the Protection of low particulate vacuum for SRF from catastrophe failure of neighboring UHV

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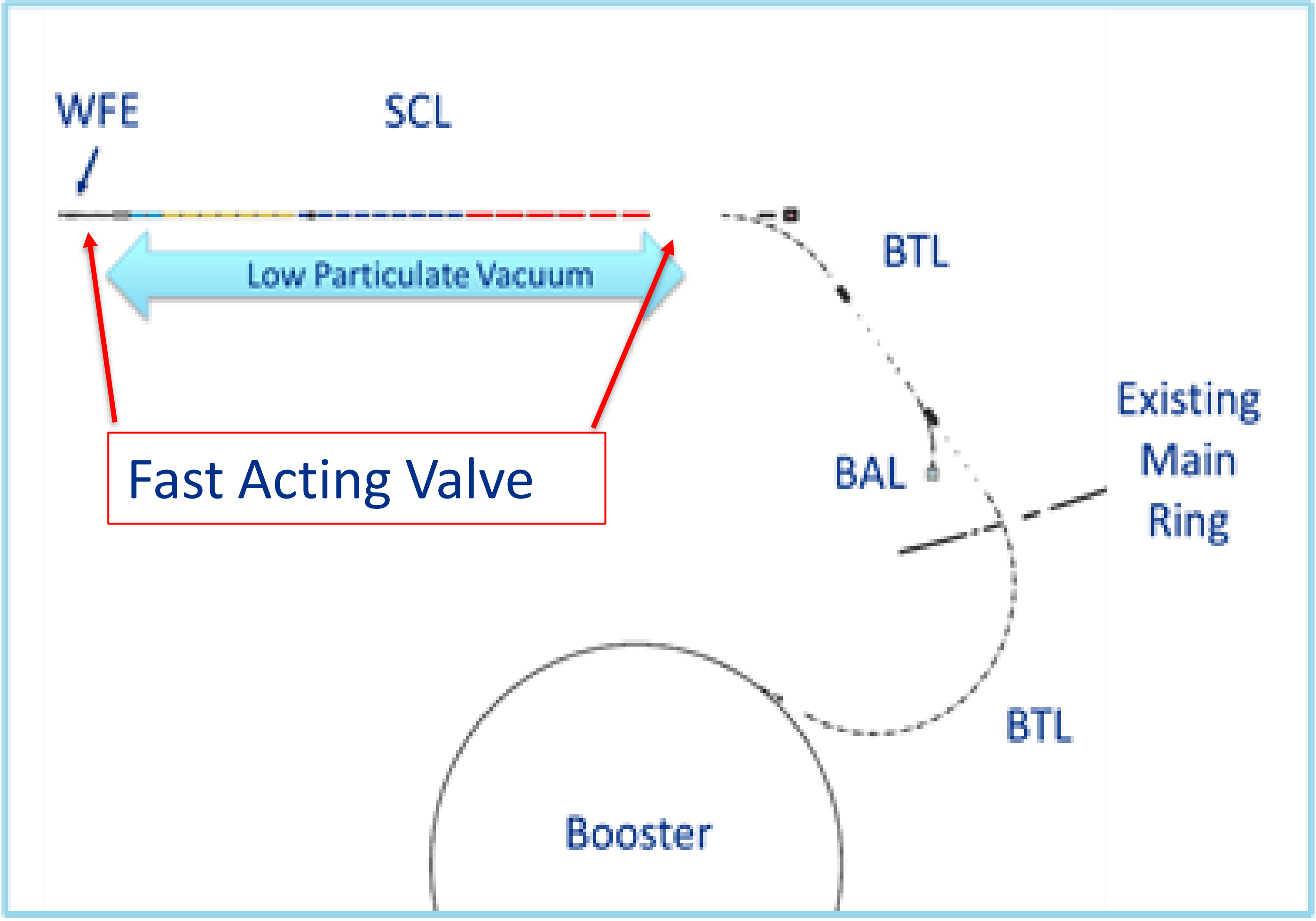
Outline

1. PIP2 scheme of protection
2. PIP2IT test result
3. DPI efficiency
4. CFD Simulation
5. Summary

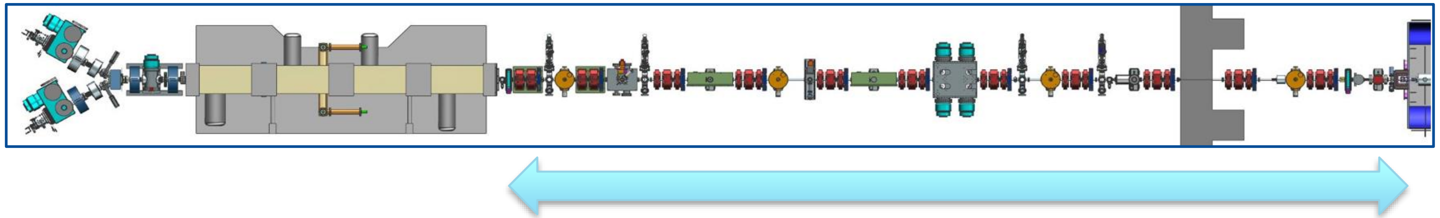
PIP2 VACUUM DESIGN: Fast Acting Valve Allocations

Fast Acting Valves:

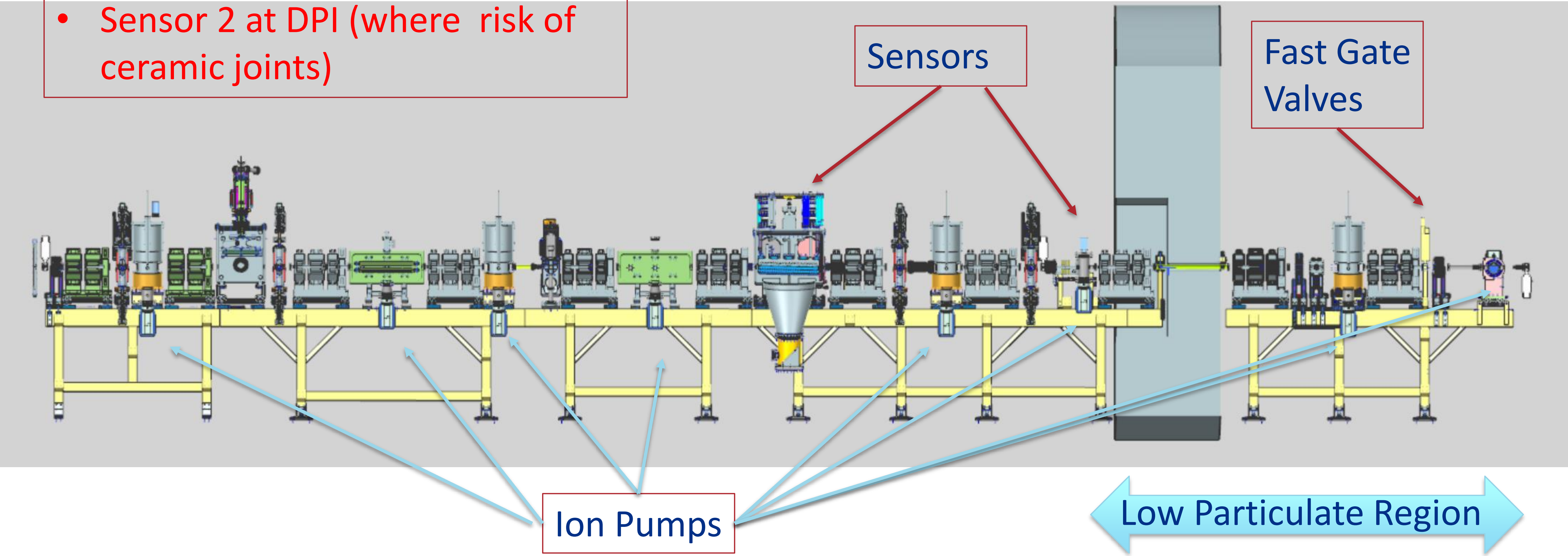
- Preventing large gas flux (especially particulates come with) entering SCL in case of vacuum catastrophe
- Allocate both ends Upstream and Downstream of SCL



