DAMIC

August 25th, 2015

DAMIC 1kg at SNOLAB

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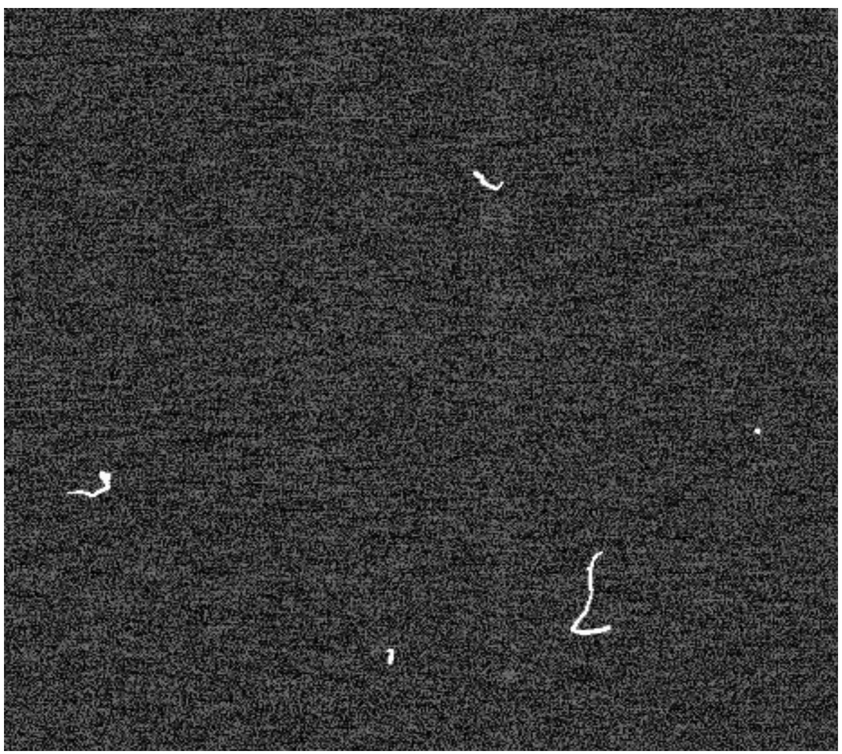
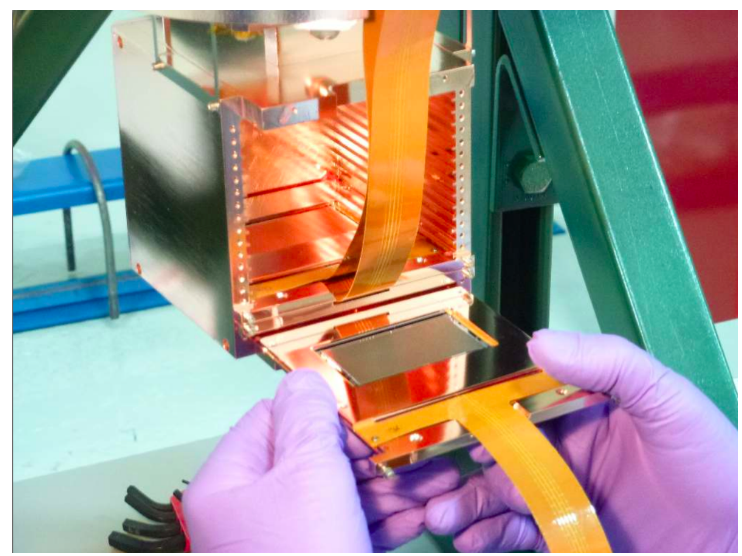
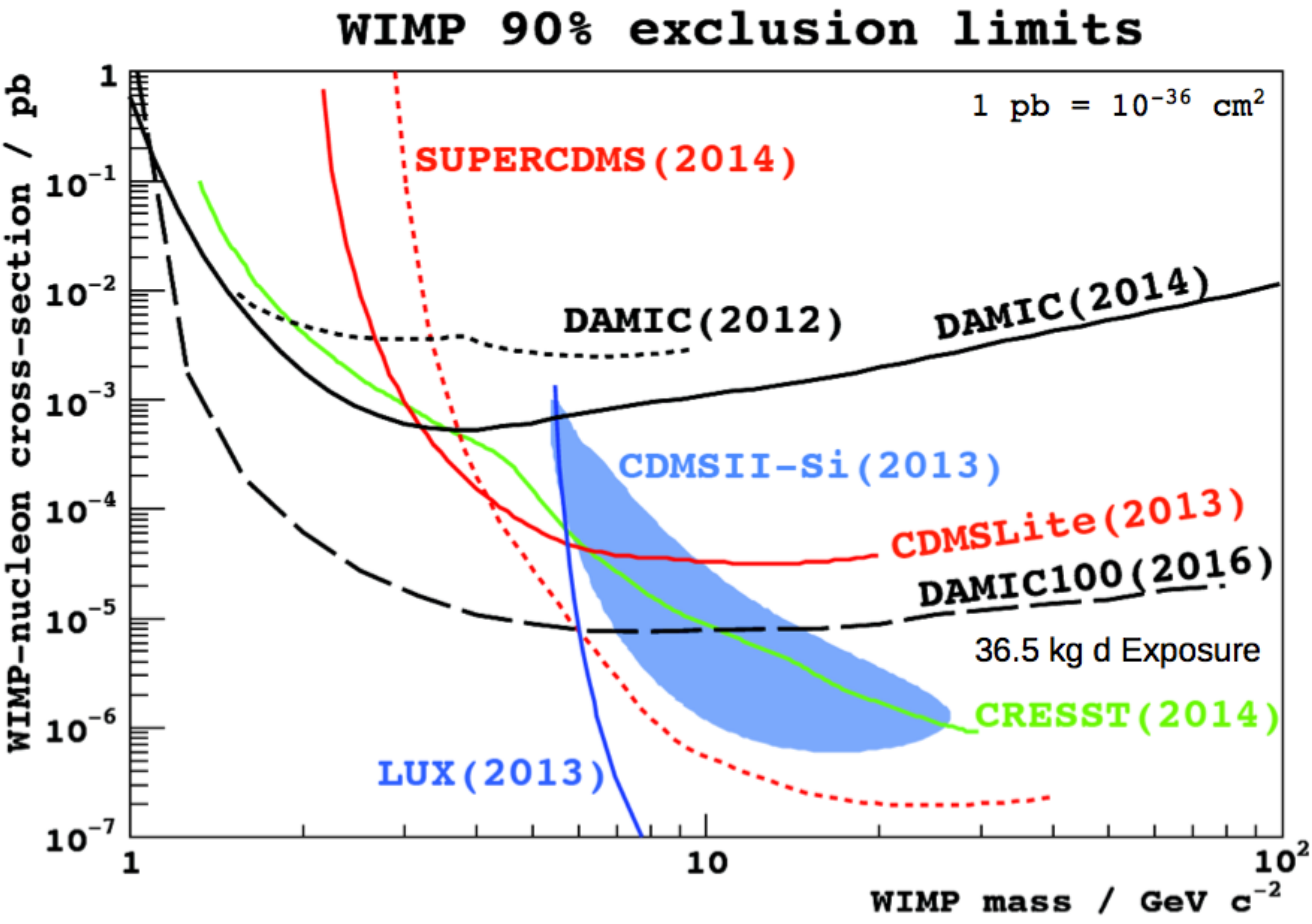
THE UNIVERSITY OF CHICAGO
PHYSICAL SCIENCES

KICP





Dark Matter in CCDs sensitivity



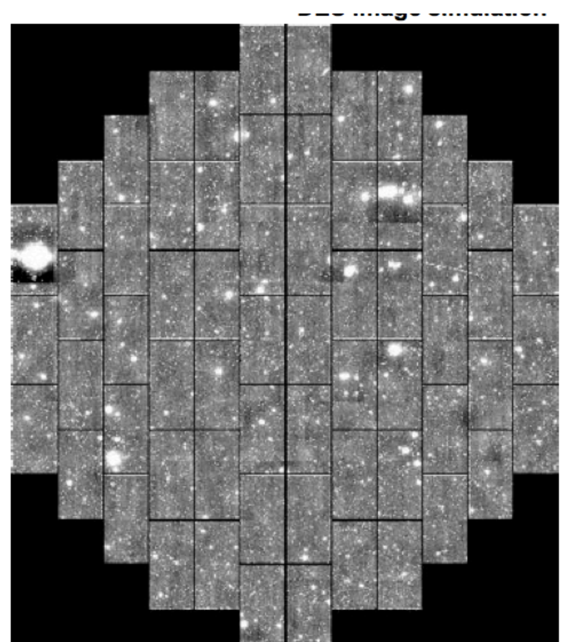
COSMIC RAYS AND OTHER NONSENSE IN ASTRONOMICAL CCD IMAGERS

DON GROOM
Lawrence Berkeley National Laboratory

(Accepted 23 July 2003)

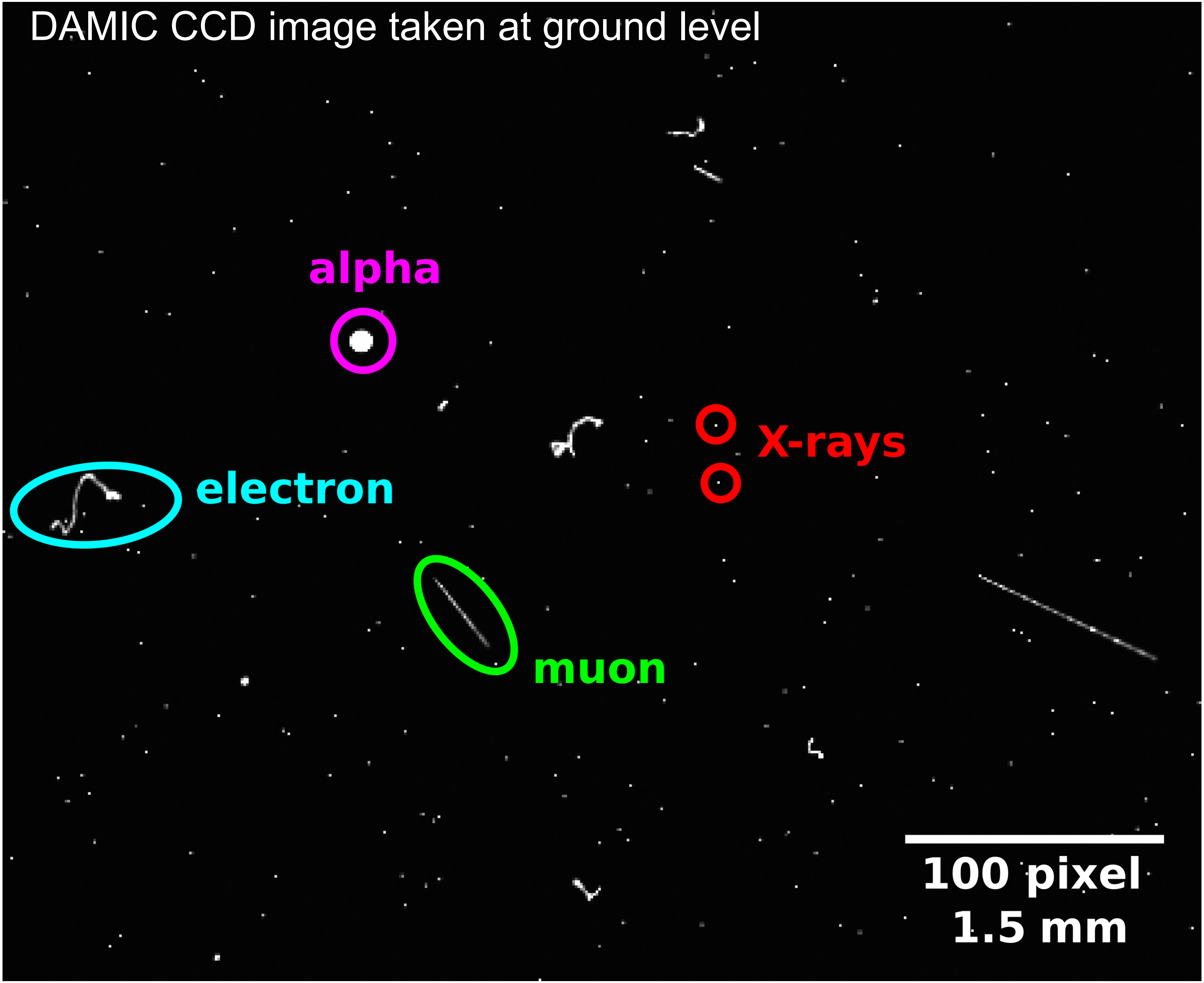
DAMIC enabled by

Abstract. Cosmic-ray muons make recognizable straight tracks in the new-generation CCD's with thick sensitive regions. Wandering tracks ('worms'), which we identify with multiply-scattered low-energy electrons, are readily recognized as different from the muon tracks. These appear to be mostly recoils from Compton-scattered gamma rays, although worms are also produced directly by beta emitters in dewar windows and field lenses. The gamma rays are mostly byproducts of ^{40}K decay and the U and Th decay chains. Trace amounts of these elements are nearly always present in concrete and other materials. The direct betas can be eliminated and the Compton recoils can be reduced significantly by the judicious choice of materials and shielding. The cosmic-ray muon rate is irreducible. Our conclusions are supported by tests at the Lawrence Berkeley National Laboratory low-level counting facilities in Berkeley and 180 m underground at Oroville, California.

