WIMP Technology and Infrastructure Introduction

Direct Dark Matter Detection Report Community Feedback Meeting

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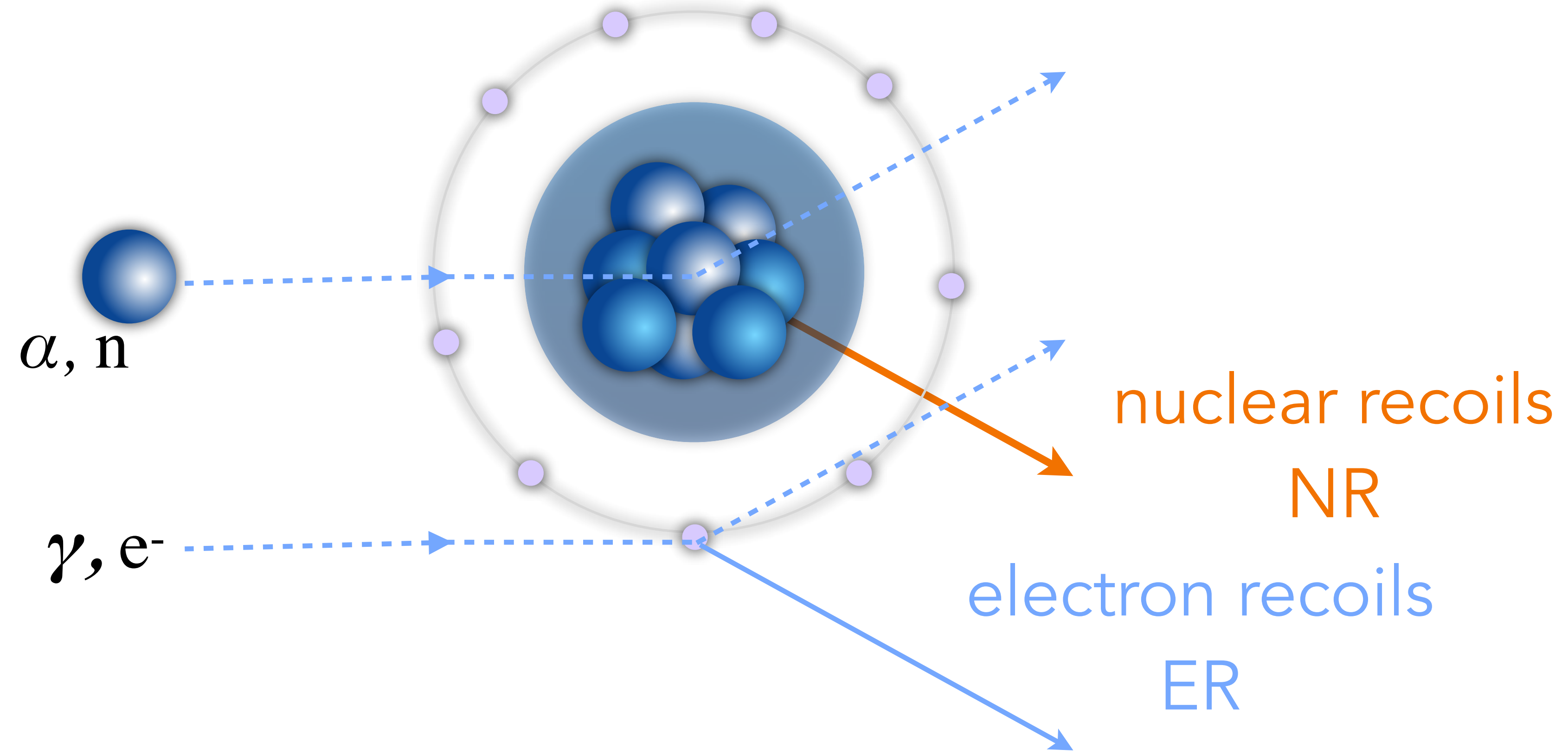
February 2, 2021

Backgrounds

DM direct detection experiments main challenge



Background minimization

➡ a few signal events observed during the experiment's exposure yield a high statistical significance

➡ background-free exposure to enhance discovery potential and avoid misinterpretation of positive signals

- **ER background sources:**
  - long-lived natural radioisotopes (^{238}U, ^{232}Th chains and their daughters, e.g., ^{214}Pb; ^{40}K)
  - cosmogenic activation (e.g., ^{3}H, ^{39}Ar)
  - anthropogenic isotopes (e.g., ^{60}Co, ^{85}Kr, ^{110m}Ag, ^{137}Cs).
  - elastic collisions of low-energy solar neutrinos with atomic electrons
- **α background sources:**
  - radioactivity from detector surfaces with a fraction of the α-energy is lost in insensitive detector regions
- **NR background sources:**
  - radiogenic neutrons from (α;n) and spontaneous fission reactions
  - cosmogenic neutrons induced by cosmic ray muons
  - coherent scattering of neutrinos off target nuclei (*neutrino floor*, no hard limit)

Achieved ^{222}Rn concentrations		
Experiment	**Activity/rate**	**Target**
DEAP-3600	0.15 μBq/kg	LAr
PandaX-II	8 μBq/kg	LXe
LUX	66 μBq/kg	LXe
XENON1T	4.5 μBq/kg	LXe

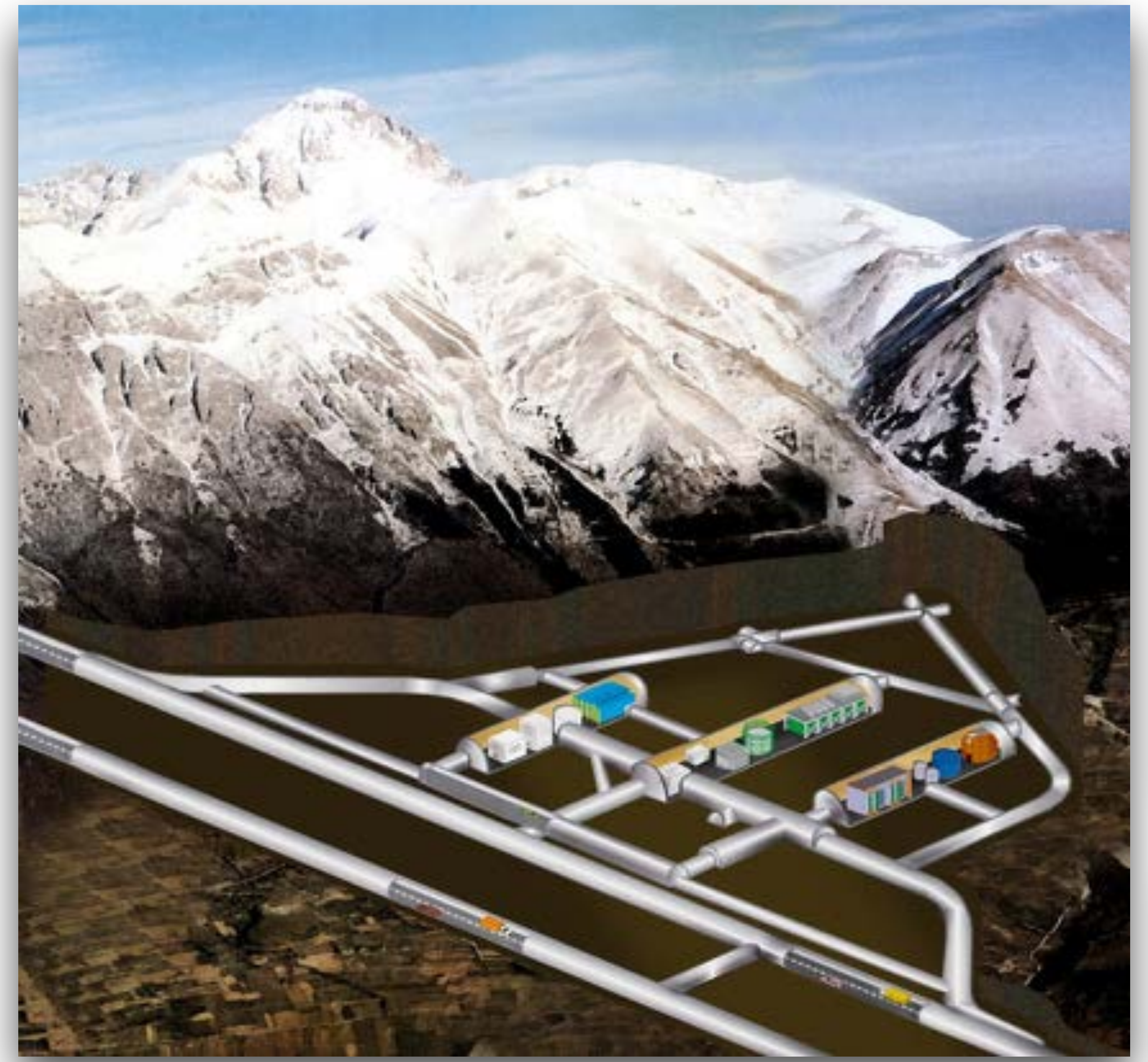
Future DM detectors can also conduct neutrino physics

