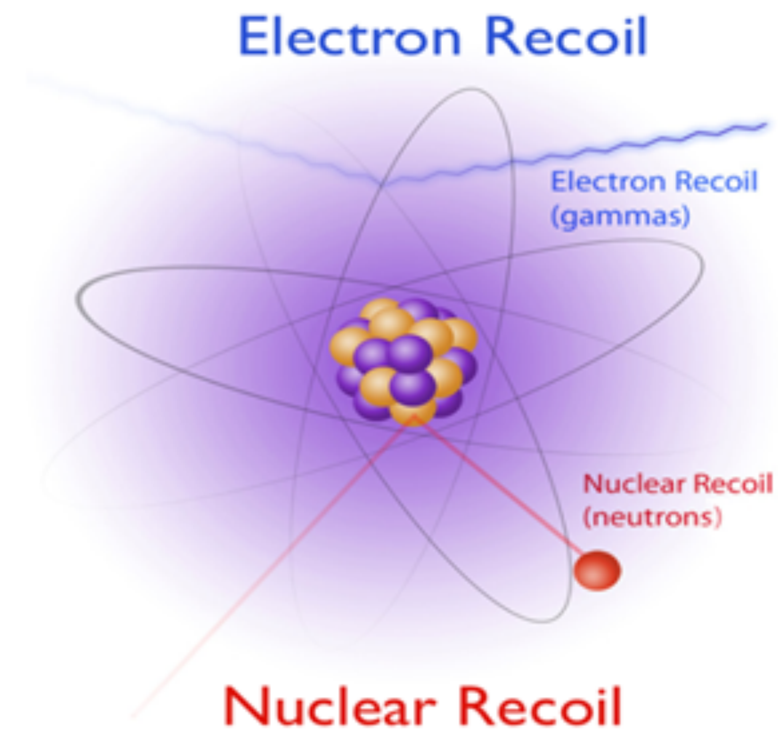


Experimental searches for WIMP dark matter

Blair Edwards
Yale University

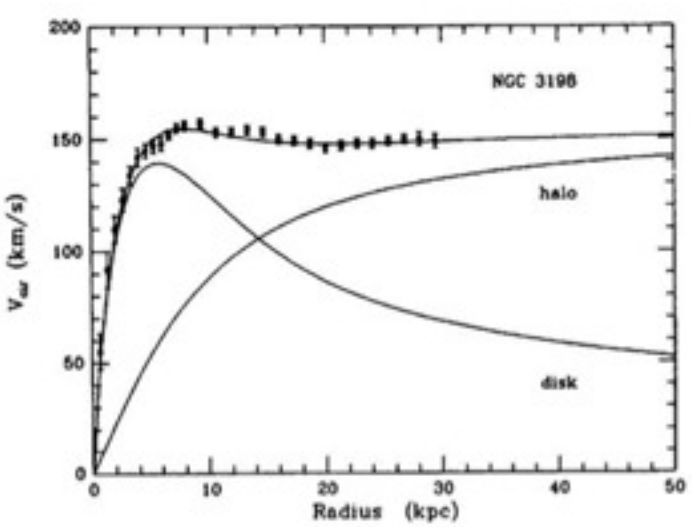
Lattice meets Experiment 2013 - Brookhaven National Laboratory
5th December 2013

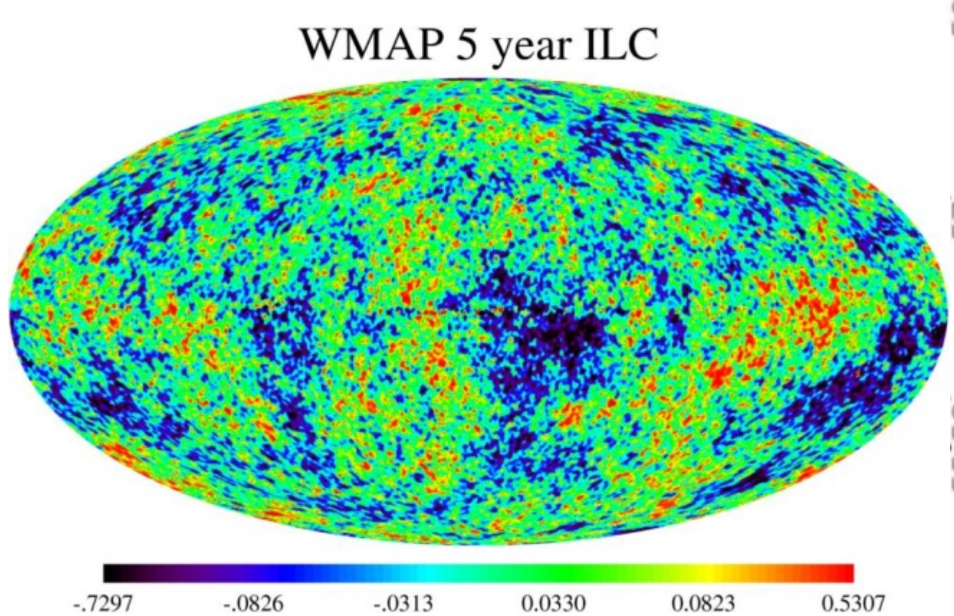
Yale

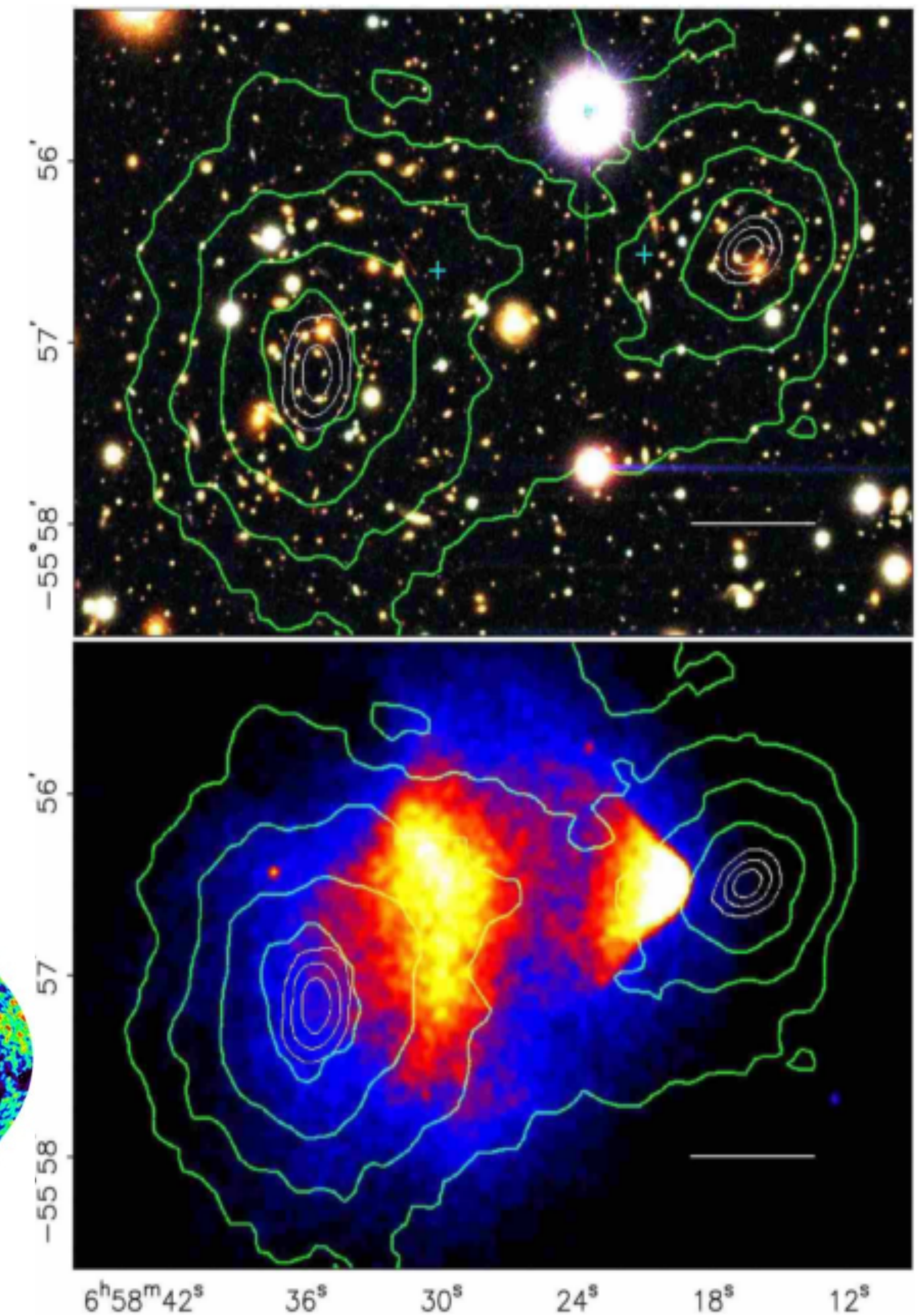
LUX

Dark Matter

- 27% of the energy composition of the universe
- Properties:
    - Stable and electrically neutral
    - Non-baryonic
    - Non-relativistic
- Estimated local density: $0.3 \pm 0.1 \mathrm{GeV} \cdot \mathrm{cm}^{-3}$
- Candidates: WIMPs, axions…







Searching for WIMPs

Accelerators: Look for dark matter candidates at the LHC.

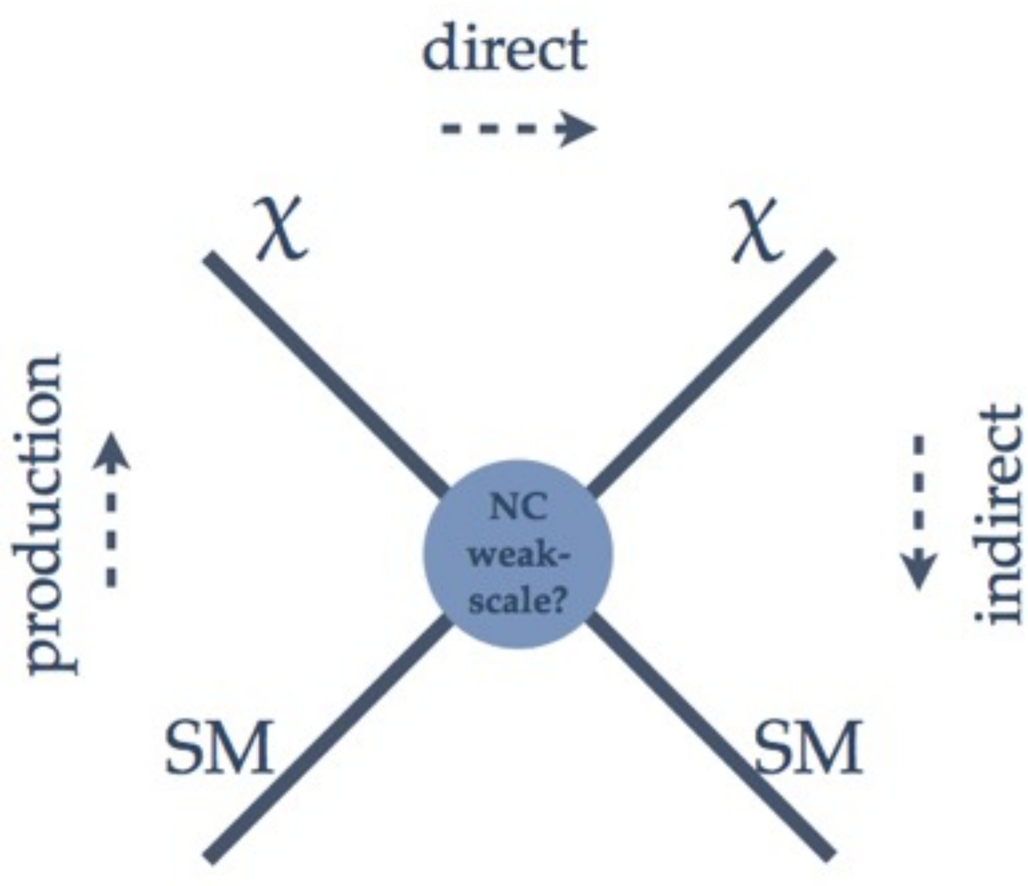
Squark and gluino decays result in leptons, jets, and missing energy.

BUT:

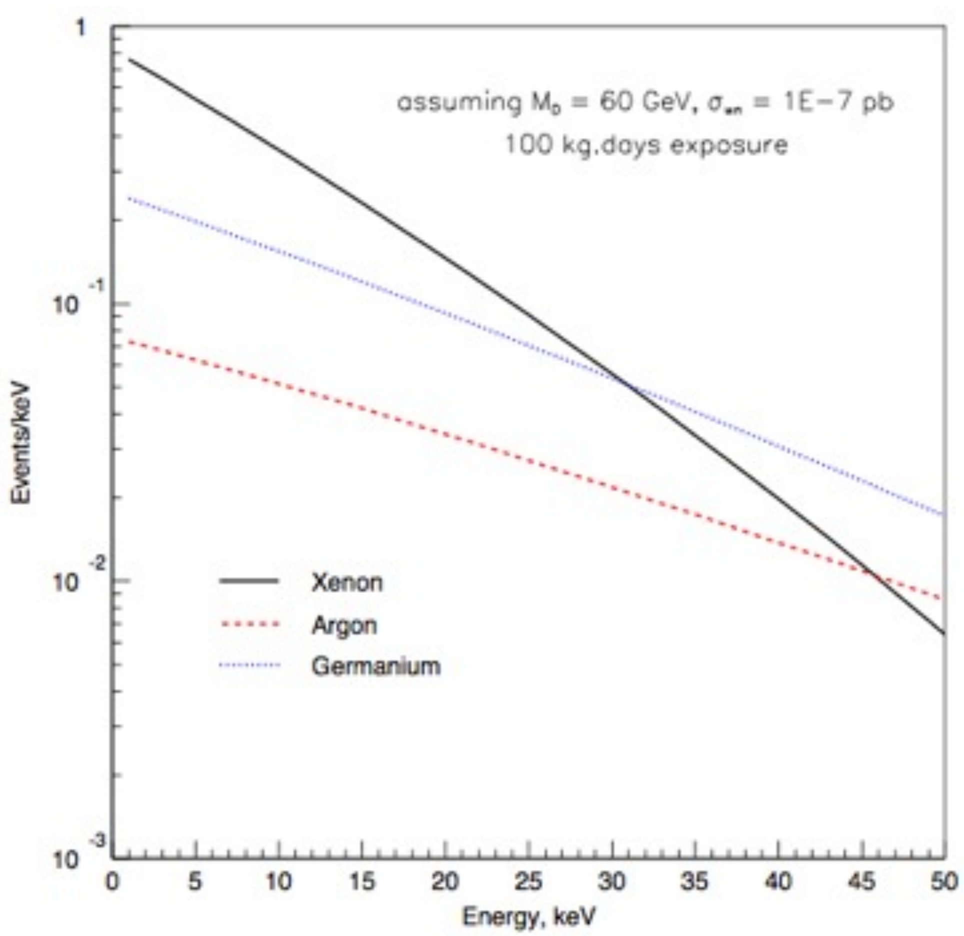
1) can't show that dark matter candidate is stable
2) hard to determine couplings/interactions of dark matter candidate
3) can't prove that candidate particle actually makes up the dark matter

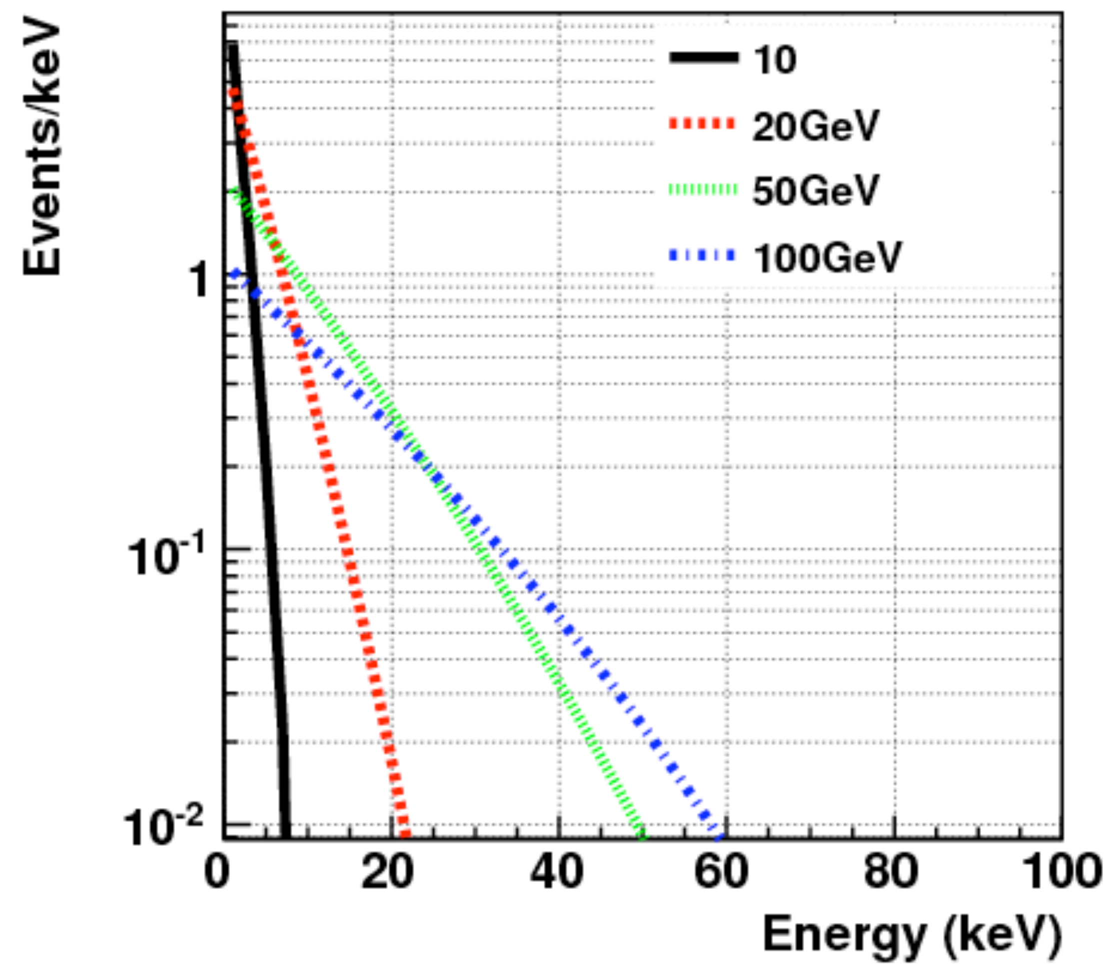
Indirect Searches: Look for $\chi\chi$ annihilation in form of high energy cosmics, neutrinos

