DarkSide latest results and prospects

Rencontres du Vietnam: Windows on the Universe
ICISE, Quy Nhon - August 5-11, 2018

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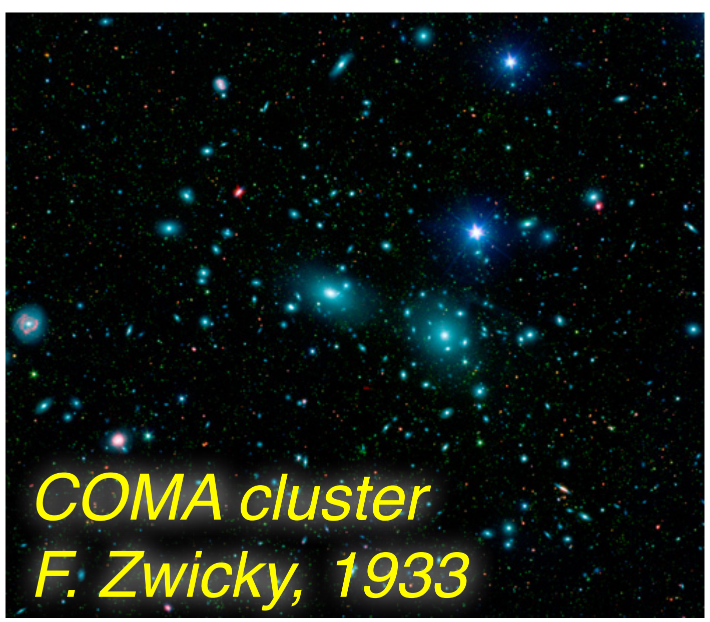
AMHERST CENTER FOR FUNDAMENTAL INTERACTIONS
Physics at the interface: Energy, Intensity, and Cosmic frontiers
University of Massachusetts Amherst

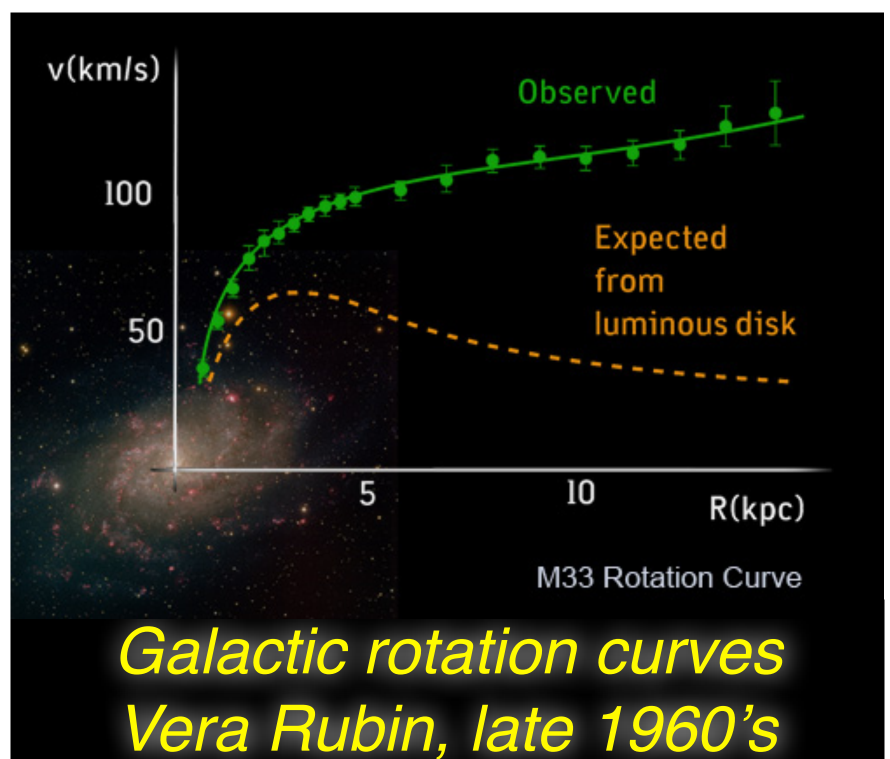
Evidence for Dark Matter

Bullet cluster, 2000's
gravitational lensing + X-rays

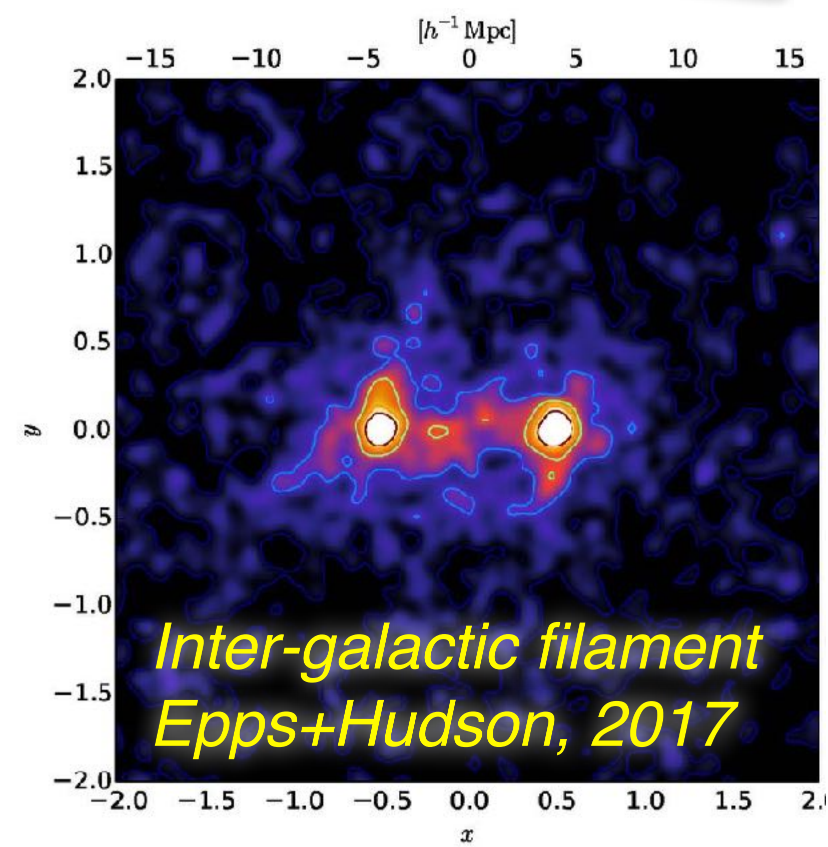
- *evidence for Dark Matter at various astrophysical and cosmological scales*
- *dark matter composition one of the Big Questions in science*
- *a compelling possibility is that dark matter is made of Weakly Interacting Massive Particles (WIMPs), an early Universe freeze-out remnant*



COMA cluster
F. Zwicky, 1933



Galactic rotation curves
Vera Rubin, late 1960's



Inter-galactic filament
Epps+Hudson, 2017

Outline and executive summary of results

- *Direct dark matter detection with Liquid Argon TPC's*
- *DarkSide-50*
  - *DS-50 detector and its defining characteristics*
  - *Recent DS-50 results*
- *DarkSide-20k and Global Argon Collaboration (GADMC)*

1

Heavier WIMPs (>10 GeV) — arXiv:1802.07198
DarkSide-50 532-day WIMP dark matter search with low-radioactivity argon

2

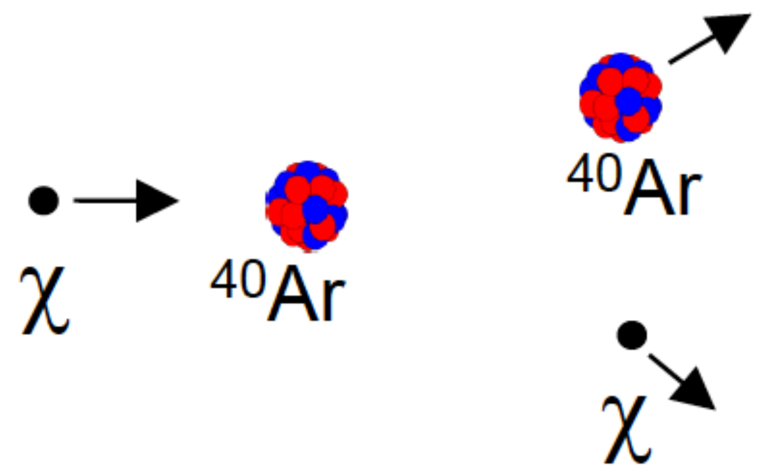
Lighter WIMPs (2-10 GeV) — arXiv:1802.06994 (to appear in PRL)
Low-mass Dark Matter Search with the DarkSide-50 Experiment

3

sub-GeV dark matter — arXiv:1802.06994
Constraints on Sub-GeV Dark Matter-Electron Scattering from the DarkSide-50 Experiment

Dark matter detection with noble liquid detectors

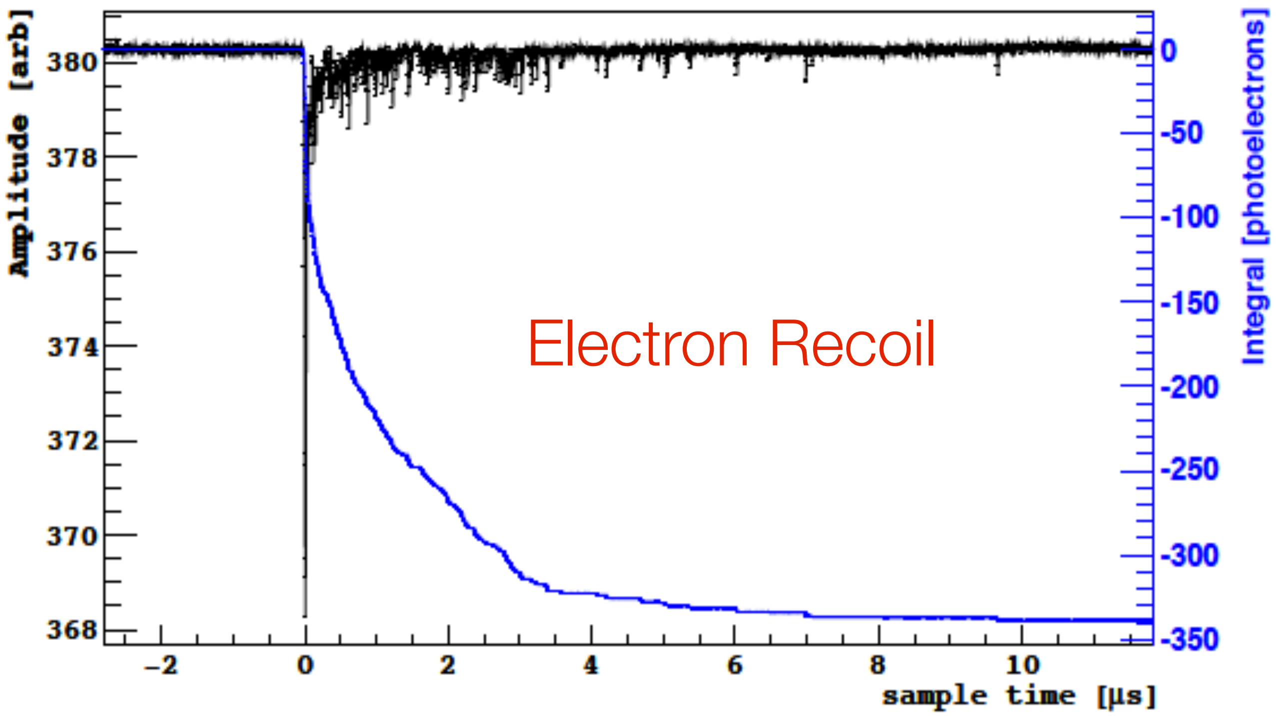
- *Large, noble-liquid TPC's are excellent dark matter detectors*
- *Search for WIMP-nucleus coherent scattering*

