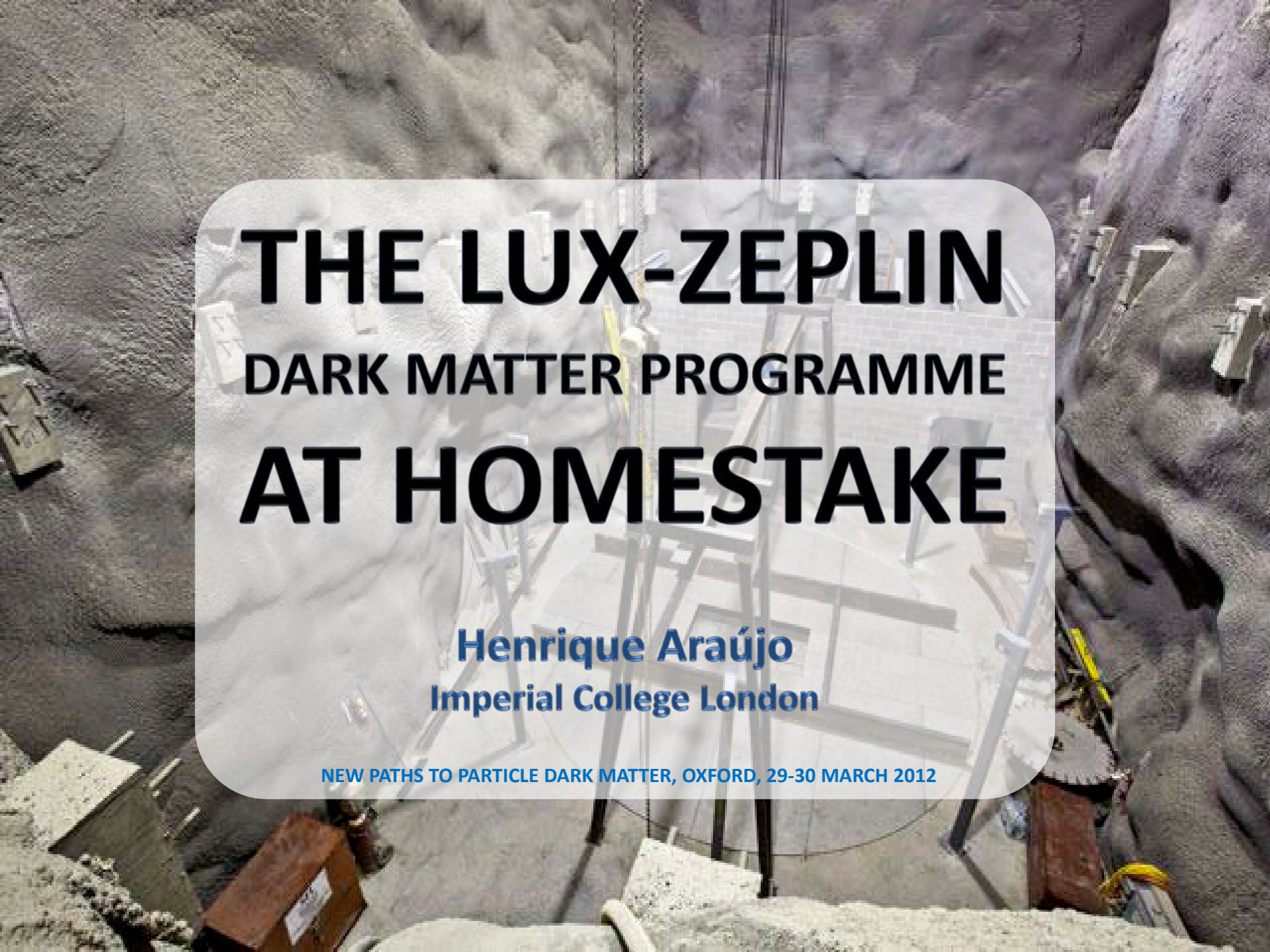


THE LUX-ZEPLIN DARK MATTER PROGRAMME AT HOMESTAKE

Henrique Araújo
Imperial College London

NEW PATHS TO PARTICLE DARK MATTER, OXFORD, 29-30 MARCH 2012

The LUX Collaboration

Brown

Richard Gaitskell	PI, Professor
Simon Fiorucci	Research Associate
Monica Pangilinan	Postdoc
Jeremy Chapman	Graduate Student
Carlos Hernandez Faham	Graduate Student
David Malling	Graduate Student
James Verbus	Graduate Student

Case Western

Thomas Shutt	PI, Professor
Dan Akerib	PI, Professor
Mike Dragowsky	Research Associate Professor
Tom Coffey	Research Associate
Carmen Carmona	Postdoc
Karen Gibson	Postdoc
Adam Bradley	Graduate Student
Patrick Phelps	Graduate Student
Chang Lee	Graduate Student
Kati Pech	Graduate Student
Tim Ivancic	Graduate Student

Harvard

Masahiro Morii	PI, Professor
Michal Wlasenko	Postdoc
John Oliver	Electronics Engineer

Lawrence Berkeley + UC Berkeley

Murdoch Gilchriese	Senior Physicist
Bob Jacobsen	PI, Professor
David Taylor	Engineer
Mia ihm	Graduate Student

Lawrence Livermore

Adam Bernstein	PI, Leader of Adv. Detectors Group
Dennis Carr	Mechanical Technician
Kareem Kazkaz	Staff Physicist
Peter Sorensen	Postdoc

SD School of Mines

Xinhua Bai	PI, Professor
Mark Hanardt	Graduate Student

Collaboration was formed in 2007 and fully funded by DOE and NSF in 2008.

University of Maryland

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

Texas A&M

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

UC Davis

Mani Tripathi	PI, Professor
Robert Svoboda	Professor
Richard Lander	Professor
Britt Hollbrook	Senior Engineer
John Thomson	Senior Machinist
Matthew Szydagis	Postdoc
Jeremy Mock	Graduate Student
James Morad	Graduate Student
Nick Walsh	Graduate Student
Michael Woods	Graduate Student
Sergey Uvarov	Graduate Student

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

University of South Dakota

Dongming Mei	PI, Professor
Wengchang Xiang	Postdoc
Chao Zhang	Postdoc
Dana Byram	Graduate Student
Chris Chiller	Graduate Student
Angela Chiller	Graduate Student

University of Rochester

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

UC Santa Barbara

Harry Nelson	PI, Professor
Mike Witherell	Professor
Dean White	Engineer
Susanne Kyre	Engineer

Yale

Daniel McKinsey	PI, Professor
Peter Parker	Professor
James Nikkel	Research Scientist
Sidney Cahn	Lecturer/Research Scientist
Alexey Lyashenko	Postdoc
Ethan Bernard	Postdoc
Richard Ott	Postdoc
Blair Edwards	Postdoc
Louis Kastens	Graduate Student
Nicole Larsen	Graduate Student
Evan Pease	Graduate Student

The LUX Collaboration

Brown — XENON10

Richard Gaitskell	PI, Professor
Simon Fiorucci	Research Associate
Monica Pangilinan	Postdoc
Jeremy Chapman	Graduate Student
Carlos Hernandez Faham	Graduate Student
David Malling	Graduate Student
James Verbus	Graduate Student

Case Western — XENON10

Thomas Shutt	PI, Professor
Dan Akerib	PI, Professor — CDMS-II
Mike Dragowsky	Research Associate Professor
Tom Coffey	Research Associate
Carmen Carmona	Postdoc
Karen Gibson	Postdoc
Adam Bradley	Graduate Student
Patrick Phelps	Graduate Student
Chang Lee	Graduate Student
Kati Pech	Graduate Student
Tim Ivancic	Graduate Student

Harvard

Masahiro Morii	PI, Professor
Michal Wlasenko	Postdoc
John Oliver	Electronics Engineer

Lawrence Berkeley + UC Berkeley

Murdoch Gilchriese	Senior Physicist
Bob Jacobsen	PI, Professor
David Taylor	Engineer
Mia ihm	Graduate Student

Lawrence Livermore — XENON10

Adam Bernstein	PI, Leader of Adv. Detectors Group
Dennis Carr	Mechanical Technician
Kareem Kazkaz	Staff Physicist
Peter Sorensen	Postdoc

SD School of Mines

Xinhua Bai	PI, Professor
Mark Hanardt	Graduate Student

Collaboration was formed in 2007 and fully funded by DOE and NSF in 2008.

University of Maryland

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

Texas A&M — ZEPLIN-II

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

UC Davis

Mani Tripathi	PI, Professor
Robert Svoboda	Professor
Richard Lander	Professor
Britt Hollbrook	Senior Engineer
John Thomson	Senior Machinist
Matthew Szydagis	Postdoc
Jeremy Mock	Graduate Student
James Morad	Graduate Student
Nick Walsh	Graduate Student
Michael Woods	Graduate Student
Sergey Uvarov	Graduate Student

LIP Coimbra — ZEPLIN-II, -III

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

University of South Dakota

Dongming Mei	PI, Professor
Wengchang Xiang	Postdoc
Chao Zhang	Postdoc
Dana Byram	Graduate Student
Chris Chiller	Graduate Student
Angela Chiller	Graduate Student

University of Rochester — ZEPLIN-II

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

UC Santa Barbara — CDMS-II

Harry Nelson	PI, Professor
Mike Witherell	Professor
Dean White	Engineer
Susanne Kyre	Engineer

Yale — XENON10

Daniel McKinsey	PI, Professor
Peter Parker	Professor
James Nikkel	Research Scientist
Sidney Cahn	Lecturer/Research Scientist
Alexey Lyashenko	Postdoc
Ethan Bernard	Postdoc
Richard Ott	Postdoc
Blair Edwards	Postdoc
Louis Kastens	Graduate Student
Nicole Larsen	Graduate Student
Evan Pease	Graduate Student

The ZEPLIN-III Collaboration
(post Boulby programme)

