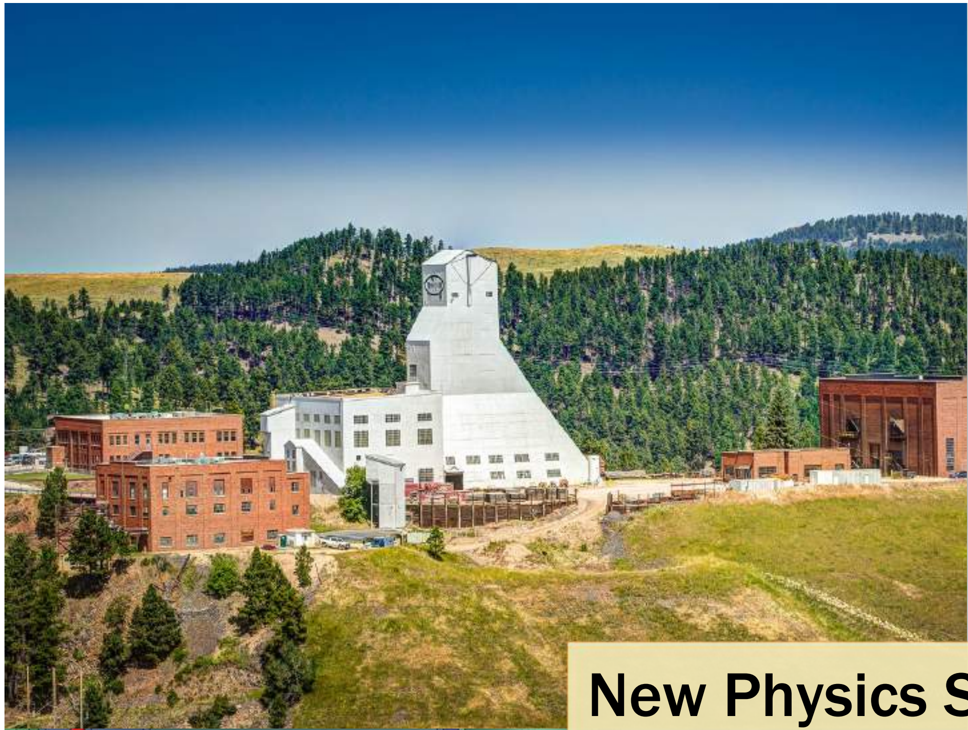
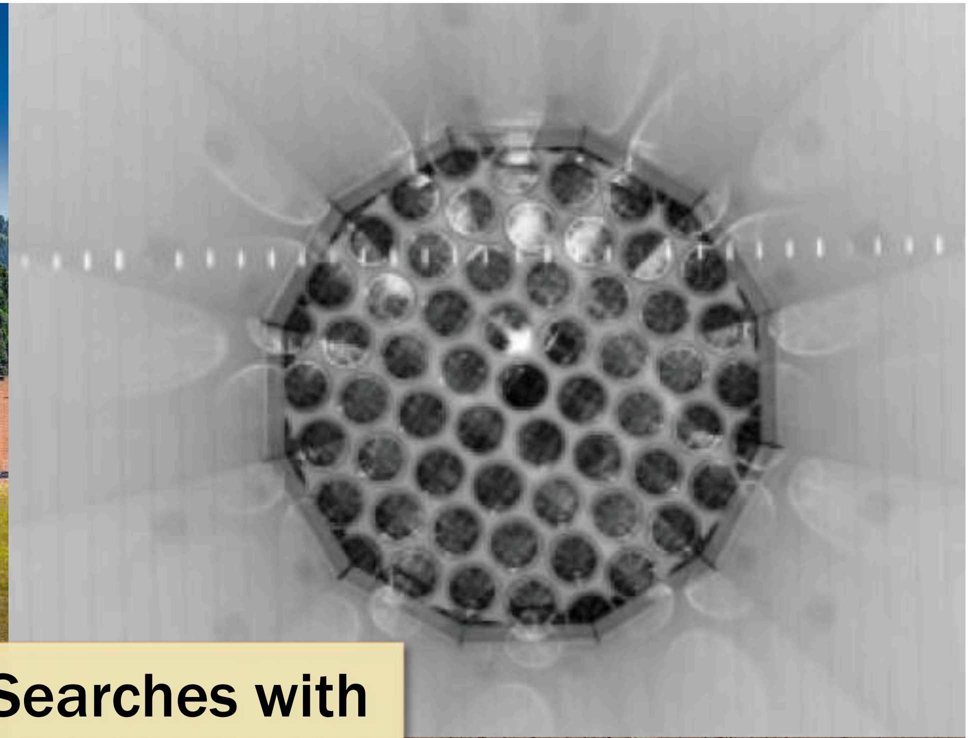
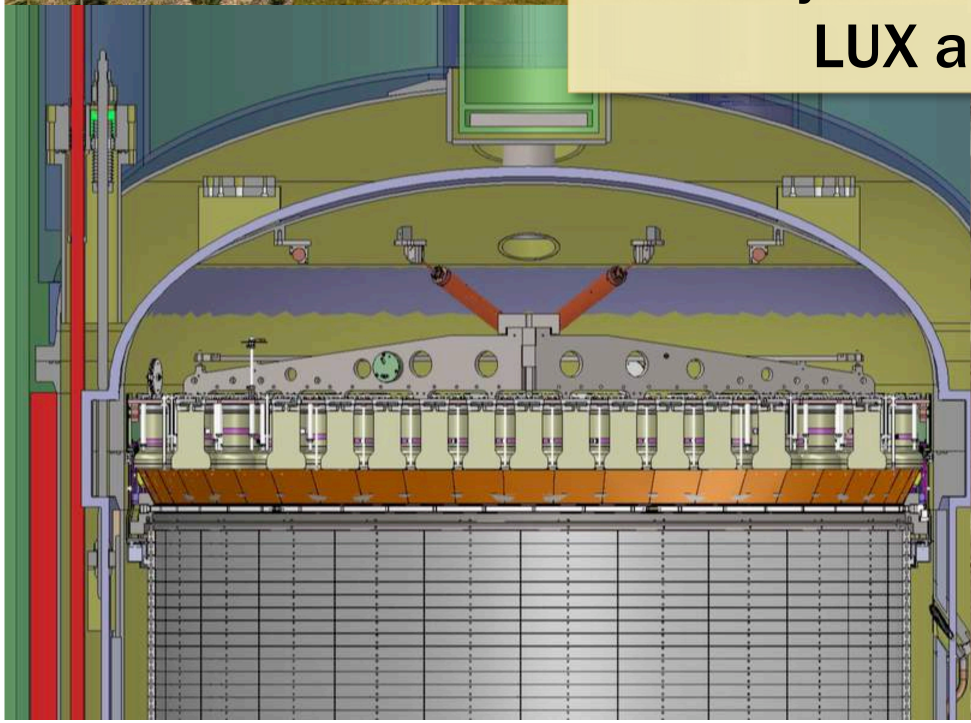




New Physics Searches with LUX and LZ



Sanford Underground Research Facility
Lead, South Dakota, USA

The LUX detector in its water tank

LUX Timeline

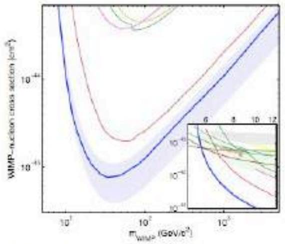
2006: LUX collaboration formed

2008: LUX funded (DOE + NSF)

July 2012: LUX moves UG

WS-2013 (95 live-days)

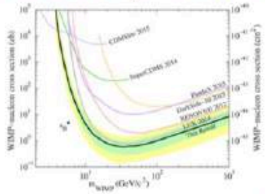
Nov 2013: First WS results reported (85.3 live-days)



PRL, 112, 091303 (2014)

WS-2014/16 (332 live-days)

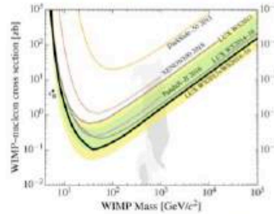
Dec 2015: Re-analysis of WS2013 published



PRL, 116, 161301 (2016)
PRL, 116, 161302 (2016)

May 2016: WS2014-16 finished

July 2016: 332-day WS result announced

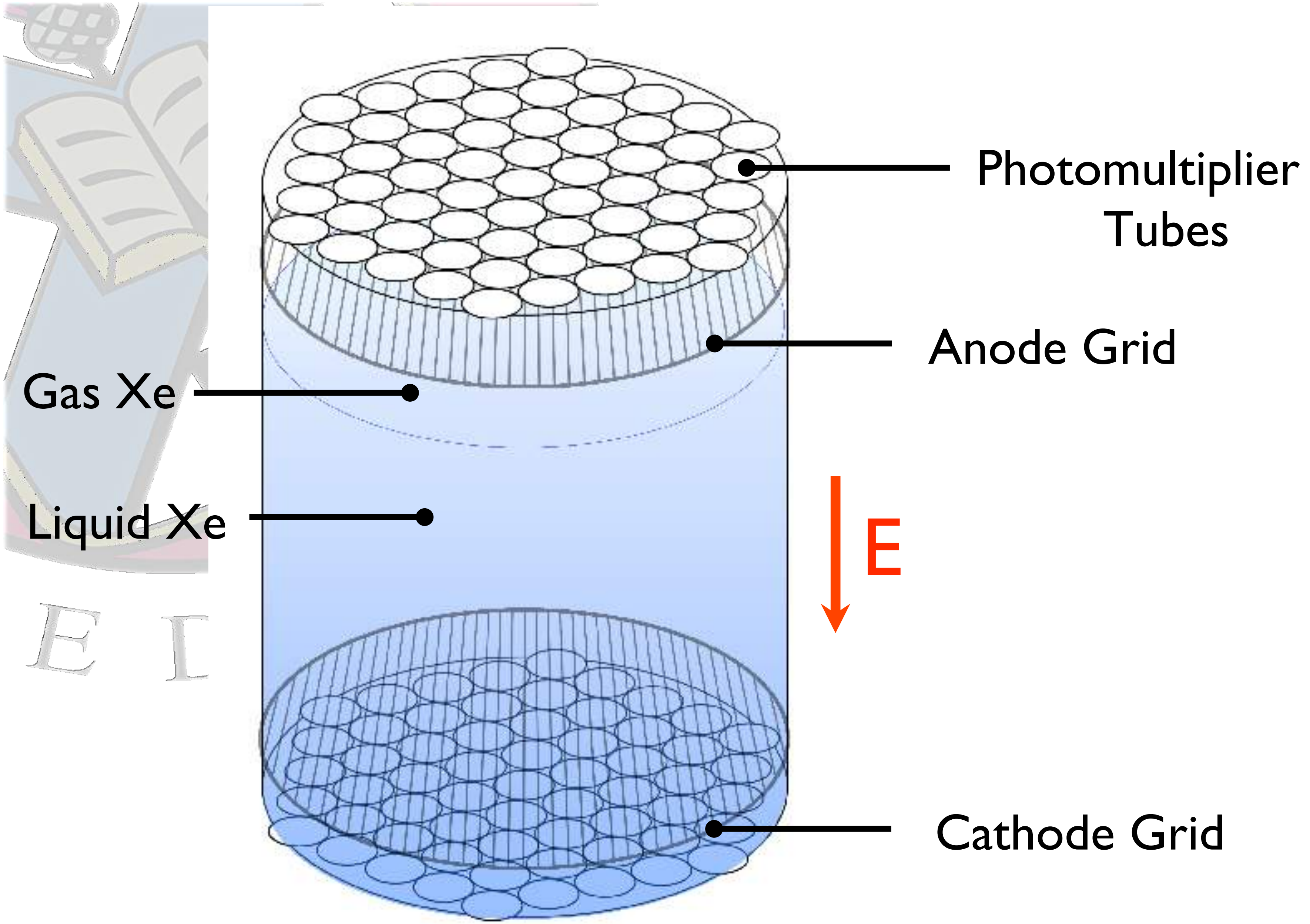


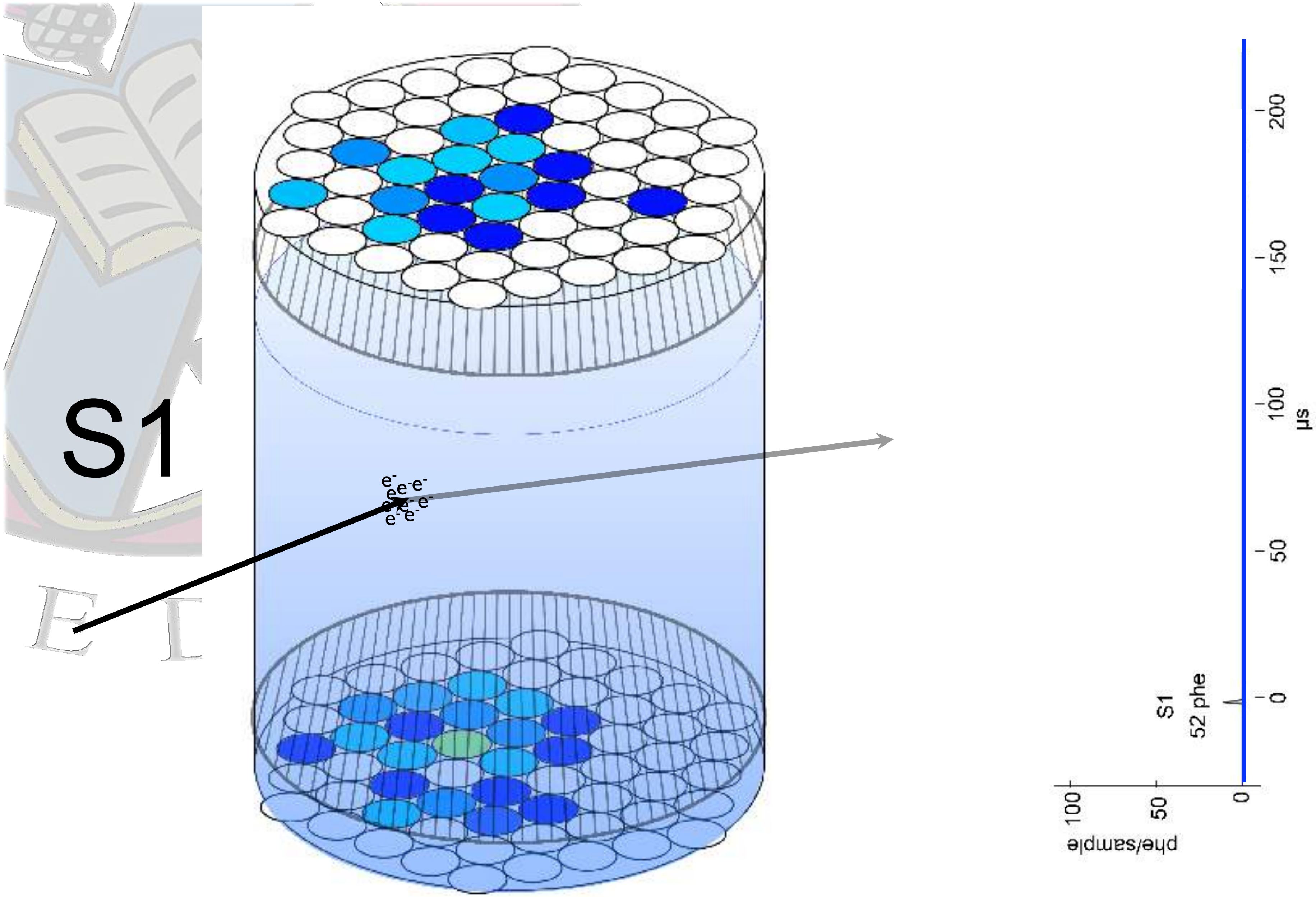
PRL, 118, 021303 (2017)

