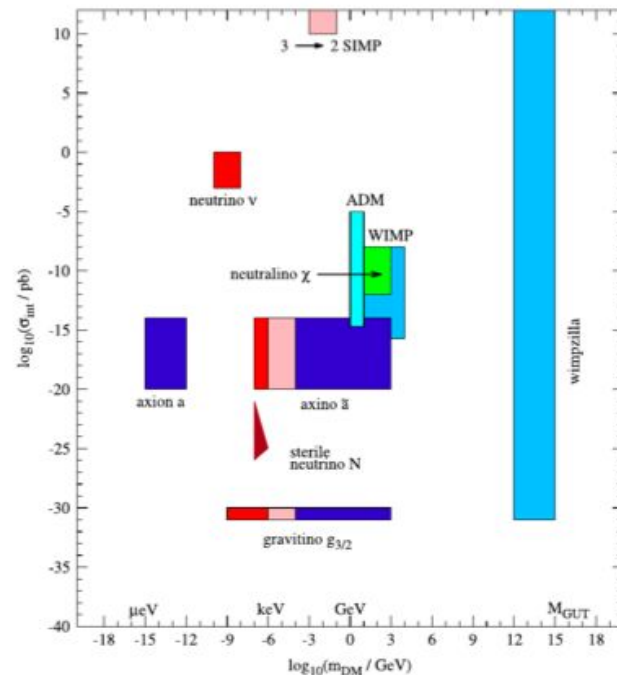
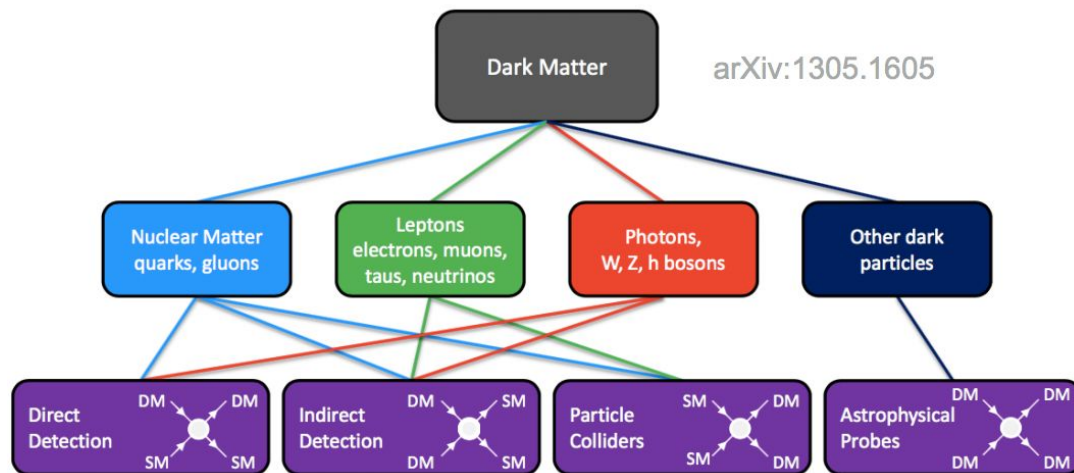




Direct Dark Matter Update

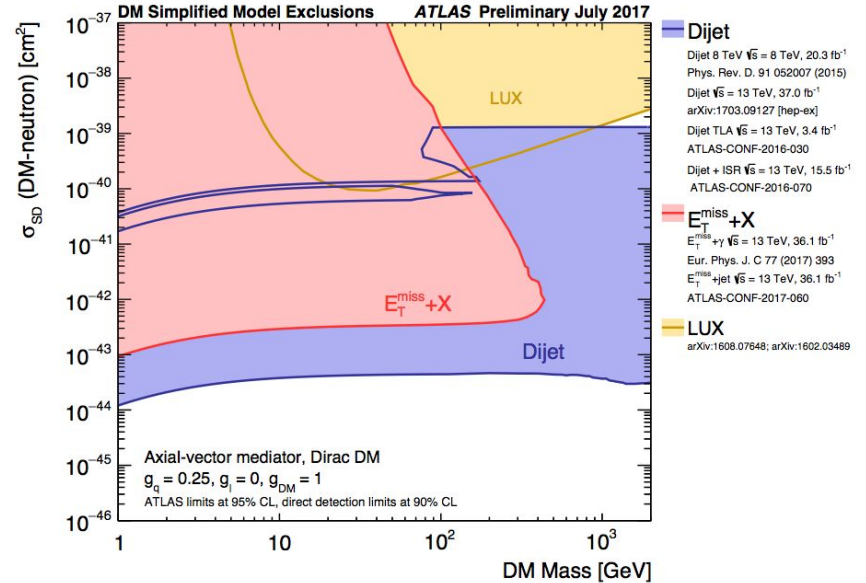
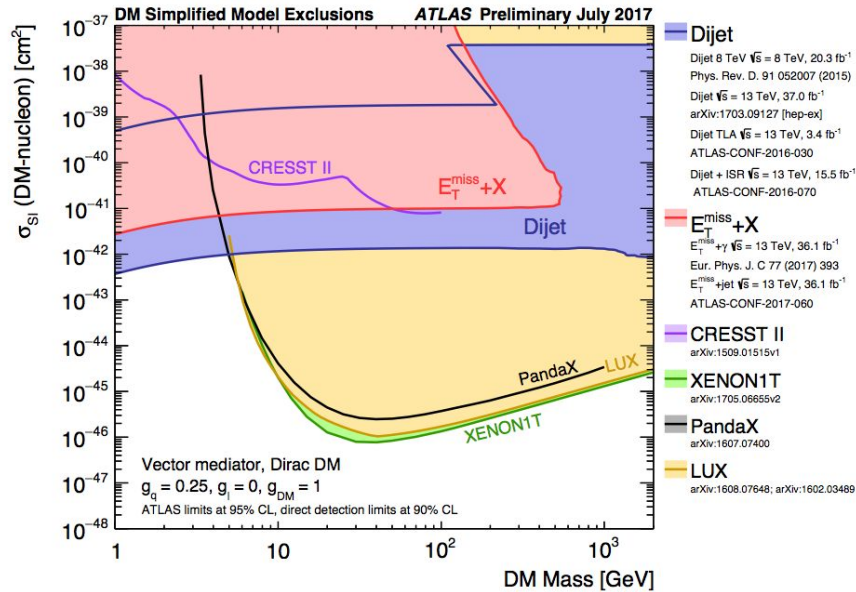
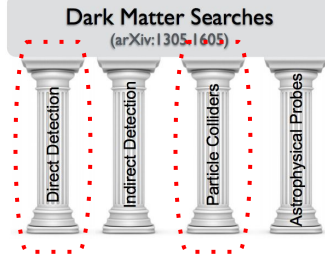
Chamkaur Ghag
UCL
20 July 2017

Dark Matter



- Direct searches for **rare** (<0.0001 /kg/day), **low-energy** (\sim keV) scattering of **thermal relics** (e.g. galactic WIMPs)
 - *Very sensitive detectors operating underground*
 - *Elastic scattering off nuclei, spin-independent, spin-dependent, EFT operators, inelastic scattering, electron scattering, annual modulation, signal directionality, ...*

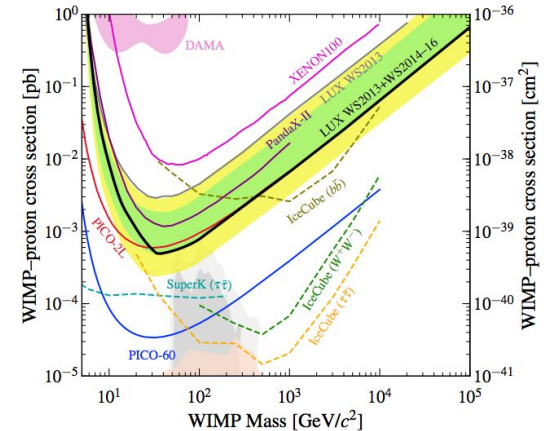
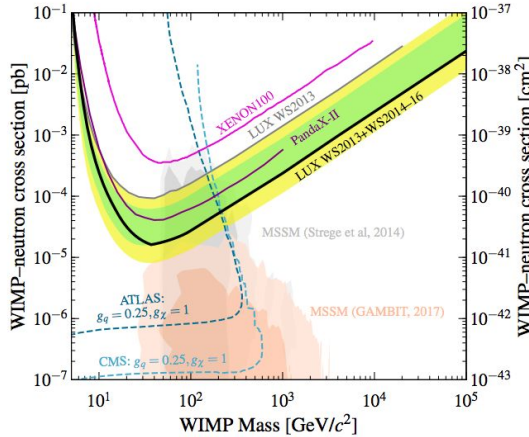
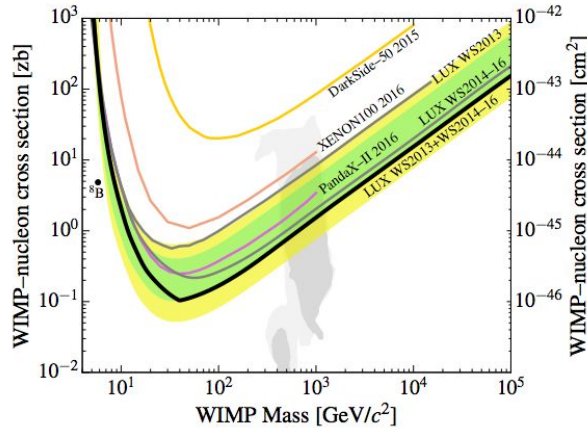
Complementarity: DD + LHC



