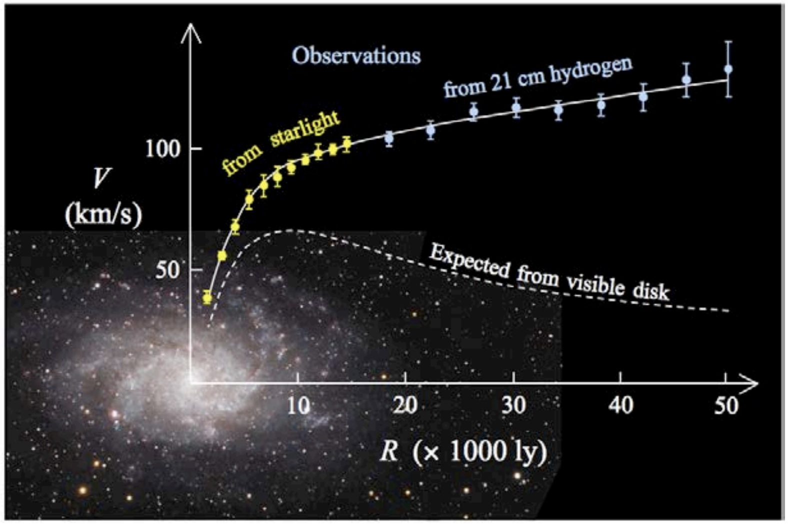
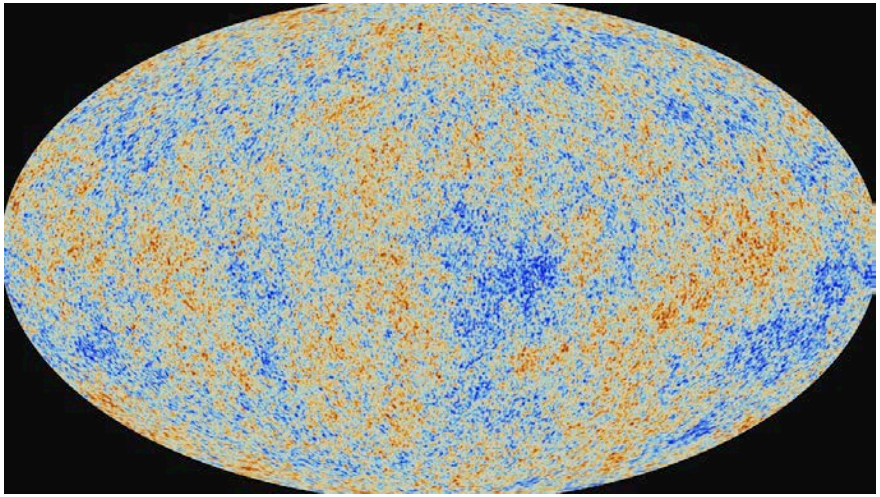
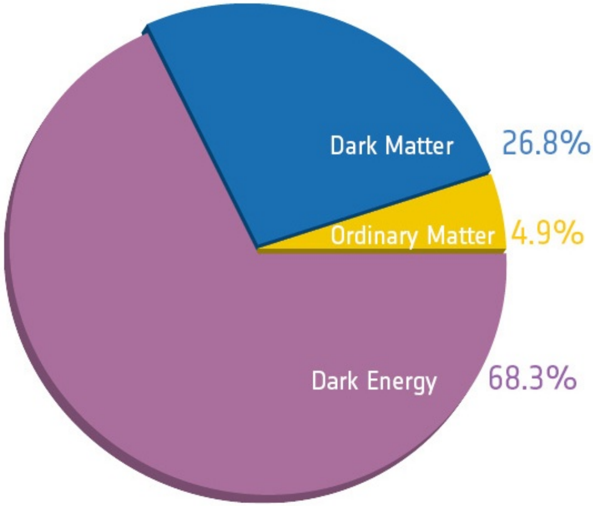


Down-to-earth searches for cosmological dark matter with LUX and LZ

Carter Hall, University of Maryland

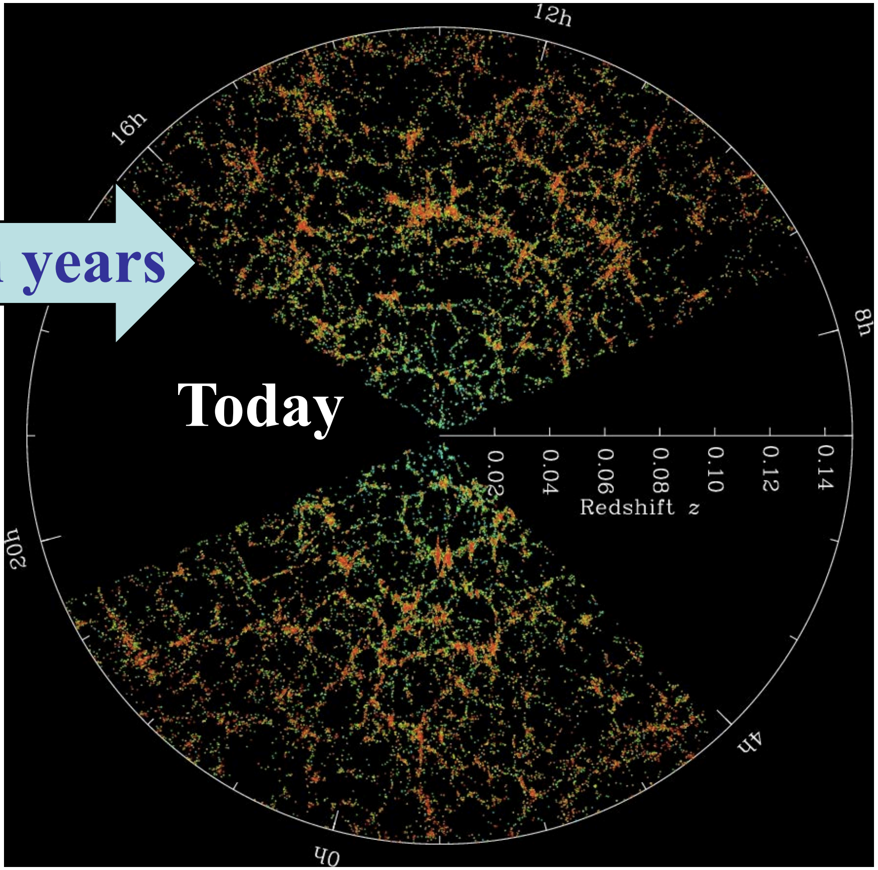
February 10, 2017



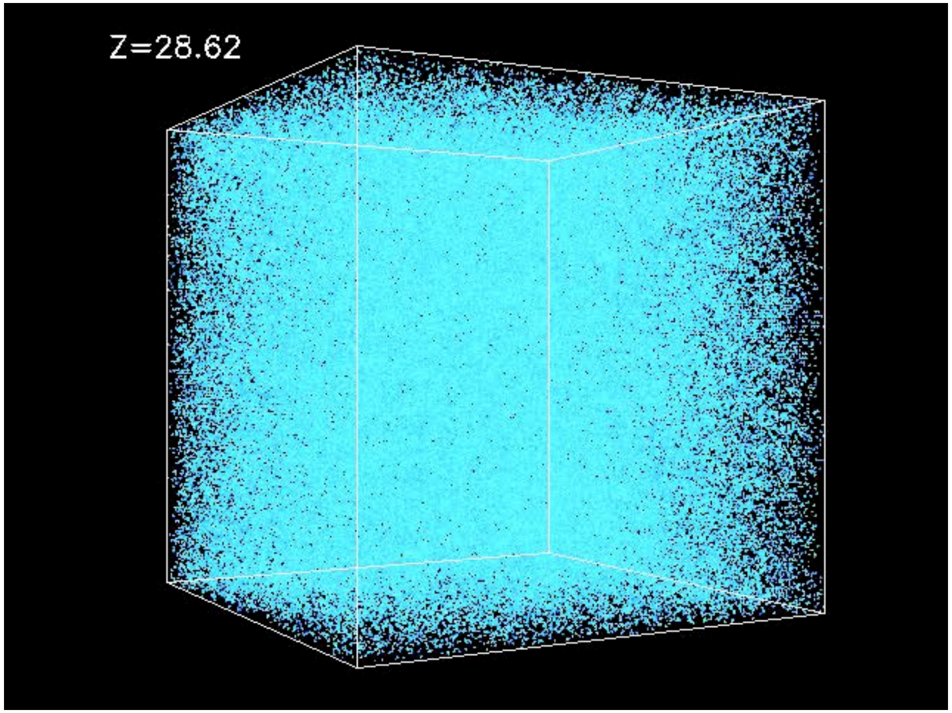


380,000 years
after the big bang

13.9 billion years

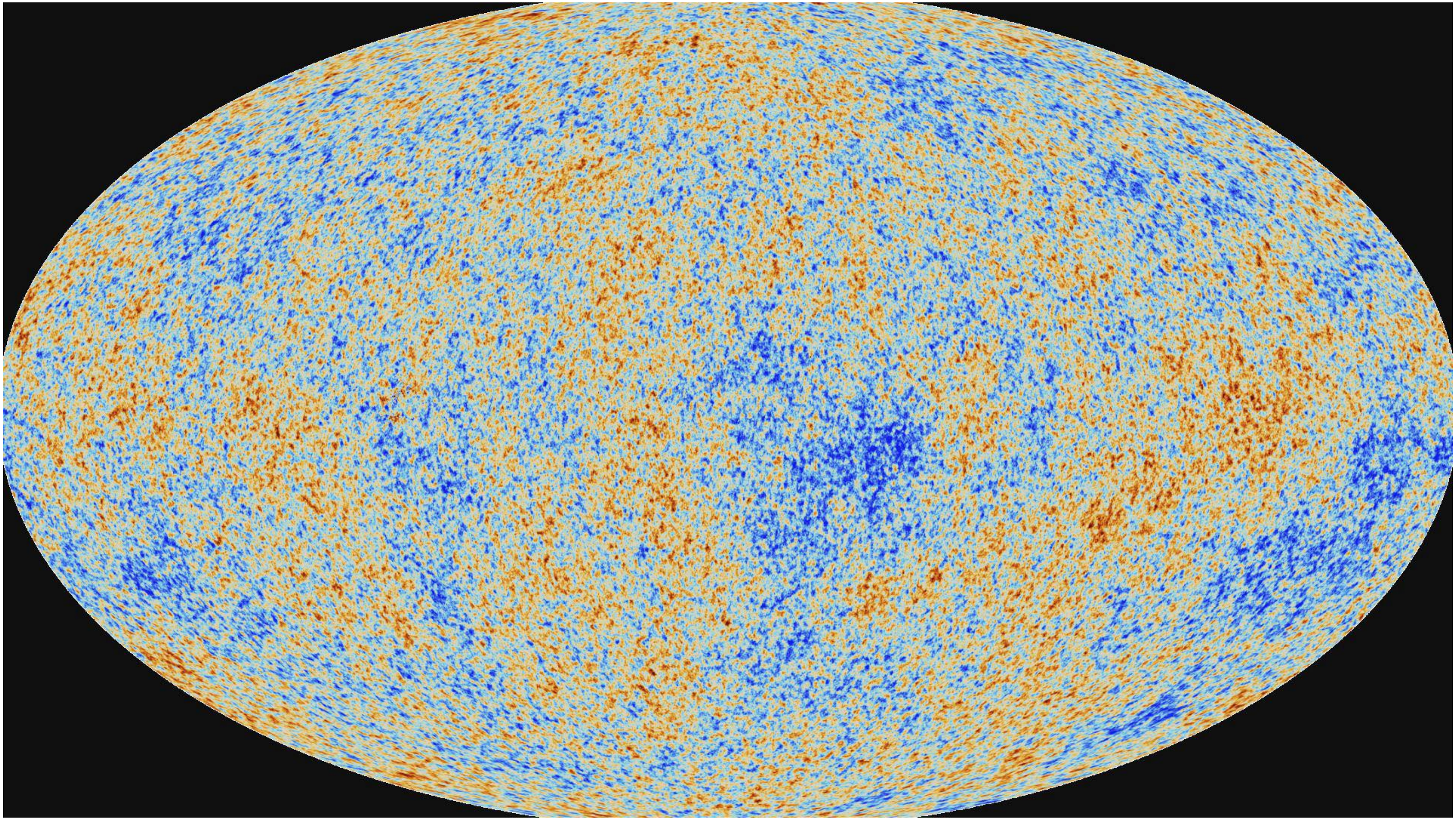


Credit: Andrey Kravtsov, KICP, U. Chicago



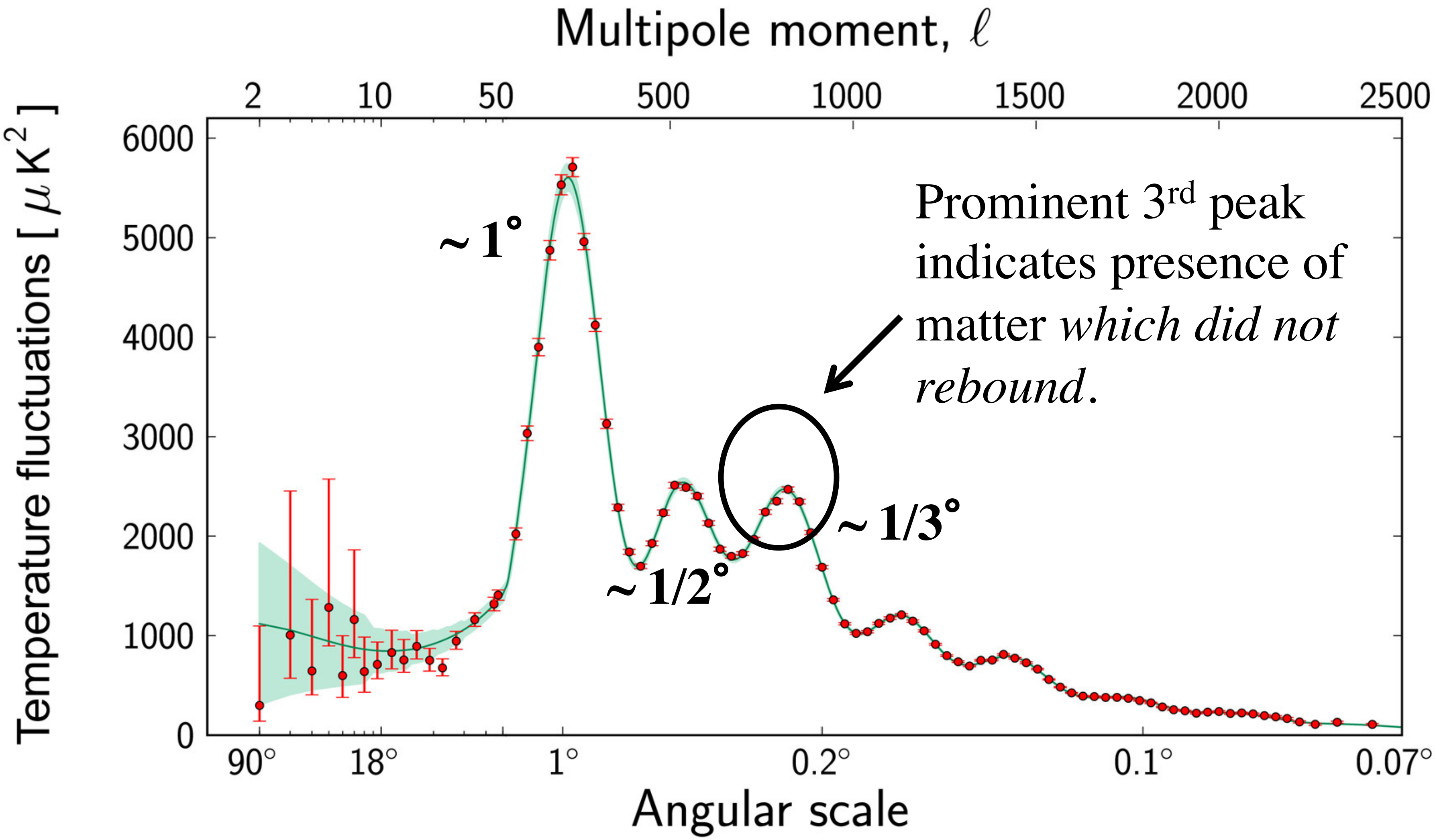
1970's - 1980's:
Cold dark matter
is needed to seed
the formation of
galaxy clusters

Temperature and density fluctuations are 1 part in 10^5.

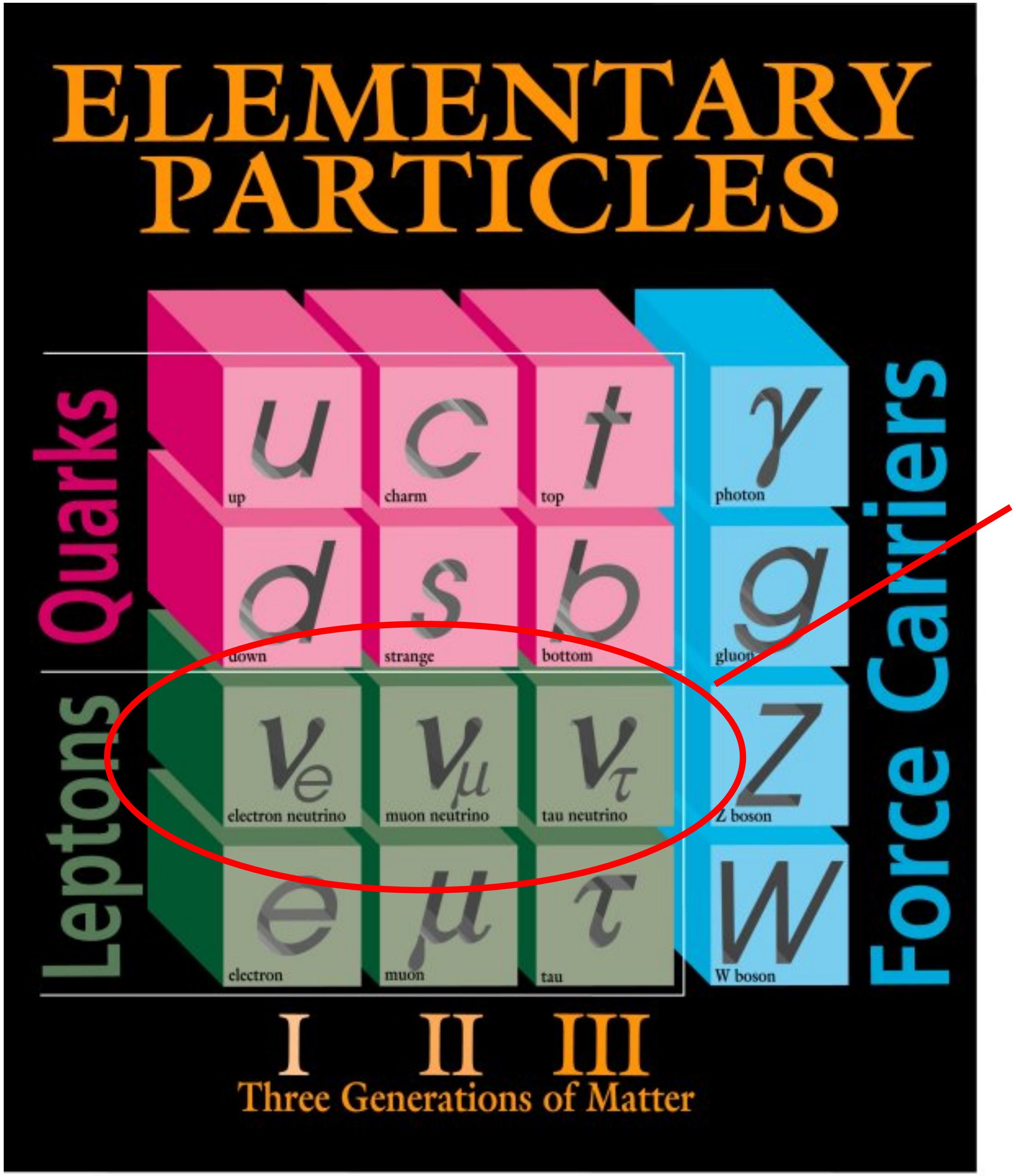


The cosmic microwave background anisotropy imaged Planck (2014).

CMB multipole expansion - measured by Planck (2014)



Prominent 3rd peak indicates presence of matter *which did not rebound*.



Fermilab 95-759

Neutrinos? – not heavy enough

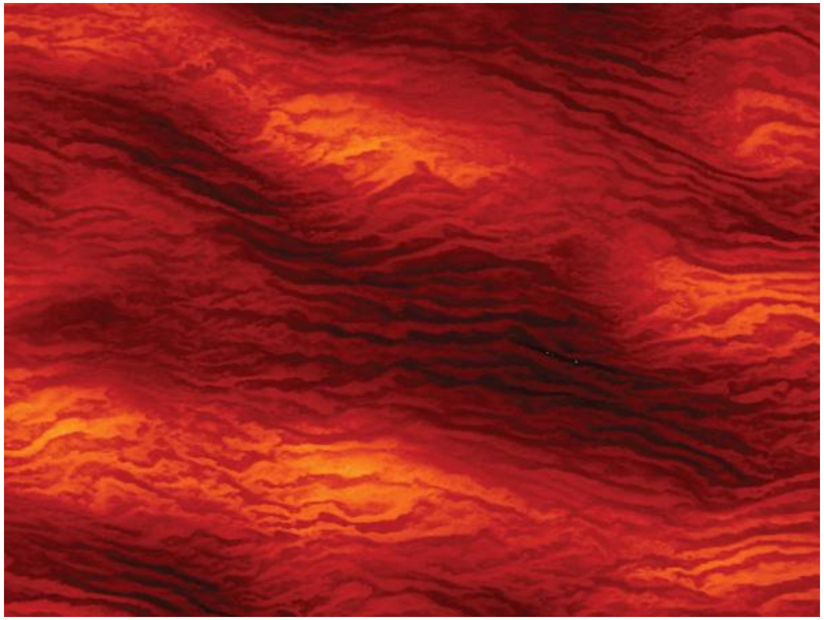
generalize

‘Weakly
Interacting
Massive
Particle’

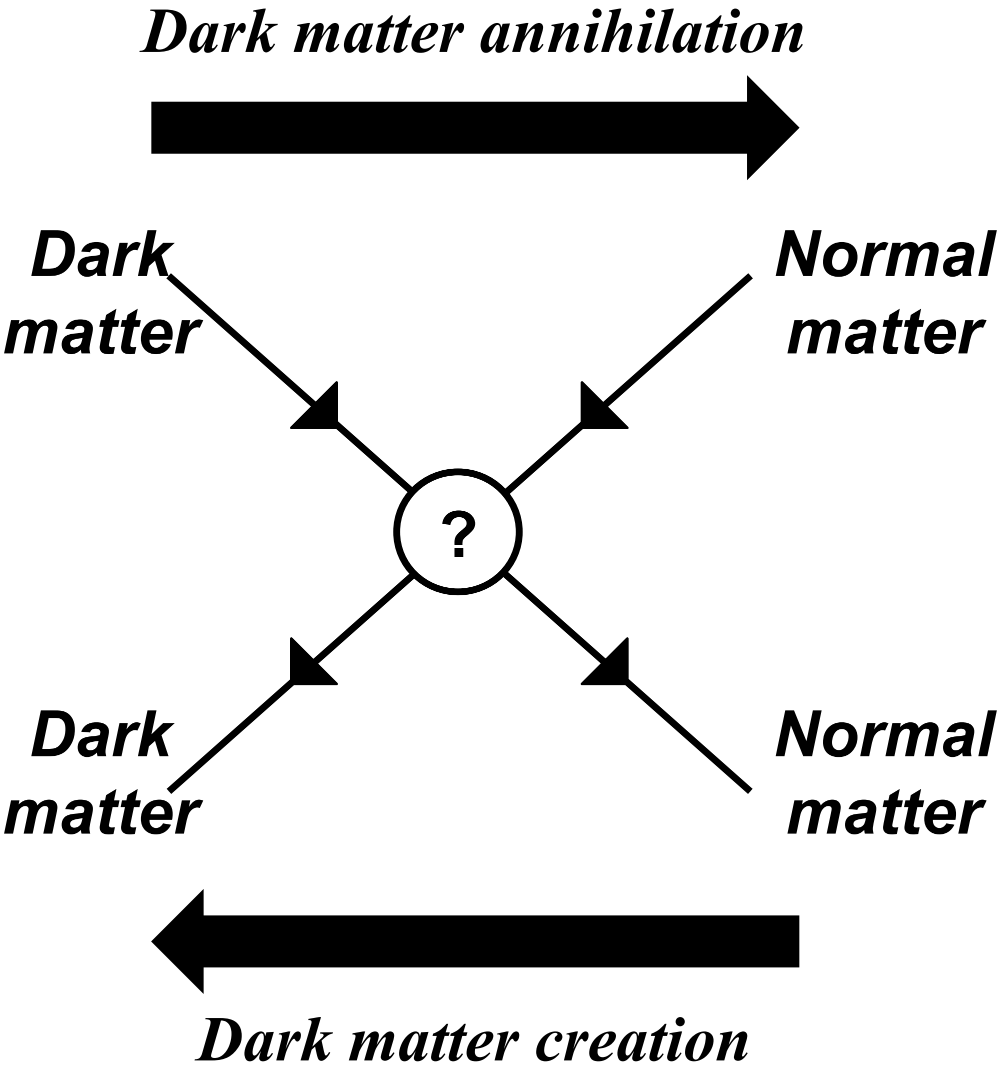
The thermal hypothesis:

Was the dark matter an interacting component in the very early universe?

