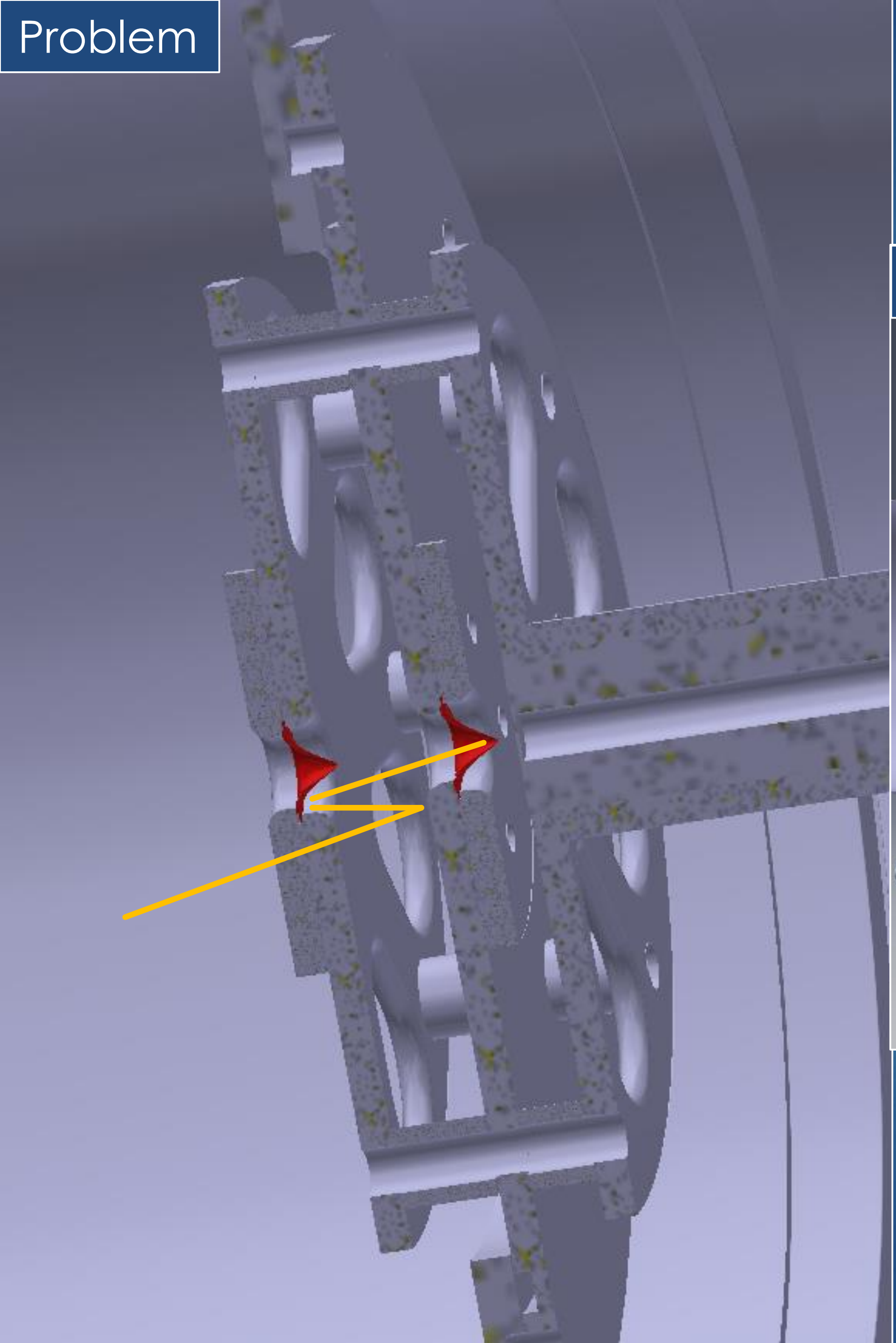

Cos^100
Texture Scaling
Texture Range
Min
1.193E+18
Max
4.214E+22
Autoscale
Include constant flow
Use colors
Logarithmic scale
Set to current
Apply
Swap
4.75MB
Current
Min: 7.763E+14
Max: 2.248E+24
Gradient
8.73e20
1.00e15
1.00e17
1.00e19
1.00e21
1.00e23
Show:
Particle density [1/m3]

