Bernard Sadoulet
Dept. of Physics /LBNL UC Berkeley
UC Institute for Nuclear and Particle Astrophysics and Cosmology (INPAC)
UC Dark Matter Initiative

Direct Detection of Dark Matter: Where Are We Going?

Three broad classes of models
- but no convincing hint so far

The immediate program
- US G2 + equivalent world wide
- The challenge of getting unambiguous results

Further in the future
- Reaching the neutrino floor
- Other creative ideas

Three Classes of Particle Dark Matter

Particles in thermal equilibrium + decoupling when non-relativistic

Freeze out when annihilation rate ≈ expansion rate

$$\Rightarrow \Omega_{DM} h^2 = \frac{3 \cdot 10^{-27} cm^3/s}{\langle \sigma_A v \rangle} \qquad \Omega_{DM} \approx 25\% \Rightarrow \sigma_A \approx \frac{\alpha^2}{M_{EW}^2}$$

Cosmology points to W&Z scale

Inversely standard particle model requires new physics at this scale

=> significant amount of dark matter

Weakly Interacting Massive Particles

Dark Matter could be due to TeV scale physics

A dark sector may be with dark matter—anti dark matter asymmetry

If similar to baryon anti-baryon asymmetry

$$\rho_{DM} \approx 5 \times \rho_{baryon} \Rightarrow M_{DM} \approx 5 \text{ GeV/c}^2$$

Physics could be as complex as our ordinary matter sector:

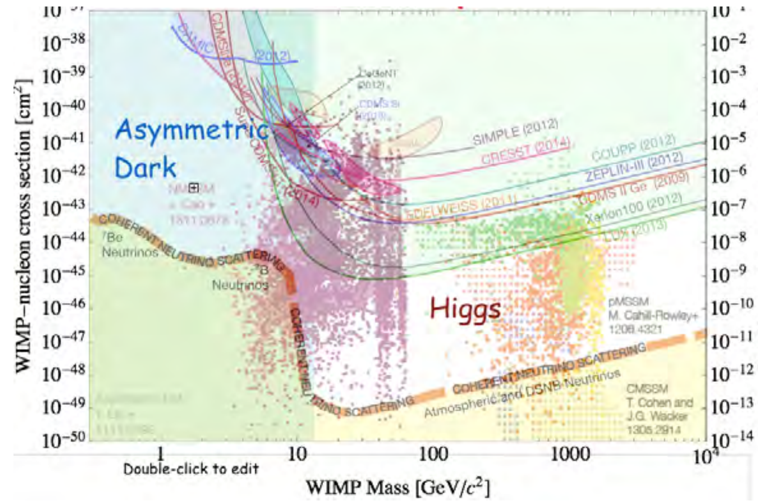
if light mediator could be at small masses

Athermal production: Result of spontaneous symmetry breaking

Main example Peccei Quinn axions to dynamically restore CP in QCD

Could detect these by scattering of galactic dark matter on a suitable target in laboratory

Recent Input from Particle Physics



Higgs at 126 GeV/c

No sign for supersymmetry

CMSSM too simple ->pMSSM,NSSM

Crisis of naturalness?

No evidence from mono-jets,mono-γ's

Note: Limits assumes high mass mediator

Dark Sector models have typically low mass mediators

Complementarity with "Dark Photon" searches

750 GeV/c2 di-gamma

If true, may have nothing to do with dark matter.

At the minimum, would indicate that with MSSM, we have been barking at the wrong tree!

Basic complementarity

LHC probes well:

- monojets if high mass mediated
- masses below $m_H/2$
- intermediate mass in decay of gluinos (≈6x LSP), but needs to produce it!

Direct Detection:

- light mediators are OK
- loses only linearly at high mass

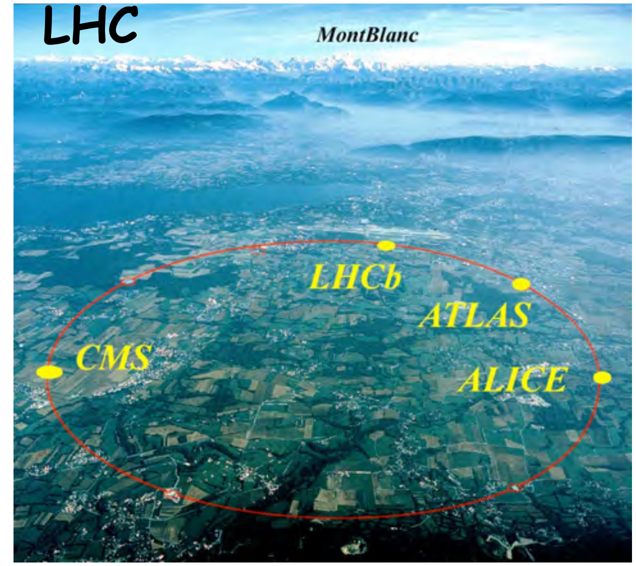
4 Complementary Approaches

Cosmological Observations

Planck

Keck telescopes

Dark Matter
Galactic Halo (simulation)



WIMP production on Earth

VERITAS, also HESS, Magic + IceCube (ν)

WIMP annihilation in the cosmos

Fermi/GLAST

WIMP scattering on Earth:e.g. Super CDMS,LUX etc.

