New results on Low mass Dark Matter search from DARKSIDE

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Sandro De Cecco

Sapienza Università di Roma, Dip. di Fisica & INFN sezione di Roma

for the **DARKSIDE Roma group**:

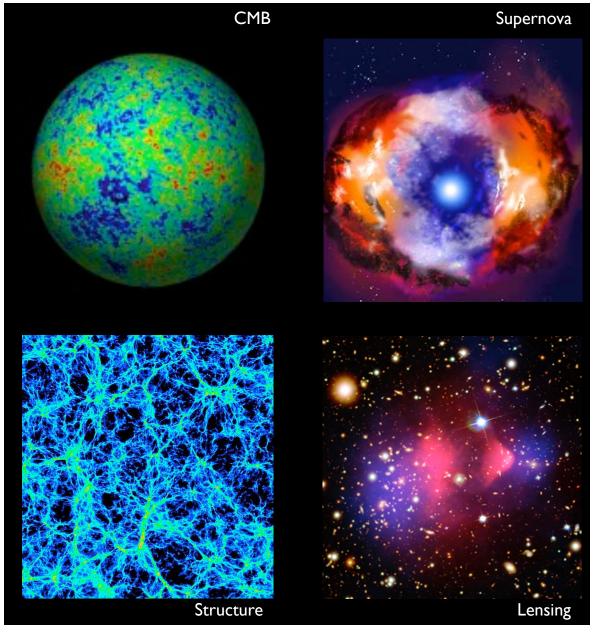
F. Ameli, V. Bocci, S.D.C., C. Dionisi, S. Giagu, V. Ippolito, A. Messina, M. Rescigno, N. Rossi,

Outline :

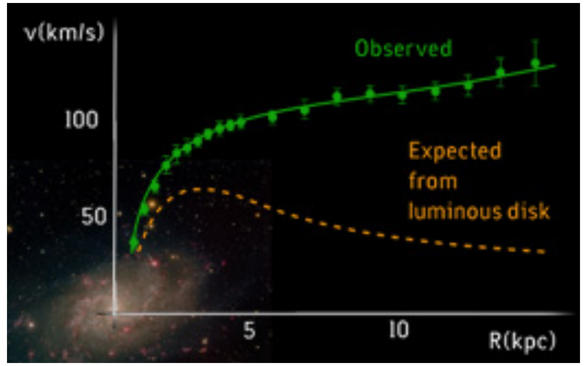
- **Introduction to direct Dark Matter searches**
- **Direct detection experiments with Noble liquid double phase TPC; why Argon target ?**
- **The DarkSide program and the current DarkSide-50 experiment at LNGS**
- **New DarkSide-50 results :**
  - ***"Low-mass Dark Matter Search with the DarkSide-50 Experiment"*** ArXiv:1802.06994
  - *"Constraints on Sub-GeV Dark Matter-Electron Scattering from the DarkSide-50 Experiment"* ArXiv:1802.06998
  - ***"DarkSide-50 532-day Dark Matter Search with Low-Radioactivity Argon"*** ArXiv: 1802.07198
- **Next goals : zero instrumental background DM direct detection with large scale LAr TPC**
- **The DarkSide-20K project: proposal for a 20t fiducial LAr TPC and future developments**

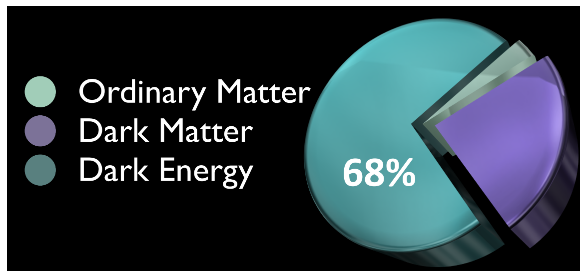
Dark Matter evidences

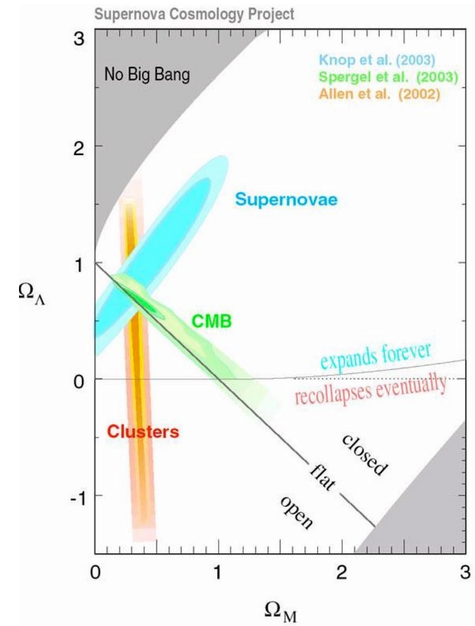
Several gravitational evidences from :



Cold DM preferred for structure formation



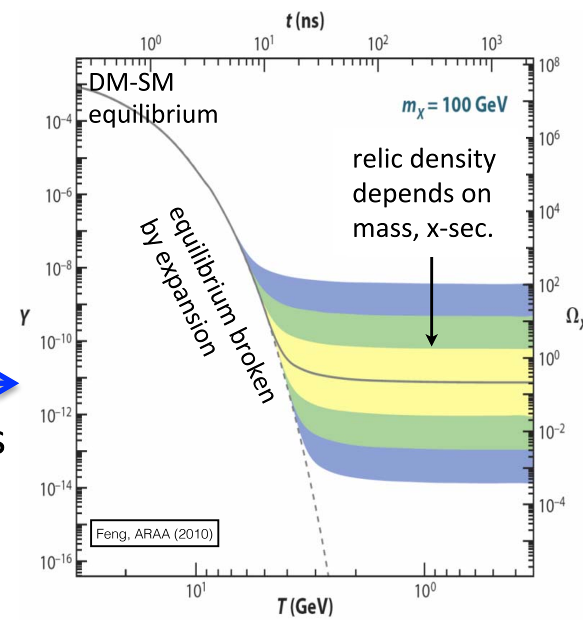




Standard Model matter only ~1/5 of tot. matter in the Universe

DM candidates in several BSM physics theories (axions,…)

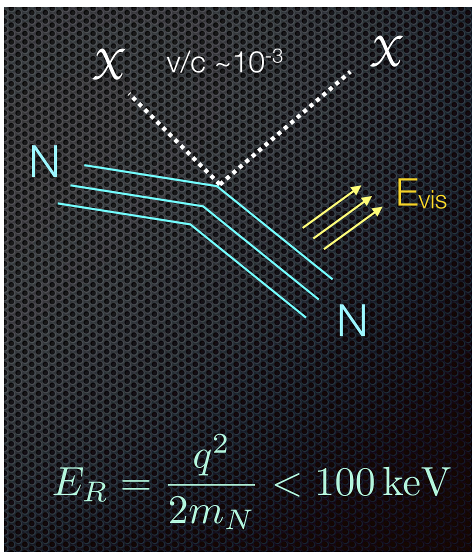
But one class referred as WIMPs (Weakly Interacting Massive Particle) has appealing features known as WIMP miracle: →
in Uni. expansion equilibrium between DM ann. and prod. leads to current relic density for DM masses in 1GeV-1TeV range

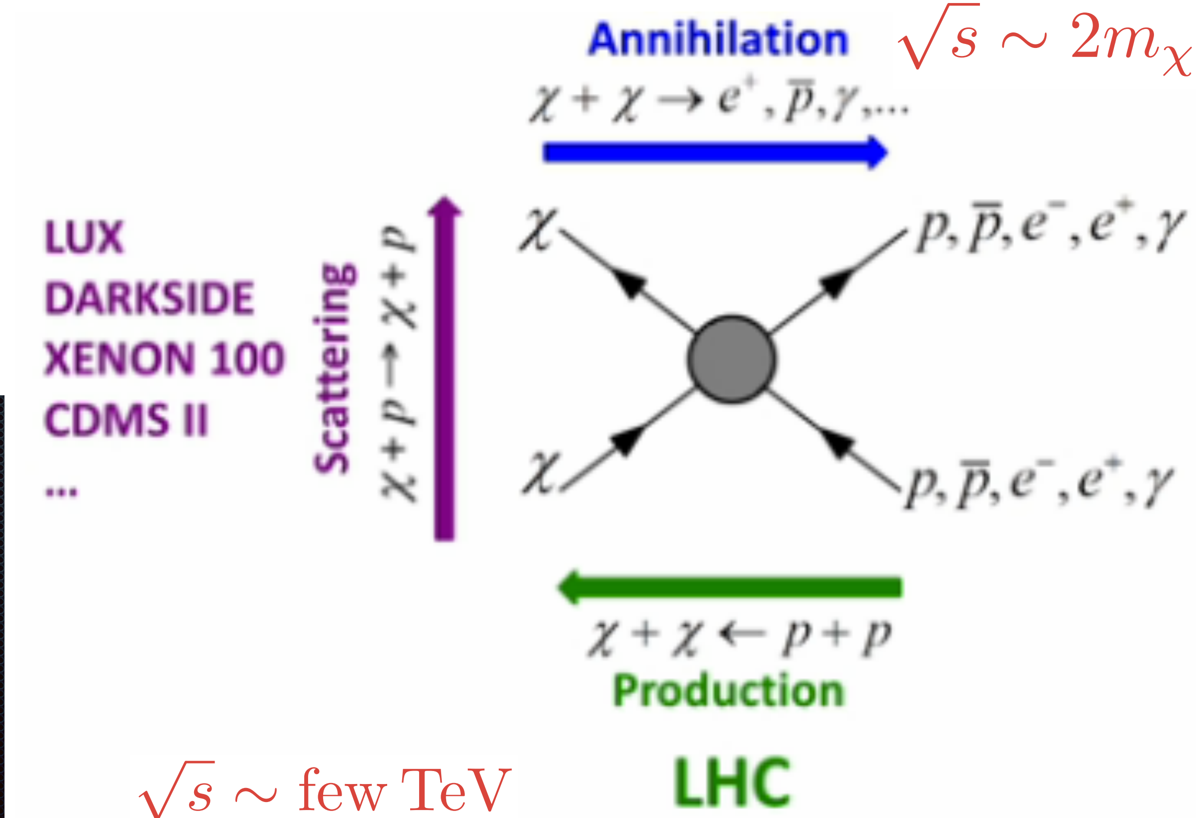


Complementary searches for DM

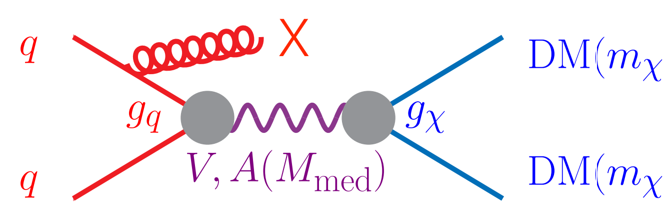
$q \leq 10\mathrm{s\,MeV}$

Direct Detection:
through coherent elastic scattering on nuclear matter.
(wide WIMP mass range)

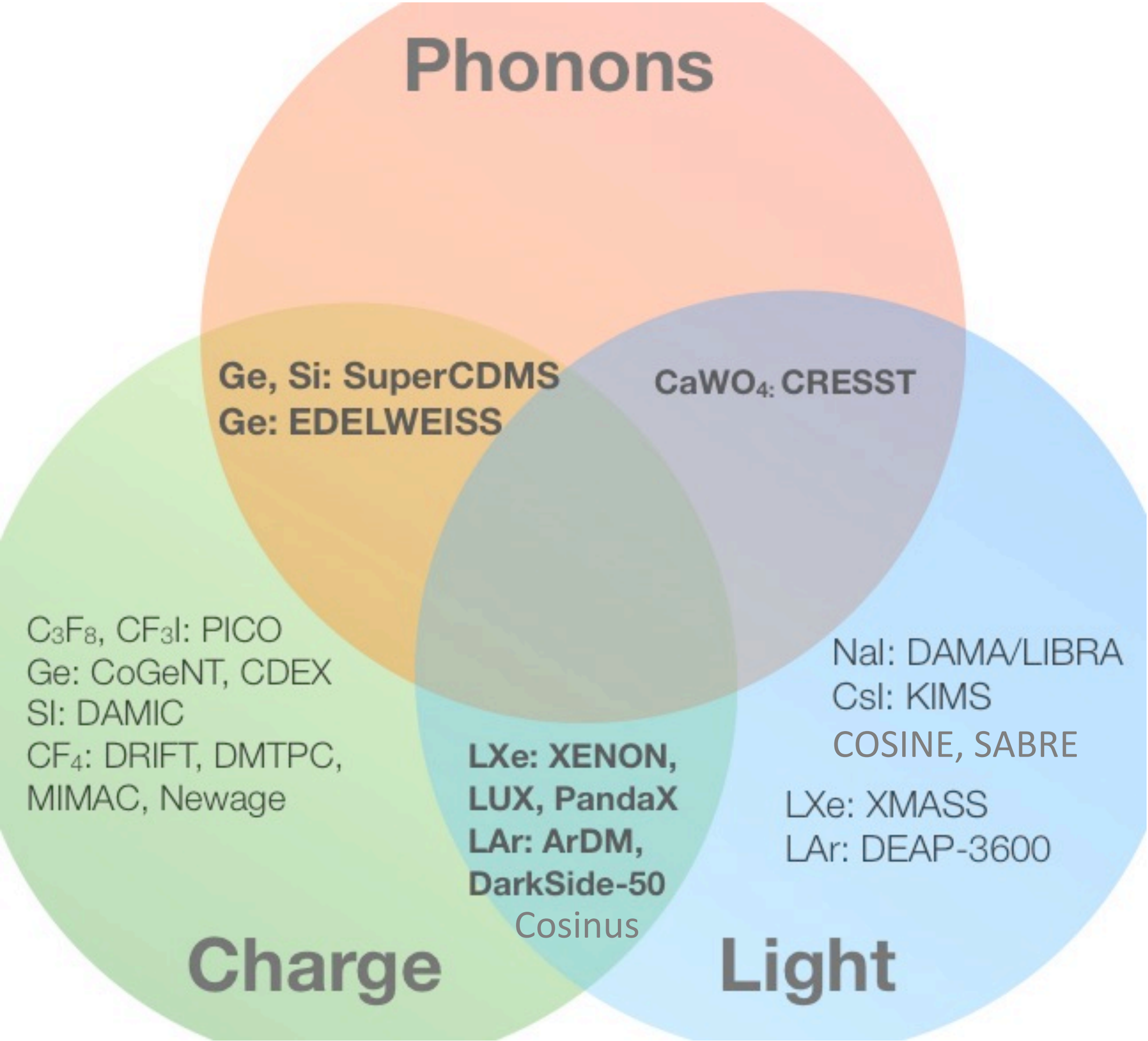




Production at LHC:
in pairs through high energy partonic inelastic collisions (WIMP mass range limited)

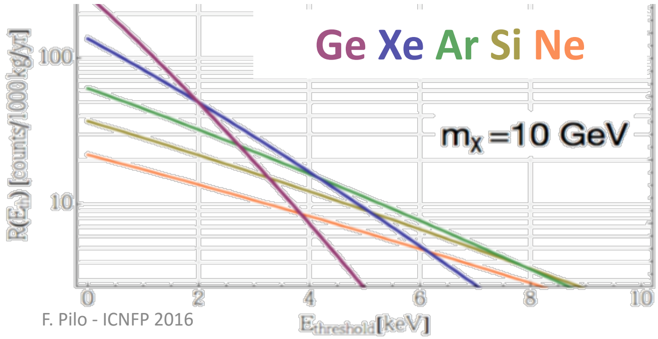


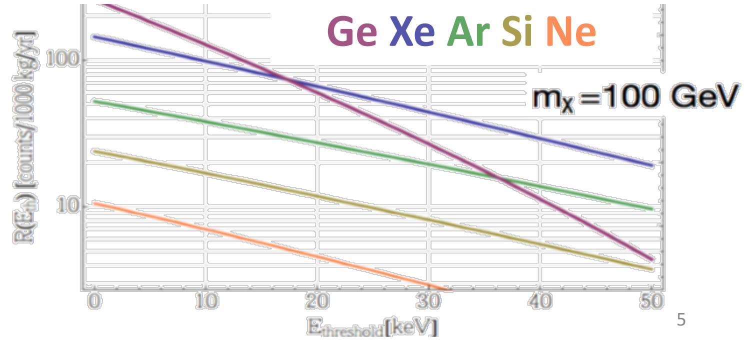
Direct detection experimental techniques



Argon as target for Dark Matter

- Abundant in nature (1% in atmosphere), limited cost.
- High scintillation light yield of ~ 40 g / keV
- Lower x-sec. than Xe at high WIMP mass but higher recoil energy spectra at low WIMP mass :





- Very different singlet/triplet scintillation decay times → **very good discrimination power :**

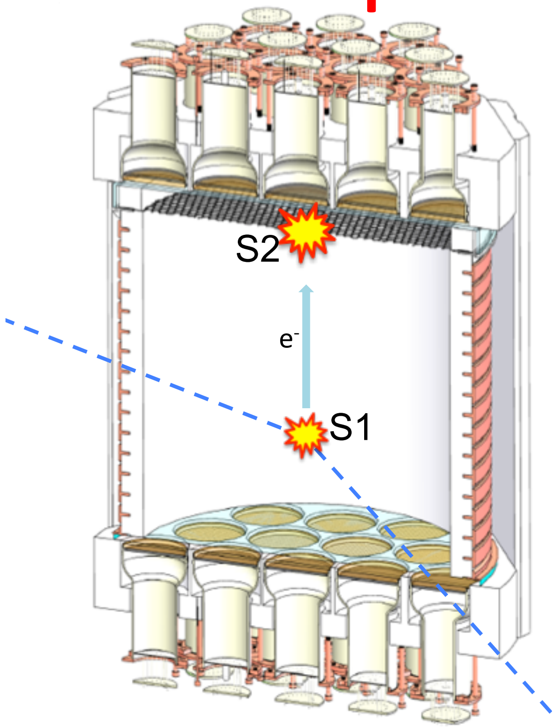
		LAr	*LKr*	*LXe*
Physical properties	Atomic number	18	36	54
	Boiling point at 1 bar, T_b (K)	87.3	119.8	165.0
	Density at T_b (g/cm^3)	1.40	2.41	2.94
Ionisation	W (eV)[1]	23.6	20.5	15.6
	Fano factor	0.11	~0.06	0.041
	Drift velocity (cm/μs) at 3 kV/cm	0.30	0.33	0.26
	Transversal diffusion coefficient at 1 kV/cm (cm^2/s)	~20		~80
Scintillation	Decay time[2], fast (ns)	5	2.1	2.2
	slow (ns)	1000	80	27/45
	Emission peak (nm)	127	150	175
	Light yield[2] (phot./Mev)	40000	25000	42000
	Radiation length (cm)	14	4.7	2.8
	Moliere radius (cm)	10.0	6.6	5.7

Excellent discrimination power!

Issues:

- scintillation light at 128nm, needs wavelength shifter TPB and 87K critical temp for PMTs
- high relative abundance of radioactive ^{39}Ar isotope (beta emitter with 1Bq/Kg in Aar)

Dual phase Time Projection Chamber



1 - Nuclear Recoil excites and ionize **Liquid Ar** producing **scintillation light S1** detected by top and bottom photosensors

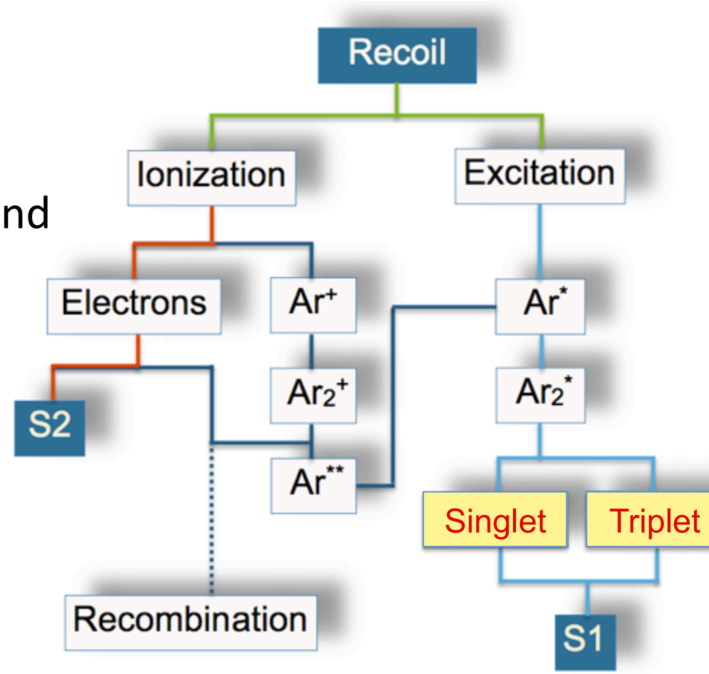
2 - **ionization electrons** are drifted to the **Ar gas** pocket region were they induce a second **delayed scintillation** light **S2 signal**

- **Time difference** between **S1** and **S2** gives **vertical position** while fraction of S2 in each photo-sensor gives x-y position.