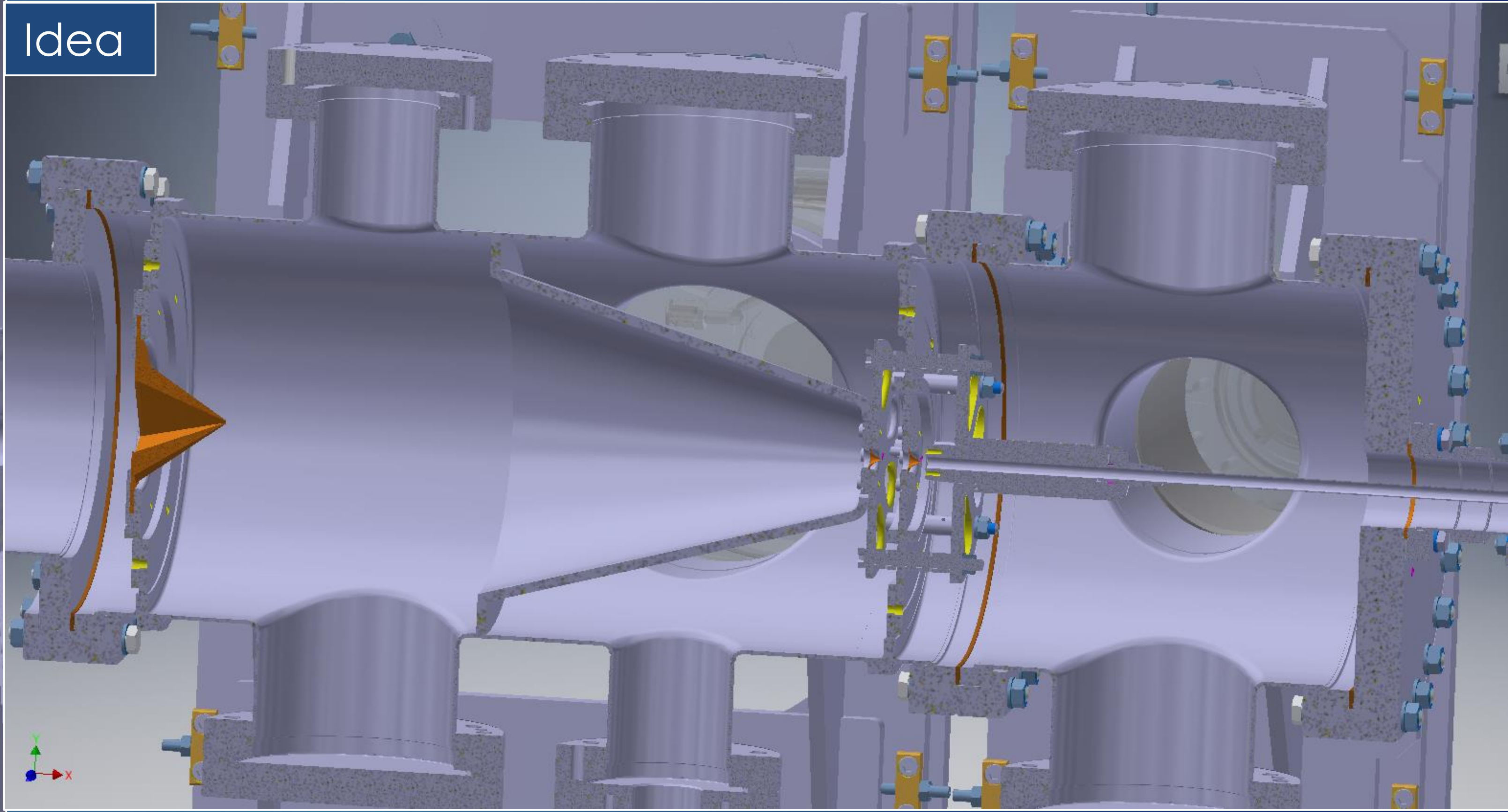

Cos^10k
Signal ~ background * 700
3E+20
2.5E+20
2E+20
1.5E+20
1E+20
5E+19
0
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162 169 176 183 190 197 204 211 218 225 232 239
Series1
Series22
Series43
Series64
Series85
Series106
Series127
Series148
Series169
Series190
Series211
Series232
0-5E+19
5E+19-1E+20
1E+20-1.5E+20
1.5E+20-2E+20
2E+20-2.5E+20
2.5E+20-3E+20

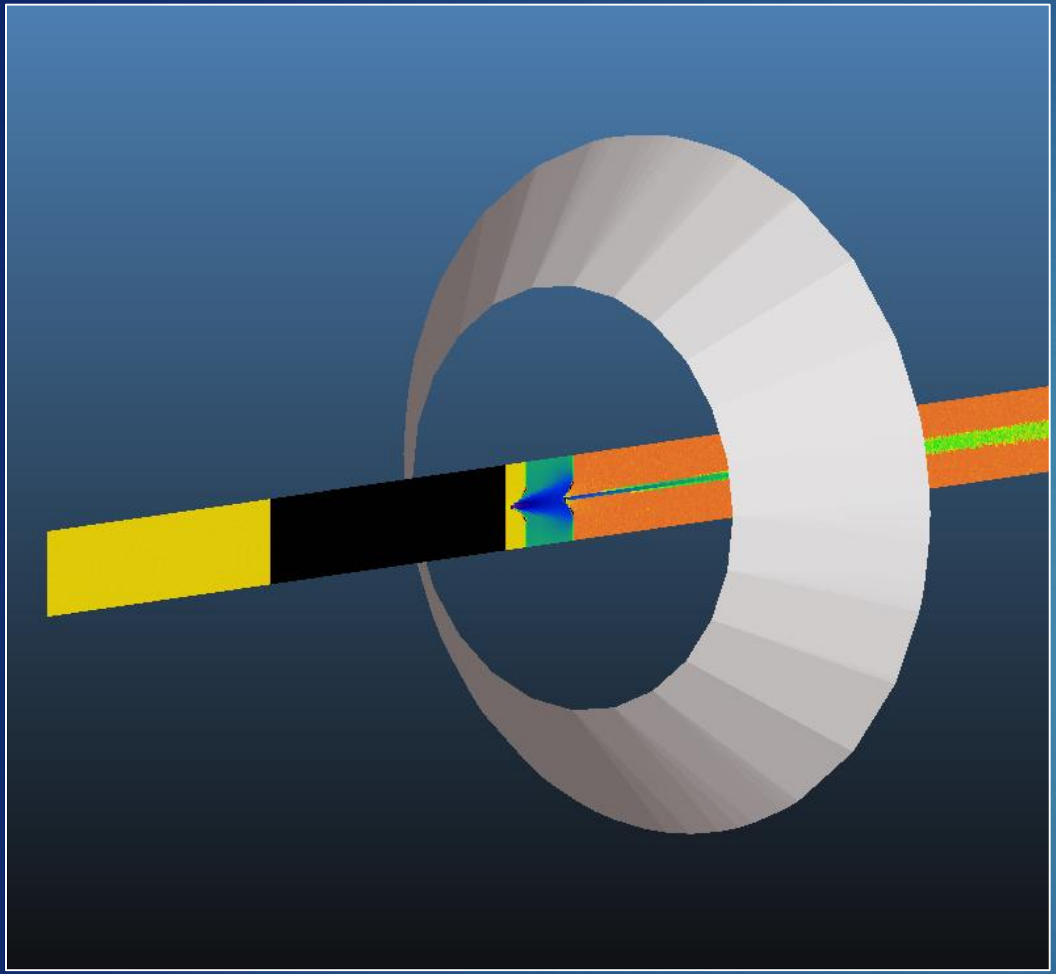


Cos^1000
Signal ~ background * 300
8E+19
7E+19
6E+19
5E+19
4E+19
3E+19
2E+19
1E+19
0
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162 169 176 183 190 197 204 211 218 225 232 239
Series232
Series211
Series190
Series169
Series148
Series127
Series106
Series85
Series64
Series43
Series22
Series1
0-1E+19
1E+19-2E+19
2E+19-3E+19
3E+19-4E+19
4E+19-5E+19
5E+19-6E+19
6E+19-7E+19
7E+19-8E+19