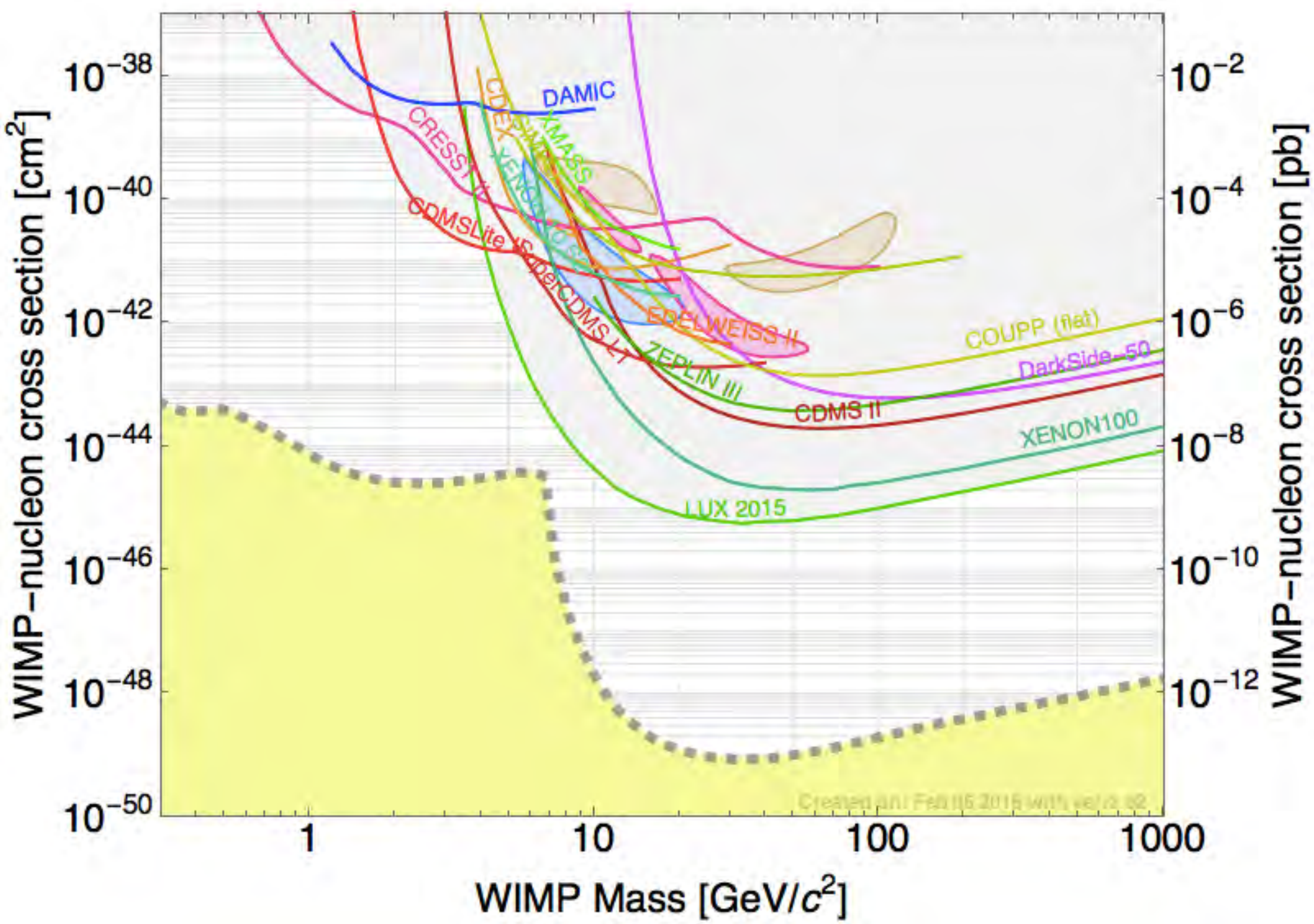
Situation in February 2016

At High Mass

Nothing so far

Broadly consistent with the absence of SS observation at LHC

Focus point solution in CMSSM ≈10^{-45} is mostly excluded



Low Mass

A number of closed contours, and strong limits

What is going on?

Low Mass ???

