

SuperNEMO helium recycling system



Elvis Penghui Li, IOP Joint APP and HEPP Annual Conference 2026

THE UNIVERSITY
of EDINBURGH



Neutrino and neutrinoless double beta decay



Neutrino

Fundamental fermion in SM, Predicted by Pauli in 1930, observed by Reines and Cowan in 1956

What we know

- Neutral charge** - only interact via weak force
- Flavours** - neutrino have 3 flavours like other fermions
- Oscillation** - Neutrino **DOES** have mass

What we don't know

Mass ordering - What is the ordering of the 3 mass state

Sterile neutrino - More than 3 flavours?

Absolute mass scale - How heavy is neutrino

Mass mechanism - Where does neutrino mass comes from

Matter asymmetry - Why is our universe matter dominated

SuperNEMO can help answering

Neutrino and neutrinoless double beta decay



→ Majorana mass mechanism

Ettore Majorana



Neutrino and neutrinoless double beta decay



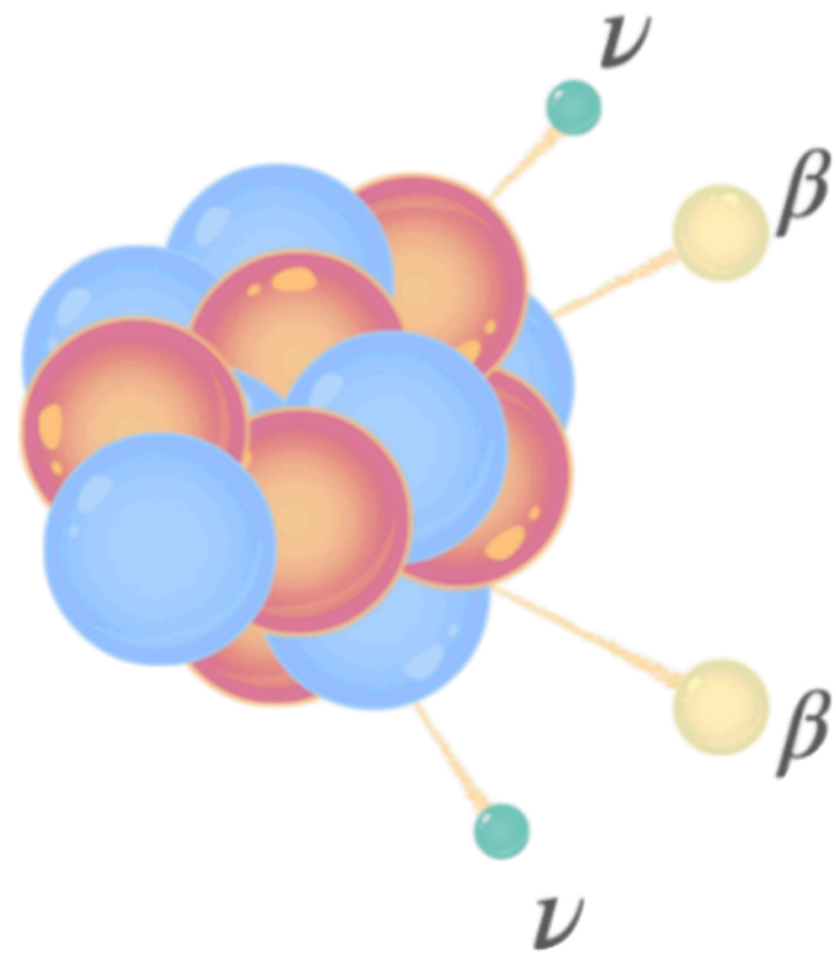
Ettore Majorana



Neutrino and neutrinoless double beta decay

Observed

Double beta decay



$$(A, Z) \rightarrow (A, Z + 2) + 2e^- + 2\bar{\nu}_e$$



Ettore Majorana

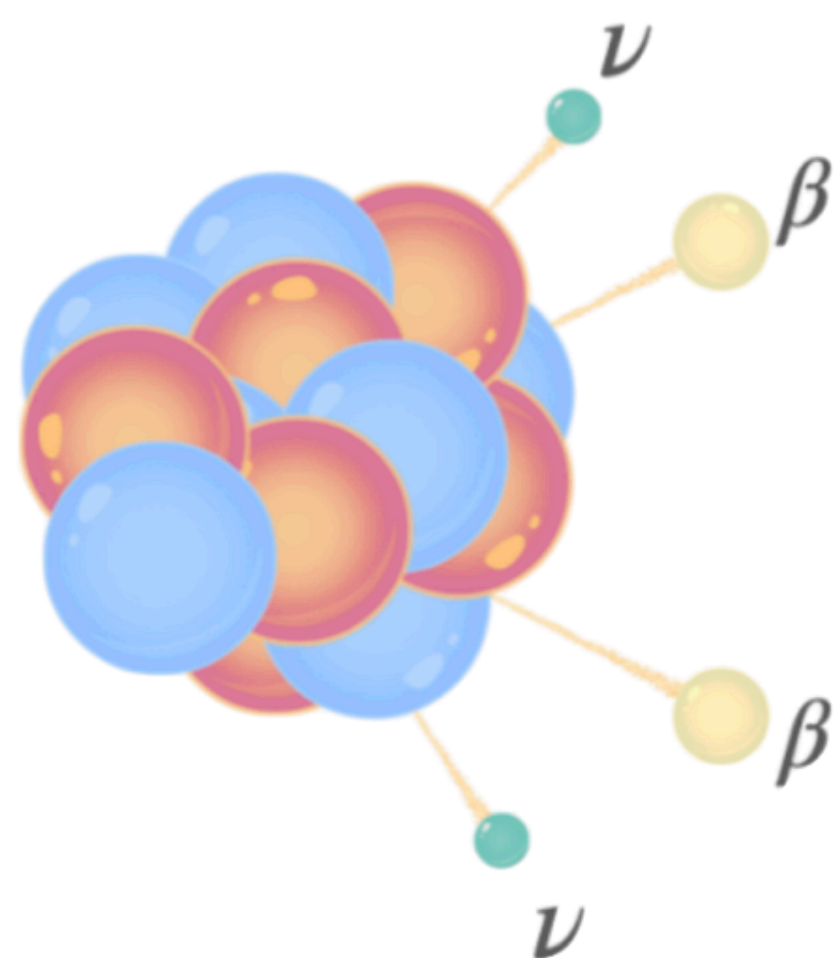
→ Majorana mass mechanism → Neutral fermions might be their own anti-particle



Neutrino and neutrinoless double beta decay

Observed

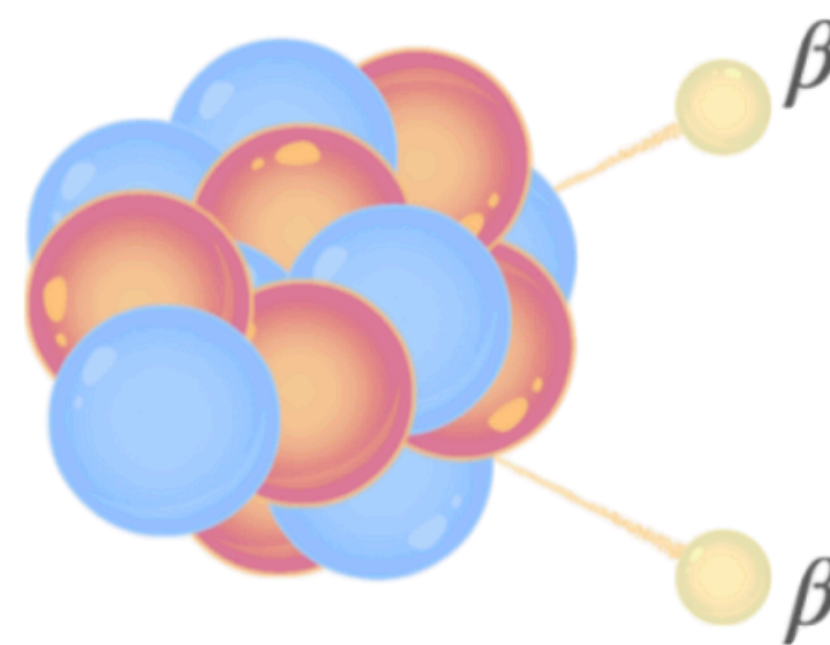
Double beta decay



$$(A, Z) \rightarrow (A, Z + 2) + 2e^- + 2\bar{\nu}_e$$

Hypothesised

Neutrinoless double beta decay



$$(A, Z) \rightarrow (A, Z + 2) + 2e^-$$



Ettore Majorana



Majorana mass mechanism



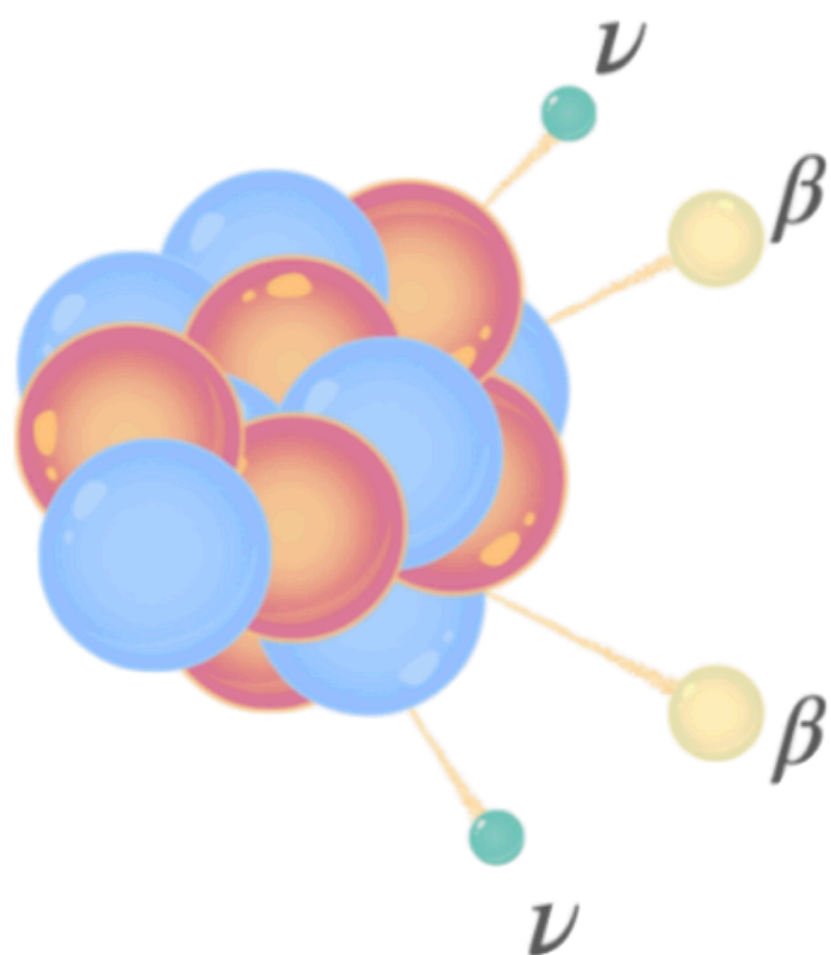
Neutral fermions might be their own anti-particle



Neutrino and neutrinoless double beta decay

Observed

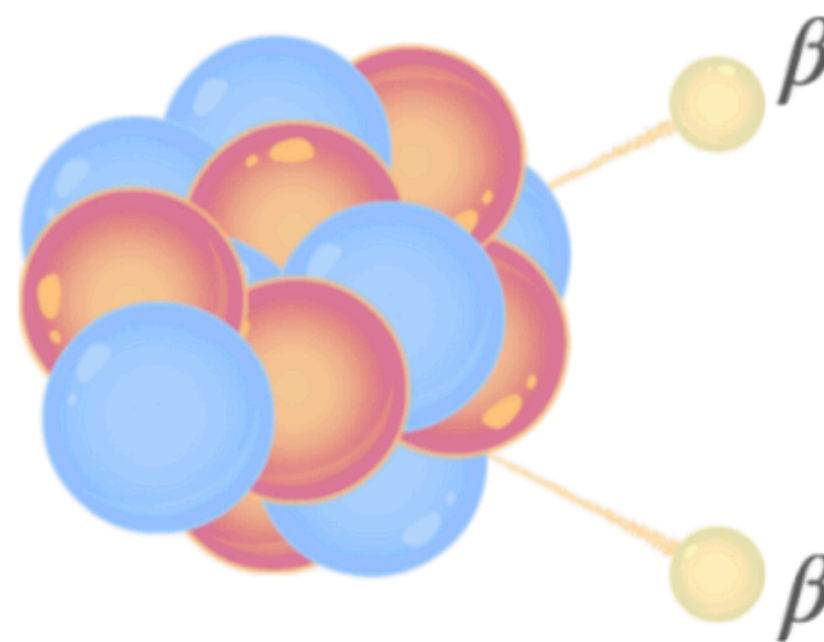
Double beta decay



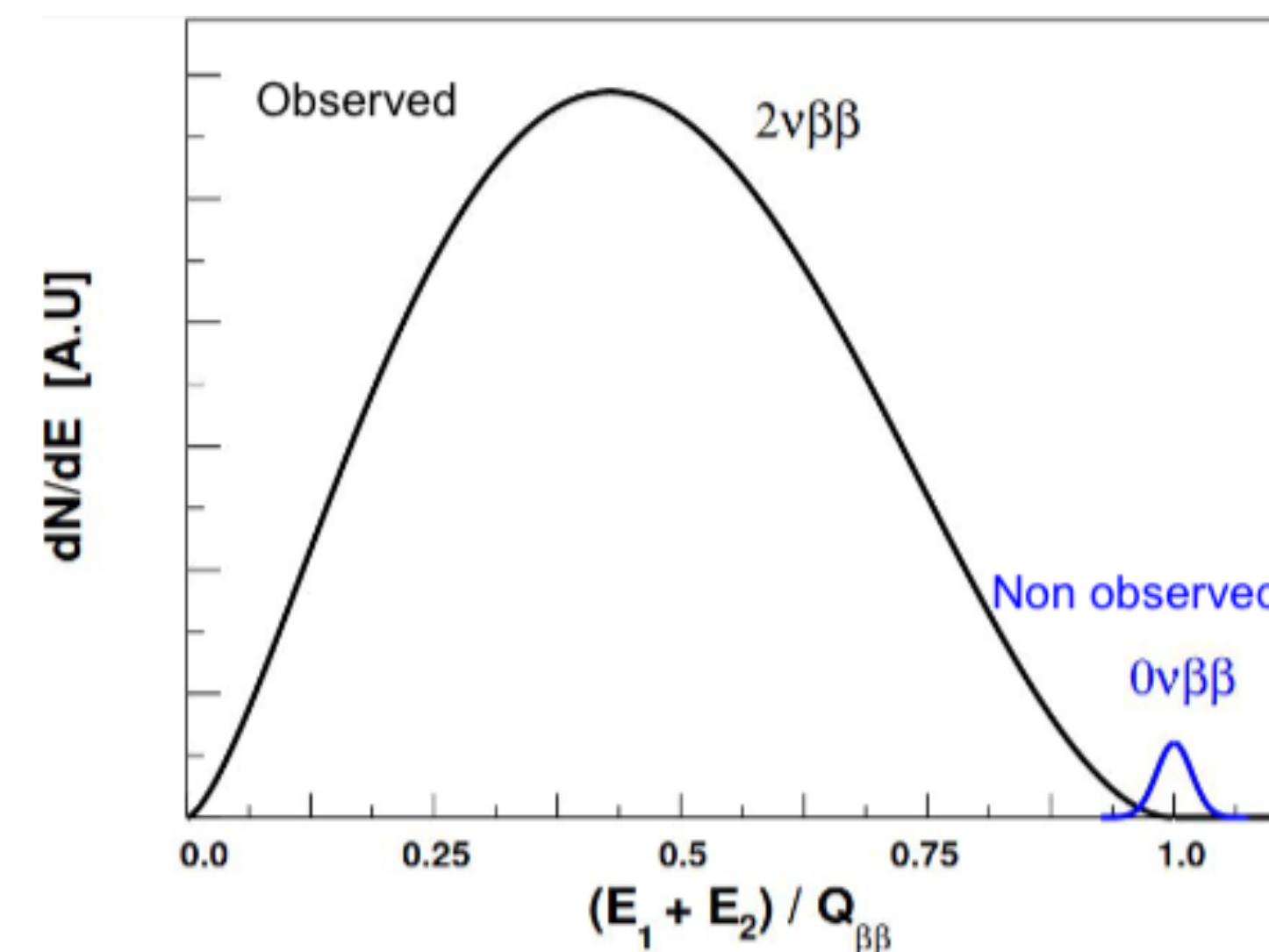
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Hypothesised

