Low energy ionization signals in DarkSide

EXCESS workshop - Rome, July 6th 2024

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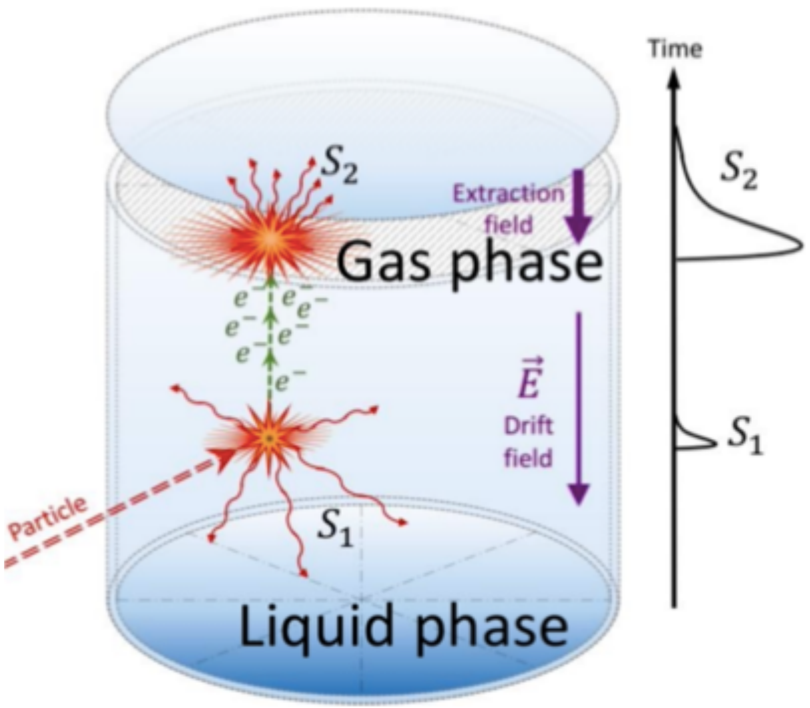
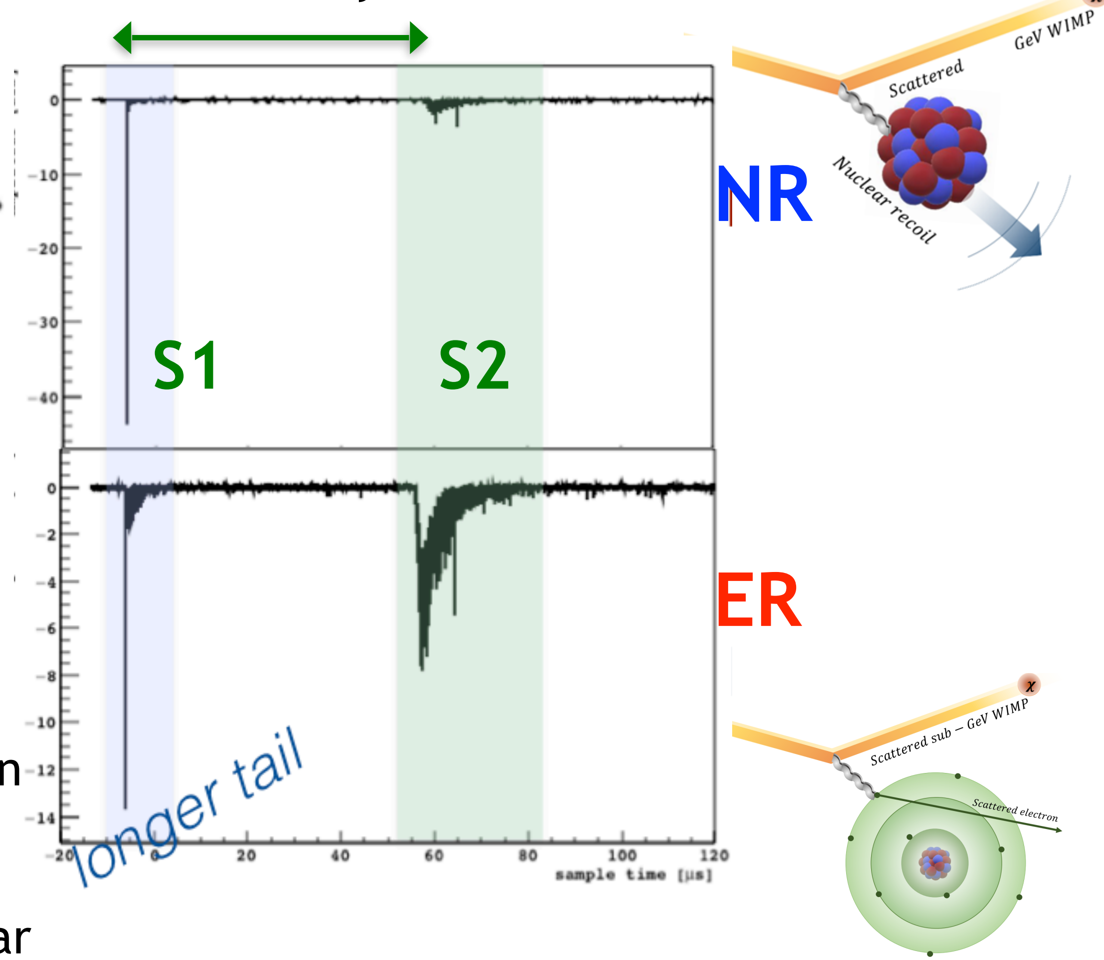
Liquid Argon double phase TPC



Time delay —> z coord.

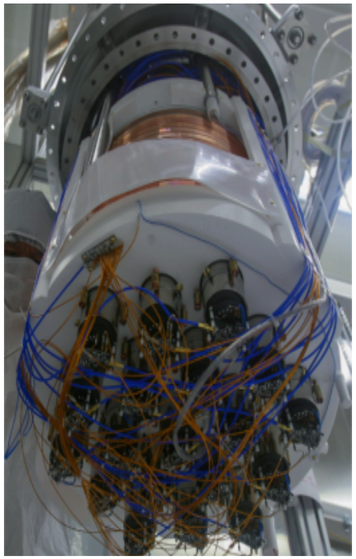


PSD specific to Argon (1 ns and 1.5 microsec singlet - triplet scintillation emission time constants.

Unlike in Xenon were they are similar and only discriminant is S2/S1 ratio (rejection power 1/250) ok also for argon

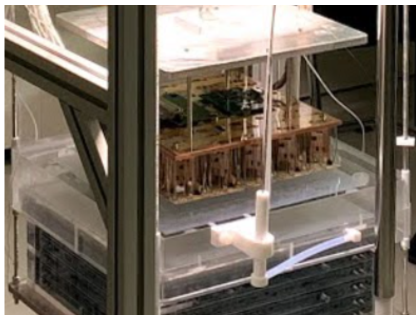
—> **Ar Pulse Shape Discrimination of ER ~10^9**

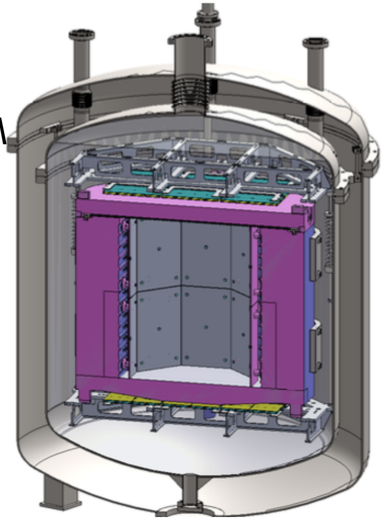
The DarkSide program timeline



Proto-0 @NA (now)

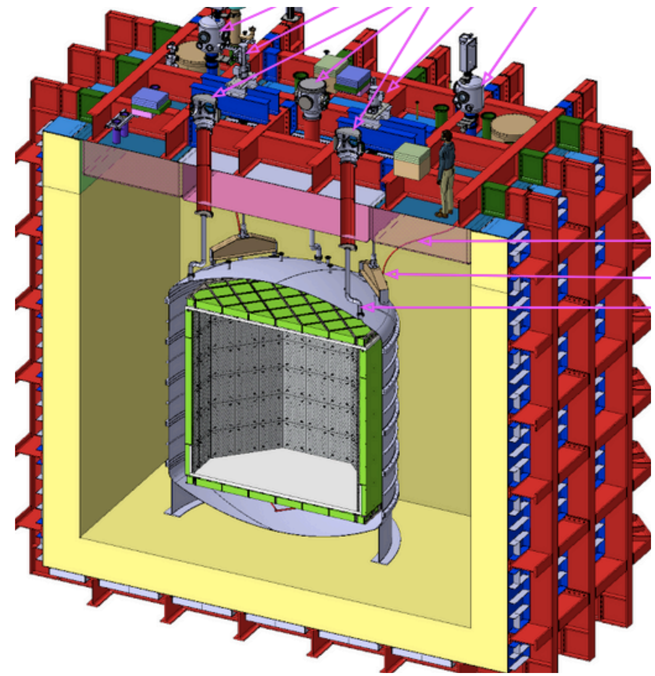
Acrylic TPC, test first PDM motherboard, S2 studies.
Running @ Napoli:





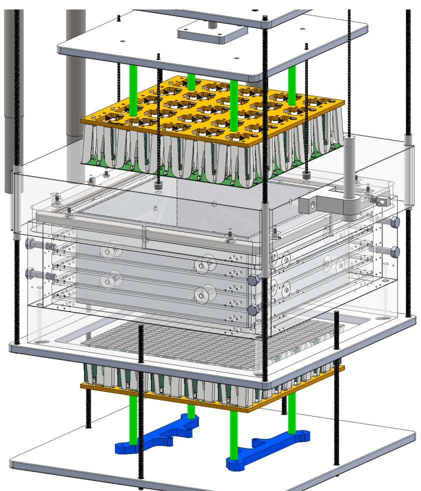
DarkSide-20k @LNGS (2023-26)

50t UAr (20t fiducial) acrylic TPC, 8280 PDM channels. Acrylic+Gd n-veto in AAr protoDUNE cryostat.100 ton-yr exposure.
TDR submitted dec.21, now baselined
Sensitivity to WIMP-nucleon cross sec. of 2.10^{-48} cm^2 at 100 GeV/c^2 WIMP mass.



DarkSide-50 (end)

Sensitivity to WIMP -nucleon cross section 10^{-44} cm^2 for a WIMP mass of 100 GeV/c^2. Leading S2 only low mass limit (2018).
—> Updated low mass DM result in 2022



TPC Mockup (2024)

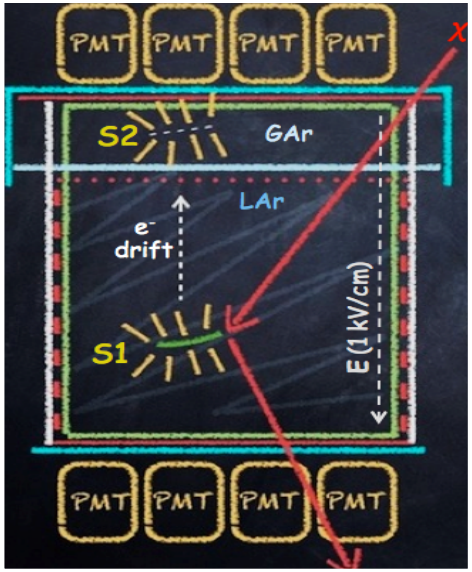
Scaled down DS20k version, 0.4t active LAr acrylic TPC.Test: final detector design & UAr cryogenics.
CERN —> now LNGS:

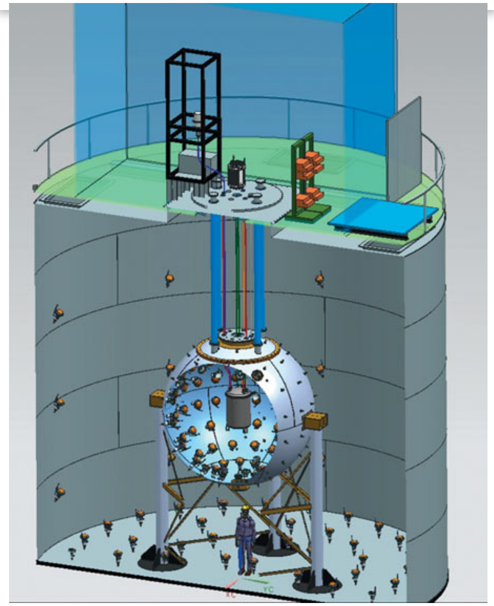
ReD @LNS (now)

Acrylic TPC to test NR response to low energy recoils

Global Ar DM Collaboration, GADMC:
ArDM, miniDEAP, DEAP-3600, DarkSide-50
… and future 300t ARGO

DarkSide-50 LAr TPC and vetoes





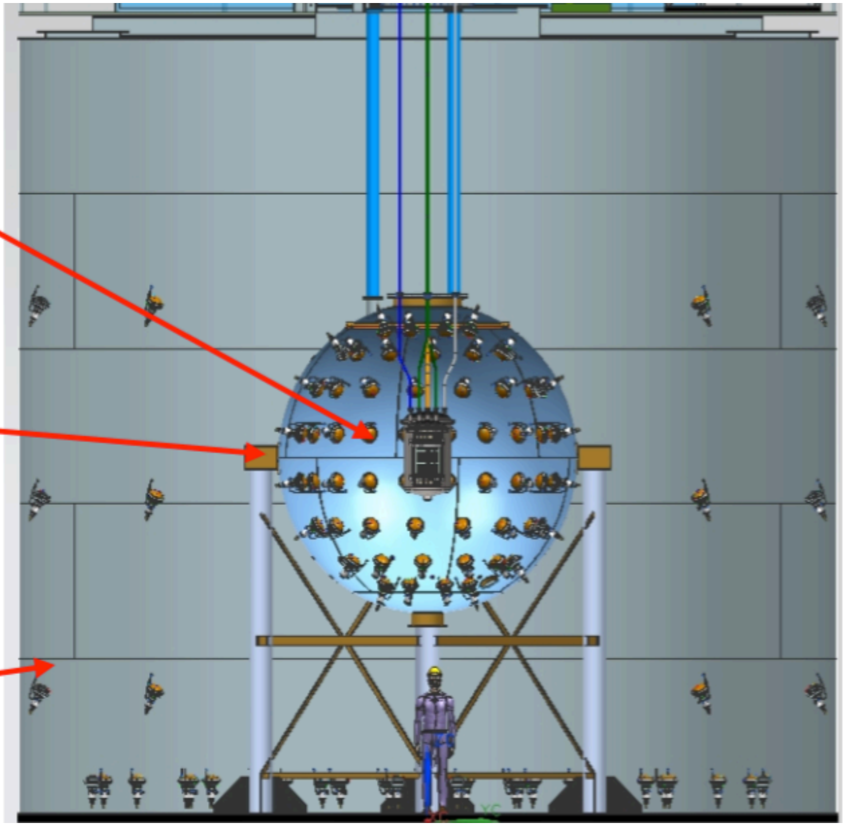
DarkSide-50 in LNGS hall C :

- 50 kg LAr active mass
- 19 PMTs top / 19 PMTs bottom cryogenic (LT bi-alkali photocathodes)
- Active neutron veto with borate-scintillator
- Data taking since 2014 until ~2018

Liquid Argon TPC
153 kg ^{39}Ar-Depleted
Underground Argon
Target

4 m Diameter
30 Tonnes
Liquid Scintillator
Neutron Veto

10 m Height
11 m Diameter
1,000 Tonnes
Water Cherenkov
Muon Veto



DS50 zero-background high mass DM search with underground Ar

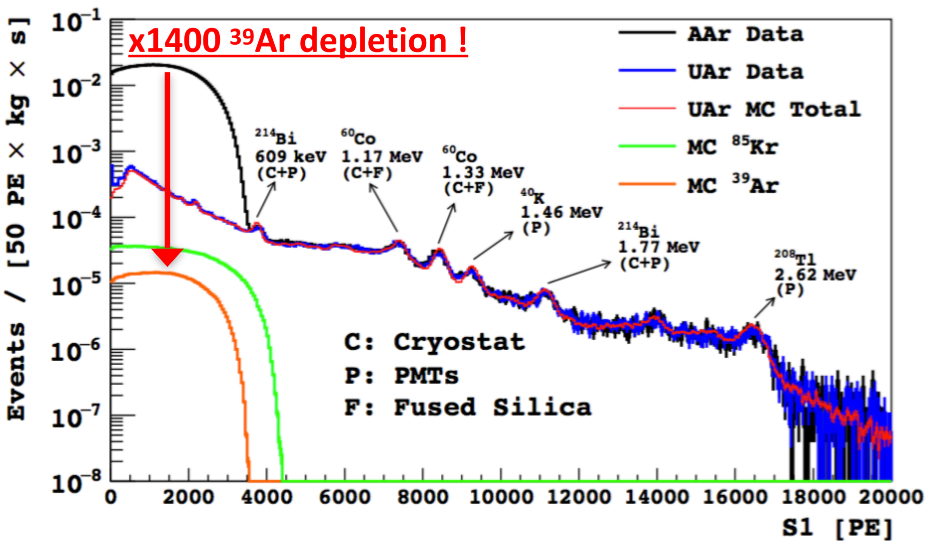
^{39}Ar β emitter (565 keV) with 269y $T_{1/2}$

Atmospheric Ar act. 1Bq/kg from ^{39}Ar

→ expect UAr depleted in ^{39}Ar

→ extract Ar from **underground source**

→ **DS50 filled with UAr in 2015**

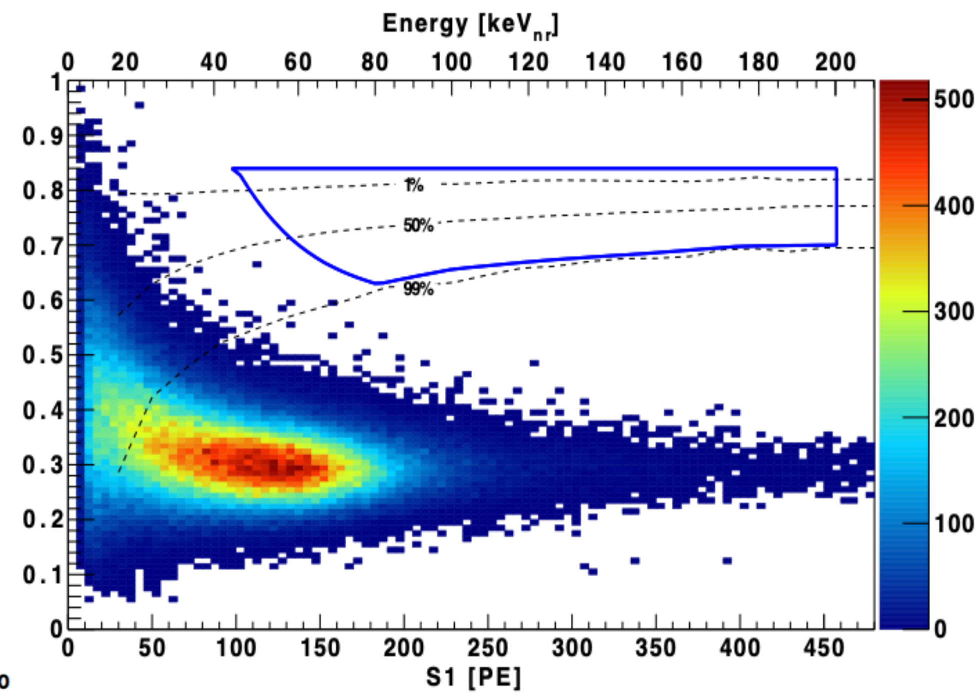


Fitted ^{85}Kr activity in UAr: 2.05 ± 0.13 mBq/kg

Fitted ^{39}Ar activity in UAr: 0.73 ± 0.11 mBq/kg

For DarkSide-20k need 100 tons of UAr Extracted at DOE Canyon (CO) with URANIA and distilled at ARIA facility in Sardinia

Based on 532 live days of DarkSide-50 with underground Argon



LAr TPC Zero-background for an exposure of about 44 ton years

—> scale to 200 ton years for DarkSide-20k

Low mass DM scattering off Argon

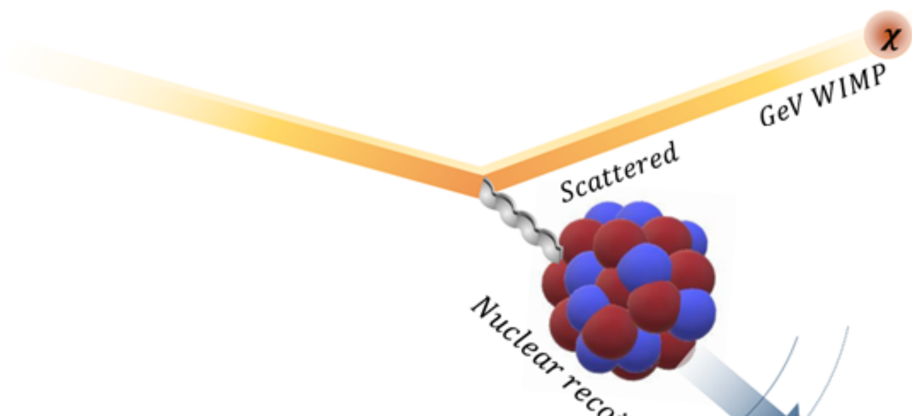
Low mass DM scattering, Ar recoil Energy :

$$E_R = \frac{q^2}{2m_N} \leq \frac{2\mu_{\chi N}^2 v^2}{m_N} \simeq 50\ keV \left(\frac{m_\chi}{100\ GeV}\right)^2 \left(\frac{100\ GeV}{m_N}\right)$$

