S&C challenges and needs for Direct Dark Matter Searches

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PPTAP Computing & Software Roadmap Workshop
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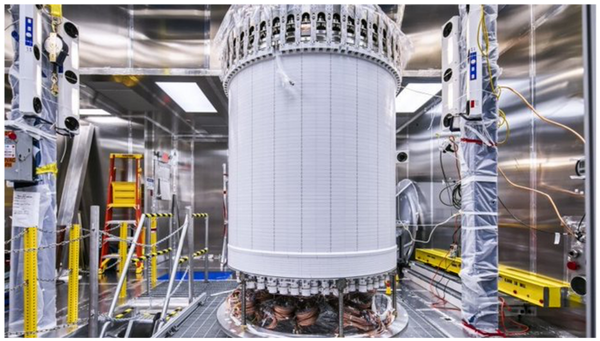
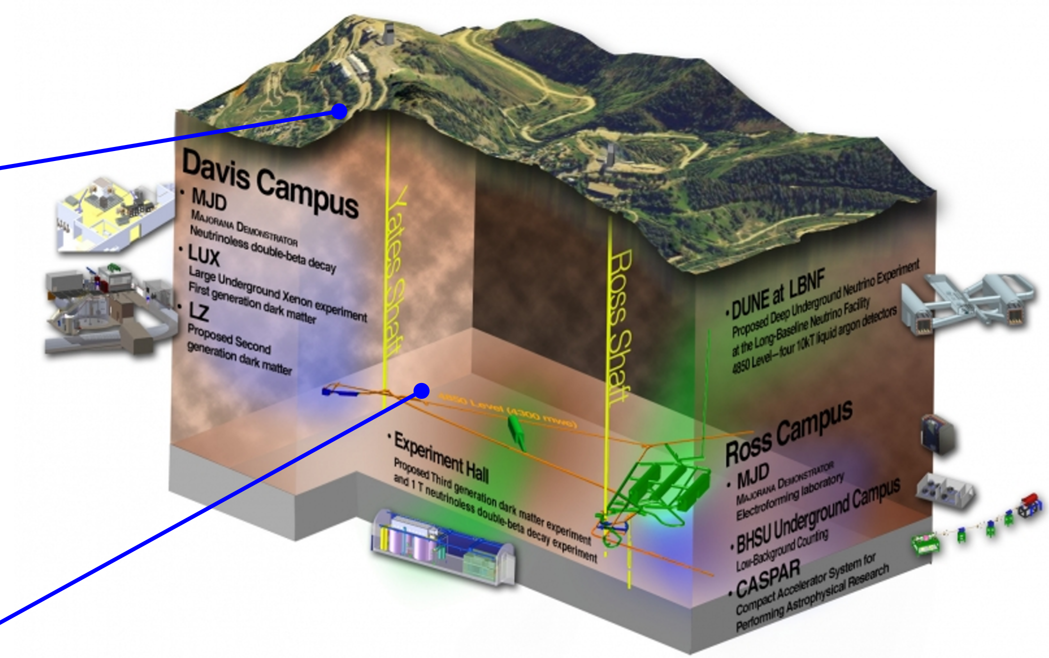
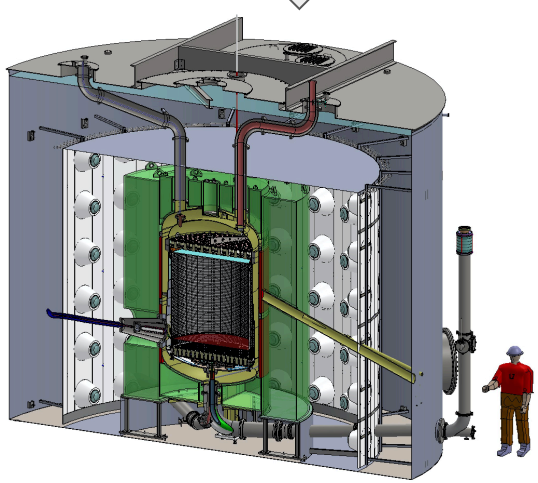
Dark Matter Direct Detection

