A Global Liquid Argon Dark Matter Search Program

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On behalf of the Global Argon Dark Matter Collaboration (GADMC)

SUSY 2019, Corpus Christi, TX

May 23rd, 2019

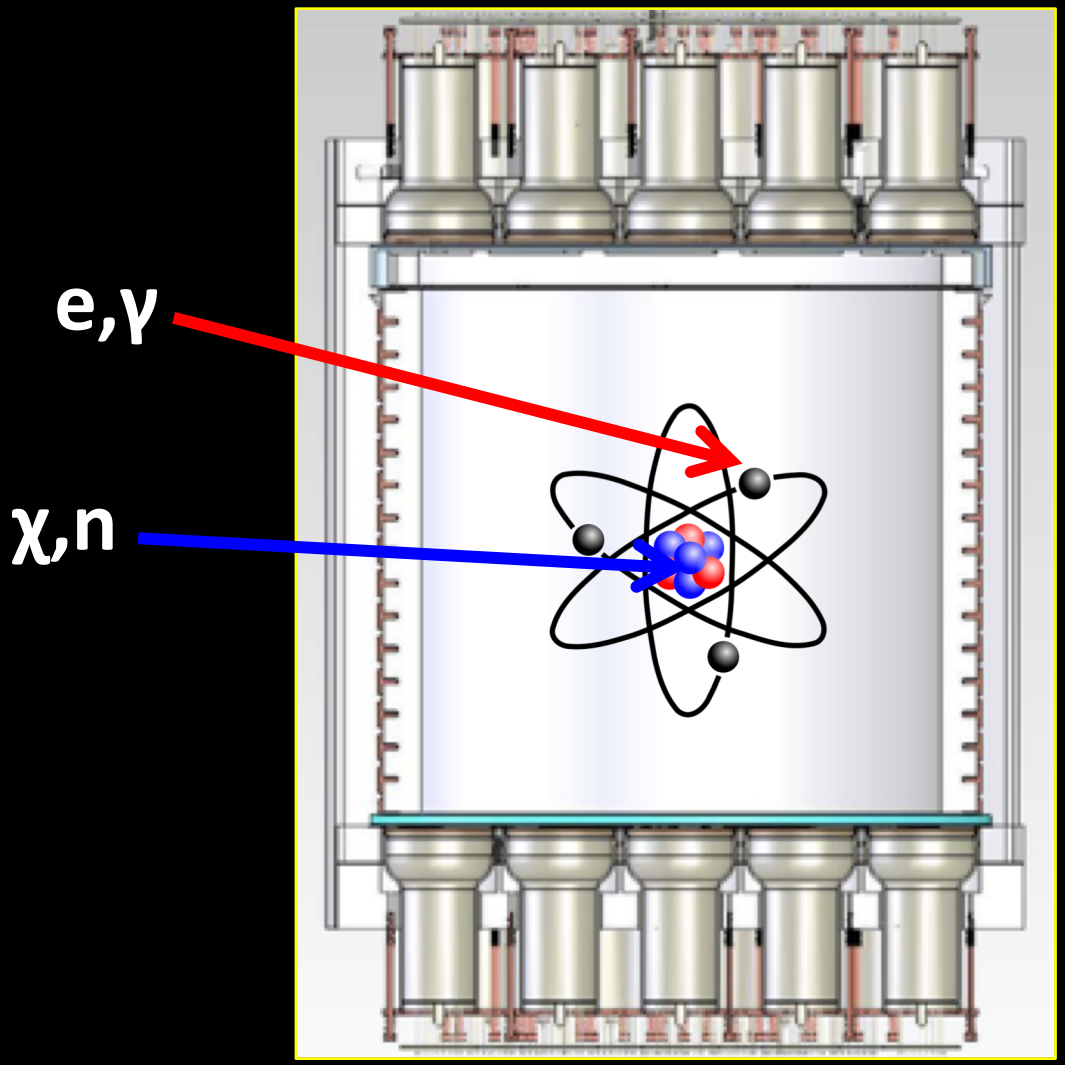
Why Liquid Argon (LAr)

- Efficient Scintillator
  - 40 photons/keV$_{ee}$ @ 128 nm
  - Transparent to own scintillation light
- High ionization yield
  - W ~10-20 eV with a high electron mobility
  - Further background discrimination with S2/S1 (factor of ~10^2)
- Powerful PSD in the scintillation signal
  - Separate ER background from the WIMP induced NR signal
  - Rejection factor of >10^9
- Simple cryogenic and gas handling with inline filter
  - Easily purified to achieve long electron drift lengths

Background Mitigation Strategy

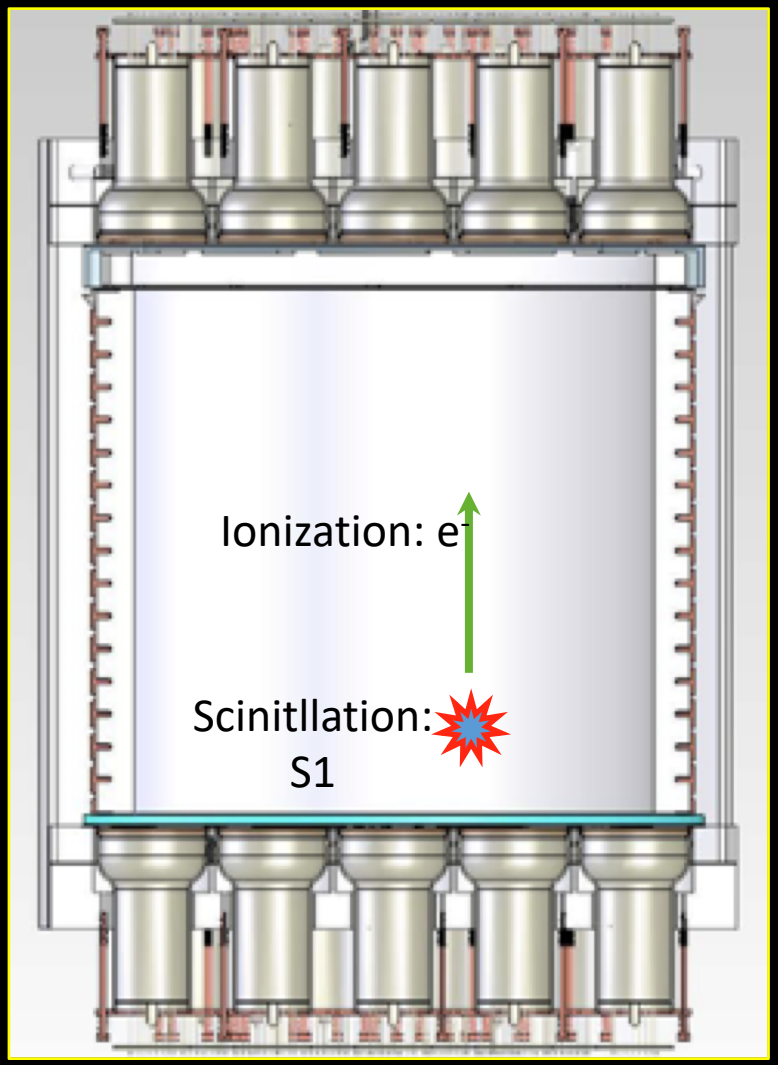
- Deep underground sites to shield cosmic rays
- Screening and selection of detector materials
- Two-phase Ar TPC: 3D-TPC fiducialization; S1 PSD, S2/S1 cut
- Active liquid scintillator neutron veto
- Underground argon (UAr) with reduced ^{39}Ar

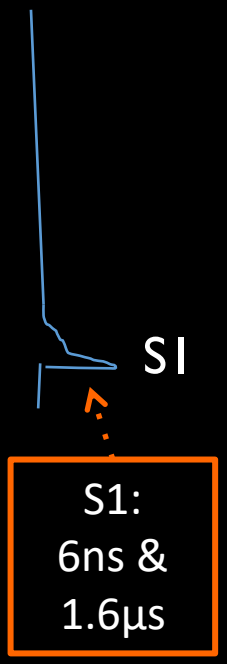
S1 Signal



S1 Signal

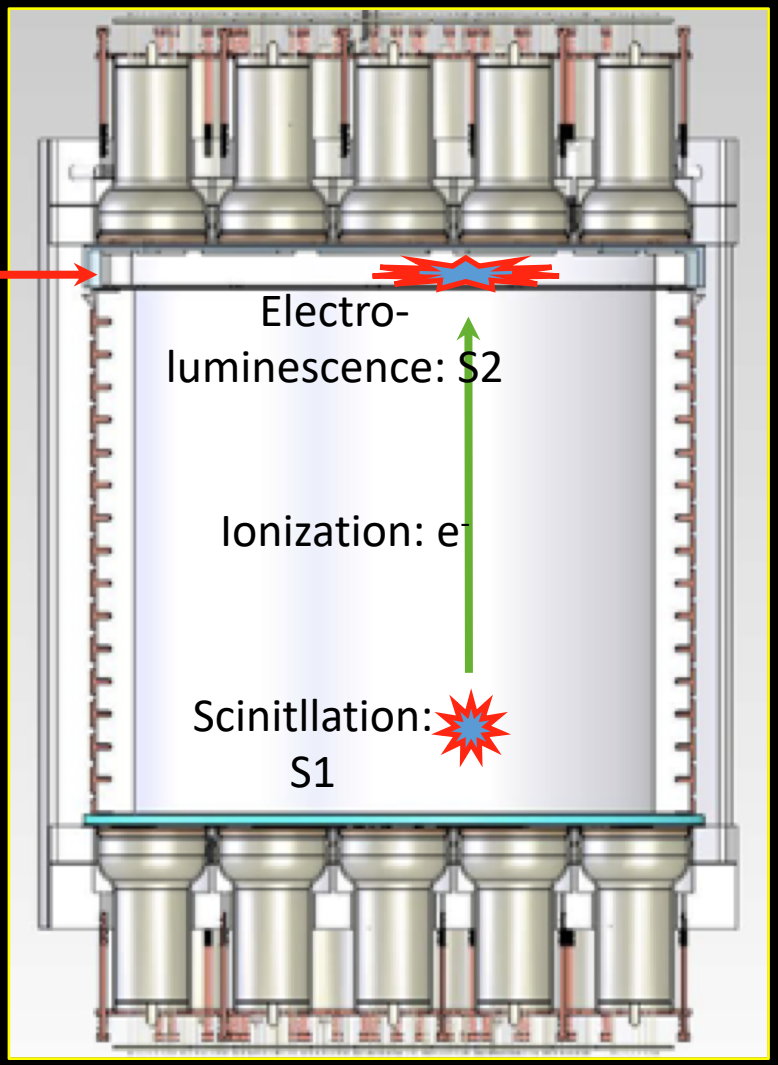
Field shaping rings
keep uniform
200 V/cm drift field

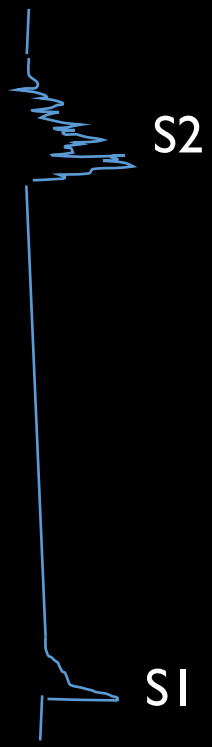




S2 Signal

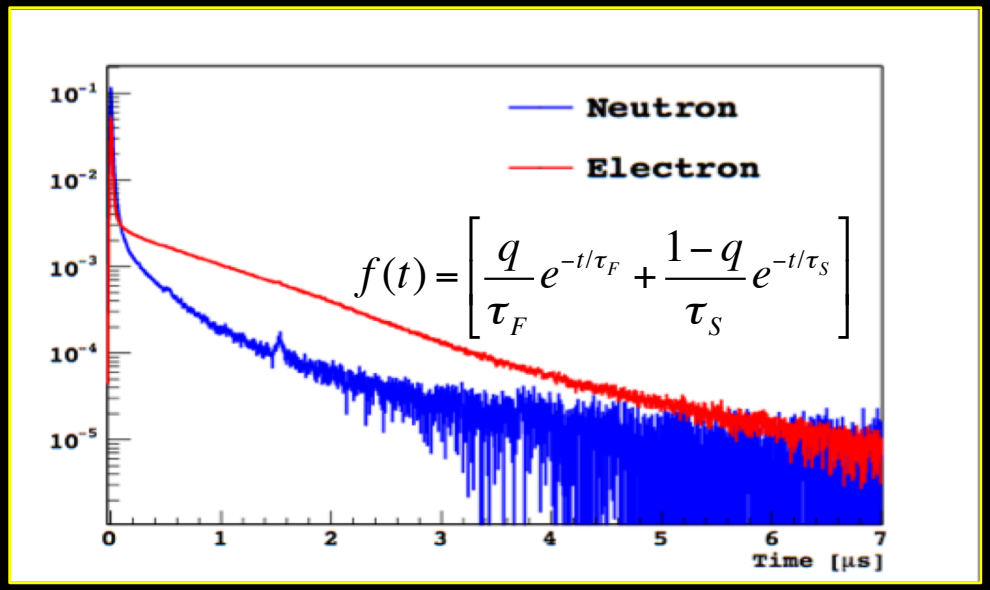
Extraction Field = ~3 kV/cm

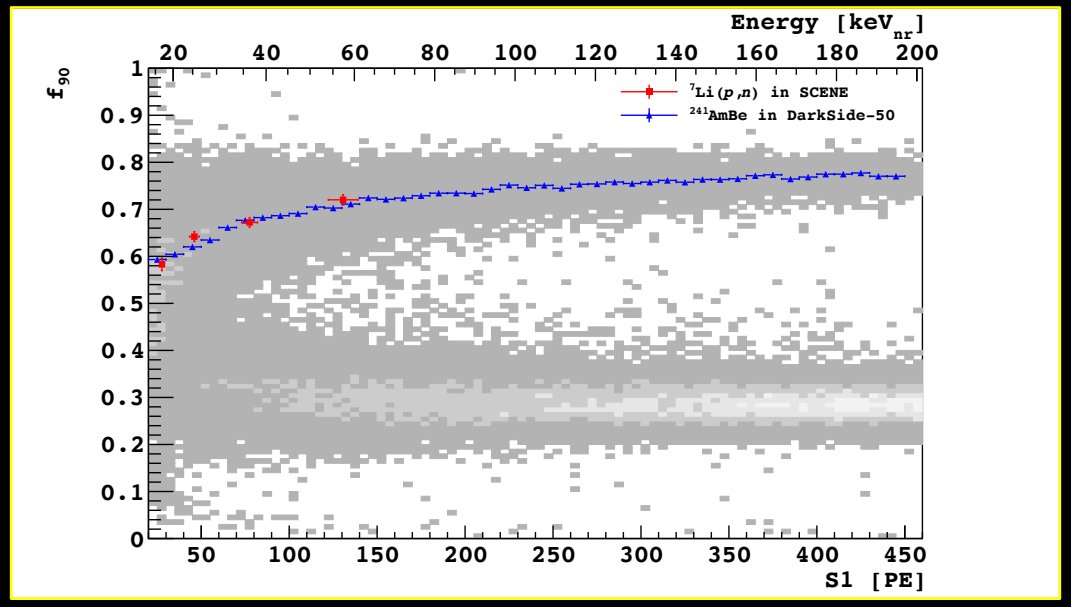




Pulse Shape Discrimination with S1

Singlet and triplet fraction difference gives >10^9 rejection between NR and ER



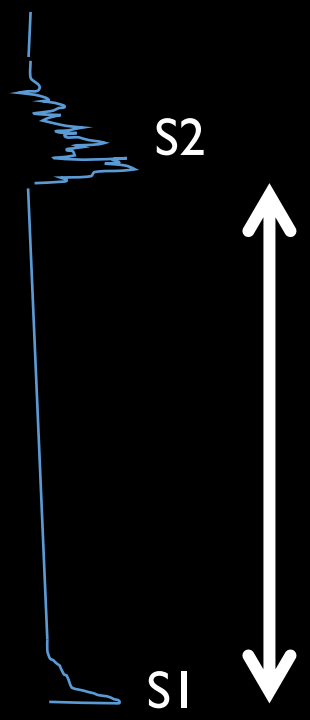


$$\tau_F = 6ns$$

$$\tau_S = 1.6\mu s$$

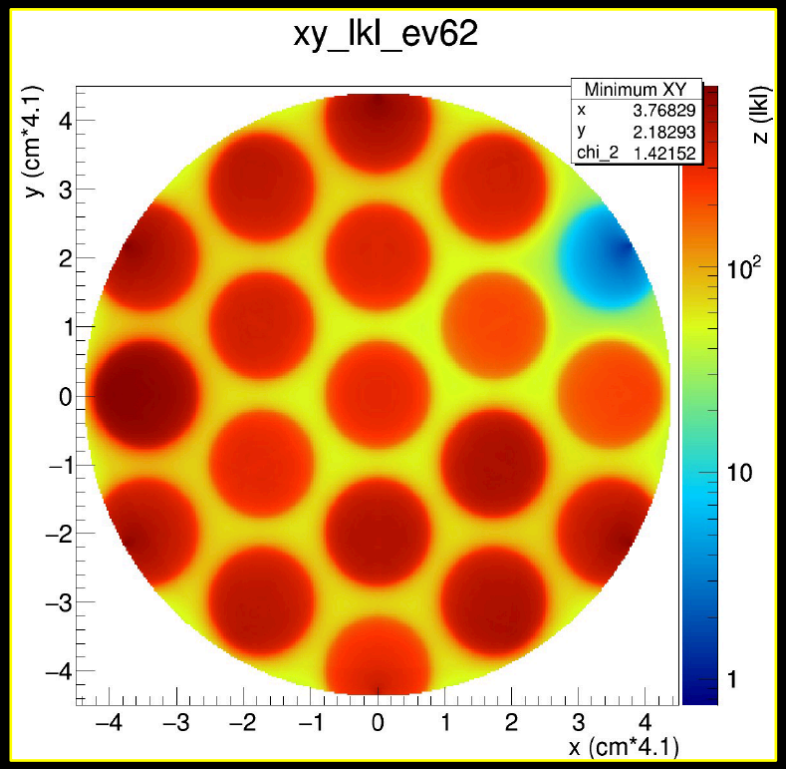
$$q = F90 = \left\{ \begin{array}{c} 0.3ER \\ 0.7NR \end{array} \right\}$$