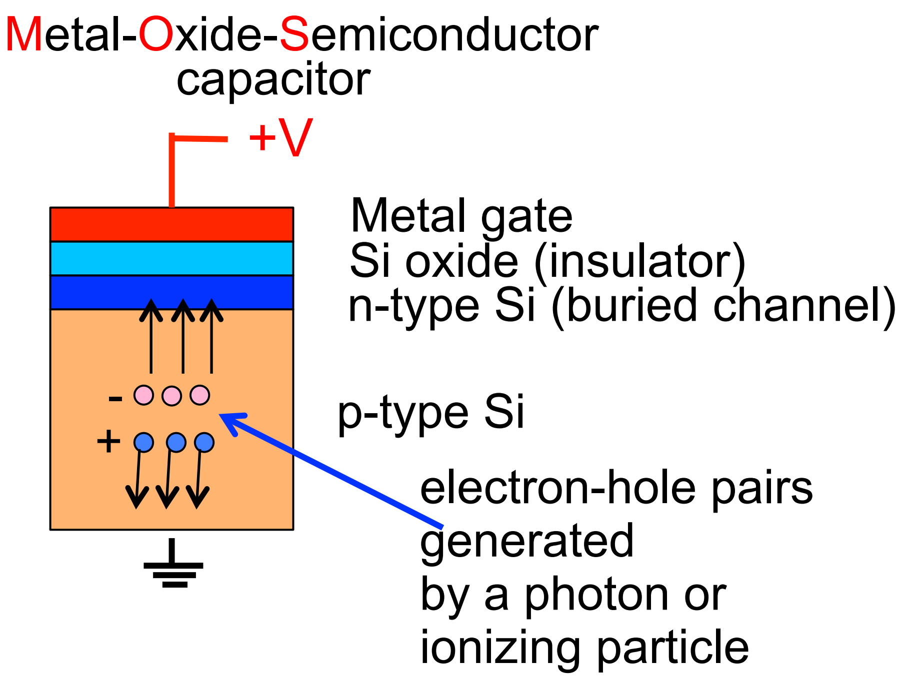


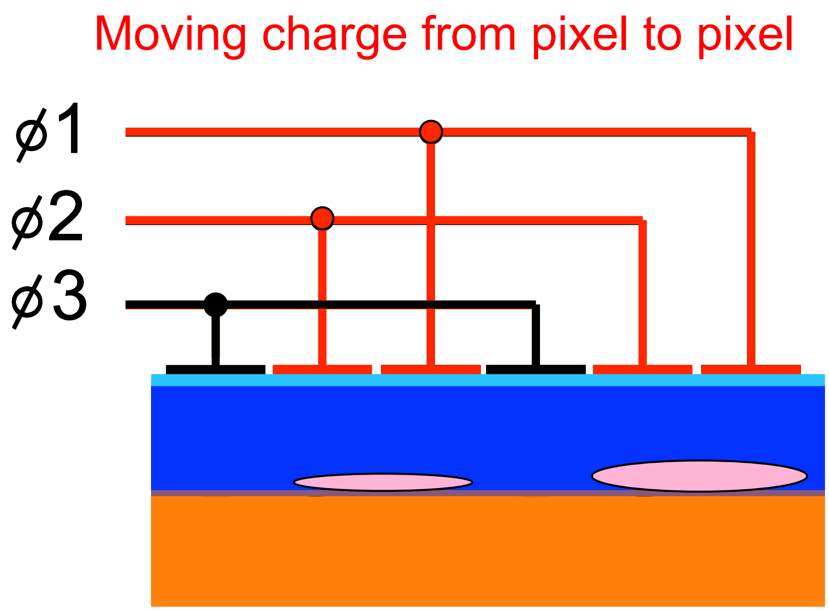
Dark Energy Survey Camera

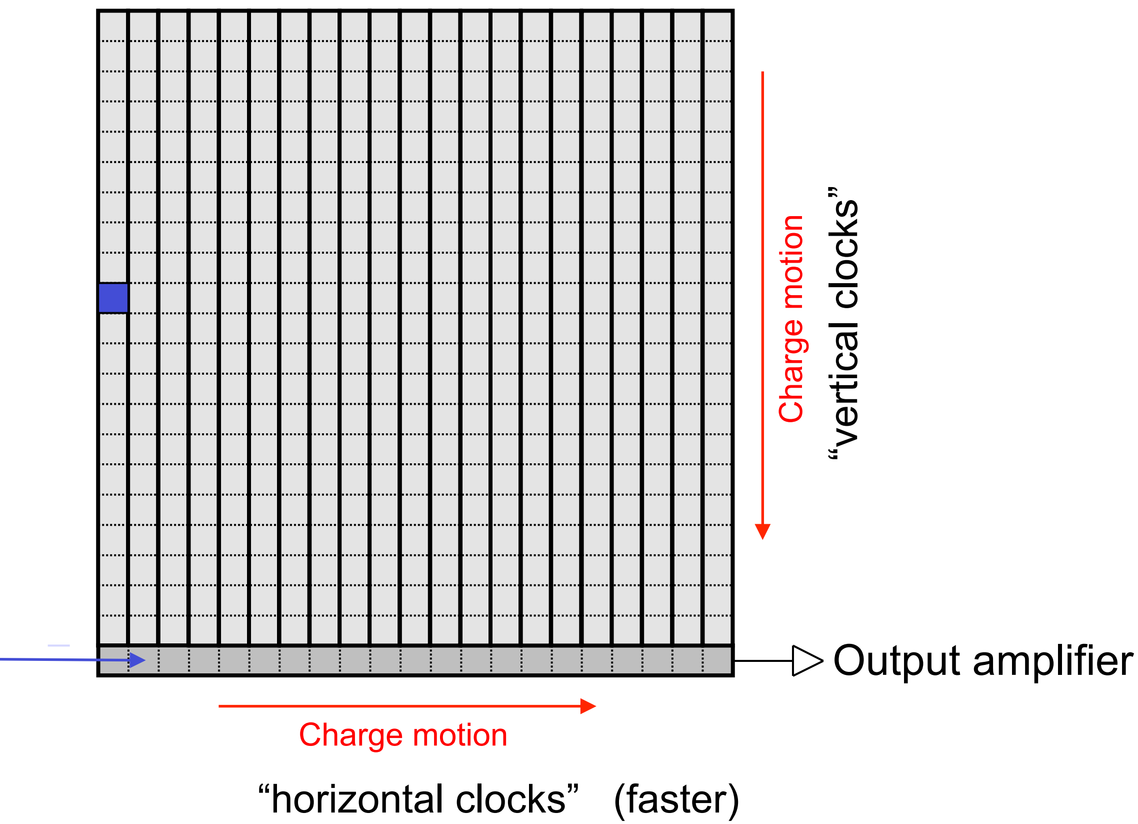
250 μm thick CCDs with enhanced IR sensitivity developed at LBNL


DAMIC CCD image taken at ground level
alpha
electron
muon
X-rays
100 pixel
1.5 mm

CCD principle

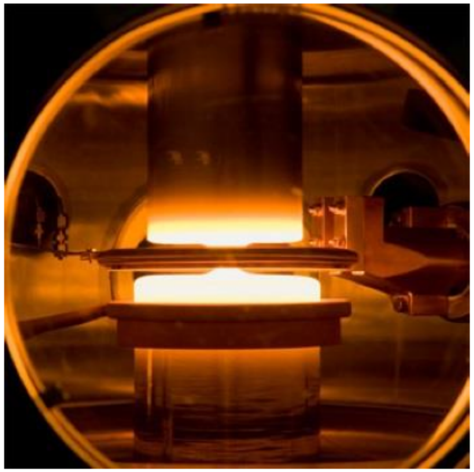
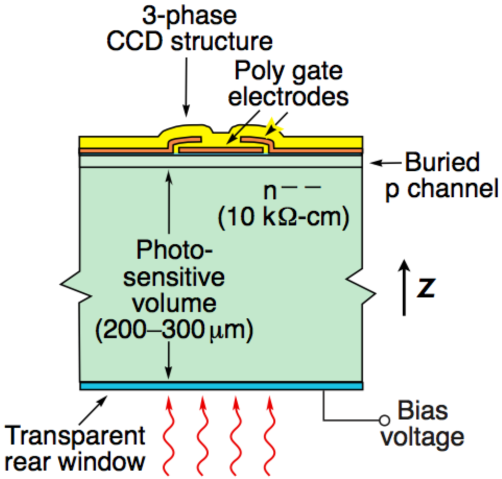


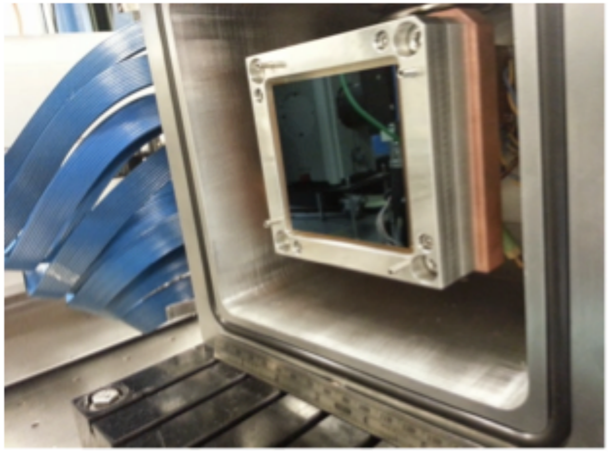




Why high resistivity, thick CCDs for DM detection

- High-resistivity (10^{11} donors/cm^3) – extremely pure silicon



- Fully-depleted over several 100s μm (typical CCDs few tens of μm)

Sizable mass (a DAMIC CCD, 6 cm x 6 cm, 4k x 4k 15 μm pixels, has a record thickness of 675 μm for a 5.9 g mass)

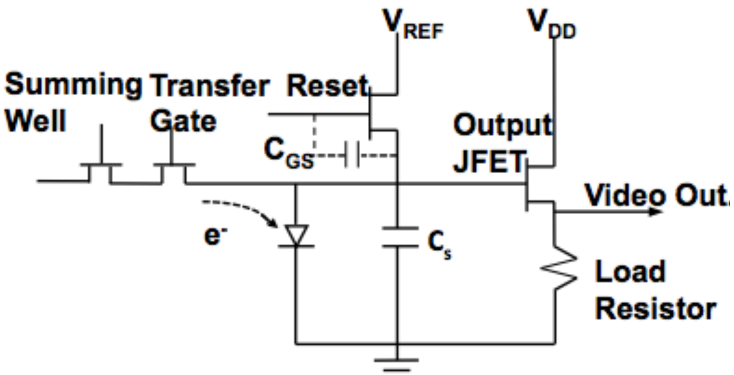
- Unprecedented low energy threshold

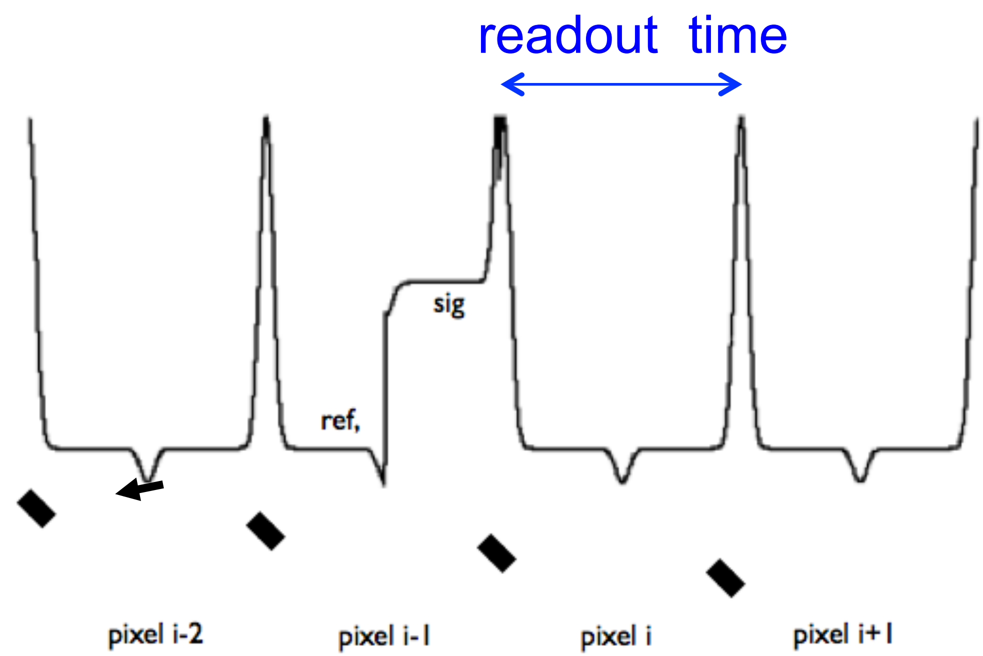
3.6 eV to produce 1 e-hole pair   Pixel noise σ ≈ 2e$^-$ ≈ 7.2 eV

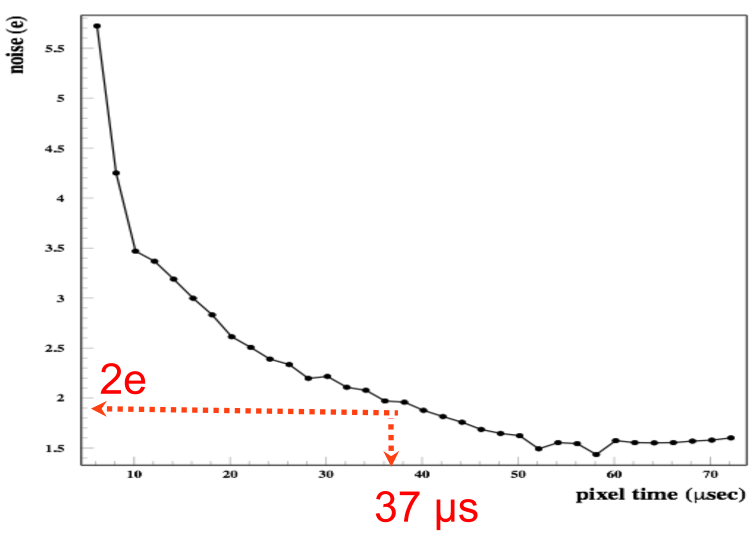
Single pixel energy threshold (5 σ) ~ 40 eV !

Lower threshold, higher WIMP recoil rate (exponential), low mass detector competitive

- Dark current < 0.1 e/pixel/day (CCD operated at 140 K): negligible noise from dark current fluctuations
- Readout noise minimized by Correlated Double Sampling: sig-ref

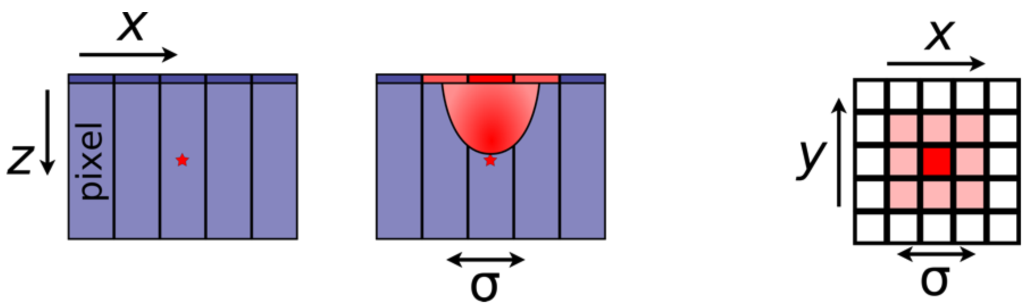






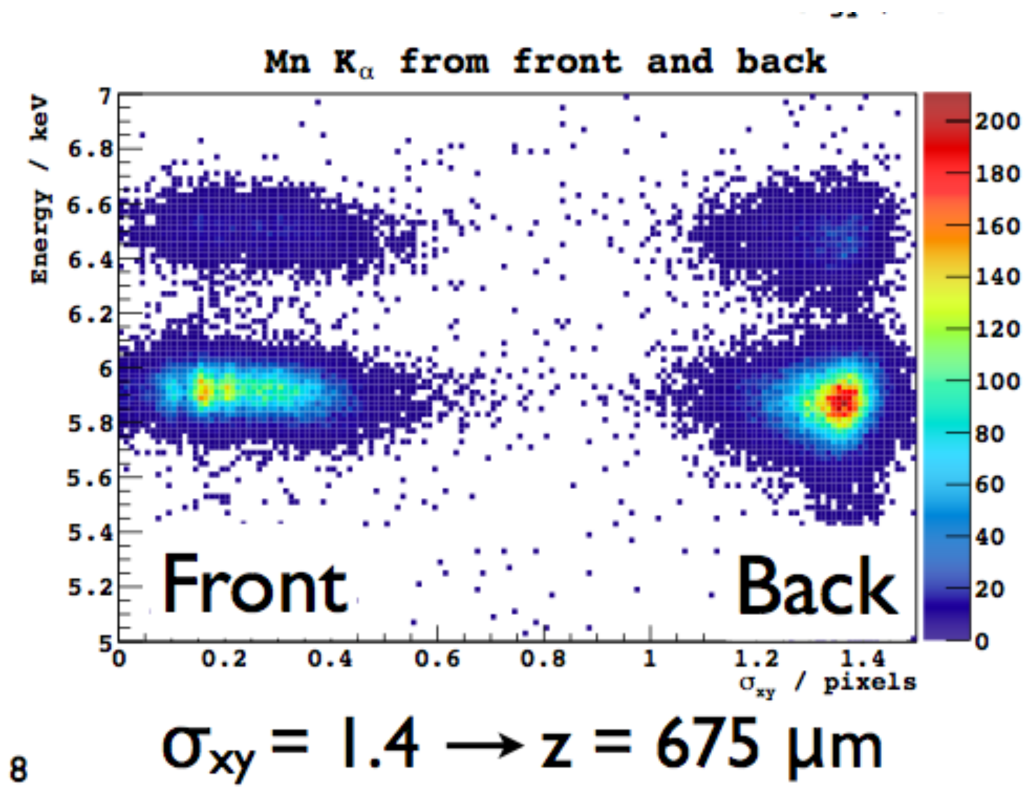
≈ 5 min to readout
a 8 Mpixel CCD

- 3D position reconstruction



The charge diffuses towards the CCD pixels gates, producing a "diffusion-limited" cluster

(σ ≈ Z allowing for fiducial volume definition and surface event rejection)