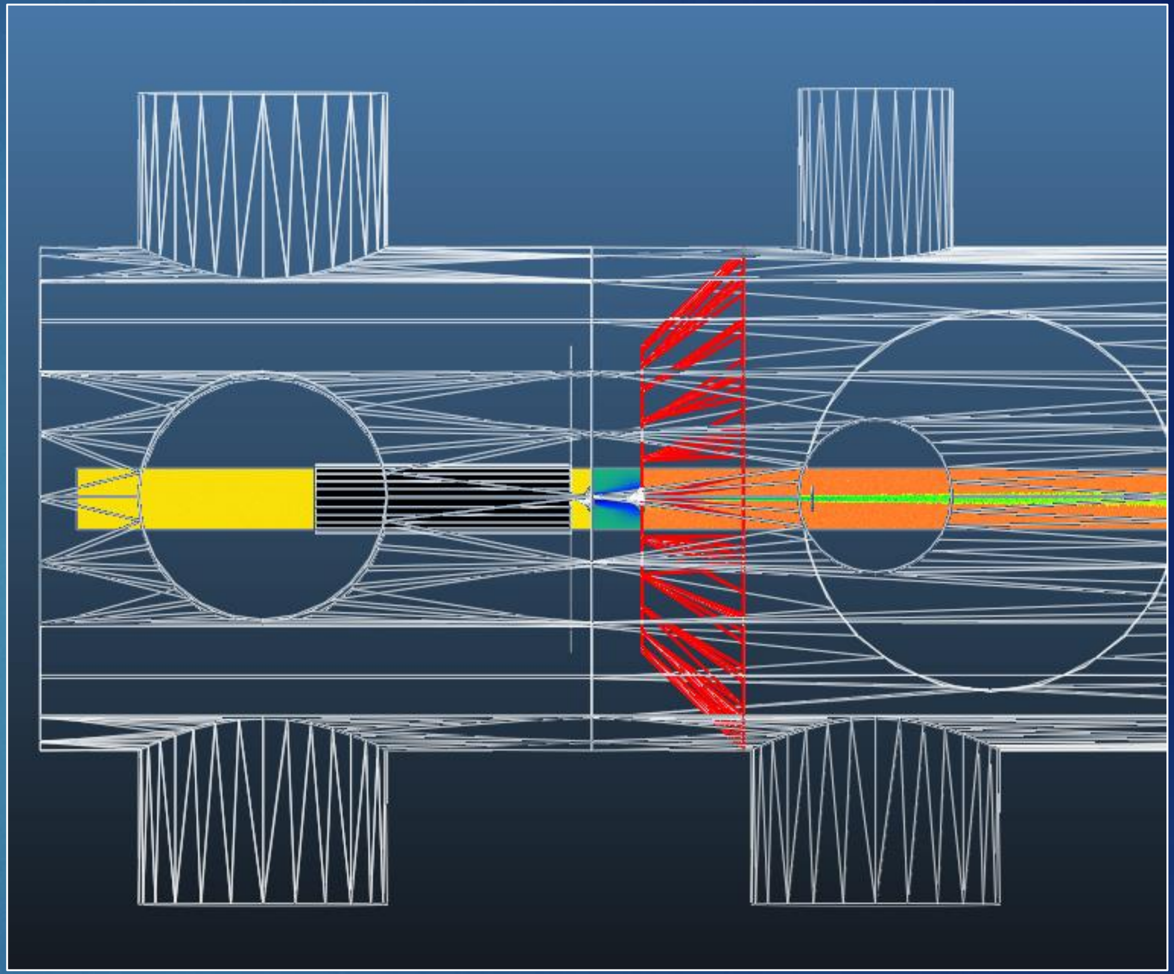

Cos^100 without gauge
Signal ~ background * 40
1.4E+19
1.2E+19
1E+19
8E+18
6E+18
4E+18
2E+18
0
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162 169 176 183 190 197 204 211 218 225 232 239
Series232
Series211
Series190
Series169
Series148
Series127
Series106
Series85
Series64
Series43
Series22
Series1
0-2E+18
2E+18-4E+18
4E+18-6E+18
6E+18-8E+18
8E+18-1E+19
1E+19-1.2E+19
1.2E+19-1.4E+19


Problem


Idea



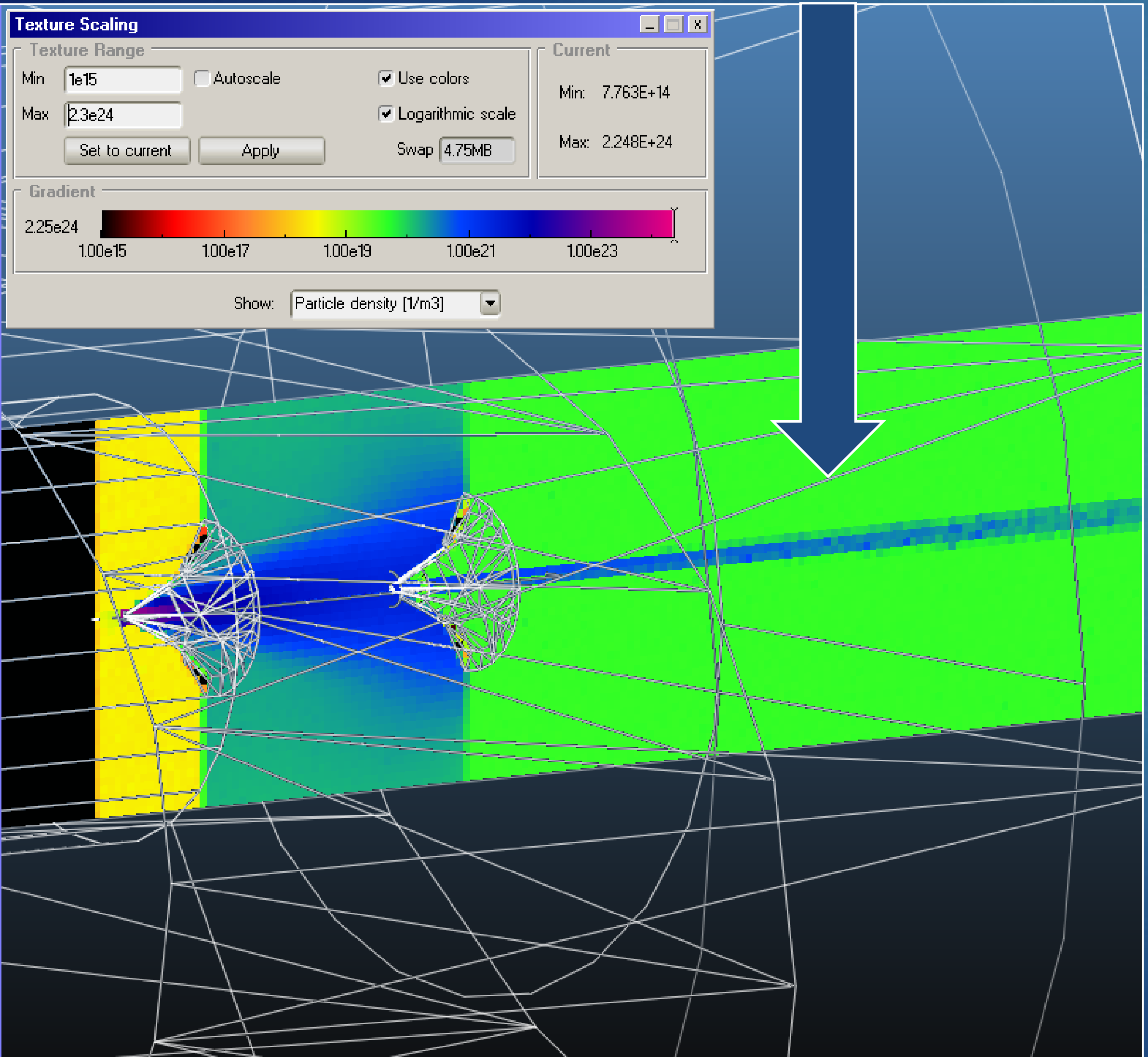
Created separator collar to isolate the volume between skimmers 1 and 2 from the one between 2 and 3