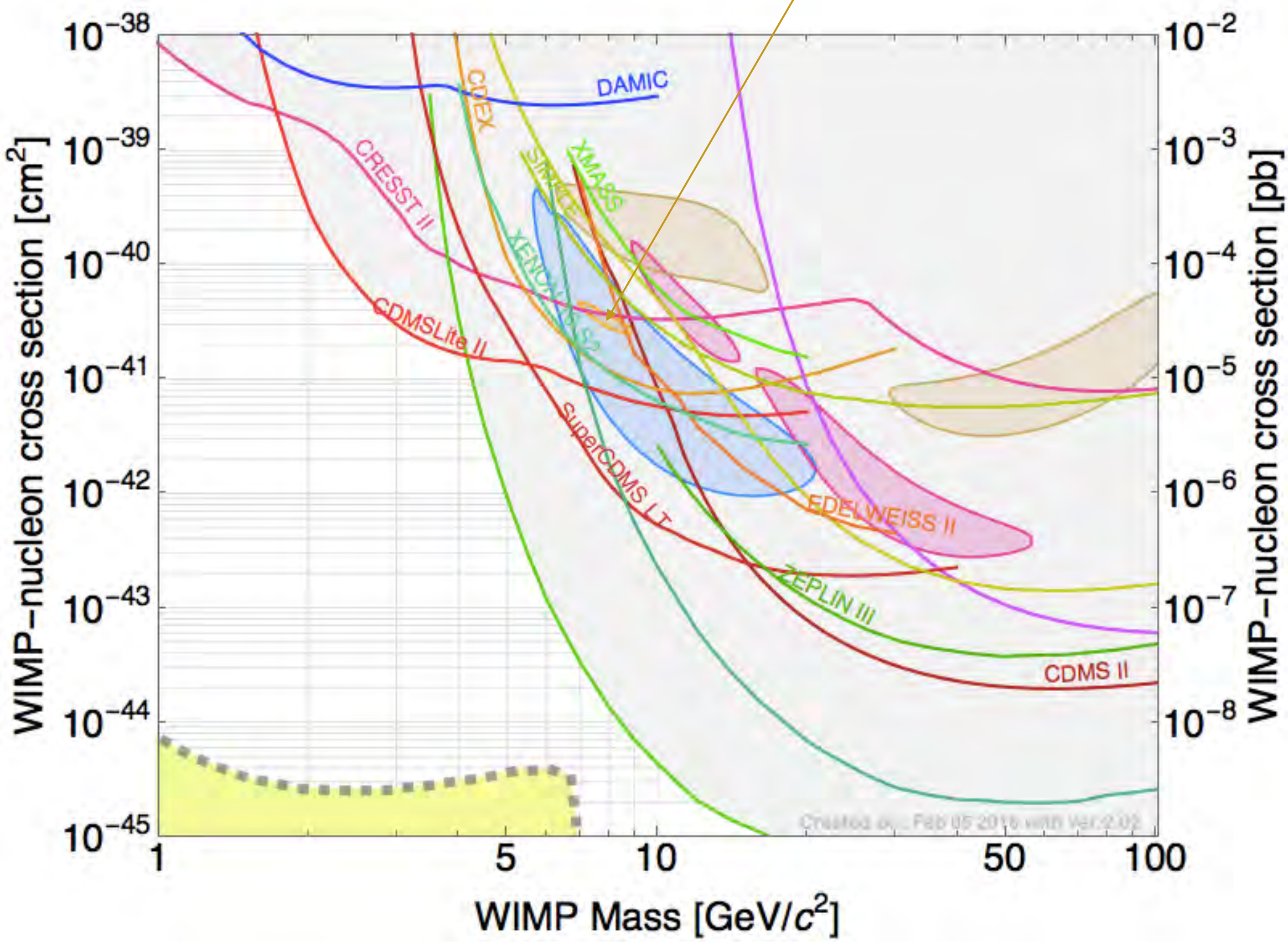
Optimistic

- Accumulation of claims in that region
- The exclusion by some experiments is based on unreliable calibration
- (but DD LUX calibration appears solid)
- Just the region expected for asymmetric dark matter

Pessimistic

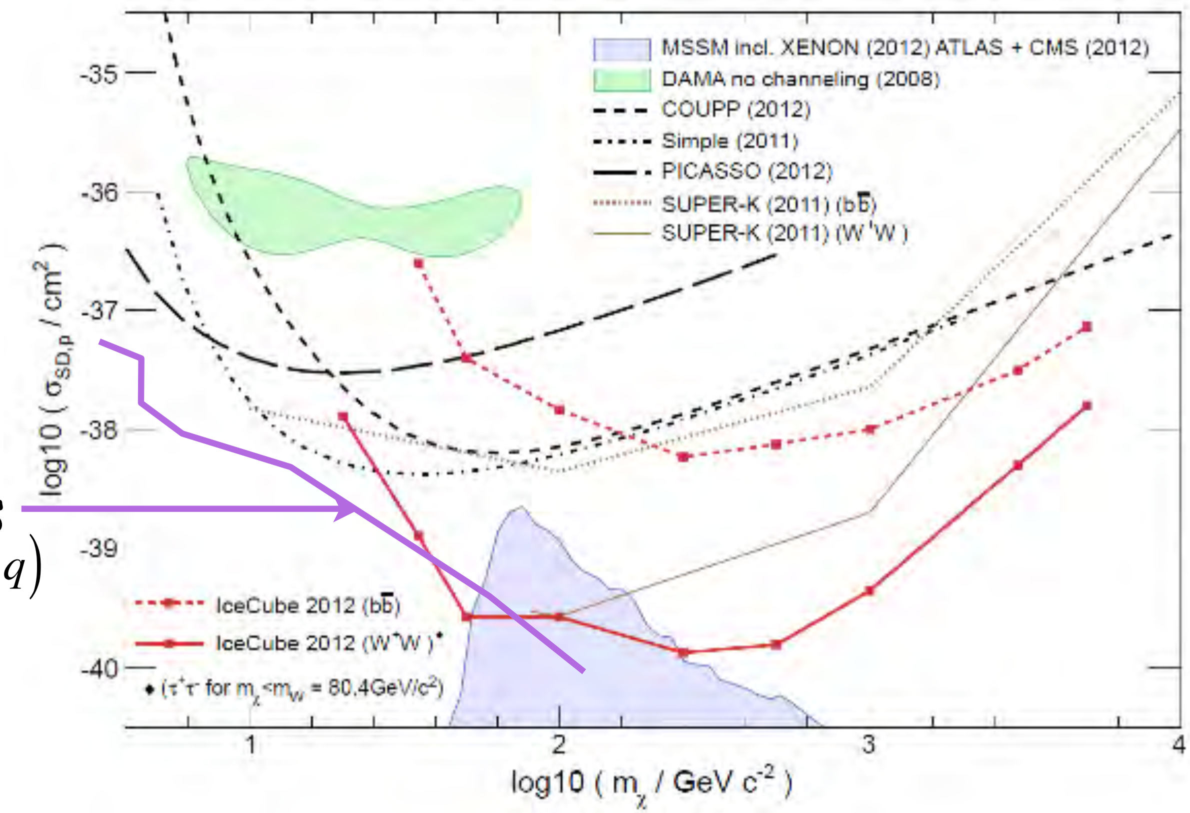
- Not compelling evidence
- Close to threshold: Outliers ?
- Excluded by
  - XENON100
  - LUX
  - SuperCDMS Soudan
  - CDEX
- CDMS does not see any significant modulation

