Sensitivity to core-collapse supernovae neutrino signals in DarkSide-20k

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XX NEUTRINO TELESCOPES

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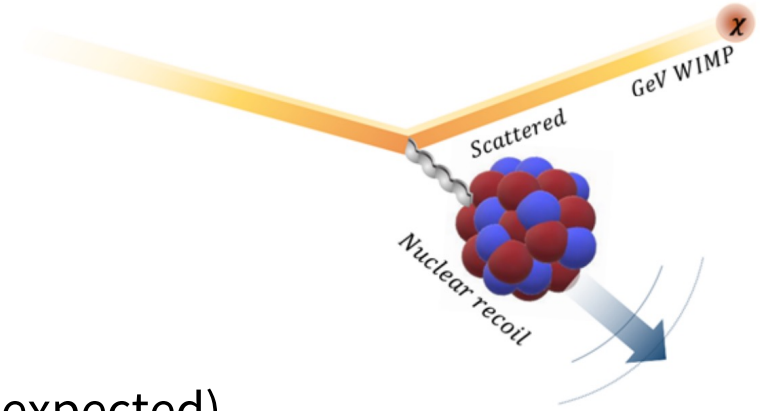
Overview

- Introduction
- The DarkSide-20k experiment
  - Structure
  - Underground Argon
  - Photoelectronics
  - Current status of the experiment
  - Sensitivity
- Core-Collapse Supernovae Neutrino Signals in DS-20k
- Conclusions

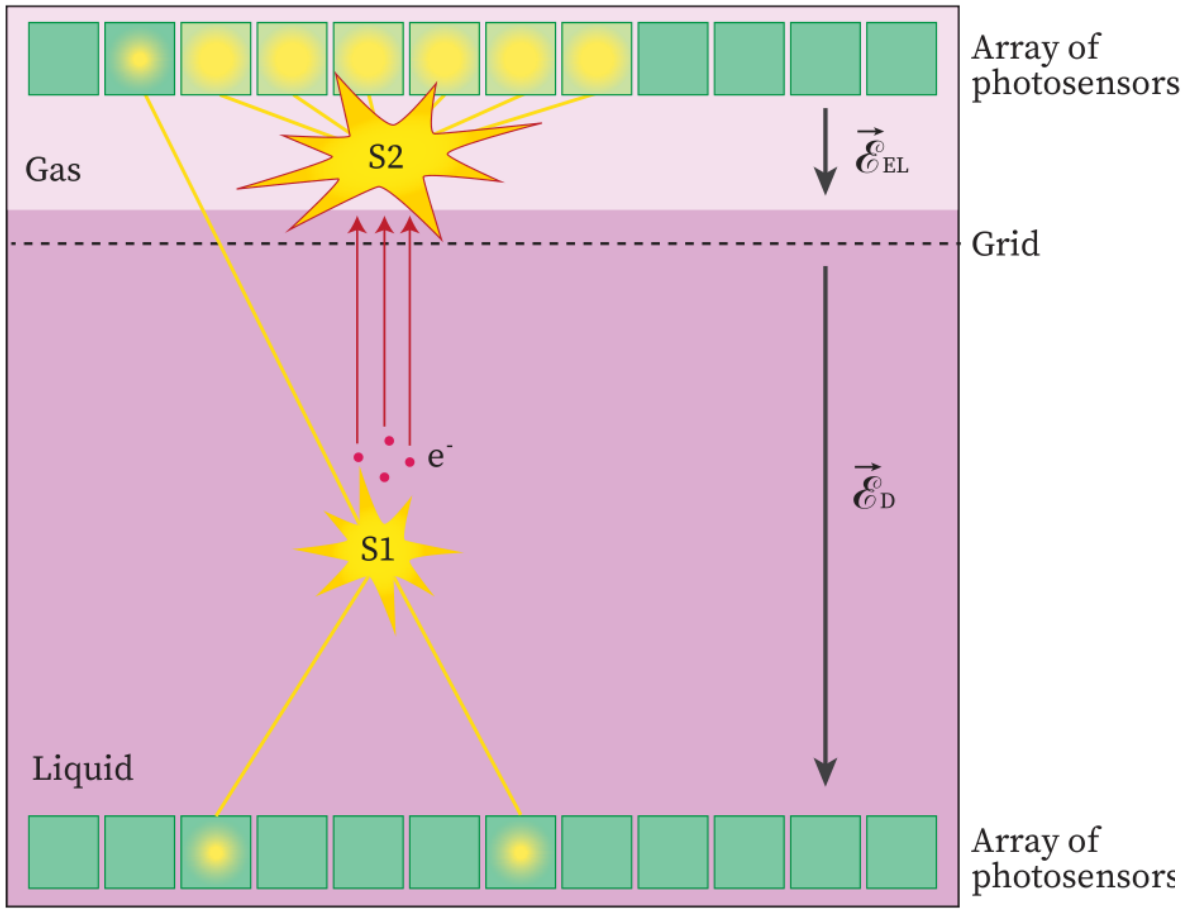
Direct detection of Dark Matter

- WIMP hypothesis: Weakly Interacting Massive Particle
- **Interaction**: Coherent elastic WIMP-Nucleus scattering ($\propto A^2$)
- **Expected signal**: nuclear recoils 1-100 keV (non relativistic)
- **Signatures**: exponential single-recoil spectra (handful of events expected)
- **Requirements:** high exposure, ultra-low background (accurate PID, material choice)

