Towards a Gas Filtration Setup for Ultra-Sensitive SF_6 Gas Based Dark Matter Searches

International Conference on Identification of Dark Matter

Vienna, Austria - 18th July 2021

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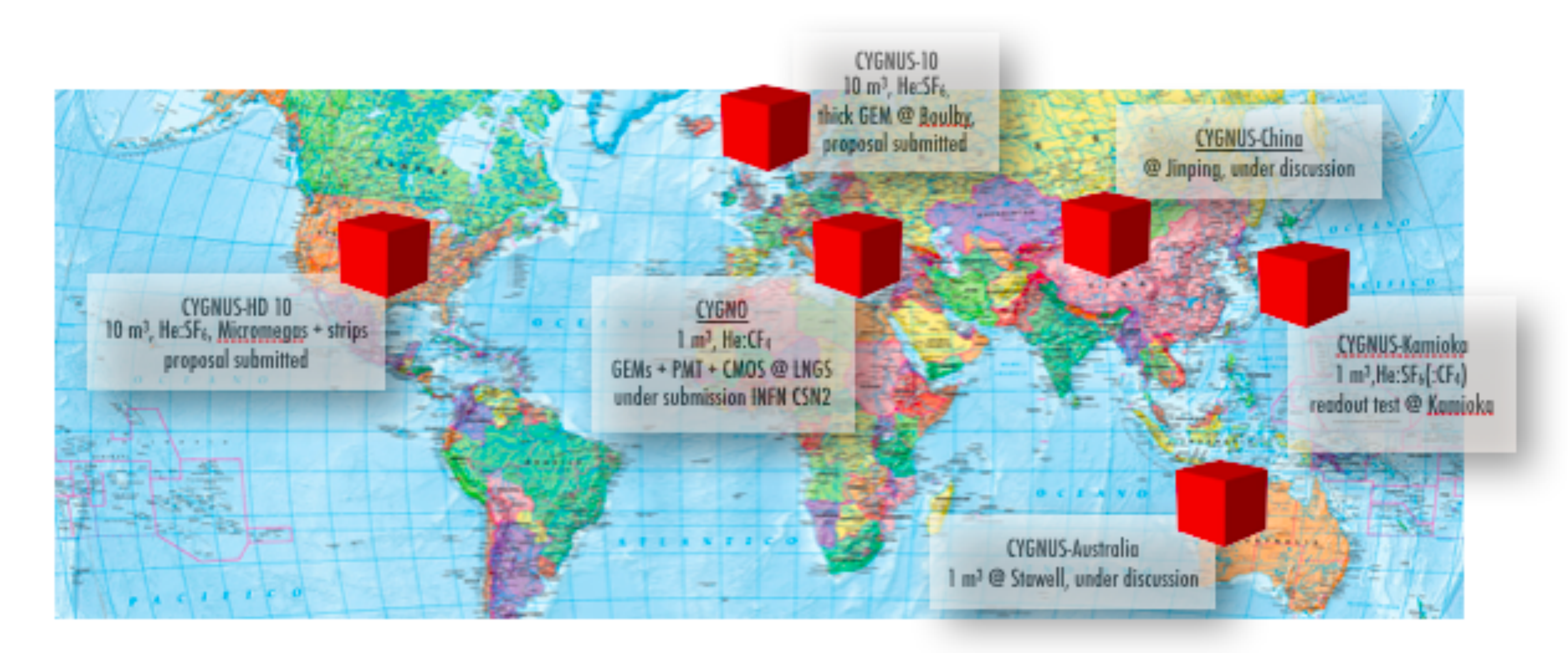
Introduction



- SF_6 gas become of interest in directional dark matter searches
- It is **crucial to use pure target gases**
- Continuously using *fresh* SF_6 gas is problematic due to strict regulations with the use F-gases
- Future large scale plans CYGNUS-1000 utilising 1000 m^3 of SF_6[3]

[3] S. E. Vahsen et al., Cygnus: Feasibility of a nuclear recoil observatory with directional sensitivity to dark matter and neutrinos, arXiv:2008.12587

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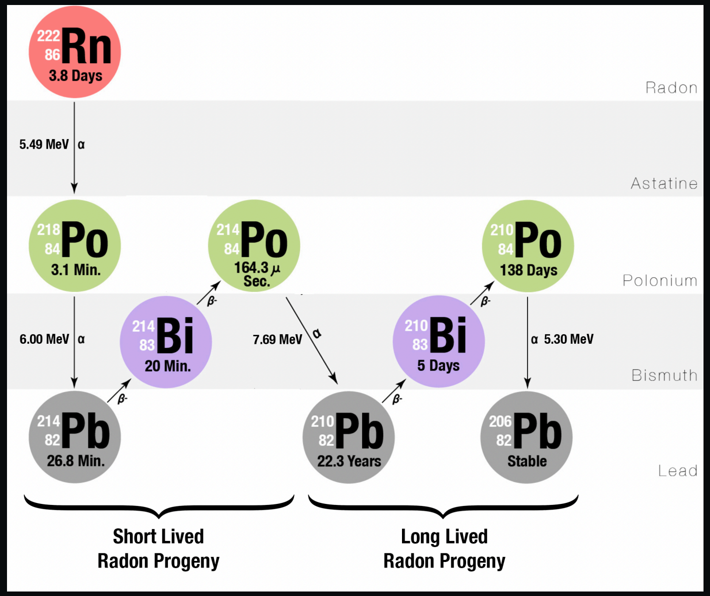

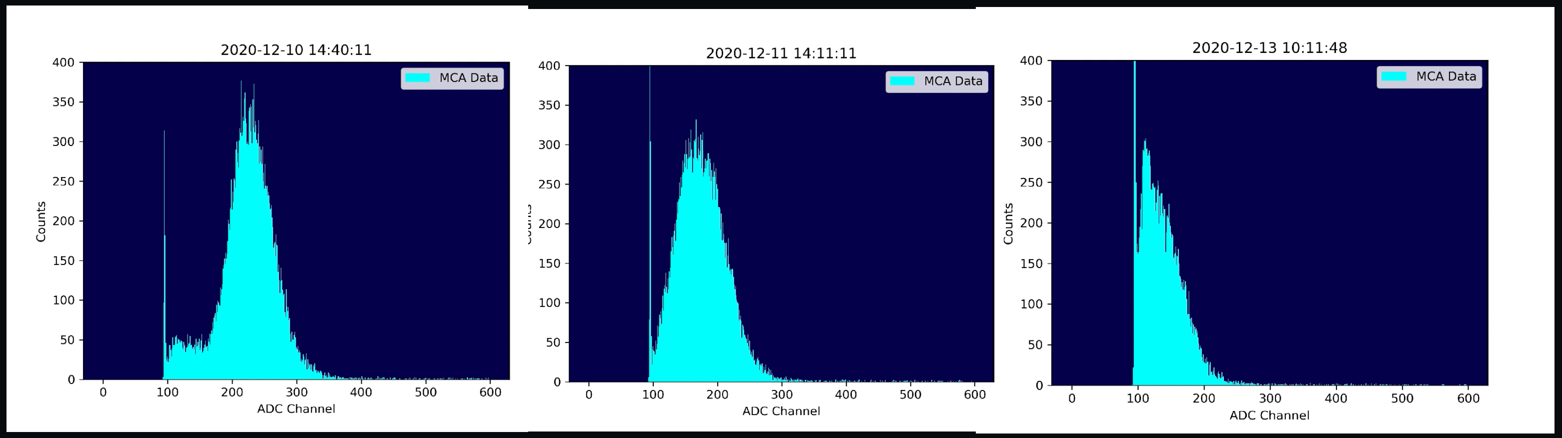

^{55}Fe Spectrum over three days

- Contaminants such as **radon** can **produce unwanted backgrounds** [1]
- Other contaminants water, nitrogen and oxygen can suppress signal [2]

[1] B. R. Battat et al., Radon in the DRIFT-II directional dark matter TPC: emanation, detection and mitigation, JINST 9 (2014) P11004.
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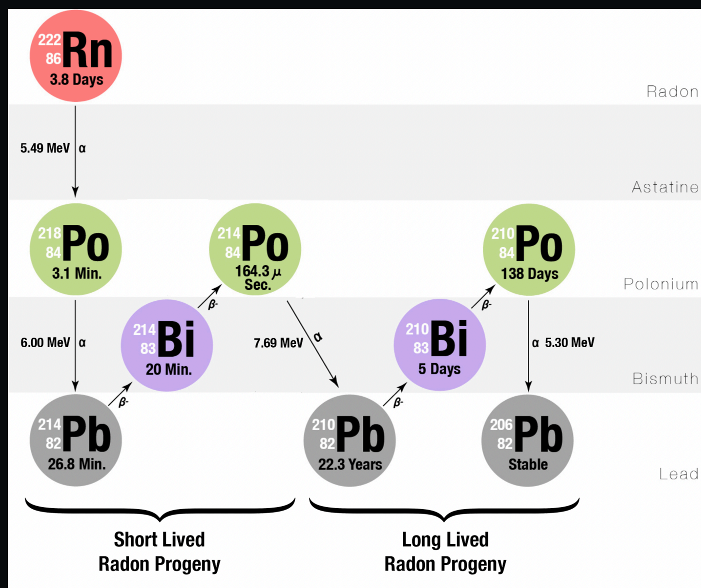

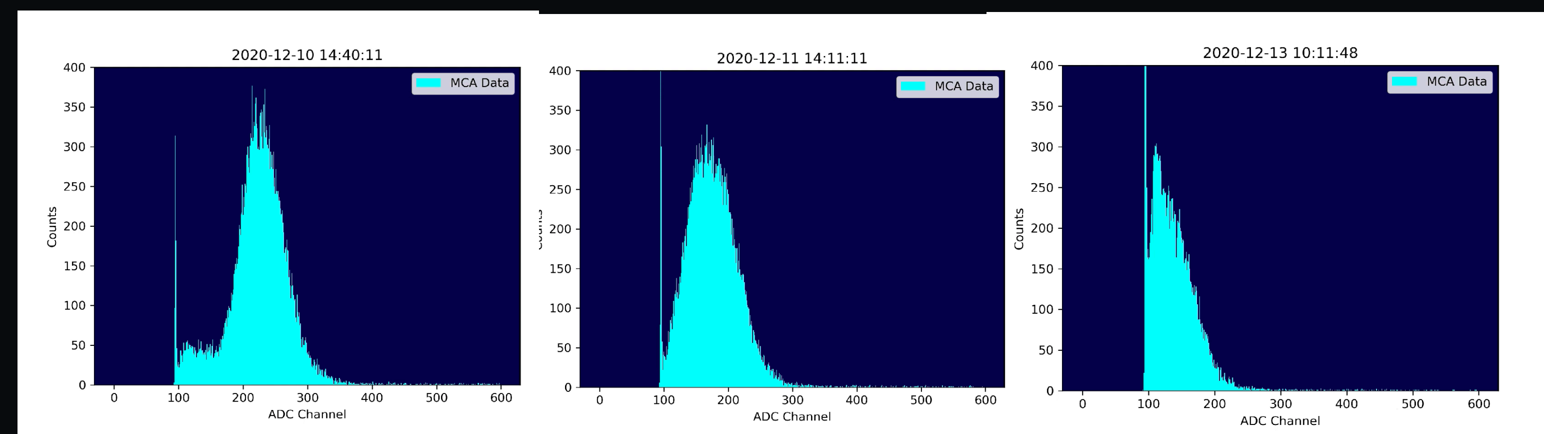

^{55}Fe Spectrum over three days

- Contaminants such as **radon** can **produce unwanted backgrounds** [1]
- Other contaminants water, nitrogen and oxygen can suppress signal [2]

We need to recycle SF_6, removing <u>radon</u> and <u>common impurities</u>

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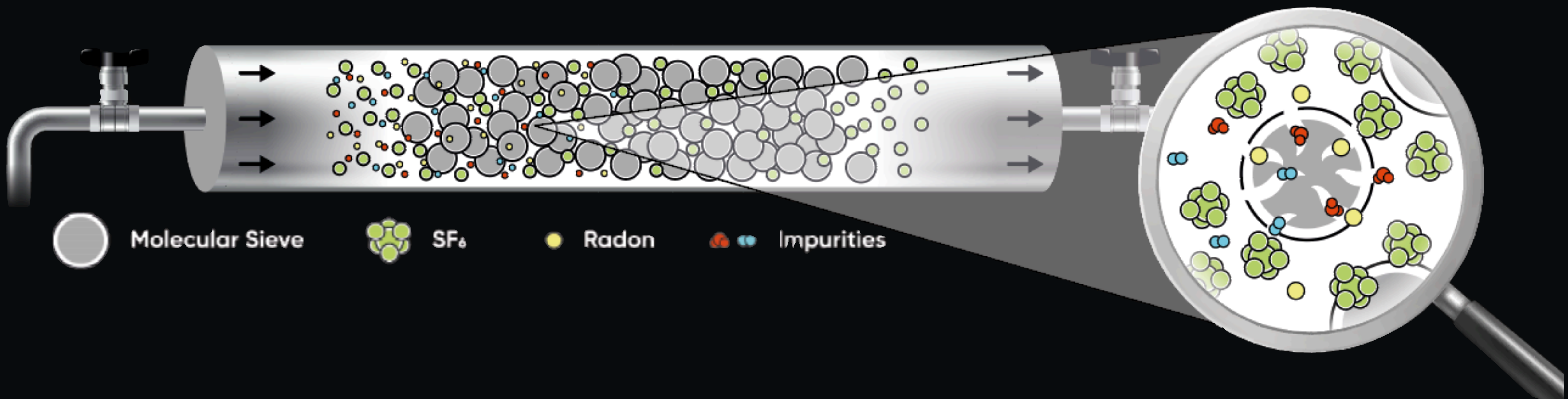
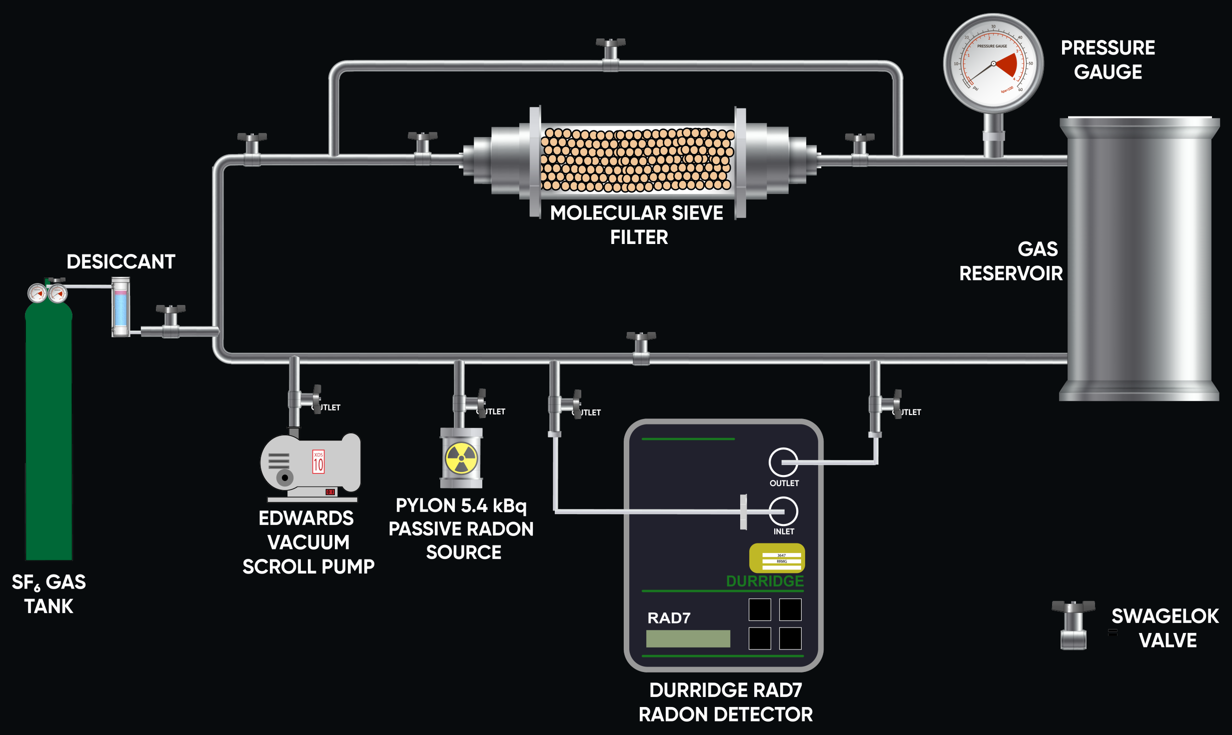
Molecular Sieves (MS)

