DAMIC : hunting for low mass WIMPs with CCDs

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

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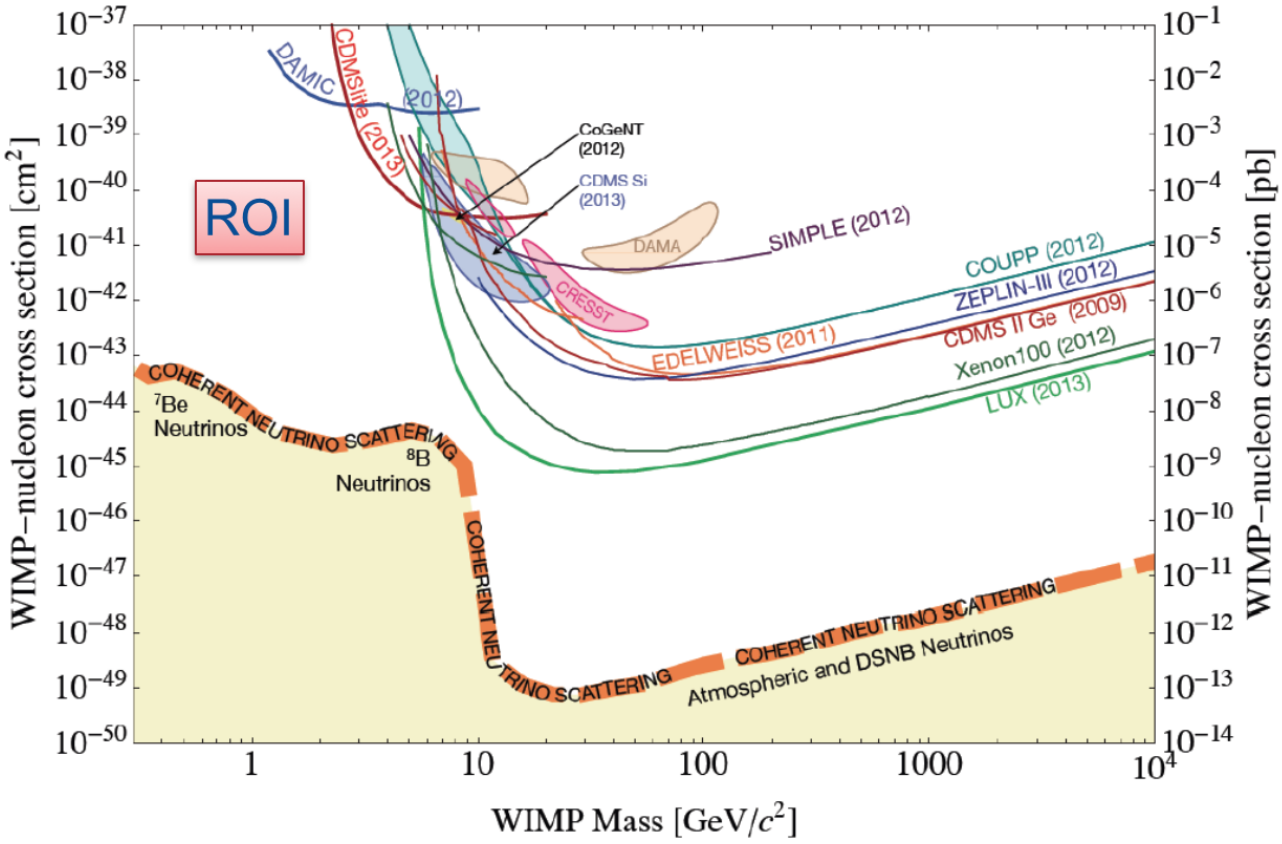
Outline

