# A multidisciplinary endeavor in experimentation in DAMIC

Fermilab, *New Perspectives 2020*

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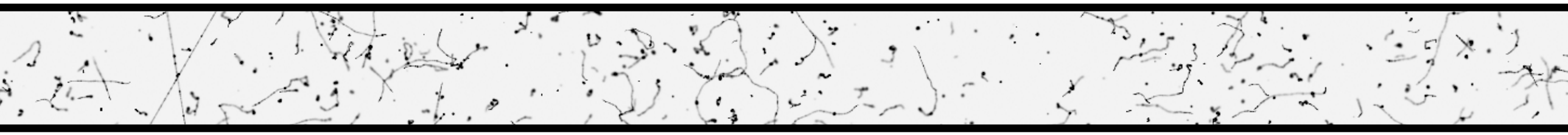
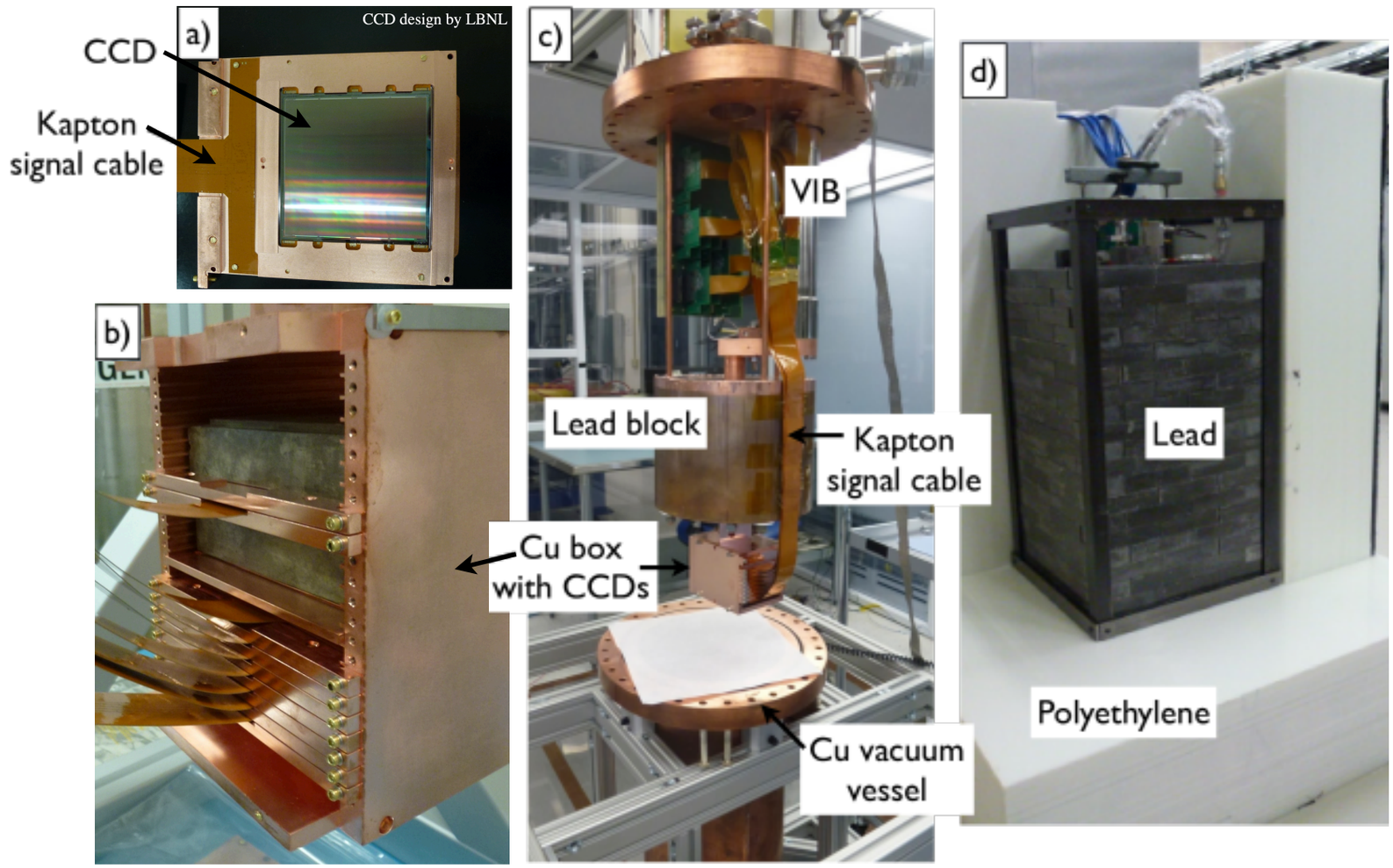