Direct Searches: Look for anomalous nuclear recoils in a low-background detector



WIMP recoil spectra





Scattering rate

Sun's velocity around the galaxy

WIMP velocity distribution

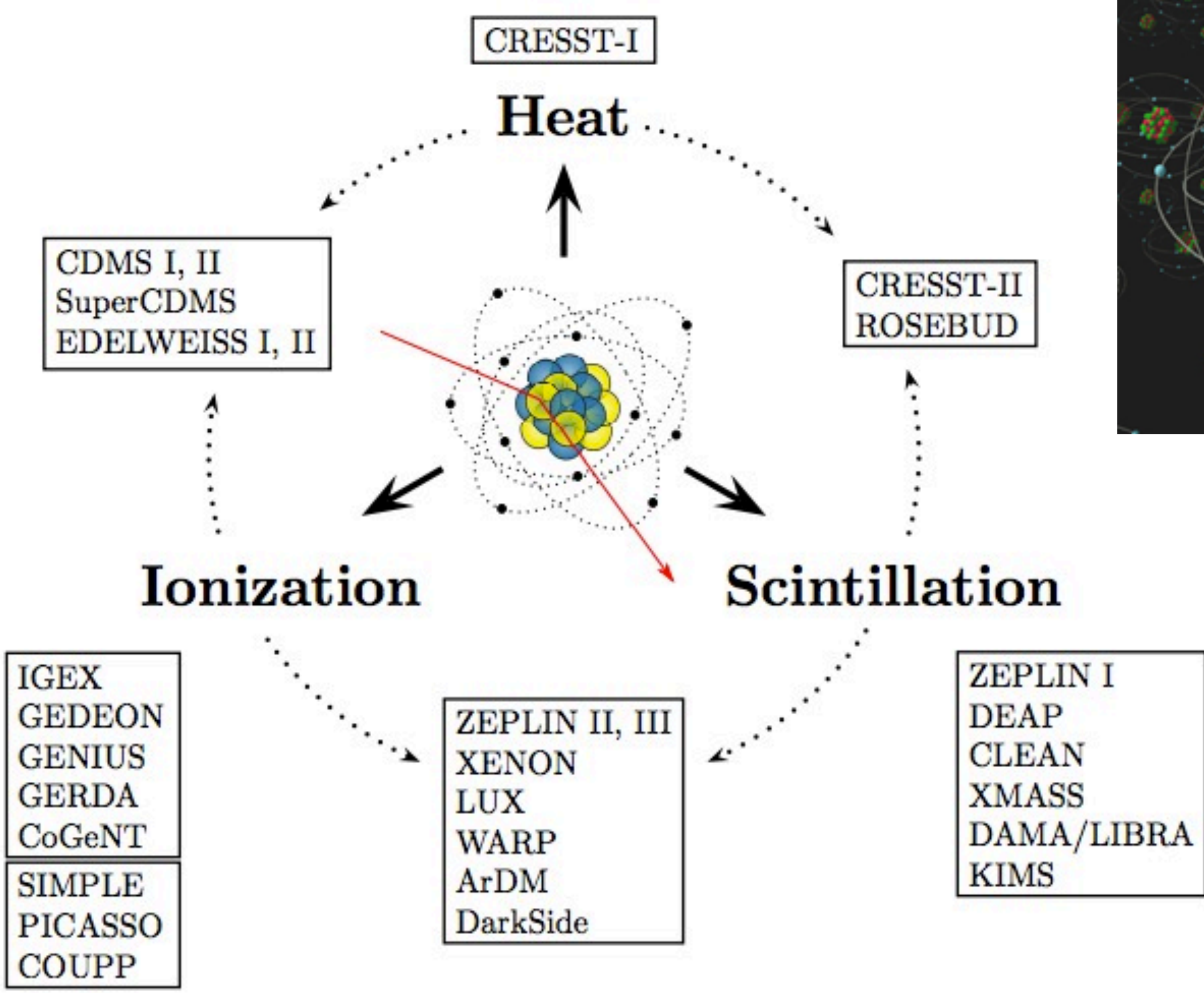
$$\mathrm{d}R/\mathrm{d}Q = (\sigma_0\rho_0 /\sqrt{\pi}\, v_0\, m_\chi\, m_r^2)\, F^2(Q)\, T(Q)$$

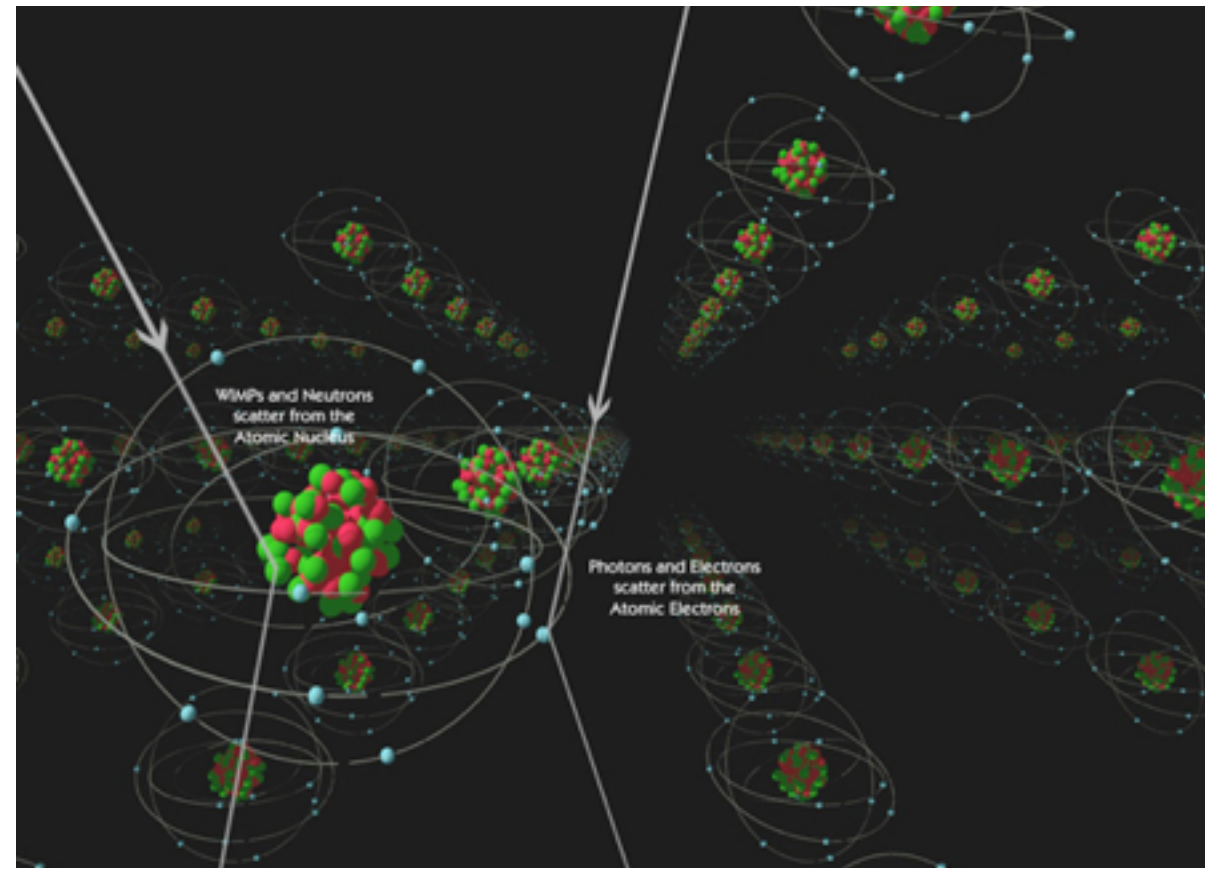
WIMP energy density, 0.3 GeV/cm^3

Form factor

Search techniques

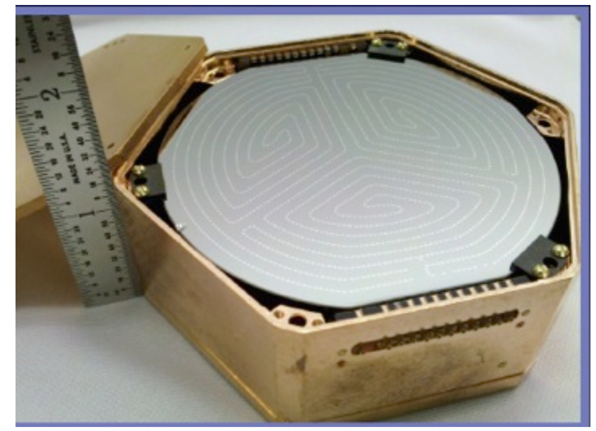
Important factors: large mass, low-radioactivity, low-energy threshold, high acceptance, ability to reject backgrounds (discrimination)



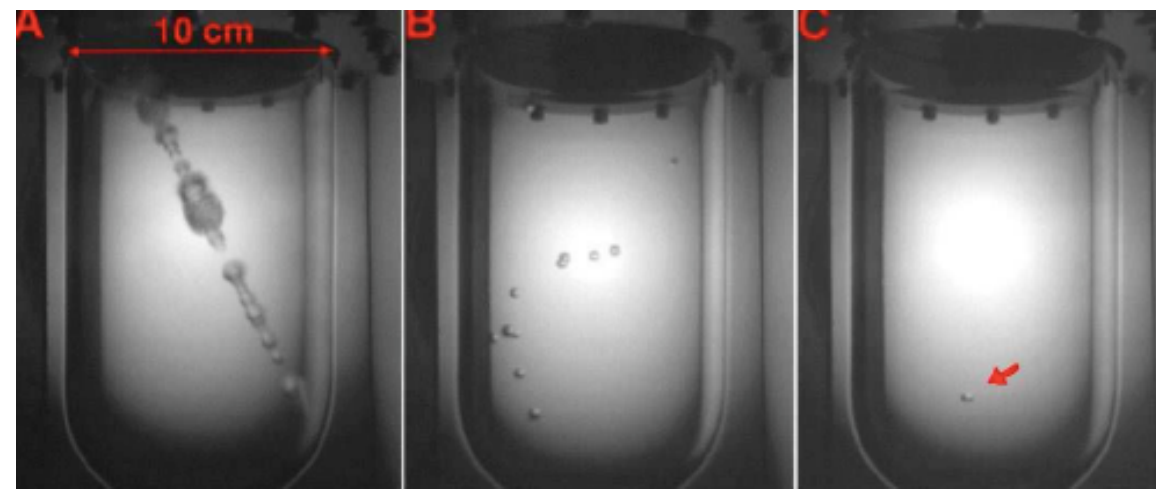


WIMP detection technologies

- **Cryogenic detectors** (CDMS, Edelweiss, CRESST): Excellent background rejection, low threshold and good energy resolution.

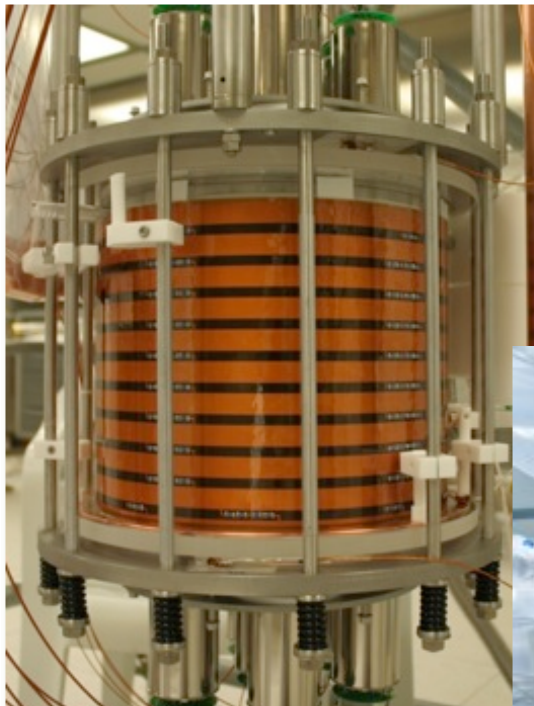


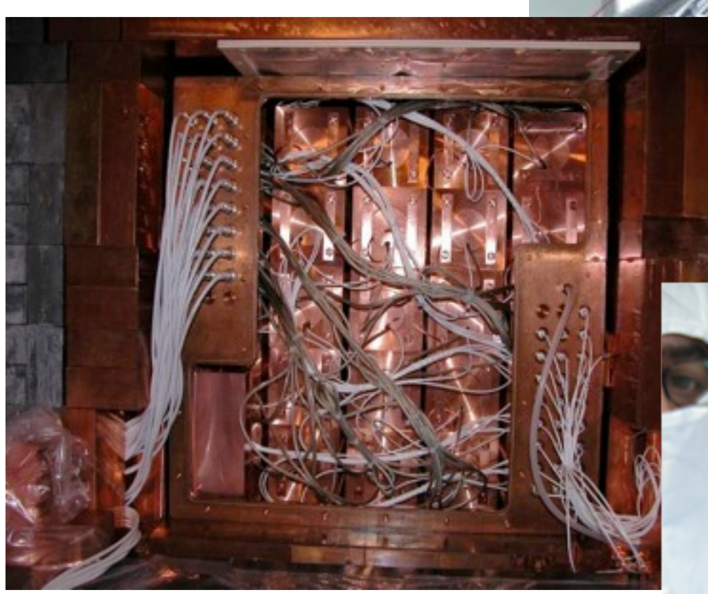
- **Threshold detectors** (COUPP, SIMPLE, PICASSO): Ultimate electron recoil rejection, inexpensive, easy to change target material for both SI and SD sensitivity.

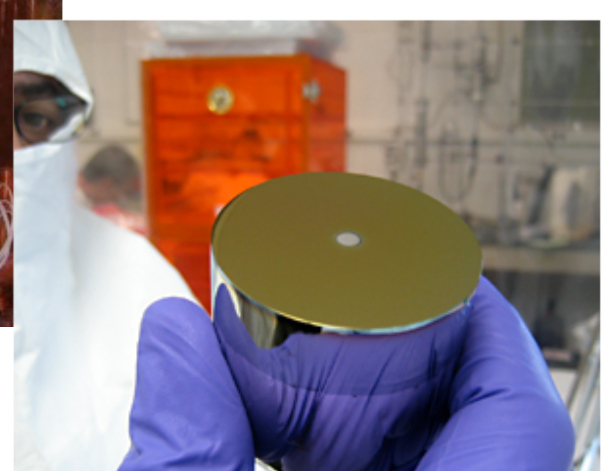


- **Single-phase LAr, LXe** (DEAP, CLEAN, XMASS): Simple and relatively inexpensive per tonne, pulse-shape discrimination and self-shielding.

WIMP detection technologies





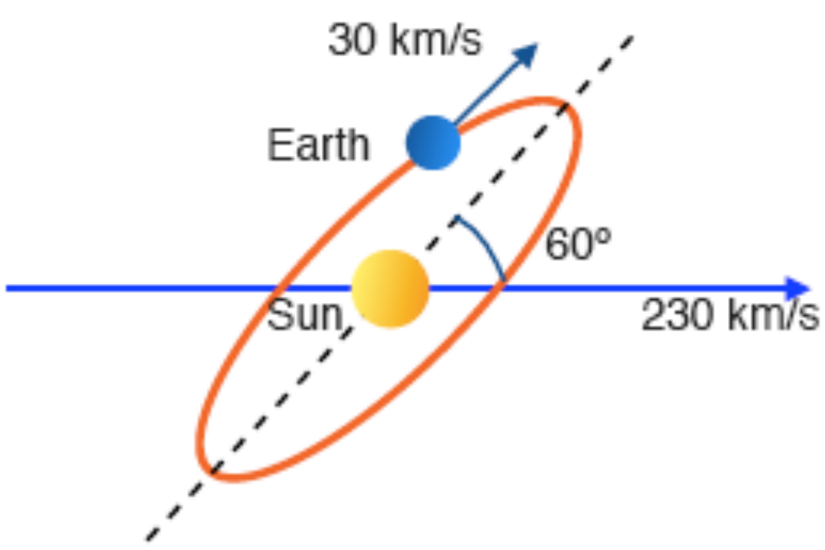


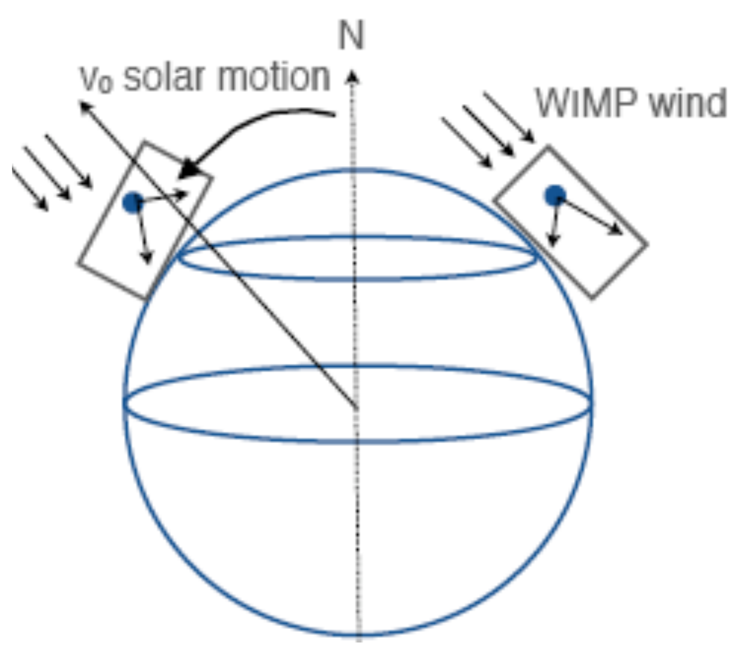
- **Dual-phase Ar** (DarkSide, ArDM): Excellent electron recoil rejection, position resolution.
- **Dual-phase Xe** (XENON, LUX, Panda-X): Suitable target for both SI and SD, low energy threshold, excellent position resolution, self-shielding.
- **Scintillating crystals** (DAMA/LIBRA, KIMS, ANAIS, ELEGANT, DM-Ice): Annual modulation with large target mass.
- **Ionization detectors** (CoGeNT, DAMIC): Very low energy threshold, good energy resolution.

