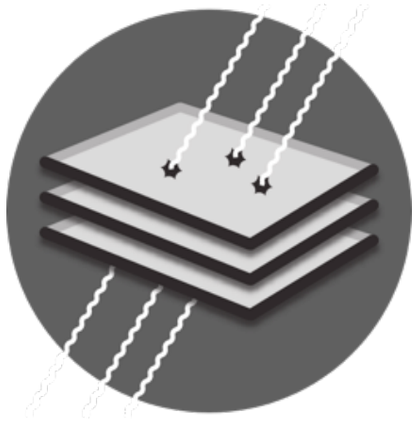
53rd Rencontres de Moriond March 17-24, 2018 • La Thuile, Italy
Cosmology 2018

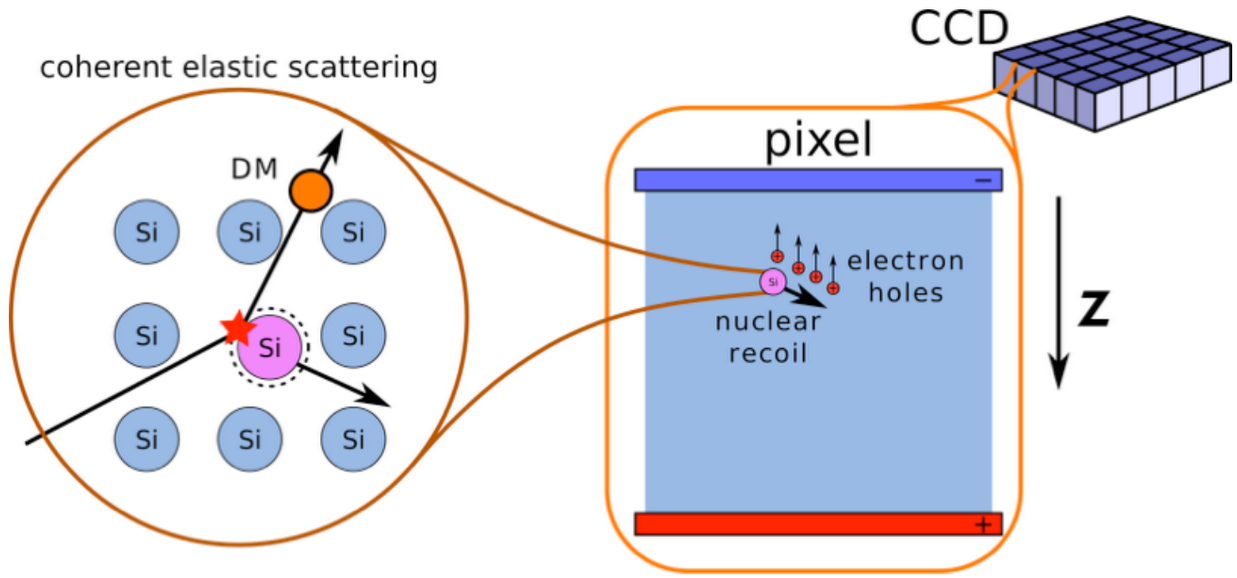


The DAMIC (Dark Matter In CCD) experiment at SNOLAB

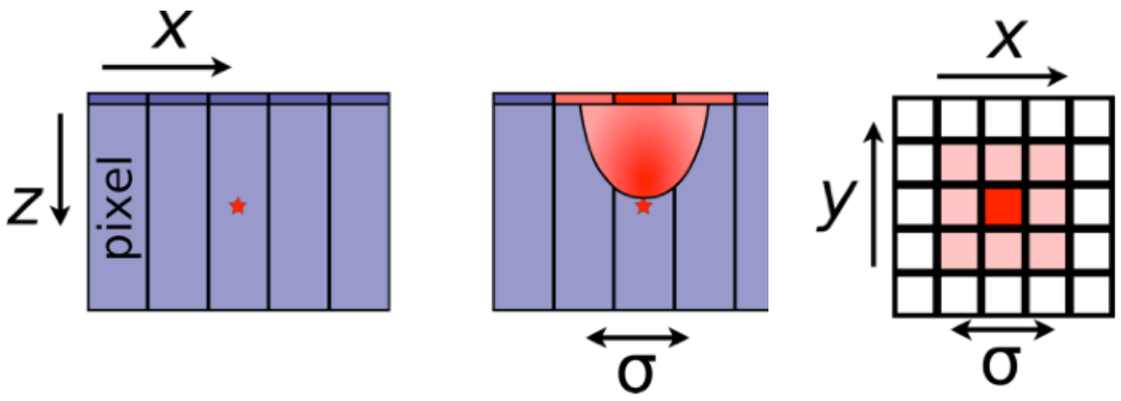
Mariangela Settimo
Subatech, CNRS-IN2P3, Nantes (France)

DAMIC : DArk Matter In CCD

Detection of point-like energy deposit from nuclear recoils induced by WIMPS interactions in the bulk of CCDs.

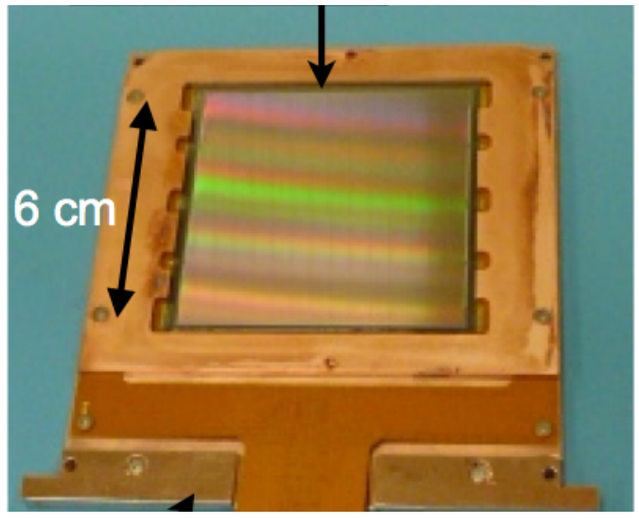


3.7 eV to create e-h pair



3D reconstruction (x, y, z) and unique spatial resolution

Charge-Coupled Device (CCD)



16 Mpix, 15 μm x15 μm, 675 μm thick, 5.9 g mass

Sensitivity to DM masses

< 10 GeV (nuclear recoil)

~ eV (electron recoil)

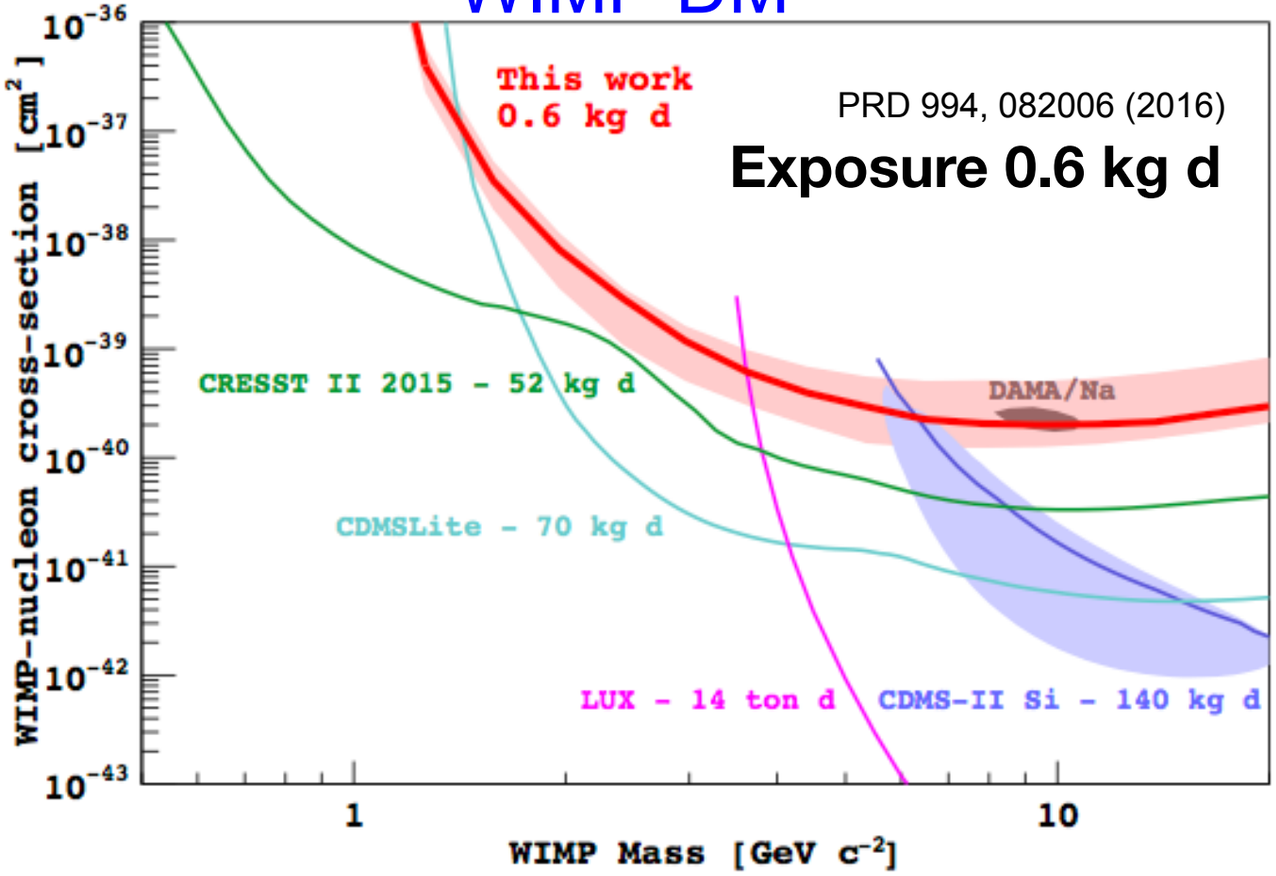
R&D program (2013-2015)

40g detector commissioned in 2017

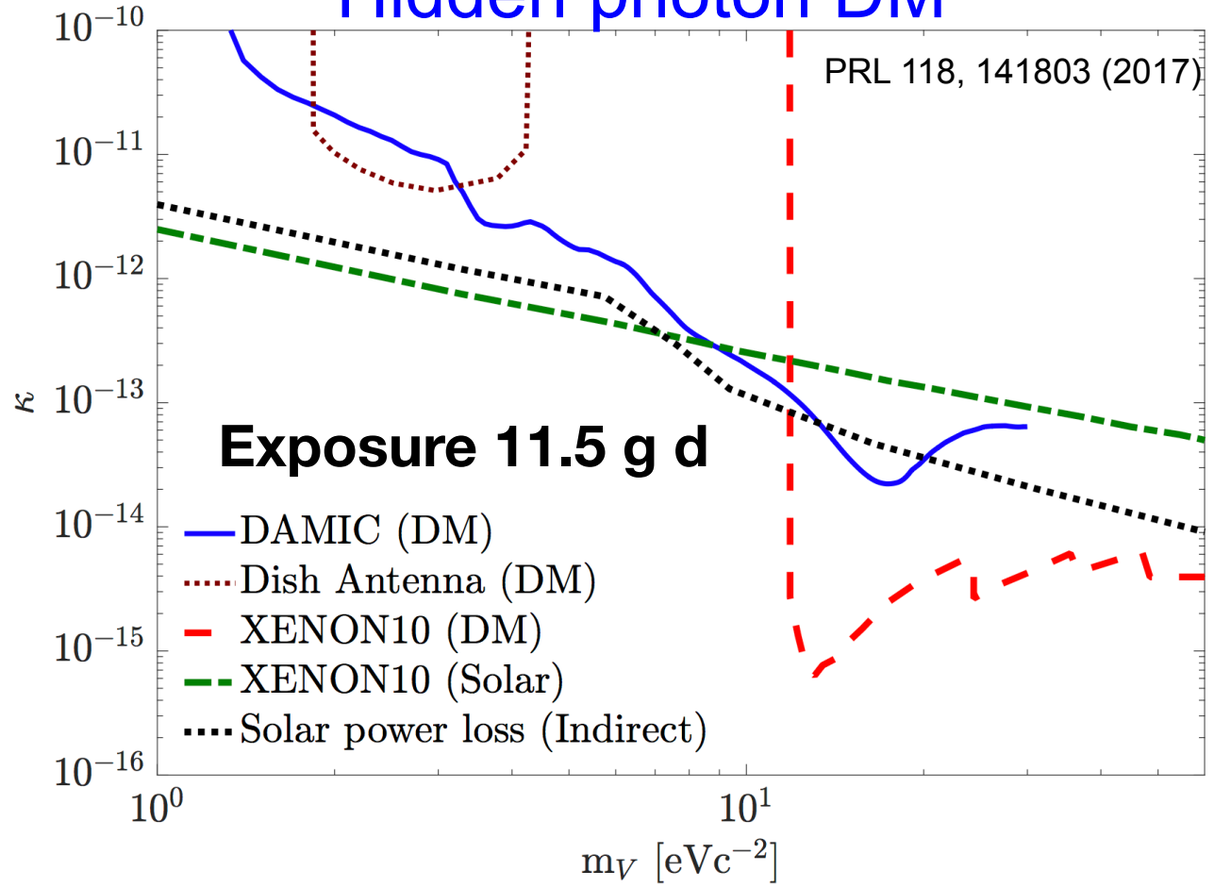
Some results with the R&D detector

Result with 10 g detector mass (data: 2015-2016)

WIMP DM



Hidden photon DM

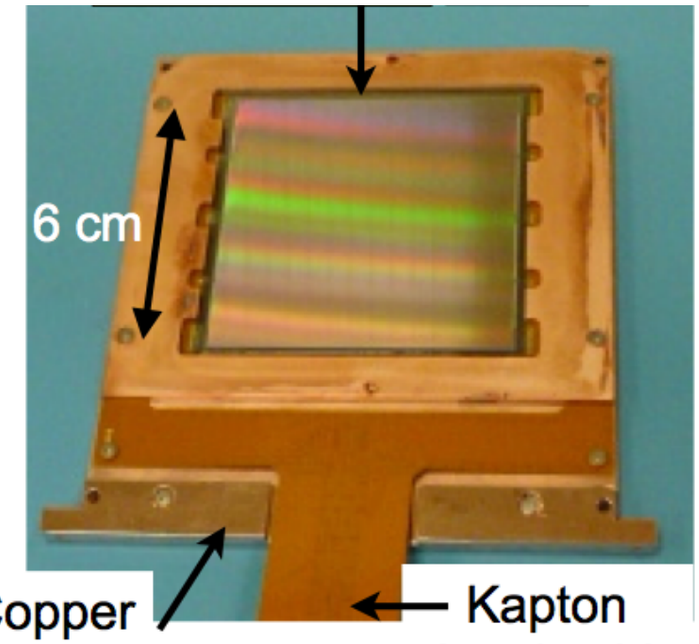


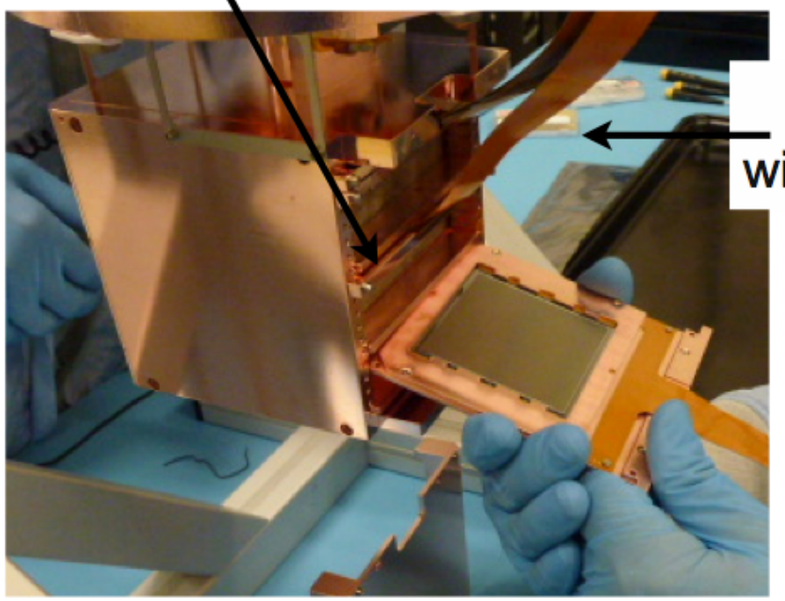
… and also:

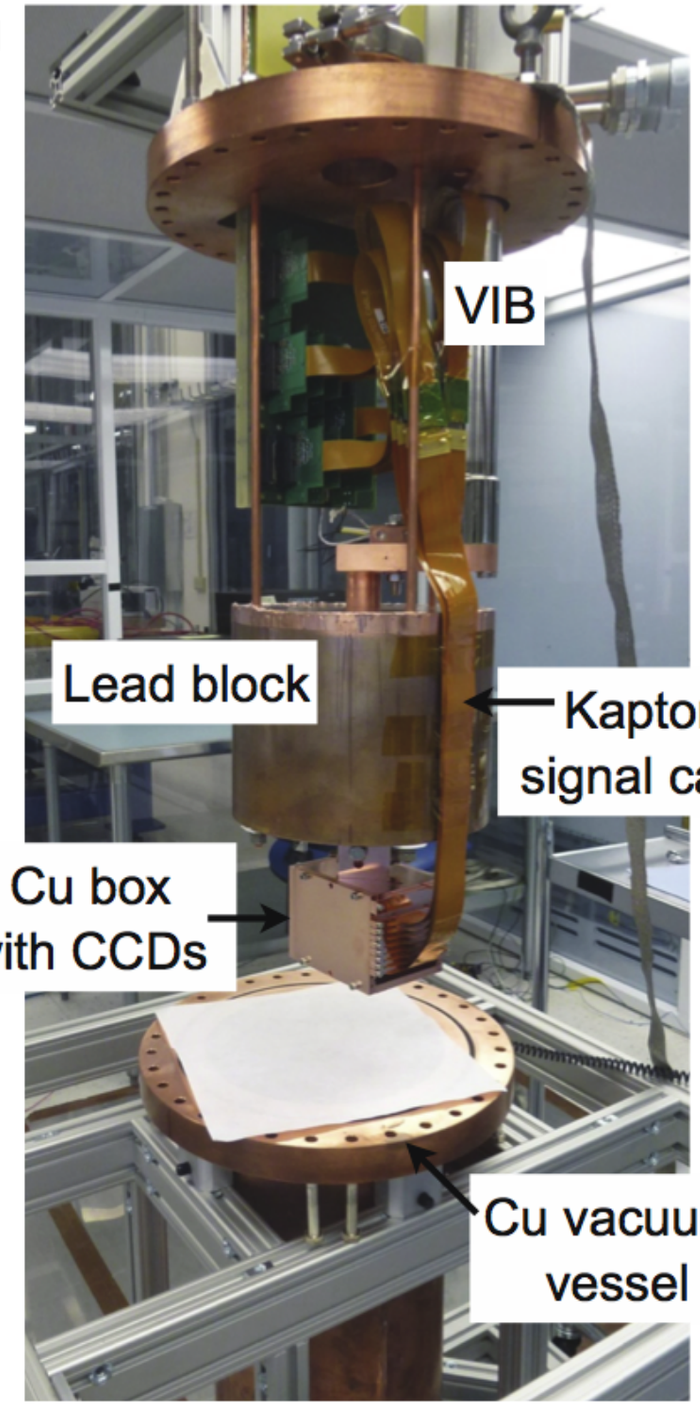
- **radioactive bkg in the silicon bulk**, 2015 *JINST* **10** P08014
- **nuclear recoil calibration**, PRD 94, 082007 (2016)
- **electron recoil calibration,** PRD 96, 042002 (2017)

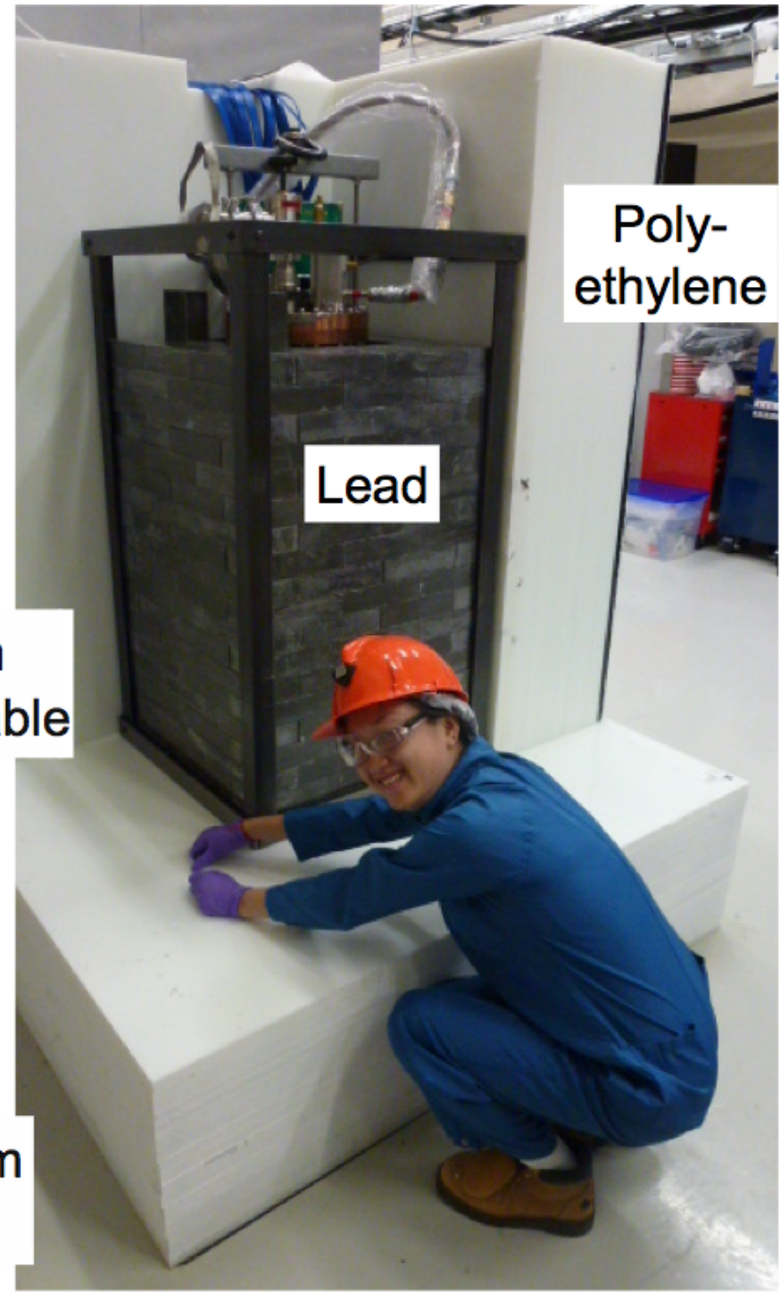
DAMIC @ SNOLAB (2000 m underground lab)

675 μm thick, 16 Mpix CCD, 6 g



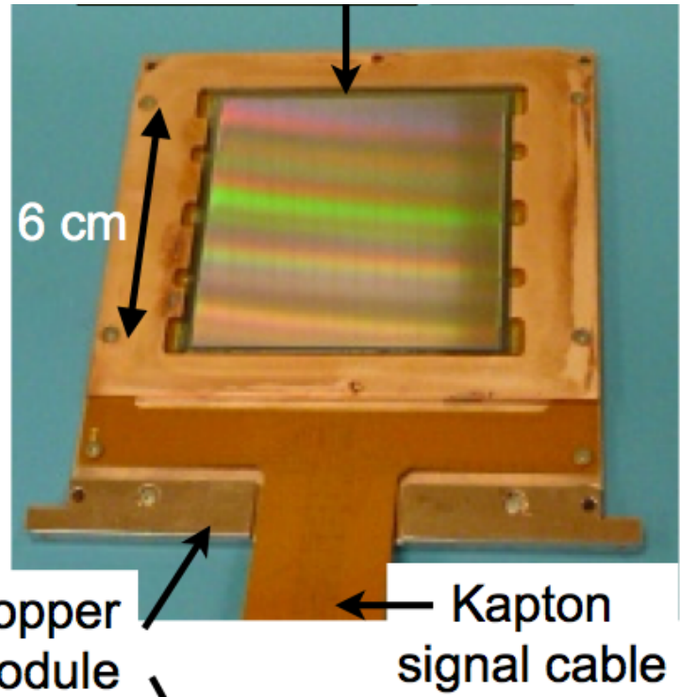


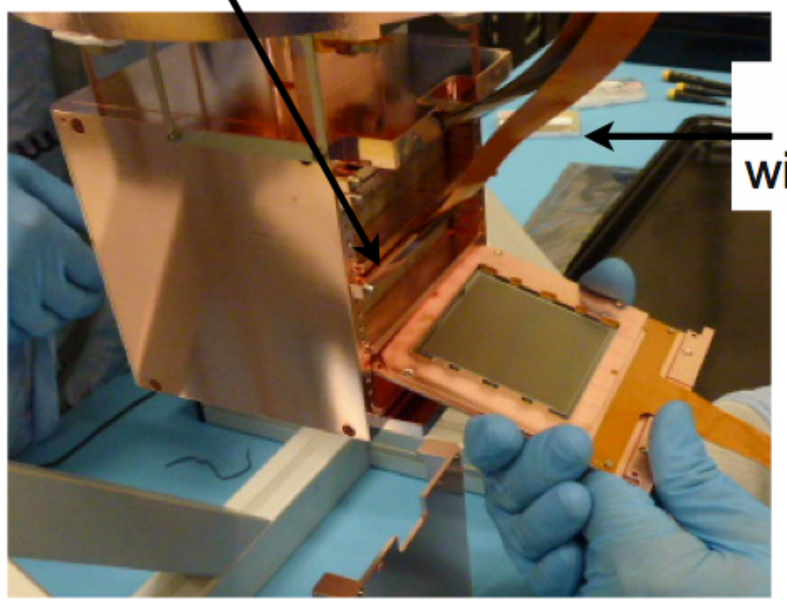


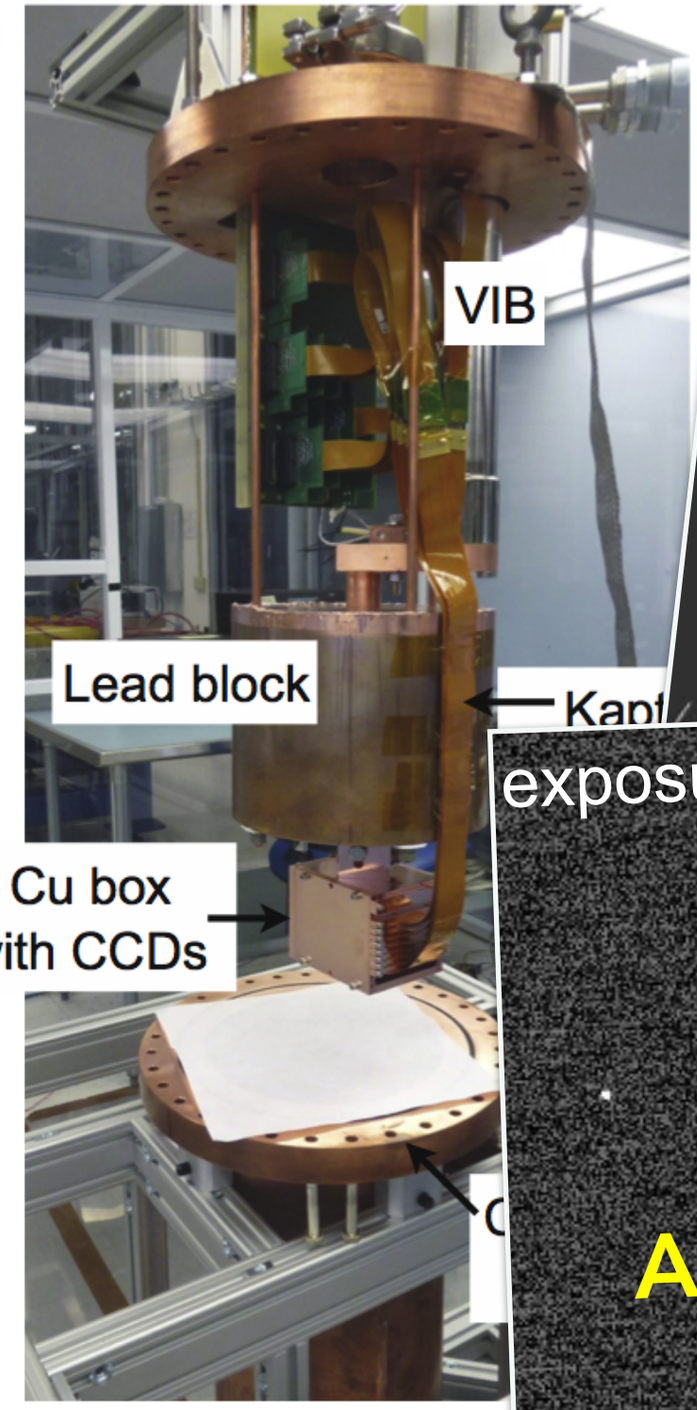


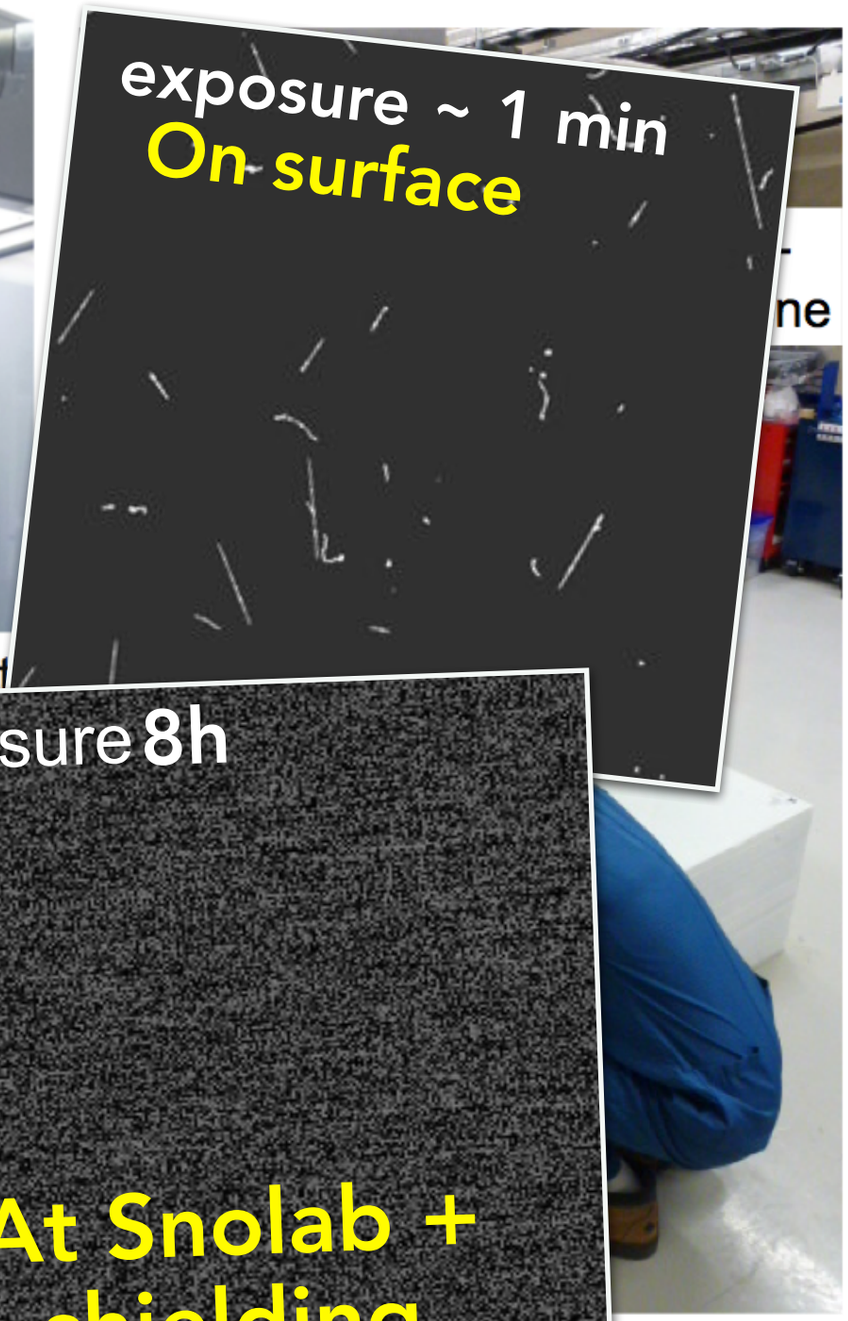
DAMIC @ SNOLAB (2000 m underground lab)