Early universe plasma



Age of universe ~ 1 nanosecond;
Temperature ~ 100 GeV



Dark matter annihilation

Dark matter

Normal matter

?

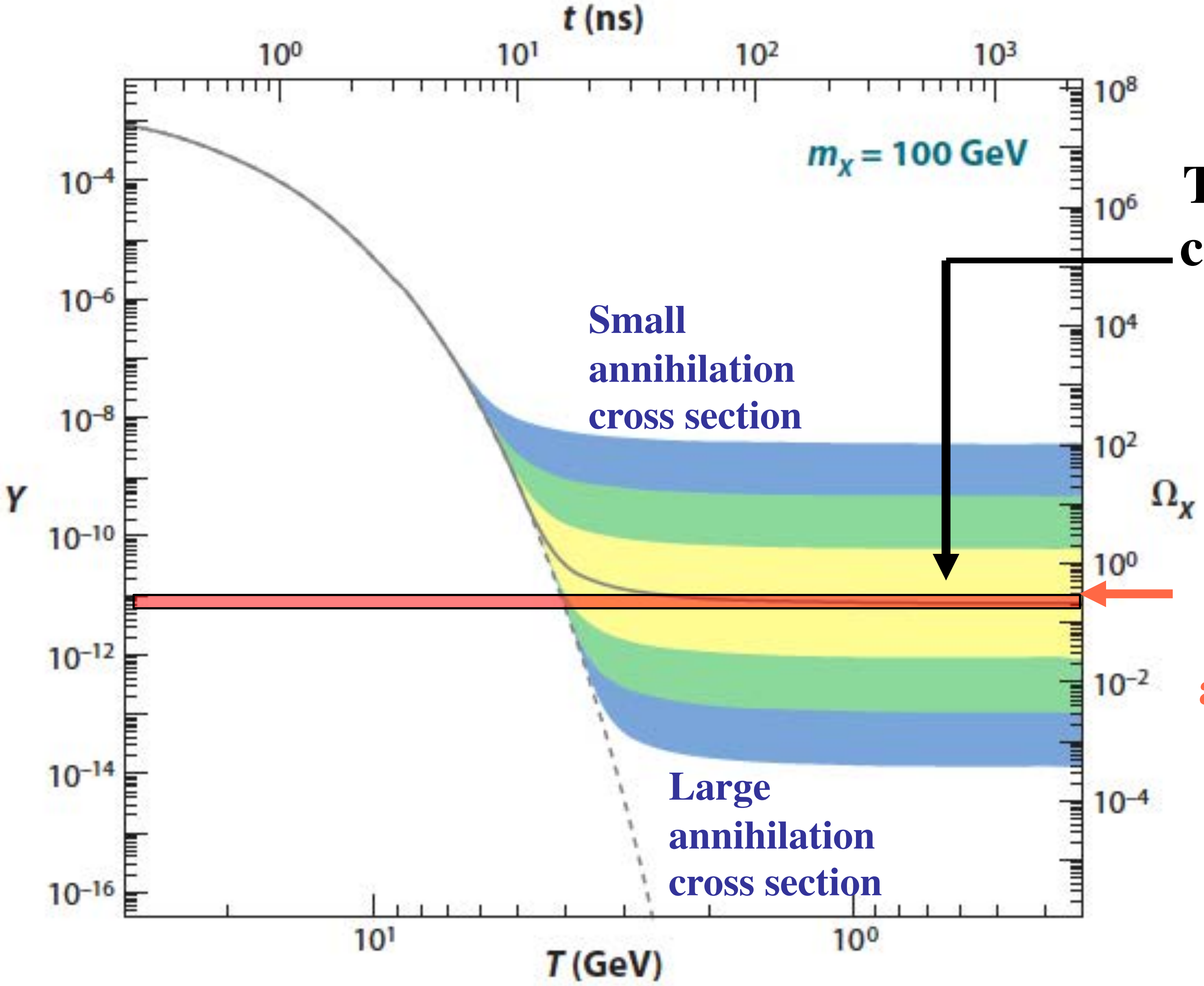
Dark matter

Normal matter

Dark matter creation

The thermal hypothesis:

Was the dark matter an interacting component in the very early universe?



Small annihilation cross section

Large annihilation cross section

Typical weak cross sections

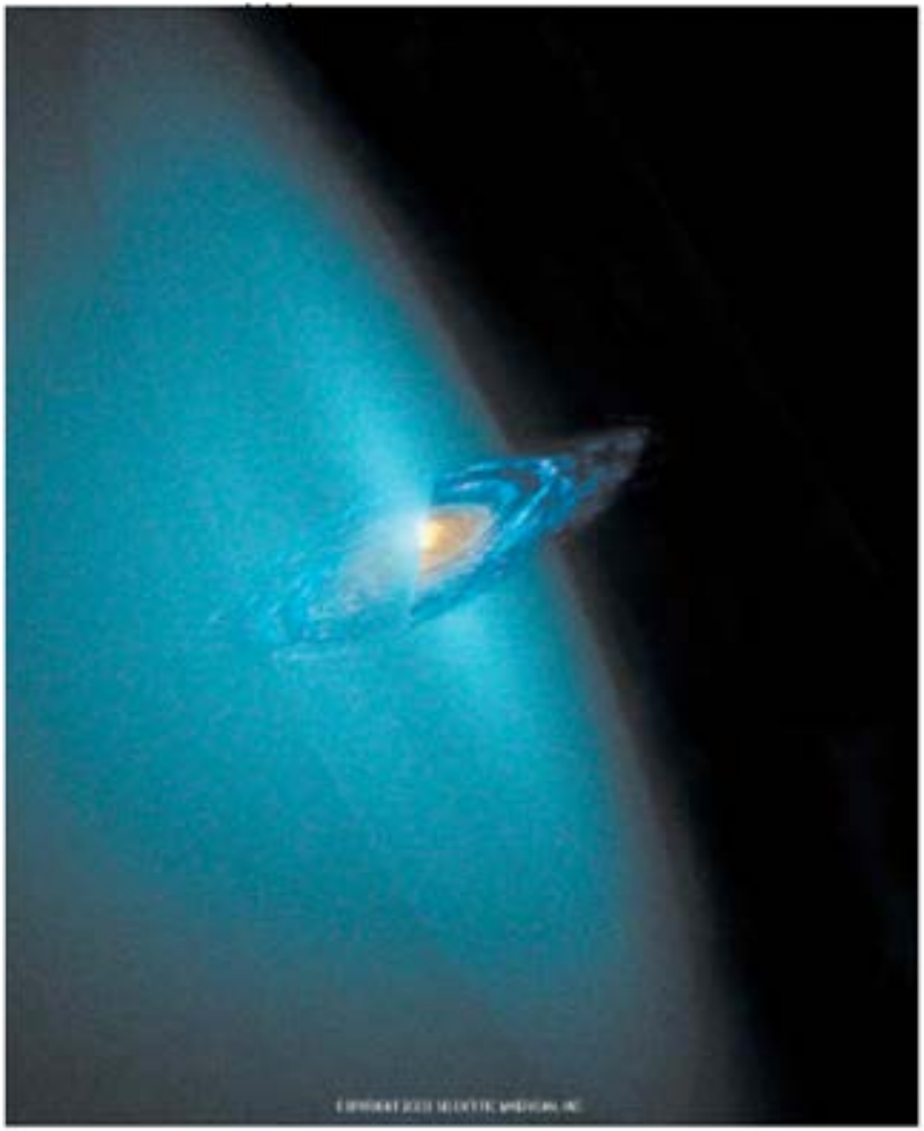
Correct dark matter abundance

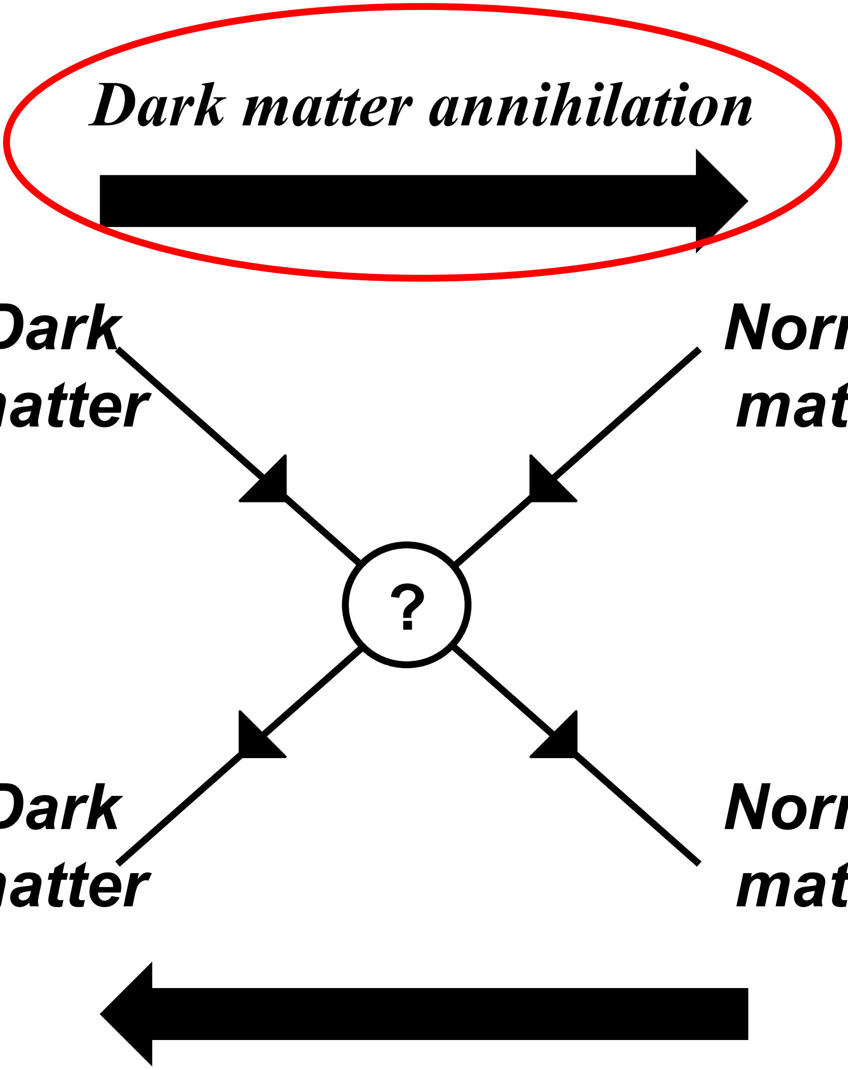
J. Feng, Annu. Rev. Astron. Astrophys. 2010. 48:495–545

The Milky Way's dark matter halo

- **Typical orbital vel.** = 230 km/sec
  ~ 0.1% speed of light

- Density: ~ 300 m_{proton} / liter
  - **WIMPs** (~100 GeV): 3 per liter
- deBroglie wavelength:
  - **WIMPs**: larger than a nucleus. Coherent scalar scattering on ordinary nuclear matter, $\sigma \sim A^2$
- Production:
  - **WIMPs**: thermal





Dark matter annihilation

Dark matter

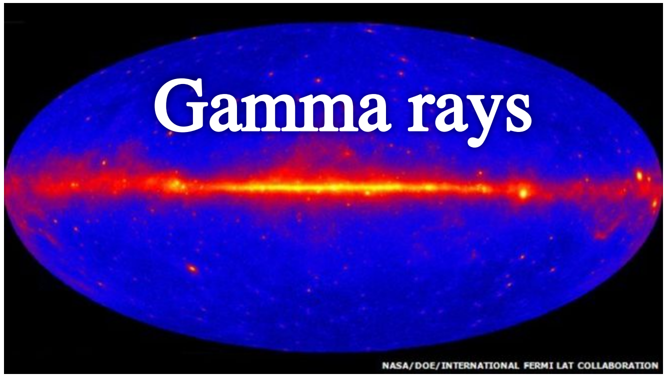
Normal matter

?

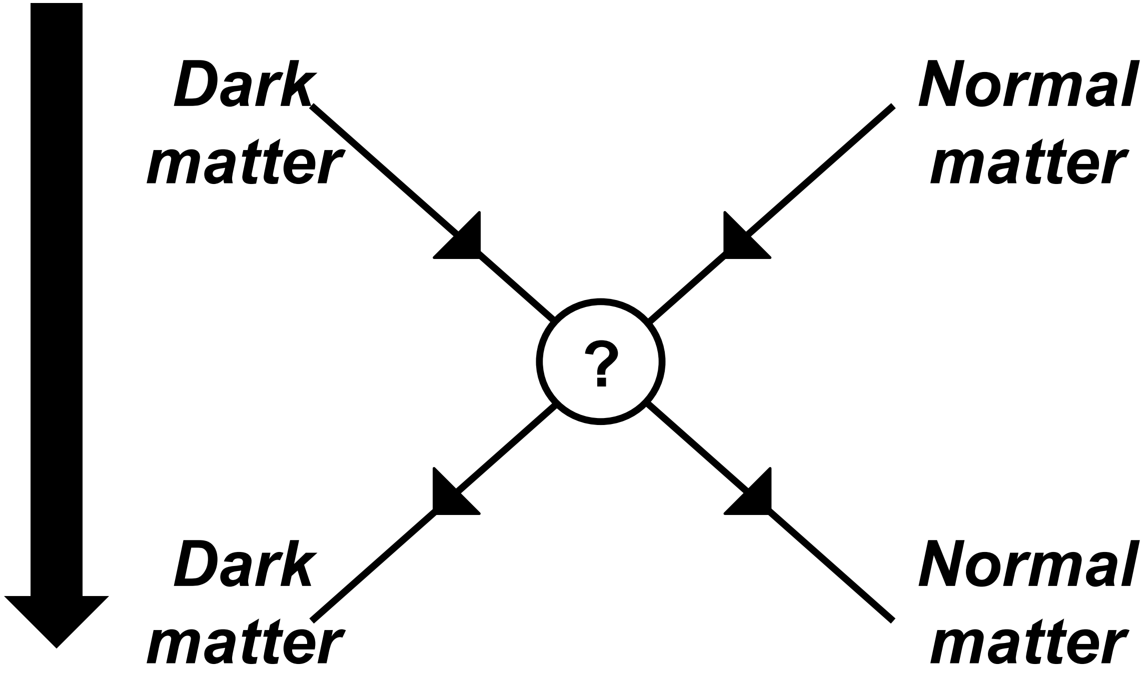
Dark matter

Normal matter

Dark matter creation



‘Direct detection’



Dark matter

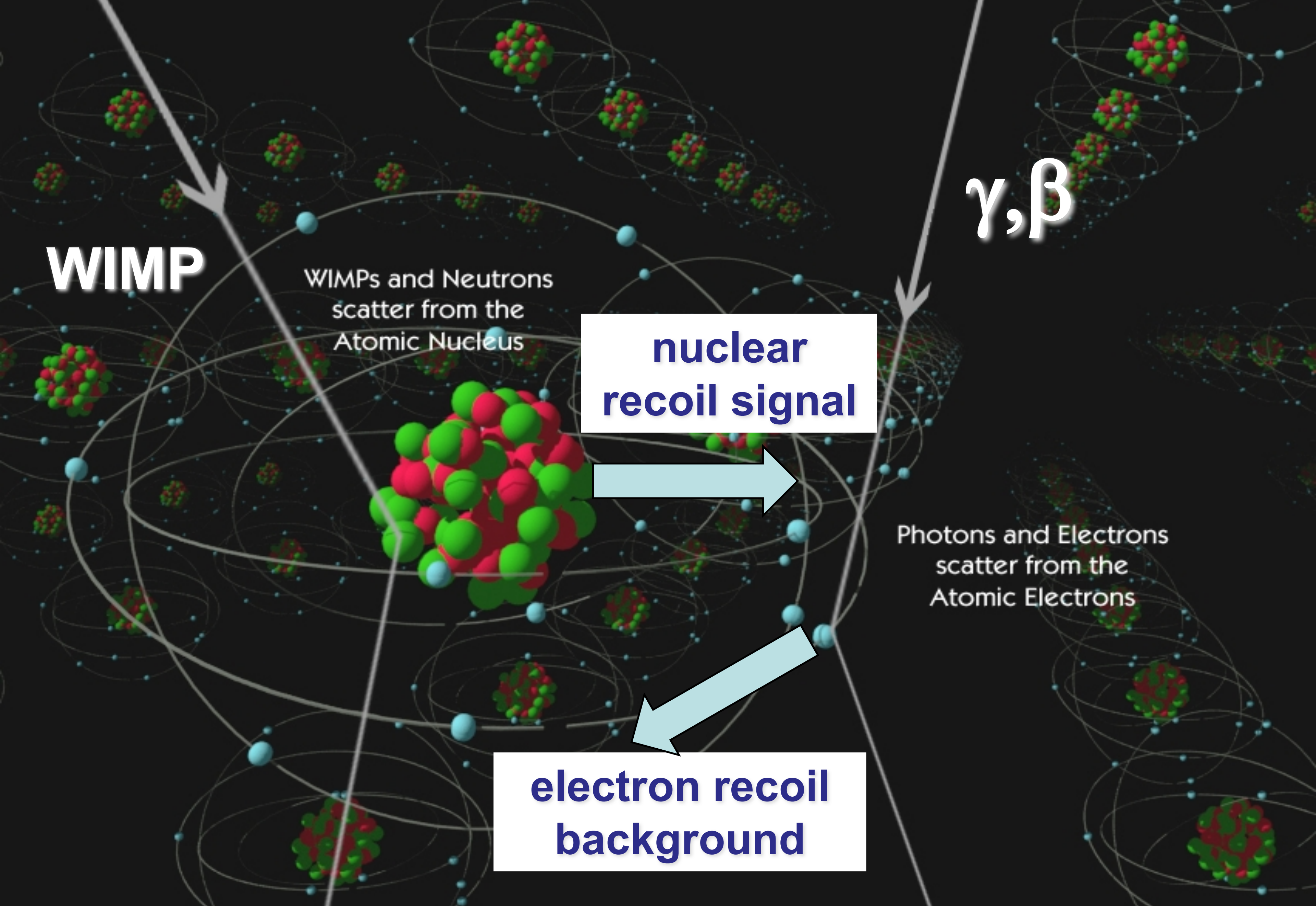
Normal matter

?

Dark matter

Normal matter

‘Direct Detection’