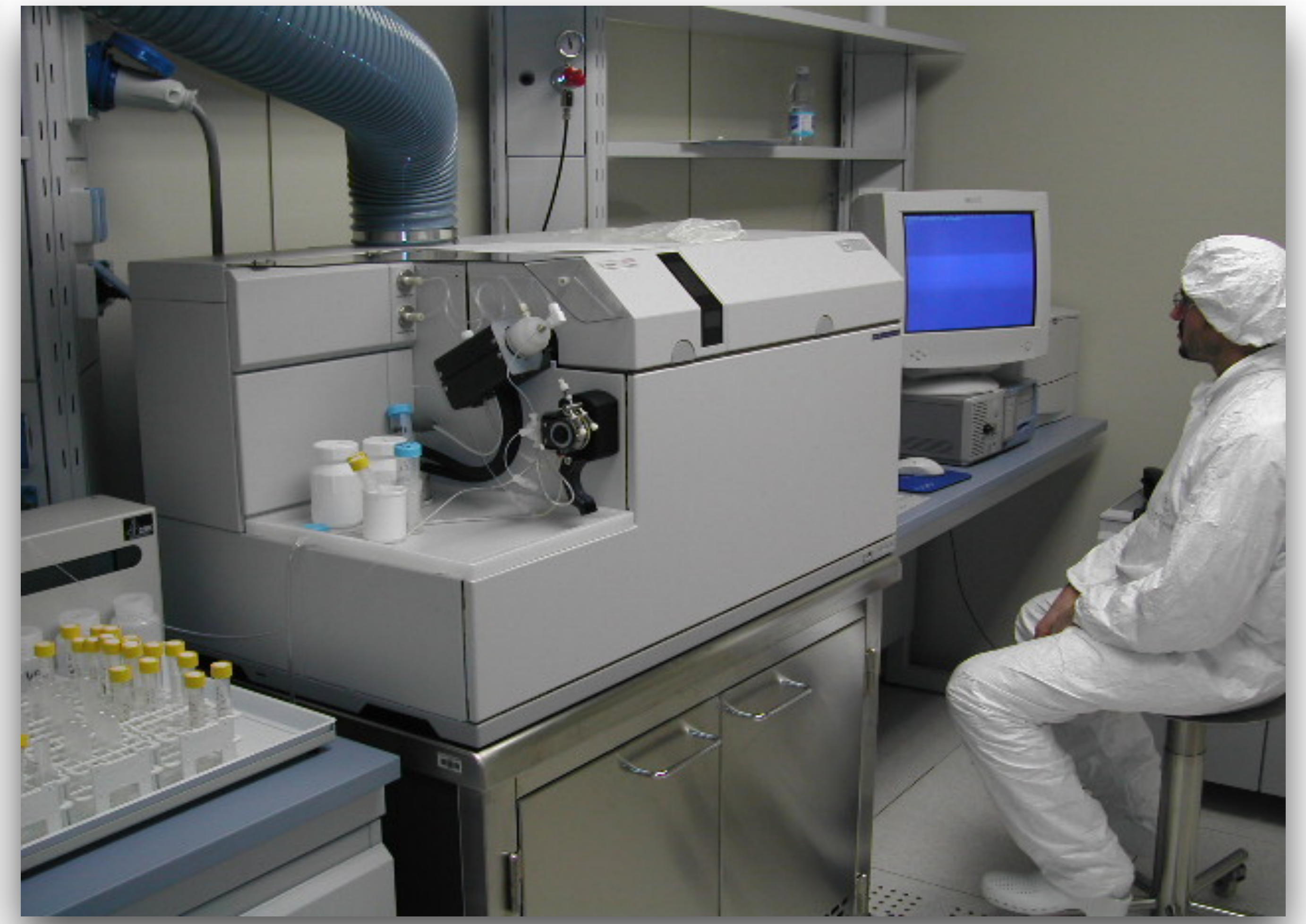
→ today's background will be tomorrow's signal

Background mitigation strategies

Reduction

- **Deep Underground Laboratories**
  - cosmogenic neutrons reduction
- **Radiopurity** of detector and target materials
  - material screening
- **Cleanliness**
  - (^{222}Rn-abated) cleanrooms
- **Purification** of target material
  - during production process (e.g., crystal growth)
  - at procurement level (e.g., low-^{39}Ar UAr; cryogenic distillation, chromatography)
  - during data taking



