DAMIC : hunting for low mass WIMPs

Junhui LIAO, University of Zürich, Switzerland
On behalf of DAMIC collaboration

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Outline

1. Brief introduction on DAMIC and its latest result
2. Quenching factor measurement
3. Using EFT to analyze DAMIC data
4. Summary

Whom we're ?

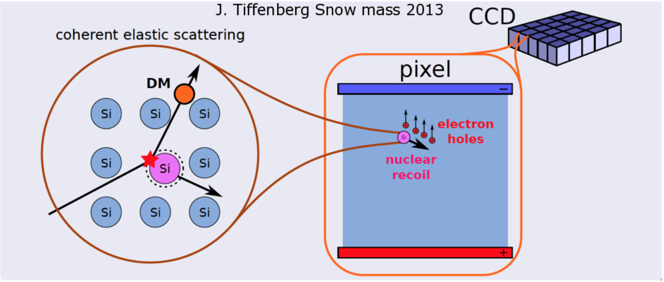
DAMIC collaboration : small teams, big dreams

- DAMIC : DArk Matter In CCDs. DAMIC has taken data since 2013.
- An international collaboration hosted by Fermilab, other institutes are : U Chicago, U Zürich, U Michigan, UNAM, FIUNA, CAB, UFRJ, Snolab.

What are our dreams : hunting for low mass WIMPs

What's the interaction of DM to matter? How to hunt ?

- Nobody knows the mechanism of the interaction yet.
- DAMIC wishes to get some kinds of clues if WIMPs scatter our detector elastically and leave a message there, :-).

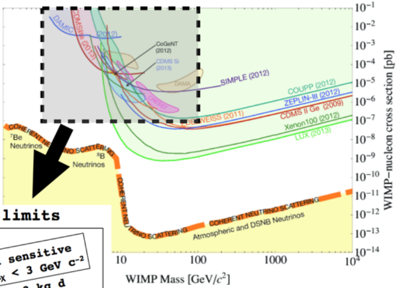


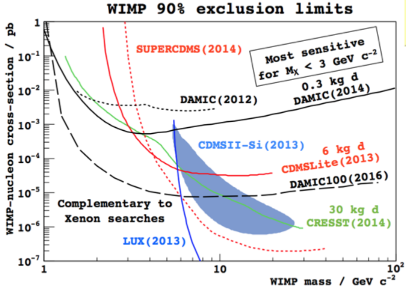
Current results

No any signal has been observed yet, so we put a limit

A. Chavarria @ CIPANP 2015

Low mass WIMPs study was favored by Asymmetirc DM model. arXiv : 1308.0338v2, 1004.0691v2 and others.

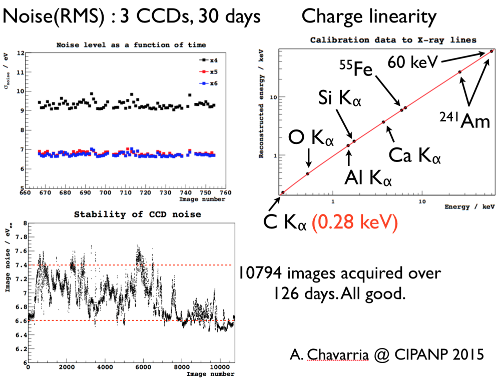




Some indirect DM detections are also kind of low mass faovored (model dependent of course). arXiv : 1007.1005v3, PhysRevLett. 1104.041302 etc.

DAMIC noise and charge lineary

- Our competitive limit results benefit a lot from CCDs' very low and stable noise and charge linearity, although its size is tiny.
- Recoil energy threshold for analysis : DAMIC, $\sim$ 60 eVee; SuperCDMS Lite, $\sim$ 170 eVee, CRESST-II, $\sim$ 600 eVee.



Why need QF(Quenching Factor) measurement

Why a DM detector need QF ?

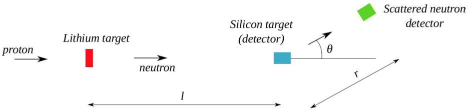
- WIMPs is neutral, so it can't ionize a detector. We can't characterize it by ionization.
- We don't know which mechanism of WIMPs interacts with a detector. We assume 1) it scatters a detector elastically; 2) the scattering will produce a recoil energy which hopefully could be tested by our detectors.

