DarkSide and Argo

Cristiano Galbiati
Princeton University
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Plan of Talk

- Two phase depleted argon TPC
  - A unique technology for a background-free search to the neutrino floor
- Letter or Intent to LNGS:
  - DarkSide-20k: dark matter
  - Argo: dark matter and solar neutrinos

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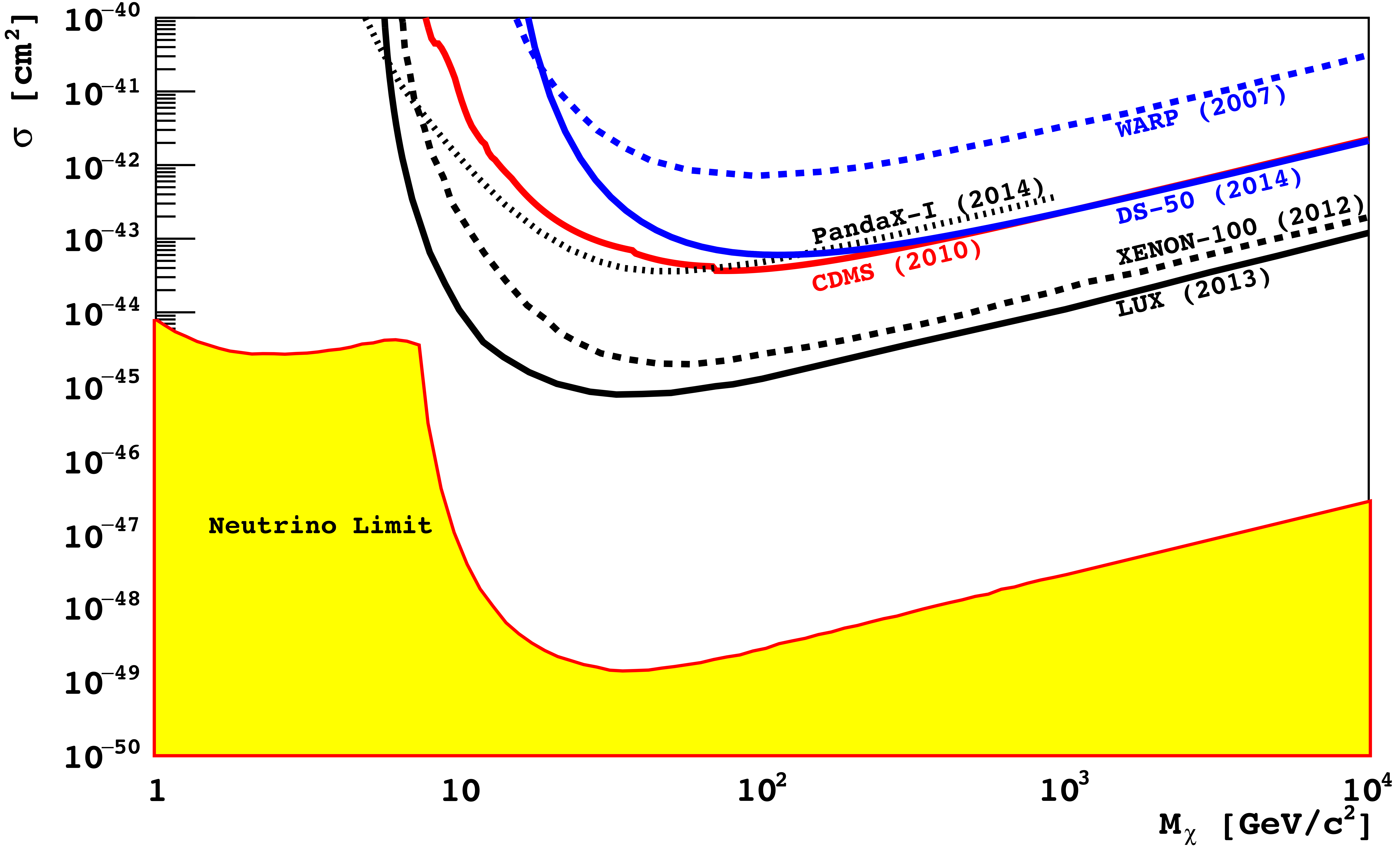
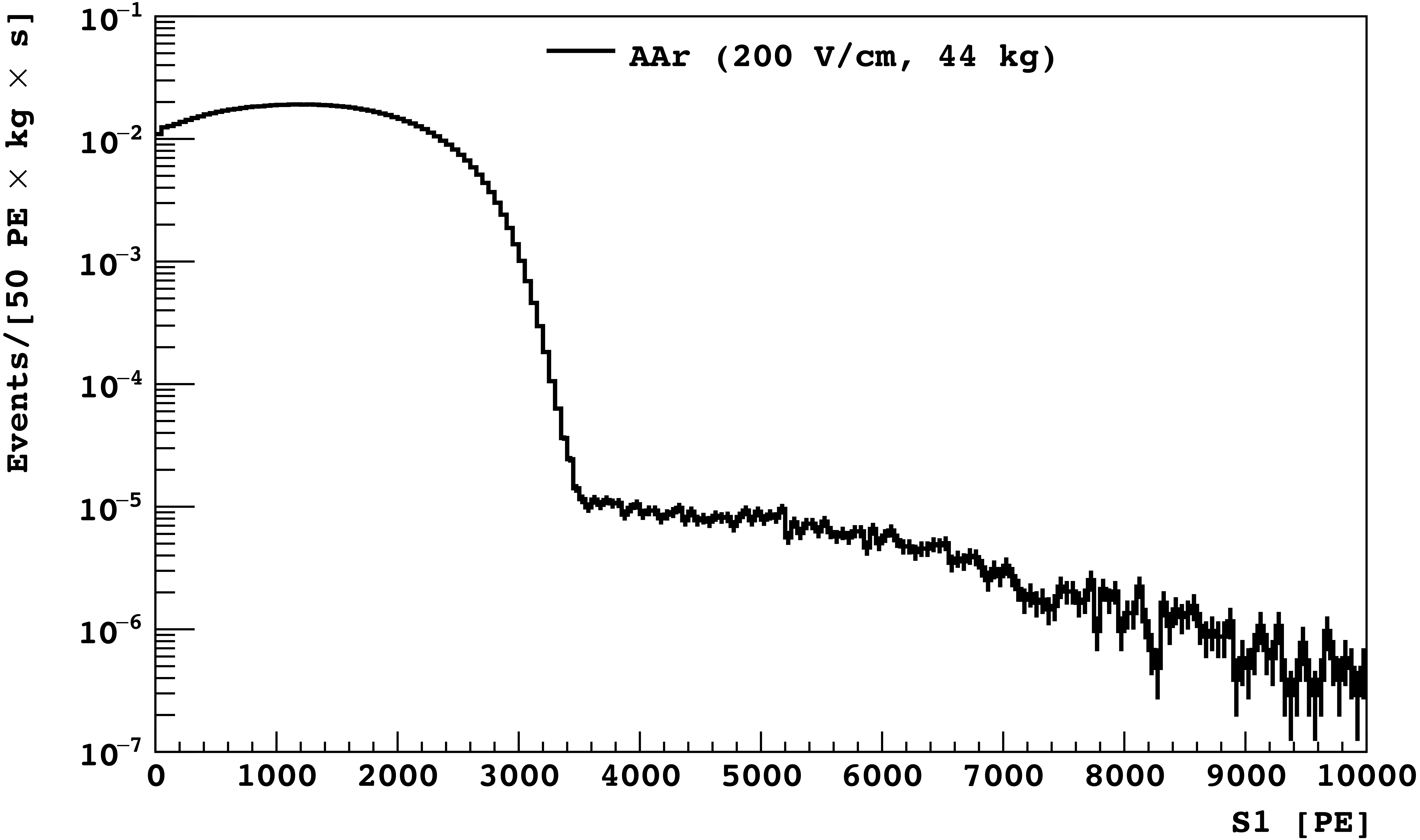
Università & INFN Roma 3 (S. Bussino, S. Mari)
University of Hawaii (J. Maricic, R. Milincic, B. Reinhold)
Virginia Tech (P. Cavalcante)