Recoil can be with electrons (**ER**) or nuclei (**NR**). Ionization and direct excitation of Ar* to form Ar_2* dimer that emits light.

Dimer excitons Ar_2* emits light in singlet or triplets. Different singlet/triplet fractions for ER and NR (NR ~70% singlet, ER ~70% triplet) diff. exc. mechanism. Ar ions can recombine and form excited Ar** states.

Also, NR ion.+thermic energy loss → **NR quenching** (less S2)



Dual phase TPC Electron Recoil rejection

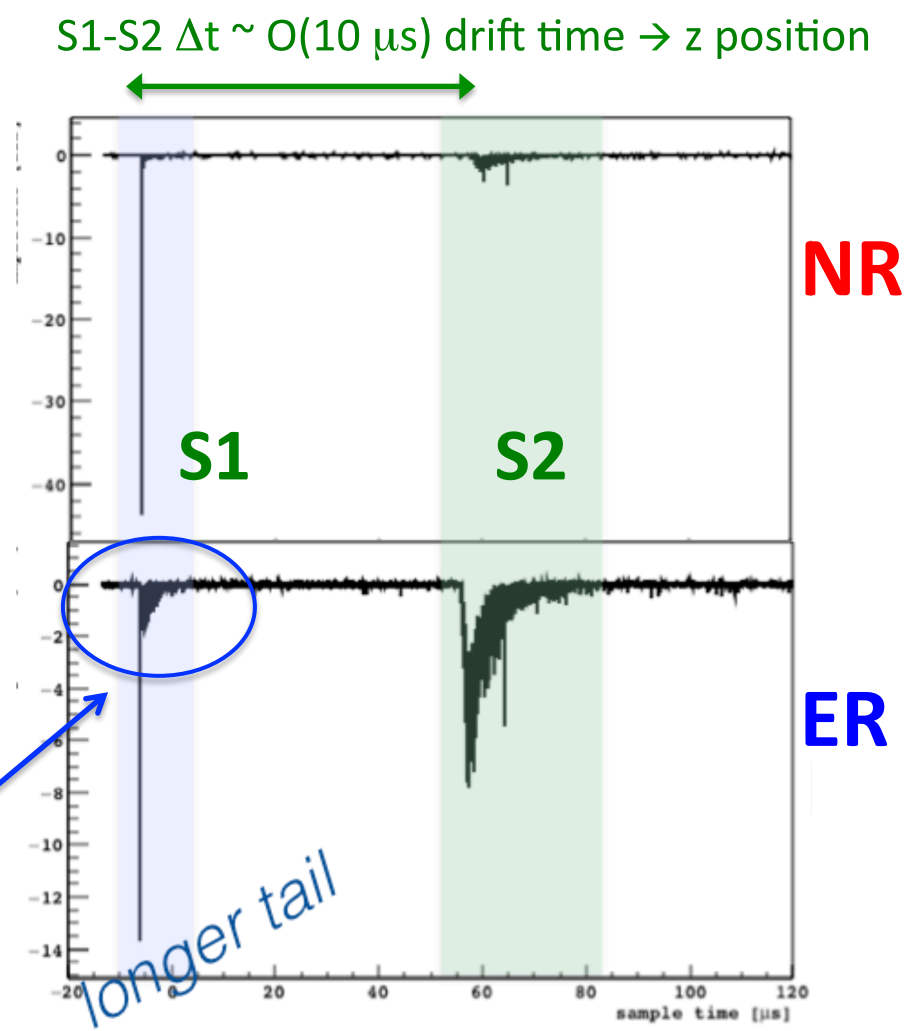
Due to Nuclear quenching, ionization signal and hence **S2** scintillation, is less intense for **NR** than for **ER**

→ separation power in **S2/S1**

gives an **ER** rejection factor of 200-300

Typically used in Xenon experiment (same in Argon) as only ER vs NR discriminant.

But, unique to Argon : **Pulse Shape Discrimination** (**PSD**) due to longer tails in ER S1 signal.

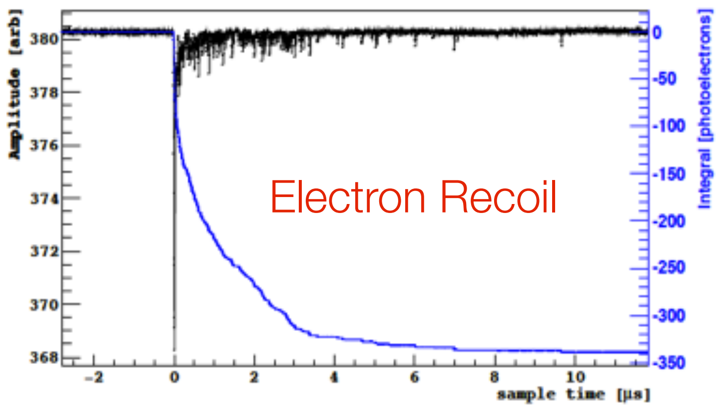


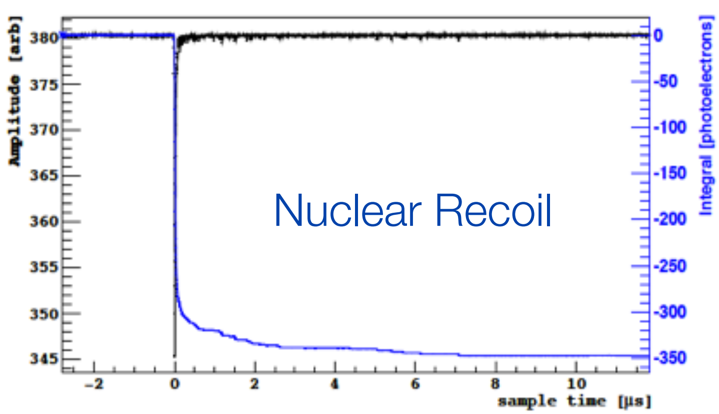
LAr Pulse Shape Discrimination

Electron and nuclear recoils produce different excitation densities in the argon, leading to different **ratios of singlet and triplet excitation states**

τ singlet ~ 7 ns

τ triplet ~ 1500 ns

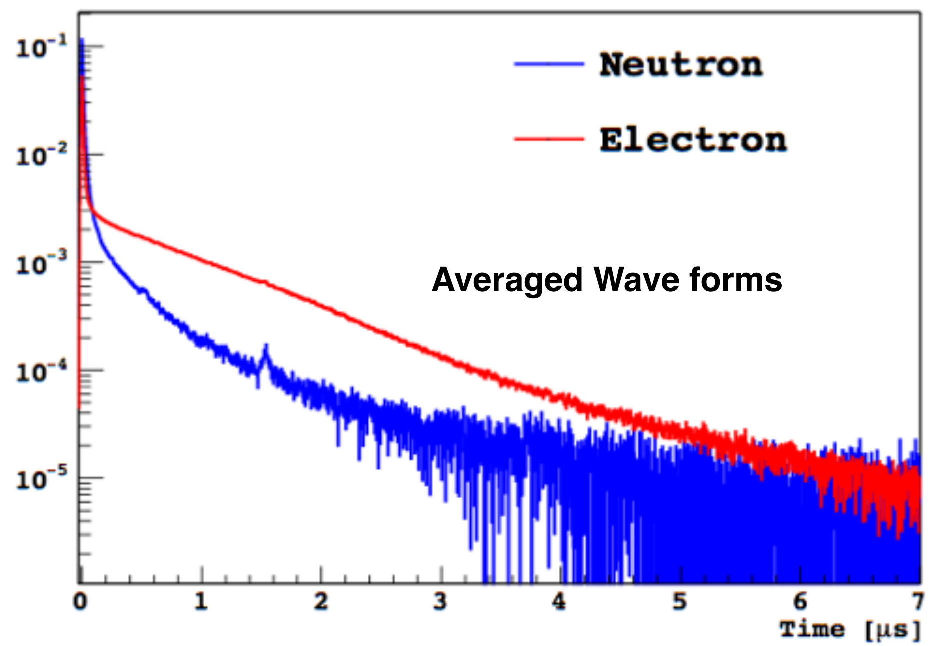




PSD parameter

F90: Ratio of detected light in the first 90 ns, compared to the total signal

~ Fraction of singlet states

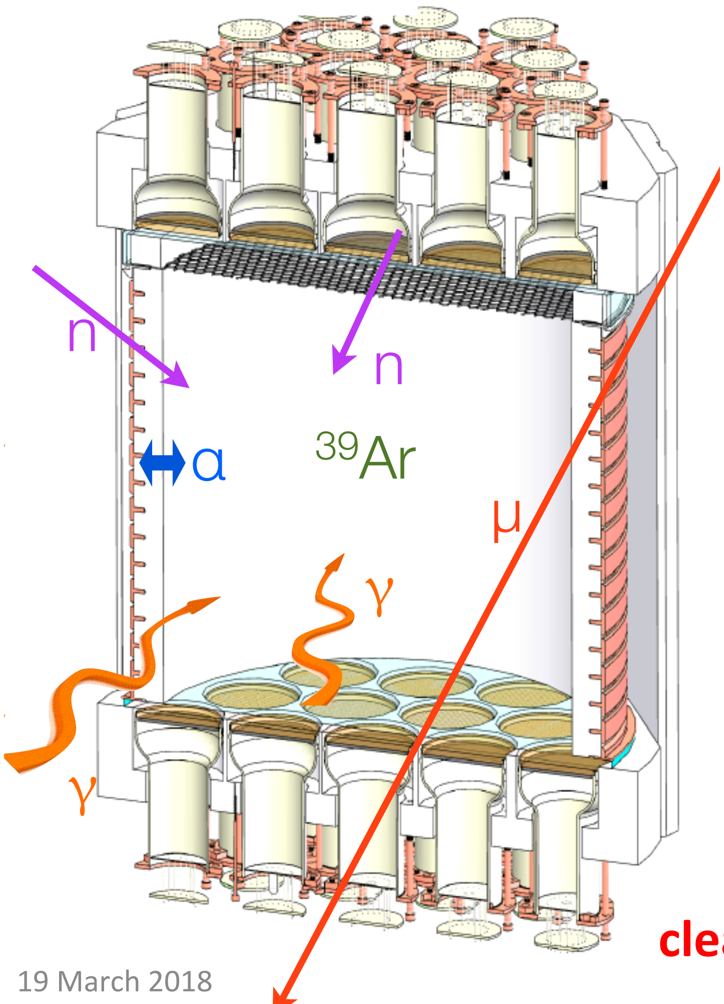


LAr TPC DM search backgrounds :

DM signal extremely rare and consists in ~10 keV energy deposit in the detector leading to ~10 photons detected. Backgrounds divided in two classes, **NR** and **ER** :

Signal Rate:

- 100 GeV, 10^{-45} cm^2 WIMP ~10^{-4}evt/kg/day



Nuclear recoils:

- μ ~10^{-4}evt/kg/day
- Radiogenic n ~$6\cdot10^{-4}$ evt/kg/day → ***Detector material purity:** U and Th decay chains, mostly (α, n) neutrons.*
- α ~10 evt/m^2/day → ***Surface events:** fiducial x-y cut and radon suppression filter*

Electron recoils:

- ^{39}Ar ~$9\cdot10^4$ evt/kg/day → ***Inner volume events:*** *→ PSD + **ARGON DEPLETION** programs **URANIA & ARIA** (also Cherenkov bck. → cuts)*
- γ ~$1\cdot10^2$ evt/kg/day

And also, solar and atmospheric:

– **ν** - electron scattering → ***reducible ER:** with PSD*

– coherent **ν** - nucleus scattering → ***irreducible NR***

KEYS :

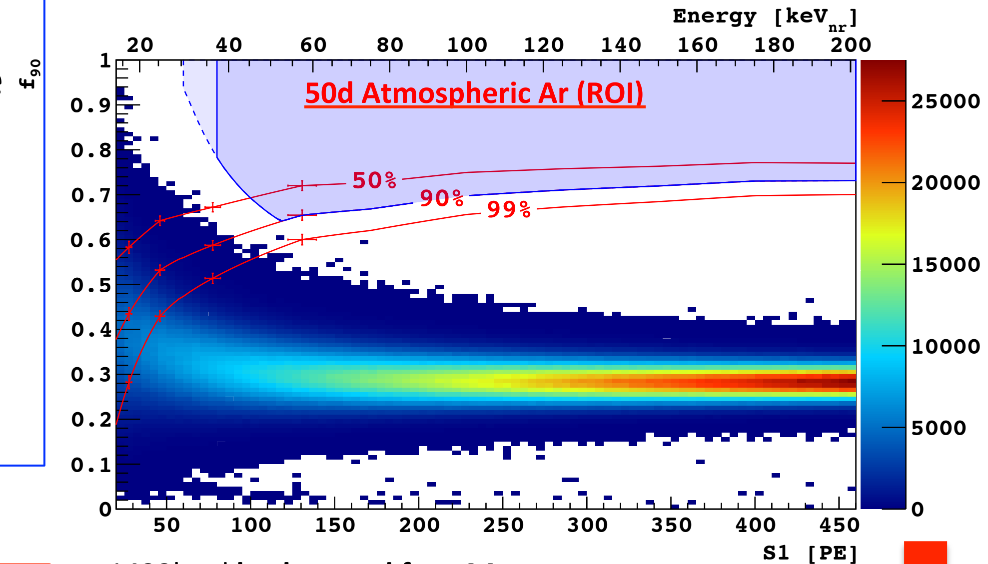
clean materials, active veto shieldings and Depleted Ar

Depleted Ar from underground source

^{40}Ar from ^{40}K decay underground
^{39}Ar cosmogenic $^{40}Ar(n,2n)^{39}Ar$ in atmosphere

→ ^{39}Ar β emitter (565 keV) with 269y $T_{1/2}$
Atmospheric Ar act. 1Bq/kg from ^{39}Ar

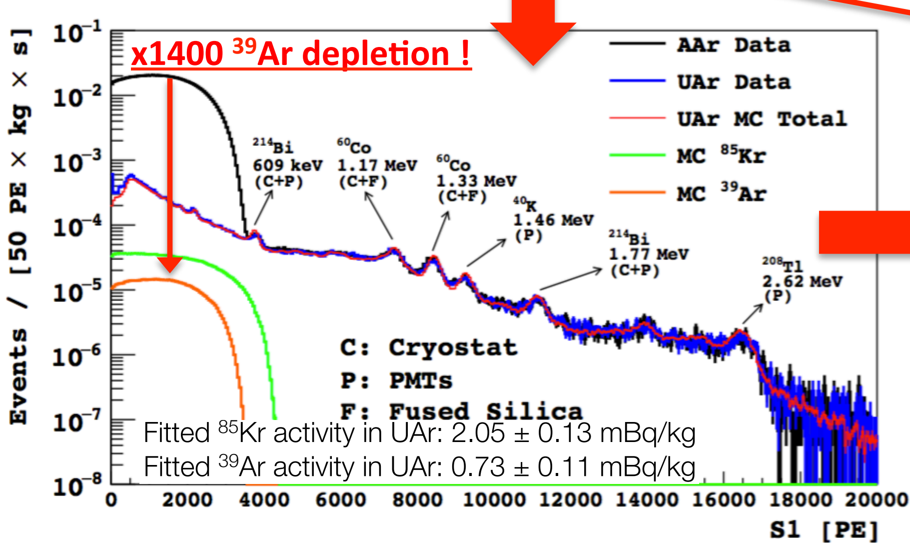
→ expect UAr depleted in ^{39}Ar
→ extract Ar from **underground source**

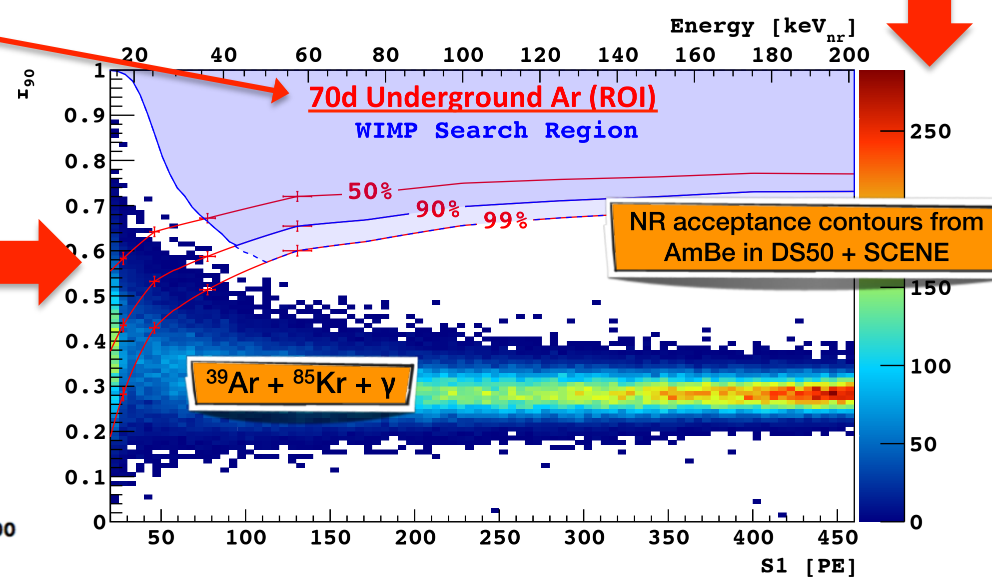


1422kg-d **background free AAr exposure**
ER rejection with PSD >1.6x10^{7} (stat. limited estimate)

→ in **2015**: fill of DS-50 with **Underground Argon**

arXiv:1510.00702v1 [astro-ph.CO] 2 Oct 2015



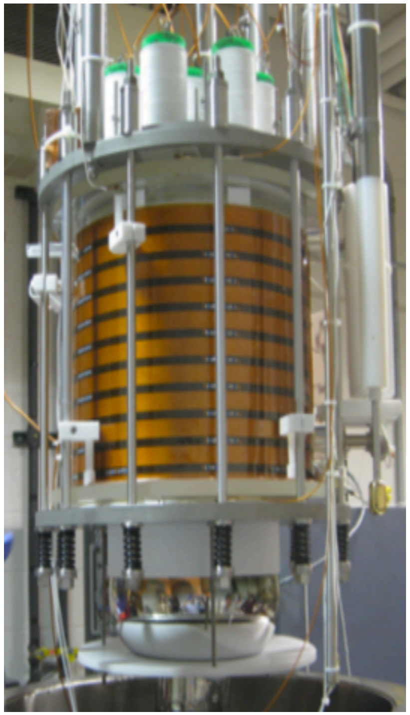


AAr + Uar → **background free** demonstrated for exposure **>5.5 t yr** → **Scaling to multi-ton LAr targets possible**

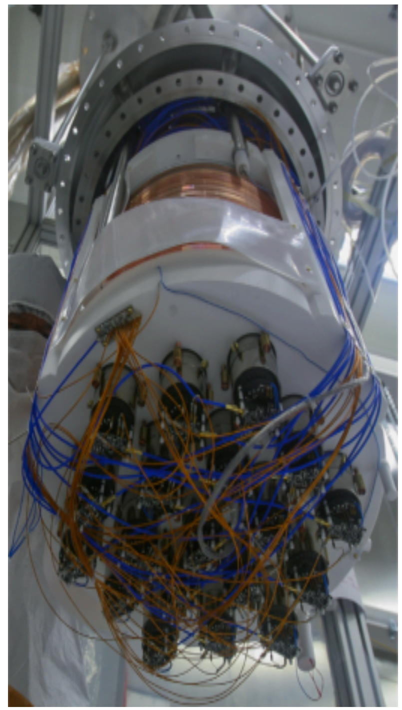
The DarkSide staged program

2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 … →

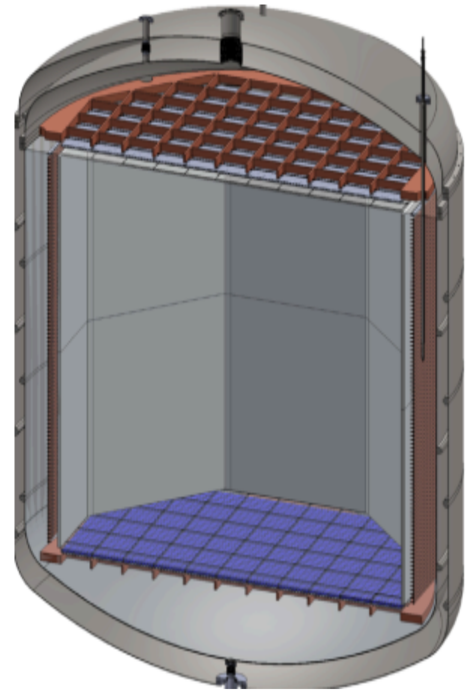
Past Present Future



DarkSide-10 (10kg)
Technical prototype
No Dark Matter goal



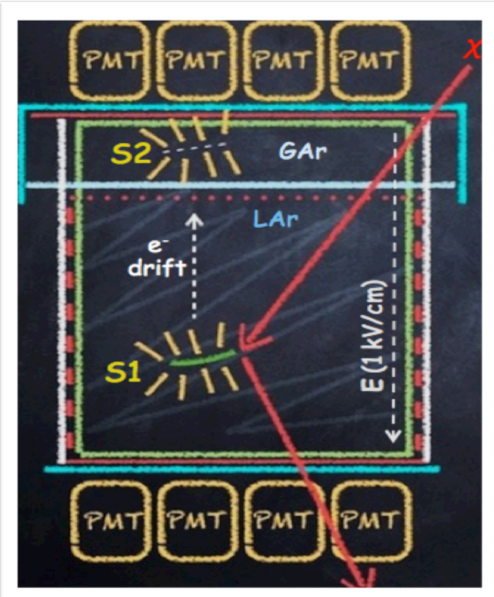
DarkSide-50 (50kg)
Sensitivity to WIMP-nucleon cross section 10^{-44} cm^2 for a WIMP mass of 100 GeV/c^2

