Lowering the Threshold at DAMA

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Identifying and Characterizing Dark Matter via Multiple Probes

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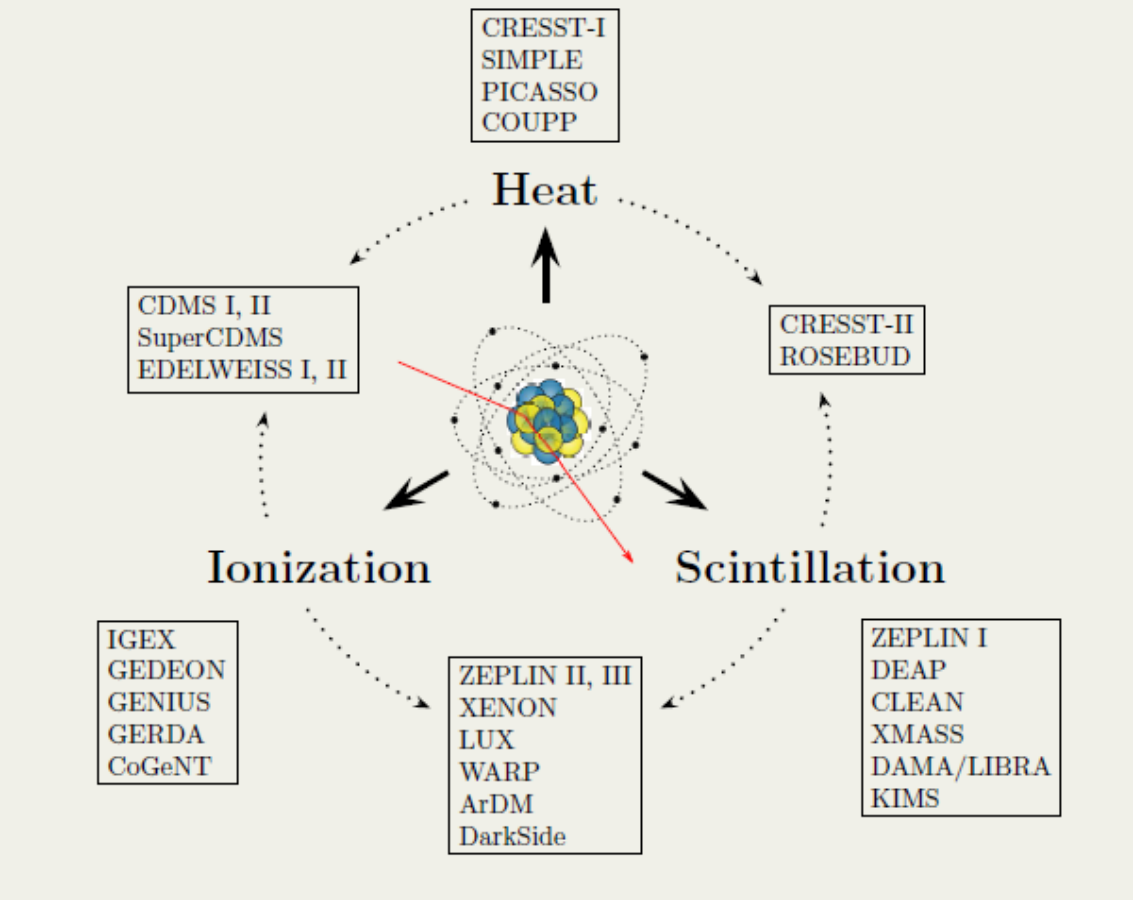
Work with Chris Savage and Pearl Sandick

Outline

- Review of Direct Detection experiments in low mass regime
  - Reverse Time Order
  - Including Future Outlook
- Current DAMA
  - Improved Binning
- DAMA Upgrade
  - Lower Threshold
- Conclusions

Current Direct Detection Experiments



Direct Detection Experiments

$$\frac{dR}{dE_R} = N_T \frac{\rho_{DM}}{m_{DM}} \int_{|\vec{v}|>v_{\min}} d^3v \, v f(\vec{v}, \vec{v_e}) \frac{d\sigma}{dE_R}$$

$$v_{\min} = \sqrt{E_R m_N / 2\mu^2}.$$ Defined by kinematics

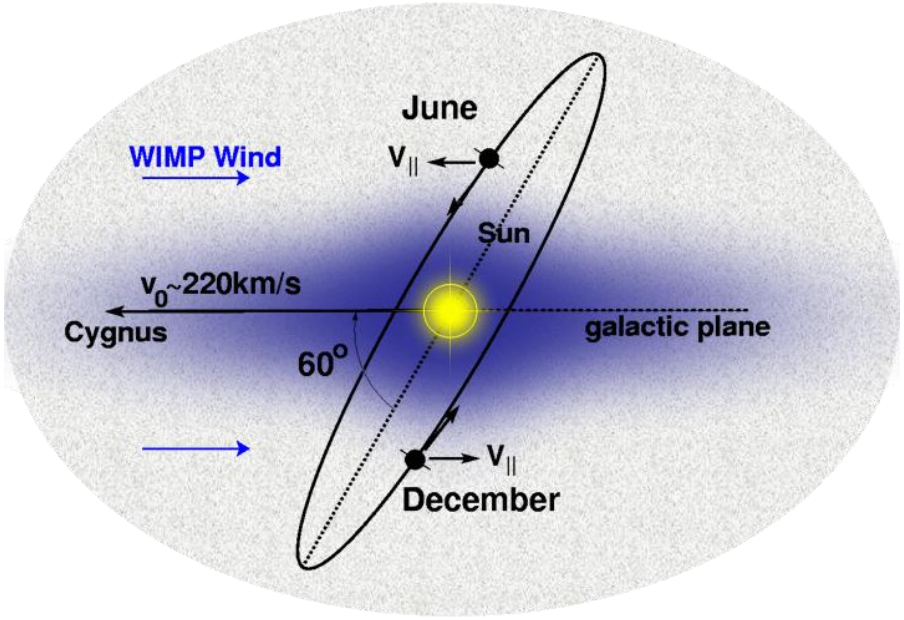
$$\frac{d\sigma}{dE_R} = \frac{m_N}{2v^2} \frac{\sigma_n}{\mu_n^2} \frac{[f_p Z + f_n (A-Z)]^2}{f_n^2} F^2(q)$$

Spin-Independent
Elastic Scattering

Signal in a detector needs inputs from
astrophysics, particle physics, and nuclear physics

Dark Matter Should Have Annual Modulation

$$\frac{dR}{dE_R} = N_T \frac{\rho_{DM}}{m_{DM}} \int_{|\vec{v}|>v_{\min}} d^3v \, v f(\vec{v}, \vec{v_e}) \frac{d\sigma}{dE_R}$$

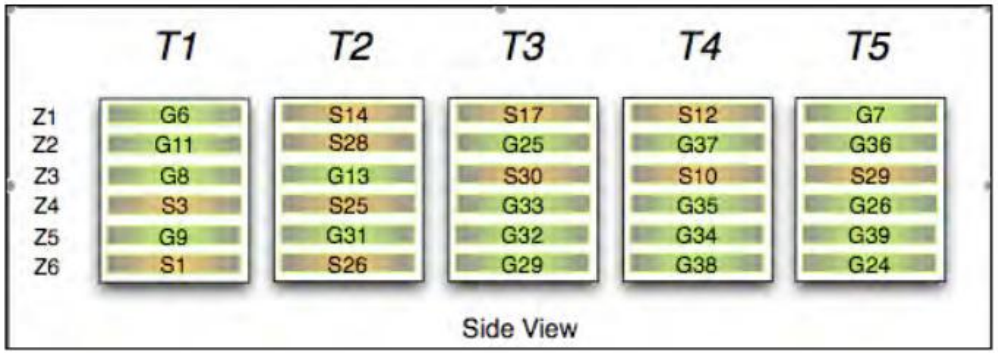


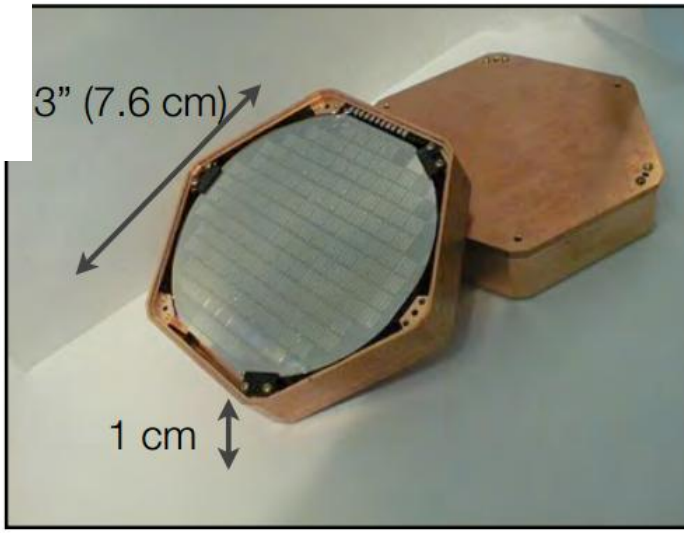
http://www.hep.shef.ac.uk/research/dm/intro.php