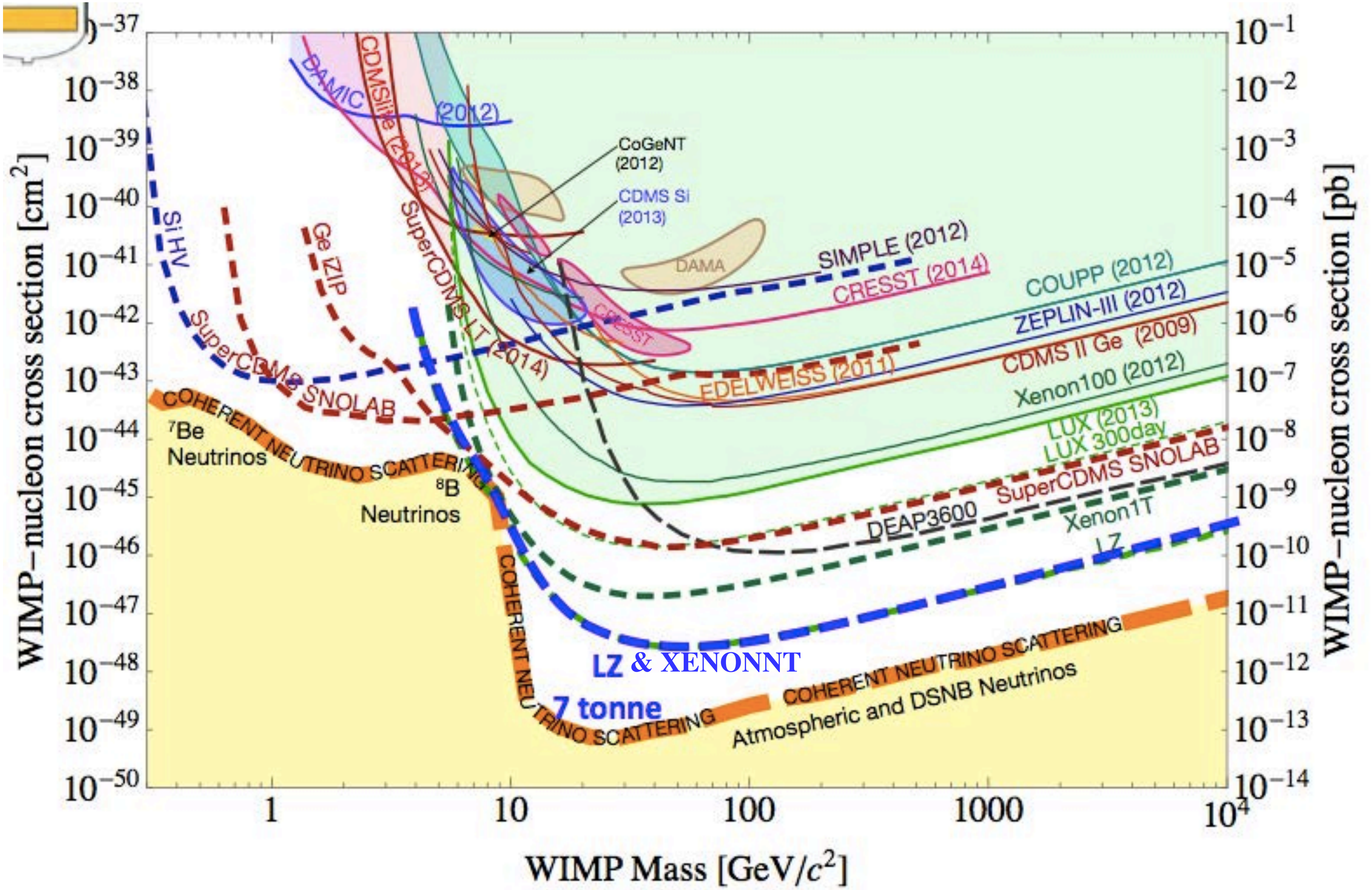
WIMP

γ,β

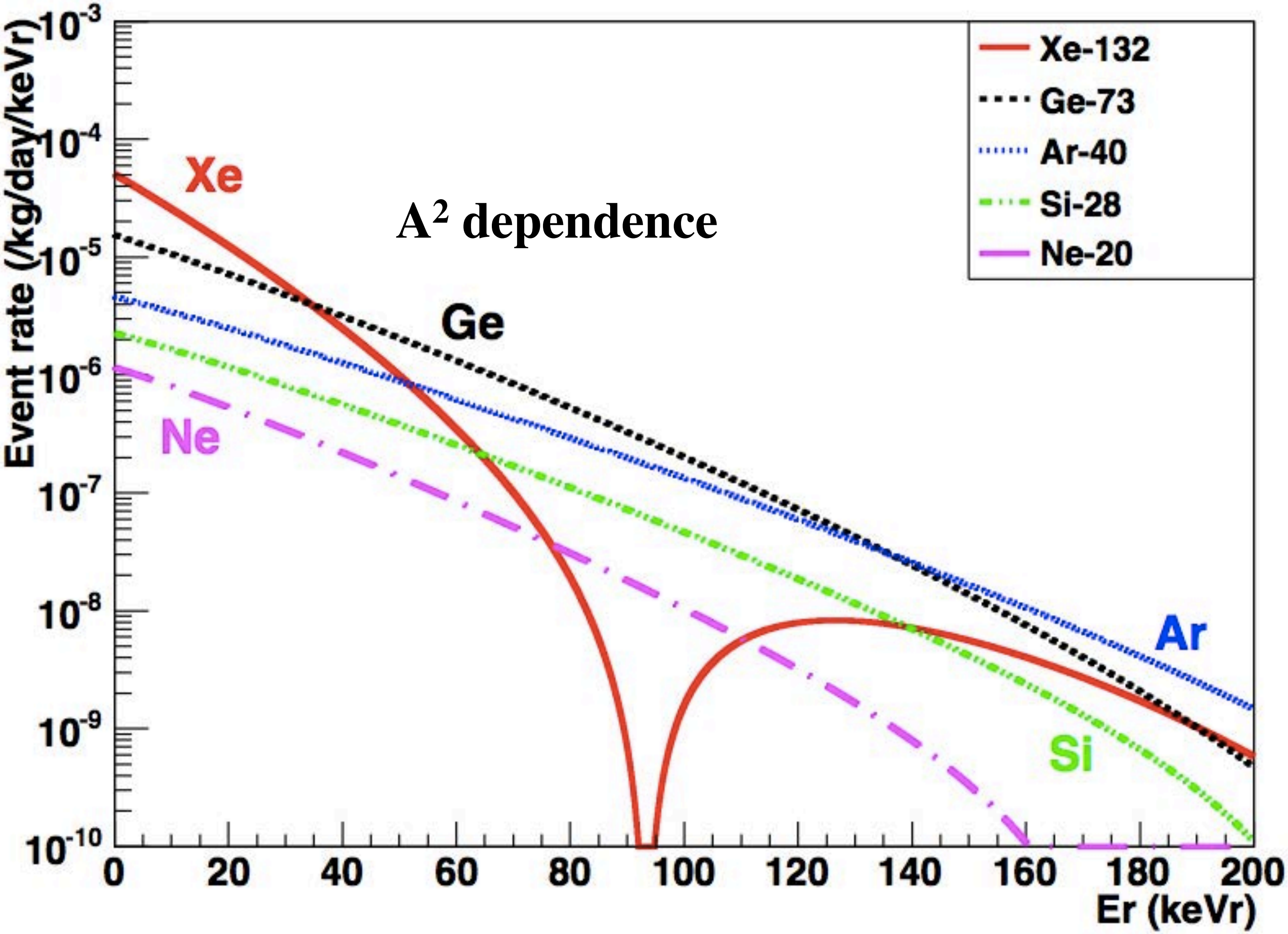
nuclear recoil signal

electron recoil background

The parameter space of direct detection



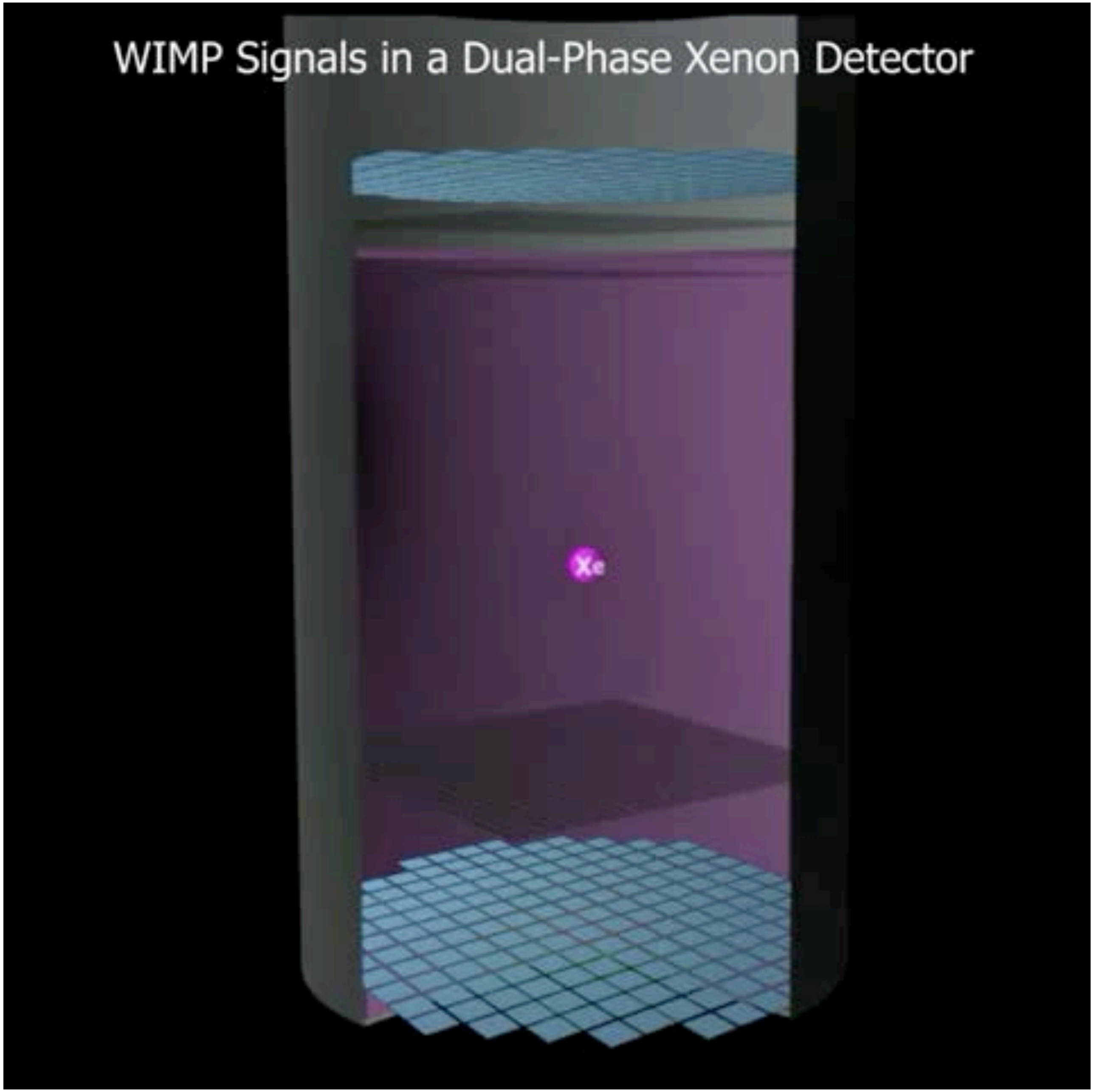
Nuclear recoil energy spectra



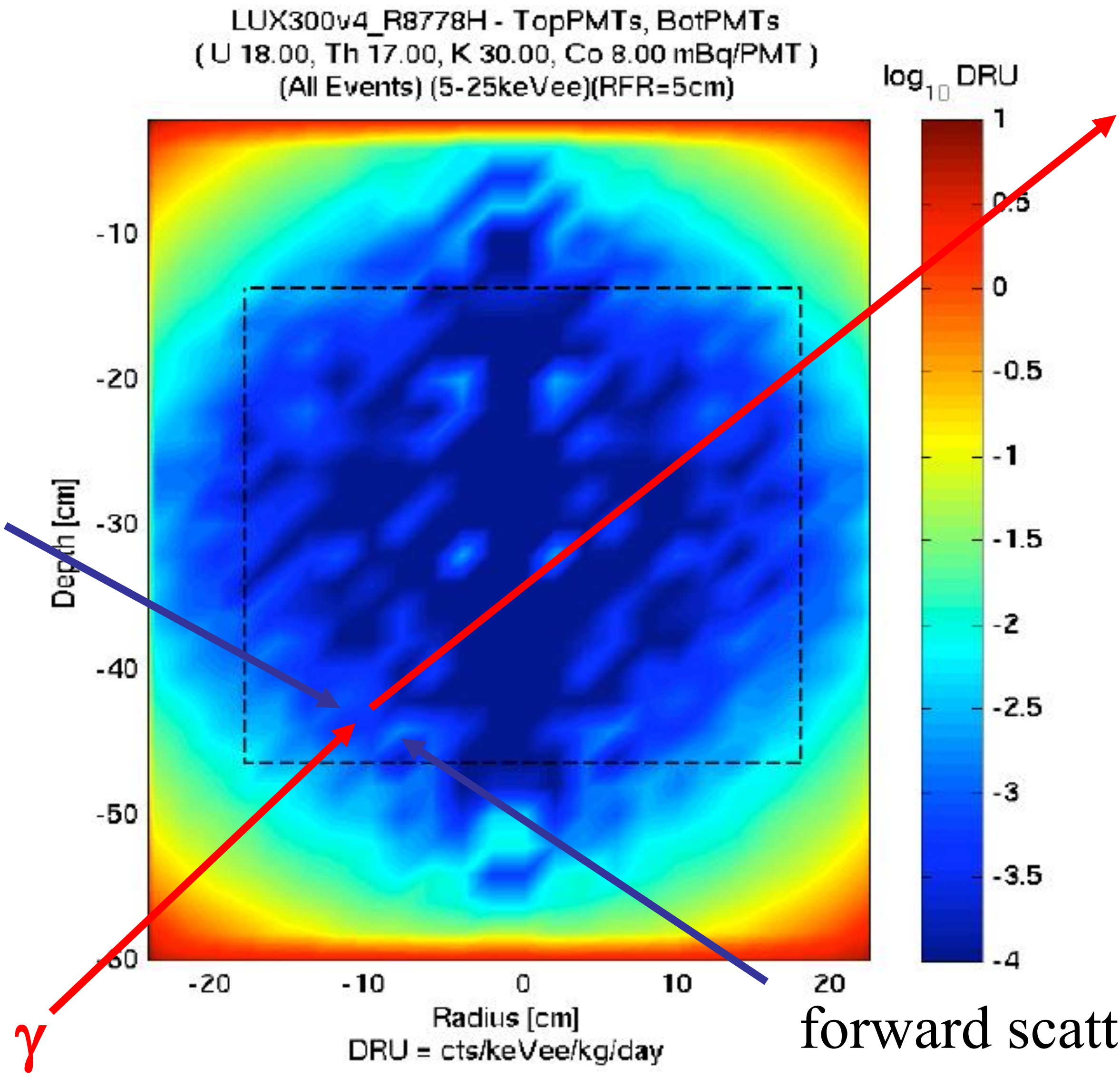
A^2 dependence

From: arXiv:1107.1295

WIMP Signals in a Dual-Phase Xenon Detector



Strong background rejection from kinematics



must
cross
full volume
without
interacting
again

~ keV
deposition

~ MeV γ

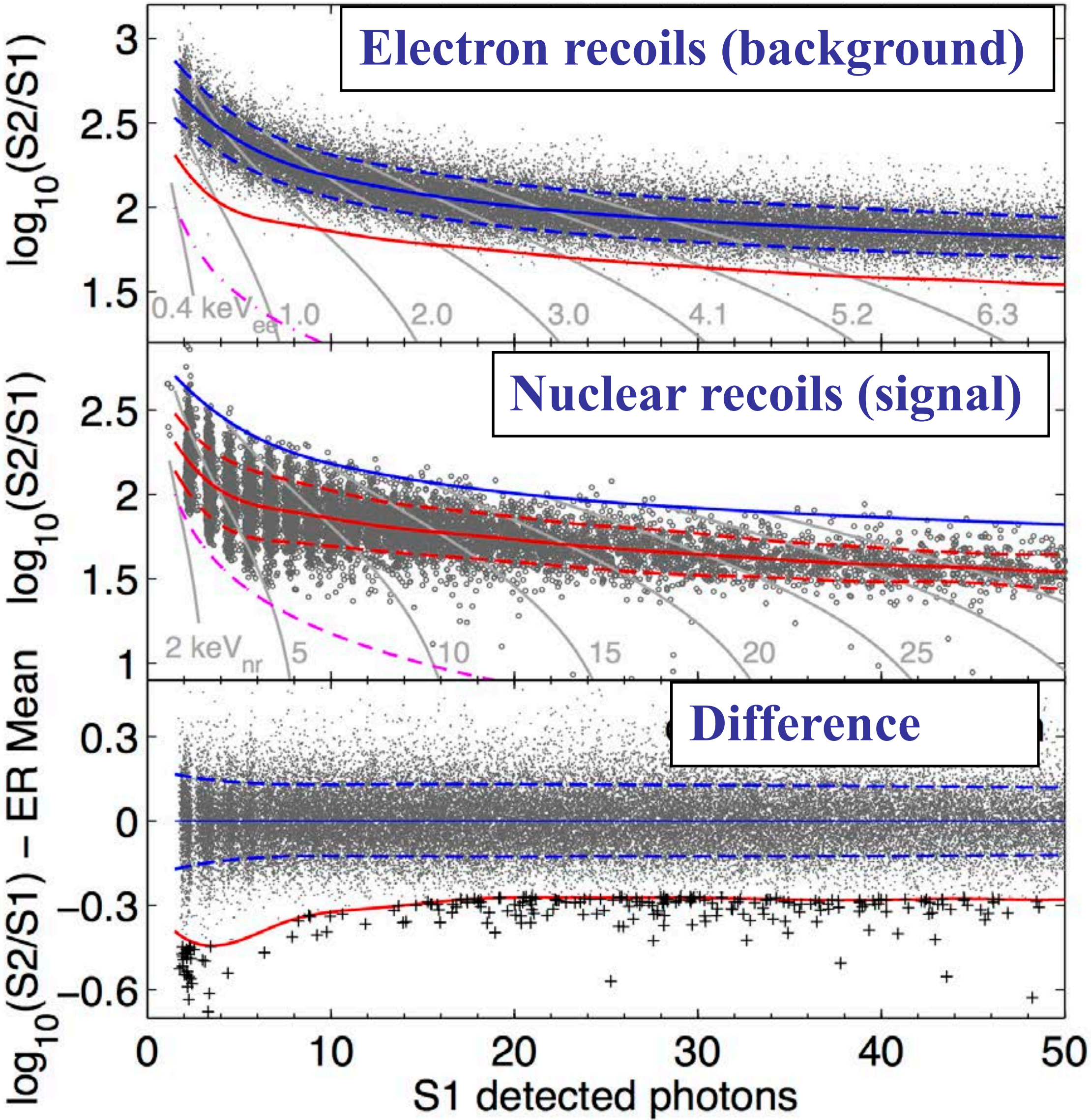
forward scattering

Particle ID: recoil discrimination in LUX

Charge/Light

Charge/Light

Charge/Light



Electron recoils (background)

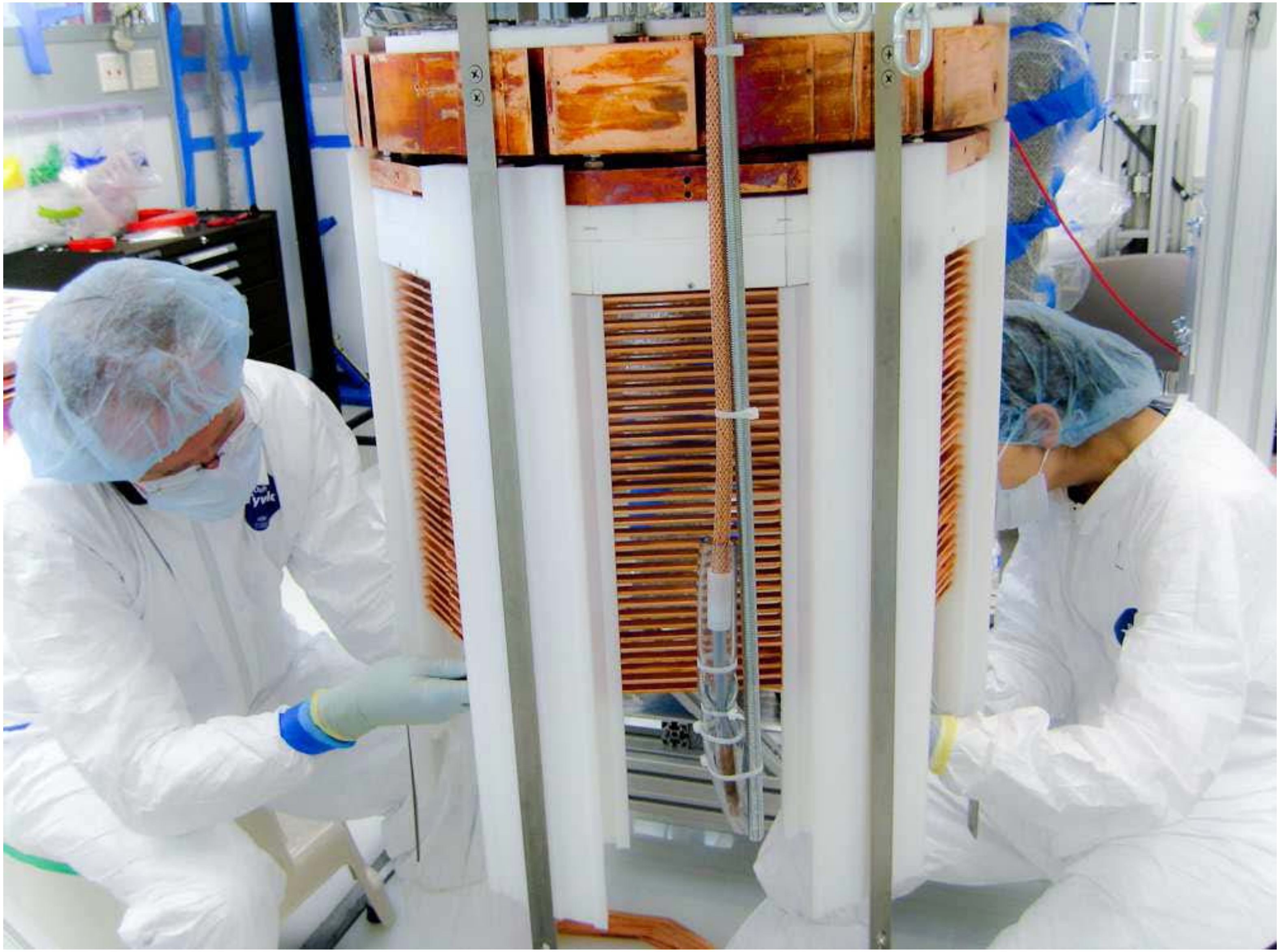
Nuclear recoils (signal)