## Outline:

1. DAMIC: an overview
2. CCDs and Dark Matter Detection
3. Image Processing
4. DAMIC Wimp Search
5. DAMIC Hidden-Sector Search

# DAMIC

- **DArk Matter In CCDs** collaboration (since 2011)
- Setup **at SNOLAB** underground laboratory (Lively, Ontario, CA)




a) Packaged DAMIC CCD

b) Copper CCD housing

c) In-vacuum setup

d) Pb and polyethylene outer shielding

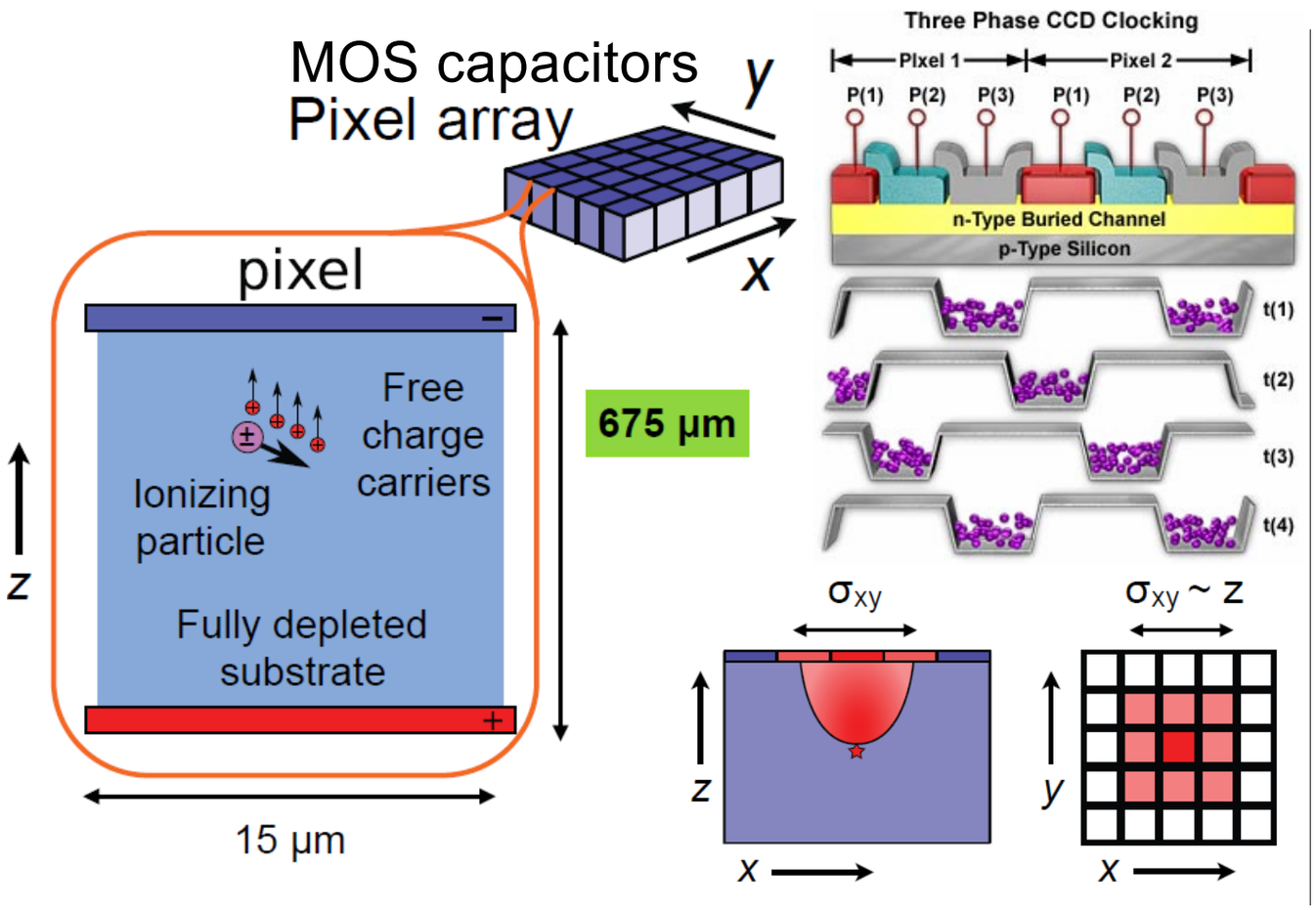
## Why CCDs?