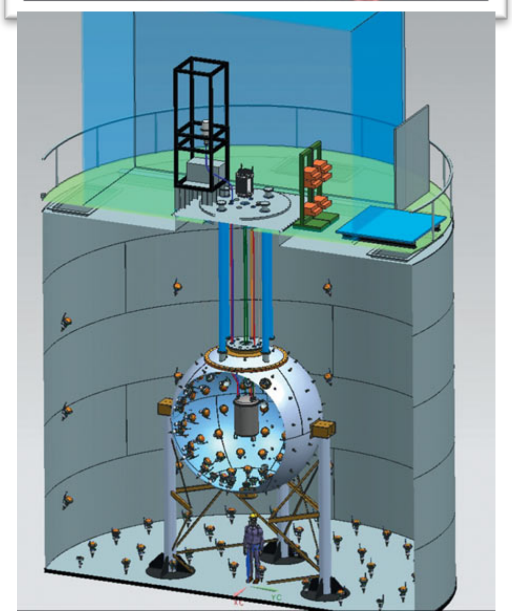


… → 300t

DarkSide-20k (20t)
Sensitivity to WIMP-nucleon cross section 10^{-48} cm^2 (10^{-47} cm^2) for a WIMP mass of 100 GeV/c^2 (1 TeV/)

DarkSide-50 LAr TPC and vetoes





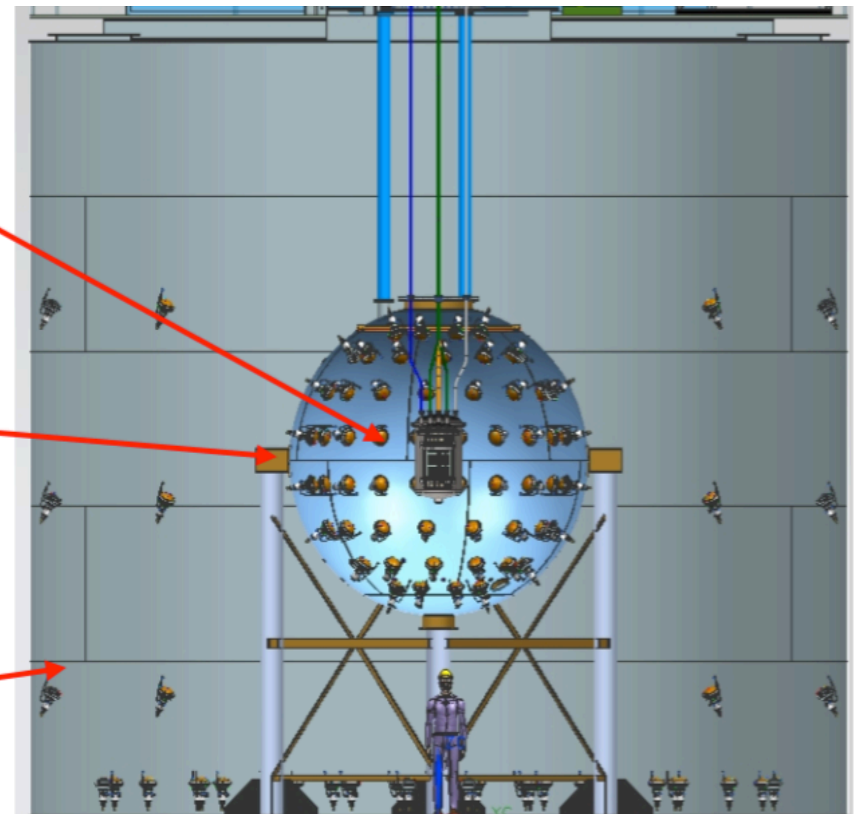
DarkSide-50 in LNGS hall C :

- 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

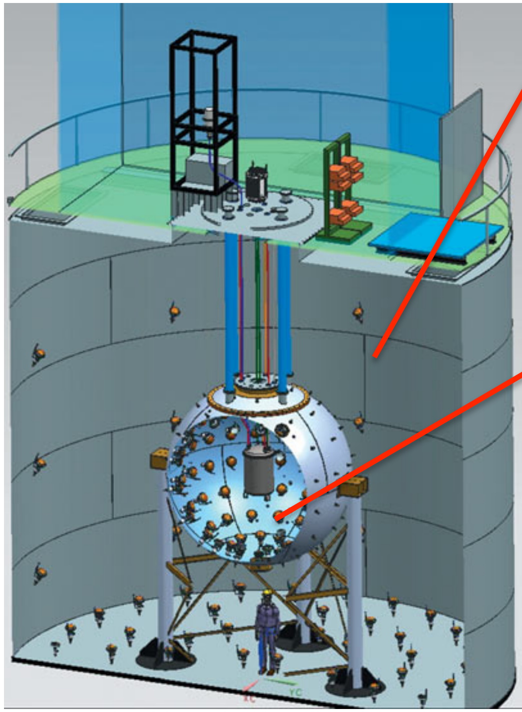
Liquid Argon TPC
153 kg ^{39}Ar-Depleted
Underground Argon
Target

4 m Diameter
30 Tonnes
Liquid Scintillator
Neutron Veto

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



Neutron background active veto



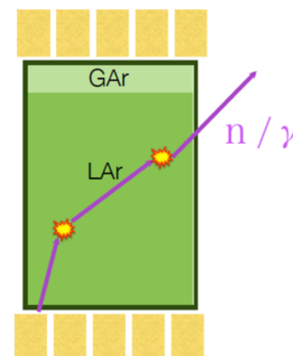
Water Tank

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

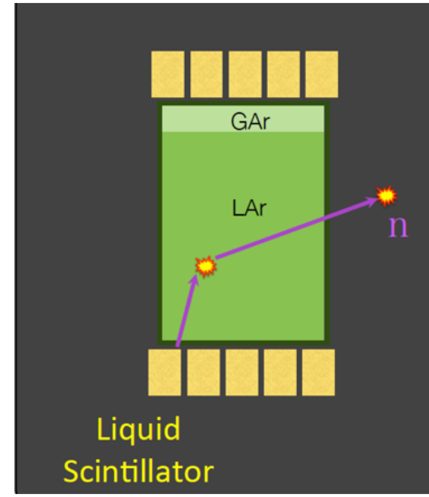
Liquid Scintillator Veto

- 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 :

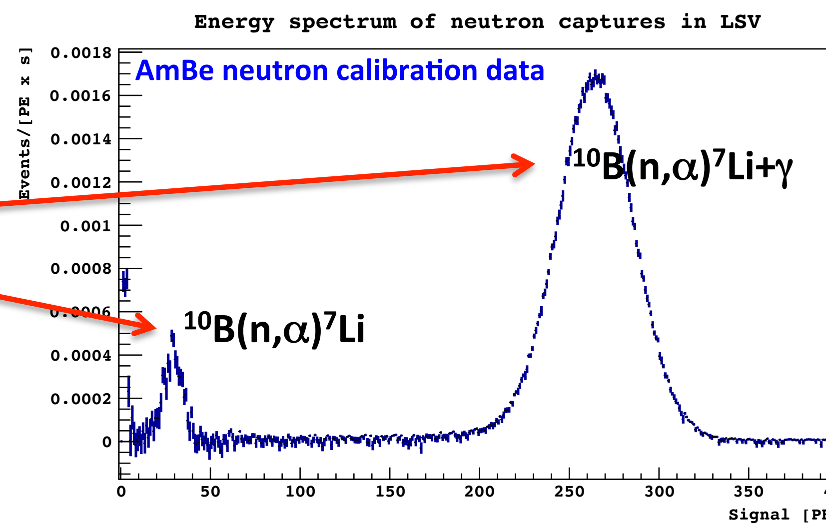


Multiple S2 signal



Observe neutron capture on ^{10}B through :

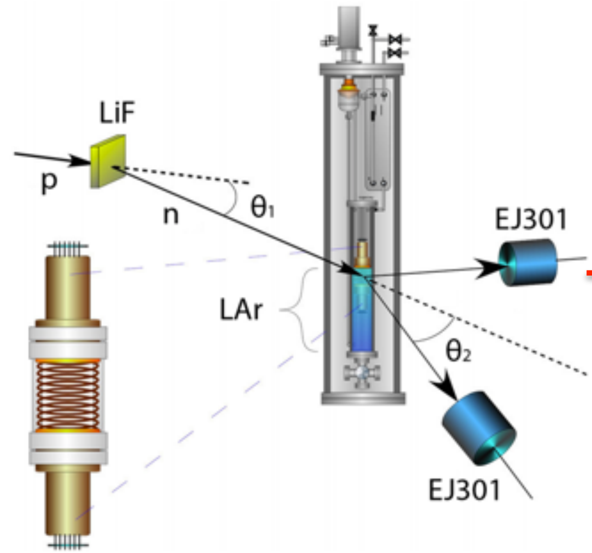
- **93.6%:** $^{10}\mathrm{B} + \mathrm{n} \Rightarrow {}^{7}\mathrm{Li}^{*} + \alpha$
  $^{7}\mathrm{Li}^{*} \Rightarrow {}^{7}Li + \gamma$ (478 keV)
- **6.4%:** $^{10}\mathrm{B} + \mathrm{n} \Rightarrow {}^{7}\mathrm{Li}$ (1015 keV) + α (1775 keV)
  α (1775 keV) equivalent to 50−60 keVee

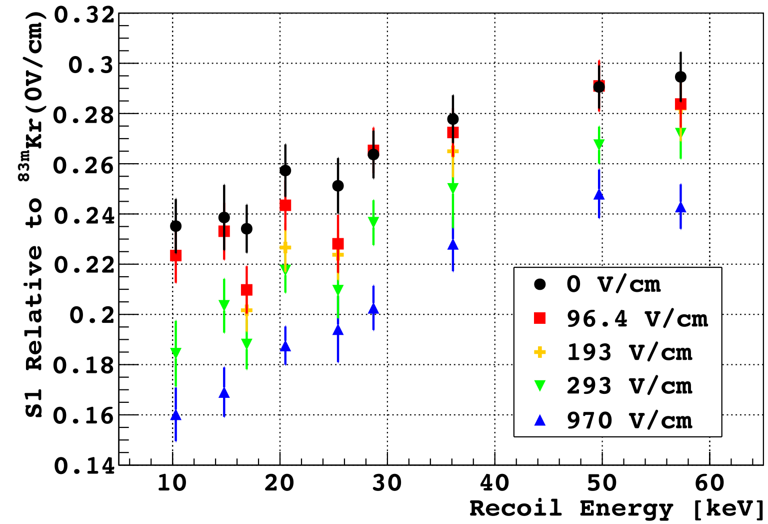


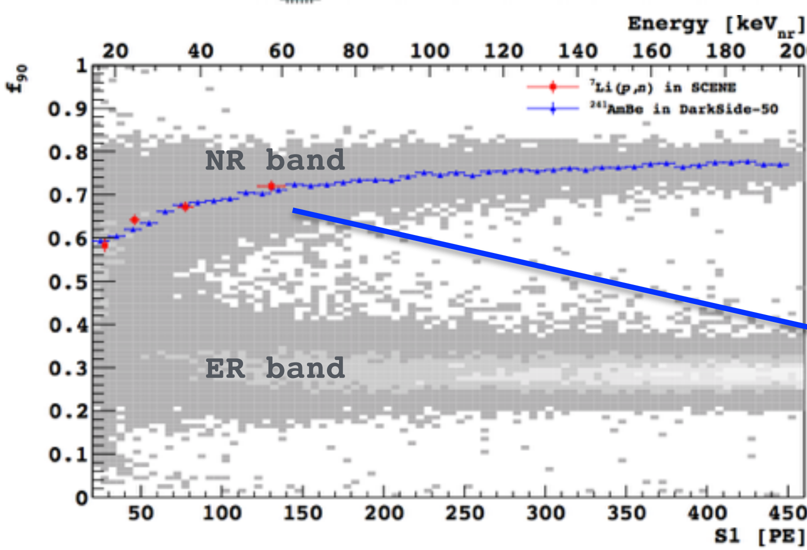
>99.1% efficiency to veto neutrons with capture signals.
Ex. : in current DS-50 data <0.02 n predicted after veto and total of 2 +- 2 tagged events.

NR calibration in LAr TPC

Use pure sample of single nuclear recoils from **neutron source** by : exposing small LAr TPC to neutron beam **SCENE** exp. @ Notre Dame (2013); and **ARIS** exp. @ ALTO Orsay (2016)

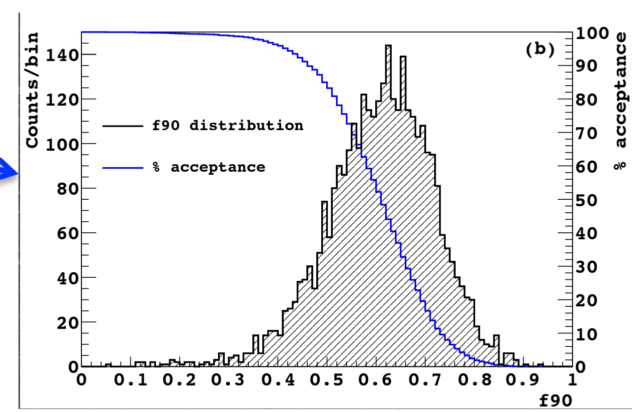






and with **in situ calibration** in DS-50 TPC with **AmBe-AmC** neutron source the LAr TPC response to **NR** measured in **SCENE**.

→ *NR acceptance bands in f90 PSD variable:*



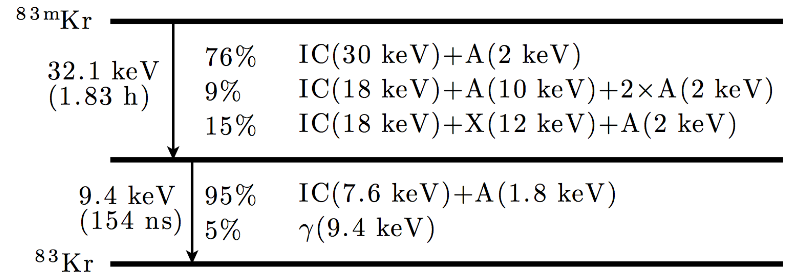
ER calibration in LAr TPC

External Calibration:

- A robotic arm (called CALIS) deploys gamma sources and neutron sources
  - ^{57}Co (γ's at 122, 136 keV)
  - ^{137}Cs (γ at 662 keV)
  - ^{133}Ba (γ's at 81, 356, 383 keV)
  - AmBe (neutrons + γ's)

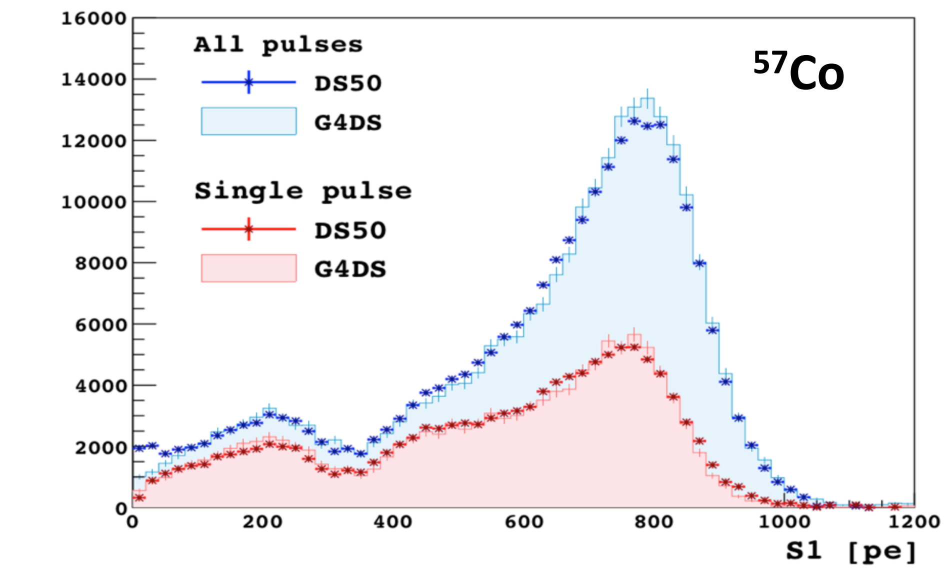
Internal Calibration:

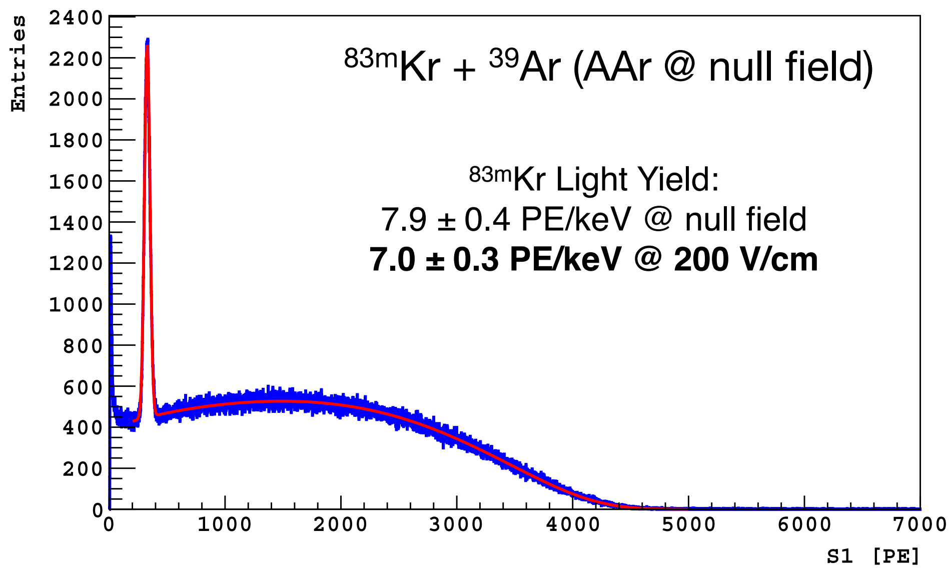
- ^{83m}Kr injected into the argon flow
  - Decays by internal conversion or Auger electrons
  - Monoenergetic total signal
  - Used to study scintillation light yield, z-dependence of light collection, S2/S1 yield



Test of the MC code

DATA-MC comparison: ^{57}Co source next to the cryostat





New DarkSide-50 result :

Low-mass Dark Matter Search

ArXiv:1802.06994

Low mass DM scatterring off Argon

Low mass DM scattering, Ar recoil Energy :

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

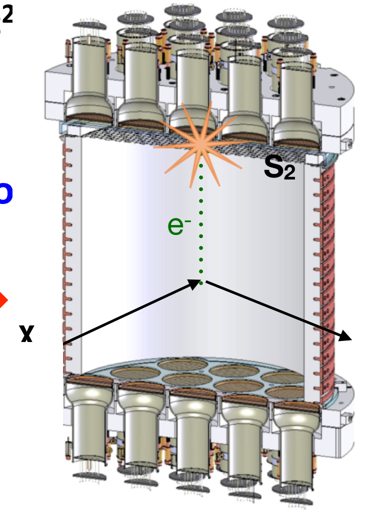
$m_N^{Ar} \sim 37$ GeV

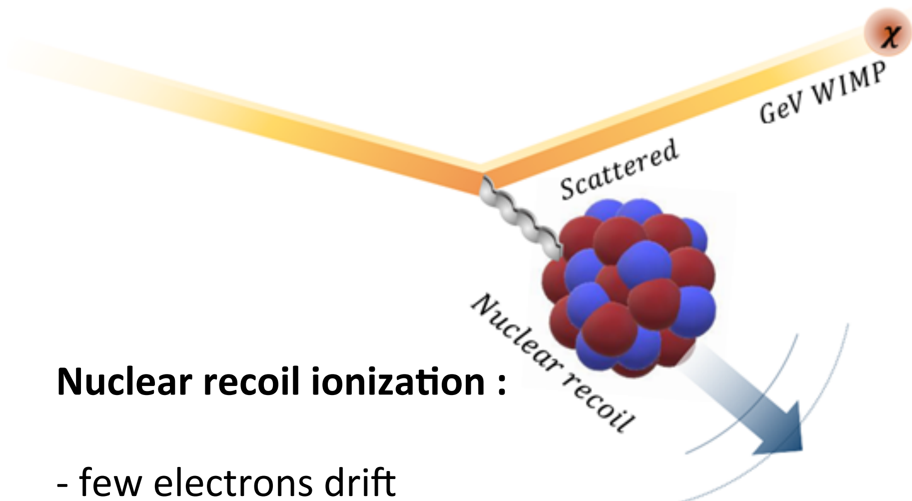
For $m_\chi = 10$ GeV ➡ $E_R \sim 1.4$ KeV

