Searching for WIMPs in the Black Hills of South Dakota:

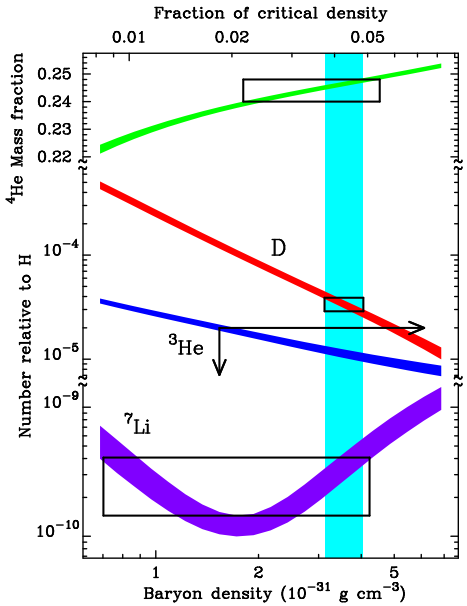
The LUX Dark Matter Experiment

Dr. Chamkaur Ghag

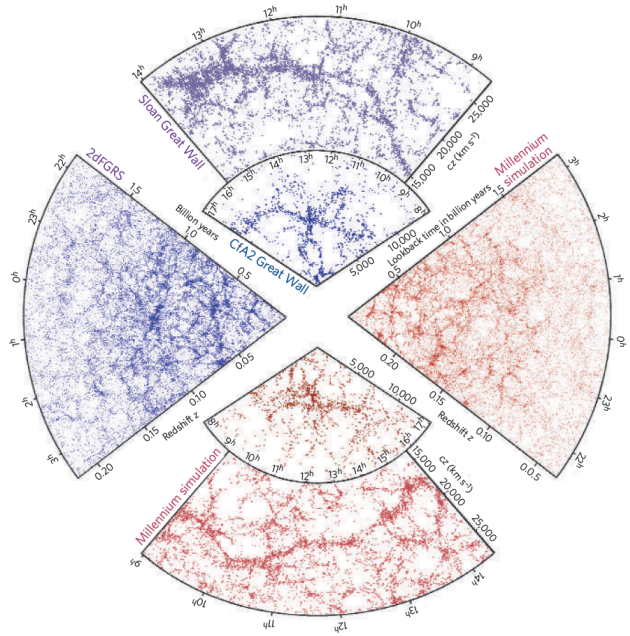
University College London

The evidence for dark matter

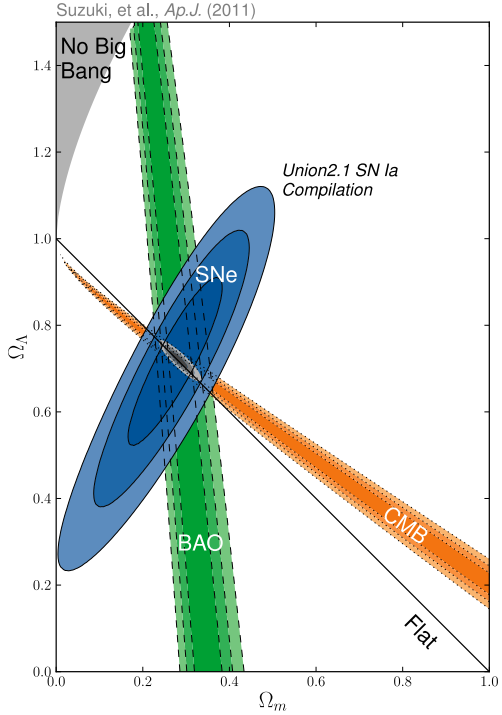
BBN



Large scale structure → CDM

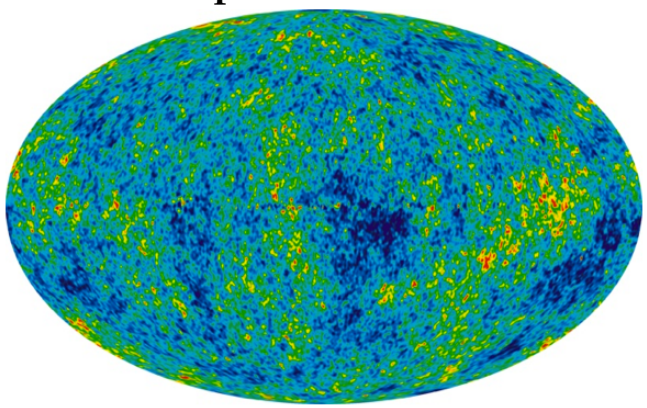


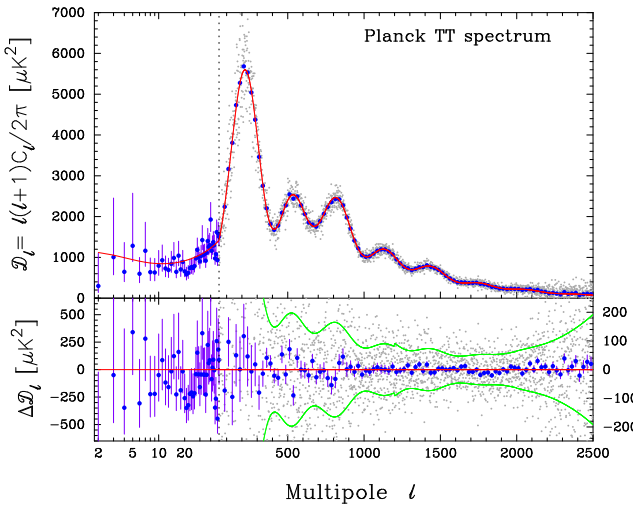
BAO + SNe + CMB



Gravitation lensing

CMB + BAO: precision tests of ΛCDM





The evidence for dark matter

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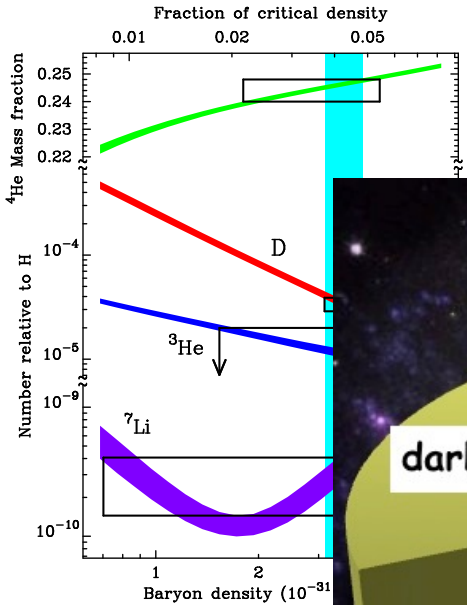

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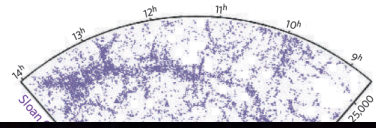
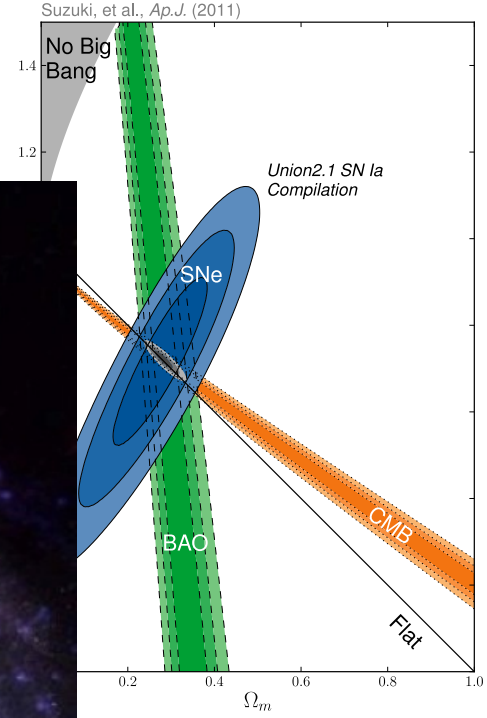
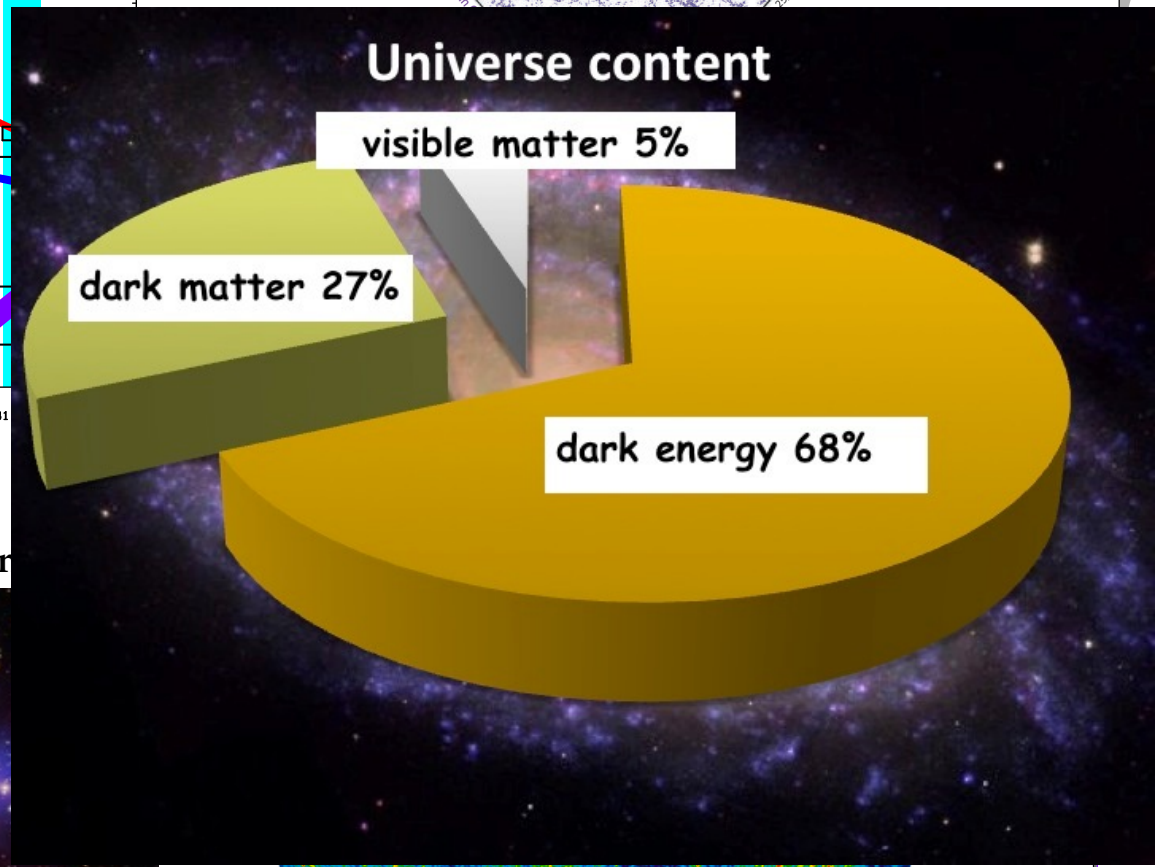
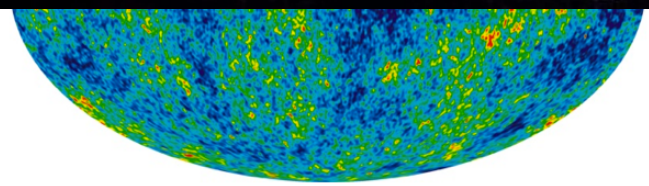


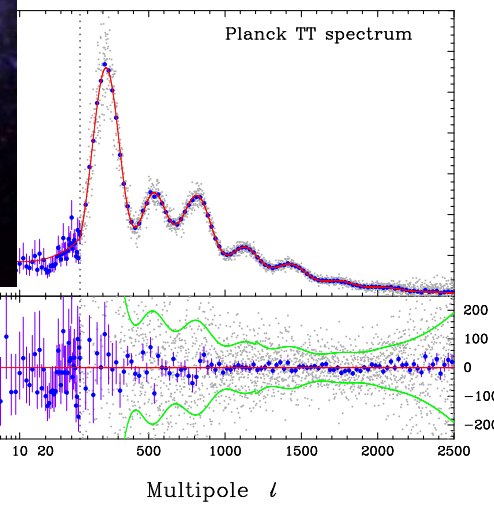
BAO + SNe + CMB





Gravitation lensi

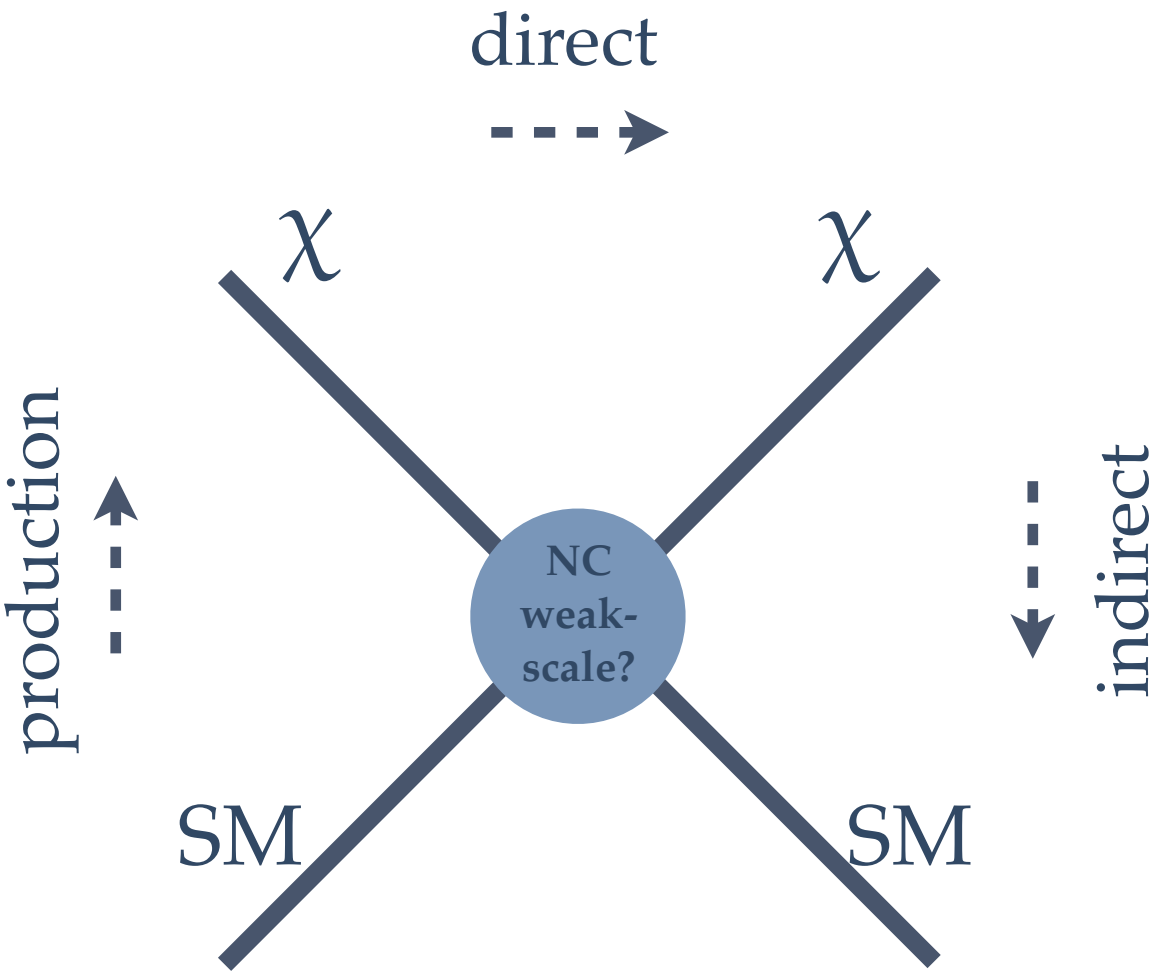




Dark Matter properties

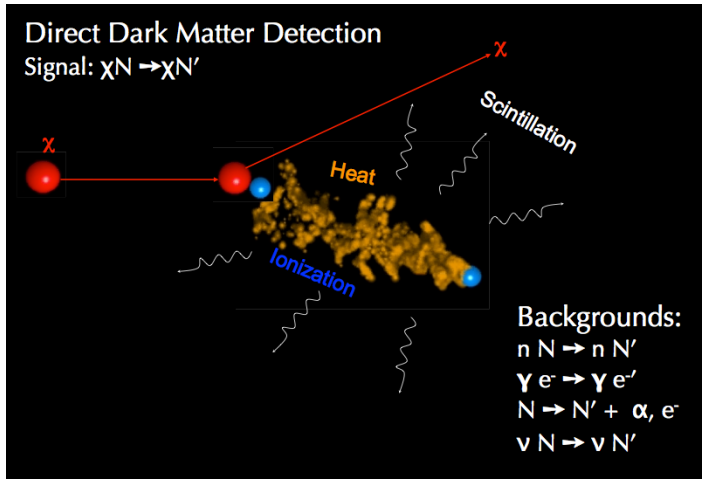
- Interacts only **weakly** with normal matter
- Expected to be **neutral** in most scenarios
- **Cold**: Non-relativistic freeze-out
- **WIMPs** favoured candidates for Cold Dark Matter
  (alternatives: axions, sterile neutrinos, ...)
- Requires **beyond standard model** physics:
  - Super-symmetry: LSP neutralino, 10^{-40} to 10^{-50} cm^2,
    Mass range GeV→TeV
  - Universal Extra Dimensions: Stable KK, similar detection properties as neutralino

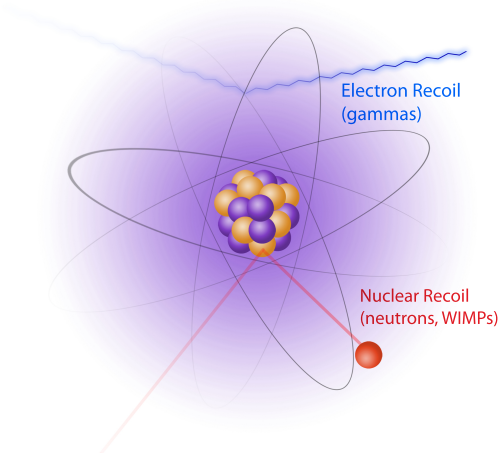
Detecting Dark Matter

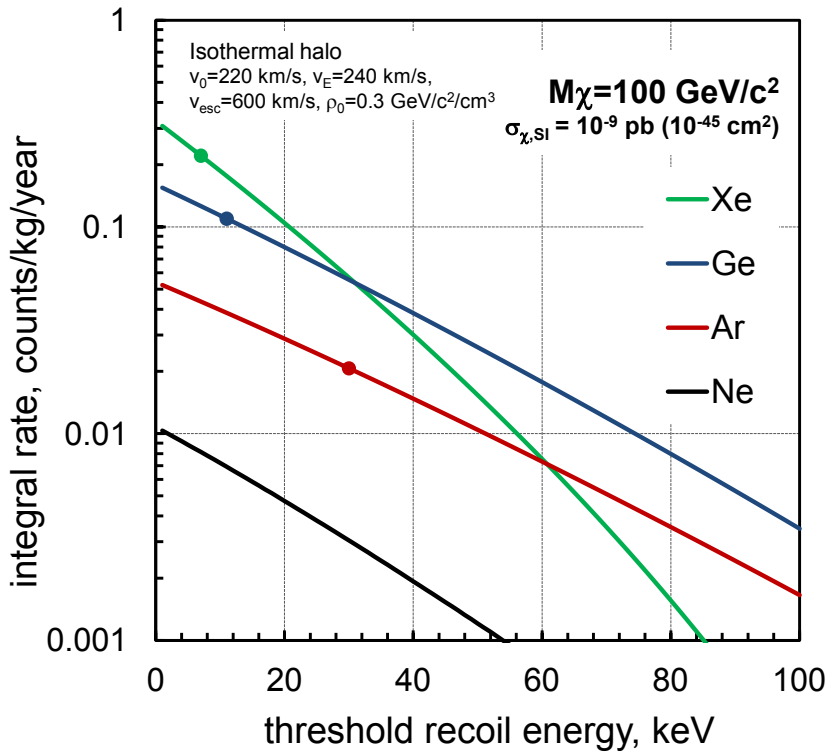


Direct detection of galactic dark matter

- Elastic scattering of galactic WIMPs off target nuclei in terrestrial detector
- WIMP speed ~ 220 km/s
  expect recoils O(10 keV)
- Spin-independent cross section $\propto A^2$
- Expect ~ 1 event/kg/year
- Requires SM backgrounds ~0
  (underground operation)