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

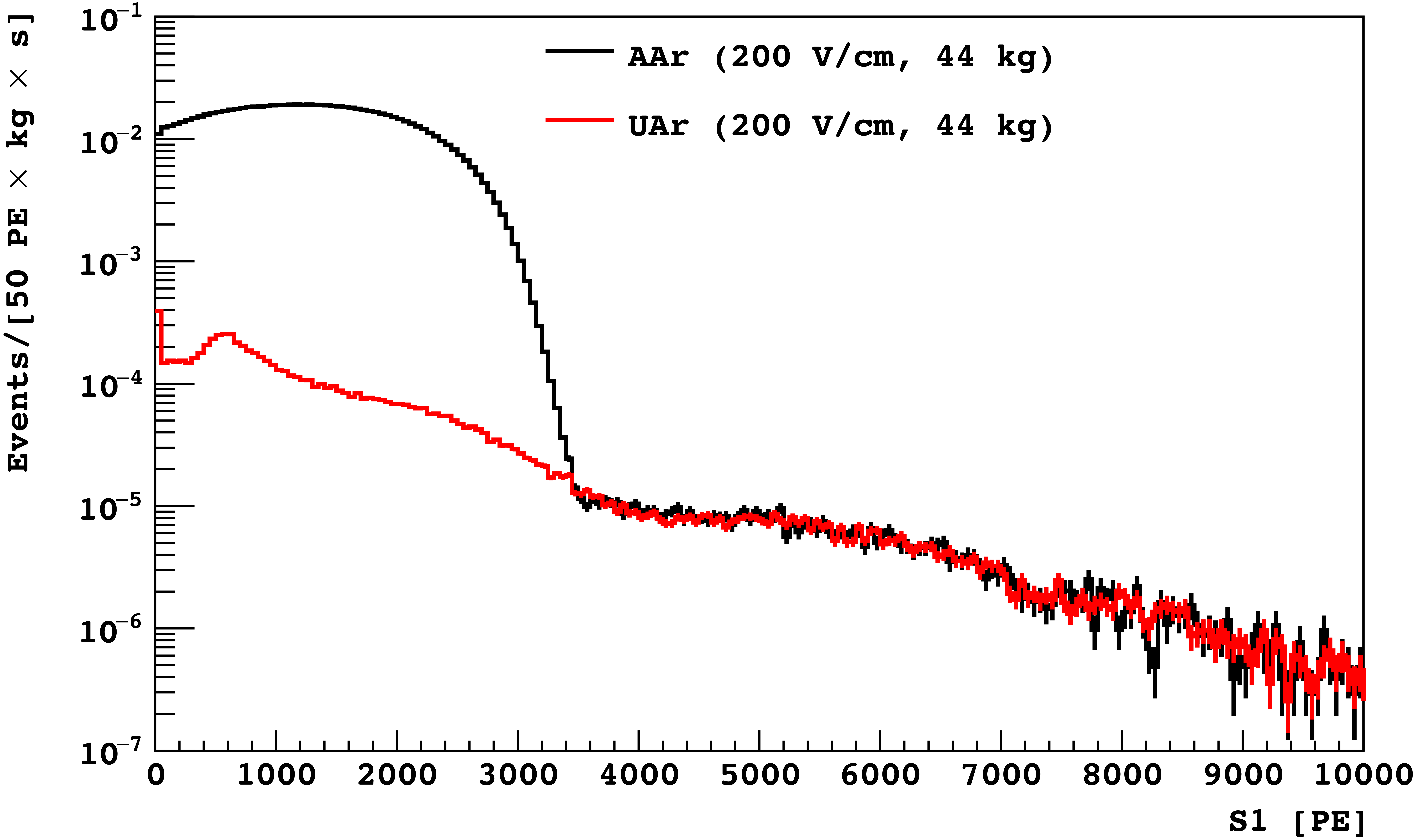
same data with S2 and radial cut
f_{90}
S1 [PE]
50%
65%
80%
90%