Sept 2016: decommissioning start

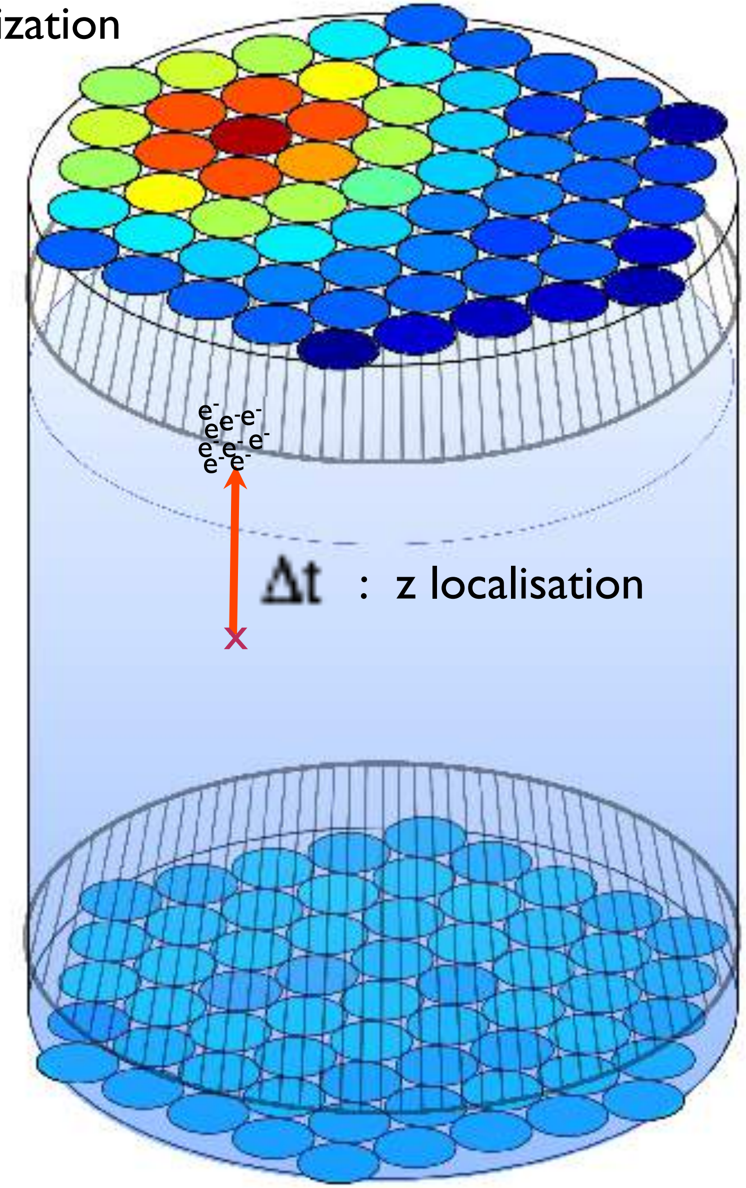
June 2017: LUX installed in a museum

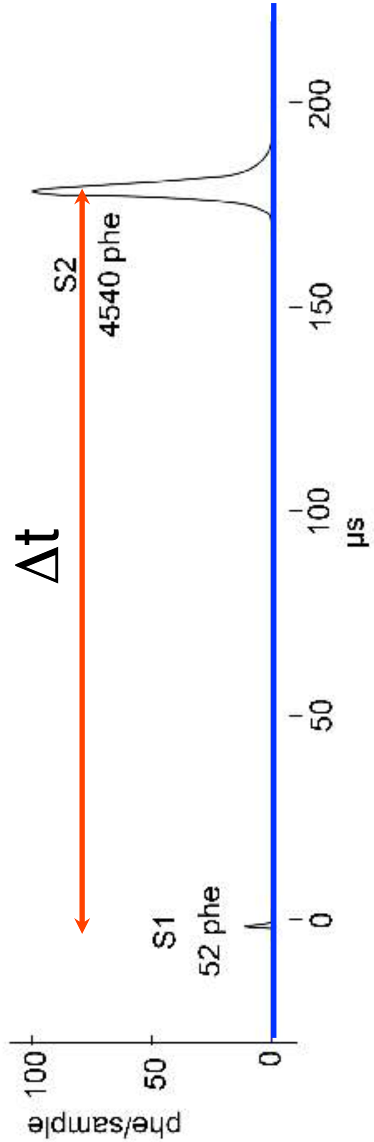
Analysis still ongoing


Photomultiplier
Tubes
Anode Grid
Gas Xe
Liquid Xe
E
Cathode Grid


S1
S1
52 phe
phe/sample
µs

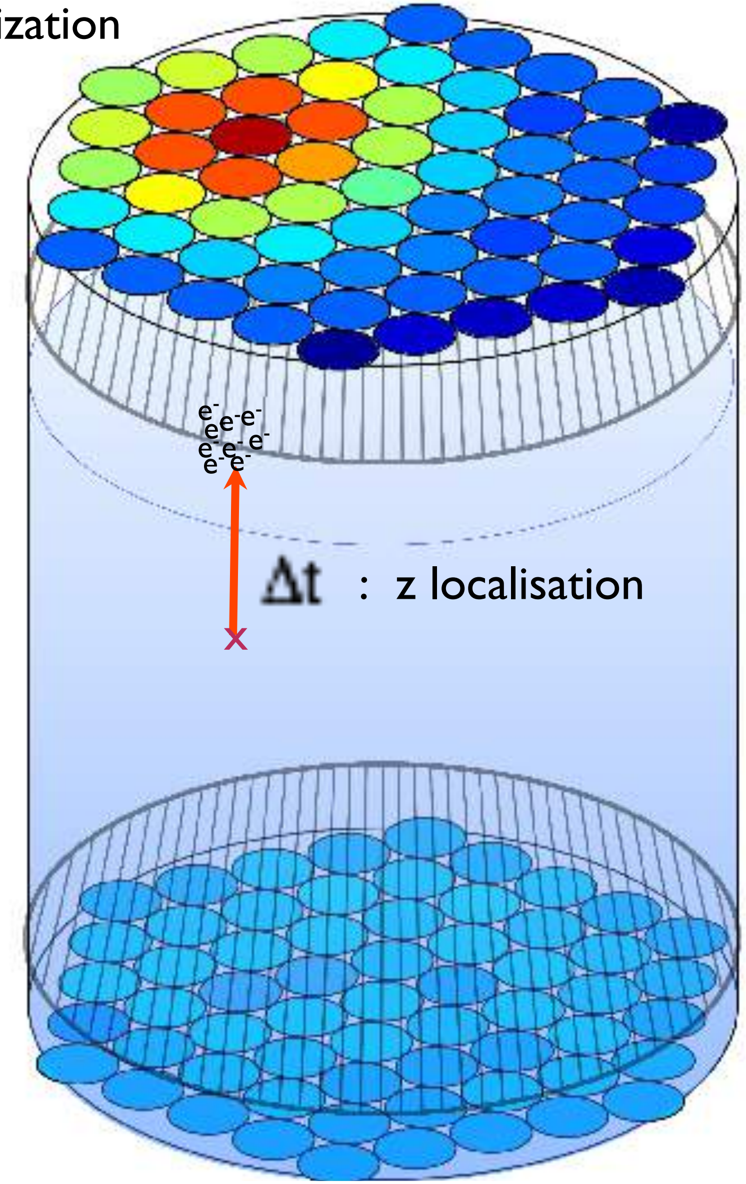
S2

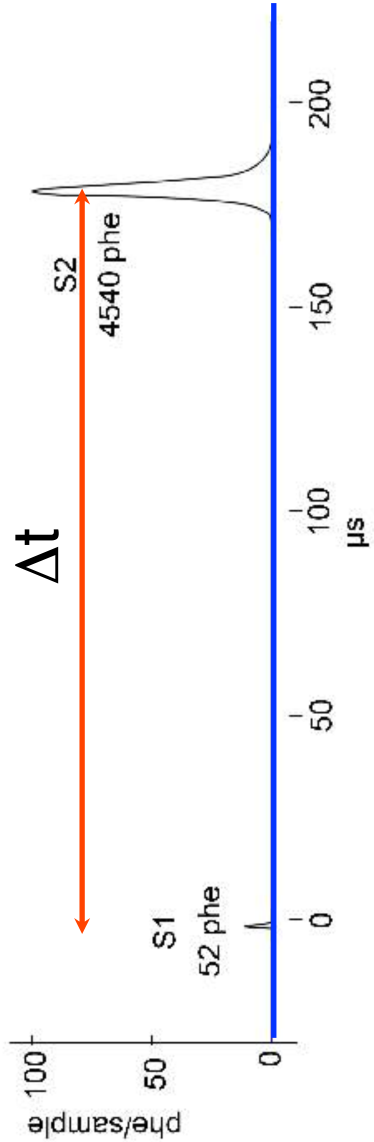

top hit pattern:
x-y localization
Δt : z localisation


Δt
S2
4540 phe
S1
52 phe
μs
phe/sample
0
50
100
150
200

top hit pattern:
x-y localization

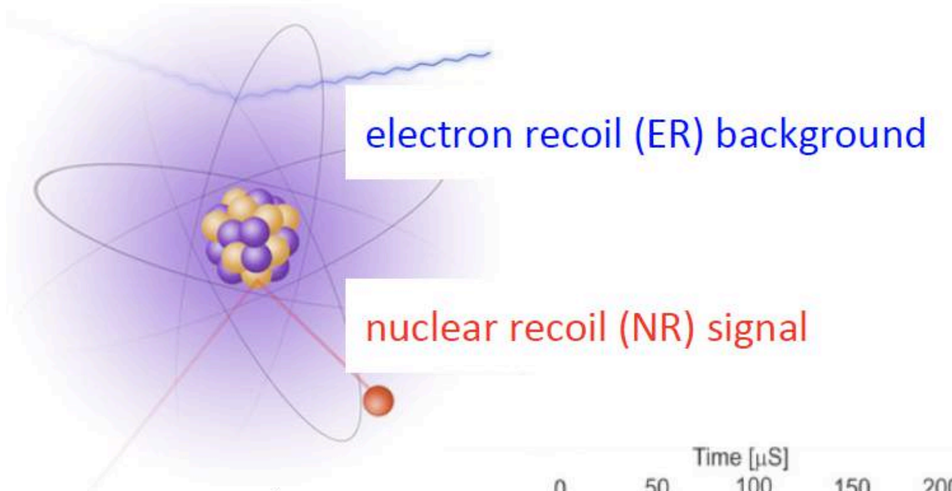
S2

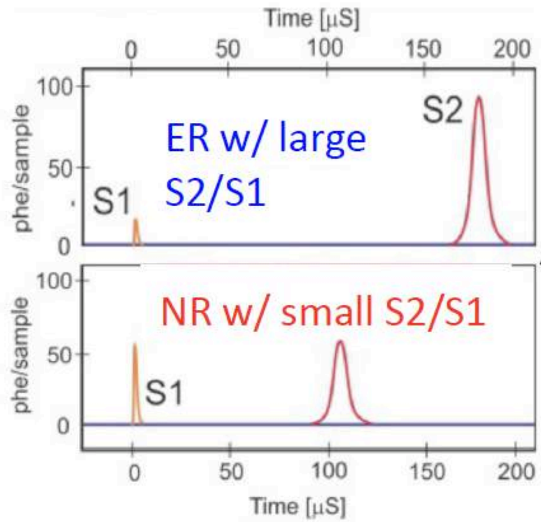




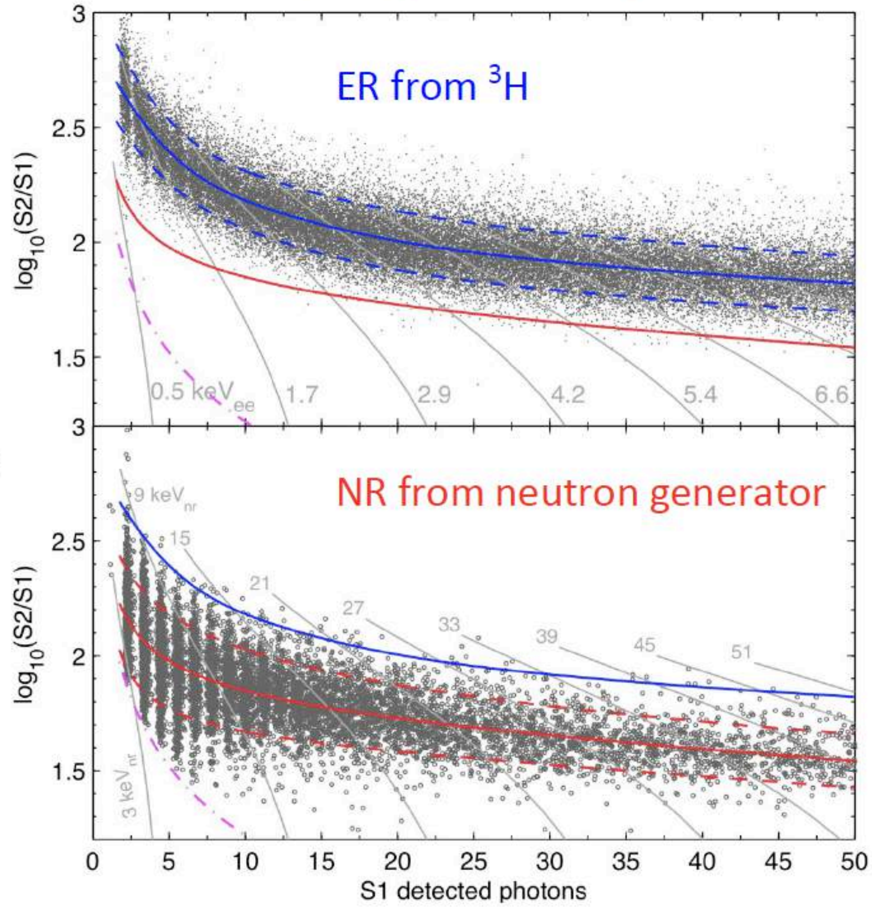
Ratio of S2 to S1 depends on the type of incident particle - allows ER (β, gamma) : NR (neutron, WIMP) discrimination >99.5%