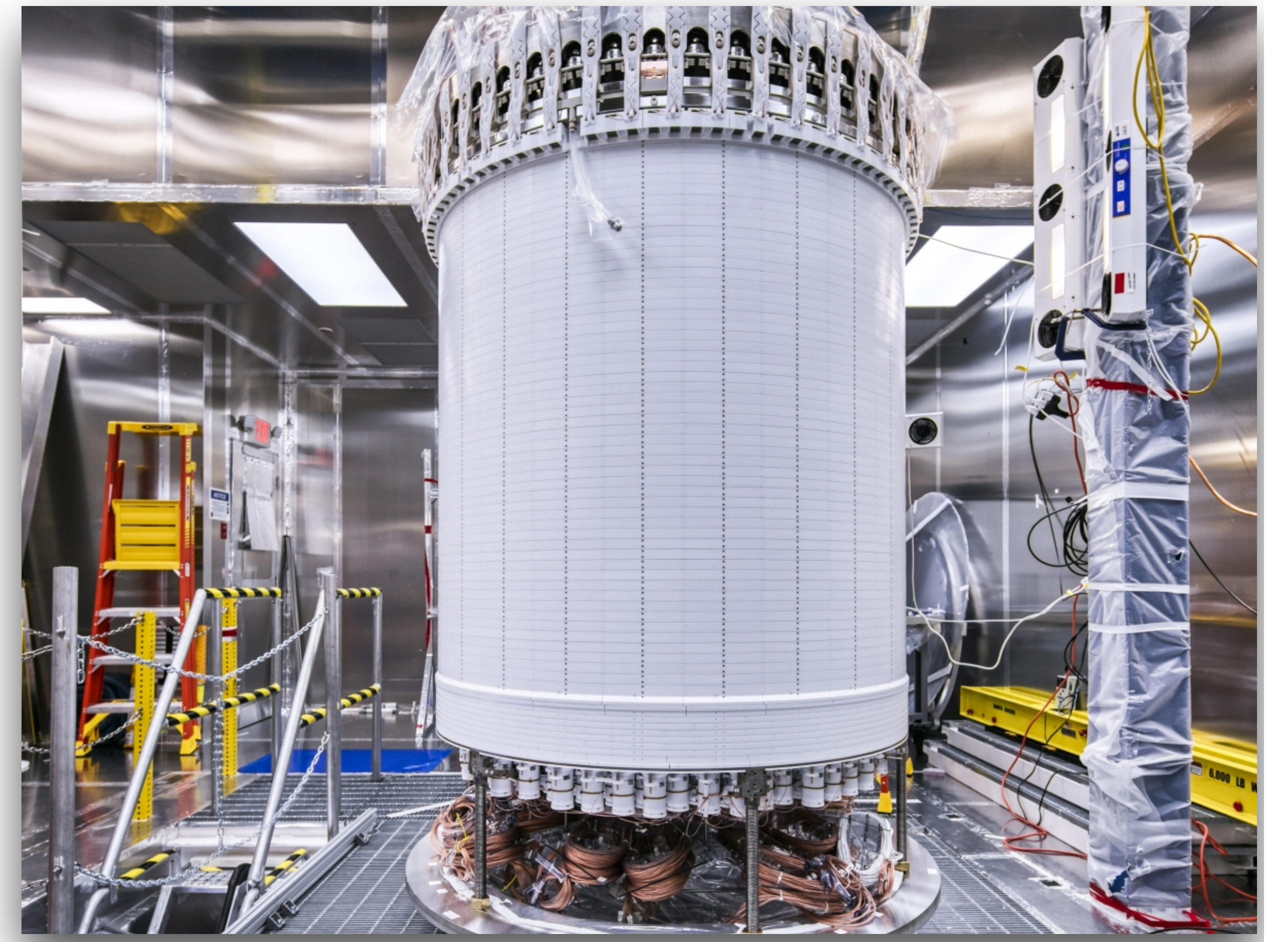


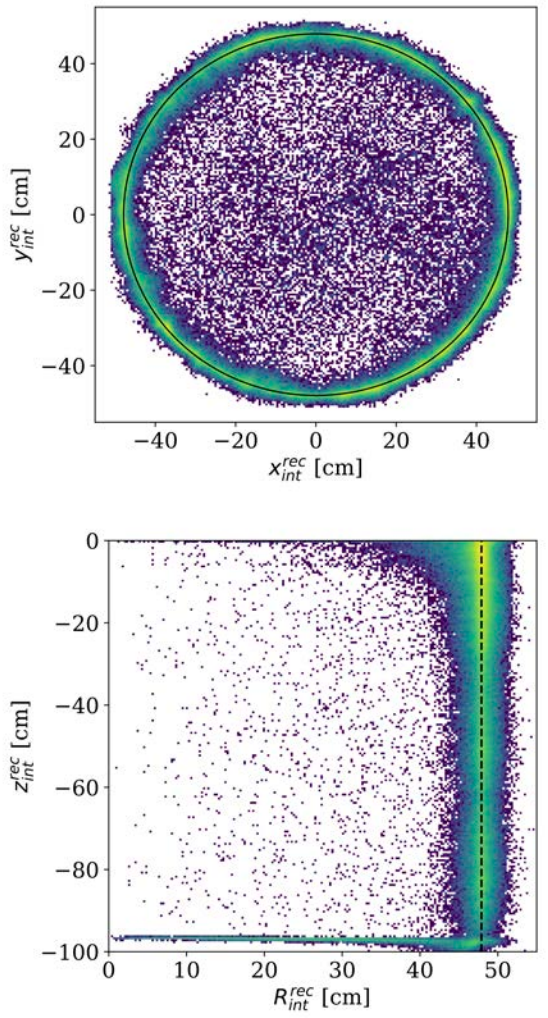
Background mitigation strategies

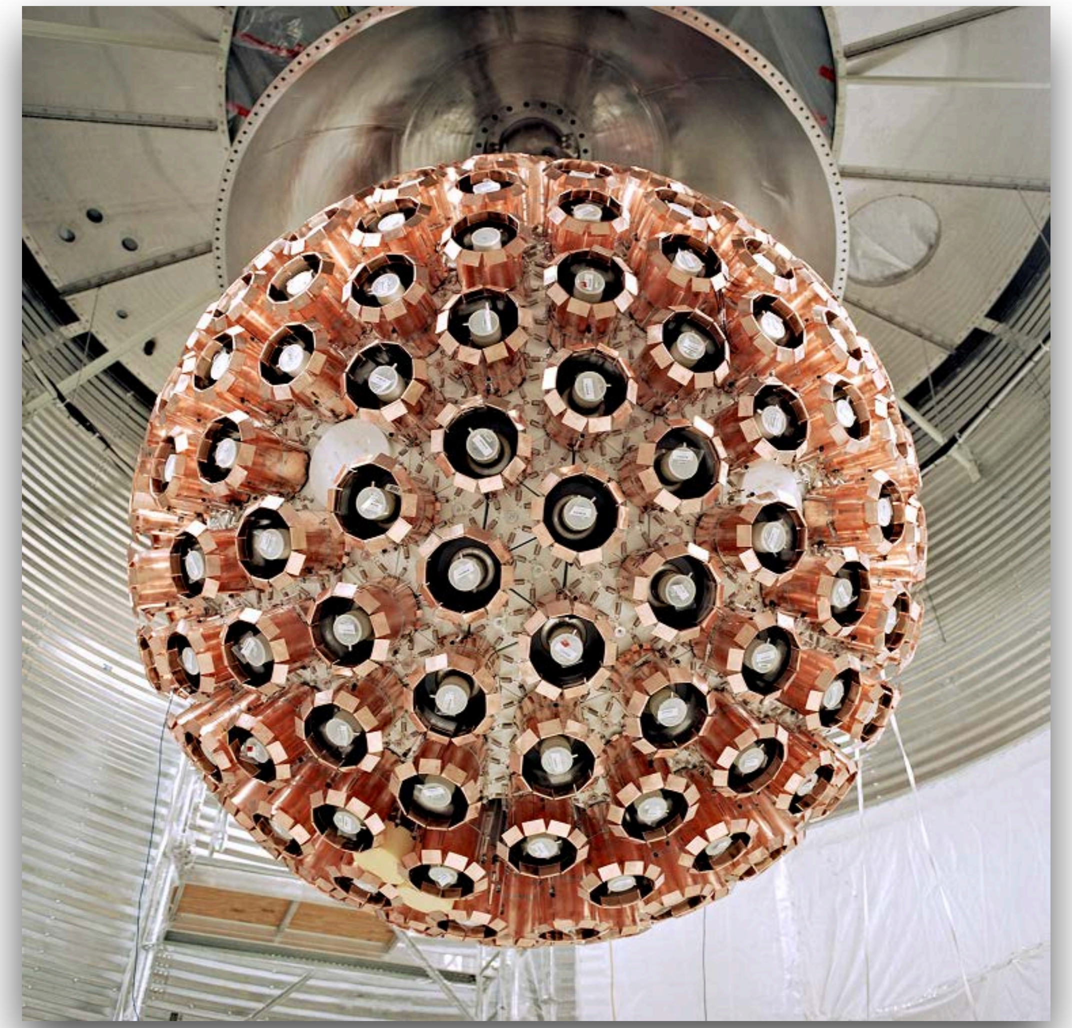
Rejection

- **Detector Design**
  - choice of appropriate materials
  - material budget optimization
  - shielding
- **Fiducialisation**
  - requires position reconstruction or surface signal discrimination techniques
- **Active rejection**
  - scintillation PSD
  - heat, scintillation, ionisation ratio
  - acoustic rejection (bubble chambers)
  - single scatter & veto

