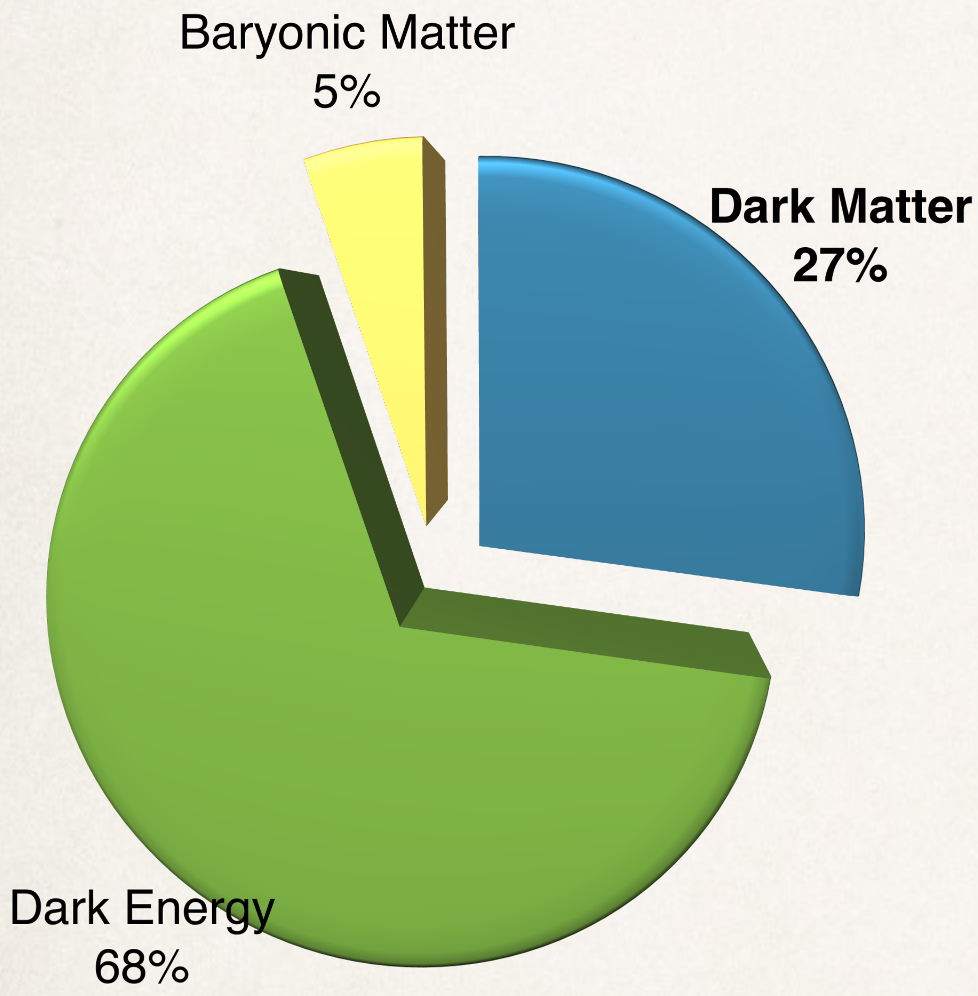
First results from the LUX experiment

Alexandre Lindote

Jornadas LIP 2014

Evidence for Dark Matter



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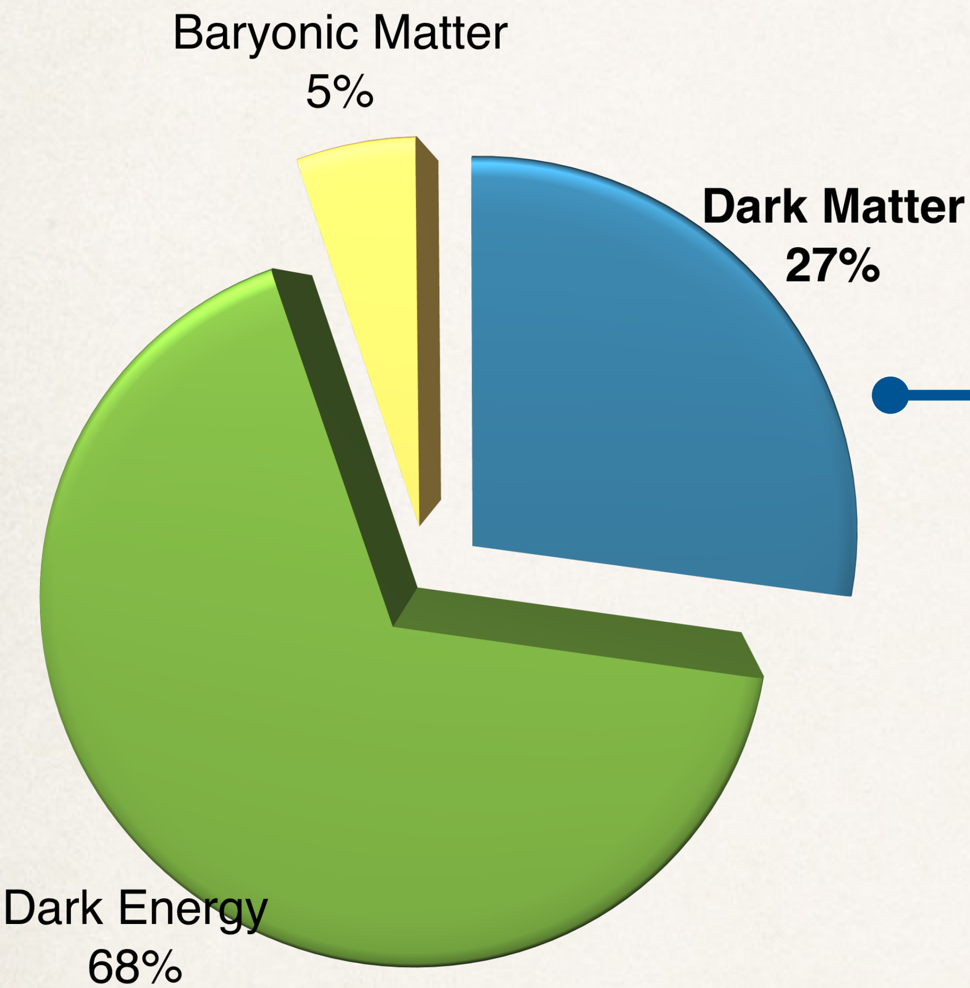
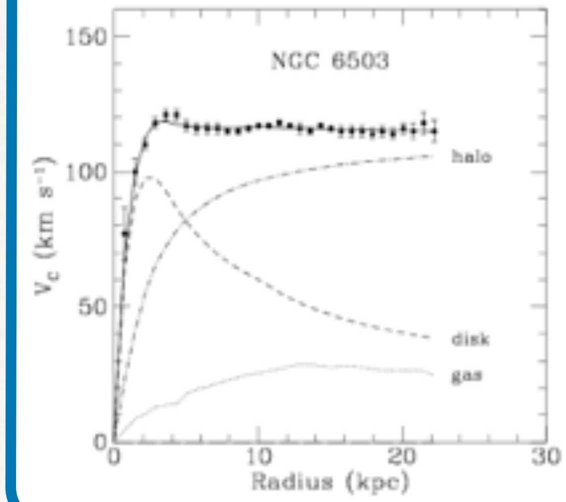
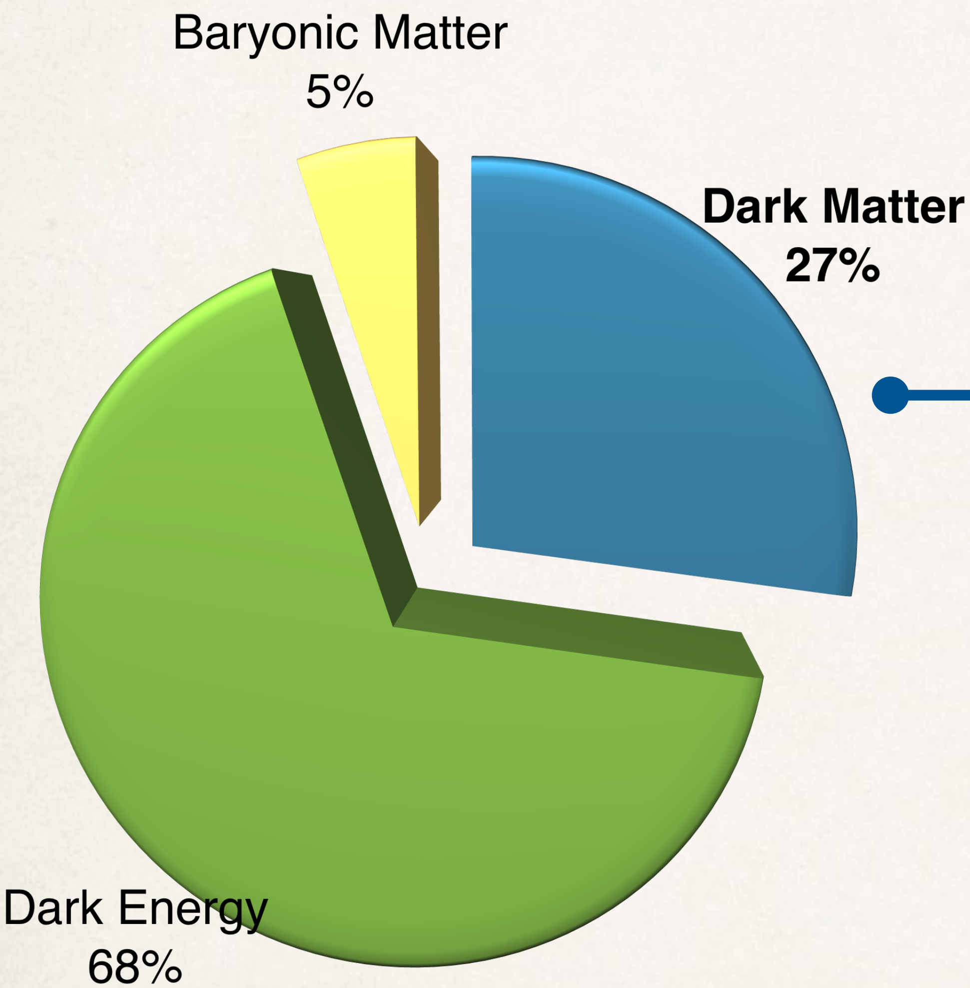
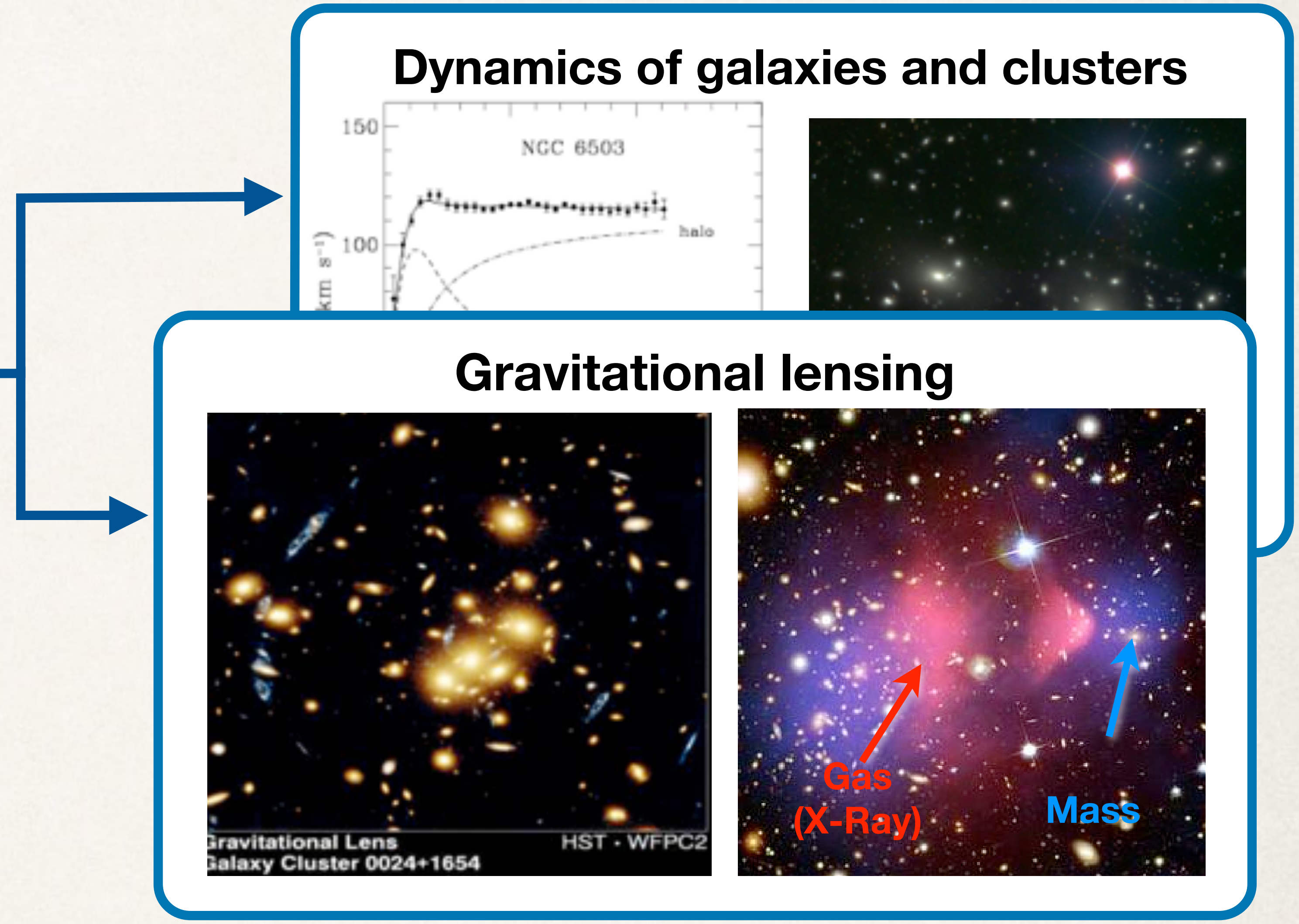


