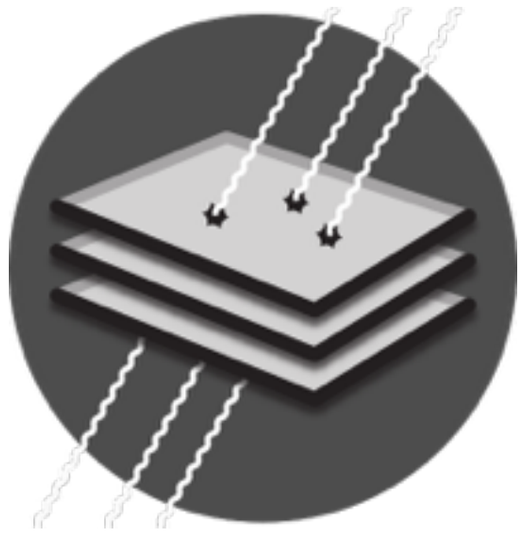


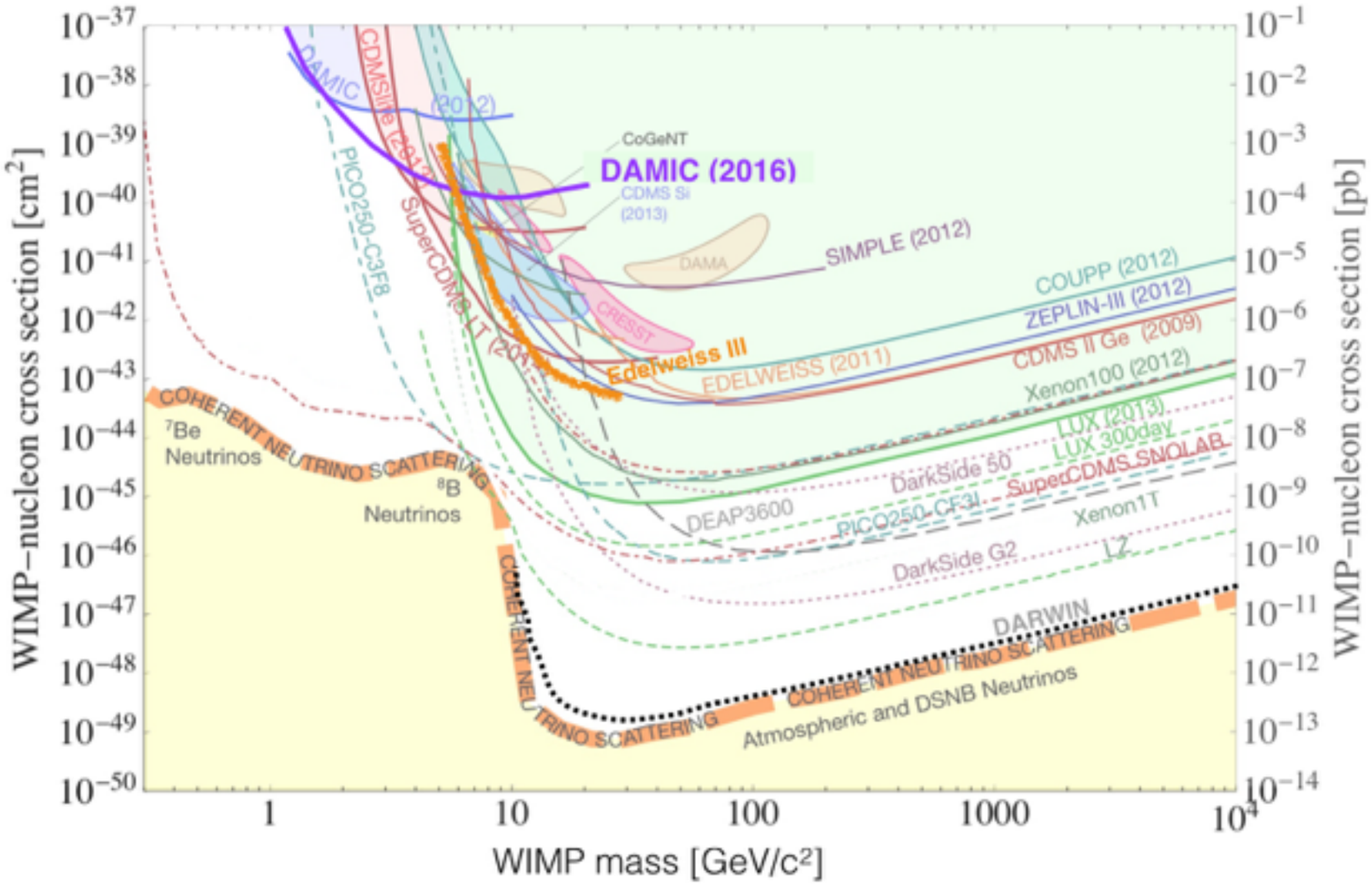
DAMIC

DARK MATTER IN CCD

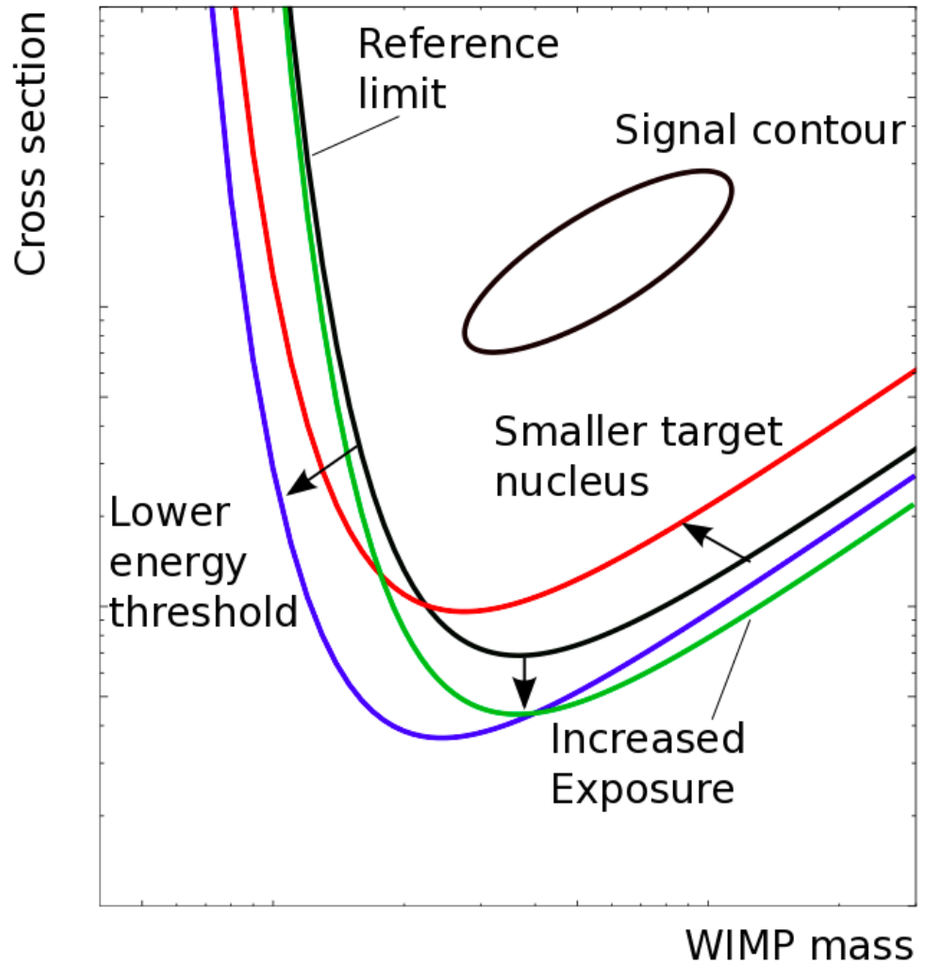
ROMAIN GAIOR (LPNHE PARIS)
FOR THE DAMIC COLLABORATION