CDMS-II Experiment

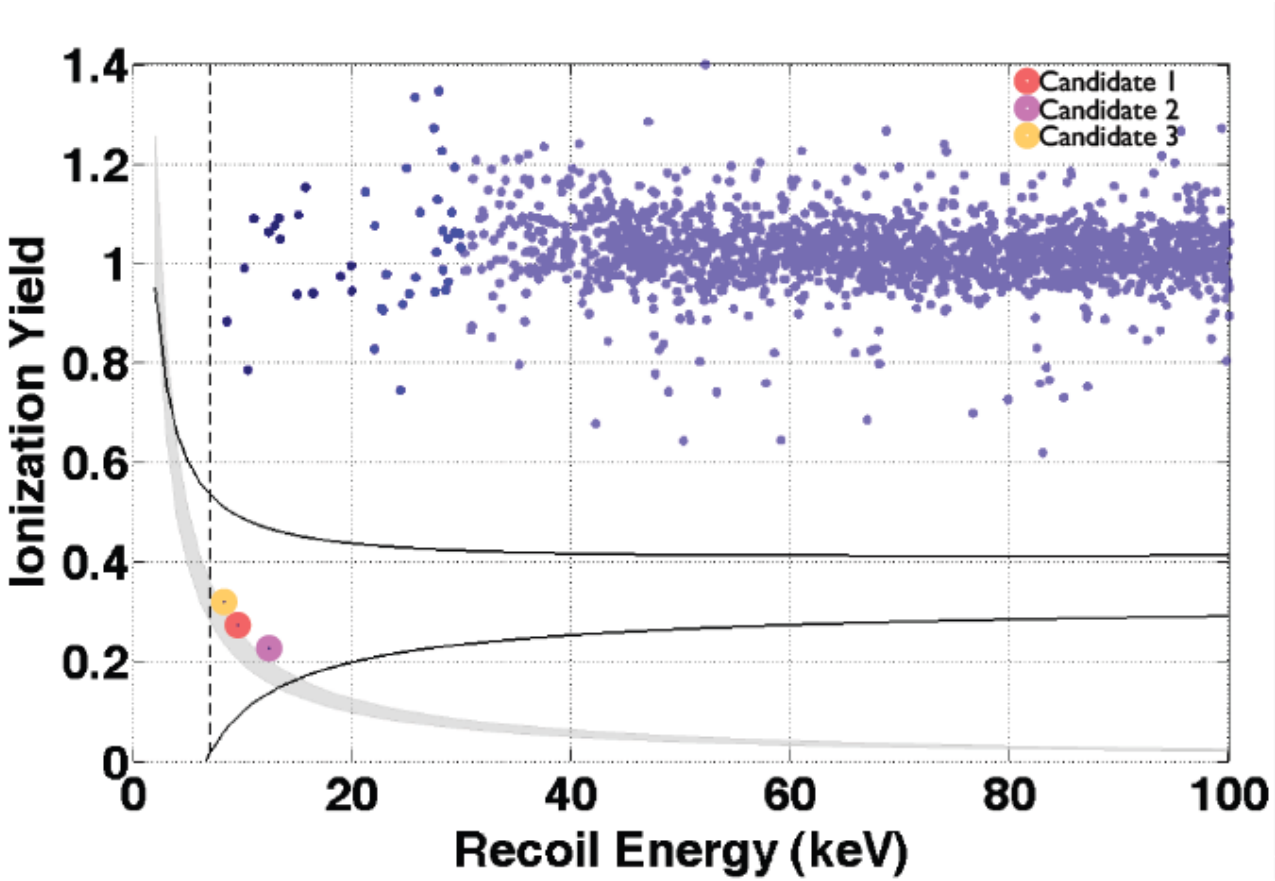
ZIP Detectors

- **Z**-sensitive **I**onization and **P**honon mediated
- 230 g Ge or 106 g Si crystals
  (1 cm thick, 7.5 cm diameter)
- Photolithographically patterned to collect athermal phonons and ionization signals
- Direct xy-position imaging
- Surface (z) event rejection from pulse shapes and timing
- 30 detectors stacked into
  5 towers of 6 detectors





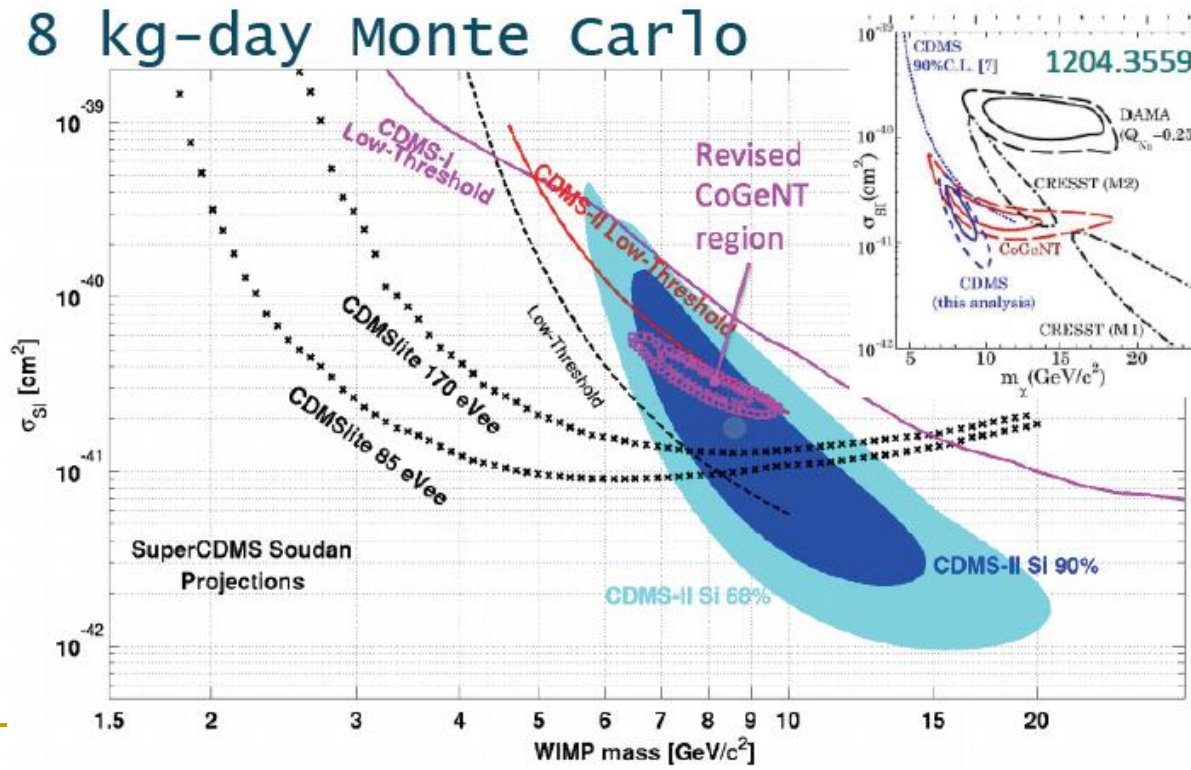
CDMS-II Si: 3 Events



8 Si detectors with 140 kg-day exposure (arXiv: 1304.4279)

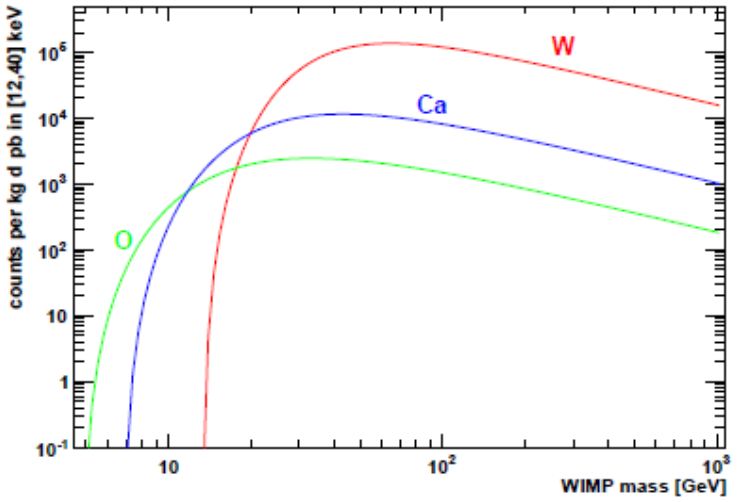
CDMS: Future Outlook

- SuperCDMS uses all Ge detectors
  - Possibly Si?
- CDMSlite (Ge)
  - Possibly Si?