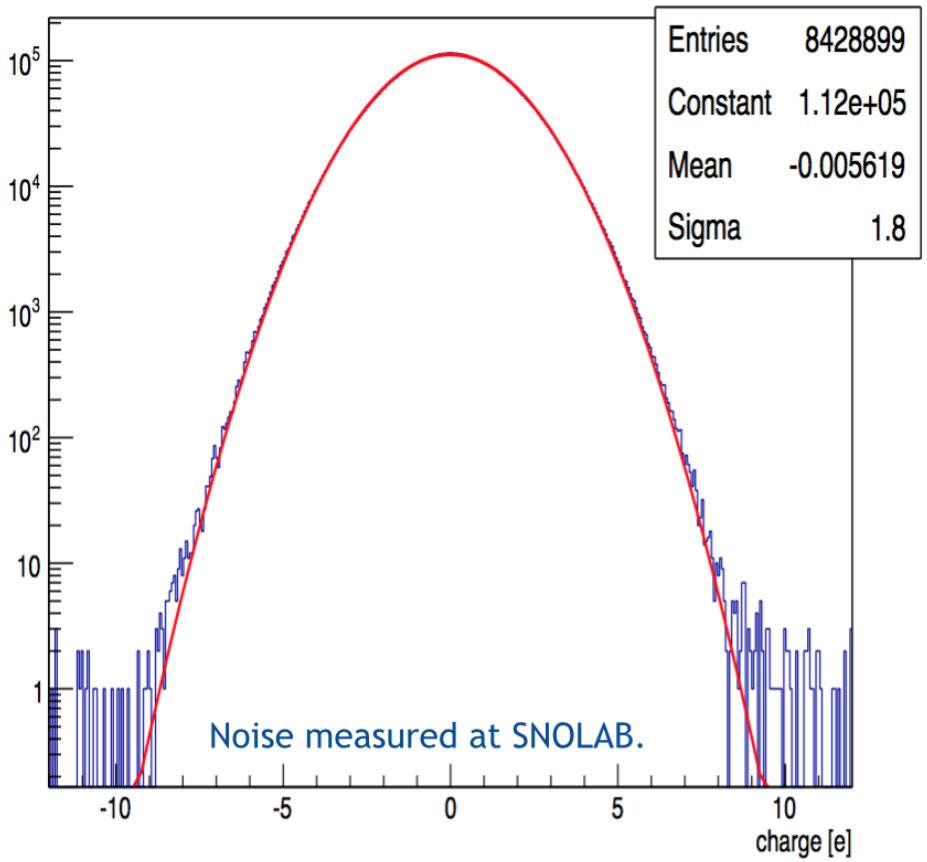
1. Brief introduction on DAMIC and its latest results
2. Quenching factor measurement
3. Using EFT to analyze DAMIC data

DAMIC science

Region Of Interest(ROI) : low mass WIMP

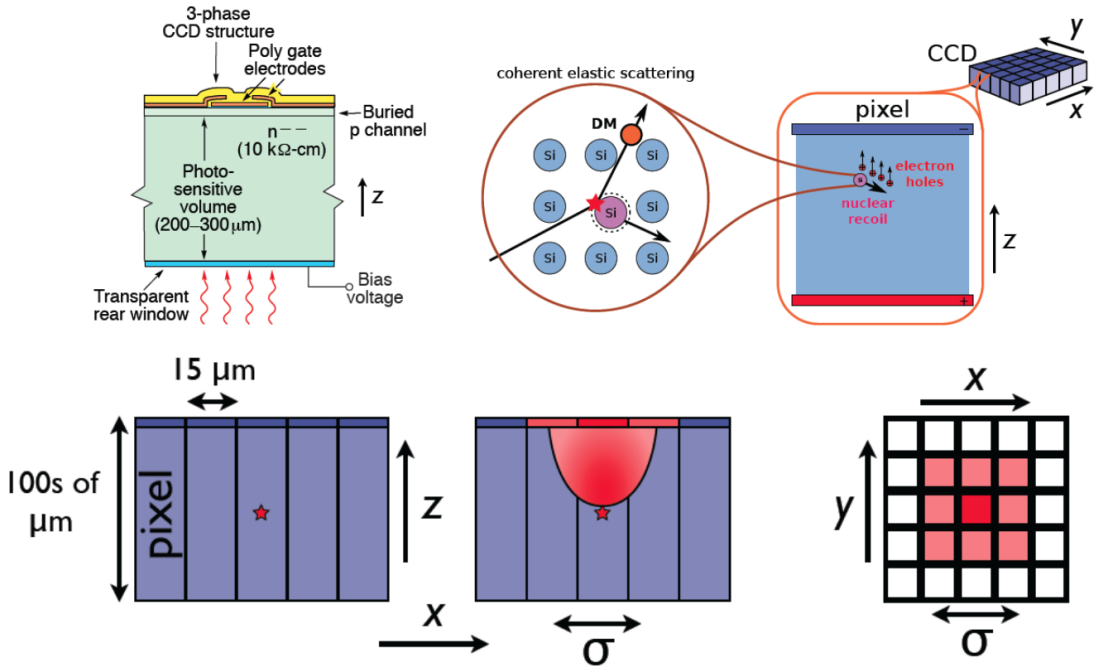


Very low noise : 1.8 e^- noise(RMS)