CoGeNT is in trouble?
cannot be nuclear physics



Spin dependent limits (e.g. p)

Finally entering SUSY region



LHC Monojets

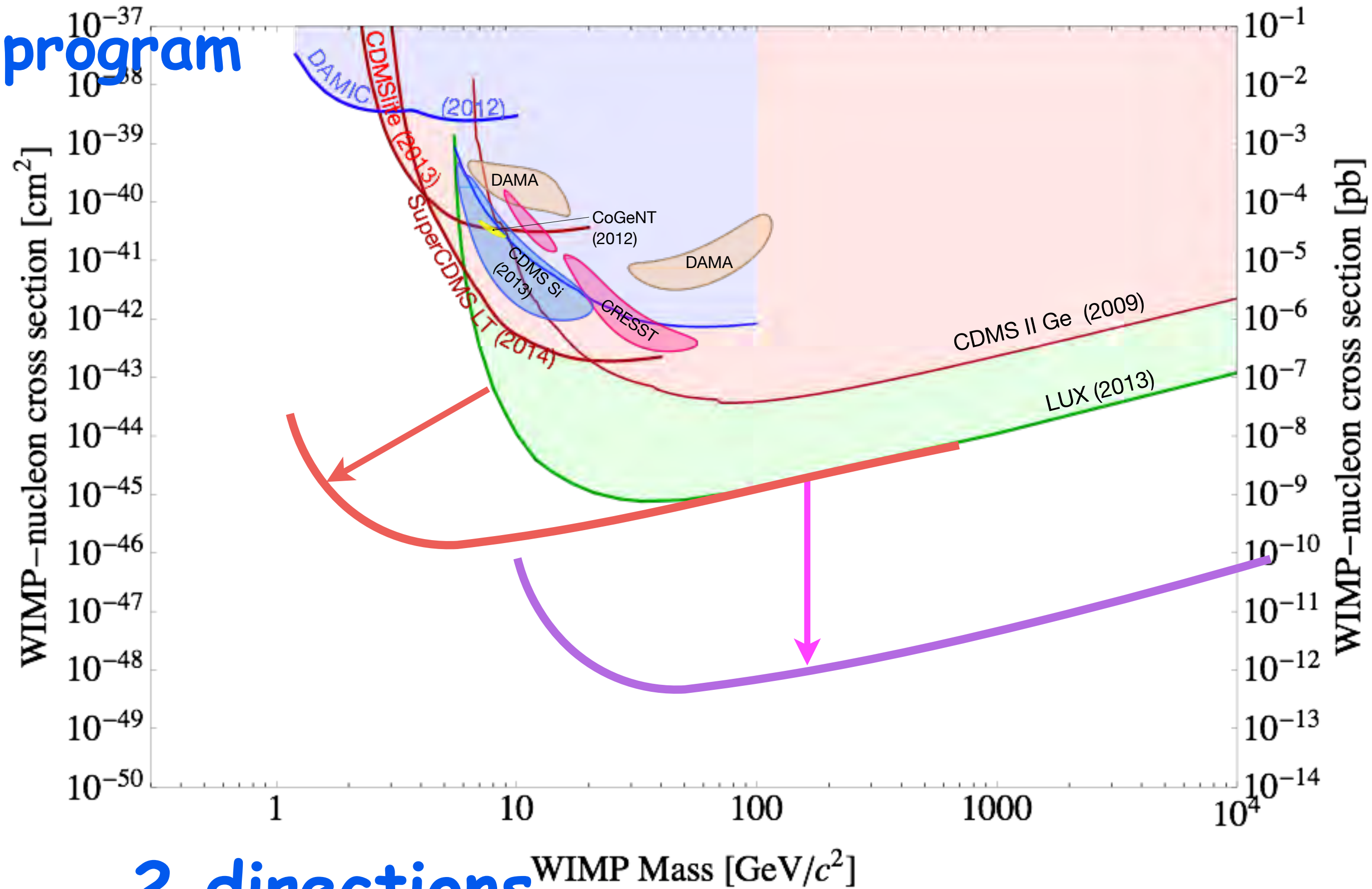
$$(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma_\mu\gamma_5 q)$$

Heavy mediator

Where Do We Want To go?