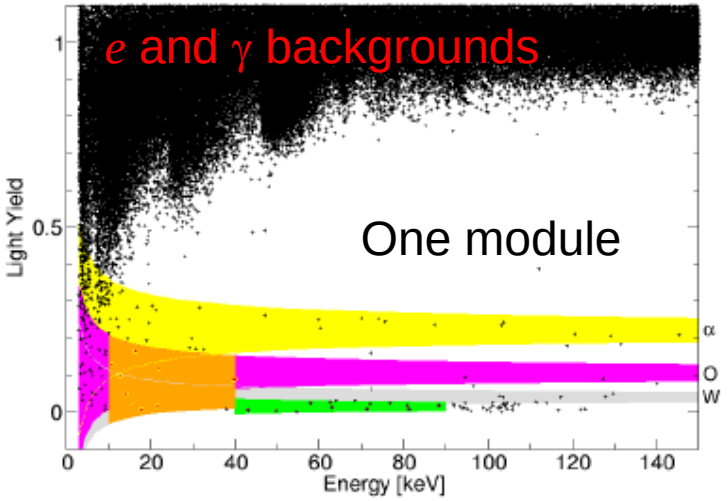


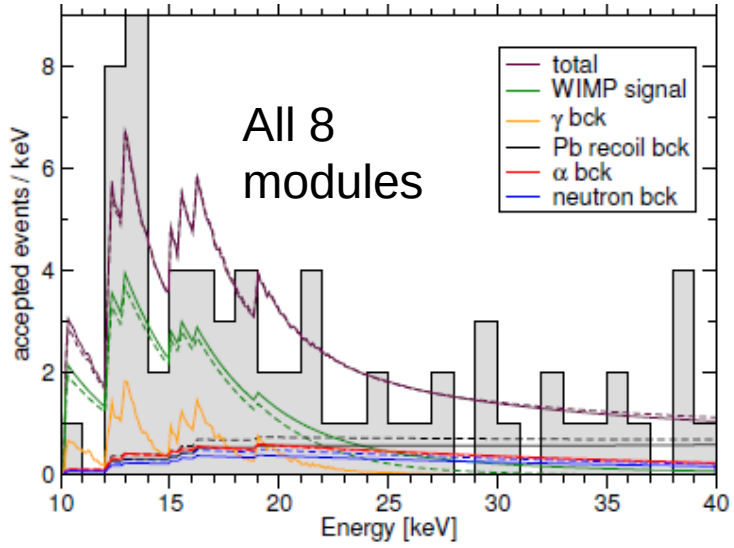
CRESST II ($CaWO_4$)

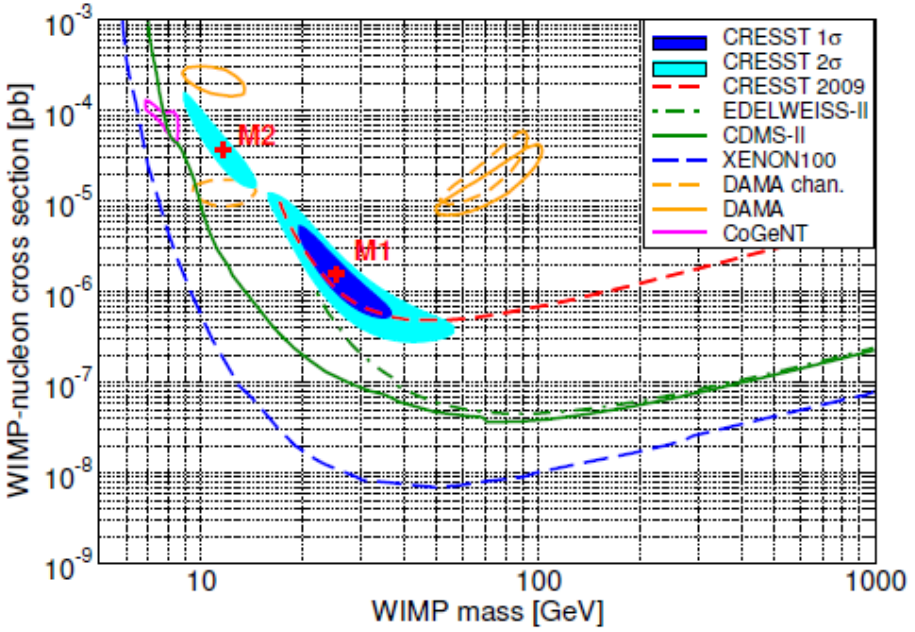
- Located in Gran Sasso National Laboratory (Italy)
- Use both scintillation and phonon signals to reject backgrounds
- Detector “modules have a cylindrical shape (40mm in diameter and height) and weigh about 300 g
- The current experimental setup can accommodate up to 33 of these crystals, constituting a maximum target mass of about 10 kg.
- First data release was for 730 kg days (2011)



CRESST sees a signal not consistent with known backgrounds





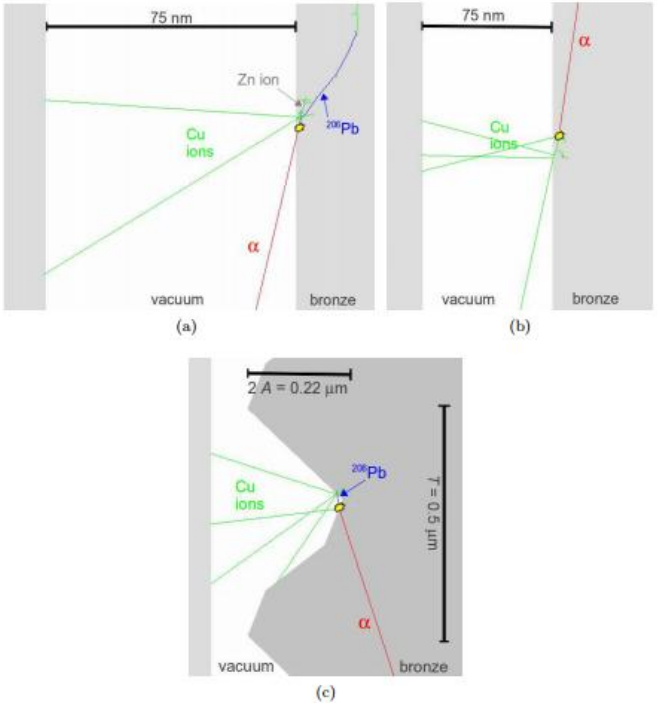


M1 rejects background only hypothesis at 4.7 σ (29 ± 8 events)

M2 rejects background only hypothesis at 4.3 σ (24 ± 8 events)

CRESST II: Future Outlook

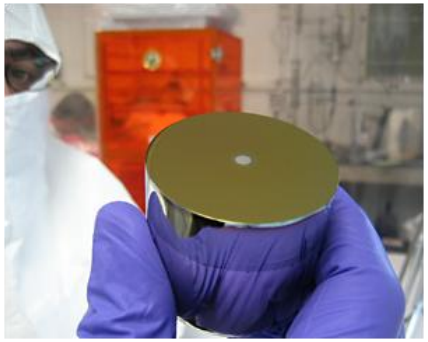
- Relatively Large Backgrounds in Detector
  - Non Scintillating Clamps
  - Rough Surface Backgrounds
- Stay Tuned