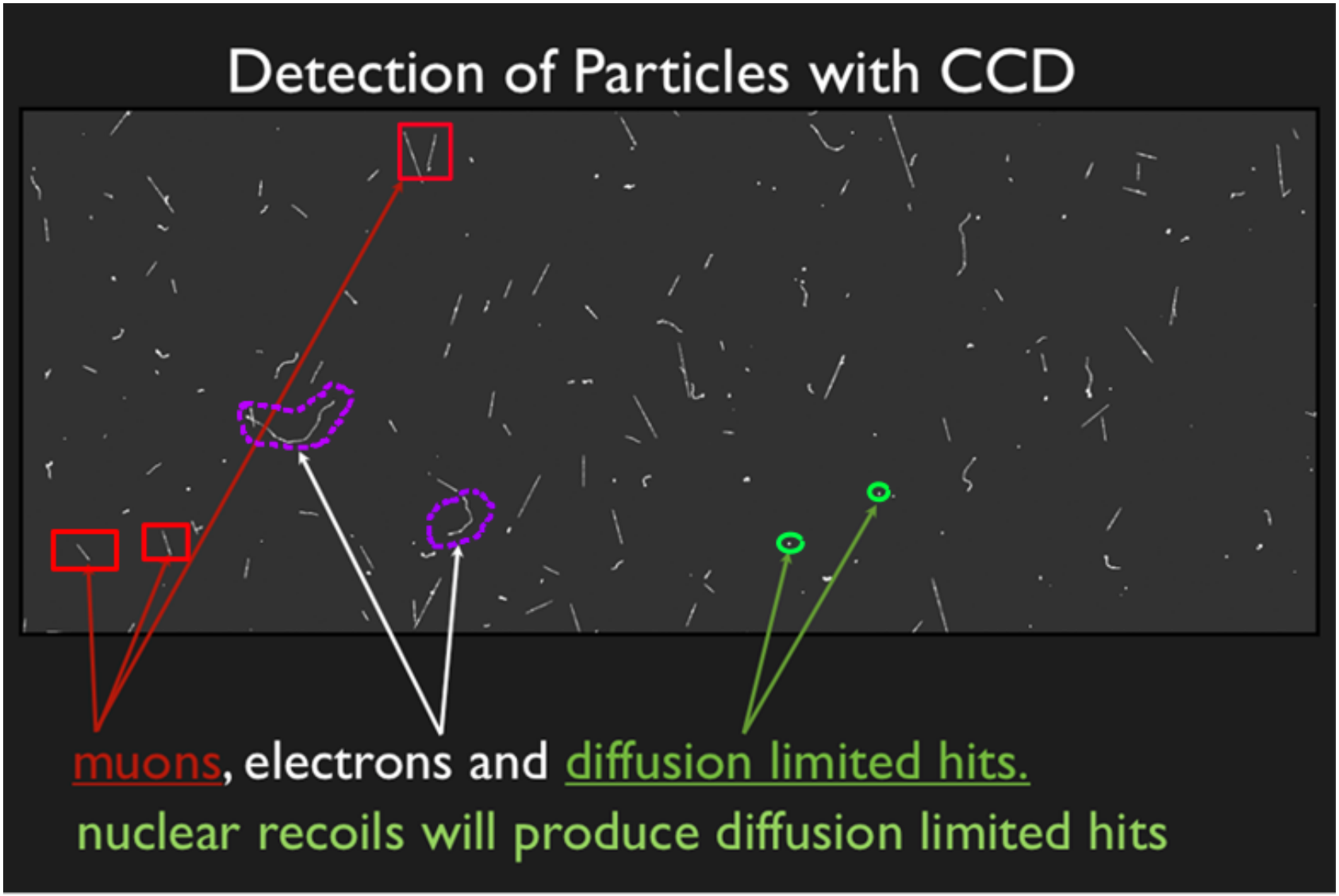
- 1 $e^- \approx 3.6$ eV $\rightarrow \approx 40$ eV threshold is possible.
- $1.8(e^-/\sigma) \times (3.6eV/e^-) \times (5\sigma) = 32eV$

DAMIC CCDs



- DECam detectors are 250 μm thickness and 8 MPix, 1g per CCD. DAMIC started with these.
- DAMIC-100 uses high-resistivity, 675 μm, 16 MPix, 5.2g per CCDs. First CCDs installed in 2014. Developed by LBNL Microsystems Lab.

signals measured by a DAMIC CCD

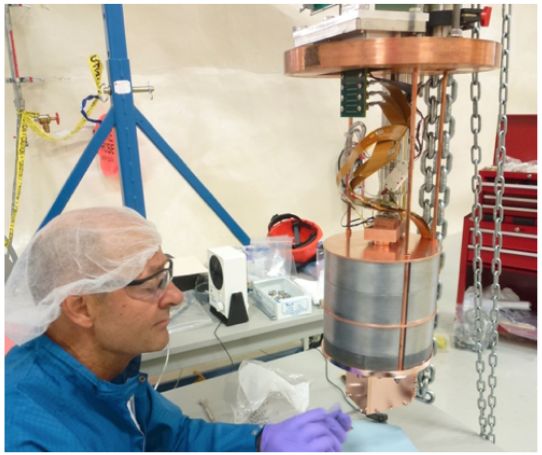


DAMIC Collaboration

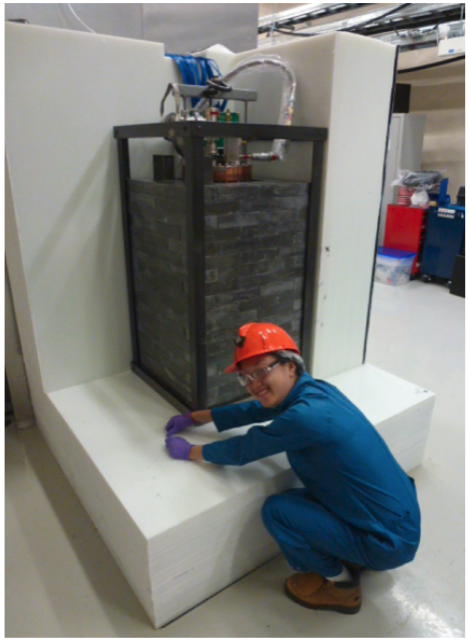
Two universities from the US, one National Laboratory and 6 institutions from abroad.