$m_N^{Ar} \sim 37$ GeV

For $m_\chi = 10$ GeV ➡ $E_R \sim 1.4$ KeV

below threshold for S1 signal at ~6 keV_{nr} (2 keV_{ee})
but above S2 threshold ~ 0.4 keV_{nr} (0.1 keV_{ee})



Nuclear recoil ionization :

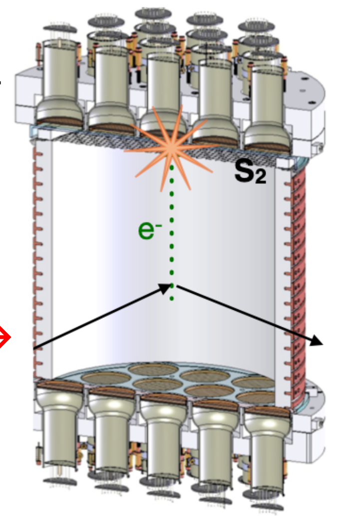
- few electrons drift
- gas pocket amplification

→ S2 signal

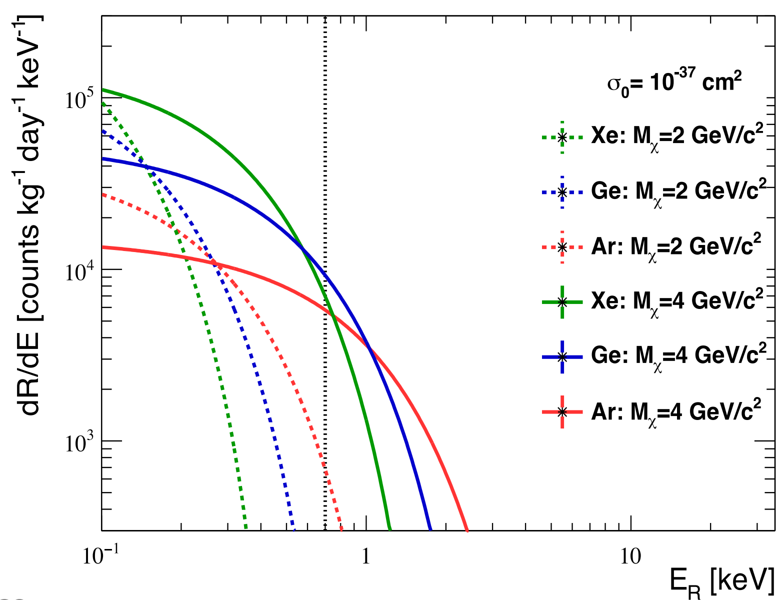
Low Mass WIMPs: < 20 GeV/c²

- Range: **0.7-15 keV_{nr}**
- **Lighter nucleus, larger recoil energy**
- **S2 ionization signal only →**

(no S1) with **g2 > 20 PE/e-**
(x-y g2 dependence, higher in core PMTs at center)



Low mass WIMPs E_R spectra for Ar, Ge, Xe

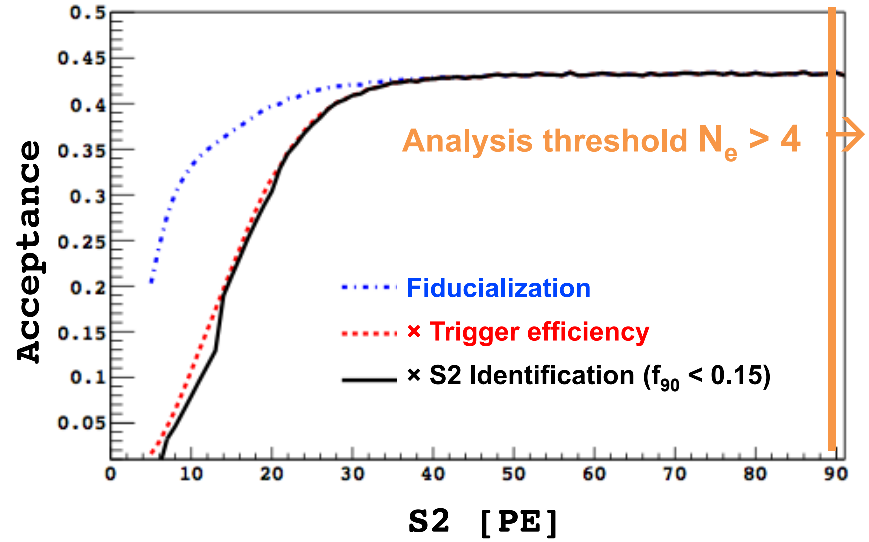


Measuring ionization only events in DS50

Detection efficiency :

Acceptance estimated with data/MC
Fiducialization: use volume under 7 central PMTs → drives acceptance, at ~40%

Analysis threshold at above 4 N_e

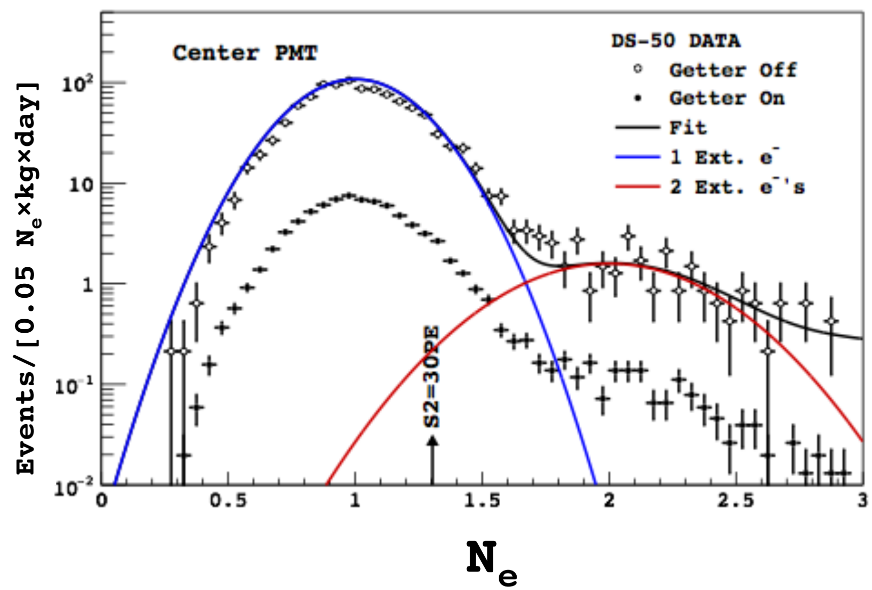


Single-electron line-shape :

- PMTs have zero dark rate at 88K
- Radioactivity very low in the detector

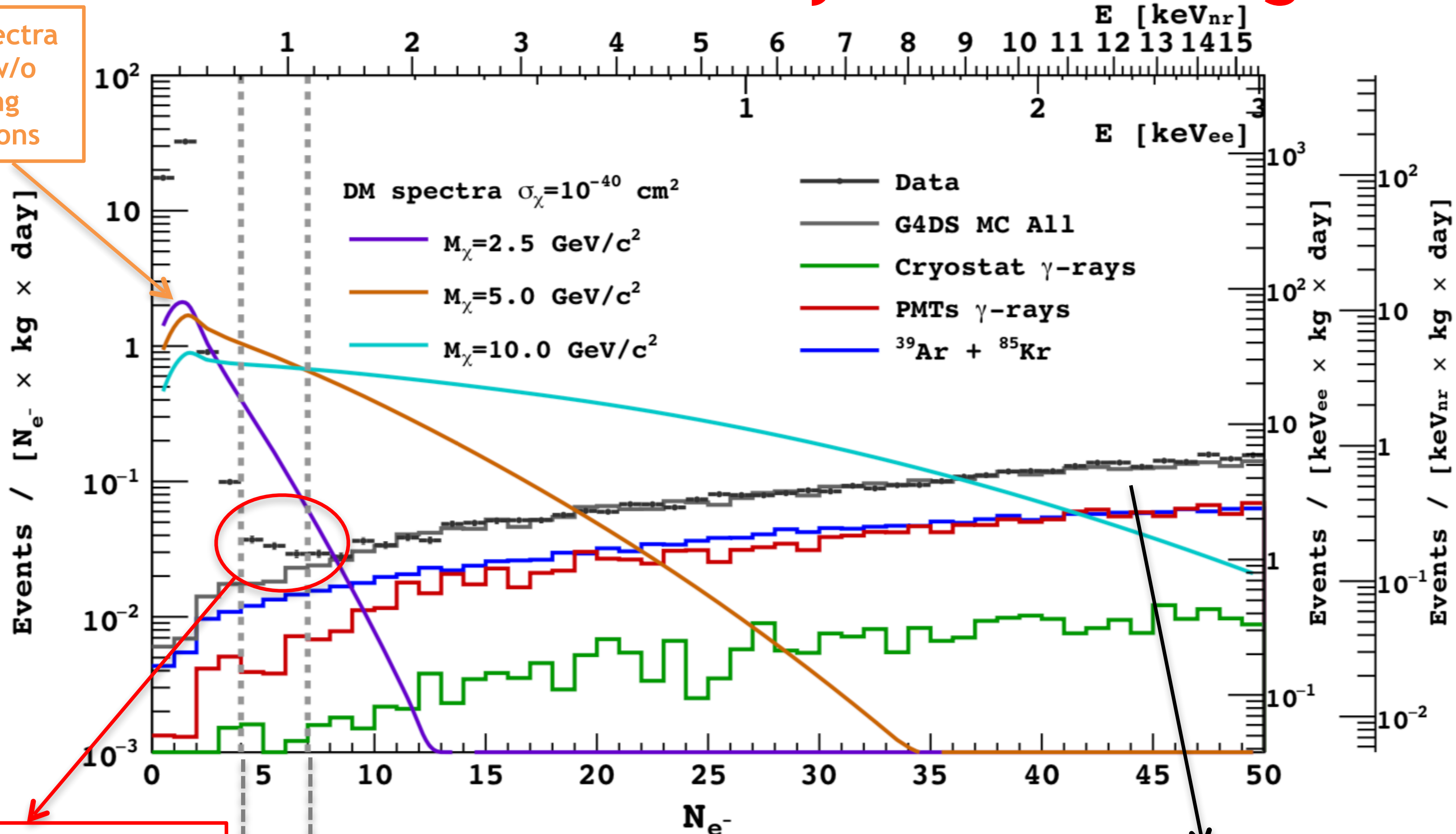
- One ionization electron (**Ne = 1**) under center PMT gives an S2 signal of **23±1 PE**
- The gain in the gas region (~70 PE/e-, reduced to 23 PE/e- when accounting for the 30% QE of the PMTs)

- **Sensitive to a single extracted electron**



Low Mass DM ionization only search background :

WIMP spectra plotted w/o quenching fluctuations



Excess of events wrt to background prediction due to trapped/delayed electrons peak.

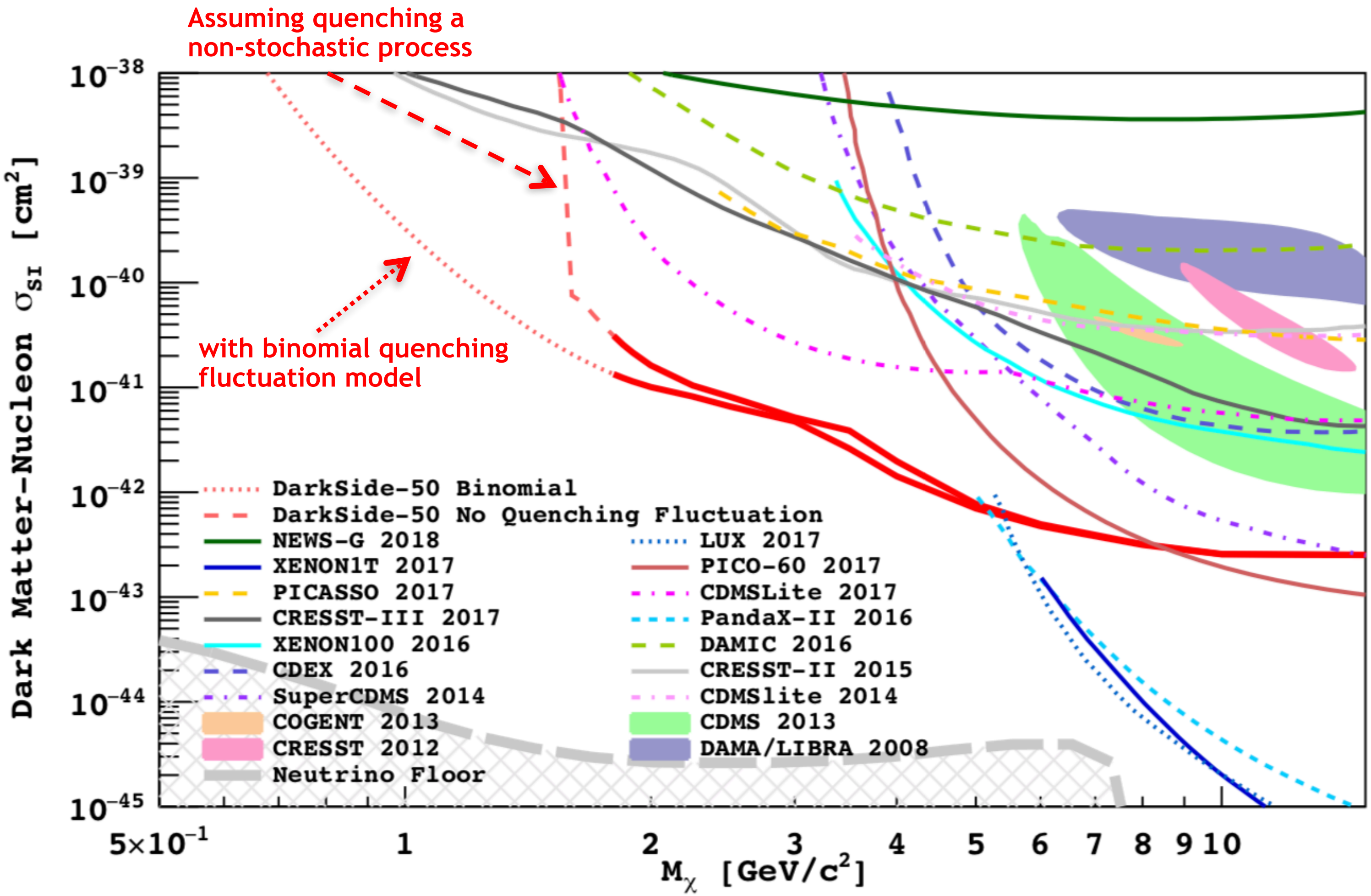
Also seen by XENON100. Studied for 2023 update —> See next

N_e > 7 analysis threshold for Mχ > 3.5 GeV in Data-MC good agreement region.

N_e > 4 analysis threshold for Mχ < 3.5 GeV. Region dominated by excess of Data over MC

In high N_e region, dominant ER backgrounds, level prediction with extrapolation from high energy spectrum MC fit, in very good agreement with data (at % level).

Low Mass DM 90% C.L. exclusion limit result :



- **Profile Likelihood Method** for N_e>4 and N_e>7 thresholds shown respectively for **M**χ **< 3.5 GeV** and **M**χ **> 3.5 GeV**
- **Uncertainties** for both WIMP signals (NR ionization yield, single electron yields) and BG spectrum (rates, ER ioniz. yield)

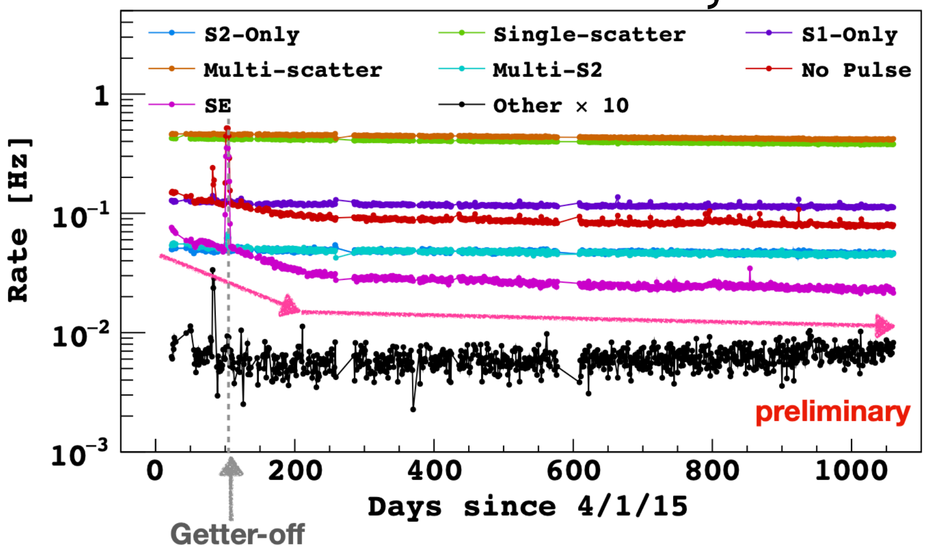
Due to lack of knowledge about fluctuation at very low recoil energy, two cases :

- **Binomial fluctuation** for NR energy quenching, ionization, and recombination processes.
- **No Fluctuation** for NR energy quenching process. Corresponding to apply hard cut off in quenched energy ~0.6 keV_{nr}

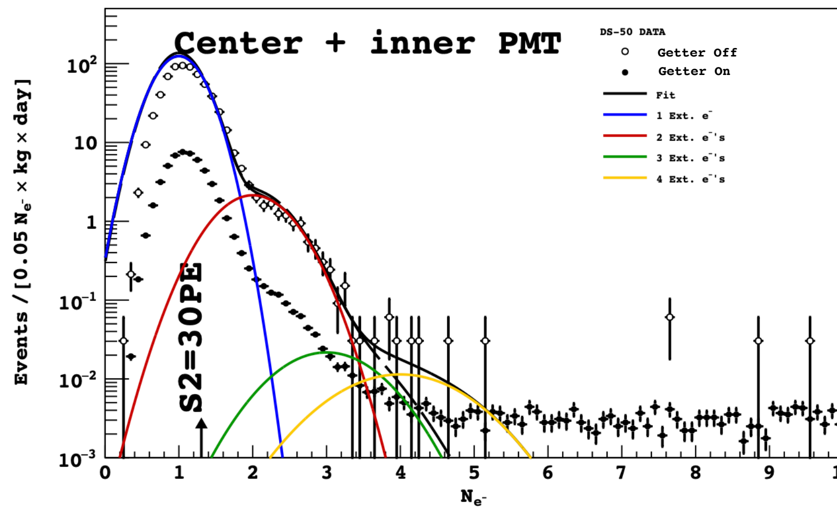
Spurious (few) electrons in S2 only data

Photo-ionization events of the cathode (within the maximum drift time) have been studied extensively in: "*A study of events with photoelectric emission in the DarkSide-50 liquid Ar TPC*" (astro part 140 2022 102704)

Time evolution and stability

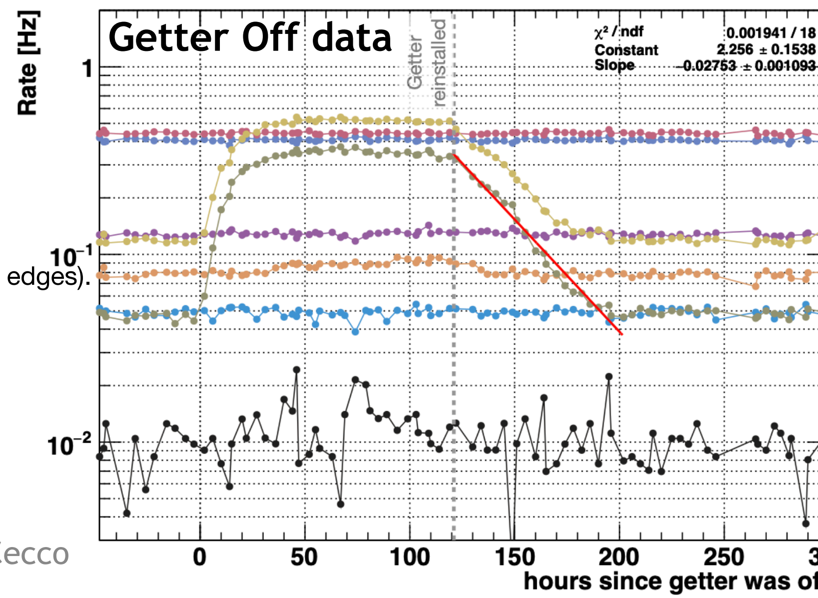


Zoom in the low Ne region



Event categorization:

- ***Multi scatter***: γ events, random pileup (S1 + multiple S2)
- ***Single scatter***: Normal events (S1 + S2)
- ***S1 only***: Cherenkov, surface events (no/small S2)
- ***No pulse***: Triggered, but pulse finder failed (noise triggers, low N_{e-} events near TPC edges).
- ***S2 only***: No /small S1, $N_{e-} \geq 4$ (low energy events)
- ***Multi S2***: Multi scatters where S1 and the first S2 pileup (due to low t_{drift})
- ***SE***: Single S2 with $N_{e-} < 4$
- ***Other***: All the rest, 1 mHz (<0.1% of all events), e.g., event with S2 + S1 + …

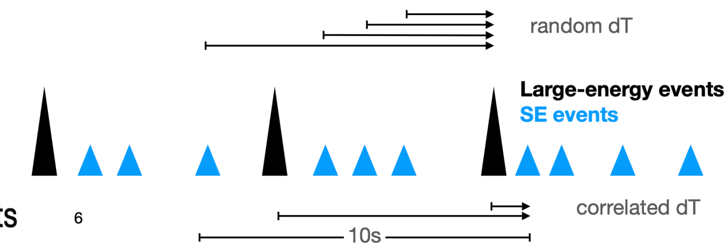


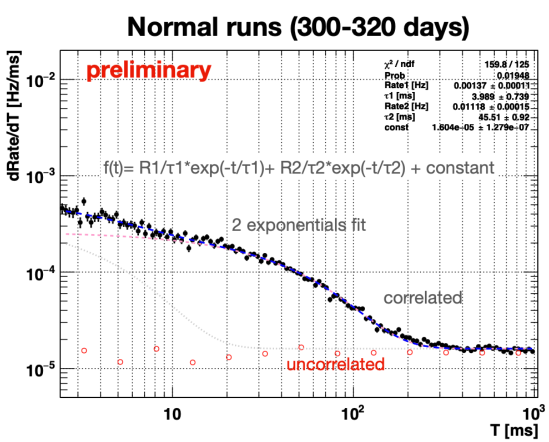
—> increase in SE and no-pulse rate

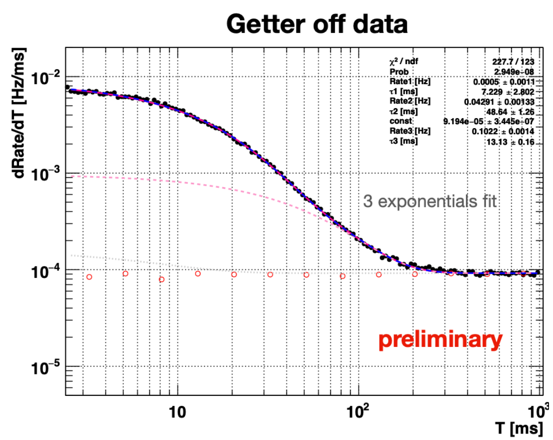
In getter off suggests a link to impurities

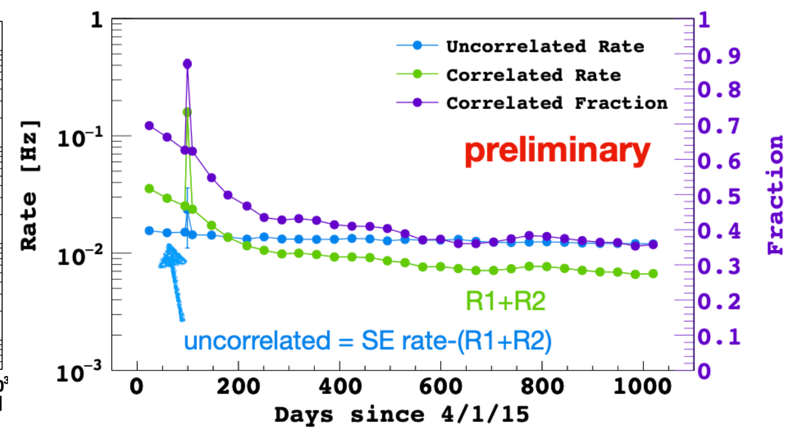
Time correlation of SE with large energy events

- large-energy events (parent events): S1>1000PE, t_drift defined (at least two pulses), and x-y position reconstructed.
- Register trigger time of events for large events and *SE* separately.
  - correlated ΔT: for each identified *SE*, fill time difference from all preceding large events within 10s from the *SE*.
  - random ΔT: for each identified large event, fill time difference from all preceding *SE* events within 10s from the large event.
- Random ΔT helpings modeling the uncorrelated fraction that is present in the correlated ΔT









A fraction of 40% - 70% of SE rate is correlated to well identified preceding events

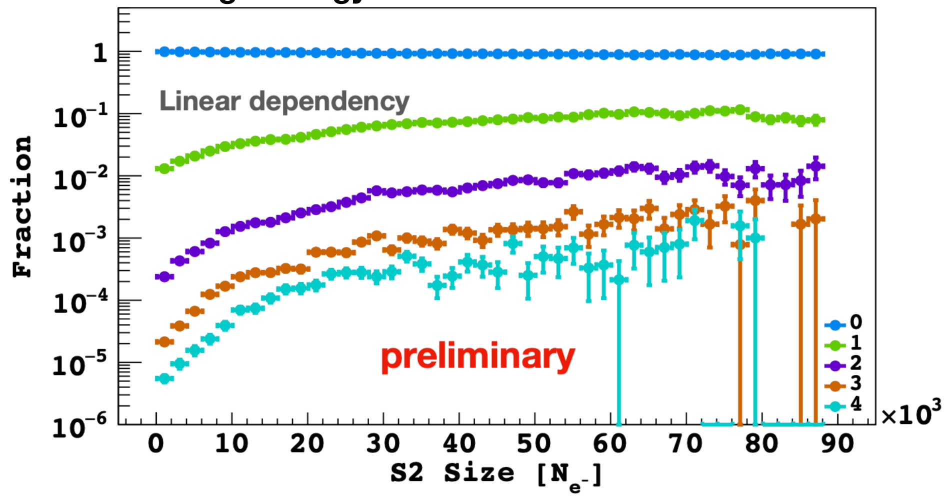
Space/Energy correlations of SE with large energy events

- For all parent events, count how many SE events follow until next parent event.
- The fraction of parent events with no SE events, one SE event, two SE events, so on, is calculated as a function of parent S2.
- Only single-scatter parent events to have a well-defined z-position.
- Clear linear relationship with z-position of parent. -> **The longer the drift time, the higher the chance of electrons to be captured.**
- Consistent with the correlated-events

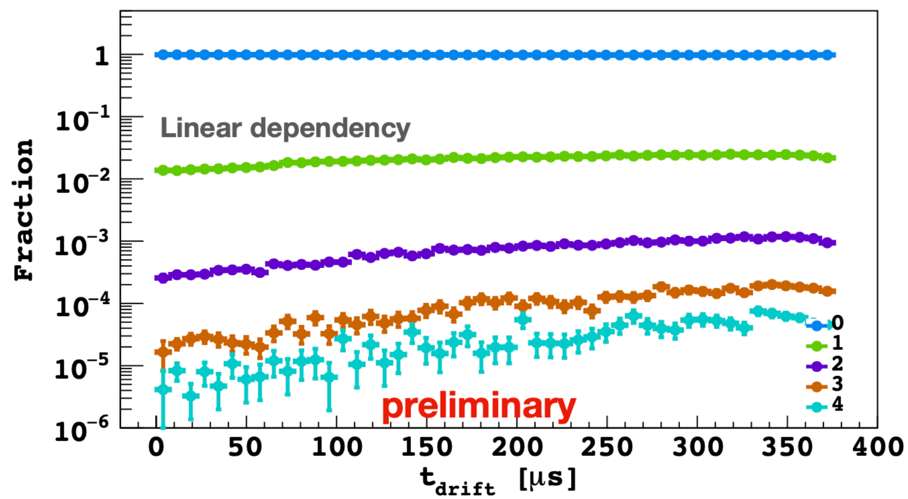
<u>Also observed (see backups):</u>

- x-y correlation between SE and parent S2
- with parent energy S1
- with total TPC activity
- with Rn trap temperature (impurity trapping efficiency)

Large energy events create more SE events.

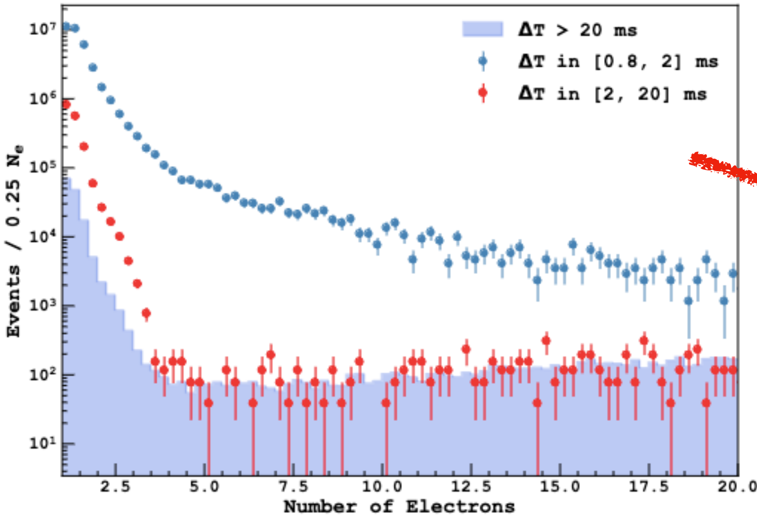


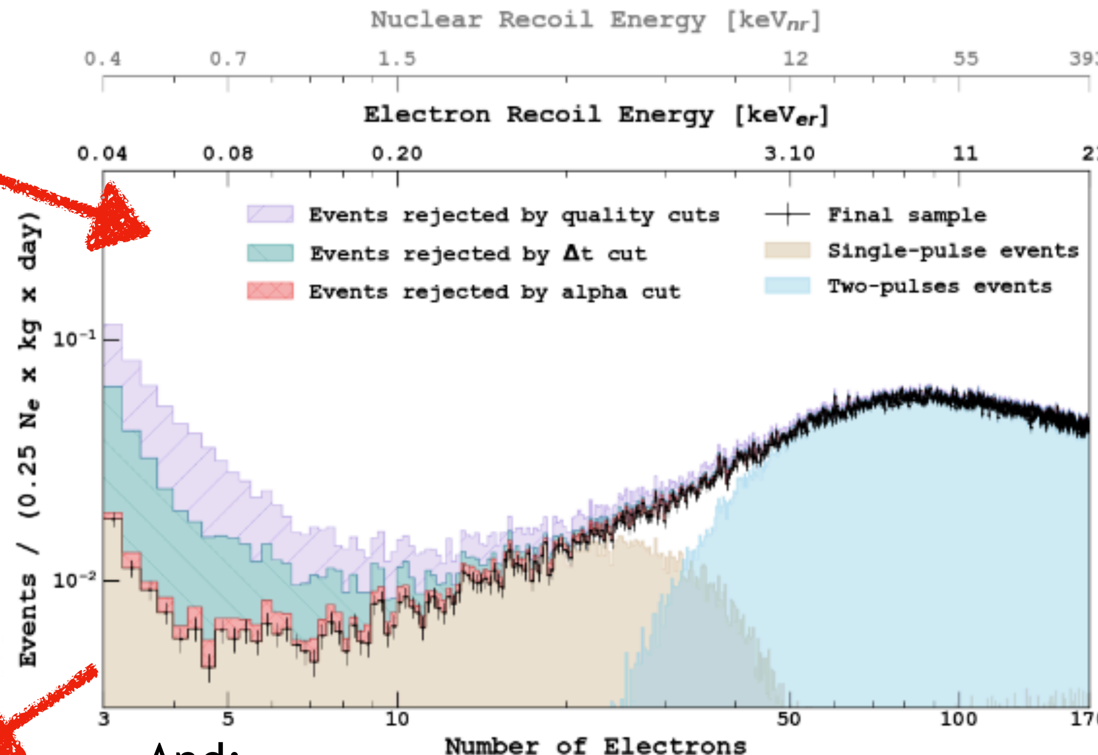
Longer drift time —> higher chance of electrons capture



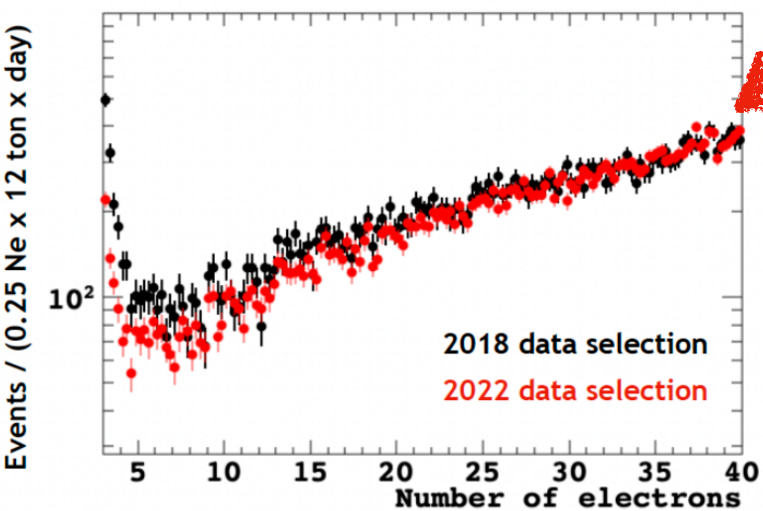
New S2 only events selection - 2023

Adding Delta T cut to reduce delayed SE:





Compare with previous selection



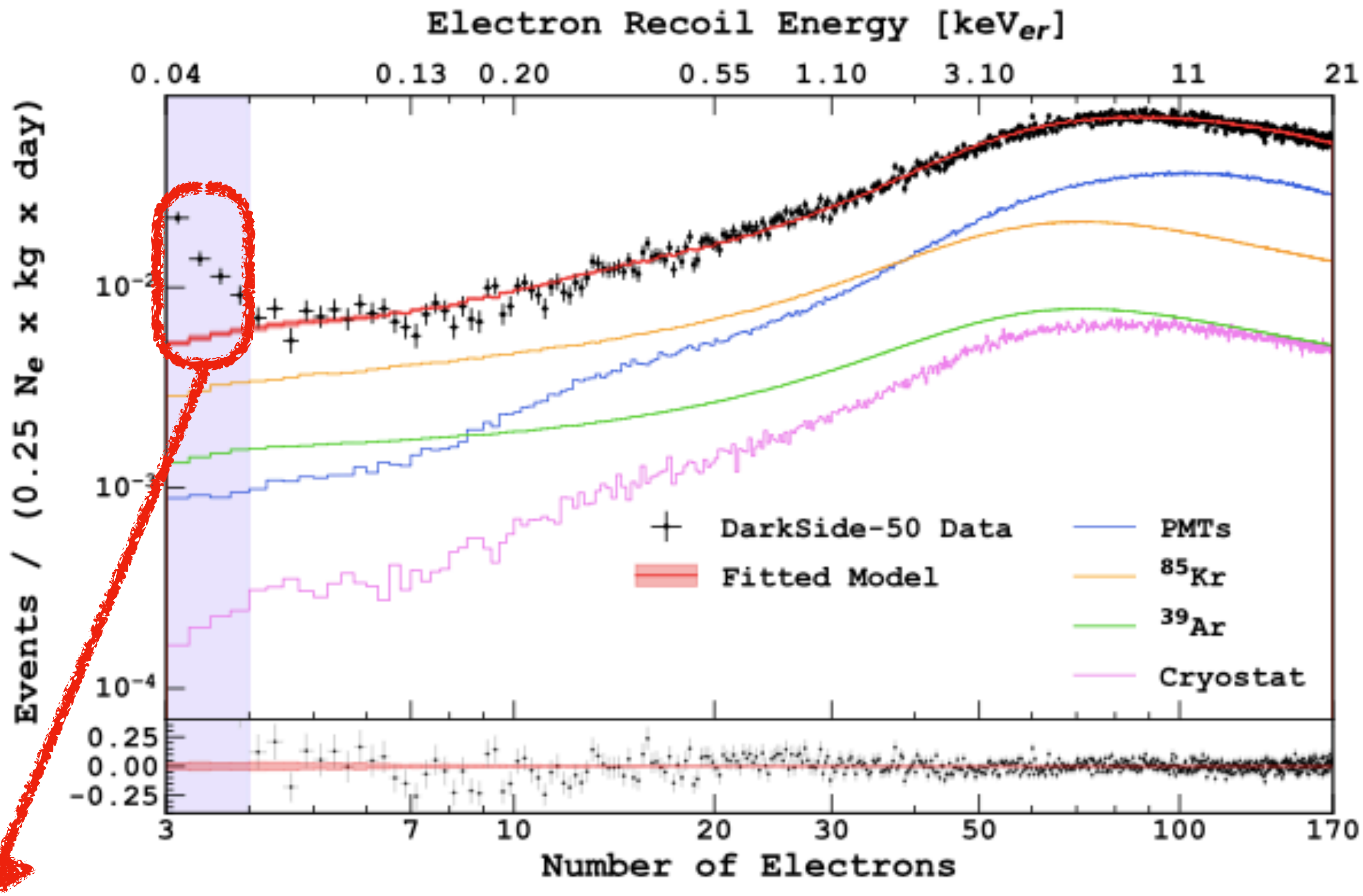
... And:

- improved calibration for both ER and NR
- Updated calculation of Beta spectrum shape for 39Ar and 85Kr
- MC backgrounds statistics

—> data/MC agreement for Ne > 4 improved

Ionization S2 only background fit

arXiv:2207.11966 - 2023 low mass analysis



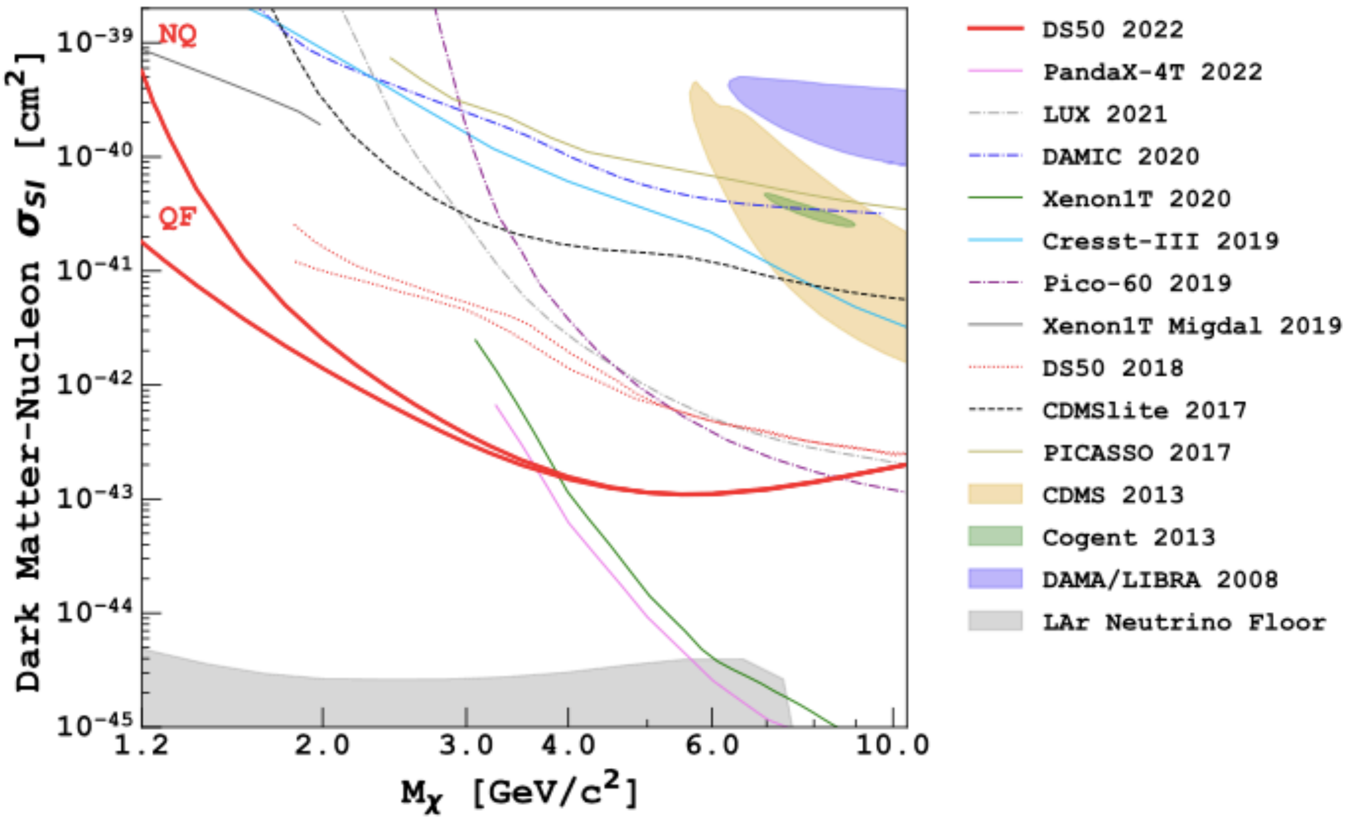
Excess in the low Ne region still prevents to lower the threshold below 4 Ne

Background only fit for 4 < Ne < 170 excellent data/MC backgrounds agreement

DS50 results in low mass DM search

DS50 2018 analysis updated in 2023 with new calibration, selection and MC.

