The U.S. campaign to observe dark matter interactions in the laboratory

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UC Santa Barbara

DURA meeting

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UCSB

Backgrounds

- Reducing backgrounds is critical.
- Radioactive impurities
  - ^{238}U and ^{232}Th chains; especially Radon and ^{210}Pb.
  - ^{129}I in NaI, ^{81}Kr in Xe, ^{39}Ar in Ar
- Cosmogenic activity
  - prompt: products of muon interactions
  - delayed: activity produced while materials above ground
- Neutrons are particularly dangerous.
  - WIMPs produce nuclear recoil (NR), not electron recoil (ER)
  - neutrons scatter several times; WIMPs only once
- Solar neutrinos
  - produce electron recoil backgrounds at ~5 evts/kev/ton/year level.

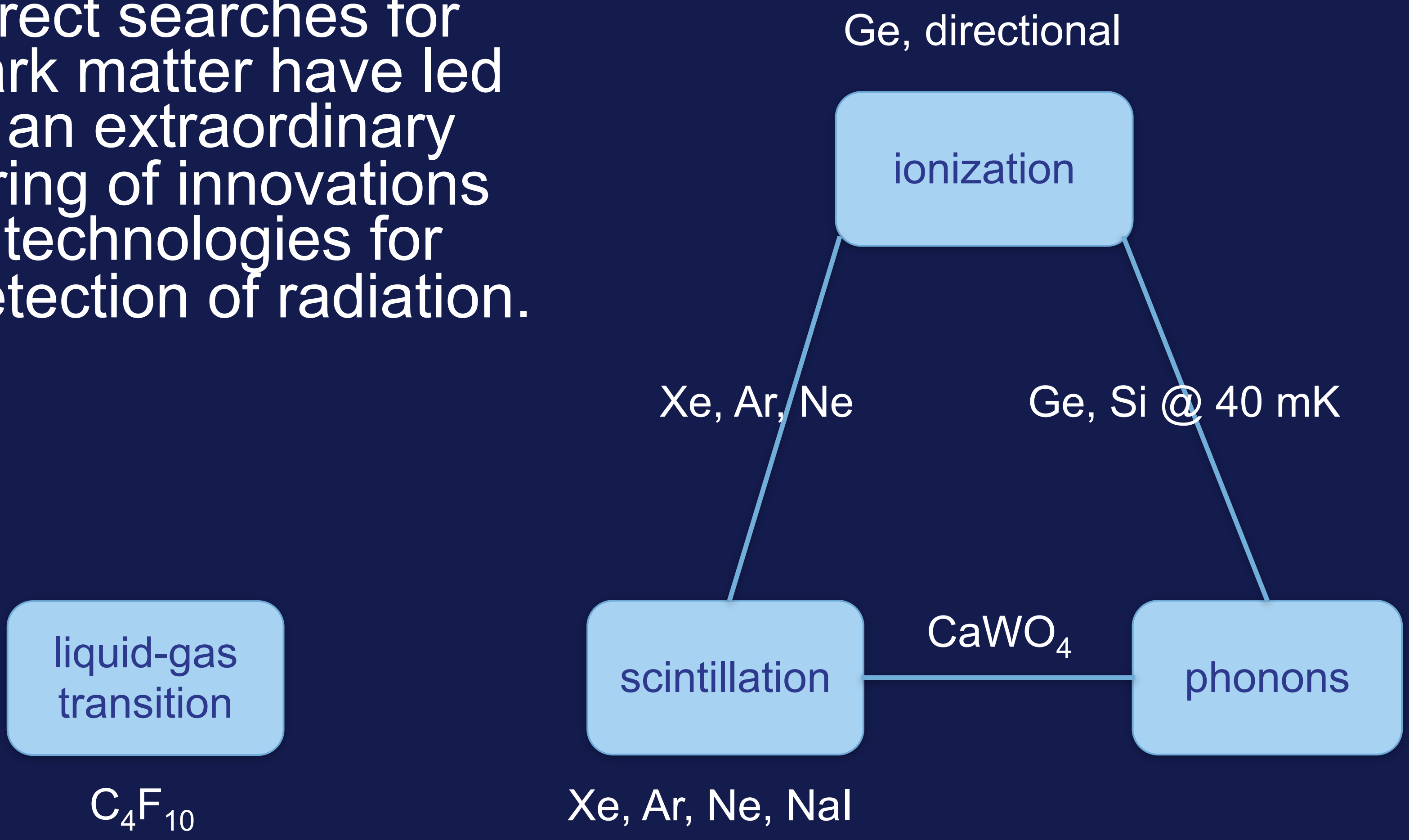
Techniques to reduce backgrounds

From ~1 count/keV/kg/d to ~1 count/keV/ton/year:

- Depth
  - Muons produce neutrons.
- Shielding
  - Water, polyethylene and/or clean lead between rock and detector
  - Self-shielding in purified noble liquids
  - Active shields for muons, gammas, neutrons
- Radiopure materials
  - Titanium vessels, electroplated copper, continuously circulated liquids, custom photomultiplier tubes...
- Specialized detectors
  - separate electron recoils from nuclear recoils

Detectors

- Direct searches for dark matter have led to an extraordinary string of innovations in technologies for detection of radiation.



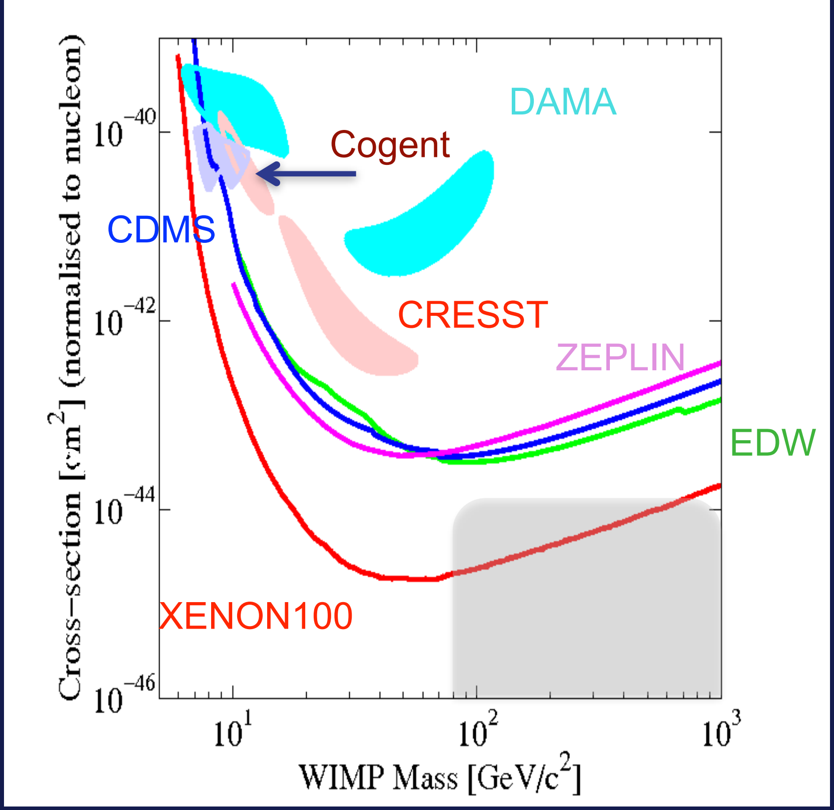
Spin-Independent results

Limits

- The lowest limits at most masses come from XENON100: 2×10^{-45} cm^2 at 50 GeV.
- CDMS II, Edelweiss II, Zeplin III limits are around 2×10^{-44} cm^2.
- Shaded is allowed region for neutralino dark matter as calculated by Cheung, Hall, Pinner, and Ruderman.

