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SEZIONE DI CAGLIARI

ON BEHALF OF THE DARKSIDE COLLABORATION

THE DARKSIDE-20K ARGON PROCUREMENT CHAIN



- Scientific motivations and organization
- Status of Urania
- Status of ARIA

THE HEART OF THE DARKSIDE-20K PROJECT: UAR

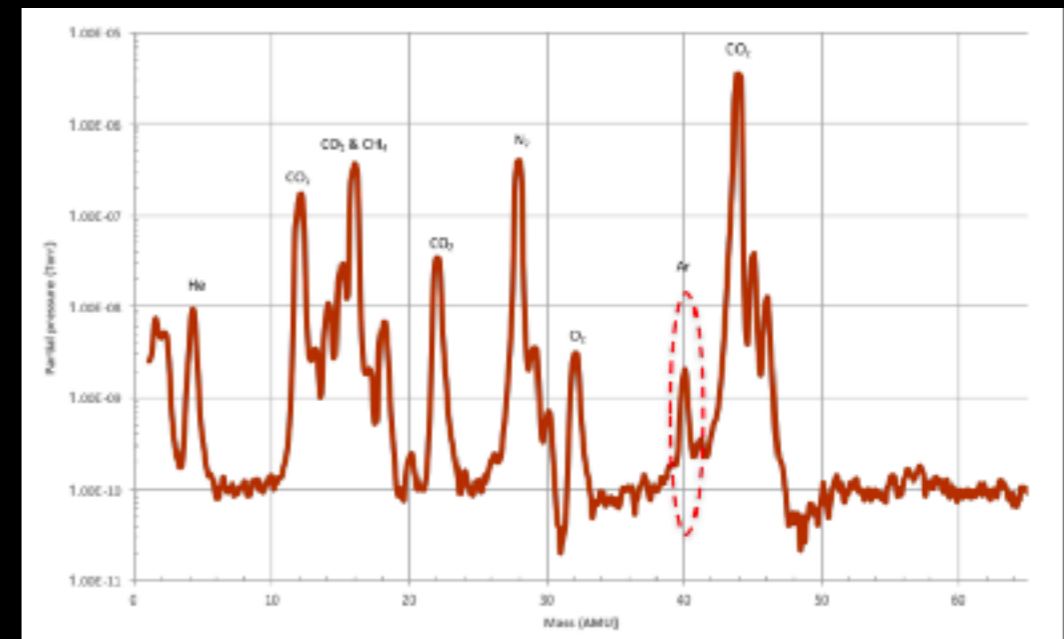
| Isotope | Abundance | Specific activity (Bq/kg _{Ar}) |
|------------------|-------------------------------|--|
| ⁴⁰ Ar | 0.9960 | Stable |
| ³⁶ Ar | 0.0033 | Stable |
| ³⁸ Ar | 0.0006 | Stable |
| ³⁹ Ar | 8.2×10^{-16} | 1.0 [7,8] |
| ³⁷ Ar | $\approx 1.3 \times 10^{-20}$ | $\approx 4.5 \times 10^{-2}$ [9] |
| ⁴² Ar | 6.8×10^{-21} | 6.8×10^{-5} [10,11] |

PHYSICAL REVIEW C **100**, 024608 (2019)

- ³⁹Ar: Q=565keV and T_{1/2}=269y;
- 8×10^{-16} g/g in the AAr; β emitter with specific activity 1Bq/Kg
- Produced in the atmosphere mainly by neutron-induced reactions of cosmic rays on ⁴⁰Ar
- Very low production going underground (UAr). Production from natural radioactivity reactions (α, n)-induced on ³⁹K

THE UAR EXTRACTION SITE

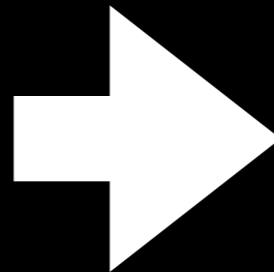
- DOE canyon, Dolores County, Colorado
- The company Kinder-Morgan (KM), extracts gas from the subsoil, which is later used for oil mining purposes, with composition: CO₂ 95%, UAr 430ppm; DarkSide "takes" the argon and returns the rest to KM
- The gas comes from the mantle ('magmatic CO₂'); the concentration of uranium and thorium in the mantle is typically at the level of ppb, 1/1000 relative to the crust (Well depth 3 KM) —> low probability of production of ³⁹Ar



| Composition | # of atoms (neutrons) yr ⁻¹ kg ⁻¹ | | | |
|--------------------------|---|----------|------------------|------------------|
| | ⁴ He | neutrons | ²¹ Ne | ³⁹ Ar |
| Upper Continental Crust | 1.64×10^{10} | 10,680 | 753 | 28.7 |
| Middle Continental Crust | 8.98×10^9 | 6114 | 416 | 13.9 |
| Lower Continental Crust | 1.53×10^9 | 1129 | 70.2 | 0.749 |
| Bulk Continental Crust | 9.43×10^8 | 6253 | 433 | 15.3 |
| Bulk Oceanic Crust | 3.79×10^8 | 260 | 15.8 | 0.0235 |
| Depleted Upper Mantle | 2.51×10^7 | 22.4 | 1.06 | 0.000257 |

(O. Šrámek, et al., *Geochimica et Cosmochimica Acta* 196 (2017) 370)

PIONEERING PLANT FOR DARKSIDE-50 SINCE 2010

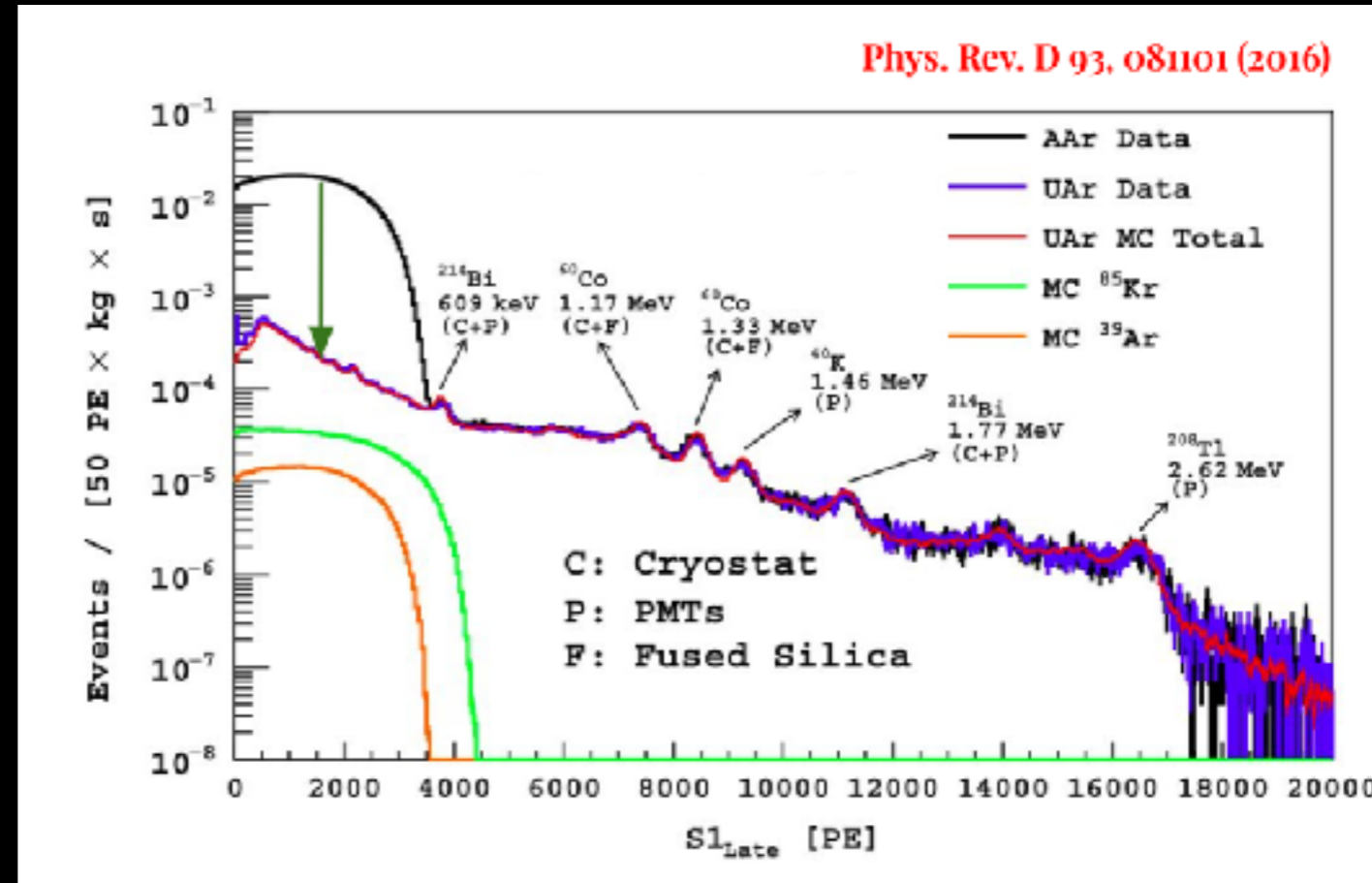


- In-situ plant: Pressure Swing Adsorption System (PSA)-> gas with 3-5% argon

- FERMILAB distillation column
- Total packing height 3.2m; 60 theoretical stages
- Extracted and purified 156kg of UAr with contamination <10ppm of N₂ at 1Kg/day
- Quantity extracted and purified not enough for Darkside-20k

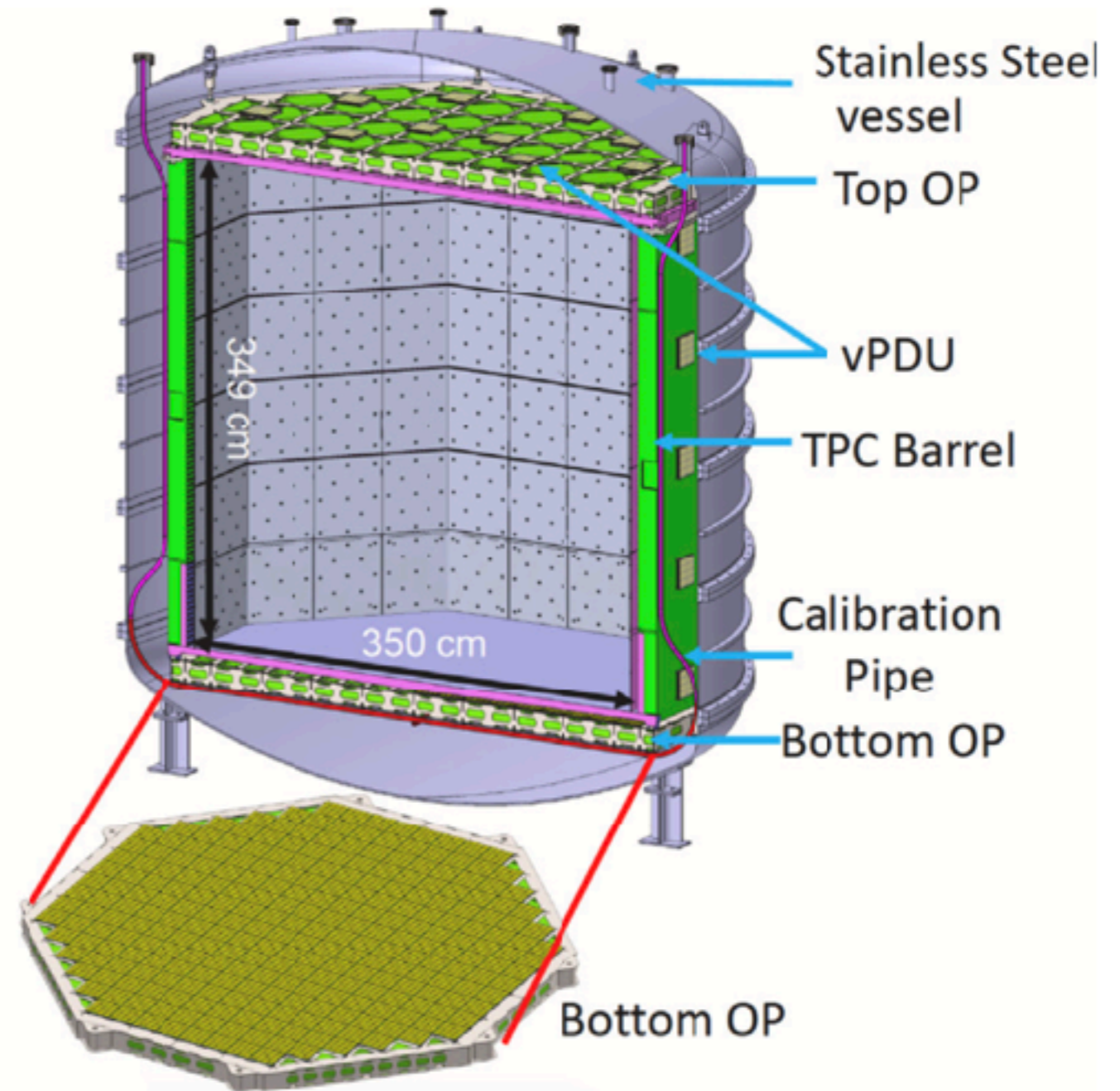
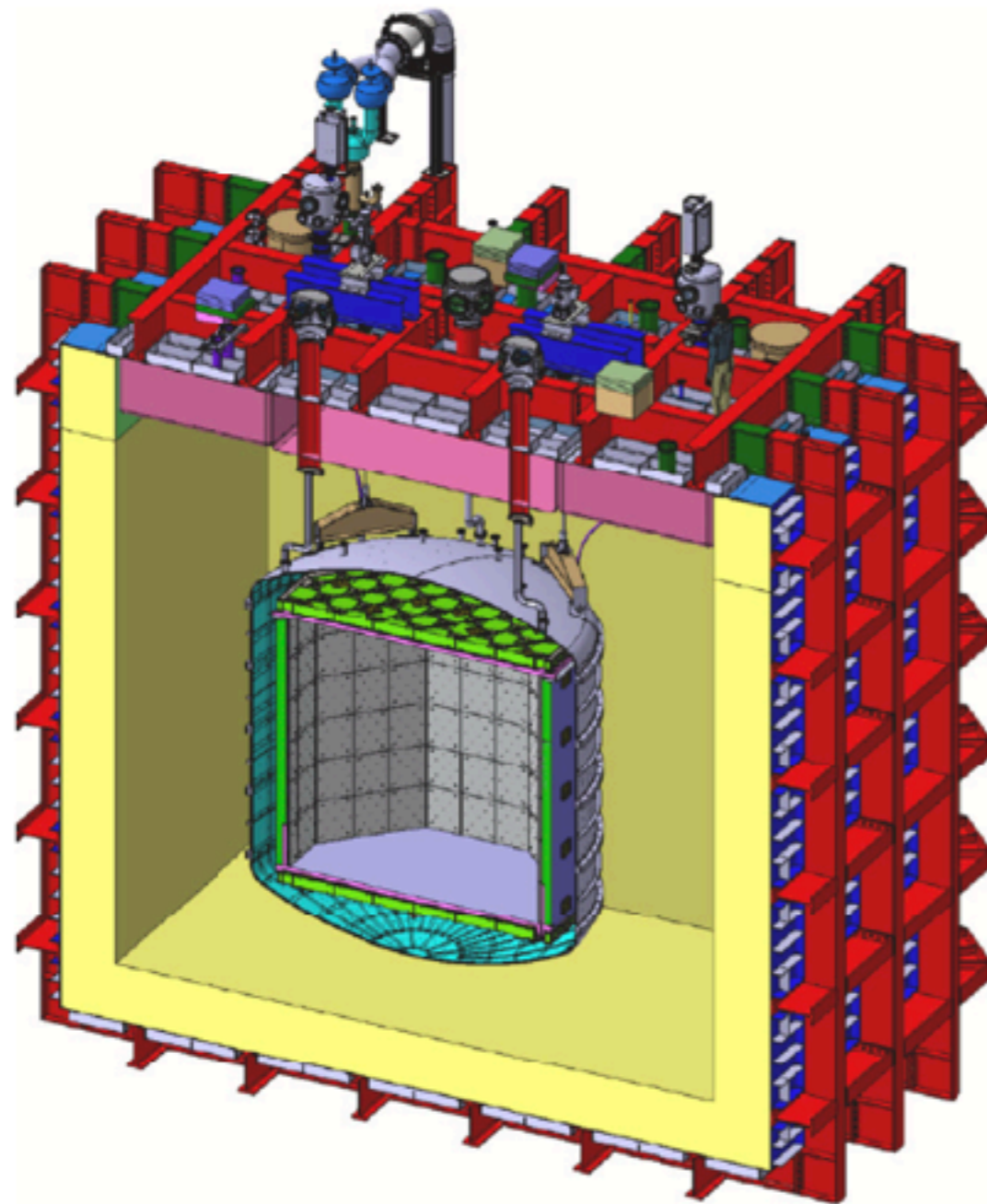
DARKSIDE-50