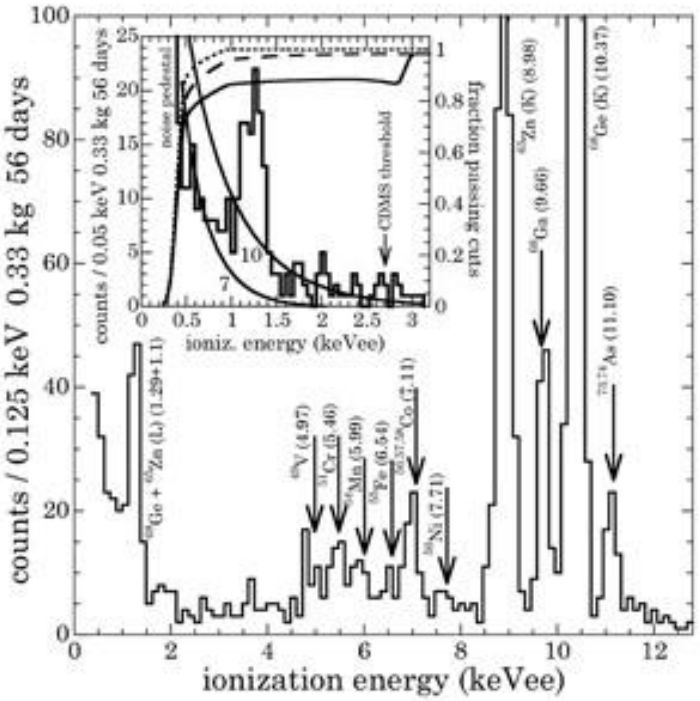
arXiv:1203.1576

The CoGeNT (Ge) detector

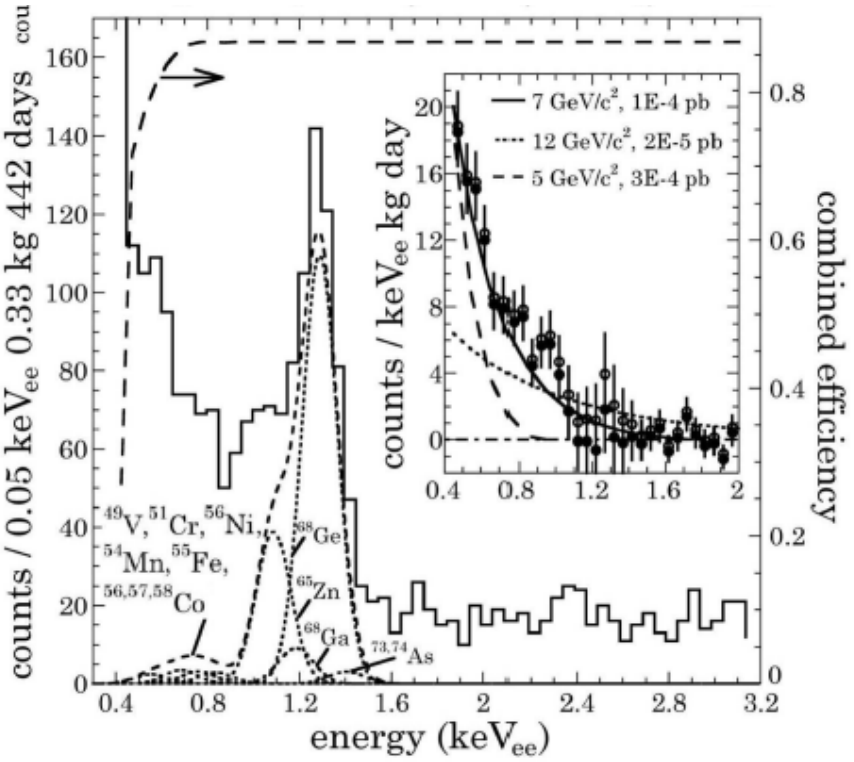
- Located in the Soudan Mine in Minnesota
- Low background and low energy threshold
- Uses ionization signal only with 0.33 kg fiducial mass
- Found an excess of events at low energy in first 56 day run (2010)
- Released 15 months of data (2011)
- Data is available by request