2-Phase TPC



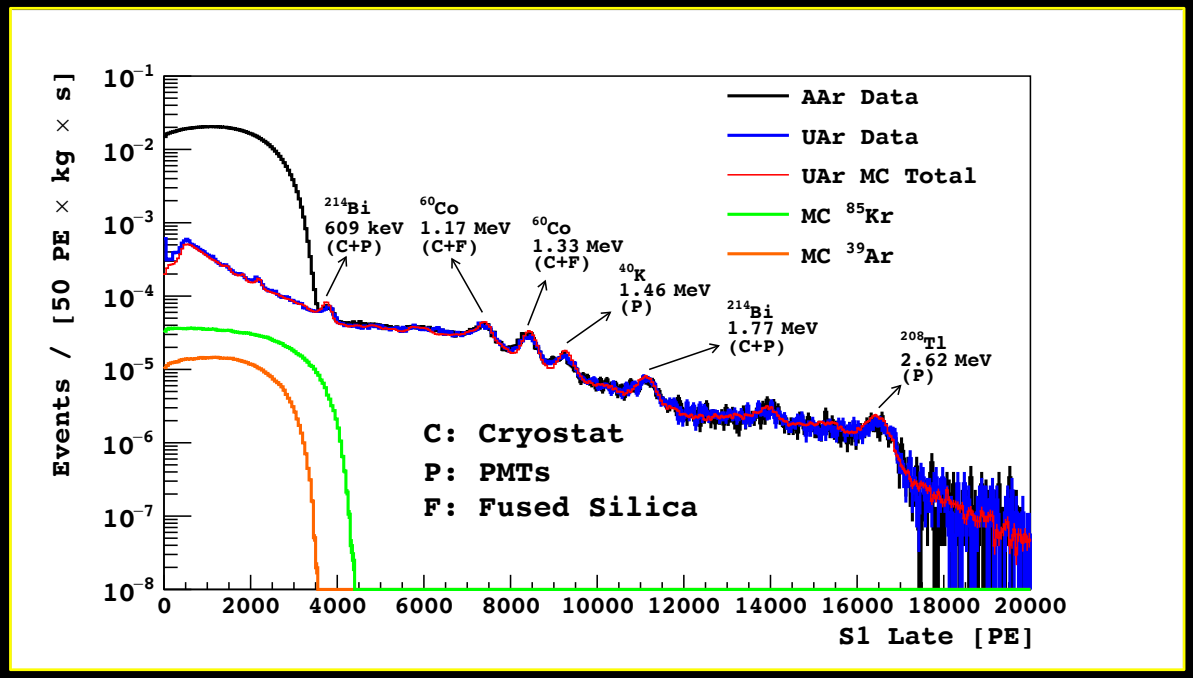
The drift time gives the z-position with mm precision

Top Array PMT light fractions for S2 give x,y location



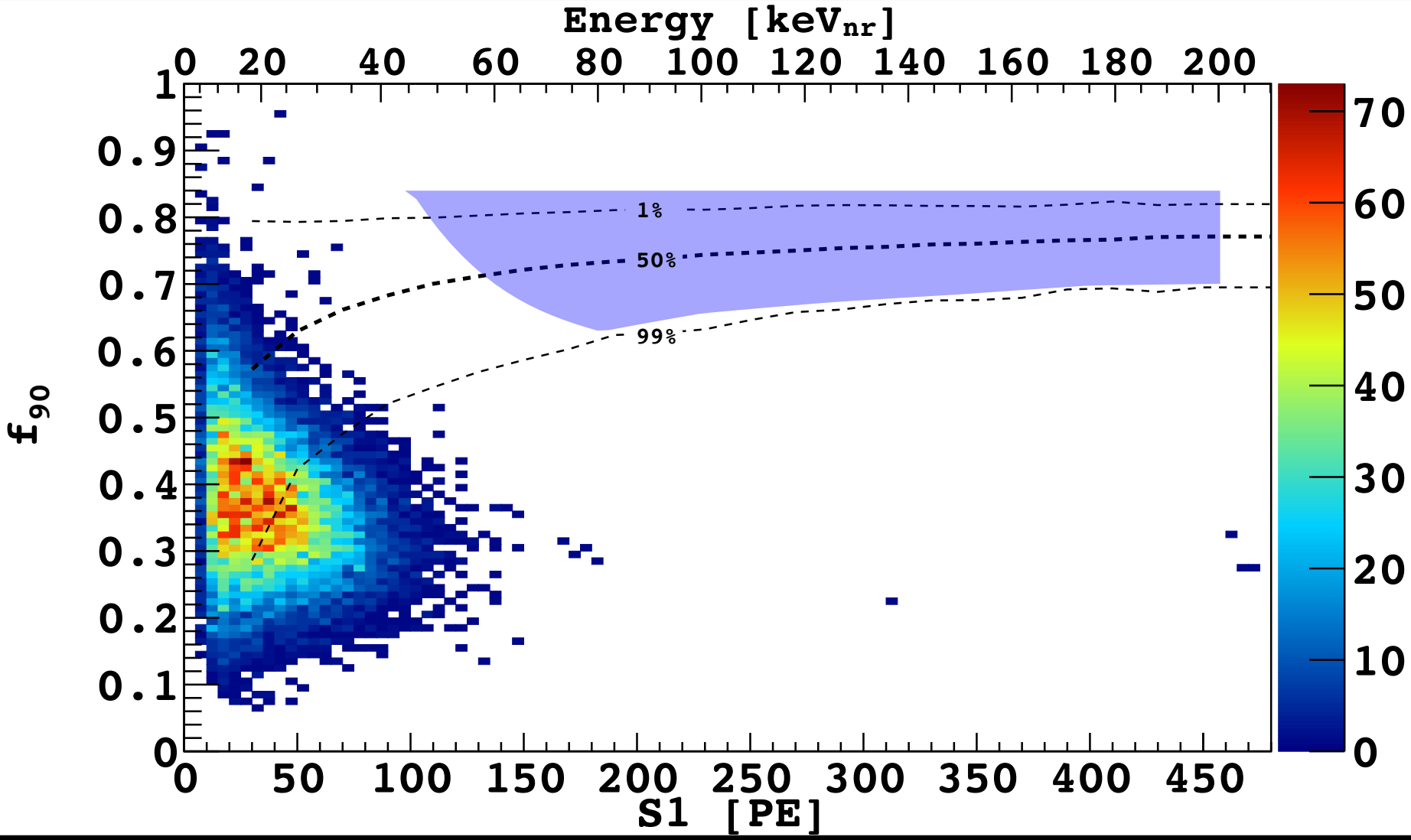
Underground Argon (UAr)

- $^{40}Ar(n,2n)^{39}Ar$ occurs in the atmosphere
- Argon that has remained underground can therefore have extremely low levels of ^{39}Ar

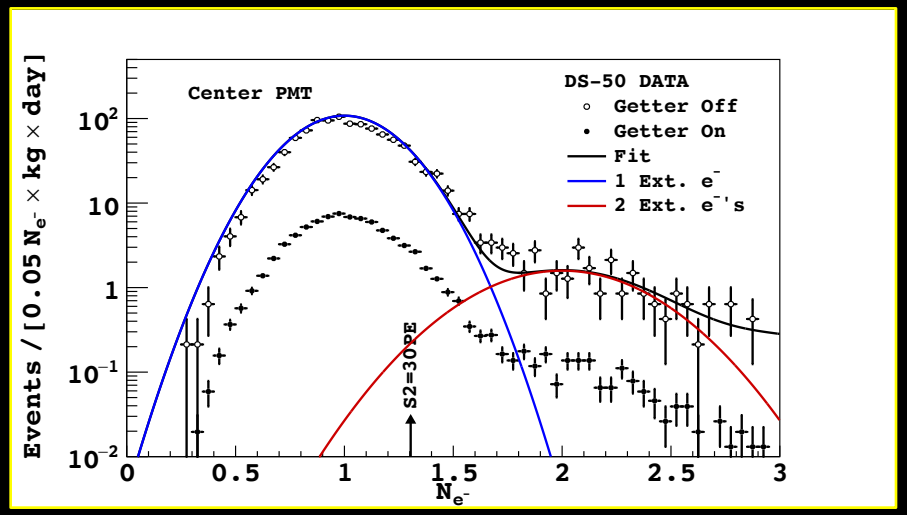


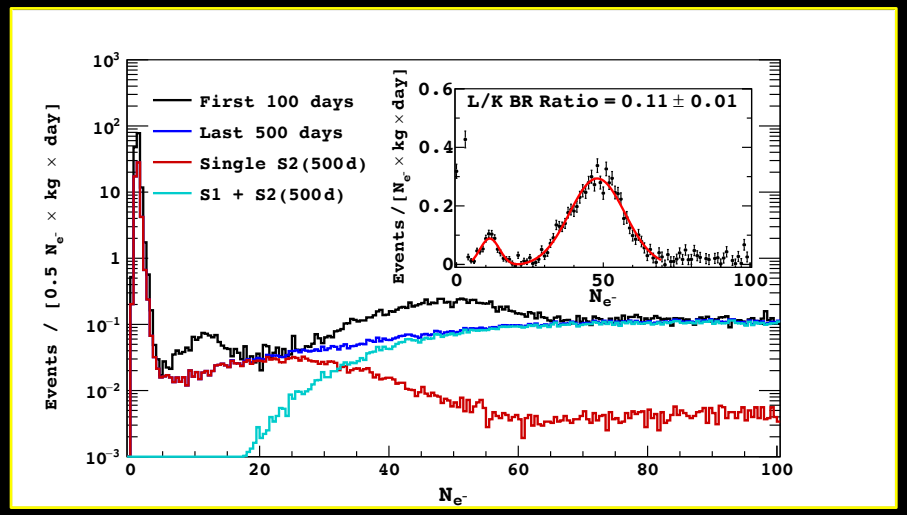
- DS-50 UAr fill measured the ^{39}Ar reduction factor: $>10^3$!!

16,660 kg day UAr exposure

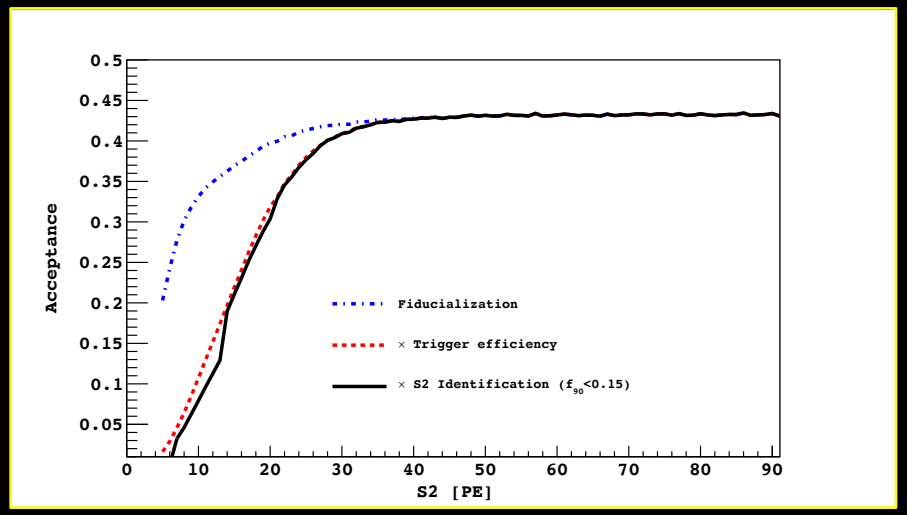


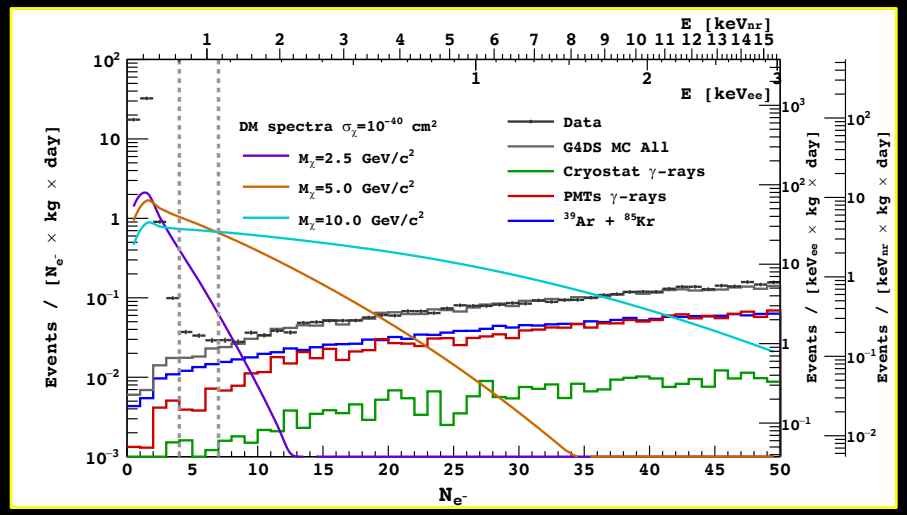
UAr Ionization Signal Analysis





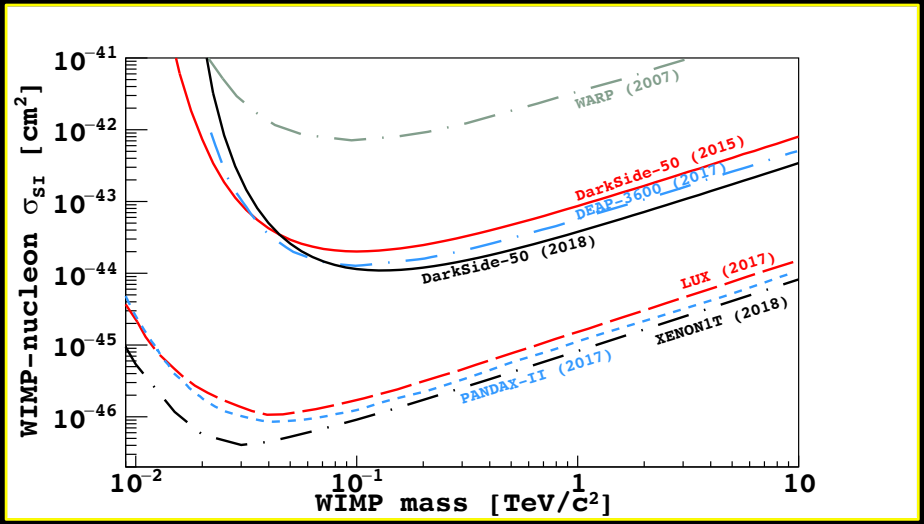
Single electron detection very efficient

