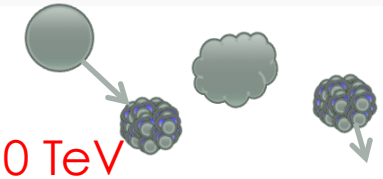
DIRECT DETECTION OF WIMP DARK MATTER

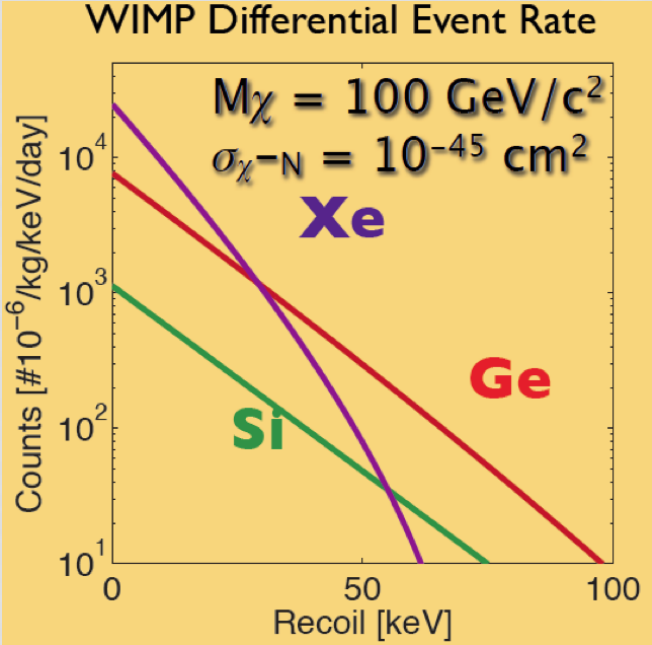
JETER HALL
FERMILAB

DIRECT DETECTION OF DARK MATTER



1 GeV – 10 TeV
$\sigma_{SI} < 10^{-44}$ cm^2
$\sigma_{SD} < 10^{-36}$ cm^2

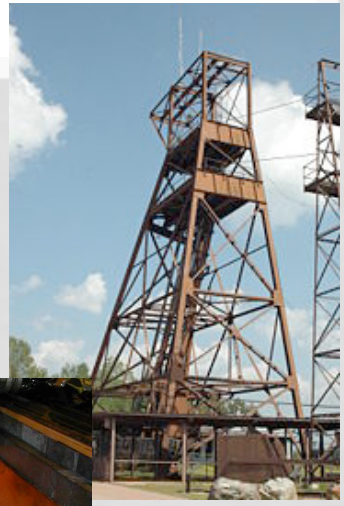
- Searching for WIMP-Nucleus elastic scattering
- In a sea of background radiation
  - Low background frontier
- Understanding and controlling backgrounds is the key to discovery
- Competitive race between different groups and target nuclei



$$\frac{dR}{dE_r} = n\left\langle v\frac{d\sigma(v,A,N,S,?)}{dE_r}\right\rangle = \frac{R_0}{E_0 k}e^{-E_r/E_0 k} \propto \int_{v_{\min}}^{v_{esc}} d^3v\frac{d\sigma}{dE_r}vf(v)$$

RADIOACTIVE BACKGROUNDS

- CDMS as an example
- 2000 m.w.e. (0.5 mile) rock overburden
- Plastic scintillator active veto
- 20 cm lead
- 50 cm polyethylene
- Copper cryostat
- 1 mm silicon endcaps
- Gaps between detectors minimized
- Rigorous cleanliness



SPIN-INDEPENDENT SCALAR INTERACTION

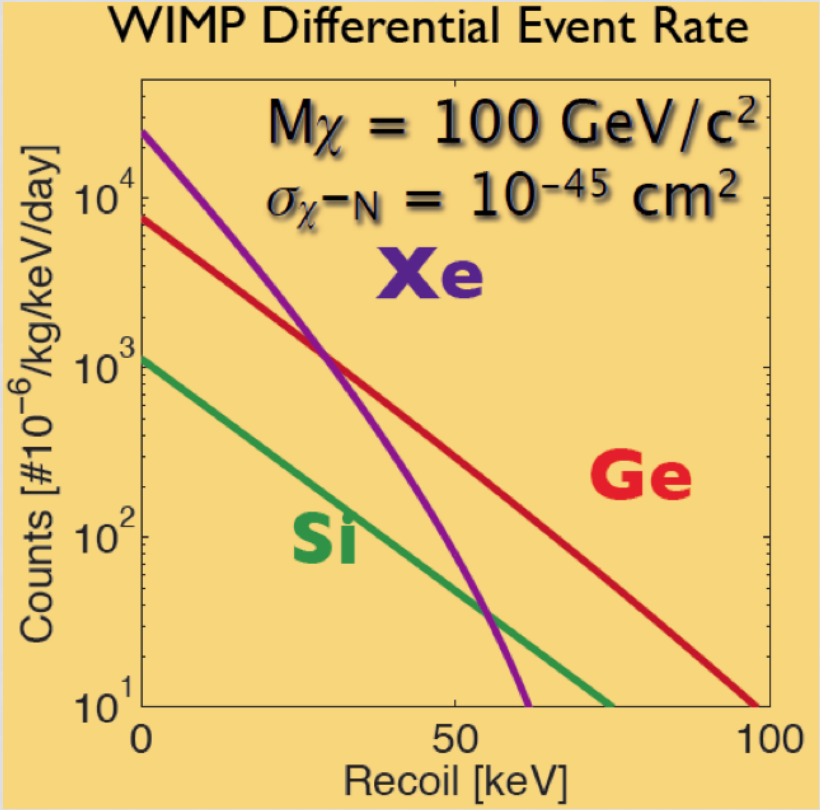
$$\sigma_{SI} \sim [Zf_p + (A-Z)f_n]^2$$

