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Dark matter searches with the DarkSide experiment

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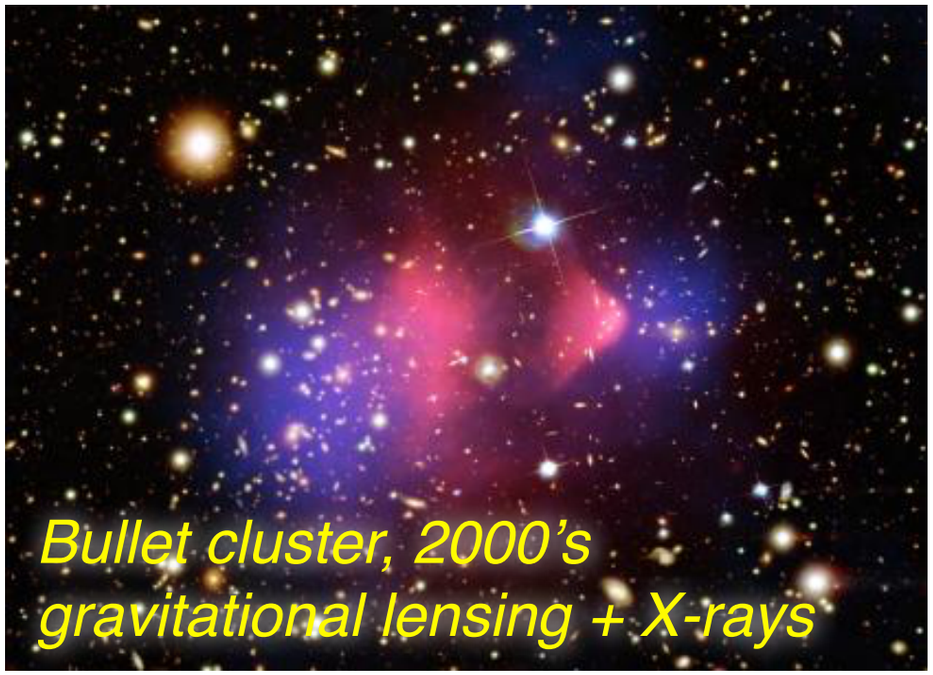
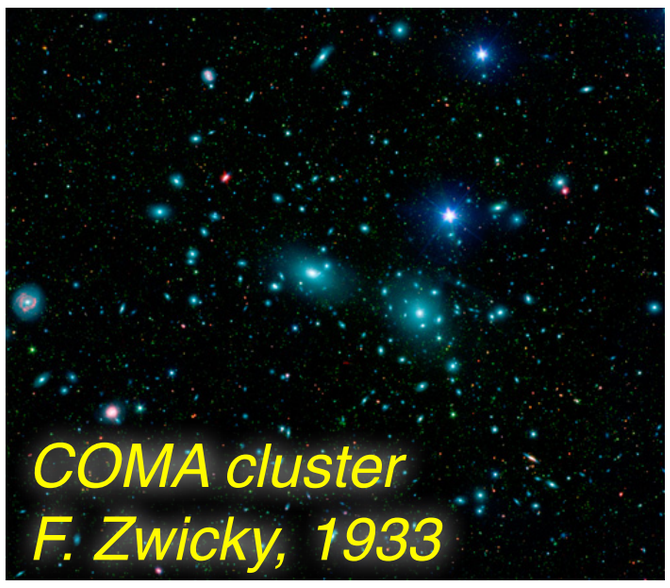
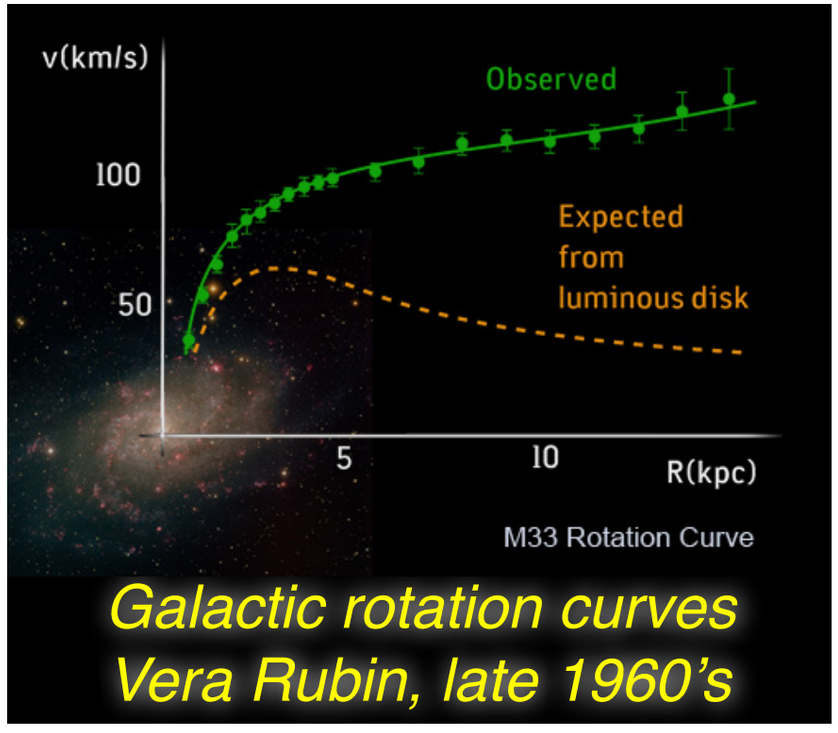
Physics at the interface: Energy, Intensity, and Cosmic frontiers
University of Massachusetts Amherst

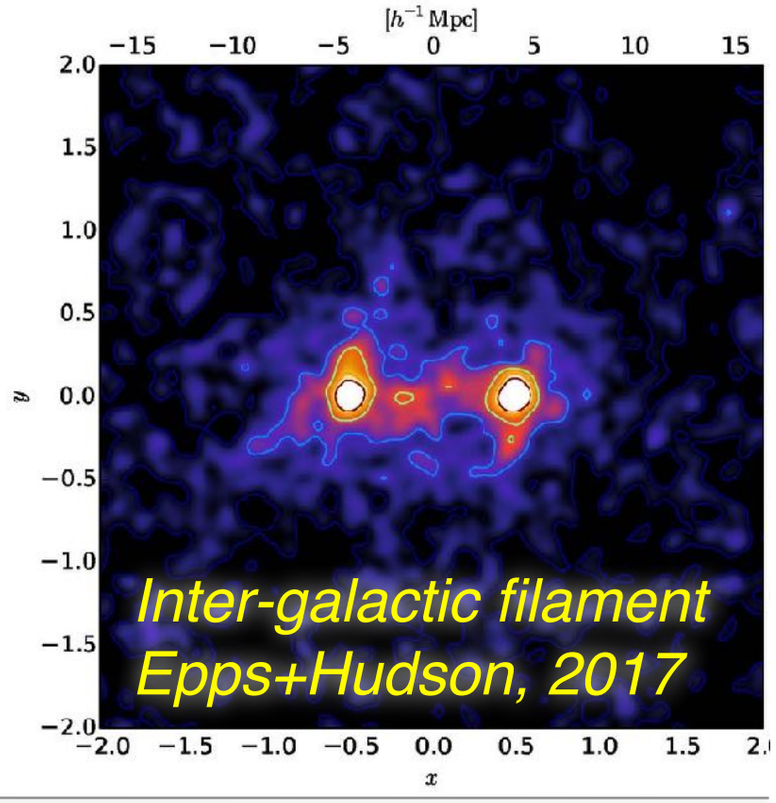
Outline — evidence for dark matter



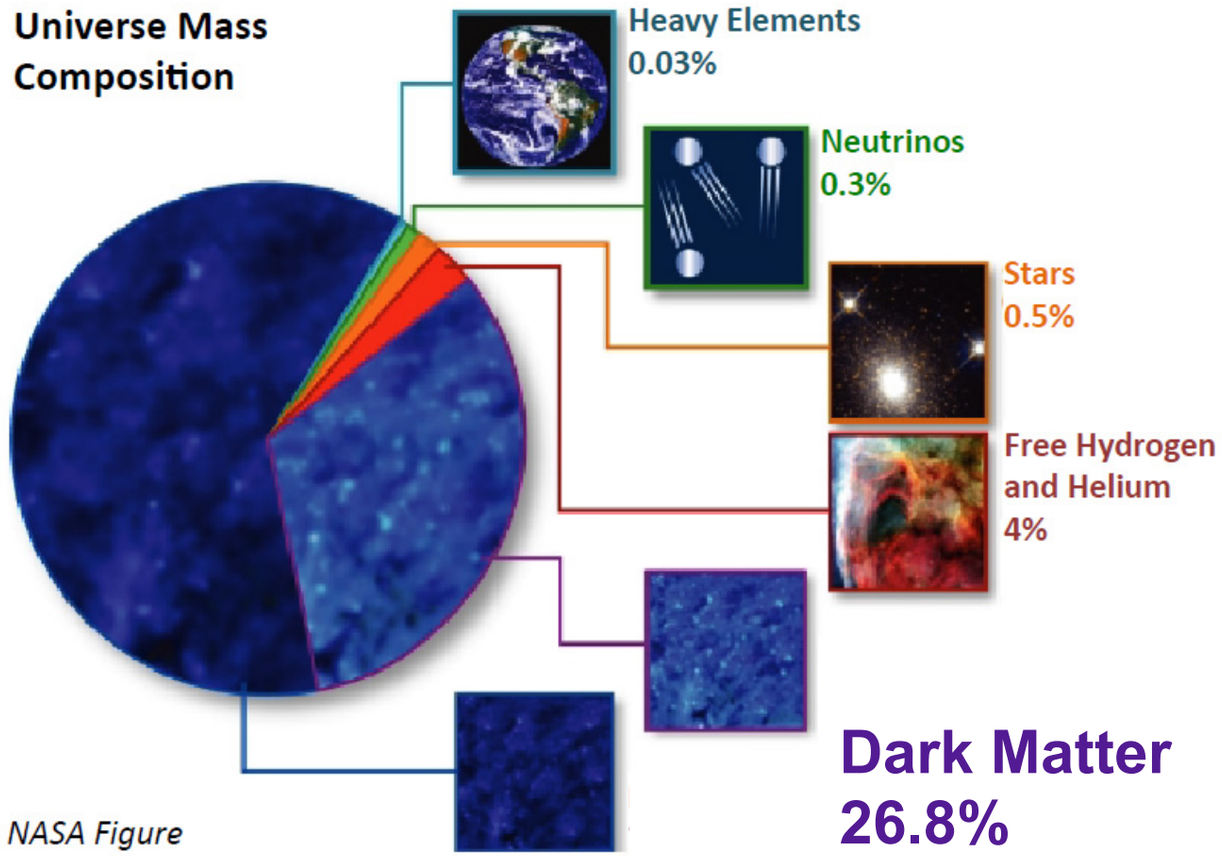
- *Evidence for dark matter*
- *Dark matter detection in liquid argon*
- *The DarkSide program*
  - *DS-50 results*
  - *DS-20 program*
  - *ARGO*
- *Outlook*

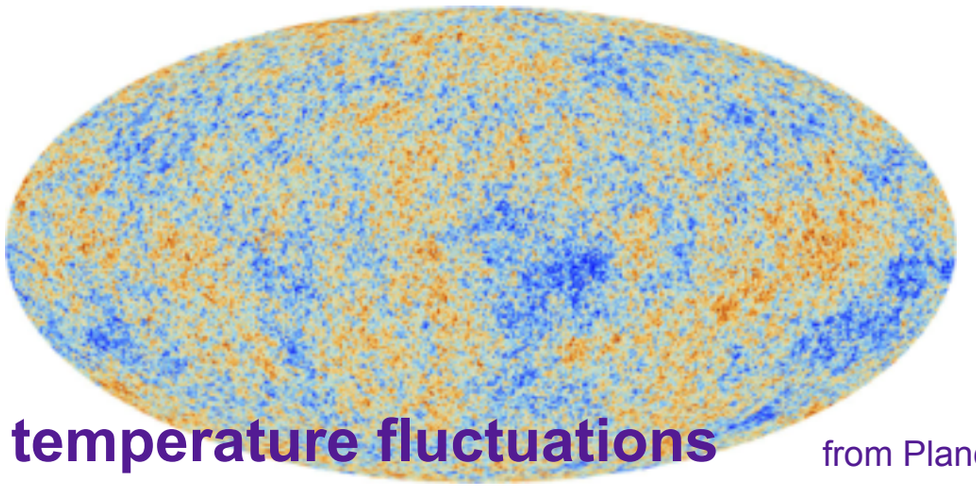






the Big Questions



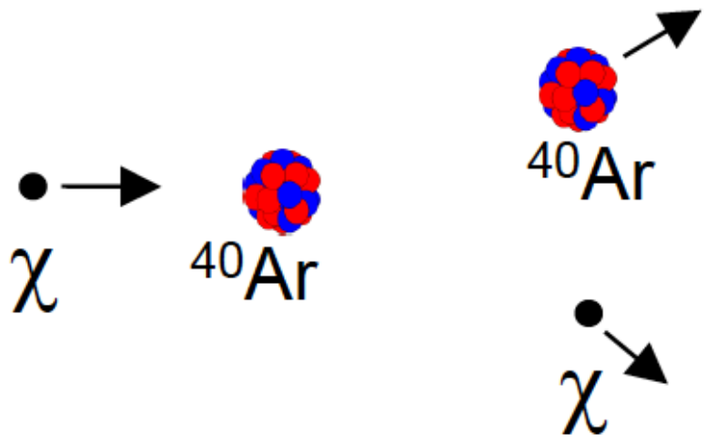


CMB temperature fluctuations from Planck

- *95% of the mass/energy density of the Universe is of as yet unknown composition*
- *what is Dark Energy? (accelerating expansion)*
- *what is Dark Matter?*
- *why is matter so abundant?*
- *why is gravity so weak? (hierarchy problem)*
- *what does the SM have so many free parameters?*

Dark matter detection with noble liquid detectors

- *Large, noble-liquid TPC's are excellent dark matter detectors*
- *Search for WIMP-nucleus coherent scattering*