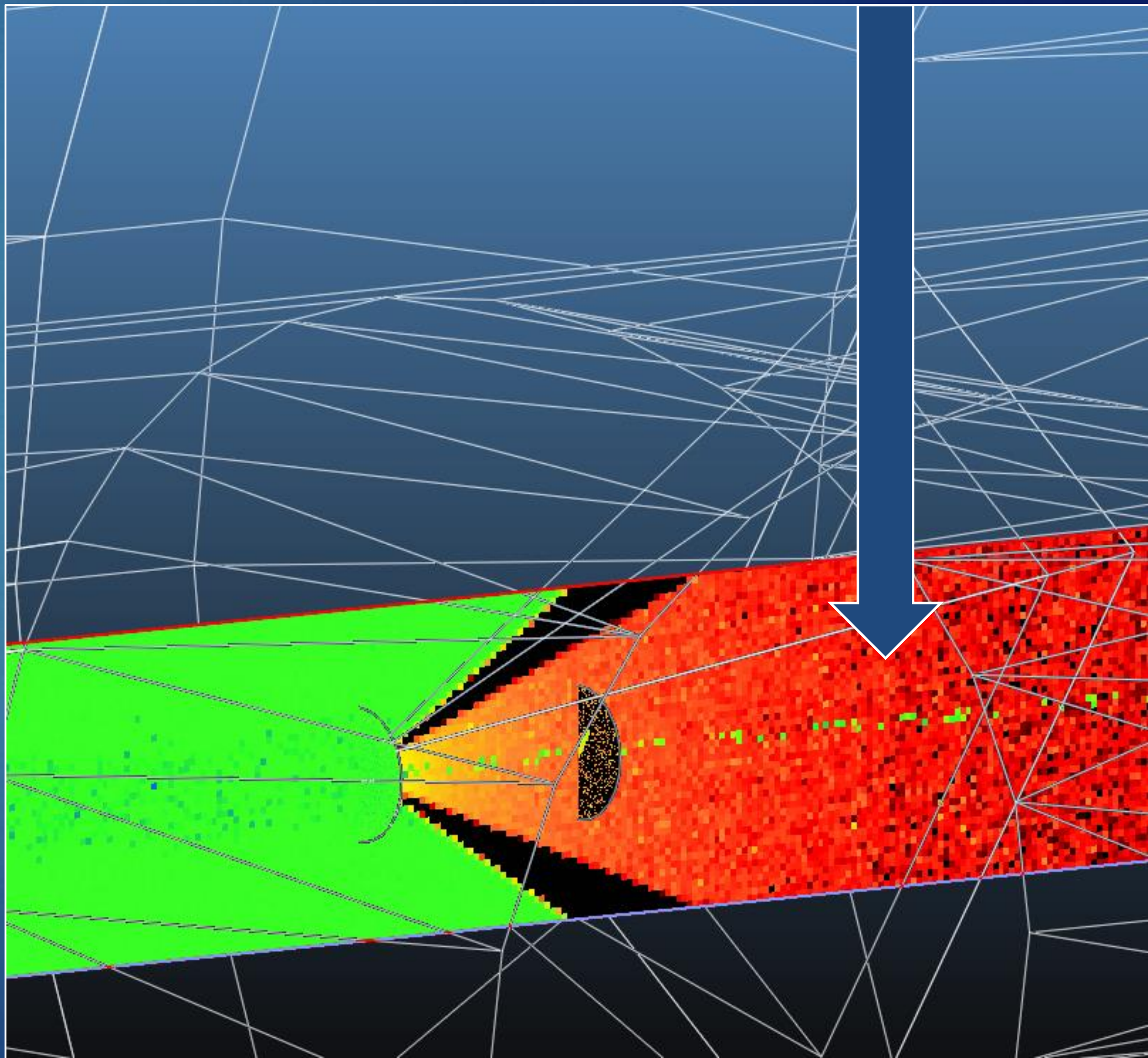
Inserted it so that molecules bouncing off skimmer 2 can't make it to the next volume