third best dark matter limit at high masses

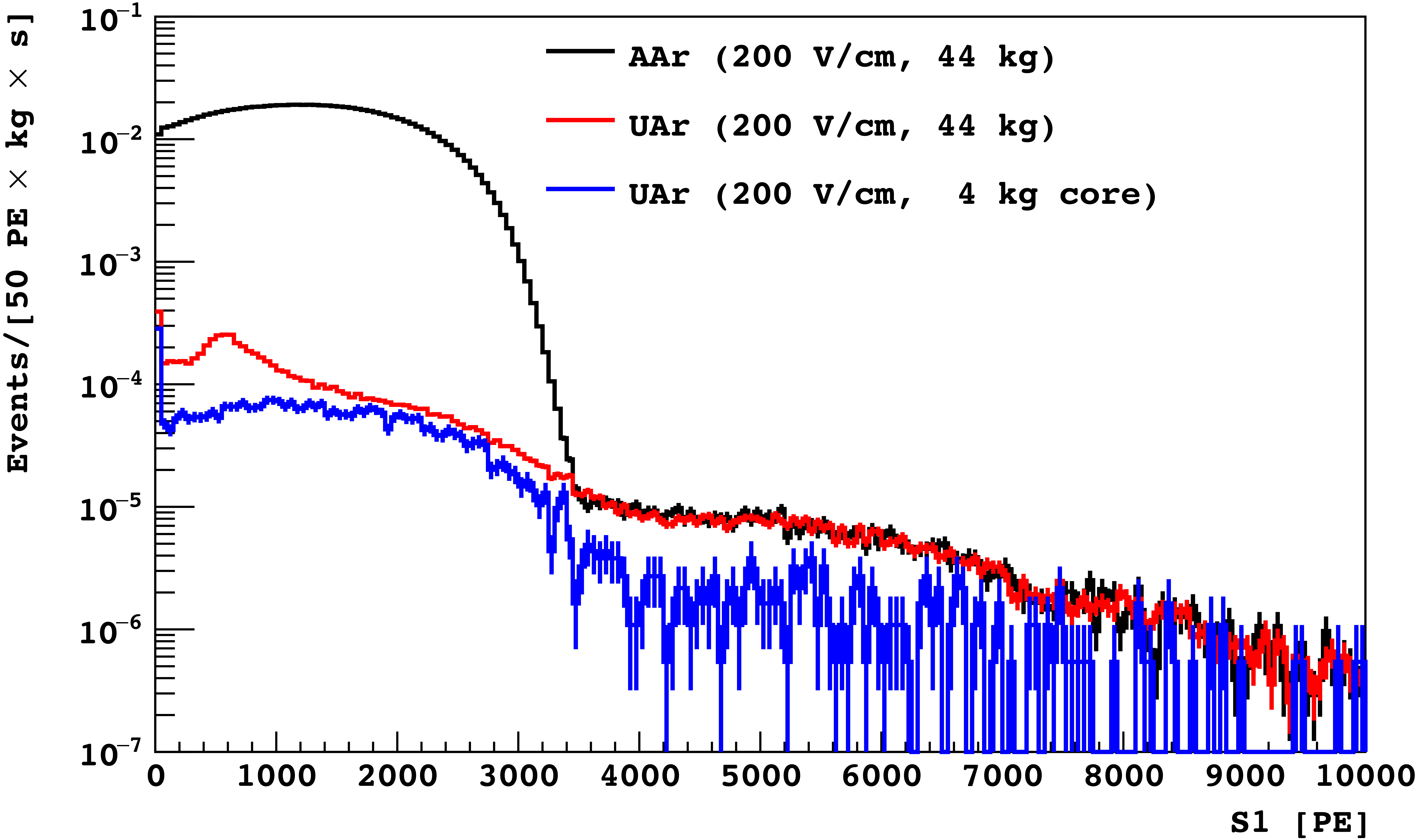




AAr (200 V/cm, 44 kg)
Events/[50 PE × kg × s]
S1 [PE]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000



AAr (200 V/cm, 44 kg)
UAr (200 V/cm, 44 kg)
Events/[50 PE × kg × s]
S1 [PE]