1) Ultra-radio pure materials and construction + low-threshold detector





2) Take deep underground



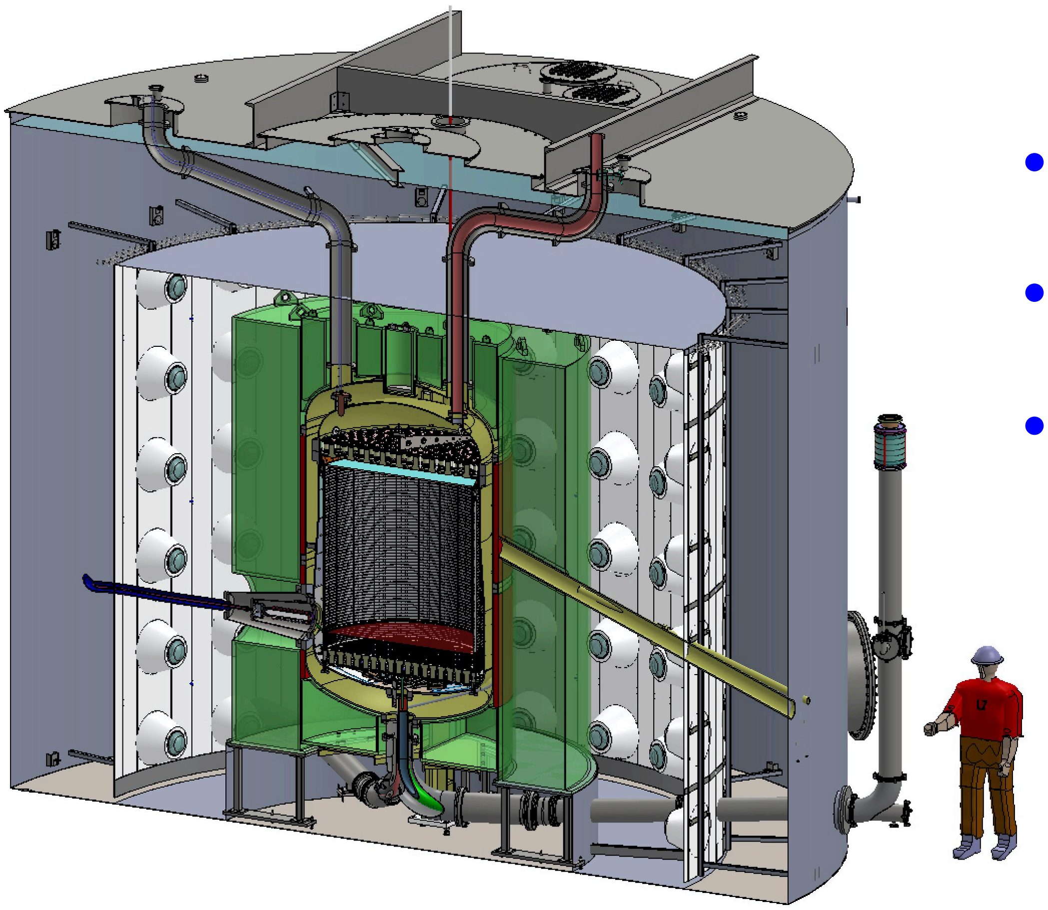
Key features relevant for S&C needs:

- Low background constraints + long exposures
- Wide-range of physics signal across full dynamic range
- Triggerless "every photon saved"