Detailed (!) Calibrations

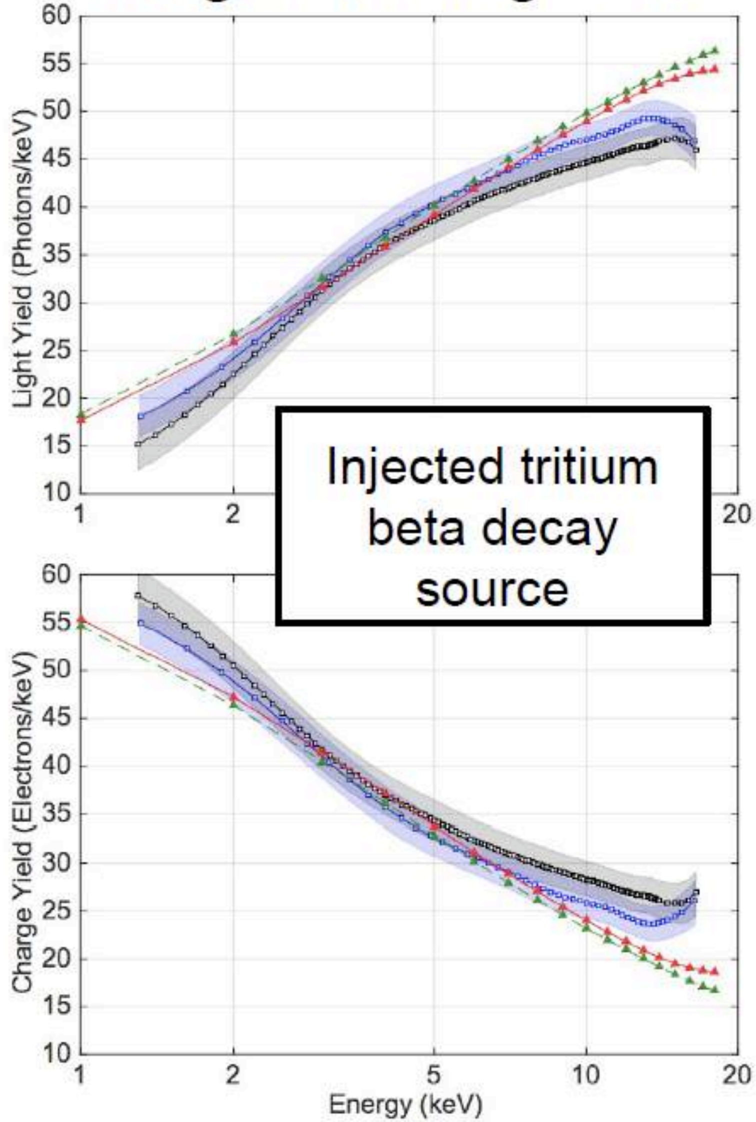




Phys Rev, D 97, 102008, 2018

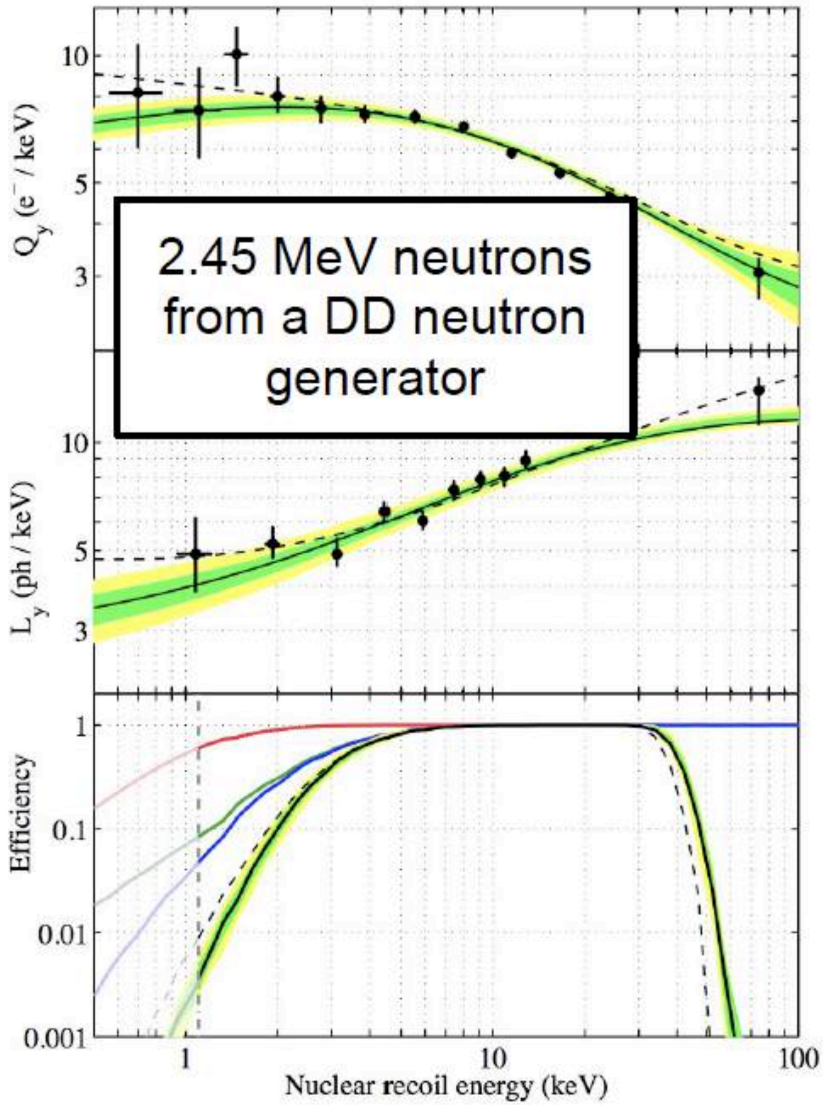


ER Light and Charge Yield



Phys Rev, D 93, 072009, 2016

NR Light and Charge Yield

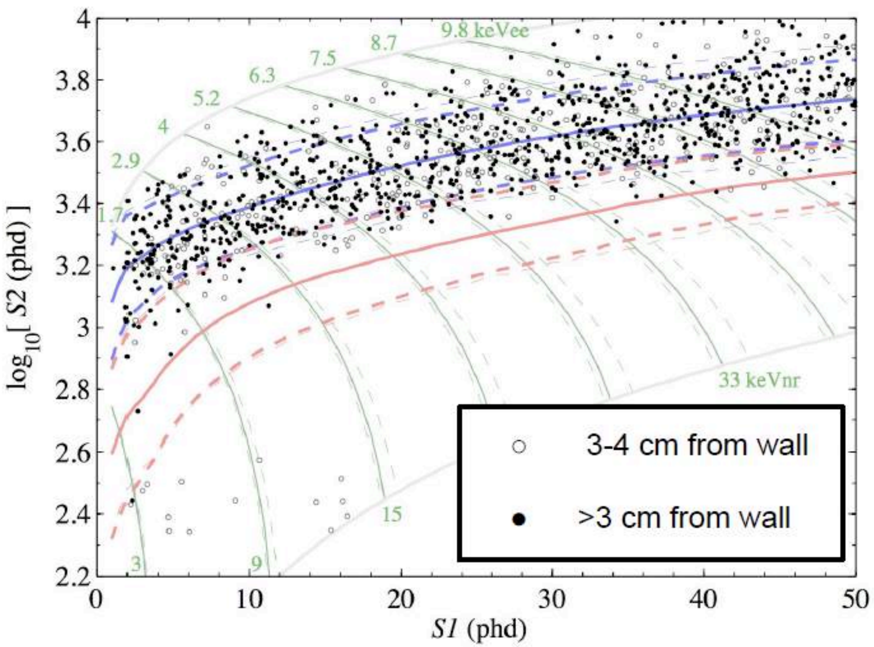


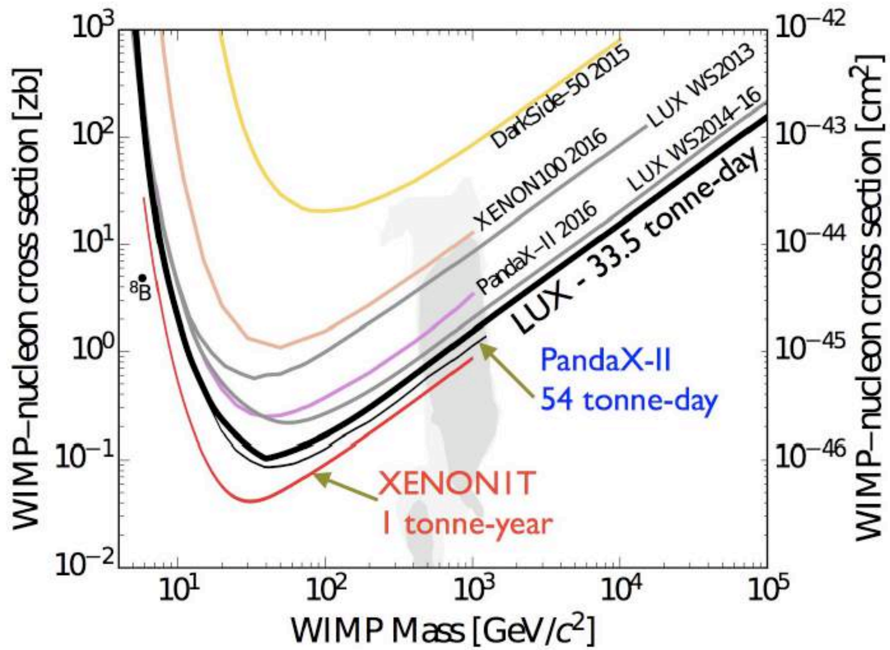
Phys Rev Lett, 116, 161301, 2016

WIMP-nucleon spin independent analysis

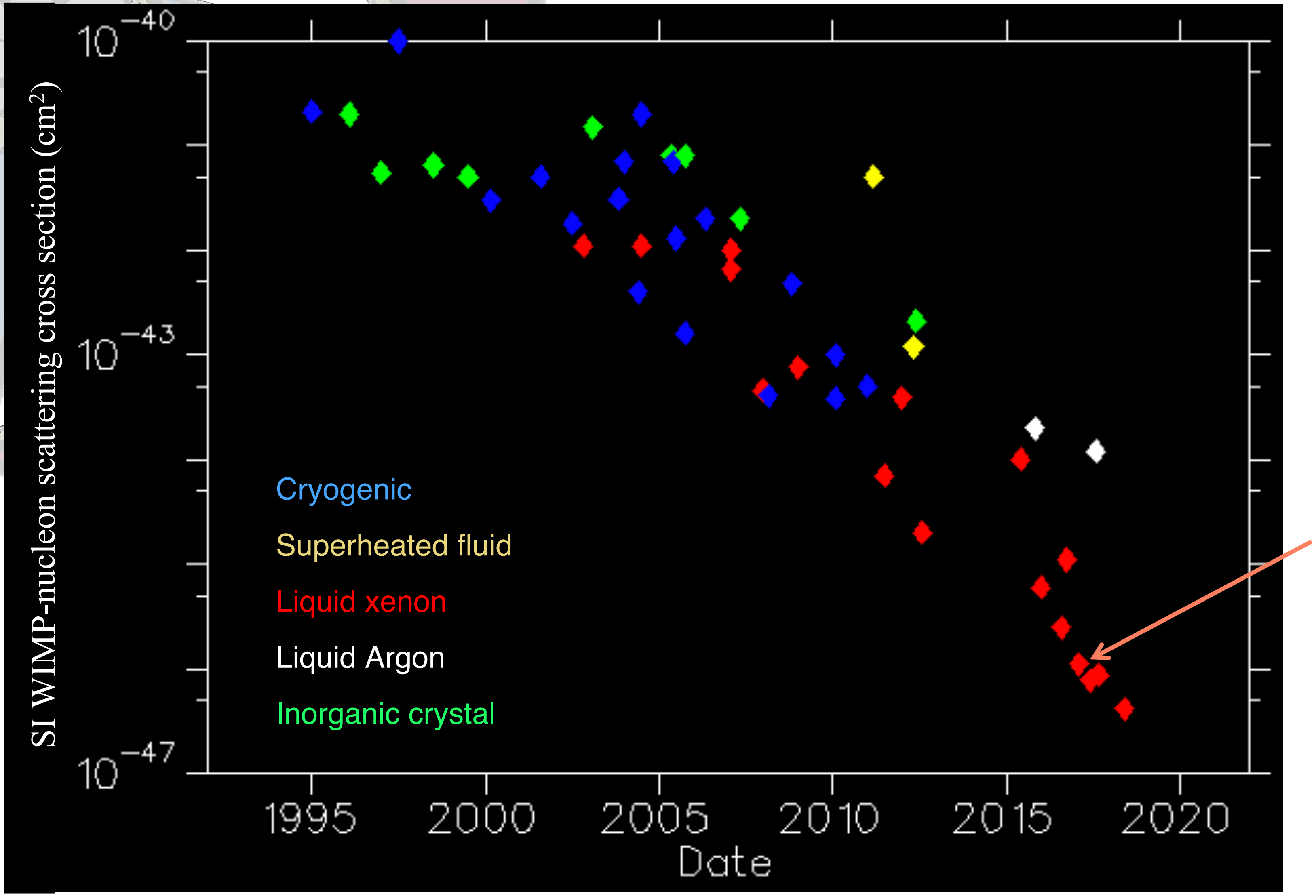
Data 'salted' to provide blinding

LUX 2017 : 427 live-days: lowest 90% CL exclusion = **0.11 zb at 40 GeV/c** (PRL, 118, 021303, 2017)



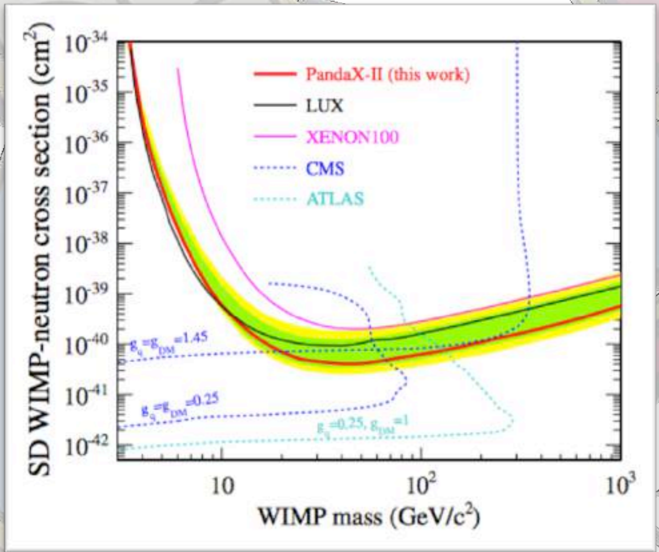


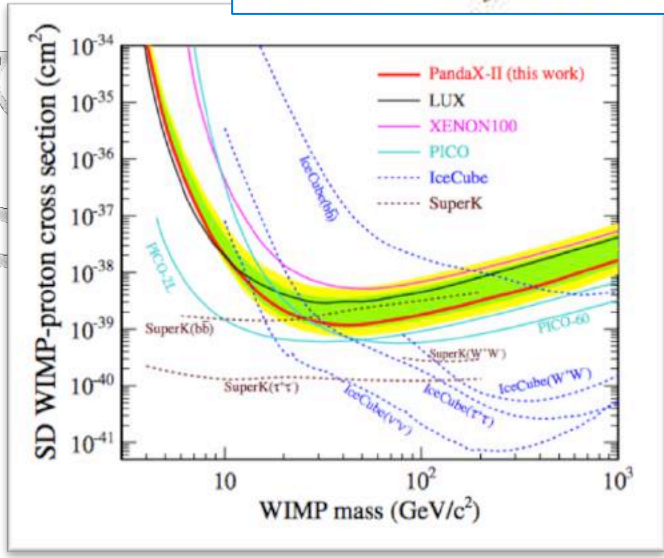
Impressive progress in the 'benchmark' SI limit!