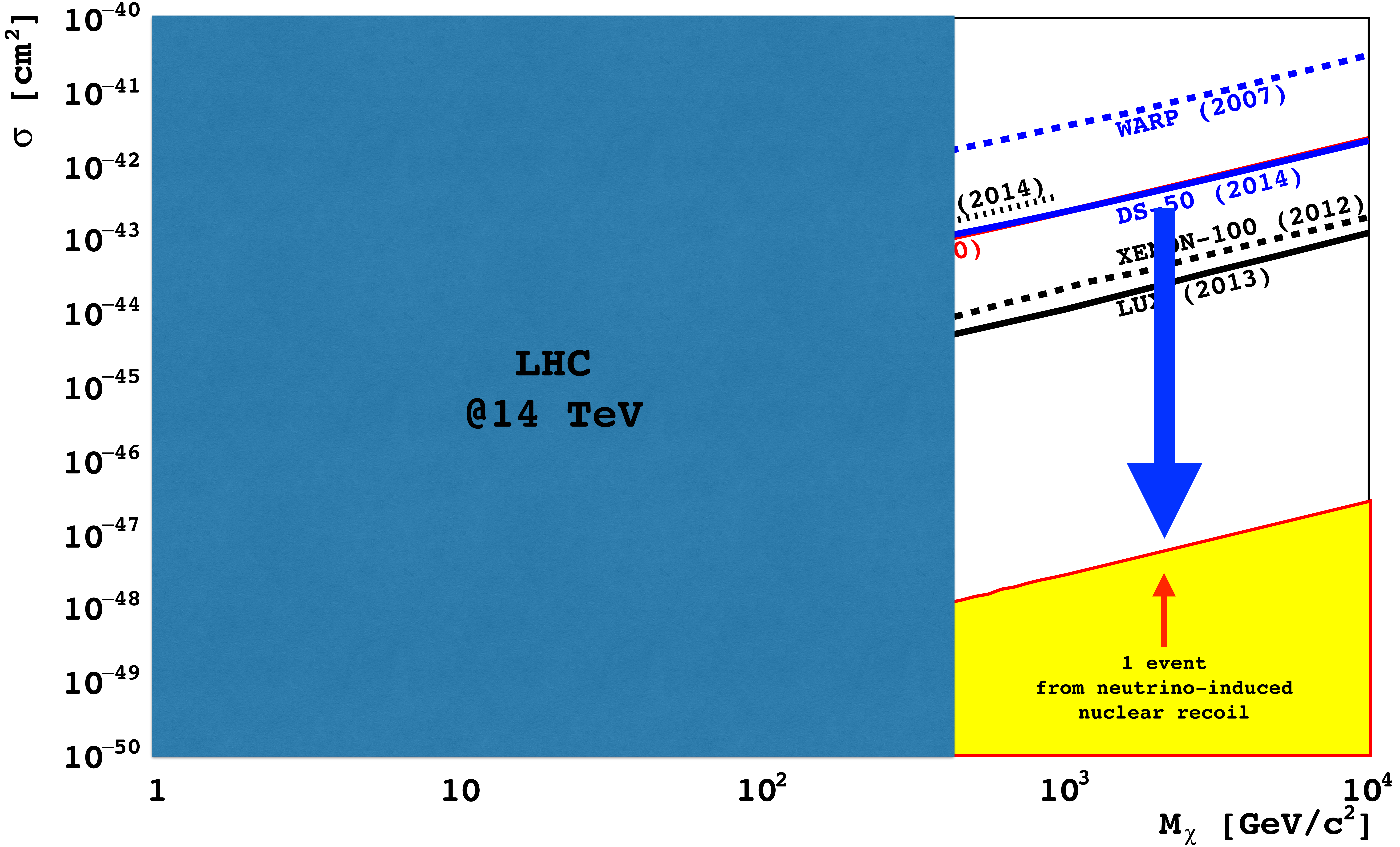
AAr (200 V/cm, 44 kg)
UAr (200 V/cm, 44 kg)
UAr (200 V/cm, 4 kg core)
Events/[50 PE × kg × s]
S1 [PE]

DarkSide-50

- Third best dark matter limit with AAr exposure of 1,422 kg×day
  - Only liquid noble dark matter experiment background-free
  - Rejection better than $1 \div 1.6 \times 10^7$ (compare $1 \div 200$ for Xe)
- Detector in final configuration
  - Underground argon isotopic depletion better than 300
  - TMB problem fixed, veto at design 99.5% neutron rejection
  - UAr science run started - additional exposure of 847 kg×day collected

What goal for the large scale exploration of dark matter?

third best dark matter limit at high masses



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}
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}
DS-20k [100 tonne×yr]	9×10^{-48}	9×10^{-47}
1 Neutrino Event [400 tonne×yr Ar or 300 tonne×yr Xe]	2×10^{-48}	2×10^{-47}
ARGO [1,000 tonne×yr]	9×10^{-49}	9×10^{-48}

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 $1 \div 200$

^{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

stronger discrimination
present value stat limited

1,000 tonne×yr (UAr/DAr)

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 $1 \div 1.6 \times 10^7$ 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

