

CCD detectors for dark matter searches

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U.Zürich

CHIPP workshop on Detector R&D
Sept. 2013

Previous results in Phys. Lett. B 711, 264-269 (2012)
[arXiv:1105.5191](#)

Thanks ...

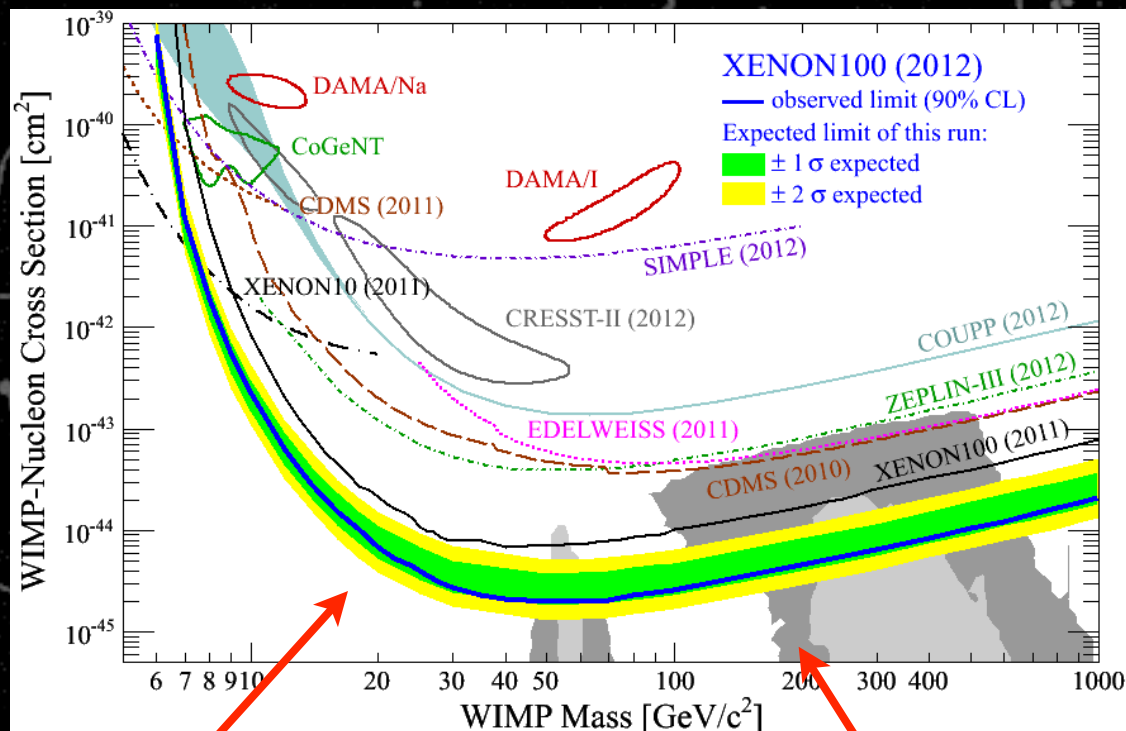


Thanks ...



For making me feel at home !

Status of DM searches



Hints of
signal at
lower masses

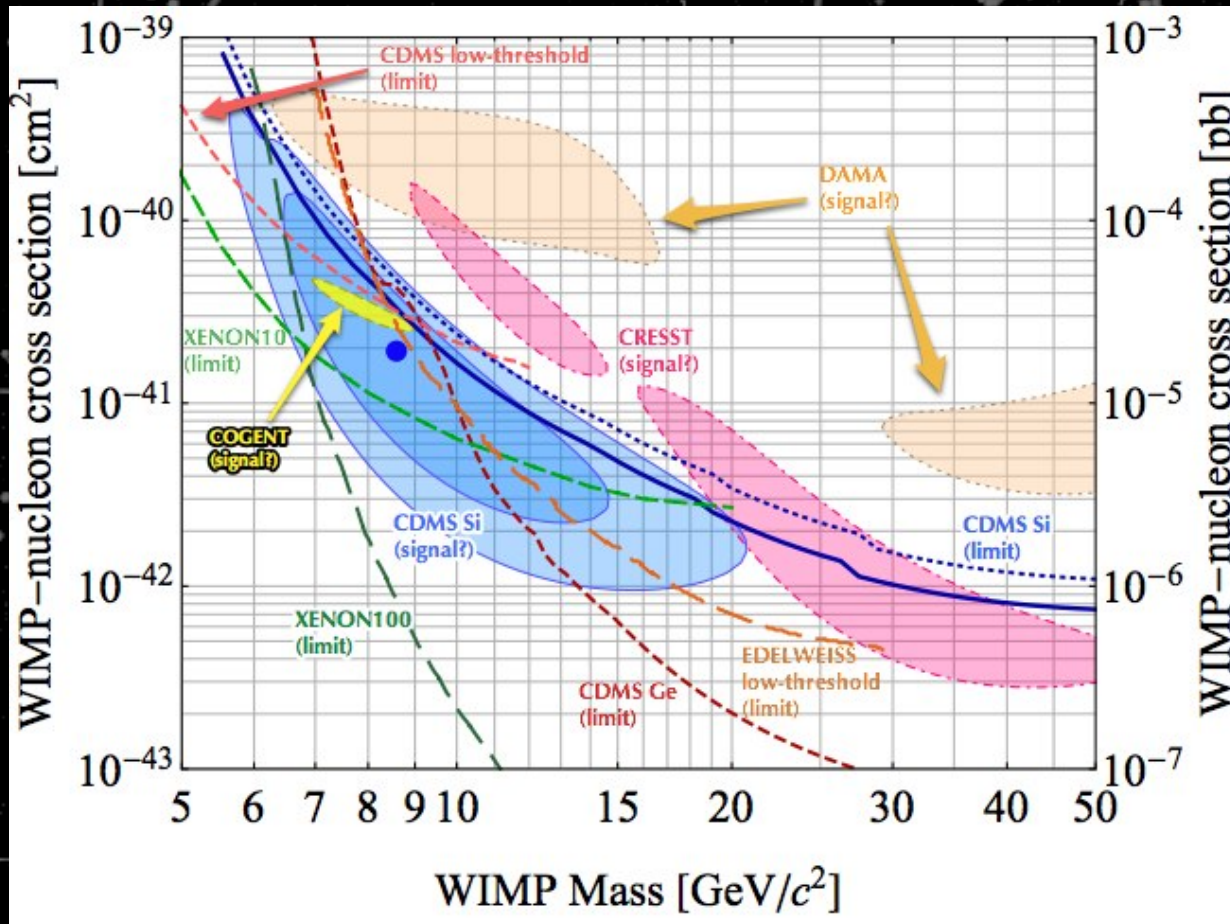
CMSSM
prefers heavy
WIMPs ~ 200
GeV
But ...
increasingly
ruled out by
LHC

Limited by threshold, typically a few keV
(need lower energy detection)