Original scenario
Cos^100 spatial distribution
700l/s shared pumping

Background density (arb.units): 4E19



Background density (arb.units): 4E16

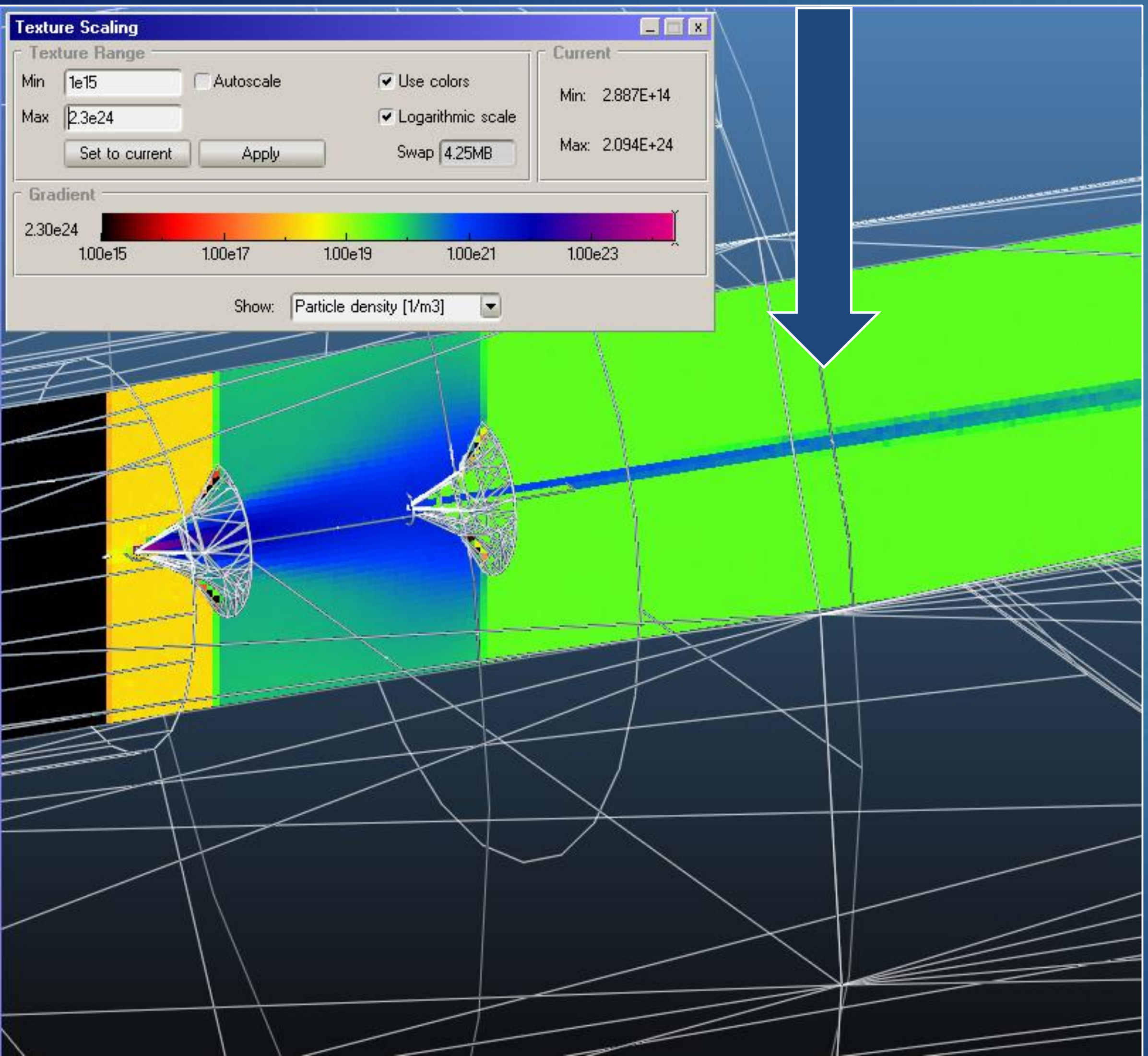


Double pumping (idea during the meeting)

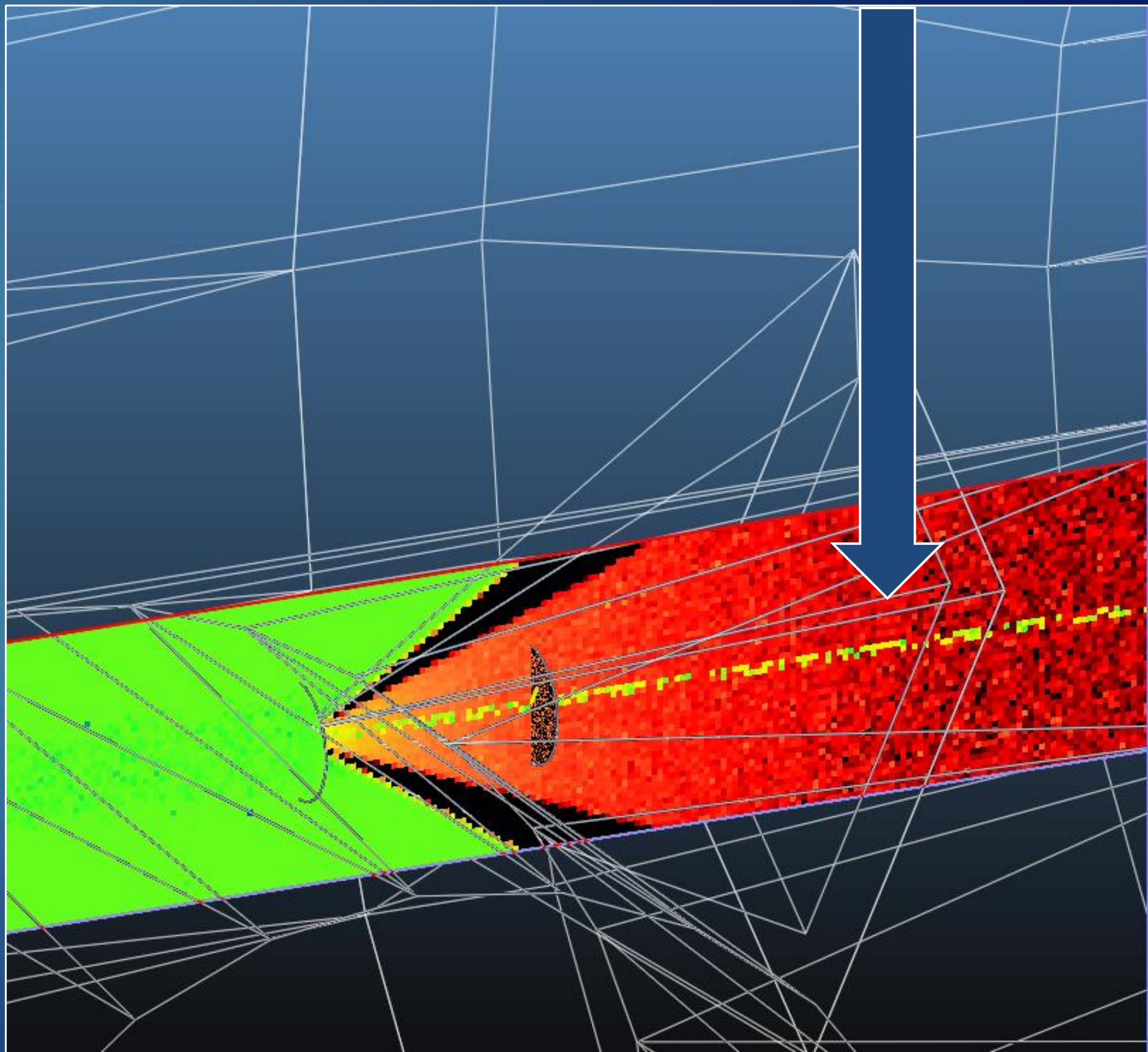
Cos^100 spatial distribution

1400l/s shared pumping

Background density (arb.units): 2.3E19
(~double pumping, half background)



Background density (arb.units): 1.8E16
(~double pumping, half background)