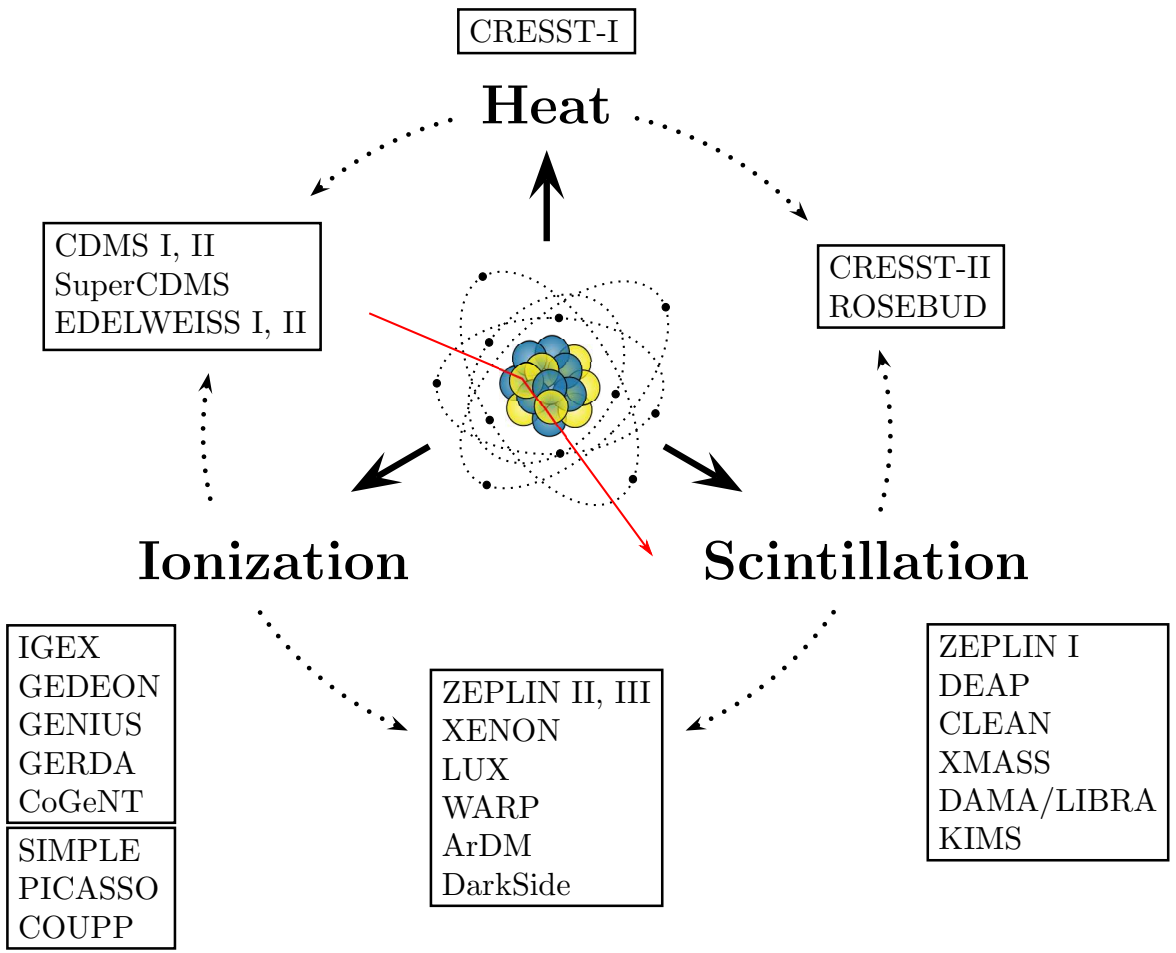




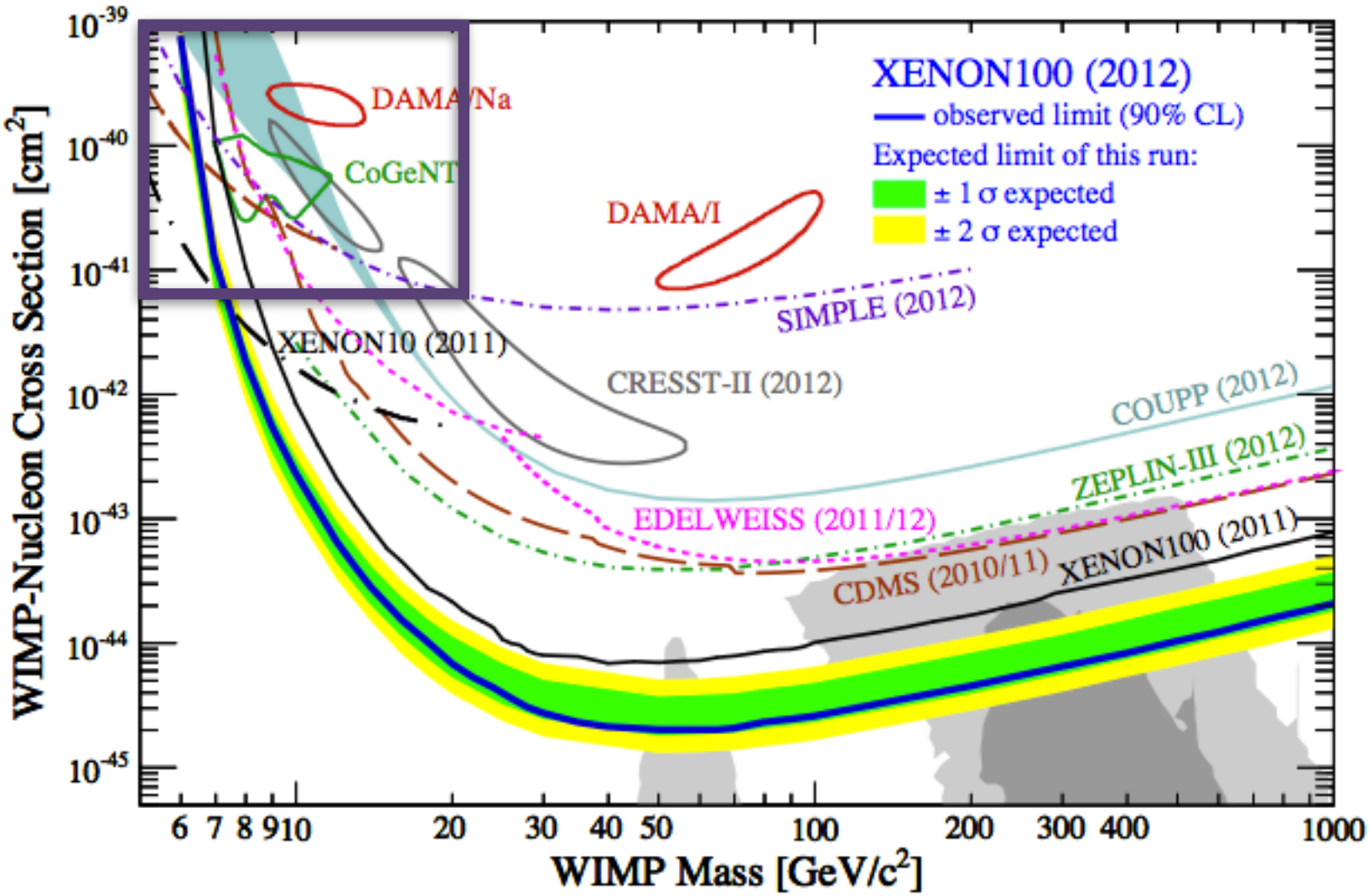


Direct detection techniques

- Requirements: large mass, low-radioactivity, low-energy threshold, high acceptance, discrimination



WIMP search status < 30th October 2013



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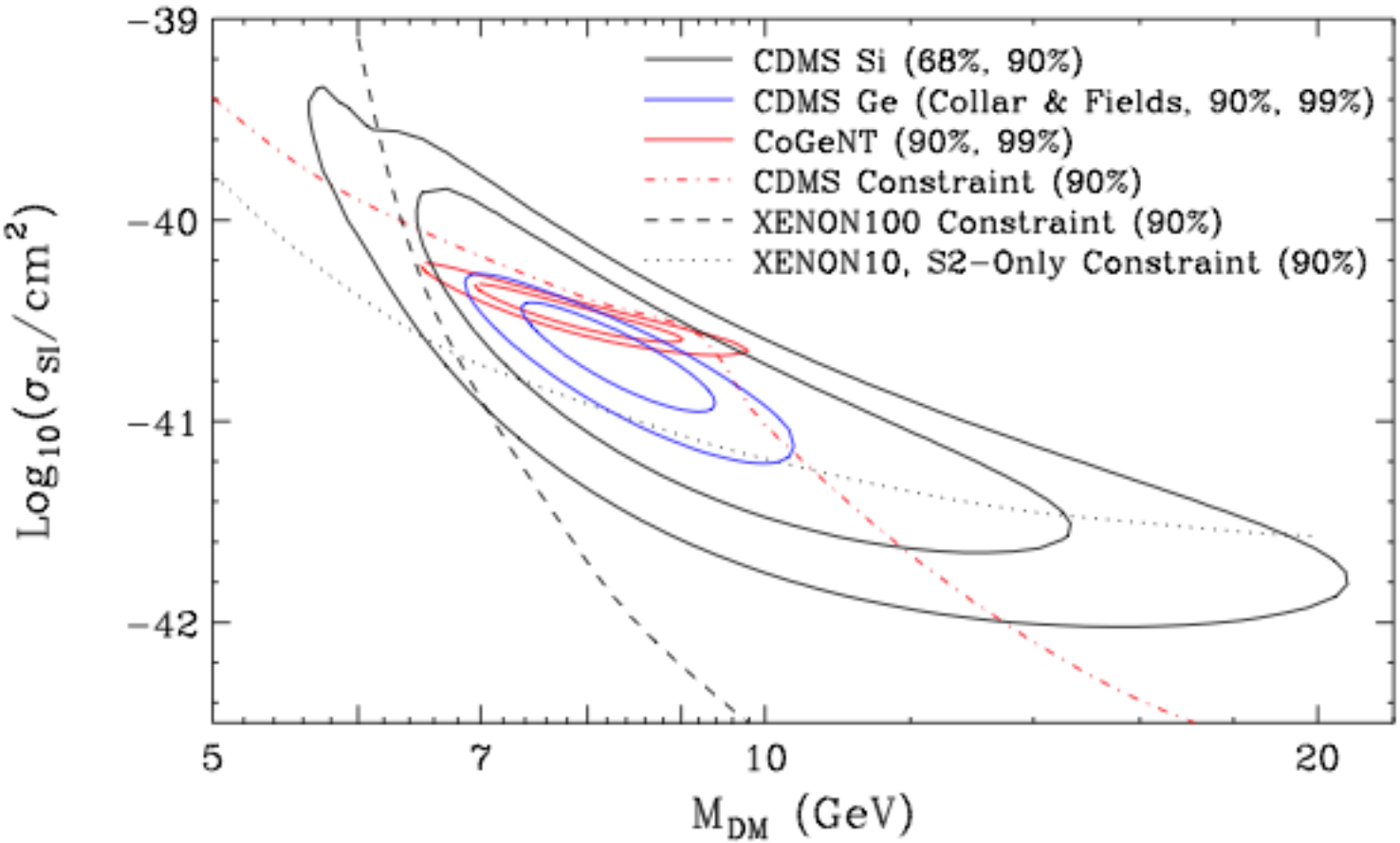

The LUX collaboration

Brown

Richard Gaitskell	PI, Professor
Simon Fiorucci	Research Associate
Monica Pangilinan	Postdoc
Jeremy Chapman	Graduate Student
David Malling	Graduate Student
James Verbus	Graduate Student
Samuel Chung Chan	Graduate Student
Dongqing Huang	Graduate Student

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Dan Akerib	PI, Professor
Karen Gibson	Postdoc
Tomasz Biesiadzinski	Postdoc
Wing H To	Postdoc
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Kati Pech	Graduate Student

Imperial College London

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Lawrence Berkeley + UC Berkeley

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Murdock Gilchriese	Senior Scientist
Kevin Lesko	Senior Scientist
Carlos Hernandez	Postdoc
Victor Gehman	Scientist
Mia Ihm	Graduate Student

Lawrence Livermore

Adam Bernstein	PI, Leader of Adv.
Dennis Carr	Mechanical Technician
Kareem Kazkaz	Staff Physicist
Peter Sorensen	Staff Physicist
John Bower	Engineer

LIP Coimbra

Isabel Lopes	PI, Professor
Jose Pinto da Cunha	Assistant Professor
Vladimir Solovov	Senior Researcher
Luiz de Viveiros	Postdoc
Alexander Lindote	Postdoc
Francisco Neves	Postdoc
Claudio Silva	Postdoc

SD School of Mines

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Tyler Liebsch	Graduate Student
Doug Tiedt	Graduate Student

SDSTA

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Mark Hanhardt	Support Scientist

Texas A&M

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Robert Webb	PI, Professor
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Clement Sofka	Graduate Student

UC Davis

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Ray Gerhard	Electronics Engineer
Aaron Manalaysay	Postdoc
Matthew Szydagis	Postdoc
Richard Ott	Postdoc
Jeremy Mock	Graduate Student
James Morad	Graduate Student
Nick Walsh	Graduate Student
Michael Woods	Graduate Student
Sergey Uvarov	Graduate Student
Brian Lenardo	Graduate Student

UC Santa Barbara

Harry Nelson	PI, Professor
Mike Witherell	Professor
Dean White	Engineer
Susanne Kyre	Engineer
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Curt Nehrkorn	Graduate Student
Scott Haselschwardt	Graduate Student

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Lea Reichhart	Postdoc
Sally Shaw	Graduate Student

Collaboration Meeting, Sanford Lab, April 2013

University of Edinburgh

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Paolo Beltrame	Research Fellow
James Dobson	Postdoc

University of Maryland

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Richard Knoche	Graduate Student
Jon Balajthy	Graduate Student

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Eryk Druszkiewicz	Graduate Student
Mongkol Moongweluwan	Graduate Student

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Chris Chiller	Graduate Student
Dana Byram	*Now at SDSTA

Yale

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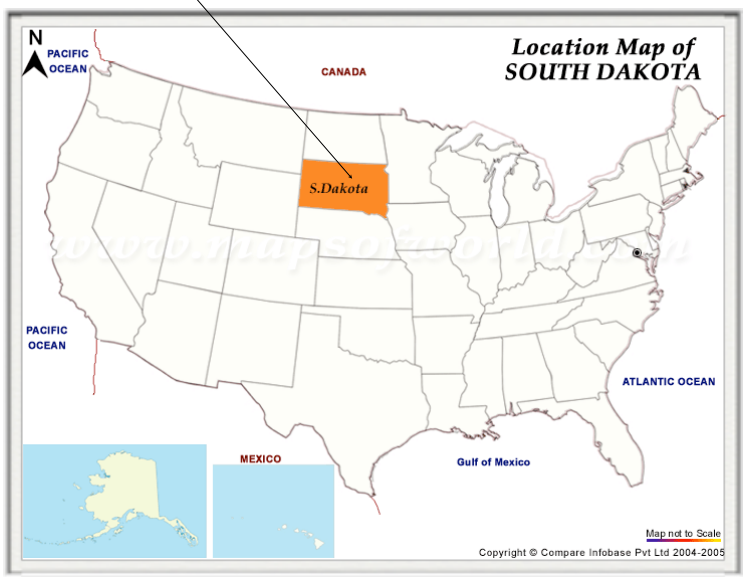
Peter Parker	Professor
Sidney Cahn	Lecturer/Research
Ethan Bernard	Postdoc
Markus Horn	Postdoc
Blair Edwards	Postdoc
Scott Hertel	Postdoc
Kevin O'Sullivan	Postdoc
Nicole Larsen	Graduate Student
Evan Pease	Graduate Student
Brian Tennyson	Graduate Student
Ariana Hackenburg	Graduate Student
Elizabeth Boulton	Graduate Student

Sanford Underground Research Facility (SURF)

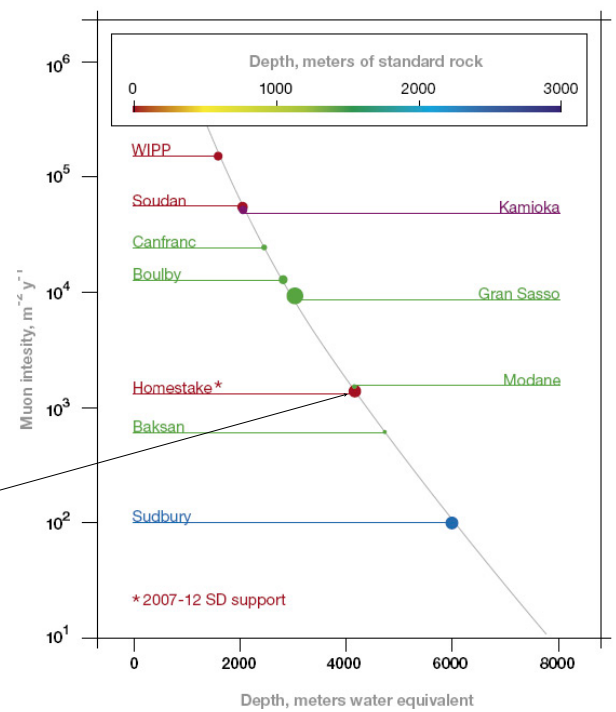
Lead, SD, located in Black Hills



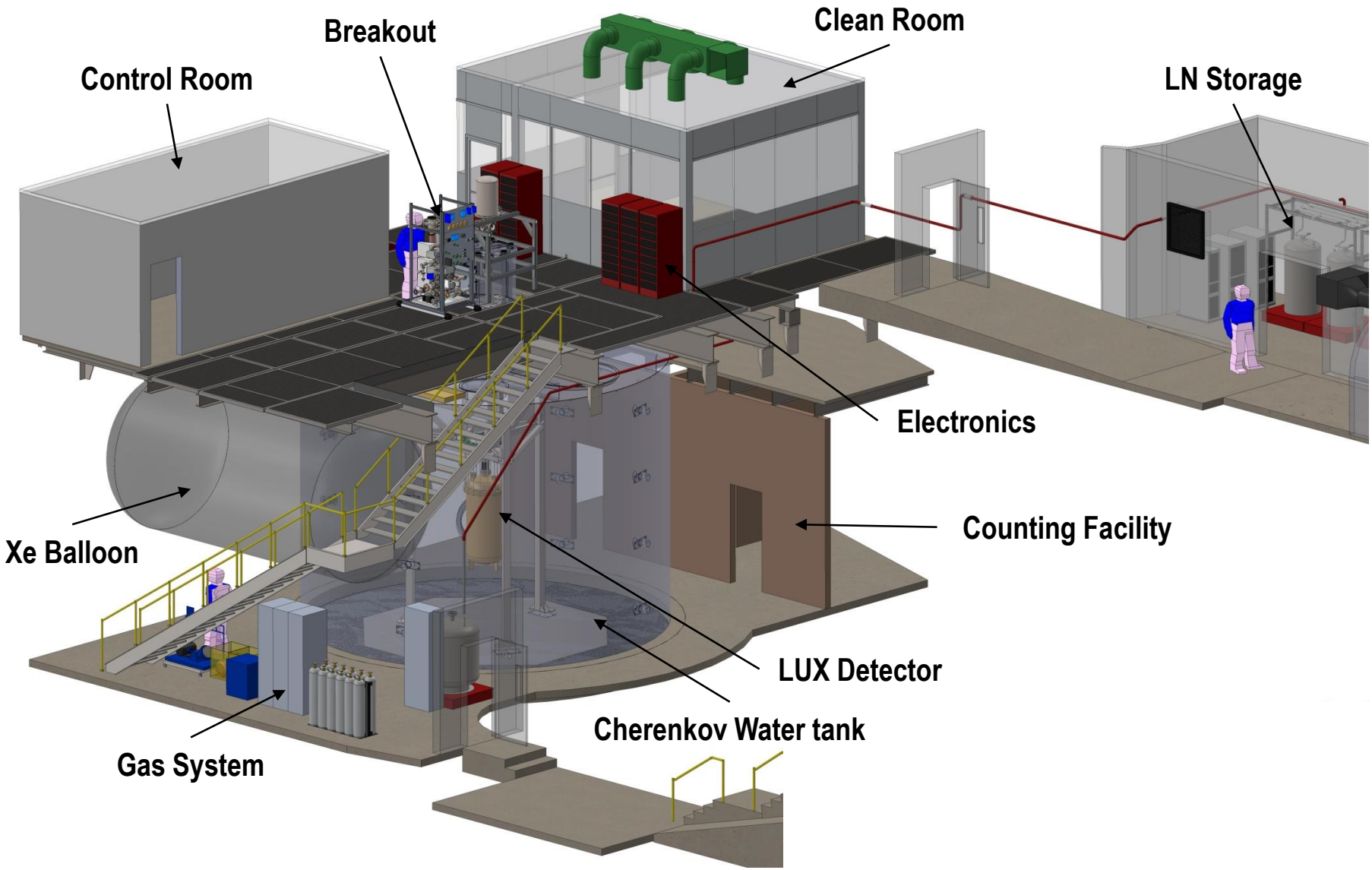
Former Homestake gold mine - refurbished for science only