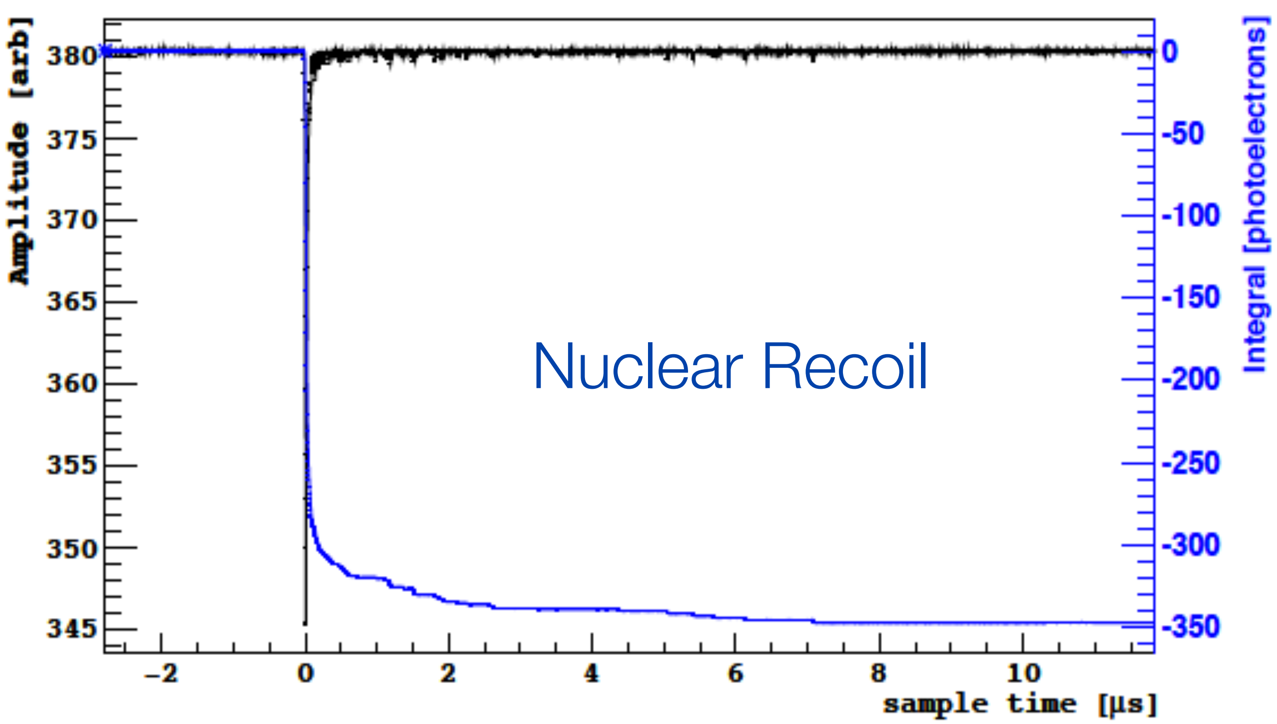


- *Scattered nucleus (10's of keV) is detected in liquid argon*

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

Pulse Shape Discrimination in LAr





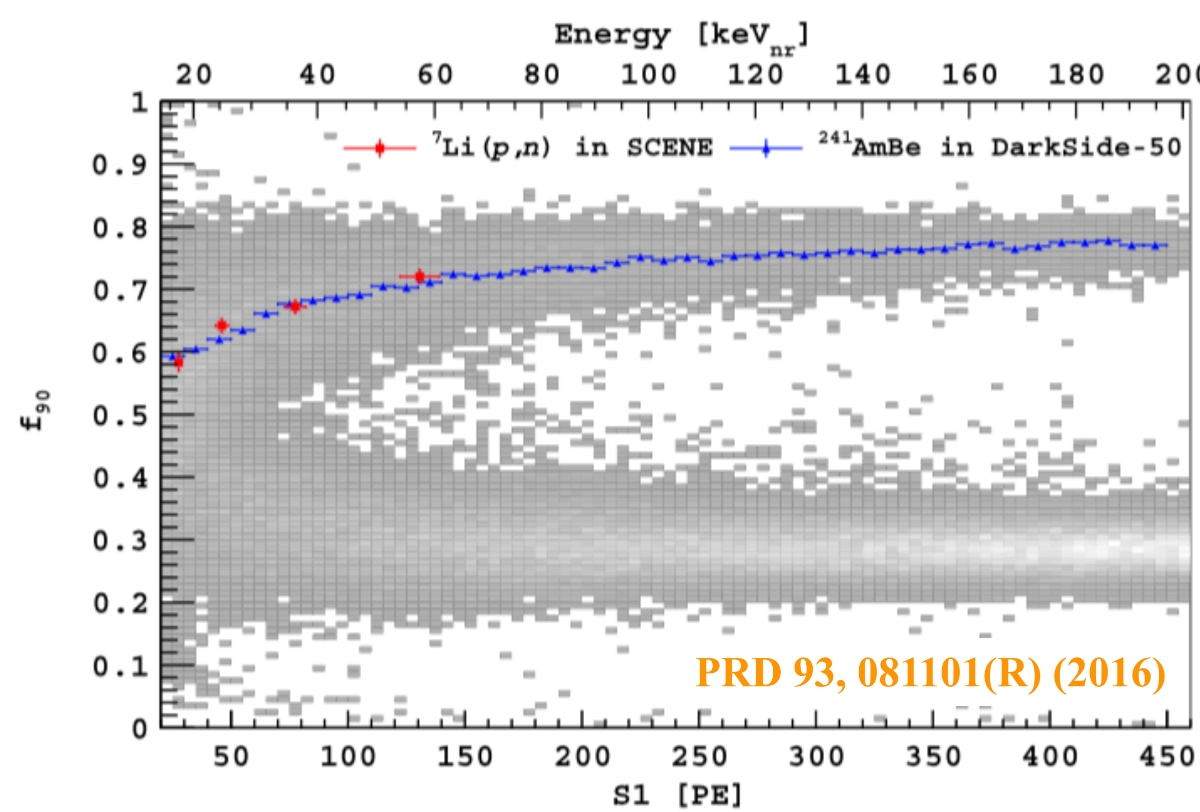
τ singlet ~ 7 ns

τ triplet ~ 1500 ns

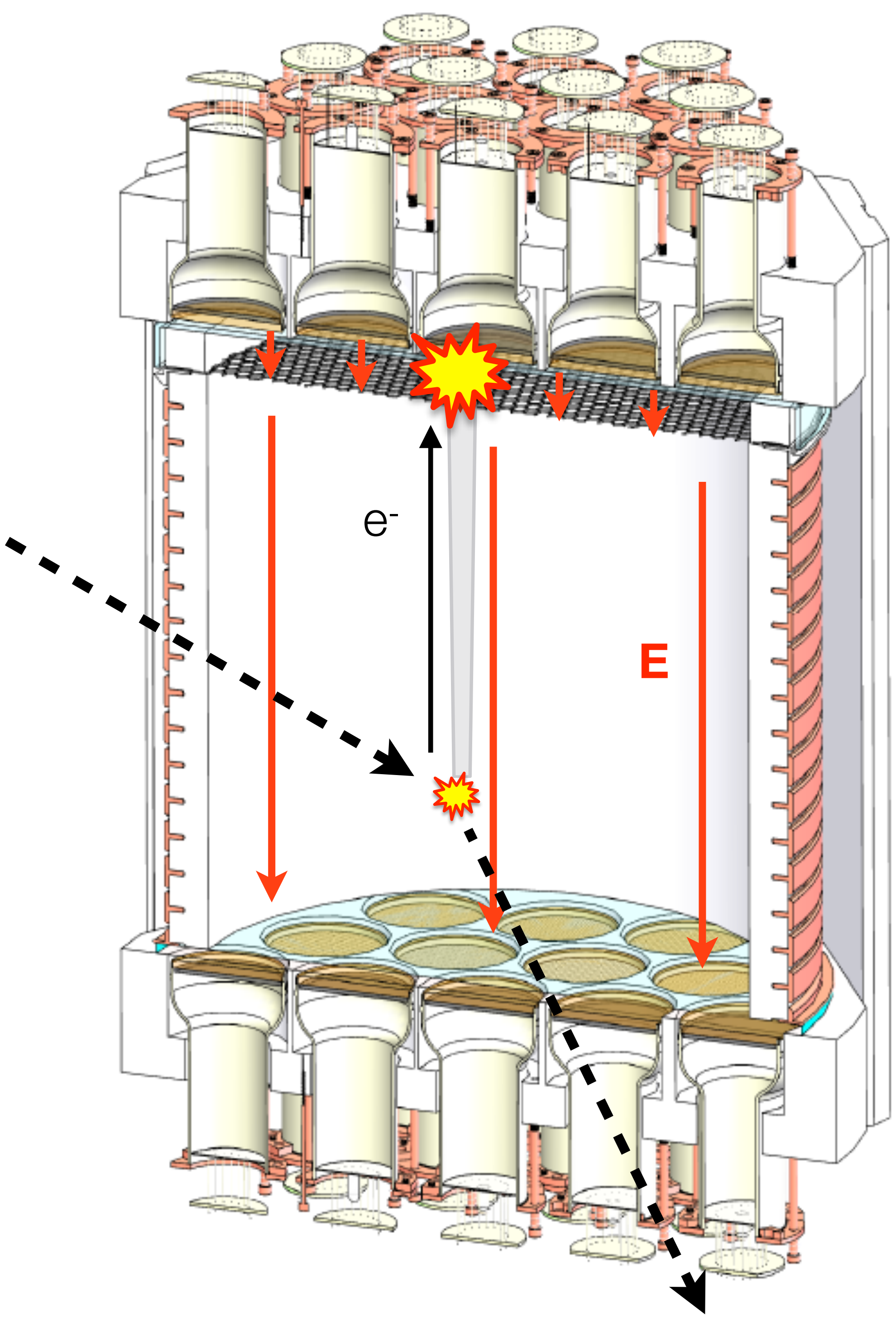
PSD parameter, F90

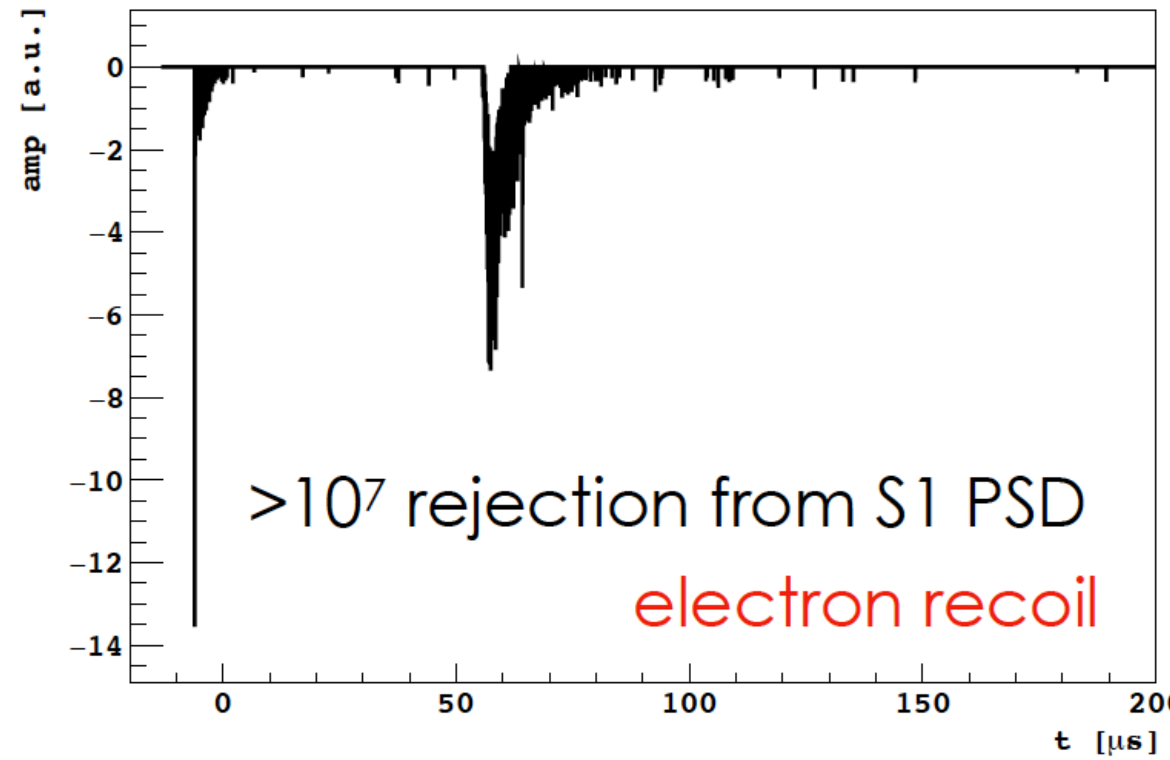
Fraction of total light detected in the first 90 ns of the pulse

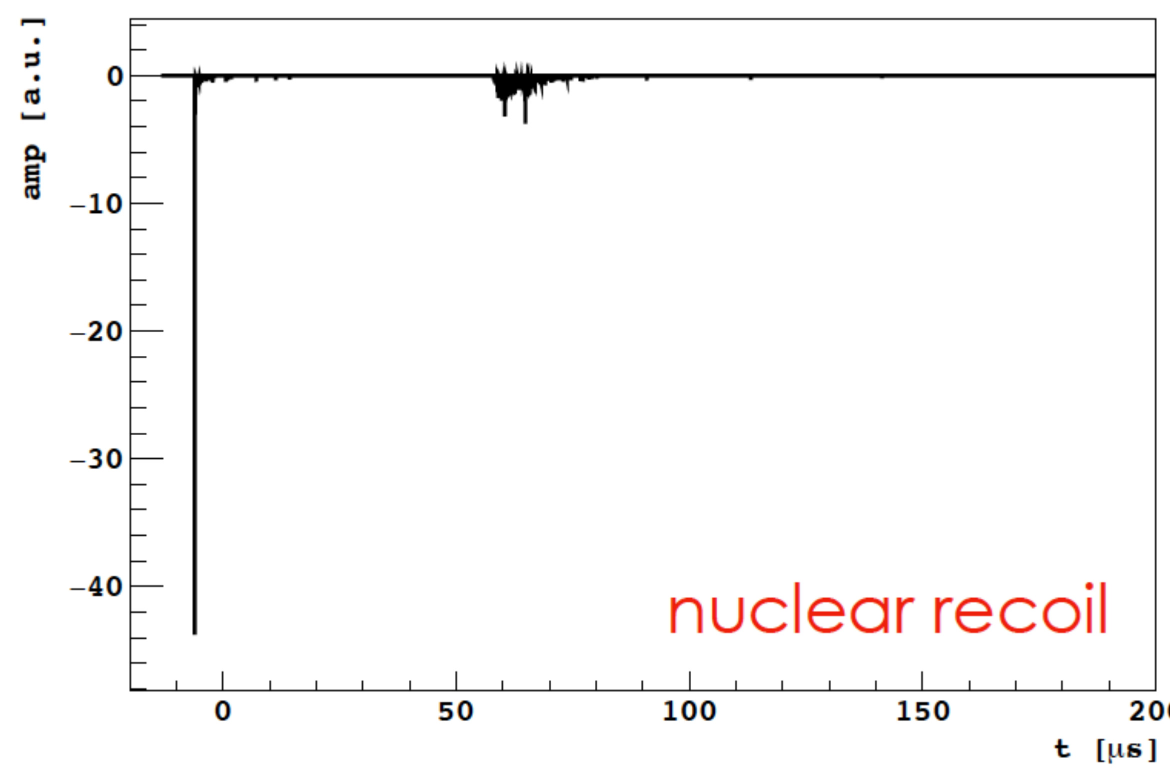
(Fraction of singlet state excited dimers)



Dual Phase Argon TPC







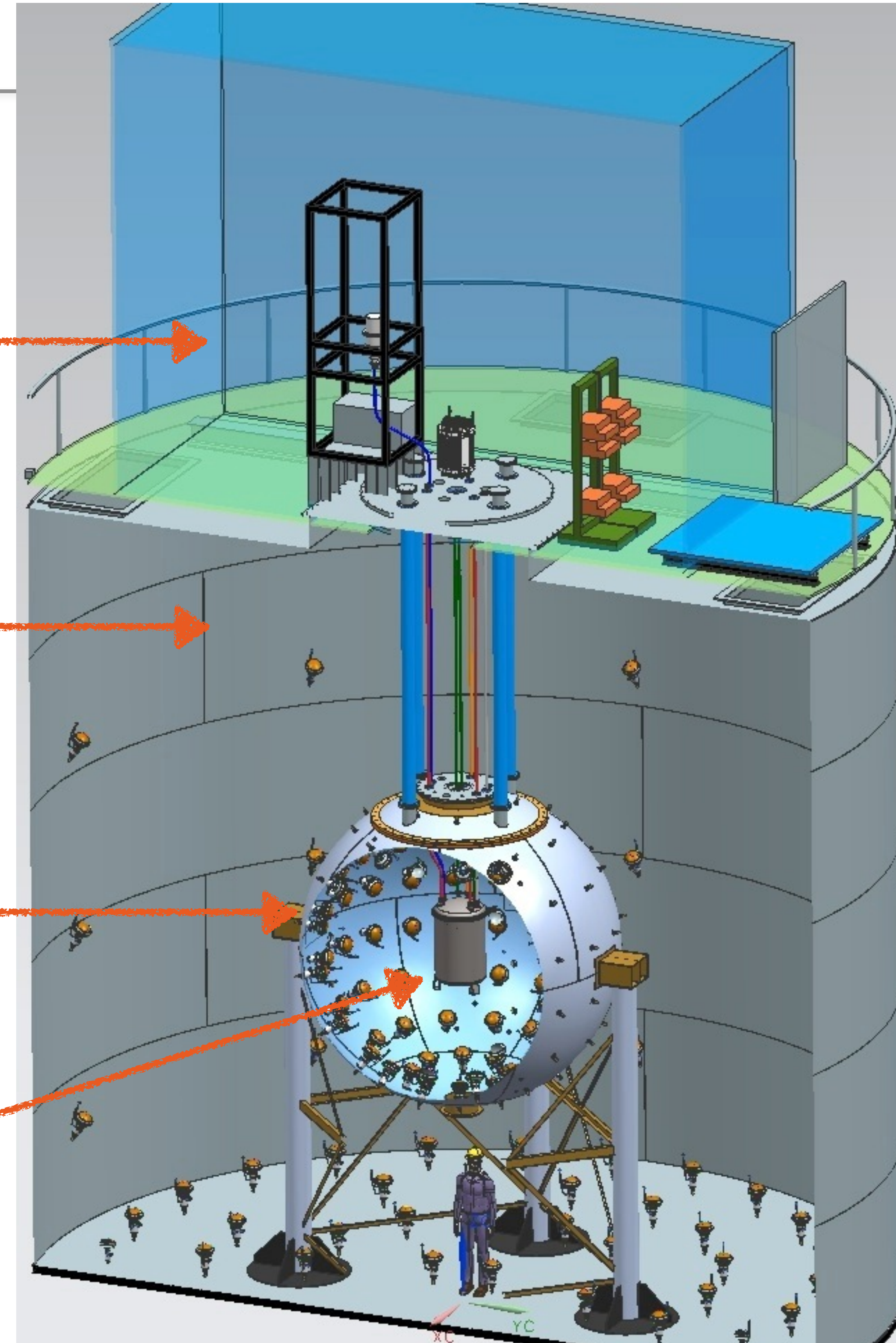
DarkSide 50 at LNGS

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

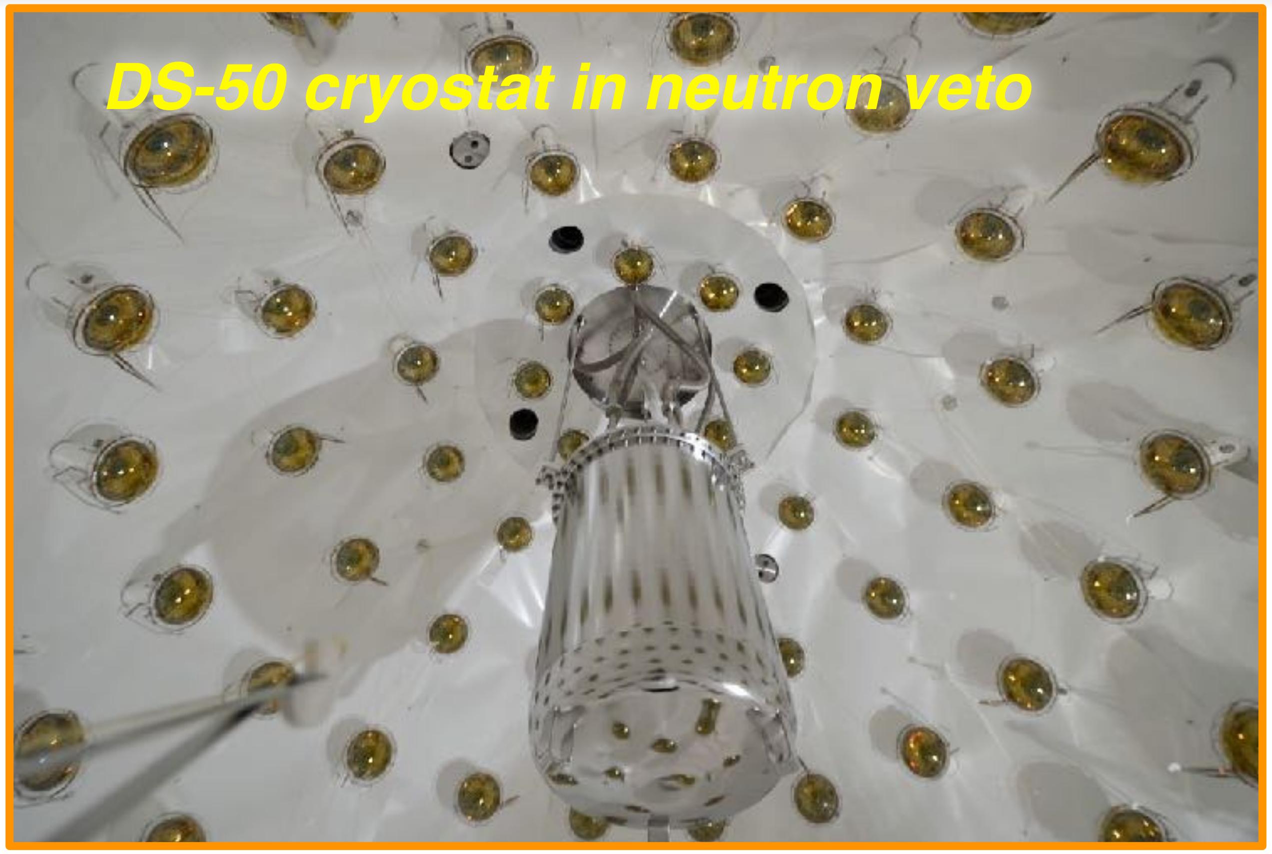
1,000-tonne Water-based Cherenkov
Cosmic Ray Veto

