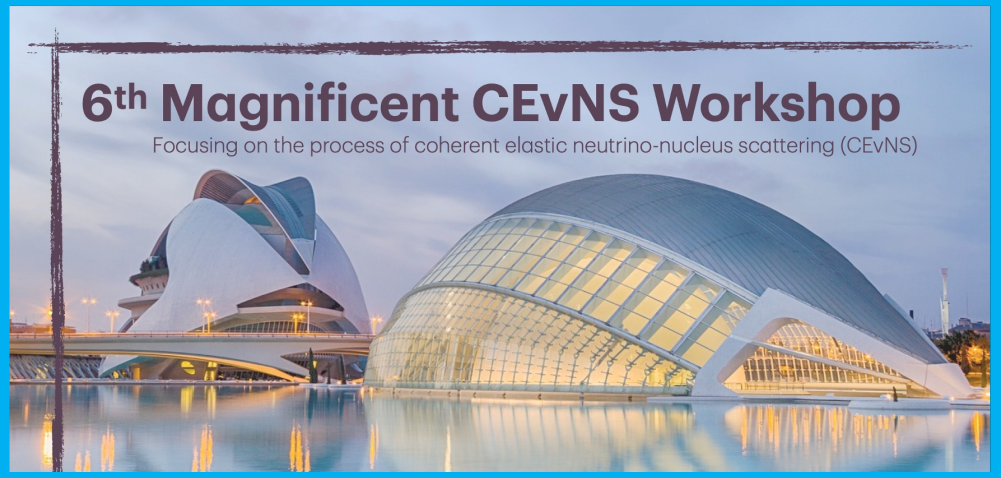
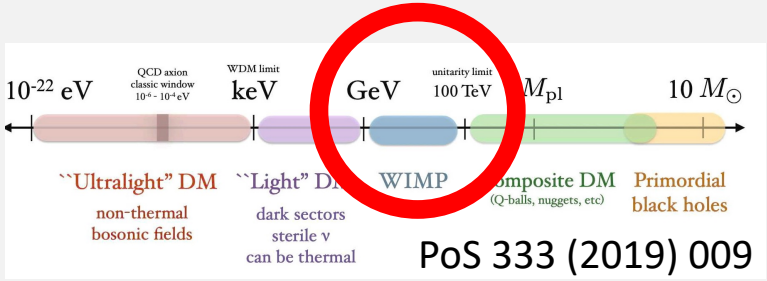


Toward the low-mass dark matter searches with DarkSide-20k: the solar neutrino and the argon-39 backgrounds

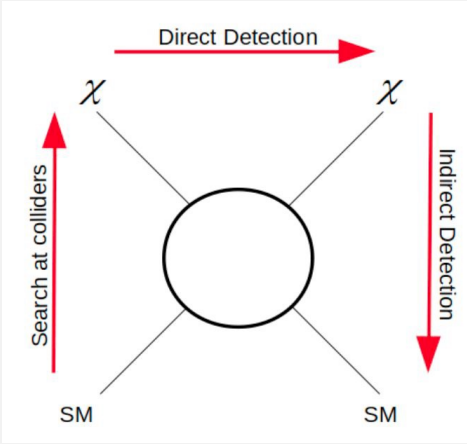
Nicola Cargioli
INFN Cagliari
on behalf of the
DarkSide-20k Collaboration

DarkSide-50

Dark matter direct detection: search for the interaction of hypothetical DM particles (i.e. WIMPs) with ordinary matter



PoS 333 (2019) 009



Phys. Rev. D 100, 022004 (2019)

Dual-phase TPCs represent the state-of-the-art for direct detection searches:

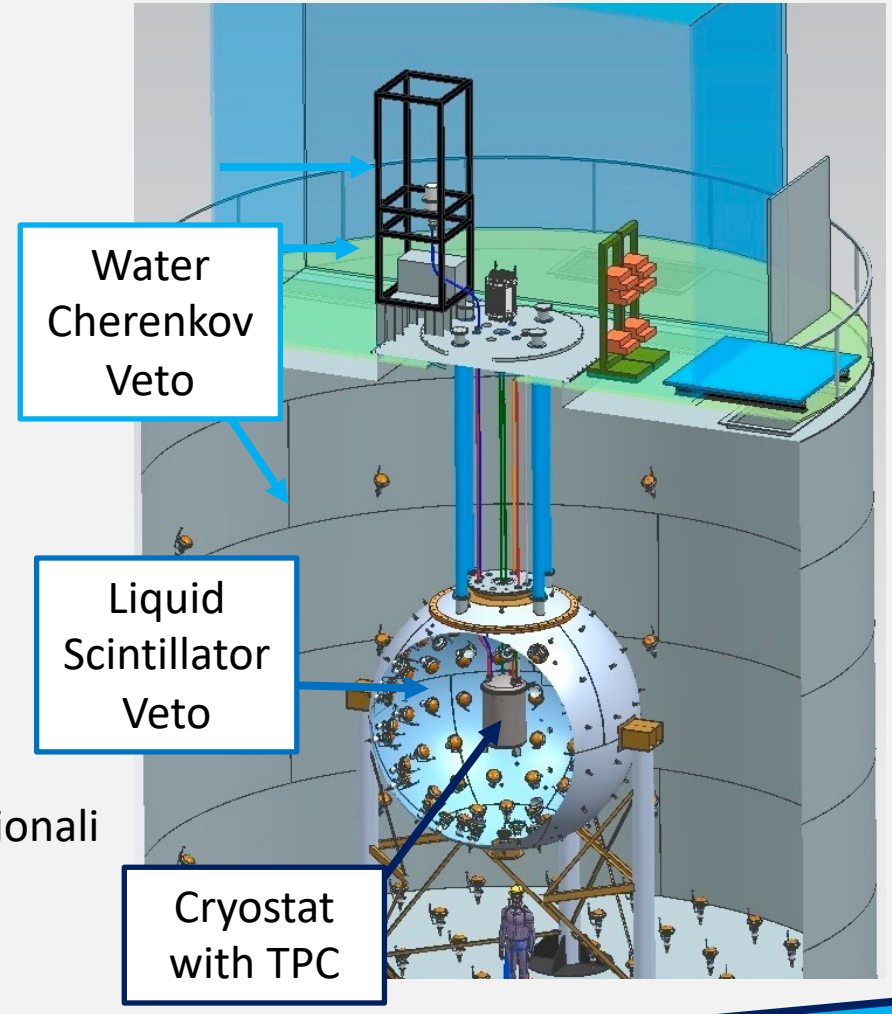
Usually Noble Elements are used as targets

