DAMIC: a search for Dark Matter with CCD's

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(for the DAMIC collaboration)

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DAMIC

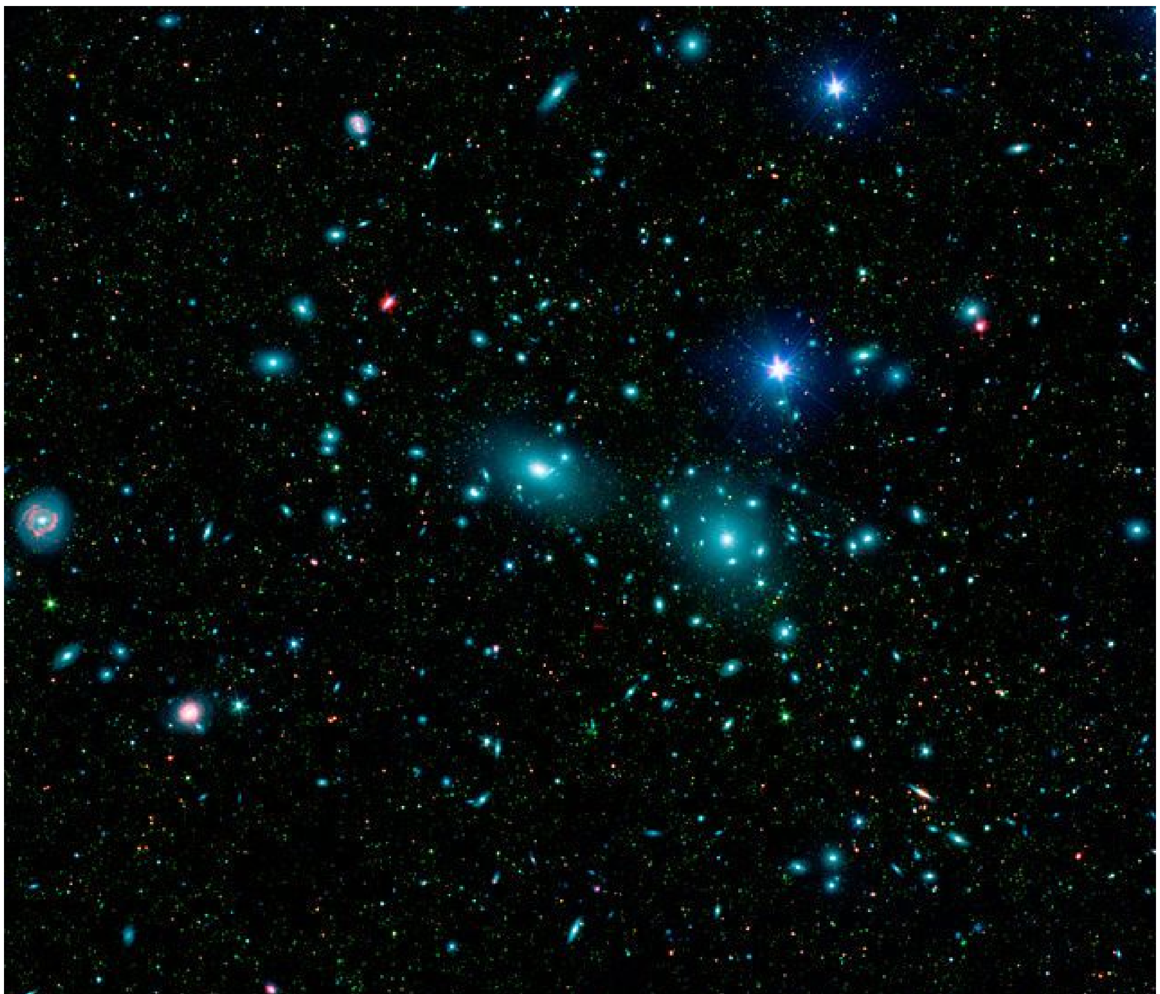
ICN

Outline

- Dark Matter and evidences
- The CCD as ionizing radiation detector
- The DAMIC experiment
- DAMIC @ SNOLAB
- Calibrations and background measurements
- Future plans (short & mid term)
- Conclusions

Dark Matter

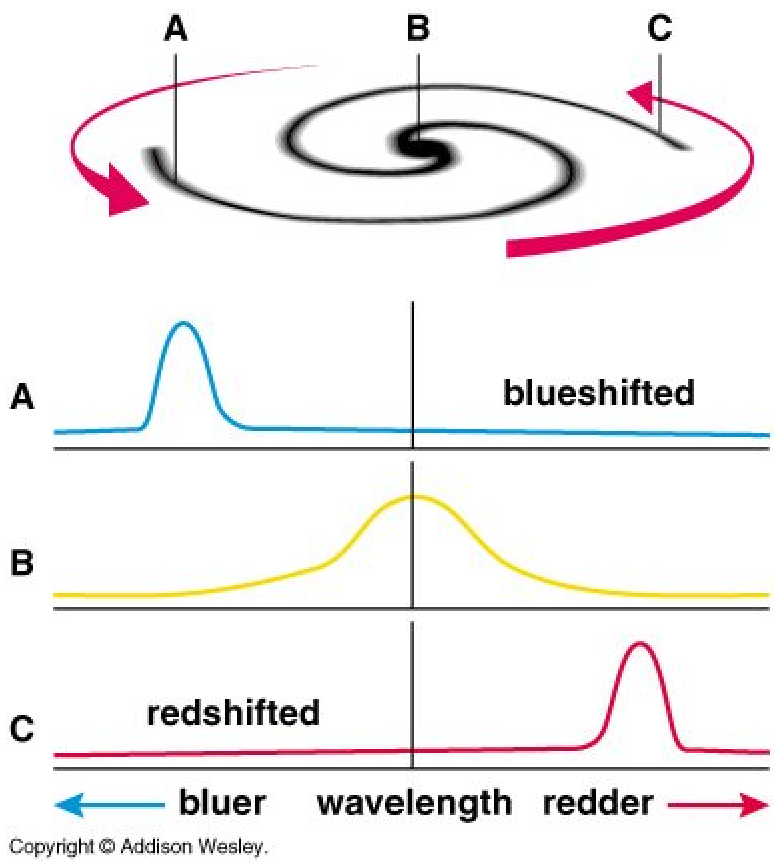
First proposed by Fritz Zwicky in 1933 when studying the motion of the *Coma* galaxy cluster.

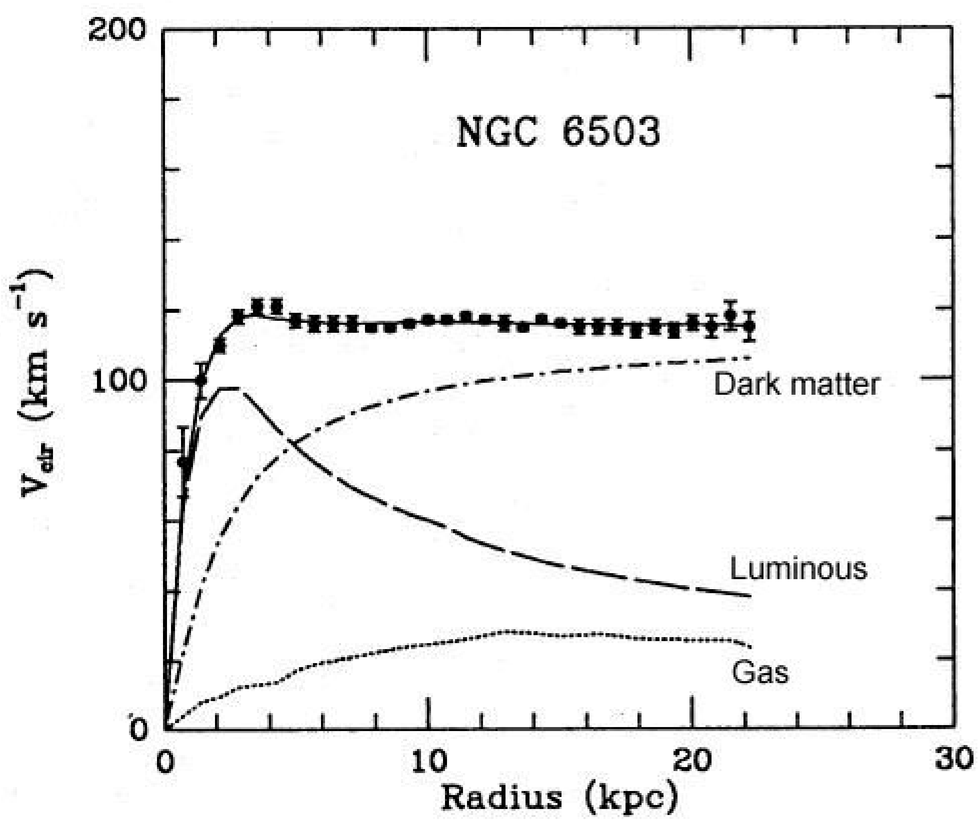


More matter than is visible is required!

Evidences for Dark Matter

Galaxy rotation curves: Matter appears to extend beyond the visible stars.

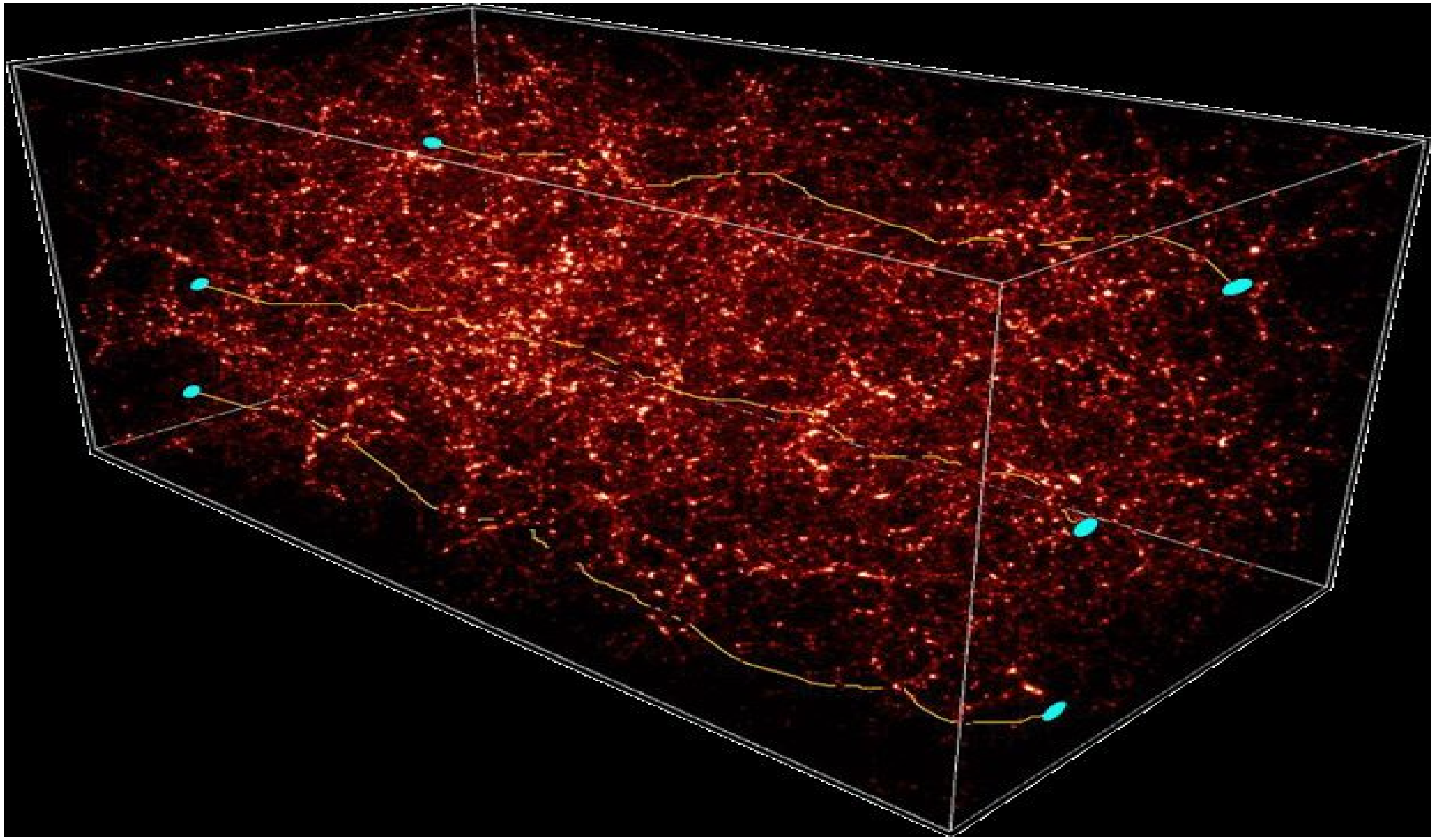




First observed by Vera Rubin in the 1970's

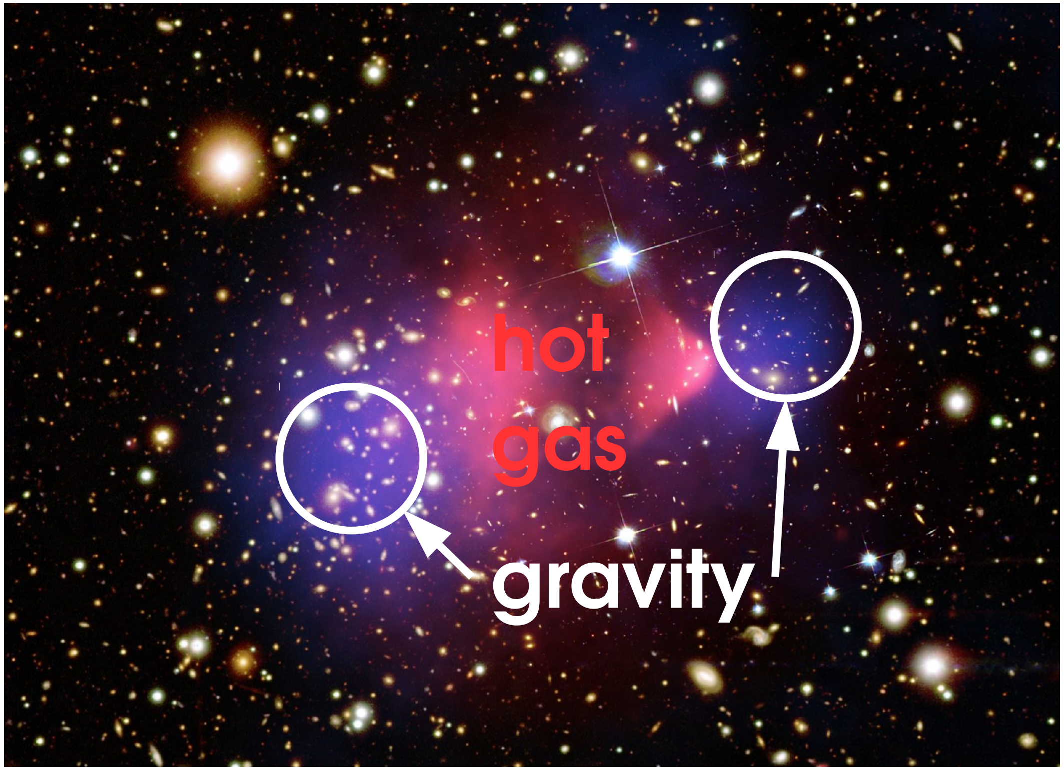
Evidences for Dark Matter

Weak gravitational lensing: cumulative effect on the trajectory of light from distant sources → maps dark matter distribution along path

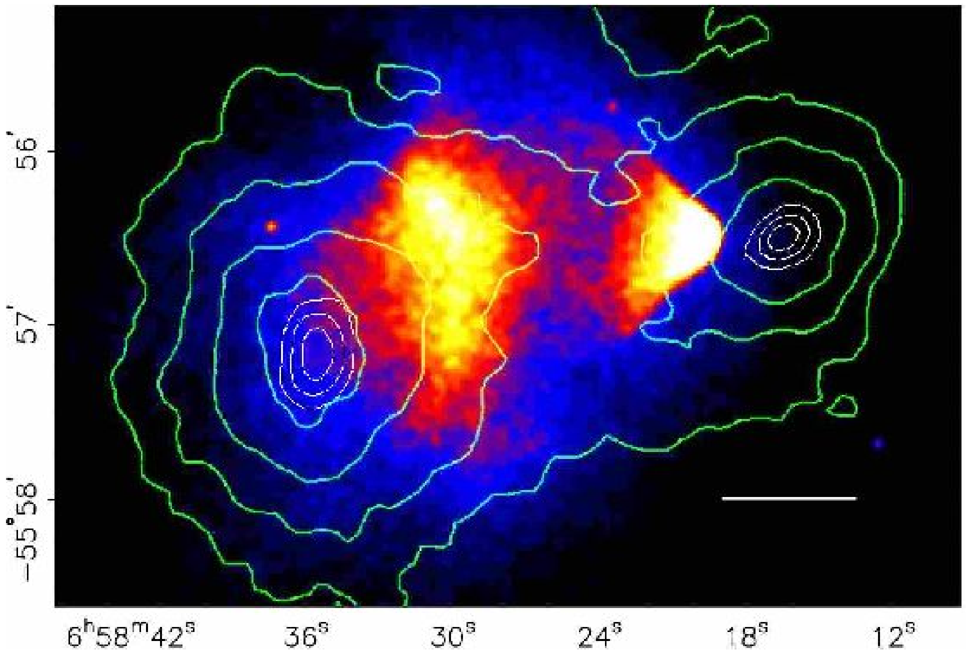


Evidences for Dark Matter

The Bullet Cluster: Prime example of offset between total mass and visible/baryonic mass.



