Depleted Argon for Dark Matter Searches

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La Biodola
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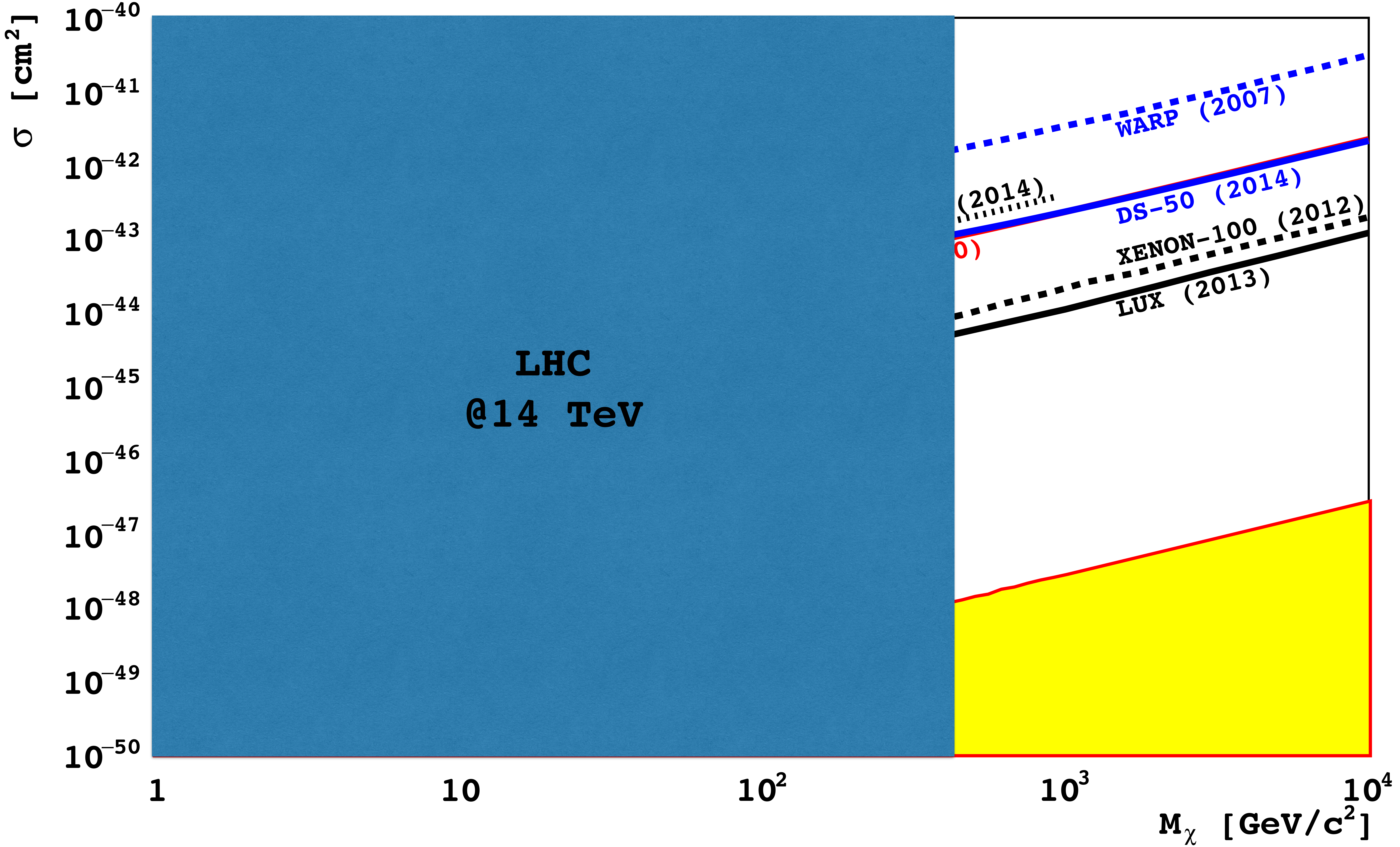
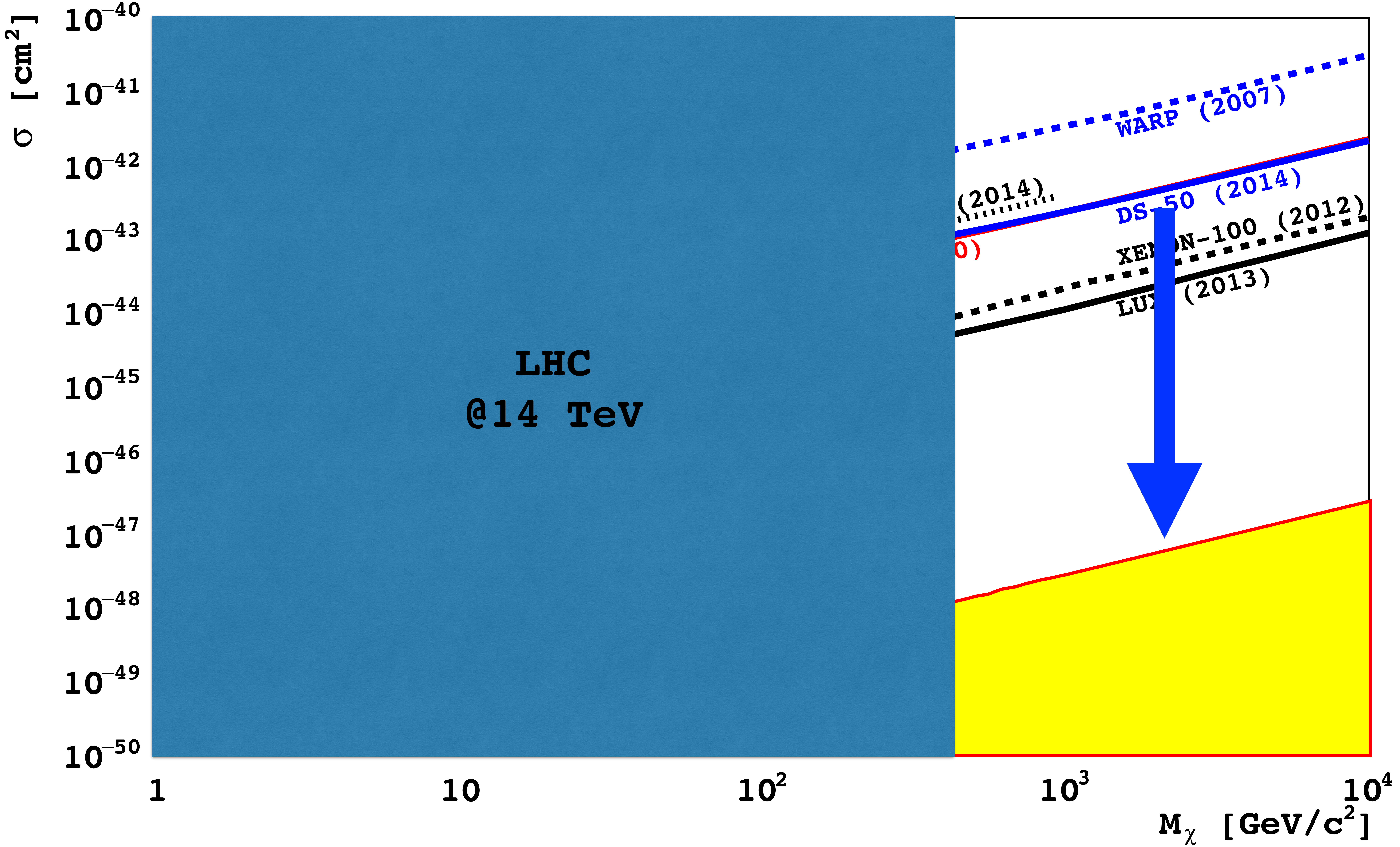
third best dark matter limit at high masses
σ [cm²]
10⁻⁴⁰
10⁻⁴¹
10⁻⁴²
10⁻⁴³
10⁻⁴⁴
10⁻⁴⁵
10⁻⁴⁶
10⁻⁴⁷
10⁻⁴⁸
10⁻⁴⁹
10⁻⁵⁰
1
10
10²
10³
10⁴
M_χ [GeV/c²]
WARP (2007)
PandaX-I (2014)
DS-50 (2014)
CDMS (2010)
XENON-100 (2012)
LUX (2013)
Neutrino Limit