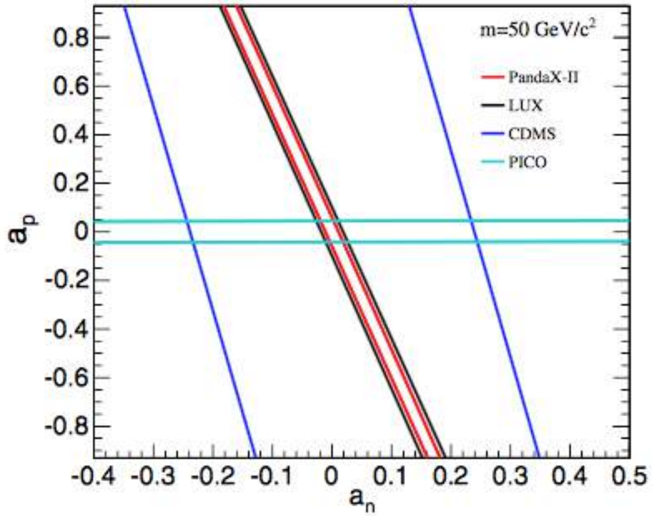


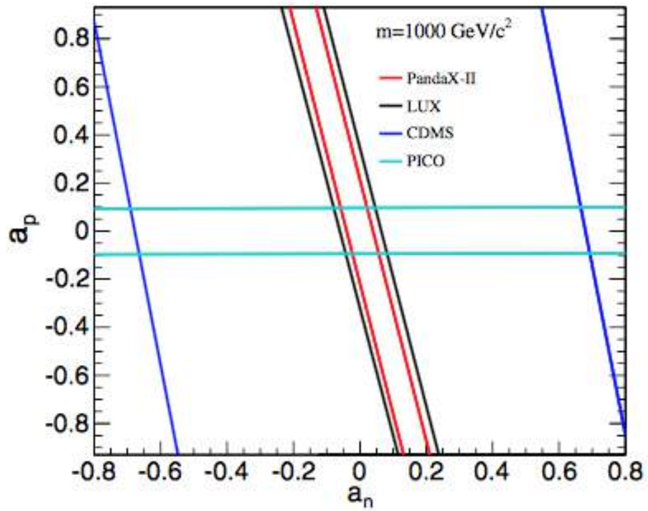
Spin dependent analysis

PRL **118**, 071301 (2017)



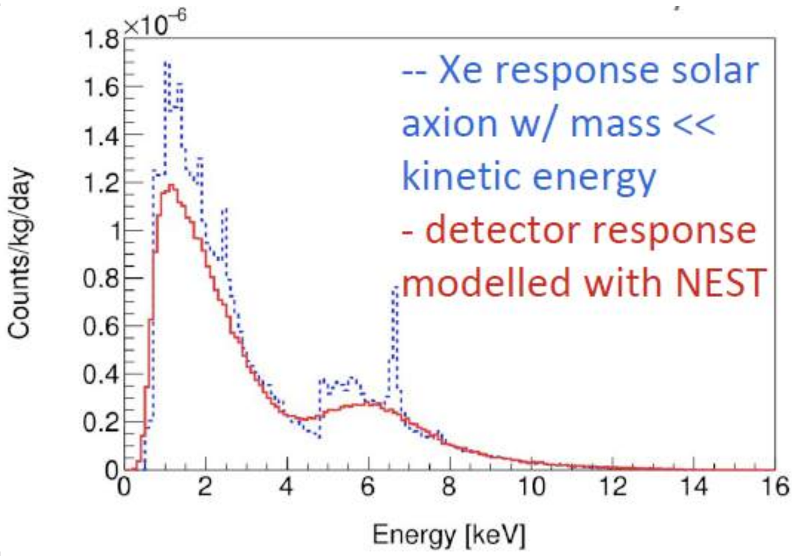


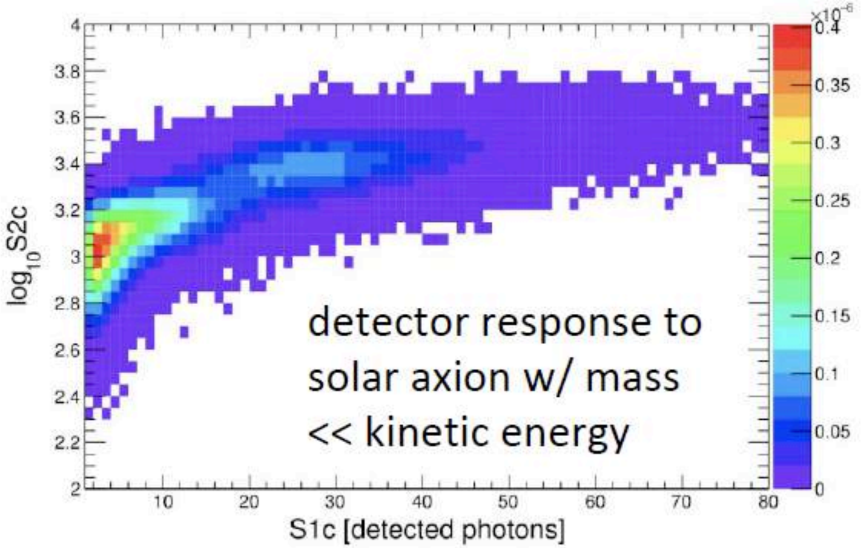


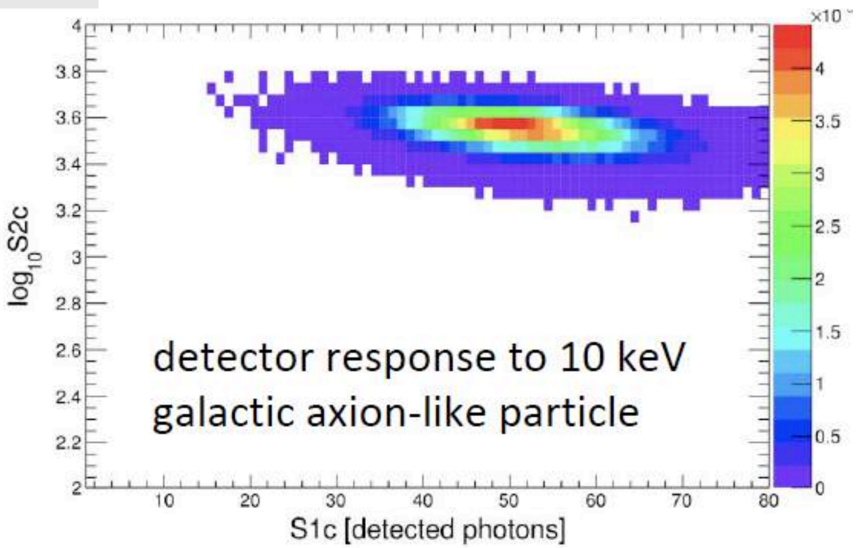


Axions/ALPs

- Peccei-Quinn solution to the strong-CP problem
- Two models considered
  - QCD axions produced and emitted from the Sun
  - Galactic keV scale axion-like particles (a DM candidate)
- An electron recoil band search



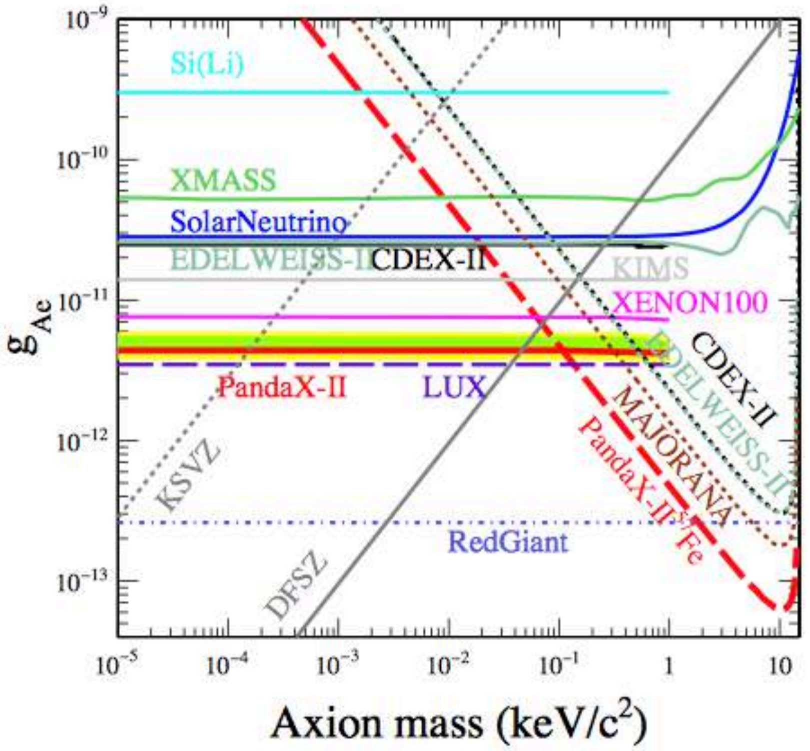




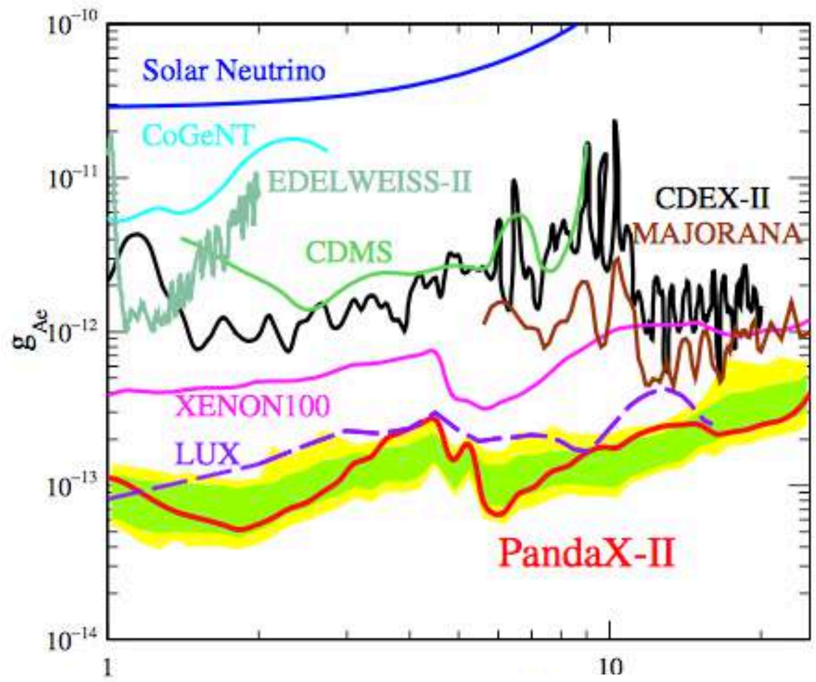
Axions/ALPs

Electron-recoil signatures

QCD axions emitted from the Sun



Galactic DM ALPs



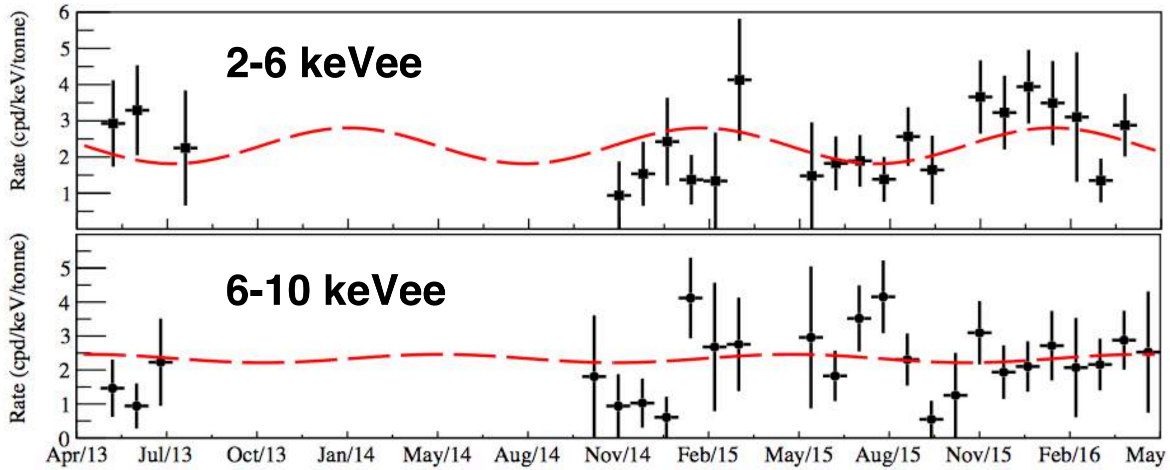
ALP mass (keV/c^2)

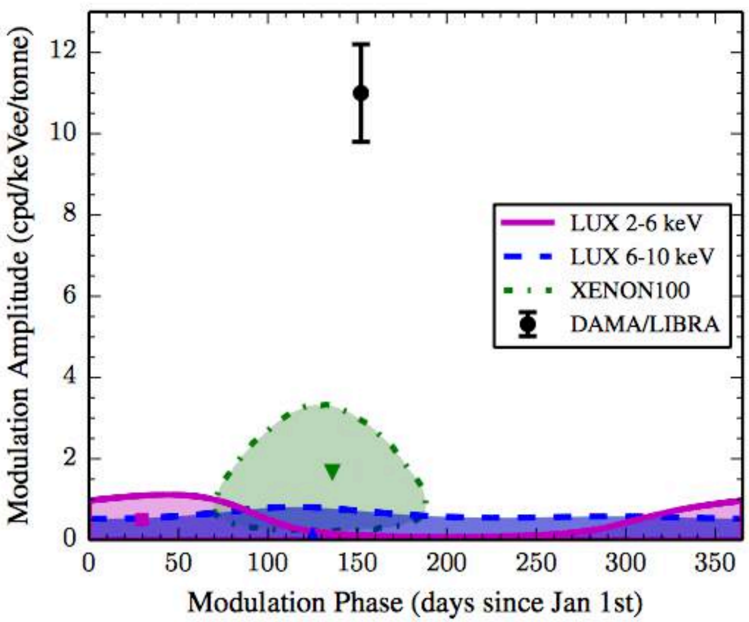
Phys. Rev. Lett. **118**, 261301

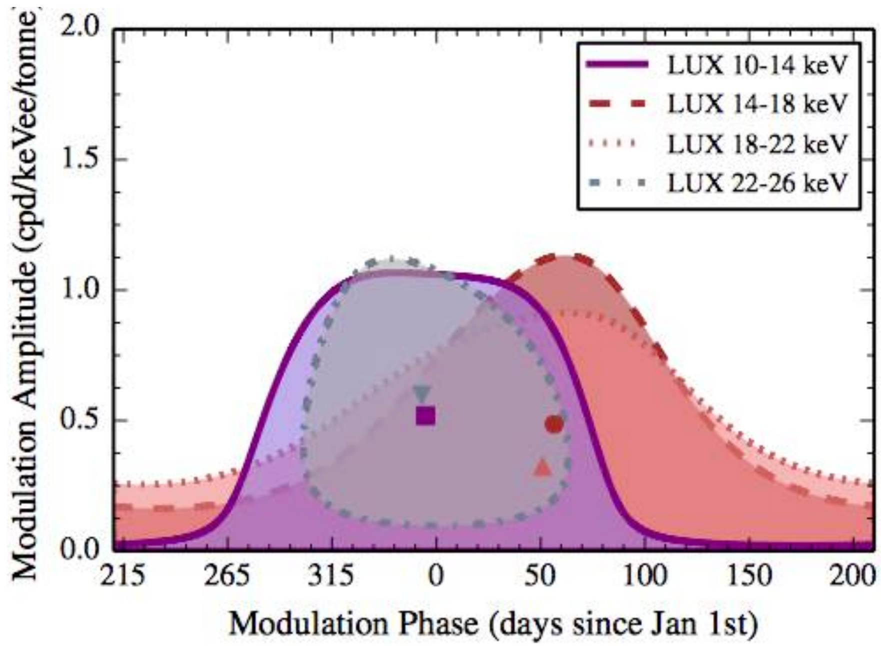
More to come soon…!