- **Imperial College London**
  - H. Araujo (A), T. Sumner (A), A. Currie (PG)
- **Rutherford Appleton Laboratory**
  - P. Majewski
- **Edinburgh University**
  - A. Murphy (A), A. Hollingsworth (PG), L. Reichhart (PG)
- **ITEP-Moscow** (joined Russian DM/CNS experiment)
  - D. Akimov (A), V. Belov, A. Burenkov, A. Kobyakin, A. Kovalenko, V. Stekhanov
- **LIP-Coimbra** (already joined LUX350 in 2011)
  - M.I. Lopes (A), J. Pinto da Cunha (A), V. Solovov (RF), L. de Viveiros (RA), A. Lindote (RA), F. Neves (RA), C. Silva (RA)

WIMP SEARCH TECHNOLOGY ZOO

Ionisation Detectors

Targets: Ge, Si, CS_2, CdTe

CoGeNT, DRIFT, DM-TPC

GENIUS, HDMS, IGEX, NEWAGE

Light & Ionisation Detectors

Targets: Xe, Ar

ArDM, Darkside, LUX, **LZ**,

WARP, XENON, ZEPLIN

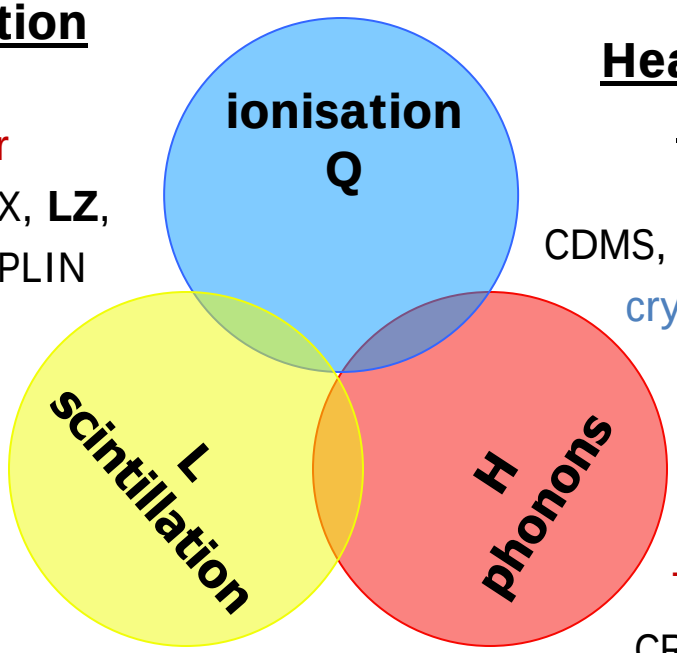
cold (LN_2)

Heat & Ionisation Bolometers

Targets: Ge,Si

CDMS, EDELWEISS, EURECA

cryogenic (<50 mK)



Scintillators

Targets: NaI, Xe, Ar

ANAIS, CLEAN, DAMA,

DEAP, KIMS, LIBRA,

NAIAD, XMASS, ZEPLIN-I

Bolometers

Targets: Ge, Si, Al_2O_3, TeO_2

CRESST-I, CUORE, CUORICINO

Light & Heat Bolometers

Targets: $CaWO_4$, BGO, Al_2O_3

CRESST, ROSEBUD

cryogenic (<50 mK)

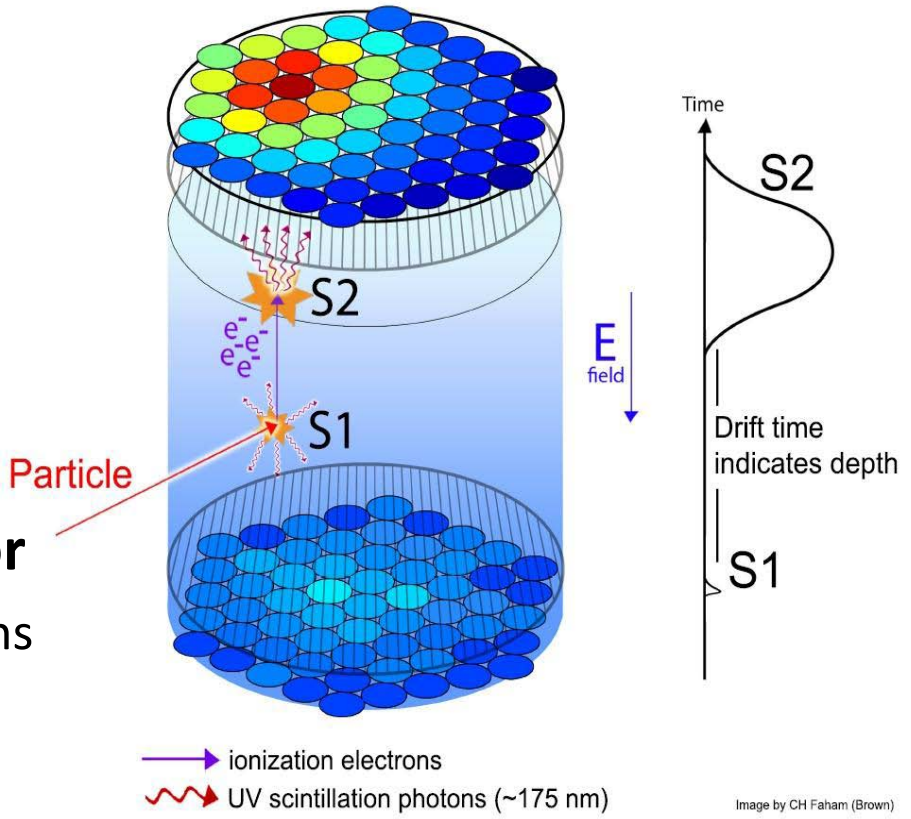
Bubbles & Droplets

CF_3Br, CF_3I, C_3F_8, C_4F_{10}

COUPP, PICASSO, SIMPLE

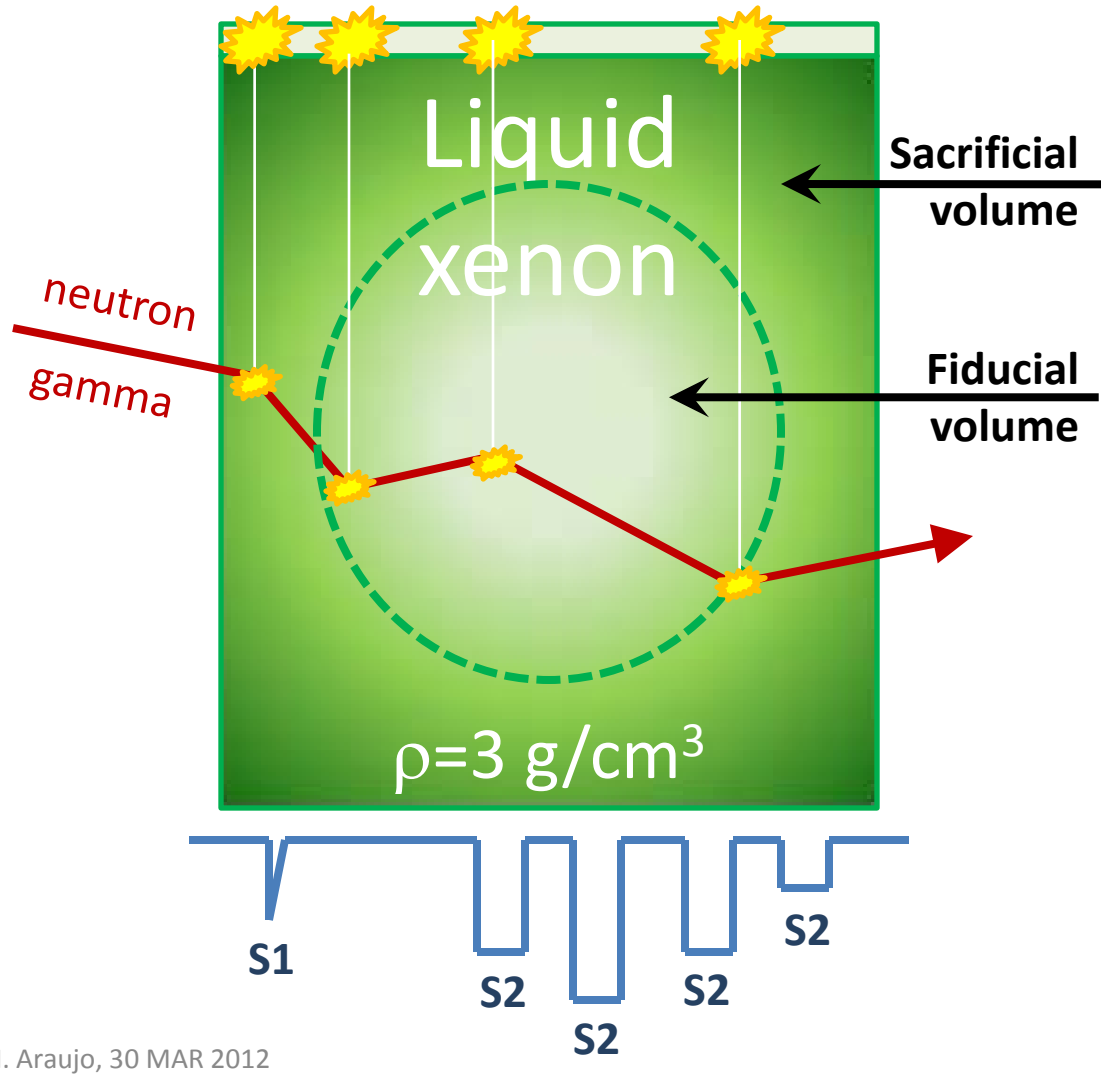
TWO-PHASE XENON DETECTORS

- **S1: LXe is an excellent scintillator**
  - Density: 3 g/cm^3
  - Light yield: ~70 ph/keV (0 field)
  - Scintillation light: 175 nm (VUV)
  - **Nuclear recoil threshold ~5-10 keV**
- **S2: Even better ionisation detector**
  - Sensitive to single ionisation electrons
  - **Nuclear recoil threshold ~1 keV**