= US G2 program

+ Axion



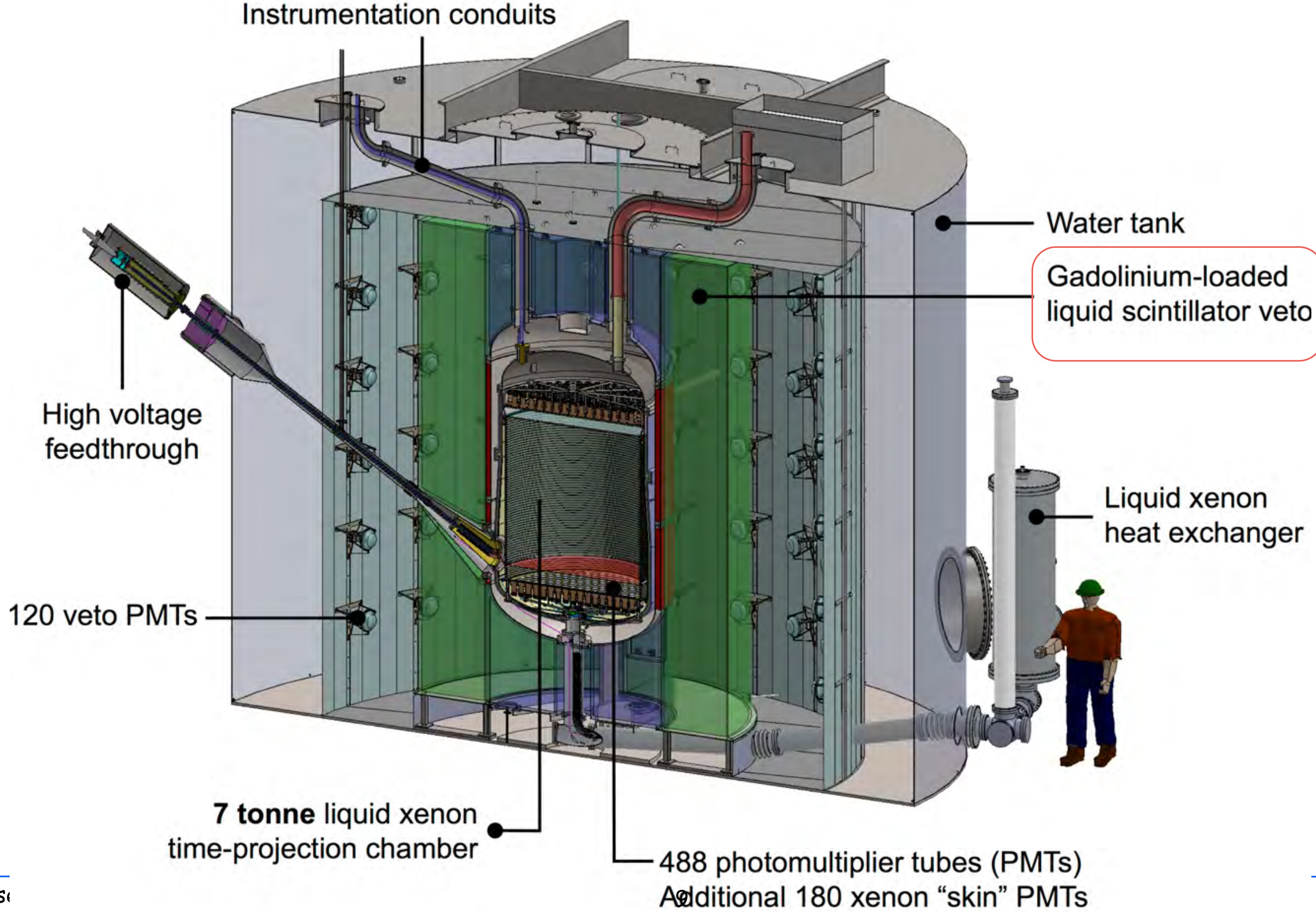
2 directions

1. Improve sensitivity at large mass

2. Improve sensitivity at small mass

US G2: LZ (≈2018)