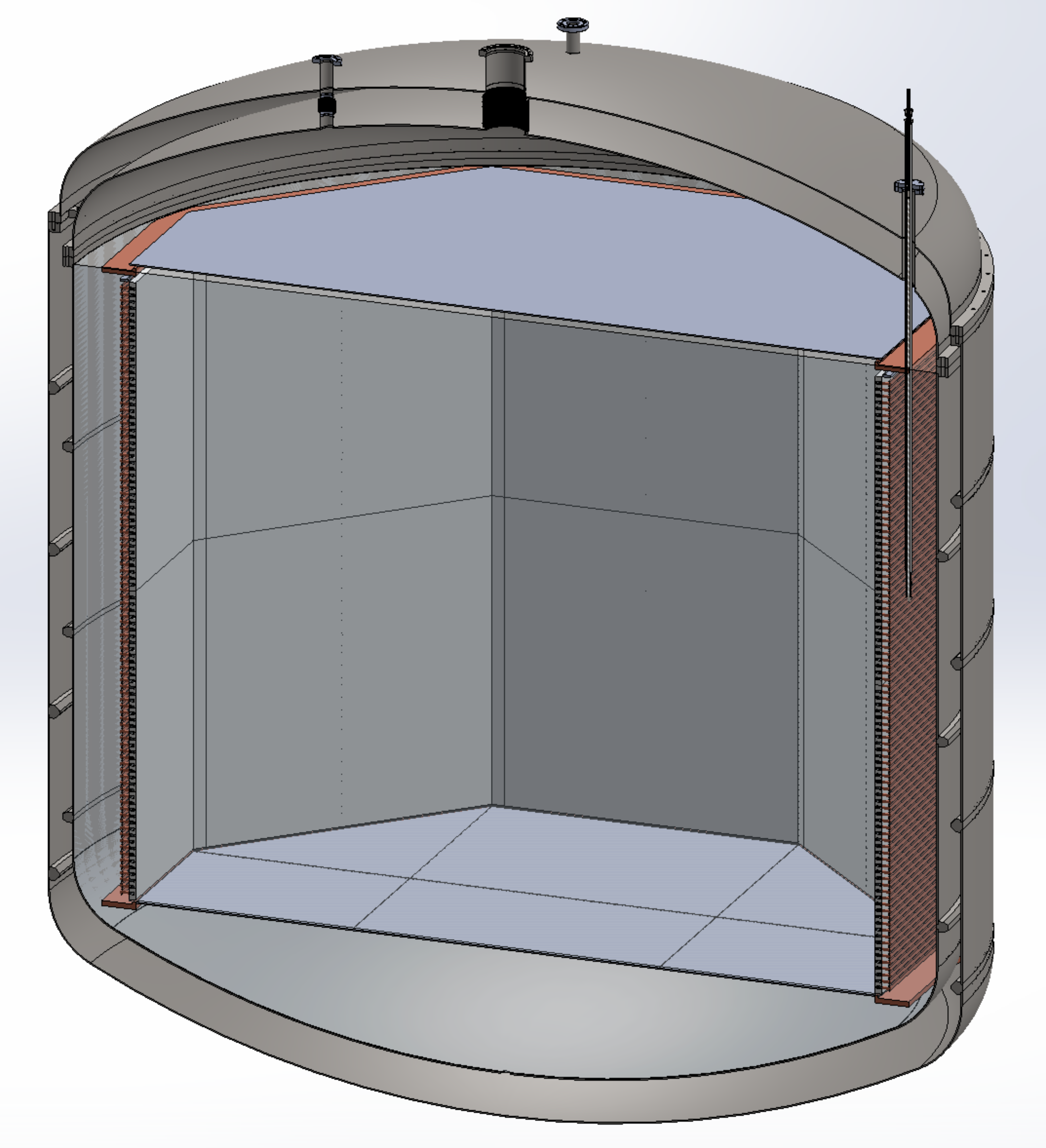
Based on what we know today, can a xenon experiment be background free at the scale of 300 tonnes$\times$yr?

No

- [3] Next generation XENON-1t experiment need to contain their electron-recoil background to below 30 μDRU for a 99.75% rejection to obtain 0.7 events in 2.7 tonne×yr exposure (1 DRU = 1 count / [$\text{keV}_{ee} \times \text{kg} \times \text{day}$])
- Is a 99.75% rejection reasonable?
  XENON-100 [2]: 2 leakage events over 400 in ROI
  LUX [5]: 1 leakage events over 160 in ROI
- [3] *pp* neutrino-electron scattering: Irreducible background, 12 μDRU ≈ 0.3 (event/tonne×yr)
- [3] ^{214}Pb from ^{222}Rn: 1mBq Rn ≈ 9 μDRU ≈ 0.2 (event/tonne×yr)
  - Is 1 mBq of ^{222}Rn reasonable? XENON-100: ≤ 1.2 mBq [2], ≃ 4 mBq [3] in 62 kg target for ^{222}Rn chain; LUX [4]: 4-20 mBq in 350 kg target for ^{222}Rn chain, 3 mBq for ^{220}Rn chain
    ^{222}Rn background to scale with surface and recirculation flow
    Borexino's success in ^{222}Rn isolation, often invoked as a proof of principle for feasibility of Xe TPC goal, is taken out of context: Borexino's ^{222}Rn contamination during fluid operations: hundreds of mBq
- [3] ^{85}Kr: 0.2 ppt ≈ 8 μDRU ≈ 0.2 (event/tonne×yr)

DarkSide-20k

- Background-free exposure of 100 tonne×yr
- Sensitivity 9×10^{-48} cm^2 @1 TeV/cm^2
  A factor 5 better than LZ
- 30 tonne (20 tonne fiducial) detector
- MC indicates UAr self-vetoing sufficient (LS veto not required)



DarkSide-20k Characteristics

- 15 m^2 of SiPM's
  Demonstrated from 15 to 50% LY increase per unit area over PMT's
  Demonstrated dark count under control
  Demonstrated noise control and good performance for 10 cm^2 SiPM's tile at 87 K
  Tile size required for DS-20k is 25 cm^2 factor 2 above what already achieved
  FBK custom design, first custom production May 2015
  Mass production possibly at L-Foundry