See Shin-Shan Eiko Yu's talk @ EPS 2017

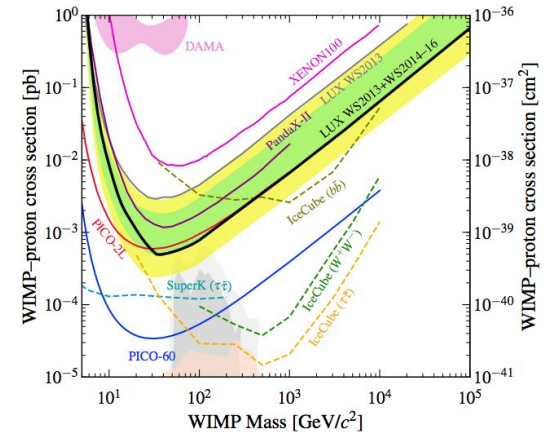
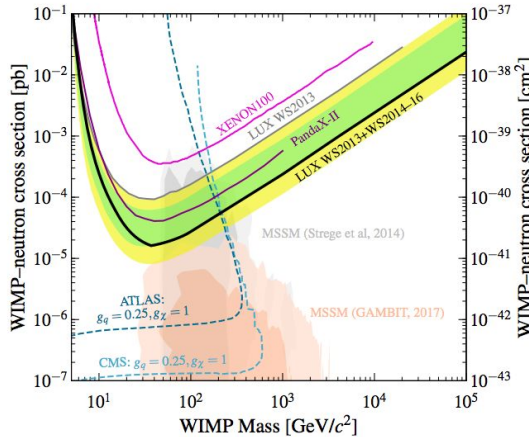
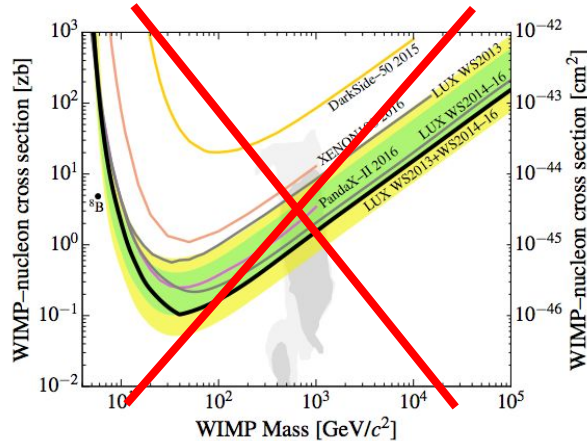
LUX @ SURF

- UK groups: Edinburgh, Imperial, UCL (+Liverpool, Sheffield)
- LUX ops. completed, detector decommissioned (making way for LZ)
- Final WIMP search results published
 - *World-leading S.I. WIMP-nucleon constraints* (Phys. Rev. Lett. 118, 021303 (2017))
 - *World-leading S.D. WIMP-neutron constraints* (Phys. Rev. Lett. 118, 251302 (2017))
- World-leading axions/ALPs results published (Phys. Rev. Lett. 118, 261301 (2017))
- Multiple analyses ongoing (non-WIMP DM, modulations, multiple-scatter, EFT, ...)
- Calibrations and light/charge yields: strong legacy



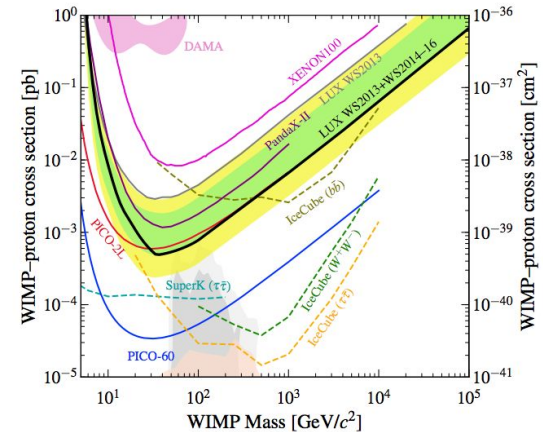
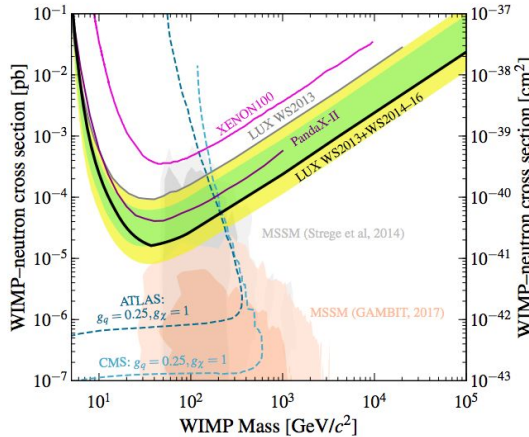
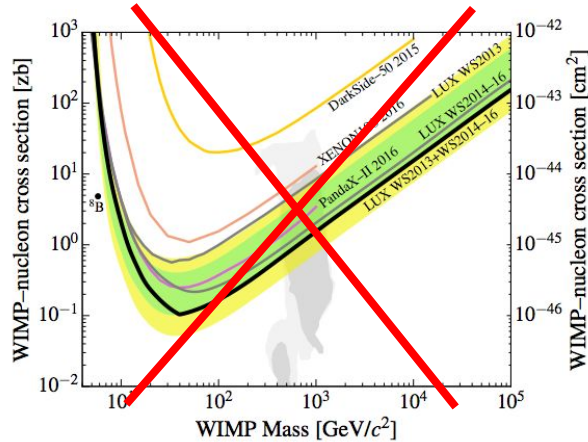
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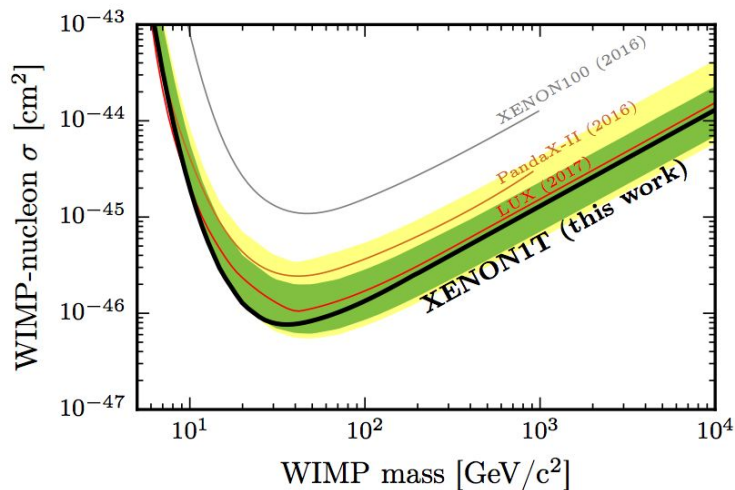