- No radiochemical impurities, scalable, high scintillation yield, particle identification, high ionization yield (etc..)
- Mainly Xenon or **Argon** based detectors

DarkSide-50:

- 50 kg dual-phase argon TPC operated at Laboratori Nazionali del Gran Sasso (LNGS)
- Boron loaded scintillator PMTs for light readout
- 30 tons liquid scintillator Neutron Veto
- 1 kton Water Cherenkov detector

Drawing of DarkSide-50



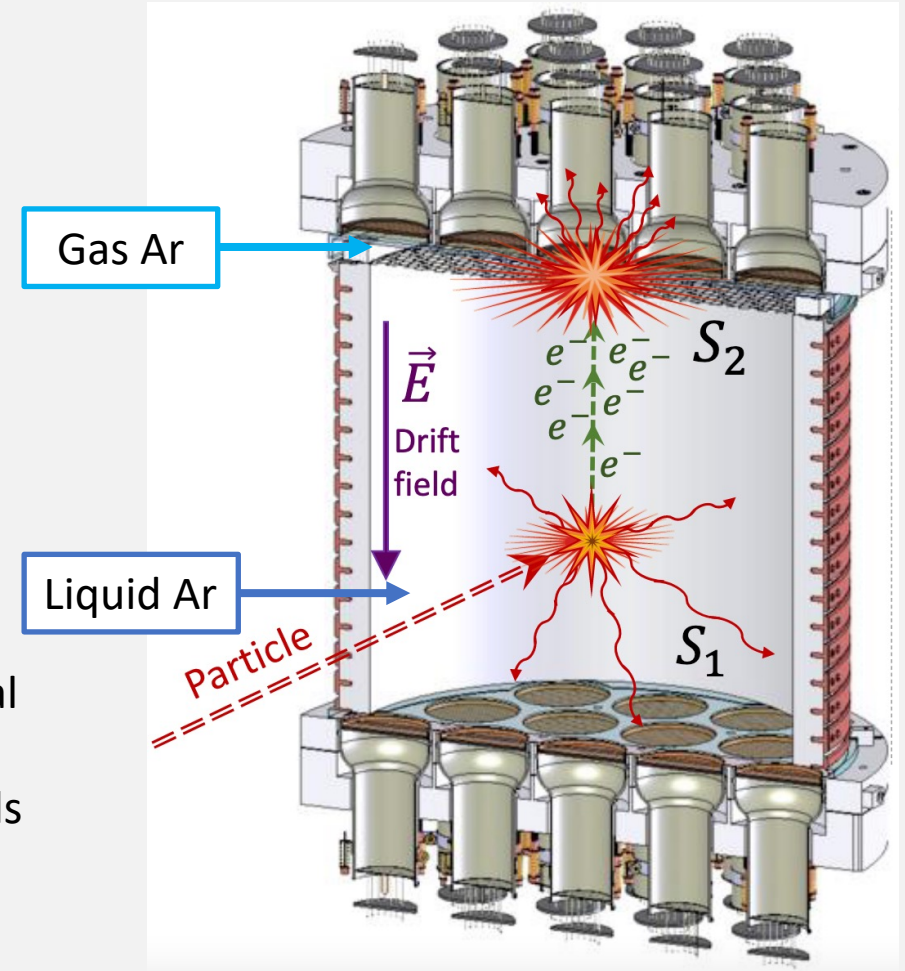
Search for Low Mass WIMPs

Why Dual-phase argon TPC?

- Pulse shape discrimination
- F90: fraction of light detected in the first 90 ns (Singlet $\sim 7\ ns$; Triplet $\sim 1.5\ \mu s$)
- S1: primary scintillation in LAr (energy information and pulse shape discrimination)
- S2: ionization signal (Z-position of the event in the chamber: drift time)