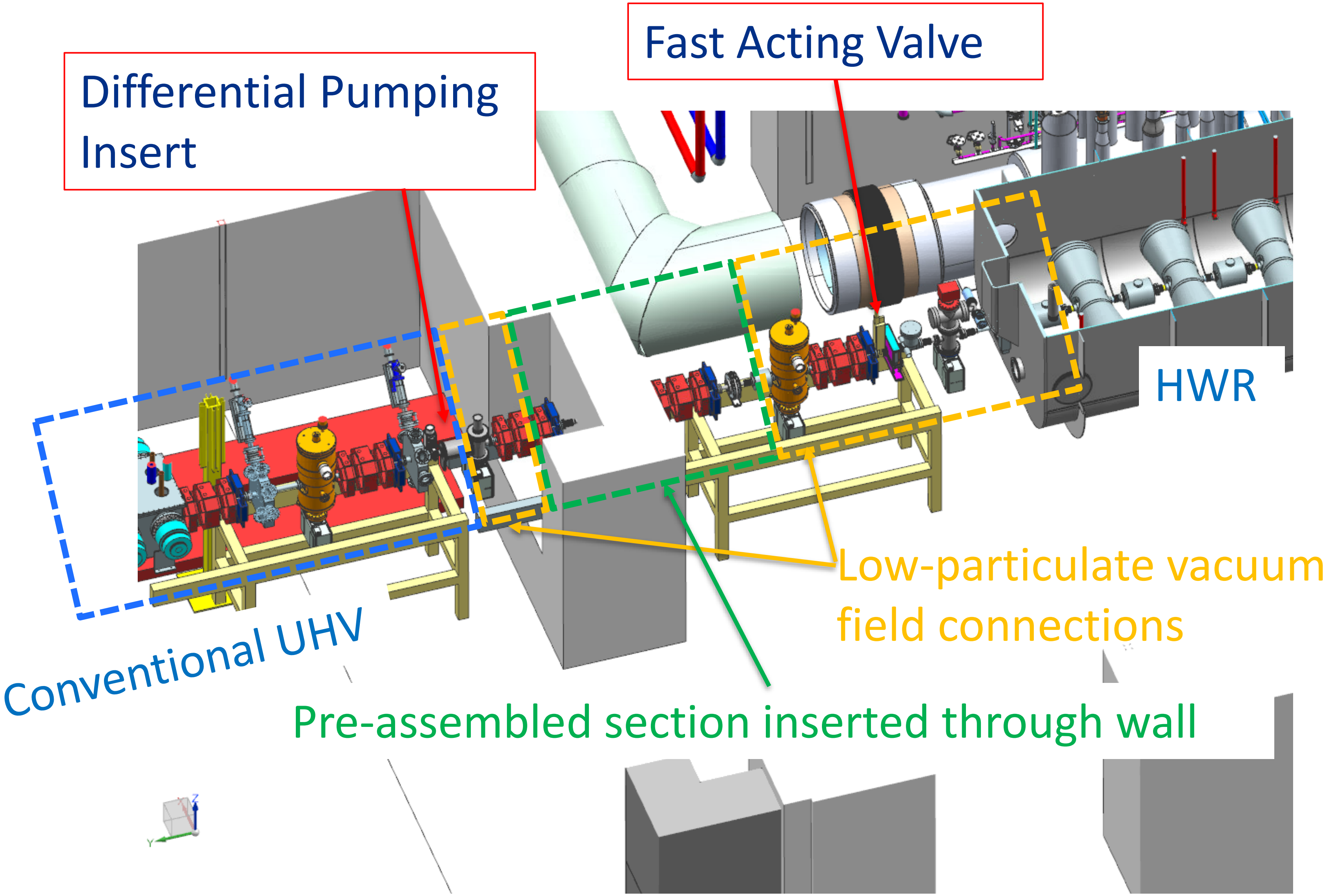
Warm Front End : MEBT



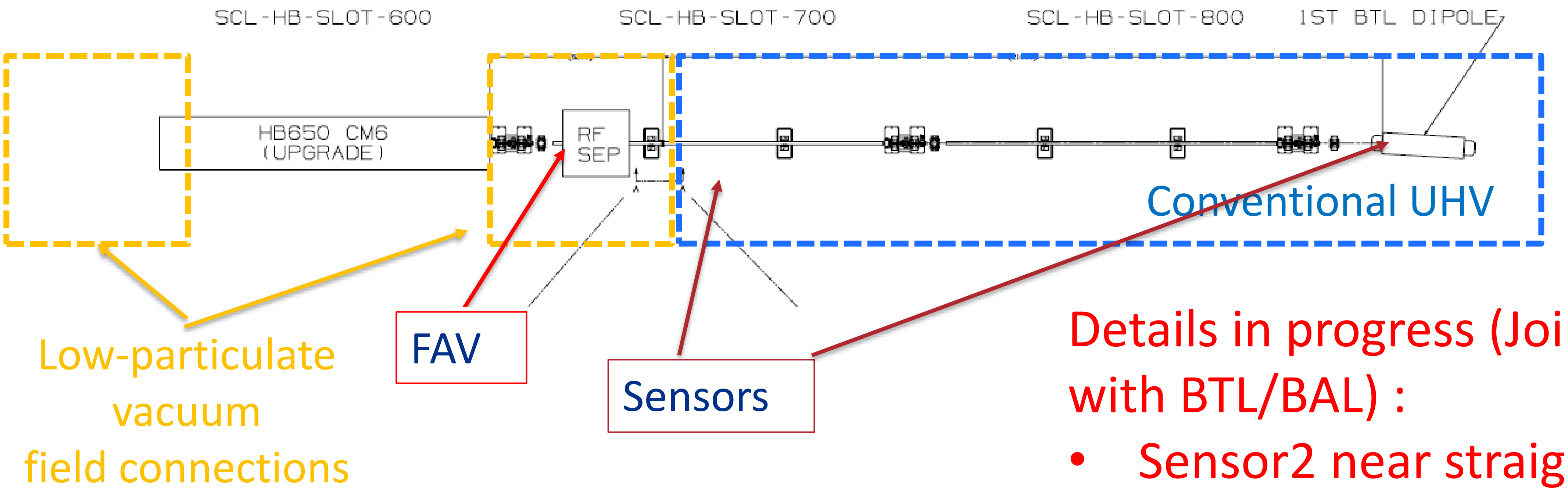
- Sensor 1 at Absorber (high pressure and particulates)
- Sensor 2 at DPI (where risk of ceramic joints)



Fast Acting Valve Allocations: Upstream at WFE



Fast Acting Valve Allocations: Downstream



Details in progress (Jointing with BTL/BAL) :

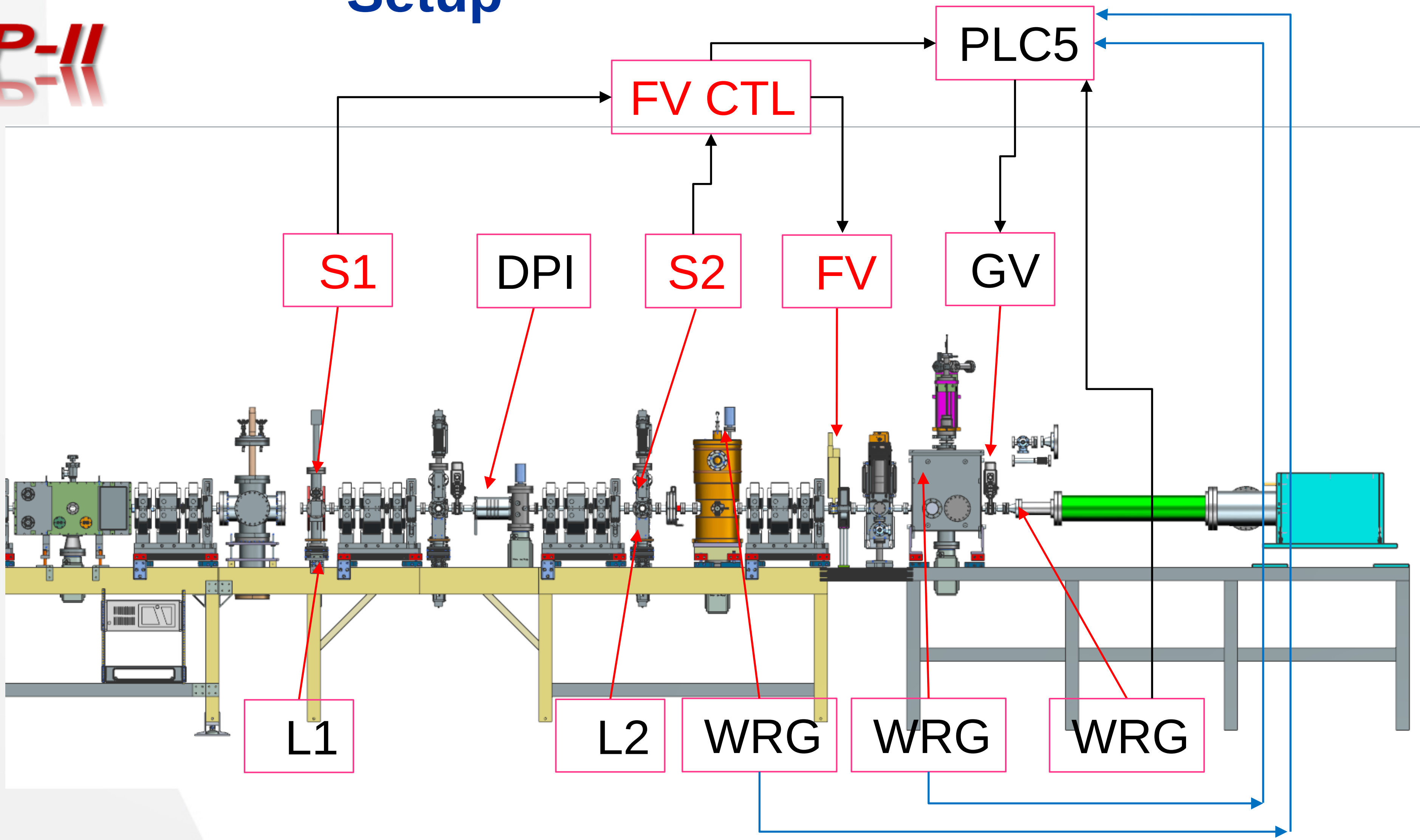
- Sensor2 near straight ahead dump
- Sensor1 near RF separator (future)
- HB650 is about 10m long

Fast Acting Valve Allocations: Tests

- The average velocity of air molecule is 467m/s at 25C. It travels 4.67m in 10ms, so ideally FAV shall be placed >4.67m downstream of detected vacuum failure, in another word, the FAV closed before gas flux arrive in the case of vacuum failure occurred and detected >4.67m upstream; some amount of gas will pass FAV if the failure is at <4.67m.
- There In PIP2IT, the distance were 1.4m and 4.2m. Nitrogen was introduced to simulate vacuum failures. The amount of gas past FAV was measured at downstream of FAV. The severity of failure was defined by the amount of gas in the 0.33liter nitrogen reservoir
- The test results shown the amount of Nitrogen past FAV was low and tolerable to CM