- Low-background titanium from Russia for cryostat

- 50 kV drift field
  Already achieved in DarkSide-10 and DarkSide-50 mockup

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

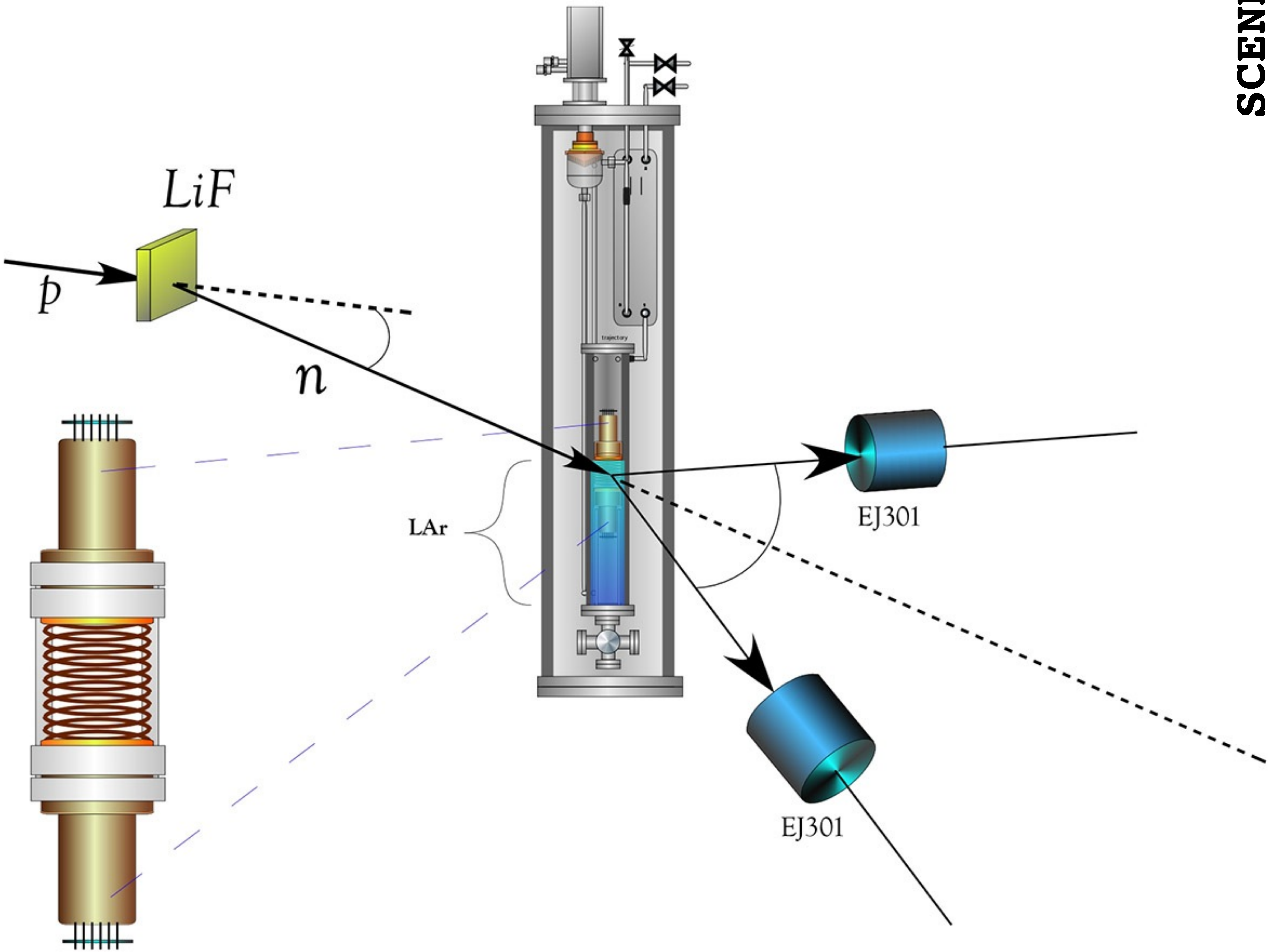
Argo

- 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

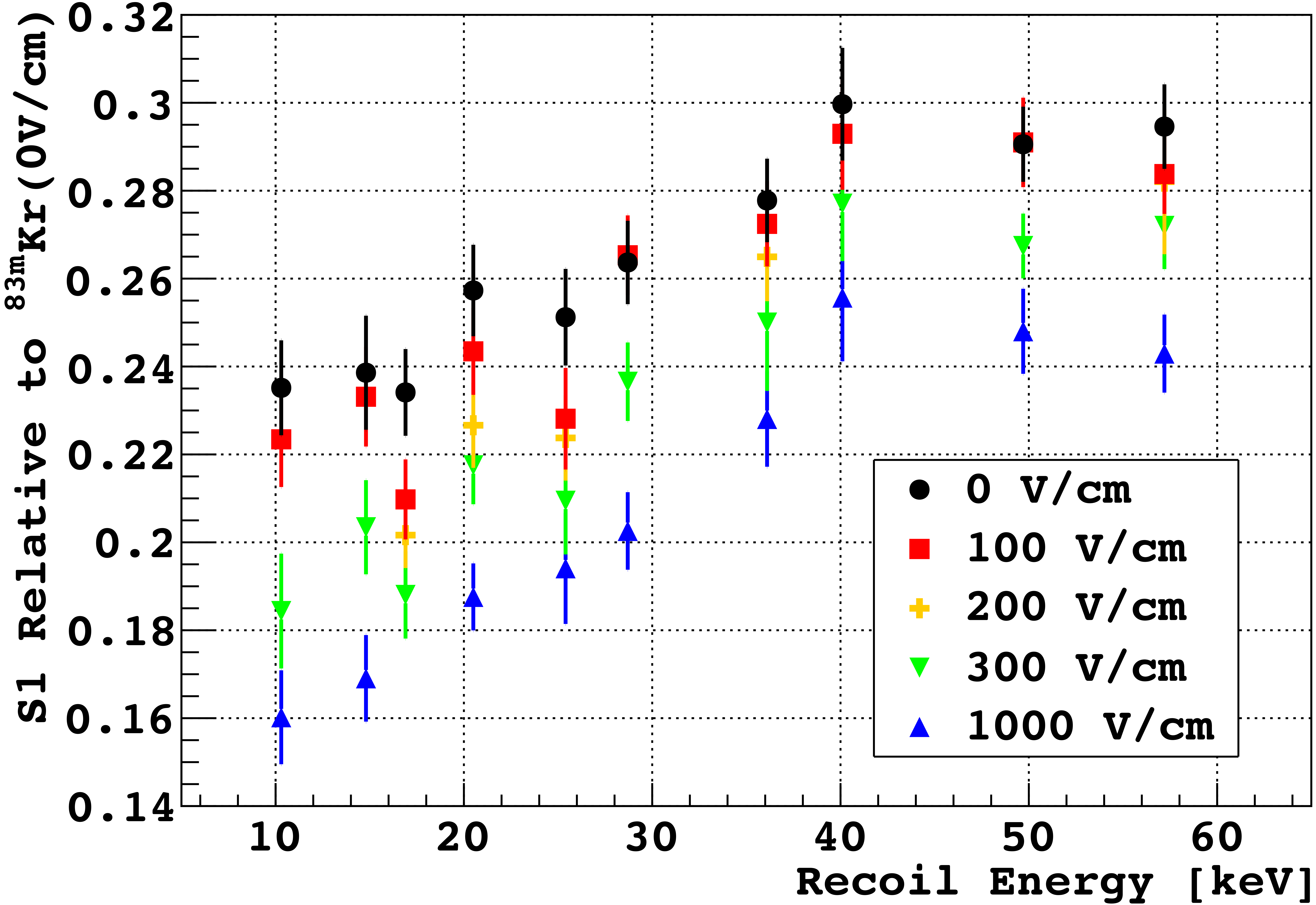
20-	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
DS-20k																				
ARGO																				