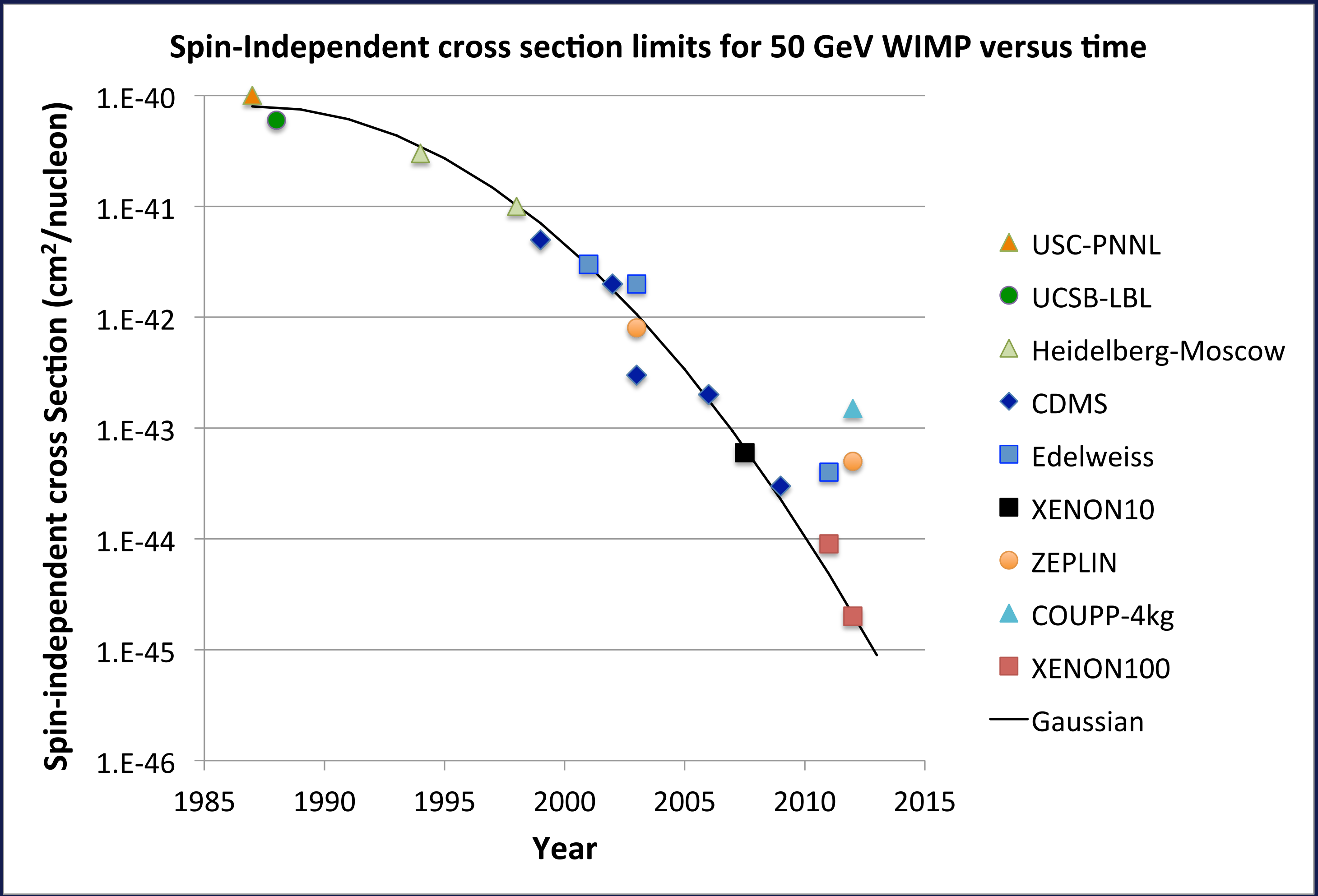
Evidence interpreted as SI WIMP:

- DAMA: 10^{-40} cm^2@ 10 GeV or 10^{-41} cm^2 @ 50 GeV.
- COGENT: 5×10^{-41} cm^2 @ 7-10 GeV.
- CRESST: 3×10^{-41} cm^2 @ 10 GeV or 10^{-42} cm^2 @ 30 GeV.



Thanks to Gaitskell, Mandic, Filippini for all dmtools.brown.edu plots!

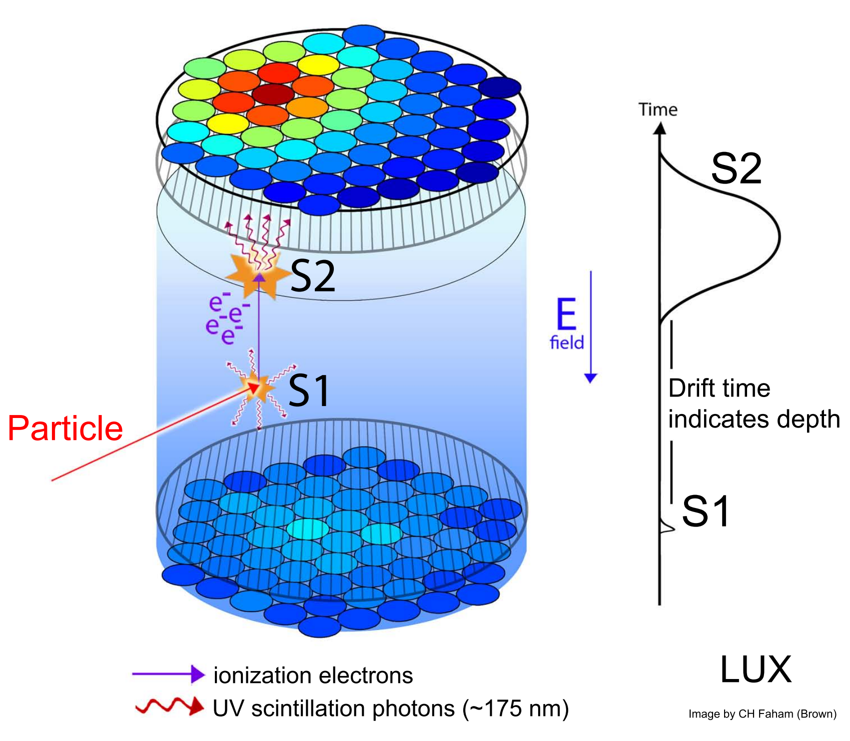
We are getting better at this.

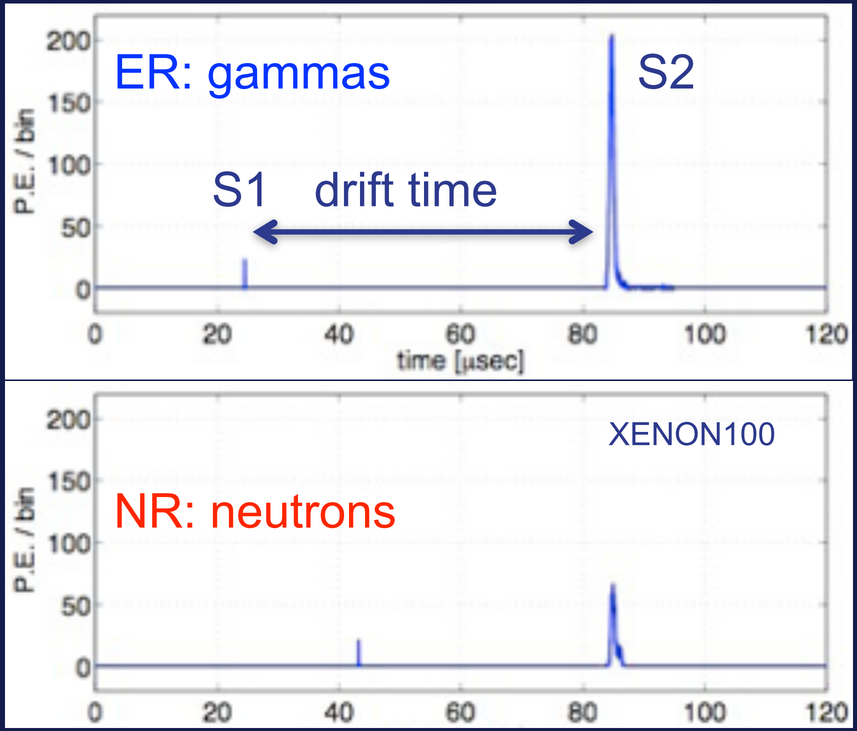


The search for dark matter has driven several extraordinary innovations in detector technology. Sensitivity doubles every year!

2-phase Xe: scintillation and ionization

Liquid Xenon is homogeneous, is dense, has high A (131) scintillates brightly in the VUV range (178 nm), and is transparent at this wavelength.