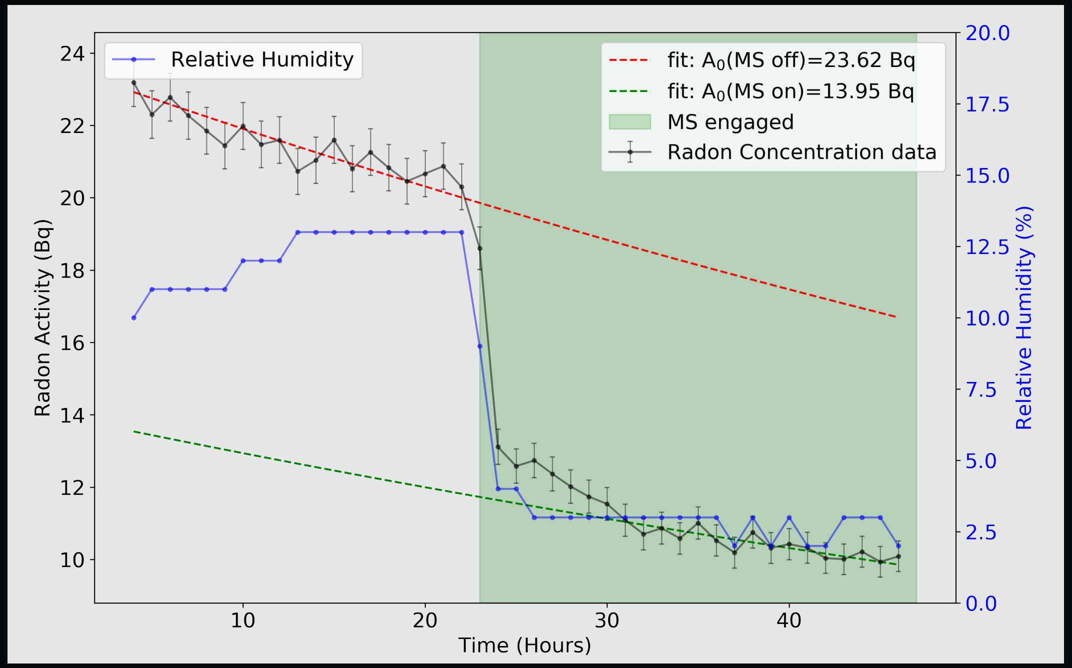


- Molecular sieves are structures with specific pore sizes (3A, 4A, 5A and 13X)
- Pores allow molecules with the critical diameter equal or below to be adsorbed on to the structure
- Molecules with diameters larger than the critical diameters pass between the bead gaps

Molecular Sieves (MS)

Demonstration of radon removal from SF_6 [4]





[4] R. R. Marcelo Gregorio et al., Demonstration of radon removal from SF6 using molecular sieves, JINST 12 (2017) P09025.

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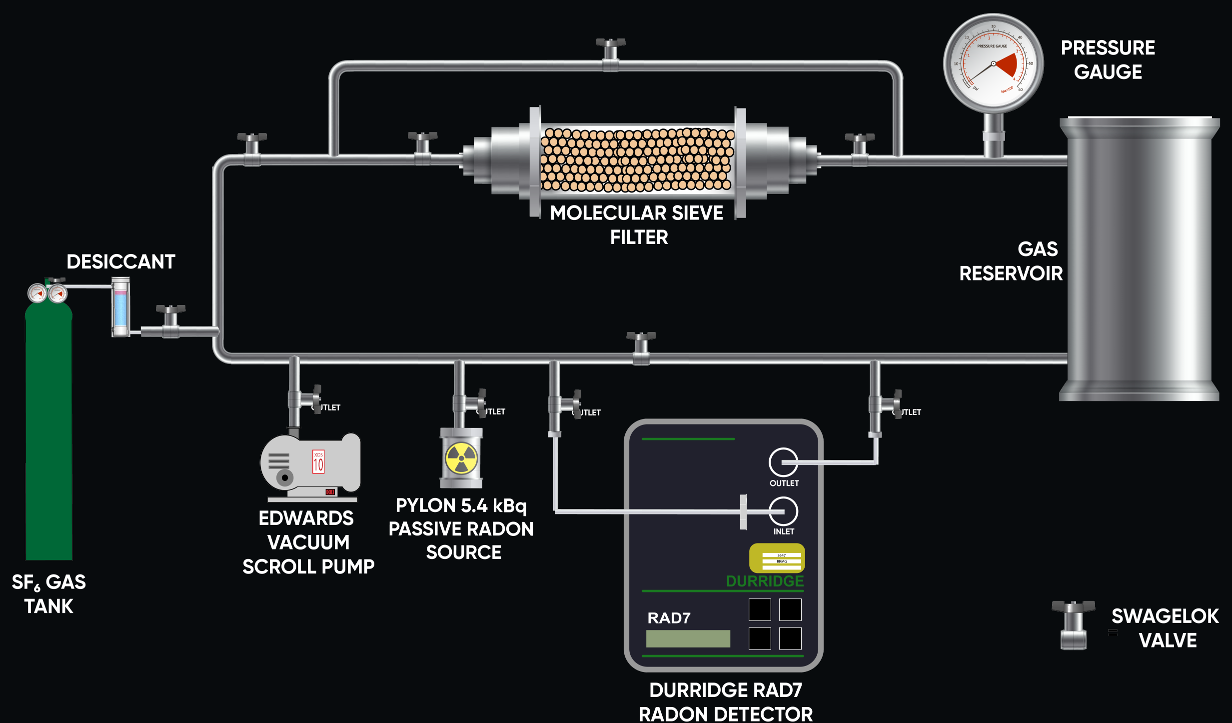

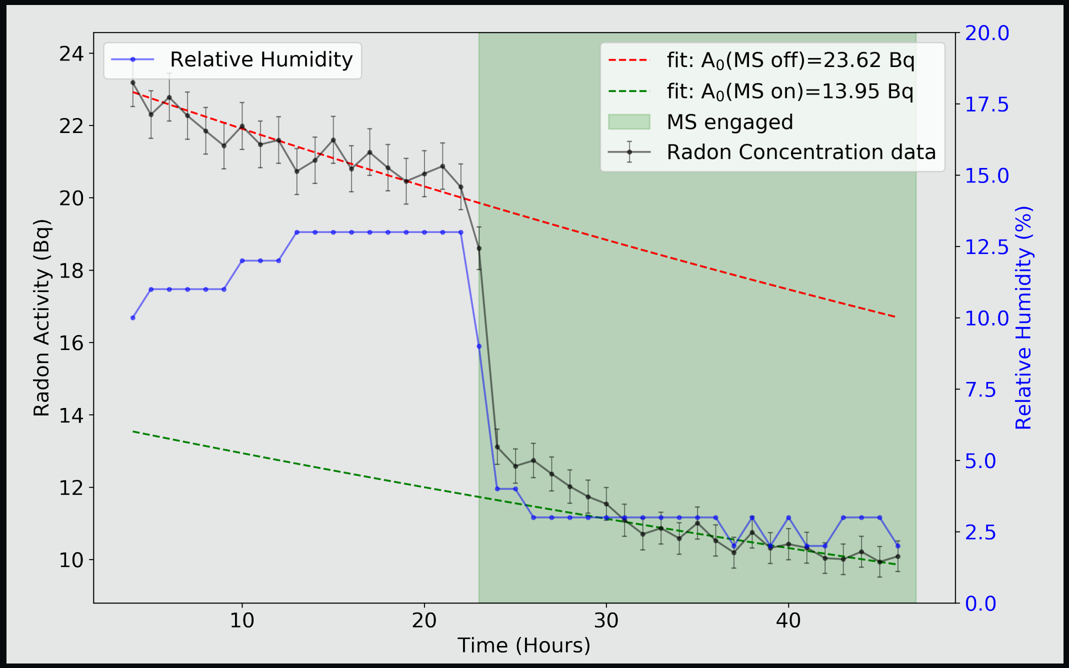

Radon removed by 5A type MS from SF_6
at room temperature **(97±1 Bq/Kg)**

[4] R. R. Marcelo Gregorio et al., Demonstration of radon removal from SF6 using molecular sieves, JINST 12 (2017) P09025.

Low Background MS

Commercial MS **intrinsically emanate radon at levels unsuitable** for ultra-sensitive rare-event physics experiments

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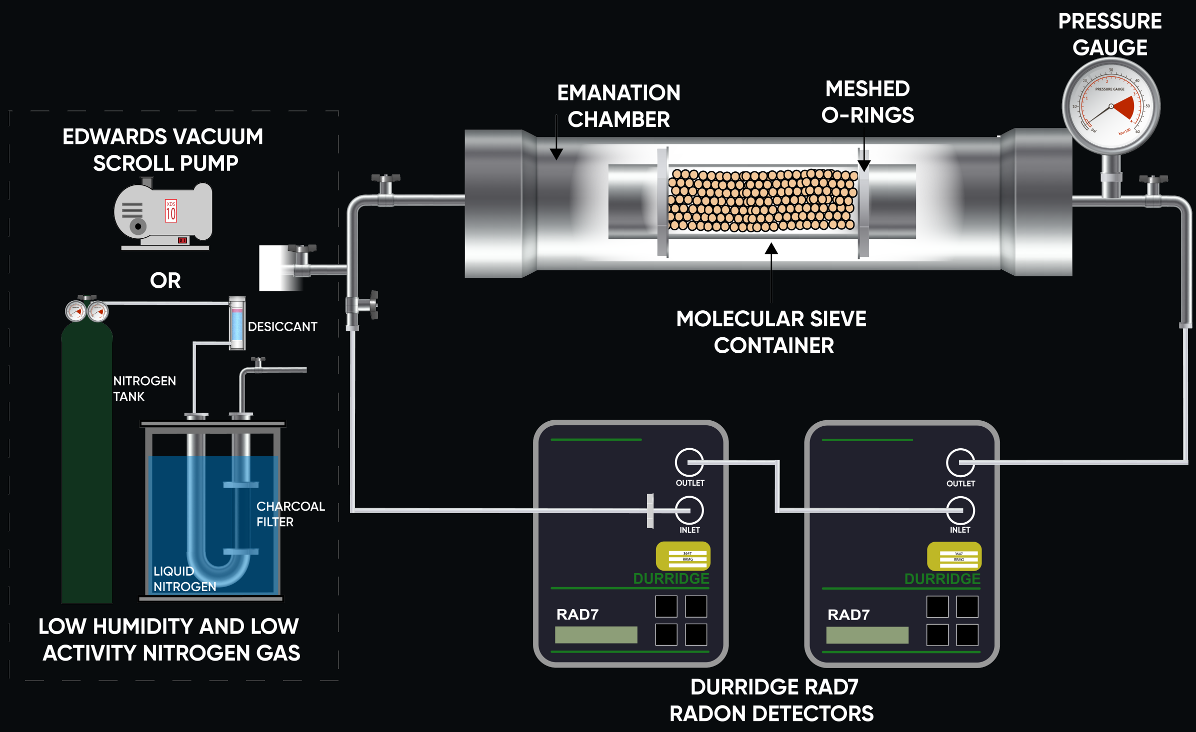

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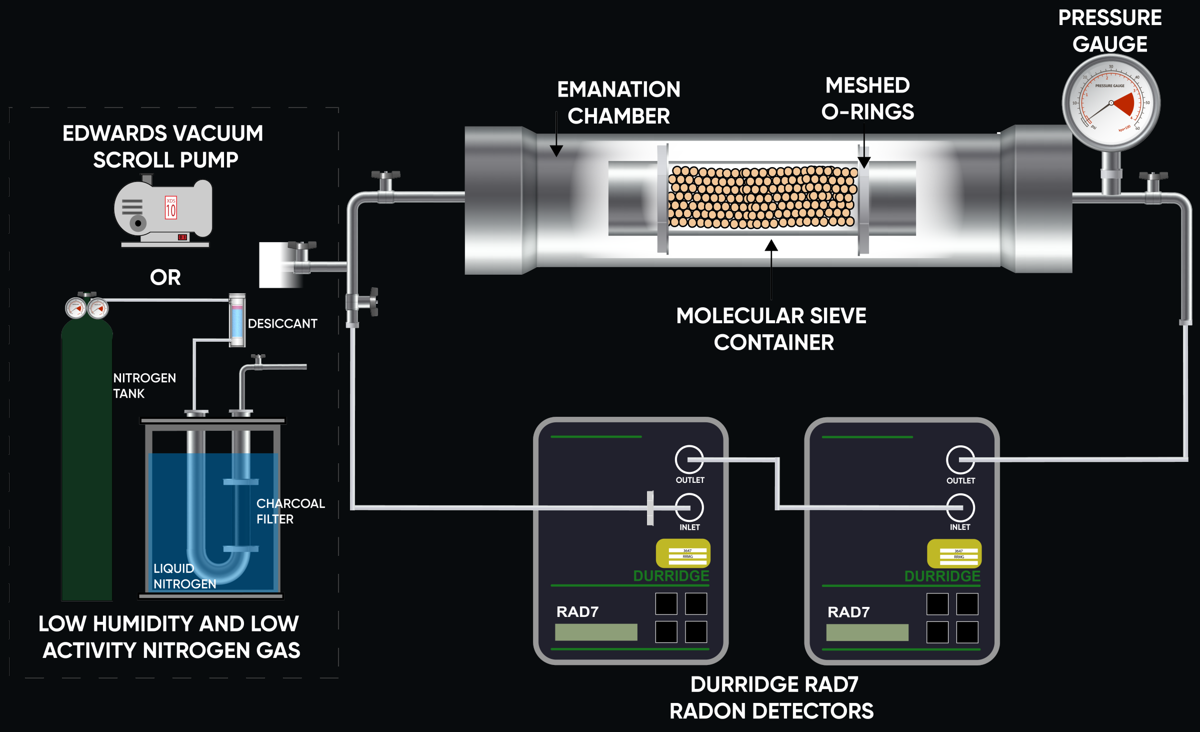

Commercial MS:
525±37 mBq/kg[5]

[5] R.R. Marcelo Gregorio et al., Test of low radioactive molecular sieves for radon filtration in SF6 gas-based rare-event physics experiments, 2021 JINST 16 P06024

Low Background MS

Nihon University in collaboration with Union Showa K.K., has developed a method of producing low radioactive MS

Commercial
Sigma-Aldrich

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MS V2

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Nihon Uni MS (V2):
<14 mBq/kg

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<14 mBq/kg

To provide a complete comparison of the MS candidates, the results from the **emanation** and **filtration** tests were combined

Low Background MS

Commercial
Sigma-Aldrich

Nihon Uni
MS V2

MS	Rn emanated mBq/kg	Rn Captured Bq/kg
Sigma Aldrich (Commercial)	525±37	97±1
Nihon-Uni (V2)	**<14**	**254±3**

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The NU-developed (V2) 5Å MS emanated radon **at least 98.9% less** per radon captured, compared to the commercial MS

Overview so far

- ✓ Removes radon - **5A Type MS**
- ✓ Low intrinsic radioactivity MS **- NU V2 MS**
- ✓ Remove common impurities[6] - **3A, 4A Type MS**

[6] Sigma-Adrich, Molecular Sieves-Technical Information Bulletin, AL-143 Mineral Adsorbents, Filter Agents and Drying Agents (2020).