Neutrinoless double beta decay



$$(A, Z) \rightarrow (A, Z + 2) + 2e^-$$



Ettore Majorana



Majorana mass mechanism



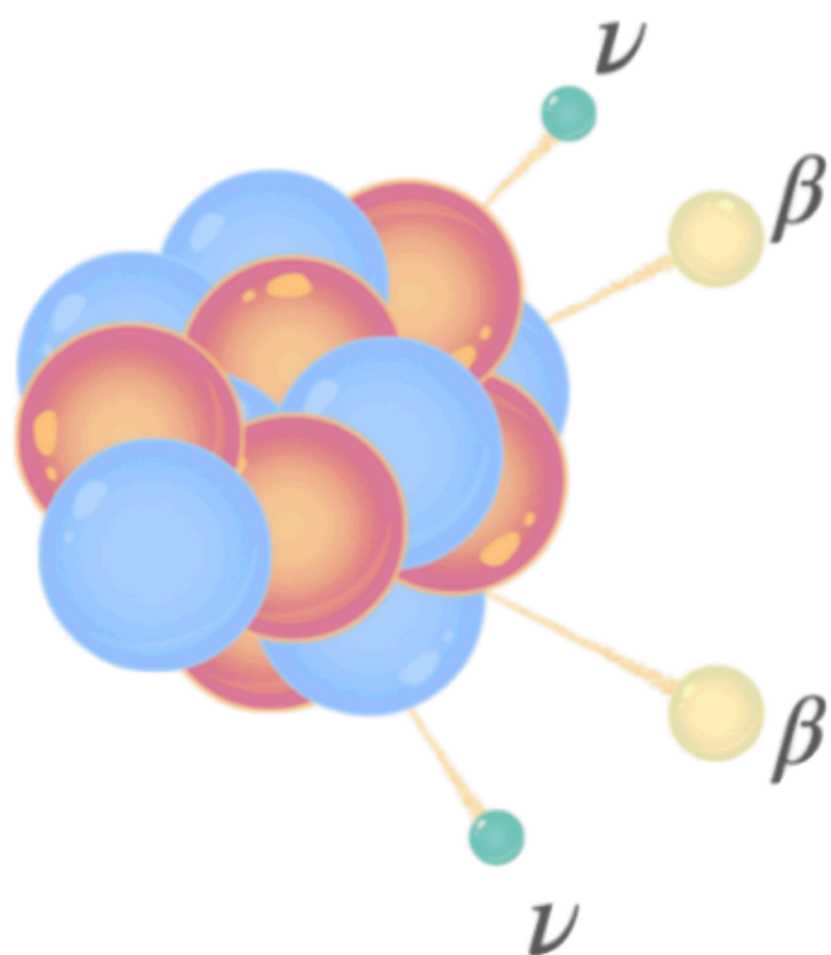
Neutral fermions might be their own anti-particle



Neutrino and neutrinoless double beta decay

Observed

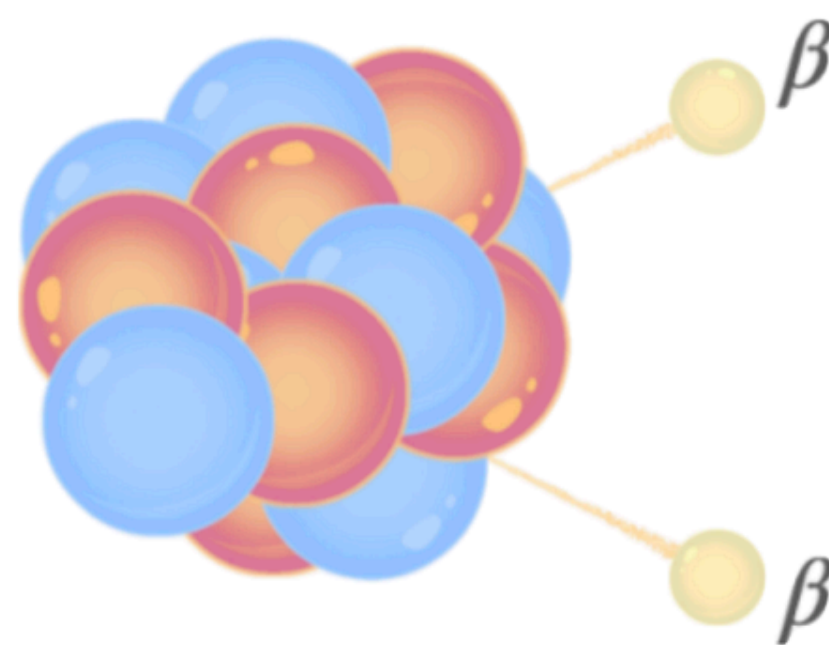
Double beta decay



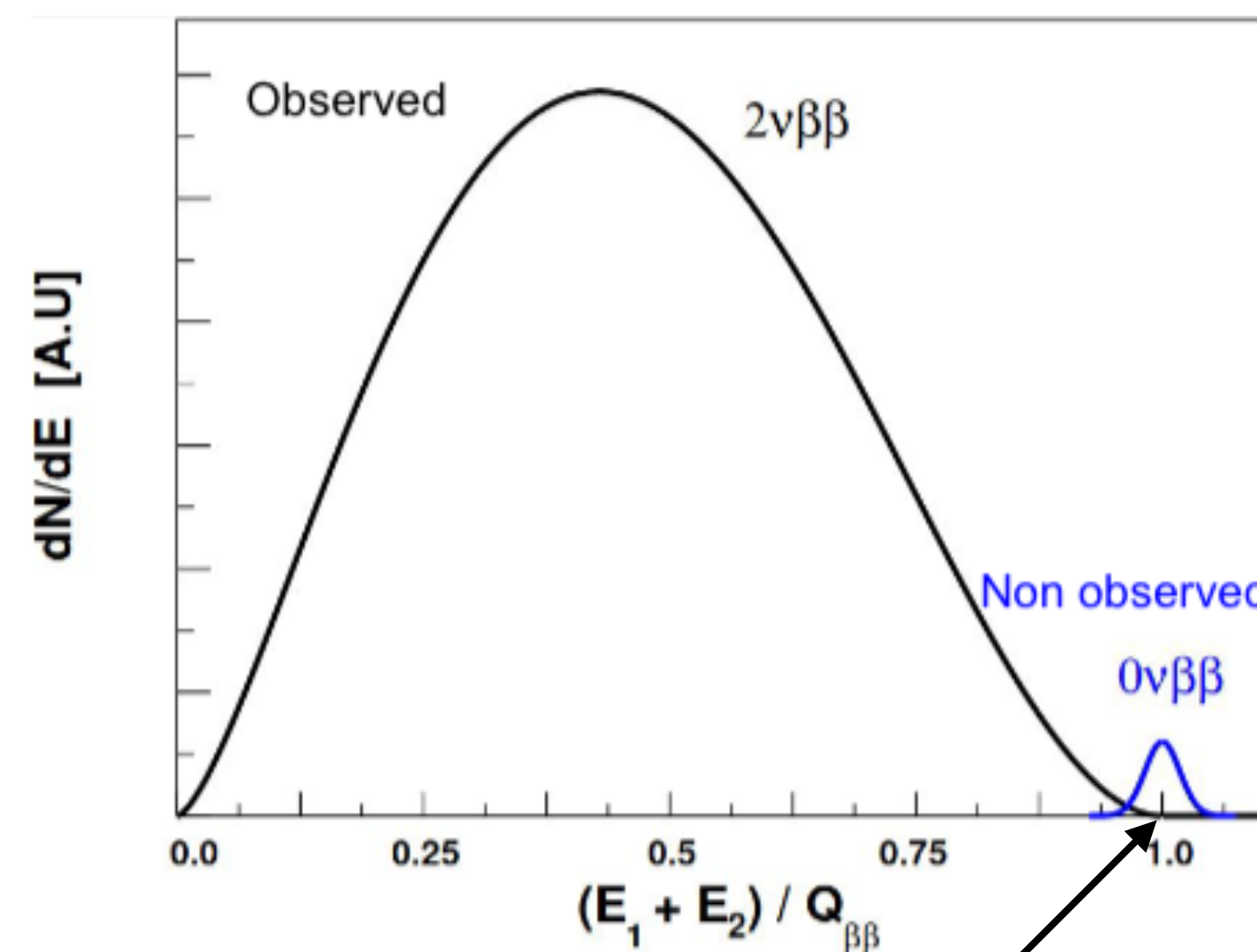
$$(A, Z) \rightarrow (A, Z + 2) + 2e^- + 2\bar{\nu}_e$$

Hypothesised

Neutrinoless double beta decay



$$(A, Z) \rightarrow (A, Z + 2) + 2e^-$$



A peak insted of a spectrum



Ettore Majorana

→ Majorana mass mechanism

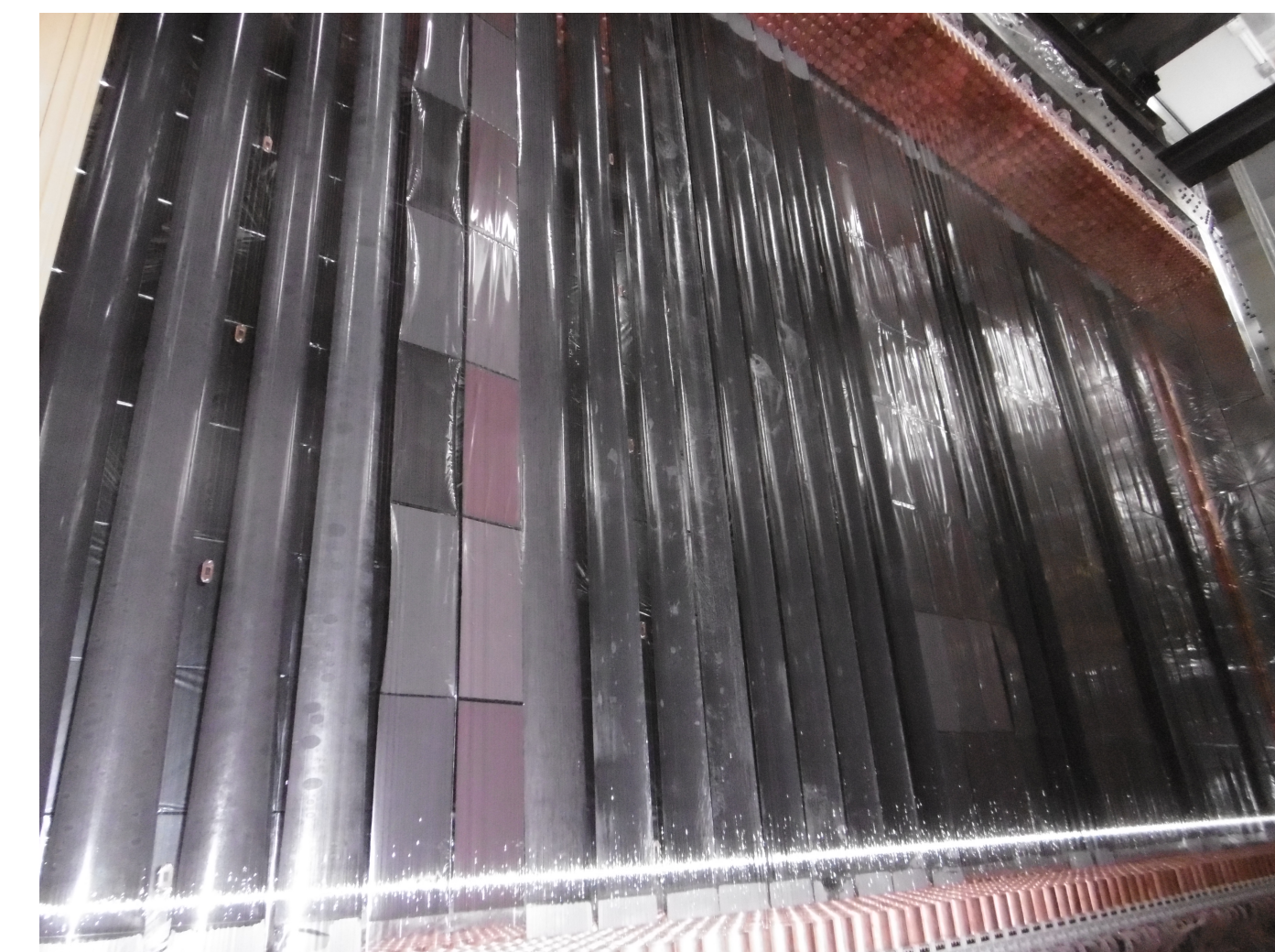
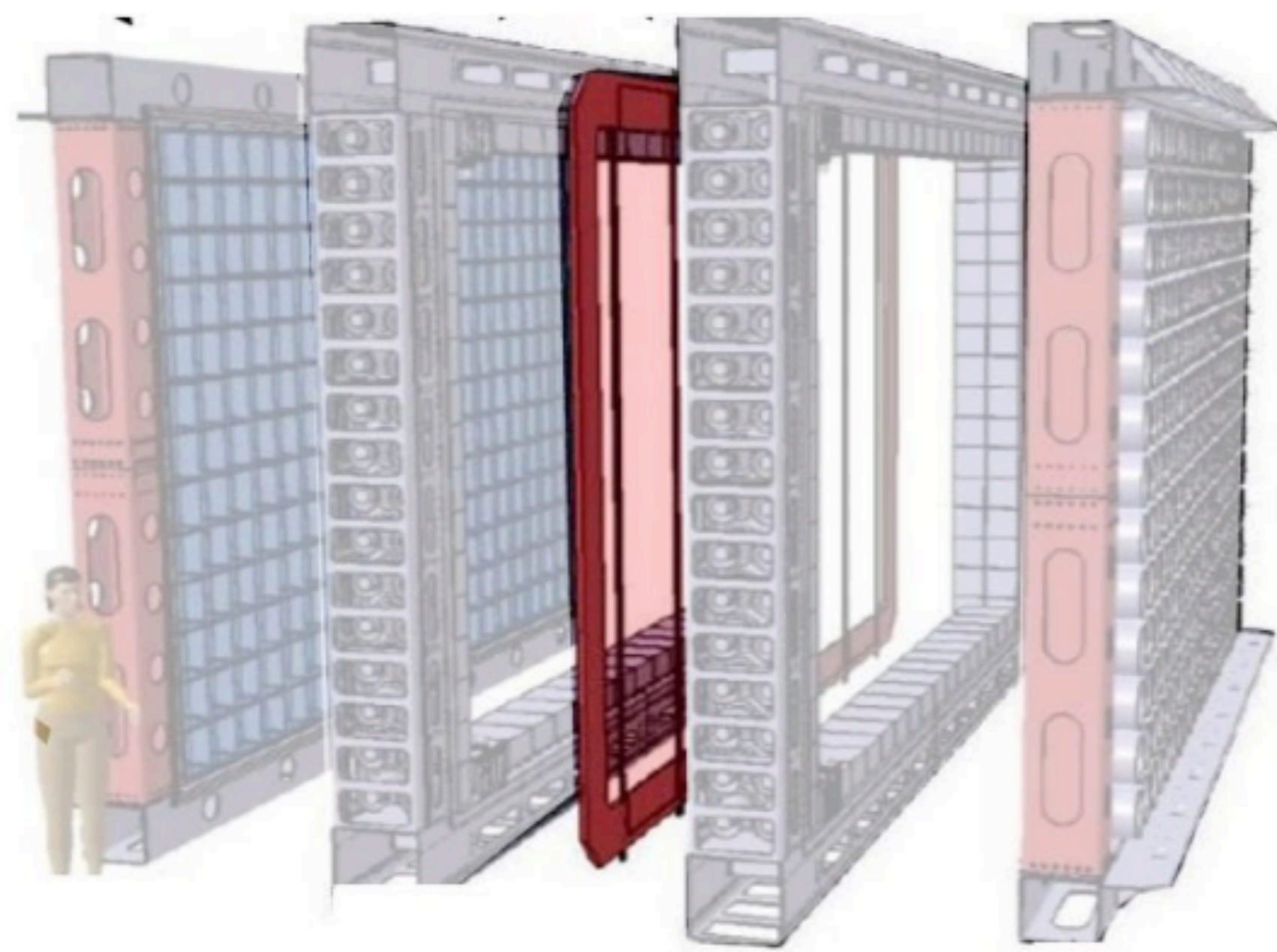
→ Neutral fermions might be their own anti-particle