assuming $f_p = f_n$

$$\sigma_{SI} \sim A^2$$

Rare event searches optimizing S/N by removing and controlling backgrounds to the level of ~1 event per year

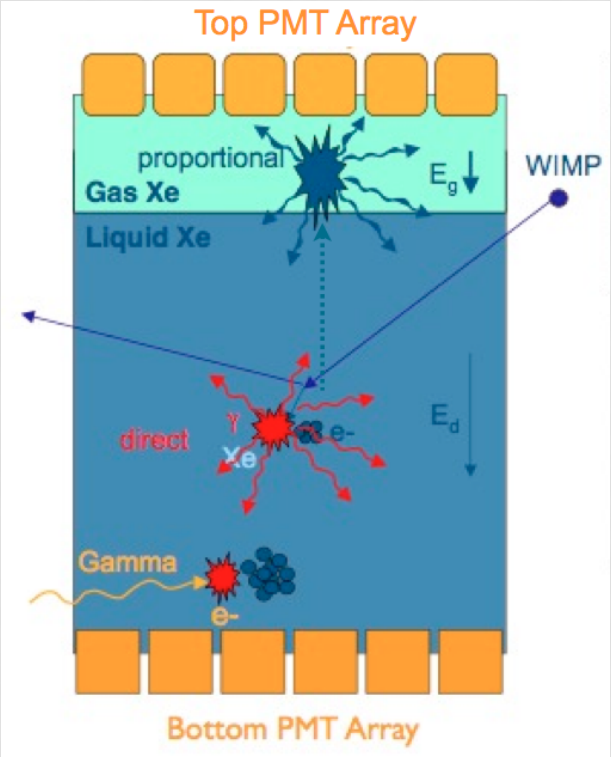
Most sensitive thus far are XENON100 and CDMS-II



LIQUID/GAS TIME PROJECTION CHAMBERS

*Aprile et al., Phys. Rev. Lett **107** 131302 (2011)*

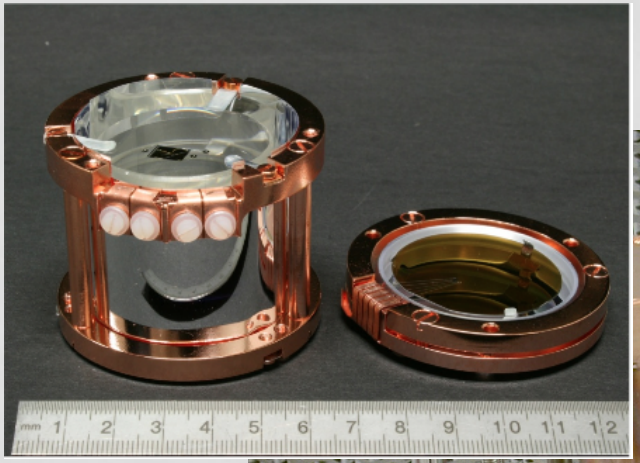
- Two signals
  - S1 – Primary scintillation light
  - S2 – Electroluminescent light measures the drifted electrons
- The S1 and S2 timing and photon distributions measure the interaction point with millimeter precision
- Xenon TPCs use the ratio of S1/S2 separate electron and nuclear recoils
  - XENON100, LUX, PandaX
- Argon TPCs use the S1 photon timing distribution to separate electron and nuclear recoils
  - DarkSide-50