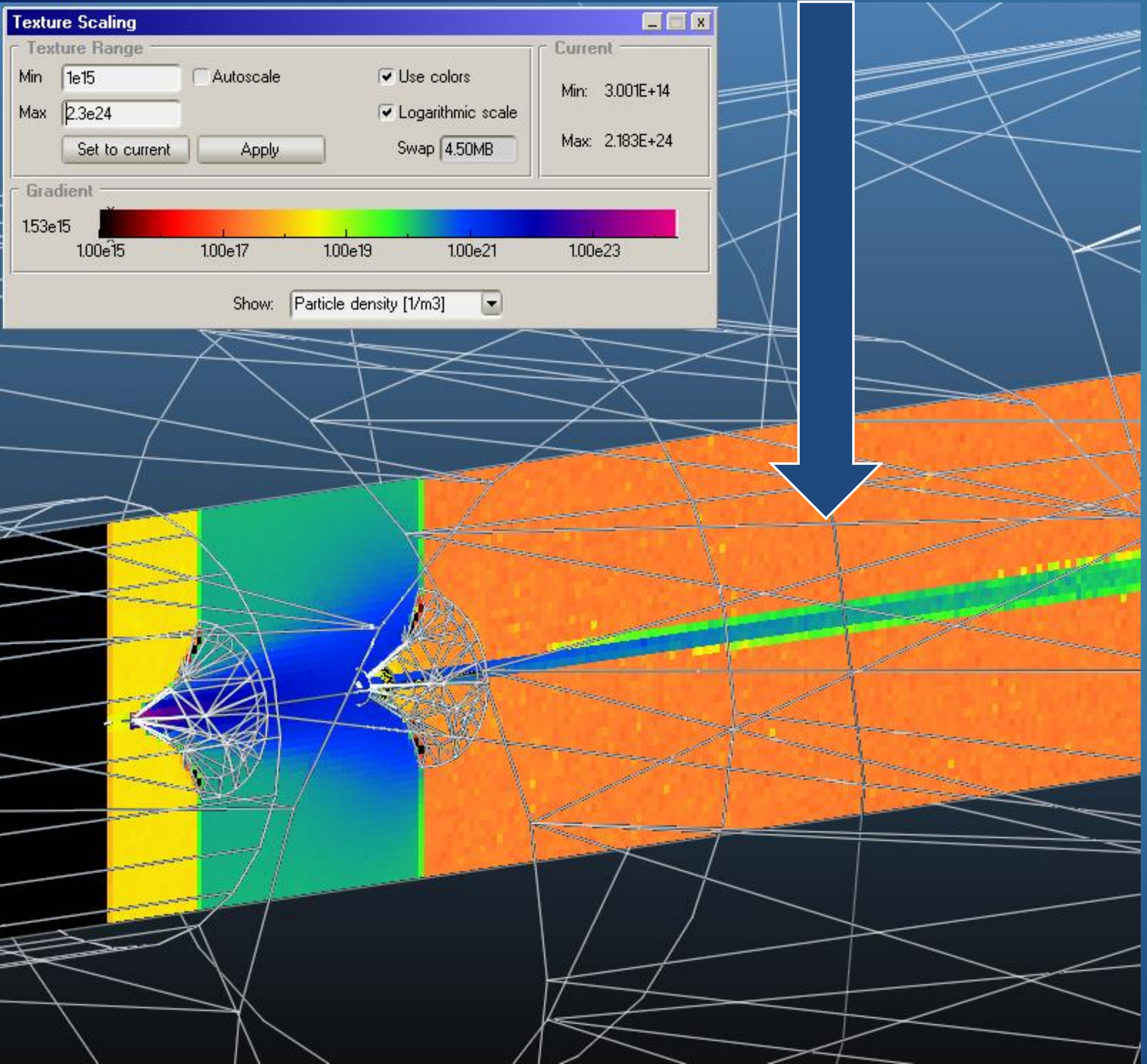


Differential pumping

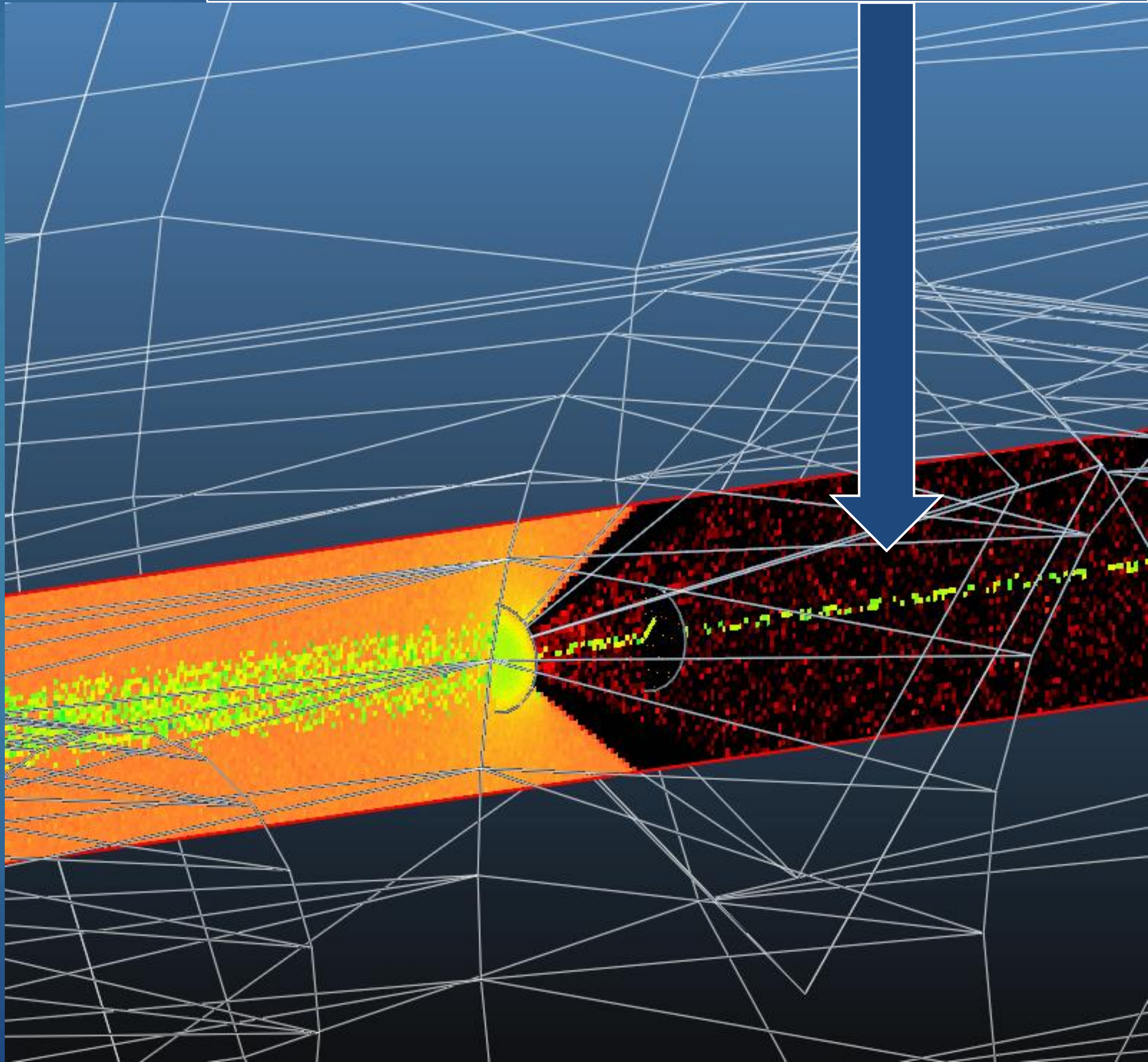
Cos^100 spatial distribution