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- ✓ Removes radon - **5A Type MS**
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→ **Design and construct a gas system**

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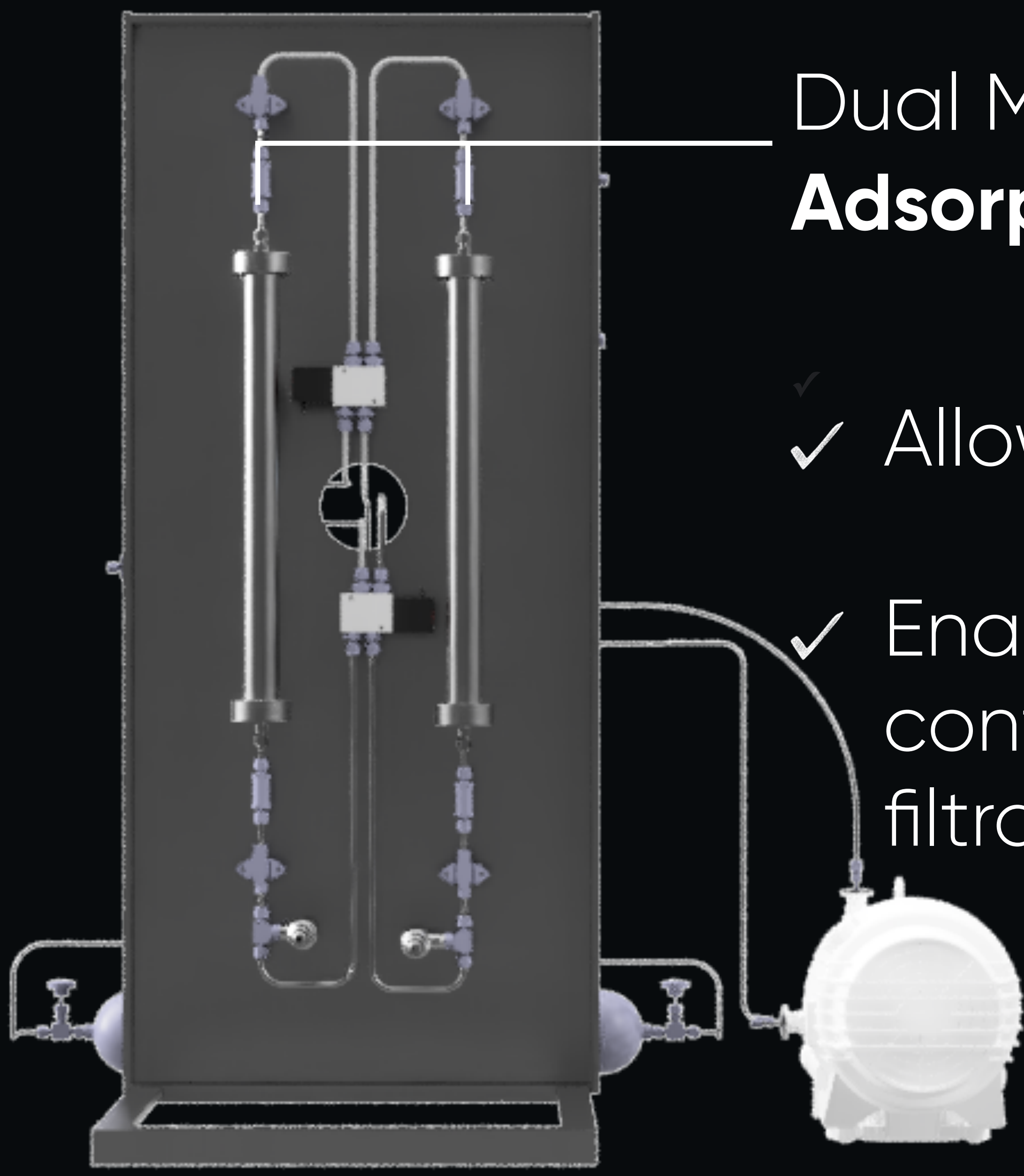
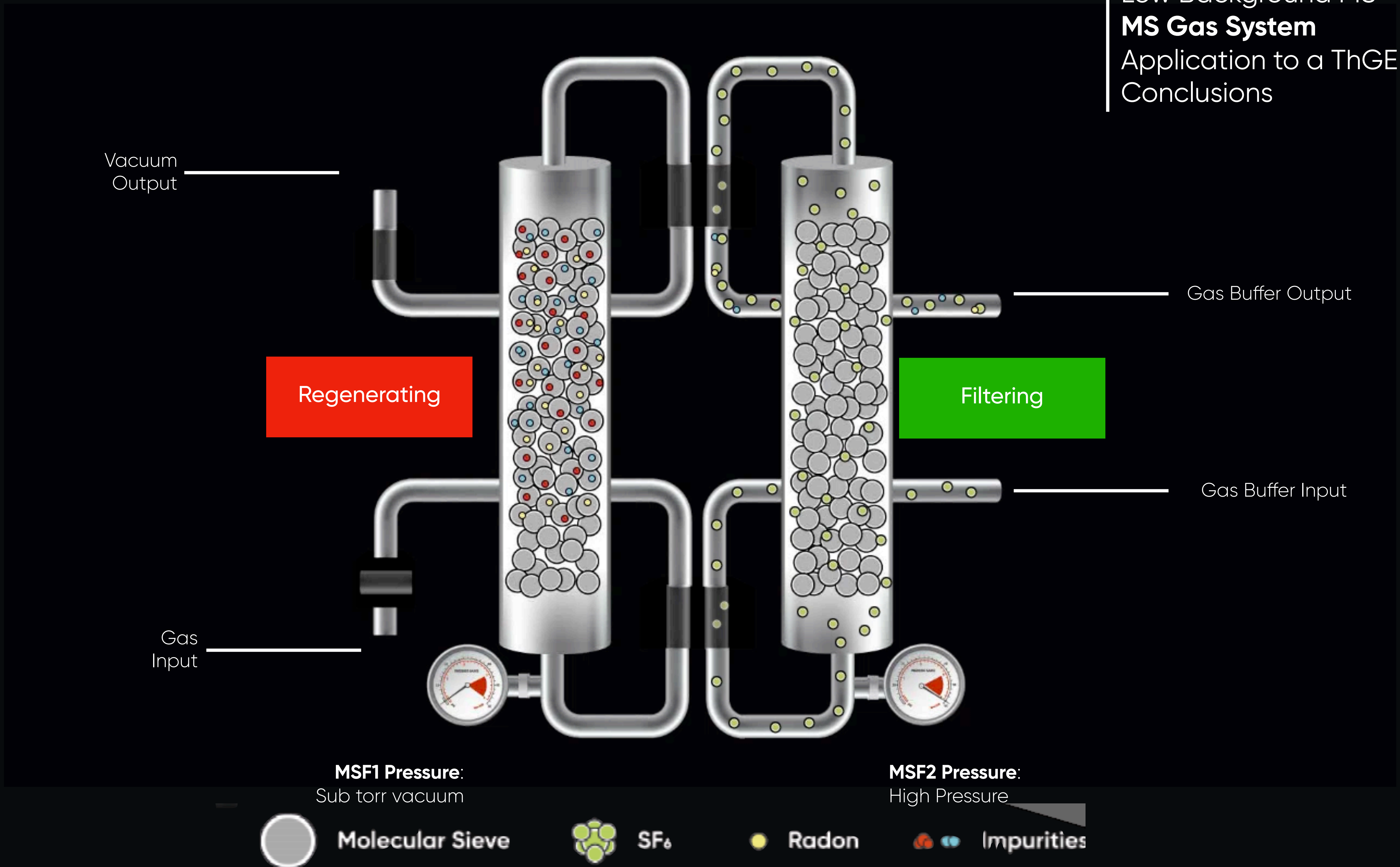
Gas System Design



Dual MS design utilises **Vacuum Swing Adsorption (VSA)** Technique

- ✓ Allows on-site Vacuum MS regeneration
- ✓ Enables the MS filter to be reused allowing continuous long-term operation of the filtration setup

Vacuum Swing Adsorption



Vacuum Swing Adsorption allows for **simultaneous filtration** and **vacuum regeneration** enabling long-term continuous use

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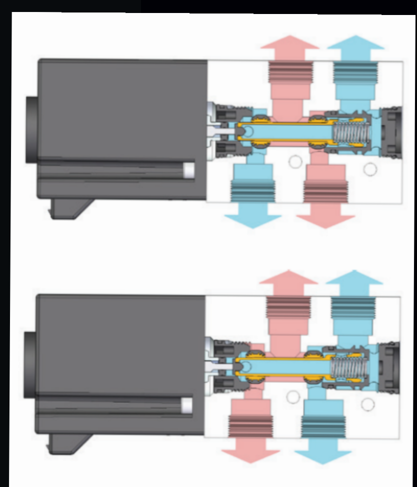