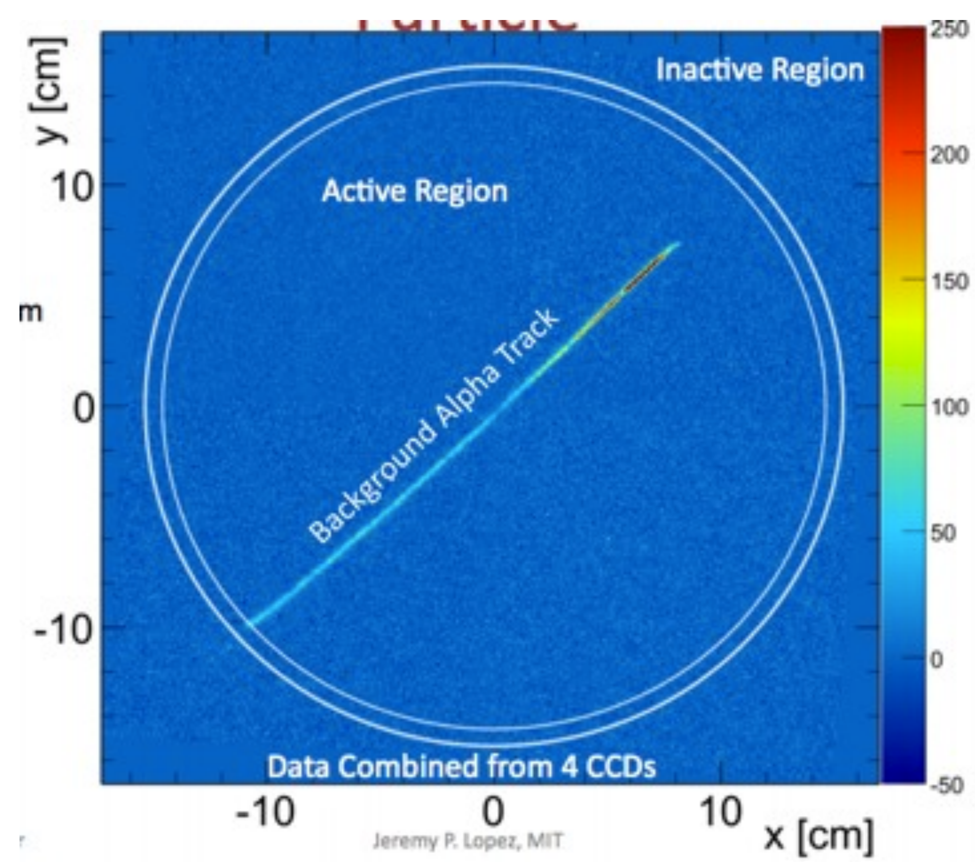
WIMP detection technologies

- Directional Detectors (DRIFT, DMTPC, D^3, MIMAC, NEWAGE, NEXT/Osprey): Usually gas-TPC imaging recoil tracks.

- In the long run, directional detection will allow one to map out the velocity distribution of the dark matter in the galactic halo, and could serve as an important input to modelling of the detailed formation history and dynamics of the galaxy.



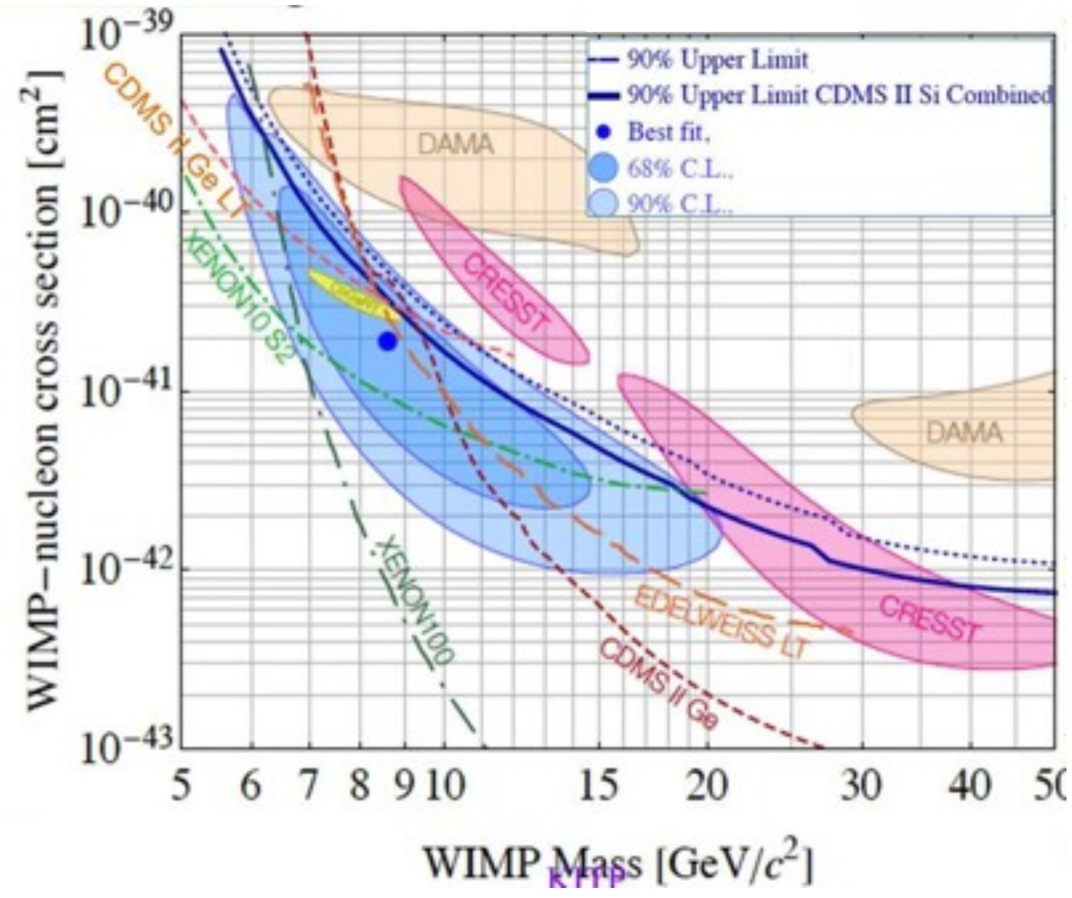




International effort

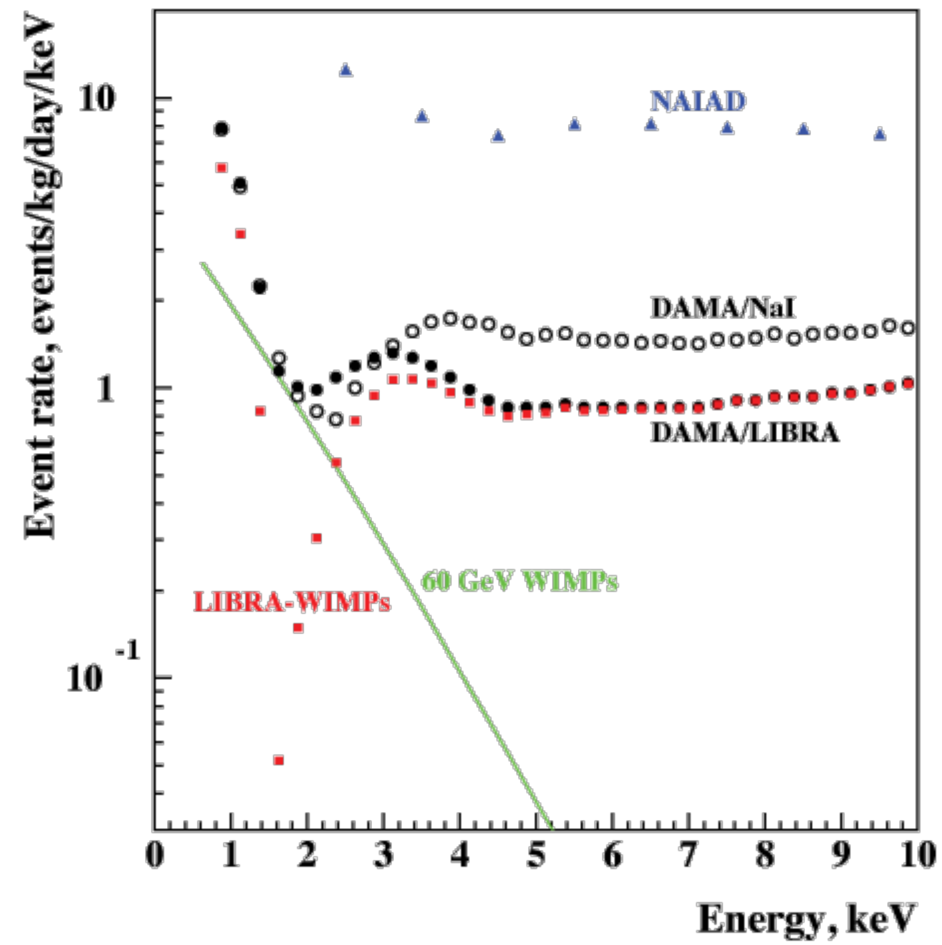
Low mass anomalies

- **DAMA**: NaI target, scintillation channel only, annual modulation seen since 1998.
- **CRESST**: $CaWO_4$ target, scintillation + heat channels, anomalous events seen in 2011.
- **CoGeNT**: Ge target, charge channel only, event excess seen since 2010.
- **CDMS**: Ge and Si targets, charge & heat channels, Si excess seen early 2013.



DAMA

- Array of NaI detectors, with PMT readout
- DAMA/NaI: 100 kg of NaI(Tl)
- DAMA/LIBRA: 250 kg of NaI(Tl)

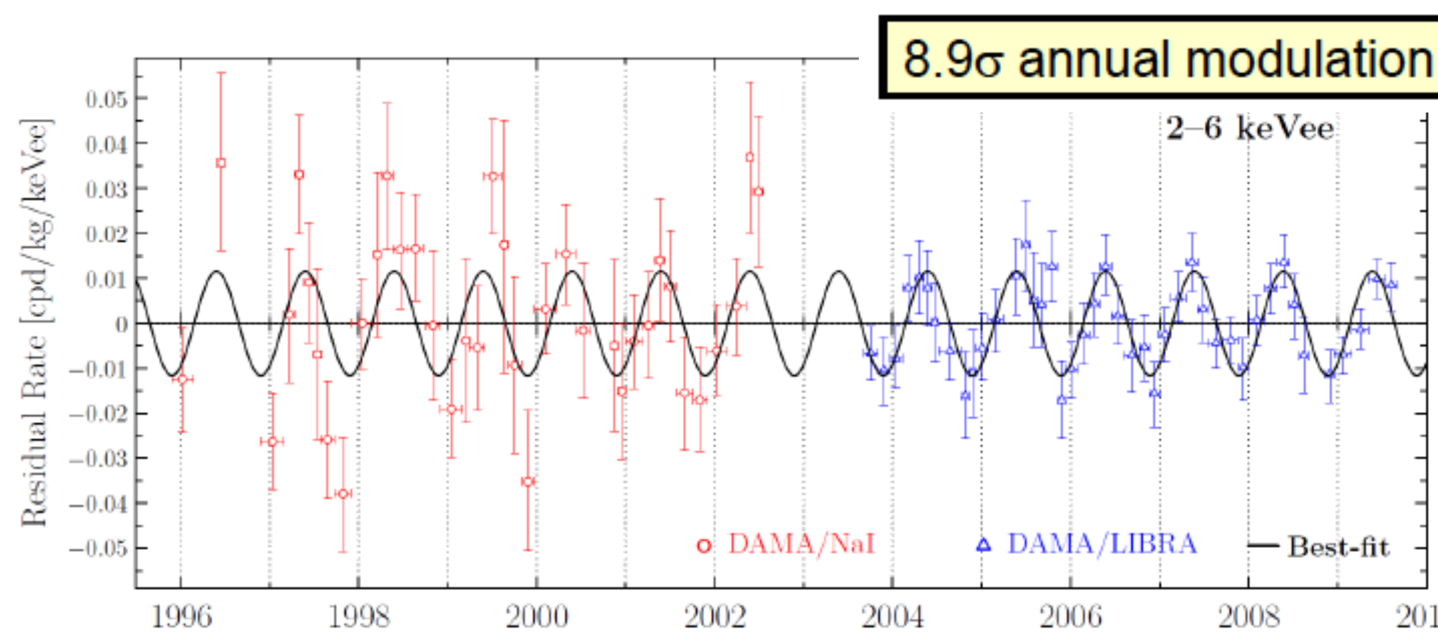


Annual modulation of 2-6 keV single hits

No modulation at higher energies

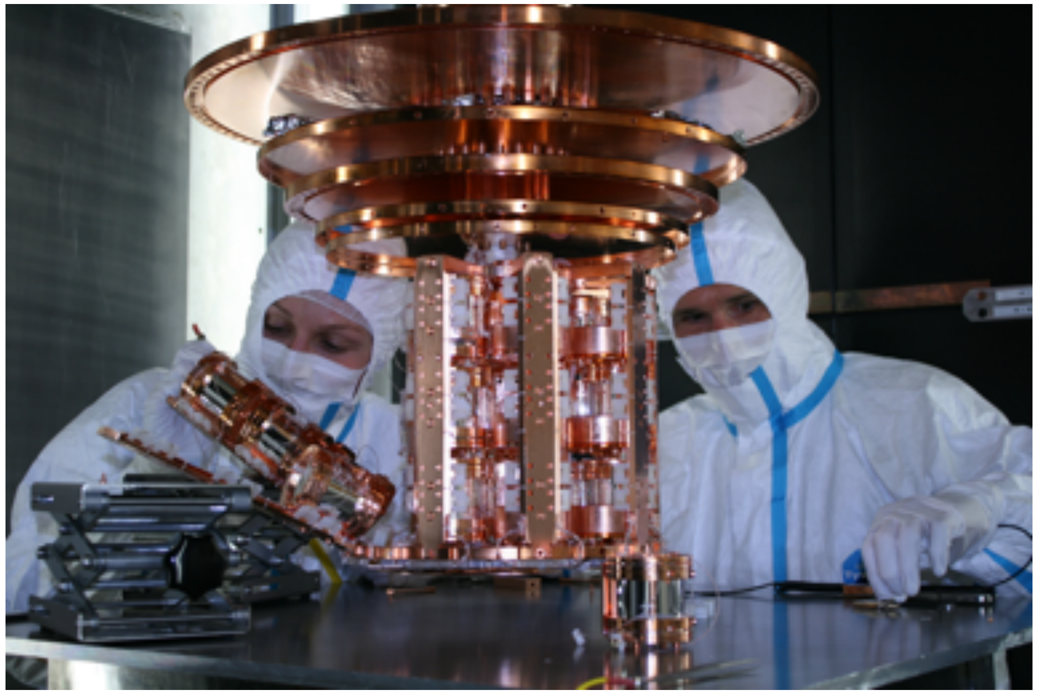
No modulation of multiple hit events

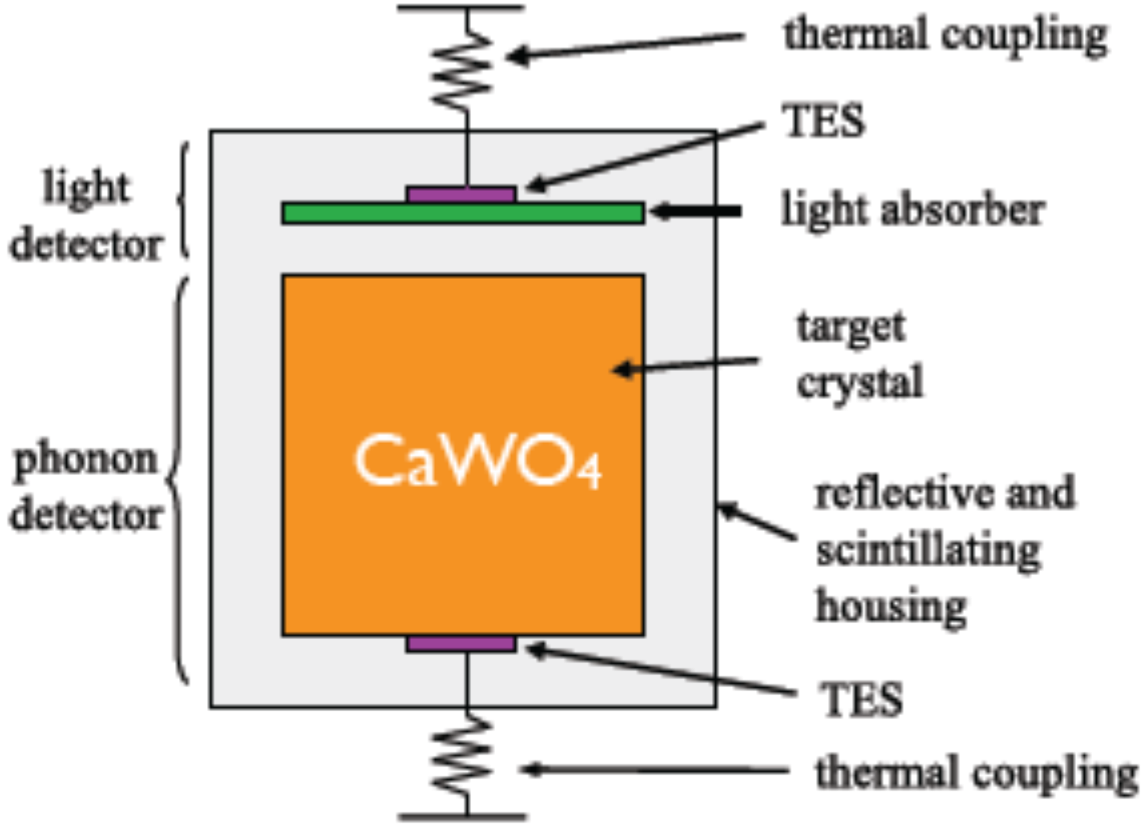
New runs: DAMA has been operating with high-QE phototubes since Dec 2010.