30-tonne Liquid Scintillator
Neutron and γ's Veto

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

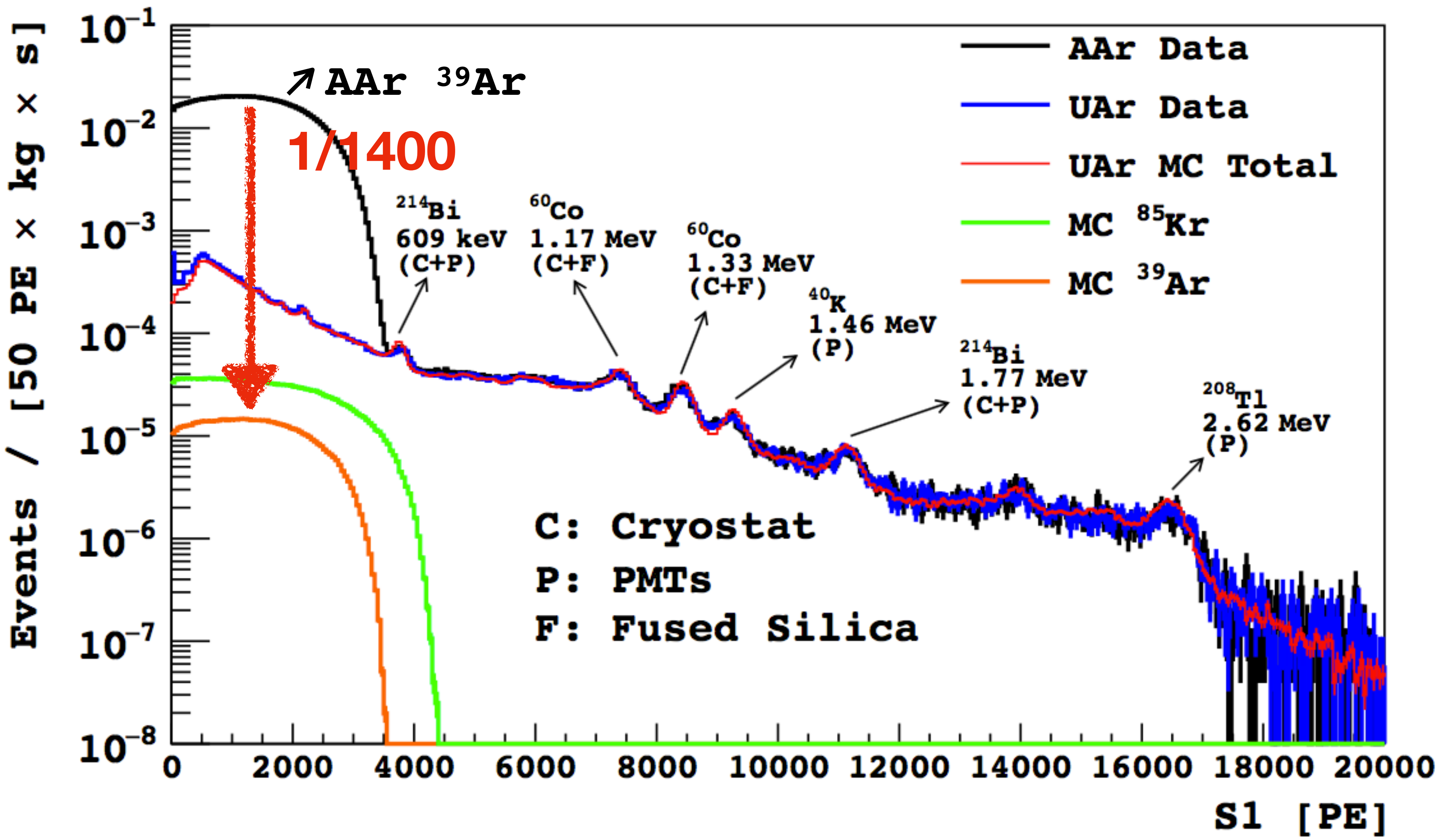


DS-50 detector



Low radioactivity argon from underground sources (UAr)

S1 spectrum at zero E-field



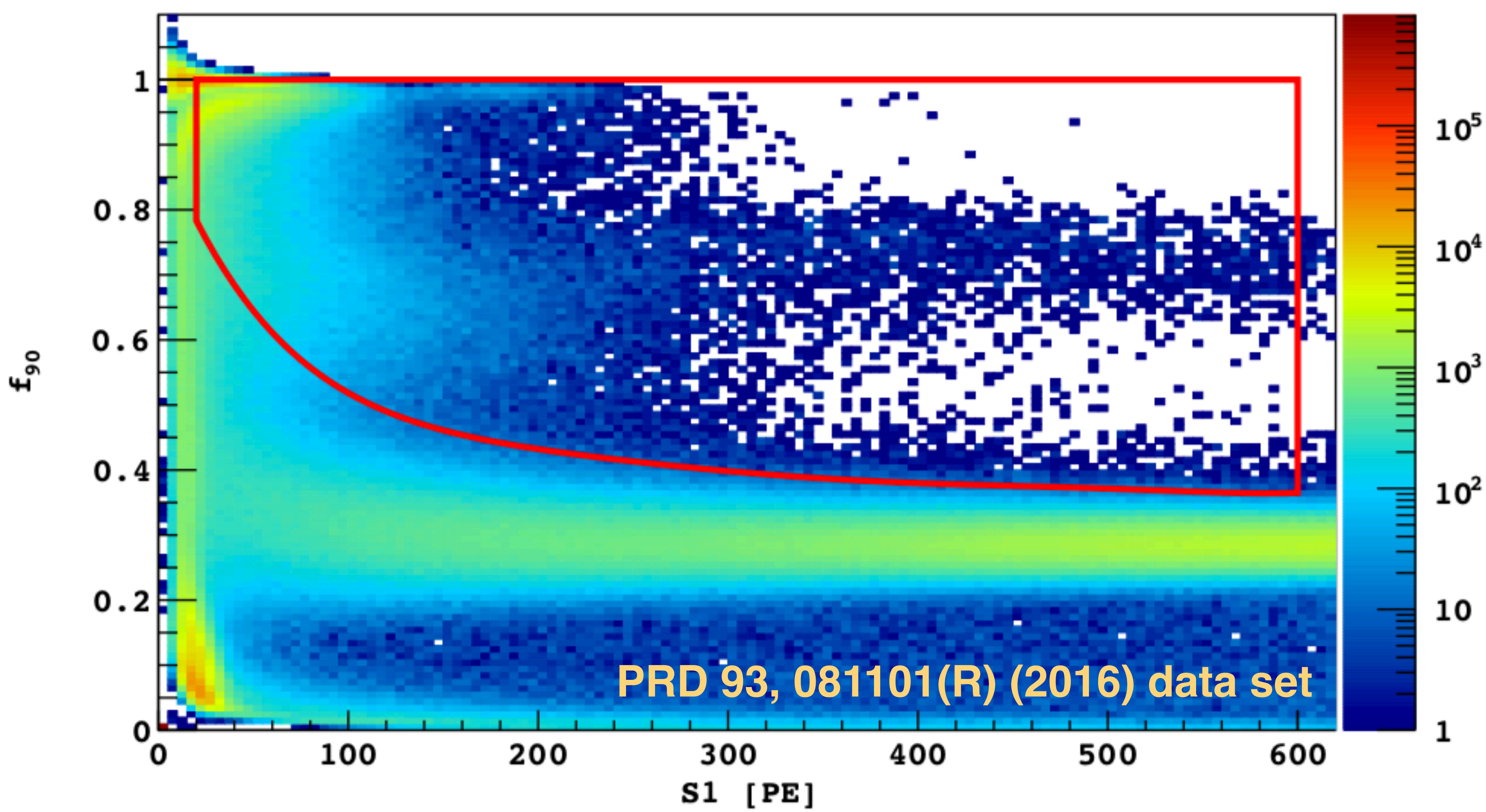
high light yield: ~8 p.e./keV$_{ee}$

(key for PSD)

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

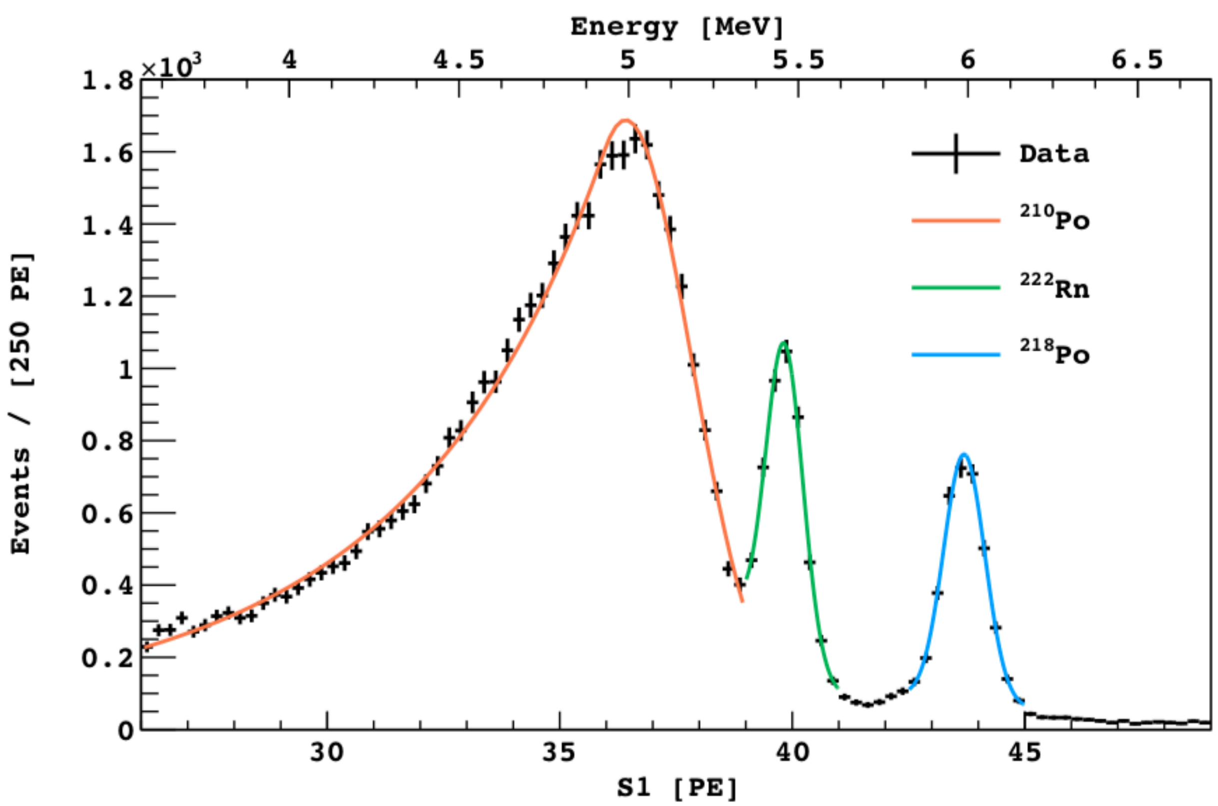
Higher mass (>10 GeV) WIMP search: blinding

- 532-day dataset
- Blind analysis (blinded region defined on previous 70-day run)
- Background-free (<0.1 events in WIMP box over entire exposure)



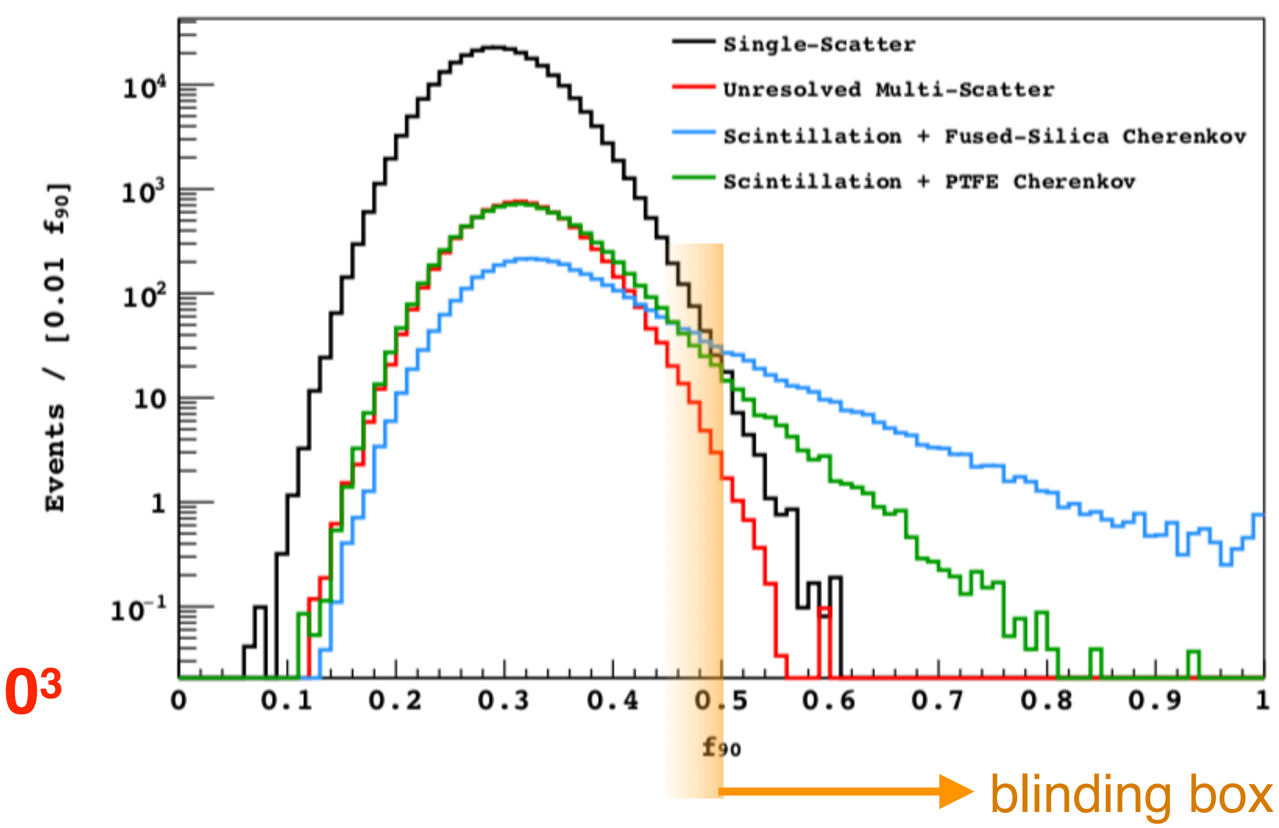
Higher mass (>10 GeV) WIMP search: backgrounds

alpha background



×10³

electron recoil background



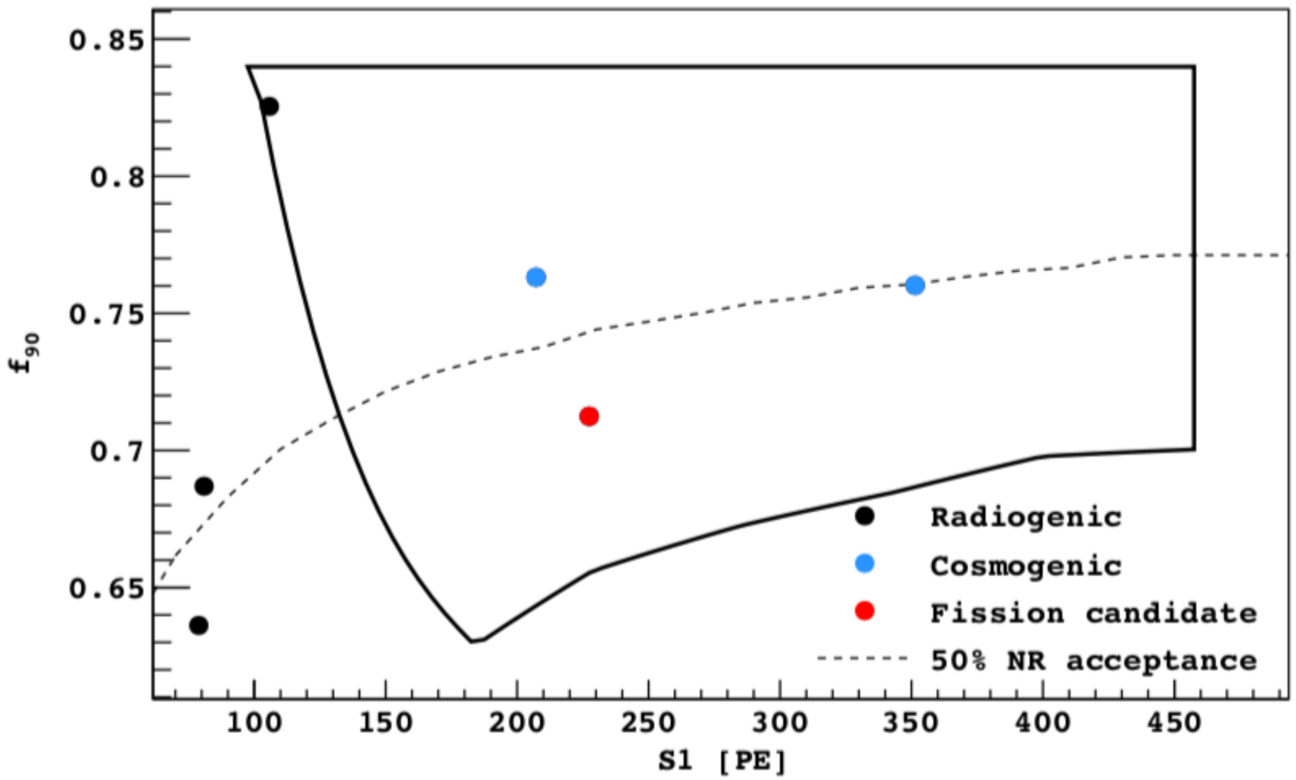
- degraded alphas
- Pb recoils + TPB fluorescence
- radiogenic (α,n) neutrons