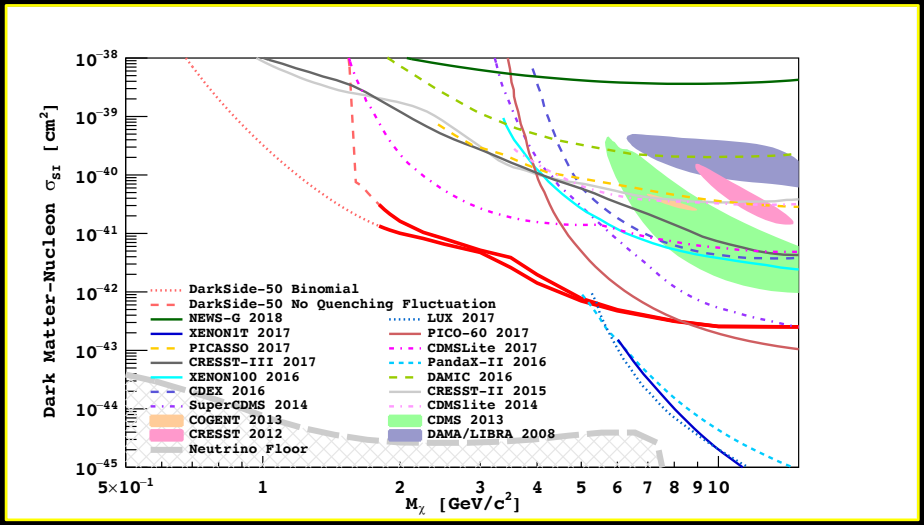




Summary of Darkside-50

- AAr 2013-2015, UAr since 04/2015
  - Cryogenics system very stable
  - TPC HV system stable for years
- LY @ null field ~8 pe/keV$_{ee}$
- 1,422 kg-days AAr + 19,276 kg-days UAr
  - No remaining background in WIMP search region!!!
- Ionization signal analysis give leading result for low-mass WIMPS





The GADMC Program

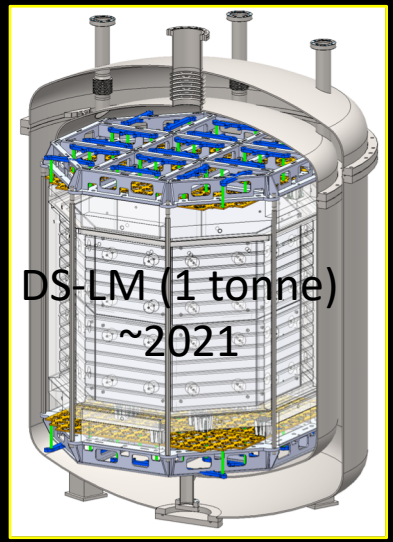
DarkSide-50 (running)

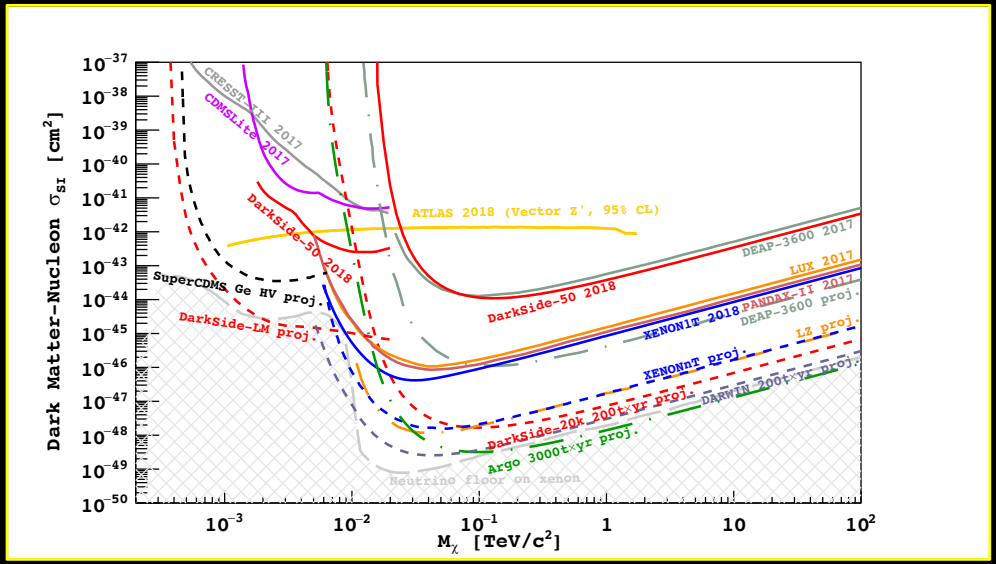
DEAP-3600 (running)

miniCLEAN

ArDM

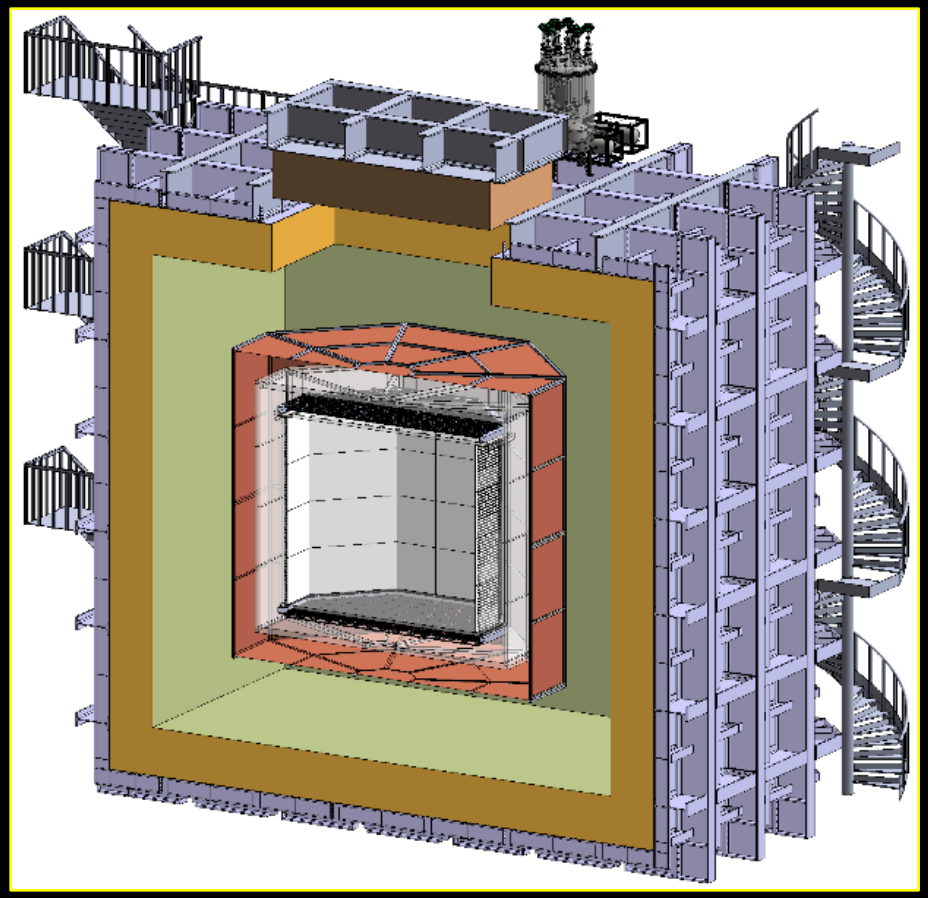
Argo (300-400 tonnes)
~2027





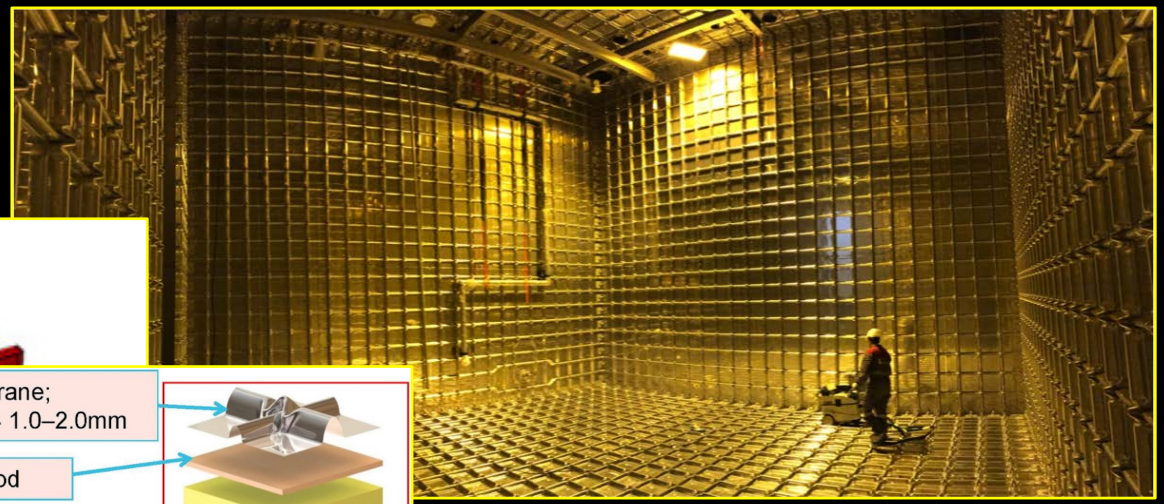
Darkside-20k: A United Front

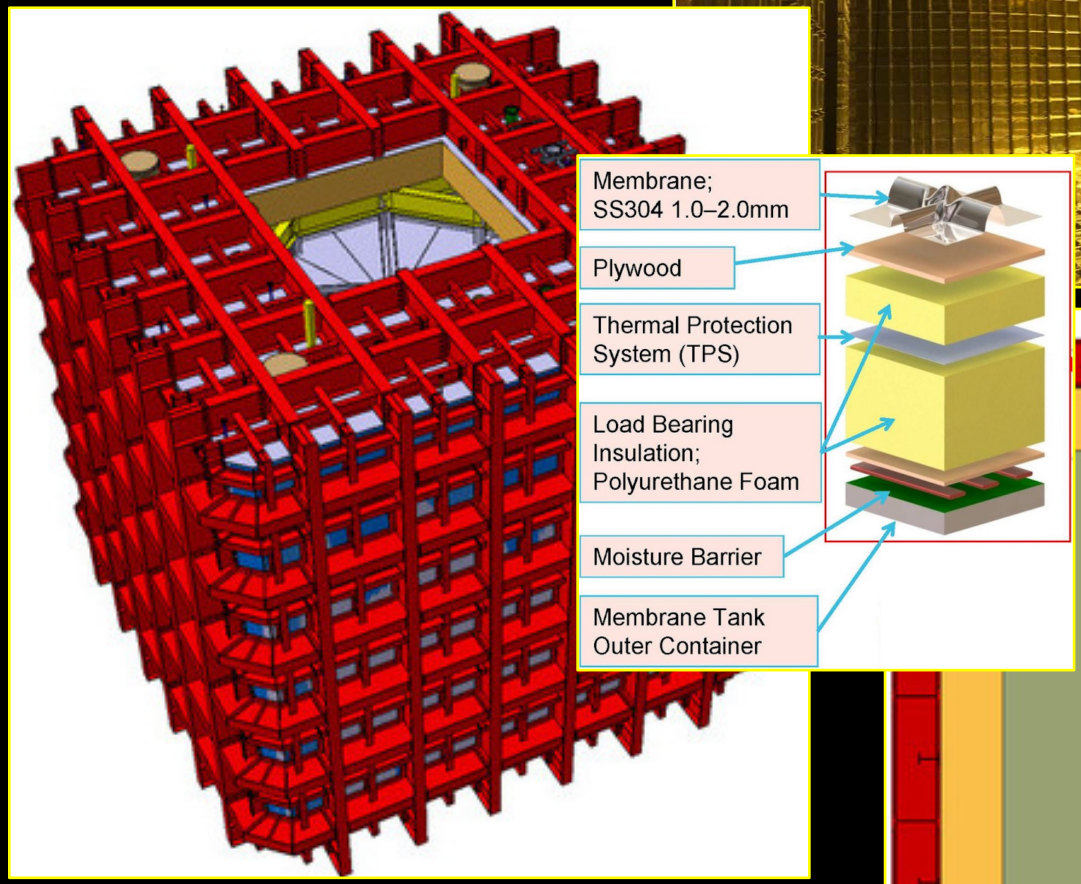
- Brings together all existing LAr dark collaborations
  - DarkSide-50
  - DEAP-3600
  - ArDM
  - miniCLEAN

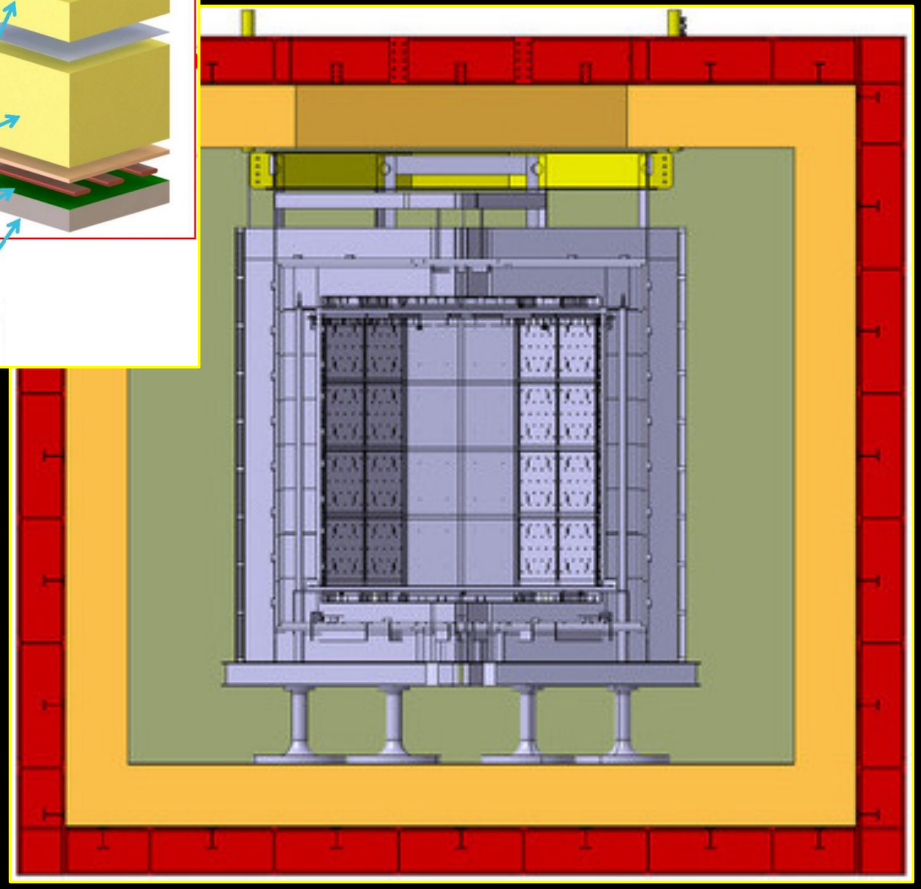


- 50 tonnes sealed PMMA
- UAr target
- Silicon photomulitipliers
- AAr-based Veto in ProtoDUNE style membrane cryostat