SCENE

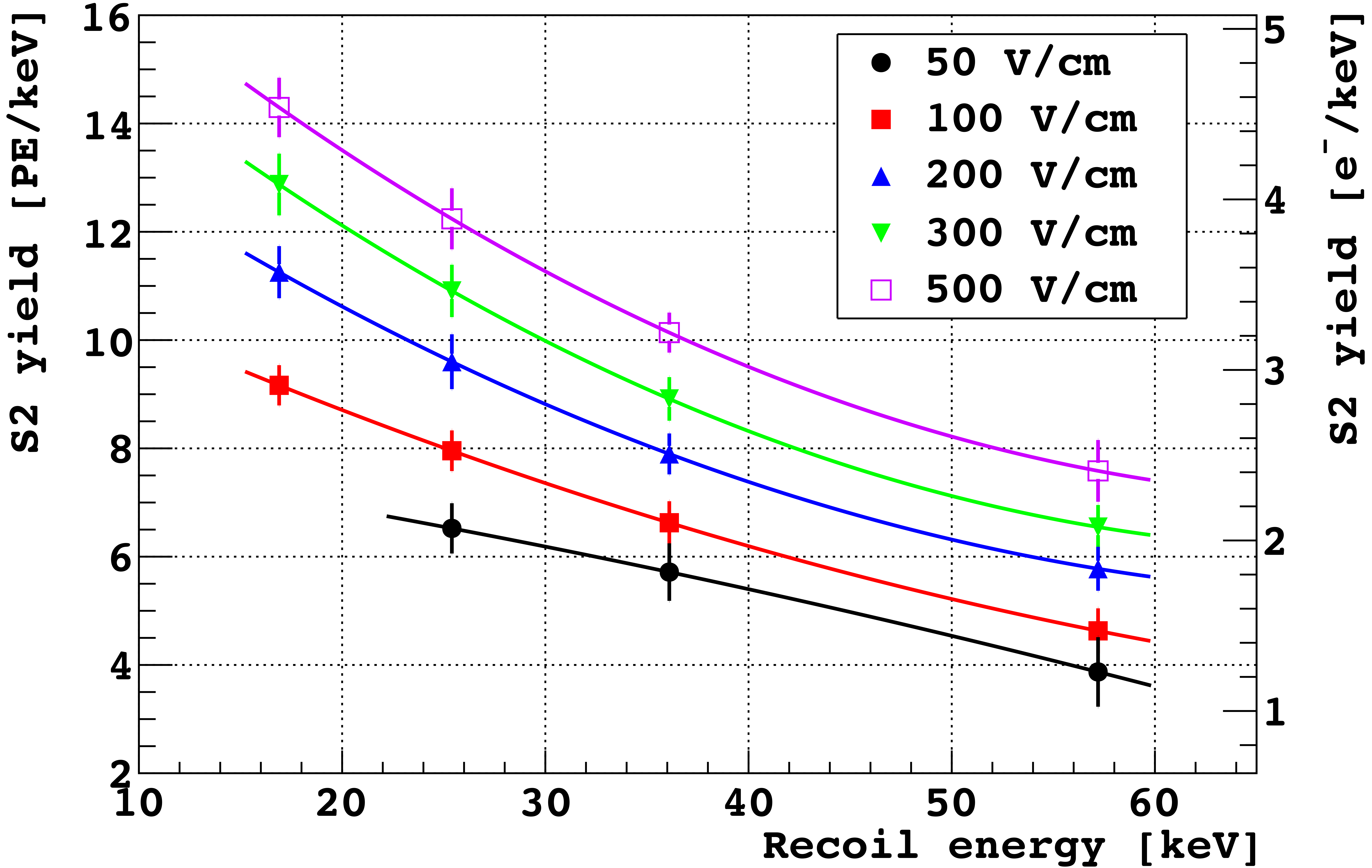
7Li(p,n) on thin LiF target to generate low energy, pulsed, monochromatic neutron beam