Limited by exposure mass
(need bigger detector)
multi-kg-sized detectors

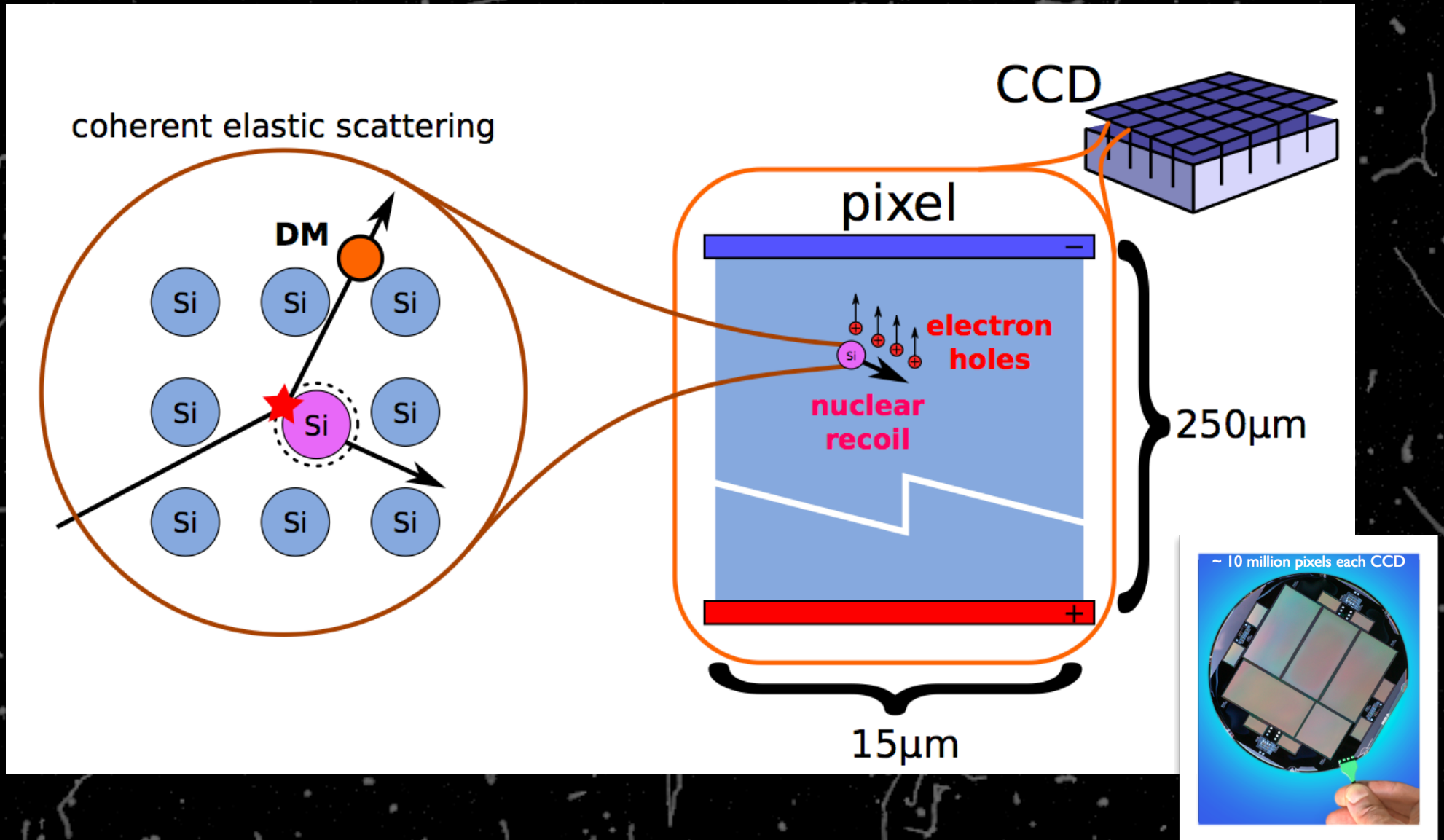
Where there may be signals

- Now large collection of low mass dark matter signals (or underestimated backgrounds)
- Though mostly excluded by Xenon10 & Xenon100

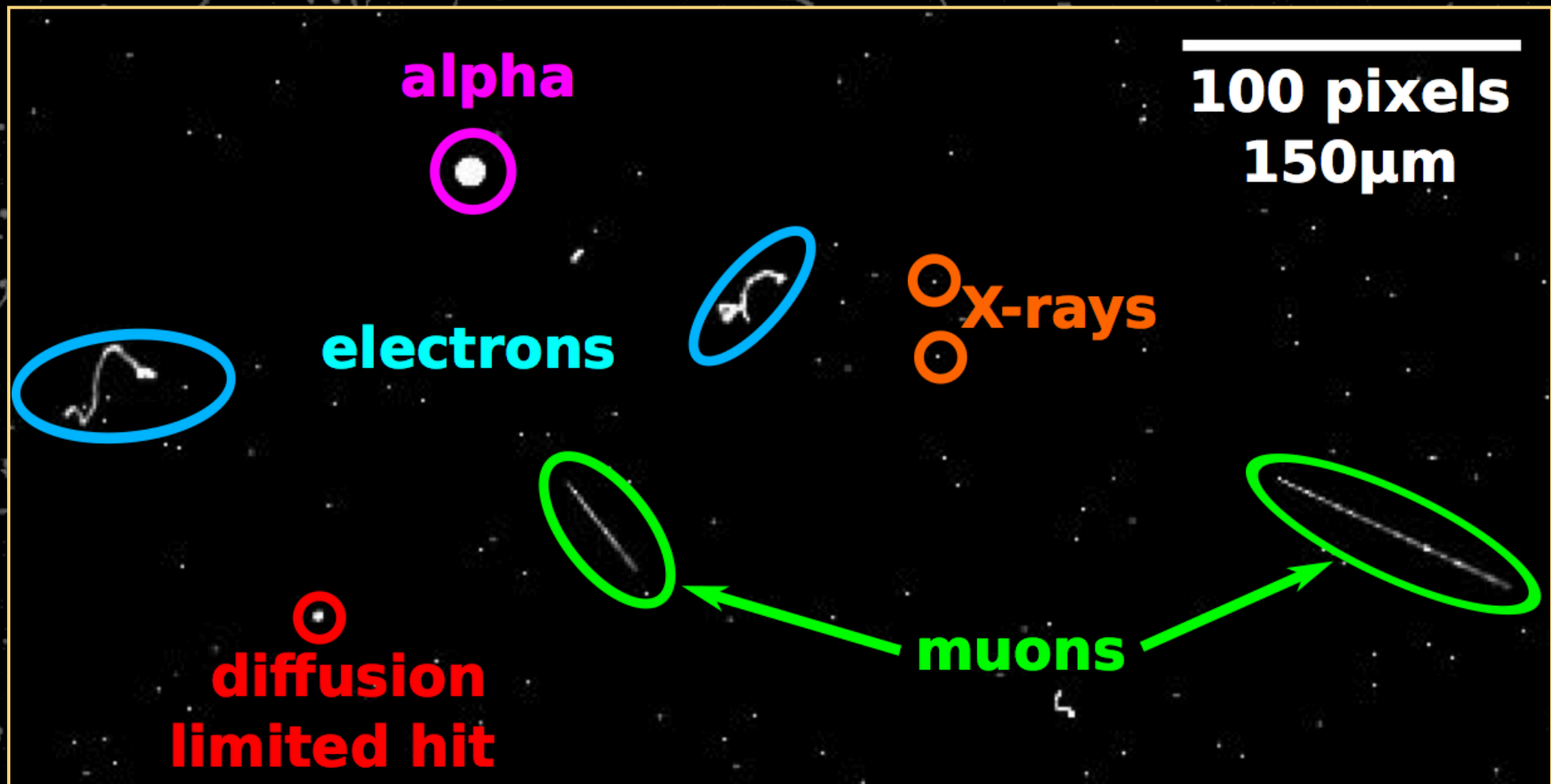


- Low mass dark matter ($\sim < 10$ GeV) search region interesting
- Key is detection of low energy nuclear recoils