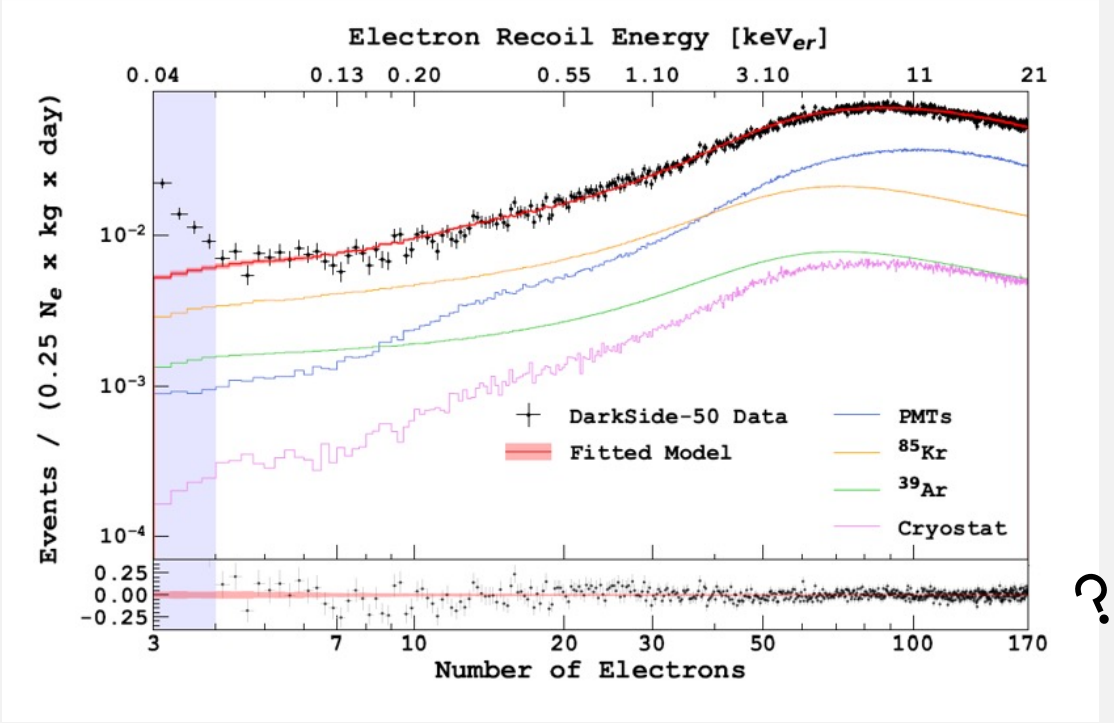
Low energy interactions:

- It is possible to reduce the threshold by restricting to S2-only signal analysis (analysis based on the number of electrons)
  - LAr ionization yield for low energy electron and nuclear recoils down to 180 eVer and 500 eVnr
- Trade-off: PSD and Z-coordinate reconstruction are unavailable
- S2 signals are amplified in GAr: possible to identify single ionization electron
- Unique sensitivity to few GeVs DM



Drawing of DarkSide-50

Backgrounds in DS-50



DS-50 Collaboration
Phys.Rev.D, 107,063001,2023

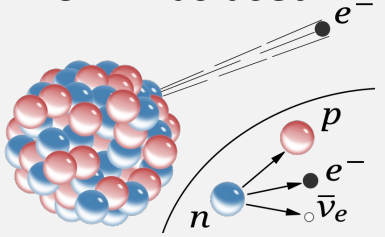
- X-rays and γ:
  - Radioactivity of the materials in the detector material
  - Noise from the light readout system (PMTs)

Fiducialisation: reduces bkg from the walls

γ

- β-decay:
  - **^{39}Ar**: cosmogenic unstable isotope
  - ^{85}Kr: anthropogenic unstable isotope

We want "better" argon: UAr was used



- Spurious electrons or "**Single Electrons**" (SEs):
  - Unknown origin (maybe related to contaminants)
  - Dominant background for $N_{e^-} \leq 4$:
  - It limits the threshold for the S2-only analysis