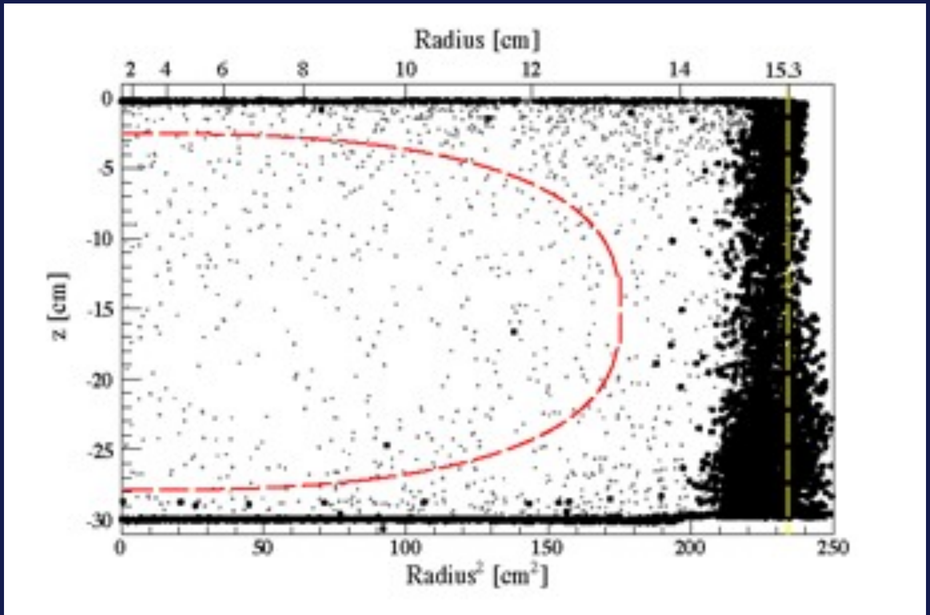
S1 light is direct scintillation. S2 light counts ionization electrons, is delayed.

Nuclear recoils produce much less ionization per energy deposit.

XENON100

R. Lang, Purdue

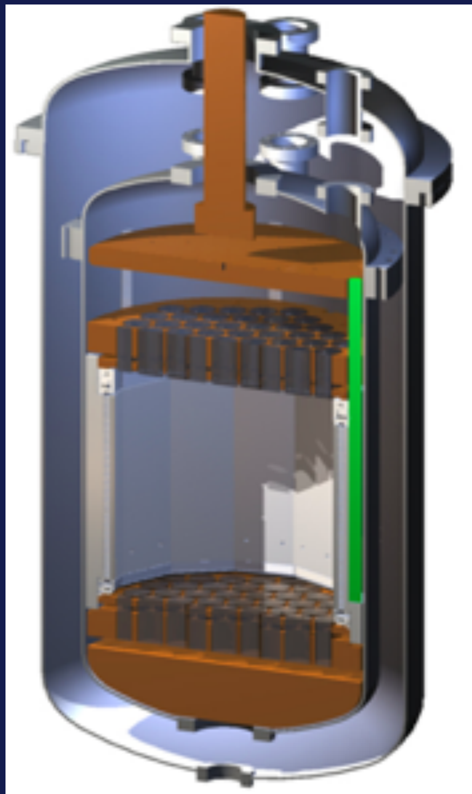
XENON100 has published results from 225 live days of operation in LNGS.



- Good position resolution and large xenon vessel gives clean fiducial volume.

Best limit to date based on
- 2 events in signal region
- 1±0.2 bg expected

LUX: Large 2-phase xenon TPC

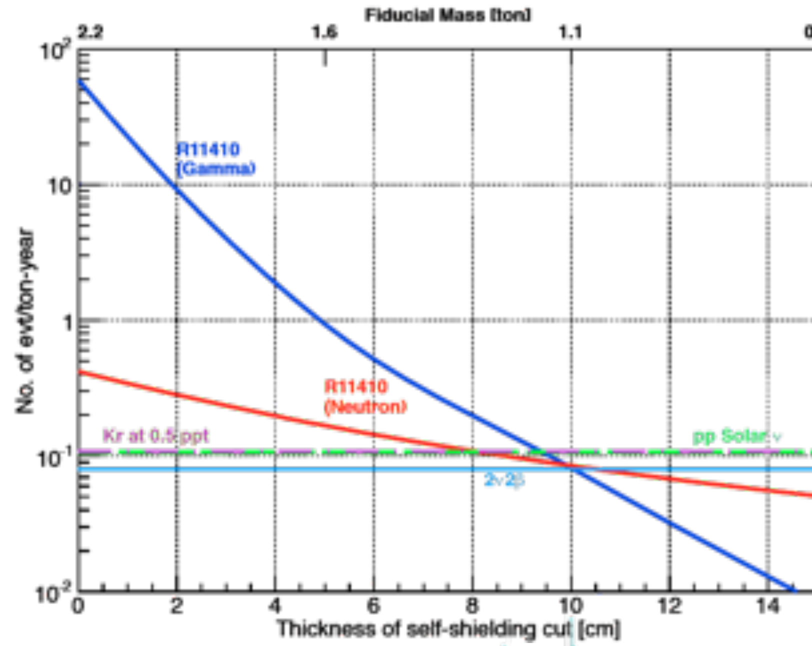


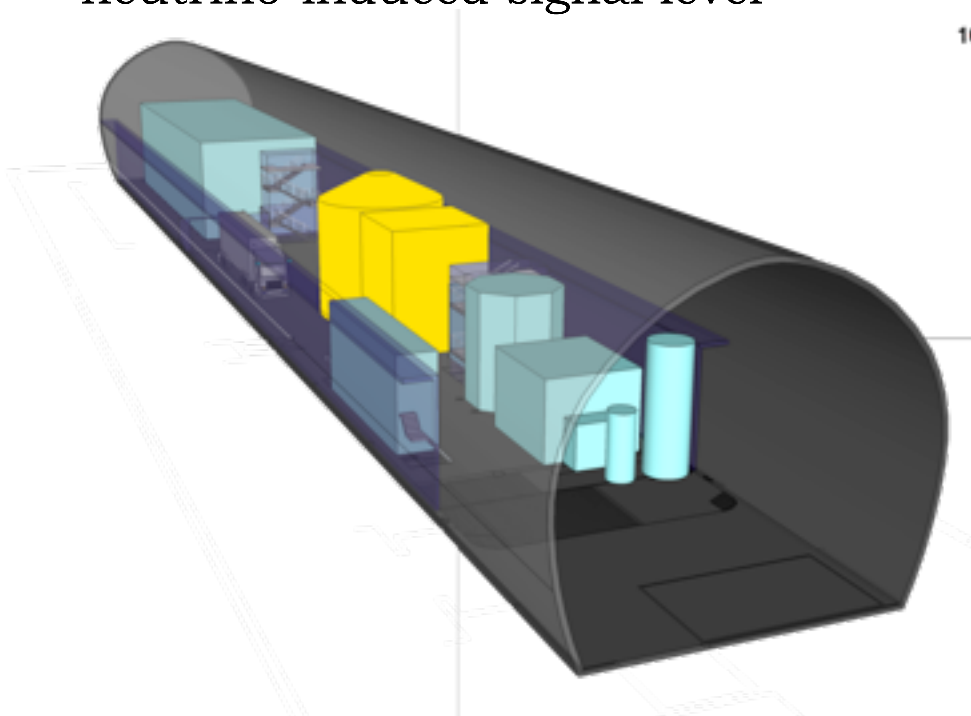
Demonstrated high light yield
- 122 2.2” PMTs
- high reflectivity PTFE
- 8 phe/keV with no E field
- >4 phe/keV with E, @122 keV

Largest xenon detector active
- 300 kg active Xe
- 100 kg fiducial
- 300-T water shield

Schedule:
- Xe condensed by 2/10/13
- first WIMP result in 2013

XENON1T
- fully funded
- construction starting this month!
- in 10m diameter water tank
- at Gran Sasso
- 1 ton fiducial xenon target
- 3.5 ton total
- external backgrounds reduced to neutrino-induced signal level





(location between ICARUS and WARP)

