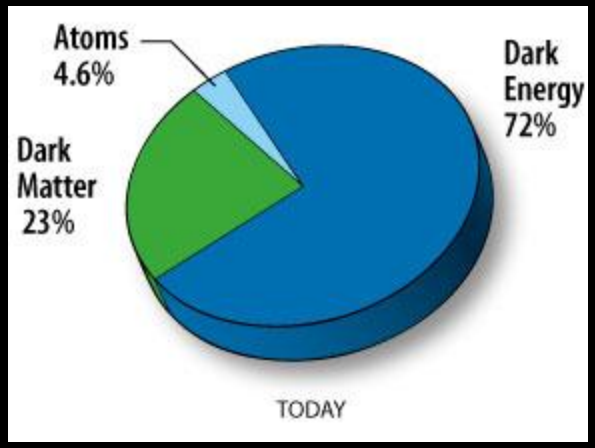
CDMS and Direct Dark Matter Searches at FNAL



Ben Loer

2012 FNAL Users' Meeting

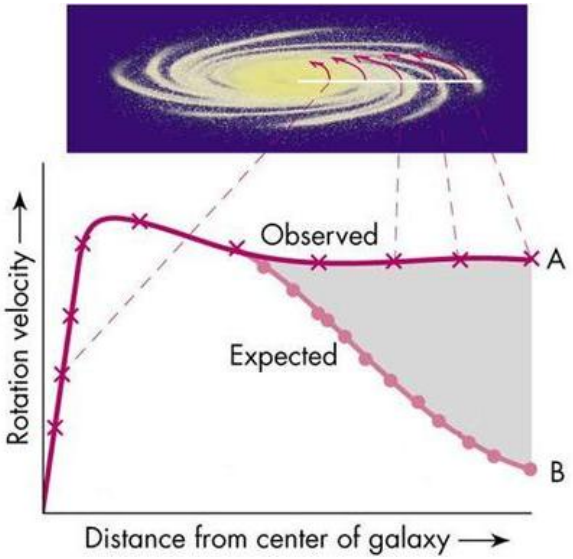
Jun 13, 2012

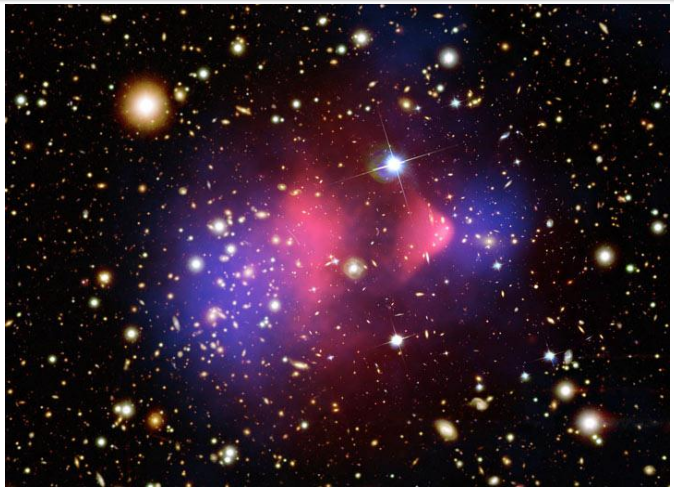
Outline

- Introduction
  - The case for cold dark matter
  - Direct dark matter search basics
- Dark matter searches at FNAL
- CDMS: Cryogenic Dark Matter Search

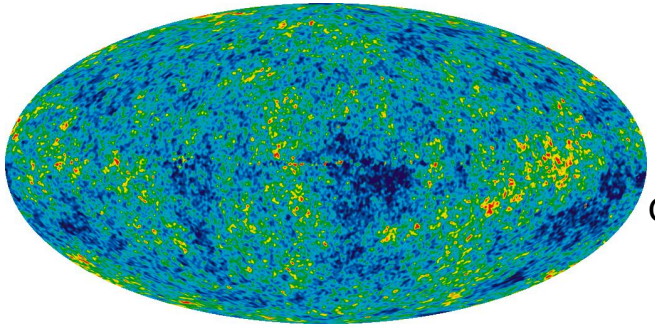
Evidence for dark matter: compelling at all scales

Single galaxies

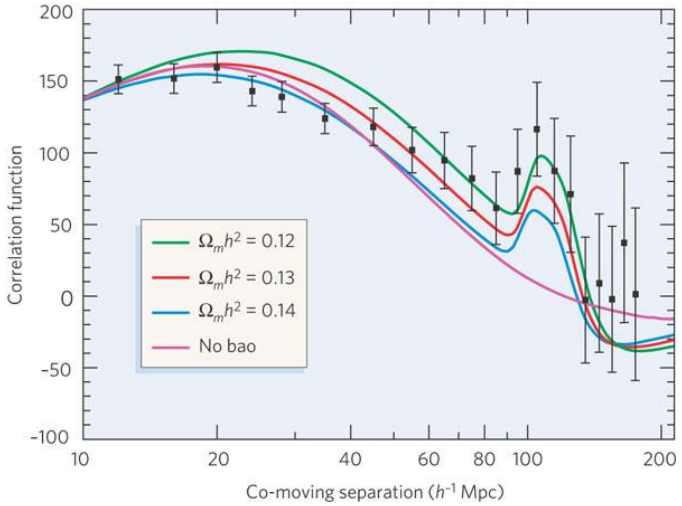




Galaxy clusters

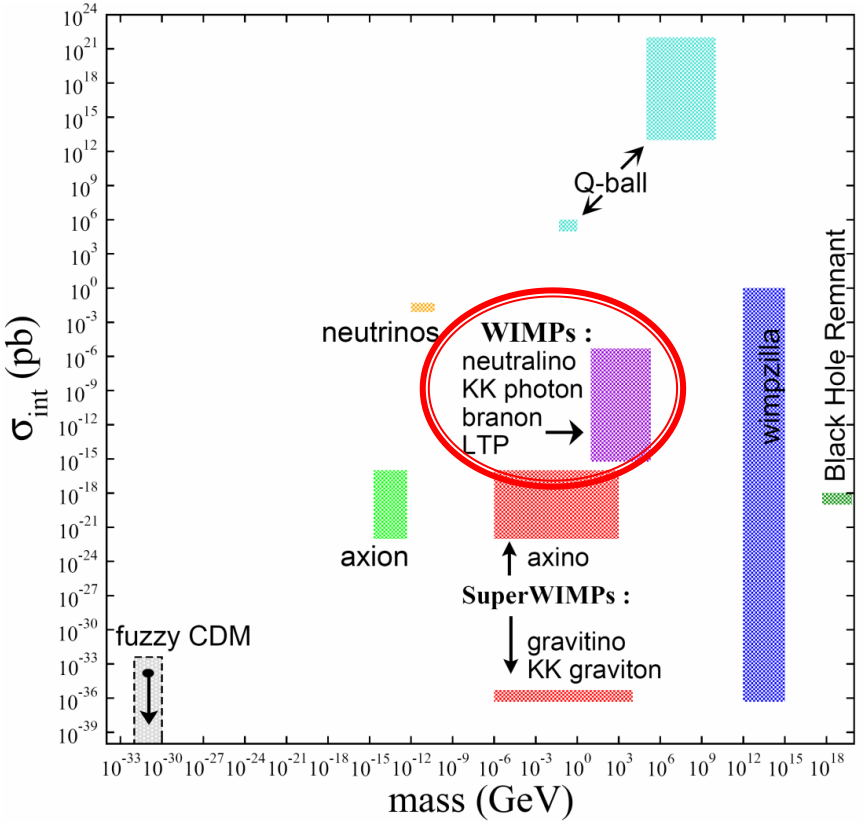


The whole observable universe



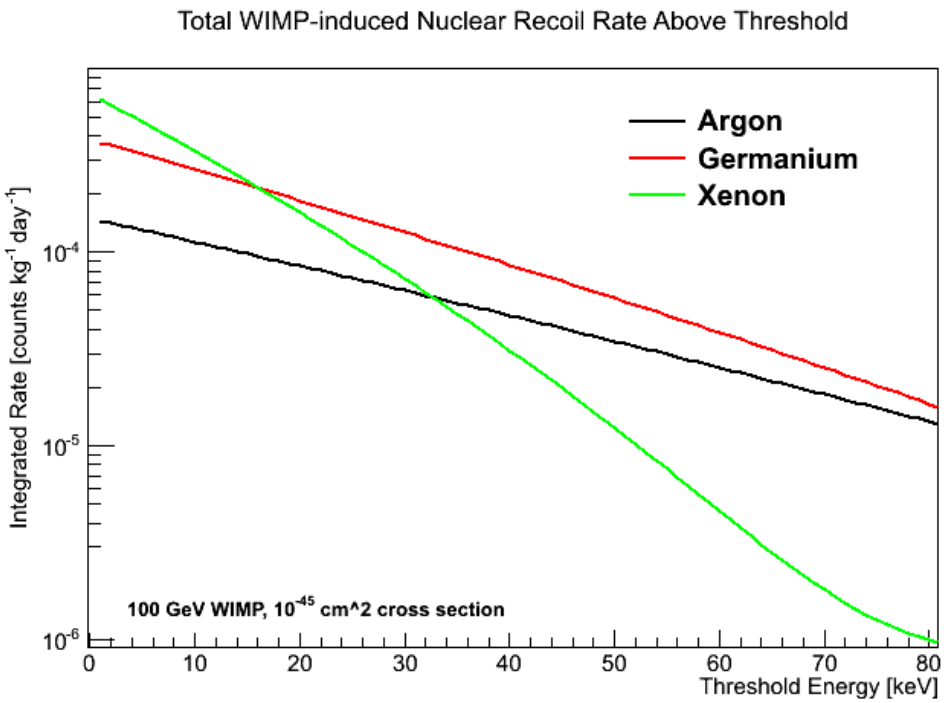
Lots of possible candidates

- Most focus on WIMP: Weakly Interacting Massive Particle
- Cosmological relic density naturally leads to ~GeV—TeV particle with weak-scale annihilation cross-sec
- Bonus: matches neutralino in many SUSY models