*2017 **IDPASC** ANNUAL WORKSHOP (2017/10/13):*
FRONTIERS OF DARK MATTER RESEARCH

MOTIVATION



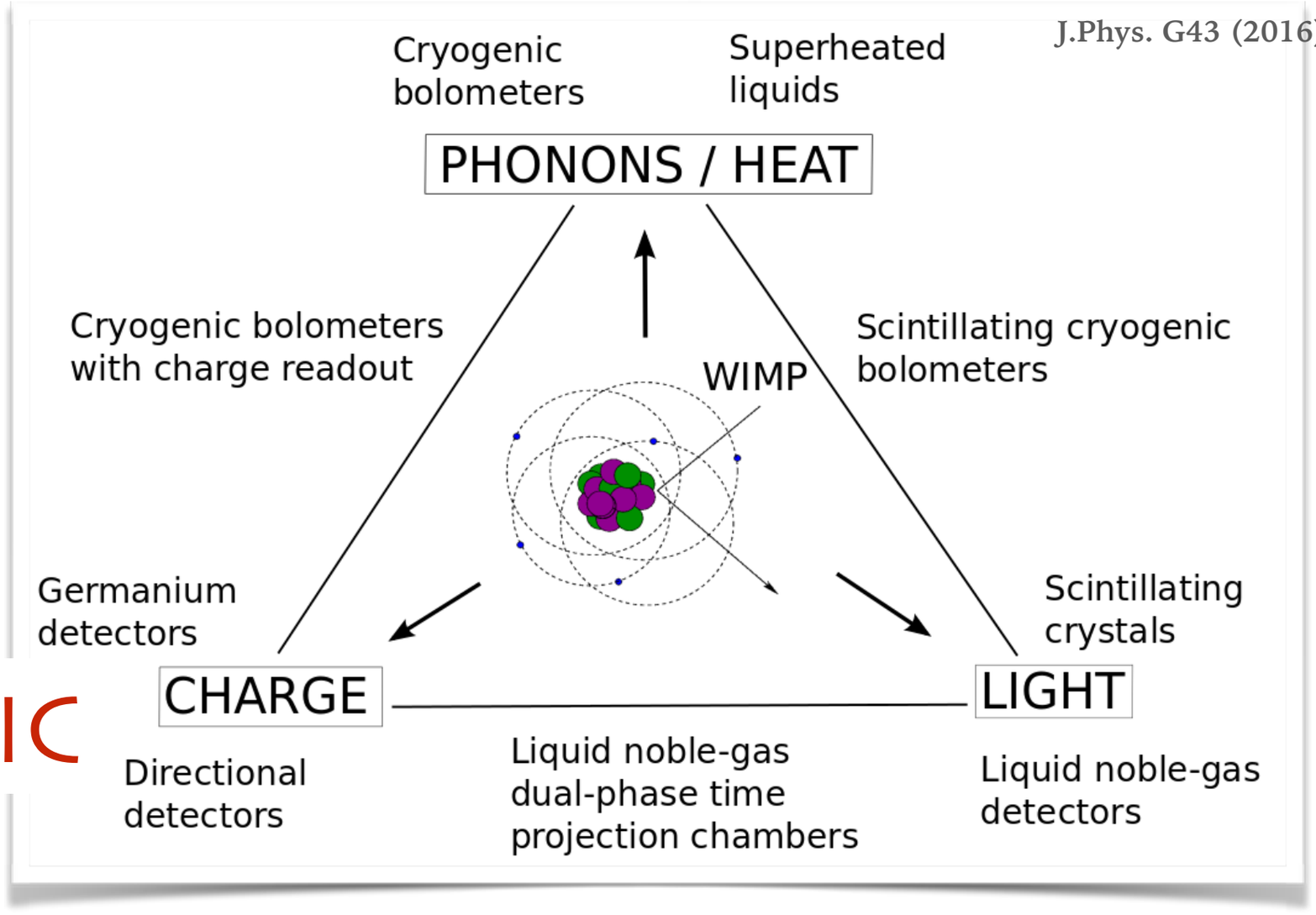
J.Phys. G43 (2016) no.1, 013001



- Low masses matter too ! (~GeV WIMP, ADM)
- low energy threshold (10-100 eV) obtained with solid (e.g. semiconductor band gap)

DIRECT DETECTION

Detect the nuclear recoil induced by the WIMP-Nucleus interaction

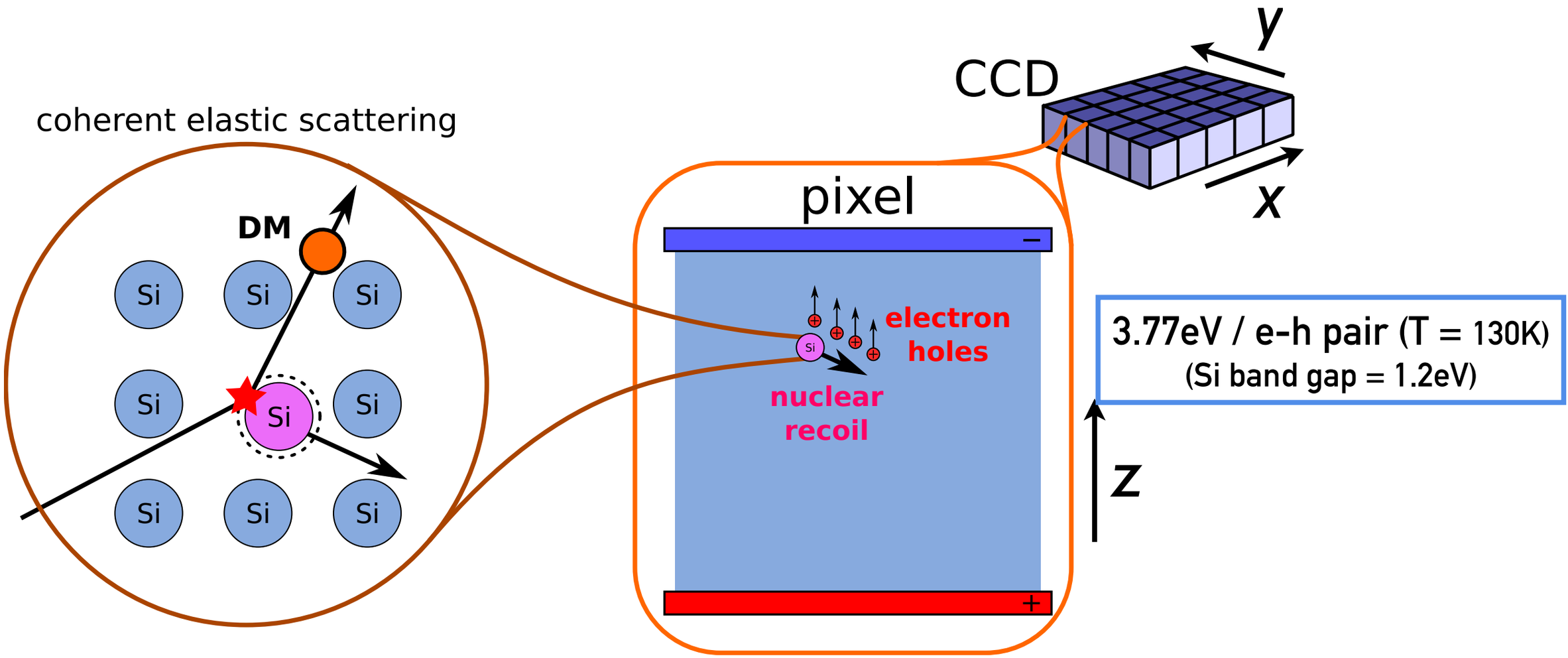


J.Phys. G43 (2016) no.1, 013001

DAMIC

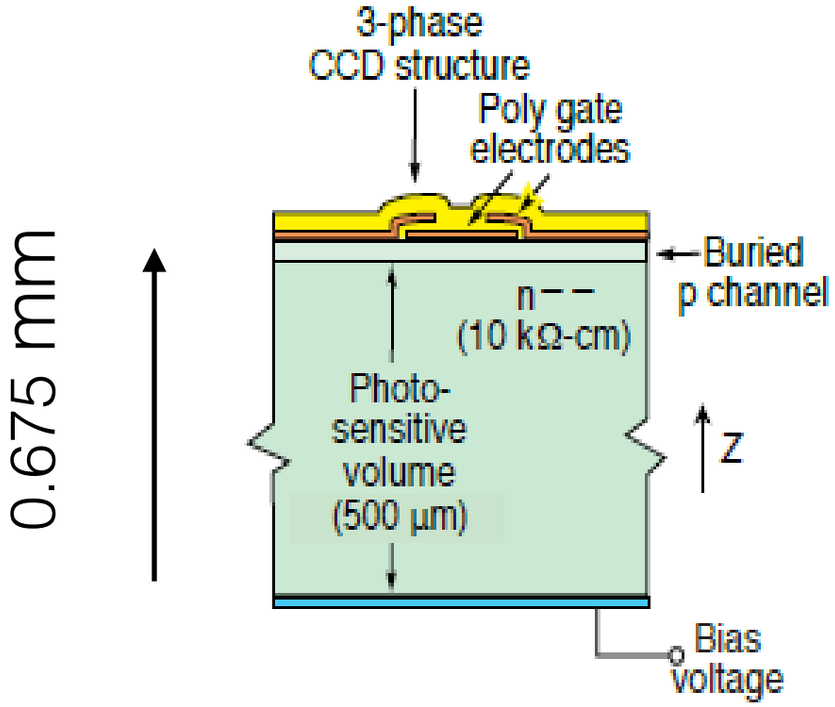
- Background (radiogenic) removal/estimation
  - Discrimination (Nuclear vs electronic recoil)
- Threshold
- Calibration
- Operation stability