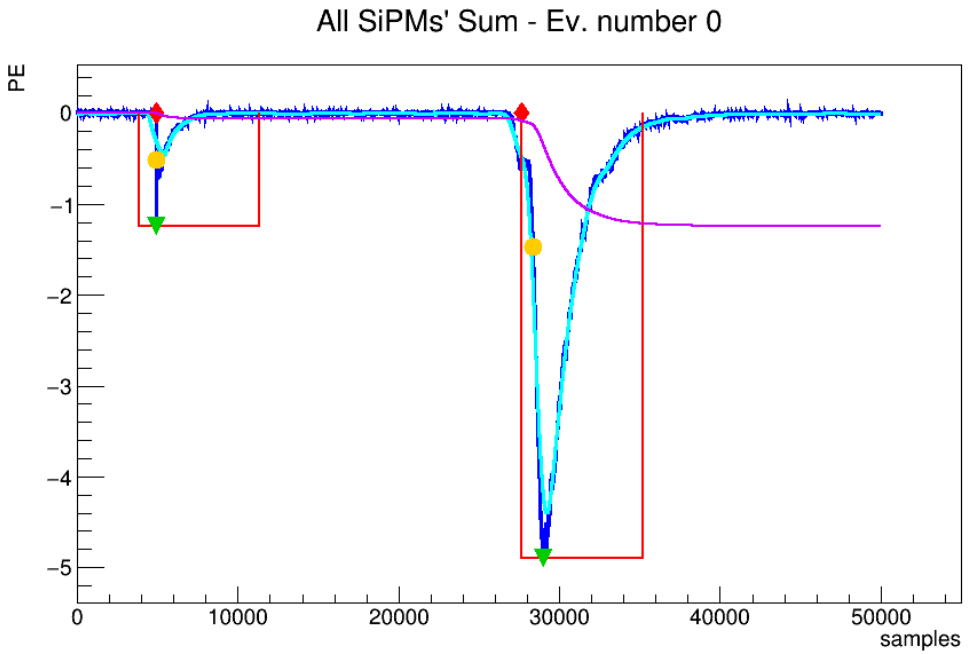


$$\frac{dR}{dE_R}(E_R, t) = N_N \frac{\rho_0}{M_\chi} \cdot \int_{v > v_{\min}} v\, f(\vec{v}, t) \frac{d\sigma}{dE_R}(E_R, v)\, d^3v$$

Two-phase Argon TPCs

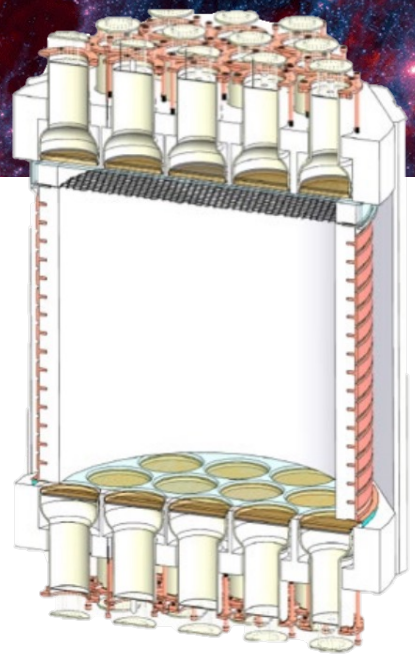


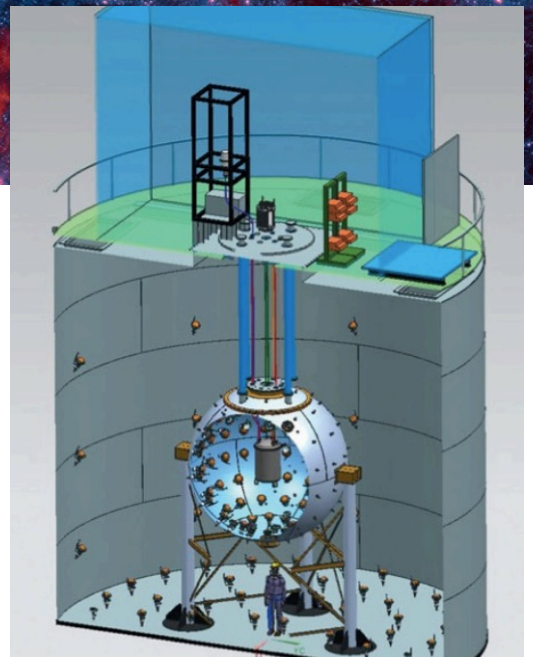
- Full 3D reconstruction:
  - xy from S2 geometrical distribution
  - z from drift time
  - Good fiducialization
- Highly efficient PID with Ar PSD