675 μm thick, 16 Mpix CCD, 6 g



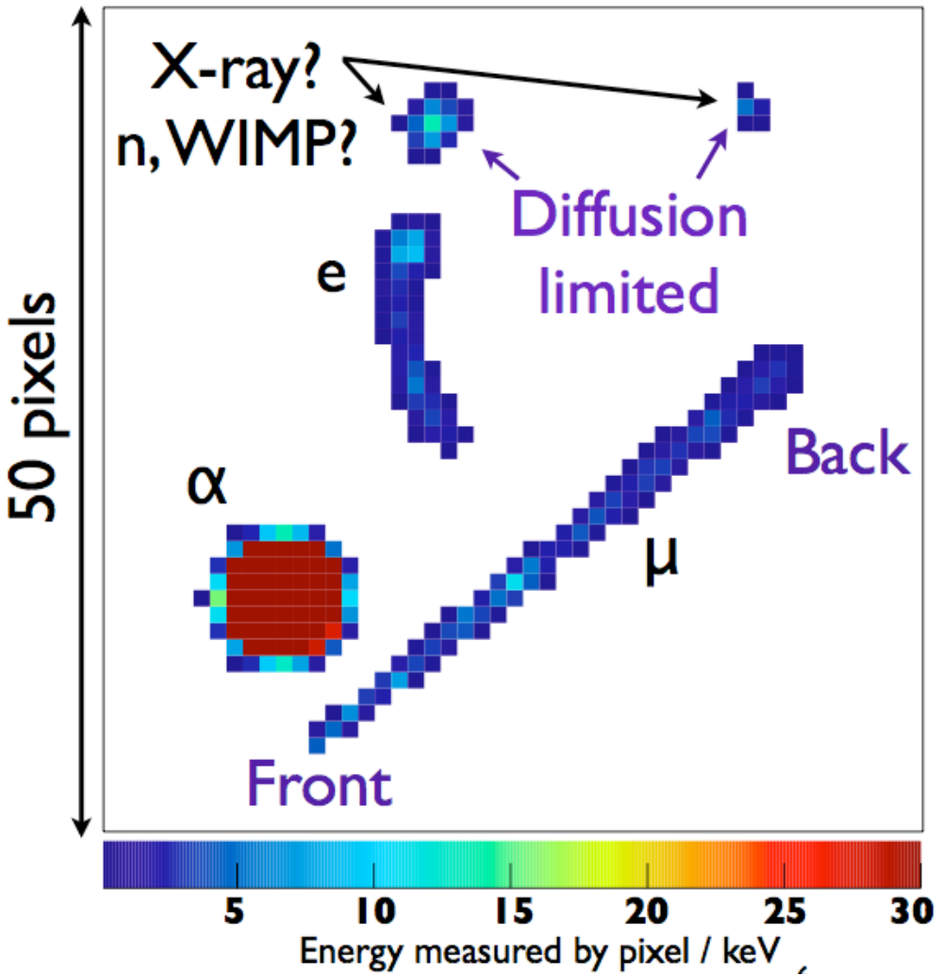






Unique spatial resolution

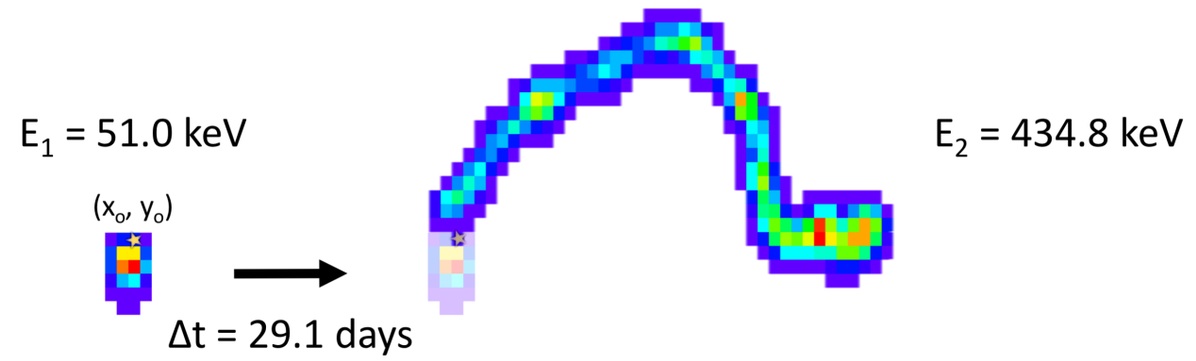
Particle identification and bulk / surface background rejection



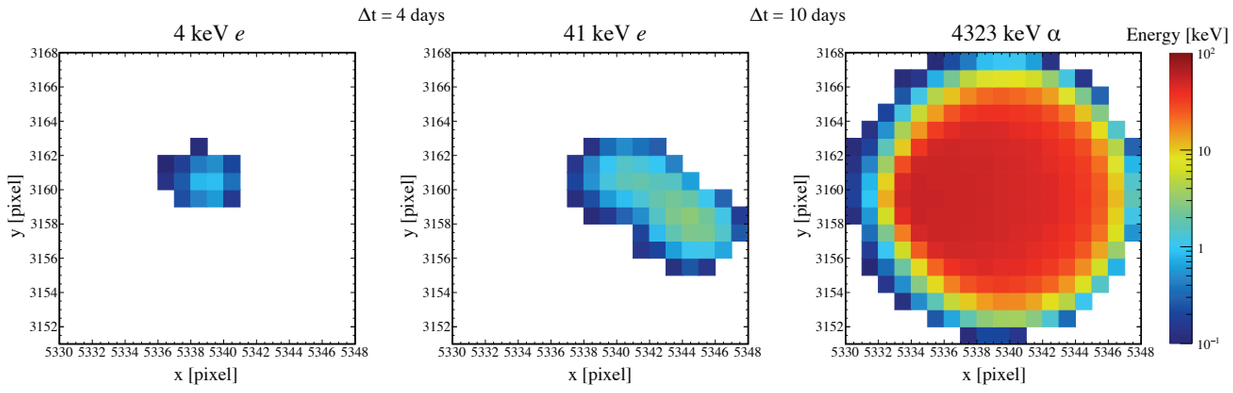
σ ≈ z : for fiducial volume definition and surface event rejection

Spatial coincidence of beta decays (^{32}Si)

^{32}Si ($T_{1/2}$= 150 y, β) → ^{32}P ($T_{1/2}$= 14 days, β)



Decay chain of a single ^{210}Pb

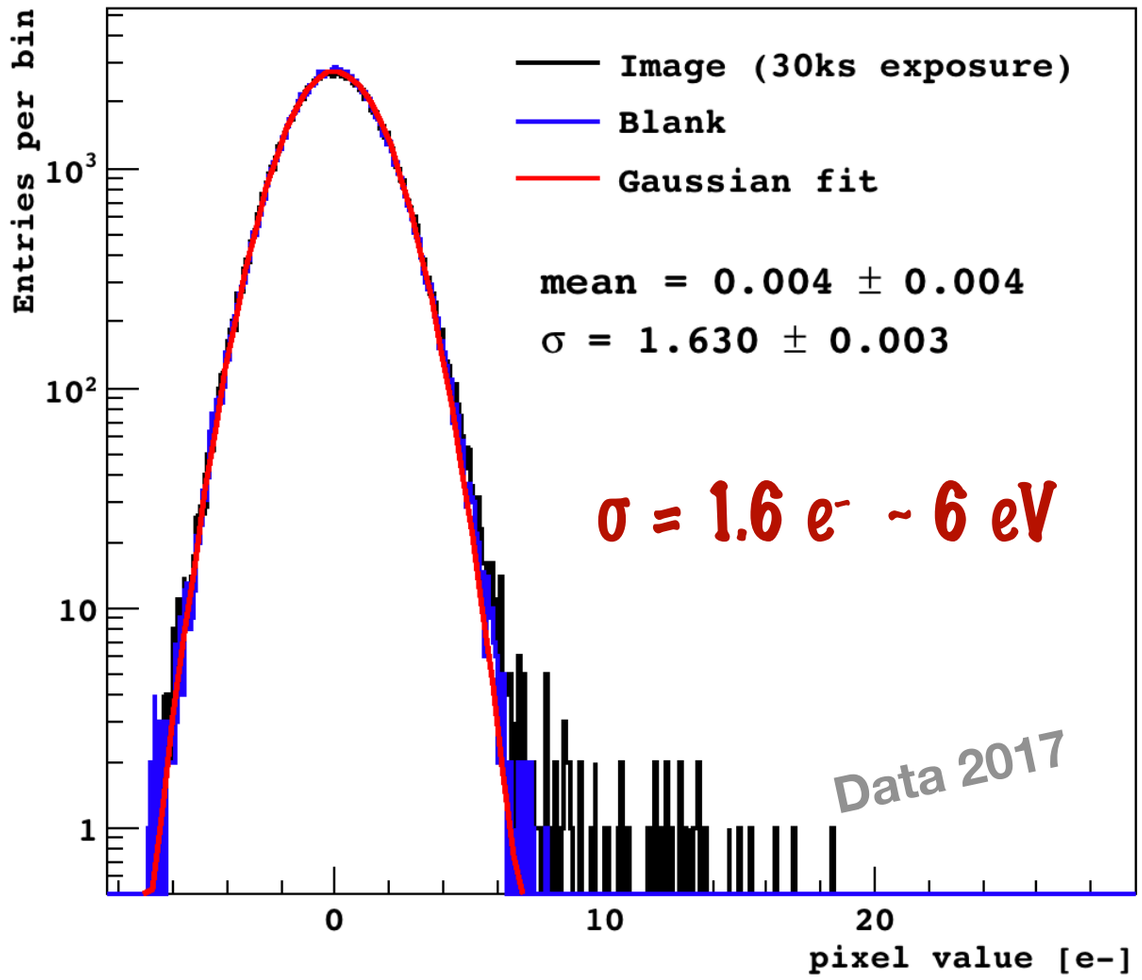


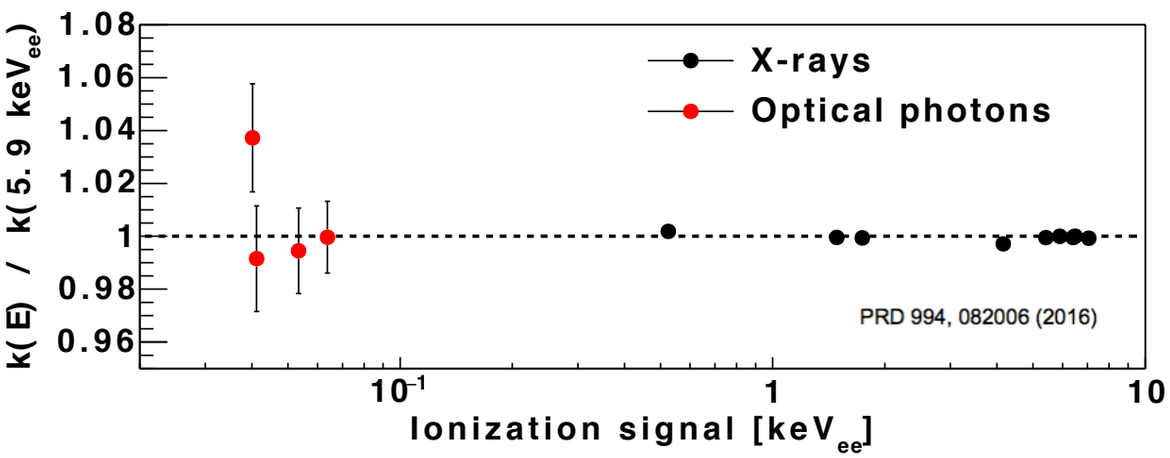
^{210}Pb ($T_{1/2}$= 22.3 y, β) → ^{210}Bi ($T_{1/2}$=5.0 days, β) → ^{210}Po ($T_{1/2}$= 138 days, α)

2015 JINST 10 P08014, PRD 994, 0820006 (2016)

Low background noise and energy threshold

Comparing **images** (8h exposure) and "Blanks" (exposure = readout time)





1. Negligible dark current:
< 0.001 e/pix/day

(the lowest ever measured in a Si detector)

2. read out noise: 1.6 e⁻ @140K

- **Energy threshold ~ 40 eVee**
  (~ 6σ above background, 3.77 eV for e-h pair in Si)

Linearity of the CCD response within ± 5% down to 40 eV_{ee}

Current detector configuration

- **7 CCDs** in stable data taking since 2017
  (1 CCD sandwiched in ancient lead)

- **40 g detector mass**

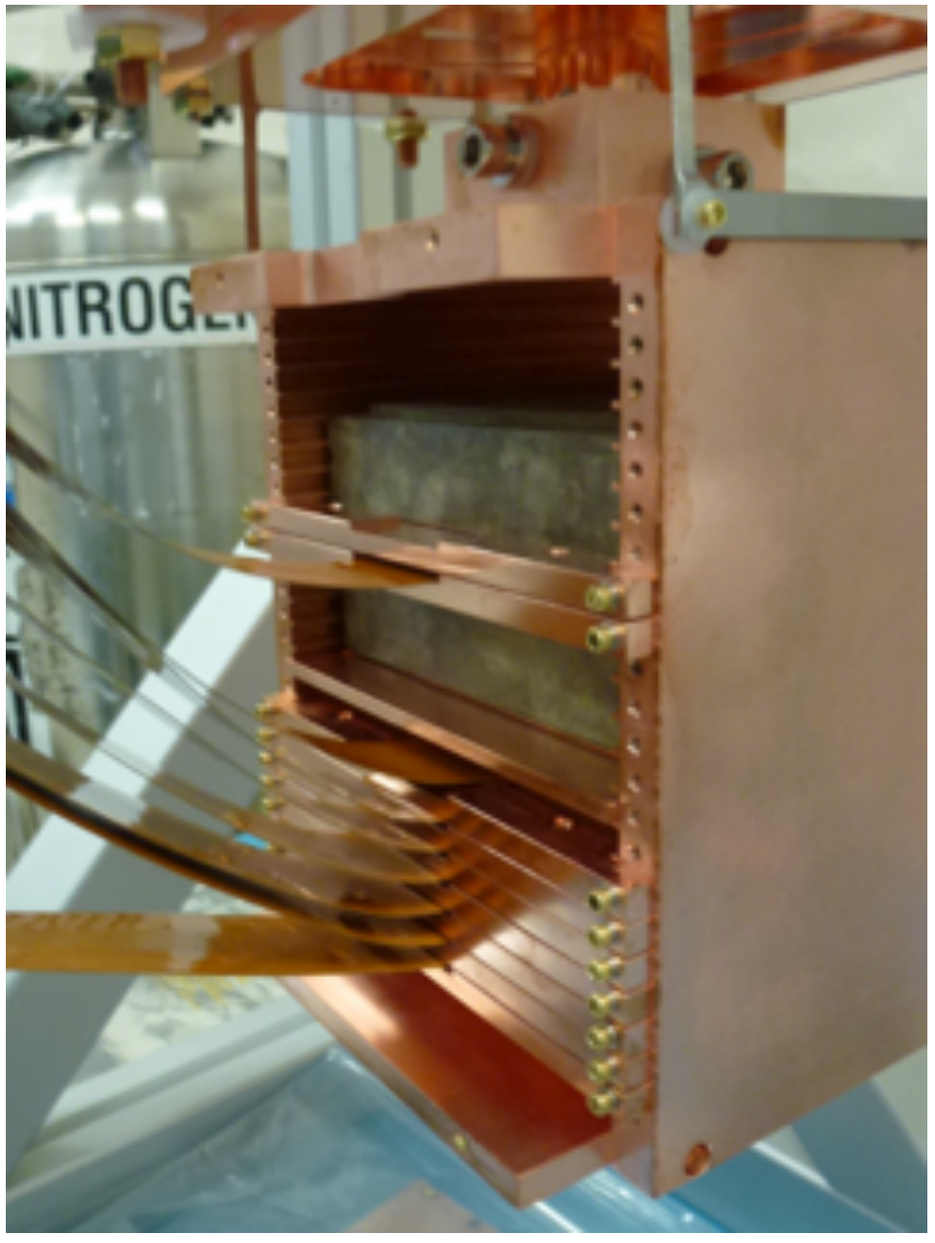
- **Operating temperature of 140K**

- **Exposure for image : 8h and 24h**

(each image acquisition is followed by a “blank” whose exposure is the readout time)

- **7.6 kg day of data for background characterization**

- So far, **4.6 kg day of data collected for DM search** (in 1x100 hardware binning)