Centro Atomico Bariloche, Argentina
Fermi National Accelerator Laboratory, USA
SNOLAB, Canada
Universidad Federal Rio Janeiro, Brazil
Universidad Nacional de Asuncion, Paraguay
Universidad Nacional Autonoma de Mexico
University of Chicago , USA
University of Michigan, USA
University of Zurich, Switzerland

DAMIC detectors assembled in Snolab



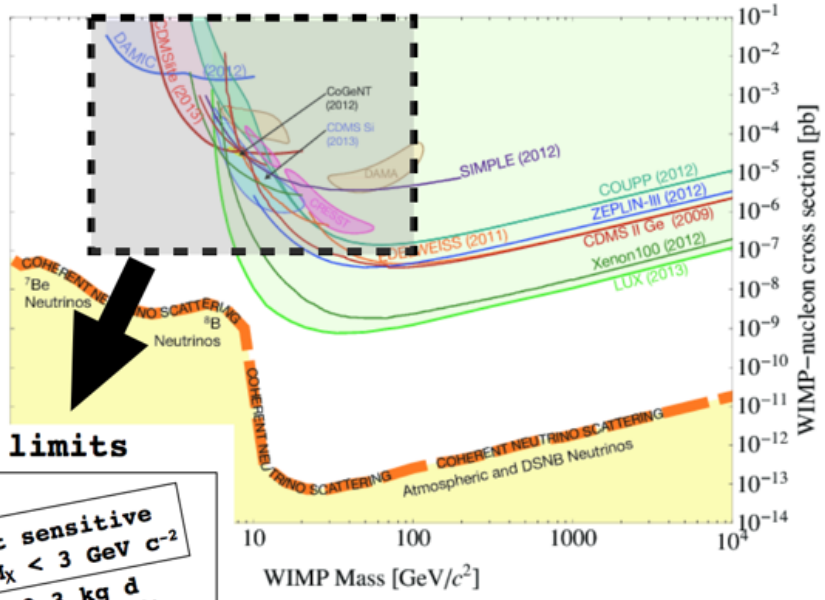
Stack mounted inside copper vessel. Inner lead shield inside vacuum. Detectors operated at -140C. Innermost inch using ancient lead.

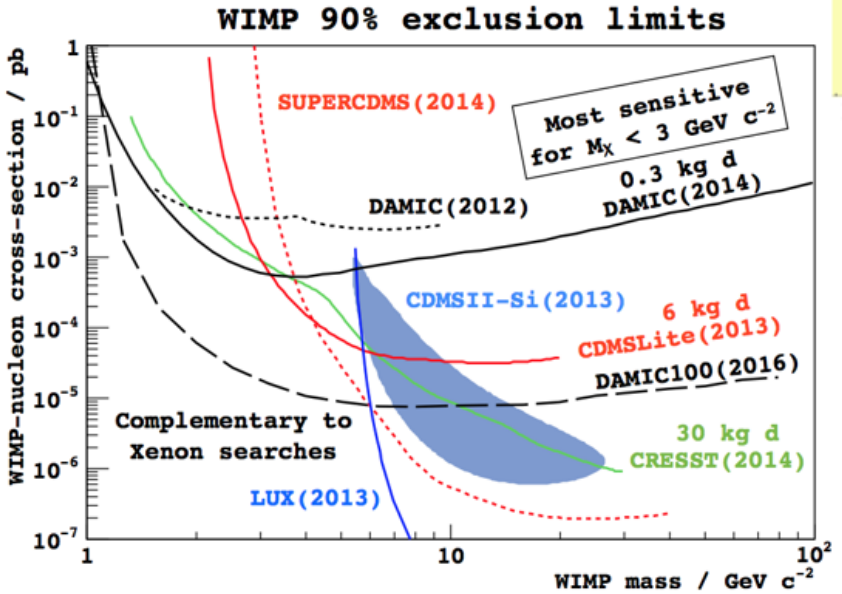


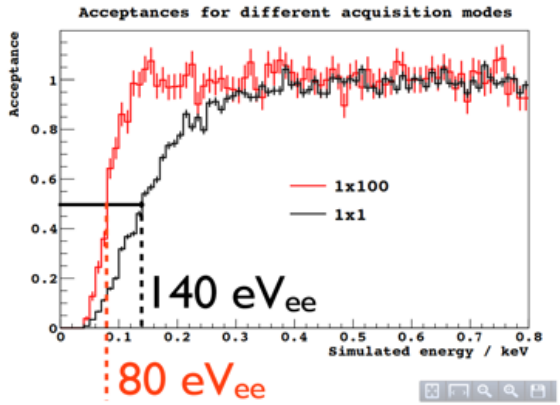
Copper vessel inside lead and poly shield.