Muon flux at 4850' level reduced by 10^7

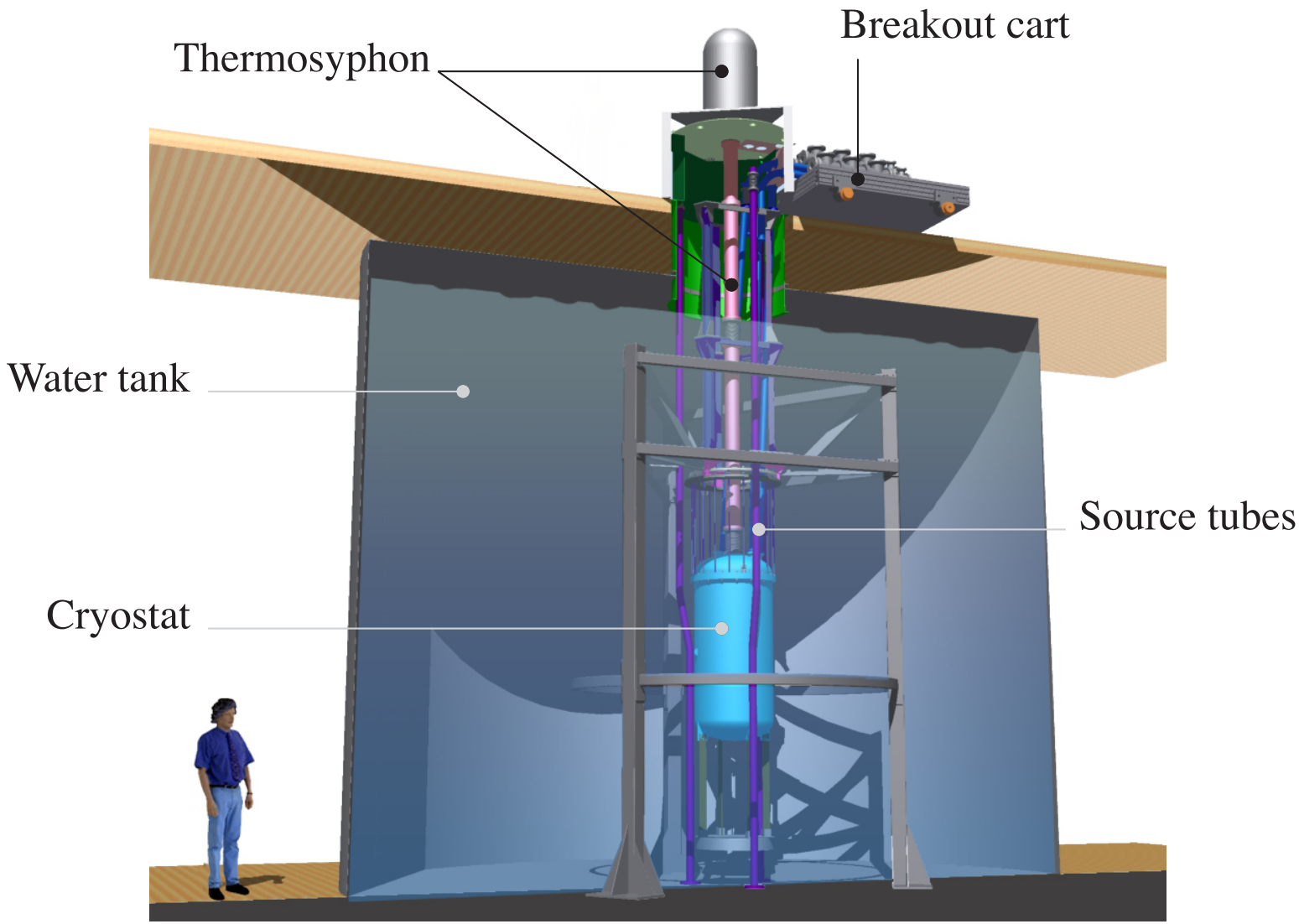
$55.2\ m^{-2}s^{-1} \rightarrow 1\times10^{-5}\ m^{-2}s^{-1}$



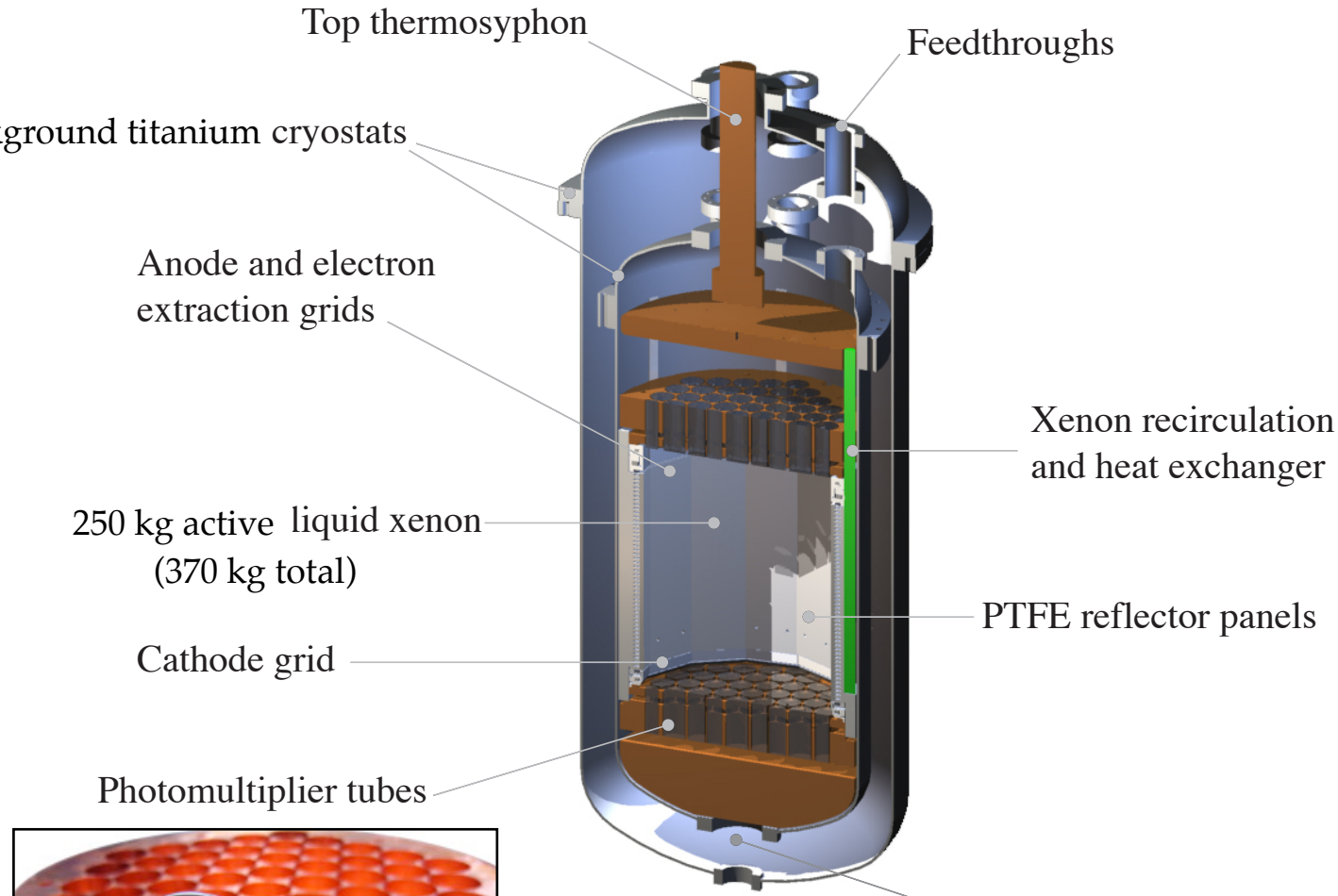
LUX in the Davis Cavern

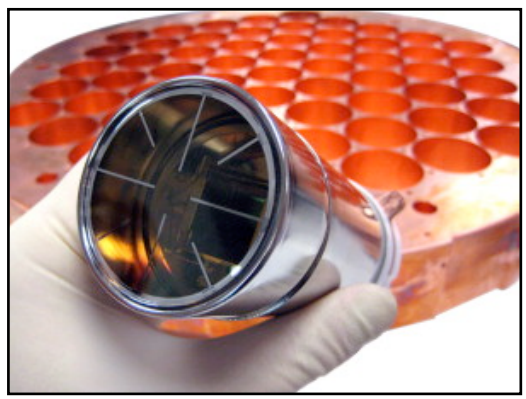


An ultra low background environment



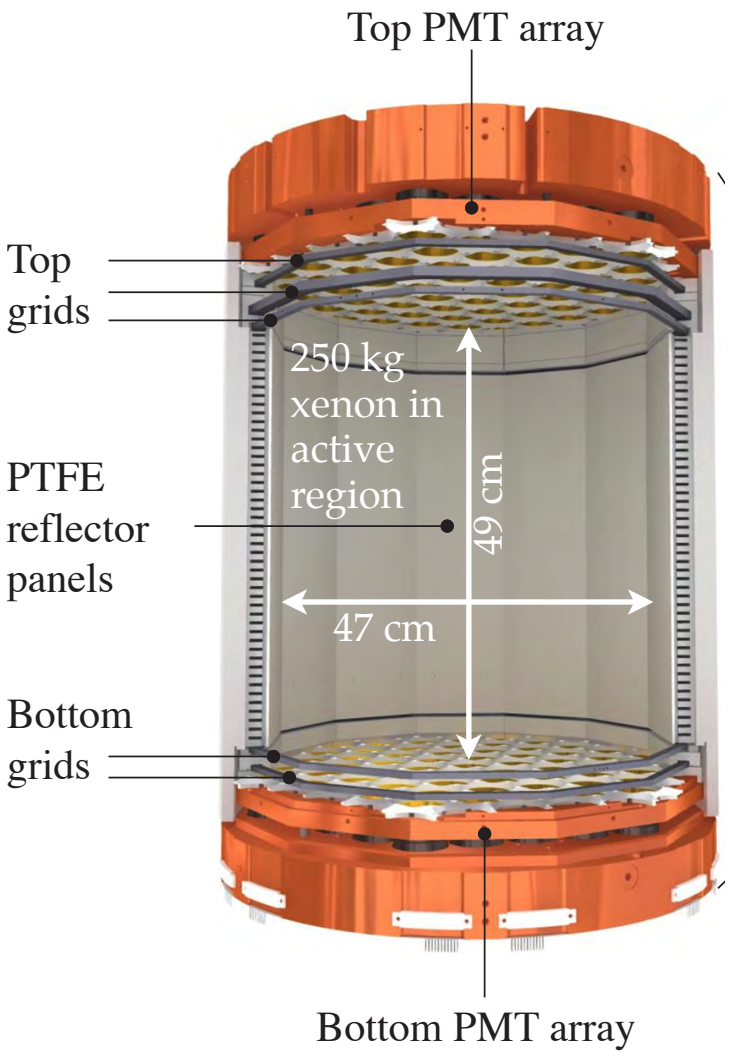
The LUX cryostat

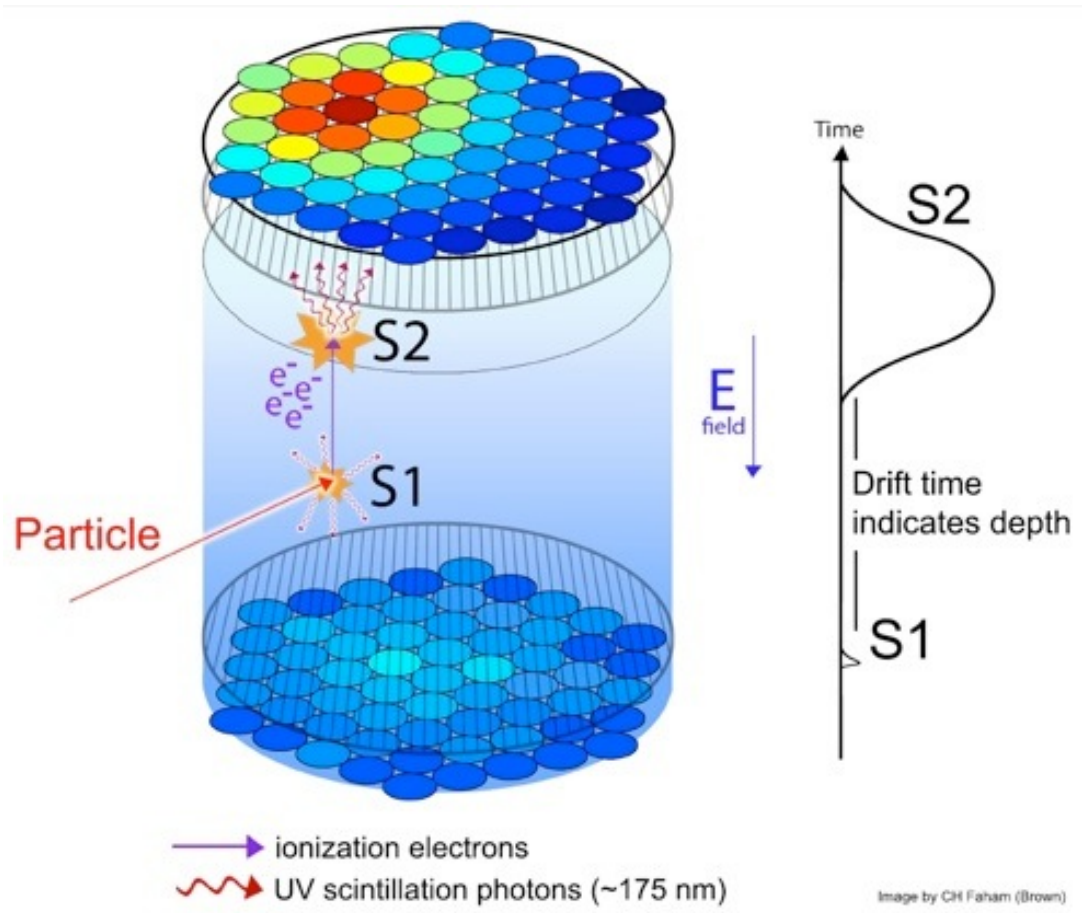




Hamamatsu R8778 PMTs (61 top, 61 bottom)

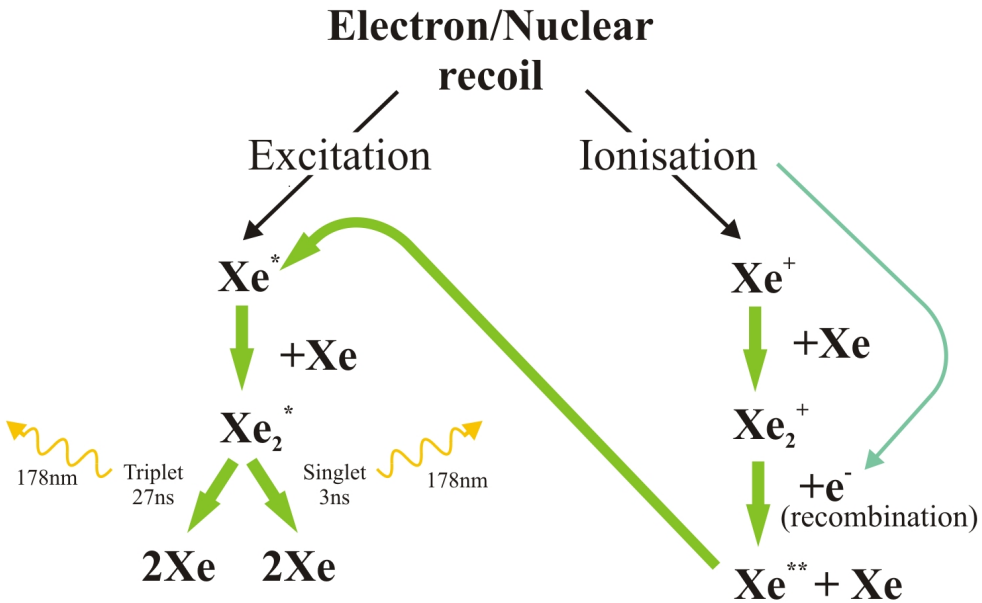
The active region of LUX

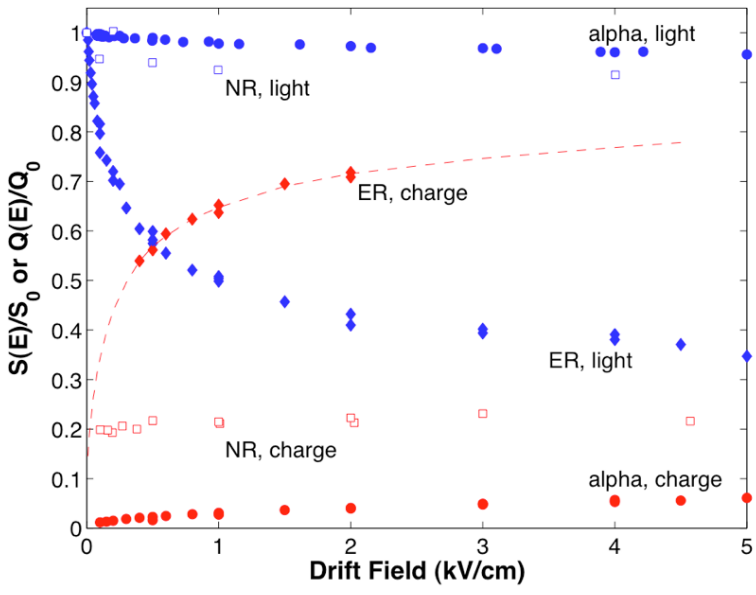




Principle of detection: dual phase xenon TPC

- Primary scintillation (S1) and secondary ionization from electroluminescence (S2)
- 3D position (mm resolution)
- S2/S1 particle discrimination
- Recoil energy correlated to S1 and S2
- Powerful Xe self-shielding



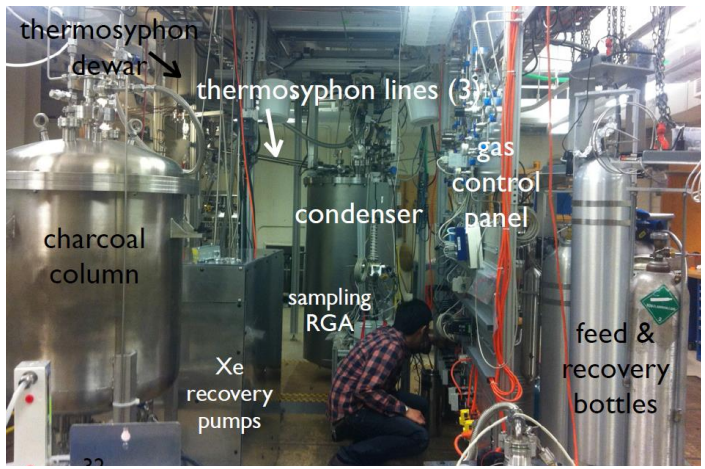


E. Aprile et al., Phys. Rev. Lett. **97**, 081302 (2006)

LUX supporting systems

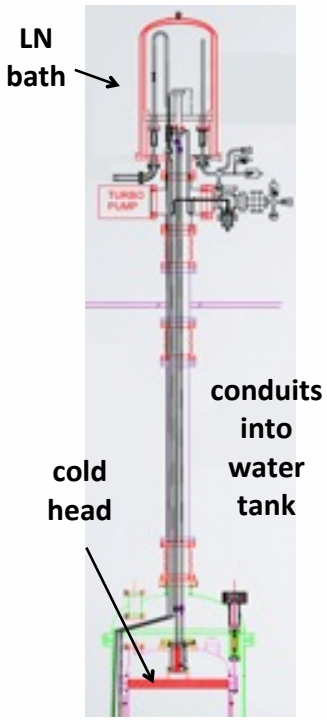
Circulation gas and sampling

Kr removal facility



130 ppb to 3.5 ppt!