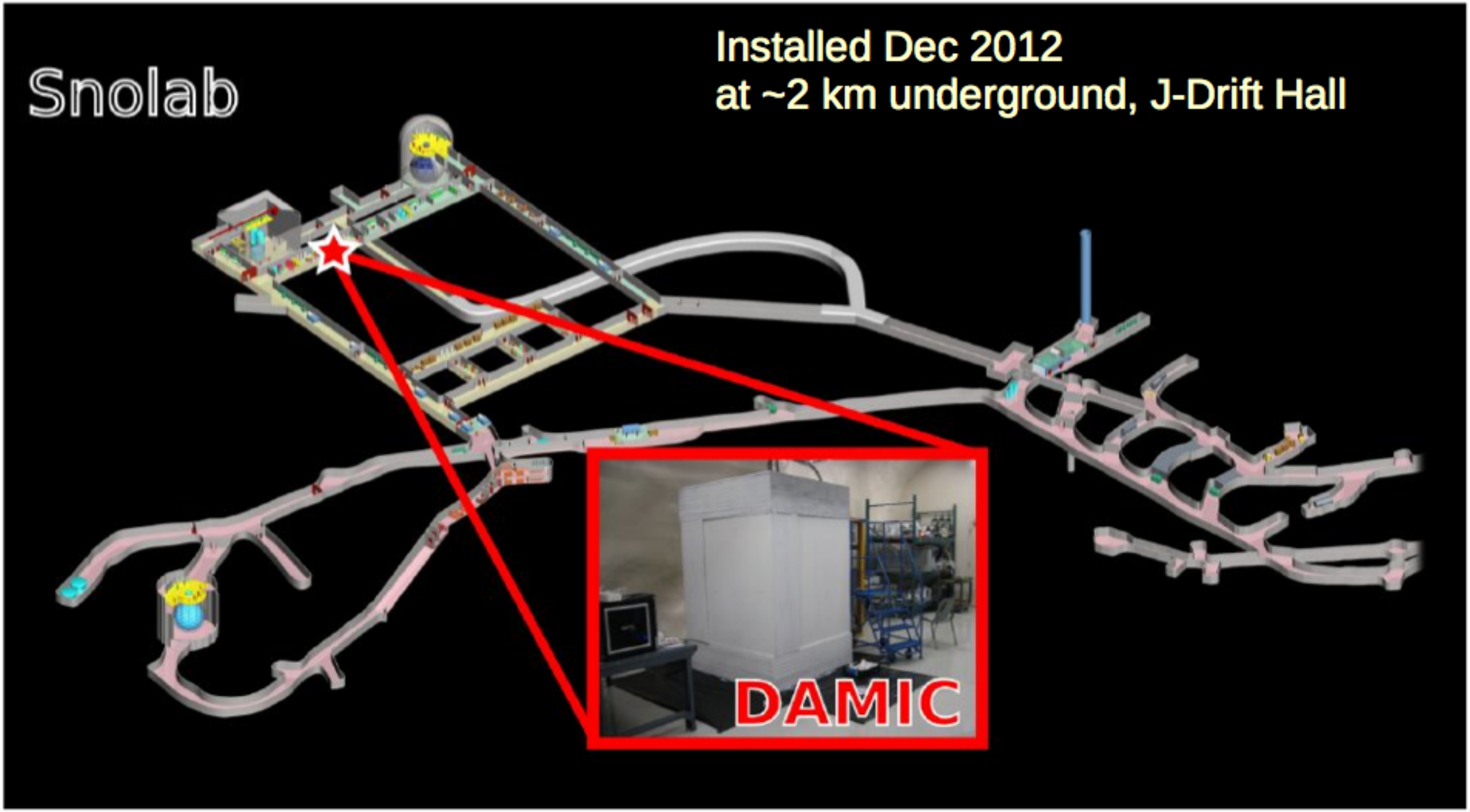


Data

^{55}Fe X-ray source

675 μm thick DAMIC CCD

DAMIC at SNOLAB

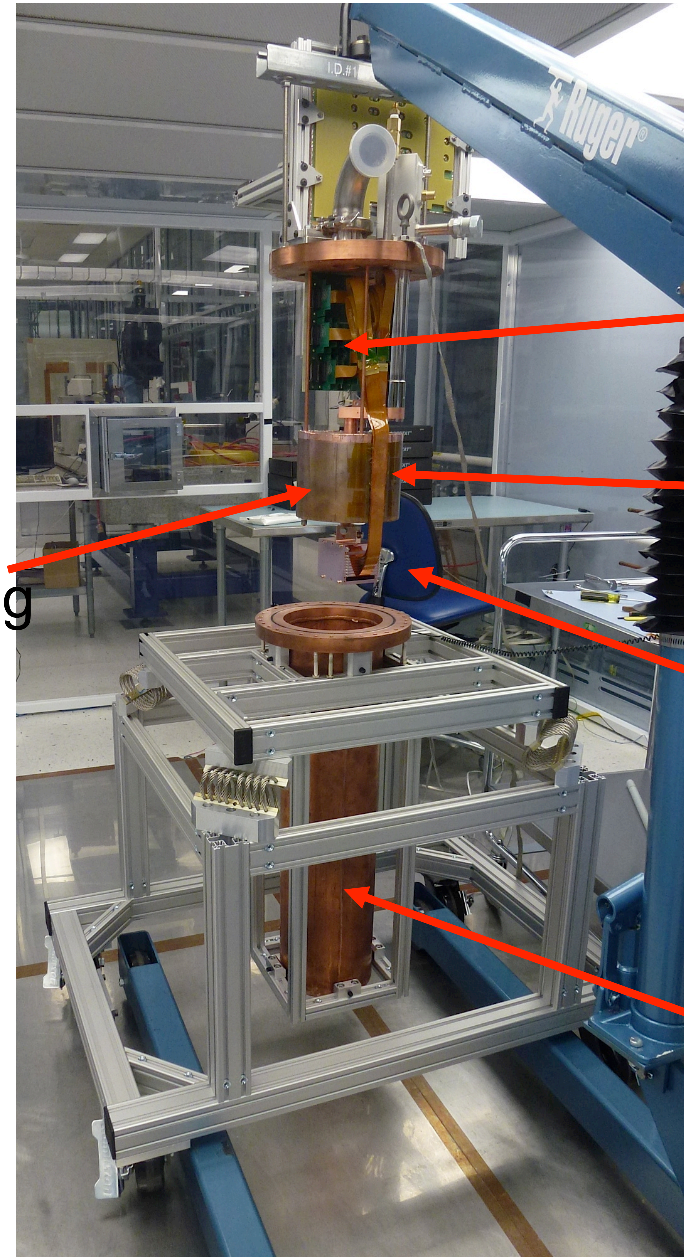


DAMIC setup at SNOLAB

vacuum and cryo lines,electronics

20” thick poly shielding

6” lead shielding



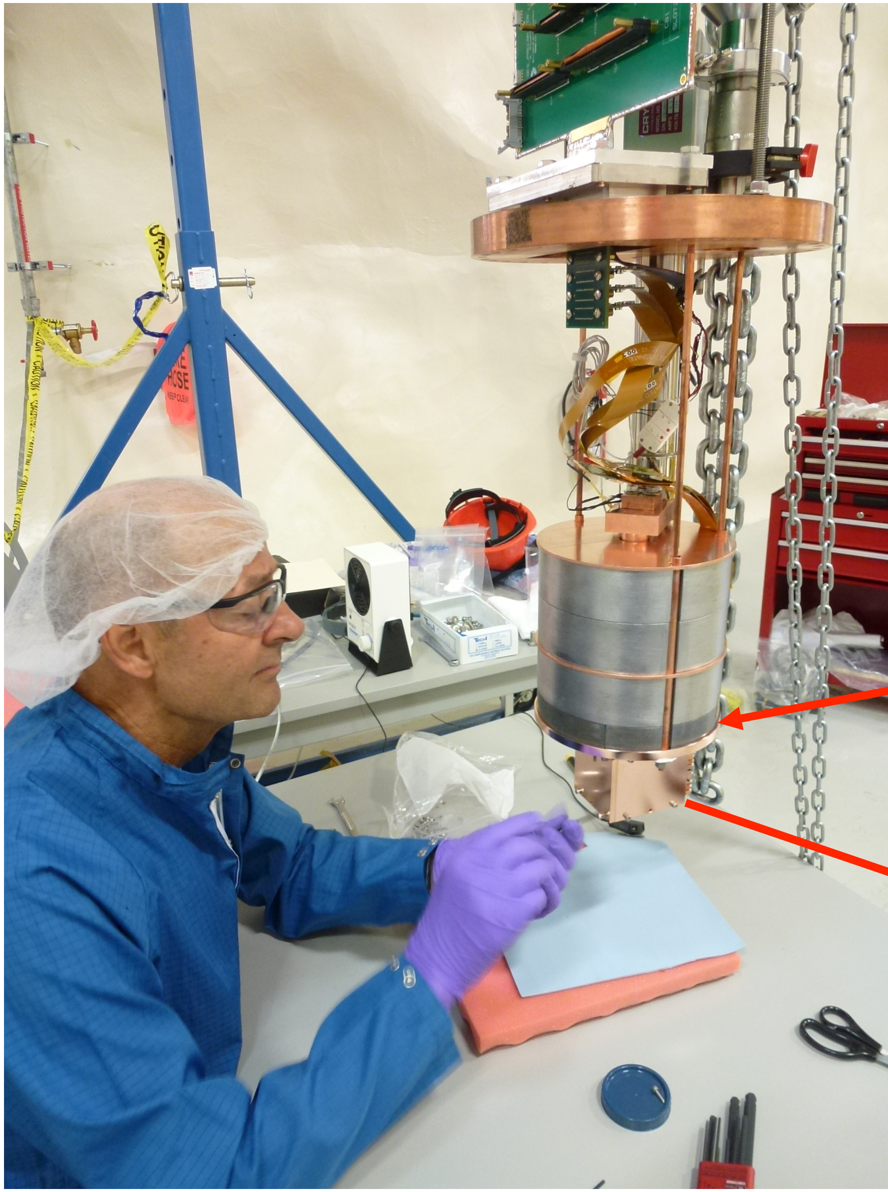
in-vacuum electronics

Kapton cable

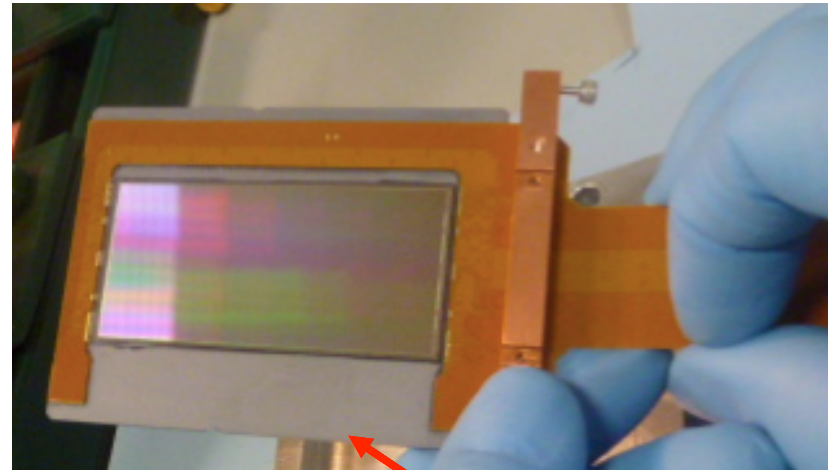
Cu box

Cu vessel

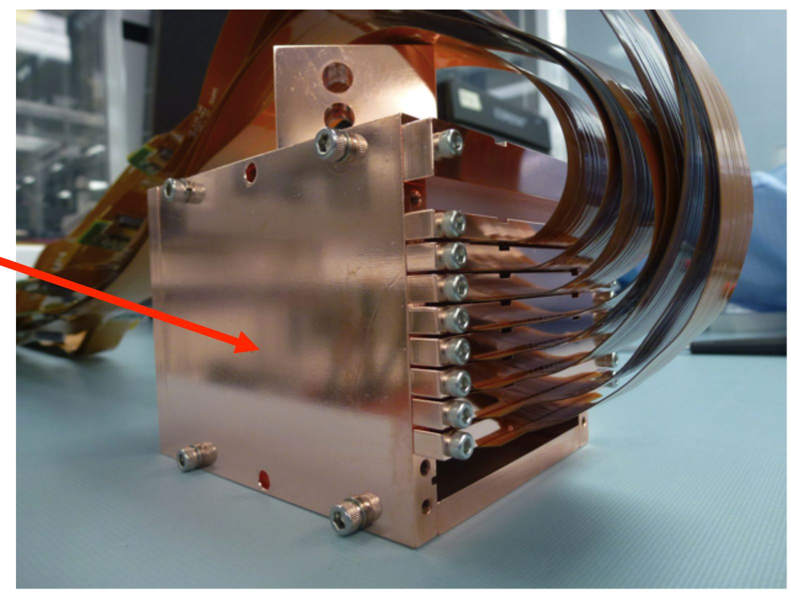
DAMIC setup at SNOLAB



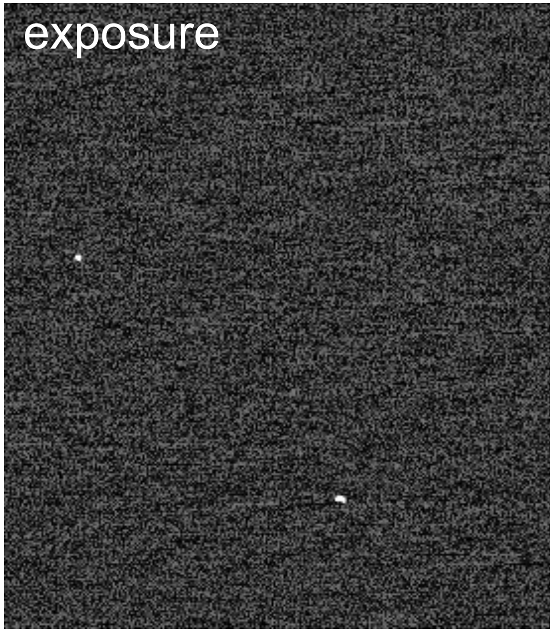
1" Spanish galleon lead

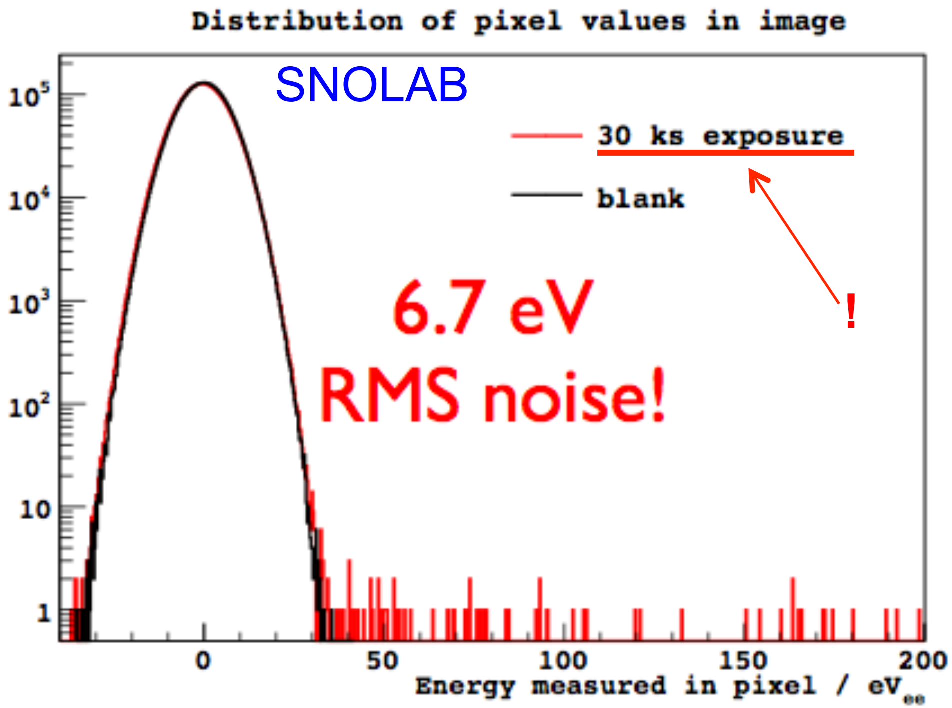