DAMIC limits

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







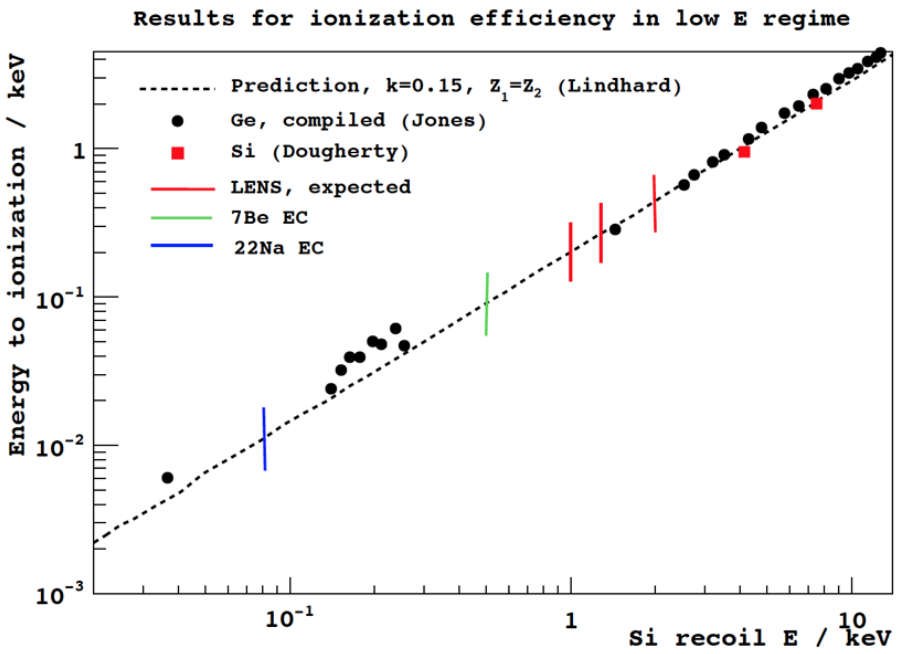
Quenching Factor(QF) measurement

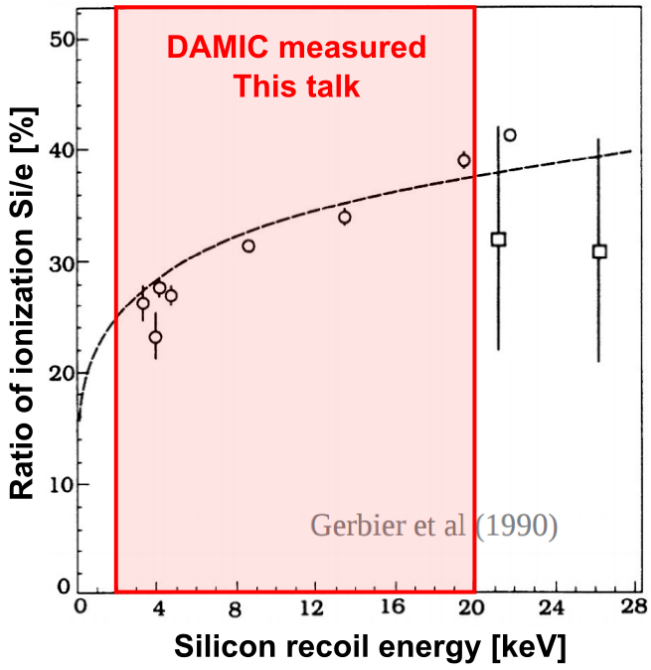
Why a DM detector needs QF ?

- Theoretical models of DM often calculated with recoil energy. While DM detectors measure ionized energy. To set a limit or claim a discovery according to models, one has to “convert” these two energies. QF is the ratio of “ionized energy / recoil energy” for a detector.
- We don’t know which kind of mechanism a WIMP interacts with a detector. We assume 1) it scatters a detector elastically; 2) part of the recoil energy could be recorded by a detector.
- For a neutron scattering, it satisfies these two assumptions. So, we can use neutrons to mimic DM scattering off a detector to get the QF of a DM detector.

QF tests

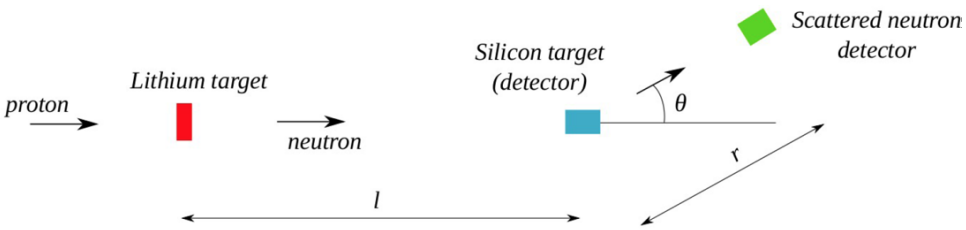
- Left plot : QF tests overview (recoil energy < 10 keV); right plot : DAMIC measured range of recoil energy(the points are not measured by DAMIC).





