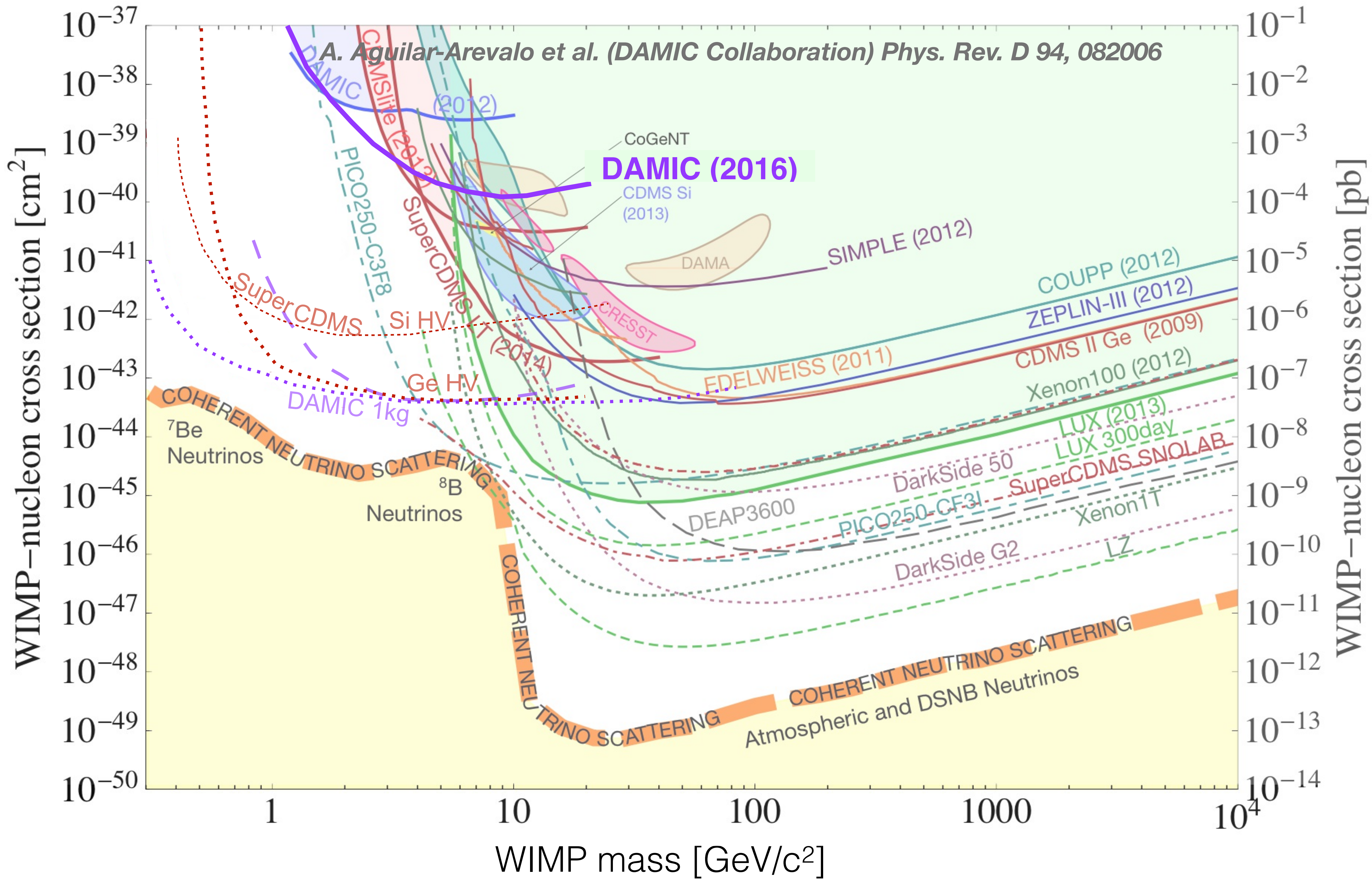
DAMIC

DARK MATTER IN CCD

ROMAIN GAIOR
(LPNHE PARIS)

DARK MATTER DAY (APC 2016/12/01)

MOTIVATION



A. Aguilar-Arevalo et al. (DAMIC Collaboration) Phys. Rev. D 94, 082006
DAMIC (2016)
CoGeNT
CDMS Si (2013)
DAMIC (2012)
CRESST
DAMA
SIMPLE (2012)
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
EDELWEISS (2011)
Xenon100 (2012)
LUX (2013)
LUX 300day
SuperCDMS SNOLAB
DarkSide 50
PICO250-CF3I
Xenon1T
DEAP3600
DarkSide G2
LZ
PICO250-C3F8
SuperCDMS
Si HV
Ge HV
DAMIC 1kg
CDMSlite (2013)
SuperCDMS LT (2014)
COHERENT NEUTRINO SCATTERING
⁷Be Neutrinos
⁸B Neutrinos
Atmospheric and DSNB Neutrinos
WIMP–nucleon cross section [cm²]
WIMP–nucleon cross section [pb]
WIMP mass [GeV/c²]

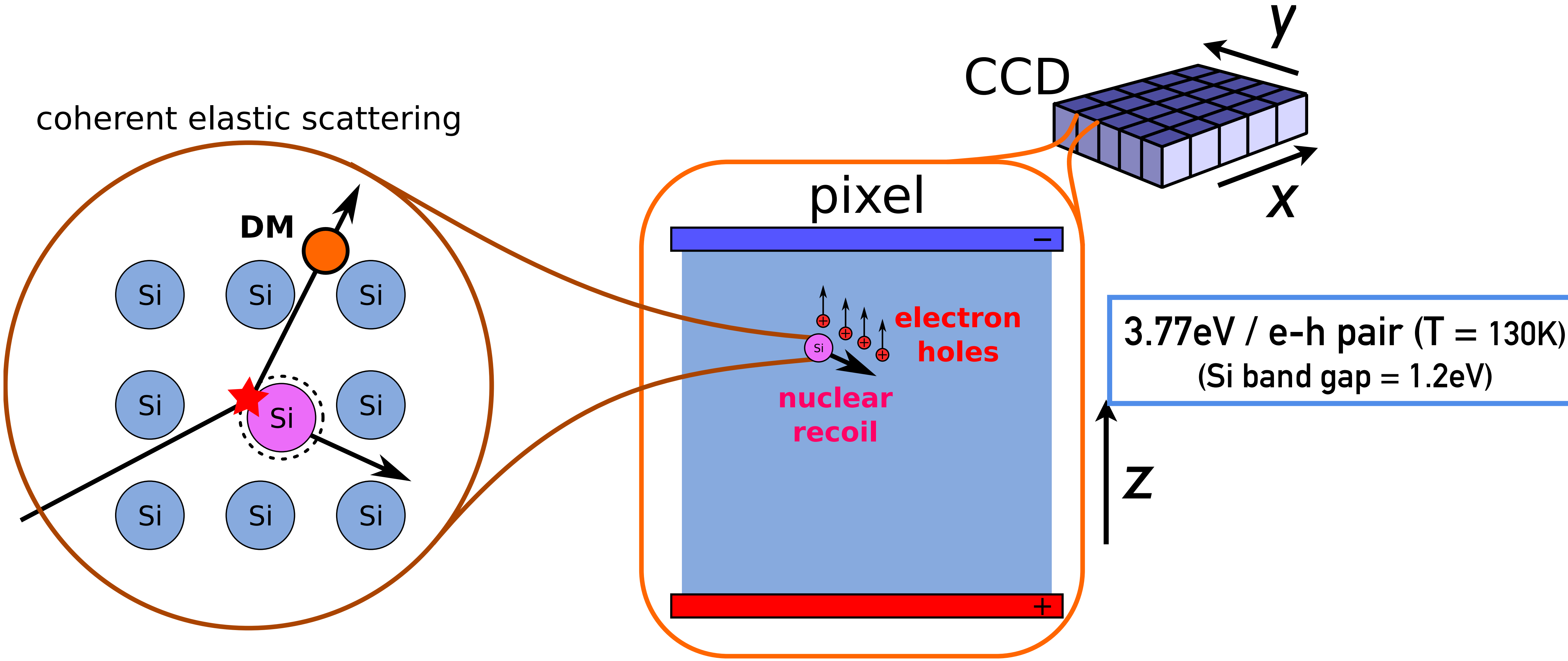
THE DAMIC COLLABORATION

- FERMILAB
- U Chicago
- U Michigan
- SNOLAB
- UNAM (Mexico)
- FIUNA (Paraguay)
- UFRJ (Brasil)
- U. Nacional del Sur
- Centro Atomico Bariloche
- U. Zurich
- **LPNHE (Paris 6/7)**

- 11 institutions
- 8 countries
- 39 collaborators

EXPERIMENTAL METHOD

DETECTION PRINCIPLE



Light mass target: $dR/dE \propto 1/m_A$

Low noise ~2e- = 7.5 eV —>low E threshold
(~ 0.06 keVee)

CCD TECHNIQUE PROS AND CONS

Pros

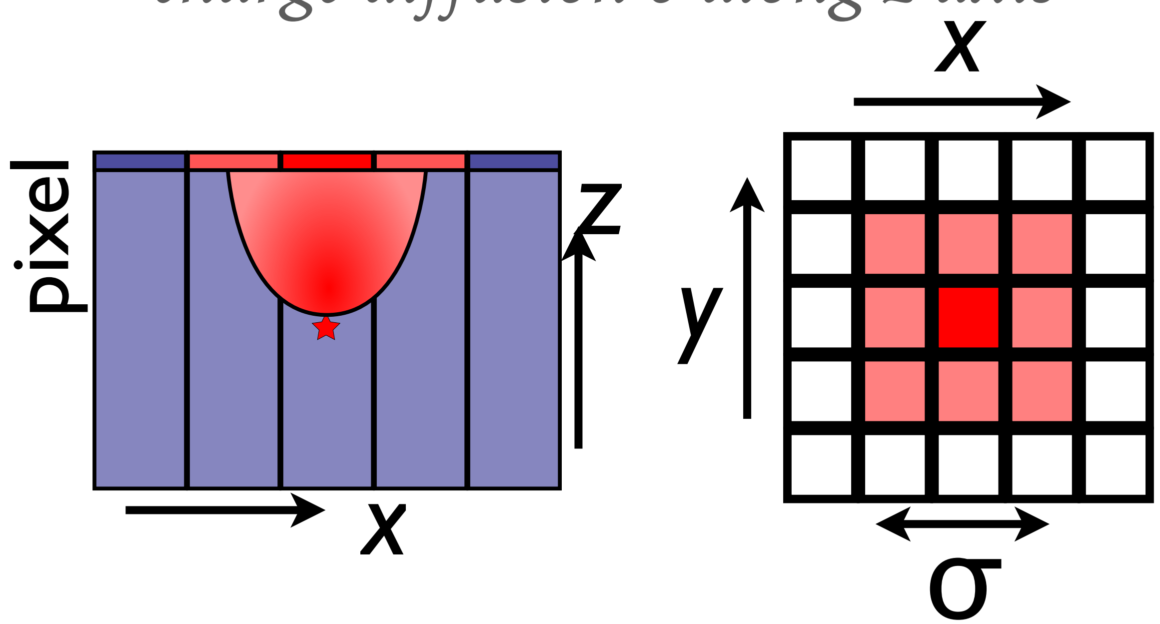
- low E threshold
- spatial resolution
  3D reconstruction
- energy resolution
- compact and "cheap" detector

Cons

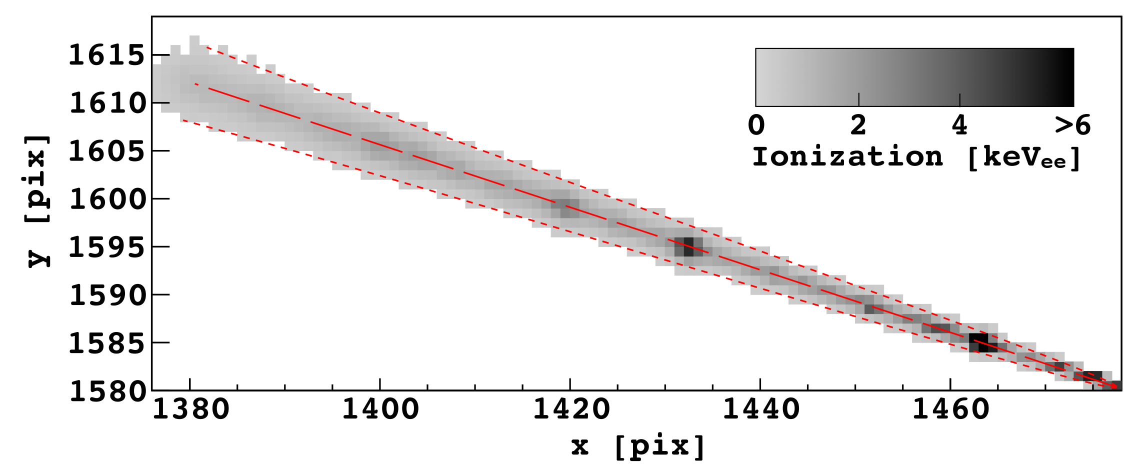
- 1 detection signal (ionisation)
- timing resolution ~ hours
- no directionality info