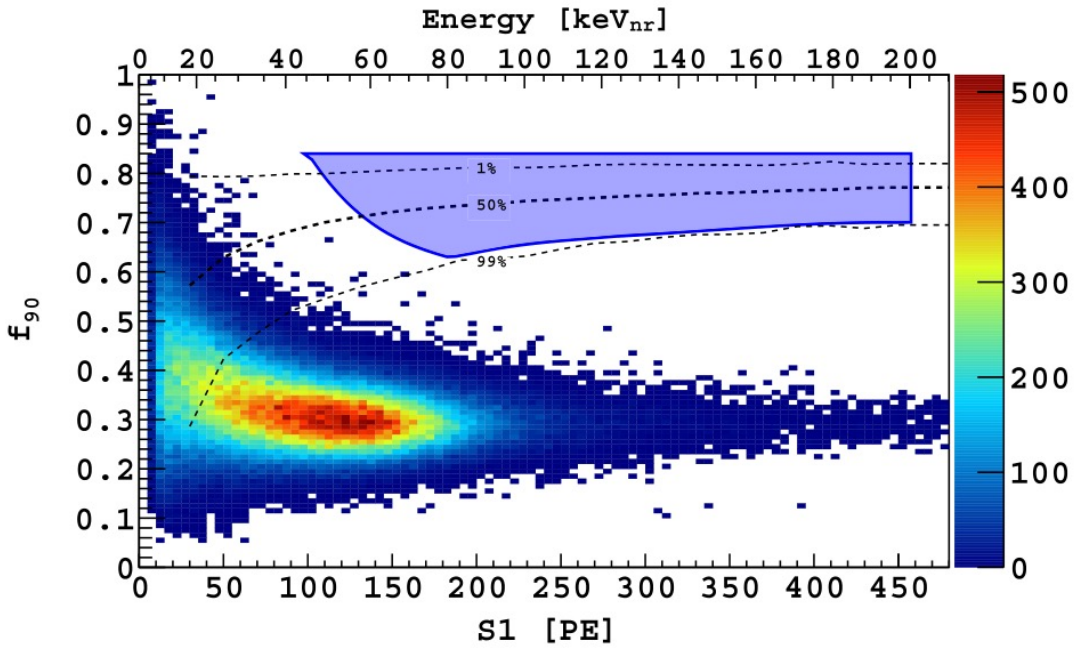


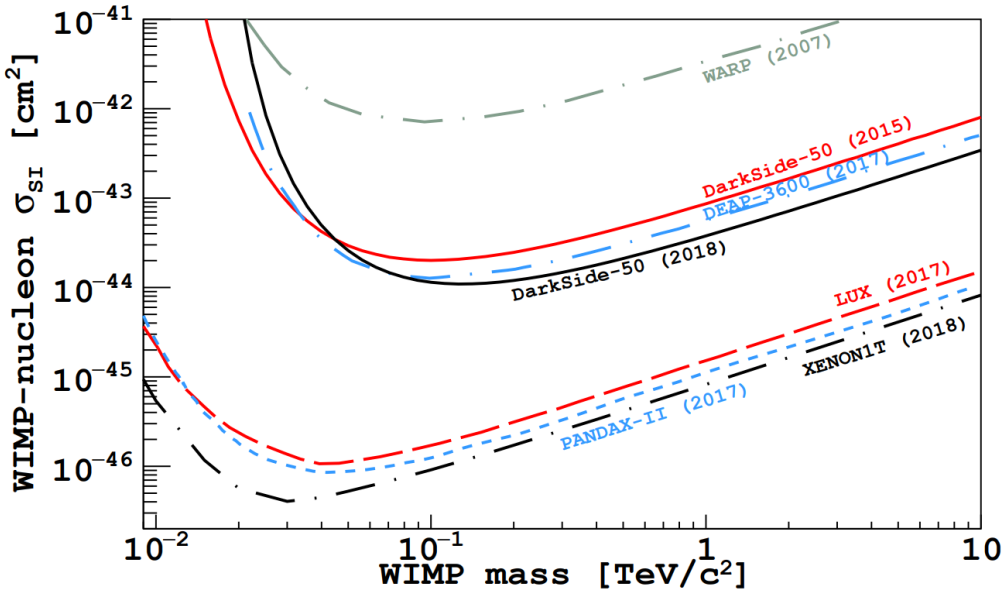
DarkSide-50

- Underground experiment at LNGS (3800 m w.e.)
- Inner Detector: fiducial volume = (46.4 ± 0.7) kg
- Two veto detectors: LSV and WCD
- 532.4 live days of UAr blinded data
- b < 0.1 for the full exposure
- 1.14×10^{-44} cm^2 90% CL limit on DM-Nucleon cross-section for 100 GeV/c^2 DM