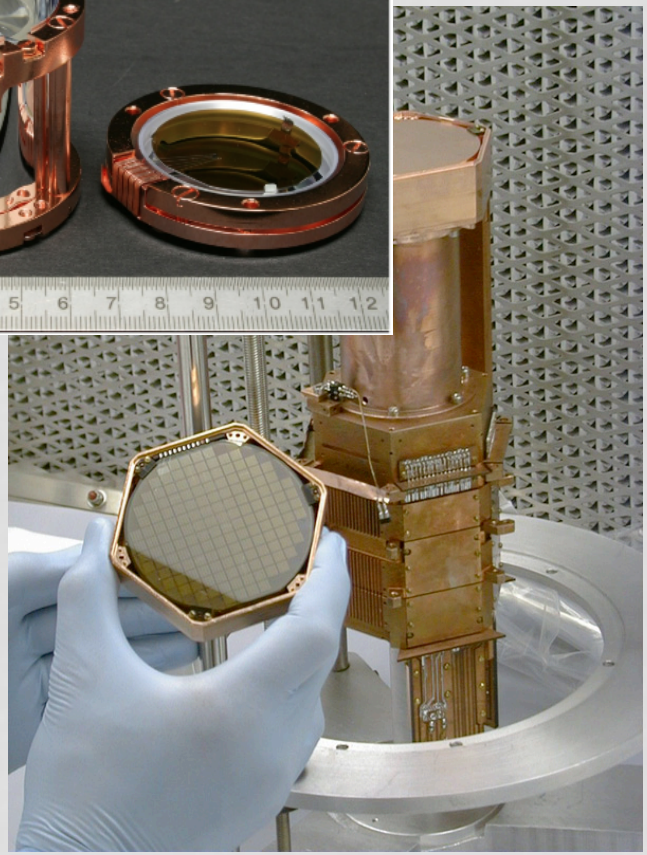


CRYOGENIC DETECTORS

*Ahmed et al., Phys. Rev. D**84** 011102 (2011)*
arXiv: 1109.0702

- Heat from particle interactions is measured
  - Thermal
    - Minimal wiring
  - Athermal/Acoustic
    - Position resolution and particle identification
- CRESST
  - Measure light from their scintillating crystals
- EDELWEISS and CDMS
  - Measure the charge carrier-pairs created in semiconductor
- The additional signal is used to separate bulk nuclear recoils from other radioactive backgrounds





SPIN-INDEPENDENT INTERACTION

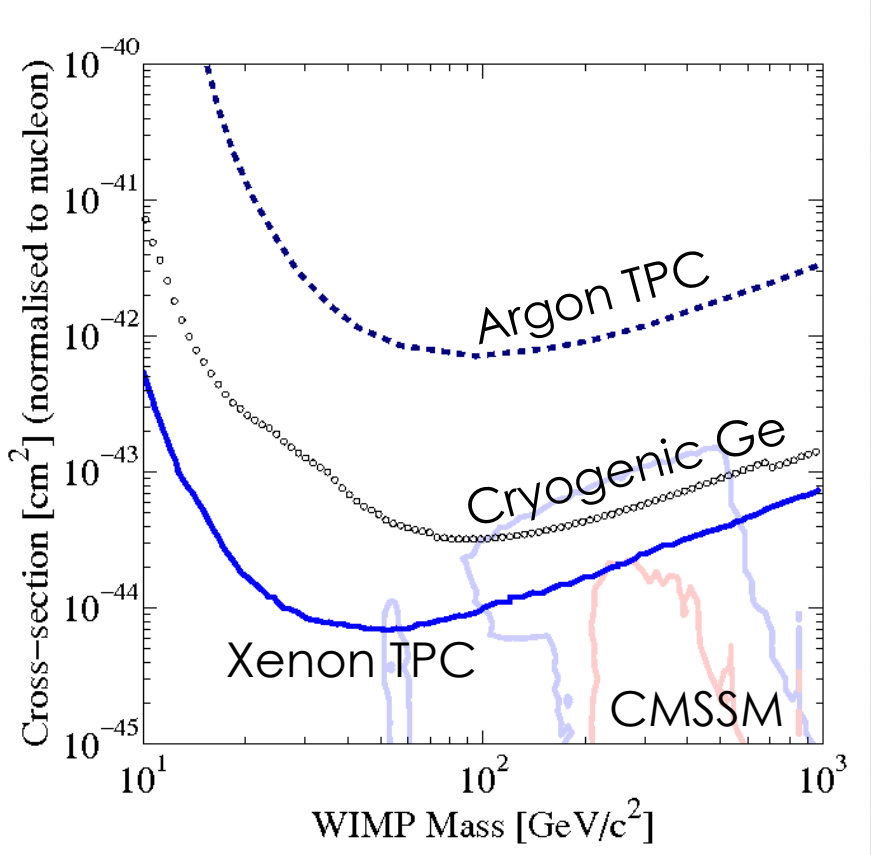
$$\sigma_{SI} \sim [Zf_p + (A-Z)f_n]^2$$

assuming $f_p = f_n$

$$\sigma_{SI} \sim A^2$$

Rare event searches optimizing S/N by removing and controlling backgrounds to the level of ~1 event per year