3D RECONSTRUCTION

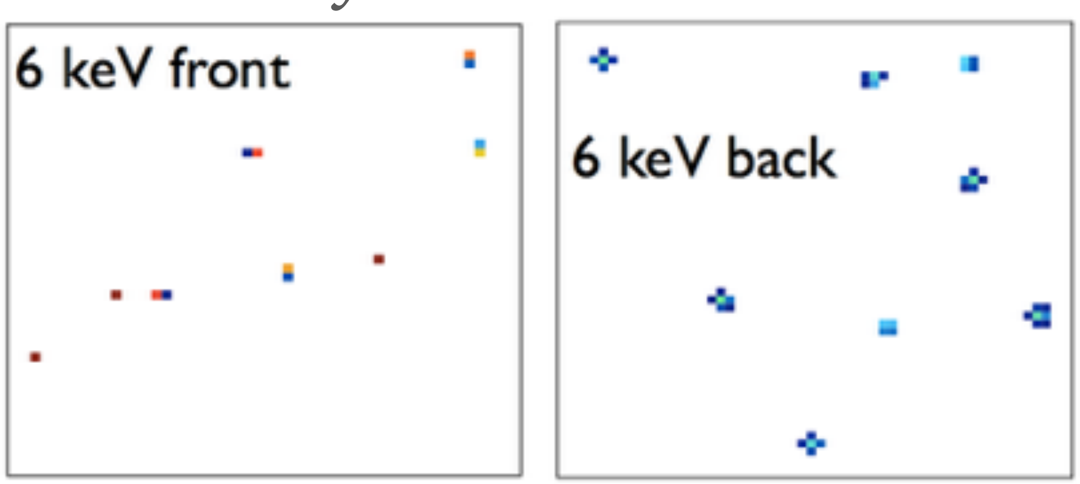
charge diffusion σ along z axis



muon track

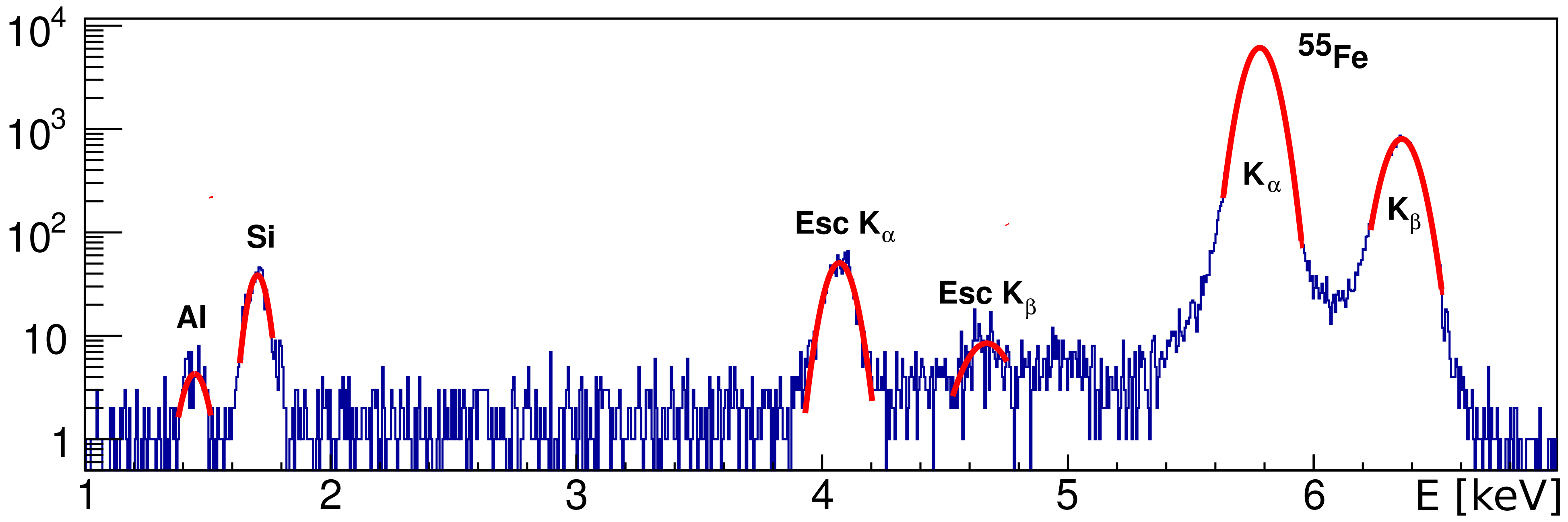


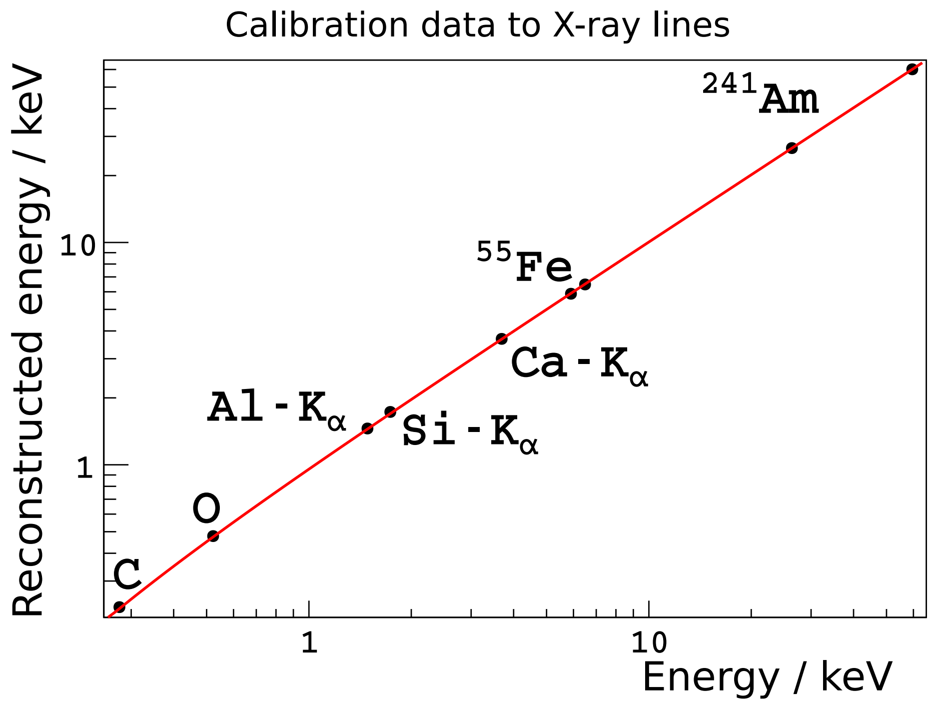
^{55}Fe X rays

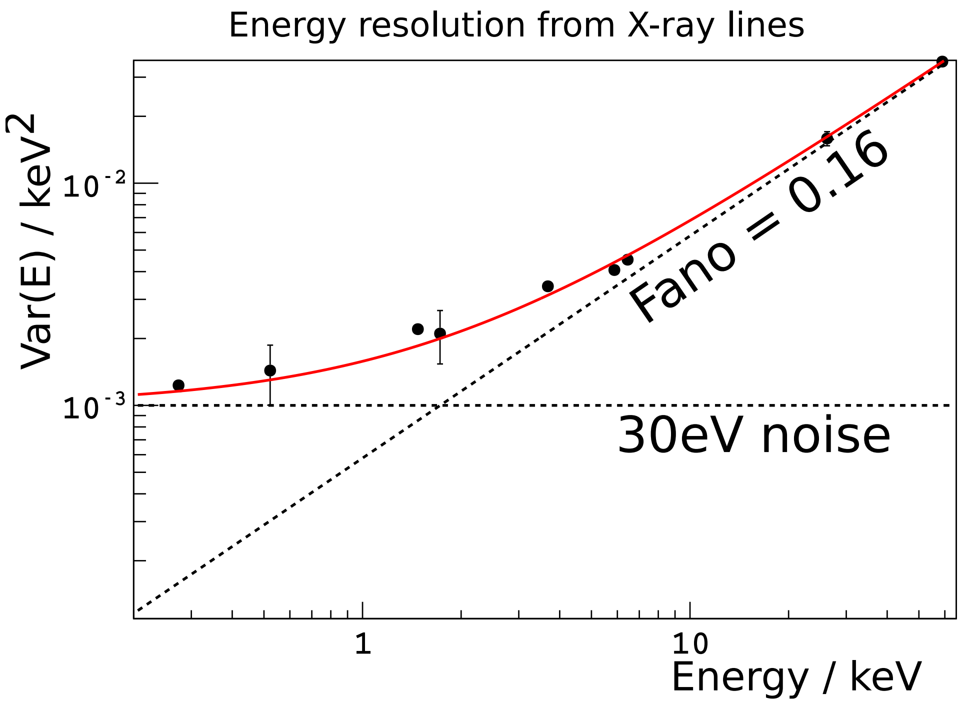


- $Z \propto \sigma_{xy}$
  - 3D reconstruction
  - surface event tagging

ENERGY LINEARITY & RESOLUTION



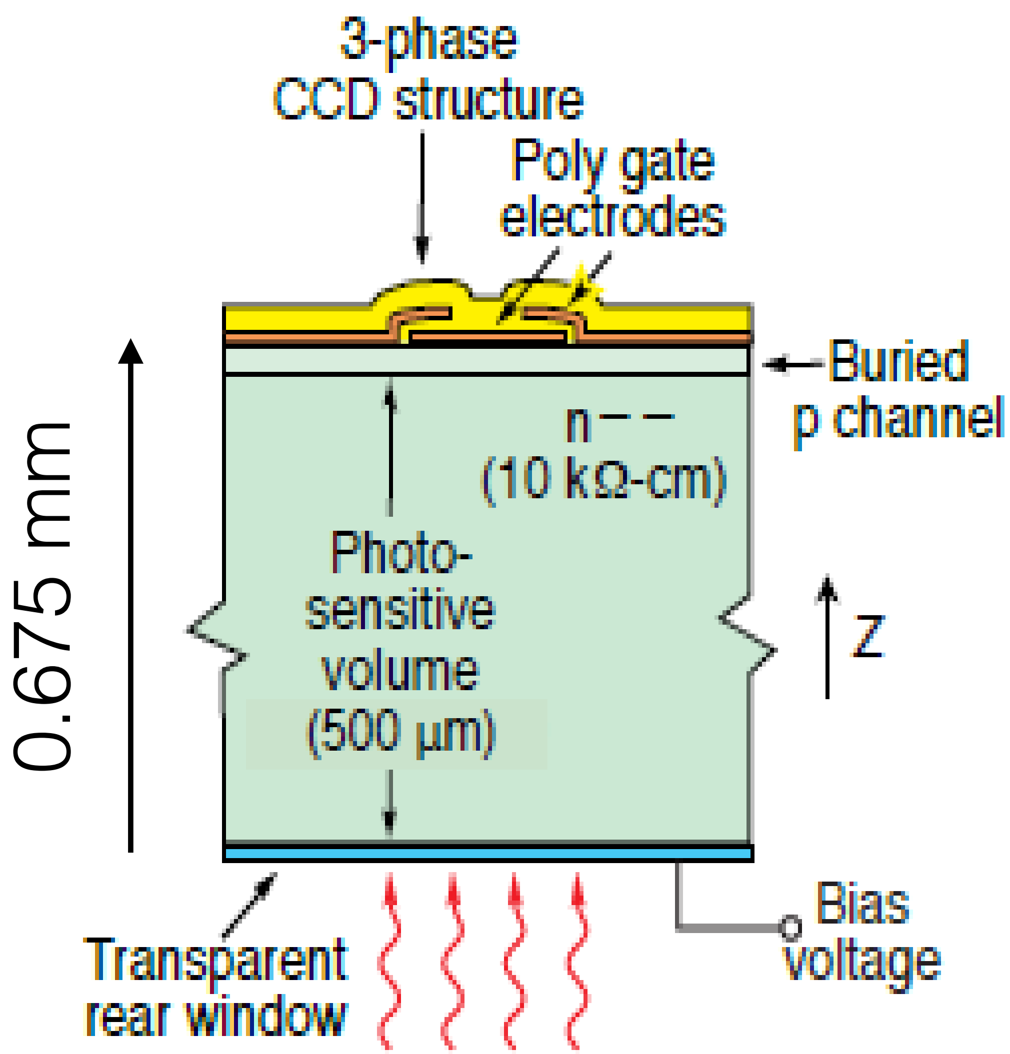




$$\sigma = \sqrt{E\mathbf{F}}$$

E resolution at 5.9 keV: : 54eVee

DAMIC CCD

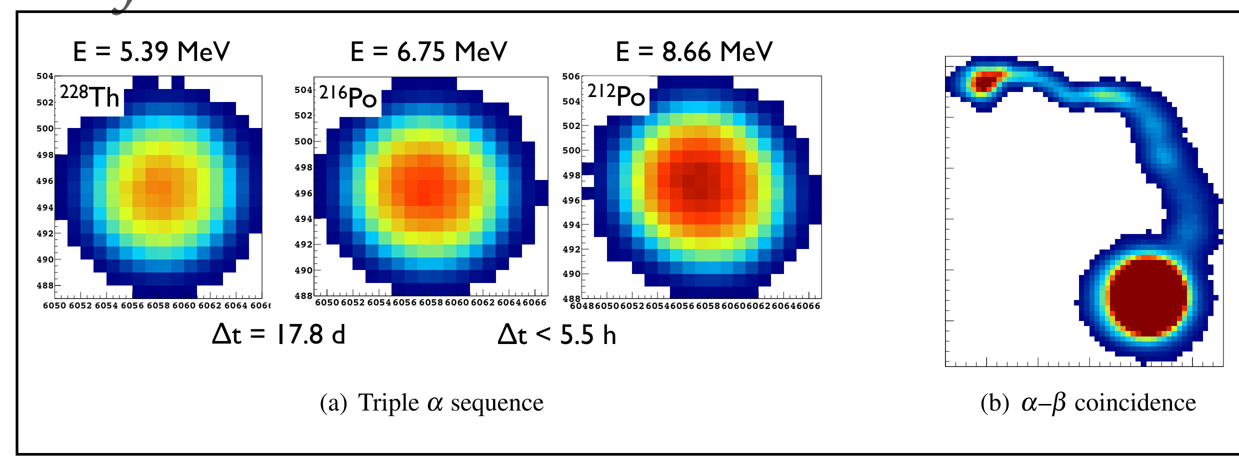


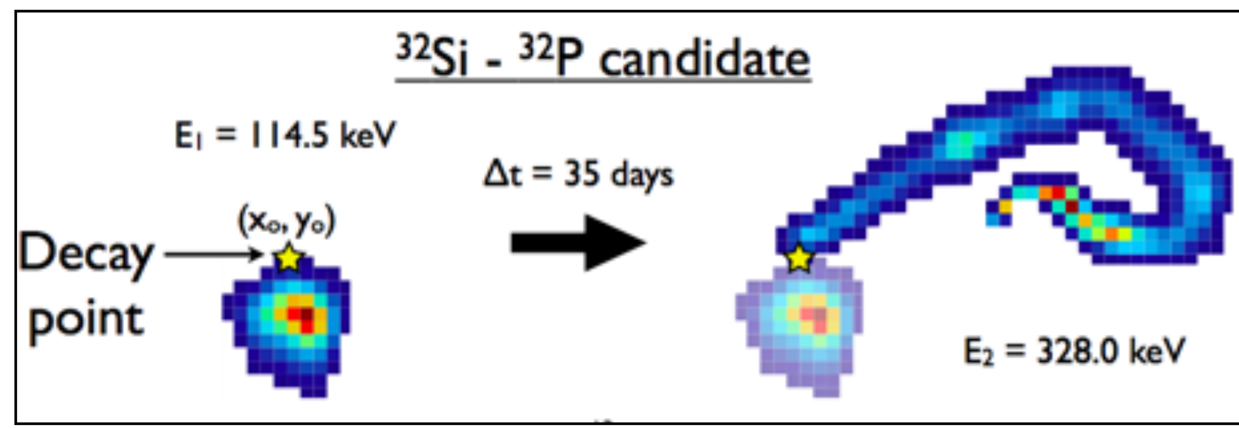
- ➤ developed at LBNL (Microsystem lab) originally for DECam
- ➤ **Thick CCD: 0.675 mm**
- ➤ **2.9g (5.8g)/ CCD**
- ➤ **8 (16) MegaPixels**
- ➤ pixel size: 15 x 15 µm
- ➤ High resistivity: 10-20 kΩ.cm (low donor density—>fully depleted at 40V)
- ➤ low dark current (10^{-3} e- /pix /day at 120K)

RADIOGENIC BACKGROUND

- no effective discrimination nuclear vs electronic recoil
  - potential bkg from β and γ