Scientific CCDs for searching for DM

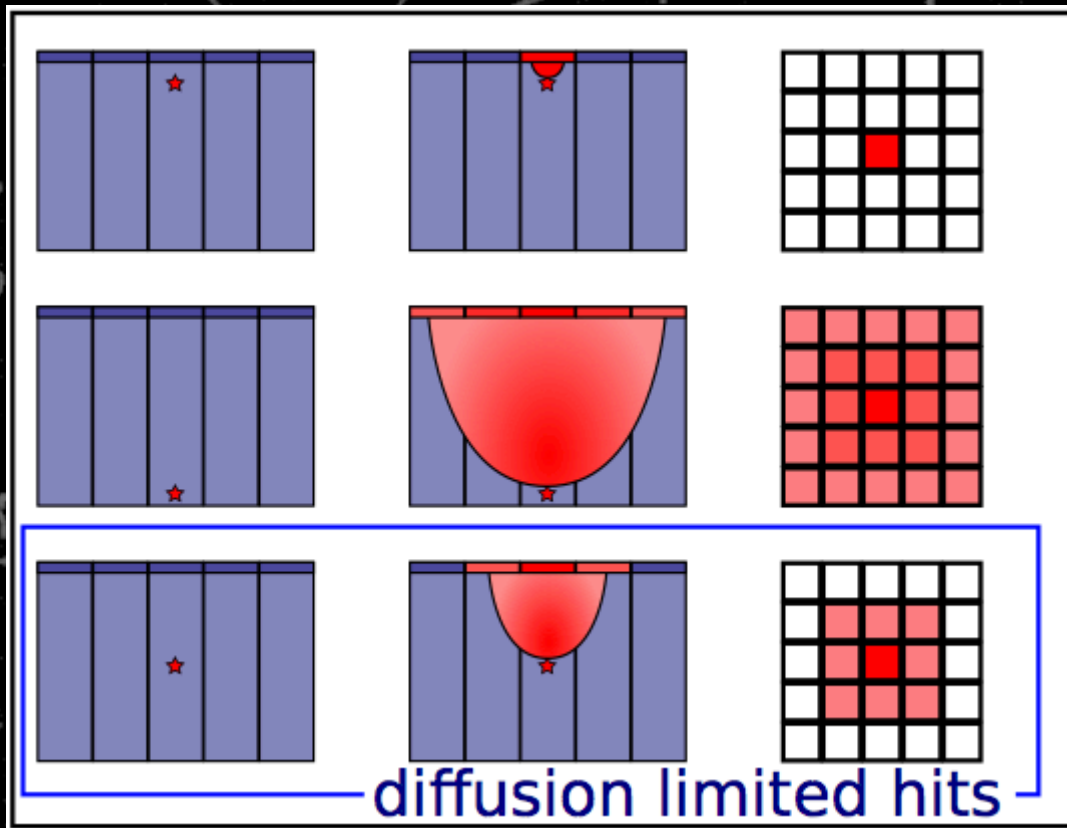


Particle identification in CCD

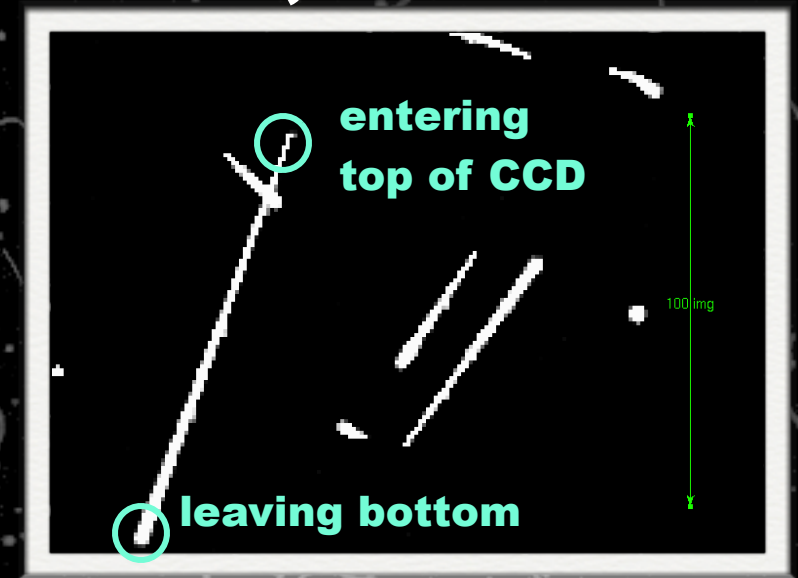


Diffusion of charge

- **Size of hit depends on location within pixel**

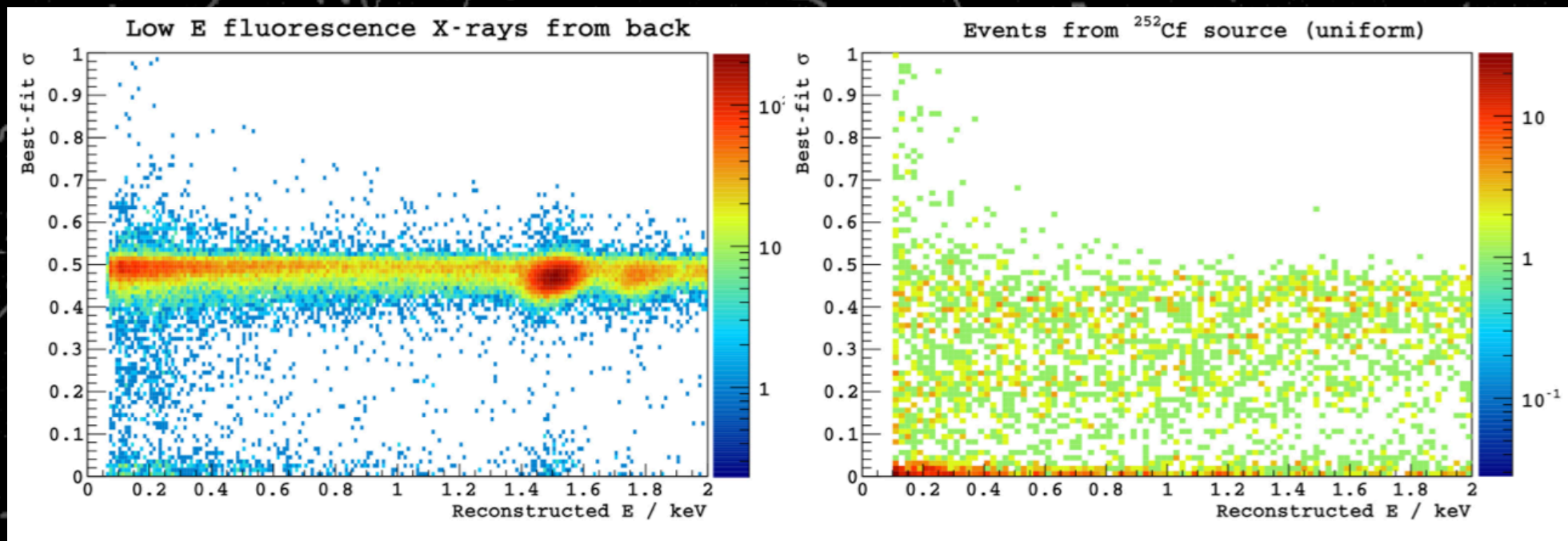


ie, muons



- **Maximal (minimal) diffusion at bottom (top) of CCD**

Self-shielding with diffusion

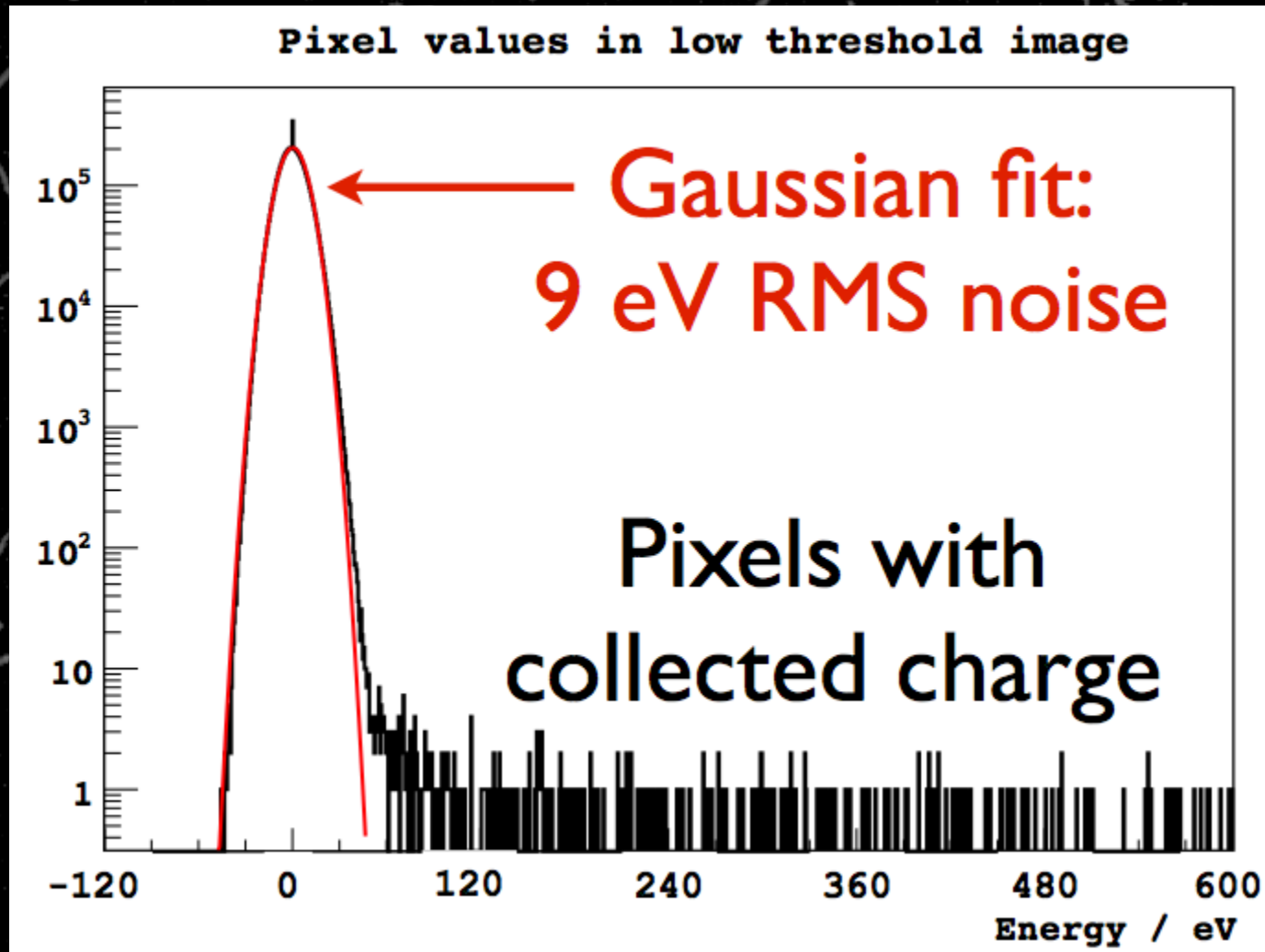


X-rays
bkg-like

Neutrons
signal-like

- **Maximal diffusion $\sim 7\mu\text{m}$ (0.5 pixel) RMS**
- **Can be used to reject surface events**