SuperNEMO source foil

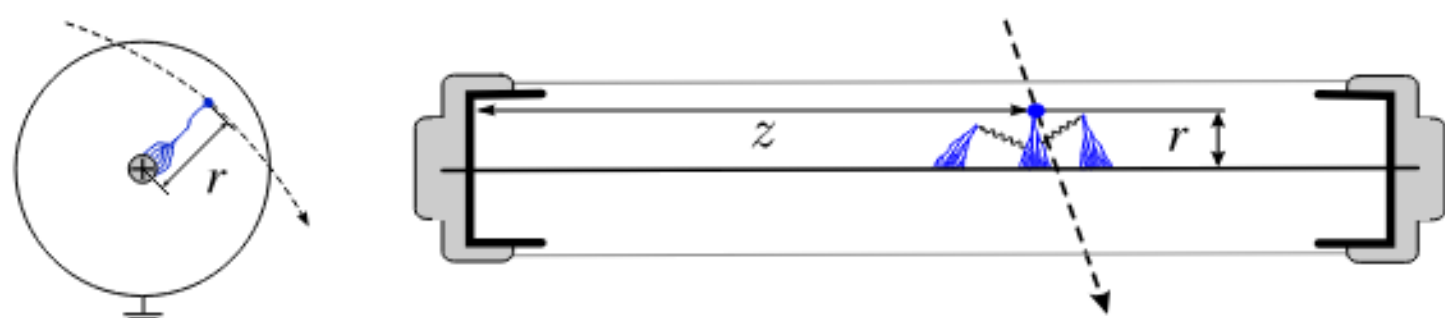
6.11kg of ^{82}Se , 96%-99% enriched

$(Q_{\beta\beta} = 2.995\text{MeV}, T_{\frac{1}{2}}^{2\nu} = 8.60 \times 10^{19} \text{ yrs})$



SuperNEMO source foil

SuperNEMO tracker system



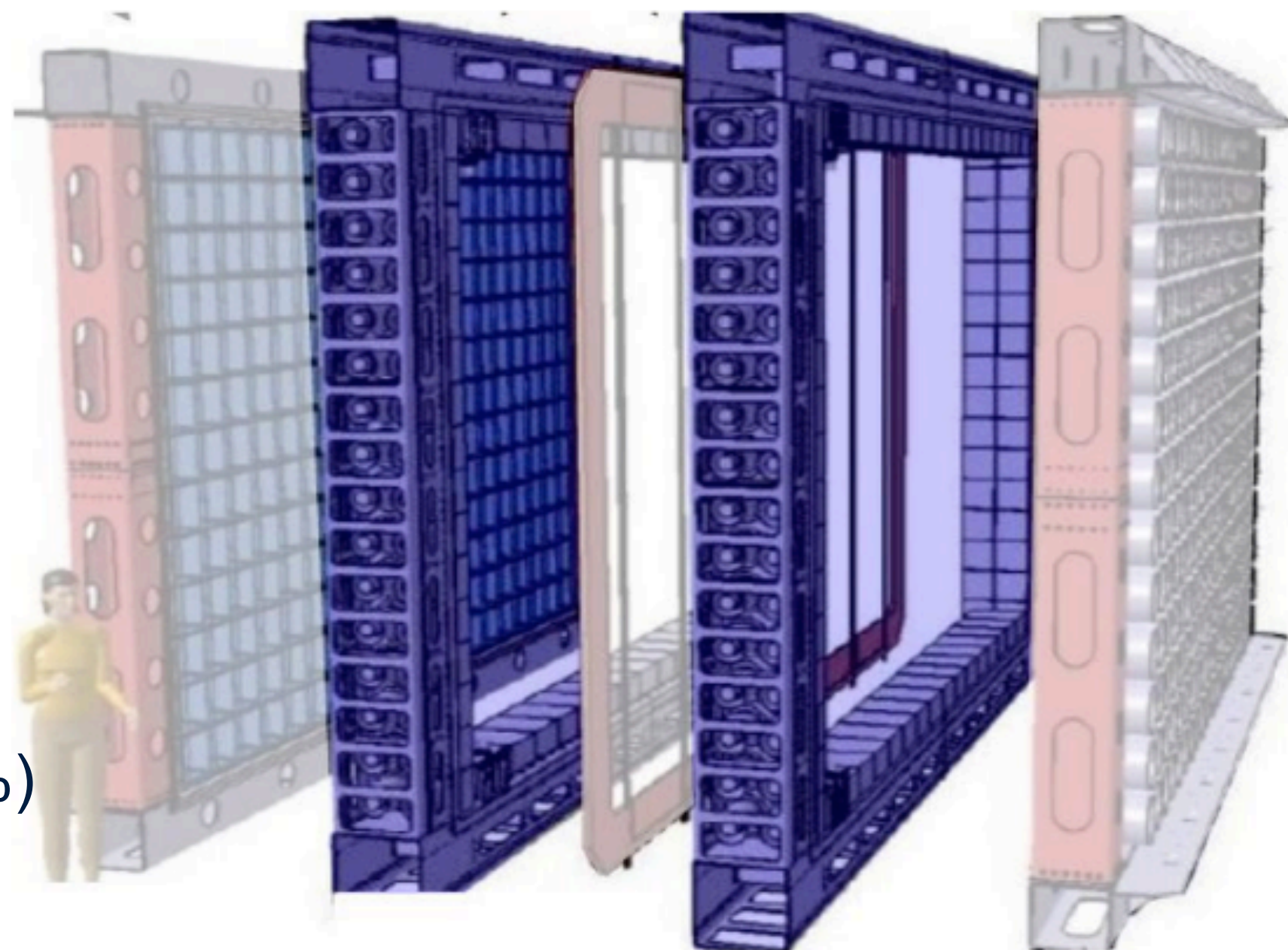
2034 Drift cells in Geiger mode

Charged particle tracking

He: Small molecules - less energy loss (95%)

Argon: Low ionisation energy - avalanche propagation (1%)

Ethanol: quenching - stop avalanche (4%)



SuperNEMO tracker



SuperNEMO calorimeter system

Individual energy measurement

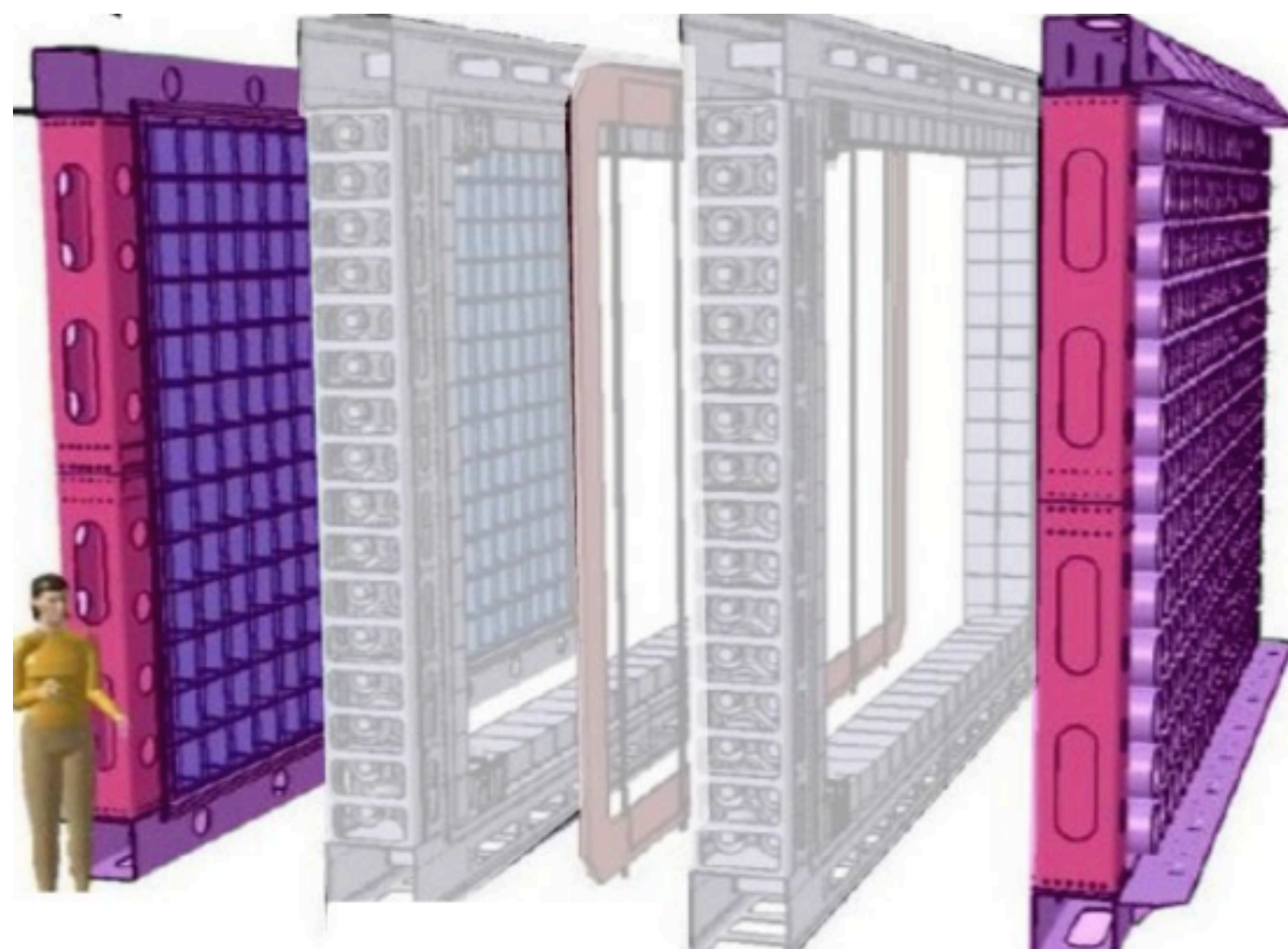
Combined with tracker



Full event topology



Nuclear measurement and studies of decay mechanisms

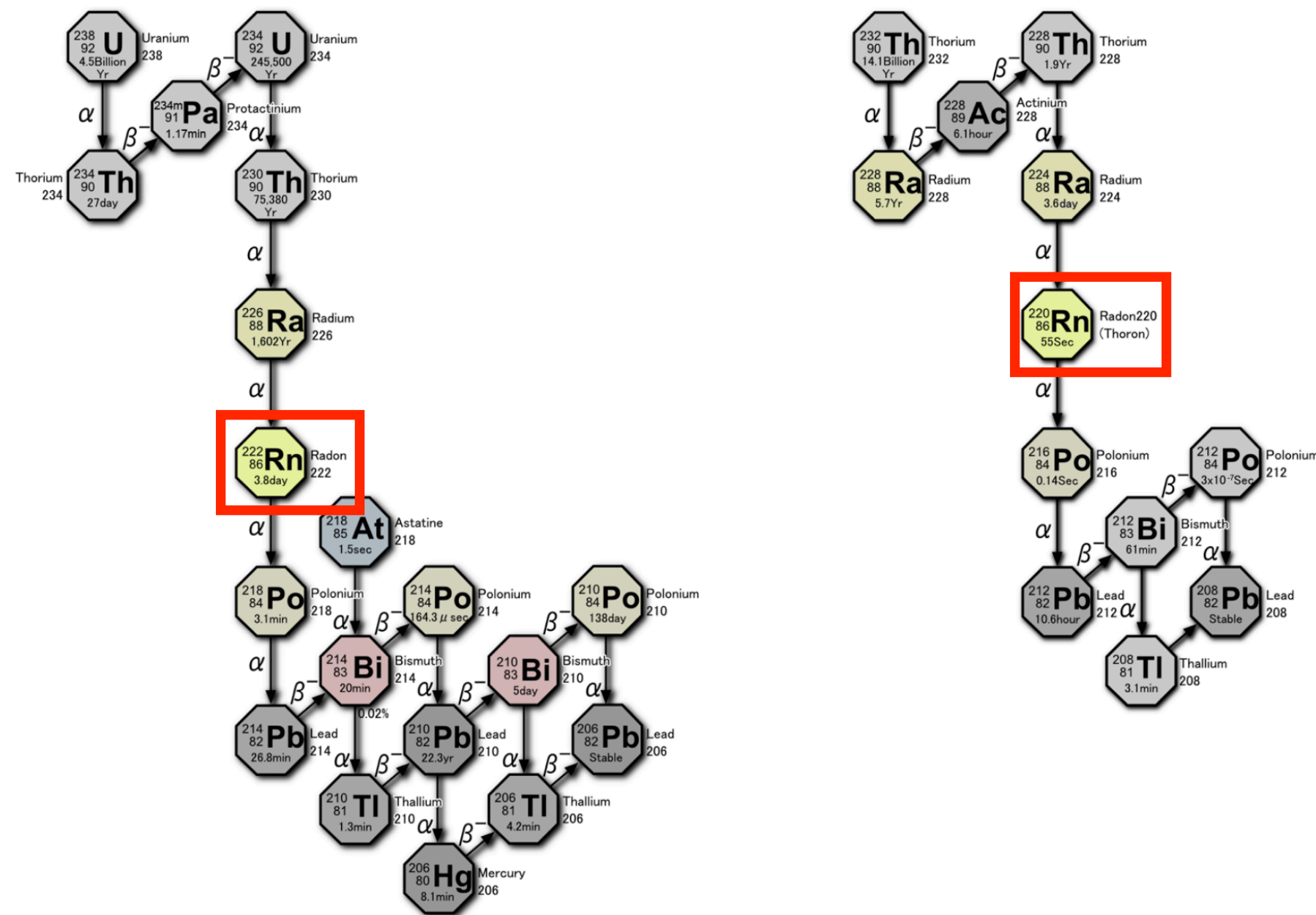


712 optical modules
(PMTs with scintillators)

Only in SuperNEMO!