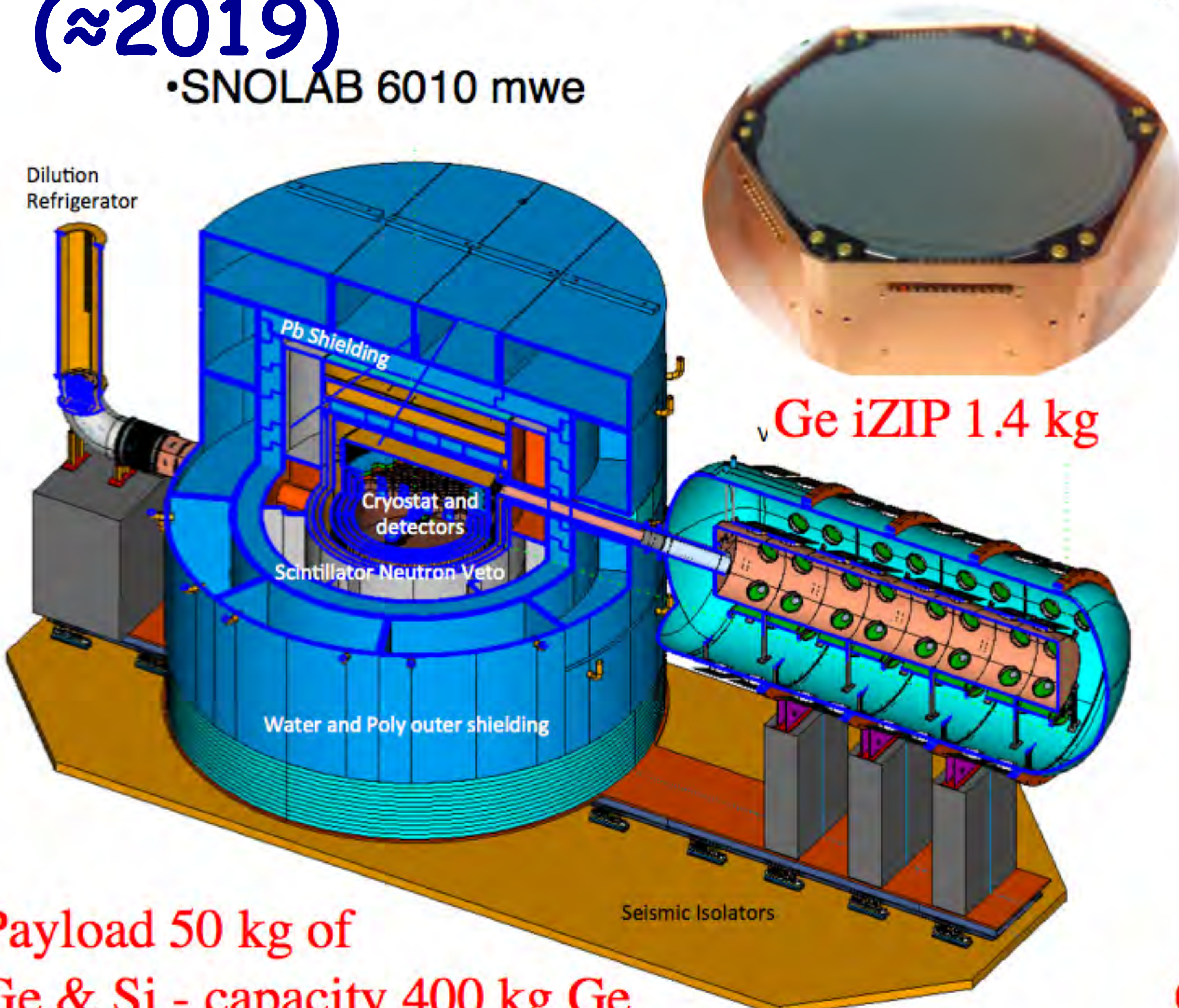
Replaces LUX at the Sanford Underground Research Facility (SURF)



SuperCDMS SNOLAB Experiment

(≈2019)