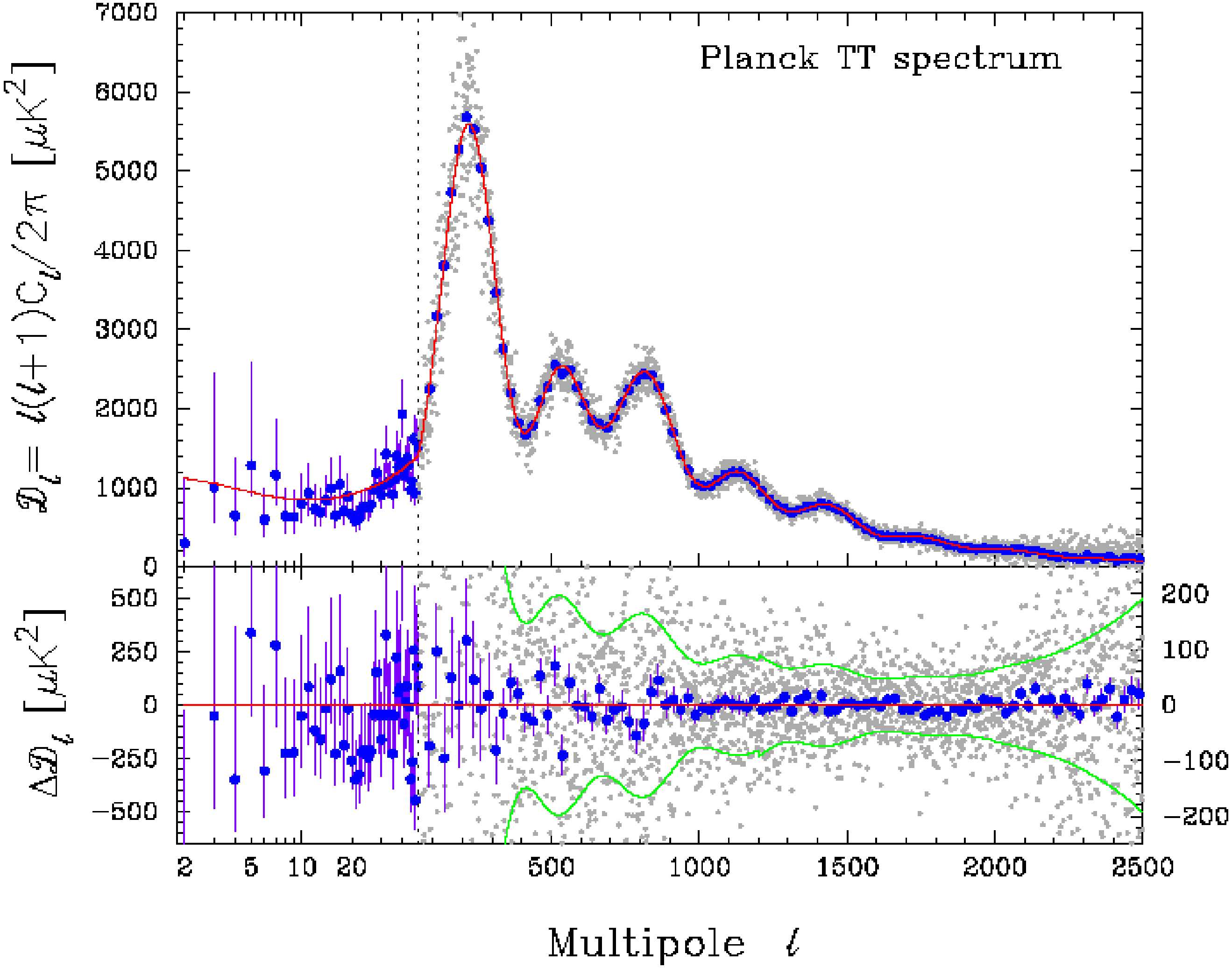
Chandra X-ray image



Contours from weak lensing

Evidences for Dark Matter

<u>CMB temperature fluctuations:</u> A good fit of the ΛCDM cosmological model to the power spectrum of temperature fluctuations of the CMB requires a ~23% of cold dark matter.



Evidences for Dark Matter

Big-Bang nucleosynthesis:

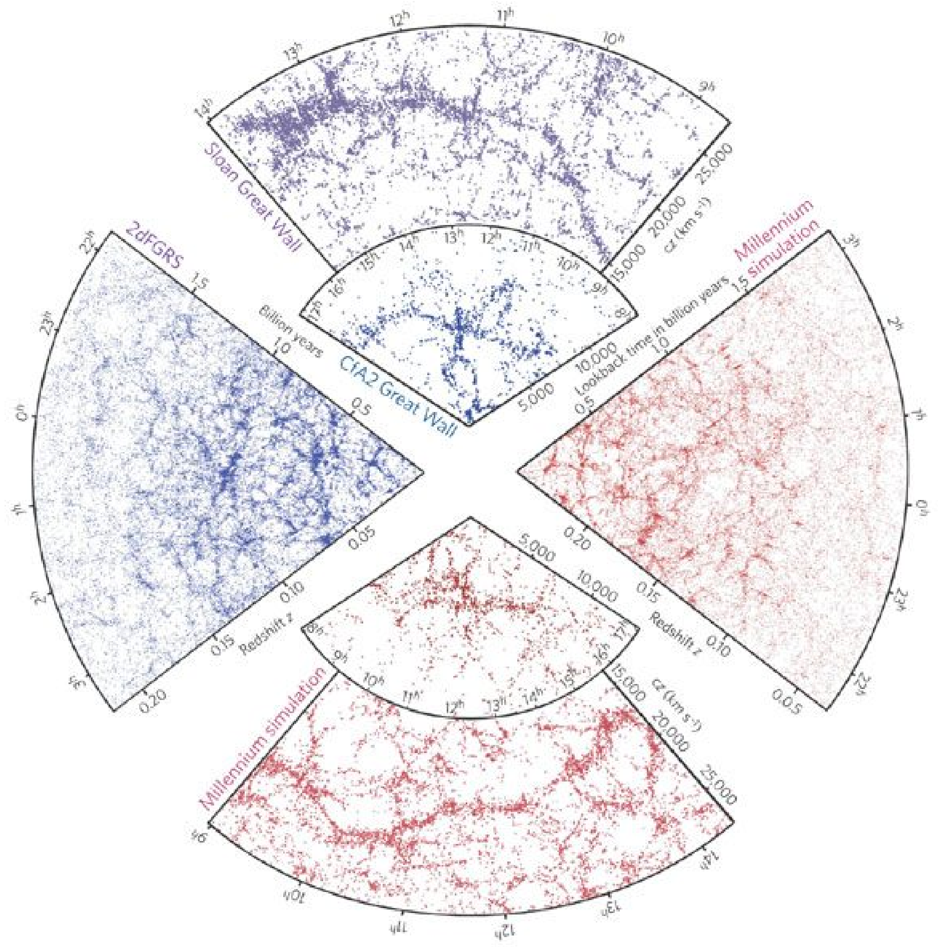
CMB measurements provide the photon density at the time when the universe became "transparent". The relative abundance of light elements is dependent on the baryon to photon density ratio.

Overall concordance of the light element abundances with predictions say that the baryon mass density Ω_b is only a few percent, but at the same time $\Omega_m=\Omega_b+\Omega_{cdm}<0.3$, hence, non-baryonic DM is needed.

The relative abundances of light elements in the Universe imply the existence of a significant fraction of non-baryonic dark matter.

Evidences for Dark Matter

Large scale structure of the universe: DM is needed to explain the formation of structure observed given the age of the Universe and the dynamics of clusters of galaxies.



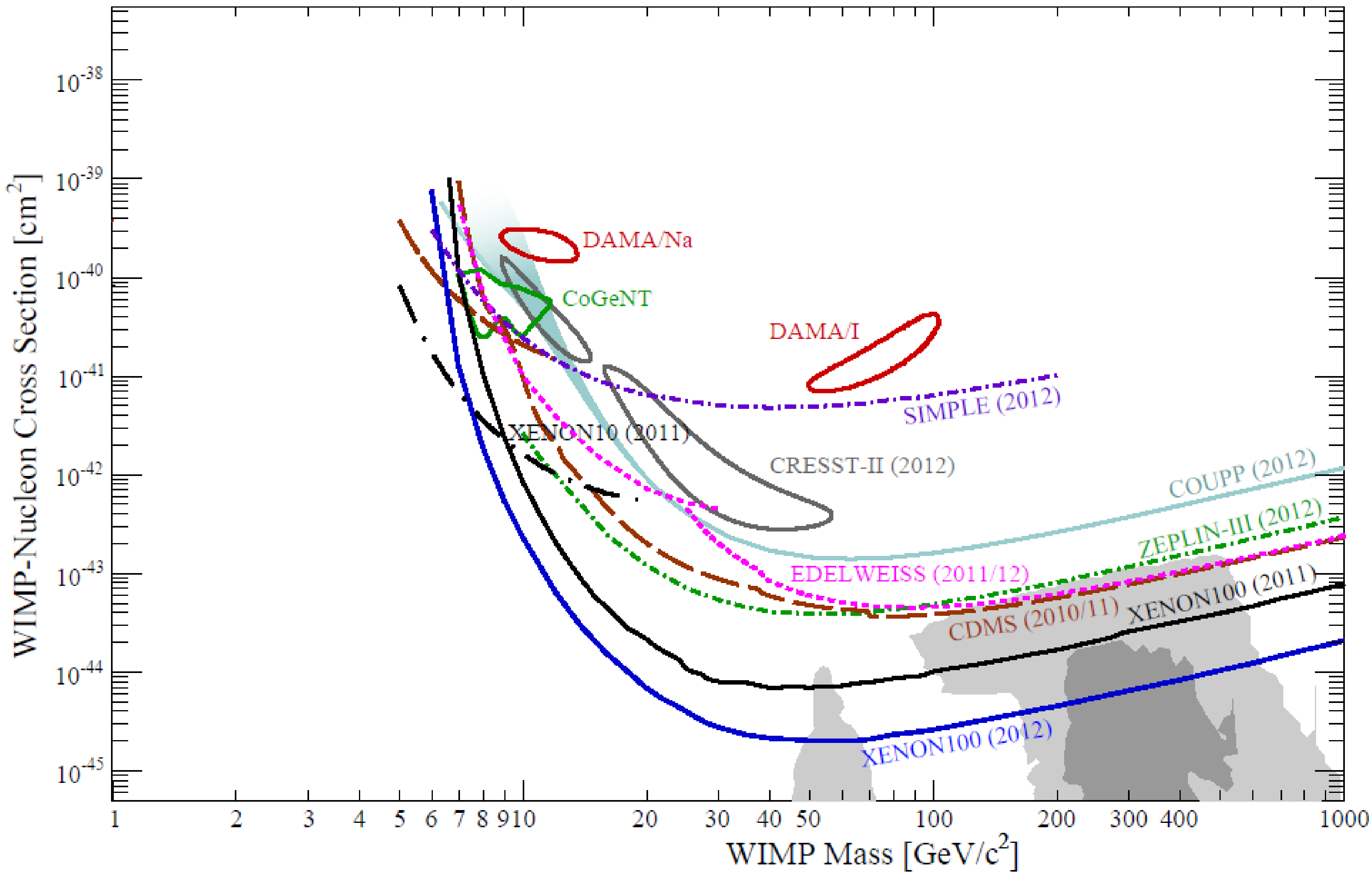
Dark Matter candidates

Some possibilities that have been proposed:

- **Weakly-interacting Massive Particles (WIMPs)**
- Massive Compact Halo Objects (MACHOS)
- Sterile neutrinos
- Axions
- Anything else

Very active field. More than 200 theory publications on light DM in 2013!

Some past Dark Matter searches



DAMIC Collaboration

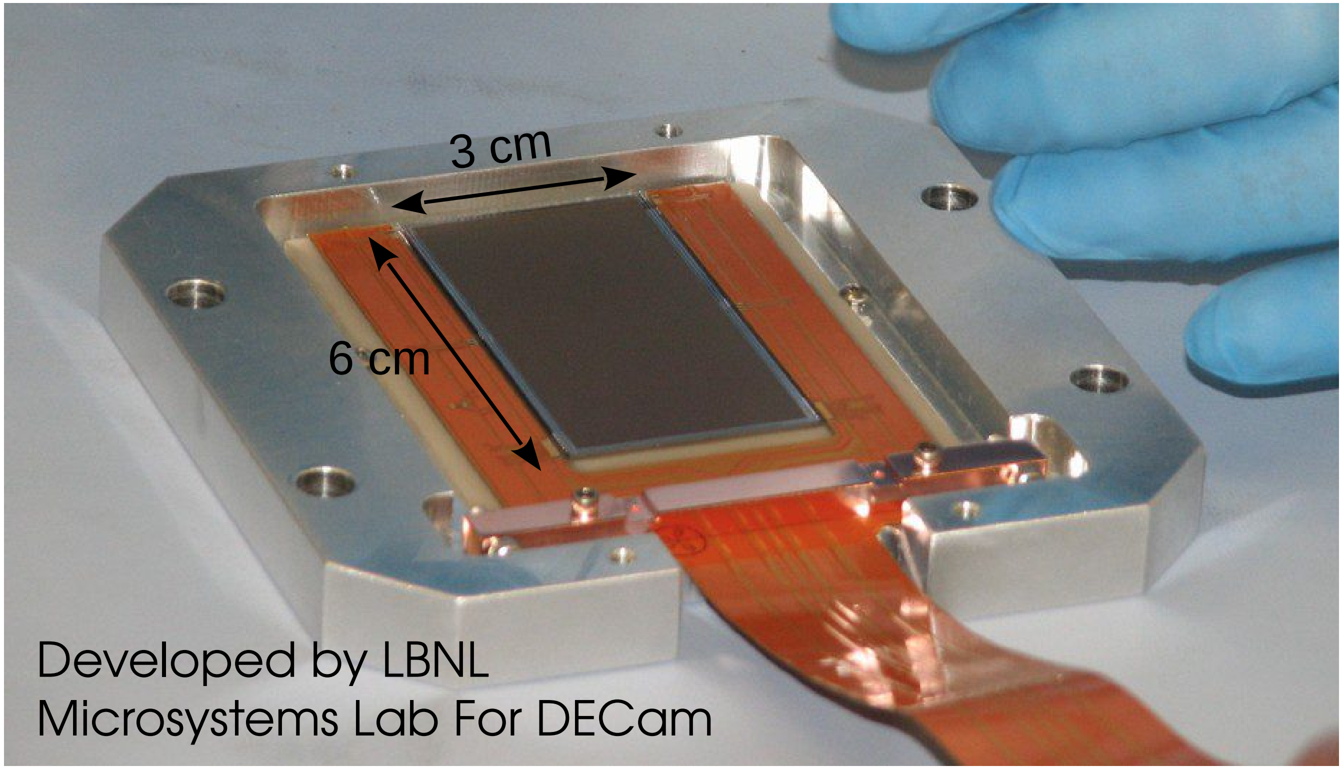
(**D**ark **M**atter **I**n **C**CDs)

International collaboration: 7 institutions from 5 countries

DAMIC

Argentina:	Centro Atómico Bariloche
Mexico:	Universidad Nacional Autónoma de México
Paraguay:	Universidad Nacional de Asunción
Switzerland:	Universität Zürich (UZH)
United States:	Fermilab, U. Chicago, U. Michigan

Charge-coupled device

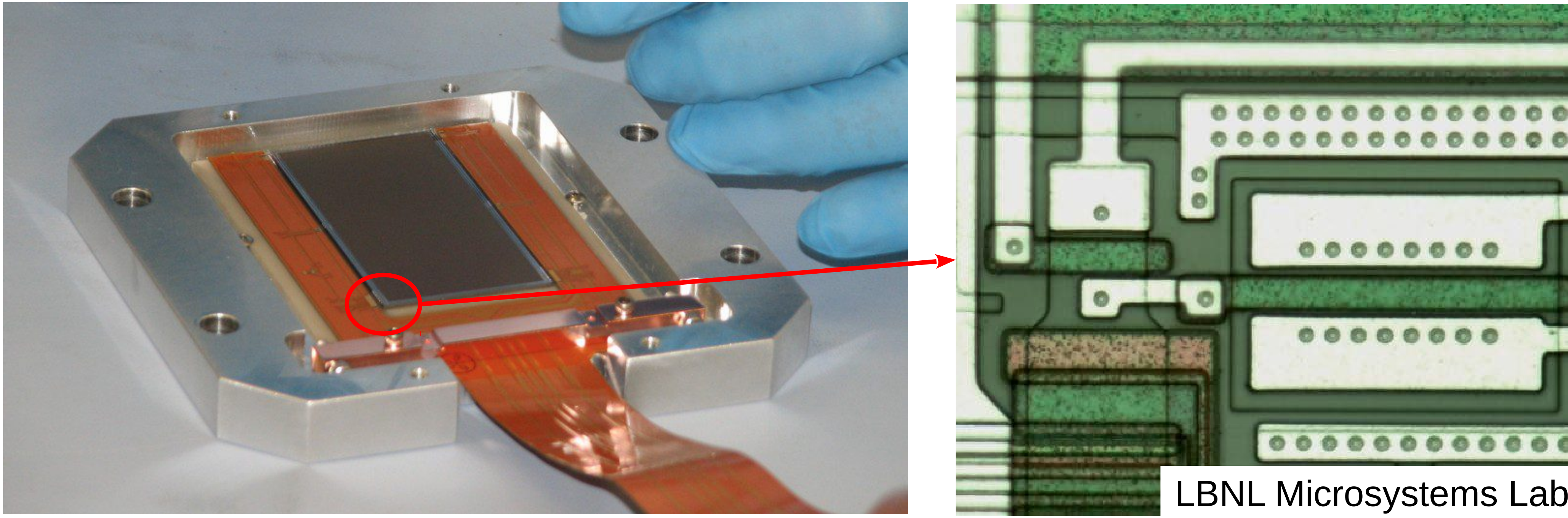


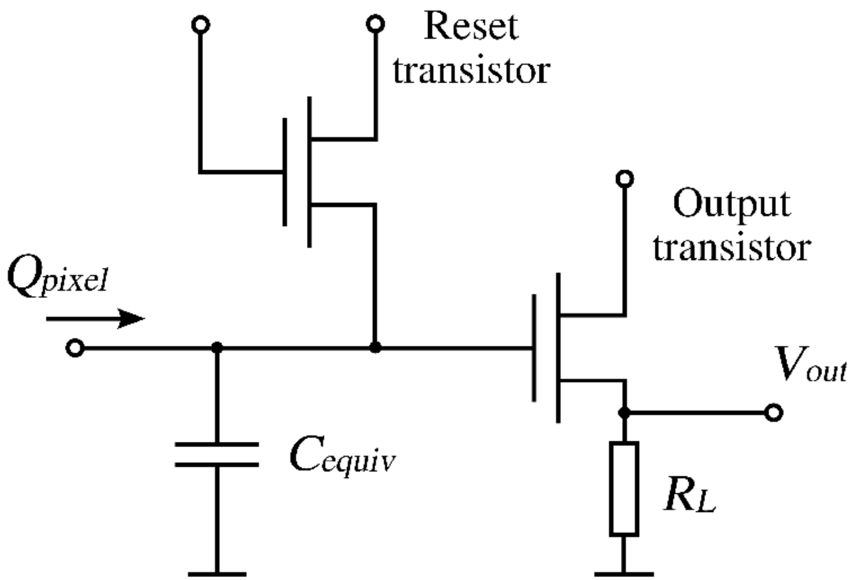
Pixel size:	15 μm x 15 μm
# of pixels:	2000 x 4000
CCD Thickness:	250 μm
CCD Mass:	1 gram
Operation Temp:	150 K