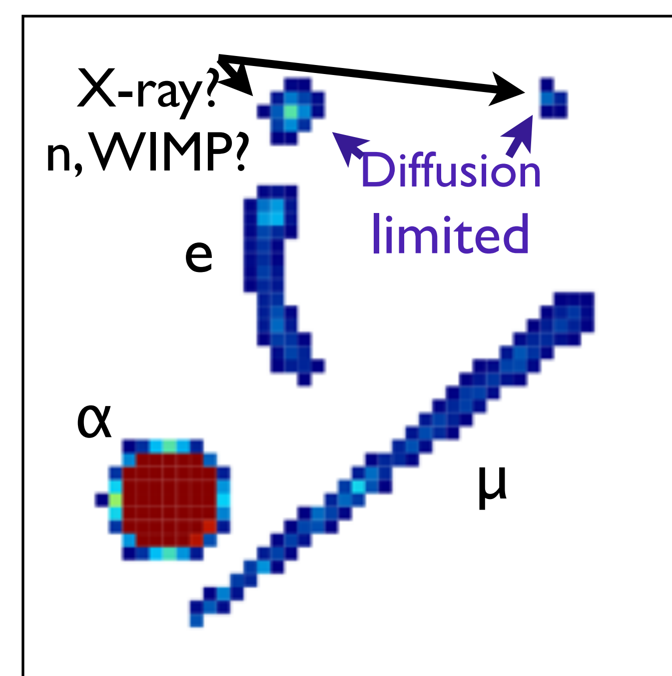
decay chain



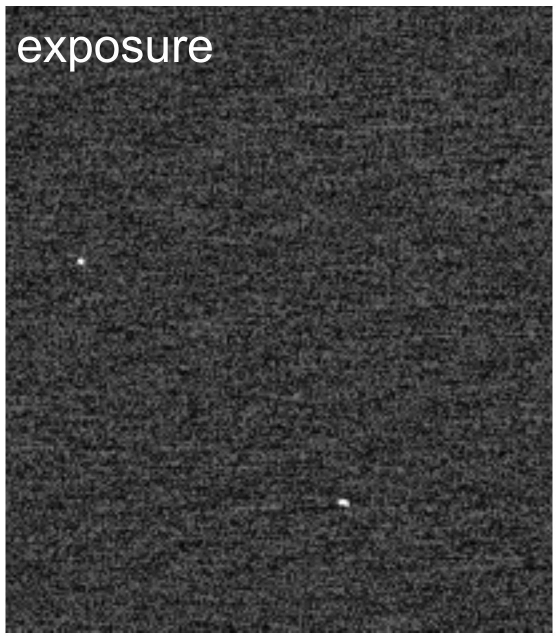


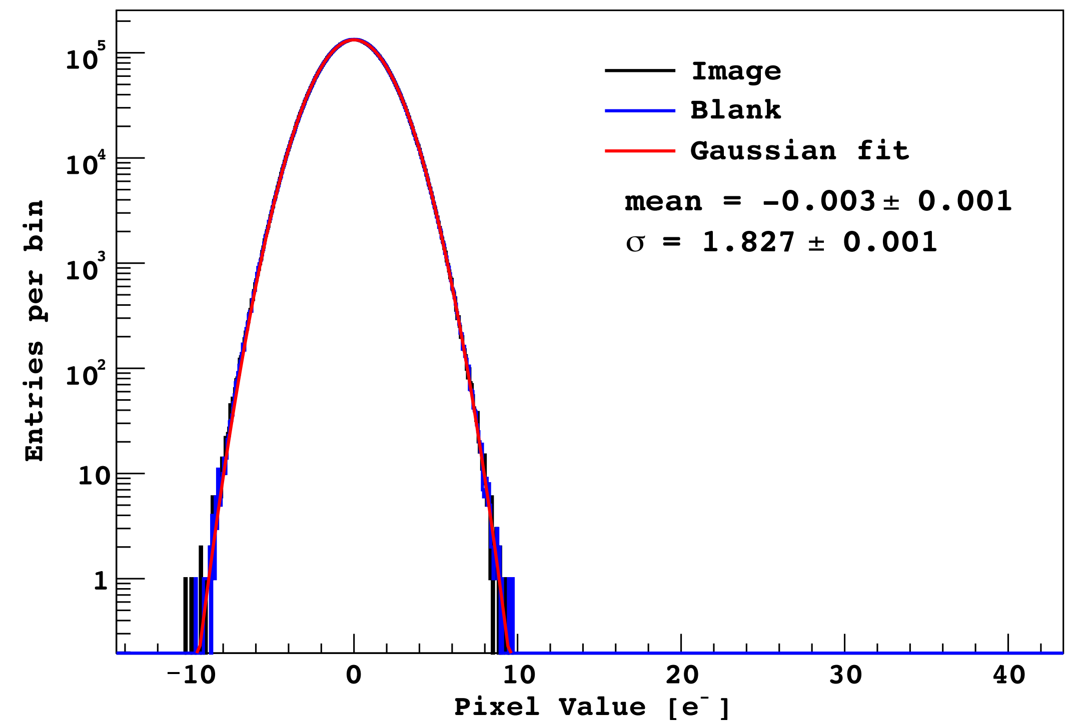
- unique spatial and energy resolution
  - observe decay chain from a single isotope
  - ^{238}U and ^{232}Th decay chain
  - ^{32}Si chain

particle identification

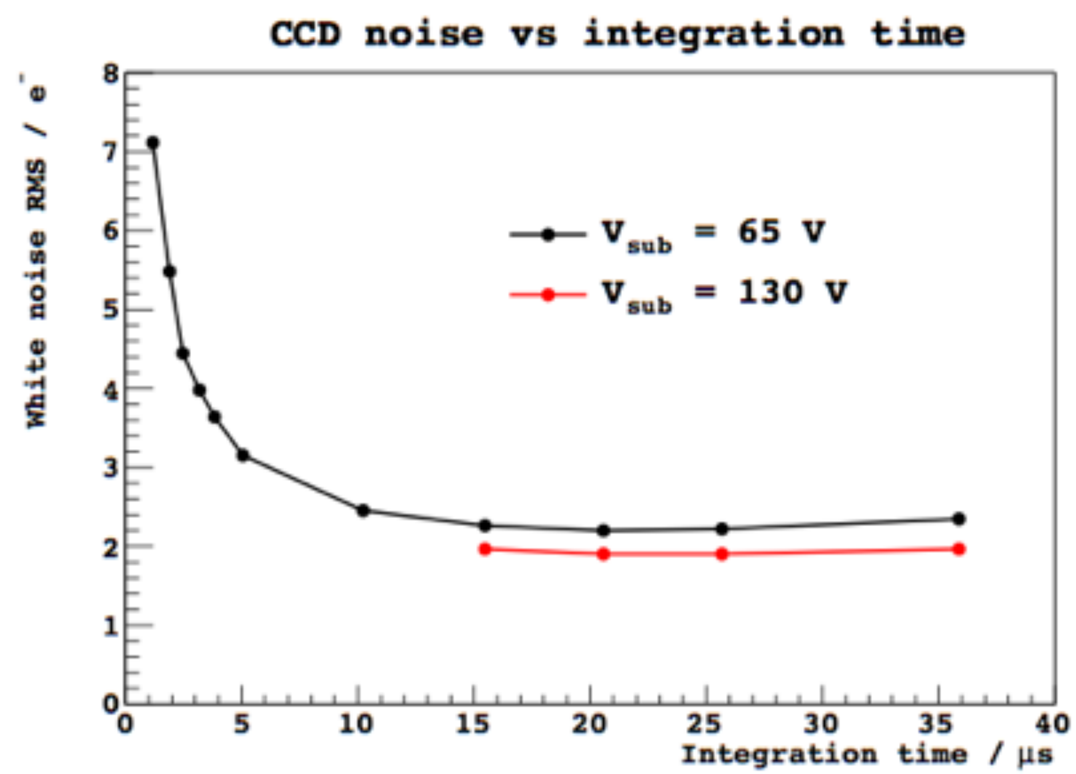


READ OUT NOISE



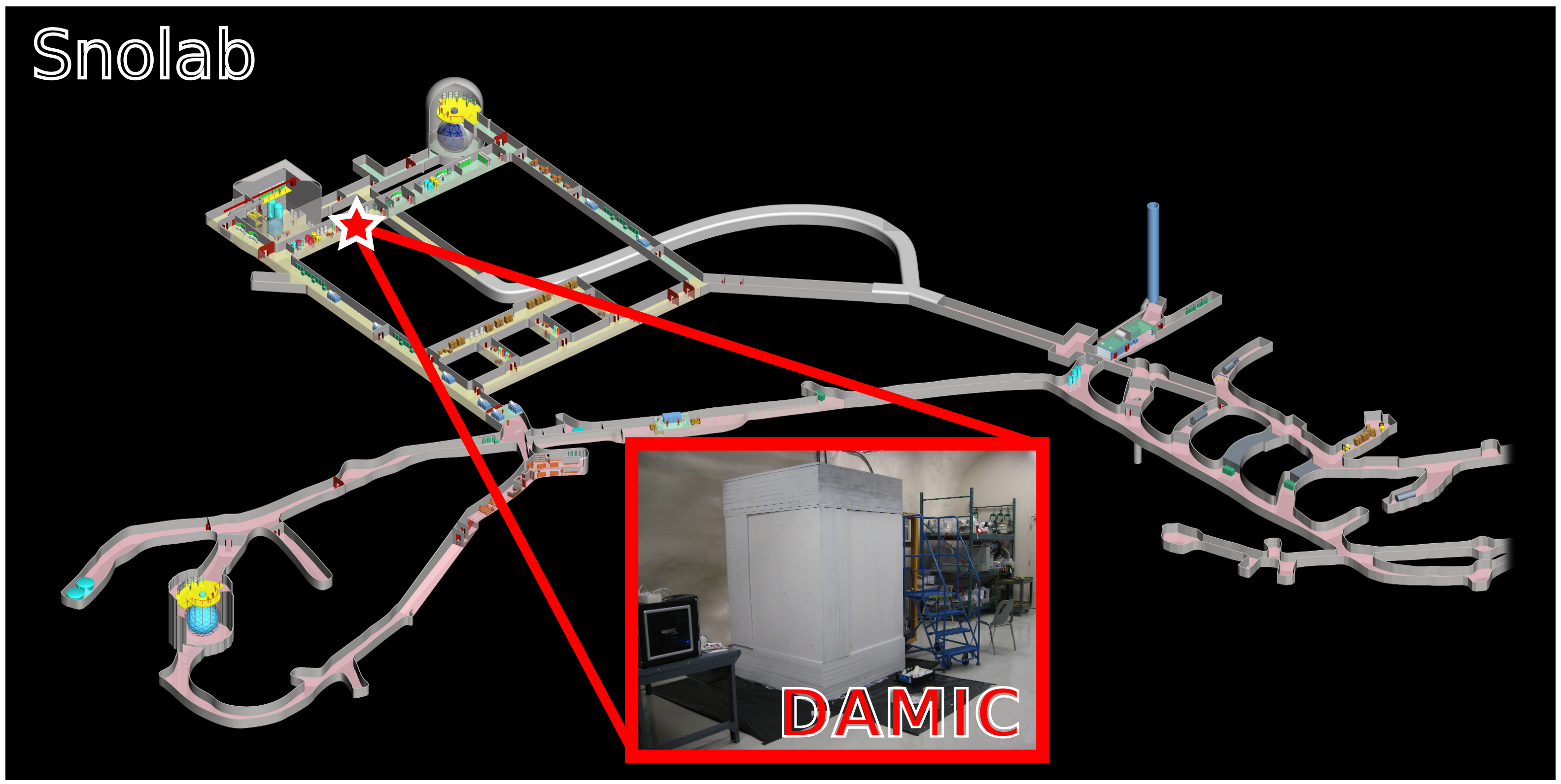


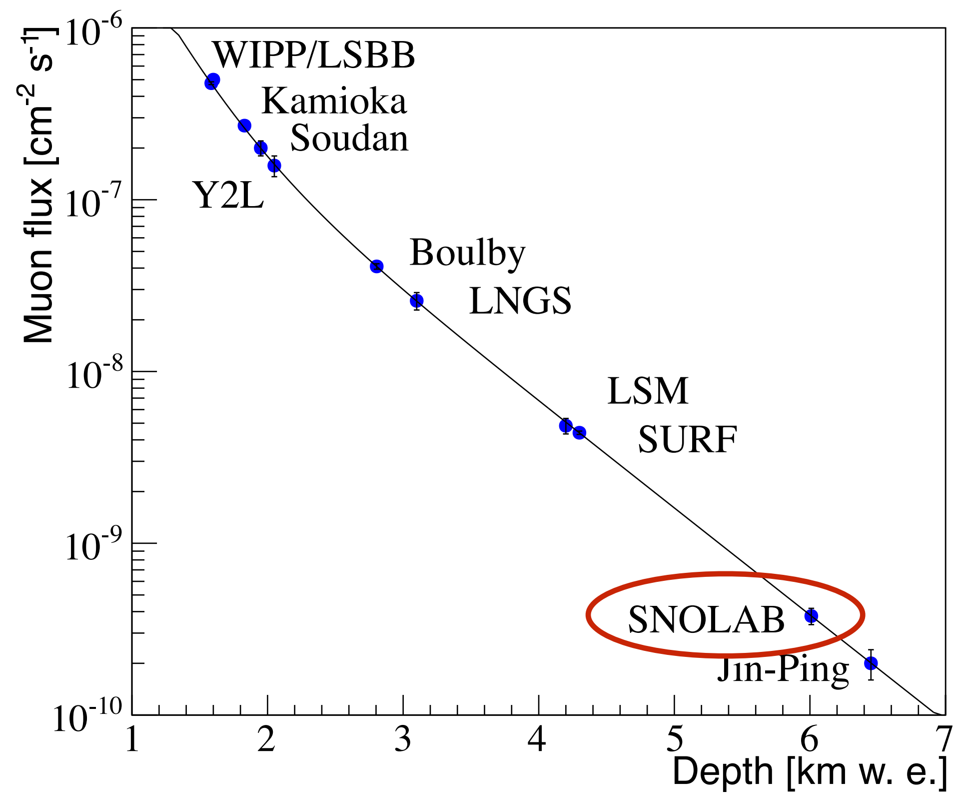
- ➤ noise limited by read out
  - ➤ improved by CDS (Correlated Double Sampling)
  - ➤ limited to 2e- with the current electronics