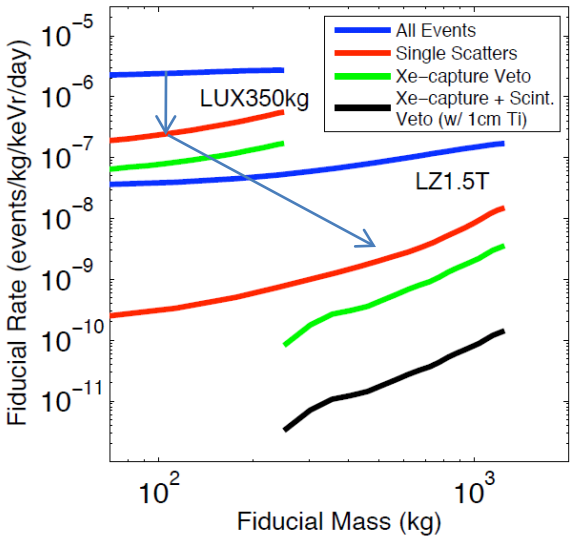
- **And a great WIMP target too**
  - Scalar WIMP-nucleon scattering rate dR/dE~A^2
  - Odd-neutron isotopes (^{129}Xe, ^{131}Xe) enable spin-dependent sensitivity
  - Excellent ionisation threshold: 'light WIMP' searches using S2 only
  - No intrinsic backgrounds (^{85}Kr can be removed effectively)

SELF-SHIELDING
with noble liquids

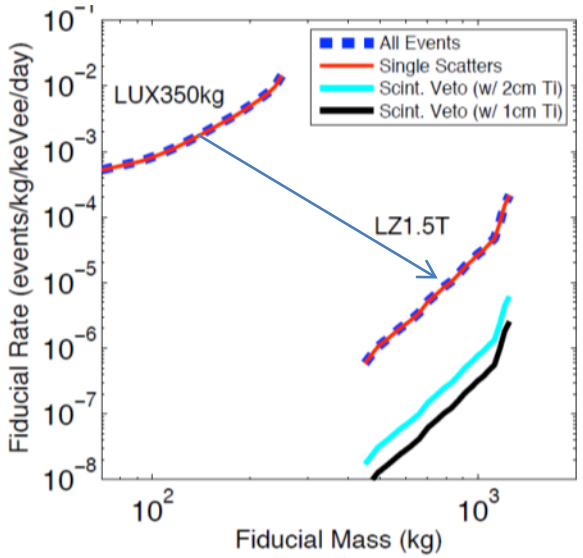


LUX → LUX-ZEPLIN 1.5t

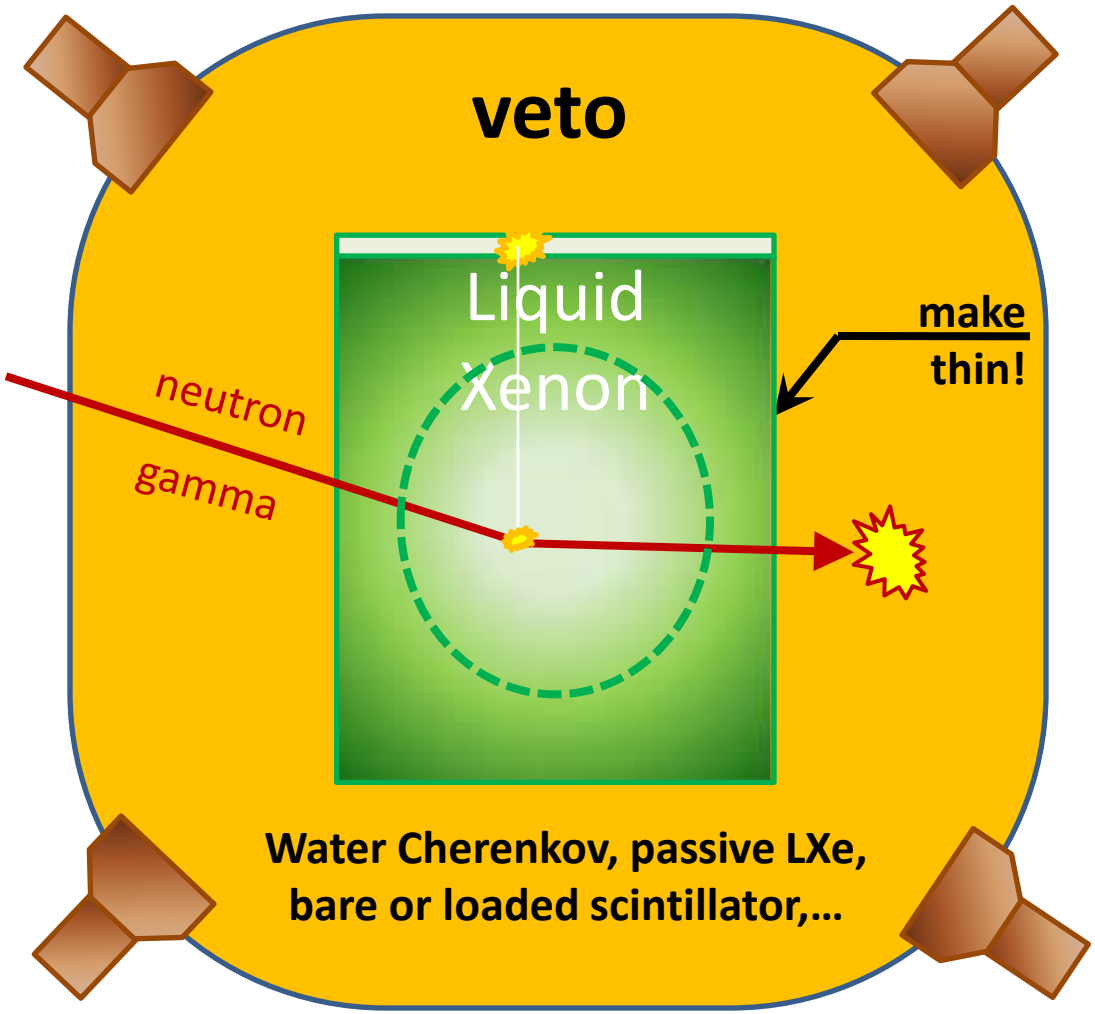
Neutrons (5-25 keV)



Gammas (5-25 keV)

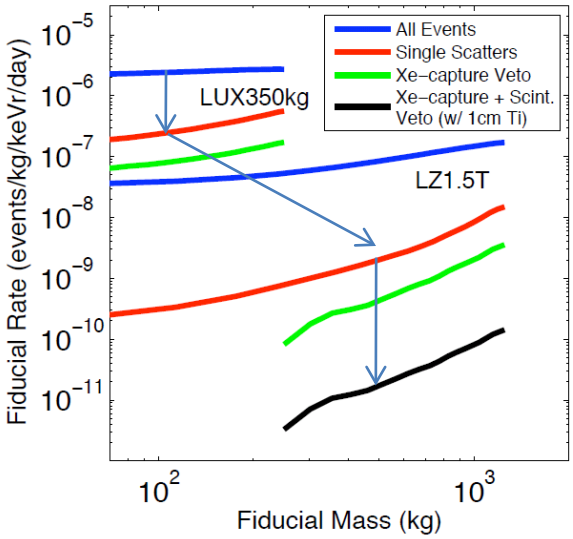


VETO DETECTOR
around WIMP target

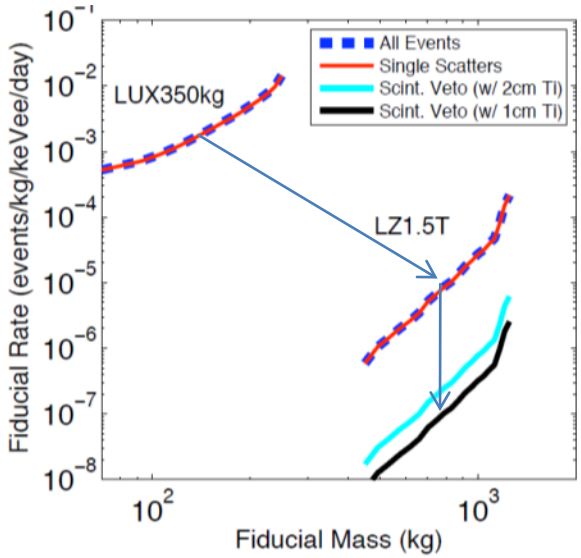


LUX → LUX-ZEPLIN 1.5t

Neutrons (5-25 keV)

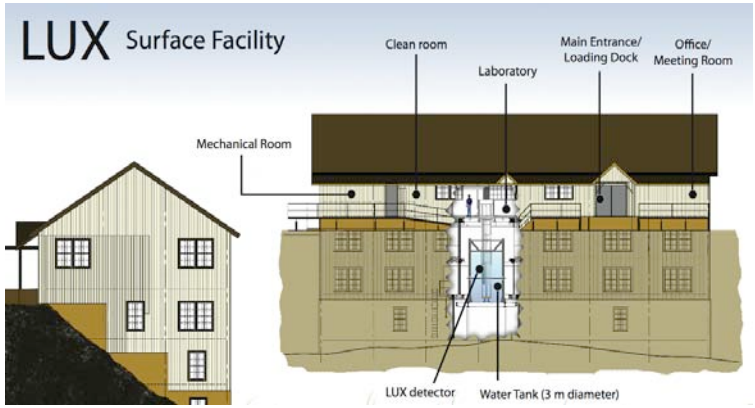


Gammas (5-25 keV)



ZEPLIN→LUX→LUX-ZEPLIN: STATUS

- MOU between ZEPLIN-III and LUX groups signed in 2008
- Final results from ZEPLIN-III published Jan. 2012
- UK-led ZEPLIN programme at Boulby completed (2001-2011)
  - Pioneering xenon technology, competitive results from 3 experiments!
- LUX350 tested in water tank on the surface at Homestake
- Beneficial occupancy of Davis Cavern April 2012
- World leading sensitivity within 2012/13