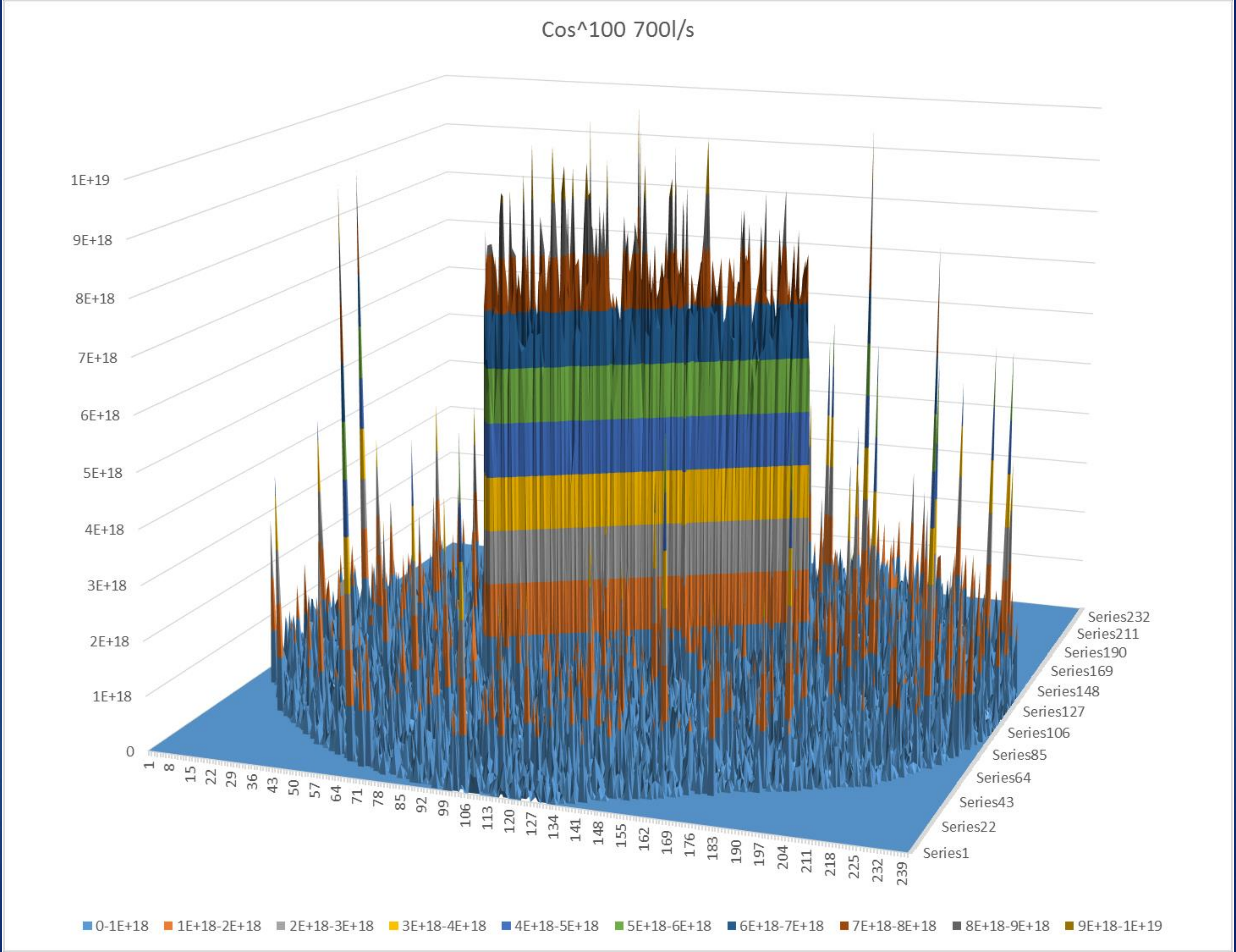
Individual pumping, 2*700l/s

Background density (arb.units): 2.2E17
(background reduced by **2 orders**)