Non zero background search. Limited by energy response at low energy and internal ER back.
World best sensitivity to GeV DM



arXiv:2207.11966 - 2023 low mass analysis

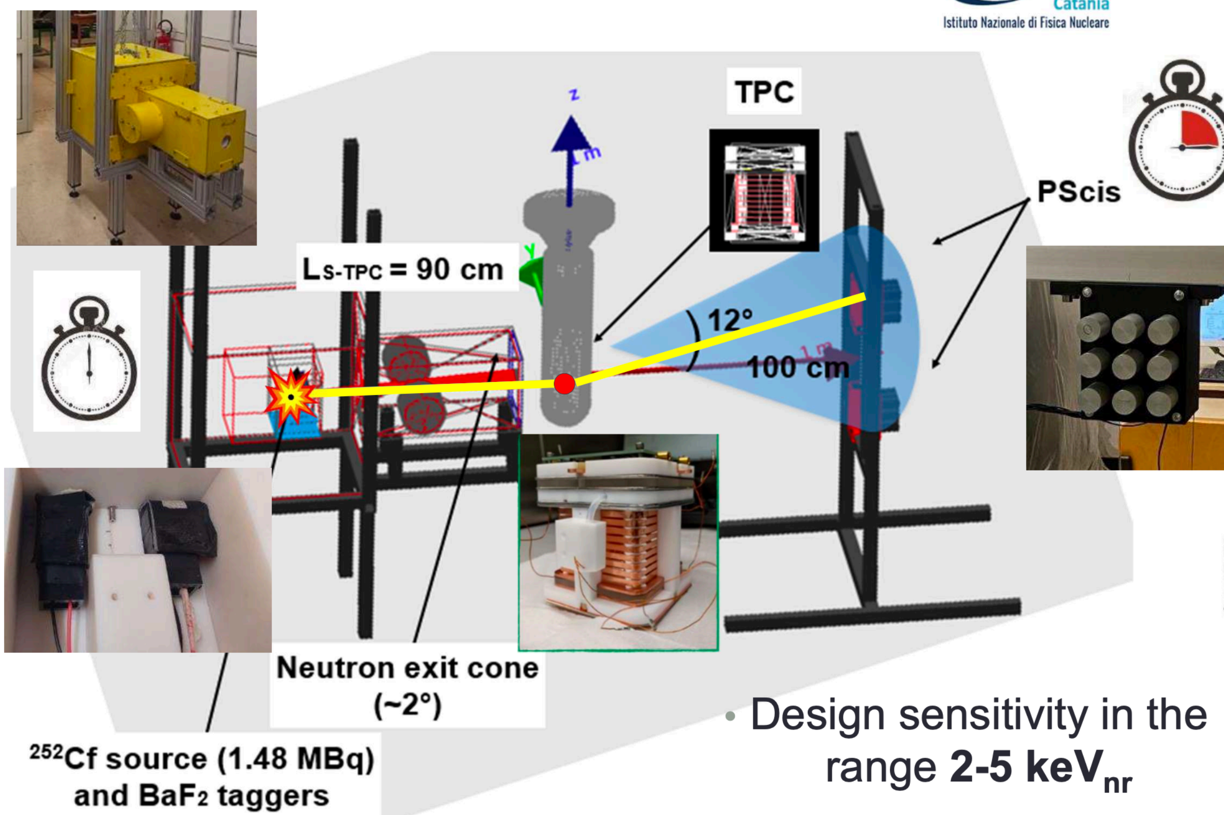
Phys. Rev. D 107, 063001 (2023)
Phys. Rev. Lett. 130, 101001 (2023)
Phys. Rev. Lett. 130, 101002 (2023)

Also:
- Migdal effect inclusion (see backup)
- ER interpretation of S2 only signature: Axions,dark photons, …
- Baiesian approach with evolved Likelihood including calibration parameters in the fit

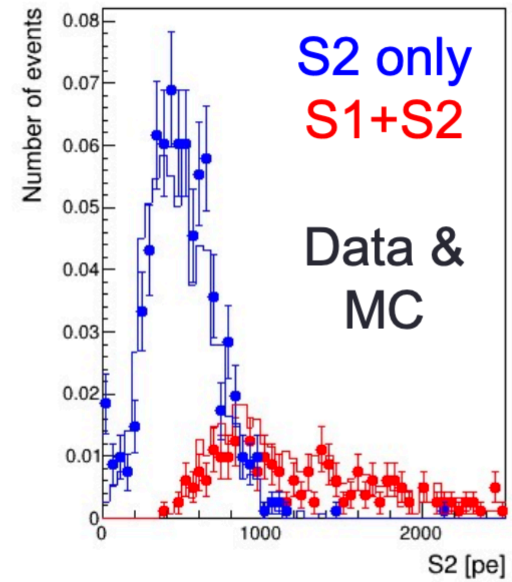
Low energy NR study with ReD experiment at LNS

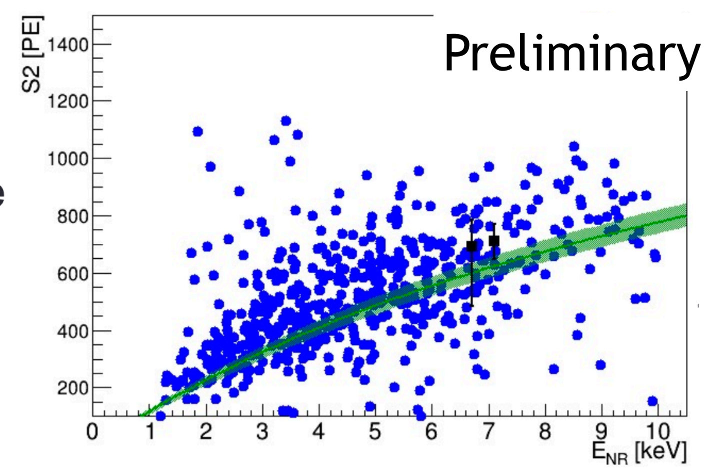
For details see: —> talk by **Luciano Pandola** next week at IDM

The ReD conceptual layout



- Design sensitivity in the range **2-5 keV$_{nr}$**



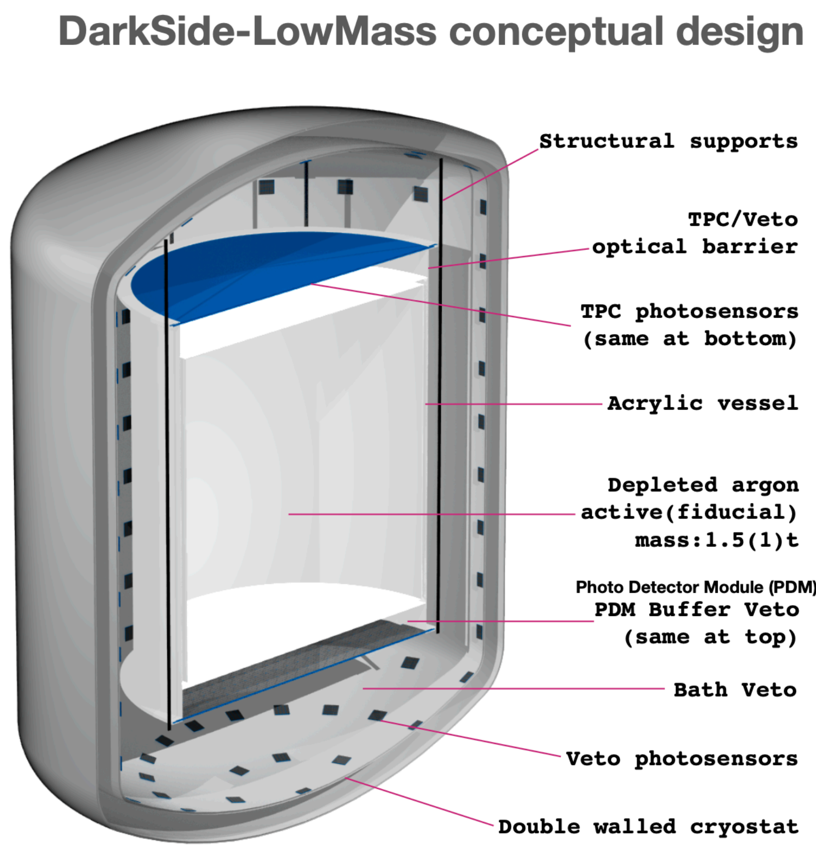


Setup being upgraded to lower NR range
Neutron gun is being commissioned in Sau Paulo Un.
will arrive in Catania to also expose ReD

Future DarkSide-LowMass concept

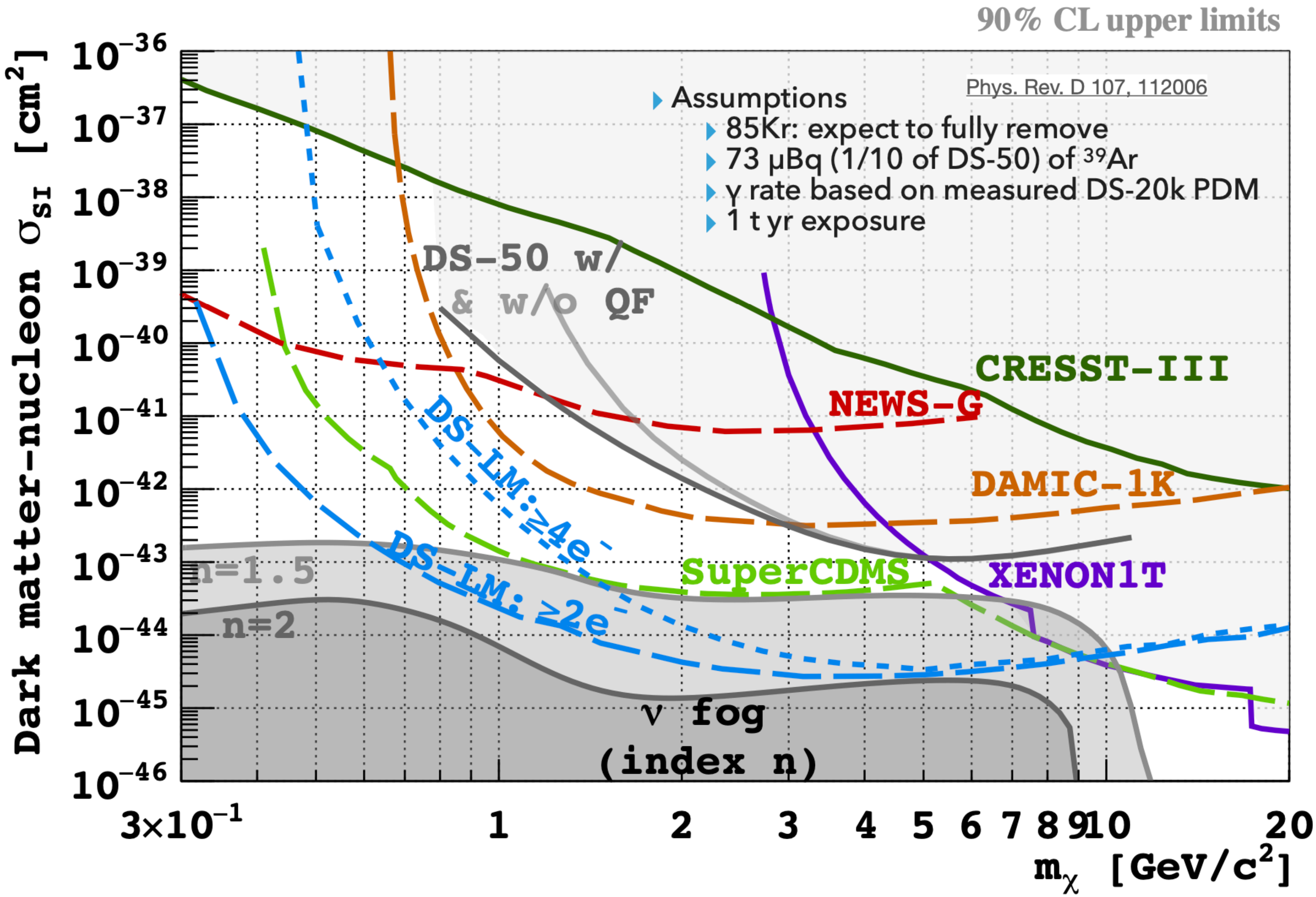
[Phys. Rev. D 107, 112006]

- Low activity of ^{39}Ar
- Low impurity
  - good electron lifetime
  - low rate of the single electron events
- Ultra-pure photo-sensor
- Pure (or no) cryostat

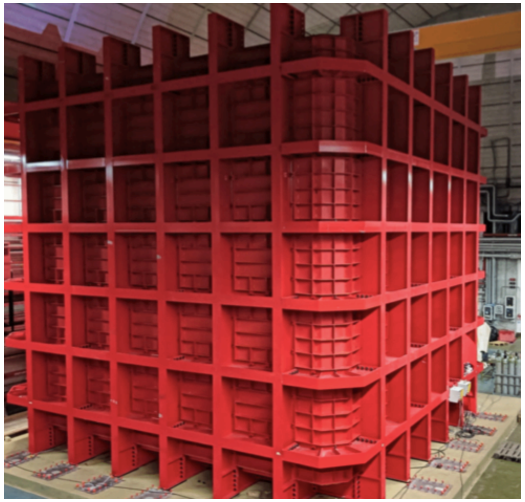


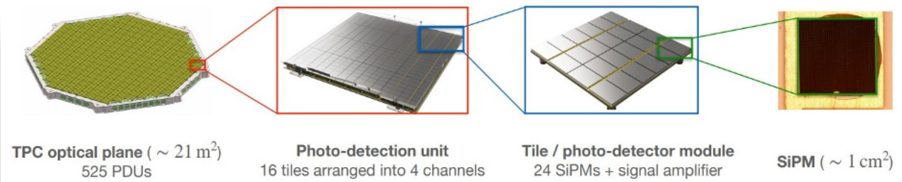
- Optimized TPC ~1 ton UAr fiducial with depletion factor x10 or x100 wrt to DS50

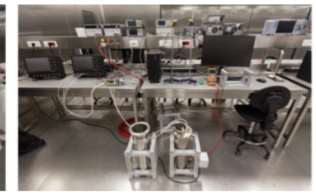
Future DarkSide-LowMass sensitivity

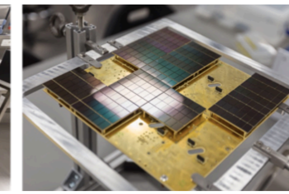


DarkSide-20k in construction at LNGS

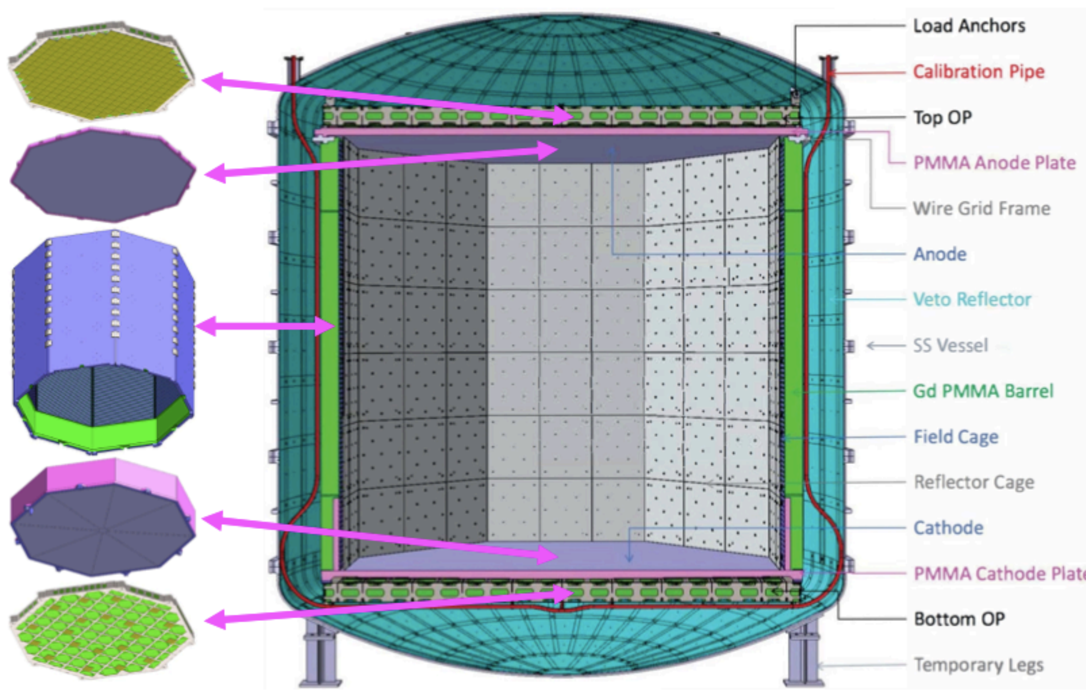




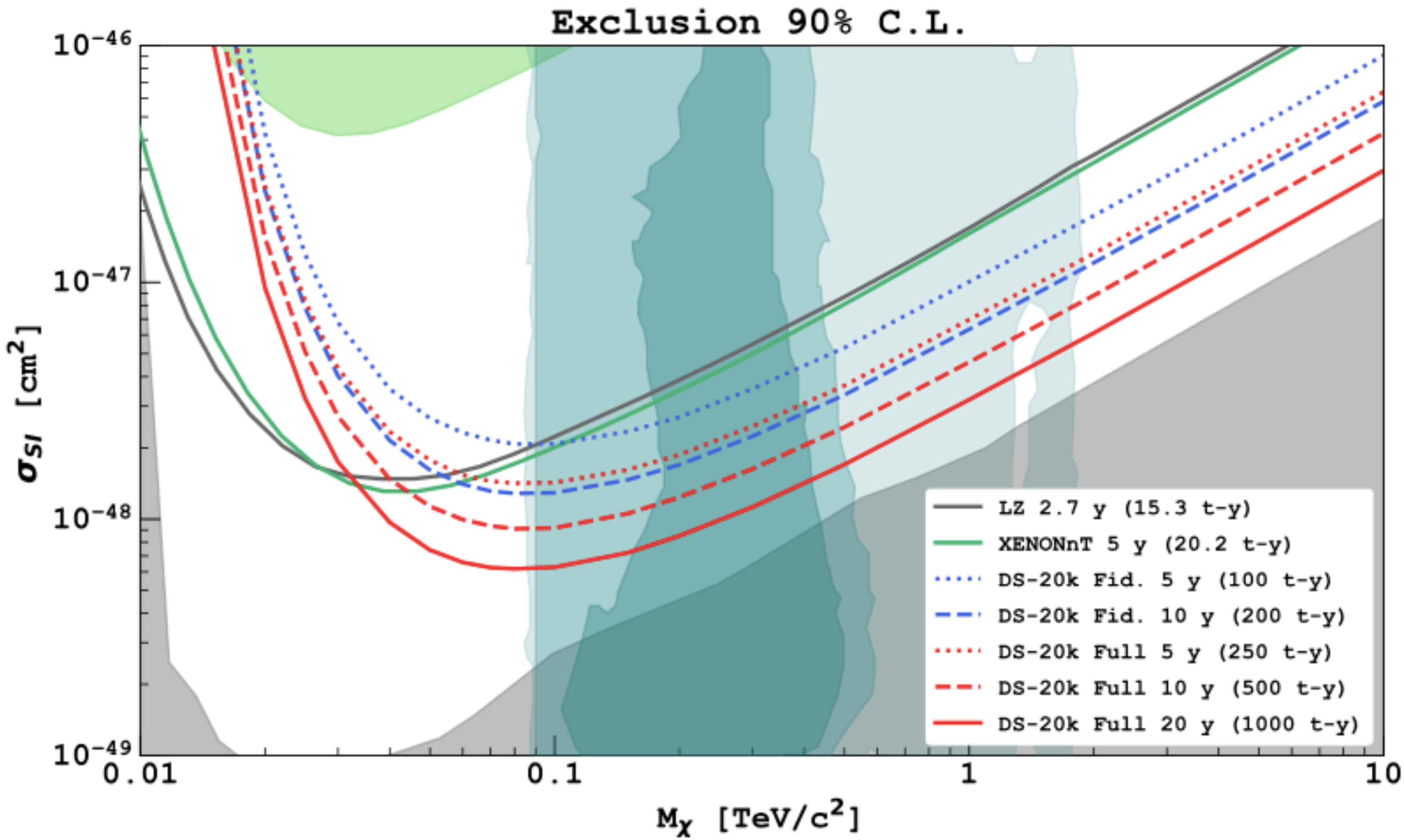




- TPC:
  - Active UAr mass: 49.7 tonnes;
  - Fiducial UAr mass: 20.2 tonnes.
- Active neutron veto
  - Gd-PMMA;
  - Active UAr mass: 32 tonnes.
- SiPM as the photosensor;
- Single readout channel size: 10 cm x 10 cm;
- TPC: 2112 channels:
  - Top and bottom optical plane (OP);
- Veto: 480 channels.