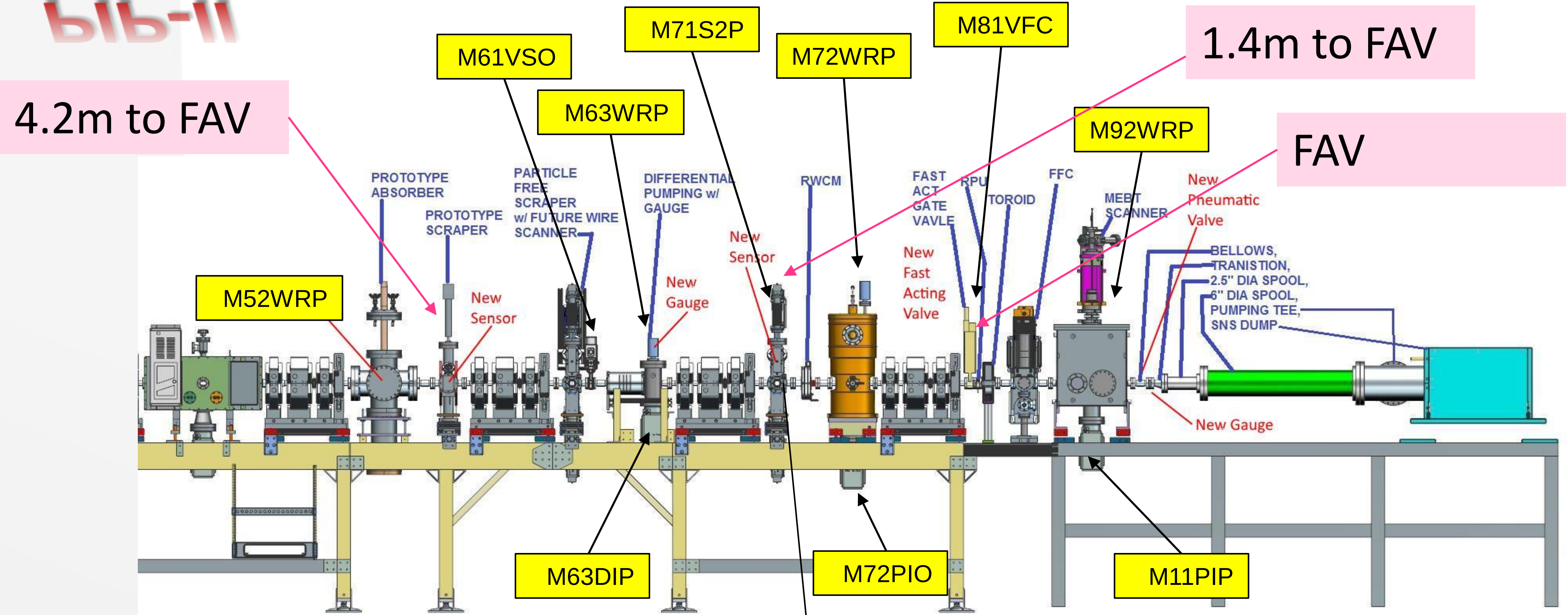
Setup

PIP-II

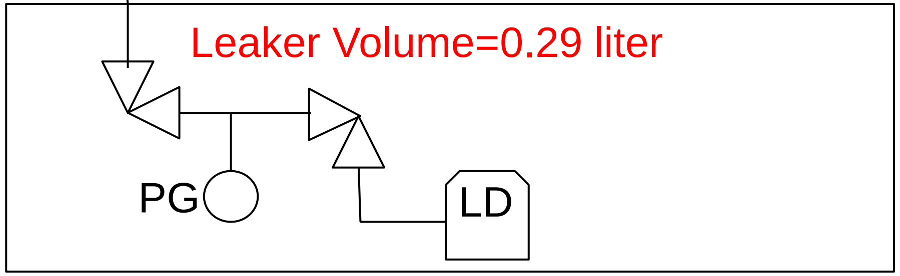


1^{st} Test on MEBT DPI-FV

PIP-II

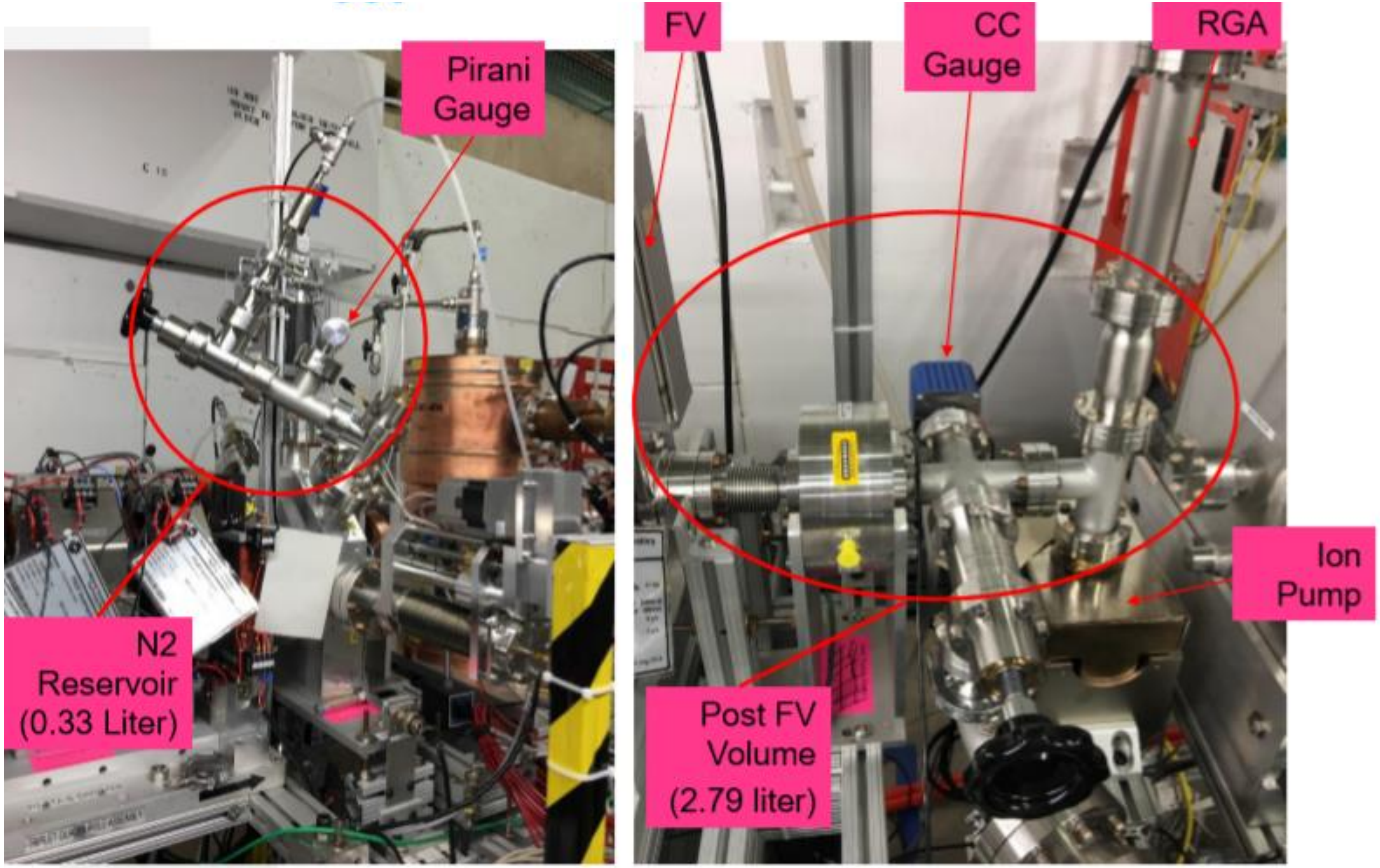


1. V1=36.5 liters(M61VSO-FV)
2. V2=95.1 liters(POST FV)
3. Permeation rate from Scanner O-Ring is about 6E-7 torr.l/s

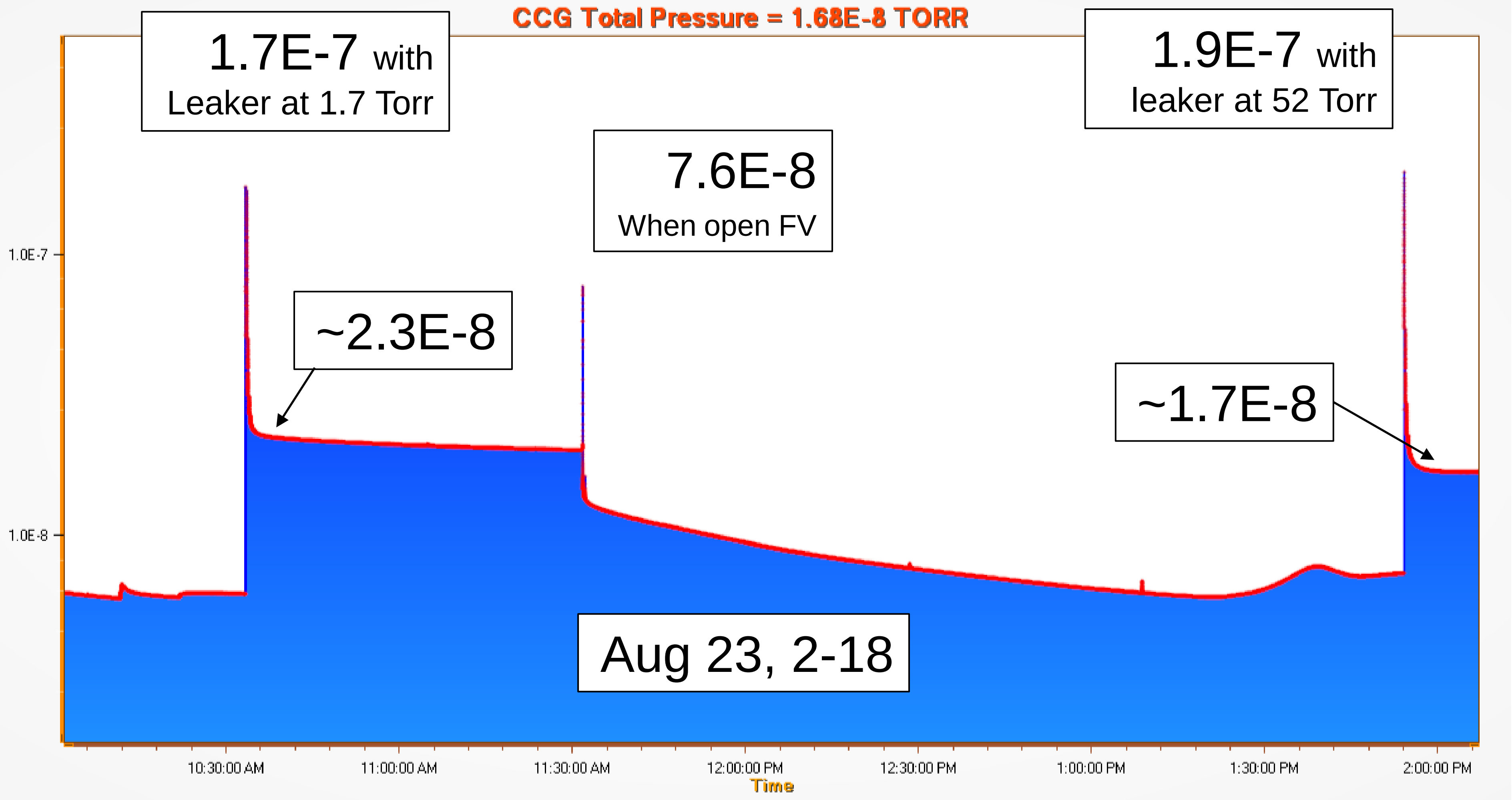