DAMIC: DETECTION PRINCIPLE



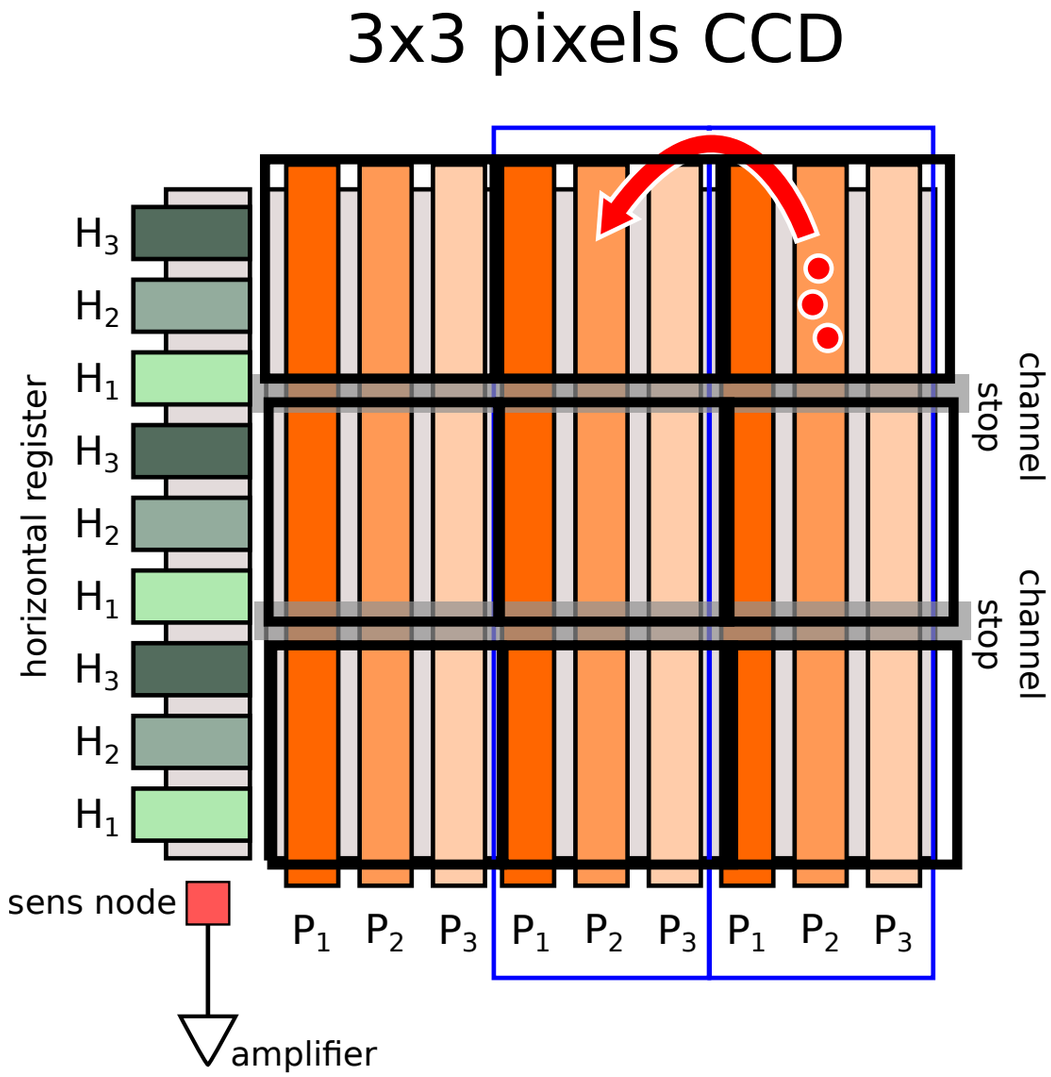
- low noise ~2e- (= 7.5 eV) —> E_{th} = **50-60 eVee**
- ~light mass target (kinetic matching)

DAMIC CCD



IEEE Transactions On Electron Devices, VOL. 50, No. 1, 225-338, Jan.. 2003

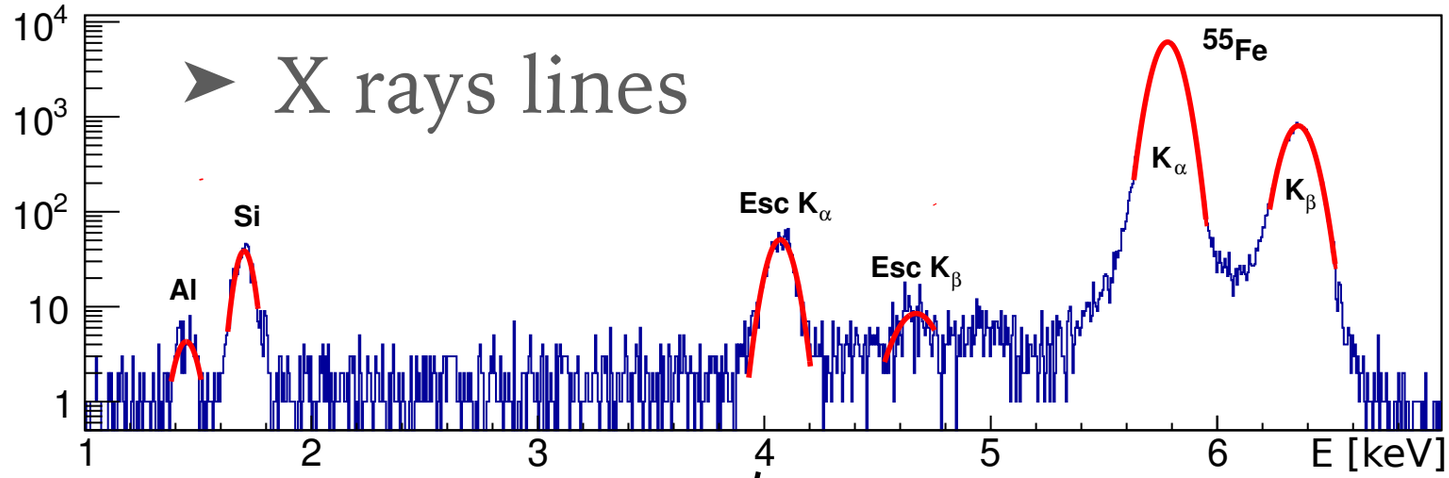
- **Thick CCD: 0.675 mm**
- **2.9g (5.8g)/ CCD**
- 8 (16) MegaPixels
- **pixel size: 15 x 15 µm**
- High resistivity: 10-20 kΩ.cm
  (low donor density—>fully depleted at 40V)
- low dark current (**10^{-3} e- /pix /day at 120K**)



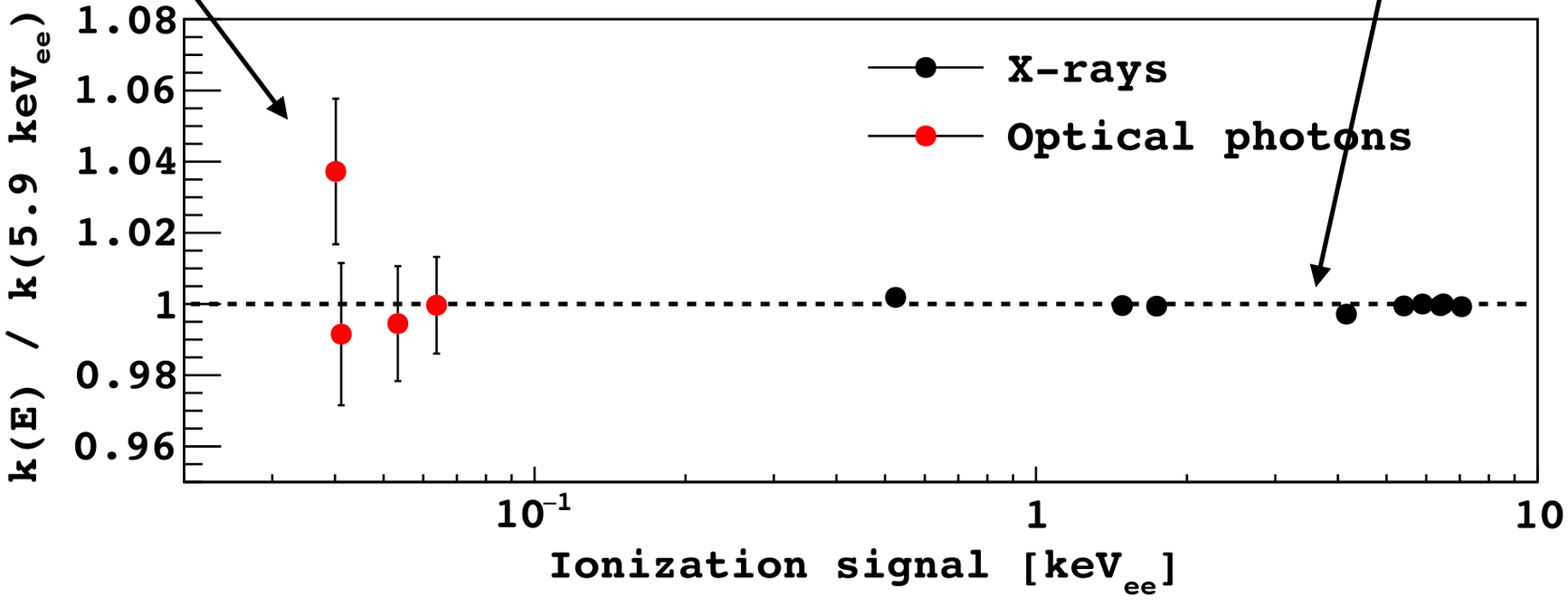
- **readout noise < 2 e-**
- readout time ~ 40us / pix