WIMP Search Challenges

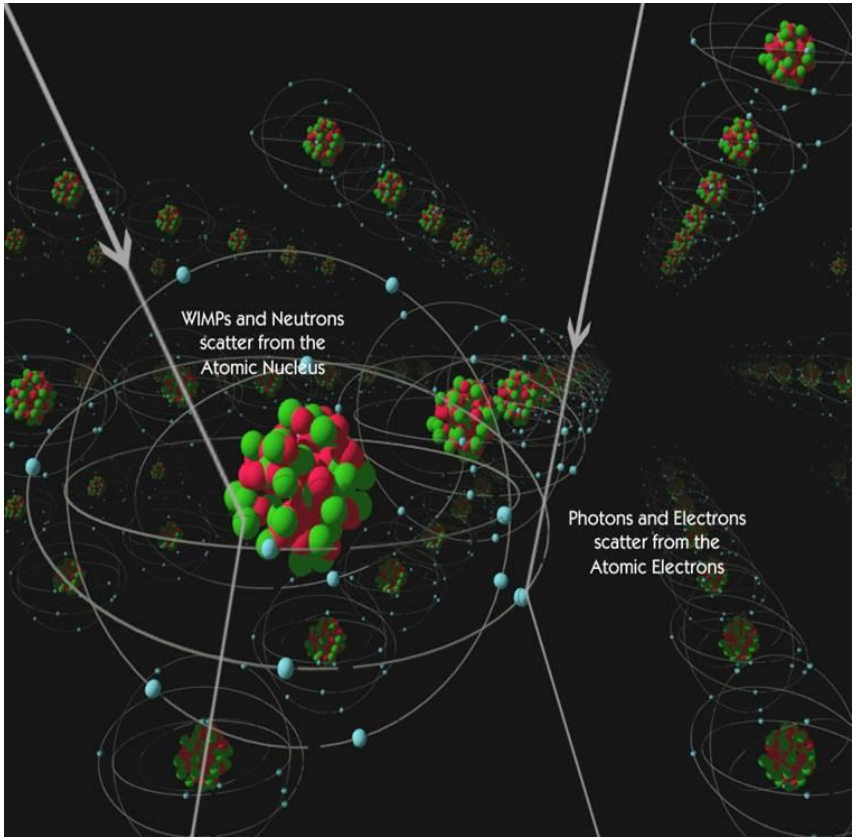
- Sharply falling exponential spectrum
- Tiny overall rate: ~few/ton/year
- Compare to "clean' copper, ~10^7/ton/year
- 1 fingerprint: ~20 decays/year



Need: Low threshold, very low backgrounds

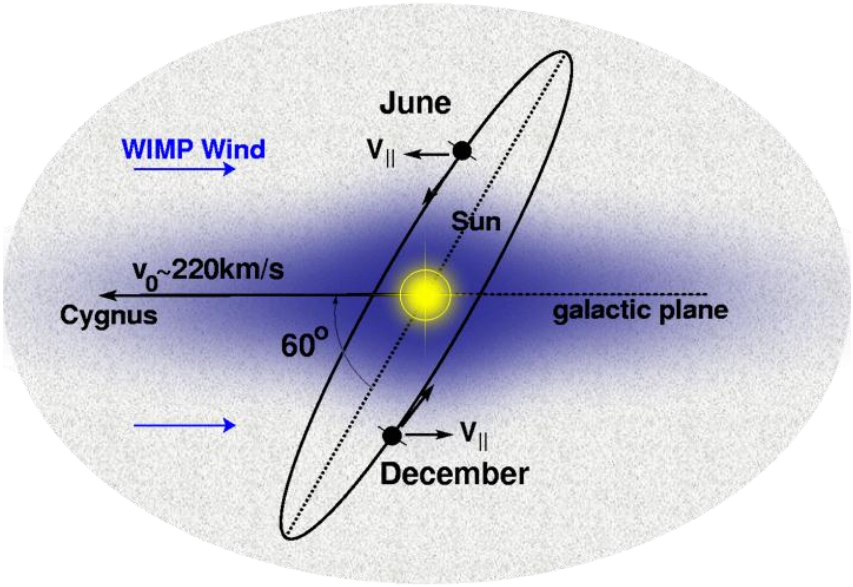
Background Rejection

- Gammas are largest background, but they have different energy deposition mechanism
- Alphas are usually higher energy, at surface
- Neutrons mimic WIMPs; good for calibration, bad for background – need lots of shielding



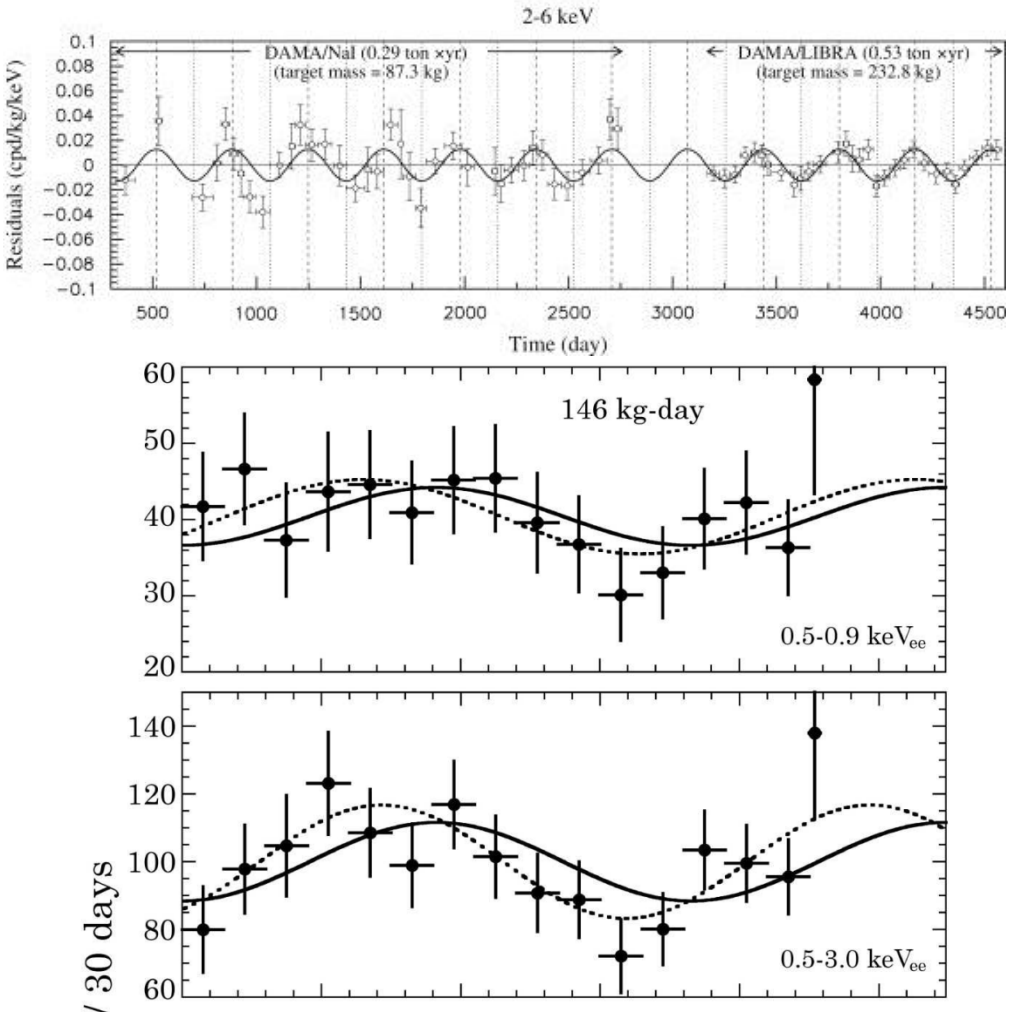
Annual modulation

- WIMP signals expected to have annual modulation
- Due to motion of earth relative to sun through "WIMP wind"
- "Smoking gun" dark matter signature