- model: 100 < S1 < 180 p.e.
- scintillation + Čerenkov events

arXiv:1802.07198

Higher mass (>10 GeV) WIMP search: neutrons

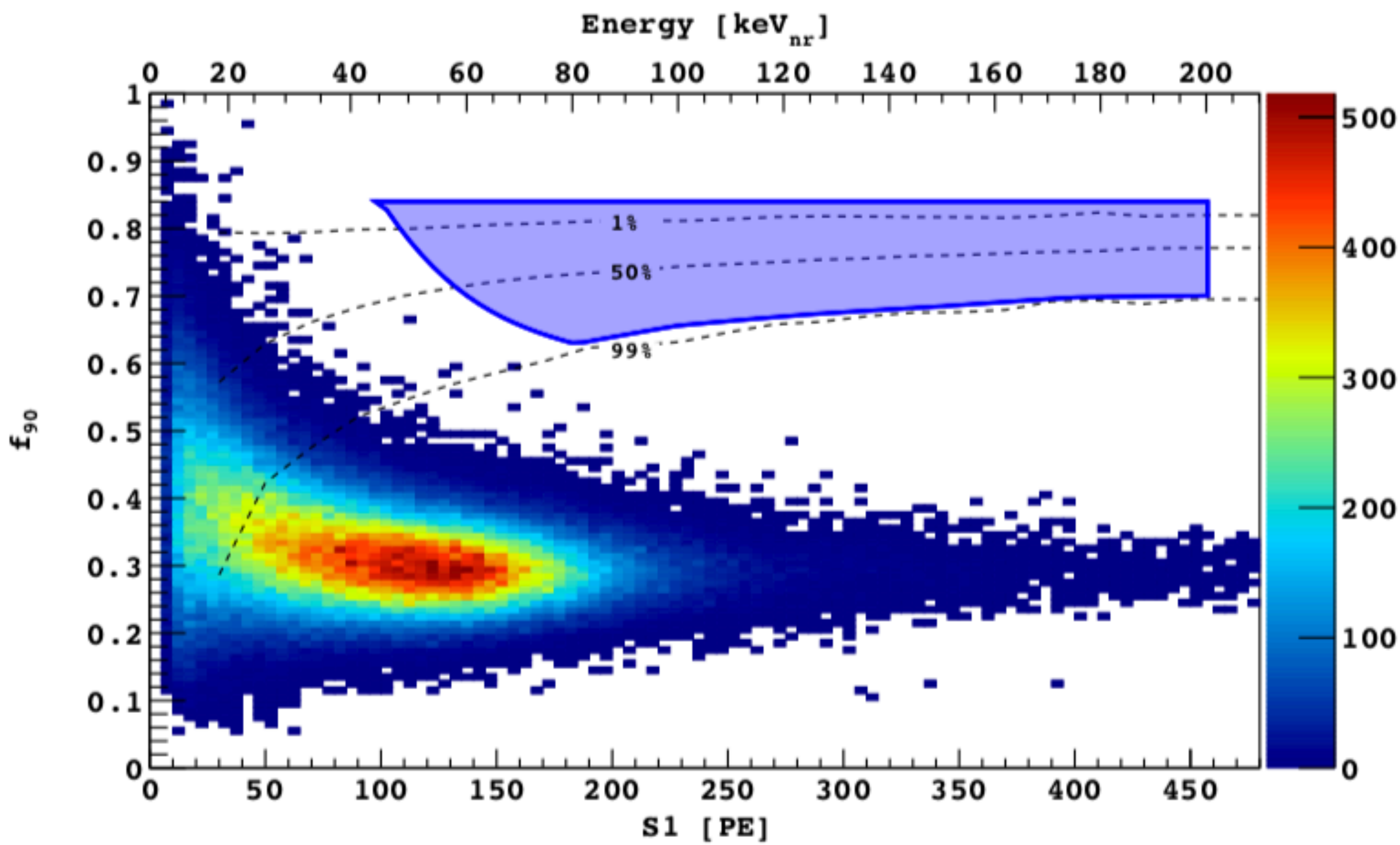
arXiv:1802.07198



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

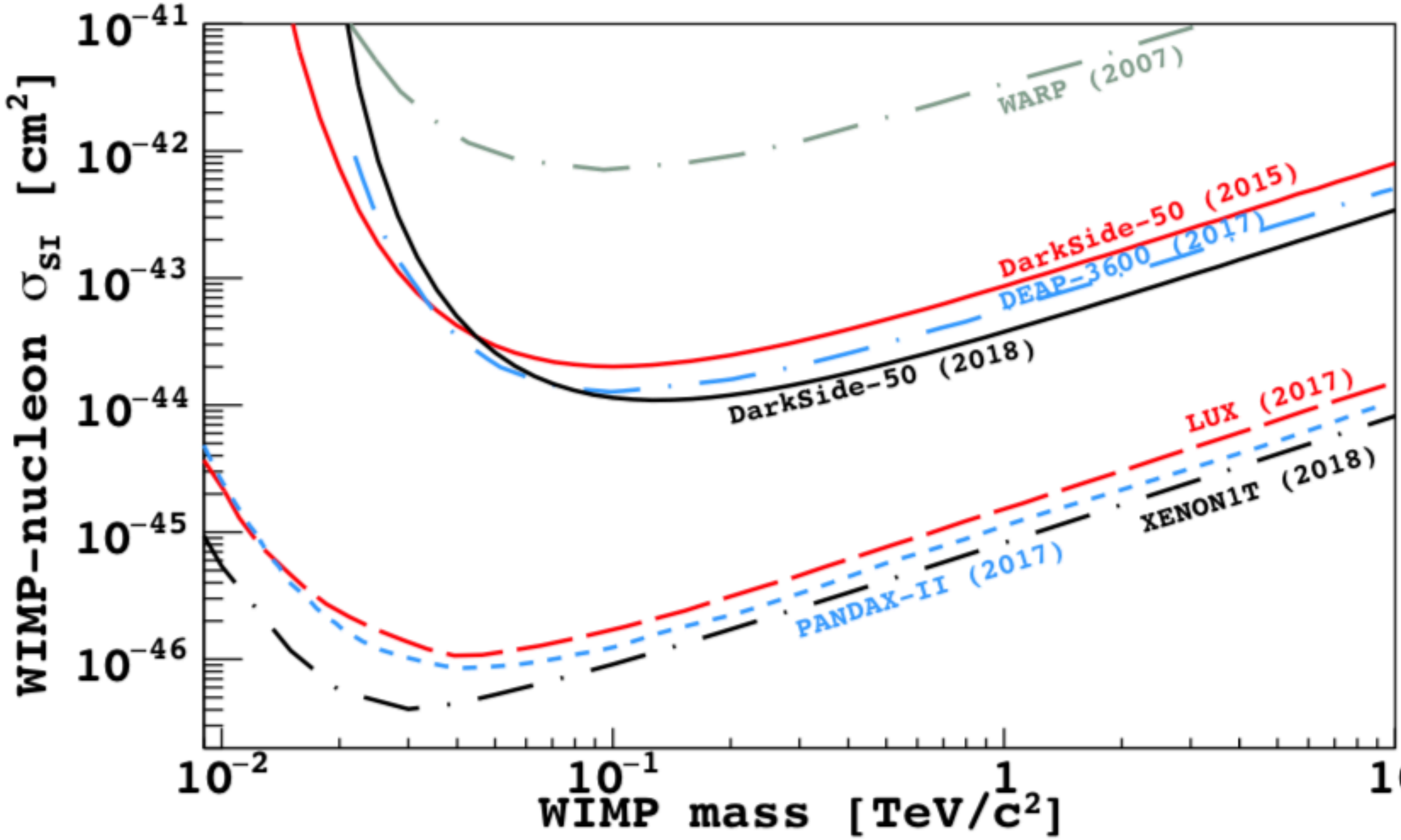
surface	0.0015 ± 0.0001
radiogenic neutrons	<0.005
cosmogenic neutrons	<0.00035
electron recoil	0.08 ± 0.04
total	0.09 ± 0.04

Higher mass (>10 GeV) WIMP search



arXiv:1802.07198

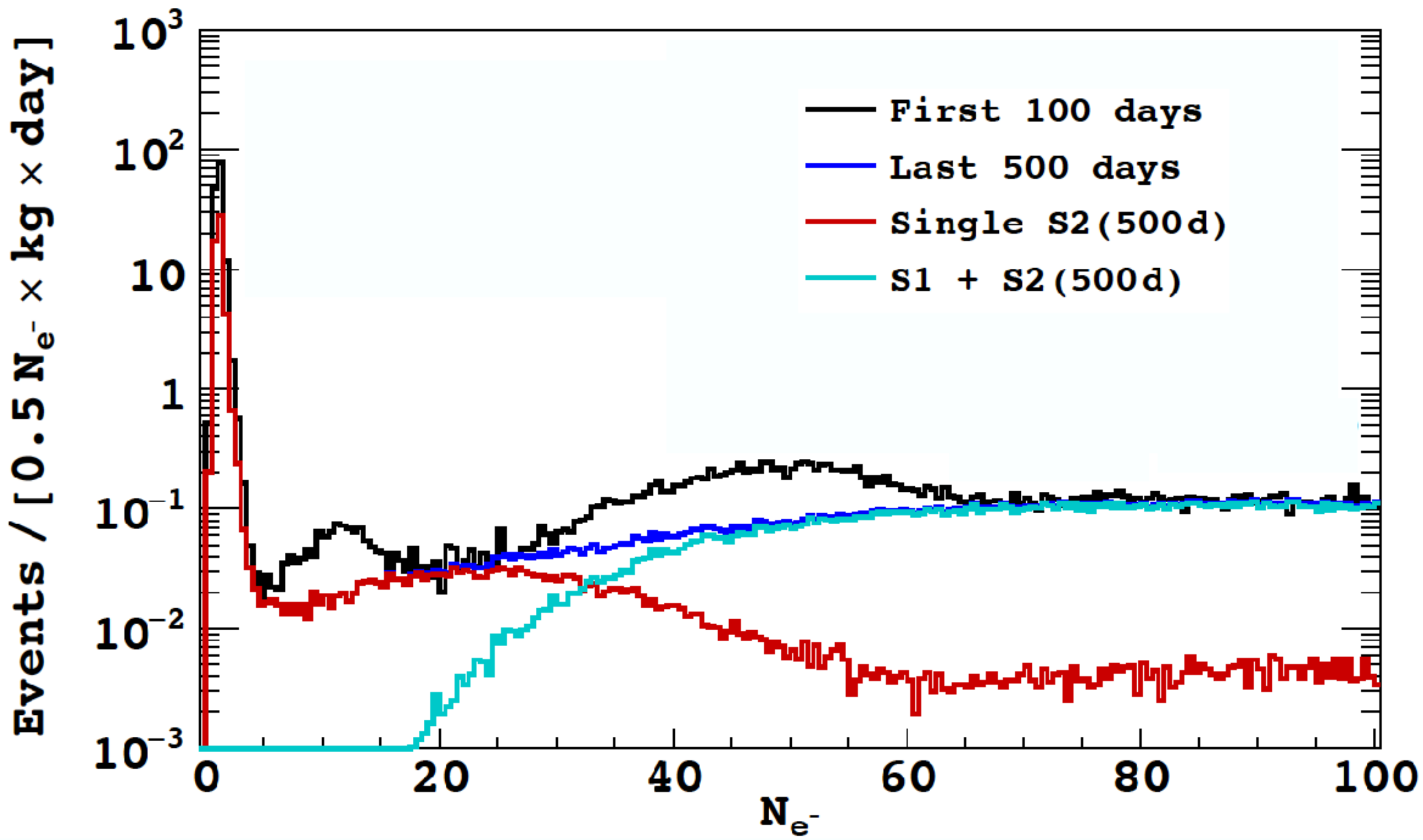
Heavy WIMP sensitivity and 90% exclusion limits

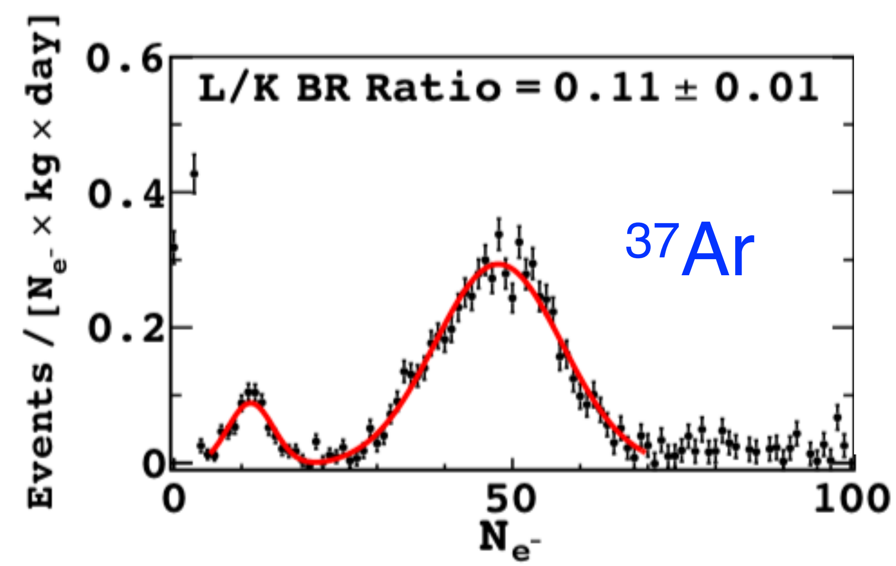


- degraded

arXiv:1802.07198

S2-only analysis

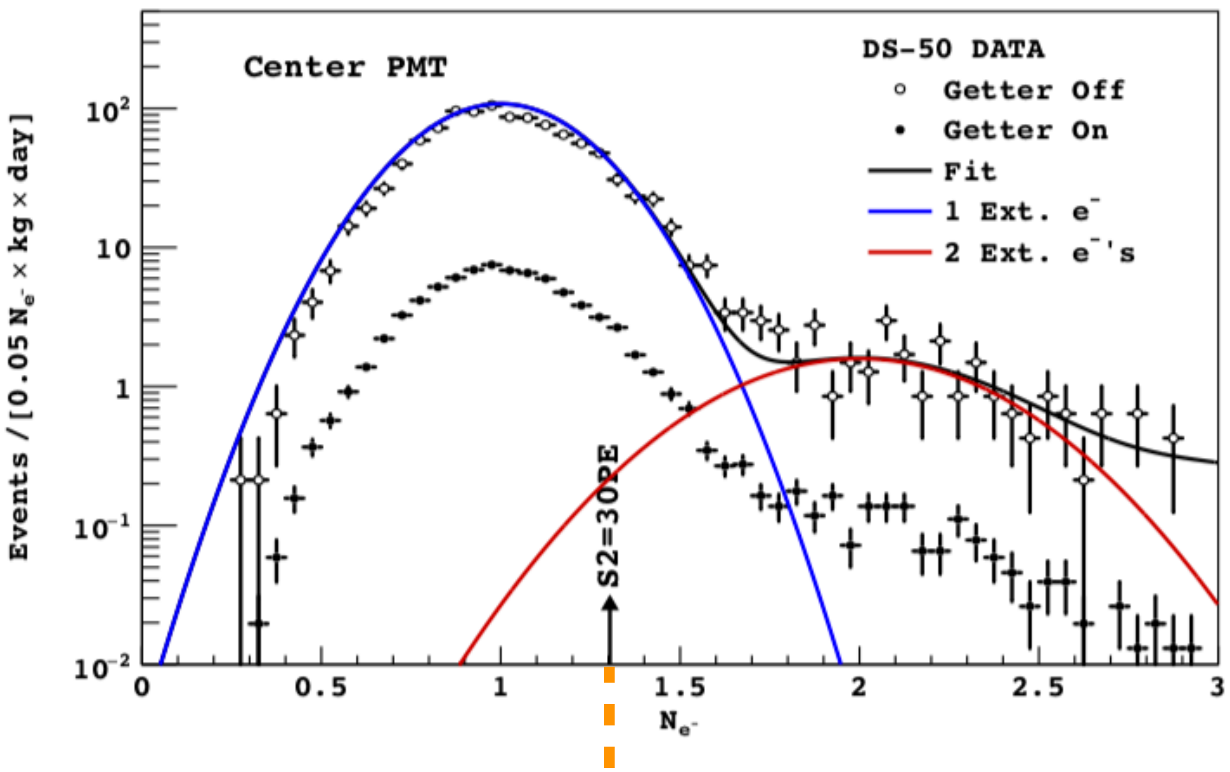




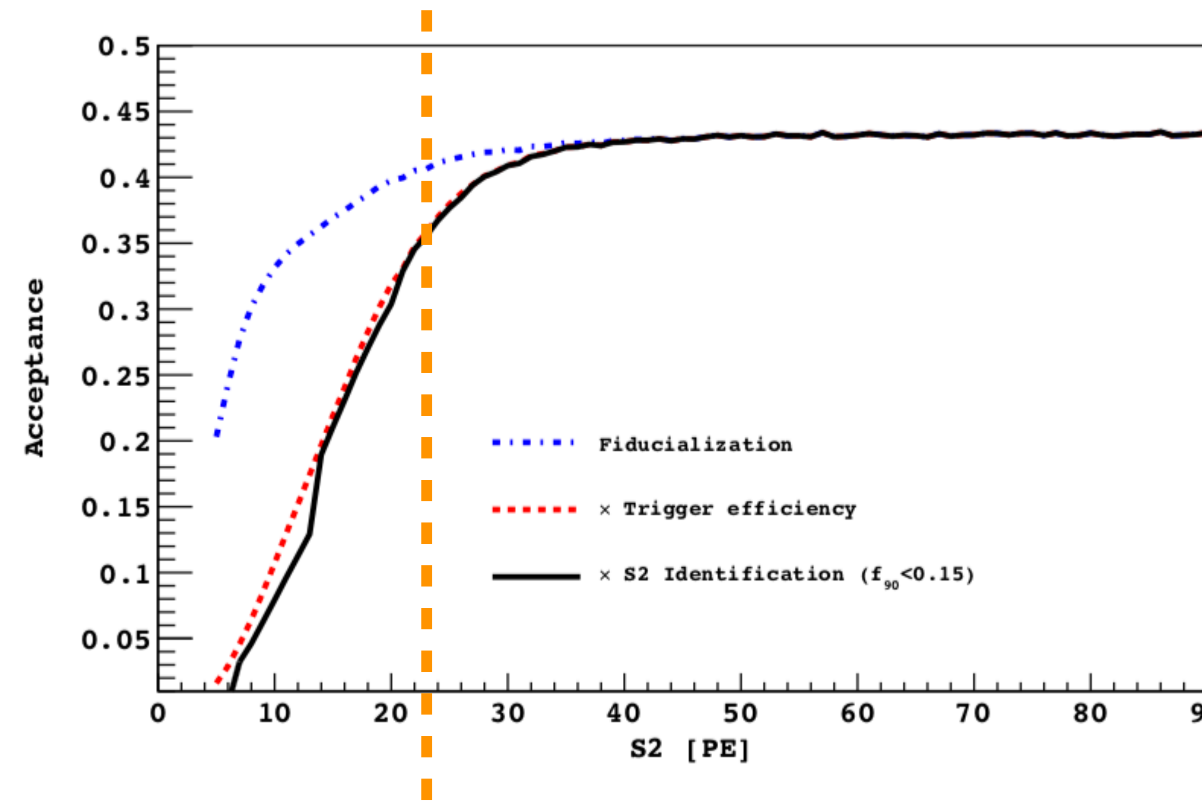
- give up S1 signal and PSD
- lower detection threshold to single electrons
- sensitivity to lower mass dark matter (with background)

arXiv:1802.06994 (to appear in PRL)

Single electron sensitivity



30 p.e.