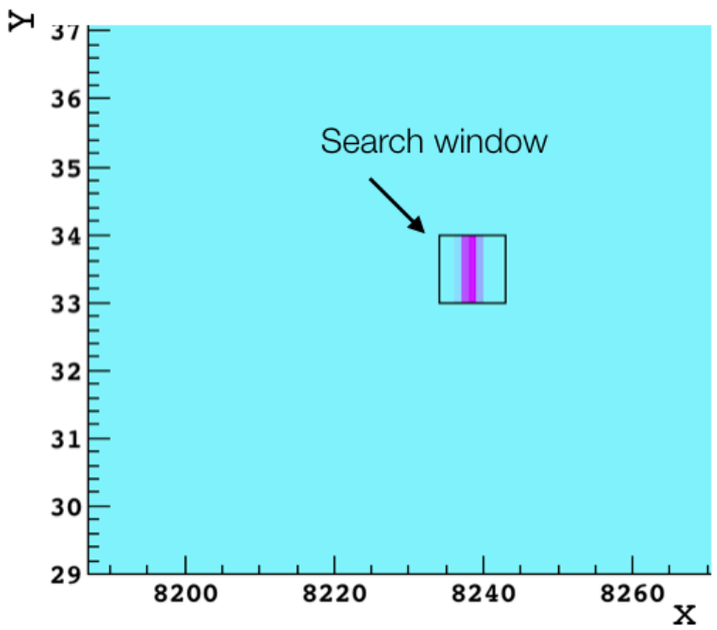


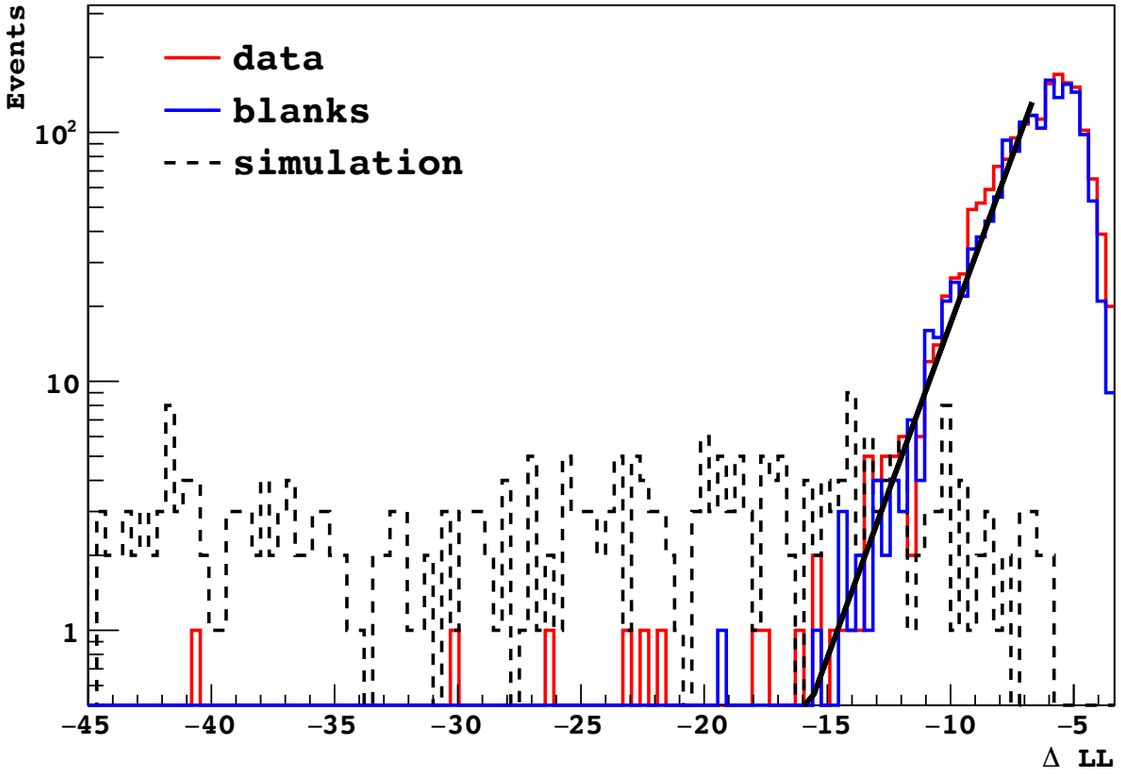
Event clusters search strategy

- Pedestal and correlated noise subtraction
  (hot pixels among several images masked)
- LL fit of the signal in a moving window
  across the image

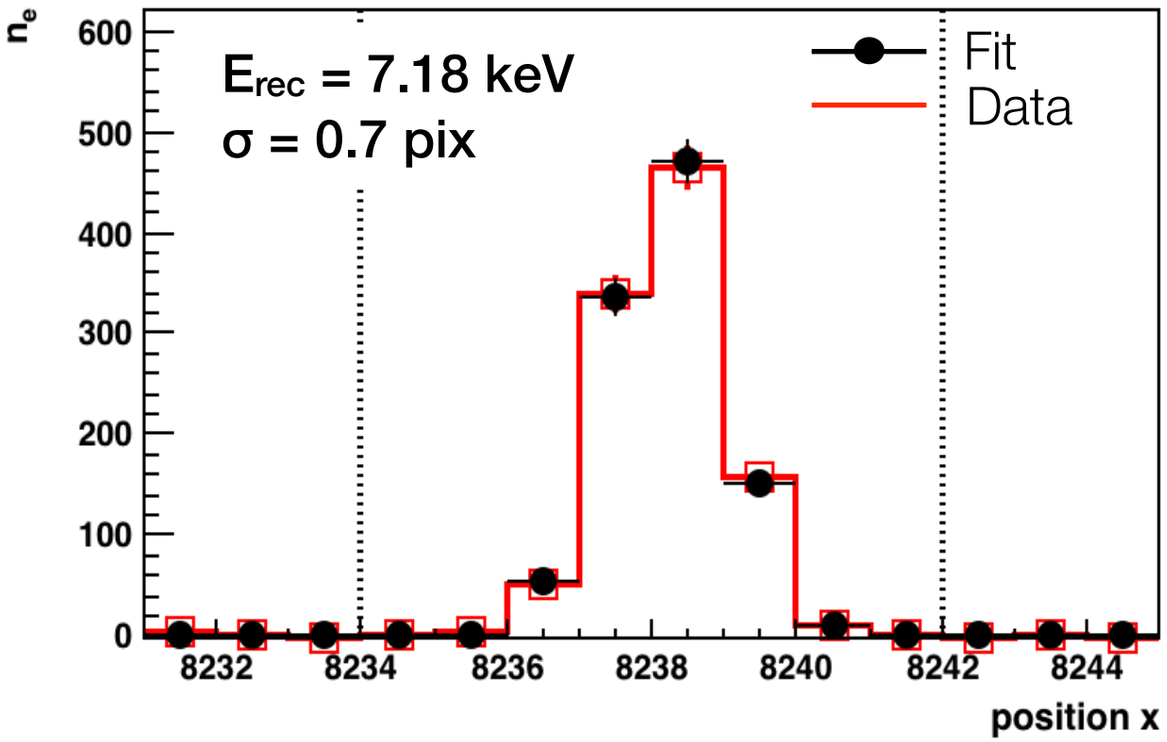
$$\Delta LL = \mathscr{L}_n - \mathscr{L}_s$$

flat noise ↑ ↑ Gaus signal + flat noise



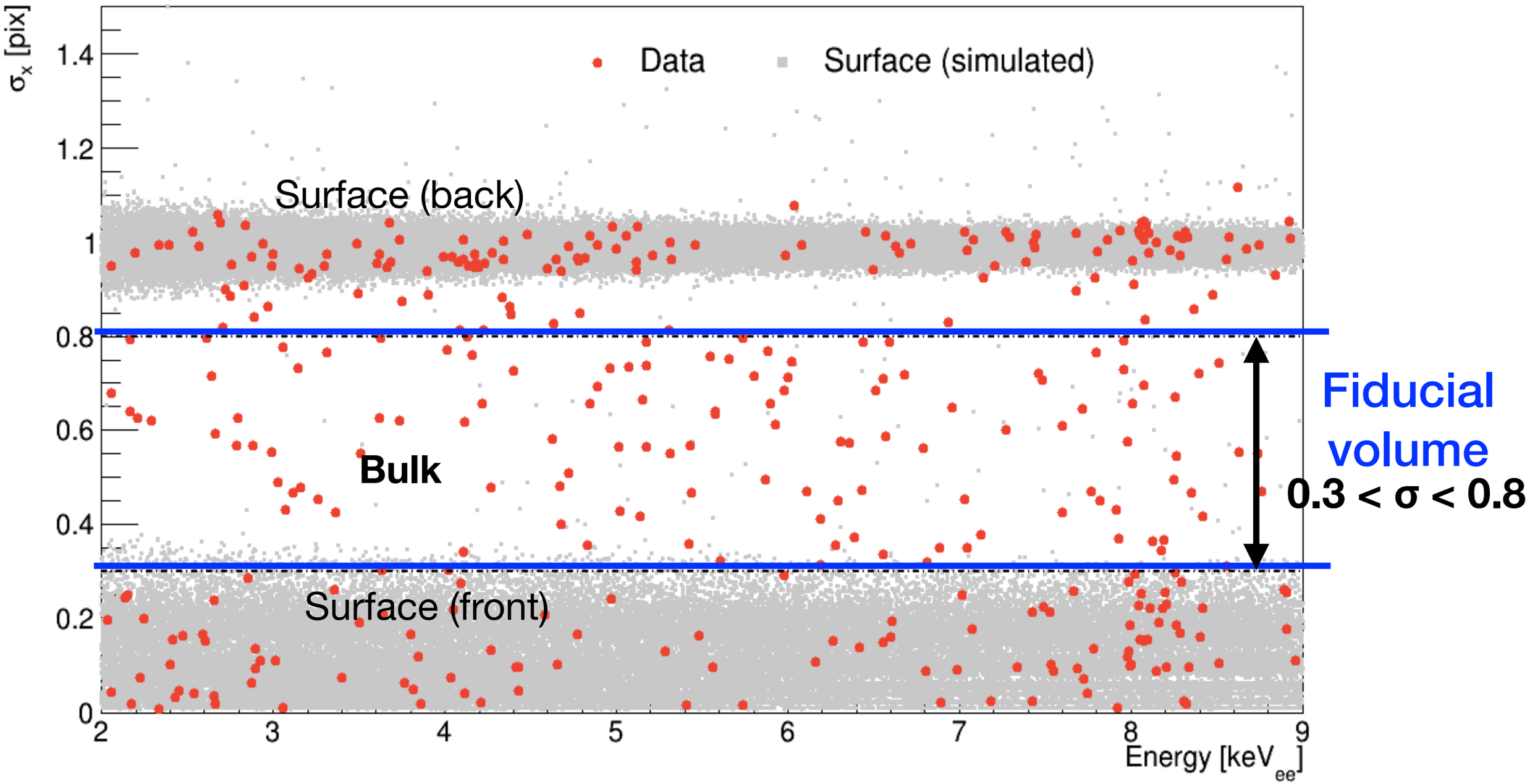


Example of one event

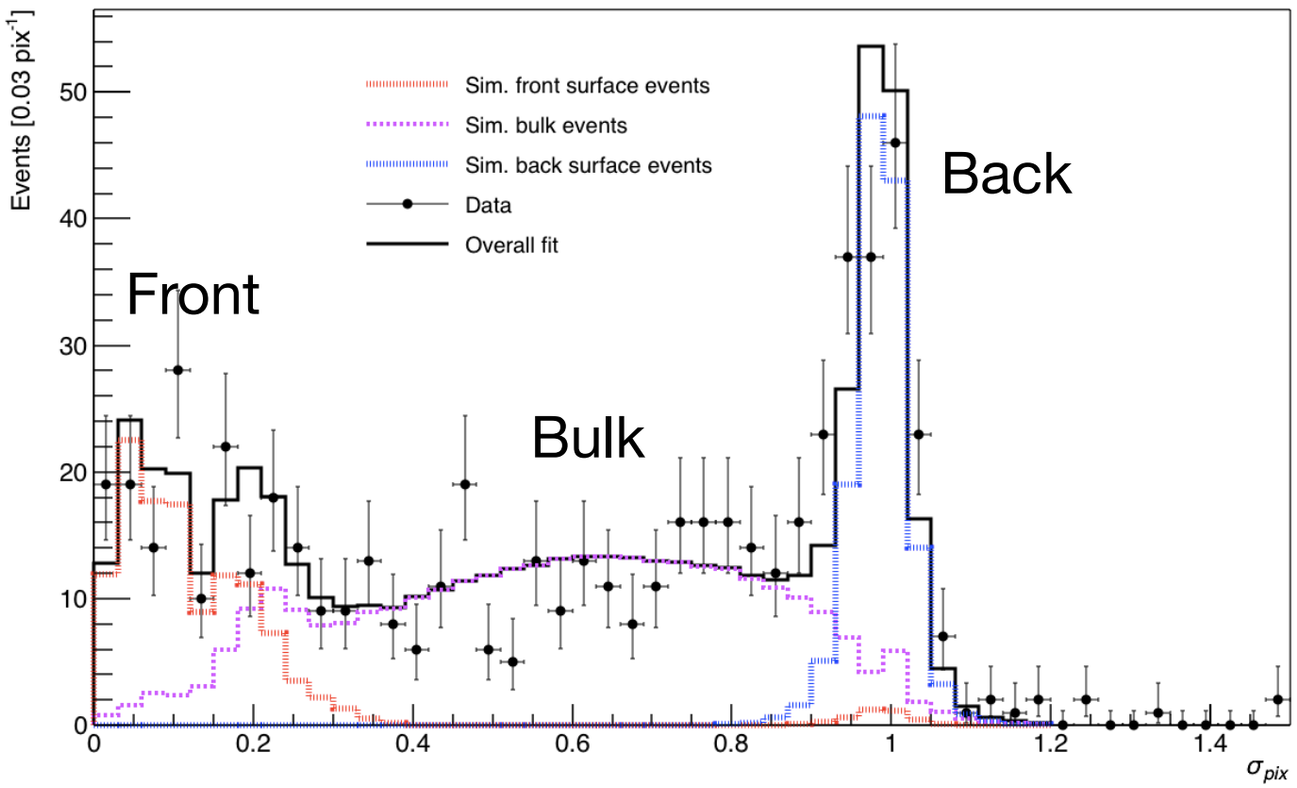


DLL cut : < 0.001 bkg events from exponential fit of the “blanks” distrib

Surface background rejection

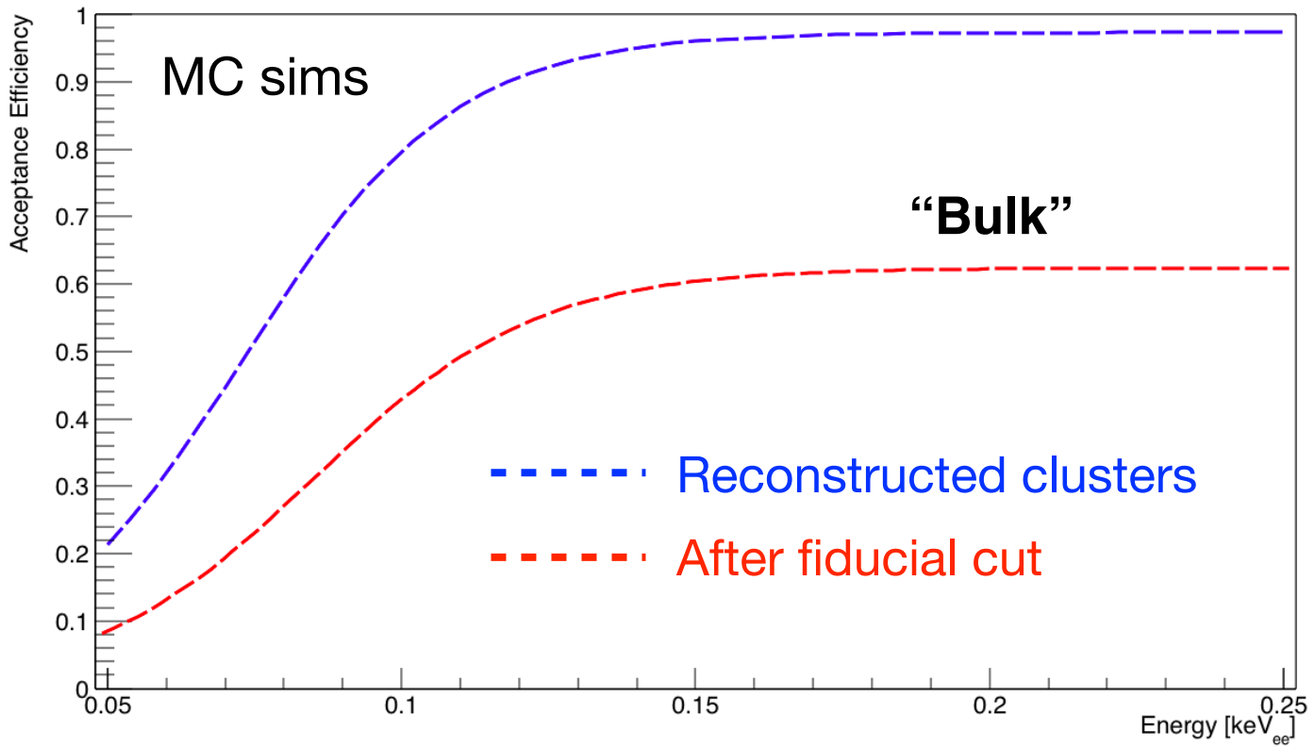


Background model and acceptance



Background on front/back surfaces of the CCD

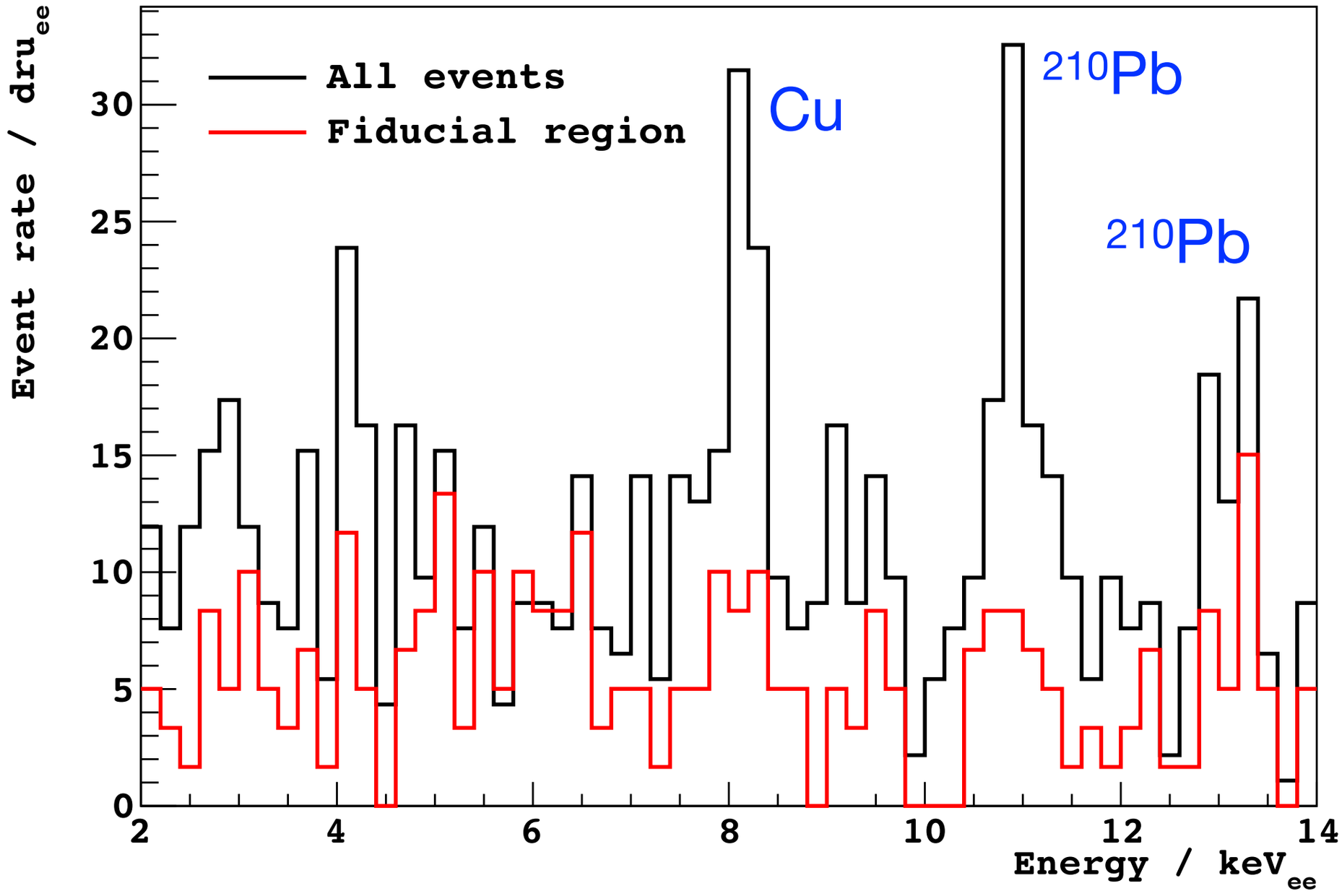
Bkg model compared to data
(50/25/25 of bulk/front/back)