Most sensitive thus far are XENON100 and CDMS-II



Limits are from WARP, EDELWEISS and CDMS, and XENON100

SPIN DEPENDENT INTERACTION

Nucleus	Z	Odd Nucleon	J	$\langle S_p \rangle$	$\langle S_n \rangle$	C_A^p/C_p	C_A^n/C_n
^{19}F	9	p	1/2	0.477	-0.004	9.10×10^{-1}	6.40×10^{-5}
^{23}Na	11	p	3/2	0.248	0.020	1.37×10^{-1}	8.89×10^{-4}
^{27}Al	13	p	5/2	-0.343	0.030	2.20×10^{-1}	1.68×10^{-3}
^{29}Si	14	n	1/2	-0.002	0.130	1.60×10^{-5}	6.76×10^{-2}
^{35}Cl	17	p	3/2	-0.083	0.004	1.53×10^{-2}	3.56×10^{-5}
^{39}K	19	p	3/2	-0.180	0.050	7.20×10^{-2}	5.56×10^{-3}
^{73}Ge	32	n	9/2	0.030	0.378	1.47×10^{-3}	2.33×10^{-1}
^{93}Nb	41	p	9/2	0.460	0.080	3.45×10^{-1}	1.04×10^{-2}
^{125}Te	52	n	1/2	0.001	0.287	4.00×10^{-6}	3.29×10^{-1}
^{127}I	53	p	5/2	0.309	0.075	1.78×10^{-1}	1.05×10^{-2}
^{129}Xe	54	n	1/2	0.028	0.359	3.14×10^{-3}	5.16×10^{-1}
^{131}Xe	54	n	3/2	-0.009	-0.227	1.80×10^{-4}	1.15×10^{-1}

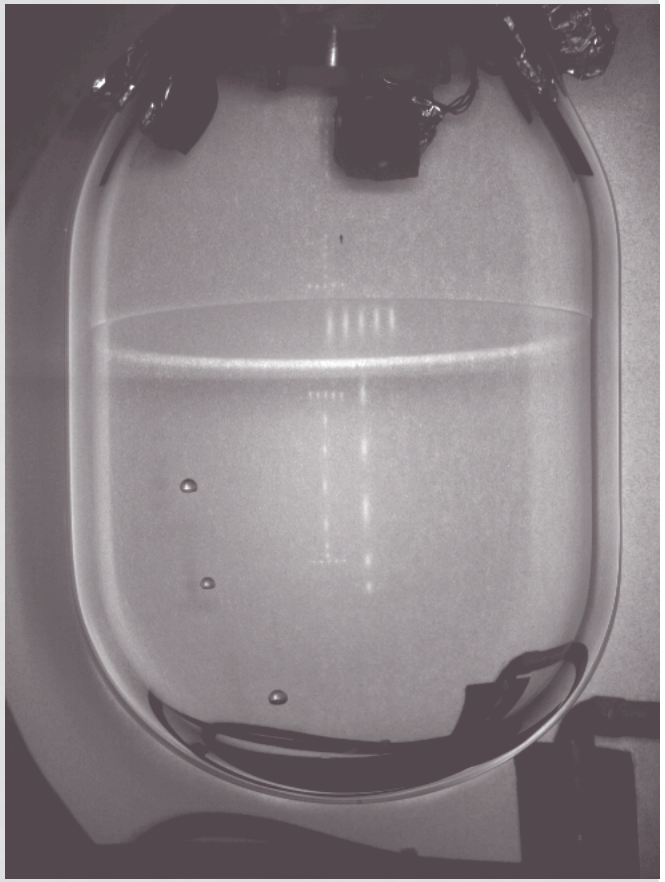
*Tovey et al., Phys. Lett. B**488** 17 (2000)*

$$\sigma_{SD} \sim [a_p \langle S_p \rangle + a_n \langle S_n \rangle]^2 \frac{J+1}{J}$$

SUPERHEATED LIQUID DETECTORS

- At low degrees of superheat, bubble chambers are only sensitive to nuclear interactions
- CF_3I bubble chambers
  - COUPP
- C_4F_{10} droplet detectors
  - PICASSO