DarkSide-20k high mass DM sensitivity



NEW: DarkSide-20k sensitivity to light DM

- assuming same UAr purity in ^{39}Ar as in DS50 (conservative), at Ne>=4, ^{39}Ar background is dominant.

- Assume ^{85}Kr is negligible (distillation in extraction site URANIA)

- SiPMs Photo Detection Modules and TPC material (PMMA) are very radio pure wrt to DS50 and the SS Vessel is far from the fiducial.

- Large detector allows effective x-y fiducialization

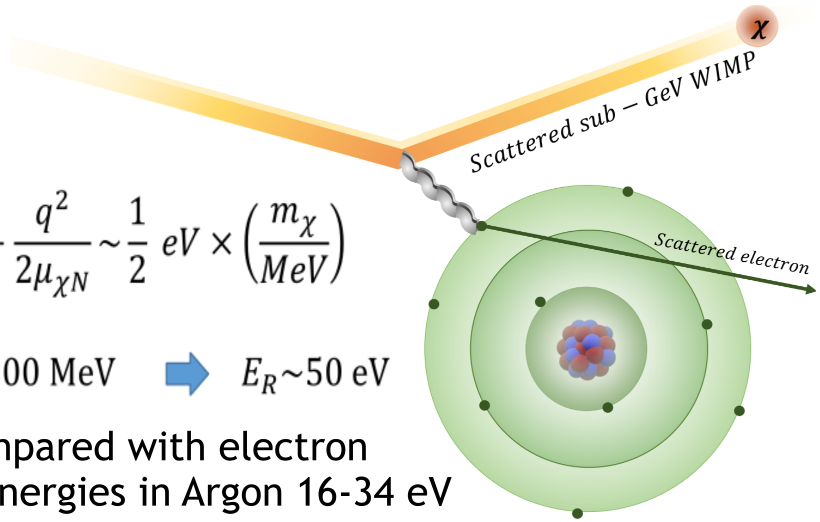
- Scale SE low Ne background as in DarkSide-LowMass. Use shape in the fit for Ne>2.

- Limits for Ne>4 and Ne>2: with 1 year data taking: O(10^2) times better than DS50

Publication being submitted this weekend. For details see:
—> talk by **Marie van Uffelen** next week at IDM

BACKUP

DM-electron scattering interpretation:



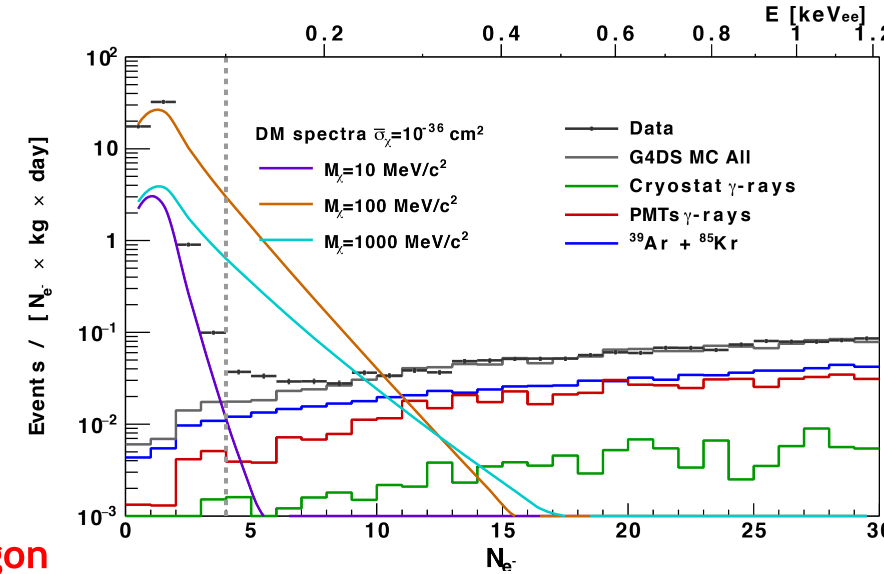
$$E_R = \vec{q}\cdot\vec{v} - \frac{q^2}{2\mu_{\chi N}} \sim \frac{1}{2}\ eV \times \left(\frac{m_\chi}{MeV}\right)$$

For $m_\chi = 100$ MeV ➡ $E_R \sim 50$ eV

to be compared with electron binding energies in Argon 16-34 eV

$E_b^{3p} \sim 16.08$ **eV** , $E_b^{3s} \sim 34.76$ **eV**

→ **ultra low mass DM scattering on e^- can ionize Argon**



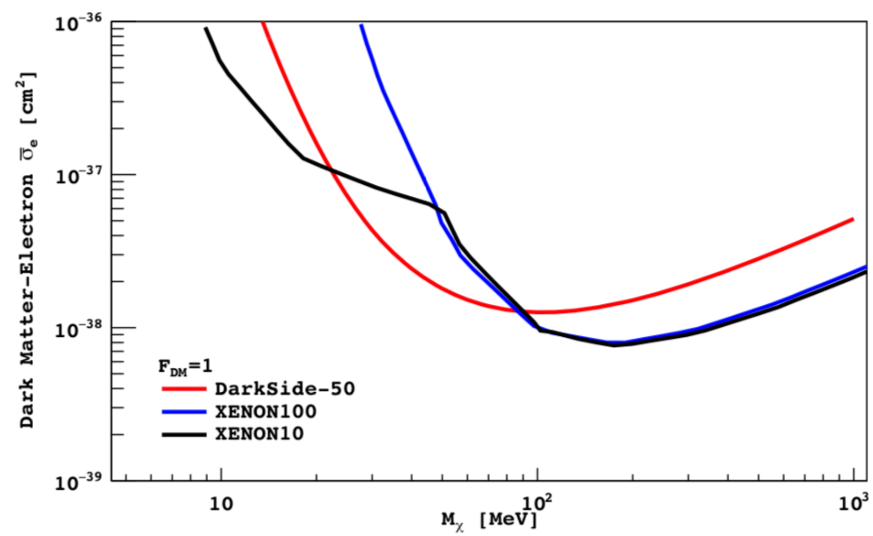
DM-electron differential scattering rate :

$$\frac{dR}{d\ln E_{\rm er}} = N_T \frac{\rho_\chi}{m_\chi} \frac{\overline{\sigma}_e}{8\,\mu_{\chi e}^2} \times \sum_{nl} \int dq\, q\, |f_{\rm ion}^{nl}(k', q)|^2\, |F_{\rm DM}(q)|^2\, \eta(v_{\rm min})$$

Tested in the two “light” and “heavy mediator regimes:

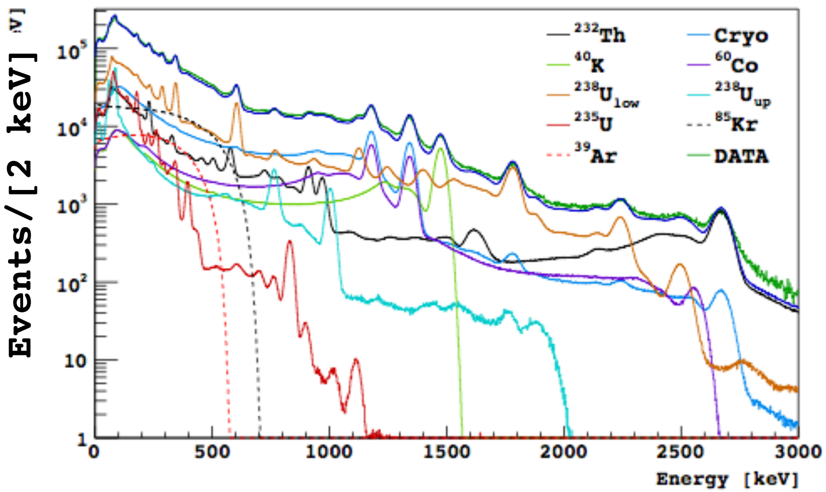
$$|F_{\rm DM}(q)|^2 = \begin{cases} 1, & m_{\rm med} \gg \alpha m_e \\ (\alpha m_e/q)^4\,, & m_{\rm med} \ll \alpha m_e\,, \end{cases}$$

F_{DM} ~ 1 → heavy mediator

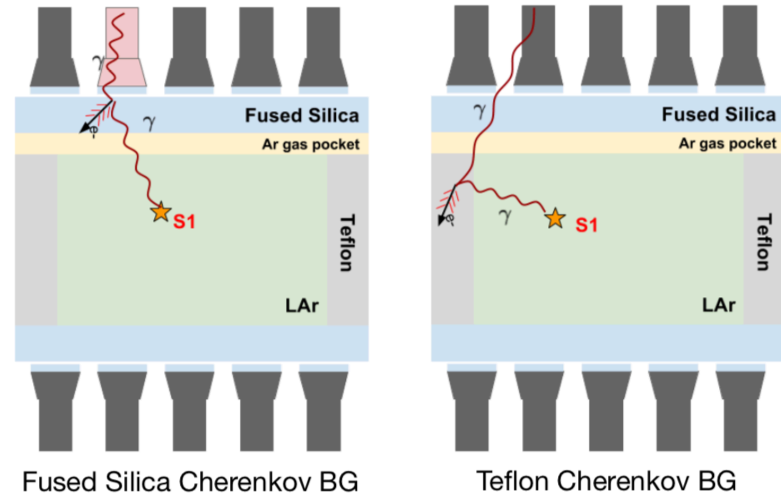


Electron recoils backgrounds

Internal ^{39}Ar and ^{85}Kr + external gammas



S1 + Cherenkov

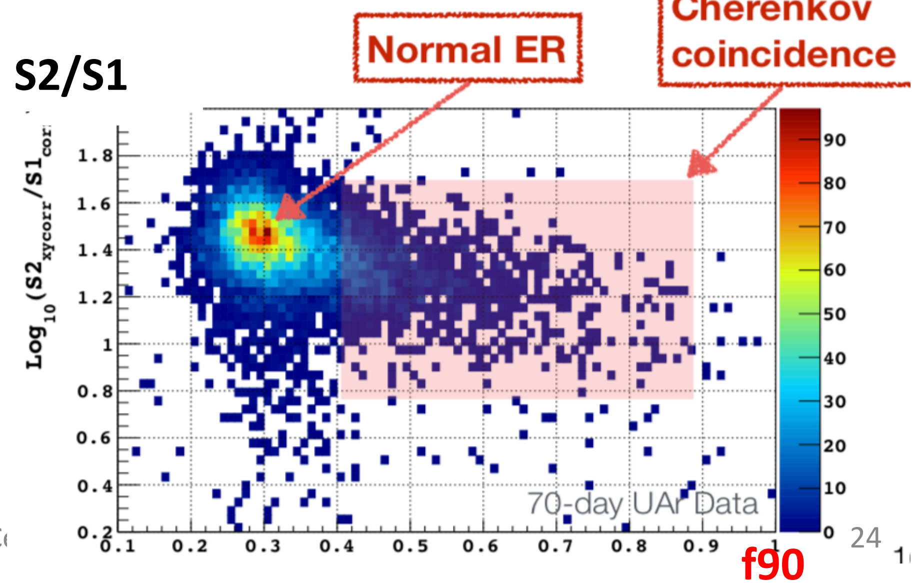


→ γ-ray multiple Compton scatters in LAr and in nearby Cherenkov radiator (Fused Silica PMT window or PTFE) : prompt Cherenkov light adds to S1 signal rise → large f90

ER Background rejection:

- Underground Ar
- S1 fraction in max PMT
- PSD: f_{90} = S1 fraction in first 90 ns

Design cuts to reduce ER to :
< 0.08 event of Total background

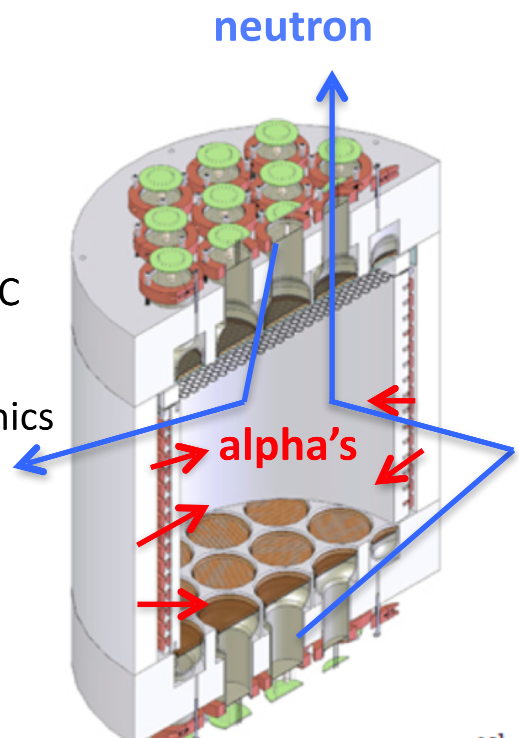


Nuclear recoil backgrounds

Neutrons

Background rejection:

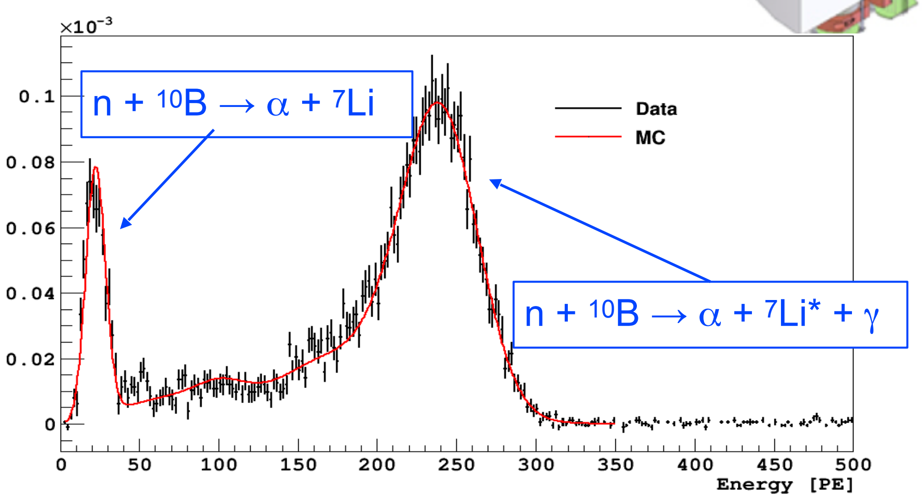
- TPC: multi-scatter
- LS Veto: efficiency from Am-C for TPC single-NR: **0.9964±0.0004**
- Water Cherenkov Veto for cosmogenics
- Neutrons in data are counted.

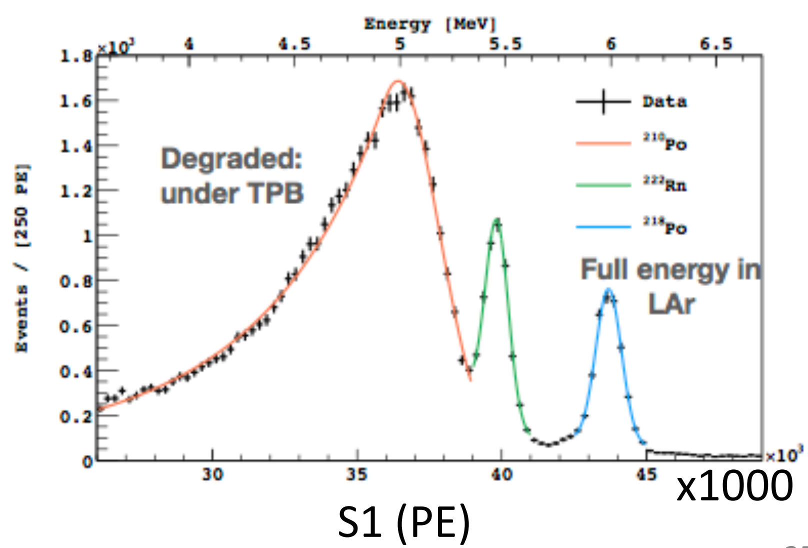


Alpha's

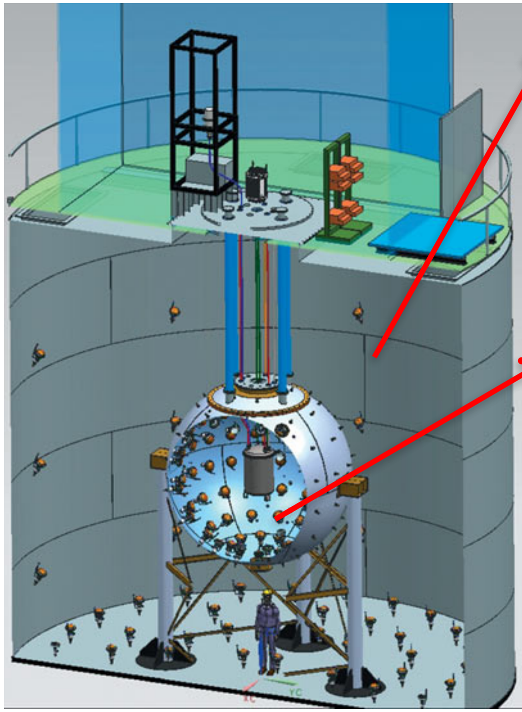
Background rejection:

- Very high S1, small fraction at low energies (cut at S1<460 PE)
- Self-vetoing in DS-50!
  - Small or no S2
  - Long scintillation tail from TPB fluorescence





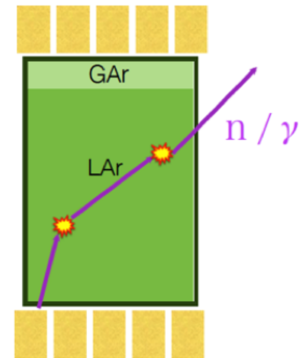
Neutron background active veto

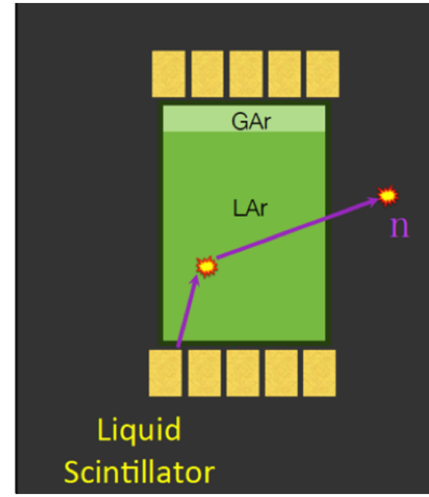


Water Tank
- 11 m diameter x 10 m high
- 80 PMTs
- Active muon veto
  - tag cosmogenic neutrons
- Passive neutron and γ shielding

Liquid Scintillator Veto
- 4 m diameter sphere
- Boron-loaded: PC + TMB
- 110 8" PMTs
- Active neutron veto
  - tag neutrons in TPC
  - in situ measurement of neutron BG
- Passive neutron and γ shielding

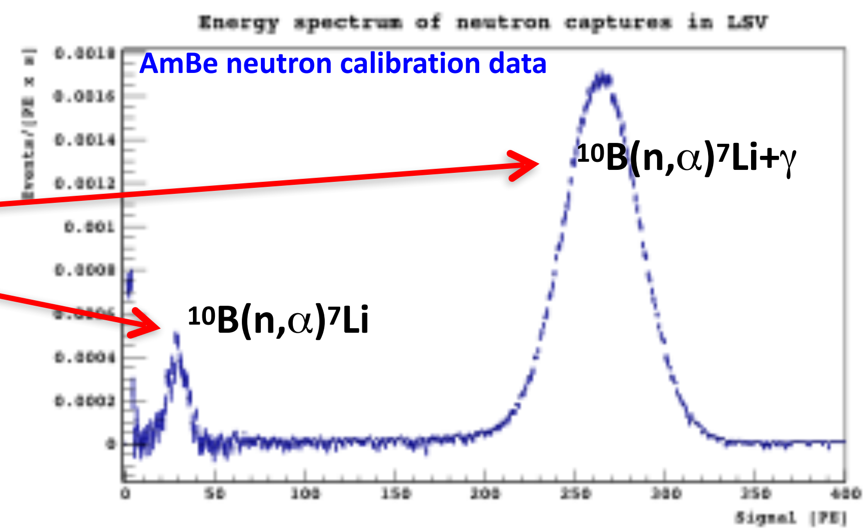
Neutron mean free path 1-10 cm, can be tagged with multiple hits in TPC and in LSV :