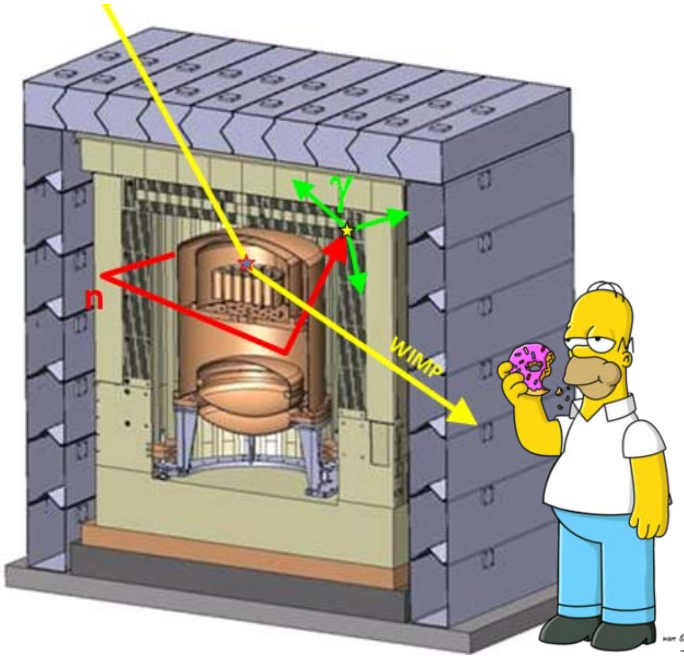


- LZ design progressing (targeting 'G2 downselect' process in US)
- 7 tonne Xe mass envisaged, plus active veto (to fit Davis water tank)

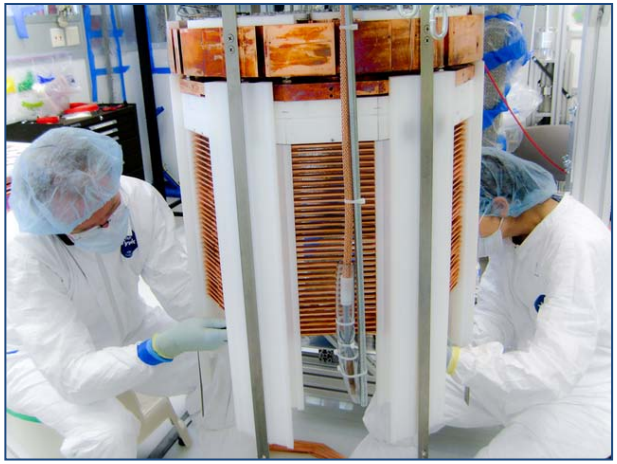
ZEPLIN-III @BOULBY

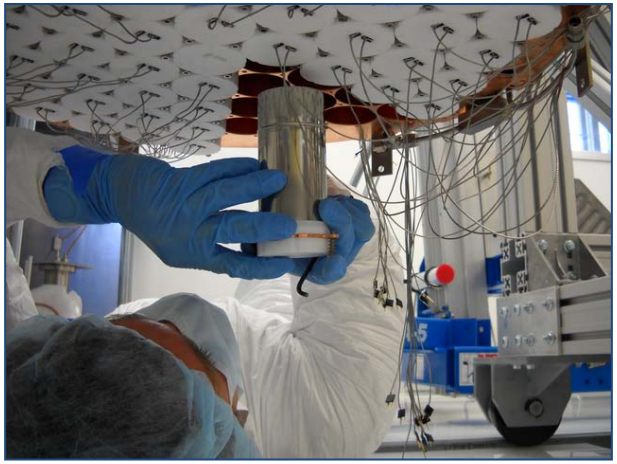
- Two science runs (2008 and 2010/11) set world class results in WIMP scattering (SI, SD, IDM)
- First ever year-long underground run of a noble liquid

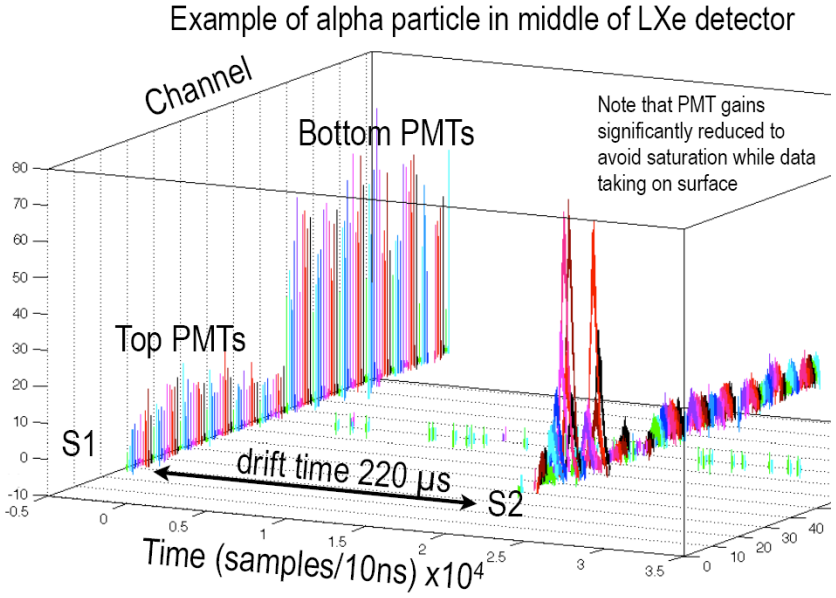
- Only high-field results to-date
- Best ER/NR discrimination LXe
- Huge experience gained with today's leading WIMP technology