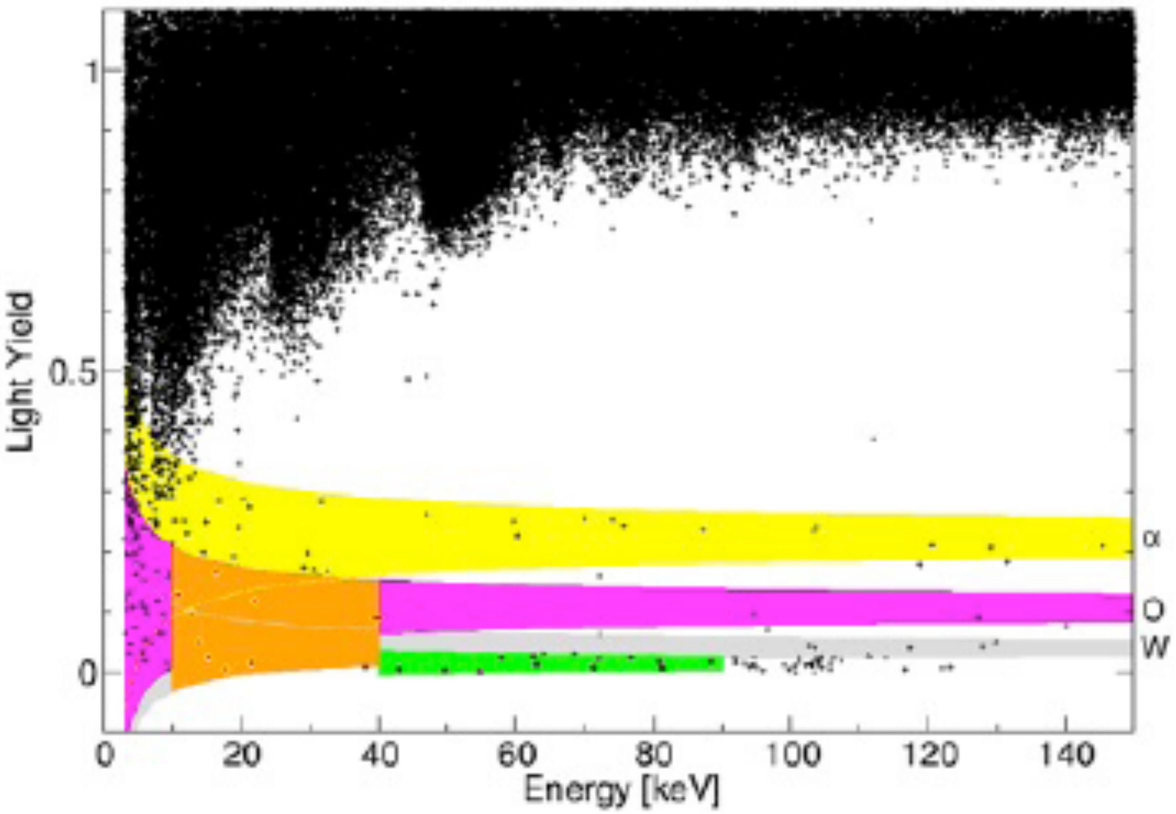


CRESST

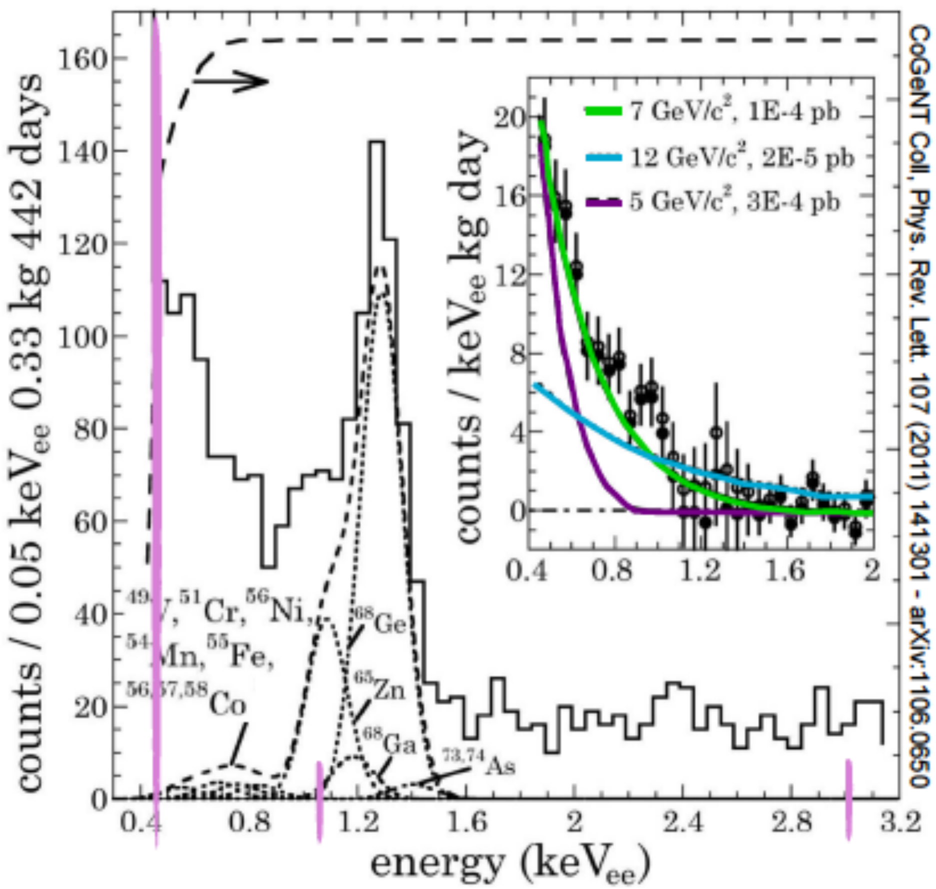
- Measure the heat and light produced by an interaction in the $CaWO_4$.
- Saw 67 events in NR region of parameter space.
- Only half can be explained by expected backgrounds.

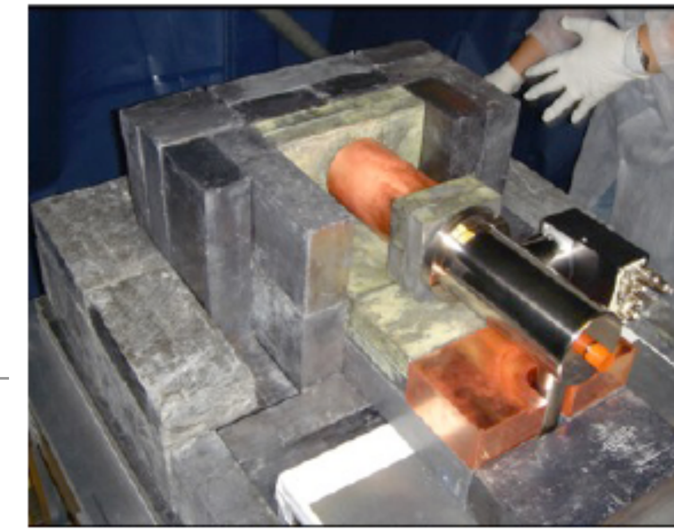


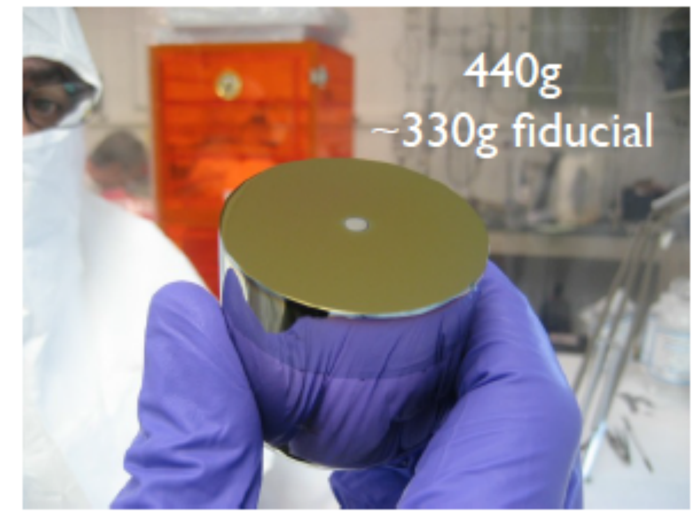




CoGeNT (P-type, point contact Germanium detectors)

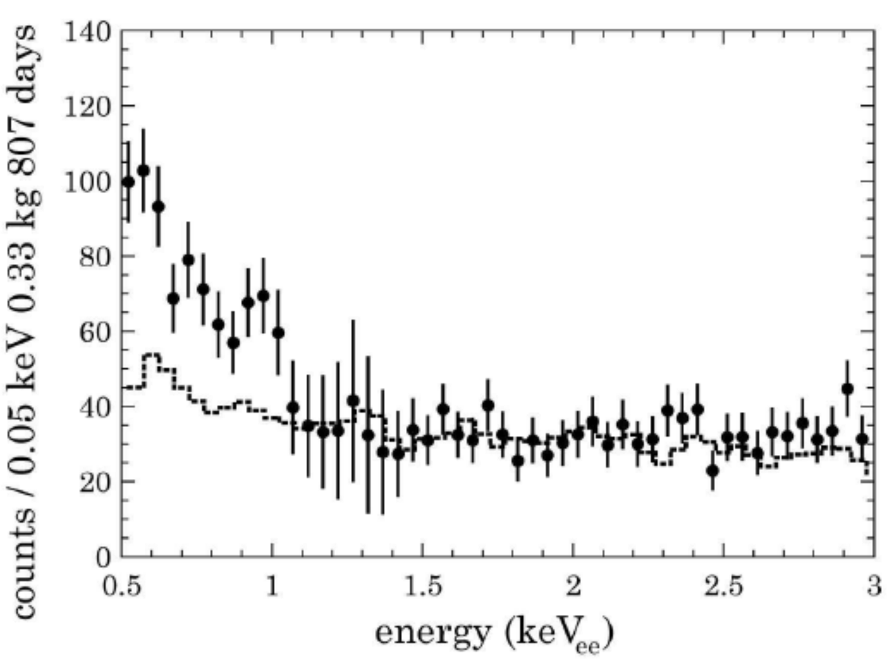






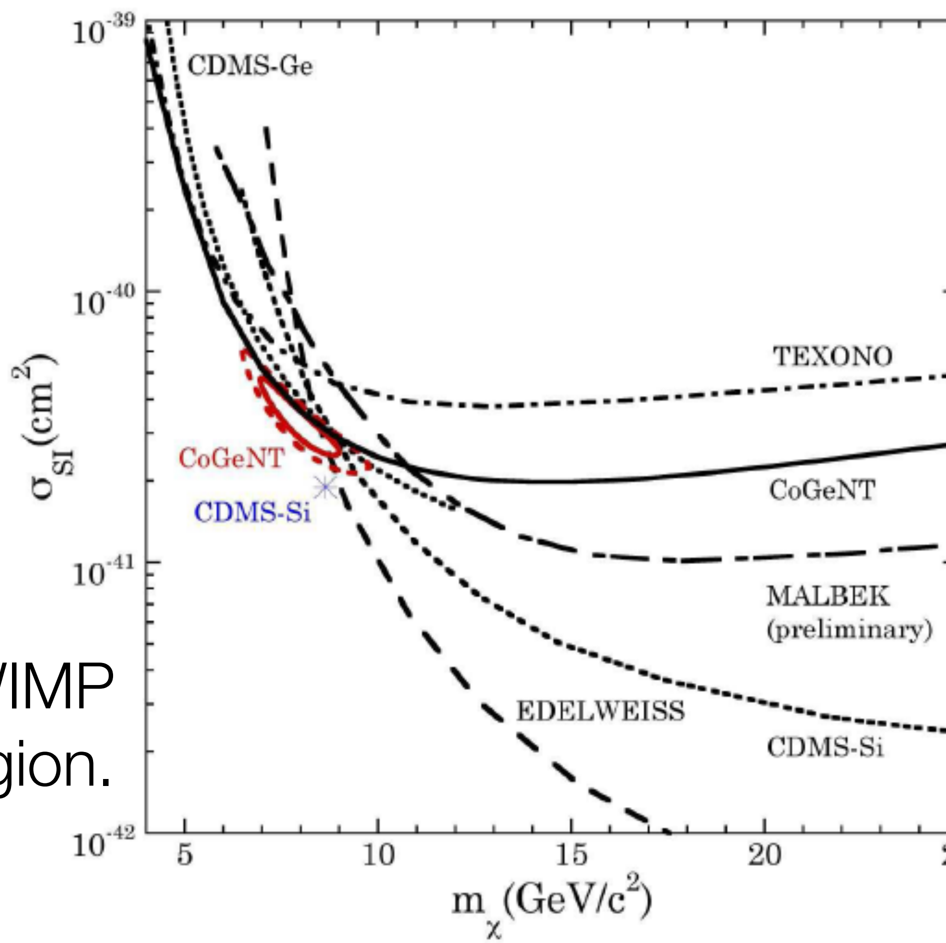
The CoGeNT detector sees an excess of events at low energy which cannot be explained by their BG models.

Could be fit by a low-mass WIMP recoil.



Energy spectrum after correcting for efficiencies and removing surface events and cosmogenics.

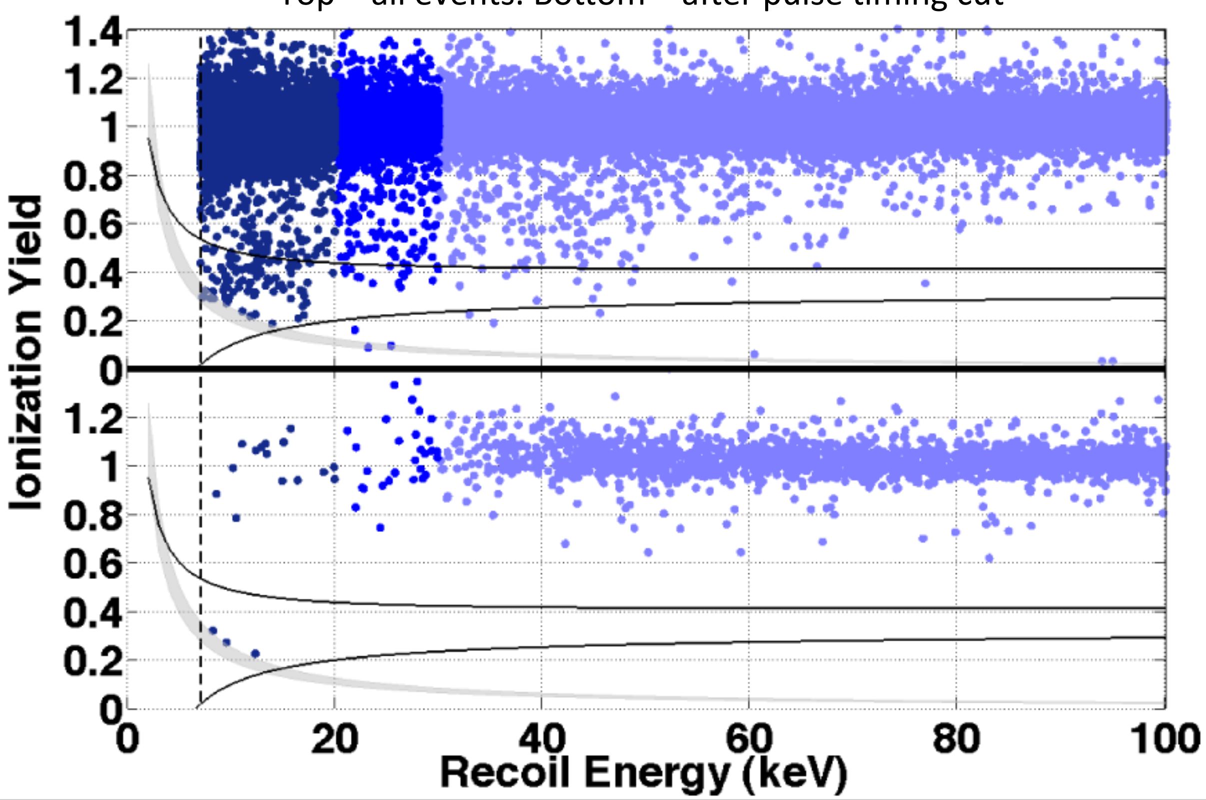
SI limits and 90% WIMP region.

