Searching for dark matter with DAMIC

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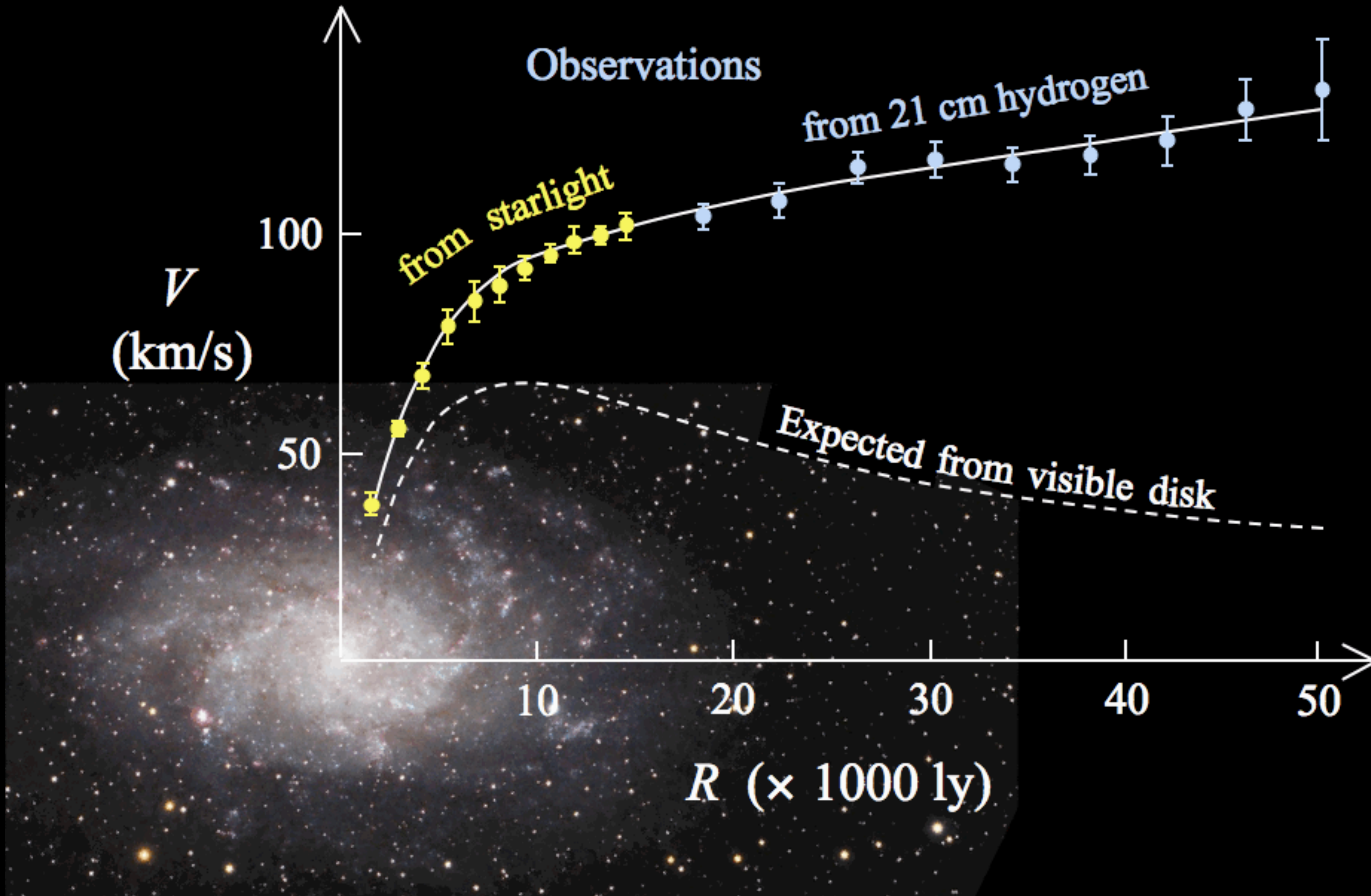
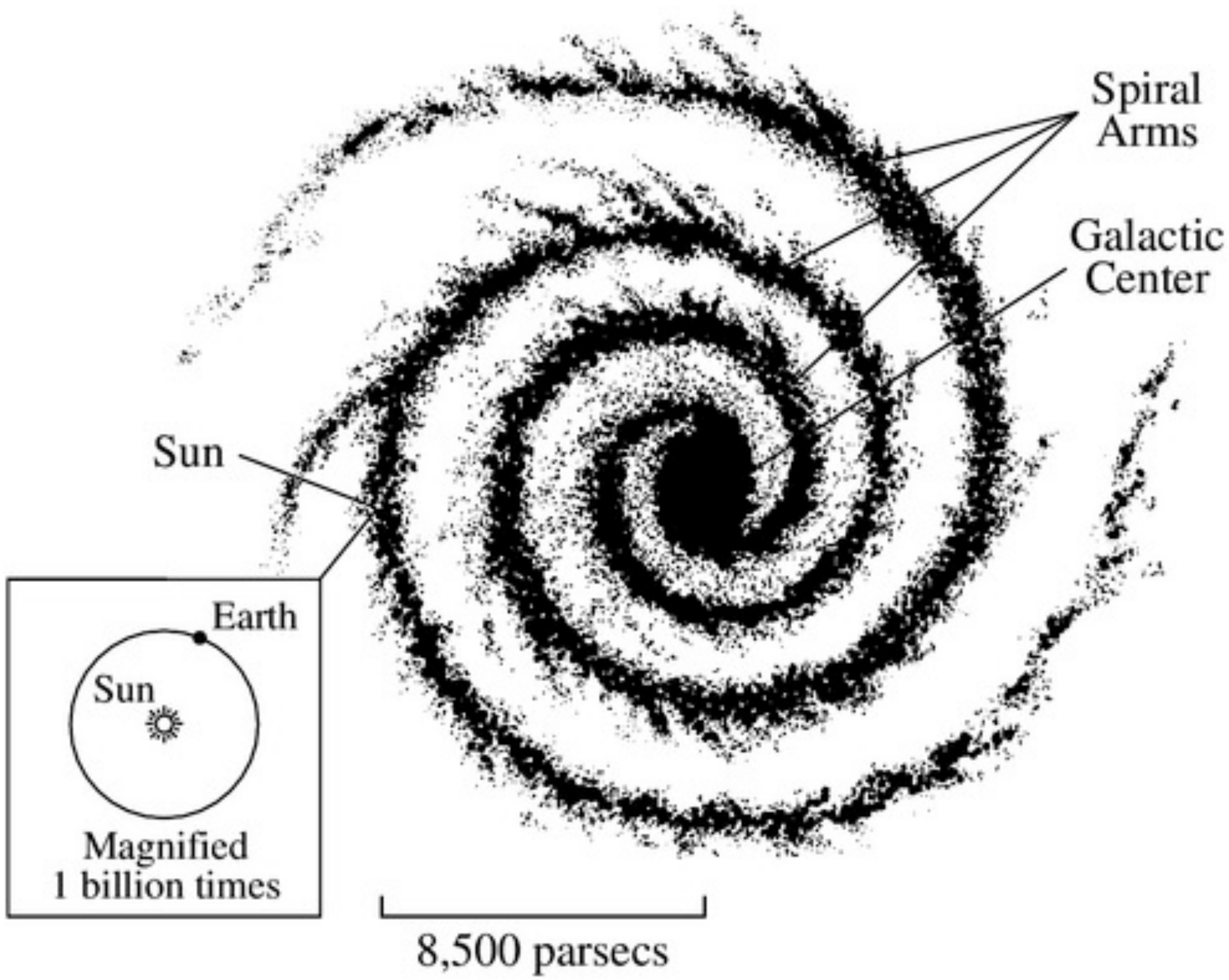
Assistant Professor

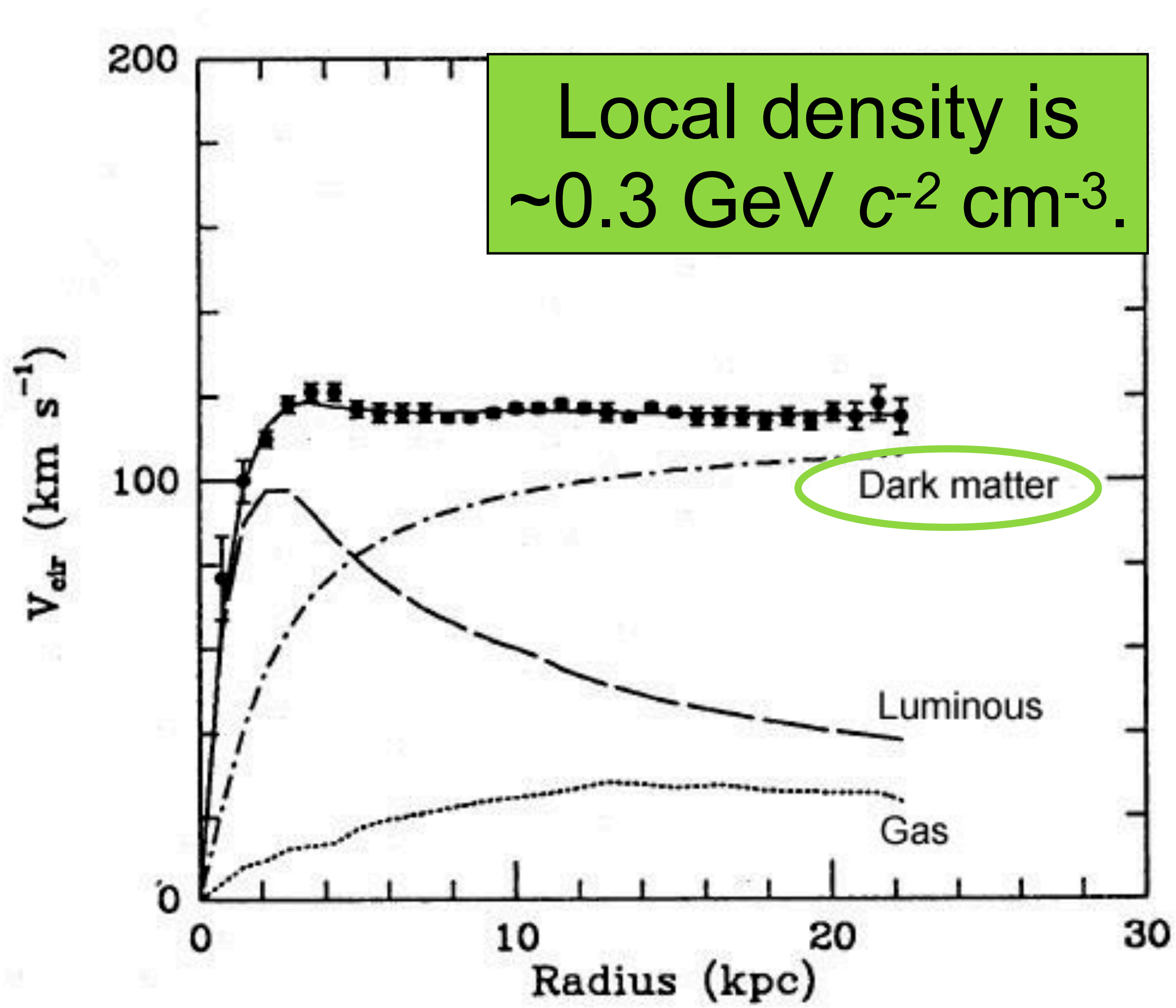
How fast do stars orbit around the galactic center?



Stars orbital velocities are higher than they are expected from Newton's law, given the mass from the stars, planets and gas in the galaxy.

Dark matter (DM)





The centripetal force exerted on the "Sun" cannot be explained by stars and gas.

Introduce massive "dark matter" in a halo around the galaxy, that we can't see but can *feel* gravitationally.