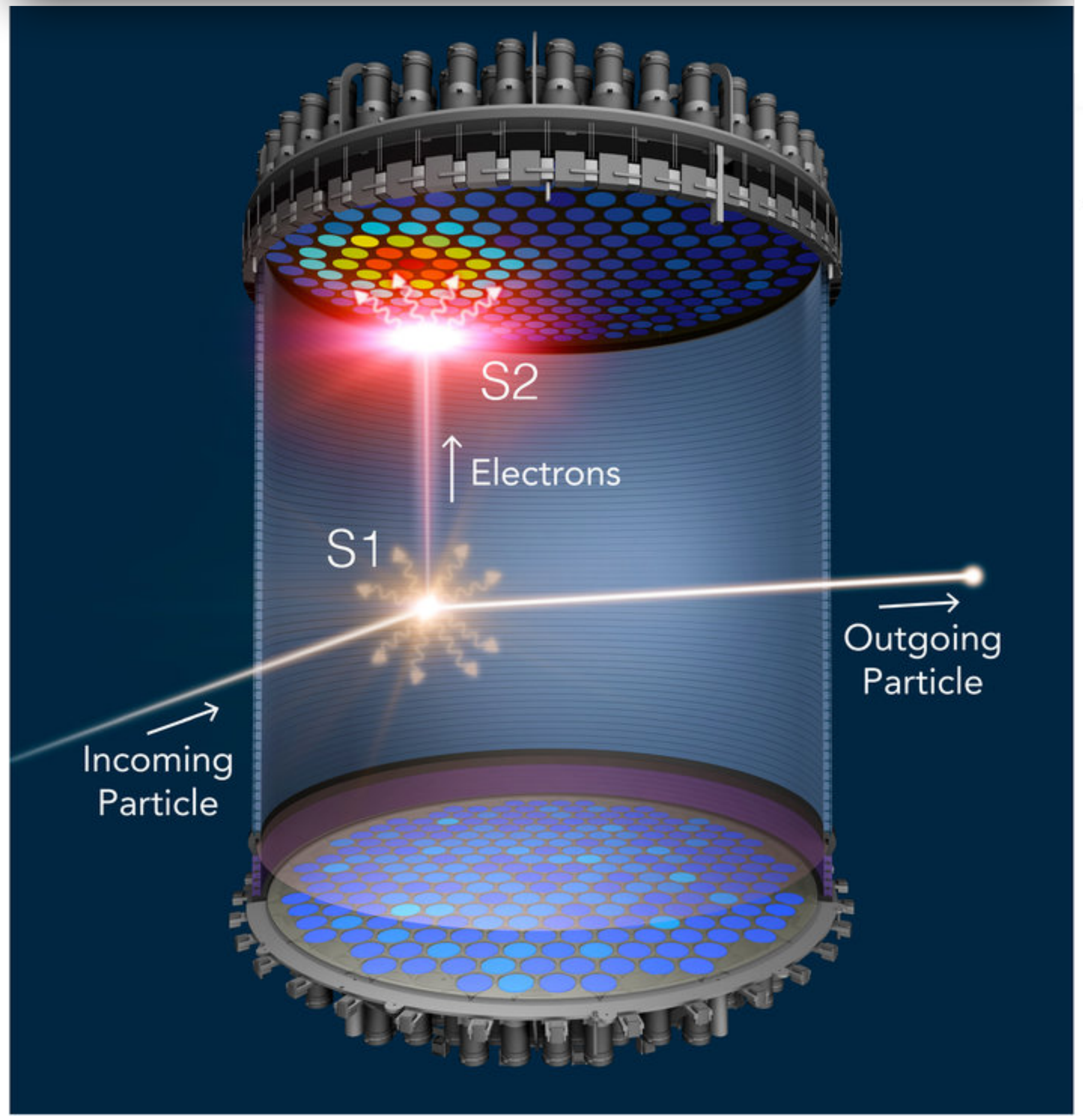
LZ TPC

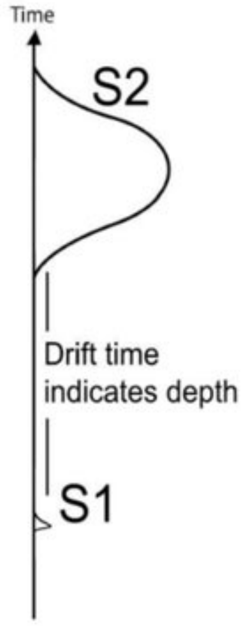


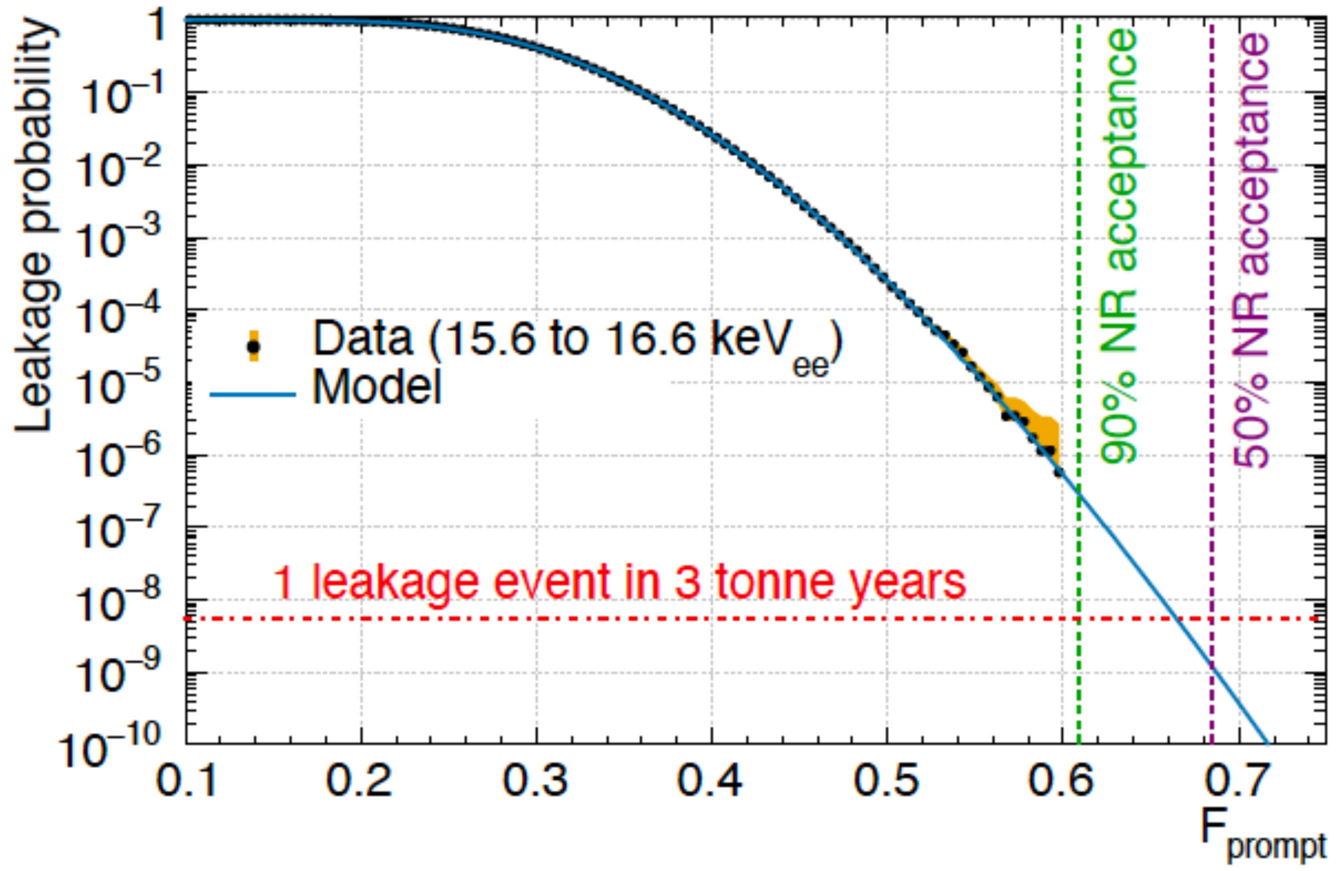




DEAP-3600



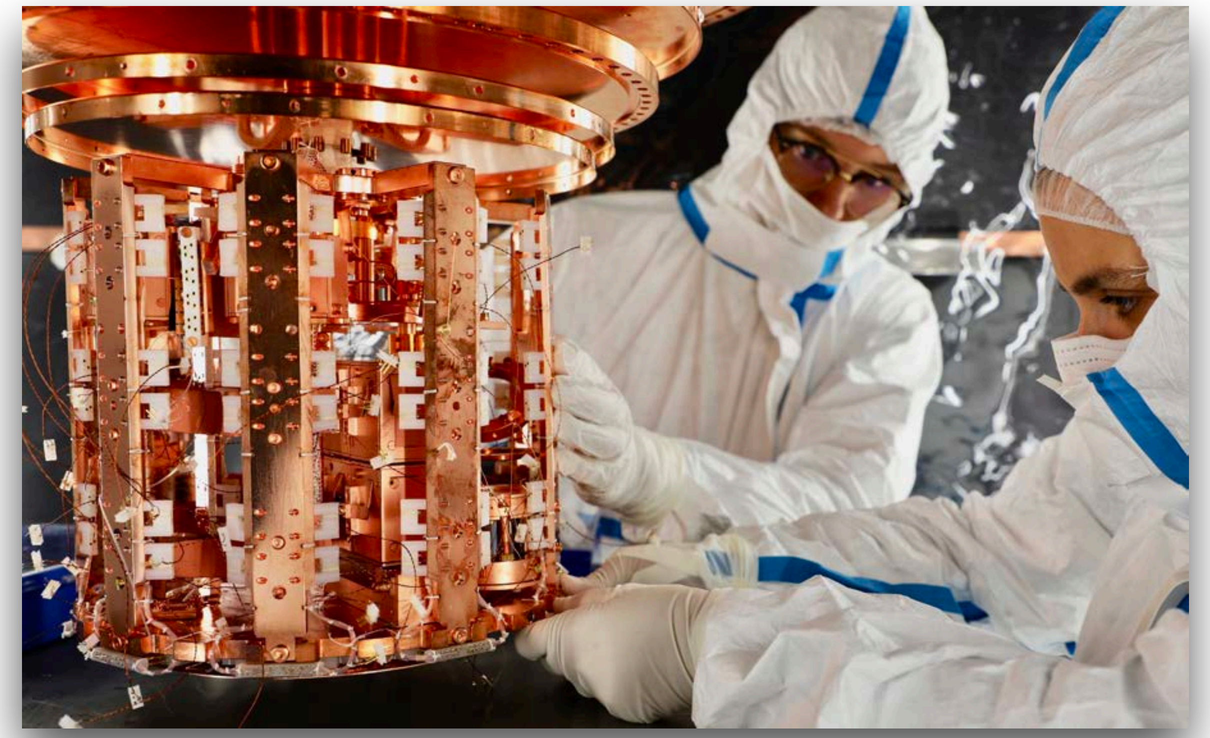




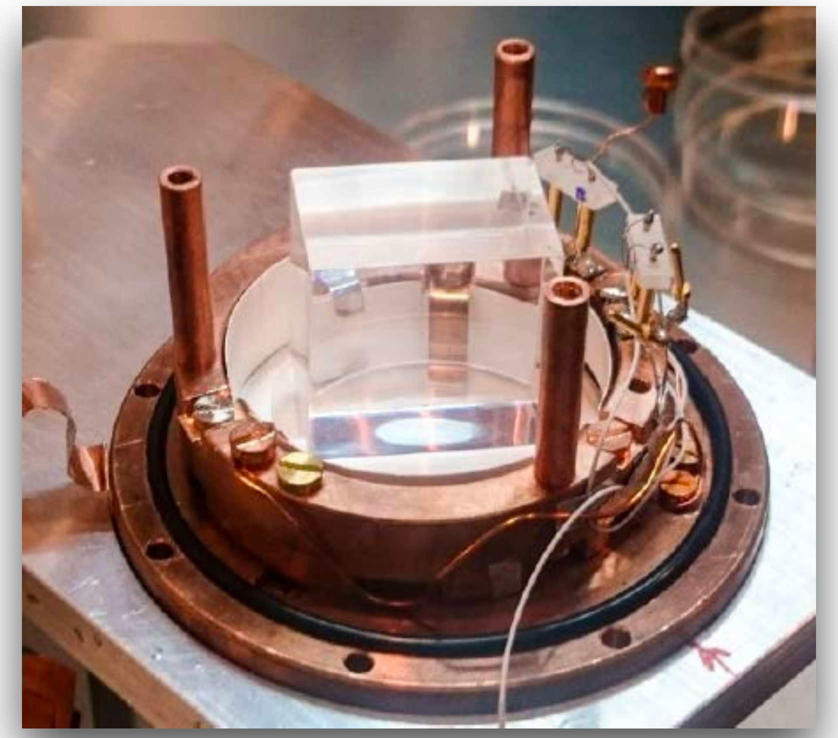
Technology challenges

kg to ton scale

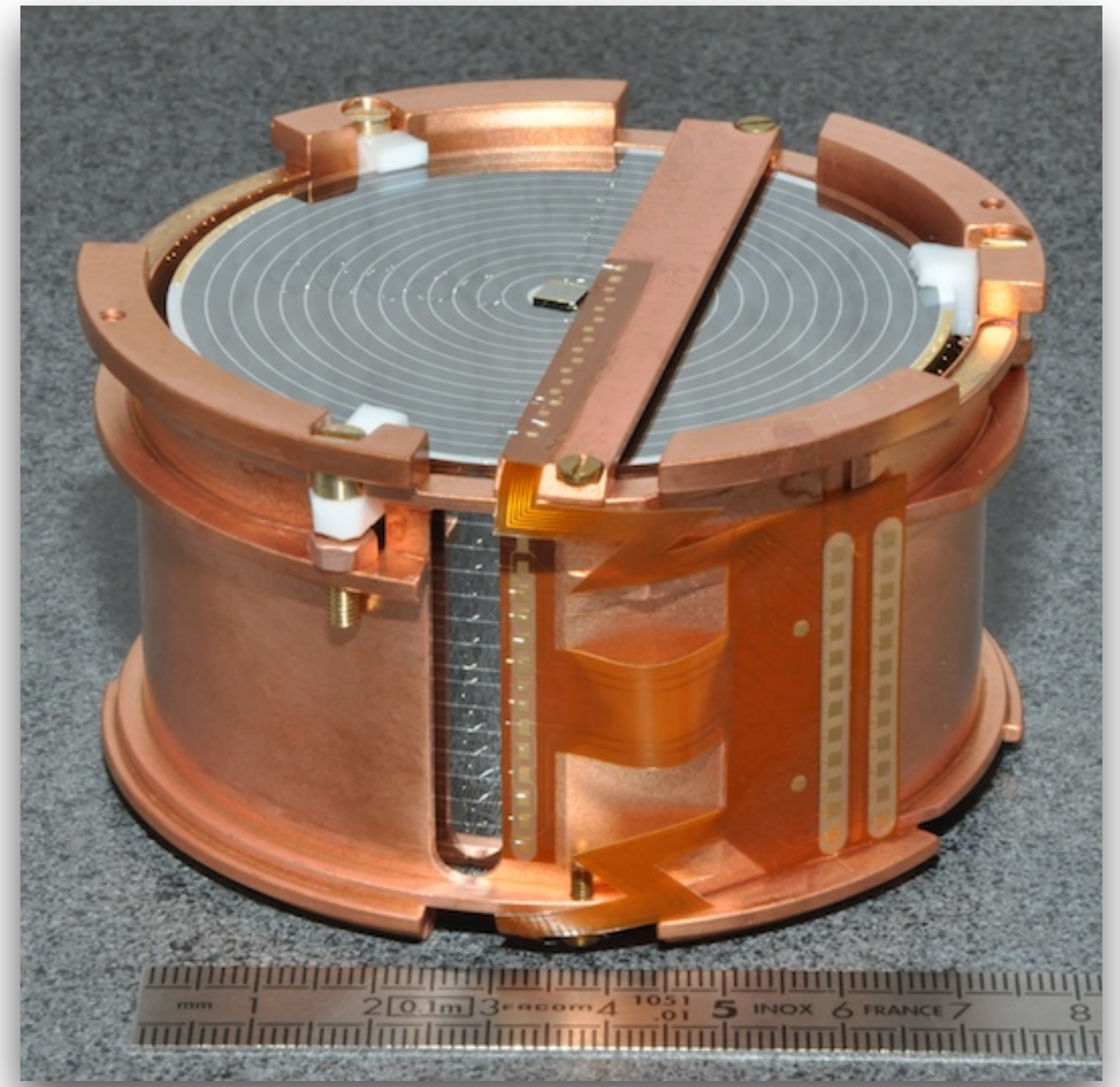
- **Background reduction**
    - powder purification for crystal growth
    - charge leakage reduction
    - underground crystal growth and detector development
- **Target mass**
    - scaling (large arrays of detectors)
- **Dry dilution cryostats**
    - need to control mechanical vibrations introduced by PT cryo-coolers
- **R&D on detector techniques**
    - NaI scintillating bolometers
    - heat sensors (TES, NTD) & low-noise electronics
    - skipper CCDs, sub-electron noise
    - sensors & readout techniques for gas chambers
    - scintillating bubble chambers