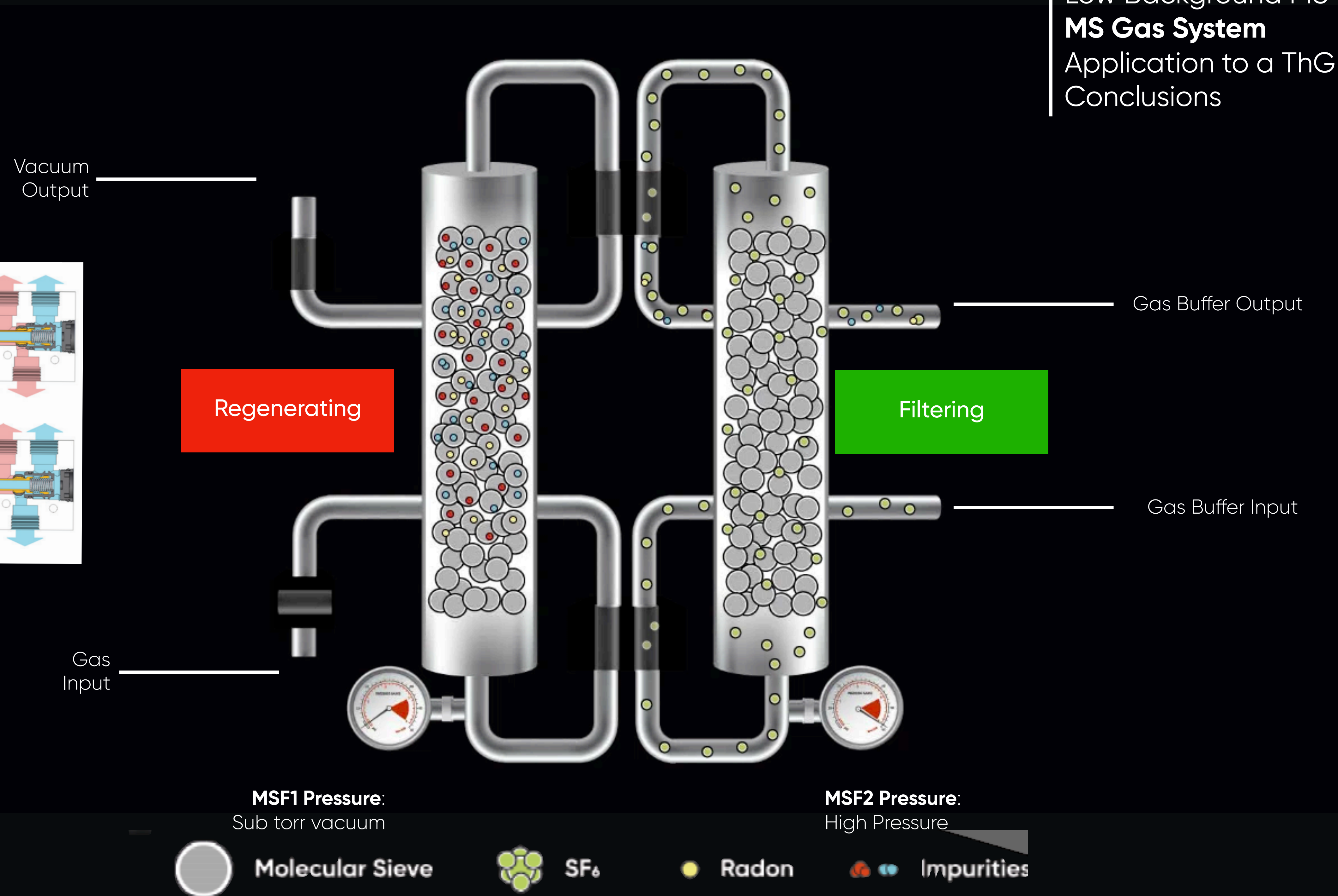

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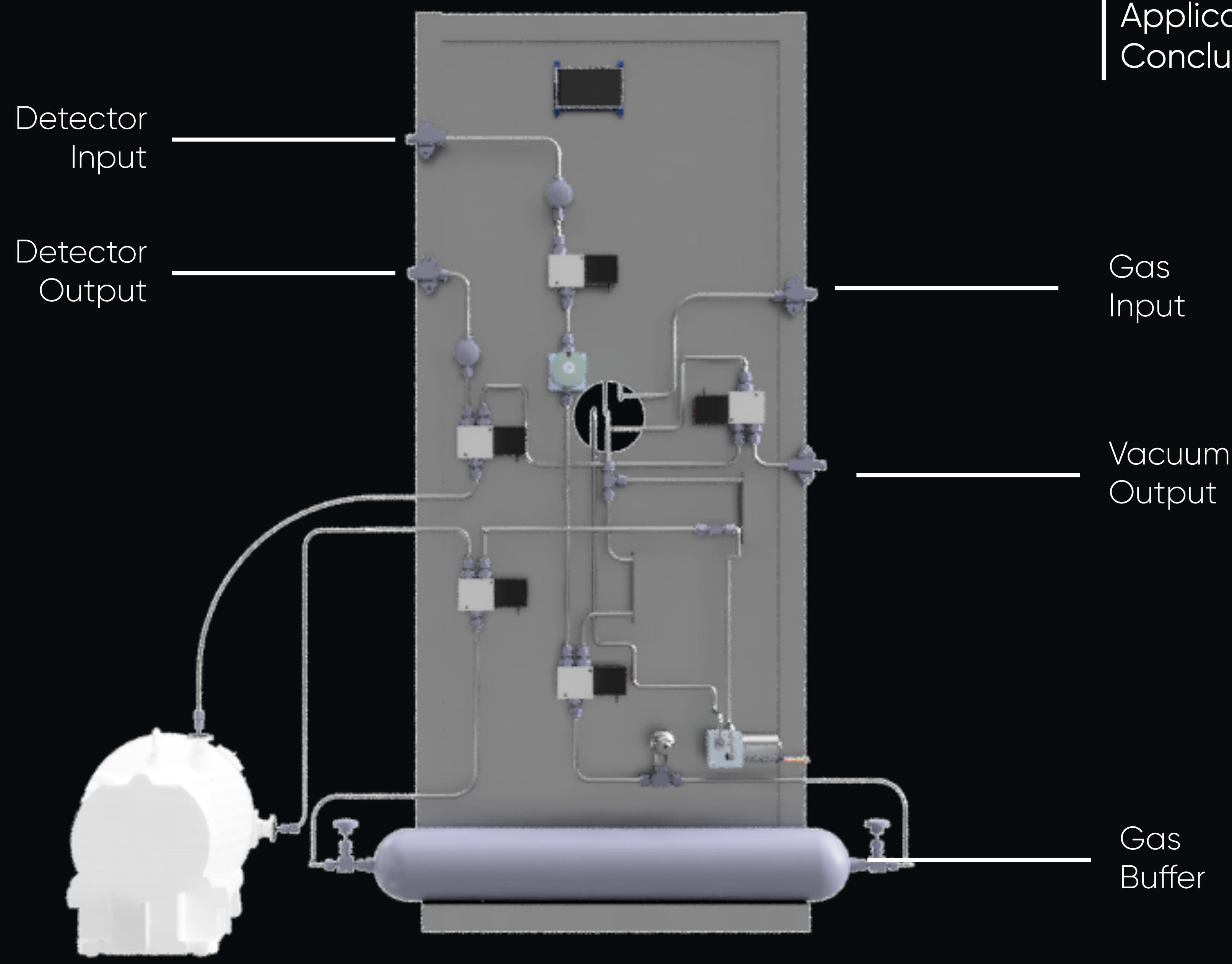
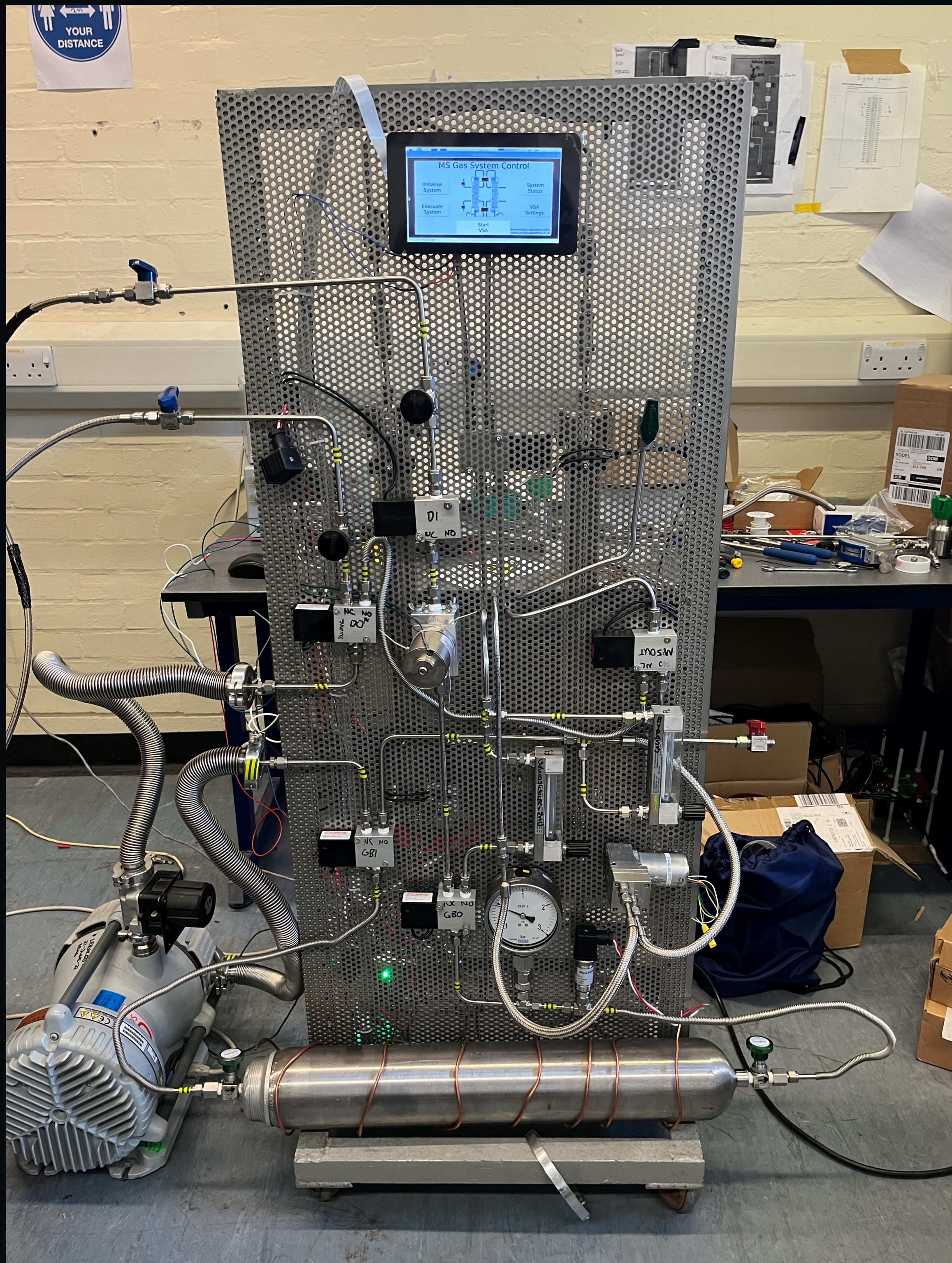
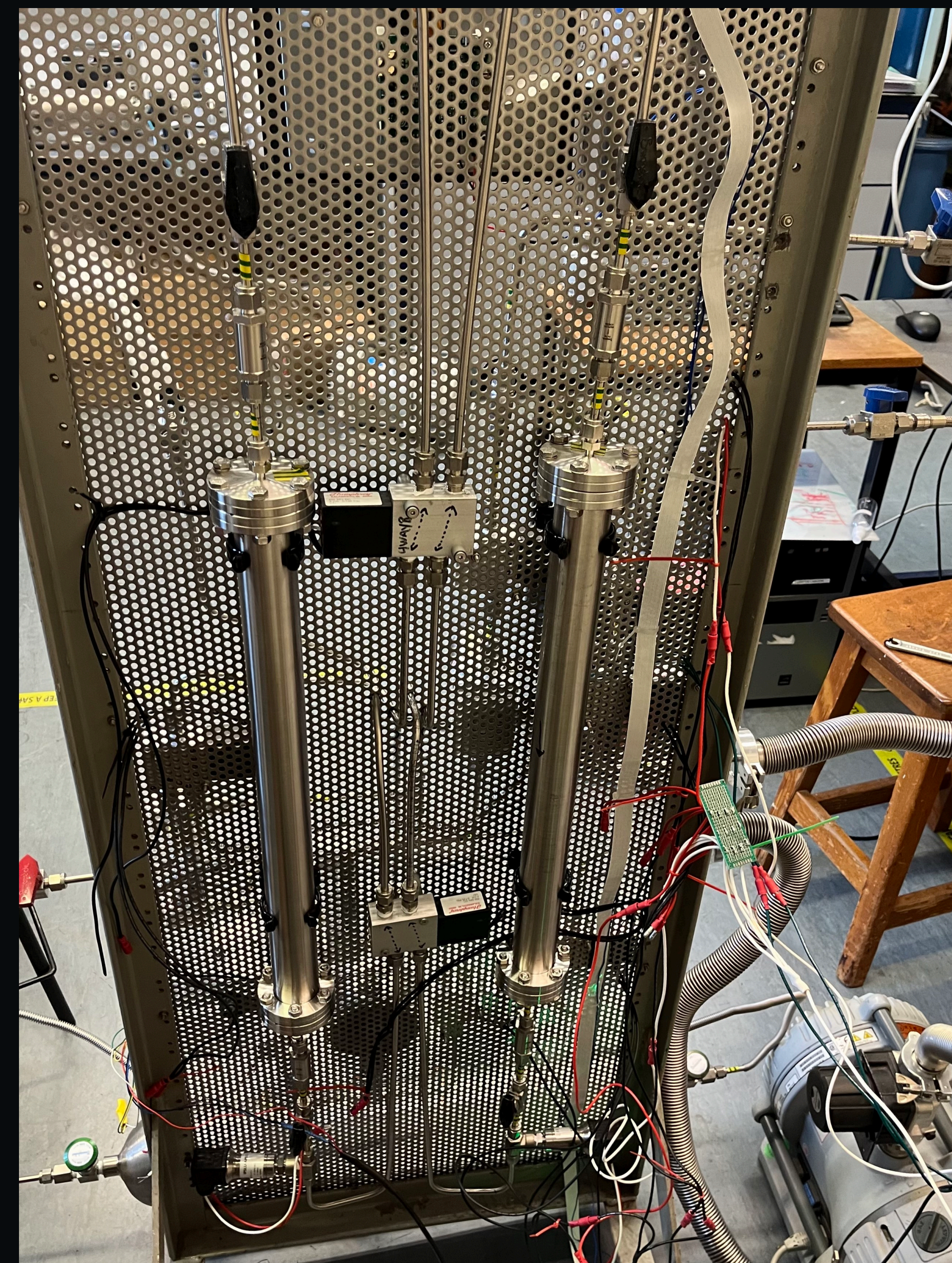
Gas System Design



Gas buffer allows operation with low pressure detectors

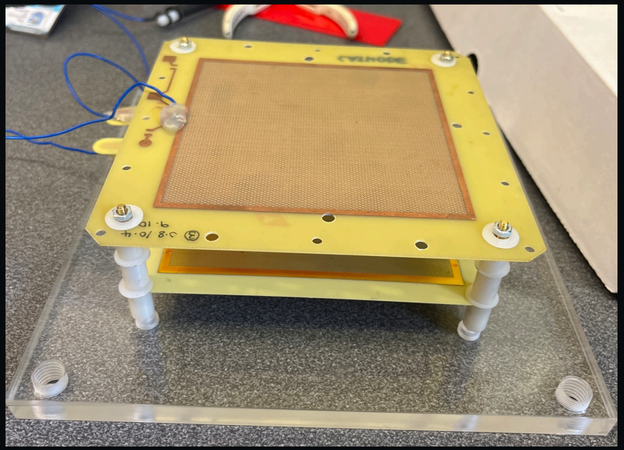
Constructed Gas System





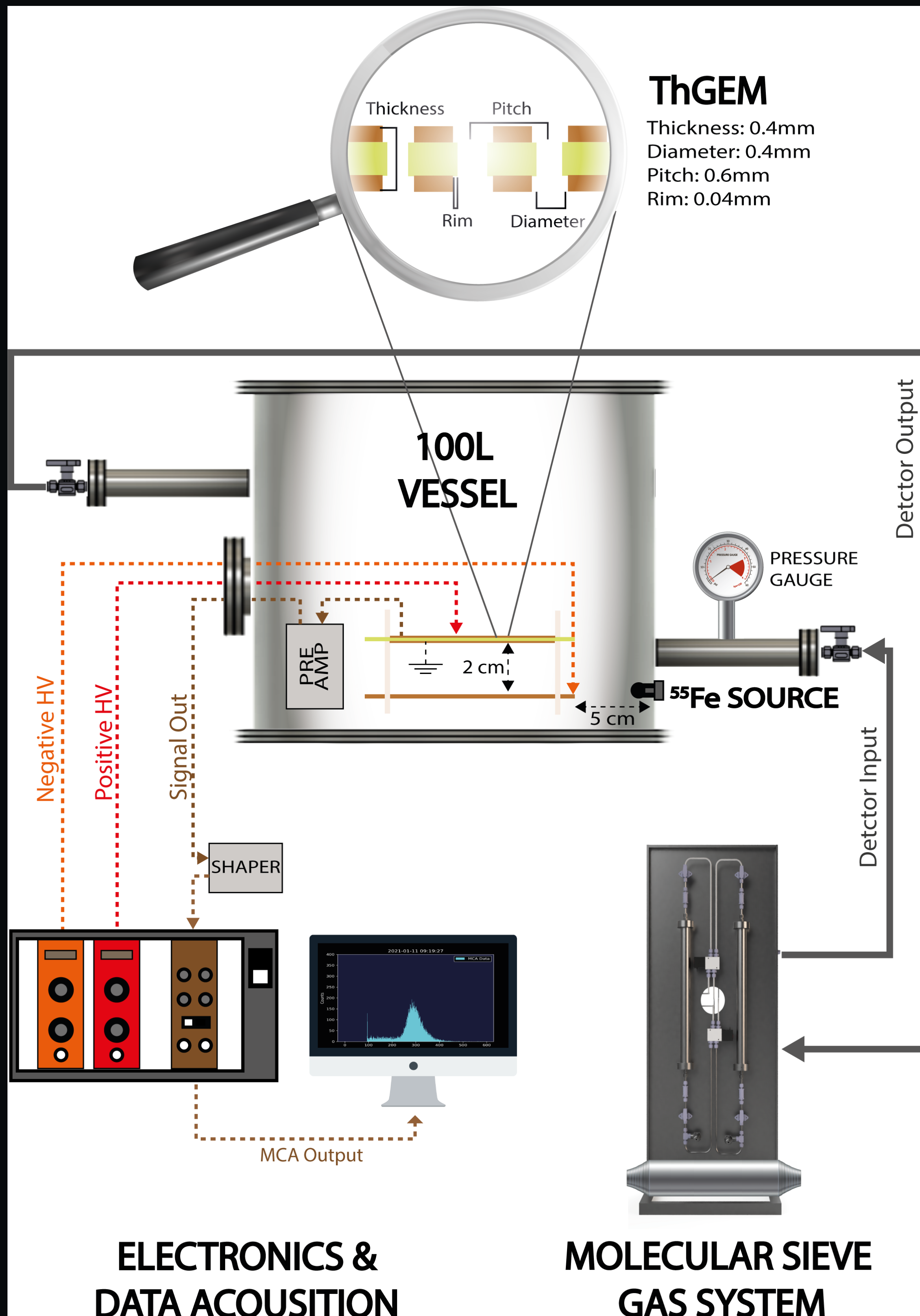
Performance Testing

ThGEM TPC (10 x 10 cm)



100L Vessel

Performance Testing



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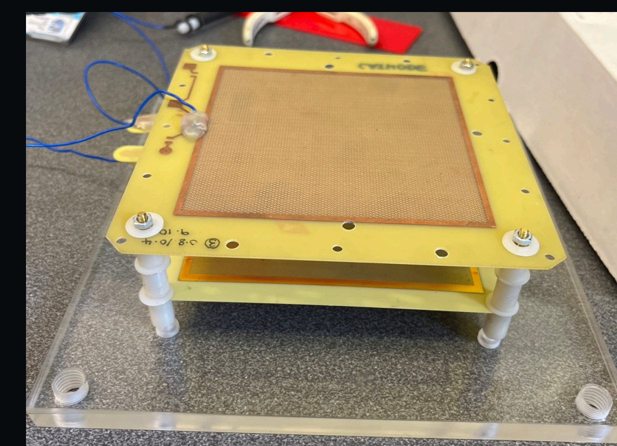


100L Vessel

Performance Testing

TEST ONE: Intrinsic radon emanation of detector

TEST TWO: Signal gas gain over time

Compare tests **with** and **without** gas system operating

TEST ONE: radon emanation

Gas: 50 Torr SF_6

Gas System Settings: One detector volume per day

VSA Setting: Swing every day

MS Filter: NU (V2) MS 5A ~ 40g in each filter

Preliminary Results

After 5 days of operation, detector gas was sampled via buffer cylinder

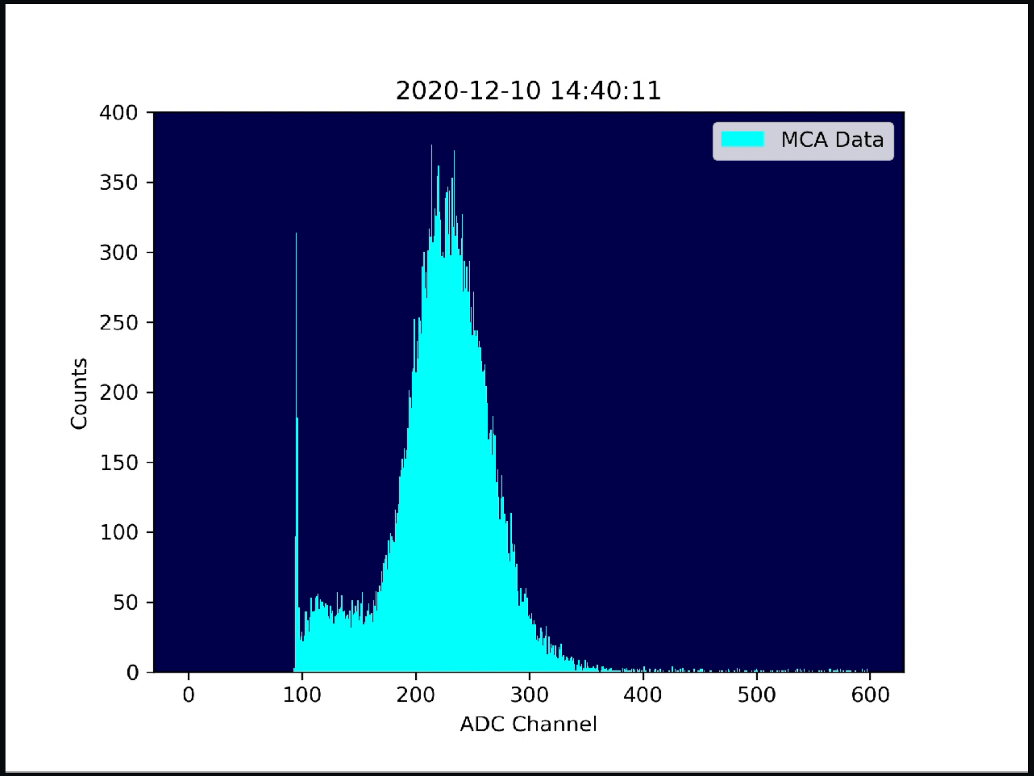
RAD7 Radon Detector
(Operates at 1 atm)