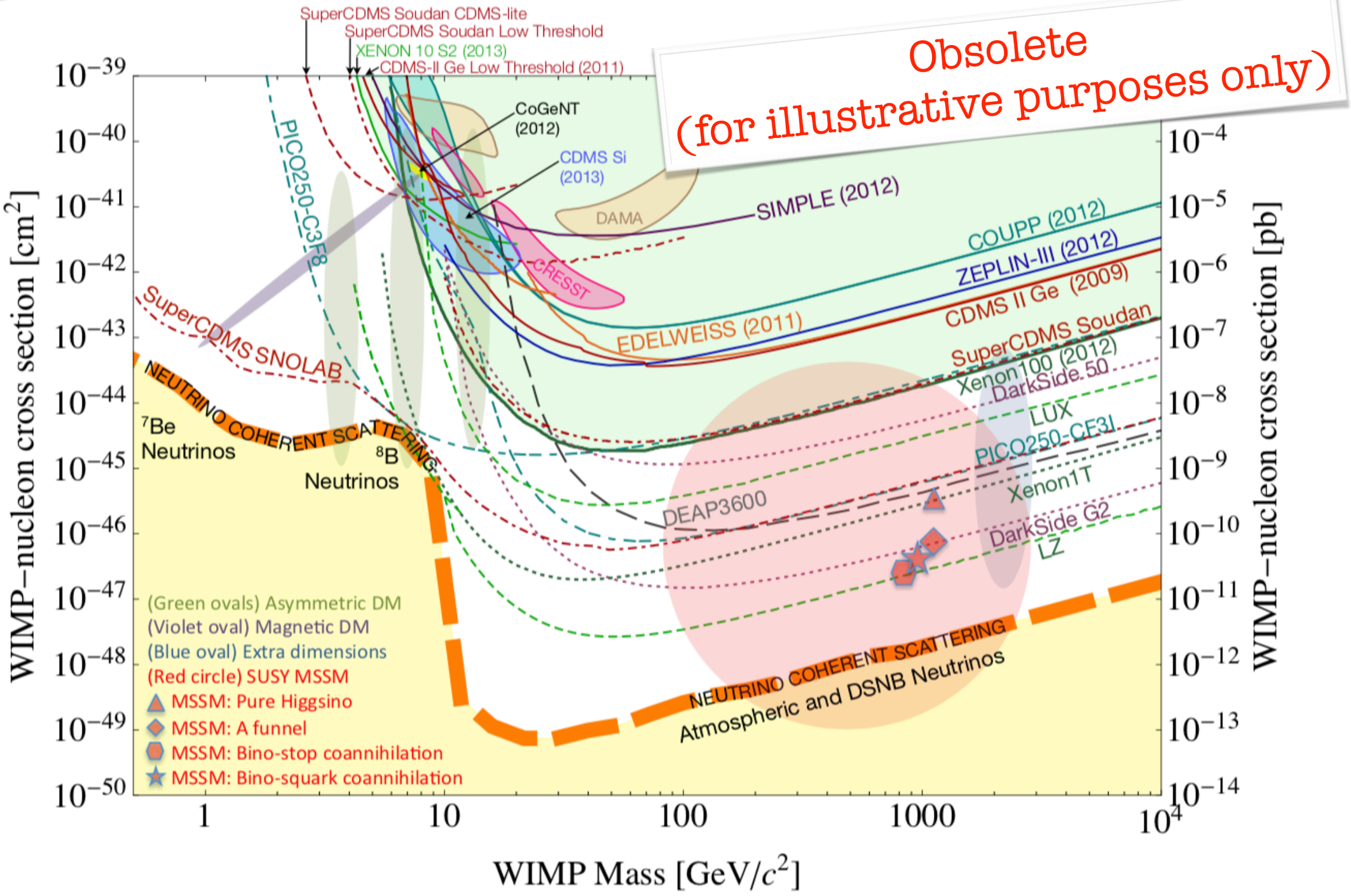
- *Scattered nucleus (10's of keV) is detected in liquid argon*

- *Dual-phase TPC enhances sensitivity to very low energy events, at the keV scale and below (x-y position obtained from electroluminescence signal)*
- *Discrimination between nuclear and electron scattering events is a key feature of LAr*
- *Xenon TPC's currently leading the field for WIMPs >10 GeV/c^2 (LUX, PandaX-II, XENON1T —> LZ, PandaX-IV, XENONnT)*

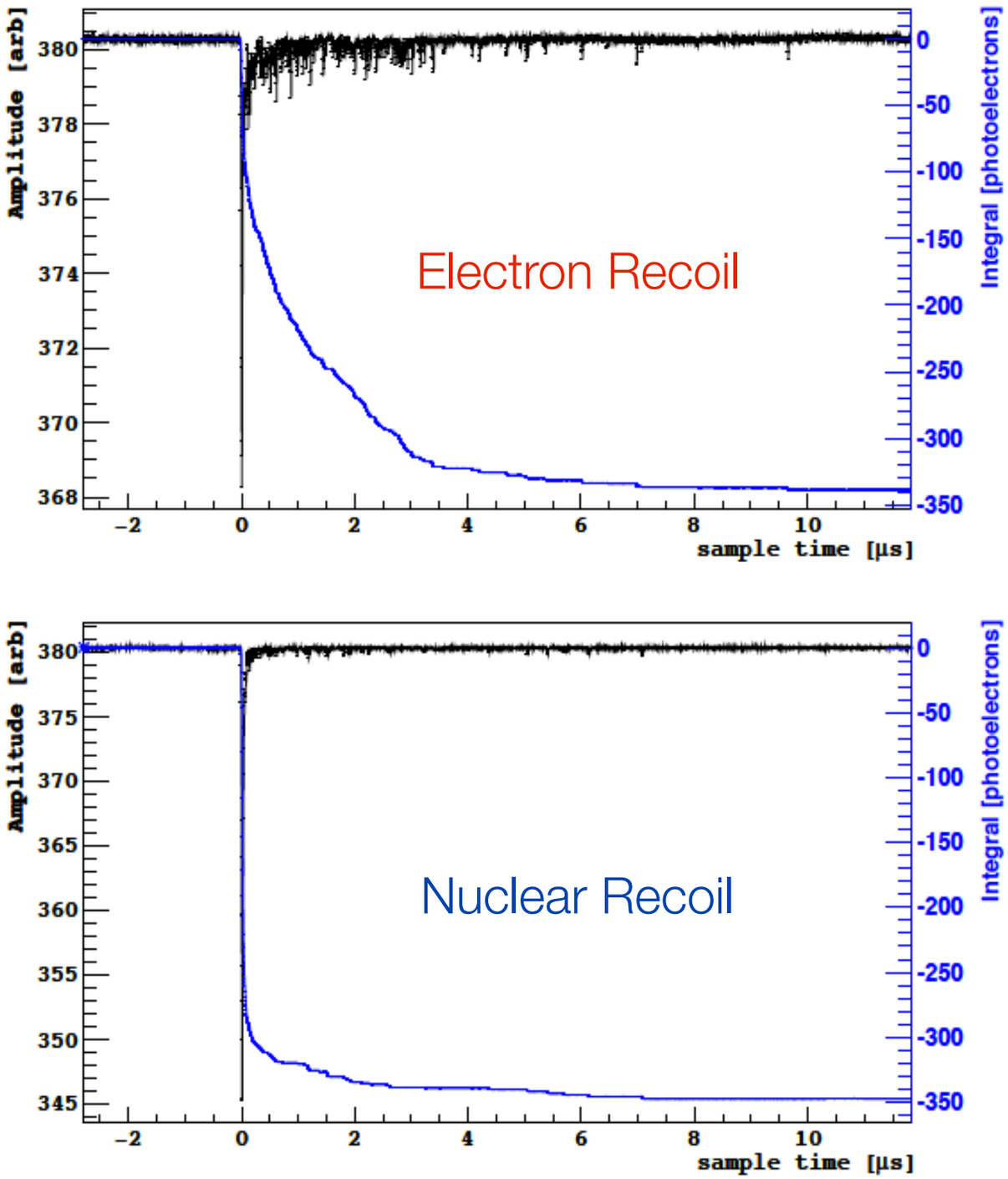
Comparing WIMP detection sensitivity

arXiv:1310.8327v2

2013 Snowmass Summary



Pulse Shape Discrimination in LAr



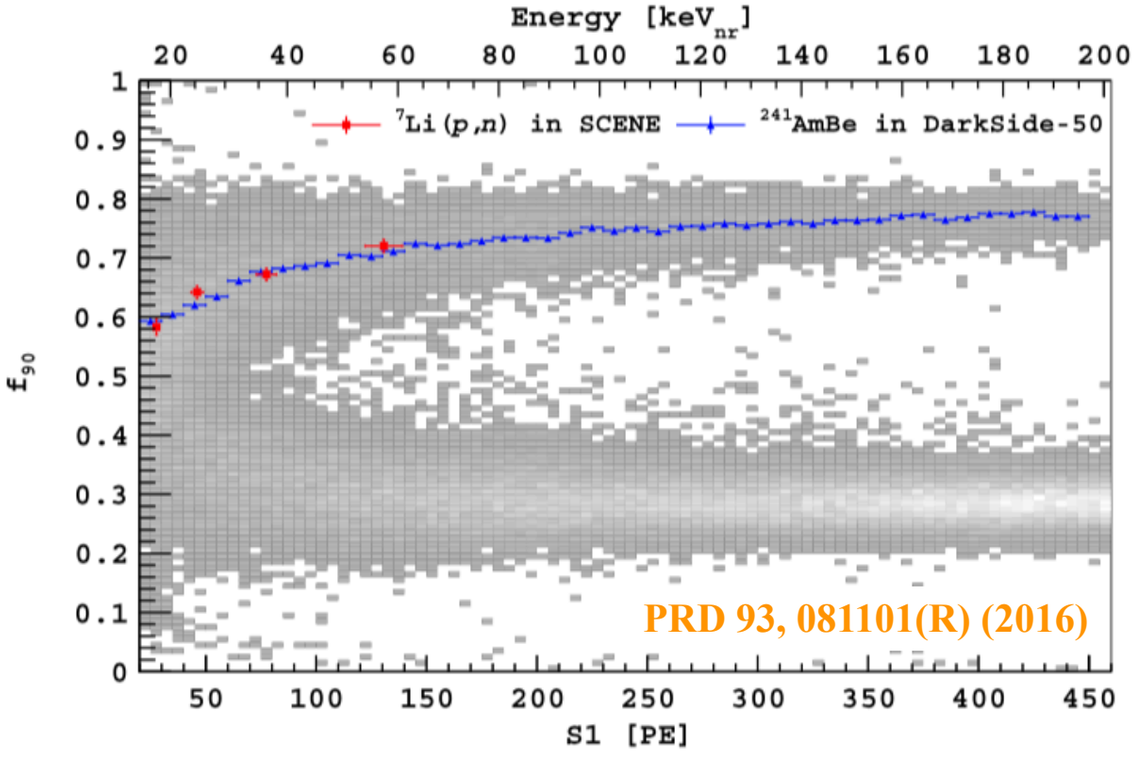
τ singlet ~ 7 ns

τ triplet ~ 1500 ns

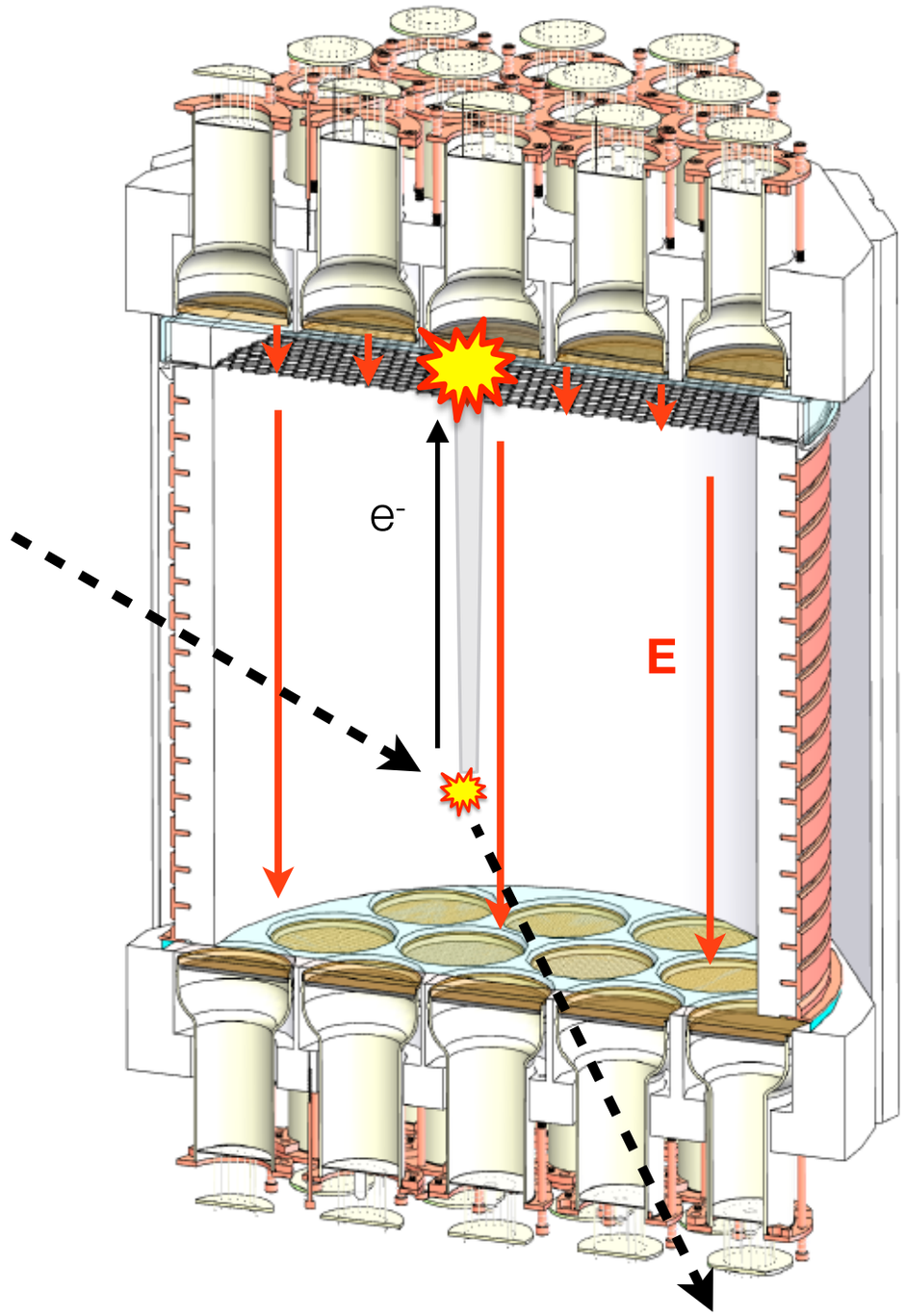
PSD parameter, F90

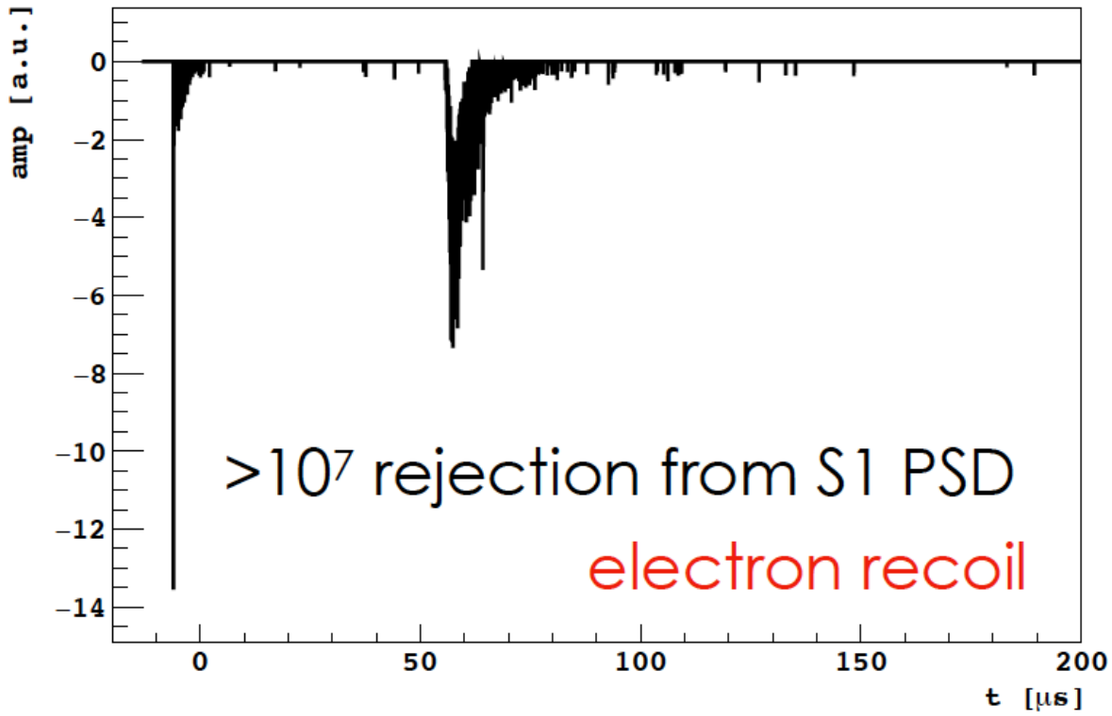
Fraction of total light detected in the first 90 ns of the pulse