Dynamics of galaxies and clusters



Evidence for Dark Matter





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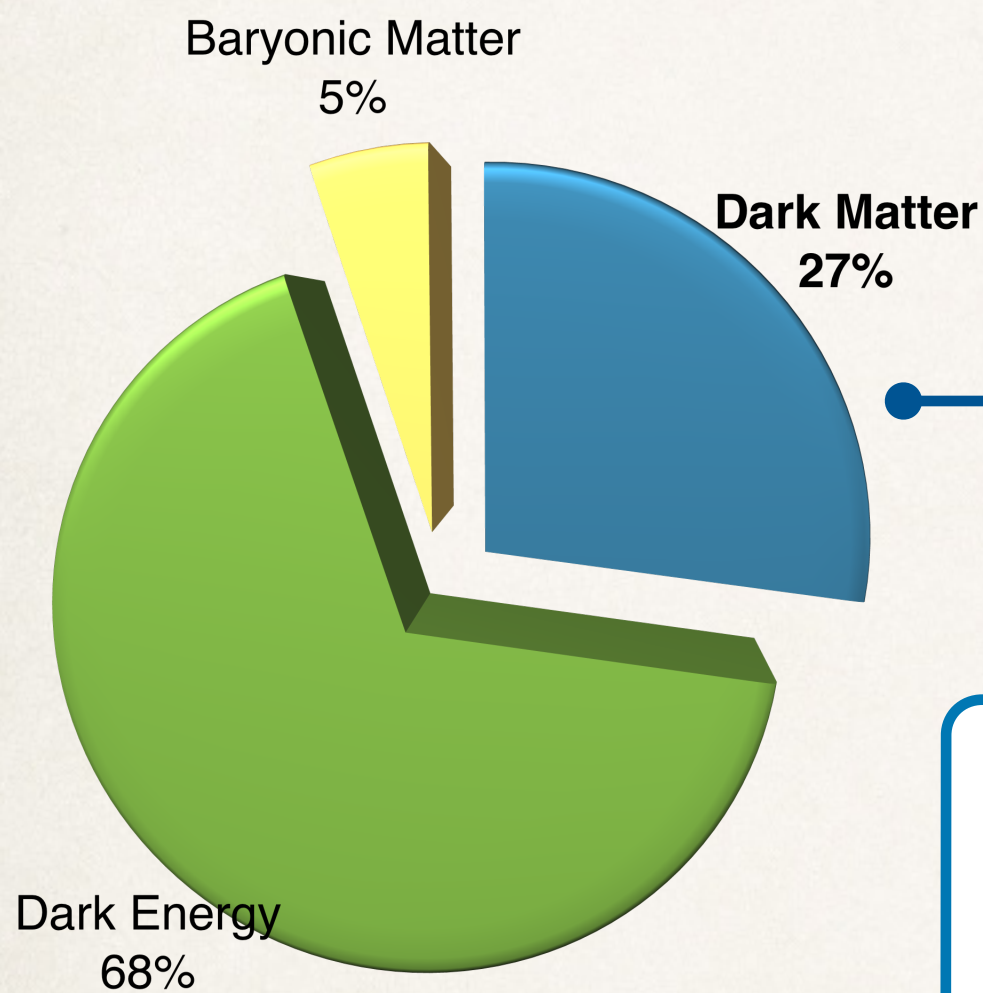

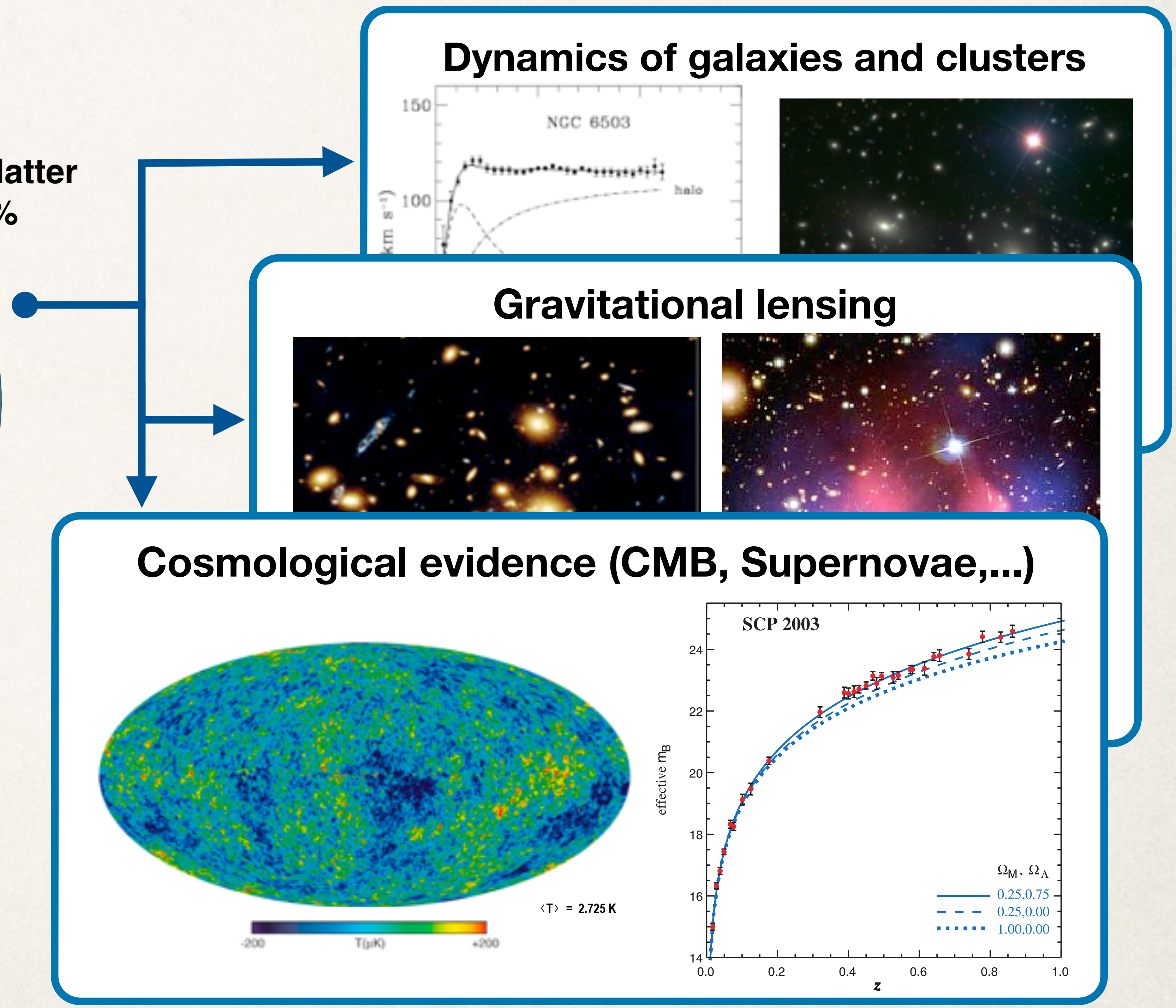

WIMP direct detection

- WIMPs are the leading DM candidates
  - Not affected by either the strong or EM forces
  - Mass scale: GeV - TeV
  - Distributed in spherical halos around galaxies
  - Interaction with the nucleus:
    - spin-independent: $\sigma \sim A^2$
    - spin-dependent: $\sigma \sim J(J+1)$

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How to search for WIMPs?

- **Colliders** - missing energy
- **Indirectly** - looking for annihilation products (e.g. γ-rays, high-energy neutrinos)
- **Directly** - looking for nuclear recoils from WIMPs

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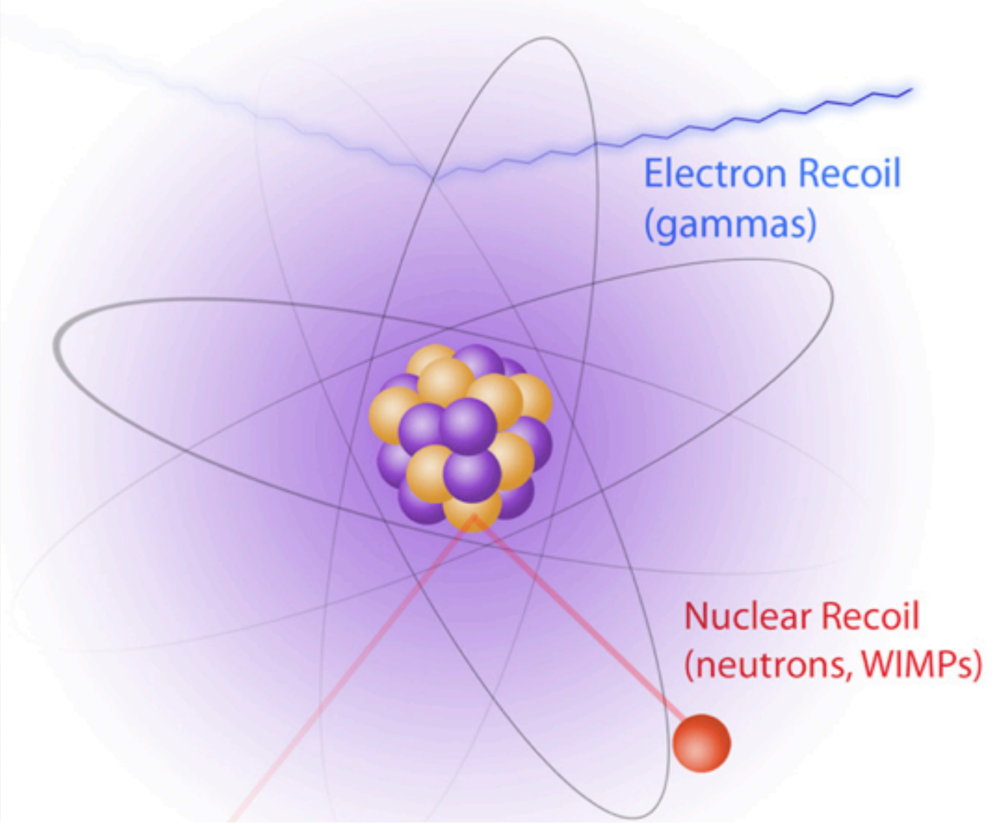
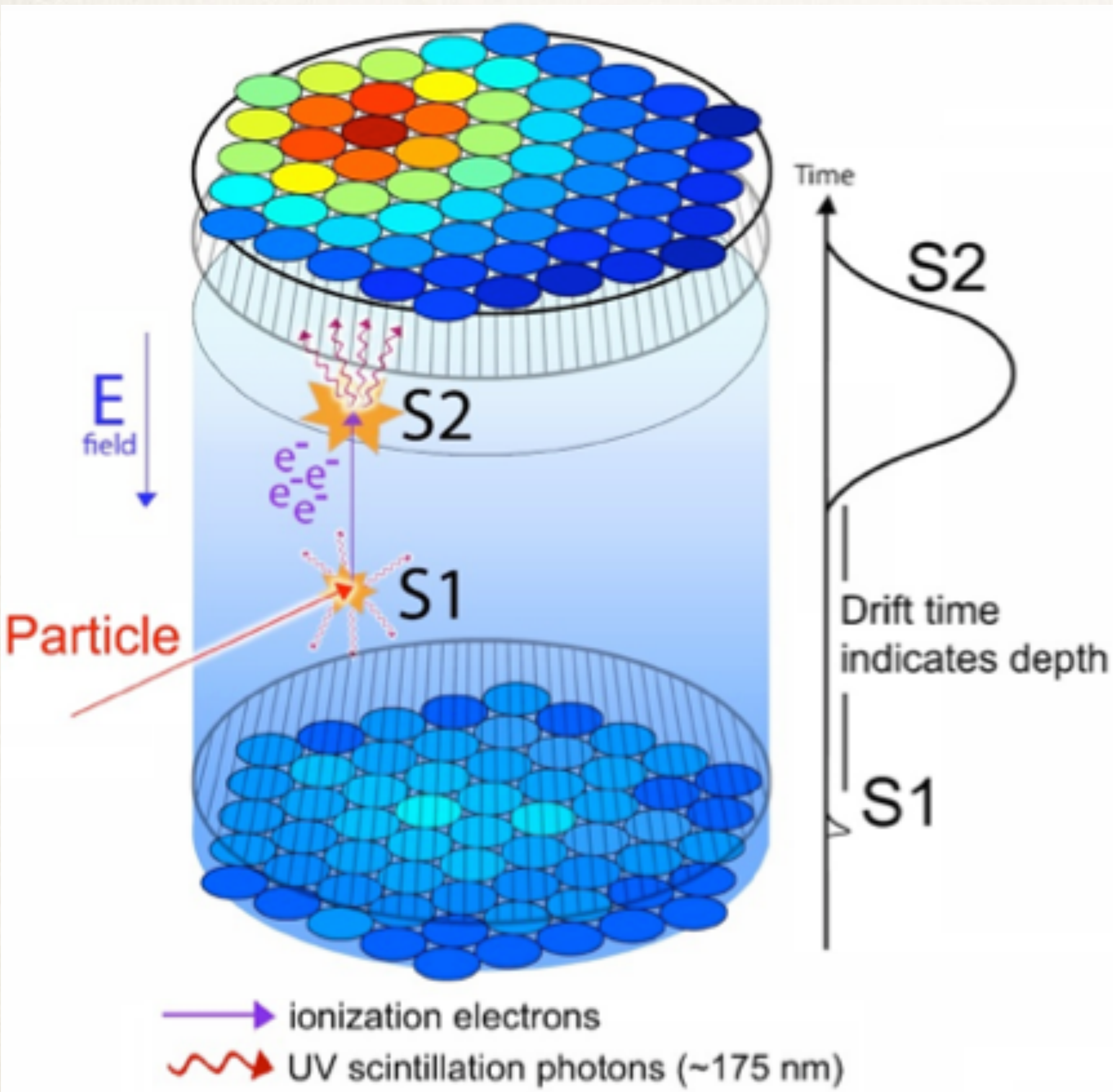


WIMPs scatter elastically off nuclei

- **Expect low energy recoils(1 - 100 keV)**
- **Expect <1 event/kg/year**
- **Requires SM backgrounds ~0**
  - underground operation

LUX - 2-phase Xe TPC



3D Position Reconstruction

- ➡ Z from time difference between S1 and S2
- ➡ XY reconstructed from light pattern

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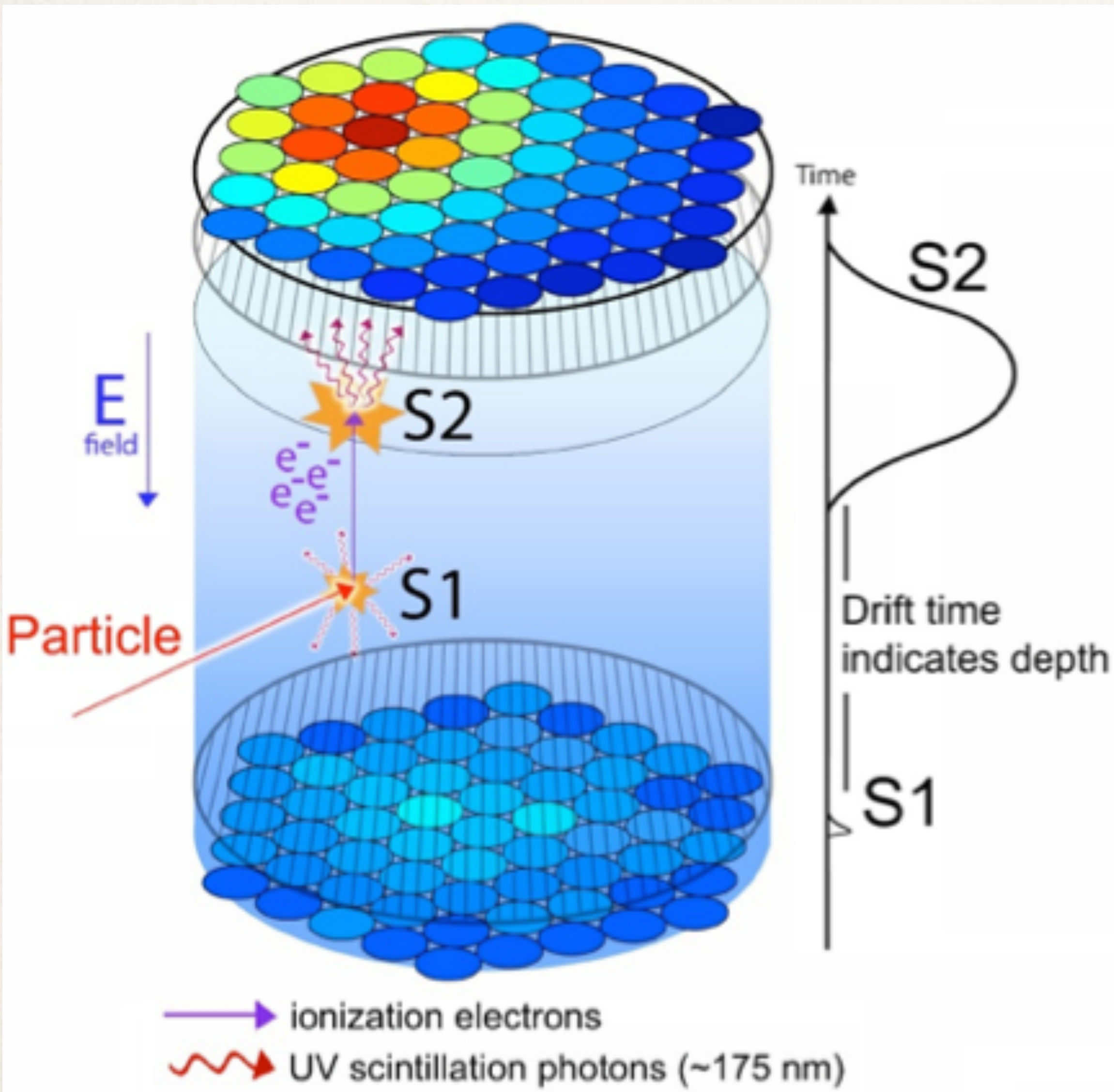