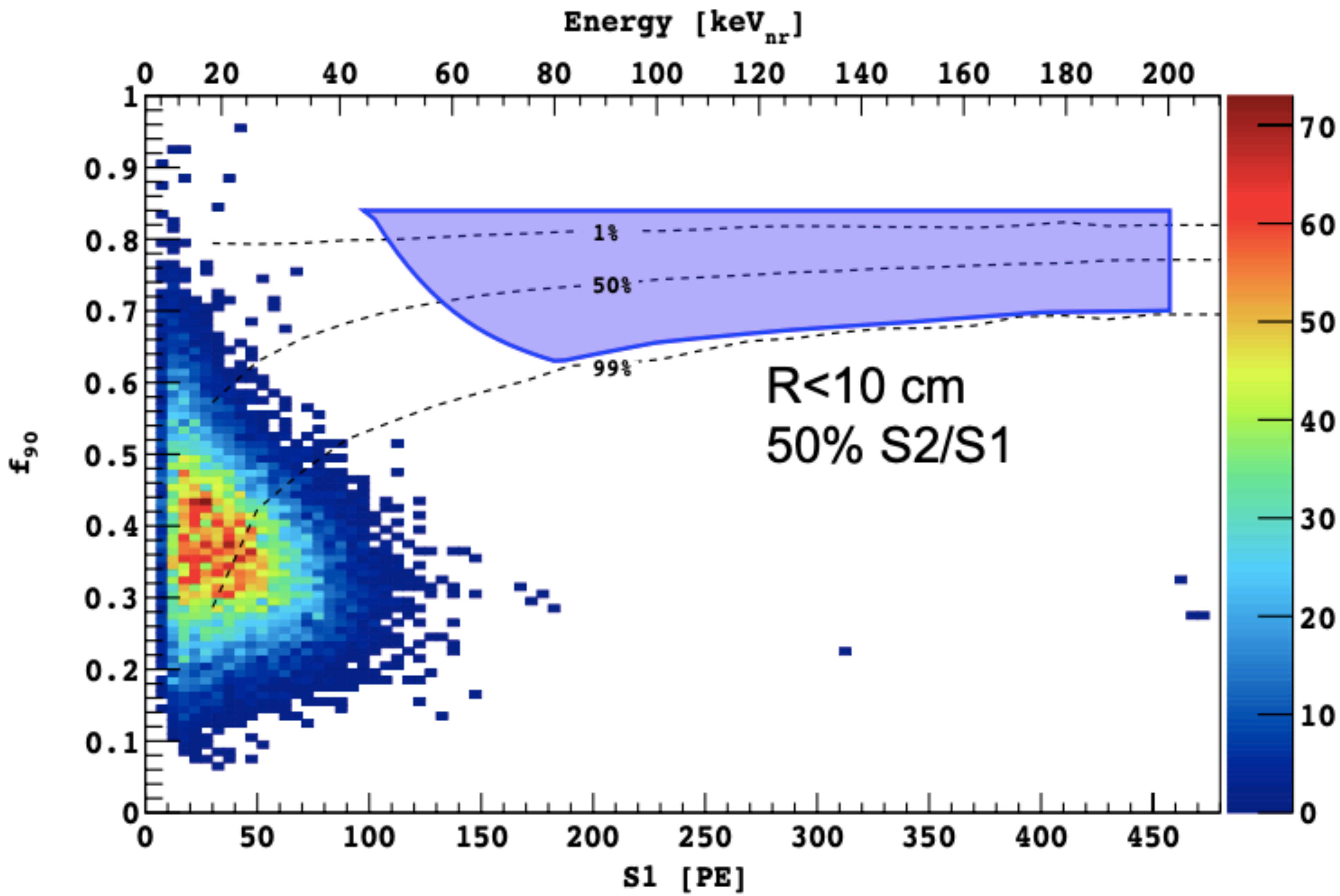
Observe neutron capture on ^{10}B through :

- 93.6%: $^{10}\text{B} + \text{n} \Rightarrow {}^{7}\text{Li}^{*} + \alpha$
  $^{7}\text{Li}^{*} \Rightarrow {}^{7}Li + \gamma$ (478 keV)
- 6.4%: $^{10}\text{B} + \text{n} \Rightarrow {}^{7}\text{Li}$ (1015 keV) + α (1775 keV)
  α (1775 keV) equivalent to 50–60 keVee

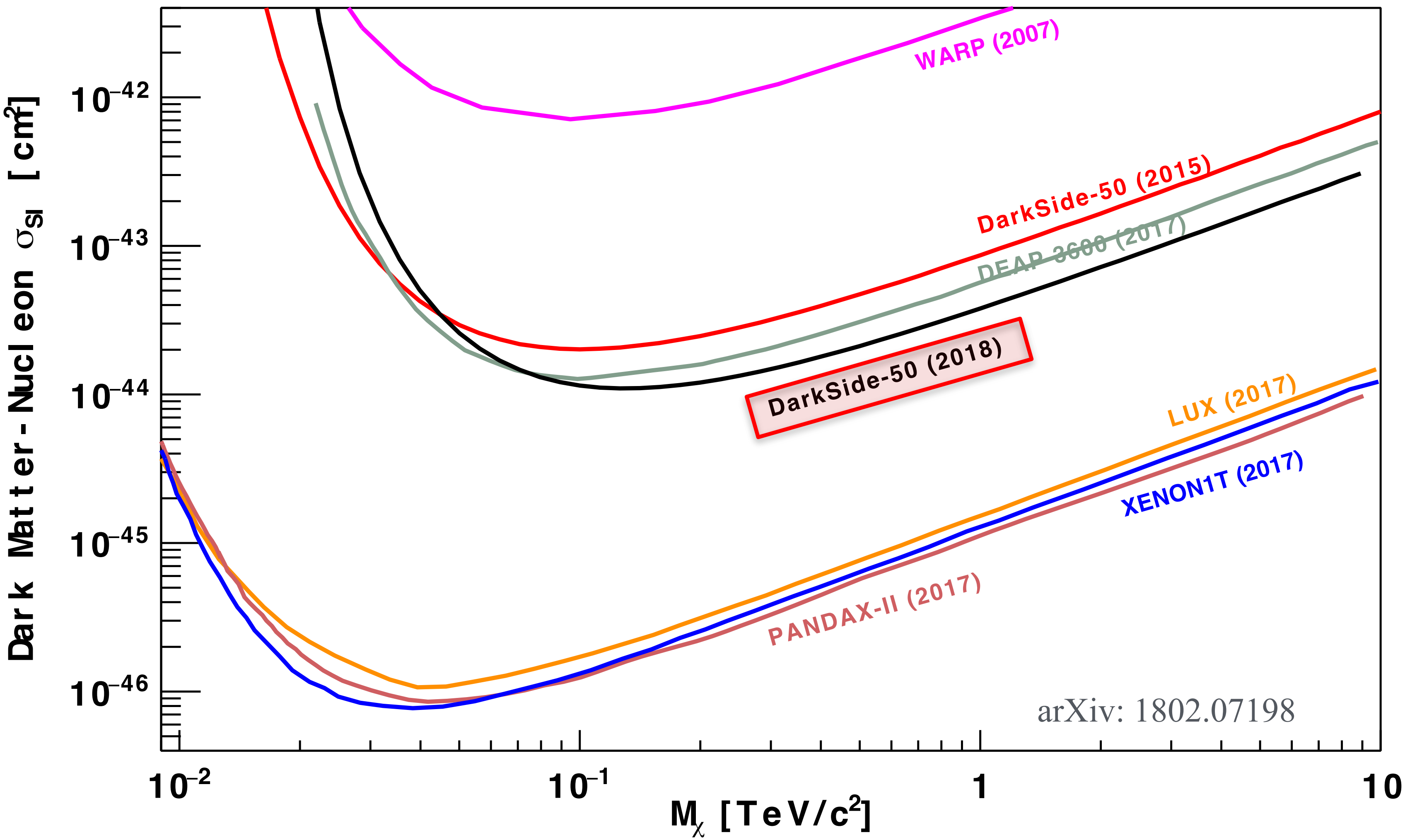


>99.1% efficiency to veto neutrons with capture signals.
Ex. : in current DS-50 data <0.02 n predicted after veto and total of 2 +- 2 tagged events.

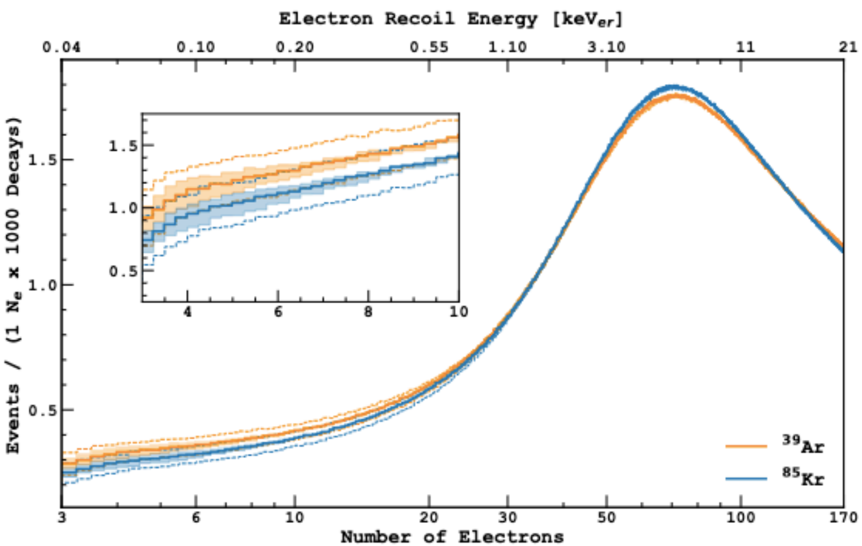
High Mass - S2/S1 additional discrimination

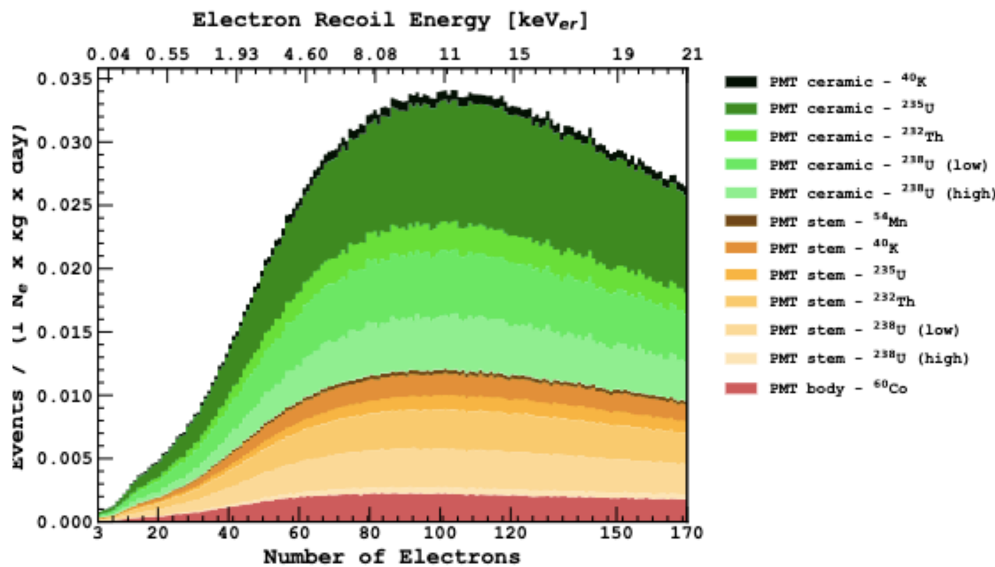


High mass 90% C.L. exclusion limit result



Ionization (S2) only backgrounds



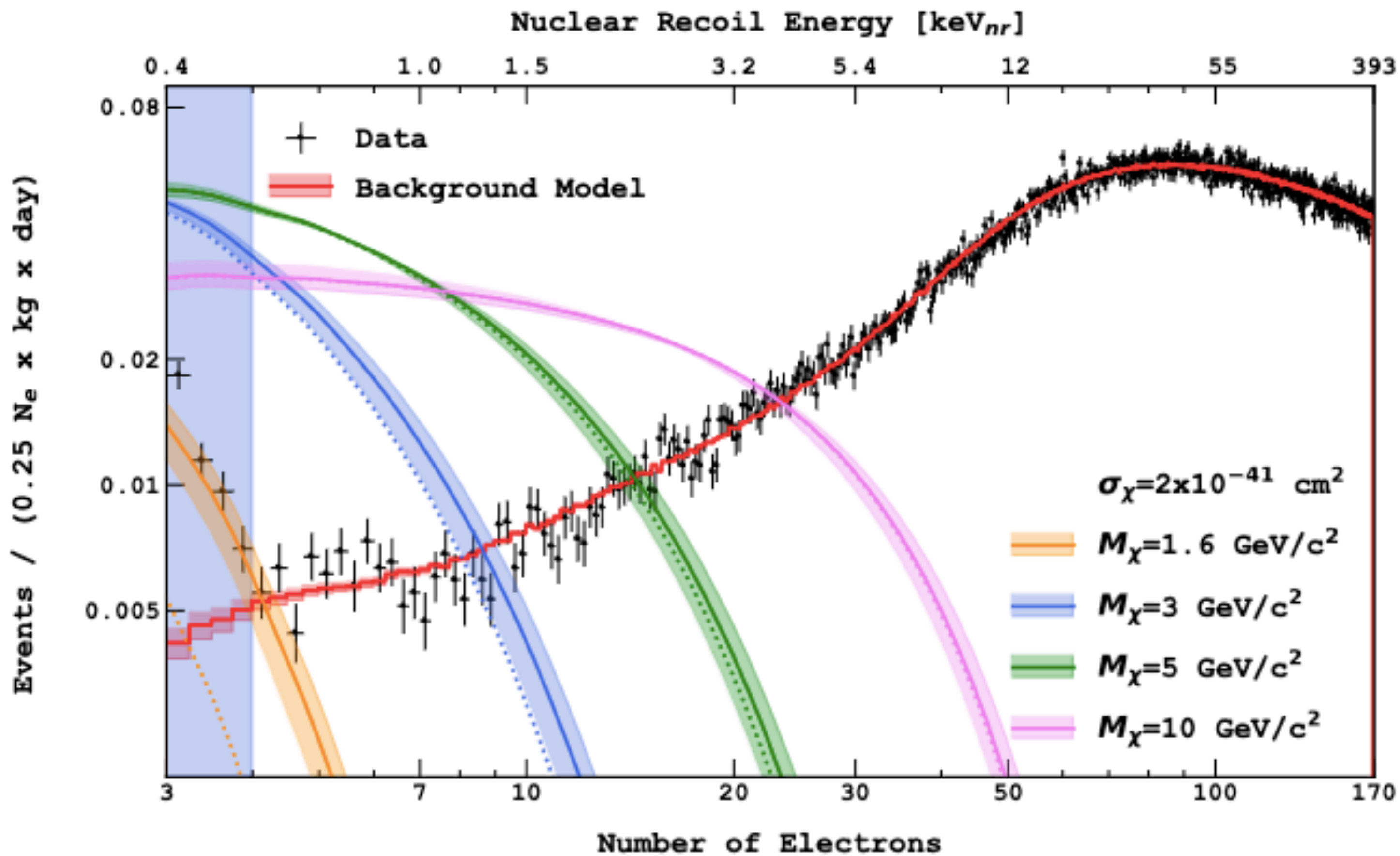


Internal ^{39}Ar ^{85}Kr:
- activity normalization
- beta spectrum shapes theory uncertainties

External gammas:
- material assays + MC

Ionization (S2) only signal model

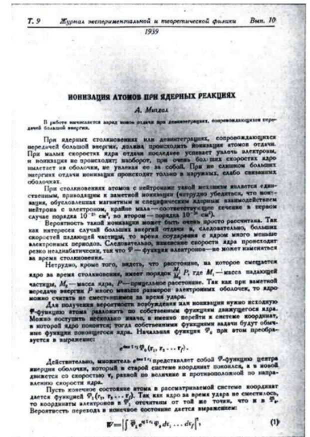
arXiv:2207.11966 - 2023 low mass analysis



Signal shape uncertainties from low energy NR calibration and quenching fluctuations —> future improvements from low energy recoils from neutron sources on small LAr TPCs: ReD experiment at LNS tandem, ^{252}Cf source, neutron d-d gun

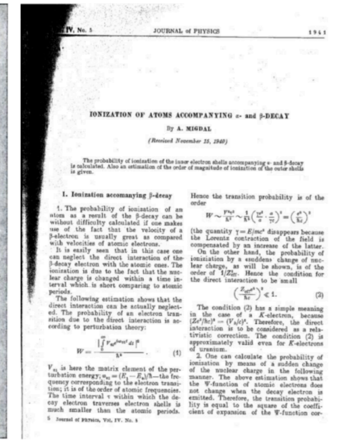
Migdal effect

» Teorizzato dal fisico russo Arkadij Benediktovič Migdal come fenomeno di ionizzazione/eccitazione di un atomo in seguito ad un urto tra il suo stesso nucleo e una particella neutra incidente. (A. Migdal “*Ionizatsiya atomov pri yadernykh reaktsiyakh*”, ZhETF, 9, 1163-1165, 1939).


Т. 9 Журнал экспериментальной и теоретической физики Вып. 10
1939

ИОНИЗАЦИЯ АТОМОВ ПРИ ЯДЕРНЫХ РЕАКЦИЯХ

А. Мигдал


IV, No. 5 JOURNAL of PHYSICS 1941

IONIZATION OF ATOMS ACCOMPANYING α- and β-DECAY

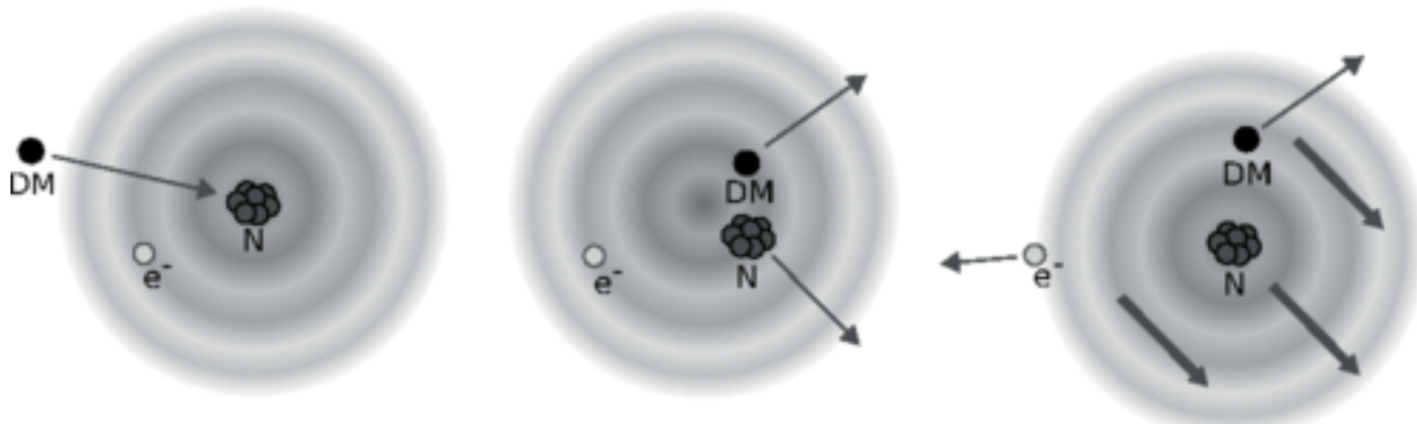
By A. MIGDAL

(Received November 15, 1940)

The probability of ionization of the inner electron shells accompanying α- and β-decay is calculated. Also an estimation of the order of magnitude of ionization of the outer shells is given.

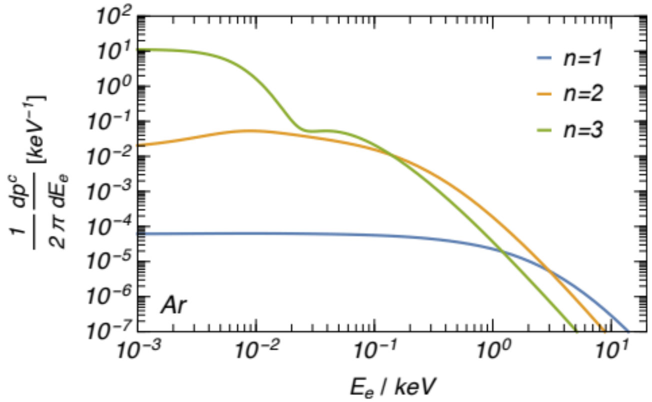
1. Ionization accomanying β-decay

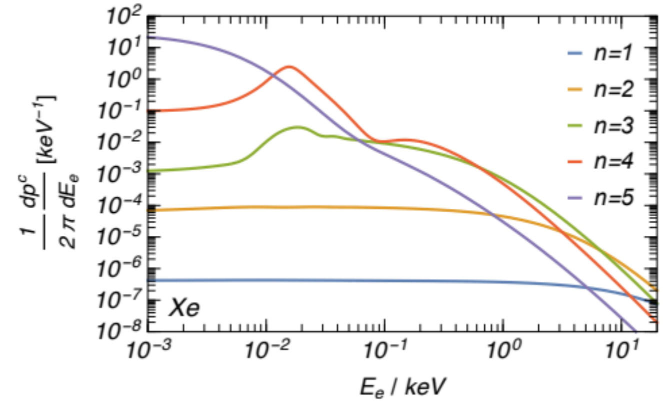
» Successivamente esteso anche a fenomeni di ionizzazione che possono accompagnare i decadimenti α e β. (A. Migdal, “*Ionization of atoms accompanying α and β-decay*”, J. Phys. Acad. Sci. USSR 4, 449, 1941).