Acceptance for bulk events
(from MC simulations)

Energy threshold : 50 eV$_{ee}$

Energy spectrum above 2 keV



≃ 5 dru in fiducial region, consistent between CCDs

a factor of ≃ 3-4 lower than our previous background level

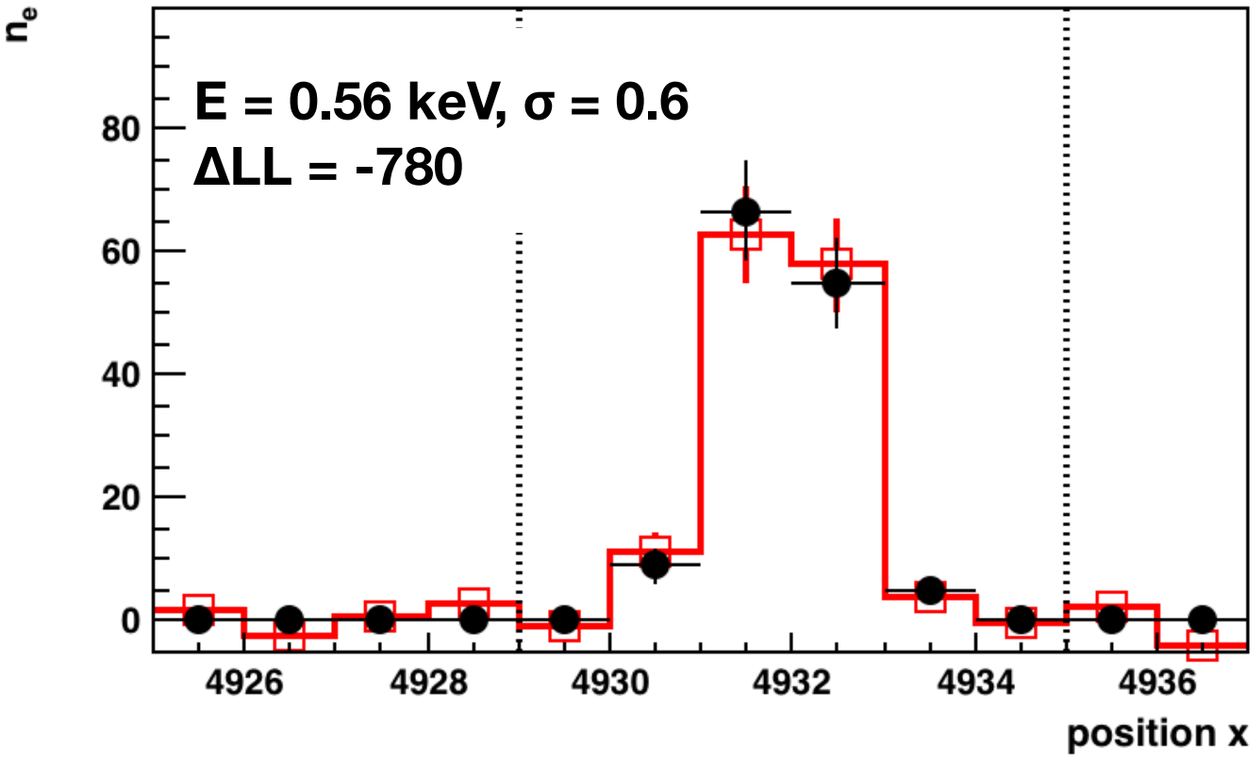
≃ 2 dru for lead sandwiched CCD

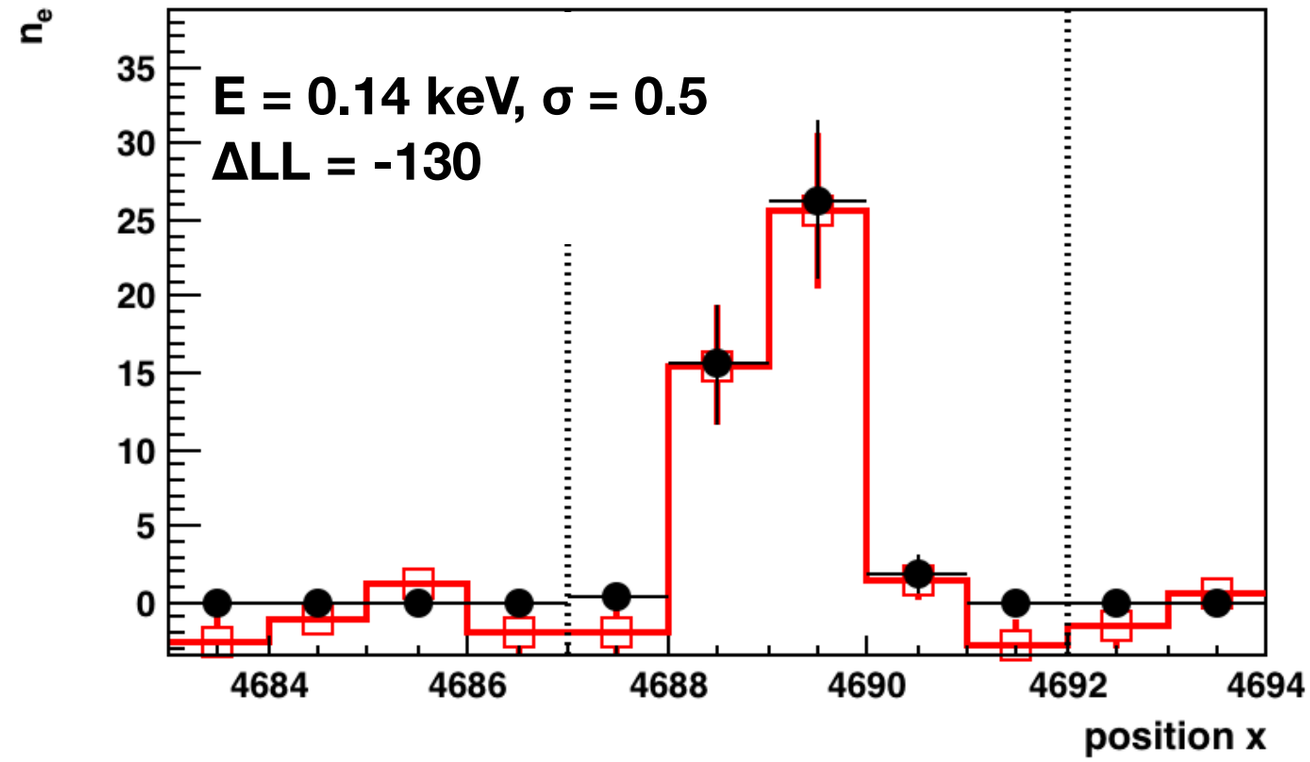
Differential rate unit (dru) = 1 event /keV/kg/day

Low energy data (0.05 - 2 keV)

Analysis of the low energy data in progress
(most sensitivity to low mass WIMPS)

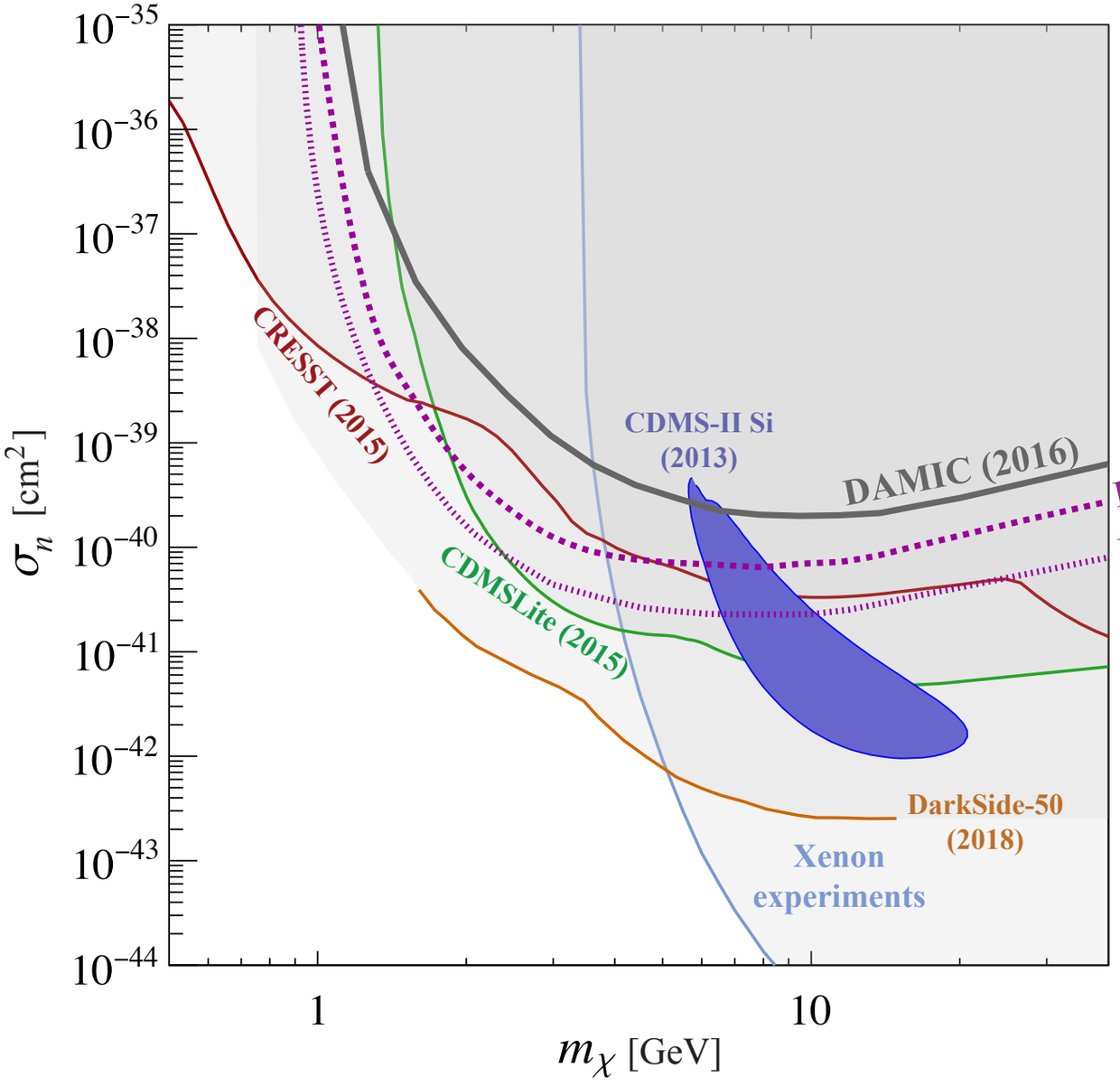
Two example events (data + fit)





- NOTE: CDMS II silicon potential signal obtained with a 7 keV_{nr} threshold (≈ 2 keV_{ee})

Expected sensitivity



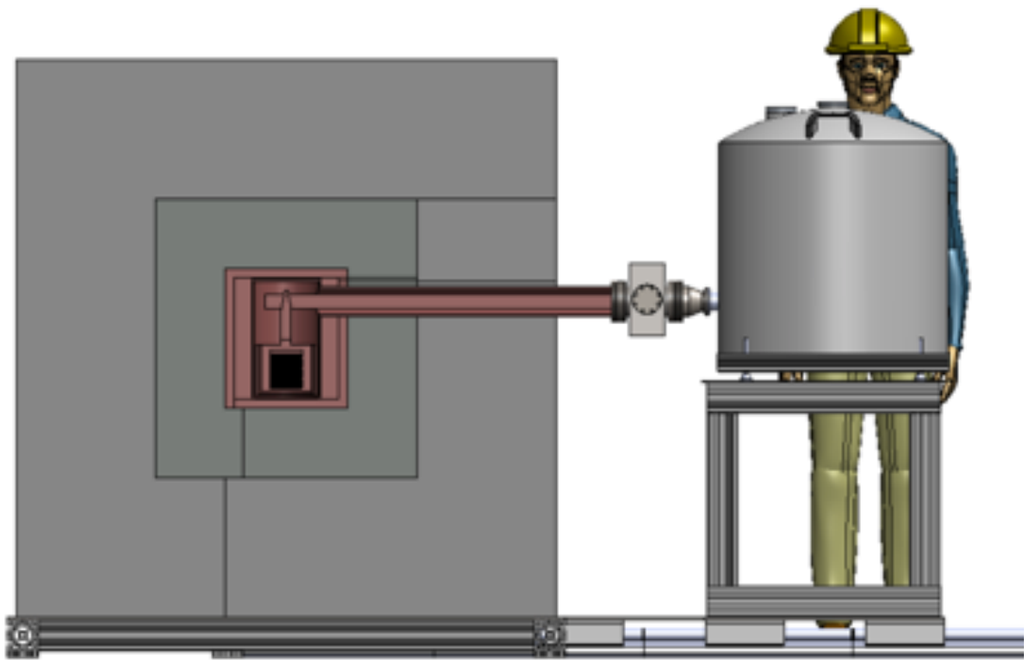
Current exposure (03/2018) and bkg (5 keV/kg/d)

exposure by end 2018

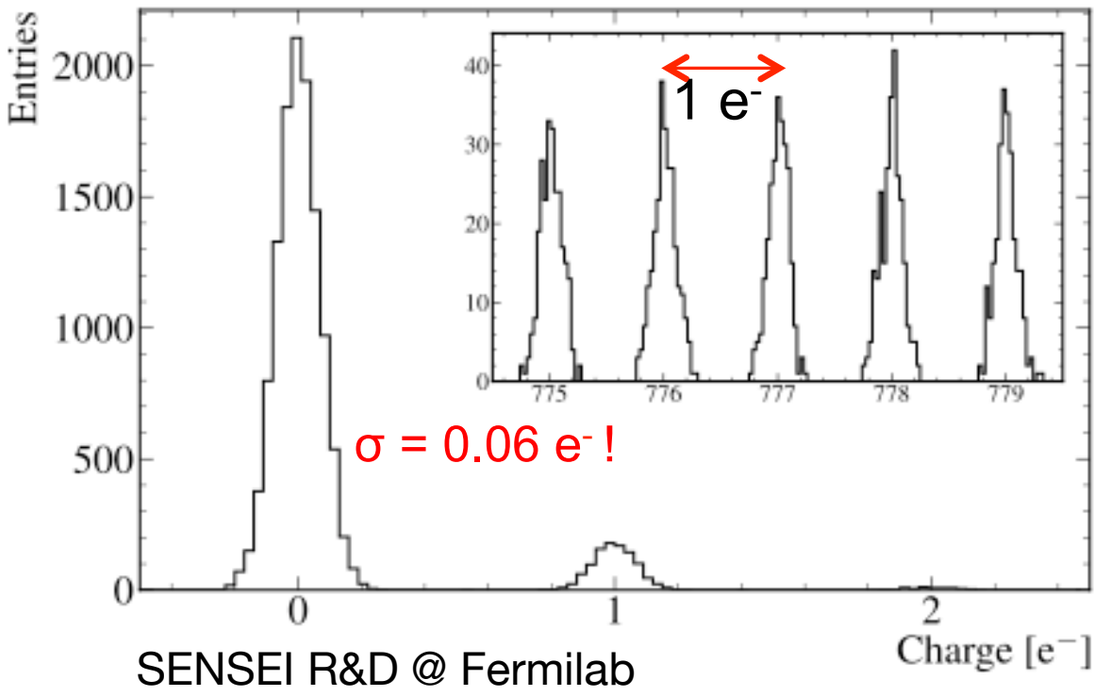
Exploring for the 1st time the CDMS signal with the silicon target and a much lower energy threshold (0.6 keV_{nr} ~ 0.05 keV_{ee})