AAr Cryostat



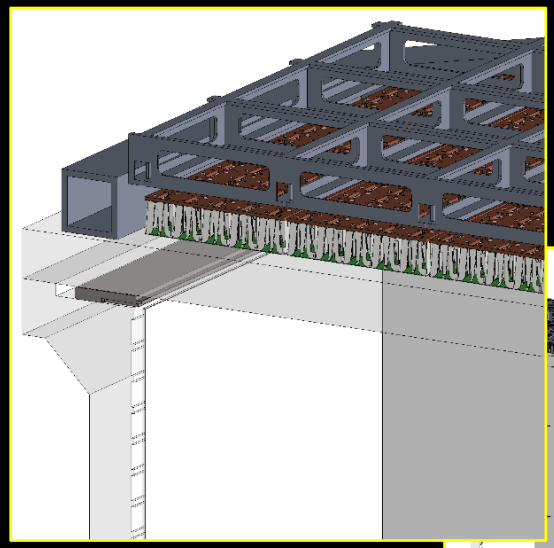


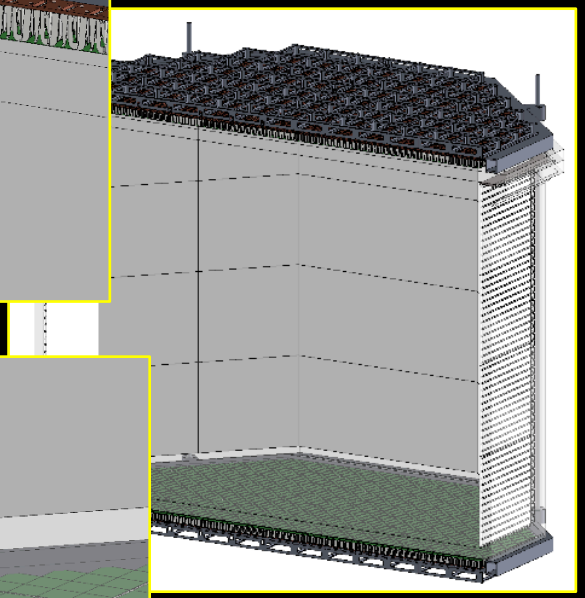


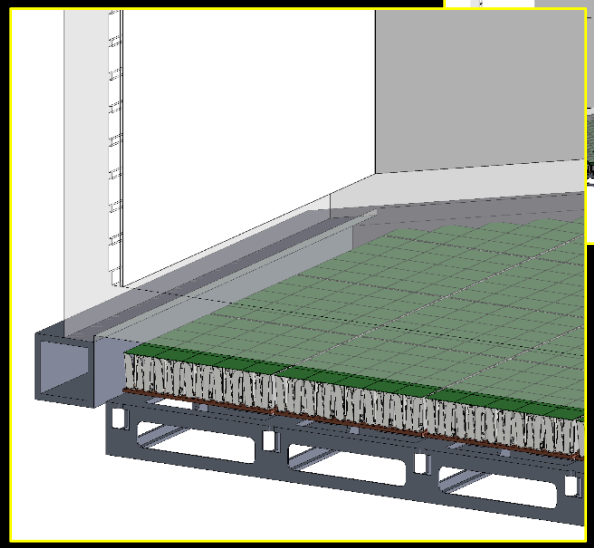
Identical size and shape as ProtoDUNEs

Side TCO replaced by “top-cap” deployment

Sealed PMMA Acrylic Vessel

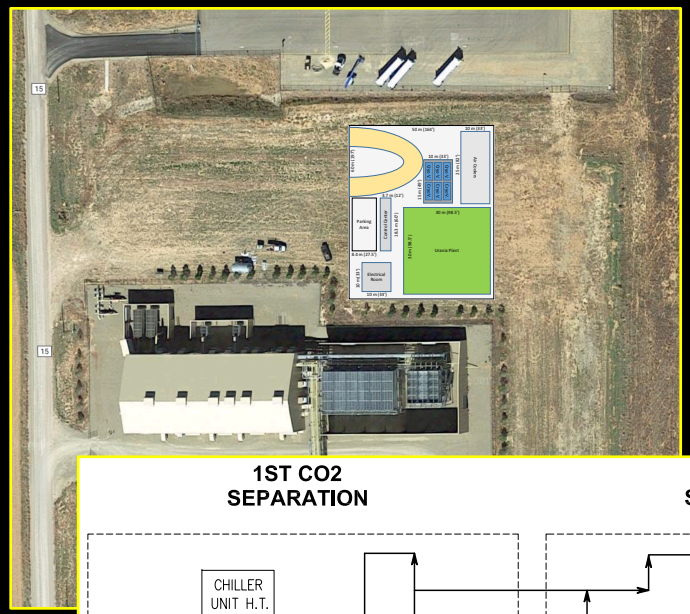






- Containment of UAr from AAr, no nearby cryostat
- Clevios+TPB coated diving-bell anode window
- SiPM planes moved outside of active volume
- Reflector from low-mass ESR foils and PMMA
- Field-rings machine-grooved and Clevios coated
- HV delivery via feedthrough and cold-cable
- Clevios+TPB coated cathode window
- Builds on experience gained from DEAP-3600

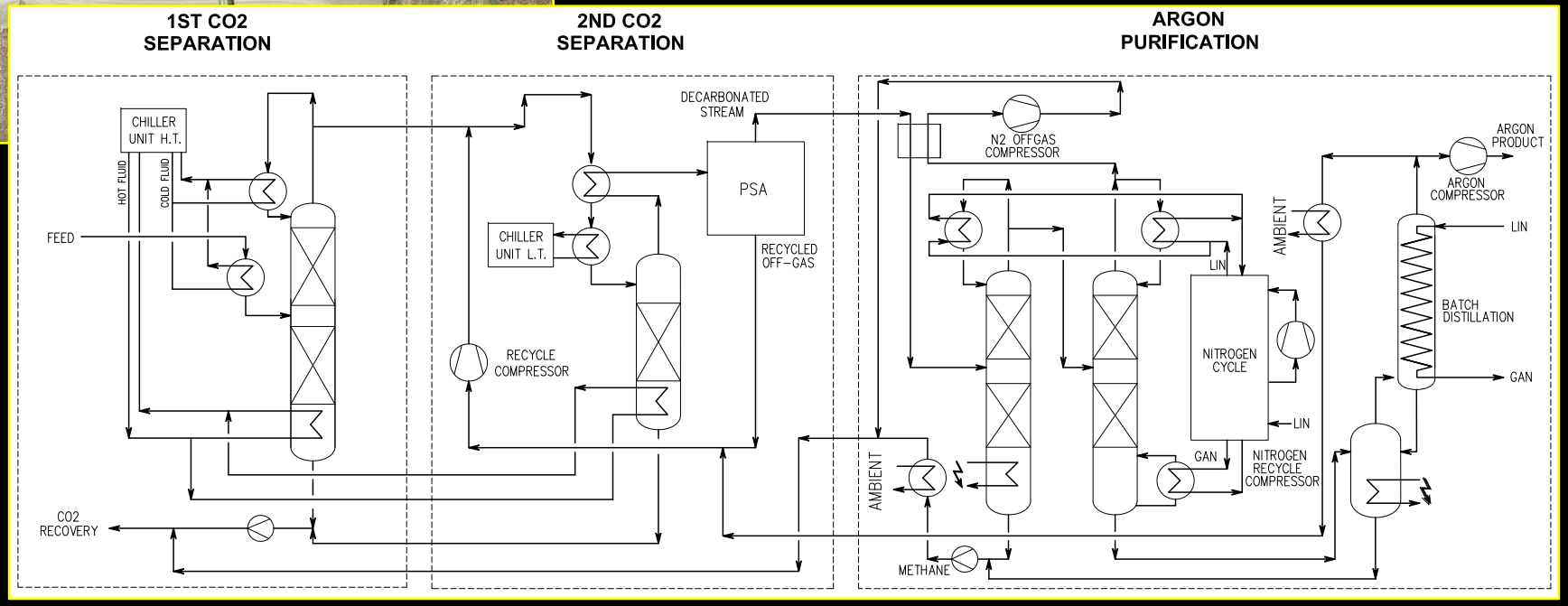
UAr: Urania



The Urania project will procure 50 tonnes of UAr from same Colorado source as for DS-50

Will extract 250 kg/day, with 99.9% purity
-> 90 tonnes/yr

UAr will be transported to Sardinia for final chemical purification at Aria

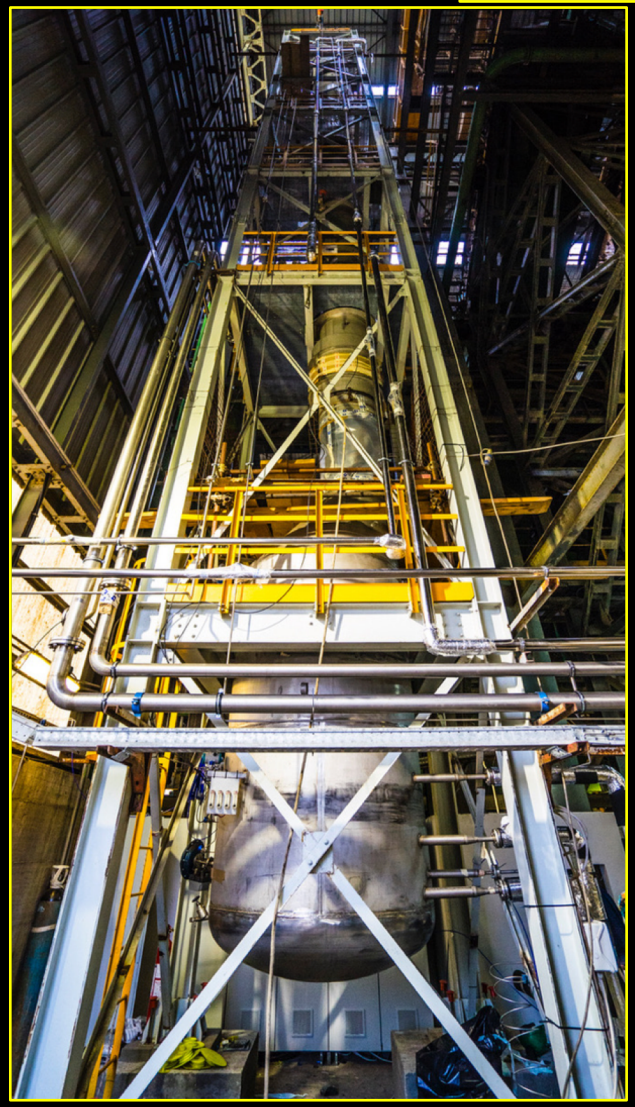


UAr: Aria

Final chemical purification of the UAr

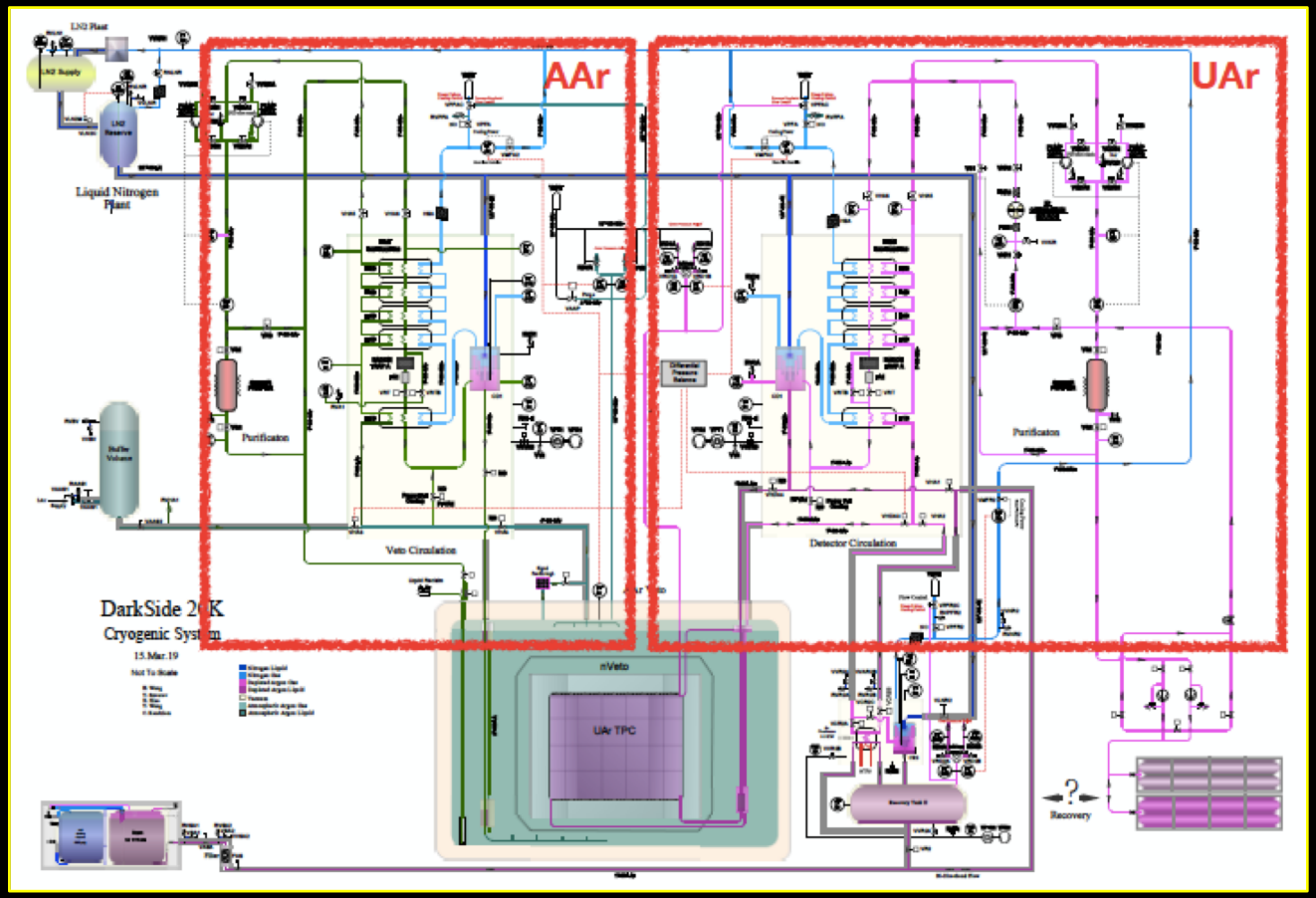
Processing of O(1 tonne/day) with 10^3 reduction of all chemical impurities

Ultimate goal is to isotopically separate ^{39}Ar from ^{40}Ar



Cryogenics

- Membrane cryostat + AAr cryogenics
- UAr cryogenics, circulation speed up to 1000 stdL/min in gas phase (by DarkSide-built circulation pump)



Large Area SiPMs

- Compact → increase coverage
- >50% PDE @ 420 nm
- 0.1 Hz/mm^2 DCR
- SiPM tiles → PDMs
- >22 m^2 of SiPMs total

25 PDMs in one Motherboard

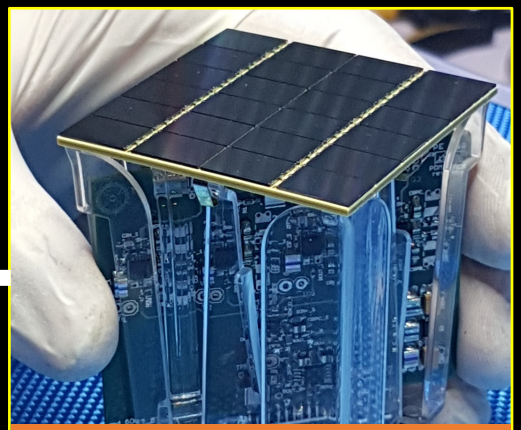
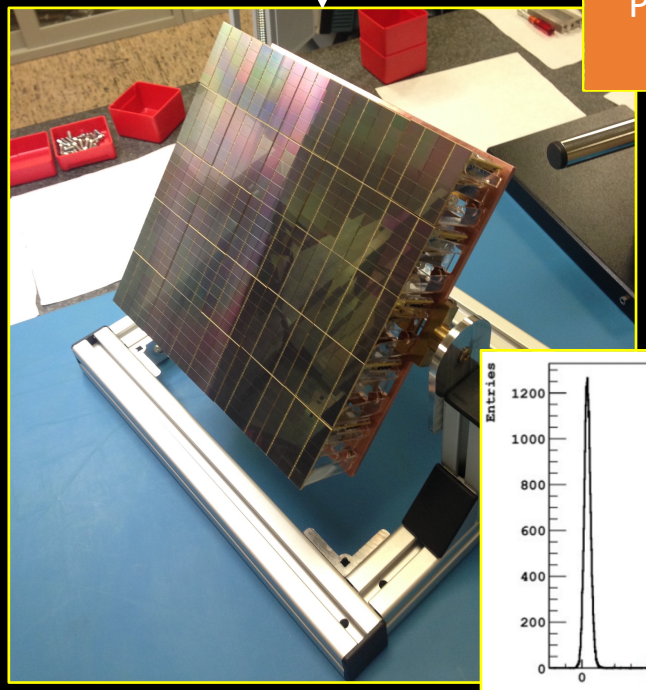
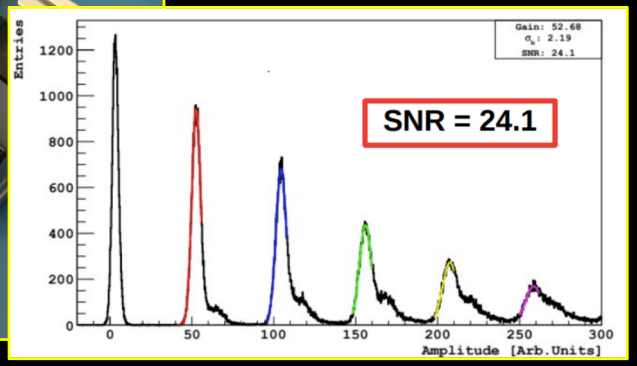
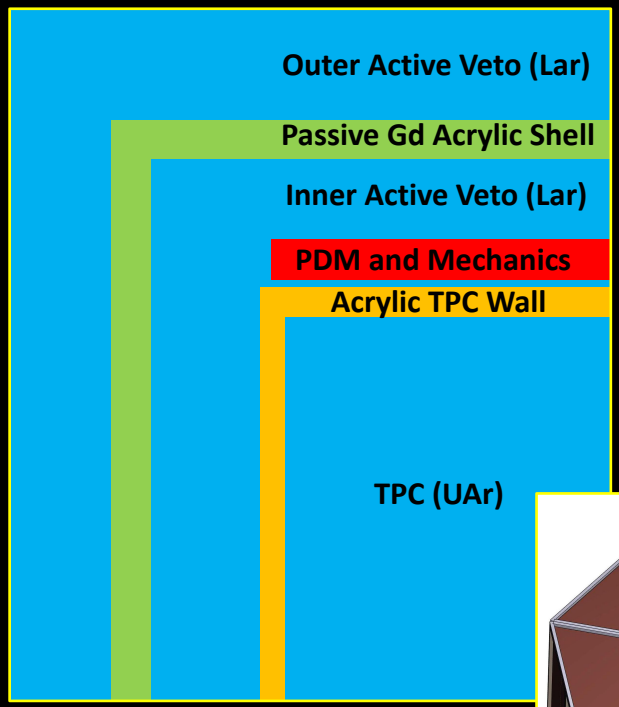


