Direct Dark Matter Research : The Damic-M* experiment

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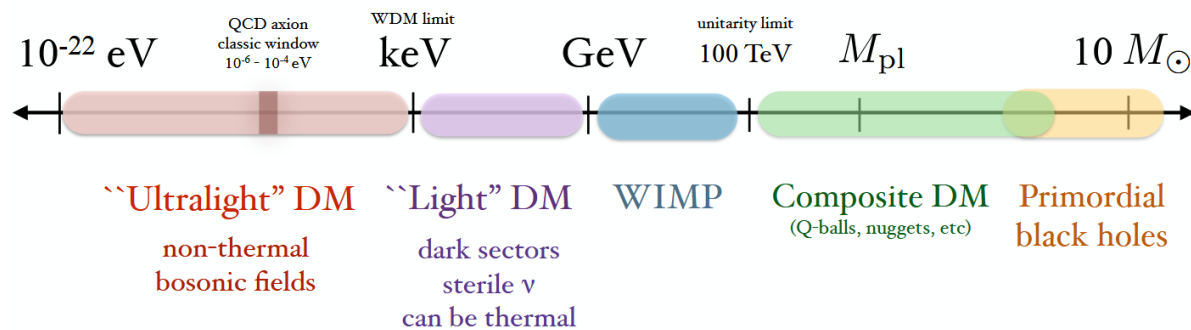
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Evidence for Dark Matter in the Universe

❖ Galaxy Rotation Curves

❖ Lensing

❖ Cluster Virialization, Mergers

❖ CMB Anisotropies

❖ Etc.

Mass scale of dark matter

(not to scale)

QCD axion
classic window
$10^{-6} - 10^{-4}$ eV

WDM limit

unitarity limit

10^{-22} eV   keV   GeV   100 TeV M_{pl} 10 $M_\odot$

``Ultralight" DM     ``Light" DM   WIMP   Composite DM   Primordial
                                                (Q-balls, nuggets, etc)   black holes

non-thermal   dark sectors
bosonic fields   sterile ν
                    can be thermal
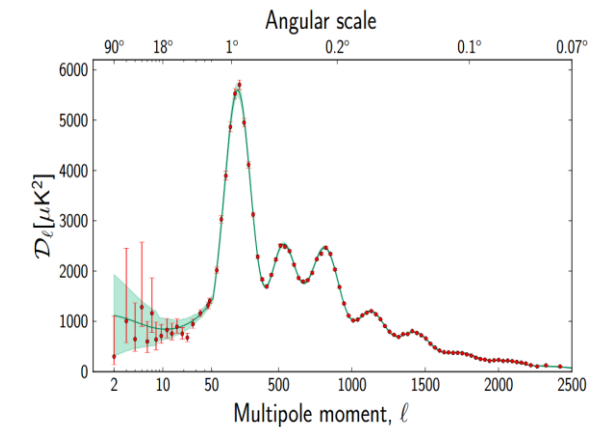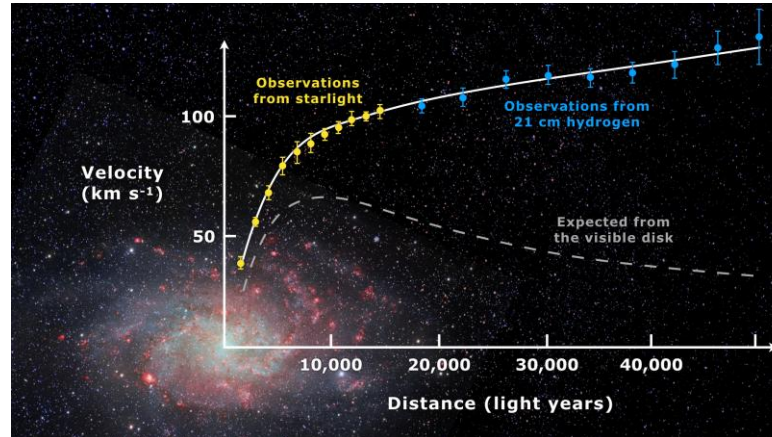
T. Lin, arxiv:1904.07915