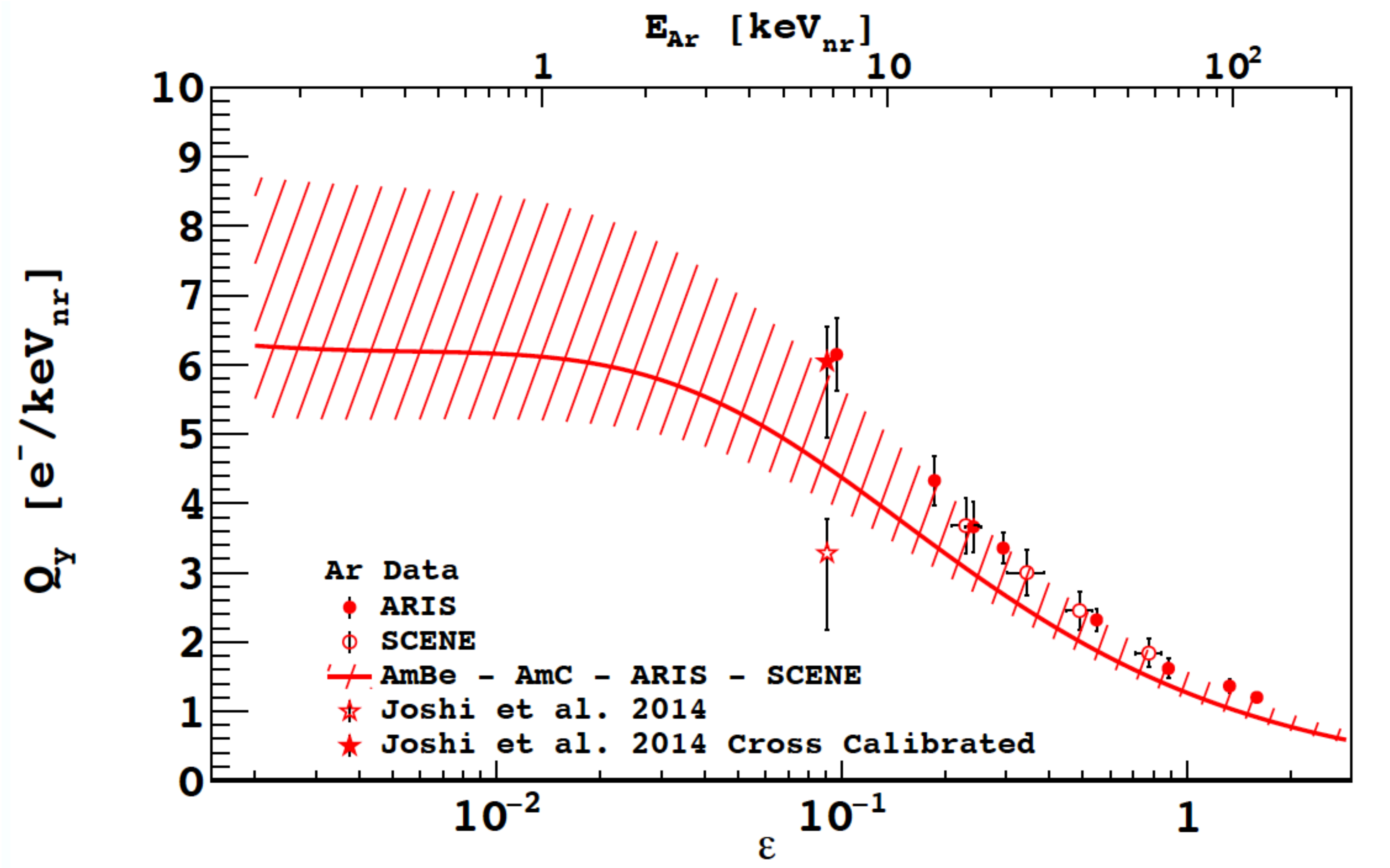


single electron

- electron signal clearly quantized down to single electron
- ~23 p.e./electron along the axis of the detector

arXiv:1802.06994 (to appear in PRL)

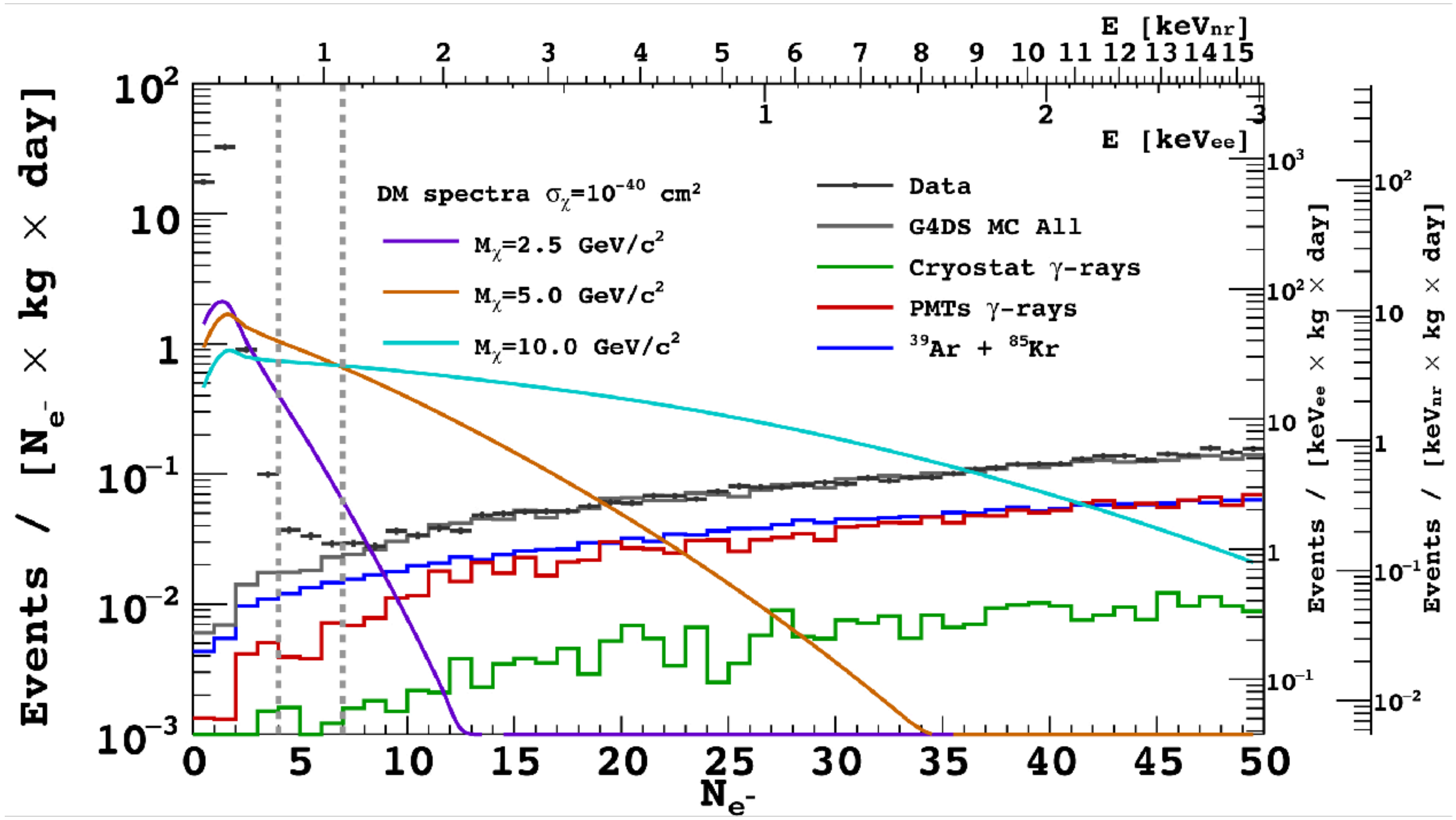
Lighter (1-10 GeV) WIMPs: ionization yield fro NR



- 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)

Lighter (1-10 GeV) WIMPs: signal vs. background

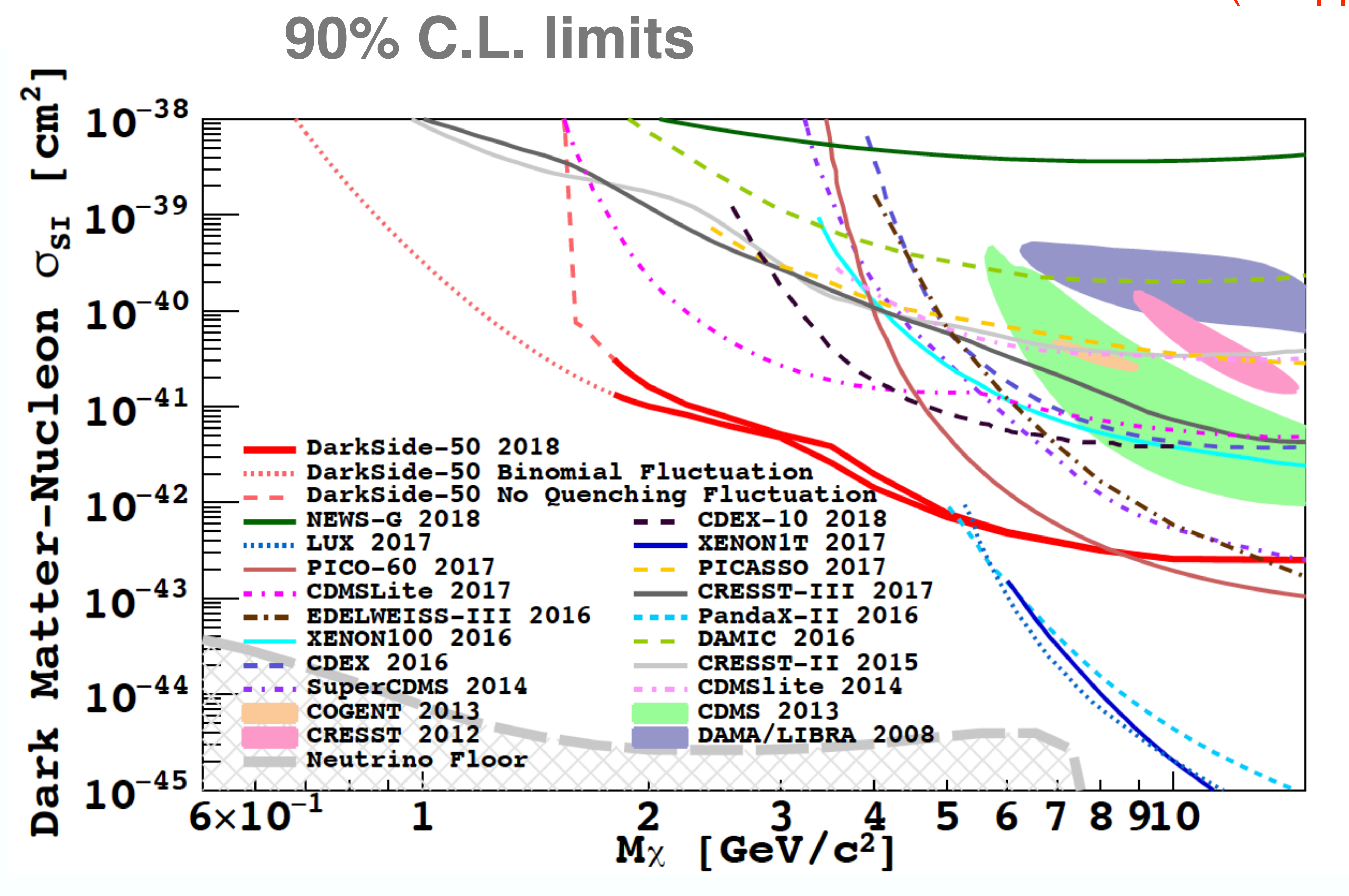


- Background measured over a much wider energy range accounts for event rate well down to several electrons
- Expected signal assumes standard DM halo
- Uncertainties in signal dominated by fluctuations in ionization yield (width of ionization distribution in LAr unknown)

arXiv:1802.06994 (to appear in PRL)

S2-only spin-independent DM-nuclear interaction

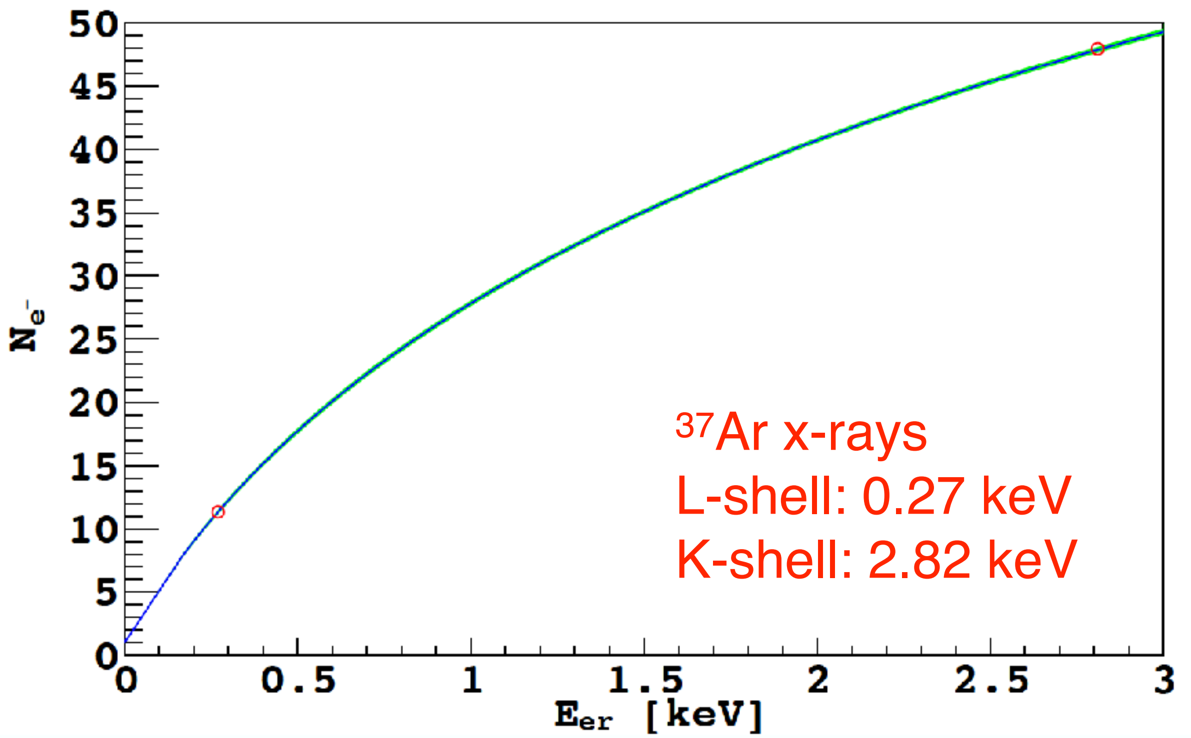
arXiv:1802.06994 (to appear in PRL)

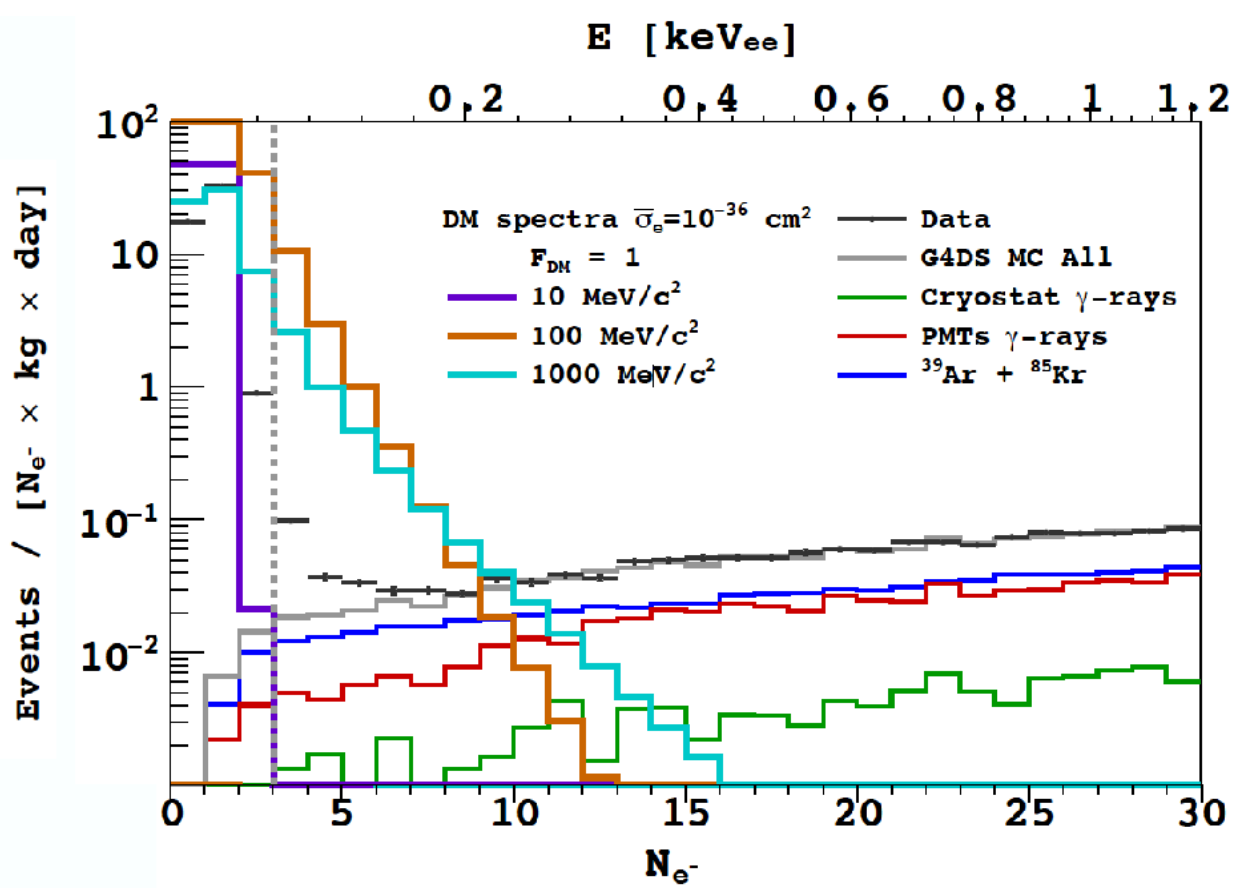


- Two cases: no quenching fluctuations and binomially distributed fluctuations

sub-GeV DM: electron recoils, spectra, background

arXiv:1802.06994



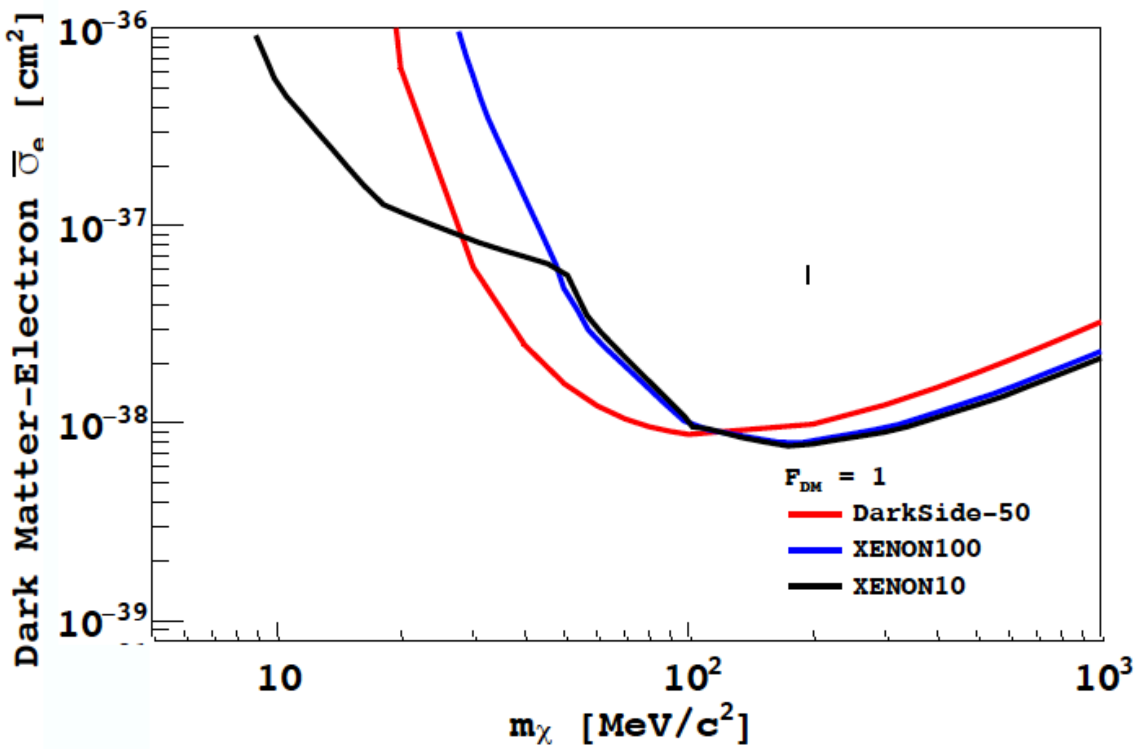


- DM-electron interaction parametrized by a DM form factor with two limiting values (heavy and light mediator)