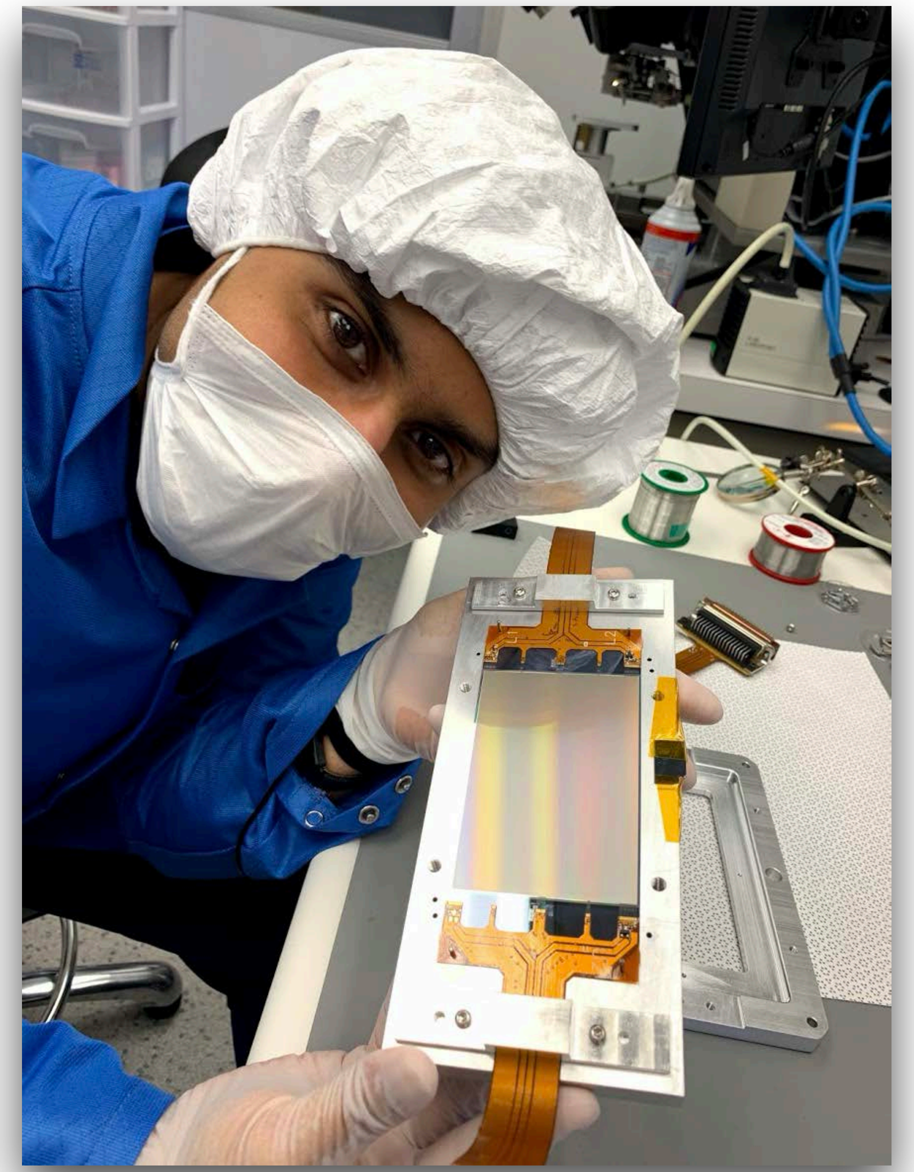
CRESST



COSINUS



EDELWEISS



DAMIC

Technology challenges

multi-ton scale: noble liquids

- **Target inventory**
  - Xe procurement challenging due to limited market availability
  - Ar depleted of ^{39}Ar wrt atmosphere to be extracted from underground wells
- **Backgrounds**
  - ^{222}Rn concentration in LXe to be reduced to <10% of solar neutrinos (0.1 μBq/kg - factor 50 wrt XENON1T and 10 wrt XENONnT design goal)
  - further ^{39}Ar depletion in LAr for low mass searches (factor 100 wrt DarkSide-50)

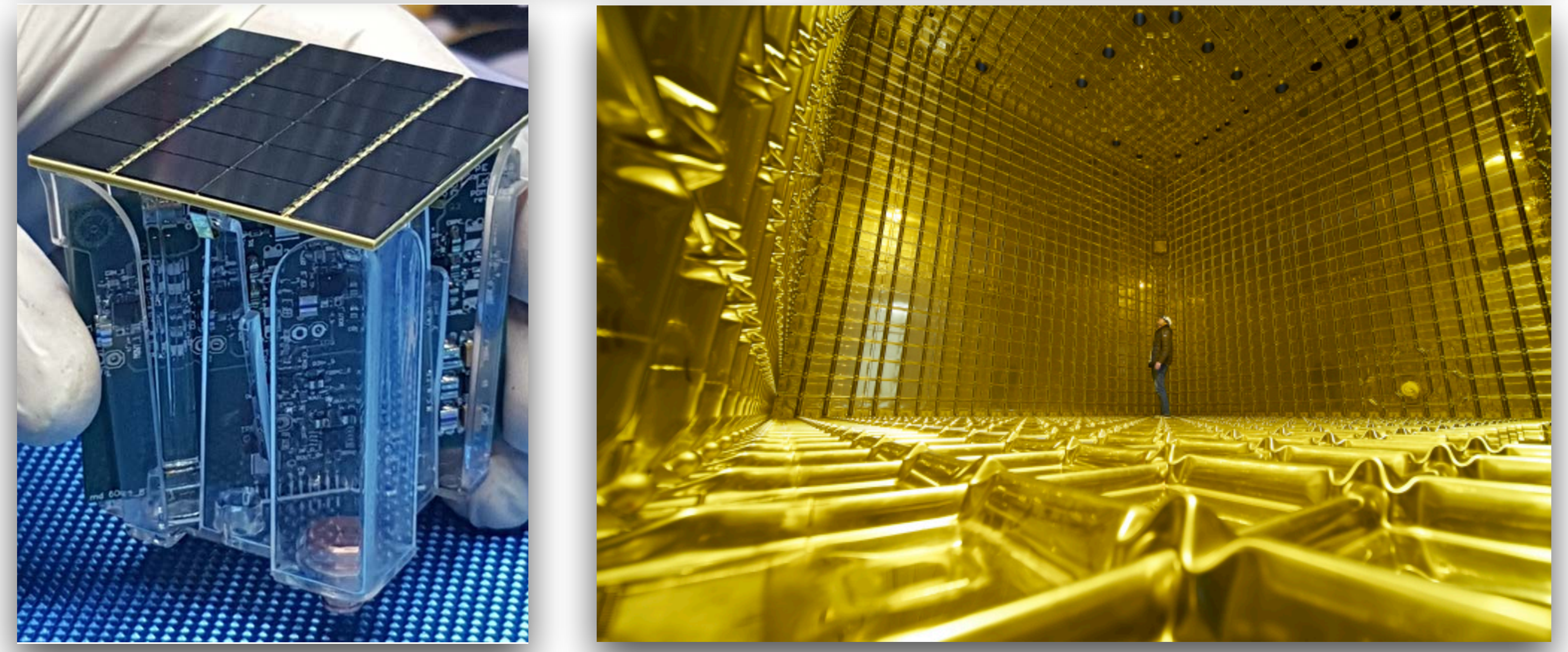
  ➡ large-volume cryogenics and purification, surface treatment, material selection

- **Detector**
  - large-scale TPC electrodes, HV ft, cryostat technology
  - understanding of detector artefacts (e.g. single electron delayed emission)
  - optimisation of light collection efficiency
  - neutron veto systems based on Gd-loaded water/acrylic or LAB liquid scintillator
- **Photosensors**
  - reduce residual radioactivity, decrease dark count rate, increase PDE

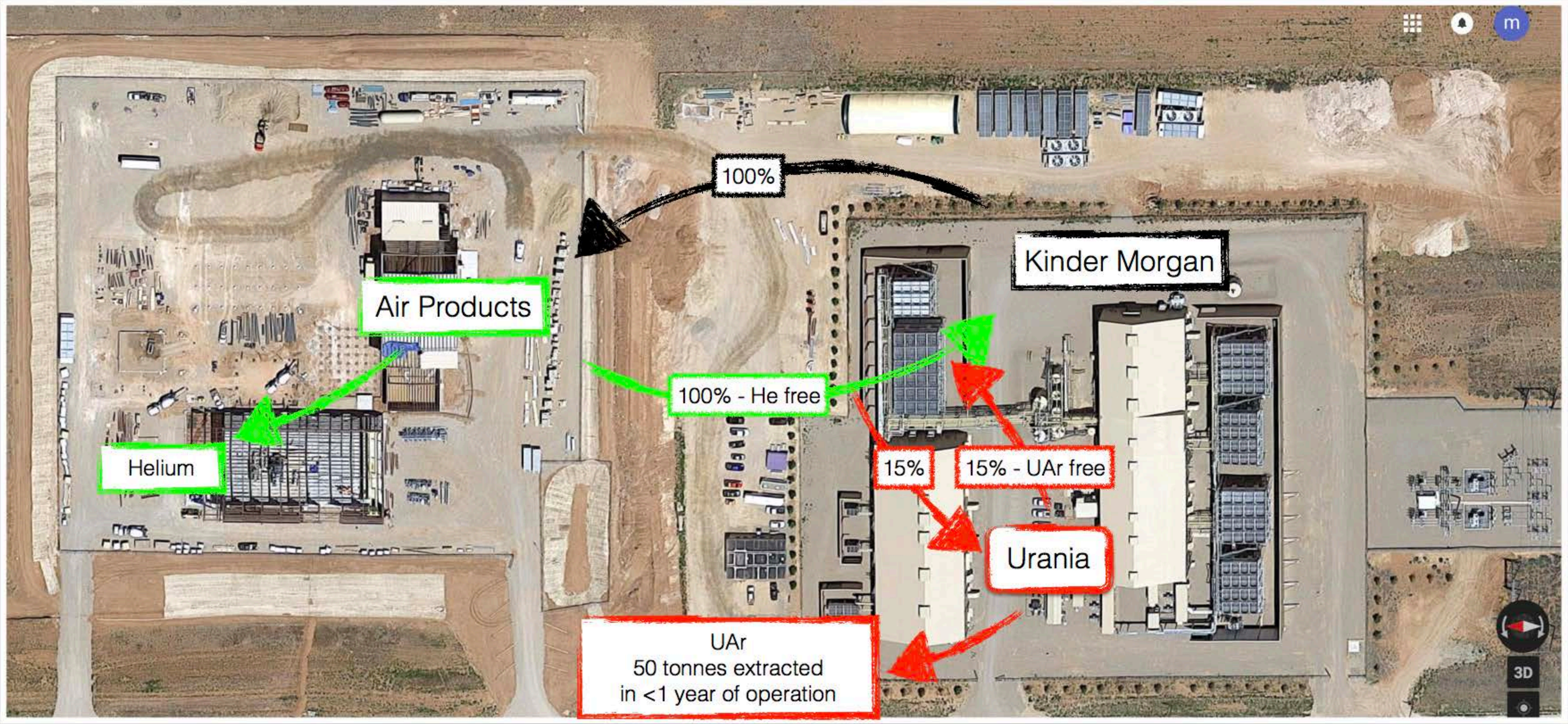
  ➡ PMTs, SiPMs, hybrid detectors, micropattern detectors