Detection of particles produced by the annihilation of SM particles

thermal freeze-out (early Univ.)
indirect detection (now)

direct detection

DM   SM

DM   SM
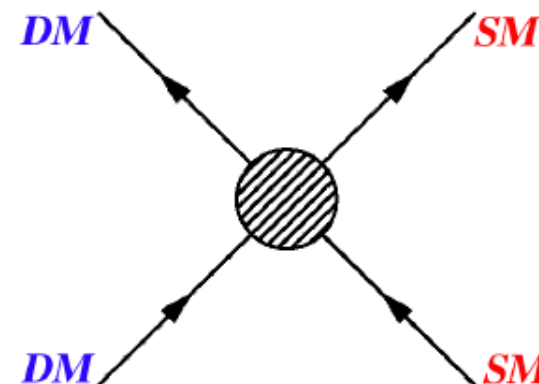
Detection of electronic/nuclear recoils

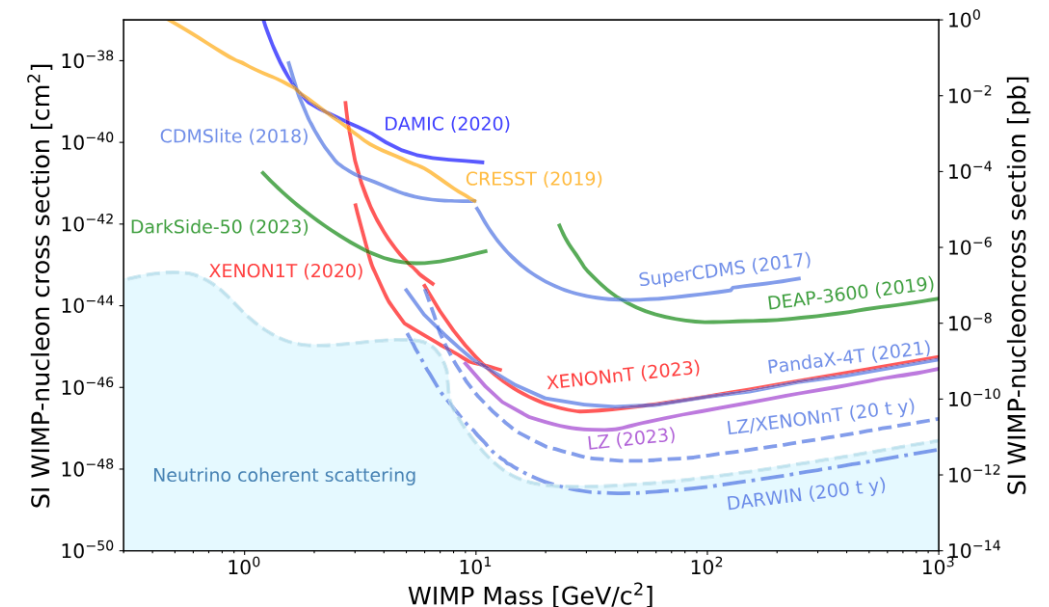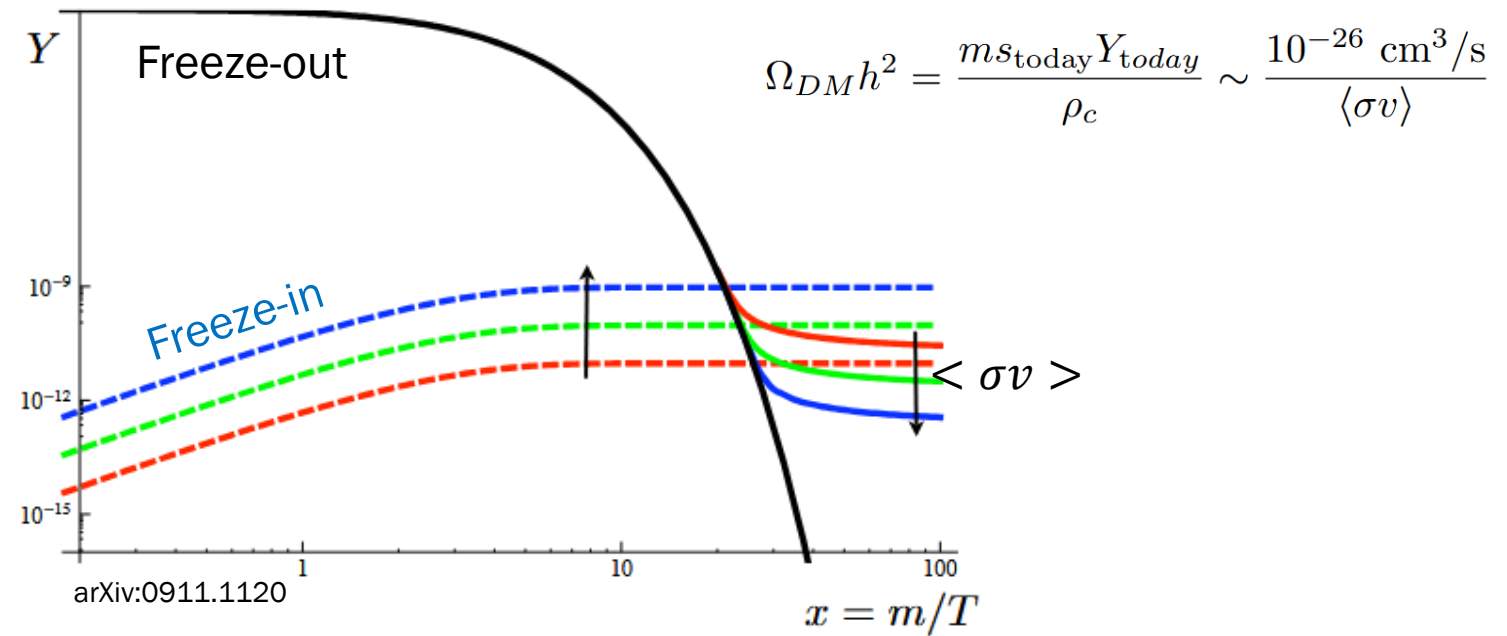Search for missing transverse energy