- Readout noise ~ 2.5 electrons RMS
- Detector Threshold < 50 eV_{ee}

Diffusion → 3D reconstruction
→ surface event rejection

Charge-coupled device





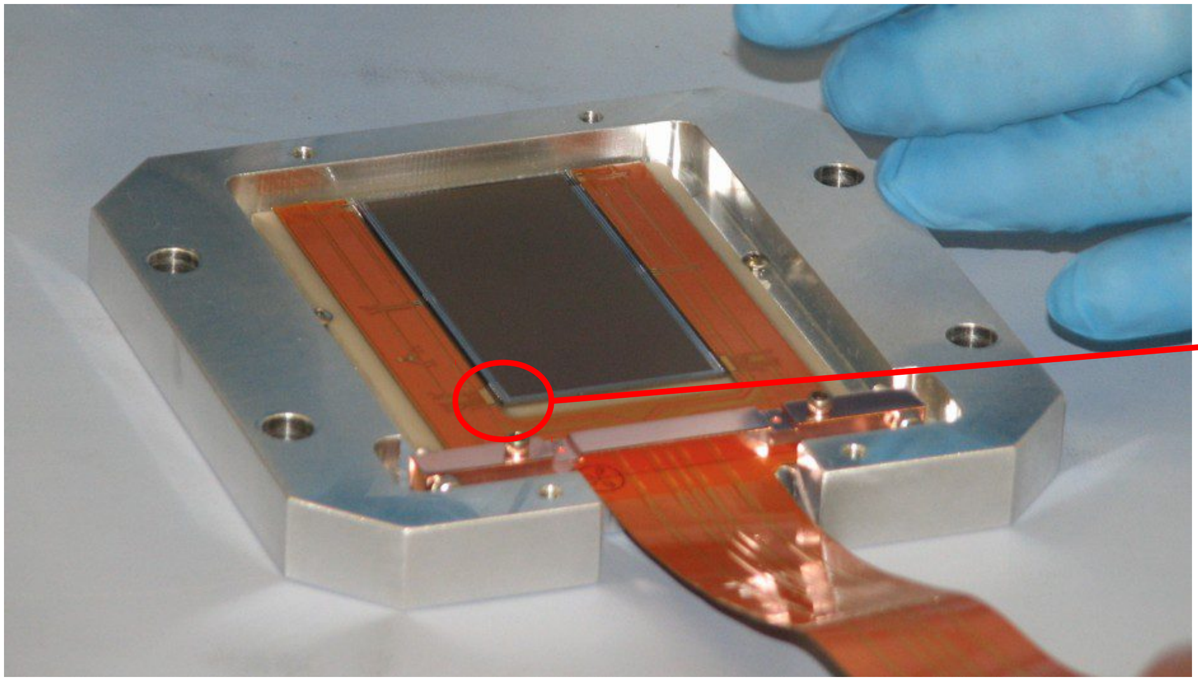
Gain ~1

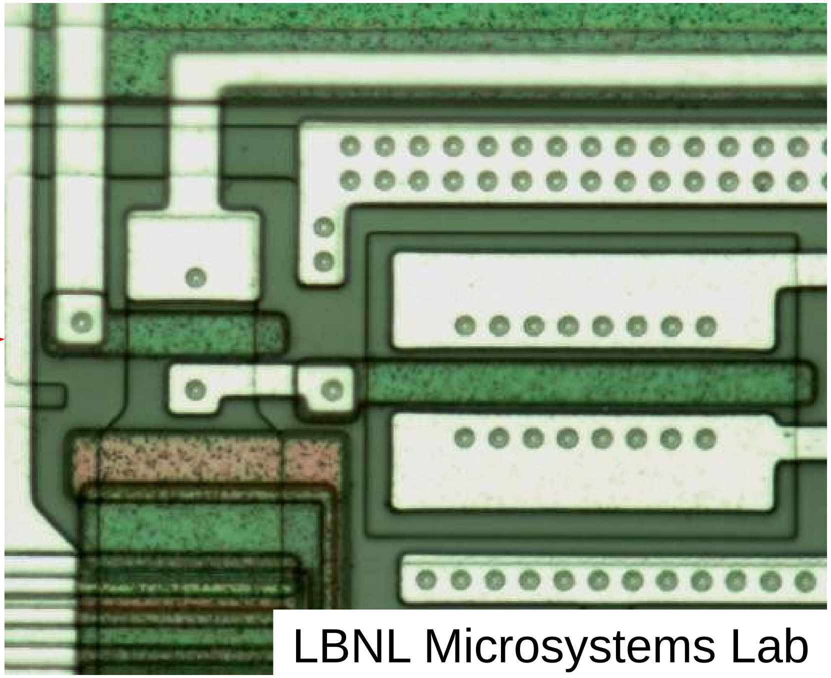
C_{equiv} ~ 0.05 pF

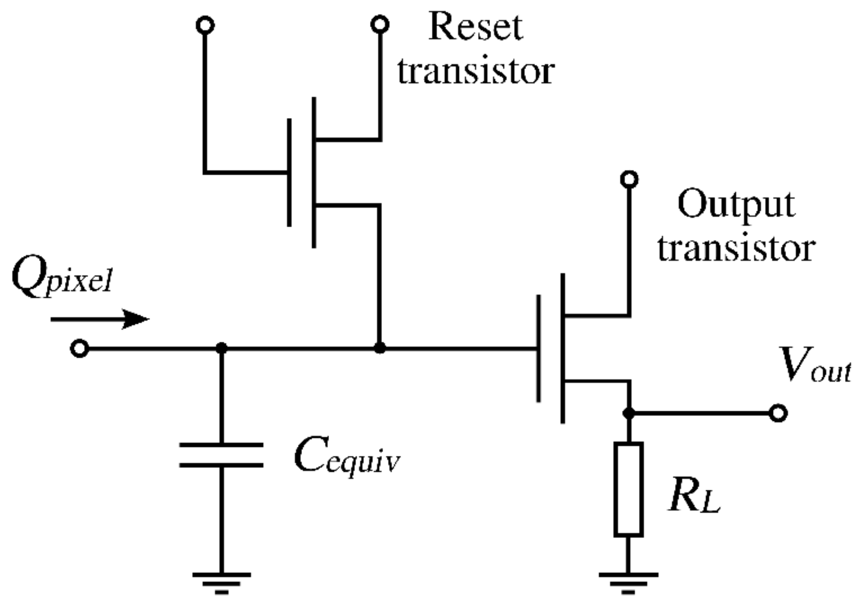
$$V = \frac{Q}{C}$$

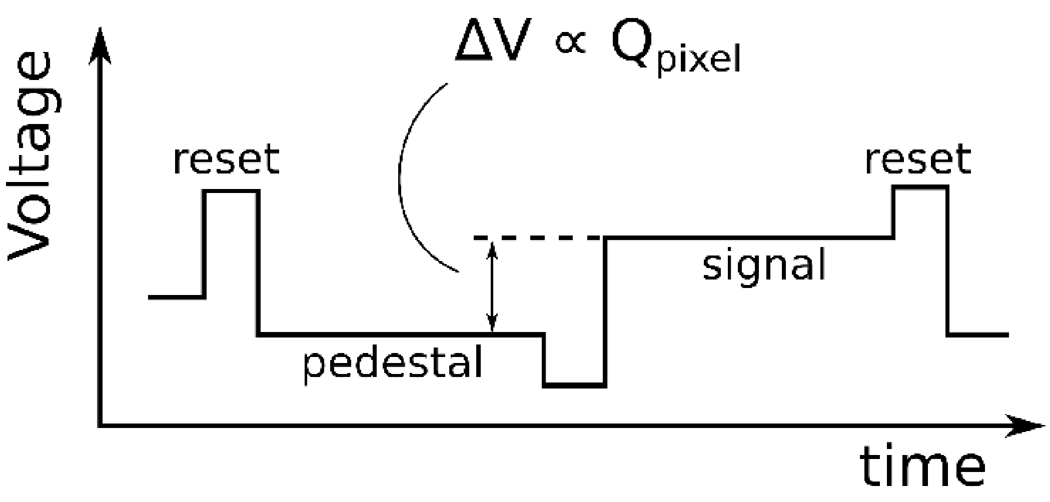
$$V_{out} \sim 3\ \frac{\mu V}{e^-}$$

Charge-coupled device



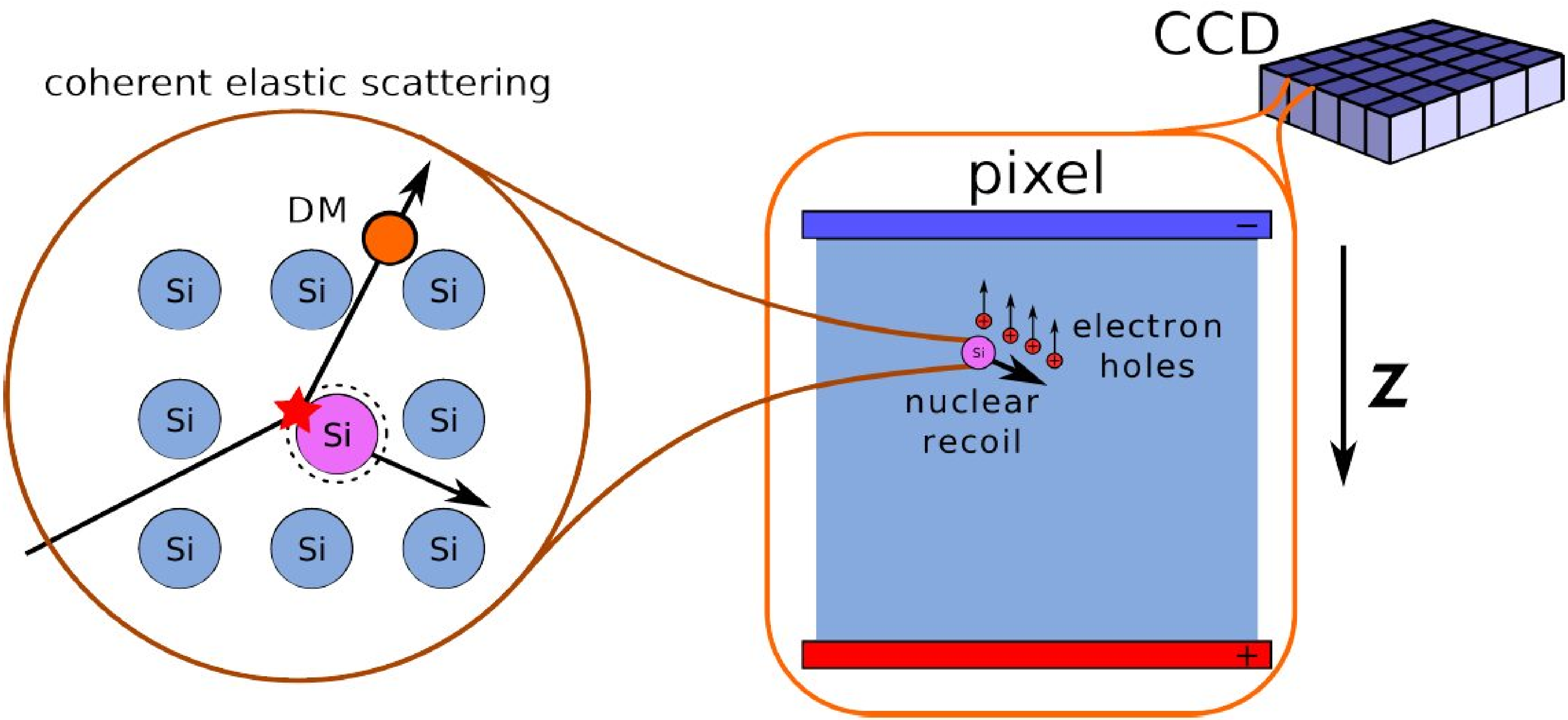




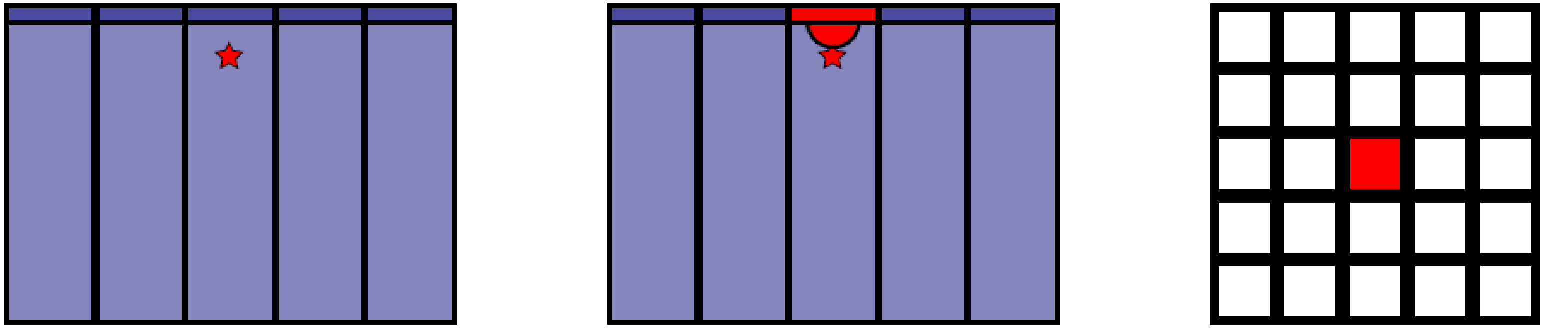


CCDs: detectors of ionizing rad.

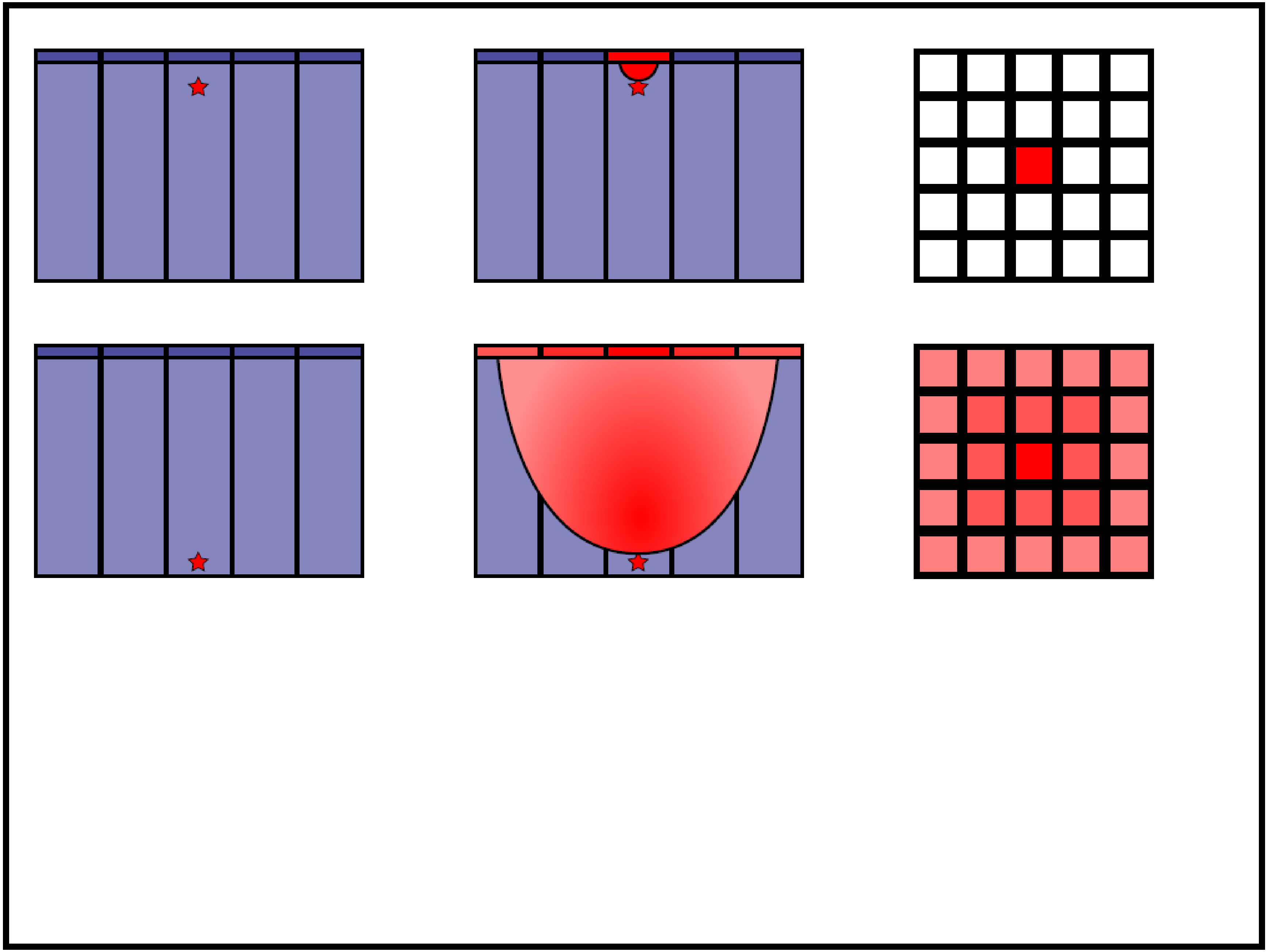
<u>Goal</u>: look for coherent WIMP-Nucleus scattering signals through the ionization of nuclear recoils in the silicon of a CCD