STATUS

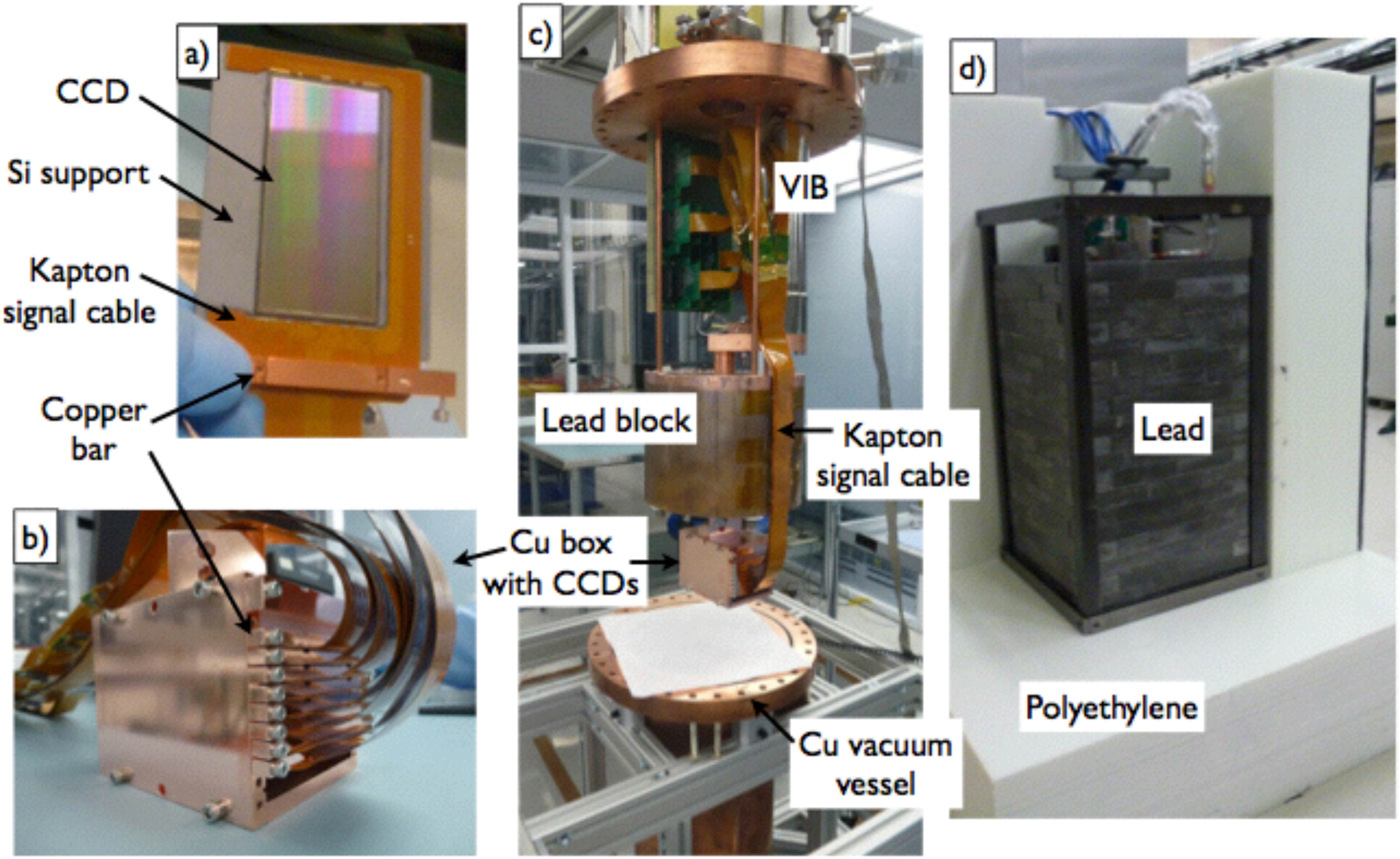
DAMIC AT SNOLAB



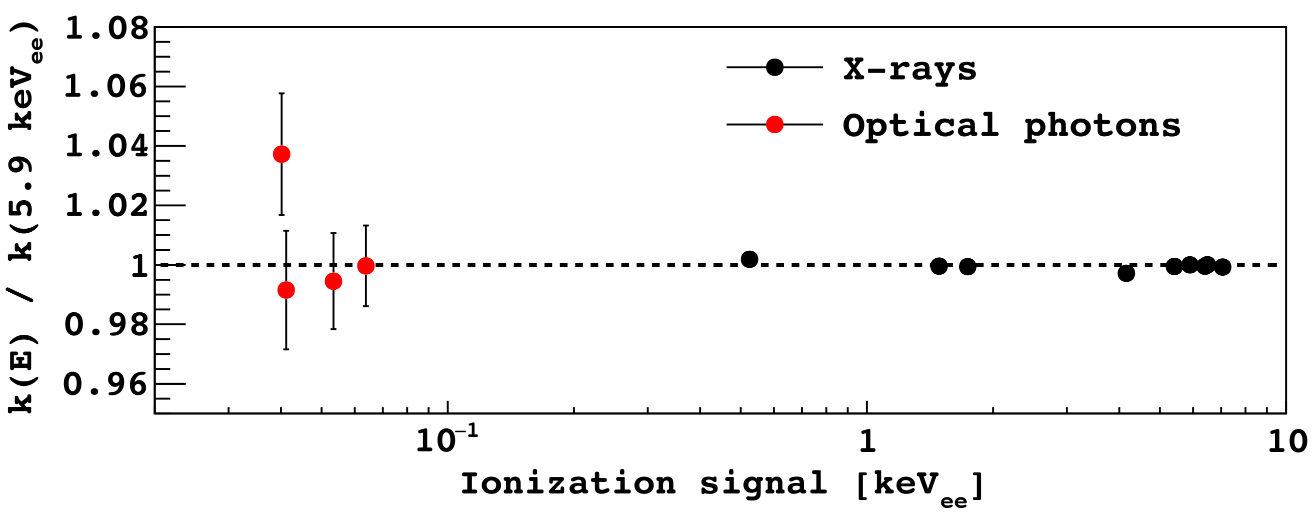


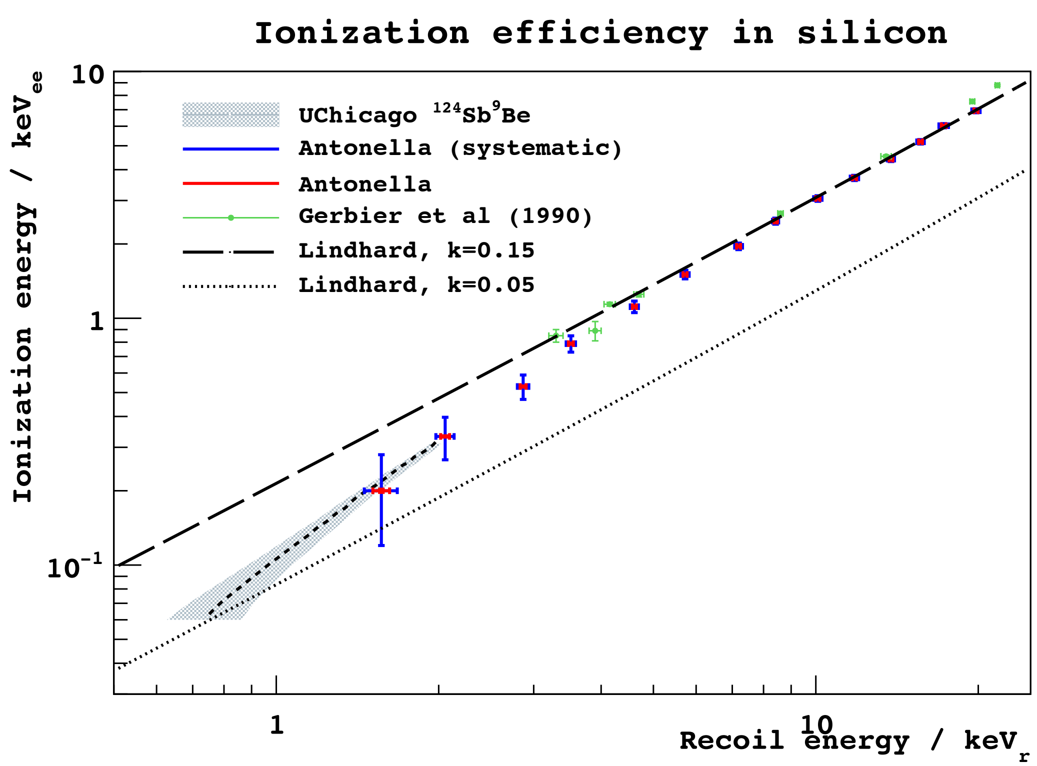
- 2 km down a mine (6000m water equivalent)
- muon rate < 0.27 $m^{-2}\ d^{-1}$ (1μ /m^2 every 3 days !)

DAMIC DETECTOR



CALIBRATION





Electronic recoil:

➤ linear response down to 40 eVee (e- recoil with X-ray and LED at low E)

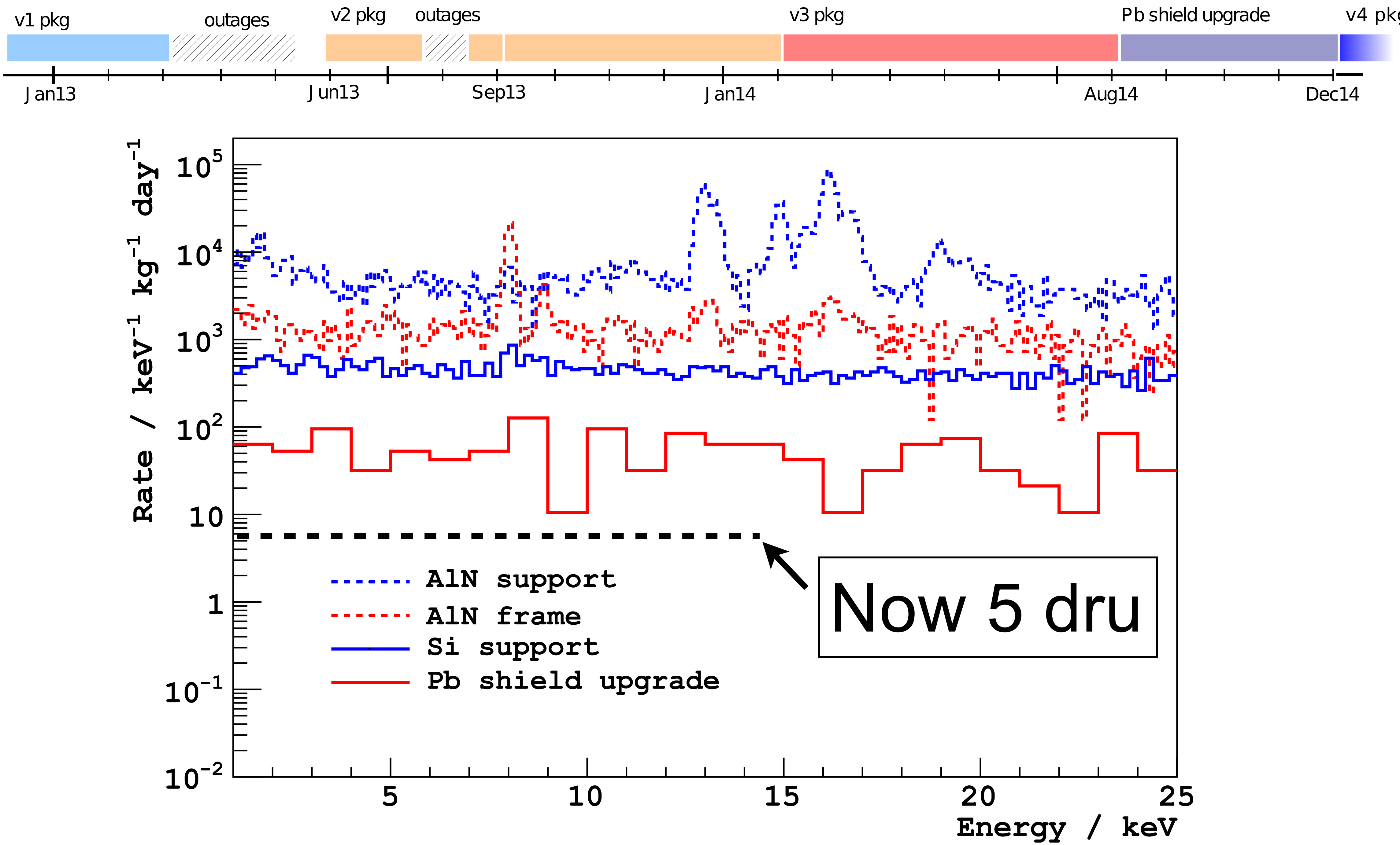
➤ resolution of 54 eVee at 5.9keVee (Fano factor of 0.133)

Nuclear recoil:

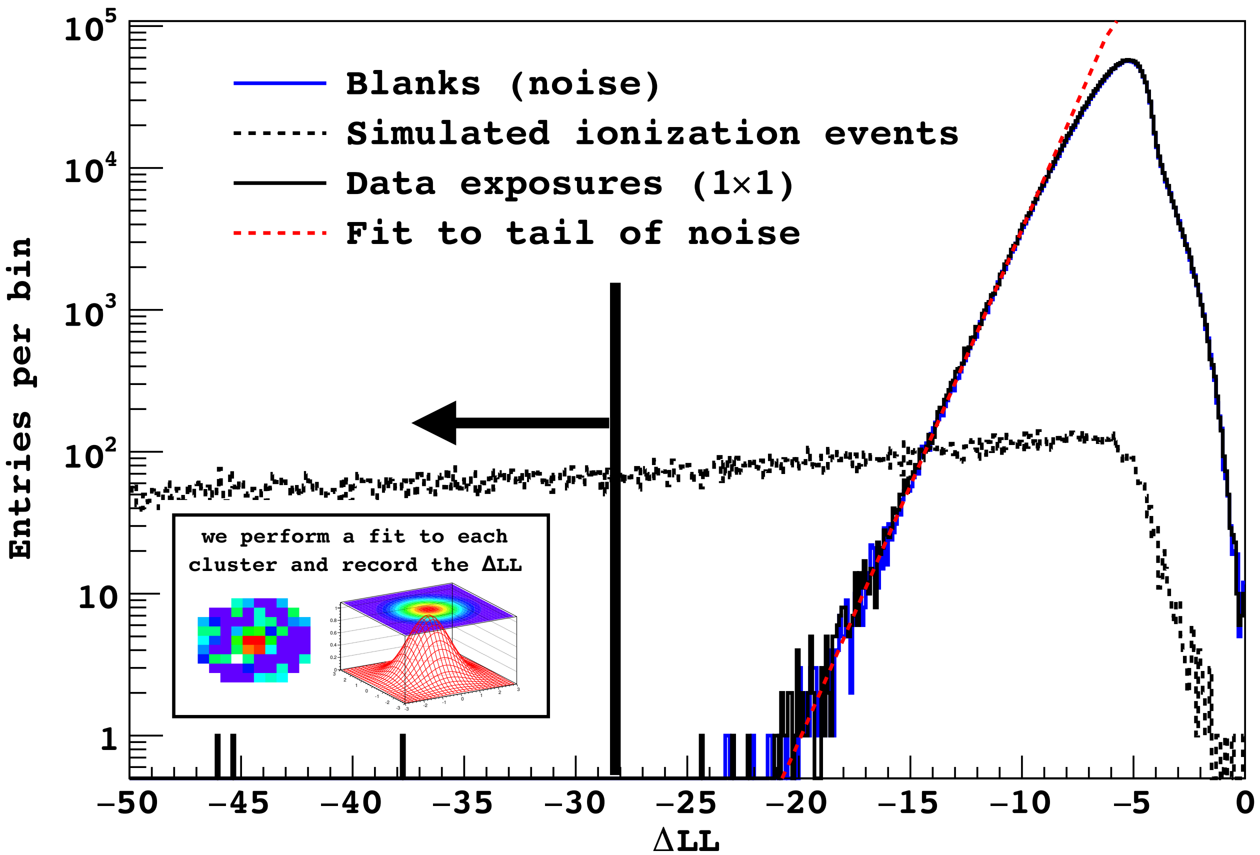
➤ fast neutron source (2-20 keVnr) photoneutron (0.7-2 keVnr) *(Phys. Rev. D 94, 082007)*

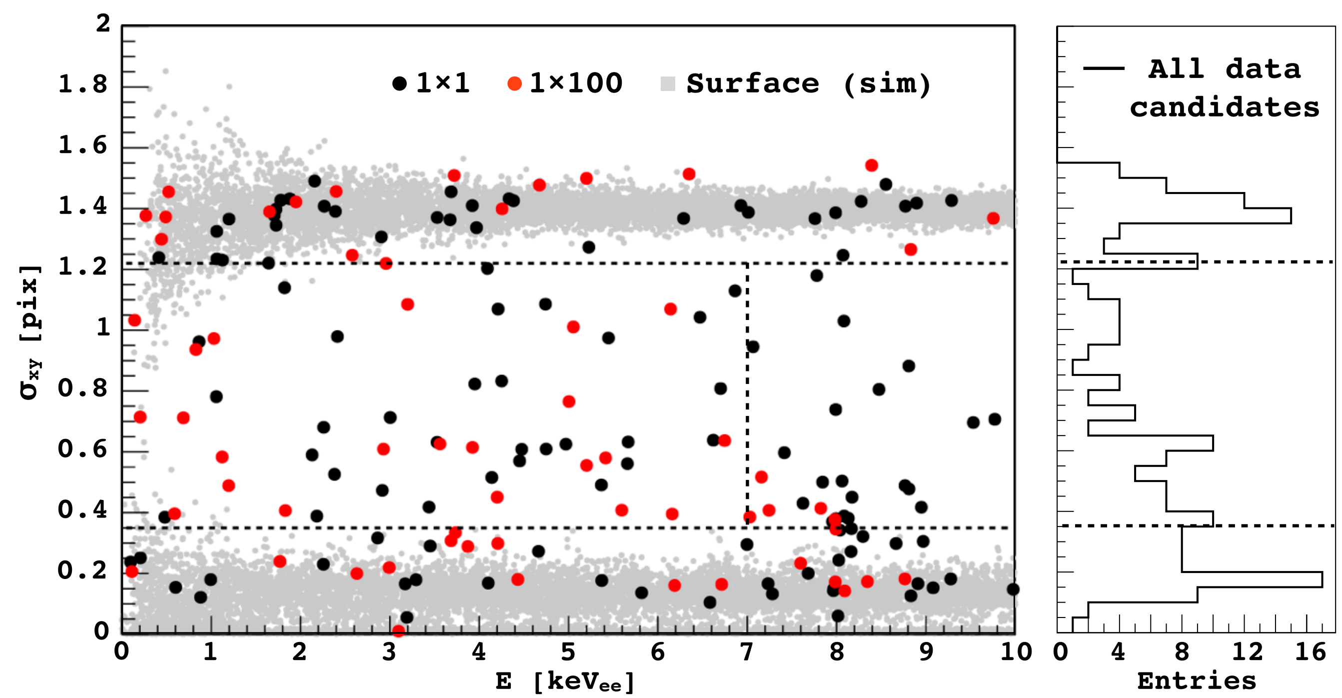
➤ Deviation from Lindhard model (at low E)