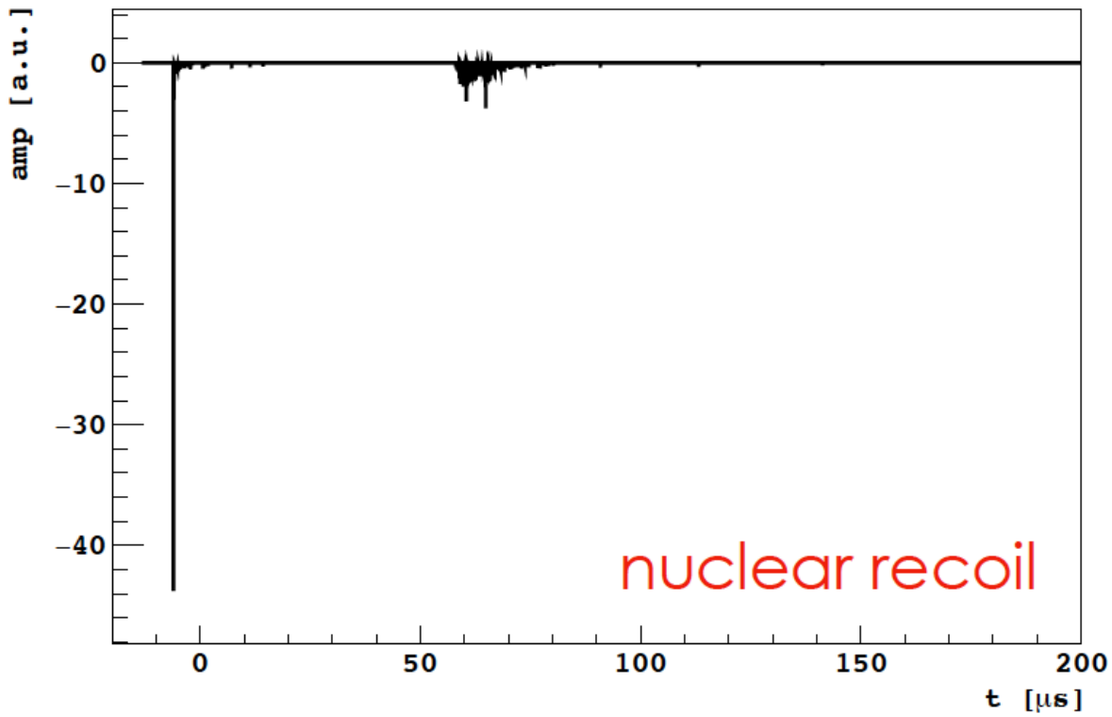
(Fraction of singlet state excited dimers)



Dual Phase Argon TPC







The DarkSide program and the GADMC

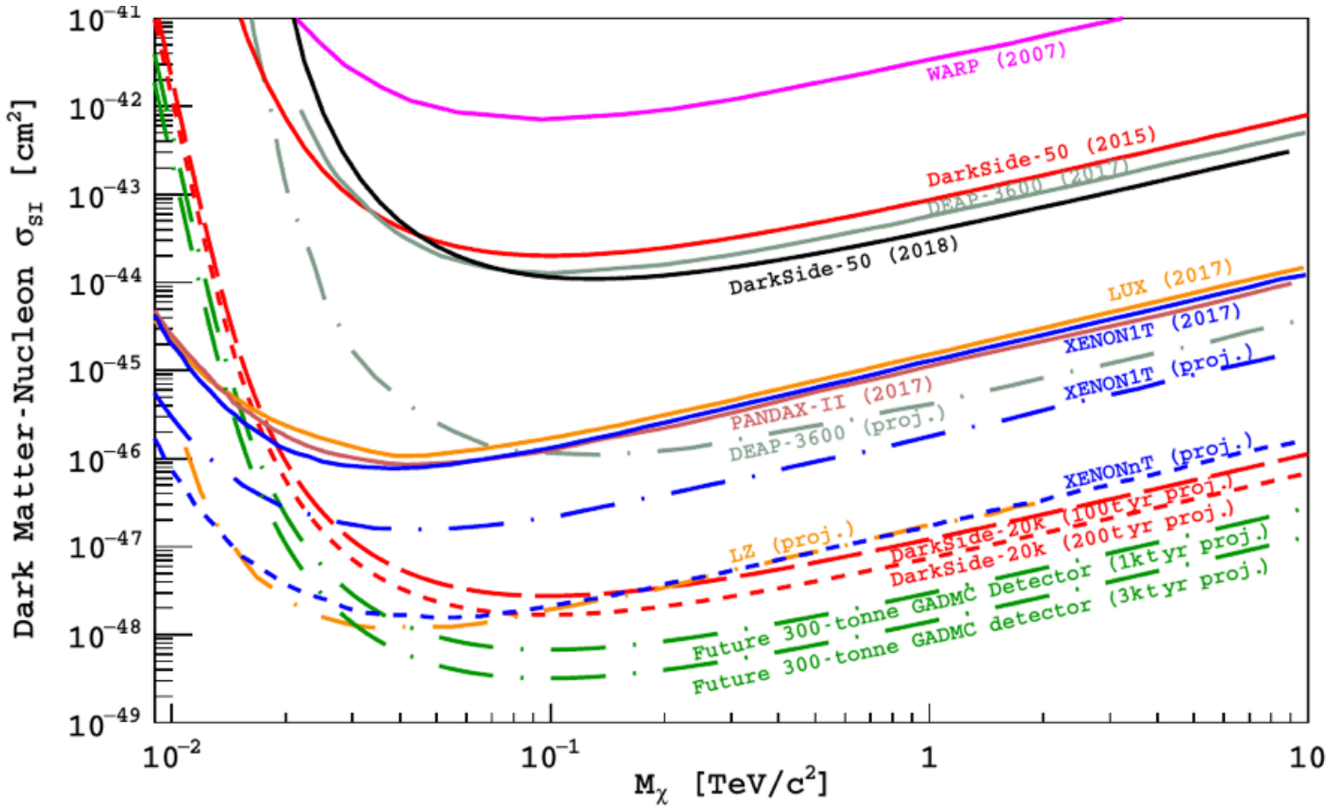
see Damian Goeldi's DEAP-3600 talk on Thursday

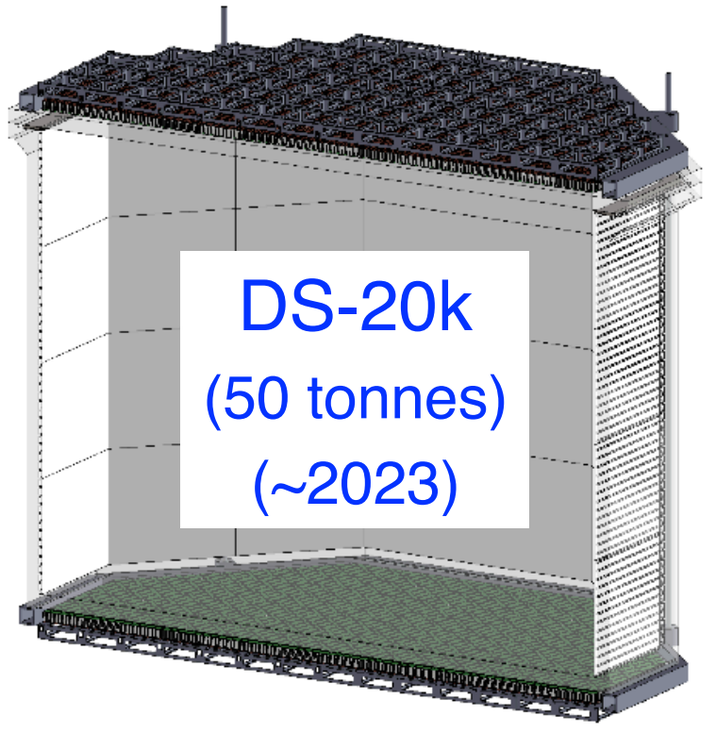
DarkSide-50 (running)

DEAP-3600 (running)

ArDM

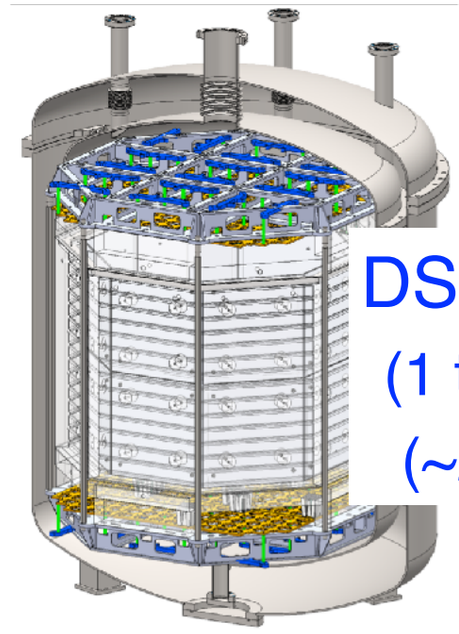
miniCLEAN





DS-20k
(50 tonnes)
(~2023)

ARGO
(300-400 tonnes)
(~2023)



DS-Proto
(1 tonne)
(~2021)

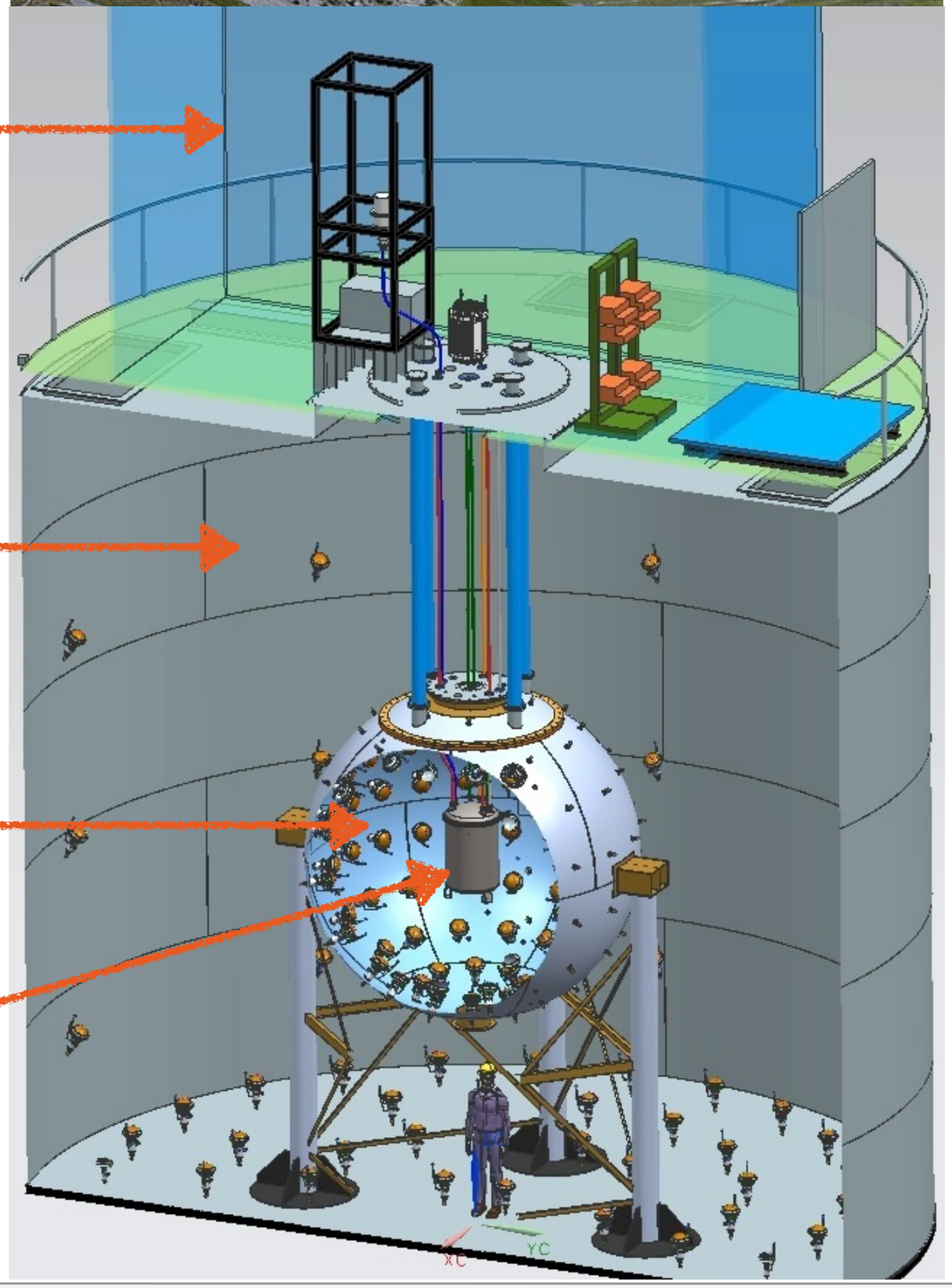
DarkSide 50 at LNGS

Radon-free **Clean Room**
(Rn levels < 10 mBq/m^3)

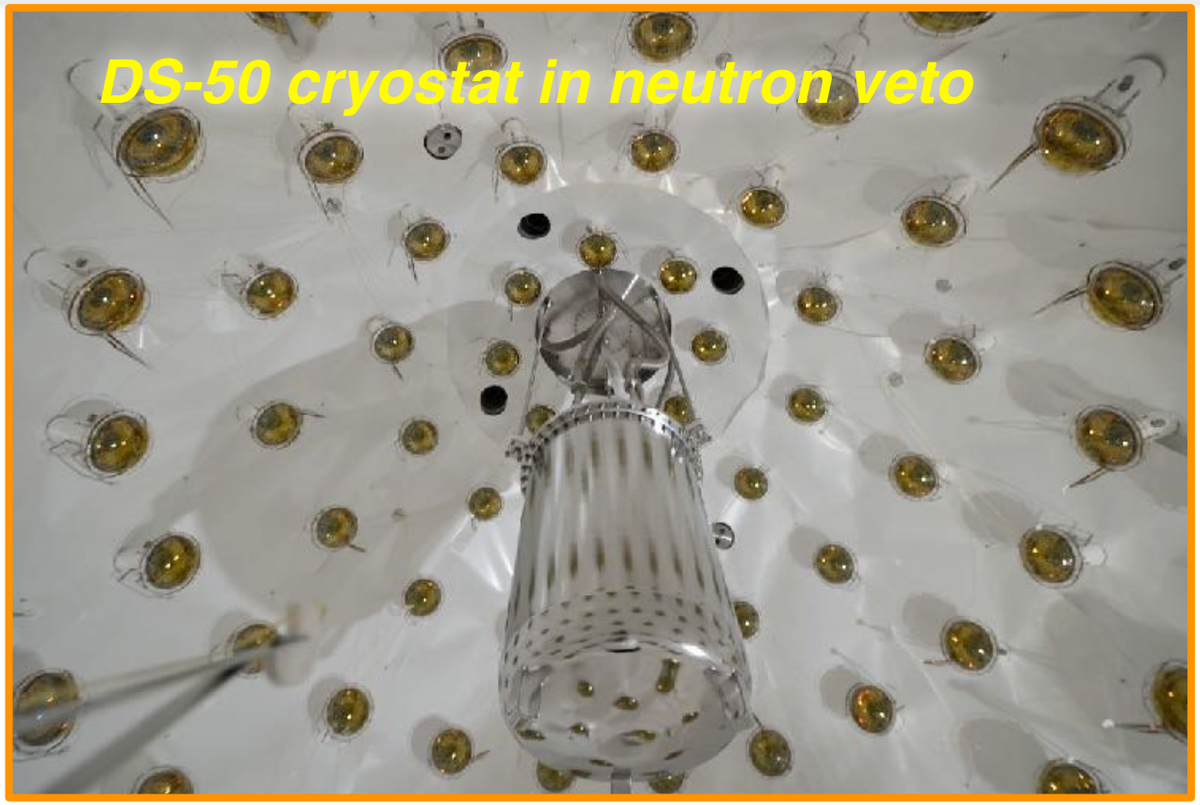
1,000-tonne Water-based Cherenkov
Cosmic Ray Veto

30-tonne Liquid Scintillator
Neutron and γ's Veto

Inner detector **TPC**
(filled with low-^{39}Ar argon)