ENERGY CALIBRATION: ELECTRON RECOIL

➤ X rays lines



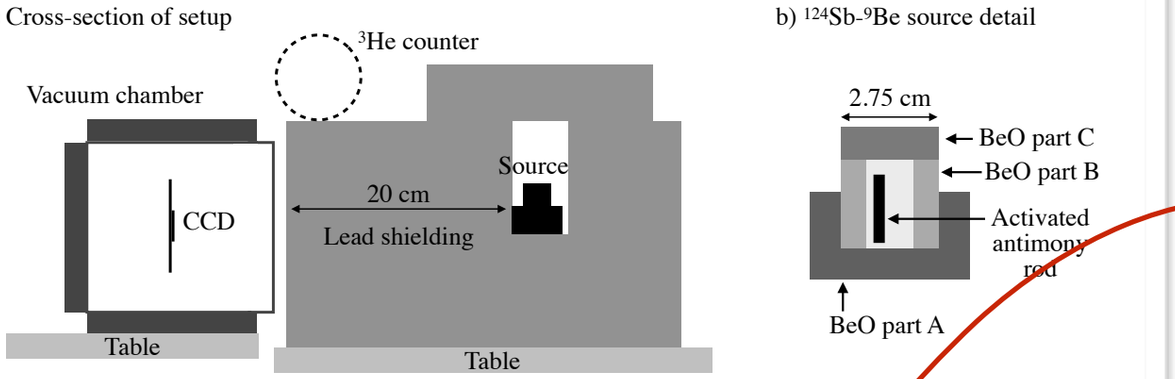
➤ LED light



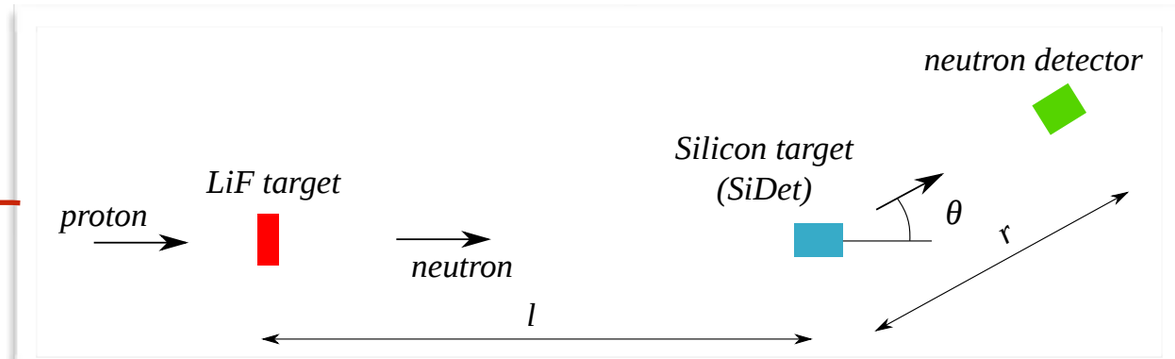
➤ linearity better than 5% from 40 eV_{ee} to 10keV_{ee}

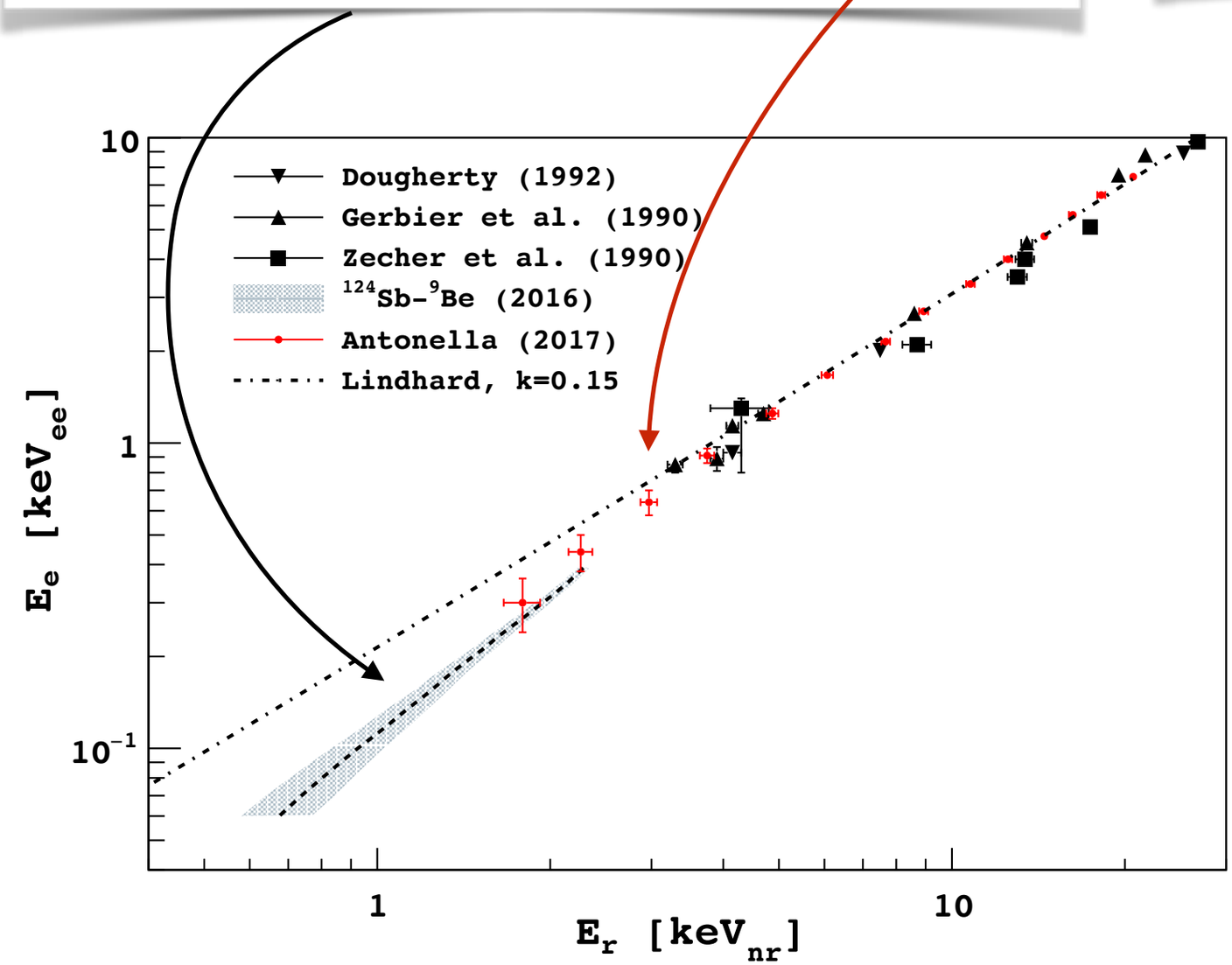
ENERGY CALIBRATION: NUCLEAR RECOIL

(Phys. Rev. D 94, 082007)



(arXiv:1702.00873)

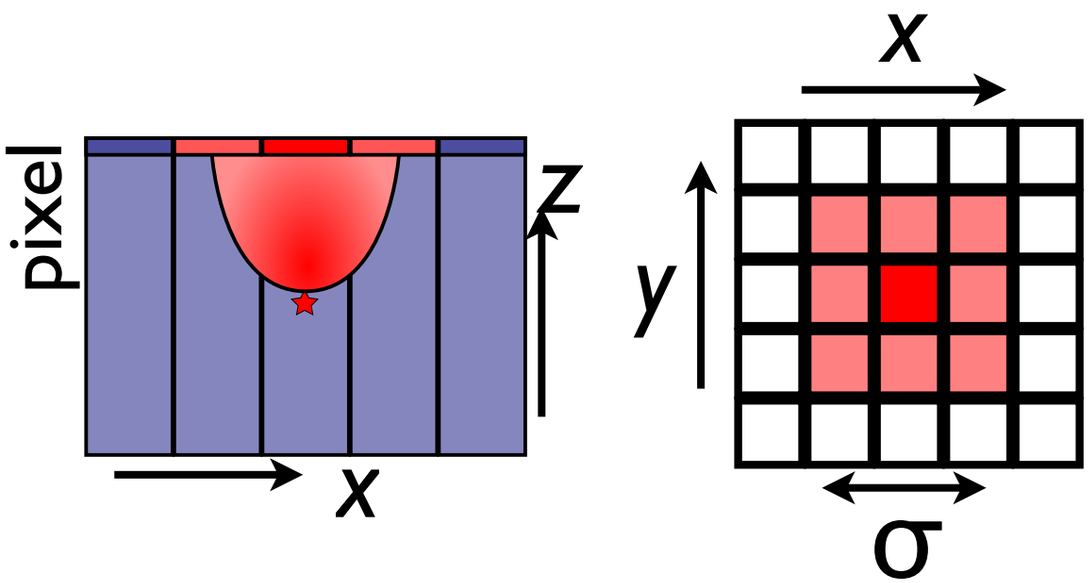




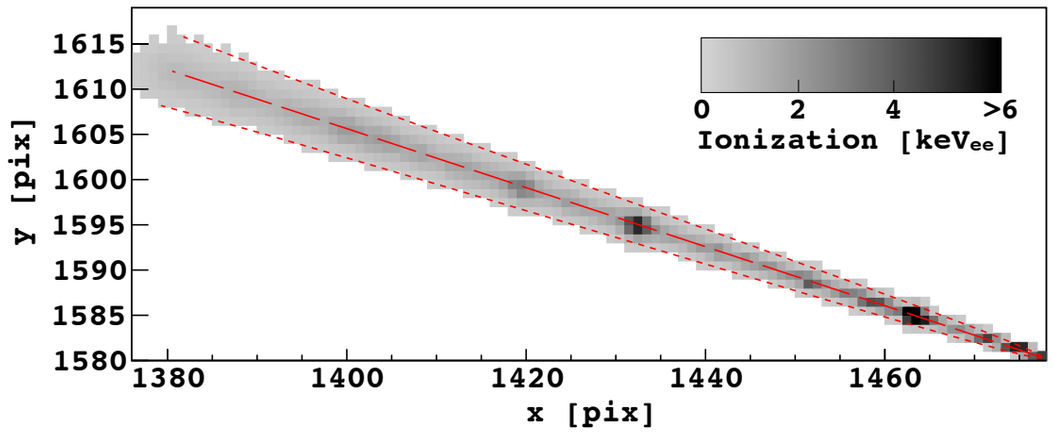
- Neutron source
- Down to recoil $E_r \sim 50 eV_{ee}$
- Deviation from Lindhard model (at low E)