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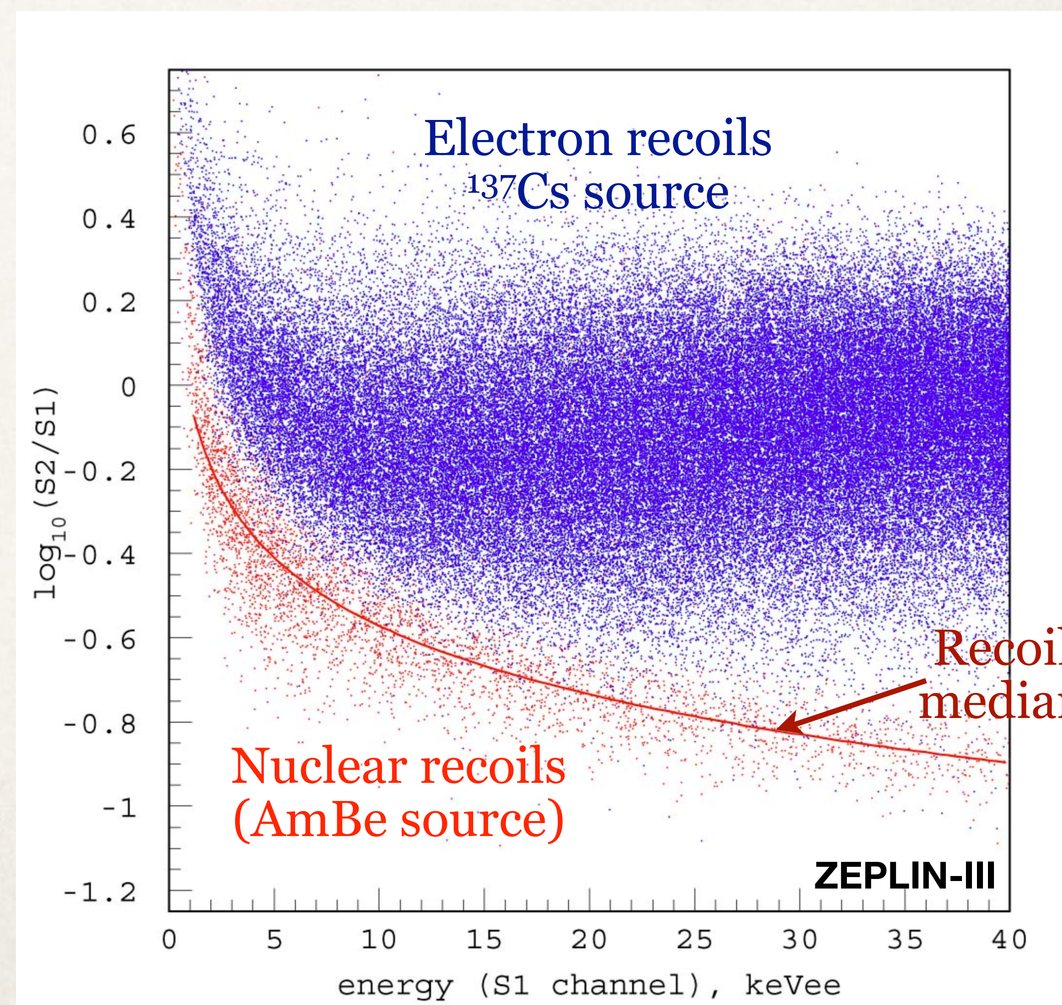
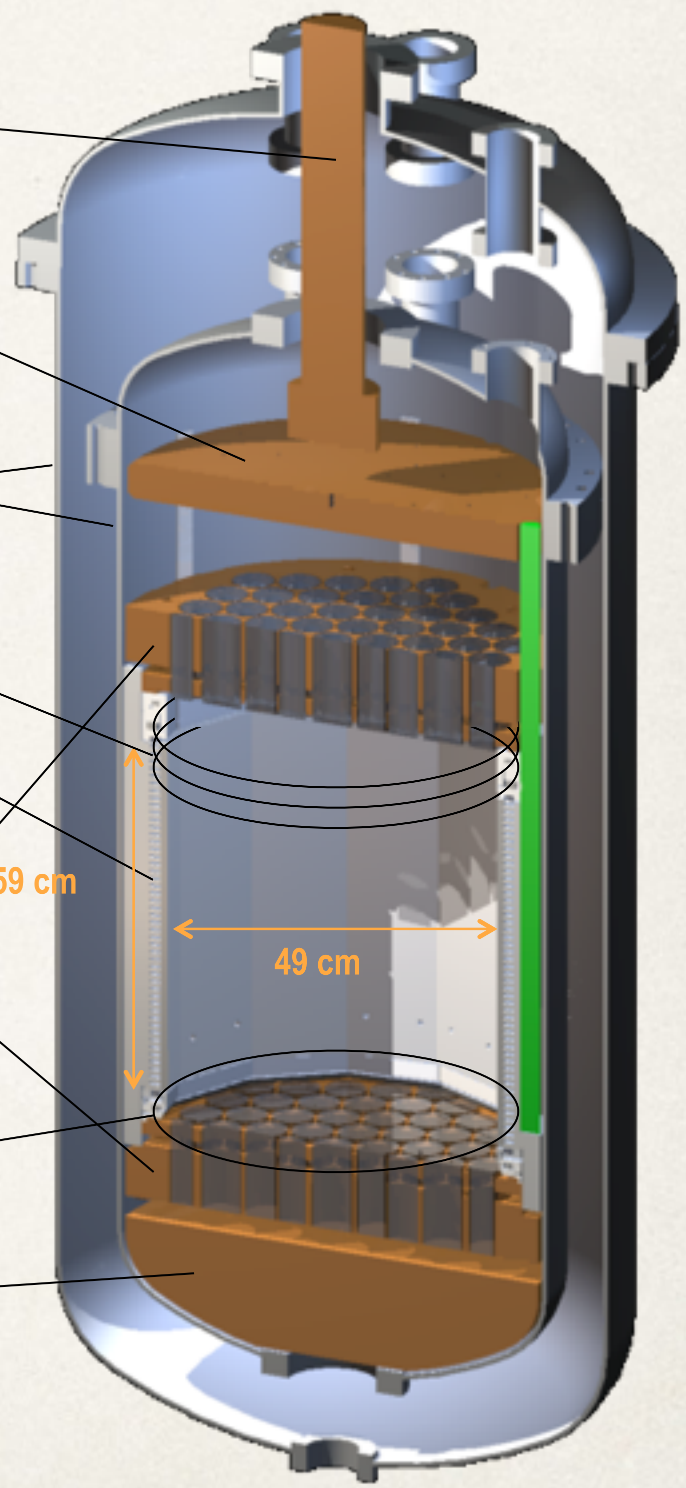
Discrimination principle

- WIMPs and neutrons interact with nuclei
  <u>short, dense tracks</u> ⇒ smaller S2/S1
- γs and e⁻ interact with atomic electrons
  <u>longer, less dense tracks</u> ⇒ higher S2/S1
- discrimination >99.5% @ 50% NR acceptance



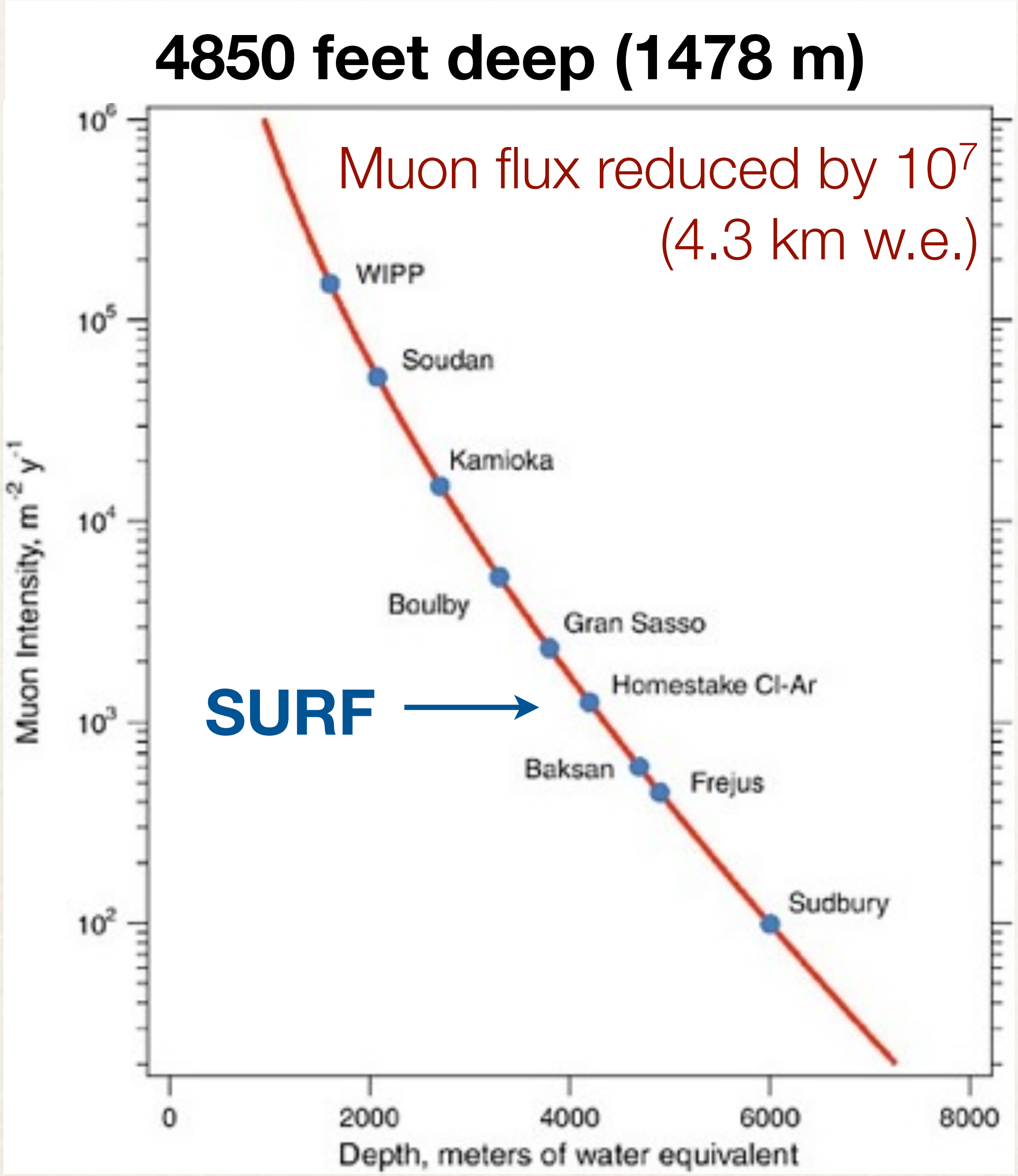
The LUX detector

- Ultra-low background xenon TPC
  - 370 kg of LXe
  - 250 kg in the active volume
  - 118 kg fiducial volume
- Drift length: 50 cm
- Active region defined by 12 PTFE slabs
- 2 PMT arrays with a total of 122 tubes
- Titanium cryostats (<0.2 mBq/kg)
- Installed inside 300 T water tank



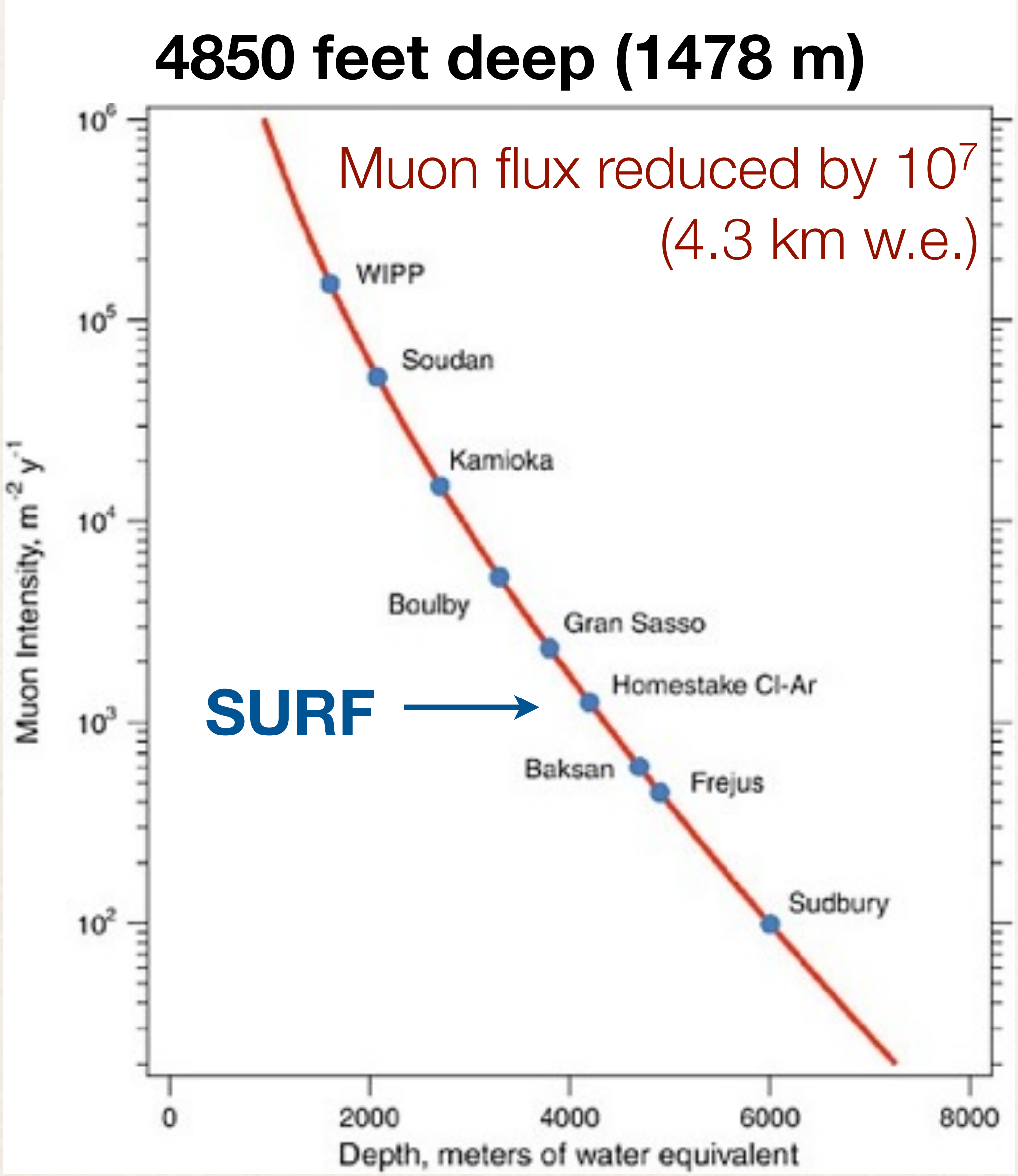
NIM. A 704, 111-126 (2013)
arXiv:1211.3788