Annual modulations

arXiv:1807.07113

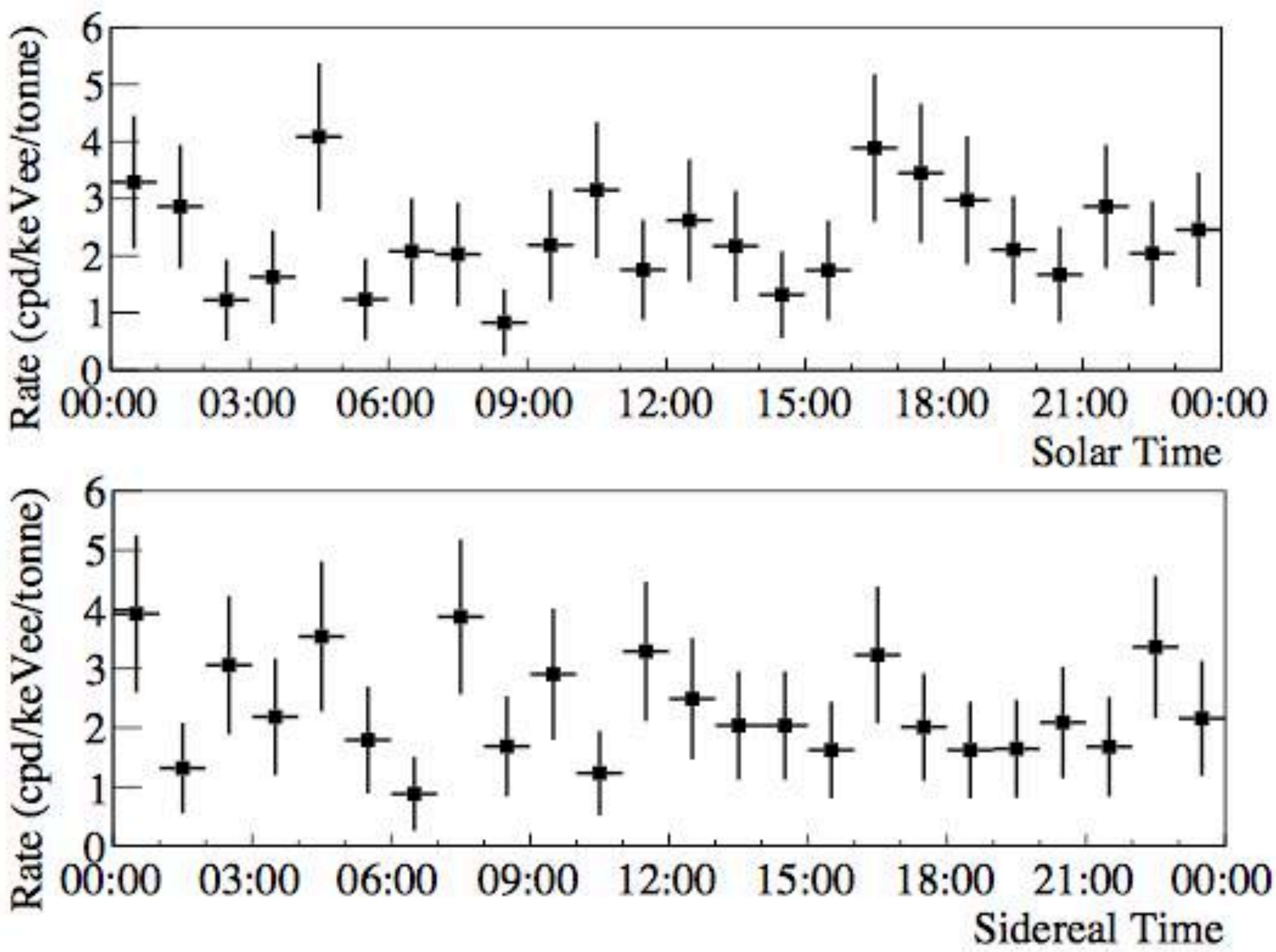






Diurnal modulations

arXiv:1807.07113



On-going LUX analyses:

- Effective field theories analysis
- Migdal and Bremsstrahlung ER-boosted searches
- Neutrinoless double beta decay of $^{134,136}Xe$
- Two-neutrino double electron capture of ^{124}Xe
- Lightly ionising particles
- …

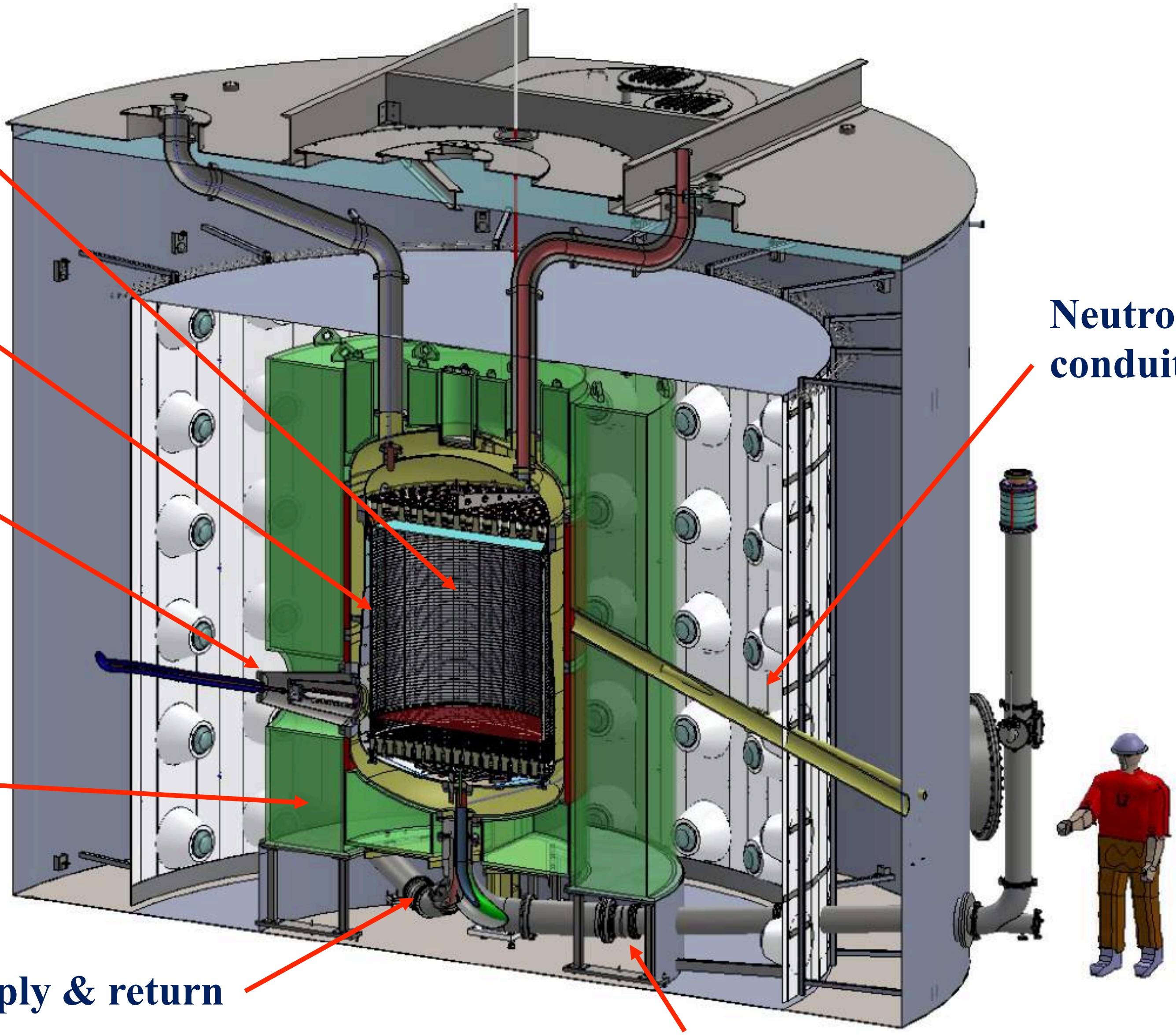
+ lots lots more…

After LUX

After LUX

…LUX - ZEPLIN

LUX-ZEPLIN (LZ) detector



Technical Design Report, arXiv:1703.09144.

LZ…

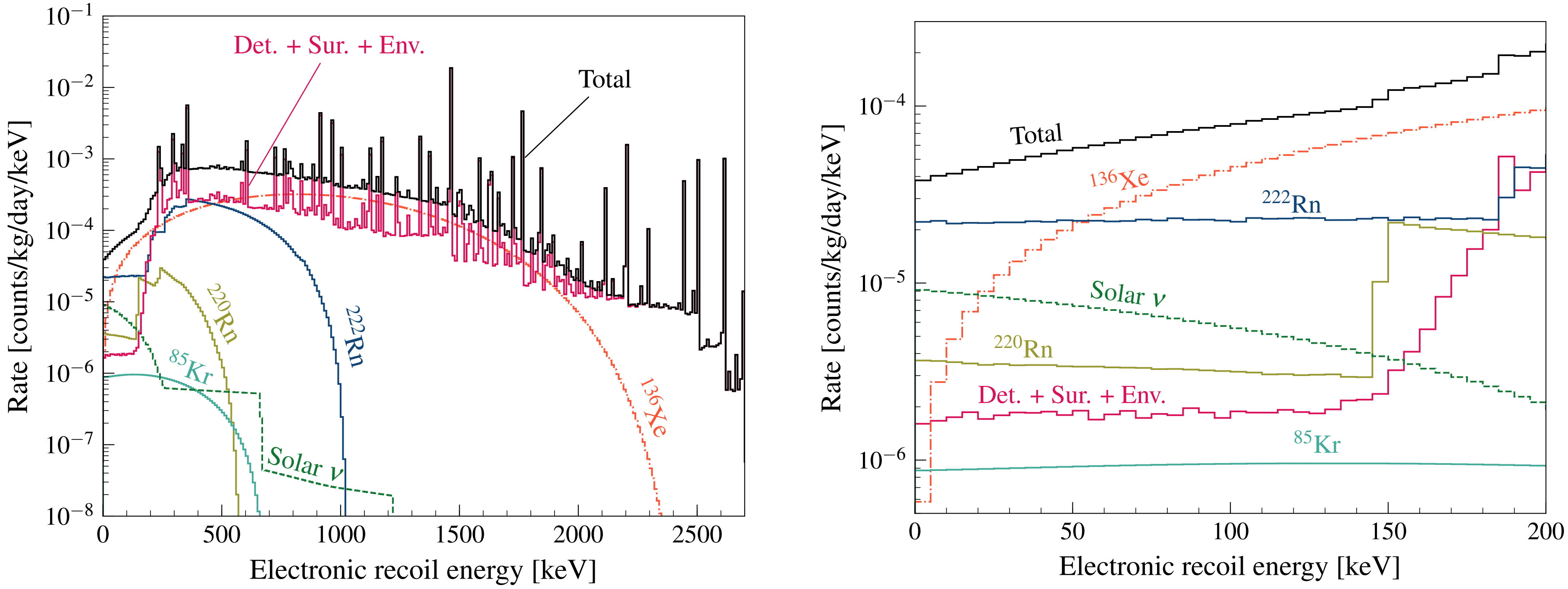
Key Facts!

- … is the successor to LUX and ZEPLIN-III
- …will be hosted by the Sanford Underground Research Facility
- …will have ~9 T total, 7 T active, 5.6 T fiducial mass of liquid xenon
- …which is about 50 times that of LUX (fiducial)
- …will have a skin region, outer detector and water tank for background suppression
- …Low energy NR sensitivity limited by astrophysical backgrounds
- …will reach a SI WIMP sensitivity of 1.6×10^{-48} cm^2 at 40 GeV/c^2
- …will have sensitivity to a range of other New Physics processes
- …is being constructed NOW; will be running by 2020