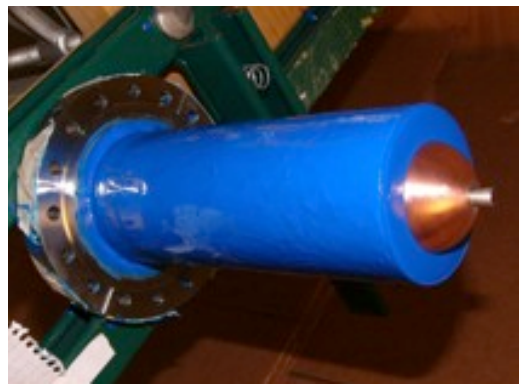
Thermosyphon



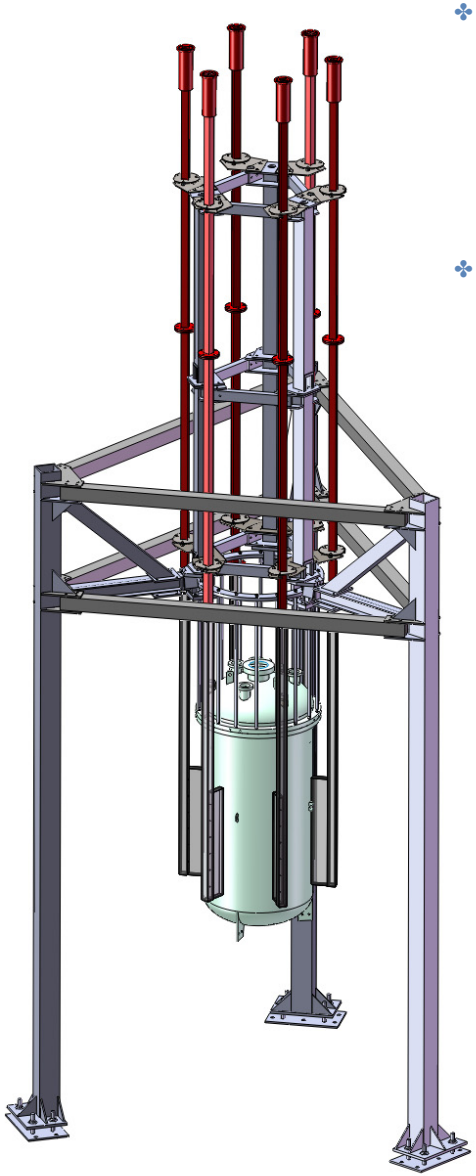
LUX Thermosyphon

Xe storage

Cathode HV feedthrough



Calibrating LUX



- External sources via source tubes:

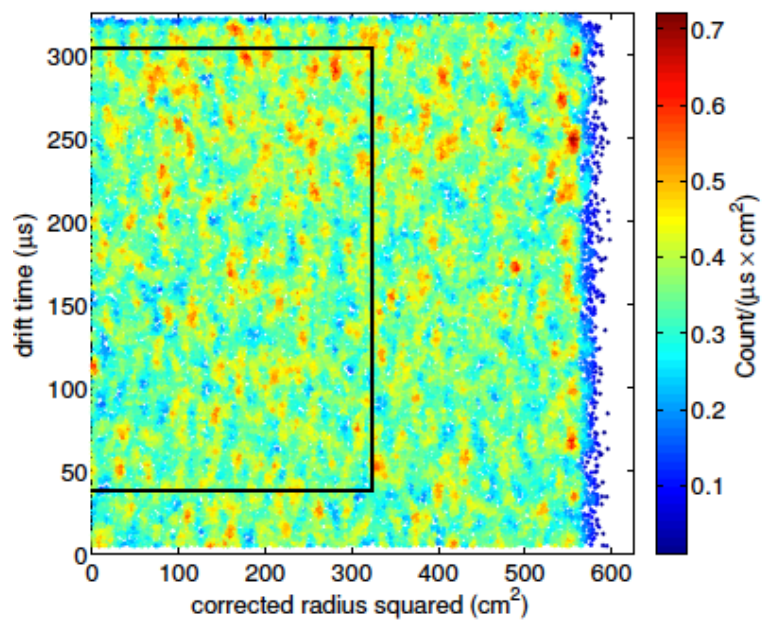
  WIMP-like

  - Americium-beryllium (AmBe) and ^{252}Cf: low energy neutrons
    → validating NR models and detector sims, NR efficiencies

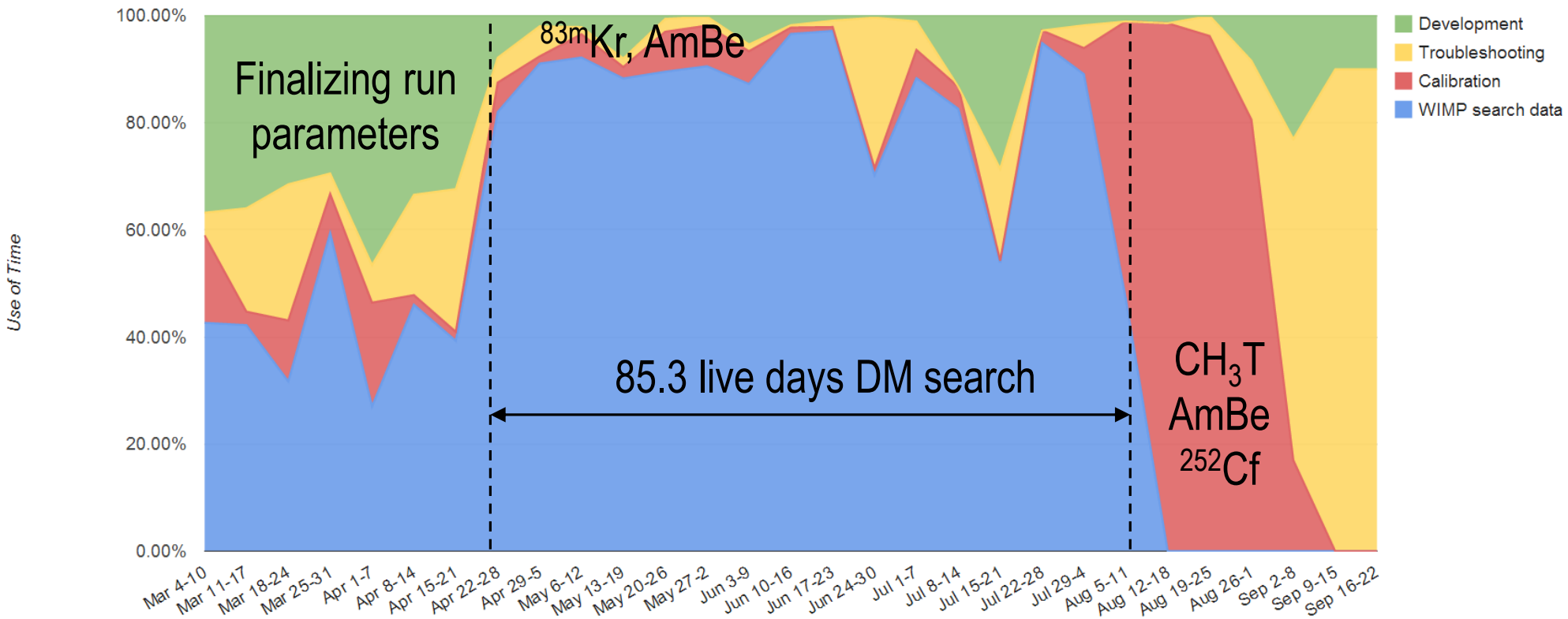
- Xenon self-shielding → internal sources injected into circulation system:

  - ^{83m}Kr: half-life ~1.8 hours, 32.1 + 9.4 keV betas
    → weekly purity & xyz maps; drift length >130 cm

  - Tritiated methane (CH3T): low energy betas (end point 18 keV)
    High stats, uniform and high purity → ER band, ER acceptance

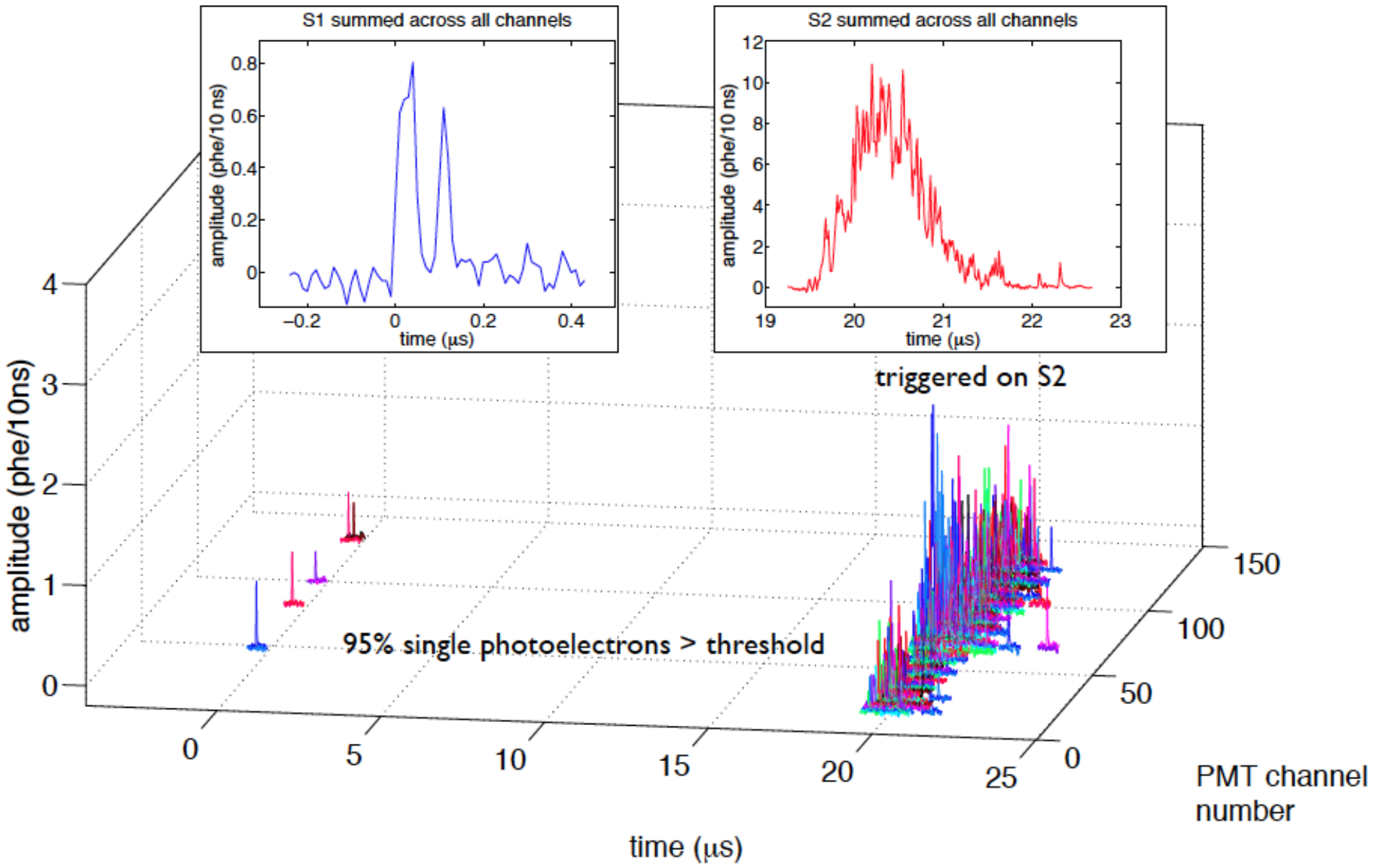


Run 3 data-taking



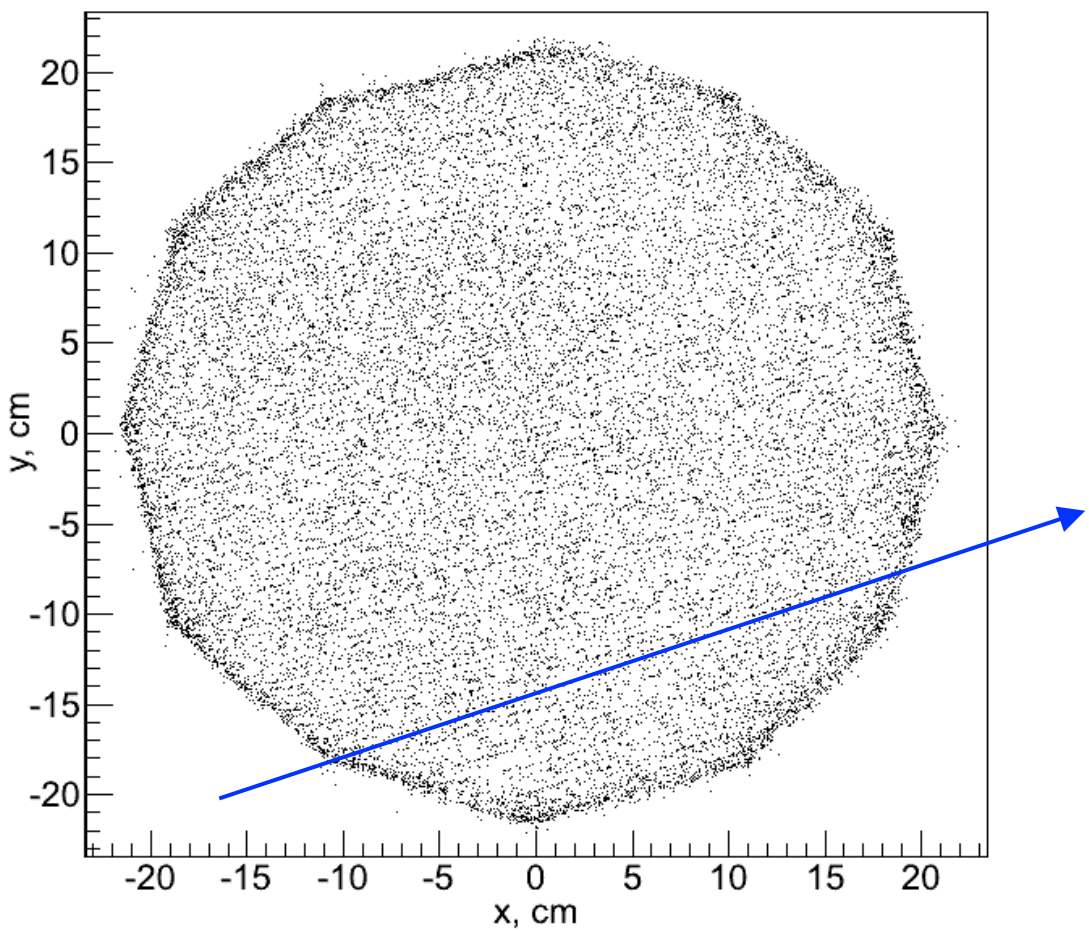
- LUX moves underground in July 2012
- Detector cool-down January 2013, Xe condensed mid-February 2013
- Kr and AmBe calibrations throughout, CH3T after WIMP search

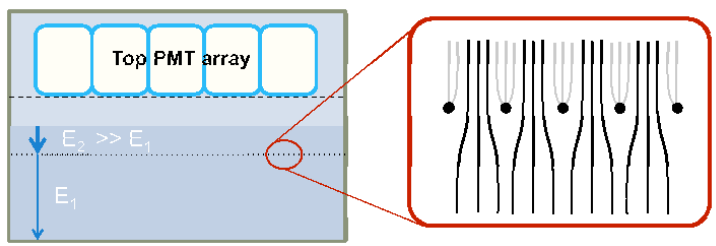
A LUX event - 1.5 keV electron recoil



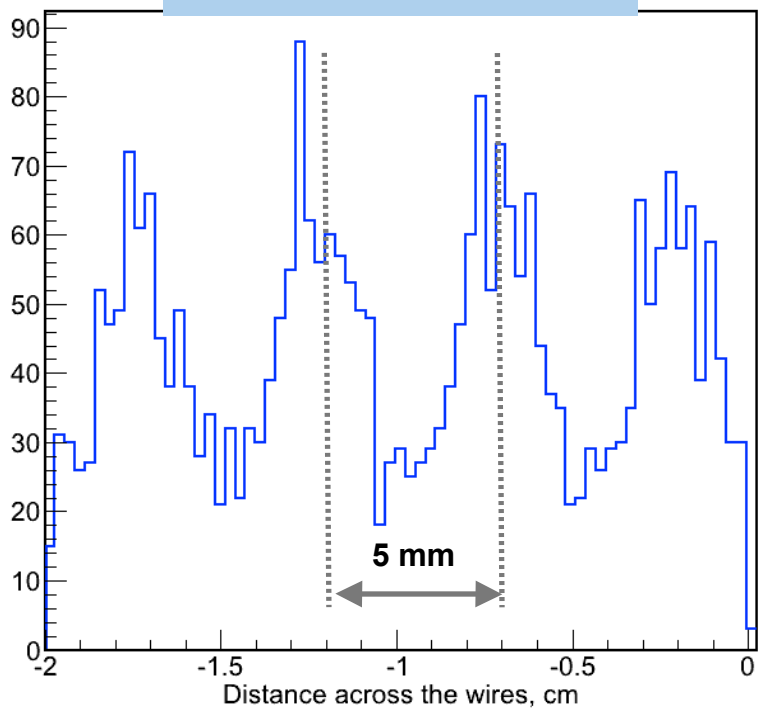
Position reconstruction

- Drift time (1.5 mm / μs) for Z-position,
- XY position fitting S2 hit pattern with LRFs from internal calibrations