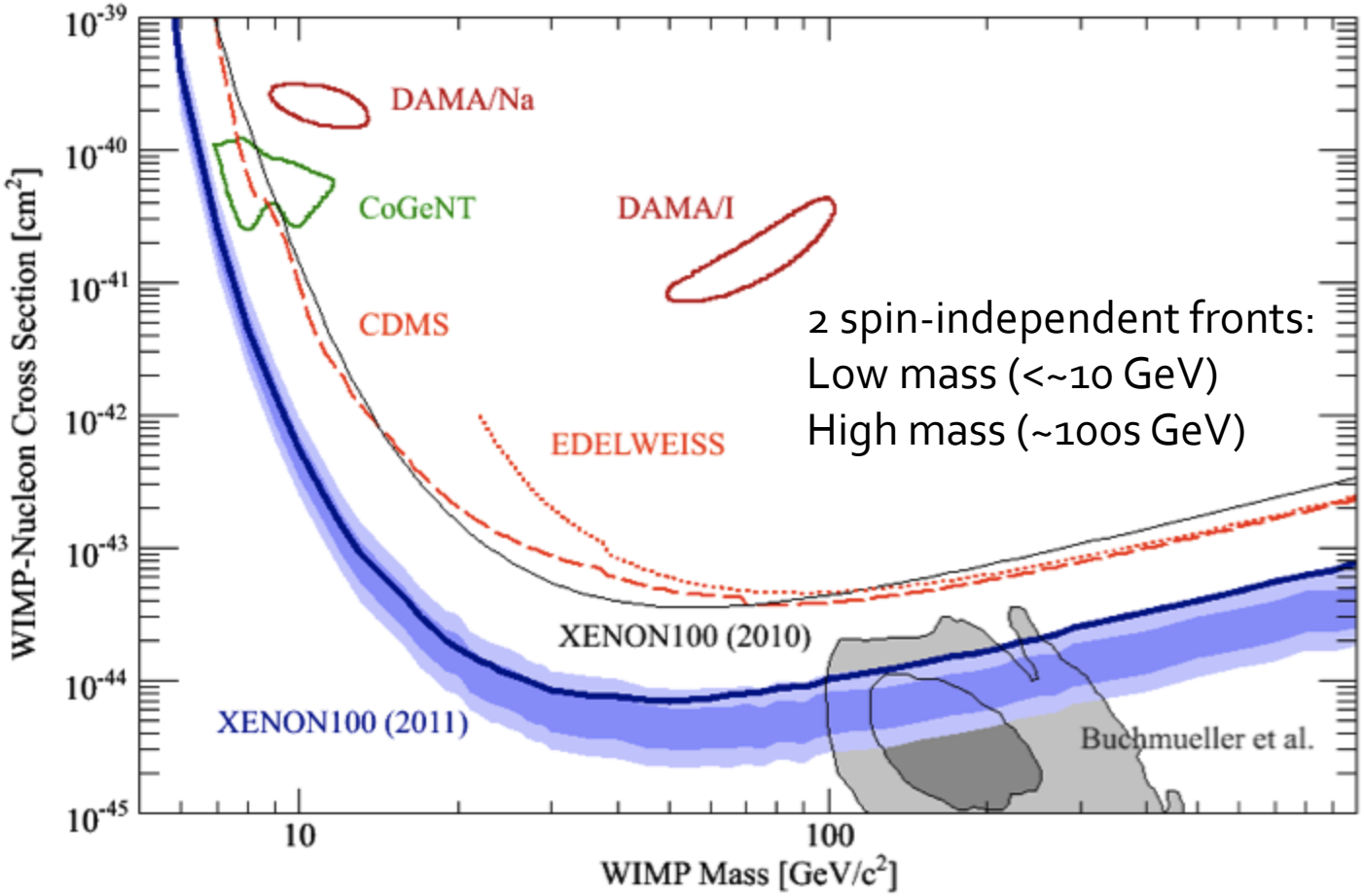
Annual modulation: Some hints

- DAMA, CoGeNT, and CRESST see low-energy signals compatible with ~7 GeV WIMP
- DAMA sees annual modulation at expected phase with >7 sigma
- CoGeNT sees (statistically) weaker modulation



Where is the community at now*?

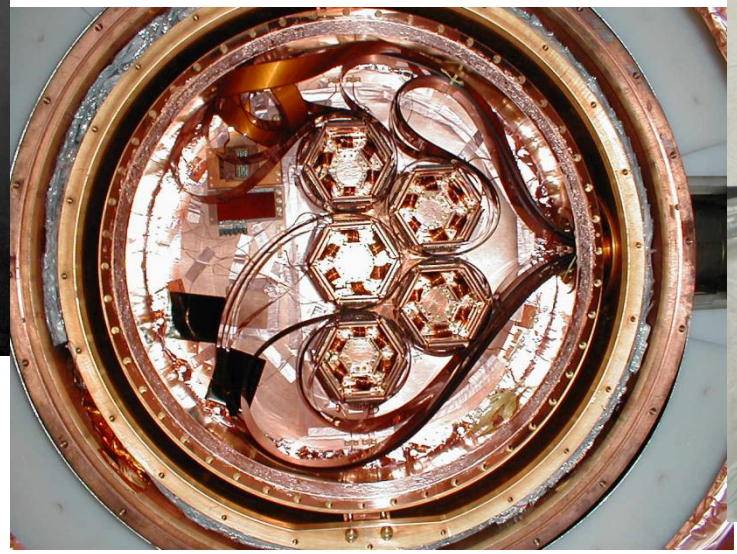
*For loose definitions of 'now'



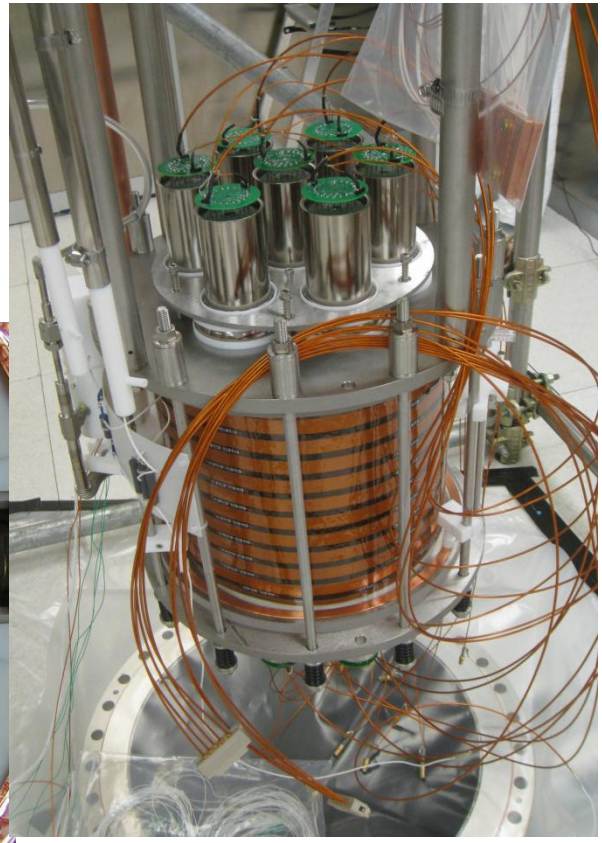
Direct WIMP Searches at FNAL

COUPP
Bubble chamber

DAMIC
CCDs (from DECam)



CDMS
Cryogenic Ge

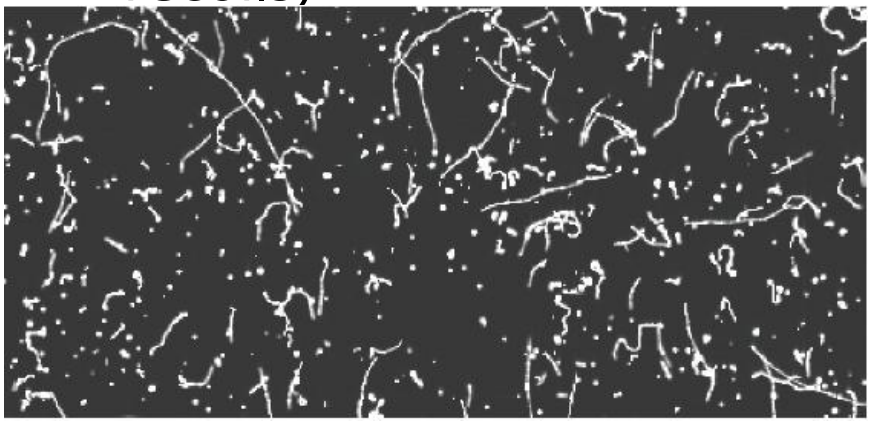


DarkSide
Argon TPC

DAMIC: CCDs

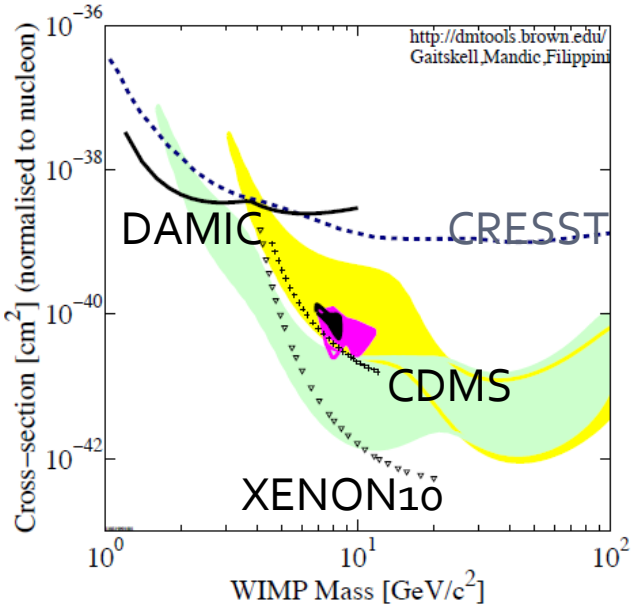
TRACK LENGTH GIVES PARTICLE DISCRIMINATION

- "Dots" are diffusion-limited hits (nuclear recoils)



LIMIT-HOLDER FOR LOW-MASS WIMPS

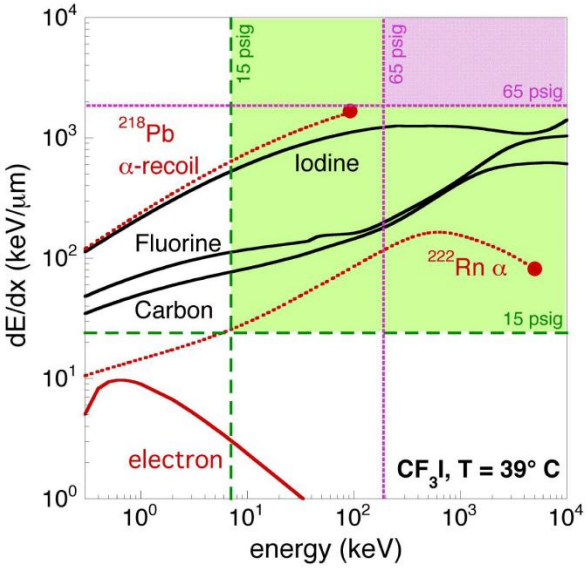
- Ultra low threshold (40 eV!)