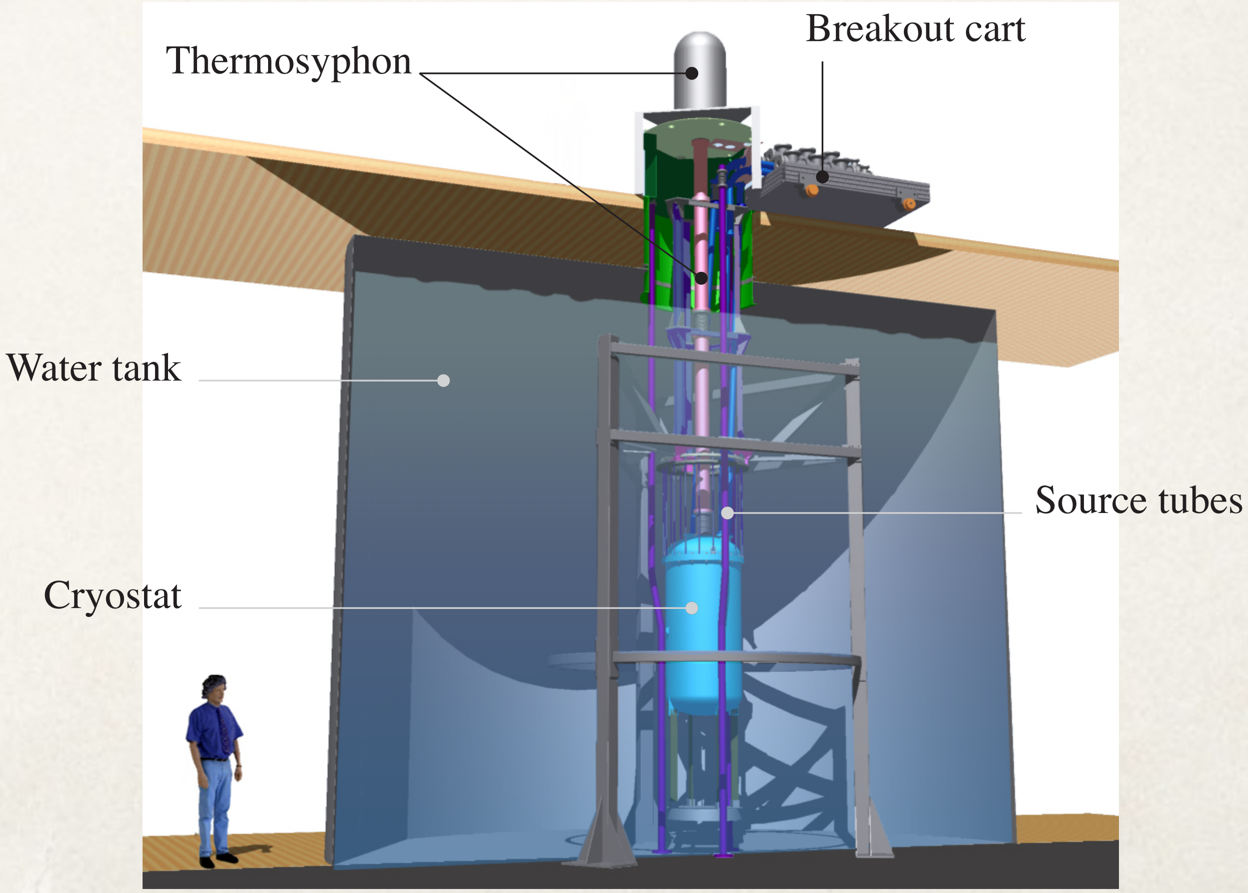
Sanford Lab (@ Homestake mine)



Sanford Lab (@ Homestake mine)

- **Water Tank**: 300 t, 3.5 m shielding
- Cherenkov muon veto
- ~10^{-9} gamma event rate reduction
- ~10^{-3} high-E neutrons (>10 MeV) rate red.
- **All external backgrounds subdominant**





Support systems

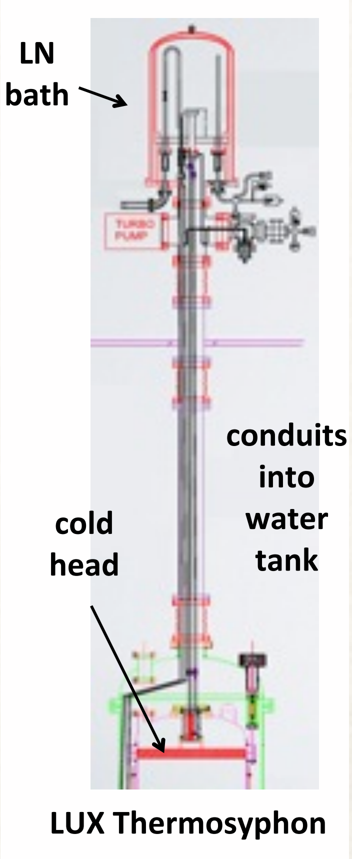
Circulation and sampling

LIP responsibilities

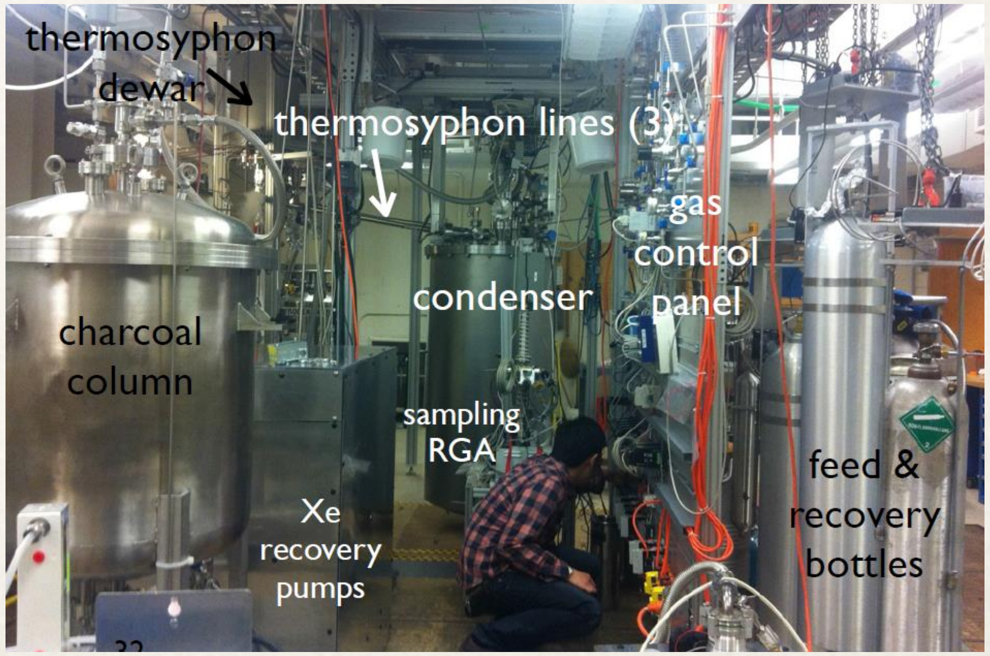
- **LN system**
  - Manages LN transfers from storage dewars to SRV, TS, SS
  - Fully automated system
  - Both hardware and software designed and built at LIP
- **Slow control**
  - Monitor hundreds of sensors (detector and support systems)
  - Controls valves, HV, etc.
  - Interface via mySQL database
  - User interface using php

Xe storage

Thermosyphon

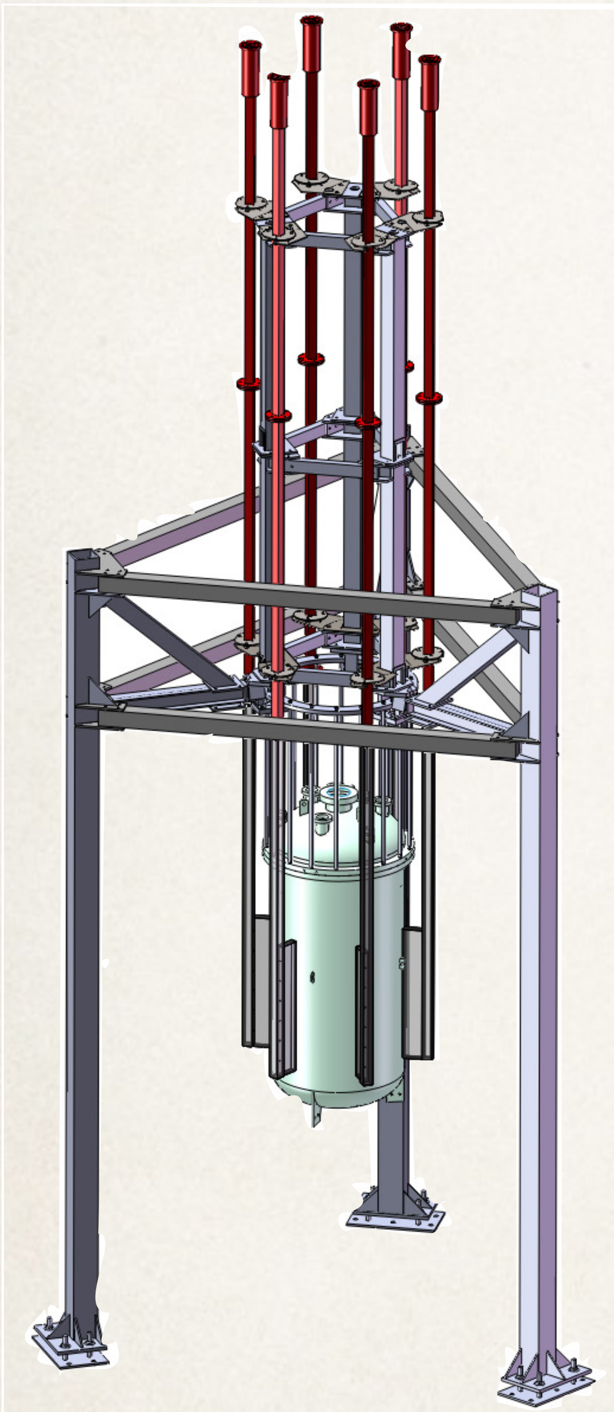


Kr removal facility

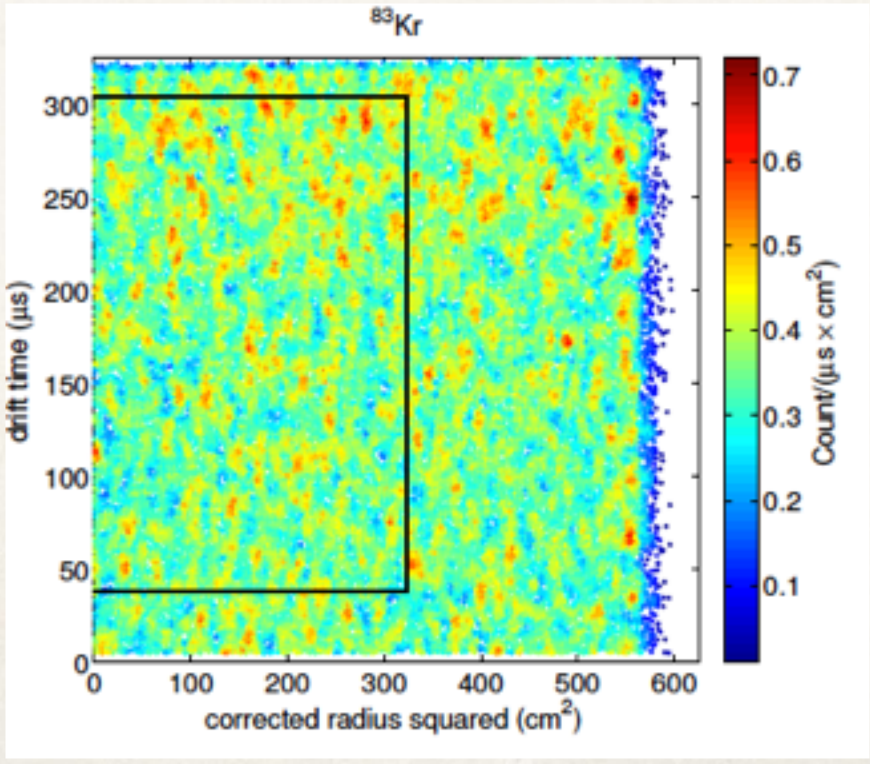


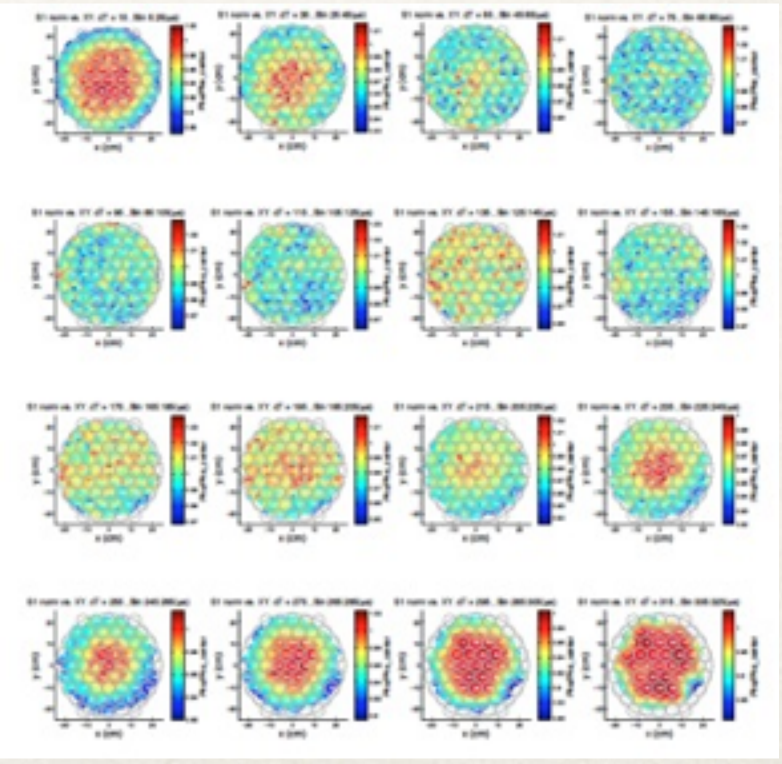
130 ppb to 3.5 ppt!