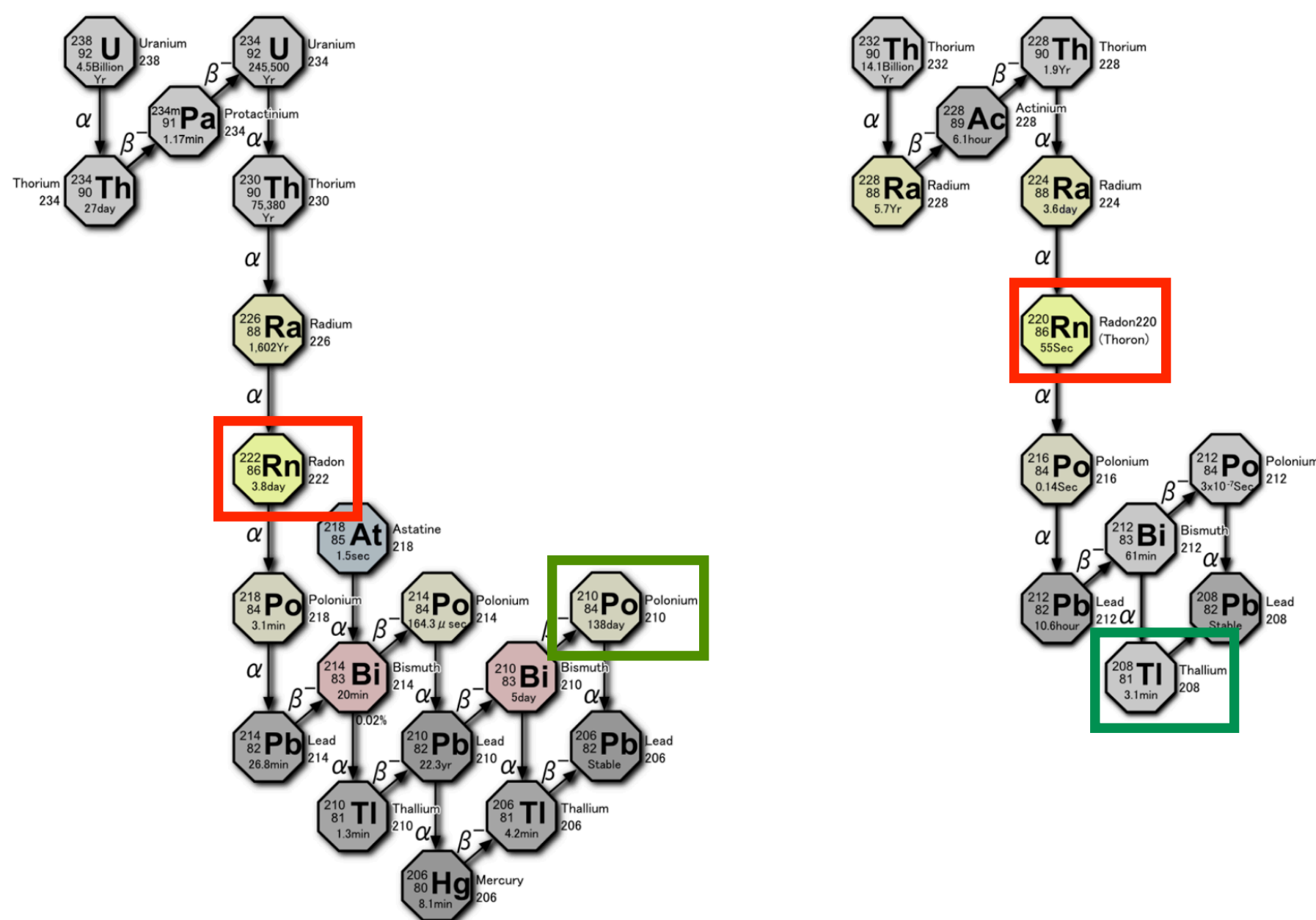


Radon in SuperNEMO



^{222}Rn & ^{220}Rn : Parents of lots backgrounds

Radon in SuperNEMO



Radon in Air



Radon in tracker

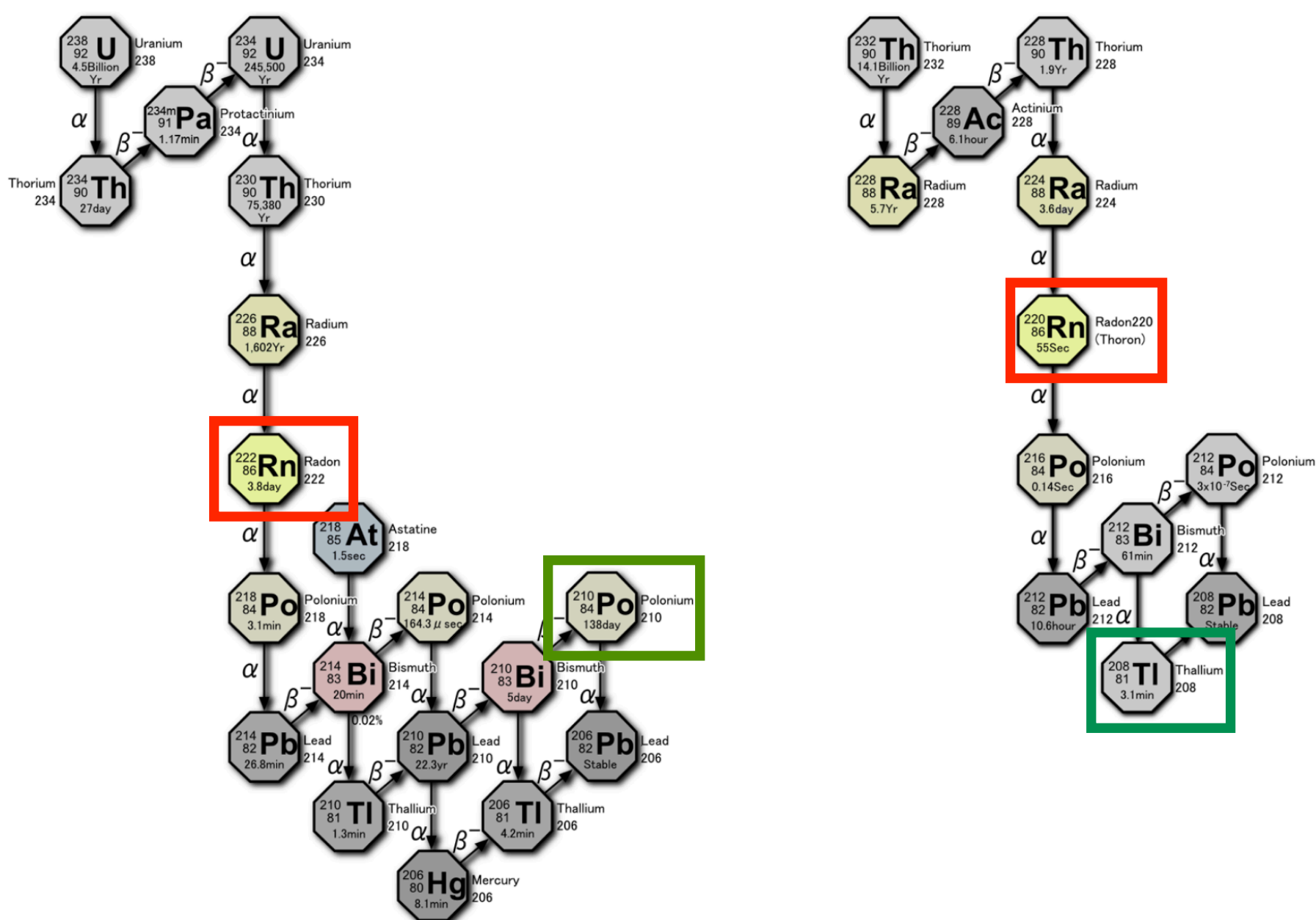


Radon progenies deposit on source foil causing background

^{222}Rn & ^{220}Rn : Parents of lots backgrounds

^{214}Bi ($Q_{\beta\beta} = 3.27\text{MeV}$) & ^{208}Tl ($Q_{\beta\beta} = 4.99\text{ MeV}$)

Radon in SuperNEMO



Radon in Air



Radon in tracker



Radon progenies deposit on source foil causing background



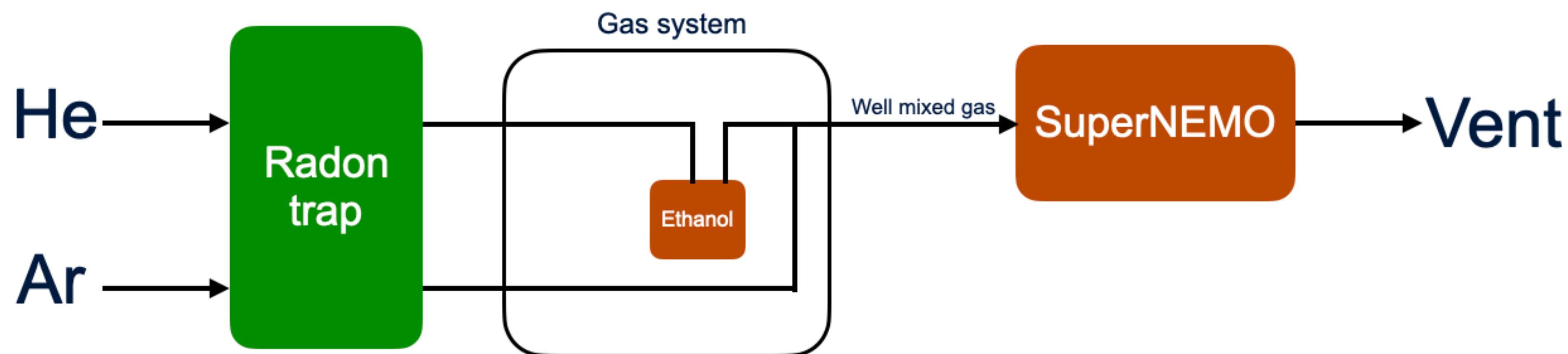
SuperNEMO Radon removal system

^{222}Rn & ^{220}Rn : Parents of lots backgrounds

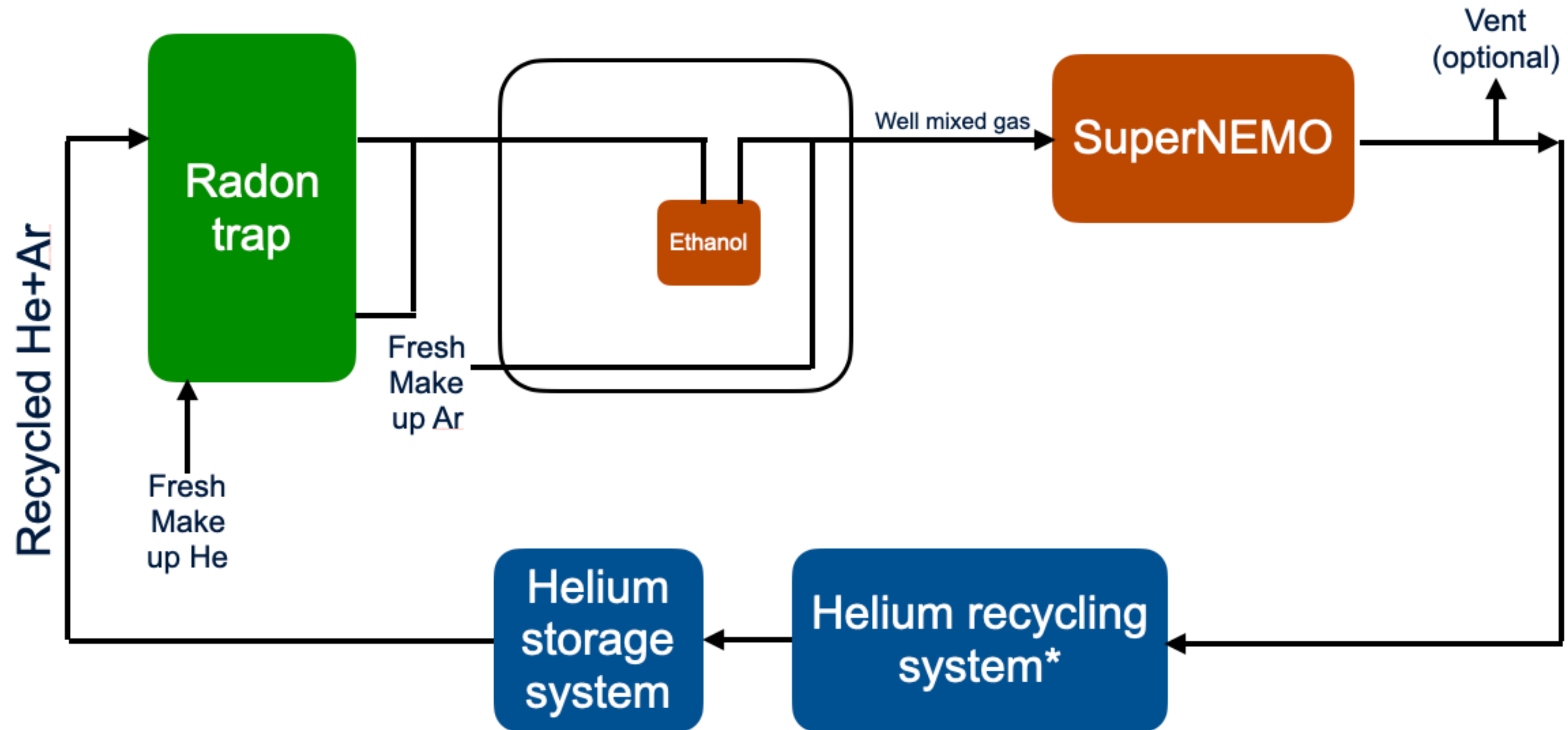
^{214}Bi ($Q_{\beta\beta} = 3.27\text{MeV}$) & ^{208}Ti ($Q_{\beta\beta} = 4.99\text{MeV}$)