Archambault et al. arXic1202.1240

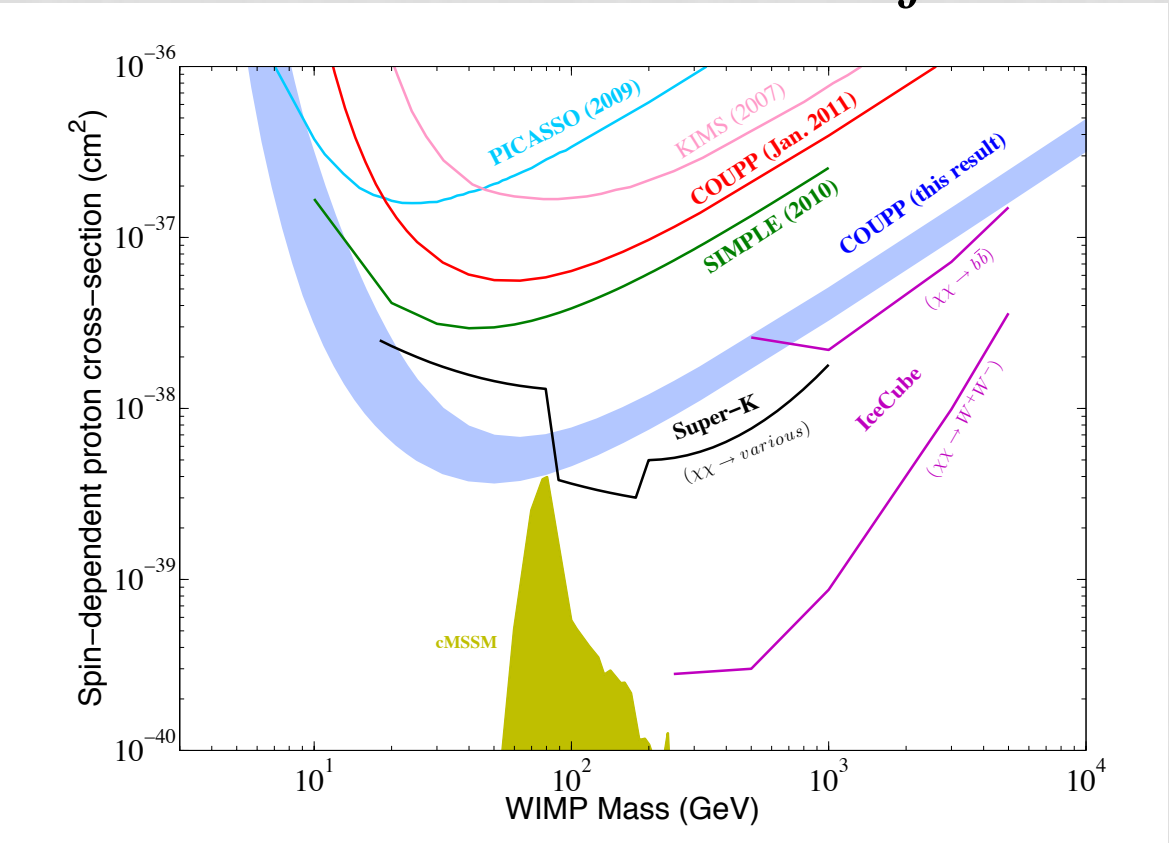


Behnke et al., Phys. Rev. Lett. ***106*** *021303 (2011)*

SPIN DEPENDENT INTERACTION

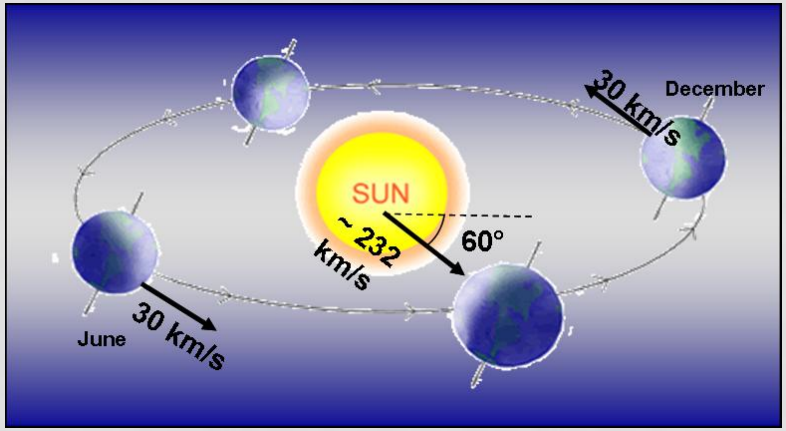
- COUPP and SIMPLE leading Flourine based detectors for WIMP-proton coupling
- CDMS and XENON leading the search for WIMP-neutron couplings
- Searches for neutrinos from annihilation in the Sun competitive
- Preliminary CDF and CMS results also relevant

$$\sigma_{SD} \sim [a_p \langle S_p \rangle + a_n \langle S_n \rangle]^2 \frac{J+1}{J}$$



ANNUAL MODULATION SEARCHES

- The modulation in the laboratory speed modulates the WIMP recoil spectrum
- Distinctive time dependence can distinguish time independent backgrounds