Gas System (Blank MS) = 9.09±1.33 mBq
Gas System (N2 V2 MS) = 2.42±0.49 mBq

73±7% DECREASE

TEST TWO: Signal Gas Gain

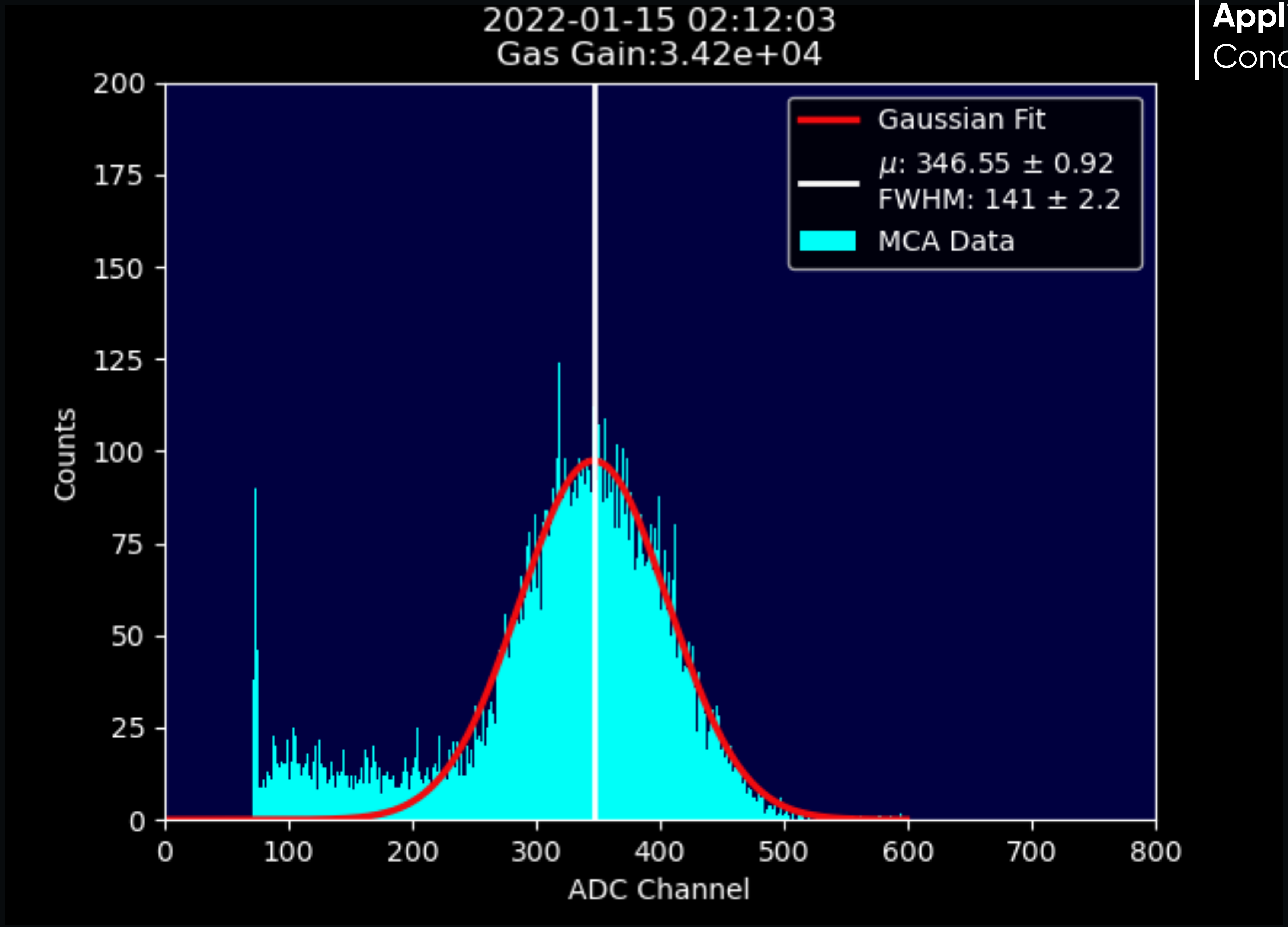
Signal deterioration during normal operation due to gas contamination (see video)



Gas: 50 Torr CF_4*
Gas System Settings: One detector volume per day
VSA Setting: Swing every day
MS Filter: 3A:4A Mixture ~500g in each filter

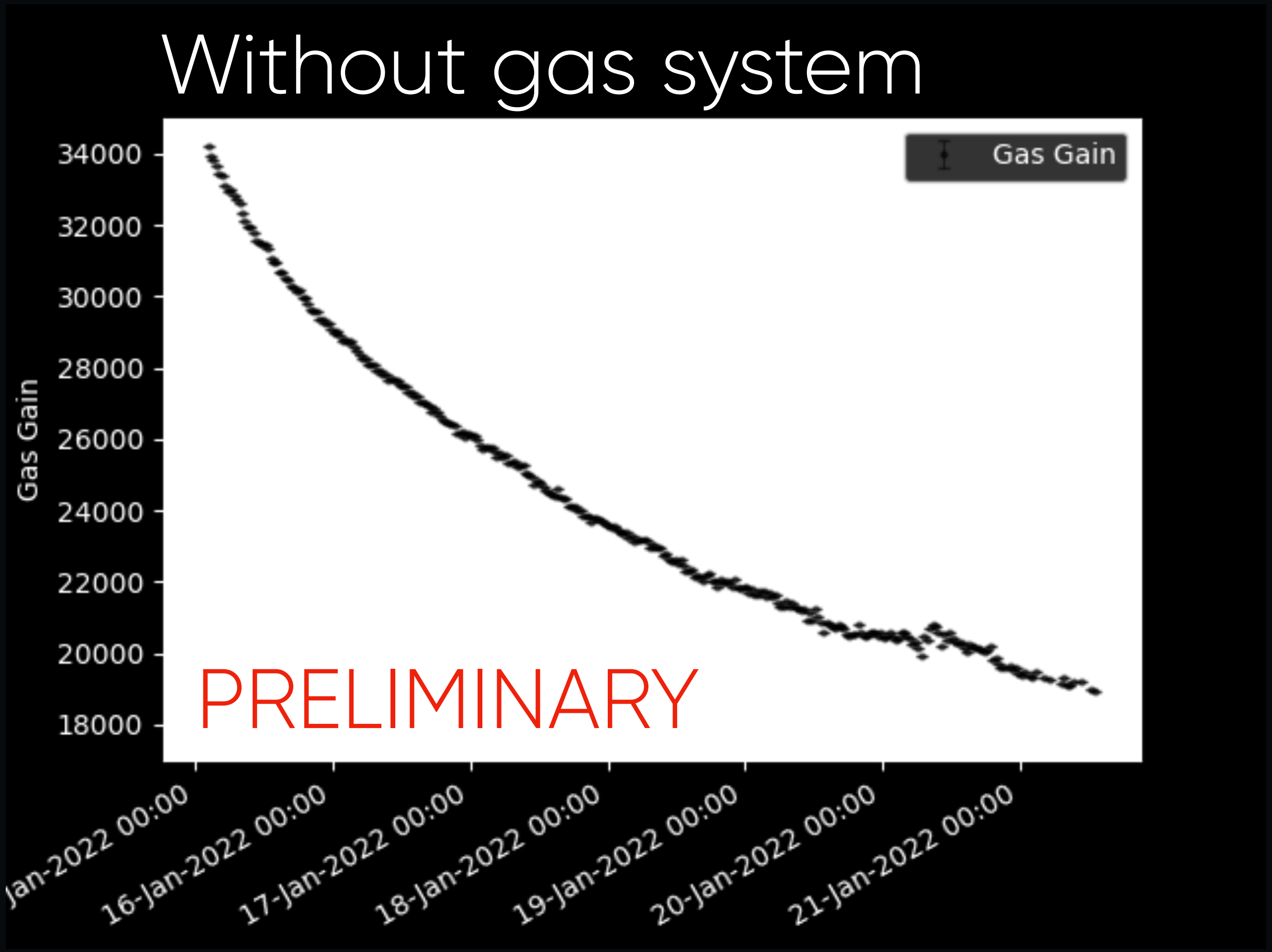
*Target gas CF_4 was used as an analogue for SF_6