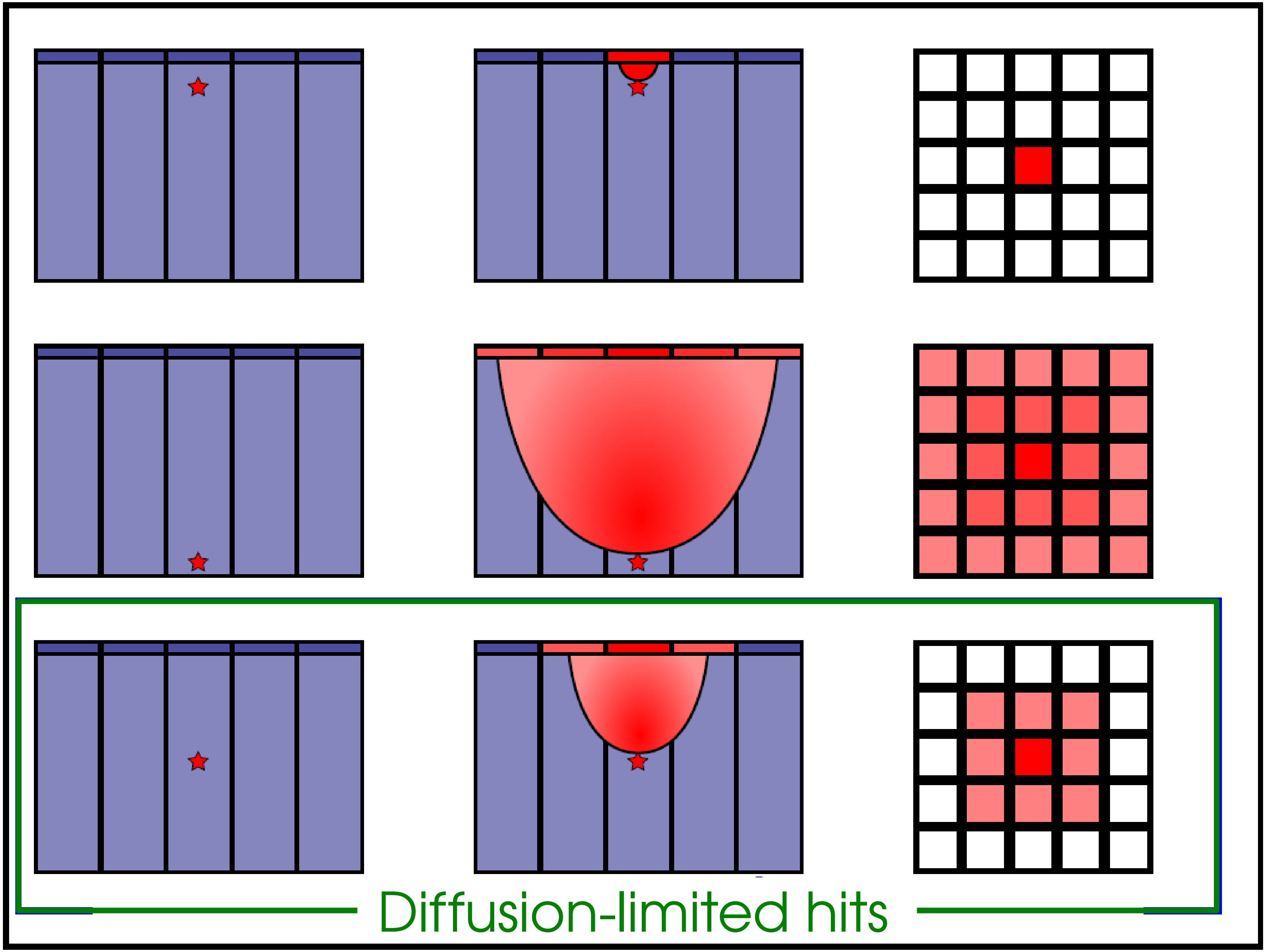
Difussion-limited hits



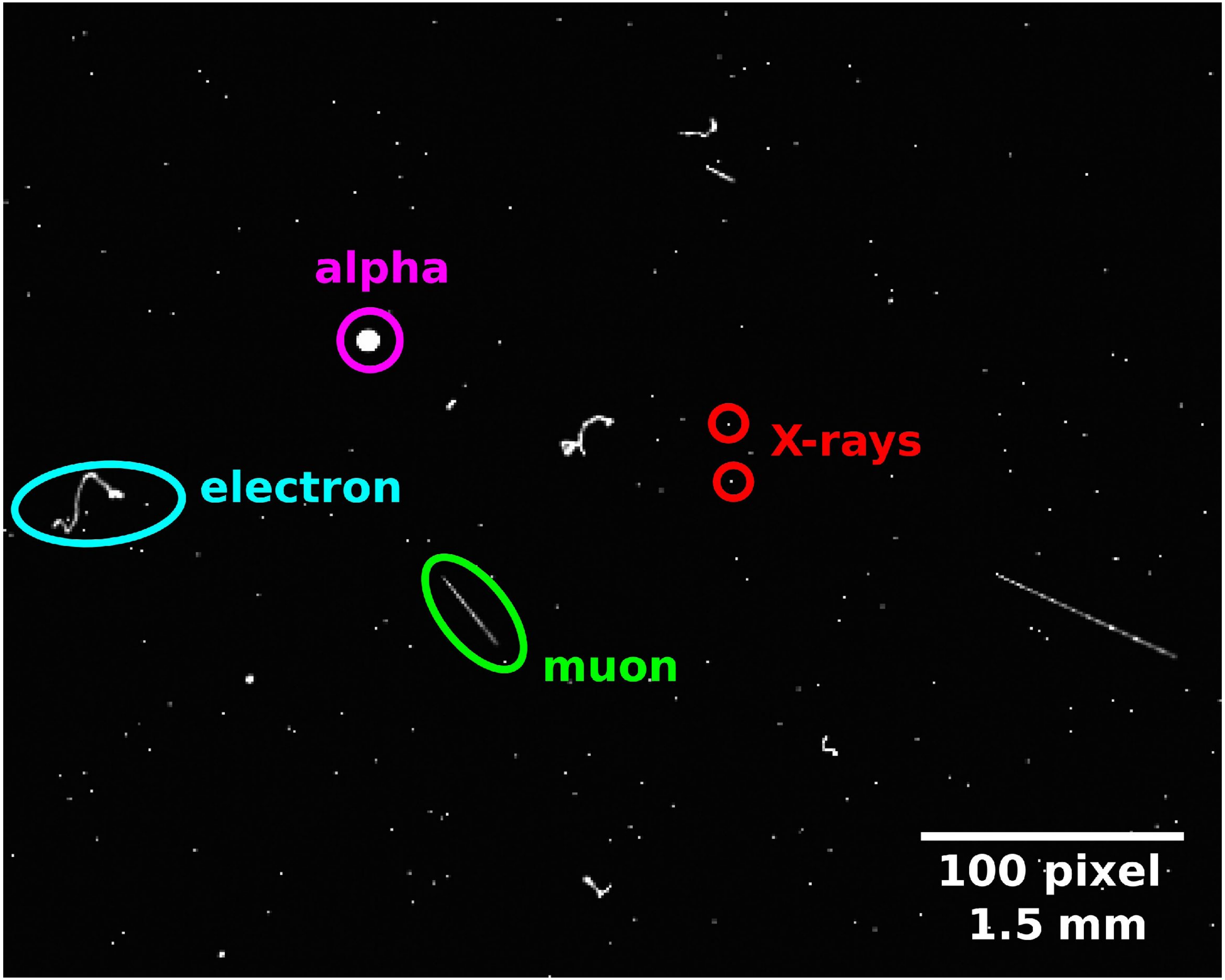
Difussion-limited hits



Difussion-limited hits

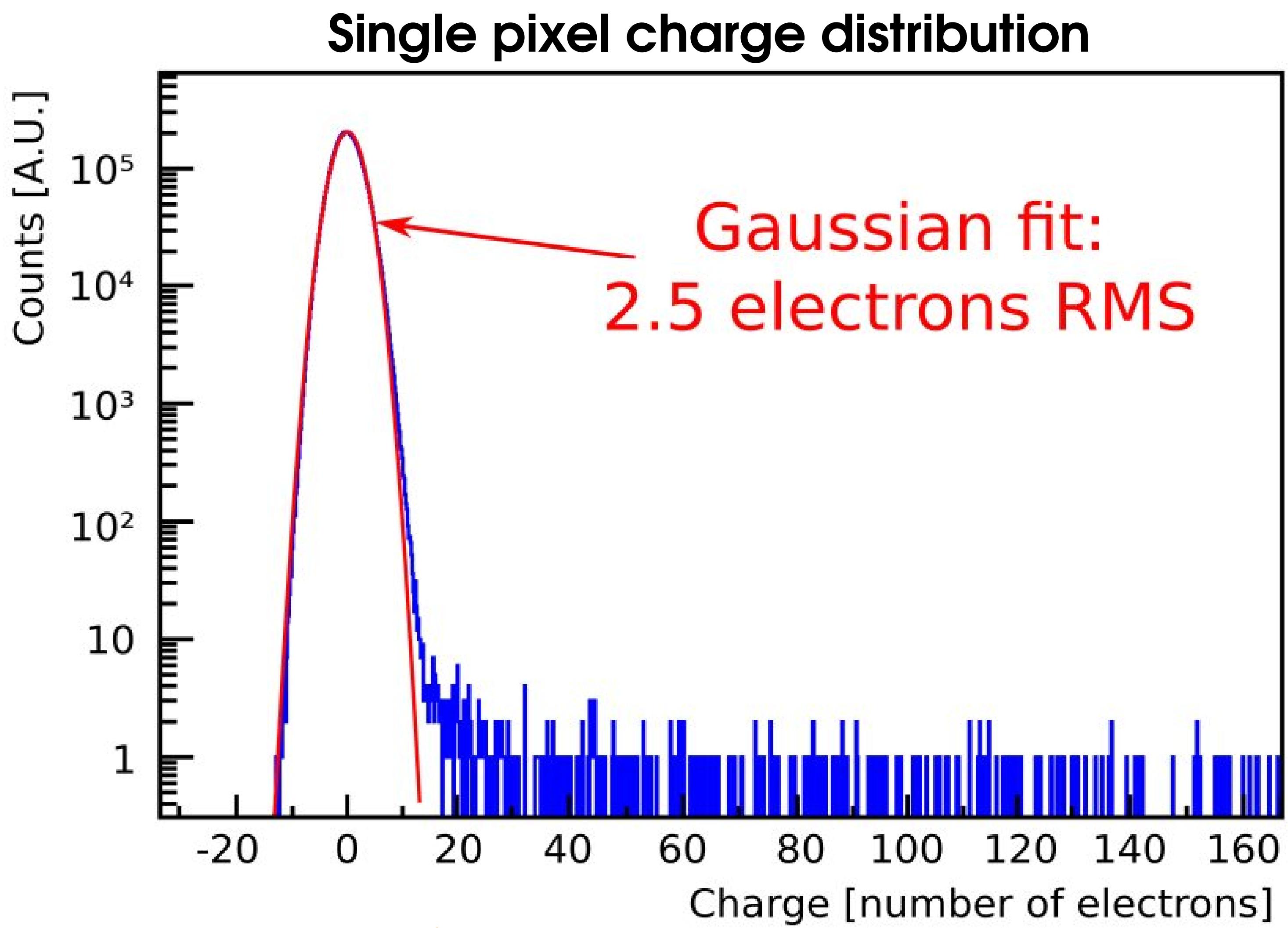


CCDs: detectors of ionizing rad.



CCD image → Powerful particle ID

CCDs: detectors of ionizing rad.