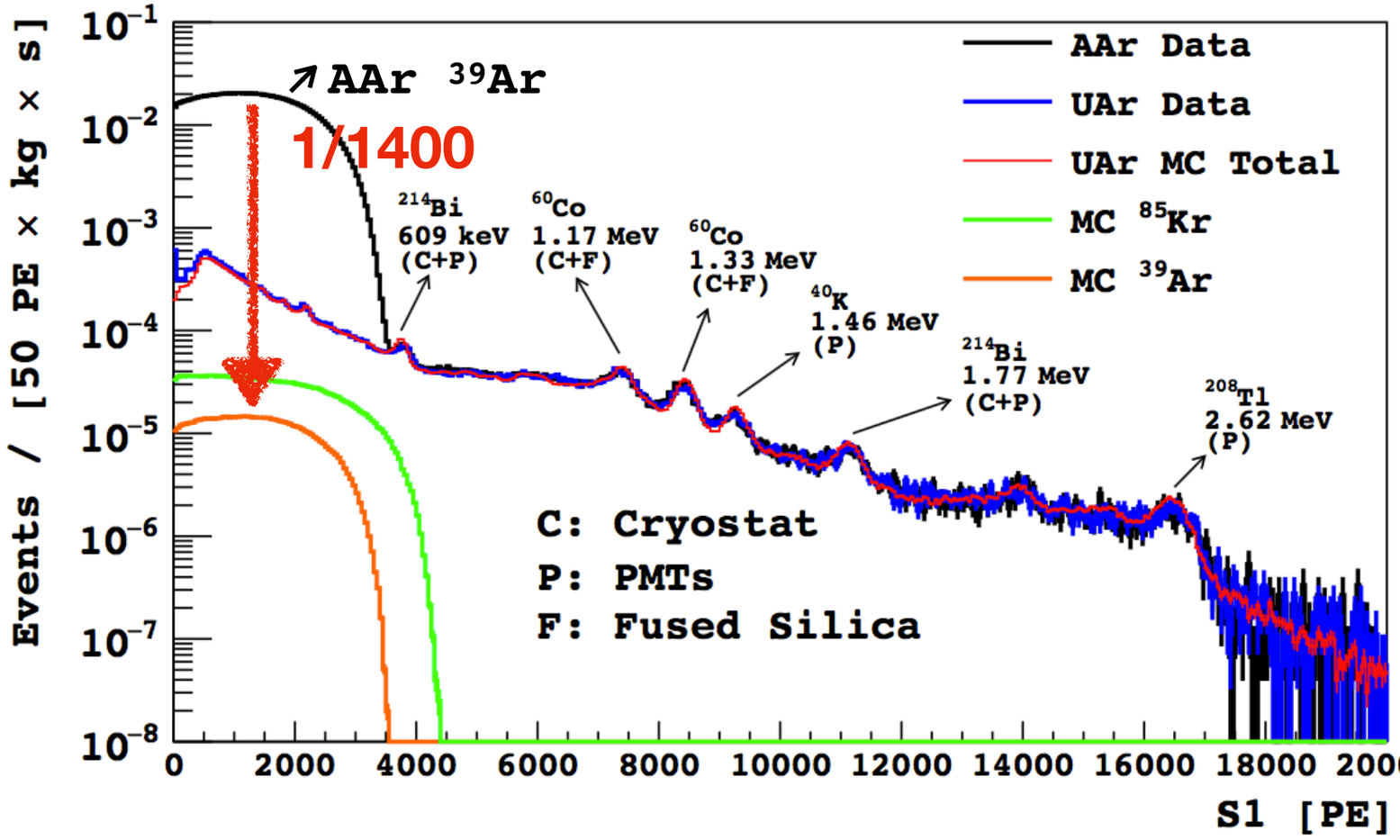


DS-50 detector



Low radioactivity Ar from underground sources

- ^{40}Ar(n,2n)^{39}Ar occurs in the atmosphere
- ^{40}Ar accumulates underground as the result of ^{40}K decays
- DS-50 UAr fill measured the ^{39}Ar reduction factor: >10^{3}



S1 spectrum at zero E-field

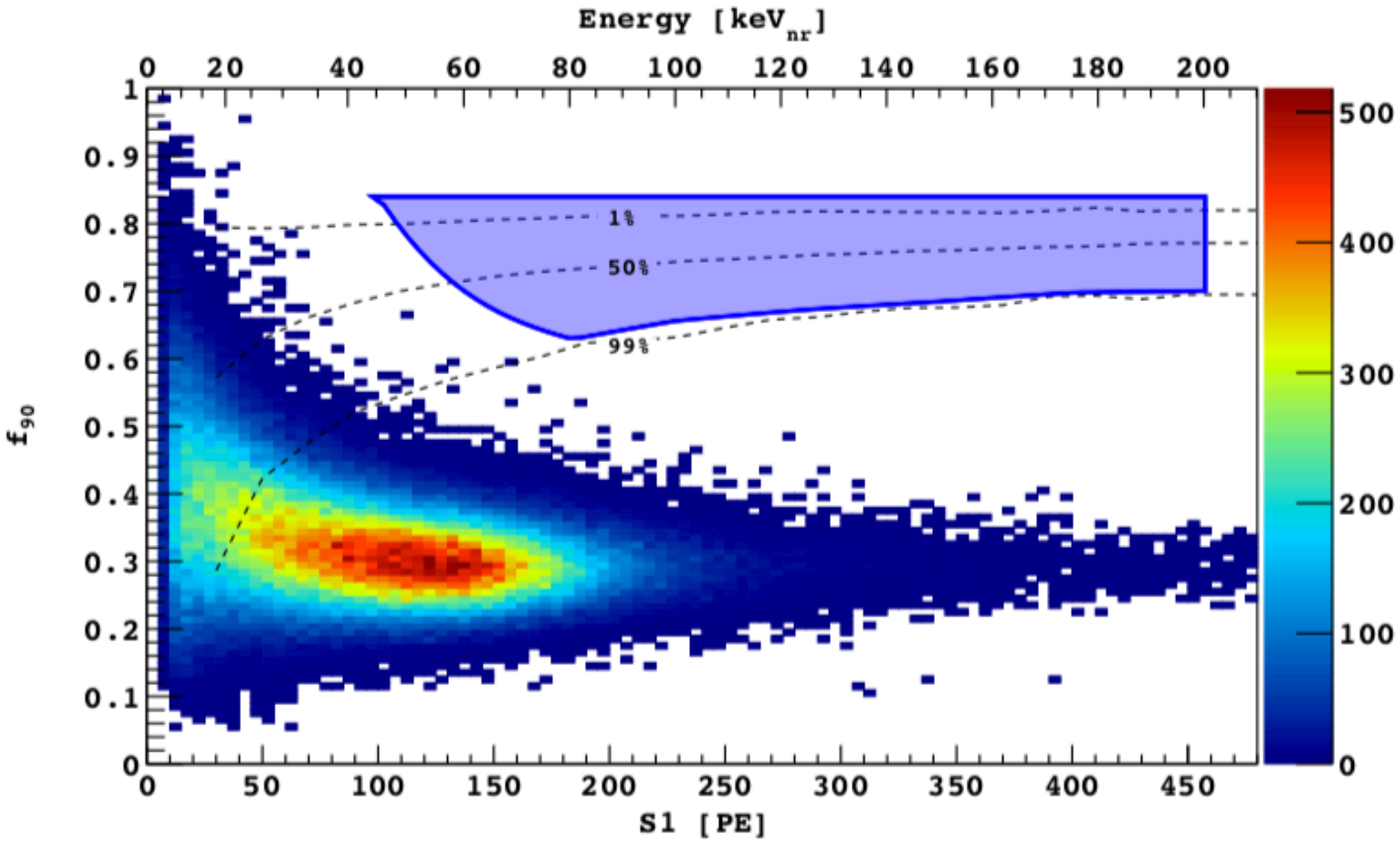
high light yield: ~8 p.e./keV$_{ee}$

(key for PSD)

Enables a background-free WIMP search at the few 10-tonne scale

Higher mass (>10 GeV) WIMP search

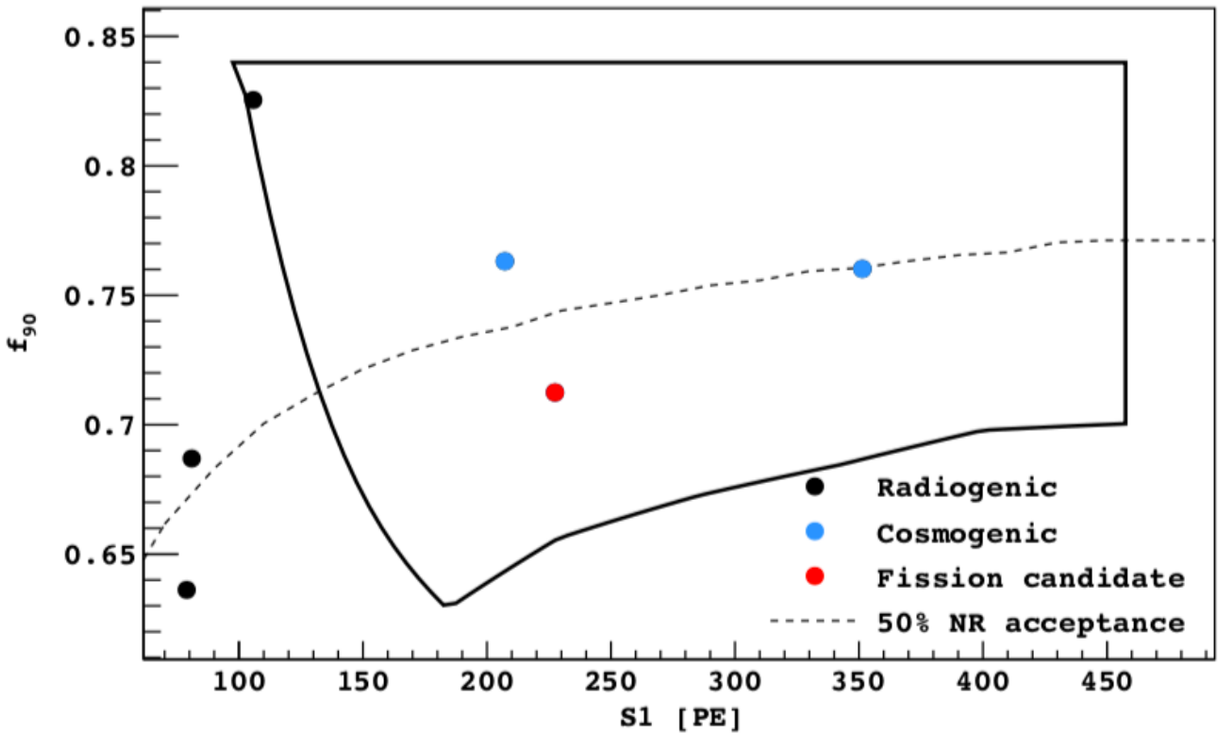
PHYSICAL REVIEW D 98 102006 (2018)
arXiv:1802.07198



no x-y cuts

Higher mass (>10 GeV) WIMP search: neutrons

PRD 98 102006 (2018)
arXiv:1802.07198

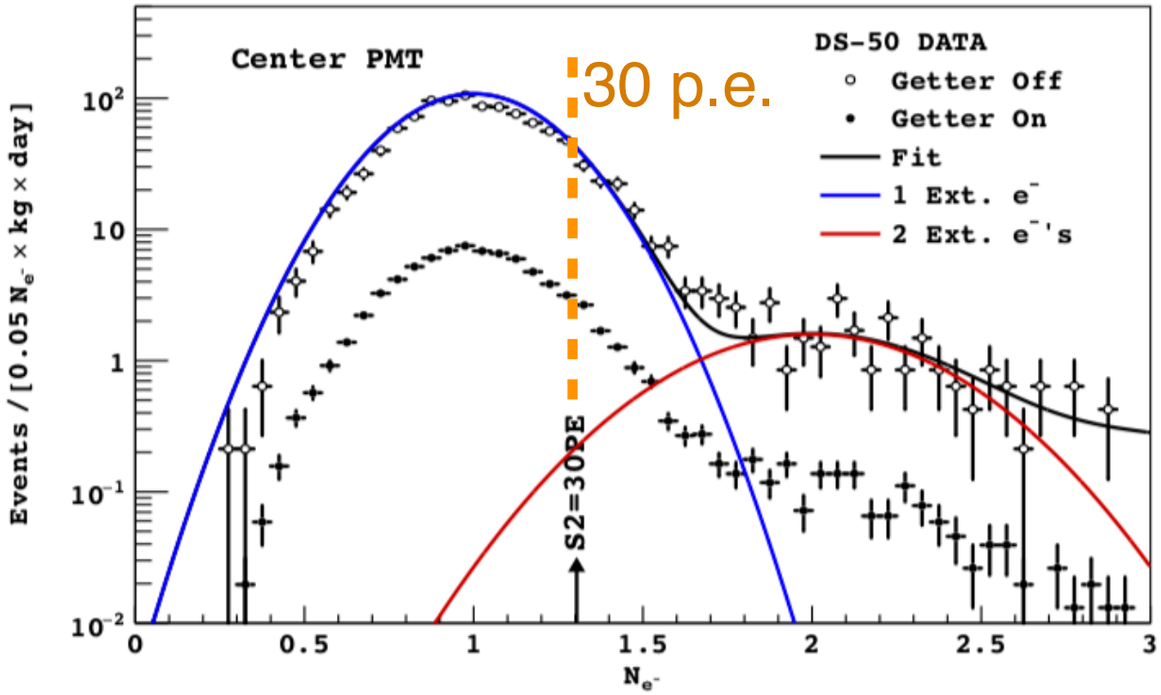


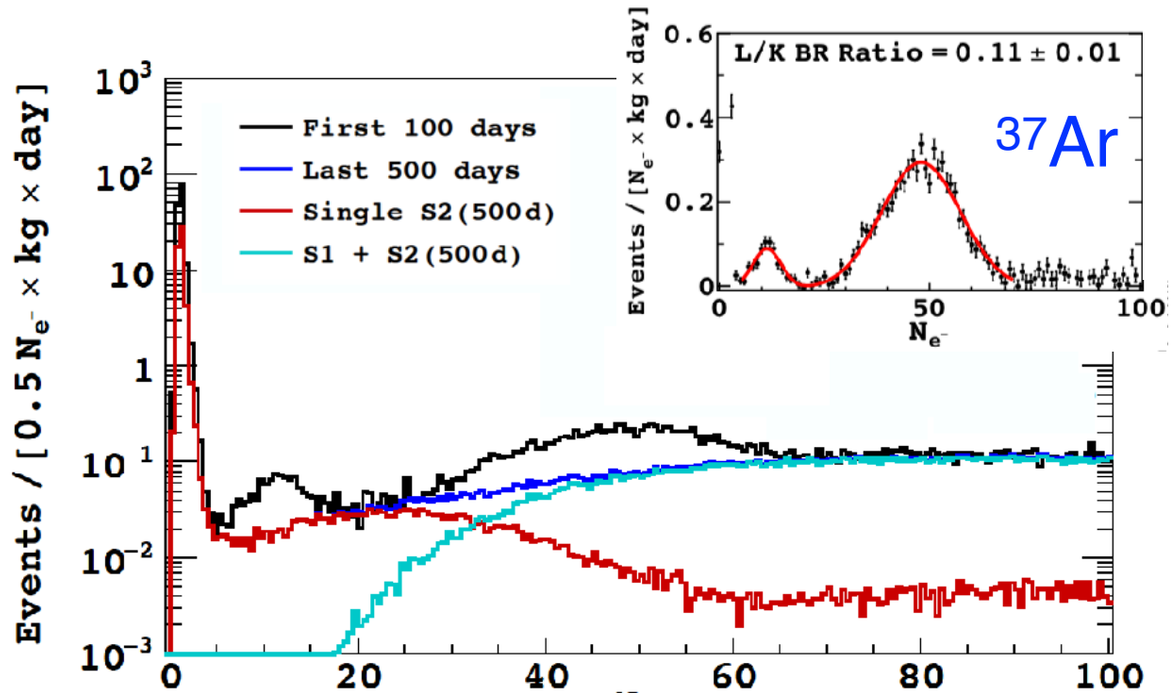
- events tagged by neutron veto
- opened to allow background prediction (with measured veto efficiencies)