Calibrating LUX

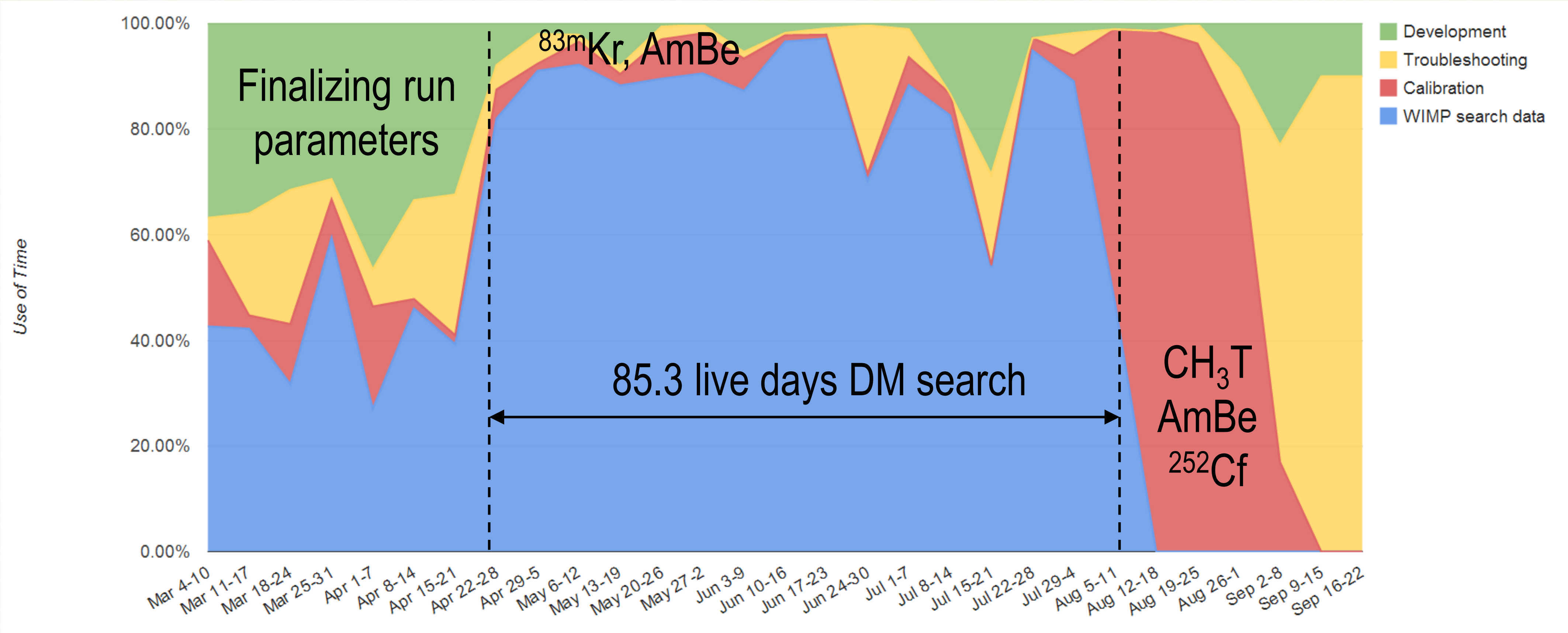


- External sources (via source tubes):
  - AmBe and ^{252}Cf for low energy neutrons
    - ➡ validate NR models and sims, NR efficiencies
- Internal sources (injected)
  - Xe self-shielding prevents **γ**s from reaching inner volume
  - ^{83m}Kr: half-life ~1.8 h; 32.1 + 9.4 keV ***β***s
    - ➡ weekly purity & XYZ maps
  - Tritiated methane (CH3T): low energy ***β***s (end point 18 keV)
    - ➡ high stats, uniform and high purity ➡ ER band, ER acceptance





Data taking



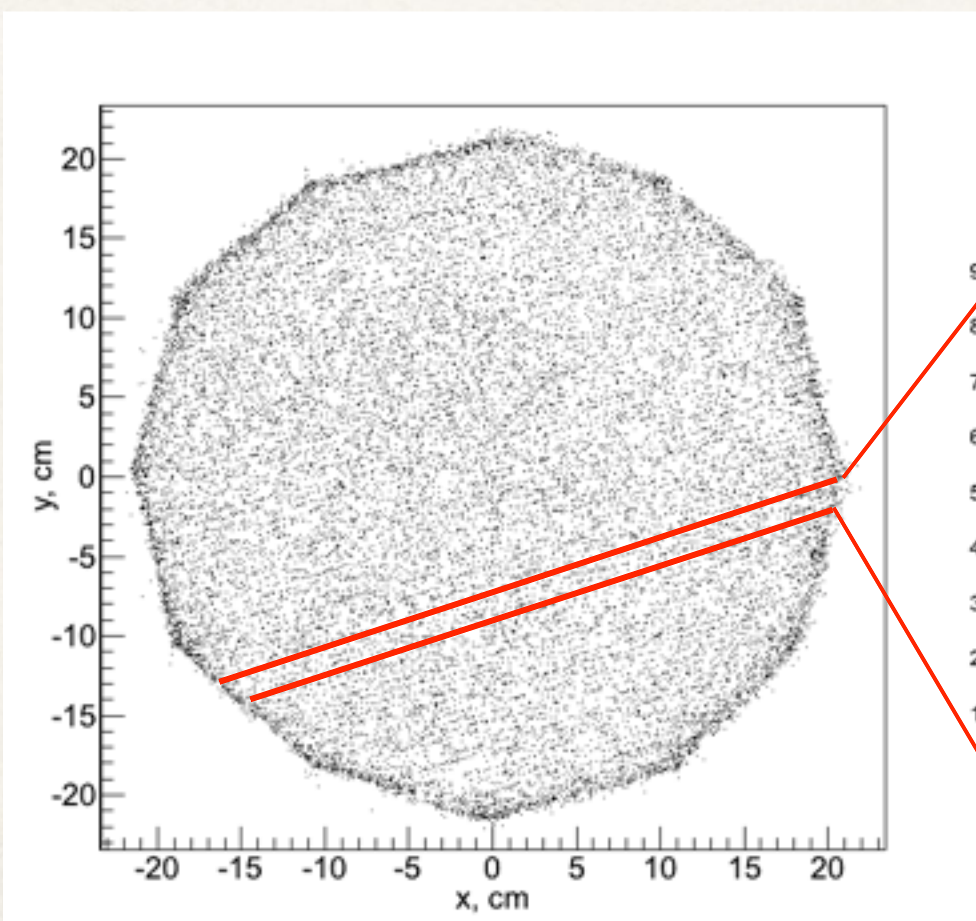
- LUX moves underground in July 2012
- Detector cool-down January 2013, Xe condensed mid-February 2013
- Kr and AmBe calibrations throughout, CH3T after WIMP search

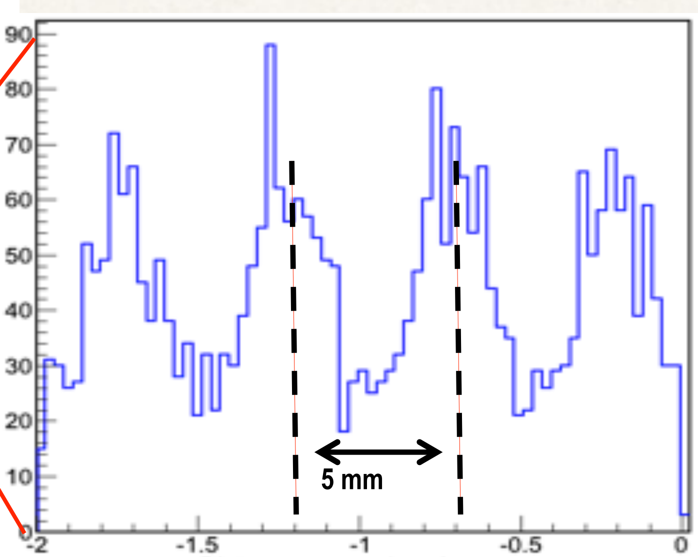
LIP responsibilities

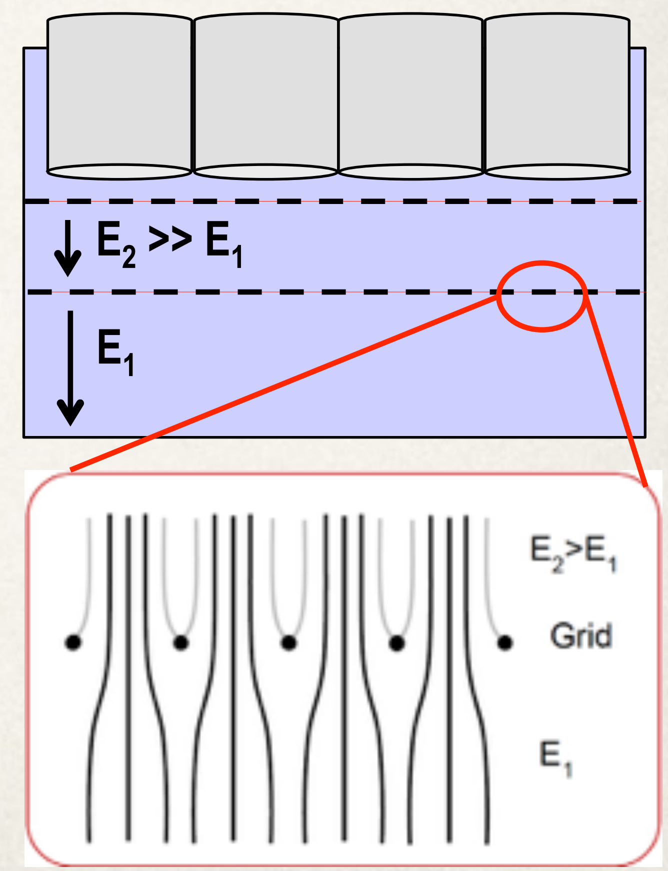
F. Neves is currently the coordinator of detector operations (6 months term)
A. Lindote is currently the data processing coordinator (6 months term)
L. deViveiros was on-site science operations coordinator (2.5 months term)
L. deViveiros was coordinator of the analysis workgroup (6 months term)

Position reconstruction

- Crucial for pulse correction and the definition of the fiducial volume
- Drift time (1.5 mm/μs) for Z-position
- Mercury algorithm for the reconstruction in the XY plane
  - Obtained by fitting the S2 hit pattern with LRFs from internal calibrations
  - Developed by V. Solovov for ZEPLIN-III *
  - Adapted and further developed for LUX by C. Silva
  - Included in the official data processing chain, and was the only PR method to be used in the first science run analysis





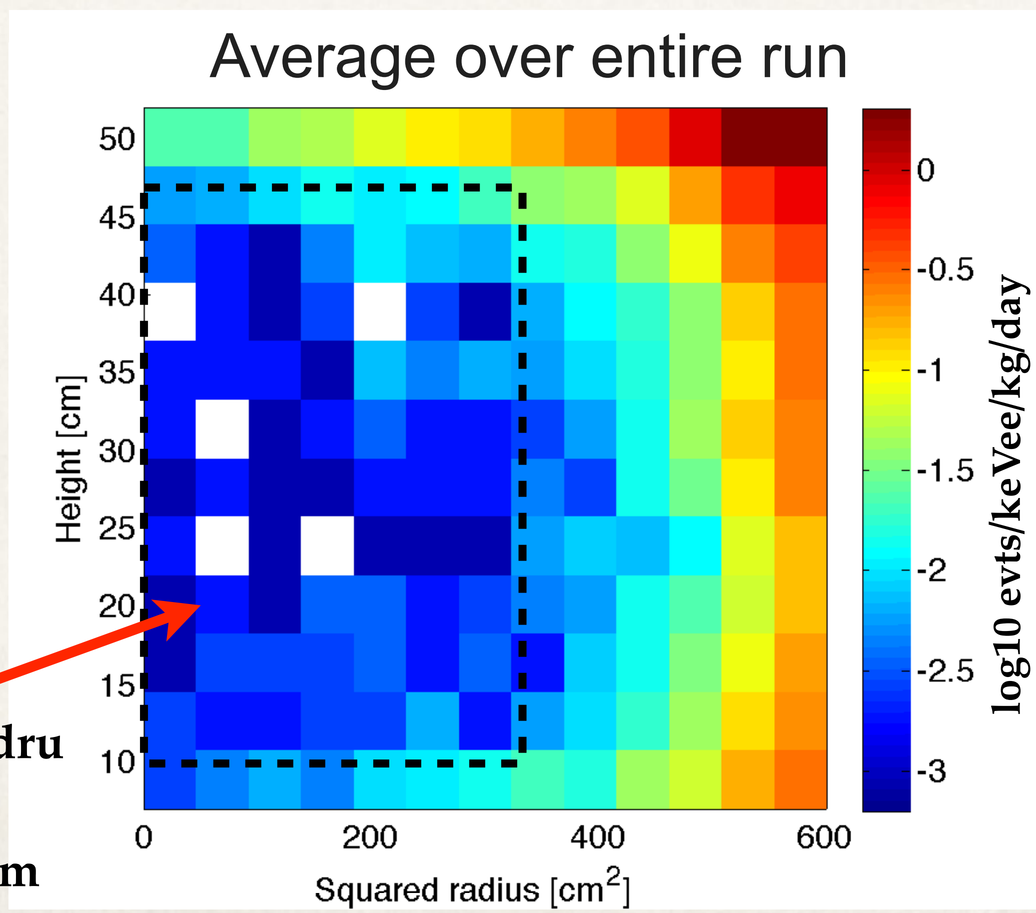


* IEEE Nucl.Sci.Symp.Conf.Rec. 2011 (2011) 1226-1233, arXiv: 1112.1481

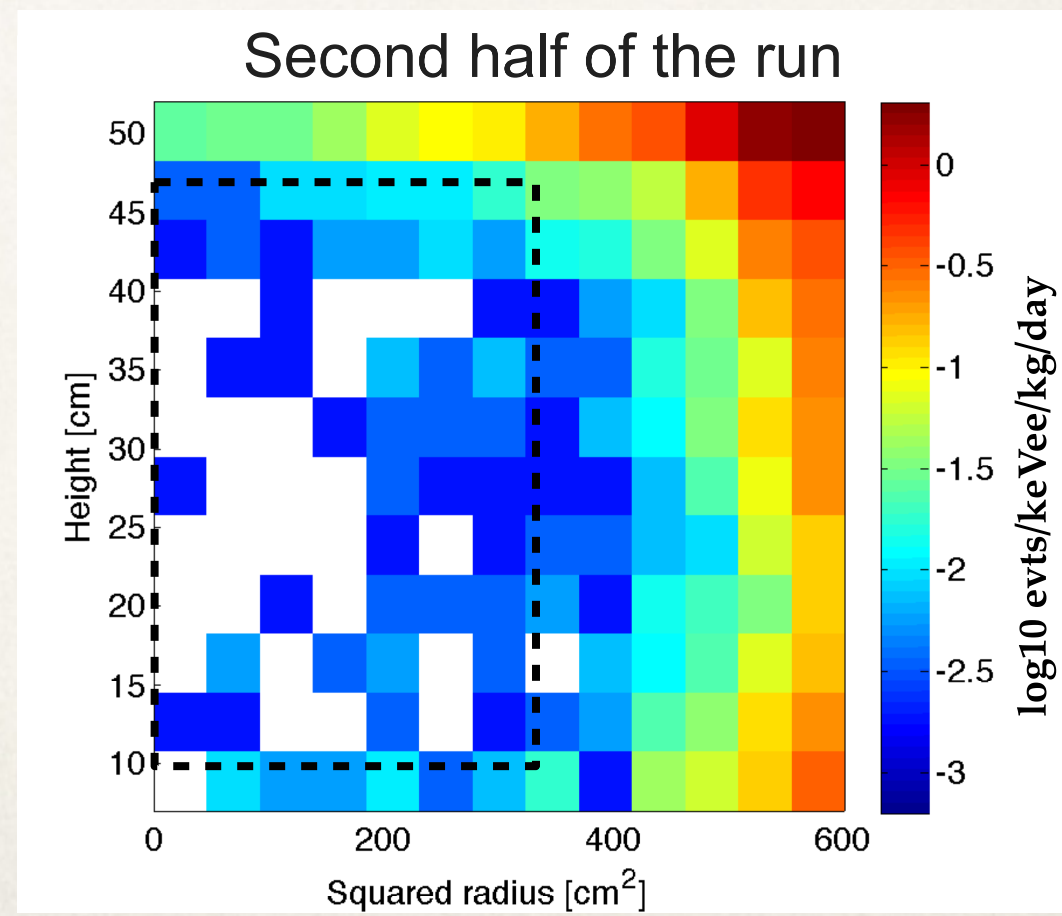
Backgrounds in LUX

Background Component	Source	10^{-3} x evts/keVee/kg/day
Gamma-rays	Internal Components including PMTs (80%), Cryostat, Teflon	$1.8 \pm 0.2_{stat} \pm 0.3_{sys}$
^{127}Xe (36.4 day half-life)	Cosmogenic 0.87 → 0.28 during run	$0.5 \pm 0.02_{stat} \pm 0.1_{sys}$
^{214}Pb	^{222}Rn	$0.11\text{-}0.22_{(90\%\ CL)}$
^{85}Kr	Reduced from 130 ppb to 3.5 ± 1 ppt	$0.17 \pm 0.10_{sys}$
Predicted	Total	$2.6 \pm 0.2_{stat} \pm 0.4_{sys}$
Observed	Total	$3.6 \pm 0.3_{stat}$