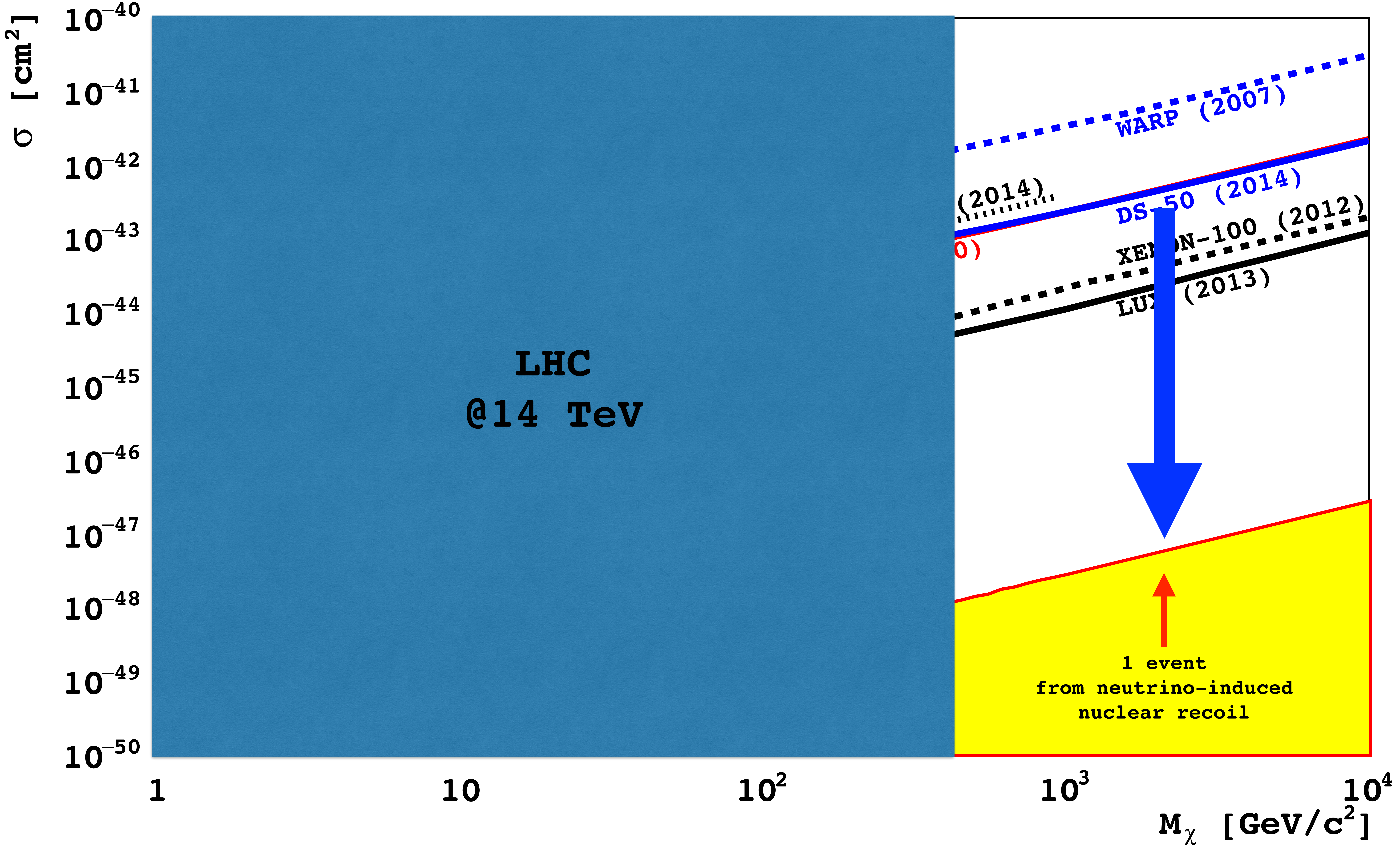
third best dark matter limit at high masses