Why neutron is "the chosen one " ?

- (Fast)Neutron is neutral and, scatters a detector elastically(the interaction of neutron to a detector is primarily strong interaction).
- The neutron beam for this test is mono-energy peaked @ 550KeV(FWHM $\sim$ 150KeV), produced by $\sim$2 MeV incident protons with an reaction of $^{7}Li(p, n_0)^{7}Be$.

Quenching factor experiment introduction

- Left plot : schematic drawing; right plot : a picture of beam test.
- With kinematics, one can figure out $E_{NR} = f(\Delta t)$, where Δt could be measured by scintillator bars.

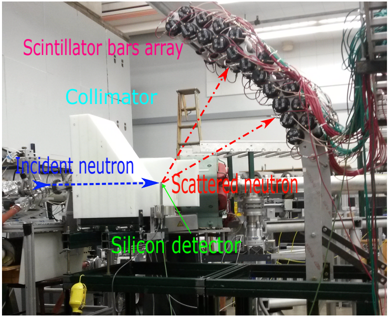


$$E_{NR} = E_n \frac{2}{(A+1)^2}\left[A + \sin^2\theta - \cos\theta\sqrt{A^2 - \sin^2\theta}\right]$$

$$E_n = \frac{m}{2(\Delta t)^2}\left[l + r\,\frac{(A+1)}{\cos\theta + \sqrt{A^2 - \sin^2\theta}}\right]^2$$

- θ Scattering angle
- A Atomic mass
- E_n Neutron energy
- E_{NR} Energy of Nuclear recoil
- Δt = neutron total Time-of-flight

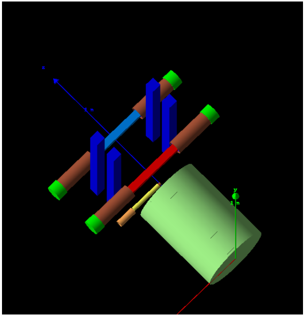
F. Izraelevitch @ DAMIC collaboration meeting, Mar 2014

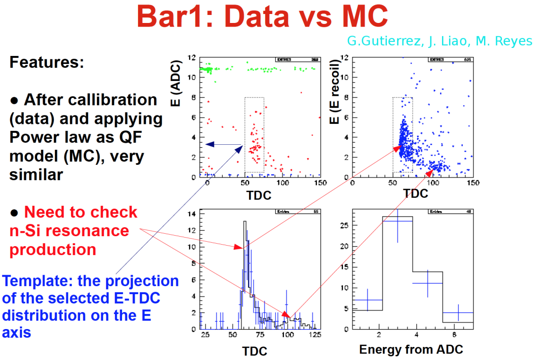


Geant4 simulation for quenching factor experiment

2013 beam test, two bars setup

- Left plot : Geant4 geometry ; right plot : data vs Geant4 simulation.

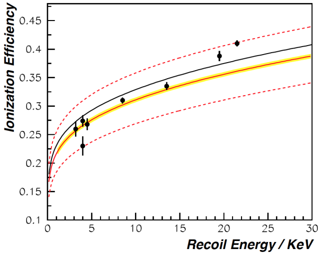




Geant4 simulation for quenching factor experiment

Summarized plot of 2013 beam test

- Summary on 2013 data and, our estimation for 2015 beam test. This plot has shown in *"Fermilab today" Nov-21-14* , when we were young, :-).