- Extremely low noise and dark current ⇒ sensitivity to ~$e^-$
- 3D track reconstruction and event discrimination capability

## ...for Dark Matter?

- Record CCD thickness + several CCDs ⟹ massive target (~40 g)
- Different DM search options:
  - WIMP-nucleus coherent scattering
  - Hidden sector light DM-$e^-$ interactions

# DARK MATTER IN CCDs



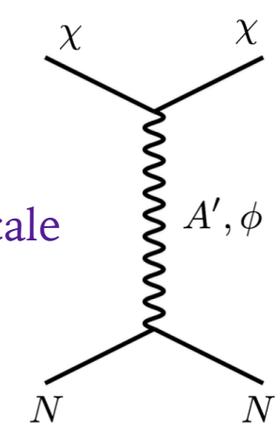

**DAMIC scientific-grade CCDs:**

- Developed at LBNL: polySi gate, buried channel structure
- Fully depleted (40 V substrate)
- High resistivity ~ 10 kΩ·cm
- Much thicker than usual: 675 $\mu$m

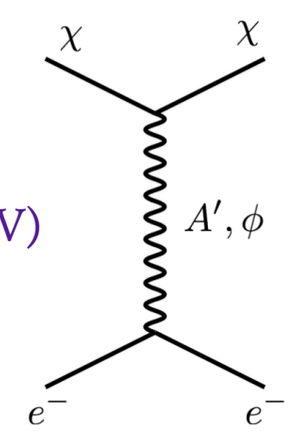
**Performance:**

- Charge transfer inefficiency < $10^{-6}$
- Readout noise ~1.6 e- (6 eV)
- Dark current < $10^{-3}$ $e^-$/pix/day

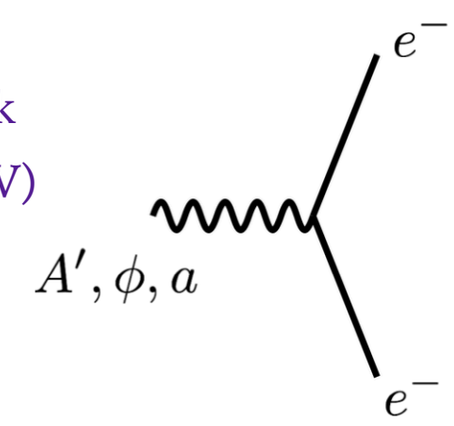
Low mass WIMPs (<10 GeV) keV-scale nuclear recoil