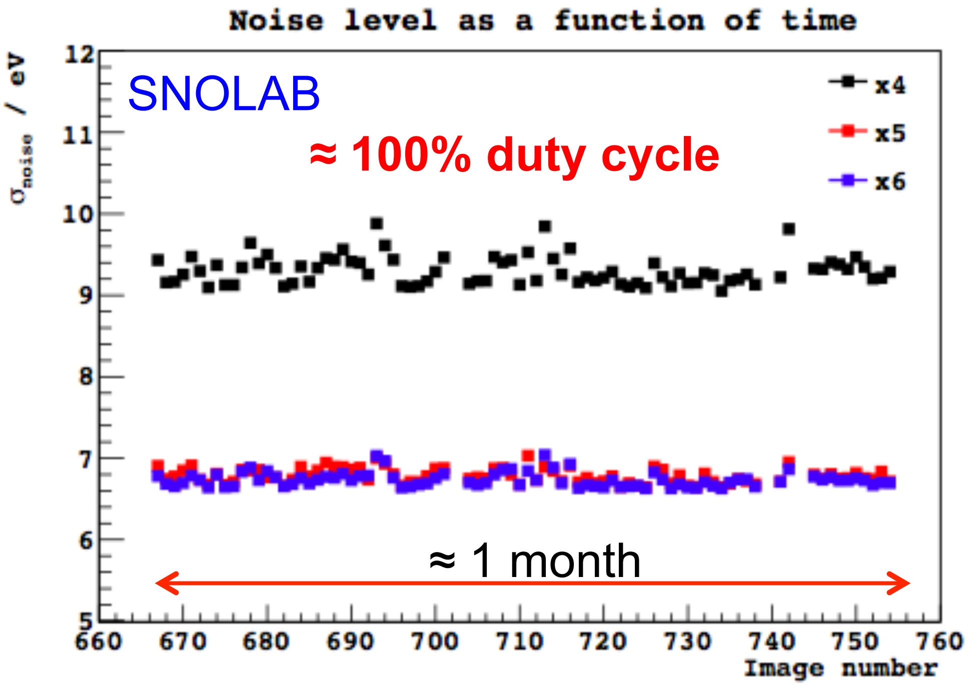
Si support

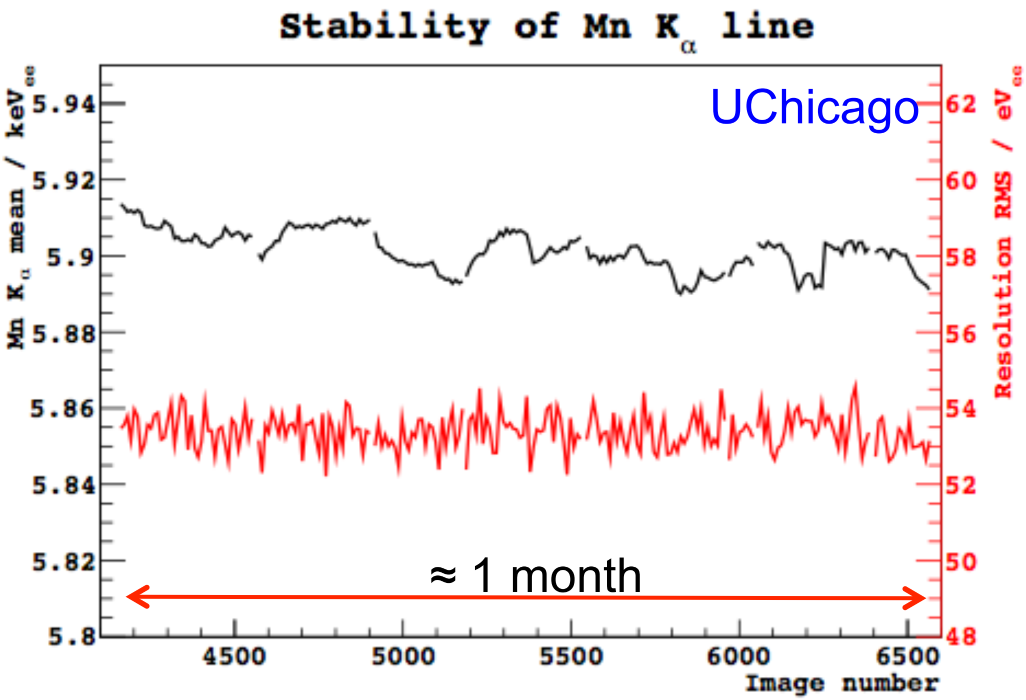


DAMIC CCD performances

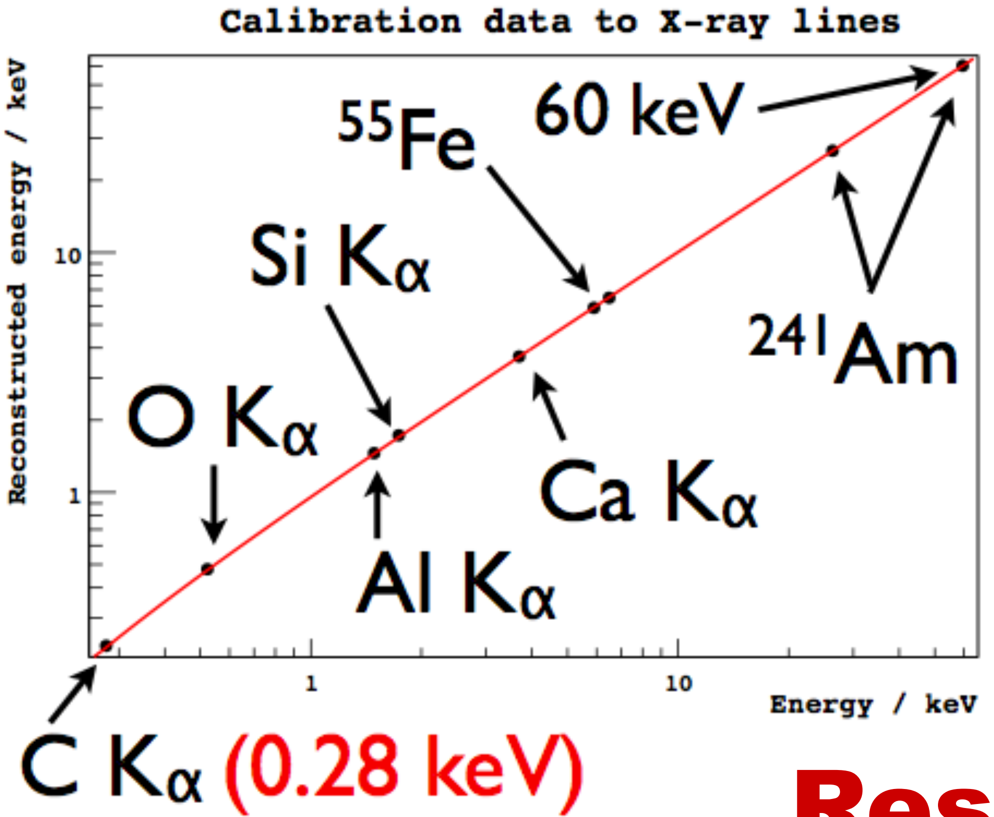


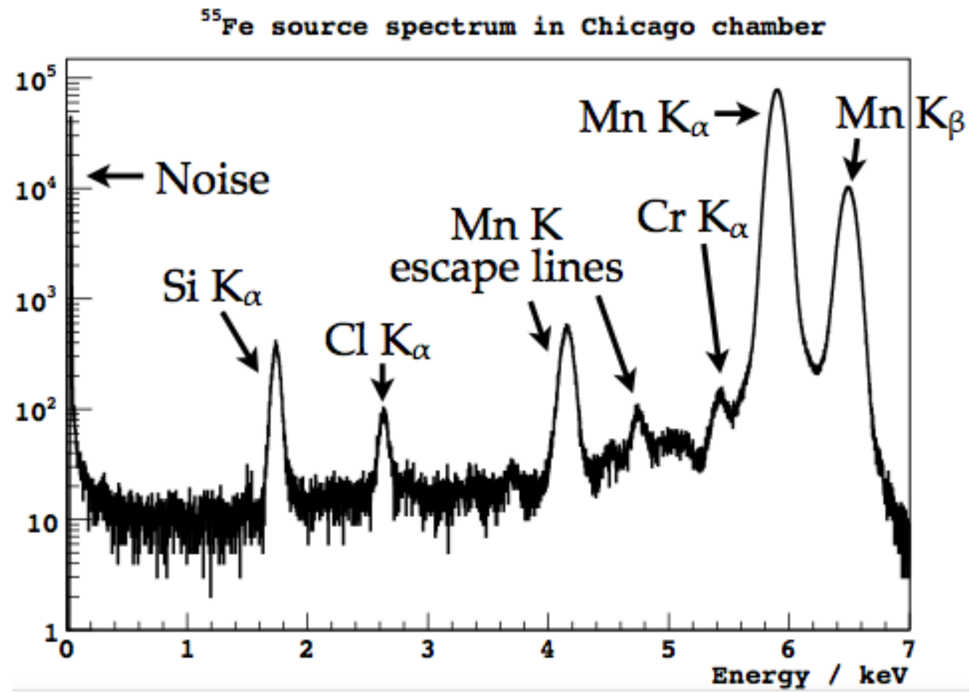


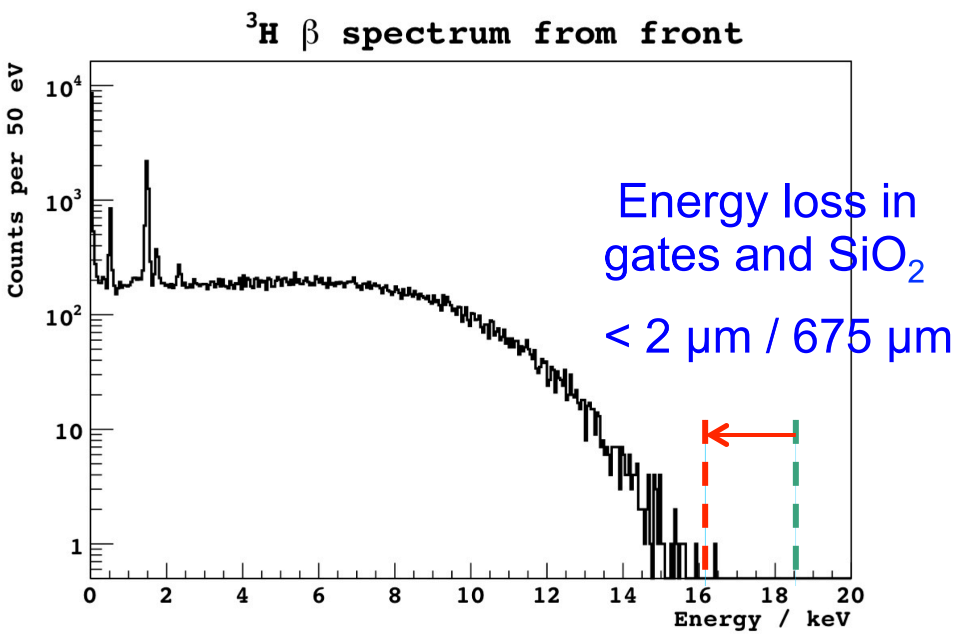


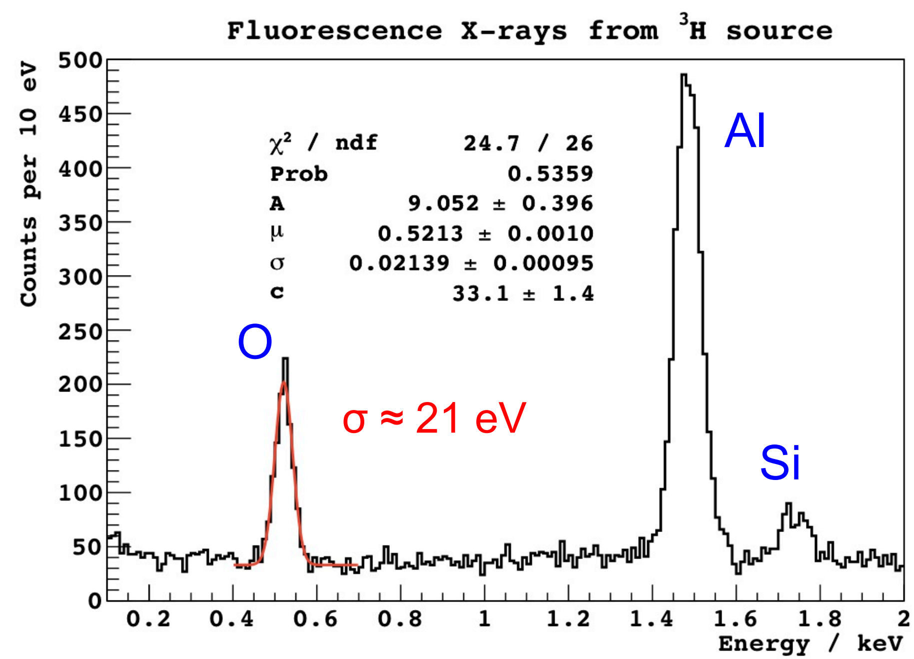


Response to electrons



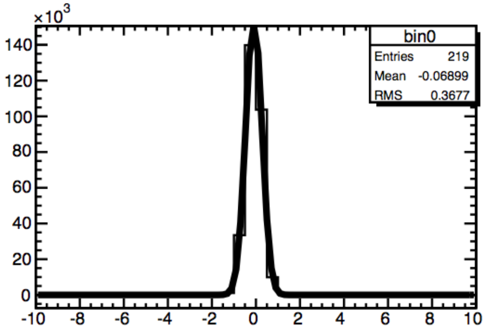




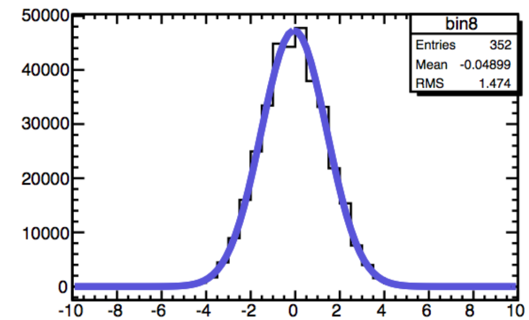


Depth reconstruction

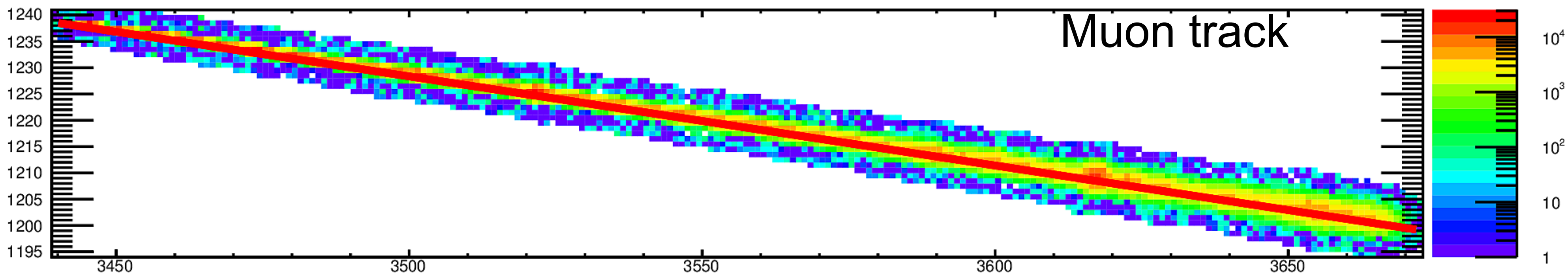
front



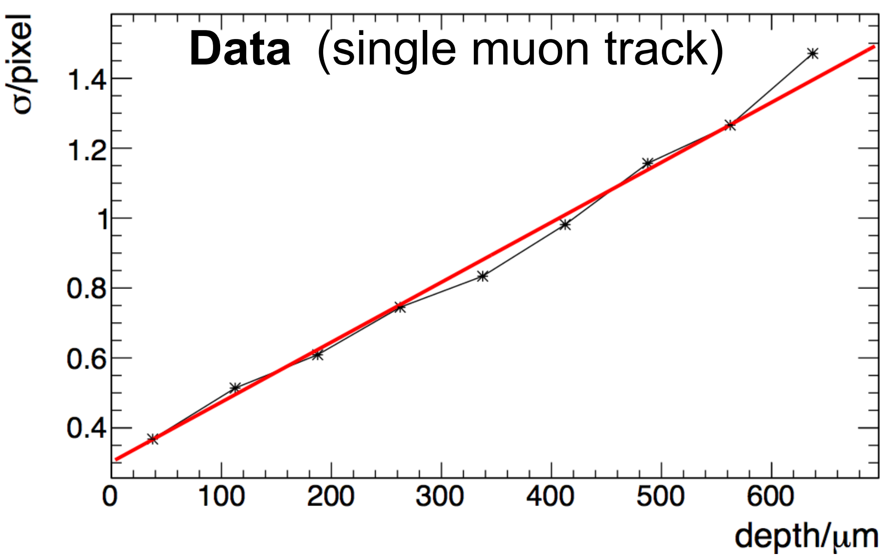
back



- Calibration with muon tracks (at ground level)