production at colliders

Dark Matter production and the Wimp Miracle

❖ Multiple production scenarios :

  ❖ Freeze-in/out

  ❖ Gravitational

  ❖ Etc.

❖ Weak-Scale Cross Section and m_{DM} : WIMP Miracle

❖ The Waning of the WIMP ?

Freeze-out

$$\Omega_{DM}h^2 = \frac{ms_{\text{today}}Y_{today}}{\rho_c} \sim \frac{10^{-26}\ \text{cm}^3/\text{s}}{\langle\sigma v\rangle}$$

Freeze-in

$<\sigma v>$

arXiv:0911.1120

Nucl. Phys. B 1003 (2024) 116473

An alternative to the Wimp paradigm : The Hidden Sector

- ❖ The SM is not complete (neutrino, dark matter, ...)

- ❖ New Interactions may exist !

- ❖ Simple natural extension of the Standard Model : new U(1) symmetry
  - ❖ Dark QED
  - ❖ Electroweak extension

- ❖ Leads to MeV-scale Dark Matter

New bosons expected to mediate new interactions

New spin-1 bosons ↔

new gauge symmetries beyond $SU(3) \times SU(2) \times U(1)$

Simplest possibility

$$SU(3) \times SU(2) \times U(1) \times \textbf{extra } U(1)$$

new gauge coupling (g'') ↔ *intensity of new interaction* $(\propto g''^2)$

Pierre FAYET, "The U BOSON as a generalized DARK PHOTON"

$$\mathcal{D}_\mu = \partial_\mu - igT_3 W_\mu^3 - \frac{i}{2}g'YB_\mu - \frac{i}{2}g''XC_\mu,$$

Symmetry breaking

Modification of the Z boson's coupling constant and a new gauge boson in the electroweak theory

$$A_\mu = \sin\theta_W W_\mu^3 + \cos\theta_W B_\mu,$$
$$\tilde{Z}_\mu = \cos\xi\cos\theta_W W_\mu^3 - \cos\xi\sin\theta_W B_\mu - \sin\xi C_\mu,$$
$$A'_\mu = \sin\xi\cos\theta_W W_\mu^3 - \sin\xi\sin\theta_W B_\mu + \cos\xi C_\mu.$$