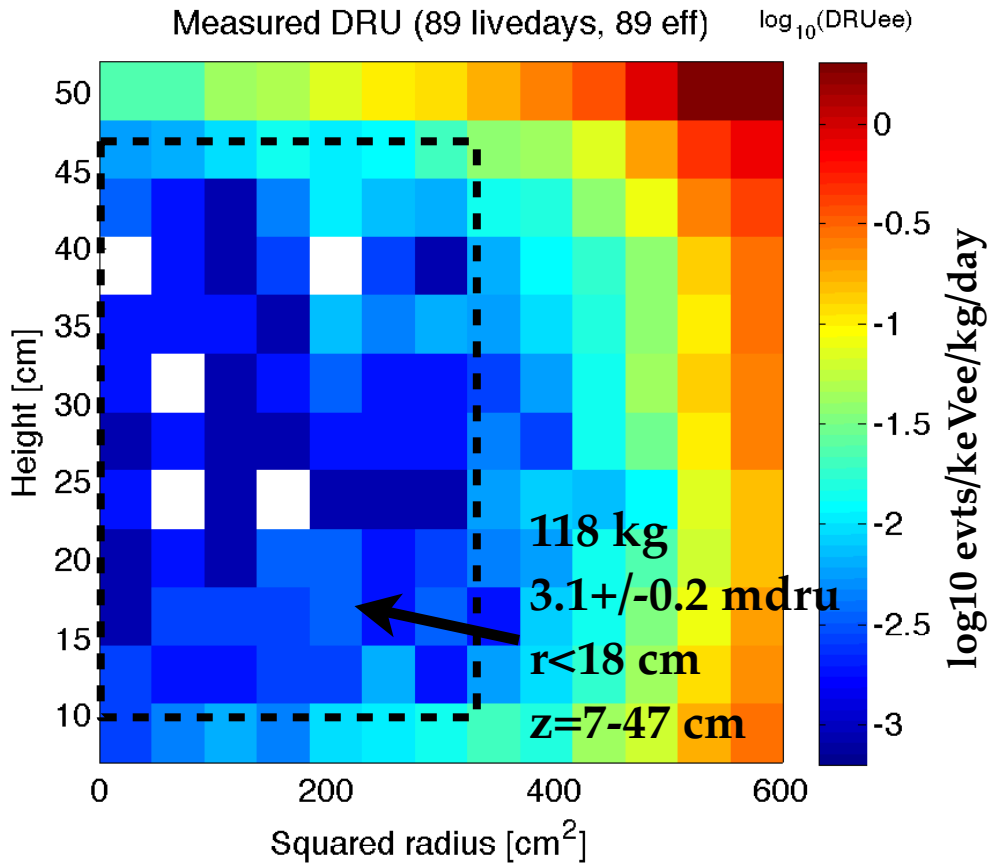


Projection along the wires



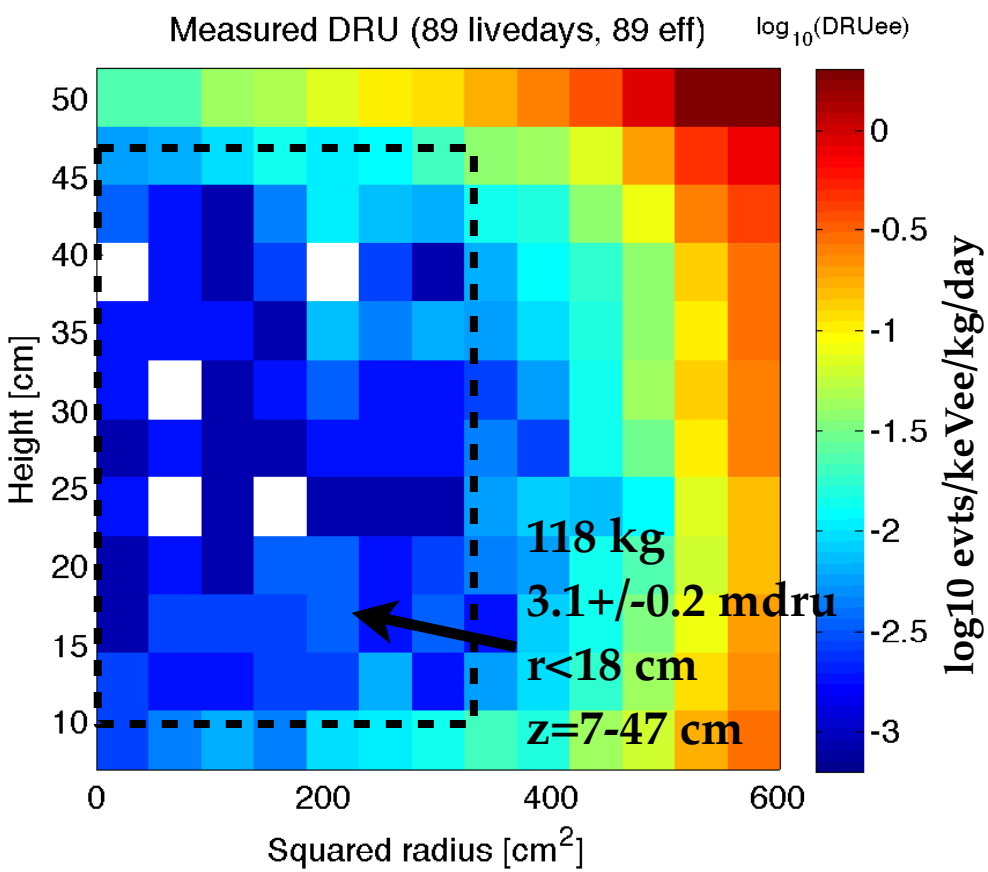
Backgrounds in LUX

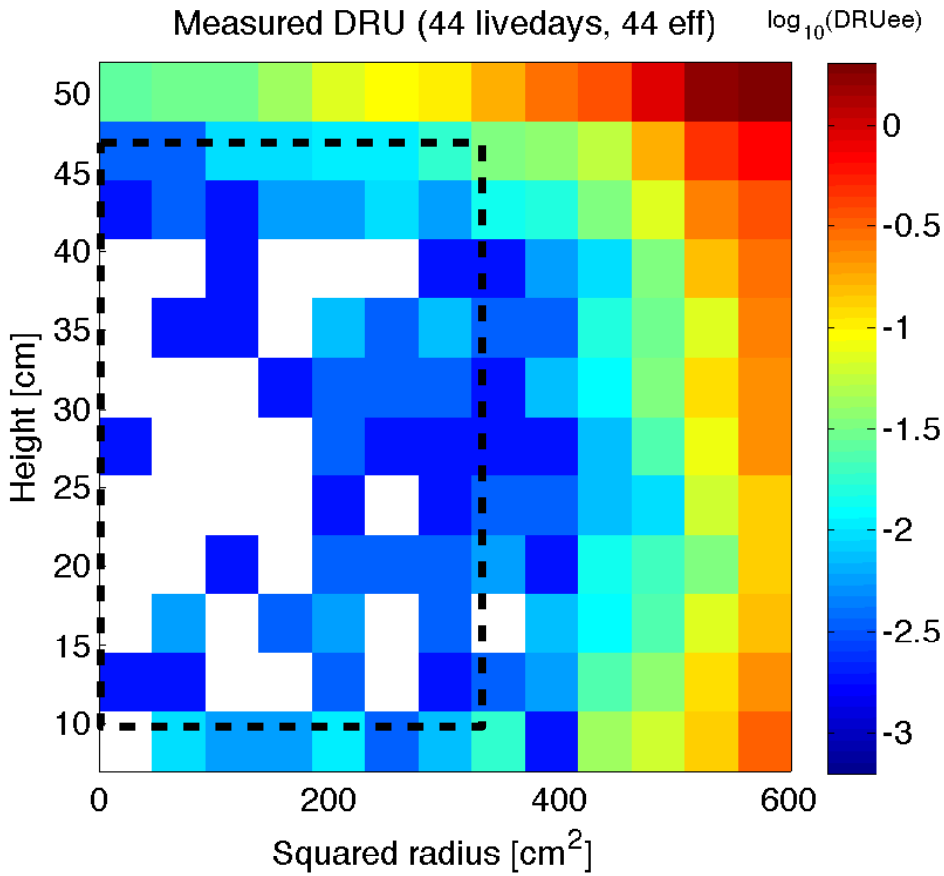
Source	Background rate, $mDRU_{ee}$
γ-rays	$1.8 \pm 0.2_{stat} \pm 0.3_{sys}$
^{127}Xe	$0.5 \pm 0.02_{stat} \pm 0.1_{sys}$
^{214}Pb	0.11–0.22 (90% C. L.)
^{85}Kr	$0.13 \pm 0.07_{sys}$
Total predicted	$2.6 \pm 0.2_{stat} \pm 0.4_{sys}$
Total observed	$3.1 \pm 0.2_{stat}$



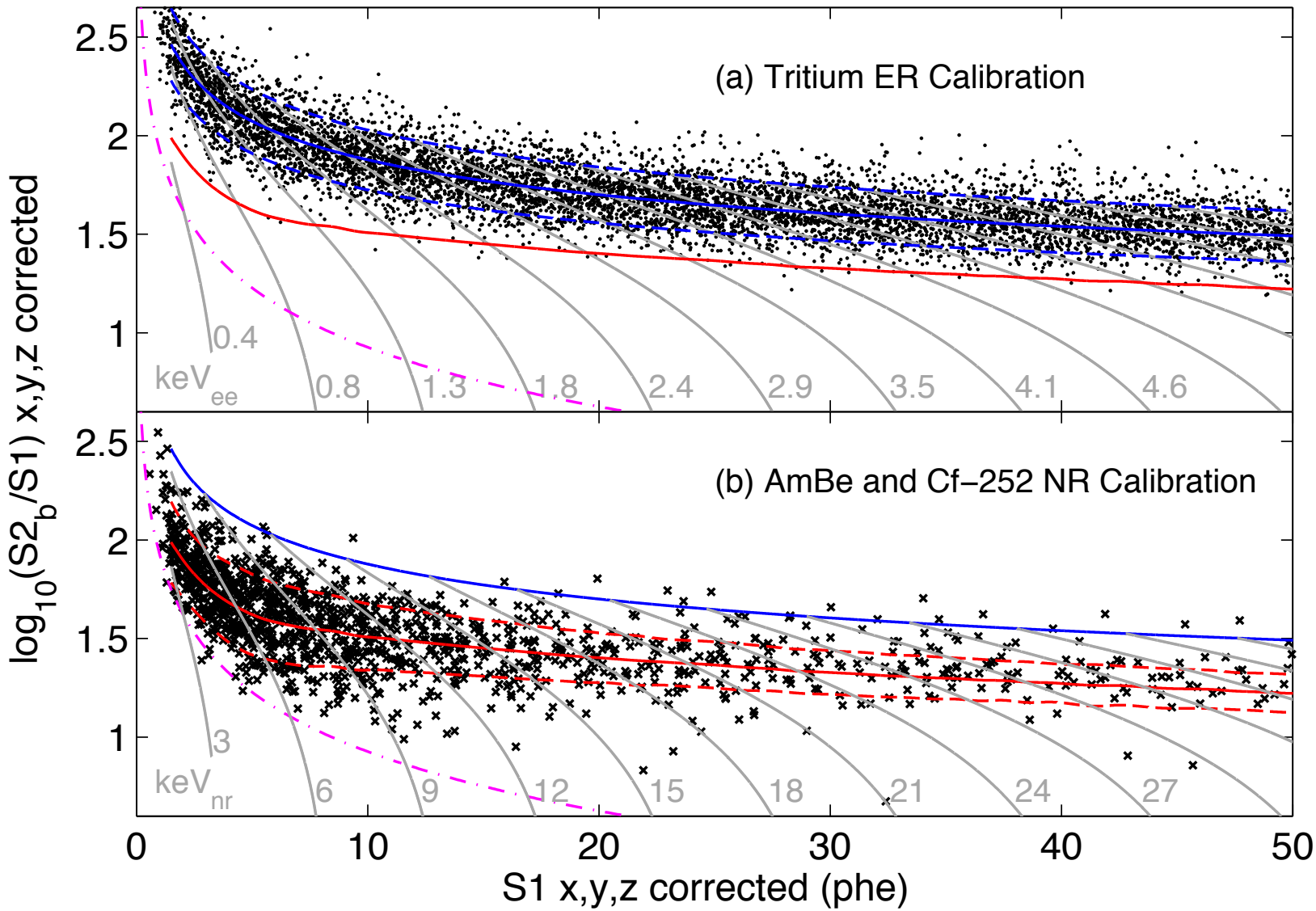
The most radioactively quiet place in the world!

…and still dropping!



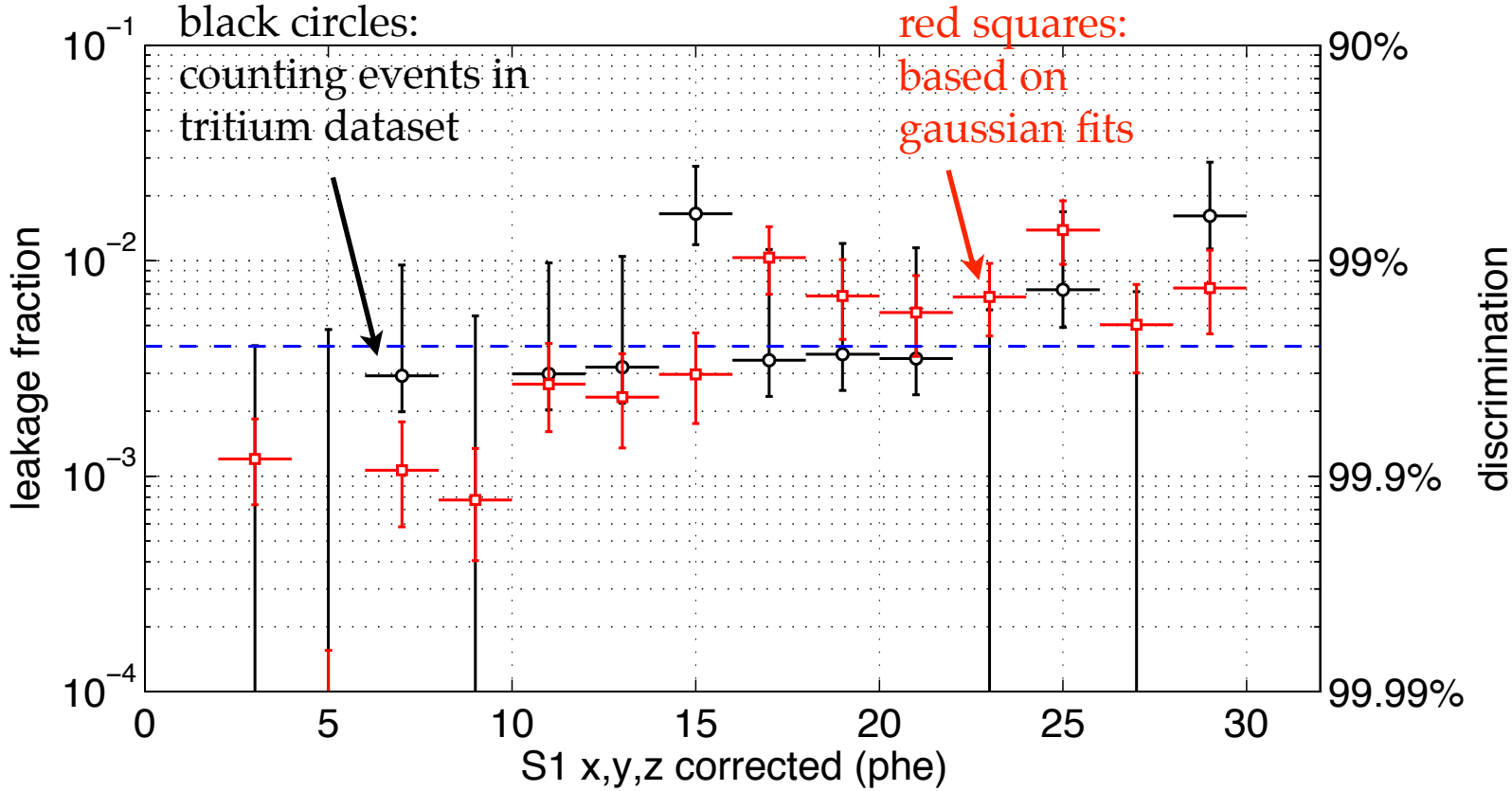


Calibrations



Discrimination

- For 50% NR acceptance at 181 V/cm average discrimination **99.6%**



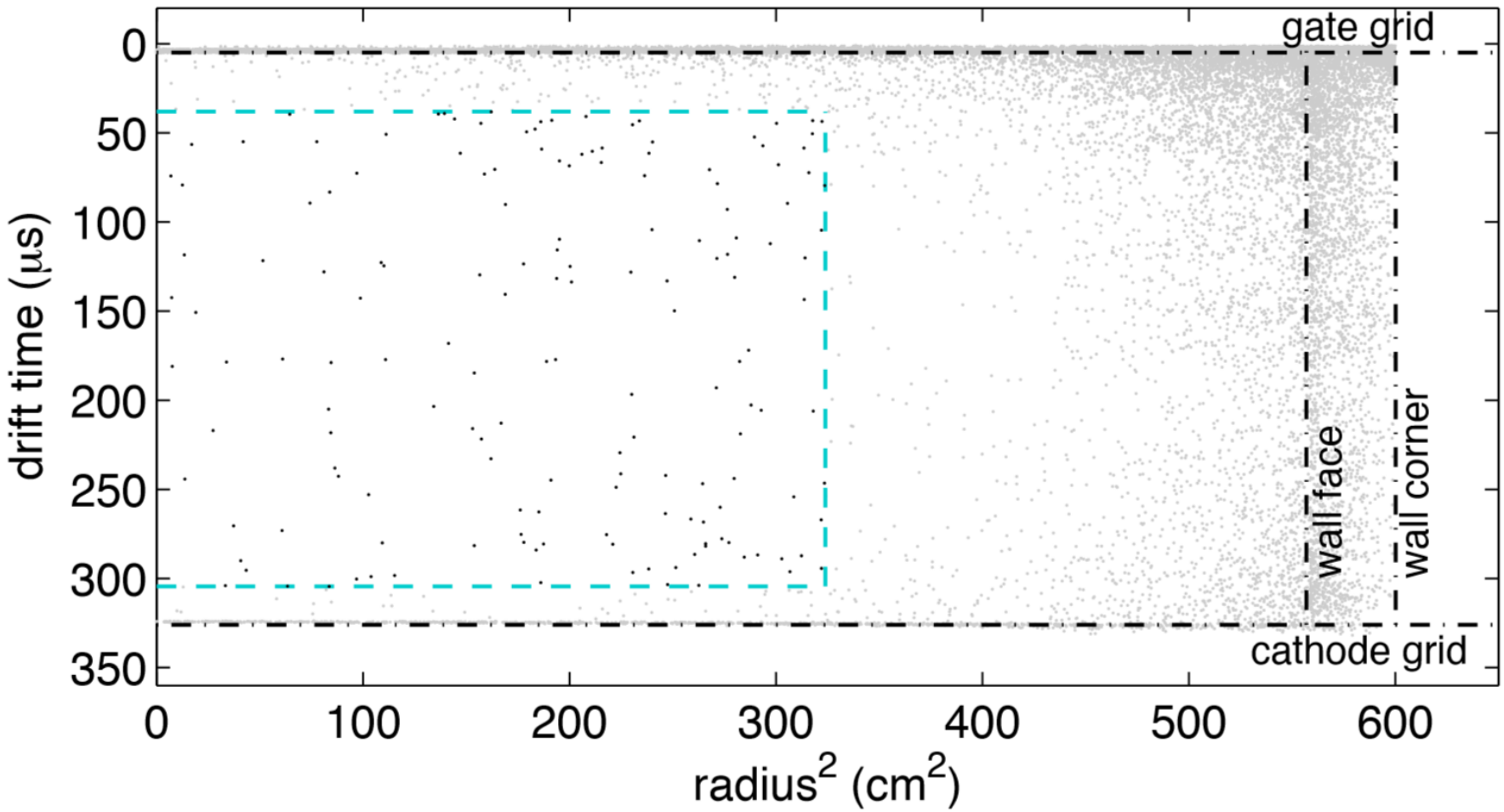
Run 3 event selection and cuts

Cut	Events Remaining
all triggers	83,673,413
detector stability	82,918,902
single scatter	6,585,686
S1 energy $(2 - 30$ phe$)$	26,824
S2 energy $(200 - 3300$ phe$)$	20,989
single electron background	19,796
fiducial volume	160