XENON1T @ Gran Sasso

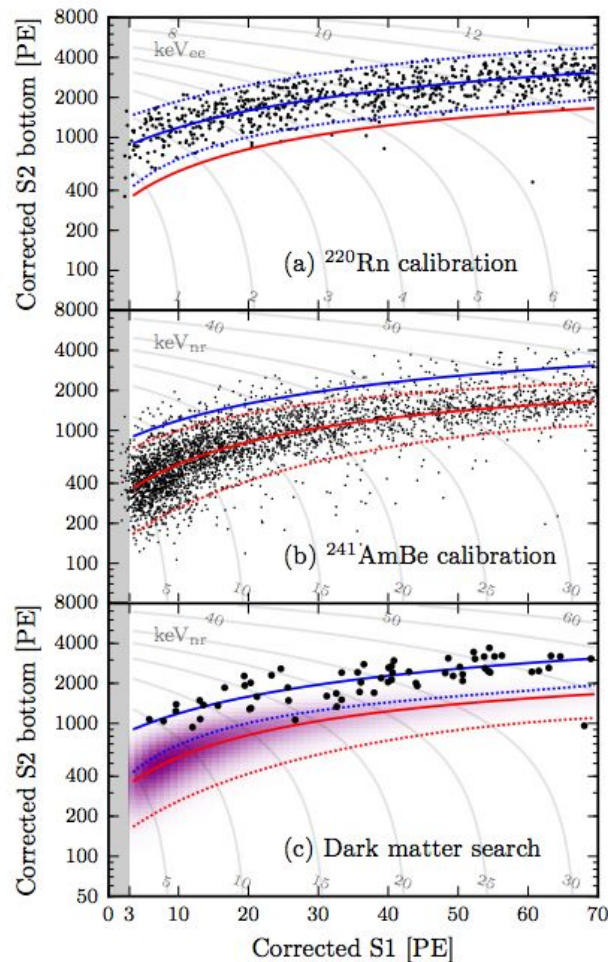


XENON1T @ Gran Sasso

- New results from 34 live day blinded run
- 1 T fiducial mass (2.2 T active mass)
- Now: 1 year science run
 - Panda-X (China) may compete
- Next: Upgrade to XENONnT

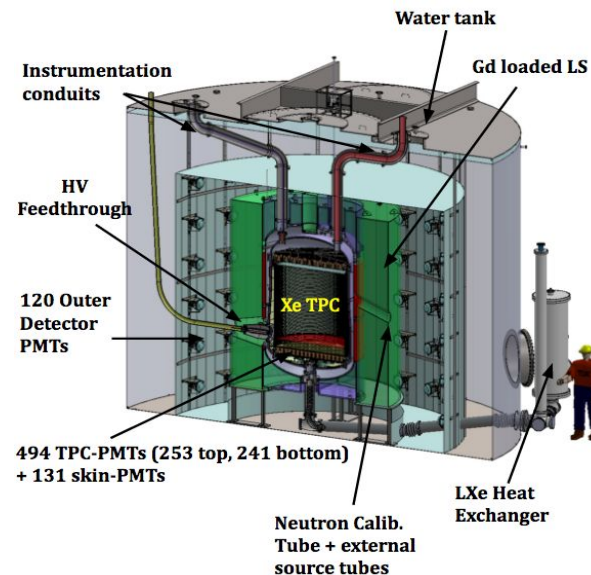
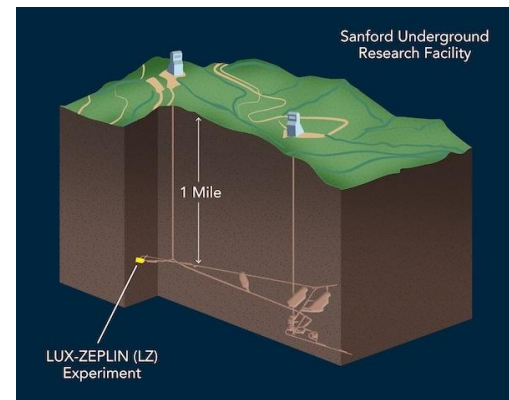


arXiv:1705.06655

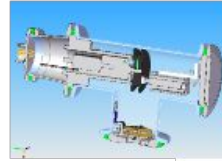


Lux-Zeplin (LZ)

- STFC funded construction project + CG
- U.S. DOE CD-3 approved Feb. '17 (TDR arXiv:1703.09144)
- UK Groups (9/39), approx. 50/227 members
 - **Bristol:** *P.I. leaving for US, remaining in LZ; Bristol re-applying*
 - **Edinburgh:** *Cleanliness*
 - **Imperial:** *PMTs & bases, Data Centre, Detector system (project co-lead)*
 - **Liverpool:** *Outer Detector calibration systems*
 - **Oxford:** *Internal Sensors*
 - **RAL:** *Cryostat (project co-lead), calibration source delivery*
 - **Royal Holloway:** *Optical simulations*
 - **Sheffield:** *Background Simulations*
 - **UCL:** *Backgrounds & Assays (project co-lead), Simulations (WG Convenor)*
- UK has 2/7 Exec. Board and 6/30 Technical Board members
- UK PMTs delivered ($\frac{1}{3}$), 50% assay/bkg, cryostat in '17, Data Centre
- Commissioning late 2019



Lux-Zeplin (LZ)