$$g_A(T_3, Y, X) = eQ,$$
$$g_{\tilde{Z}}(T_3, Y, X) = g\cos\theta_W\cos\xi\, T_3 + g'\sin\theta_W\cos\xi\,\frac{Y}{2} + g''\sin\xi\,\frac{X}{2},$$
$$g_{A'}(T_3, Y, X) = g\cos\theta_W\sin\xi\, T_3 + g'\sin\theta_W\sin\xi\,\frac{Y}{2} + g''\cos\xi\,\frac{X}{2}.$$
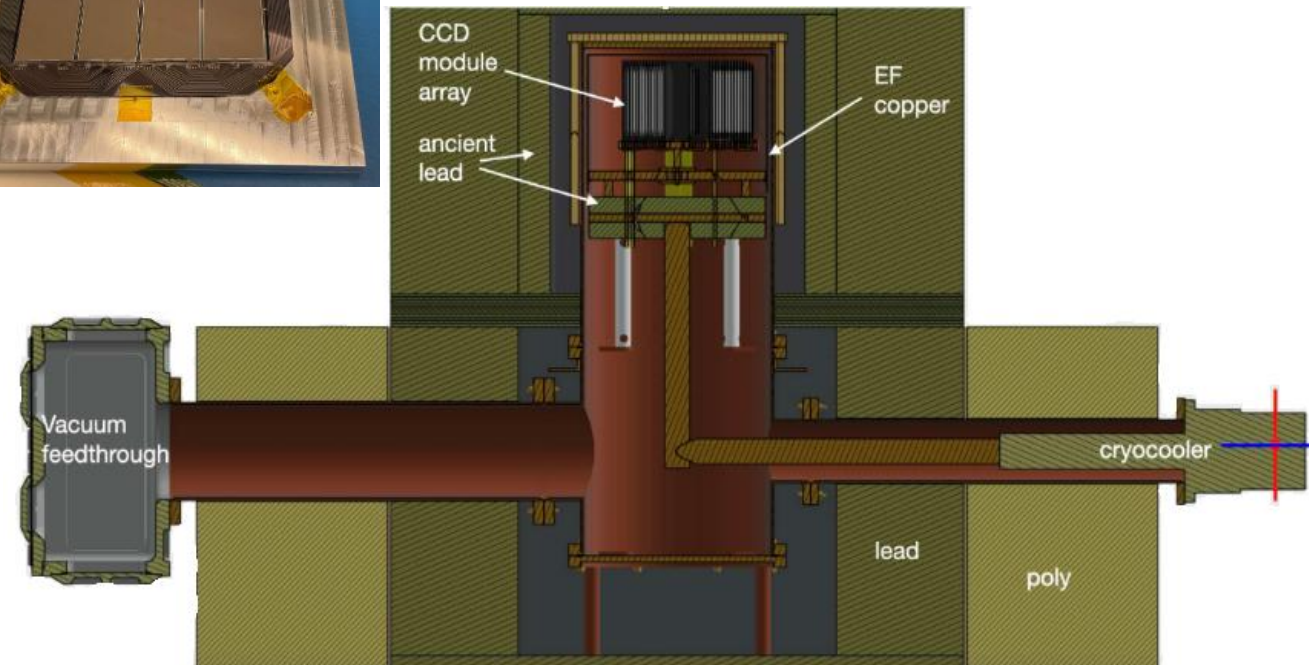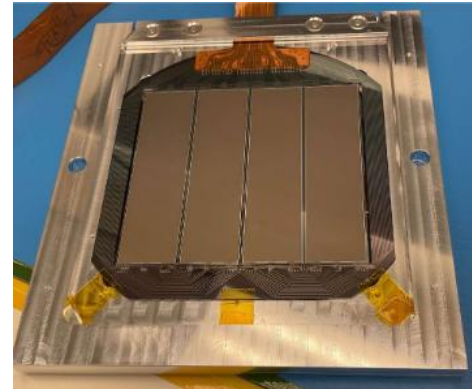
Olivier Deligny, DAMIC-M internal note