Setup of 2nd Test

2nd Test With Smaller and Tighter Volume *(Leak From Downstream of DPI)*



Vacuum Gauge Reading in Small Volume *(Leak From Upstream of DPI)*



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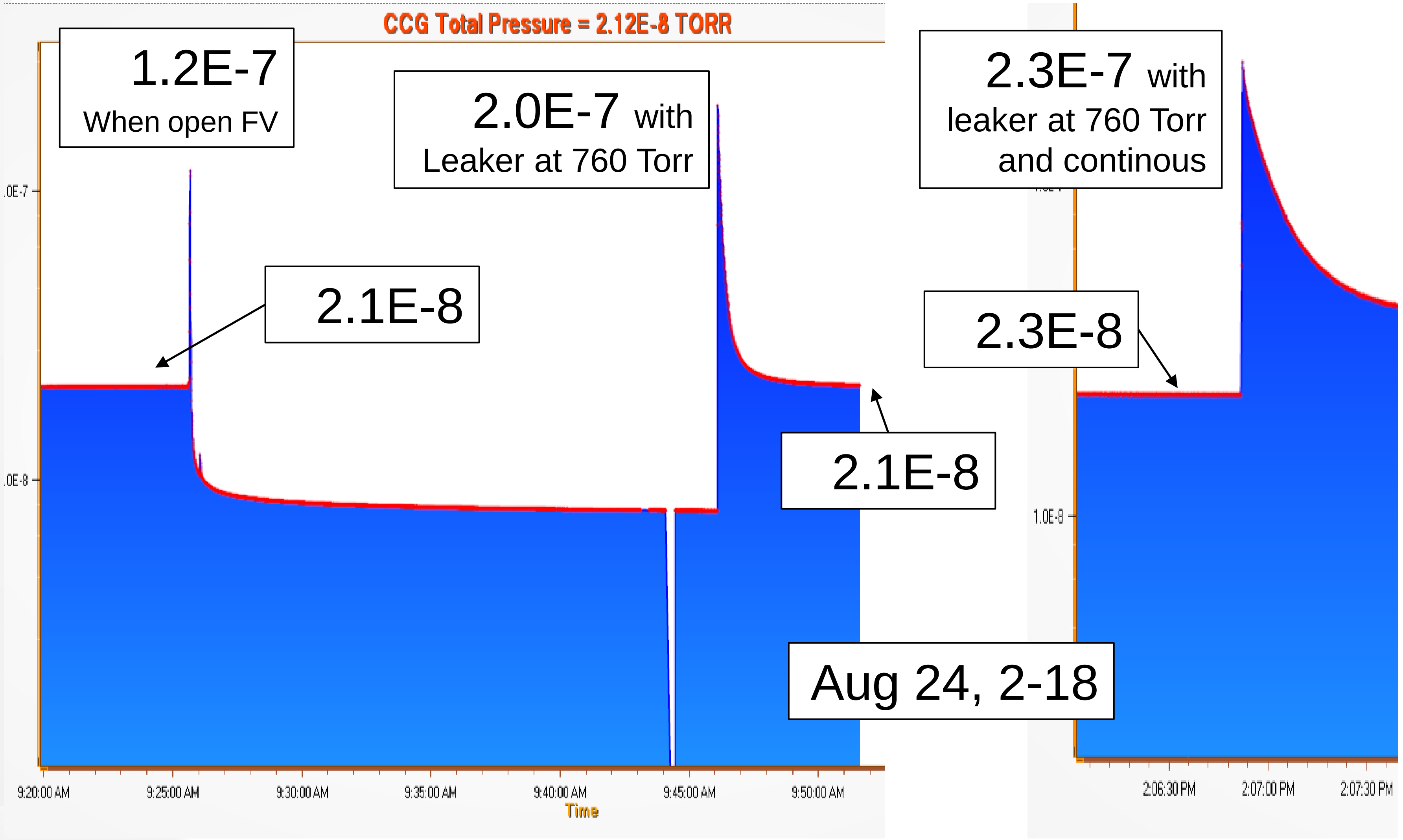
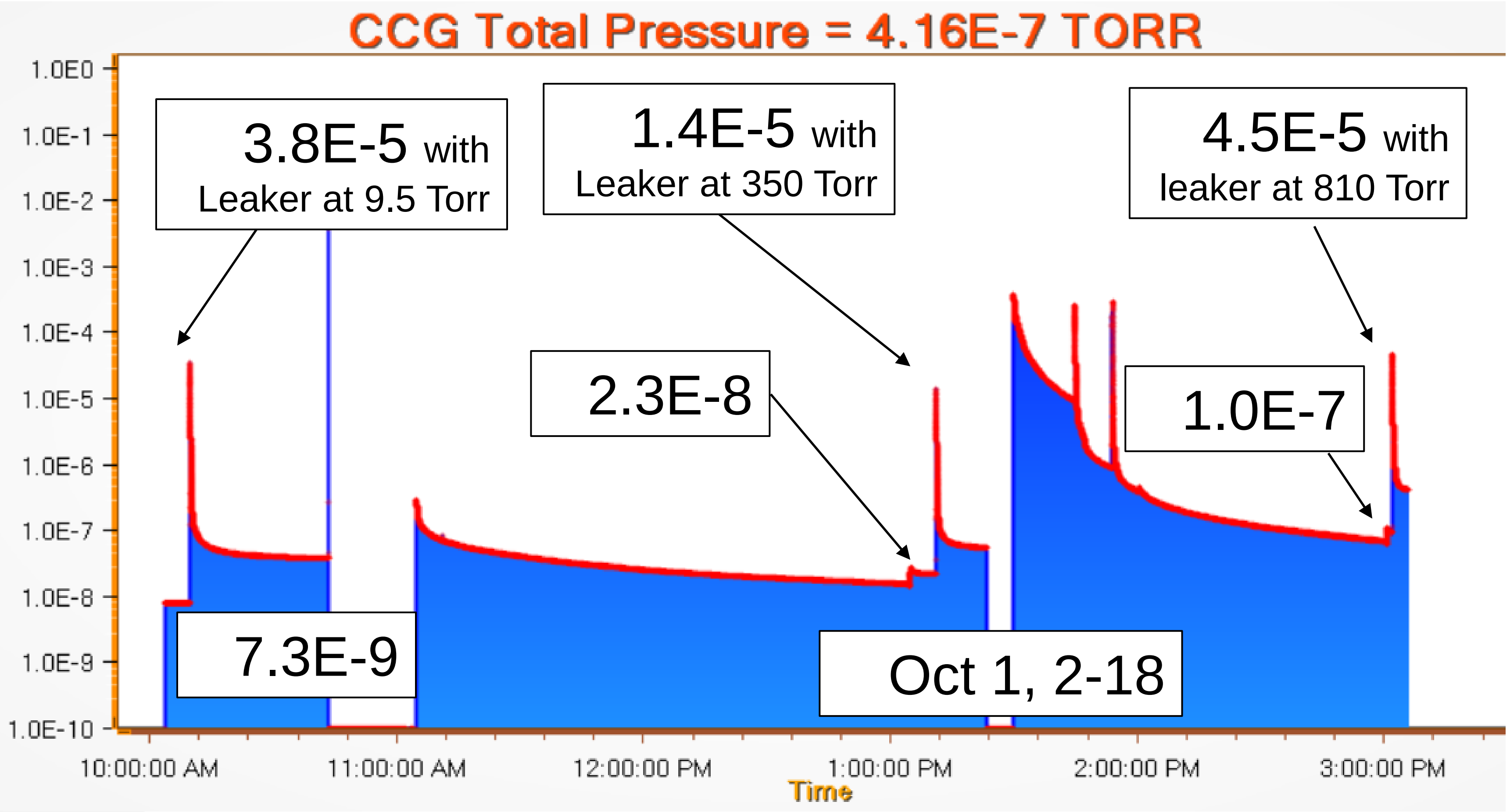
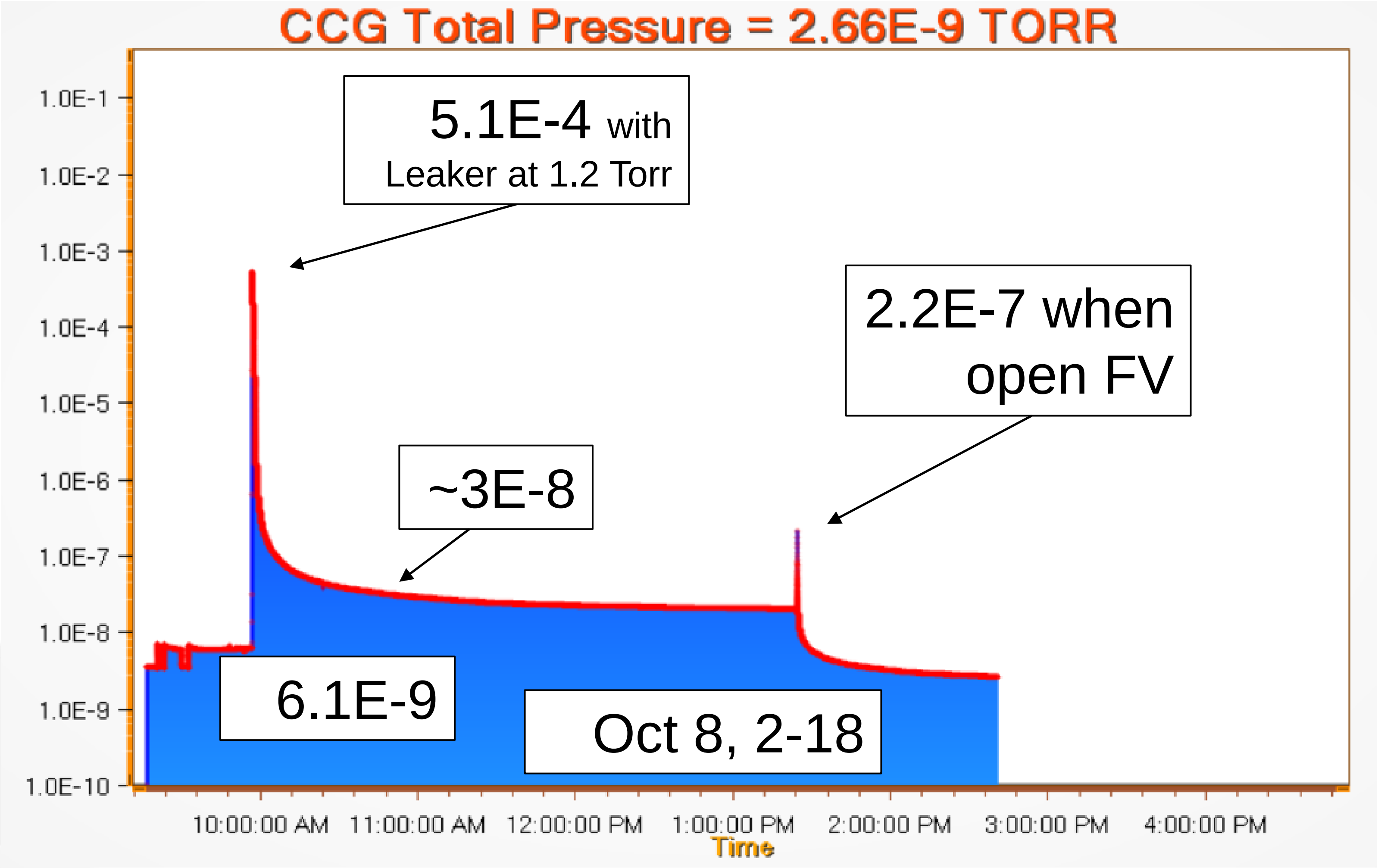