Calibration delivery

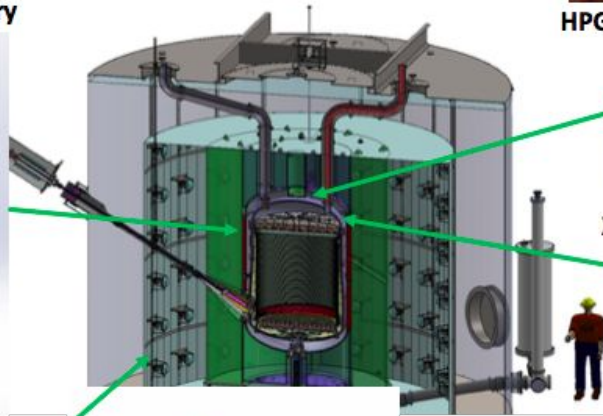


Titanium cryostat



OD optical calibration

UK SCOPE



HPGe/ICP-MS/Rn screening

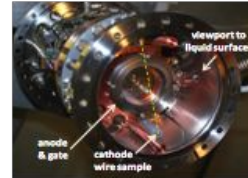


1/3 TPC PMTs
Xenon-space PMT bases

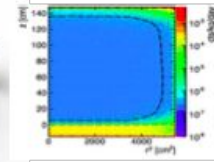


Monitoring sensors

System Testing

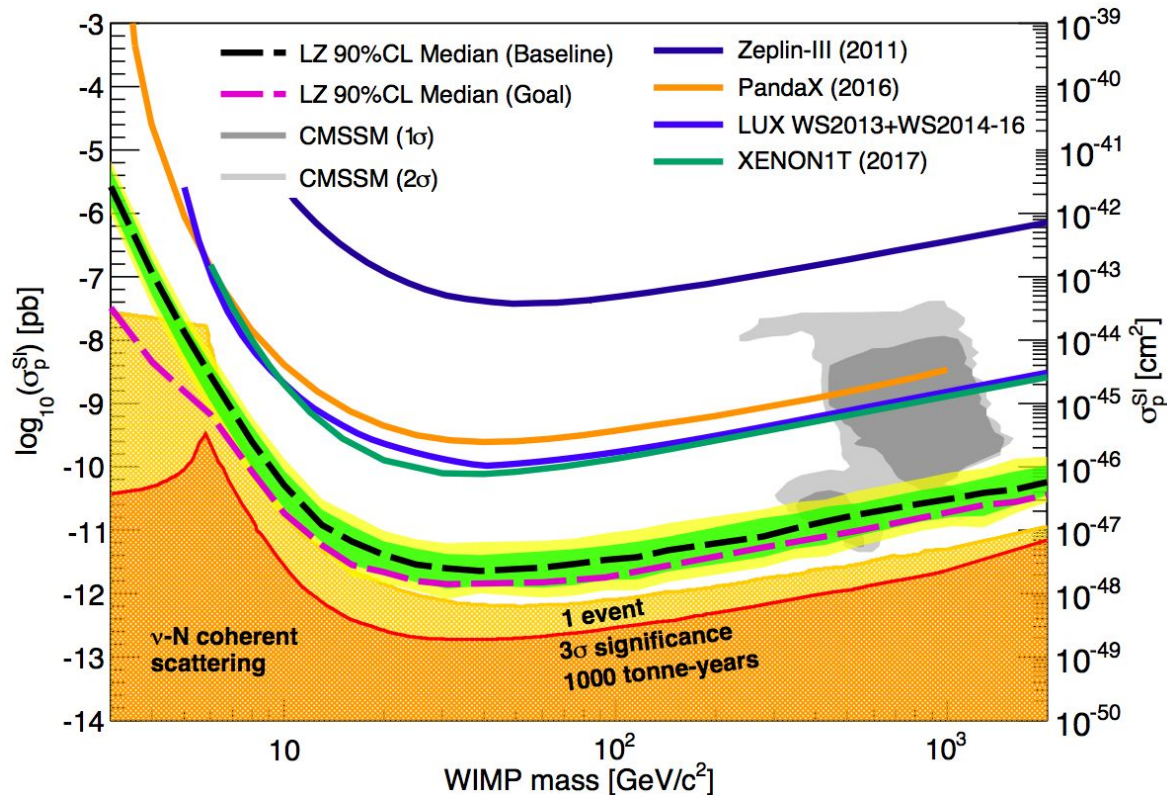


UK Data Centre



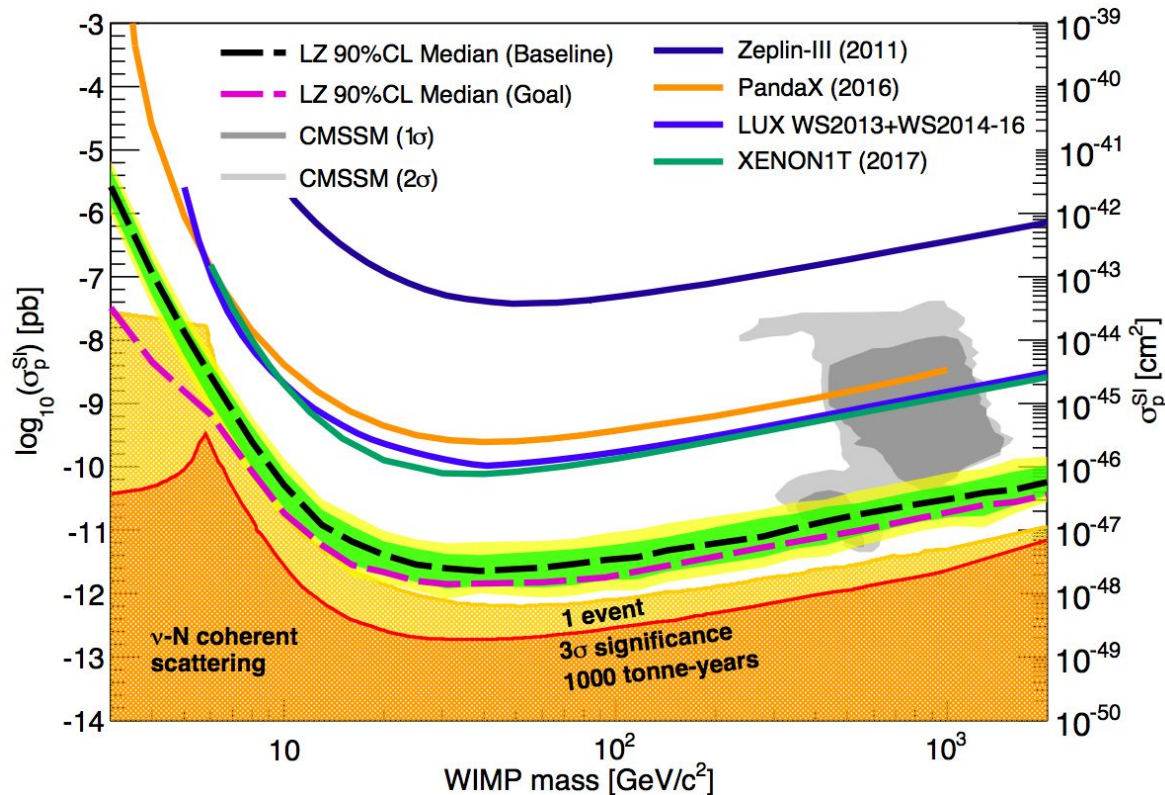
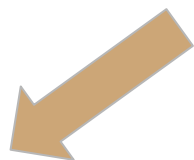
Simulations

Lux-Zeplin (LZ)



Lux-Zeplin (LZ)

**THRESHOLD &
ATOMIC MASS
MATTERS
CRYOGENIC
DETECTORS**



**SIZE (x TIME)
MATTERS
NOBLE LIQUIDS**



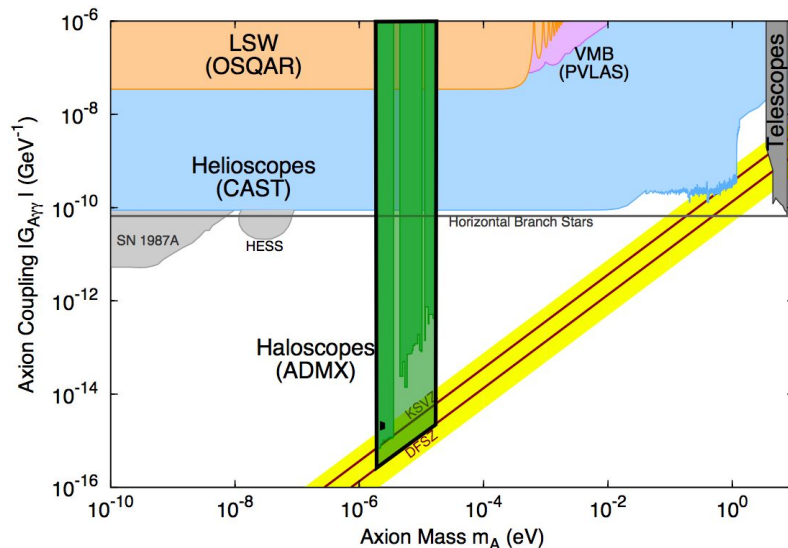
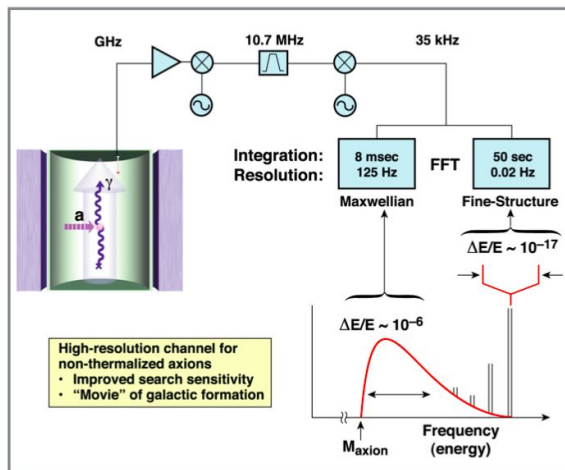
DMUK Community

- Direct Detection
 - **ADMX-Gen2:** Axions (Lancaster, Sheffield)
 - **DarkSide-20k:** 2-phase LAr TPC (RHUL)
 - **DEAP-3600:** Single phase LAr (RHUL, RAL, Sussex)
 - **DRIFT & CYGNUS:** Directionality R&D (Sheffield)
 - **LUX:** 2-phase LXe TPC (Edinburgh, Imperial, Liverpool, Sheffield, UCL)
 - **LUX-ZEPLIN:** 2-phase LXe TPC (Bristol, Edinburgh, Imperial, Liverpool, Oxford, RAL, RHUL, Sheffield, UCL)
 - **SABRE:** NaI(Tl) detectors in Italy and Australia (Imperial)
 - **SuperCDMS:** Cryogenic Ge detectors for low-mass WIMPs (IPPP)
- Theory and Phenomenology
- DMUK expanding to include wider UK research interests (LHC, indirect, more theory! ...)
- Two 1-day meetings per year (summer/winter)
 - *Next in Edinburgh, 28th July 2017 (<https://indico.cern.ch/event/629502/>)*
- Summer school
- Outreach
- Website ... (coming soon!)