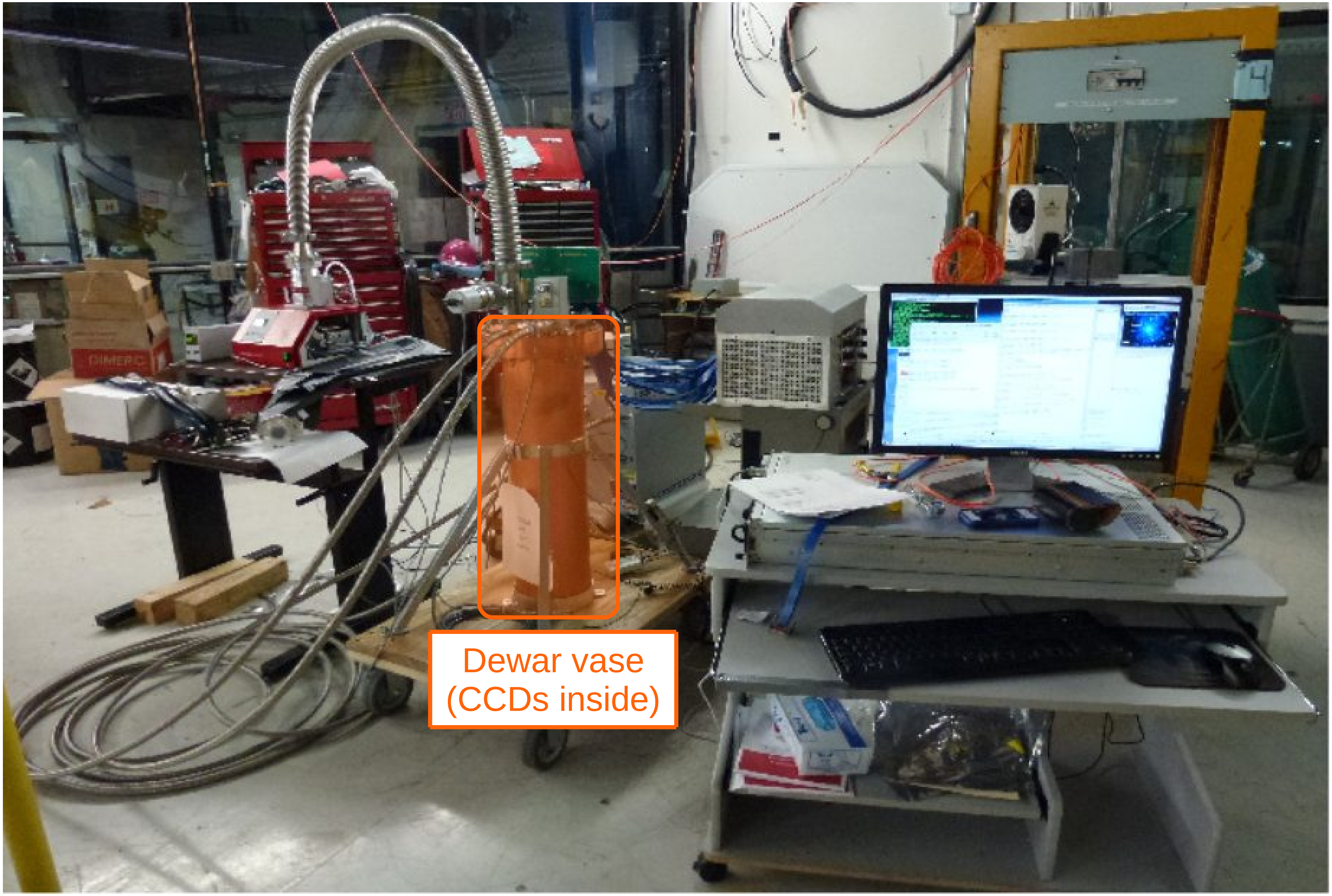


noise distribution

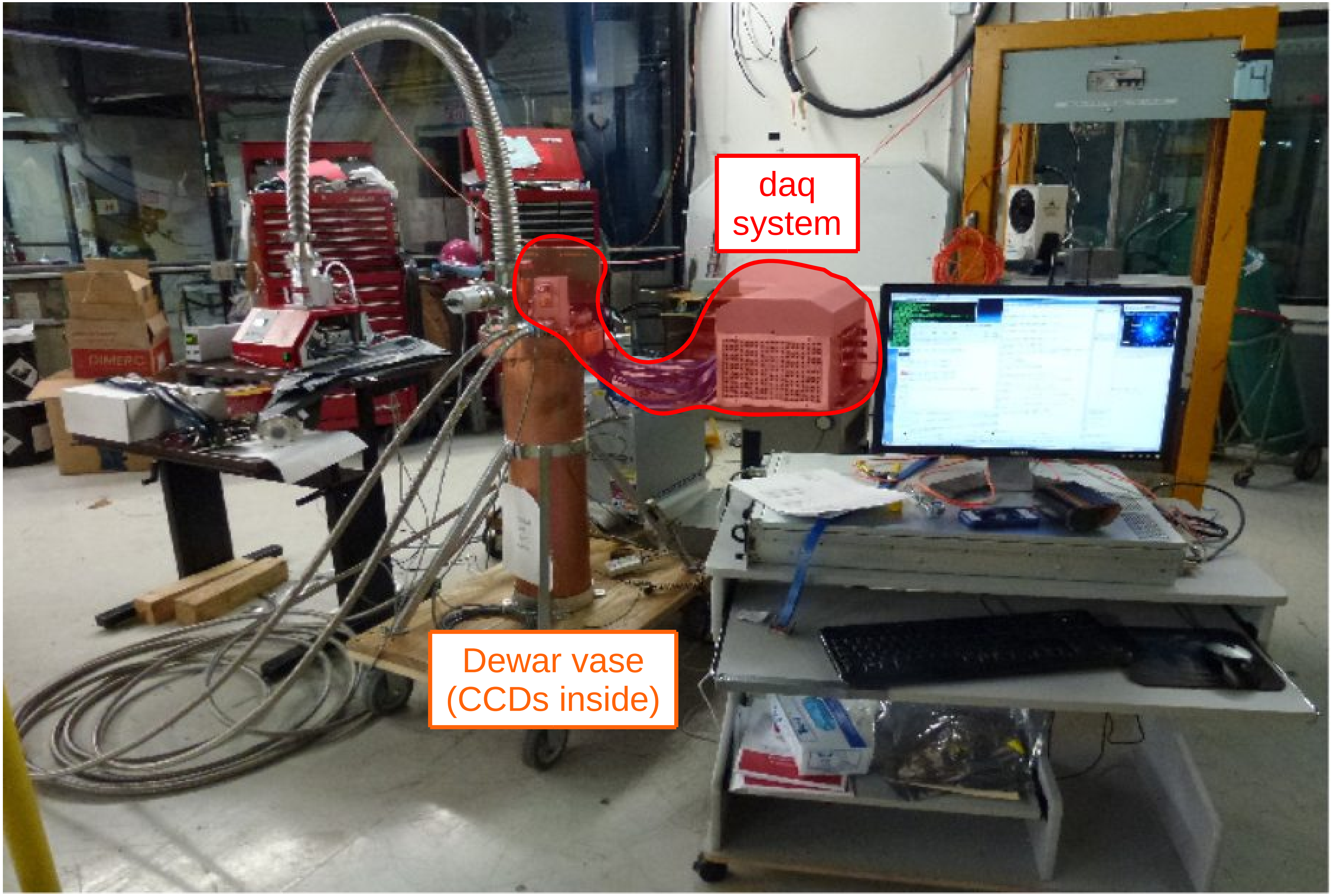
Charge deposited by ionizing radiation

DAMIC detector components

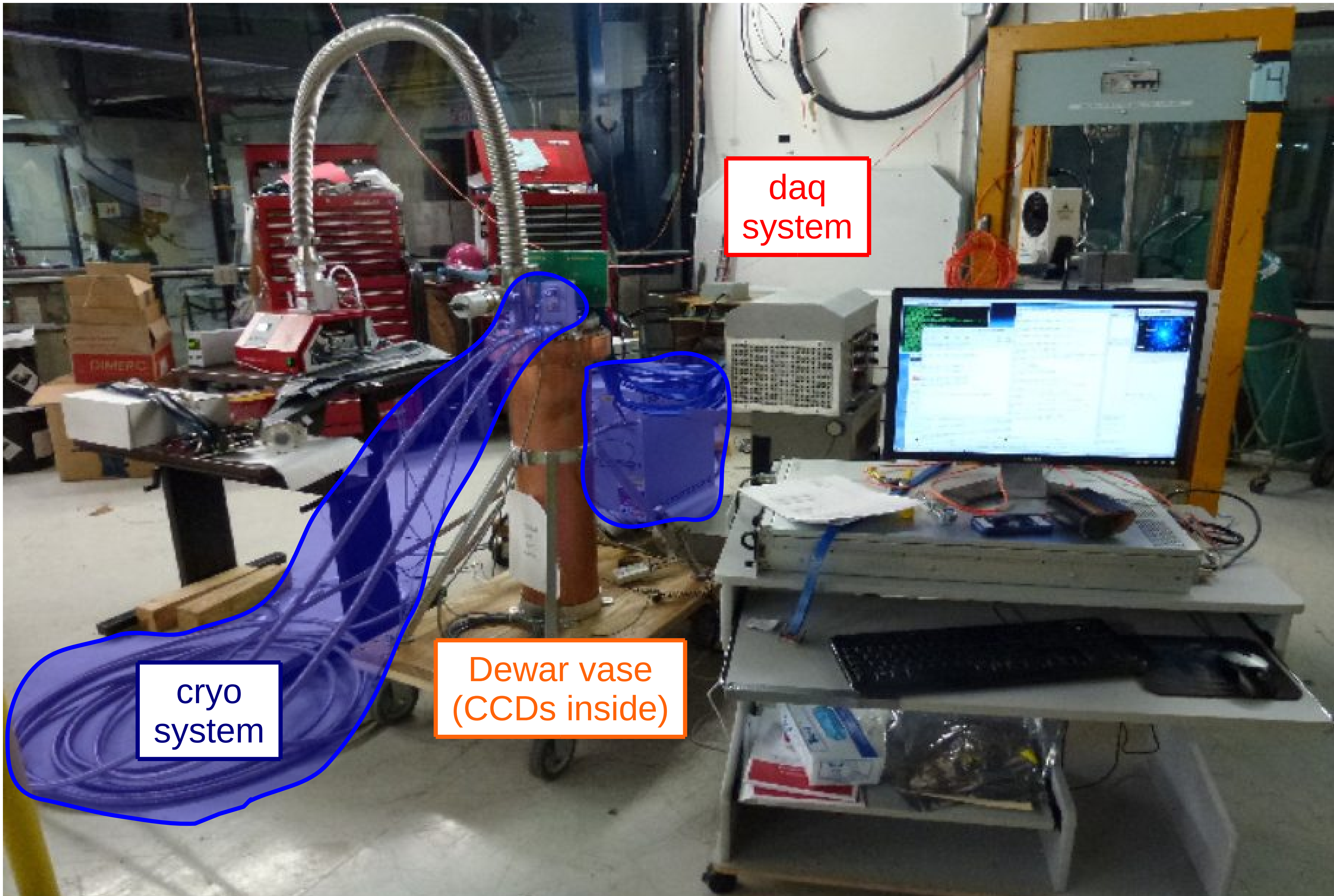
DAMIC detector components



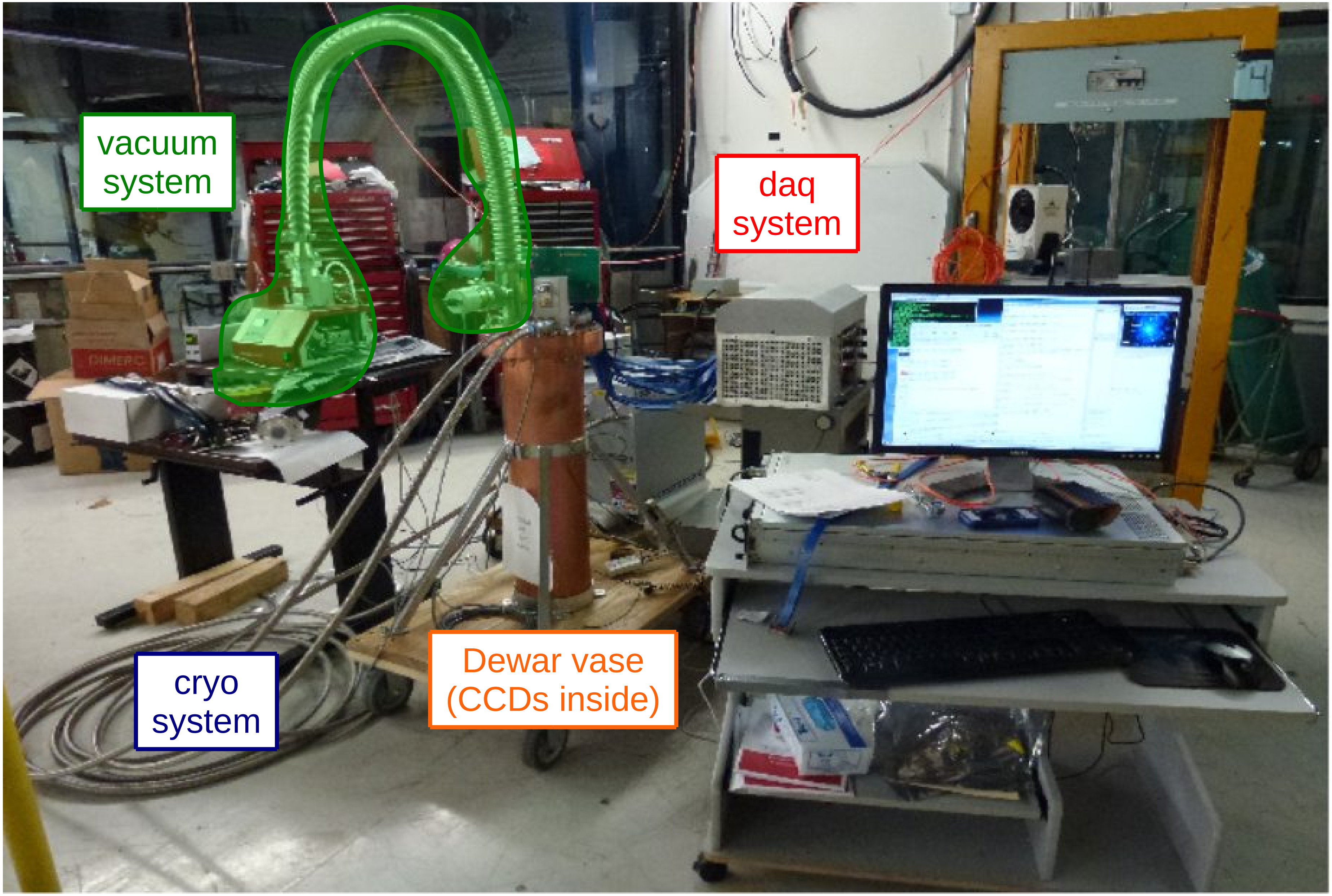
DAMIC detector components



DAMIC detector components

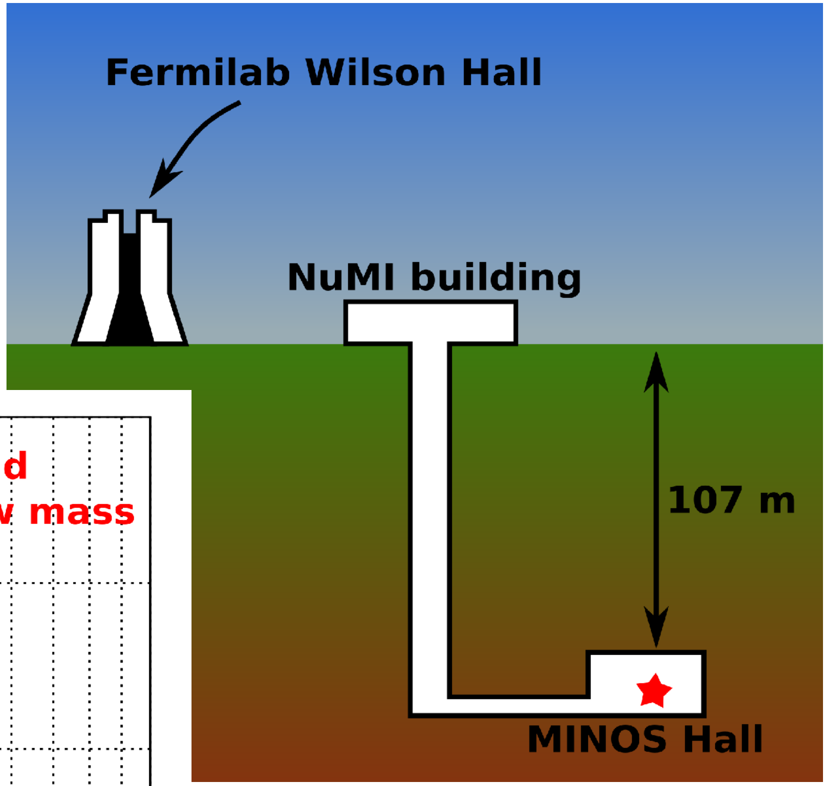


DAMIC detector components

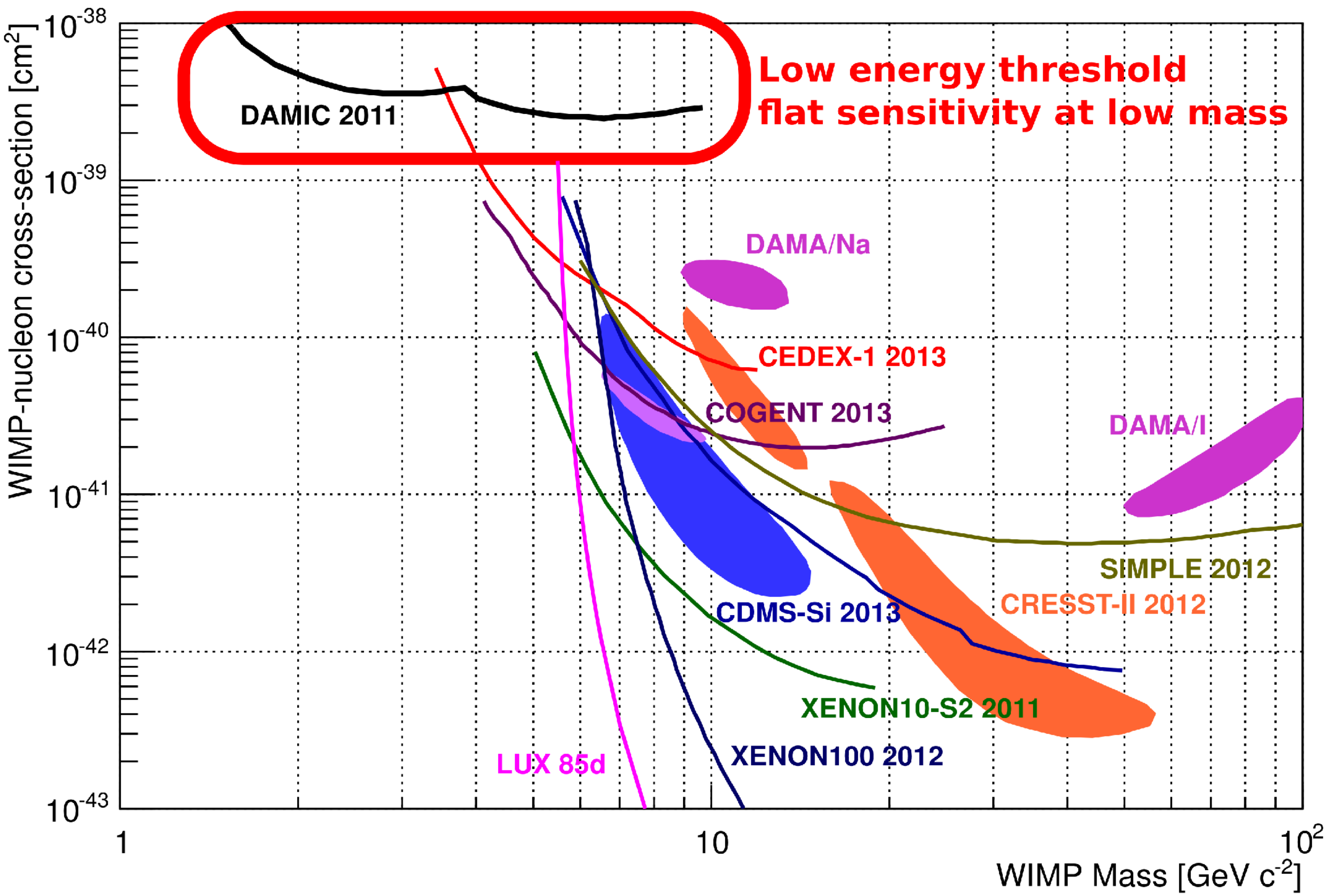


DAMIC proof of principle

- Run at MINOS ND hall @ FNAL (2011)
- Most restrictive limit on σ for masses < 5 GeV