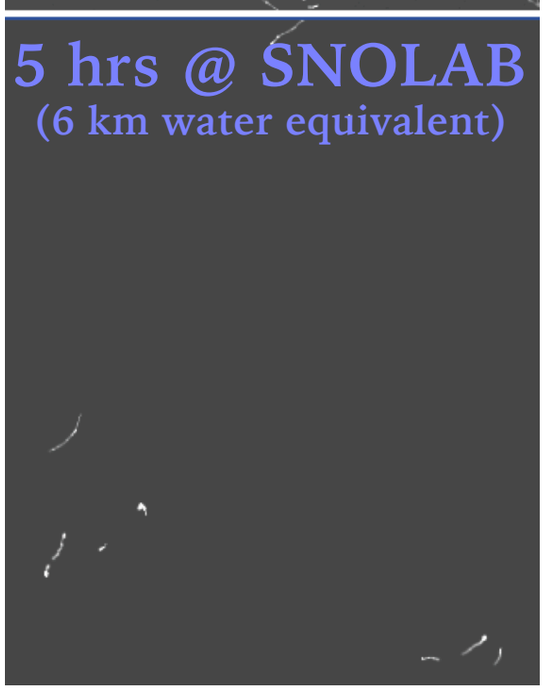

Hidden-sector light DM (~MeV) electronic recoil




Massive dark photon (~eV) electronic absorption



# IMAGE PROCESSING

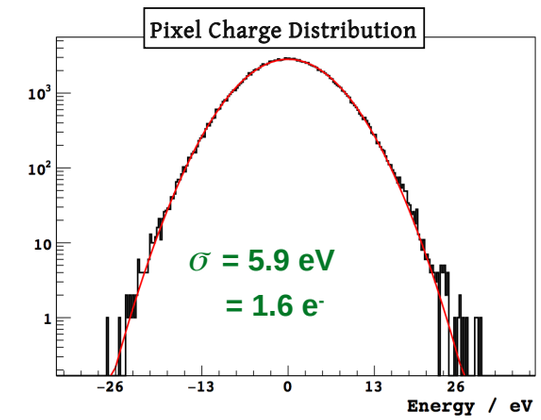



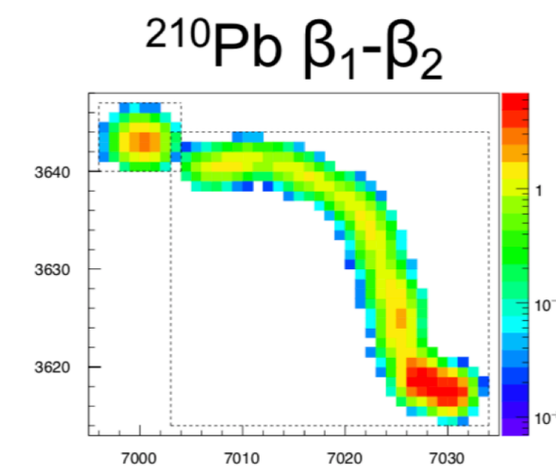

**What information do we extract from our images ?**

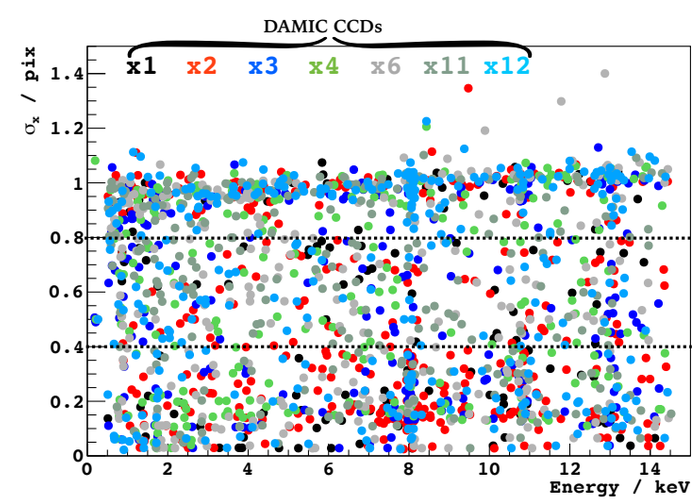
- Pixel charge distribution
- E-σ (depth) distribution of energy-deposit clusters

**What do we do with it ?**

- Characterize our detector performance
- Constrain radio-impurities content (coincidence analysis)
- Build a tailored background model with the aid of simulations
- Search for a dark matter excess!