third best dark matter limit at high masses



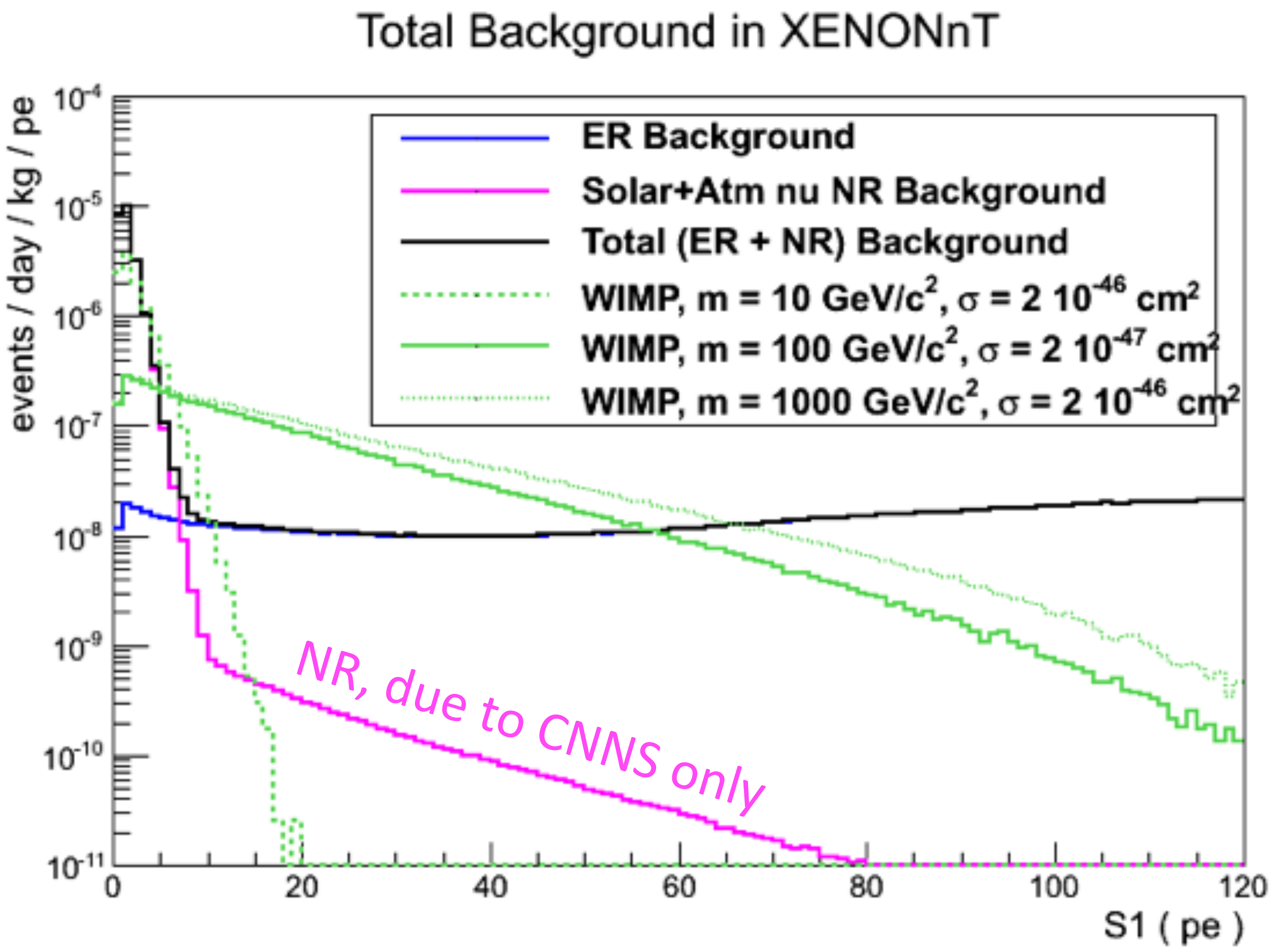
third best dark matter limit at high masses



What does it take?

- ~500 tonnes×year exposure
  - 400 tonnes×year for argon, 300 tonnes×year for xenon
- By the way, it has to be background free

XENONnT Backgrounds



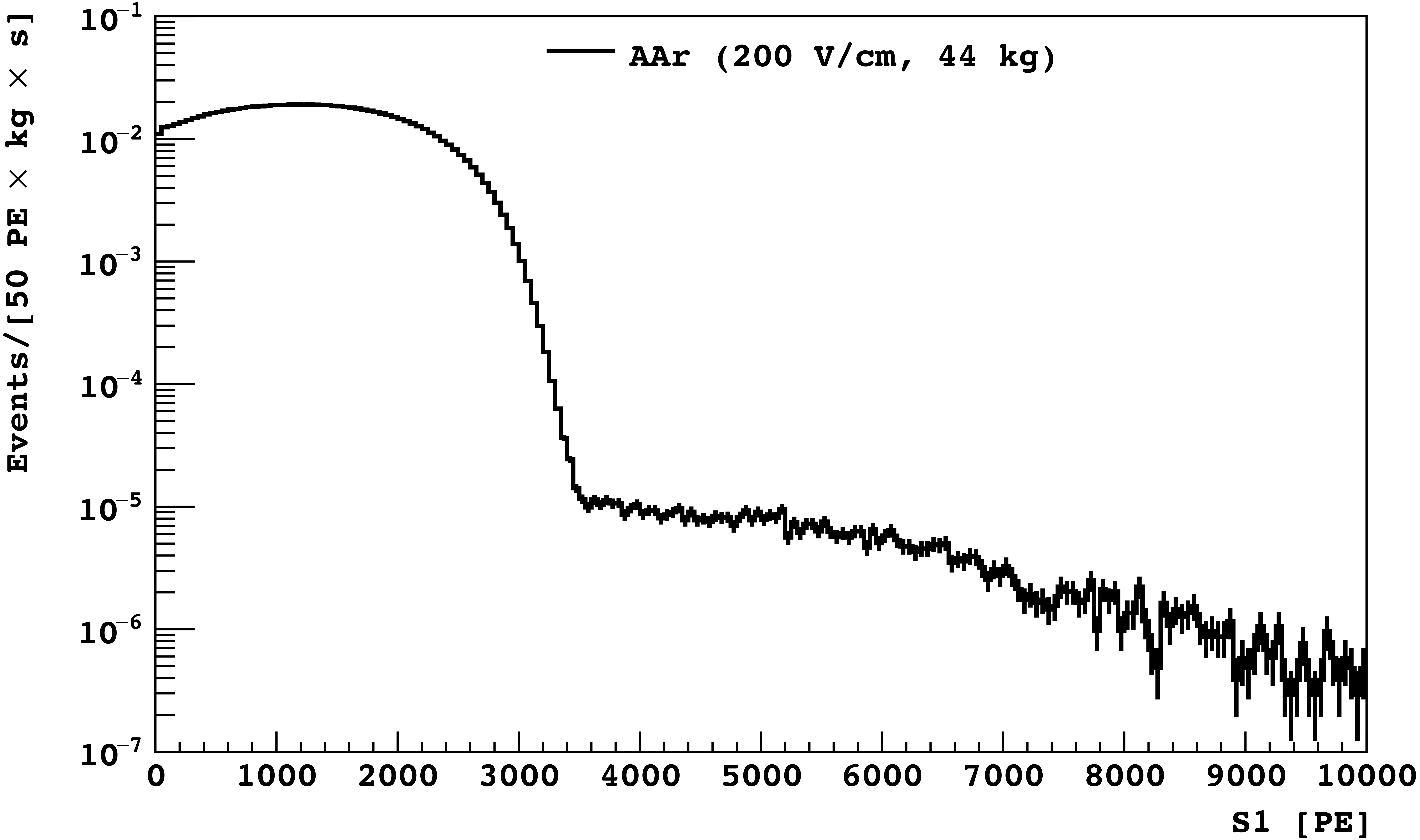
S1 in [3, 70] pe,
ER discrimination 99.75%,
NR acceptance 40%.