Needs to be studied

ν

- In DS-50 neutrinos contribution is negligible

The Ar-39 problem

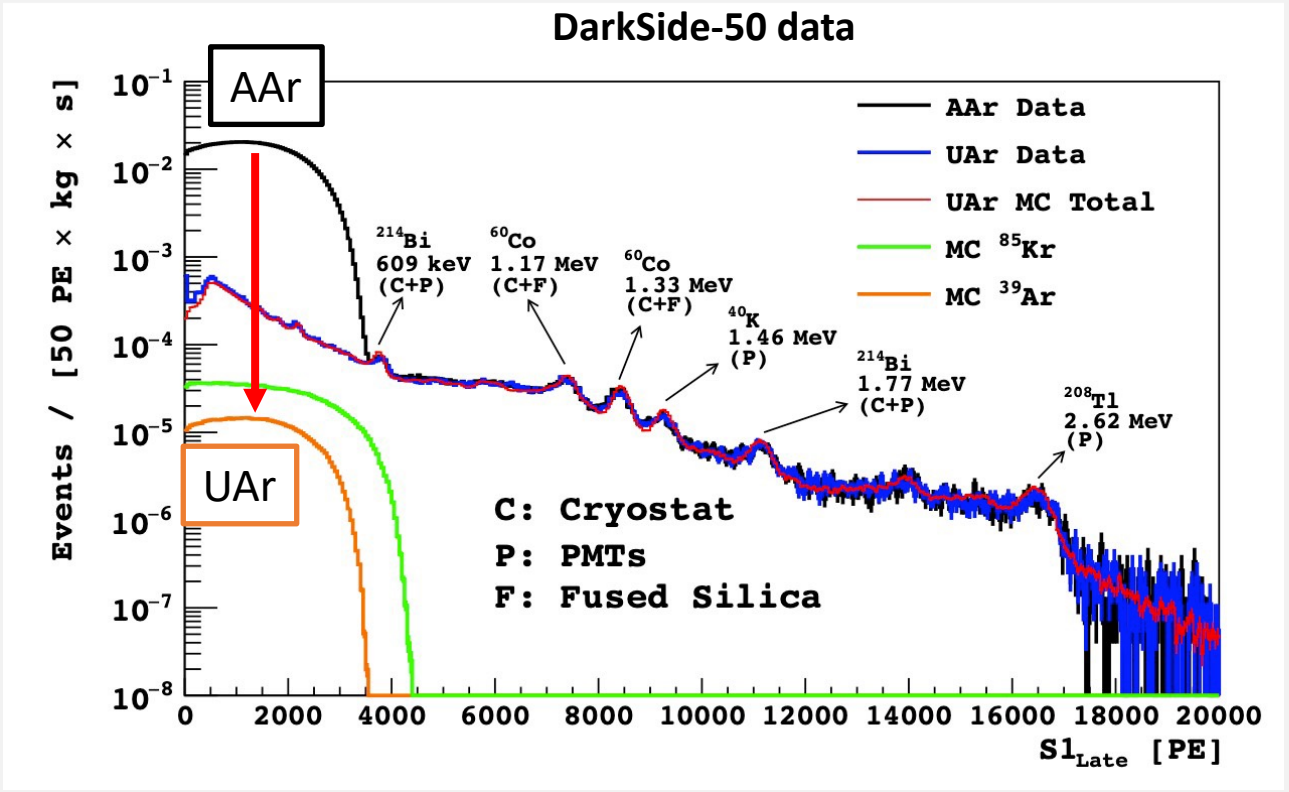
^{40}Ar
stable

^{39}Ar
unstable

^{39}K
stable

^{39}Ar is an unstable isotope of argon of cosmogenic origin

- Present in AAr
- β-decays to ^{39}K
- Half life 269 years
- Endpoint energy 565 keV
- In AAr the activity is typically 1 Bq/kg

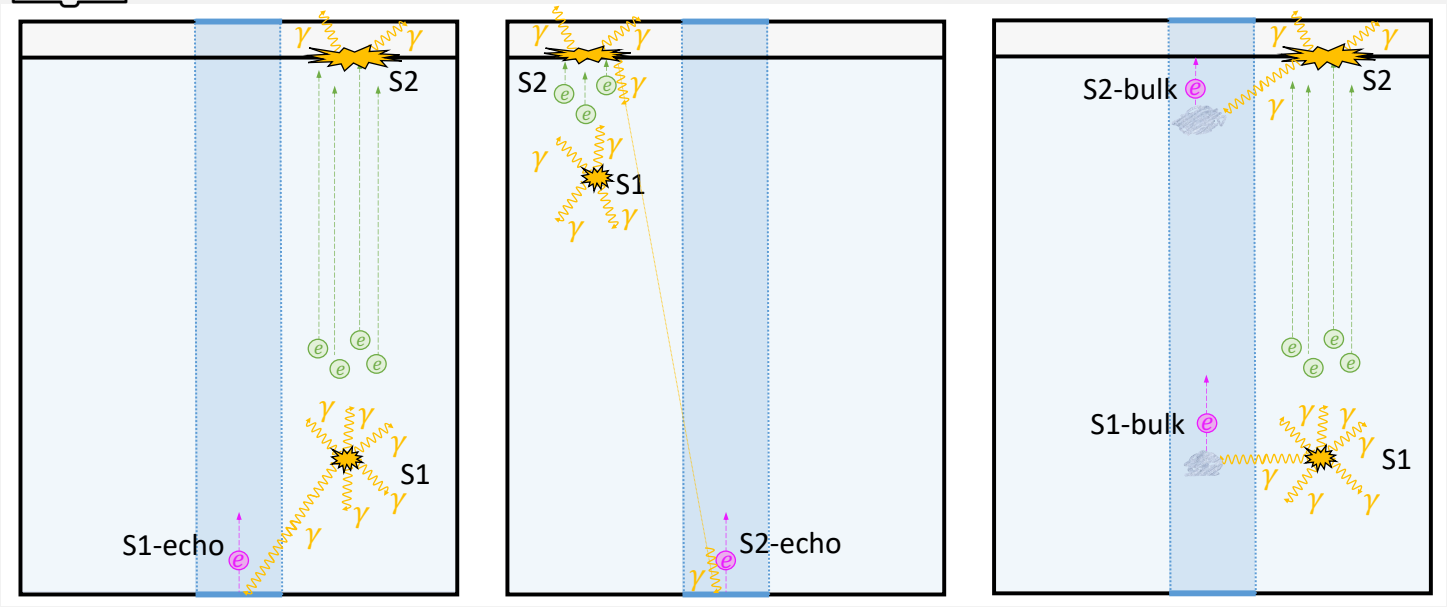


Argon extracted from underground is naturally shielded from cosmic rays
In DS-50 an underground argon source was employed:

- UAr: 1400 reduction of ^{39}Ar activity wrt AAr

The Single Electron problem

N.C. PhD thesis



By analysing the DS-50 data we identified **ONLY** part of the events:

DS-50 Collaboration
Astropart. Phys. 140 (2022) 102704

Time correlation

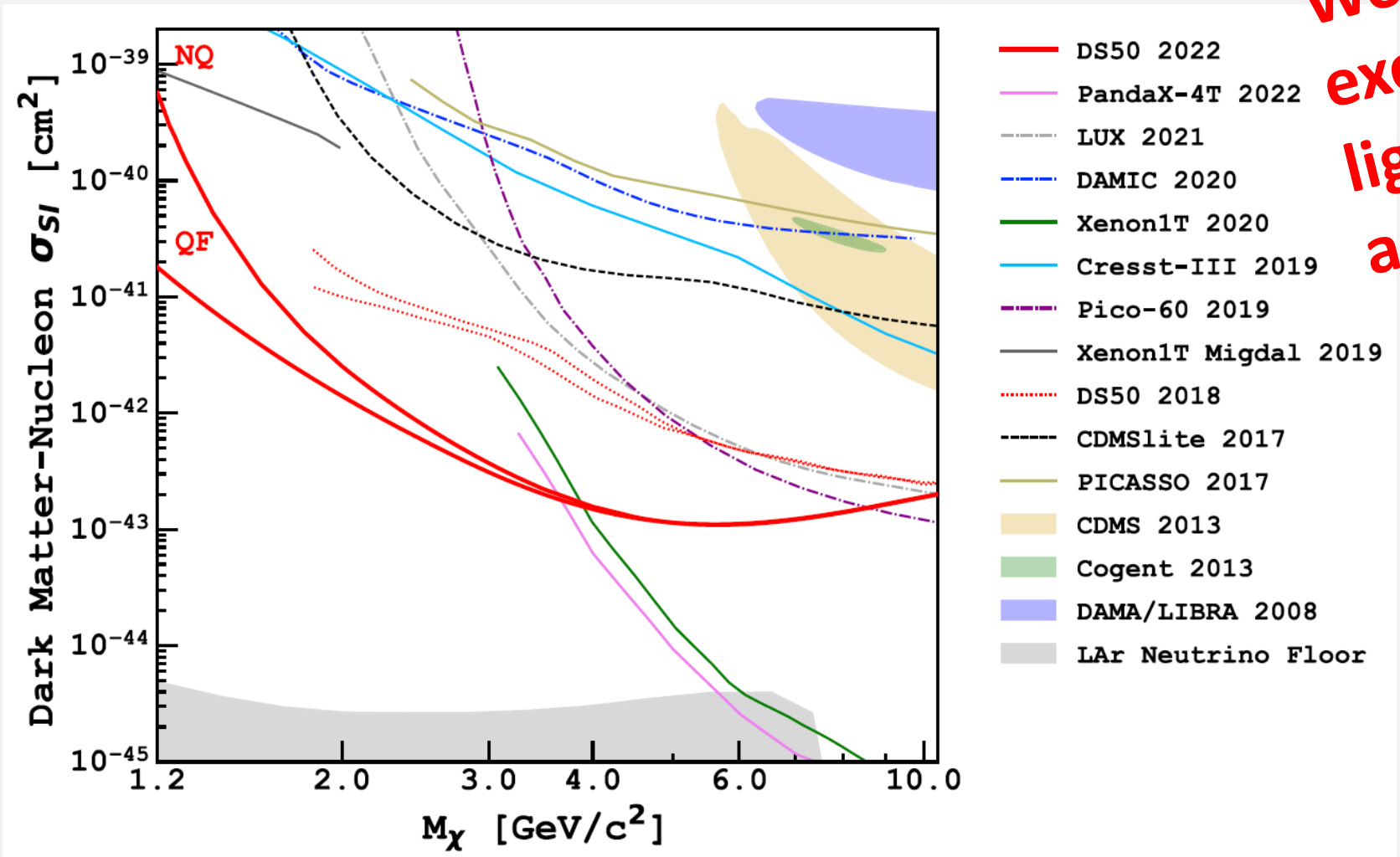
- **S1-echo**: photo-ionization of the cathode from S1 light
- **S2-echo**: photo-ionization of the cathode from S2 light

No Time correlation

- **S1-bulk**: electron extracted from the liquid from S1 light
- **S2-bulk**: electron extracted from the liquid from S2 light

A correlation with the impurities in liquid argon has been observed but still a lot to be understood