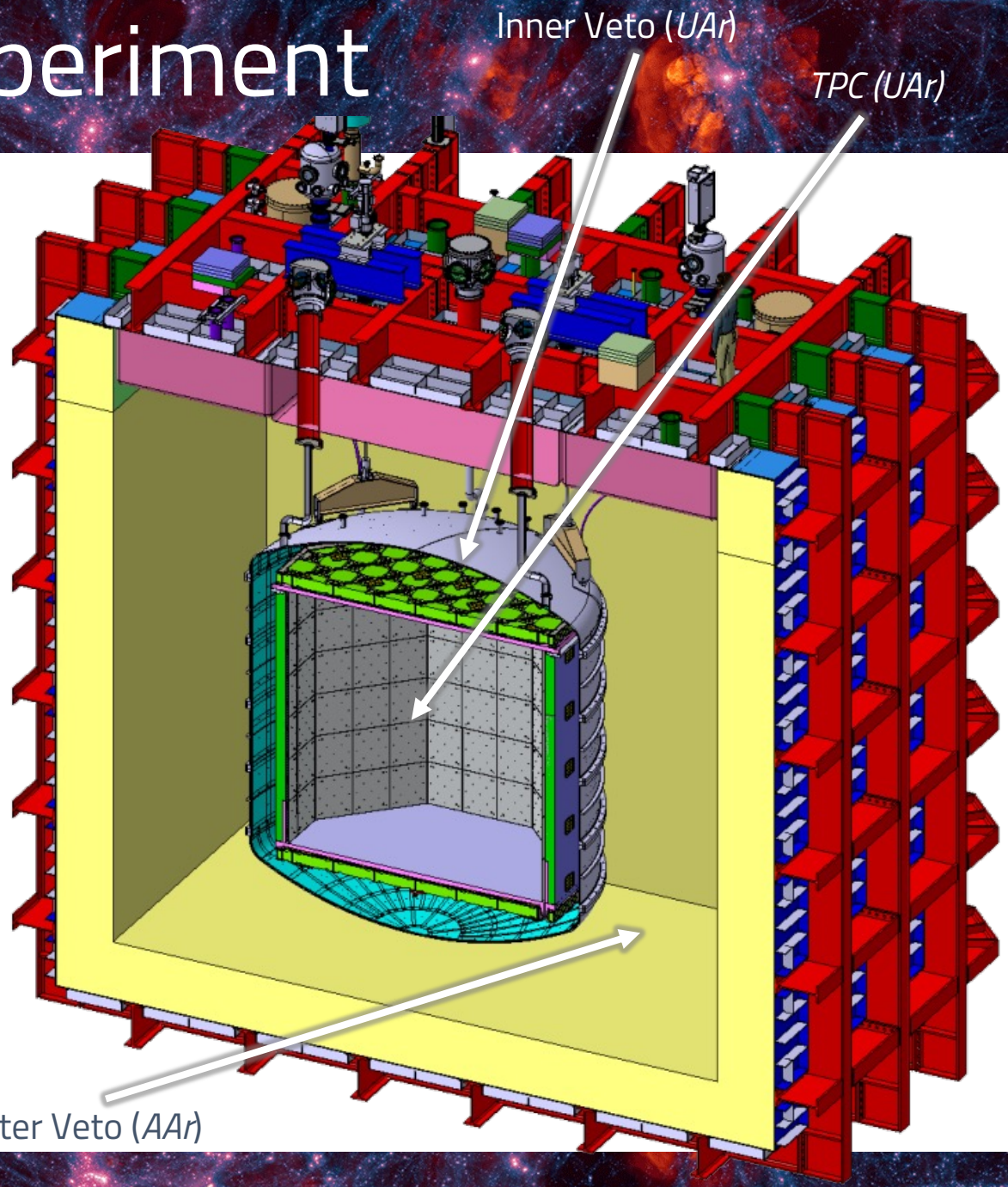






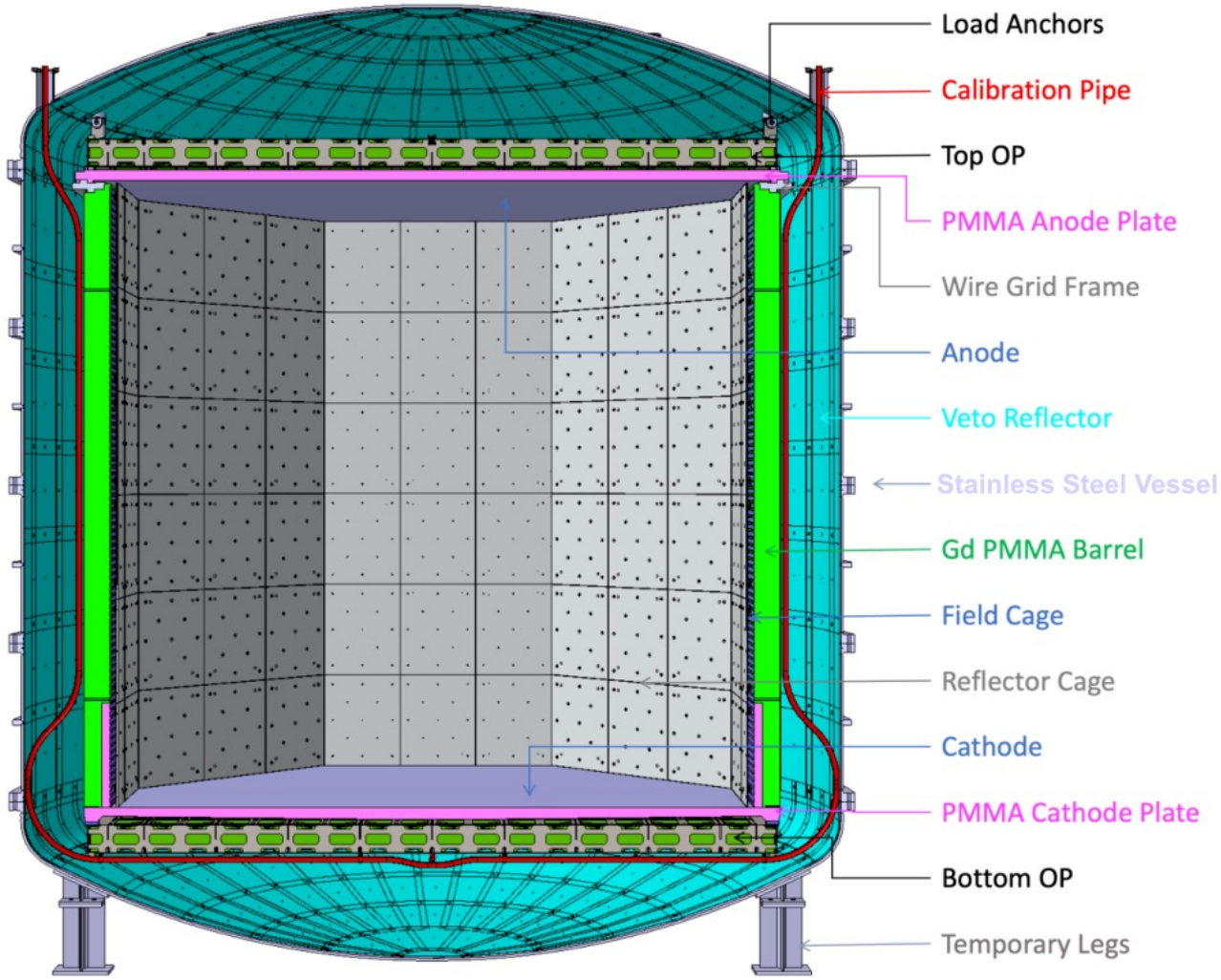
The DarkSide-20k Experiment

- In construction at Hall C of LNGS (3800 m w.e.)
- Nested detector structure:
  - **Outer Veto:**
    - Muon veto
    - ProtoDUNE like membrane cryostat 8x8x8 m^3
  - **Inner Detector:**
    - Stainless steel vessel containing the TPC and inner veto
    - 100 t of UAr (including TPC UAr)
    - **Veto:**
      - Veto for neutrons and gammas
      - Neutron capture with Gd-infused PMMA walls of the TPC
    - **Two-phase Ar time projection chamber**
      - *…next slide*
- Target background < 0.1 (excluding neutrinos) in 200 t yr



The two-phase TPC of DS-20k

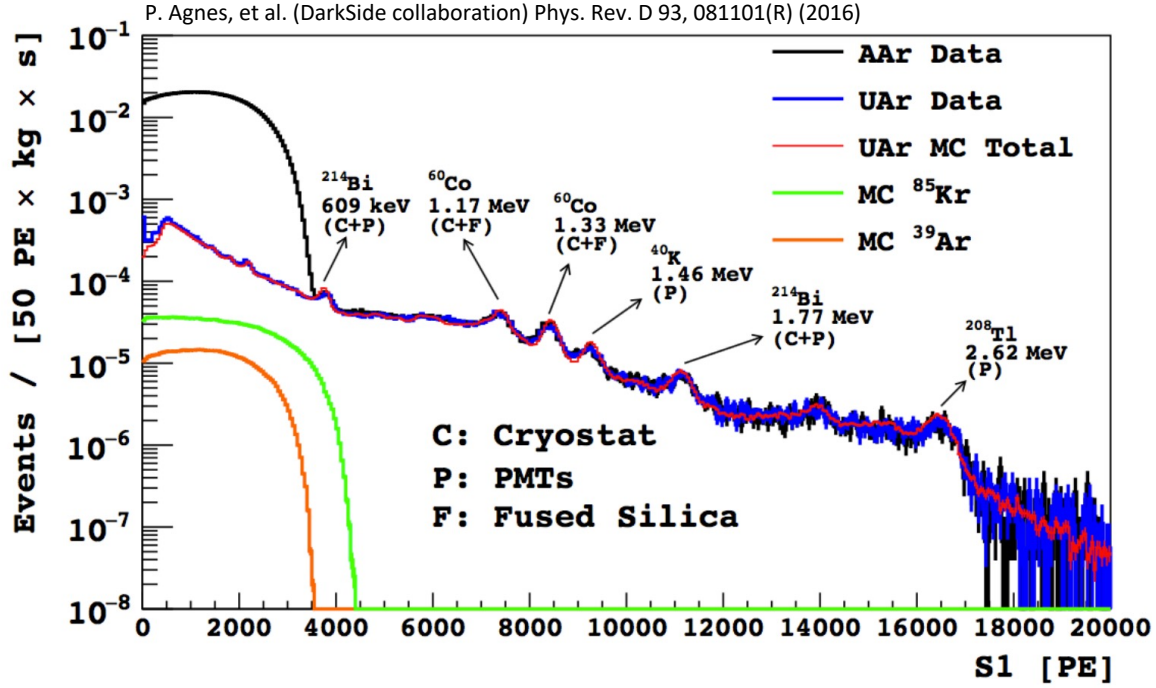
- **DarkSide-20k TPC:**
  - **Walls**:
    - Gd-PMMA
    - WSR Reflector
    - TPB wavelenght shifter
  - **Top and bottom:**
    - PMMA
    - TPB wavelenght shifter
    - Optical planes comprised of SiPM photo-detector units
  - **Fields**:
    - Clevios coating for Anode, Cathode, Field Cage
    - Wire grid of stainless steel, supported by a suited frame
    - Drift field (*nominal*) = 200 V/cm
    - Extraction field (*nominal*) = 2.8 kV/cm
    - Luminescence field (*nominal*) = 4.2 kV/cm
  - **Drift length =** 348 cm
  - Active UAr mass in TPC = 49.7 t
  - Gas pocket thickness = (7.0 ± 0.5) mm
  - Spatial resolution: xy < 5 cm, z ~ 1 mm