ER:
- negligible materials radioactivity
- 0.2 ppt Kr/Xe and 1 microBq/kg Rn-222, as in XENON1T
- solar neutrino elastic scattering

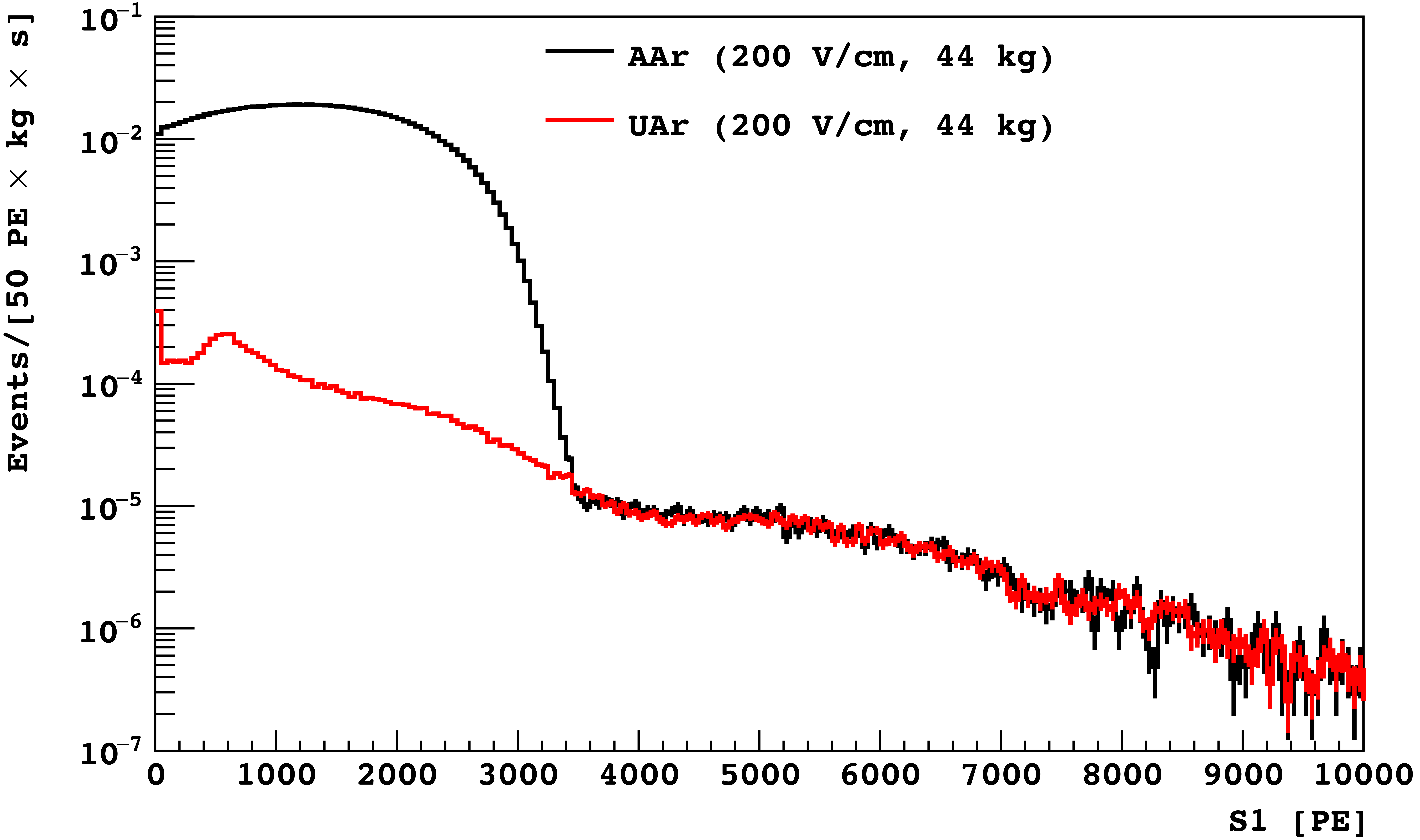
NR:
- negligible n-background
- neutrino coherent scattering

Source	Background (ev. / ton / y)
ER (intrinsic + solar ν)	*0.27*
NR from neutrino coherent scattering	*0.55*
Total	*0.82*