PIP-II

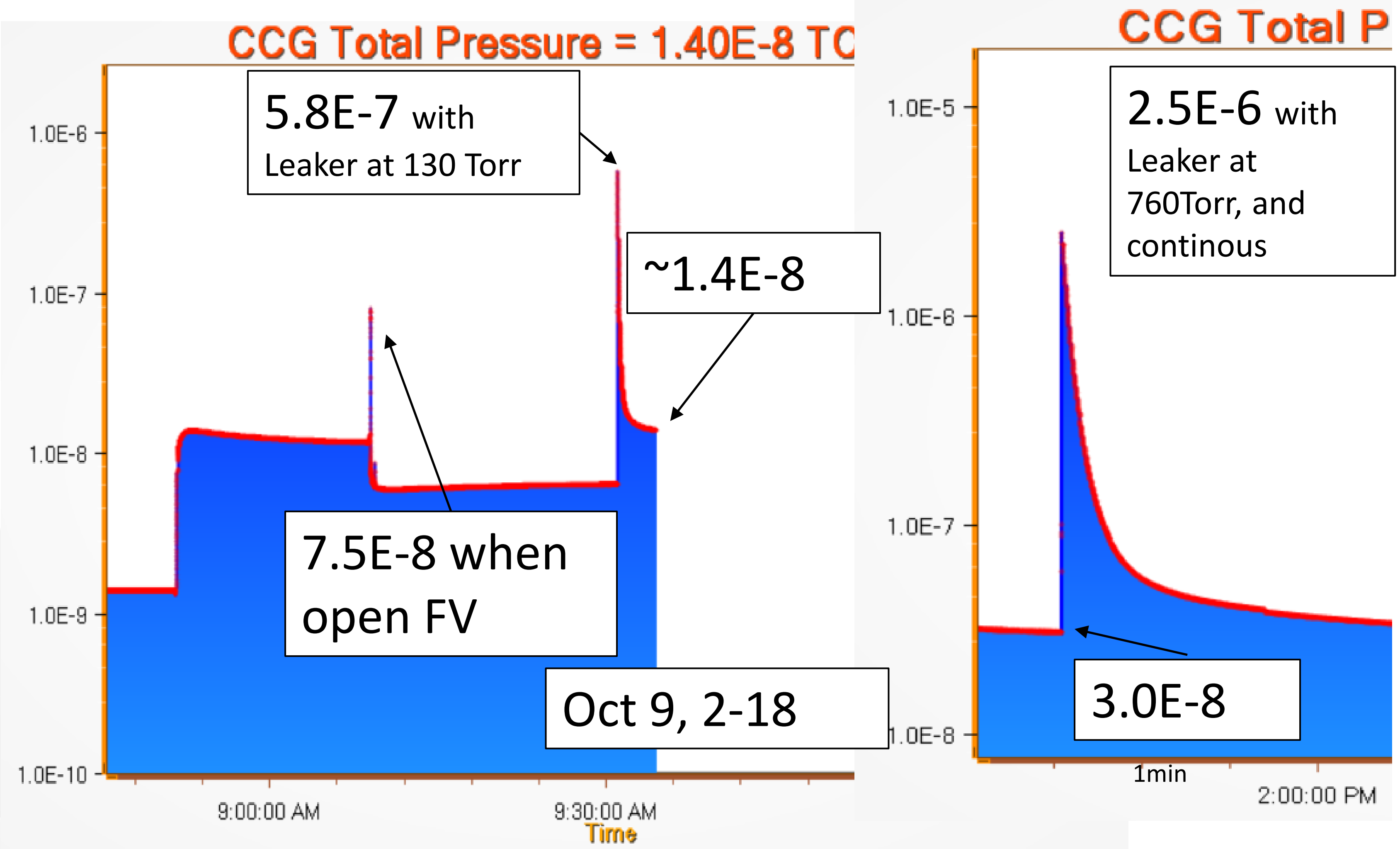


Fermilab

Vacuum Gauge Reading in Small Volume*(Leak From Downstream of DPI)*

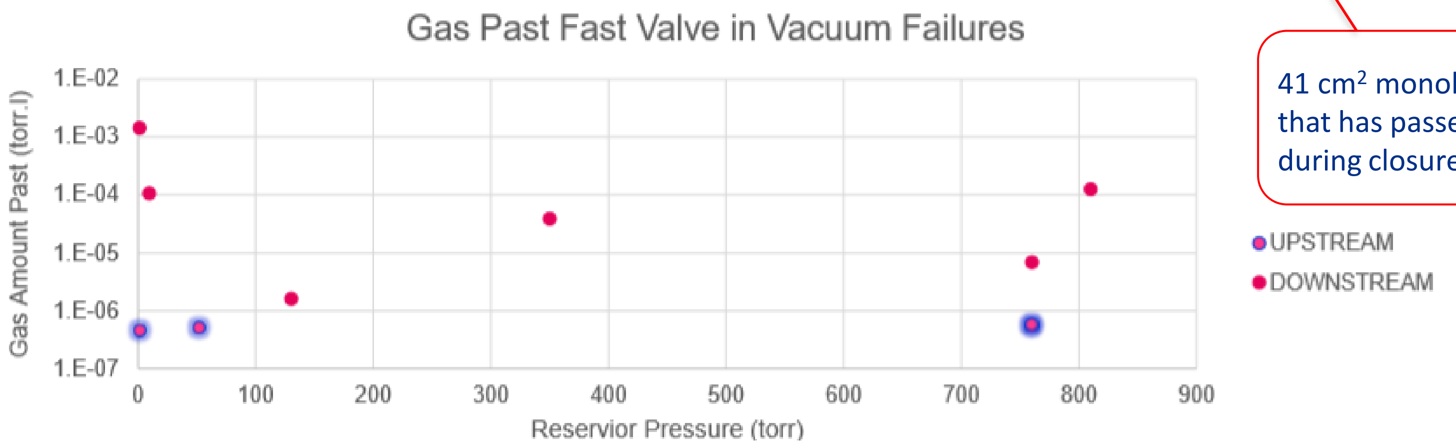


2^{nd} Test With Smaller and Tighter Volume *(Leak From Downstream of DPI)*



FAV test Summary of Results

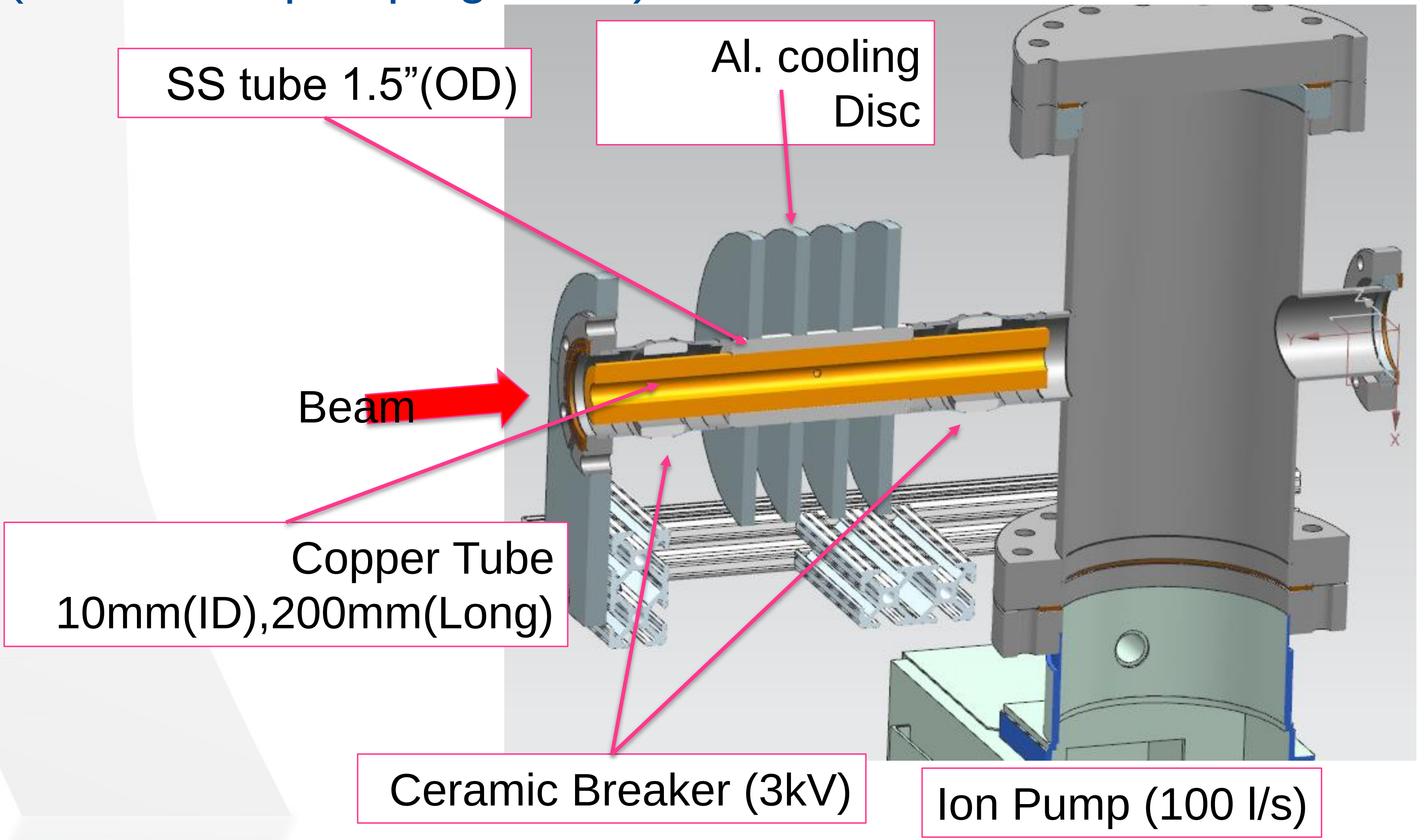
	Leaker Reservoir	CCG500 Reading		dP	Gas Amount	monolayer coverage	Leaker Location
		P0 (before)	P1 (after)				
	torr	torr	torr	torr	torr.liter	cm^2	
23-Aug	1.7	6.2E-09	1.7E-07	1.6E-07	4.6E-07	1.3E-02	US DPI
	52	7.5E-09	1.9E-07	1.8E-07	5.1E-07	1.5E-02	
24-Aug	760	7.9E-09	2.0E-07	1.9E-07	5.4E-07	1.6E-02	
	760	2.3E-08	2.3E-07	2.1E-07	5.8E-07	1.7E-02	
1-Oct	9.5	7.3E-09	3.8E-05	3.8E-05	1.1E-04	3.1E+00	DS DPI
	350	2.1E-08	1.4E-05	1.4E-05	3.9E-05	1.1E+00	
	810	1.0E-07	4.5E-05	4.5E-05	1.3E-04	3.6E+00	
8-Oct	1.2	6.1E-09	5.1E-04	5.1E-04	1.4E-03	4.1E+01	
9-Oct	130	6.0E-09	5.8E-07	5.7E-07	1.6E-06	4.6E-02	
	760	3.0E-08	2.5E-06	2.5E-06	6.9E-06	2.0E-01	