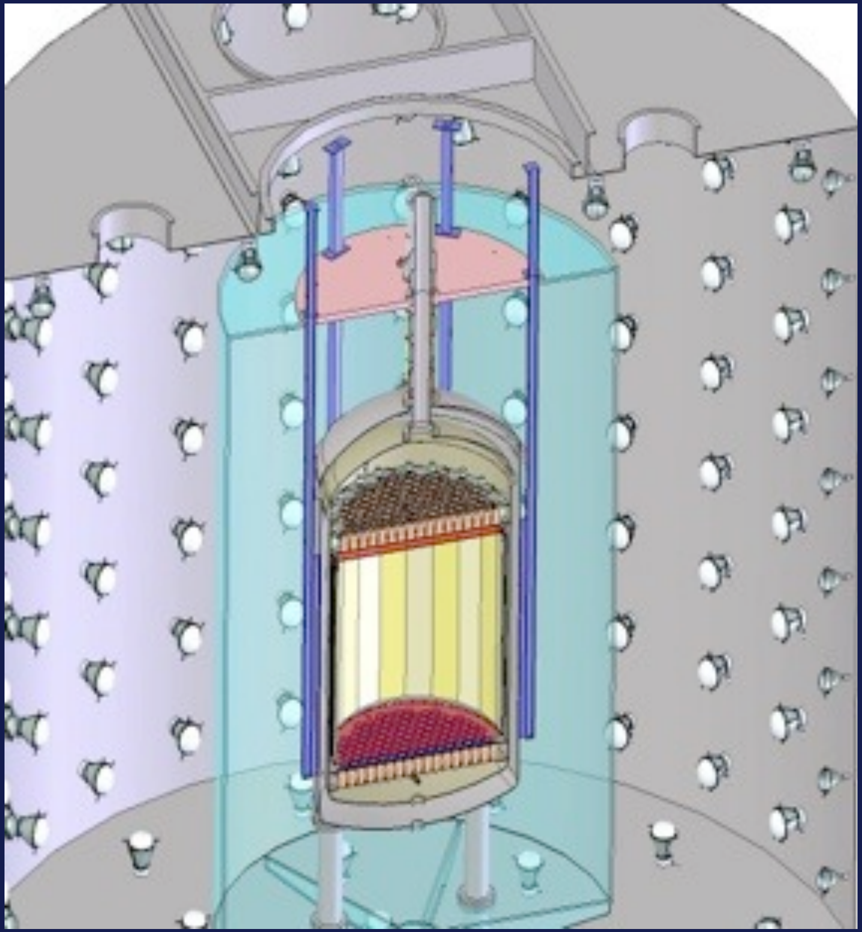
LZ: A proposed 6-ton (fiducial) LXe experiment

LUX+ZEPLIN collaborations

- A 25-fold scaling of LUX, which fits in the existing Davis water tank, remarkably.

- Fiducial volume = 6 ton
  - 60x LUX
  - 6x XENON1T

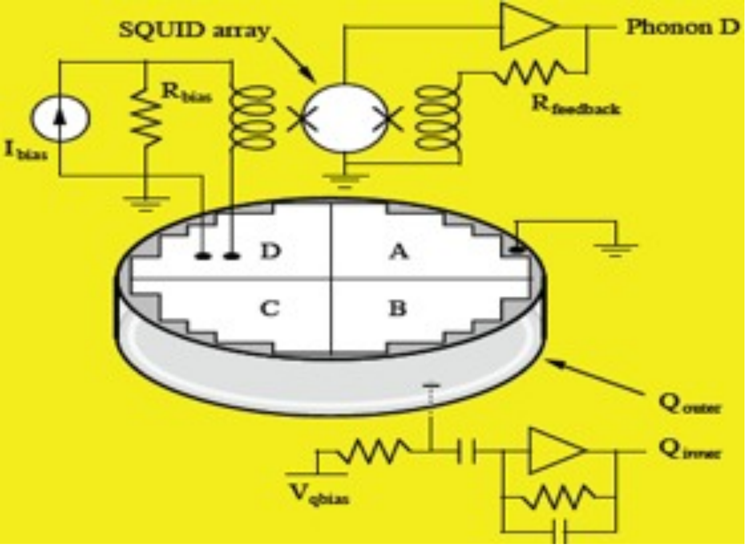
- Designed to reduce and measure major backgrounds
  - 0.75 m thick Gd-loaded scint. shield
  - instrumented Xe "skin"
  - effective for neutron and gamma backgrounds.

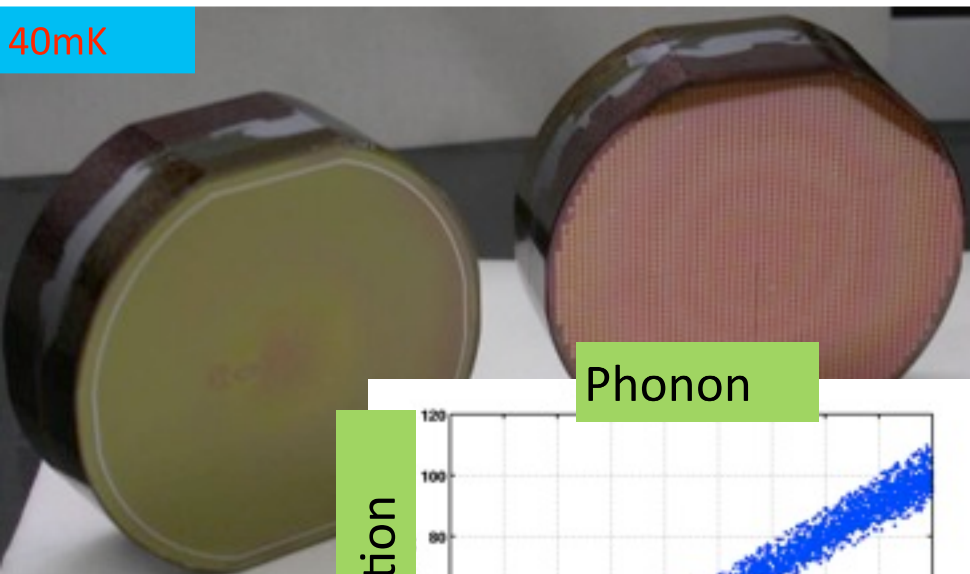


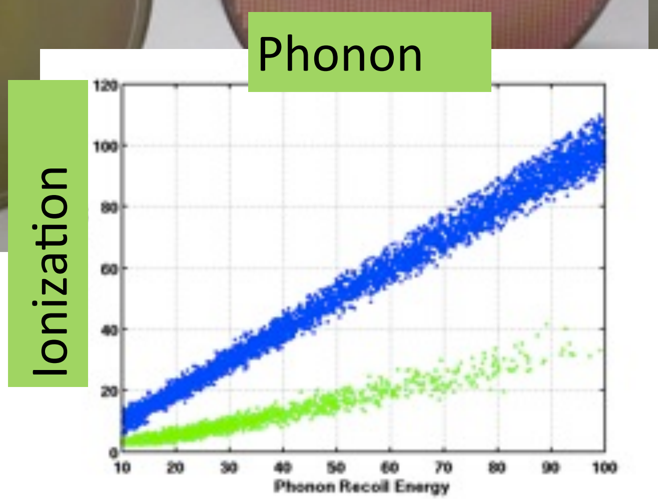
~700 events from pp neutrinos in 1000 days before ER-NR cuts

CDMS: The Big Picture

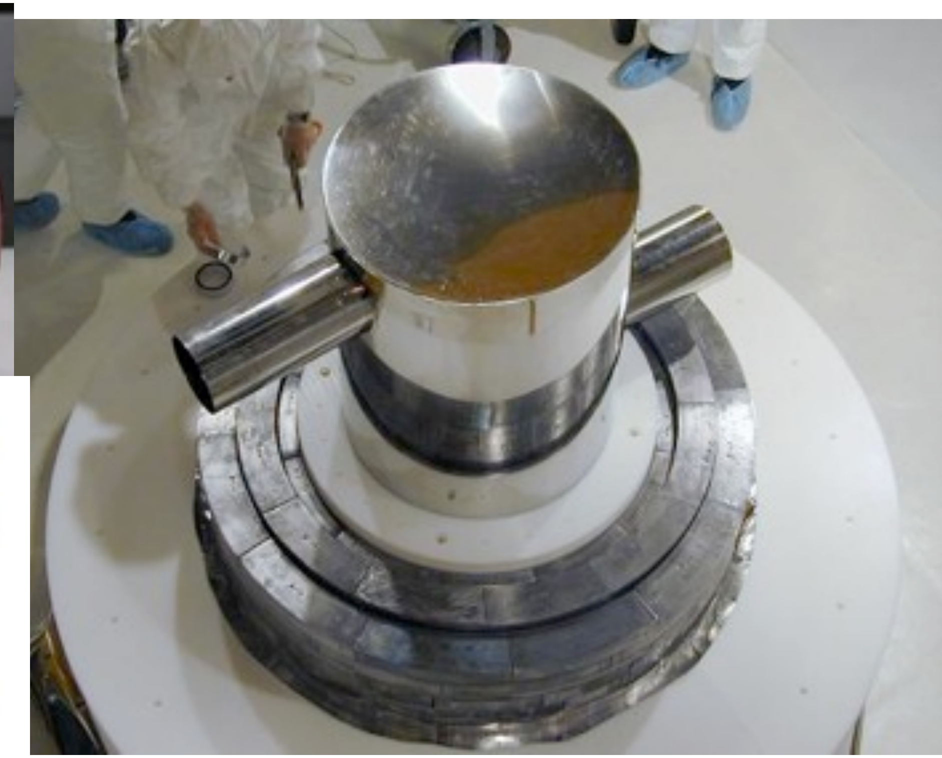
Cryogenically cooled Ge detectors with photo lithographically patterned Transition Edge Sensors for good energy and position resolution