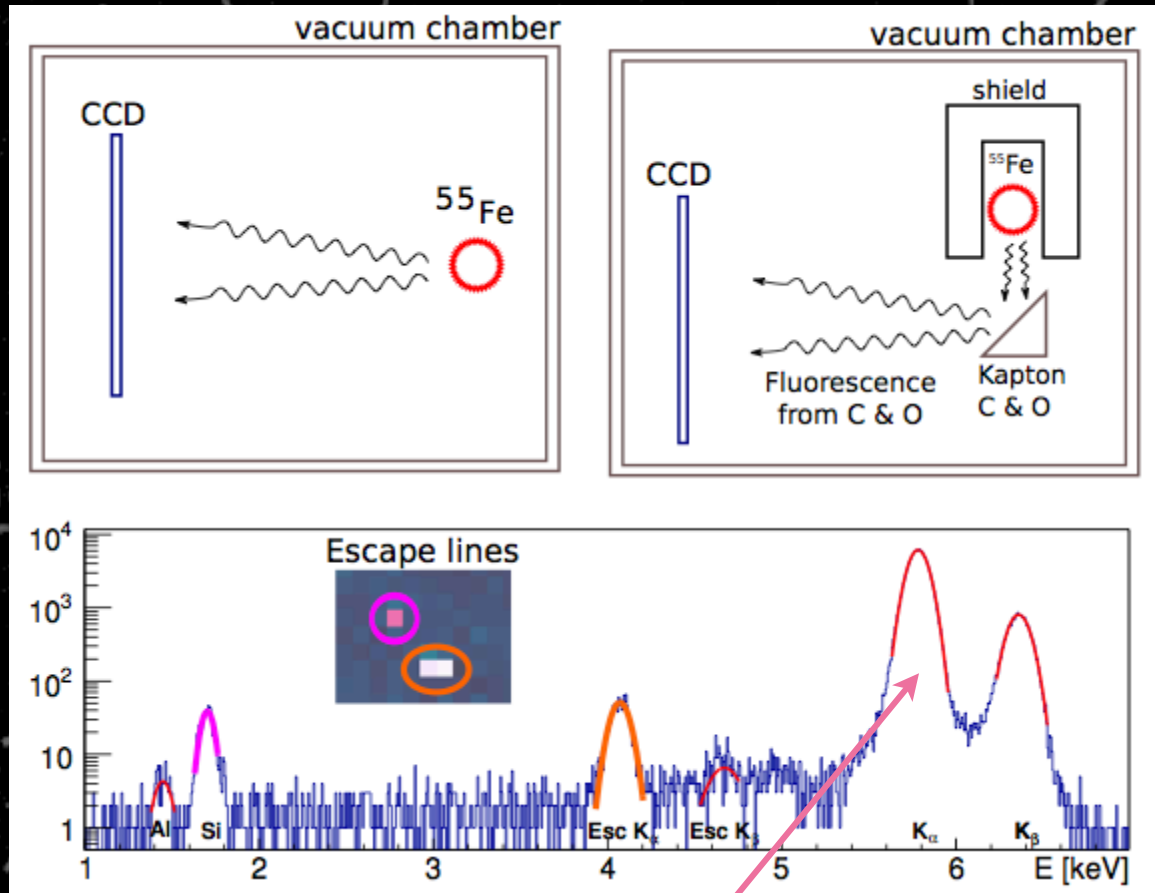
Noise measurement



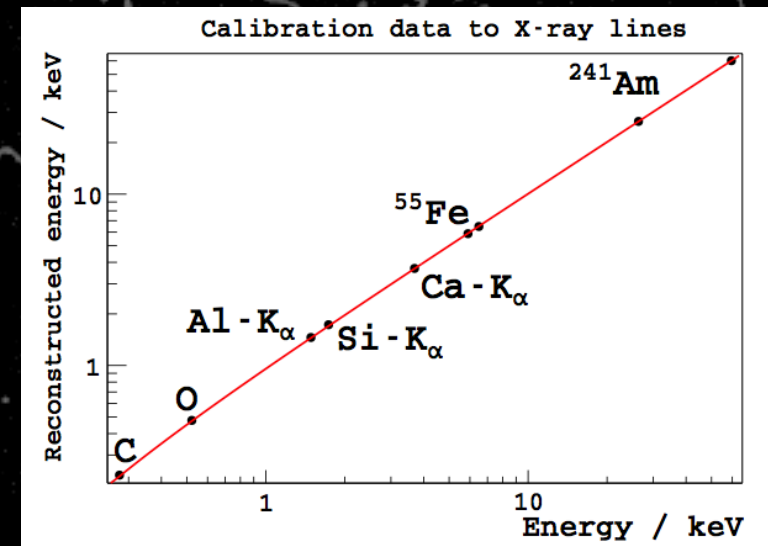
- **Allows lowest energy threshold of current dark matter experiments ~ 50 eV**

Energy calibration

- **X-rays and fluorescence X-rays**



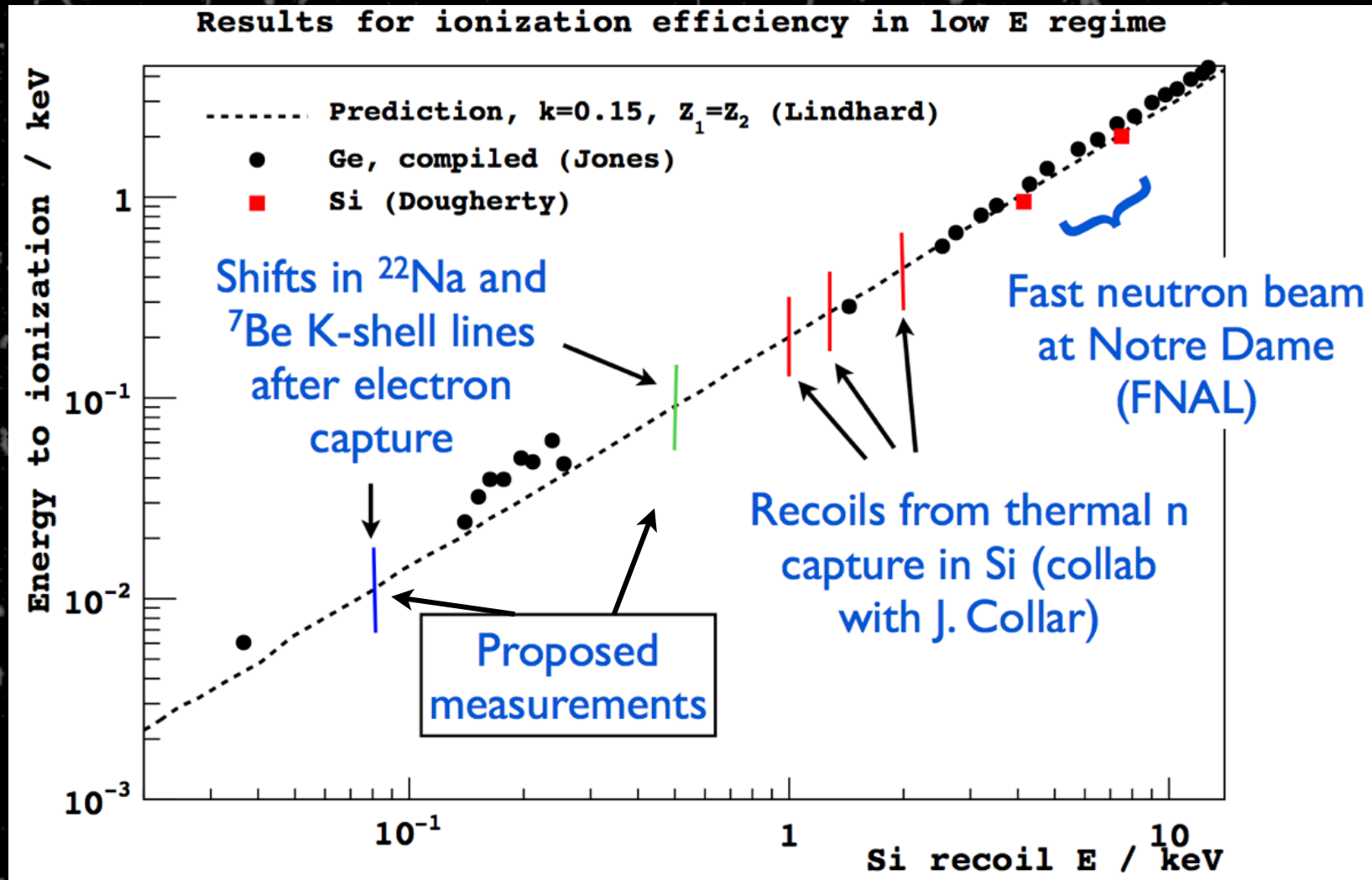
- **60 eV RMS at 6 keV**



- **Linear response**

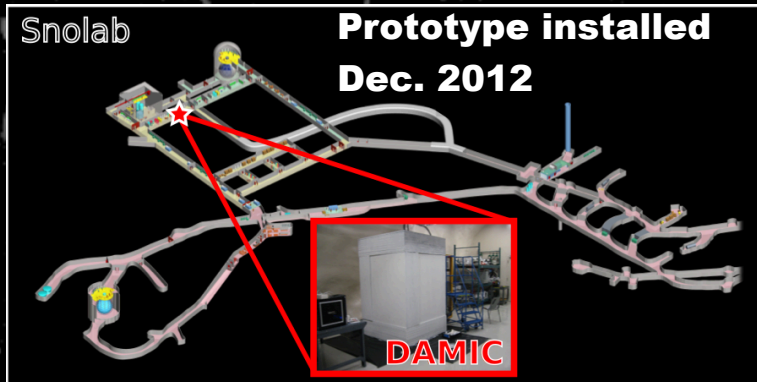
Ionization efficiency for nuclear recoils