3D RECONSTRUCTION

charge diffusion σ along z axis



muon track



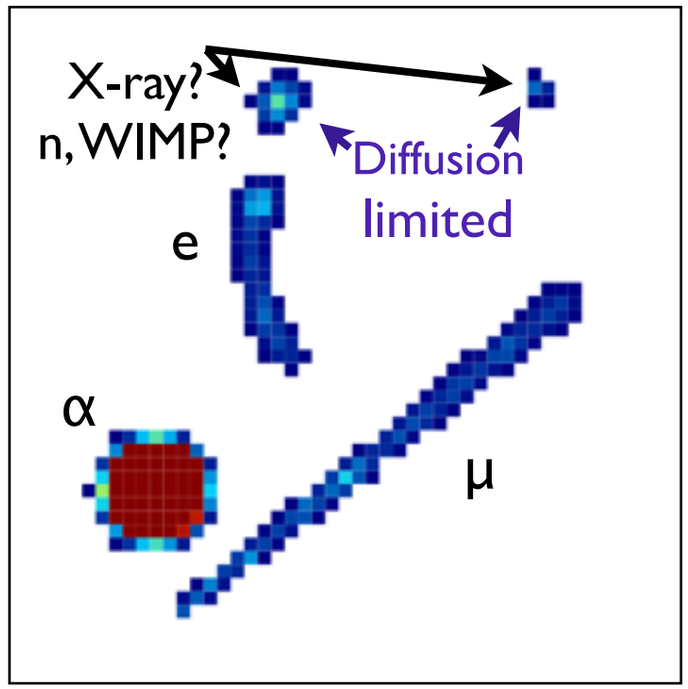
- 3D reconstruction
- surface event tagging

^{55}Fe X rays

RADIOGENIC BACKGROUND

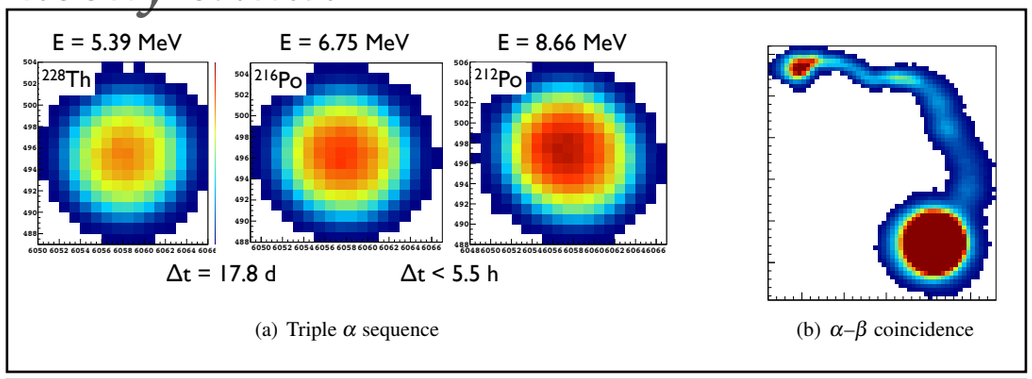
particle identification

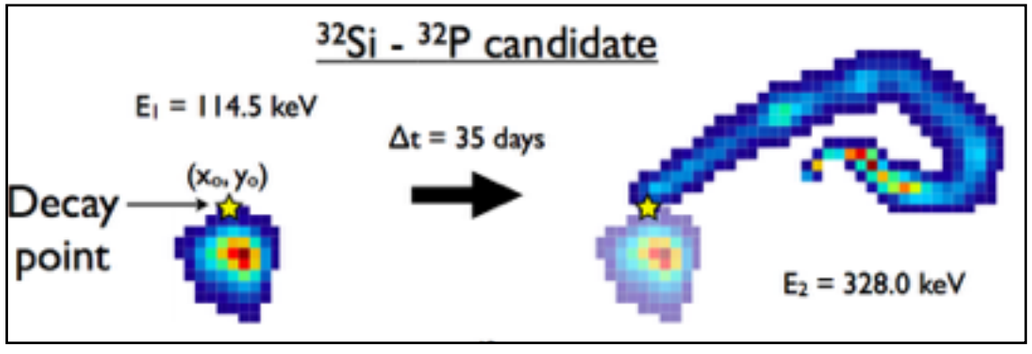
- no effective discrimination nuclear vs electronic recoil
  - potential bkg from low energy β and γ



- unique spatial and energy resolution
  - observe decay chain from a single isotope*
  - ^{238}U and ^{232}Th chain
  - ^{32}Si, ^{210}Pb chains
  - ^{3}H ?