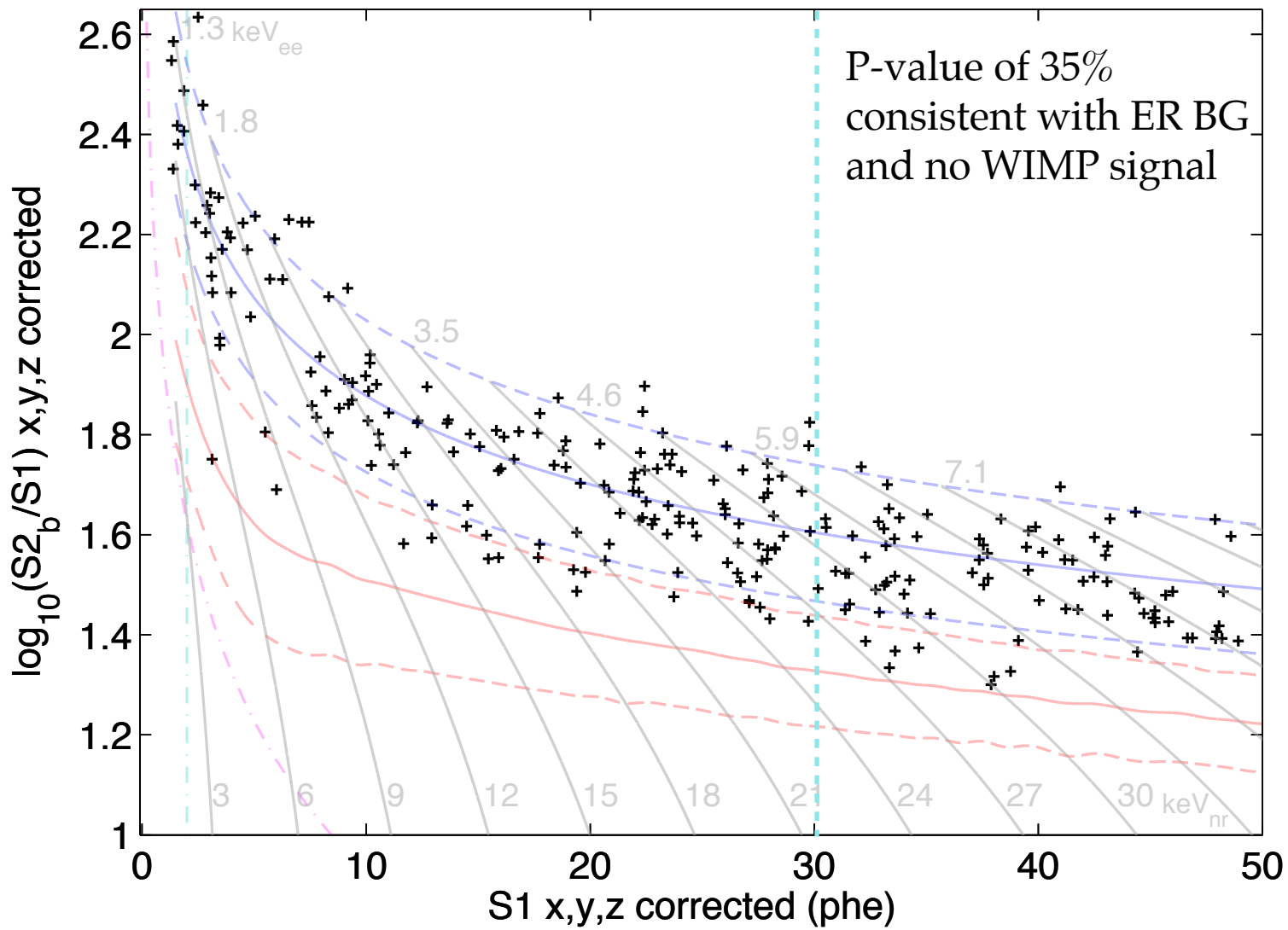
- 118 kg fiducial volume defined by:
  - Z cut: 38 < drift time < 305 μs (320 μs is max drift time)
  - Reconstructed radial position < 18 cm

LUX WIMP search data, 85.3 live-days, 118 kg FV

- After all selection cuts:
  160 candidate events in fiducial (r < 18 cm and 7 cm < z < 47 cm)



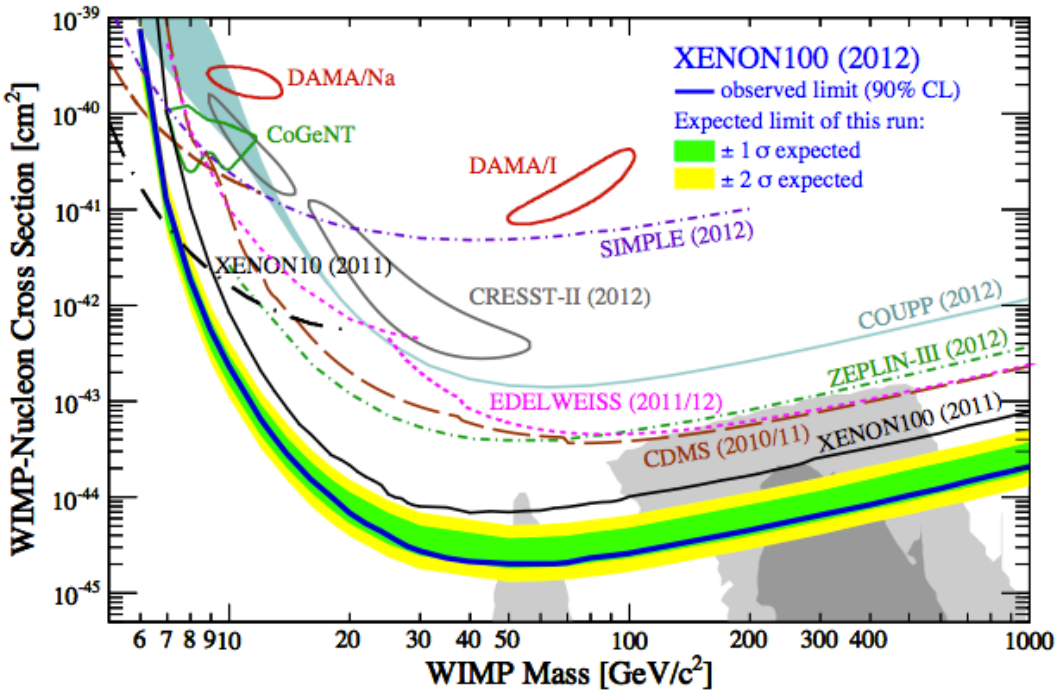
LUX WIMP search data, 85.3 live-days, 118 kg FV

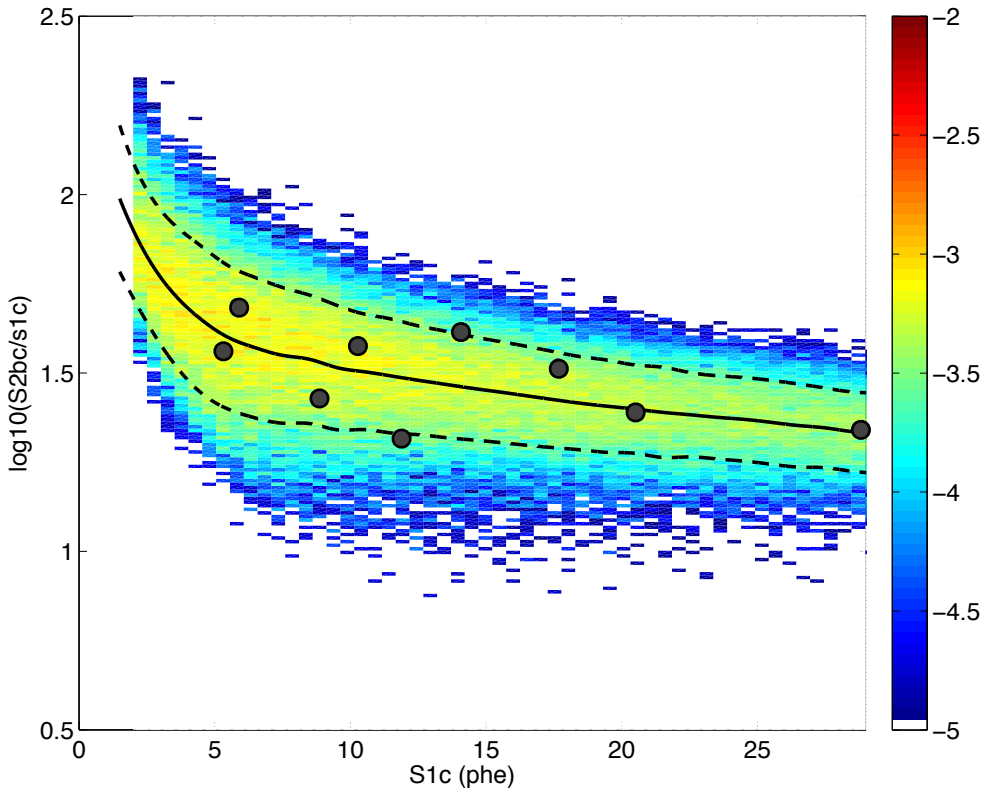


Simulated response for hypothetical WIMP signals

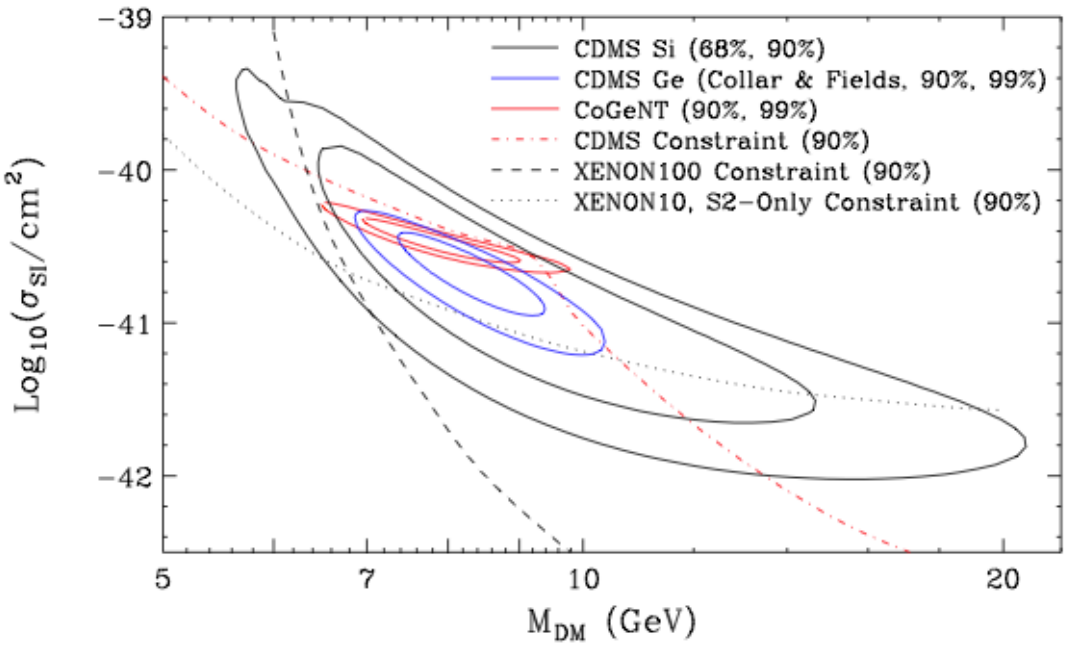
For 1000 GeV WIMP @ 1.9 $\times 10^{-44}$ cm^2, XENON100 90% CL:

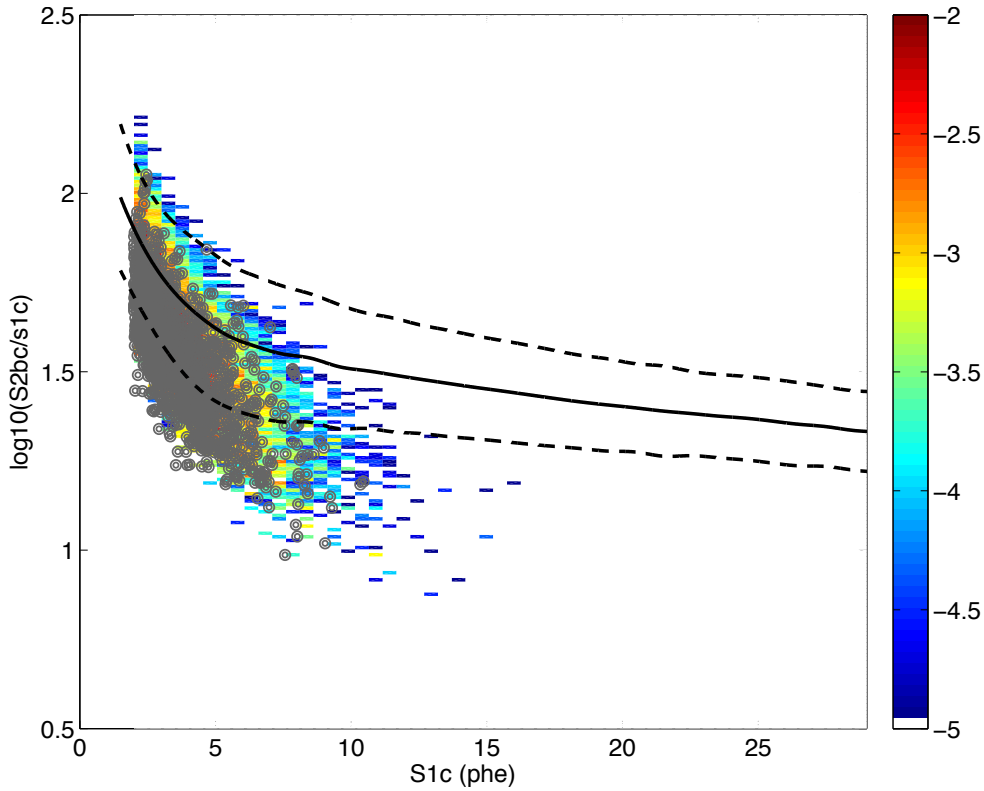
→ **expect 9 WIMPs in LUX search**





Simulated response for hypothetical WIMP signals

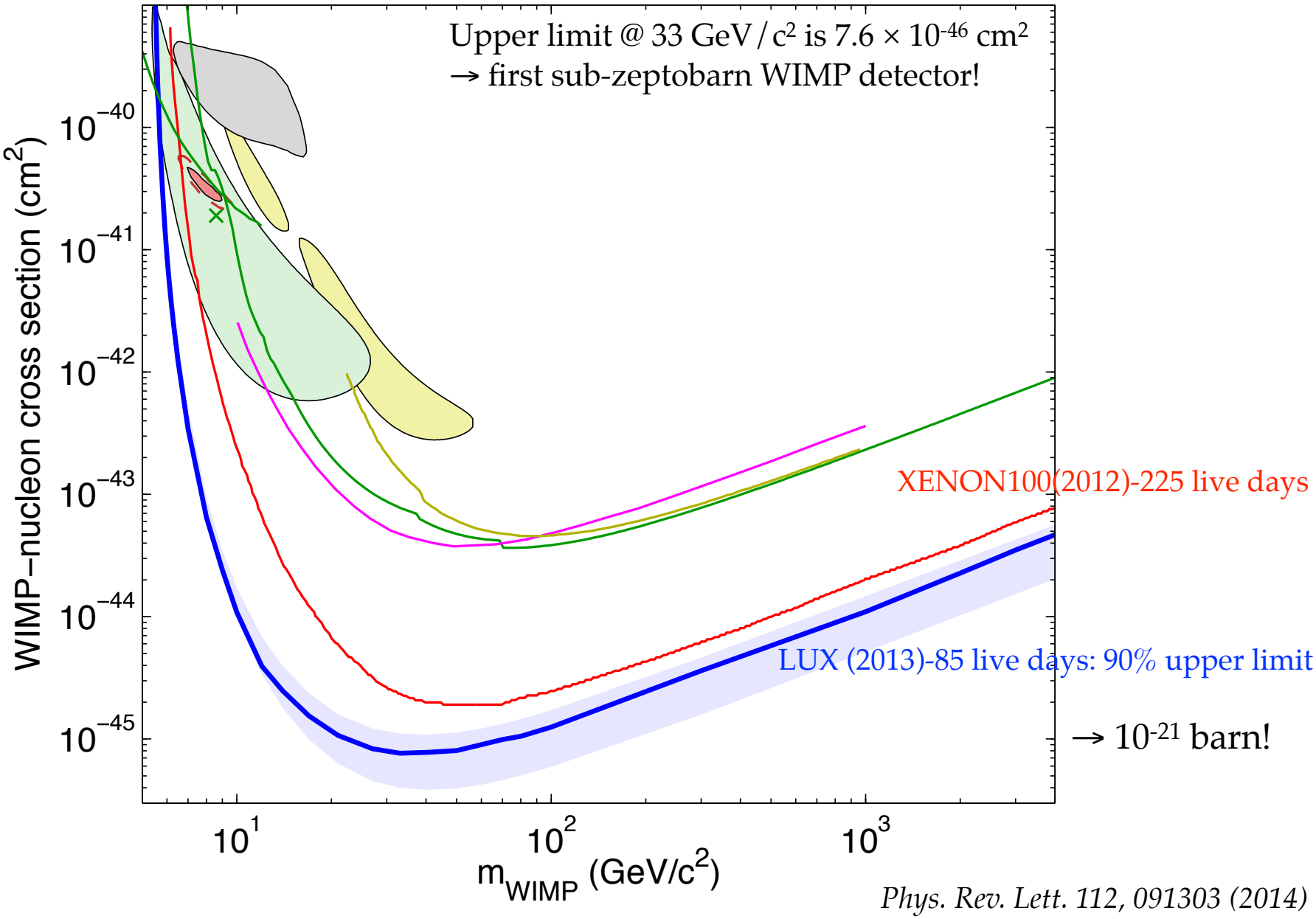




For 8.6 GeV WIMP @ 2.0 $\times 10^{-41}$ cm^2,
CDMS II Si (2012) 90% CL ….