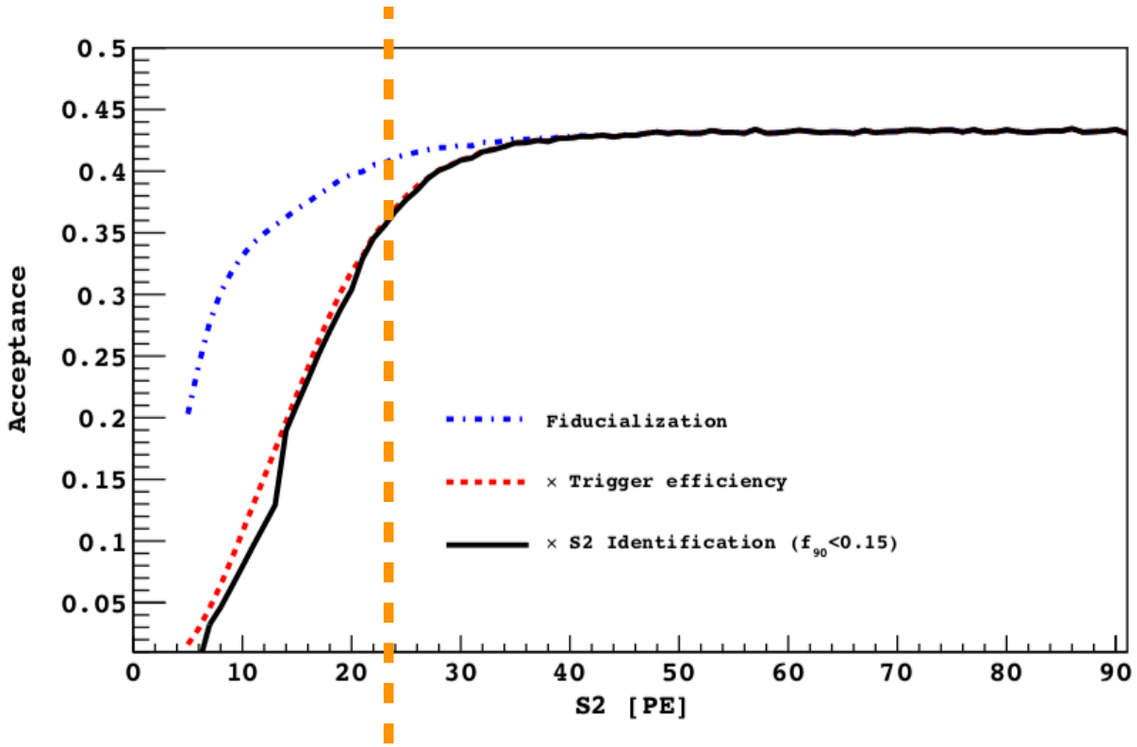
surface	0.0015 ± 0.0001
radiogenic neutrons	<0.005
cosmogenic neutrons	<0.00035
electron recoil	0.08 ± 0.04
total	0.09 ± 0.04

S2-only analysis with DS-50

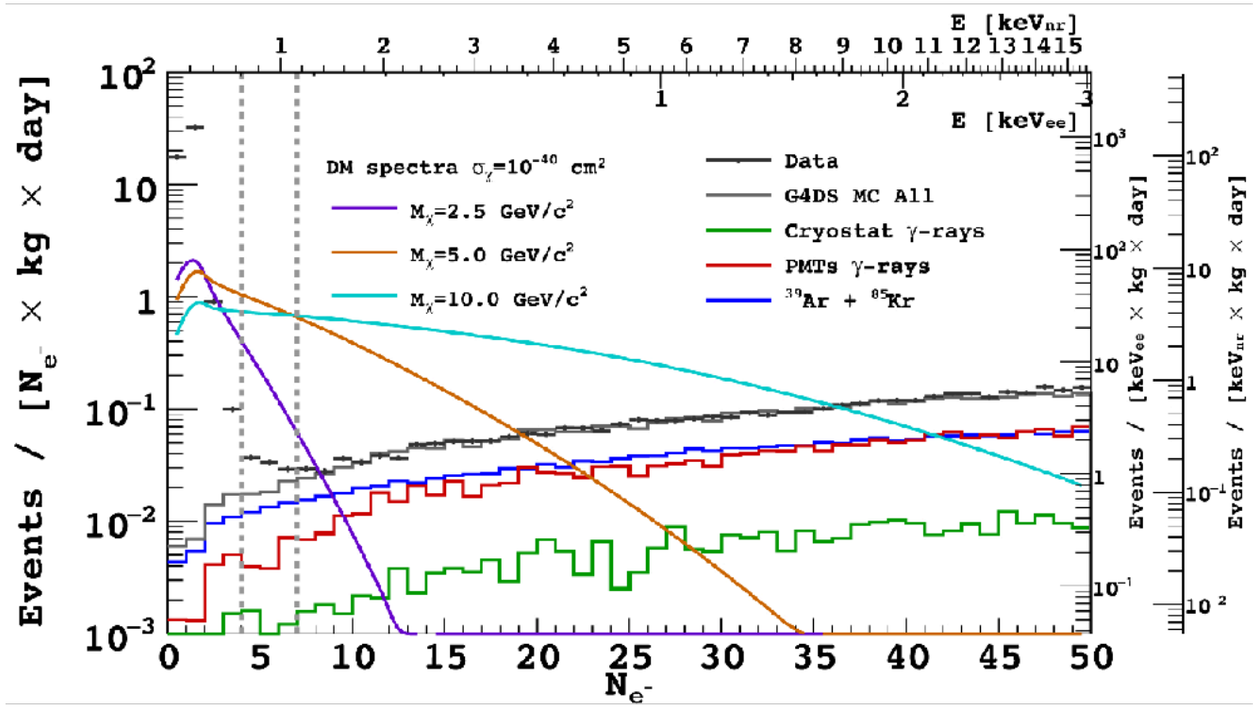
PRL121, 081307 (2018)
arXiv:1802.06994







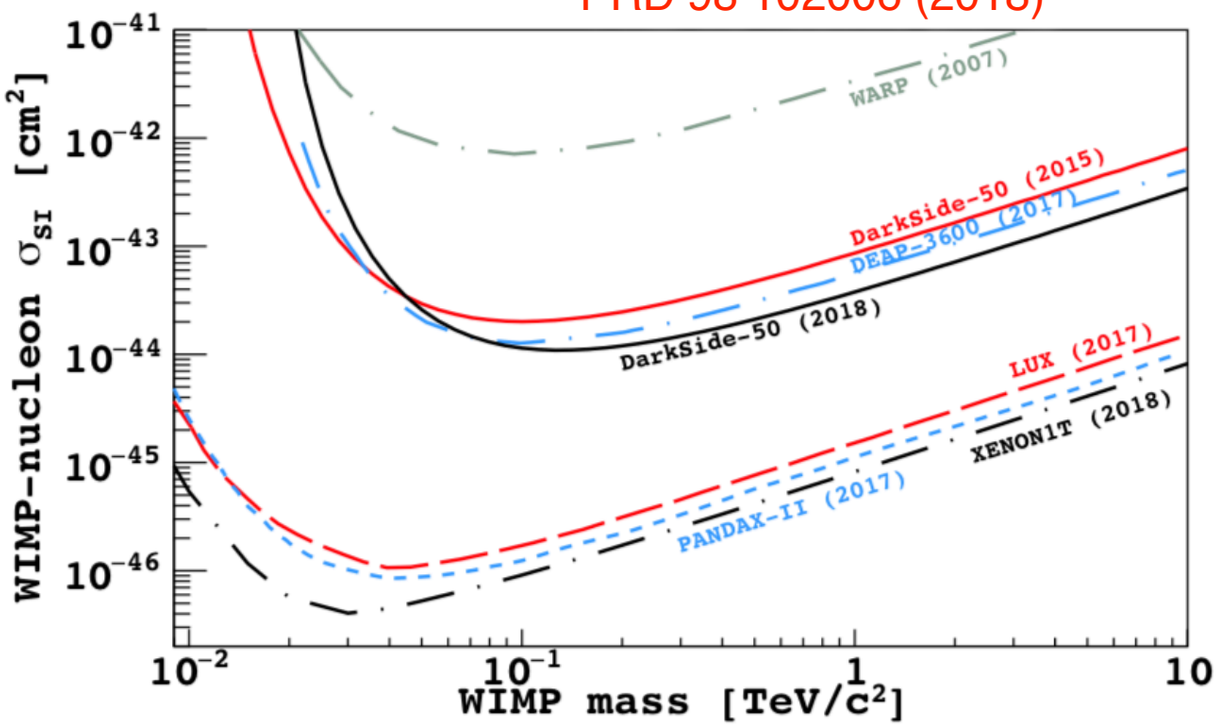
single electron



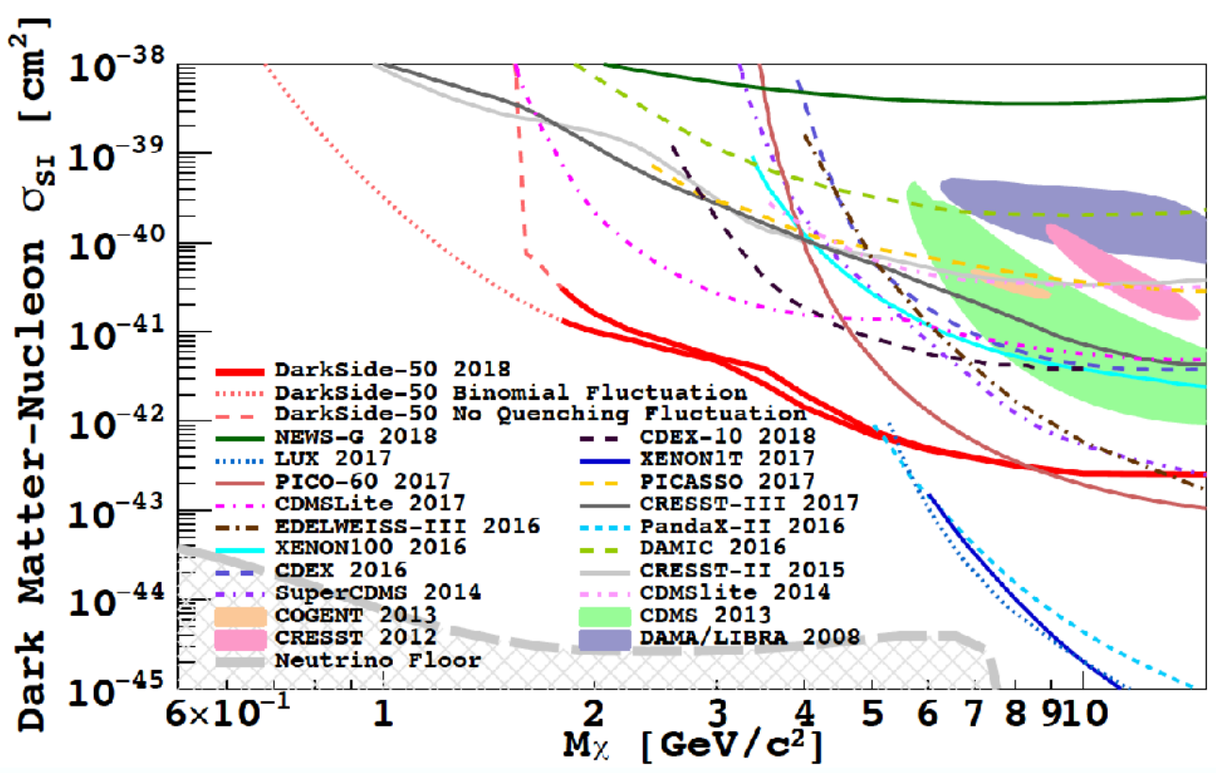
DS-50 WIMP search results

- Heavy WIMP search since 2013
  - zero background
  - cryogenics and HV very stable
  - AAr (1422 kg-d)
  - UAr 19276 kg-d)
  - LY (null field) ~ 8 pe/keV$_{ee}$

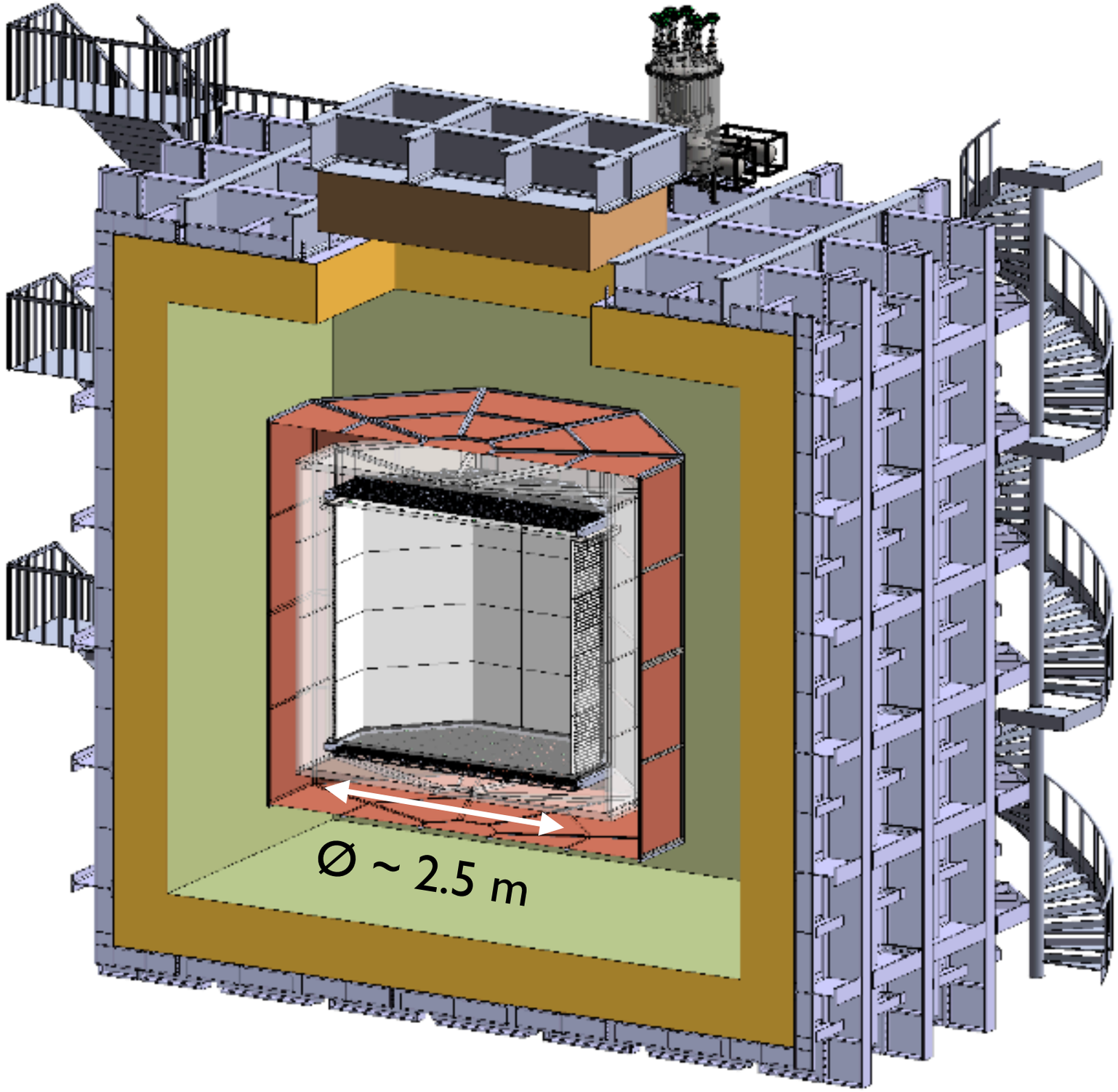
PRD 98 102006 (2018)