Damic-M in Dark Matter research

❖ Direct Dark Matter experiment

❖ Skipper-CCD detectors

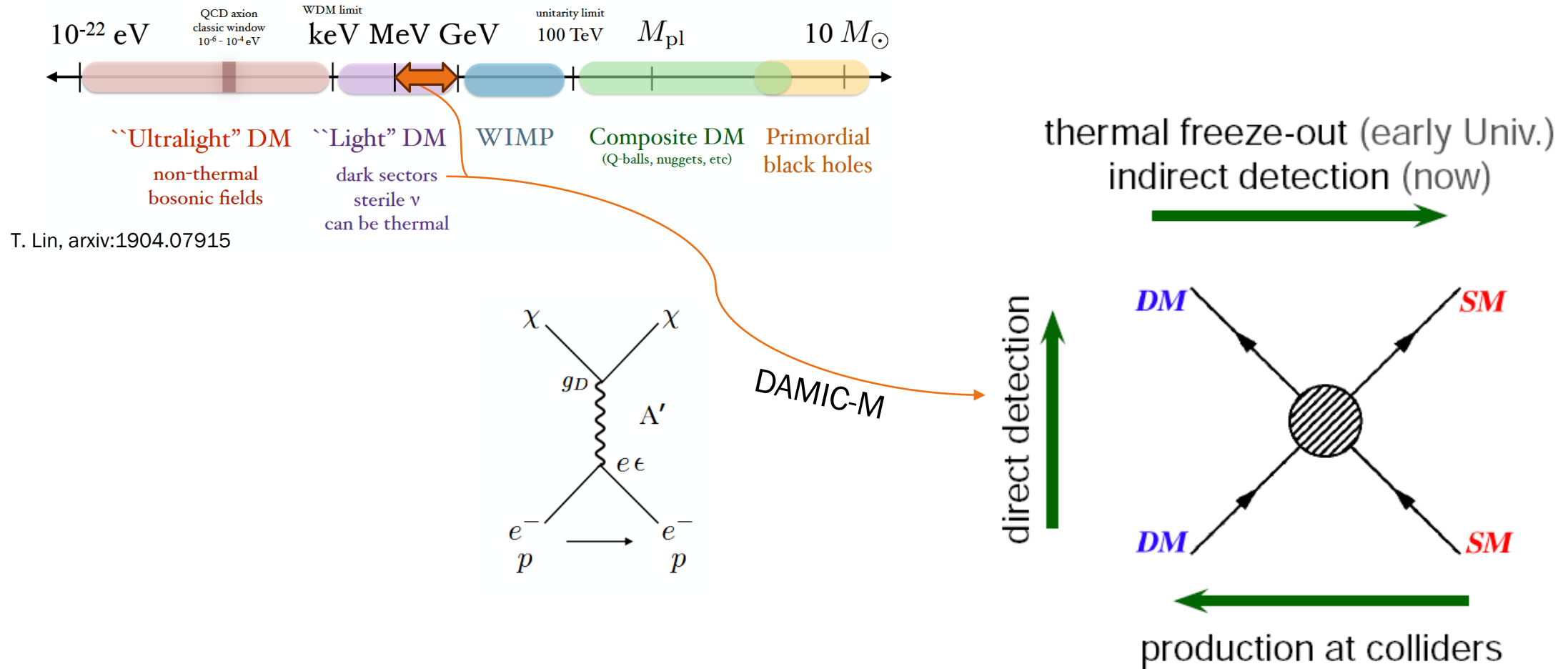❖ Single electron detection capability

    ❖ For low-mass dark matter :

$$E_{Target} < 4 \frac{M_{DM}}{M_{Target}} E_{DM}$$

❖ Sub-electron readout noise

❖ World-leading limits on hidden sector Dark Matter

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WIMP

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T. Lin, arxiv:1904.07915

χ χ

g_D

A'

$e\,\epsilon$

e^- $\longrightarrow$ e^-
p p

DAMIC-M

thermal freeze-out (early Univ.)
indirect detection (now)