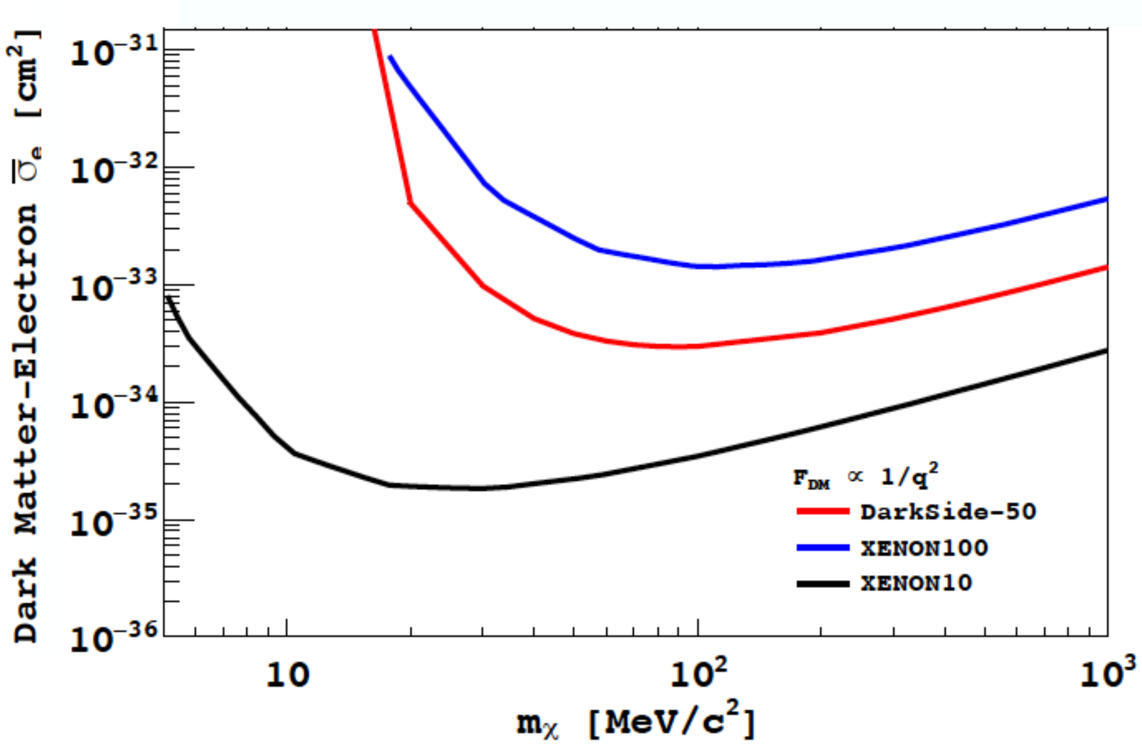
$$|F_{\rm DM}(q)|^2 = \begin{cases} 1, & m_{\rm med} \gg \alpha m_e \\ (\alpha m_e/q)^4, & m_{\rm med} \ll \alpha m_e\,, \end{cases}$$

DM-electron 90% C.L. limits

arXiv:1802.06994

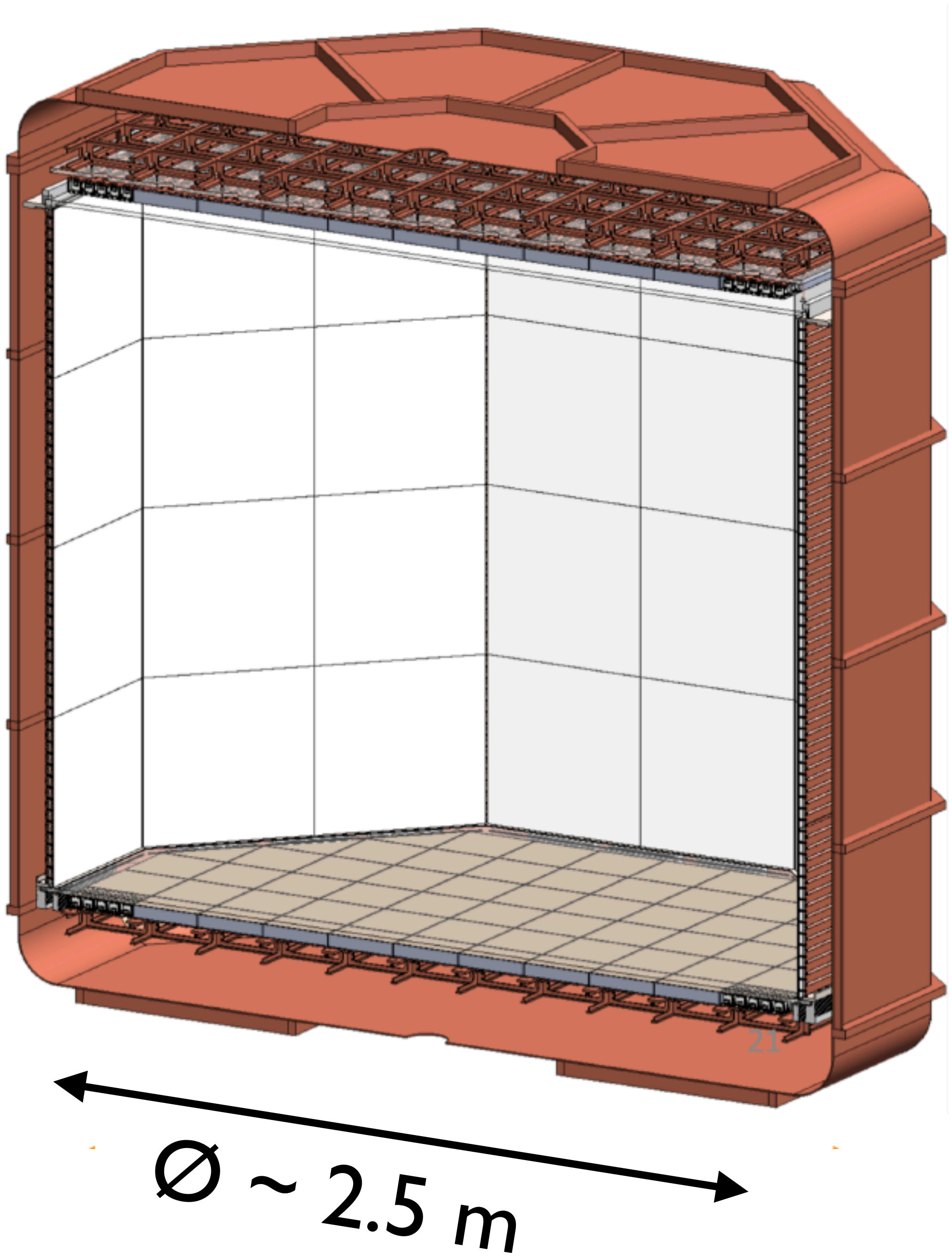


- Heavy mediator
- DS-50 has competitive sensitivity in the 25-100 MeV DM mass range



- Light mediator
- XENON10 has best sensitivity

Beyond DS-50: DS-20k and GADMC



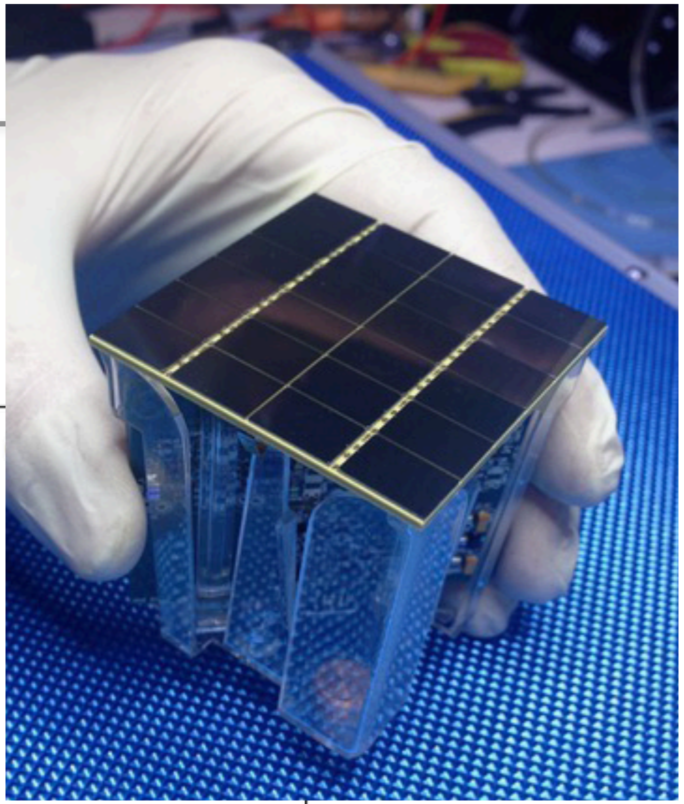
DarkSide-20k at Gran Sasso

- 50-tonne LAr dual-phase TPC
- 30 tonnes fiducial
- 20 m^2 of SiPM scintillation detecting surface
- background-free:
  <0.1 'instrumental' background event in 100 tonne-year exposure

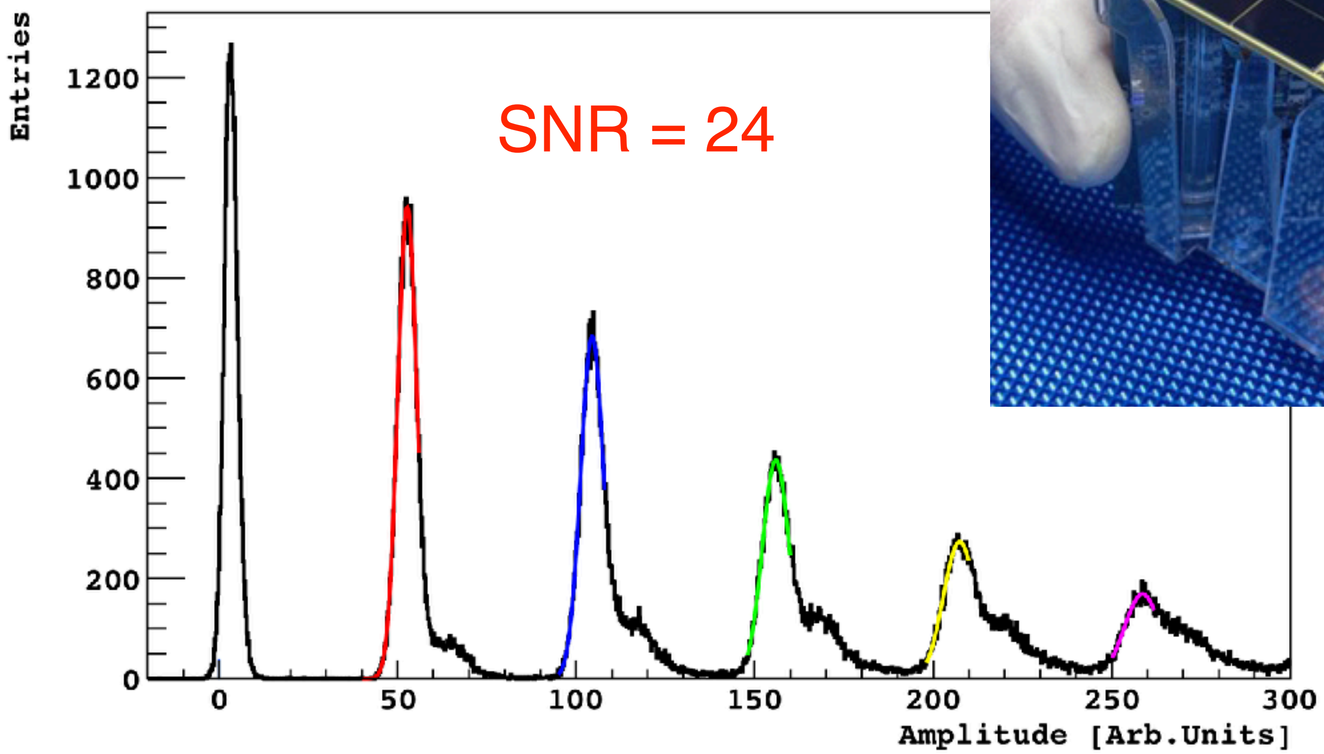
GADMC

- merger of all existing LAr dark matter experiments

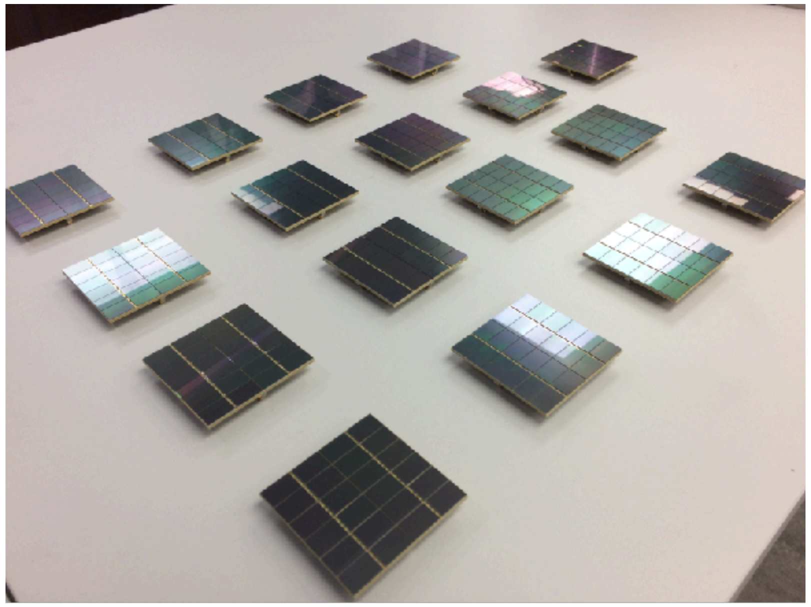
SiPM modules: a replacement for PMTs

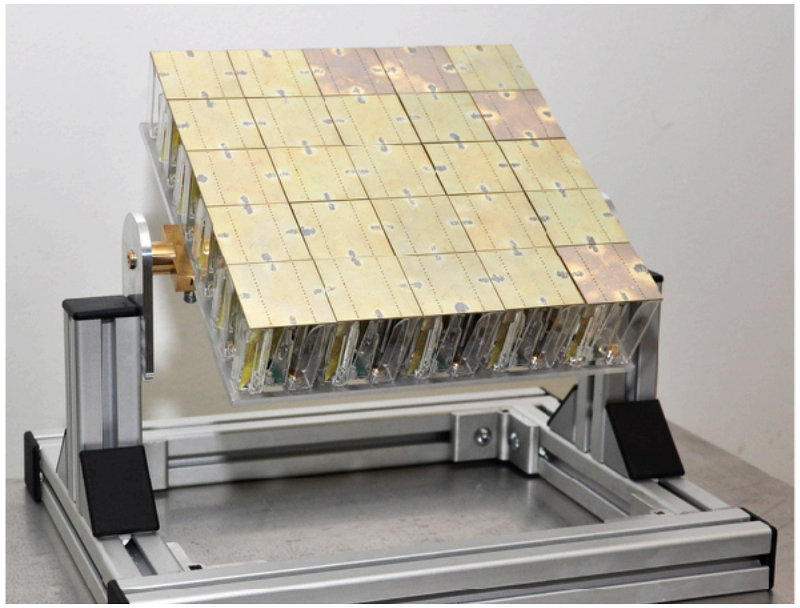


- 5×5 cm² single-channel modules (array of 24 SiPMs)



- PDE > 40%
- <10 ns timing resolution
- <250 Hz dark rate
  + correlated noise
  (cryogenic electronics)
- compact and radio-clean