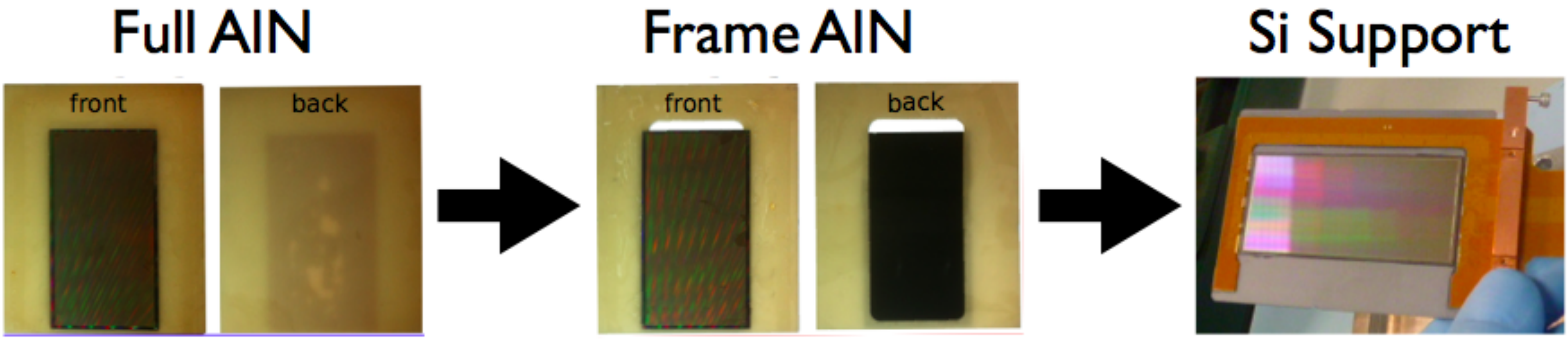


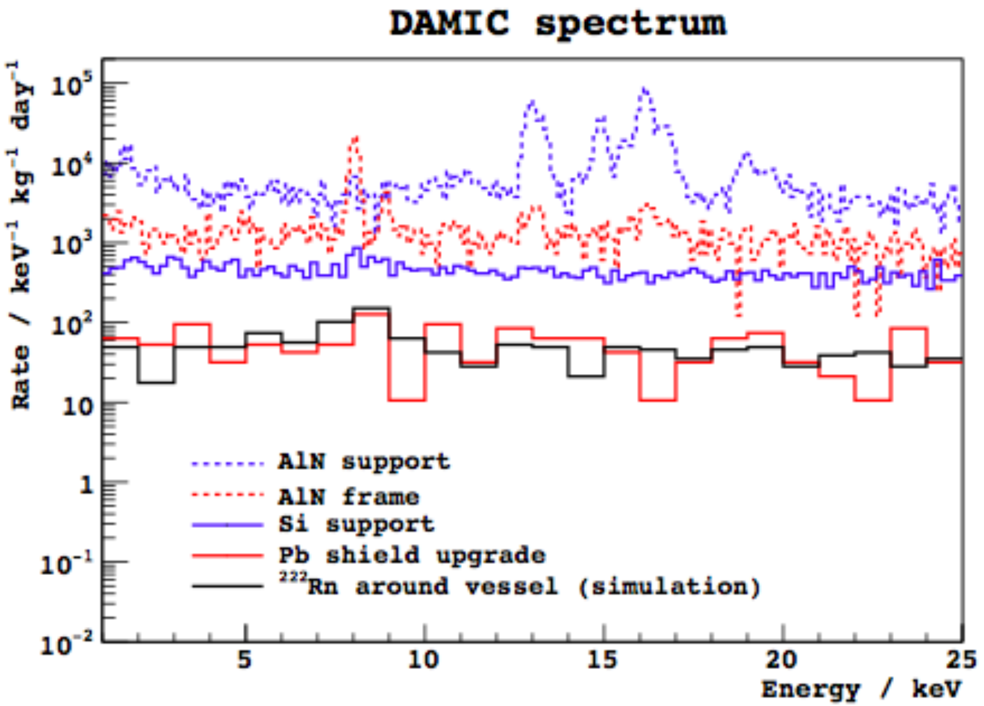
675 μm thick CCD



- Diffusion model validated by muon and X-ray data

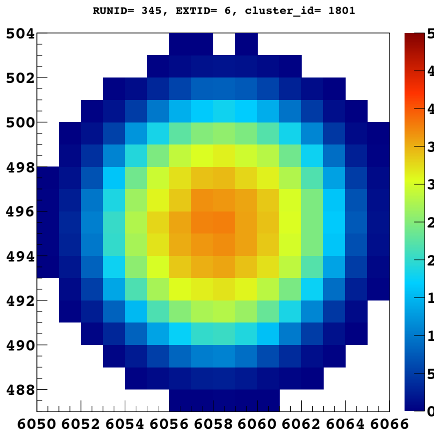
R&D: background reduction



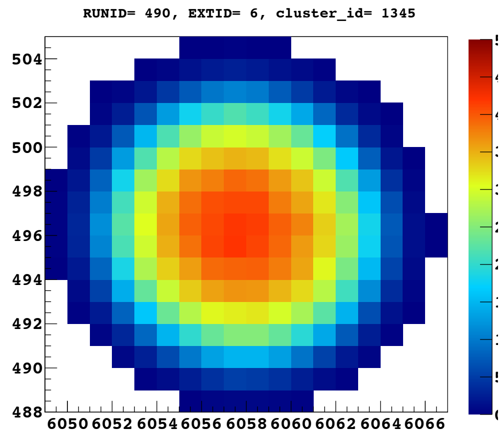


DAMIC unique spatial reconstruction

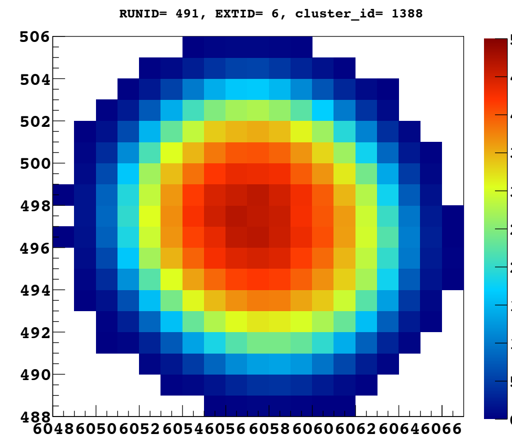
E = 5.4 MeV



E = 6.8 MeV



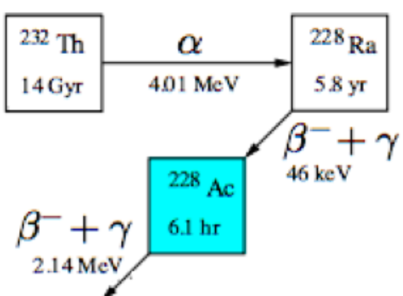
E = 8.8 MeV

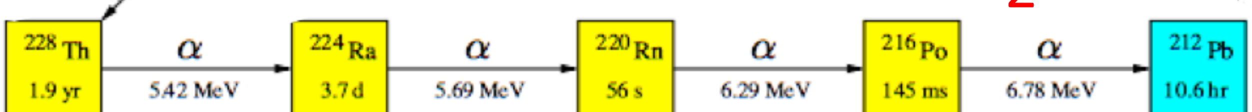


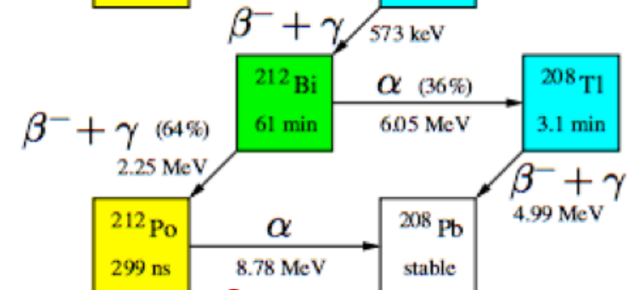
1 Δt = 17.8 d 2 Δt = 5.5 h 3

Three α at the same location!

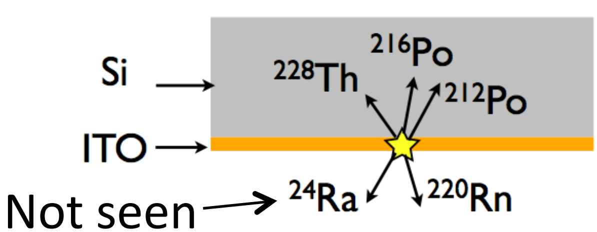
Powerful method to measure U/Th bkg in the bulk



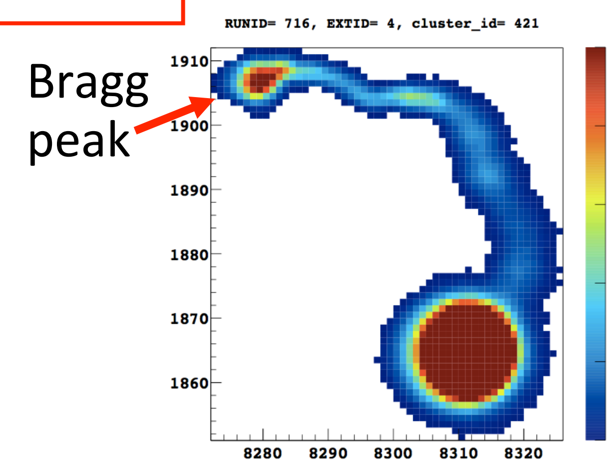




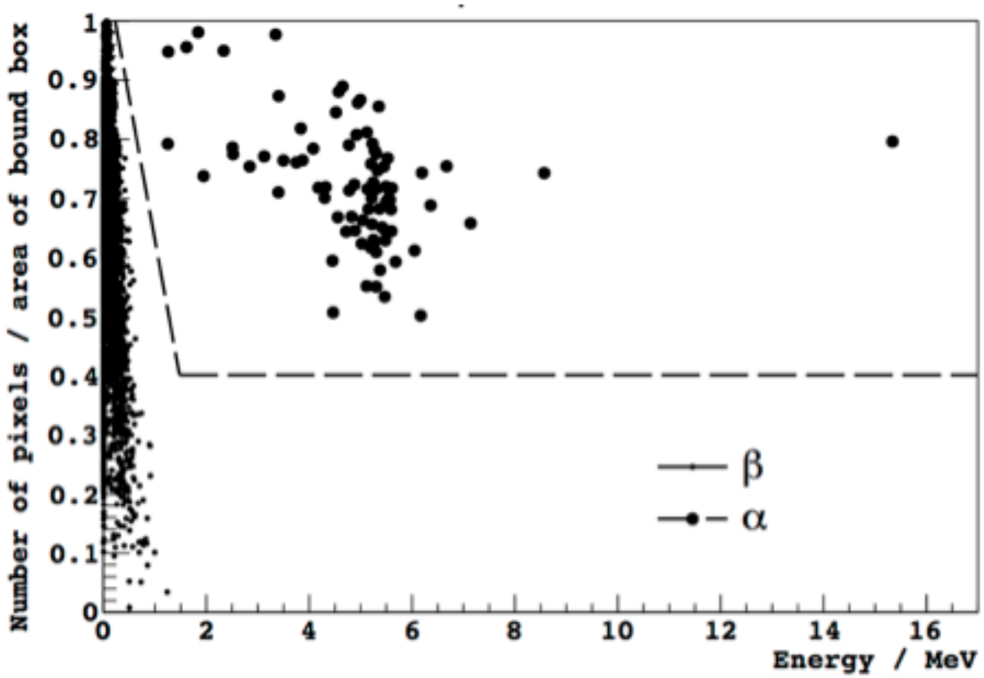
1 2 3

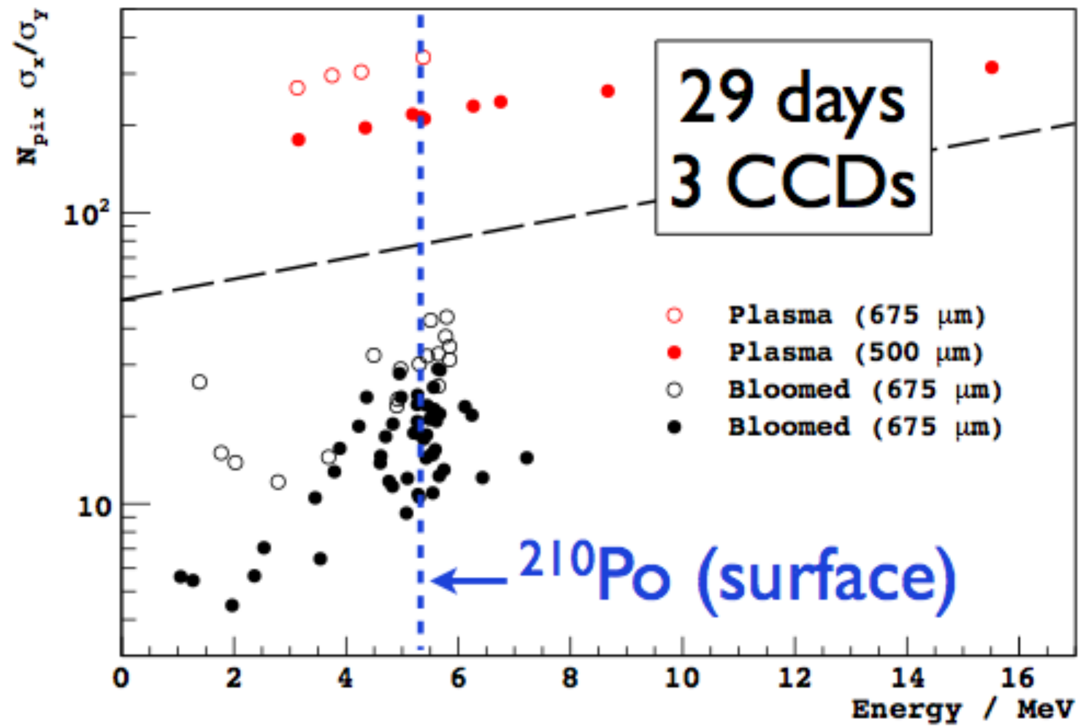


Example of α + β

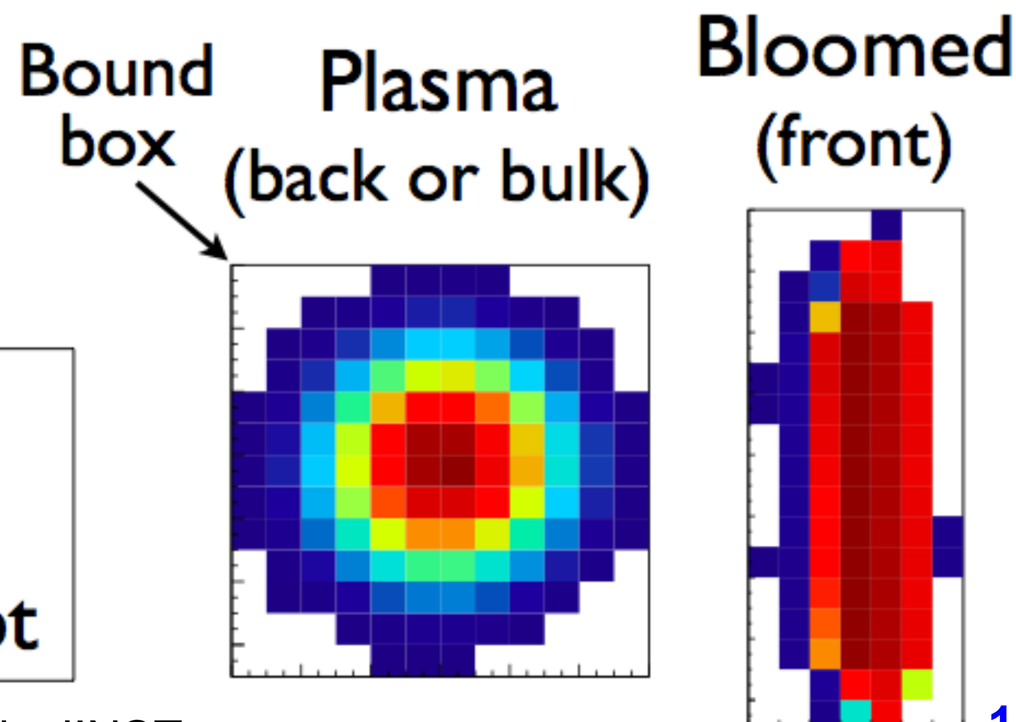


α particles





α-β discrimination based on shape of track.