Photo-Detector Module
PDM





LAr+Gd-Doped PMMA Veto

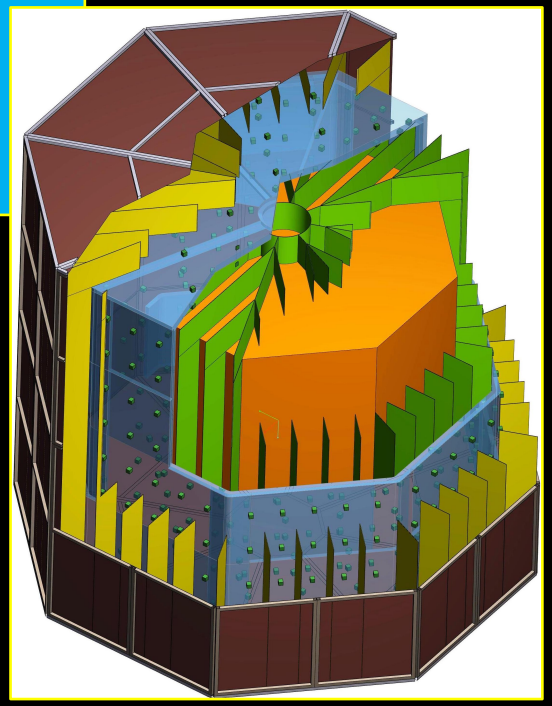


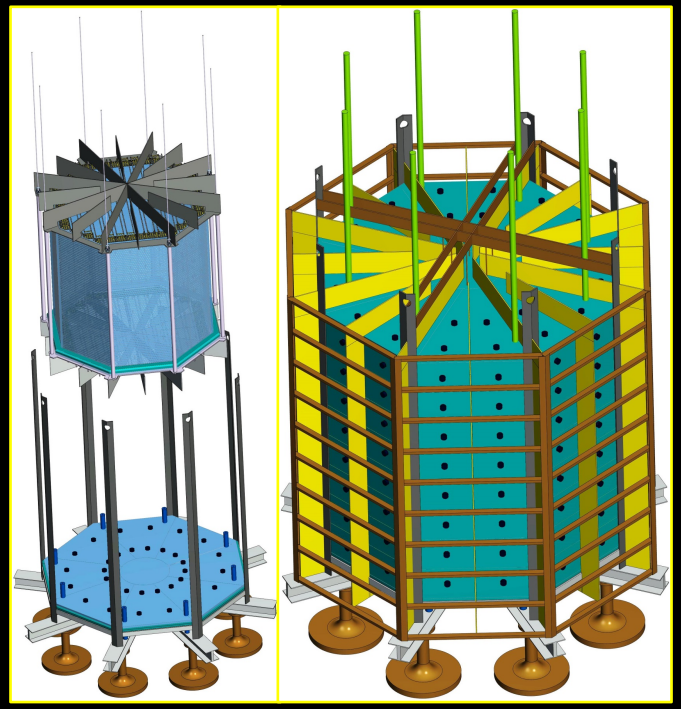
TPC optically isolated from AAr volumes

Passive shell of Gd-doped PMMA (n moderation/capture)

Inner/outer layers of active AAr for n capture gamma detection

Optically/electrically isolated from outside AAr by copper vessel





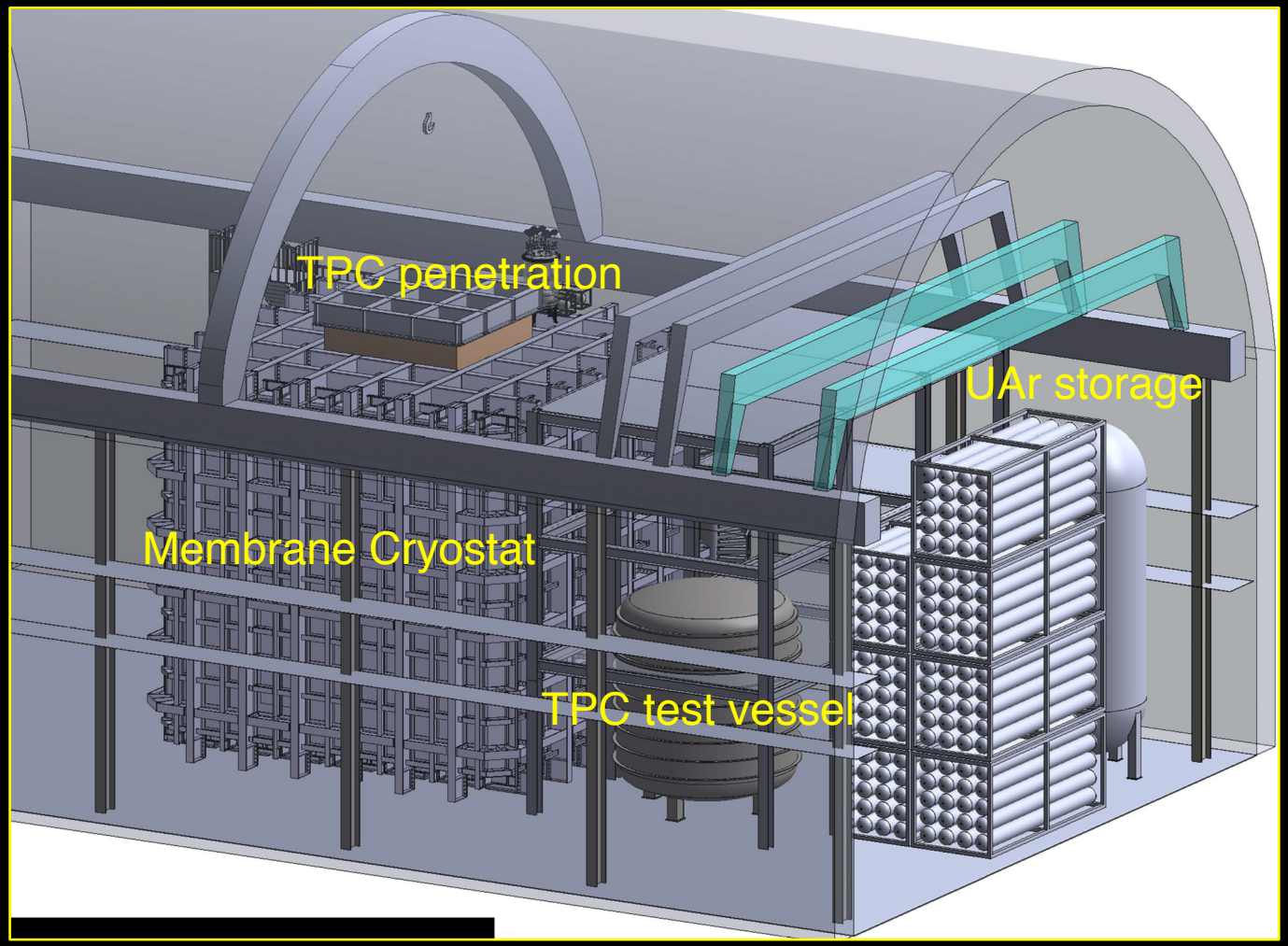
Segmented approach to reduce overall rate from ^{39}Ar in AAr

Integration: CERN

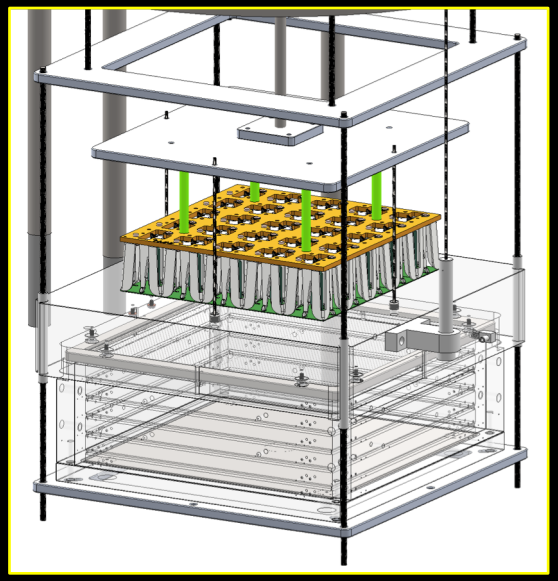
The integration between the protoDUNE like membrane cryostat and the DarkSide-20k TPC is being designed by both protoDUNE engineers and GADMC engineers

Overall integration at LNGS Hall C,
TPC will be tested in a test vessel before installing into the membrane cryostat

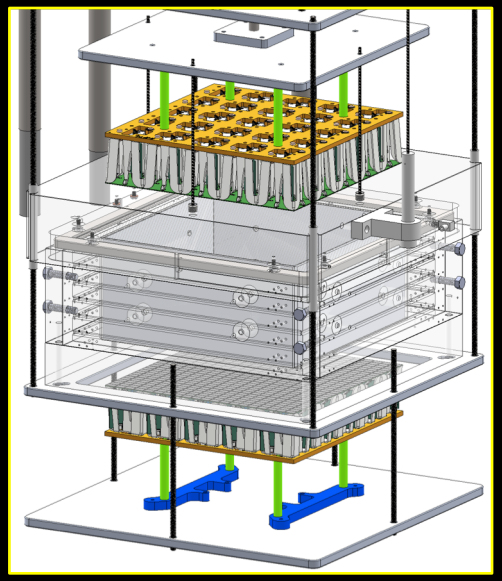
DarkSide-20k is now a CERN recognized experiment (RE37)



DS-Protos at CERN



DS-proto-proto v1

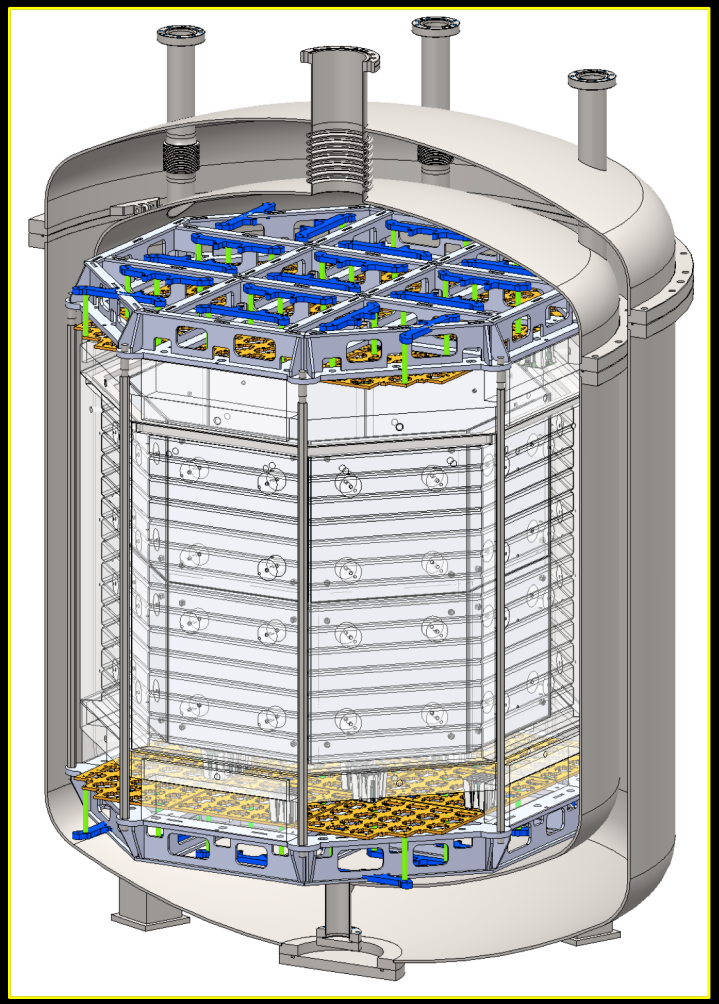


DS-proto-proto v2

Integrated acrylic TPC for S2 study
With SiPMs as photosensors
Under construction @CERN

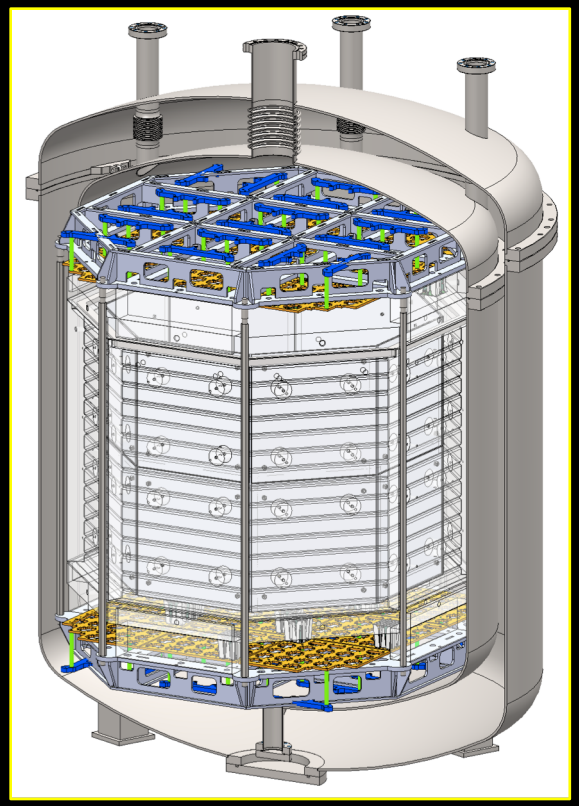
Key techniques: SiPM integrated test
Conductive polymer (Clevios)
ESR as reflectors
Acrylic bonding