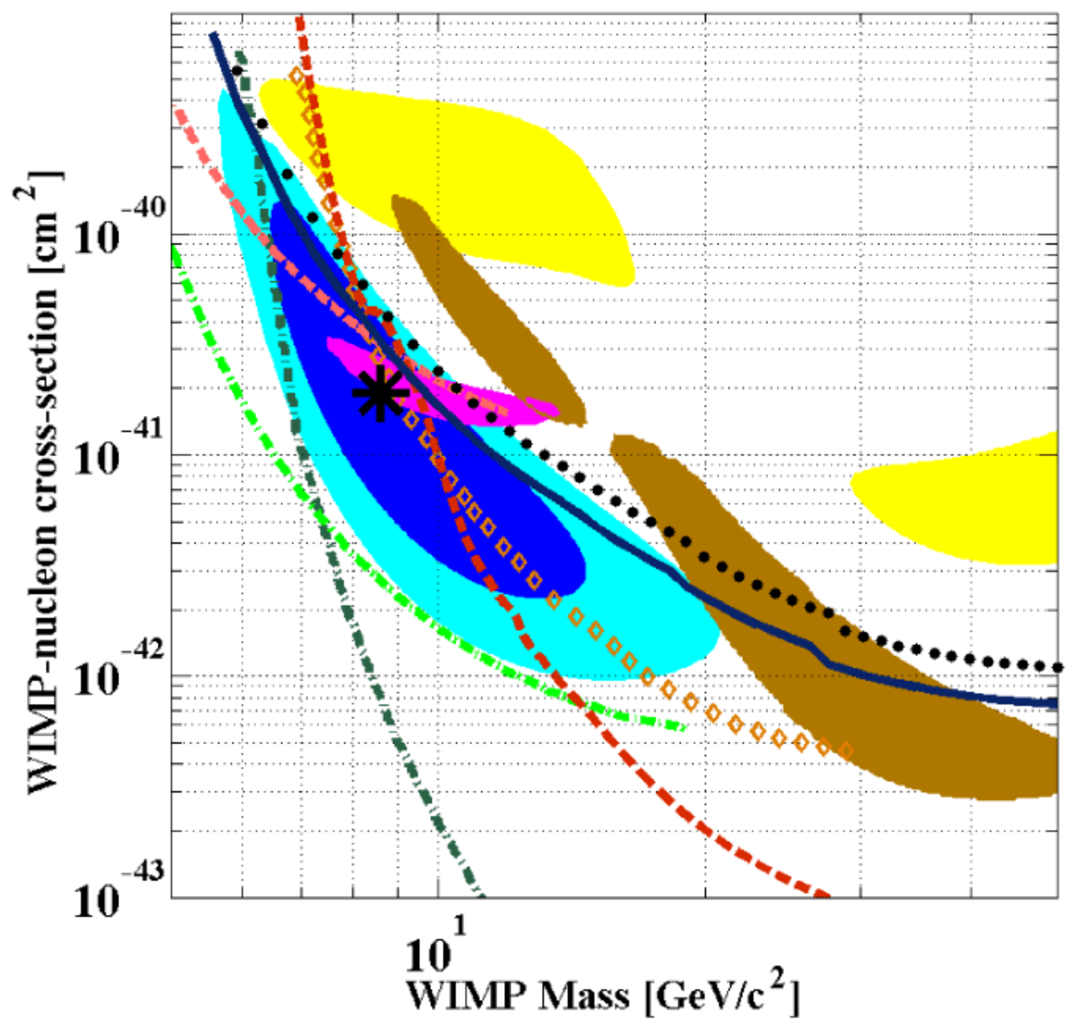


CDMS-II Si results (Agnese *et al*, arXiv:1304.4279)

- Blind analysis of eight Si detectors, with 140.2 kg day exposure, from July 2007 – Sept 2008
- For low-mass WIMPs, more recoil energy is transferred to Si than to Ge.
- Three events seen, with a 5.4% probability of a statistical fluctuation producing 3+ events.
- Best fit under WIMP hypothesis gives 8.6 GeV mass, 1.9e-41 cm^2 WIMP-nucleon cross-section
- "We do not believe this result rises to the level of a discovery, but it does call for further investigation"

Top = all events. Bottom = after pulse timing cut

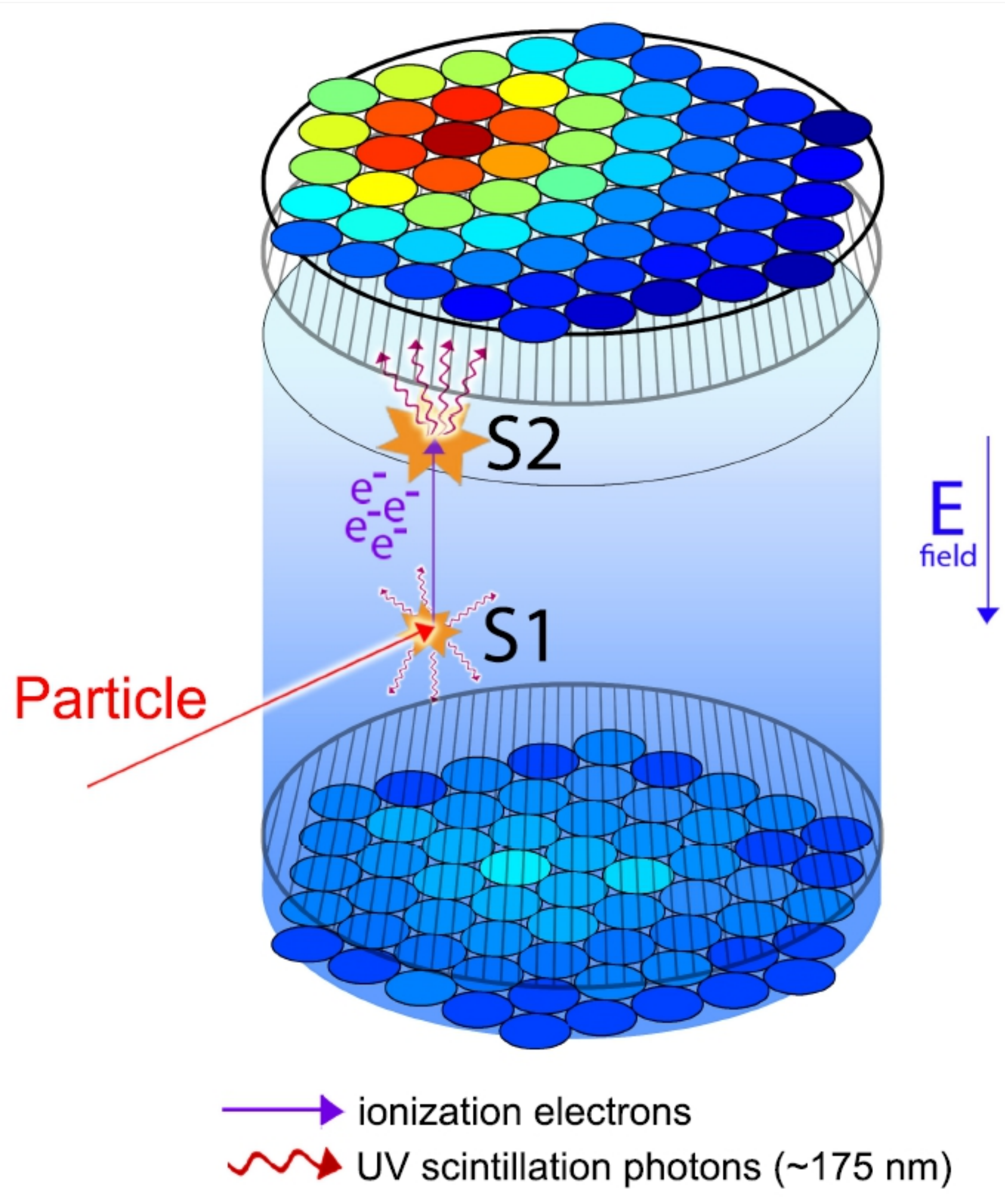


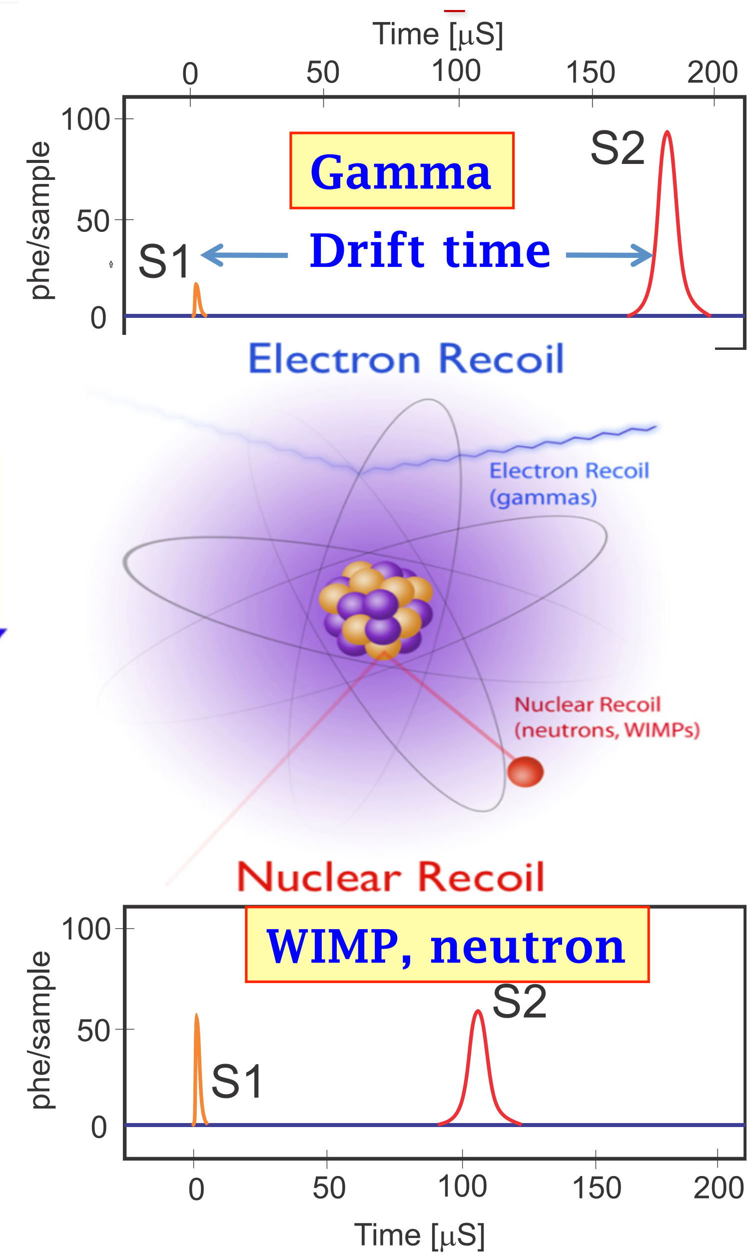


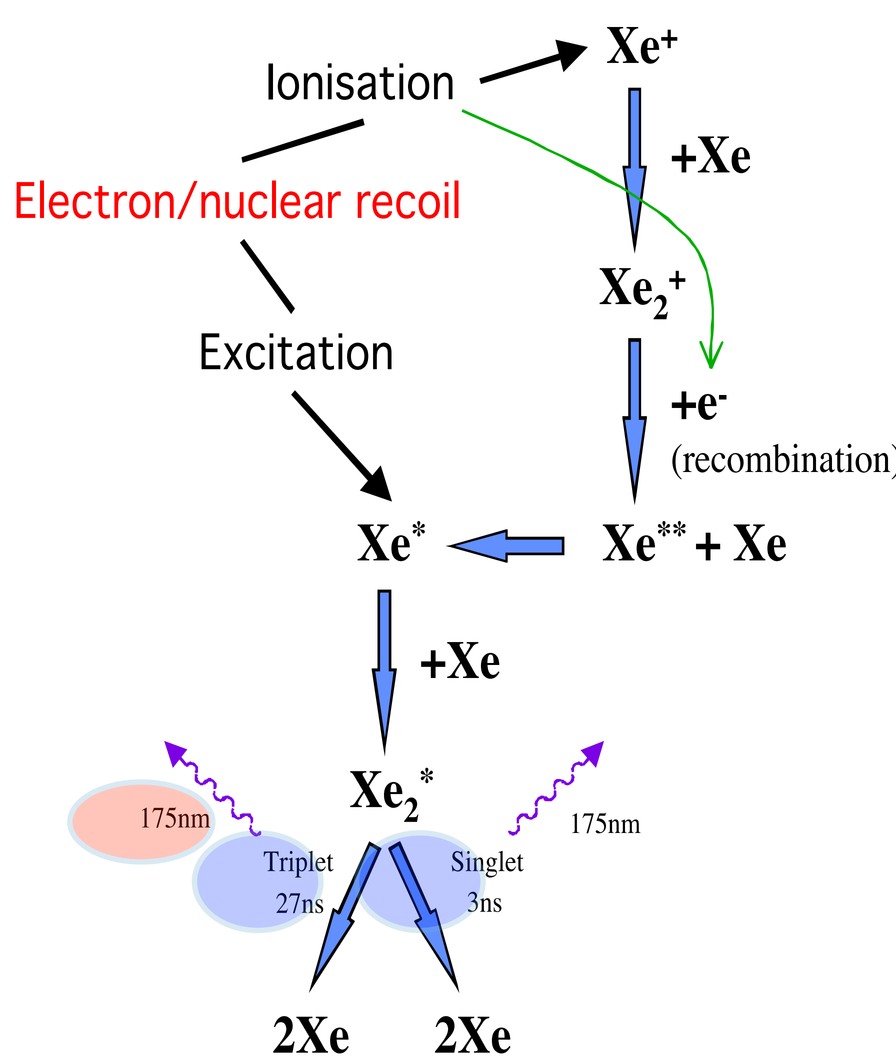
Noble Liquid Revolution

- Noble liquids are relatively inexpensive, easy to obtain, and dense.
- Easily purified
  - low reactivity
  - impurities freeze out
  - low surface binding
  - purification easiest for lighter noble gases
- Ionization electrons may be drifted through the heavier noble liquids.
- Very high scintillation yields
  - noble liquid do not absorb their own scintillation
  - 30,000-40,000 photons/MeV
  - modest quenching factors for nuclear recoils
- Easy construction of large, homogeneous detectors.