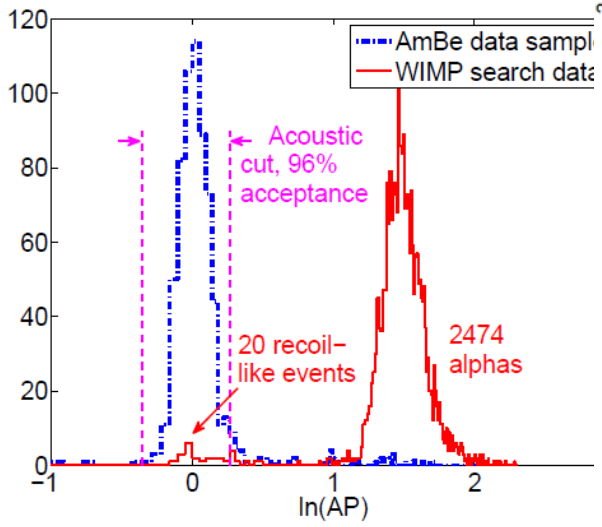


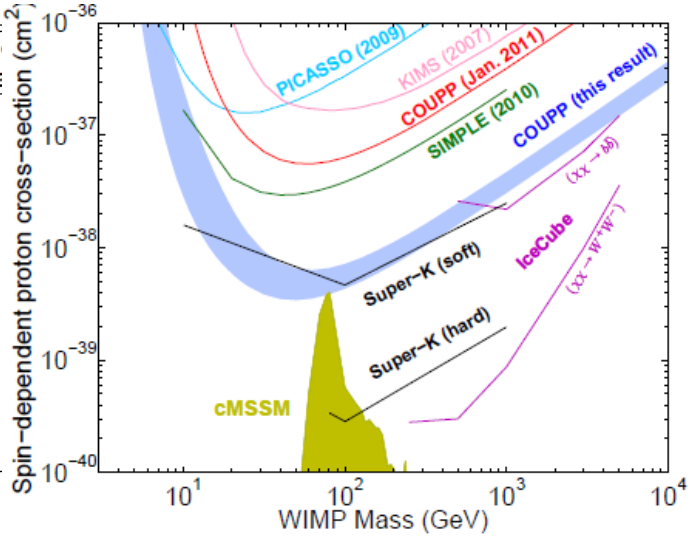
Moving to SNOLAB with 10g of CCDs and neutron shield

COUPP: Bubble Chamber

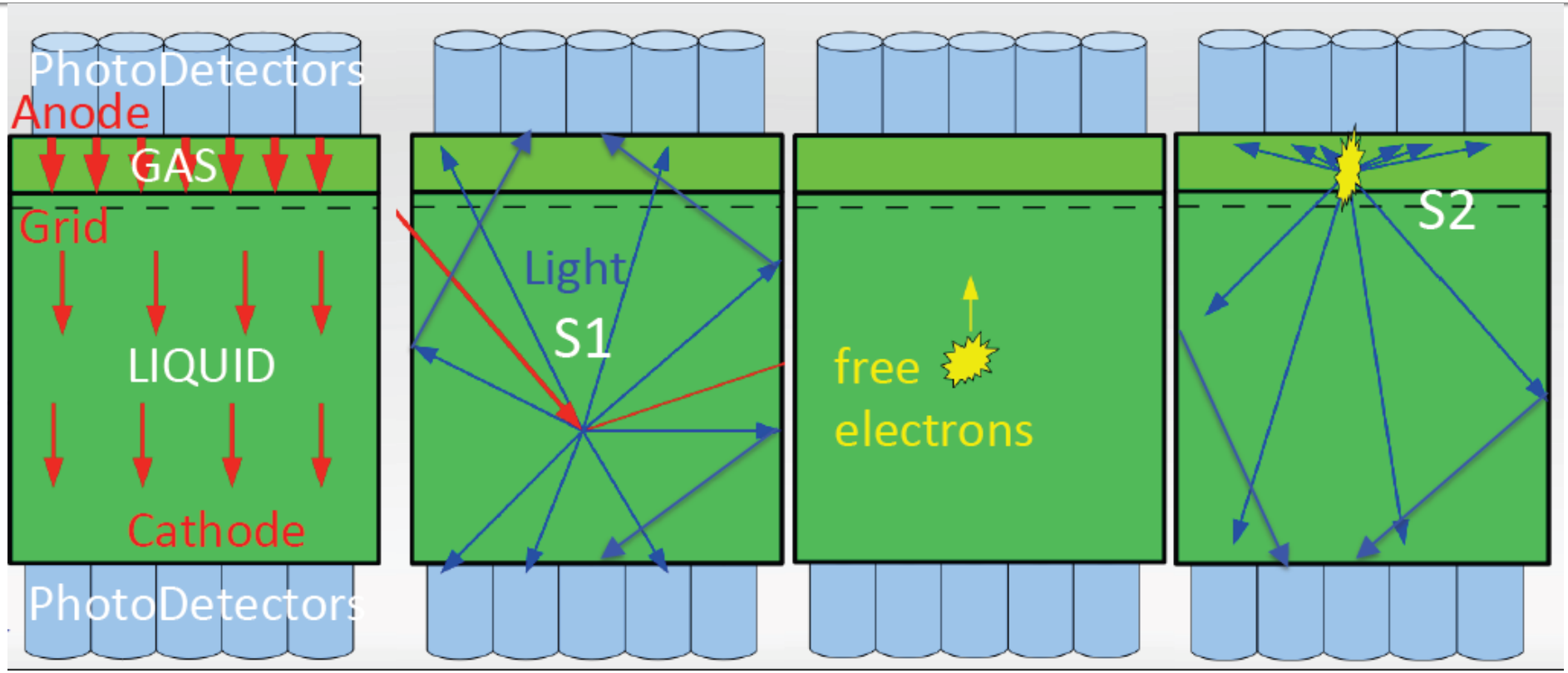
- Nucleation threshold insensitive to MIPs
- Acoustic sensors provide alpha rejection
- 4kg chamber at SNOLAB leading spin-dependent result
- Upgrading to 60 kg late 2012







DarkSide: Dual-phase argon TPC



Liquid active volume with small drift field Gas multiplication volume

Primary interaction creates scintillation (S1)

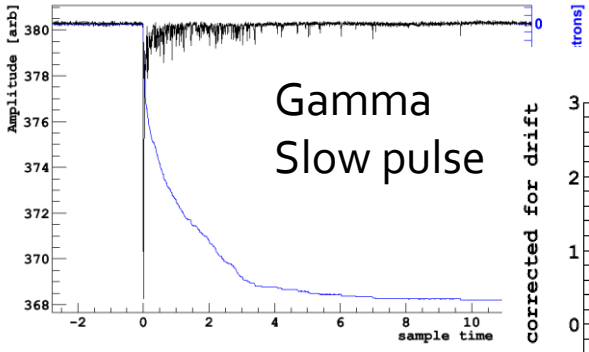
Ionized electrons drift toward gas region

High field in gas makes secondary scintillation (S2) (light-gain only)

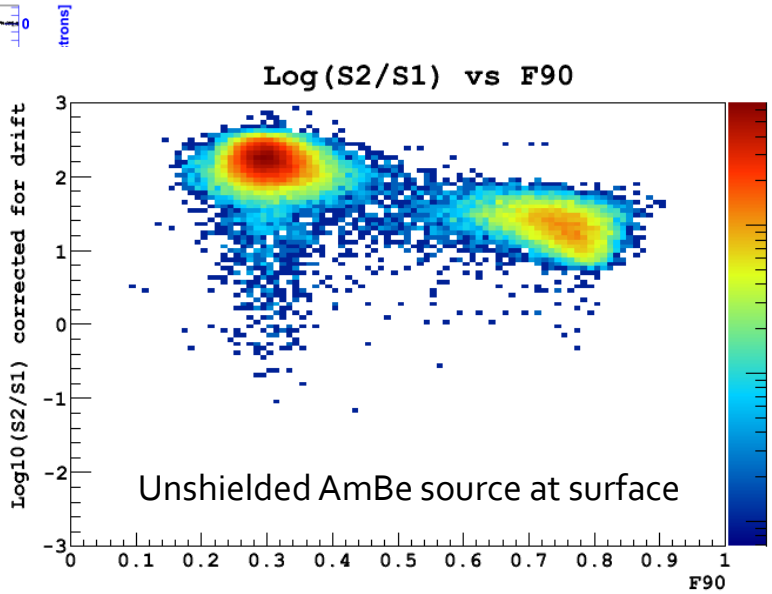
Argon TPC background rejection

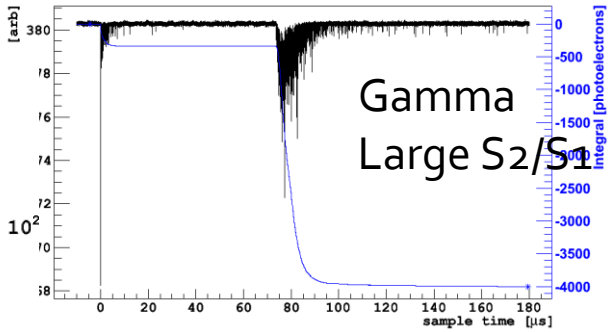
Primary scintillation gives energy, PSD

Secondary scintillation gives position, Ratio gives ionization yield (~dE/dx)