- SNOLAB 6010 mwe

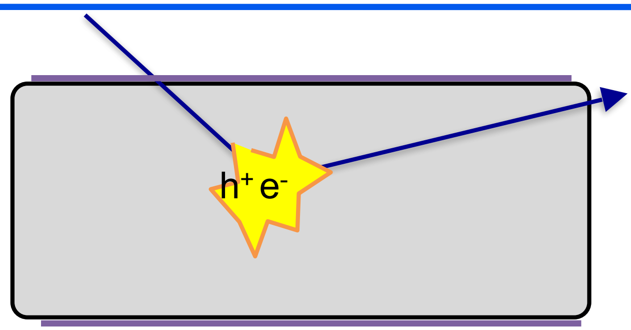


Ge iZIP 1.4 kg

Payload 50 kg of
Ge & Si - capacity 400 kg Ge

Ge Tower 8.4 kg

CDMS: Use of Phonons and Cooper Pairs



<1meV quanta

=> sensitivity but requires ≈30mK

detailed information about the event

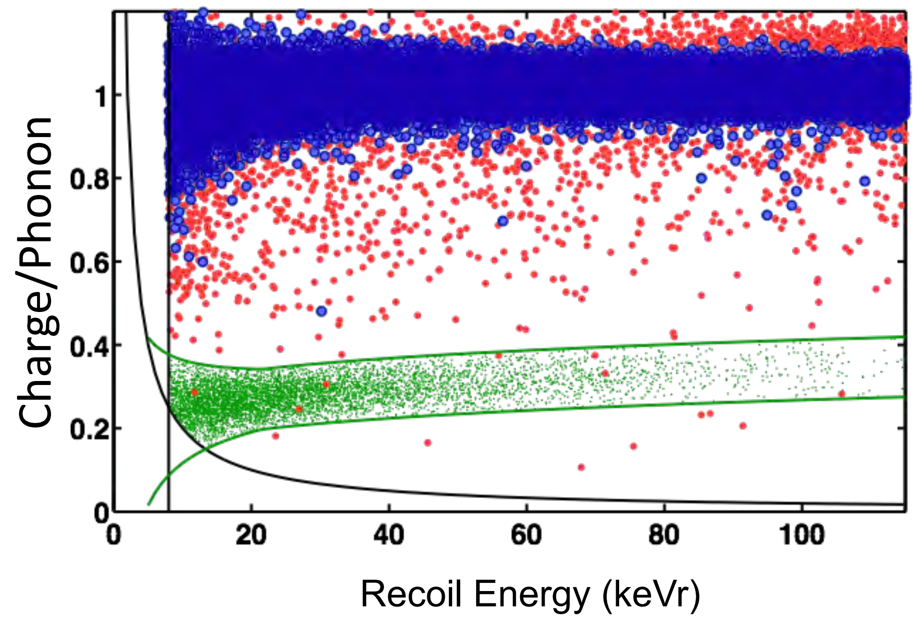
Recognition of nuclear recoils

Nuclear Recoils

- 8% e^-/h^+
- 92% phonons

Electron Recoils

- 25% e^-/h^+
- 75% phonons



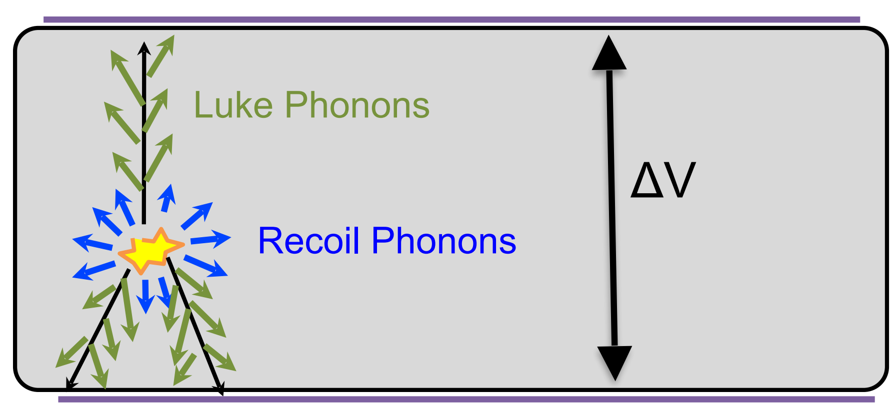
Fiducialization ionization or phonons

We can efficiently get rid of surfaces

Amplification of ionization

CDMS-HV: give up nuclear recoil ID

$$E_{\text{total}} = E_{\text{initial phonons}} + Nq\Delta V$$



The "Immediate" Future

US G2 + Equivalent

Xenon 1T + 7T

XMASS 1.5T 2017, 7T 2019

Not all same statistical assumptions!

SuperCDMS+Eureca

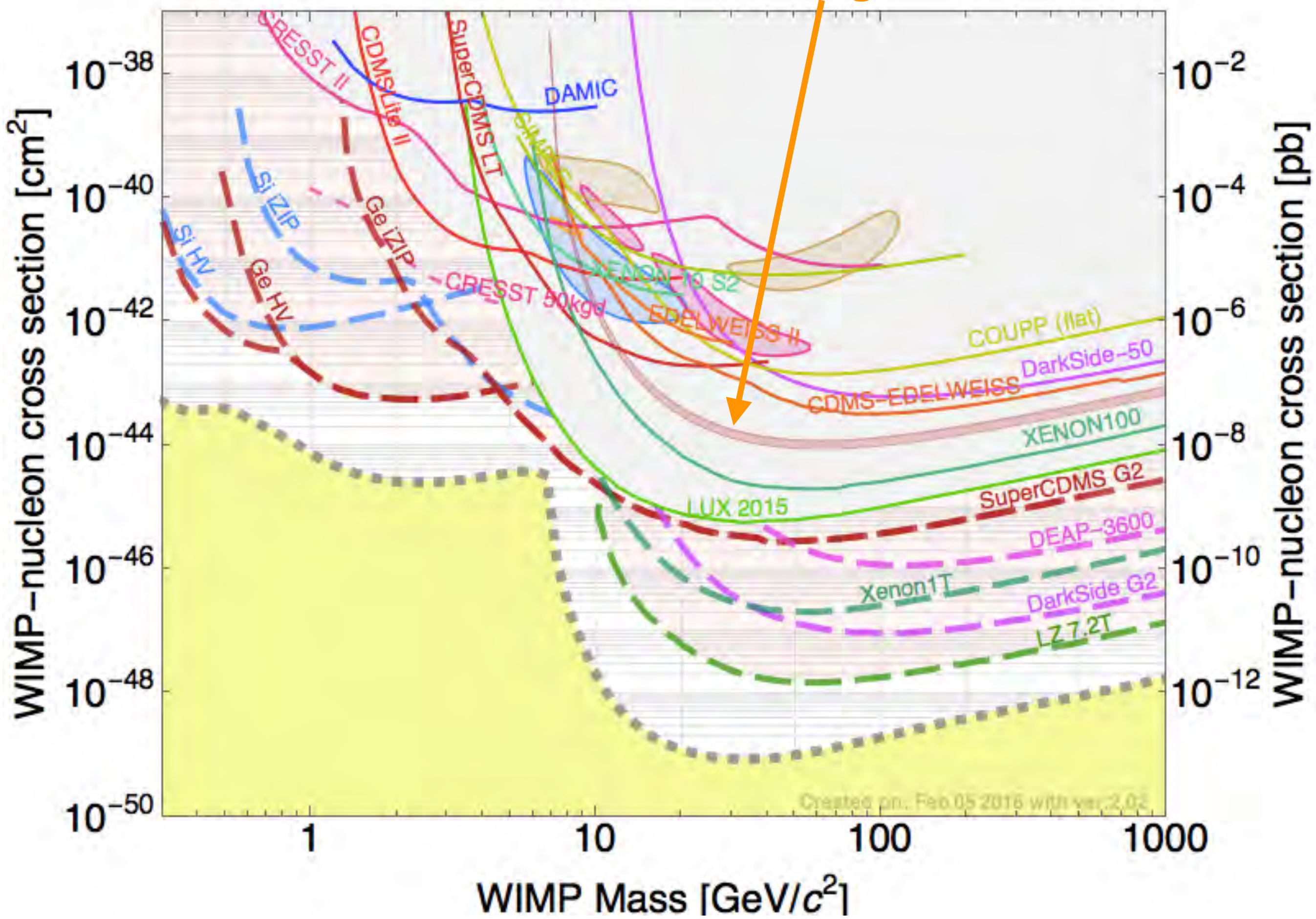
Serious discussion of merging at SNOLAB.