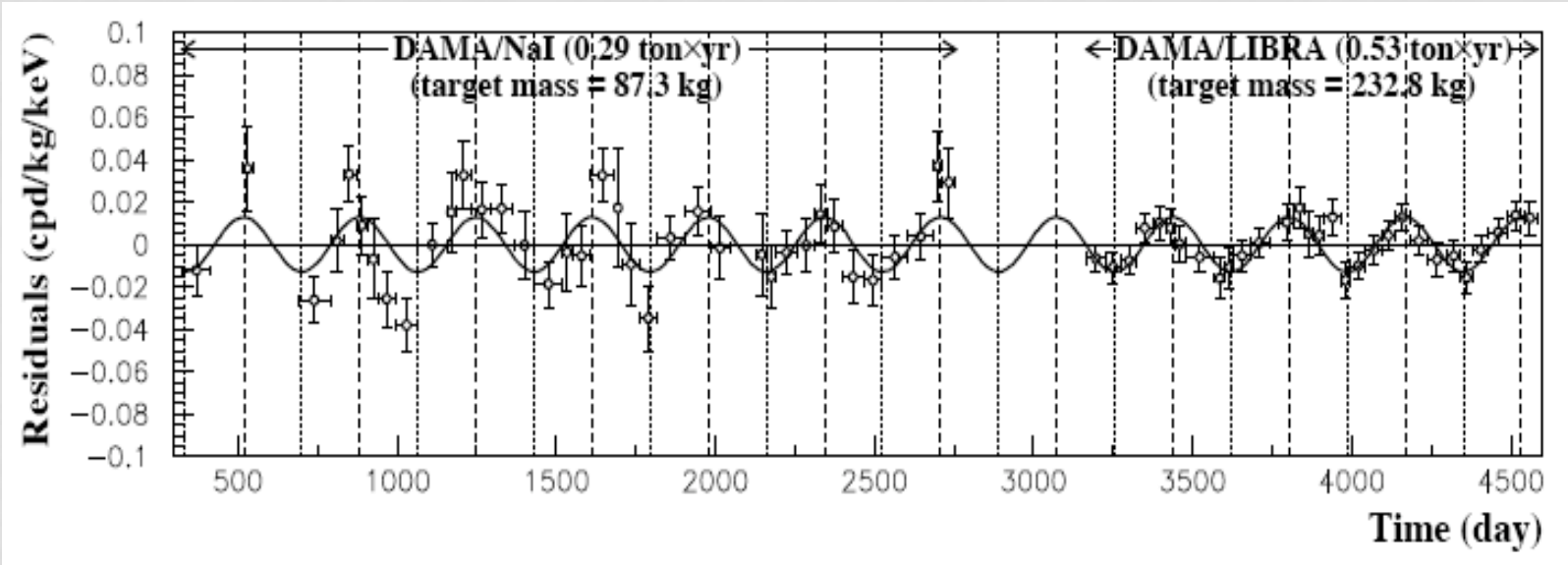


$$\frac{dR}{dE_r} \propto \int_{v_{\min}}^{v_{esc}} d^3v \frac{d\sigma}{dE_r} v f(v)$$

SCINTILLATING CRYSTAL ARRAYS

- DAMA and KIMS have run arrays of 250 kg NaI and 100 kg CsI respectively
- DAMA has run for over a decade
- DM-Ice now looking at deploying ~250 kg NaI in the Southern Hemisphere to check weather related effects

ANNUAL MODULATION SEARCHES

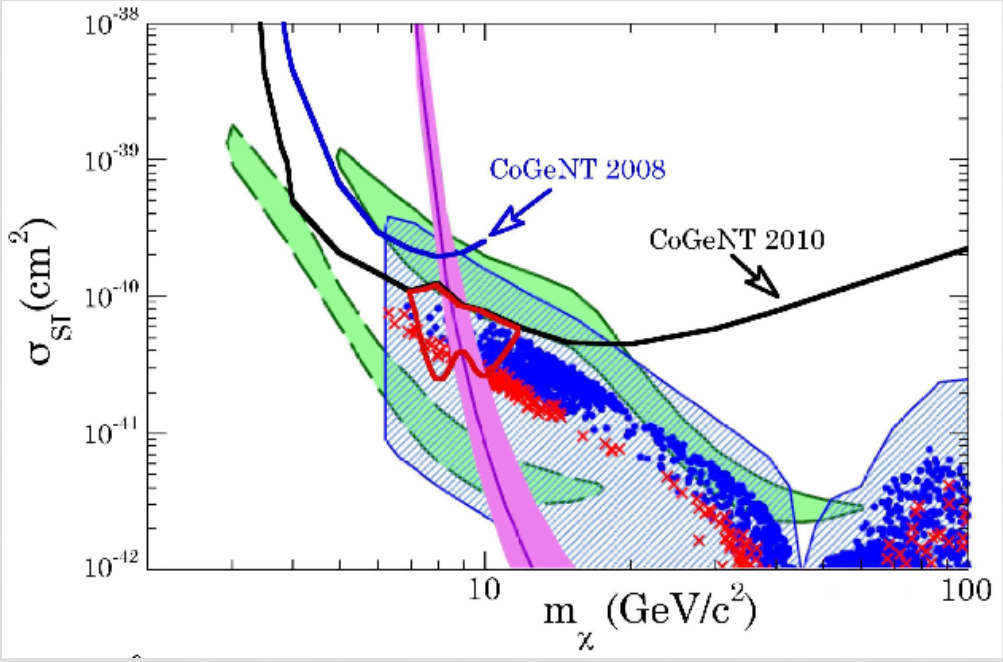


*Bernabei et al., Eur. Phys. J. C **56** 333 (2008)*

- DAMA has detected an annual modulation with high statistical significance (8 sigma)
- In 5 years, no one has come up with a standard model explination
- The phase of the modulation is consistent with that expected for dark matter
- However, most of the parameter space is ruled out by the null results of other searches, focus has been on low mass region where systematic errors are significant

LOW MASS (<10 GEV) WIMPS

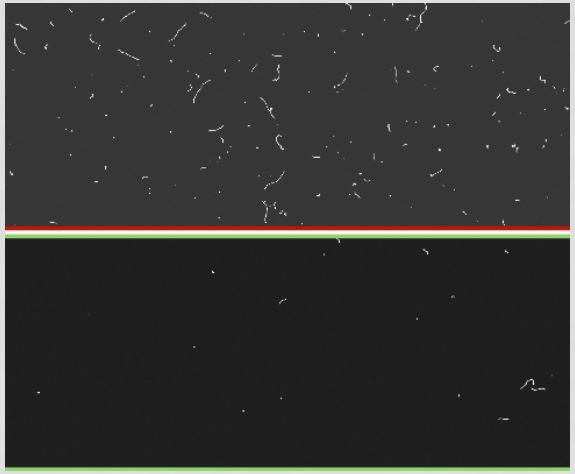
- Low mass WIMP region has been motivated by DAMA, CoGeNT, and other astrophysical observations (Hooper arXiv:1201.1303)
- A number of analyses have been initiated to search for WIMPs lighter than 10 GeV
- Detection is challenging when the WIMP is lighter than the target nuclei