Difference

Electron recoil rejection factor: 200 -500

Light →

LUX assembly – 2010 - 2011



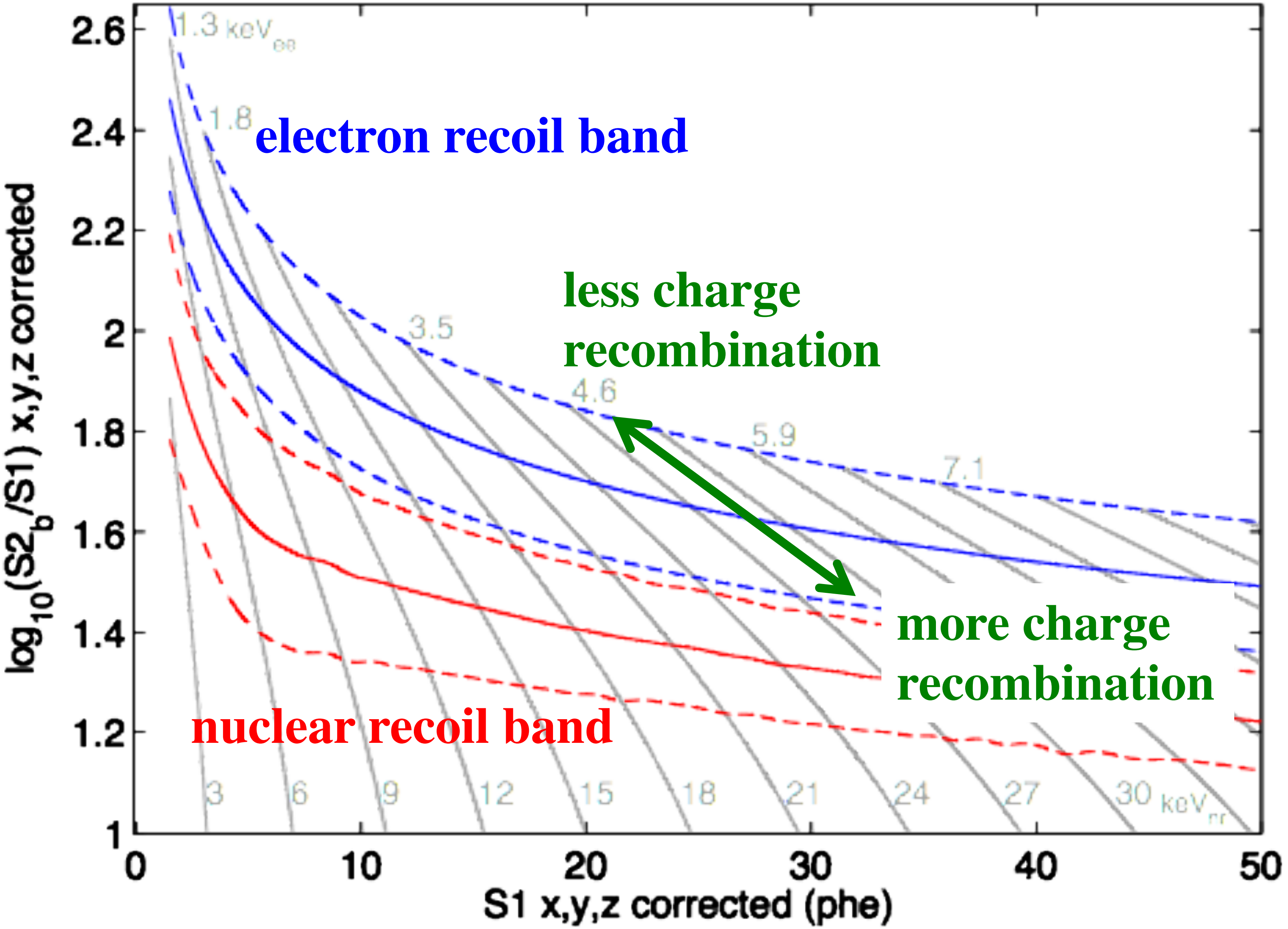
370 kg of liquid xenon

Sanford Underground Research Facility

Davis Cavern 1480 m
(4200 mwe)
LUX Water Tank
South Dakota USA

LUX installed underground, Sept. 2012

LUX recoil bands



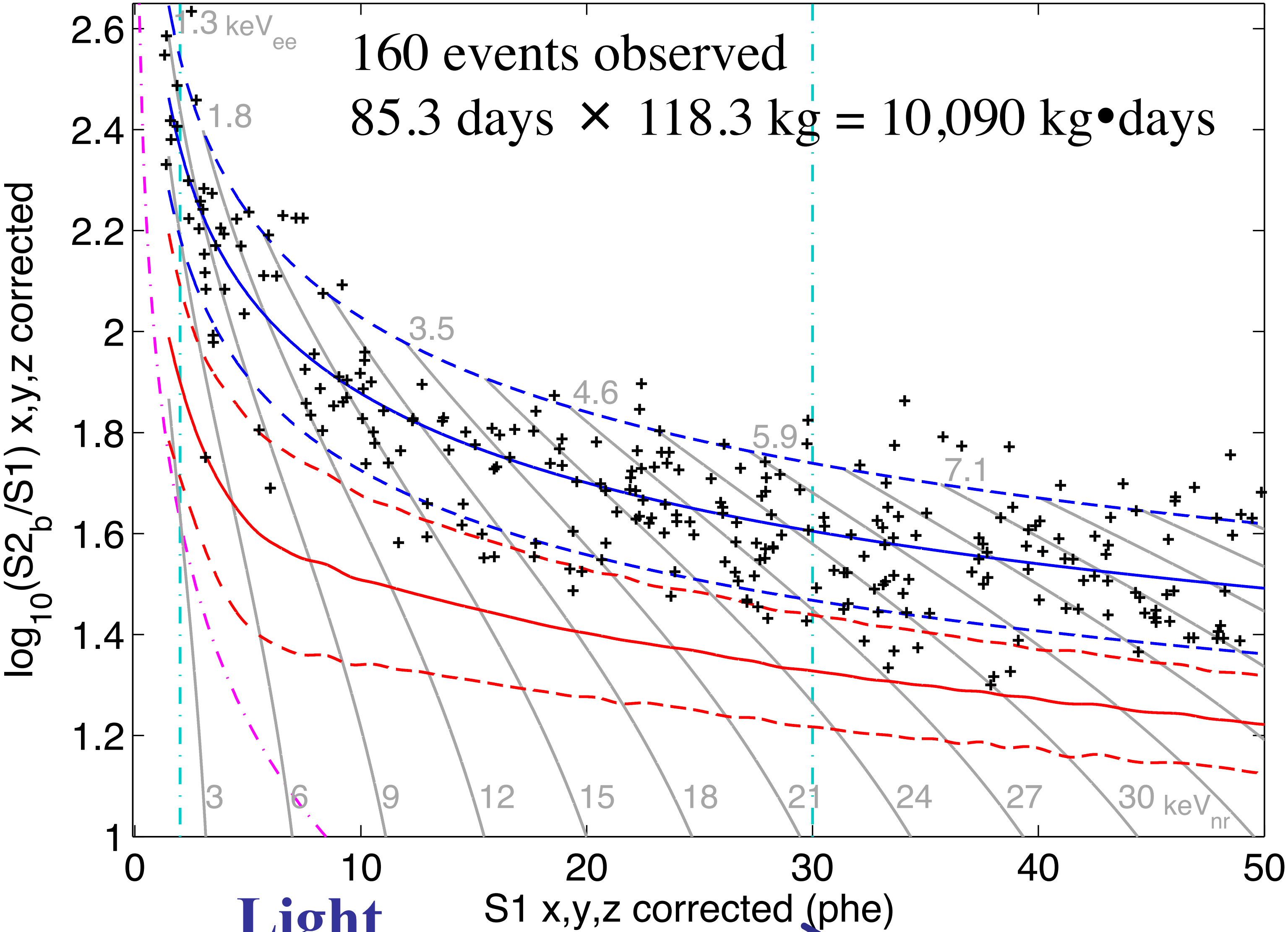
electron recoil band

less charge recombination

more charge recombination

nuclear recoil band

LUX WIMP search data (2013)



160 events observed

85.3 days × 118.3 kg = 10,090 kg•days

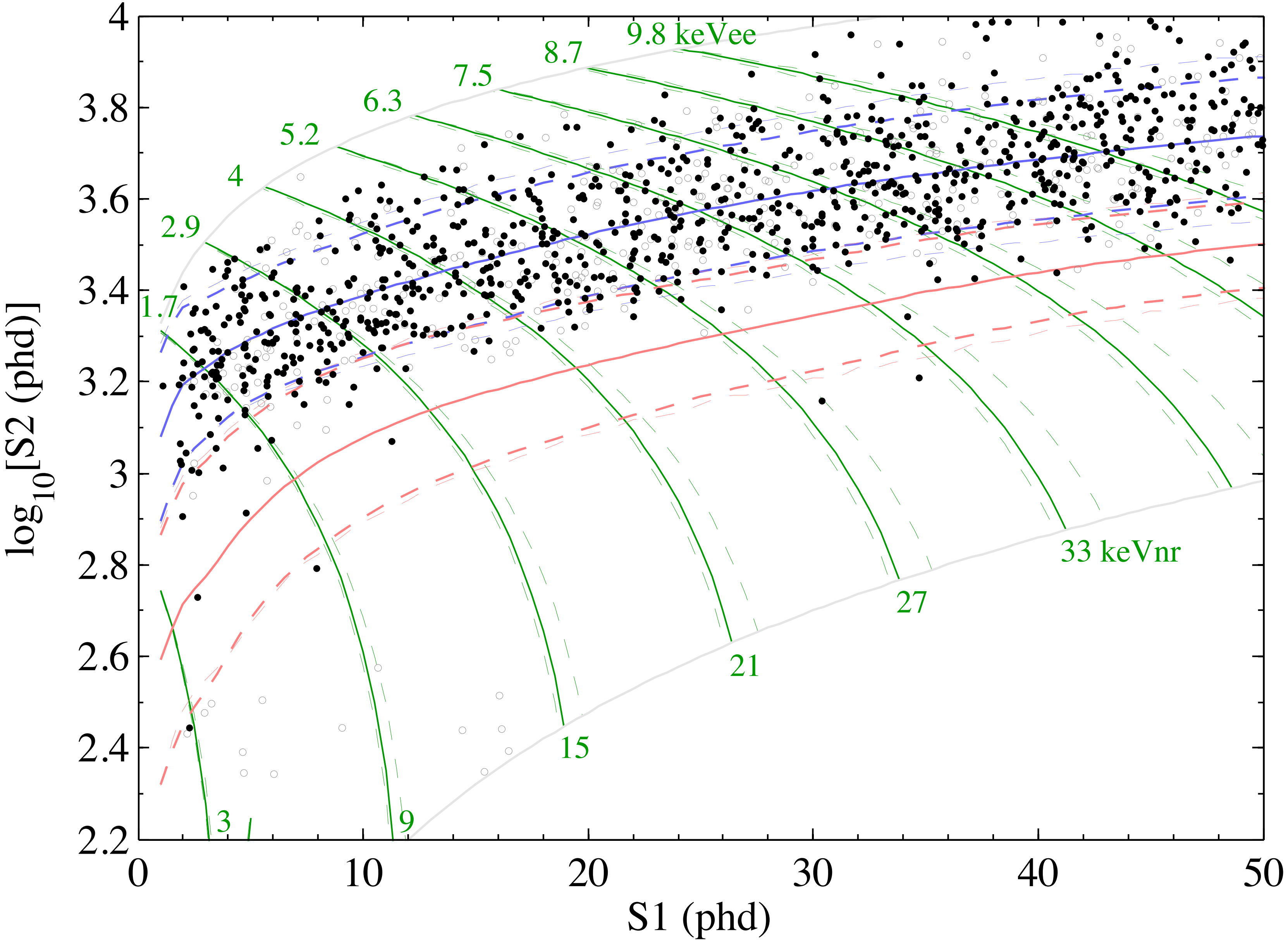
Charge / Light

Light →

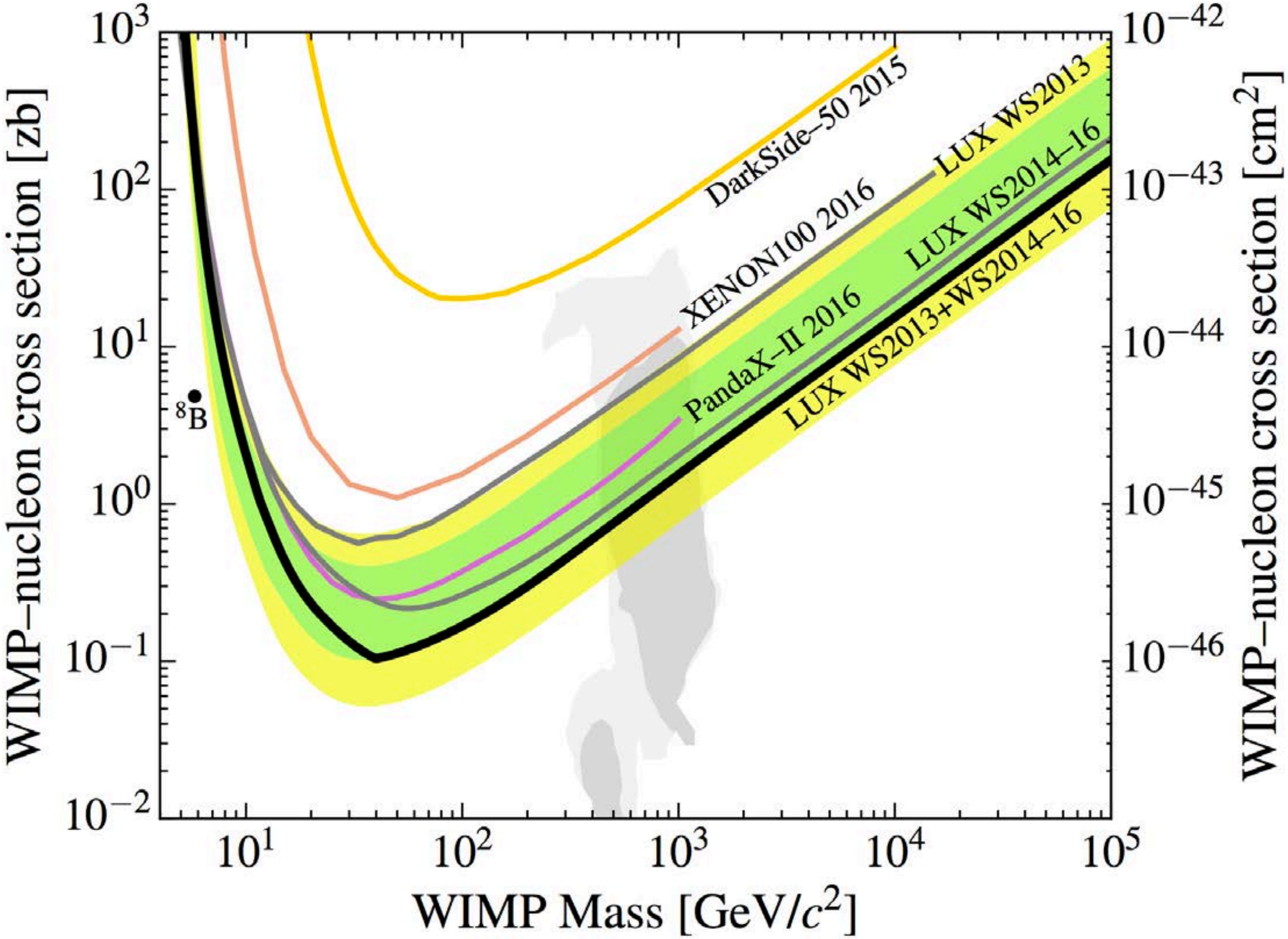
2013 initial results (Run 3): Phys.Rev.Lett. 112 (2014) 091303.

2015 re-analysis of Run 3: Phys.Rev.Lett. 116 (2016) 161301.

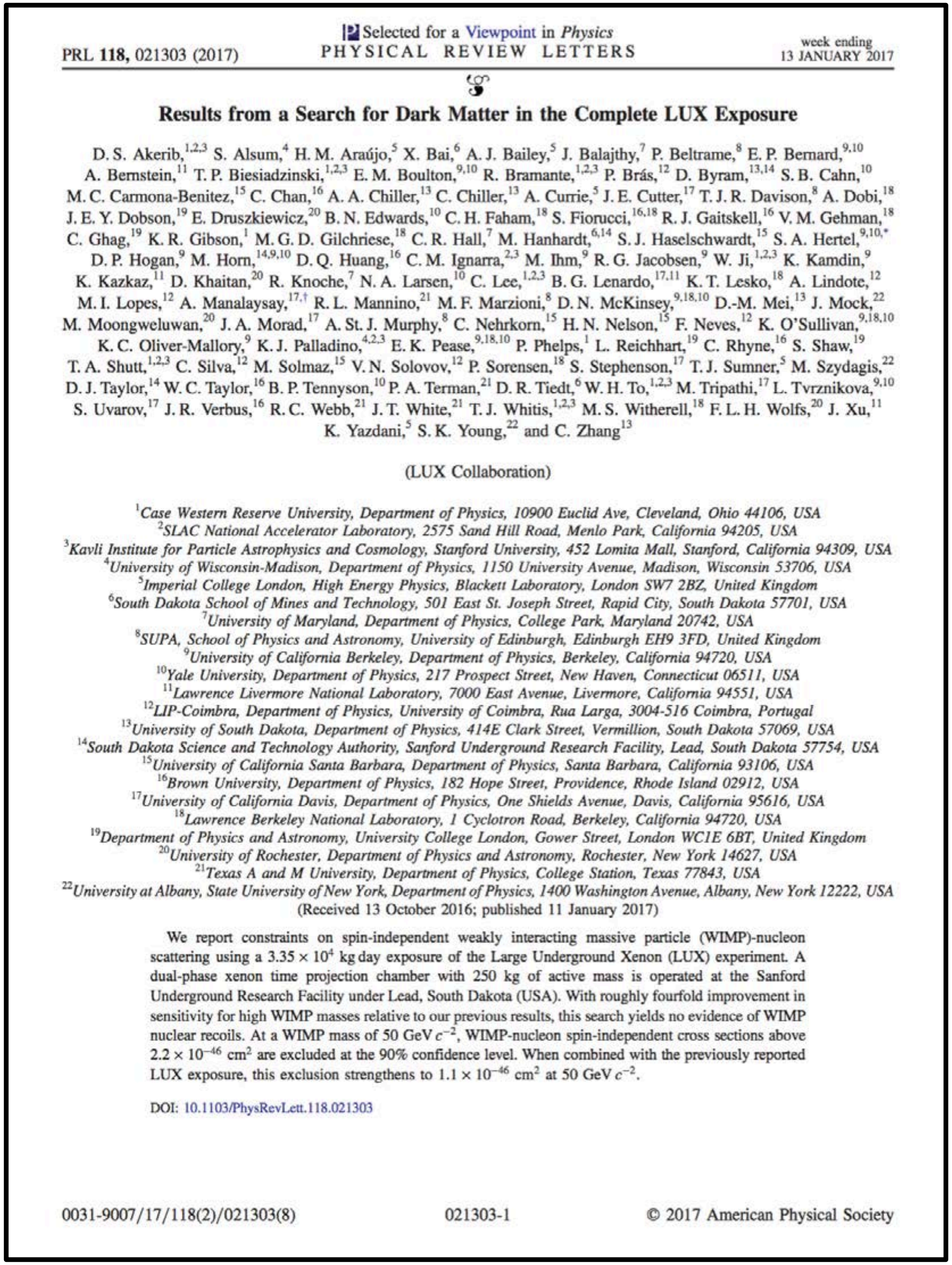
LUX WIMP search data (2014-2016)



LUX WIMP search – Full exposure (2013-2016) Run 3 + Run 4 combined



arXiv:1608.07648, Phys.Rev.Lett. 118 (2017) no.2, 021303



Selected for a Viewpoint in *Physics*
PRL **118,** 021303 (2017) PHYSICAL REVIEW LETTERS week ending 13 JANUARY 2017

Results from a Search for Dark Matter in the Complete LUX Exposure

D. S. Akerib,[1,2,3] S. Alsum,[4] H. M. Araújo,[5] X. Bai,[6] A. J. Bailey,[5] J. Balajthy,[7] P. Beltrame,[8] E. P. Bernard,[9,10] A. Bernstein,[11] T. P. Biesiadzinski,[1,2,3] E. M. Boulton,[9,10] R. Bramante,[1,2,3] P. Brás,[12] D. Byram,[13,14] S. B. Cahn,[10] M. C. Carmona-Benitez,[15] C. Chan,[16] A. A. Chiller,[13] C. Chiller,[13] A. Currie,[5] J. E. Cutter,[17] T. J. R. Davison,[8] A. Dobi,[18] J. E. Y. Dobson,[19] E. Druszkiewicz,[20] B. N. Edwards,[10] C. H. Faham,[18] S. Fiorucci,[16,18] R. J. Gaitskell,[16] V. M. Gehman,[18] C. Ghag,[19] K. R. Gibson,[1] M. G. D. Gilchriese,[18] C. R. Hall,[7] M. Hanhardt,[6,14] S. J. Haselschwardt,[15] S. A. Hertel,[9,10,*] D. P. Hogan,[9] M. Horn,[14,9,10] D. Q. Huang,[16] C. M. Ignarra,[2,3] M. Ihm,[9] R. G. Jacobsen,[9] W. Ji,[1,2,3] K. Kamdin,[9] K. Kazkaz,[11] D. Khaitan,[20] R. Knoche,[7] N. A. Larsen,[10] C. Lee,[1,2,3] B. G. Lenardo,[17,11] K. T. Lesko,[18] A. Lindote,[12] M. I. Lopes,[12] A. Manalaysay,[17,†] R. L. Mannino,[21] M. F. Marzioni,[8] D. N. McKinsey,[9,18,10] D.-M. Mei,[13] J. Mock,[22] M. Moongweluwan,[20] J. A. Morad,[17] A. St. J. Murphy,[8] C. Nehrkorn,[15] H. N. Nelson,[15] F. Neves,[12] K. O'Sullivan,[9,18,10] K. C. Oliver-Mallory,[9] K. J. Palladino,[4,2,3] E. K. Pease,[9,18,10] P. Phelps,[1] L. Reichhart,[19] C. Rhyne,[16] S. Shaw,[19] T. A. Shutt,[1,2,3] C. Silva,[12] M. Solmaz,[15] V. N. Solovov,[12] P. Sorensen,[18] S. Stephenson,[17] T. J. Sumner,[5] M. Szydagis,[22] D. J. Taylor,[14] W. C. Taylor,[16] B. P. Tennyson,[10] P. A. Terman,[21] D. R. Tiedt,[6] W. H. To,[1,2,3] M. Tripathi,[17] L. Tvrznikova,[9,10] S. Uvarov,[17] J. R. Verbus,[16] R. C. Webb,[21] J. T. White,[21] T. J. Whitis,[1,2,3] M. S. Witherell,[18] F. L. H. Wolfs,[20] J. Xu,[11] K. Yazdani,[5] S. K. Young,[22] and C. Zhang[13]

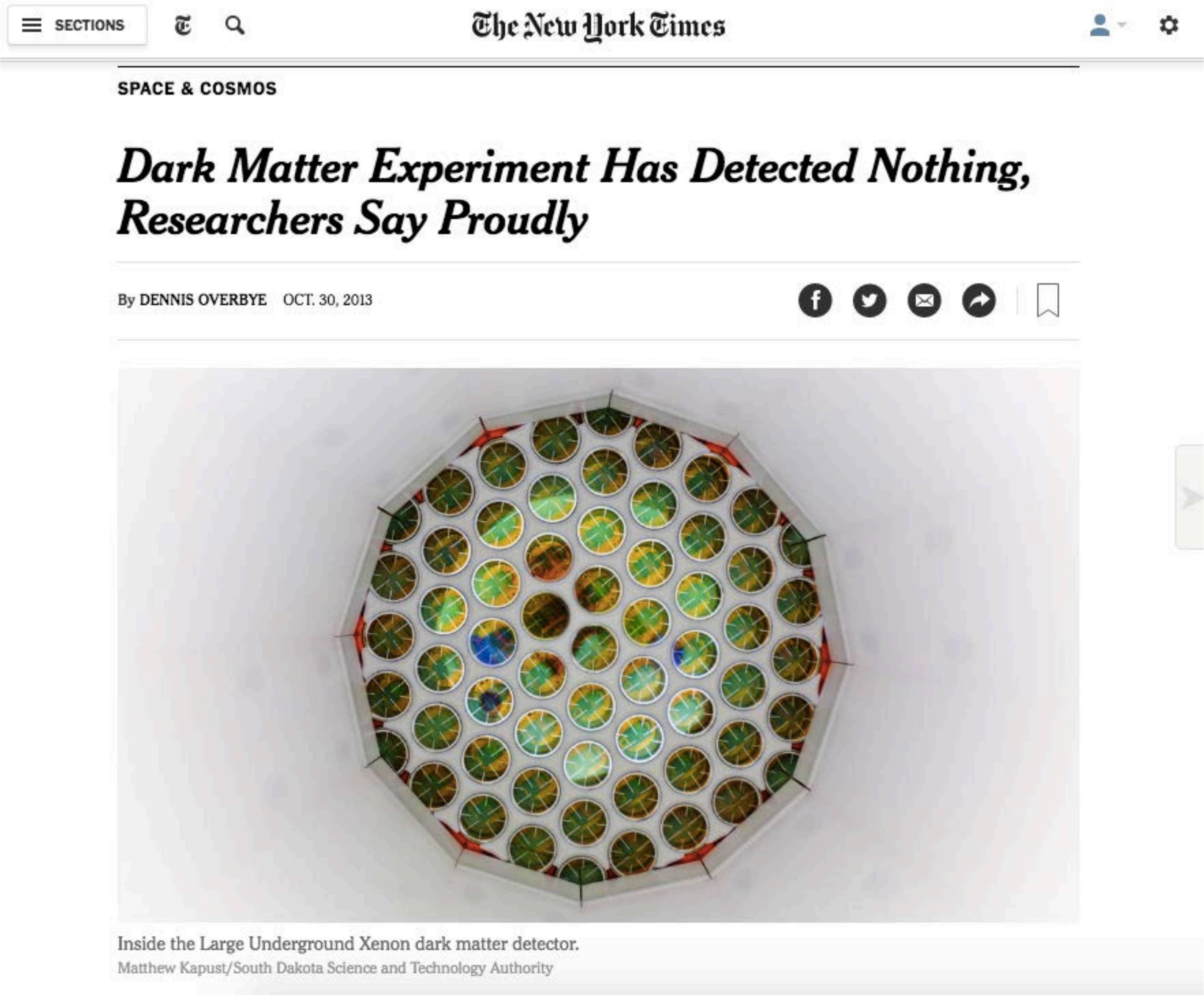
(LUX Collaboration)

[1]*Case Western Reserve University, Department of Physics, 10900 Euclid Ave, Cleveland, Ohio 44106, USA*
[2]*SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, California 94205, USA*
[3]*Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, 452 Lomita Mall, Stanford, California 94309, USA*
[4]*University of Wisconsin-Madison, Department of Physics, 1150 University Avenue, Madison, Wisconsin 53706, USA*
[5]*Imperial College London, High Energy Physics, Blackett Laboratory, London SW7 2BZ, United Kingdom*
[6]*South Dakota School of Mines and Technology, 501 East St. Joseph Street, Rapid City, South Dakota 57701, USA*
[7]*University of Maryland, Department of Physics, College Park, Maryland 20742, USA*
[8]*SUPA, School of Physics and Astronomy, University of Edinburgh, Edinburgh EH9 3FD, United Kingdom*
[9]*University of California Berkeley, Department of Physics, Berkeley, California 94720, USA*
[10]*Yale University, Department of Physics, 217 Prospect Street, New Haven, Connecticut 06511, USA*
[11]*Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, California 94551, USA*
[12]*LIP-Coimbra, Department of Physics, University of Coimbra, Rua Larga, 3004-516 Coimbra, Portugal*
[13]*University of South Dakota, Department of Physics, 414E Clark Street, Vermillion, South Dakota 57069, USA*
[14]*South Dakota Science and Technology Authority, Sanford Underground Research Facility, Lead, South Dakota 57754, USA*
[15]*University of California Santa Barbara, Department of Physics, Santa Barbara, California 93106, USA*
[16]*Brown University, Department of Physics, 182 Hope Street, Providence, Rhode Island 02912, USA*
[17]*University of California Davis, Department of Physics, One Shields Avenue, Davis, California 95616, USA*
[18]*Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, California 94720, USA*
[19]*Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT, United Kingdom*
[20]*University of Rochester, Department of Physics and Astronomy, Rochester, New York 14627, USA*
[21]*Texas A and M University, Department of Physics, College Station, Texas 77843, USA*
[22]*University at Albany, State University of New York, Department of Physics, 1400 Washington Avenue, Albany, New York 12222, USA*

(Received 13 October 2016; published 11 January 2017)

We report constraints on spin-independent weakly interacting massive particle (WIMP)-nucleon scattering using a 3.35×10^4 kg day exposure of the Large Underground Xenon (LUX) experiment. A dual-phase xenon time projection chamber with 250 kg of active mass is operated at the Sanford Underground Research Facility under Lead, South Dakota (USA). With roughly fourfold improvement in sensitivity for high WIMP masses relative to our previous results, this search yields no evidence of WIMP nuclear recoils. At a WIMP mass of 50 GeV c^{-2}, WIMP-nucleon spin-independent cross sections above 2.2×10^{-46} cm^2 are excluded at the 90% confidence level. When combined with the previously reported LUX exposure, this exclusion strengthens to 1.1×10^{-46} cm^2 at 50 GeV c^{-2}.