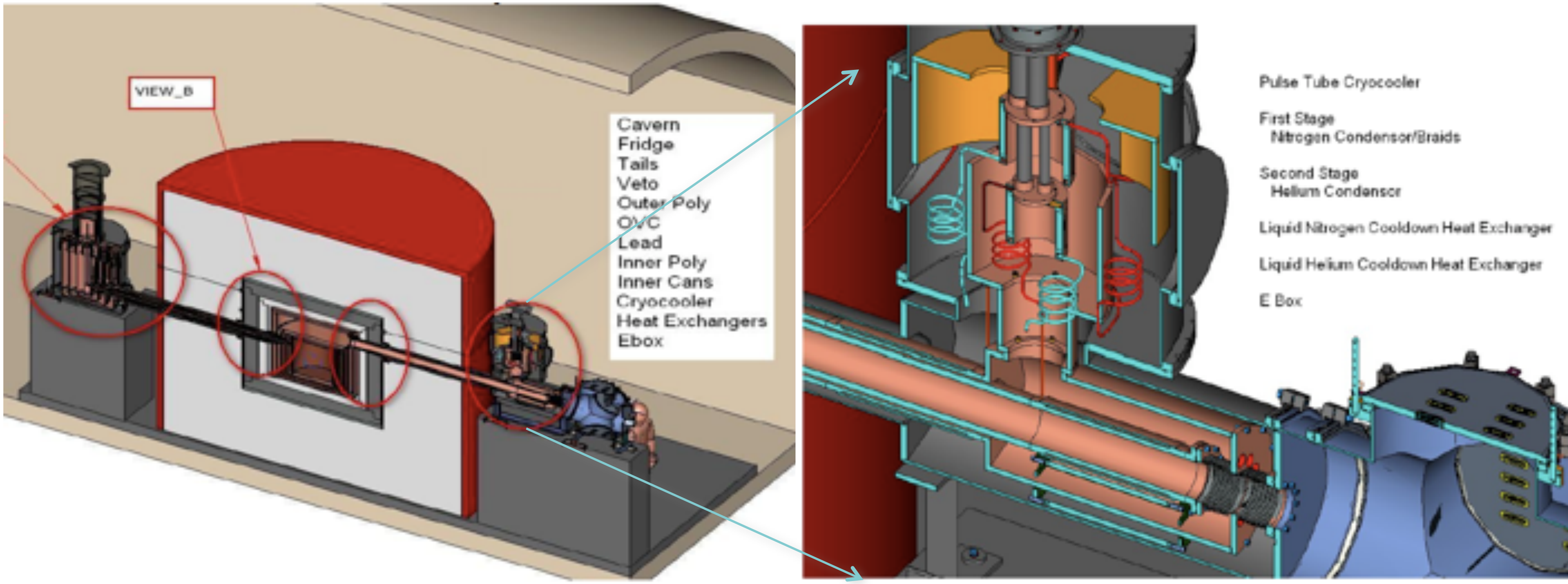


X-Y-Z Position from Phonon Pulse Timing



- Passive Shielding (Pb, poly, *depth*)
- Active Shielding (muon veto shield)

SuperCDMS SNOLAB (200 kg Ge in 400 kg Cryostat)



- New fridge and shield design work in progress at FNAL.
- Detector fabrication at Stanford/SLAC/Texas A&M
- Direct readout of all electrical channels, similar to CDMS II
- R&D being performed on internal neutron shielding

Argon experiments coming soon

- Large LAr detectors well understood, and several are being built for neutrino physics
- New background feature in Argon is cosmogenic ^{39}Ar, $t_{1/2}$= 269 y, β with 565 keV endpoint.
  - 10^{10} decays/ton-year from natural Ar
  - Need to suppress by ~10^9 to get down to solar νs
- Rejection comes from
  - Pulse shape discrimination, very powerful at high energies
  - Ionization/phonons for 2-phase Ar
  - Acquiring Argon depleted in ^{39}Ar

The DarkSide Program: Direct WIMP Searches with Two-phase Argon TPCs

DarkSide Collaboration: USA, Italy, China, Poland, Russia, UK, Ukraine

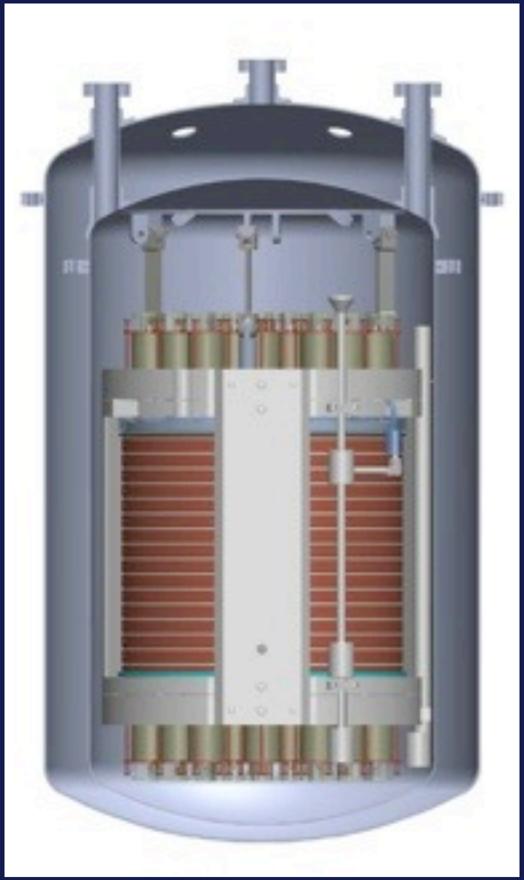
DS-10 –
10-kg prototype
Full TPC operation, high light yield
700 days of running (500 in LNGS)

DS-50 –
50 kg active, 33 kg fiducial
Sensitivity 2×10^{-45} cm^2 in 3 yr run
Under construction in LNGS Hall C

DS-G2 –
5 tonnes total, 3.3 tonnes fiducial
Sensitivity 2×10^{-47} cm^2 in 3 yr run
Fits in DS-50 shield/veto facility
R&D/design phase