SICC

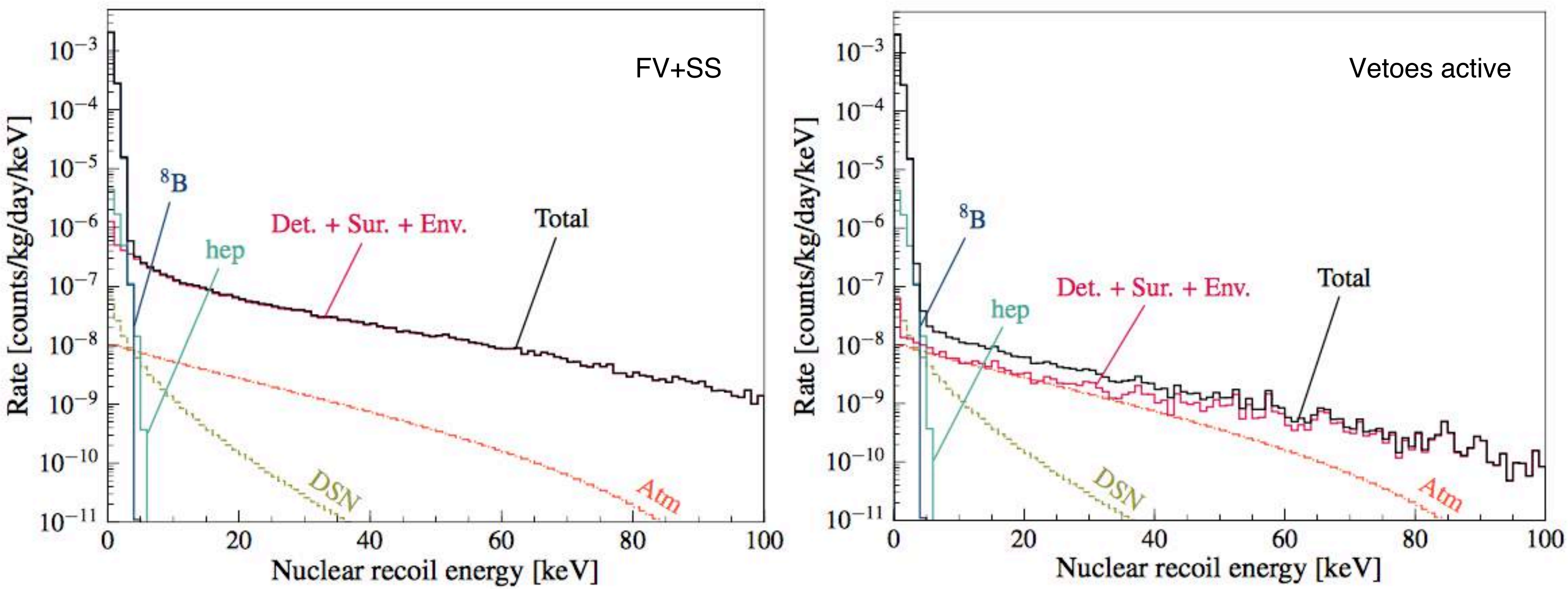

EXIT

Background Single Scatter **ER** events



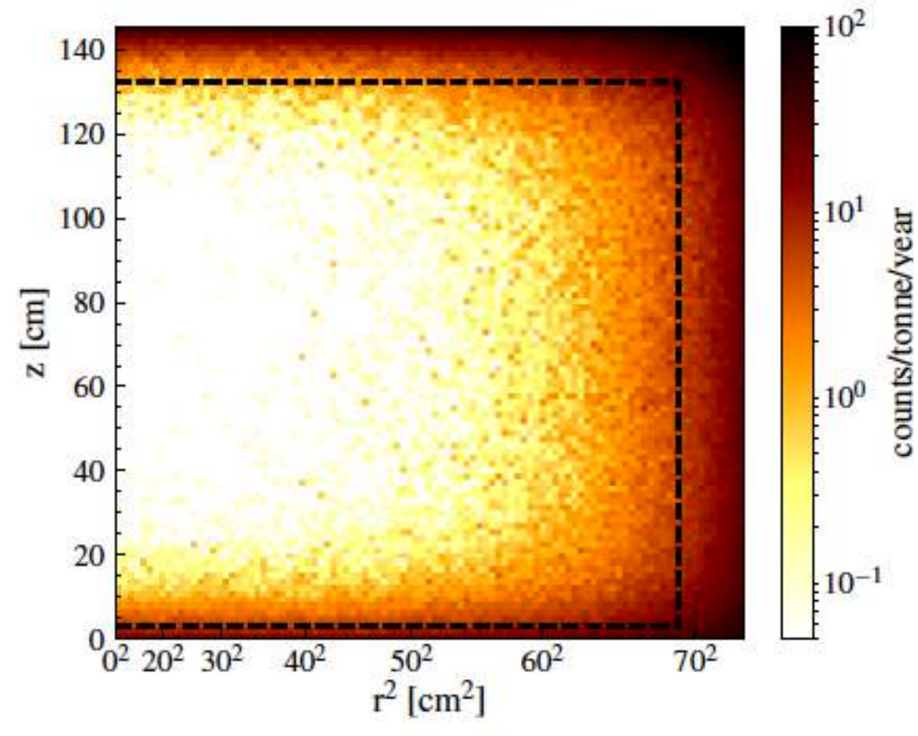
- Energy spectra of electron recoil background from various sources.
- ^{222}Rn dominates at low energies.
- Environmental background and components are not major sources of background events.

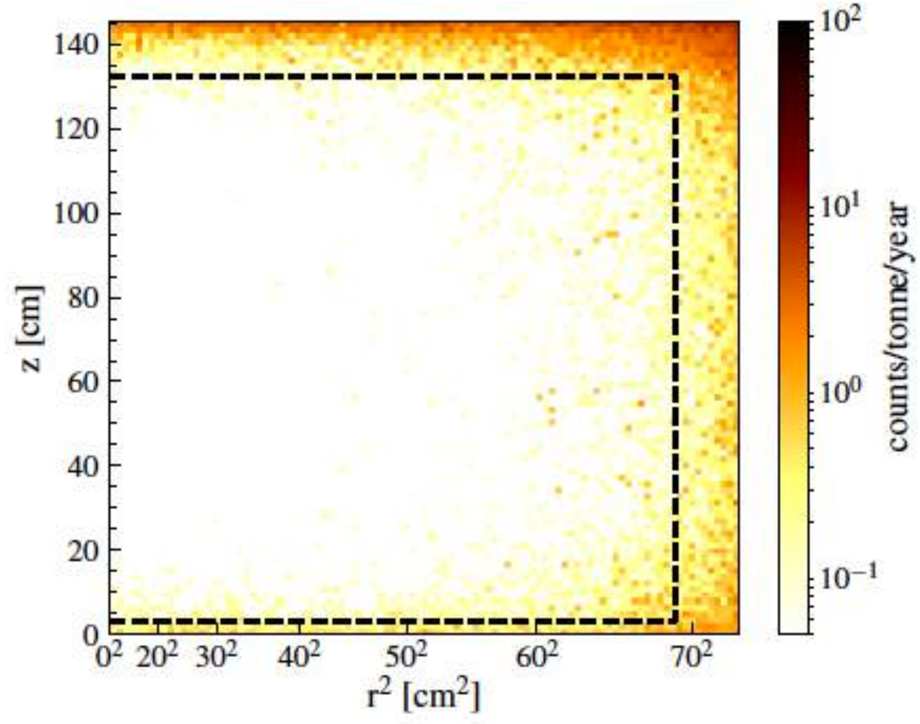
Background Single Scatter **NR** events



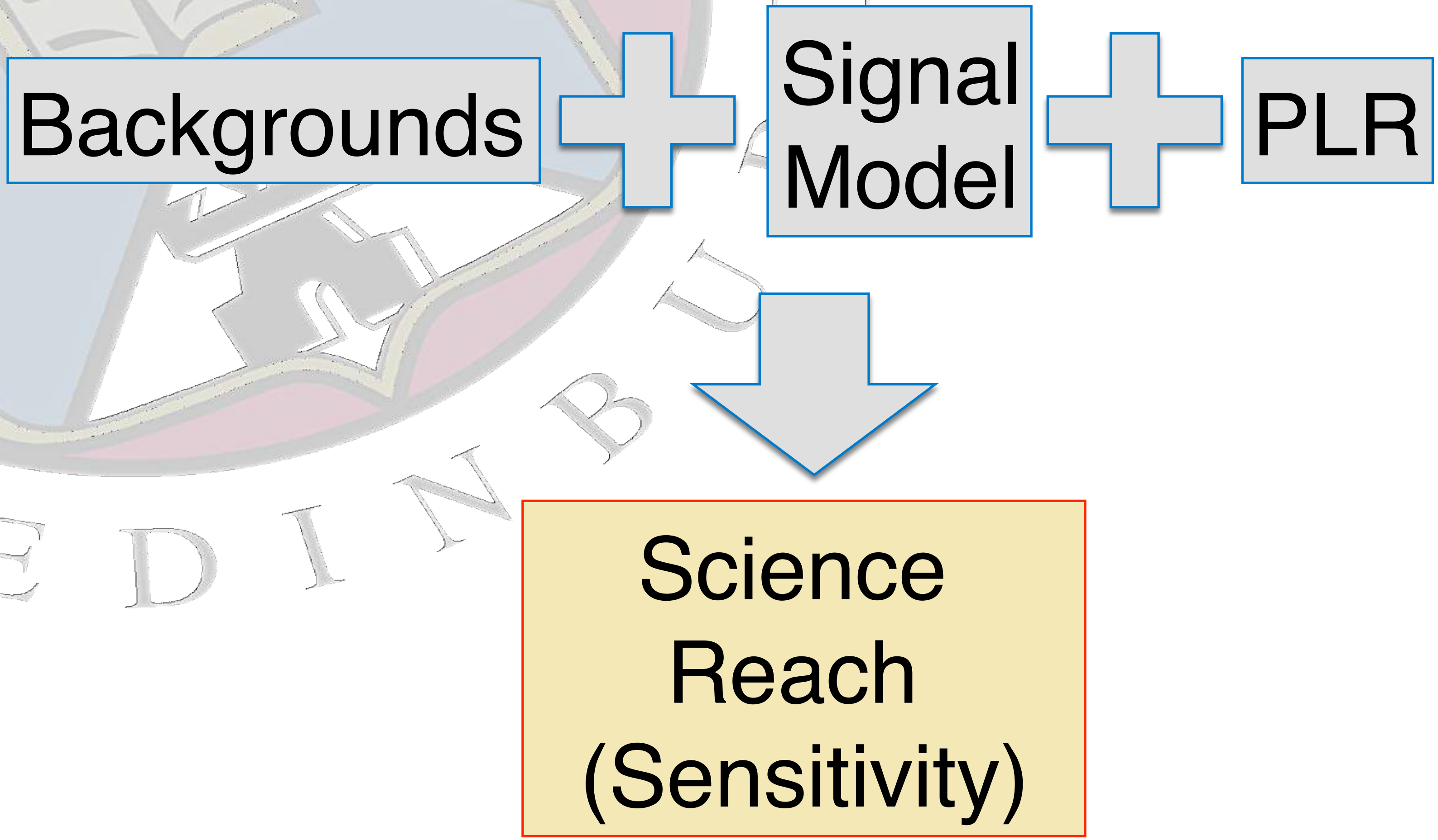
- Single scatter NR before (left) and after (right) skin and OD coincidence rejection
- Rate at low energy (<4 keV) dominated by ^{8}B CNNS

Background Single Scatter **NR** events





- Single scatter nuclear recoil events in the LXe active volume before (left) and after (right) rejecting events in coincidence with veto system (LXe skin and the Outer Detector (OD).


Backgrounds
Signal Model
PLR
Science Reach (Sensitivity)

What this means for WIMPs…

arXiv:1802.06039

039v1 [astro-ph.IM] 16 Feb 2018

Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment

D.S. Akerib,[1,2] C.W. Akerlof,[3] S.K. Alsum,[4] H.M. Araújo,[5] M. Arthurs,[3] X. Bai,[6] A.J. Bailey,[5,a] J. Balajthy,[7] S. Balashov,[8] D. Bauer,[5] J. Belle,[9] P. Beltrame,[10] T. Benson,[4] E.P. Bernard,[11,12] T.P. Biesiadzinski,[1,2] K.E. Boast,[13] B. Boxer,[14] P. Brás,[15] J.H. Buckley,[16] V.V. Bugaev,[16] S. Burdin,[14] J.K. Busenitz,[17] C. Carels,[13] D.L. Carlsmith,[4] B. Carlson,[18] M.C. Carmona-Benitez,[19] C. Chan,[20] J.J. Cherwinka,[4] A. Cole,[12] A. Cottle,[9] W.W. Craddock,[1] A. Currie,[5,b] J.E. Cutter,[21] C.E. Dahl,[22,9] L. de Viveiros,[19] A. Dobi,[12,c] J.E.Y. Dobson,[23,d] E. Druszkiewicz,[24] T.K. Edberg,[7] W.R. Edwards,[12,e] A. Fan,[1,2] S. Fayer,[5] S. Fiorucci,[12] T. Fruth,[13] R.J. Gaitskell,[20] J. Genovesi,[6] C. Ghag,[23] M.G.D. Gilchriese,[12] M.G.D.van der Grinten,[8] C.R. Hall,[7] S. Hans,[25] K. Hanzel,[12] S.J. Haselschwardt,[26] S.A. Hertel,[27] S. Hillbrand,[21] C. Hjemfelt,[6] M.D. Hoff,[12] J.Y-K. Hor,[17] D.Q. Huang,[20] C.M. Ignarra,[1,2] W. Ji,[1,2] A.C. Kaboth,[28,8] K. Kamdin,[12,11] J. Keefner,[18] D. Khaitan,[24] A. Khazov,[8] Y.D. Kim,[29] C.D. Kocher,[20] E.V. Korolkova,[30] H. Kraus,[13] H.J. Krebs,[1] L. Kreczko,[31] B. Krikler,[31] V.A. Kudryavtsev,[30] S. Kyre,[26] J. Lee,[29] B.G. Lenardo,[21] D.S. Leonard,[29] K.T. Lesko,[12] C. Levy,[32] J. Li,[29] J. Liao,[20] F.-T. Liao,[13] J. Lin,[11,12] A. Lindote,[15] R. Linehan,[1,2] W.H. Lippincott,[9] X. Liu,[10] M.I. Lopes,[15] B. López Paredes,[5] W. Lorenzon,[3] S. Luitz,[1] J.M. Lyle,[20] P. Majewski,[8] A. Manalaysay,[21] R.L. Mannino,[33] C. Maupin,[18] D.N. McKinsey,[11,12] Y. Meng,[17] E.H. Miller,[6] J. Mock,[32,12,f] M.E. Monzani,[1,2,g] J.A. Morad,[21] E. Morrison,[6] B.J. Mount,[34] A.St.J. Murphy,[10] H.N. Nelson,[26] F. Neves,[15] J. Nikoleyczik,[4] K. O'Sullivan,[12,11,h] I. Olcina,[5] M.A. Olevitch,[16] K.C. Oliver-Mallory,[12,11] K.J. Palladino,[4] S.J. Patton,[12] E.K. Pease,[12] B. Penning,[35] A. Piepke,[17] S. Powell,[14] R.M. Preece,[8] K. Pushkin,[3] B.N. Ratcliff,[1] J. Reichenbacher,[6] C.A. Rhyne,[20] A. Richards,[5] J.P. Rodrigues,[15] R. Rosero,[25] P. Rossiter,[30] J.S. Saba,[12] M. Sarychev,[9] R.W. Schnee,[6] M. Schubnell,[3] P.R. Scovell,[13] S. Shaw,[26] T.A. Shutt,[1,2] J.J. Silk,[7] C. Silva,[15] K. Skarpaas,[1] W. Skulski,[24] M. Solmaz,[26] V.N. Solovov,[15] P. Sorensen,[12] I. Stancu,[17] M.R. Stark,[6] T.M. Stiegler,[33] K. Stifter,[1,2] M. Szydagis,[32] W.C. Taylor,[20] R. Taylor,[5] D.J. Taylor,[18] D. Temples,[22] P.A. Terman,[33] K.J. Thomas,[12,i] M. Timalsina,[6] W.H. To,[1,2] A. Tomás,[5] T.E. Tope,[9] M. Tripathi,[21] C.E. Tull,[12] L. Tvrznikova,[36,11,12] U. Utku,[23] J. Va'vra,[1] A. Vacheret,[5] J.R. Verbus,[20,j] E. Voirin,[9] W.L. Waldron,[12] J.R. Watson,[11,12] R.C. Webb,[33] D.T. White,[26] T.J. Whitis,[1,37] W.J. Wisniewski,[1] M.S. Witherell,[12,11] F.L.H. Wolfs,[24] D. Woodward,[30,k] S.D. Worm,[8,l] M. Yeh,[25] J. Yin,[24] and I. Young[9]

(The LUX-ZEPLIN Collaboration)