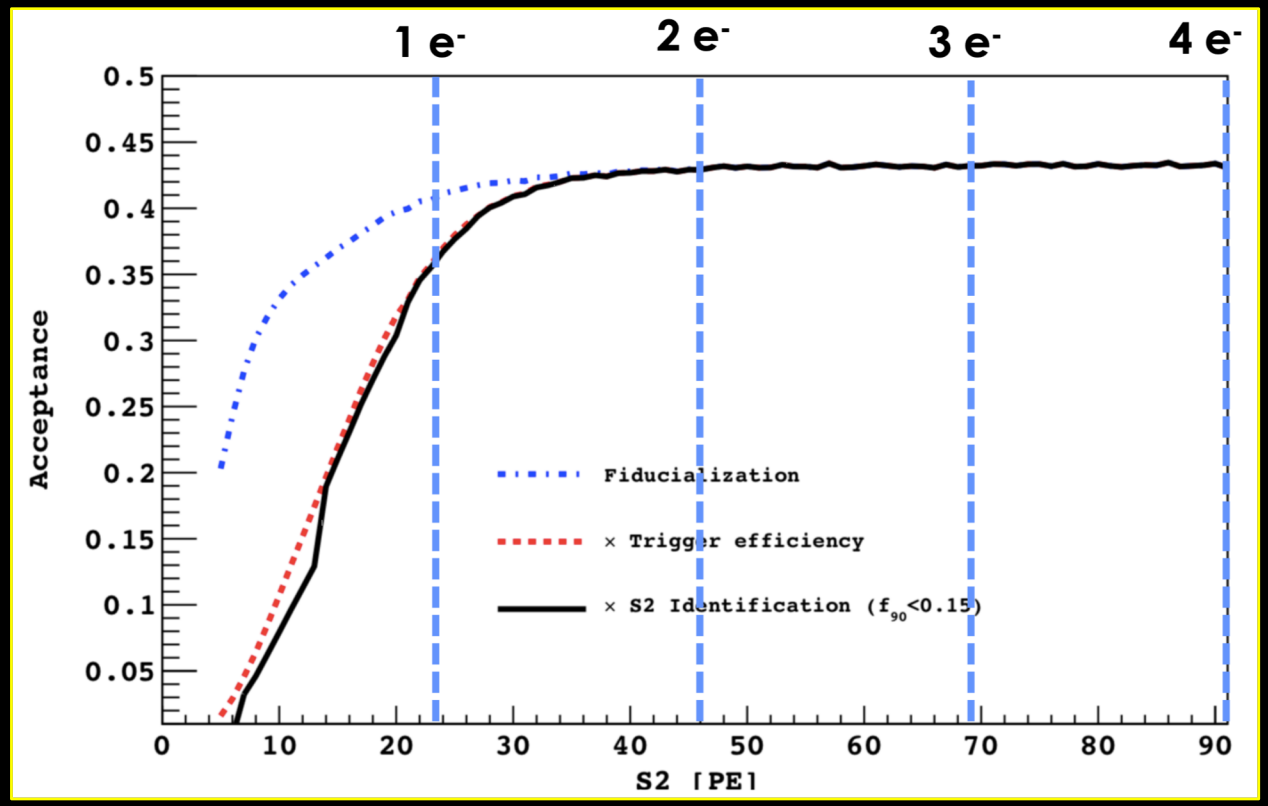
Proto_1ton: scaled down version
of DS-20k, sealed acrylic TPC
Will be assembled @CERN in Q2 2020



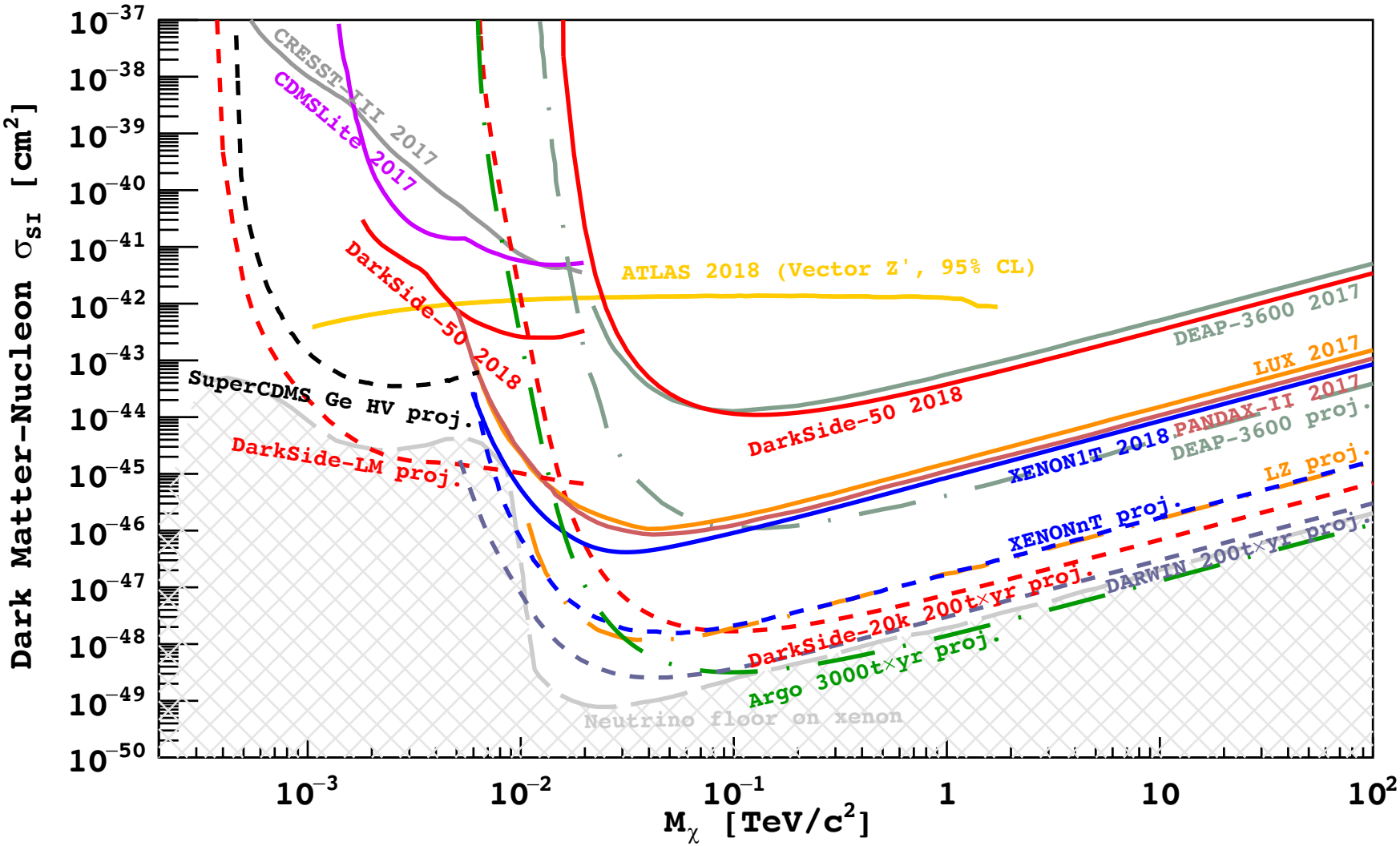
DS-LowMass

- Potential to reuse DS-Proto (~1 tonne) TPC @ LNGS
- 350 kg active volume
- Active Neutron Veto
- Low mass sensitivity has been demonstrated by DS-50 (S2 only analysis)





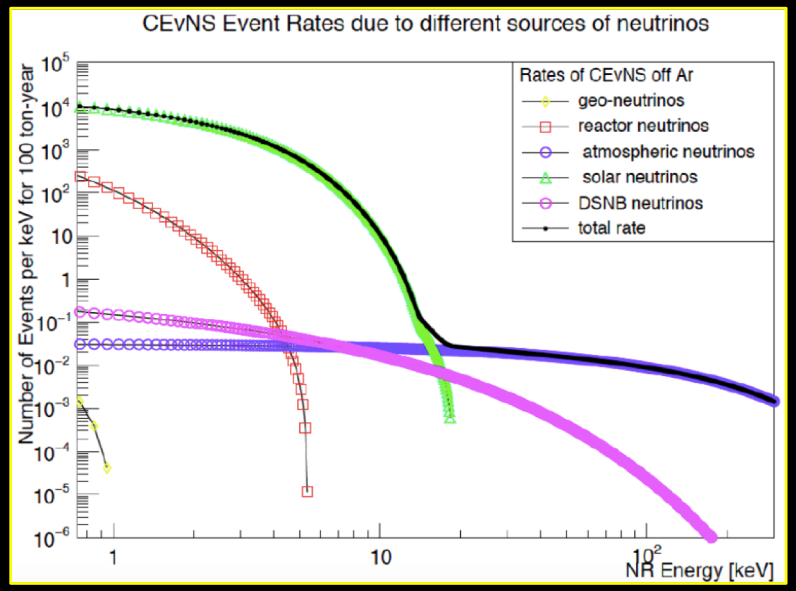
Ultimate WIMP Sensitivity



Neutrino Detection in DS-20k

- DS-20k will be sensitive to coherent elastic neutrino nucleus scattering (CEvNS)

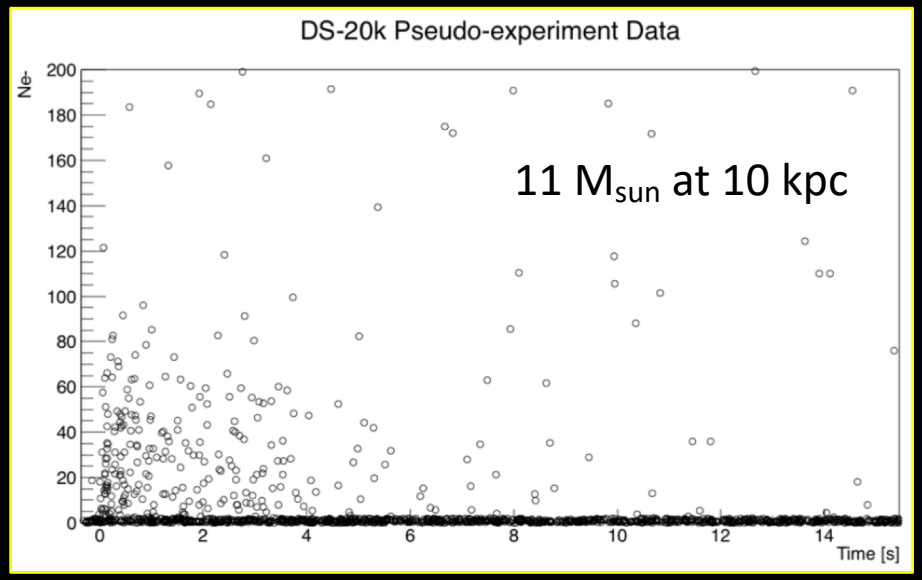
- Neutral current interaction → Flavor blind measurement that is not affected by oscillations

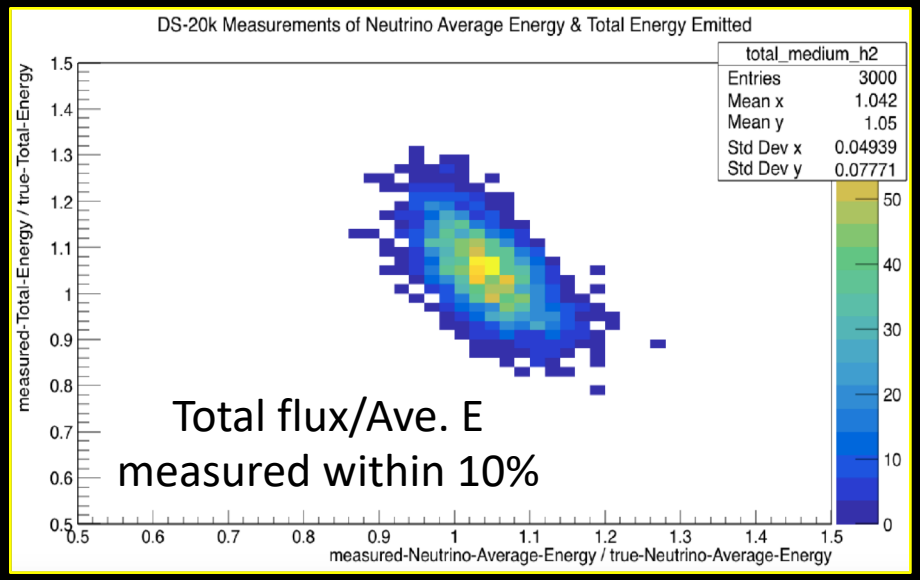


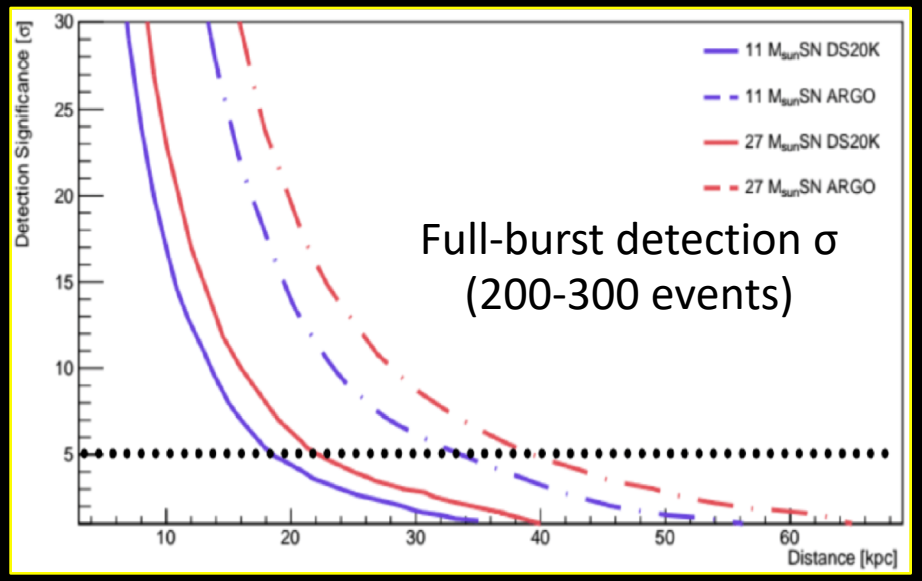
Neutrino Sources	Events > 0.15 keV	Events > 3.0 keV	Events > 15.0 keV
Solar	23442 ±4162	3411 ±600	0.1 ±0.02
Atmospheric	1.8 ±0.3	1.7 ±0.3	1.4 ±0.2
Reactor	634.2 ±142.3	0	0
Geo	34.8 ±11.0	0	0
DSNB	0.8 ±0.2	0.4 ±0.1	0.1 ±0.03
Total	24113.6 ±4315.8	3413.1 ±600.4	1.6 ±0.25

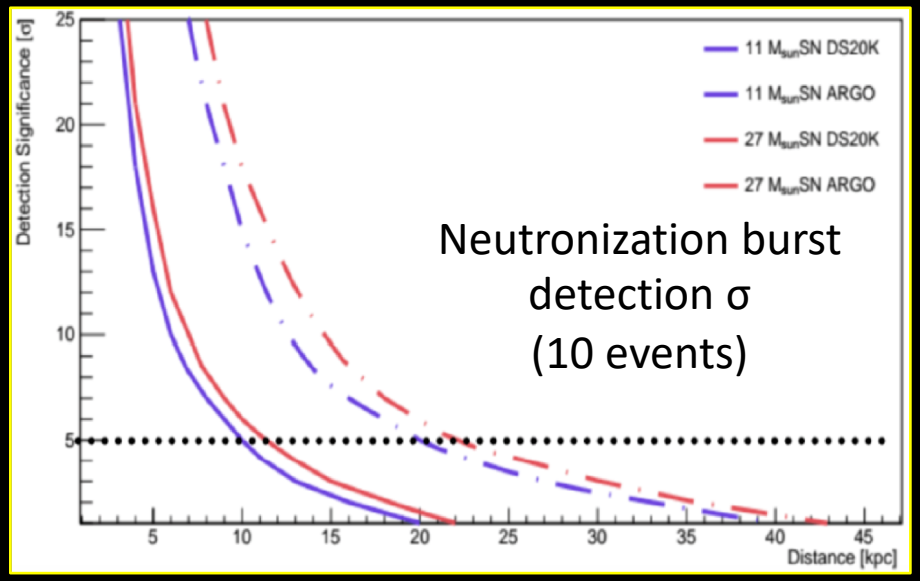
Table 3.2: Expected number of CEvNS events for DarkSide-20k

Supernova Neutrinos in DS-20k







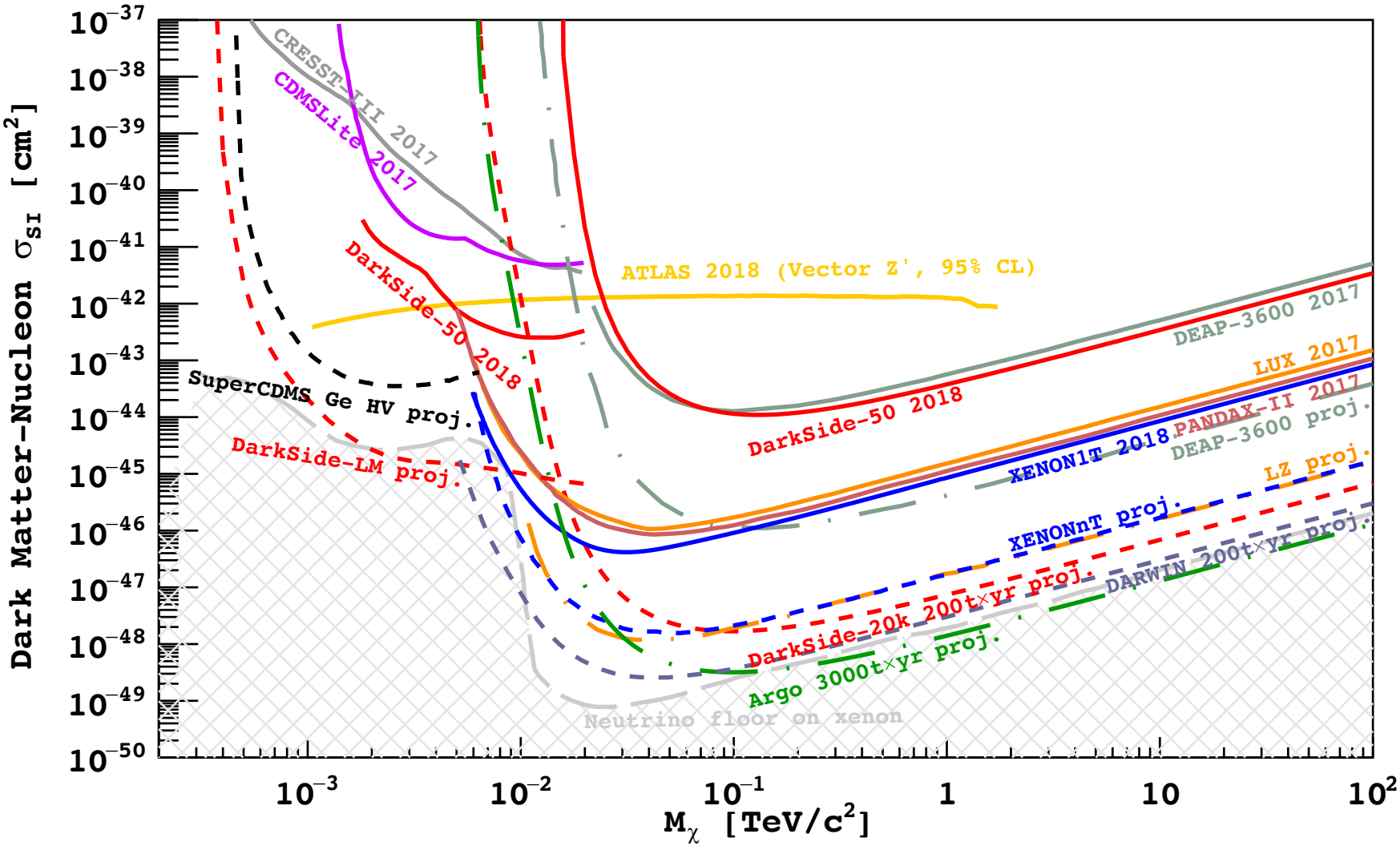


Thank You!