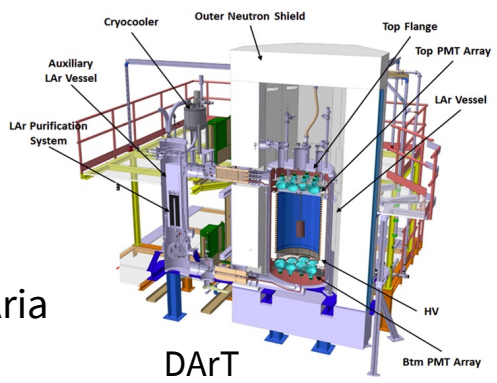


Argon procurement for DS-20k

- Atmospheric Argon (AAr): ~1 Bq/kg from ^{39}Ar
  - Cosmogenic radio isotope, β endpoint 565 keV
  - Pile-up issue (no background)
- Underground Argon: ~ 1/1400 Bq/kg
  - Demonstrated by DS-50 [Phys. Rev. D **93**, 081101(R)]
- **Argon in DS-20k will be UAr:**
  - URANIA
    - Extraction facility in a CO2 mine in Cortez, CO, USA
    - 99.99% purity @ extraction rate 250-330 kg/day
  - ARIA [arxiv:2301.09639]
    - Distillation tower in Nuraxi-Figus (SU), Italy
    - Chemical purification rate: 1 t/day
    - First run of isotopic separation with Ar *(EPJC (2023) **83**: 453)*
  - DArTinArDM
    - Facility at LSC in Canfrac *(JINST 15 (2020) 02, P02024)*
    - Measurement of ^{39}Ar abundance in Uar from Urania/Aria
    - First test with DS-50 UAr

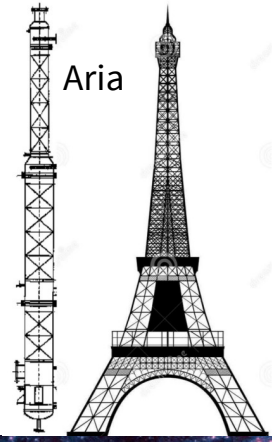
P. Agnes, et al. (DarkSide collaboration) Phys. Rev. D 93, 081101(R) (2016)



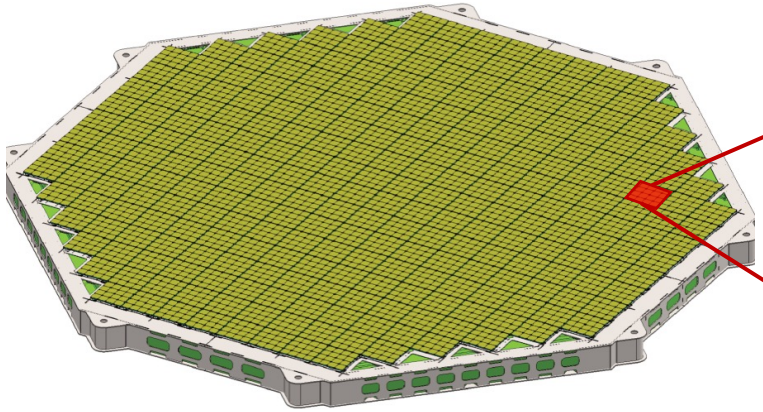


DArT

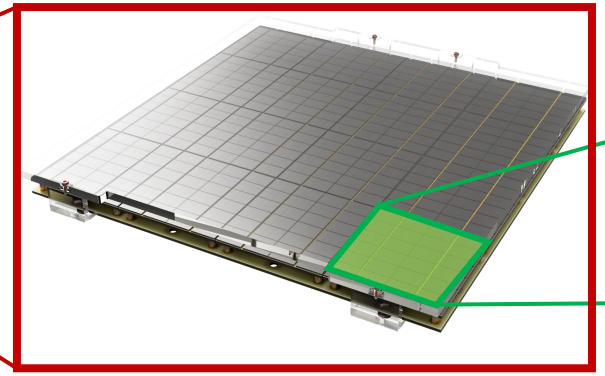

Aria


Aria

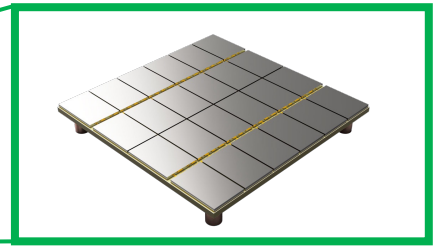
Photoelectronics of DS-20k



Optical planes: ~2x10 m^2
Total PDUs used: 525
100% coverage



PDU: 20x20 cm^2
16 Tiles assembled on a Motherboard
4 Readout Channel



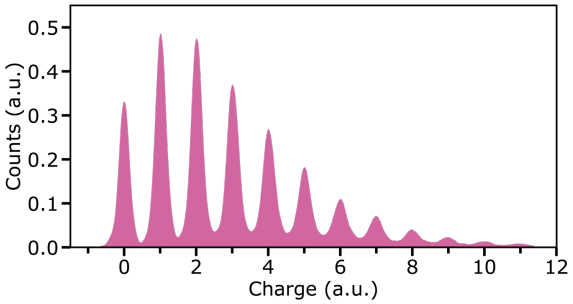
Tile: 5x5 cm^2
24 SiPMs directly mounted on a FEB
SiPM: NUV-HD-CRYO developed by FBK and produced by LFoundry

PDU: Modular photosensor unit

- **TPC PDU**:
  - PDU assembled in Nuova Officina Assergi (NOA)
    - NOA is a 420 m^2 ISO-6 clean room with a reduced Rn concentration
    - 525 TPC PDUs to be tested at the Naples Test Facility
- **VETO PDU**:
  - Assembled in UK
  - 120 VETO PDUs to be tested in multiple facilities in UK and Poland