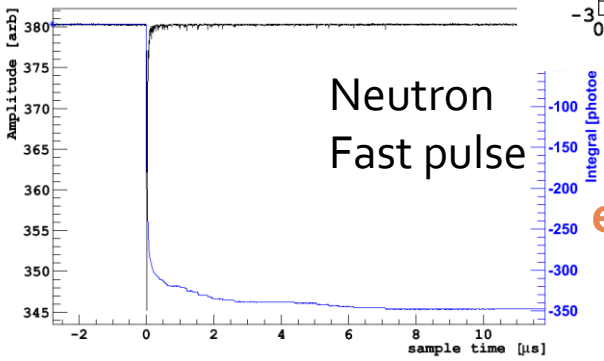


Gamma
Slow pulse



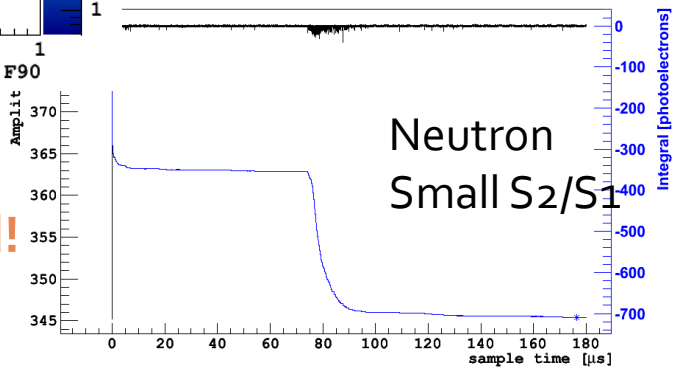


Gamma
Large S2/S1



Neutron
Fast pulse

Discrimination power, sensitivity depend exponentially on light yield!



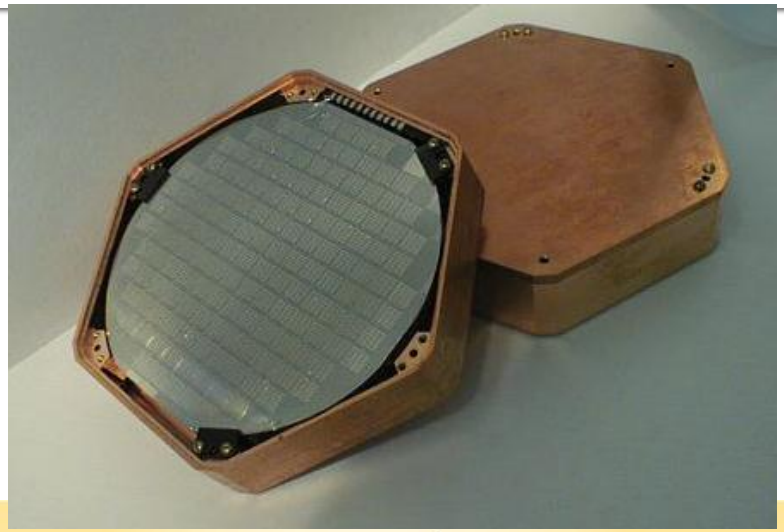
Neutron
Small S2/S1

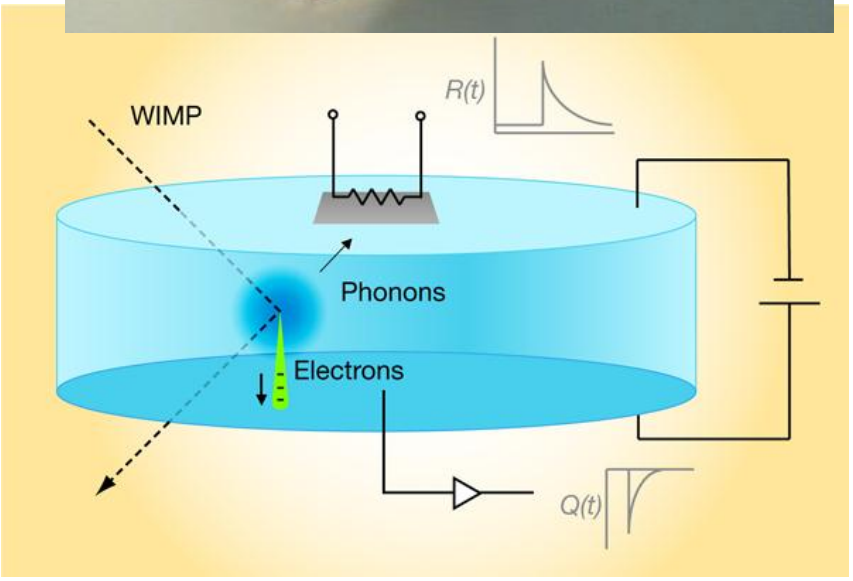
DarkSide Highlights

- Underground argon reduces ^{39}Ar background > x100
- DS-10 kg measured 9 p.e./keV light yield: best in field
- DS-50 kg under construction now; employs high-efficiency neutron veto and huge water shield
- Data incoming early 2013, plan for 3-year campaign

CDMS: Cold Germanium Crystals

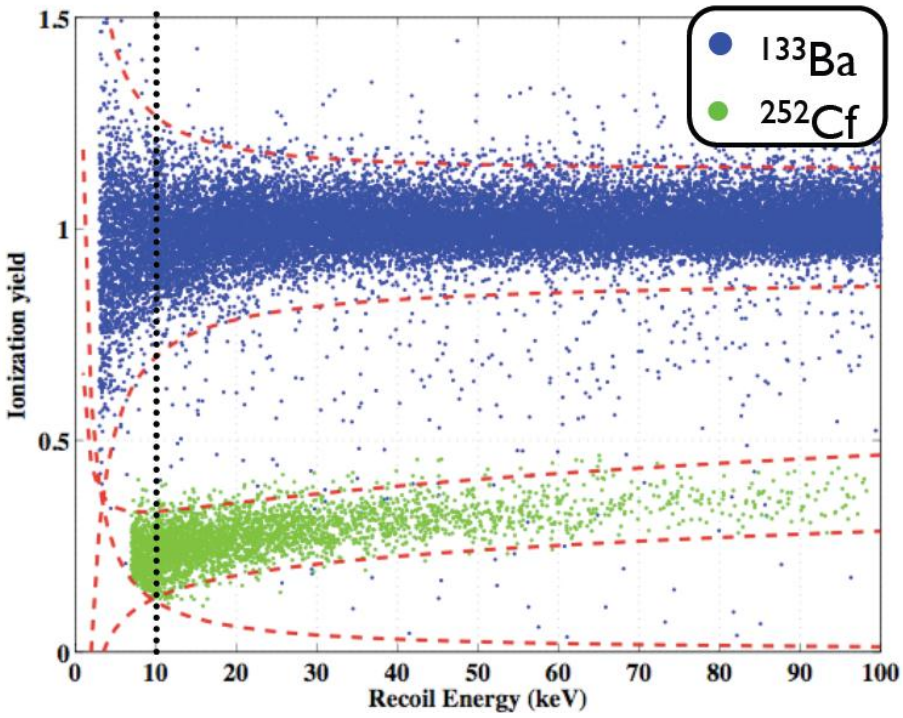
- ZIP: Z-sensitive Ion and Phonon detector
- Recoil in Ge crystal ionizes electrons and excites the lattice (phonons)
- Apply an electric field-> collect and measure free electrons/holes
- TES measures phonons





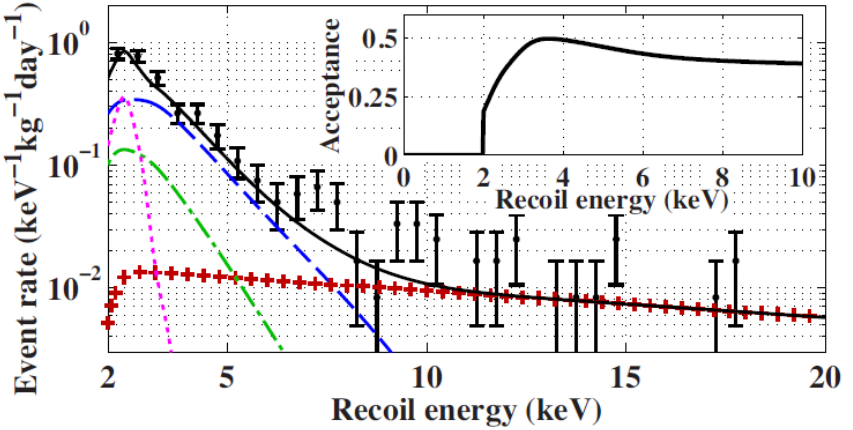
CDMS

- Neutrons/WIMPs hit nucleus, excite more phonons than ions
- Ratio of ionization/phonon signal removes gammas

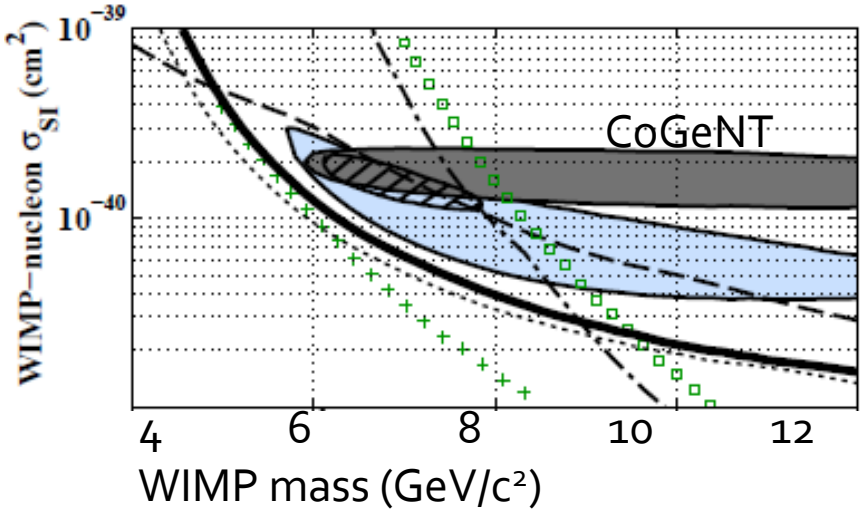


CDMS II Low Threshold Analysis - 2011

- Based on 2 years of data already analyzed at 10 keV threshold
- Push analysis down to 2 keV threshold
- Backgrounds higher, less well understood
- Net result: no evidence for WIMP signal above background.
- The result (solid black) excludes most of DAMA and CoGeNT allowed regions