The cryostat is designed to allow such upgrades

Neutrino floor

- None of these experiments reach the "neutrino floor" which assumes subtraction by a factor ≈20
- ^8B coherent neutrino scattering would be interesting: Proof of sensitivity + observation of Coherent Neutrino Scattering

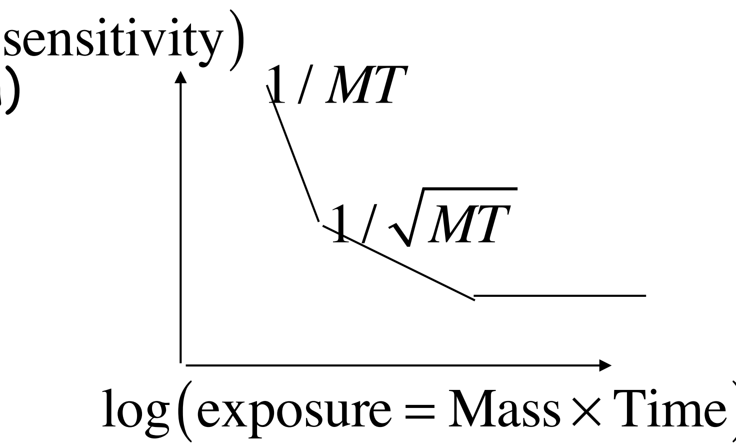
What we can do with
9 kg SuperCDMS at Soudan
We are lacking mass!



How to Get Unambiguous Results?

Lessons learned in the last few years

Need for good calibration (yields)
Need for good understanding of backgrounds
Difficulty from outliers (need redundant information)



Unambiguous results

The goal should be negligible background!
We should not abandon blind analyses:
- only unbiased way

Use likelihood methods to get confirmation of a signal
- But extremely sensitive to background model. What about the unknown unknowns?

Use knowledge acquired about leaking backgrounds to design better

Complementarity of experiments

Real proof requires 2 experiments, which are as different as possible
We should pursue both the low and high mass regions (different paradigms)
We need a variety of targets to elucidate couplings and protect against cancellation. Xe, Ge,Ar, missing F, or Na

Further Out Ideas: Reaching Neutrino Floor

At high WIMP mass

greater target mass with appropriate reduction of the background (radon emanation, ^{39}Ar)

- 20T -50T of Argon
- Darwin: Xe+ Ar
- PICO (cheap)
- H_2O_2 detectors (Druikier) for neutrino geology: extremely cheap?

At low mass

plenty of mass,
plenty of signal with Luke-Neganov amplification in SuperCDMS HV approach
but need to

- reduce background
  - ^{32}Si, ^{3}H, ^{210}Pb on surfaces
- restore background rejection
  - Matt Pyle: increase phonon resolution down to 10eV rms
  - (should go as T_c^3 but needs careful control of parasitic power, but demonstrated by space experiments, such as Sapphire)
    - => restoration of nuclear recoils discrimination for HV mode of operation:
    - e.g., 1 e-h pair for electron recoil =3 eV, total phonon energy at 100V= 3+100 eV
      for nuclear recoil= 30 eV, total phonon energy at 100V= 30+100 eV
    - => ionization+ phonon with phonon measurement only by using the locality of Luke Phonon emission.

Simpler low mass ideas? e.g. large gas spheres (Gerbier,Giomataris arXiv:1512.04346)

Even Further Out Ideas

Directionality for conventional WIMPs

If WIMP is at high mass: 10 tons of low pressure gas (100 torr)=10,000m^3 with cubic mm pixels. Clever schemes based e.g., on CCDs

Even, DNA (Druikier) which through sequencing tricks could provide nm resolution

Go drastically lower in mass ≈ keV (warm dark matter)

Kathryn Zurek/Matt Pyle: breaking Cooper Pair in superconductors

difficulty of dealing with single quanta (cf. QBits)

Axion-like particles

Peter Graham and Surjeet Rajendran

time varying nuclear electric dipoles which would precess in an electric field (cf NMR)

+ Dima Budker et al.: Phys. Rev. X 4, 021030 (2014) arXiv:1306.6089

CASPEr =>very low mass axions 10^{-9} to 10^{-6} eV

Dark Photons as Dark Matter

Peter Graham and Surjeet Rajendran: Hidden Electric Field

Radio in a Faraday cage

+ Kent Irwin Phys. Rev. D 92, 075012 (2015) arXiv:1411.7382v2

Where Are We Going?

Importance of the 13 TeV LHC run

- Discovery of supersymmetry
  - Why so high scale?
  - Is this responsible for Dark Mattter: detect in Cosmos
- No supersymmetry (750 GeV di-gamma?)
  - End of the naturalness concept?
  - Even larger importance of direct detection -> Dark Sector (low mass) + High Mass

Importance of G2 + equivalent program

- Pushing both down and left

Do not be afraid to be creative

- Search broadly, not only under the theoretical lamp post
- However, try to reach critical mass: unambiguous results

CDMS could use a few more collaborators

Fascinating time

4 prong approach=>

complementary coverage

constrain theory speculations