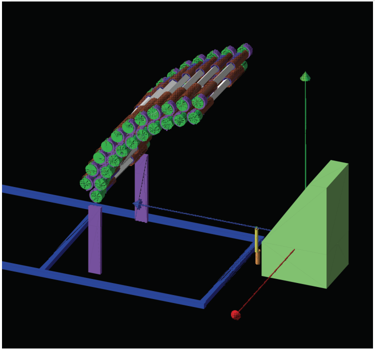
By DAMIC collaboration and G.Gutierrez

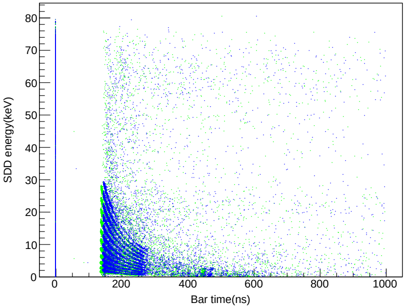
Plot of the Ionization Efficiency for silicon as a function of nuclear Recoil Energy. The black line and dots with error bars show the best measurements to date, by Gerbier et al., 1990. The solid red line shows our fit to preliminary data, from 2-20 KeV. The dashed lines display the 1 \sigma error bands. In our next run we expect these errors, for points every 1KeV, to shrink to the yellow band. The recoil energy range will cover from 1-30 KeV.

Geant4 simulation for quenching factor experiment

2015 beam test, 21 bars setup

- Left plot : Geant4 simulation geometry. Right plot : Geant4 simulated results, deposited energy in silicon detector and the flight time registered in the array of scintillator bars.
- Analysis of 2015 data is in progress ...





How EFT arises ?

EFT, Effective Field Theory

- Most models of WIMPs invoke new physics at the energy scale of $\geq 100 GeV$. In reality, the momentum transfer in direct detection is $\leq$ 100s of MeV. At such low energies, those apparently different models (at $\geq 100 GeV$) lead to the same simple non-relativistic effective theory.
- The "traditional" SI/SD models already introduce form factor to consider when the momentum transfer is large compared to the inverse nuclear size. However, once momentum transfers reach "deep" enough, not only form factors, but operators arise.
- EFT can be described by four parameters : the DM velocity $v \sim 10^{-3}c$, momentum transfer q, the mass of DM m_χ and the nucleus mass m_N.

14 EFT operators

$\mathcal{O}_1 = 1_\chi 1_N$ (Spin Independent)

$$\mathcal{O}_3 = i\vec{S}_N \cdot \left[\frac{\vec{q}}{m_N} \times \vec{v}^\perp\right]$$

$\mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N$ (Spin Dependent)

$$\mathcal{O}_5 = i\vec{S}_\chi \cdot \left[\frac{\vec{q}}{m_N} \times \vec{v}^\perp\right]$$

$$\mathcal{O}_6 = \left[\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right]\left[\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right]$$

$$\mathcal{O}_7 = \vec{S}_N \cdot \vec{v}^\perp$$

$$\mathcal{O}_8 = \vec{S}_\chi \cdot \vec{v}^\perp$$

$$\mathcal{O}_9 = i\vec{S}_\chi \cdot \left[\vec{S}_N \times \frac{\vec{q}}{m_N}\right]$$

$$\mathcal{O}_{10} = i\vec{S}_N \cdot \frac{\vec{q}}{m_N}$$

$$\mathcal{O}_{11} = i\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}$$

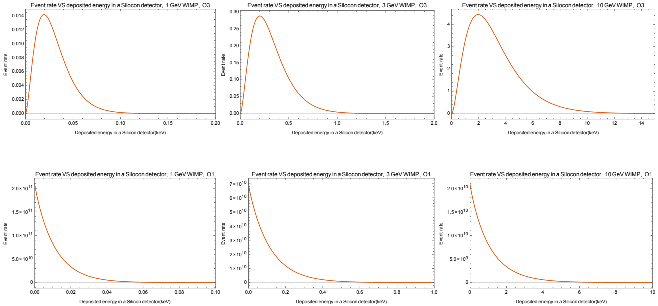
$$\mathcal{O}_{12} = \vec{S}_\chi \cdot \left[\vec{S}_N \times \vec{v}^\perp\right]$$

$$\mathcal{O}_{13} = i\left[\vec{S}_\chi \cdot \vec{v}^\perp\right]\left[\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right]$$

$$\mathcal{O}_{14} = i\left[\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right]\left[\vec{S}_N \cdot \vec{v}^\perp\right]$$

$$\mathcal{O}_{15} = -\left[\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right]\left[\left(\vec{S}_N \times \vec{v}^\perp\right) \cdot \frac{\vec{q}}{m_N}\right]$$

Comparisons of $\mathcal{O}1$, $\mathcal{O}3$ with three WIMP masses.