Design for long, zero-background run

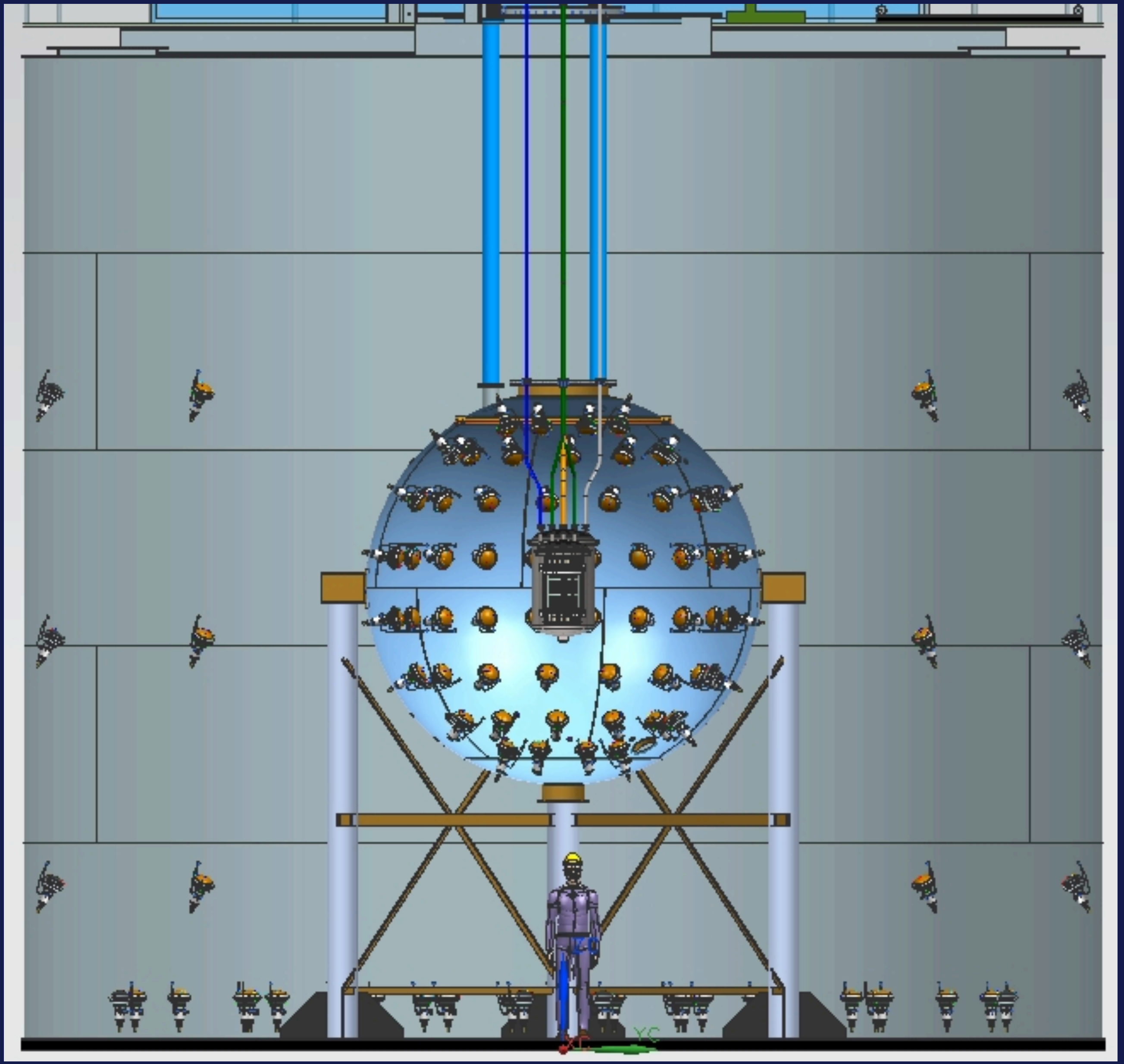
- Pulse Shape Discrimination (PSD) of Primary Scintillation, S1, (rejects e/γ)
- Ionization:Scintillation Ratio, S2/S1 (rejects e/γ)
- Sub-cm 3D Spatial Resolution (identify surface bkgs)
- Underground argon (avoid event pile-up from ^{39}Ar)
- Borated-Liquid-Scintillator Neutron Veto (identify neutrons with >99% efficiency)
- Water shield (identify muons and avoid cosmogenic neutrons)
- Screen and select all detector materials for minimum radioactivity



DS-50 TPC in cryostat

P. Meyers, Princeton

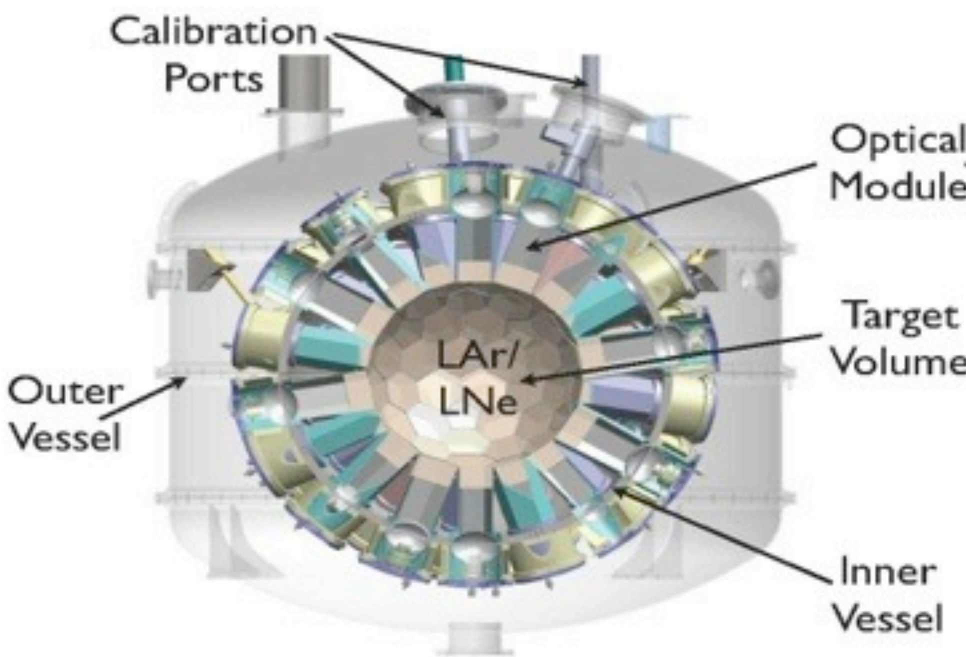
DS-50 commissioning underground begins Spring 2013

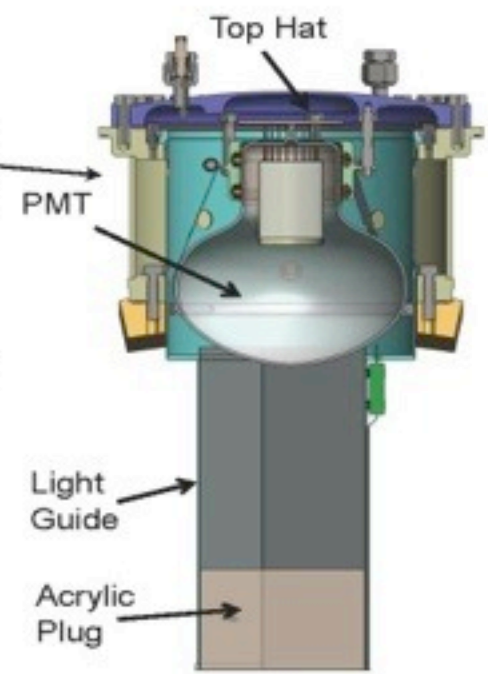


DS-50 Cryostat in 4-m Neutron Veto in 11-m Water Tank

MiniCLEAN Modular Design

- 4π coverage to maximize light-yield at threshold …
  - 3D Position Reconstruction
  - Particle-ID via Pulse-shape discrimination
- Radon-free assembly …
- "Cold" design allows both LAr & LNe …
- No electric fields … PMTs only active component …
- Fast signals (τ_3 = 1.6 μs) avoid pulse-pileup in LAr …