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

Low Mass WIMPs: < 20 GeV/c²

- Range: **0.7-15 keV_{nr}**
- **Lighter nucleus, larger reco energy**
- **S2 ionization signal only →** (no S1)
- Profile Likelihood Analysis



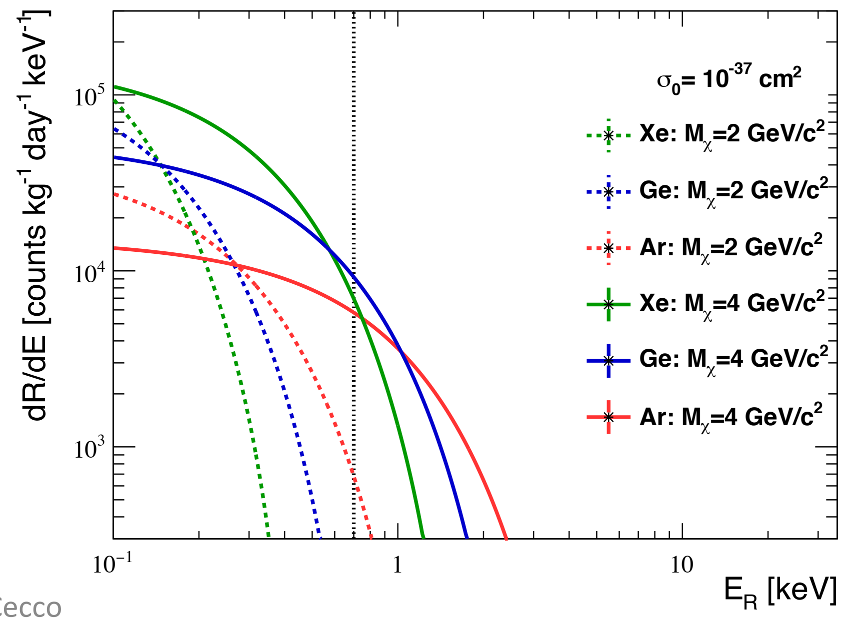


Nuclear recoil ionization :

- few electrons drift
- gas pocket amplification

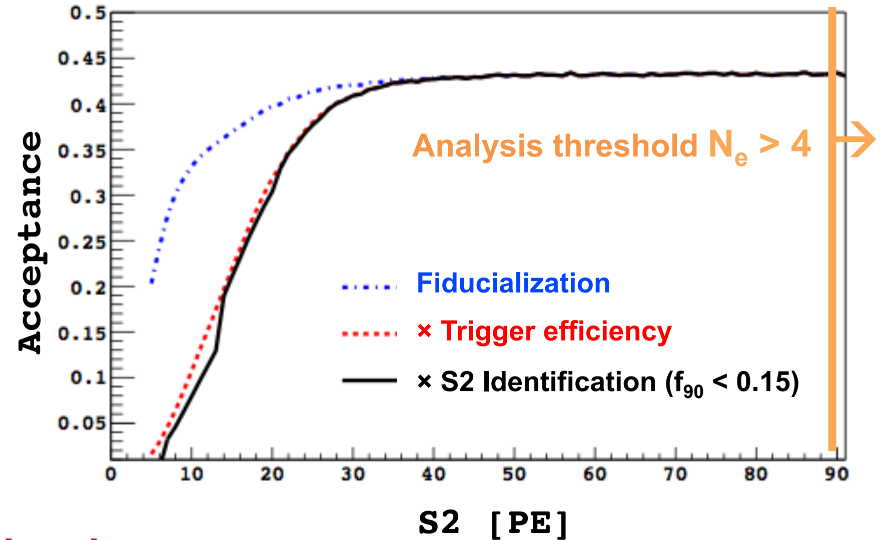
→ S2 signal

Low mass WIMPs E_R spectra for Ar, Ge, Xe



Measuring ionization only events

Detection efficiency :



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

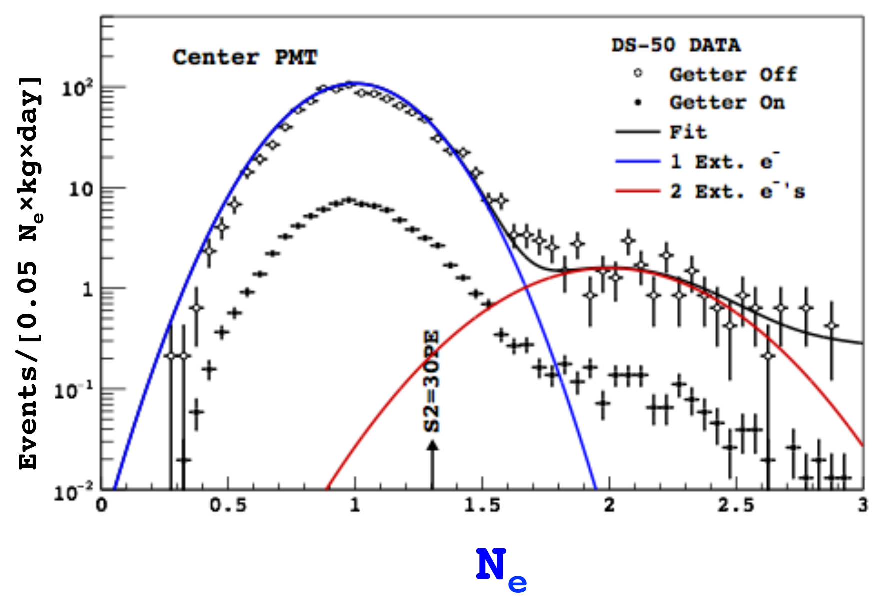
Analysis threshold at above 4 N_e

Single-electron lineshape :

- 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**

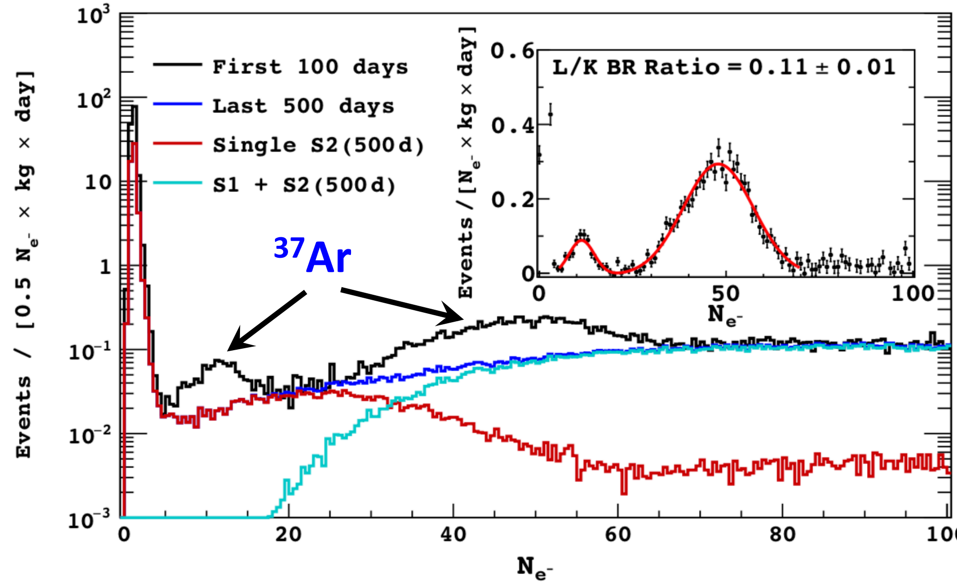


Low Mass: Electron and Nuclear Recoil Scales

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** :

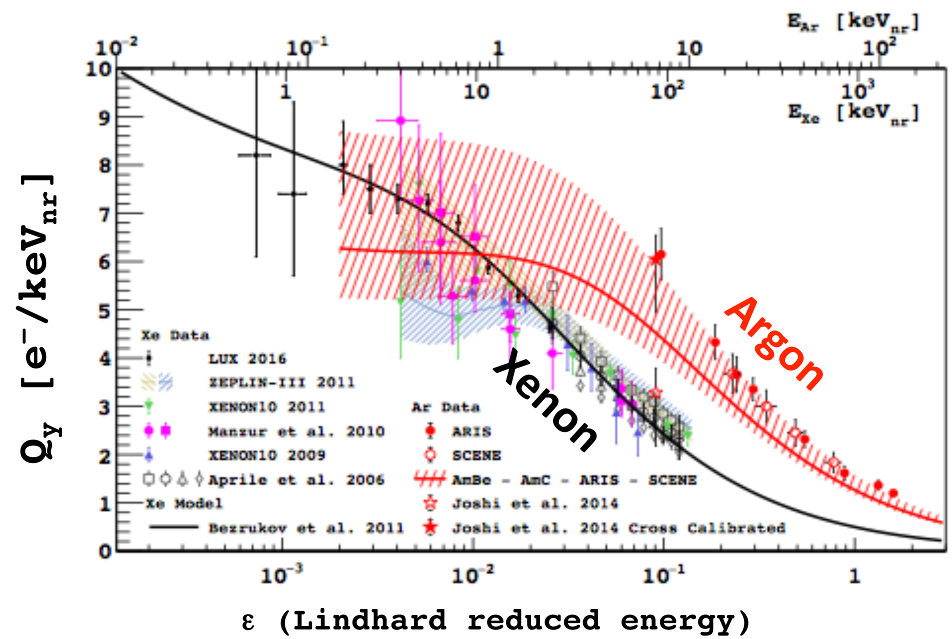
E = 0.27 keV → Ne = 11
E = 2.8 keV → Ne = 47.9



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**

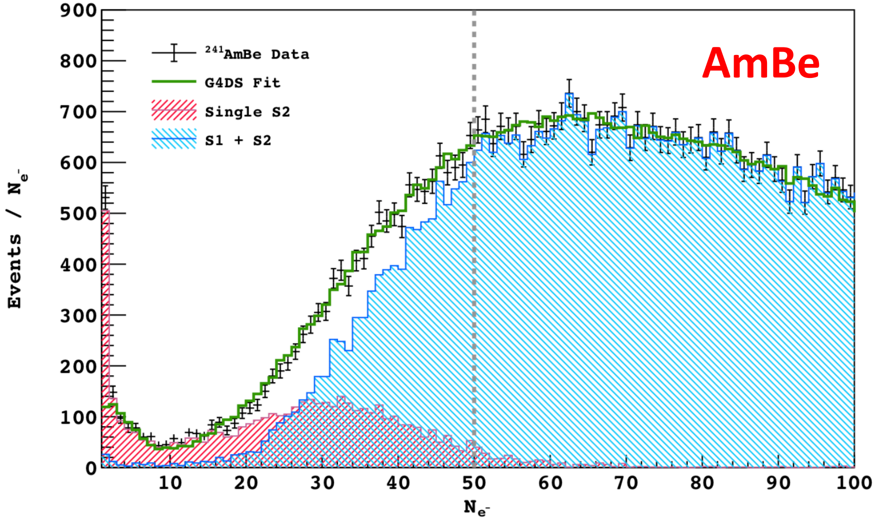
Uncertainty red band from deviations wrt external neutron calibrations (ARIS, SCENE).

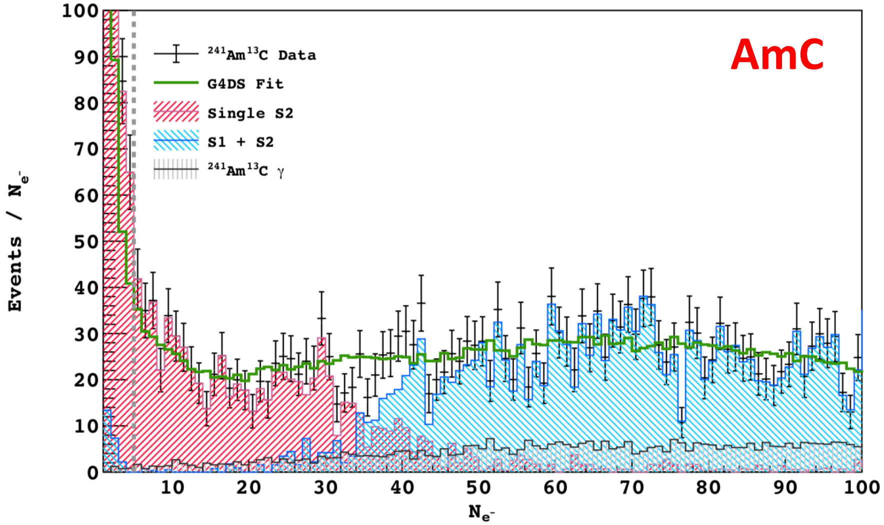


Low Mass: Nuclear Recoil Scale AmBe and AmC fit

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

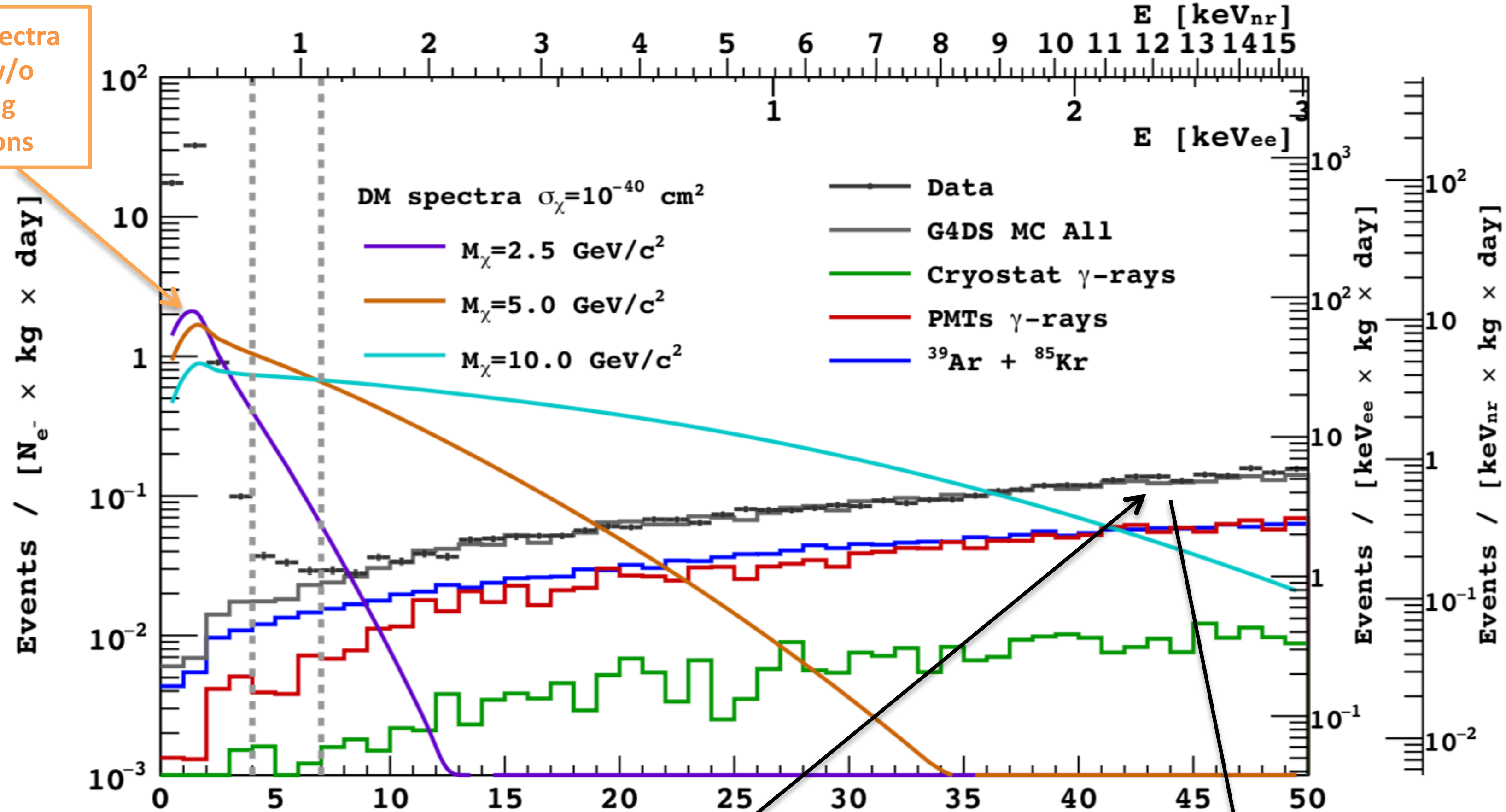
Gammas from ^{241}Am decay accounted with MC

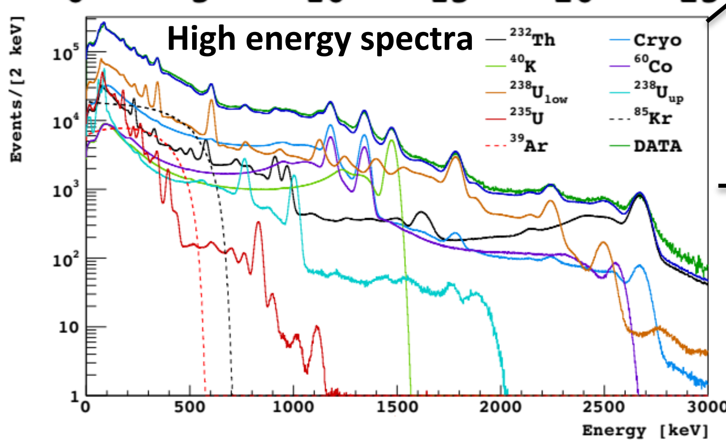
Accidentals subtracted using UAr normalized by the exposure

No inefficiency

Low Mass DM ionization only search background :

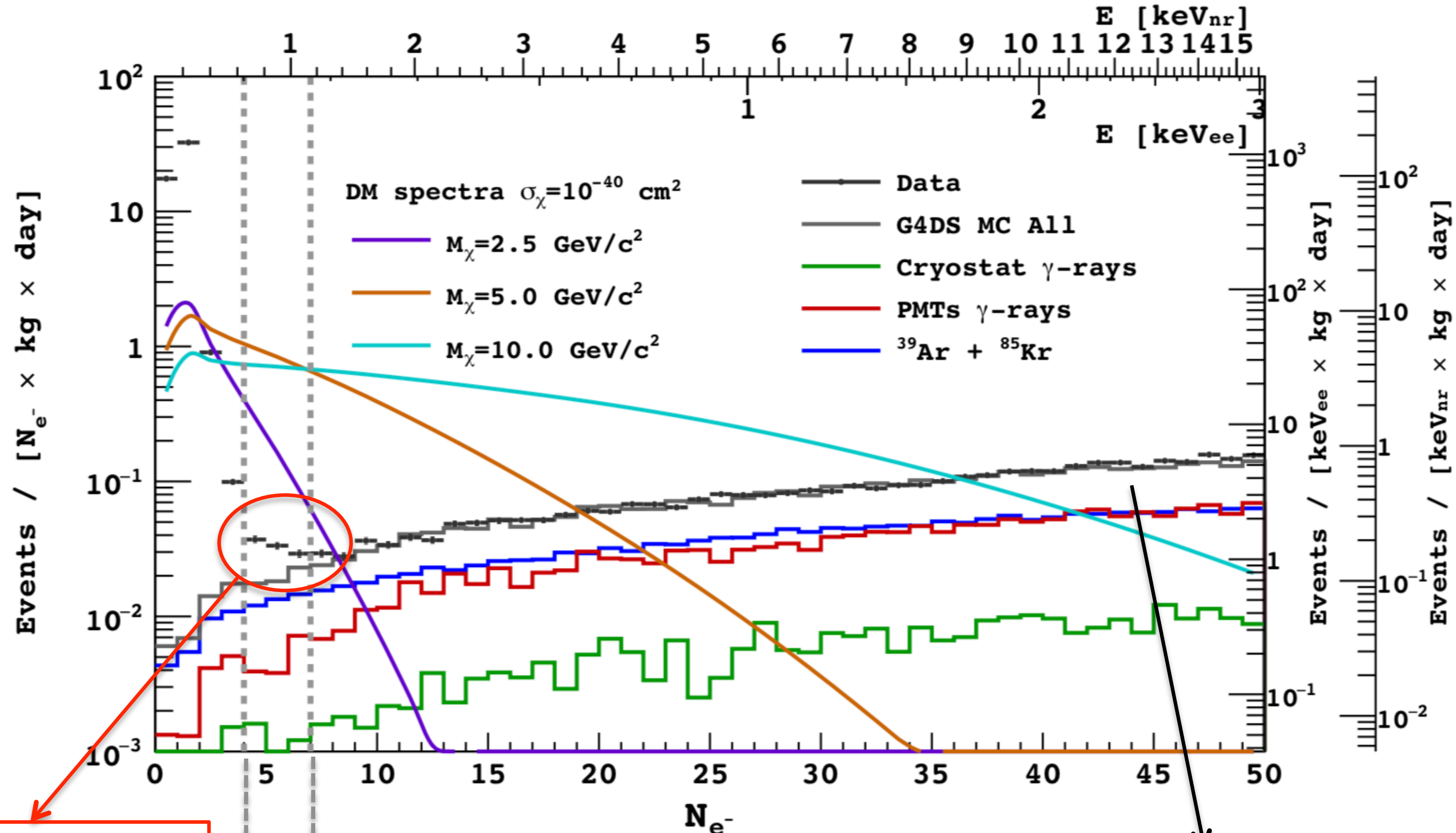
WIMP spectra plotted w/o quenching fluctuations