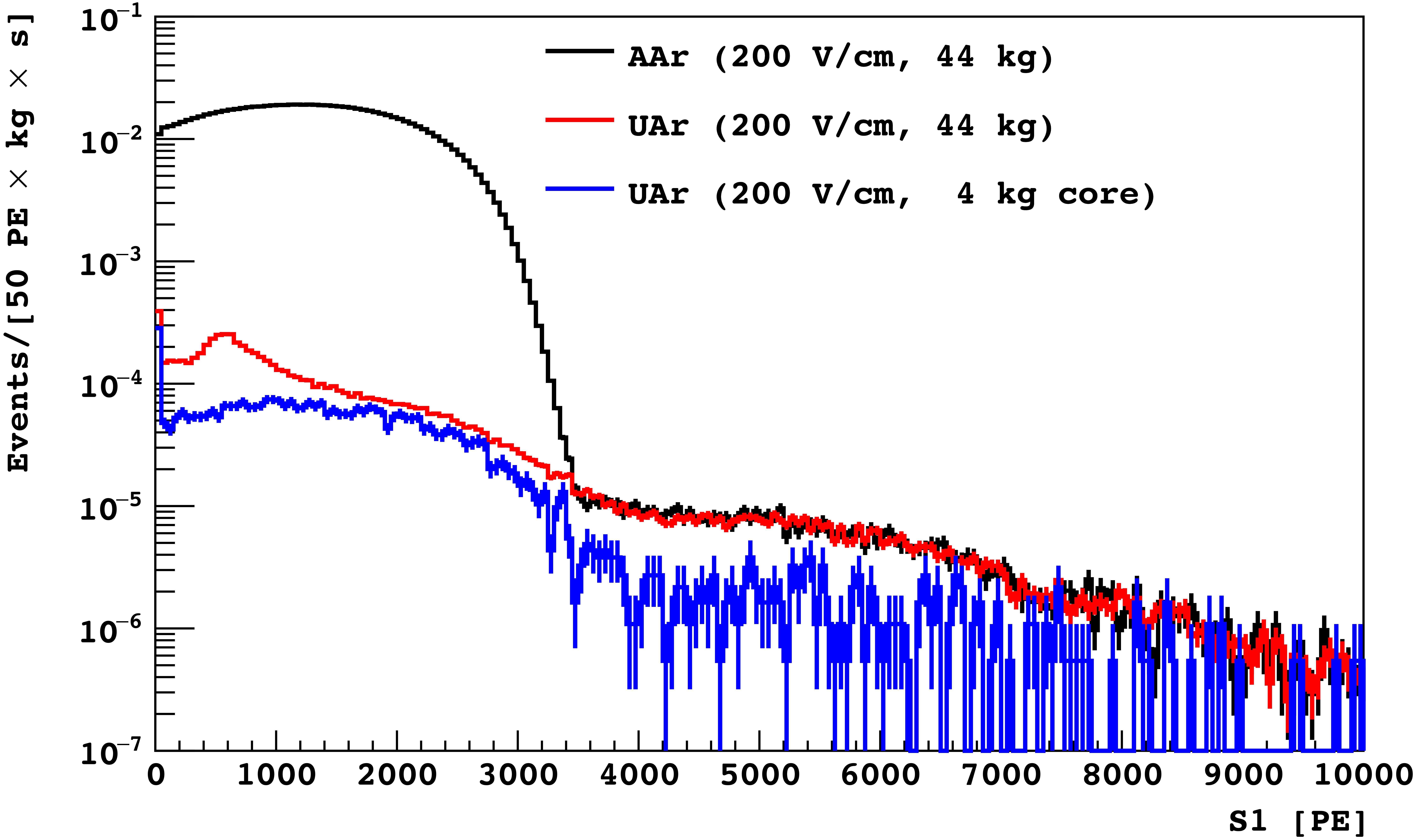
1,422 kg×day - zero background - S1 only
f90
S1 [PE]
50%
65%
80%
90%
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
100
150
200
250
300
350
400
450
0
5000
10000
15000
20000
25000
30000
35000



AAr (200 V/cm, 44 kg)
Events/[50 PE × kg × s]
S1 [PE]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000



AAr (200 V/cm, 44 kg)
UAr (200 V/cm, 44 kg)
Events/[50 PE × kg × s]
S1 [PE]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000



AAr (200 V/cm, 44 kg)
UAr (200 V/cm, 44 kg)
UAr (200 V/cm, 4 kg core)
Events/[50 PE × kg × s]
S1 [PE]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000

Experiment	σ [cm^2] @1 TeV/c^2	σ [cm^2] @10 TeV/c^2
LUX [10k kg×day Xe]	1.1×10^{-44}	1.2×10^{-43}
XENON [7.6k kg×day Xe]	1.9×10^{-44}	1.9×10^{-43}
DS-50 [1.4k kg×day Ar]	2.3×10^{-43}	2.1×10^{-42}

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DS-50 [1.4k kg×day Ar]	2.3×10^{-43}	2.1×10^{-42}
ArDM [1.5 tonne×yr Ar]	8×10^{-45}	7×10^{-44}
DEAP-3600 [3.0 tonne×yr Ar]	5×10^{-46}	5×10^{-45}
XENON-1ton [2] [2.7 tonne×yr Xe]	3×10^{-46}	3×10^{-45}
LZ [1] [15 tonne×yr Xe]	5×10^{-47}	5×10^{-46}

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DS-20k [100 tonne×yr]	9×10^{-48}	9×10^{-47}

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ARGO [1,000 tonne×yr]	9×10^{-49}	9×10^{-48}

^{39}Ar Rejection

1,422 kg×day (@AAr)

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1,422 kg×day (@AAr)

x 300
(^{39}Ar AAr/^{39}Ar UAr)

already achieved

1 tonne×yr (UAr)

^{39}Ar Rejection

1,422 kg×day (@AAr)

x 300
(^{39}Ar AAr/^{39}Ar UAr)

already achieved

1 tonne×yr (UAr)

additional active isotopic depletion

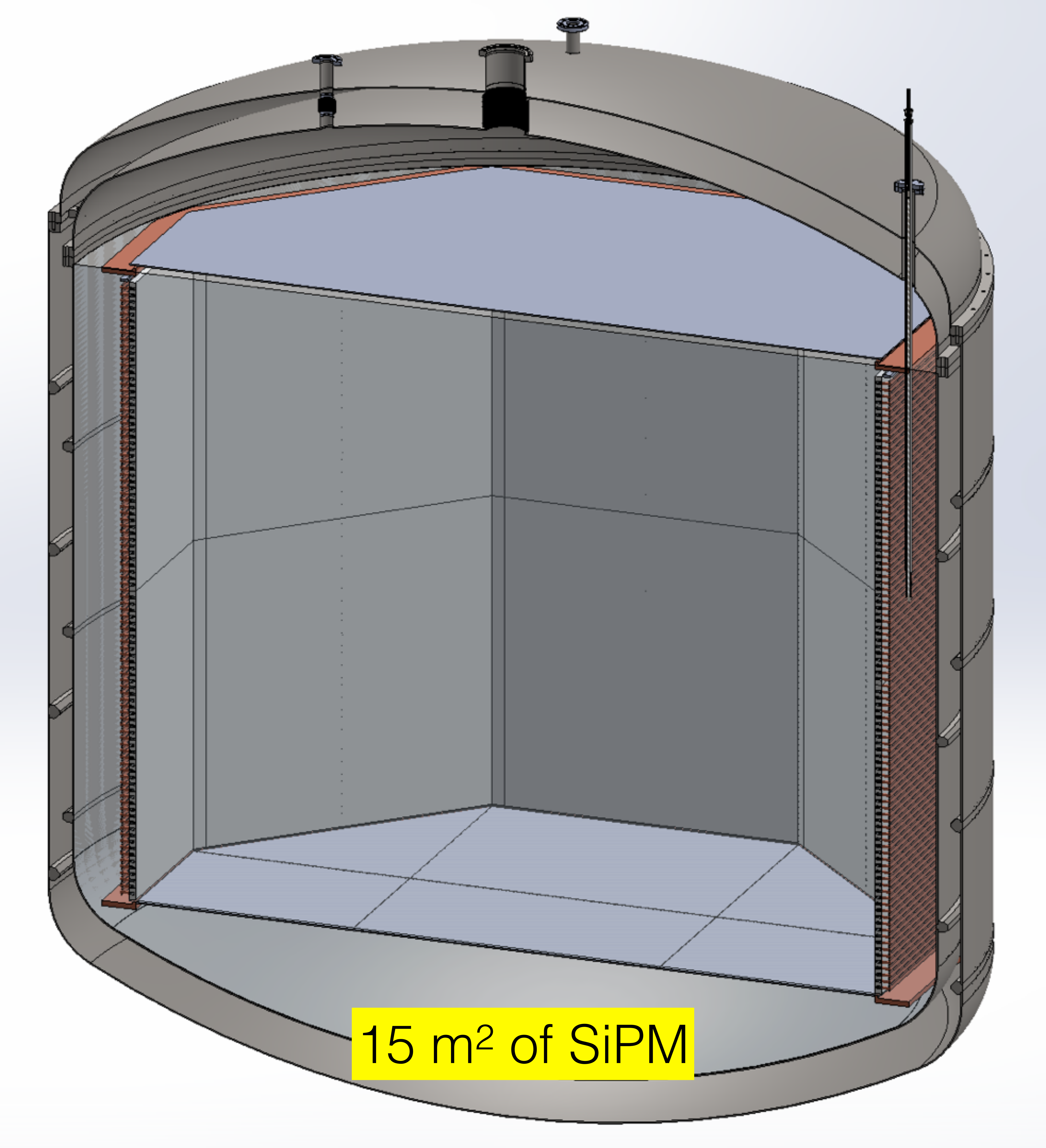
higher light yield
stronger discrimination
present value stat limited