- Challenge is to provide dependable calibration down to 50 eV energy threshold

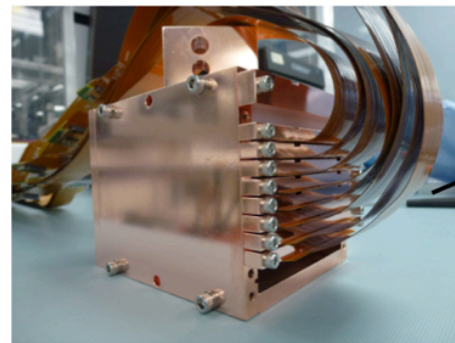
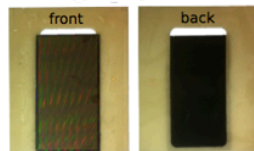


Experimental setup

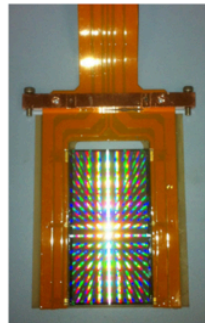
- DAMIC prototype in operation at SNOlab



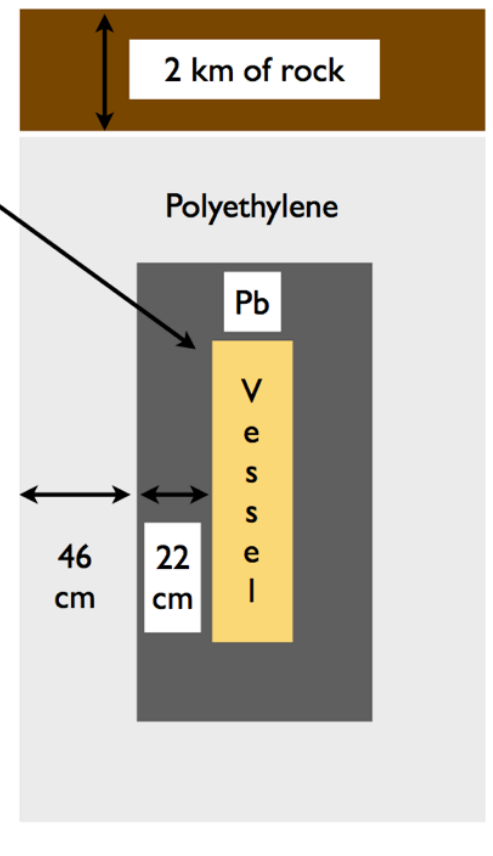
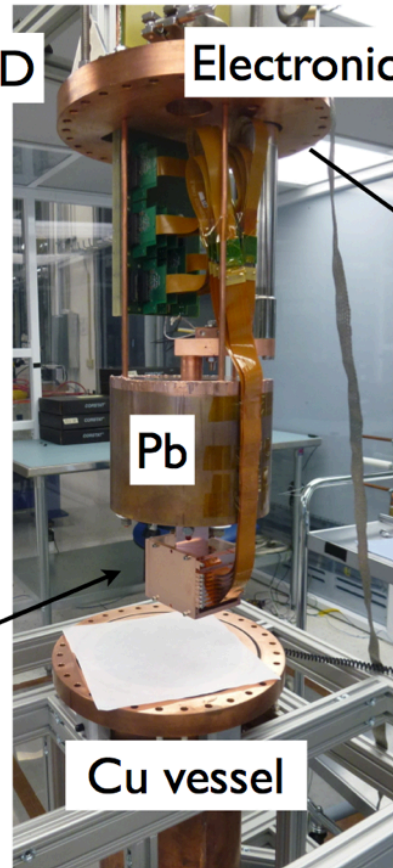
Frame AlN



Wired CCD

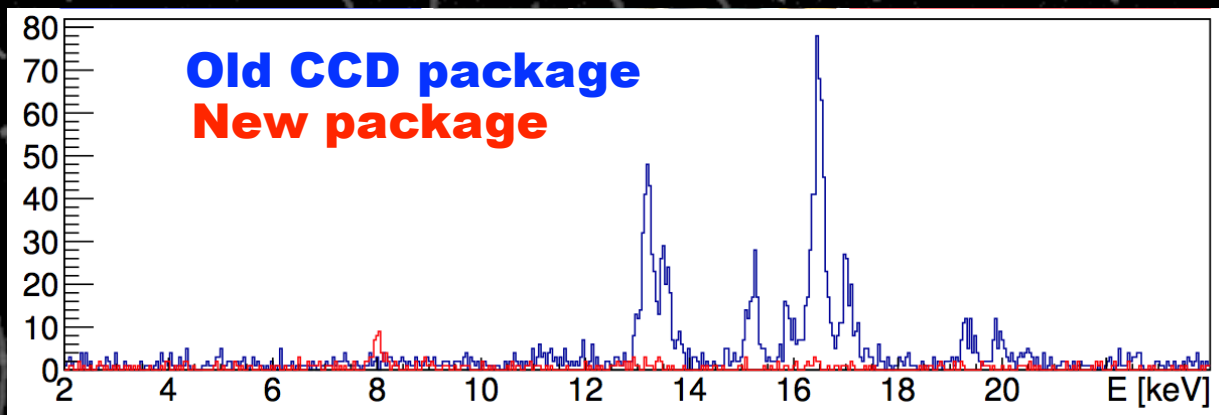
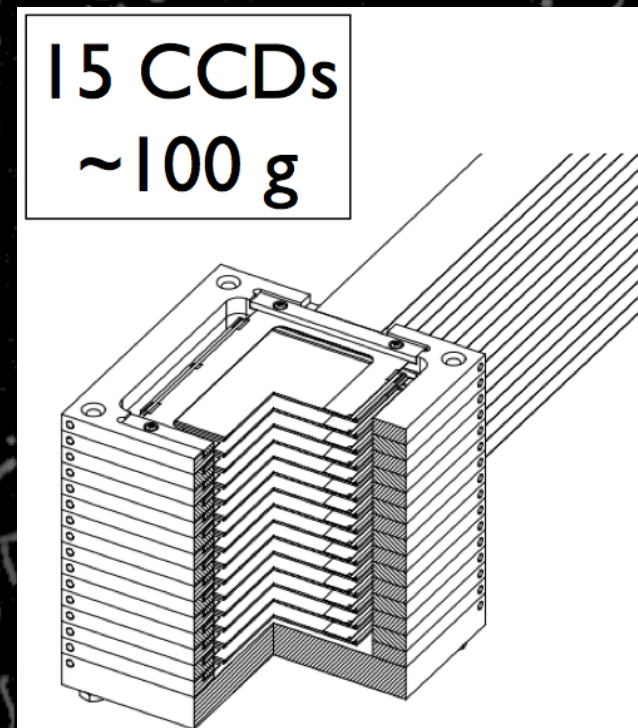


Electronics



Upgrade to DAMIC 100

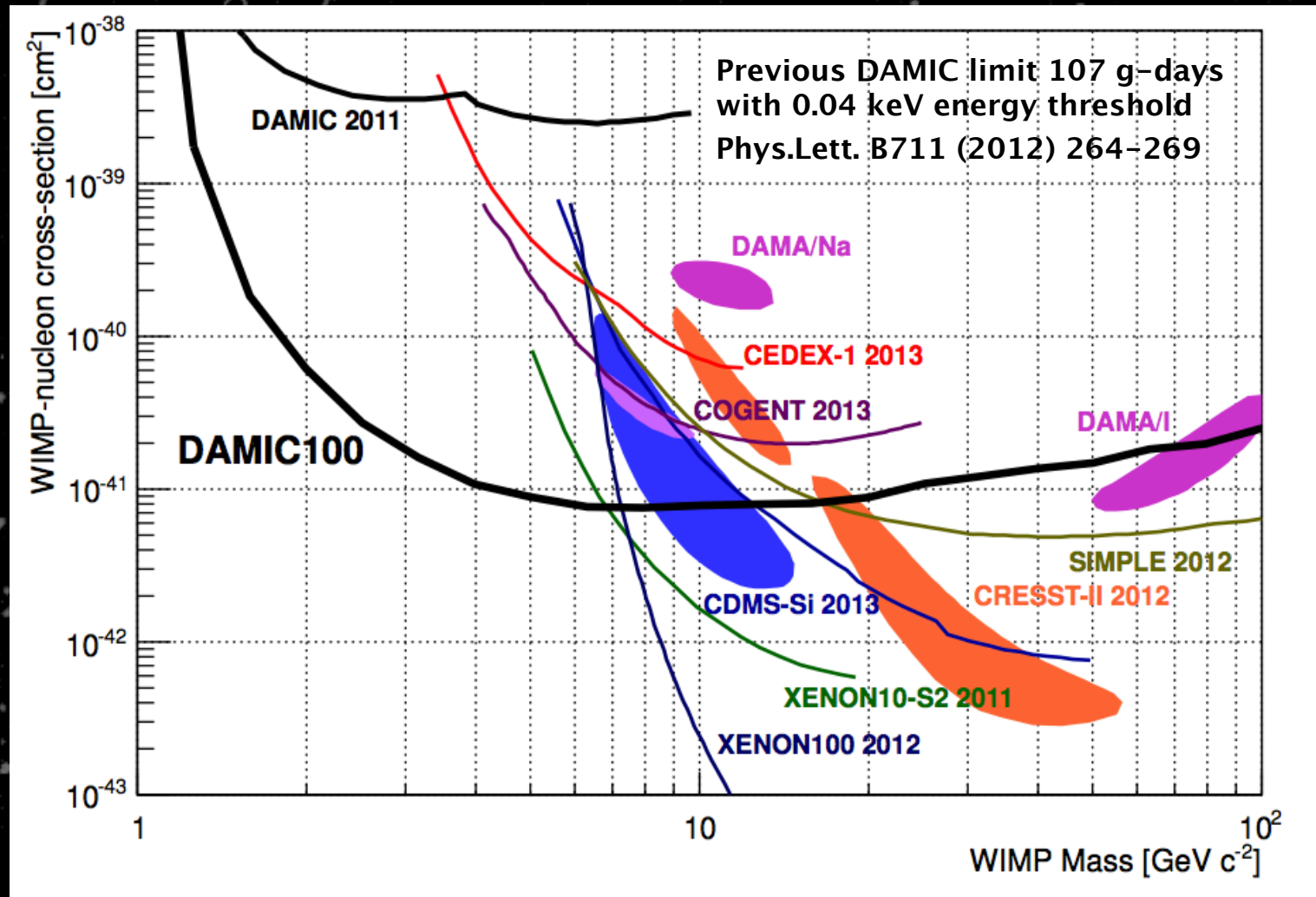
- **LBL CCD group is building us even thicker, fully depleted high resistivity CCDs (500 μm)**
 - 4 times the mass
 - Can now reach 100 g of detector mass
- **Prototype revealed dominant background from U^{238} in Al N substrate of CCD package $\sim 3 \text{ Bq kg}^{-1}$**
 - Solved in new CCD design
 - Also removed astronomy-related material additions