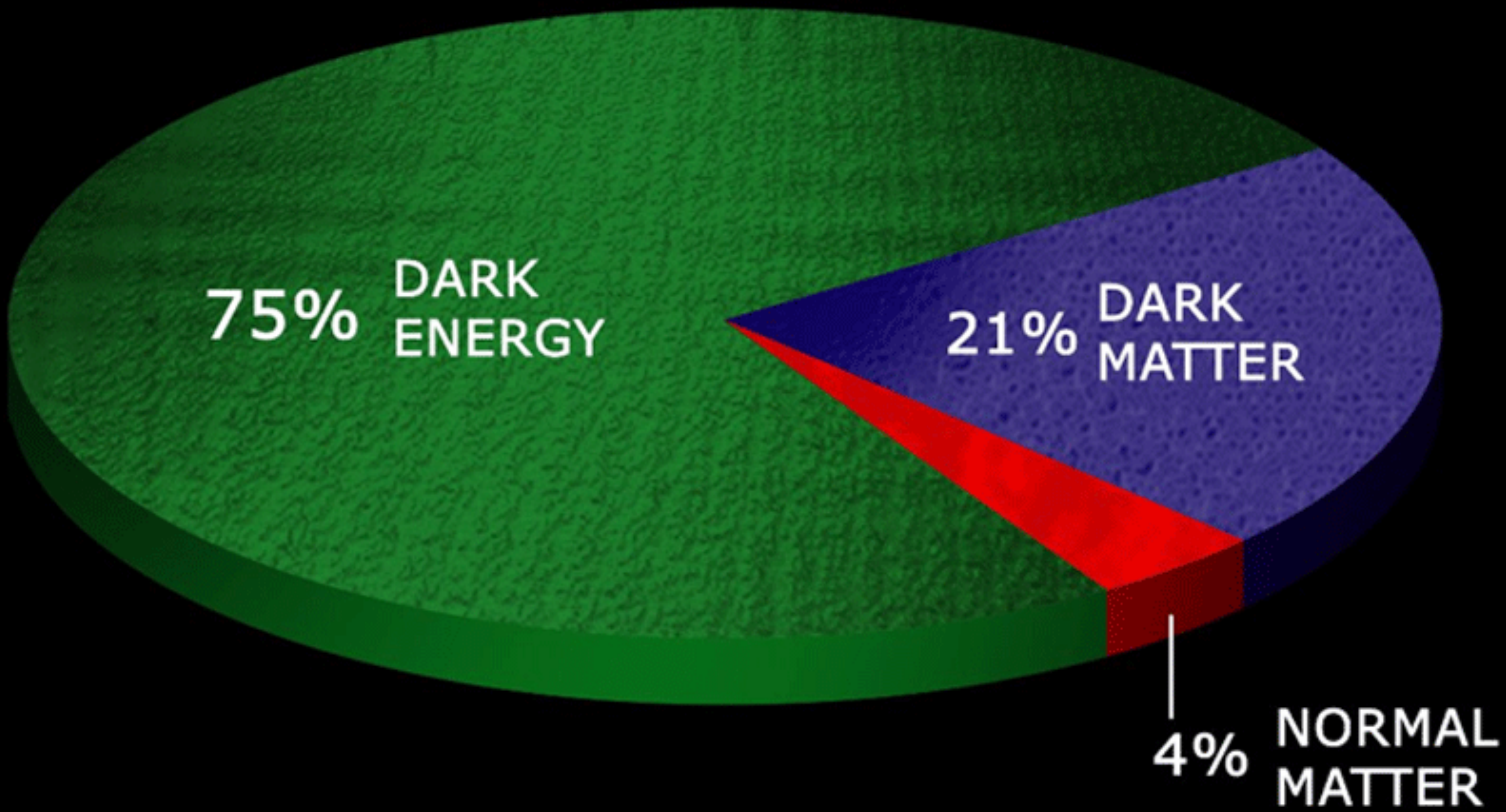
Cluster dynamics

Bullet cluster

The distribution of visible matter from X-ray spectroscopy does not agree with the distribution of all matter from gravitational lensing.

Also evidence from the distribution of galaxies in the universe and the cosmic microwave background.

Composition of the Universe



Dark “matter”

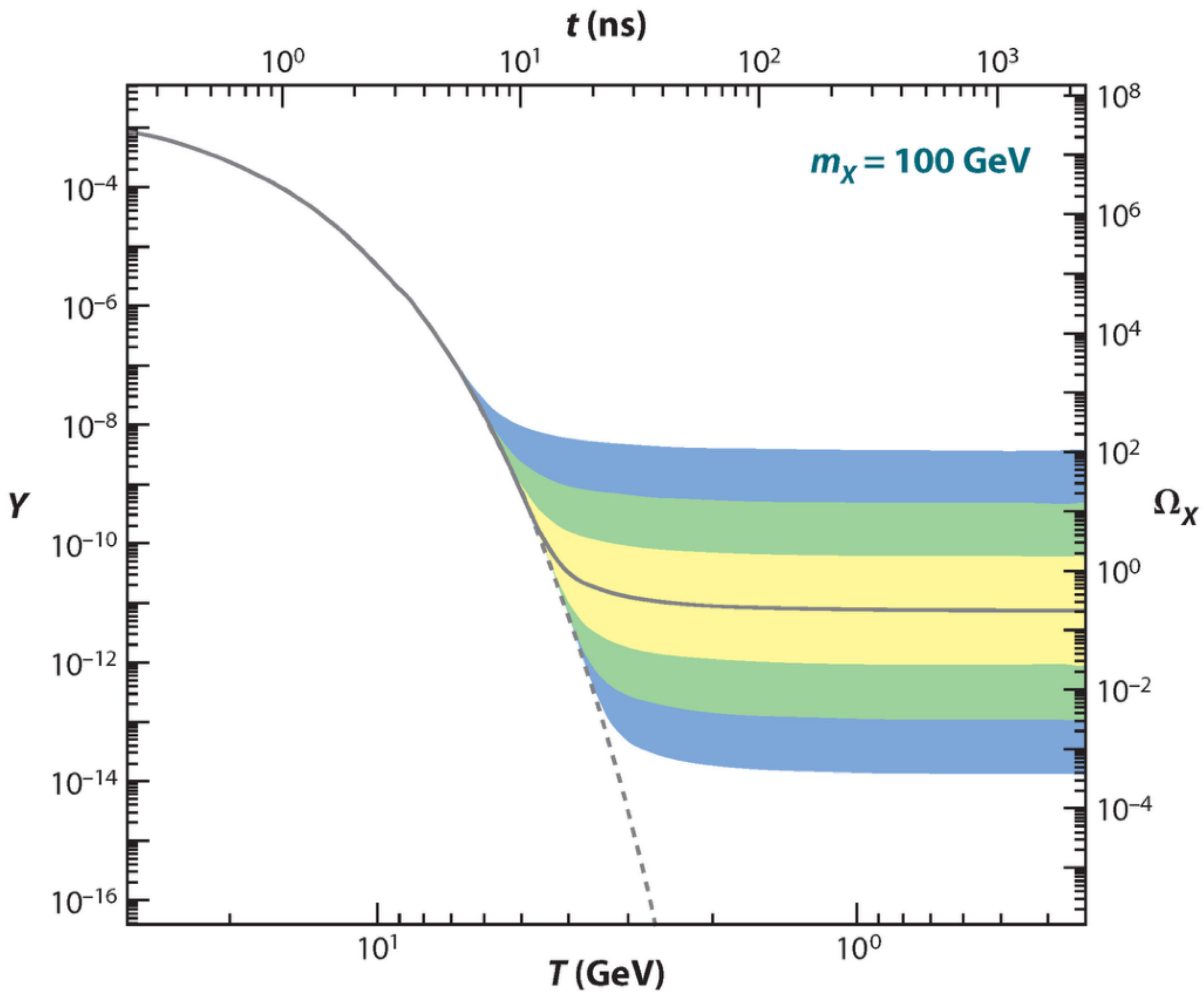
- Dark matter *is matter* in the sense that it is a source of gravity, i.e., it distorts space-time.
- However there is a second definition of matter: that which is made of “building blocks,” i.e., particles, for which we can write down a quantum field theory.
- We are trying to discover this secondary nature of dark matter: searching for interactions between the building blocks of dark matter with those of ordinary matter.
- It is a profound problem that confronts the very definition of “matter.”
- My approach is well within the boundaries of “normal” science. The correct answer might be revolutionary.

What is particle DM?

- Everything we know is made of particles, therefore it is likely that DM is also made of particles.
- It has to not interact directly with photons, i.e. it cannot have any electromagnetic charge.
- It has to be stable.
- It has to be slow enough to clump and form the dark matter halo around galaxies.
- No known particle has these properties: **New particle.**

Dark matter is a problem from cosmology with ***huge*** *implications for particle physics!*

WIMPs



Any DM candidate has a history in the Early Universe!

- Weakly interacting massive particles (WIMPs).
- Produced in the Big Bang together with other particles.
- In thermal equilibrium with SM particles in the Early Universe.
- The Universe expands and cools, eventually the WIMPs are too far apart to find each other and annihilate: their number is "frozen out."
- The expected density today is the same as dark matter: "the WIMP miracle."

WIMP signal

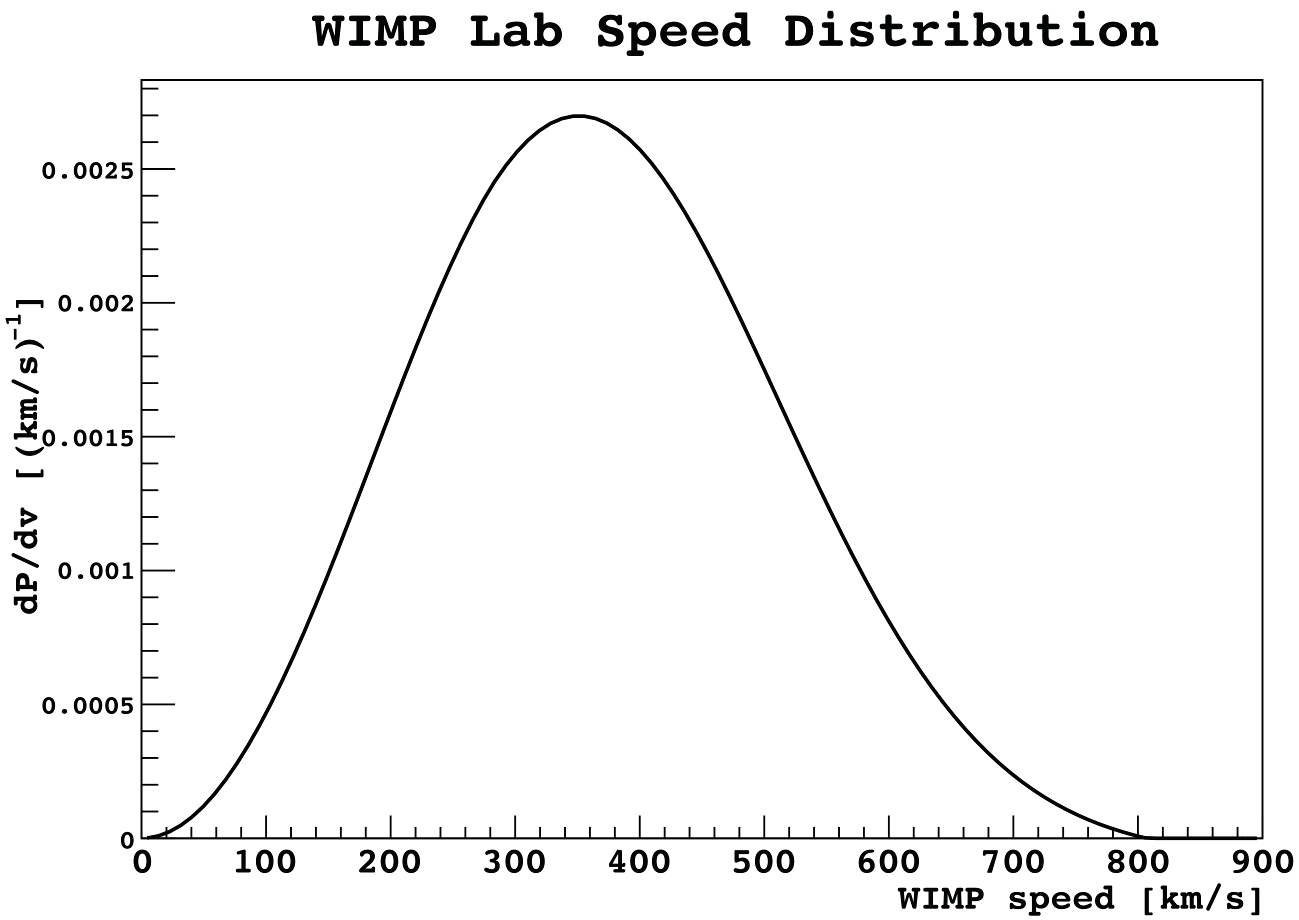
Dark matter is *cold*, i.e., it is bound to the galaxy.