41 cm^2 monolayer of gas that has passed the FAV during closure

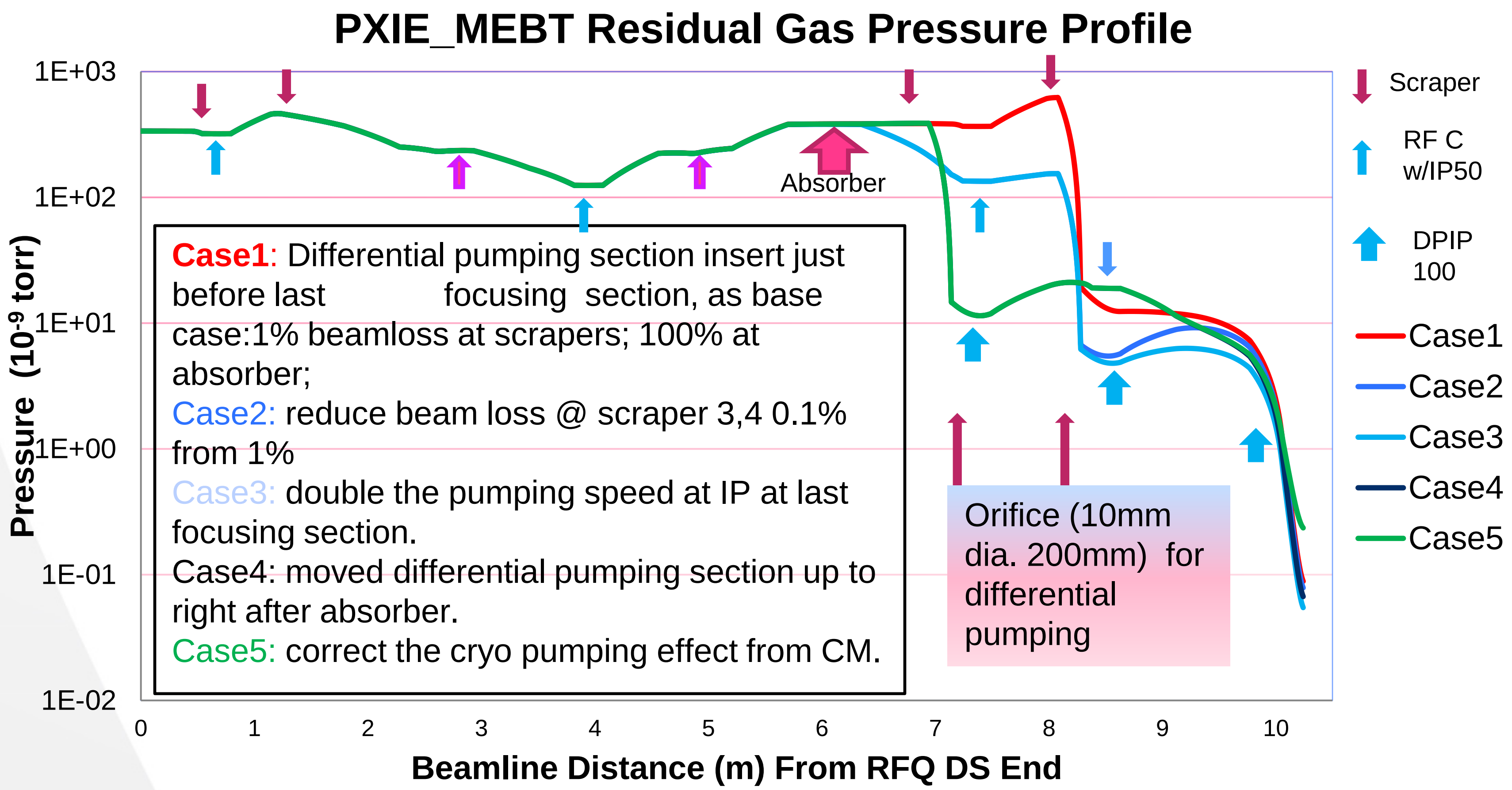
Gas flux into CM is sufficiently low

DPI (differential pumping insert)



PIP-II

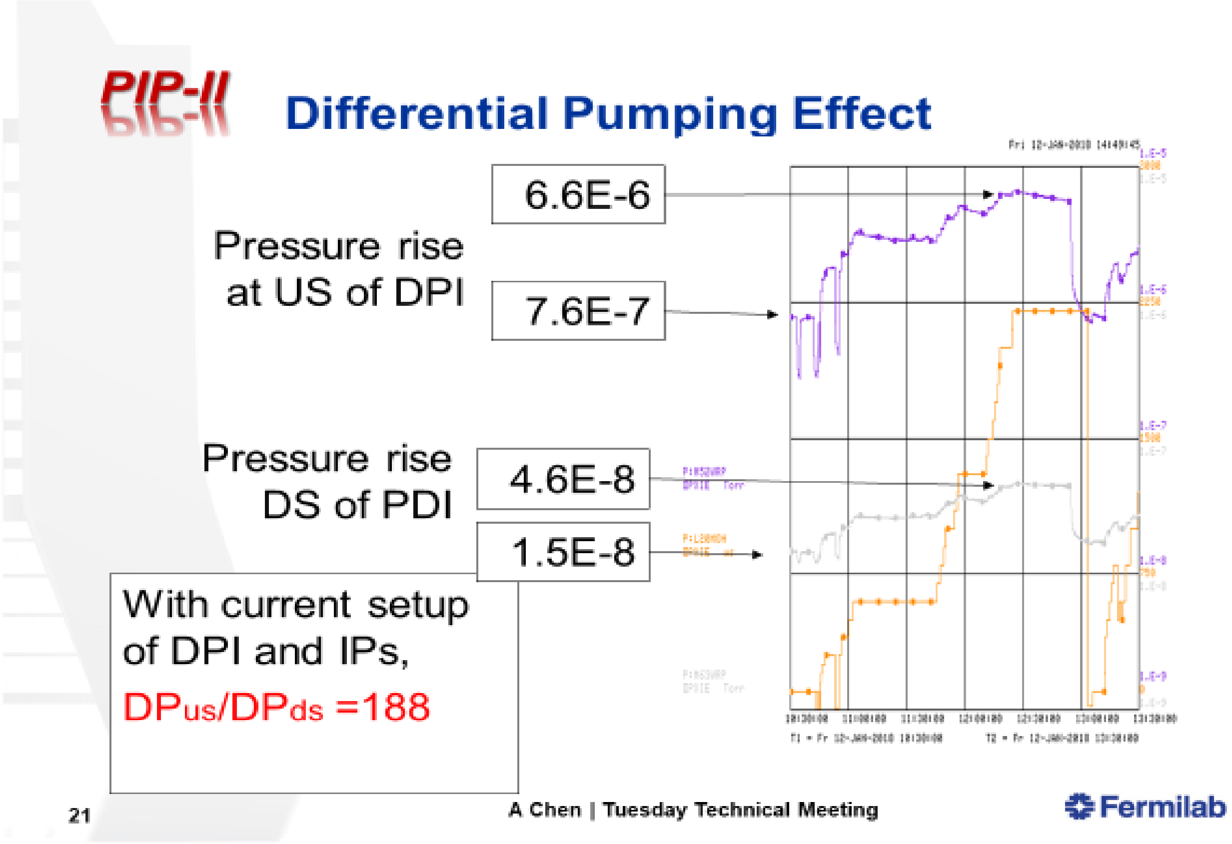
PXIE Vacuum *(pressure profile in MEBT)*



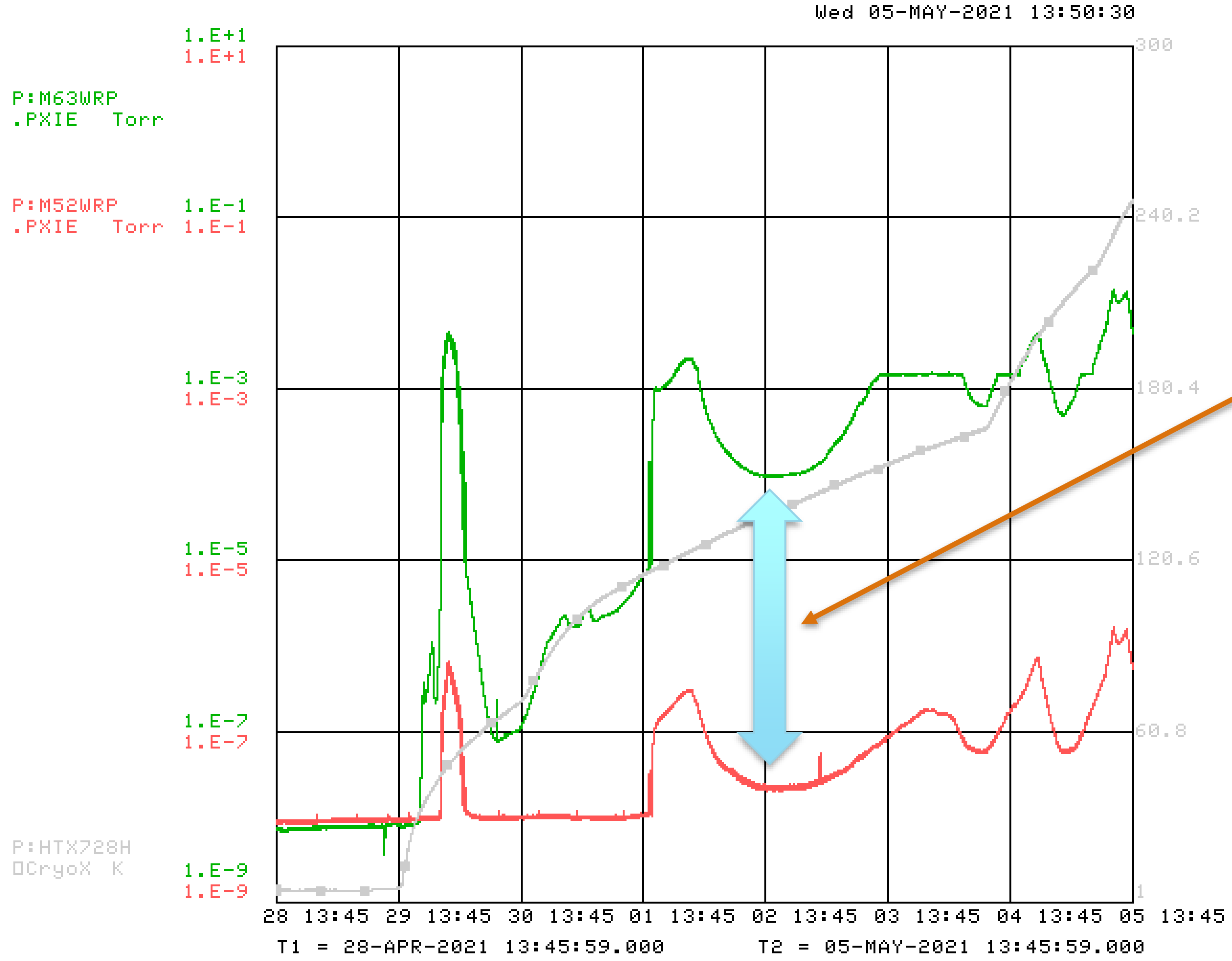
OLAV-VI: Chen, Baffles, Lambert, Campos, Andrews, Tang