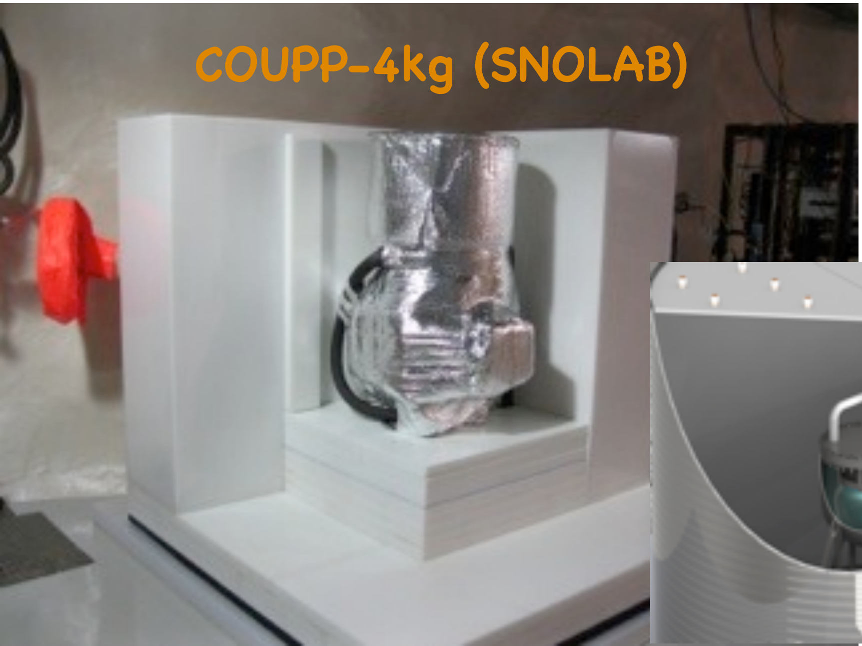




COUPP: A Bubble Chamber search for Dark Matter

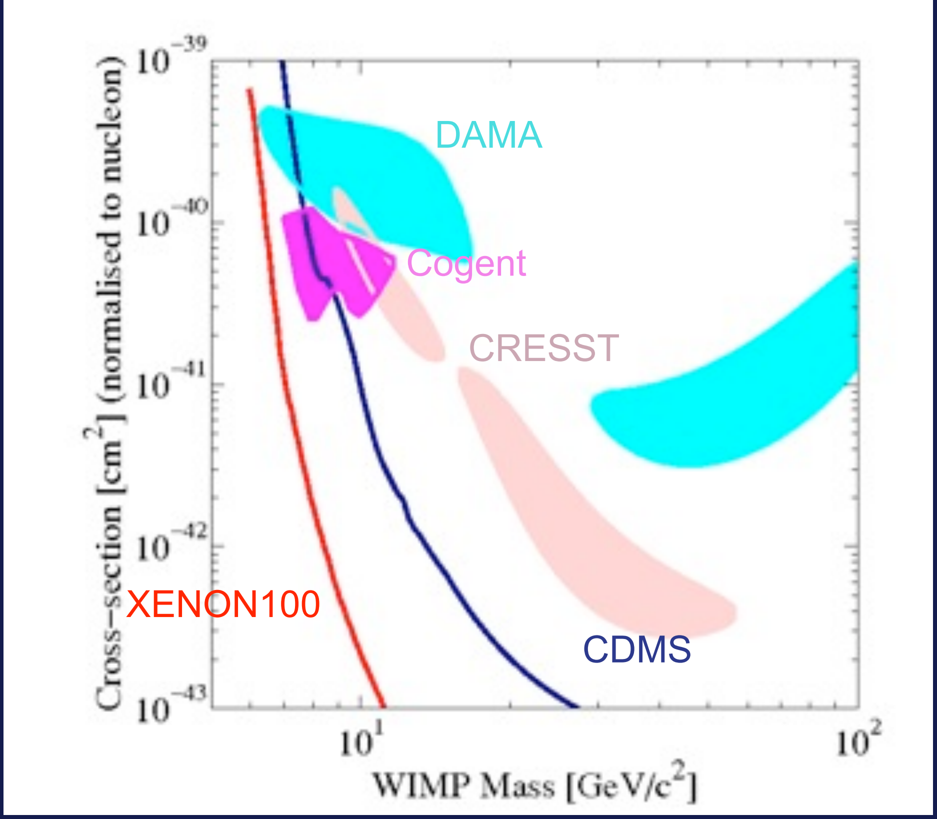
J. Collar, Chicago

- 4 kg chamber taking data again at SNOLAB after removal of (α,n) sources.
- World's best spin-dependent (SD) WIMP-nucleus coupling sensitivity, and very near CDMS' spin-independent (SI) sensitivity.
- 60 kg chamber to be commissioned at SNOLAB January 2013. We expect world's best sensitivity for both SD & SI couplings from this device.
- 500 kg design in progress (NSF funded, DOE pending). Planned start of construction 2013, installation at SNOlab during 2015.



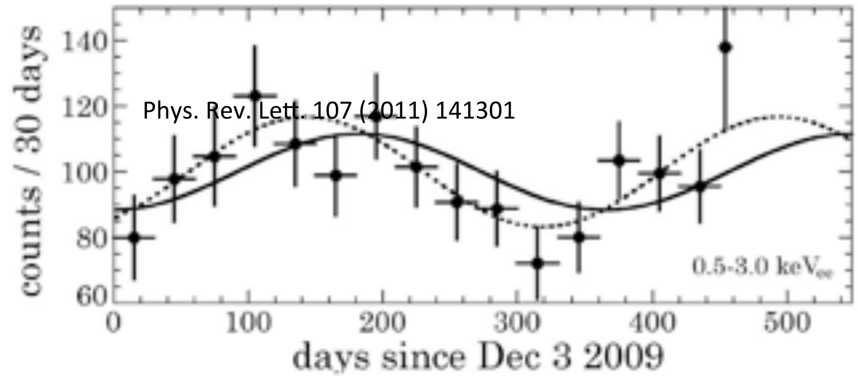
Low-mass WIMPS (~10 GeV)

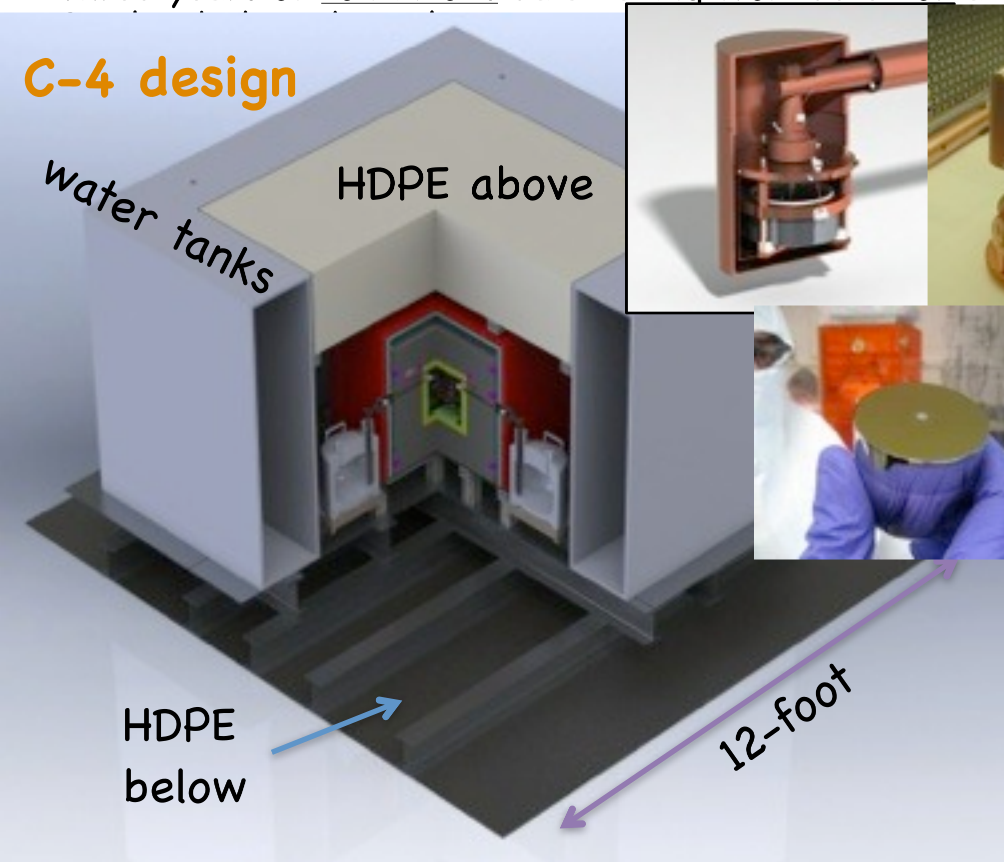
- The primary particle physics paradigm for DM is that the mass is at electroweak scale.
  - LHC searches rule out a neutralino with mass less than about 80 GeV.
- But one should search as sensitively as possible for WIMP masses in the 10 GeV region.
- Experiments are pushing thresholds lower.
  - lower noise
  - higher light yield for noble liquids
- All experiments realize they need robust neutron calibrations that extend down to threshold.

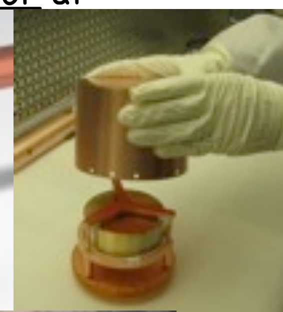


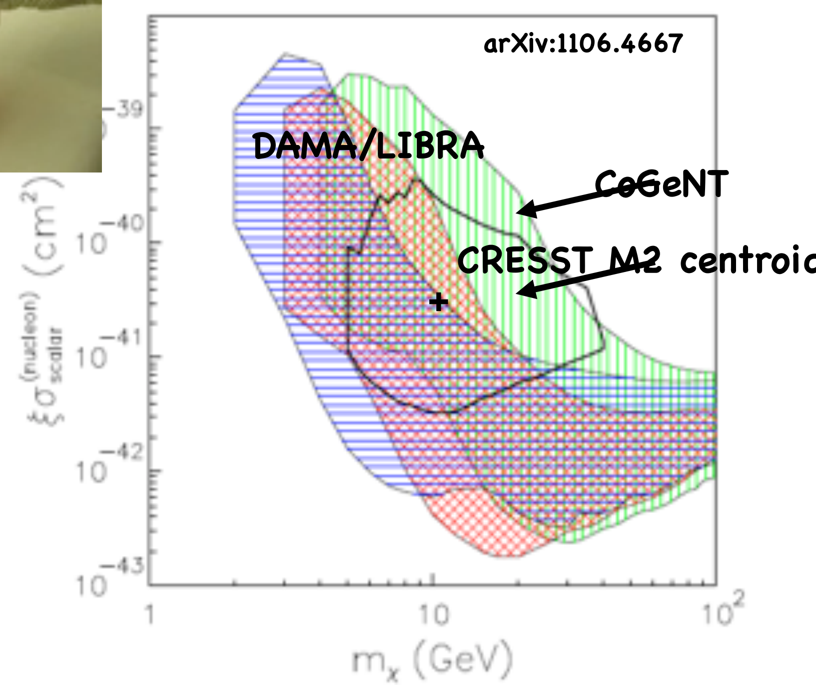
CoGeNT: dedicated search for light-mass WIMPs