Liquid Xenon detectors

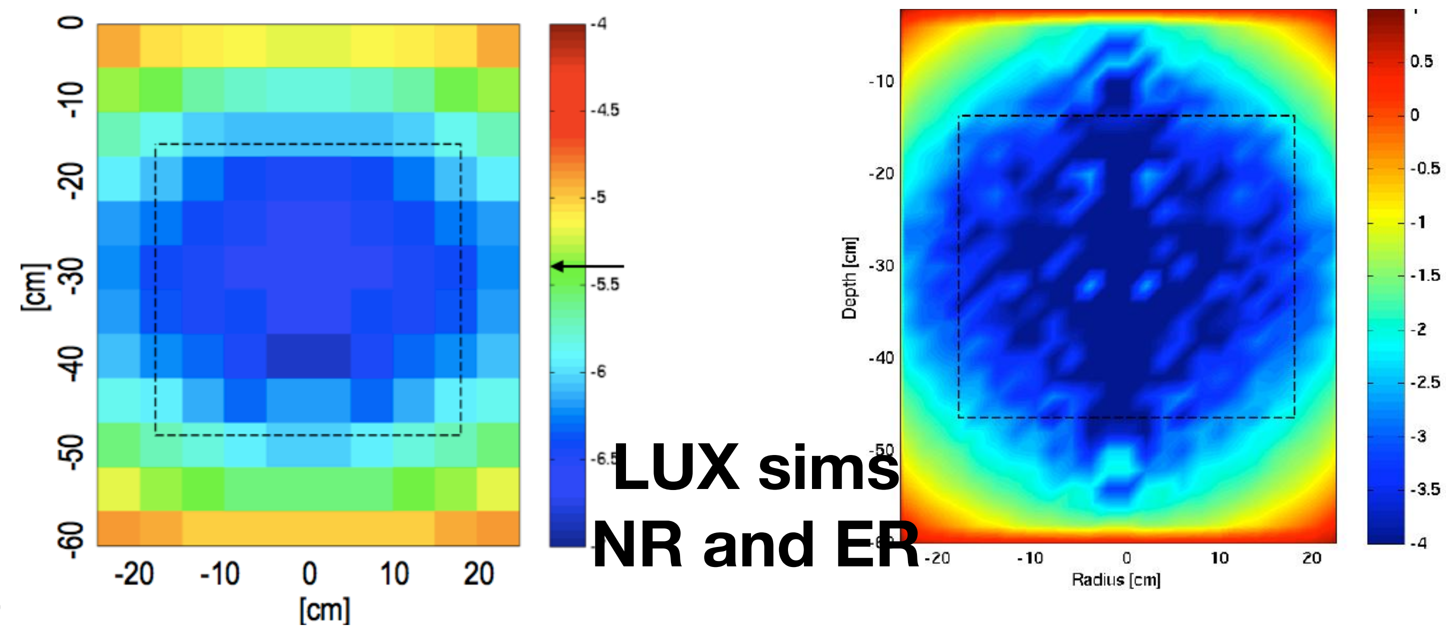


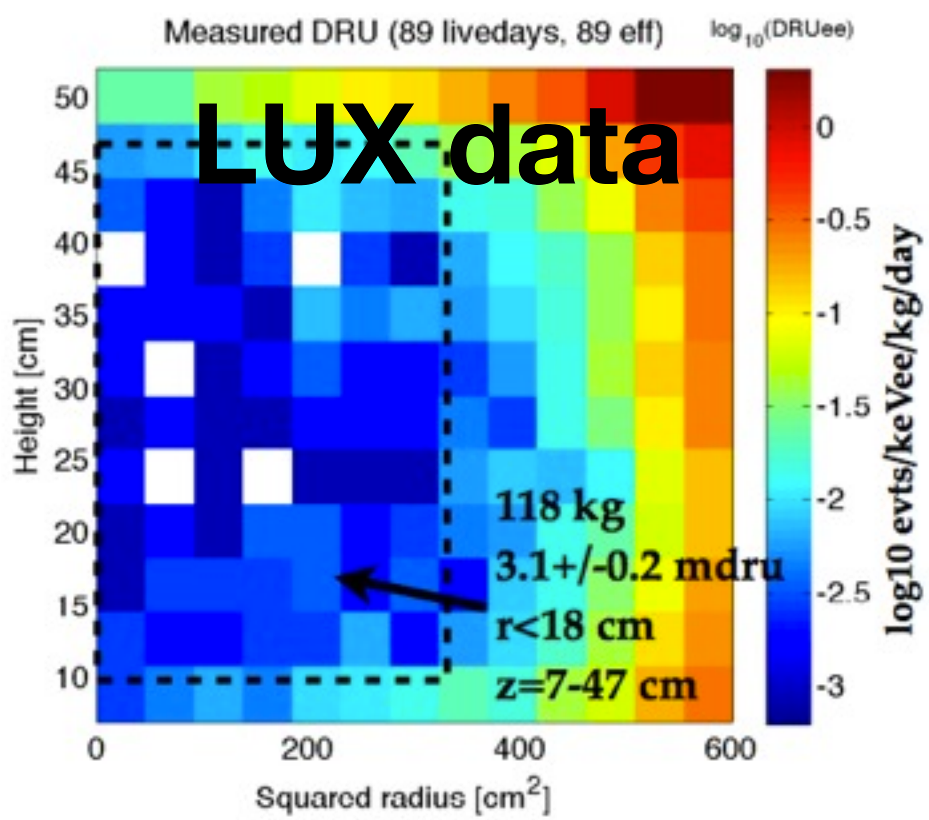


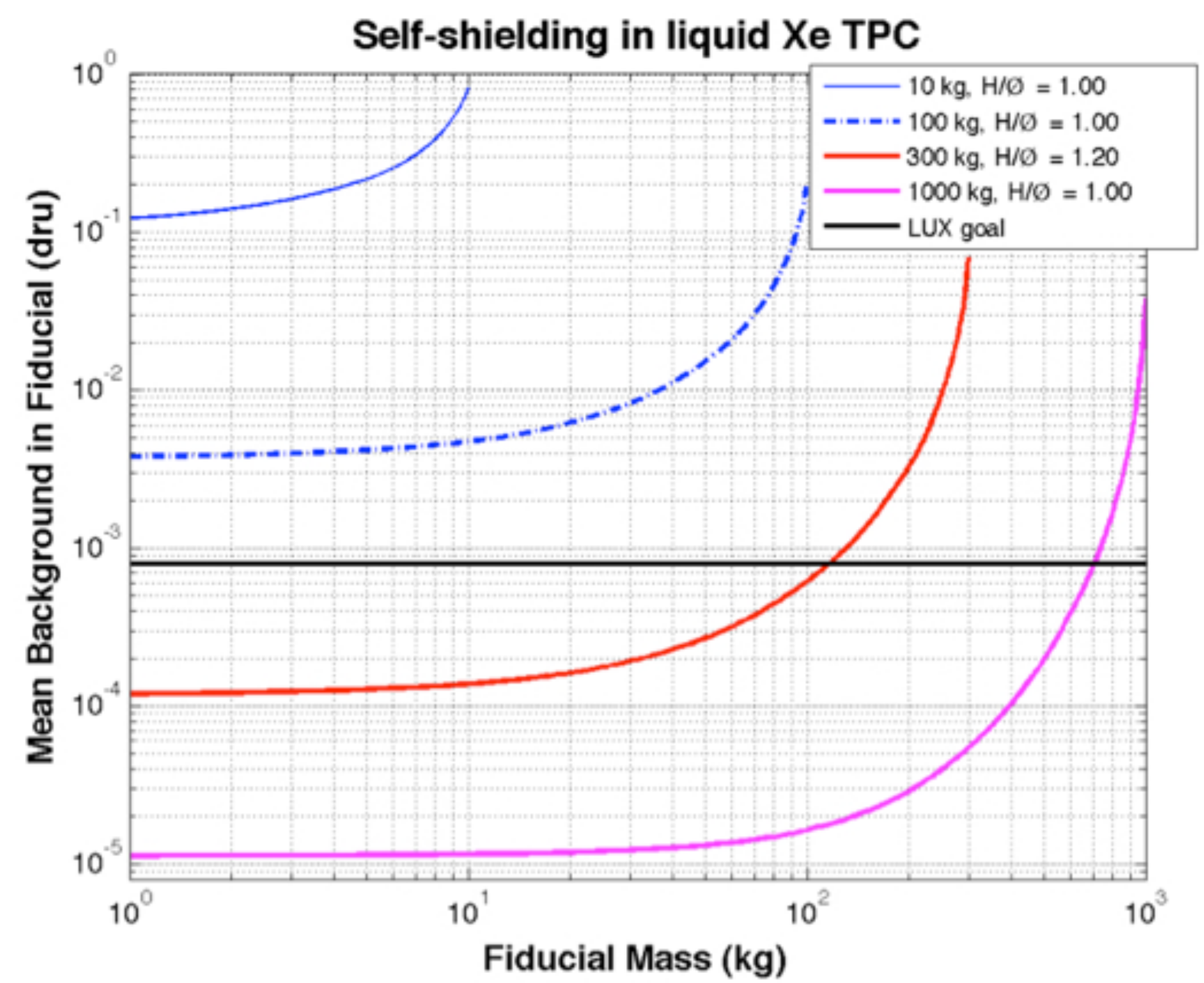


Xenon self-shielding

- Liquid xenon density = 3 g/cm^3.
- To cause a background event, gamma rays and neutrons must penetrate into the fiducial volume, scatter once, and then escape without scattering again.
- Gamma ray, neutron backgrounds drop exponentially with detector size.

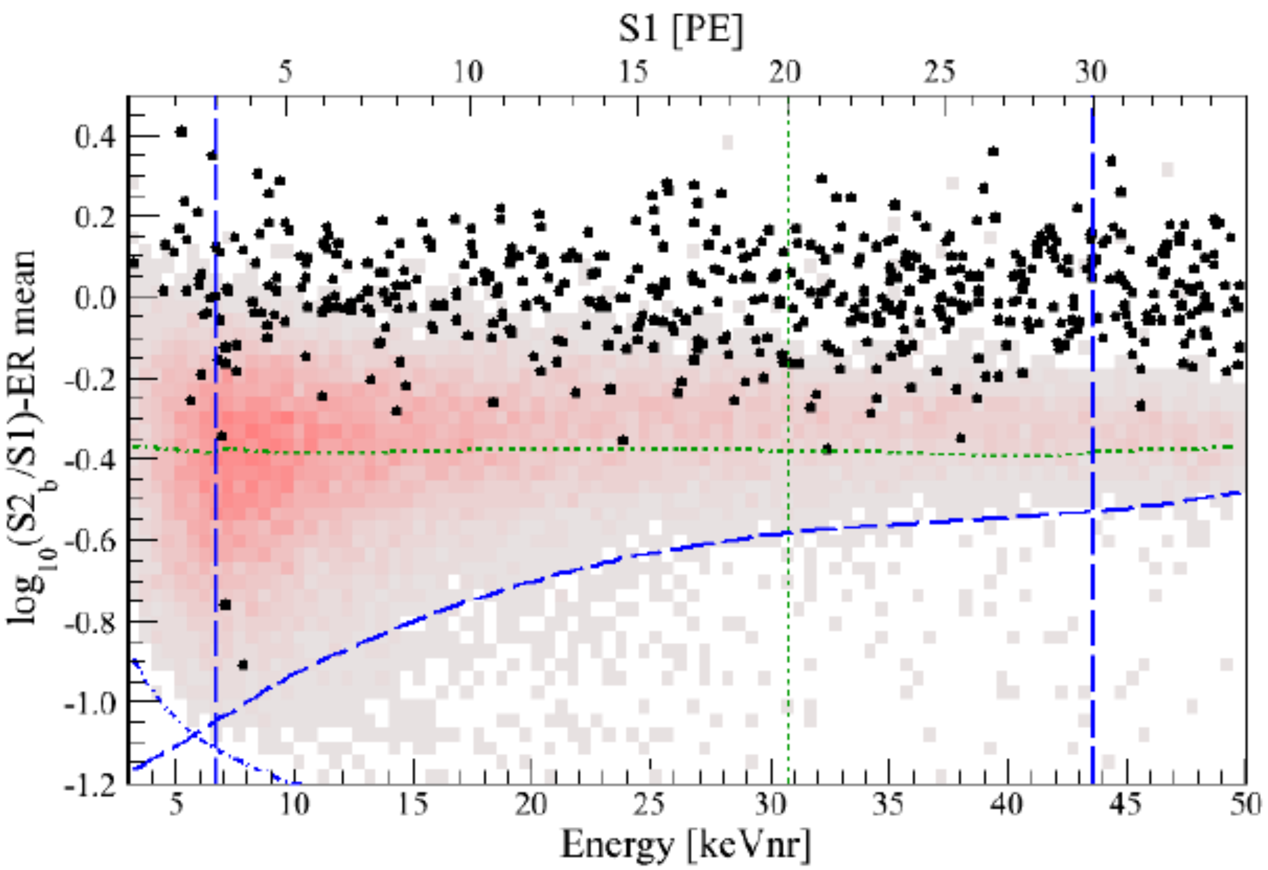


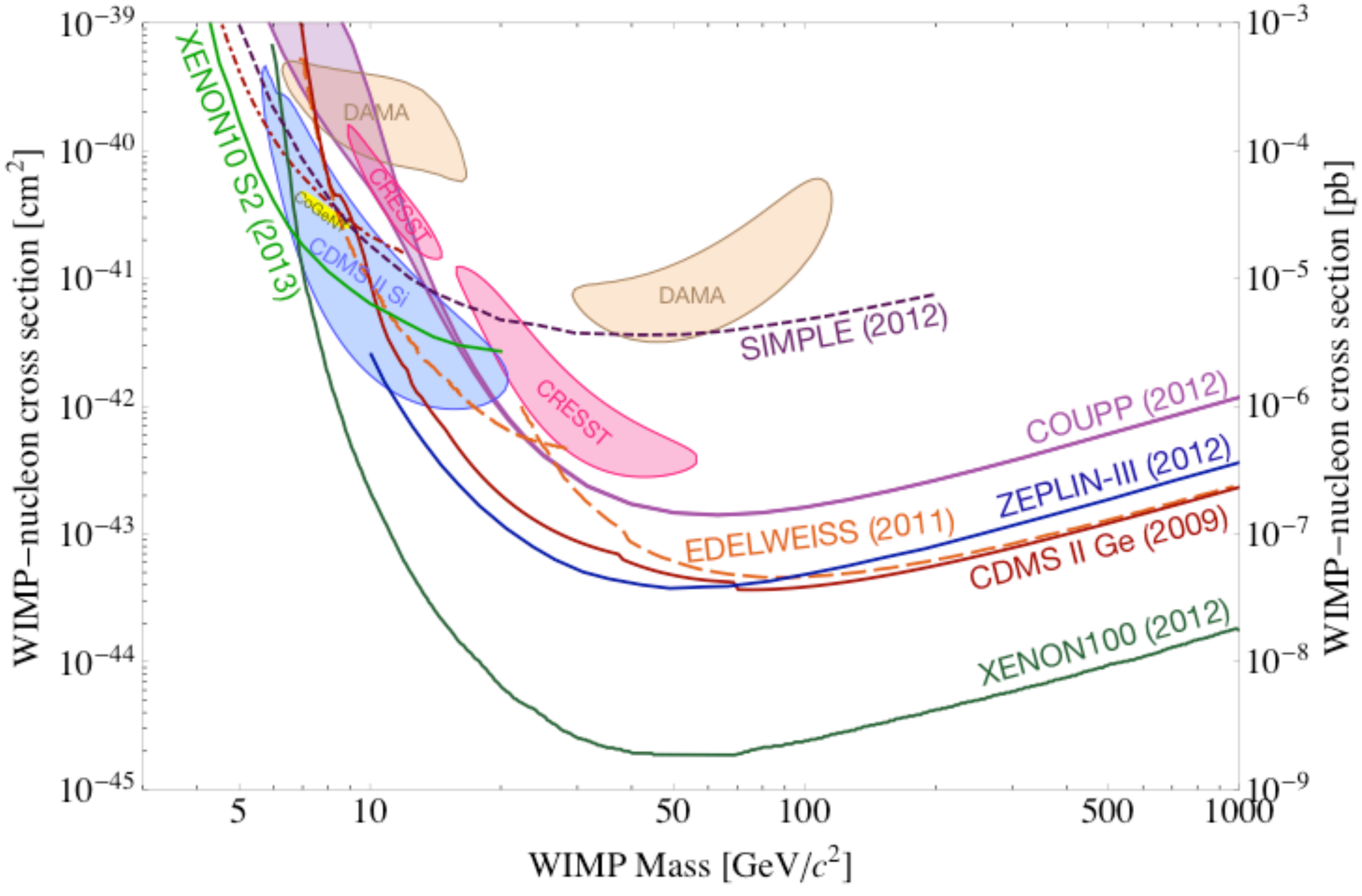




XENON100

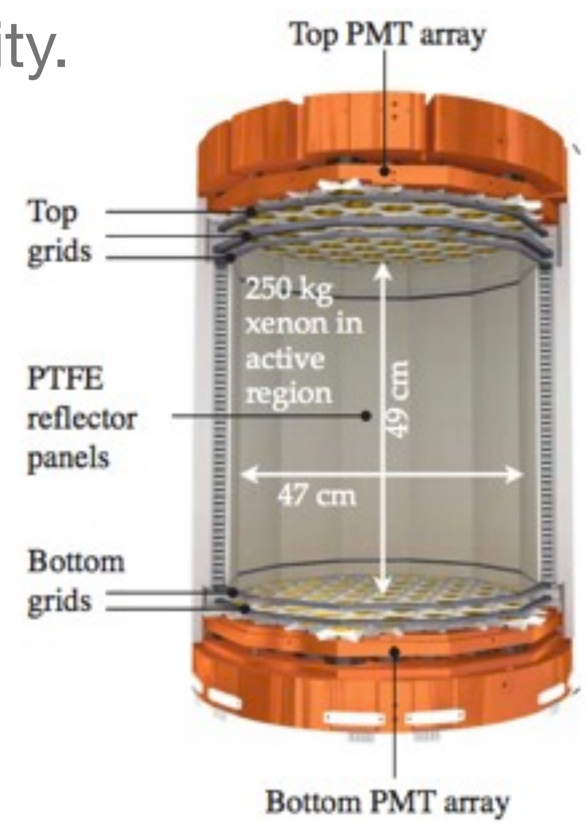
- Two-phase Xe detector with 62 kg active target, 34 kg fiducial mass 242 1-inch square PMTs: 1 mBq (U/Th) and ~30% QE
- Multilayer passive shield (Cu, Poly, Pb+Water)
- Background rate of 5.3e-3 events/keV/kg/day after veto cut, before discrimination
- 19 ppt of Kr contamination

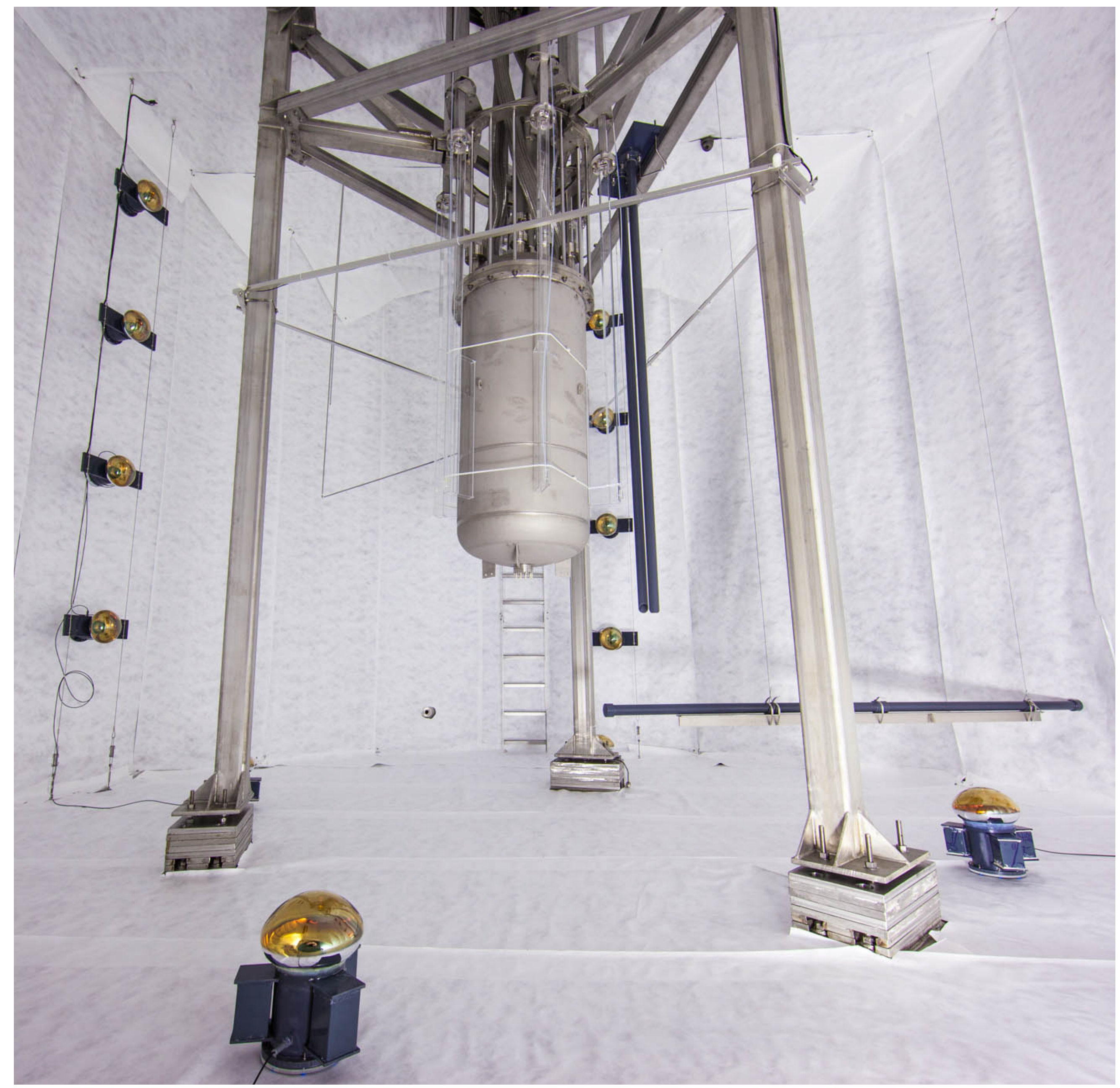




Large Underground Xenon (LUX) experiment

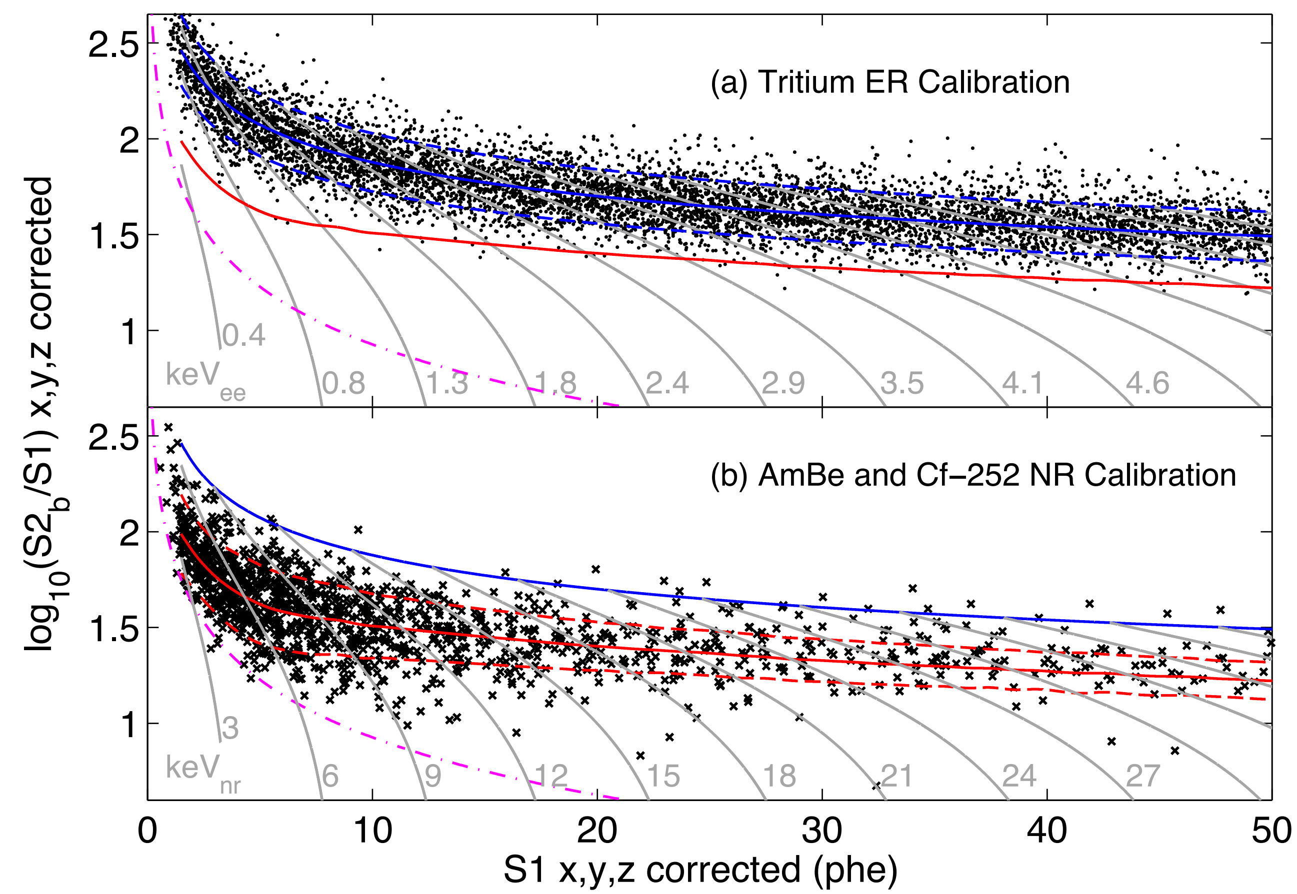
- LUX began operation UG at the beginning of the year and acquired 85.3 live-days of WIMP search data.
- The detector holds 250 kg of active liquid xenon, with a fiducial volume of 118 kg.
- Active target viewed by 122 low-radioactivity PMTs.
- Detector constructed from low background materials, with measured levels of radioactivity.