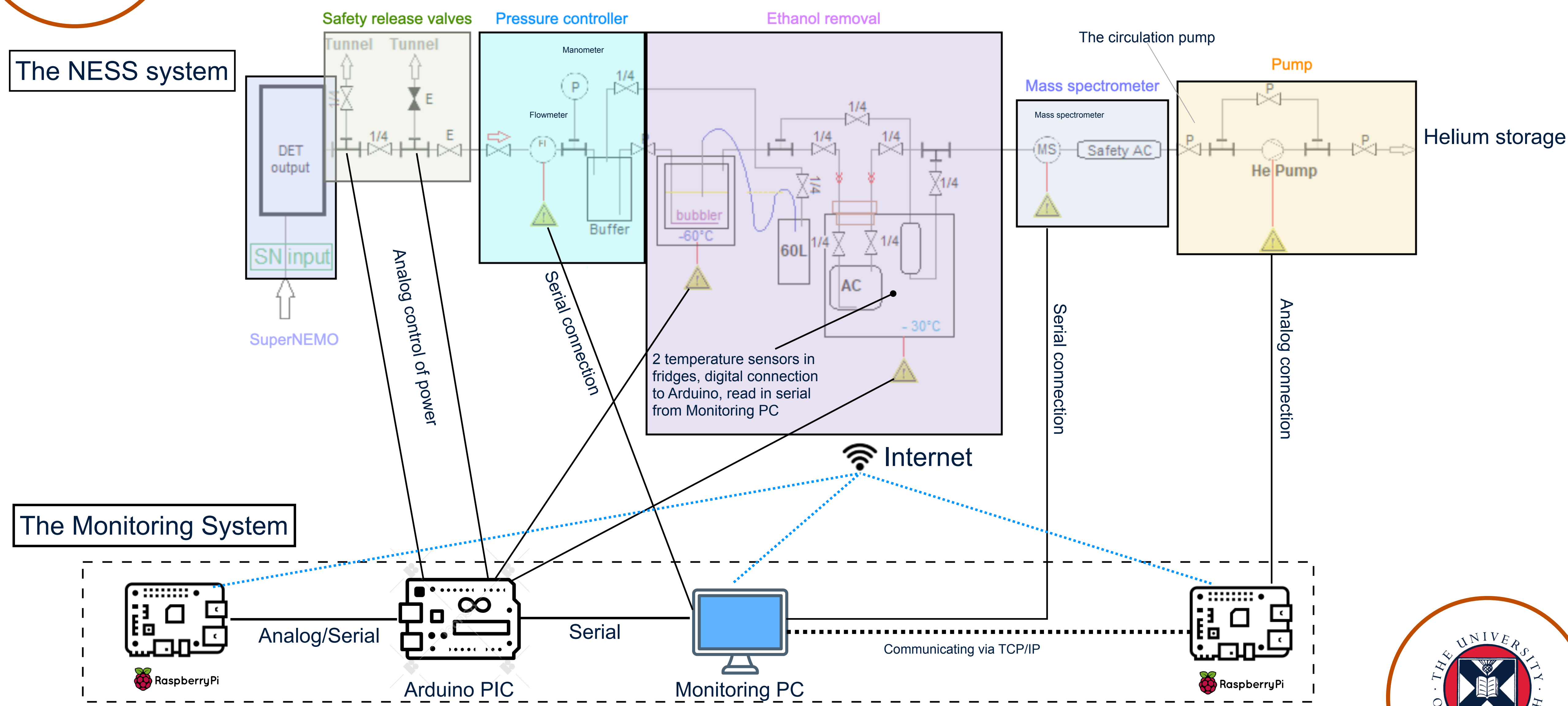
SuperNEMO gas circulation



SuperNEMO gas circulation

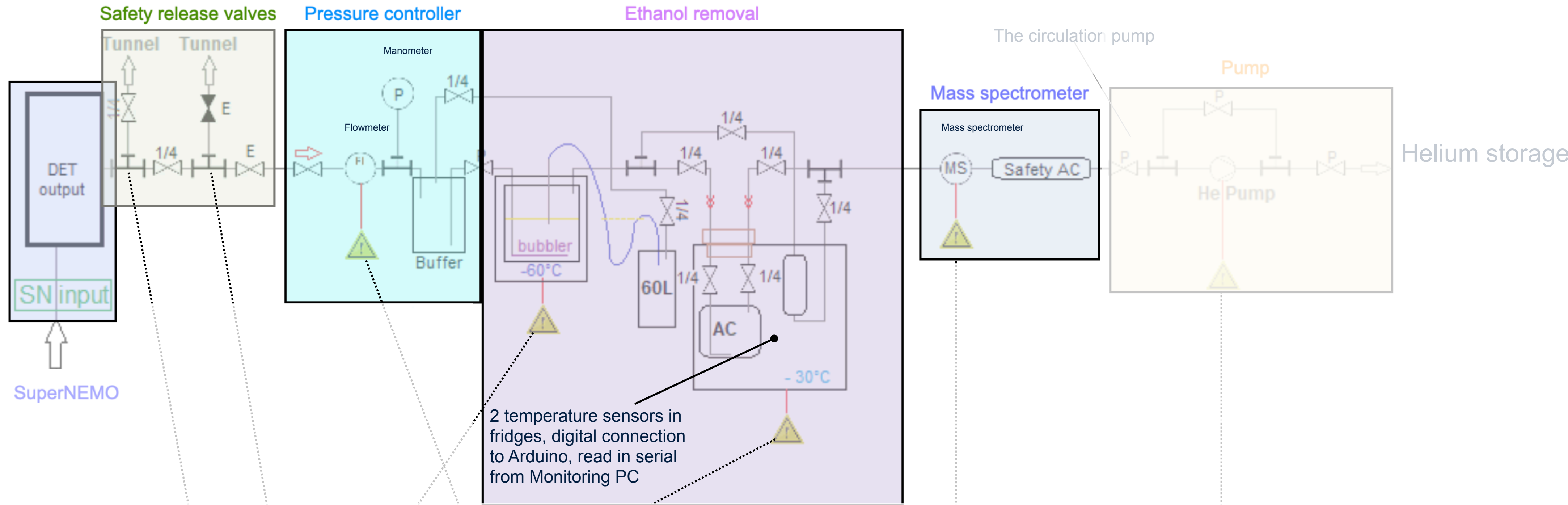


SuperNEMO helium recycling system

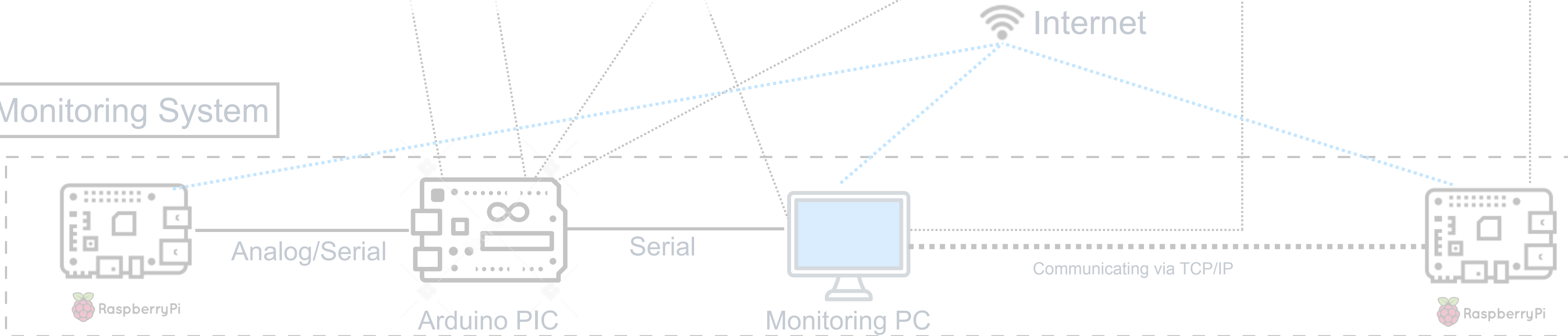


SuperNEMO helium recycling system

The NESS system

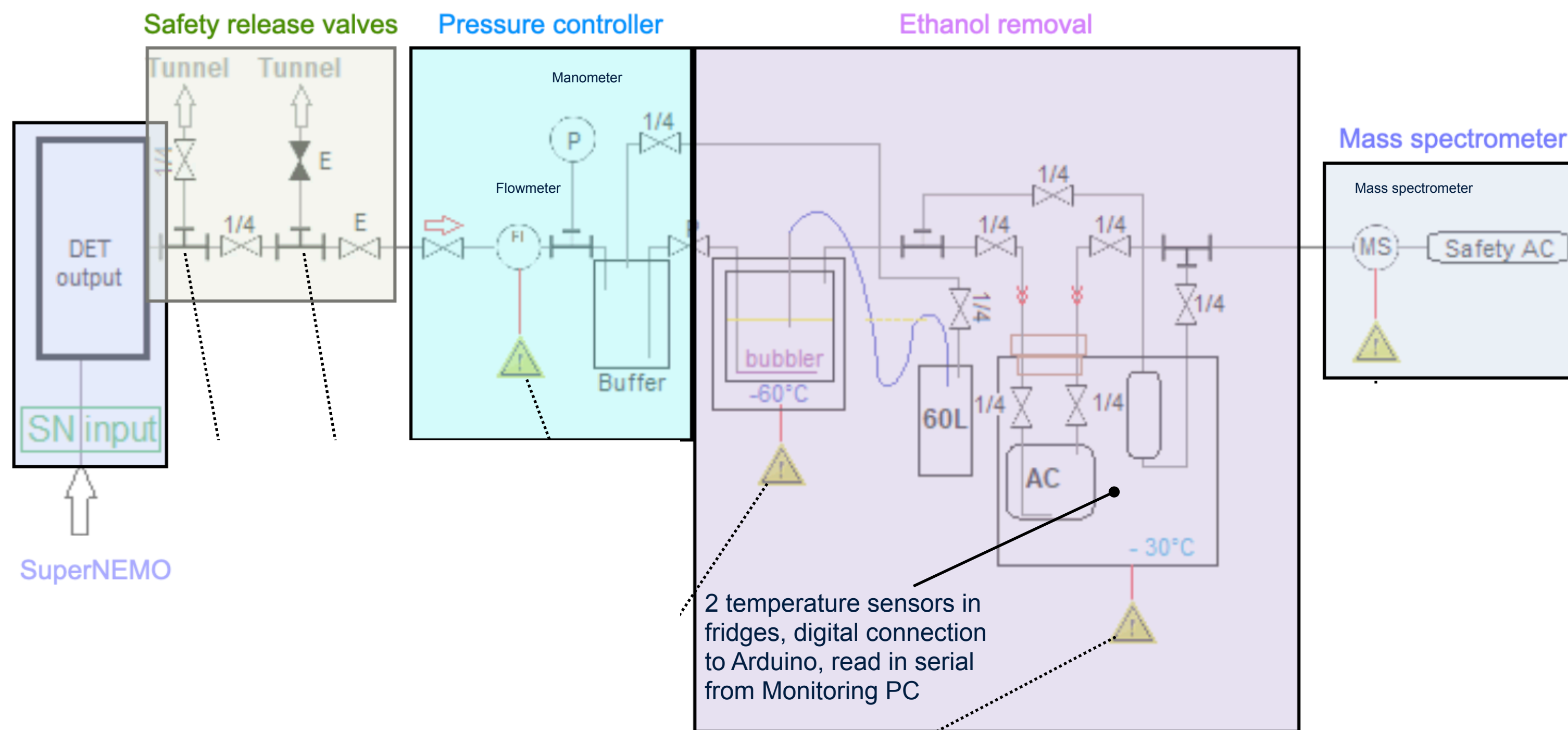


The Monitoring System



SuperNEMO helium recycling system

The NESS system



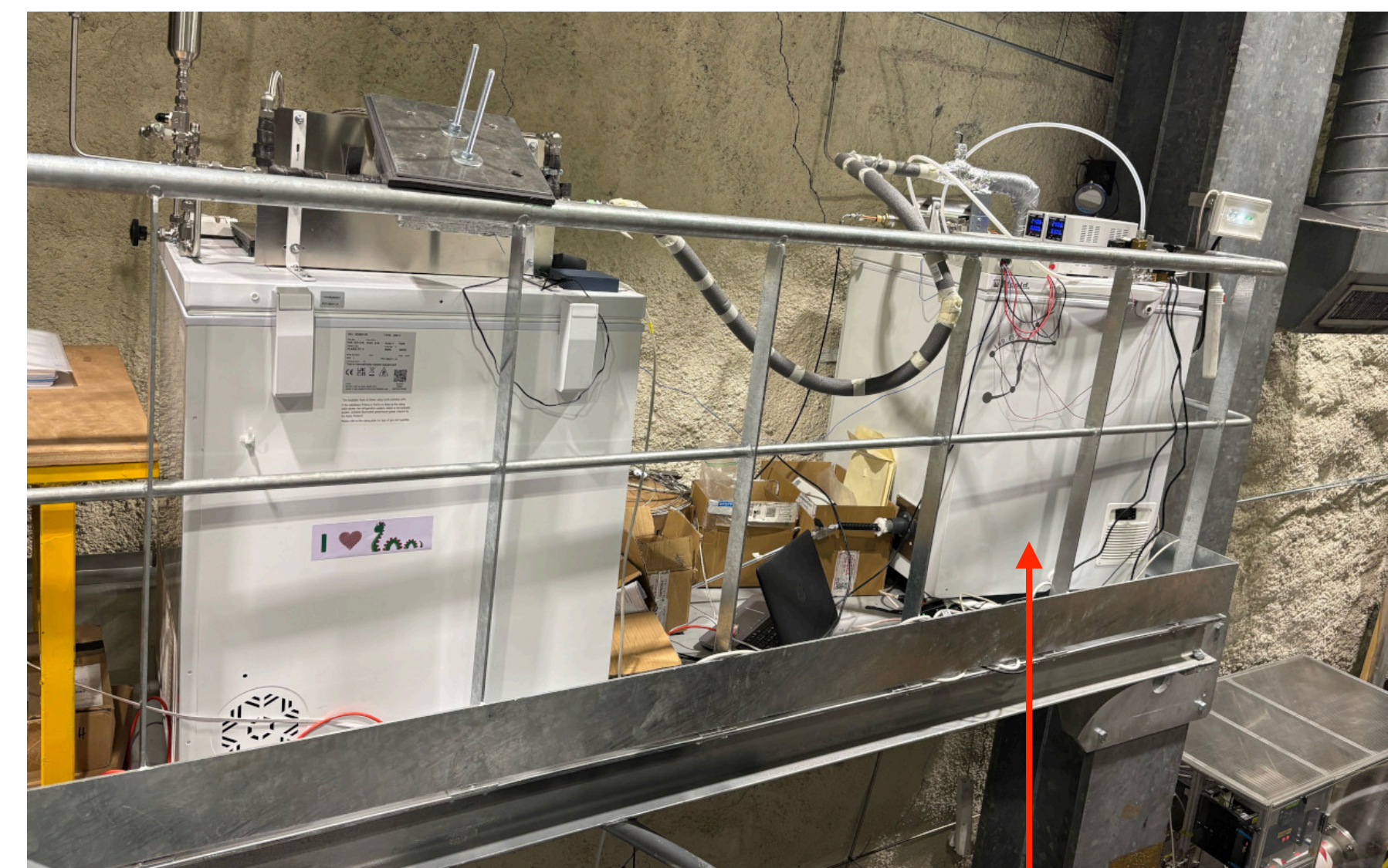
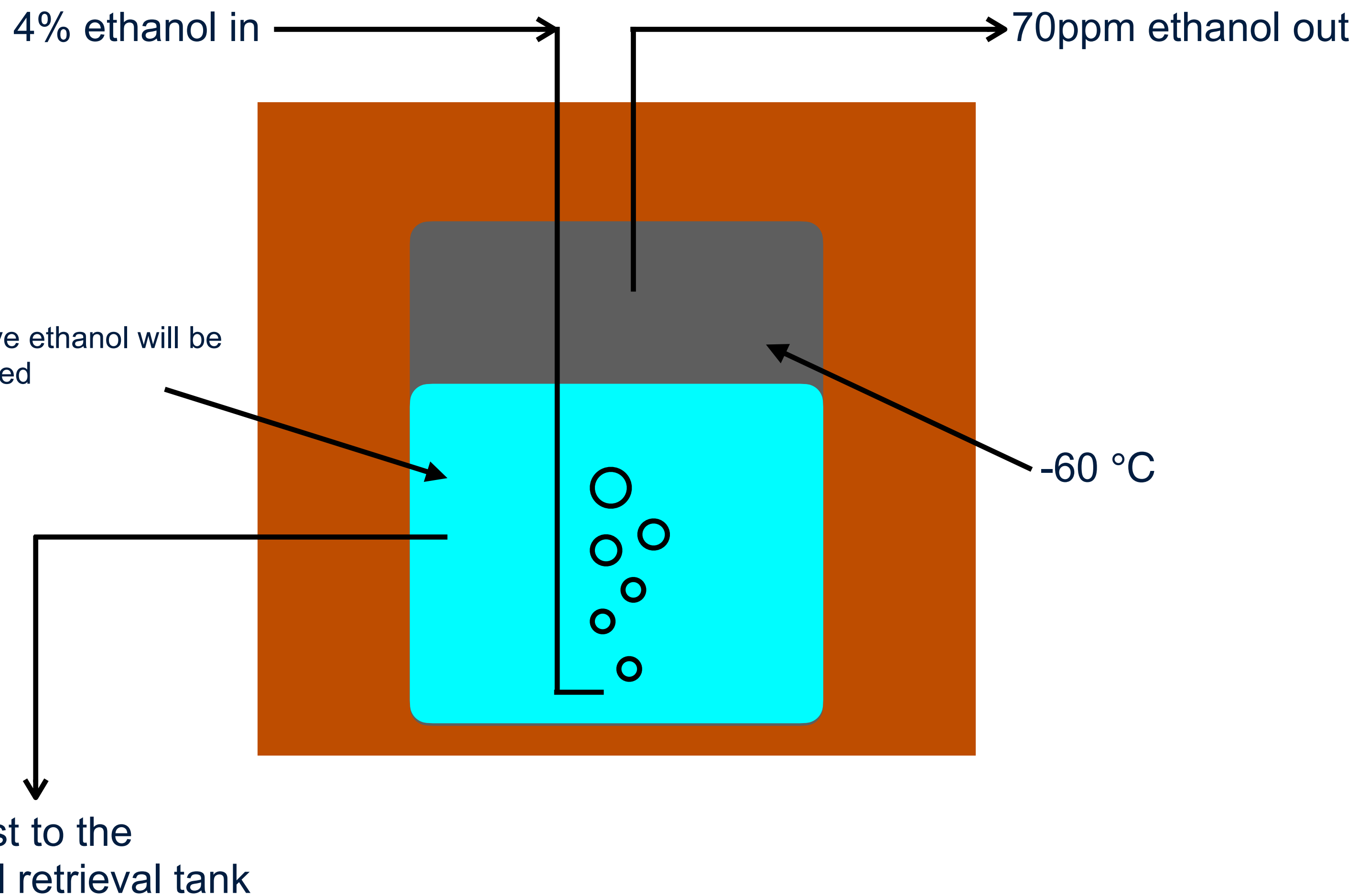
2-Step ethanol removal