2015 QF beam test : introduction

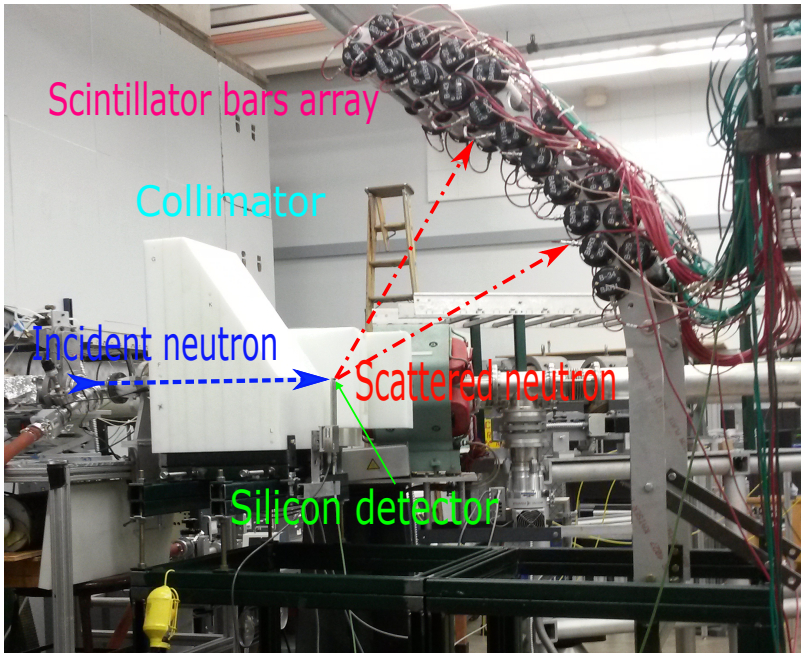
- Left plot : schematic drawing; right plot : a picture of beam test.
- Beam test at University of Notre Dame(Thanks for supports!).
- With kinematics, one can figure out $E_{NR} = f(\Delta t)$, where Δt is the time of flight of scattered neutrons which could be measured by scintillator bars.



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

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

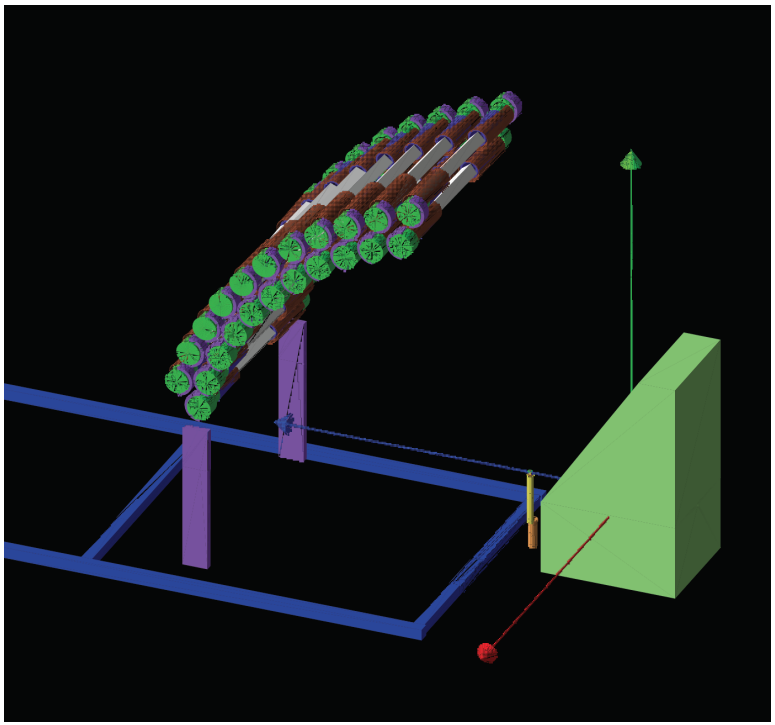
- θ Scattering angle
- A Atomic mass
- E_n Neutron energy
- E_{NR} Energy of Nuclear recoil
- Δt = neutron total Time-of-flight