Cosmogenic activation

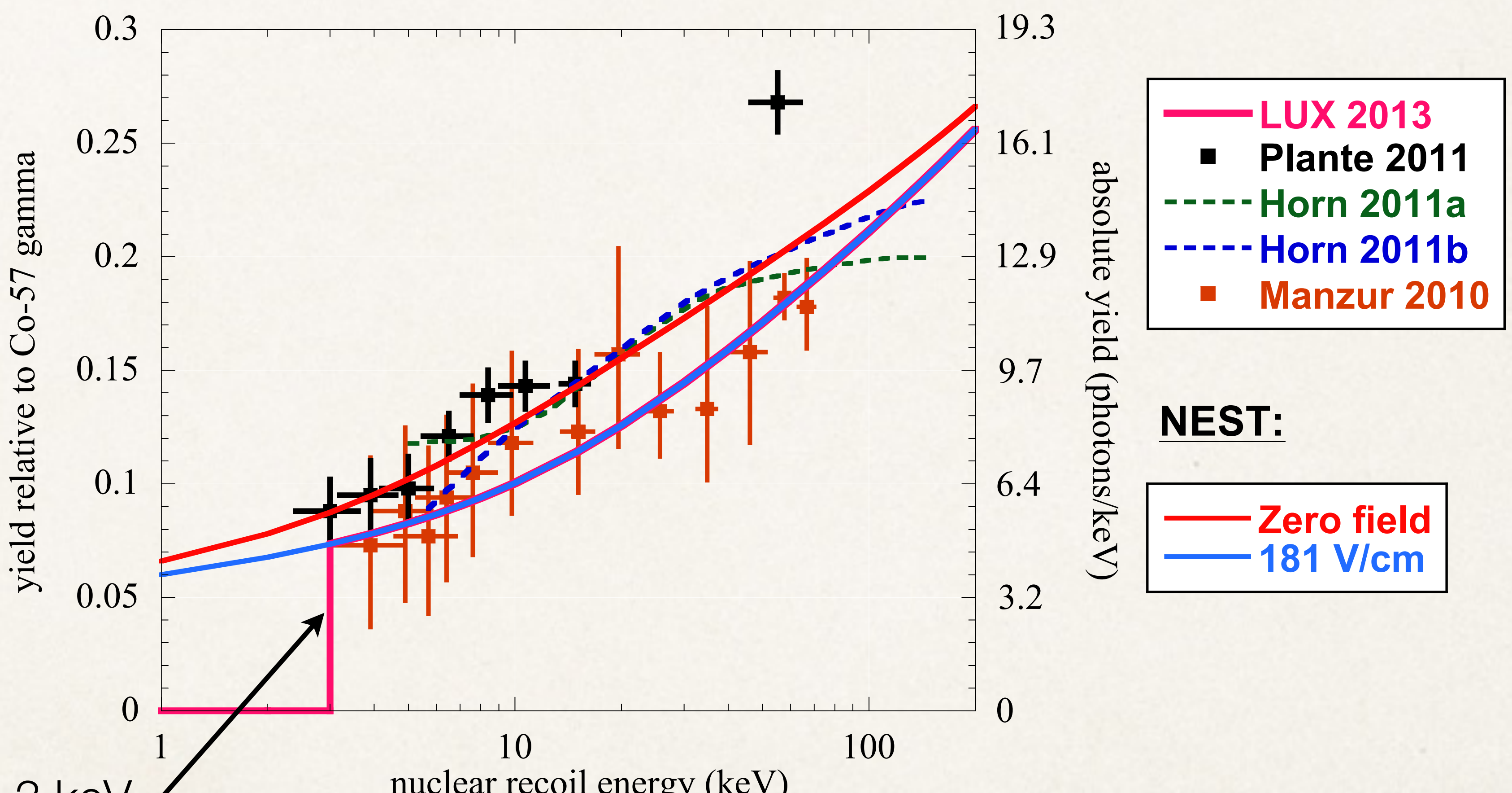


118 kg
3.1 ± 0.2 mdru
r < 18 cm
7 < z < 47 cm



Xenon light yield for NR

- Scintillation in LXe is quenched for NR (relatively to ER interactions)
- Modelled using NEST (Noble Element Simulation Technique)
  - ➡ based on canon of existing experimental data.
- Artificial cut-off assumed below 3 keV (no measurements, conservative approach)
- Includes predicted electric field quenching of light signal (to 77-82% of the zero field light yield)

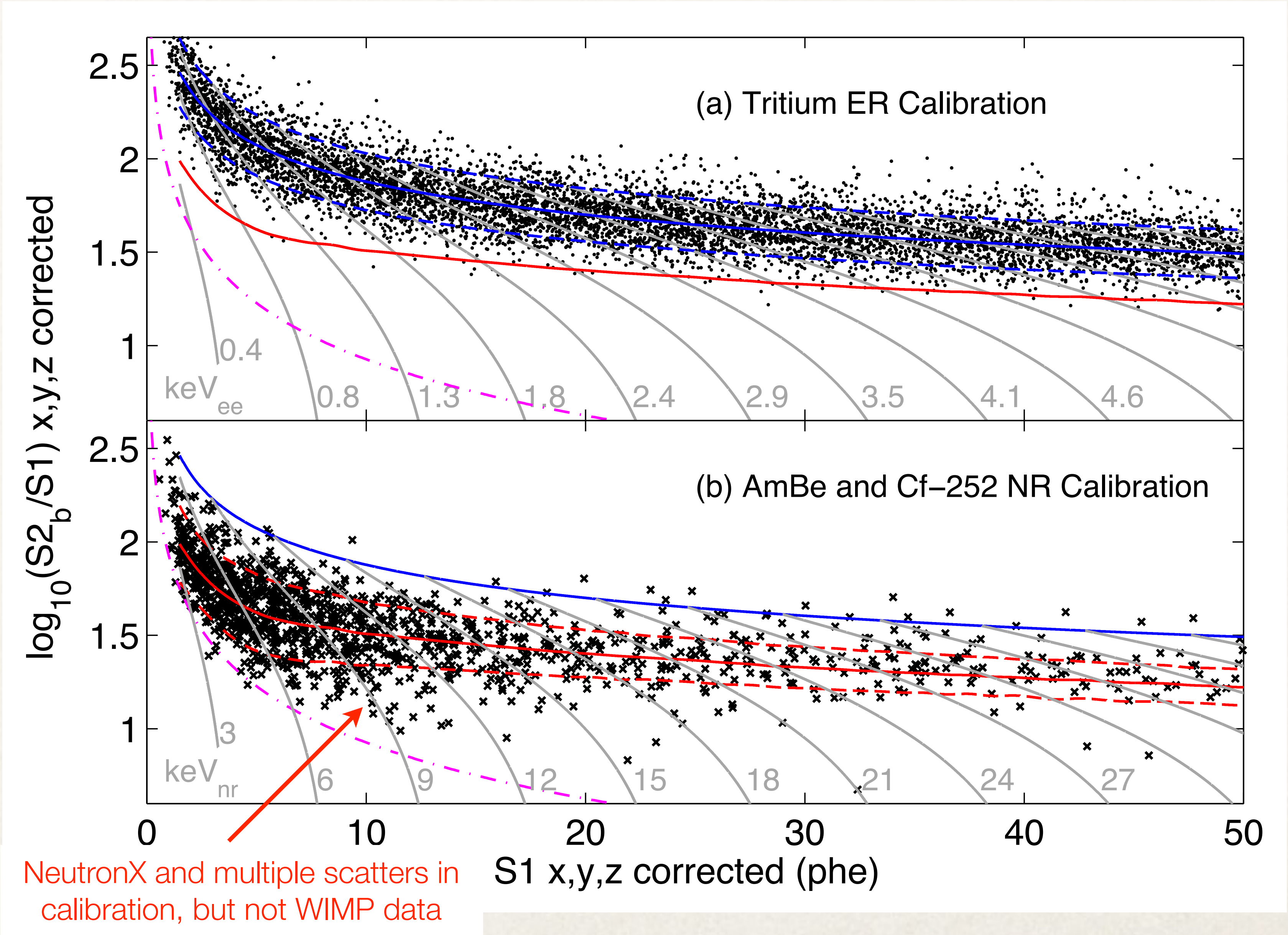


⇒ set hard threshold at 3 keV
Very conservative!

- ➡ Photon detection efficiency: **14%**
- ➡ Charge yield: **26 phe/e$^-$**

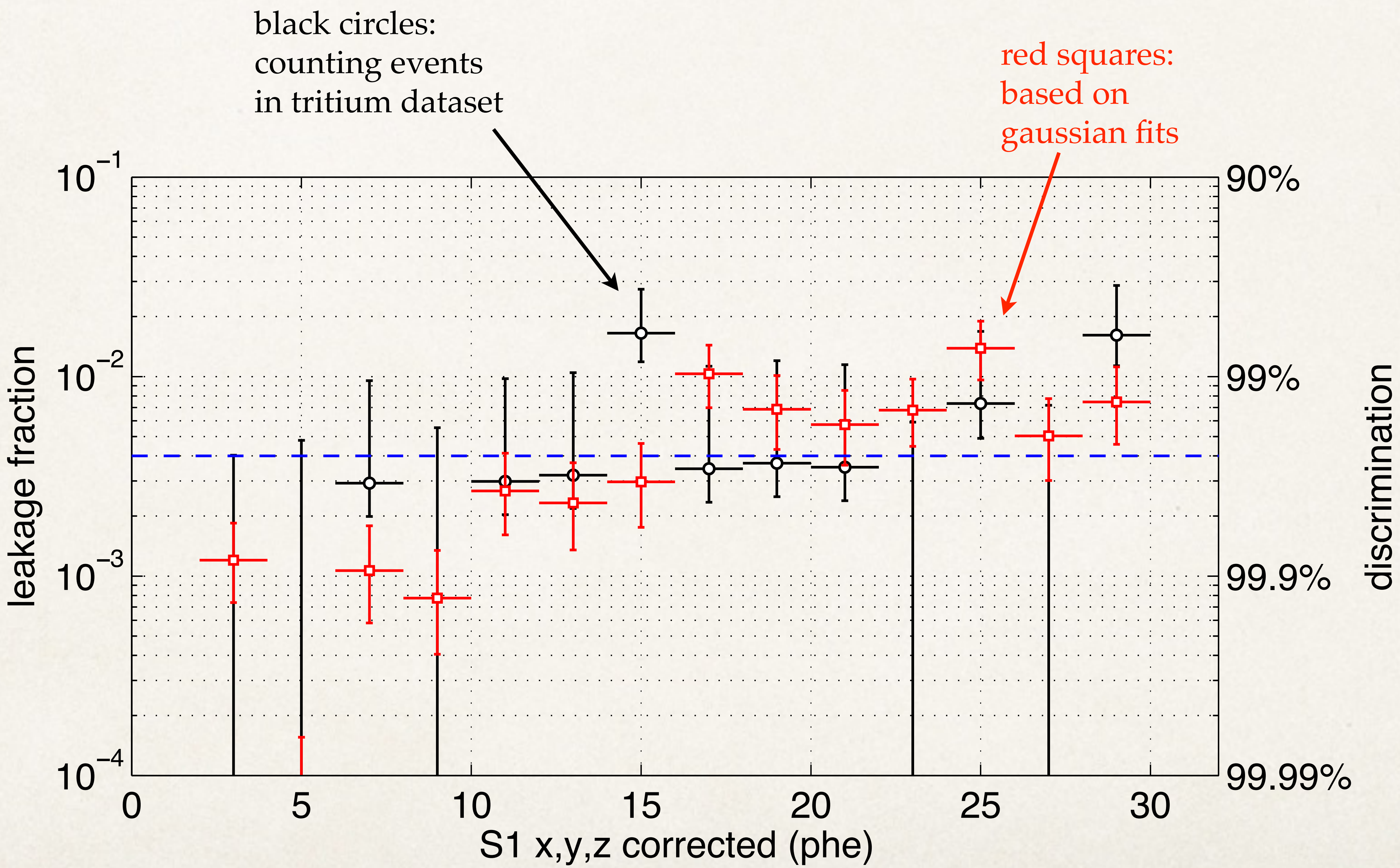
Calibrations

- Tritium provides very high statistics electron recoil calibration (200 events/phe)
- Neutron calibration is consistent with NEST + simulations