DARWIN

DARKSIDE



Low radioactivity argon



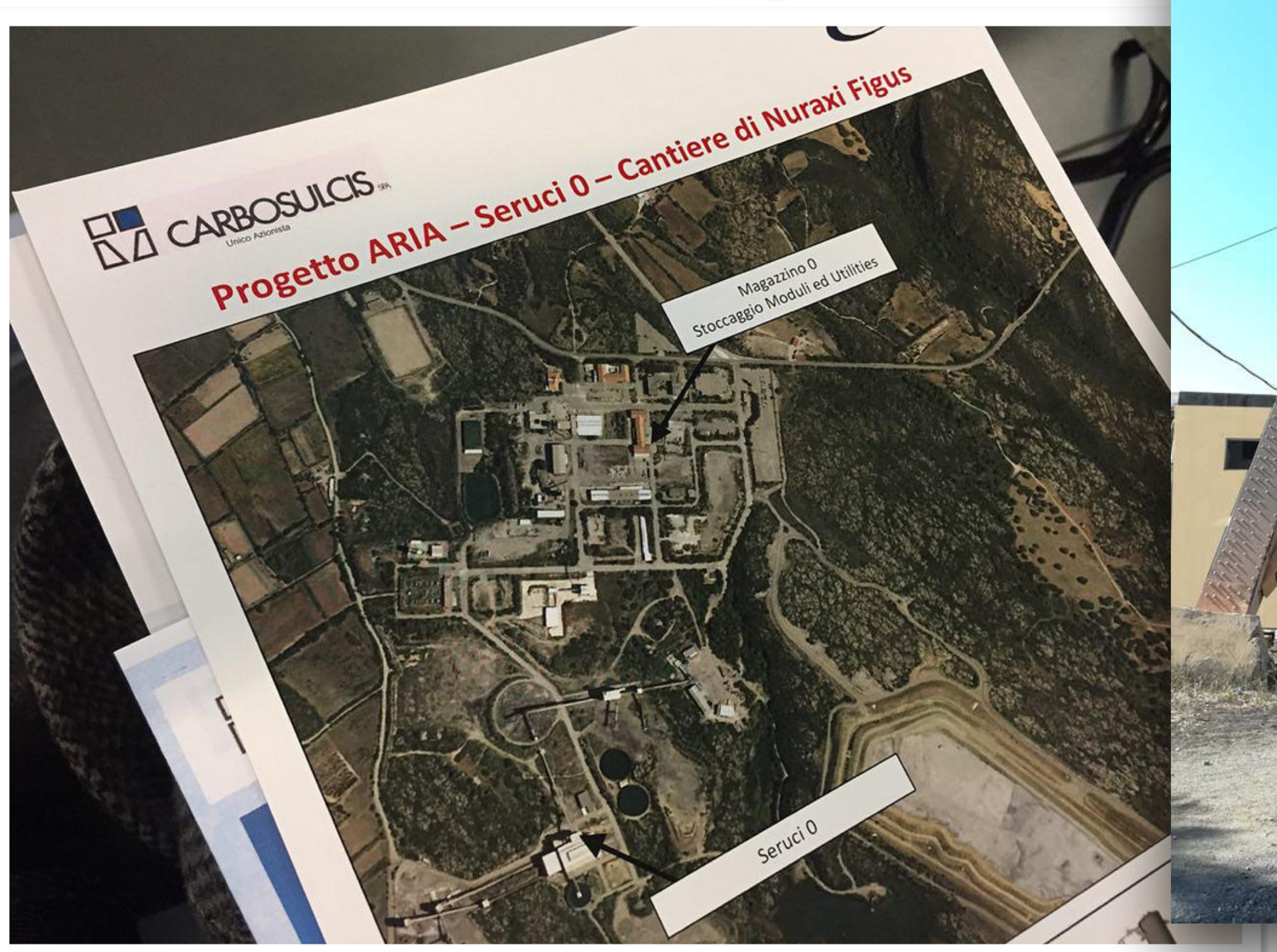
URANIA

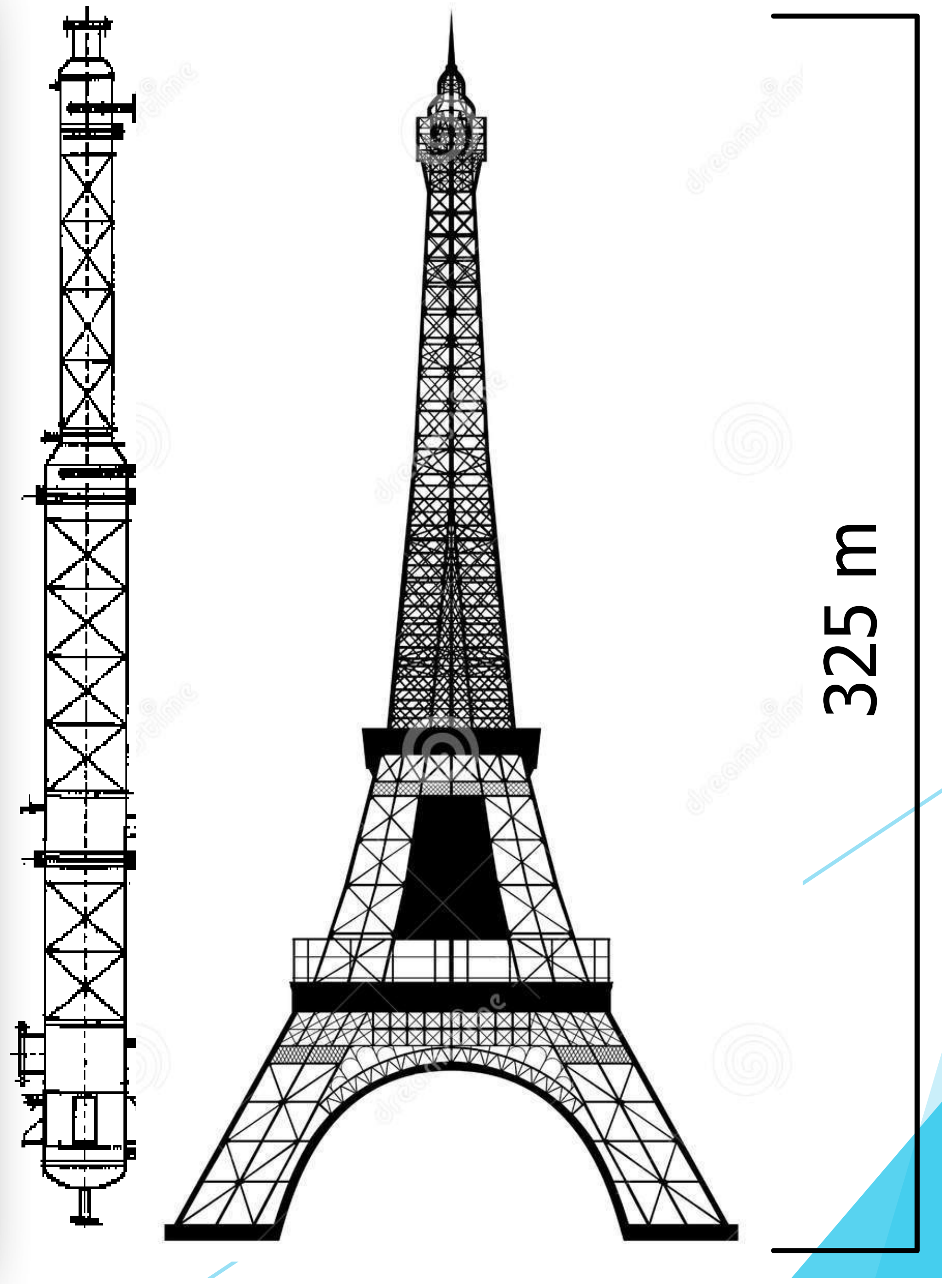
330 kg/day

- ➡ <1yr to for 50 tonnes of UAr
- ➡ can provide UAr for neutrino expts (LEGEND, COHERENT,…)

10 kg/day with a depletion factor of 10

- ➡ <1yr to process DS-LM inventory of UAr
- ➡ also rare stable isotopes such as ^{18}O, ^{13}C (medical physics) and ^{15}N (nuclear reactors)





Xenon distillation

- Cryogenic distillation column developed for XENON to reduce Kr concentration in Xe to suppress radioactive ^{85}Kr
    - delivering gas with a ^{nat}Kr concentration of <0.026 ppt, better than required for DARWIN
- Ultra-low (Rn) background gas pumps developed in context of XENON and nEXO
    - ➡ Technology currently being transferred to medical applications (PET)