DOI: 10.1103/PhysRevLett.118.021303



The New York Times

SPACE & COSMOS

Dark Matter Experiment Has Detected Nothing, Researchers Say Proudly

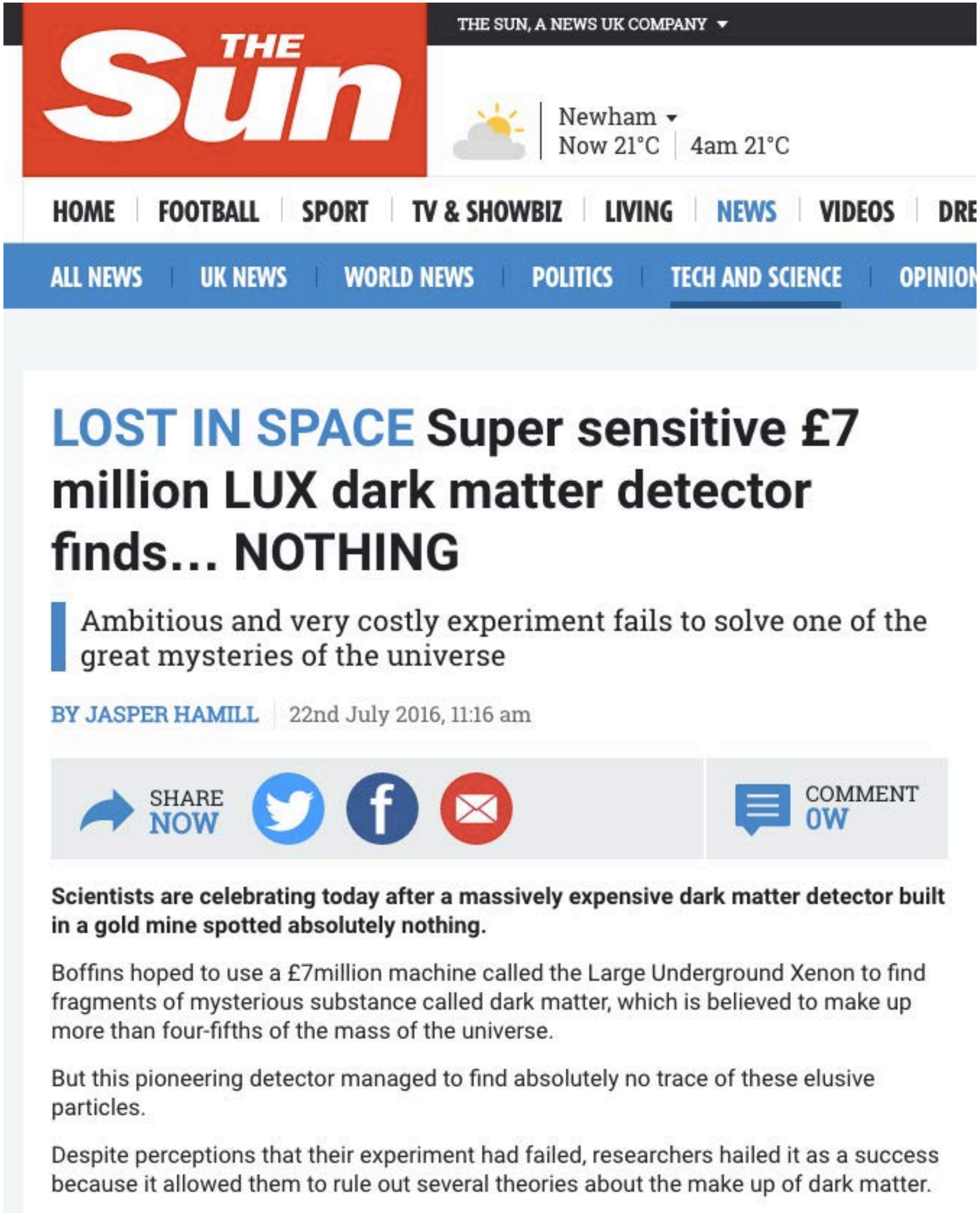
By DENNIS OVERBYE OCT. 30, 2013

Inside the Large Underground Xenon dark matter detector.

Matthew Kapust/South Dakota Science and Technology Authority

October 30, 2013

July 22, 2016



LOST IN SPACE Super sensitive £7 million LUX dark matter detector finds… NOTHING

Ambitious and very costly experiment fails to solve one of the great mysteries of the universe

BY JASPER HAMILL | 22nd July 2016, 11:16 am

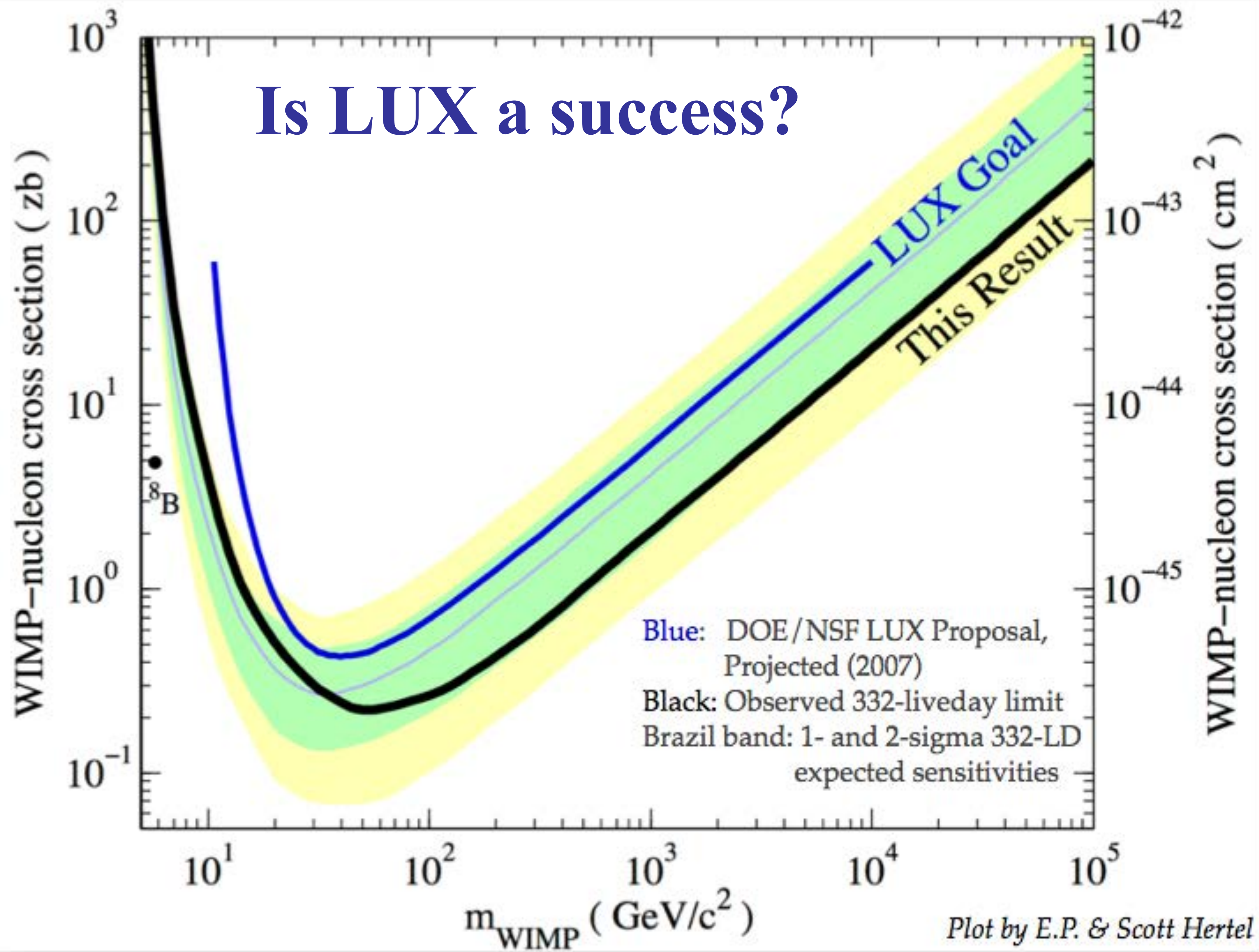
Scientists are celebrating today after a massively expensive dark matter detector built in a gold mine spotted absolutely nothing.

Boffins hoped to use a £7million machine called the Large Underground Xenon to find fragments of mysterious substance called dark matter, which is believed to make up more than four-fifths of the mass of the universe.

But this pioneering detector managed to find absolutely no trace of these elusive particles.

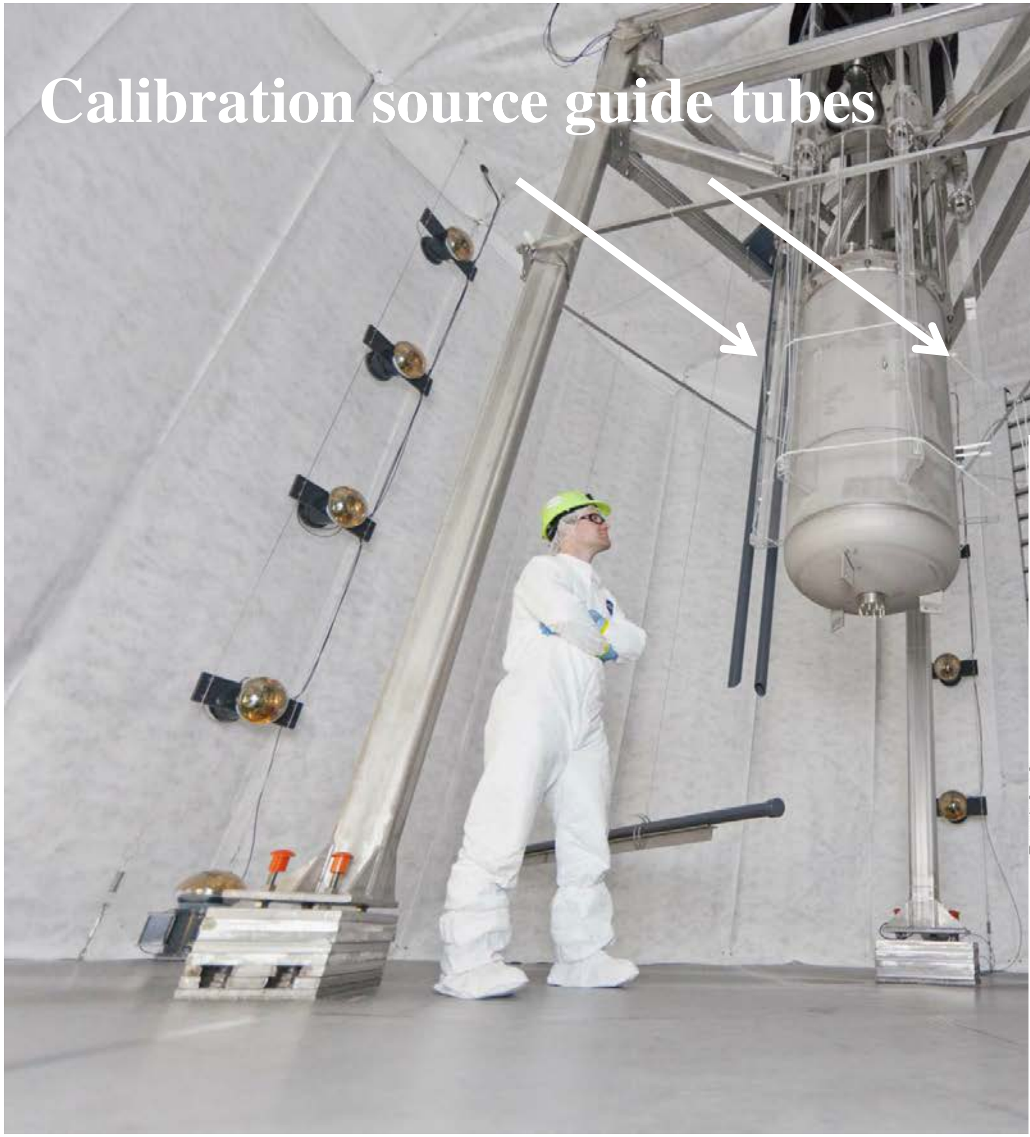
Despite perceptions that their experiment had failed, researchers hailed it as a success because it allowed them to rule out several theories about the make up of dark matter.

Is LUX a success?



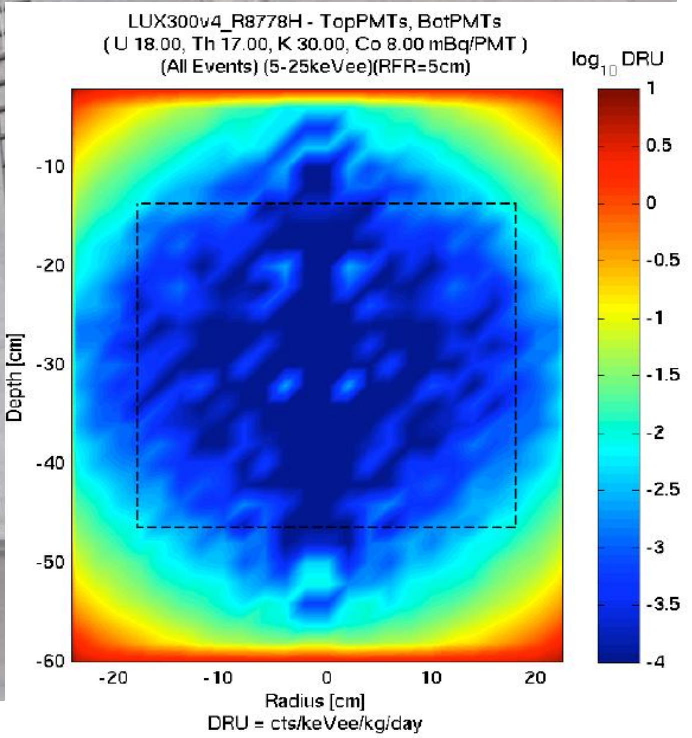
Plot by E.P. & Scott Hertel

Calibration: external gamma sources (^{137}Cs)

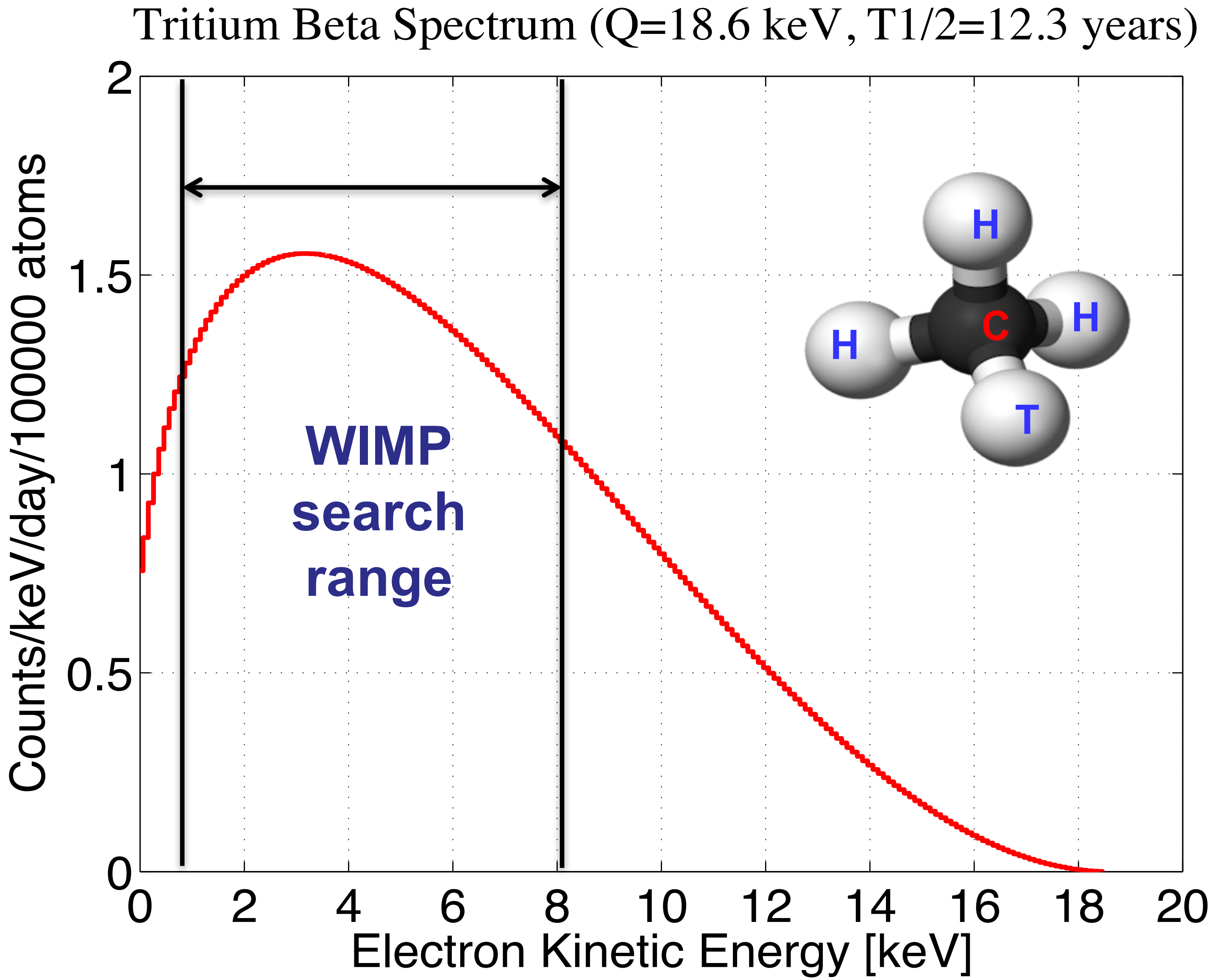


Calibration source guide tubes

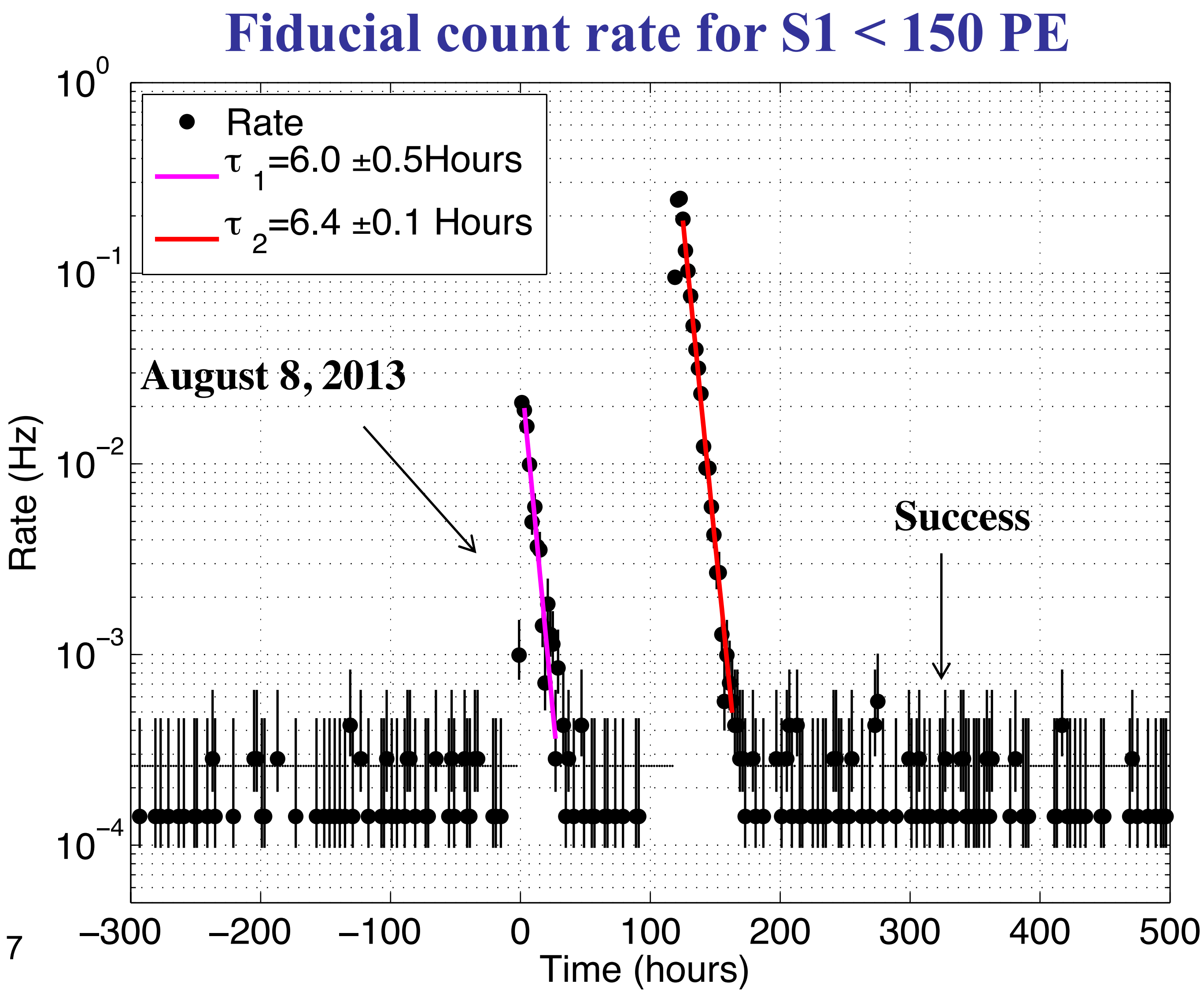
Self-shielding makes external gamma sources mostly ineffectual