direct detection

DM   SM

DM   SM

production at colliders

Max Planck Institute for Nuclear Physics

Skipper-CCD

❖ Multiple non-destructive charge measurments

❖ Readout noise divided by $\sqrt{N_S}$
   ❖ Sub-electron reading noise

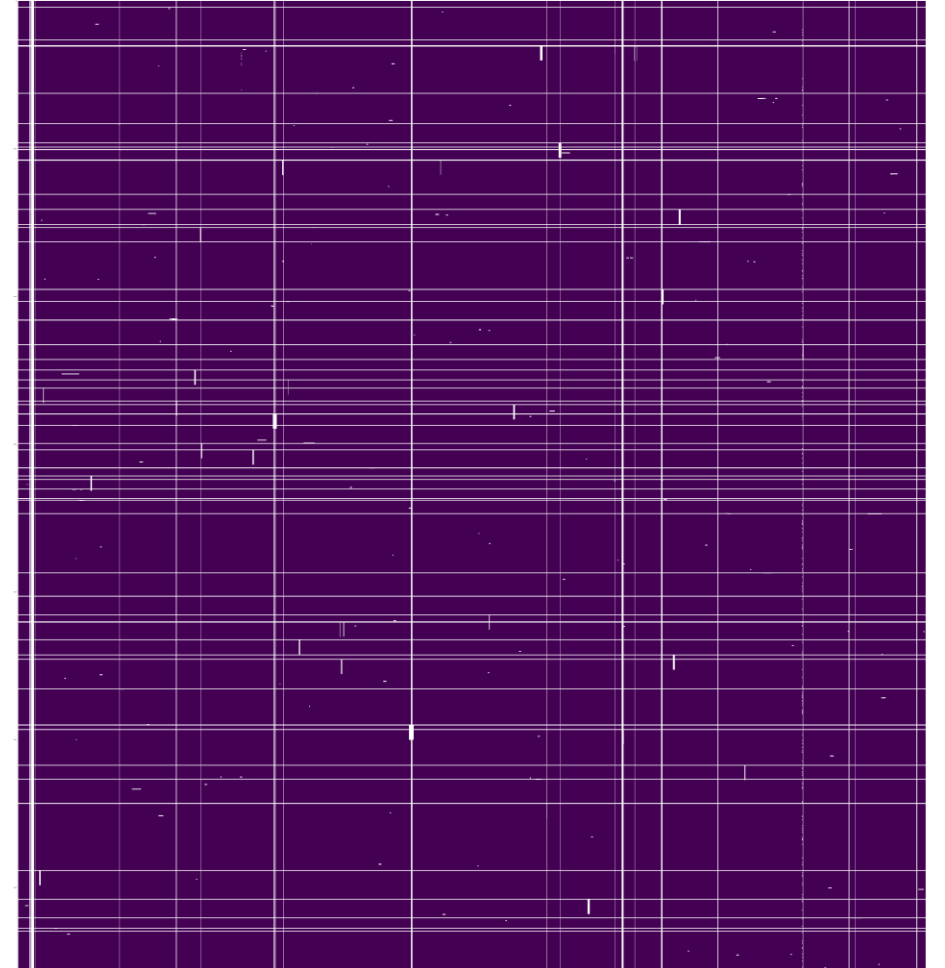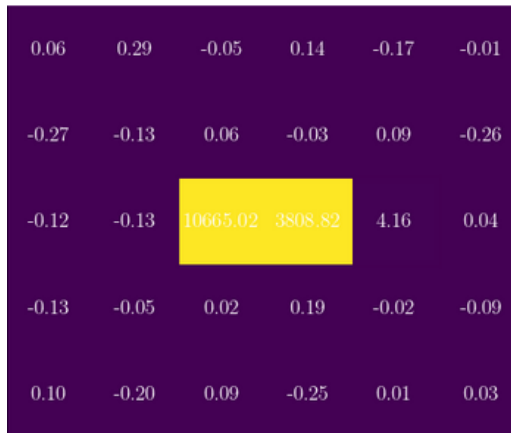❖ Allows us to explore small energy deposits