CoGeNT



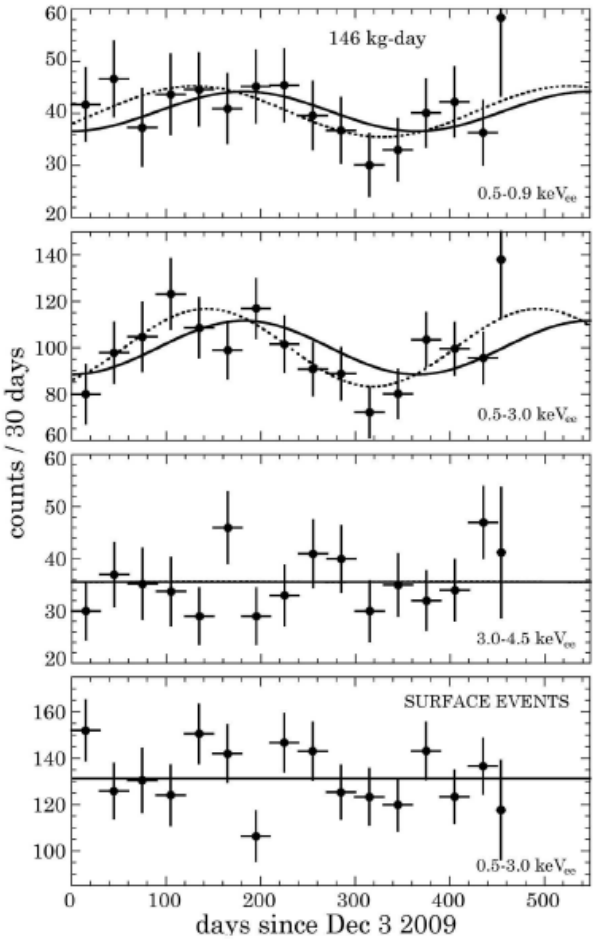
arXiv:1002.4703



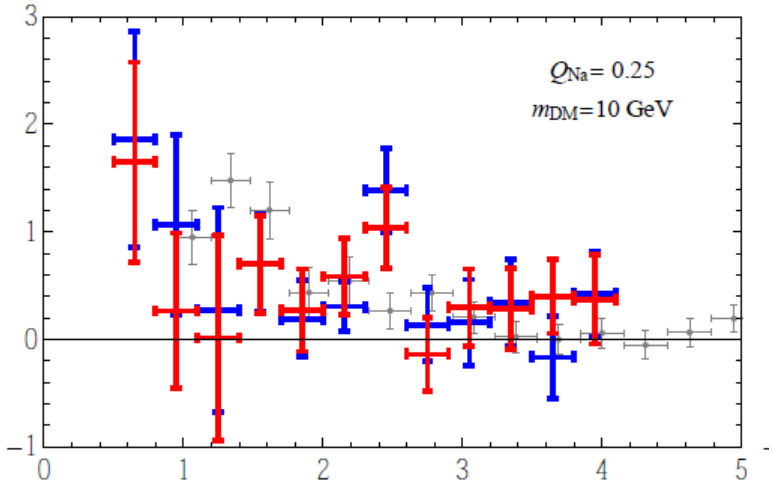
arXiv:1106.0650

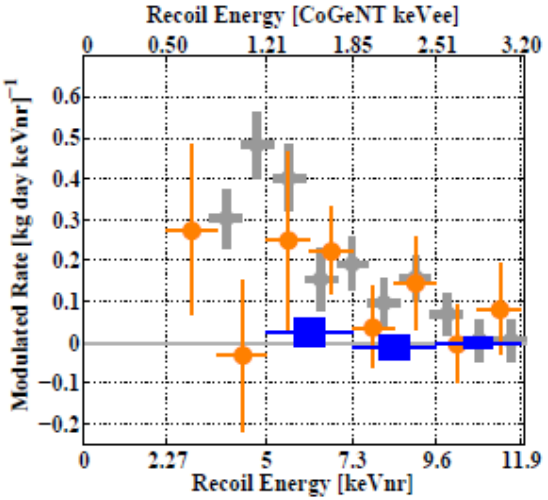
CoGeNT Modulation

arXiv:1110.5338



arXiv:1106.0650





arXiv:1203.1309

CoGeNT: Future Outlook

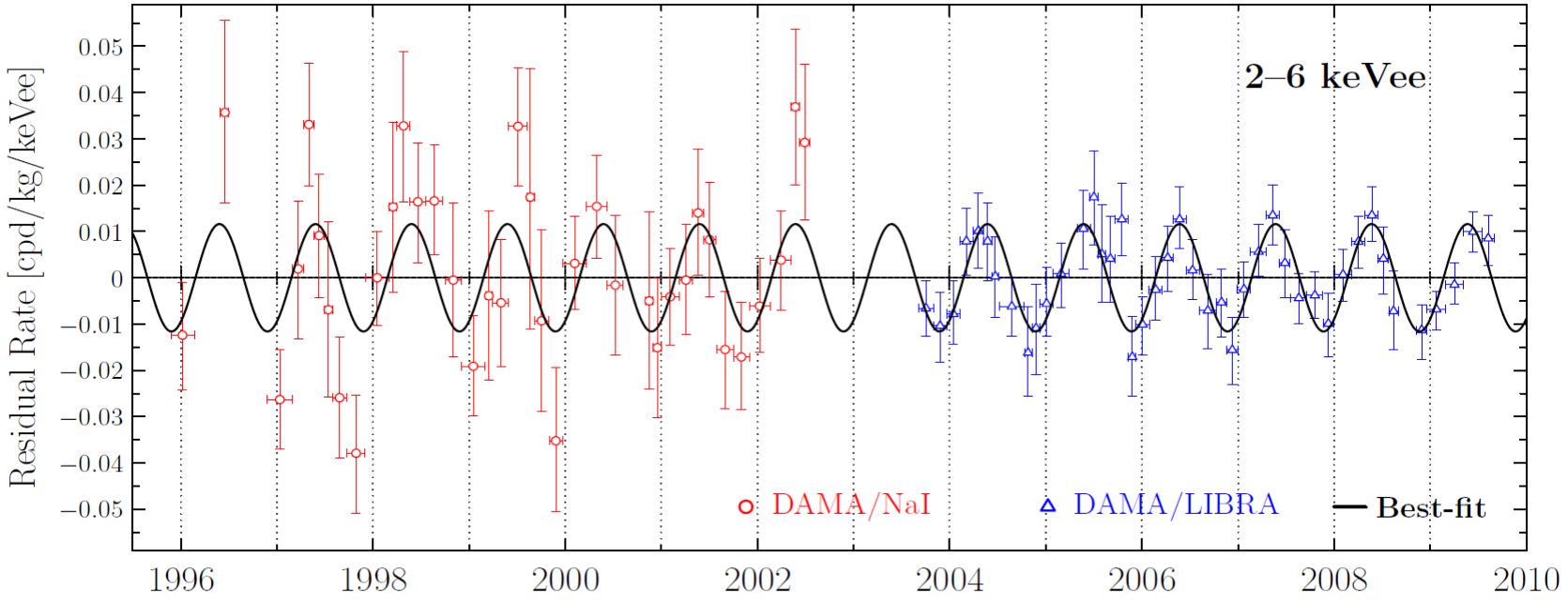
- Three years of data now taken
- Is excess still there?
  - Surface events seem to be under better control
- Is modulation still there?
  - Has higher energy modulation gone away?
- C4 (arXiv:1210.6282)

DAMA and DAMA/LIBRA (NaI)

- Located in Gran Sasso National Laboratory (Italy)
- Detects only scintillation signal
  - Backgrounds are fairly large
  - Only sensitive to the annual modulation of a dark matter signal
- DAMA used ~100 kg of NaI
  - Collected data over 7 annual cycles
  - Exposure of 0.29 ton-year
- DAMA/LIBRA upgraded to ~250 kg
  - Released data for 6 annual cycles (2010)
  - Exposure of 0.87 ton-year
- Most other experiments have exposures measured in kg years

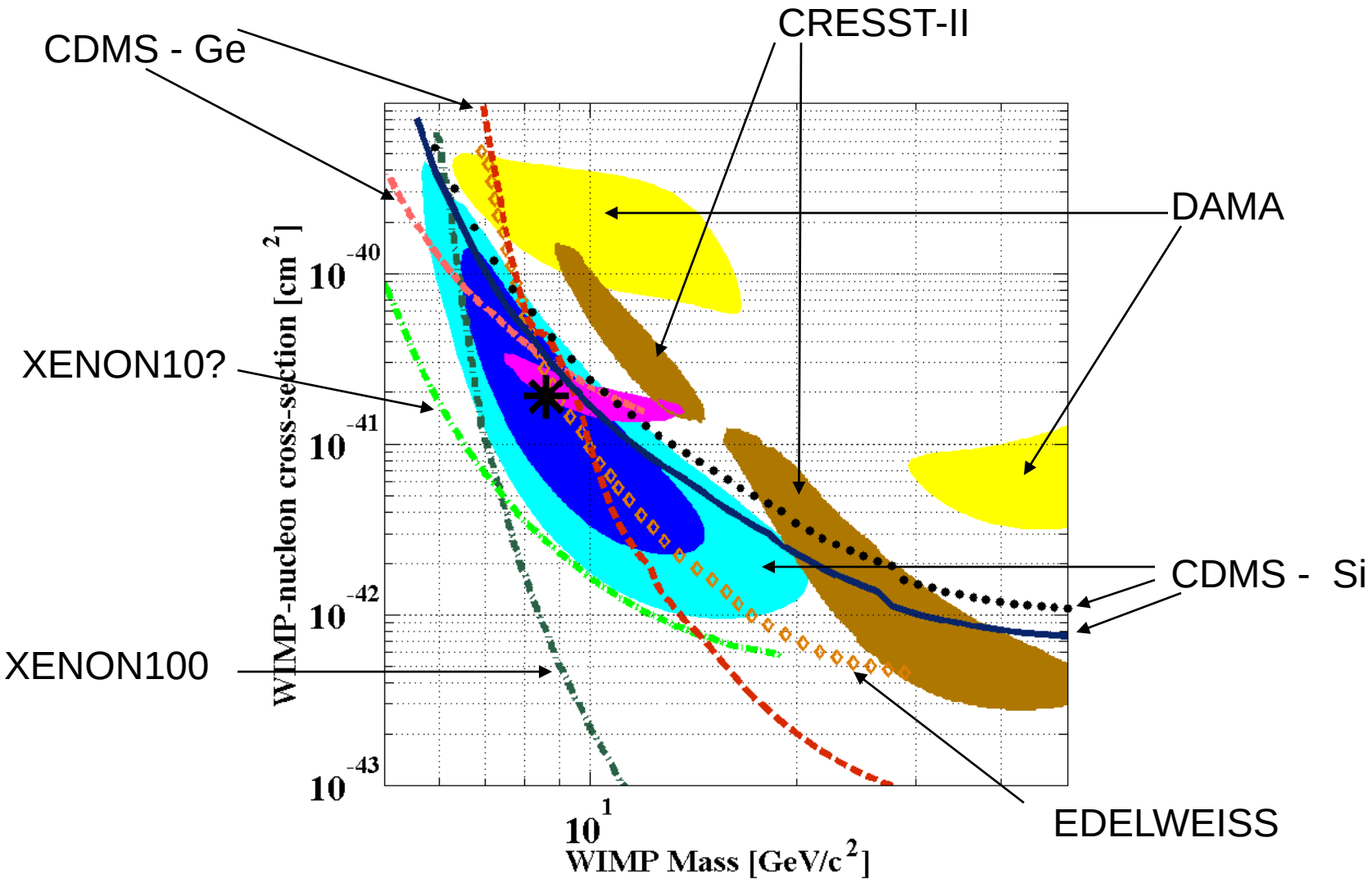
DAMA Results

- Modulation search using NaI crystals (scintillation only)
  - DAMA/NaI: 1996-2002 R. Bernabei *et al.*, Riv. Nuovo Cim. **26N1**, 1 (2003)
  - DAMA/LIBRA: 2003-2009 R. Bernabei *et al.*, Eur. Phys. J. **C67**, 039 (2010)



8.9σ annual modulation

Low Mass Region, a.k.a. Abstract Art



arXiv:1304.4279

WIMP Fits to DAMA data

Chi-squared analysis

Assumptions:

- Standard Halo Model
- Spin-independent elastic scattering
- Quenching: $Q_I = 0.09$, $Q_{Na} = 0.30$
- Account for detector energy resolution

Binning

Original bins (36):