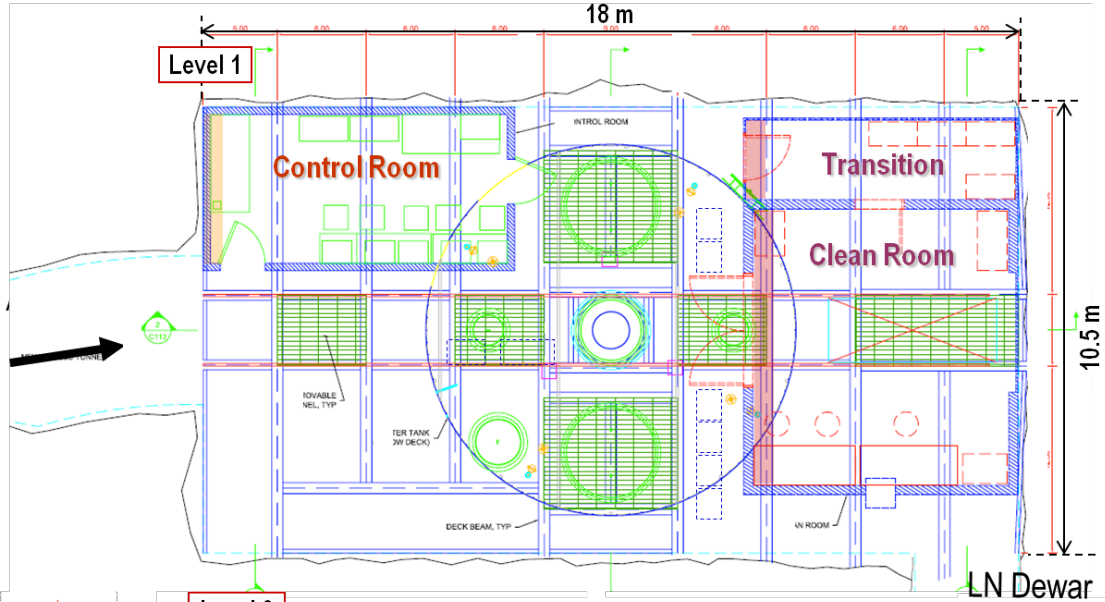
LUX350 – TRIED & TESTED & READY TO GO

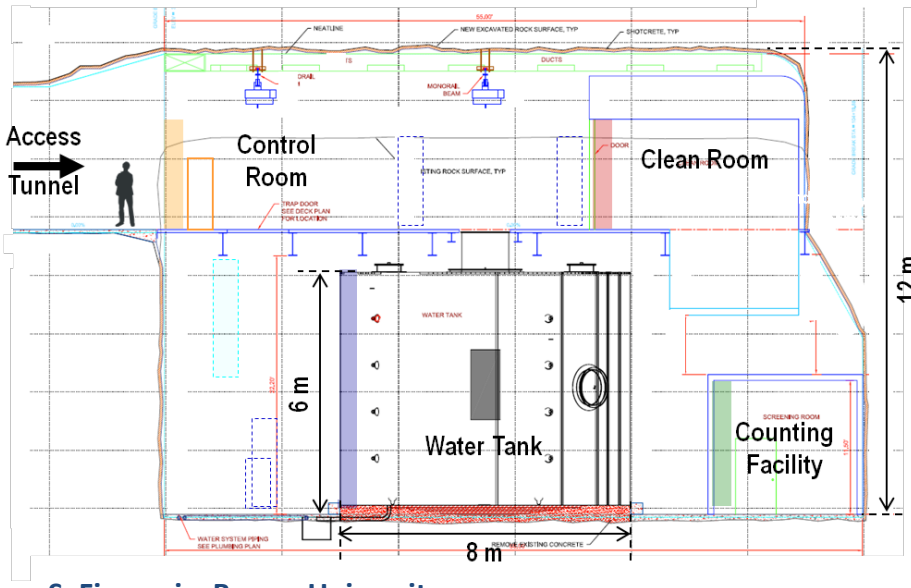


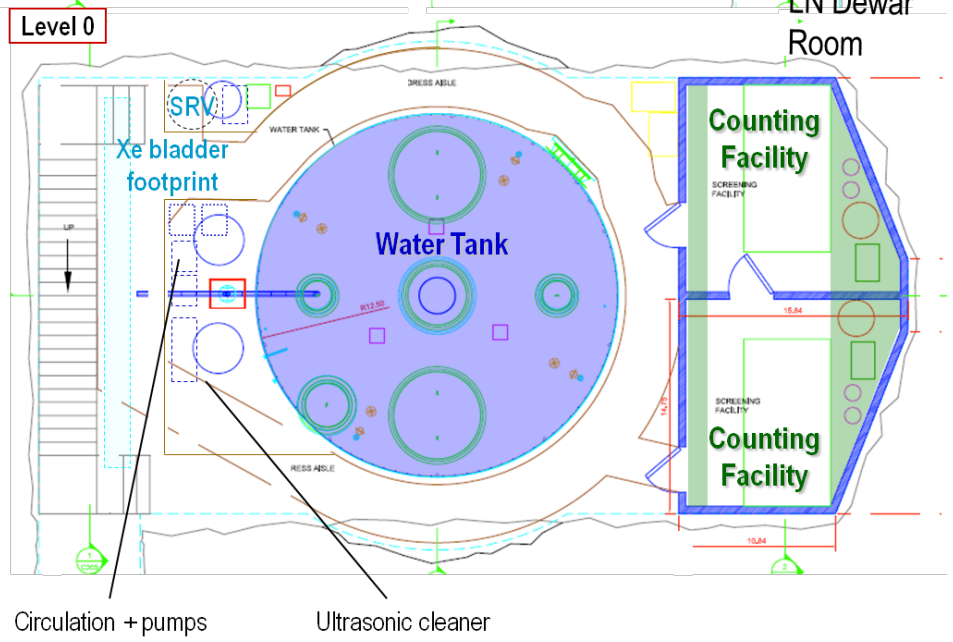




Sanford Laboratory
Davis Cavern - 4850 ft

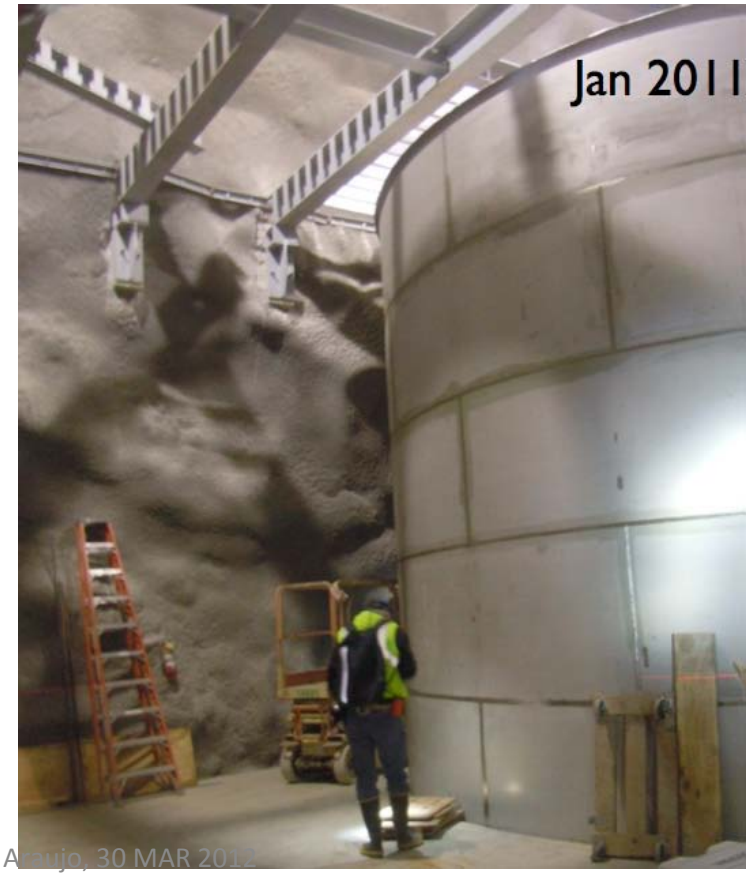






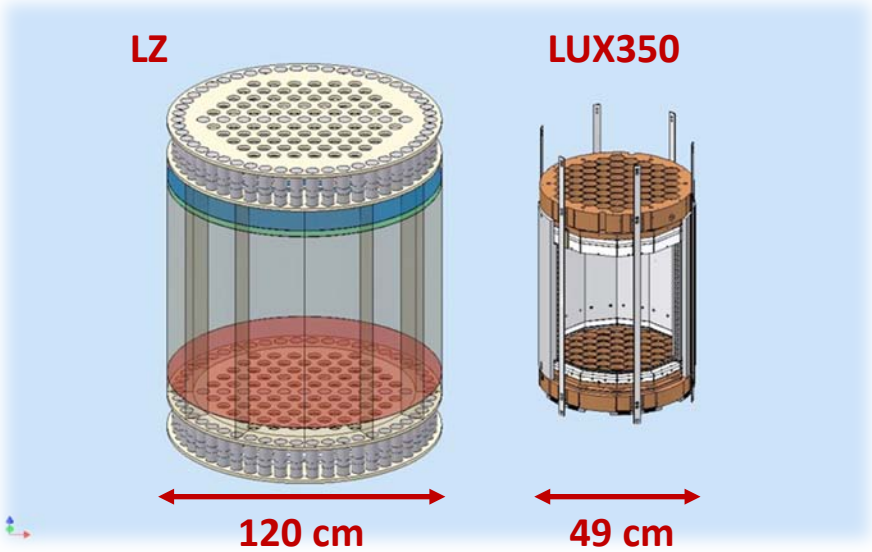
S. Fiorucci – Brown University

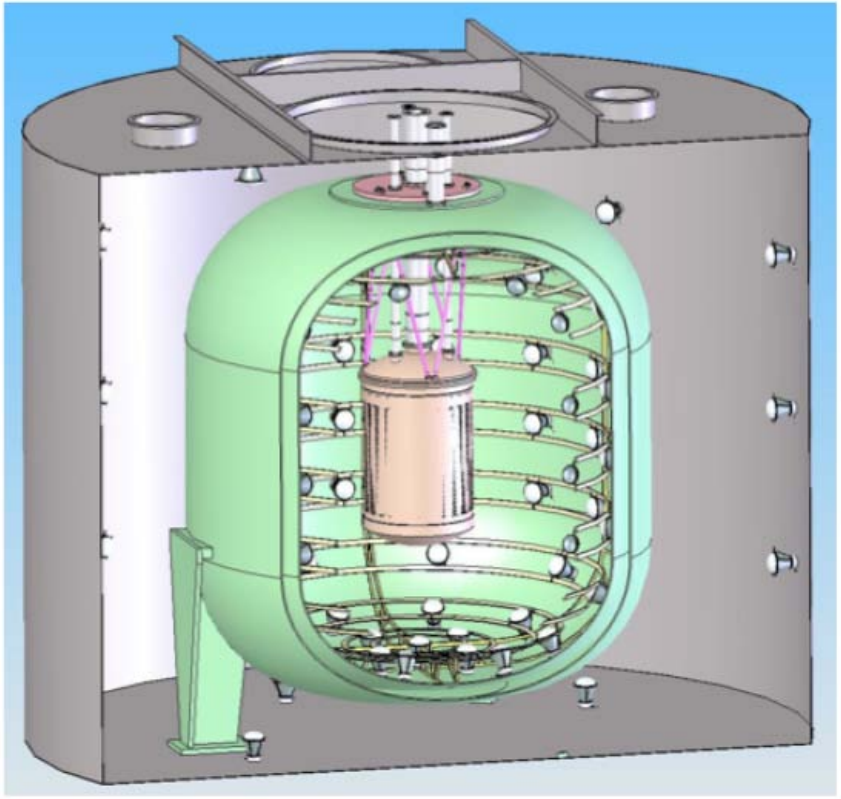
DAVIS COMPLEX AT HOMESTAKE



LZ DESIGN

- **Concept design: 7 tonne active xenon TPC in Davis water tank**
  - Huge n/γ self-shielding factors achievable with very compact system
  - Sensible scale-up of LUX350 (fact: successful programmes have been progressive ones!)
  - 15x mass factor (only 2.5x linear); reasonable HV and e-lifetime requirements
- Active shield: instrumented Xe skin + scintillator + water
- Background-free run feasible
  - Assumed modest discrim. (99.75%)





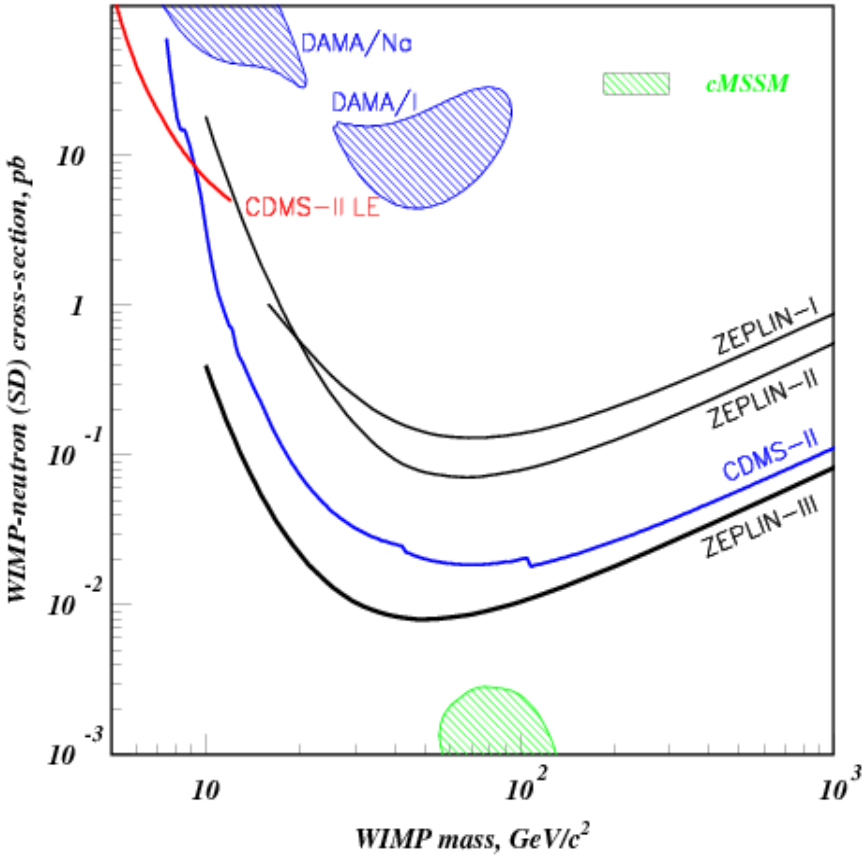
LZ TIMESCALES: US "G2 DOWNSELECT"