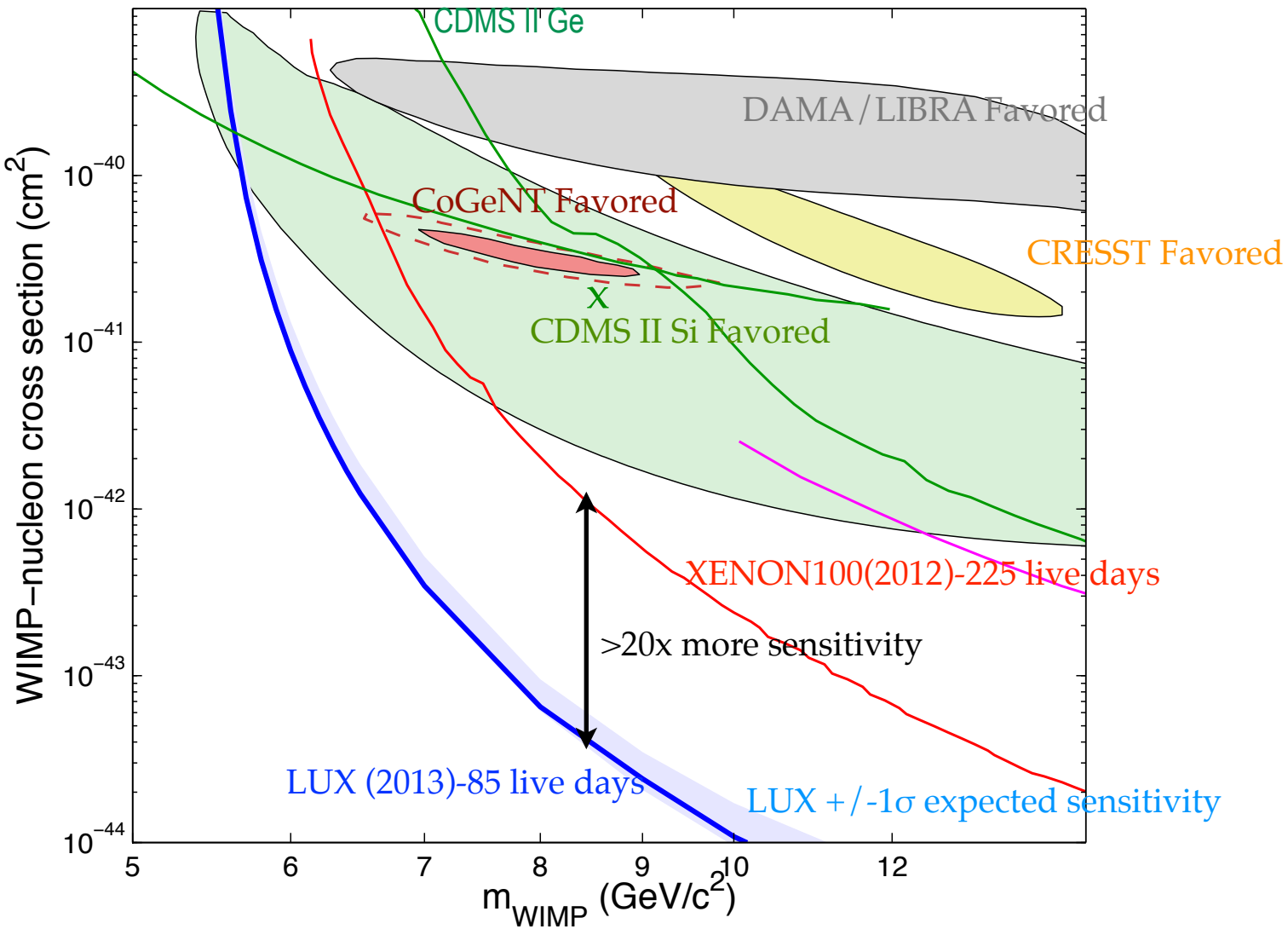
→ **expect 1550 WIMPs in LUX search**

Spin-independent sensitivity



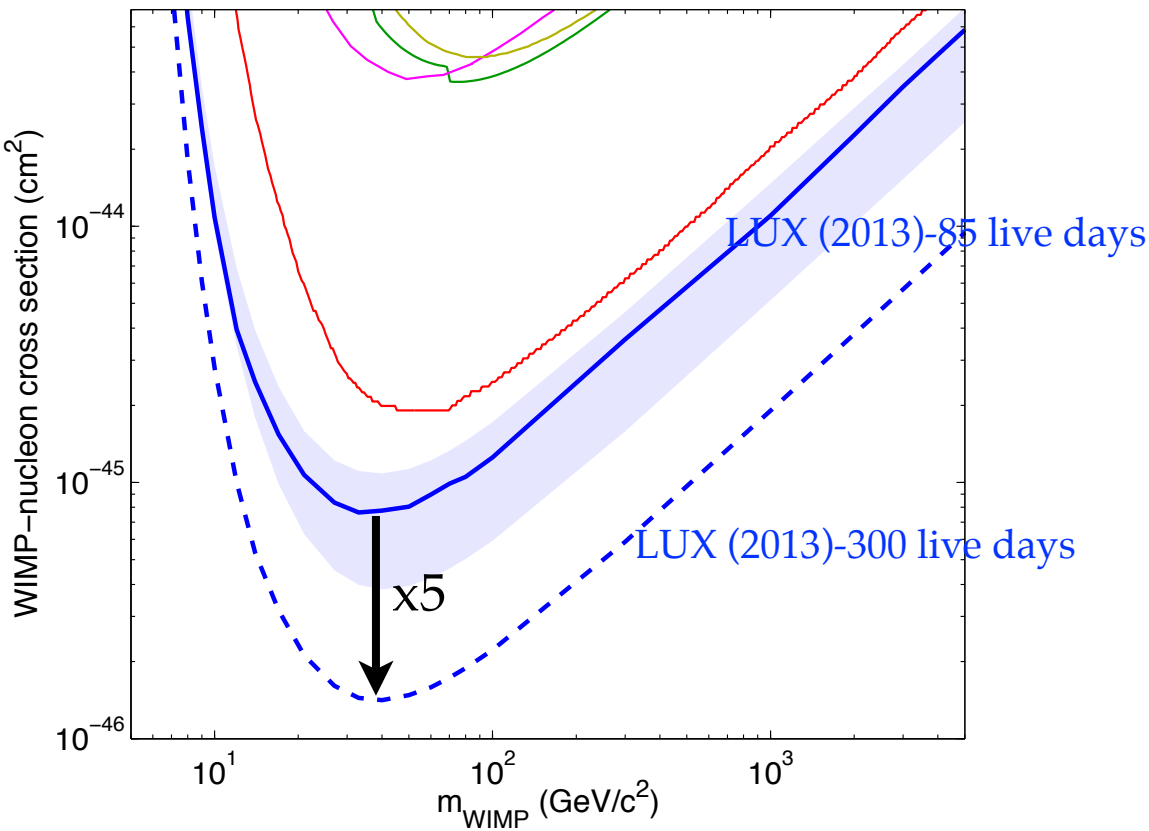
Phys. Rev. Lett. 112, 091303 (2014)

Low-mass WIMPs excluded



Phys. Rev. Lett. 112, 091303 (2014)

What's next: LUX 300 day run



- 300 day run planned for 2014/2015
- Cosmogenic cool-down plus potential for further improvements (calibration, analysis, …)
- Still not background limited and expect factor of ~5 improvement in sensitivity → discovery possible!

Onwards and downwards

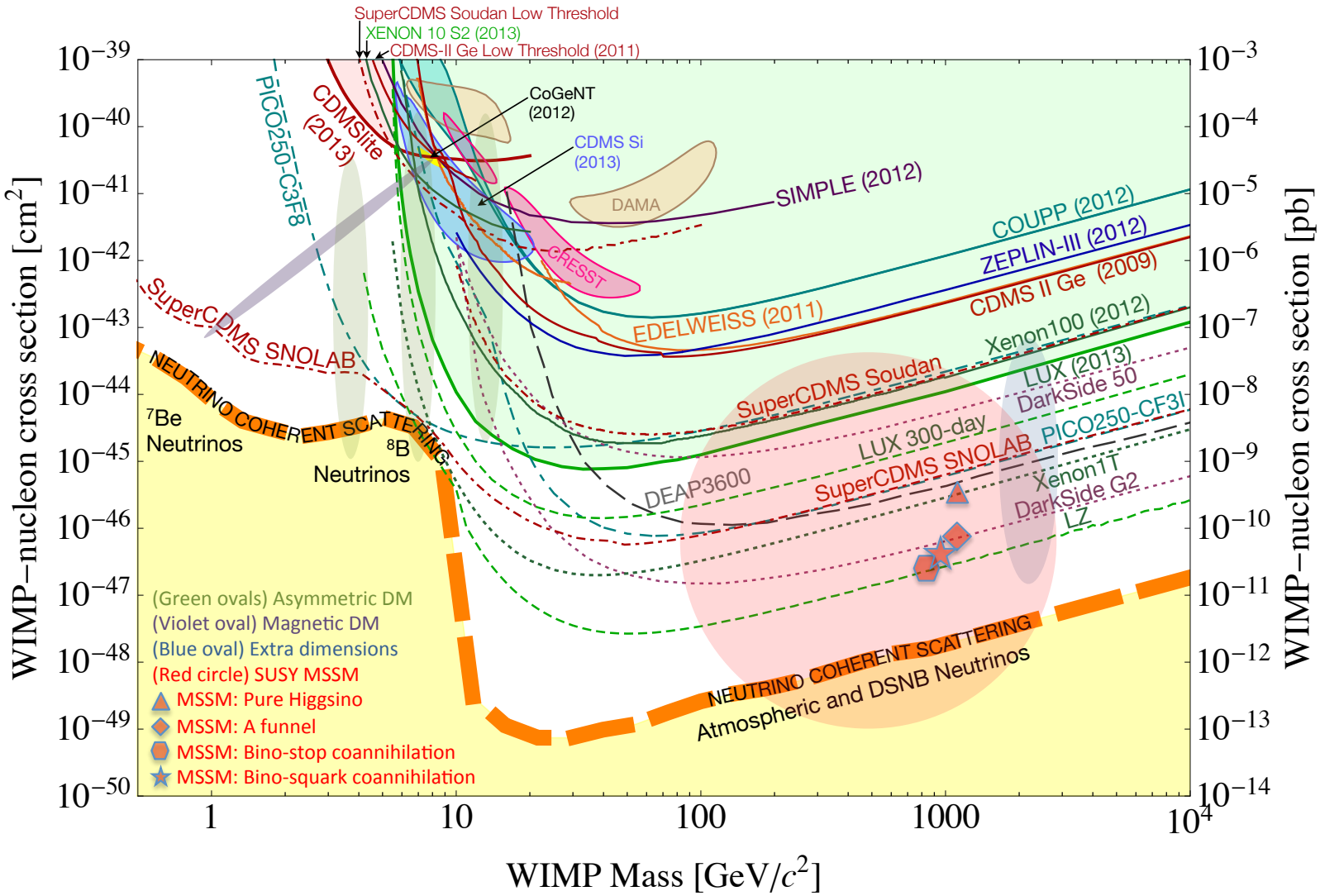
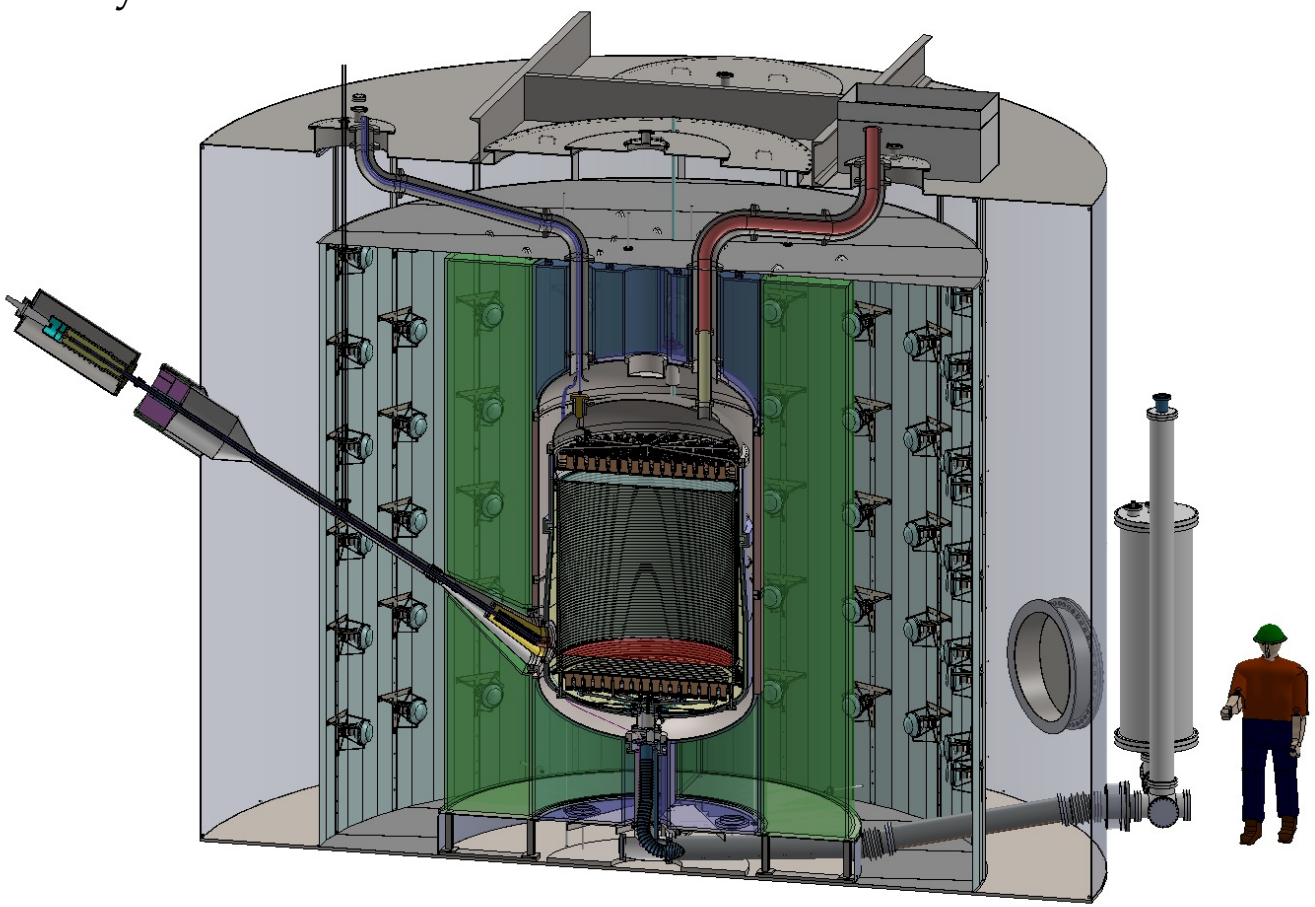


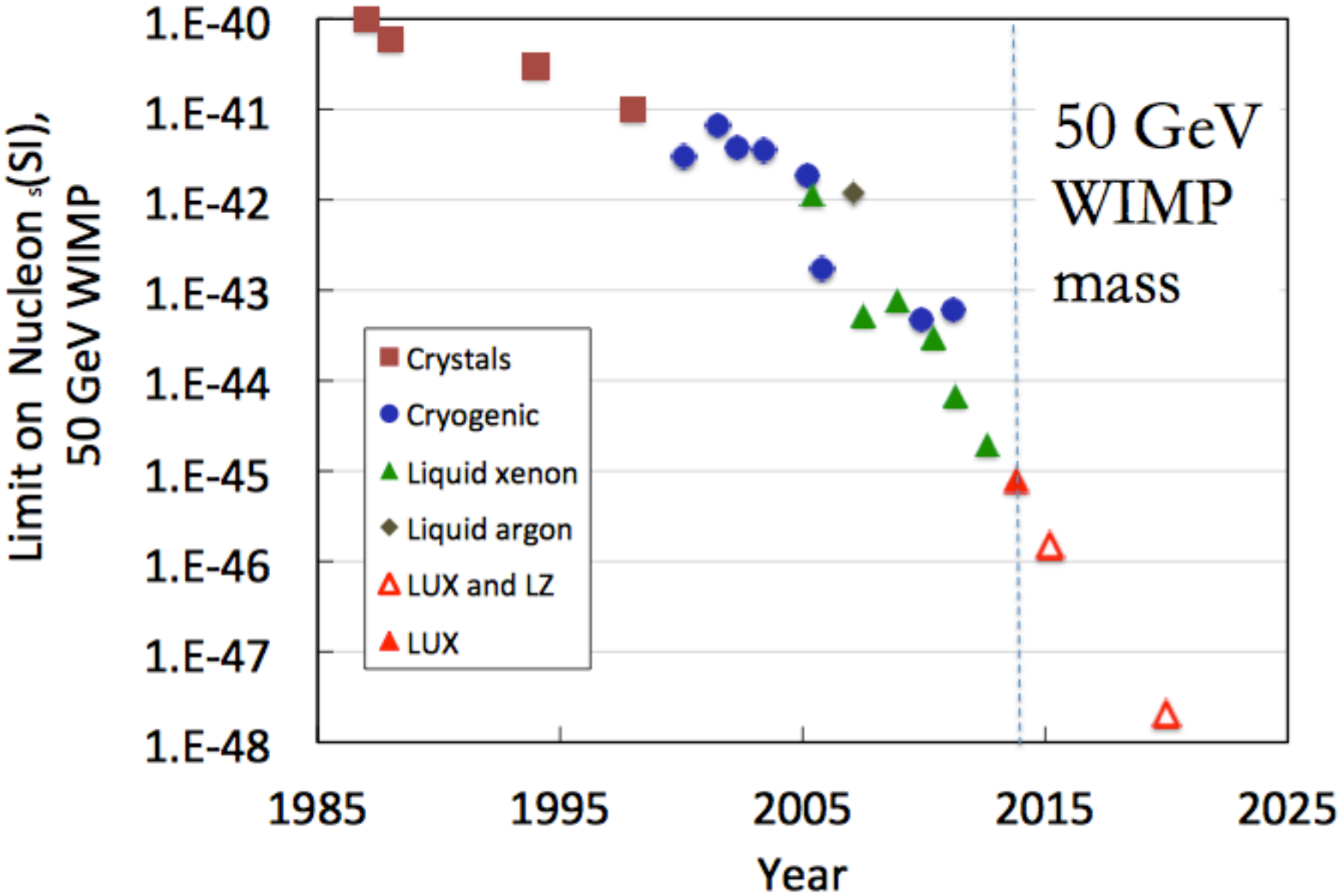
Fig. from SNOMASS CF1 WIMP Dark Matter Detection summary arXiV:1310.8327

Longer term: LUX-ZEPLIN (LZ)

- 50 times LUX fiducial mass, active scintillator veto, Xe purity at sub ppt level
- Selected by US agencies with SuperCDMS and ADMX-II as 'G2' experiments
- UK responsible for several key areas (cryostat, TPC, background), contributing to many more



LZ Projections



Summary

- With 85.3 live-days LUX set world's best limit on spin-independent scattering:
  - 90% UL 7.6×10^{-46} cm^2 @ 33 GeV/c^2 → first sub-zeptobarn WIMP detector
  - Low-mass WIMPs fully excluded by LUX
- LUX at the frontier of dark matter direct detection - exciting times ahead with the 300 day run, WIMP discovery possible!
- LZ successor will approach irreducible background limit for direct detection experiments

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THANKS FOR LISTENING

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Why The LUX Results Matter To Dark Matter - And To WIMPs

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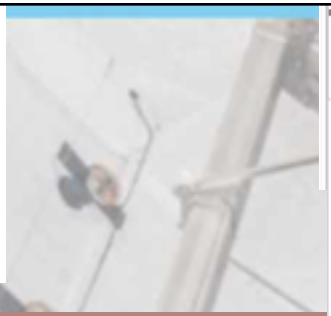

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Dark matter

Absence of evidence, or evidence of absence?