Data Analysis



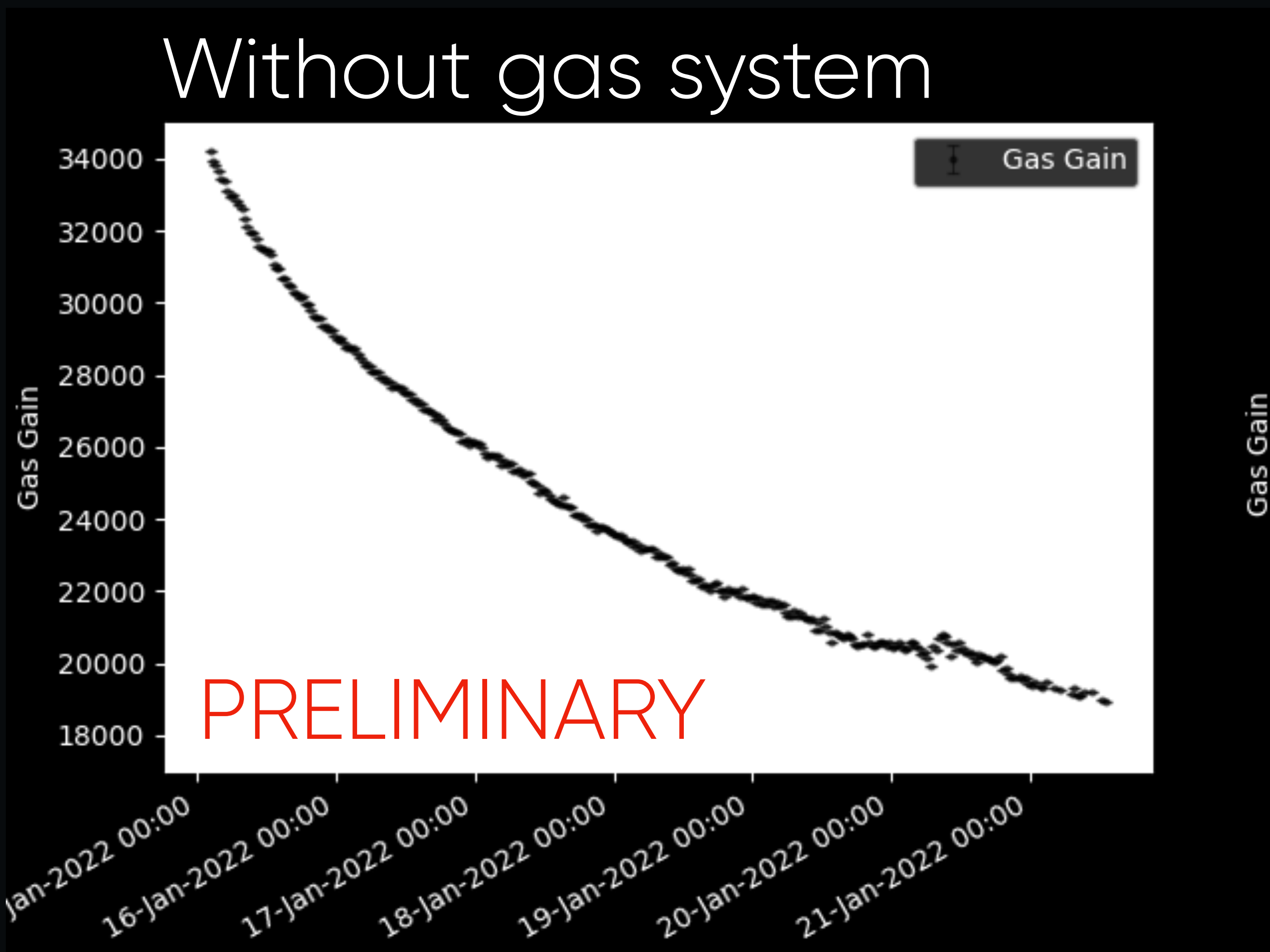
$$GAIN = \mu_{ADC} \times 71.4 - 105$$

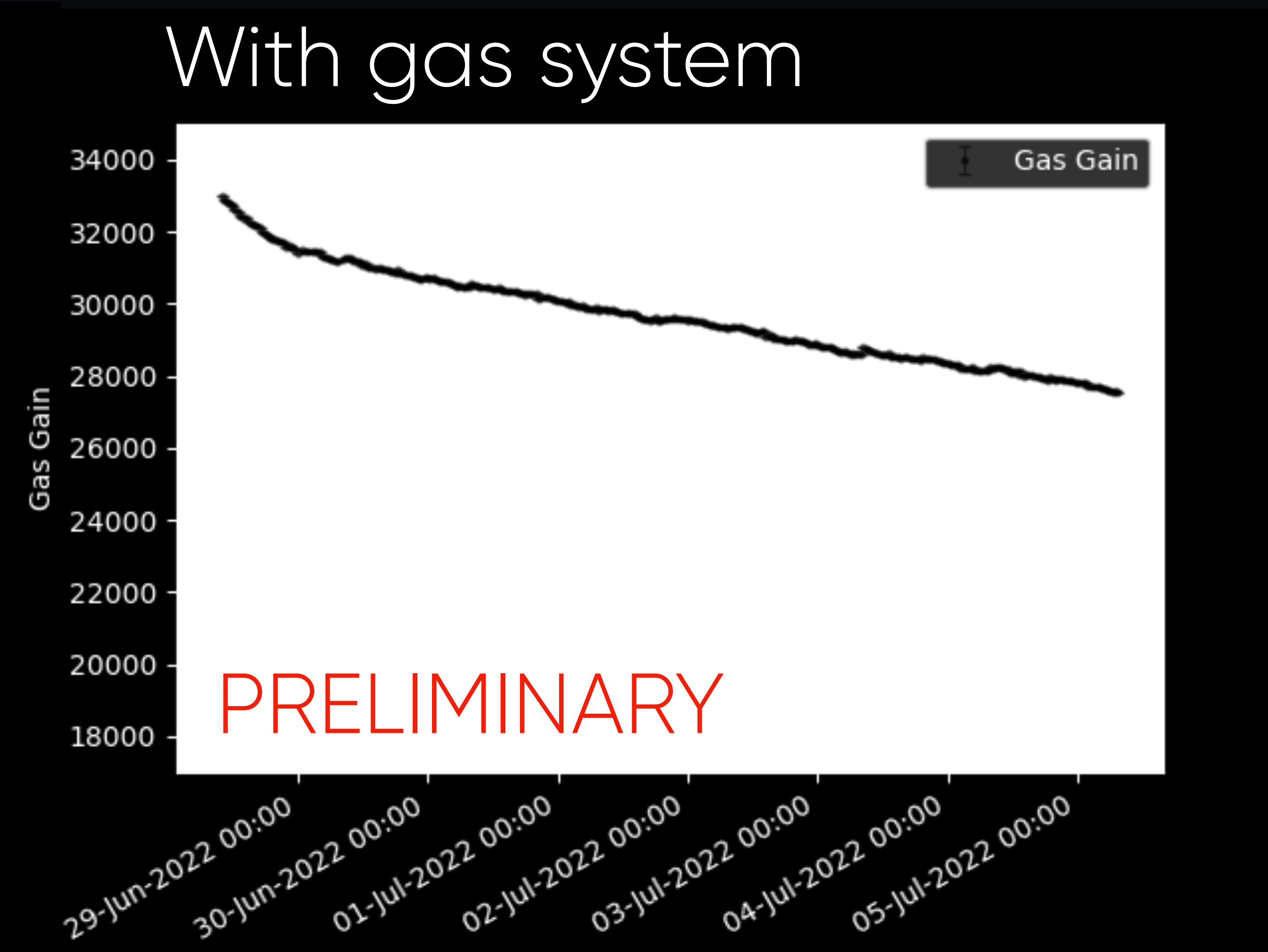
Preliminary Results 150h



Without gas system: 3.42 x10^4 —> 1.91 x10^4 **(-7.4% per day)**

Preliminary Results 150h





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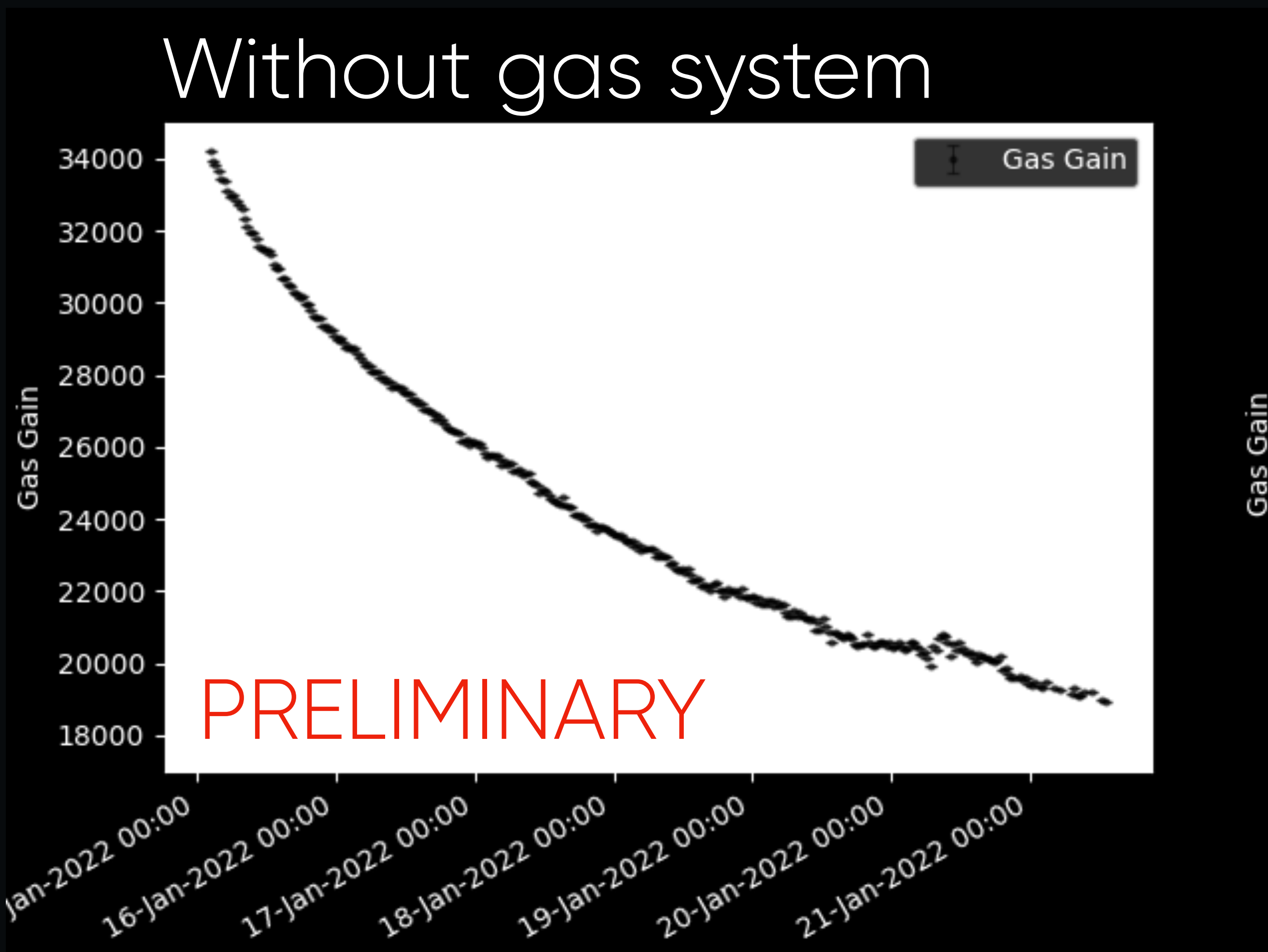
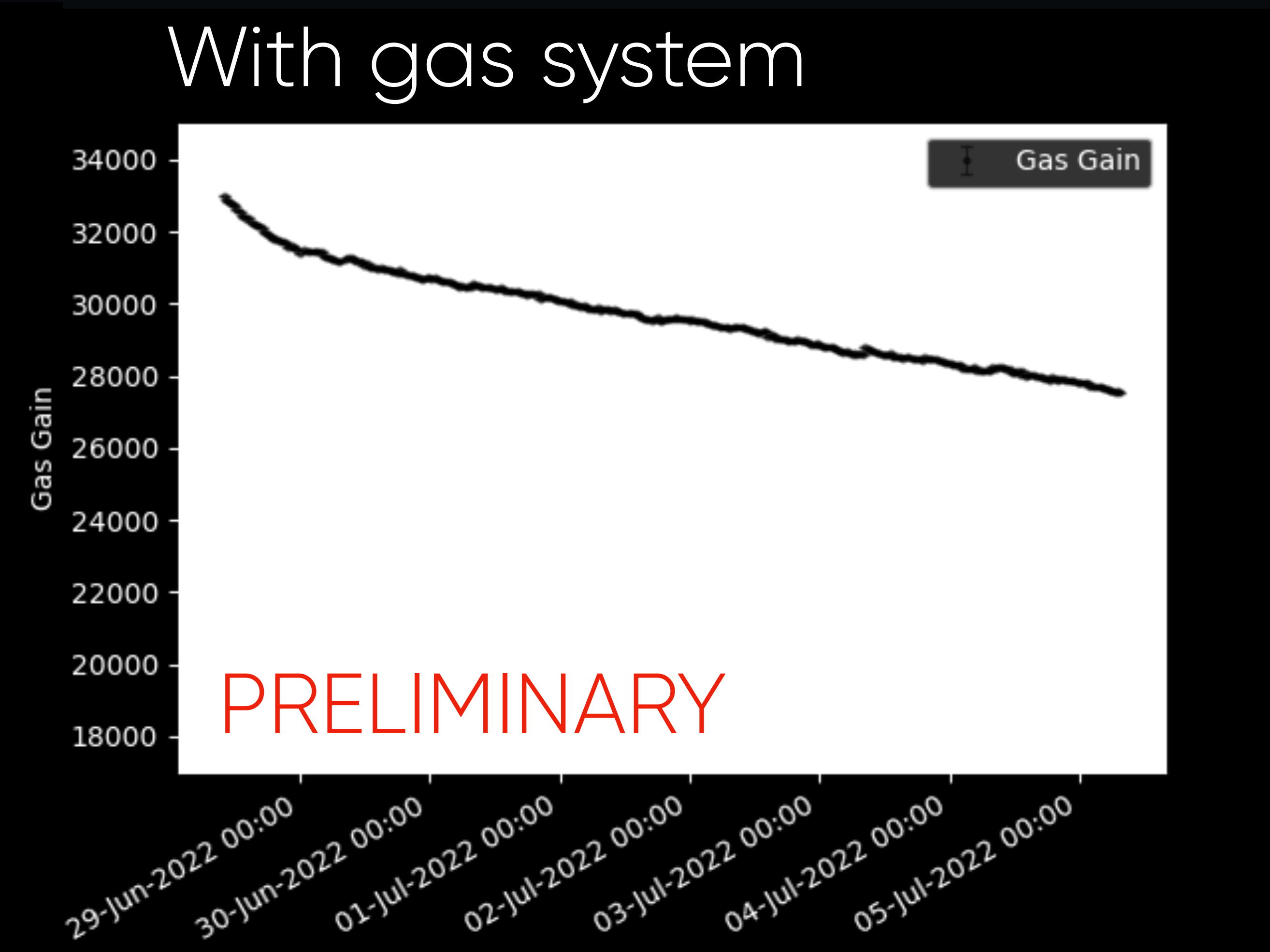
Preliminary Results 150h





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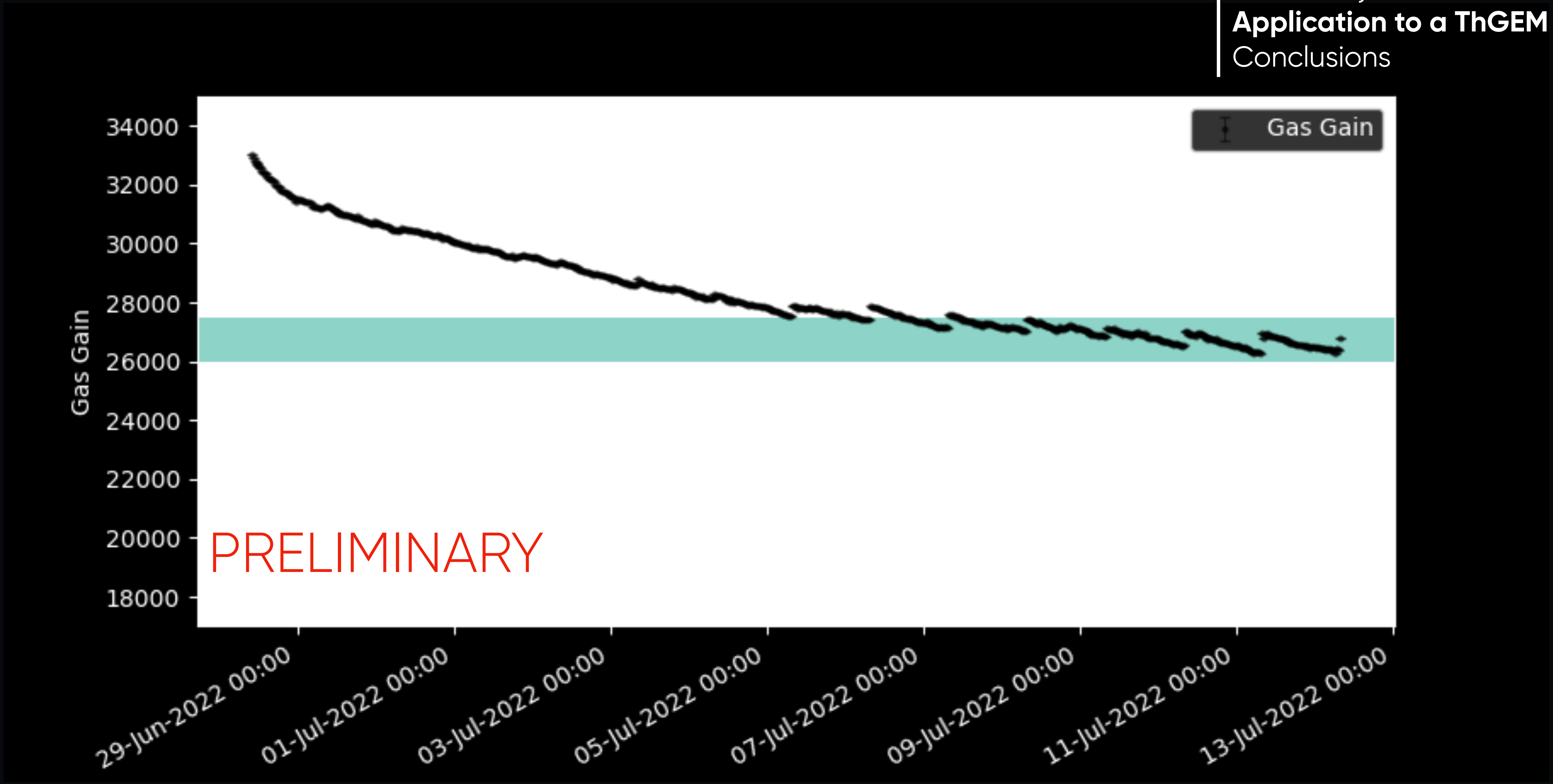
MS Gas System has slowed gas deterioration

Preliminary Results - 150h+



Equilibrium between MS Gas System Filtration & Contamination

MS Gas System operation indicates towards a stable gain

Next Steps

1) **Lower radon intrinsic activity**
2) **Stability at a higher level of gain**

Equilibrium between Gas System **Filtration** vs **Contamination**

Improve filtration rate
- Use more molecular sieves
- Recirculation rate
- Cooling

Improve contamination rate
- Cleaner detector
- Screening gas system parts
- Outgassing and leaks

Conclusions

- Demonstrated the removal of radon from SF_6 with MS
- Identified a suitable low background MS
- Designed Vacuum Swing Adsorption MS Gas System ideal for long term continuous use
- Tested performance of the gas system with small scale ThGEM TPC
- Devised a method to reduce the total gas used in ultra-sensitive SF_6 gas-based experiments

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Back up slides - Low Background MS




MS	Geometry	Rn emanated mBq/kg	Rn Captured Bq/kg	Emanated per captured $\times 10^{-3}$
Sigma Aldrich (Commercial)	8-12 mm uniform	525±37	97±1	5.4±0.7
Nihon-Uni (V1)	1-2 cm Granules	99±23	35±2	2.8±0.4
	Fine Powder	680±30	330±3	2.1±0.1
Nihon-Uni (V2)	**Powder**	**<32**	**254±3**	**<0.12**