DAMIC BACKGROUND SPECTRUM



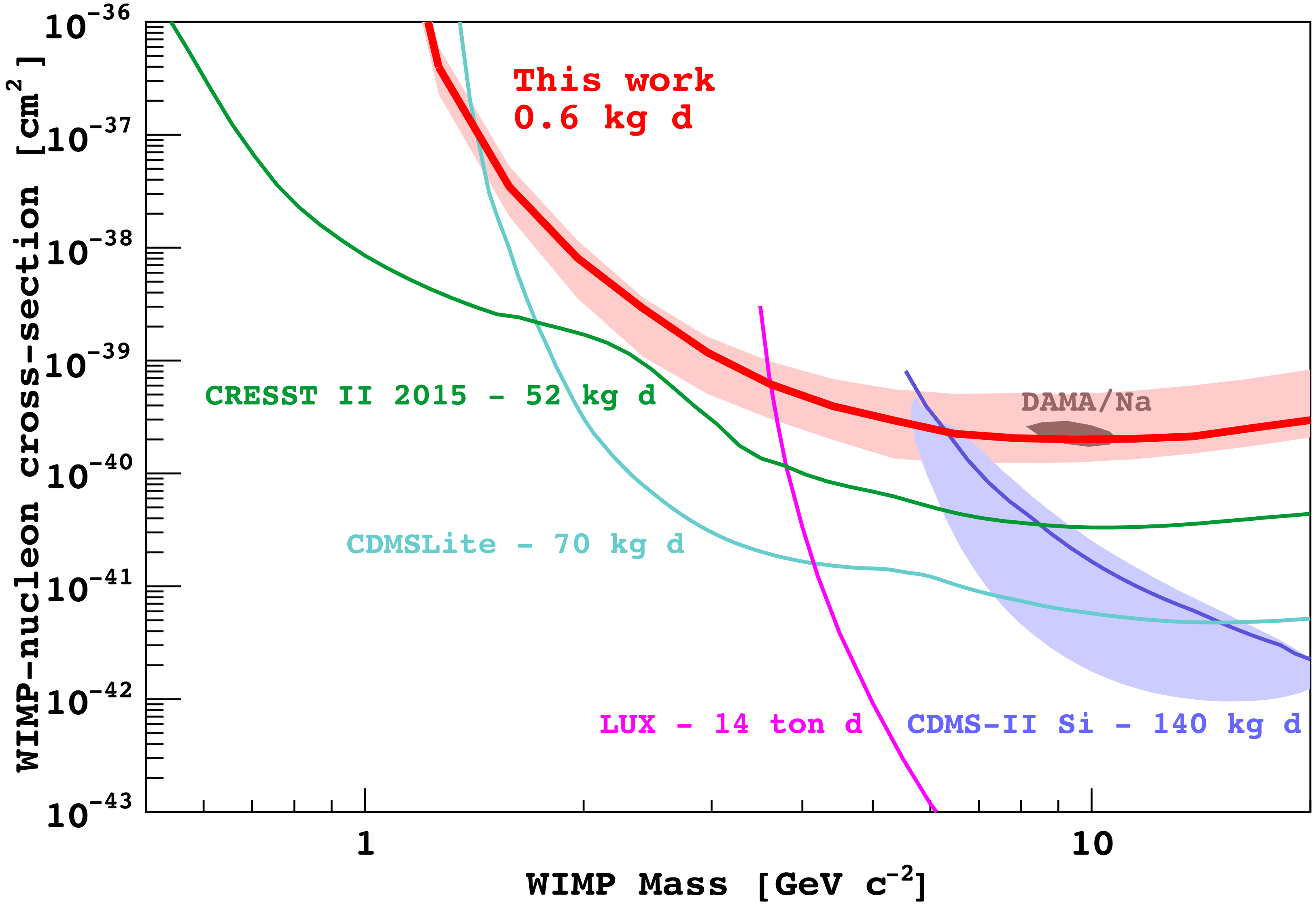
ANALYSIS STEPS





1. data selection (E < 10 keVee, noisy pixel)
2. find hits with LL clustering algo. (comparison bkg vs bkg+signal)
3. exclusion of surface events
4. fit of the candidate spectrum

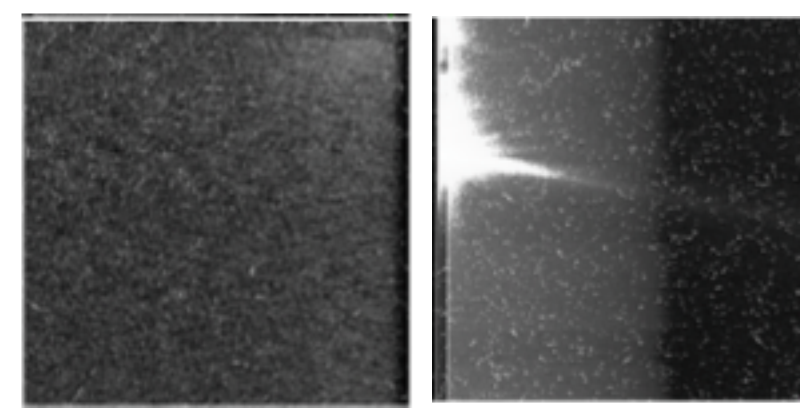
RESULTS



- compatible background hypothesis (Compton scatt.)
- sensitivity at low mass WIMP ($m_x < 10$ GeV/c^2)
- exclusion of a part of CDMSII signal with same target (Si)

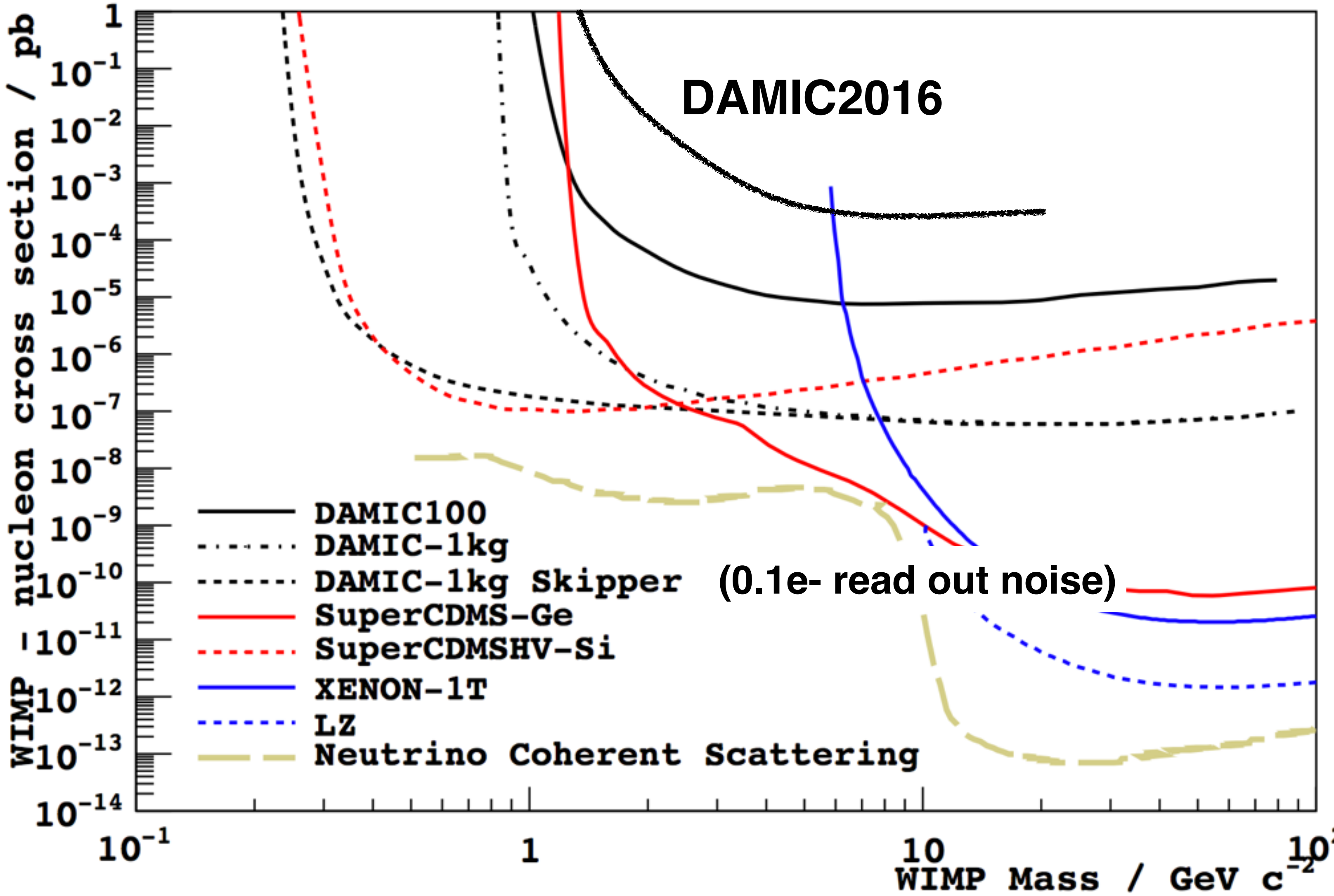
STATUS OF OPERATION

- April 2016: installation of 6 new CCDs (8 total)
  - replaced copper box and modules
  - replacement of parts of the shielding with ancient lead (Roman lead from Modane)
  - cleaning and etching
- Issues appeared on 2 CCDs
  - Tests/fix at Fermilab since then
  - due to mechanical stress
- 10 CCDs (~60g) to be installed in January 2017



FUTURE PLANS

DAMIC FORESEEN SENSITIVITY



- target mass to **kg scale**
- detector threshold down to ~**8 eVee (~ 0.3e-)**
- background ~ **0.01 d.r.u.**

INCREASE MASS

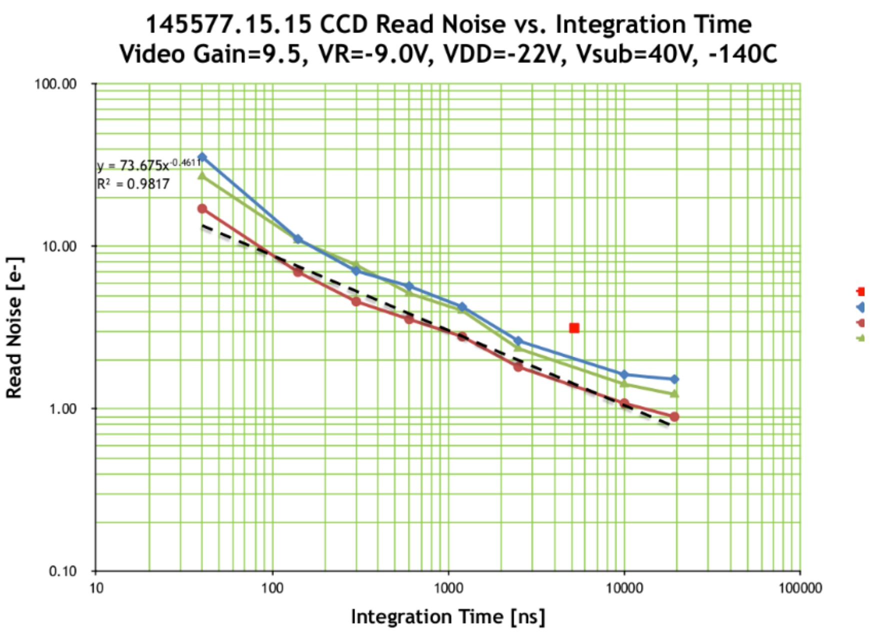
- current mass: 5.8g /CCD (DAMIC100=>18CCDs)
- goal: increase CCD mass 3X (DAMIC1000=>~50CCDs)
  - ~1mm with same fabrication process
    ~ few mm with new fabrication process (dev. at U. Chicago)
  - larger format :4k x 4x —> 6k x 6k

kg scale DAMIC is feasible with current technology in a short time

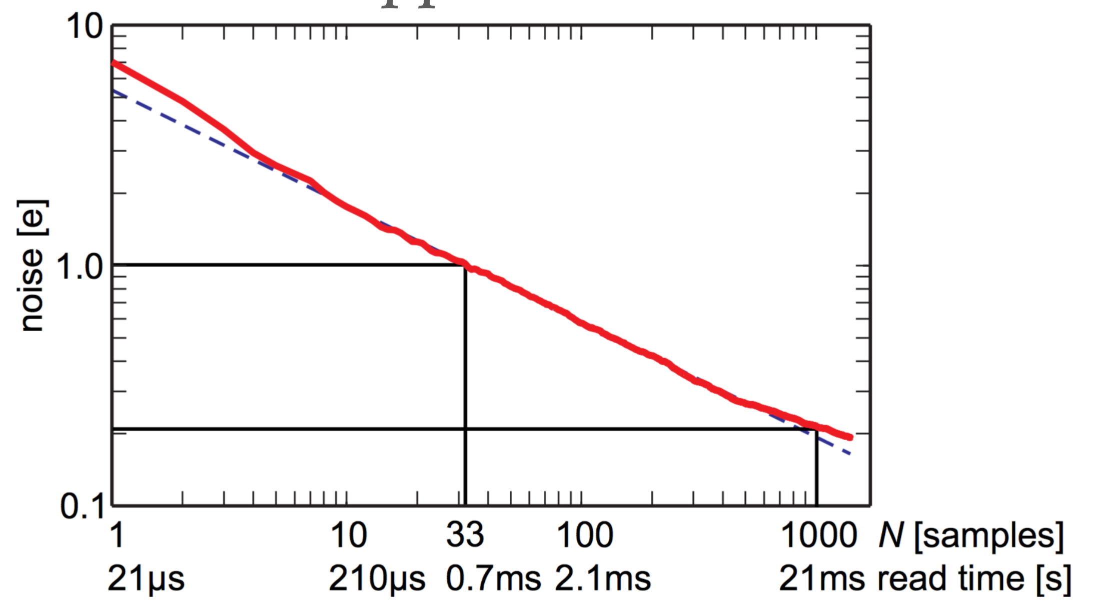
LOWER THE ENERGY THRESHOLD & BACKGROUND

➤ read out noise goal: <0.3e- (w.r.t. 2 now)

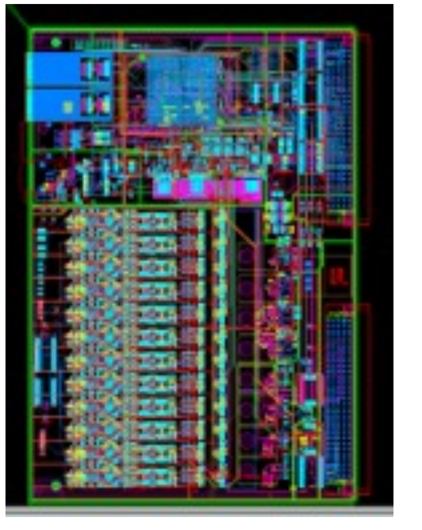
first amplifier optimisation



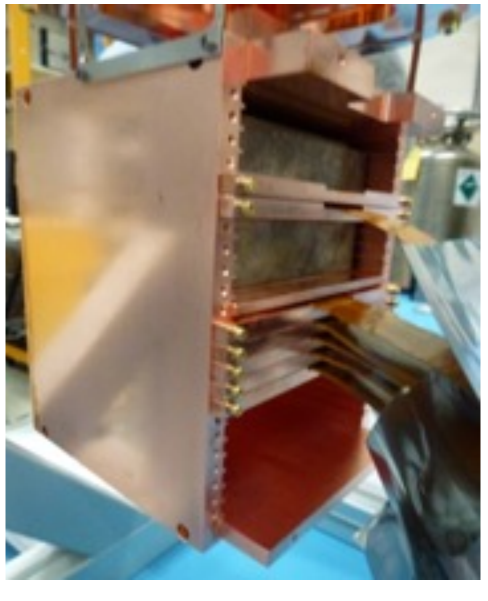
skipper CCD



Digital filtering



➤ radio background goal: 0.01 d.r.u (w.r.t. 5 now)