Hence, the dark matter particle speed is ~the same as stars: 100s km/s.

$$E_\chi = \frac{1}{2} M_\chi v^2$$

$$E_\chi = \frac{1}{2} M_\chi c^2 \beta^2 \qquad \beta \approx 10^{-3}$$

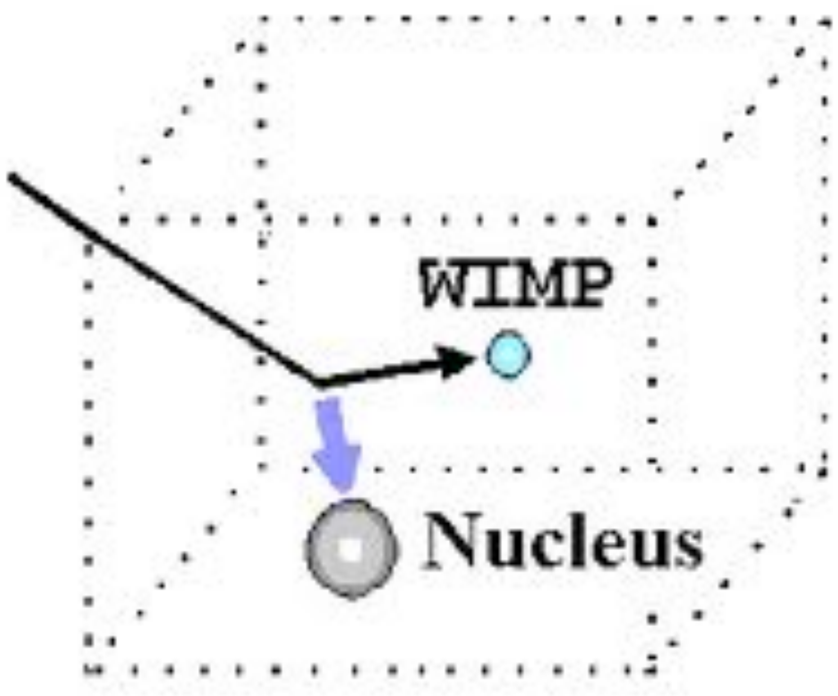
$$E_\chi \approx \left(\frac{M_\chi c^2}{\mathrm{GeV}} \right) \mathrm{keV}$$

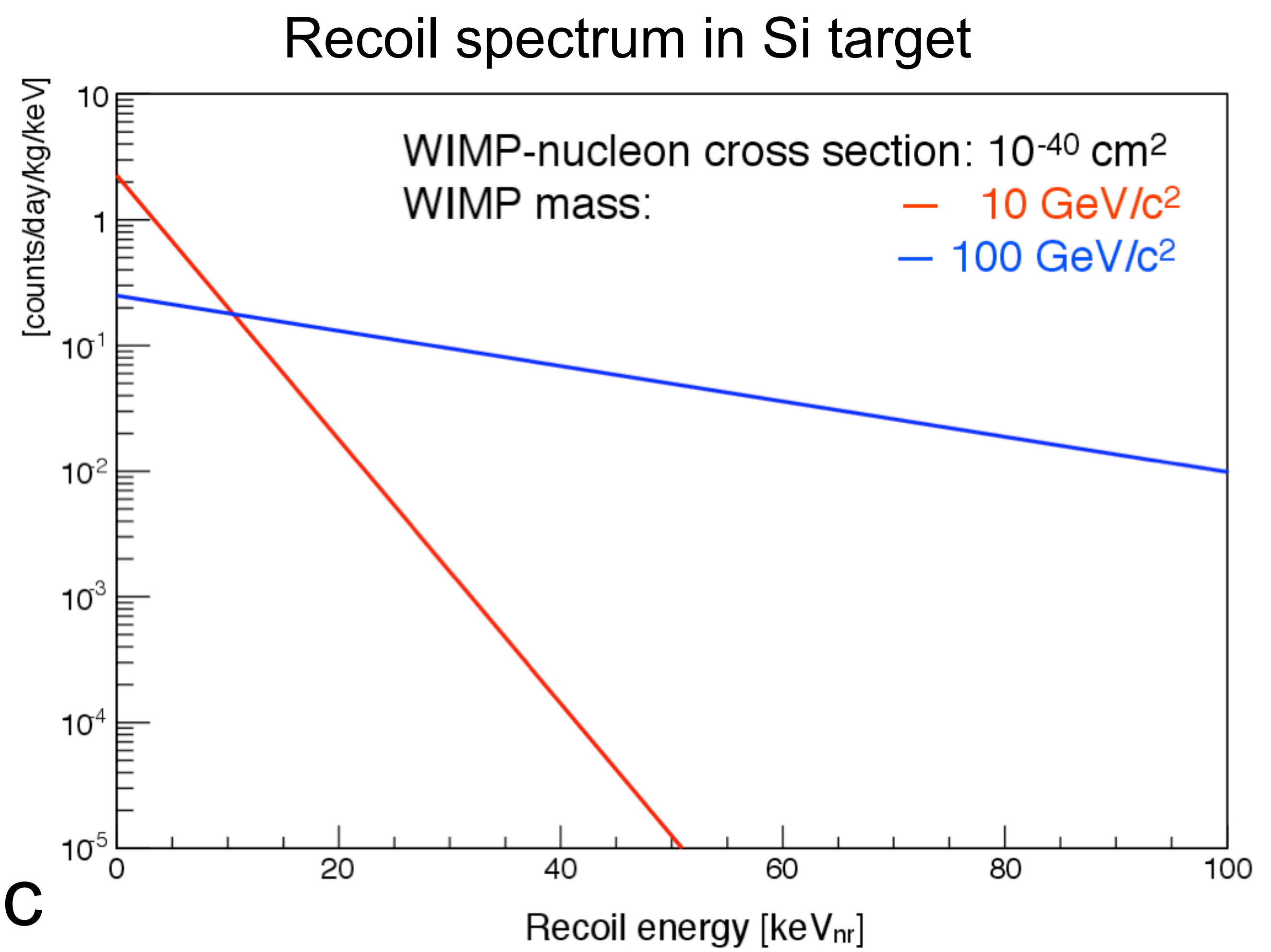


We do not know the particle mass (M_χ).

A 1 GeV (proton-mass) particle has 1 keV of kinetic energy (very little).

WIMP-nucleus ES





Best case: $M_T = M_\chi$ + elastic

$$E_T \leq E_\chi$$

For low mass: $M_T \gg M_\chi$

$$E_T < 4\frac{M_\chi}{M_T}E_\chi$$

Maximum energy transfer when *M ~ A.*

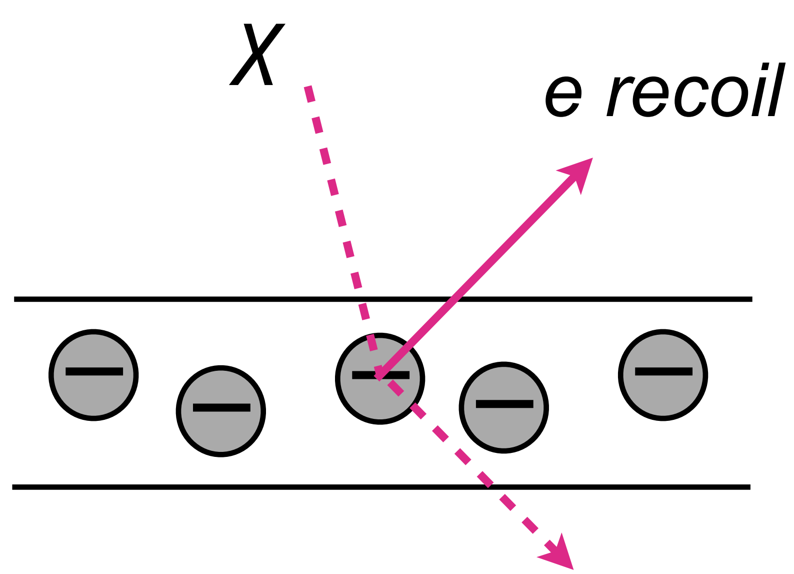
Lower recoil energies for smaller WIMP masses.

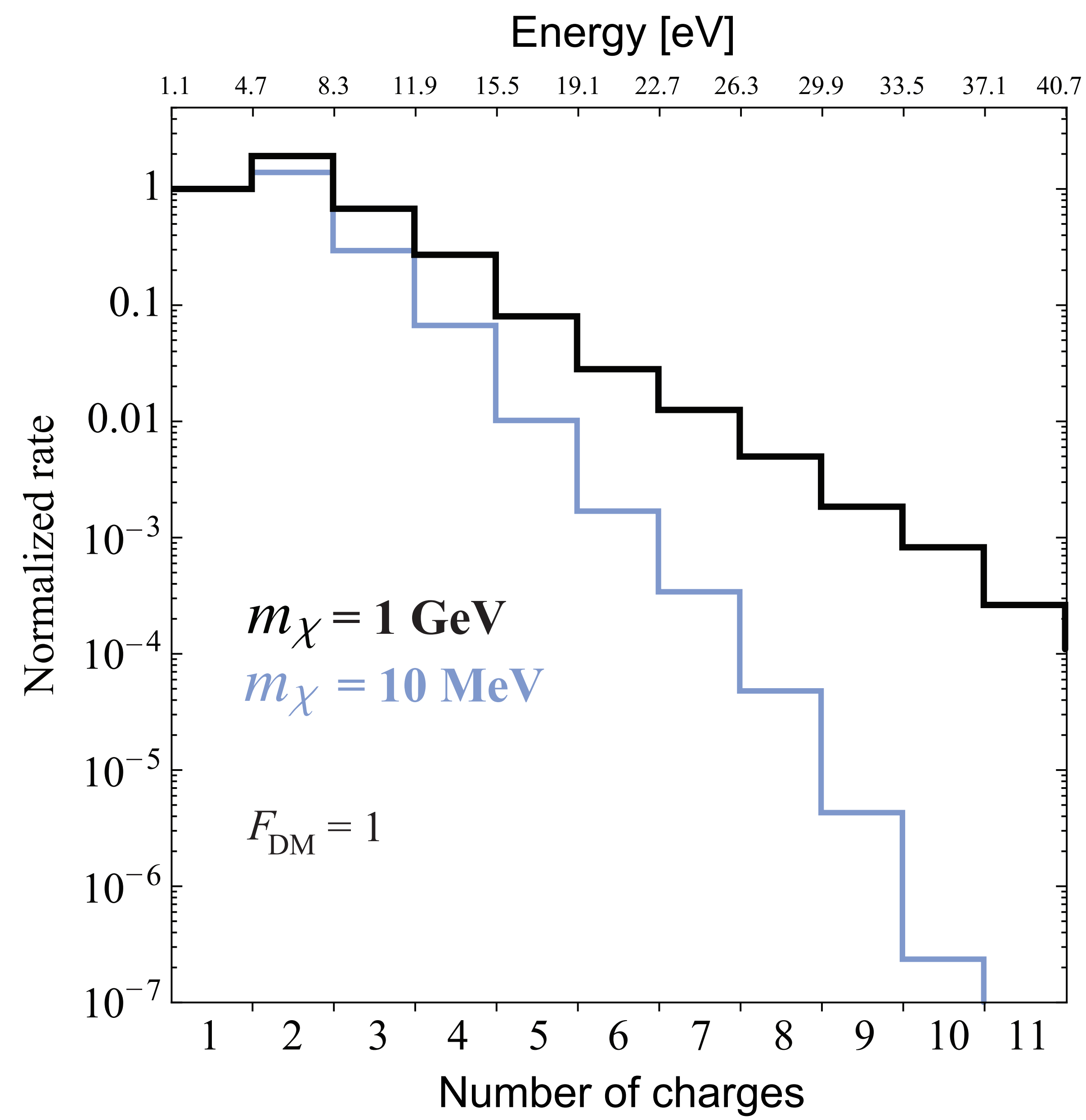
WIMP-electron S

Electrons are much lighter target than the nuclei.

Electrons are *bound* in nuclei, with non-zero momentum.

In semiconductors, e.g., silicon, the binding energy is only 1 eV.