DAMIC-M @ *Laboratoire Souterrain de Modane*

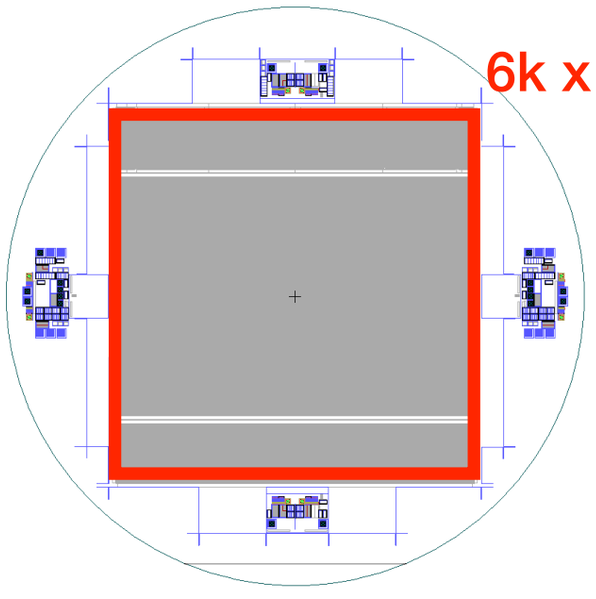
A 0.5 kg detector for WIMPs and dark-sector candidates at low-masses



- Largest CCD ever built
  (6k x 6k x 1mm, mass 20 g)
- Skipper readout for sub-eV noise
- Bkg reduction to a fraction of dru
  (improved design, materials, procedures)



SENSEI R&D @ Fermilab



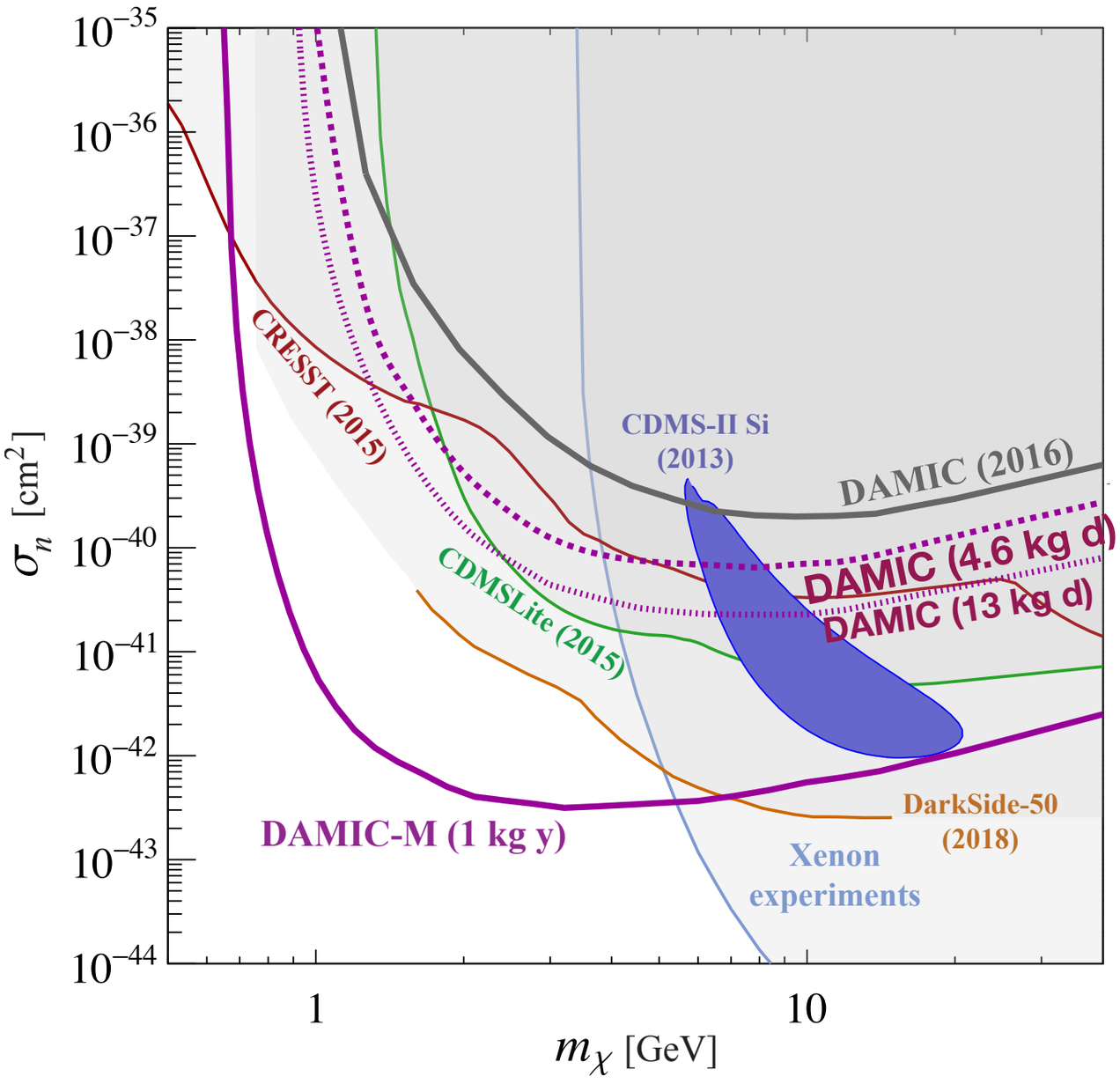
6k x 6k CCD, 1mm thick, 20g

Wafer-layout by
J.Holland (LNBL)

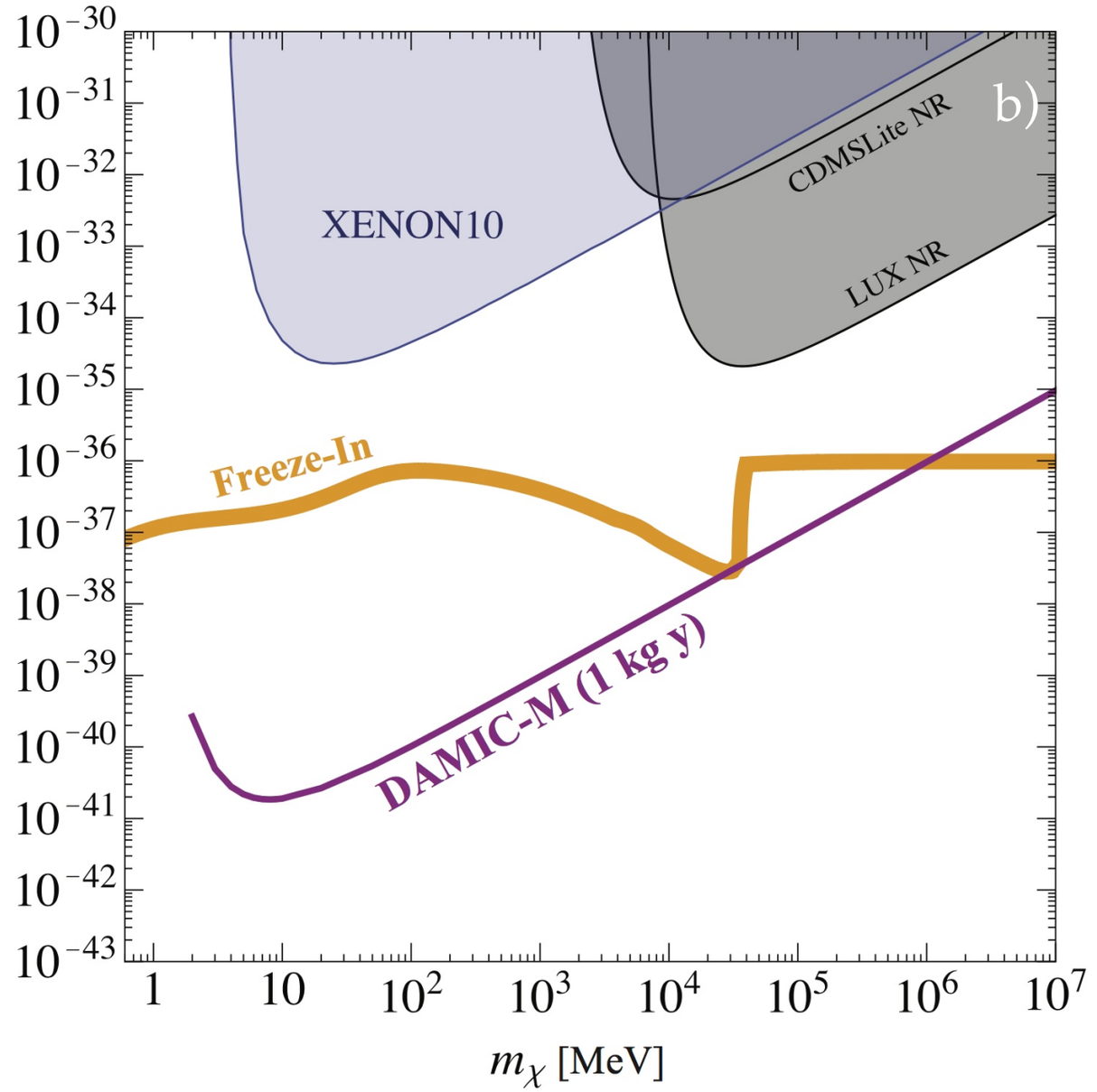
1st skipper CCDs (10g) at UW in summer for testing

DAMIC-M sensitivity to DM searches

WIMP search



DM-electron scattering via ultra-light hidden photon



Outlook

DAMIC operating with 40g detector since 2017.
Collected exposure:
- 4.6 kg d so far, ~ 13kg day by the end of 2018

High quality data:
- 50 eV threshold
- Low noise (dominated by readout)
- Few dru background

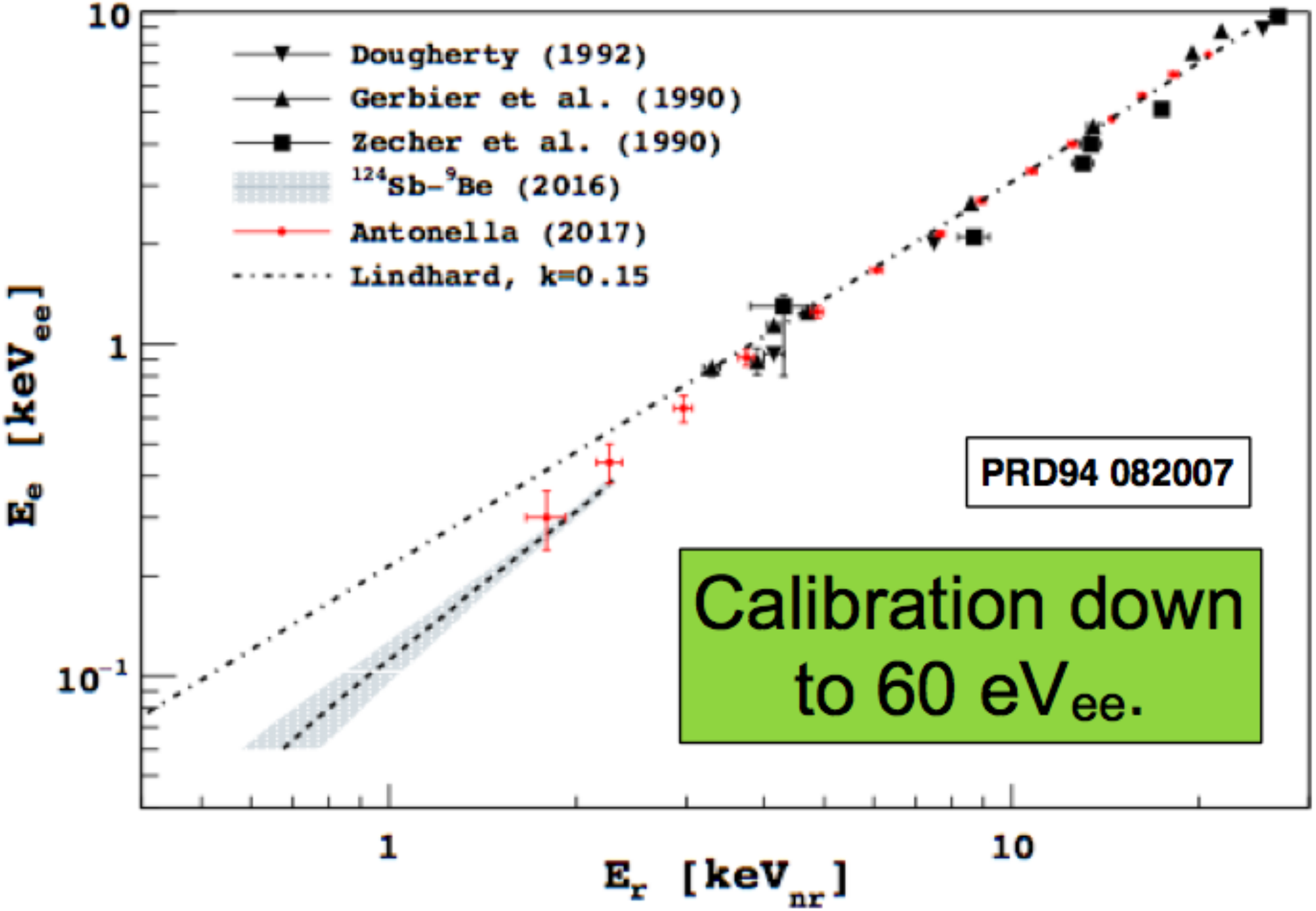
These data will provide essential information for the next generation of silicon detectors (DAMIC-M, SuperCDMS):
- spectrum below 2 keV
- Cosmogenic and radiogenic background in silicon
- CCD dark current at lowest temperature

Next stage : a kg size DAMIC detector at LSM, in France
A large skipper CCD will be characterized this year (SNOLAB setup continuing running)

Thank you

BACKUP

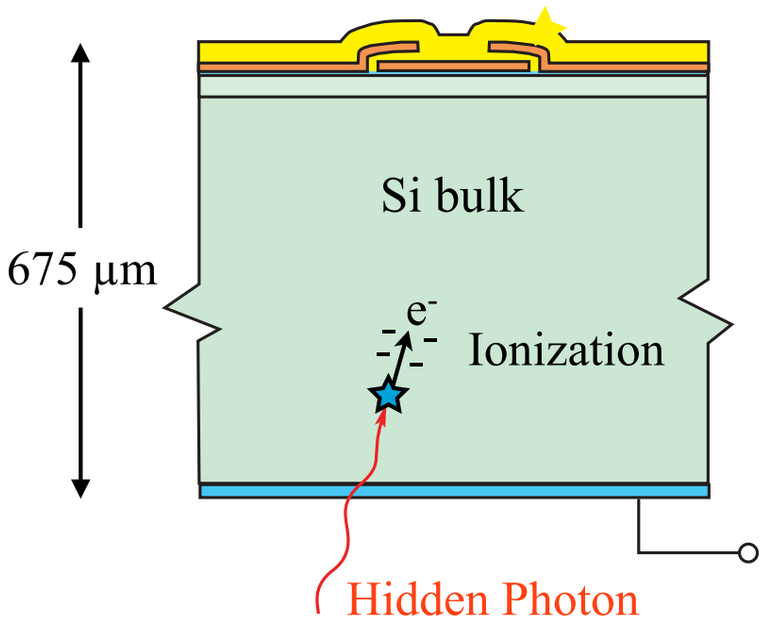
Nuclear-recoil ionization efficiency in silicon



deviation from Lindhard theory observed – crucial for low-mass WIMP searches with silicon detectors