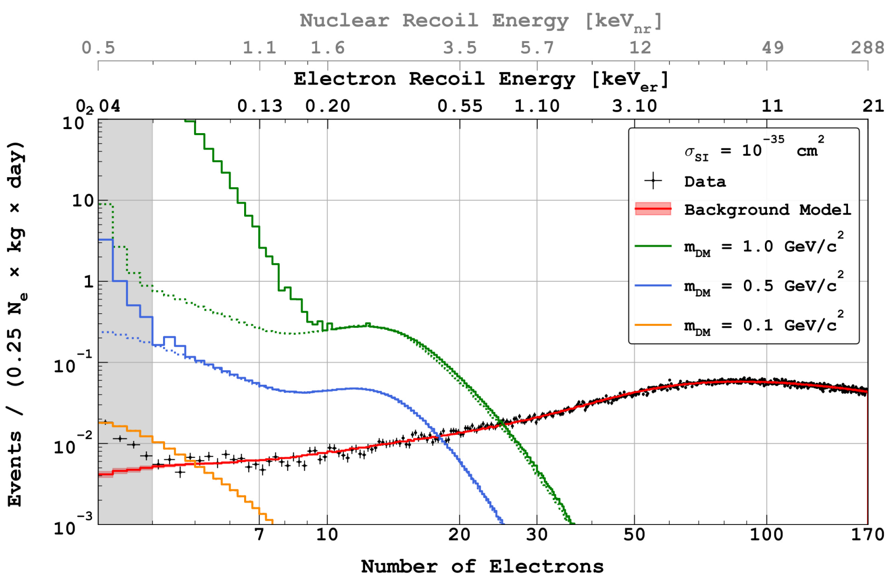
DS50 results Migdal effect

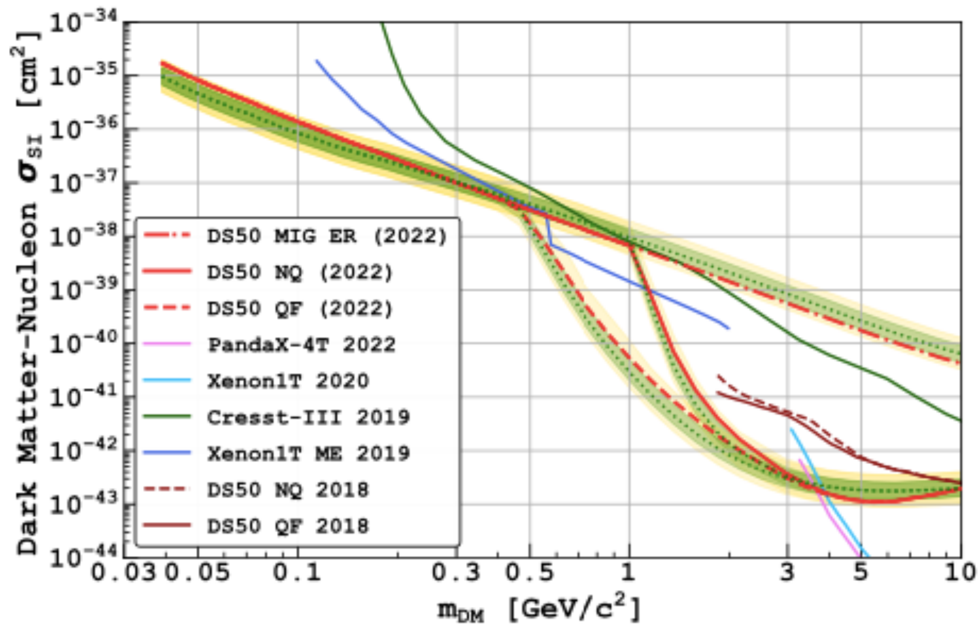
» Differential ionization probability as a function of electron atomic shell





Sub-GeV S2 only Migdal signal spectra in Ne —> sensitivity to sub GeV DM particles



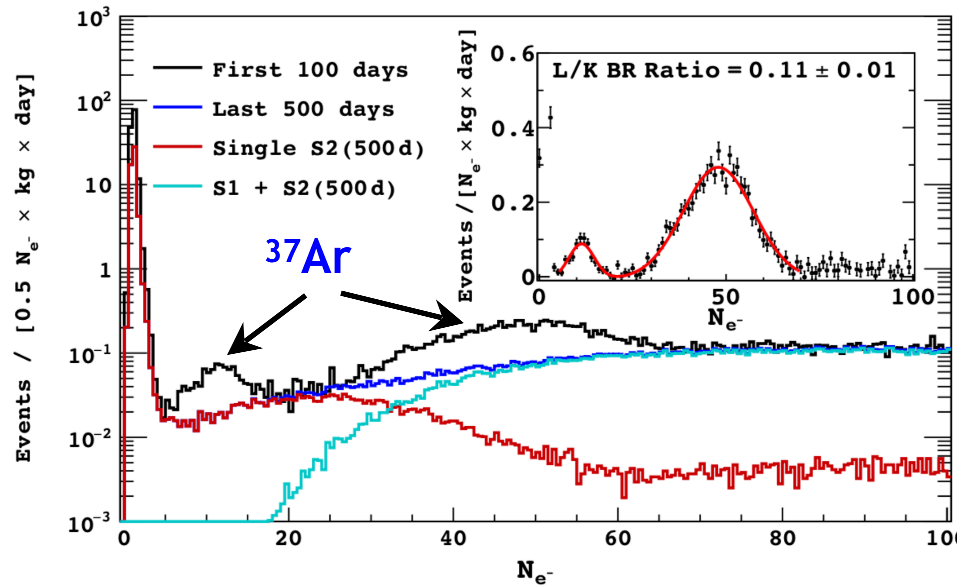


Electron and Nuclear Recoil low energy scales in DS50

Electron Recoil energy scale :

With first 100 days UAr dataset, very low-energy **ER calibration peaks** from ^{37}Ar ($t_{1/2}$ = 37d). **^{37}Ar lines** :

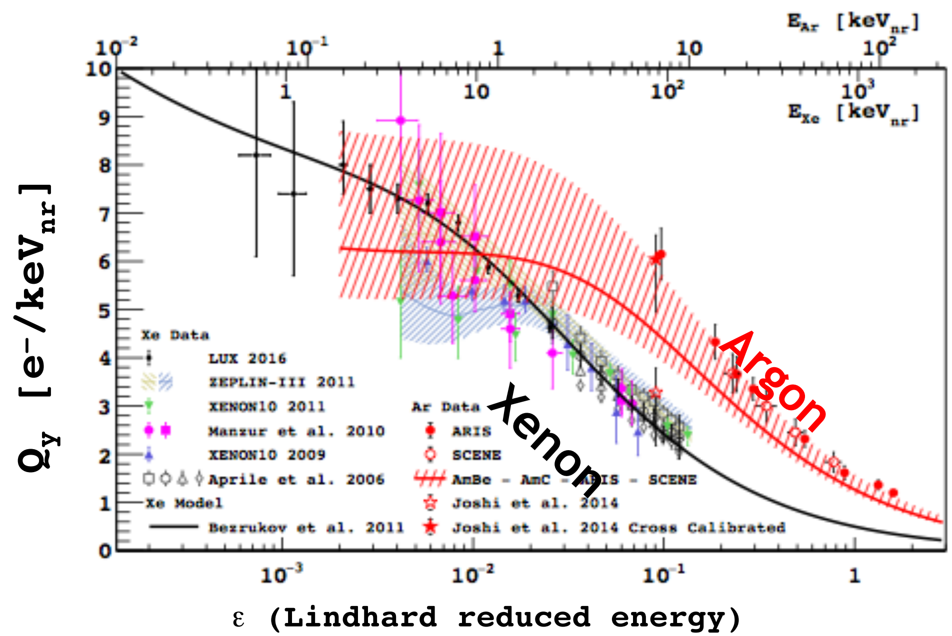
E = 0.27 keV → N_e = 11
E = 2.8 keV → N_e = 47.9



Nuclear Recoil Ionization yield Q_Y:

NR primary ionization yield in LAr from MC template **fit** (red line) to DS-50 **Am-Be** and **Am-^{13}C** neutron spectra **data**

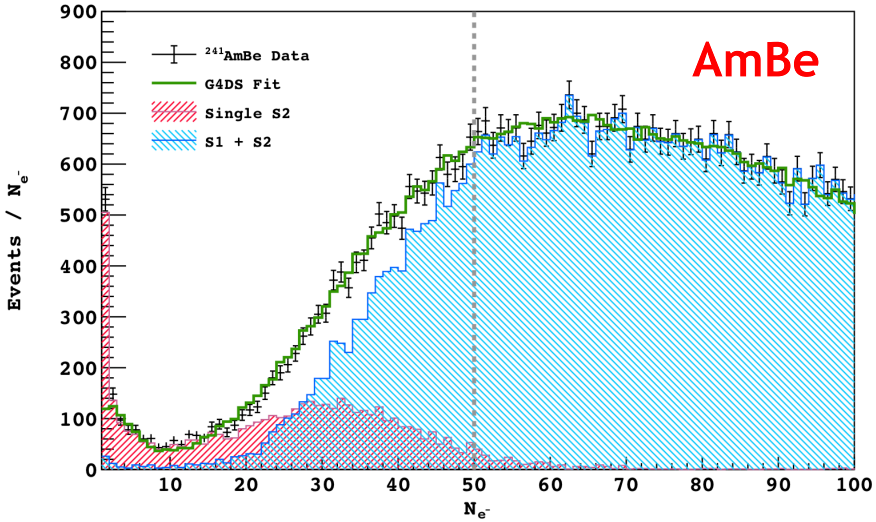
Uncertainty red band from deviations wrt external neutron calibrations (ARIS, SCENE).

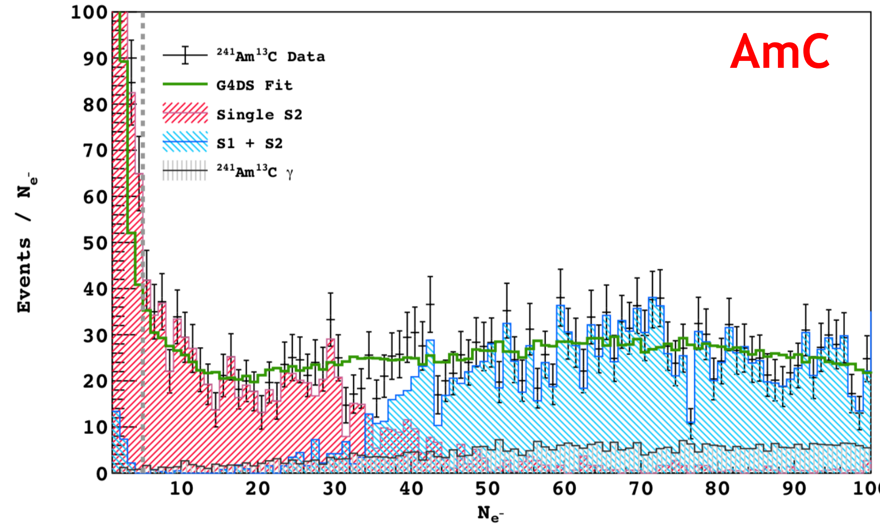


Nuclear Recoil Scale AmBe and AmC fit

MC + Ionization model [1] fit to NR data from AmBe and AmC.

[1] *F. Bezrukov, F. Kahlhoefer, and M. Lindner, Astropart. Phys. 35, 119 (2011).*





AmBe neutrons selected in coincidence with 4.4 MeV gamma in the veto

Random/correlated background strongly suppressed

Strong inefficiency for S2 only events

No gamma emission correlated with **AmC** (alpha,n) reaction

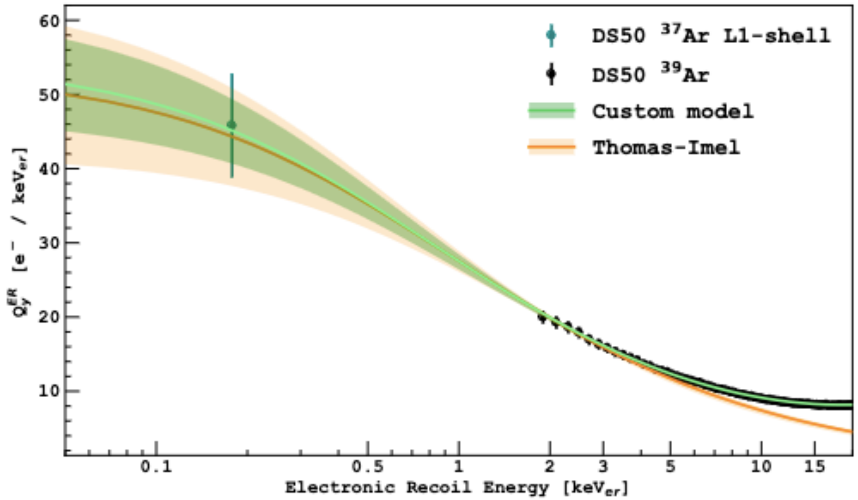
Gammas from ^{241}Am decay accounted with MC

Accidentals subtracted using UAr normalized by the exposure

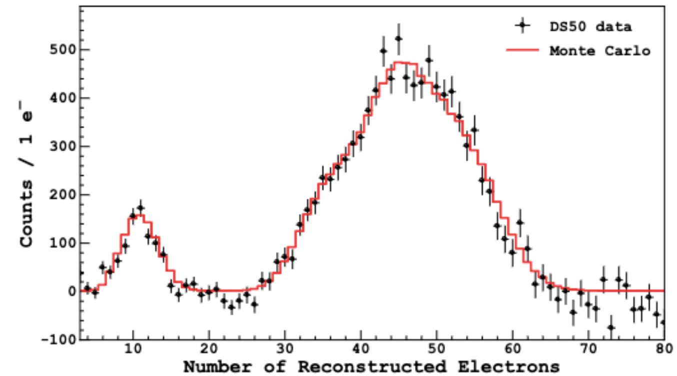
No inefficiency

NEW CALIBRATION: Calibration of the liquid argon ionization response to low energy electronic and nuclear recoils with DarkSide-50

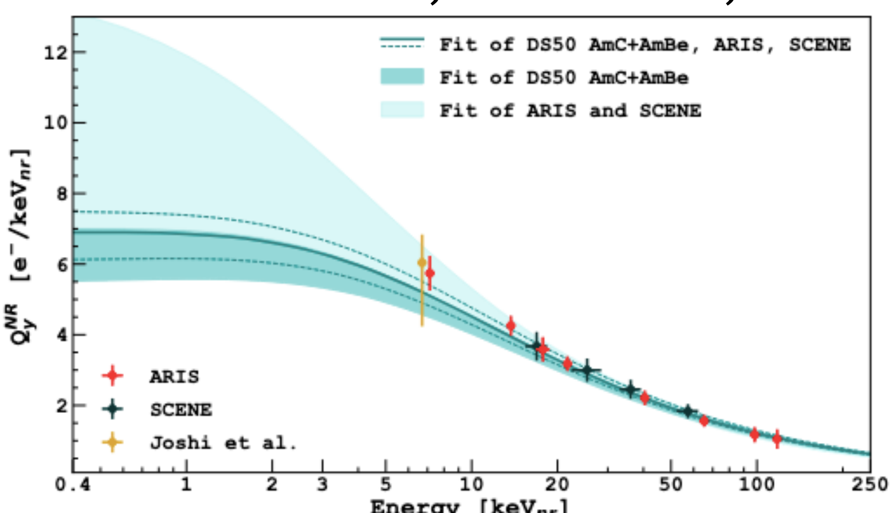
ER calibration: high energy gammas, ^{37}Ar



Cosmogenic activated ^{37}Ar in UAr first 100 days



NR calibration: Am-Be, Am-C sources, n beams



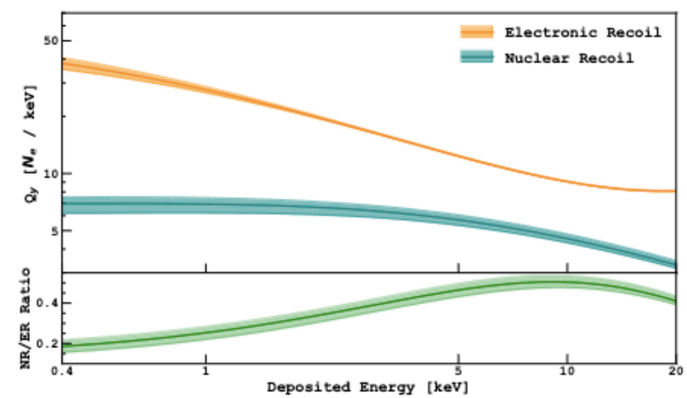
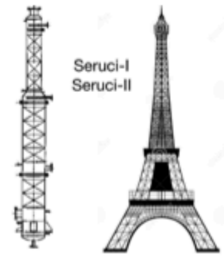


FIG. 1. LAr ionization response to nuclear (NR) and electronic (ER) recoils as a function of the deposited energy, as measured by DarkSide-50 [16].

The Underground Argon road: URANIA and ARIA

Production – URANIA – Cortez, CO, US

- Industrial scale extraction plant
- Extraction rate: 250-330 kg/day
- Production capability ≈ 120 t over two years for DS-20k
- UAr purity: 99.99%



Purification – Aria – Sardinia, IT

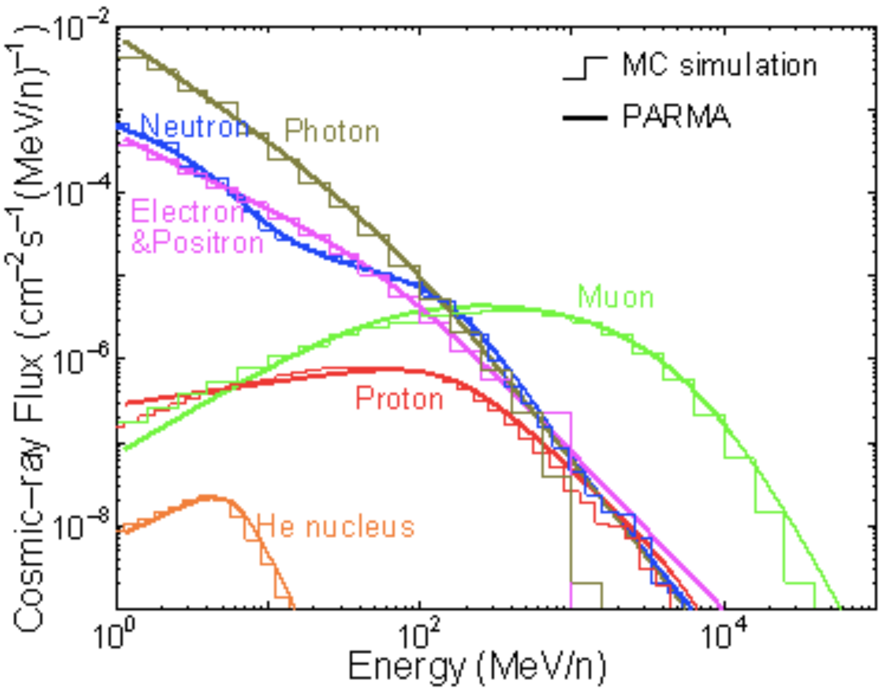
Eur. Phys. J. C (2021) 81:359

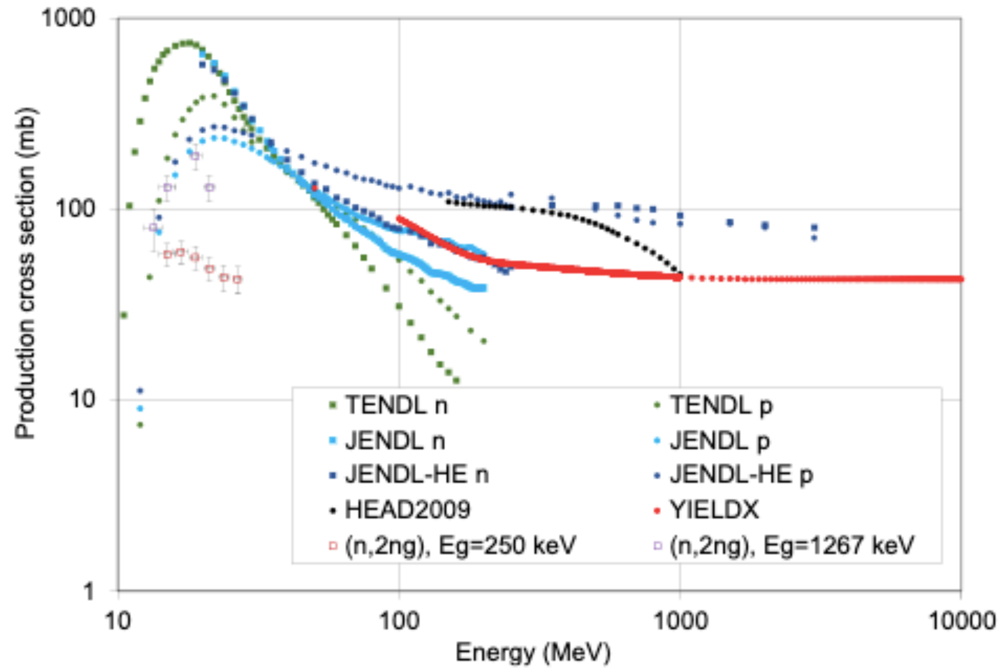
- Seruci-0 (demonstrator) tested
- 350 m cryogenic distillation column
- O(1 tonne)/day capability
- Resulting UAr purity: 99.999%

UAr also of interest for other future experiments: LEGEND, COHERENT, Argo, DuNe …
URANIA and ARIA currently in construction.