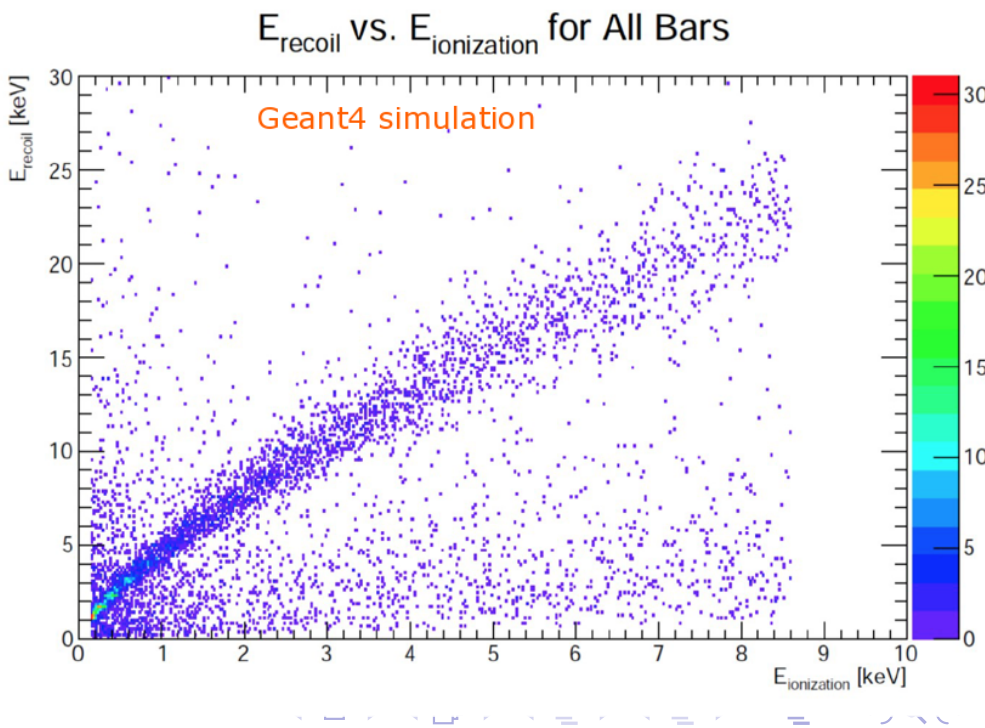


2015 QF beam test : simulation results

2015 beam test, 21 bars setup

- Left plot : Geant4 simulation geometry. Right plot : Geant4 simulated results, ironized energy V.S. recoil energy.
- Analysis of 2015 beam test data is in progress.

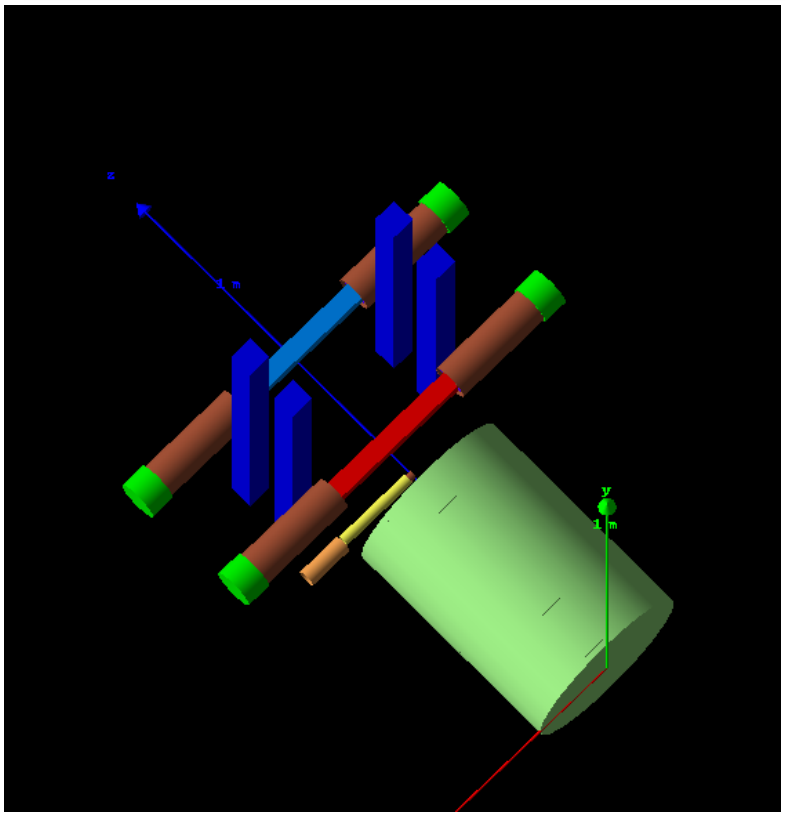




2013 QF beam test : introduction

two bars setup

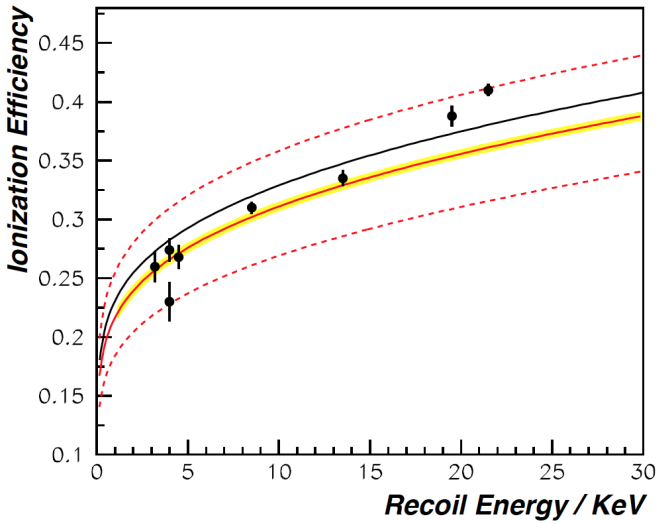
- Plot : top view of the setup of two bars beam test(Geant4 simulation drawing) .