Infrastructure

World-wide underground laboratories

Infrastructure

European underground laboratories

- Four major laboratories in Europe
  - ➡ fundamental for the continuation of the ongoing and upcoming projects
- LSM extension proposed (new hall)
- Most important large laboratories for DM searches outside Europe:
  - SNOLAB in Ontario (Canada) ($3x10^{-6}$ mu/m²/s, >30000 m³)
  - Jinping (CJPL) in Sichuan (China) ($2x10^{-6}$ mu/m²/s, >200000 m³)
  - SURF in South Dakota (USA)
  - Kamioka in Japan
  - Yangyang in South Korea

Laboratory	LNGS	LSC	LSM	Boulby
Country	Italy	Spain	France	UK
Depth (m.w.e.)	3600	2450	4800	2820
Muon Flux ($mu/m^2/s$)	3×10^{-4}	3×10^{-3}	5×10^{-5}	4×10^{-4}
Volume (m3)	180000	8250	3500	4000
Access Road	Road	Road	Road	Shaft
Personnel	O(100)	O(10)	O(10)	O(5)
DM Experiment	8	2	3	1

LNGS still largest UG lab in the world

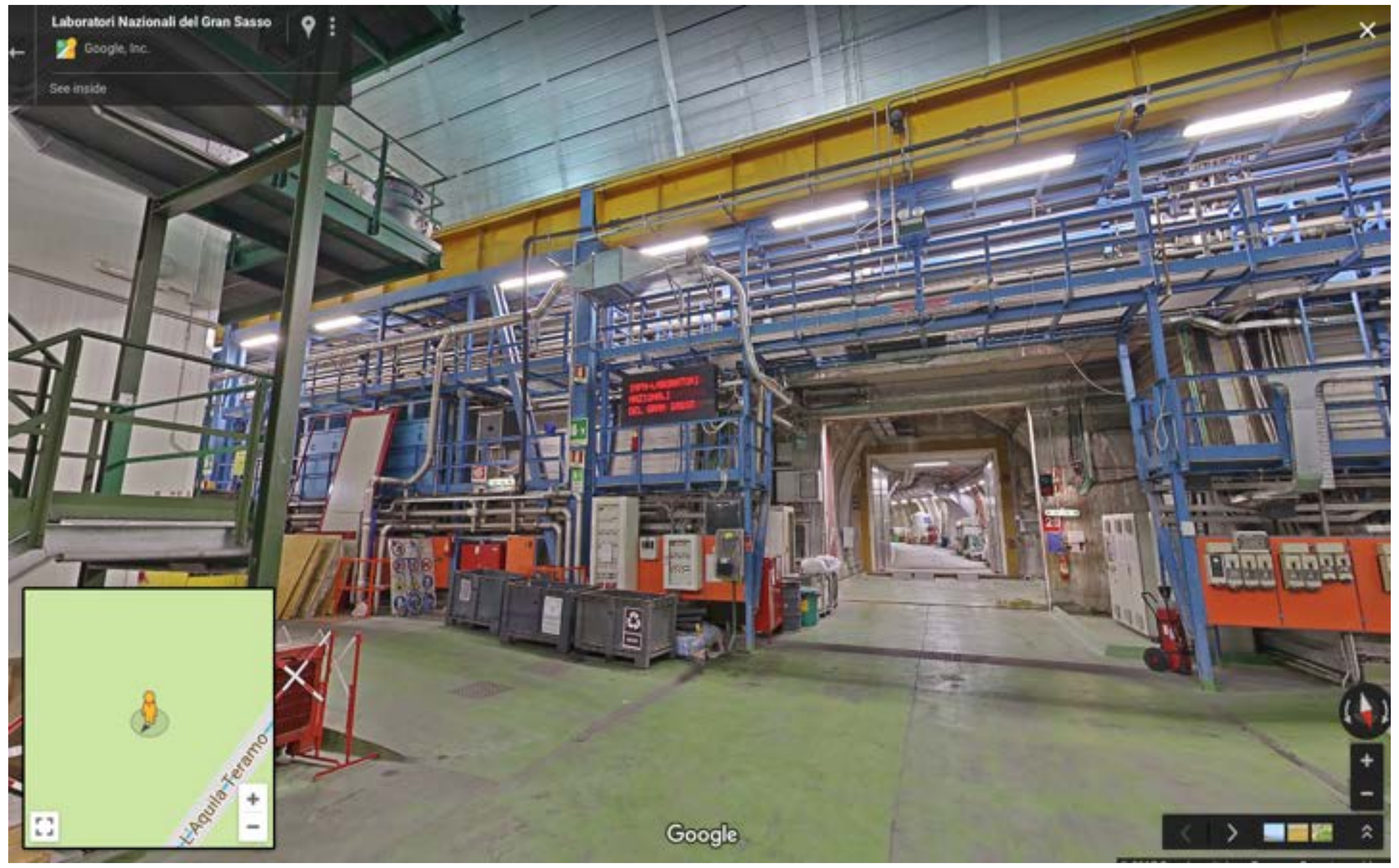
Deep Underground Laboratories (DULs)

Facilities

➡ Also for DBD, solar ν, supernova ν, …, with similar requirements

- **Underground space**
  - shields
  - storage facilities (e.g. ReStoX, ARGUS)
- **Materials radiopurity**
  - germanium spectroscopy from 1 mBq/kg to 50 mBq/kg
  - ICP-MS from 1 to 10 mBq/kg
  - radon detection and mitigation systems, Rn-free cleanrooms (mBq/m^3)
  - specific detectors developed by individual research groups or within international collaborations (e.g. BiPo-3, GeMPI, DArT)
- **Dedicated infrastructures**
  - copper electroforming units
  - clean underground workshops
  - advanced 3D printing facilities
  - radiopure SiPM packaging facilities
  - crystal growth facilities
  - underground test platforms and large-volume mK-cryostats