- 50 modules under way
- 400 will follow in 2019

Low-radioactivity Argon procurement and purification

URANIA

- extraction plant in Cortez, Colorado
- ~250 kg/day of low-39Ar argon

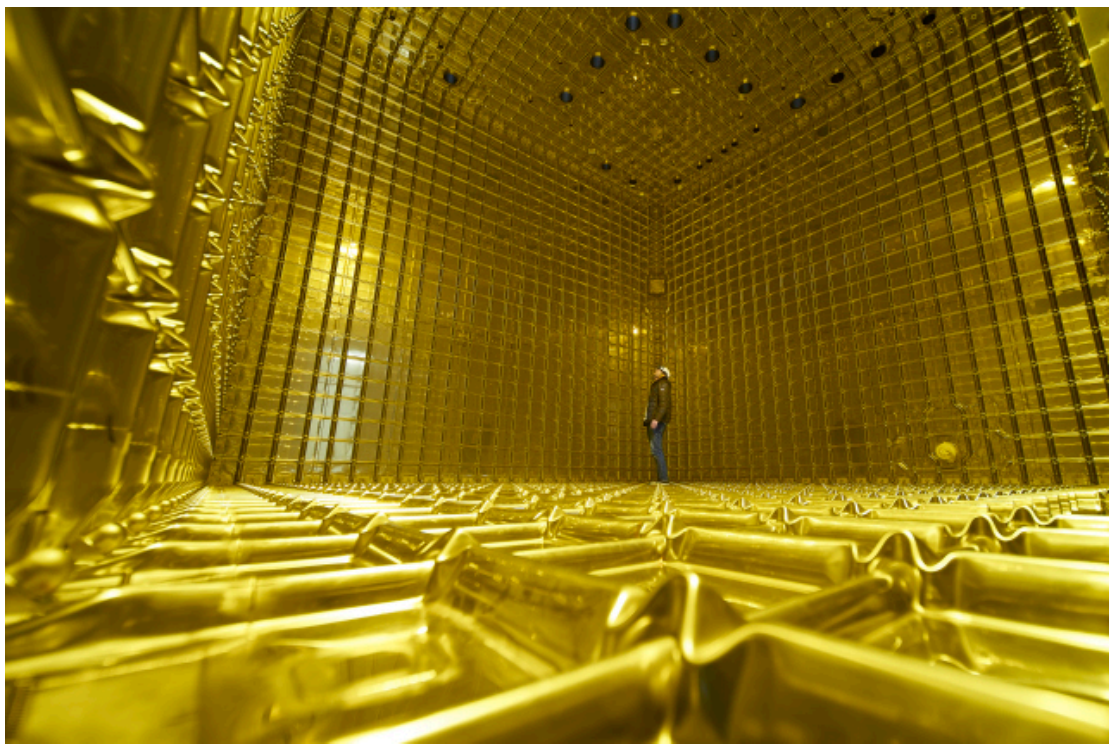
ARIA

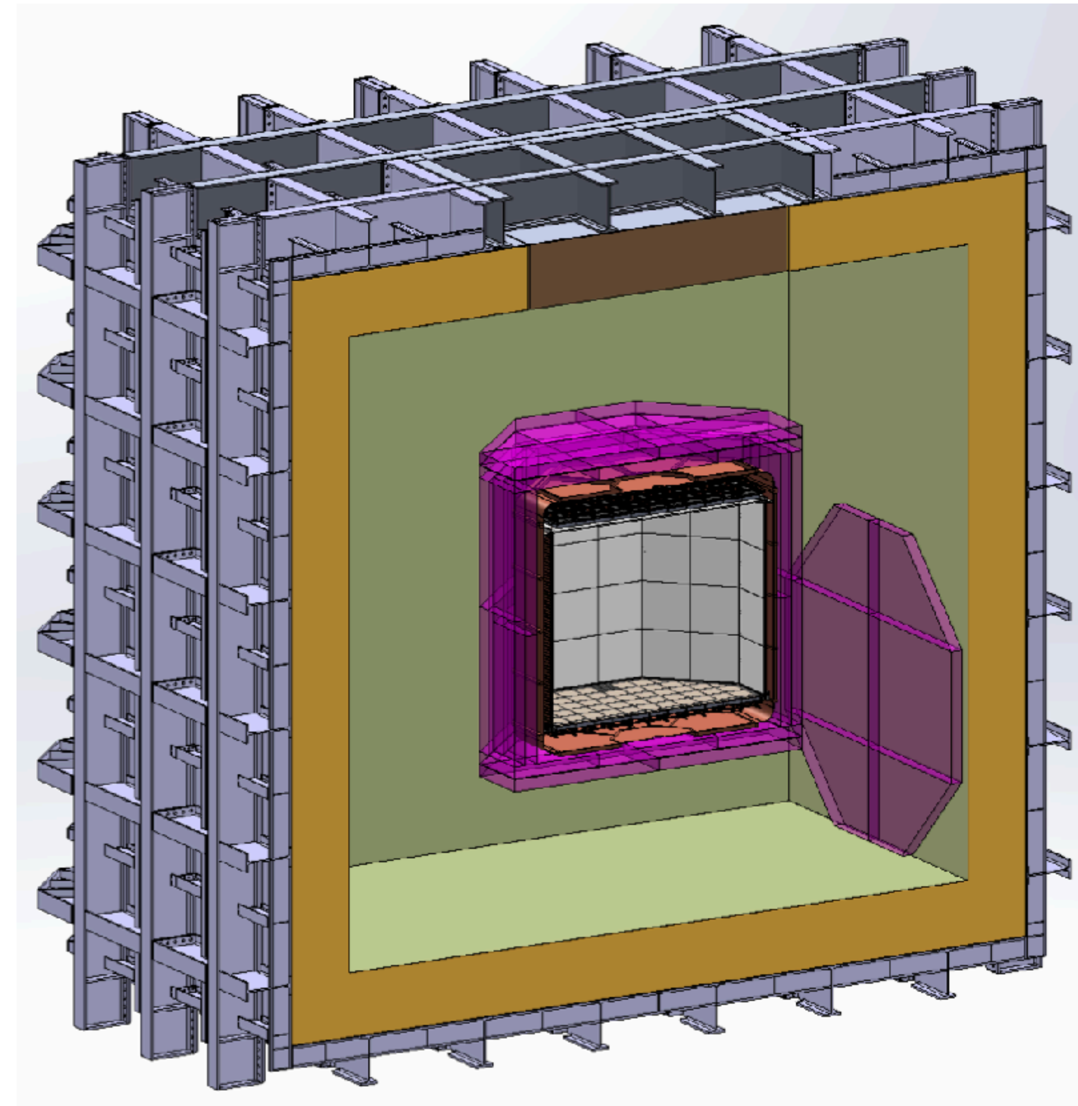
- distillation plant in Seruci, Sardinia
- purification of UAr from, e.g., krypton
- further isotopic depletion

- 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

ProtoDUNE cryostat



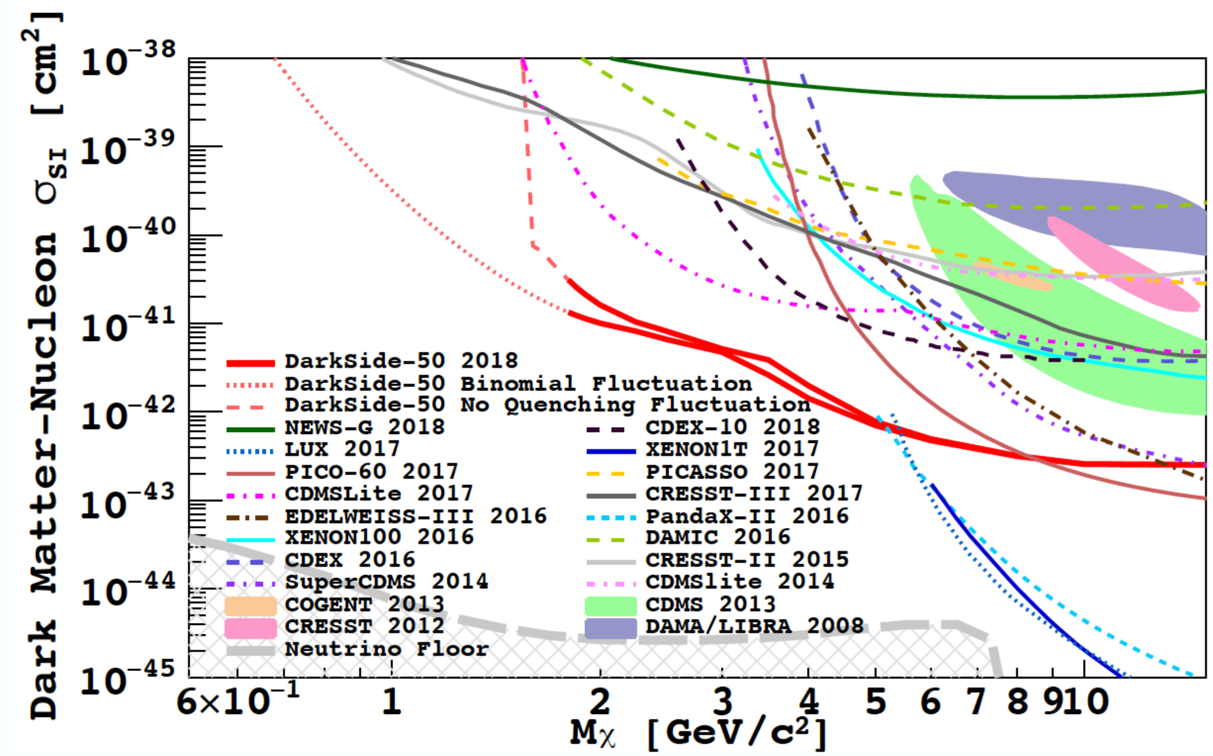


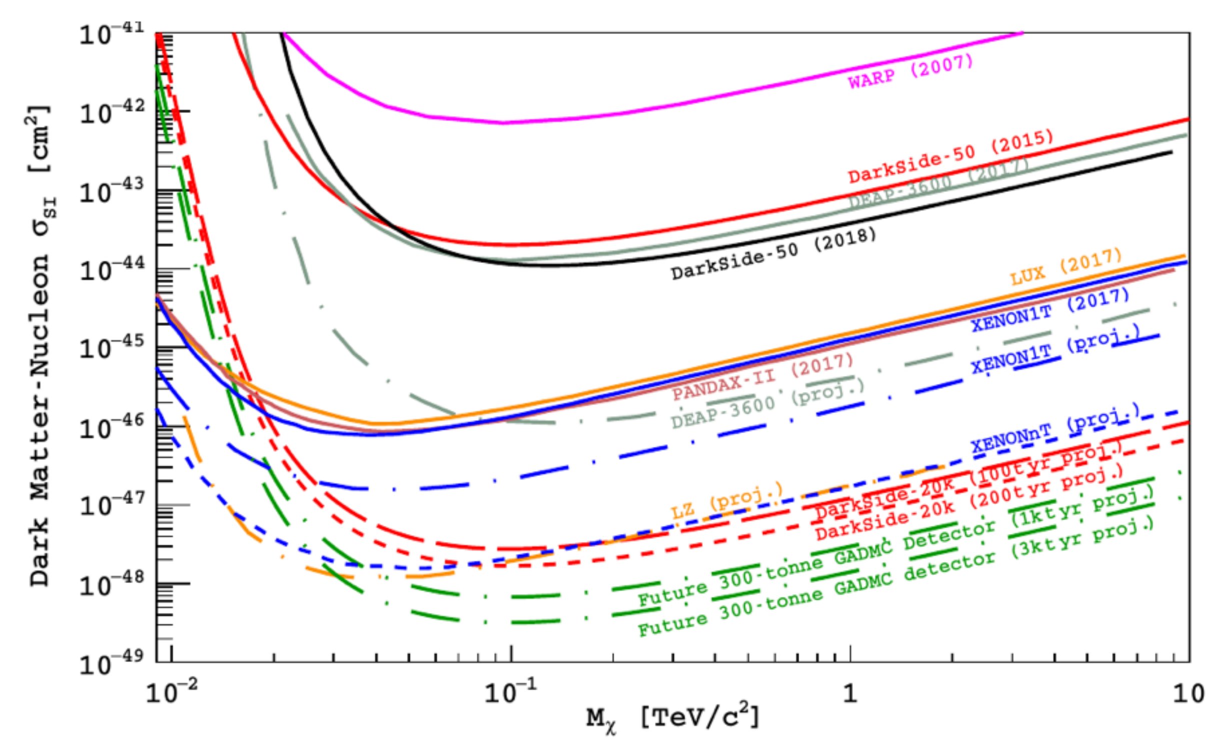
- no double cryostat (radioactivity reduction)
- plastic scintillator as neutron veto under study

Conclusions and Outlook

stay hungry, my friend

- *LAr TPC technology is proven competitive for a wide range of WIMP masses for*
  - *best sensitivity for 1.8-5.5 GeV*
  - *bg-free for >10 GeV*
- *Ambitious dark matter search program with the Global Argon Collaboration*
  - *DarkSide-20k @ LNGS (tens bg-free tonne-year exposure)*
  - *Future massive detector ~ ktonne-year exposure (possibility of neutrino physics)*
- *DarkSide offers a program of discovery multi-messenger astro-physics, complementary to (and beyond in mass) the reach LHC searches.*



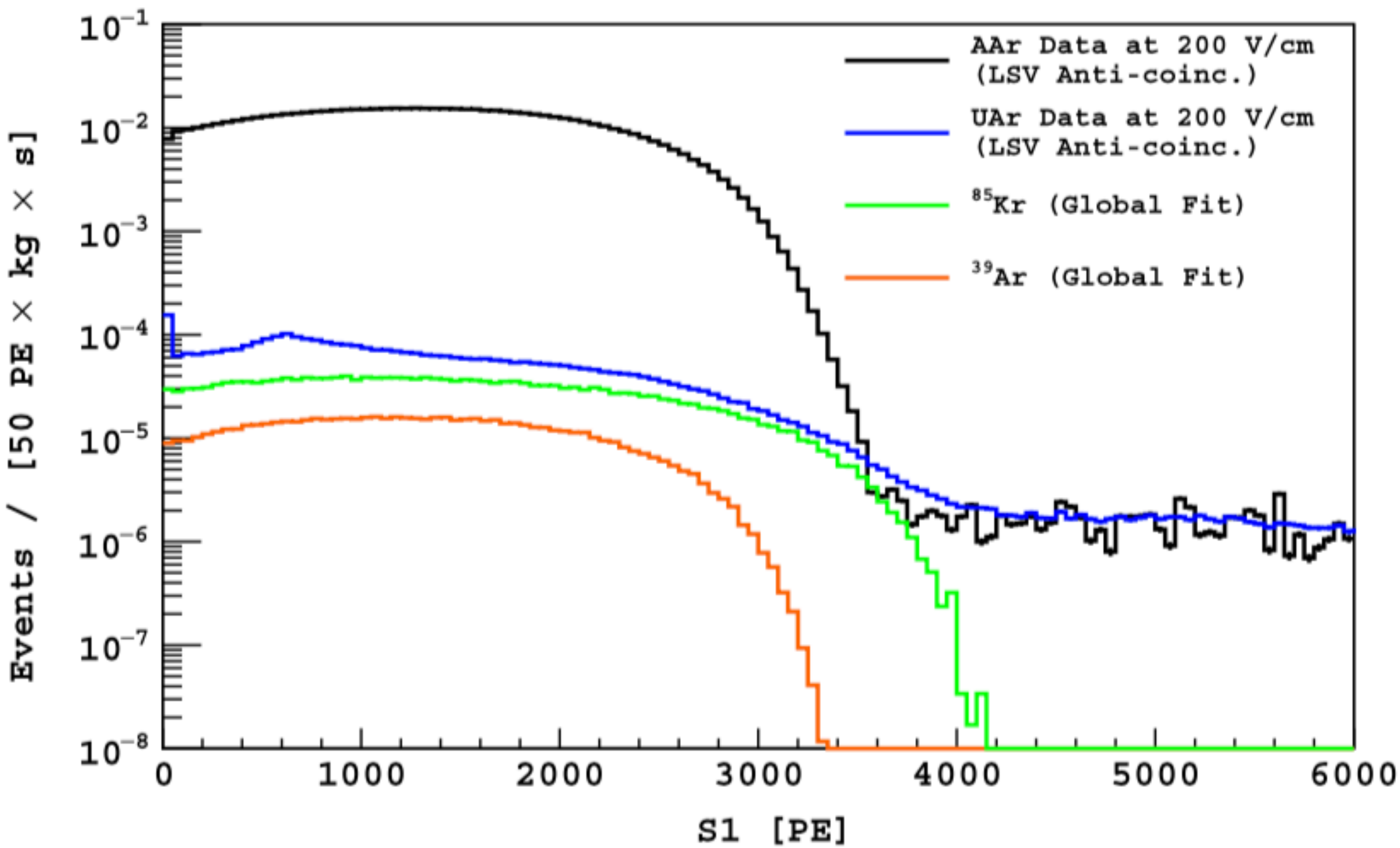


MẶT TỐI

extra slides

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

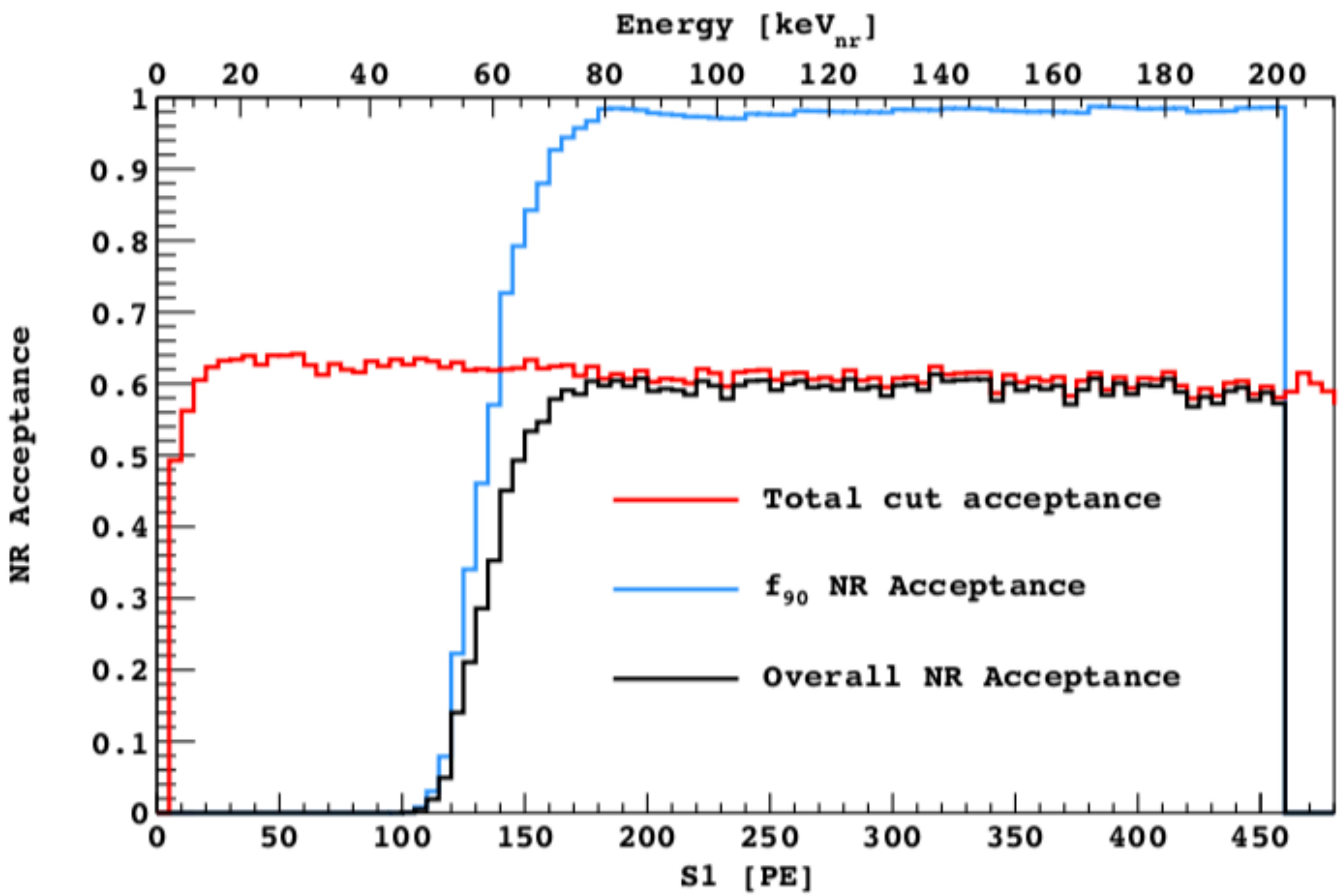
200 V/cm drift field



PRD 93, 081101(R) (2016)