- ^{85}Kr : 1.8 ± 0.1 mBq/kg
- ^{39}Ar : 0.7 ± 0.1 mBq/kg

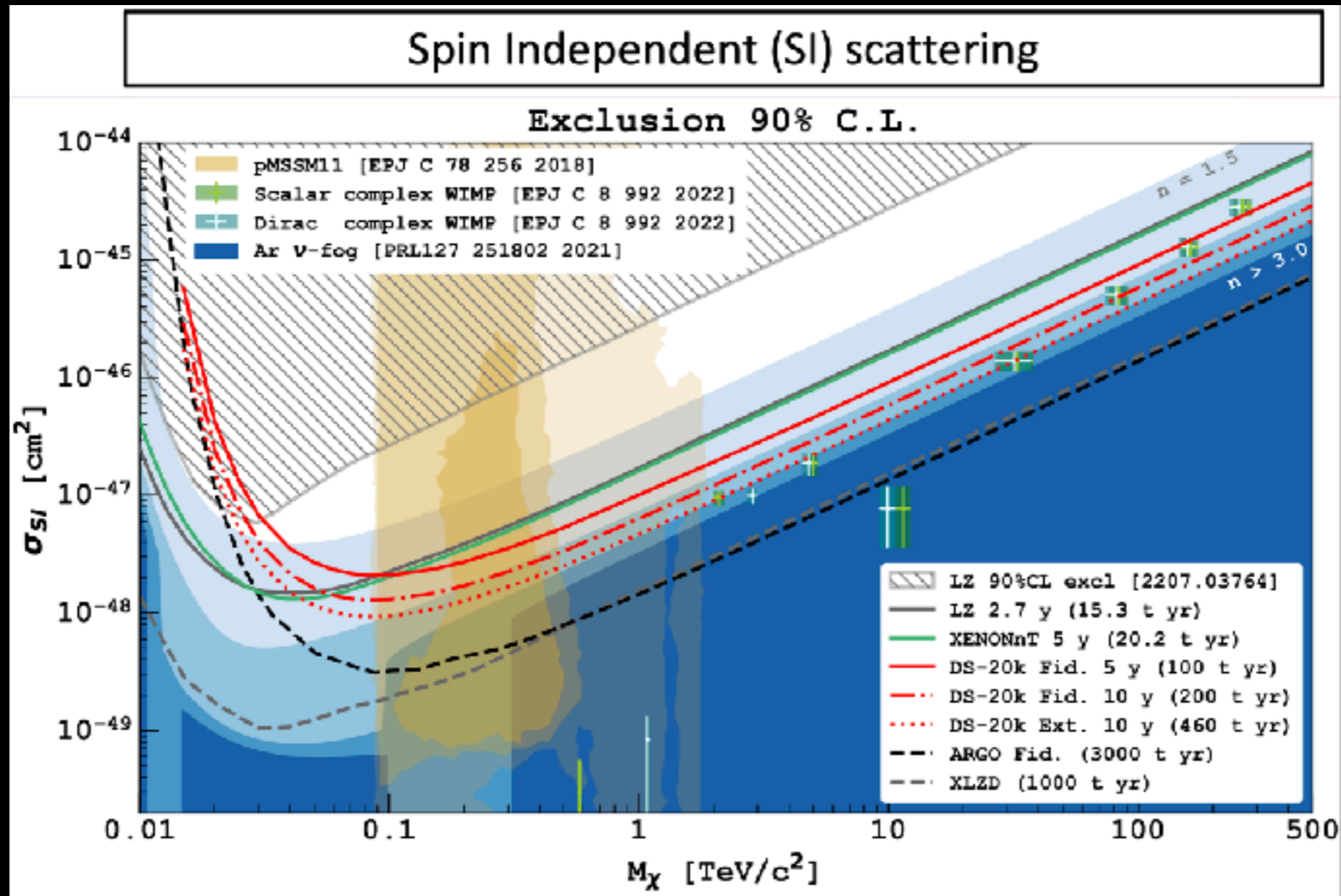


For DS50 results please see the talk of T.Hugues Aug 29th
4.45PM Dark Matter session

DARKSIDE-20K



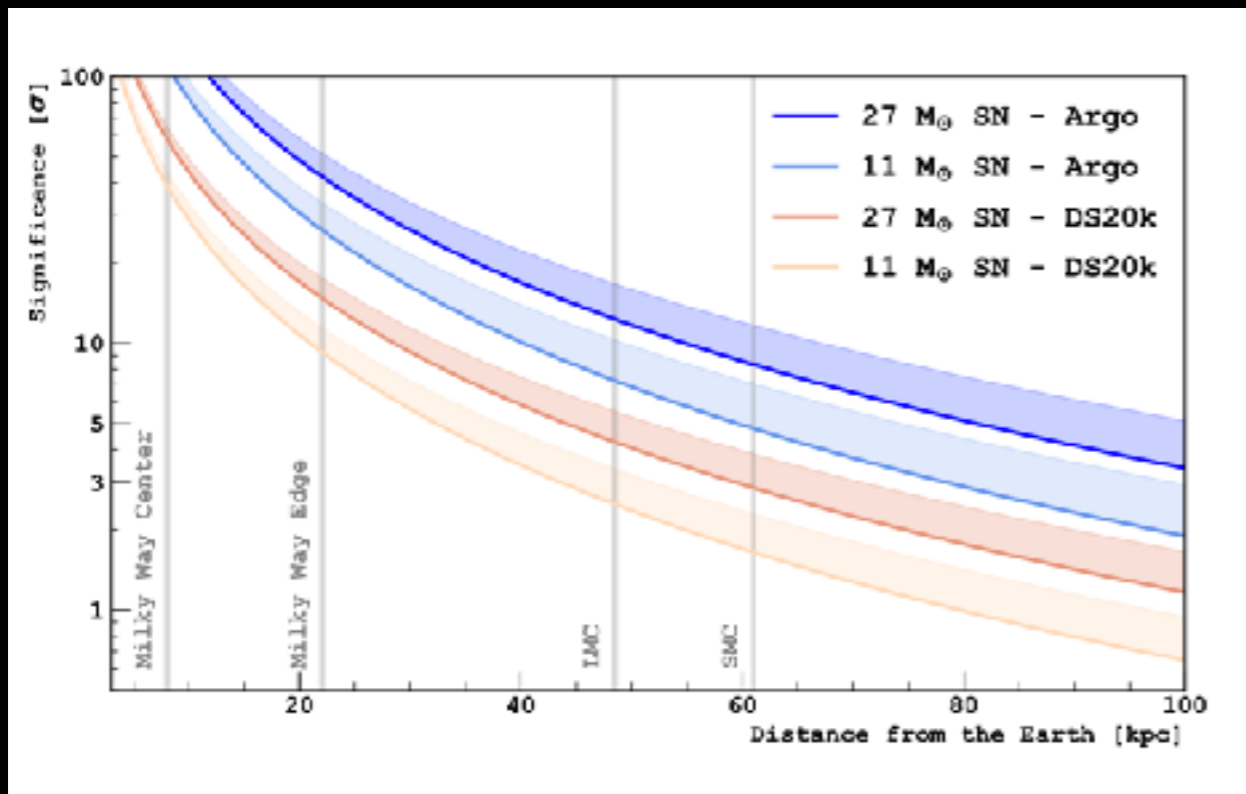
DARKSIDE-20K GOALS: WIMP DARK MATTER



- See 29/8 Yi Wang Dark Matter session

DARKSIDE-20K GOALS: NEUTRINOS FROM SN

- At LNGS in the near future (after removing liquid scintillator detectors) the most sensitive detector to detect neutrinos from SN



| | DarkSide-20k | Argo |
|-----------------------------|--------------|--------|
| 11- M_{\odot} SN- ν s | 181.4 | 1396.6 |
| 27- M_{\odot} SN- ν s | 336.5 | 2591.6 |
| ^{39}Ar | 4.3 | 33.8 |
| external background | 1.8 | 8.8 |
| single-electrons | 0.7 | 5.1 |

- With CEvNS $\sim 500\text{eV}_{\text{NR}}$ threshold, 10kpc

WHY WE NEED UAr IN DARKSIDE-20K

- Reconstruction issues with pile-up in the TPC in 3.5m drift length (3.8 ms time)
- Dead time when vetoing (800 μ s coincidence time window)
- At present assuming UAr is 1400 x less radioactive than AAr

Astropart.Phys. 152
(2023) 102878

| | TPC rate (Hz) | Veto rate (Hz) |
|-------|-------------------|--------------------|
| Gamma | $\mathcal{O}(50)$ | $\mathcal{O}(100)$ |
| Beta | 36 | 26 |

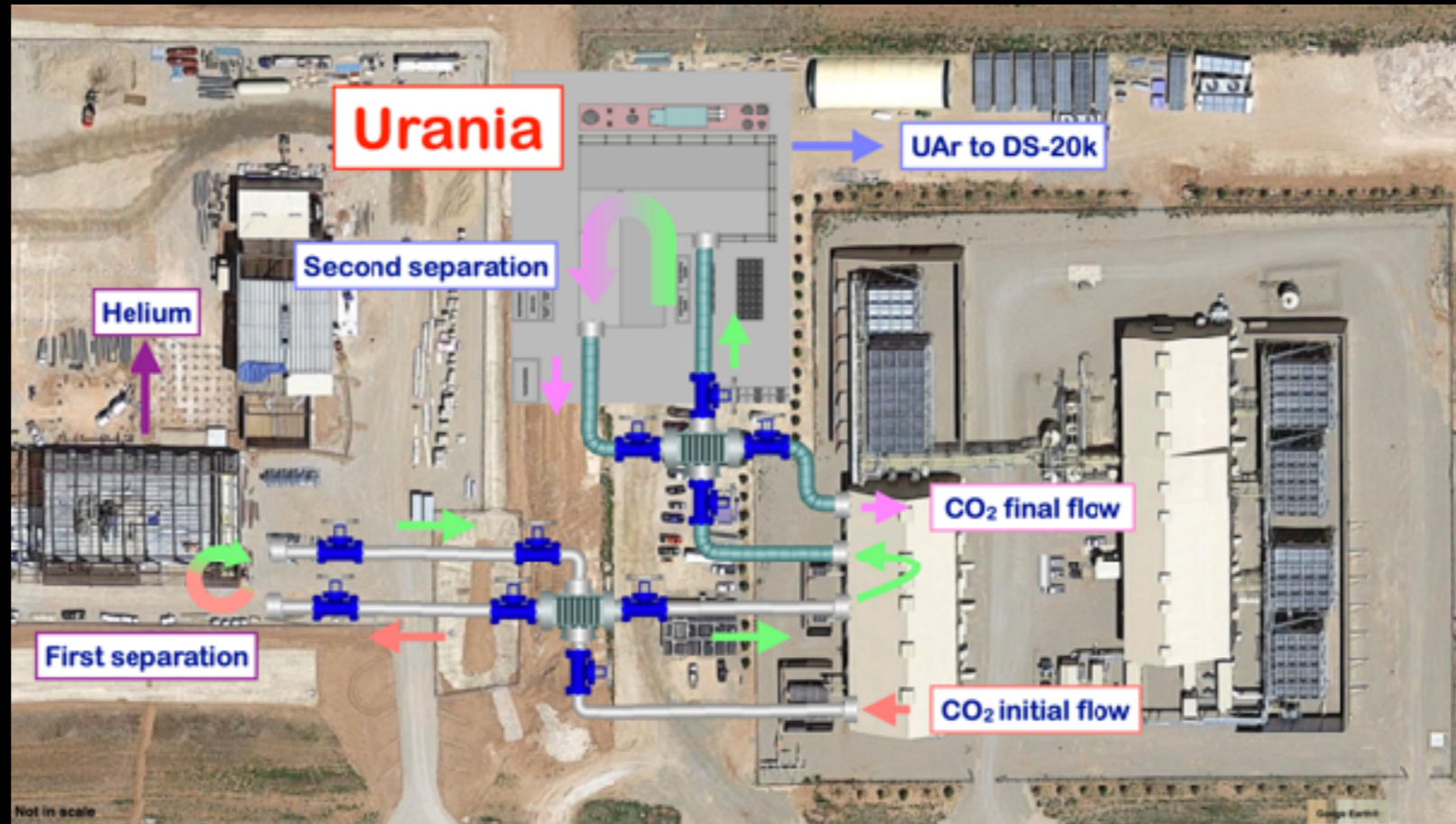
THE UAR PATH



TUBS, CC BY-SA 3.0 <<https://creativecommons.org/licenses/by-sa/3.0/>>
via Wikimedia Commons, name labels and arrows added by the presenter