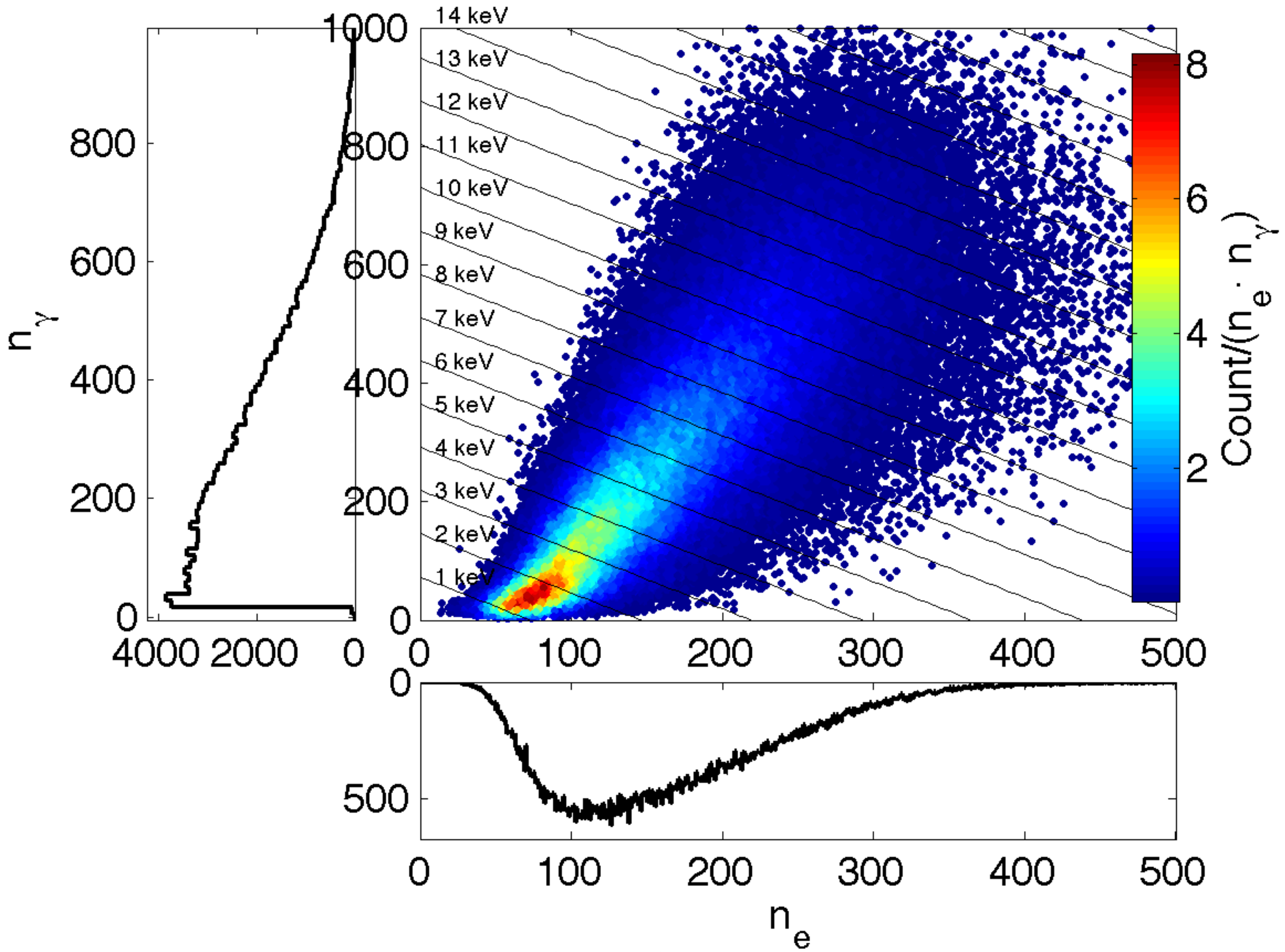
Tritium: an ideal electron-recoil band calibration source



Injection and removal of tritium from LUX, August 2013

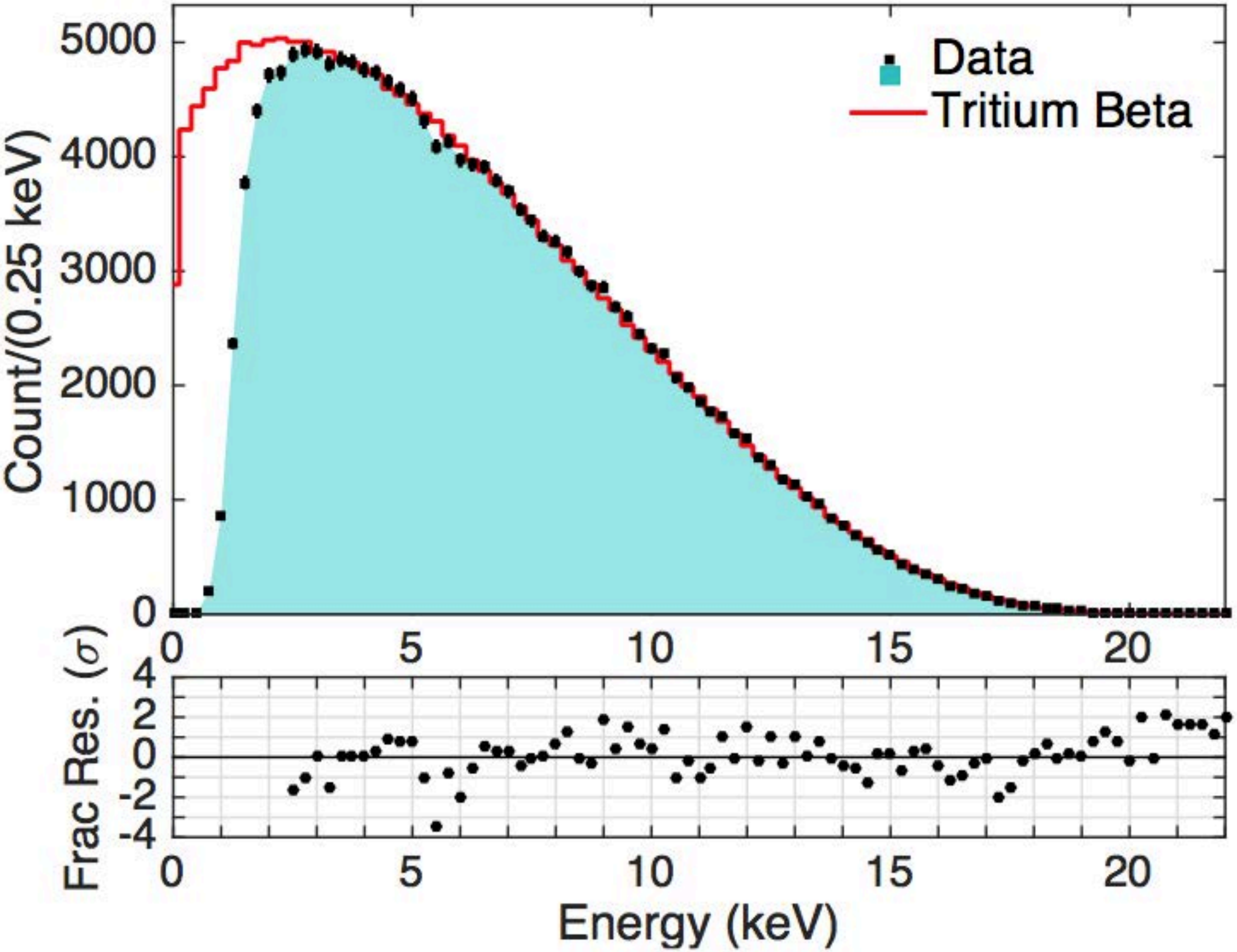


Charge vs Light from tritium in LUX at 170 V/cm



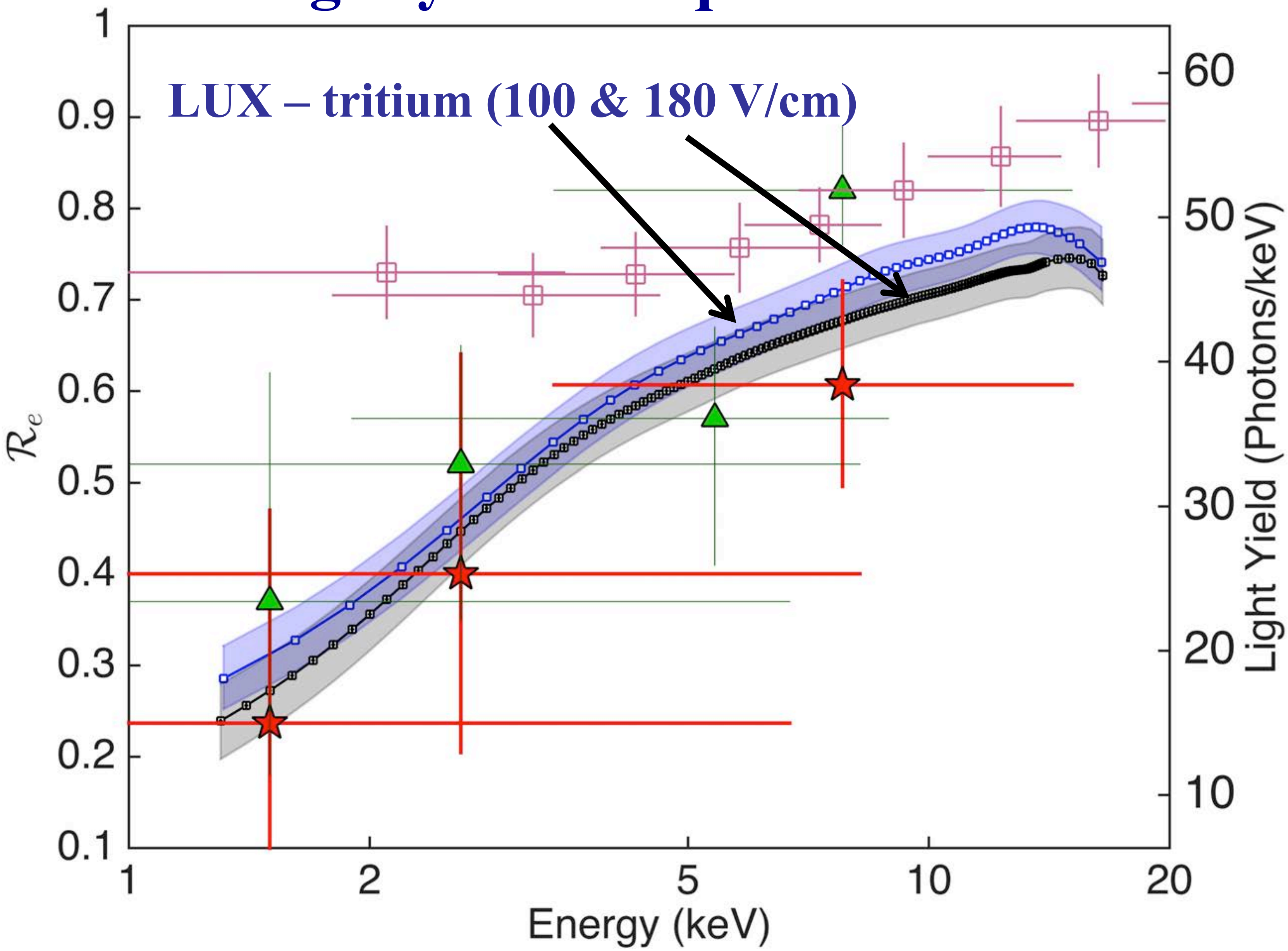
178,000 fiducial tritium events

Tritium combined-energy spectrum



178,000 fiducial tritium events – December 2013

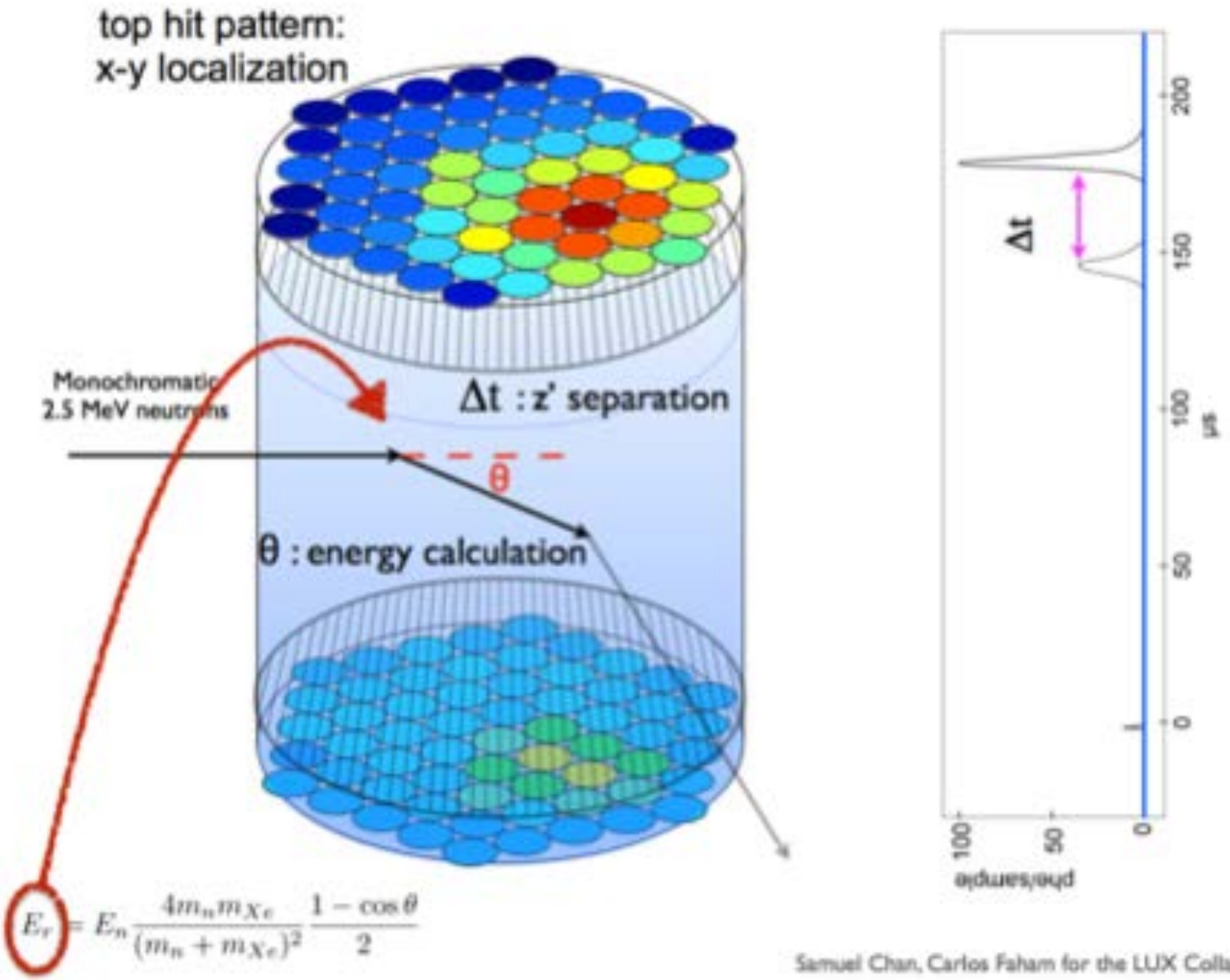
Light yield of liquid xenon



LUX – tritium (100 & 180 V/cm)

Nuclear-recoil calibration w/mono-energetic neutrons

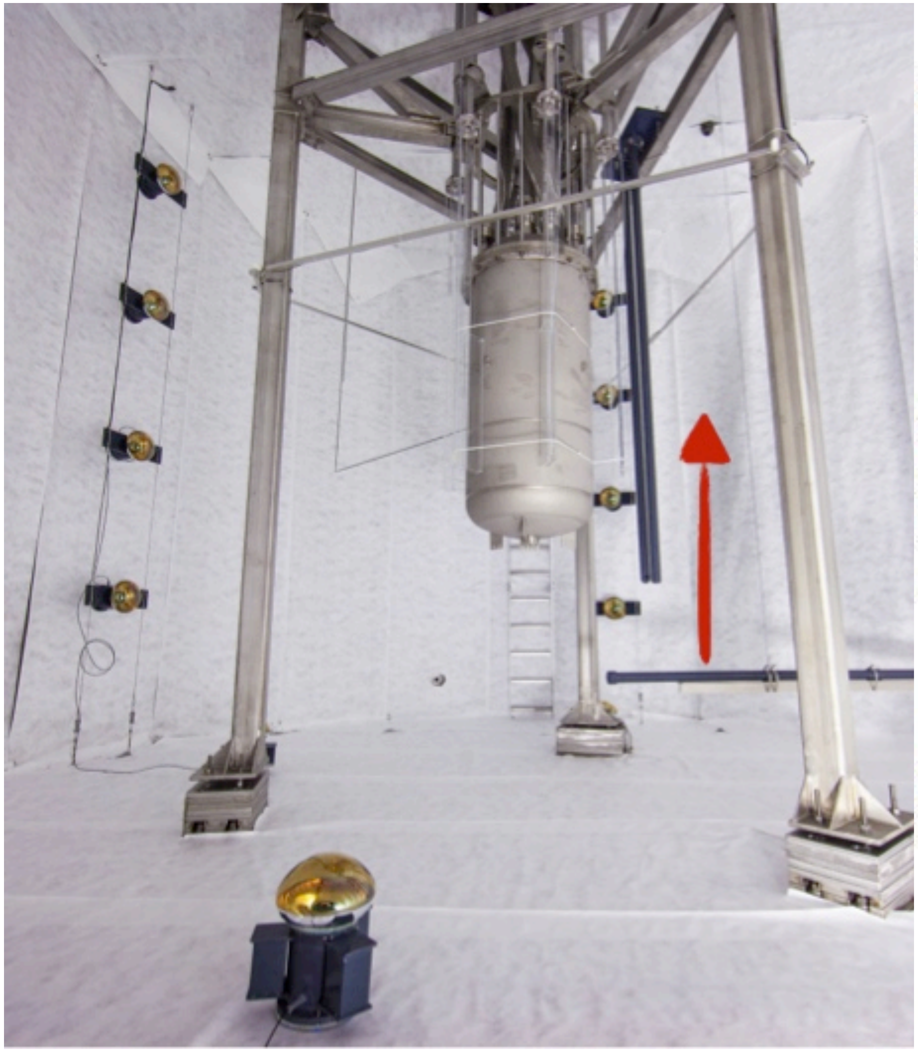
$D + D \rightarrow n + {}^{3}He \quad E_n = 2.45\ \mathrm{MeV}$

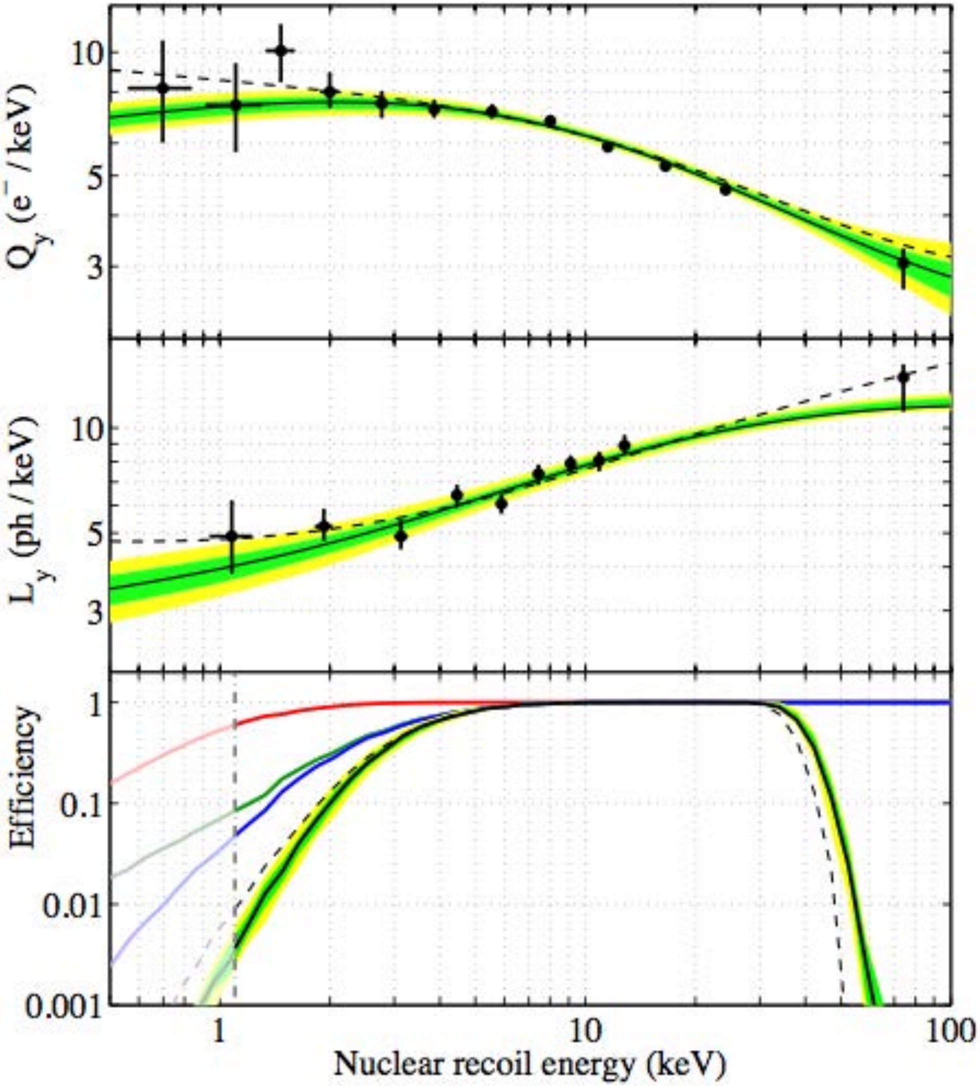


$$E_r = E_n \frac{4 m_n m_{Xe}}{(m_n + m_{Xe})^2} \frac{1-\cos\theta}{2}$$

Samuel Chan, Carlos Faham for the LUX Collaboration

Nuclear-recoil calibration of LUX
Neutron scattering with a neutron generator





LUX -> LZ (2020)

Scale up LUX fiducial mass by x40

LZ:

Total Xe - 10 Ton
Active Xe – 7 Ton
Fiducial Xe – 5.6 Ton

LZ Timeline

Year	**Month**	**Activity**
2012	March	LZ collaboration forms in response to FOA for G2 dark matter experiments
	September	CD-0 for G2 dark matter experiments
	December	LZ starts receiving R&D support from DoE & NSF
2013	November	LZ R&D report submitted to agencies
2014	May	P5 endorses G2 program
2014	July	LZ Project selected by DOE and NSF
2015	March	CD1 Review – conceptual design
2016	April	CD2 Review – project baseline
2017	January	CD3 Review – construction start
2020	*Spring*	*Ready for data taking*