decay chain

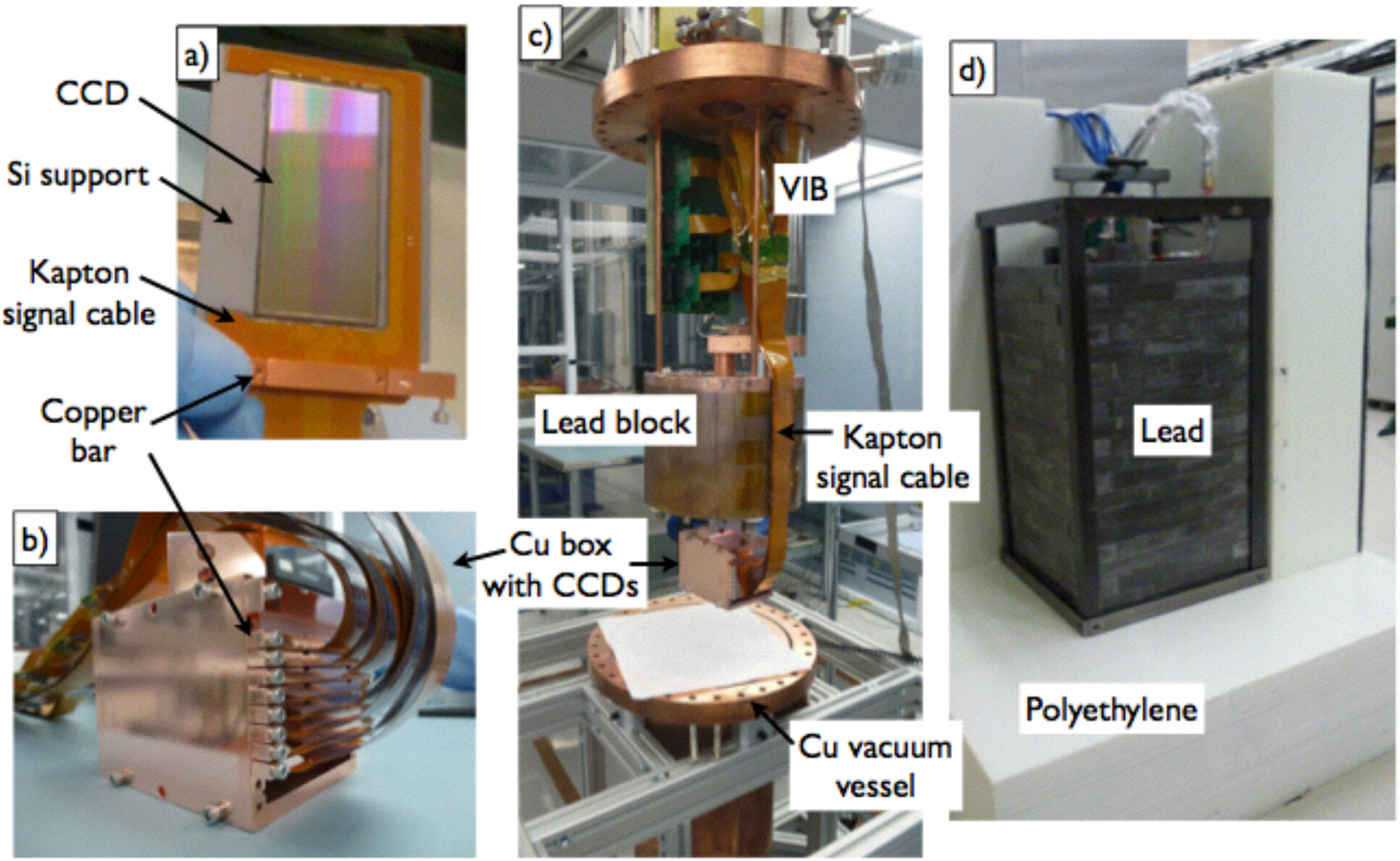




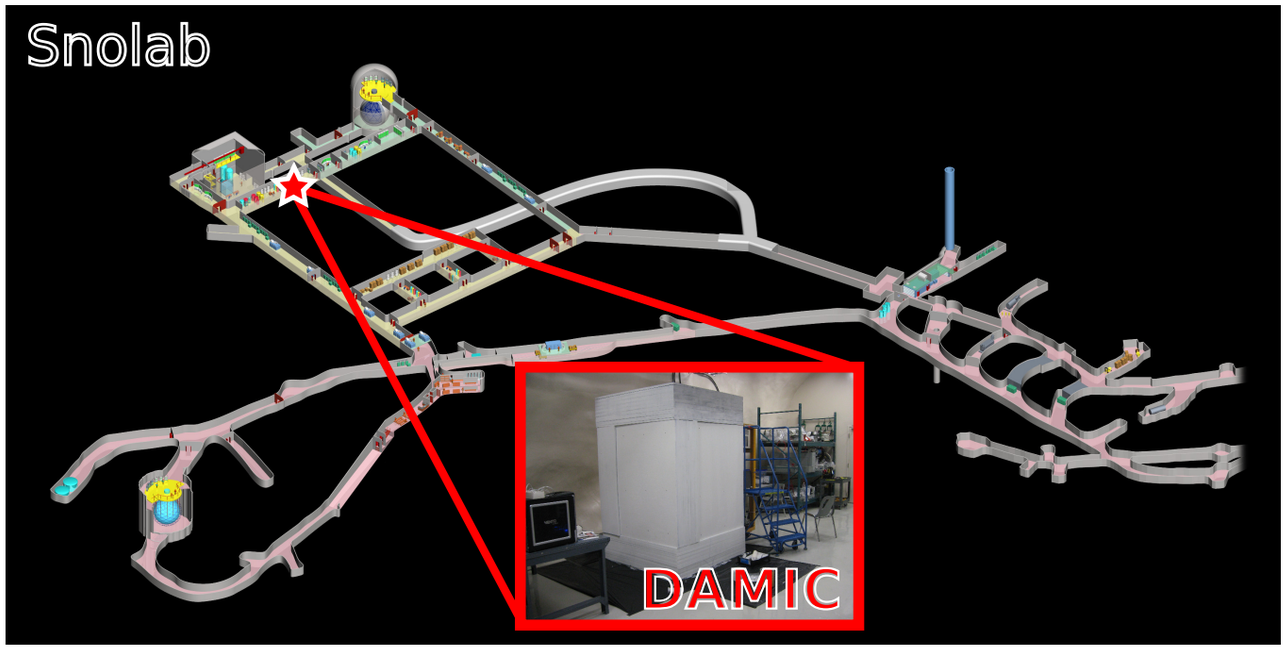
(JINST 10 (2016) no.08, P08014 arXiv:1506.02562 [astro-ph.IM])

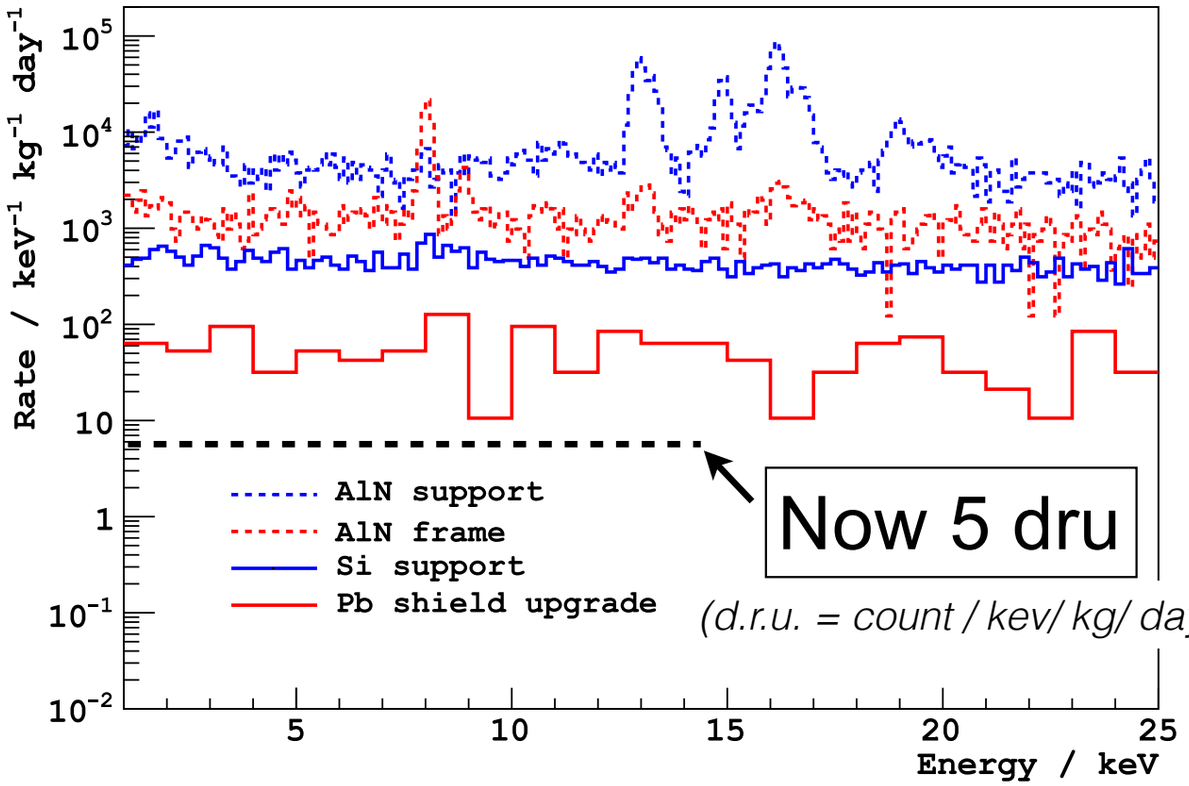
DAMIC AT SNOLAB (2016)