Alexrk2, CC BY-SA 3.0 <<https://creativecommons.org/licenses/by-sa/3.0/>>
via Wikimedia Commons, name labels and arrows added by the presenter

URANIA: A NEW HIGH-PRODUCTION PLANT



- 250kg/day of UAr
- INFN/NSF/DOE/CFI/PNNL

URANIA

16,250 Nm³/h

- CO₂ 95.5%
- N₂ 3.5%
- CH₄ 0.92%
- Ar 440 ppm
- He 50 ppm

3,250 Nm³/h

- CO₂ 77.7%
- N₂ 17.5%
- CH₄ 4.5%
- Ar 0.22%
- He 250 ppm

CO₂ 20%

650 Nm³/h

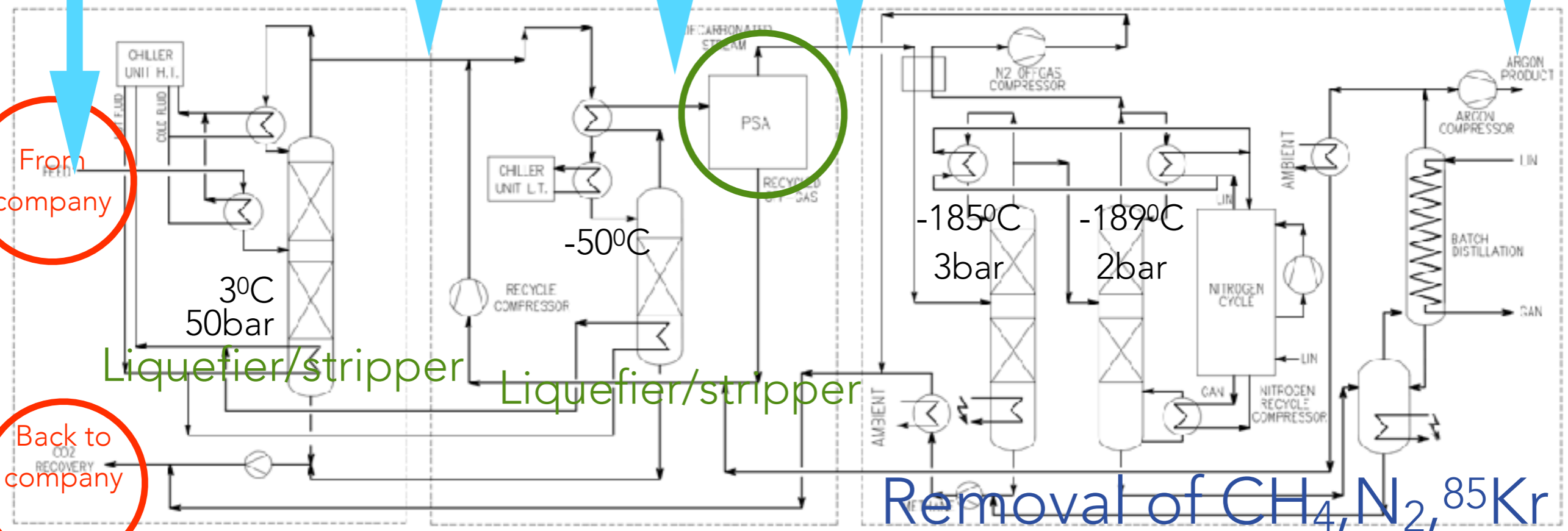
- CO₂ 10-20 ppm
- N₂ 80.8%
- CH₄ 18.1%
- Ar 1.0%
- He 0.116%

6.25 Nm³/h,
Ar 99.9%

1ST CO₂
SEPARATION

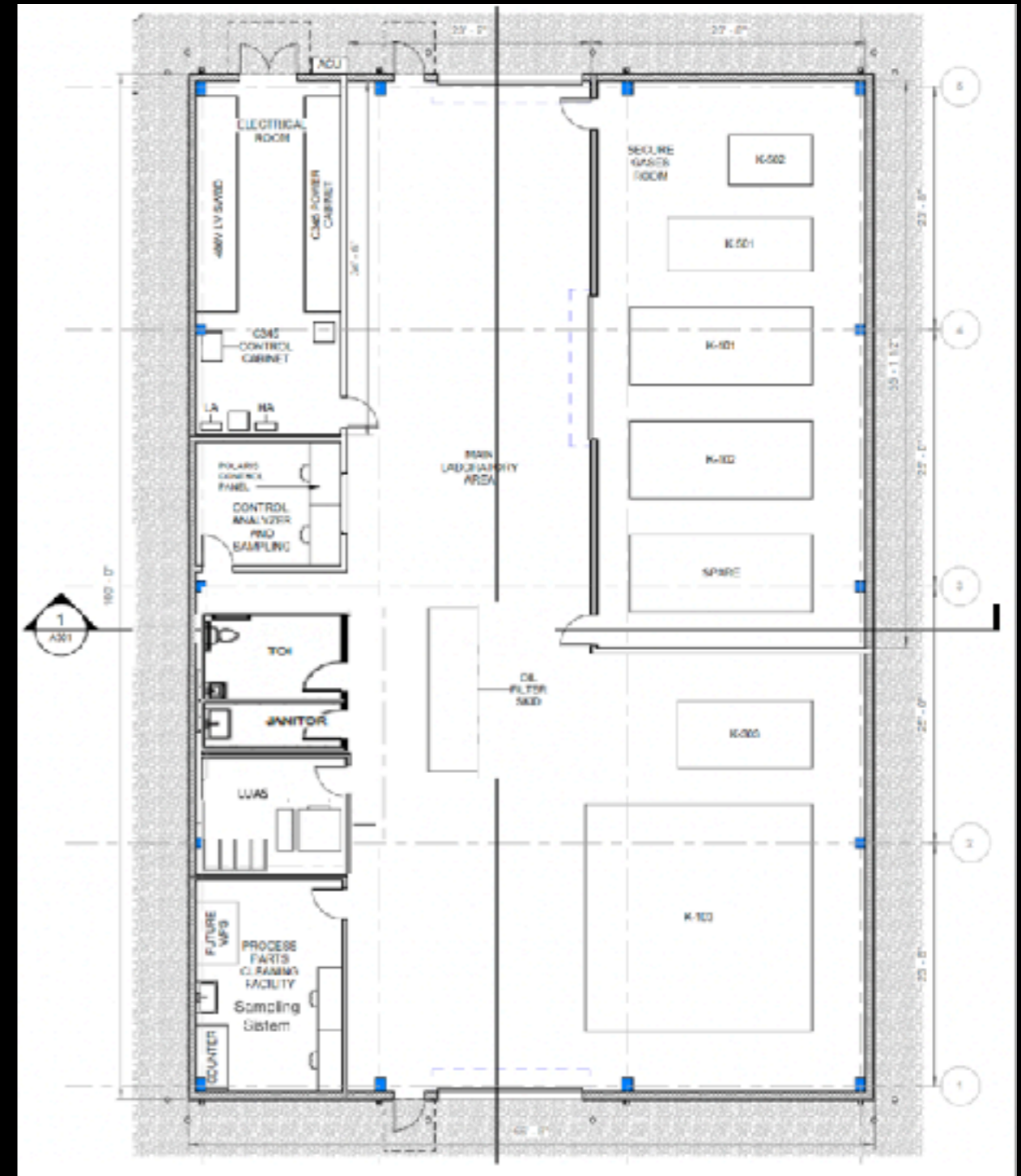
2ND CO₂
SEPARATION

ARGON
PURIFICATION



PRELIMINARY LAYOUT

- Online sampling system
- Offline sampling system (test samples of about 1kg to be sent to LSC Spain for testing with DART, see talk by L. Luzzi 29/8 17.30 DM session)



URANIA PLANT BUILT@POLARIS



VACUUM LEAK CHECKS@POLARIS



IN USA







NEXT STEPS URANIA

- KM is going to prepare the connections to their plant, drawings ready.
- The University of Houston manages the site construction project and plant installation
- Design drawings being completed
- Ready to bid for site installation contractors

TRANSPORTATION

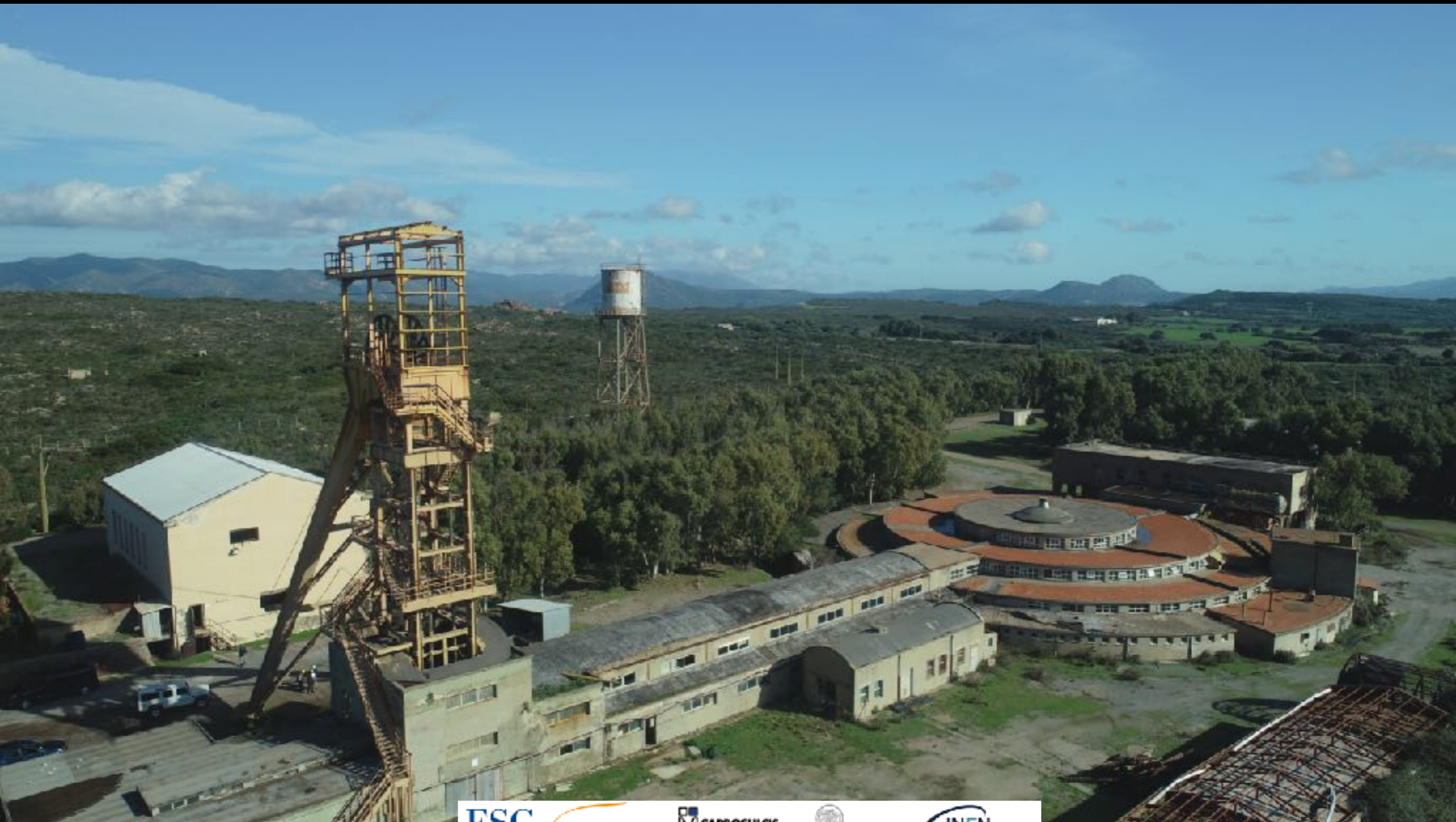
- We are considering liquid containers: final choice of specific container in progress
- The activity of ^{39}Ar induced during extraction, purification and transport on surface, in baseline conditions, is evaluated to be $<5\%$ of the UAr activity measured in DarkSide-50 (*Astropart.Phys.* 152 (2023) 102878), and thus considered acceptable.
- Other products in the UAr such as ^{37}Ar and ^3H are shown not to be relevant due to short half-life and assumed purification methods.

FURTHER PURIFICATION OF THE UAR

- The purity of the gas from URANIA: 99.99%
- For DarkSide-20k we need much greater purity (at least two orders of magnitude): ARIA
- The purification carried out with ARIA can proceed at 1t/day, confirmed by simulations with professional software, validated by measurements on the prototype column and with parameters measured by experimental runs
- ARIA was designed for the isotopic distillation of ^{39}Ar . Chemical purification is 'easier'.