1,000 tonne×yr (UAr/DAr)

DarkSide-20k and Argo LoI Signatories

D. Franco, A Tonazzo (APC Paris)
D. Alton (Augustana)
A. Kubankin (Belgorod)
K. Keeter, B. Mount (BHSU)
A. Devoto, M. Lissia, M. Mascia, S. Palmas (Cagliari)
A. Machado, E. Segreto (Campinas)
M. Leal, L. Romero, R. Santorelli (CIEMAT)
S. Horikawa, K. Nikolics, C. Regenfus,
A. Rubbia (ETH)
S. Pordes (Fermilab)
A. Gola, C. Piemonte (FBK & TIFPA)
M. Pallavicini, G. Testera, S. Zavatarelli (Genova)
S. Davini (GSSI)
E. Hungerford, A. Renshaw (Houston)
M. Guan, J. Liu, Y. Ma, C. Yang, W. Zhong (IHEP)
M. Misziazek, K. Pelczar, M. Woicik, G. Zuzel
(Jagiellonian)
K. Fomenko, A. Sotnikov, O. Smirnov (JINR)
M. Skorokhvatov (Kurchatov)
N. Canci, F. Gabriele, G. Bonfini, A. Razeto,
N. Rossi, F. Villante (LNGS)
S. De Cecco, C. Giganti (LPNHE Paris)

D. D'Angelo, G. Ranucci (Milano)
A. Chepurnov, G. Girenok, I. Gribov,
M. Gromov, I. Zilcov (MSU)
H. Back (PNNL)
M. Ghioni, A. Gulinatti, L. Pellegrini, I. Rech,
A. Tosi, F. Zappa (PoliMi)
C. Galbiati, A. Goretti, A. Ianni,
P. Meyers, M. Wada (Princeton)
C. Dionisi, S. Giagu, M. Rescigno (Roma 1)
S. Bussino, S. Mari (Roma 3)
A. Derbin, V. Muratova, D. Semenov,
E. Unzhakov (St. Petersburg)
C. Jollet, A. Meregaglia (Strasbourg)
C.J. Martoff, J. Napolitano, J. Wilhelmi (Temple)
E. Pantic (UC Davis)
Y. Suvorov, H. Wang (UCLA)
A. Pocar (UMass Amherst)
F. Ortica, A. Romani (Perugia)
S. Catalanotti, A. Cocco, G. Covone,
G. Fiorillo, B. Rossi (Napoli)
J. Maricic, R. Milincic, B. Reinhold (Hawaii)
P. Cavalcante (Virginia Tech)


15 m^2 of SiPM


20-
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
DS-20k
ARGO

What are the backgrounds for large scale, high mass dark matter searches?

Elastic scatters of *pp* solar neutrinos

Radioactive noble gases (^{39}Ar)

Elastic Scatters of *pp* Solar Neutrinos on Electrons

- 200 events/tonne×yr in 30-200 keV_{nr} ROI for argon means 80,000 background events @neutrino floor
  - No problem due to β/γ rejection better than $1 \div 1.6 \times 10^7$
- 20 events/tonne×yr in 0-10 keV_{ee} ROI for xenon means 6,000 background events @neutrino floor
  - Irreducible background due to rejection limited to 1÷200

Based on what we know today, can a depleted argon experiment be background free at the scale of 400 tonnes$\times$yr?

Yes

- *pp* neutrino-electron scattering
  Not a concern thanks to pulse shape discrimination

- ^{214}Pb from ^{222}Rn and ^{85}Kr
  Not a concern thanks to pulse shape discrimination

- ^{39}Ar
  Discrimination proven so far on exposure of 1 tonne×yr UAr equivalent
  No deviations from statistical behavior of discrimination
  Current $1\div1.6\times10^{7}$ rejection limited by statistics
  SiPM should allow to increase light yield by ×1.5, which projects to more than 3 additional orders of magnitude in discrimination at the same threshold
  Further isotopic depletion of ^{39}Ar available if required

DarkSide Depleted Argon Sources

- Urania
  - expansion of Colorado UAr extraction facility to reach 100 kg/day
- Aria
  - Giant cryogenic distillation column in Seruci, Sardinia
  - Gas purification AND active isotopic depletion exploiting finite vapor pressure difference $^{39}Ar/^{40}Ar$

DarkSide Depleted Argon Verification

- ~1 kg argon detector in a shallow underground location at Seruci for initial assessment
  ^{39}Ar sensitivity: 1 mBq/kg
  Factor 10^3 depletion (2-3 times better than DS-50)