Summer DMUK Meeting		
Friday 28 Jul 2017, 07:50 → 21:00 Europe/London		
Lecture Theatre A (JCMB, Edinburgh)		
Description: A UK-wide meeting of all those interested in dark matter research		
08:00	→ 08:55	Registration: Teas/coffees/pastries
08:55	→ 09:00	Welcome
09:00	→ 09:30	Direct dark matter detection Speaker: Henrique Araujo (Imperial College London)
09:30	→ 10:00	DEAP - First results Speaker: Joseph Walid (Royal Holloway, University of London)
10:00	→ 10:30	Chiral effective theory of dark matter detection Speaker: Fady Bishara (University of Oxford)
10:30	→ 11:00	Coffee
11:00	→ 11:30	Signals at the threshold Speaker: Christopher McCabe (King's College London)
11:30	→ 12:00	Statistical issues in dark matter searches Speaker: Louis Lyons (Imperial College GB)
12:00	→ 12:20	Dark Matter Day - Presentation Speaker: Lucy Stone (STFC)
12:20	→ 13:00	Dark Matter Day - Discussion
13:00	→ 14:00	Lunch
14:00	→ 14:30	Dark Matter with CTA
14:30	→ 15:00	Dark matter at the LHC Speaker: Allan Barr (University of Oxford GB)
15:00	→ 15:30	Prospects at future colliders Speaker: Christos Leonidopoulos (University of Edinburgh GB)
15:30	→ 15:50	Boulby underground science laboratory Speaker: Mrs. Emma Meehan (STFC)
15:50	→ 16:10	Coffee
16:10	→ 16:30	Neutrino Astronomy and Direct Detection Speaker: Dr. Jonathan Davis (King's College London)
16:30	→ 16:50	Digging into the neutrino floor Speaker: Mr. Angelides Nicolas (University of Edinburgh)
16:50	→ 17:10	Axion dark matter Speaker: Edward Daw (The University of Sheffield)
17:10	→ 17:30	Cygnus Speaker: Dr. Warren Lynch (University of Sheffield)
17:30	→ 18:00	Global constraints on dark matter theories with GAMBIT Speaker: James McFay (Imperial College London)
19:00	→ 21:00	Dinner at 'Amber' restaurant & whisky bar

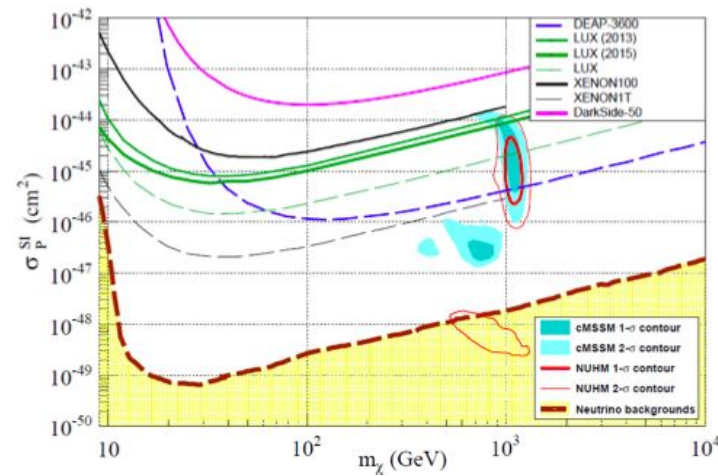
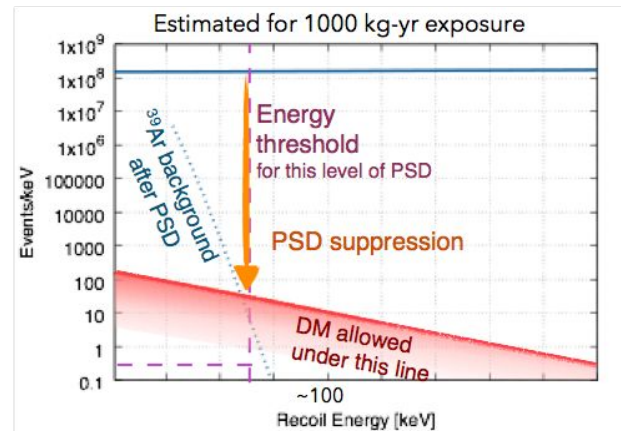
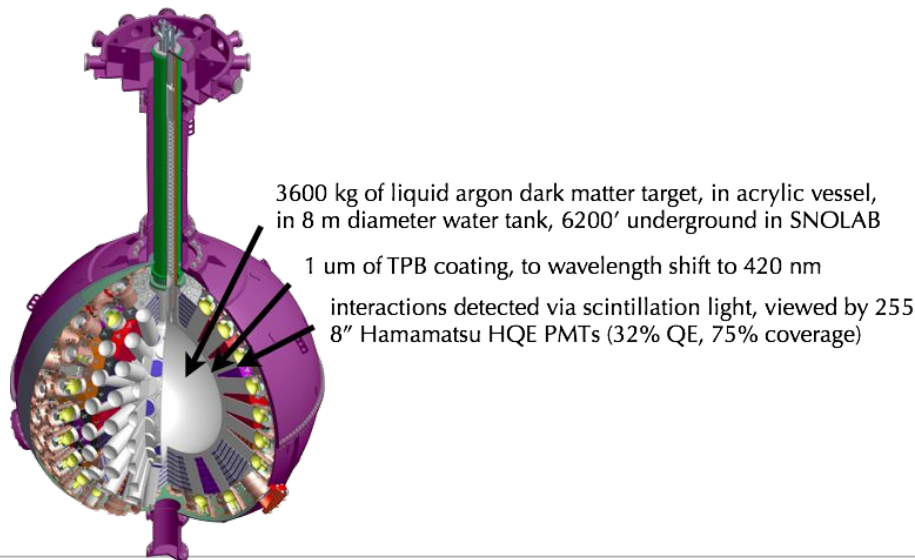
ADMX-Gen2

- Axions from QCD symmetry breaking mechanism
 - *Light (order $10 \mu\text{eV}$) pseudoscalar, stable particles*
- ADMX-Gen2 is a Dark Matter axion search using a tuned electromagnetic resonator in a magnetic field
- UK groups (Lancaster, Sheffield) developing active cavity resonators to enhance ADMX range
 - *Good prospects to improve rate of axion mass coverage*



DEAP-3600 @ SNOLab

- Single phase LAr, 3.6 Ton (1 Ton fiducial)
- Pulse shape discrimination (PSD) for particle ID
 - $\times 250$ difference in scintillation time constants between ER and NR
 - PSD demonstrated to 1×10^{-8} level
 - E_{th} determined by PSD (^{39}Ar β -decay, 1 Bq/kg, Q-value ~ 550 keV)
- Ar \ll Xe \$\$, kTon detectors feasible



(assuming $E_{th} = 20$ keV, 1000 kg fiducial mass, 3 year run)

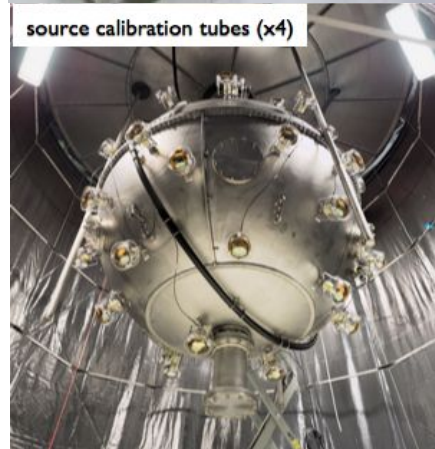
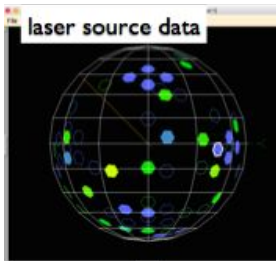
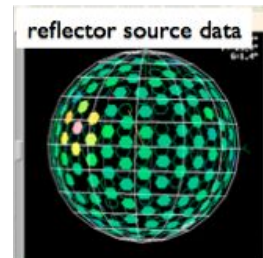
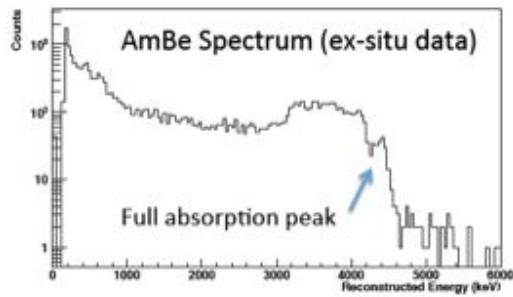
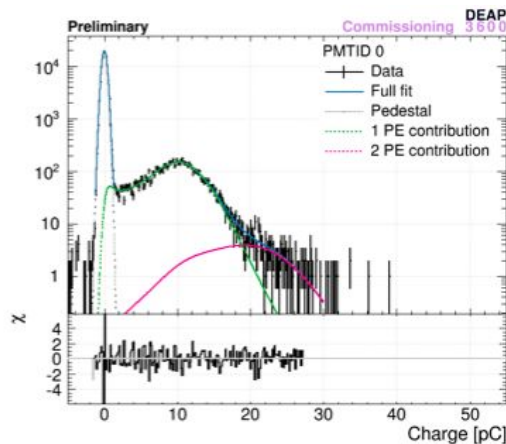
DEAP-3600: Calibration System (UK)