Fabiocarboni, CC BY-SA 3.0 <<https://creativecommons.org/licenses/by-sa/3.0/>>, via Wikimedia Commons

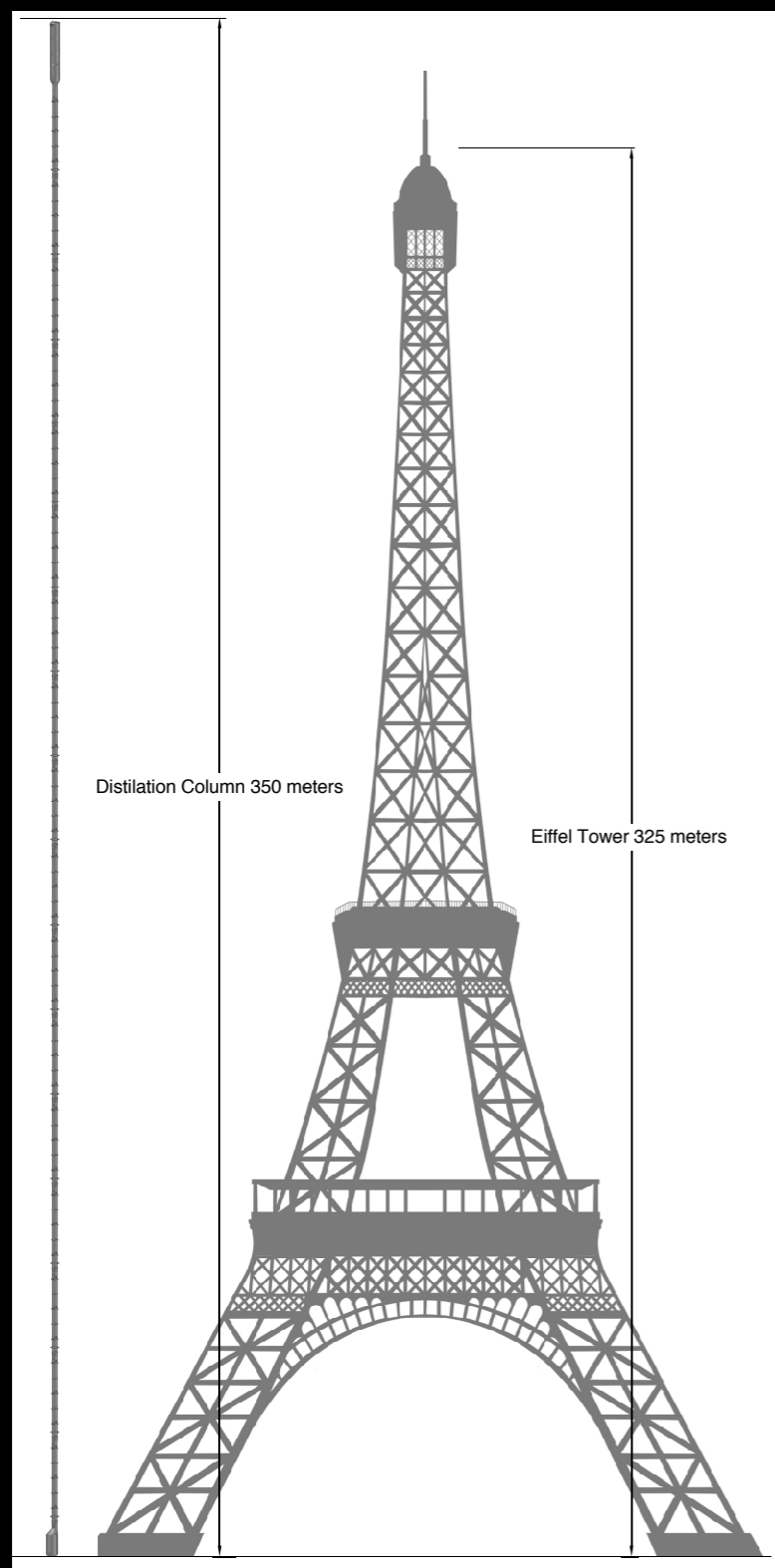


2000 A.C.

2000 B.C.

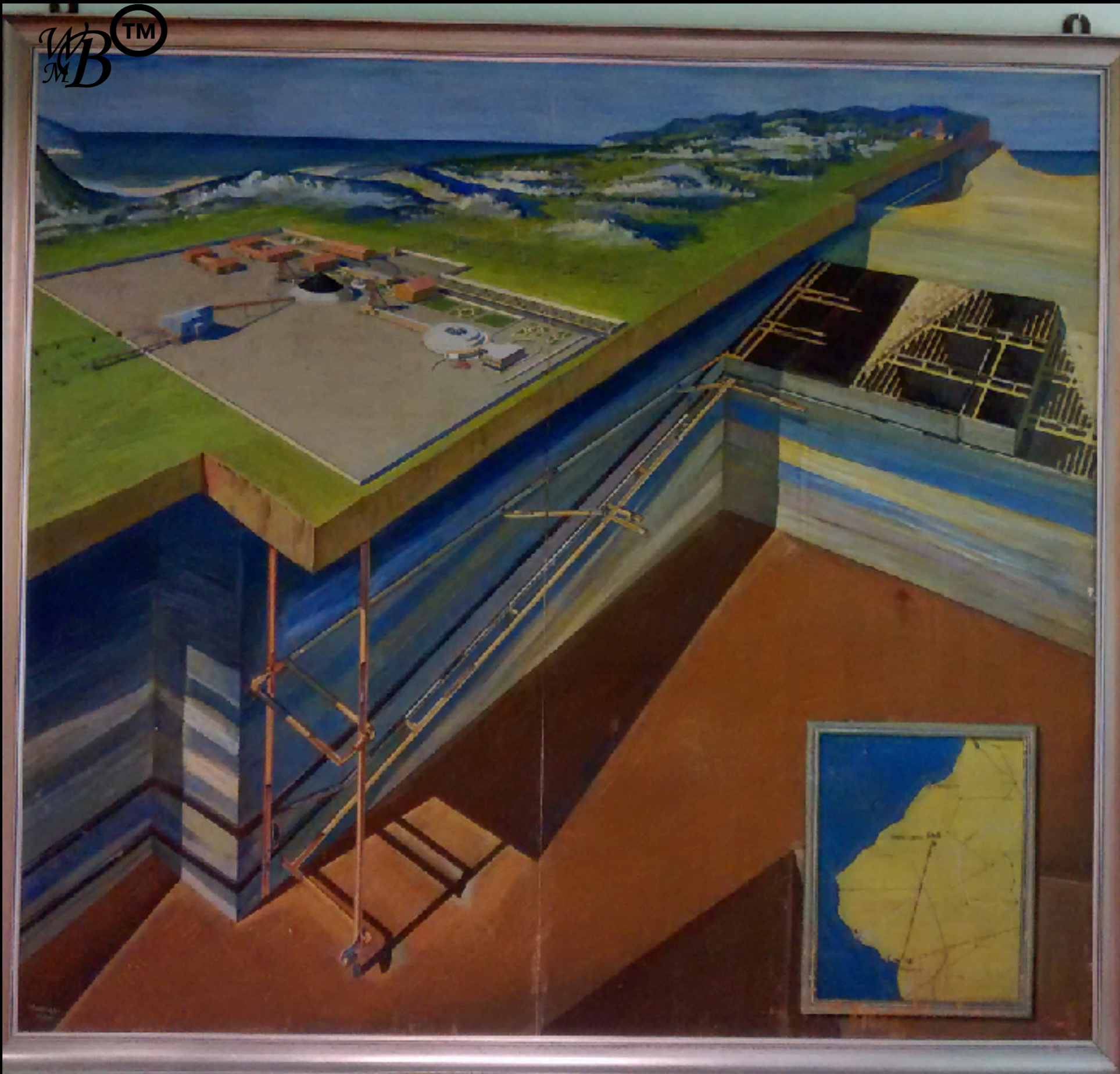


THE ARIA PROJECT

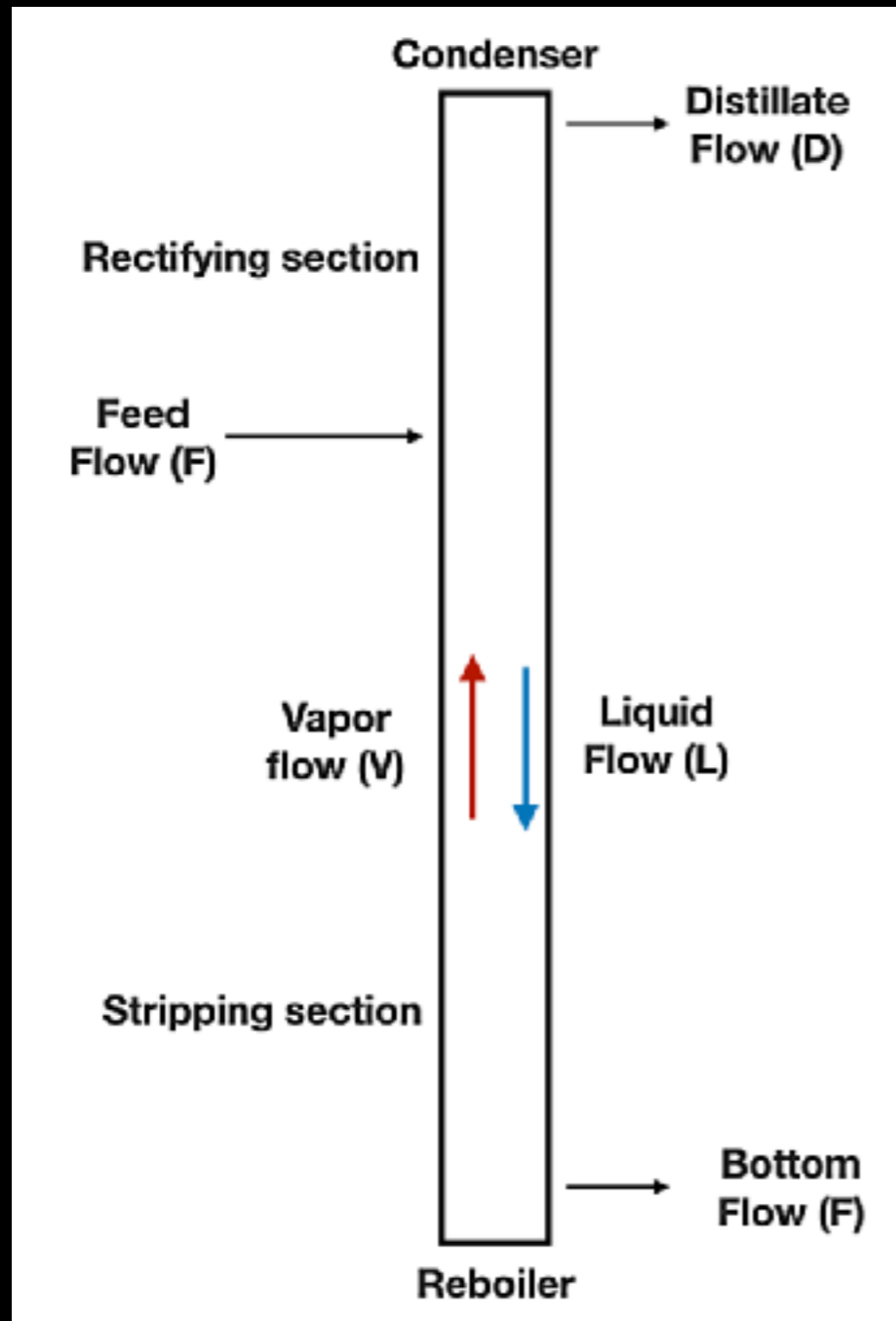


ISOTOPIC DISTILLATION:
DIFFERENCE IN VOLATILITY
VERY SMALL
—> MANY STAGES OF
DISTILLATION

VERY LOW BOILING
TEMPERATURES
—> CRYOGENIC PLANT



THE STRUCTURE OF THE COLUMN



VACUUM LEAK TESTS: CERN



MODULES READY IN SARDINIA