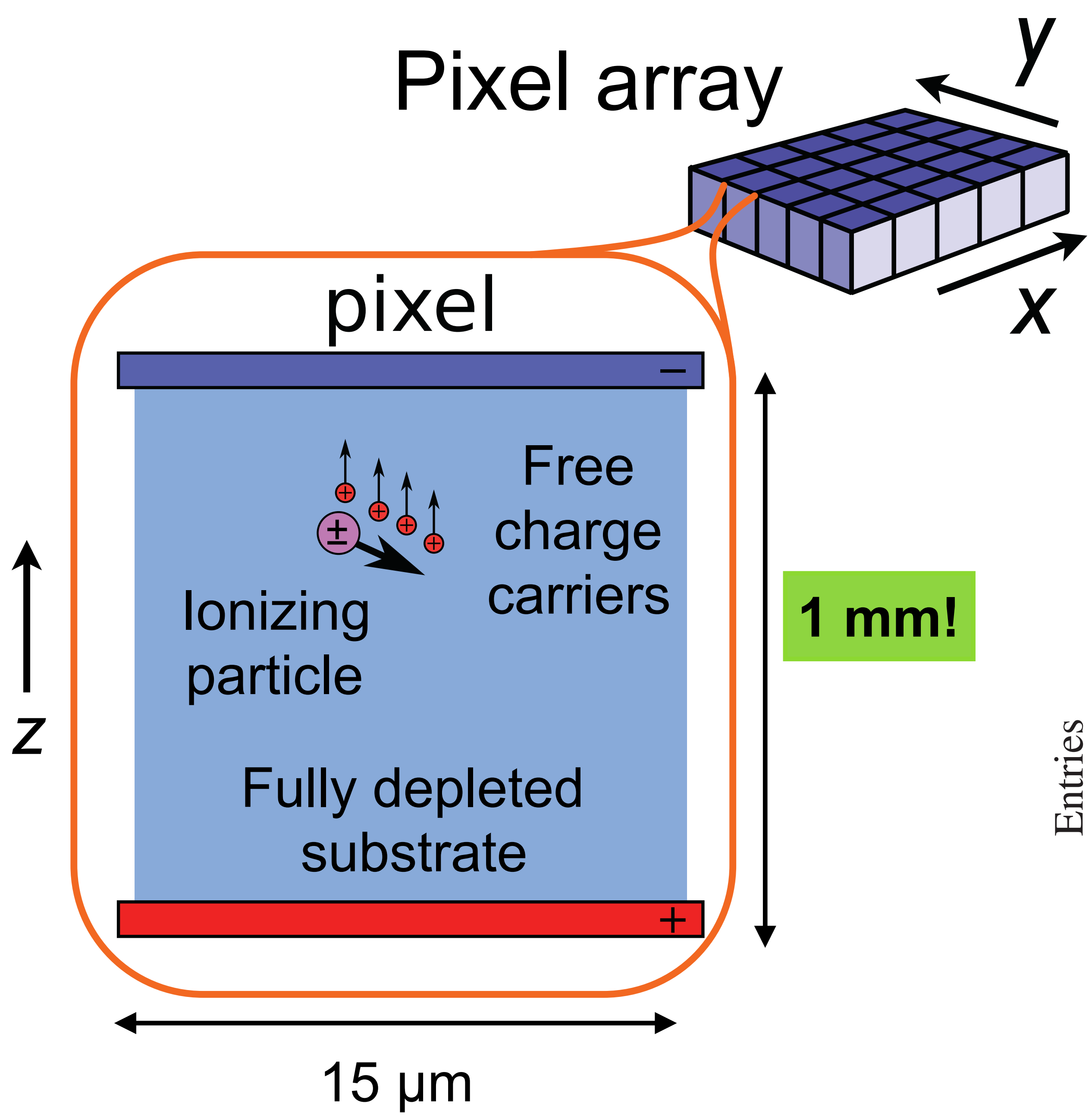


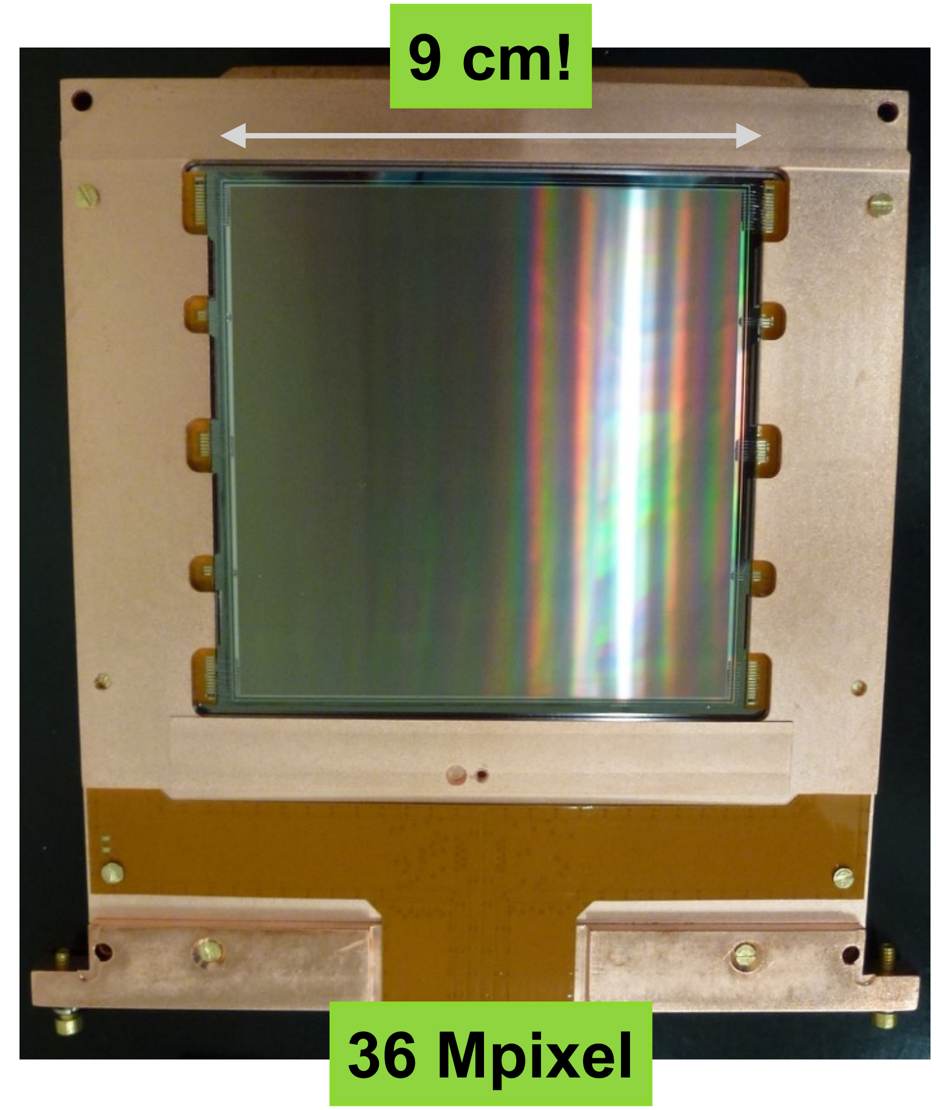


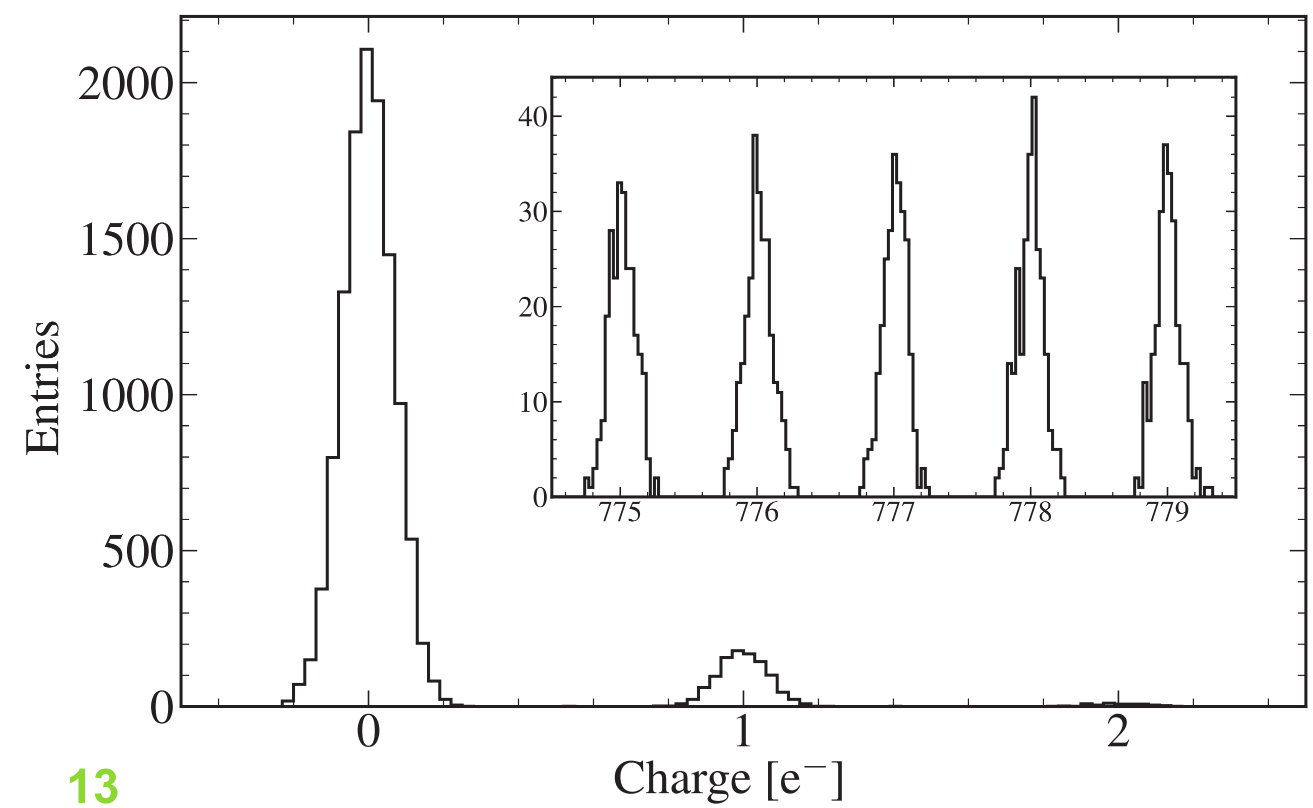
DM-electron scattering can extract sufficient kinetic energy to ionize a semiconductor (albeit with large phase-space suppression in sensitivity).