Second generation direct search experiments

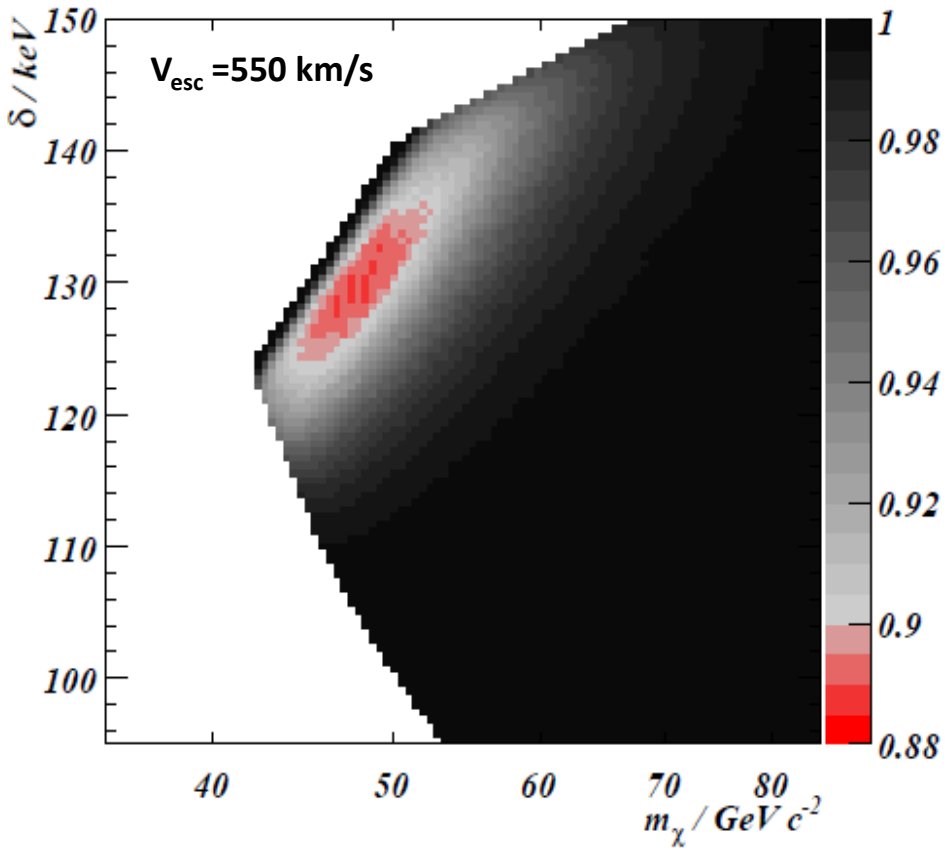
- DOE proposal by July 2012
  - 1 year funding for R&D, including pre-conceptual design and work to reduce scientific, technical or cost risks
  - No experiments to enter project phase during this year of funding
- NSF proposal by May 2012
  - 1 year funding for R&D, engineering and design
- **Summer 2013: project down-selection**
  - Coordinated between the two agencies
- Construction funds in 2014-16 for selected G2 projects (2 large)
  - $29M from DOE (increase under discussion); probably similar from NSF
- Exploitation phase from 2017
  - Scalar cross-section reach 10^{-11} pb (10^{-47} cm^2) in <1 year run
- **STFC reviewing UK involvement (£6M is ~1/3 of G2 experiment)**

ZEPLIN→LUX→LUX-ZEPLIN: SCIENCE

WORLD STATUS: SD WIMP-NEUTRON



INELASTIC DARK MATTER



Z1: Alner *et al.*, Proc. 5th Int. W. IDM: 218 (2005)

Z2: Alner *et al.*, Phys. Lett. B 653: 161 (2007).

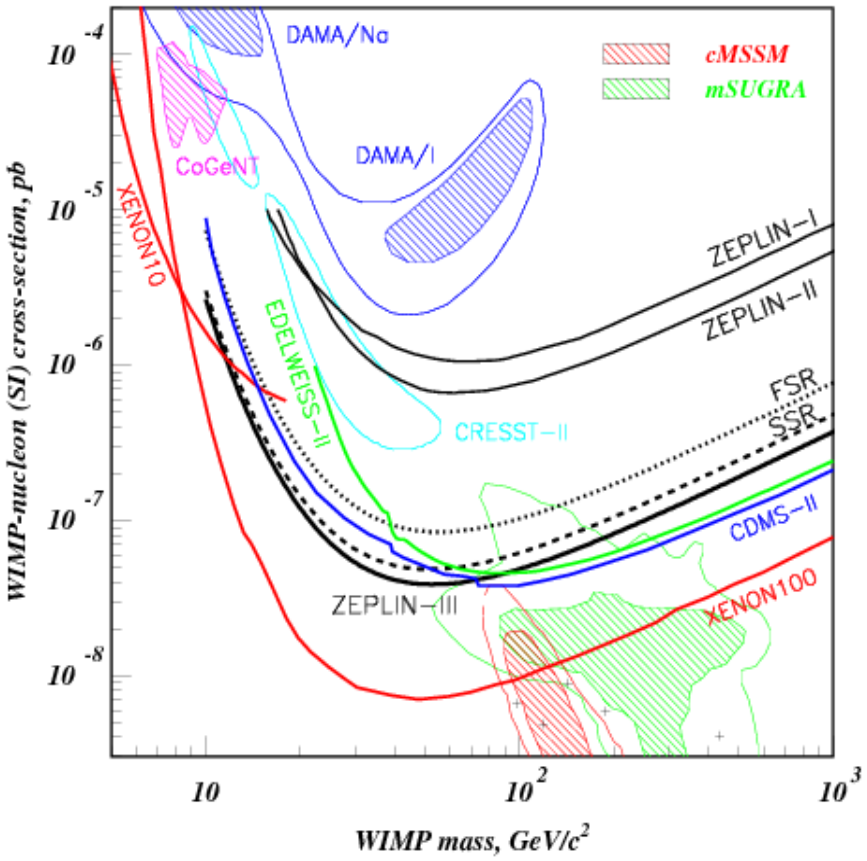
Z3: Lebedenko *et al.*, Phys. Rev. Lett. 103: 151302 (2009)

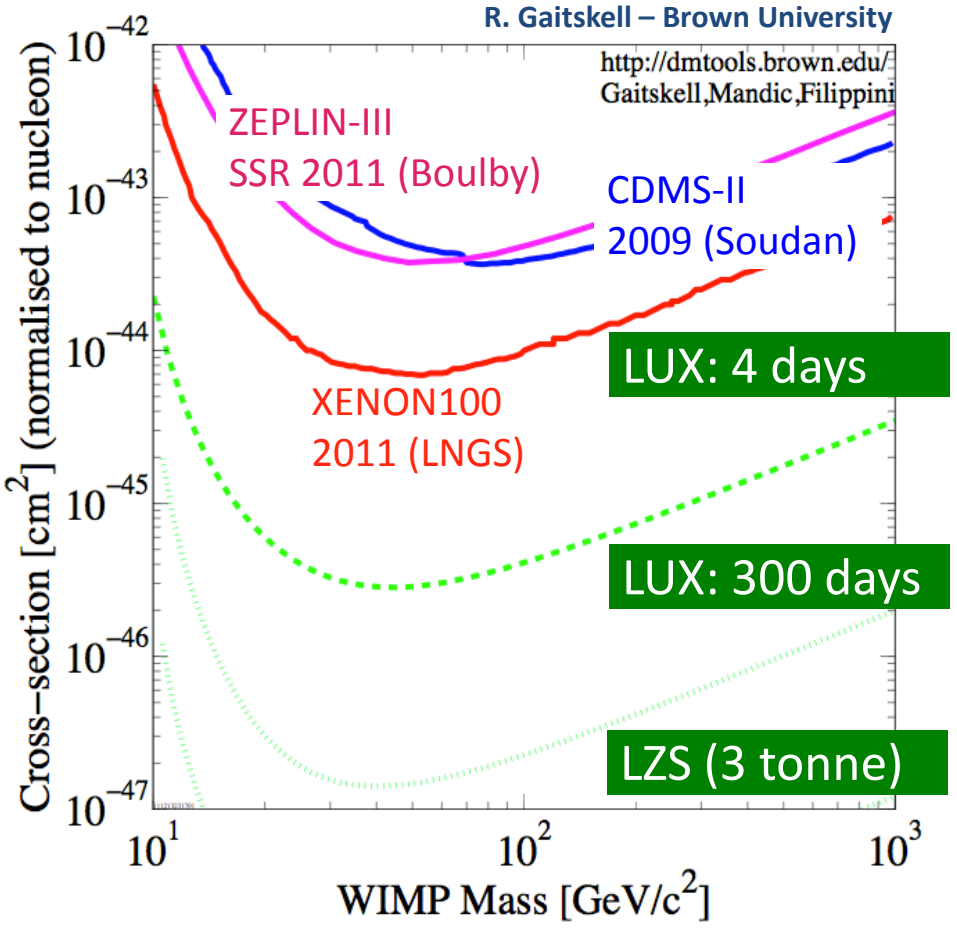
Z3: Akimov *et al.*, Phys. Lett. B. 709: 14 (2012)

Z3: Akimov *et al.*, Phys. Lett. B. 692: 180 (2010)