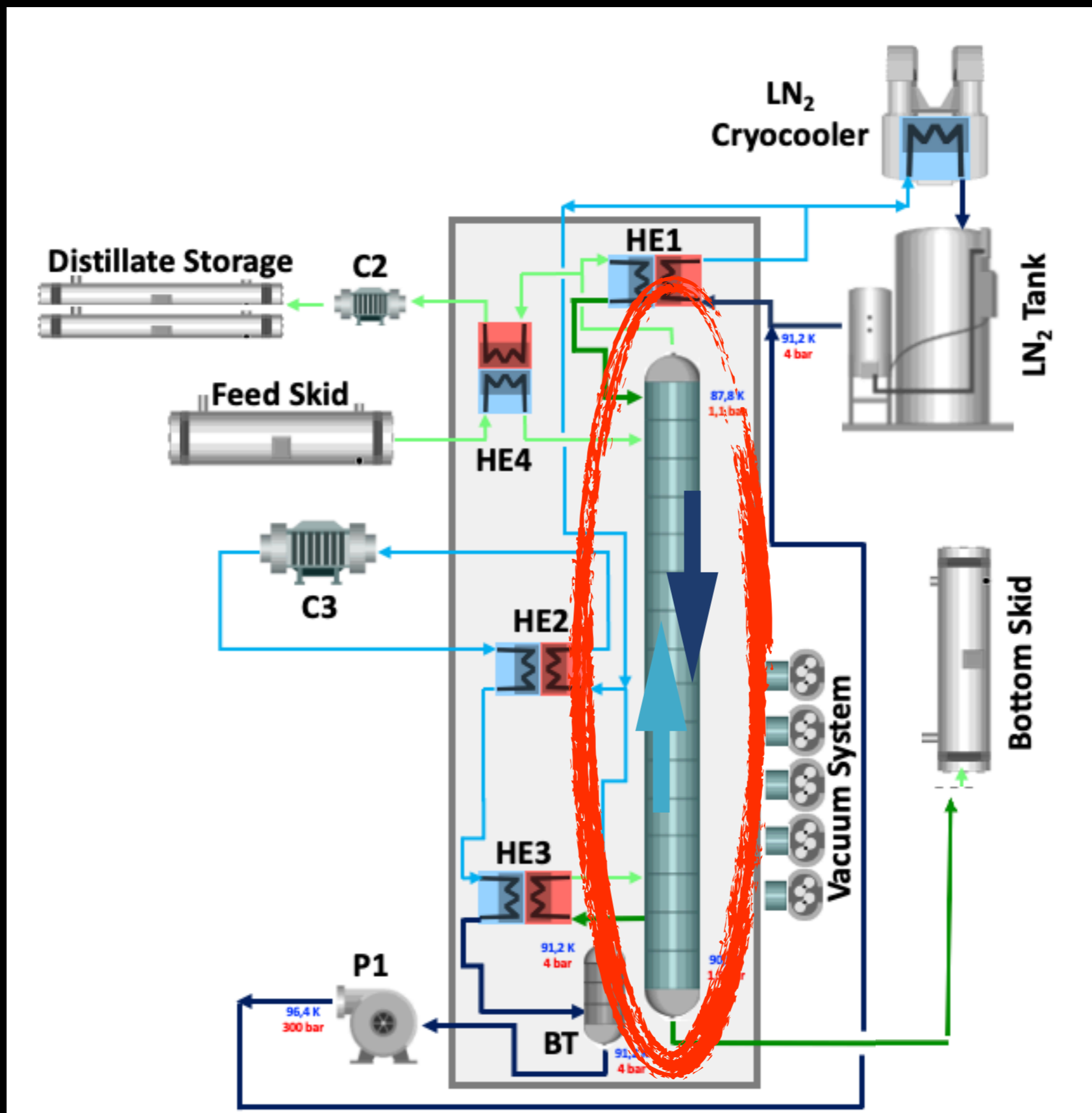
THE PACKING

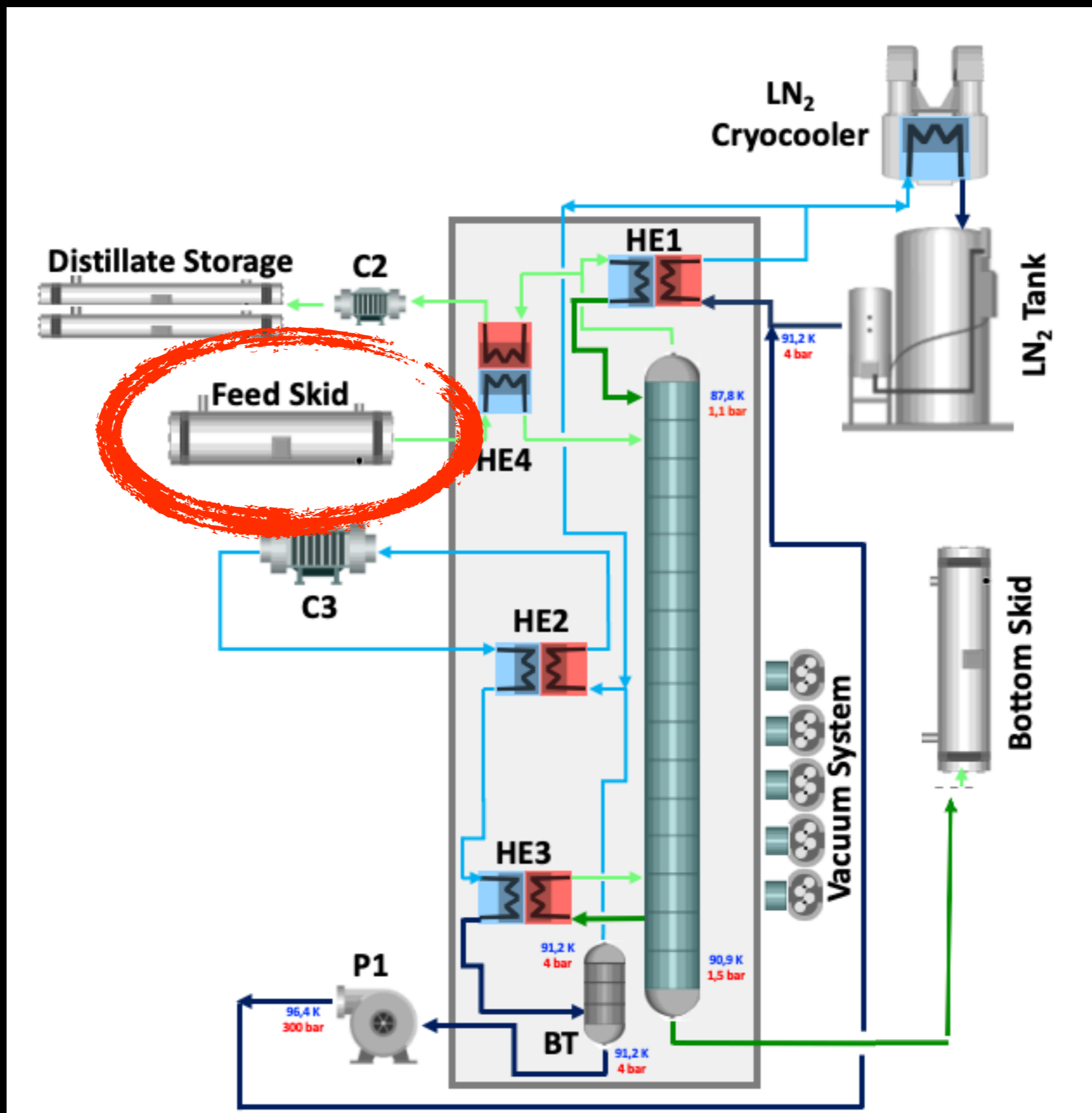
- 30cm diameter
- Packing height 287m
- Theoretical stages 2870
- Plant described in detail in Eur.Phys.J.C 81 (2021) 4, 359

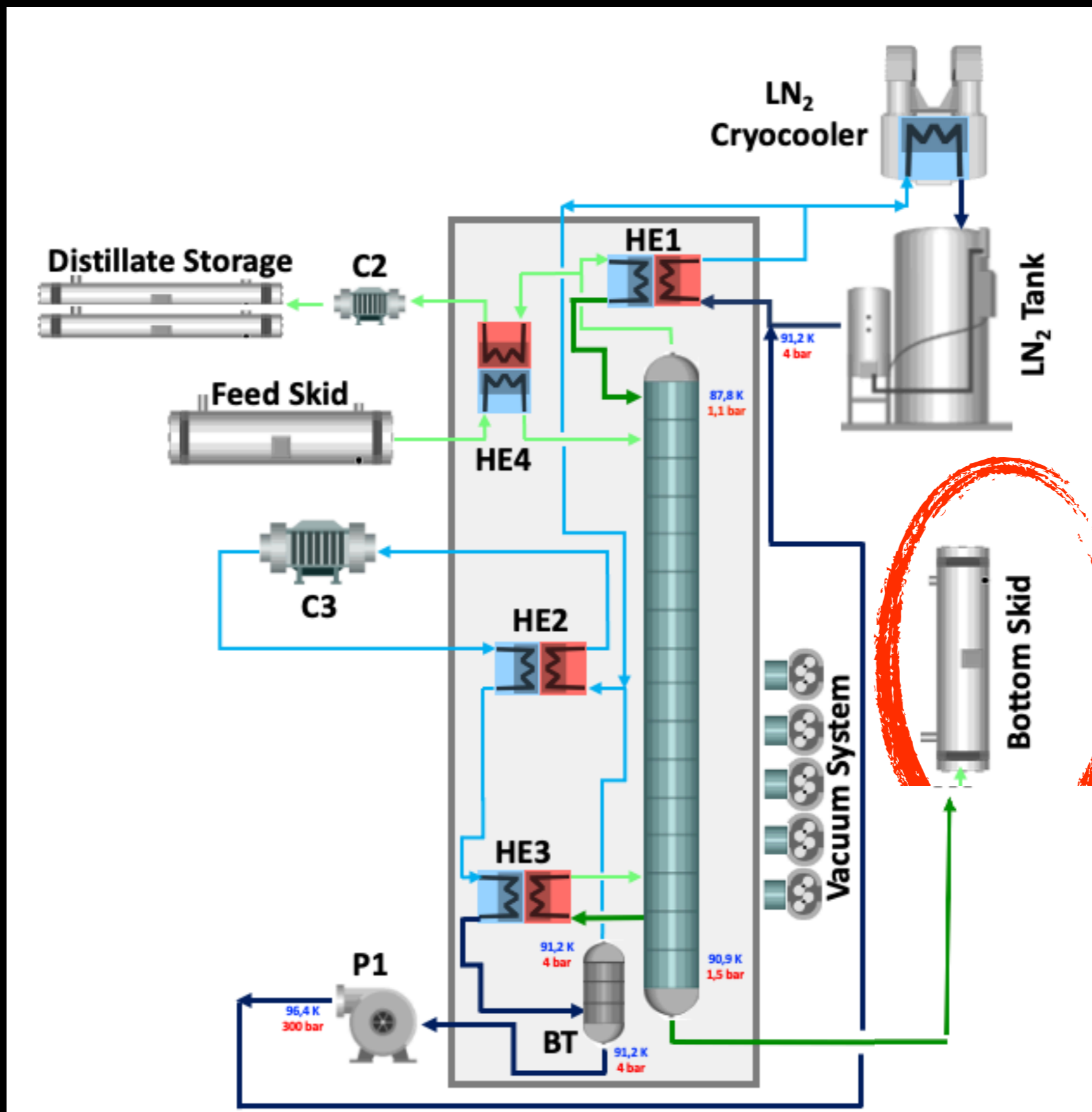


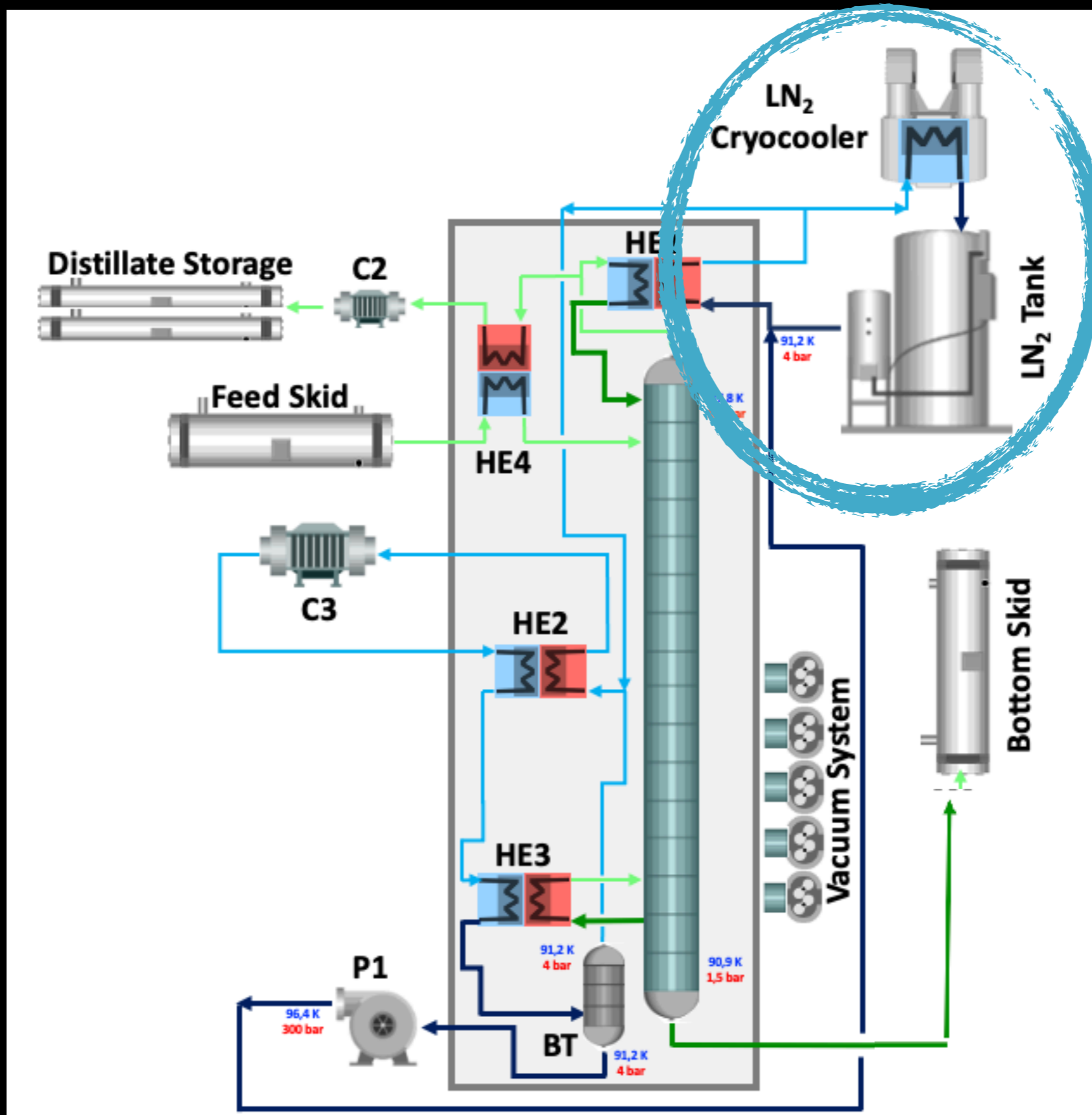
THE DISTRIBUTOR













Courtesy of Linea Verde, RAI



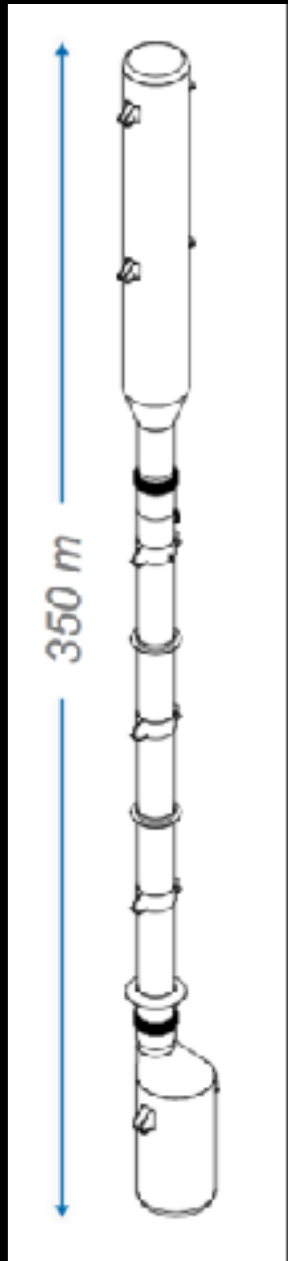
<https://www.carbosulcis.eu>

SUPPORT INSTALLATION.



Per gentile concessione, Carbosulcis S.p.A.