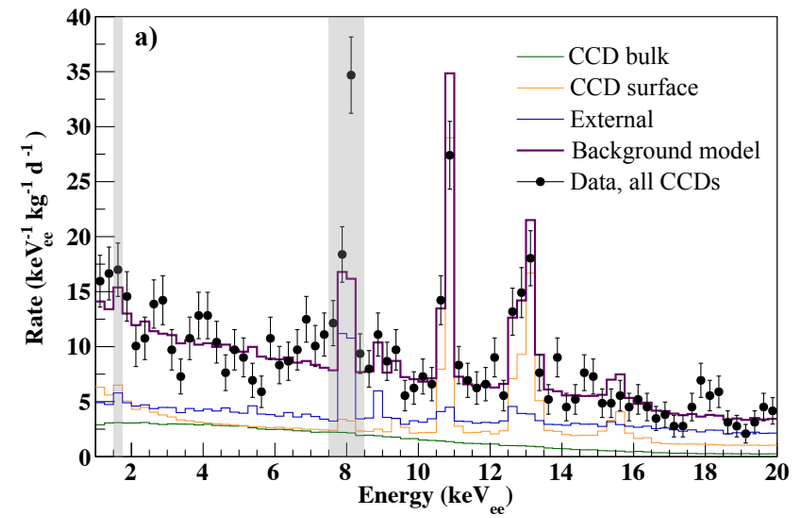



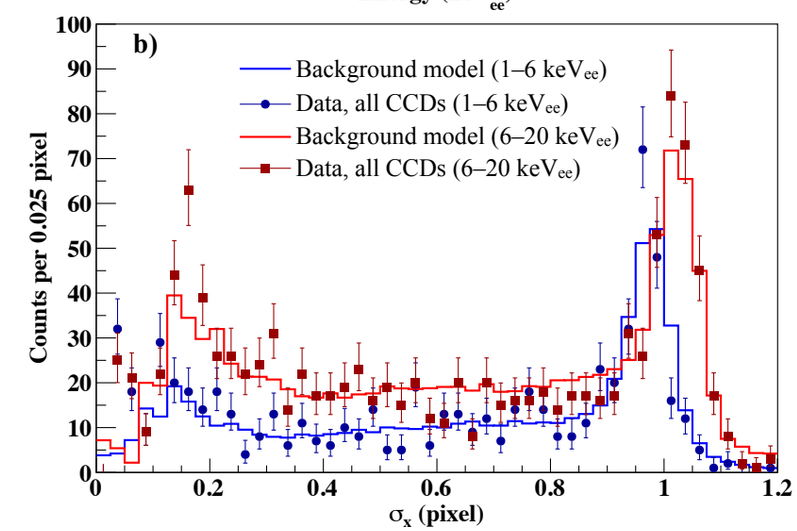



# DAMIC WIMP SEARCH

## How do we search for WIMPs?

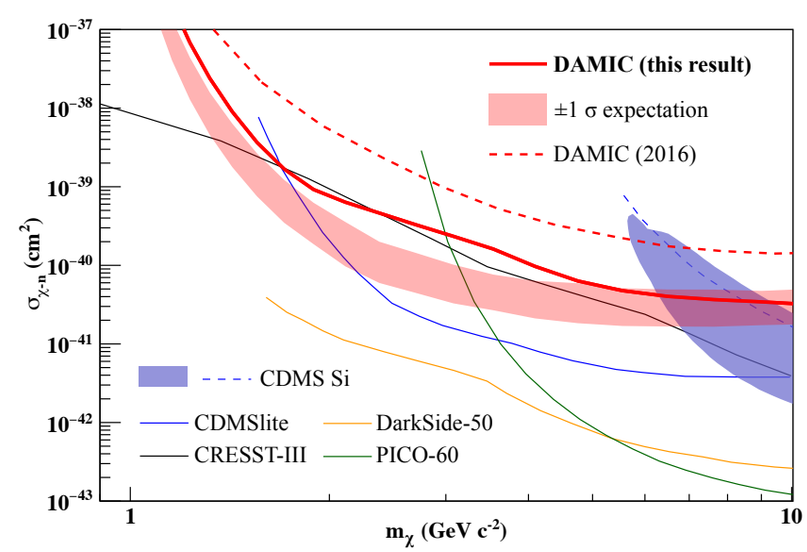
- Background model construction – *ab initio* Monte Carlo:
  - **Decay** of 23 isotopes and **tracking** simulated across 65 detector volumes with Geant4
  - **CCDs response simulation**: charge generation and transport, pixelation and readout noise
  - **Clustering**
  - Binned **likelihood fit** in WIMP-safe region (6-20 keV) $\Longrightarrow$ extrapolate in ROI (0-6 keV)
- Bulk excess search: joint extended-likelihood fit
- WIMP-nucleus cross section constraint