2013 QF beam test : results

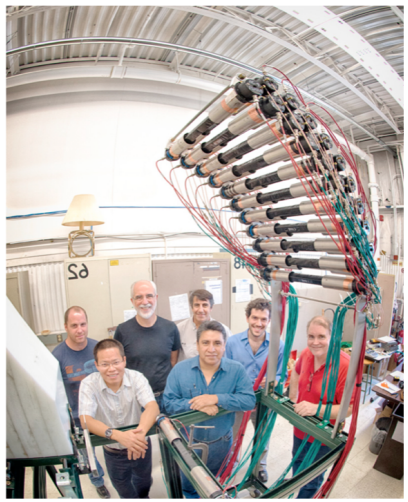
Analyzing results of 2013 beam test

- Left plot : results of 2013 beam test data and estimation for 2015 beam test data. Right plot : part of people involved in QF test.



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.



1)Neutron recoil experiment using beam at Notre Dame (FNAL/Michigan/ Zurich/Guanajuato).

How EFT arises ?

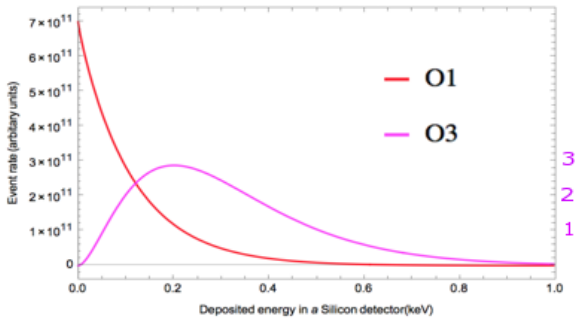
EFT, Effective Field Theory

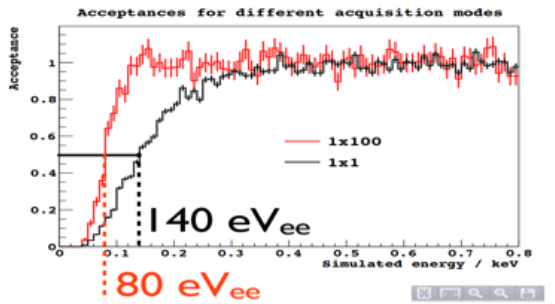
- Most models of WIMPs invoke new physics at the energy scale of $\geq 100 GeV$. In reality, the momentum transfer in direct detection is $\leq$ 100s of MeV. At such low energies, those apparently different models (at $\geq 100 GeV$) lead to the same simple non-relativistic effective theory.
- The "traditional" SI/SD models introduced form factor to consider when the momentum transfer is large compared to the inverse nuclear size. However, once momentum transfers big enough, not only form factors, but (12)new operators arise.
- EFT can be described by : 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(totally 28 parameters, 2 for each)

- Left plot : All of the 14 EFT operators.
- Right upper plot : Event rates for $\mathcal{O}1$ and $\mathcal{O}3$ operators with 3 GeV WIMPs. Right lower plot : DAMIC acceptance under two kinds of readout methods : "1×100" and "1×1".

$$\mathcal{O}_1 = 1_\chi 1_N \quad \text{(Spin Independent)}$$
$$\mathcal{O}_3 = i\vec{S}_N \cdot \left[\frac{\vec{q}}{m_N} \times \vec{v}^\perp\right]$$
$$\mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N \quad \text{(Spin Dependent)}$$
$$\mathcal{O}_5 = i\vec{S}_\chi \cdot \left[\frac{\vec{q}}{m_N} \times \vec{v}^\perp\right]$$
$$\mathcal{O}_6 = \left[\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right]\left[\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right]$$
$$\mathcal{O}_7 = \vec{S}_N \cdot \vec{v}^\perp$$
$$\mathcal{O}_8 = \vec{S}_\chi \cdot \vec{v}^\perp$$
$$\mathcal{O}_9 = i\vec{S}_\chi \cdot \left[\vec{S}_N \times \frac{\vec{q}}{m_N}\right]$$
$$\mathcal{O}_{10} = i\vec{S}_N \cdot \frac{\vec{q}}{m_N} \quad \text{ArxiV : 1008.1591}$$
$$\mathcal{O}_{11} = i\vec{S}_\chi \cdot \frac{\vec{q}}{m_N} \quad \text{Arxiv : 1203.3542}$$
$$\mathcal{O}_{12} = \vec{S}_\chi \cdot \left[\vec{S}_N \times \vec{v}^\perp\right] \quad \text{Arxiv : 1308.6288}$$
$$\mathcal{O}_{13} = i\left[\vec{S}_\chi \cdot \vec{v}^\perp\right]\left[\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right] \quad \text{ArxiV : 1503.03379}$$
$$\mathcal{O}_{14} = i\left[\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right]\left[\vec{S}_N \cdot \vec{v}^\perp\right]$$
$$\mathcal{O}_{15} = -\left[\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right]\left[\left(\vec{S}_N \times \vec{v}^\perp\right) \cdot \frac{\vec{q}}{m_N}\right]$$





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 considering different DM interaction operators is under review and will be available soon.