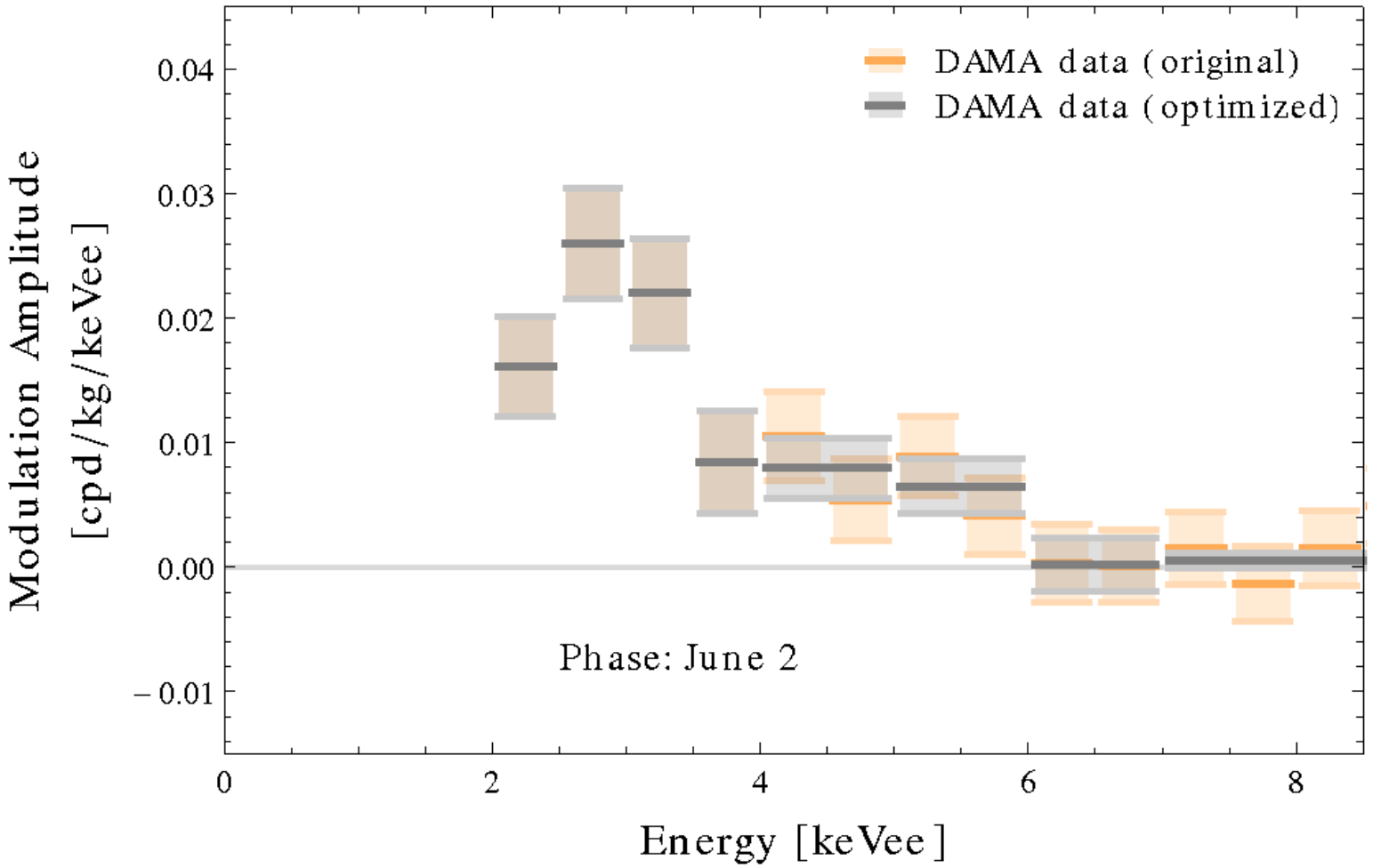
- Most narrower than energy resolution
- Most expected to have negligible signal

$\Rightarrow$ Sensitivity of goodness-of-fit weakened!

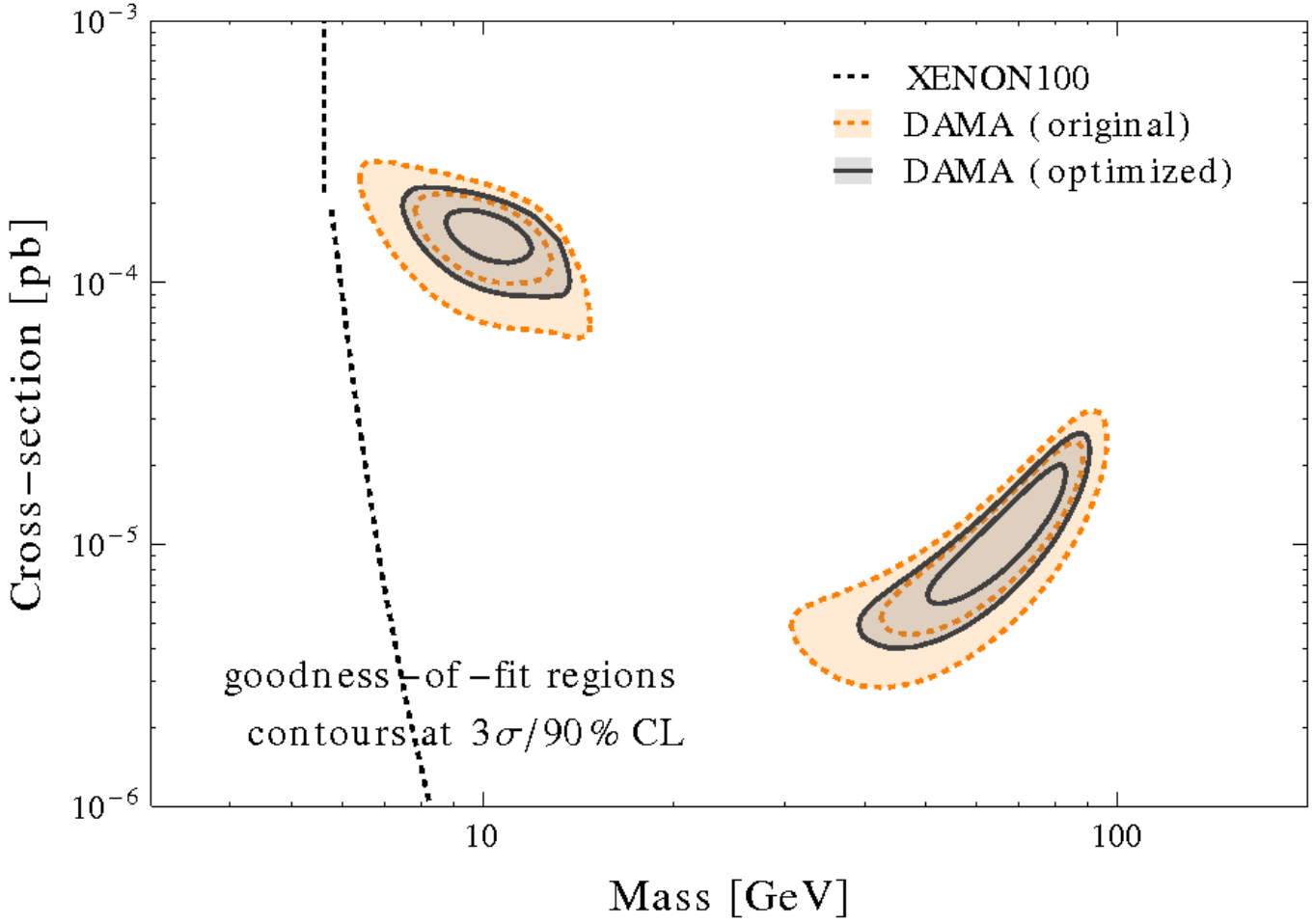
More optimal choice of bins (8):

- Combine bins much smaller than energy resolution
- Combine all bins above 7 keVee
- See Chris Savage's talk for details of how we arrived at our binning choice