virtual tour: https://www.lngs.infn.it/en



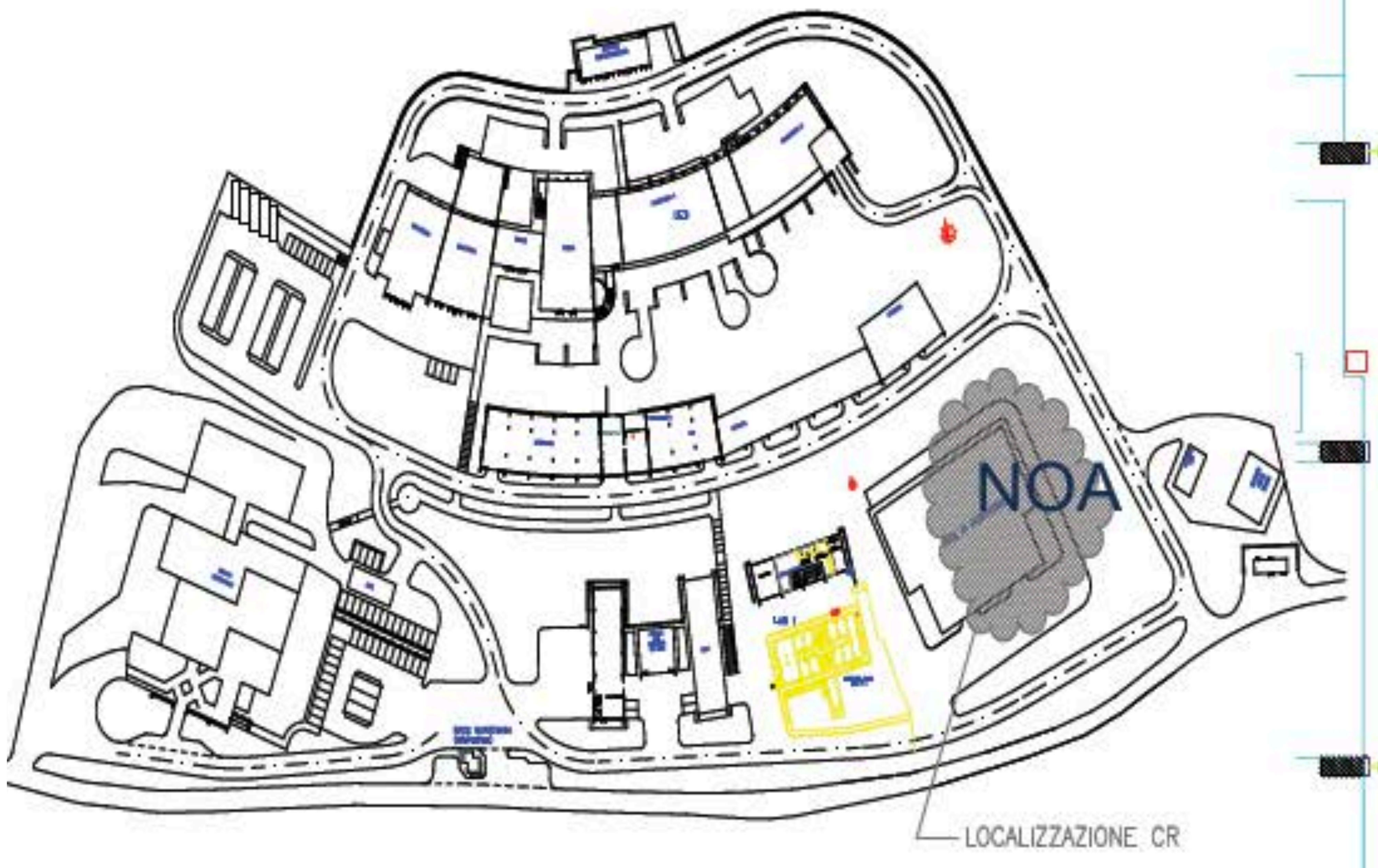
LNGS

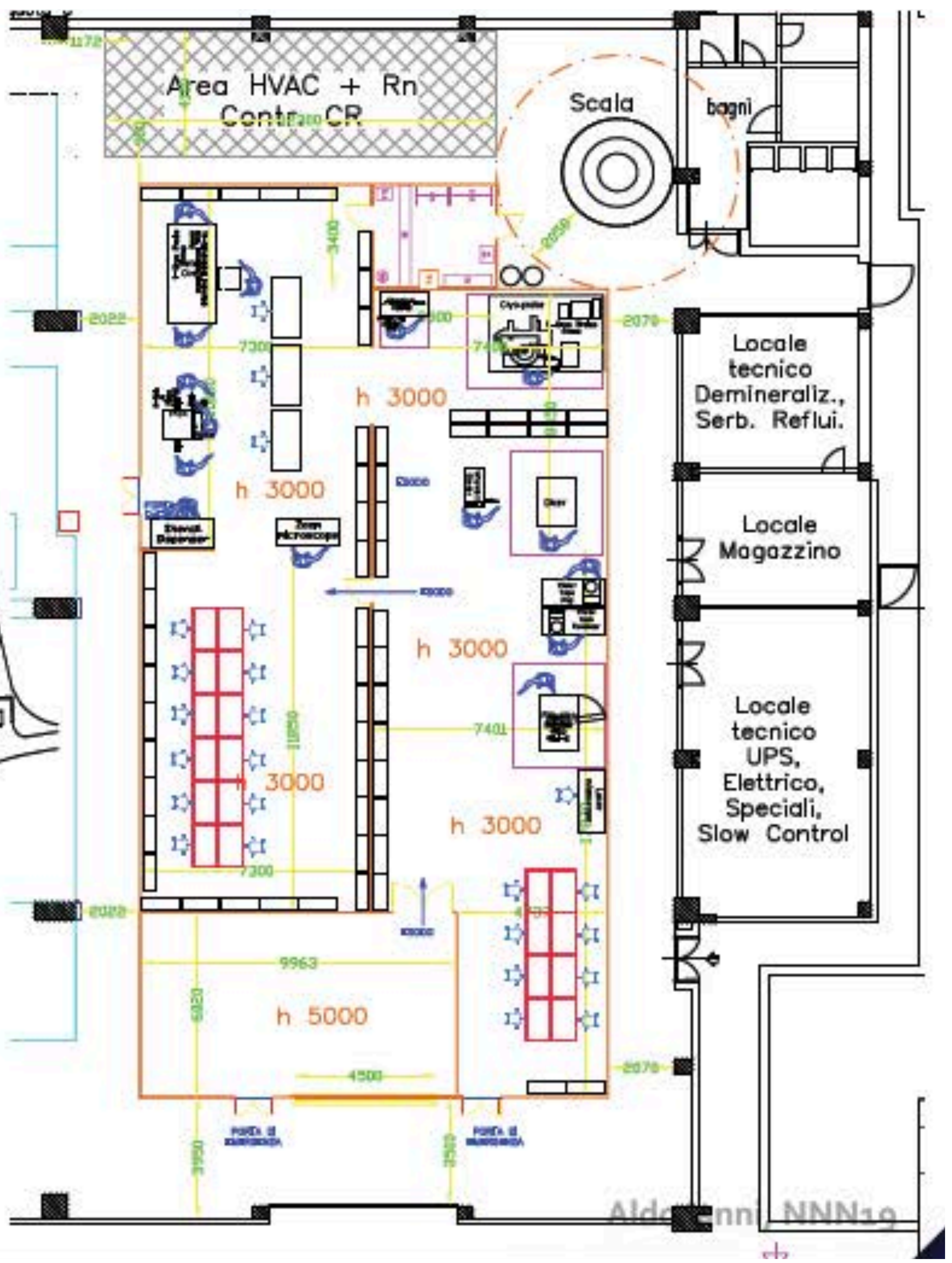
LSC

Nuova Officina Assergi @ LNGS

Radioclean packaging for cryogenic applications

- 400 m^2 radon-free ISO6 cleanroom on surface at LNGS
- top quality equipment for the packaging of silicon devices
    - cryogenic and room temperature wafer probing
    - dicing
    - fully automated flip-chip bonding
- radio-pure processes for SMD PCB productions
- space available for detector assembling in radon-free environment





➡ Utility for large-scale LAr and LXe detectors (DUNE, LEGEND, nEXO, NEXT, DARWIN, …)

Deep Underground Laboratories (DULs)

Coordination

Increasing size of experiments calls for larger investment of human, technological and financial resources

➡ **Need for a global strategy for international collaboration:**

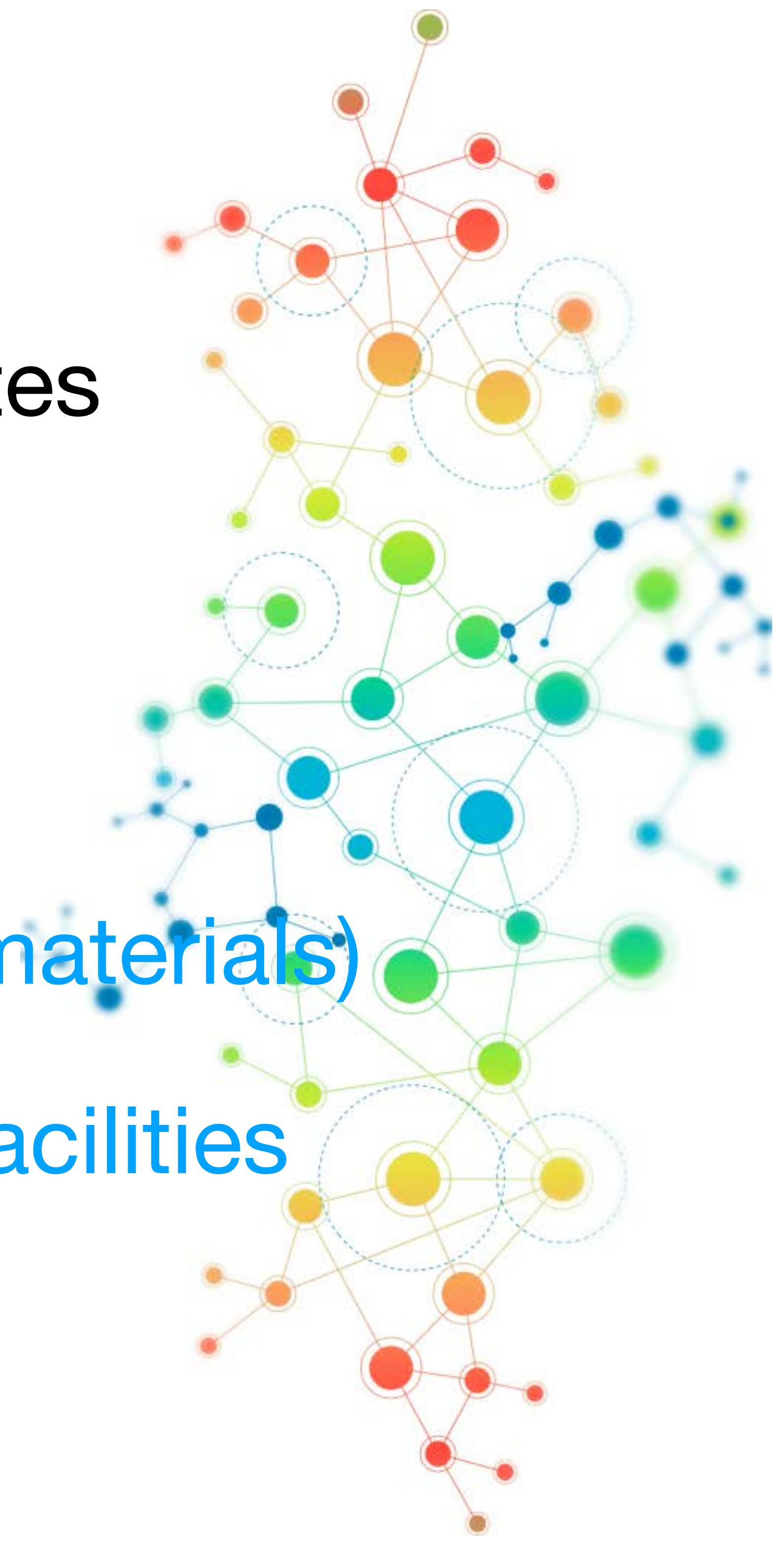
- specialized national laboratories → “network” by pooling resources and expertise
- supranational structure, on the CERN model, “distributed” across different experimental sites

➡ Transnational network across DULs

- common regulations
- operational standards and procedures (security, safety, management of resources and materials)
- open access policies, sustainable collaboration and shared infrastructure and support facilities

Networking previous attempts:

- DULIA: attempt to establish a network between LNGS, LSC, LSM, Boulby and CallioLab
- SNOLAB + LNGS: proposal for an *Underground Global Research Infrastructure*



European Laboratory of Underground Science

A strategic initiative

- Proposal for a distributed but integrated structure of underground laboratories
- Coordinated environment for astroparticle physics in Europe and beyond
- Leveraging synergies and existing infrastructure & know-how
- Promoting new cross-disciplinary initiatives
- Crucial to further development of Underground Science infrastructures

European Research Infrastructure Consortium (ERIC)

- **Strategic empowerment**
    - Member States can benefit from introducing the codecision procedure in the supranational scenario
- **International organisation**
    - VAT exempt and duty free
    - with its own procurement procedures like CERN
    - more flexible to adapt to specific requirements
- **Governance** defined by the Statute
- **Funding** improved
- **Open access** for associated and third countries
    - simplified access rules
    - researcher and knowledge exchange (again like CERN)

European Laboratory of Underground Science

Fostering cooperation between APPEC community, DULs and CERN

- **Direct detection synergic with accelerator searches at CERN**
  - LHC and DD experiments probe complimentary range in WIMP and mediator masses
  - discovery of new particle at LHC would need confirmation to prove it is the cosmological DM
  - discovery of WIMP in DD would boost construction of a new-generation particle collider
- **Technologies**
  - cryostat technology
  - large-volume cryogenics and purification
  - TPC design and optimization, high voltage delivery
  - SiPM + cold electronics
- **Increased collaboration**
  - common challenges with LAr neutrino detectors (DAQ, optics, etc.)
  - large overlap of European LAr neutrino and dark matter communities

ARIA MODULES @ CERN

DS20k CRYOGENICS @ CERN

➡ CERN open to DM community to enhance synergies resulting from development of common technologies

Key Points

- Achieving background levels below neutrino floor main challenge for next generation DD experiments
- Technology innovations push forward ultra low background techniques with potential interdisciplinary benefits
- Advanced infrastructures distributed in national underground laboratories
- Emerging need to improve coordination among DULs
- Strategic initiative to establish and operate an European Laboratory of Underground Science