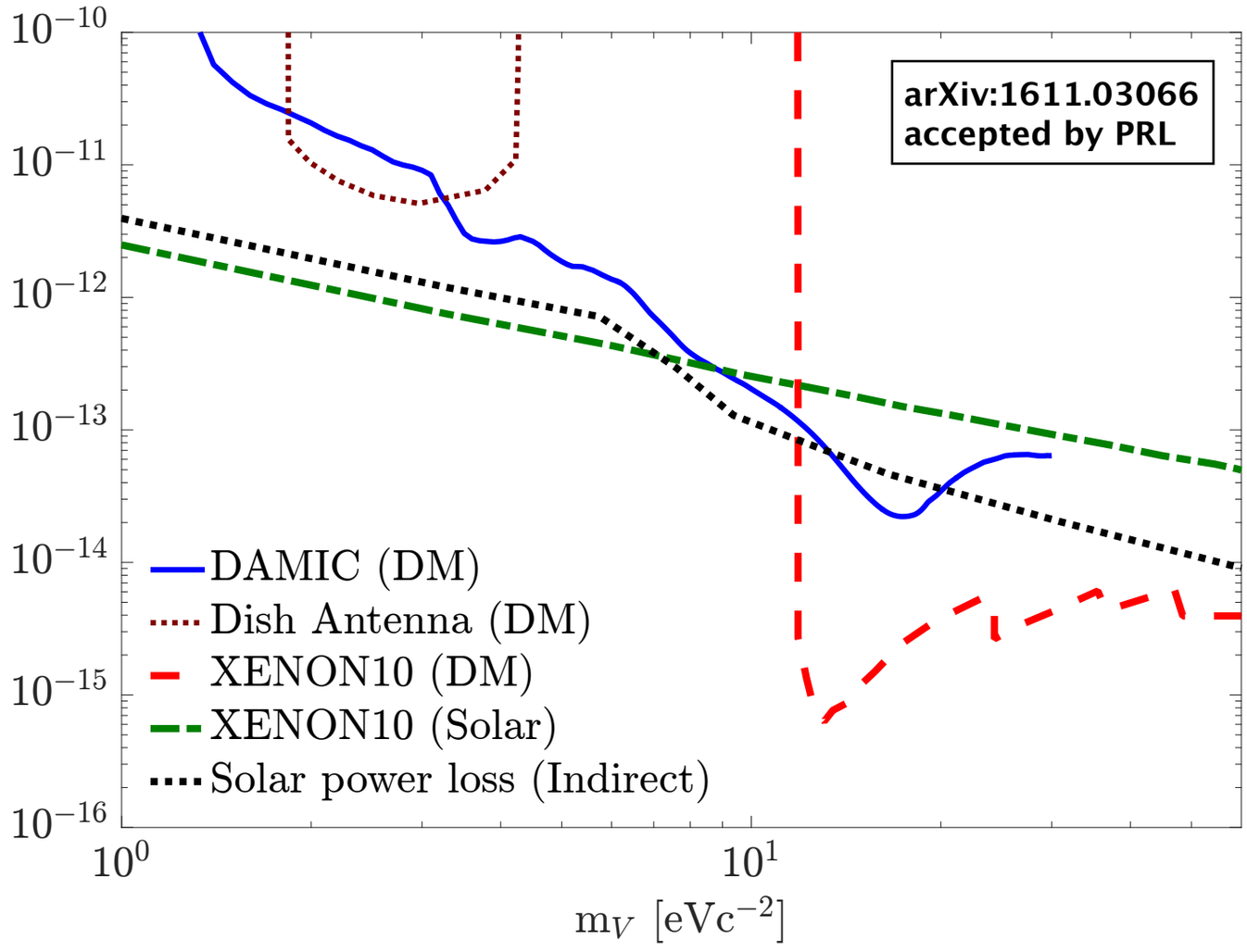
Hidden photon search

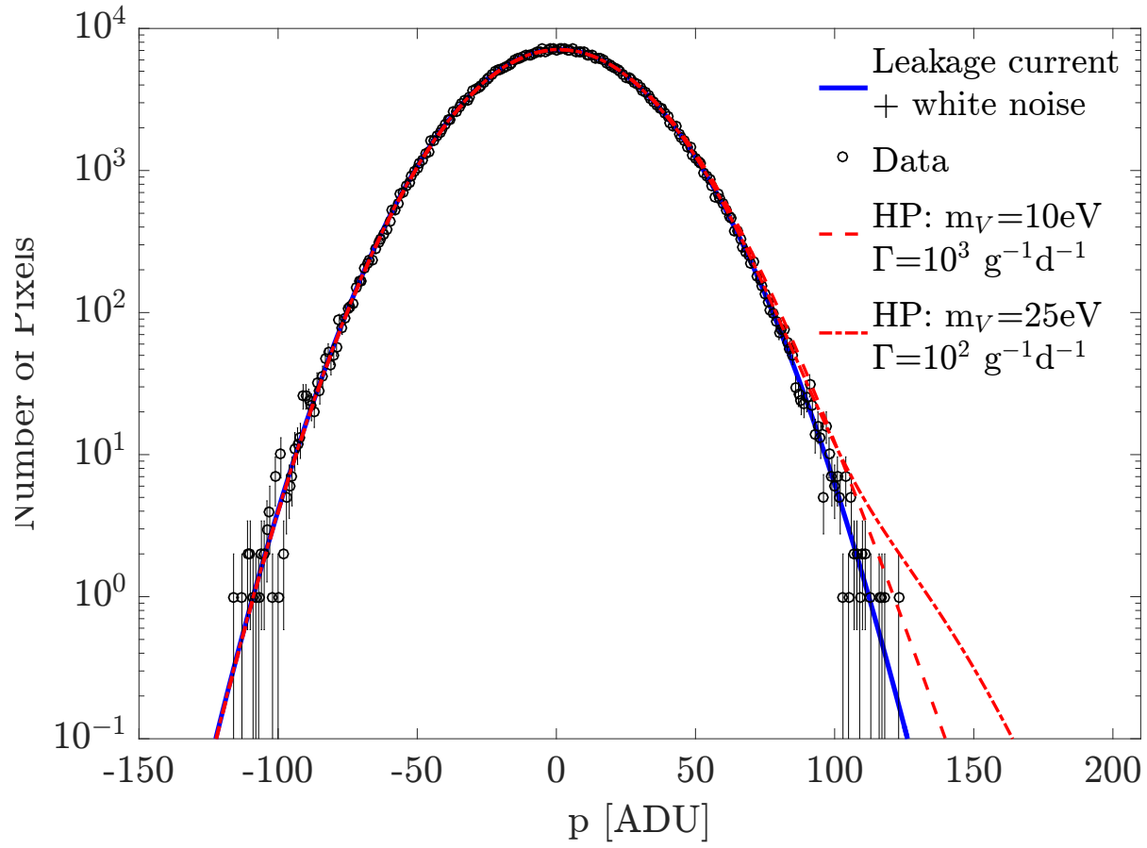
Absorption of hidden-photon dark matter.



~1 week of data with 1 CCD.

Leakage current **4 e⁻ mm⁻² d⁻¹**.





Pixel distribution consistent with white noise + uniform leakage current.

ββ coincidences

64 keV 1.2 MeV

$^{210}Pb \longrightarrow ^{210}Bi \longrightarrow ^{210}Po$

$T_{1/2}$ = 5 d

0.22 MeV 1.7 MeV

$^{32}Si \longrightarrow ^{32}P \longrightarrow ^{32}S$

$T_{1/2}$ = 14 d

<u>57 days of data in 1 CCD:</u>

^{210}Pb < 37 $kg^{-1}d^{-1}$
(95% C.L.)

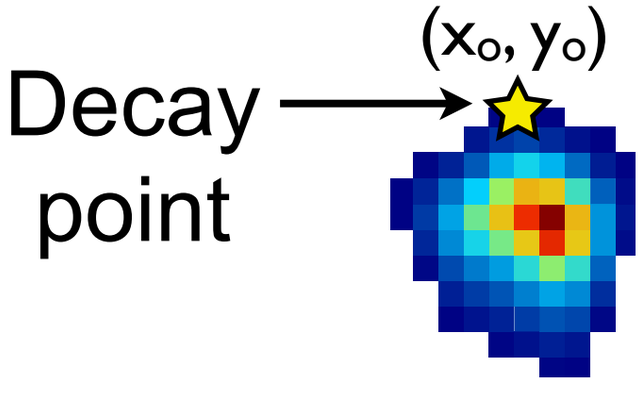
^{32}Si = 80^{+110}_{-65} $kg^{-1}d^{-1}$
(95% C.L.)

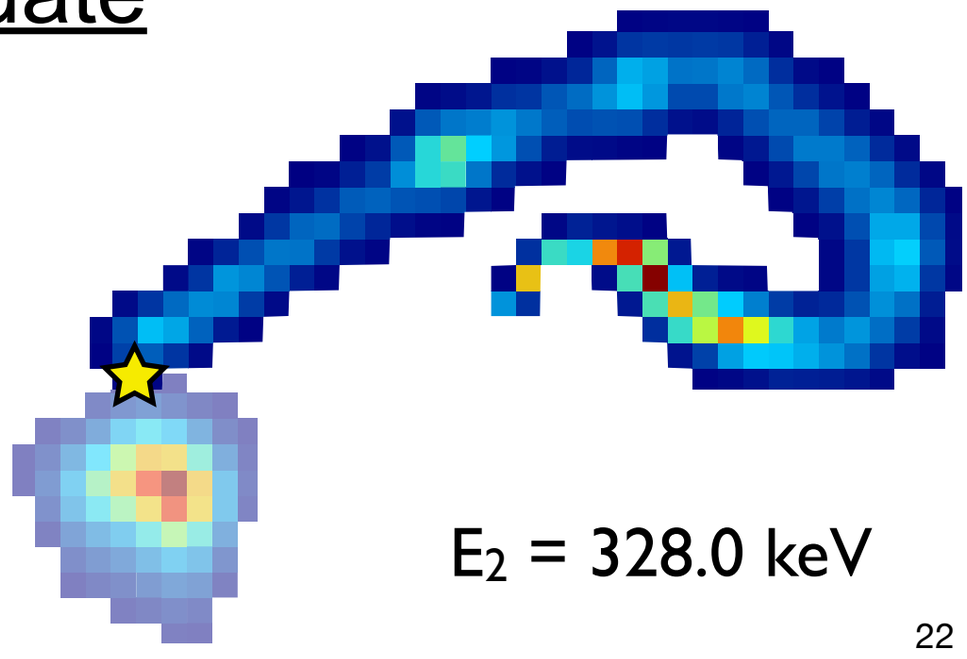
JINST 10 P08014

<u>^{32}Si - ^{32}P candidate</u>

E_1 = 114.5 keV

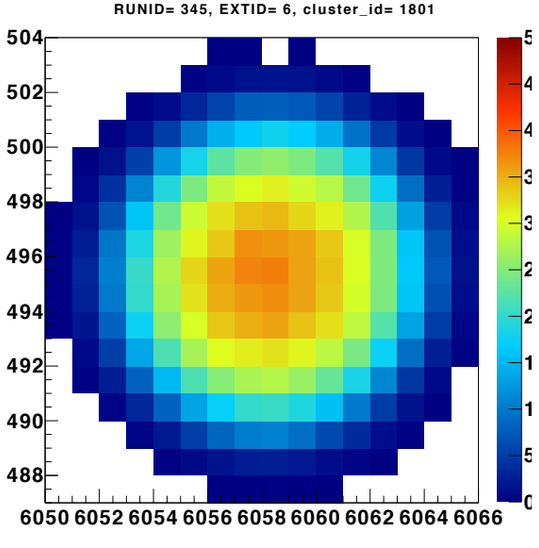
Δt = 35 days



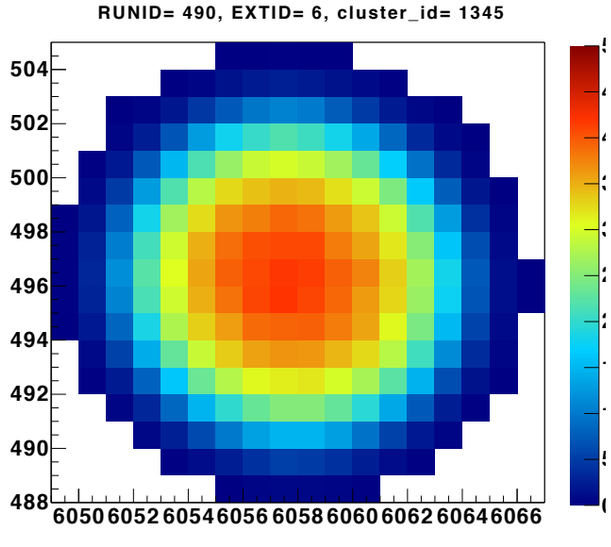


DAMIC background characterization

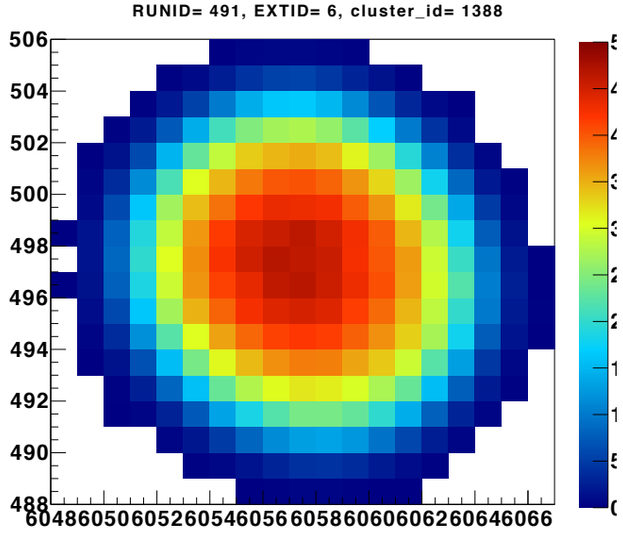
E = 5.4 MeV



E = 6.8 MeV



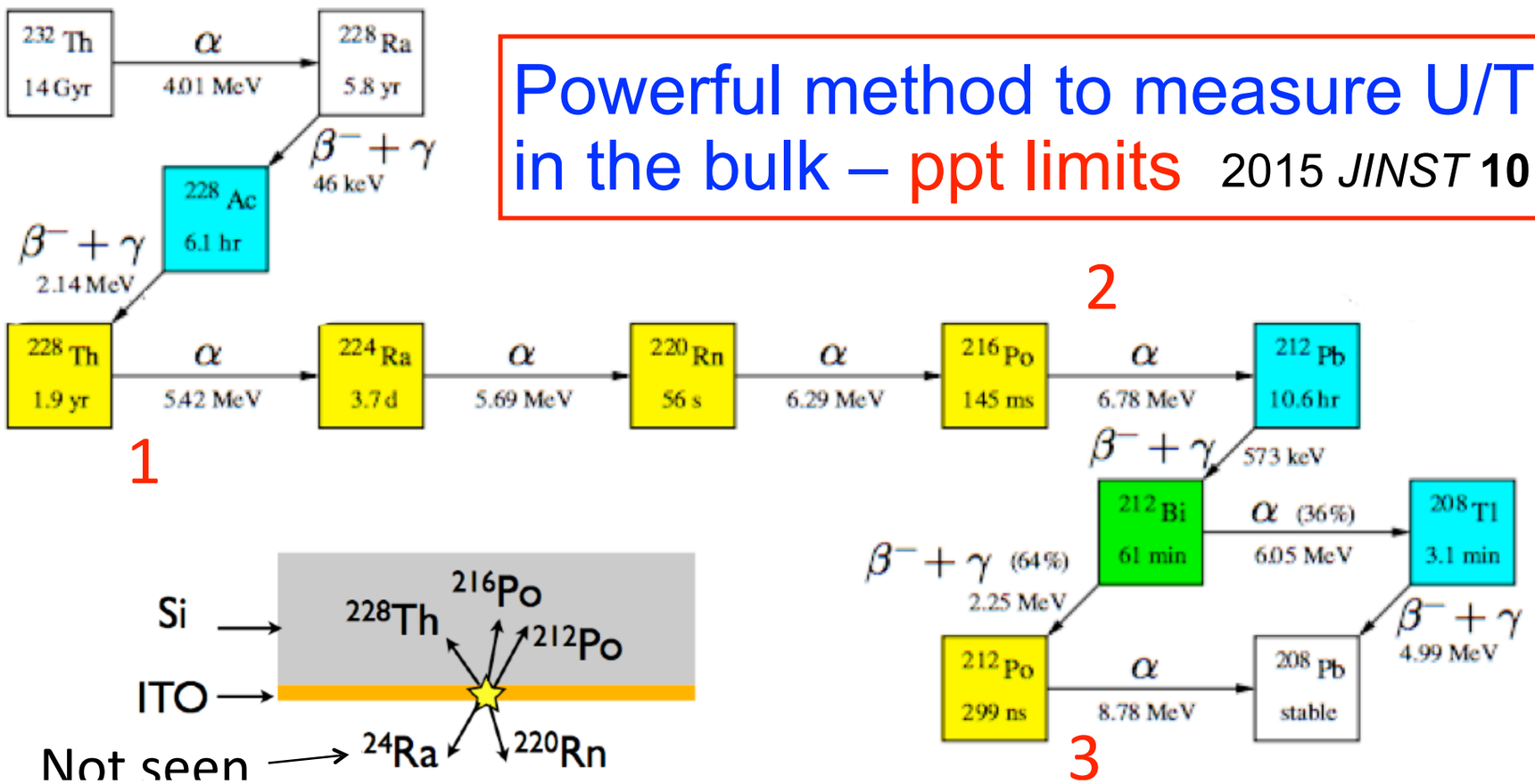
E = 8.8 MeV



1 $\Delta t = 17.8$ d 2 $\Delta t = 5.5$ h 3

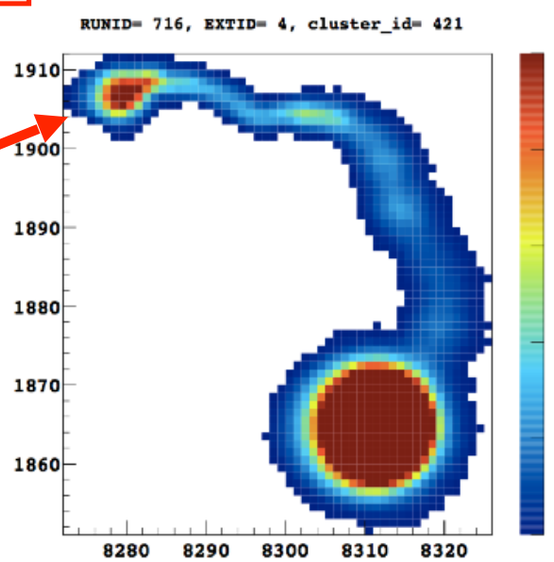
Three α at the same location!