## DAMIC WIMP searches

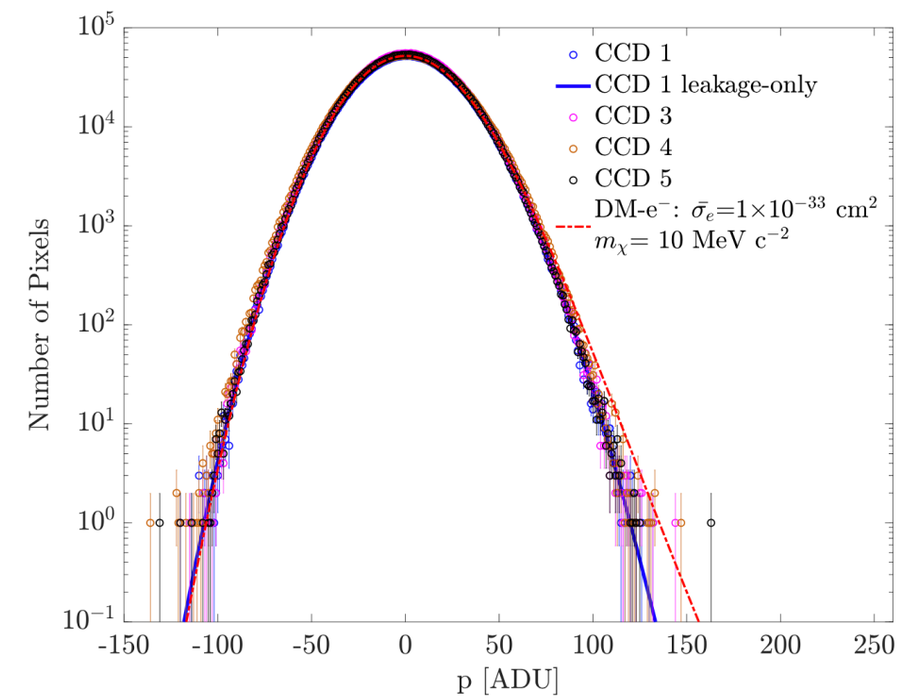
- 0.6 kg d search in 2016 to demonstrate potential to explore low-mass WIMP range (<10 GeV/c²)
- 10.9 kg d search in the last 2 years: submitted to PRL (2020) [arXiv:2007.15622]