28 central modules







PROTOTYPE COLUMN



28m





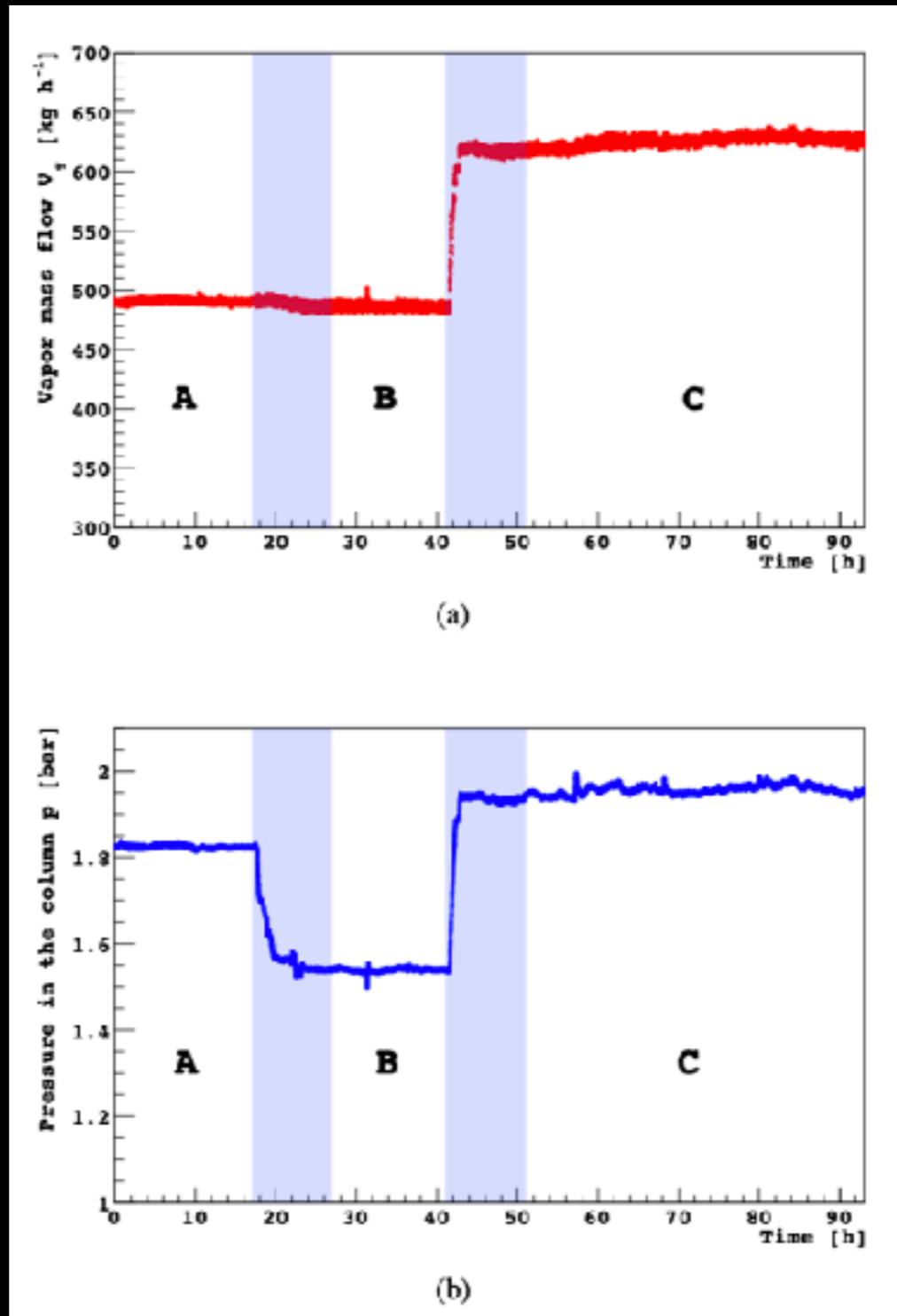


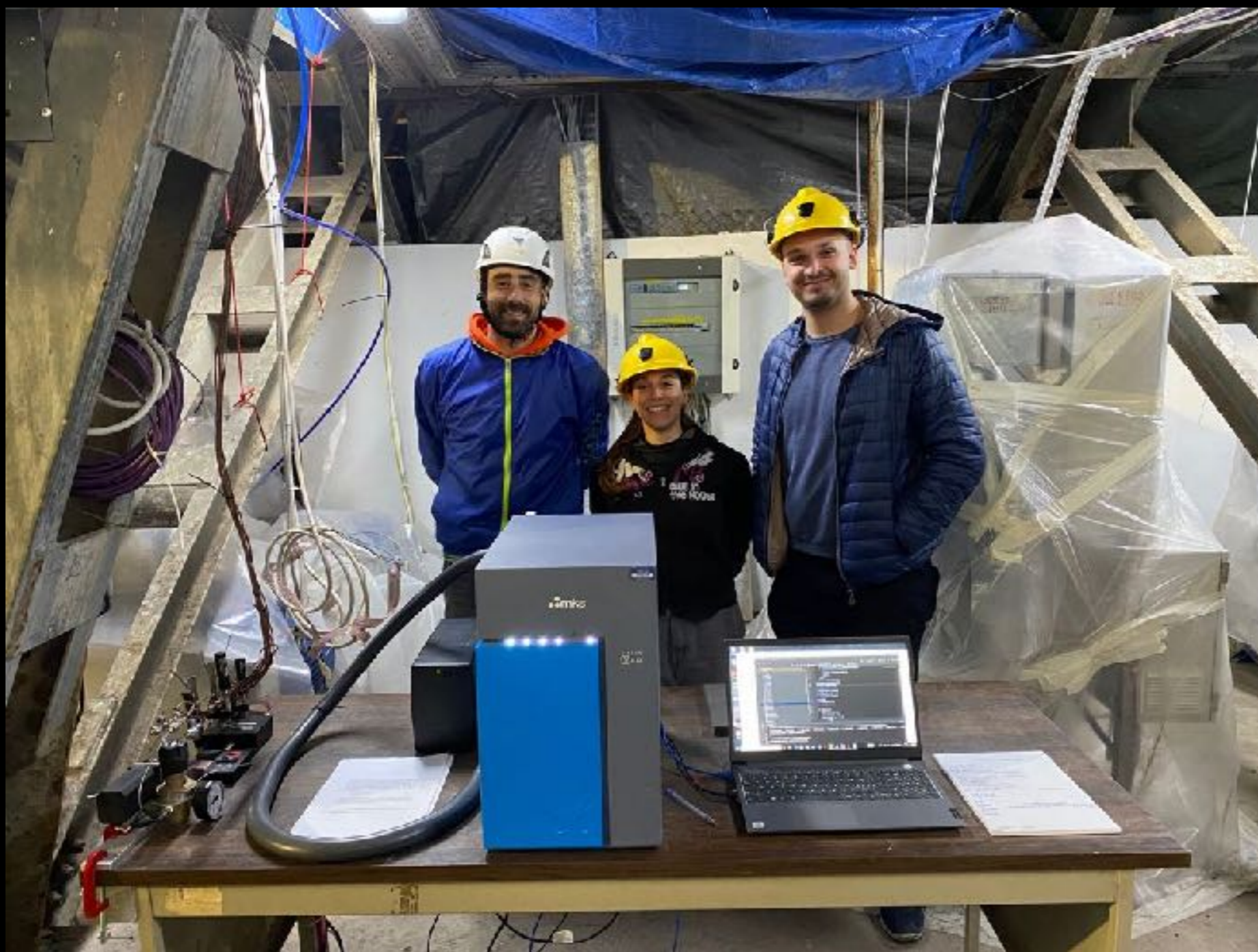
- 4 cryocooler Stirling



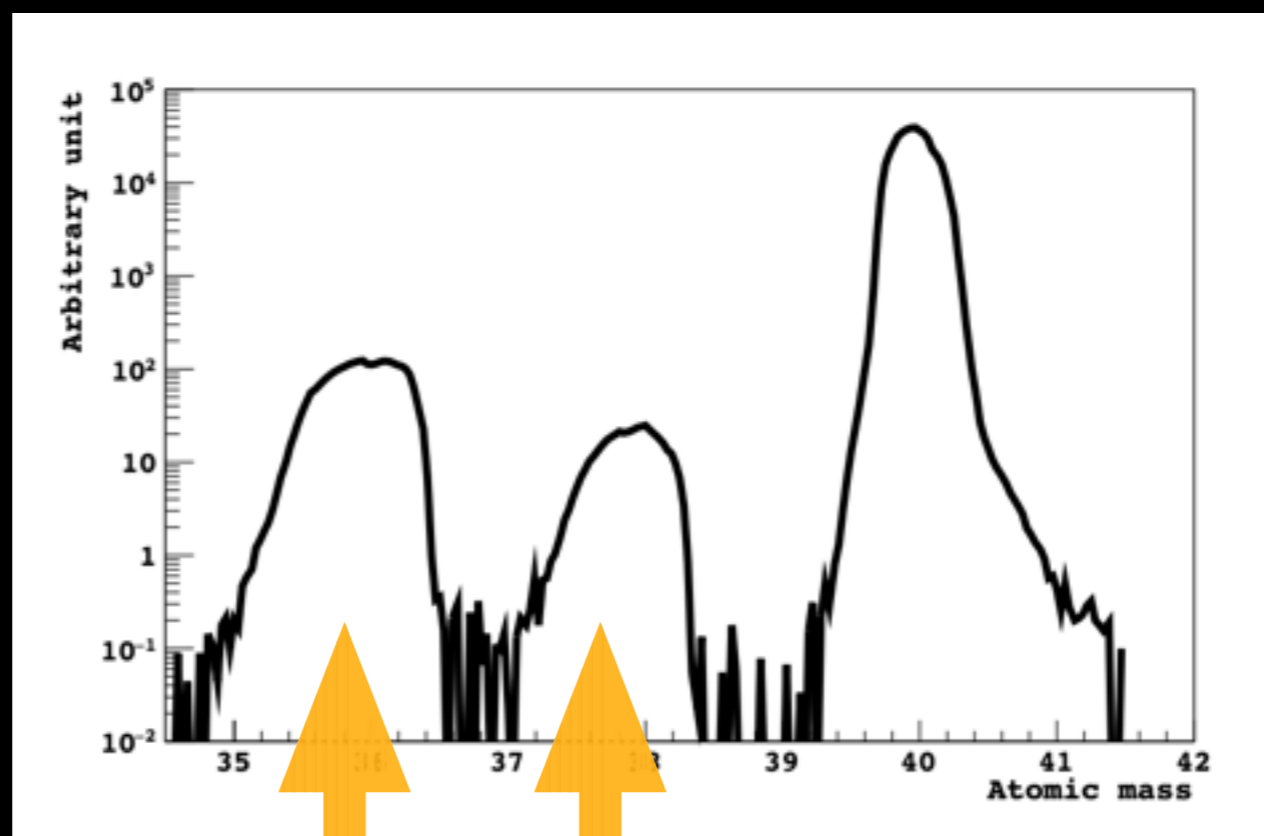
DISTILLATION TEST WITH ARGON

2021



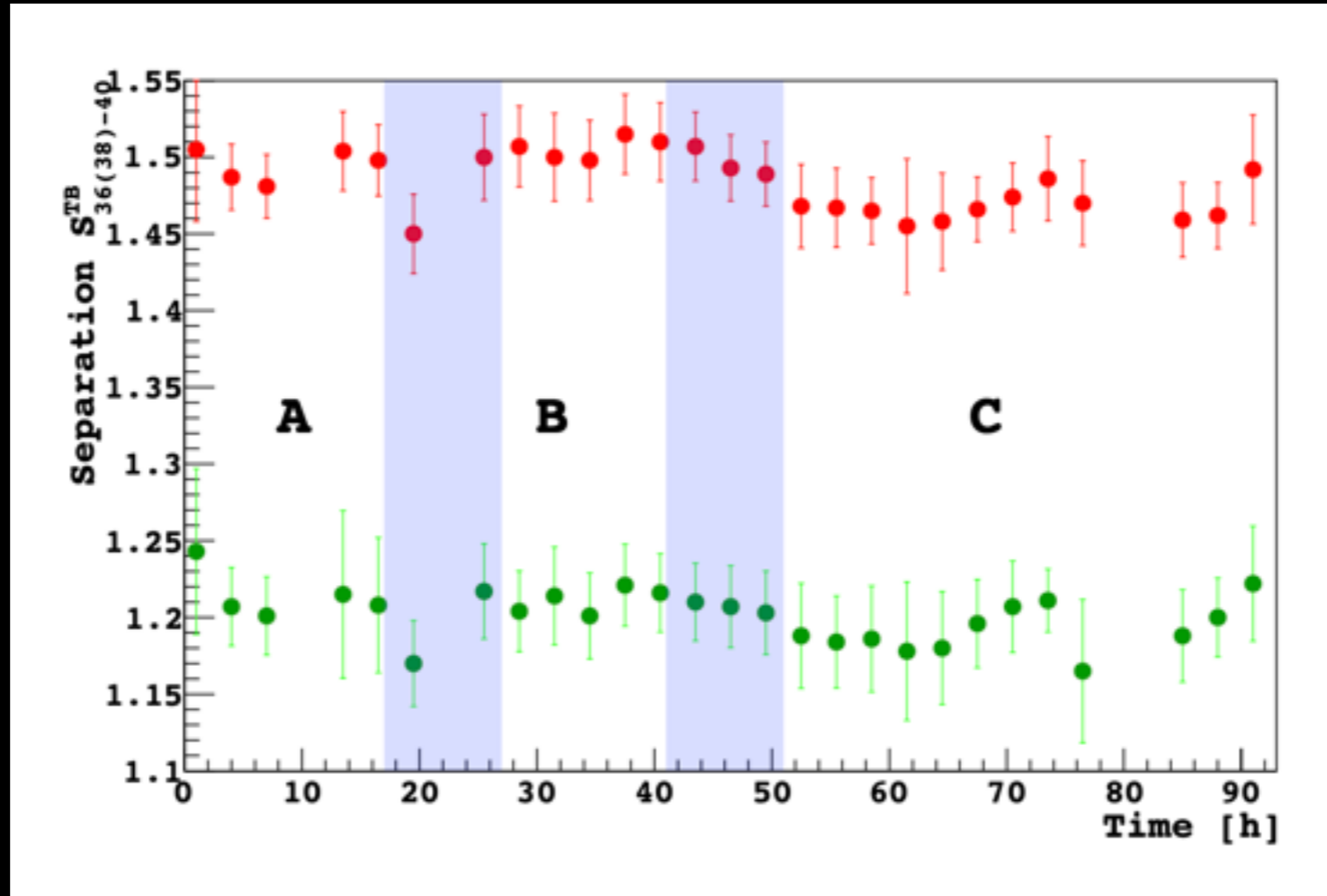


ARGON STABLE ISOTOPES



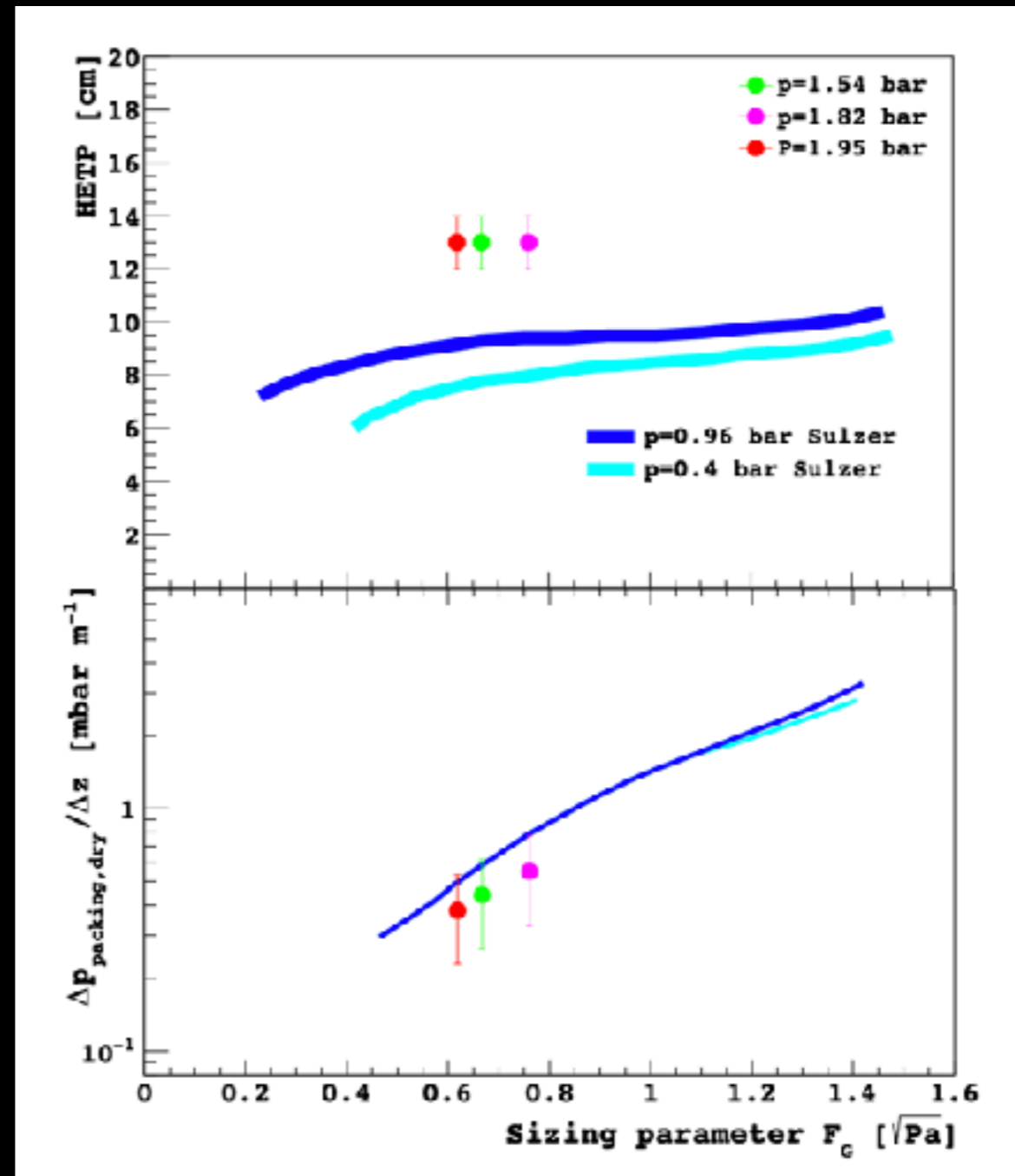
^{36}Ar ^{38}Ar
 0.33% 0.063%

SEPARATION



$$S_{36-40} = S_{T-B} = \frac{\left(\frac{x_{36}}{x_{40}}\right)_T}{\left(\frac{x_{36}}{x_{40}}\right)_B}$$

- DarkSide-20k's article
- *Eur.Phys.J.C* 83 (2023) 5, 453
- Technology works!