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 ionization only search background :



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

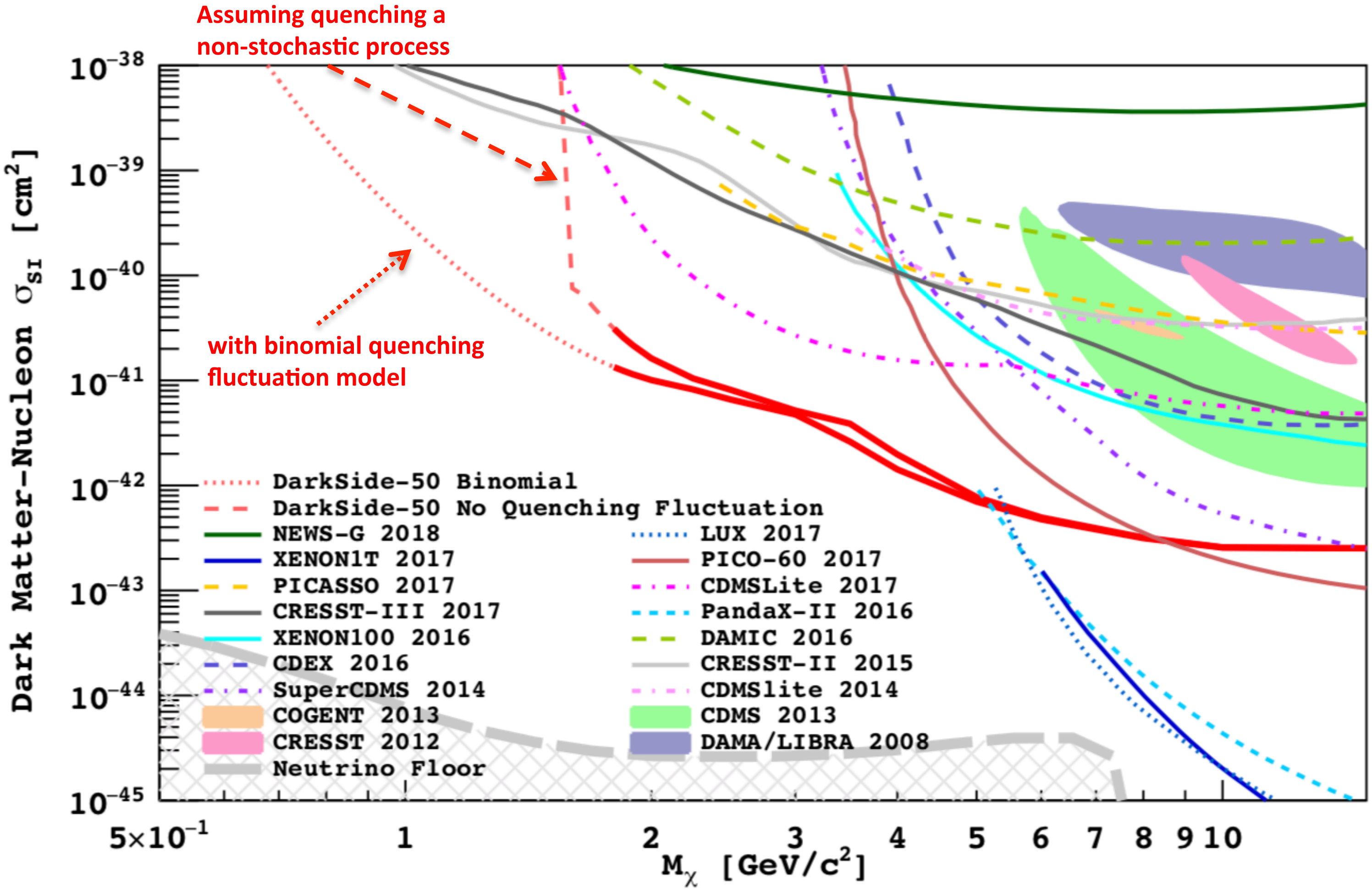
Also seen by XENON100. Further studies ongoing.

N_e > 7 analysis threshold for Mχ > 3.5 GeV. In this region Data MC agreement is good

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 :

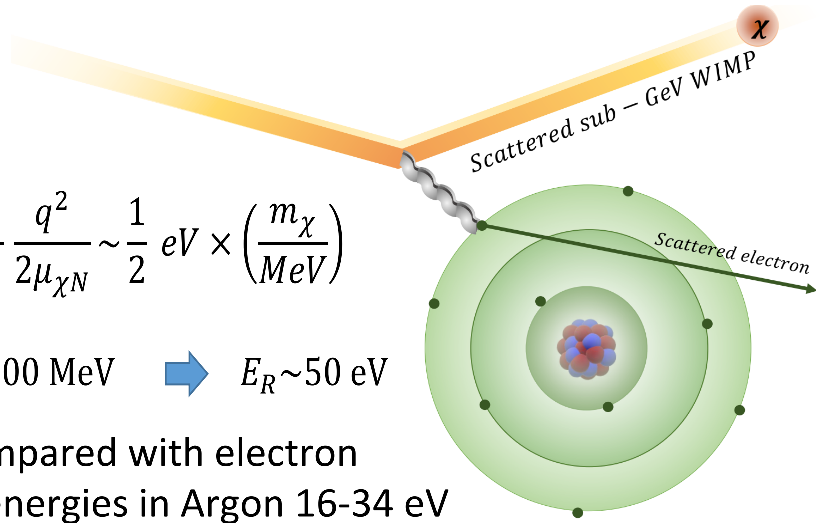


- **Profile Likelihood Method** for $N_e>4$ and $N_e>7$ thresholds shown respectively for **Mχ < 3.5 GeV** and **Mχ > 3.5 GeV**
- **Uncertainties** for both WIMP signals (NR ionization yield, single electron yields) and BG spectrum (rates, ER ioniz. yield)

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}

S2-only analysis interpretation for DM-electron scattering



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

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

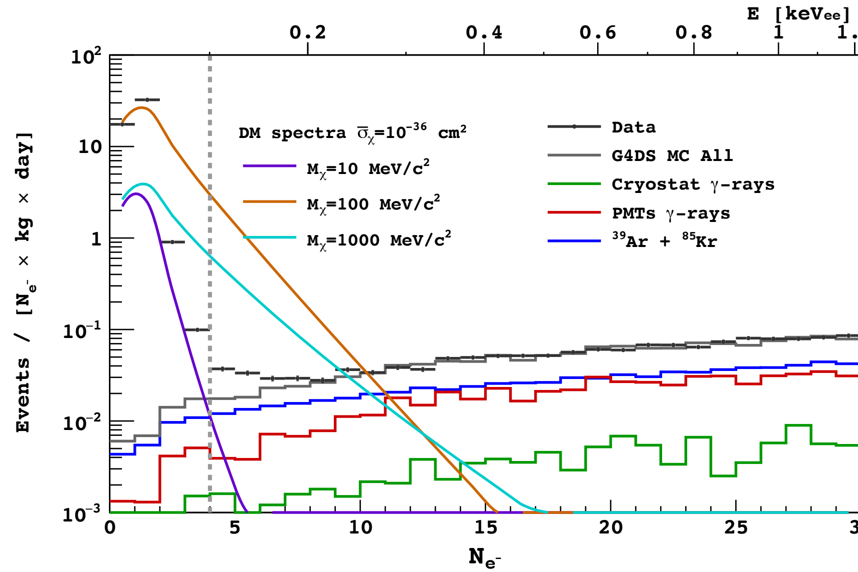
→ **ultra low mass DM scattering on e^- can ionize Argon**

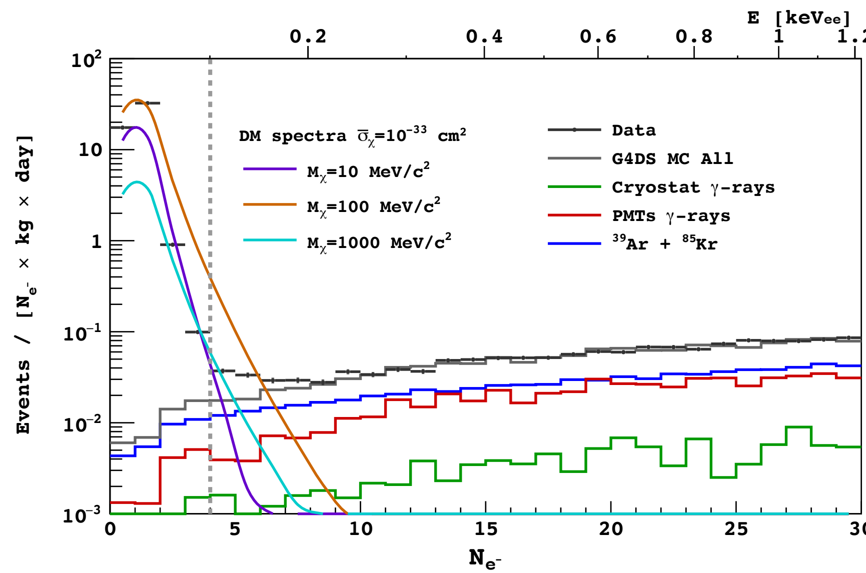
DM-electron differential scattering rate :

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

Tested in the two "light" and "heavy mediator regimes :

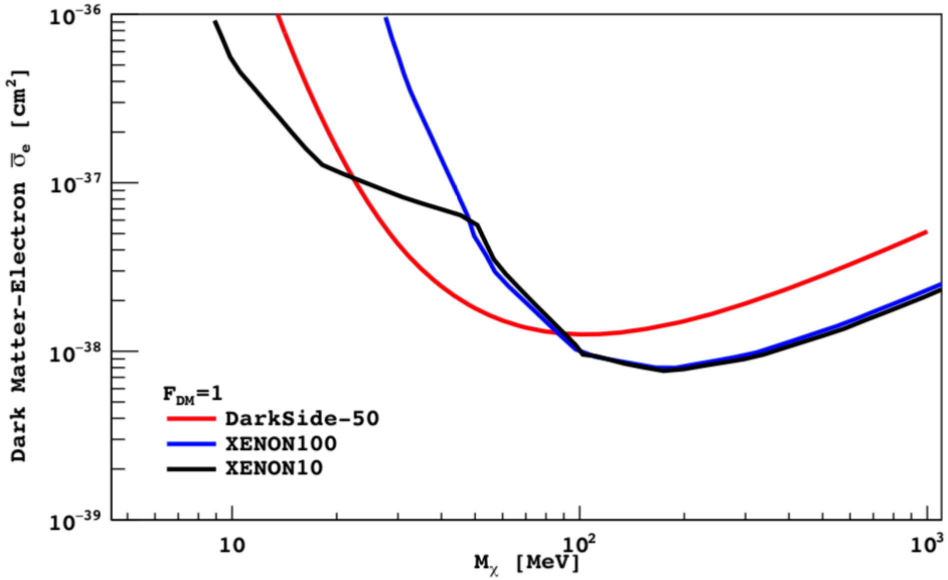
$$|F_{\rm DM}(q)|^2 = \begin{cases} 1, & m_{\rm med} \gg \alpha m_e \\ (\alpha m_e/q)^4, & m_{\rm med} \ll \alpha m_e, \end{cases}$$



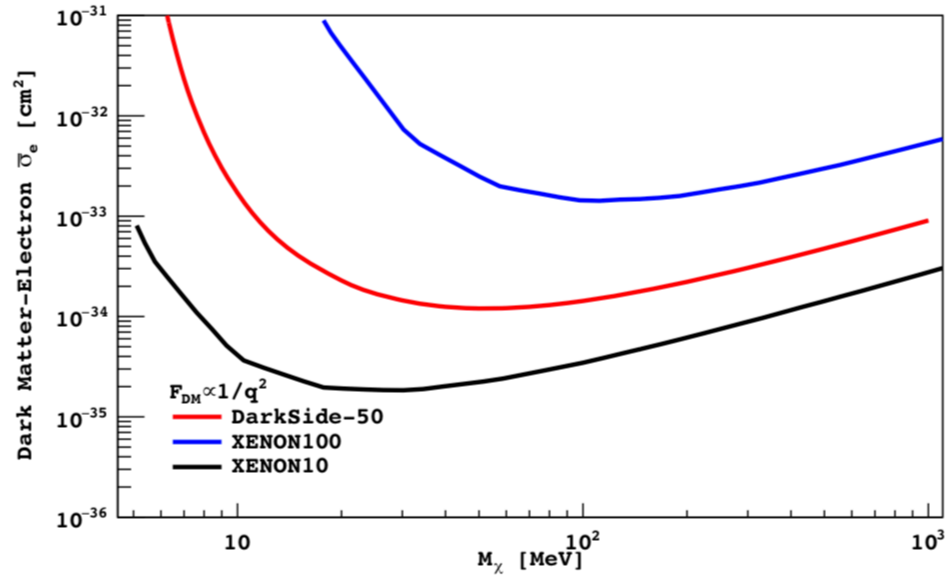


S2-only analysis interpretation for DM-electron scattering

F_{DM} ~ 1 → heavy mediator



F_{DM} ∝ 1/q2 → light mediator



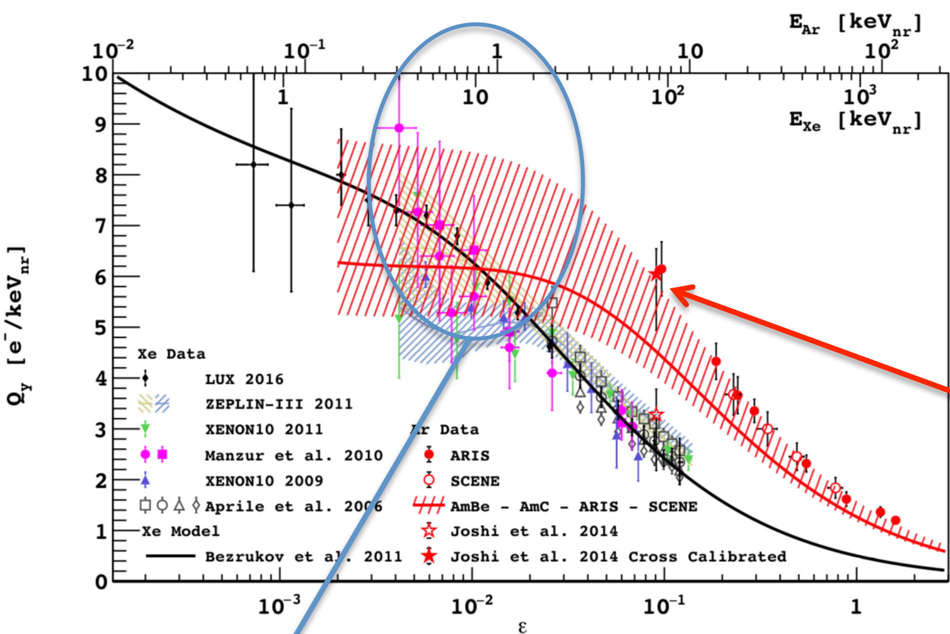
Profile Likelihood Method is used

Uncertainties from ER ionization yield and single electron yields are included both DM spectra and BG spectra. Rates uncertainties are included in BG spectra.

In the case of a heavy mediator, FDM = 1, we improve the current exclusion limit in the range from 20 MeV/c² to 80 MeV/c².

Low Mass : toward better insight on NR response

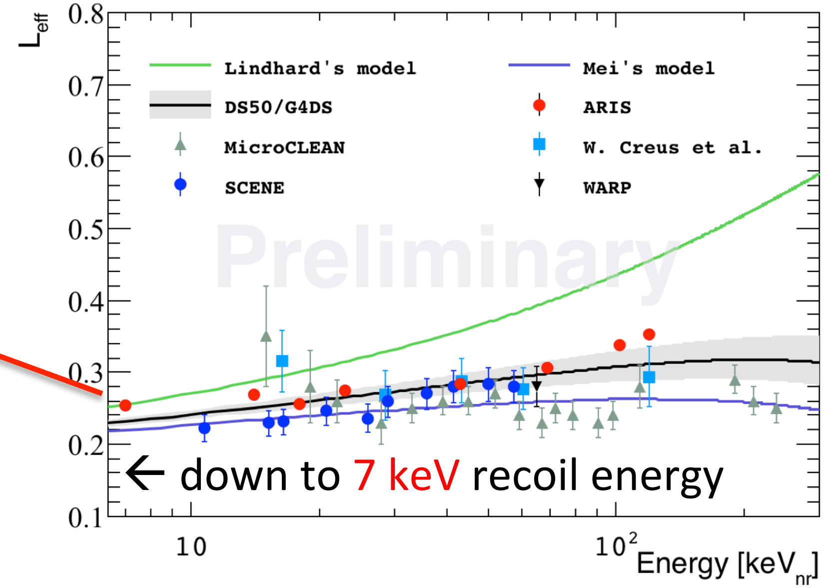
Ionization yield for Nuclear recoils:



Region of interest for GeV Dark Matter masses at <= 1keV recoil energy.

Small LAr TPC exposure to ALTO tandem Licorne neutron beam (Li + p → n + Be)

The **ARIS experiment** (2016) :

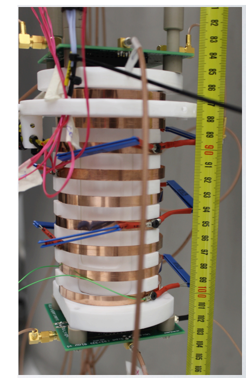


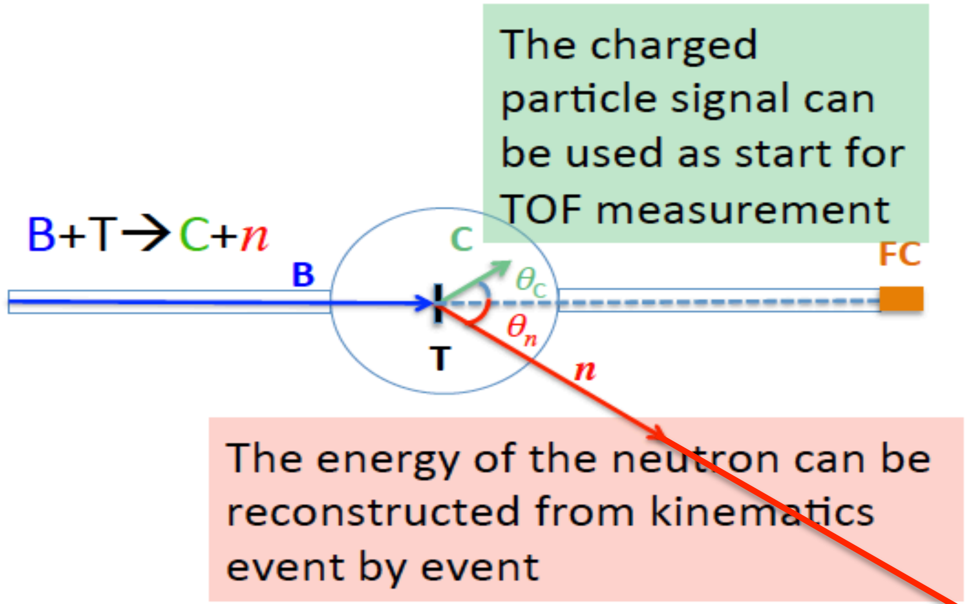
arXiv:1801.06653

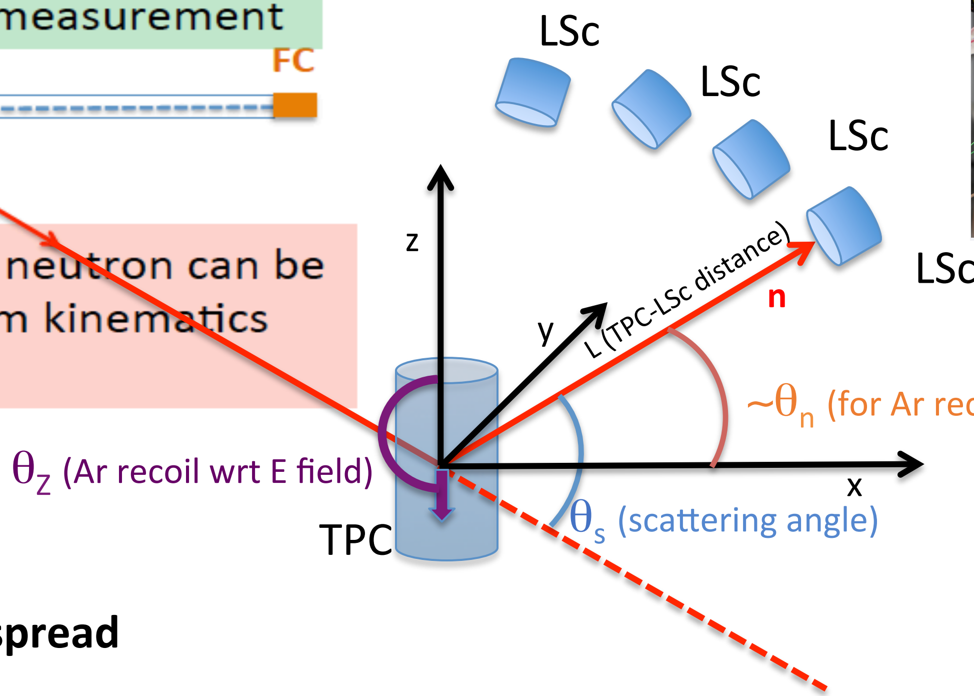
→ need direct measurements at LOW ENERGY on neutron beams in the near future …

future ReD experiment at LNS

All Lsci detector share same distance L to the **TPC** and same scattering angle θ_s (hence same recoil energy)
Different azimuth position correspond to different θ_z.