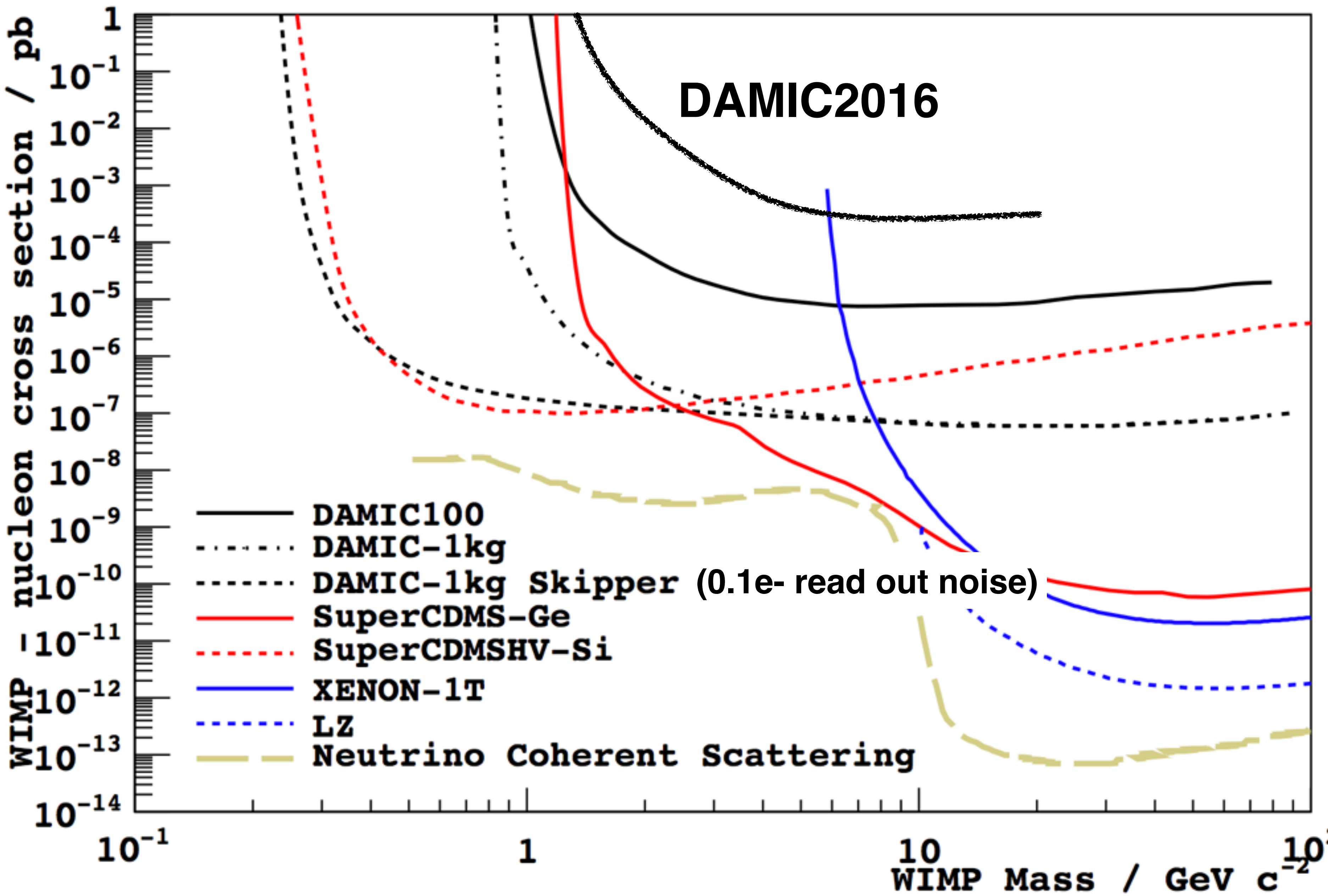


➤ Use electroformed copper

➤ already one module in test

➤ eventually limited by ^{32}Si background

DAMIC FORESEEN SENSITIVITY



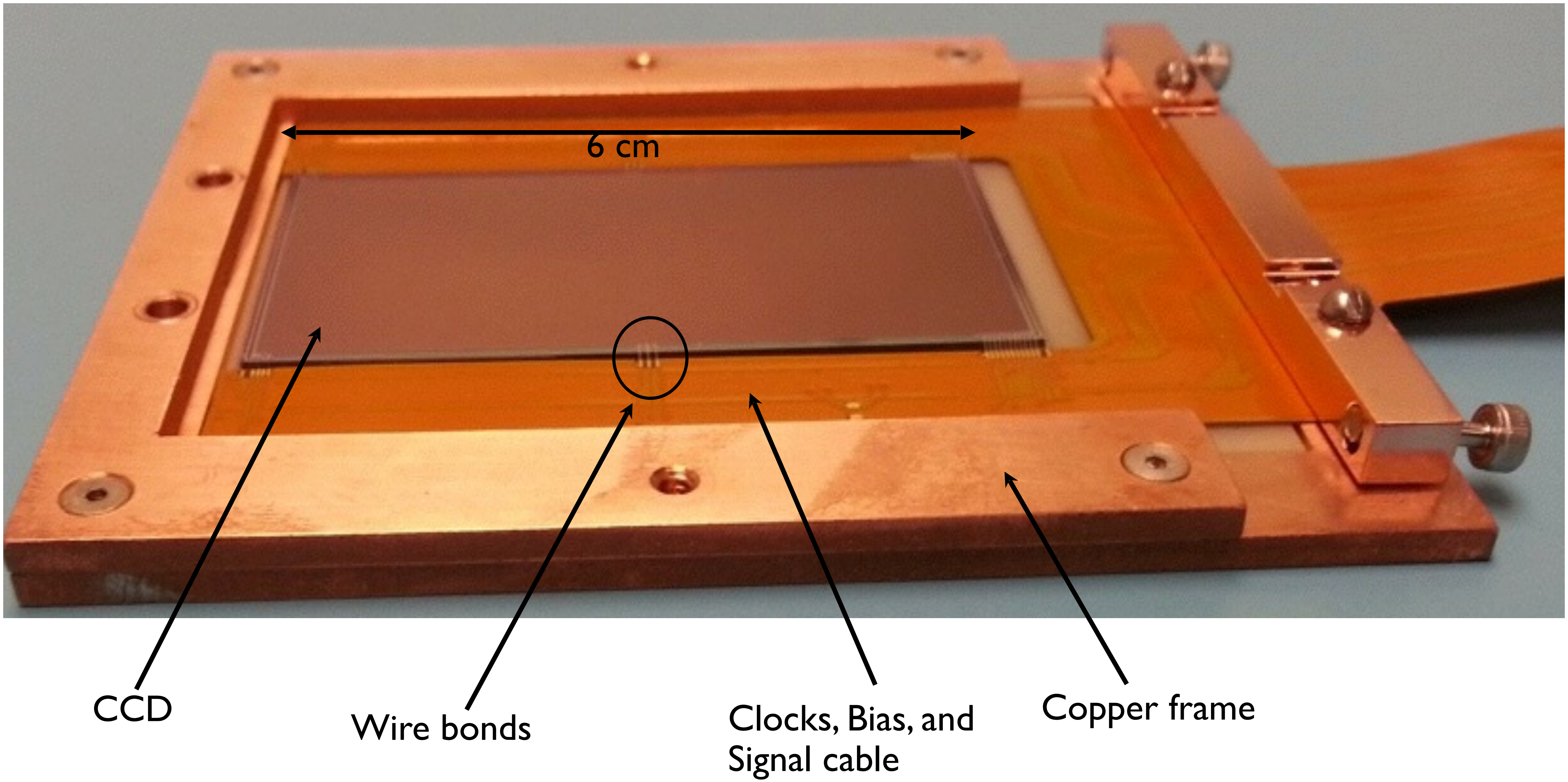
- target mass to **kg scale**
- detector threshold down to ~**8 eVee (~ 0.3e⁻)**
- background ~ **0.01 d.r.u.**

CONCLUSION

- CCD is an efficient DM detector for low mass WIMP
  - stable operation
  - very good energy & spatial resolution
- After a phase of development / bkg reduction DAMIC has released competitive limits
- Currently upgrading to DAMIC100
- Development for DAMIC1KG:
  - electronics to reduce readout noise
  - CCD fabrication to increase the mass

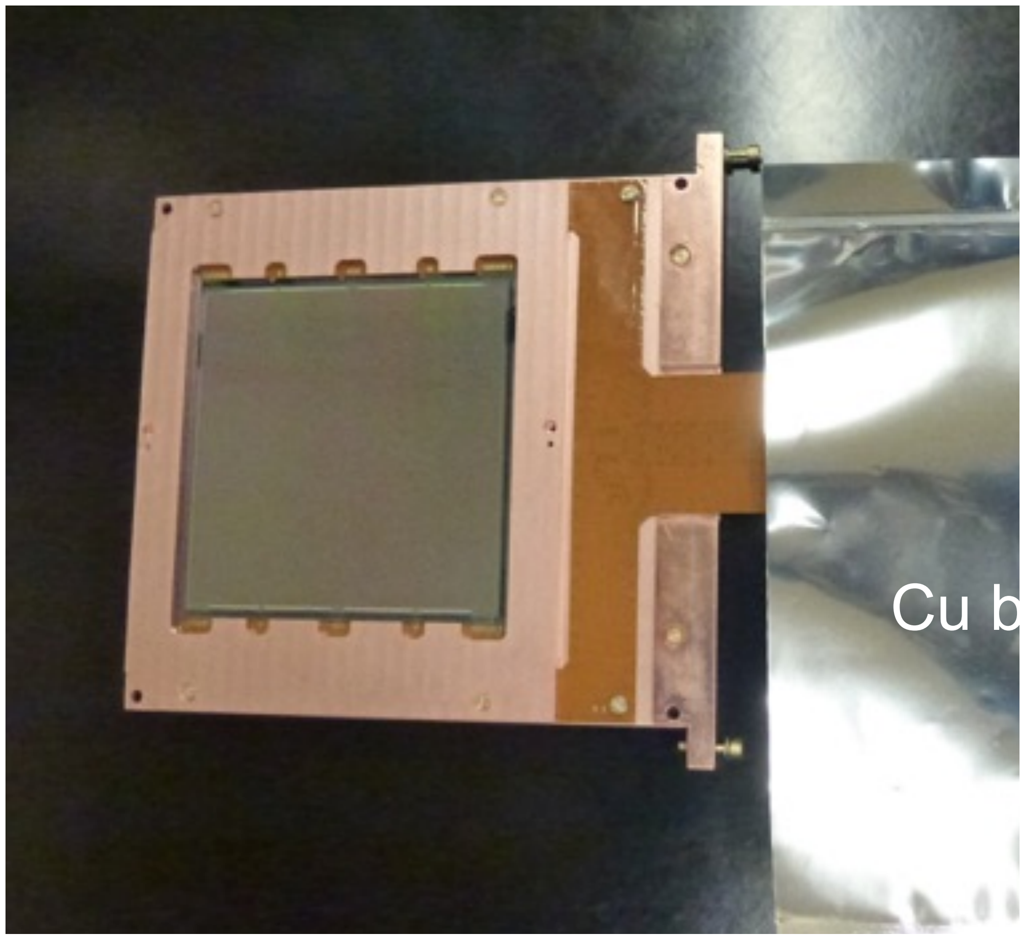
THANKS FOR YOUR ATTENTION

CCD

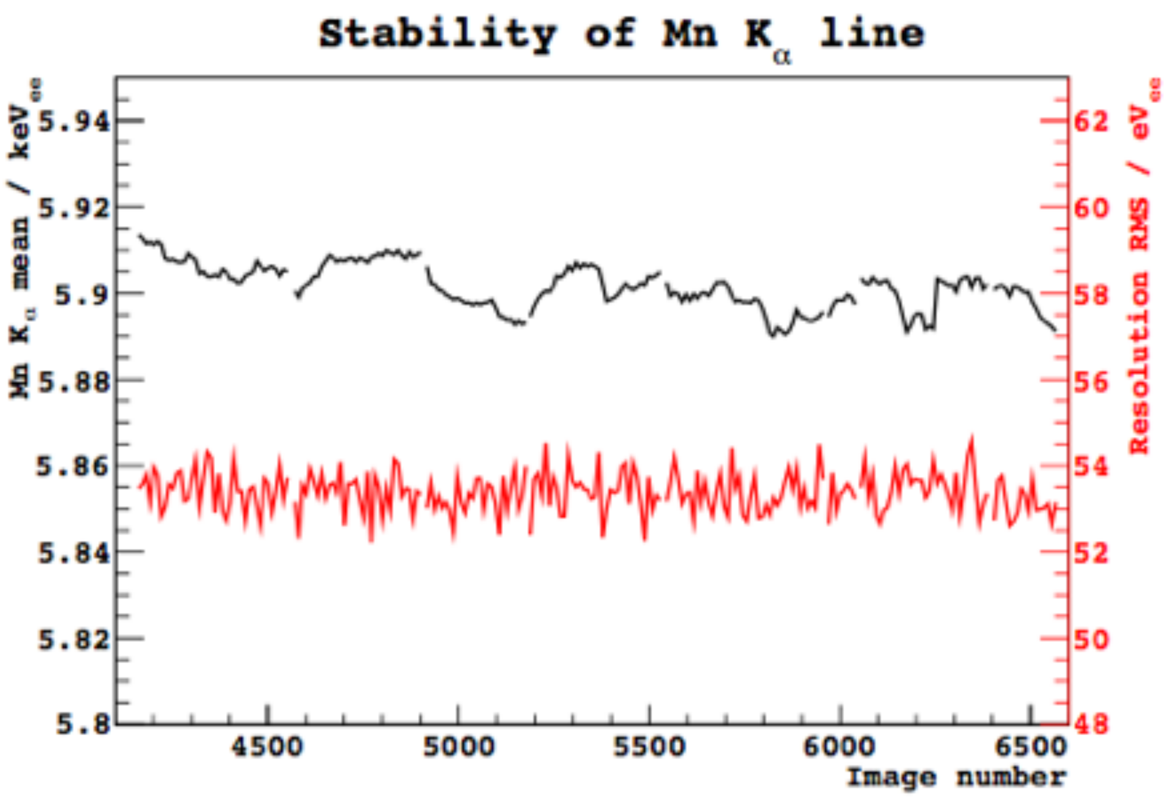

6 cm
CCD
Wire bonds
Clocks, Bias, and Signal cable
Copper frame

SIGNAL HYPOTHESIS

CCD



Stability


Stability of Mn K_α line
Mn K_α mean / keV_{ee}
Resolution RMS / eV_{ee}
5.94
5.92
5.9
5.88
5.86
5.84
5.82
5.8
62
60
58
56
54
52
50
48
4500
5000
5500
6000
6500
Image number