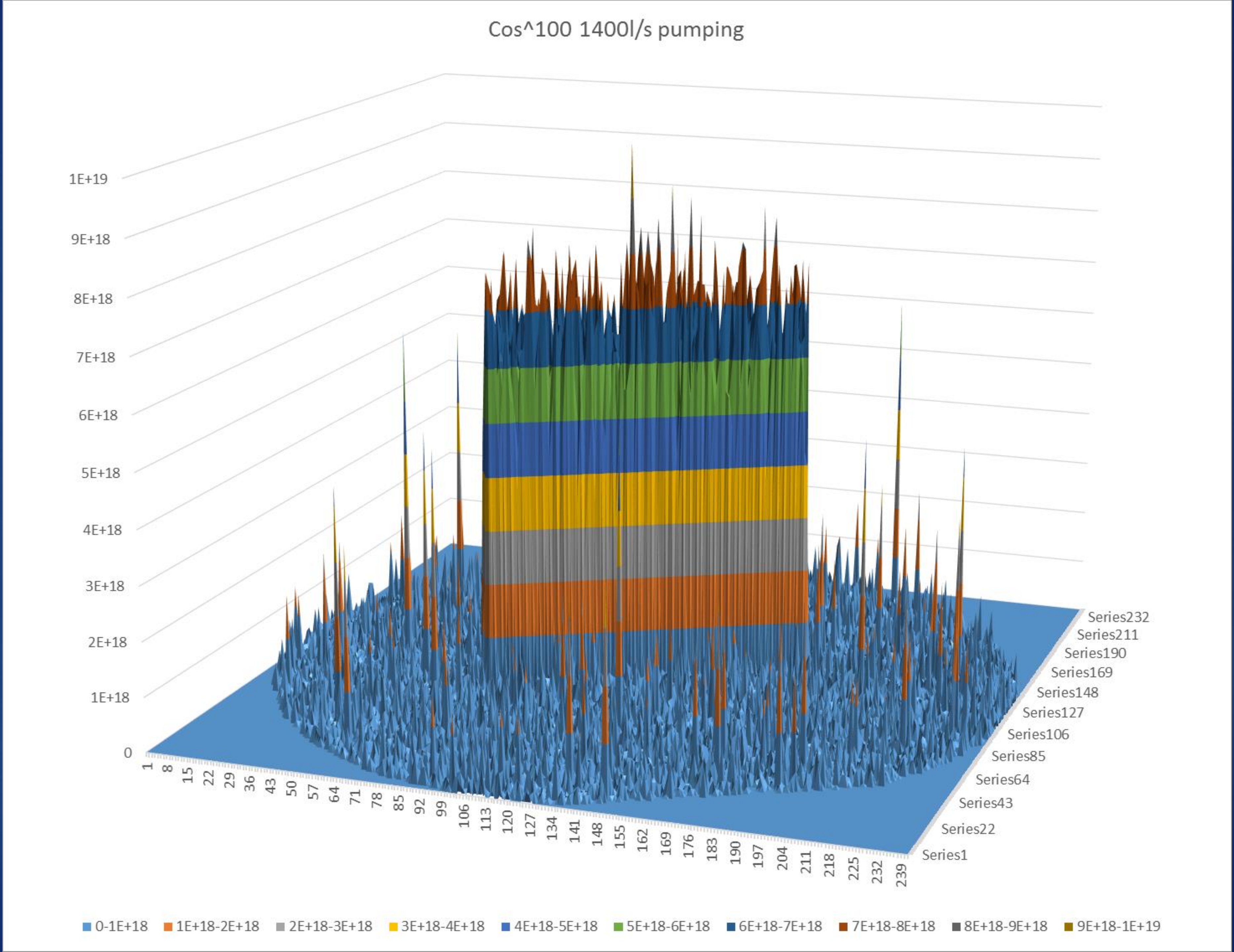


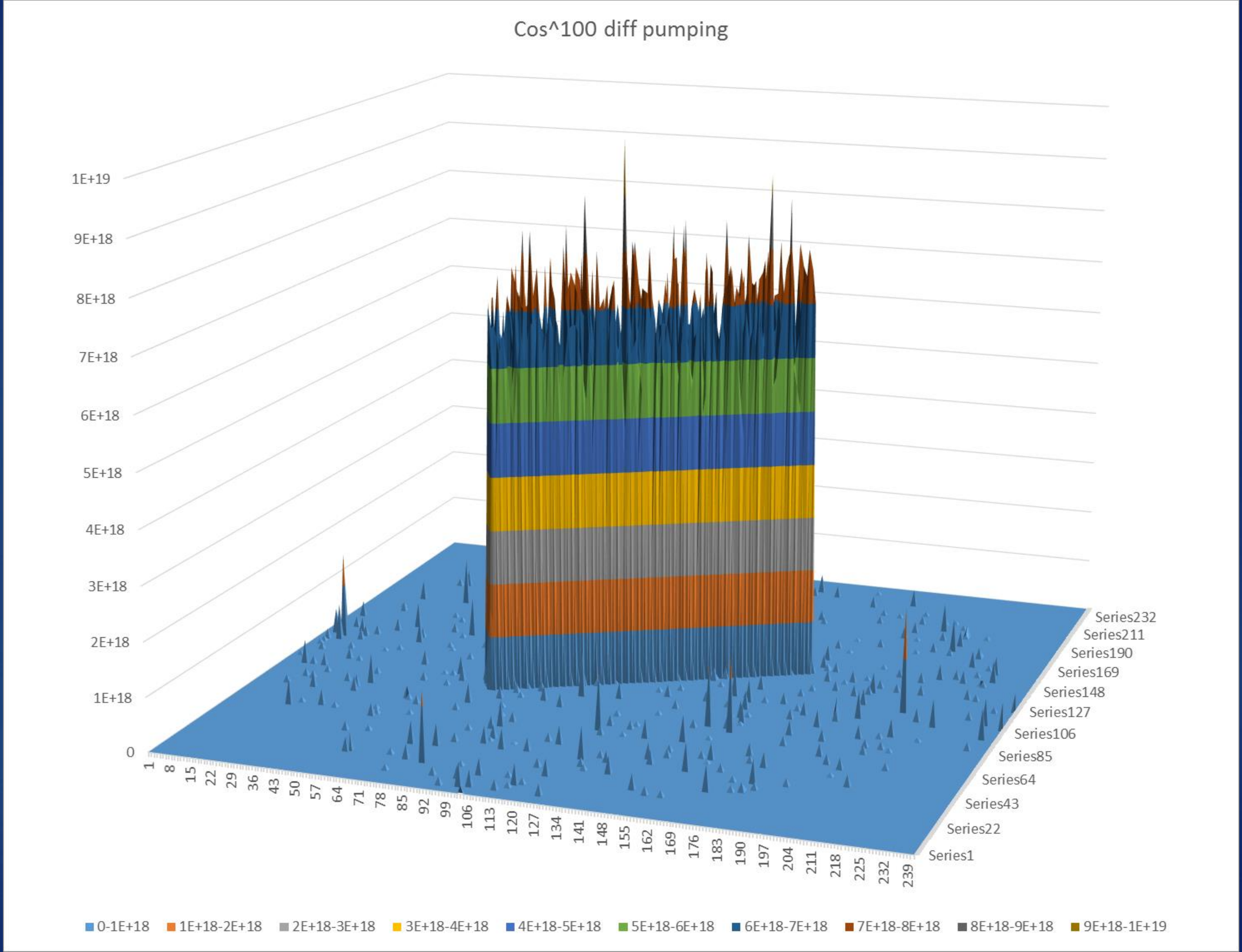
Background density (arb.units): 1.4E15
(background very low in this volume, difficult to estimate due to low statistics, **around 1 order lower**)





Cos^100 700l/s
1E+19
9E+18
8E+18
7E+18
6E+18
5E+18
4E+18
3E+18
2E+18
1E+18
0
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162 169 176 183 190 197 204 211 218 225 232 239
Series1
Series22
Series43
Series64
Series85
Series106
Series127
Series148
Series169
Series190
Series211
Series232
0-1E+18
1E+18-2E+18
2E+18-3E+18
3E+18-4E+18
4E+18-5E+18
5E+18-6E+18
6E+18-7E+18
7E+18-8E+18
8E+18-9E+18
9E+18-1E+19


Cos^100 1400l/s pumping
0
1E+18
2E+18
3E+18
4E+18
5E+18
6E+18
7E+18
8E+18
9E+18
1E+19
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162 169 176 183 190 197 204 211 218 225 232 239
Series1
Series22
Series43
Series64
Series85
Series106
Series127
Series148
Series169
Series190
Series211
Series232
0-1E+18
1E+18-2E+18
2E+18-3E+18
3E+18-4E+18
4E+18-5E+18
5E+18-6E+18
6E+18-7E+18
7E+18-8E+18
8E+18-9E+18
9E+18-1E+19



Cos^100 diff pumping
1E+19
9E+18
8E+18
7E+18
6E+18
5E+18
4E+18
3E+18
2E+18
1E+18
0
1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162 169 176 183 190 197 204 211 218 225 232 239
Series1 Series22 Series43 Series64 Series85 Series106 Series127 Series148 Series169 Series190 Series211 Series232
0-1E+18 1E+18-2E+18 2E+18-3E+18 3E+18-4E+18 4E+18-5E+18 5E+18-6E+18 6E+18-7E+18 7E+18-8E+18 8E+18-9E+18 9E+18-1E+19

Conclusion

- My calculation shows that individually pumping the volume between skimmers 1 and 2 would drastically improve the signal to noise ratio after skimmer 3 (at least a factor of 10)
- Gerhard's mechanical team prefers to avoid an extra cone (alignment, mechanical stability)
- Doubling the (shared) pumping would increase the SNR from ~40 to ~80, which might still be sufficient
- Adding the cone and the individual pumping would boost SNR to around 500, as in previous slide