- Ionization-only signal allows sensitive searches for low mass WIMPs
  - Two cases: no quenching fluctuations and binomially distributed fluctuations
  - background measured at higher energy is extrapolated to low energy



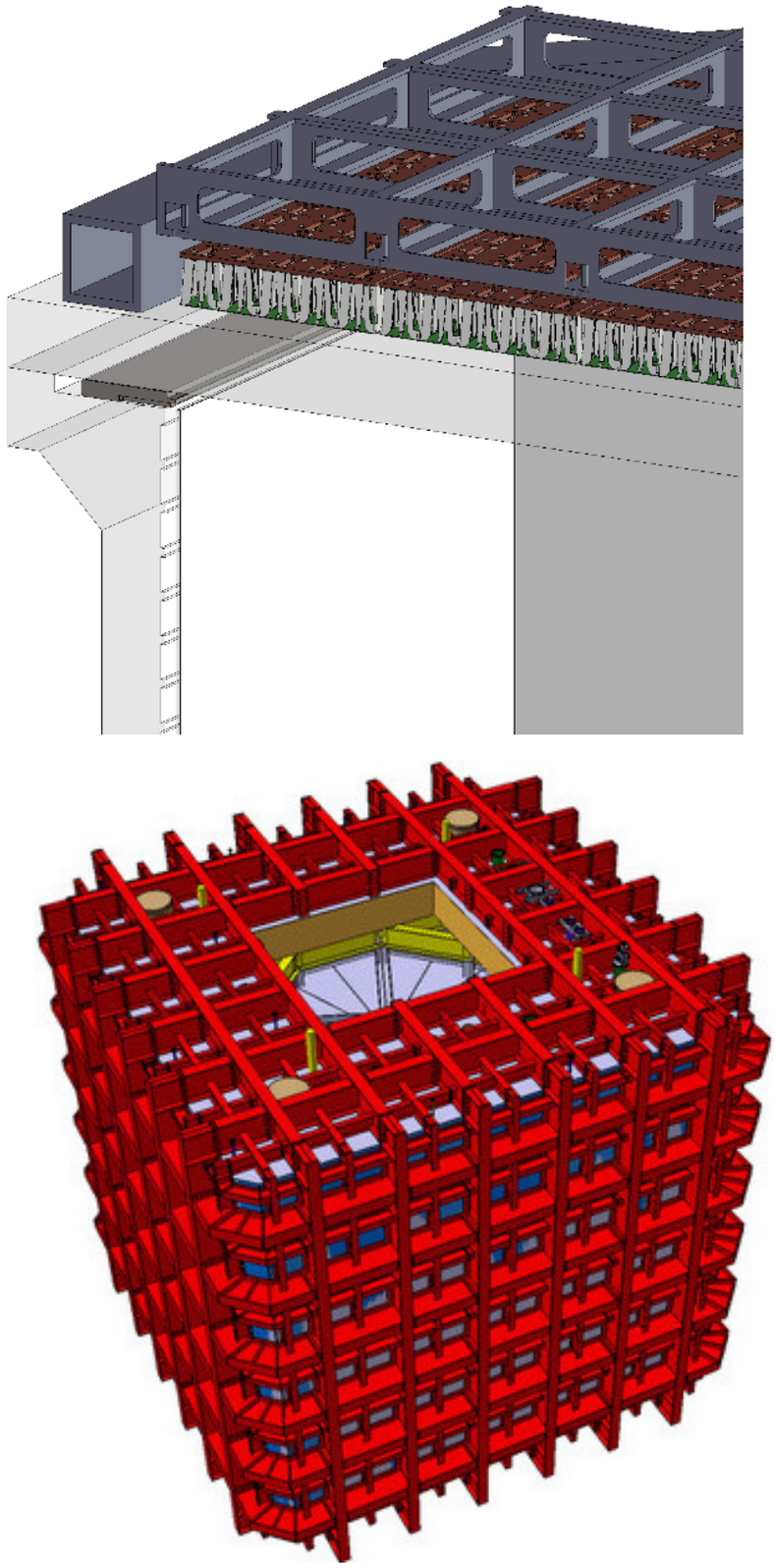
Beyond DS-50: DS-20k



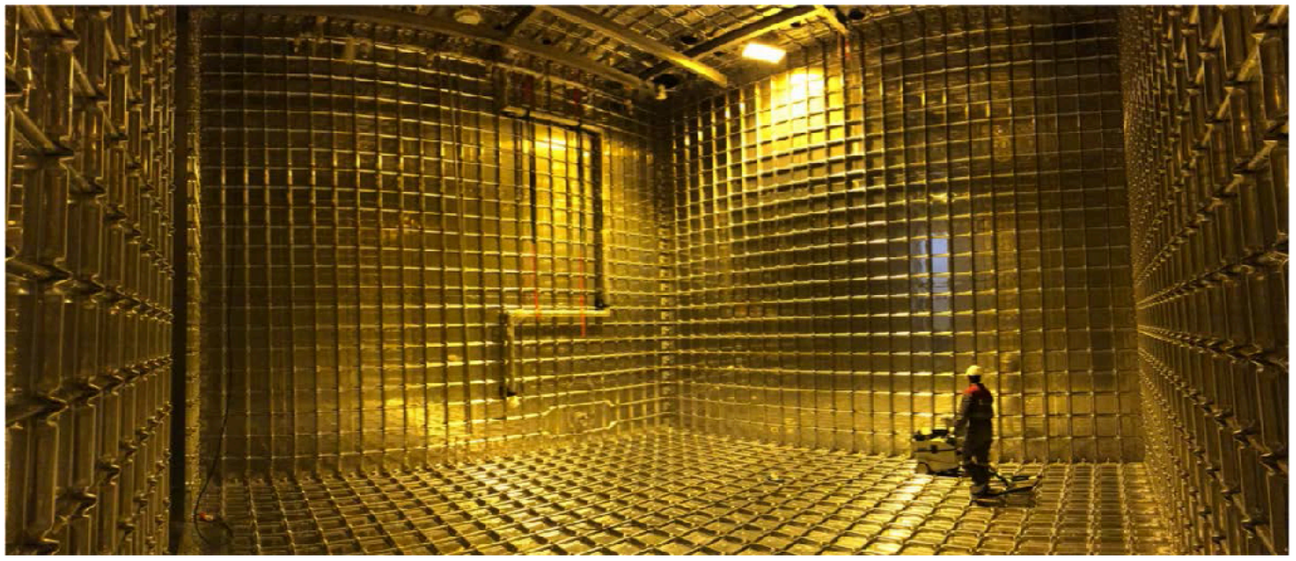
DarkSide-20k at Gran Sasso

- 50-tonne LAr dual-phase TPC in sealed PMMA (acrylic) vessel
- 30 tonnes fiducial
- 20 m^2 of SiPM scintillation detecting surface
- background-free: <0.1 ‘instrumental’ background event in 100 tonne-year exposure
- AAr veto in protoDUNE-style membrane cryostat

Cryostat and PMMA vessel

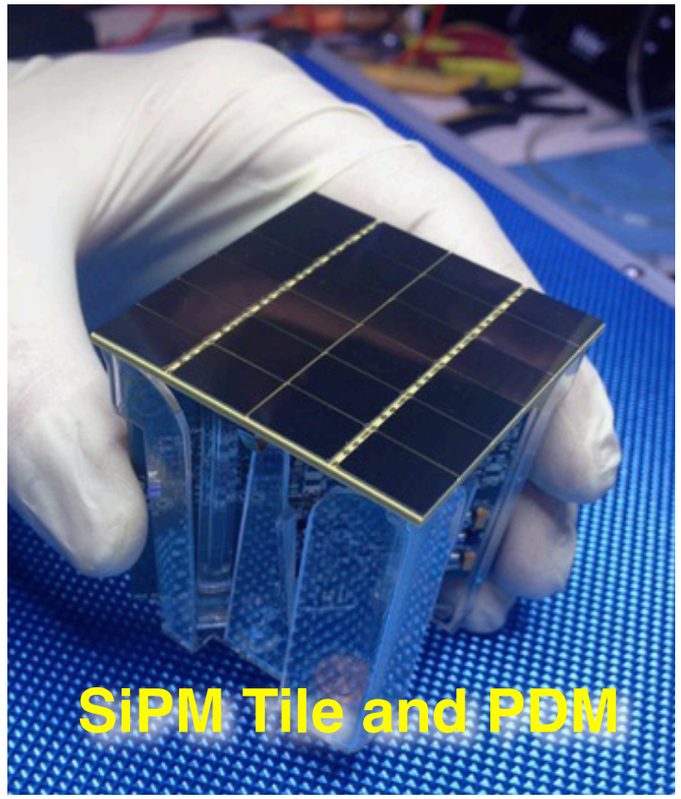


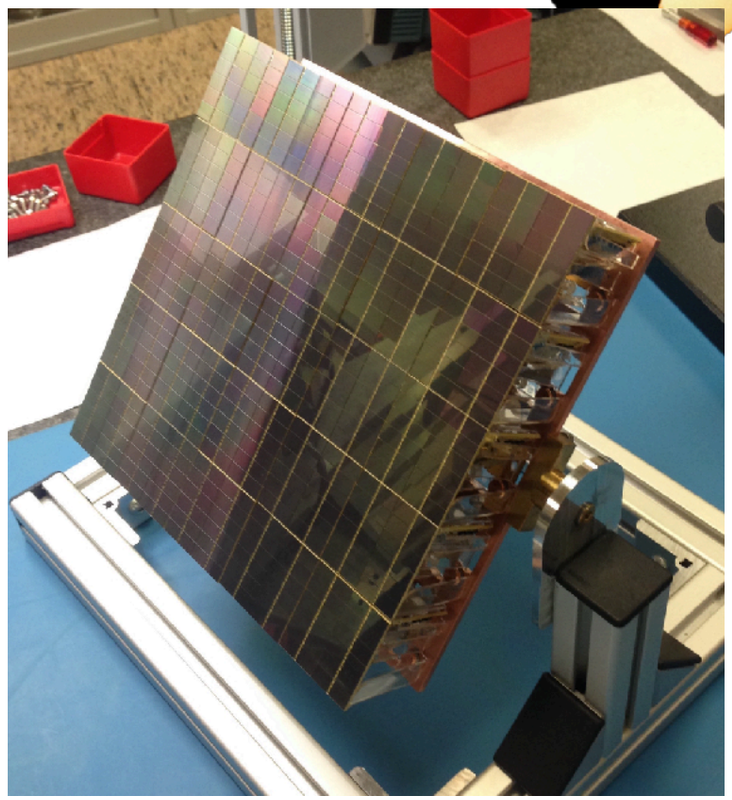
- Radioactivity from cryostat pushed far from UAr
- SiPM outside of UAr volume, no feedthroughs
- Clevios+TPB coated diving bell anode window and cathode window
- Filed rings machine grooved and Clevios-coated
- Low-mass ESR (enhanced specular reflector) foils and PMMA
- Embeds experience on acrylic fabrication and thin coatings from DEAP-3600

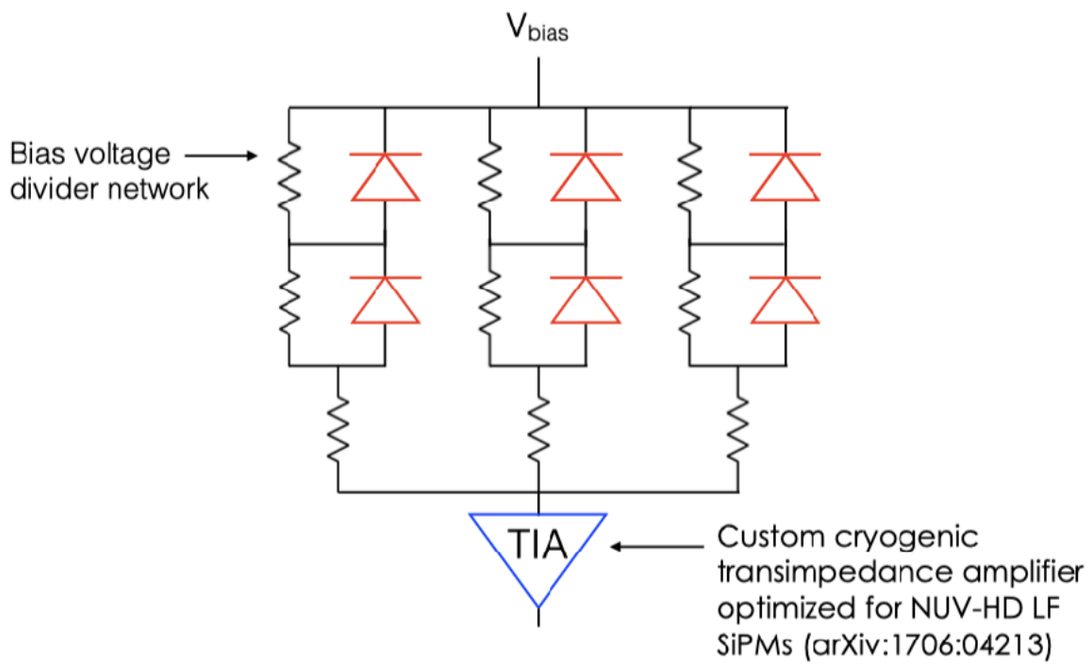


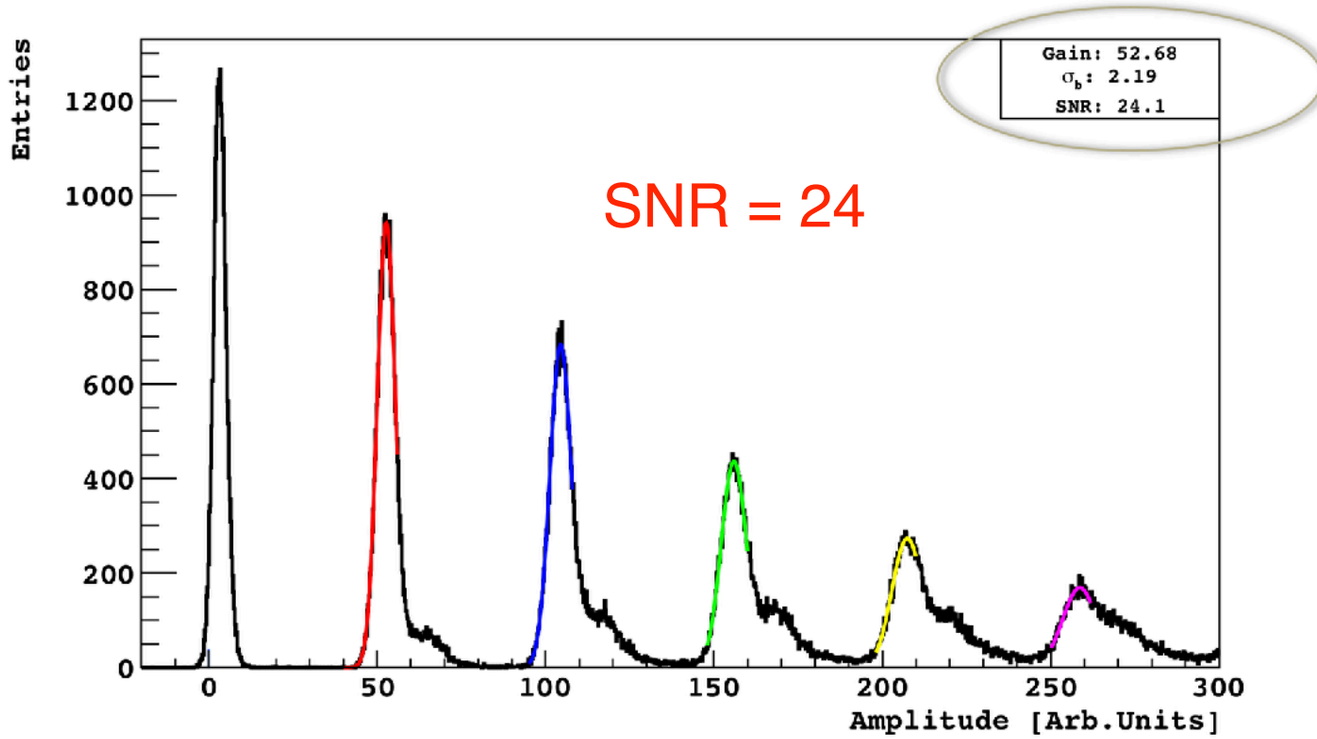
SiPM modules: a replacement for PMTs

- 5×5 cm² single-channel modules (array of 24 SiPMs)
- FBK NUV-HD (high fill factor)
- PDE > 45% at 420 nm (3 V over-voltage)
- <10 ns timing resolution
- 0.1 Hz/mm² dark rate
- compact and radio-clean