Limits on contamination:

^{238}**U** < 5 kg^{-1} d^{-1} = 4 ppt

^{232}**Th** < 15 kg^{-1} d^{-1} = 43 ppt

arXiv:1506.02562 to appear in JINST

β-β sequences

from Radon

$$^{210}Pb \xrightarrow[\tau_{1/2} = 5\ d]{64\ keV} {}^{210}Bi \xrightarrow{1.2\ MeV} {}^{210}Po$$

$$^{32}Si \xrightarrow[\tau_{1/2} = 14\ d]{0.22\ MeV} {}^{32}P \xrightarrow{1.7\ MeV} {}^{32}S$$

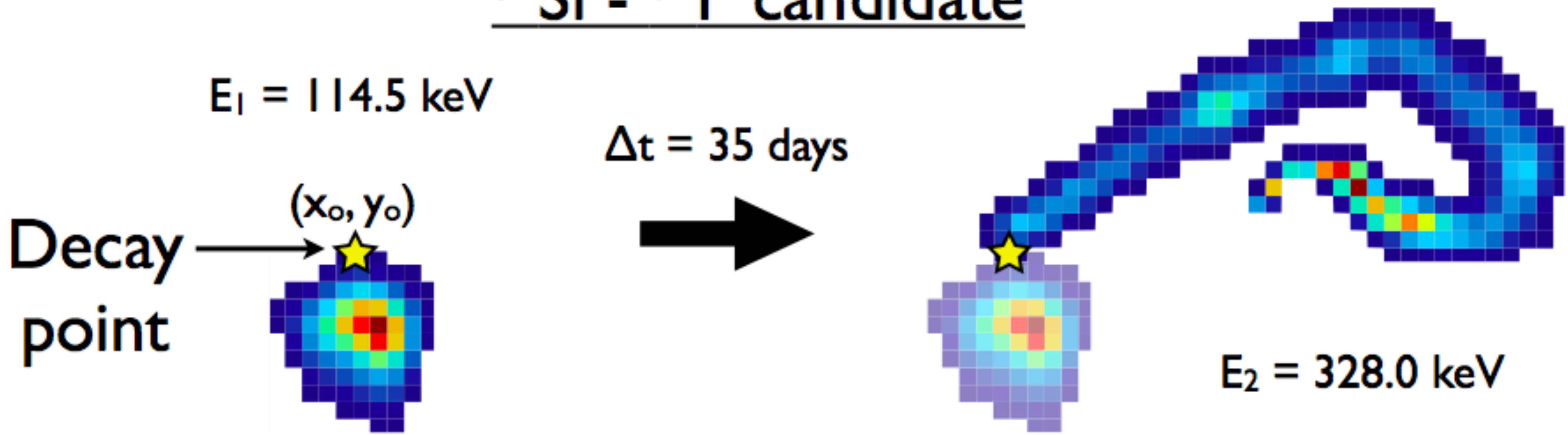
Cosmogenic

Sequence of βs starting in the same pixel of the CCD in different images

These are backgrounds that are very hard to estimate and **must be demonstrated** to be low for any proposed dark matter search in Si without electron rejection.

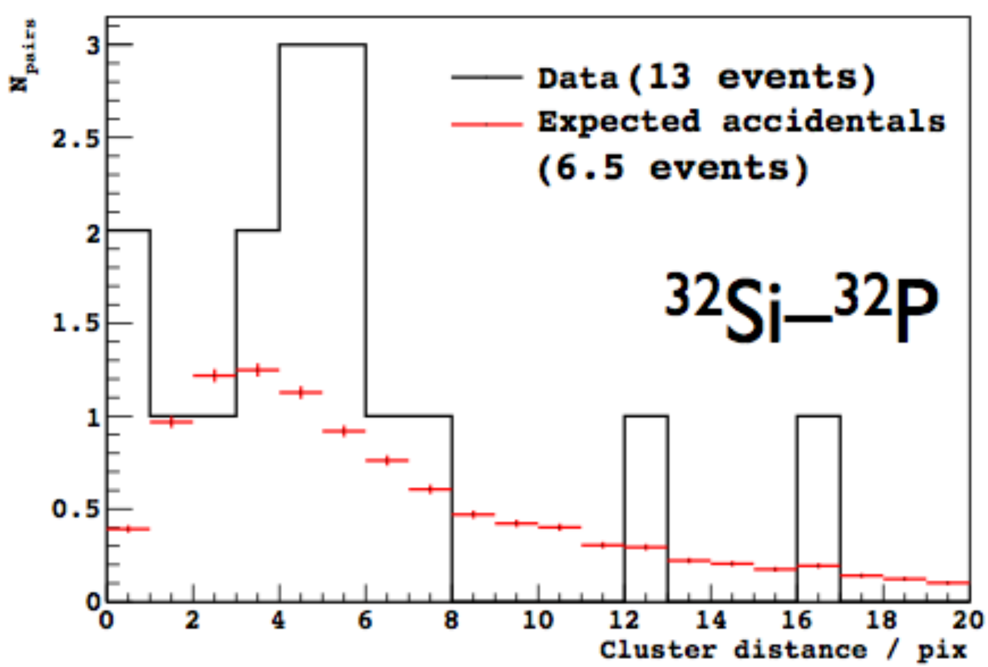
300 $kg^{-1}\ d^{-1}$ of ^{32}Si + ^{32}P correspond to ~2 dru at low energies.

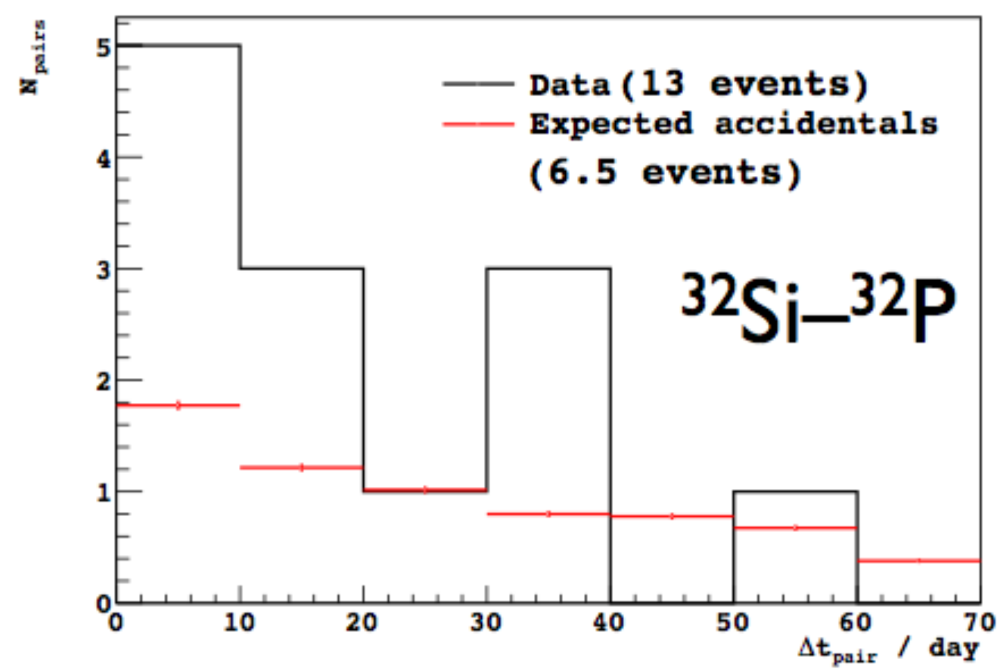
^{32}Si - ^{32}P candidate



$$^{32}\mathrm{Si} = 80^{+110}_{-65}\,\mathrm{kg}^{-1}\,\mathrm{d}^{-1}\ (95\%\ \mathrm{CI})$$

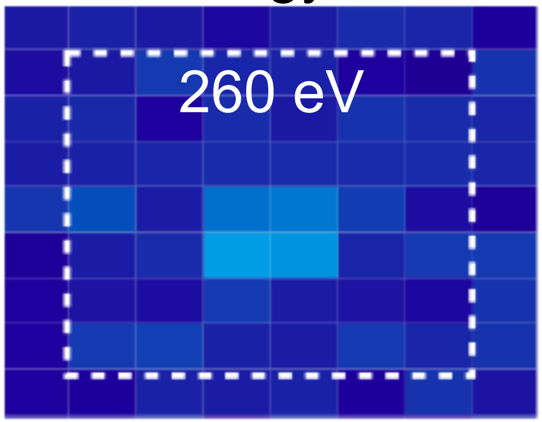
arXiv:1506.02562
to appear in JINST

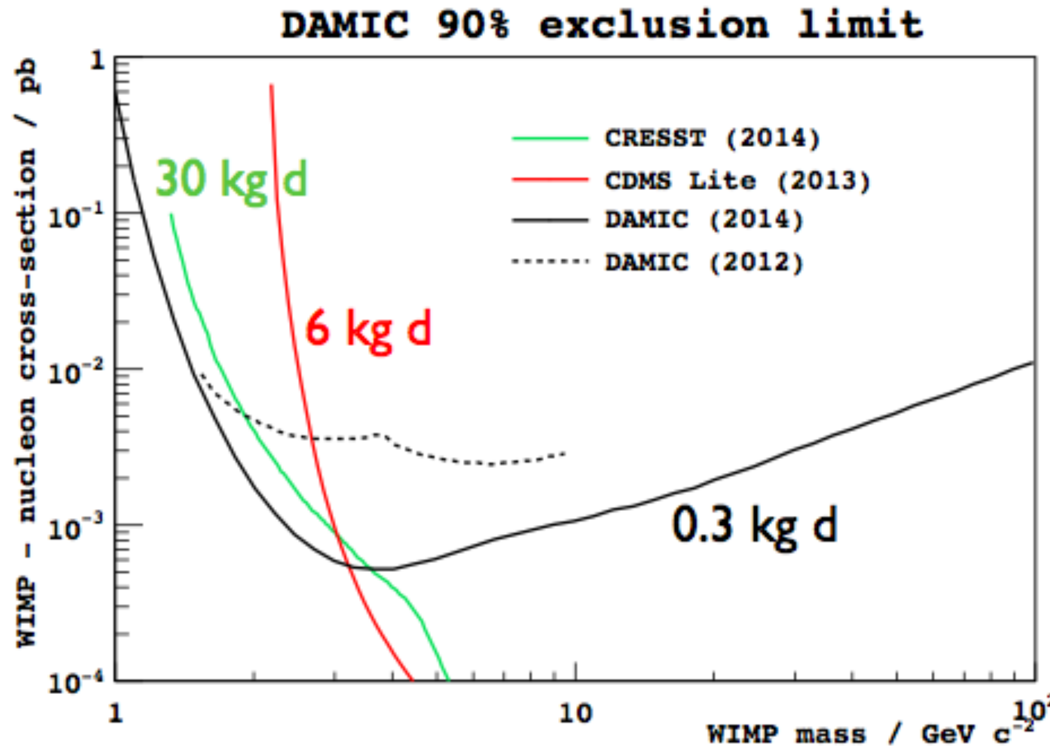


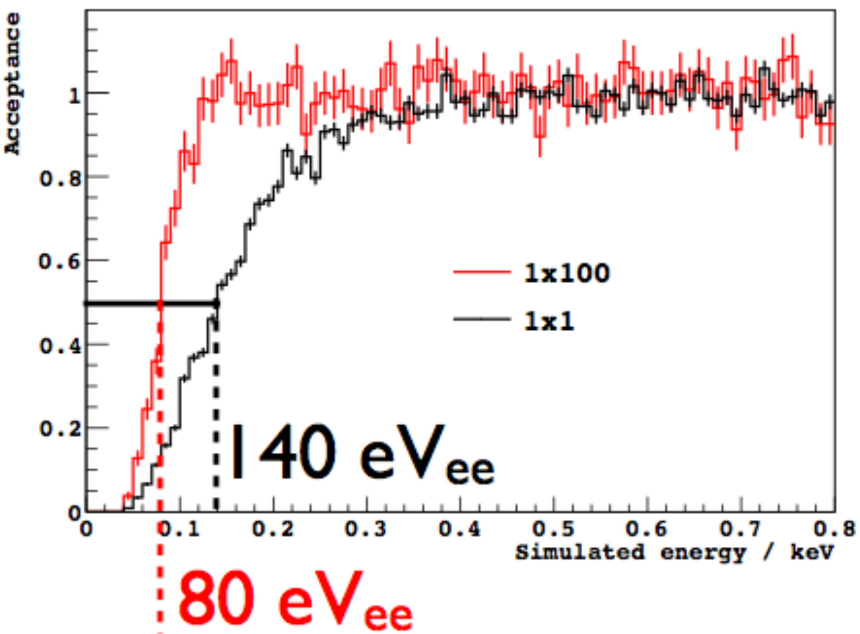


WIMP search with R&D data

lowest energy candidate

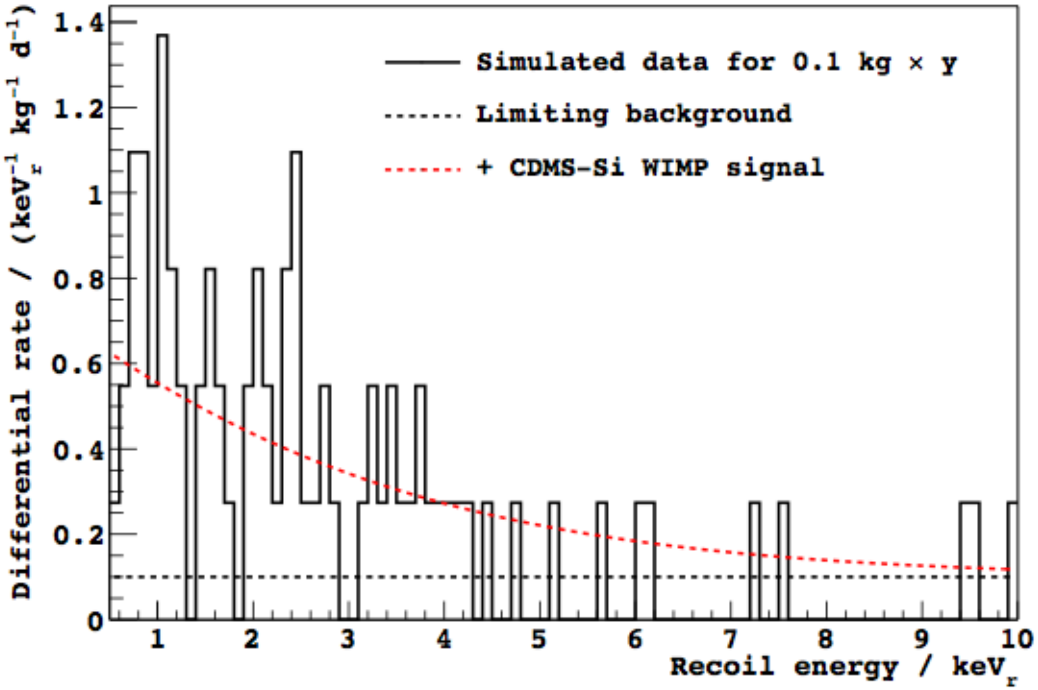






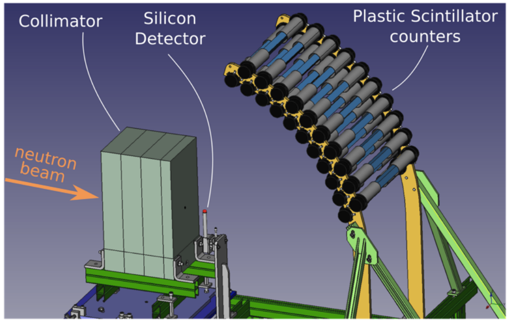
Improving the energy threshold with hardware binning: the charge of several pixels is added before readout, better signal over noise since readout noise stays the the same. Some data collected at SNOLAB

DAMIC calibration (keV_{nr})



No measurements of nuclear recoil ionization efficiency below 4 keV_{nr} !