Vary L, beam energy and θ_n

Study recoil energy and angular spread due to detector geometry to find optimal comprimes between acceptance and resolution

New DarkSide-50 result :

High Mass Dark Matter search based on 532-day with Low-Radioactivity Argon

ArXiv:1802.07198

High mass WIMP search

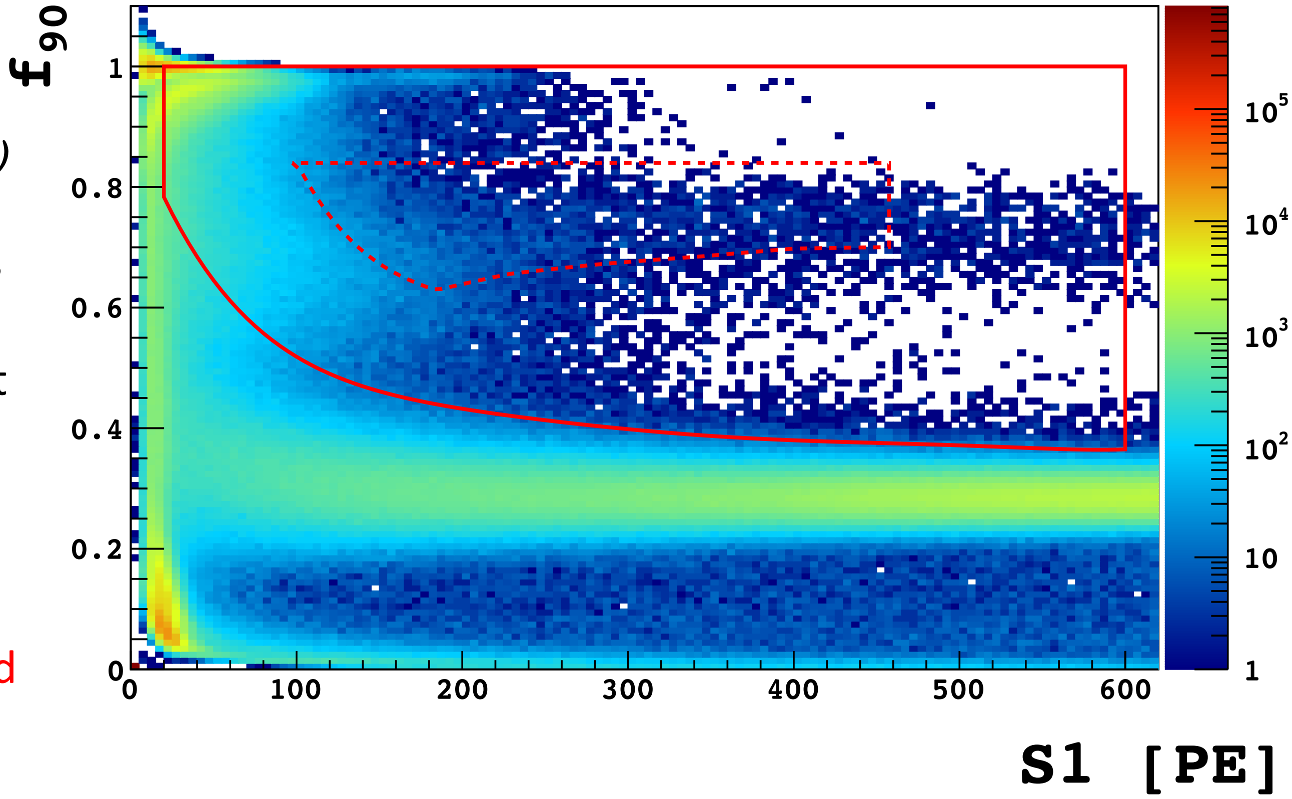
a **Blind Analysis** of 534 live-days of data

Blinding box (red outline) shown with 71-day data: *PR D 93, 081101 (2016)*

f_{90} = S1 fraction in first 90 ns

Goal: design an analysis that will have <0.1 event of background in the to-be-designed search box.

Final box chosen: dashed red

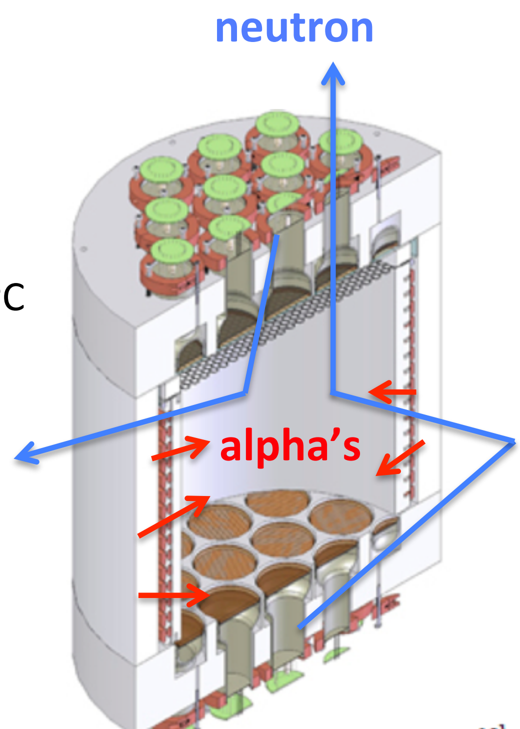


Nuclear recoil backgrounds

Neutrons

Background rejection:

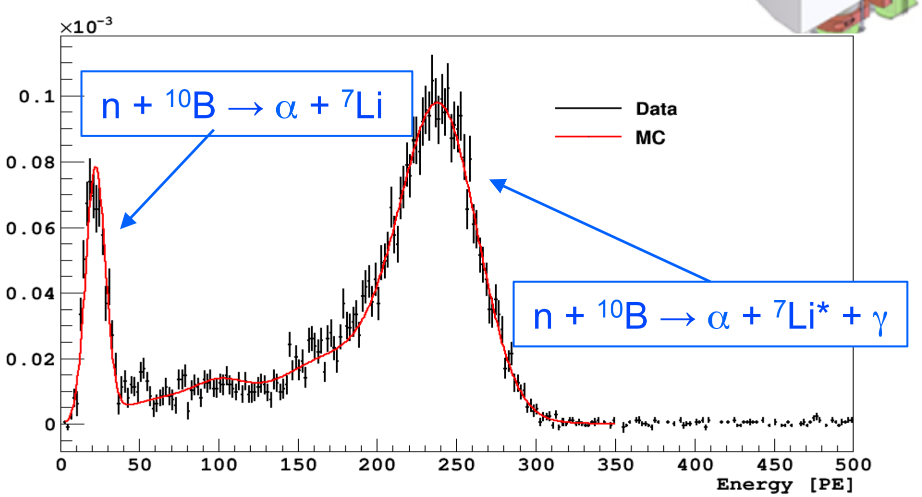
- TPC: multi-scatter
- LS Veto: efficiency from Am-C for TPC single-NR: **0.9964±0.0004**
- Water Cherenkov Veto for cosmogenics
- Neutrons in data are counted.

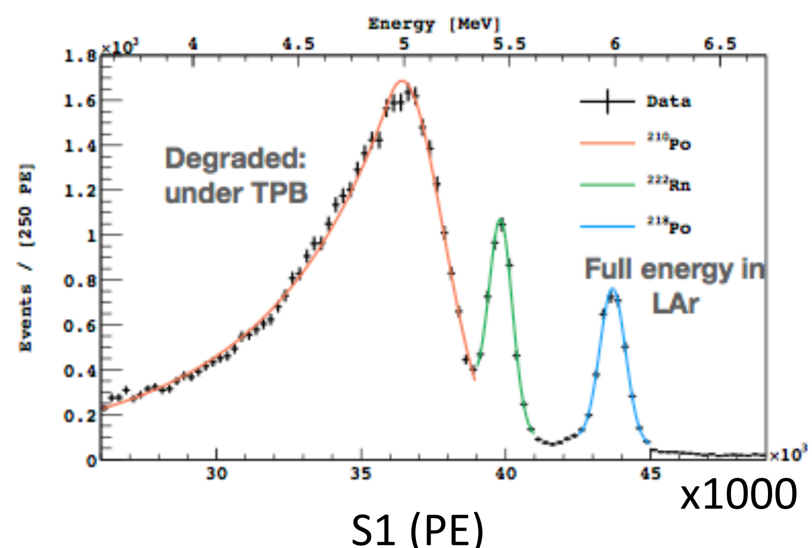


Alpha's

Background rejection:

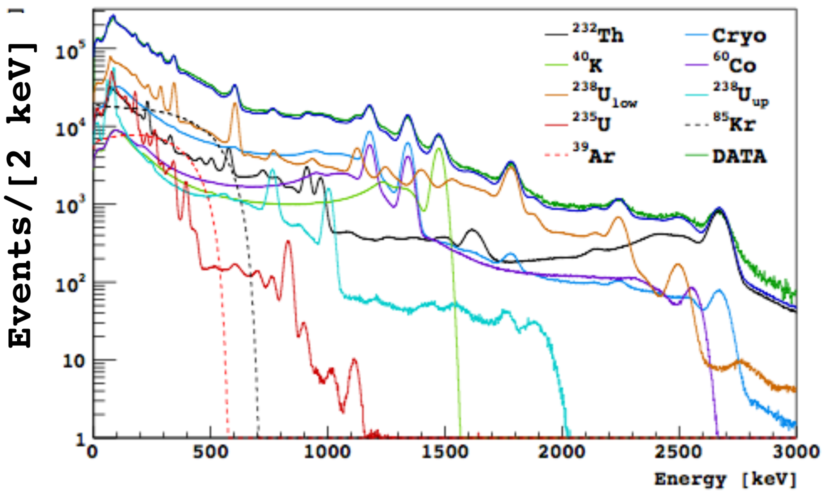
- Very high S1, small fraction at low energies (cut at S1<460 PE)
- Self-vetoing in DS-50!
  - Small or no S2
  - Long scintillation tail from TPB fluorescence



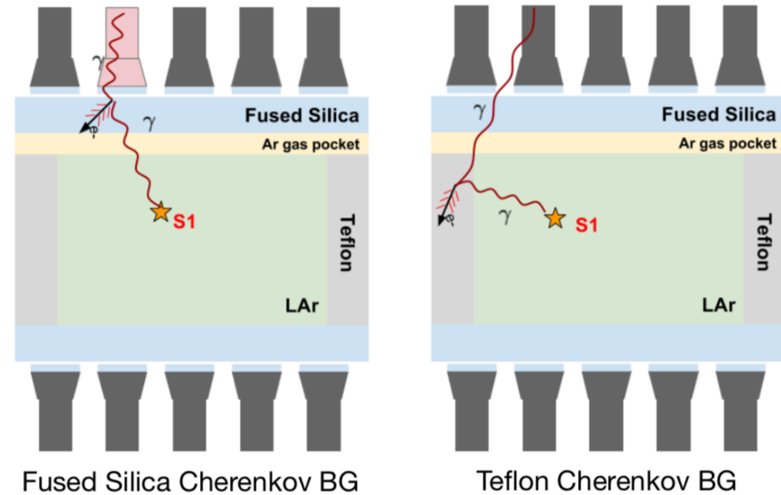


Electron recoils backgrounds

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



S1 + Cherenkov

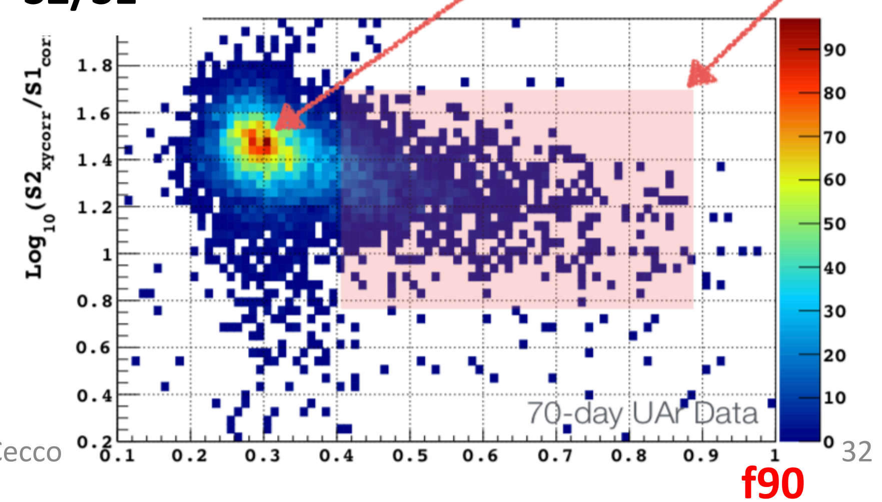


→ γ-ray multiple Compton scatters in LAr and in nearby Cherenkov radiator (Fused Silica PMT window or PTFE) : prompt Cherenkov light adds to S1 signal rise → large f90

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

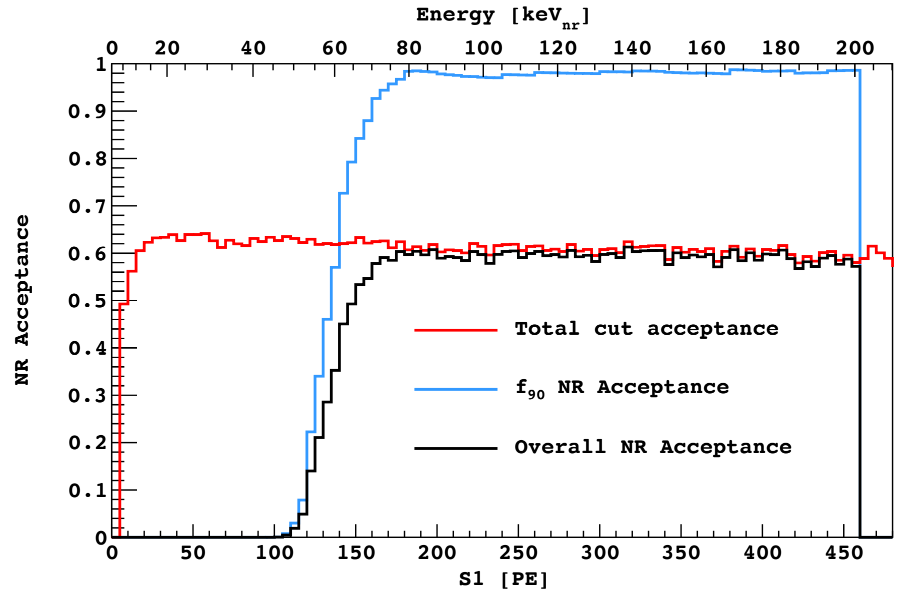


High mass WIMP search acceptance and background

Summary of analysis cuts acceptances:

Cut	Livetime/Acceptance
All channels	545.6 d
Baseline	545.6 d
Time since prev	545.3 d
Veto present	536.6 d
Cosmo activ	532.4 d
Muon signal	0.990
Prompt LSV	0.995
Delayed LSV	0.835
Preprompt LSV	0.992
N pulses	0.978
S1 start time	1
S1 saturation	1
Min uncorr S2	0.996
xy-recon	0.997
S2 F90	1
Min corr S2/S1	0.995
Max corr S2/S1	0.991
S2 LE shape	1
$S1_p$ max frac	0.948
S1 TBA	0.998
Long S1 tail	0.987
Radial cut	0.84
S1 NLL	>0.99
Combined	0.609

Total WIMP acceptance:

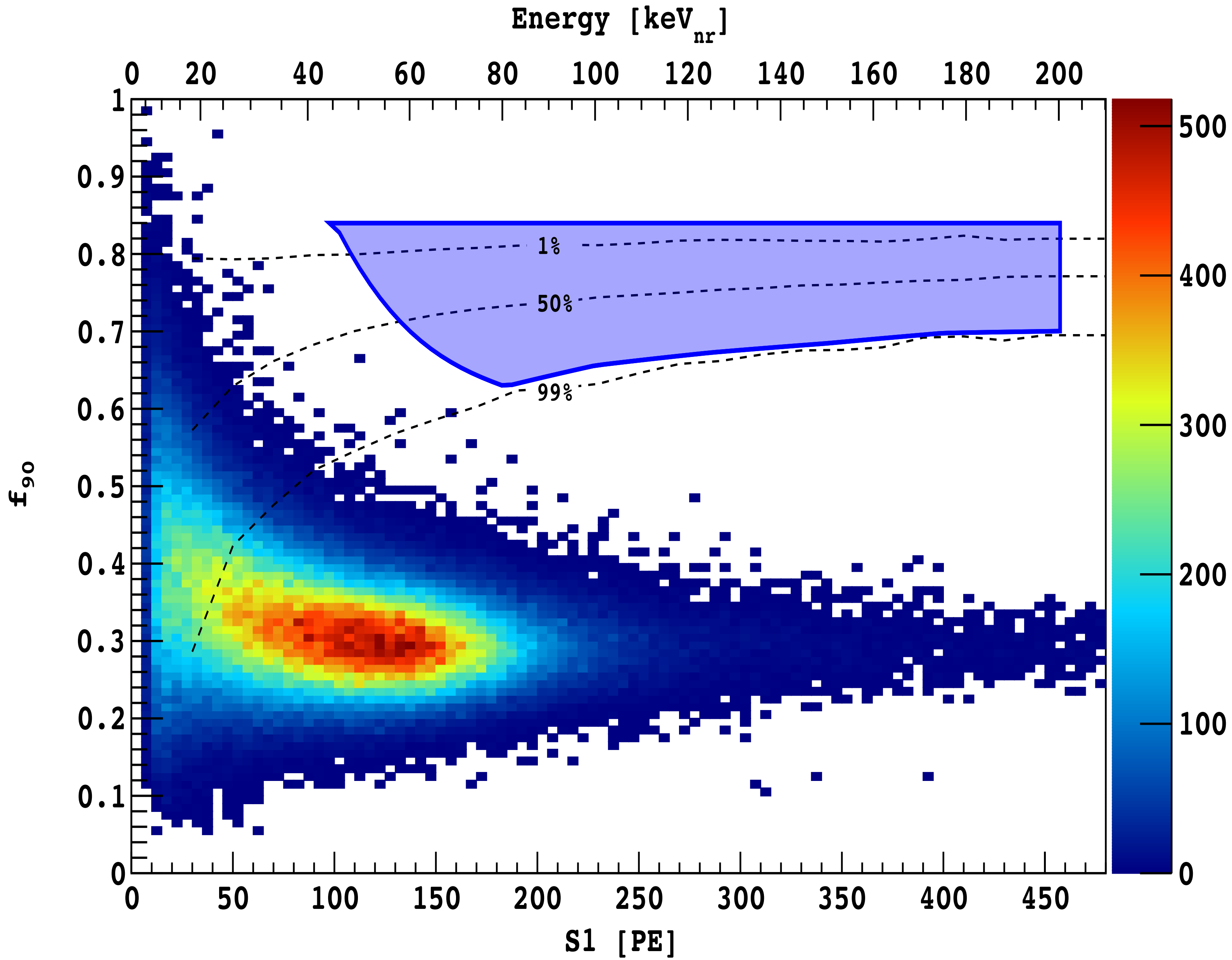


Total background expectation :