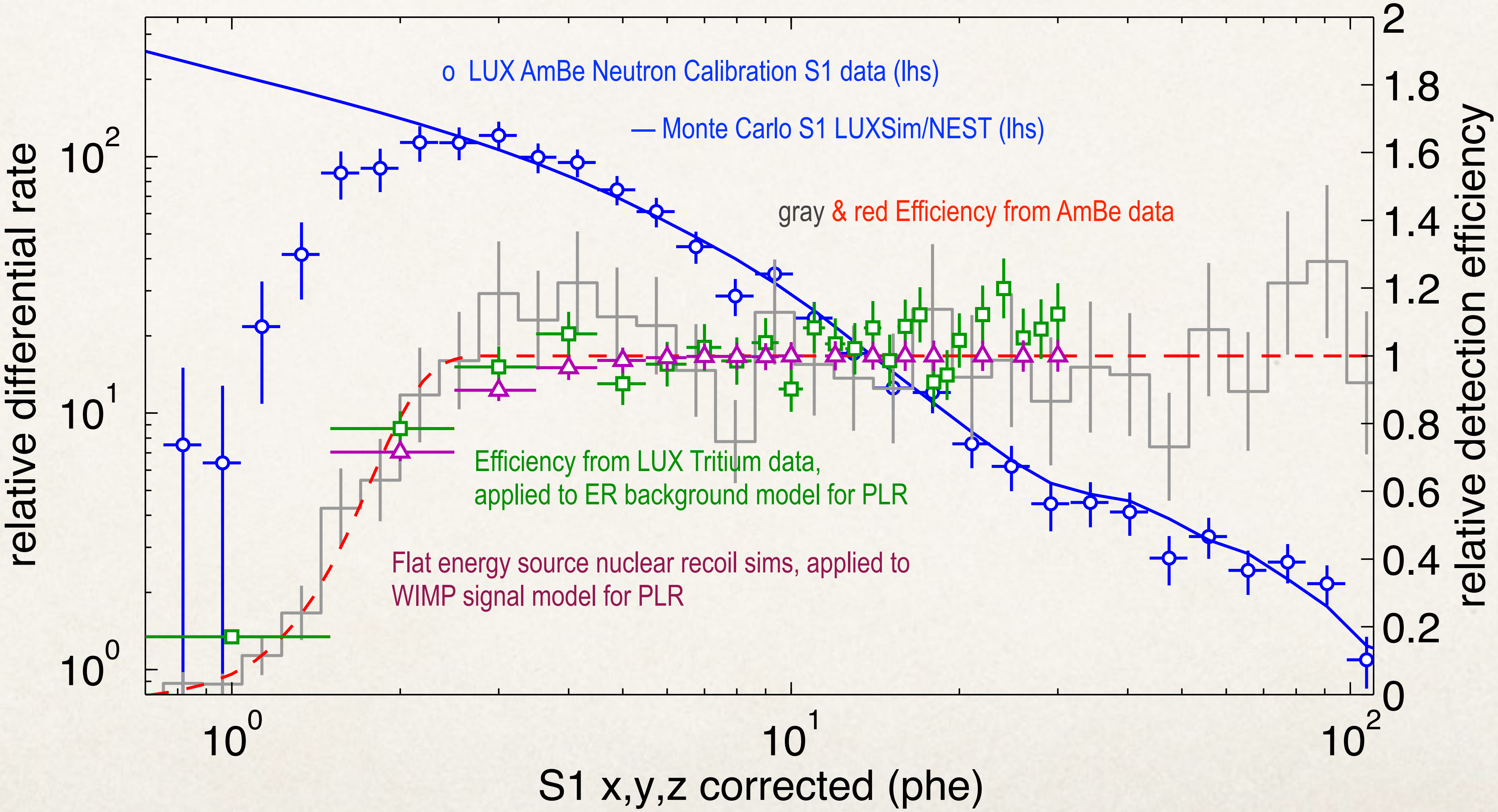
Discrimination

- Discrimination at 50% NR acceptance is 99.6%



Golden efficiency

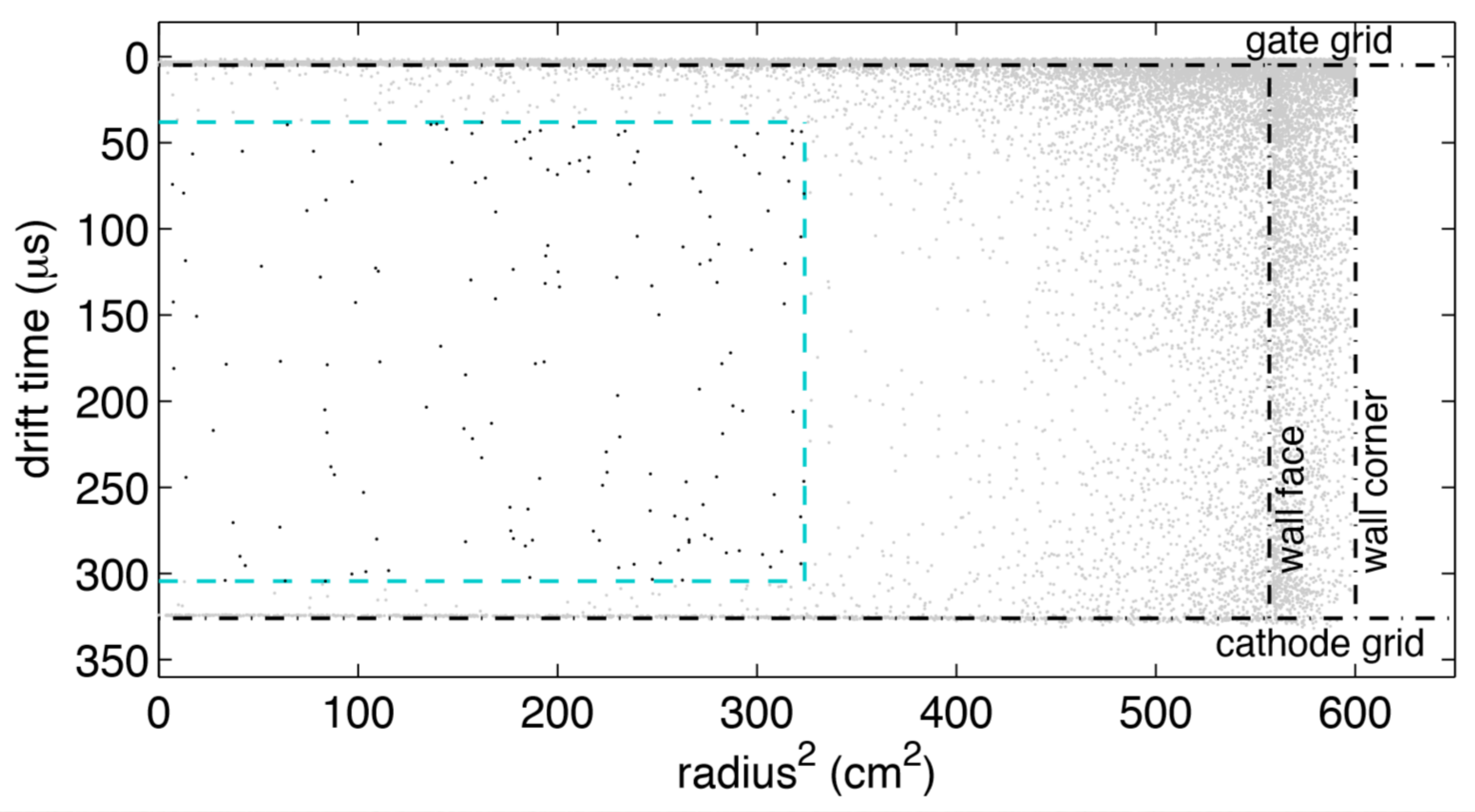
- Cumulative efficiency of: finding the S2 pulse, finding the S1 pulse, and finding (only) one of each in a given event
- Measured independently using AmBe, Tritium, LED data and full NR simulations using a flat spectrum



Event selection and cuts

- Non-blind analysis
- Cuts were minimised to avoid bias
- 85.3 live-days
- 118 kg fiducial volume
- 160 events in fiducial volume

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



WIMP search data — discrimination

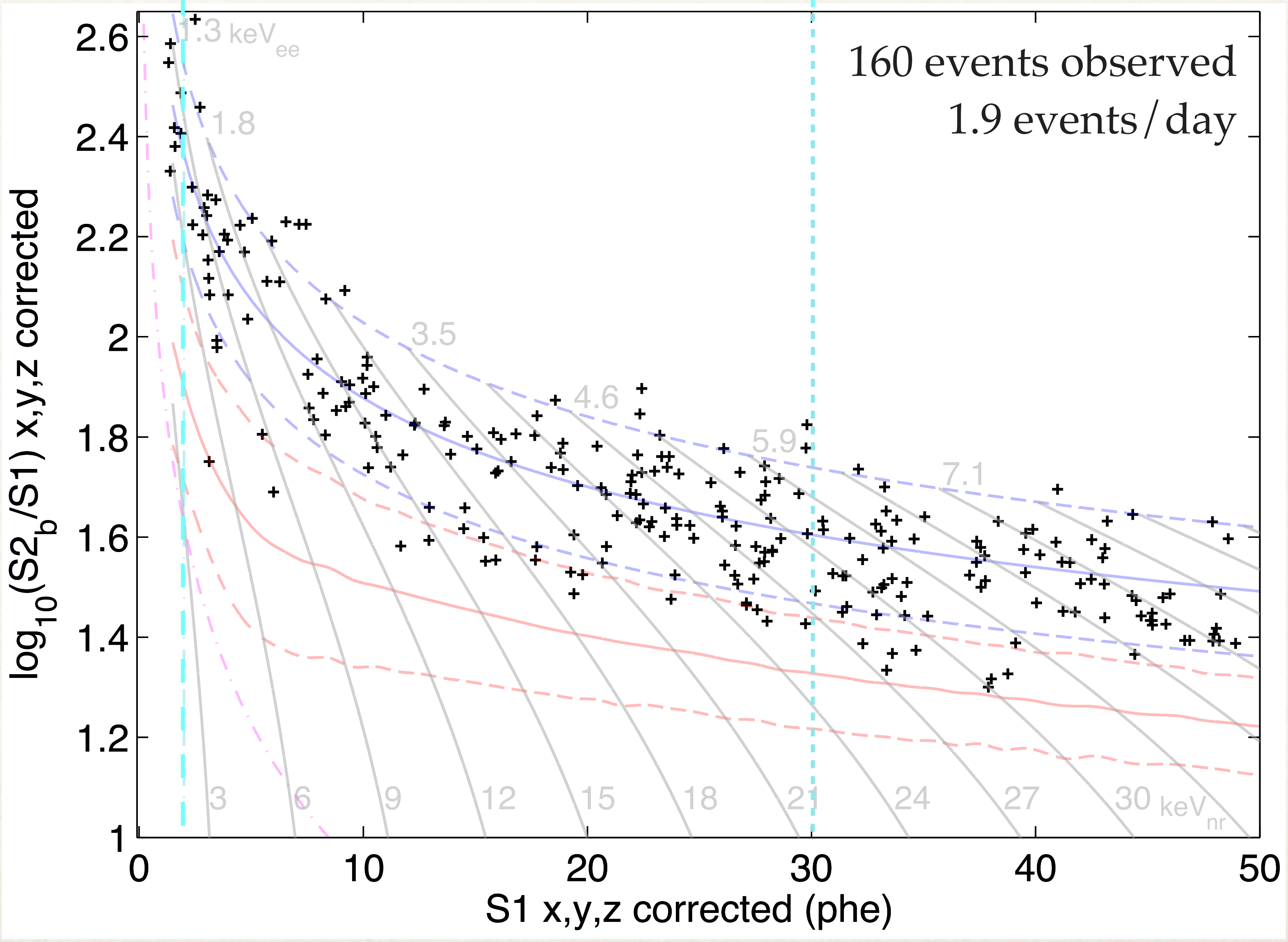
99.6 ± 0.1 % leakage below NR mean, so expect 0.64 ± 0.16

Distribution is consistent with ER background and no WIMP signal

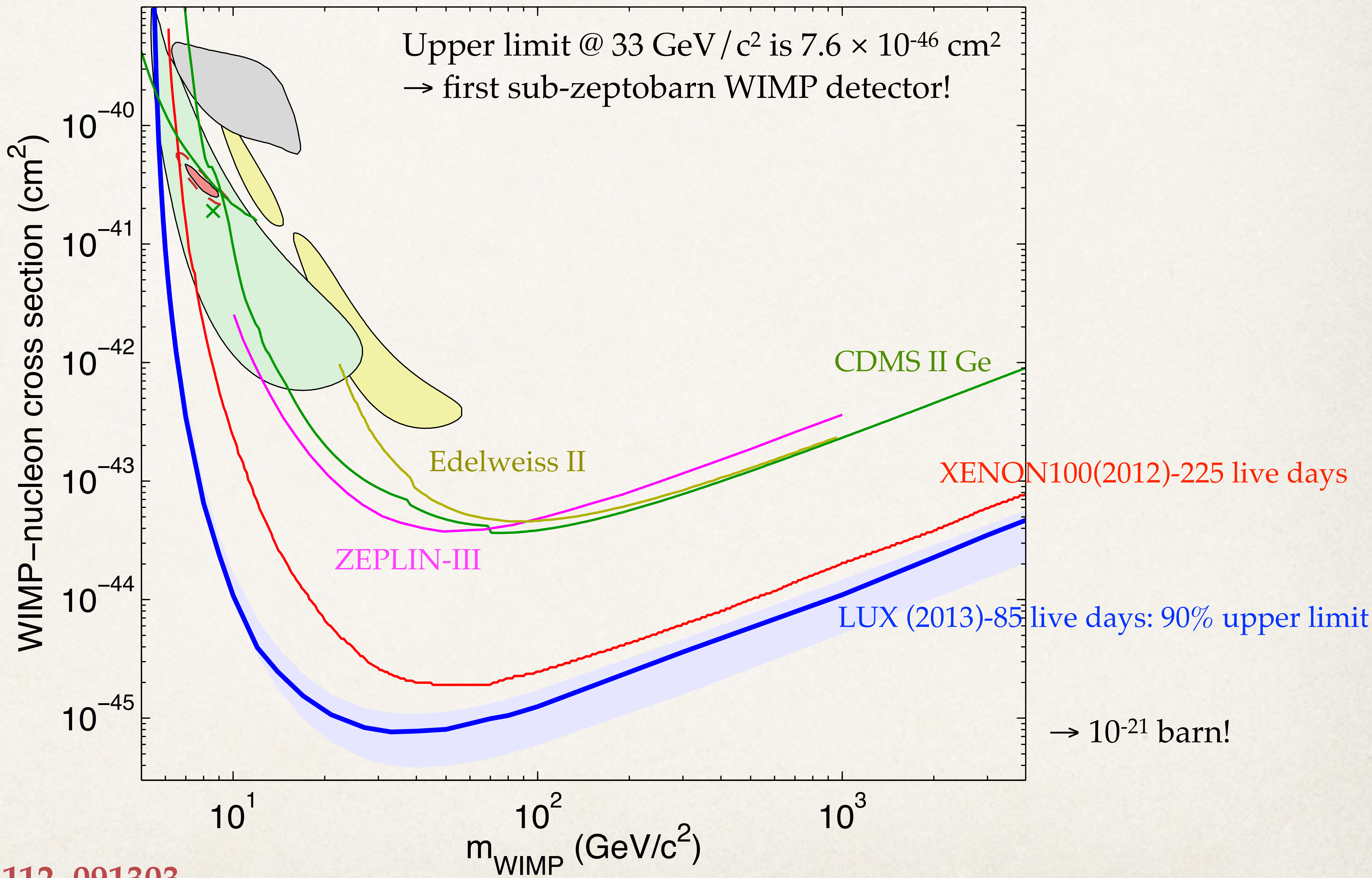
conservative S1 pulse identification > 50%