ZEPLIN→LUX→LUX-ZEPLIN: SCIENCE

WORLD STATUS: SPIN-INDEPENDENT





Z1: Alner *et al.*, Astropart. Phys. 23: 244 (2005)

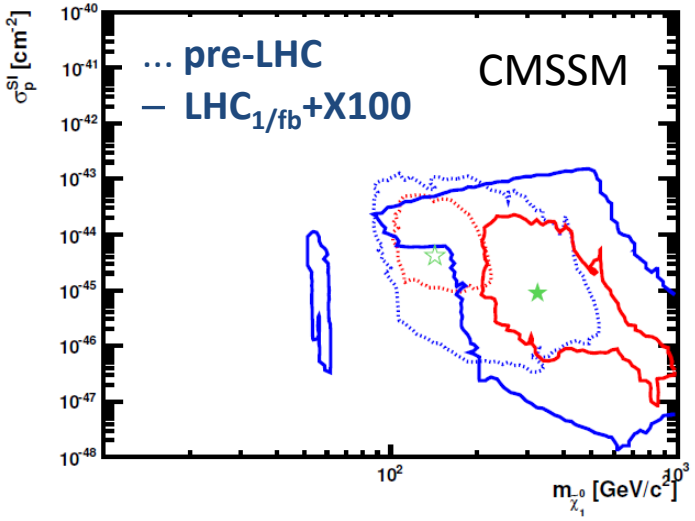
Z2: Alner *et al.*, Astropart. Phys. 28: 287 (2007)

Z3: Lebedenko *et al.*, Phys. Rev. D 80: 052010 (2009)

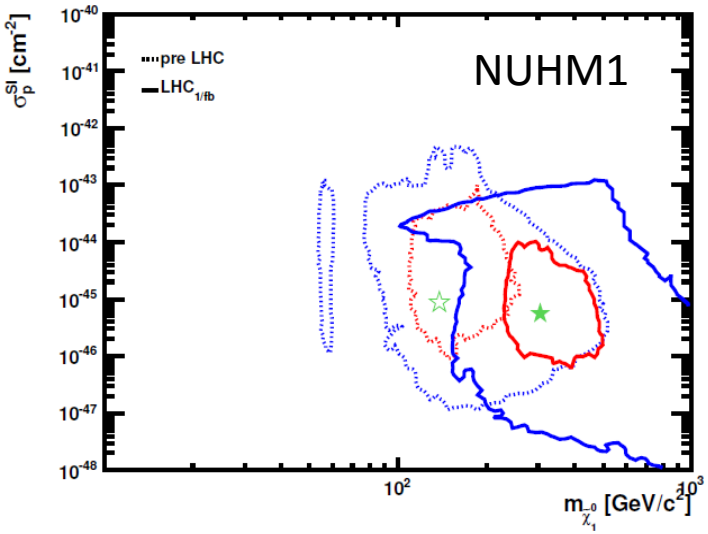
Z3: Akimov *et al.*, Phys. Lett. B. 709: 14 (2012)

SUSY, THE LHC & XENON(100)

Buchmuller et al, arXiv:1110.3568



(Frequentist/MasterCode)



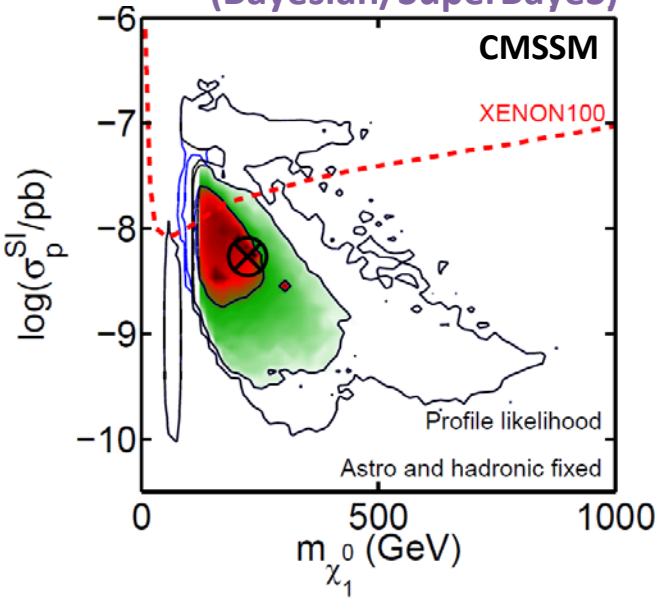
XENON100 result had significant impact on LHC-driven SUSY searches so far

LUX350 data will have dramatic effect in one year's time

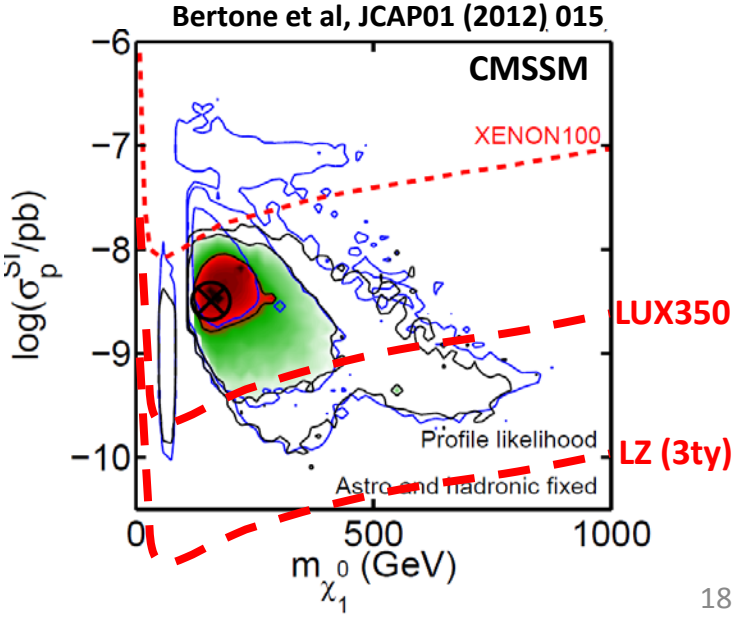
LZ can cover CMSSM region by 2017 (including bits out of reach of the LHC)

Or provide stats to study positive signal

(Bayesian/SuperBayeS)



Bertone et al, JCAP01 (2012) 015



SUSY, THE LHC & XENON(100)

Bertone et al, JCAP01 (2012) 004

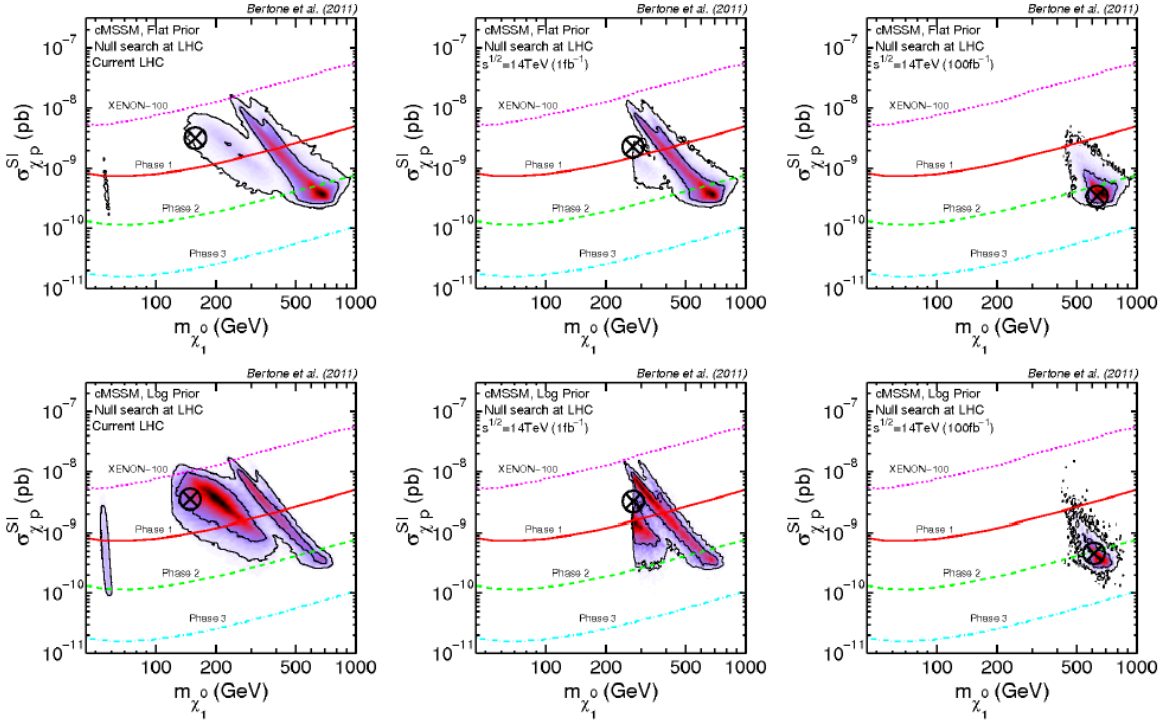


Figure 2. Favoured region in the cMSSM once current constraints and future null searches at the LHC are taken into account, for flat priors (top) and log priors (bottom). We assume null searches at the LHC with the following combinations of $\sqrt{s}$ and integrated luminosities (from left to right): current LHC, 14 TeV and 1 fb^{-1}, and 14 TeV and 100 fb^{-1}. The encircled black cross represents the best-fit point. The inner and outer solid, black contours delimit the 68% C.L. and 95% C.L. posterior regions respectively. We also show the current 90% C.L. exclusion limit from XENON-100 (magenta dotted), and the expected reach for for Phase 1 (solid red curve, expected to be reached by $\sim$2012), Phase 2 (dashed green curve) and Phase 3 (dash-dotted cyan curve, expected to to be reached around 2020) future direct detection experiments.