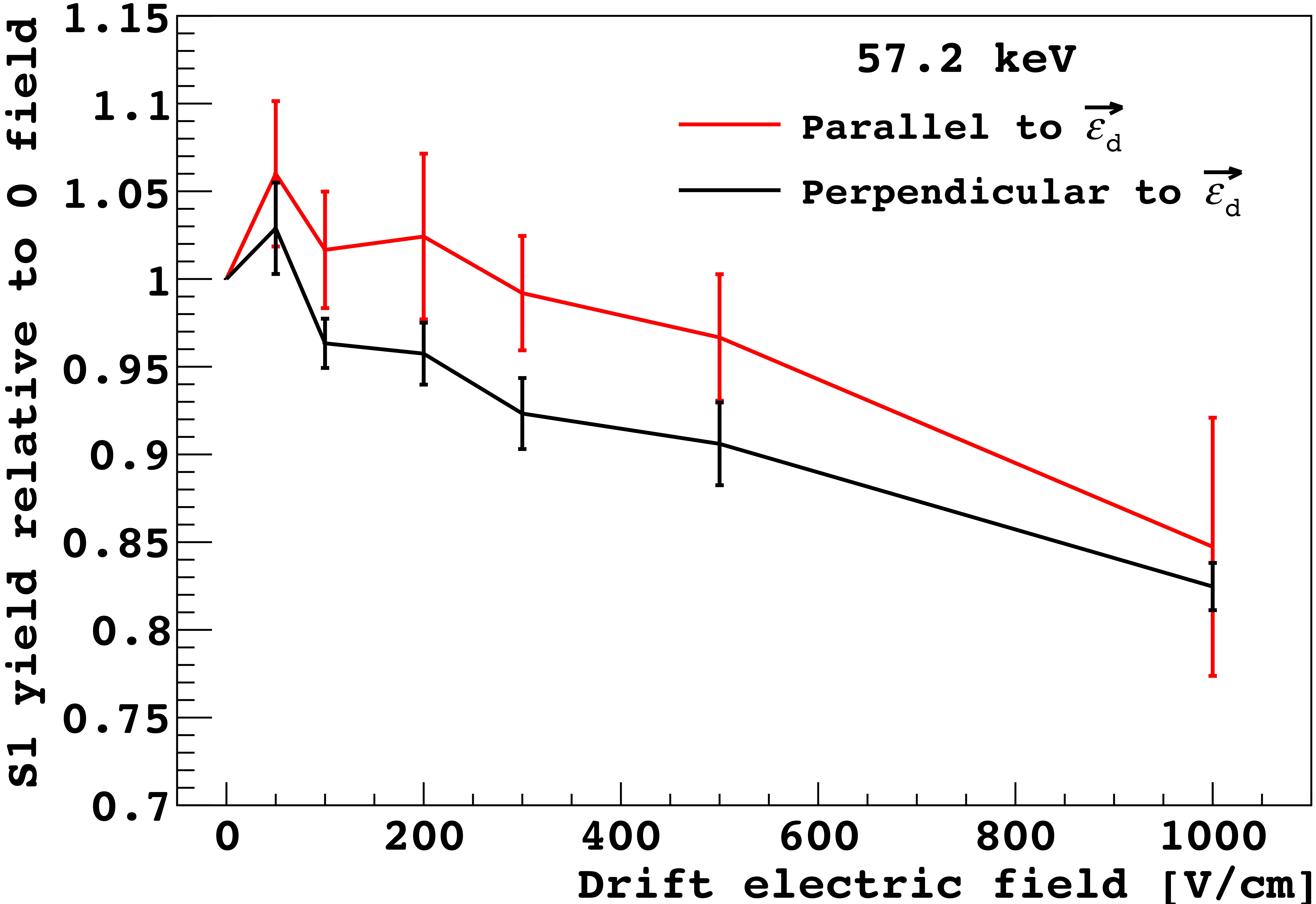
Triple coincidence between pulse proton beam, LAr TPC, liquid scintillator detectors for detection of scattered neutrons



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



S2 yield [PE/keV]
S2 yield [e⁻/keV]
Recoil energy [keV]
50 V/cm
100 V/cm
200 V/cm
300 V/cm
500 V/cm
2
4
6
8
10
12
14
16
10
20
30
40
50
60
1
2
3
4
5



57.2 keV
Parallel to $\vec{\mathcal{E}}_d$
Perpendicular to $\vec{\mathcal{E}}_d$
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

Very Low Threshold DM Searches

- Gaseous argon detectors have reached record thresholds below 100 eV
  - I. Giomataris et al., “A novel large-volume spherical detector with proportional amplification read-out”, Journal of Instrumentation 3, P09007 (2008).
- Availability of depleted argon made available by the Urania and Aria programs may enable construction of ultra-low background gaseous argon detectors
  - Suitable to explore dark matter interactions on electrons
  - Suitable to monitor supernovae explosions via the detection of neutrino-induced coherent scattering of argon nuclides

Conclusions

- DS-20k most ambitious program proposed, goes more than ×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 continued excellence in dark matter exploration
  DS-20k and Argo have sound and credible strategy to keep background-free through their stated goals
  Unique physics capability
  Real competitor for large-scale background-free exploration of dark matter is single-phase argon (both approaches, TPC and single-phase argon, require UAr/DAr)
  INFN leading strategy procurement of depleted argon with Urania and Aria

- Exploration of possible directional signal continues with dedicated experiment at Naples
  Unique possibility of conjugating directionality with zero background strategy

The End

References

DarkSide

[0] P. Agnes et al. (DarkSide Collaboration), arxiv:1410.0653

XENON

[1] E. Aprile et al. (XENON Collaboration), Physical Review D 83, 082001 (2011)
[2] E. Aprile et al. (XENON Collaboration), Physical Review Letters 109, 181301 (2012)
[3] G. Plante et al. (XENON Collaboration), The Multi-Ton XENON Program at the Gran Sasso Laboratory , DM2014 Conference (2014)

LUX/LZ

[4] K. Gibson et al. (LUX Collaboration), The LUX Experiment, Presentation at TAUP 2013 Conference (2013)
[5] D. S. Akerib et al. (LUX Collaboration), Physical Review Letters 112, 091303 (2014)