NITROGEN DISTILLATION

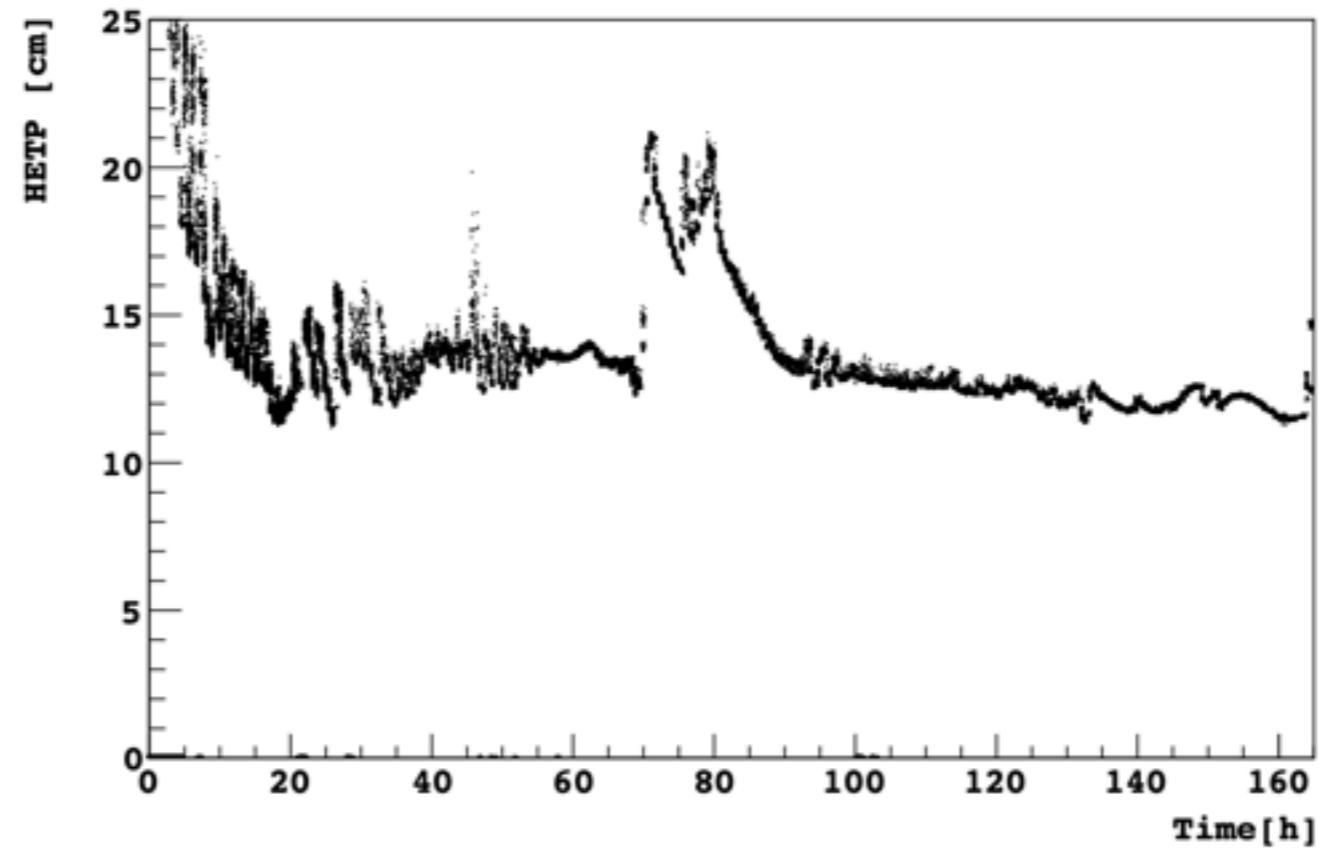


Fig. 16 HETP vs. time for $^{29}\text{N}_2$ - $^{28}\text{N}_2$ distillation in the prototype plant.

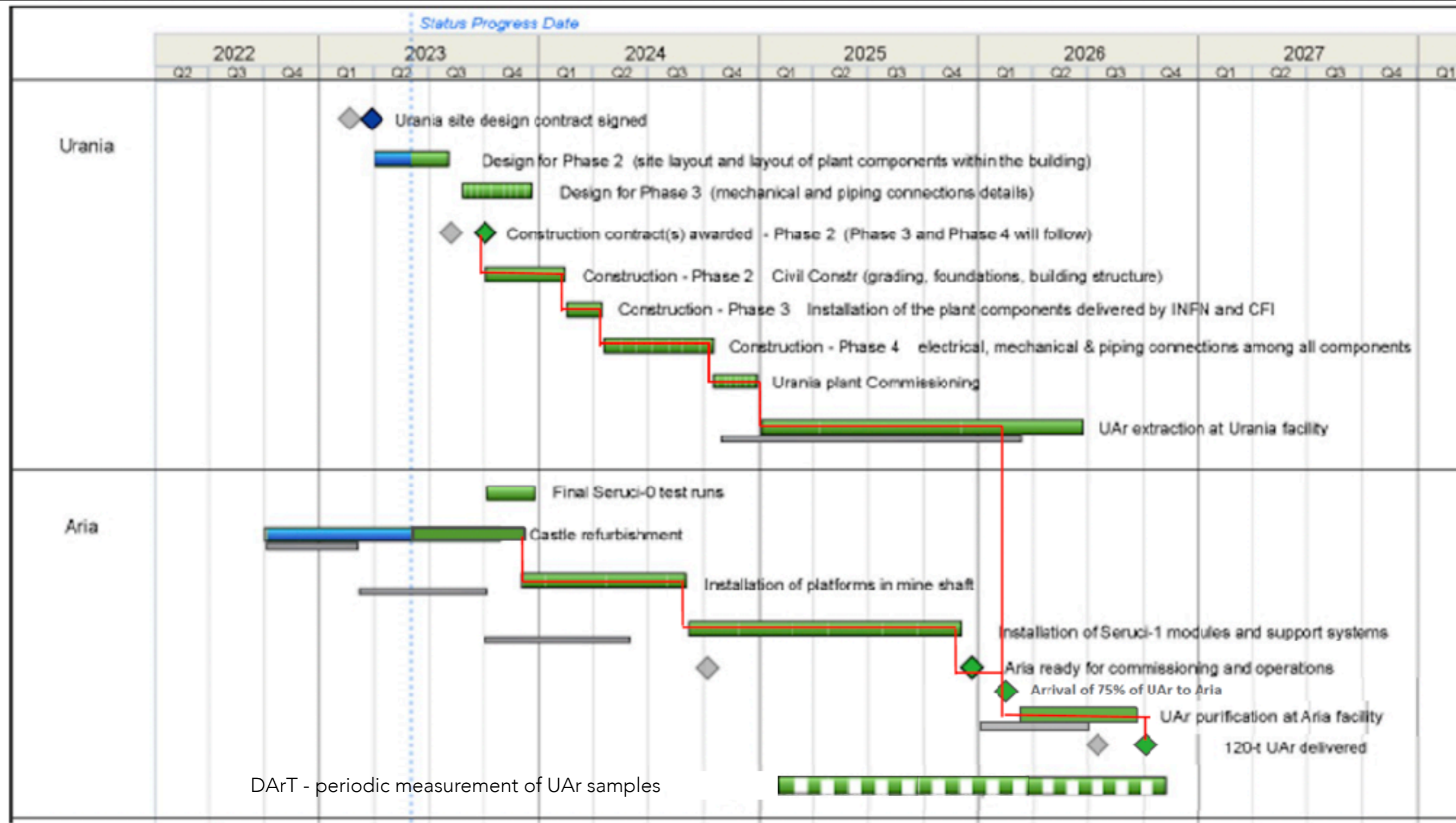
- Eur.Phys.J.C 81 (2021) 4, 359

RENOVATION OF THE MINING CASTLE IN PROGRESS





TIMELINE



OTHER EXPERIMENTS WHICH MAY BENEFIT FROM THE UAR

We recently signed with the **LEGEND** Collaboration an agreement for the provision of 25 t of UAr for the LEGEND1000 argon veto, after the DarkSide-20k production

—> suppression of ^{42}Ar

- A lot of interest in the UAR from other experiments
 - COHERENT 1 t (CEvNS)
 - **ARGO 400t (dark matter)**
 - DUNE MoO $\sim \text{O}(10,000)$ t (Dark matter, SN_ν , $2\beta 0\nu$); MoO Workshop 2022 (https://congresos.adeituv.es/dune_science/)

- THE END

RADIOACTIVITY MEASUREMENTS

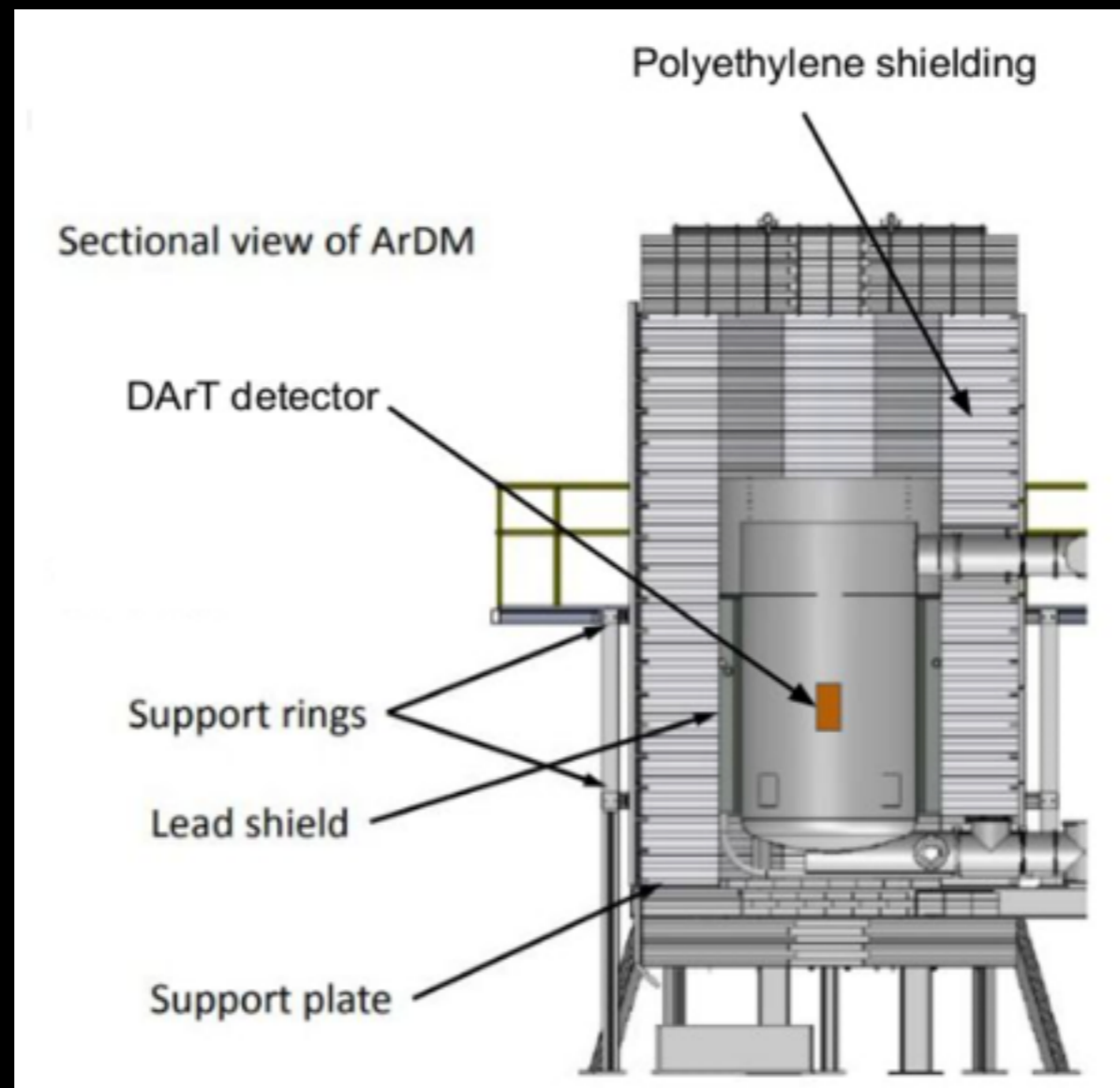
How do we know the radioactivity of the extracted UAr?

A. Indirect measurement: air infiltration, or $^{36}\text{Ar}/^{40}\text{Ar}$ measurement with UGA

B. Direct measurement: batch mode.

- There are 2 radiometric laboratories in the world that measure ^{39}Ar and ^{37}Ar using gas proportional counting: the University of Bern in Switzerland and Pacific Northwest National in the United States. These technologies are able to reach ^{39}Ar levels at approximately 2.5% of the atmospheric concentration, or about 25 mBq/kg
- An emerging technology is the use of atom trap trace analysis, which has been demonstrated in measuring ^{39}Ar for understanding ocean ventilation, able to reach 1.7% of the atmospheric concentration.