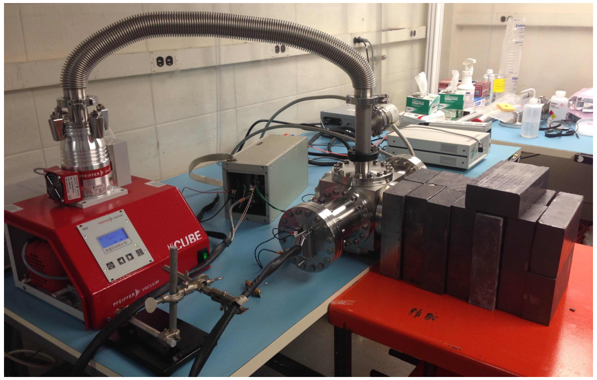
University of Notre Dame



eg. $^{28}Si + n \longrightarrow {}^{29}Si + \gamma$

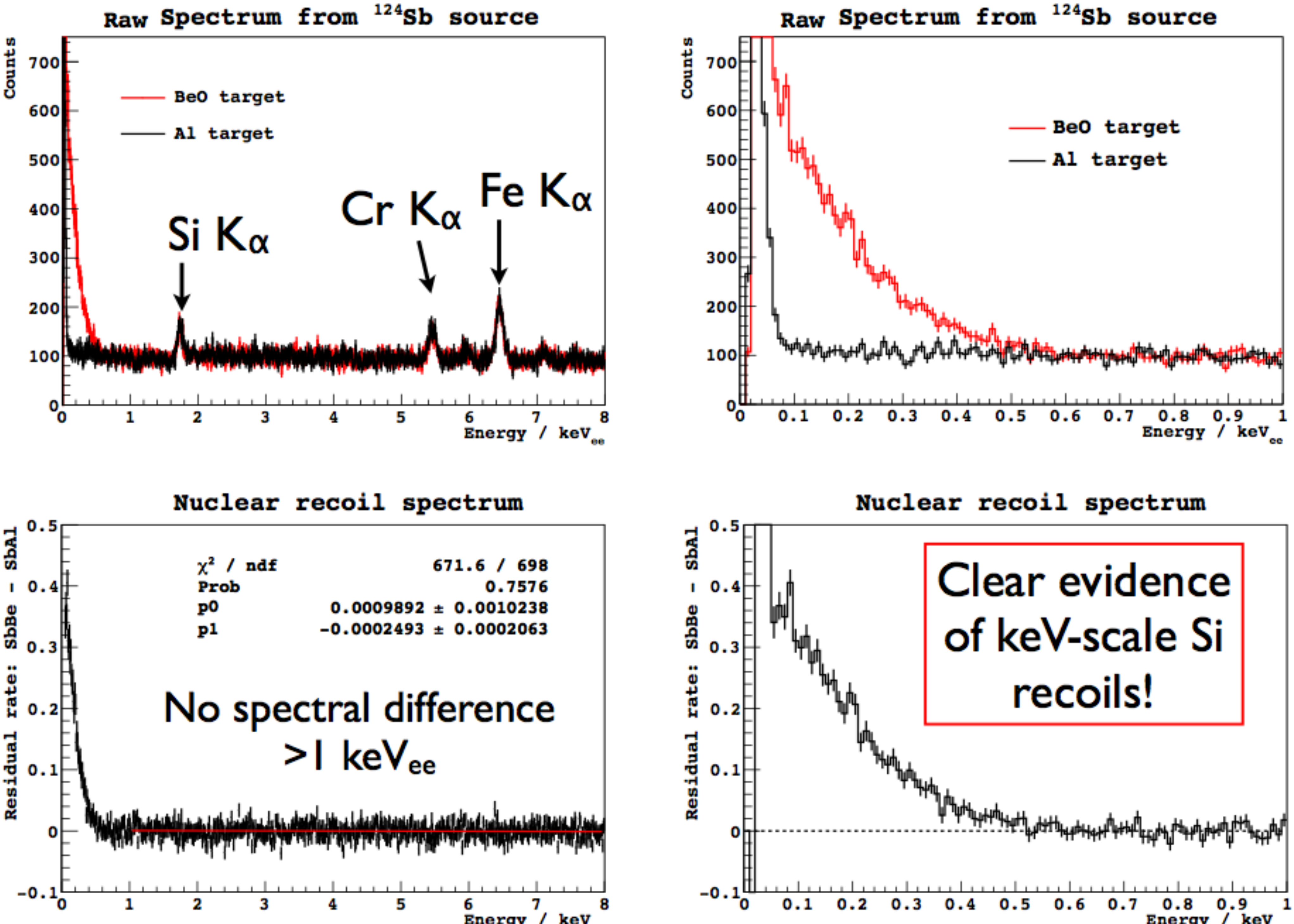
Argonauta reactor (UFRJ, Rio de Janeiro)

340 Watt, thermal neutron flux few $10^5/cm^2/s$



Sb/Be "monochromatic" neutron source (24 keV), U. Chicago

CCD activation with proton beam (CDH proton center, Illinois) Nuclear recoil from EC of ^{22}Na

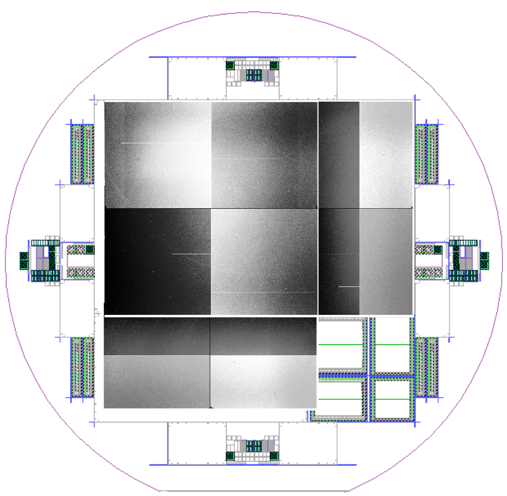


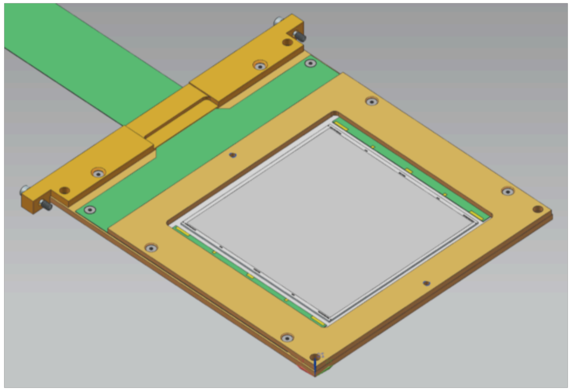
Raw Spectrum from 124Sb source
Counts
BeO target
Al target
Si Kα
Cr Kα
Fe Kα
Energy / keVee
Raw Spectrum from 124Sb source
Counts
BeO target
Al target
Energy / keVee
Nuclear recoil spectrum
Residual rate: SbBe - SbAl
χ2 / ndf 671.6 / 698
Prob 0.7576
p0 0.0009892 ± 0.0010238
p1 -0.0002493 ± 0.0002063
No spectral difference
>1 keVee
Energy / keVee
Nuclear recoil spectrum
Residual rate: SbBe - SbAl
Clear evidence
of keV-scale Si
recoils!
Energy / keVee

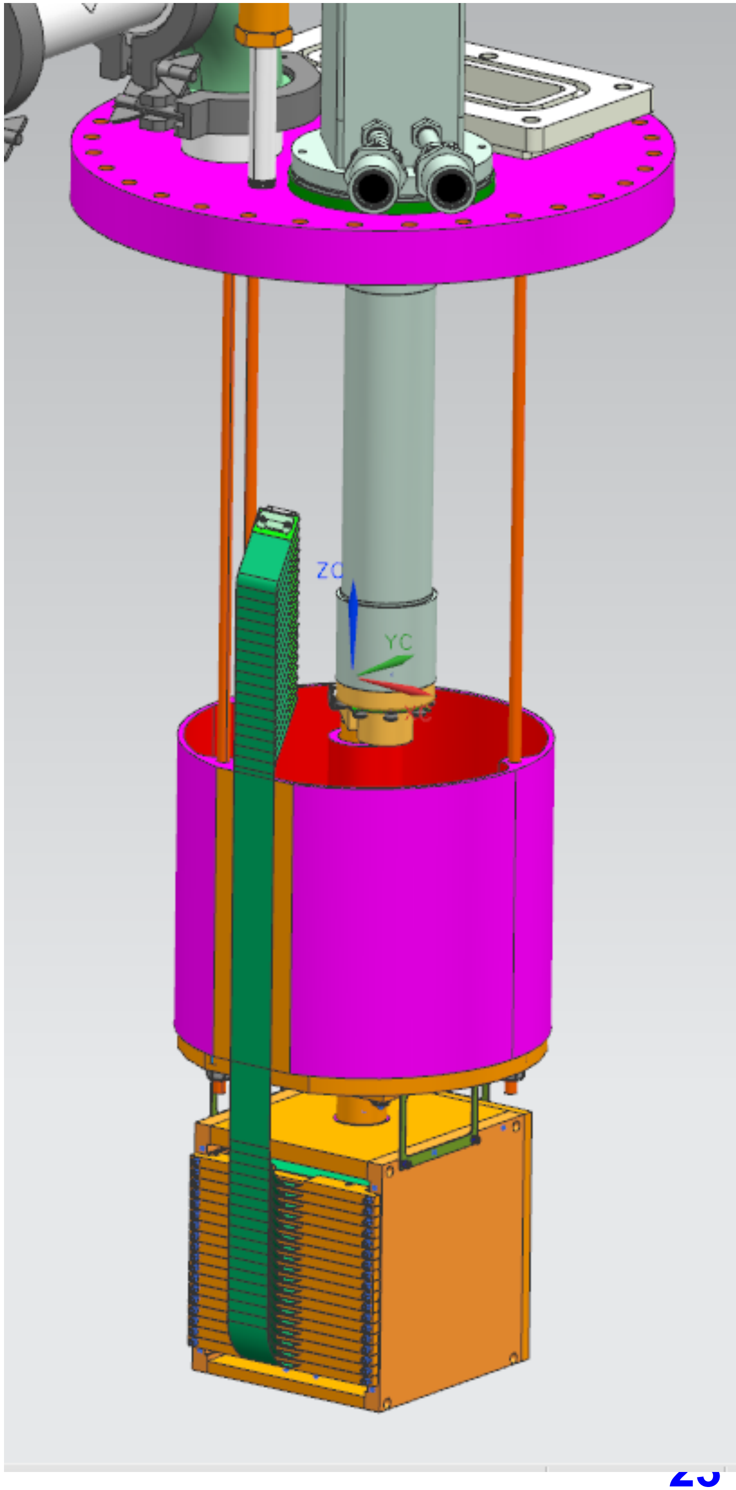
DAMIC100

- 100 g detector - 18 CCD 4k x 4k 675 µm
- Minimal changes of current SNOLAB setup: Cu box, CCD support and cable

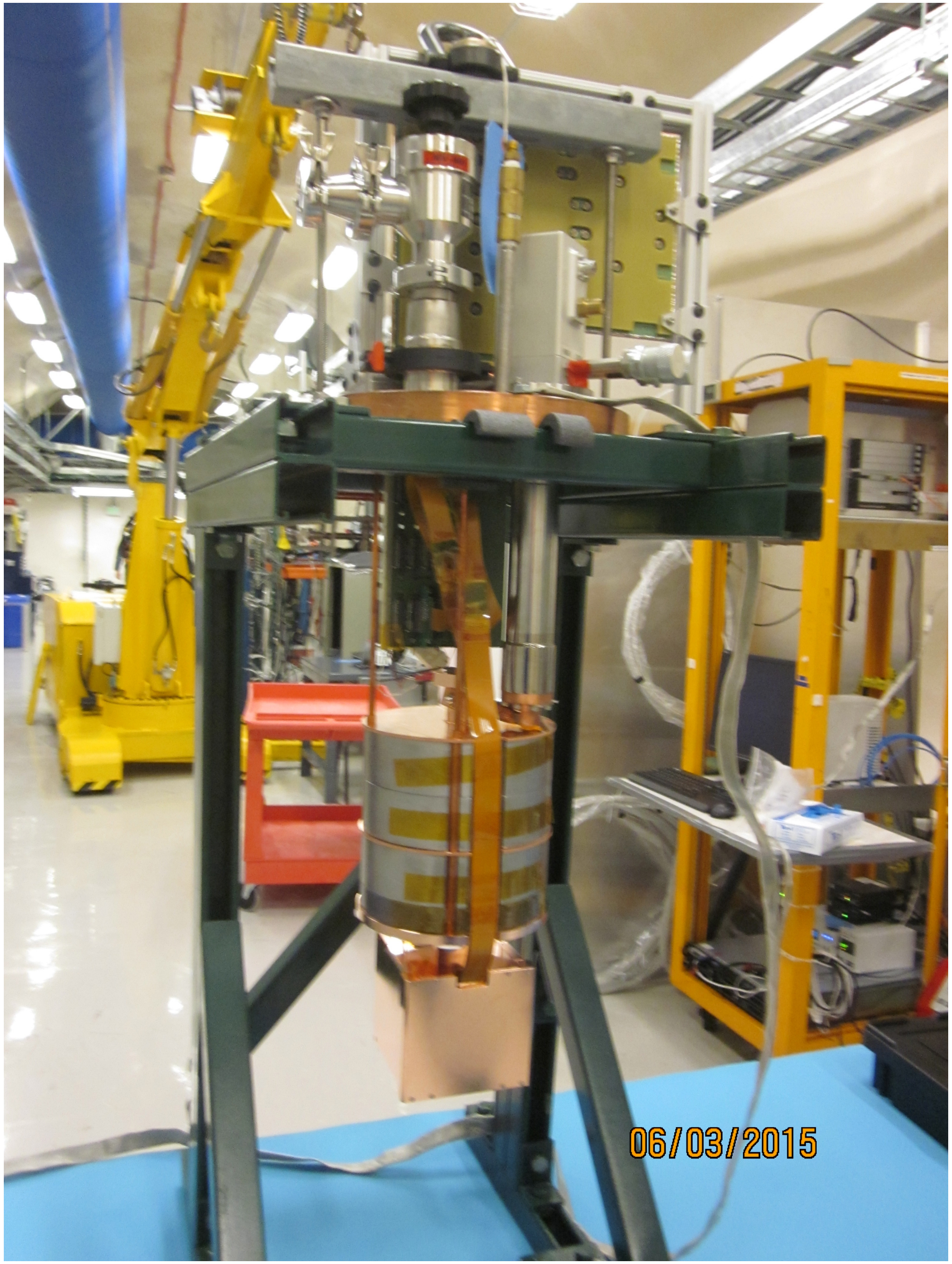
  expected bkg ≈ event/keV/kg/day
- Detectors designed by LBL and fabricated by DALSA
  - 23 wafers, packaging started, high yield