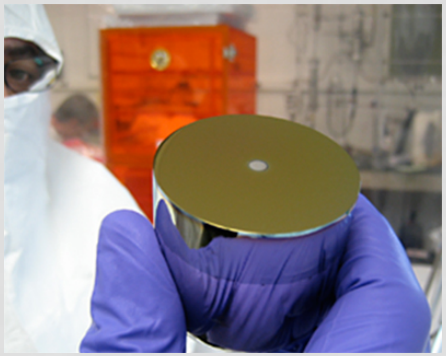
Aalseth et al., PRL 106, 131301 (2011)

SEMICONDUCTOR IONIZATION DETECTORS

- First WIMP dark matter limits
  - Ahlen et al., PLB 195 (1987)
- Competitive in searches for <10 GeV WIMPs
- CoGeNT
  - Point contact p-type germanium diode
- DAMIC
  - Search with thick silicon CCD devices
- Measurement of single ionization signal leads to higher backgrounds than dual-signal detectors



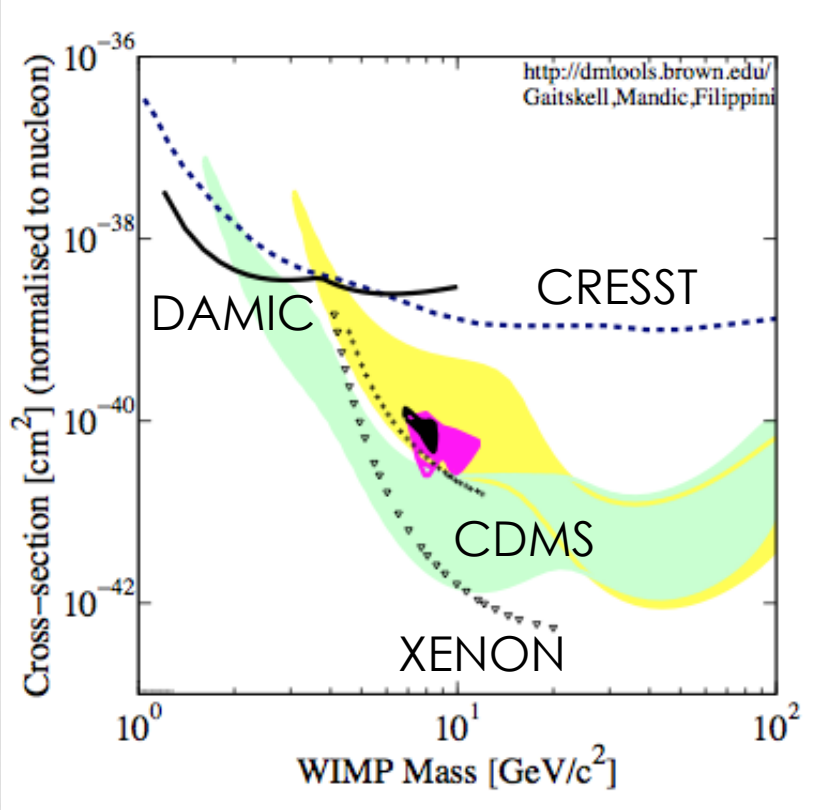
Barreto et al., arXiv: 1105.5191, to appear in PLB



Aalseth et al., Phys. Rev. Lett. ***106*** *131301 (2011)*

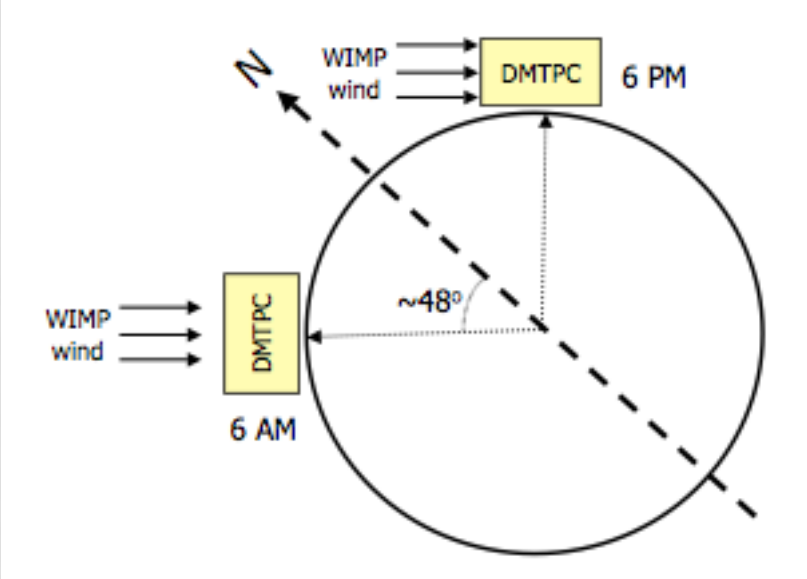
LOW MASS (<10 GEV) WIMPS

- Low mass WIMP region has been motivated by DAMA and other astrophysical observations (Hooper arXiv:1201.1303)
- A number of analyses have been initiated to search for WIMPs lighter than 10 GeV
- Detection is challenging when the WIMP is lighter than the target nuclei
- Lowering the threshold is also important for probing more of the expected WIMP velocity space (Fox et al. Phys.Rev.D83:034007,2011)
- Collider constraints also relevant for these <10 GeV WIMPs