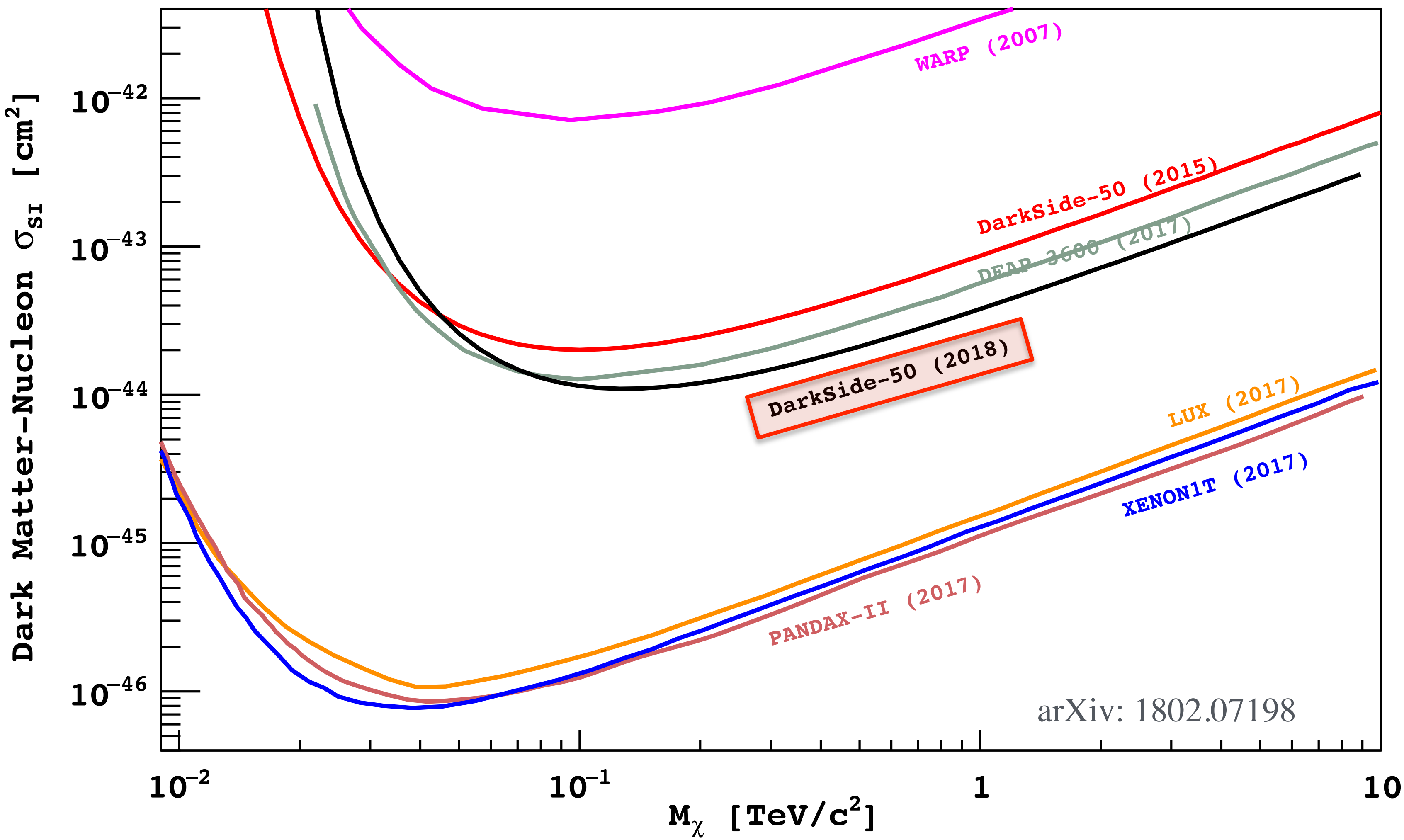
Background	Events surviving all cuts
Surface Type 1	0.0006 ± 0.0001
Surface Type 2	0.00092 ± 0.00004
Radiogenic neutrons	< 0.005
Cosmogenic neutrons	< 0.00035
Electron recoil	0.08 ± 0.04
Total	0.09 ± 0.04

Goal of < 0.1 events achieved: open the box!

All analysis cuts + LS veto to remove neutron candidates : zero events in the signal region

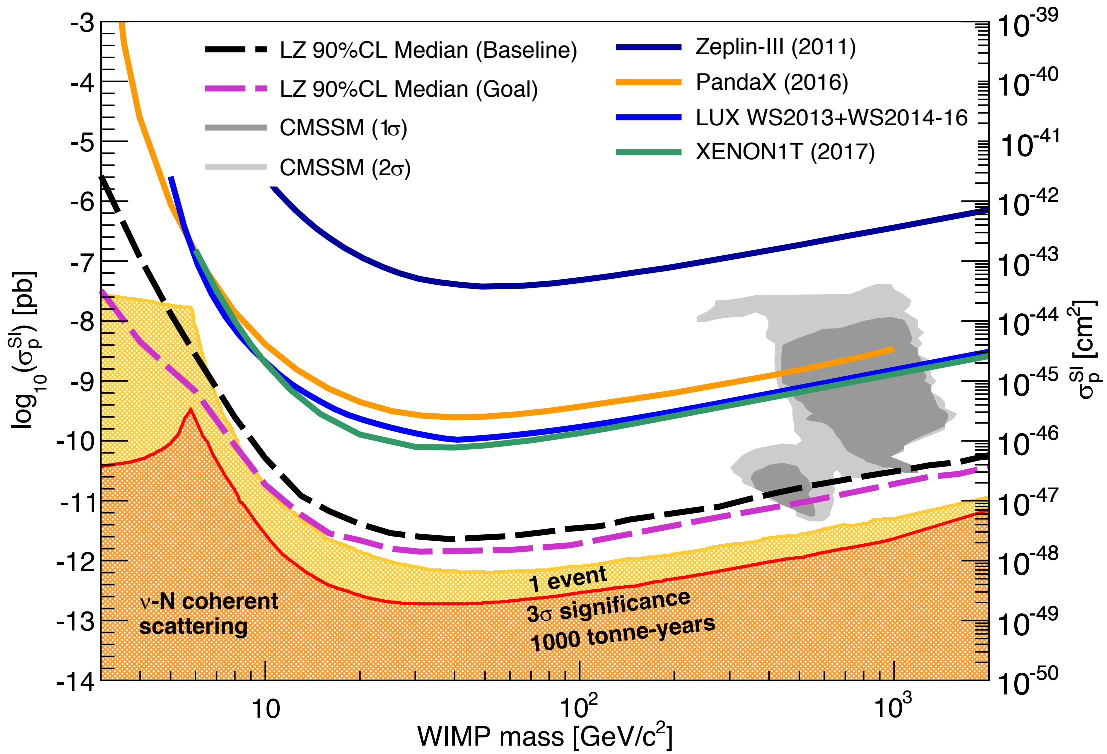


High mass 90% C.L. exclusion limit result



DarkSide-20k best future competitor: LZ Xe exp.

LZ Spin-Independent WIMP Sensitivity



- Baseline WIMP sensitivity is 2.3 x 10^{-48} cm^2 @ 40 GeV/c^2 (arXiv:1703.0914).
- 1000 days, 5.6 tonne fiducial mass.
- Begin on-site assembly spring 2018, install underground 2019, first data spring 2020.

DarkSide-20k best future competitor: LZ Xe exp.

LZ backgrounds summary

5.6 tonnes, 1000 days

Intrinsic Contamination Backgrounds	ER (cts)	NR (cts) (w/ SF rej.)
Subtotal (Detector Components)	**9**	**0.072**
222Rn (1.81 µBq/kg)	681	-
220Rn (0.09 µBq/kg)	111	-
natKr (0.015 ppt g/g)	25	-
natAr (0.45 ppb g/g)	2	-
210Bi (0.1 µBq/kg)	40	-
Laboratory and Cosmogenics	5	0.06
Fixed Surface Contamination	0	0.39
Subtotal (Non-ν counts)	**873**	**0.52**
Physics Backgrounds		
136Xe 2νββ	67	0
Astrophysical ν counts (pp+7Be+13N)	255	0
Astrophysical ν counts (8B)	0	0**
Astrophysical ν counts (Hep)	0	0.21
Astrophysical ν counts (diffuse	0	0.05
Astrophysical ν counts (atmospheric)	0	0.46
Subtotal (Physics backgrounds)	322	0.72
Total	1,190	1.24
Total (with 99.5% ER discrimination,	5.97	0.62
	6.59	

Radon dominates ER backgrounds

Gamma backgrounds (PMTs, cryostat) are negligible.

pp solar neutrinos, elastic scattering on atomic electrons

Coherent neutrino scattering on xenon nuclei

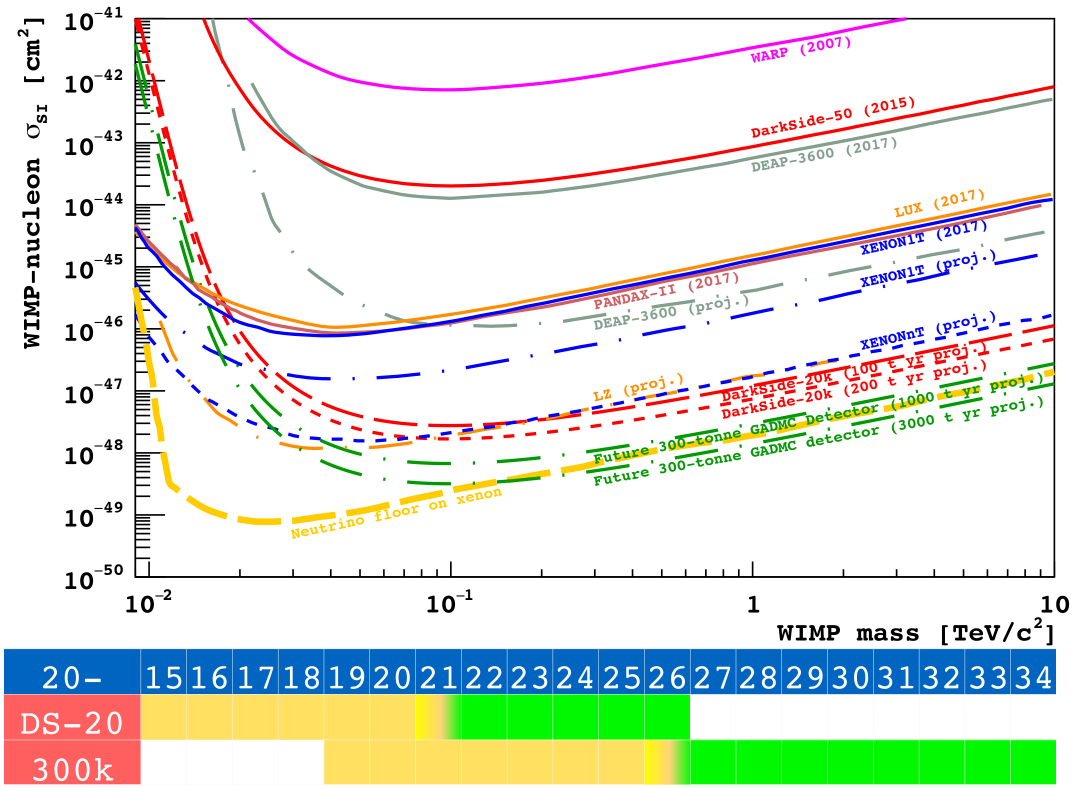
Not a 0-background search :

at high exposures **intrinsic limitation** from **Radon** and **solar pp ν Electron Recoils**

Scaling to large DAr exposures, next steps :

ArDM
DarkSide
DEAP
MiniCLEAN

} A Single Global Program for Direct Dark Matter Search
Currently taking data: ArDM, DarkSide-50, **DEAP-3600**
Next step: DarkSide-20k at LNGS (2021-)
Last Step: **300 tonnes detector**, location t.b.d **(2027-)**



DarkSide-20k approved by INFN and LNGS in April 2017 and by NSF in Oct 2017

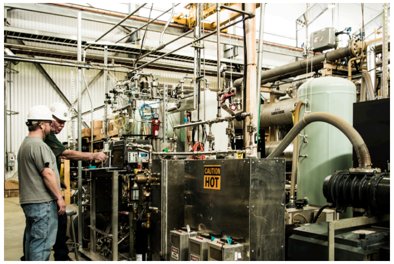
Officially supported by LNGS, LSC, and SNOLab

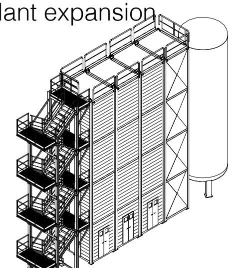
30 tonnes (20 tonnes fiducial) of low-radioactivity underground argon

14 m² of SiPM coverage

Underground/Depleted Ar : URANIA & ARIA projects

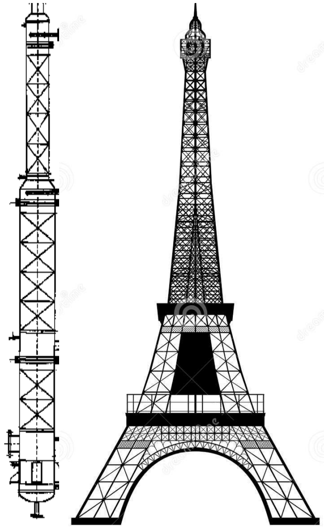
- **URANIA**:
  - Replacement of the Ar extraction plant in Colorado to reach capacity of 100 kg/day of UAr
  - Cost: 3.2M€
    - MIUR/INFN Progetto Premiale 2013 (2.3M€)
    - NSF + other US sources (0.9M€)
    - discussion with CERN towards the possibile commissioning and test at the Neutrino Platform
- **ARIA**:
  - 350 m tall distillation column in the Seruci mine in Sardinia for chemical and isotopic purification of UAr
  - Exploits finite vapor pressure difference between 39Ar/40Ar (39Ar reduction factor of 10 per pass at the rate of 100 kg/day)
  - Protocollo di Intesa between INFN and Regione Sardegna
  - Cost: 12.5M€
    - INFN (4M€)
    - NSF + other US sources (1.3M€)
    - CARBOSULCIS (4.5M€)
    - Regione Autonoma Sardegna (2.7M€)

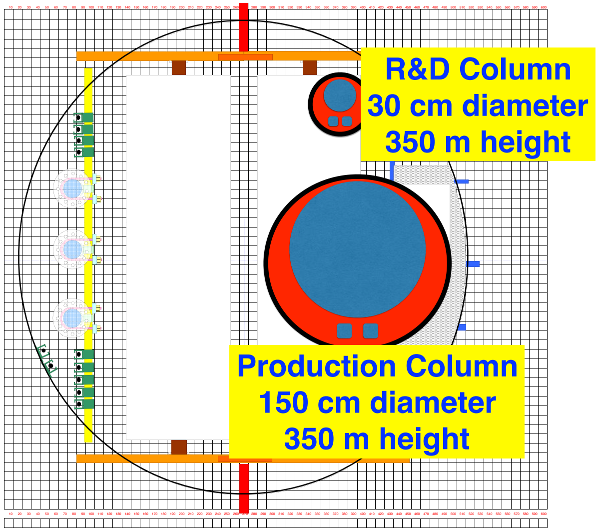




extraction of UAr with activity (measured by DS-50) of $(0.73\pm0.11)\times10^{-3}$Bq/kg

+ dedicated stage suppression of ^{85}Kr





Seruci I —>removal of chemical impurities at 1t of Ar/day; also of ^{85}Kr with factor 1000 per pass

10kg/day isotopic distillation for ^{39}Ar —>rate too low for DS-20k

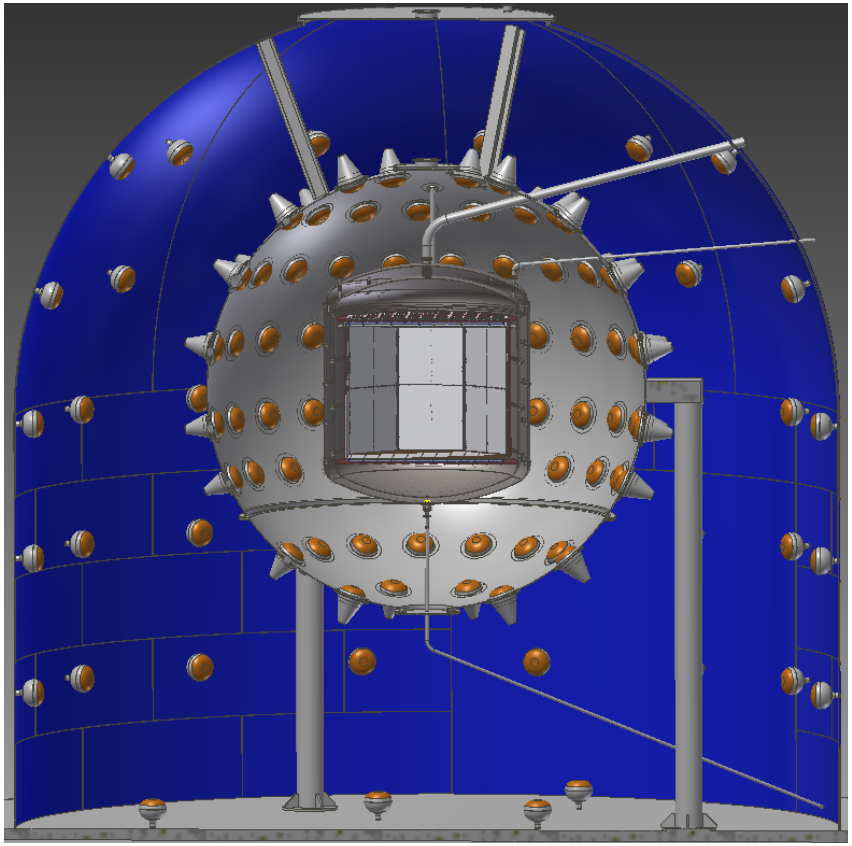
Seruci II —>150kg/day for ^{39}Ar : 30t —> 200d

DarkSide-20k Tech. Proposal, baseline design :

Baseline design :
(arXiv:1707.08145)

- 30 ton total, **20 ton** fiducial UAr
- Liquid Argon target extraction and purification from underground (**URANIA**, US) and ^{39}Ar depletion with cryogenic distillation (**ARIA**, Sardinia)
- $15m^2$ of **cryogenics SiPM photosensors** (low radioactivity, increased LY) - assembly and test at Nuova Officina Assergi - NOA
- high efficiency LS **active neutron veto**
- 15m diameter water tank muon veto
- ER background from residual ^{39}Ar
- SS/Ti cryostat and PTFE largest sources of (α, n) Nuclear Recoils backgrounds

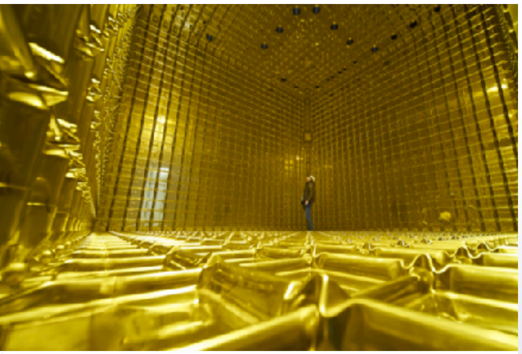
→ **a 100 ton yr background free exposure :**



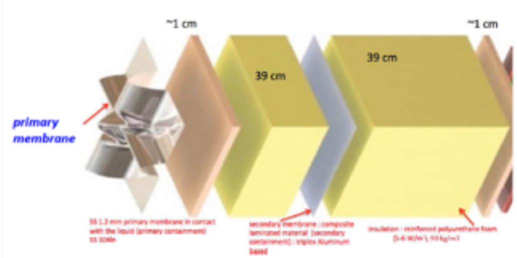
Background	Events in ROI $[100\,t\,yr]^{-1}$	Background $[100\,t\,yr]^{-1}$
Internal β/γ's	1.8×10^8	0.06
Internal NRs	negligible	negligible
e^--ν_{pp} scatters	2.0×10^4	negligible
External β/γ's	10^7	<0.05
External NRs	<81	<0.15
Cosmogenic β/γ's	3×10^5	$\ll$0.01
Cosmogenic NRs	–	<0.1
ν-Induced NR	1.6	–

DarkSide-20k, design evolution :