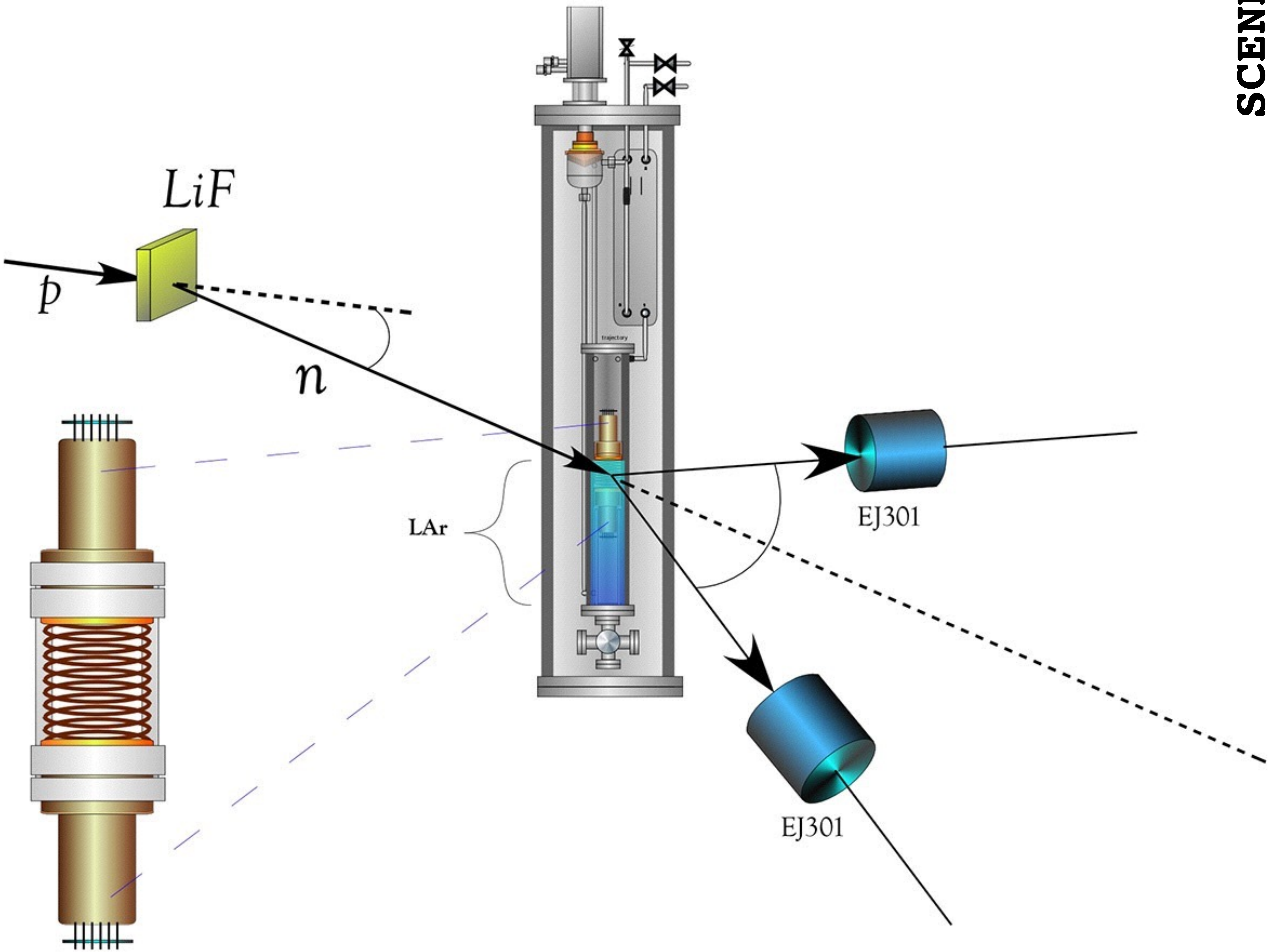
- ArDM for high-sensitivity tests of tonne-scale batches
  ^{39}Ar sensitivity: 10 μBq/kg
  Factor 10^5 depletion

Argo

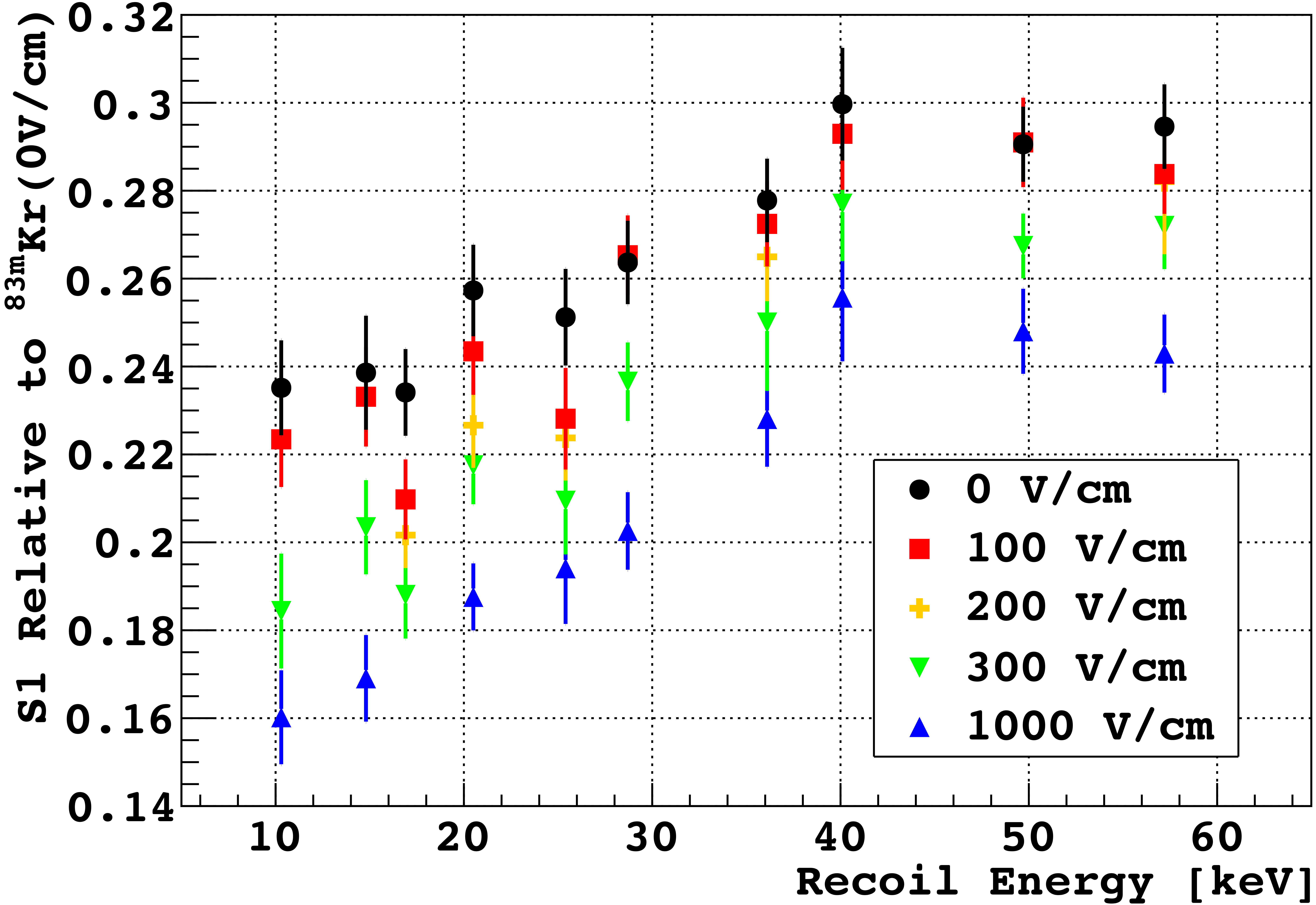
- Background-free exposure of 1,000 tonne×yr
- Sensitivity 9×10^{-49} cm^2 @1 TeV/cm^2
  Covers space throughout neutrino floor
- Permits precision measurements of solar neutrinos
  TPC affords very sharp definition of fiducial volume
  Argon ten times brighter than organic liquid scintillator
  Statistical precision 2% for ^{7}Be, 10% for *pep*, and 15% for CNO neutrinos
  Systematics under study
  Cosmogenics under control
- 300 tonne detector
  Requires Borexino-style shield for solar neutrinos study