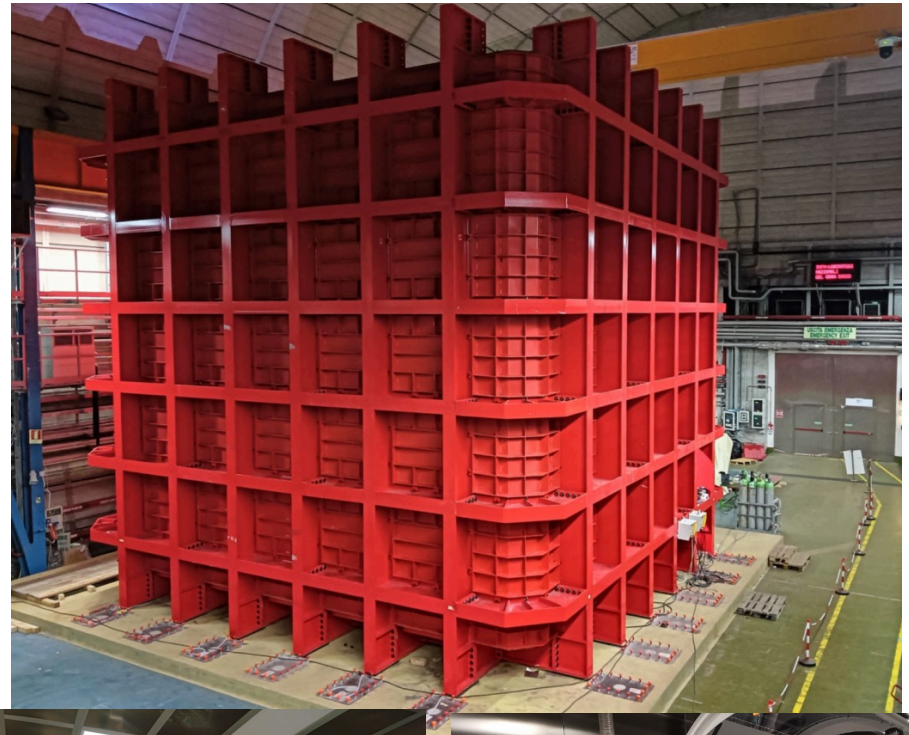
NOA at LNGS

Prototype PDU data from Naples Laser calibration (1 CH, 7 V o.v.)



Current Status of DS-20k

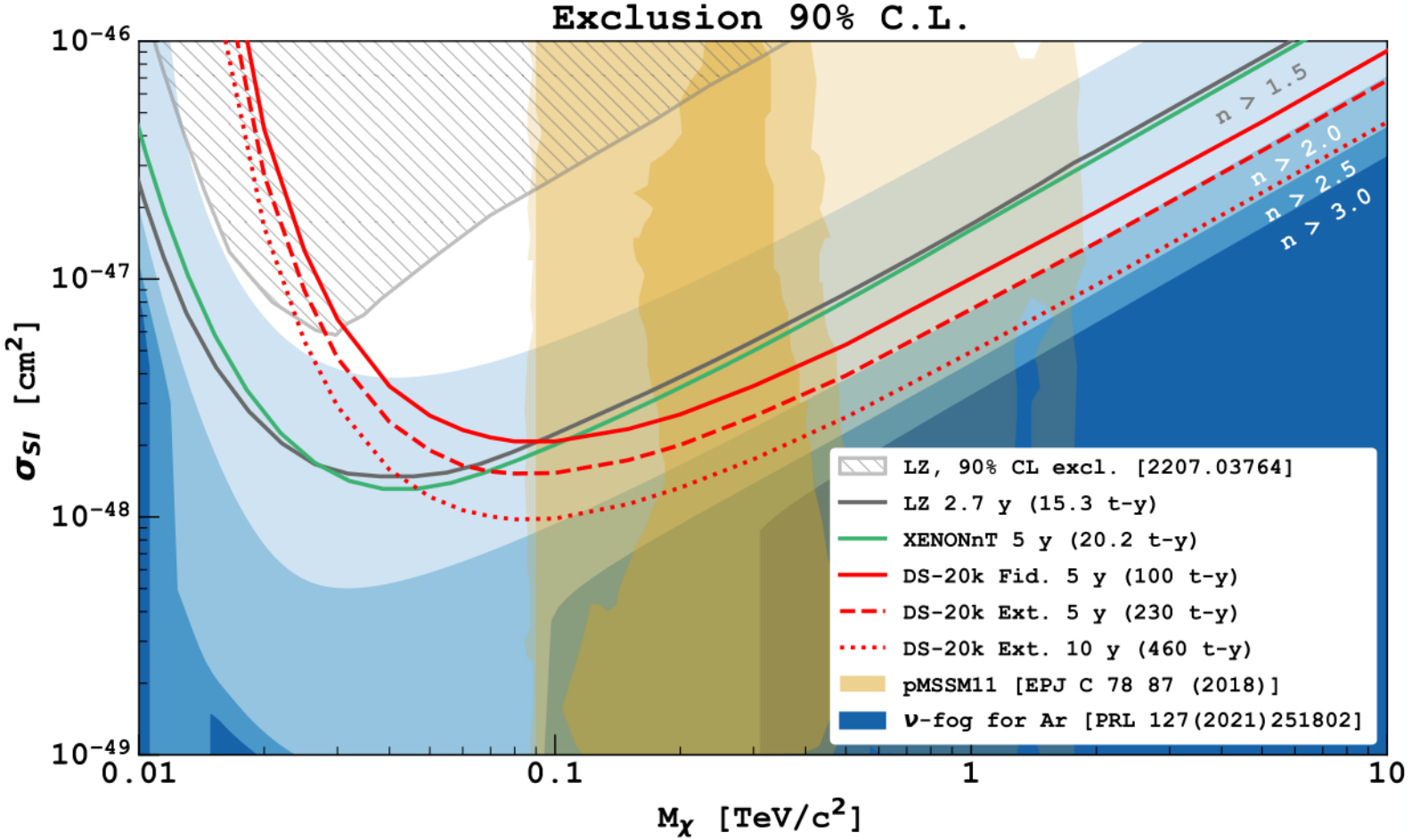
- **Infrastructure**:
  - Steel support for the cryostat built at Hall C in LNGS
  - Procurement for cryogenics and cryostat cold structure in progress → installation in 2024H1
- **Prototypes**:
  - Darkside Proto-0 will run in 2023Q4 in Naples
  - DS-20k Mockup operations started, functional in 2024 at LNGS
- **Photo-electronics**:
  - NOA operational and testing SiPM wafers
  - Naples PDU Test Facility ready for mass testing before 2023Q4
  - vPDU production in UK starting before end of year
  - vPDU test facilities in commissioning



Sensitivity of DS-20k

- Upper limits for a 1 TeV/c^2 WIMP (90% C.L. exclusion) of 6.3 x 10^{-48} cm^2
- First measurement of the neutrino “fog” for n > 1.5
- Expected 3.2 neutrinos in 200 t-y