Bubbler fridge

Adsorption fridge



The bubbler fridge



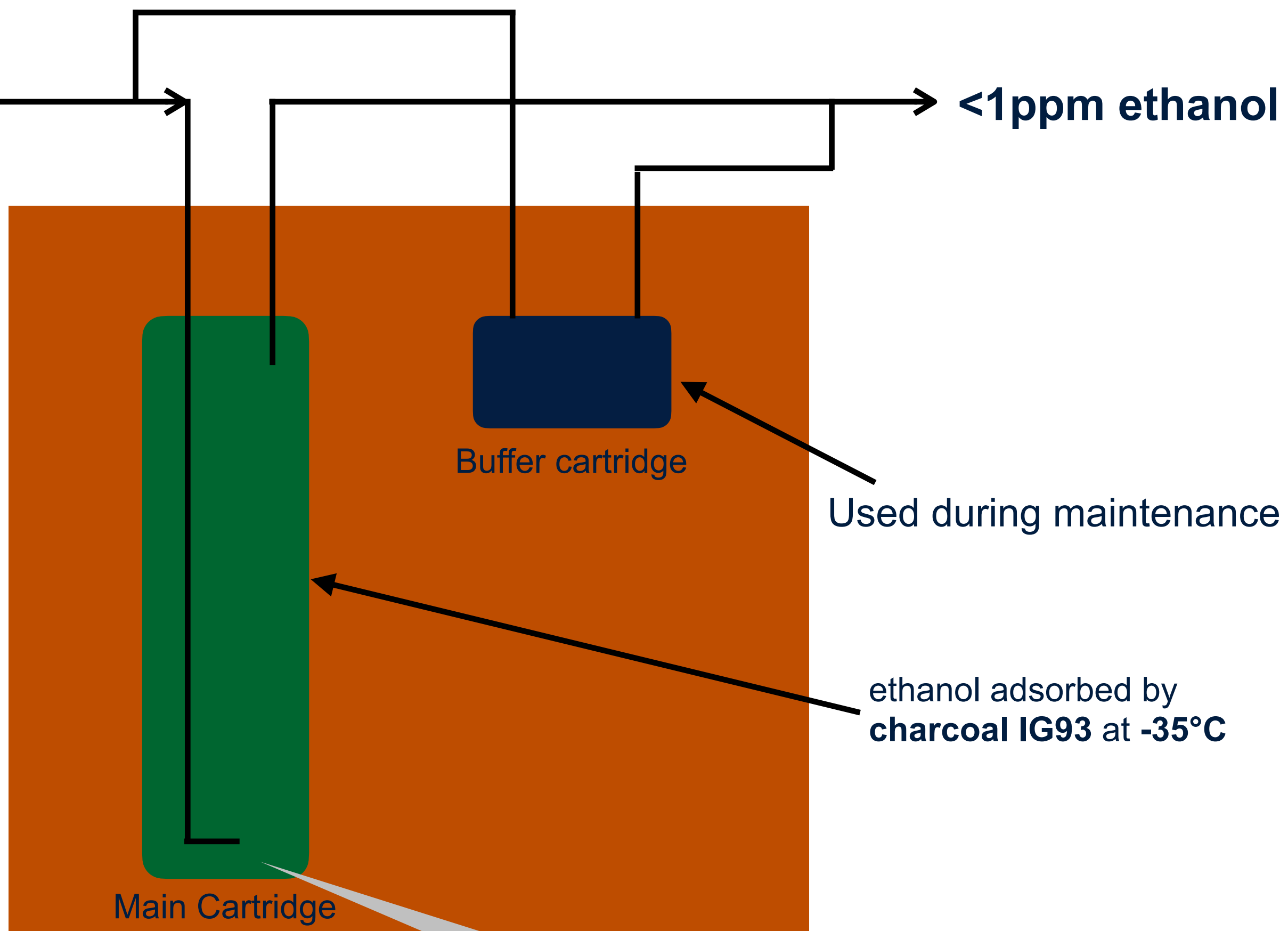
Bubbler fridge



The adsorption fridge

70ppm ethanol in

<1ppm ethanol out



Maintenance interval 1 month+

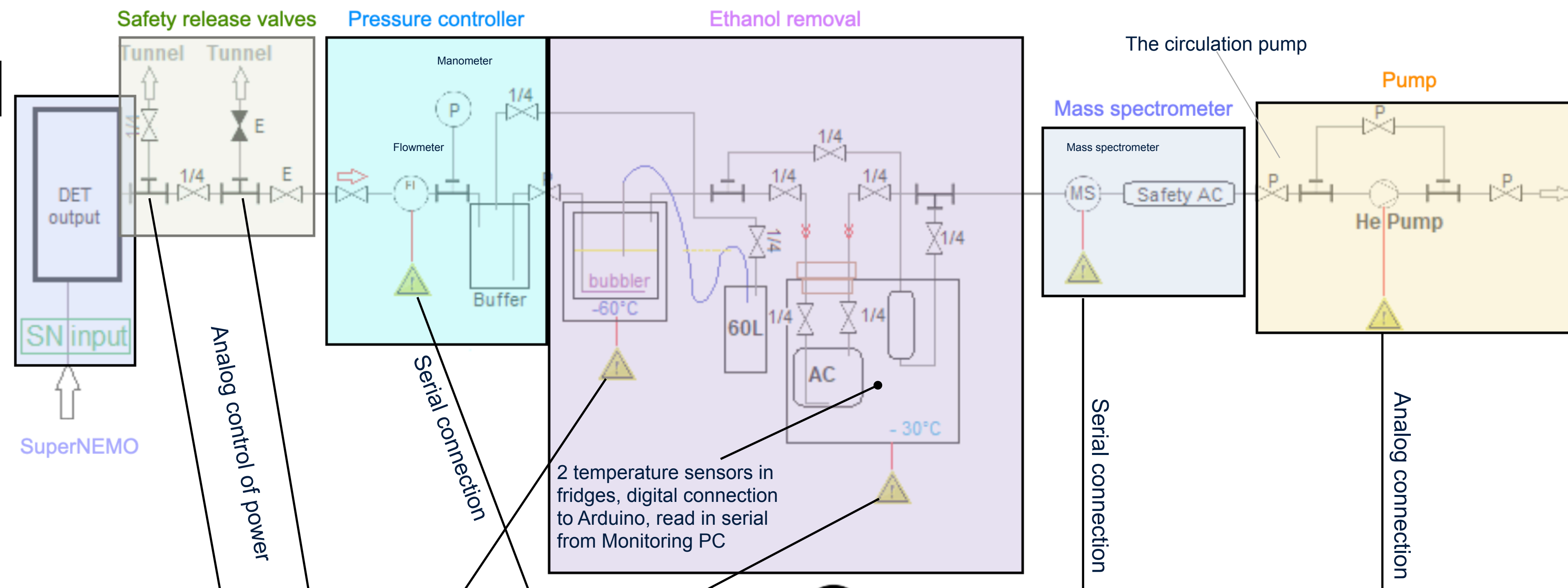


Adsorption fridge

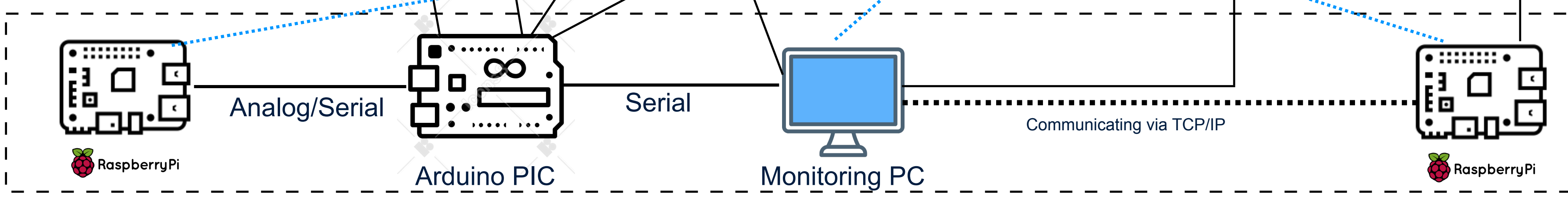


SuperNEMO helium recycling system

The NESS system



The Monitoring System

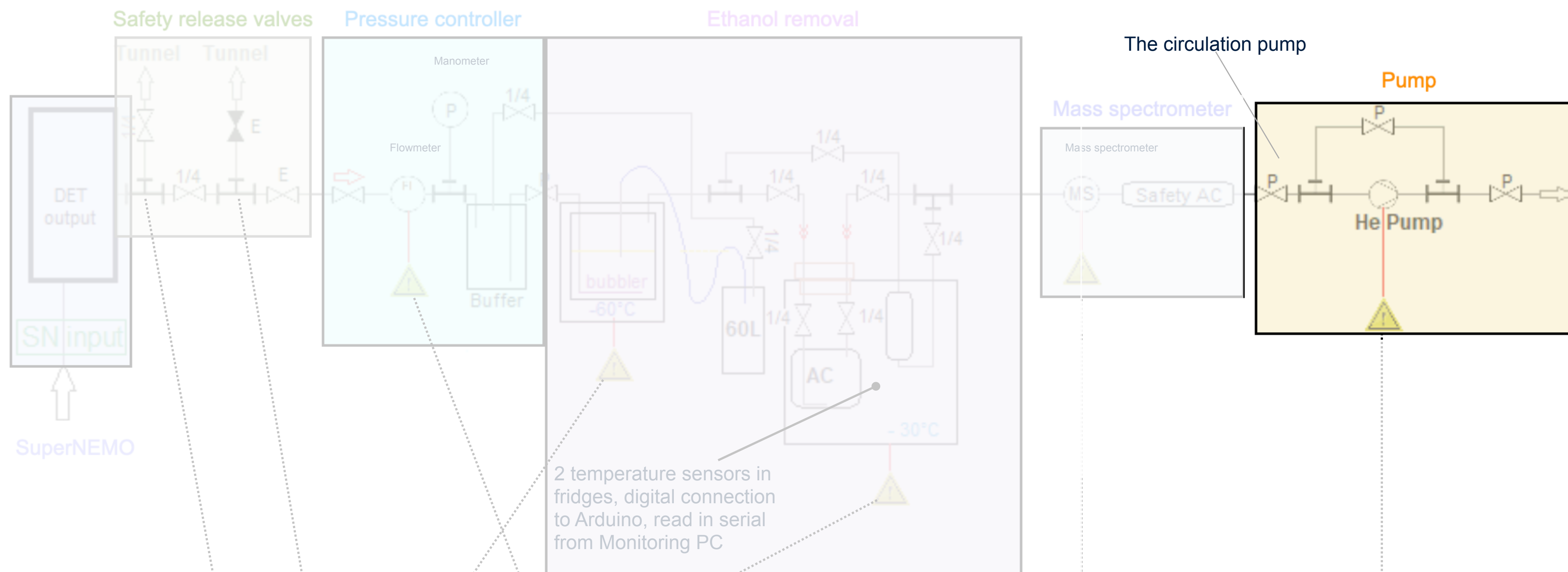


Helium storage



SuperNEMO helium recycling system

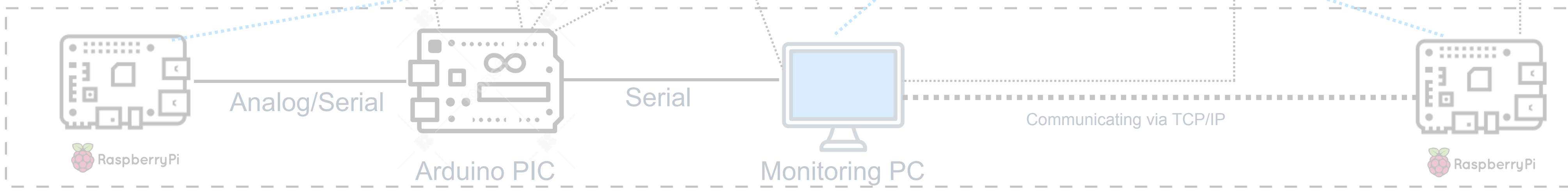
The NESS system



2 temperature sensors in fridges, digital connection to Arduino, read in serial from Monitoring PC