Low Mass WIMPs in DS-50



World-Best exclusion limit on light WIMPs was achieved by DS-50

So…
What's next?
Let's get larger

DS-50 Collaboration
Phys.Rev.D, 107,063001,2023

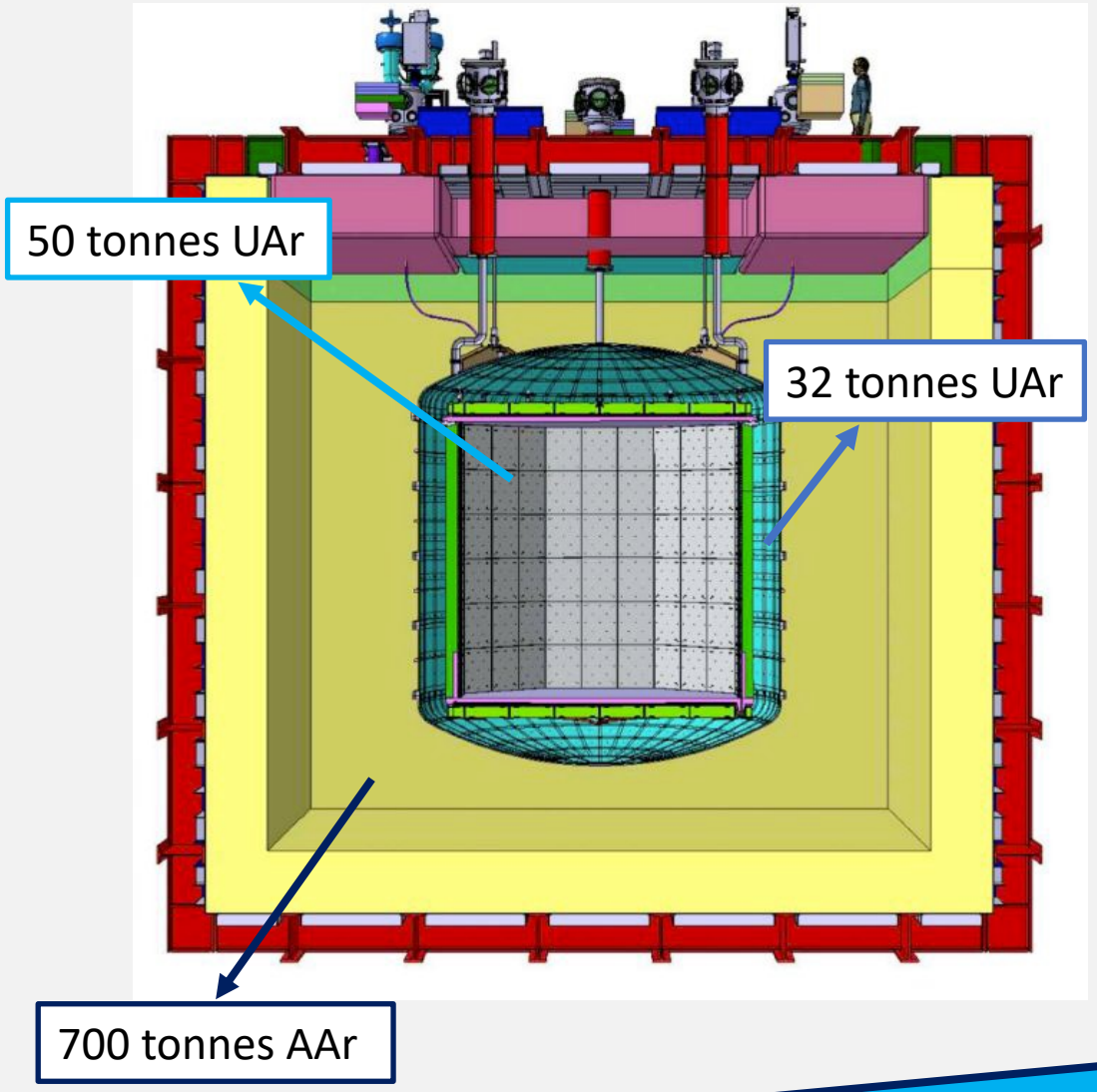
The DS-20k Experiment

- Dual Phase TPC: 50 (20) tonnes active (fiducial) UAr
- Under construction at Laboratori Nazionali del Gran Sasso (Italy)
- Commissioning expected by end 2026
- Part of the Global Argon Dark Matter Collaboration (GADMC)

- 700 ton of AAr acting as muon veto: instead of Water Cherenkov Veto

- 32 ton of UAr acting as neutron veto: instead of Liquid Scintillator Veto

- Light Readout: large array of custom cryogenic low-noise SiPMs: instead of PMTs



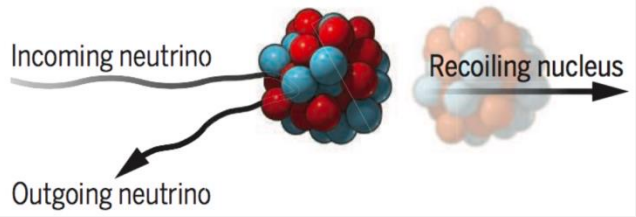
Low Mass WIMPs in DS-20k

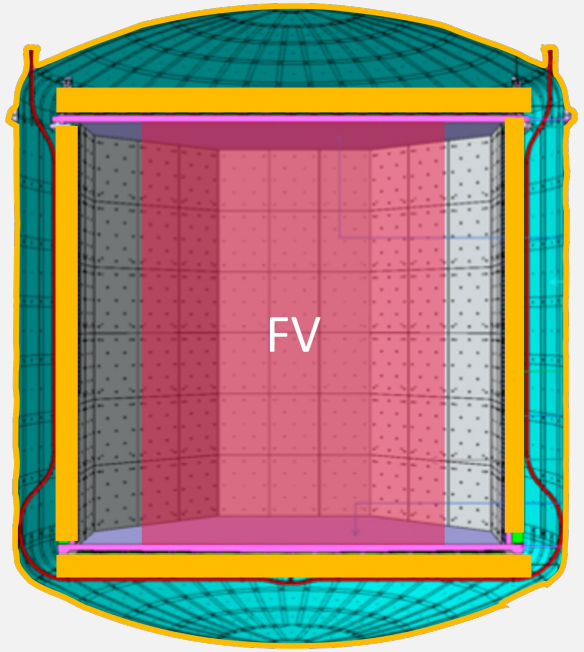
- X-rays and γ:
  - Radioactivity of the materials in the cryostat, SiPMs and Vessel
  - Expected to be a factor of 2.5 per surface area orthogonal to the electron drift direction lower than DS-50

Materials chosen to be very radiopure
Fiducialisation: reduces bkg from the walls

- Neutrinos:
  - non-negligible in DS-20k
  - **CEvNS** from solar neutrinos
  - **vES** from solar neutrinos

ν





- Spurious electrons or "**Single Electrons**" (SEs):
  - Needs assumptions on contaminants concentration
  - Scaled from DS-50 with the trigger rate and maximum drift time

Global Argon Dark Matter Collaboration
Phys.Rev.D, 107, 112006 (2023)

- β-decay:
  - ^{39}**Ar** and ^{85}Kr: can we improve with respect to DS-50?

Neutrinos: CEvNS and vES

COHERENT ELASTIC NEUTRINO NUCLEUS SCATTERING:

$$\frac{d\sigma_{\nu_\ell-\mathcal{N}}(E_\nu, T_{nr})}{dT_{nr}} \cong \frac{G_F^2\, m_N}{\pi}\left(1-\frac{m_N T_{nr}}{2E_\nu^2}\right)[Q_W F_W(q^2)]^2$$

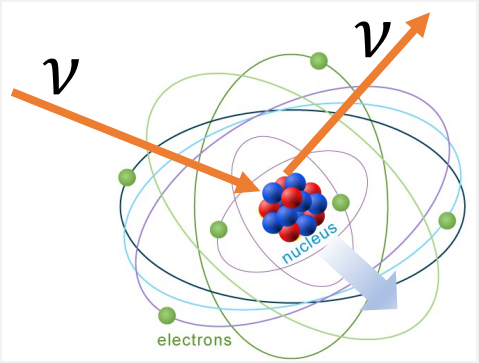
- Solar Neutrinos: mainly ^8B
- Energy deposits less than 10 keV_{nr} in UAr
- We include radiative corrections