Low-radioactivity Argon procurement and purification

URANIA

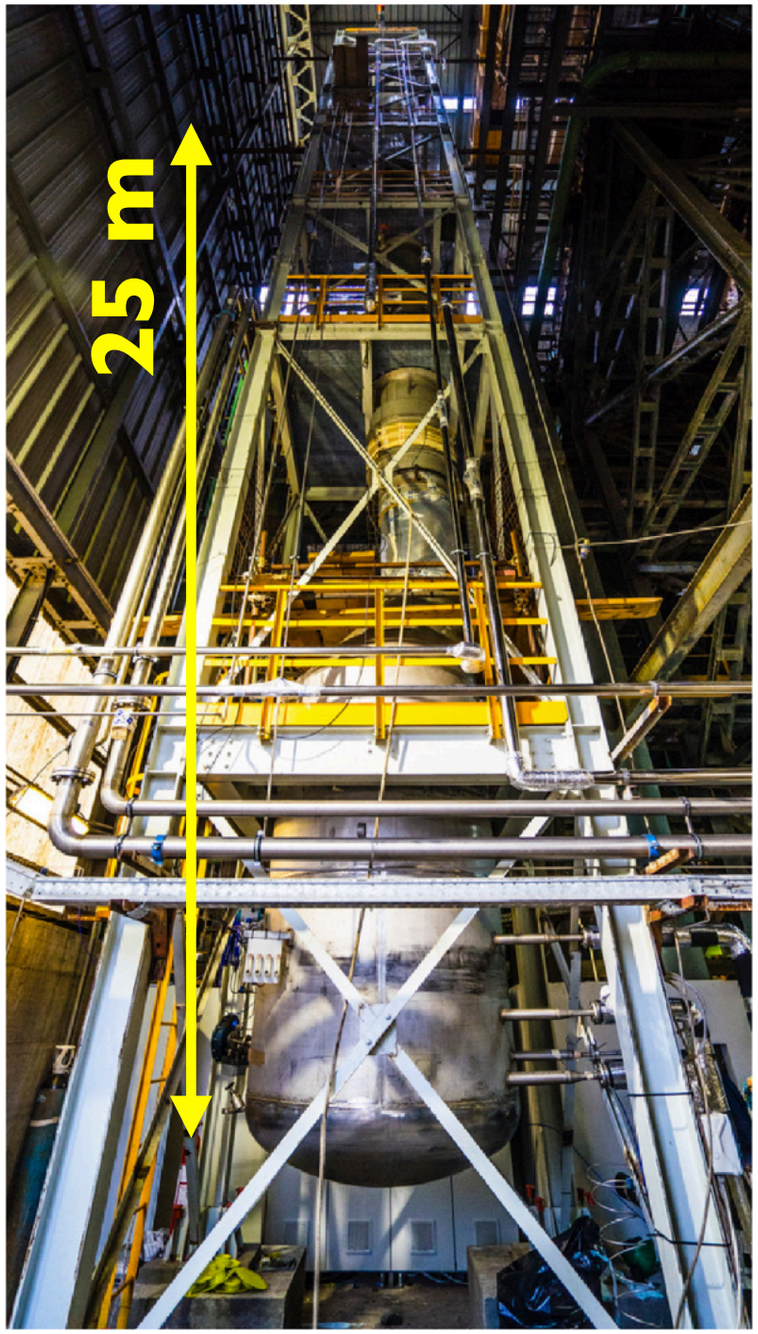
- extraction plant in Cortez, Colorado
- ~250 kg/day of low-^{39}Ar argon (99.9% pure)

ARIA

- distillation plant in Seruci, Sardinia
- purification of UAr from, e.g., krypton
- further isotopic depletion

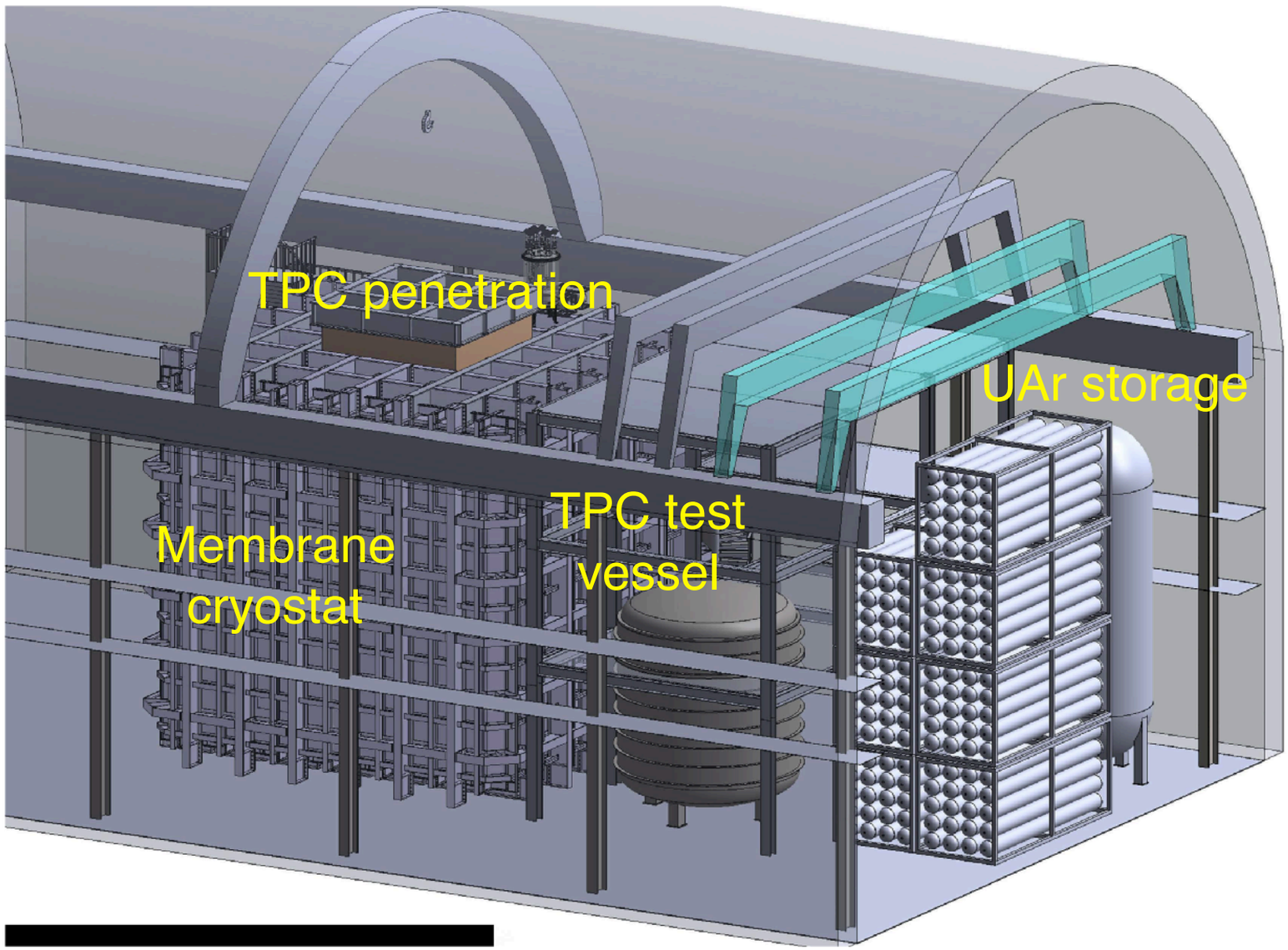
- Seruci-1 column is 350 m long, installed in a mine shaft (30 cm diameter)
- Seruci-2 column 1.5 m diameter

Seruci-0 prototype column



DS-20k veto, cryogenics, and integration

- 1,000 stdL/min gas UAr recirculation
- Passive shell of Gd-doped PMMA immersed in active AAr veto (TPC optically isolated)
- Independent UAr and AAr cryogenics



- DS-20k is a recognized CERN experiment
- GADMC + CERN engineers working out the integration at LNGS
- 1-tonne DS-Proto will test key DS-20k technologies (PMMA vessel and bonding, Clevios films, reflectors) (assembled at CERN 2020)

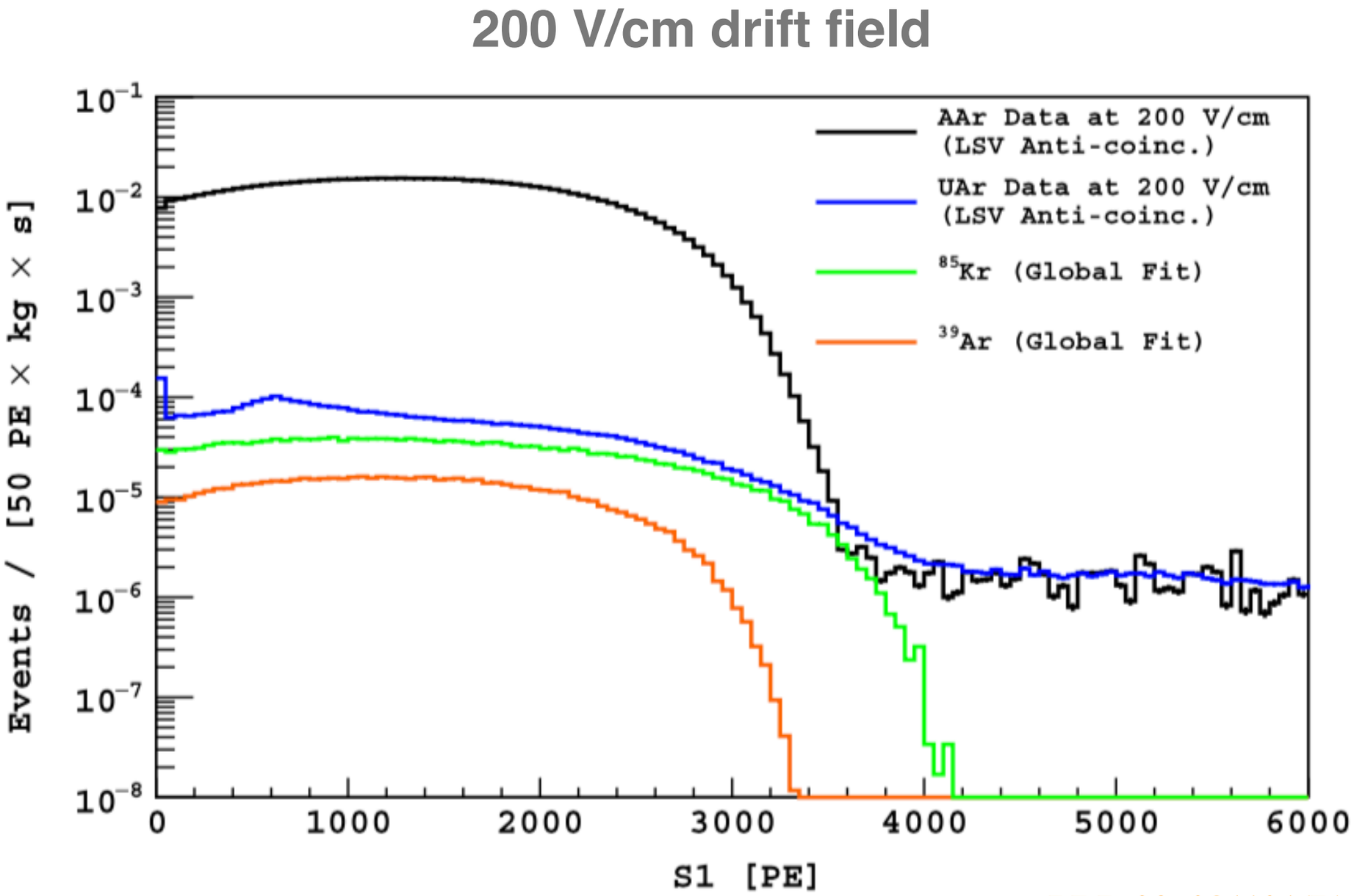
Summary and Outlook

stay hungry, my friend

- Liquid argon is a proven, scalable technology for bg-free WIMP searches down to the neutrino floor
- An ambitious program is in place by the GADMC with the 50-tonne DS-20k detector as the next step of the program
- An super-depleted, ultra-low background ton-scale detector could push the ionization-only sensitivity for low-mass WIMPs several orders of magnitude
- A multi 100's tonnes ARGO detector can push WIMP sensitivity well into the neutrino floor (as well as be a very sensitive neutrino detector (solar, CEvNS)

extra slides

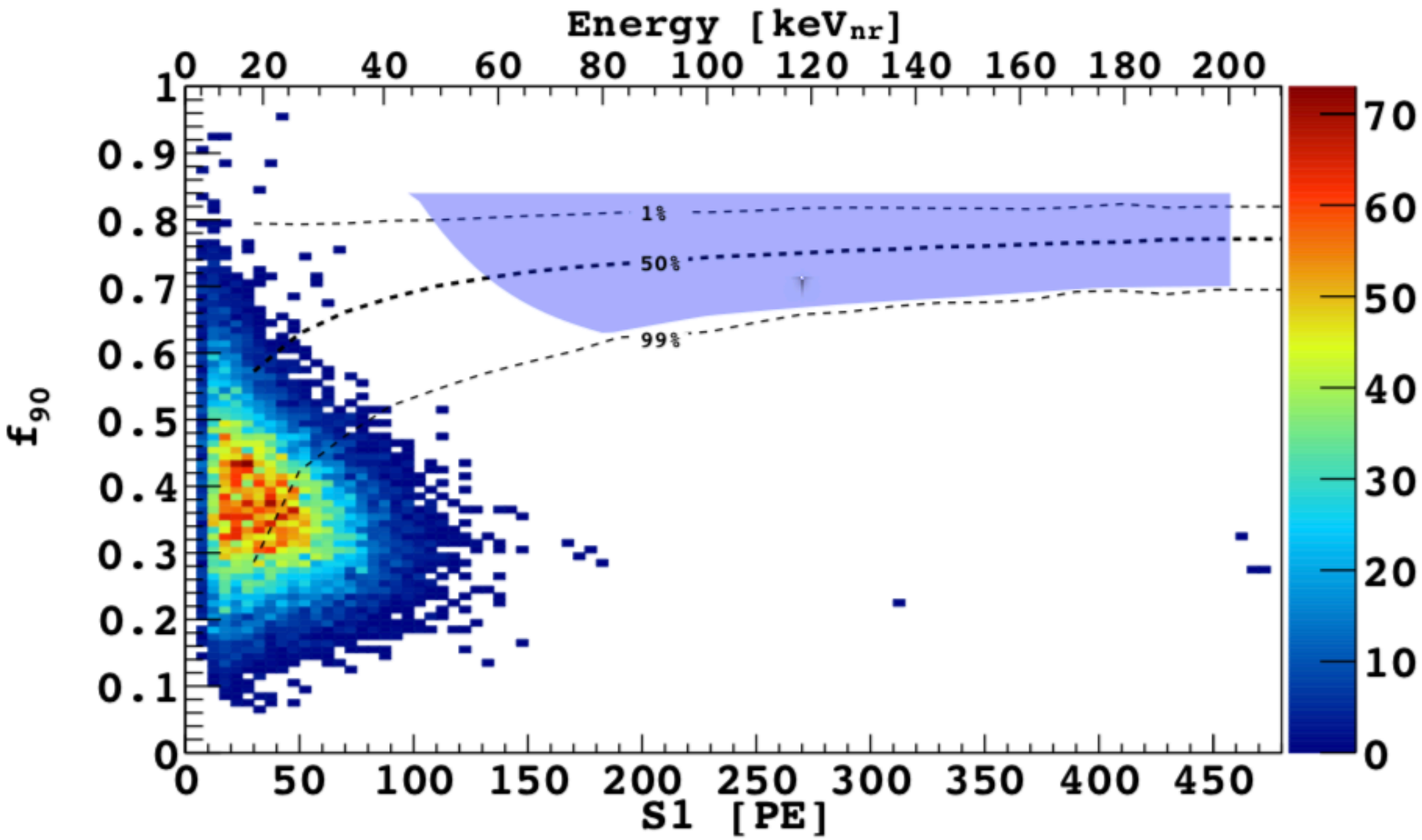
^{85}Kr background and ^{37}Ar



PRD 93, 081101(R) (2016)