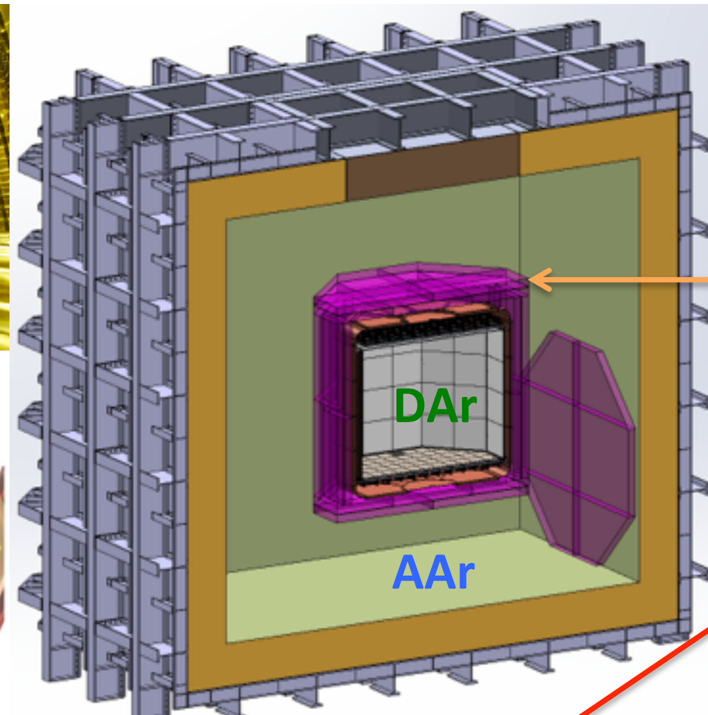
- a **ProtoDUNE** like large cryostat (8x8x8 m3 inner dim.) filled with750t **AAr**, also as shielding
- Much simpler design and concept : allows for **fully radio-pure materials close to TPC**
- **Fully scalable** to future modular and/or larger size (300 tons)

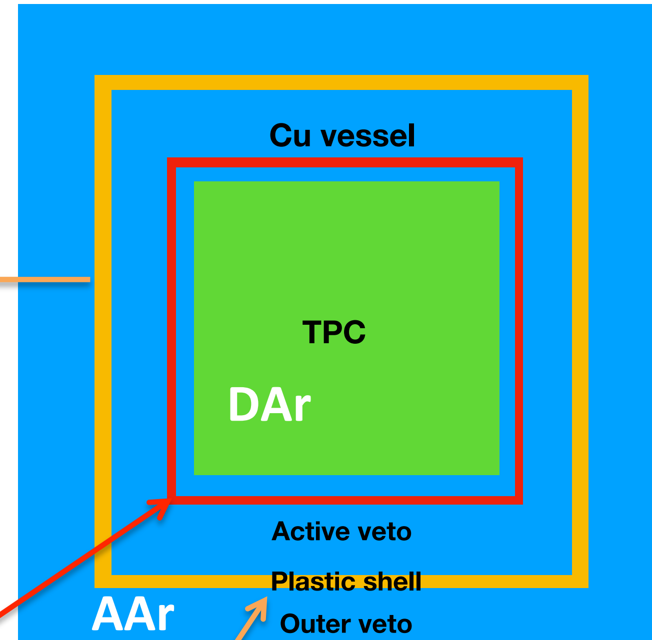


LNG technology : firm GTT



Internal : polyurethane ~78 cm, 90 kg/m³, heat input ~6.5 W/m²





Radio pure **Copper/Titanium Vessel** separation between outer AAr and inner TPC **Depleted Ar**.

Plastic Scintillator Veto, (solid) with Boron, Gadolinium or Lithium doping for neutron capture. R&D on going

DarkSide-20k, design evolution :

- a **ProtoDUNE** like large cryostat (8x8x8 m3 inner dim.) filled with750t **AAr**, also as shielding
- Much simpler design and concept : allows for **fully radio-pure materials close to TPC**
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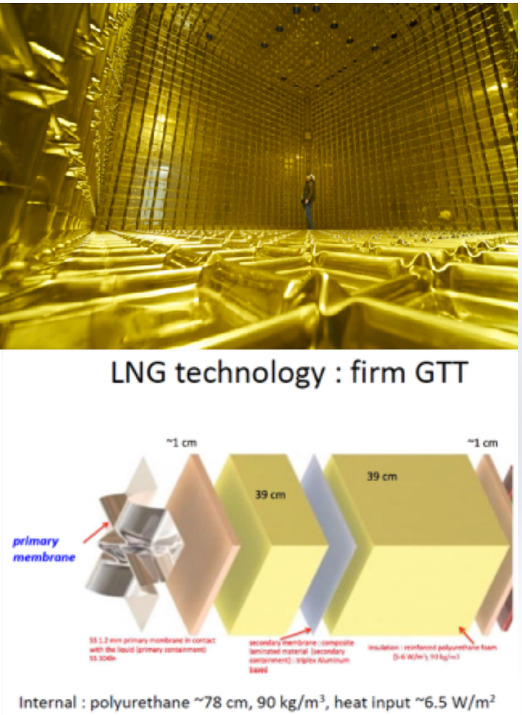
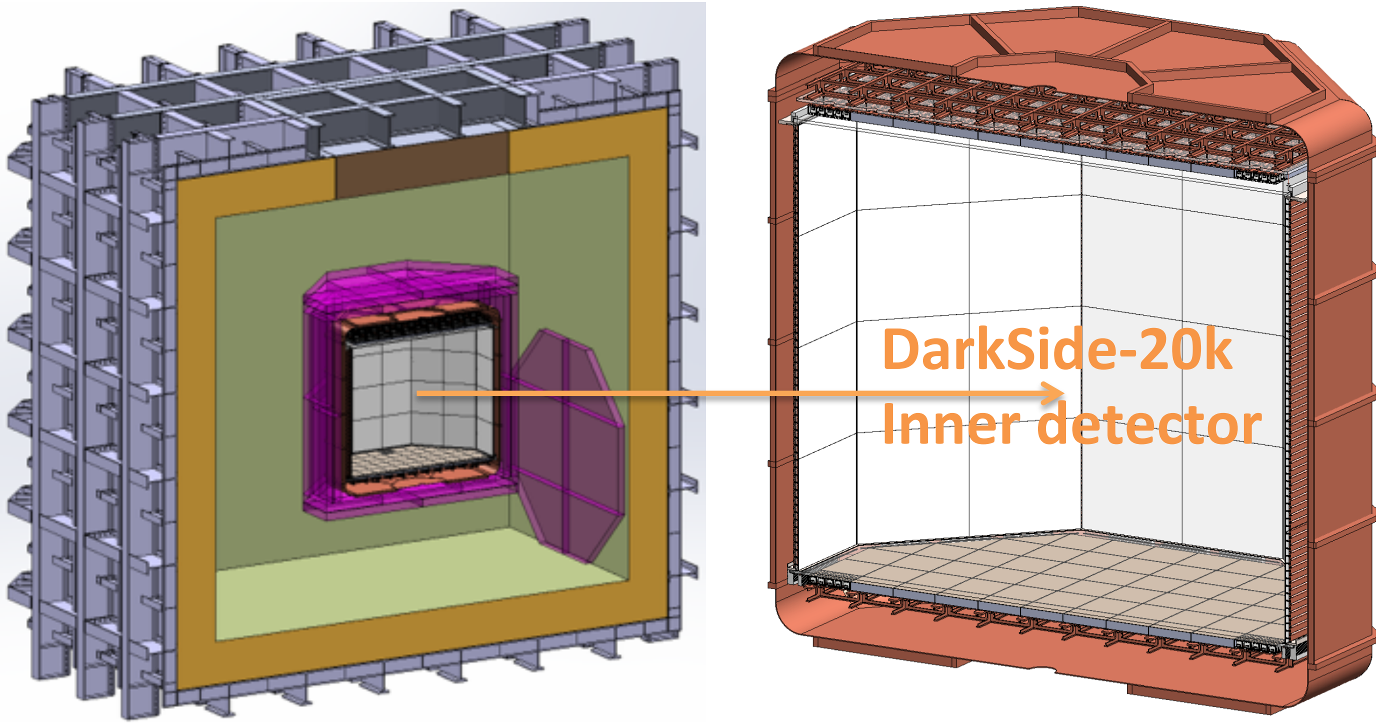
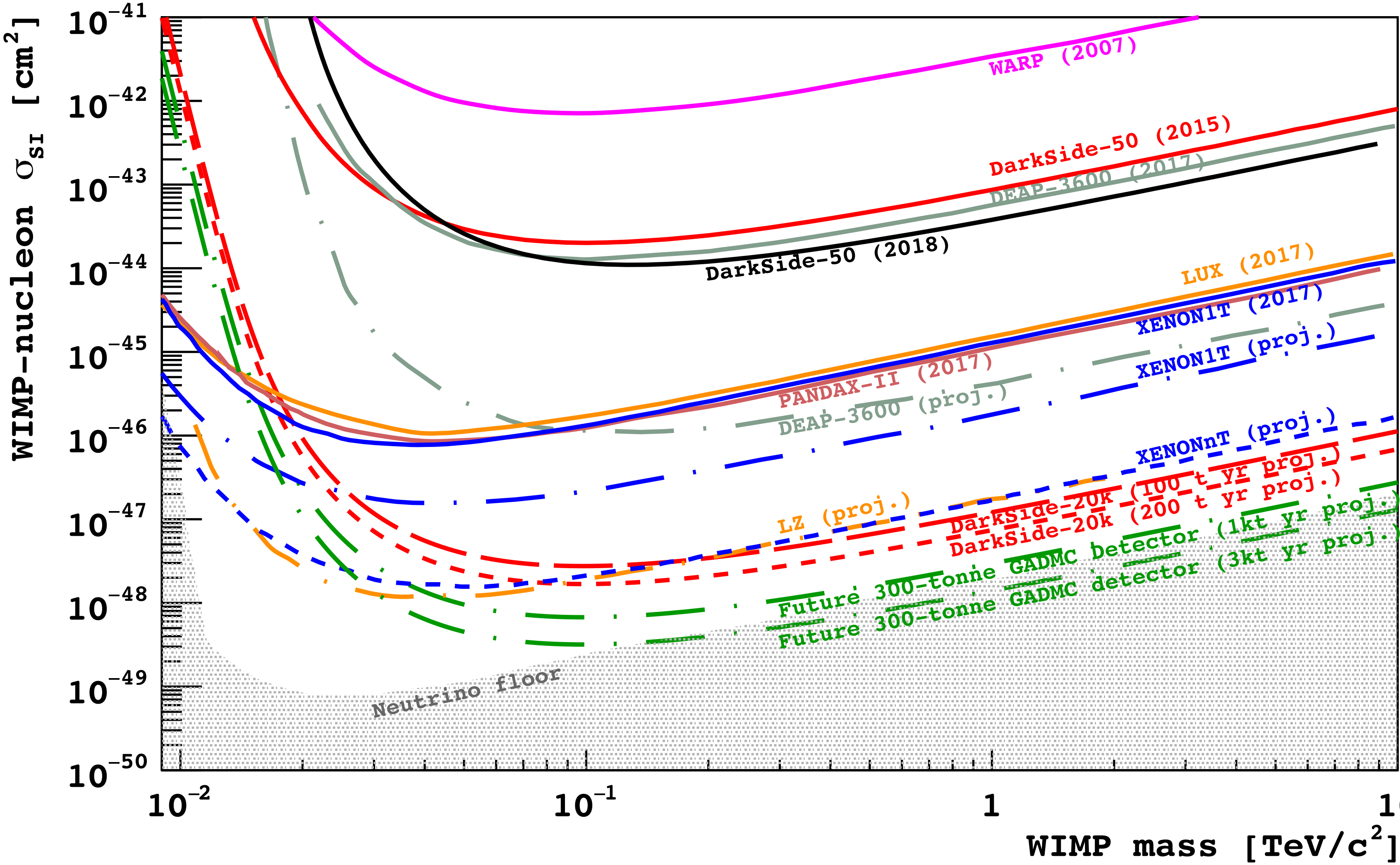




DarkSide-20k Inner detector : Vessel + Depleted LAr TPC
- Ultra radio pure Copper/Titanium Vessel removes higher source of ***n*** background
- TPC reflector change from PTFE to Acrylic + 3M foils, will reduce significantly Cherenkov and ***n*** backgrounds
- **Increase fiducial mass** 20t→**30t**, TPC self ***n*** veto, release eff. PS veto → **larger exposure !**

DarkSide-20k and GADMC high mass projections :



On the way to DarkSide-20k : DS-proto

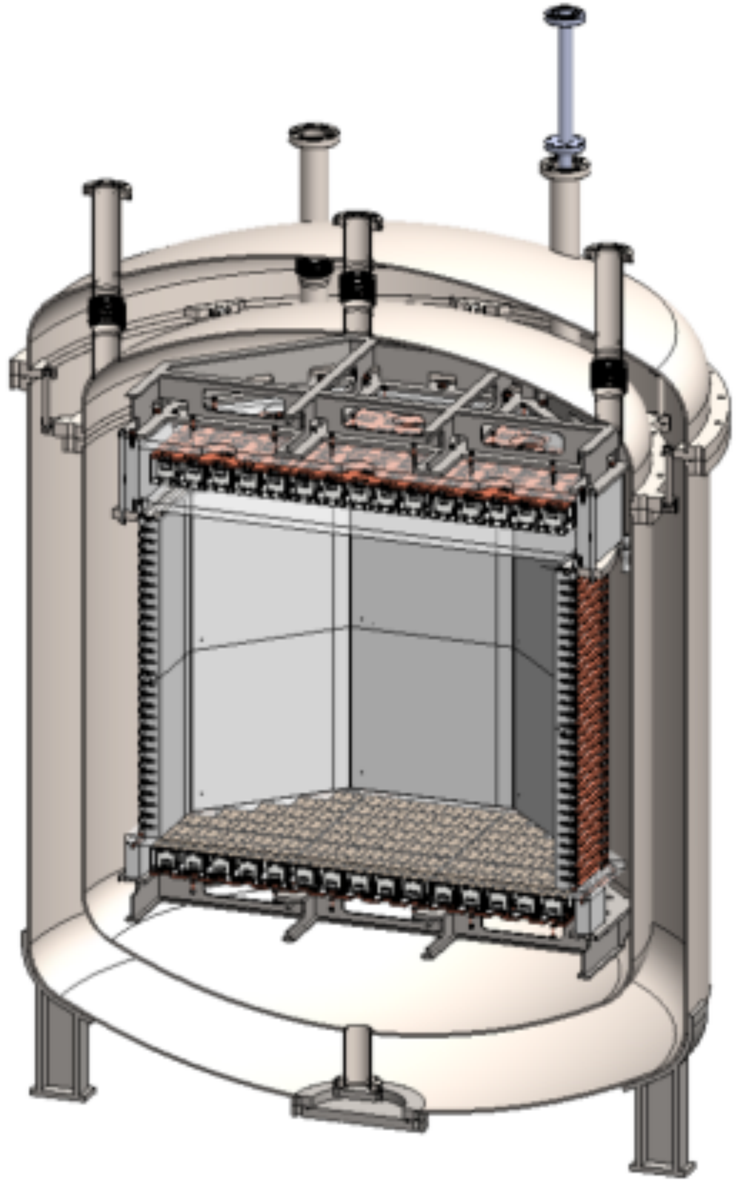
- Testing the full scale components intended for use in DarkSide-20k

➡ O(1m) linear dimensions to validate mechanics and SiPM photosensors

➡ ton scale to test full size DarkSide-20 cryo system

TPC assembly and integration test

- All the components of the prototype designed and built in the different institutions of the DarkSide Collaboration
- Is currently under construction, to be assembled and tested **at CERN starting 2018** and later at LNGS
  - ➡ will perform cryogenic tests and eventually more at Cern facilities until mid-2019 (agreement)
  - ➡ proposal to run the test underground at LNGS approved by the collaboration in June 2017

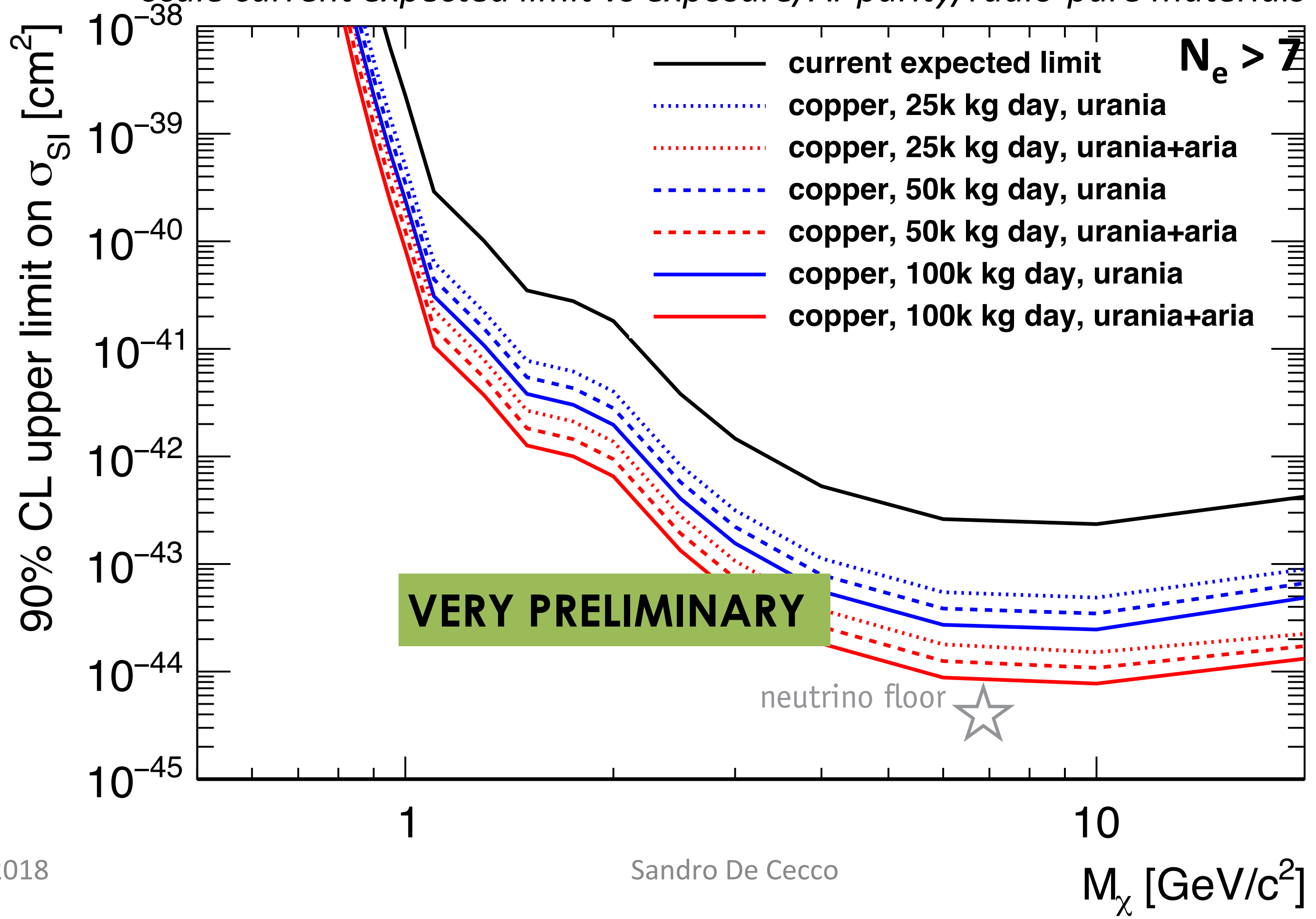


Very preliminary low mass limit projections

→ With intermediate size (~1ton) dedicated LAr TPC detector, before DS-20k operations :

- Underground Ar purification with URANIA (remove Kr) + isotopic ^{39}Ar distillation with ARIA
- low radioactivity SiPM and ultra radio pure criostat (copper or Titanium)
- to be run underground with passive and/or active veto system

scale current expected limit vs exposure/Ar purity/radio-pure materials :



Summary

- **Background free high mass WIMPs search mode** established with DarkSide-50 operations with underground Argon**:**
  - Starting **large exposure future experiments** with → 20t (→ 300t) DAr target to reach sensitivity at the atmospheric neutrino floor level for WIMP from O(10 GeV) to multi TeV masses
  - in the frame of ***GLADMC*** Global Liquid Argon Dark Matter Collaboration (INFN, NSF, Canada …) merging all the existing LAr collaborations (DEAP3600, ArDM, DarkSide)
  - At the 2020 horizon ***DarkSide-20k*** and ***DS-proto*** (2018) already under advanced design, R&D and construction. External calibration ***ReD*** experiment also planned.
- **New Ionization based low mass DM search** mode, with DarkSide-50 LAr TPC, results in **world leading exclusion limit** in few GeV's WIMPs mass range.
  - This opens the way to medium term future dedicated LAr TPC optimized for S2 only analysis, **potential to reach the solar neutrino floor level** with only an order of magnitude higher exposure.
- **DARKSIDE experimental program**: is very rich, diversified and exciting with many opportunities for new ideas to develop both for detector physics and dark matter analysis results from now on, and through the next decade.