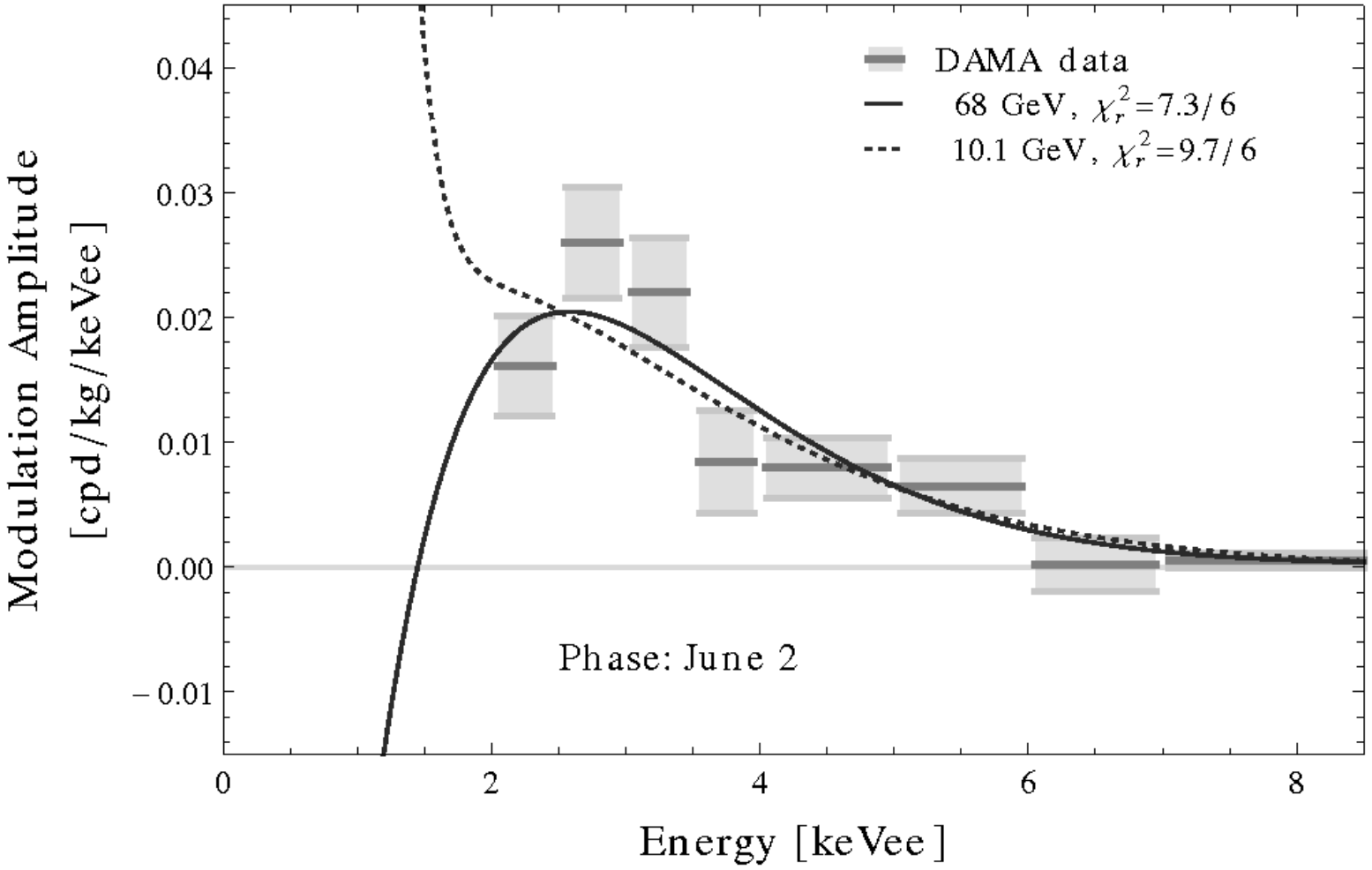
Binning


DAMA data (original)
DAMA data (optimized)
Phase: June 2
Modulation Amplitude [cpd/kg/keVee]
Energy [keVee]
0.04
0.03
0.02
0.01
0.00
−0.01
0
2
4
6
8

Binning


XENON100
DAMA (original)
DAMA (optimized)
goodness-of-fit regions
contours at 3σ/90% CL
Cross-section [pb]
Mass [GeV]
10^-3
10^-4
10^-5
10^-6
10
100