- **Calibration Systems**

- Tagged Na-22 Cal A,B,E pipes, Cal F racetrack (RAL)
- Tagged AmBe in Cal A,B,E; multi-wavelength laser ball (RHUL)
- Optical calibration sources in neck (laser- and LED-flasks), PMT lightguide reflectors (fixed), and neck laser (Sussex)

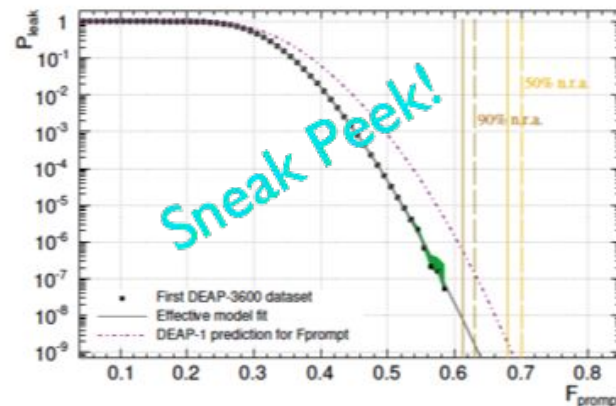
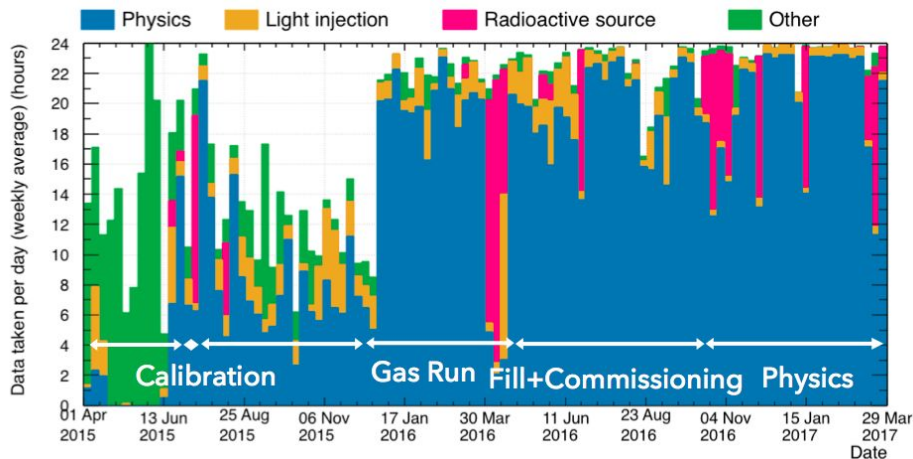
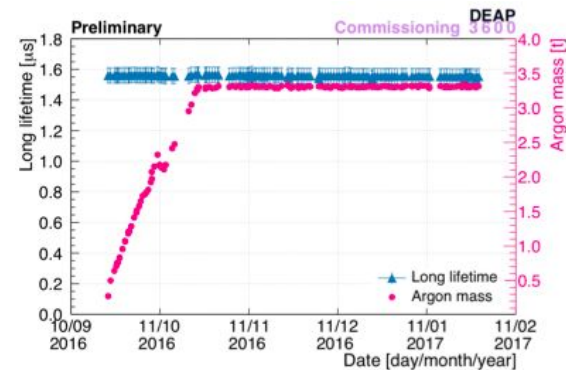
- **First DEAP-3600 commissioning papers**

- PMT calibration: [arXiv:1705.10183](https://arxiv.org/abs/1705.10183)
- PMT afterpulsing: [arXiv:1703.06204](https://arxiv.org/abs/1703.06204)



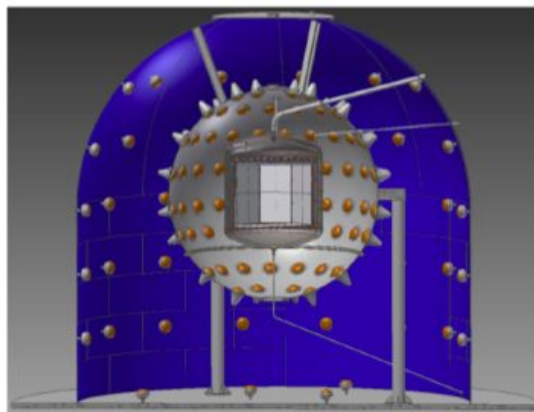
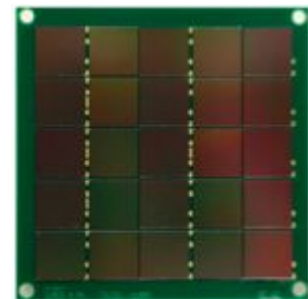
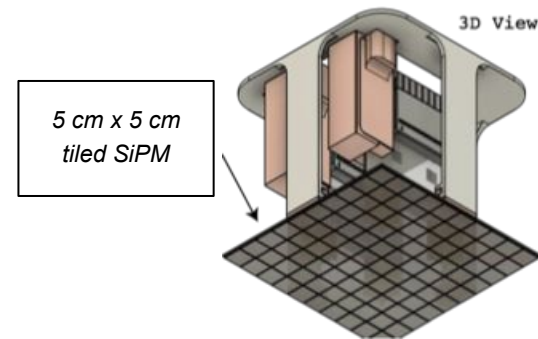
DEAP-3600: Status

- Collected 500,000 kg-days raw exposure since Physics run start Nov '16
 - PMT response well understood, Ar triplet lifetime stable to 1%*
 - Background rejection from PSD better than projected at 20 keV_{ee}*
 - First physics results from detector fill-period data at TAUP 2017***

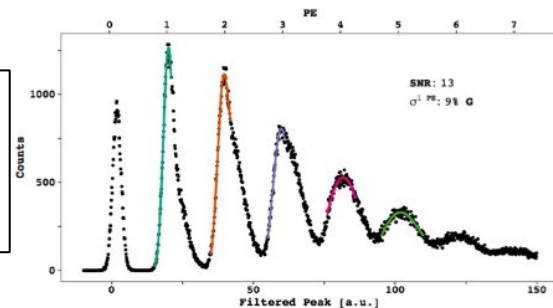


DARKSIDE-20k @ Gran Sasso

- **DarkSide-50:** 50 kg 2-phase LAr TPC
 - *Zero background limit (Phys. Rev. D 93, 081101 (2016))*
 - *Demonstrated use of depleted underground Ar*
- **DarkSide-20k:** Coordination of all LAr experiments
 - *23 ton LAr 2-phase TPC*
 - *LNGS approval May 2017*
 - *Designed for 100 ton-year exposure with depleted underground Ar*
 - *First large-scale use of large-area cryogenic SiPMs for light readout*

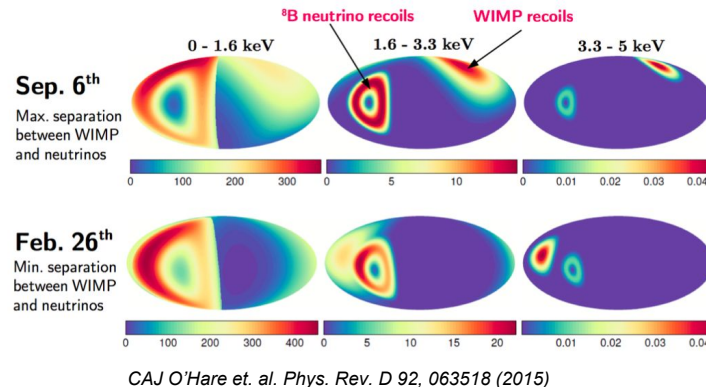
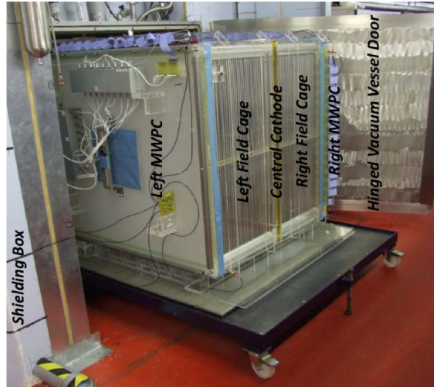


45% PDE and
0.1 Hz/mm² noise
goals achieved
(EPS-HEP 2017)