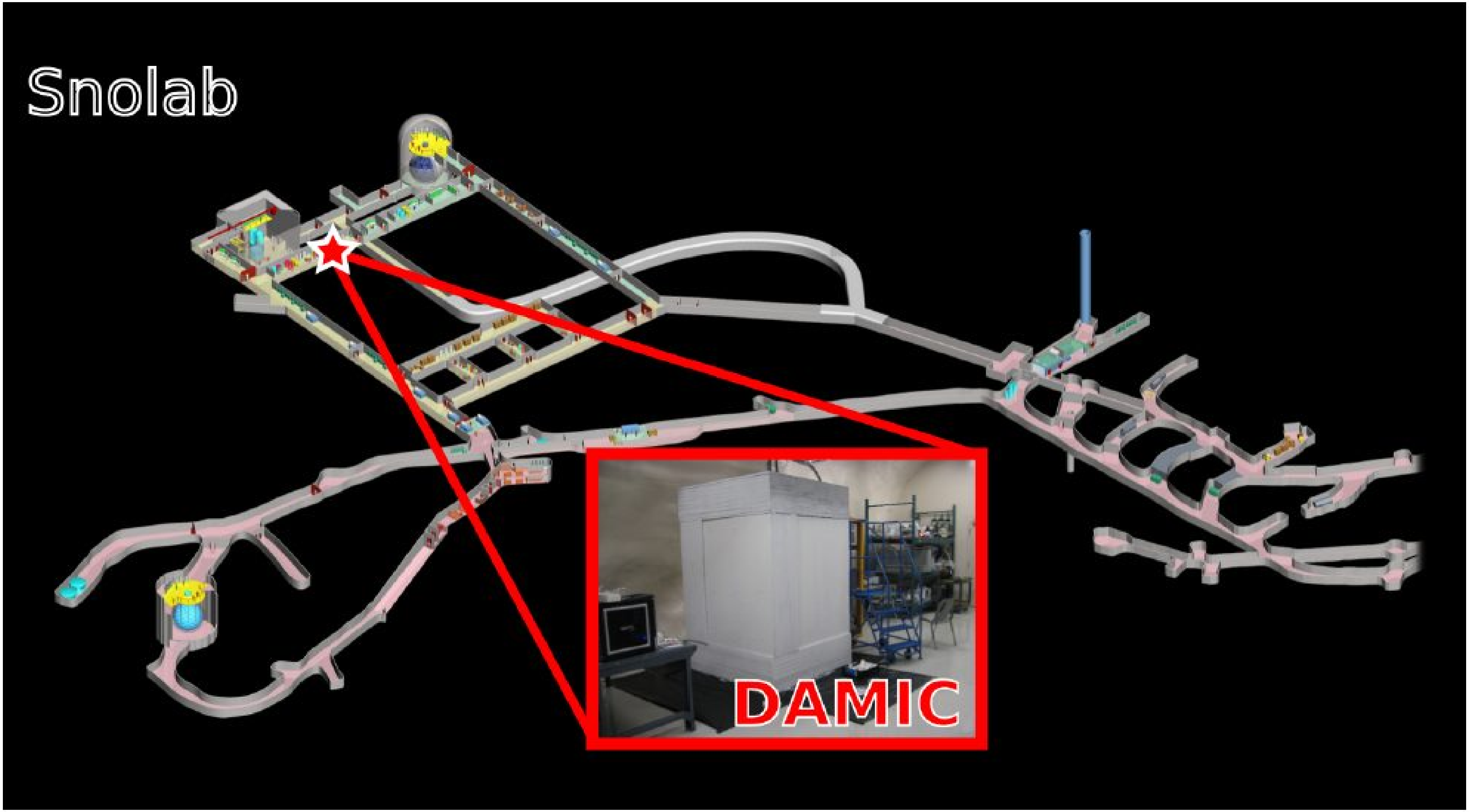
Phys. Lett. B711 (2012), 264-269



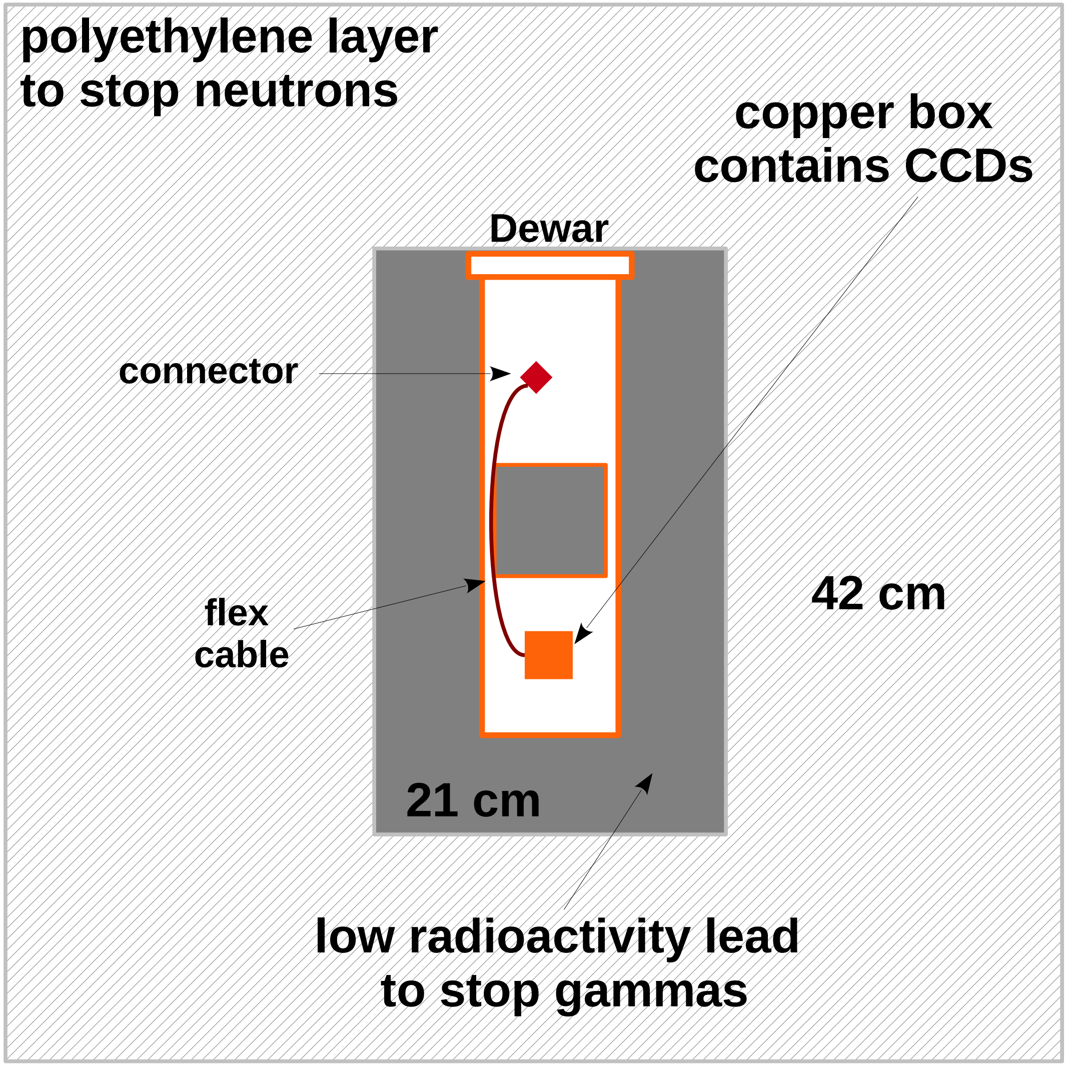
Exposure: 107 g-day

DAMIC @ SNOLAB

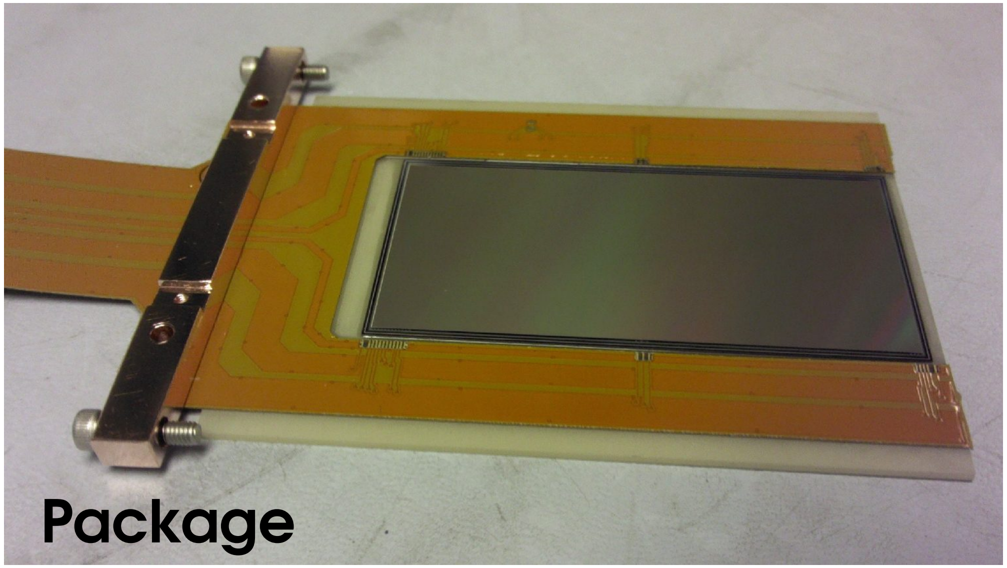
Installed Dec 2012

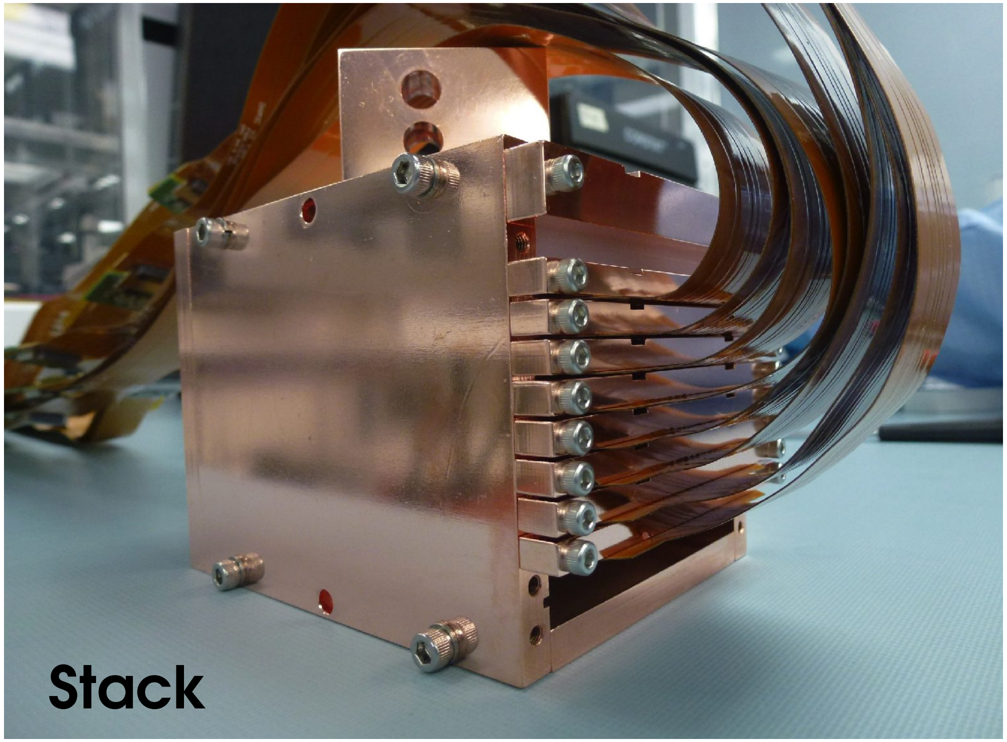


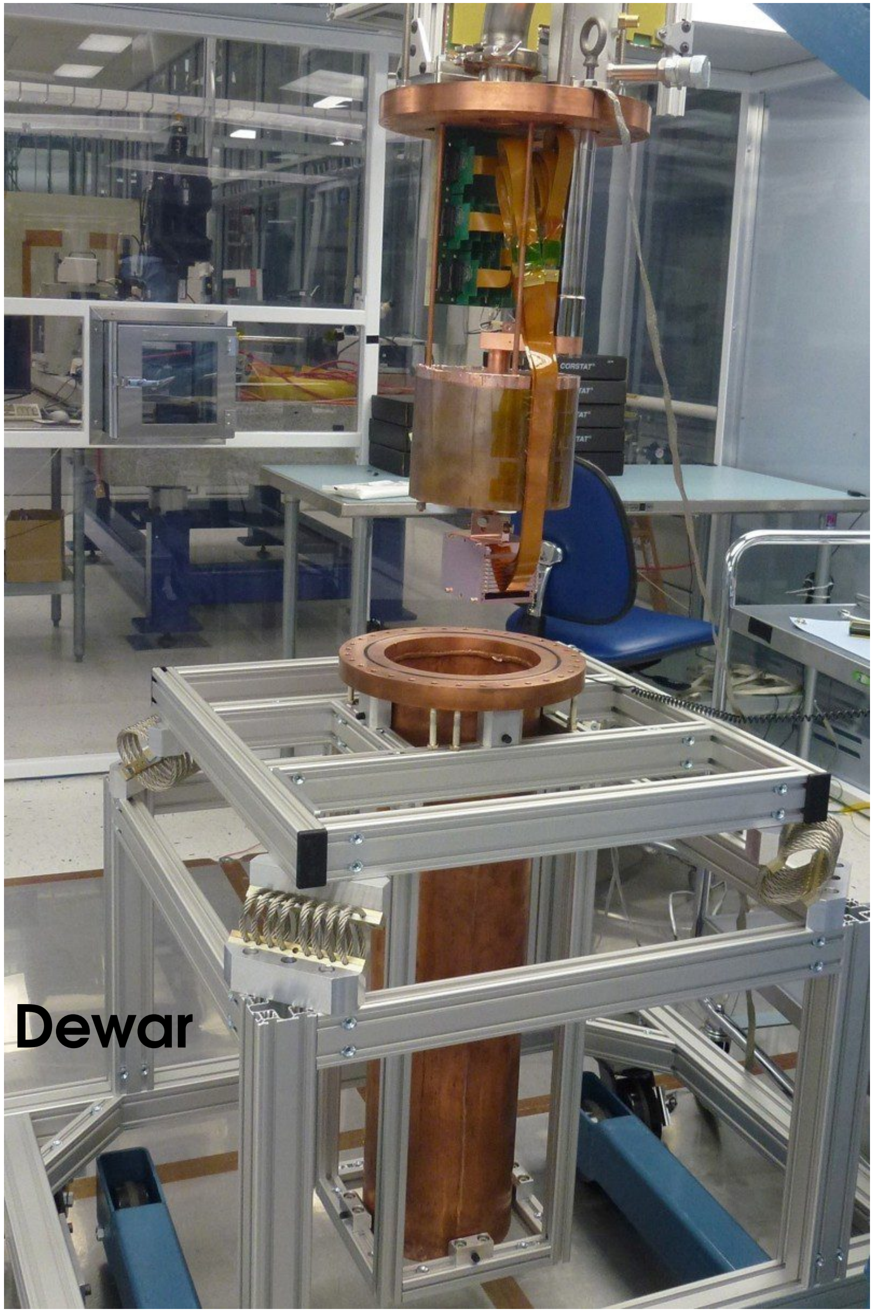
DAMIC @ SNOLAB



DAMIC @ SNOLAB

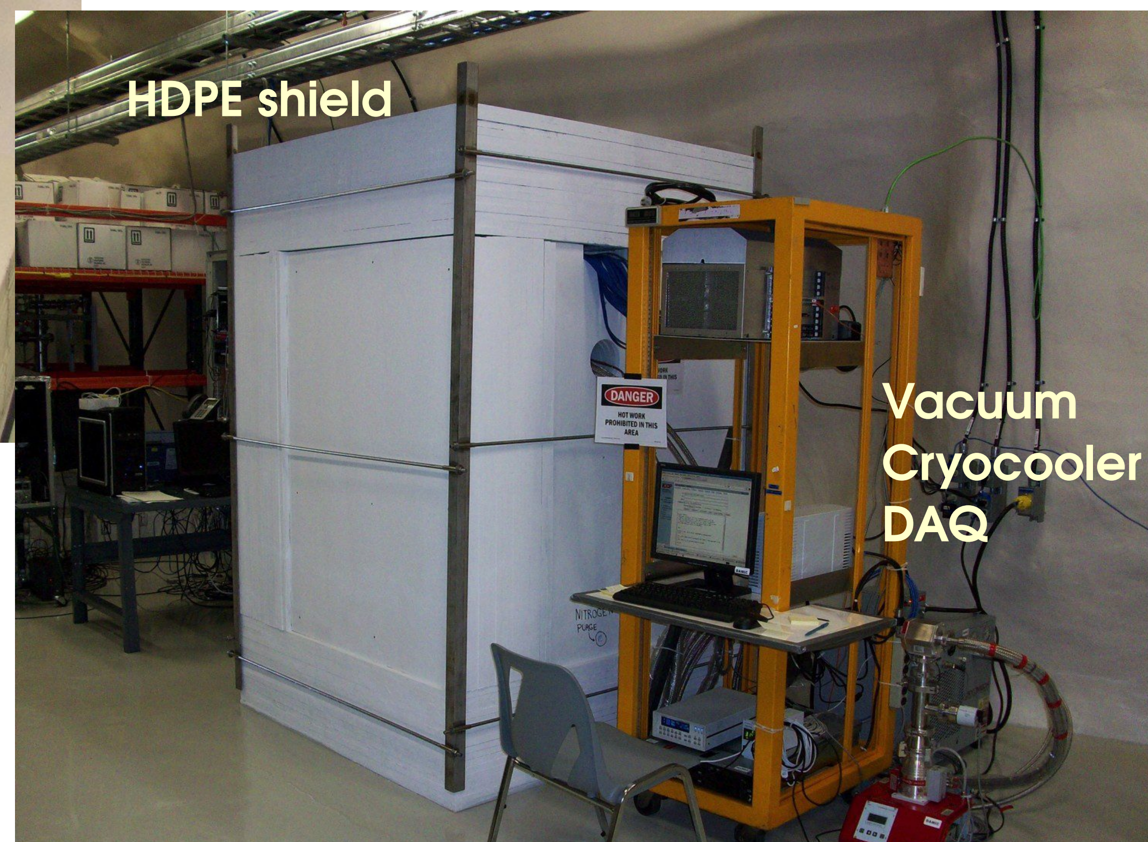




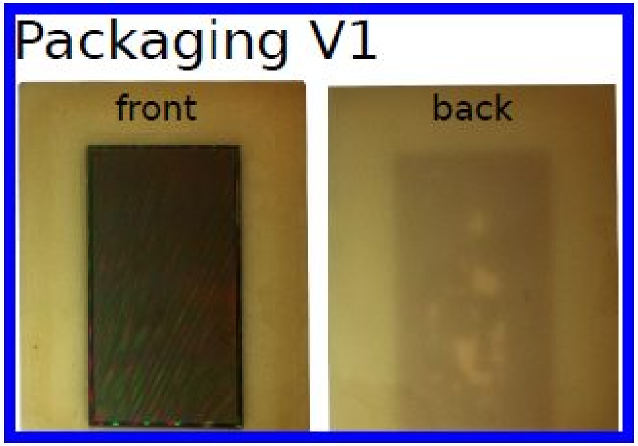


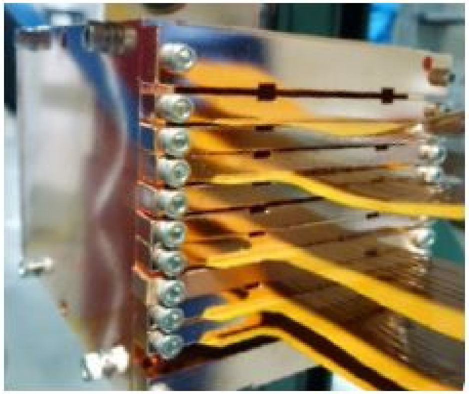
DAMIC @ SNOLAB

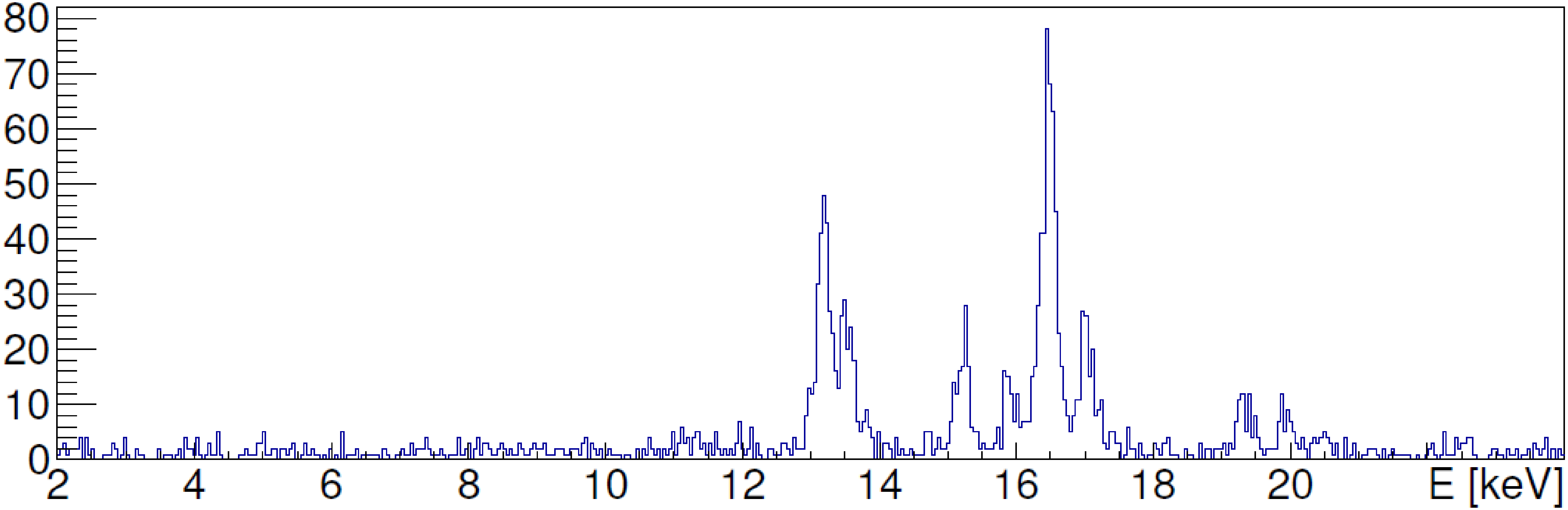
Installed: December 2013



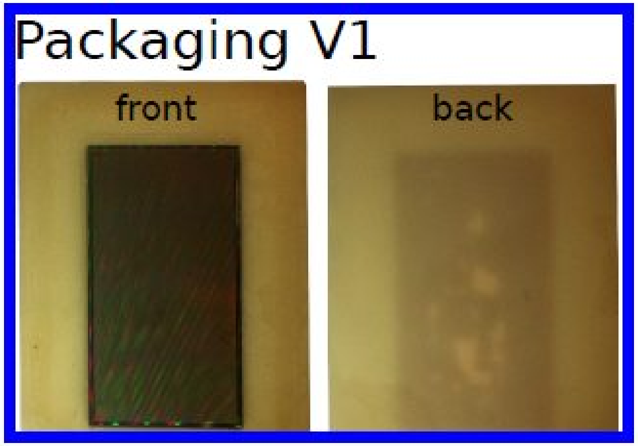
DAMIC @ SNOLAB

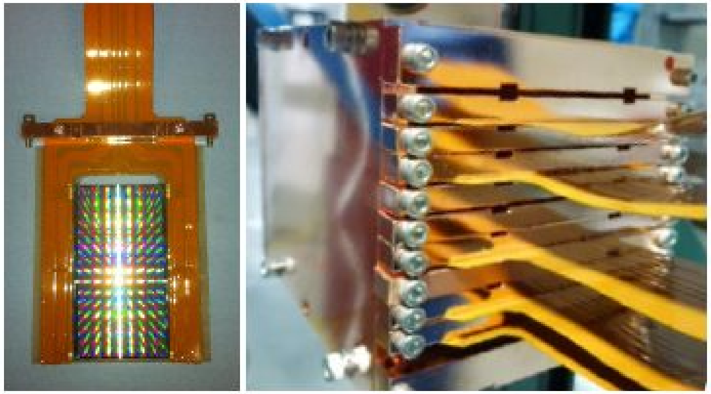


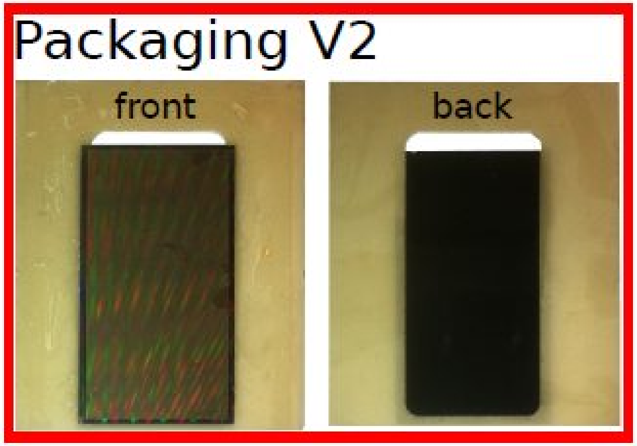


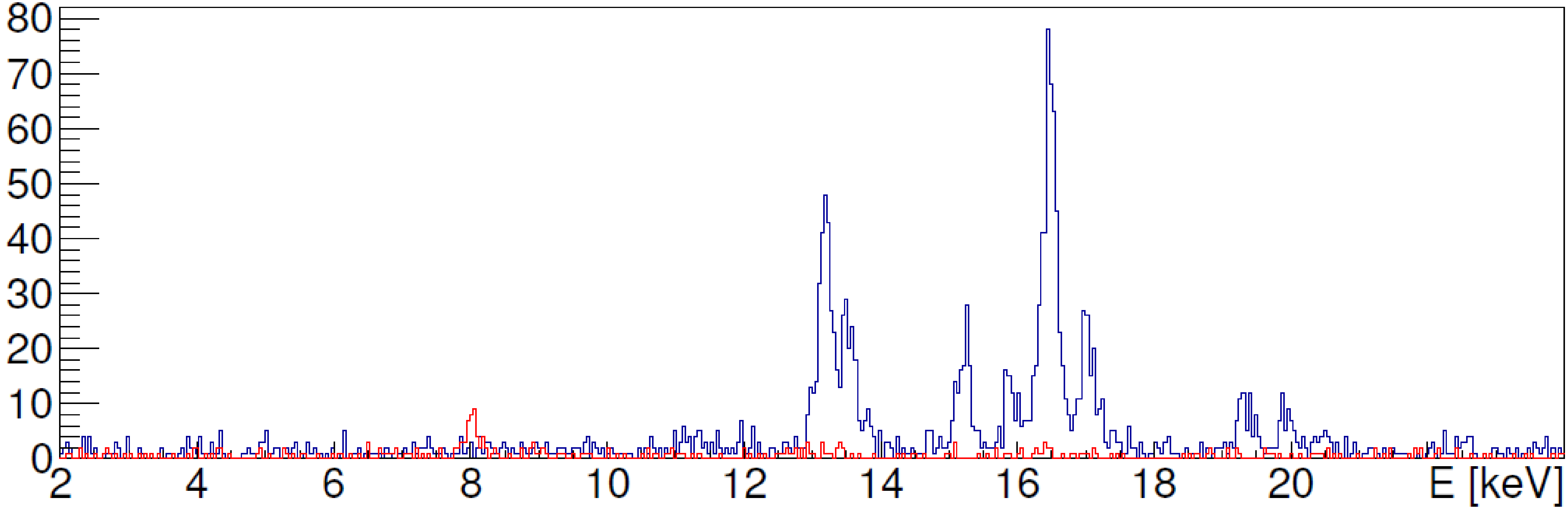


DAMIC @ SNOLAB





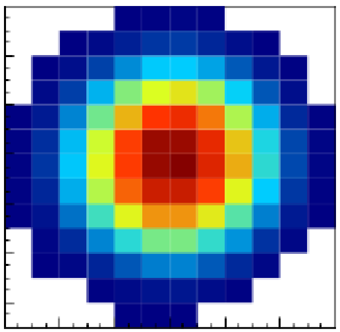




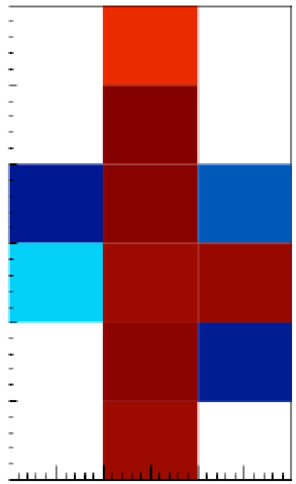
V1 packaging: U & Th contamination in support. Quickly recognized.