LZ = LUX + ZEPLIN

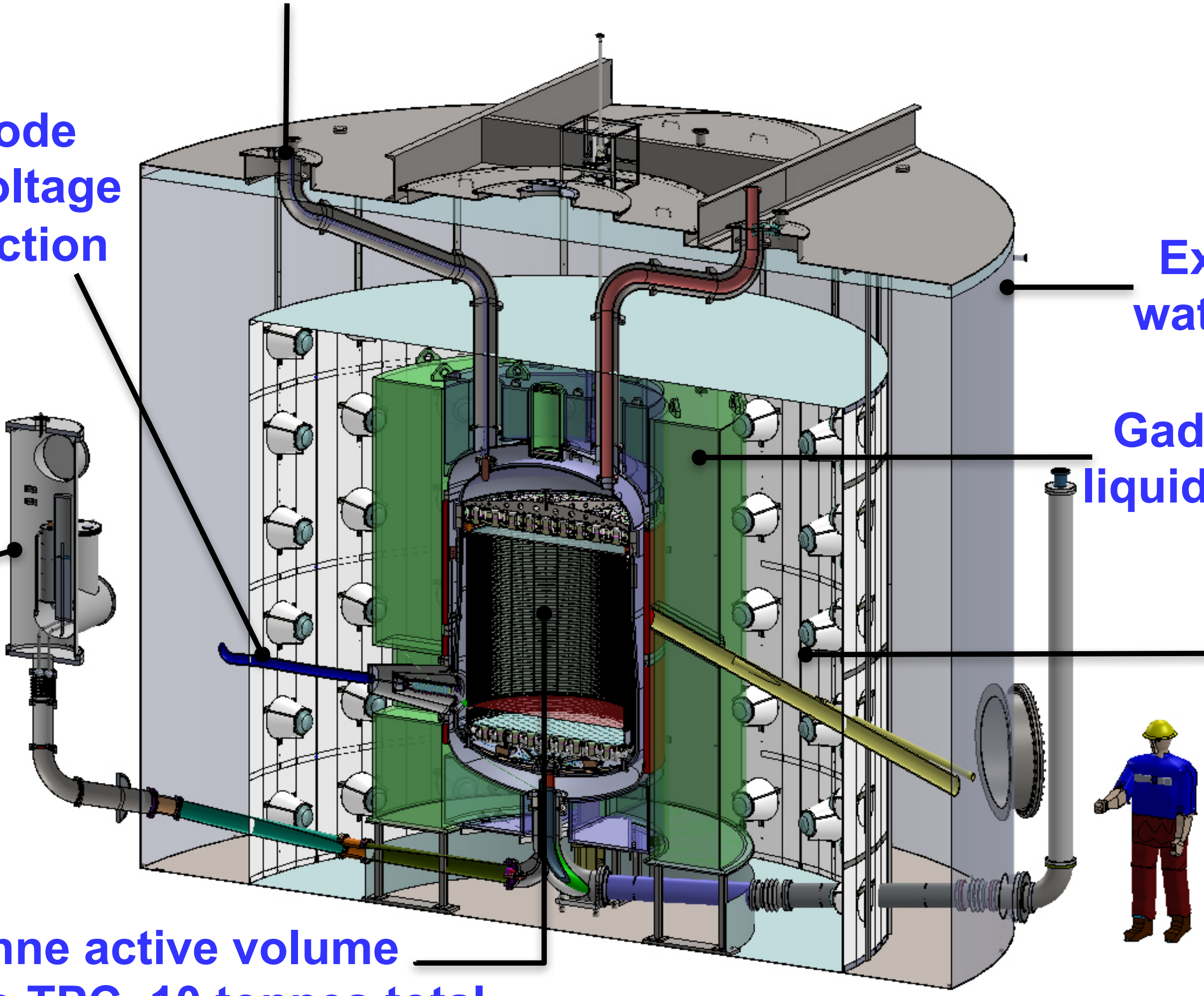
38 Institutions, 217 People

Black Hills State University
Brookhaven National Laboratory (BNL)
Brown University
Fermi National Accelerator Laboratory (FNAL)
Kavli Institute for Particle Astrophysics and Cosmology (KIPAC)
Lawrence Berkeley National Laboratory (LBNL)
Lawrence Livermore National Laboratory (LLNL)
Northwestern University
Pennsylvania State University
SLAC National Accelerator Laboratory
South Dakota School of Mines and Technology
South Dakota Science and Technology Authority (SDSTA)
STFC Rutherford Appleton Laboratory (RAL)
Texas A&M University
University at Albany (SUNY)
University of Alabama
University of California (UC), Berkeley
University of California (UC), Davis
University of California (UC), Santa Barbara
University of Maryland
University of Massachusetts
University of Michigan
University of Rochester
University of South Dakota
University of Wisconsin-Madison
Washington University in St. Louis
Yale University

Center for Underground Physics (Korea)
Imperial College London (UK)
LIP Coimbra (Portugal)
MEPhI (Russia)
STFC Rutherford Appleton Laboratory (UK)
University College London (UK)
University of Bristol (UK)
SUPA, University of Edinburgh (UK)
University of Liverpool (UK)
University of Oxford (UK)
University of Sheffield (UK)

LZ collaboration meeting - Oxford, UK
August 2016

The LZ Experiment – coming in 2020



Instrumentation conduits

Cathode
high voltage
connection

Existing
water tank

Gadolinium-loaded
liquid scintillator vet

Liquid Xe
heat
exchanger
tower

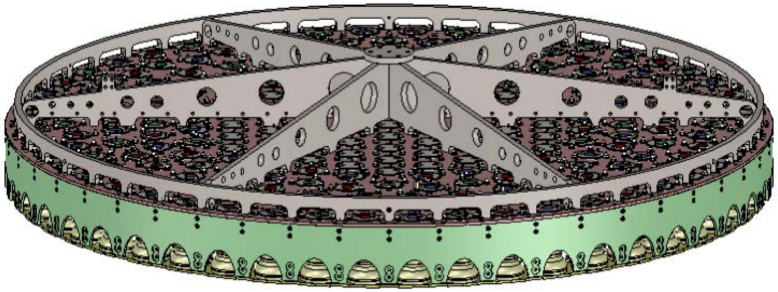
Outer
detector
PMTs

7 tonne active volume
liquid Xe TPC. 10 tonnes total

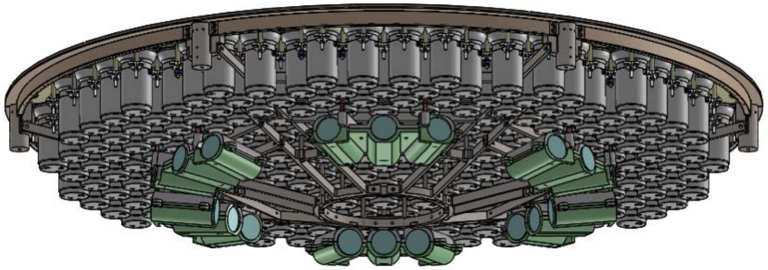
TPC

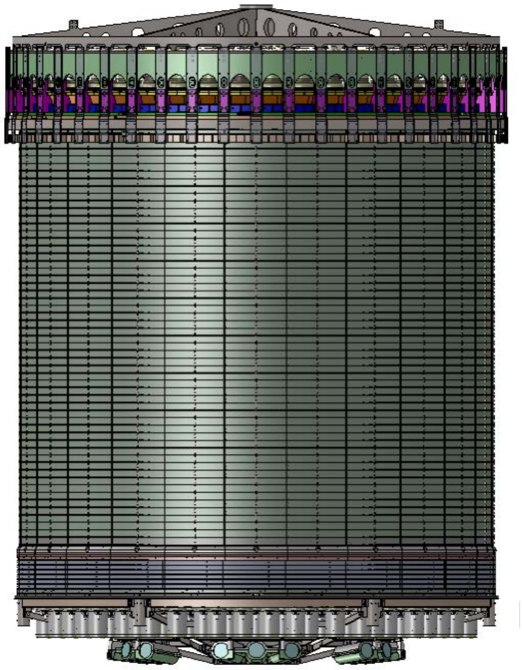
- Detailed design of top and bottom PMT arrays advanced

TOP



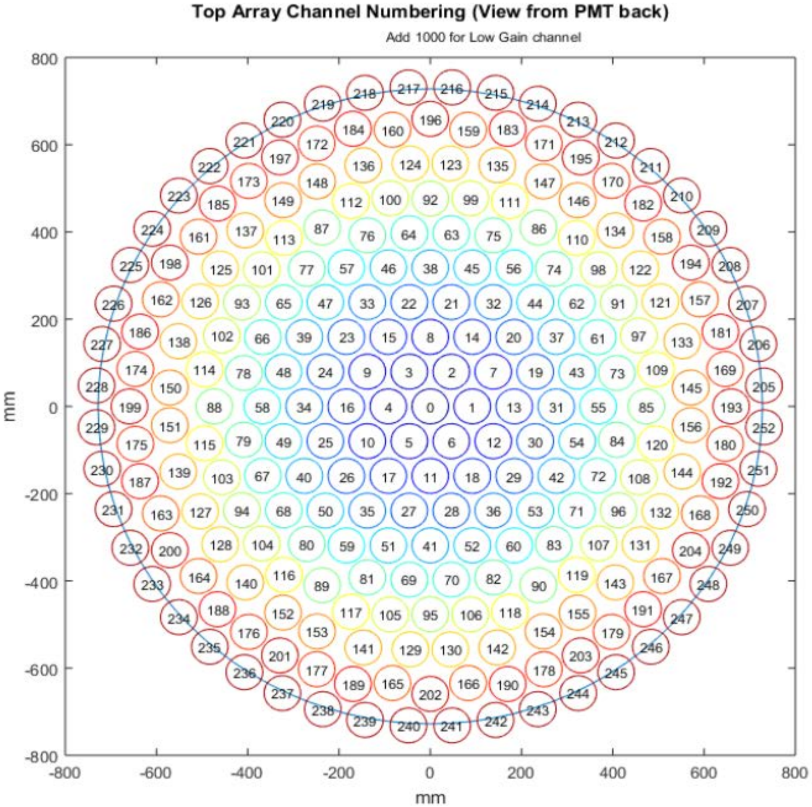
BOTTOM



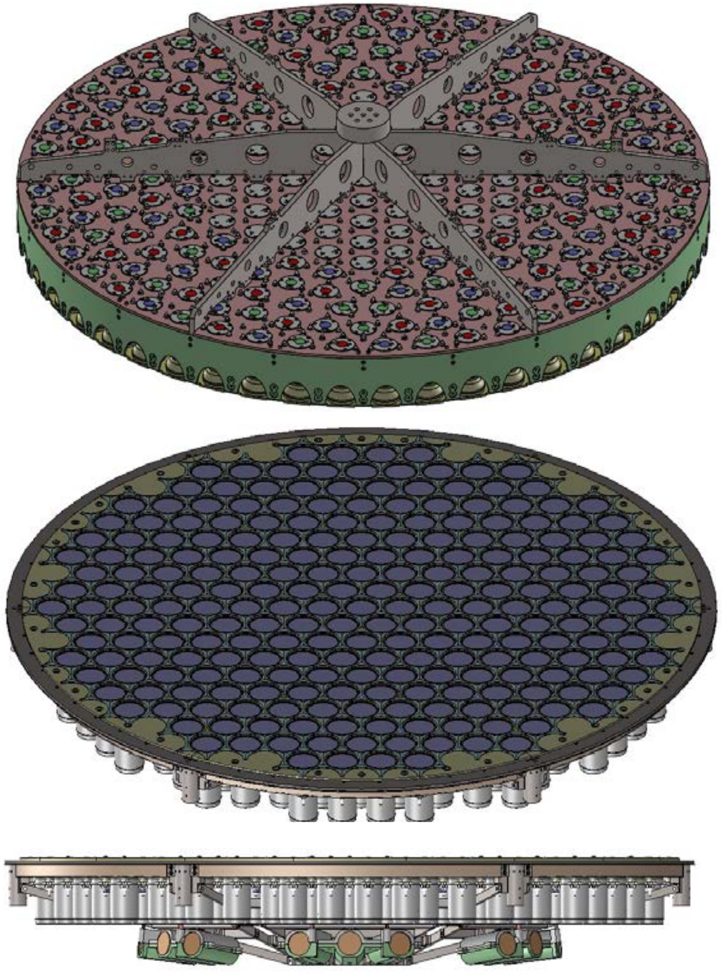


- Array assembly planning well underway
- TPC field cage design advanced
- Titanium for array supports and TPC field rings in hand
- PTFE procurement about to begin

PMTs


Top Array Channel Numbering (View from PMT back)

Add 1000 for Low Gain channel

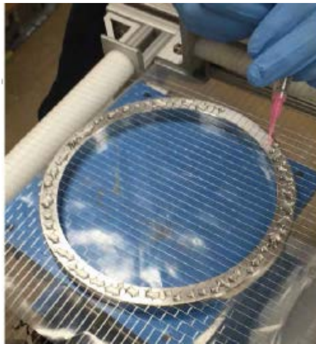


- TPC: 241 (bottom) + 253 (top) x 3” Ø, R11410
- Skin top : 93 x 1” R8520
- Skin: 38 x 2” R8778 LUX PMTs
- Joint US/UK procurement
- 172 UK PMTs manufactured - order complete, on schedule
- US delivery schedule picks up now
- Testing keeping pace, QE good, radioactivity on target

TPC System Test @ SLAC

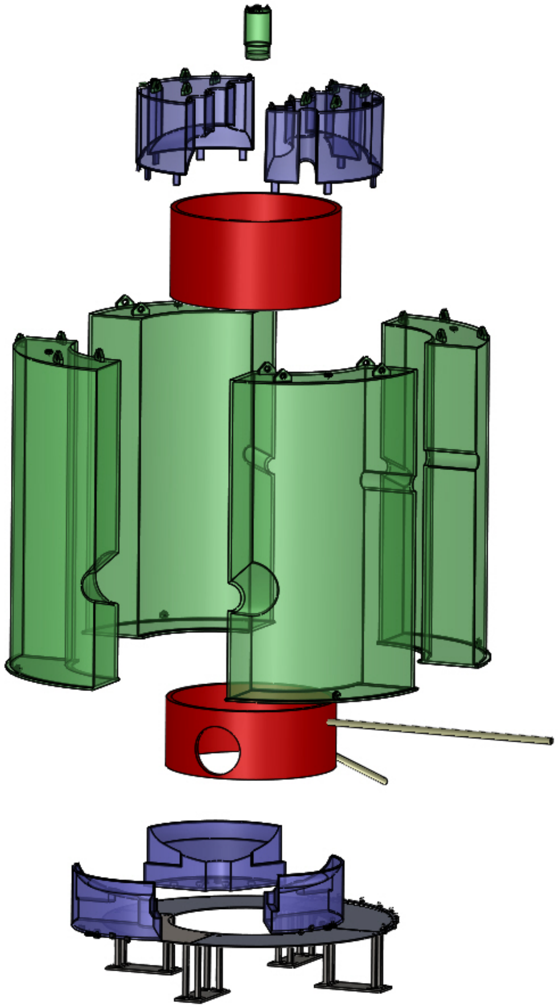
Items Tested
TPC PTFE/field shaping rings
Prototype small grid fab & treatment
TPC sensors integration
PLC control & software
Fluid flow(weir, etc) design input
Thermosyphon design input
Cathode high voltage performance
Gate-anode performance
Gas circulation (up to 100 slpm)

Next up: full diameter (1.5m) grid testing integrated into system this year.



Outer Detector

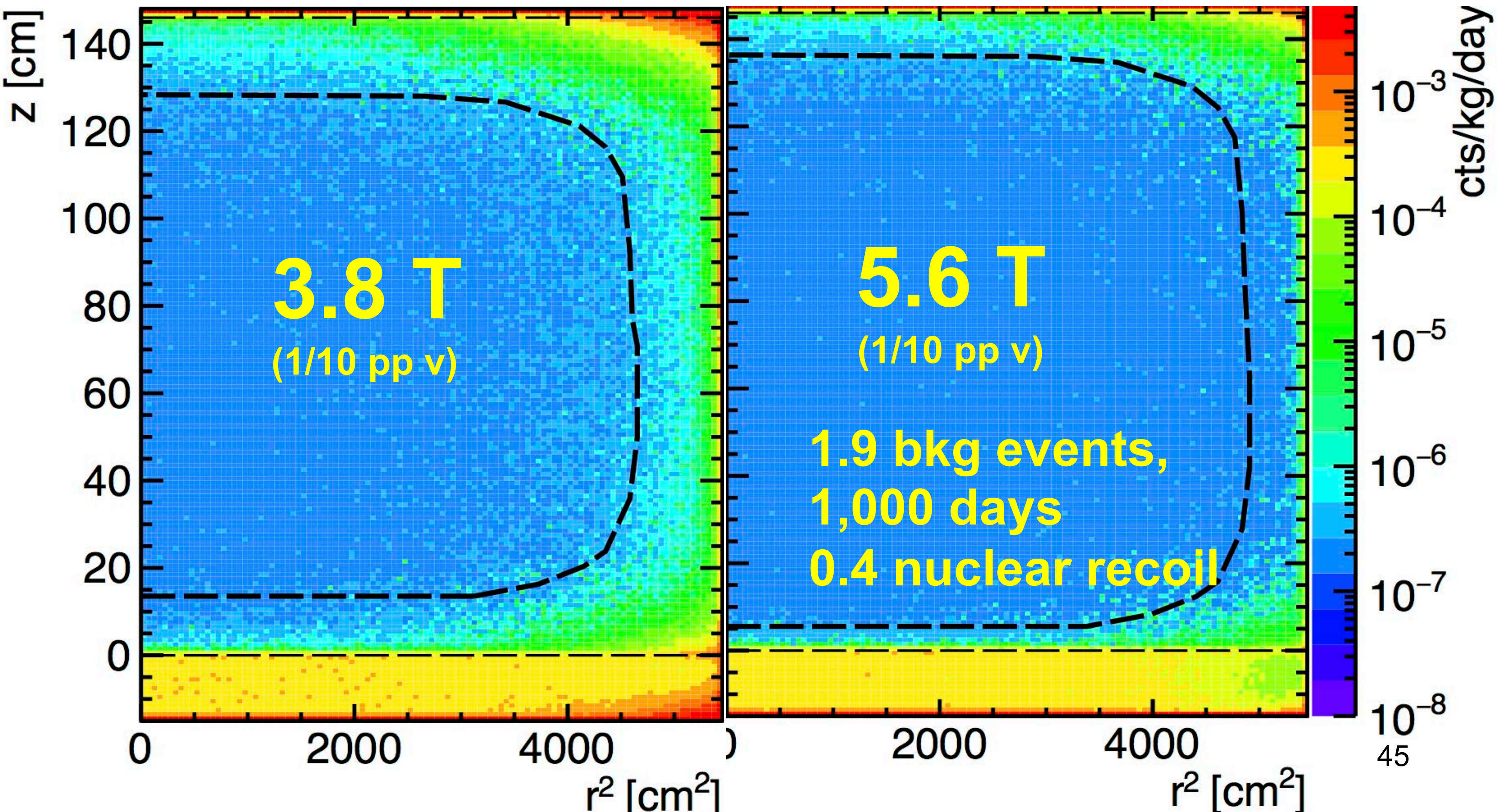
- US, UK (PMT calibration), South Korea (PMTs)
- Bid process for acrylic vessel fabrication completed and contract recently awarded
- Ramping up capability for Gadolinium-loaded liquid scintillator production at BNL, prototype quantity made and delivered.
- South Korea has ordered their share of PMTs for this system. U.S. share will be ordered when funds available.
- Small-scale prototype (1/1000 scale) going into LUX water tank now to measure backgrounds



Outer Detector Veto

TPC alone

w/LXe skin, OD veto



3.8 T
(1/10 pp ν)

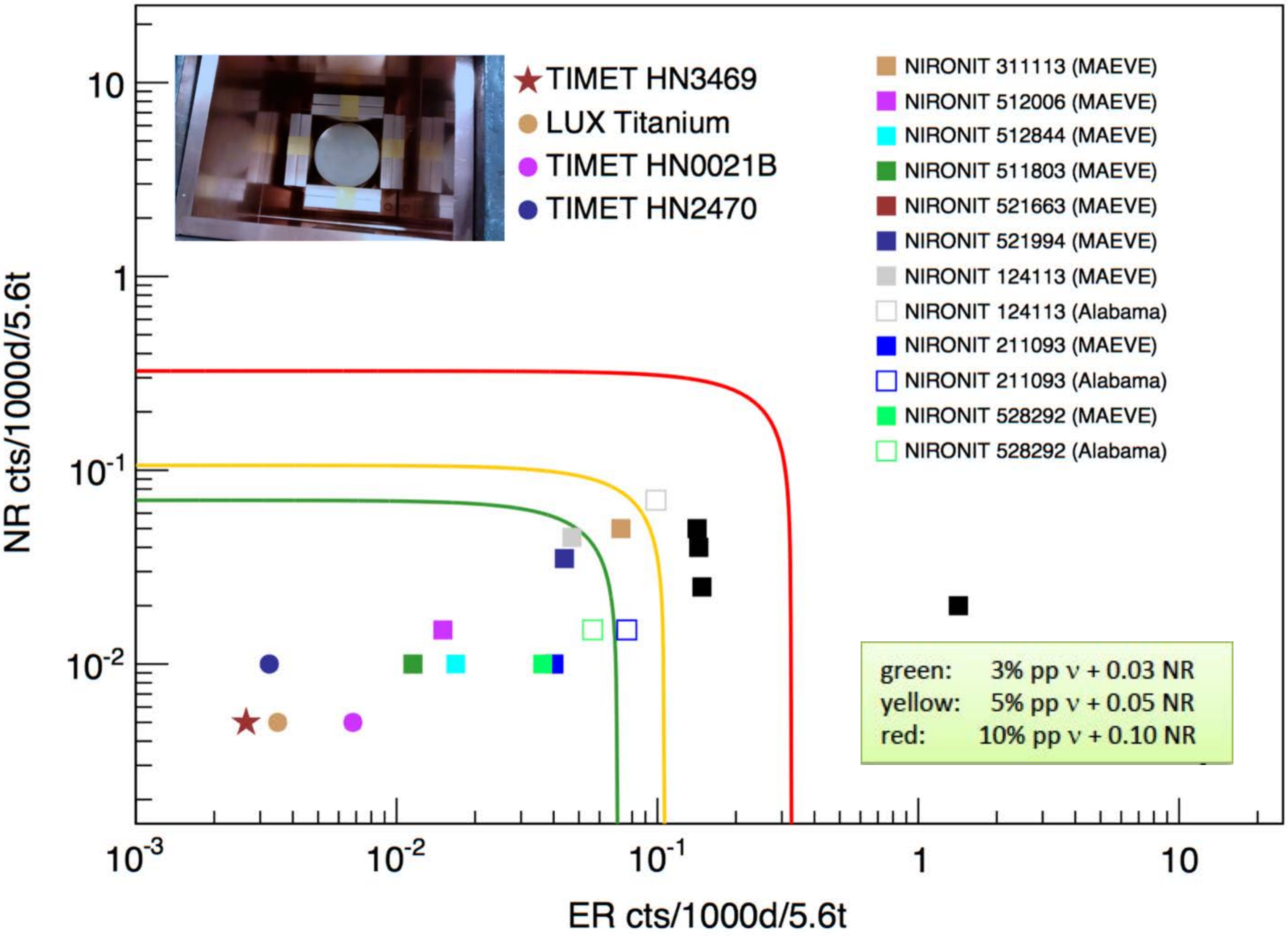
5.6 T
(1/10 pp ν)

1.9 bkg events,
1,000 days
0.4 nuclear recoil

Titanium Cryostat

- Ultra-low radioactivity Ti material in hand
- Under contract with Loterios in Italy
- Vessel fabrication design done
- Plate fabrication complete
- Forged parts delivered
- UK responsibility