Acceptance

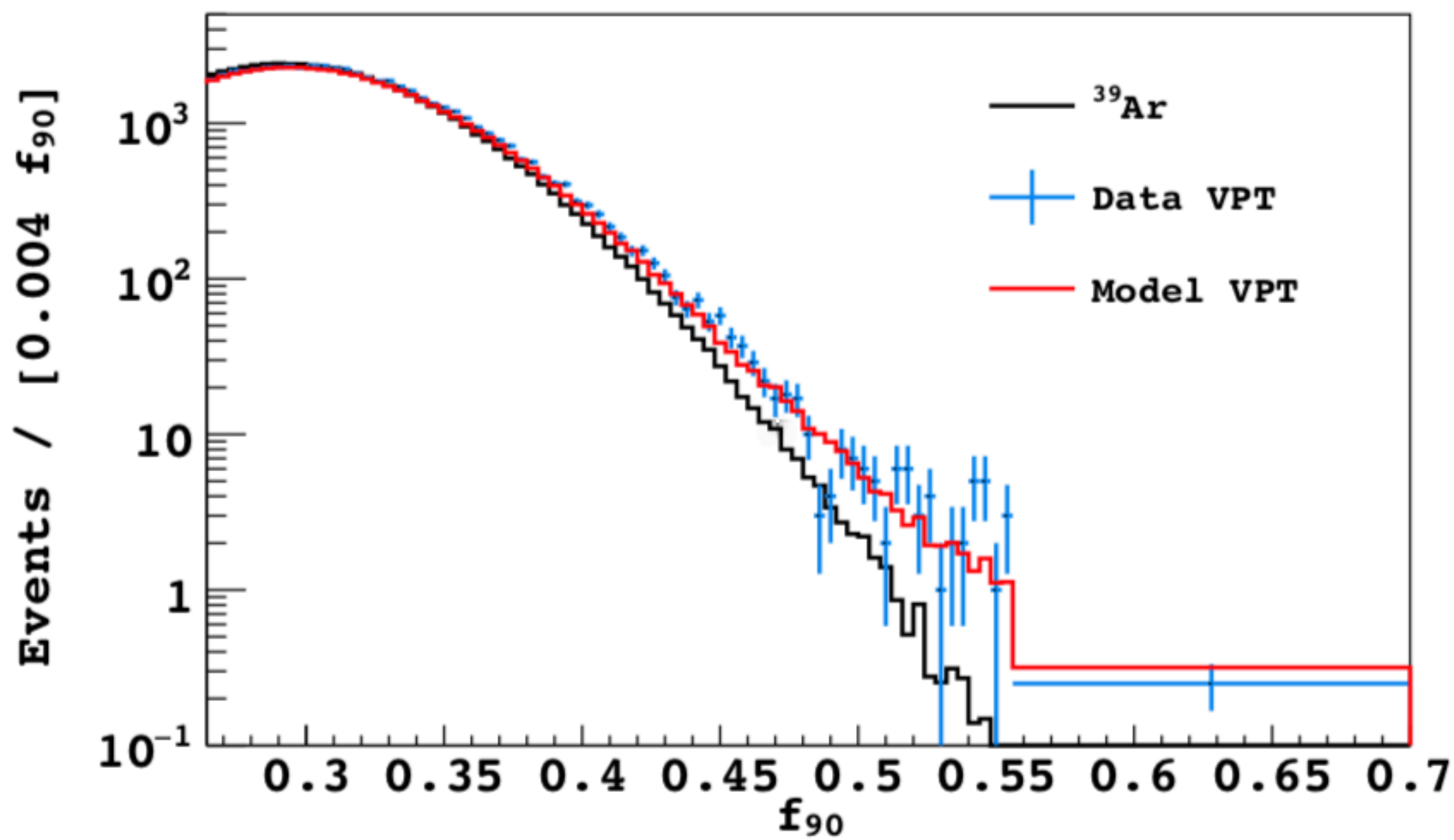
- NR energy scale cross-calibrated with SCENE



arXiv:1802.07198

f90

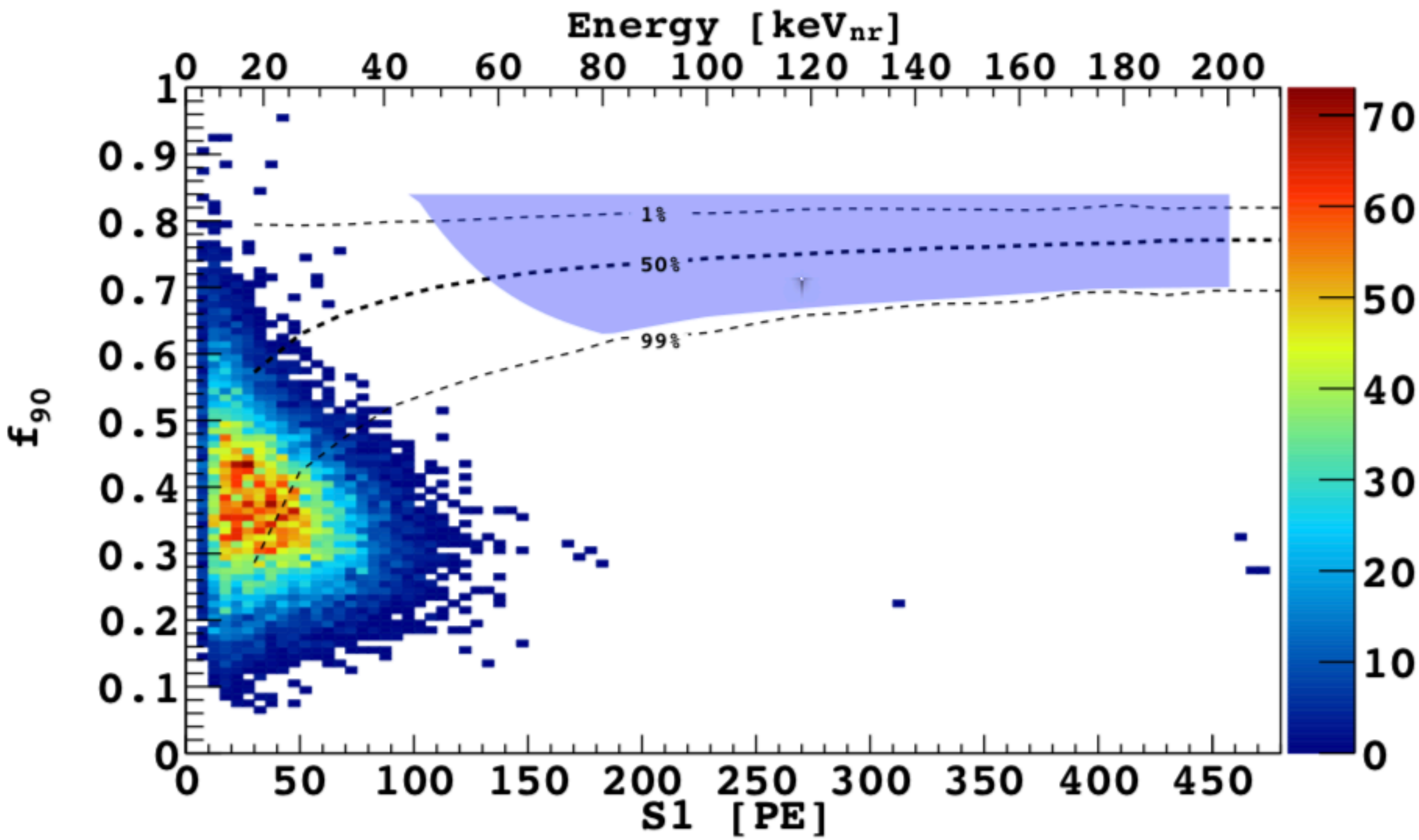
- normalization of simulation is absolute, using measured radioactivity values



arXiv:1802.07198

Acceptance

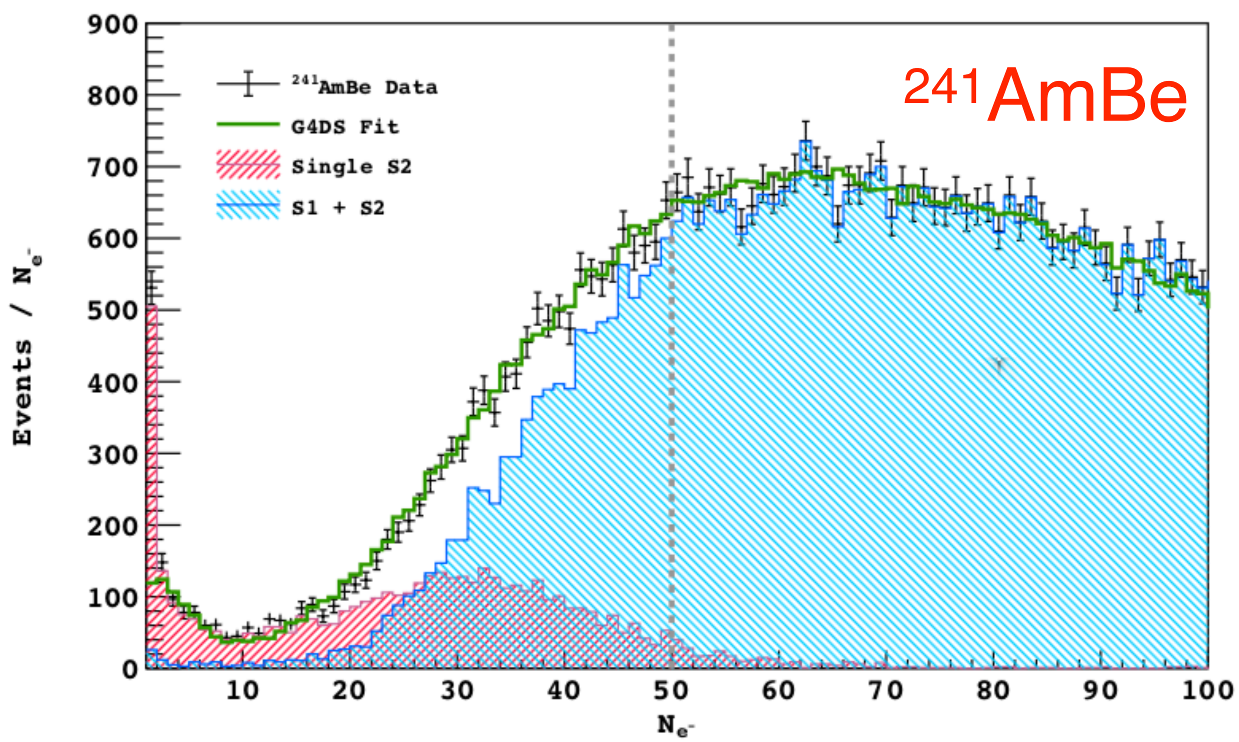
- All analysis cuts + tightened radial cut + S2/S1 cut

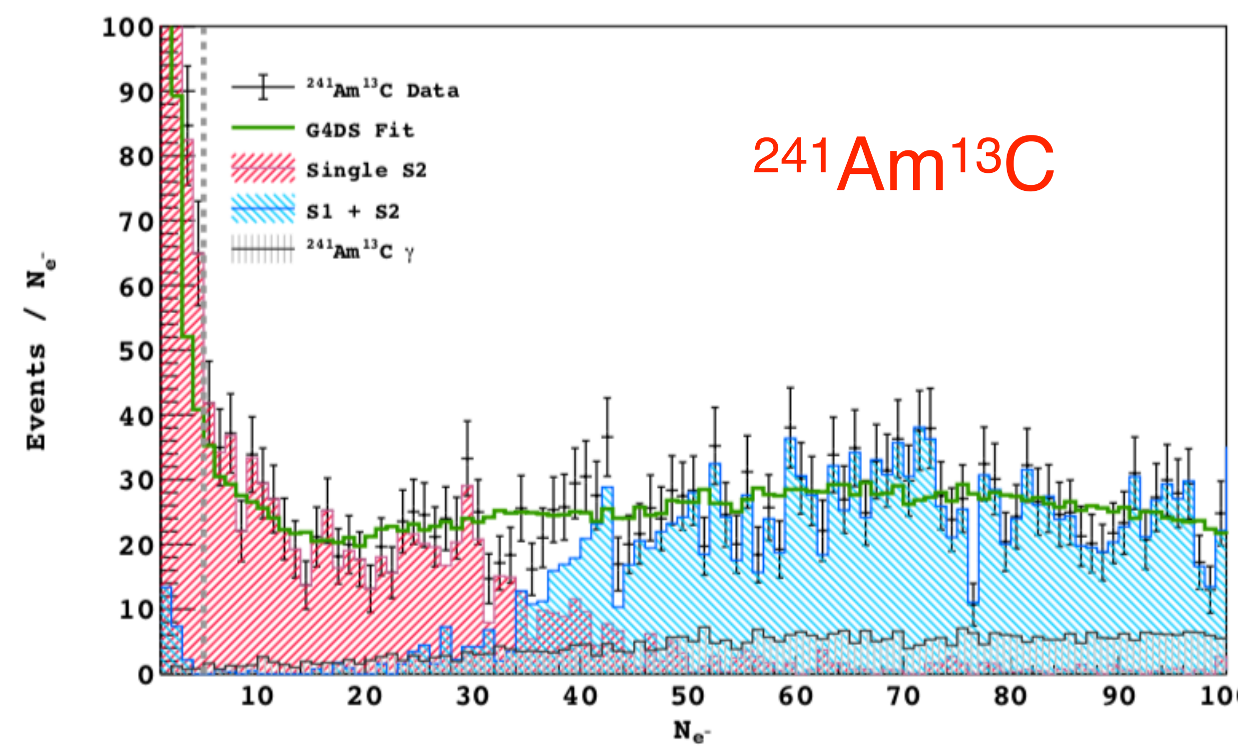


arXiv:1802.07198

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%*

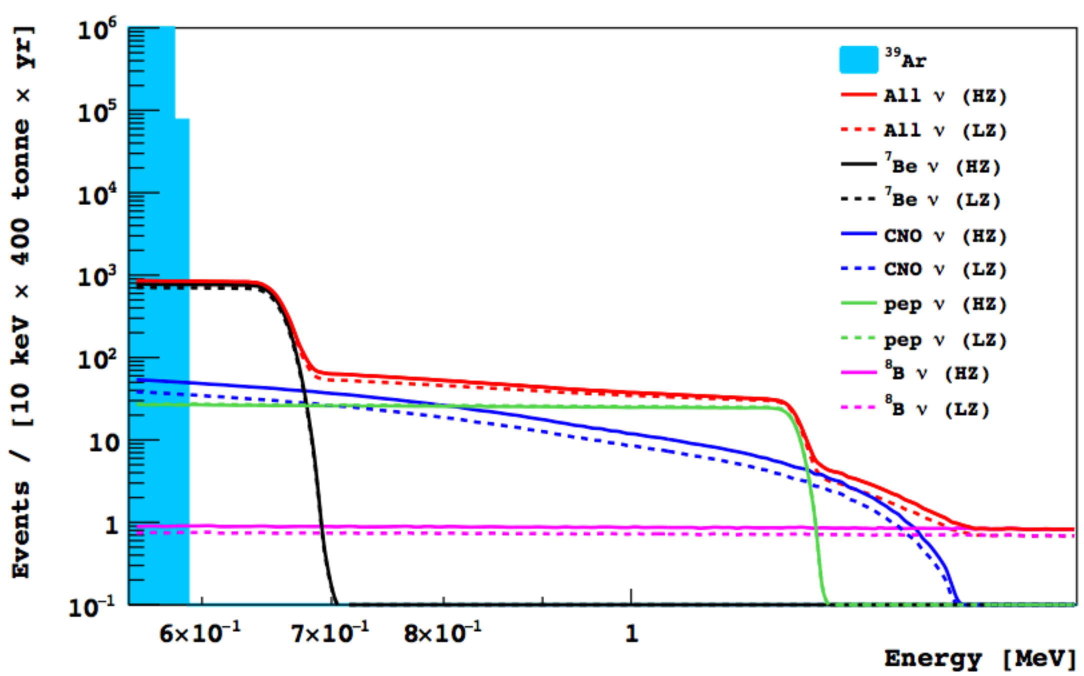


Figure 1. Simulated solar neutrino spectra in a 400 tonne-yr LAr TPC exposure, assuming σ =1.3% energy resolution at 1 MeV, corresponding to a PE yield of 6 PE/keV. The blue shaded area represents the tail of the ^{39}Ar contamination, intrinsic to underground LAr.

^{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]