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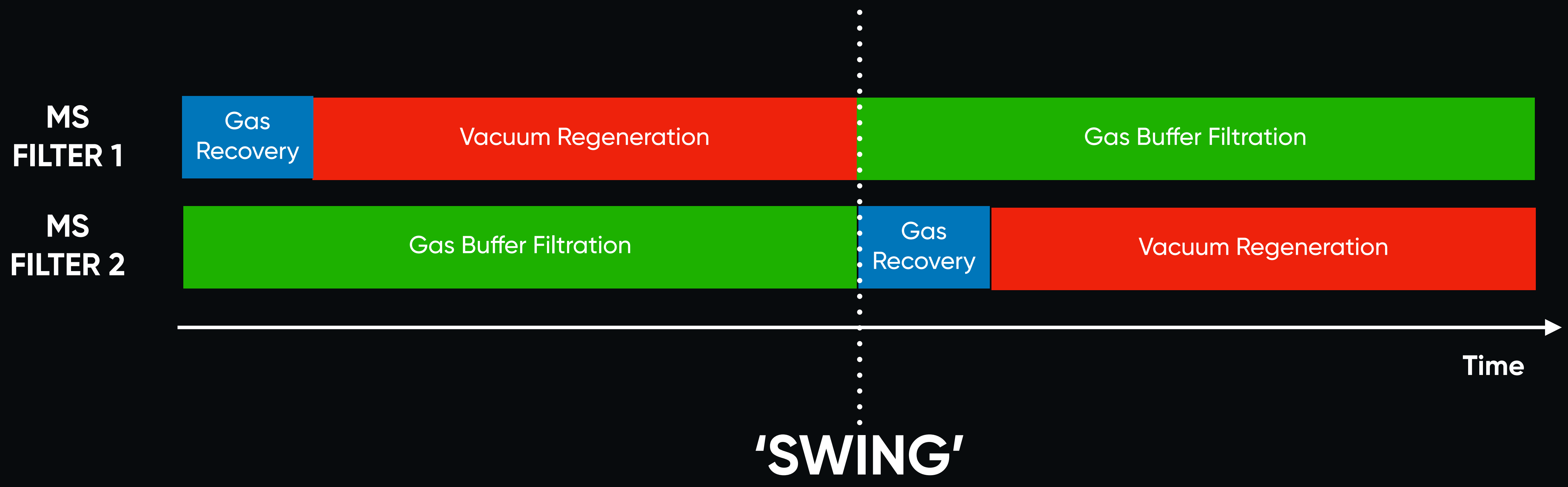
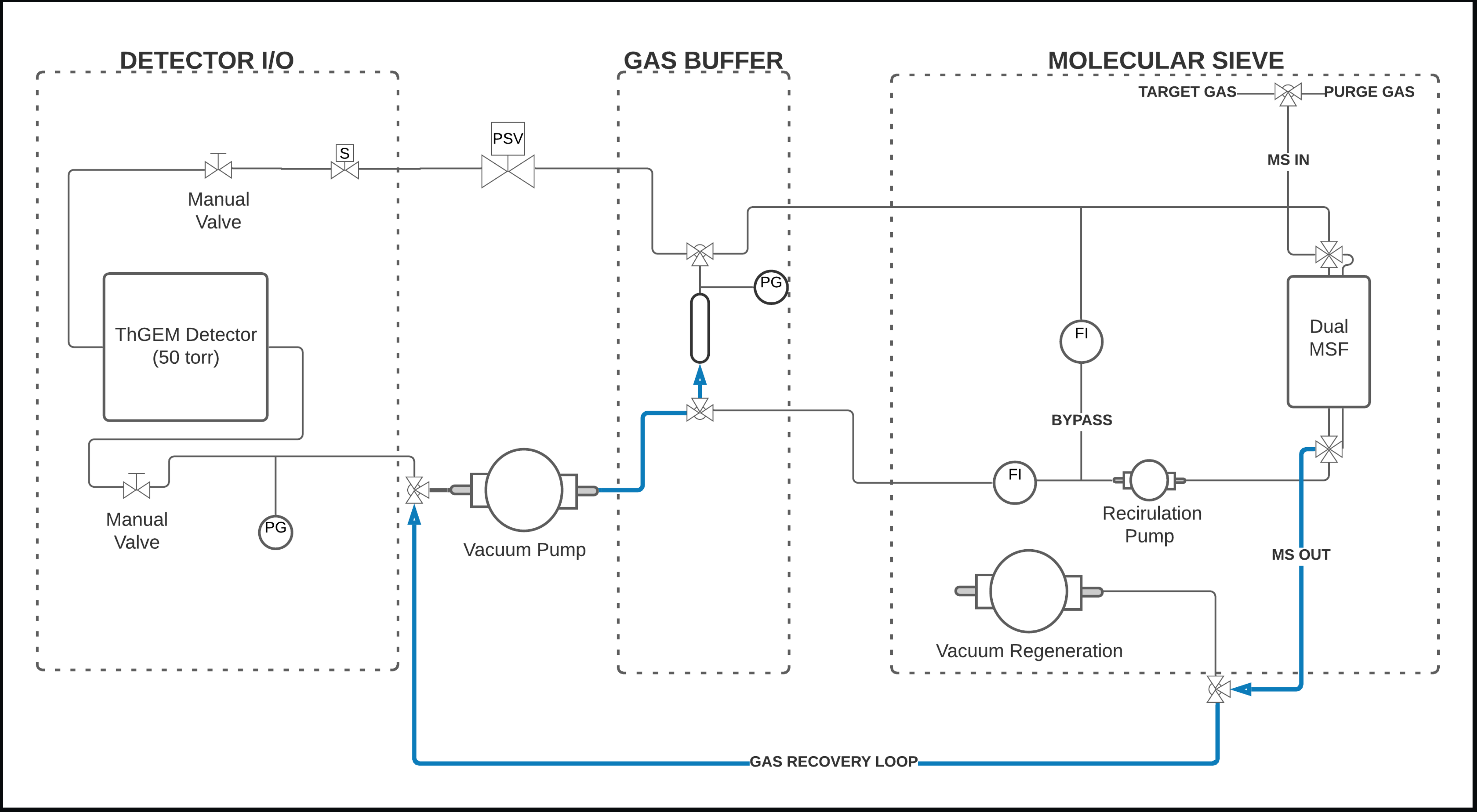
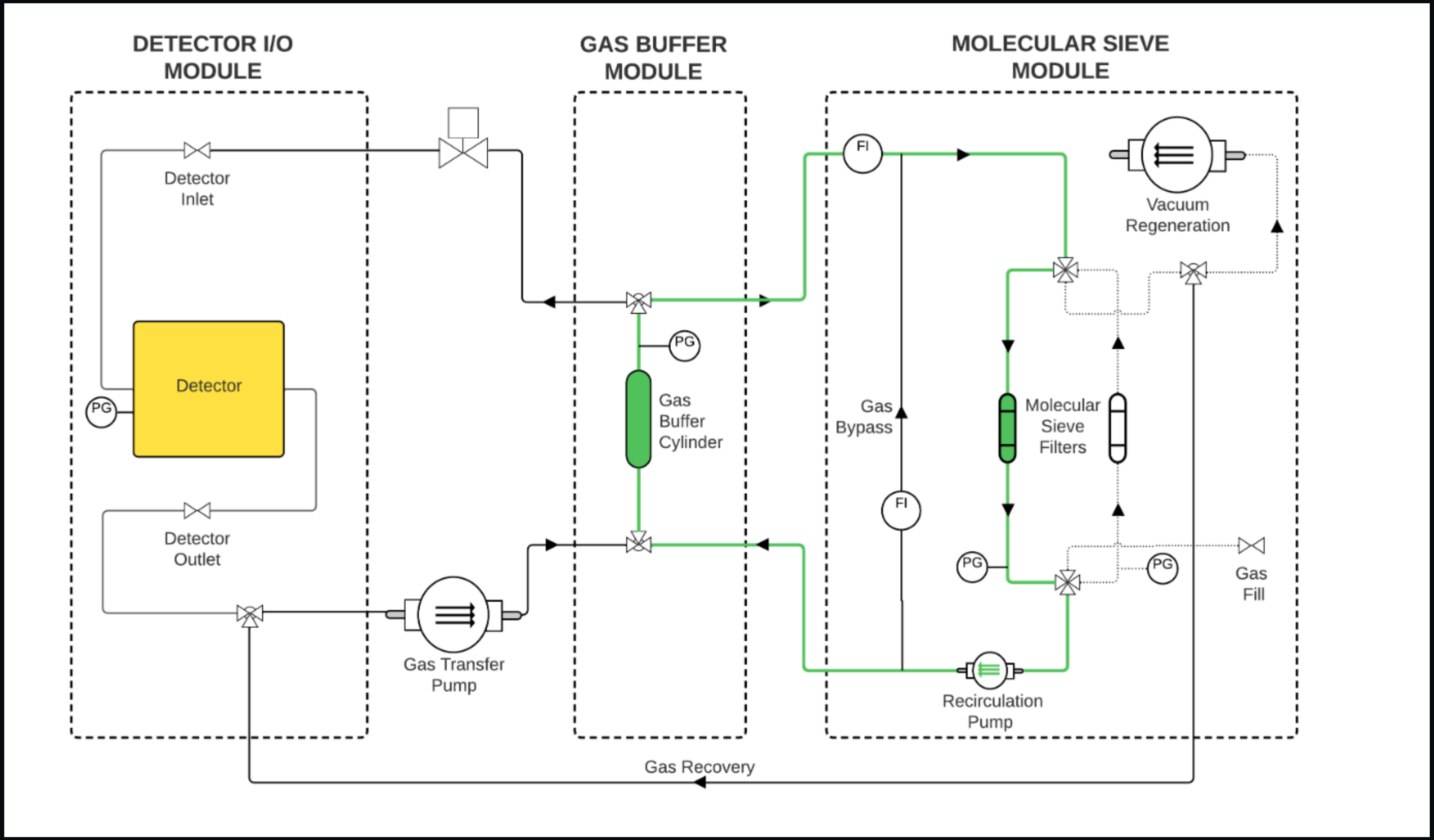
Back up slides - VSA Timeline



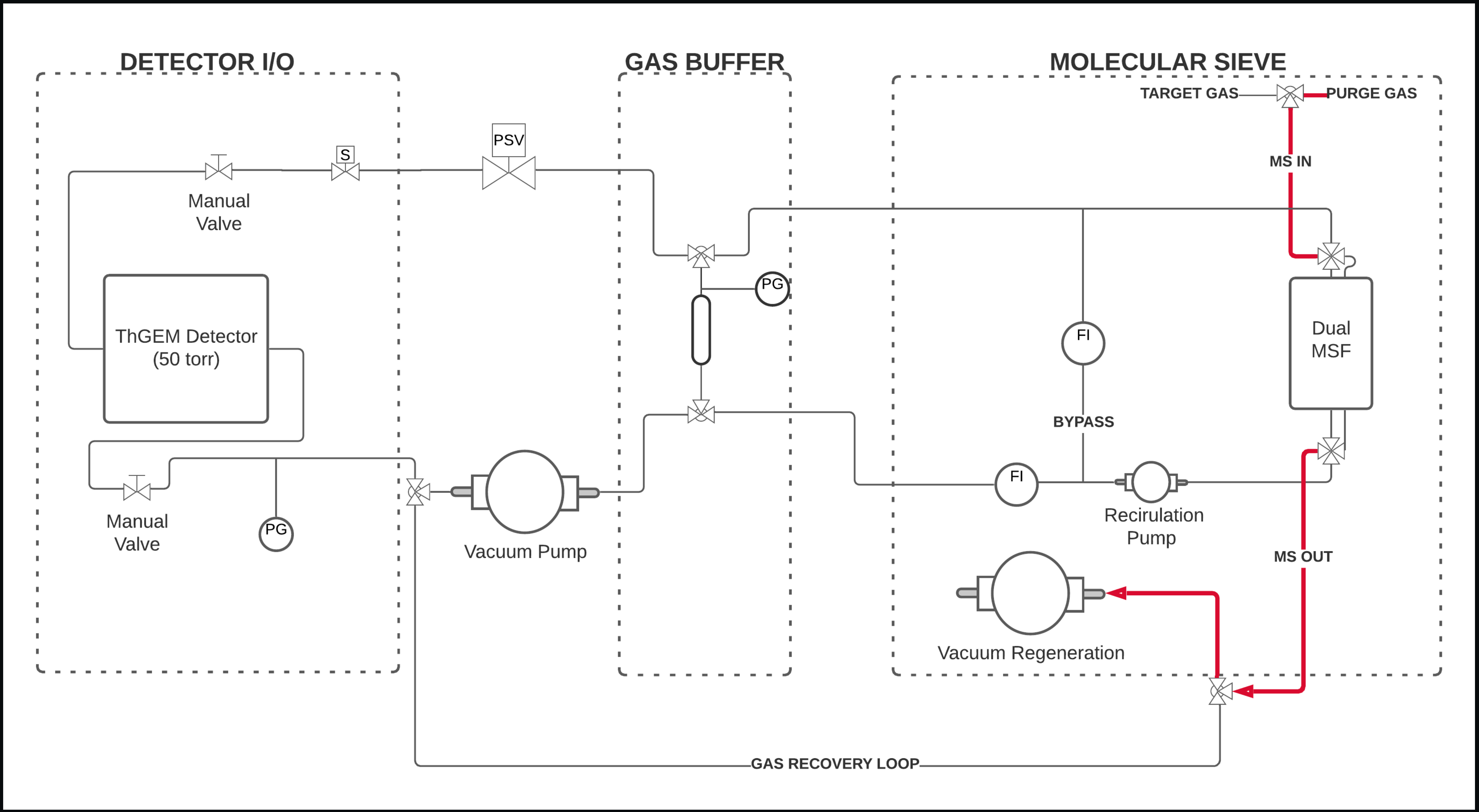
Back up slides - Gas Recovery



Back up slides - Gas System Operation



Back up slides - Vacuum Regeneration



Back up slides - Application to Other Gases

3A/4A- removes N_2, O_2 and H_2O
5A - removes radon

Back up slides - Application to Other Gases

Does the MS absorb the desired target gas?

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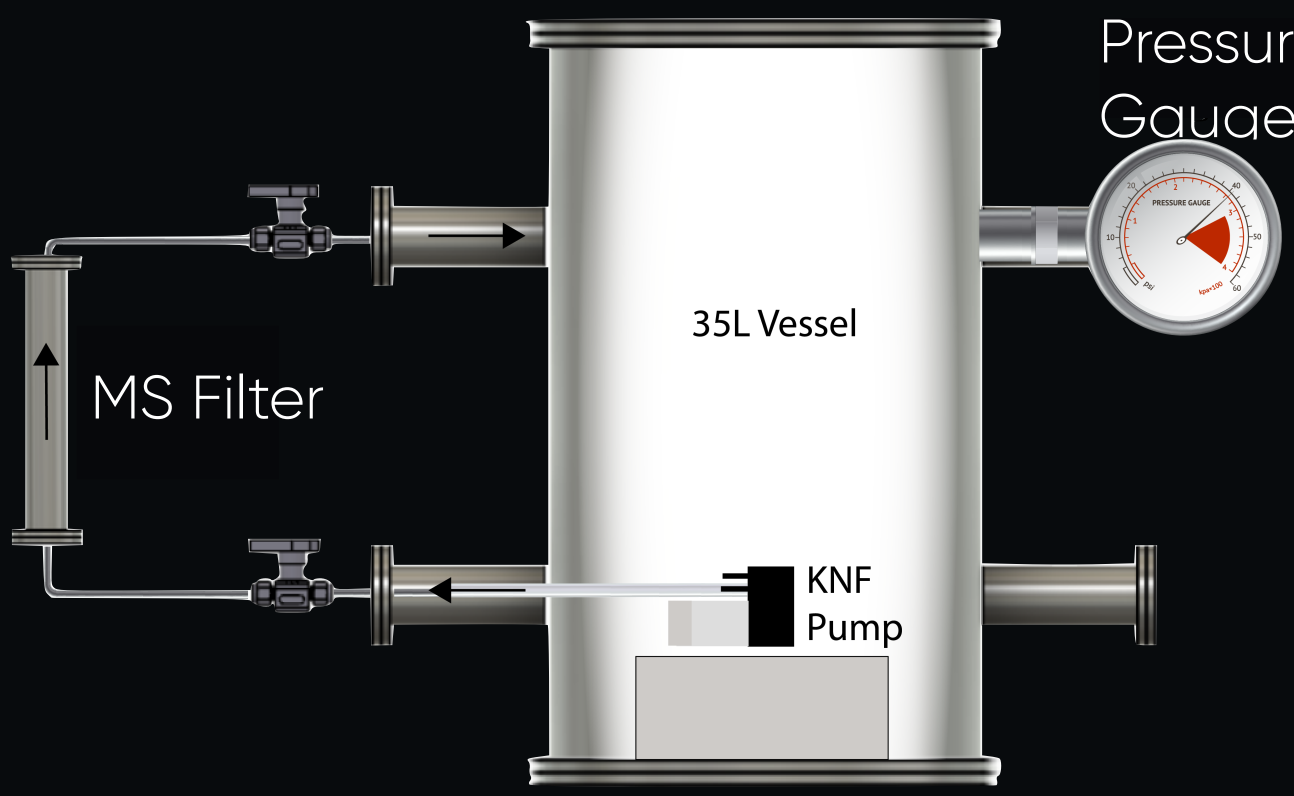