The 'nightmare scenario': no physics BSM at the LHC

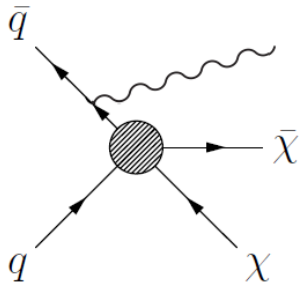
[…] phase 3 direct detection experiments will be able to probe entirely the favoured region of the cMSSM parameter space in the nightmare scenario of particle physics, therefore providing a unique opportunity to test SUSY even in case of null searches at the LHC.

[a Higgs detection] in the appropriate mass range would provide additional motivation to continue the study of Supersymmetry with astroparticle experiments.

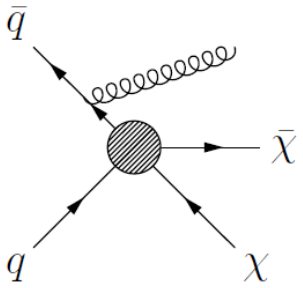
LHC & DIRECT SEARCHES

Monojec & Monophoton final state using 4.7 fb^{-1} of CMS data

S. Worm, CMS Moriond EWK "Hot Topic" 2012

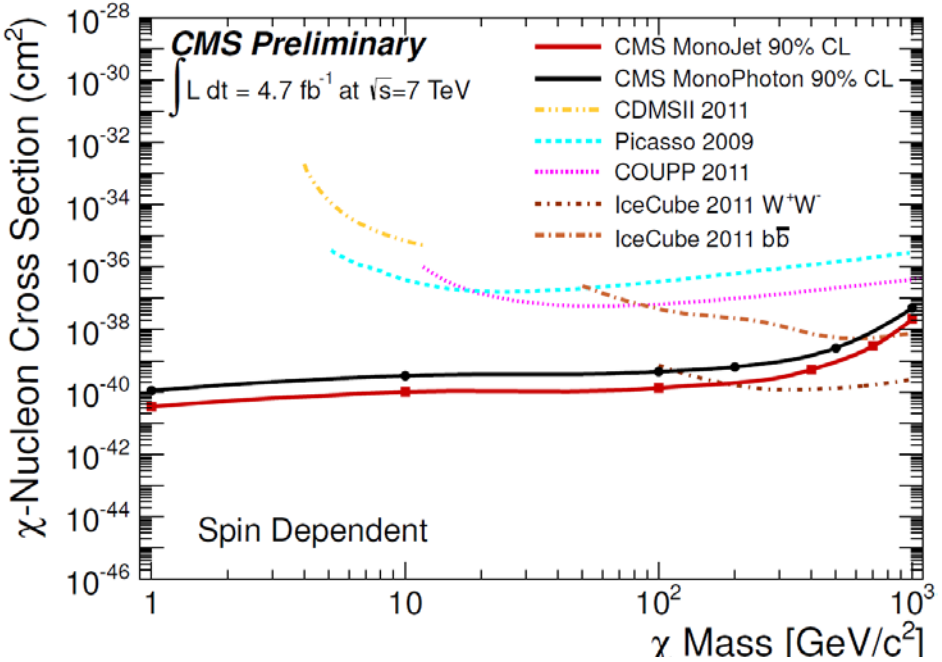


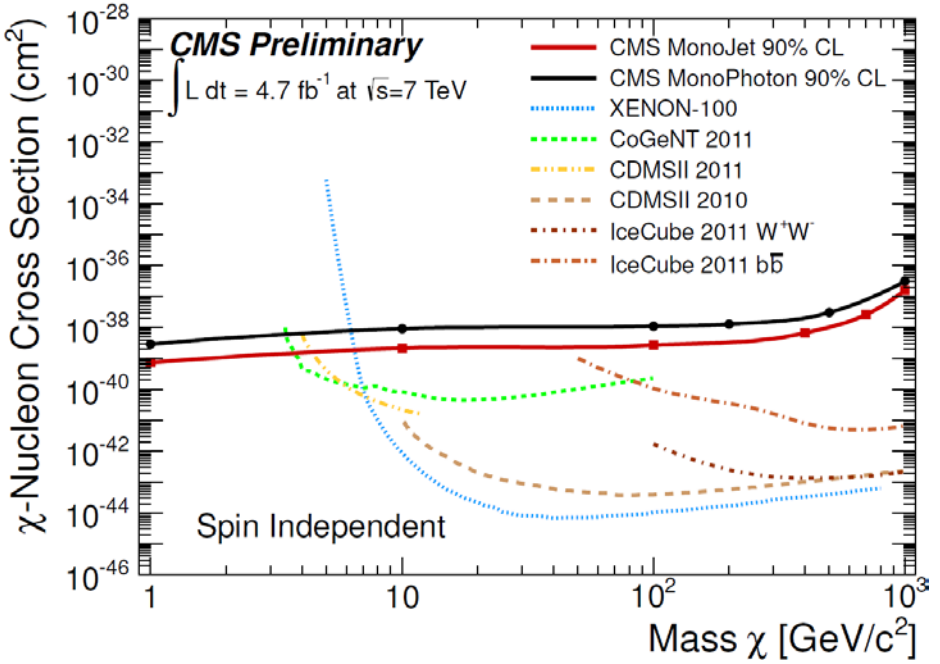
Monophoton + MET



Monojet + MET

EXO-11-059, EXO-11-096 reports





WIMPS AND ASTROPHYSICS

- **What does (our) galactic dark matter look like?**
  - Local density? Clumpiness? Velocity distribution? Co-rotation? Stealth galaxies?
  - Results from indirect searches and from multiple DS targets are essential

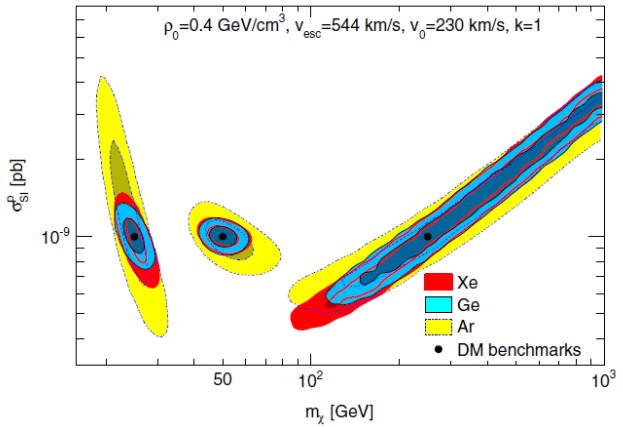
TABLE I. Characteristics of future direct dark matter experiments using xenon, germanium, and argon as target nuclei are shown. In all cases the level of background in the fiducial mass region is negligible for the corresponding effective exposure. See Sec. III for further details.

Target	ϵ [ton × yr]	η_{cut}	A_{NR}	ϵ_{eff} [ton × yr]	E_{thr} [keV]	$\sigma(E)$ [keV]	Background events/ϵ_{eff}
Xe	5.0	0.8	0.5	2.00	10	Equation (7)	<1
Ge	3.0	0.8	0.9	2.16	10	Equation (6)	<1
Ar	10.0	0.8	0.8	6.40	30	Equation (8)	<1

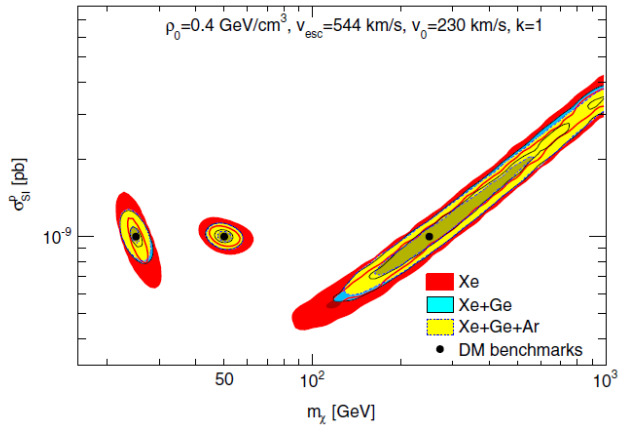
FORWARD LOOK TO 2018
(G2 expts with UK participation)

LUX-ZEPLIN	Xe	10	tonne·yr
EURECA	Ge	1	tonne·yr
DEAP3600	Ar	5	tonne·yr

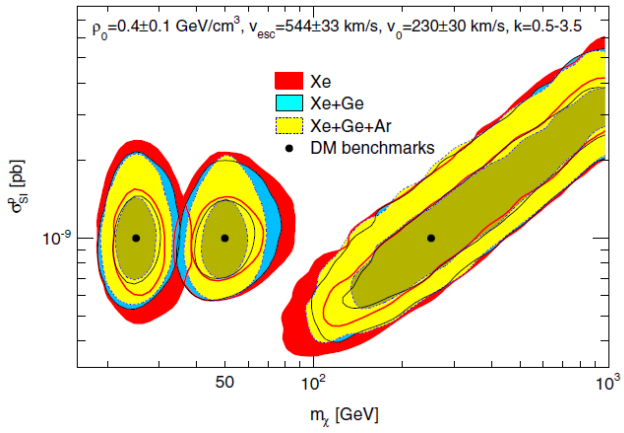
Fixed astrophysics: individual targets



Fixed astrophysics: combined datasets



Uncertain astrophysics: combined datasets



SUMMARY

- **Route to detection & study: a <u>progressive</u> programme**
  - UK-led **ZEPLIN** pioneered liquid xenon for WIMP searches
    Delivered wealth of peer-reviewed science & technology
  - **LUX350** expected to lead in sensitivity in one year's time
    Built detector tested on the surface, going underground in April
  - **LZ** could discover at 10^{-10} pb or exclude at 10^{-11} pb in 1 year run
- **Experimental approach: a <u>lower risk</u> programme**
  - Background free strategy (self-shielding, modest discrimination)
  - Two-phase Xe technology: high TRL (ZEPLIN, XENON, LUX)
  - Teams with huge track record in DM searches
  - Much infrastructure inherited from LUX350
- **Exciting physics for heavy and light WIMPs!**
  - Returns for particle physics, cosmology, astrophysics, theory