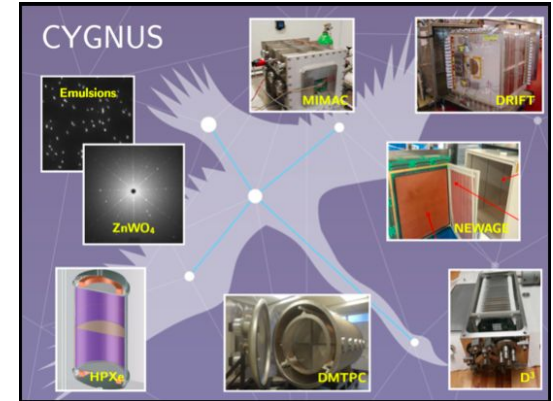


Directionality

- **DRIFT**: Directionality pioneer based at Boulby
 - Recently demonstrated head-tail and axial discrimination with neutrons
 - Zero background, target mass limited
- **CYGNUS**: International collaboration of directionality experiments (UK spokesperson, Sheffield)
 - Targeting low WIMP mass region (1-50 GeV) with directionality and recoil discrimination
 - Distributed network at different latitudes, starting with 10 m³ experiments
 - High pressure / low pressure operation
 - Negative ion SF₆ target with x8000 gains demonstrated (Sheffield)
 - Low background micromegas readout



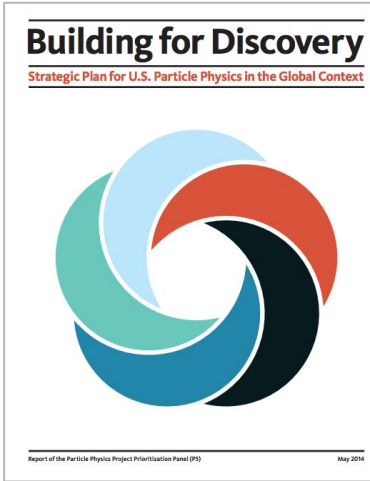
CAJ O'Hare et. al. Phys. Rev. D 92, 063518 (2015)



Theory & Phenomenology

- **Improved Simplified Models for LHC Dark Matter searches:**
 - Very active field: important UK contributions (*Imperial, IPPP, KCL, Sussex*)
 - UK leading role e.g. ‘Dark Matter Interpretations for Direct Detection’ workshop (Aug 2016); Imperial international workshop ‘Towards the next generation of simplified dark matter models’ & Phys Dark Univ 16 (2017) white paper
- **Advances in direct detection:**
 - Improved theory for matching dark matter models to observable signals (*Oxford*)
 - New signals from exotic dark matter (*RHUL*)
 - Novel searches for low mass dark matter (*KCL*)
 - Direct detection as neutrino detectors (*KCL, IPPP*)
- **Axions in the sky:**
 - Axion dark matter astronomy (*Nottingham*)
 - Axion mini-clusters in micro-lensing surveys (*KCL*)
 - Novel X-ray signatures (*Oxford*)
- **GAMBIT:** Global fitting package; explore complementarity of searches (*Glasgow, Imperial*)
- **Gravitational waves:** Exotic signals from dark sectors/string theory (*Oxford, IPPP*)
- **Neutrinos:** Dark matter in high-energy neutrino signals (*Imperial, IPPP*)
- **Improved Solar Models:** transporting heat with dark matter (*Imperial*)

'Generation-3' (G3)



*The results of G2 direct detection experiments and other contemporaneous dark matter searches will guide the technology and design of third-generation experiments. As the scale of these experiments grows to increase sensitivity, the experimental challenge of direct detection will still require complementary experimental techniques, and international cooperation will be warranted. The **U.S. should host at least one of the third-generation experiments** in this complementary global suite.*

Report of the Particle Physics Project Prioritization Panel 17

Table 1 Summary of Scenarios								
Project/Activity	Scenarios			Science Drivers				
	Scenario A	Scenario B	Scenario C	Higgs	Neutrinos	Dark Matter	Geom. Asym.	The Unknown (Frontier)
Large Projects								
Muon program: Mu2e, Muon g-2	Y, Muon g-2 requires revised	Y	Y					I
HL-LHC	Y	Y	Y	✓	✓	✓	✓	E
LBNF + PIP-II	Y, LBNF components aligned relative to Scenario B	Y	Y, enhanced		✓		✓	I, C
ILC	R&D only	R&D, possibly small hardware commitments. See text.	Y	✓	✓	✓	✓	E
NuSTORM	N	N	N		✓	✓		I
RADAR	N	N	N	✓				I
Medium Projects								
LSST	Y	Y	Y		✓		✓	C
DM G2	Y	Y	Y			✓		C
Small Projects Portfolio	Y	Y	Y		✓	✓	✓	All
Accelerator R&D and Test Facilities	Y, reduced	Y, reduced	Y, enhanced	✓	✓	✓	✓	E, I
LMB	Y	Y	Y		✓		✓	C
DM G3	Y, reduced	Y	Y		✓			C

Recommendation 20: Support one or more G3 direct detection experiments, guided by results of the preceding searches. Seek a globally complementary program and increased international partnership in G3 experiments

'Generation-3' (G3)



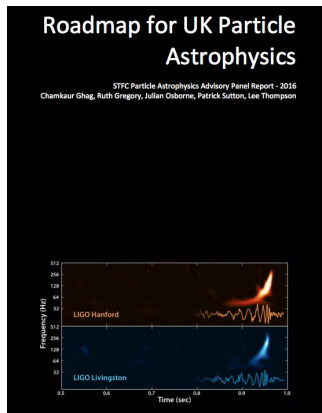
Direct dark matter detection (Recommendation #5):

- *Maintain rich (experiments and R&D) program searching for WIMP & non-WIMP dark matter*
- *Towards a global strategy for the ultimate noble-liquid (argon & xenon) detectors by 2019*

F. Linde (IDM, Sheffield, 2016)

Launch of the new European Astroparticle Physics Roadmap 2017-2027 delayed to September 2017

‘Generation-3’ (G3)

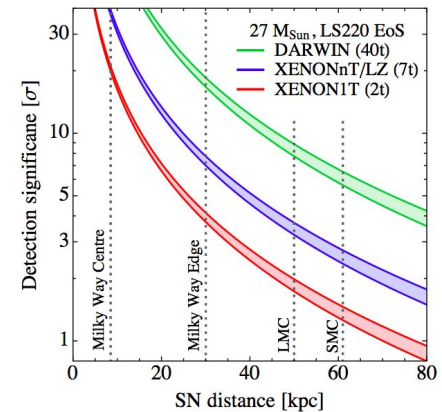
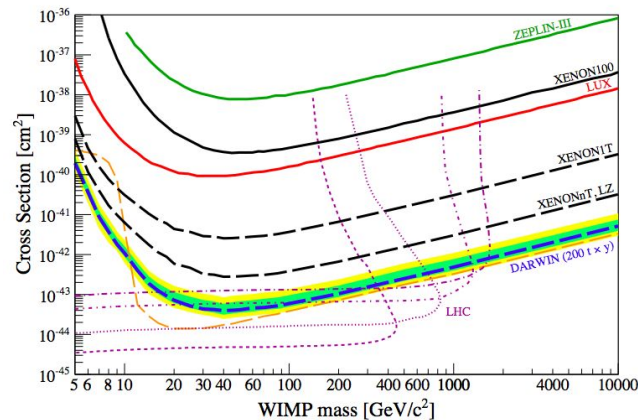
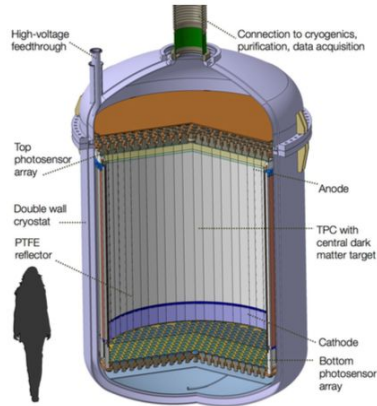


*Lessons learnt from LUX and designs of LZ, both now concluded, and from DEAP-3600 and XENON1T, both undergoing commissioning, indicate areas of R&D that require further work [...] **engineering issues related to up-scaling** (e.g., electrode grids); identification and mitigation of **non-fiducialisable backgrounds**; **noble liquid technology** and characteristics; and **optical and electrical properties** of materials (e.g., PTFE) [...] **low background techniques** and **background model development** is applicable to any G3 experiment irrespective of the chosen technology.*

Recommendation: We recommend support of R&D to continue to capitalise on successful consolidation of UK expertise and significant previous investment, facilitating UK leadership at G3 at the appropriate timescale.