DAMIC 100 :
Fermilab, U. Chicago,
U. Zürich, U. Michigan,
UNAM, FIUNA, CAB

Projected sensitivity

- DAMIC 100 with 1 year of data



- Will test much of low mass interesting region

Ongoing R & D

- **Neutron energy response at low energy**
 - **Electron Capture from irradiated silicon (calibration at ~ 100 eV) : could be done at PSI**
- **Lower energy calibrations still needed**
- **Improved readout - multiple sampling (skipper) of CCD data can yield sub-eV noise**
- **CCD limitation is long exposure time : 1000s of seconds - no timing to reject triggerable backgrounds**
- **Other types of silicon detectors with fast readout and low background noise can be investigated**

Conclusions

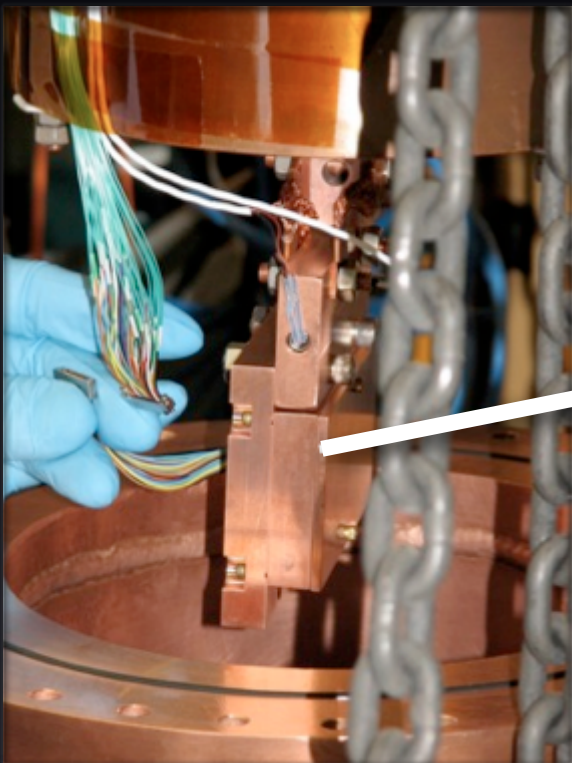
- **CCDs are a viable particle detector for low mass dark matter**
- **Can provide useful constraints on an exciting mass range for dark matter**
- **Relatively cheap (DAMIC 100 ~ 400 kCHF)**
- **Detector R&D advancing with thick, high resistivity, low noise scientific CCDs**
- **U. Zürich is playing a leading role in this experiment**
 - **Building a CCD lab for testing and calibrations**