- According to EFT, $\mathcal{O}1 = \mathbf{1}$, is the usual SI(Spin Independent) model. $\mathcal{O}3 = i\vec{S}_N \cdot [\frac{\vec{q}}{m_N} \times \vec{v}^{\perp}]$. $\vec{S}_N$ is the spin of nucleon, $\vec{q}$ is the momentum transfer, $\vec{v}^{\perp}$ is the velocity of WIMP, m_N is the mass of nucleon.

Coefficients of each operator

- The total 28 coefficients of 14 operators(proton and neutron both have one) are the parameters of EFT.
- The following plot shows the coefficients of each operator of SuperCDMS paper for 10 and 300GeV WIMP.
- Need to evaluate these coefficients based on DAMIC data, then set (new)limits for operators.

Operator coefficient	SuperCDMS Soudan	CDMS II Ge	CDMS II Si
$(c_1^0)^2 * m_{weak}^4$	8.98×10^{-5} (—)	1.19×10^{-3} (1.13×10^{-5})	3.06×10^{-3} (7.73×10^{-4})
$(c_3^0)^2 * m_{weak}^4$	3.14×10^{4} (—)	1.06×10^{5} (3.08×10^{1})	8.59×10^{5} (1.37×10^{4})
$(c_4^0)^2 * m_{weak}^4$	8.77×10^{1} (—)	1.24×10^{3} (1.53×10^{1})	3.94×10^{3} (1.02×10^{3})
$(c_5^0)^2 * m_{weak}^4$	6.34×10^{5} (—)	5.30×10^{6} (4.82×10^{3})	2.67×10^{7} (1.55×10^{6})
$(c_6^0)^2 * m_{weak}^4$	4.54×10^{8} (—)	1.55×10^{9} (5.21×10^{5})	2.44×10^{10} (3.70×10^{8})
$(c_7^0)^2 * m_{weak}^4$	8.44×10^{7} (—)	1.76×10^{9} (1.62×10^{7})	3.19×10^{9} (929×10^{8})
$(c_8^0)^2 * m_{weak}^4$	4.30×10^{2} (—)	7.68×10^{3} (3.51×10^{1})	1.70×10^{4} (3.49×10^{3})
$(c_9^0)^2 * m_{weak}^4$	1.95×10^{5} (—)	1.32×10^{6} (4.84×10^{3})	9.17×10^{6} (7.34×10^{5})
$(c_{10}^0)^2 * m_{weak}^4$	9.22×10^{4} (—)	5.83×10^{5} (1.09×10^{3})	4.34×10^{6} (2.86×10^{5})
$(c_{11}^0)^2 * m_{weak}^4$	5.13×10^{-1} (—)	3.23×10^{0} (6.59×10^{-3})	1.86×10^{1} (1.34×10^{0})
$(c_{12}^0)^2 * m_{weak}^4$	1.03×10^{2} (—)	6.33×10^{2} (1.04×10^{0})	2.45×10^{3} (1.69×10^{2})
$(c_{13}^0)^2 * m_{weak}^4$	4.28×10^{8} (—)	1.44×10^{9} (4.12×10^{5})	2.50×10^{13} (1.36×10^{12})
$(c_{14}^0)^2 * m_{weak}^4$	5.00×10^{11} (—)	4.91×10^{12} (1.06×10^{10})	2.64×10^{13} (1.72×10^{12})
$(c_{15}^0)^2 * m_{weak}^4$	1.32×10^{8} (—)	2.76×10^{8} (1.26×10^{4})	4.44×10^{9} (1.48×10^{7})

TABLE I. SuperCDMS and CDMS II 90% confidence level upper limits on the square of the dimensionless EFT coefficient for pure isoscalar interaction for a 10 GeV/c^2 (300 GeV/c^2) WIMP for all isoscalar EFT operators. The upper limits vary in accordance with the relative strength of the interaction in silicon and germanium.

arXiv : 1503.03379v1

Summary

Summary

- DAMIC has set a new limit on low mass WIMPs($\leq 3GeV$).
- Quenching factor beam tests. 2013 dataset produced promising results. Data analysis for 2015 beam test is in progress.
- EFT analysis for DAMIC data has been started.