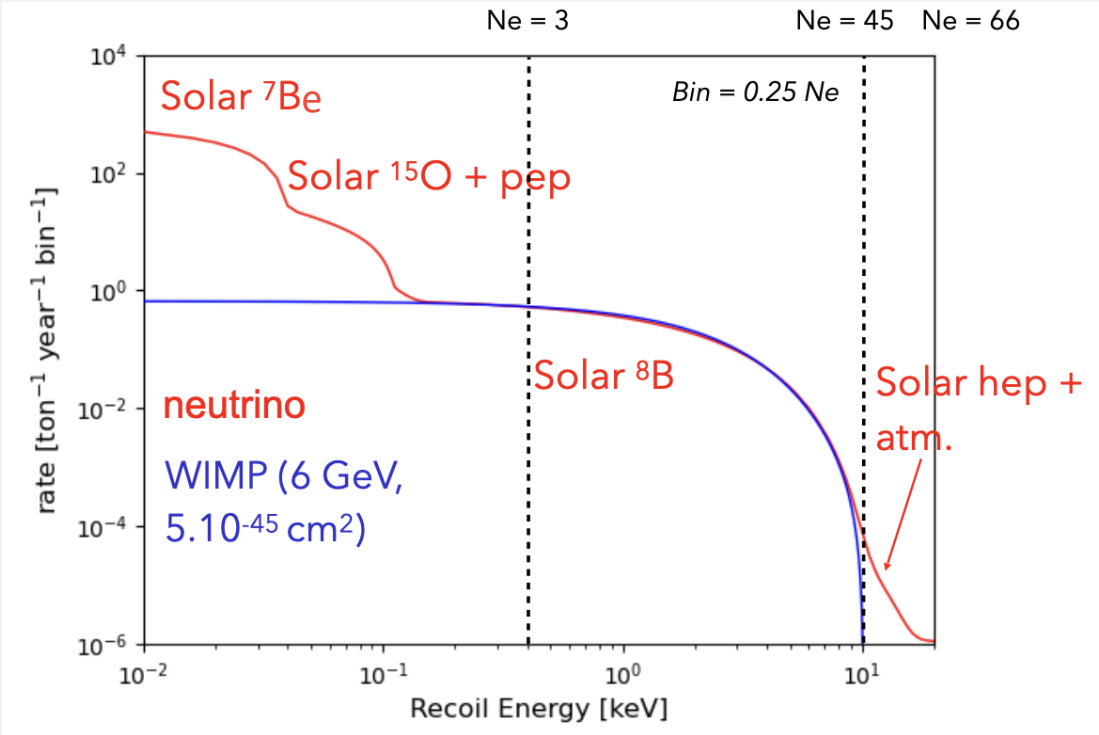
Look at F. Dordei Talk!

- Mimics the signal of a WIMP for m_χ=6 GeV and σ=$5 * 10^{-45}$ cm^2

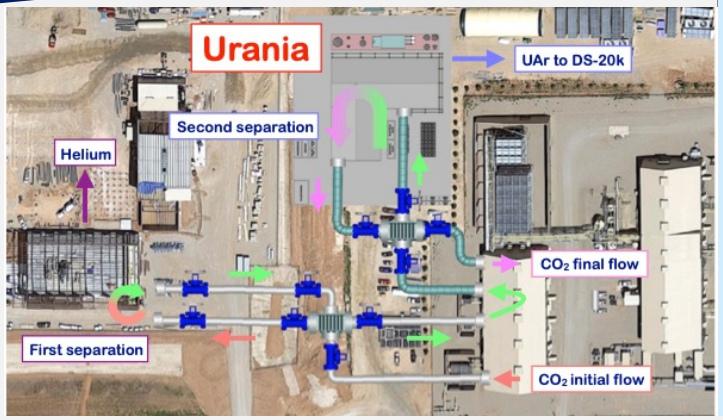
ELASTIC NEUTRINO ELECTRON SCATTERING

- Main contribution from pp neutrinos (Ev<2 MeV)
- Becomes larger than CEvNS for $N_e- > 30$



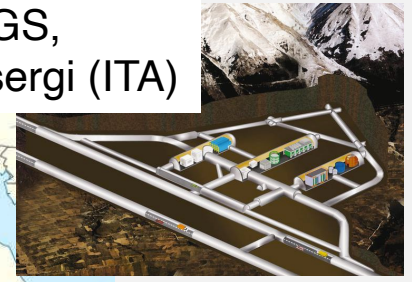


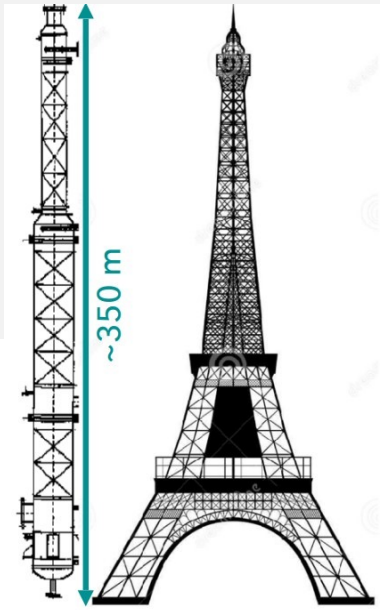
Depletion and Purification



URANIA:

- Expansion of the plant
- CO_2 extraction industrial plant
- Reach capacity of extraction of 250 kg/day of UAr
- purity 99.99% at the exit