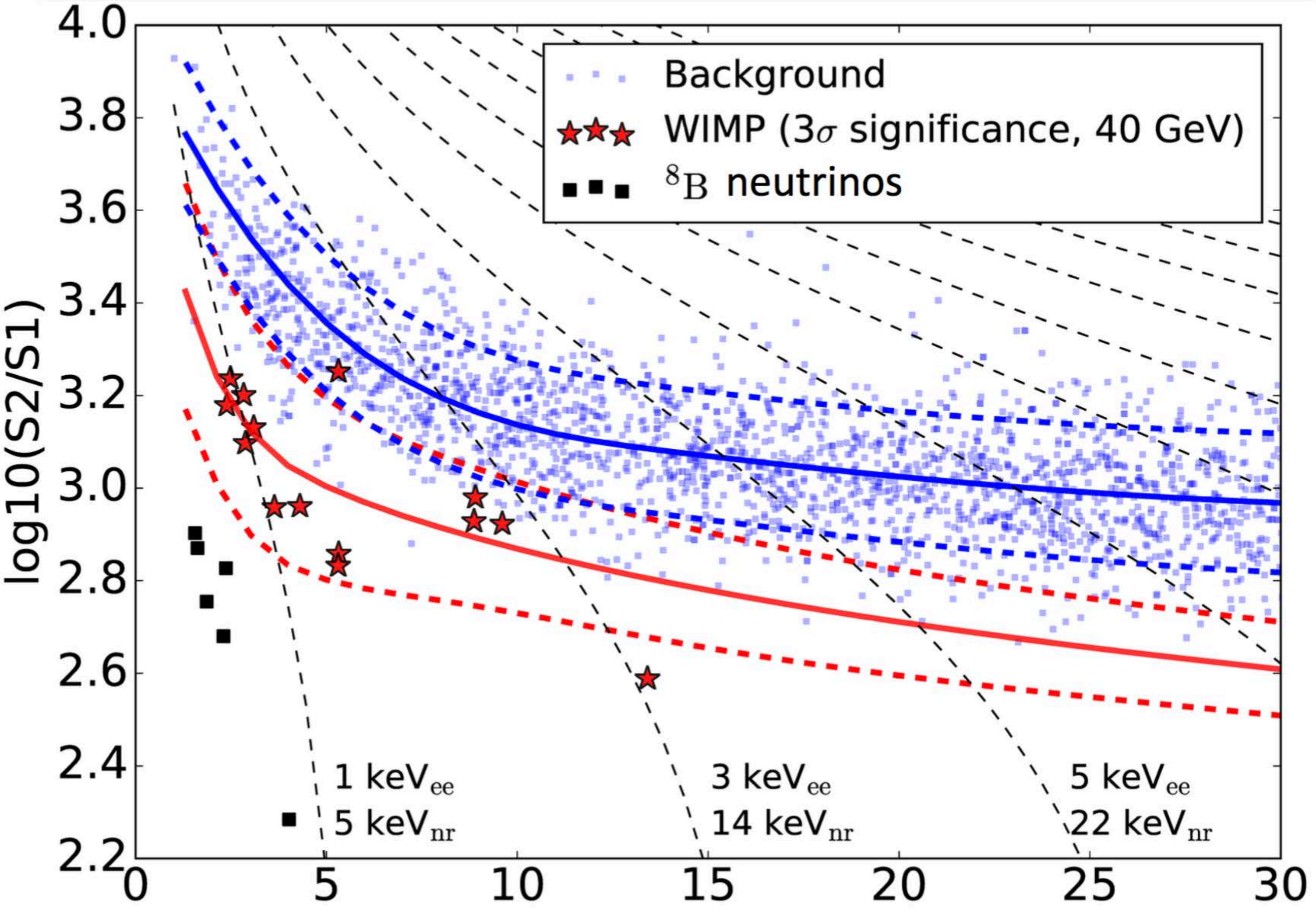
ER & NR Backgrounds from titanium



Background summary

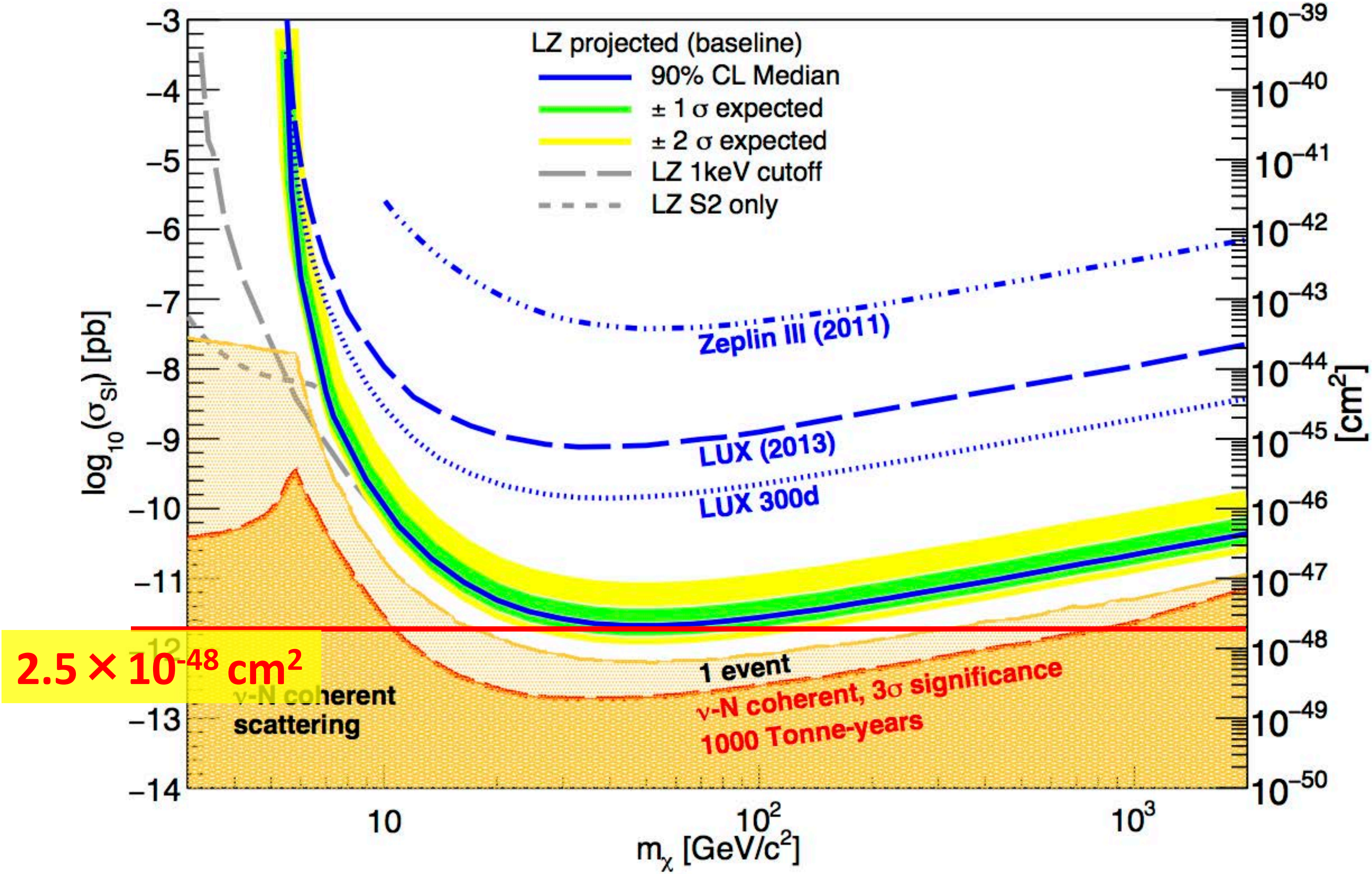
Intrinsic Contamination Backgrounds	**ER (cts)**	**NR (cts)**
Detector material backgrounds	6.2	0.07
222Rn	722	-
220Rn	122	-
85Kr	24.5	-
39Ar	2.47	-
210Bi	40	
Lab, Cosmogenic, surface contaminants	4.5	0.43
Subtotal (Non-neutrino counts)	**921**	**0.5**
Physics Backgrounds	**ER (cts)**	**NR (cts)**
136Xe 2νββ	67	-
Astrophysical ν counts (pp+7Be)	255	-
Astrophysical ν counts (8B)	-	***
Astrophysical ν counts (Hep)	-	0.2
Astrophysical ν counts (diffuse supernova)	-	0.05
Astrophysical ν counts (atmospheric)	-	0.46
Total	**1240**	**1.22**
Total (w/ 99.5% ER discrim., 50% NR accept.)	**6.22**	**0.61**
ER + NR grand total cts	**6.82**	

LZ full exposure – 1000 days, 5.6 Tons



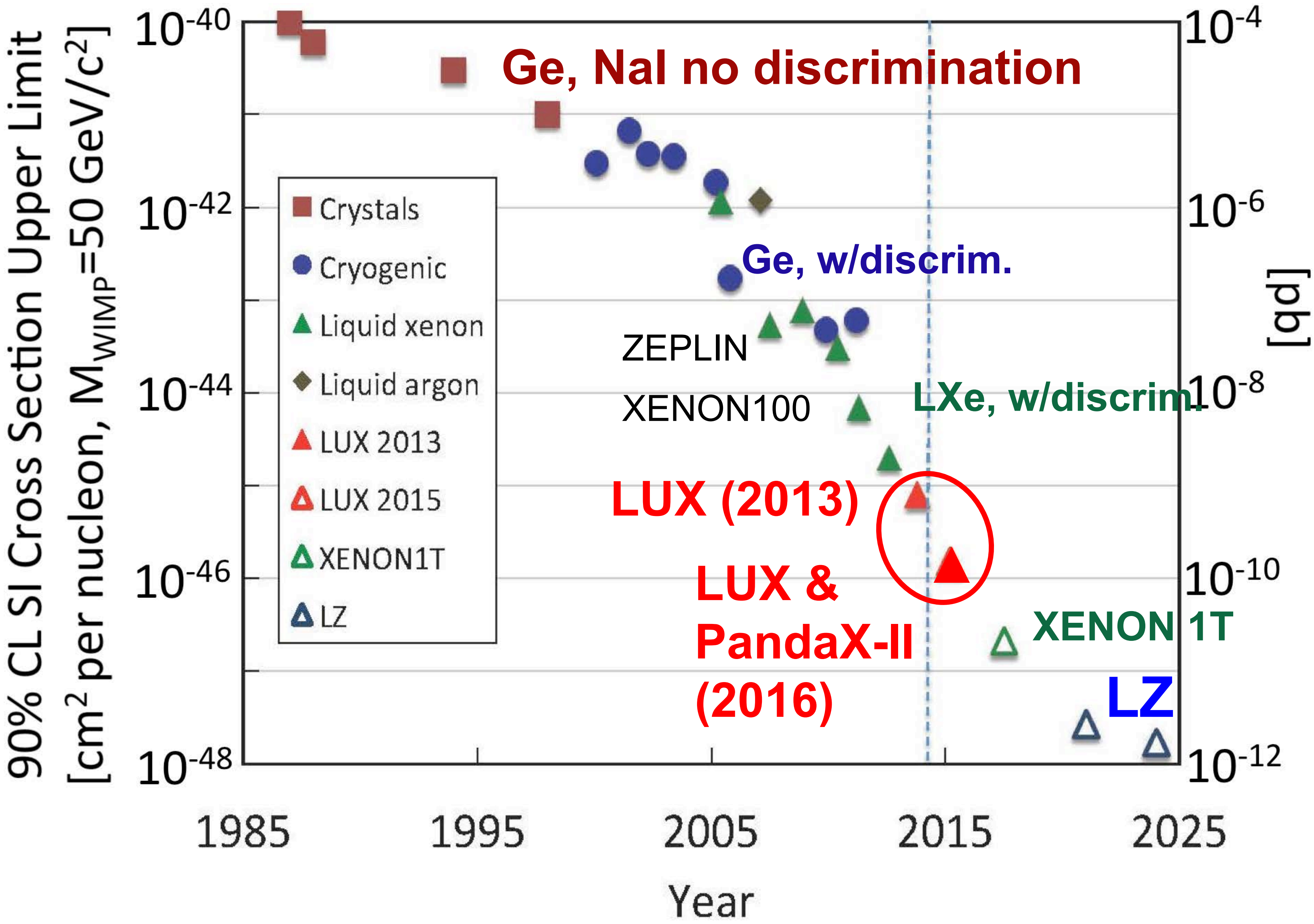
LZ Sensitivity

(5.6 Tonnes, 1000 live days)



2.5×10^{-48} cm^2

History of WIMP sensitivity @ 50 GeV



Ge, NaI no discrimination

Ge, w/discrim.

LXe, w/discrim.

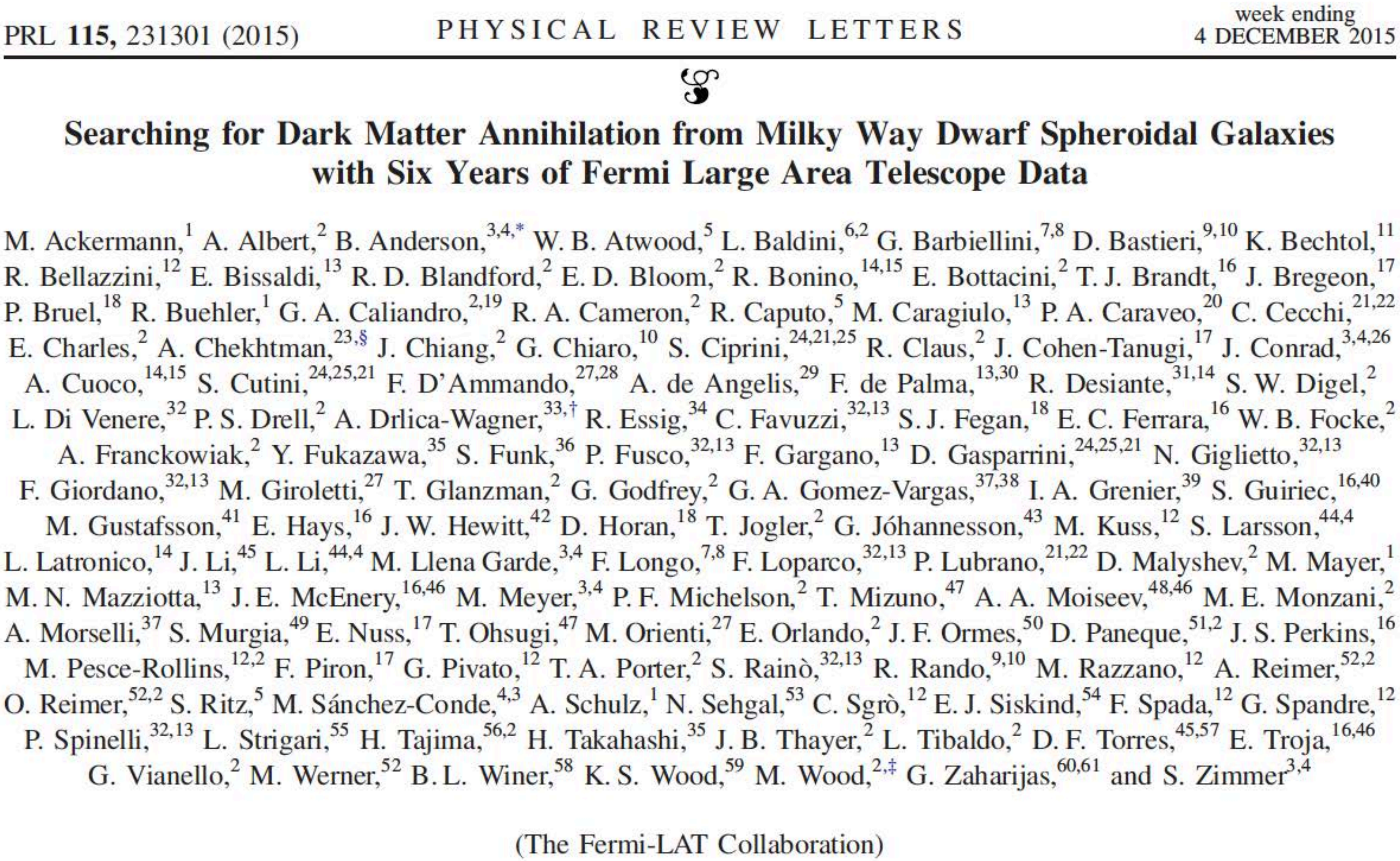
LUX (2013)

LUX & PandaX-II (2016)

XENON 1T

LZ


LUX-ZEPLIN
S.U.R.F.



PRL **115,** 231301 (2015) PHYSICAL REVIEW LETTERS week ending 4 DECEMBER 2015

Searching for Dark Matter Annihilation from Milky Way Dwarf Spheroidal Galaxies with Six Years of Fermi Large Area Telescope Data

M. Ackermann,[1] A. Albert,[2] B. Anderson,[3,4,*] W. B. Atwood,[5] L. Baldini,[6,2] G. Barbiellini,[7,8] D. Bastieri,[9,10] K. Bechtol,[11] R. Bellazzini,[12] E. Bissaldi,[13] R. D. Blandford,[2] E. D. Bloom,[2] R. Bonino,[14,15] E. Bottacini,[2] T. J. Brandt,[16] J. Bregeon,[17] P. Bruel,[18] R. Buehler,[1] G. A. Caliandro,[2,19] R. A. Cameron,[2] R. Caputo,[5] M. Caragiulo,[13] P. A. Caraveo,[20] C. Cecchi,[21,22] E. Charles,[2] A. Chekhtman,[23,§] J. Chiang,[2] G. Chiaro,[10] S. Ciprini,[24,21,25] R. Claus,[2] J. Cohen-Tanugi,[17] J. Conrad,[3,4,26] A. Cuoco,[14,15] S. Cutini,[24,25,21] F. D'Ammando,[27,28] A. de Angelis,[29] F. de Palma,[13,30] R. Desiante,[31,14] S. W. Digel,[2] L. Di Venere,[32] P. S. Drell,[2] A. Drlica-Wagner,[33,†] R. Essig,[34] C. Favuzzi,[32,13] S. J. Fegan,[18] E. C. Ferrara,[16] W. B. Focke,[2] A. Franckowiak,[2] Y. Fukazawa,[35] S. Funk,[36] P. Fusco,[32,13] F. Gargano,[13] D. Gasparrini,[24,25,21] N. Giglietto,[32,13] F. Giordano,[32,13] M. Giroletti,[27] T. Glanzman,[2] G. Godfrey,[2] G. A. Gomez-Vargas,[37,38] I. A. Grenier,[39] S. Guiriec,[16,40] M. Gustafsson,[41] E. Hays,[16] J. W. Hewitt,[42] D. Horan,[18] T. Jogler,[2] G. Jóhannesson,[43] M. Kuss,[12] S. Larsson,[44,4] L. Latronico,[14] J. Li,[45] L. Li,[44,4] M. Llena Garde,[3,4] F. Longo,[7,8] F. Loparco,[32,13] P. Lubrano,[21,22] D. Malyshev,[2] M. Mayer,[1] M. N. Mazziotta,[13] J. E. McEnery,[16,46] M. Meyer,[3,4] P. F. Michelson,[2] T. Mizuno,[47] A. A. Moiseev,[48,46] M. E. Monzani,[2] A. Morselli,[37] S. Murgia,[49] E. Nuss,[17] T. Ohsugi,[47] M. Orienti,[27] E. Orlando,[2] J. F. Ormes,[50] D. Paneque,[51,2] J. S. Perkins,[16] M. Pesce-Rollins,[12,2] F. Piron,[17] G. Pivato,[12] T. A. Porter,[2] S. Rainò,[32,13] R. Rando,[9,10] M. Razzano,[12] A. Reimer,[52,2] O. Reimer,[52,2] S. Ritz,[5] M. Sánchez-Conde,[4,3] A. Schulz,[1] N. Sehgal,[53] C. Sgrò,[12] E. J. Siskind,[54] F. Spada,[12] G. Spandre,[12] P. Spinelli,[32,13] L. Strigari,[55] H. Tajima,[56,2] H. Takahashi,[35] J. B. Thayer,[2] L. Tibaldo,[2] D. F. Torres,[45,57] E. Troja,[16,46] G. Vianello,[2] M. Werner,[52] B. L. Winer,[58] K. S. Wood,[59] M. Wood,[2,‡] G. Zaharijas,[60,61] and S. Zimmer[3,4]

(The Fermi-LAT Collaboration)

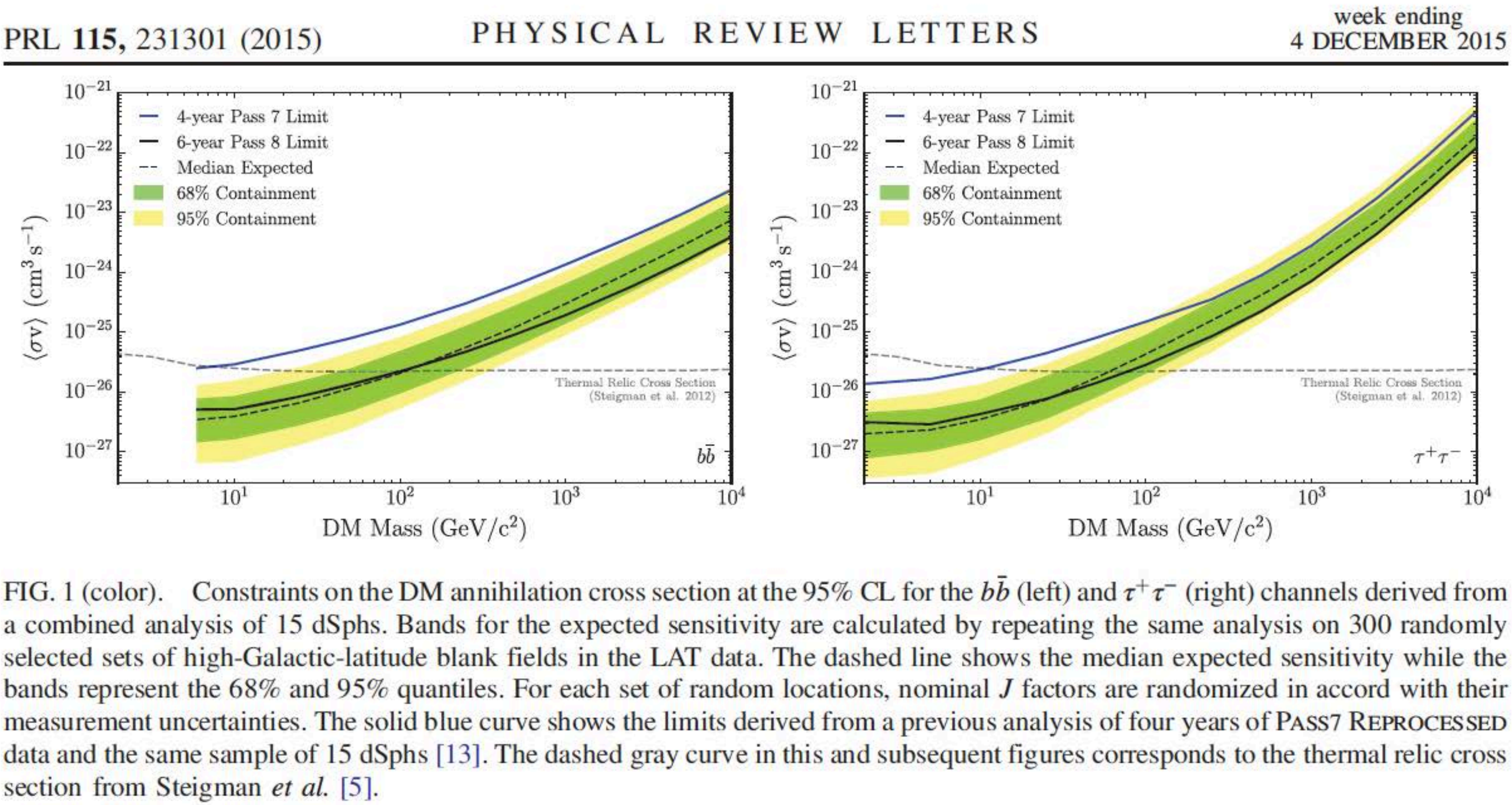


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FIG. 1 (color). Constraints on the DM annihilation cross section at the 95% CL for the $b\bar{b}$ (left) and $\tau^+\tau^-$ (right) channels derived from a combined analysis of 15 dSphs. Bands for the expected sensitivity are calculated by repeating the same analysis on 300 randomly selected sets of high-Galactic-latitude blank fields in the LAT data. The dashed line shows the median expected sensitivity while the bands represent the 68% and 95% quantiles. For each set of random locations, nominal J factors are randomized in accord with their measurement uncertainties. The solid blue curve shows the limits derived from a previous analysis of four years of PASS7 REPROCESSED data and the same sample of 15 dSphs [13]. The dashed gray curve in this and subsequent figures corresponds to the thermal relic cross section from Steigman *et al.* [5].