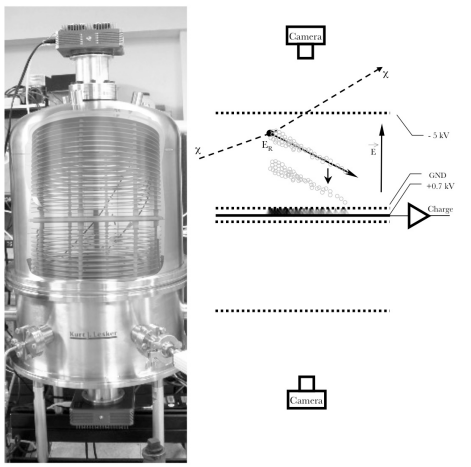
DIRECTIONAL DETECTORS

- The Sun's motion in the halo creates a preferential direction for the WIMP induced nuclear recoils
- Additionally this signal should modulate daily as the Earth rotates



DIRECTIONAL DETECTORS

- Low pressure gas time projection chambers are used
- DMTPC
  - CF_4
  - CCD readout
  - Battat et al. PLB 695 (2011)
- DRIFT
  - CS_2 , CF_4 mixture
  - Daw et al., arXiv:1110.0222

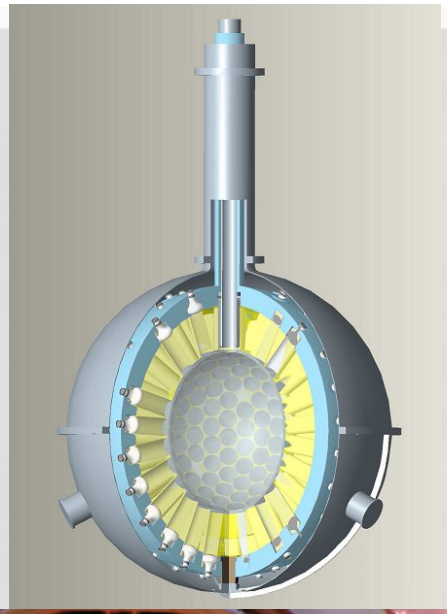


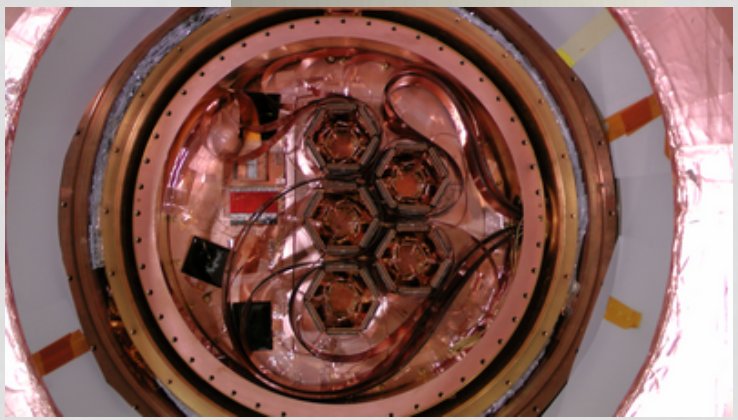
DIRECT DETECTION OF WIMP DARK MATTER

- Why so many detectors?
- I have tried to break up the usual list of all direct detection of WIMP experiments
- Many of the detectors are designed to approach the problem from different physics directions (WIMP couplings, annual modulation, directional detection, low mass)
- Multiple targets (detections) is essential to identify a dark matter signal (ie DAMA)

FUTURE DETECTORS

- Single phase Argon and Xenon detectors are starting to turn on and produce results
  - Single phase trades degraded position resolution for reduced detector complexity
  - DEAP/CLEAN plan on commissioning two large detectors in the coming years
  - XMASS has started to report results
- Xenon TPCs are expected to make progress
  - XENON100 has reduced intrinsic contamination
  - LUX is moving underground
- Cryogenic detectors are scaling up
  - CDMS has deployed an array with ~4X sensitivity





CONCLUSIONS

- There are many dark matter technologies
- The physics of the dark sector could be complicated, so multiple target nuclei and search strategies are employed
- Sensitivities are rapidly increasing, in low background searches, but also in lowering energy thresholds and developing direction sensitive detectors
- No projections, but spin-independent cross-sections at the level of 10^{-46} cm^2 are the immediate target

UNDERGROUND LABORATORIES