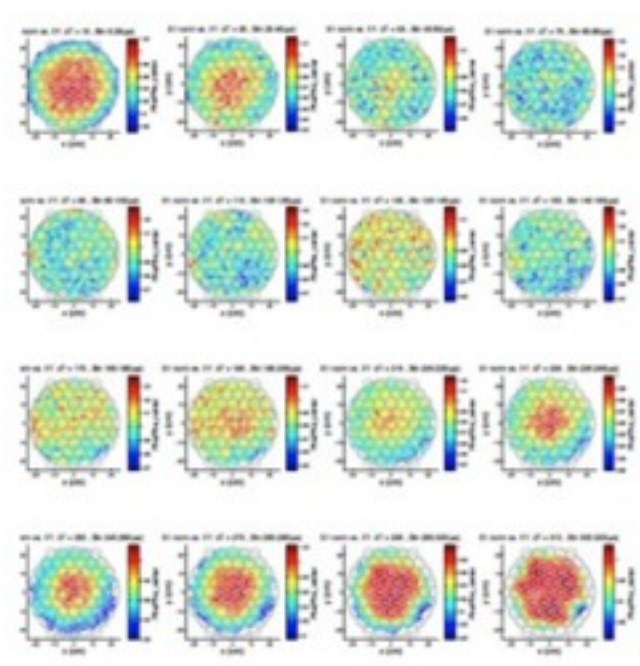




LUX calibrations

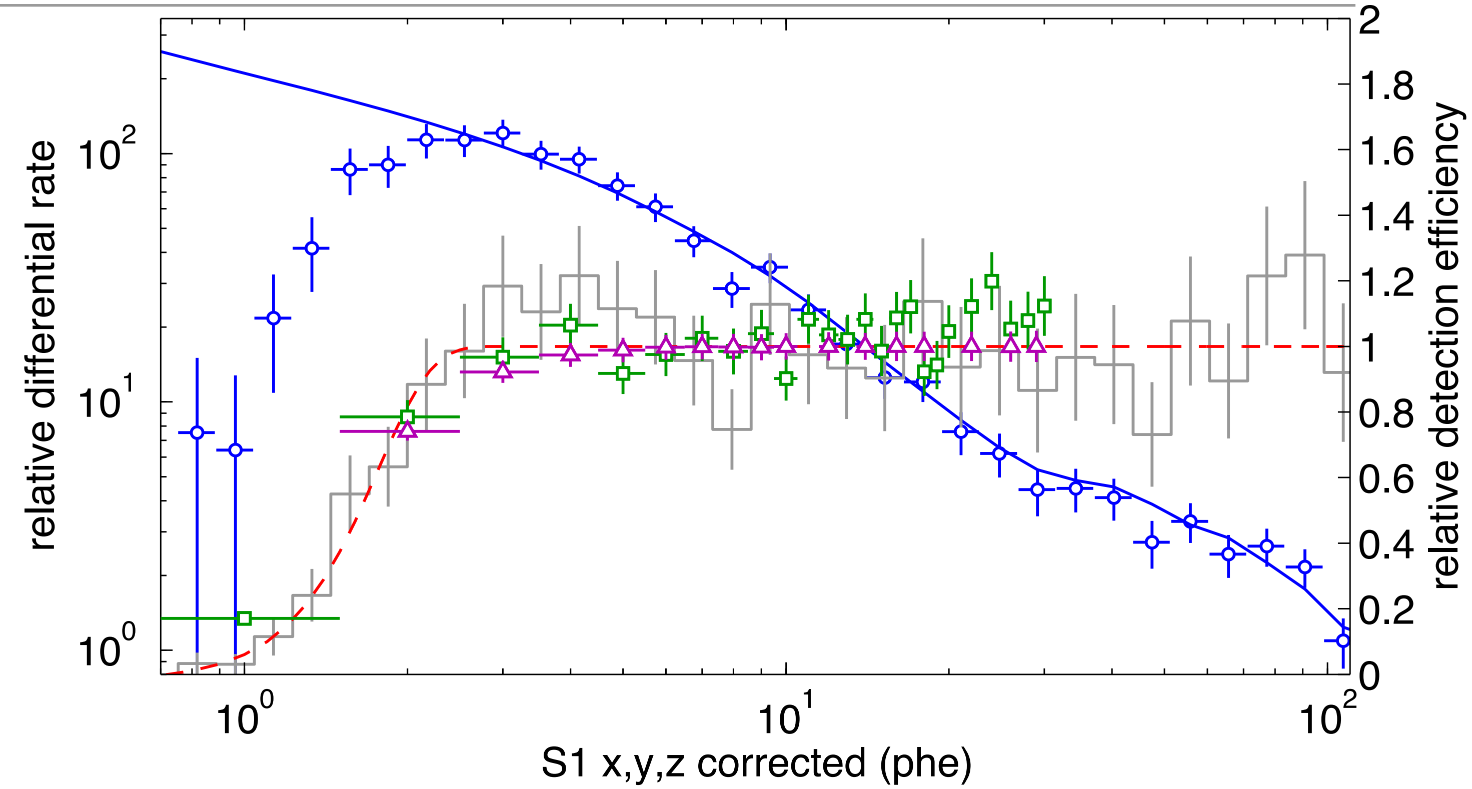
- LUX is the best calibrated liquid xenon dark matter experiment ever.
- AmBe & ^{252}Cf neutron sources used to calibrate NR signal band.
- Tritiated methane internal source used to calibrate ER band with unprecedented precision.
- ^{83m}Kr internal source used to monitor detector stability and map and correct detector light response as a function of position.

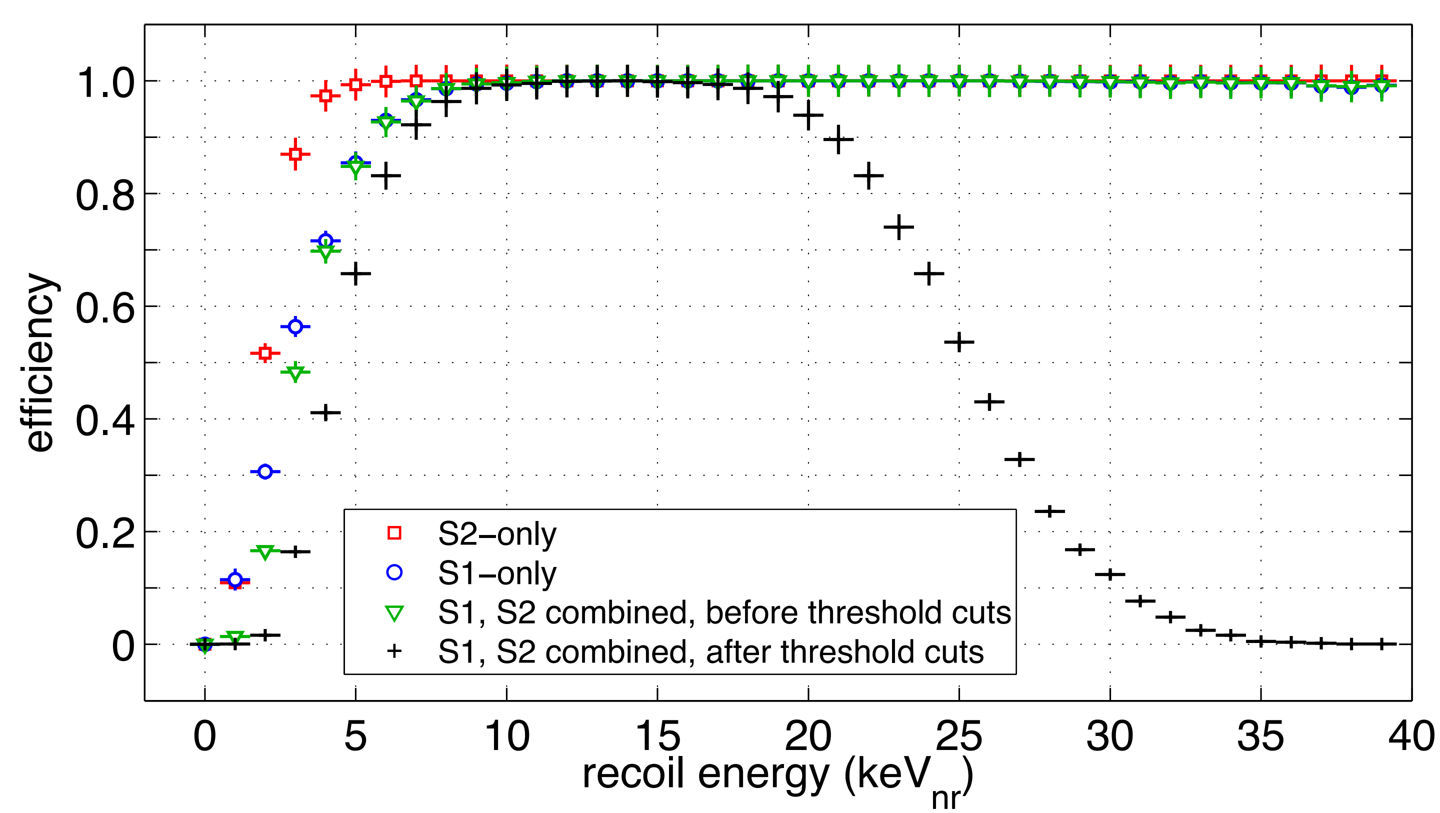




LUX detection efficiencies

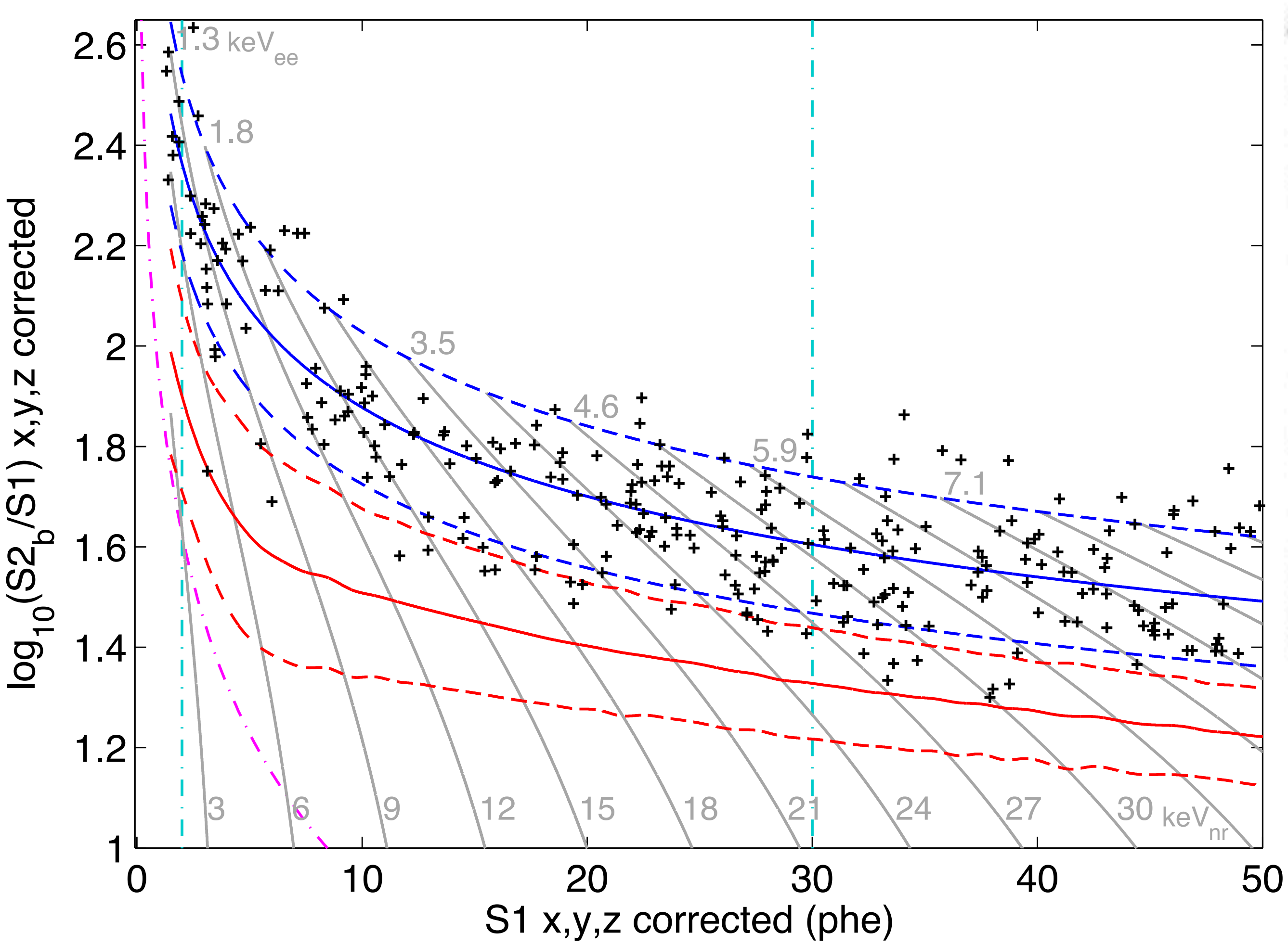
- Various methods used to measure the detection efficiency for NR in LUX, including matching of AmBe data with simulations, processing NR simulations, tritium data, LED data.
- All in excellent agreement, showing an energy threshold of at 4.3 keV_{nr}. Lower than all previous LXe dark matter experiments.