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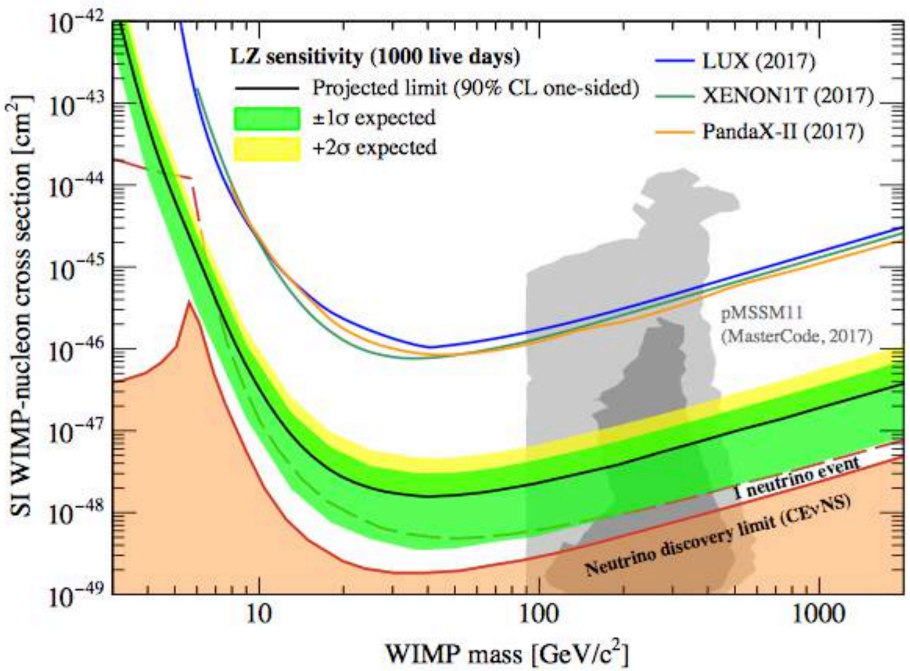
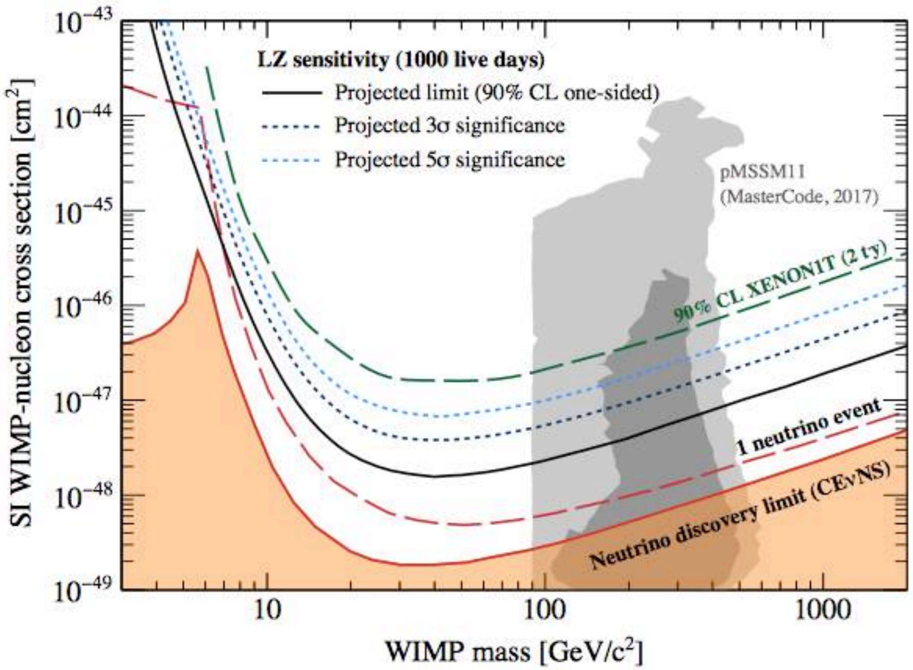
[3] *University of Michigan, Randall Laboratory of Physics, Ann Arbor, MI 48109-1040, USA*
[4] *University of Wisconsin-Madison, Department of Physics, Madison, WI 53706-1390, USA*
[5] *Imperial College London, Physics Department, Blackett Laboratory, London SW7 2AZ, UK*
[6] *South Dakota School of Mines and Technology, Rapid City, SD 57701-3901, USA*
[7] *University of Maryland, Department of Physics, College Park, MD 20742-4111, USA*

WIMP SI Sensitivity

https://arxiv.org/pdf/1802.06039.pdf



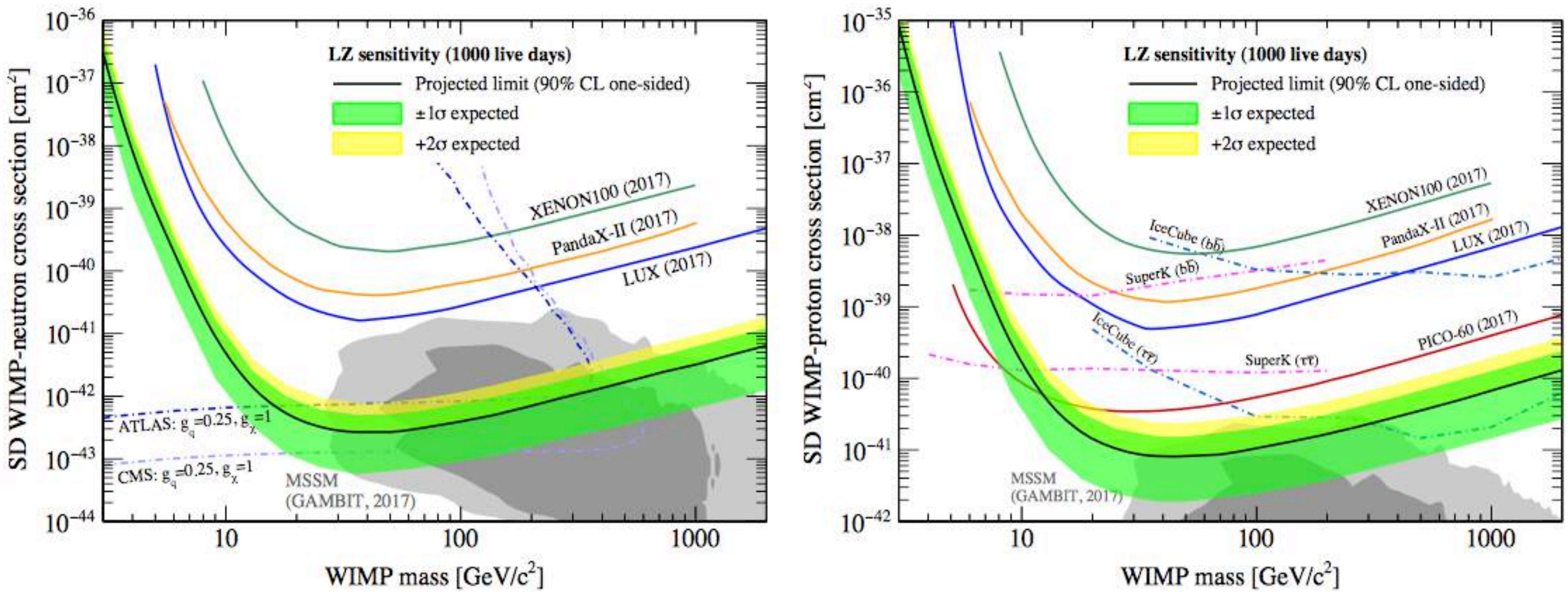


- Spin-independent cross section exclusion sensitivity
- Spin-independent cross section discovery potential

5600 ton.days

WIMP SD Sensitivity

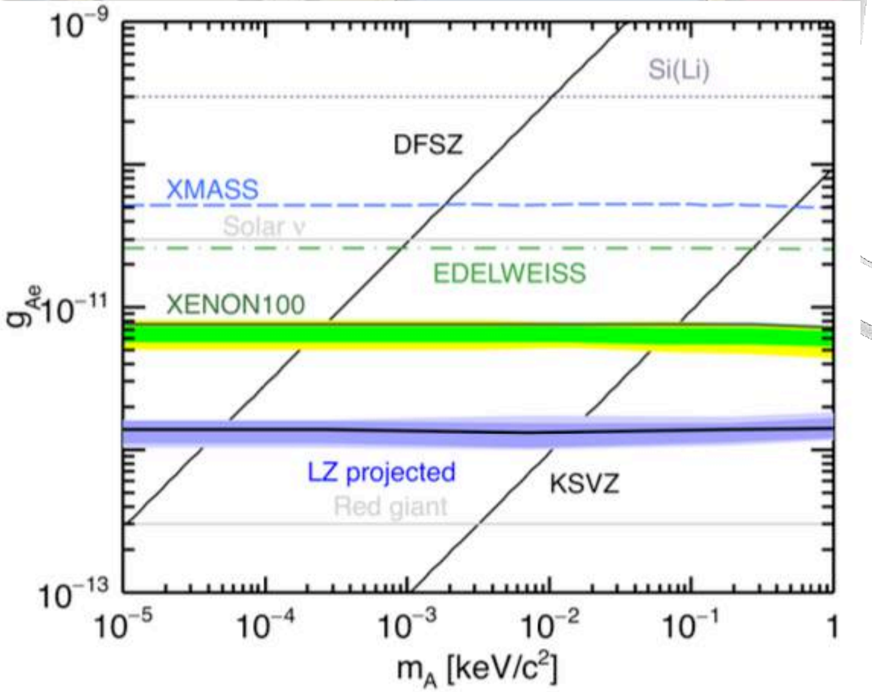
https://arxiv.org/pdf/1802.06039.pdf

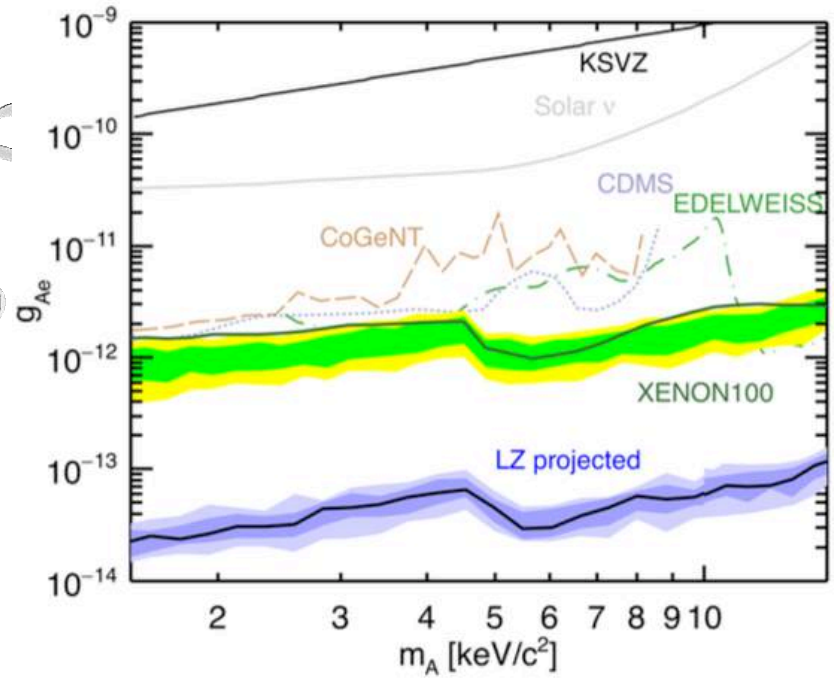


- SD WIMP-neutron (left) and WIMP-proton (right) scattering for a 1000 live day run with a 5.6 tonne fiducial mass.

Axions and ALPs

https://arxiv.org/abs/1703.09144





- Solar QCD axions (left) and galactic axion-like particle (right) sensitivities for 5600 live ton-days

To summarise…

Great Progress

To summarise…

Great Progress

Still lots to do

To summarise…

Great Progress

Still lots to do

Roll on 2020!

Huge progress over the past 2 decades. ~5 orders of magnitude in sensitivity, detector physics, low background physics

Main focus remains WIMPs, but opportunities exist for other New Physics

Roll on 2020!

Event yields from known sources

- 5.6 tonnes
- 1000 days
- 1.5 to 6.5 keV

Background Source	ER (cts)	NR (cts)
Detector Components	**9**	**0.07**
Surface Contamination	**40**	**0.39**
Laboratory and Cosmogenics	**5**	**0.06**
Xenon Contaminants	**819**	**0**
222Rn	681	0
220Rn	111	0
natKr (0.015 ppt g/g)	24	0
natAr (0.45 ppb g/g)	3	0
Physics	**322**	**0.51**
136Xe 2νββ	67	0
Solar neutrinos (pp+7Be+13N)	255	0
Diffuse supernova neutrinos	0	0.05
Atmospheric neutrinos	0	0.46
Total	1195	1.03
with 99.5% ER discrim., 50% NR eff.	**5.97**	**0.51**

Event yields from known sources

- 5.6 tonnes
- 1000 days
- 1.5 to 6.5 keV

Radon dominates ER backgrounds

νe scattering of *pp* solar ν's; (atomic electron recoils)

Background Source	ER (cts)	NR (cts)
Detector Components	**9**	**0.07**
Surface Contamination	**40**	**0.39**
Laboratory and Cosmogenics	**5**	**0.06**
Xenon Contaminants	**819**	**0**
222Rn	681	0
220Rn	111	0
natKr (0.015 ppt g/g)	24	0
natAr (0.45 ppb g/g)	3	0
Physics	**322**	**0.51**
136Xe 2νββ	67	0
Solar neutrinos (pp+7Be+13N)	255	0
Diffuse supernova neutrinos	0	0.05
Atmospheric neutrinos	0	0.46
Total	1195	1.03
with 99.5% ER discrim., 50% NR eff.	**5.97**	**0.51**

Event yields from known sources

- 5.6 tonnes
- 1000 days
- 1.5 to 6.5 keV

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Neutrons, including alpha-n on PTFE → 0.39