3) Run until you see signal/background limited

Dark Matter Direct Detection

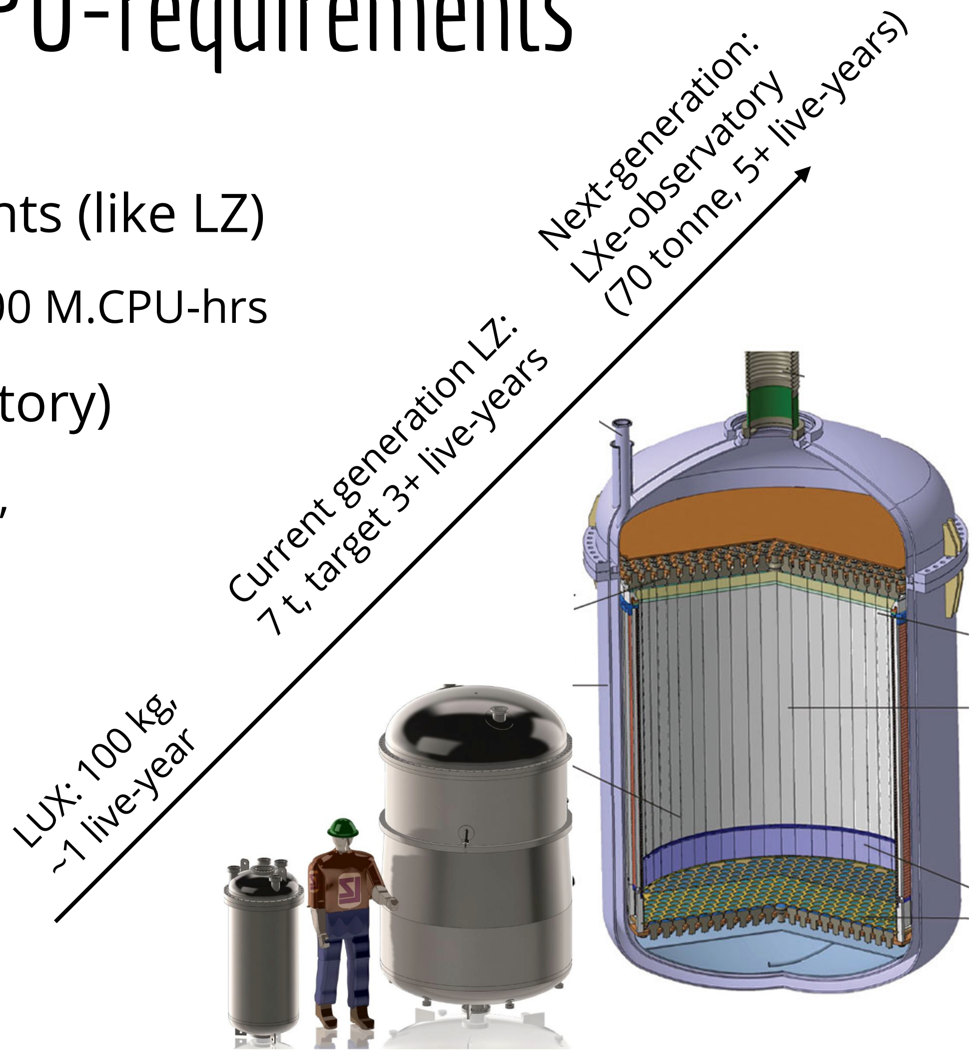
- *Taking LZ/LXe as example in following, but many S&C R&D needs likely to apply to other DM experiments [Ar/DarkSide programme, SuperCDMS, low-mass]*



- Simulations challenge from self-shielding
- Low event BG rates 1-100 Hz...
- ...but long exposures & high stats calibrations add up → large datasets

For context: data and CPU-requirements

- Current generation experiments (like LZ)
  - 3 live-years, O(10 PB) data, >200 M.CPU-hrs
- Next generation (LXe-observatory)
  - 5-10 live-years, O(100 PB) data,
    > 0.2 M.CPU-years
- c.f. HL-LHC experiment:
  - 1-3 EB and 10-40 M.CPU-years
  - DM is factor 10-100 less



DM experiments not facing same Exascale challenge as LHC but still areas where S&C R&D required or can bring significant improvement

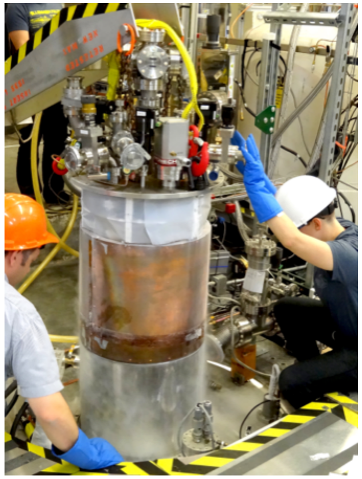
QSFP/low-mass/other smaller experiments

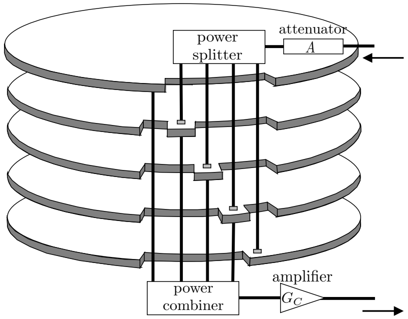
- Not all DM experiments at same stage or require UG running
- Quantum Sensors for the Hidden Sector (QSHS)
    - **Particle theory** → time on HPC clusters for numerical simulations of the dynamics of possible new light particles and dark matter candidates (typically ~1 M.CPU-hrs) → burgeoning field → benefit from time with RTPs/computer scientists not specific R&D
    - **Device design simulations** → device and detector design make use of finite element tools → ANSYS-HFSS and multiphysics tools from the Cadence package → essential tools for designing quantum systems → previously available through Europractice suite hosted by STFC → important to maintain access
- Whilst CPU/disk requirements not at not at same level benefit from continued access to licenses, CPU/disk resources and (presumably) access to RTPs

QSHS

members

QUANTUM SENSORS FOR THE HIDDEN SECTOR





Quantum limited resonance circuit readout for axion haloscope E. Daw, NIMA 921 (2019) 50-56

Thanks for Ed Daw and Ed Hardy for providing input.