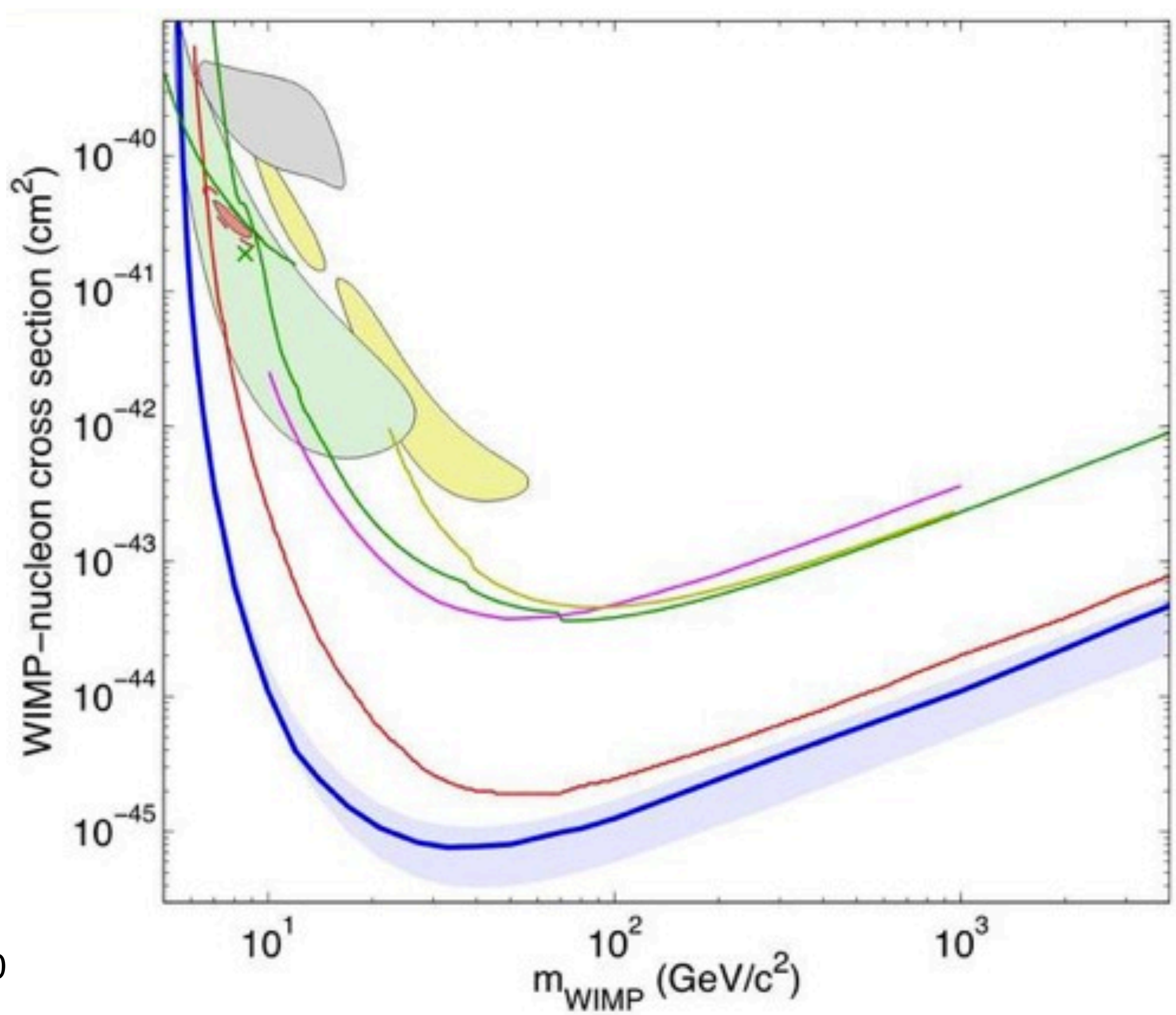




LUX results

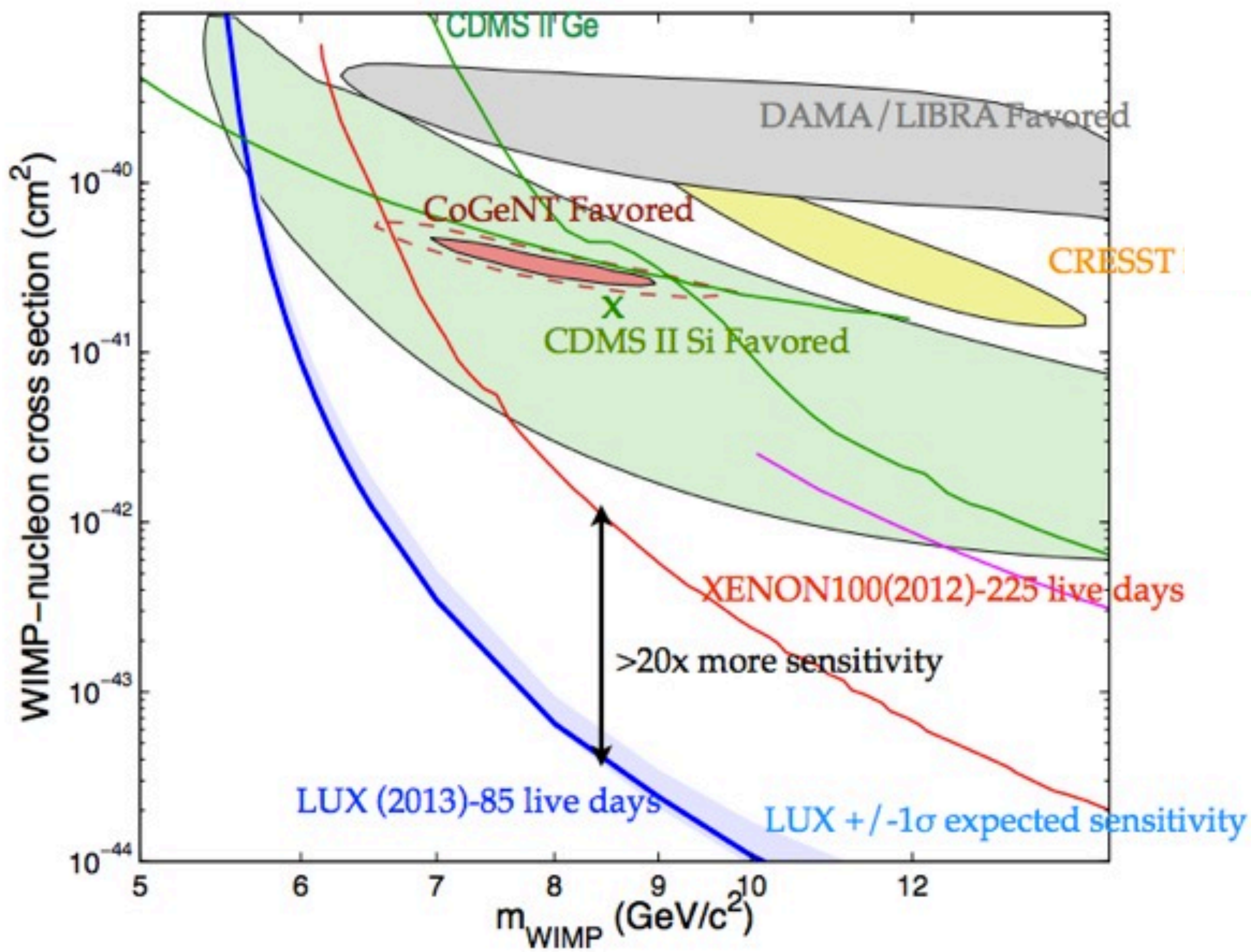
- ML techniques used to extract limits on WIMP-nucleon scattering cross-section from 85.3 days of WS data.
- Significant improvement in world-best sensitivity, especially at low-mass!
- LUX plan a second 300-day run which will improve sensitivity by a further factor of 5.



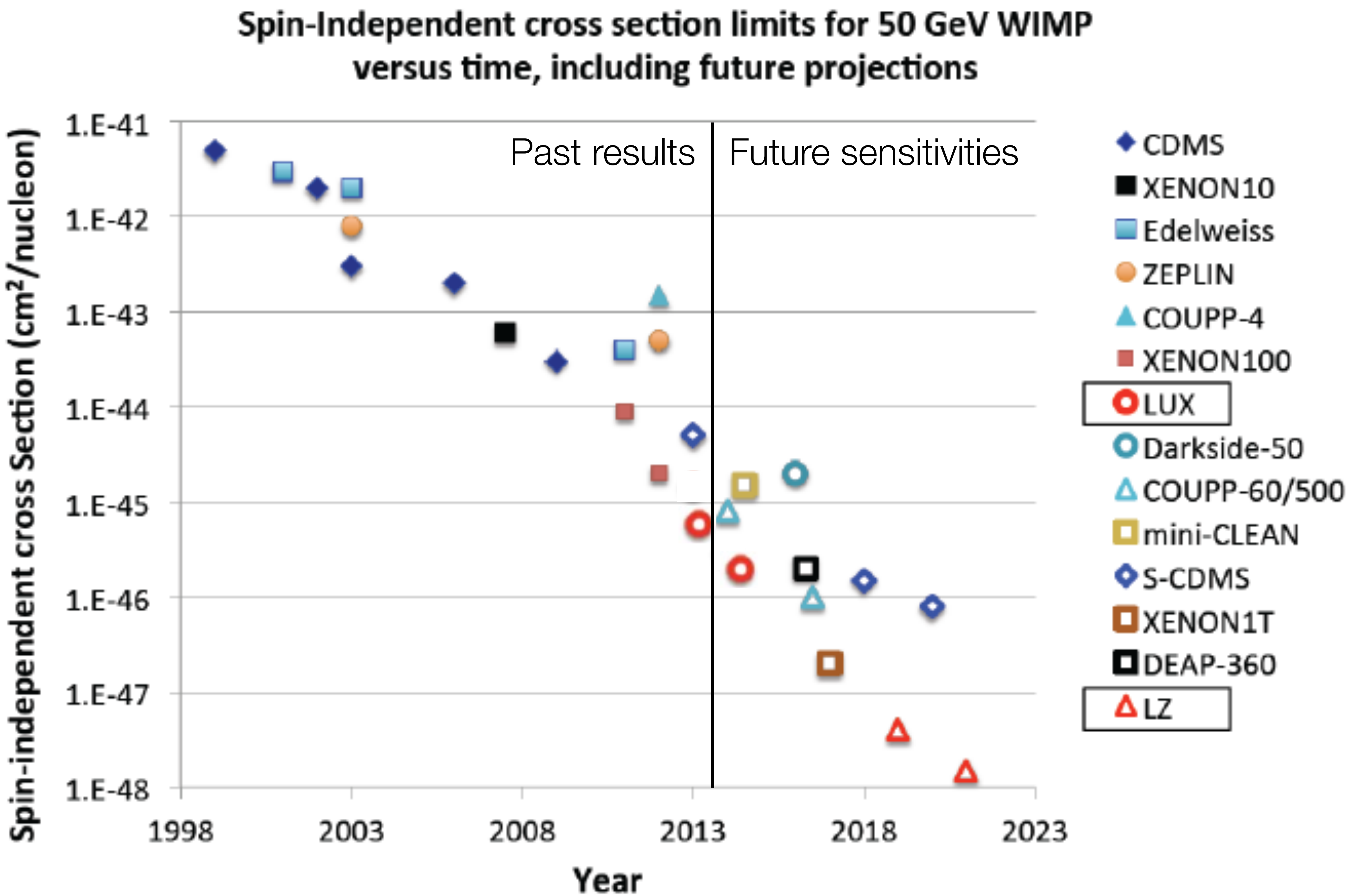


Tension with previous low-mass results

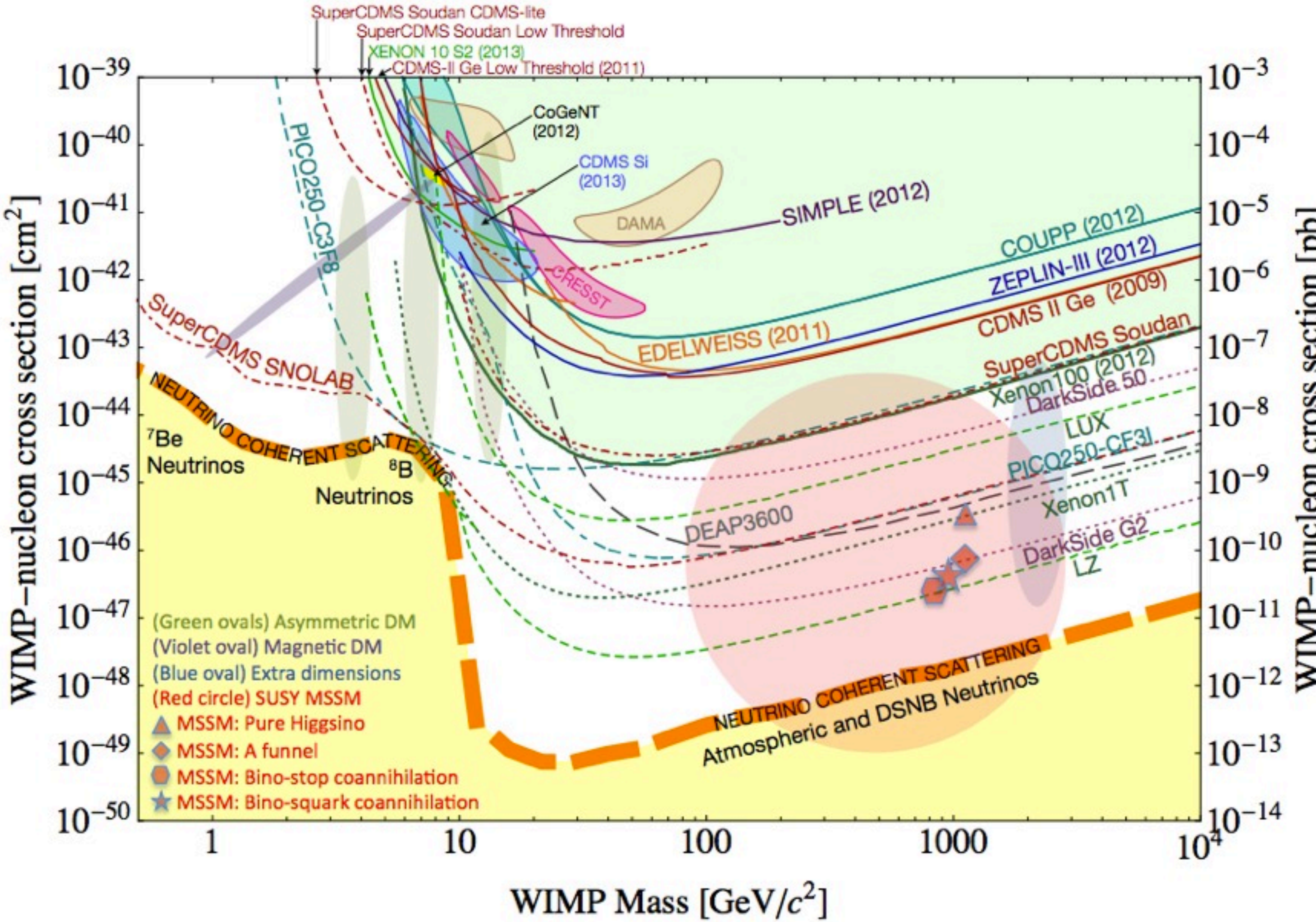
- Significant improvement in sensitivity over previous xenon experiments from lower energy threshold.
- Now in major conflict with previous low-mass results (for given astrophysical parameters).
- For a WIMP with the CDMS-Si best fit properties, we would expect to see about 1550 events in LUX data.
- Some questions about the light output of liquid xenon for low energy NR. But even with the conservative approach used by LUX still see major discrepancy.



Sensitivity progress past, present and future

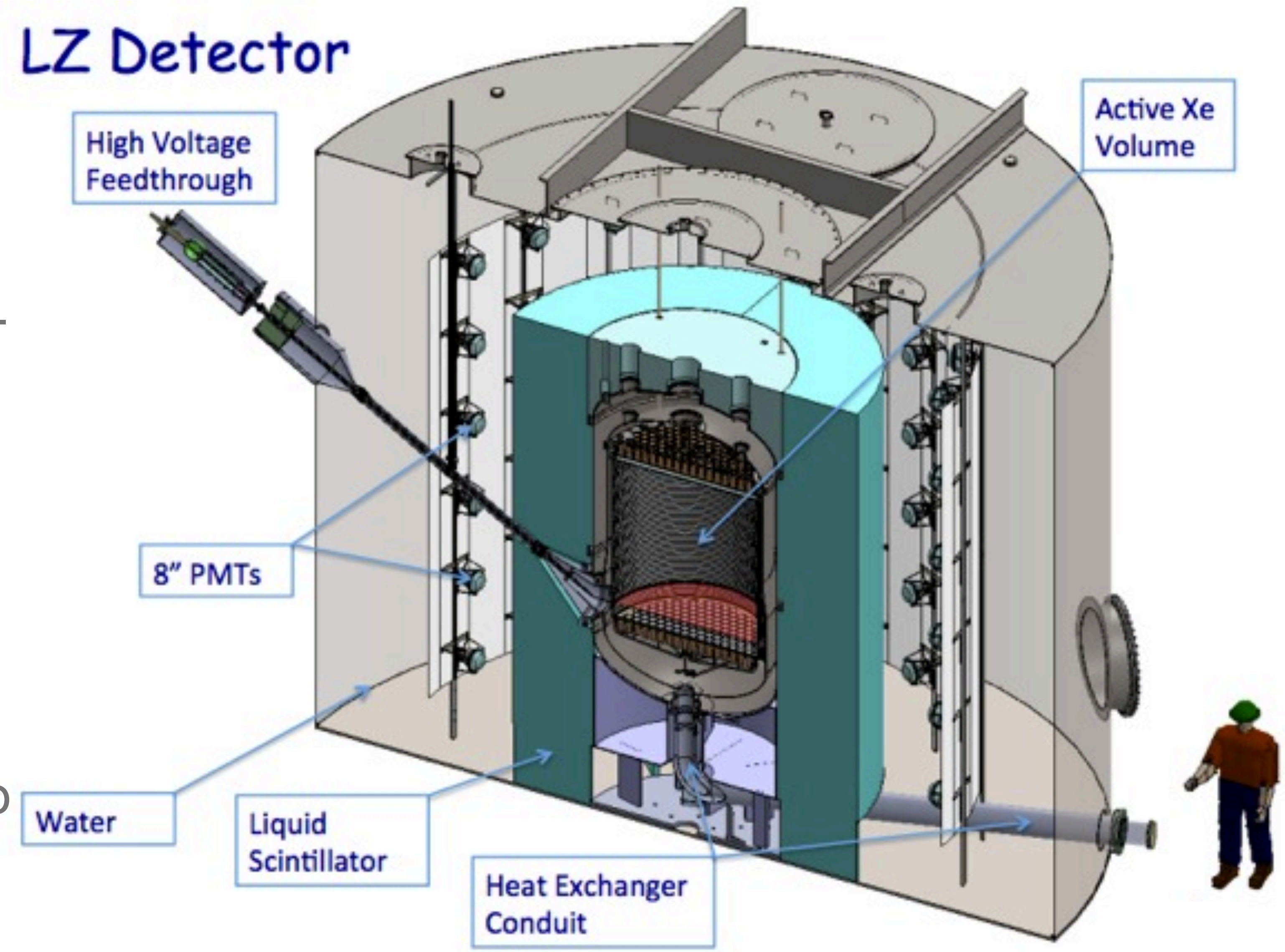


Onwards and downwards



LUX-ZEPLIN

- 20 times LUX Xenon mass, active scintillator veto, Xe purity at sub ppt level"
- Ultimate direct detection experiment - approaches coherent neutrino scattering backgrounds"
- Proposal for US down-select process end of Nov., decision expected Jan 2014 "
- If approved will be deployed Davis lab 2016+



Summary

- Exciting times in the field of direct dark matter searches!
- A number of low-mass WIMP claims have been made, although these are all in conflict with recent results from large liquid xenon detectors.
- We will continue to see improvements in the sensitivity of such detectors in the coming years.
- Further data will be available in the near future to provide even more confidence in the liquid xenon results at low-mass.
- If future cryogenic and crystal detectors were to see the same low-mass excesses in future improved experiments, additional theories may be required to explain any discrepancy.

Thanks........questions?