Coherent scattering of atmospheric ν's on Xe nuclei → 0.46

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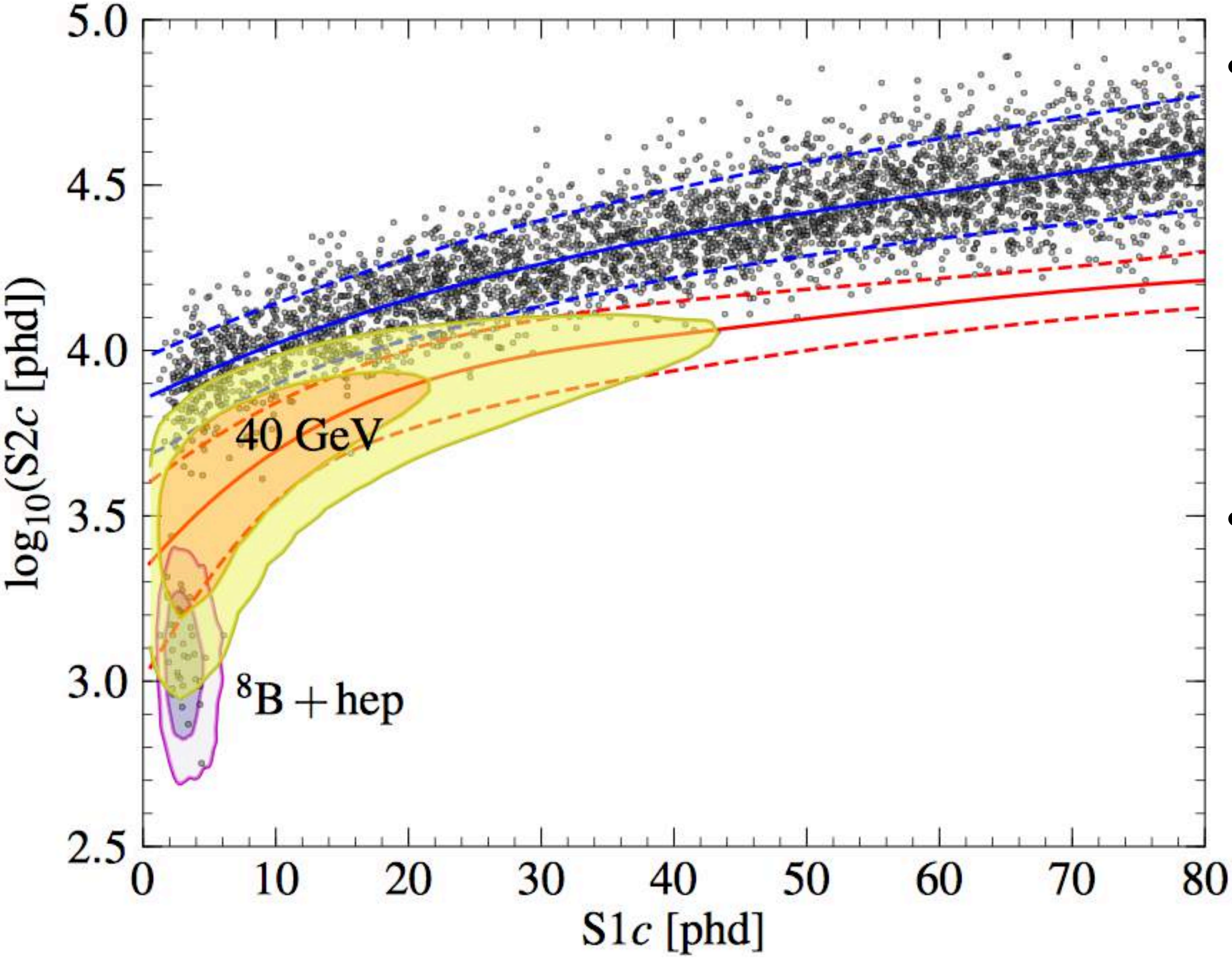
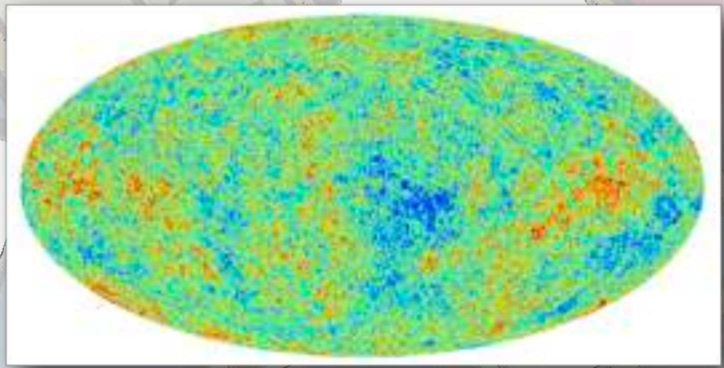
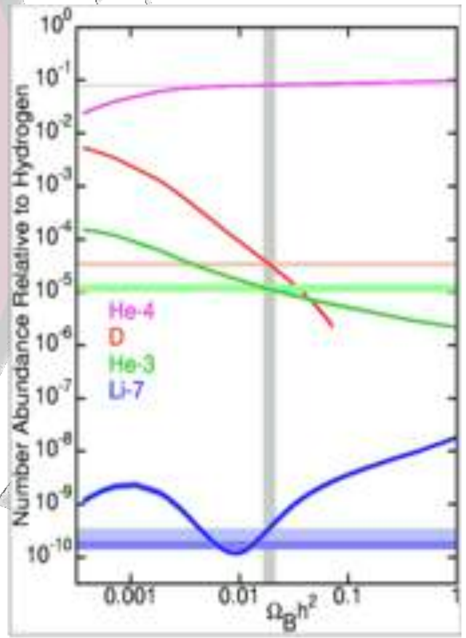
Simple WIMP search box "Cut & Count" type numbers

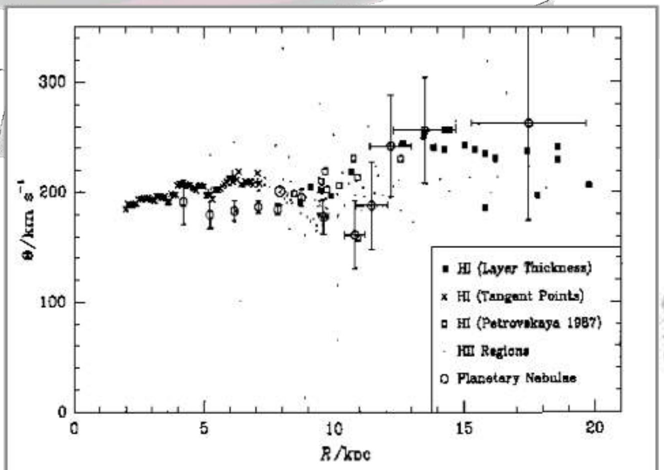
Event yields are not the whole story!



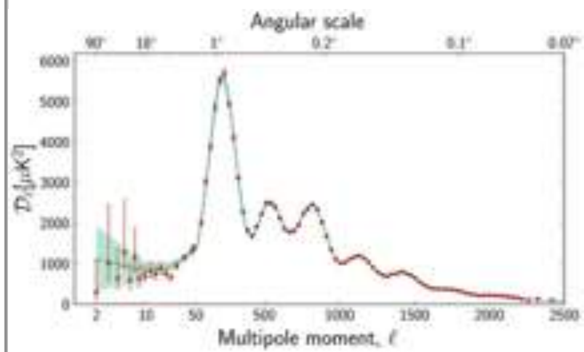
- CNNS of ^{8}B dominates at lowest energy (36 events for 5600 ton.days!)
- PLR approach to identify signal/set limits

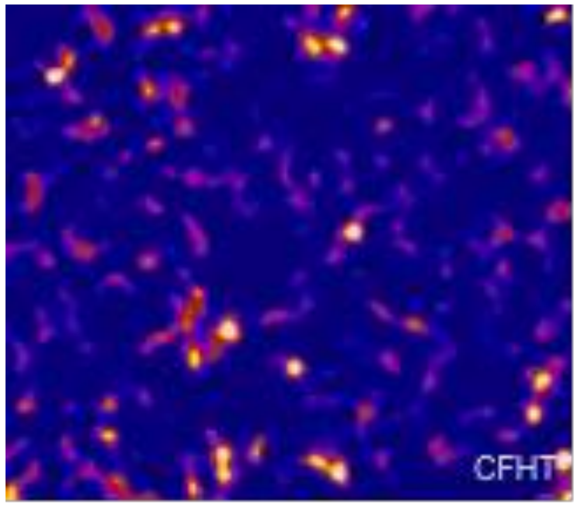


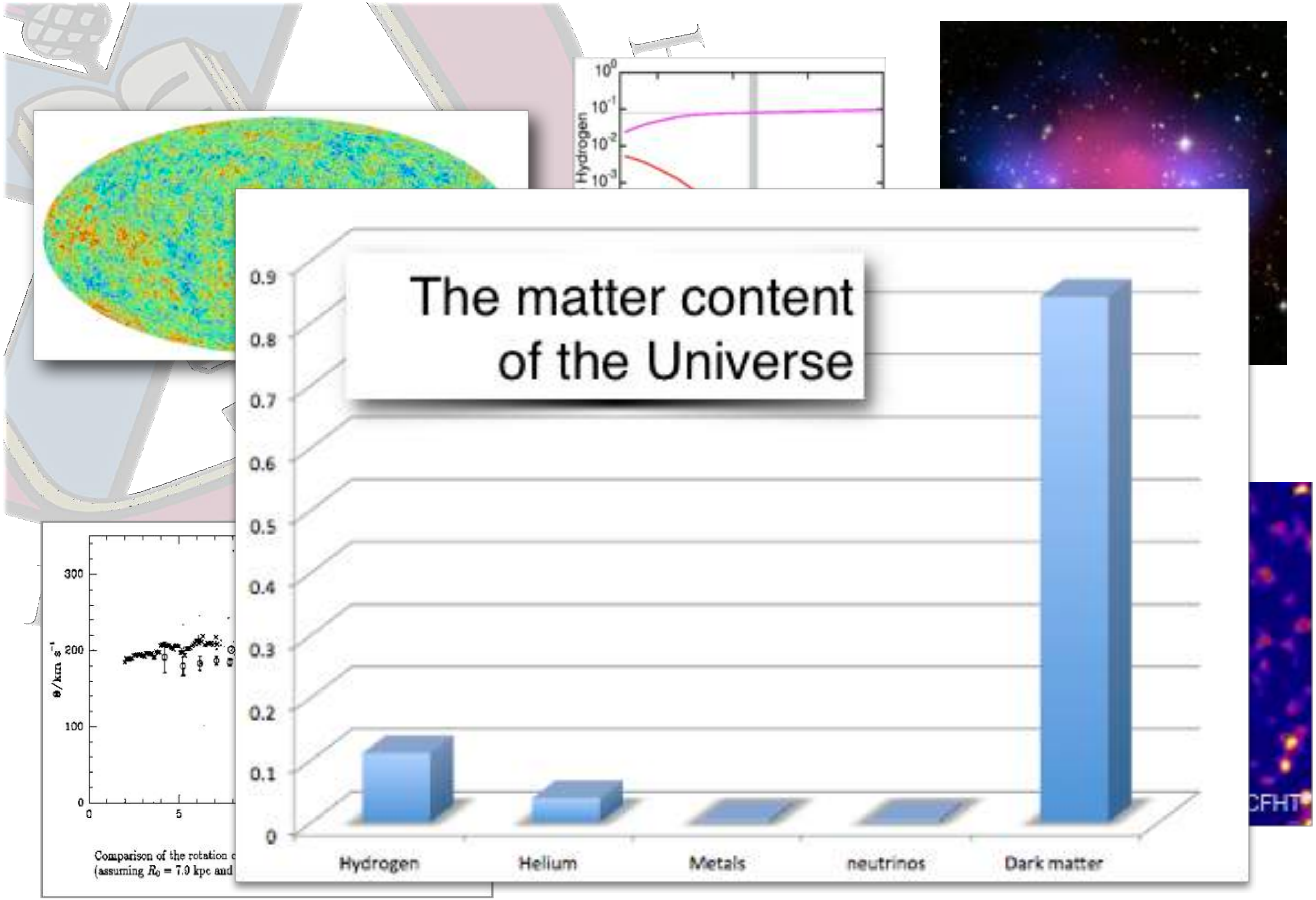




Comparison of the rotation curves calculated by all the methods discussed (assuming $R_0 = 7.9$ kpc and $\Theta_0 = 200$ km s^{-1}).



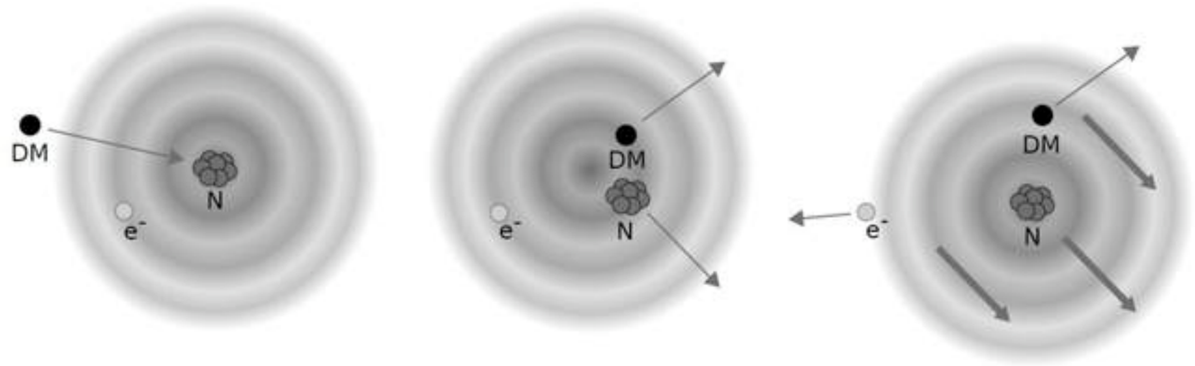



The matter content of the Universe
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Hydrogen
Helium
Metals
neutrinos
Dark matter
CFHT

Migdal and Bremsstrahlung effects

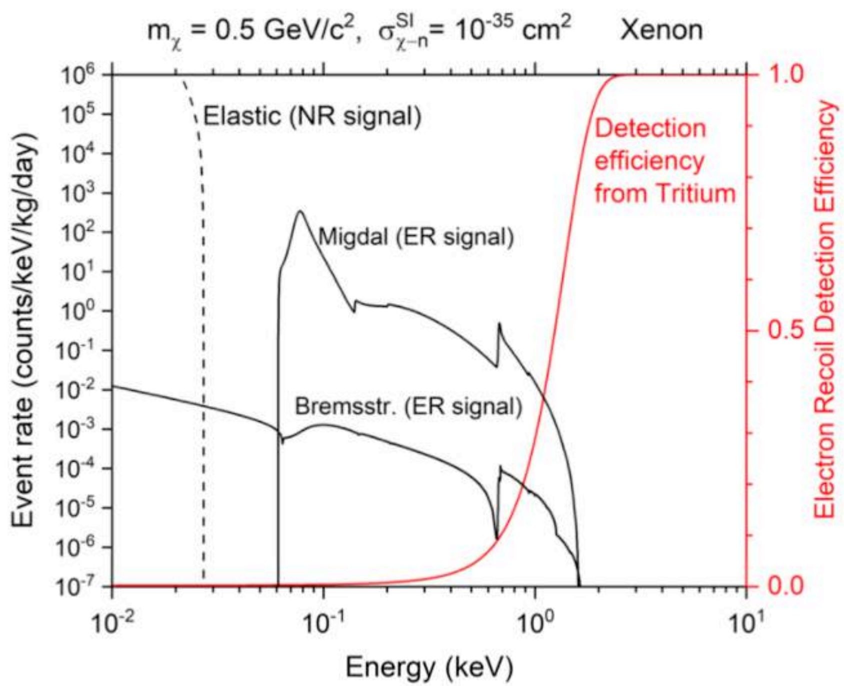
arXiv:1711.09906

Dolan, Kahlhoefer & McCabe

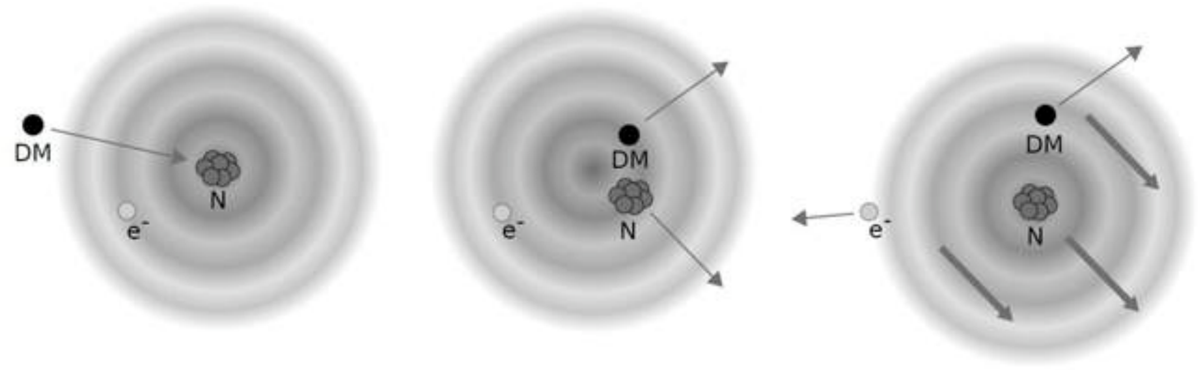


- <u>Migdal</u>: Recoiling nucleus 'leaves the electron cloud behind', with consequent ionisation and scintillation
- <u>Bremsstrahlung:</u> Real photon emission from accelerating nuclear charge

Both become sources of ER, and in fact dominate over NR for low WIMP mass due to kinematics



Migdal and Bremsstrahlung effects



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- Bremsstrahlung: Real photon emission from accelerating nuclear charge

Both become sources of ER, and in fact dominate over NR for low WIMP mass due to kinematics

I could show you, but then I'd be in trouble...