DAMIC @ SNOLAB

Alpha search

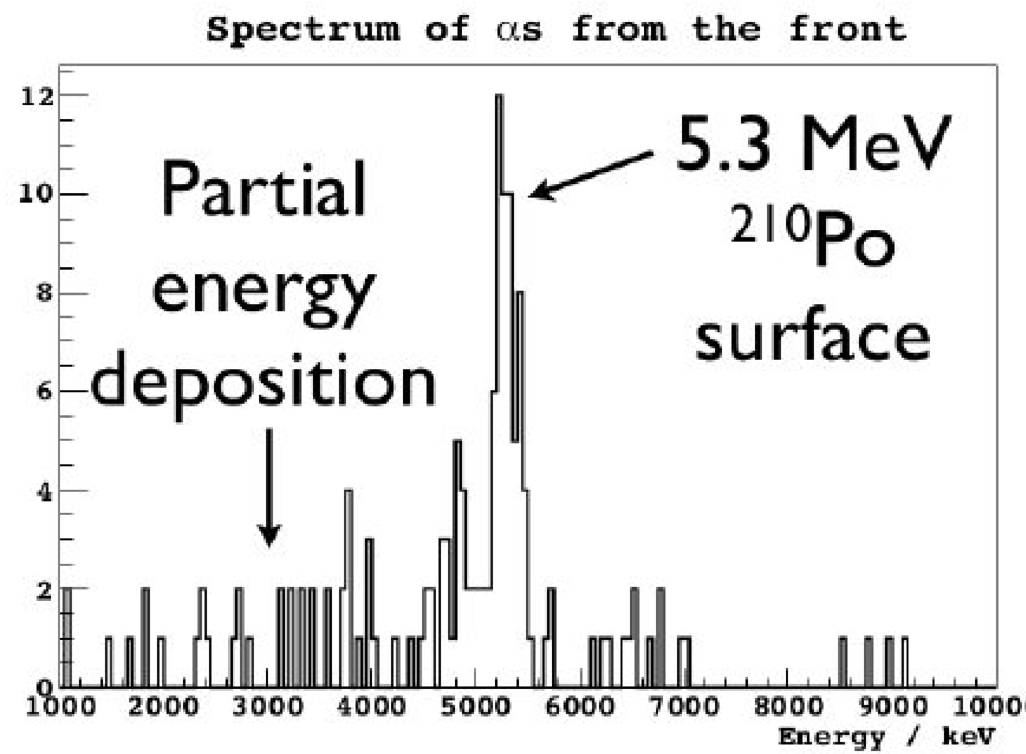


Back or Bulk
(plasma)



Front (bloomed)

2-month run with 4 CCDs
to measure α rate
(Exp. 0.245 kg d)



<u>Bulk contamination</u>

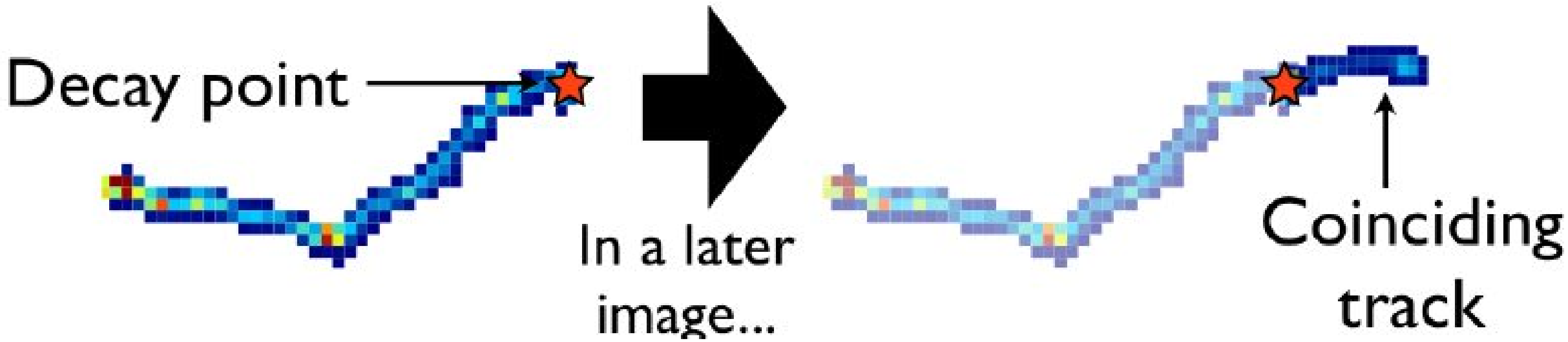
^{232}Th: <0.14 mBq kg^{-1} (35 ppt)

^{238}U: <0.22 mBq Kg^{-1} (18 ppt)

Surface α: 0.13 cm^{-2} d^{-1}

DAMIC @ SNOLAB

Spatial coincidences



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

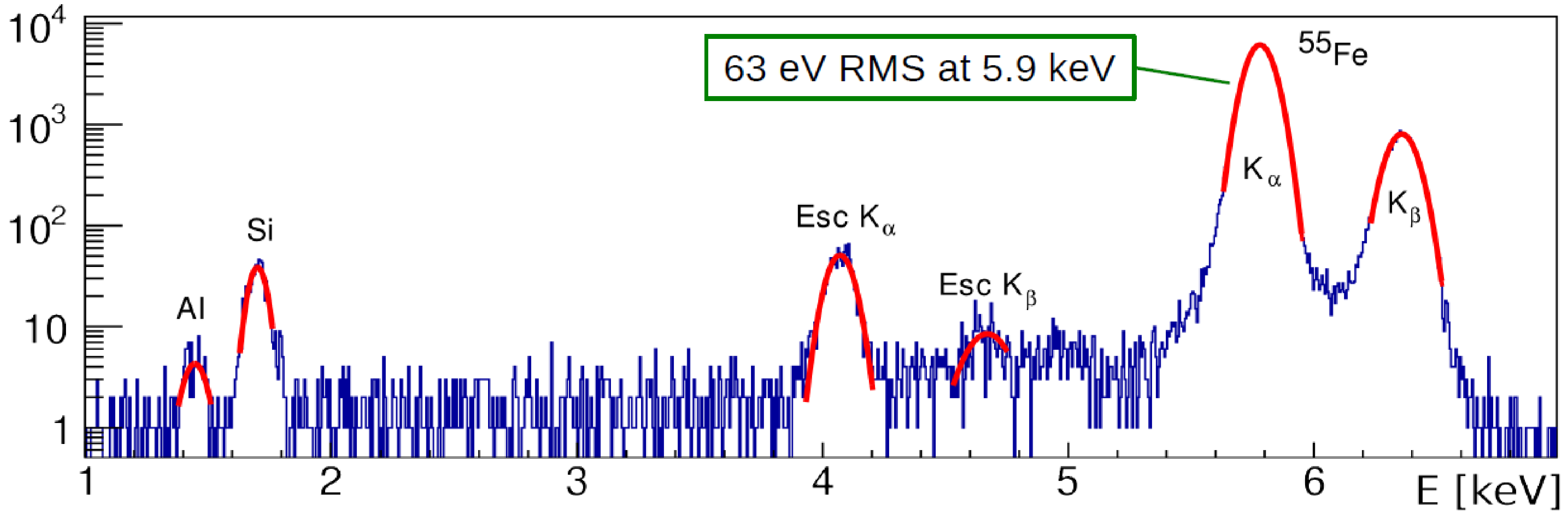
	0.22 MeV		1.7 MeV	
^{32}Si	⟶	^{32}P	⟶	^{32}S
		$\tau_{1/2} = 14$ d		

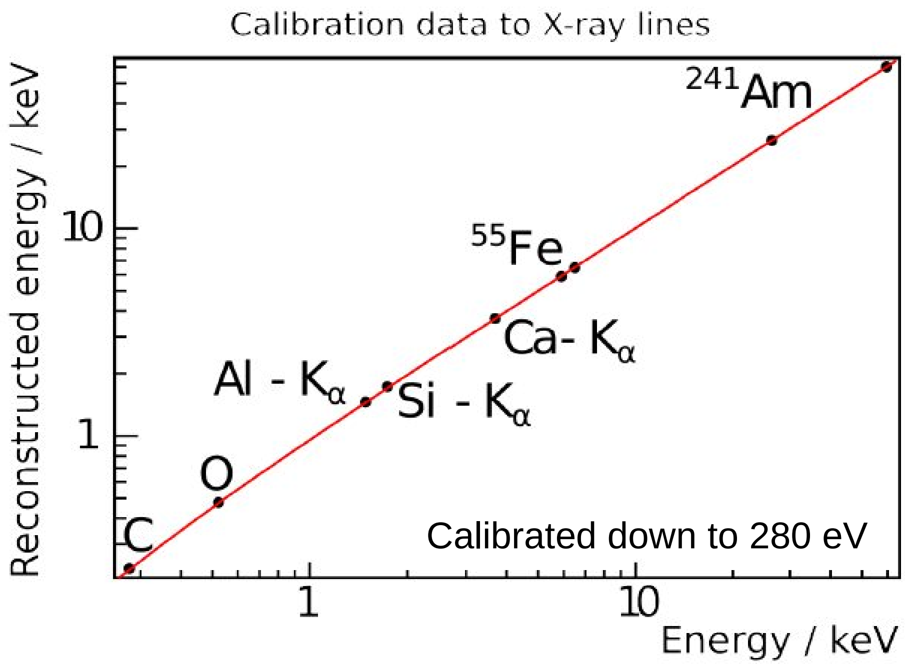
Sequence of β's starting in the same pixel of the CCD in different images

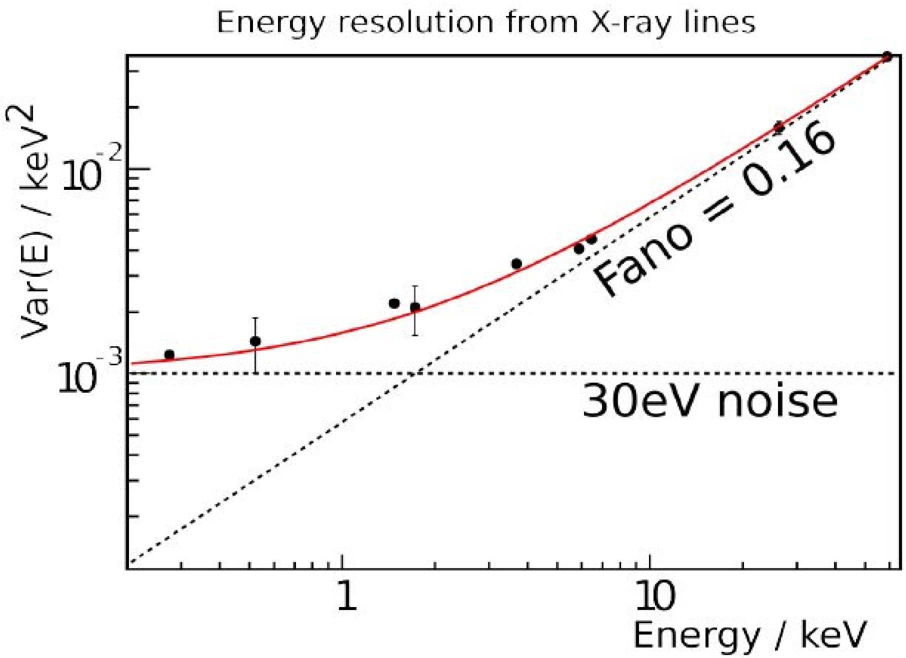
Search from 38 days of data x 2 CCDs limited by accidentals:

^{32}Si: < 72 mBq kg^{-1}
^{210}Pb: < 12 mBq kg^{-1}

Energy calibration, X-rays

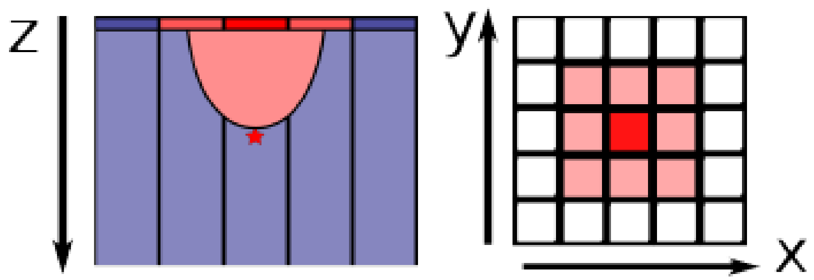


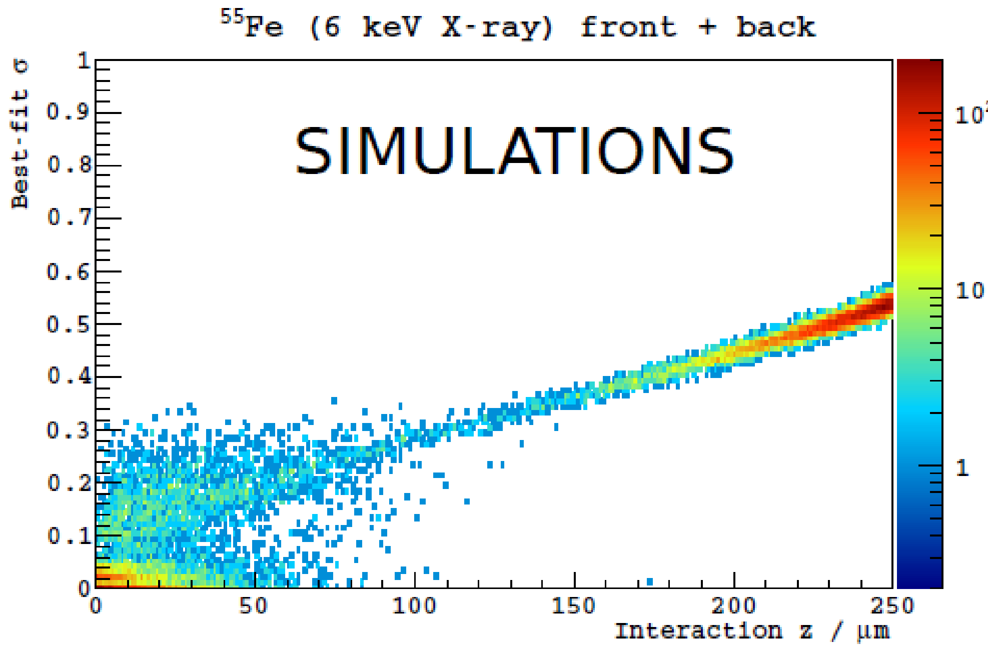


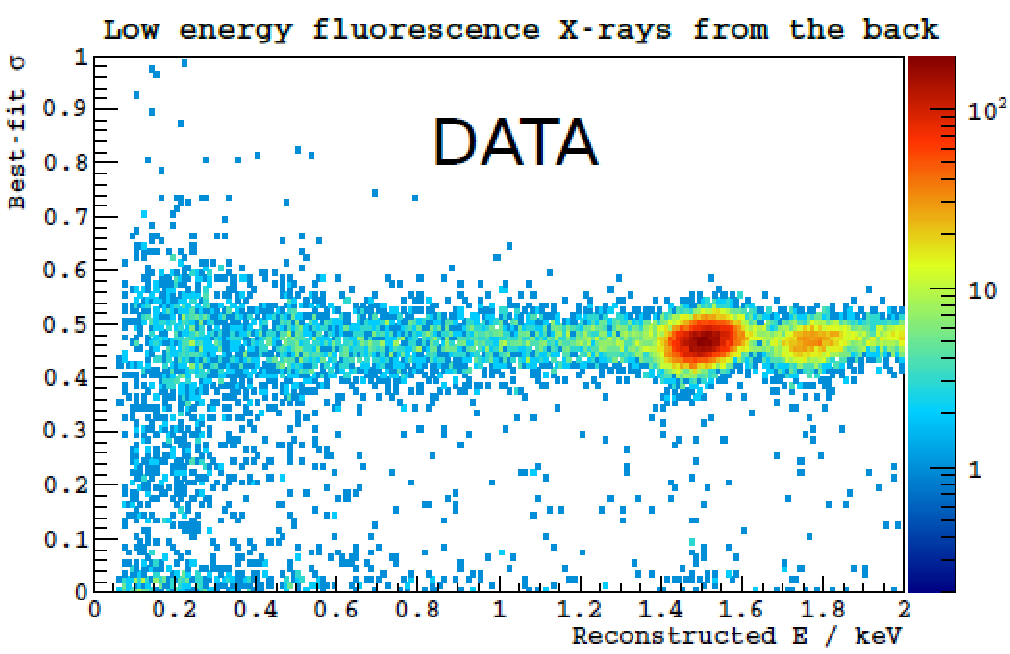


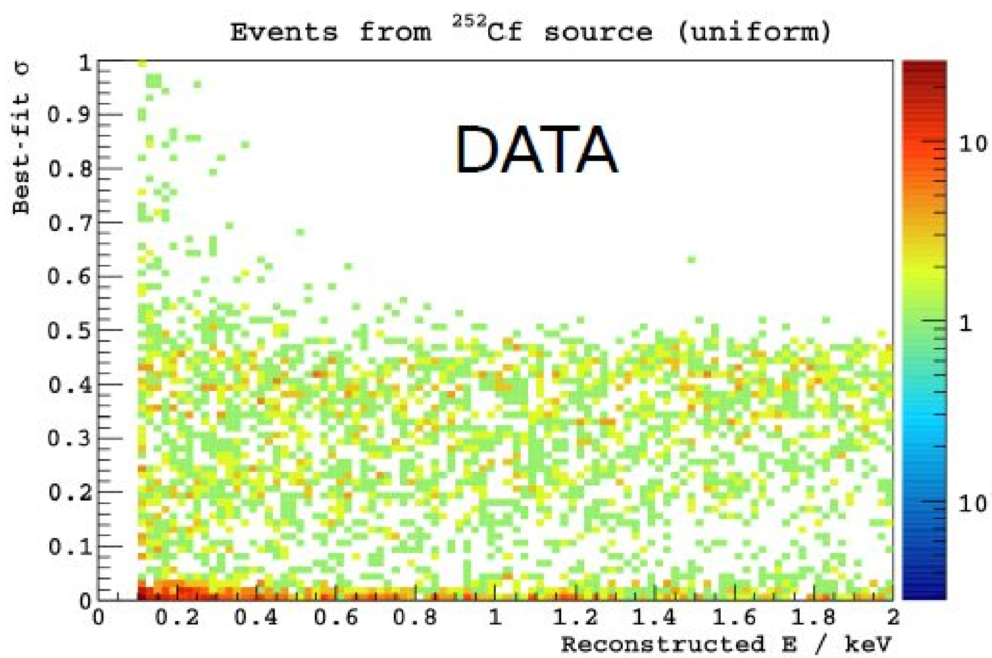
Event reconstruction

- Fit radial spread of cluster (σ)
- Estimate z position in CCD bulk









Ionization efficiency in Silicon

Literature: only down to ~4 keV

DAMIC program

FAST NEUTRONS: Elastic scattering experiment with a Silicon Drift Diode

THERMAL NEUTRONS: Capture experiment $^{28}Si + n \rightarrow {}^{29}Si + \gamma$

– Si(Li) diode + γ in coincidence

- CCD at a nuclear reactor

PROTONS: Activation at a proton beam

→ Irradiate a CCD

→ Bulk radioisotopes → electron capture decay

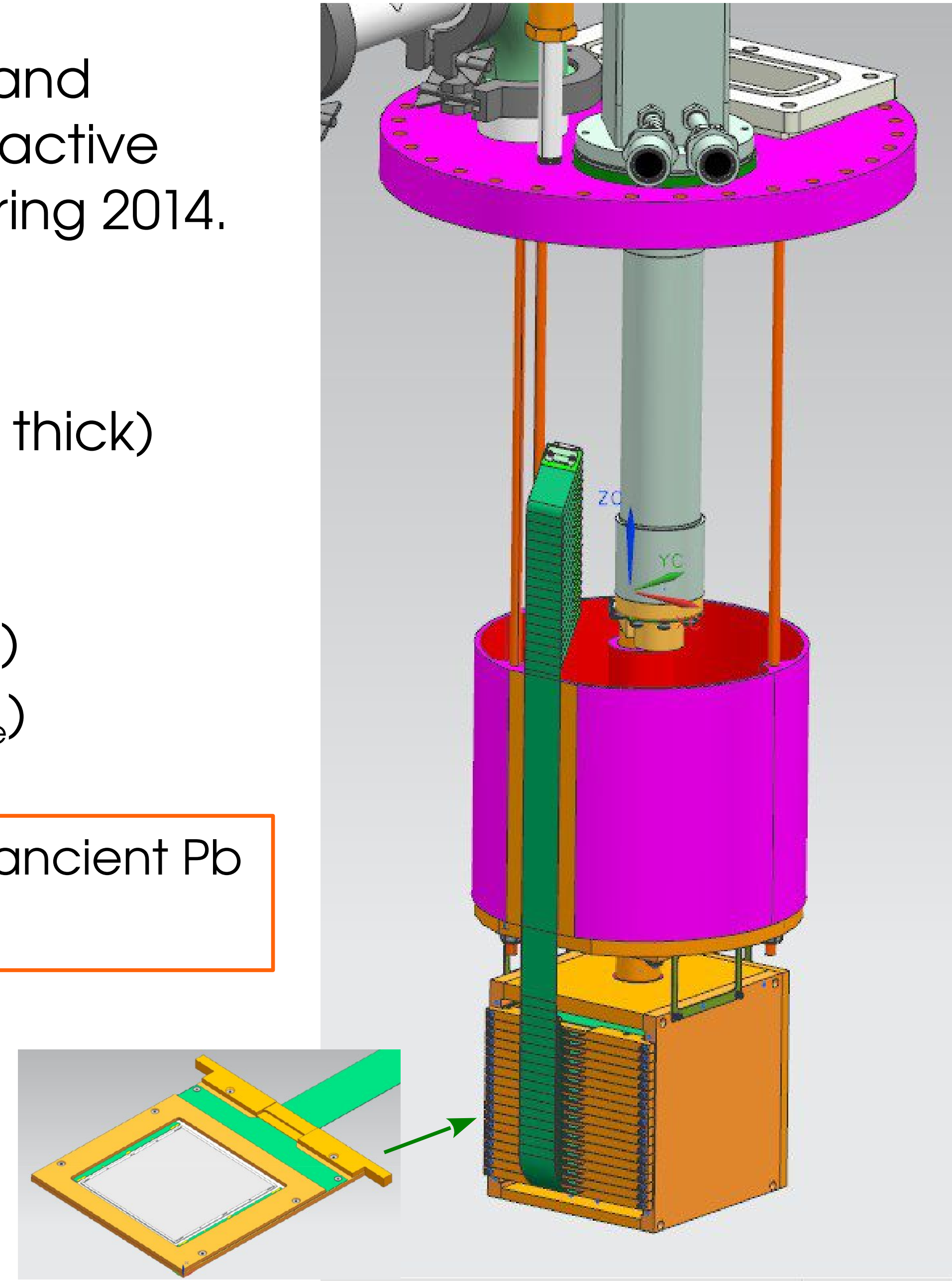
→ K-shell line + shift (nuclear recoil due to ν or γ emission)

Near future: DAMIC100

We are currently working on the design and construction of a detector with 100 g of active mass that will be installed at SNOLAB during 2014.