DART IN ARDM AT LSC

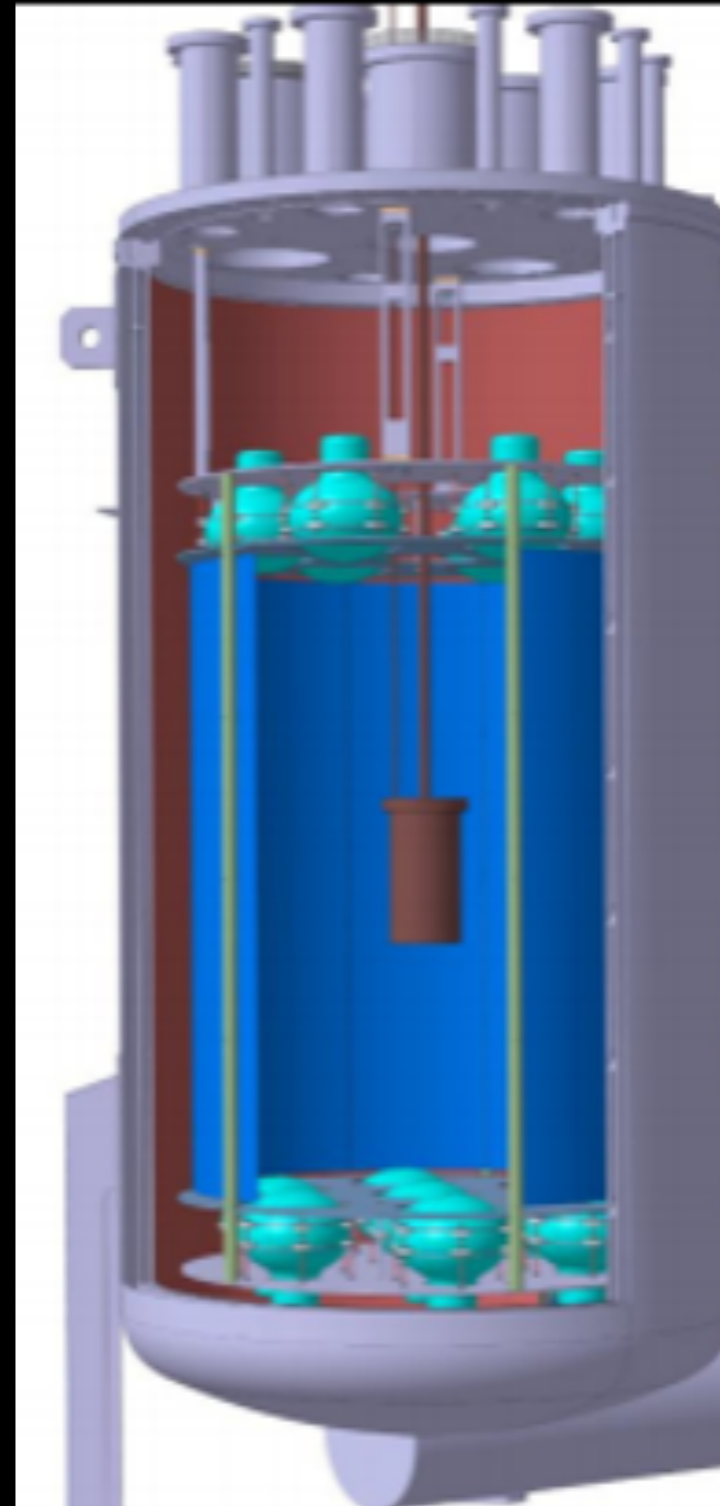


DARTINARDM

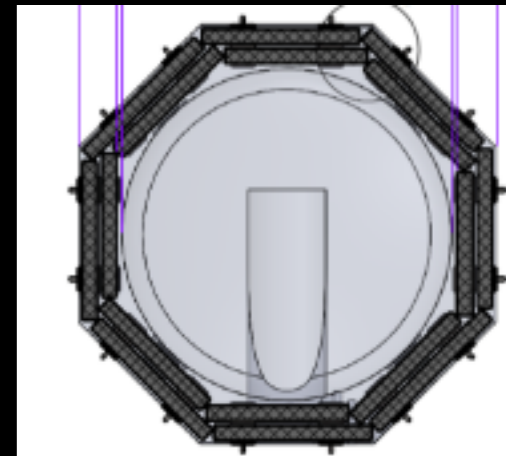
C.E. Aalseth et al 2020 JINST
15 P02024

Expected sensitivity to ^{39}Ar
90% UL for $\text{DF}=60,000$
(To be compared to 1,400 for
UAr as measured by
DarkSide-50)

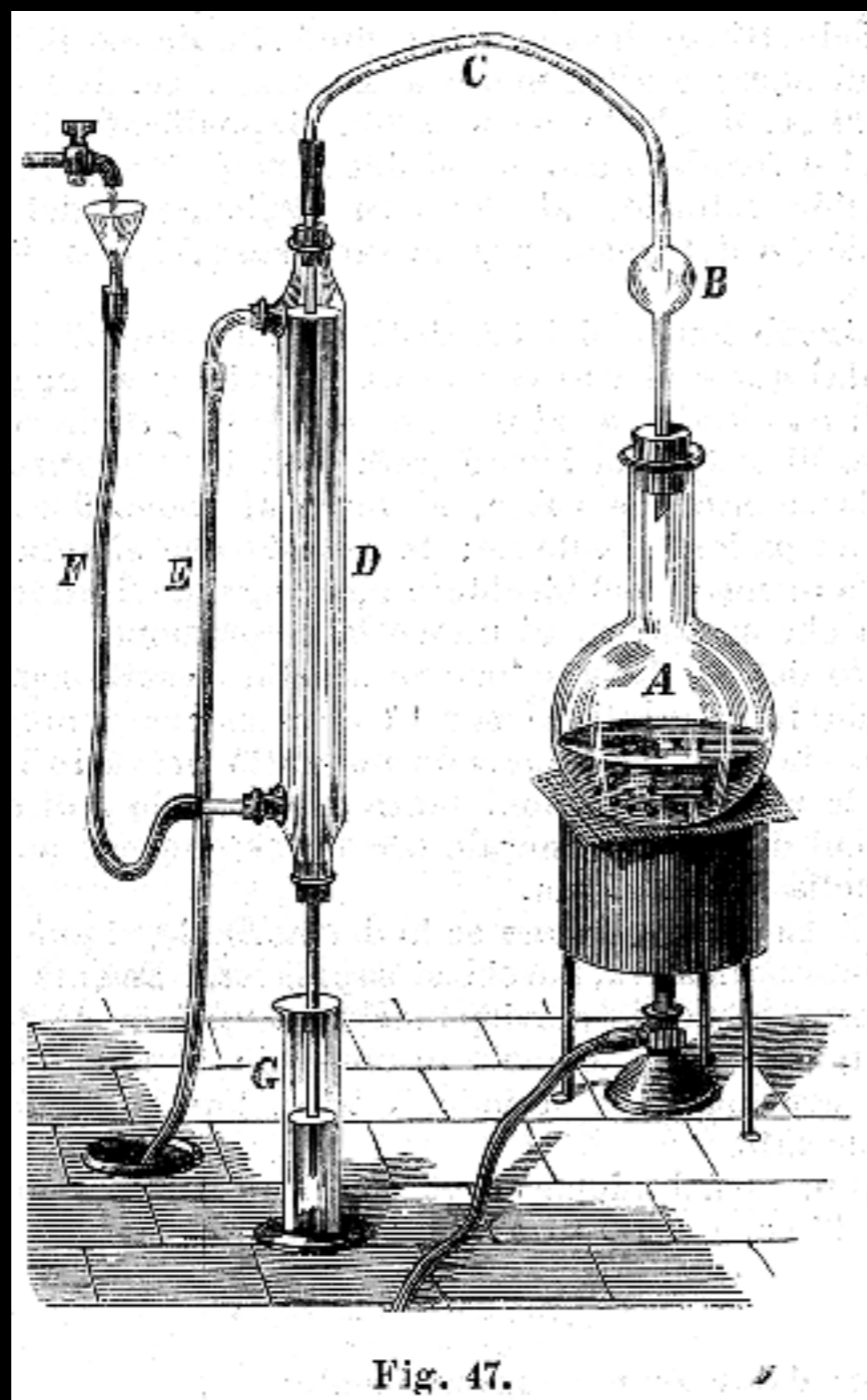
Under study a more sensitive
detector and limit setting to
 ^{42}Ar content



+



CONDENSATORE



RIBOLLITORE

UNO STADIO DI
DISTILLAZIONE

valeg96, Public domain, via Wikimedia Commons da
Alessandri, P. E. Analisi Volumetrica Applicata Ai Prodotti Commerciali e Industriali; Ulrico Hoepli: Milano, 1895.

SI SFRUTTANO LE DIVERSE VOLATILITA' DEI
COMPONENTI CHE SI VOLGIONO SEPARARE



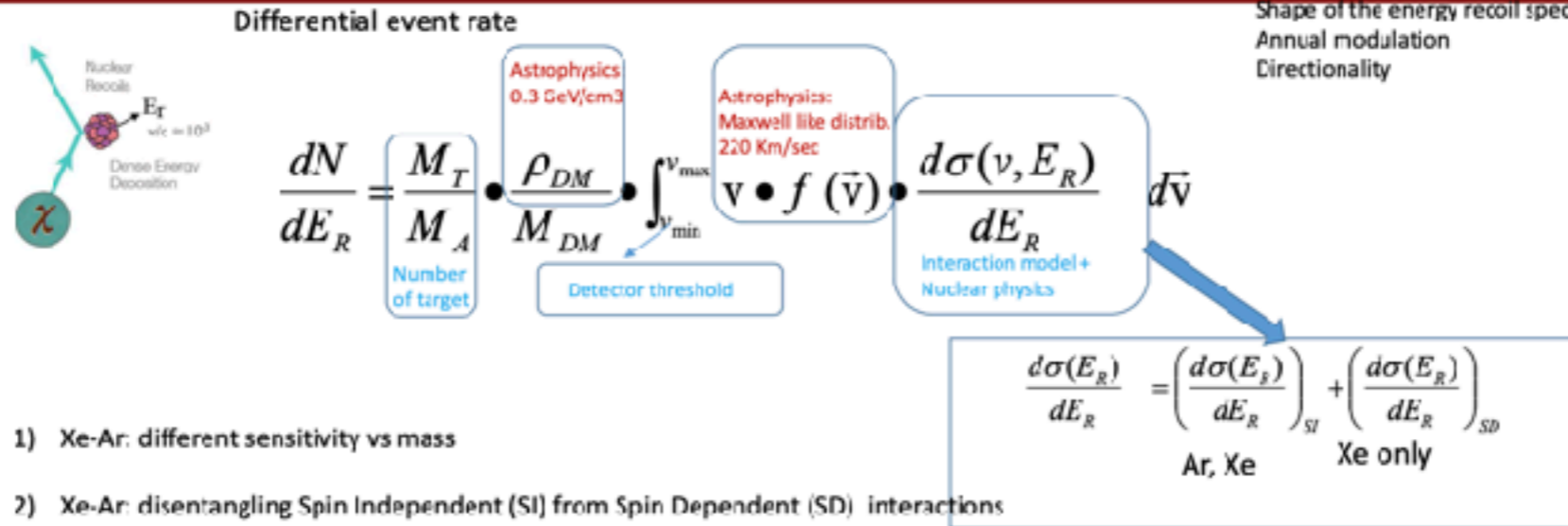
Andy Beecroft / Distillation Columns at Saltend / [CC BY-SA 2.0](https://creativecommons.org/licenses/by-sa/2.0/) Creative Commons Attribution Share-alike license 2.0











- 1) Xe-Ar: different sensitivity vs mass
- 2) Xe-Ar: disentangling Spin Independent (SI) from Spin Dependent (SD) interactions
- 3) Simultaneous detection in Xe-Ar may break the mass-coupling degeneracy
Effective field theory
Most general Lagrangian with 14 operators & several couplings

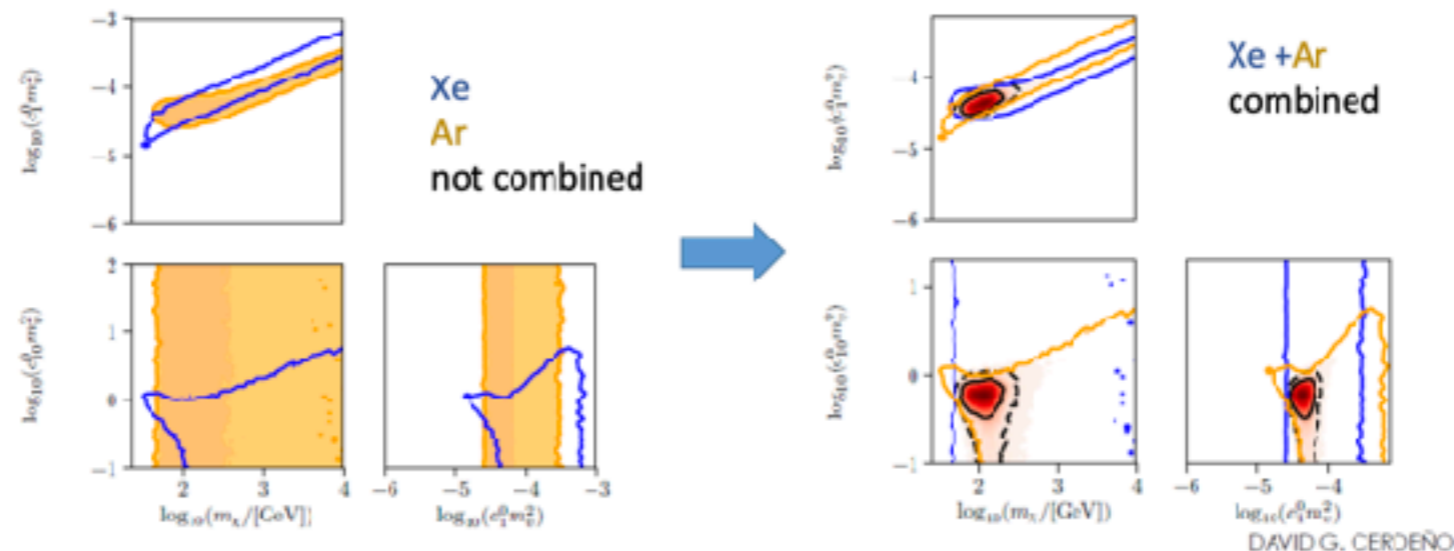
Haxton, Fitzpatrick 2012-2014

Gemma Testera, INFN-CVI meeting - Venice, October 13, 2021

A single target cannot determine mass and coupling

Example: scalar DM & scalar coupling
100 GeV

<https://conferences.ippp.dur.ac.uk/event/661/contributions/4090/attachments/3417/3738/2018-04-Durham.pdf>



The experimental response is sensible to the target
Combining results helps in removing the degeneracy