Fermilab

DPI Performance (during PIP2IT operation)

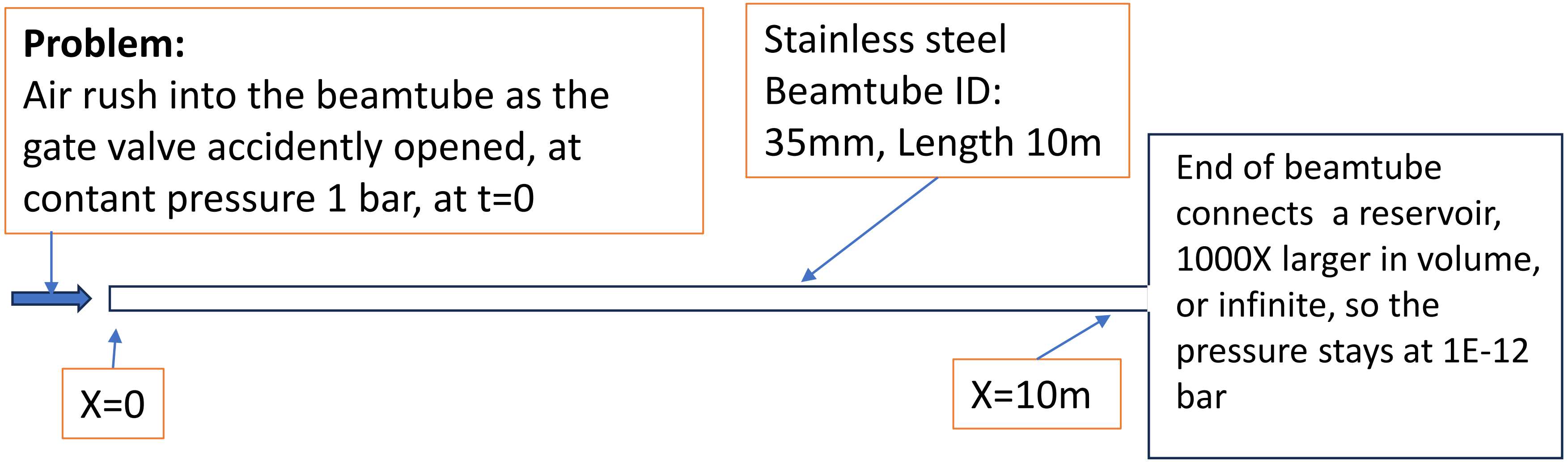


DPI Performance (during HWR warming up)



Pressure Separation due to DPI effect make it possible to measure gas amount precisely

CFD Simulation: Problem setup



1) Initial vacuum space with P(x,0)=1E-12 bar
2) Find Pressure profile inside beamtube P(x,t) if possible;
3) Find critical time tc (in ms) that P(10, tc)=1E-7 bar;
4) Find total amount of air entered the reservoir until time tc
5) The propagating speed of pressure(at 1E-7bar)wave along the beamtube.

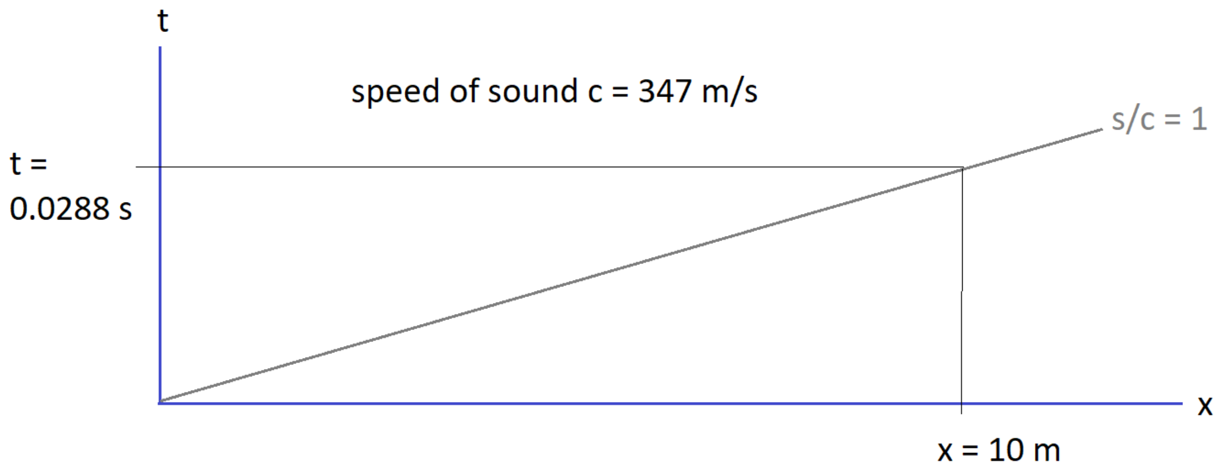
Speed of sound in air (ideal gas)

$$c_{\text{sound}} = \sqrt{\frac{K_s}{\rho}} = \sqrt{\left(\frac{\partial P}{\partial \rho}\right)_s} = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{\gamma RT}{M}}$$

Specific heat of air at constant pressure = 1005 J/kg-K, specific heat of air at constant temperature = 718 J/kg-K. ratio γ = 1005/718 = 1.4. Mole weight of air is 28.96 g, the gas constant R = 8.3145 J/K-mole. We have

$$c = c_{\text{sound}} = \sqrt{\frac{\gamma RT}{M}} = \sqrt{\frac{1.4 \times 8.3145 \times 300}{28.96 \times 10^{-3}}} = 347 \text{ m/s}.$$

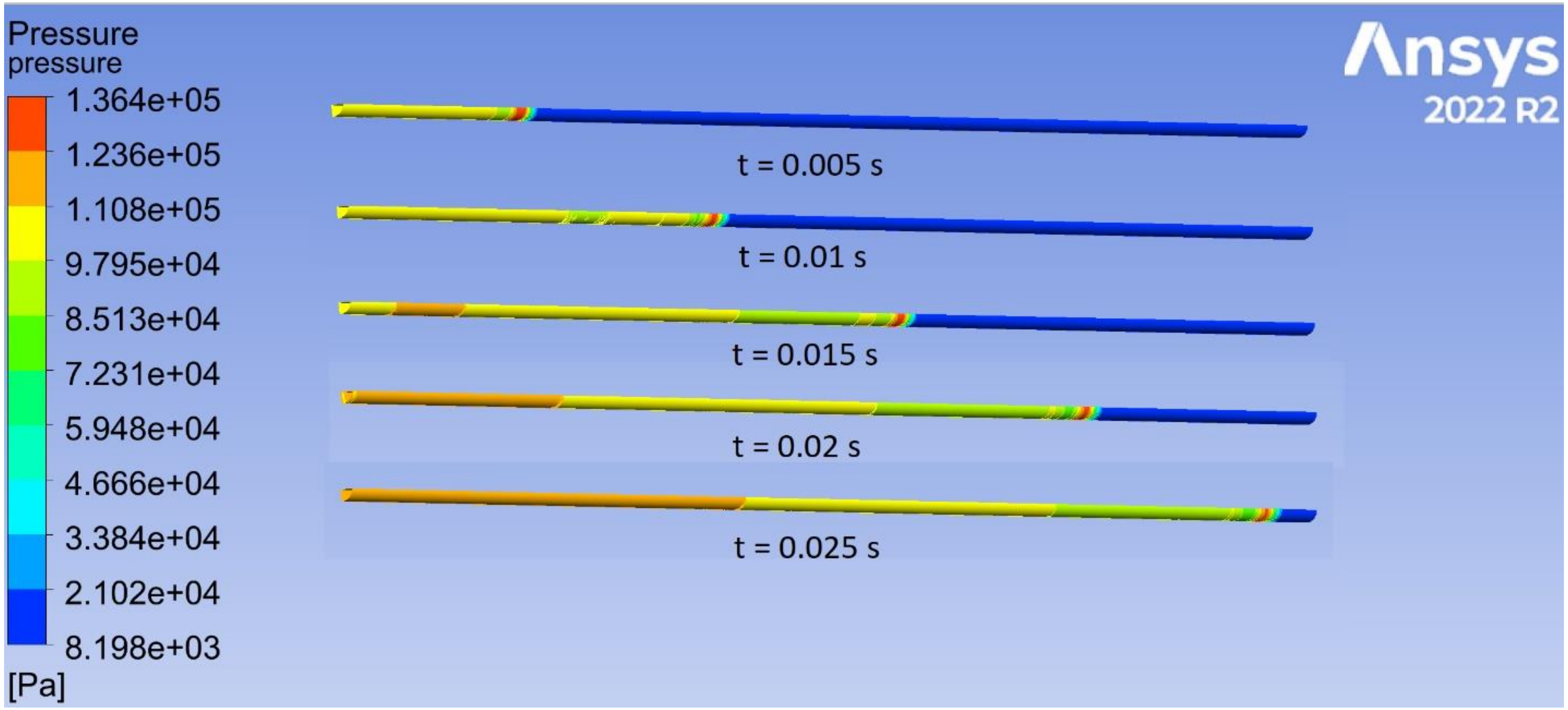
The length of vacuum tube = 10 m, time for sound wave to travel 10 m length = 0.0288 s.