Internet

The Monitoring System



SuperNEMO helium recycling system

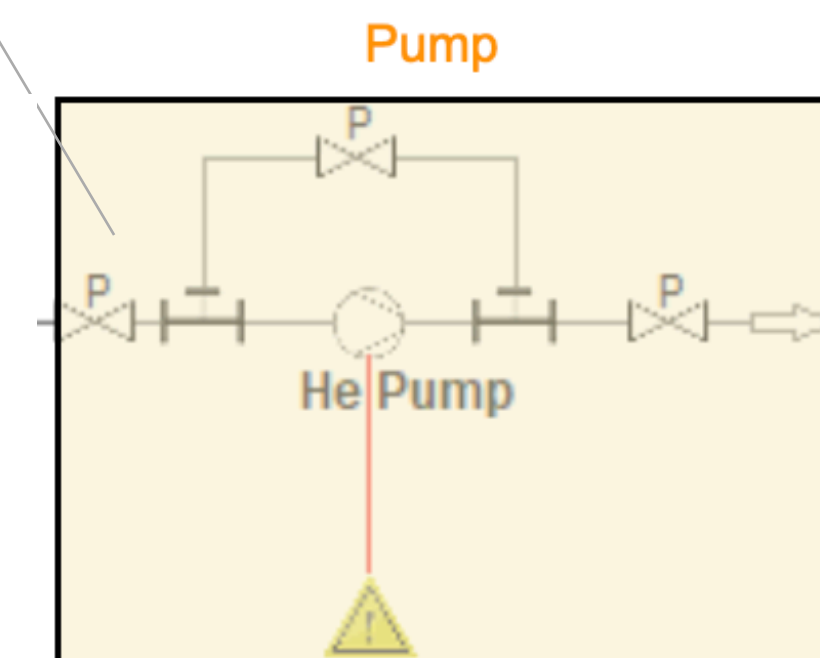
The NESS system

“Engine” of NESS

Circulation pump

Compression and storage system

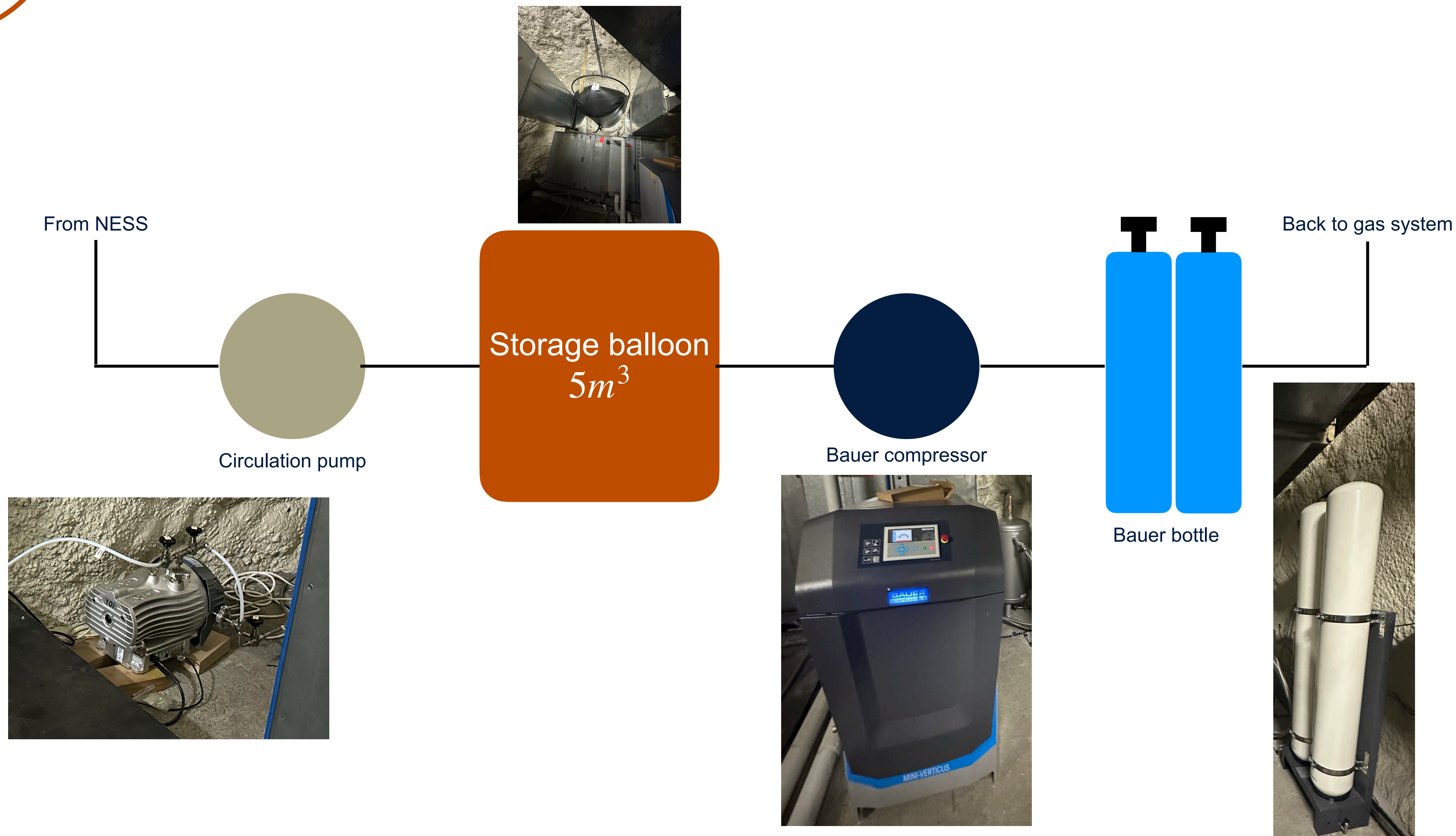
The circulation pump



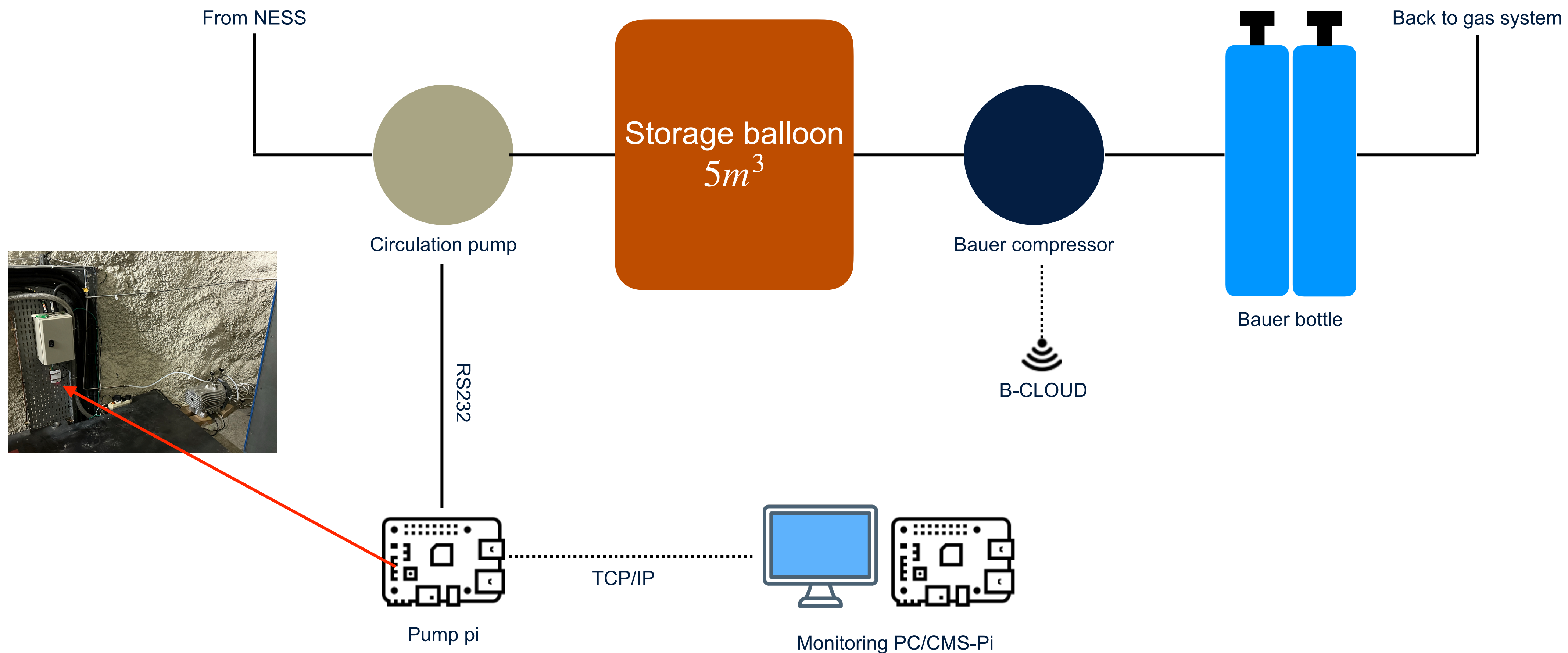
Helium storage



Circulation pump



Circulation pump



The Remixing of recycled gas

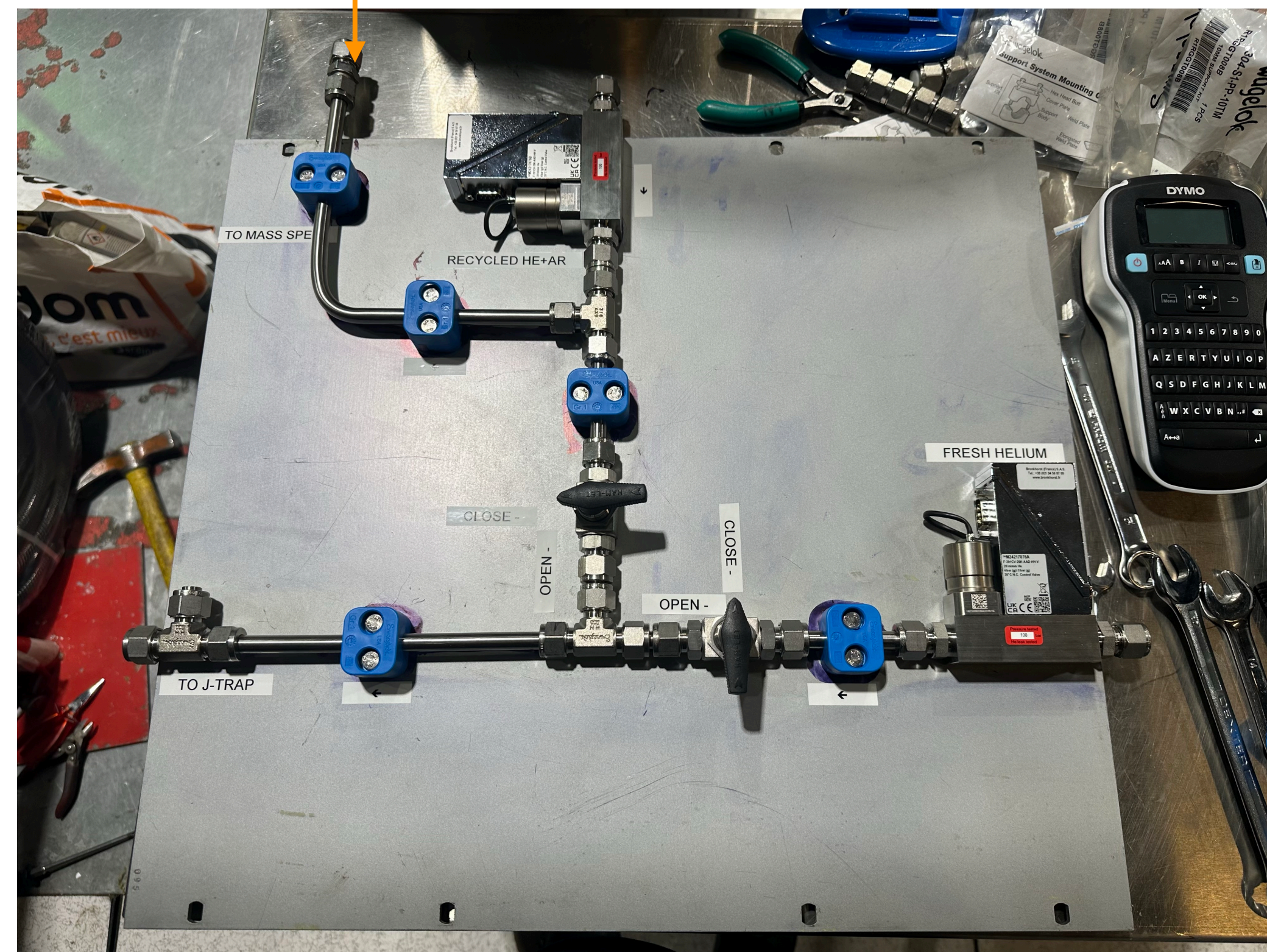
Remixing system

- Ensure the flow are normalise to the old gas system
- Overpressure in Radon-trap
- Ensure correct ratio of correct mixture
- Balancing between different bottle pressure