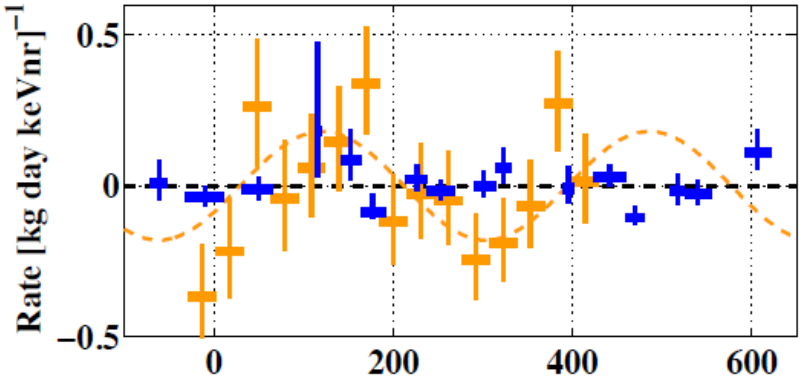


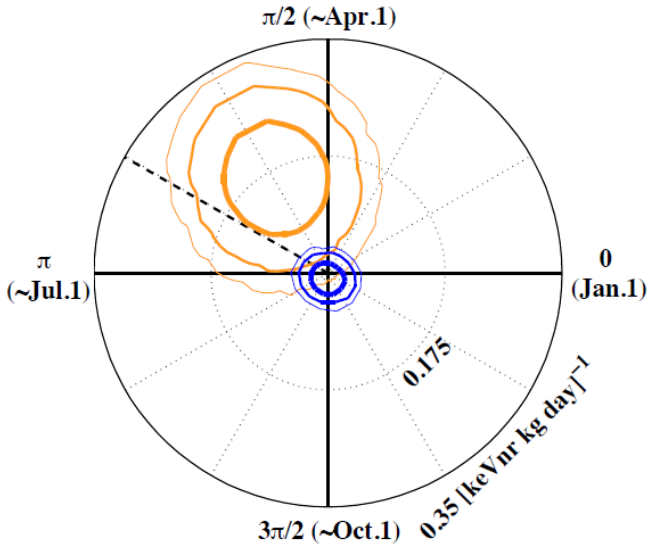
DAMA



CDMS II Annual Modulation Search – 2012

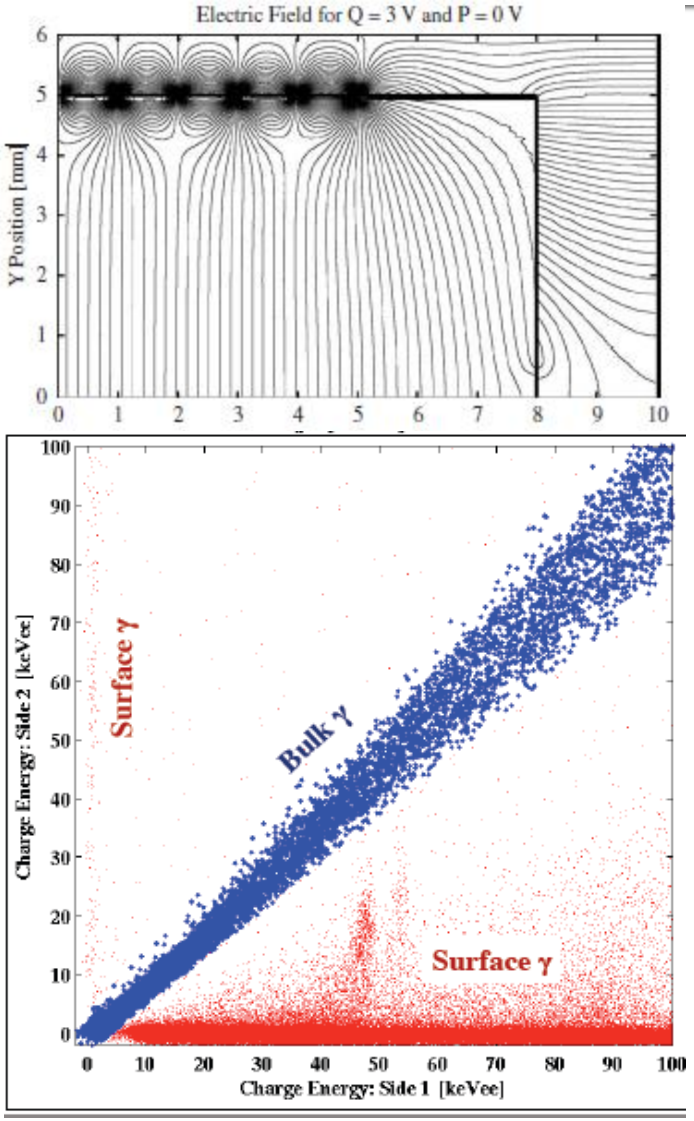
- No evidence for annual modulation in nuclear recoil data (blue)
- Tension with CoGeNT (orange), which also uses germanium in Soudan





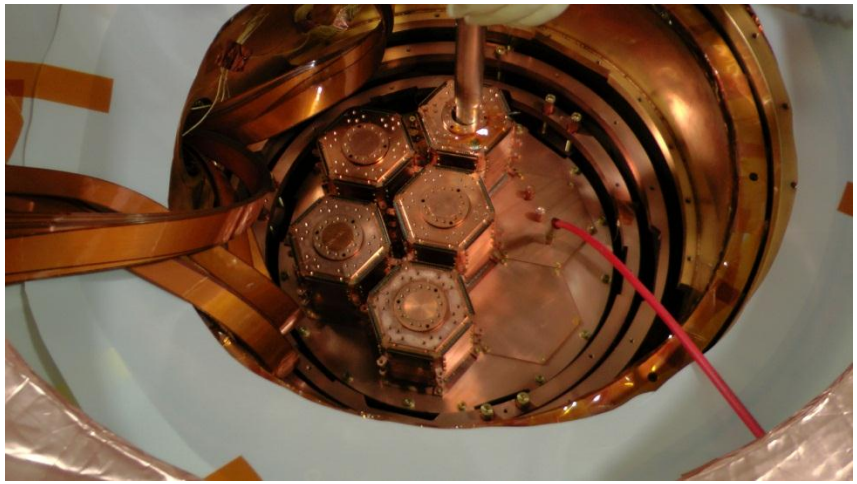
SuperCDMS: Enter the iZIP

- CDMS II 10keV threshold result limited by surface events
- iZIPs have Interleaved phonon and charge sensors on both sides
- Surface events show up clearly on one side or the other
- Reduces surface background by > x50,
- Improves fiducial volume by ~x2



SuperCDMS Soudan: Running now

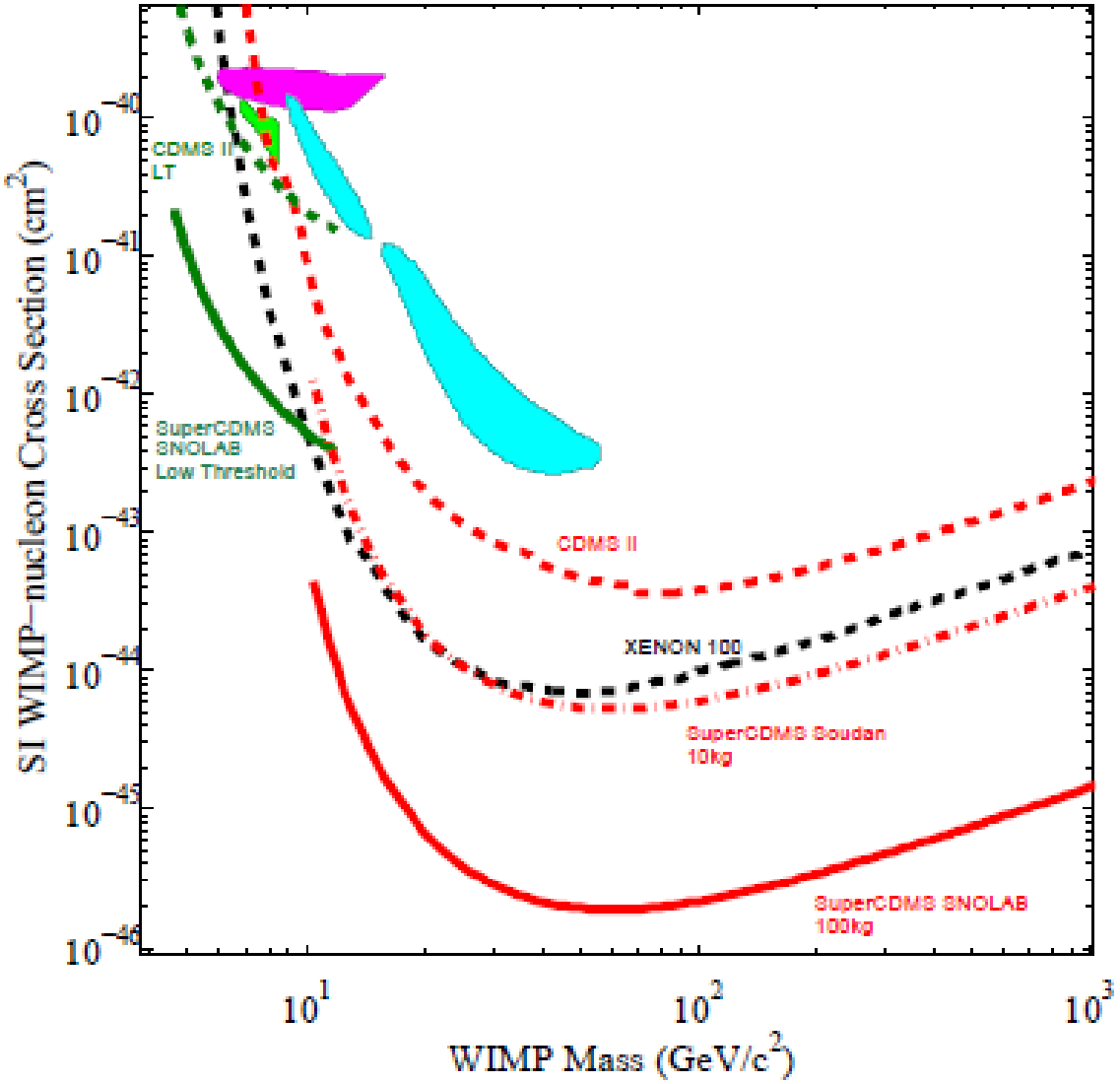
- 15 iZIPs: 5 towers of 3 iZIPs each, total 9kg
- 2 with implanted Pb210 sources to measure surface rejection
- Started taking data in March,
  plan to run for 2 years