DAMIC

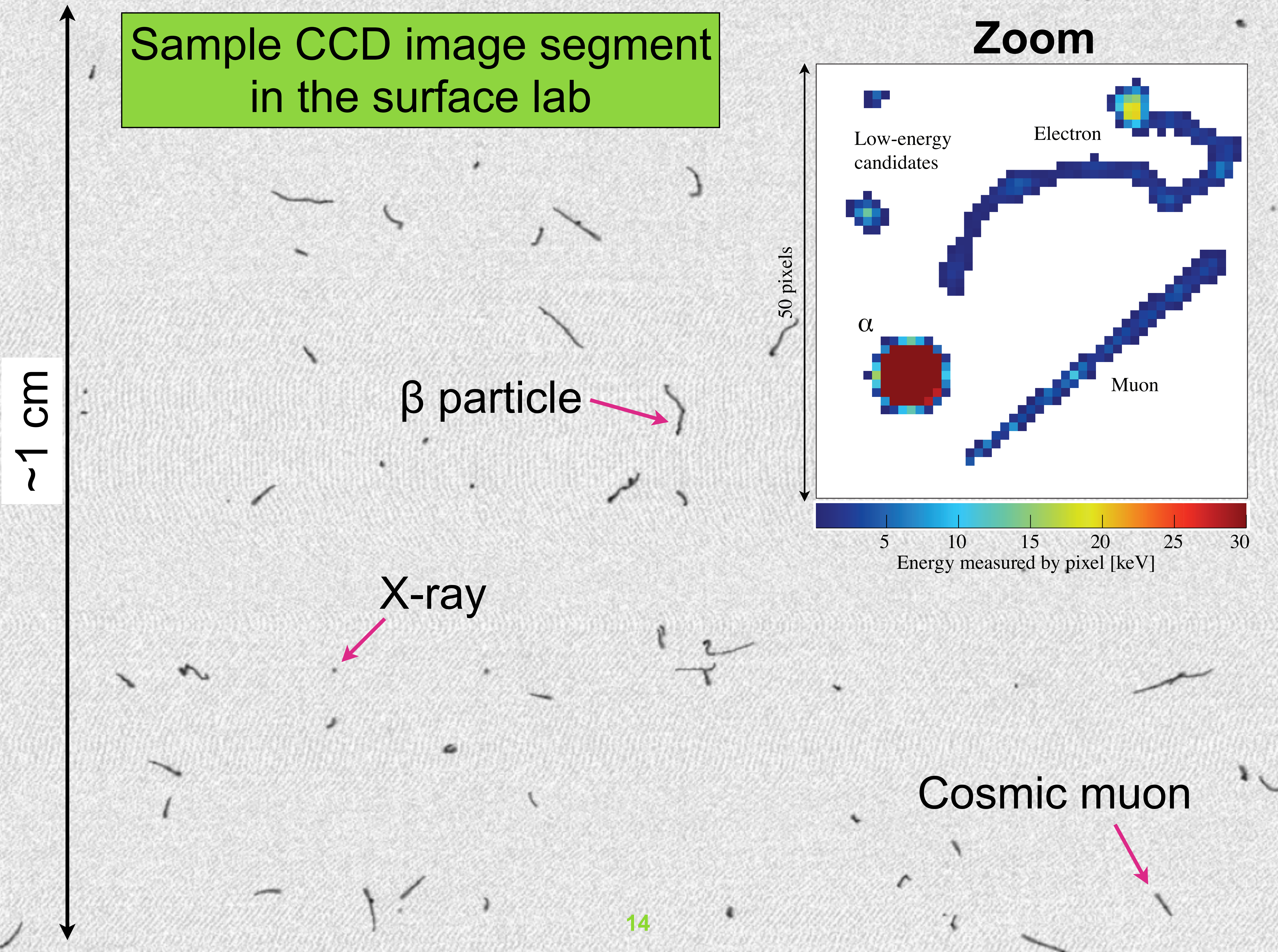
Count charges in the most massive charge-coupled devices (CCDs) ever built!



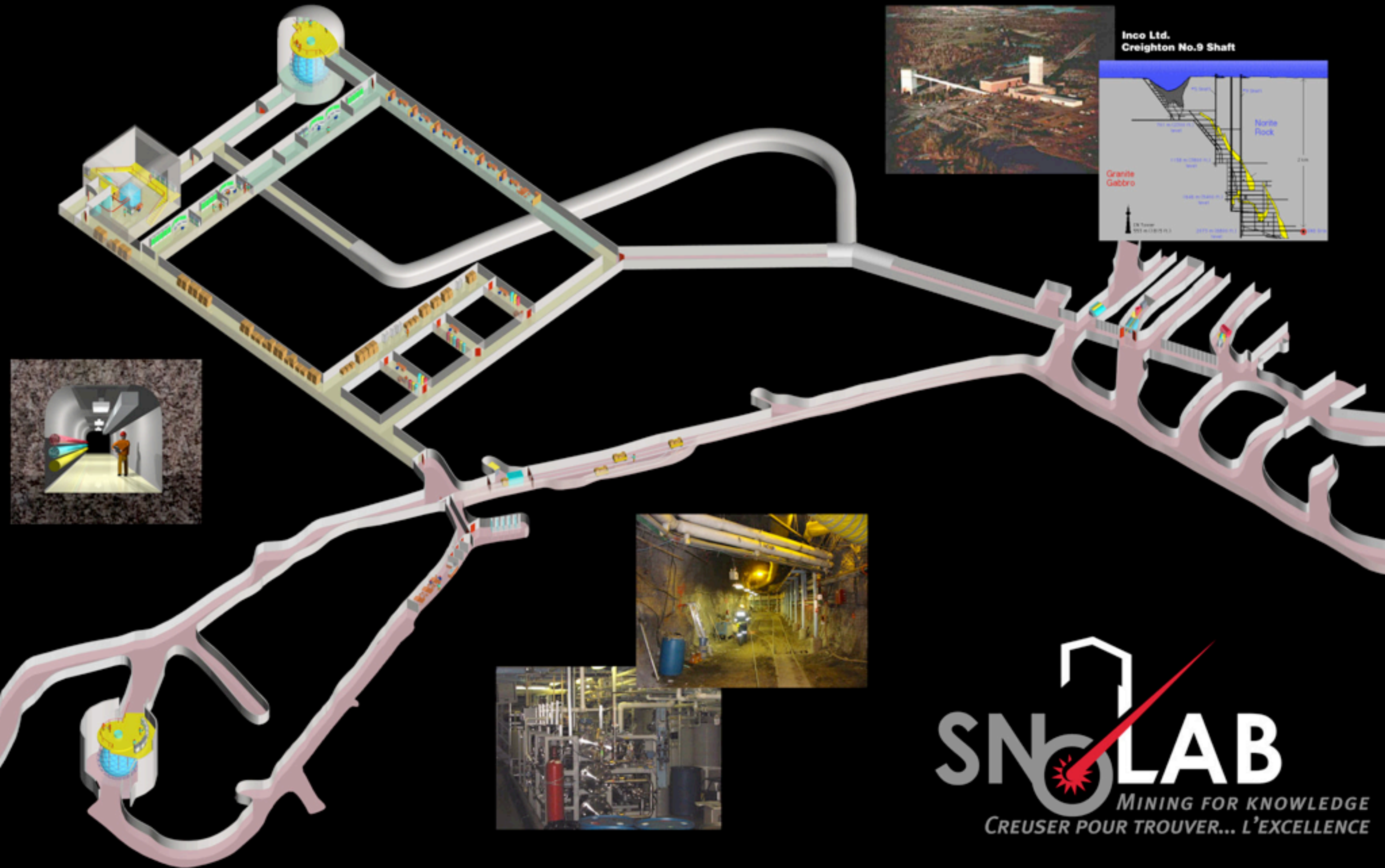




Sample CCD image segment in the surface lab

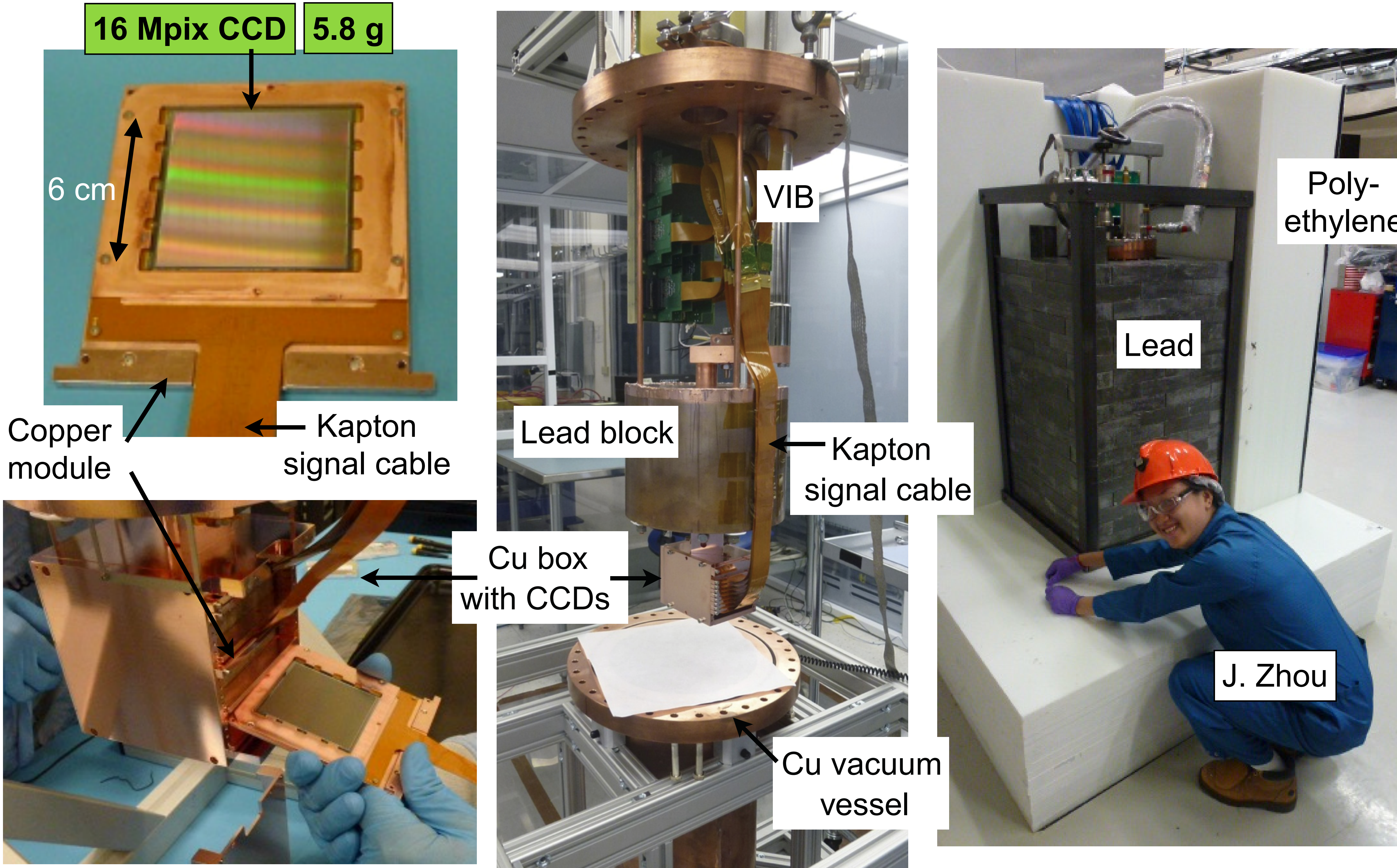


2 km underground



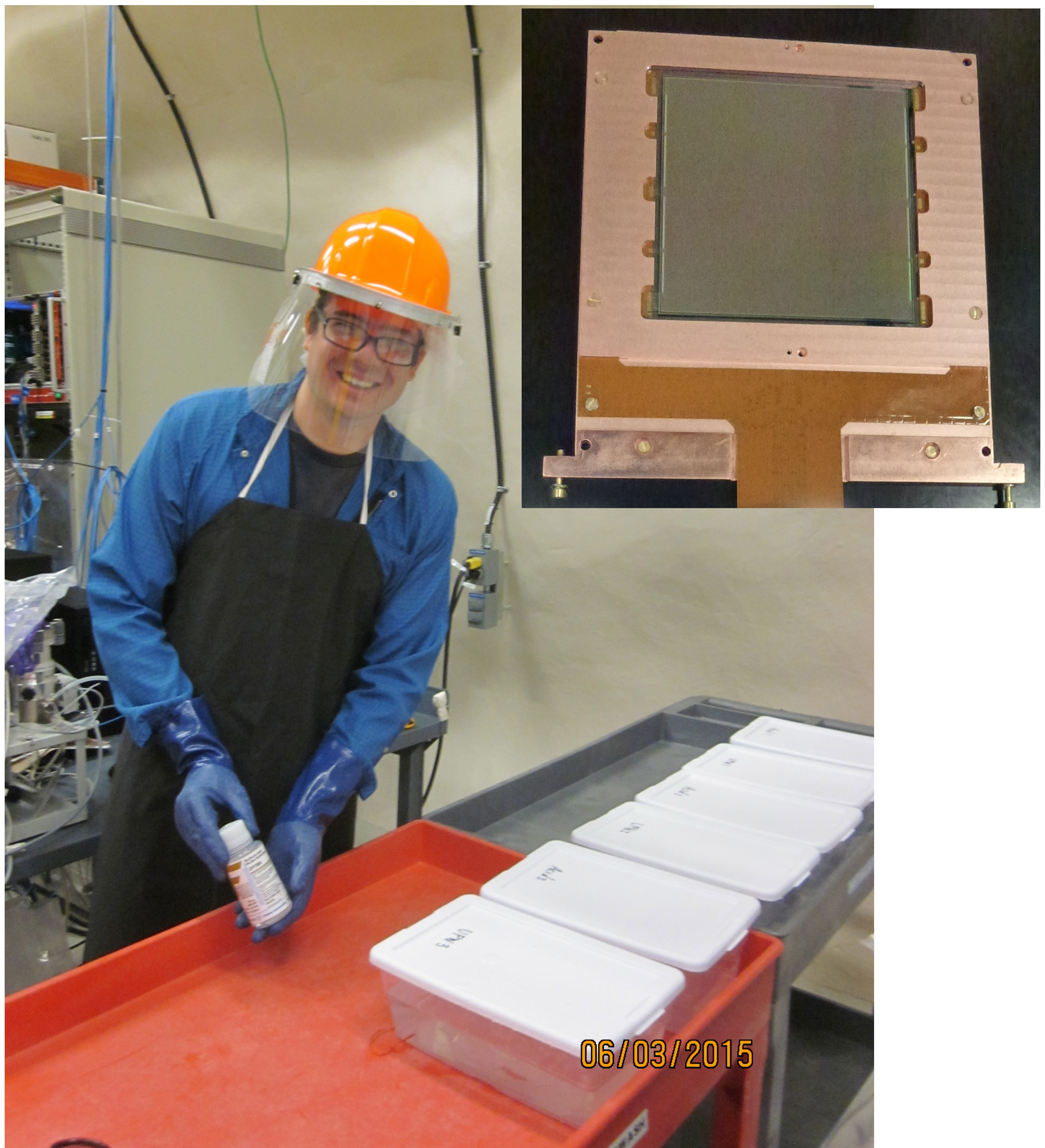
SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE

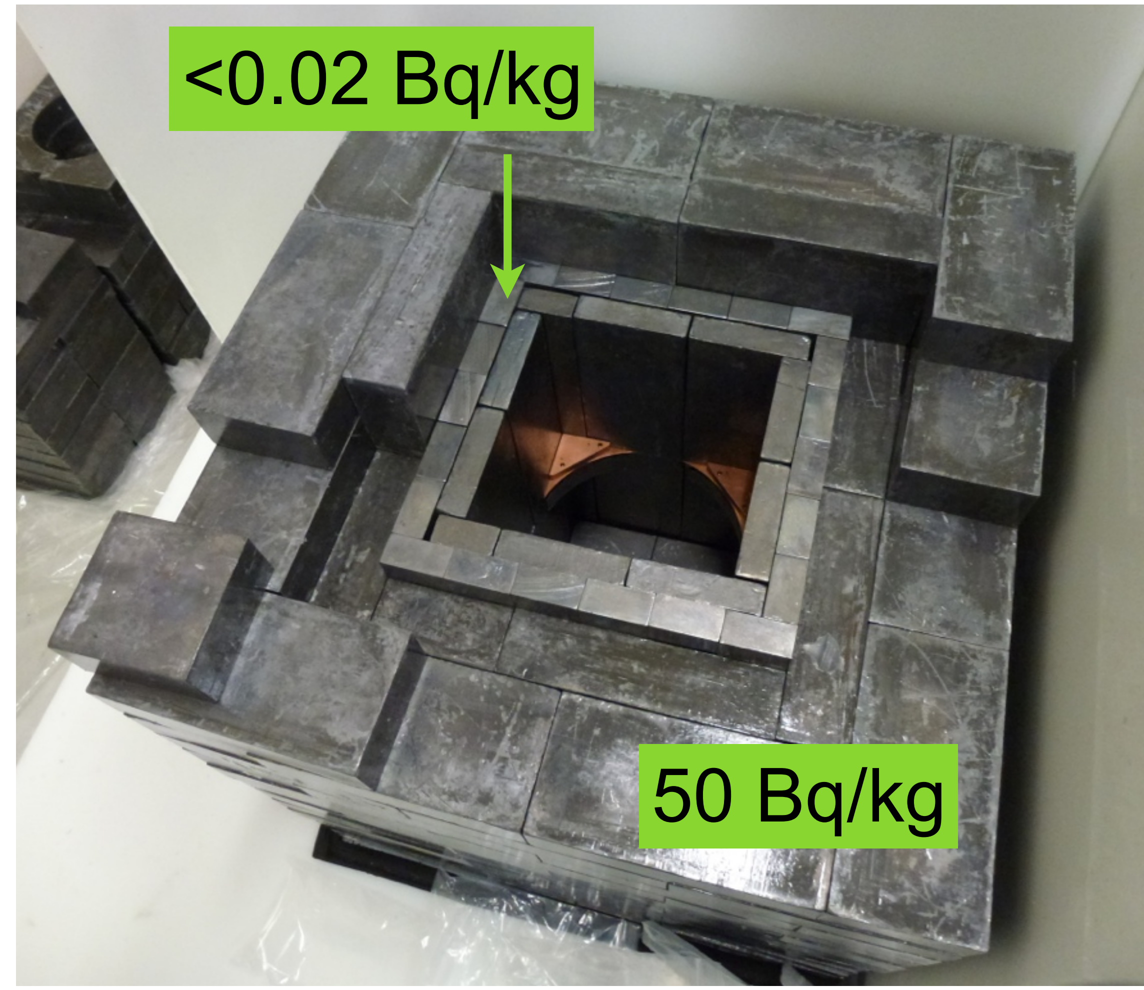
SNOLAB Installation



Low radioactivity

Extensive selection of copper, special machining and chemical cleaning.





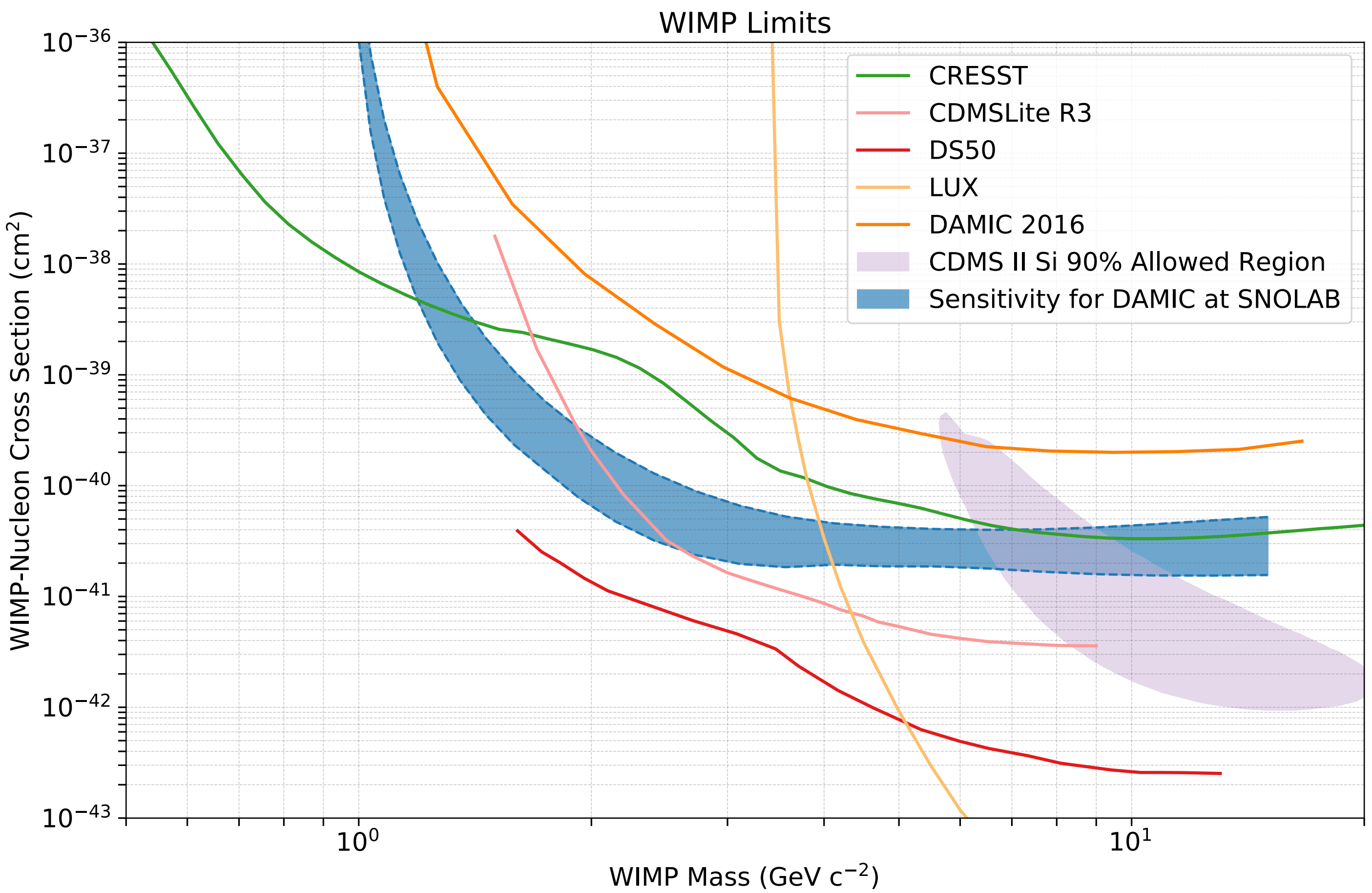
Lead shielding to stop external γs: Inner 2” of lead is ancient to stop bremsstrahlung from ^{210}Bi decay.

Nitrogen purge around lead to suppress radon «1 Bq/m^3.

Results from SNOLAB

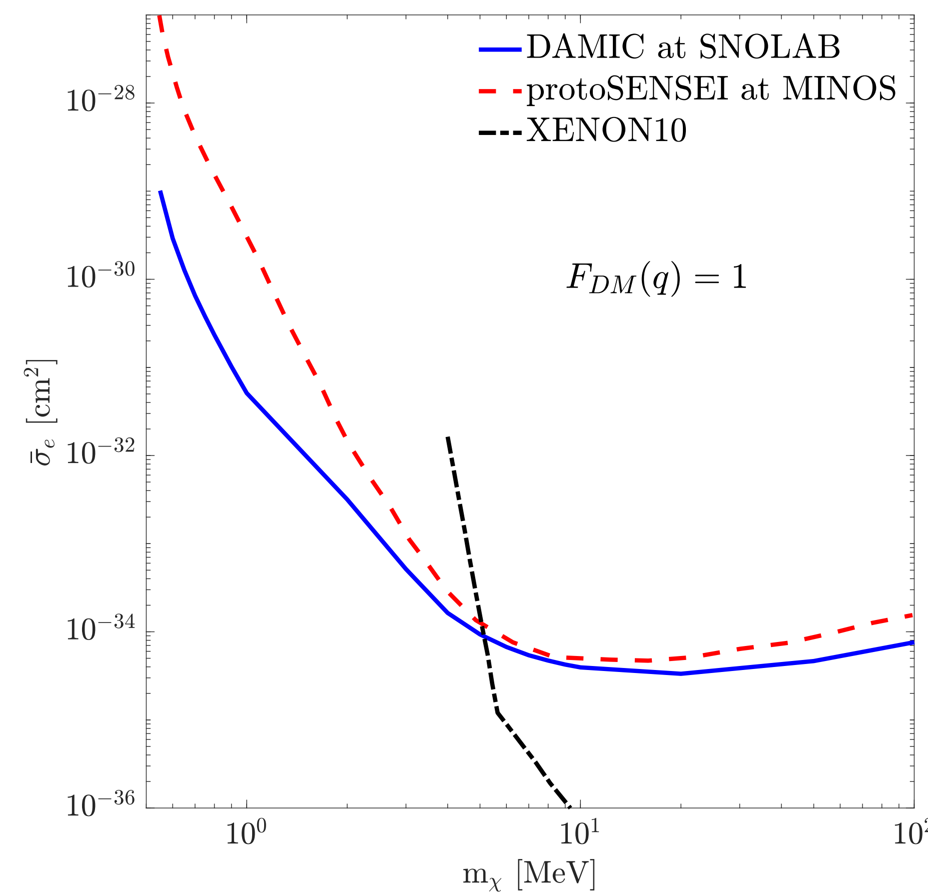
DAMIC places constraints in the amplitude of the DM signal by analysis of the spectrum of energy depositions by ionizing particles in the CCDs

DM-nucleus scattering



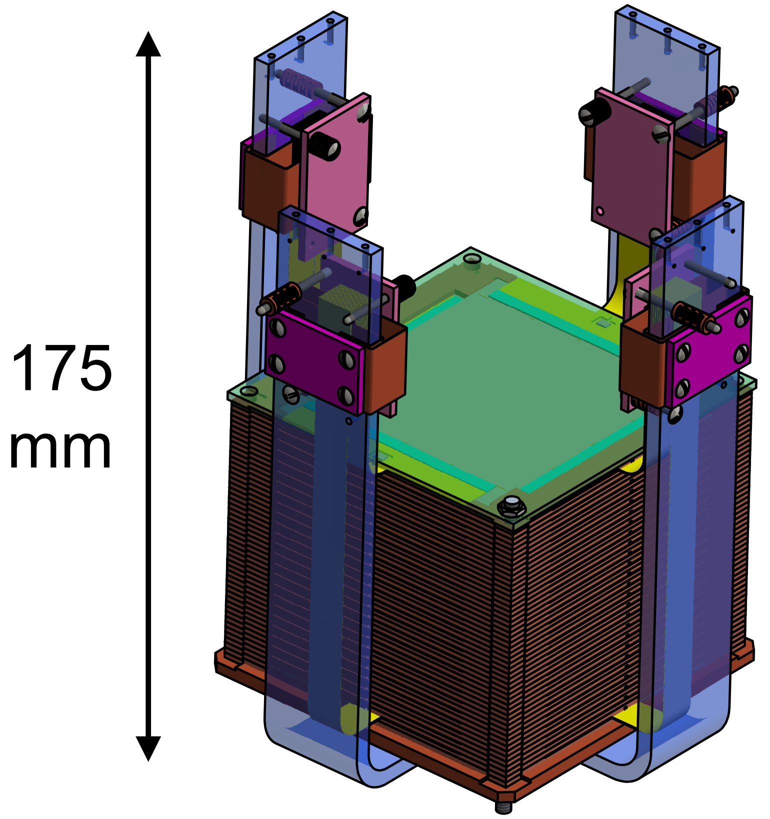
Best silicon limit, probing the CDMS-II Si anomaly!