SCENE

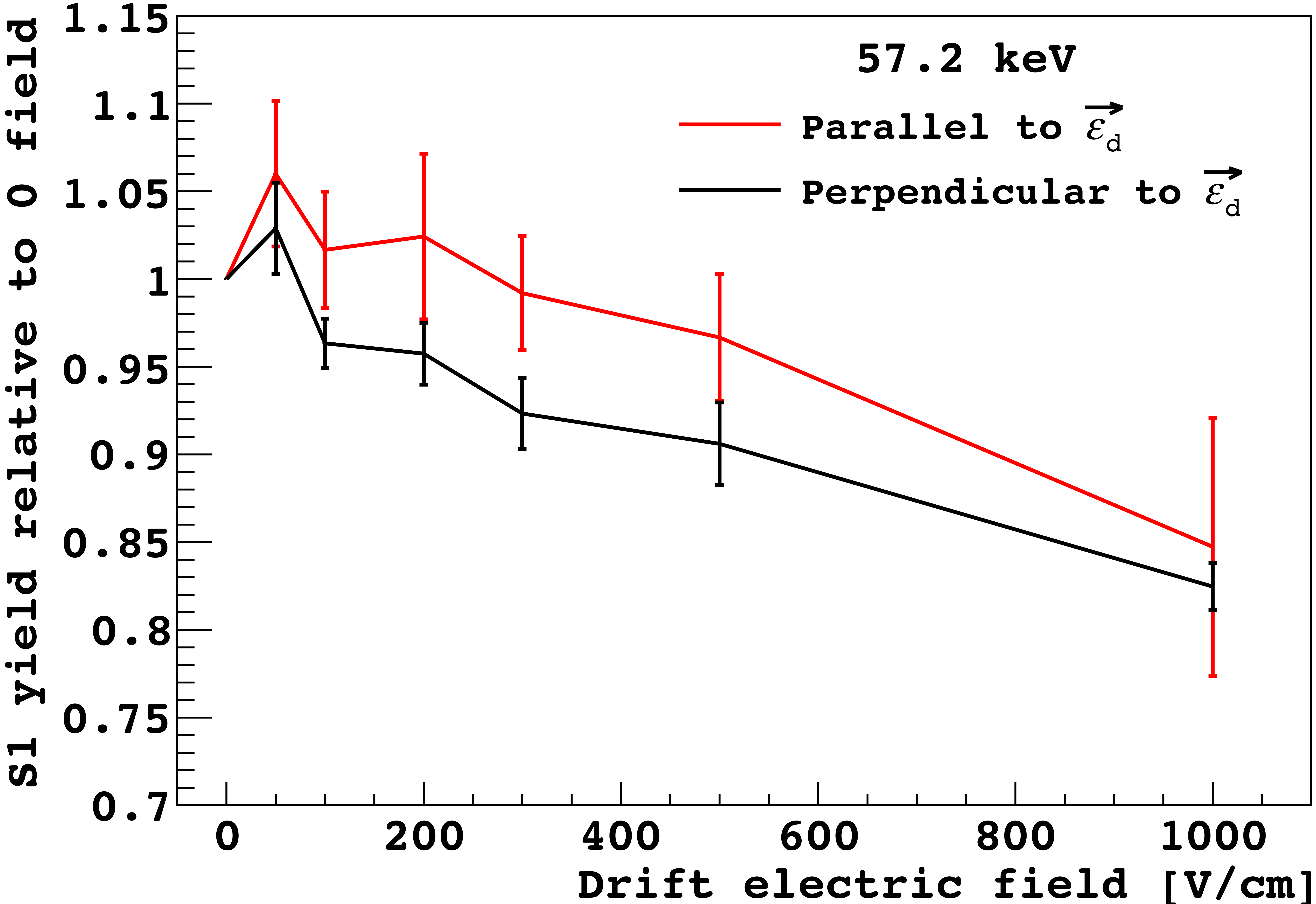
7Li(p,n) on thin LiF target to generate low energy, pulsed, monochromatic neutron beam



Triple coincidence between pulse proton beam, LAr TPC, liquid scintillator detectors for detection of scattered neutrons



S1 Relative to 83mKr(0V/cm)
0.32
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
10
20
30
40
50
60
Recoil Energy [keV]
0 V/cm
100 V/cm
200 V/cm
300 V/cm
1000 V/cm


57.2 keV
Parallel to $\vec{\mathcal{E}}_{\mathrm{d}}$
Perpendicular to $\vec{\mathcal{E}}_{\mathrm{d}}$
S1 yield relative to 0 field
Drift electric field [V/cm]
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0
200
400
600
800
1000

Directional Dark Matter Test @Napoli

- Participating groups: Naples, Roma 1, APC-IN2P3, Princeton, Temple, UCLA
- Coordinator: Giuliana Fiorillo (Napoli)
- Refurbishment of Tandem accelerator to create dedicated proton line for experiment under way
- Permanent array of liquid scintillator neutron coincidence counters planned
- Start of operations with LAr TPC in October 2015
- Will provide facility available for calibration of other detectors with monochromatic, pulsed neutron beam

Conclusions

- DS-20k most ambitious program proposed, goes more than $\times 5$ beyond LZ
- Argo to cover entire parameter space through neutrino floor and to enable precision measurements of solar neutrinos significantly beyond Borexino capability
- Letter of Intent submitted to LNGS April 27 2015
- Background-free requirement key element: DarkSide-20k and Argo have unique capabilities
- Exploration of possible directional signal with dedicated experiment at Naples. Unique possibility of conjugating directionality with zero background strategy

The End