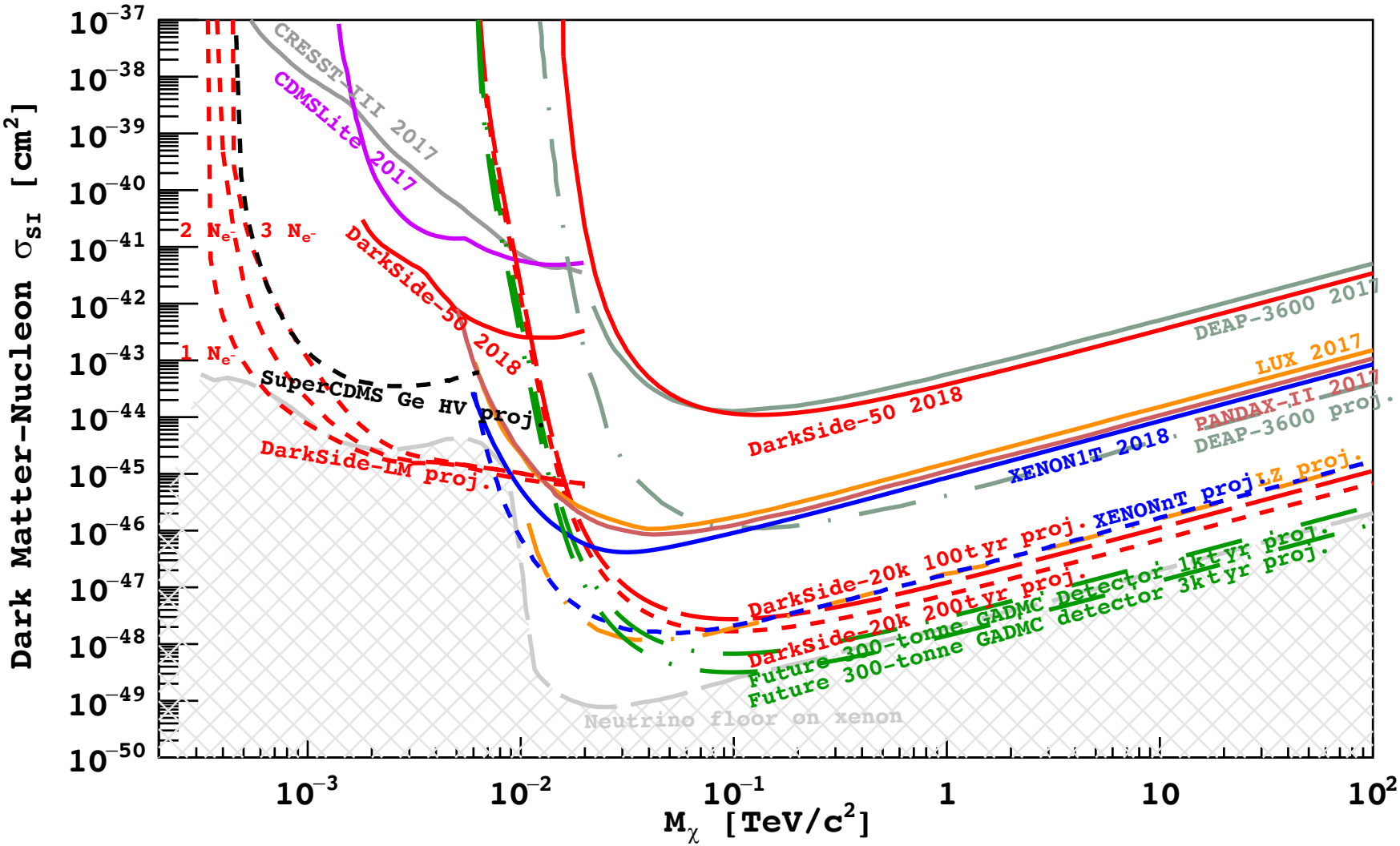
University of Alberta
APC
LNGS
GSI
Augustana University
БелГУ 1876
Black Hills State University
Brookhaven National Laboratory
Alma Mater Studiorum Bologna A.D. 1088
Carleton University
Universitas Carolina Pragensis
Unicamp Universidade Estadual de Campinas
Centro Fermi Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
INFN LNS
Universitas Hennae Studiorum
ETH Zürich
Fort Lewis College Established 1911
University of Hawai'i Manoa
University of Houston Founded 1927
Instituto de Física Universidade de São Paulo
Institute of High Energy Physics Chinese Academy of Sciences
INFN
IPN Institut de Physique Nucléaire Orsay
INSTM
Joint Institute for Nuclear Research JINR
Laurentian University Université Laurentienne
INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati
LPNHE Paris
Lodz University of Technology
Manchester 1824 The University of Manchester
MEPhI Moscow Engineering Physics Institute
Politecnico Milano
Universitas Studiorum Mediolanensis
Friedrich-Wilhelms-Universität Bonn
НГУ
Studium Generale Civitatis Berolini A.D. MCCCVIII
In Supremae Dignitatis 1343
Pacific Northwest National Laboratory Proudly Operated by Battelle Since 1965
Queen's University
Studium Urbis
Roma Tre Università degli Studi
Studium Salernitanum
SNOLAB
University of Sussex
Universitas Sancti Andreae
Temple University
Fondazione Bruno Kessler
TIFPA Trento Institute for Fundamental Physics and Applications
Universitas Athesina Studiorum
Politecnico di Torino
Universitas Studiorum Sagiensis
TRIUMF
Technische Universität München
Universidad Nacional Autónoma de México
University of California Davis
University of California UCLA
University of Massachusetts Amherst
Universidade de São Paulo
Universidad Zaragoza
Virginia Tech