DM-e scattering



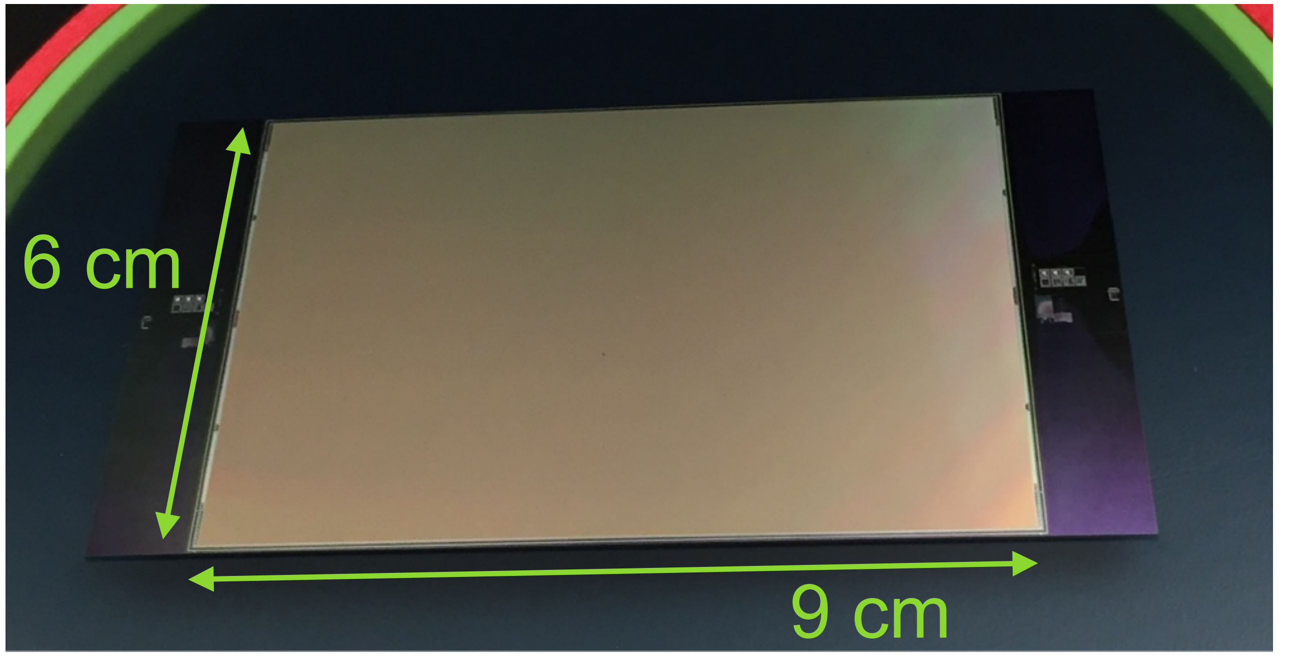
Best limit below 5 MeV!

DAMIC-M



- **50 CCDs** (0.7 kg target mass) at LSM (France).
- Most massive CCDs ever built (**6k x 6k x 0.675 mm, mass 14 g**).
- Skipper readout for **sub-eV noise.**
- **Background reduction to a fraction of dru** (improved design, materials, procedures).

24 Mpix CCD at UW: 10 g!



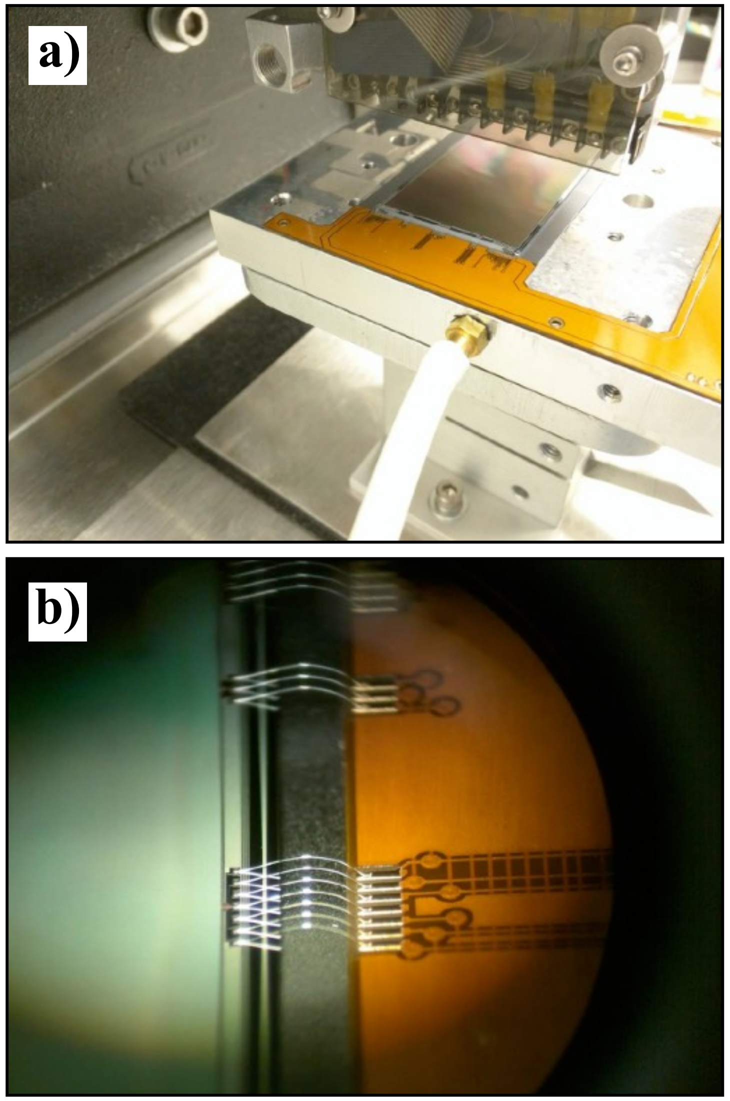
Institutions:

The University of **Chicago**, University of **Washington**, Pacific Northwest National Laboratory (**PNNL**), **SNOLAB**, Laboratoire de Physique Nucléaire et de Hautes Energies (**LPNHE**), Laboratoire de l'Accélérateur Linéaire (**LAL**), the Laboratoire Souterrain de Modane/Grenoble (**LSM**), University of **Zurich**, **Niels Bohr Institute**, University of **Southern Denmark**, University of **Santander**, Centro Atómico **Bariloche**