Cosmogenic Argon activation

^{39}Ar ^{37}Ar ^{42}Ar activation from cosmogenic neutrons on ^{40}Ar during transportation

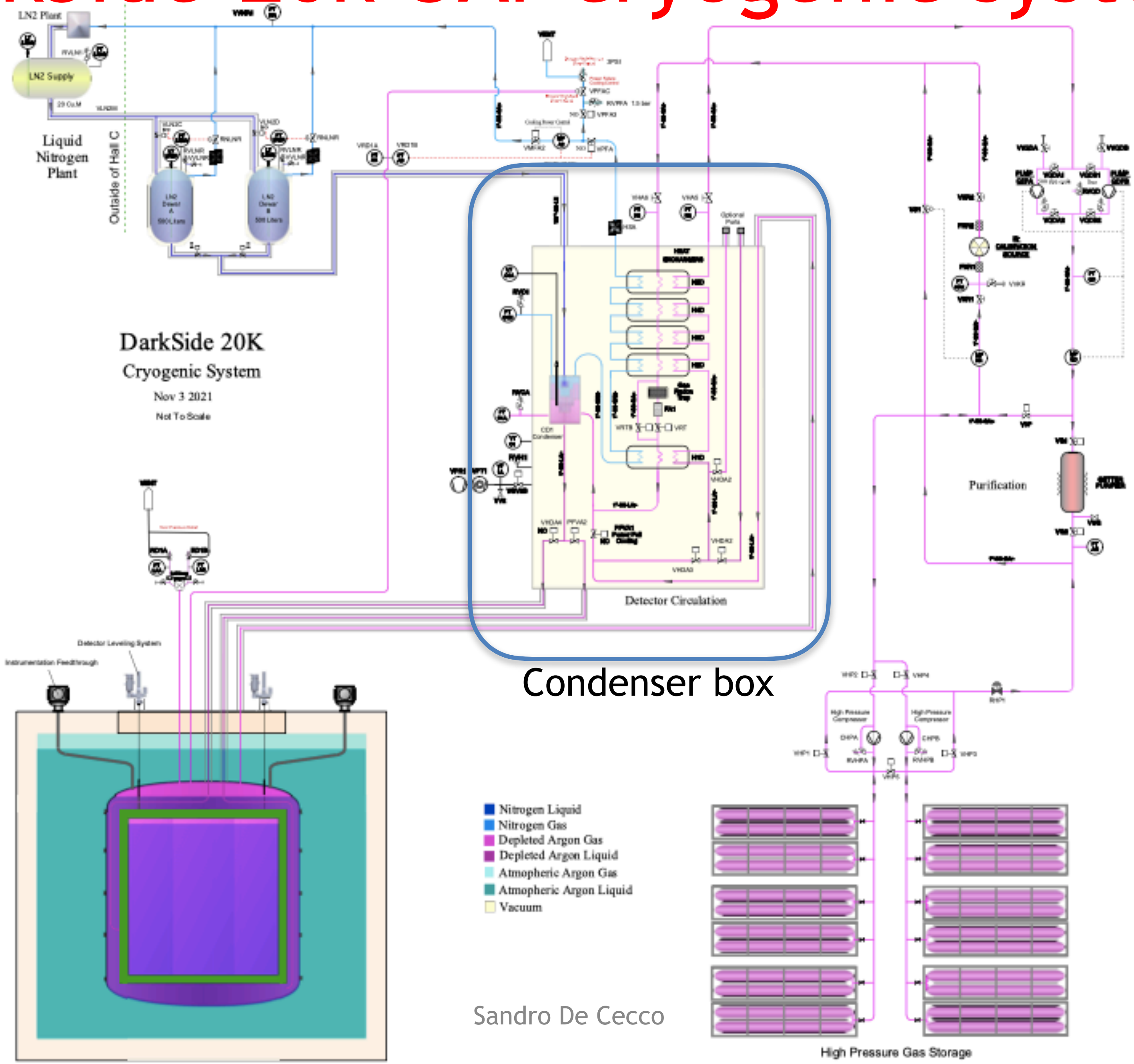




Study of cosmogenic activation above ground for the DarkSide-20k experiment - *Astropart.Phys.* 152 (2023) 102878.

The activity of ^{39}Ar induced during extraction, purification and transport on surface is evaluated to be 2.8% of the activity measured in UAr by DarkSide-50 experiment

DarkSide-20k UAr cryogenic systems

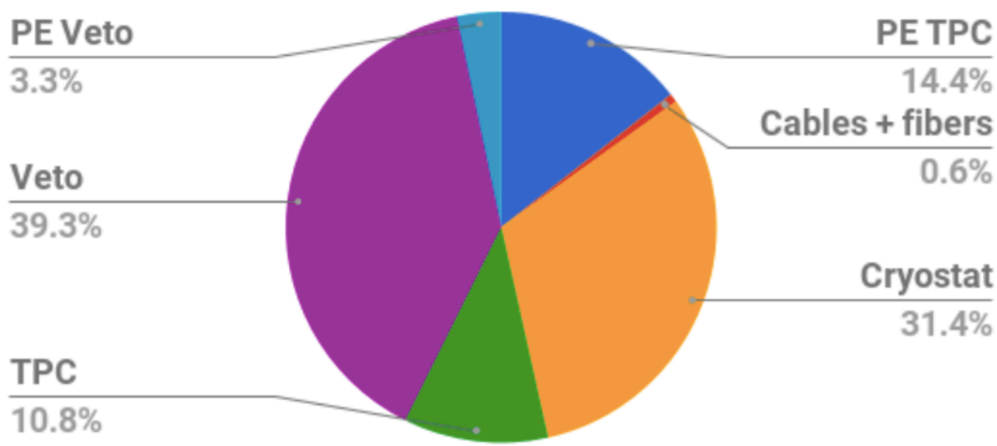


General neutron background budget in 200 t yr

Total NR background events from alpha-n neutrons in 200 t yr : 0.095

Background type	Bg events in ROI $[200\,\mathrm{t\,yr}]^{-1}$
(α,n) neutrons from U and Th	9.5×10^{-2}
Fission neutrons from U-238	$<2.3 \times 10^{-3}$
Neutrons from Rn-222 diffusion and surface plate-out	$<1.4 \times 10^{-2}$
Cosmogenic neutrons	$<6.0 \times 10^{-1}$
Neutrons from the lab rock	1.5×10^{-2}
Random surface α decay + S2 coincidence	$<5.0 \times 10^{-2}$
Correlated ER + Cherenkov	$<1.8 \times 10^{-2}$
Uncorrelated ER + Cherenkov	$<3.0 \times 10^{-2}$
ER	$<1.0 \times 10^{-1}$

TABLE 26. Nuclear recoil (NR) backgrounds expected during the full DS-20k exposure, based on current data and Monte Carlo simulations. The right column is the total number of events surviving the veto cut, fiducial volume cut, and PSD.



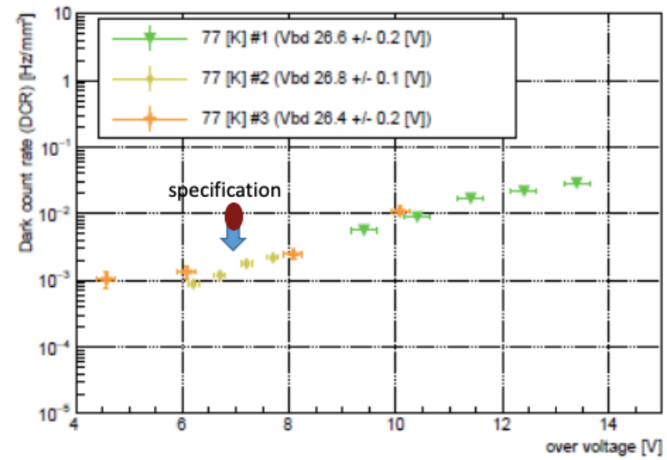
... + 3.2 events from CEvNS (irreducible atmospheric ν background))

DarkSide-20k cryogenic SiPMs

Technology change from PMT to low background SIPMs to cover large areas w high efficiency

Parameter	1 SiPM
Pixel pitch	30 X 30 μm²
Fill Factor	76.6%
Active area	689 μm²
Number of cells	94904
Total Area	11.7 x 7.9 mm2
Breakdown voltage[77 K]	26.8 +- 0.2 V
Internal Cross Talk Prob. [77 K]	<33% (7 V over voltage)
Dark noise rate [77 K]	<0.01 Hz/mm2 (7 V over voltage)
After Pulse prob. [77 K] within 5 μs	<10%
PDE [77 K] @420 nm	>40%
Single Cell Capacitance	62.5 +-2.5 fF

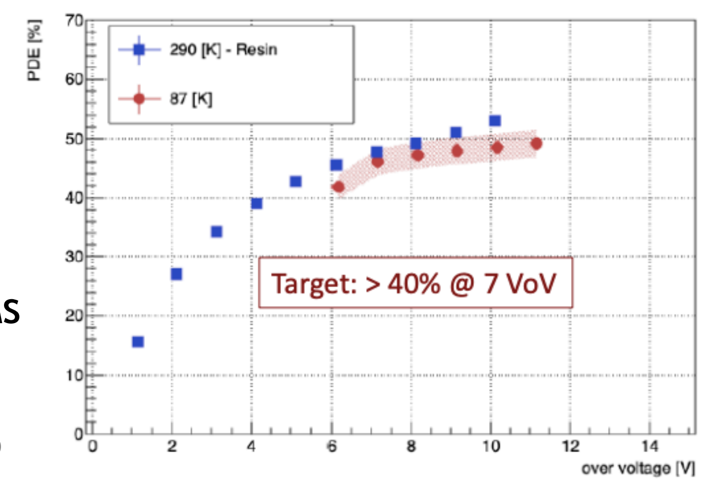
Dark noise rate



S/N ratio > 8; time res. ~ 10 ns

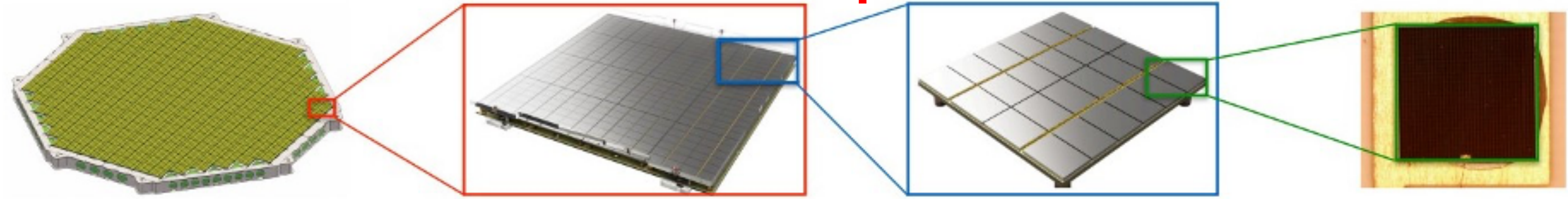
PDE: Particle detection efficiency @420 nm 87K

After a careful calibration of the light source and mea



- NUV-HD-cryo SiPMs R&D by FBK & DarkSide
- Preproduction tested at cold in several sites
- Tech. Transfer and Production at LFoundry (SiPMs produced in 2022, currently tested
- Mass assembly is starting at LNGS

Photo Detection Units production and test



TPC optical plane ($\sim 21\ m^2$)
525 PDUs

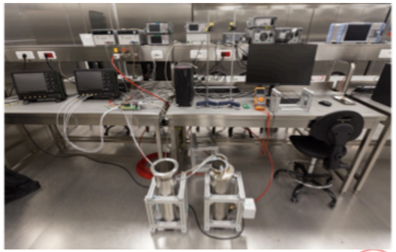
Photo-detection unit
16 tiles arranged into 4 channels

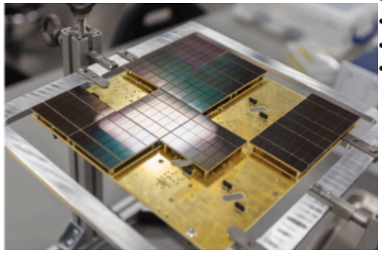
Tile / photo-detector module
24 SiPMs + signal amplifier

SiPM ($\sim 1\ cm^2$)

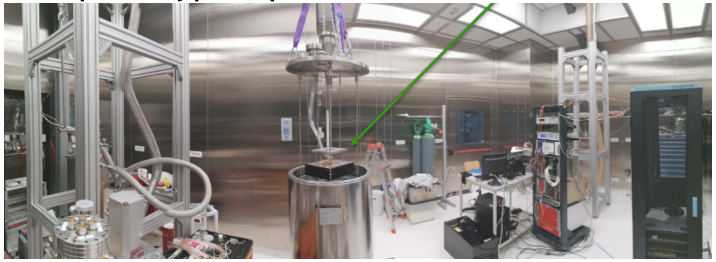
PDU assembly and mass production at NOA clean room, a 400 m^2 new infrastructure at LNGS

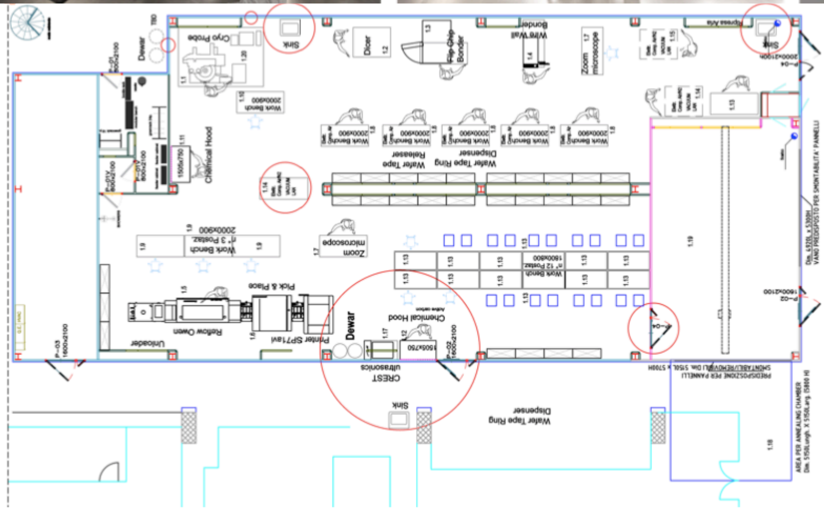
- 16 Tiles
- 1 single PCB for the Tile and amplifier (signal peaking time few ns)
  - 24 SiPM: 4s 6p + TIA amplifier based on discrete elements for TPC
  - 24 SiPM: 4 X(2s3p) + ASIC amplifier (for the Veto)
- 1 single 20X20 Arlon based PCB with all functions implemented (MB+, Mother Board +)
- Thin structure
- Sum of 4 amplified tile signals
- Differential output

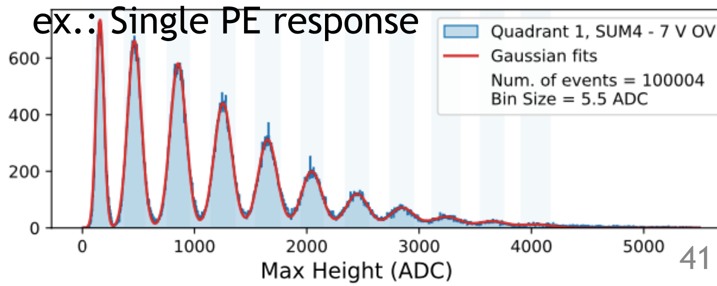




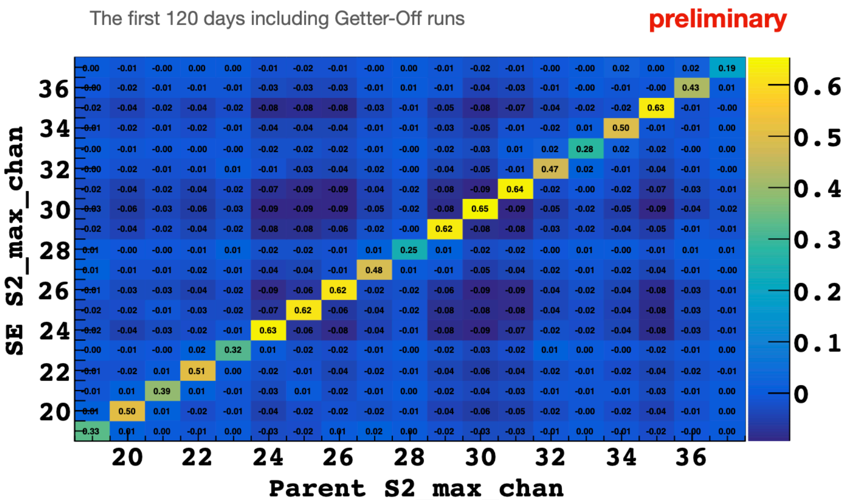
PDU mass test at Napoli cryogenic facility also now testing long term performances and PDU prototypes, proto0 for S2 reco + DAQ.

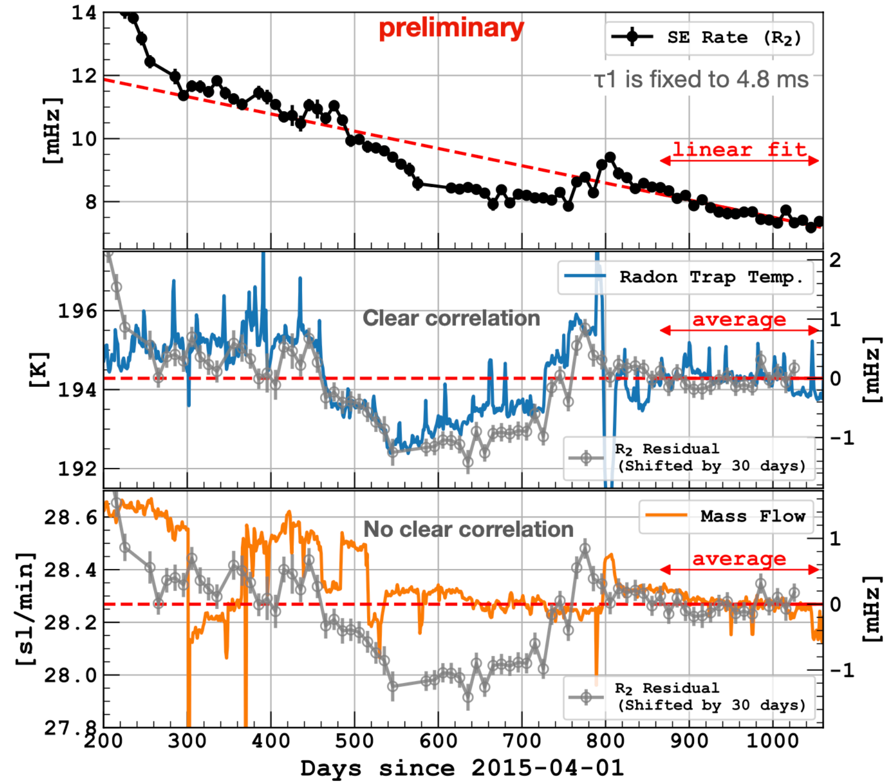


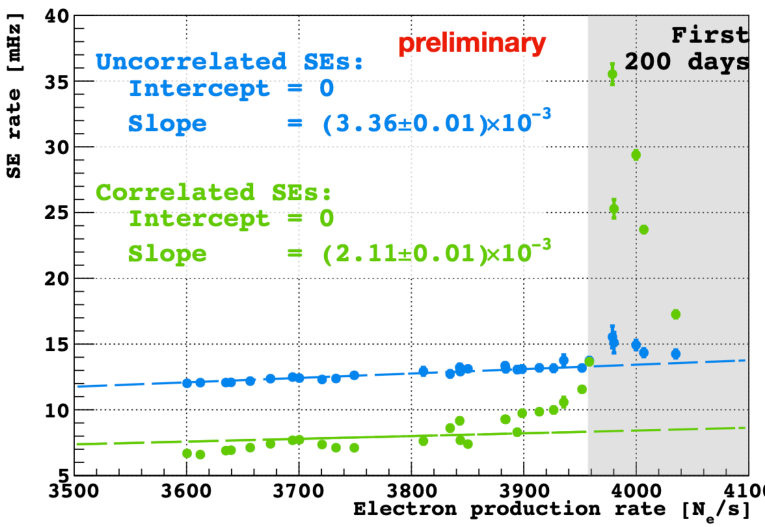




Other SE correlations







Total Activity in TPC