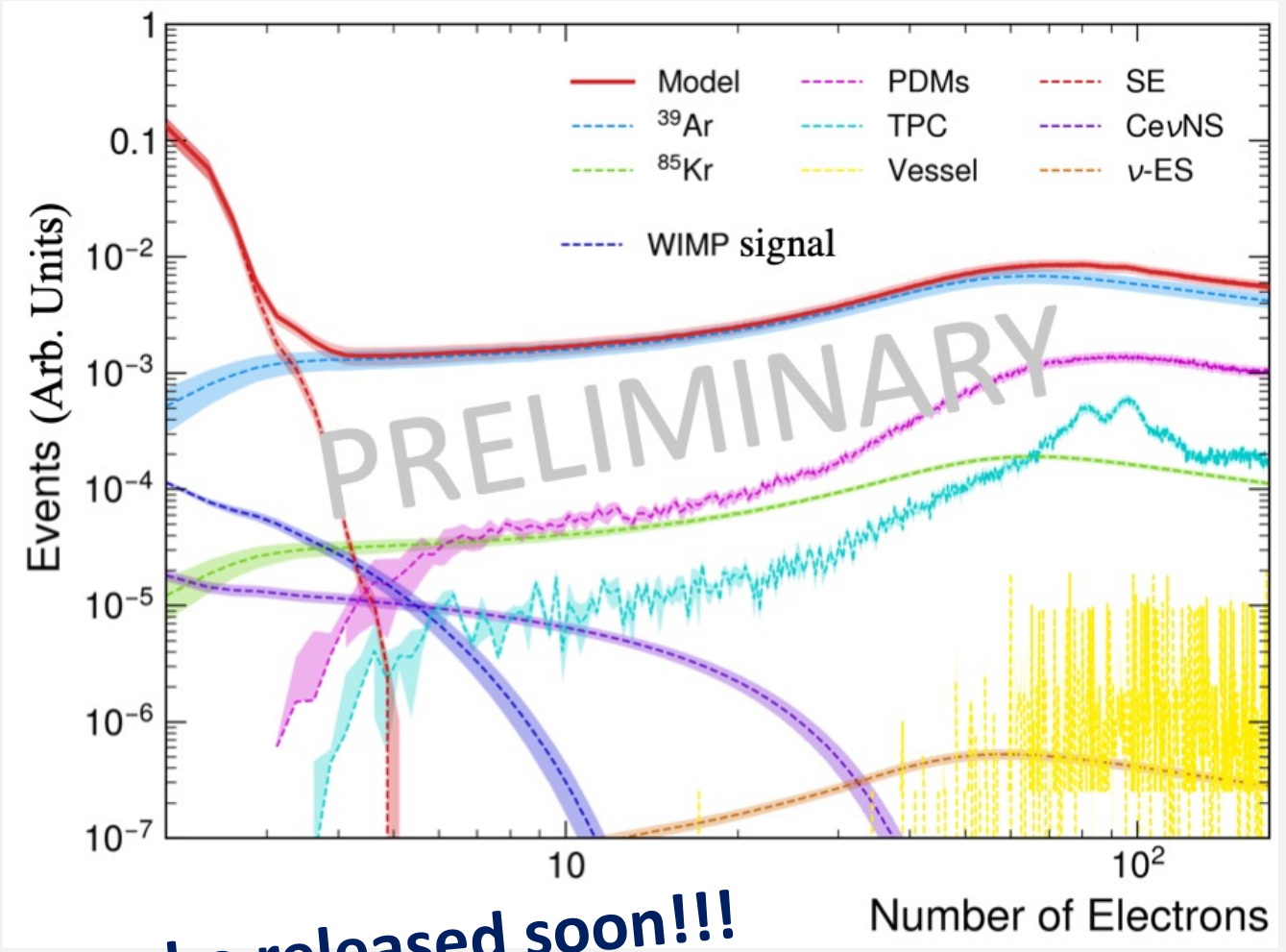
ARIA:

- 350 m cryogenic distillation column
- O(1 tonne/day) with x10^2 reduction of all chemical impurities
- 10 kg/day with x10 reduction of $^{39}Ar/^{40}Ar$
- Seruci-0 column tested in 2019 with LN2 and with Ar in 2021
- Demonstrated isotopic separation of ^{36}Ar, ^{38}Ar, ^{40}Ar
- No isotopic separation for DS-20k target

DS-20k Collaboration Eur.Phys.J.C 81 (2021) 4, 359
DS-20k Collaboration Eur.Phys.J.C 83 (2023) 5, 453

Backgrounds in DS-20k

- X-rays and γ:
  - SiPMs bkg is 1-2 order of magnitude lower than $^{39}\mathrm{Ar}$
- Neutrinos:
  - **CEvNS** : at the level of gamma/x rays from the walls
  - **vES:** at the level of gamma/x rays from the vessel
- Spurious electrons or "**Single Electrons**" (SEs):
  - In DS-20k expected to be the dominant bkg for $N_e - < 4$
- β-decay:
  - $^{39}\mathbf{Ar}$: activity assumed to be 0.73 mBq/kg (DS-50 level)
  - $^{85}\mathrm{Kr}$: activity assumed to be 19 μBq/kg (reduced by a factor 100 wrt DS-50)



Sensitivity to low mass WIMPs to be released soon!!!

Final Remarks

DS-20k will have a dual-phase argon TPC with 50 (20) tonnes active (fiducial) mass

- Currently under construction
- Largest dark matter detector ever built
- Commissioning expected by end 2026

High sensitivity to light dark matter particles (sensitivity to be released soon):

- Key ingredients:
  - CEvNS
  - vES
  - ^{39}Ar: Urania and Aria projects
  - Single Electron signals

High sensitivity to high-mass WIMPs:

- Main background sources are given by atmospheric neutrino CEvNS and neutrons from the materials

Thank you for your attention!
Question Time