SuperCDMS SNOLAB: Coming soon!

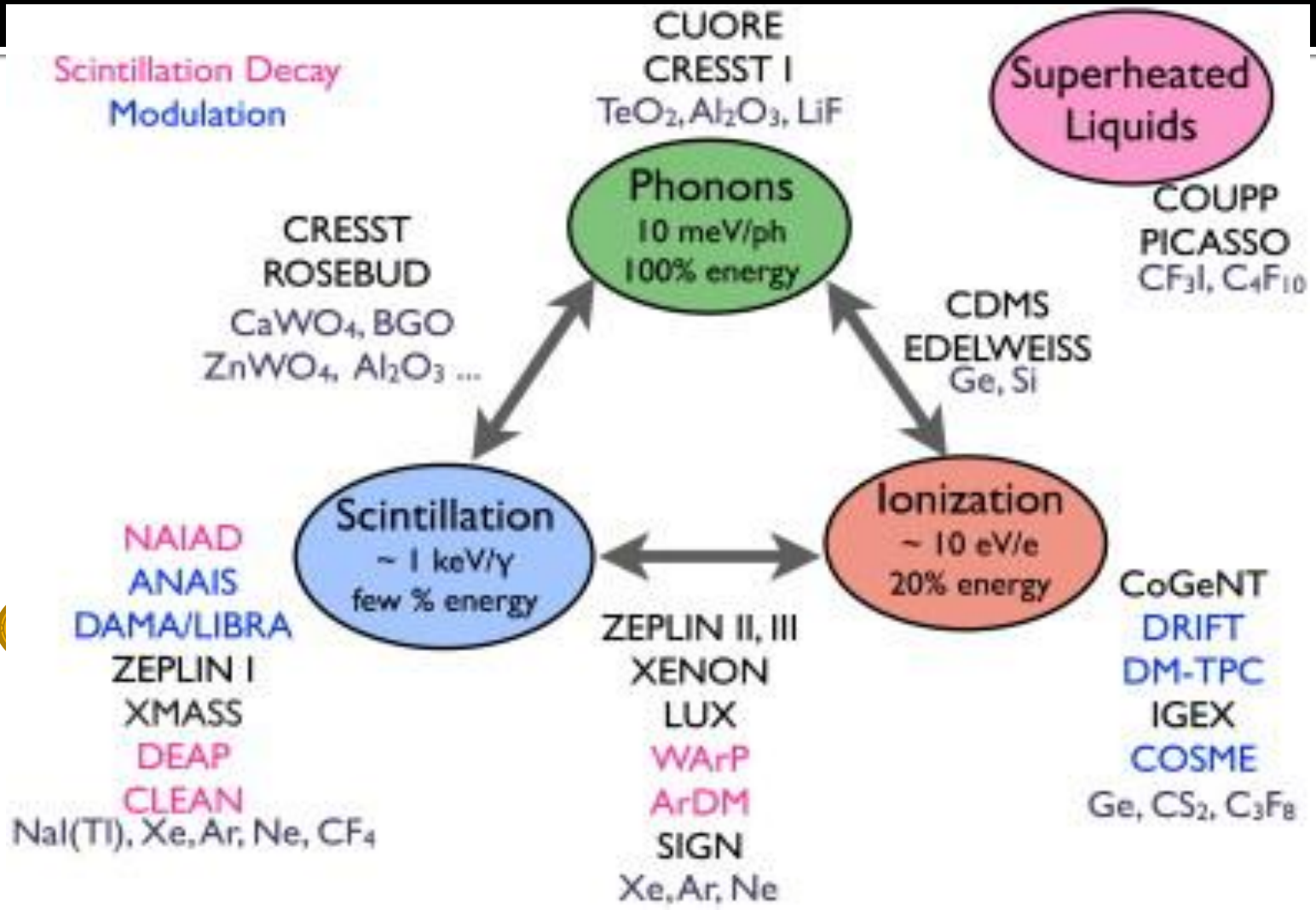
- Planned at least 100 kg total mass (72 iZIPs)
- Also investigating upgrade to a liquid scintillator active neutron veto
- Deeper site + better material screening + iZIPs + neutron veto = 0 background!