Backups

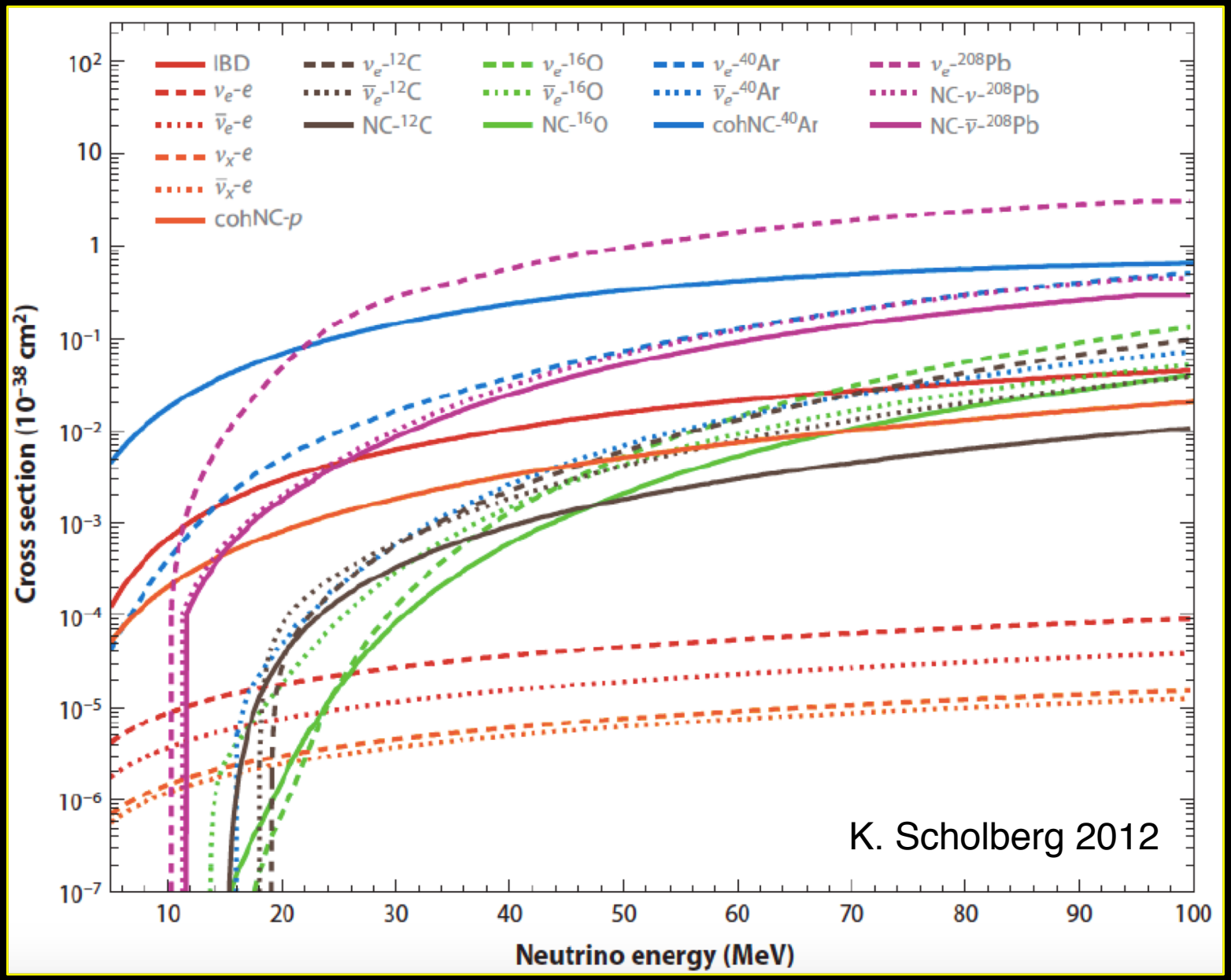
Projected Sensitivities



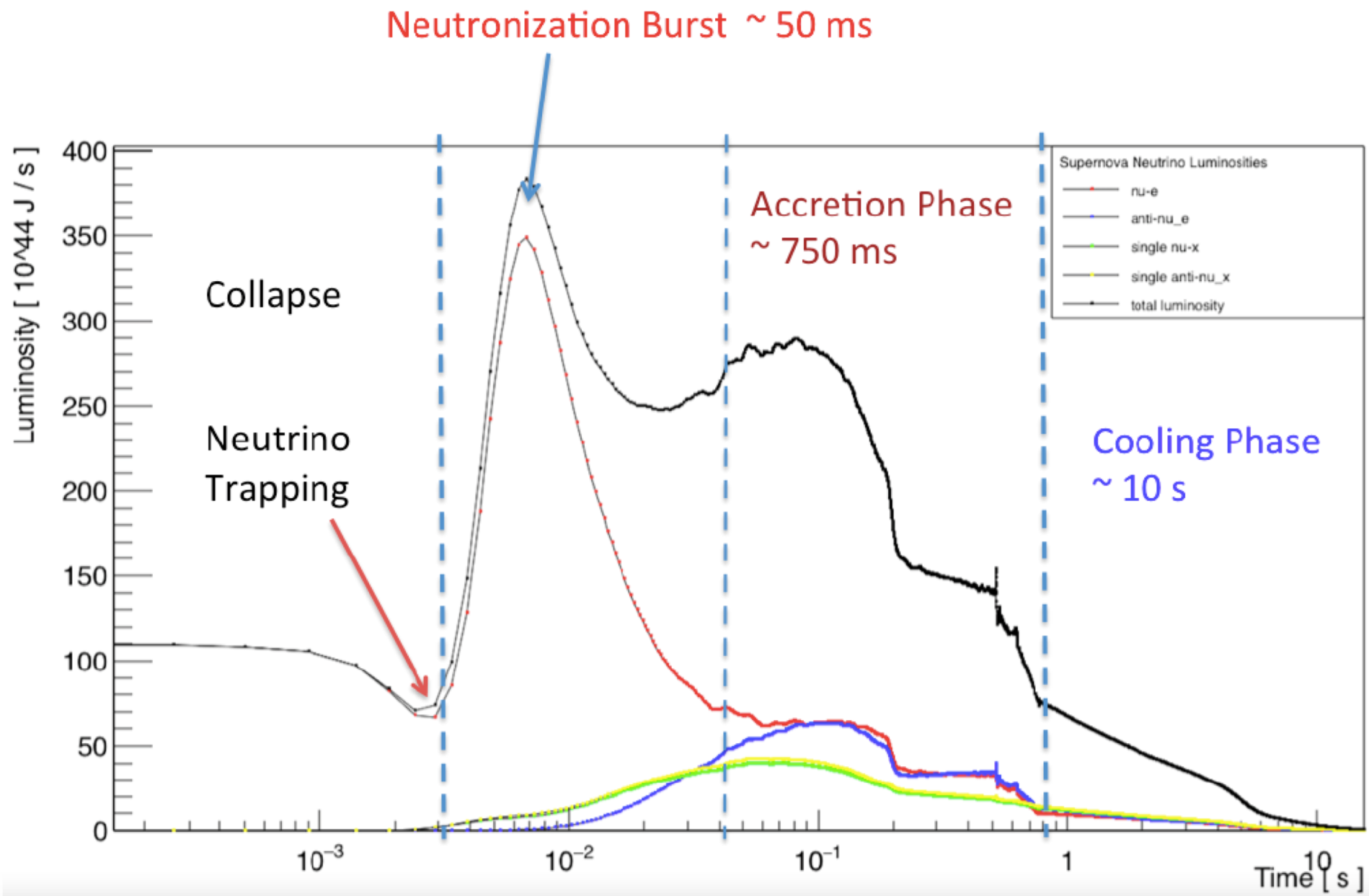
Projected Sensitivities



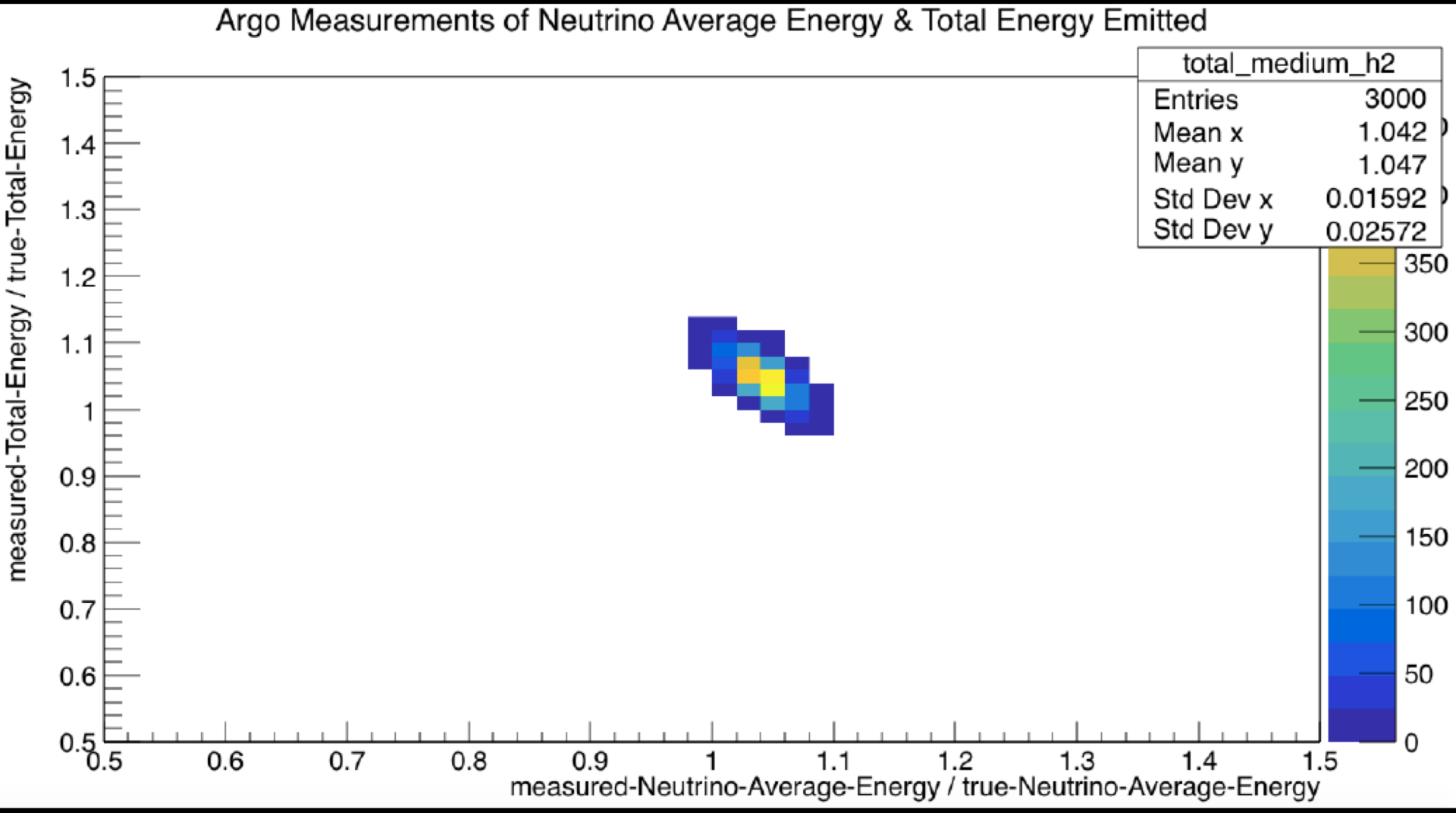
Neutrino Cross Section in LAr



SN Flux Time-evolution



SN Neutrinos in Argo



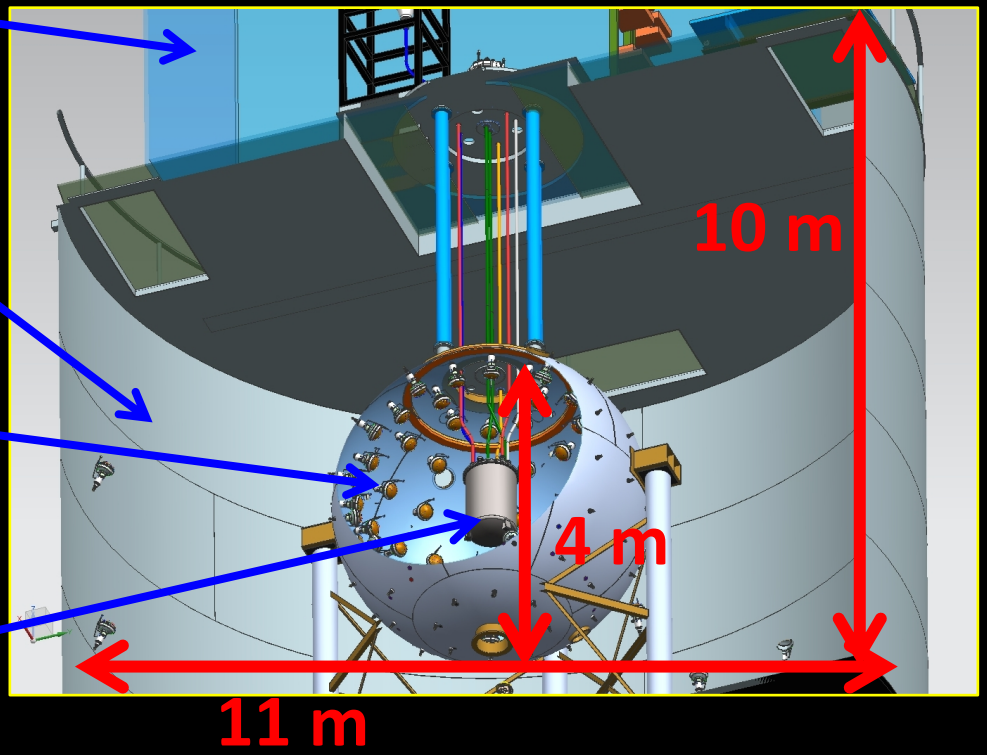
The Darkside-50 Detector

Rn-free clean room
(10-15 mBq/m^3 in 110 m^3)

Water Cherenkov muon veto:
1 kton H_2O

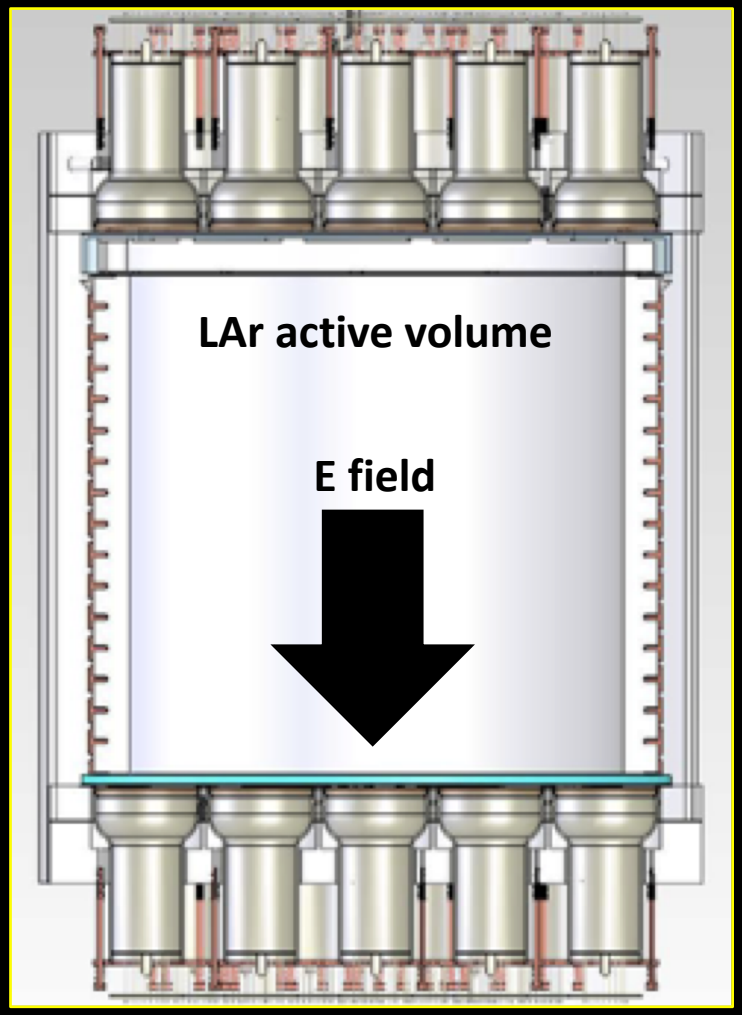
Boron-loaded liquid scintillator
~30 ton (50% TMB + 50% PC)

Two-Phase LAr TPC
50 kg active volume



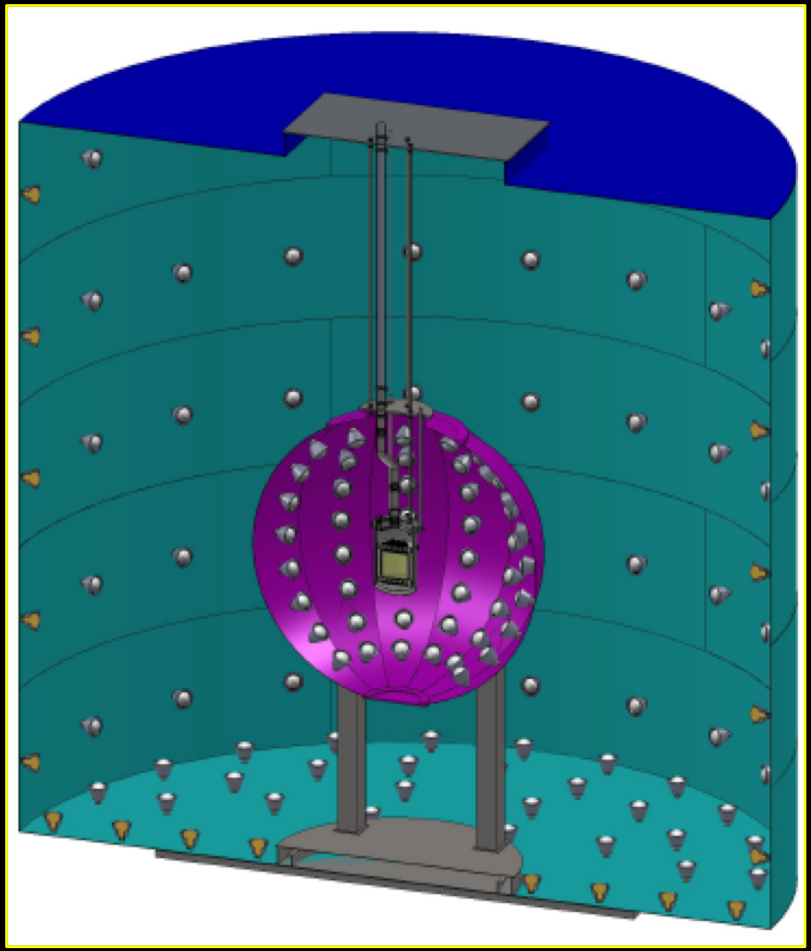
Darkside-50 TPC

- PTFE Cylinder
  - h=36 cm, d=36 cm, 46 kg (44 kg fiducial), inner surface is coated with TPB
- 38 3” Hamamatsu PMTs:
  - R11065: 19(top) + 19(bottom)
  - Cold amplifier (low PMT HV)
- Cathode and anode windows:
  - Fused silica w/ ITO transparent layers (15 nm) & TPB
- Field shaping copper rings:
  - Uniform electric field: E_{drift}=220 V/cm E_{gas}= 2.8kV/cm
- Fused silica diving bell
  - Gas pocket holding for S2 signal

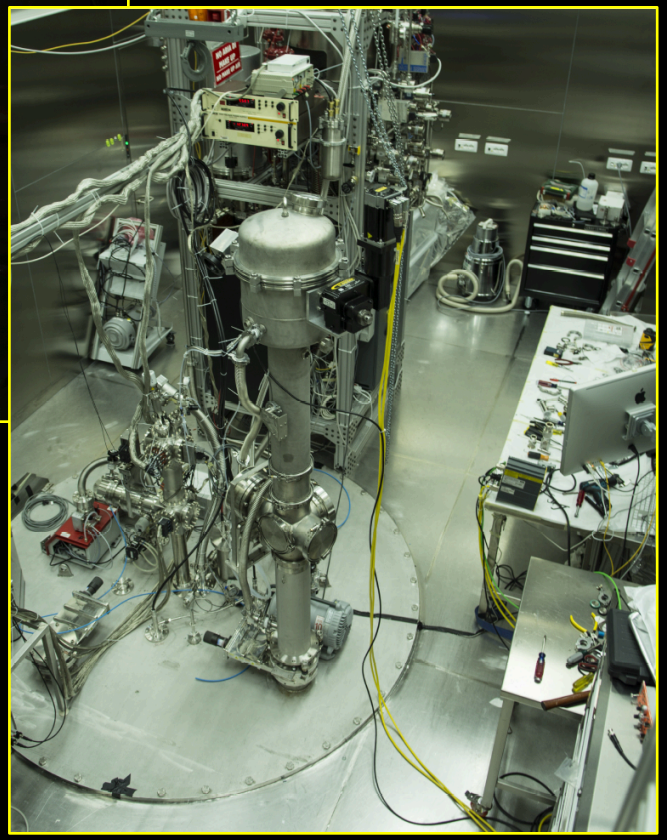


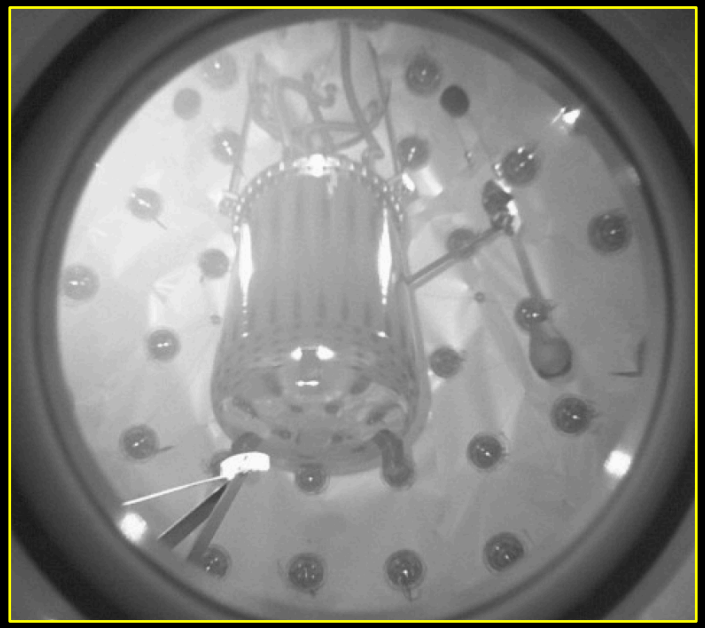
Veto Detectors

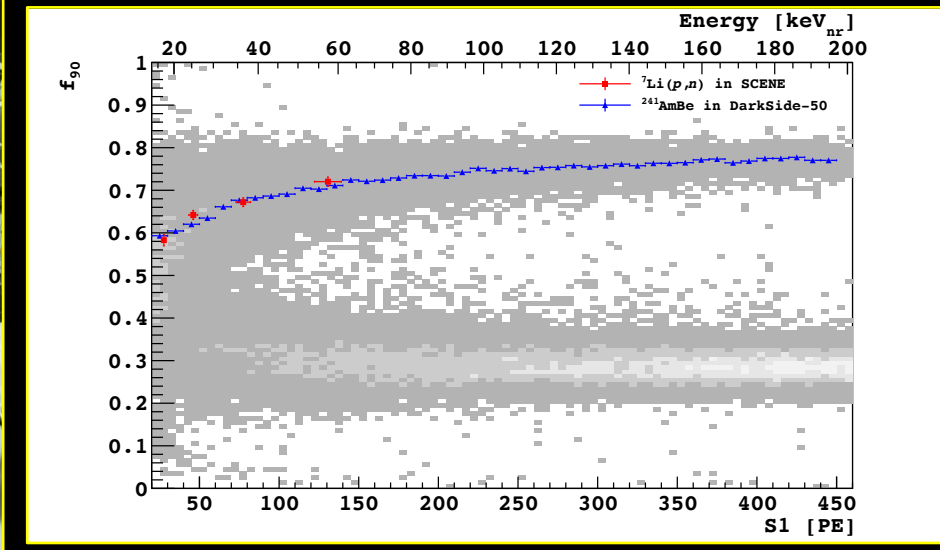
- Water Cherenkov Veto
  - Muon flux reduced by 10^6 (>99% efficient)
  - 80 PMTs, 11 m diameter x 10 m high
  - Detect the Cerenkov light produced by the muons and other showering particles
  - Provides passive gamma and neutron shielding
- Liquid Scintillator Veto
  - 4 m boron-loaded liquid scintillator (PC:TMB)
  - 110 8” PMTs
  - Efficiently detect escaping neutrons and veto any associated nuclear recoil backgrounds
    - >99% efficiency for neutrons
  - Provide *in situ* measurement of the neutron background rate



Calibration System







Backgrounds

- Internal radioactivity
- Gamma Rays
- Cosmic muons
- Radiogenic neutrons
- Fast neutrons