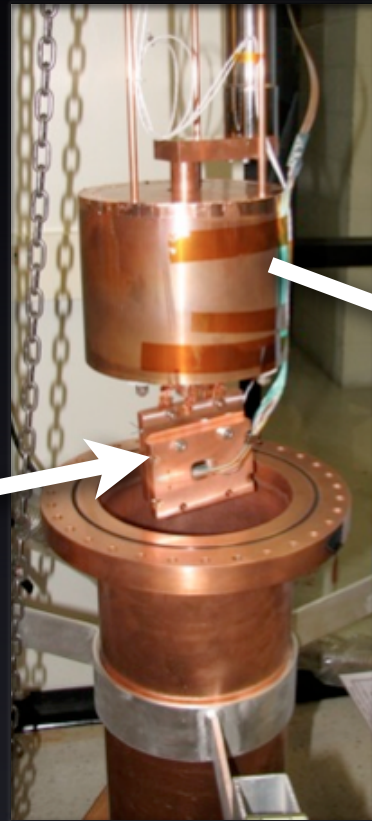
BACKUPS

DAMIC 2011

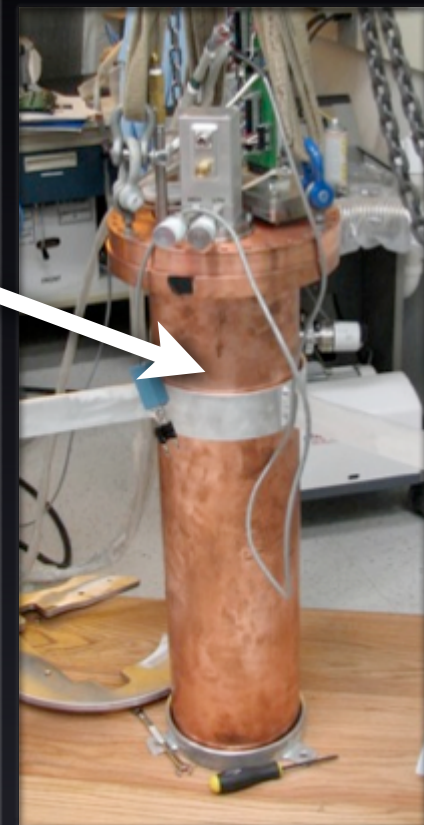
**CCD Inside a
cold Cu box**



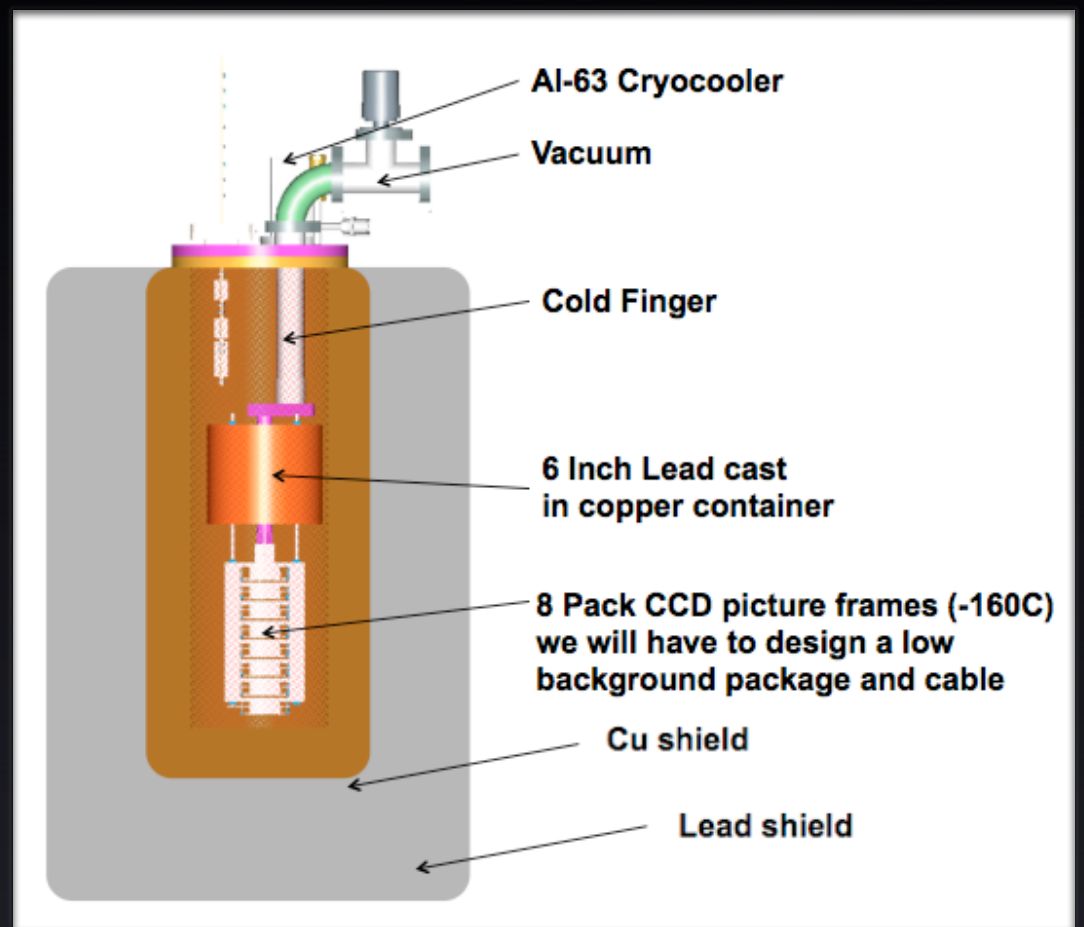
Lead Bucket



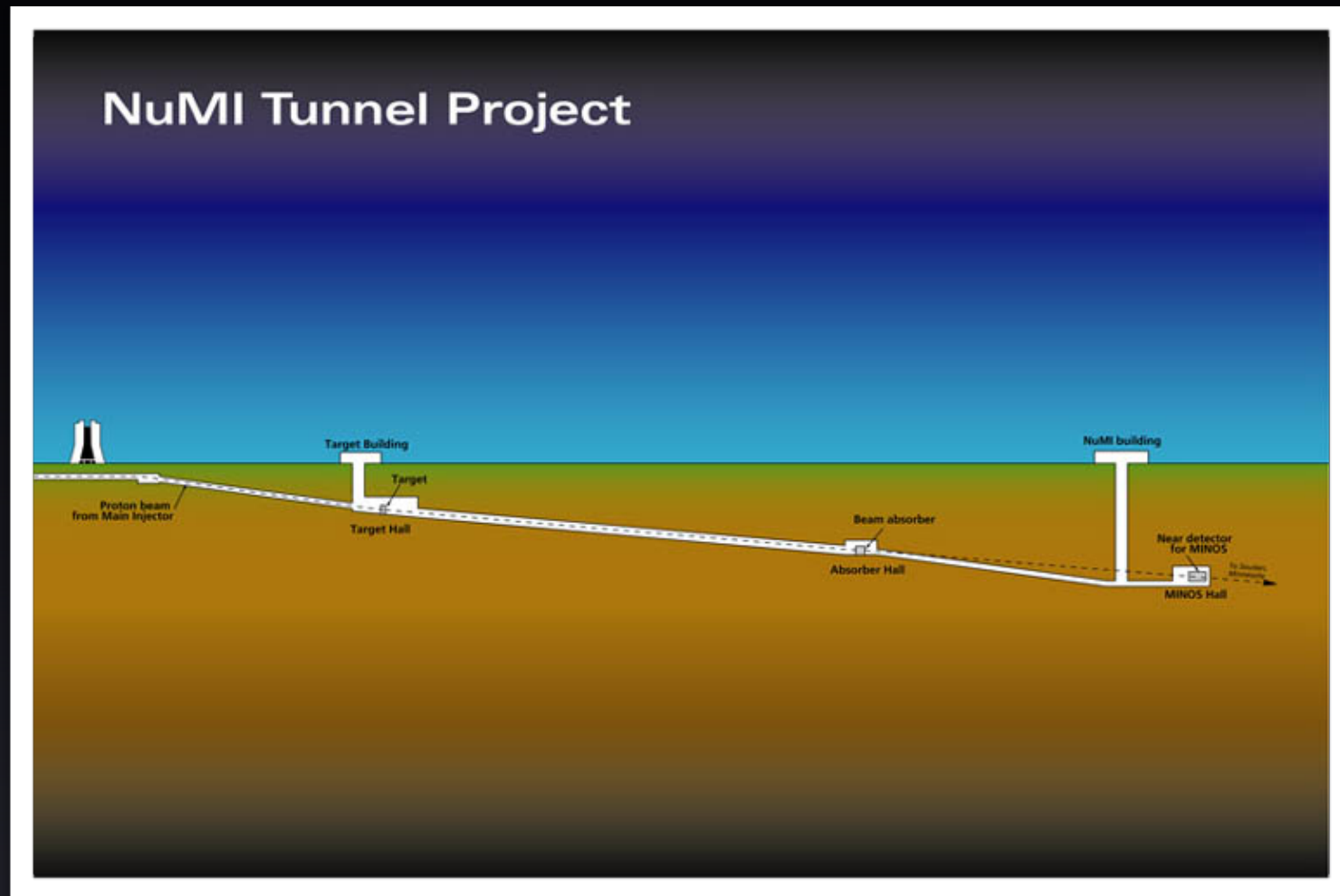
**Cylindrical
Cu Dewar**



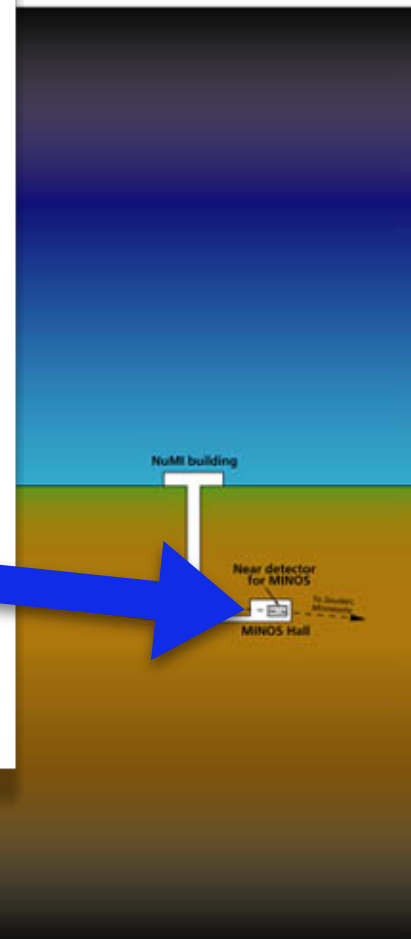
DAMIC 2011



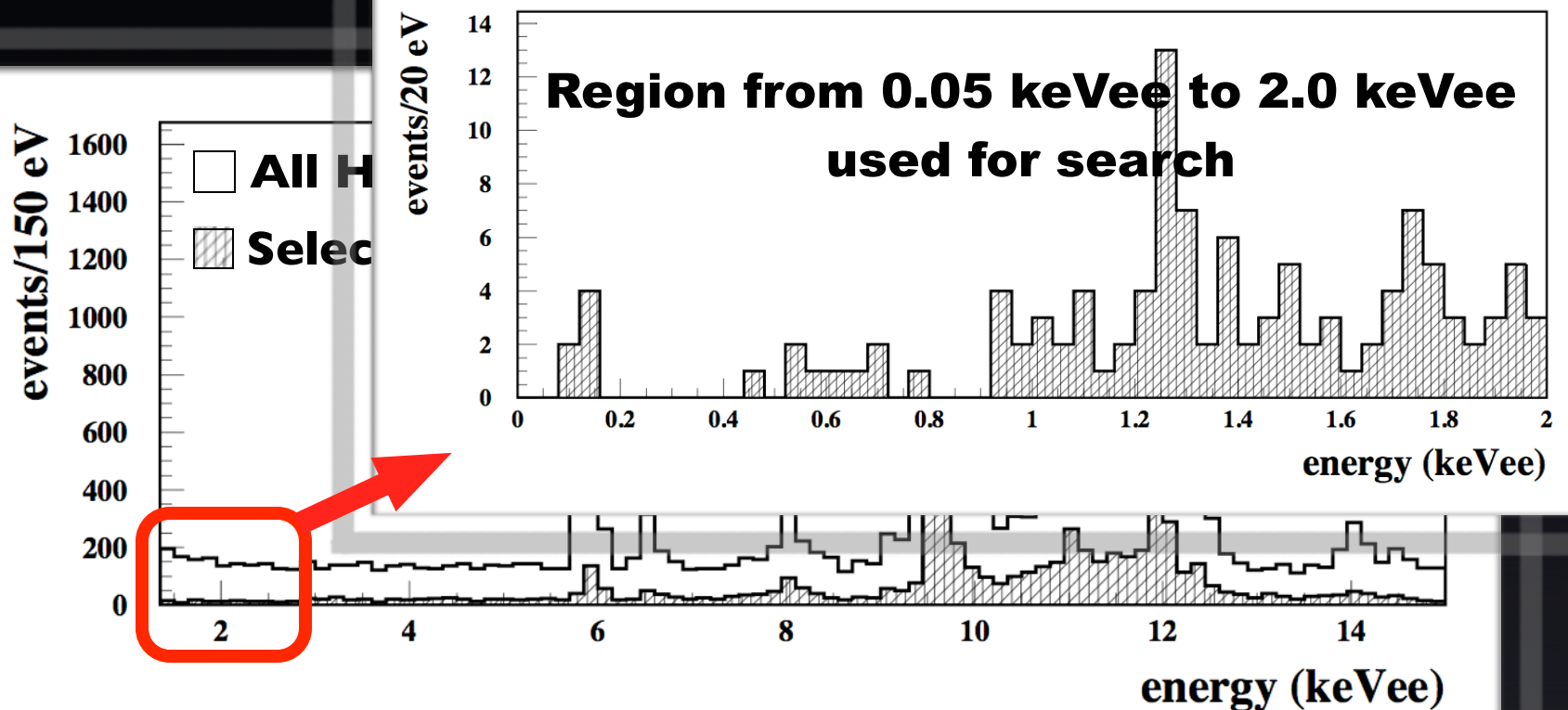
DAMIC 2011



DAMIC 2011



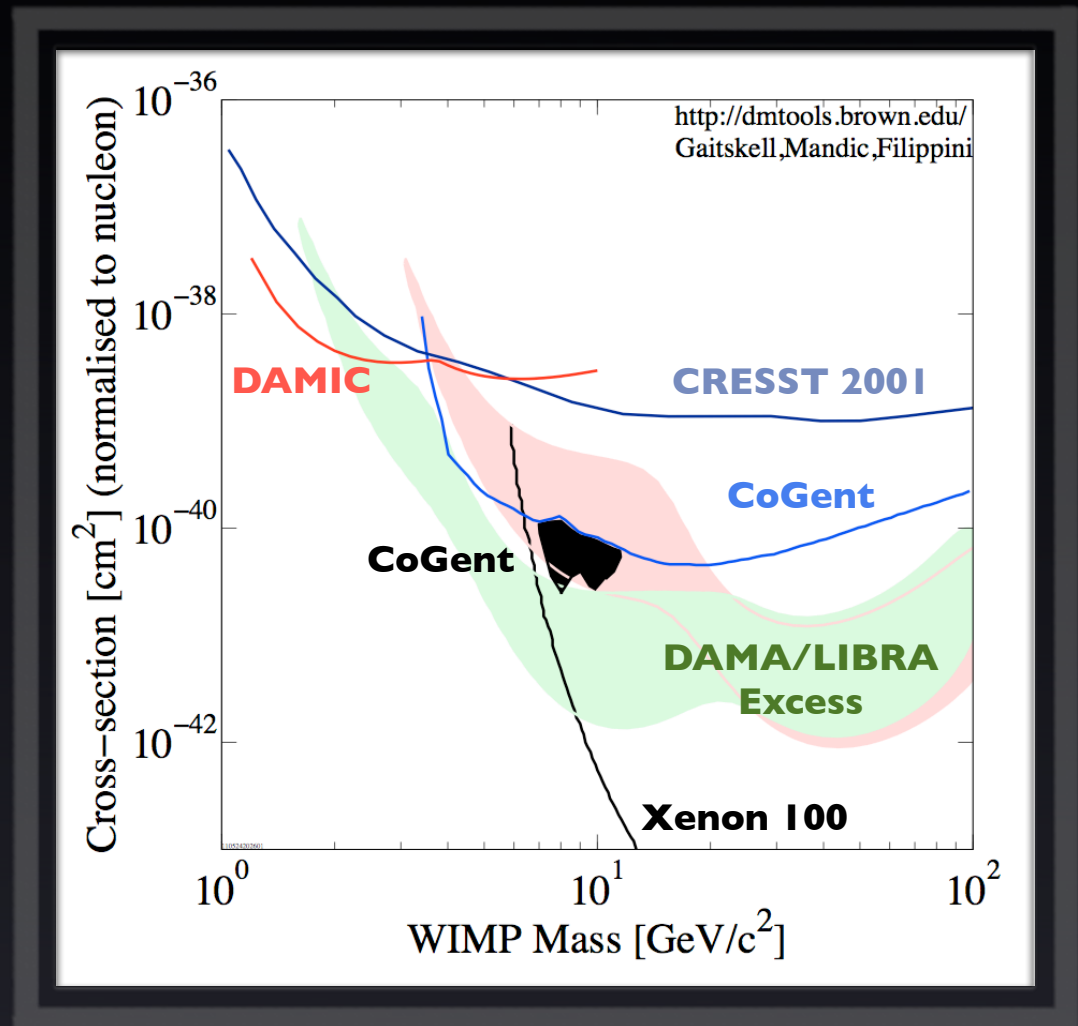
Energy Spectrum



Results from 2011 Run

- **Wimp density**
→ **0.3 GeV/cm**
- **$V_{\text{earth}} = 244 \text{ km/s}$**
- **$V_{\text{escape}} = 650 \text{ km/s}$**

Assumes Lindhard quenching factor
for conservative limits



Results from First Run

Direct Search for Low Mass Dark Matter Particles with CCDs

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(Dated: August 17, 2011)

A direct dark matter search is performed using fully-depleted high-resistivity CCD detectors. Due to their low electronic readout noise (RMS \sim 7 eV) these devices operate with a very low detection threshold of 40 eV, making the search for dark matter particles with low masses (\sim 5 GeV) possible. The results of an engineering run performed in a shallow underground site are presented, demonstrating the potential of this technology in the low mass region.