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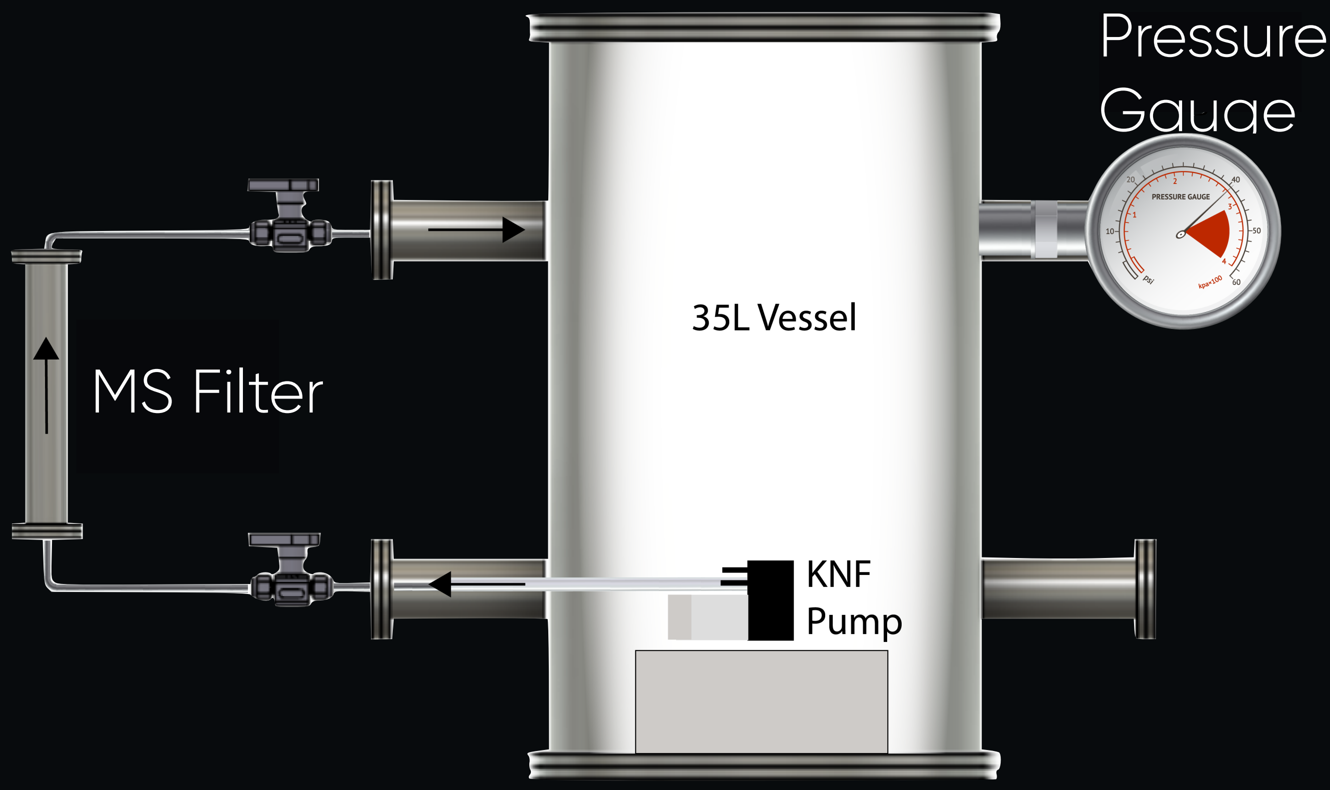

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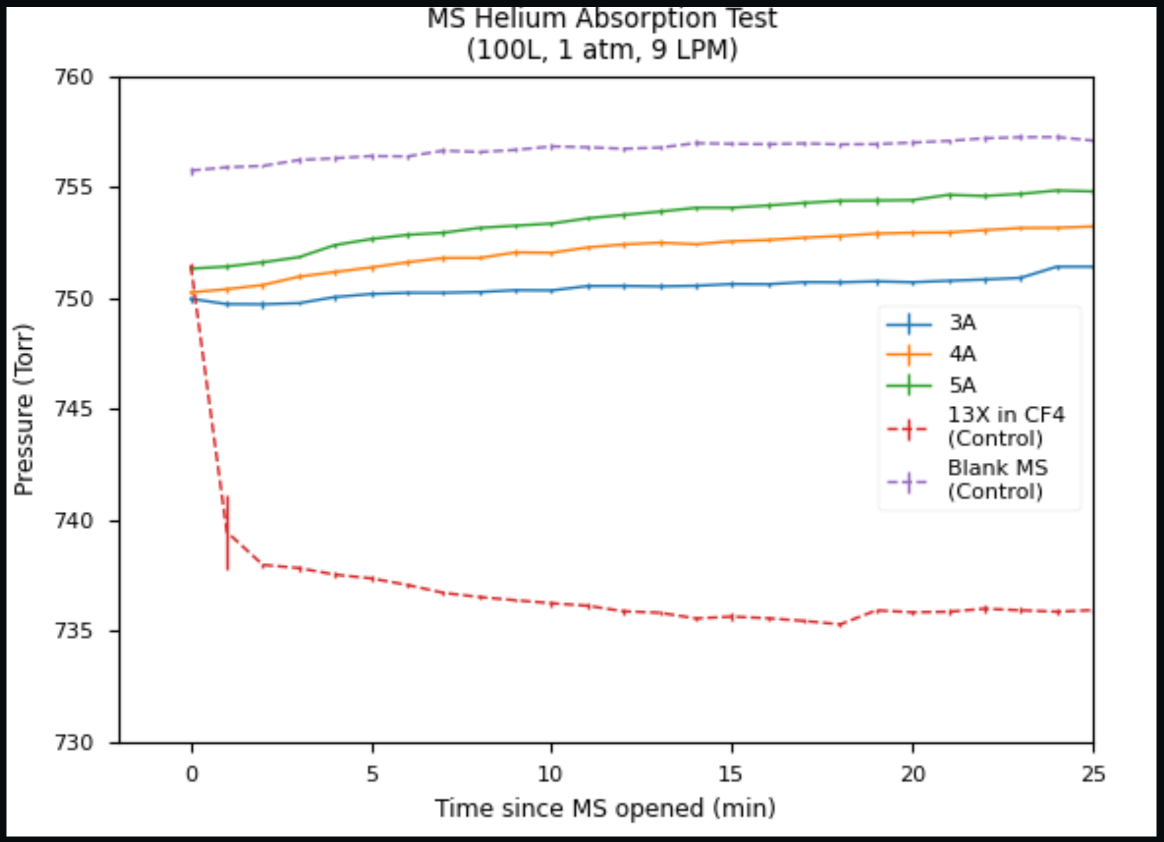

Back up slides - MS Low Background Target

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Goal is to **maximise amount of MS allowed** by radioactive budget of an experiment (eg CYGNUS-1000m^3 ~ 1 mBq [5])

Back up slides - Gain Calibration

$$GAIN = \frac{N_{Tot}}{N_{Pair}}$$

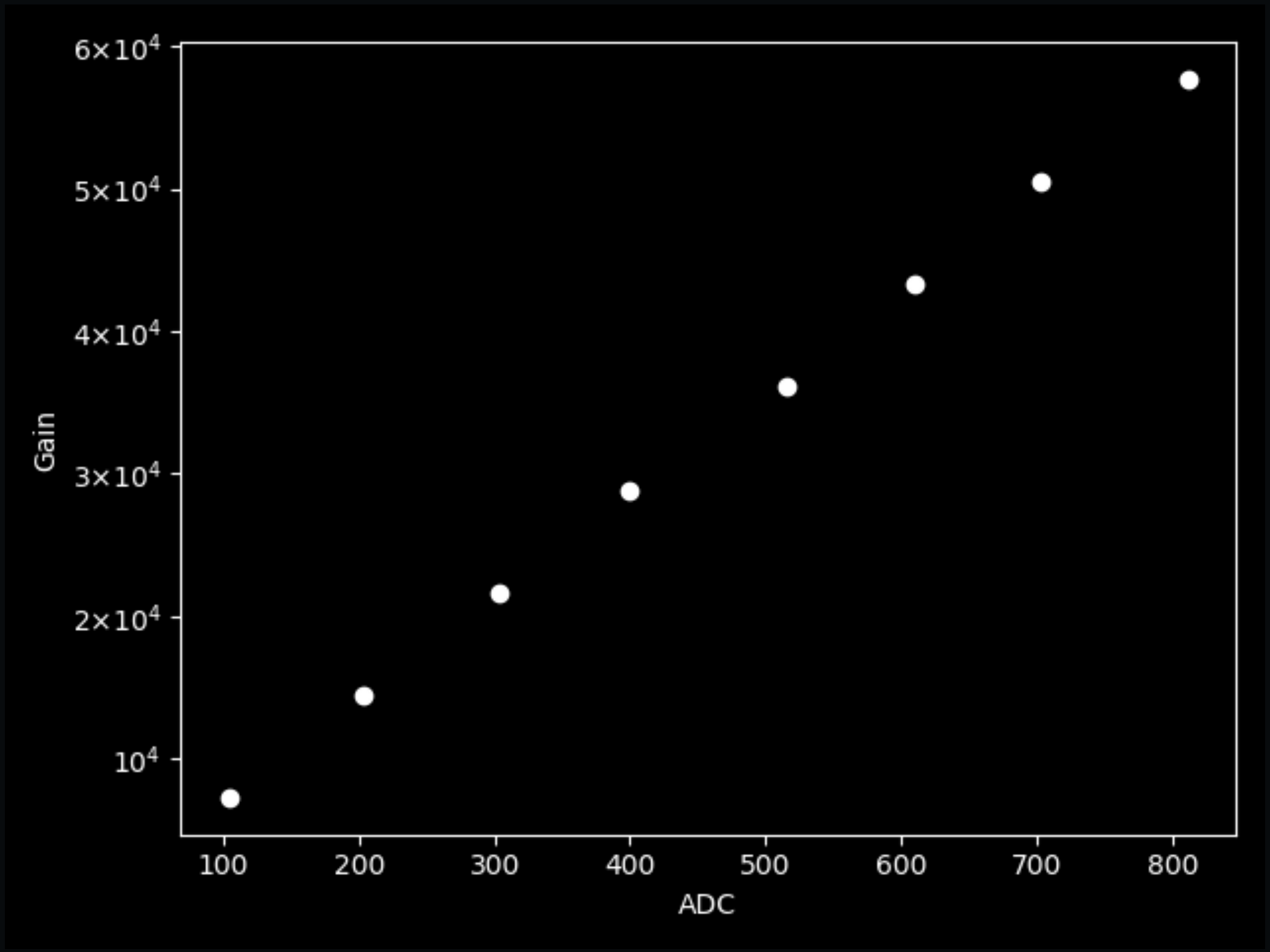
$$N_{Tot} = \frac{VC}{e} \qquad N_{Pair} = \frac{E}{W}$$

N $_{Tot}$ - Total number of charge read out by electronics
V - Voltage measure by MCA
C - Capacitance of preamp (1pF)
e - Charge of electron

N $_{Pair}$ - Average number of electron pair created by ^{55}Fe in CF4
E - Energy of ^{55}Fe source (5.89 keV)
W - Average energy required to create electron pain in gas (34 eV)

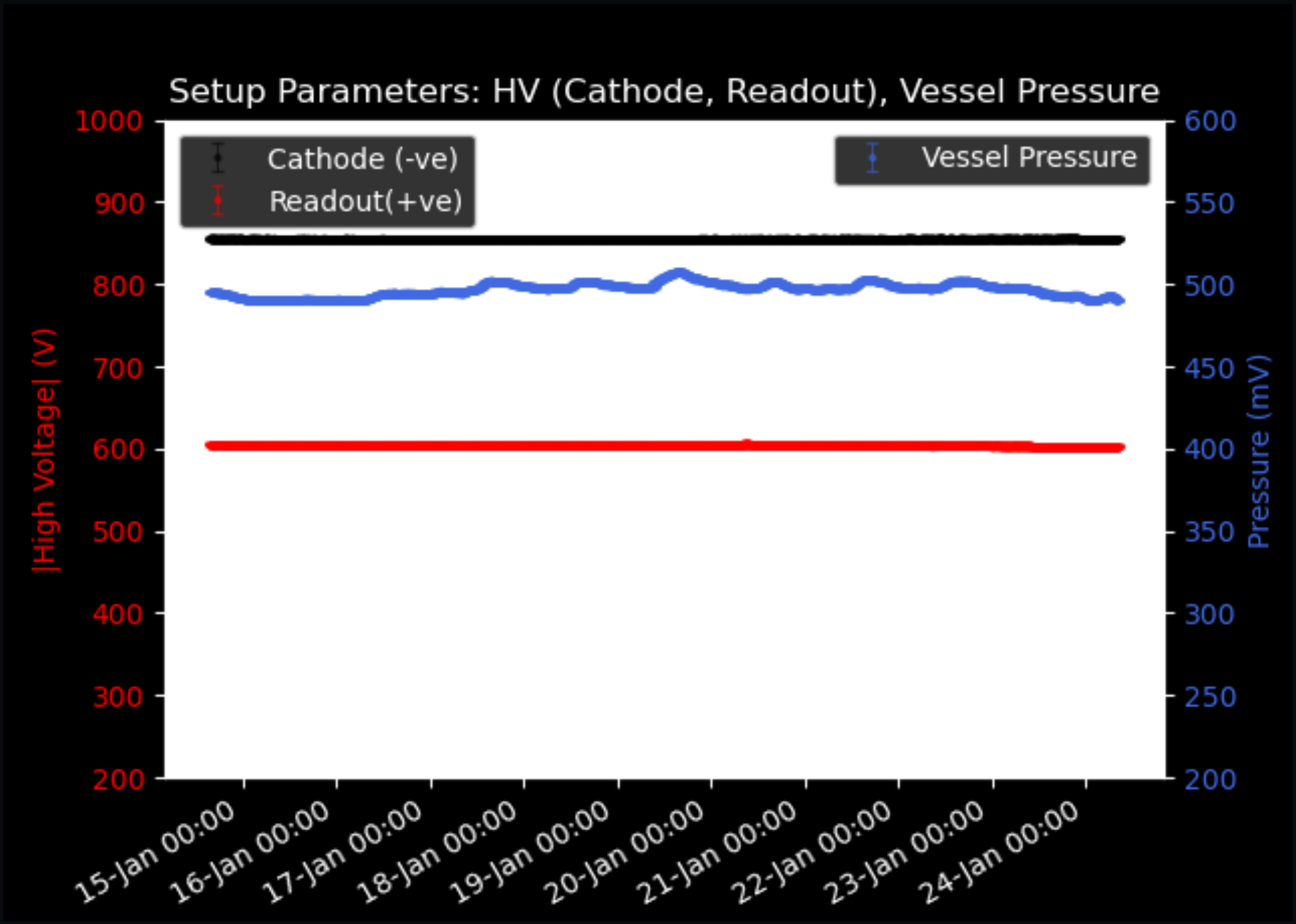
Back up slides - Gain Calibration

Test Pulse (mV)	ADC
200	104
400	203
600	303
800	400
1000	516
1200	610
1400	703
1600	811



$$GAIN = ADC \times 71.4 - 105$$

Back up slides - Other Gain Parameters



Cathode:
-855V (std -0.3V)
Readout:
604V (std 0.4V)

Detector Pressure:
50.3 torr (std 0.4 torr)