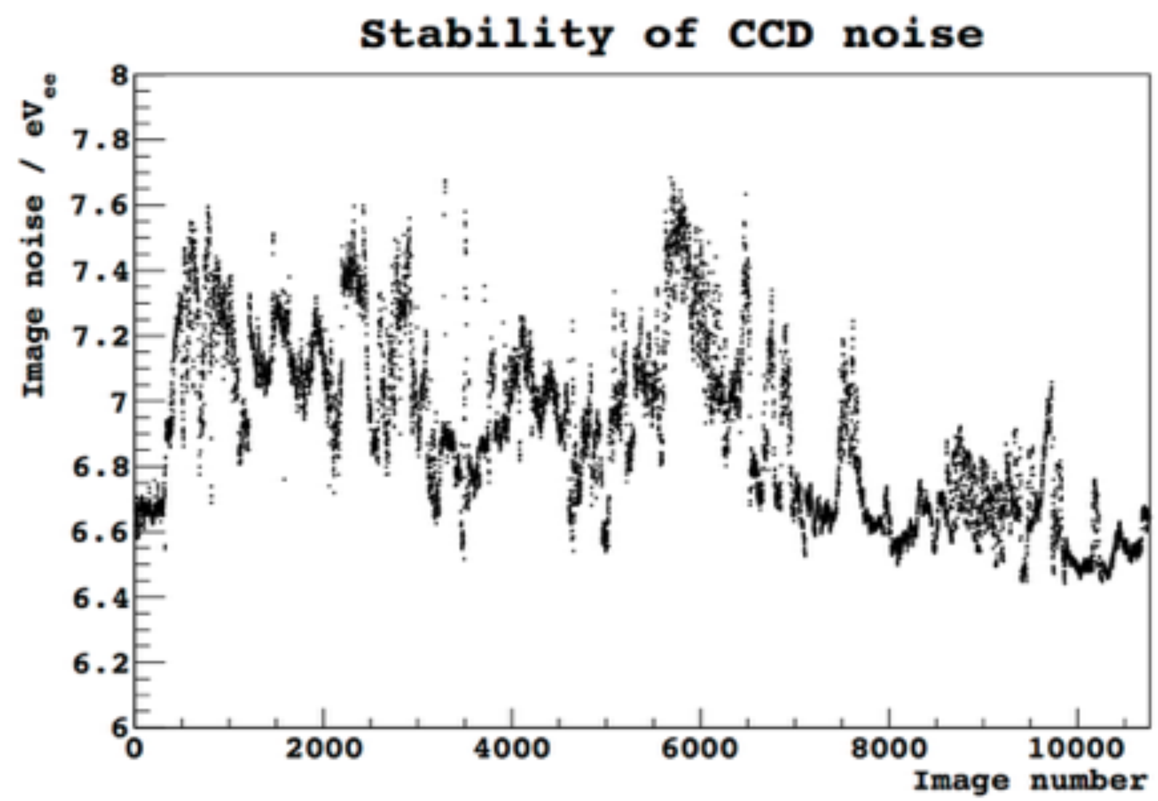
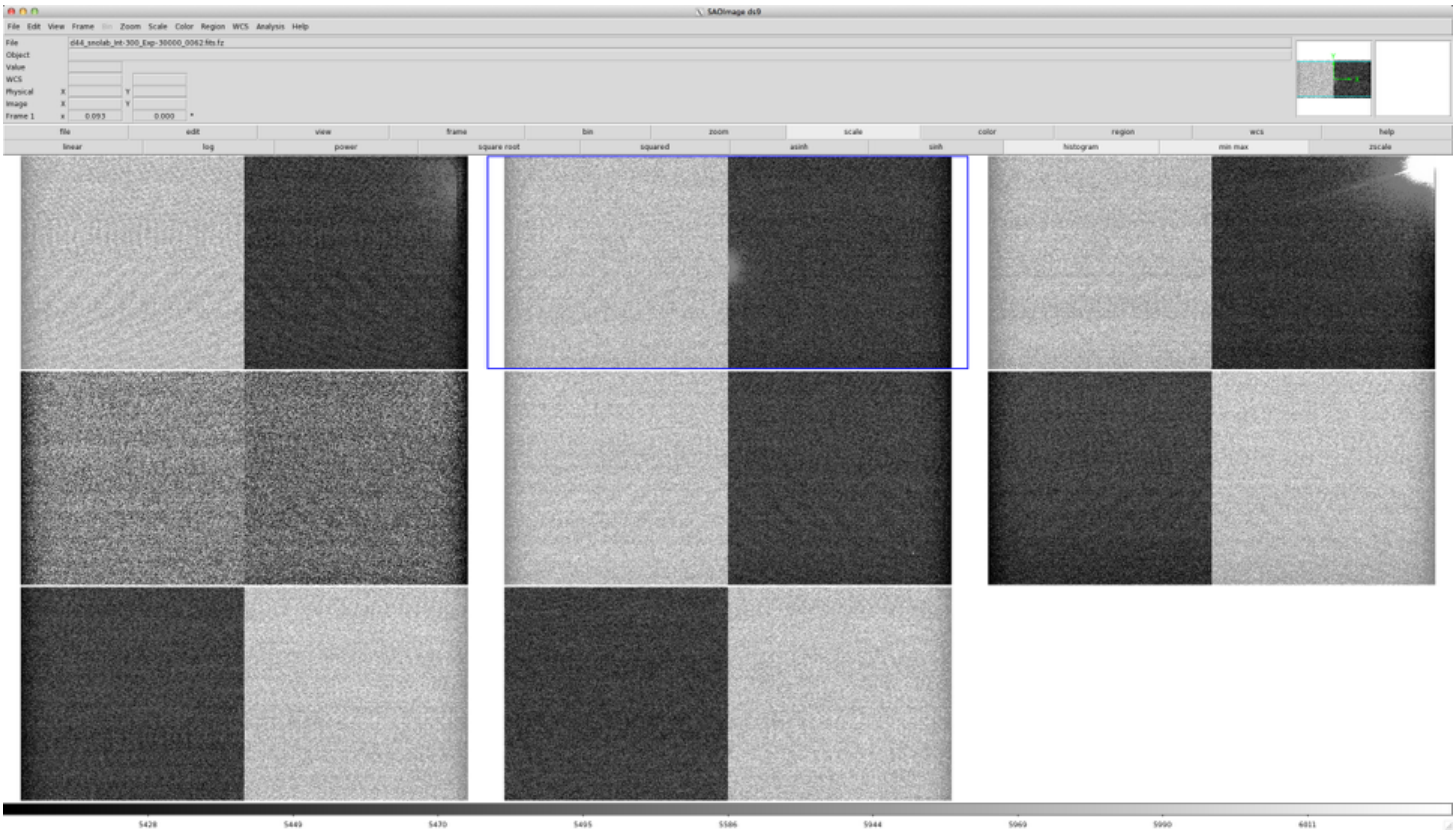
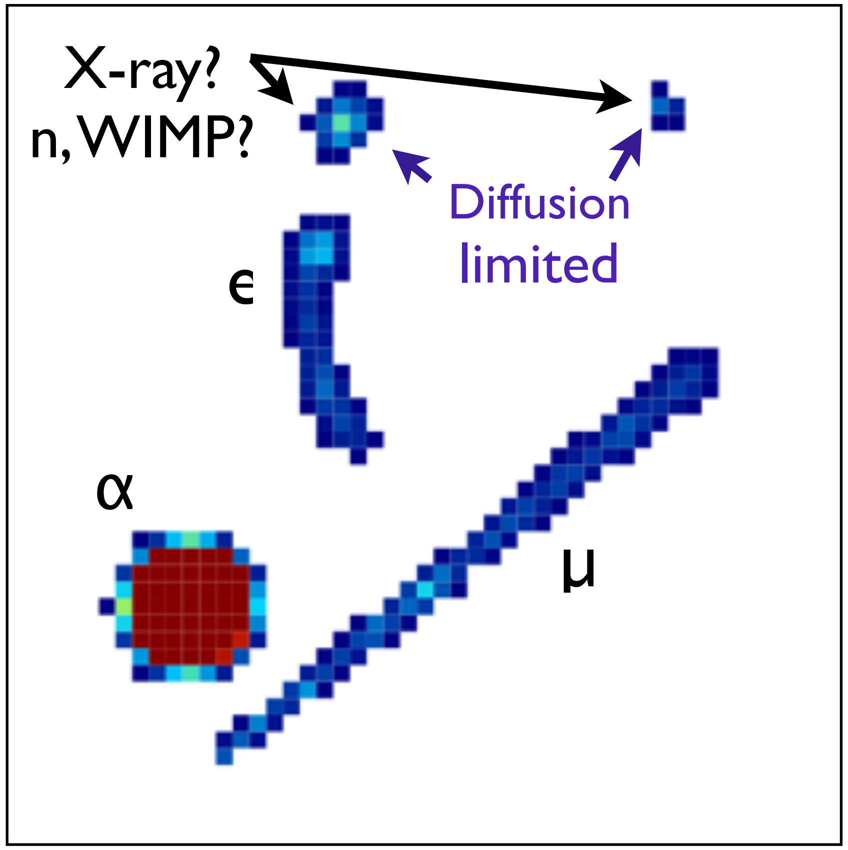

Stability of CCD noise
Image noise / eV_{ee}
8
7.8
7.6
7.4
7.2
7
6.8
6.6
6.4
6.2
6
0
2000
4000
6000
8000
10000
Image number