PACS numbers: 93.35.+d, 95.55.Aq

I. INTRODUCTION

There have been several direct-detection experiments searching for dark matter (DM) performed in recent years, and several more in development. [1]. Most of these experiments have been optimized for detecting the elas-

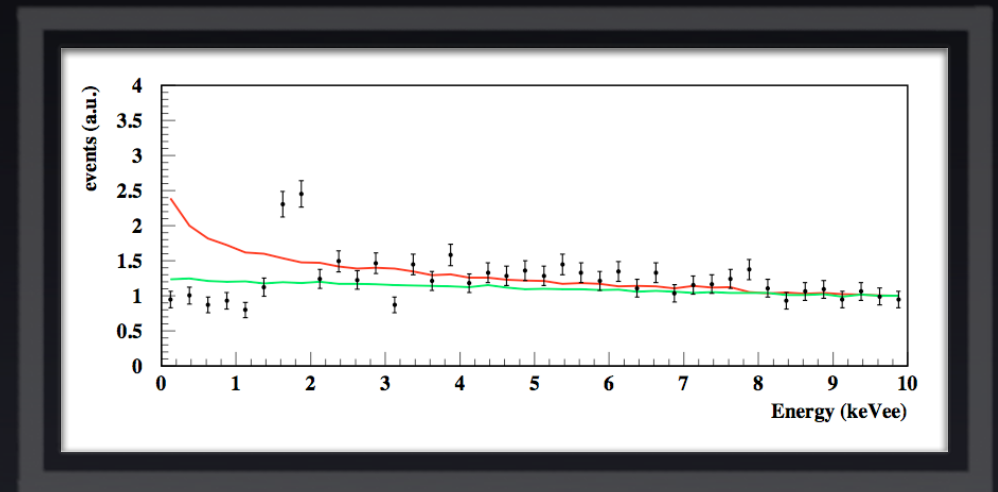
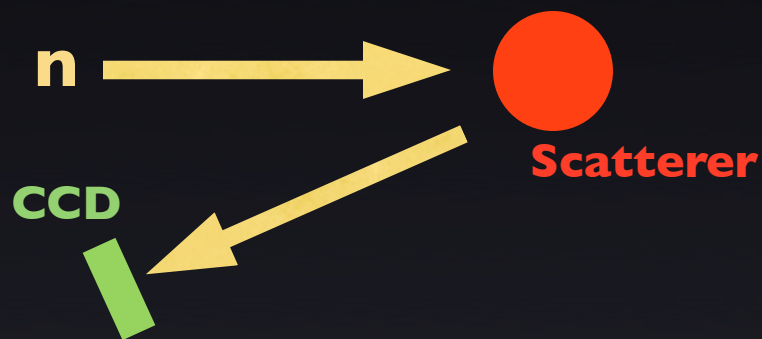
of their very low fiducial mass. The use of thick, fully-depleted CCDs allows for a lower threshold than conventional CCDs. The Dark Matter in Geology experiment is the first DM search using this technology.

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Ramping Up!

Calibrating to Lower Energy

- **Using a mono-energetic beam of neutrons to calibrate quenching factor to very low energies**



Naturalness of Dark Matter Mass scale

1. “Wimp miracle” scale :

- Why do SUSY cross-sections provide correct relic DM density ?

$$M_{\text{DM}} \sim 100 \text{ GeV}$$

2. “Baryon-DM coincidence” scale :

- Why is the DM abundance so close to matter ?

$$\rho_{\text{DM}} \sim 5 \cdot \rho_{\text{M}}$$

- What if dark matter is more baryon-like ?
- Assume $N_{\text{DM}} \sim N_{\text{baryon}}$ in early universe

$$M_{\text{DM}} \sim 5 \text{ GeV}$$

Asymmetric DM hep-ph/1111.0293