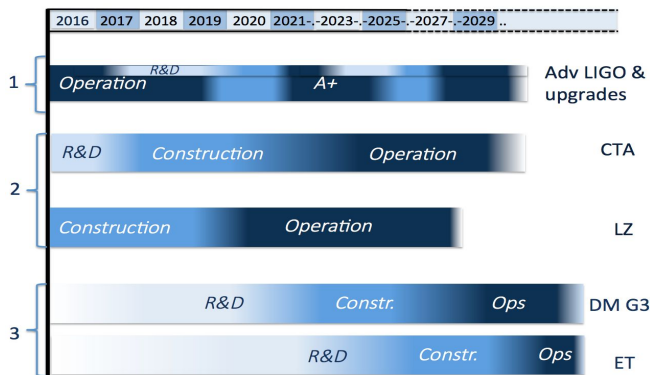
'Generation-3' (G3) UK R&D

- G3 R&D proposal being co-ordinated by Hans Kraus (Oxford)
- Mapped to UK expertise
 - *engineering issues related to up-scaling (e.g., electrode grids)*
 - *identification and mitigation of non-fiducialisable backgrounds*
 - *noble liquid technology and characteristics*
 - *optical and electrical properties of materials (e.g., PTFE)*
 - *low background techniques and background model development (applicable to any G3 technology)*
- SOI to be submitted Summer '17



Roadmap for UK Particle Astrophysics (2016)

1. **Advanced LIGO:** *exploitation to profit from major UK investment and leadership in this new field of astronomy, and development and implementation of initial upgrades to the system*
2. **LUX-ZEPLIN:** *exploitation, building on current investment and substantial UK expertise and leadership*
CTA: *construction and exploitation, building on current investment and substantial UK expertise and leadership*
3. **Einstein Telescope:** *support of R&D for future GW detectors, to facilitate future UK participation in ET*
G3 Dark Matter: *support of R&D to facilitate UK participation in a future G3 experiment*



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Balance of Programmes:
Review of PA in 1st QTR 2018

Last year...

COMMUNITY BOARD

• **PPAP ROADMAP (2015)**

*The UK has a leading role in the **LUX-ZEPLIN (LZ)** consortium, which aims to develop a multi-tonne detector at the SURF facility in South Dakota, based on the two-phase xenon technology pioneered by the UK-led ZEPLIN collaboration. Some institutes also participate in the LUX experiment, which has the current world-leading sensitivity. In addition, the **DRIFT** and **DMTPC** gas TPC technologies have directional capability and may be able to determine whether the Dark Matter flux is correlated with the Earth's galactic motion. Funding for LZ has recently been approved through the experiments grants line and is being sought through Consolidated Grants for exploitation. DMTPC is supported in the UK through Consolidated Grants.*

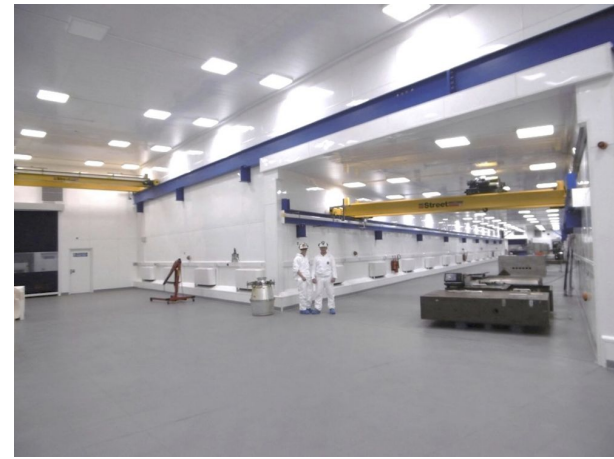
- **Recommendation 22: The UK should provide capital-phase support for construction of the tonne-scale LUX-ZEPLIN Dark Matter experiment and continue R&D towards directional sensitivity.**

Since then:

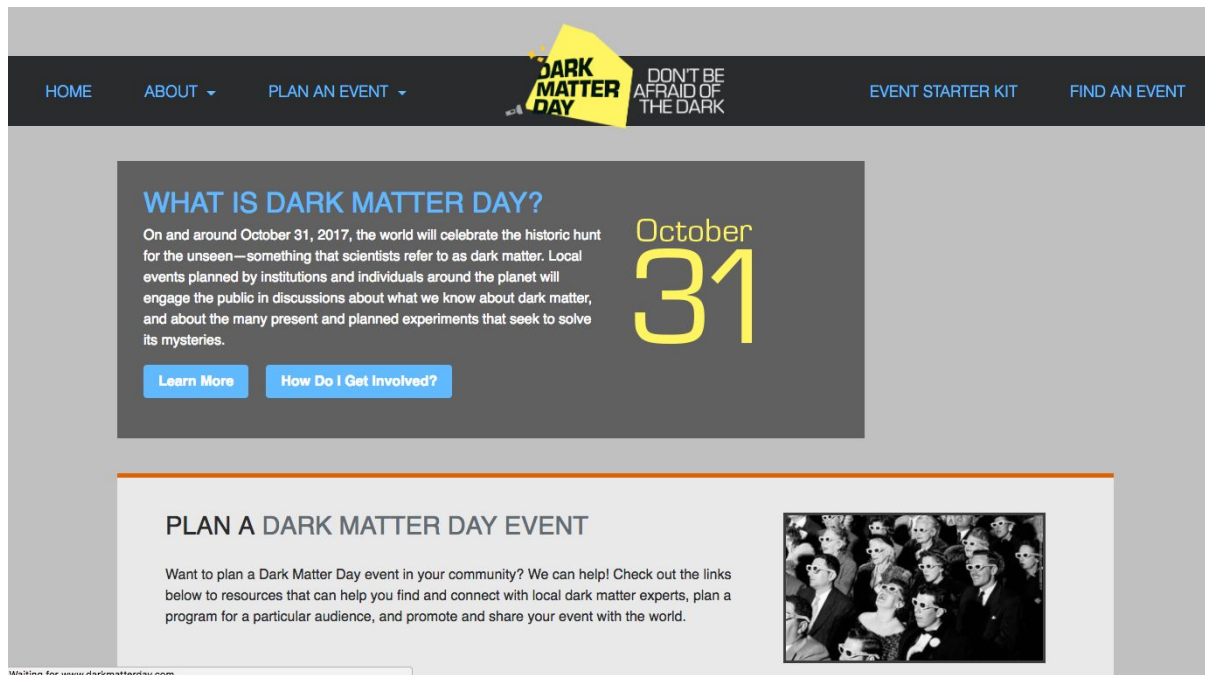
- **LZ**
 - Funding profile approved by the DOE through to commissioning
 - CG funding approved for period Mar 2018 – Sep 2019
 - R&D for potential G3 from 2017/2018

Boulby Underground Laboratory

- New laboratory fully commissioned (ISO 6/7 cleanroom)
- Boulby Underground Germanium Suite ('BUGS')
 - 3 ULB detectors (+pre-screener)
 - 100 ppt (g/g) $^{238}\text{U}/^{232}\text{Th}$ chain sensitivity
 - Approx. 100 samples/year
 - LZ, SuperNEMO, Super-K (Gd), ...
 - Industry (Canberra, Lead Shield, Photek, ...)
 - 3 new 'S-ULB' detectors being commissioned (Summer '17)
 - N-type BEGe, 160% p-type, 100% p-type
 - 10 ppt (g/g) $^{238}\text{U}/^{232}\text{Th}$ chain sensitivity (G3 DM; next-gen $0\nu\beta\beta$)
 - ...attracting several international projects
- Surface contamination assay equipment installation (by end '17)
 - Radon plate-out sensitivity to $<0.5 \text{ mBq/m}^2$
- Much science beyond AP/PP
 - Geology/geophysics, env. radiation, μ -tomography for deep geological (incl. CCS), life in extreme environments, planetary exploration tech. R&D



Dark Matter Day



www.darkmatterday.com

DARK MATTER DAY IS COMING!



31ST OCTOBER 2017

Acknowledgements and post-disclaimer!

- Many thanks to all that provided input for experimental and theory updates...
 - *H. Araujo, E. Daw, C. McCabe, J. Monroe, N. Spooner*
- Apologies for oversights or omissions...
 - *Non-trivial to do justice to all the great work UK researchers are involved in!*