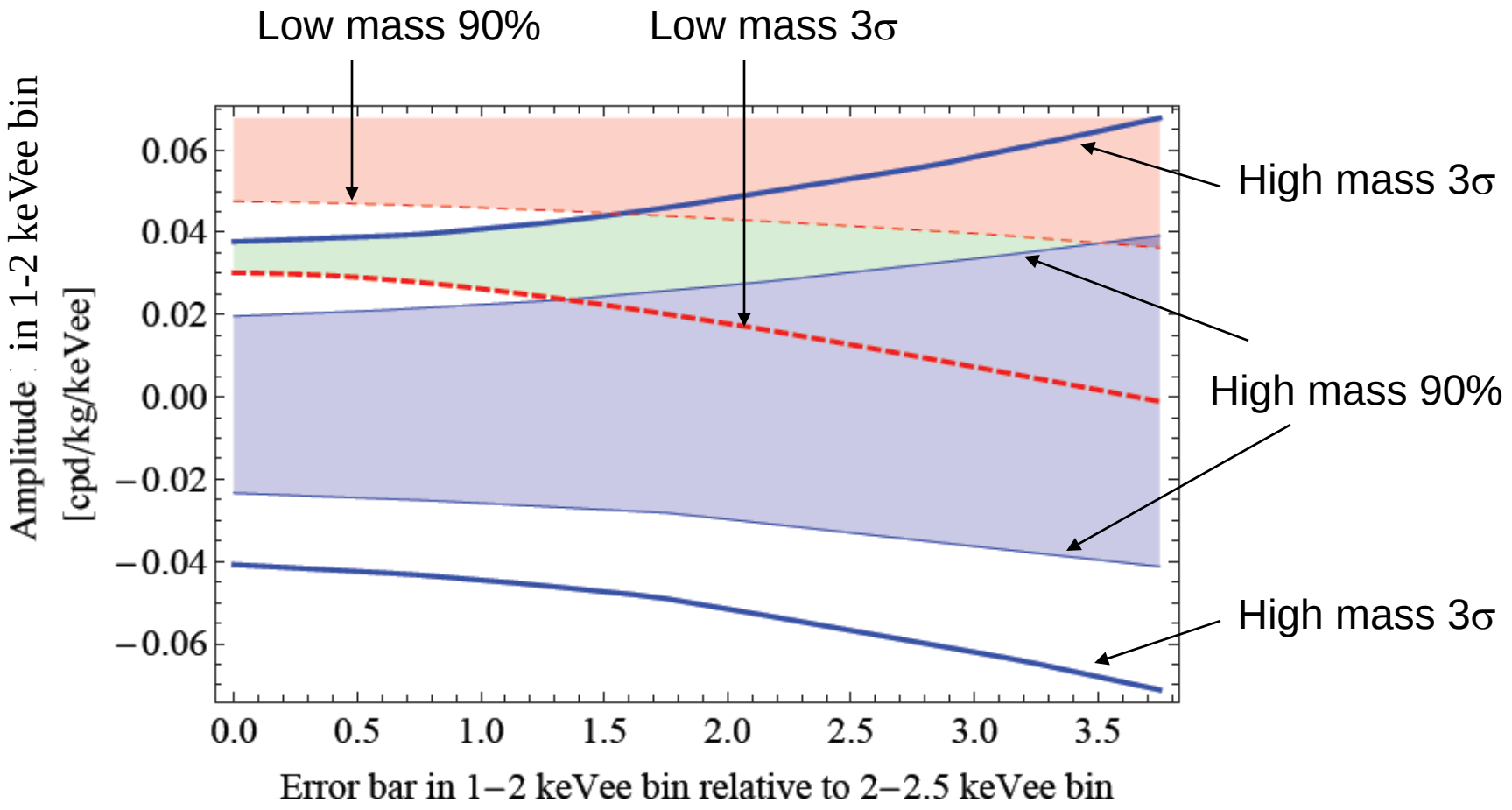
Low-threshold Models



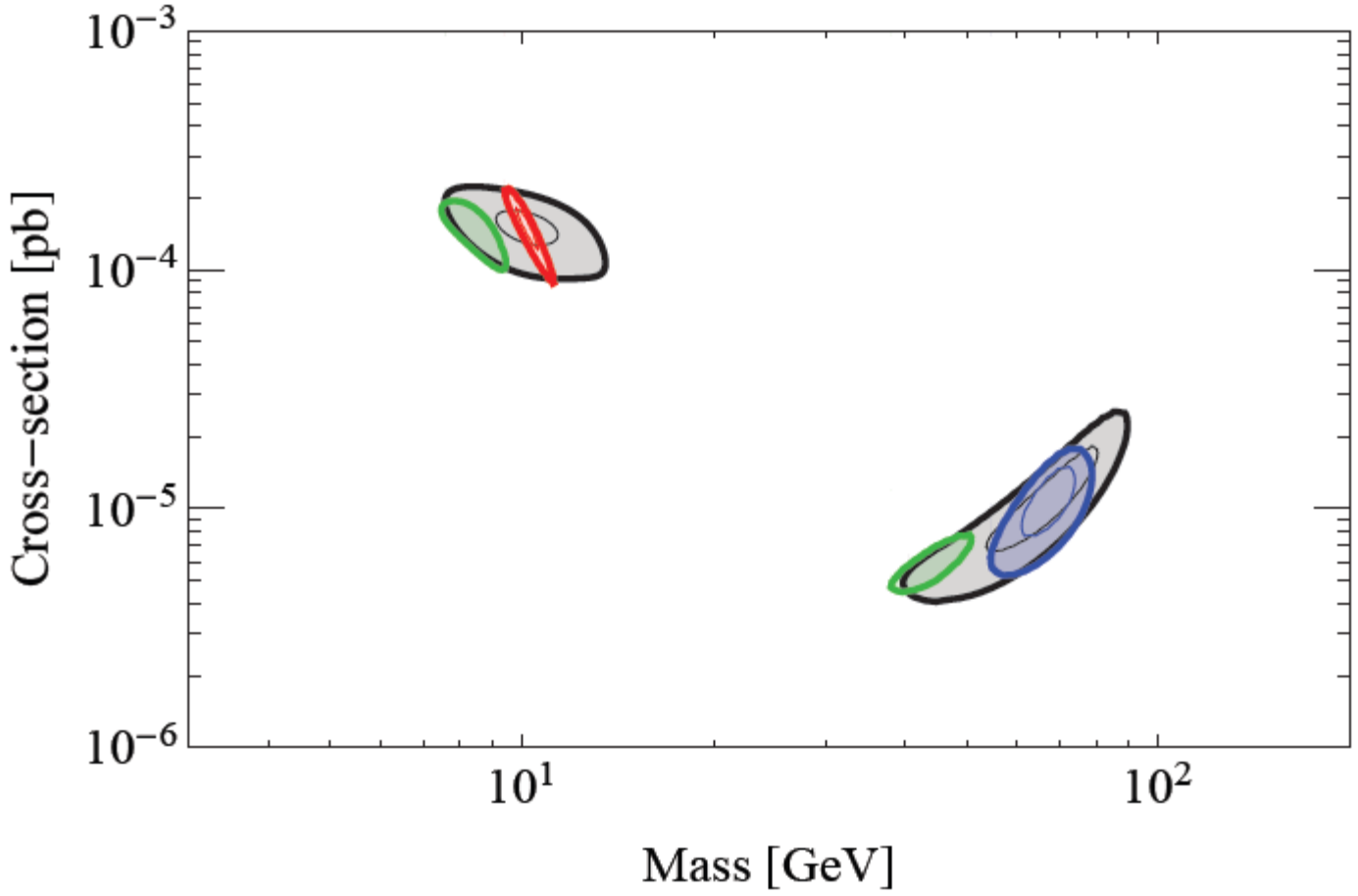
DAMA's Lower Threshold

- In 2010, DAMA upgraded all their PMT's.
  - Allow threshold to be lowered (2 $\rightarrow$ 1 keVee)
  - Can we break low mass and high mass degeneracy?
  - Minimum amplitude still consistent with low mass WIMP
- One bin analysis (1-2 keVee)
- Two bin analysis (1-1.5 keVee and 1.5-2 keVee)

One Bin Analysis

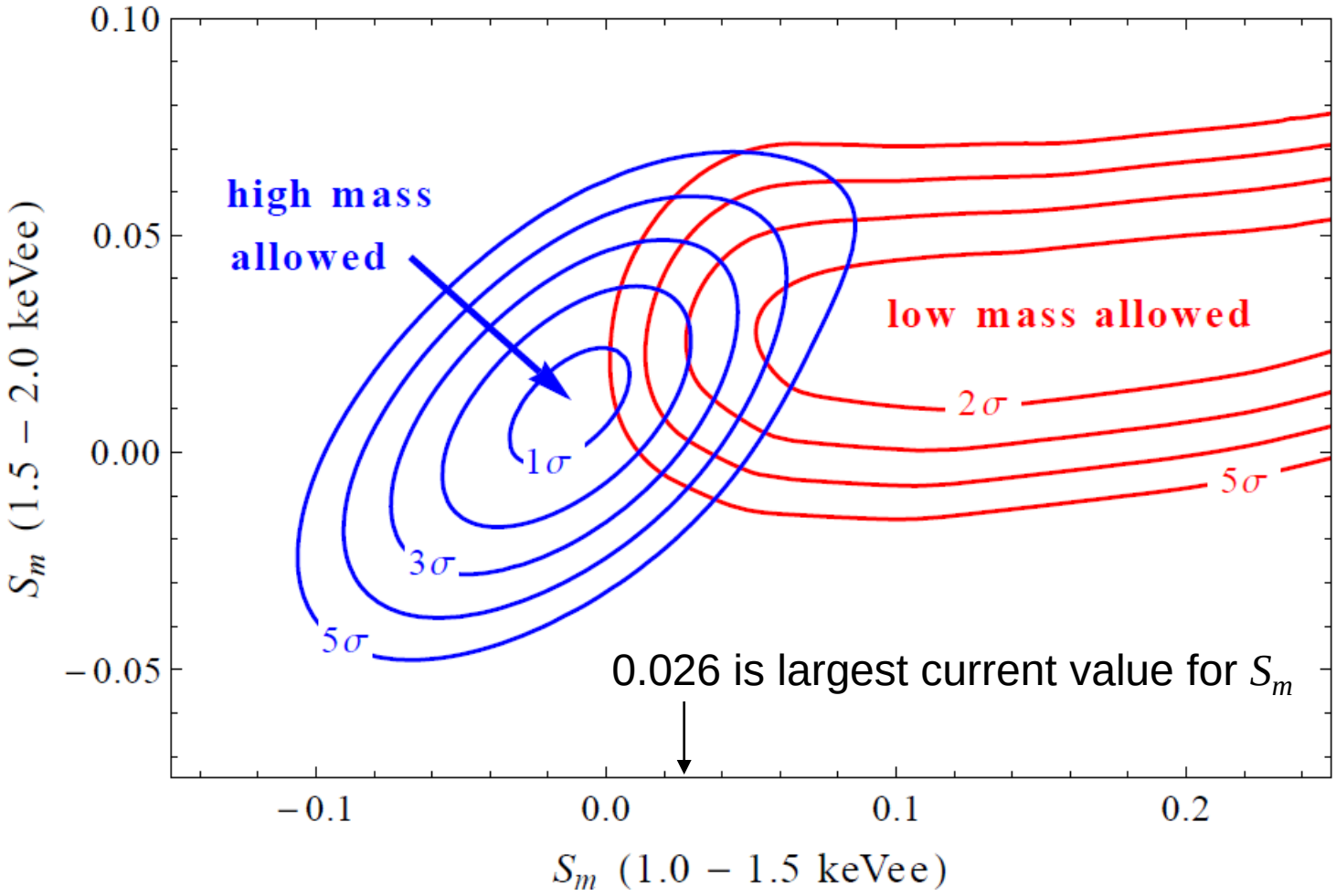


New allowed regions for lower threshold



Assumes similar size error bar in 1-2 keVee bin as for 2-2.5 keVee bin

Two Bin Analysis



Using conservative error bars for each bin

Conclusions

- Low Threshold for modulation experiment is very valuable
  - Distinguish between low and high mass WIMP if target has heavy and light element
  - Phase reversal (modulation amplitude becomes negative) is a very distinctive signature of a dark matter signal
- Low mass region is extremely confusing
  - Many possible signals
  - Many exclusions
- Current (and upcoming) detectors should help to clarify things very soon
  - CoGeNT, CDMSlite, SuperCDMS
  - DAMA's upgrade, DMIce
  - LUX, XENON1T
- Indirect detection signal at similar mass range in Fermi LAT data?
  - Galactic Center
  - Inner Galaxy (See Tim Linden's Talk)

Thanks for your attention

"May you live in interesting times."

Go Bulls!