- **What about core-collapse supernovae neutrinos?**



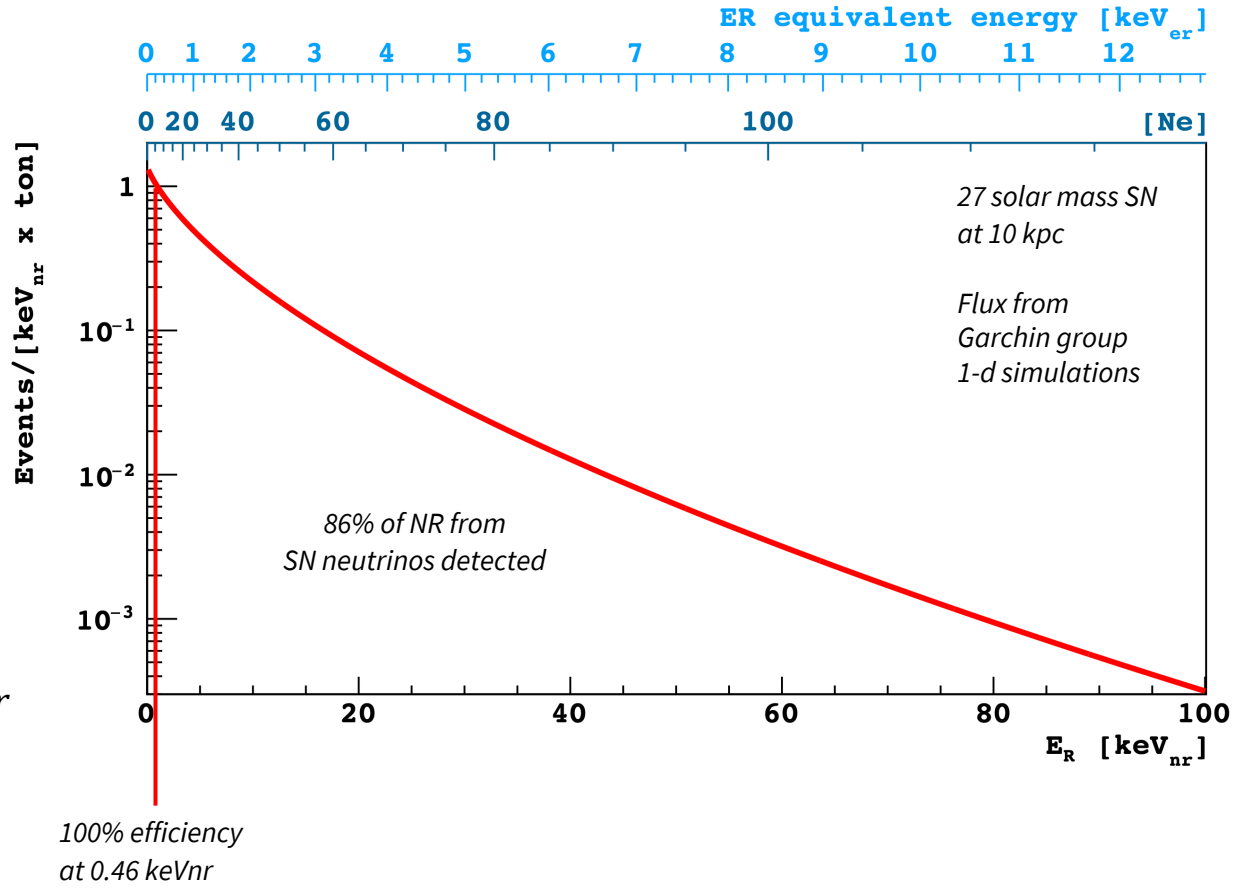
Detection of a Supernova via CEvNS

CCSN interaction for neutrino telescopes

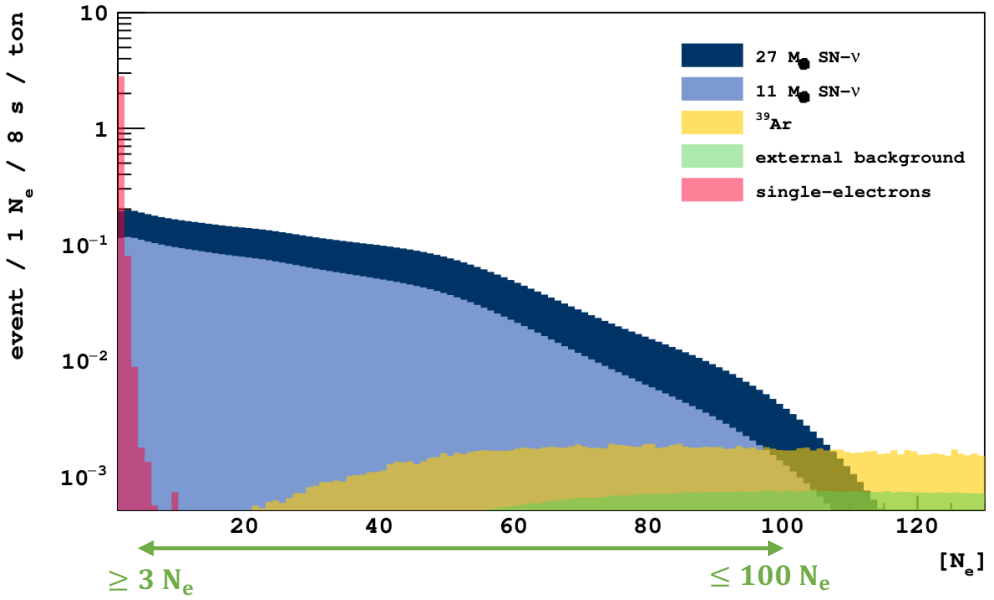
- **Charged Current**:
  - High energy [O(10 MeV)]
  - Mostly electron (anti-)neutrinos
  - "Low" Cross Section
- ***CEvNS* (Neutral Current)**:
  - Low energy [O(10 keV)]
  - Flavor Blind
  - "High" cross-section:

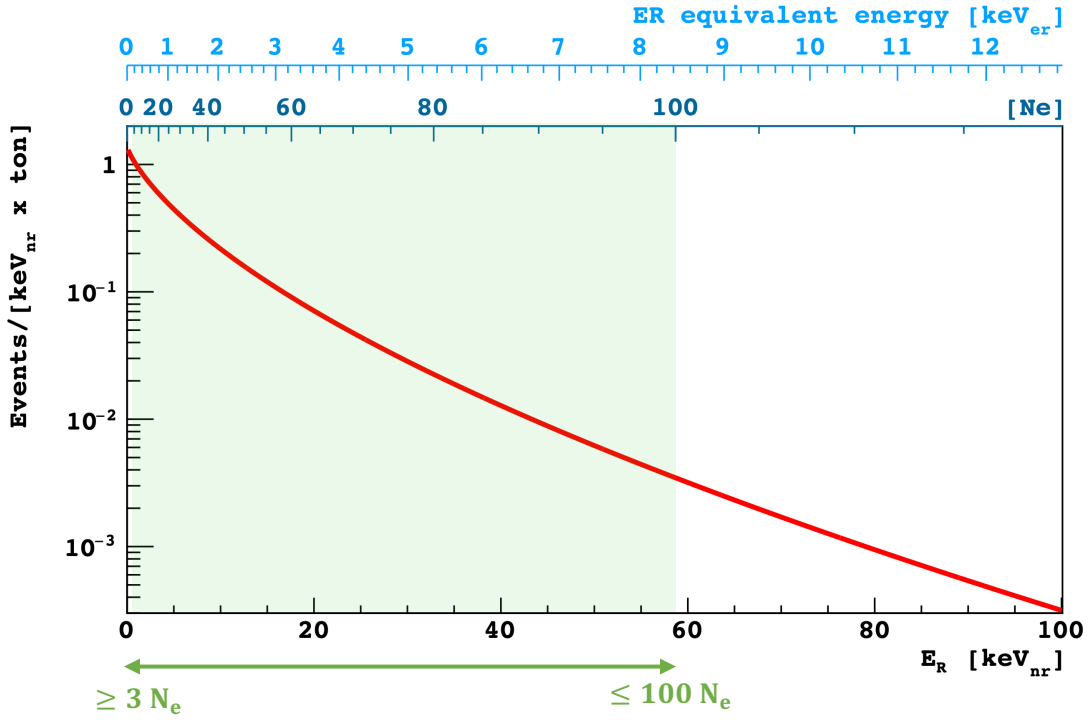
Not a problem for DS-20k

$$d\sigma(E_v, E_r) = \frac{G_F^2}{4\pi} Q_W^2 m \left(1 - \frac{mE_r}{2E_v^2}\right) F^2(q) dE_r$$



Background and No. of events





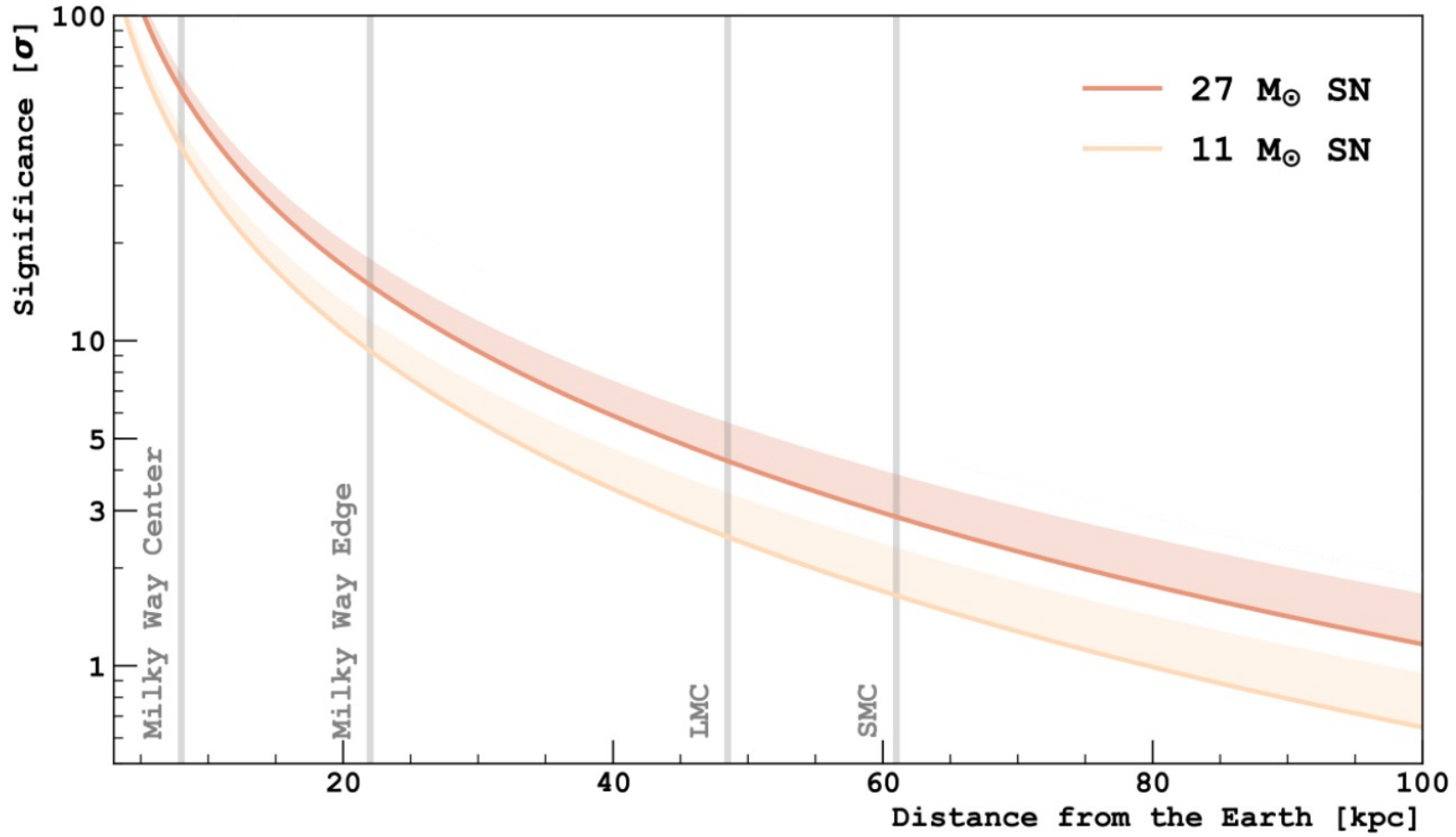
- Time resolution of 1.1 ms
- Background dominated by ^{39}Ar above 10 N_e
  - 0.5 Hz below 100 N_e cut from ^{39}Ar
  - 0.2 Hz of external background
- Below 10 N_e, background is single-electrons
  - 380 mHz/ton, reduced to ~0.5% with 3 N_e cut
- Time window: 8 s

Source	No. Of Events
11 $M_\odot$ SN-vs	181
27 $M_\odot$ SN-vs	337
^{39}Ar	4.3
External background	1.8
Single-electrons	0.7

S/B of 24 (45) for a 11 (27) $M_\odot$

Sensitivity to SN neutrinos

- Discovery potential covers distances up to the edge of the Milky Way for a 11 $M_\odot$ SN
- Slightly higher discovery sensitivity than XENONnT and LZ
- Will provide another input for triangulation of SN by joining SNEWS 2



Full Reference:
The DarkSide-20k collaboration *et al* JCAP03(**2021**)043
DOI 10.1088/1475-7516/2021/03/043

Conclusions

- DarkSide-20k for WIMP direct search:
  - two-phase argon TPC with 20 t fiducial volume
  - at LNGS Underground Laboratories
  - ultra-low background goal
  - Cryogenic SiPM based optical readout
  - Underground-extracted radiopure argon
- The construction of DS-20k is ongoing…
- It will be sensitive to core-collapse supernovae up to the edge of the Milky Way
  - … providing total neutrino flux normalization by measuring the flavor-insensitive CEvNS…
  - …and will be part of SNEWS2

Credits for the banner image: Illustris Simulation


Thank you!