- **100 g active mass of Si:**
  18 CCD's (5.5 g, 6 cm x 6 cm, 650 μm thick)
  Fits existing dewar & shield
- **Background:**
  Current: 100 ev/(kg day keV_{ee})
  DAMIC100: few ev/(kg day keV_{ee})

Pb-shield upgrade: low ^{210}Pb + ancient Pb
CCD package: high resistivity Si



Studying activity of materials to get full advantage of the mass increase.

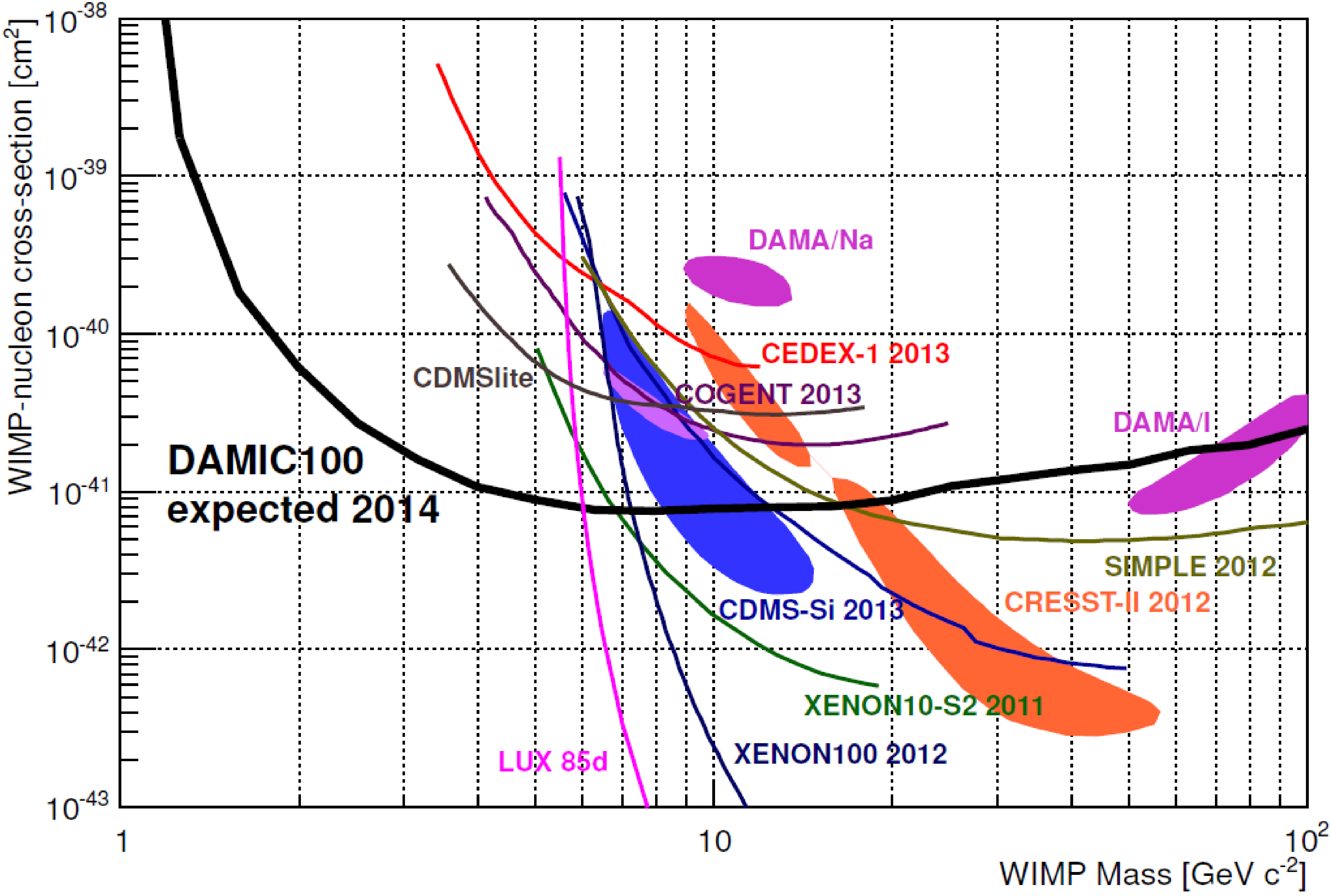
DAMIC-South

Goals:

- Definitively test the annual modulation of a possible signal
- Further the collaboration between Latin American groups with Fermilab
- Contribute to the formation of groups and human resources for Andes and other future underground labs.

UNAM group has a leading role in the detector/shielding design and thermal analysis.

DAMIC100 sensitivity



Summary

- CCDs are good candidates to detect the low energy recoils produced by DM particles.
- CCD technology is scalable and compact.
- The low mass of CCD's is compensated by their low threshold.
- Readout noise RMS 2.5 electrons → threshold < 50 eV_{ee} , at 5σ.
- Charge diffusion → 3D track reconstruction, good particle ID and surface event rejection.
- Electron recoil calibration down to 0.28 keV_{ee}.
- Strong calibration program for nuclear recoils at low energies.
- DAMIC experiment is installed at SNOLAB and is taking data.
- DAMIC100 will be installed in 2014!

Thank you !

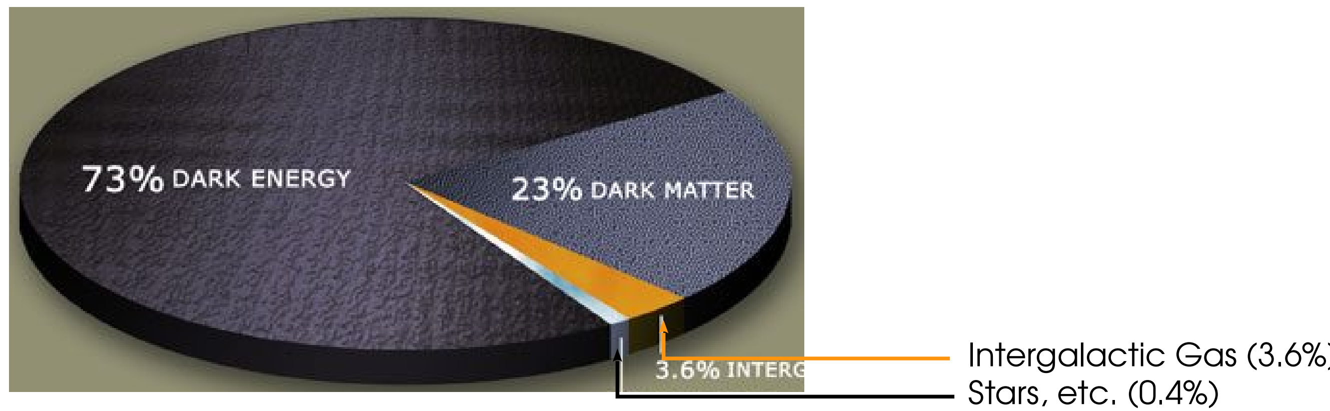
Backup Slides

Dark Matter

Astrophysical & Cosmological observations → Evidence for Dark Matter

Standard Cosmological Model (ΛCDM): Ω_Λ(~73%) + **Ω_{cdm}(~23%)** + Ω_b(~4%)

Dark Matter (DM):
- Interacts only Gravitationally
- Does not emit/disperse EM rad.
- Makes up ~23% of Universe
- All other properties unknown

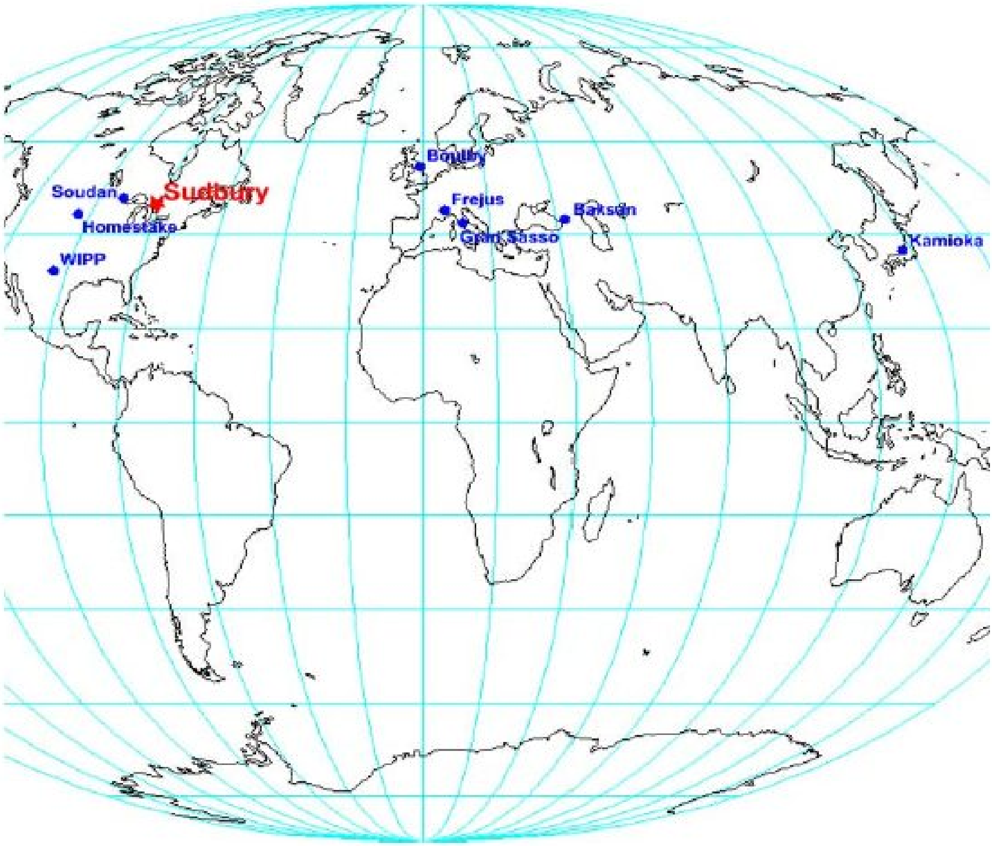


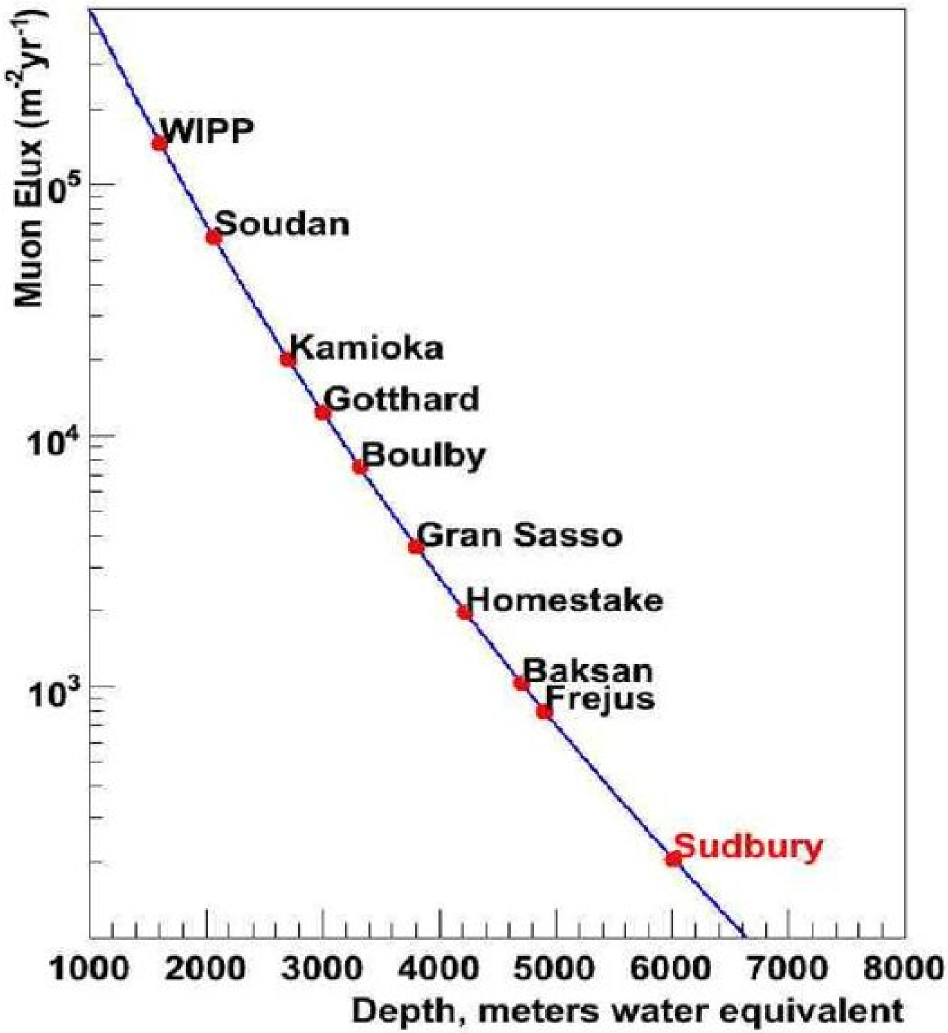
Evidence from:

Rotation curves of galaxies/clusters
Gravitational lensing
Bullet Cluster
CMB temperature fluctuations
Large scale structure of Universe
Big-Bang nucleosynthesis from CMB (^{3}He & ^{7}Li abundances)

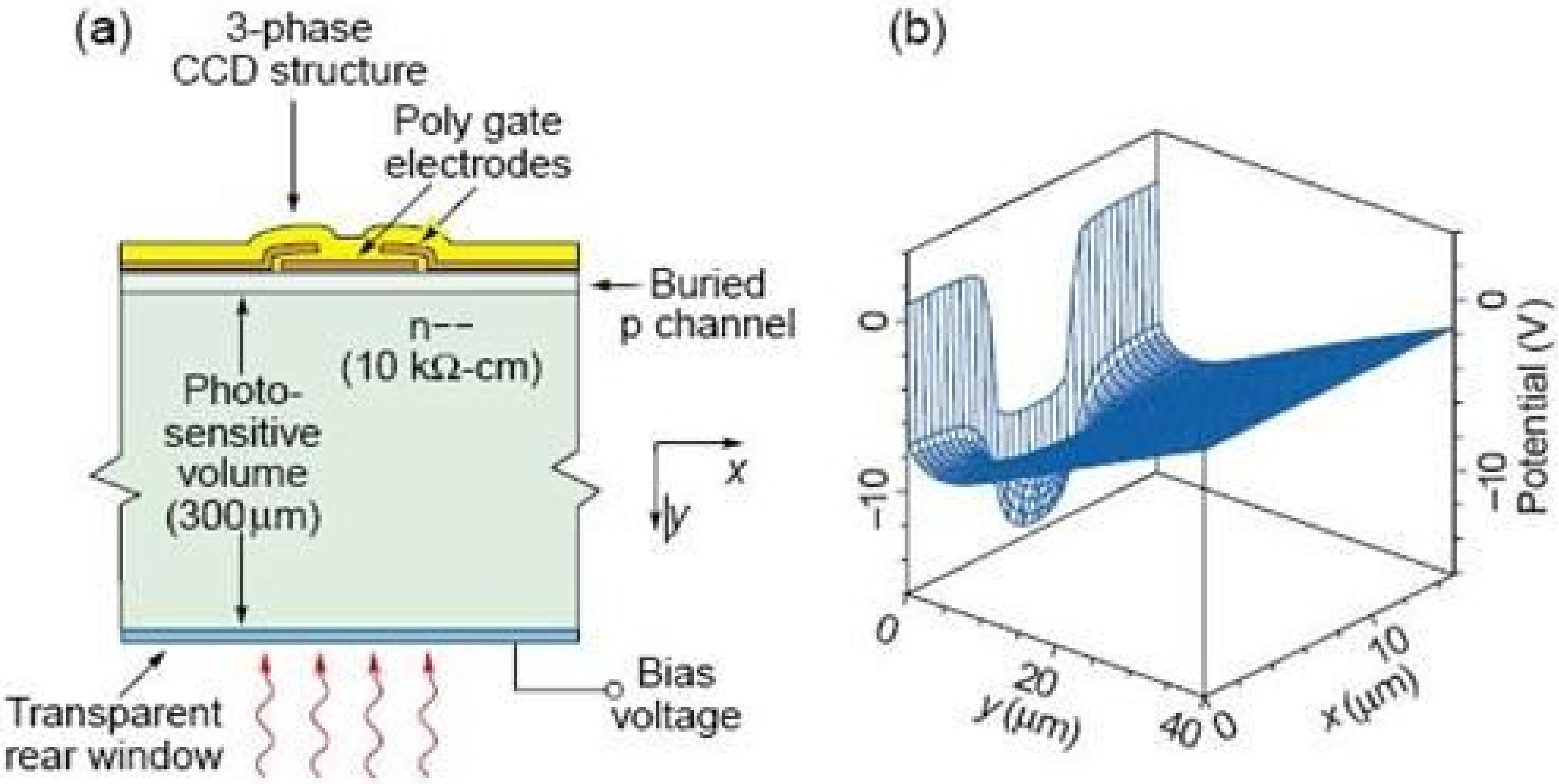
Candidate: **WIMP**
(**W**eakly **I**nteracting **M**assive **P**articles)
Mass: 1–1000 GeV/c^2,
Cross section, s: 10^{-43} – 10^{-38} cm^2

DAMIC @ SNOLAB





Charge-coupled device



Generated carriers (holes) are trapped at the potential well at the gate electrodes, where they are stored for later readout.