UK strengths in software and computing in area of Dark Matter direct detection (my view)

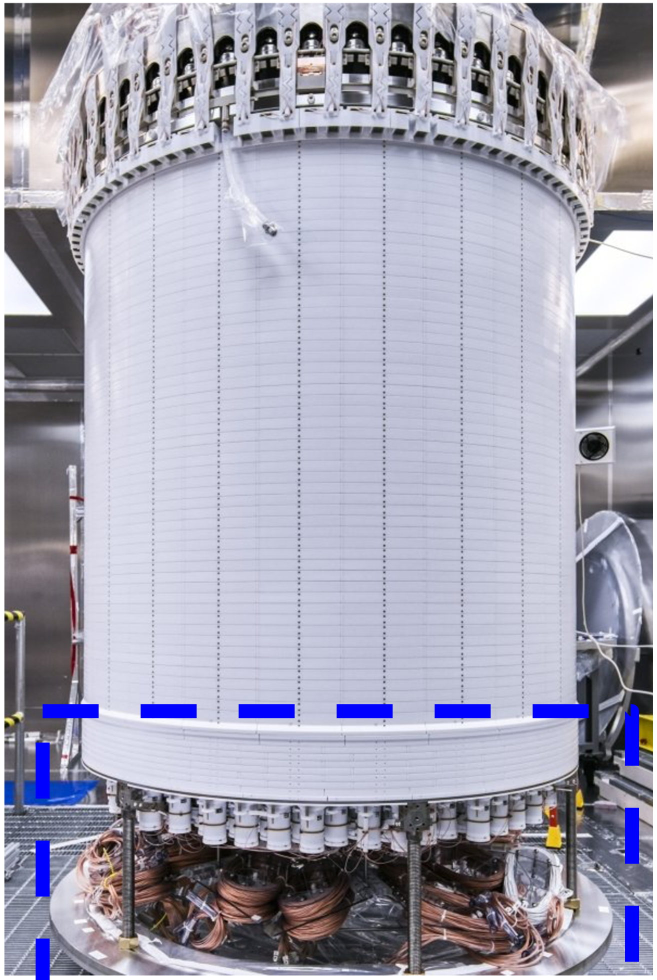
- Expertise in low-background simulations (GEANT4-based) & background model building
- Distributed compute & storage (via GridPP)
    - For data processing, simulations and analysis building on experience from LHC experiments
    - For example, Imperial hosts one of LZ's two data centres
- Expertise in modern development and release engineering practices (CI/CD, automation, DevOps)
    - Facilitating adoption within the DM experiments
    - Strong industry links through CDTs

S&C challenges currently running experiments

- Keeping up with modern software development/release engineering practices
    - Potential huge physicist-hours efficiency gains with more RTPs/exp
- Speedup GEANT4-based low-background simulations
    - In particular high-fidelity full optical sims
- Ensuring data format and analysis tools allow staying at cutting edge of techniques from data science/industry
- At end of experiment: long-term data archival, open data, software sustainability

S&C challenges future experiments

- Same challenges with regards to sustainable modern software development
- Energy efficient software/computing
- Longer run times/larger detectors
  - Factor >10 increase data rates and CPU-requirements
  - Similar for simulation stats
- Increase in channels → cabling impractical given background requirements (low-radon)
  - Cryogenic on-board waveform digitisation



Channel readout: LZ at limit of what can be done with cable readout given radon-requirements

Software and Computing R&D needs

N.B a selective and likely biased list… expecting discussion in breakout sessions

- How to keep up with modern software development/release engineering practices → training, RTPs, demonstrator projects
- Simulation optimisation/performance
  - Use of GPUs for low-background detector optical simulations (GEANT4 + Opticks); ML techniques such as GANs
  - Application of event-biassing techniques for rare-event searches
- Readout techniques → commercial FPGAs and SoC ASICs for near-sensor waveform digitisation (low-radon, performance at cryogenic temperatures)
- Exploration of common tools/frameworks (within HEP, within rare-event search community)