image example

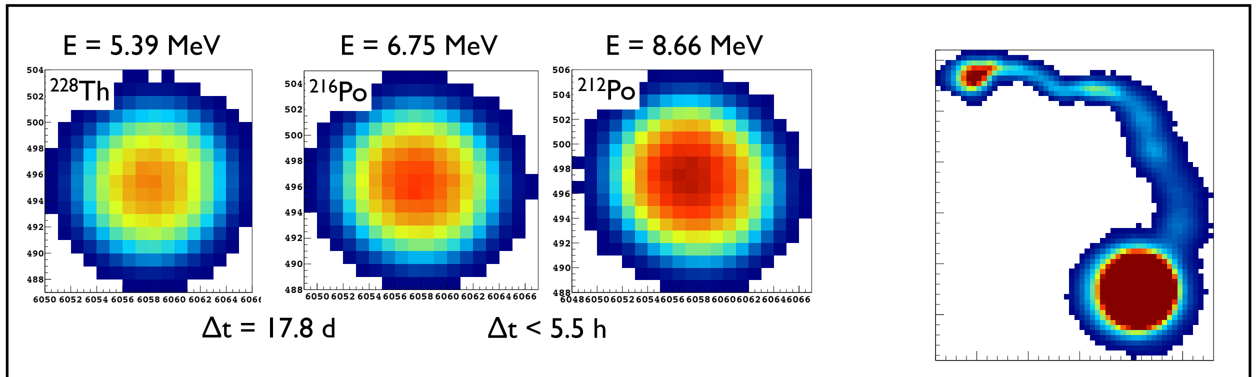


UNDERSTANDING BACKGROUND

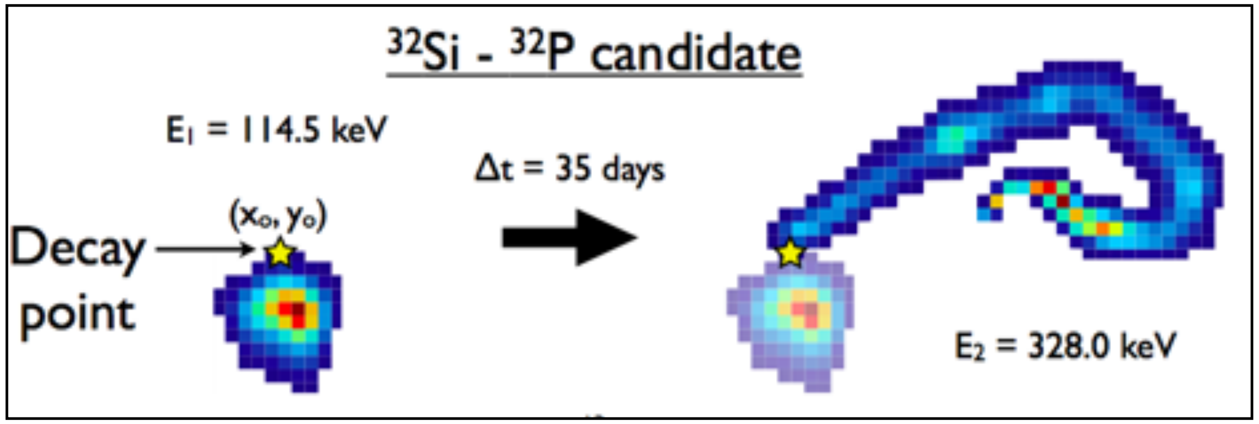
particle identification



decay chain

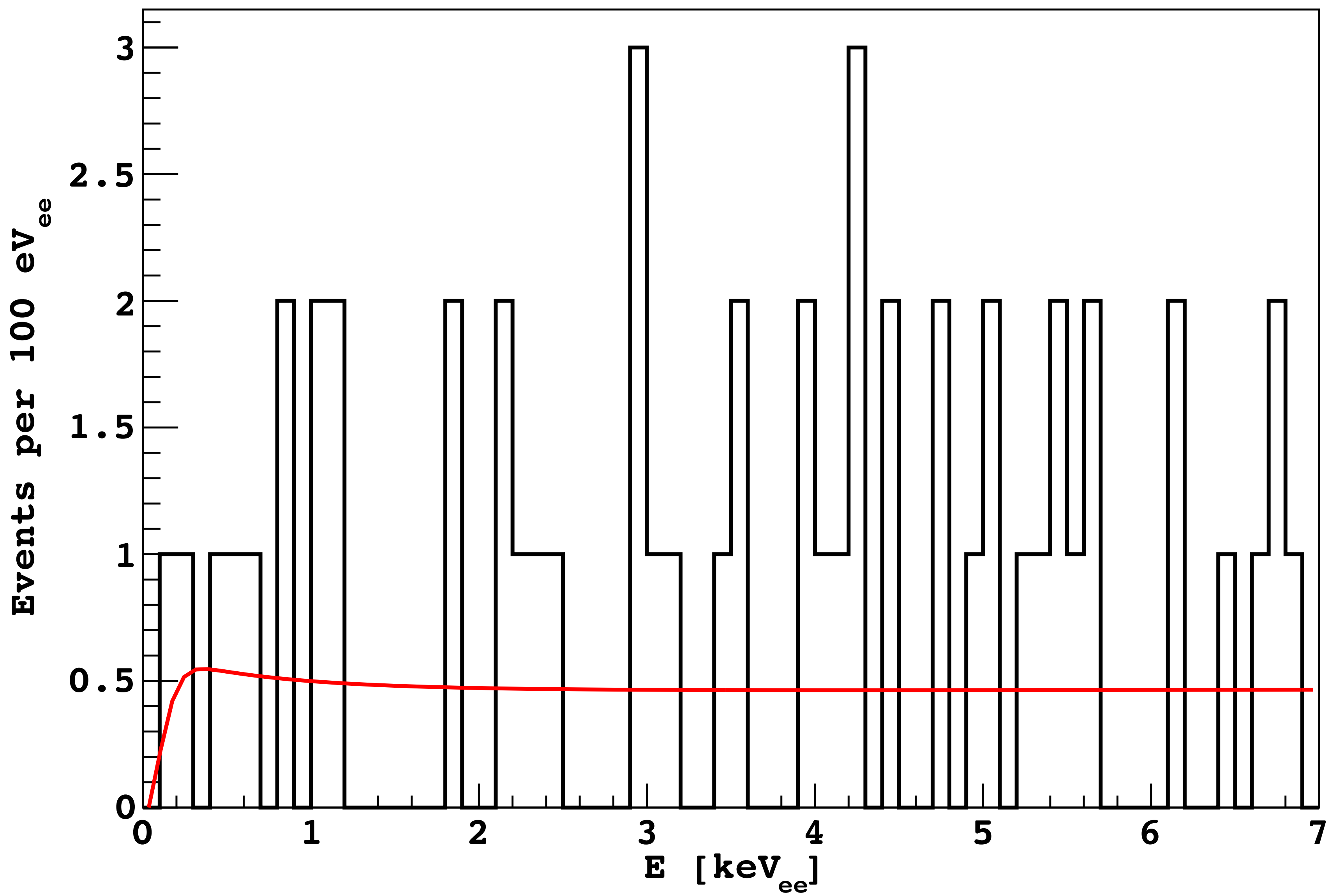


(a) Triple α sequence (b) α–β coincidence

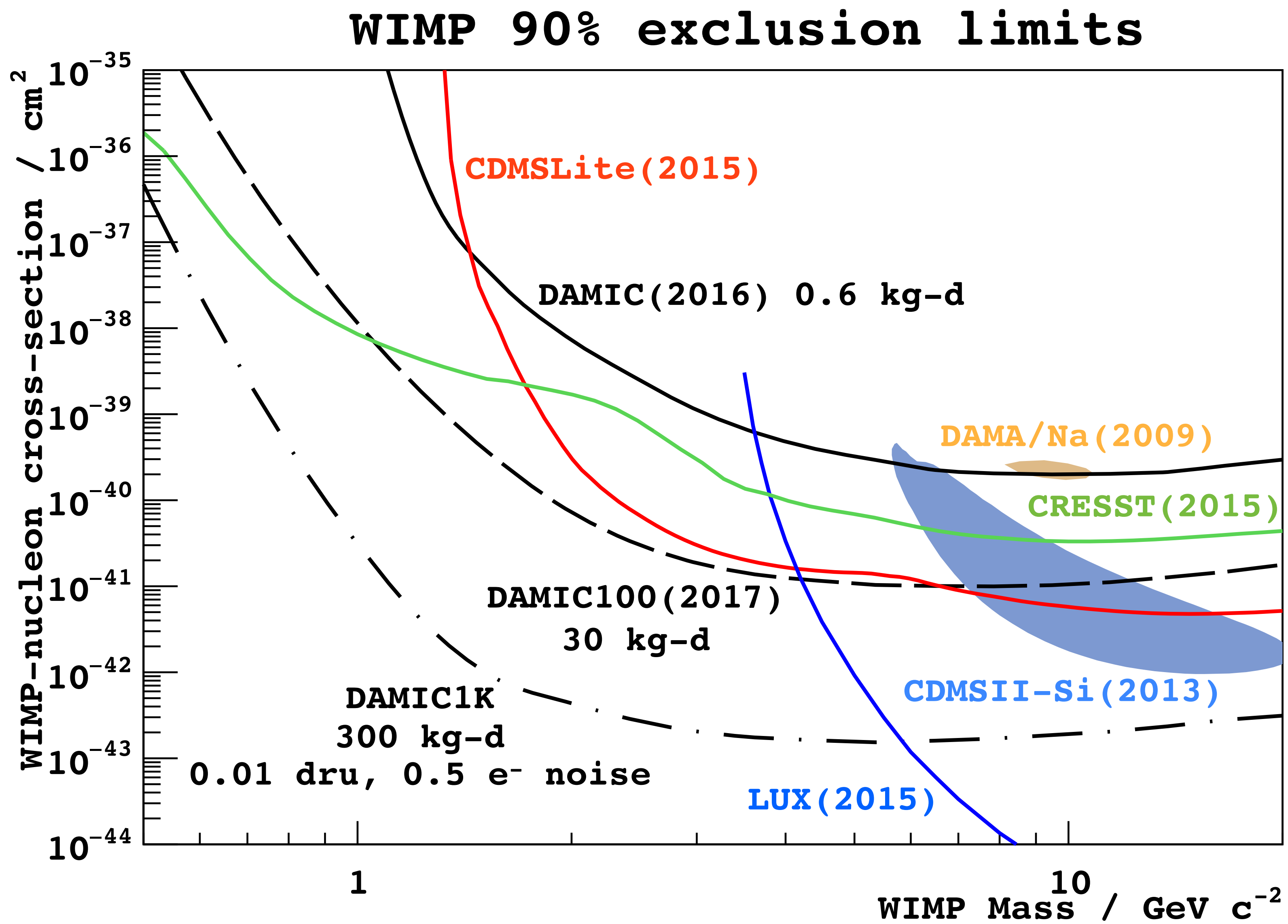


- Radiogenic background identification (2015 *JINST* **10** P08014)
  - Th and U contamination
  - ^{32}Si bkg estimation

DM candidate spectrum

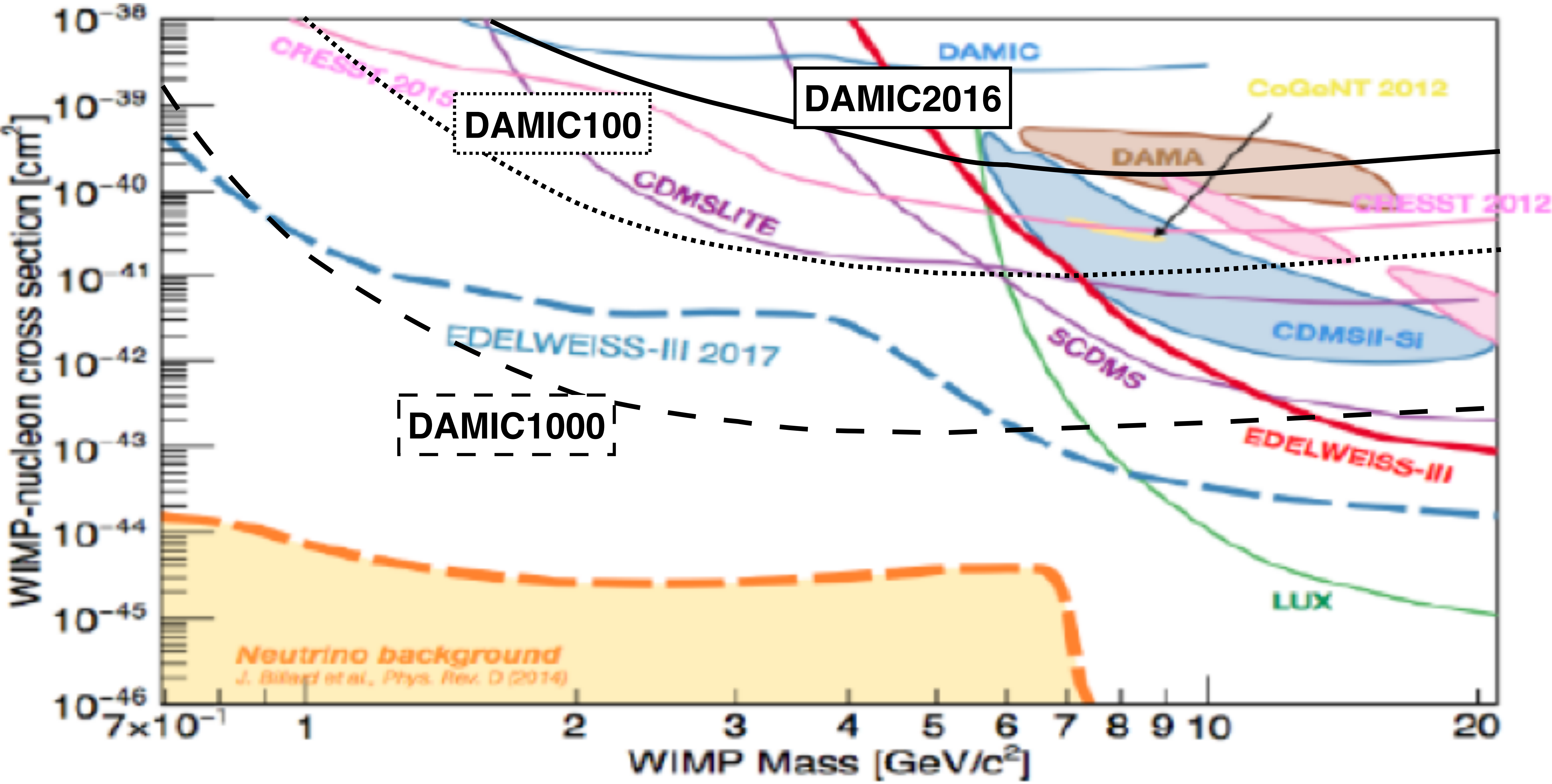


DAMIC FORESEEN SENSITIVITY

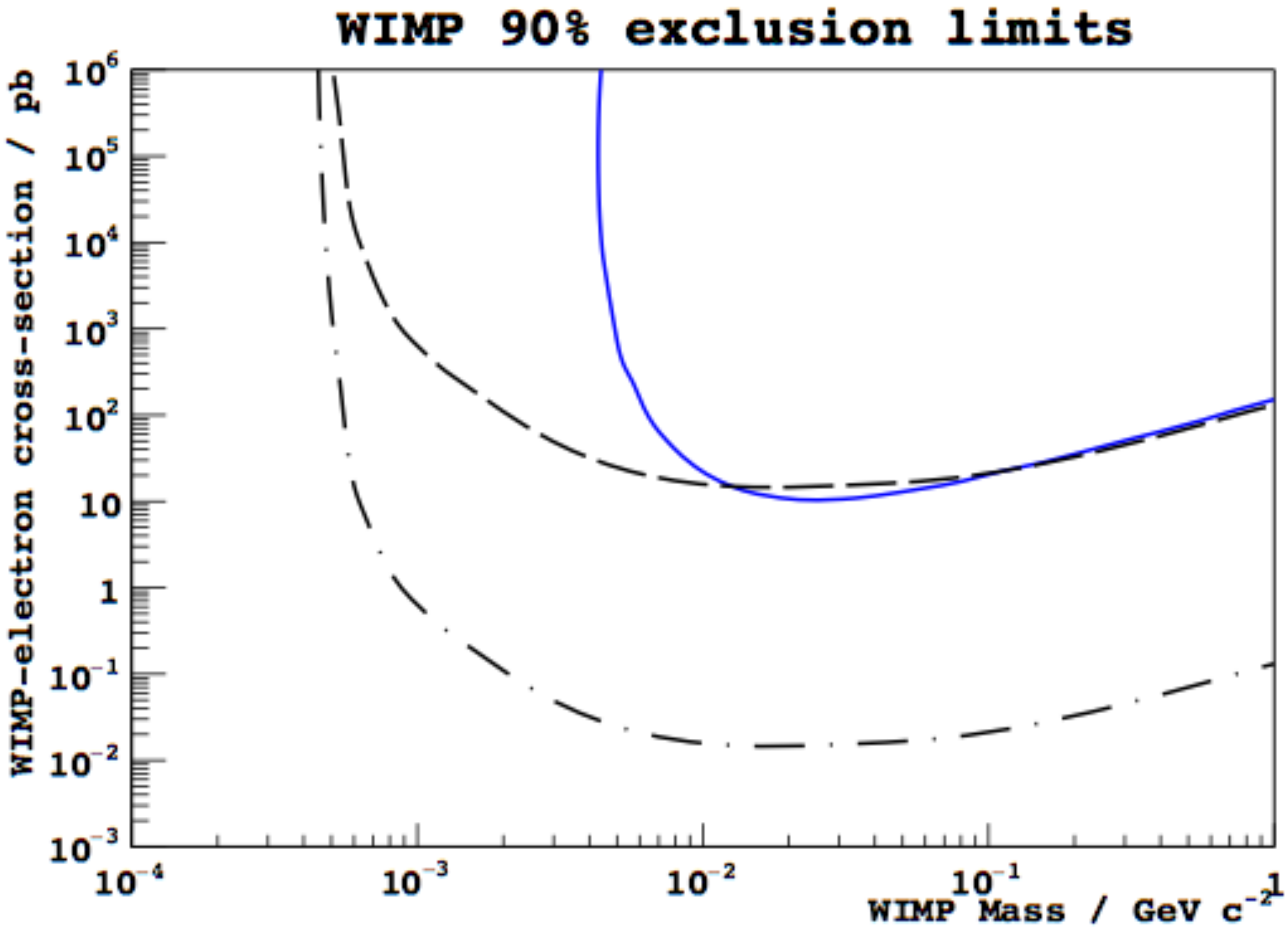


- target mass to **kg scale**
- detector threshold down to ~**8 eVee (~ 0.3e$^-$)**
- background ~ **0.01 d.r.u.**

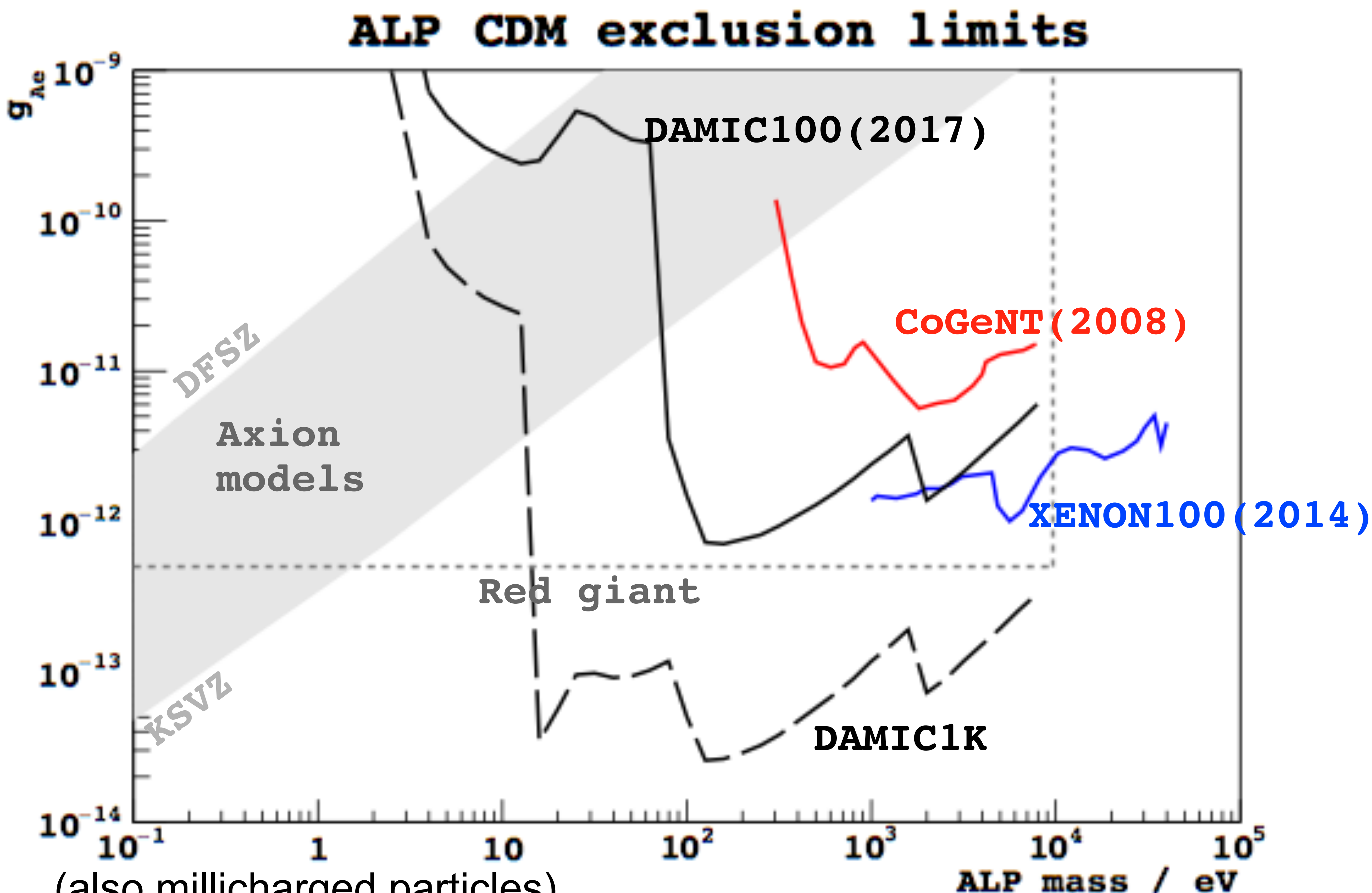
COMPARISON OF EXPECTED SENSITIVITY



Electron recoil



Axion like particle



(also millicharged particles)