SuperCDMS SNOLAB Projected Sensitivity

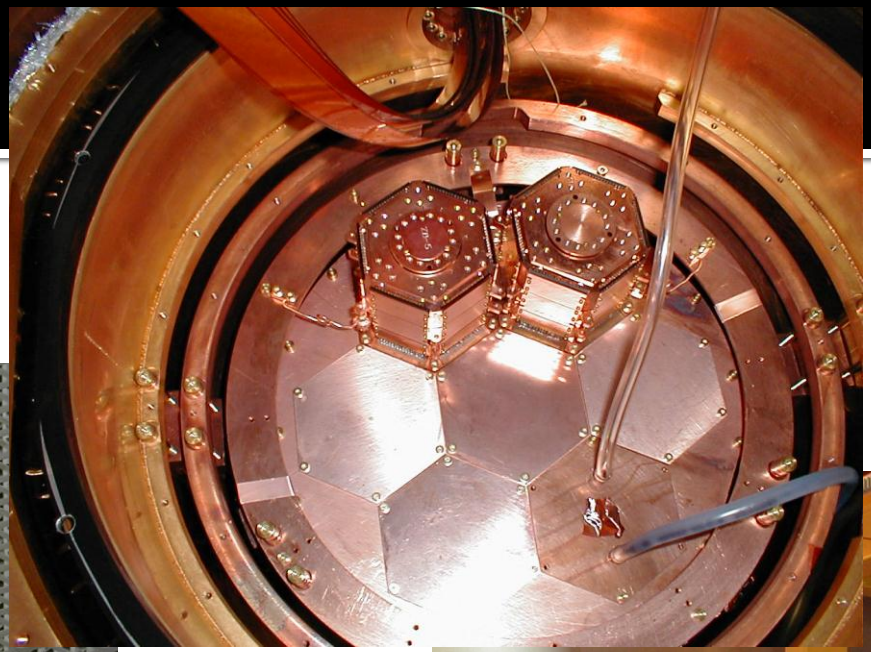


Extra material

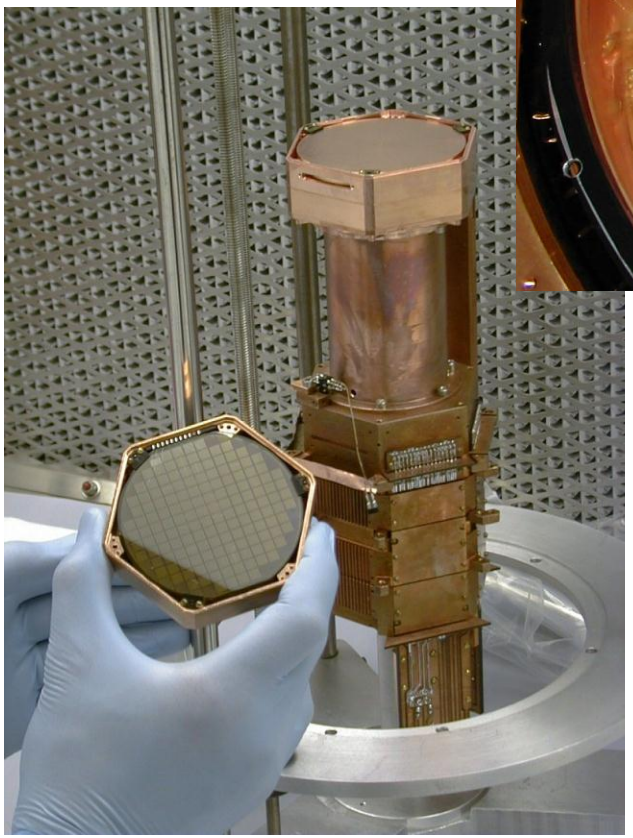
WIMP Technology Distribution



CDMS II Installation



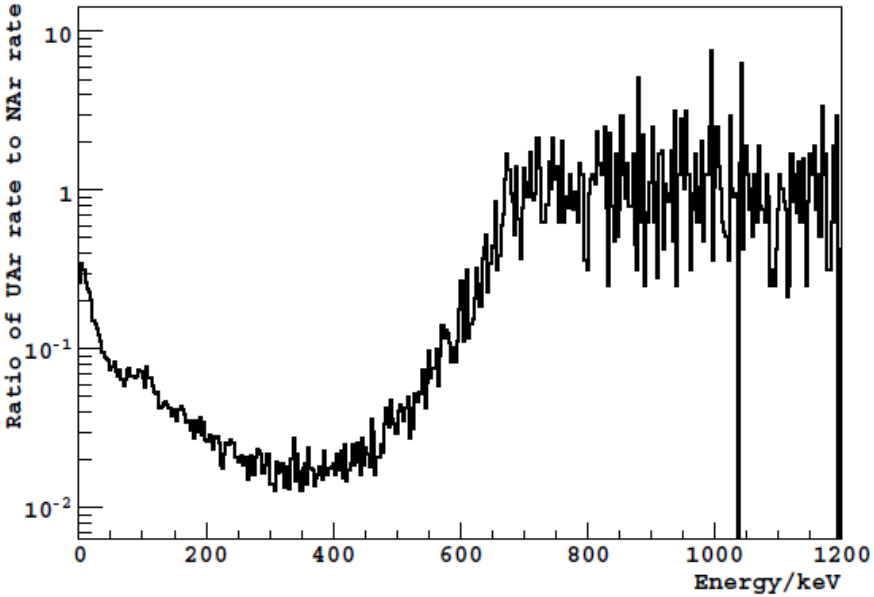
Tower assembly



Shielding assembly

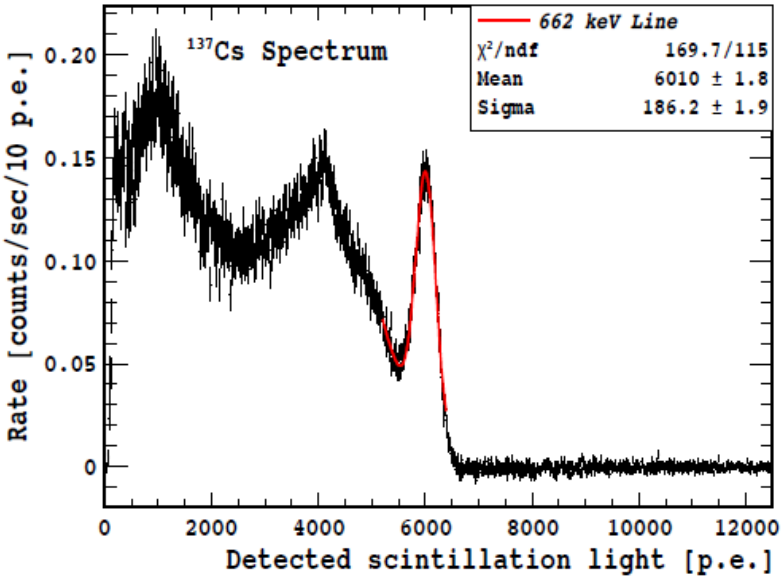
DarkSide

- Use of underground argon reduces ^{39}Ar background by to

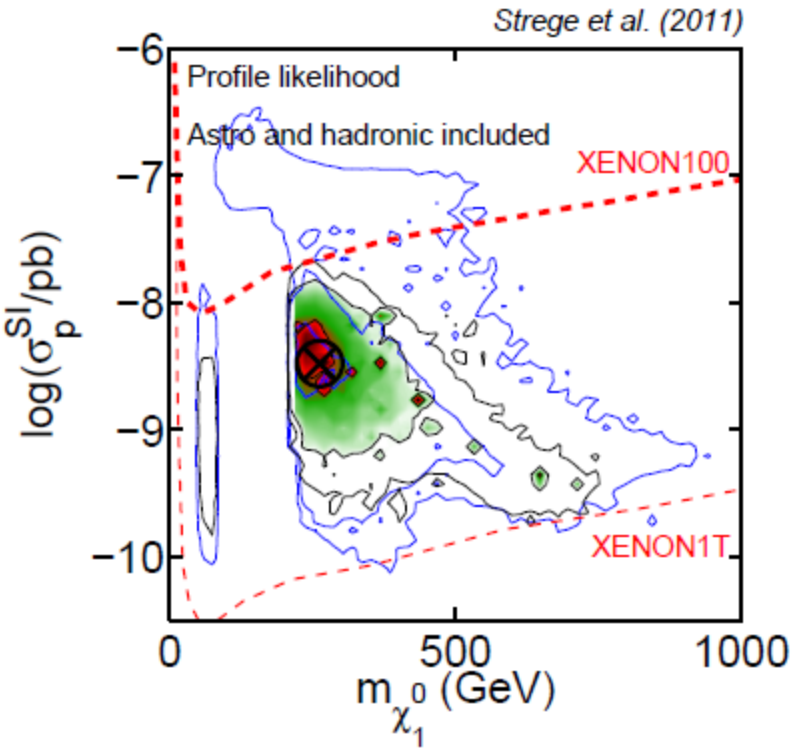


DarkSide

- 10 kg prototype operating at LNGS
- 9 p.e./keV light yield best reported for argon

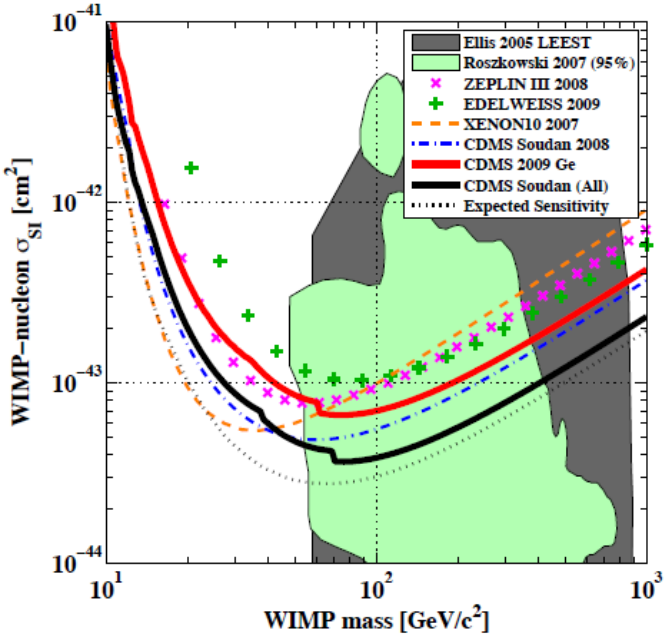


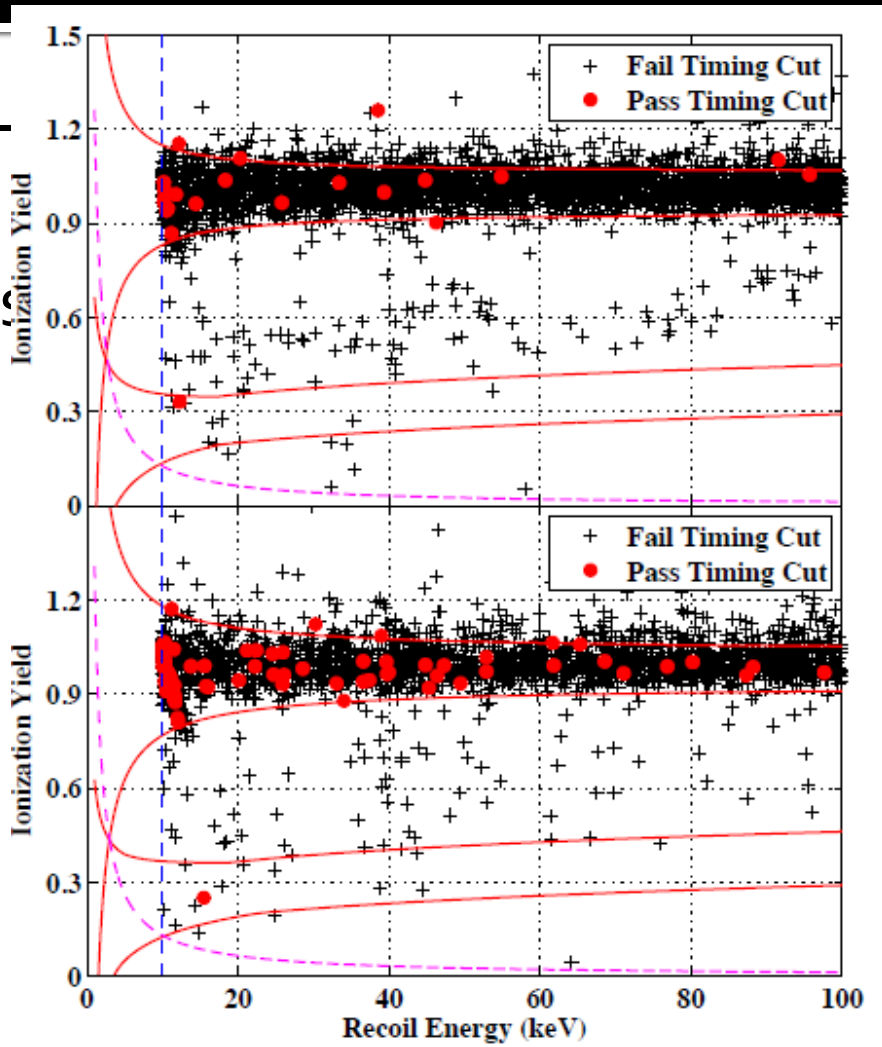
Tevatron exclusion



CDMS II Results - 2009

- Dec 2009: then best spin-independent sensitivity
- Limited by surface events





Surface Events in CDMS II ZIPs

- Limiting background in CDMS II 10 keV threshold analysis was surface events
- Free electrons/holes have some ballistic motion
- Some is lost for events near surface
- Pushes yield down into WIMP search box