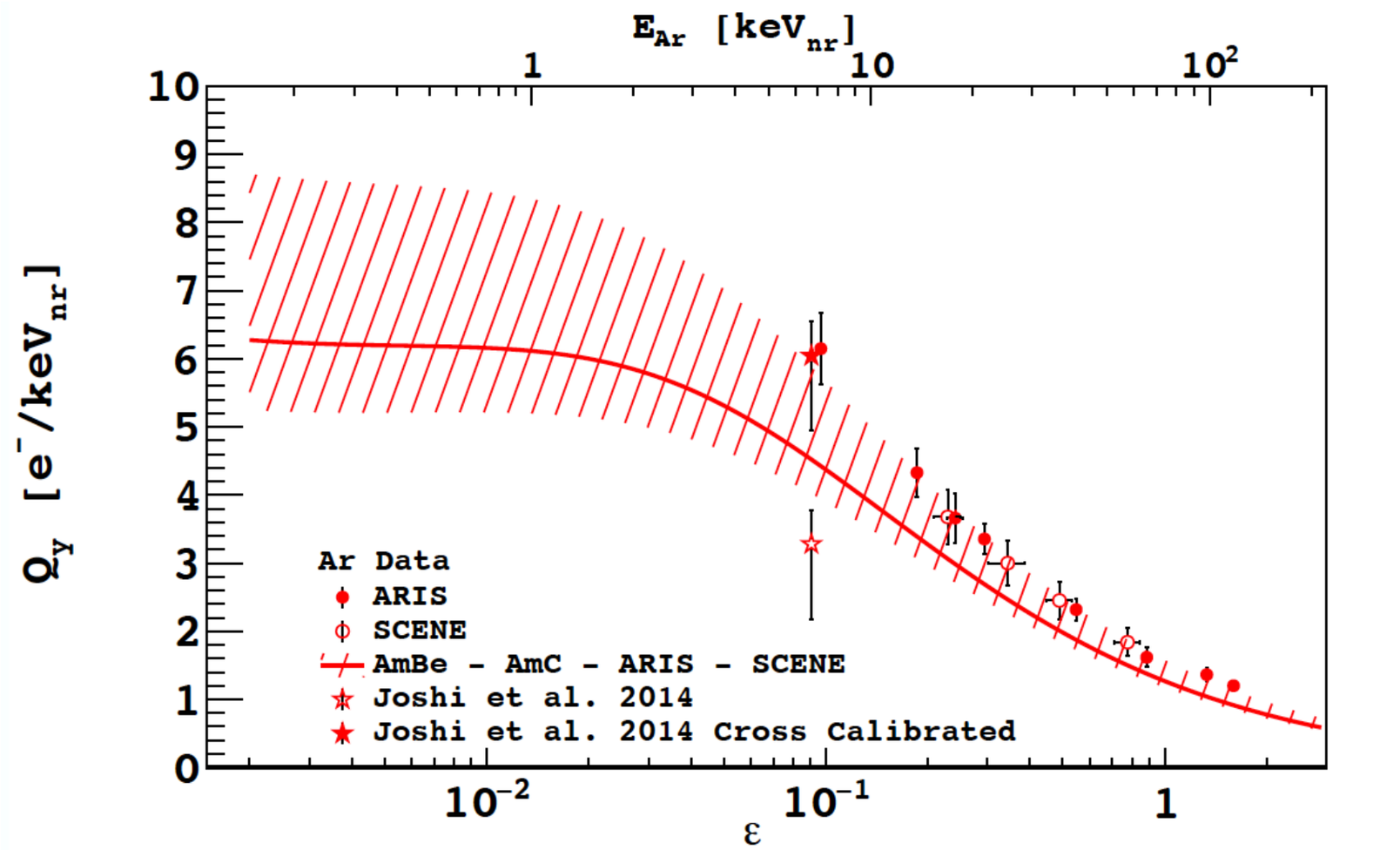
532-day WIMP search

- All analysis cuts + tightened radial cut + S2/S1 cut



arXiv:1802.07198

Lighter (1-10 GeV) WIMPs: ionization yield fro NR

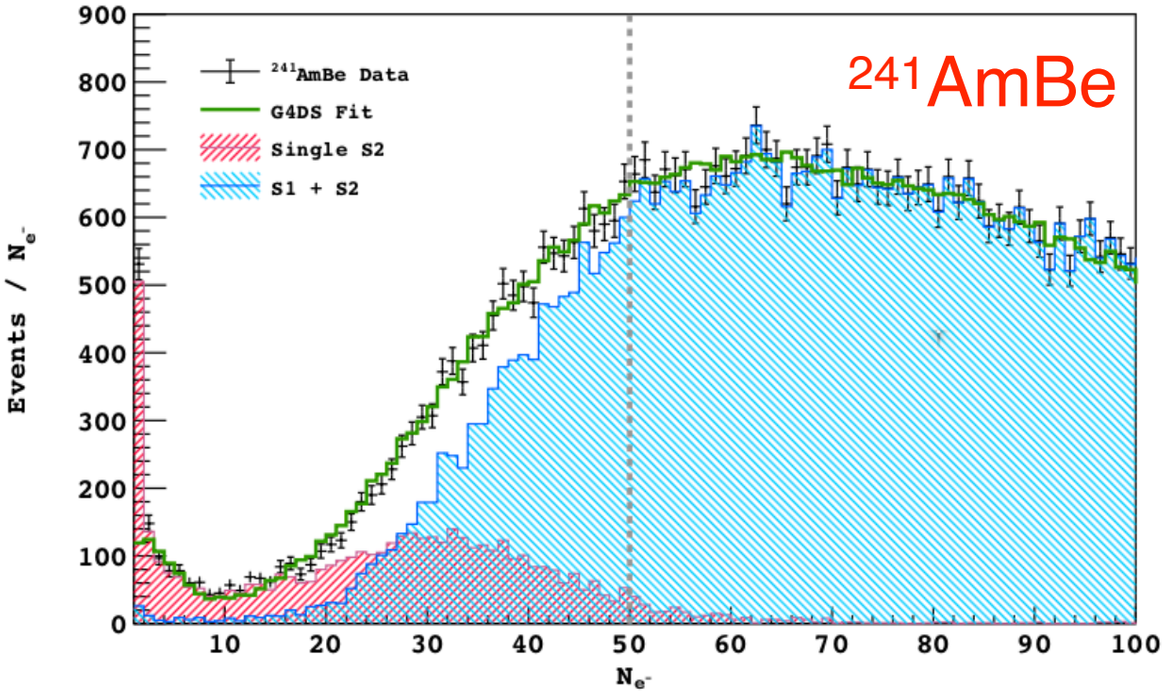


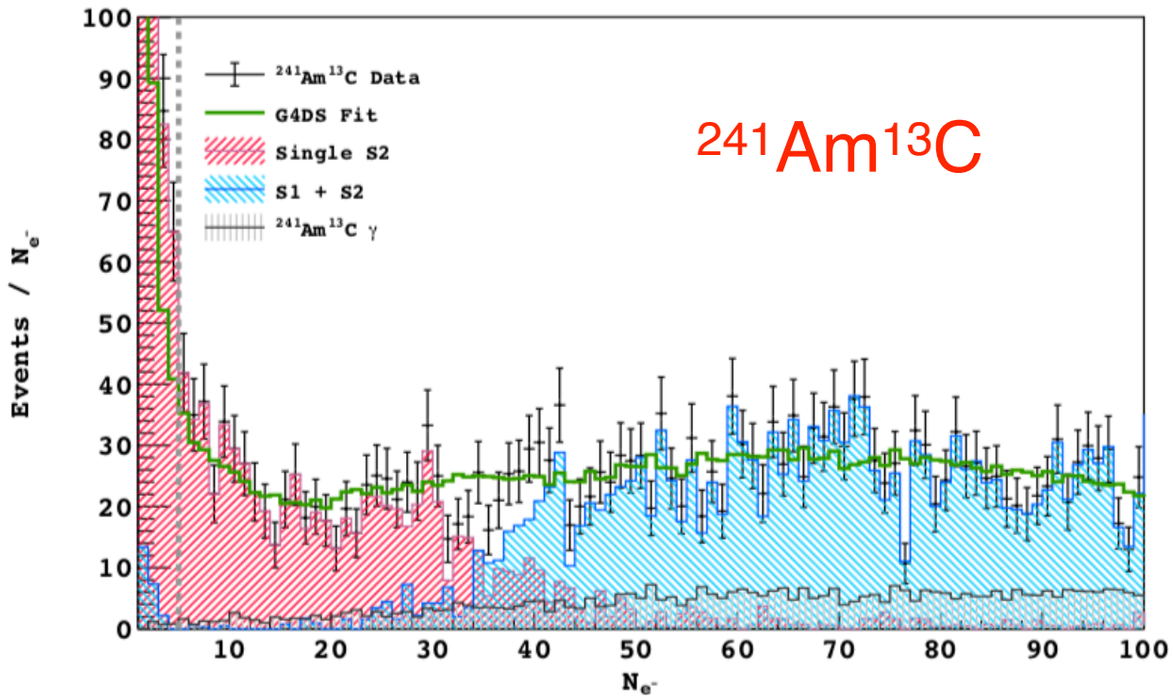
- Ionization yield from NR energy (Bezrukov model)
- Measured with DS-50 neutron calibrations and neutron beam experiments SCENE and ARIS
  (scintillation yield converted to ionization yield with DS-50 data)
- ReD experiment collecting data: sub-keV NR, directionality

arXiv:1802.06994 (to appear in PRL)

DS-50 S2 yield calibration (Bezrukov model)

- All analysis cuts + tightened radial cut + S2/S1 cut





- require 4.4 MeV gamma ray detected in veto

arXiv:1802.06994 (to appear in PRL)

Solar neutrinos with a ~300 tonne LAr experiment

JCAP08(2016)017

Neutrino Source	Low Metallicity (LZ)		High Metallicity (HZ)	
	All	[0.6–1.3] MeV	All	[0.6–1.3] MeV
pp	107.9 ± 2.0	0	107.0 ± 2.0	0
pep	2.28 ± 0.05	1.10 ± 0.02	2.23 ± 0.05	1.07 ± 0.02
^{7}Be	36.10 ± 2.60	2.85 ± 0.21	39.58 ± 2.85	3.13 ± 0.23
CNO	3.06 ± 0.30	0.64 ± 0.06	4.28 ± 0.44	0.90 ± 0.09
^{8}B	0.30 ± 0.04	0.035 ± 0.005	0.36 ± 0.06	0.042 ± 0.007
Total		4.63 ± 0.22		5.14 ± 0.25

Table 2. Expected solar neutrino rates in cpd/100 tonne of LAr active mass, comparing the low-metallicity [21] and high-metallicity [22] predictions using the Standard Solar Model and neutrino oscillation parameters from the MSW-LMA [14, 15] region with $\Delta m^2 = 7.54\times10^{-5}\,\mathrm{eV}^2$ and $\sin^2(\theta_{12}) = 0.307$.

- *measure CNO solar neutrino flux with ~15% uncertainty*
- *measure Be-7 neutrinos at ~2%*
- *measure pep neutrinos at better than 10%*

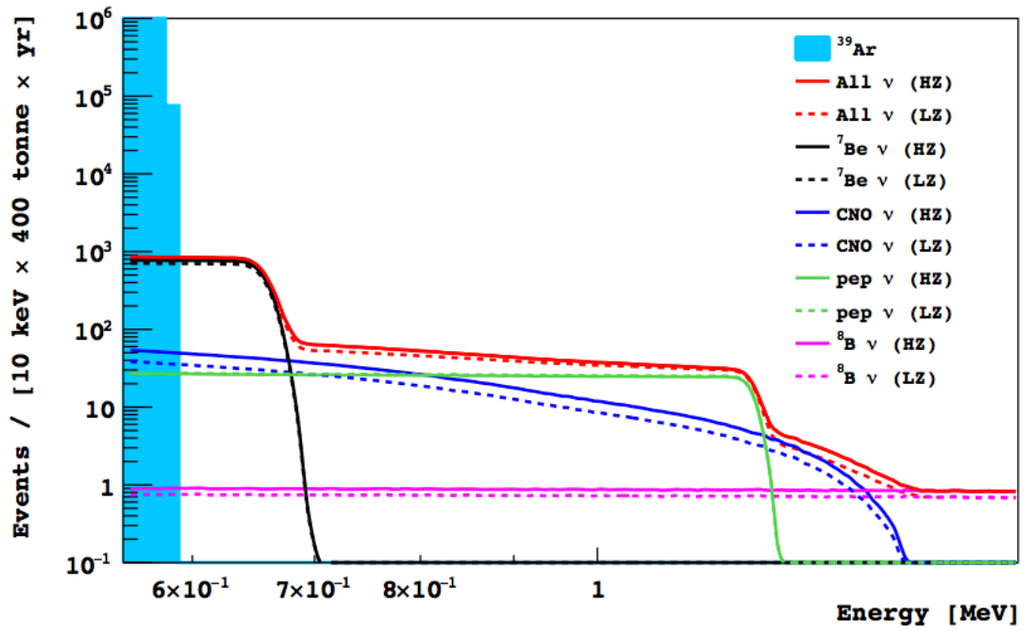


Figure 1. Simulated solar neutrino spectra in a 400 tonne-yr LAr TPC exposure, assuming σ =1.3% energy resolution at 1 MeV, corresponding to a PE yield of 6 PE/keV. The blue shaded area represents the tail of the ^{39}Ar contamination, intrinsic to underground LAr.

^{222}Rn	Low Metallicity			High Metallicity		
Activity	$\sigma(^7Be)$	$\sigma(pep)$	$\sigma(CNO)$	$\sigma(^7Be)$	$\sigma(pep)$	$\sigma(CNO)$
10	1.77 ± 0.01	8.4 ± 0.1	16.7 ± 0.1	1.72 ± 0.01	9.0 ± 0.1	12.5 ± 0.1
20	1.80 ± 0.01	8.7 ± 0.1	17.0 ± 0.1	1.70 ± 0.01	9.1 ± 0.1	12.7 ± 0.1
40	1.82 ± 0.01	9.3 ± 0.1	17.9 ± 0.1	1.72 ± 0.01	9.8 ± 0.1	13.1 ± 0.1
60	1.84 ± 0.01	9.7 ± 0.1	18.6 ± 0.1	1.76 ± 0.01	10.2 ± 0.1	13.9 ± 0.1
80	1.85 ± 0.01	10.0 ± 0.1	19.6 ± 0.1	1.76 ± 0.01	10.6 ± 0.1	14.2 ± 0.1
100	1.87 ± 0.01	10.5 ± 0.1	20.0 ± 0.1	1.79 ± 0.01	11.0 ± 0.1	14.8 ± 0.1
200	1.96 ± 0.01	12.1 ± 0.1	23.2 ± 0.2	1.88 ± 0.01	12.9 ± 0.1	17.2 ± 0.1

Table 5. Solar neutrino rate uncertainties [%] as a function of the ^{222}Rn contamination [10 μBq/(100 tonne) = 0.8 cpd/100 tonne]