- Annual modulation of unknown origin, measured with 0.4 kg PPC germanium crystal at Soudan, in possible agreement with DAMA/LIBRA & (now) CRESST. Compatible with a light WIMP interpretation.
- C-4 expansion to start 2013 in Soudan (x12 present target mass, significant reduction in bckg and threshold expected). First detector arriving Jan 2013.
- C-4 detectors to feature measures against parallel-f electronic noise (i.e., lower threshold).
- Three years of continuous data-taking from detector at



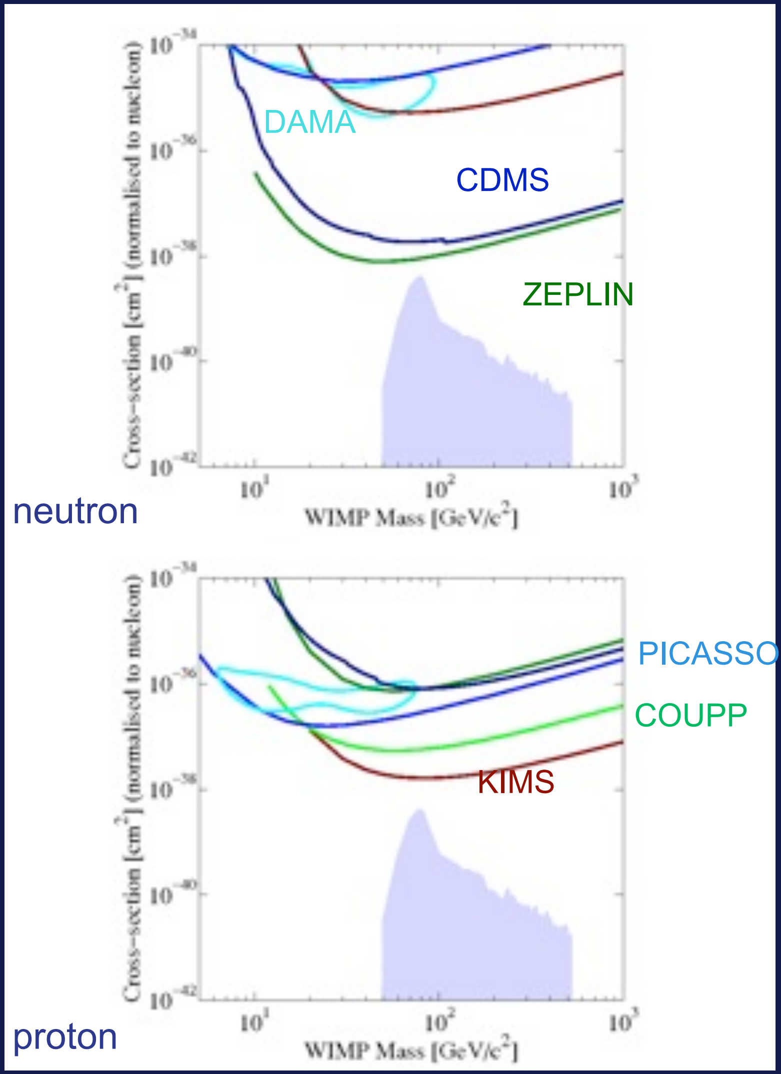




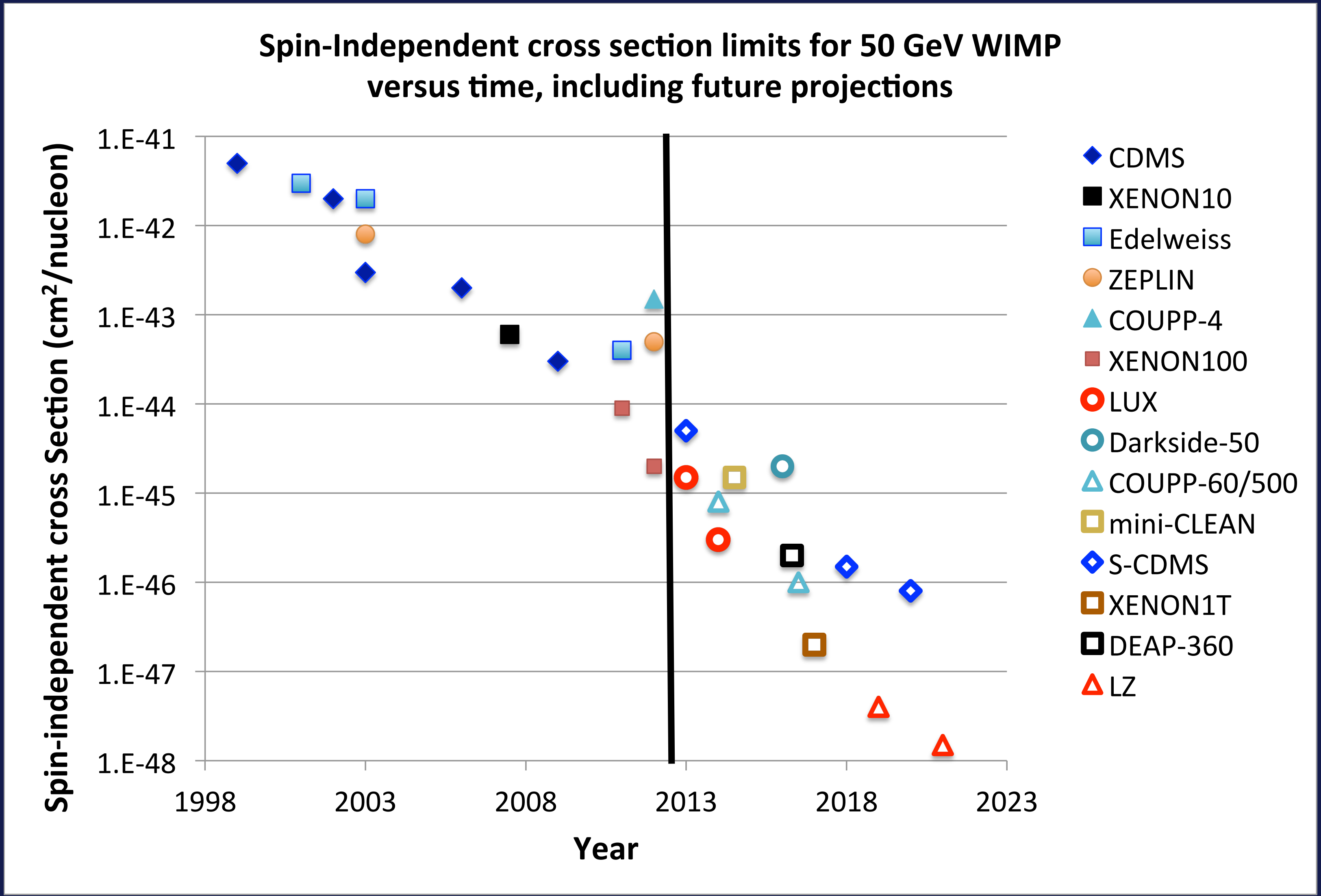


Spin-Dependent cross sections

- The coupling of the WIMP to nuclei may depend on spin, and therefore only see odd-neutron (or odd-proton) isotopes.
- The cross section sensitivities are 10^{-38} cm^2 rather than 10^{-45} cm^2 per nucleon.
- For odd proton targets, COUPP (CF_3I) and KIMS (CsI) are most sensitive.



Future projections are uncertain, and the uncertainty grows with time.



Conclusions

- If the WIMP hypothesis is correct, we have a good chance of observing dark matter in the laboratory.
  - Possibly soon.
- The US has had a leading role in the campaign to detect dark matter since its beginning in 1987.
  - We can and should lead it into the discovery era.
- We need to design and build experiments that will make a definitive discovery possible.
  - Even lower backgrounds, well measured.