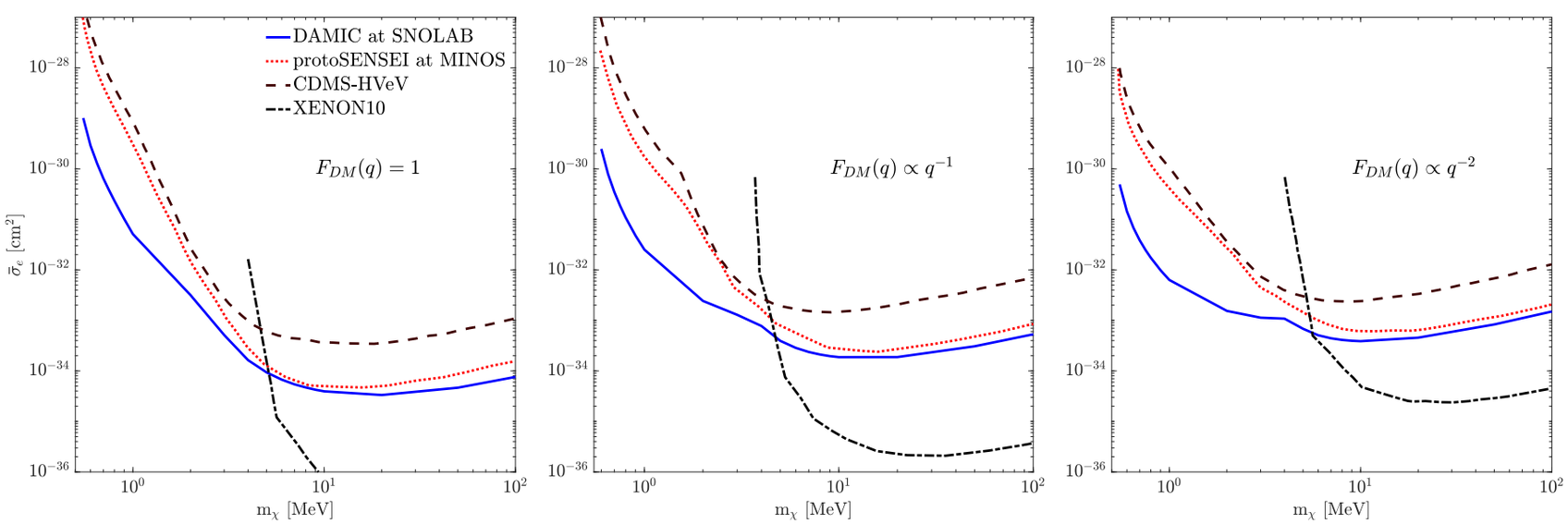
# DAMIC HIDDEN-SECTOR SEARCH

**How do we search for hidden-sector candidates?**

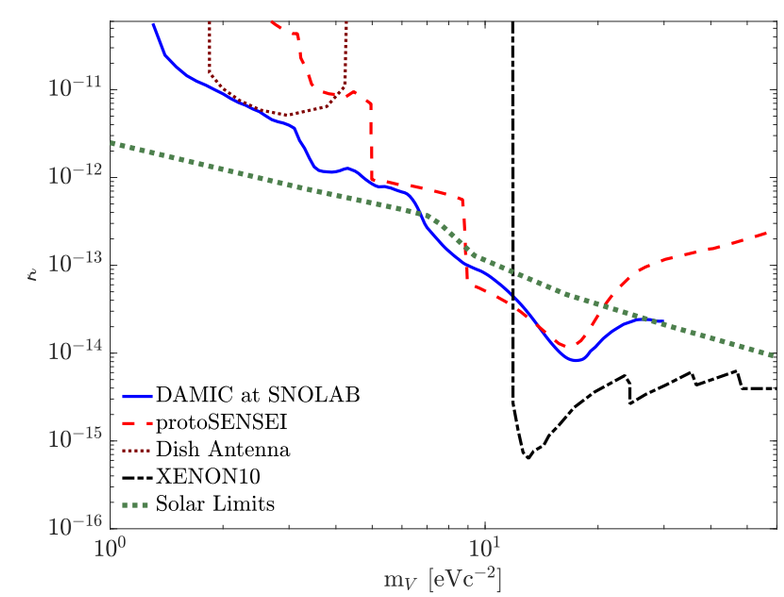
- Characterize relevant noise: electronic noise and dark current
- Estimate expected hidden-sector particle(s) signal
- Include detector effects (diffusion, pixelation, etc.)
- Likelihood analysis
    - Bulk excess search
    - Limits in ($\sigma_e$ $m_\chi$) space ($\sigma_e \rightarrow \kappa$ for hidden photons)




90% C.L. upper limits on the DM-electron free scattering cross section




90% C.L. upper limits on the hidden-photon DM kinetic mixing parameter $\varkappa$



# CONTRIBUTIONS

- DAMIC latest WIMP search:
  - ➡ Geant4 simulation of setup contaminants to build background model
  - ➡ Demonstrate negligibility of neutron radiation as mimic of WIMP signal
  - ➡ Markov-chain MC likelihood analysis
- R&D efforts for DAMIC-M (see talk by G. Papadopoulos - NP 1.0):
  - ➡ Automated chain to optimize setup parameters
  - ➡ Test setup development

# *Glad to tell you about us!*

*Michelangelo Traina*