SuperNEMO gas system

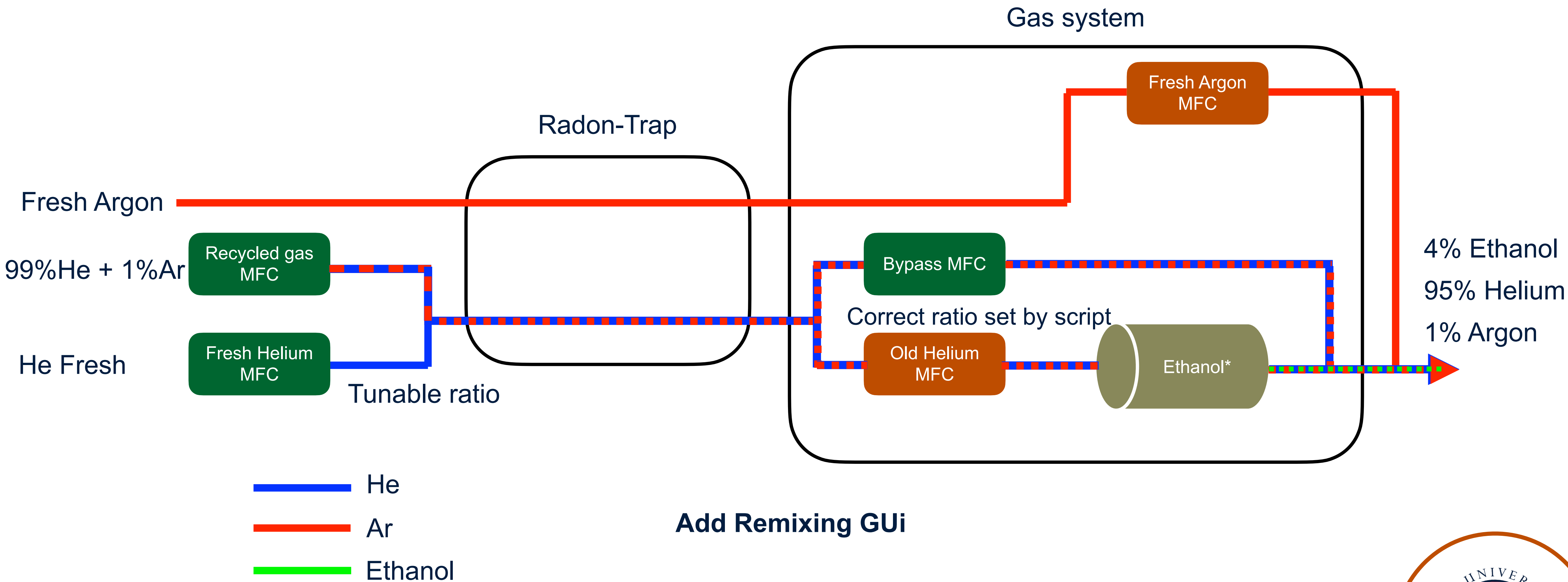
Bypass to mass spec



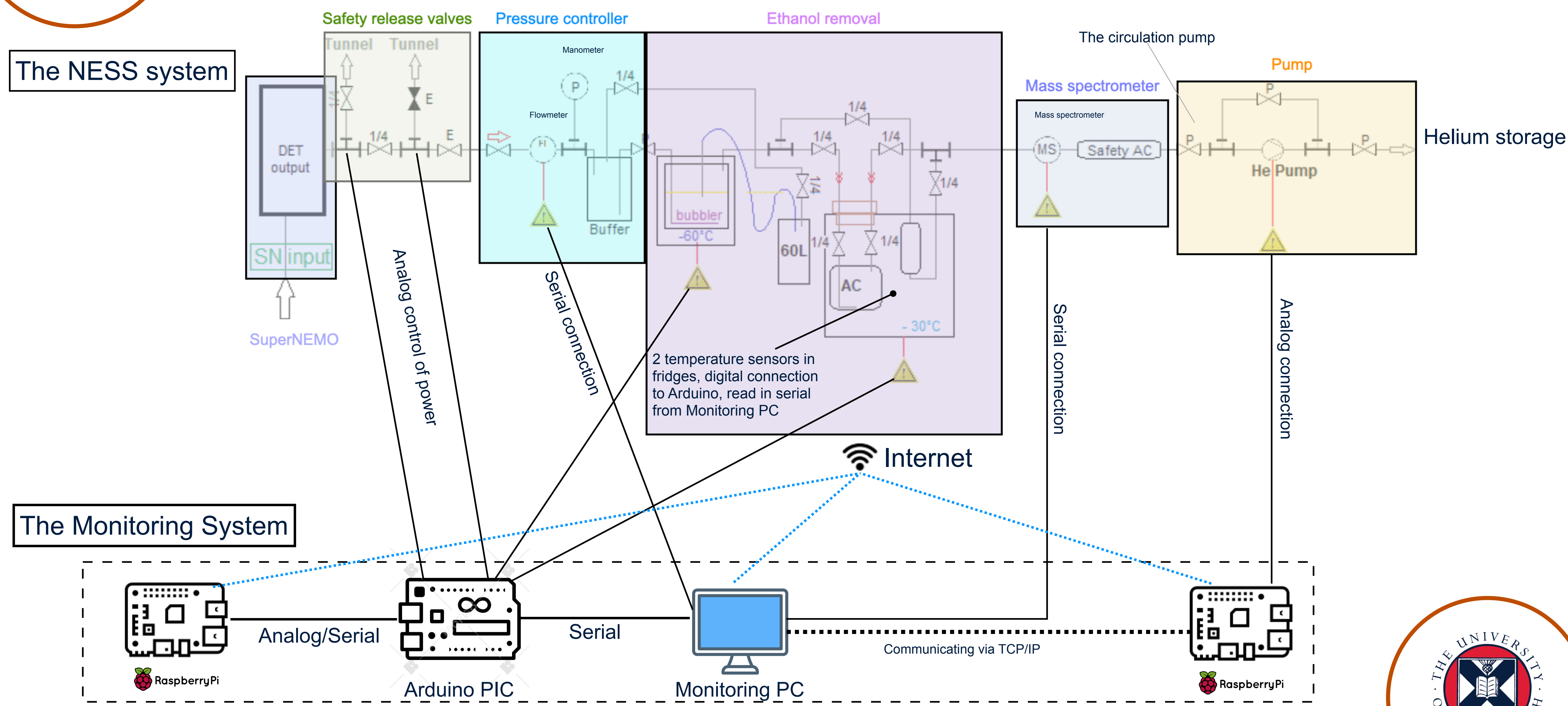
The remixing panel

Remixing gas flow

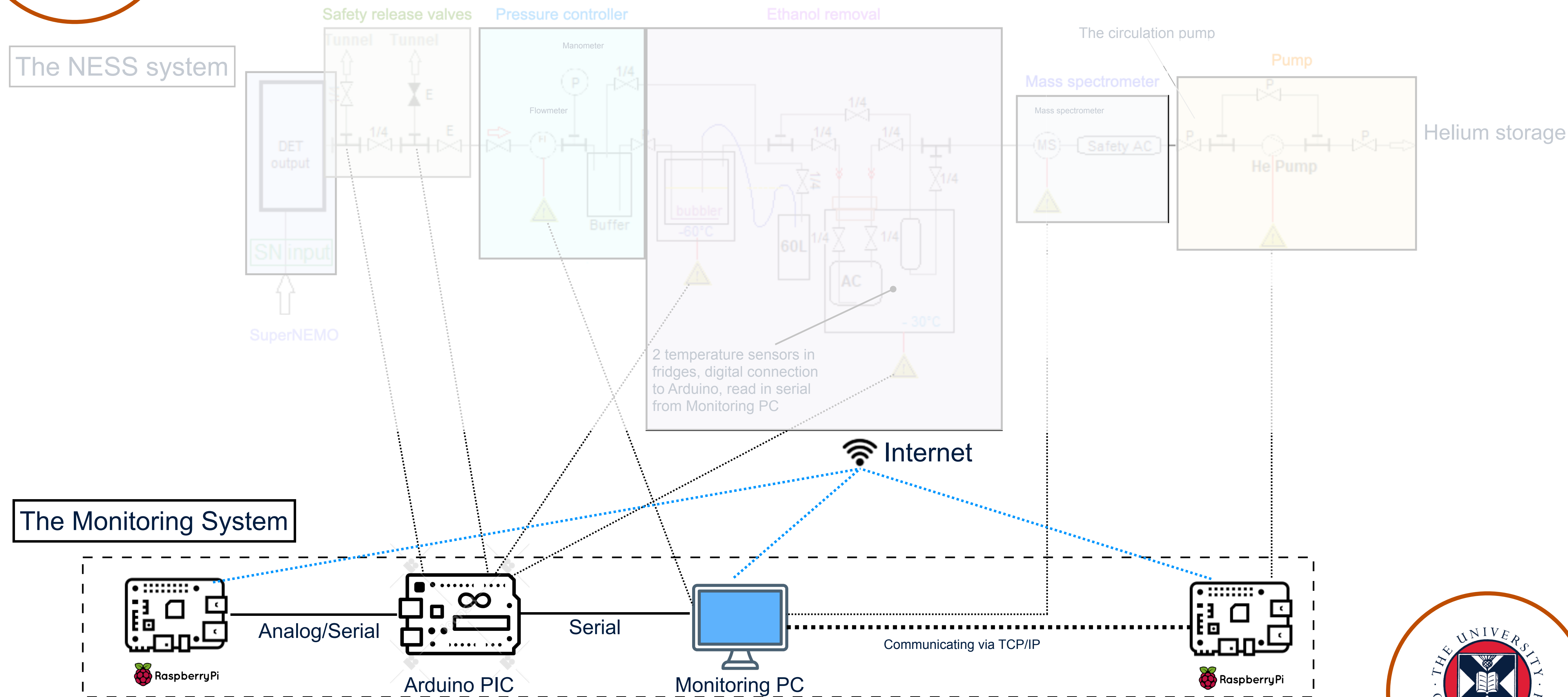
*: Simplified illustration for 2 bubblers



SuperNEMO helium recycling system



SuperNEMO helium recycling system



Control and monitoring system

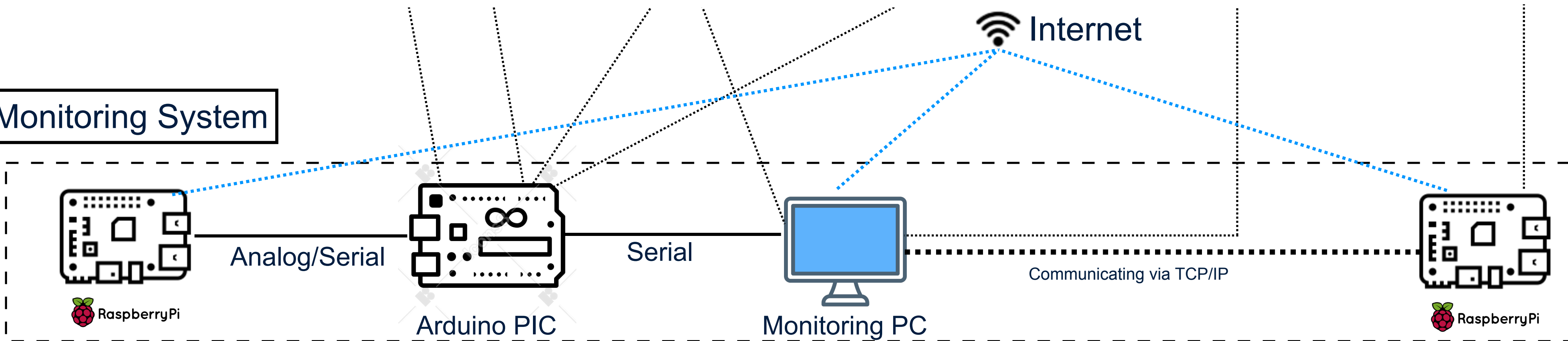
The NESS-CMS

Mass spec

Electrovalve

Monitoring PC, Arduino, Raspberry Pi ...

The Monitoring System





Solenoid valves

Ensure in any unexpected case there is no risk to SuperNEMO

- Overflow into the system
- Ethanol beyond NESS
- Power outage in the lab
- Fridge malfunctioning
- Compressor/pump malfunction

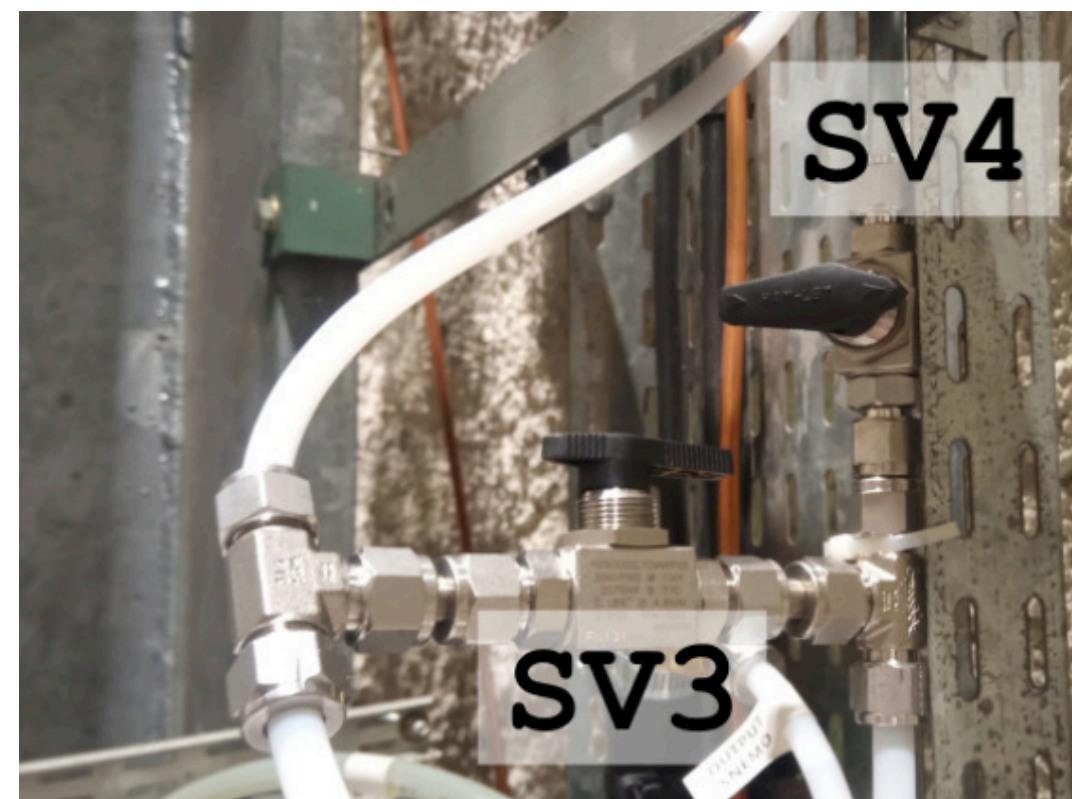
Control box

- Control components of the solenoid valve
- Additional safety to override if monitoring PC break

Additional features

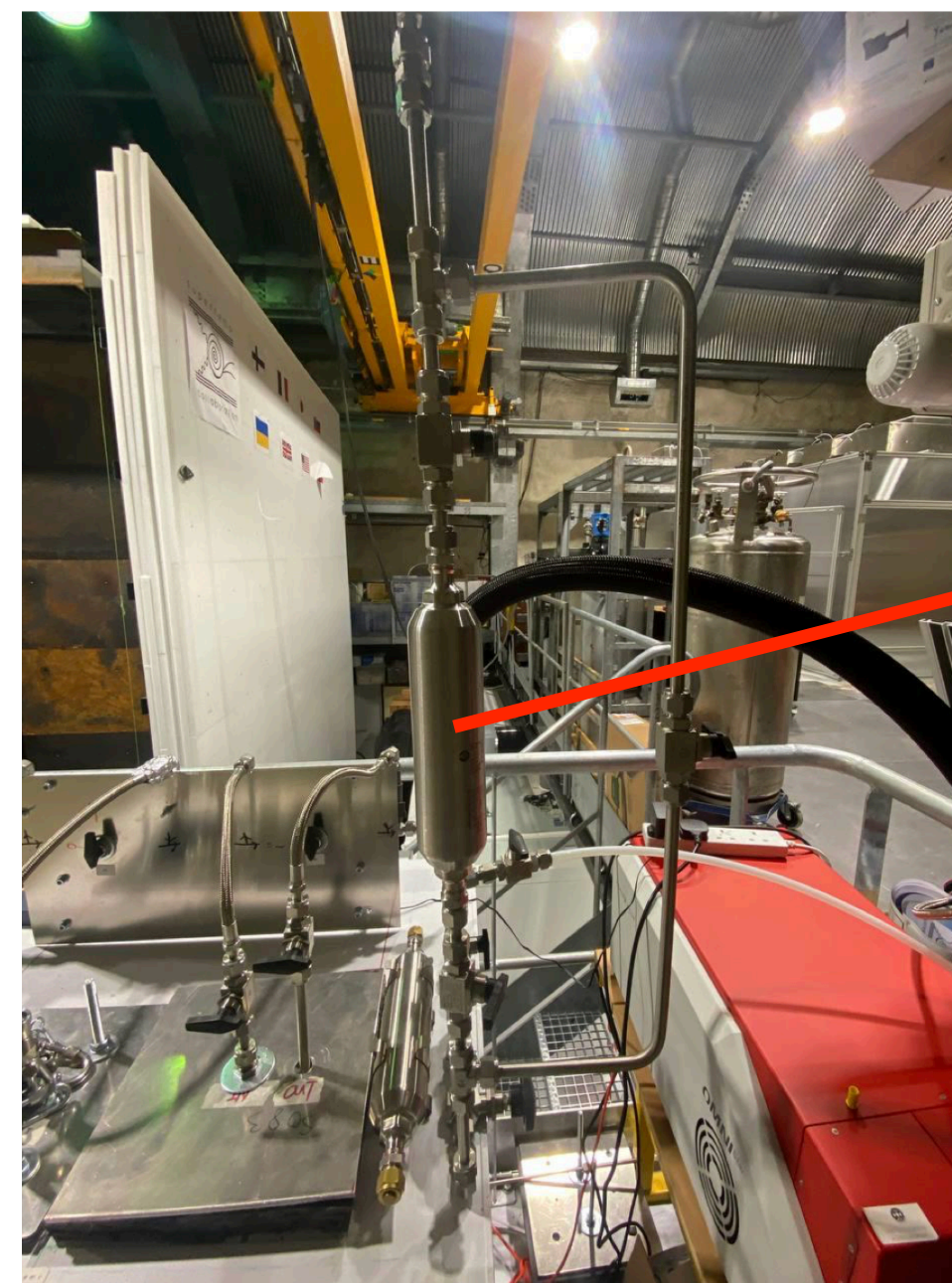
Manual valve

Manual valves to bypass
NESS, avoid overheating in
long term bypassing



Emergency bubbler

Emergency exhaust for the
compressor



Safety cartridge

Last ~2 days at nominal condition
After mass spec for protection

Summary

- **To detect double beta decay SuperNEMO use a tracker gas mixture of Helium, ethanol and Argon**
- Helium is expensive but SuperNEMO needs a lot. So we decided to recycle the helium.
- To kept the detector Radon free ethanol needs to be removed.
- We designed and build a system to remove the ethanol.
- 2 step removal: Bubbler to remove most ethanol and adsorption to take out the rest.
- Use a commercial compresor to re-pressurize the gas.
- Full remote control and monitoring with correct rebalancing.
- **Saving €120000 per year for SuperNEMO at 70% recycling efficiency**
- **My analysis! See poster #A7**