Physicists are learning more about what dark matter isn't. That will help them fin what it is

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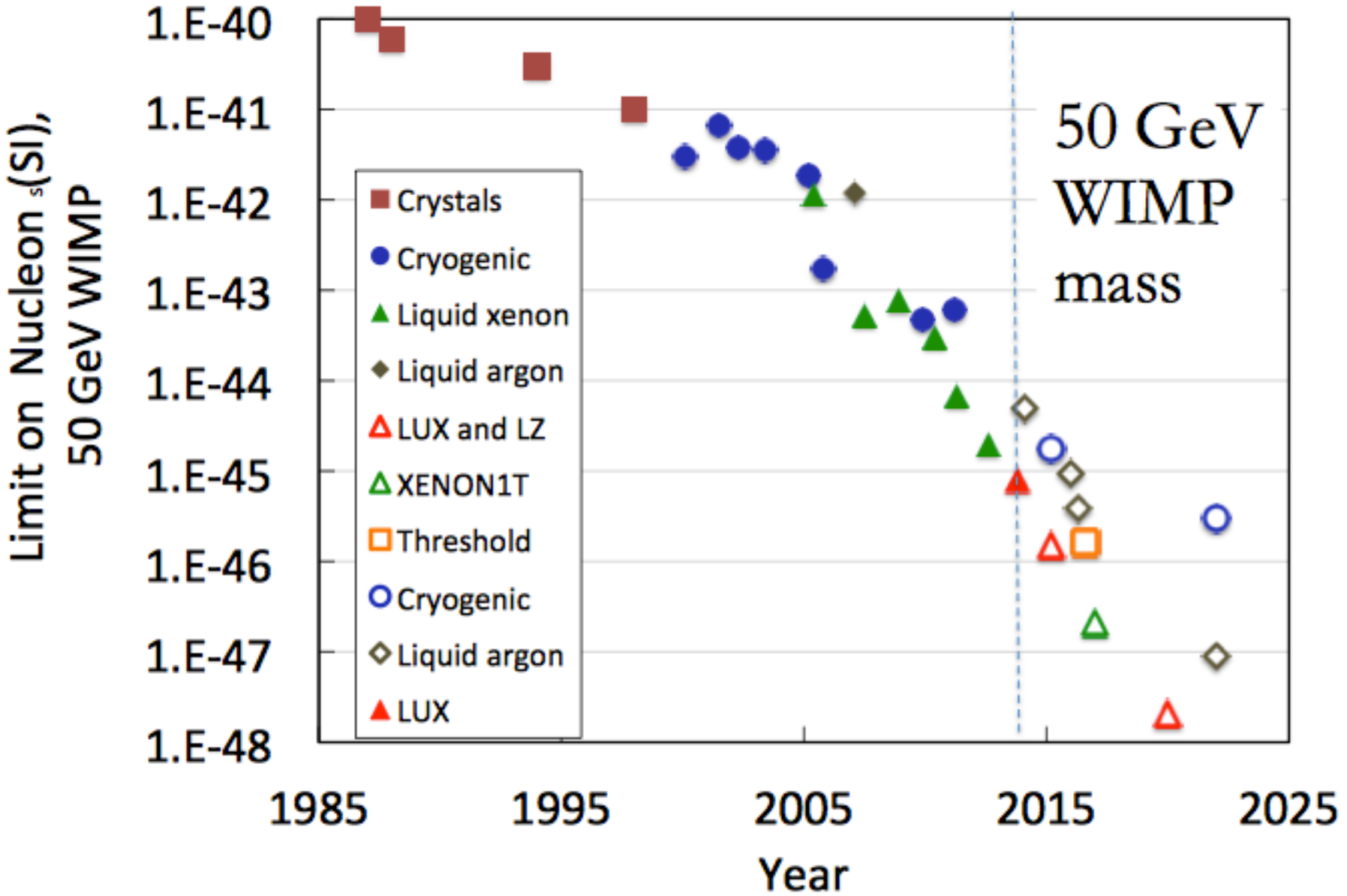
No sign of dark matter in u

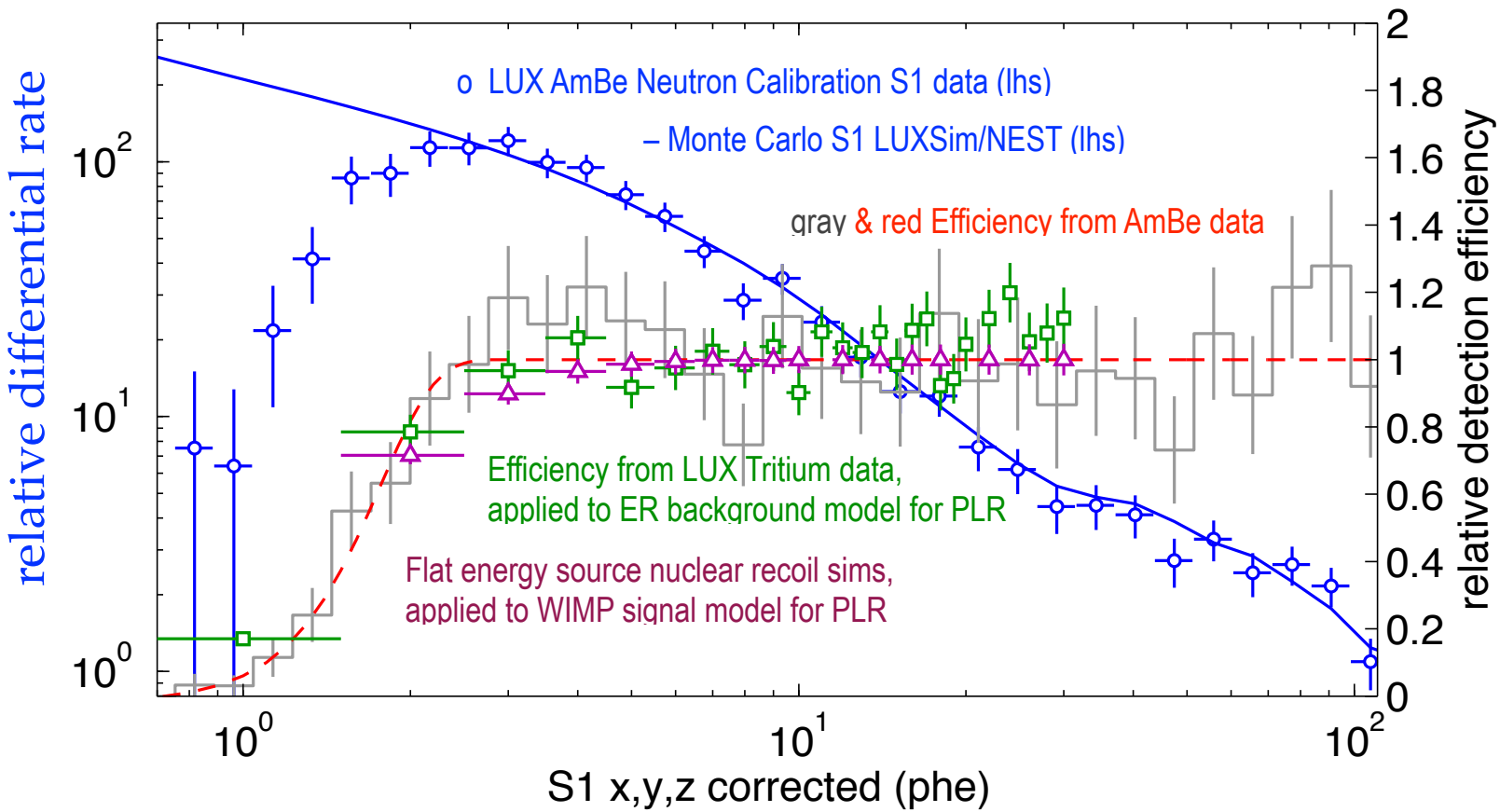
Backup Slides

LZ and all ‘G2’ Projections



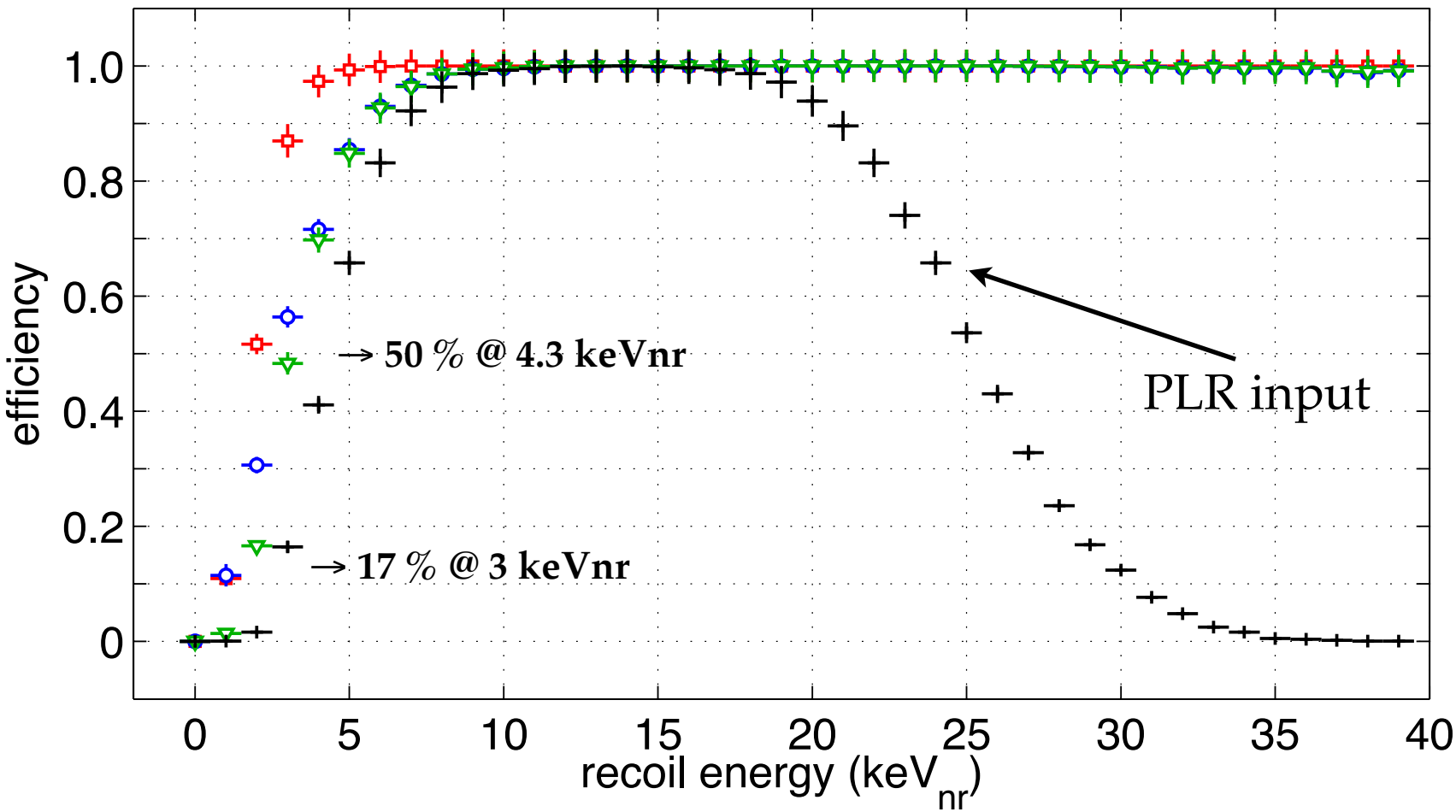
S1 efficiency

- Independent measures using AmBe, tritium, LED calibrations and full MC simulation of NR events (includes analysis cuts)

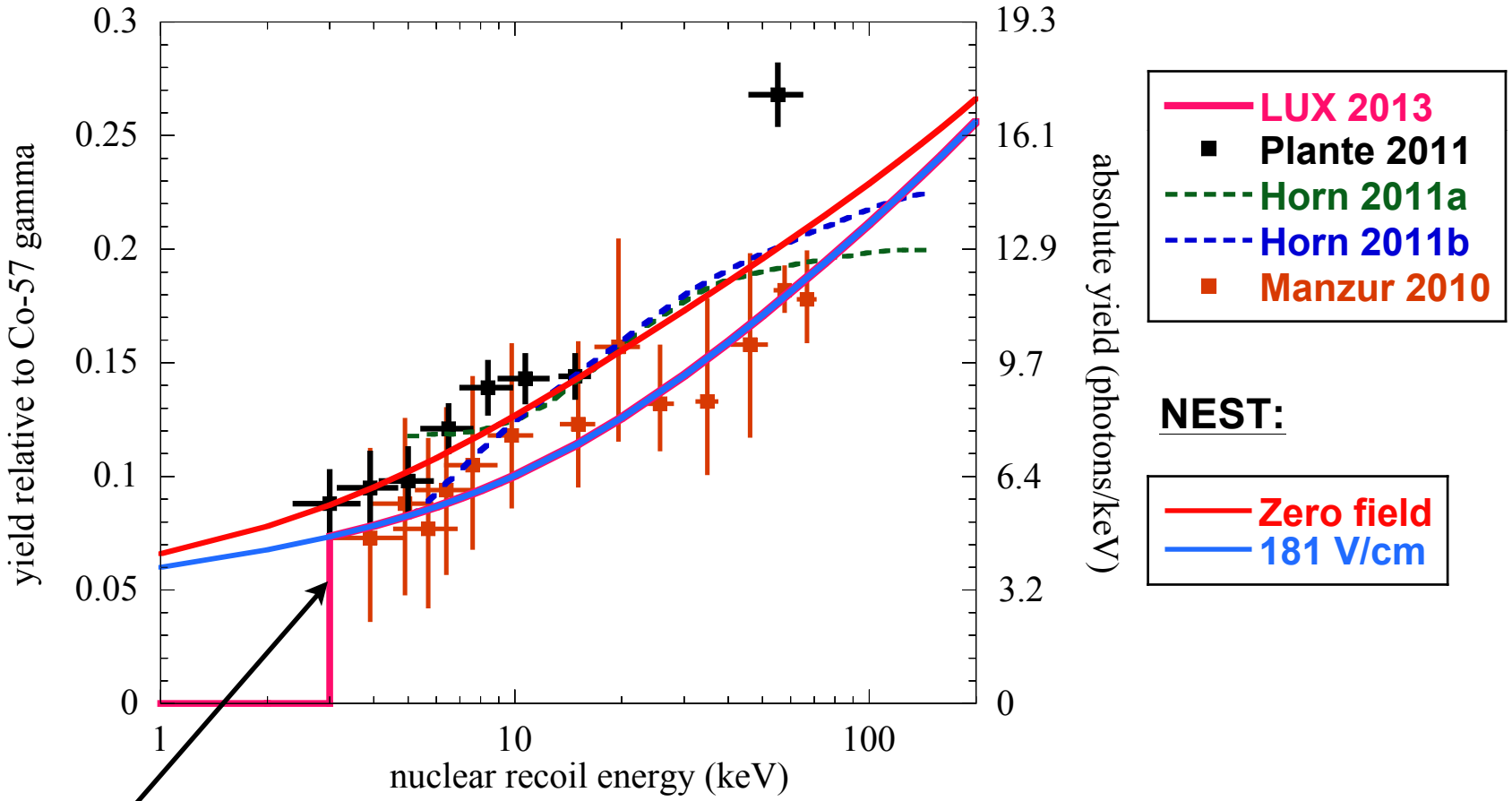


NR acceptance

- S2–only
- S1–only
- S1, S2 combined, before threshold cuts
- S1, S2 combined, after threshold cuts



Light and charge yields



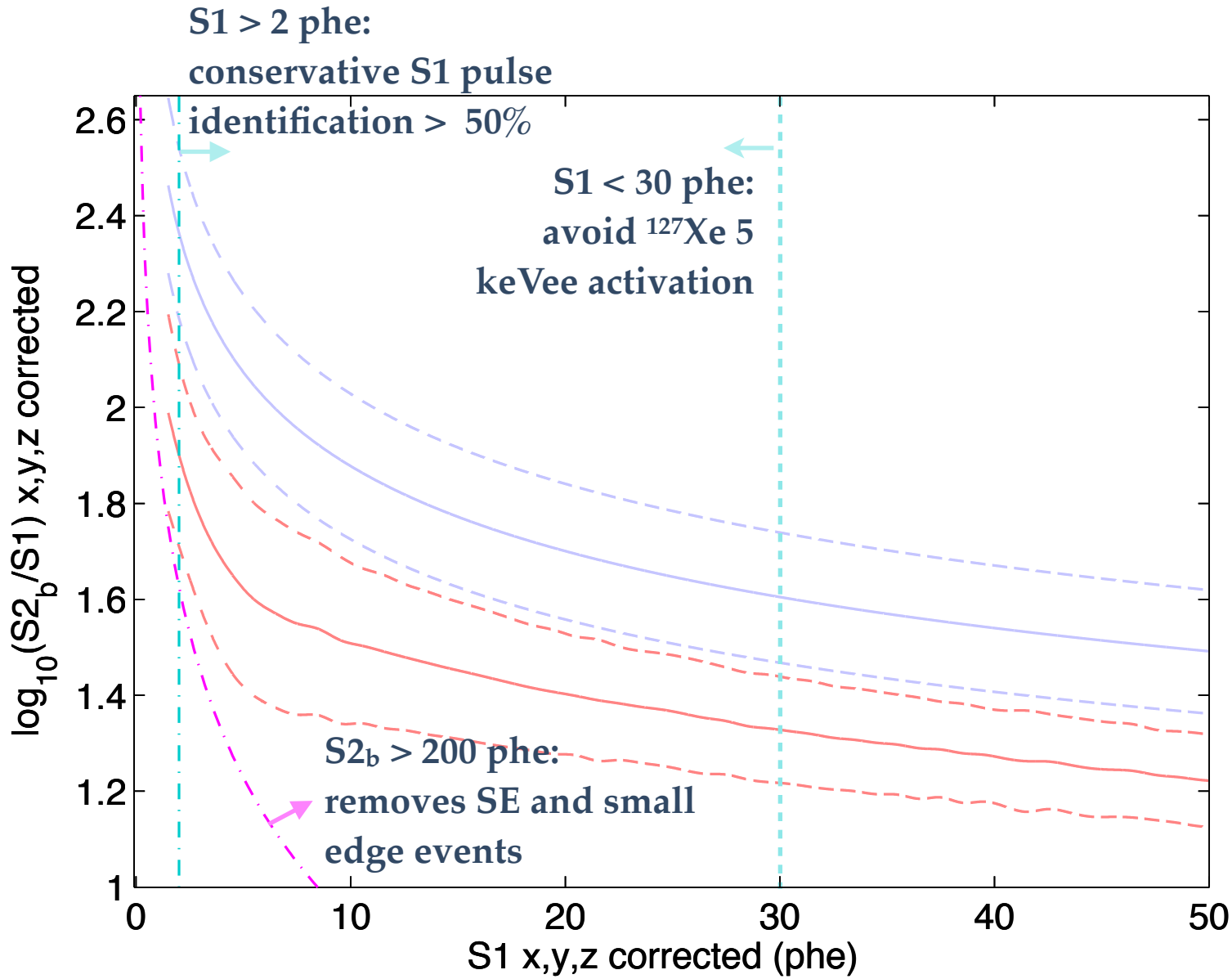
⇒ set hard threshold at 3 keVnr

Very conservative!

Photon detection efficiency: **14%**

Charge yield: **26 phe/e^-**

LUX WIMP search data, 85.3 live-days, 118 kg FV



Profile likelihood ratio for limits

- Unbinned maximum likelihood compare data with prediction on event by event basis.

4 observables: **x** = S1, log10(S2/S1), r and z

$$\mathcal{L}_{WS} = \frac{e^{-N_s - N_{Compt} - N_{Xe-127} - N_{Rn222}}}{\mathcal{N}!} \prod_{i=1}^{\mathcal{N}} N_s P_s(\boldsymbol{x}; \boldsymbol{\sigma}, \boldsymbol{\theta_s}) + N_{Compt} P_{ER}(\boldsymbol{x}; \boldsymbol{\theta_{Compt}})$$
$$+ N_{Xe-127} P_{ER}(\boldsymbol{x}; \boldsymbol{\theta_{Xe-127}}) + N_{Rn} P_{ER}(\boldsymbol{x}; \boldsymbol{\theta_{Rn}})$$

WIMP signal PDF:
- WIMP dE/dR for given mass (see earlier)
- efficiency from validated NR sims
- N_s is parameter of interest

Backgrounds as nuisance parameters:
- detector efficiencies included
- 30% uncertainty on overall rate

Ratio of this to null hypothesis used to create test statistic and extract 90% CI upper limit