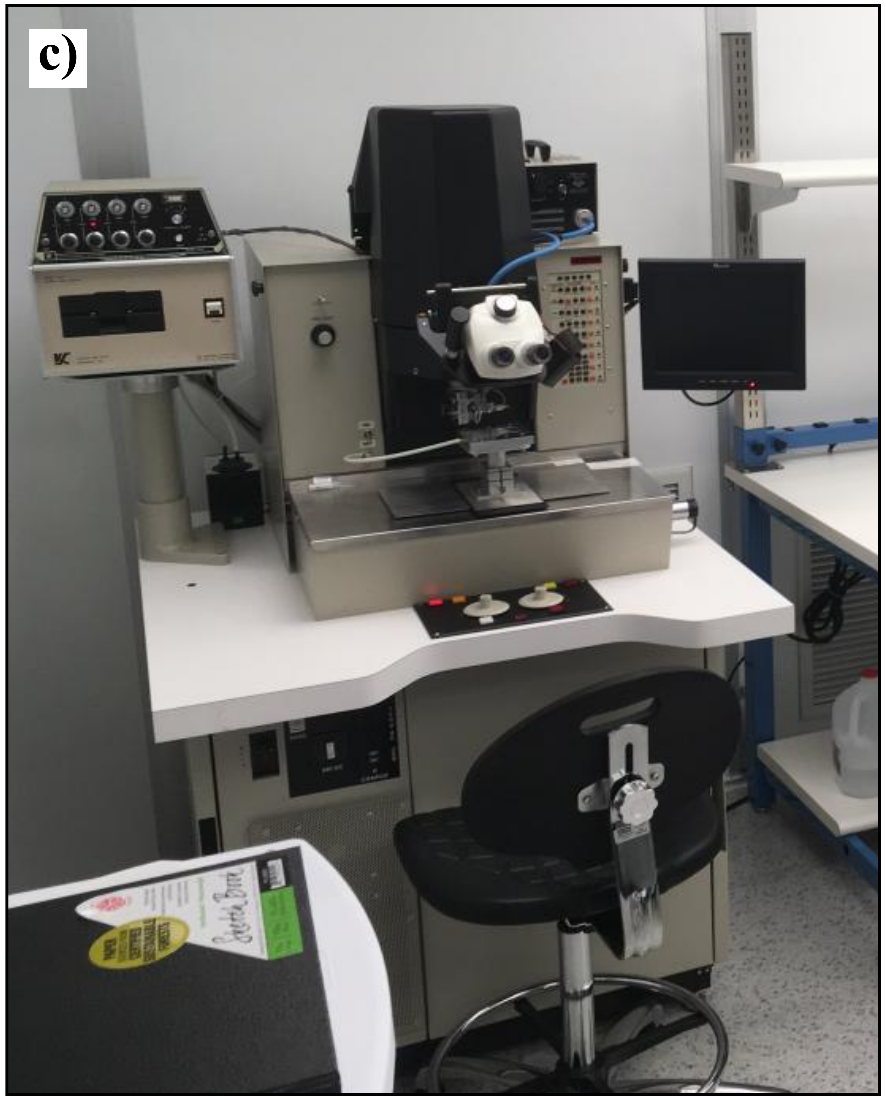
CCD package + test

UW's CCD DAMIC lab in PAB B059

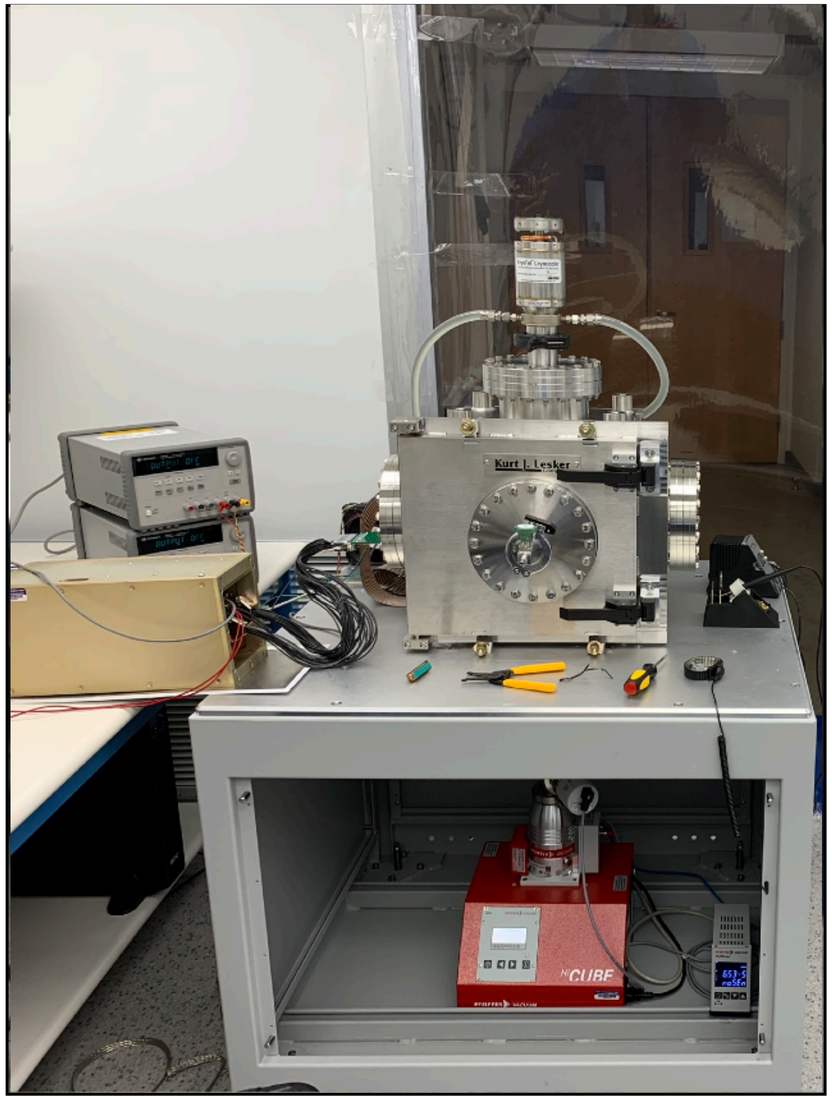
Wire bonding



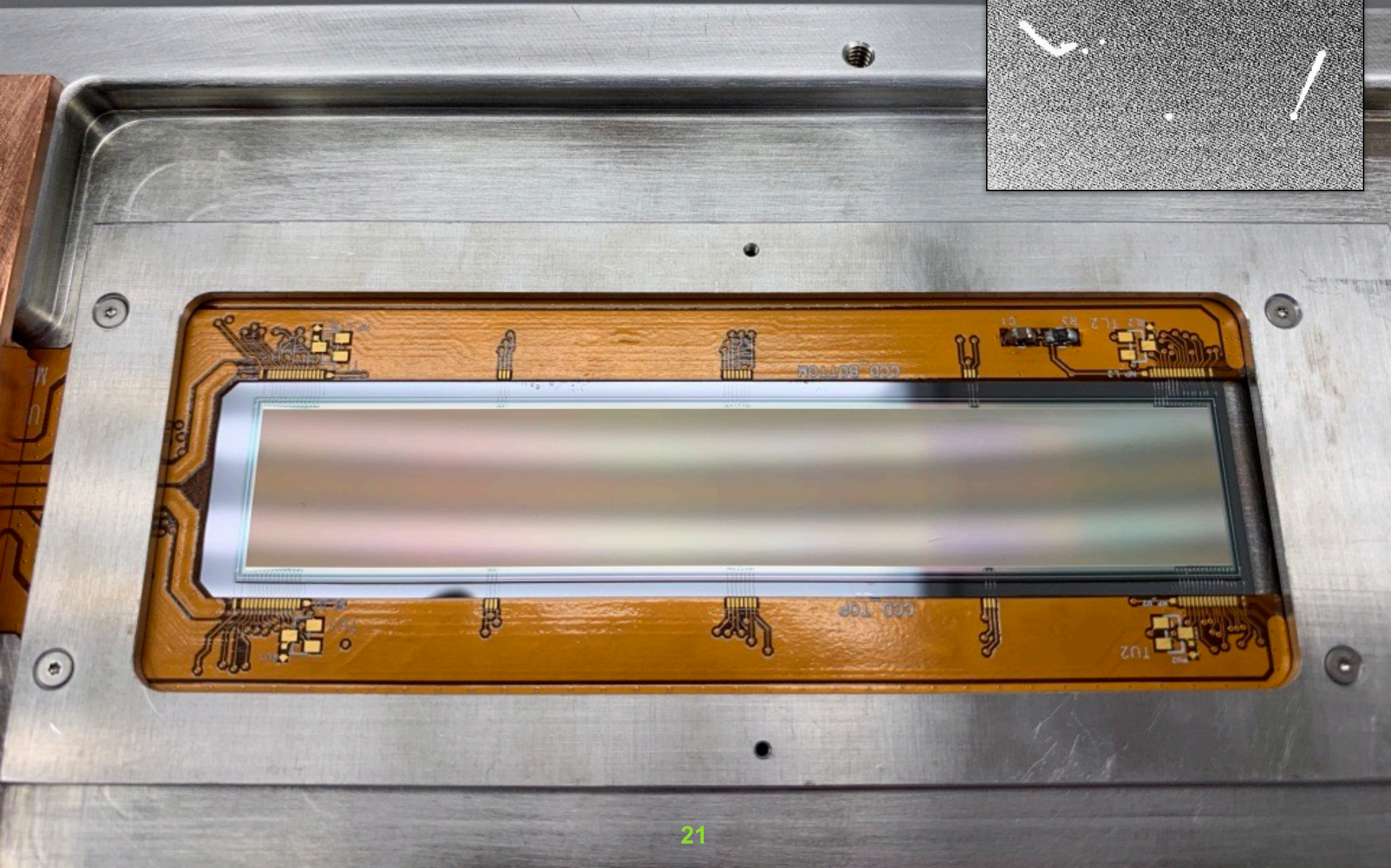
Wire bonder



Test chamber

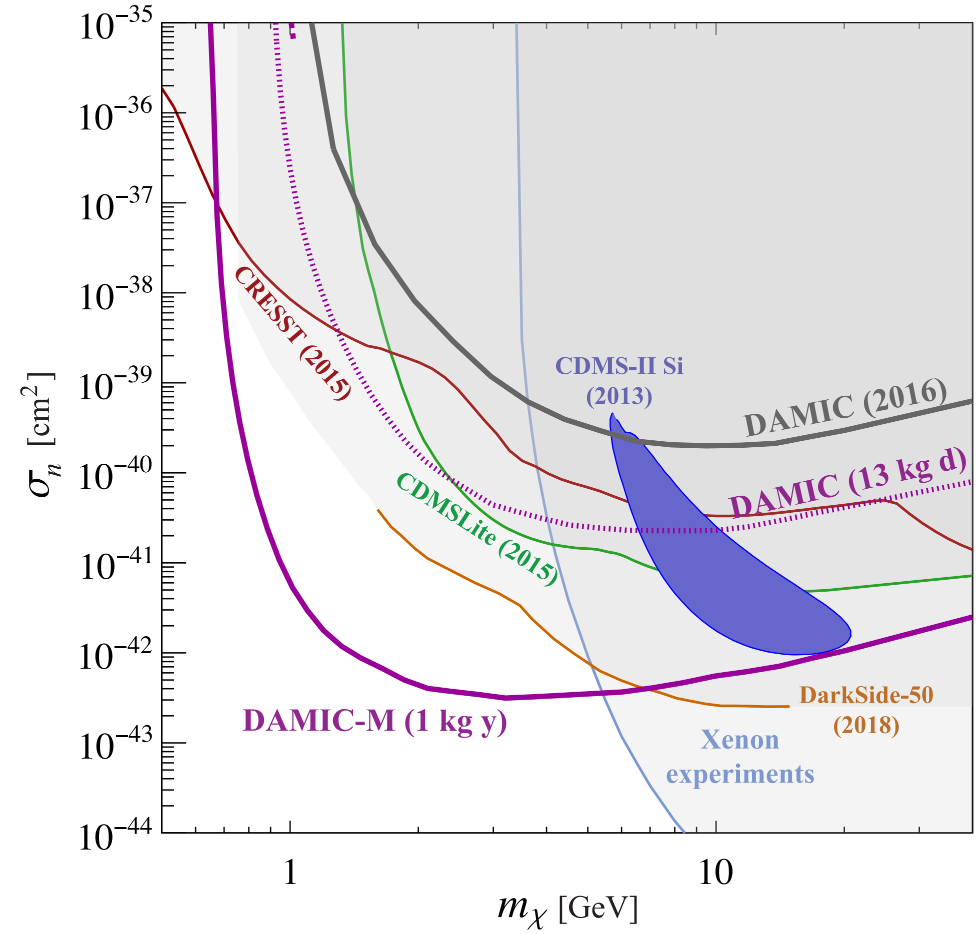


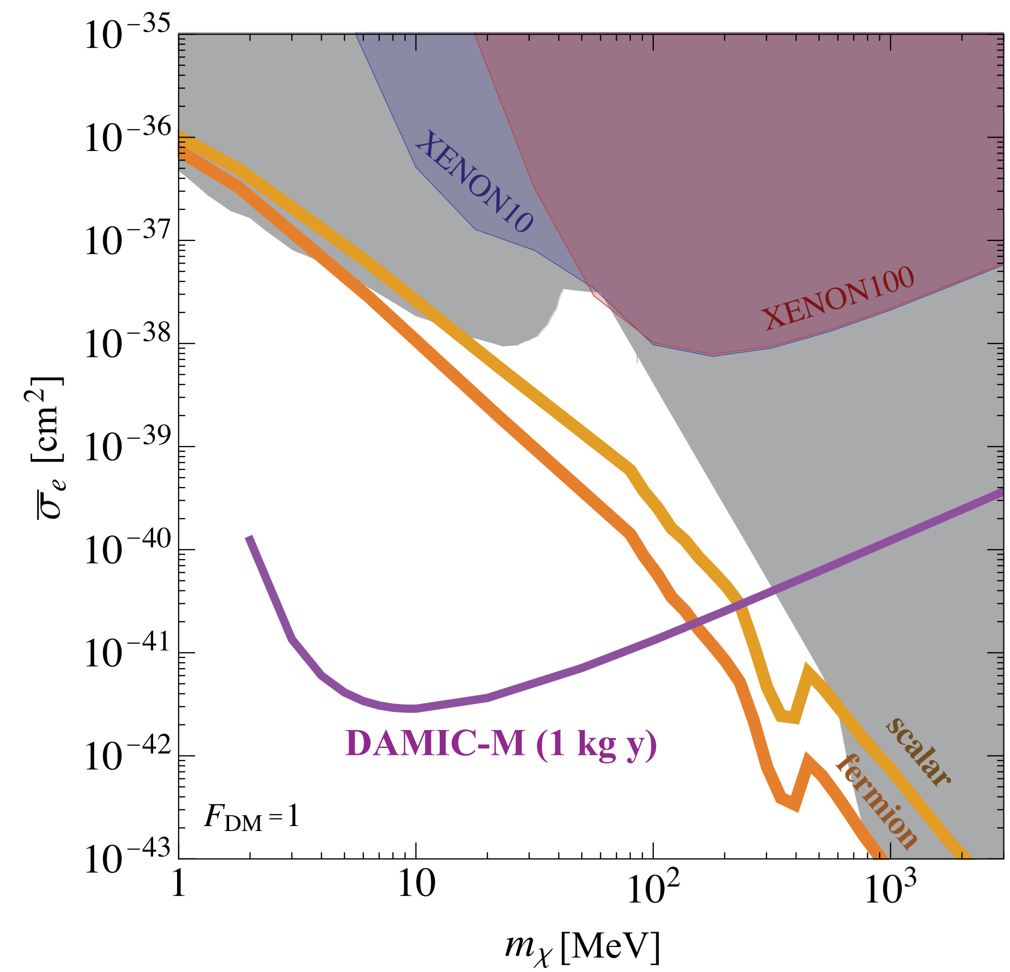
Development 1k x 6k skipper CCDs being tested at UW, Chicago and Paris



Plans

- We are currently packaging and testing the first prototype skipper CCDs for DAMIC-M (ask Emilee!).
- We plan to characterize the skipper CCD response to ionizing signals and backgrounds.
- At CENPA, we are designing and prototyping the DAMIC-M detector tower.
- We are moving to LSM by the end of the year to install the first detectors.





Graduate school

- I started graduate school in Princeton in 2007.
- Graduate school is still *school*: where you learn how to do research.
- Doesn’t define the research you will do for the rest of your career (in academia or industry).
- Get good grades (*practice the GRE!)*, show interest and passion in your statements.
- Don’t be set on *one* research group, go where the overall research of the Department interests you.
- The *environment* of the Department matters. Is the program a good fit for you. E.g., do you like *structure* or do you like *freedom*?