arxiv:1706.00028
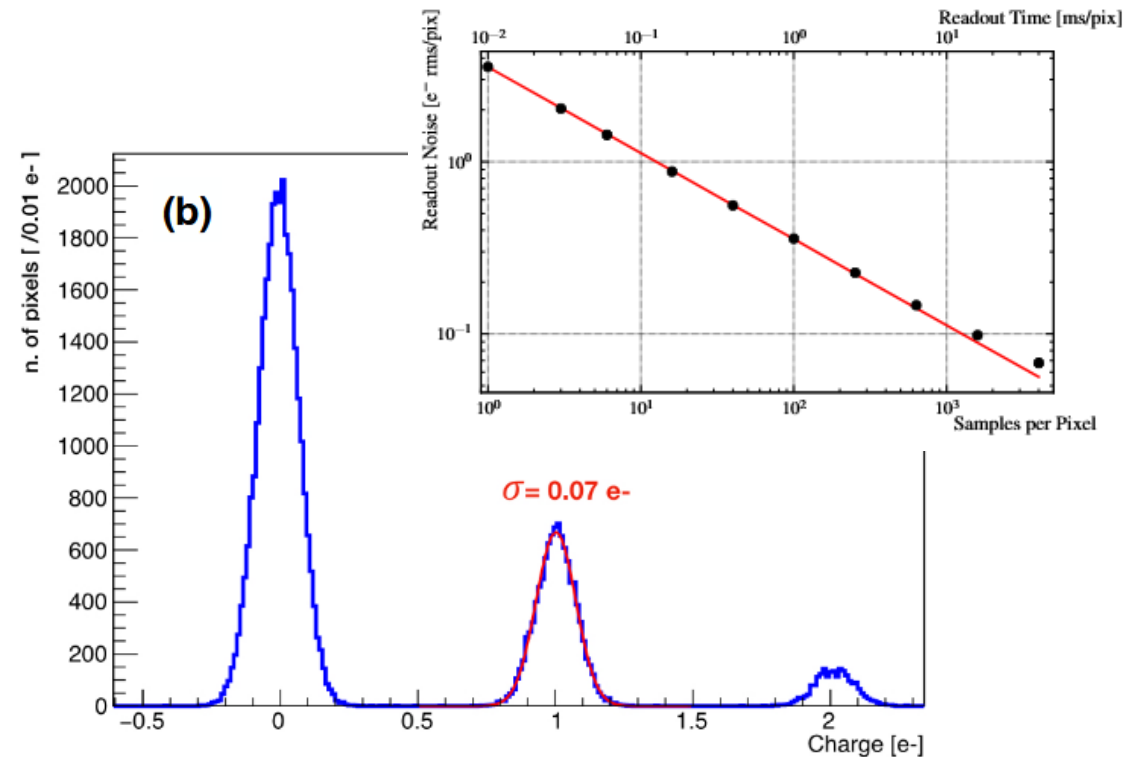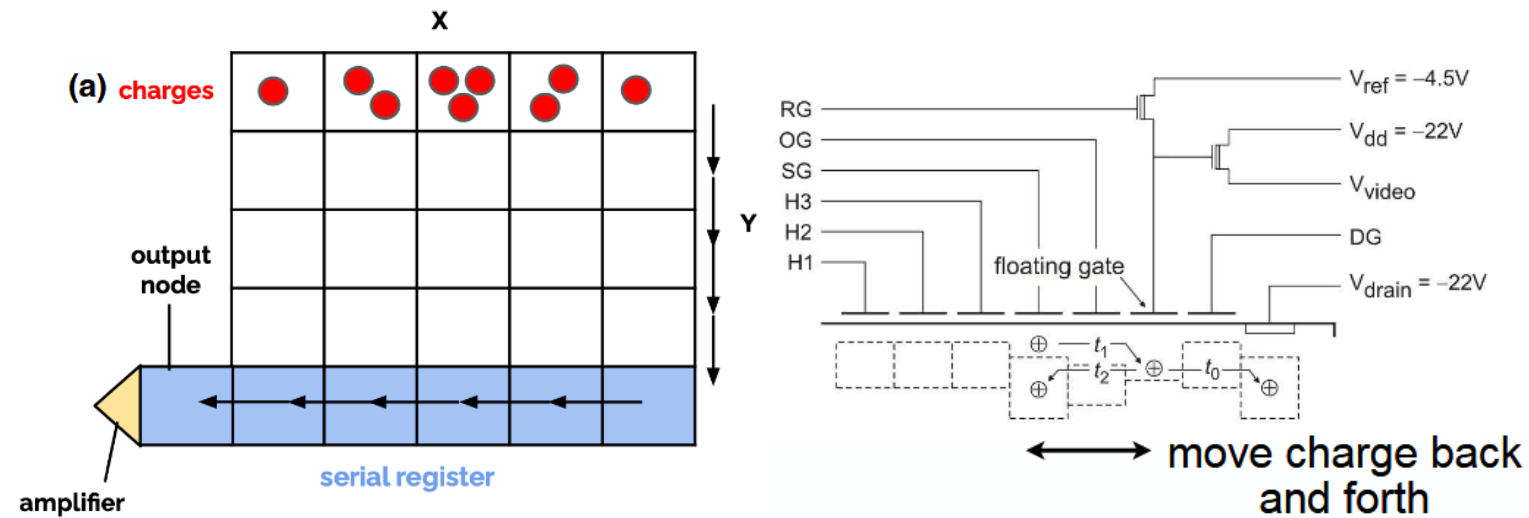
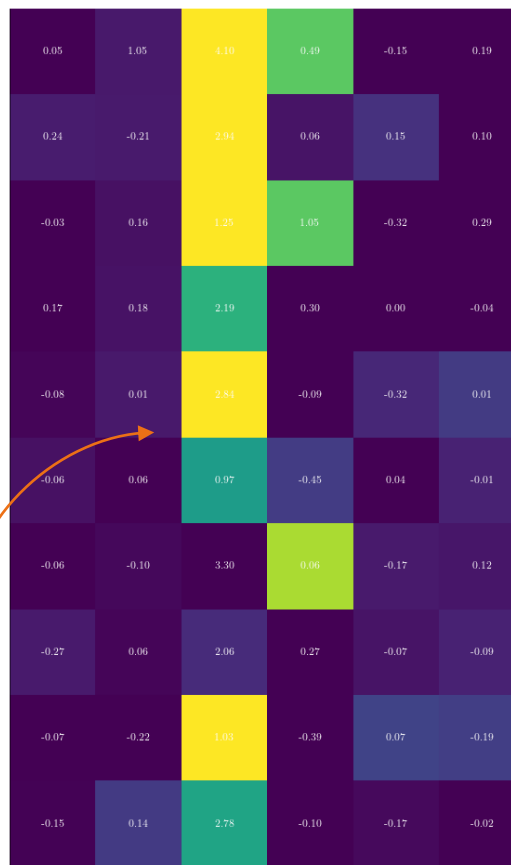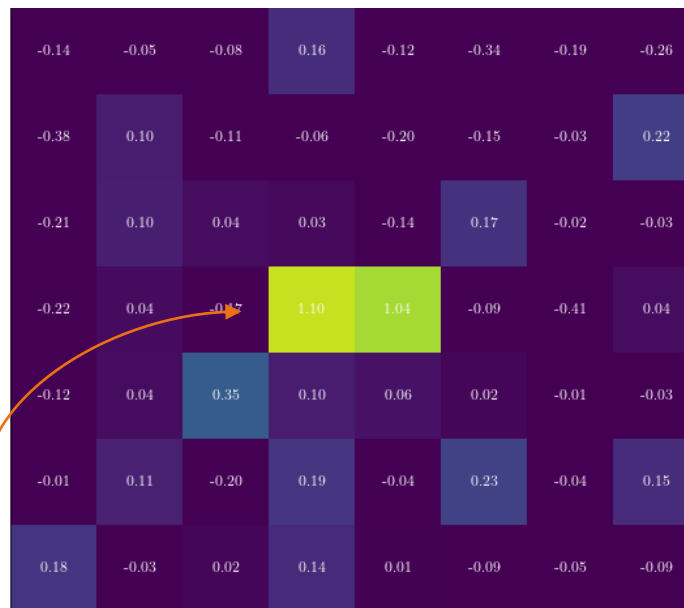# Image masking

❖ Hot region (large 1e- rate)

❖ Defects generating charges continuously

❖ Clusters of high-charge pixels (>5 e-)

❖ Cross-talk between CCDs

❖ 87% of data are kept

Pattern analysis and exclusion limits

	Expected	Observed
HDU 1	6.76	5
HDU 2	6.57	5
HDU 3	6.27	13
HDU 4	6.04	4

❖ Searching for {11} events

❖ 4 HDU of 6560*6144 pixels

❖ 3.3g.day / HDU

❖ Poissonian Dark Current give ~6 expected {11} patern events

❖ Unexplained excess in HDU 3

❖ Consistency between DC estimatiosn an observations
  ❖ No evidence of Dark Matter