2 < S1 < 30 phe

avoid ^{127}Xe 5 keVee activation

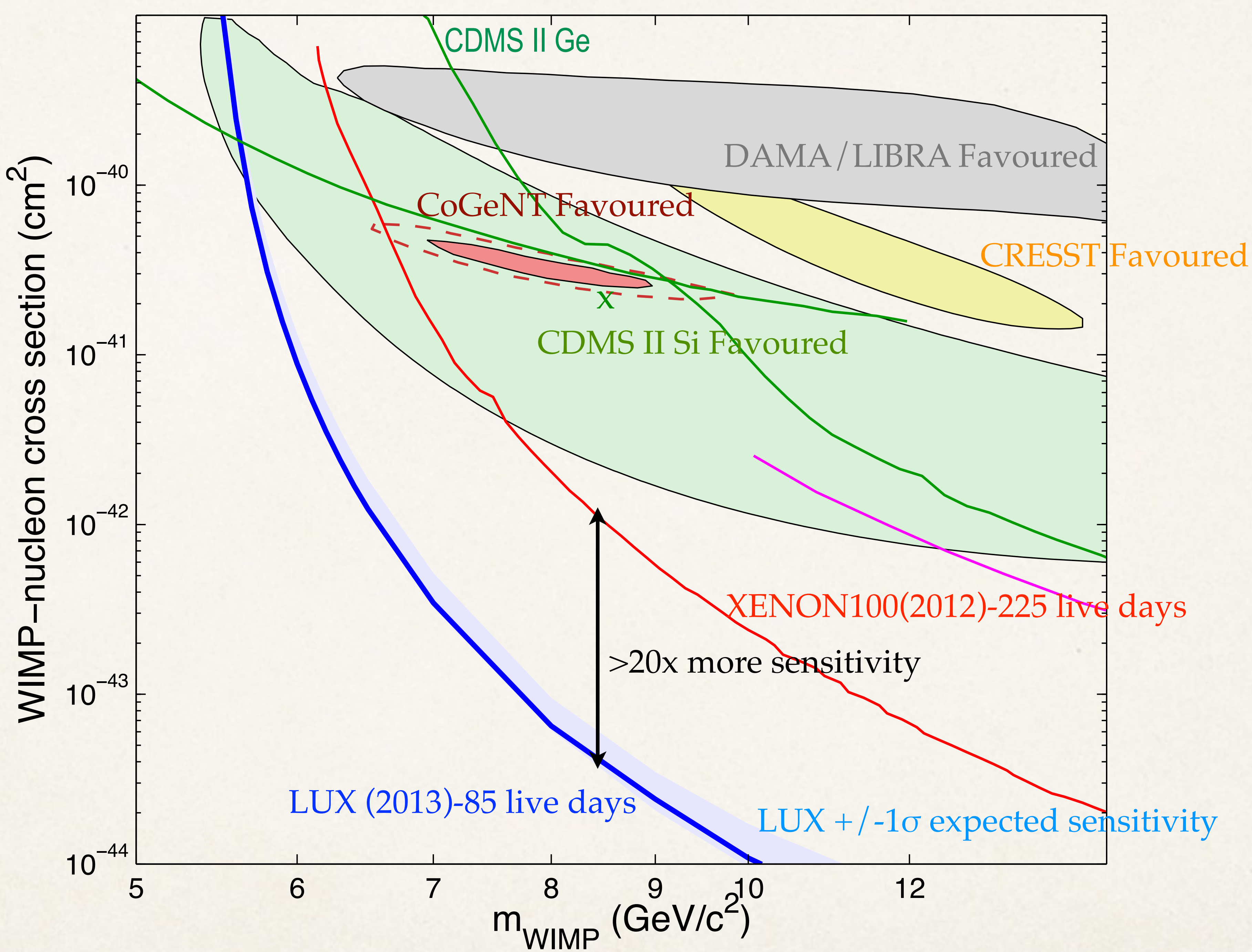


Spin-independent limit



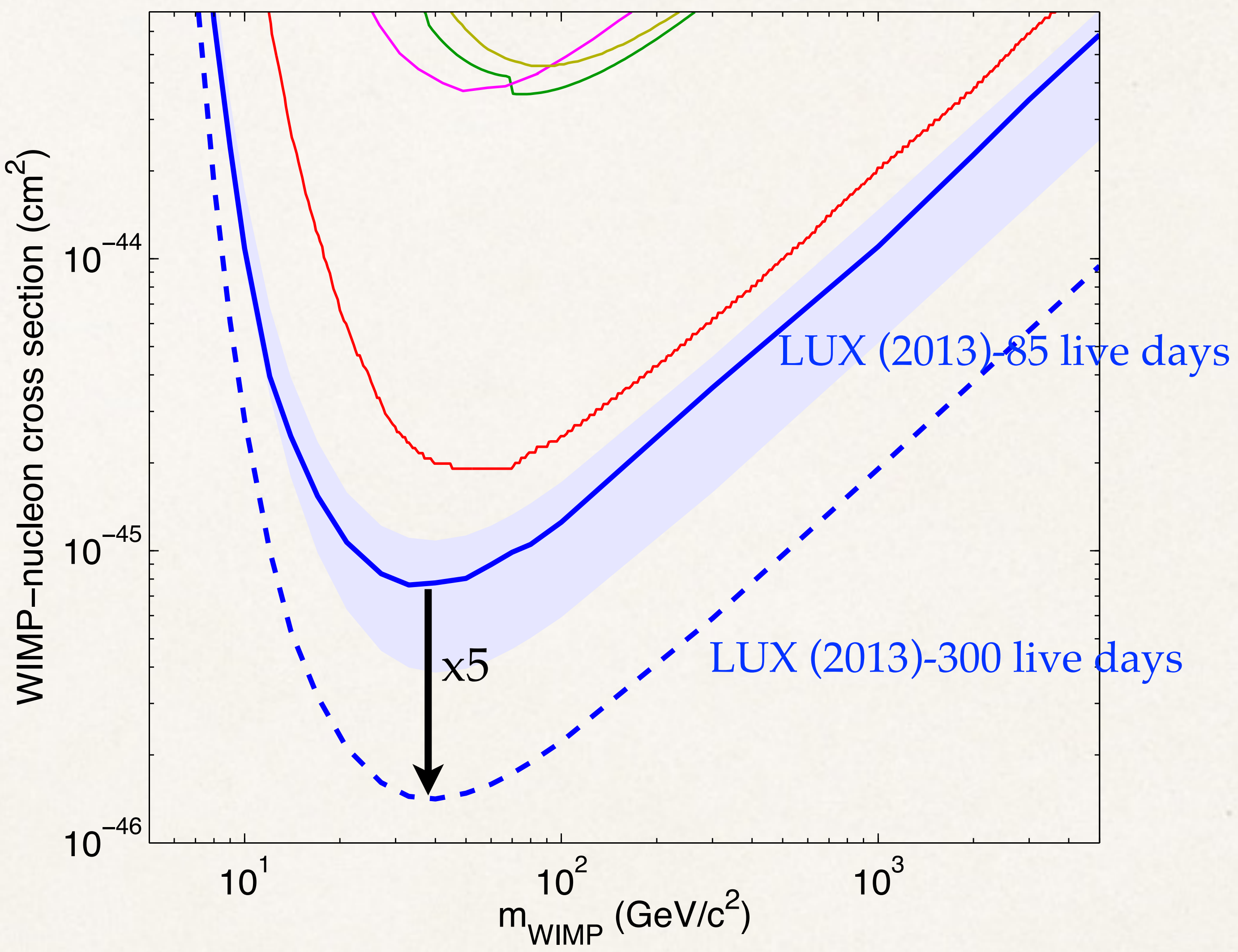
Phys. Rev. Lett. 112, 091303 (arXiv:1310.8214)

Low-mass WIMPs excluded



Phys. Rev. Lett. 112, 091303 (arXiv:1310.8214)

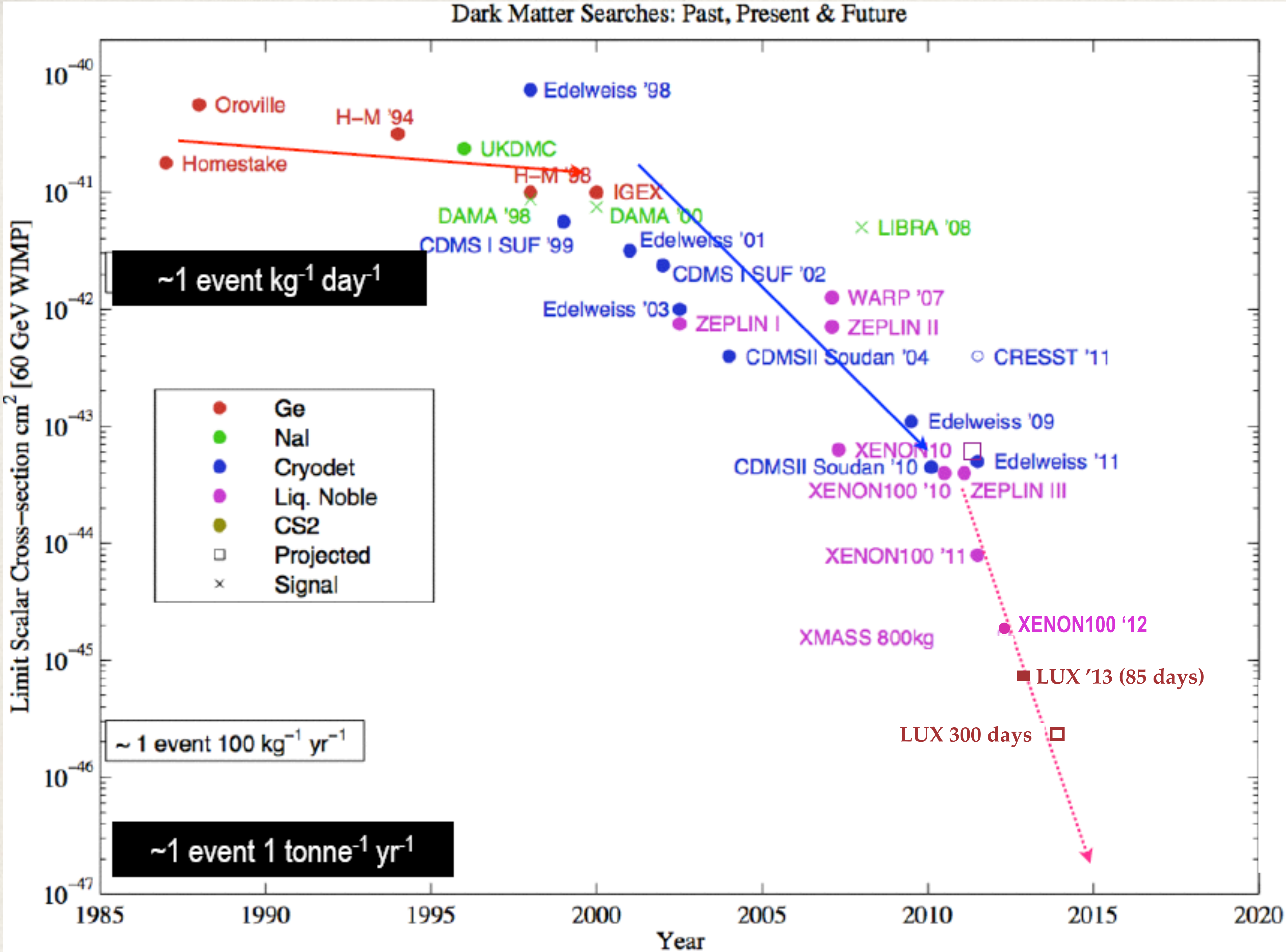
The near future: LUX 300 day run



- 300 day run planned for 2014/15
- Cosmogenic cool-down plus potential improvements (field, calibrations, …)
- Still not background limited: expect a factor of ~5 improvement in sensitivity

Summary

- With 85.3 live-days LUX set world's best limit on spin-independent scattering:
  - 90% UL 7.6×10^{-46} cm2 @ 33 GeV/c^2 → first sub-zeptobarn WIMP detector
  - Low-mass WIMPs fully excluded by LUX
  - Results paper published on PRL, expect more to follow (Phys. Rev. Lett. 112, 091303, arXiv:1310.8214)
- LIP team involved in all areas of the experiment
  - Hardware: LN system (F. Neves) and Slow Control (V. Solovov)
  - Group coordination: Detector operations (F. Neves)
On-site science operations (L. deViveiros)
Analysis group (L. deViveiros)
Data processing group (A. Lindote)
  - Data analysis: Position reconstruction (C. Silva, V. Solovov), Efficiencies (A. Lindote)
Software for the data processing chain (C. Silva, F. Neves, A. Lindote)
  - On-site work during installation, commissioning, calibration and data taking: >300 per/y
- LUX at the frontier of dark matter direct detection
  - **exciting times ahead with the 300 day run!**



Dark Matter Searches: Past, Present & Future
Limit Scalar Cross−section cm^2 [60 GeV WIMP]
Year
Oroville
H−M '94
Homestake
UKDMC
Edelweiss '98
H−M '98
IGEX
DAMA '98
DAMA '00
CDMS I SUF '99
Edelweiss '01
CDMS I SUF '02
LIBRA '08
WARP '07
ZEPLIN II
Edelweiss '03
ZEPLIN I
CDMSII Soudan '04
CRESST '11
~1 event kg^{-1} day^{-1}
Ge
NaI
Cryodet
Liq. Noble
CS2
Projected
Signal
Edelweiss '09
XENON10
Edelweiss '11
CDMSII Soudan '10
XENON100 '10
ZEPLIN III
XENON100 '11
XENON100 '12
XMASS 800kg
LUX '13 (85 days)
LUX 300 days
~ 1 event 100 kg^{-1} yr^{-1}
~1 event 1 tonne^{-1} yr^{-1}

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

Case Western

Thomas Shutt	PI, Professor
Dan Akerib	PI, Professor
Karen Gibson	Postdoc
Tomasz Biesiadzinski	Postdoc
Wing H To	Postdoc
Adam Bradley	Graduate Student
Patrick Phelps	Graduate Student
Chang Lee	Graduate Student
Kati Pech	Graduate Student

Imperial College London

Henrique Araujo	PI, Reader
Tim Sumner	Professor
Alastair Currie	Postdoc
Adam Bailey	Graduate Student

Lawrence Berkeley + UC Berkeley

Bob Jacobsen	PI, Professor
Murdock Gilchriese	Senior Scientist
Kevin Lesko	Senior Scientist
Carlos Hernandez Faham	Postdoc
Victor Gehman	Scientist
Mia Ihm	Graduate Student

Lawrence Livermore

Adam Bernstein	PI, Leader of Adv. Detectors Group
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

Xinhua Bai	PI, Professor
Tyler Liebsch	Graduate Student
Doug Tiedt	Graduate Student

SDSTA

David Taylor	Project Engineer
Mark Hanhardt	Support Scientist

Texas A&M

James White †	PI, Professor
Robert Webb	PI, Professor
Rachel Mannino	Graduate Student
Clement Sofka	Graduate Student

UC Davis

Mani Tripathi	PI, Professor
Bob Svoboda	Professor
Richard Lander	Professor
Britt Holbrook	Senior Engineer
John Thomson	Senior Machinist
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
Carmen Carmona	Postdoc
Curt Nehrkorn	Graduate Student
Scott Haselschwardt	Graduate Student

University College London

Chamkaur Ghag	PI, Lecturer
Lea Reichhart	Postdoc

Collaboration Meeting, Sanford Lab, March 2014

University of Edinburgh

Alex Murphy	PI, Reader
Paolo Beltrame	Research Fellow
James Dobson	Postdoc

University of Maryland

Carter Hall	PI, Professor
Attila Dobi	Graduate Student
Richard Knoche	Graduate Student
Jon Balajthy	Graduate Student

University of Rochester

Frank Wolfs	PI, Professor
Wojtek Skutski	Senior Scientist
Eryk Druszkiewicz	Graduate Student
Mongkol Moongweluwan	Graduate Student

University of South Dakota

Dongming Mei	PI, Professor
Chao Zhang	Postdoc
Angela Chiller	Graduate Student
Chris Chiller	Graduate Student
Dana Byram	*Now at SDSTA

Yale

Daniel McKinsey	PI, Professor
Peter Parker	Professor
Sidney Cahn	Lecturer/Research Scientist
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