DAMIC DETECTOR



DAMIC AT SNOLAB

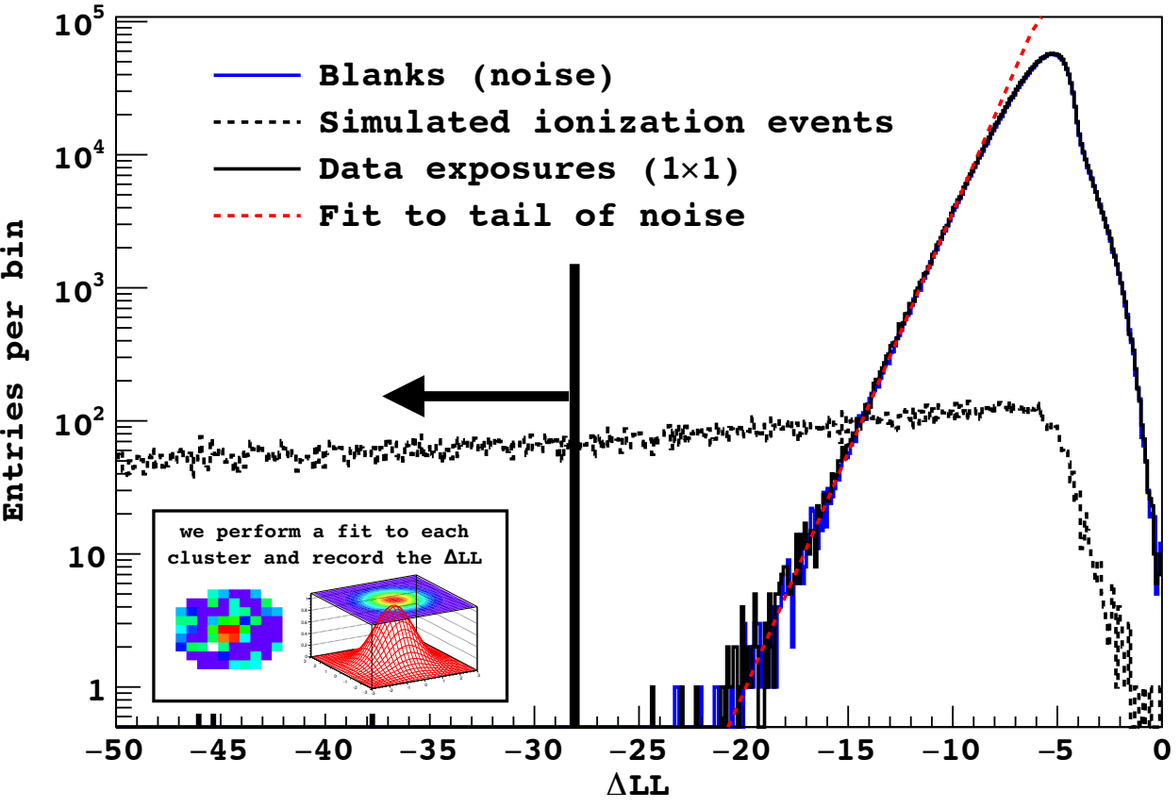


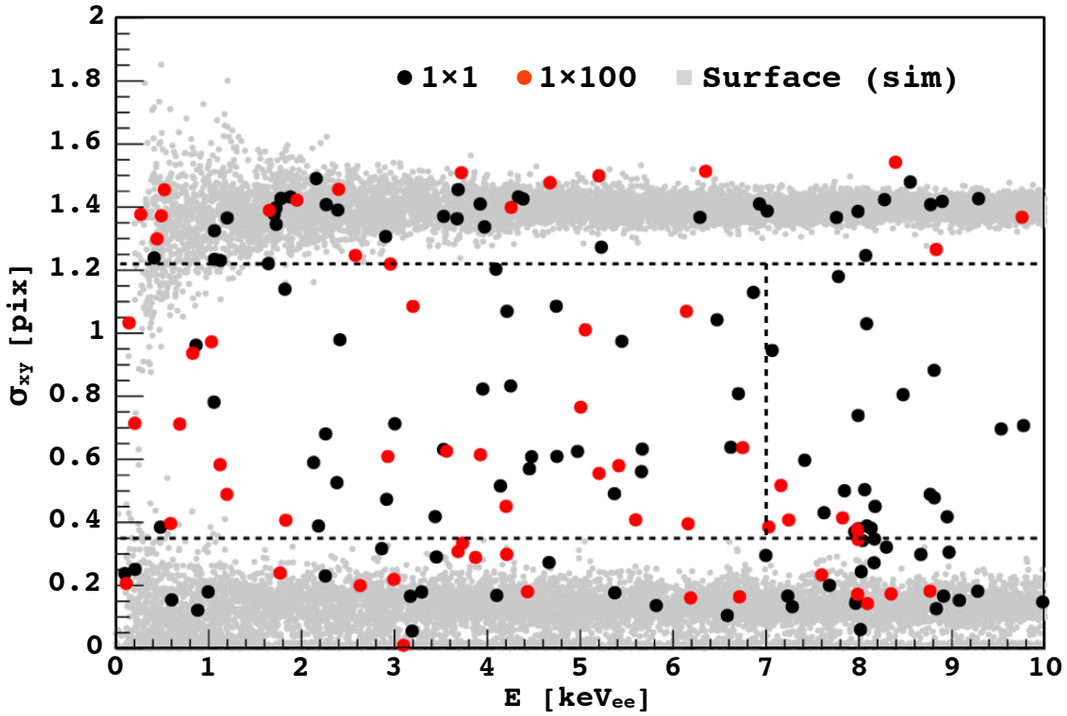


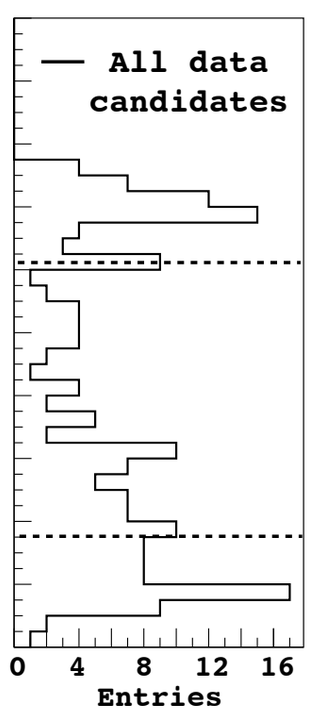
- 2 km down a mine (6000m water equivalent)
  https://www.youtube.com/watch?v=sZPLcv-ASwc
- muon rate < 0.27 m^{-2} d^{-1} (1μ /m^2 every 3 days !)

- Many effort to reduce the back noise
  - Nitrogen purge
  - Copper surface treatment

WIMP SEARCH: ANALYSIS STEPS

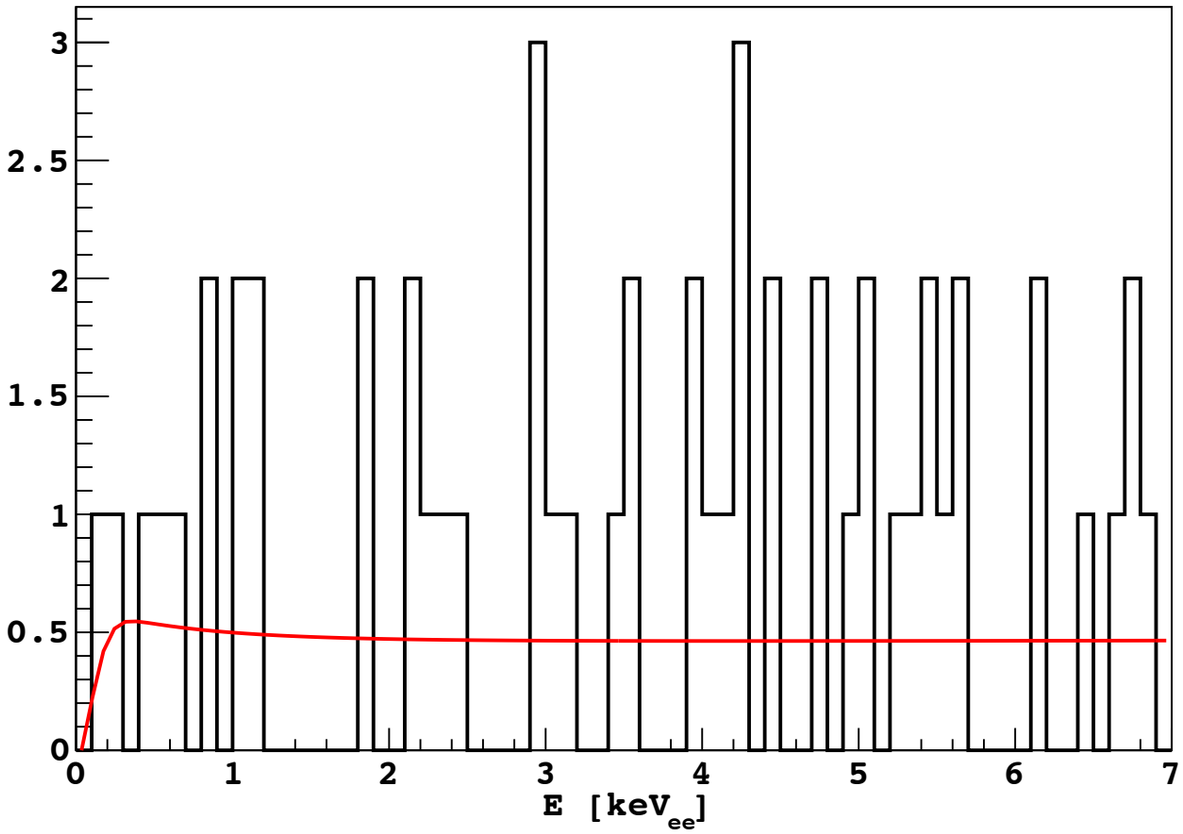


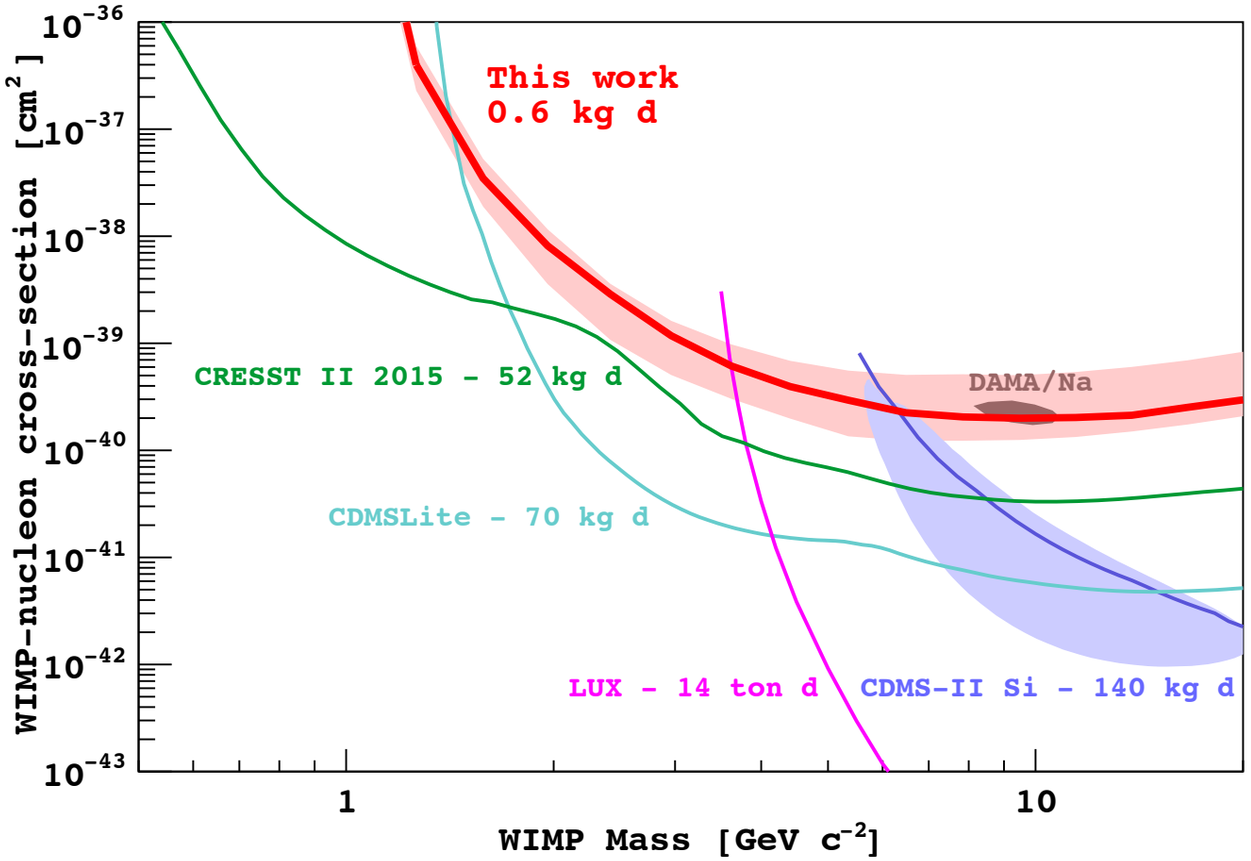




1. data selection (E < 10 keVee, noisy pixel)
2. find hits with LL clustering algo. (comparison bkg vs bkg+signal)
3. exclusion of surface events
4. fit of the candidate spectrum