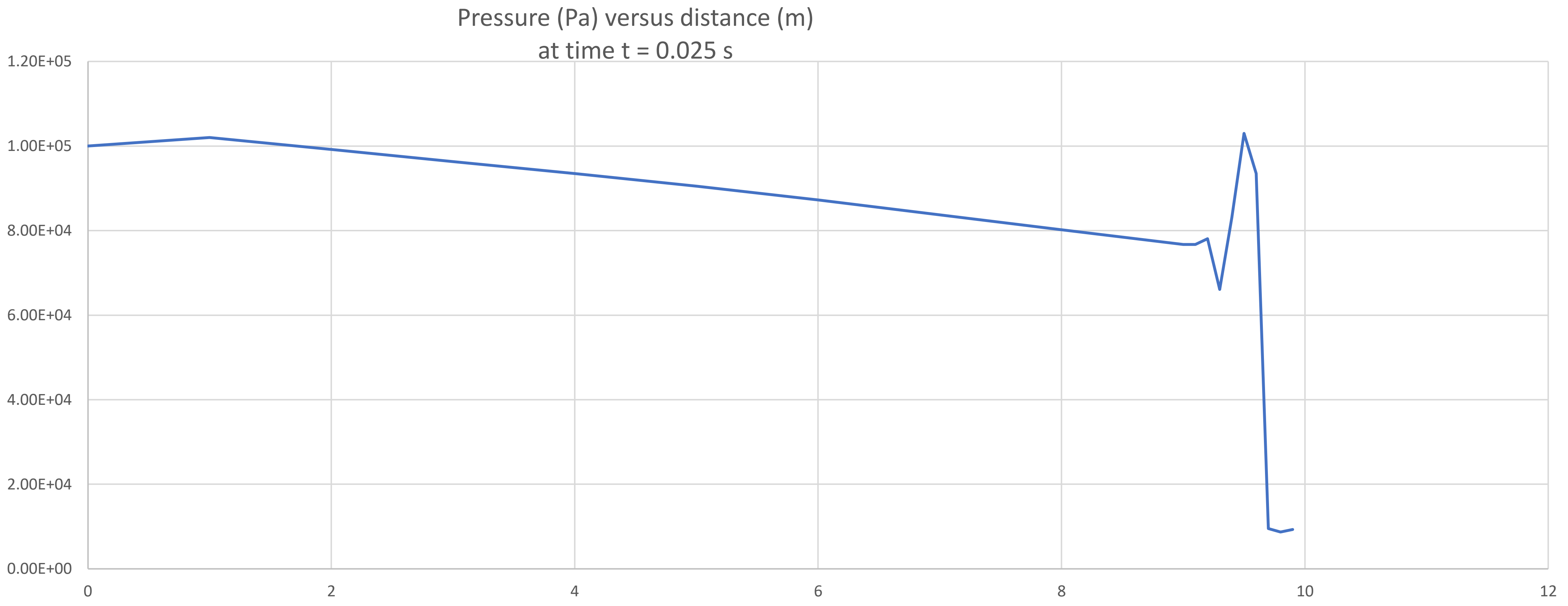
CFD model

- Make a model of tube, diameter 35 mm, length 10 m. Use symmetry, make a quarter model. The model has total 366177 nodes, 915777 elements.
- Initial condition: at $t = 0$, $p = 0.1$ bar = 10000 Pa for $0 < x < 10$ m.
- Boundary condition: at $x = 0$, $p = 1$ bar = 100000 Pa for $t > 0$.
- Time step $\Delta t = 0.0001$ s, save results for every 50 steps.
- Speed of sound = 347 m/s, time needed for pressure wave to travel 10 m is 10/347 = 0.0288 s.

Propagation of pressure wave

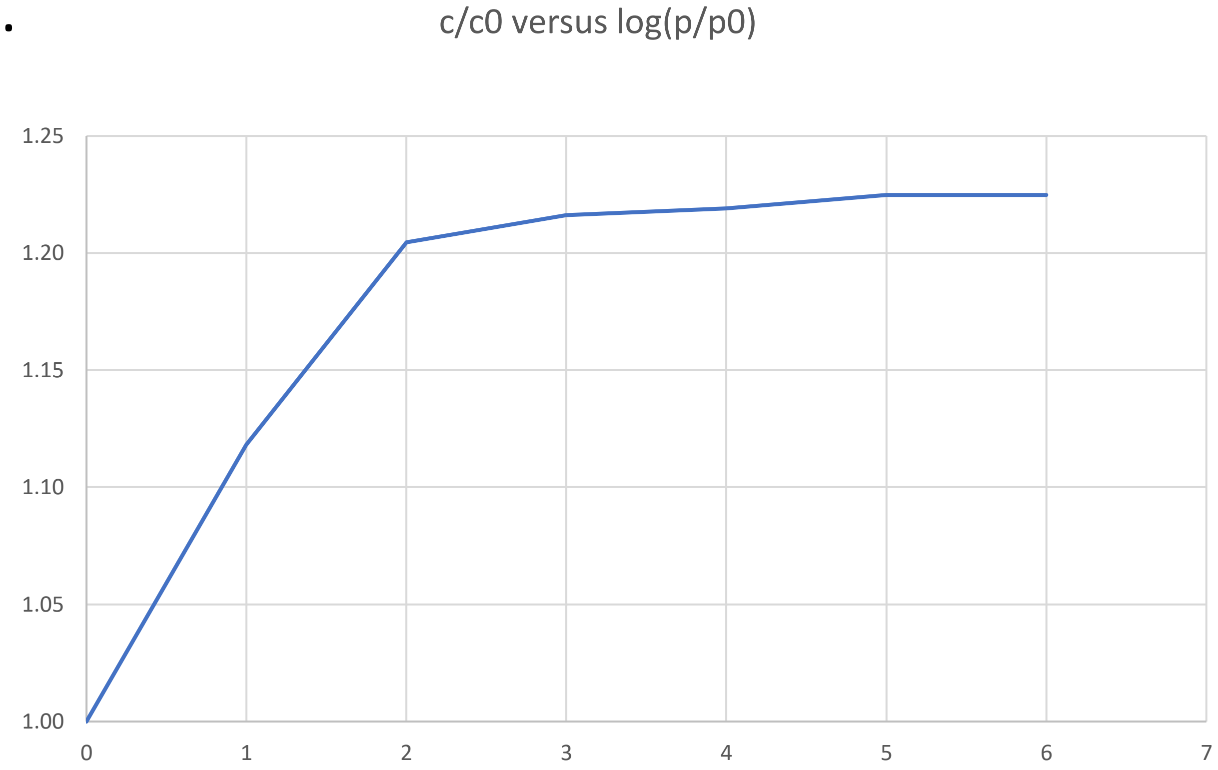


Pressure profile at time t = 0.025 s

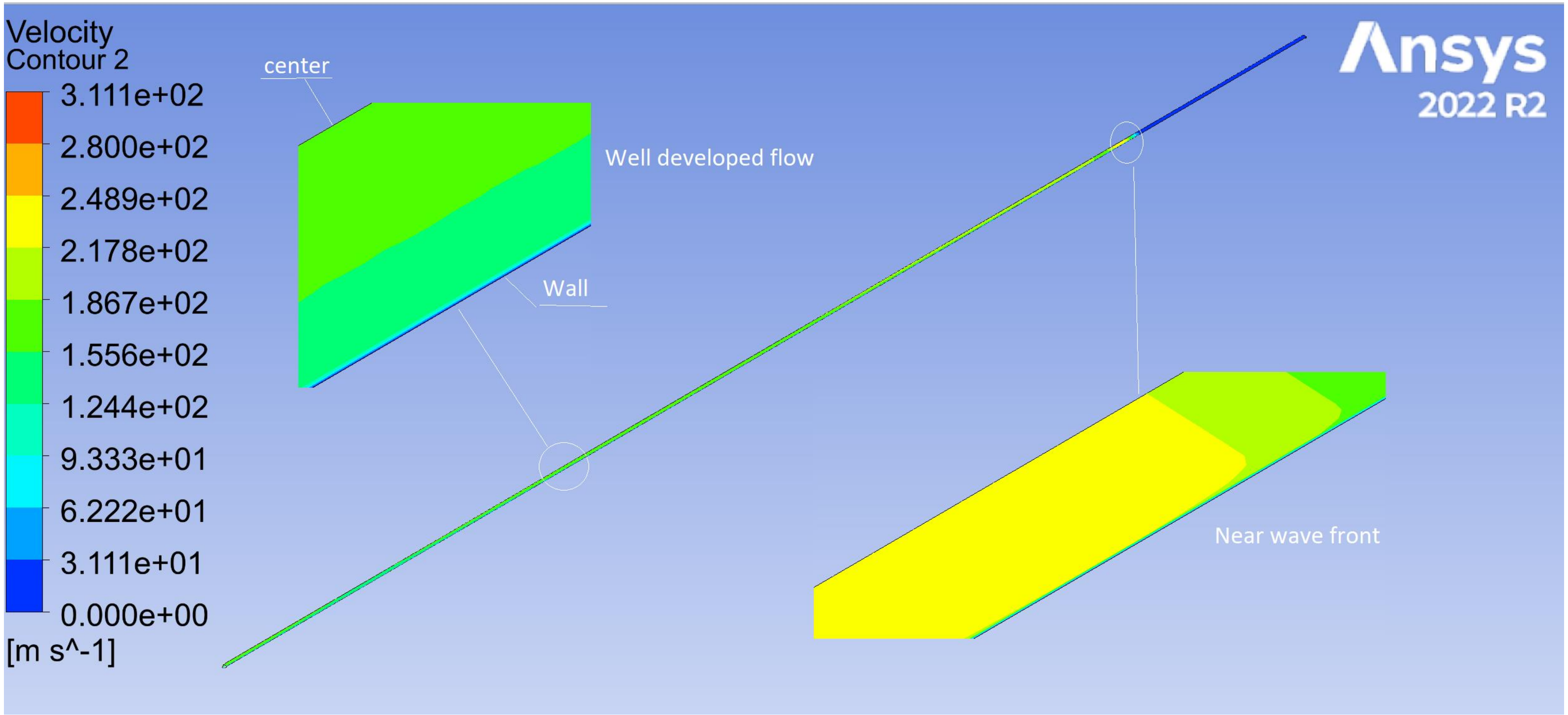


More about wave front speed

- We make more run with different initial conditions. It seems the wave front speed increases with decreased initial pressure. After $\log_{10}(p/p_0) = 5$, there is no significant change of c/c_0.



Boundary Layer in 35mm Tube



Summary

- The measured gas amount past the fast-acting valve was sufficiently low.
- CFD simulation shown the pressure wave front propagates at speed larger than sound, it increase as the pressure ratio and but tend to stable after the pressure ratio >=5; we didn’t achieve the solution of P(x,t), the real case involve multiple flow regimes, no single numerical model can handle it.
- The real pressure wave front may much less than numerical model indicate or molecular speeds
- The measured gas amount is much less than anticipated, could be due to 1) the action of opening valve manually much slower than rapture; 2) the threshold of 1E-4 torr is much lower than the pressure of wavefront, which mean valve closed before the wavefront arrive