Powerful method to measure U/Th bkg in the bulk – ppt limits 2015 *JINST* **10** P08014



Example of α + β

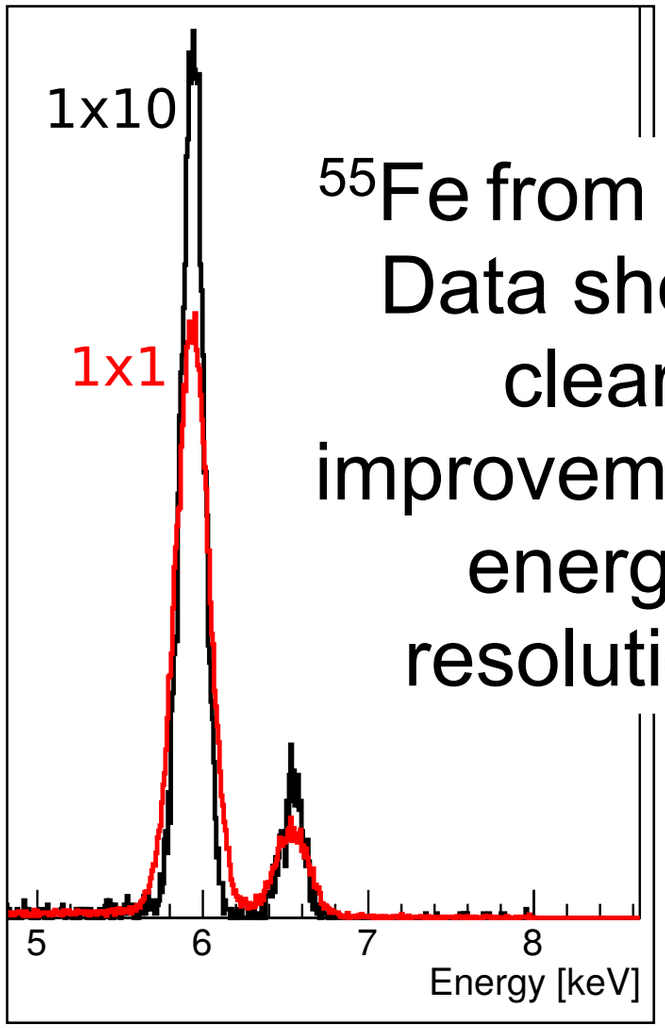
Bragg peak



Flexibility in readout

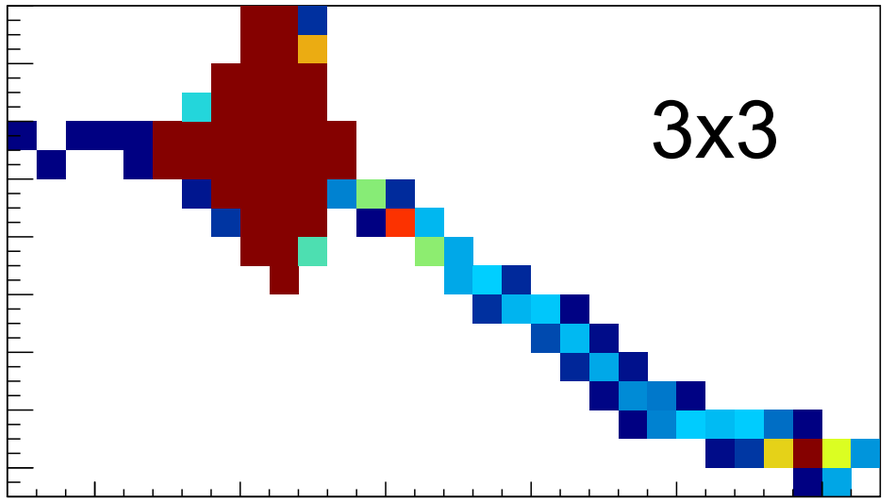
Pixels can be readout in “groups” and the total charge estimated in a single measurement.

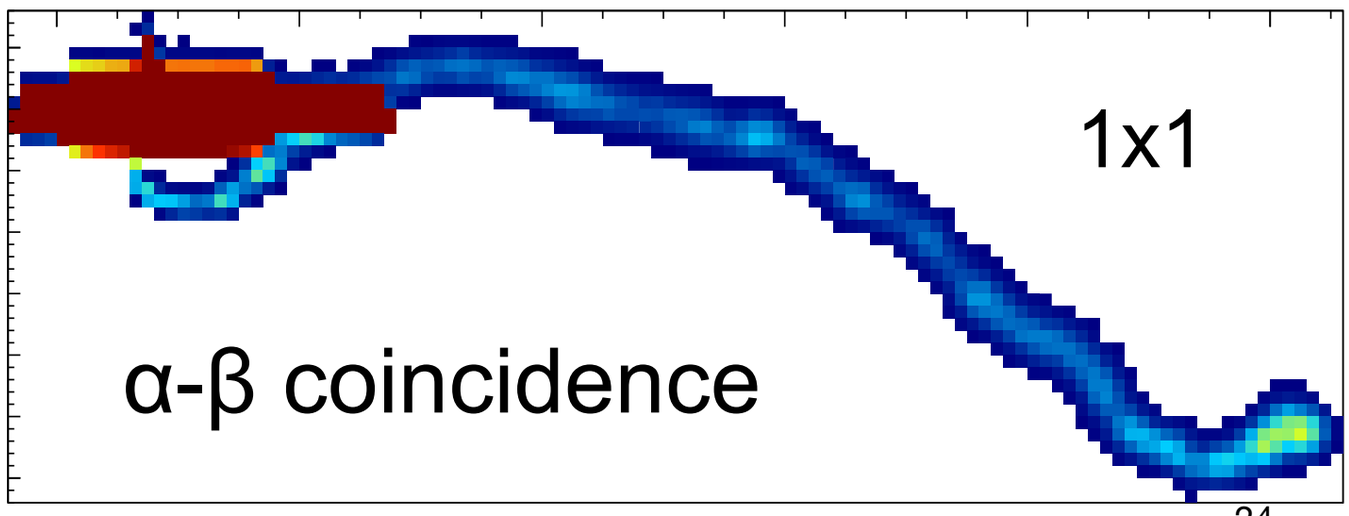
Less pixels but same noise *per* pixel!



^{55}Fe from back: Data shows clear improvement in energy resolution.

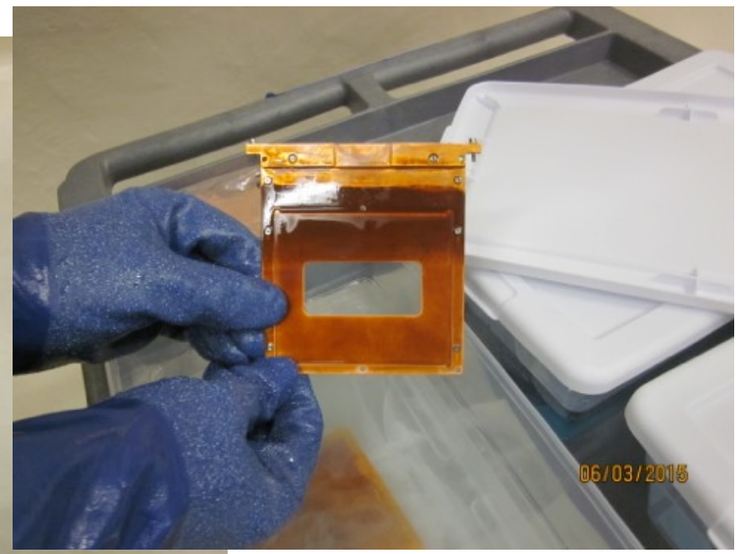
Loss of x, y and z information

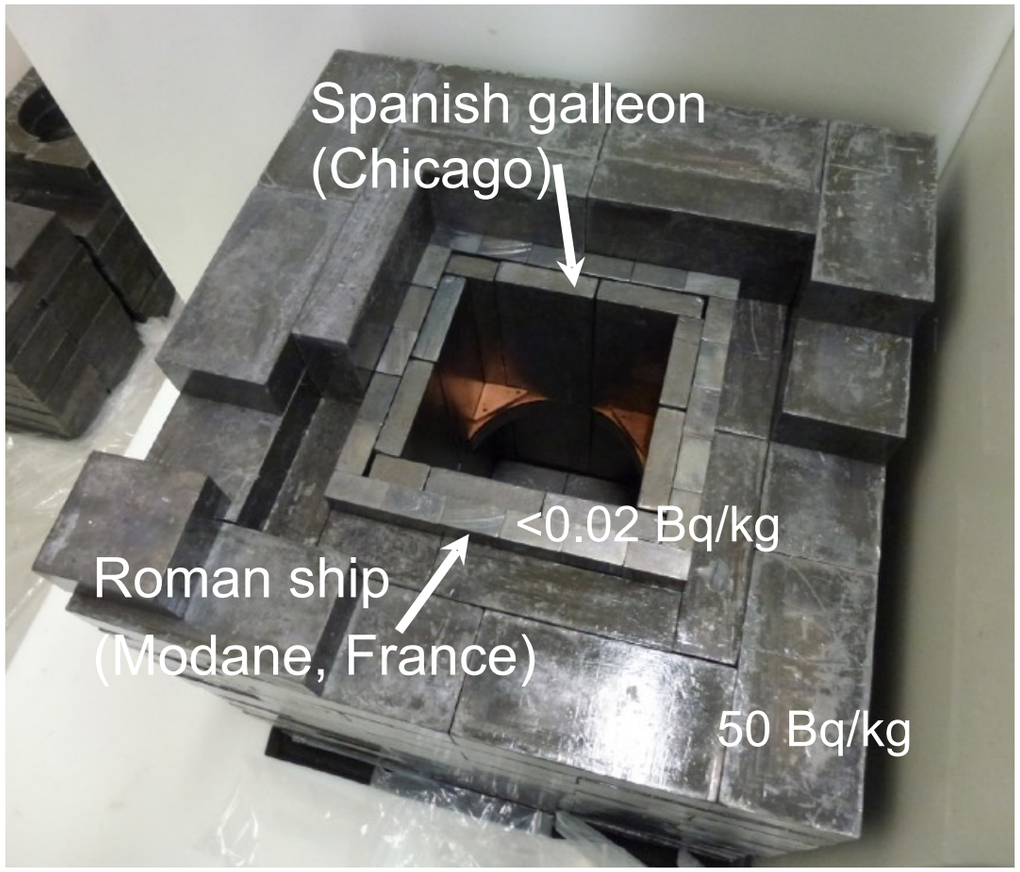




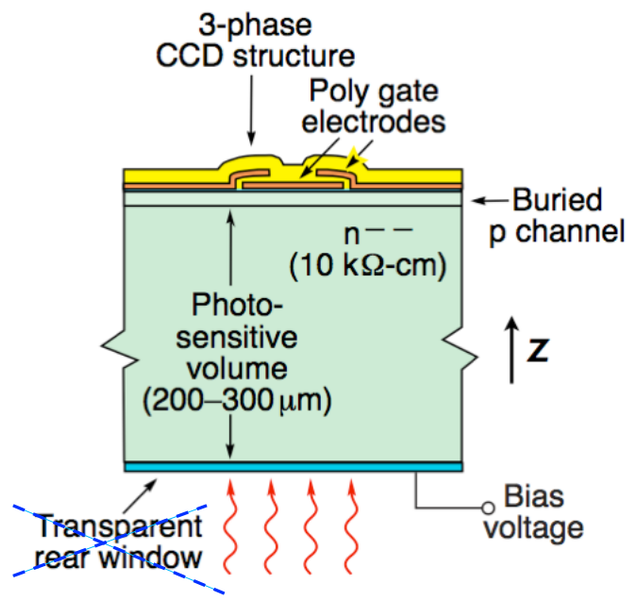
- **Lead shielding** to stop environmental γ rays

Inner 2” shielding made of ancient lead to avoid bremmstrahlung γs from ^{210}Pb β-decay (22 yrs half-life)





- **Material selection and cleaning:** copper machining, “secret” recipe etching (surface bkg)

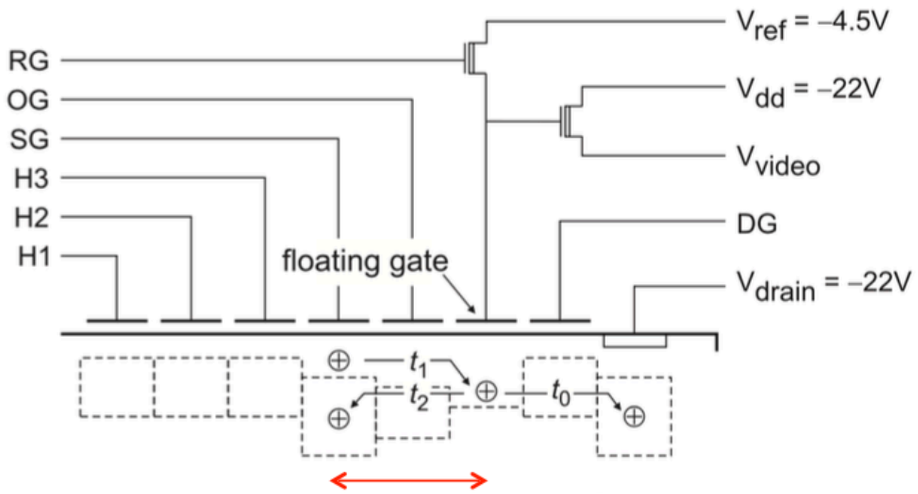


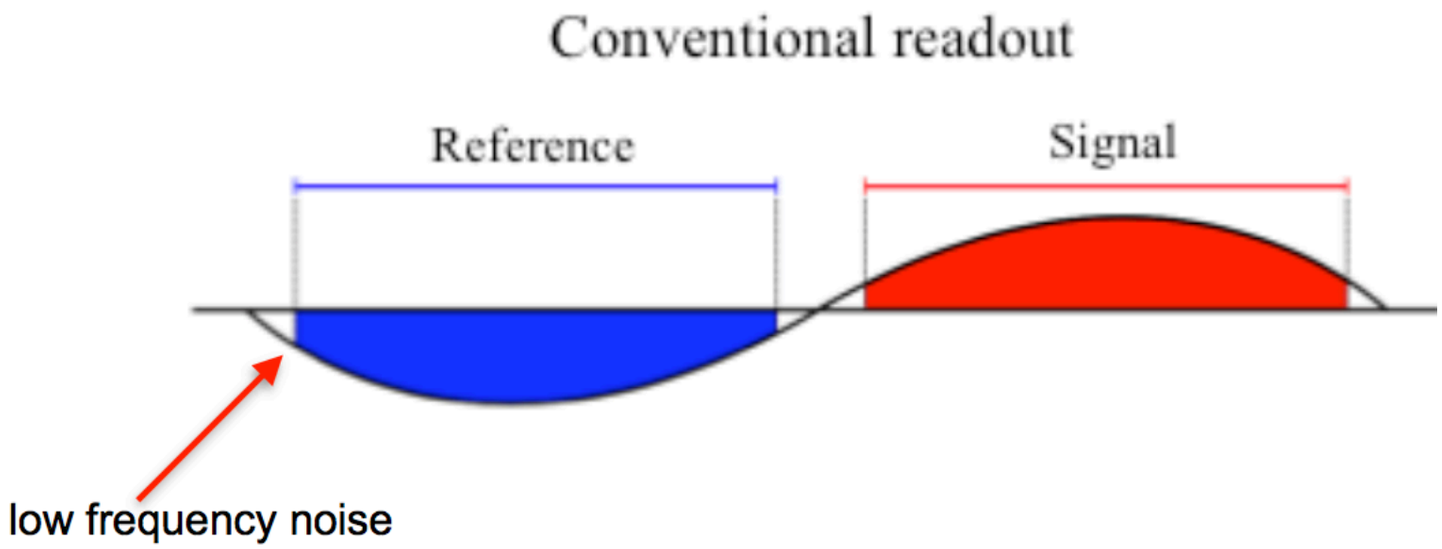
Radioactive!

DAMIC-1K sub-e⁻ noise

- Skipper readout

a novel charge readout approach which results in *single electron resolution*





Non-destructive measurement of the charge!

Measure the charge fast (kill 1/f noise) and N times (noise ≈ 1/√N)