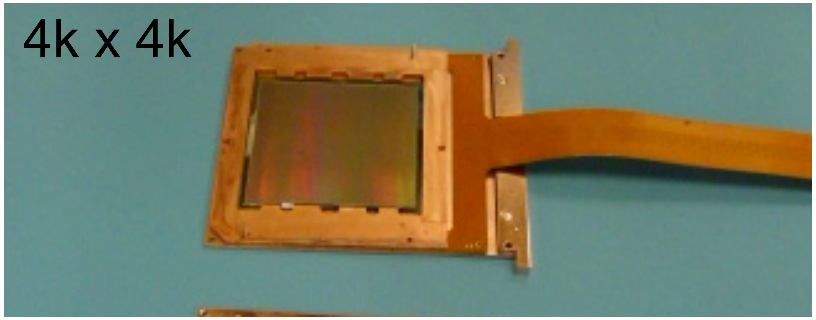


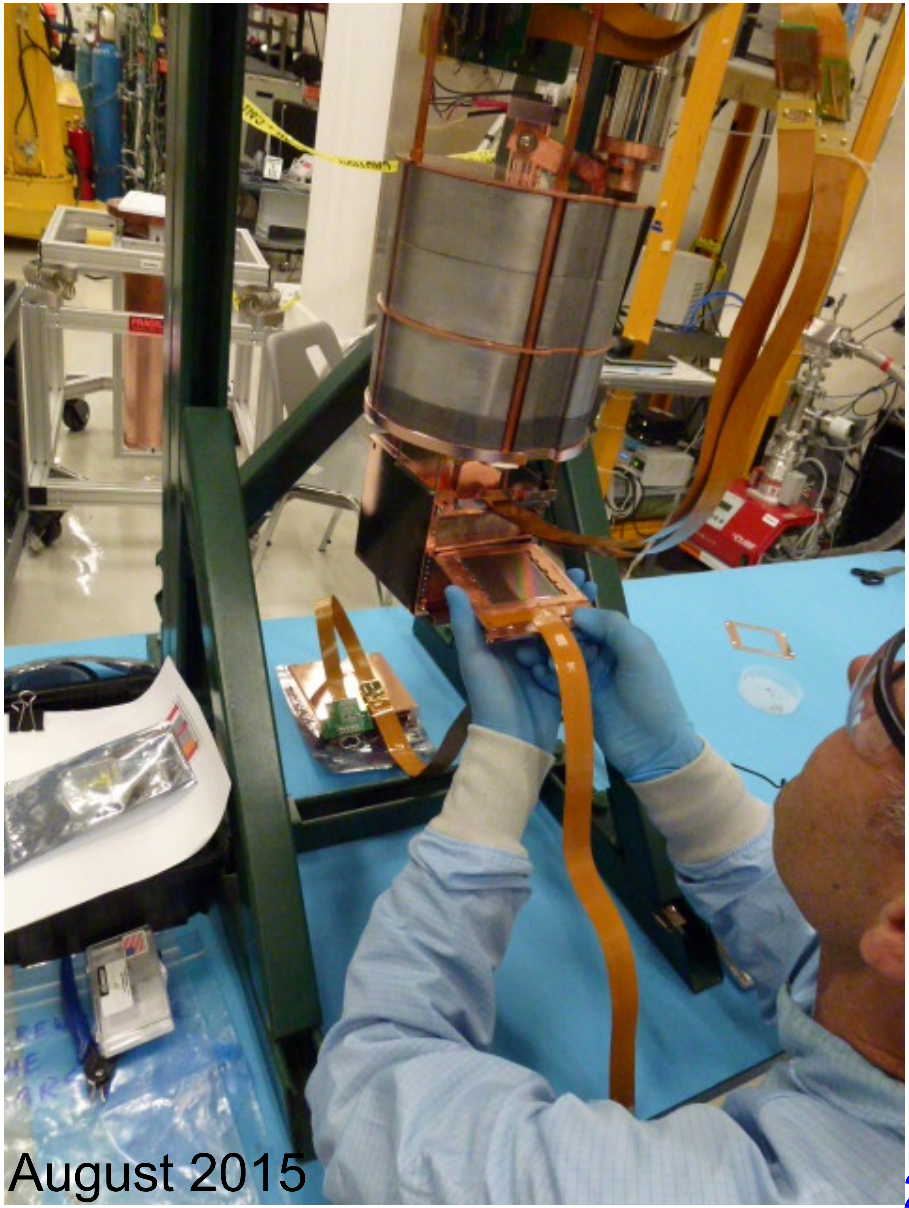




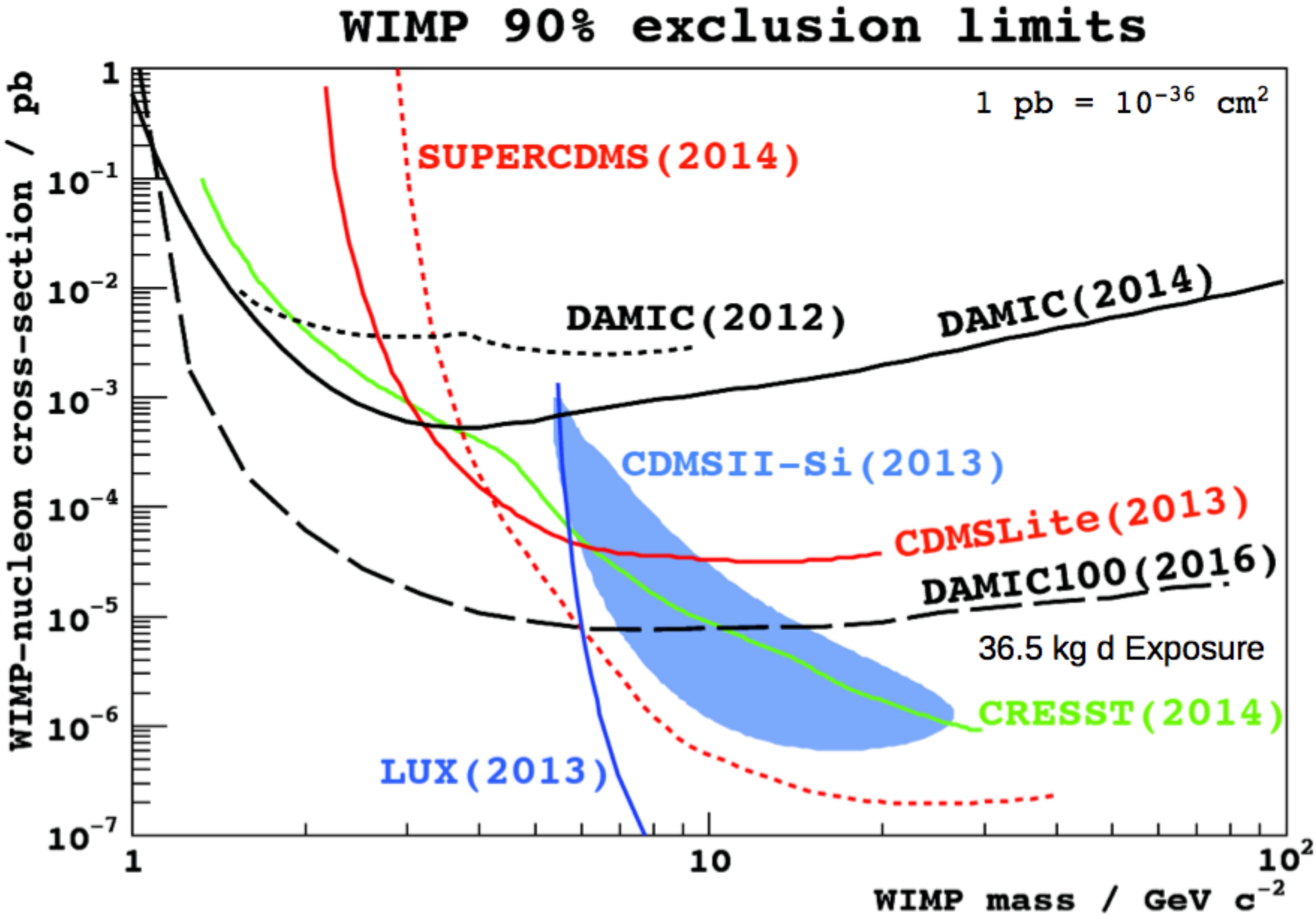
DAMIC100







DAMIC sensitivity



DAMIC Collaboration

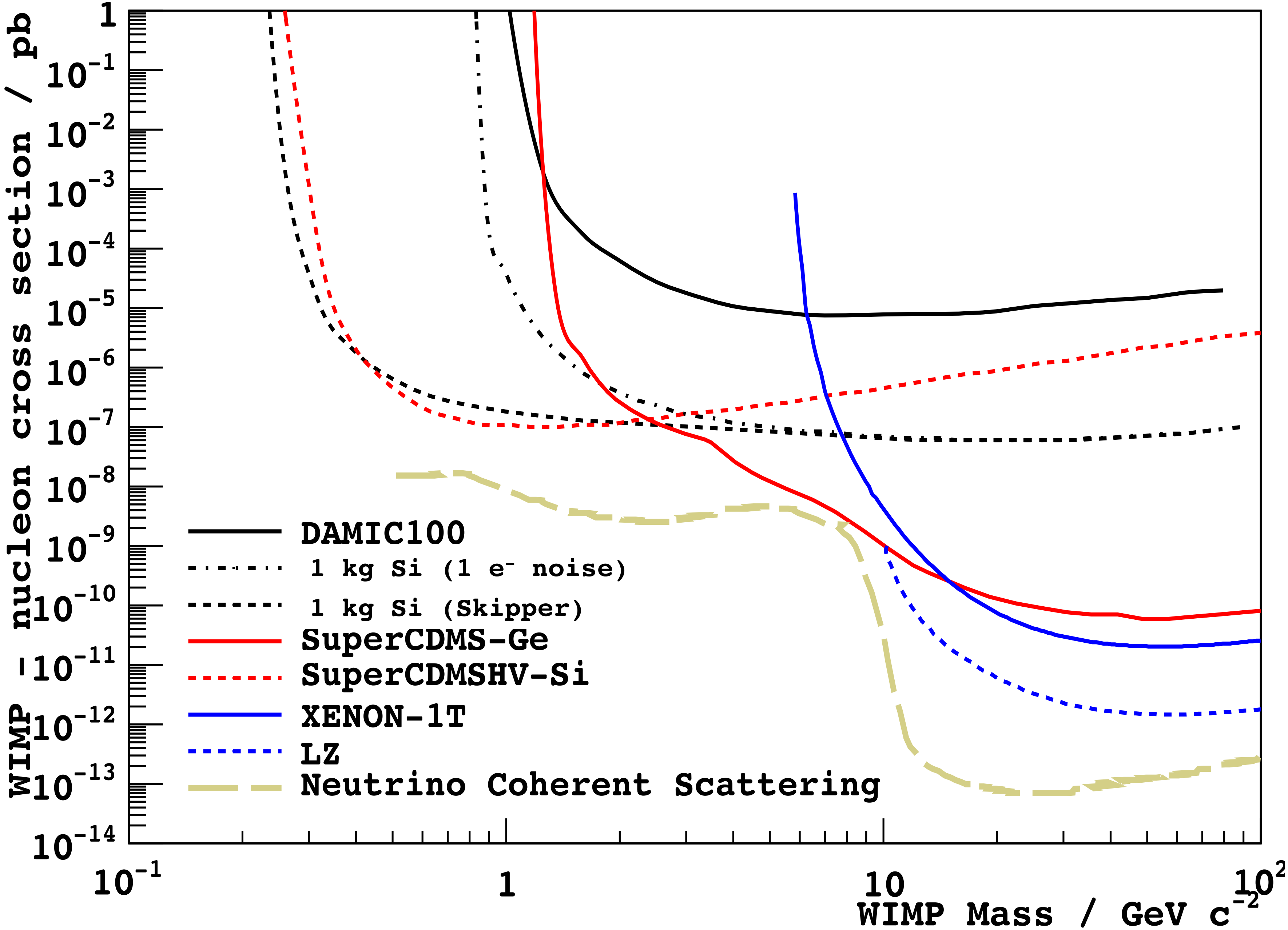
(DArk Matter In CCDs)

International collaboration: 8 institutions from 6 countries

DAMIC

Argentina:	Centro Atómico Bariloche
Brazil:	Universidade Federal do Rio de Janeiro
Canada:	SNOLAB
Mexico:	Universidad Nacional Autónoma de México
Paraguay:	Universidad Nacional de Asunción
Switzerland:	Universität Zürich (UZH)
United States:	Fermilab, U. Chicago, U. Michigan

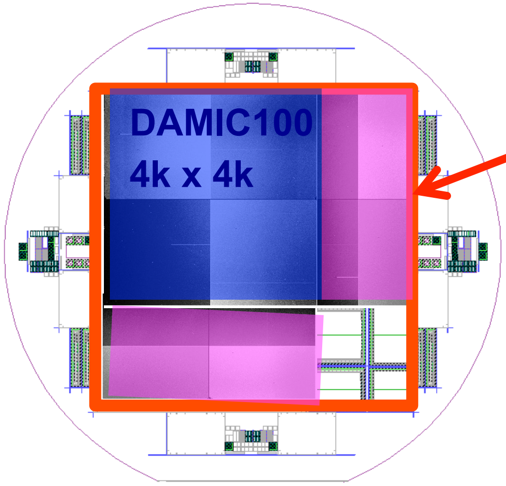
Potential of a 1 kg Si detector



Strategy for DAMIC 1kg

- Scaling mass

Silicon wafer



6k x 6k pixels, 1 mm thick

≈20 g / CCD

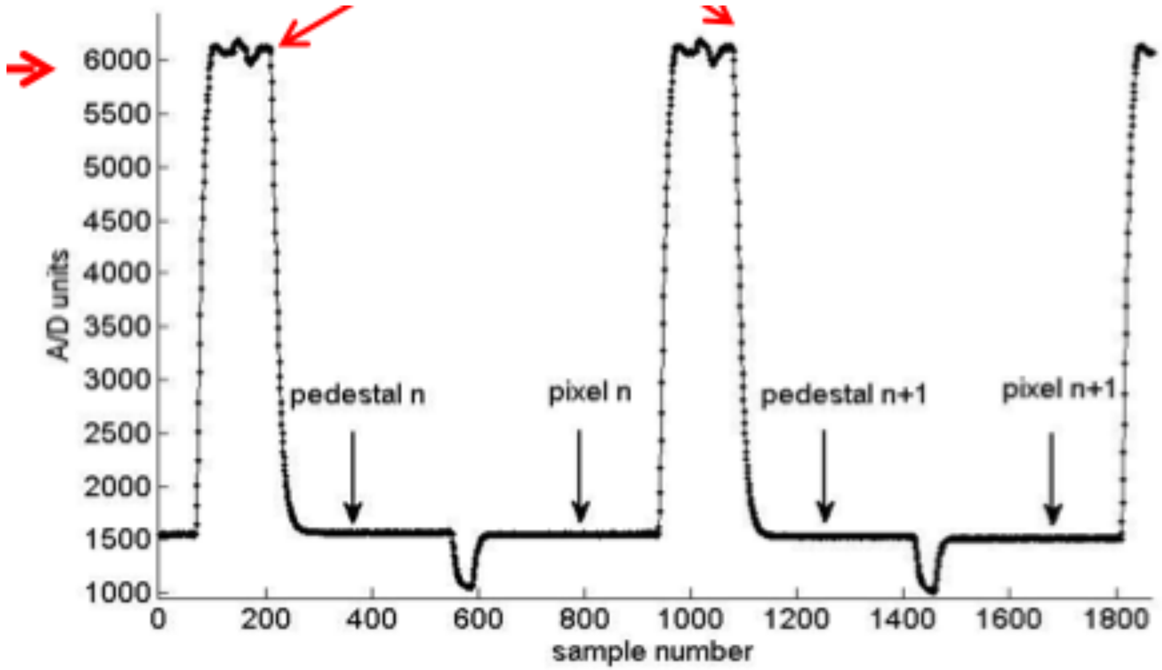
≈ 50 CCDs / 1 Kg

One batch of 24 wafers production for DAMIC100
Three batches sufficient for DAMIC 1kg

Cost does not scale linearly with mass

O(50) CCDs ok even with existing design of electronics (e.g. DECam 62 CCDs)

- Readout noise ≈ 1 e^- with digital filtering



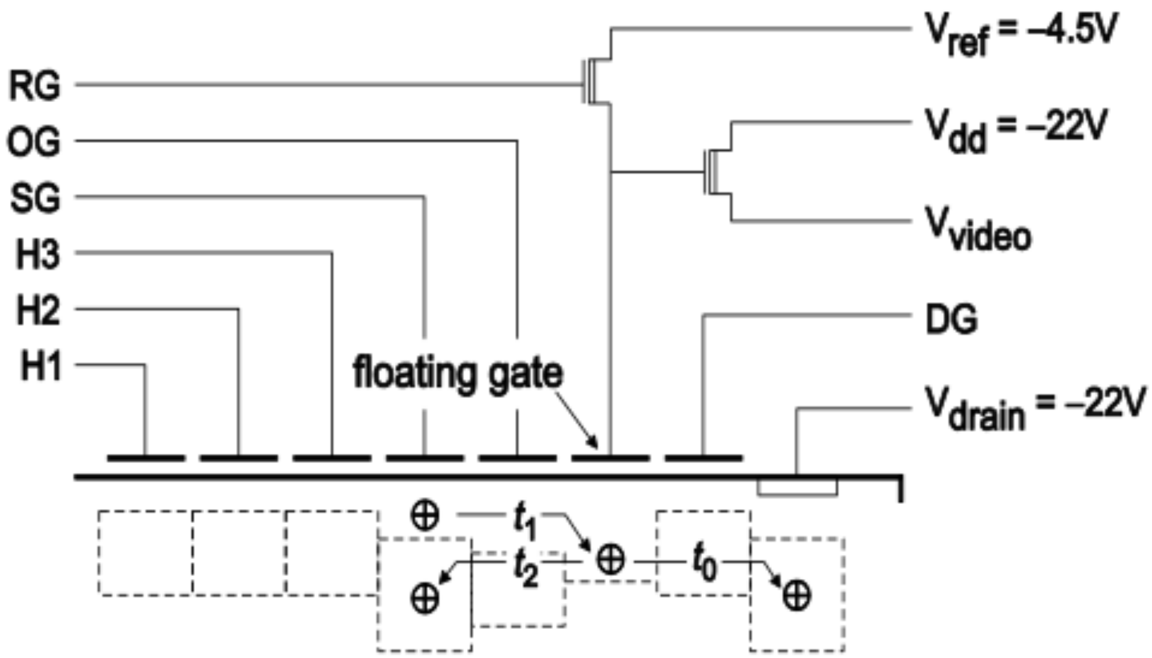
R&D at Fermilab demonstrated 1 e^- noise

A full readout currently under design, will be implemented in DAMIC100

- Digitize the video signal
- Estimate the correlated noise on a string of pixels
- Subtract the correlated noise
- Perform CDS on digitally filtered video signal

(large data storage and offline processing – feasible given 8 hours readout intervals in DAMIC; ultimately on a FPGA)

- Readout noise ≈ 1/10 e^- with skipper CCDs



R&D at Fermilab demonstrated 0.2 e^- noise

Special design of the readout node, with a floating gate output that allows for multiple readouts of the charge in each pixel

- Pixel charge is measured N times, with integration time short to keep 1/f noise negligible
- Noise improves by 1/sqrt(N)

Technology known since long time – the challenge is in the implementation on a large number of CCDs

• Background

- *Terra incognita* at these low energies; DAMIC100 first to explore
- Impact of ^{32}Si to be assessed with DAMIC100: may require use of “underground” silicon
- New design of vessel/box/packaging – underground electroformed copper / silicon
- Drastic improvement in handling procedures to avoid radioactive contamination. DAMIC 1kg will require more infrastructure at SNOLAB (space, cleanroom, etc.)

Conclusions and outlook

- During the last two years, DAMIC has carried out an intense R&D to demonstrate the potential of CCDs as DM detectors
- We have achieved stable, low noise, low background operation of large size, thick fully depleted CCDs at SNOLAB, and demonstrated low mass WIMP sensitivity with R&D data
- We are exploiting CCDs unique spatial granularity to study backgrounds with unprecedented precision
- We are pushing an ambitious program of nuclear recoil ionization efficiency measurements in Si

relevant to all silicon detectors, e.g. SuperCDMS

- DAMIC100 construction has started

- After DAMIC100 successful operation, DAMIC 1kg will be a natural step to take
  - potential scientific reach similar to G2
  - low cost
  - R&D started

DAMIC