WIMP SEARCH: RESULTS

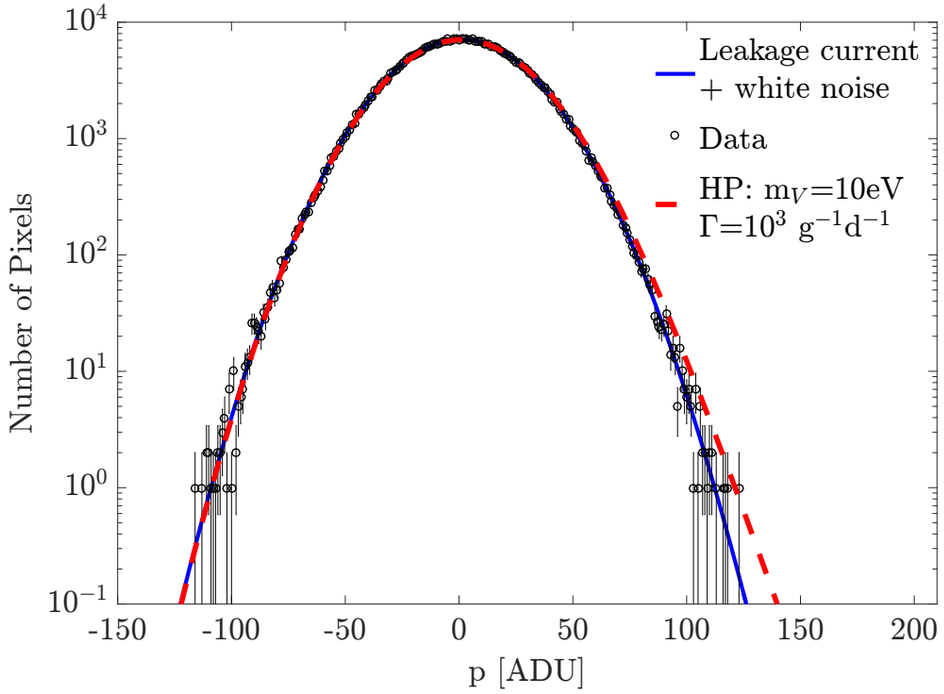


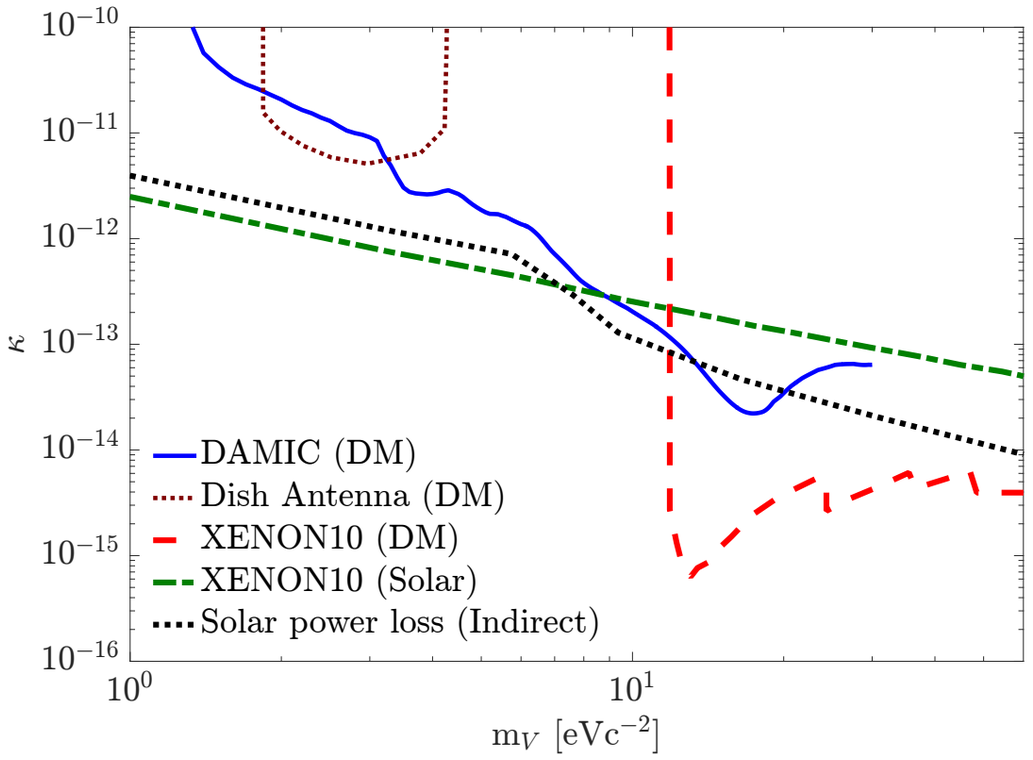


- compatible background hypothesis (Compton scatt.)
- sensitivity at low mass WIMP ($m_x < 10$ GeV/c^2)
- Limits with 0.6kg.day
- exclusion of a part of CDMSII signal with same target (Si)

HIDDEN PHOTON SEARCH

(arXiv:1611.03066, Phys.Rev.Lett. 118 (2017) no.14, 141803)



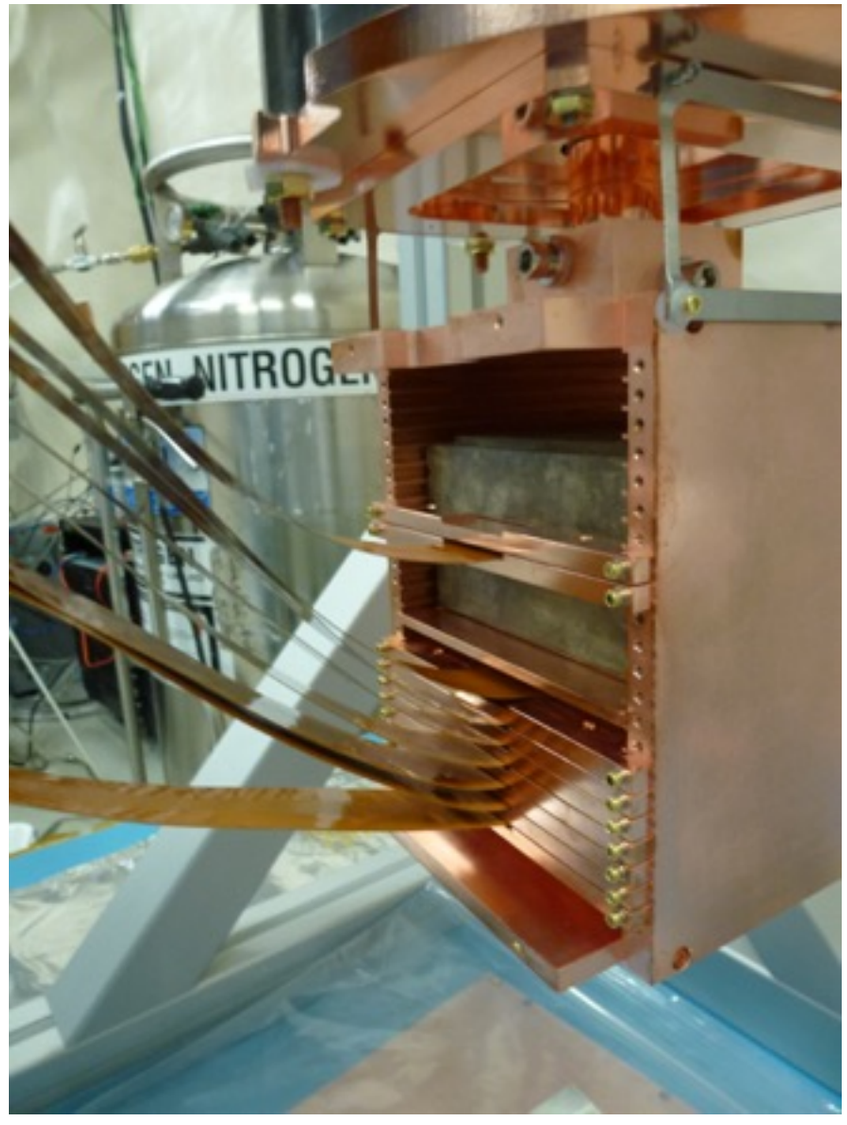


- hidden photon (m = [1-30 eV]) absorbed by electron → ionisation
- search for additional contribution in the leakage current

- most stringent direct detection limits in 3-12 eV mass region

STATUS: DAMIC 2017

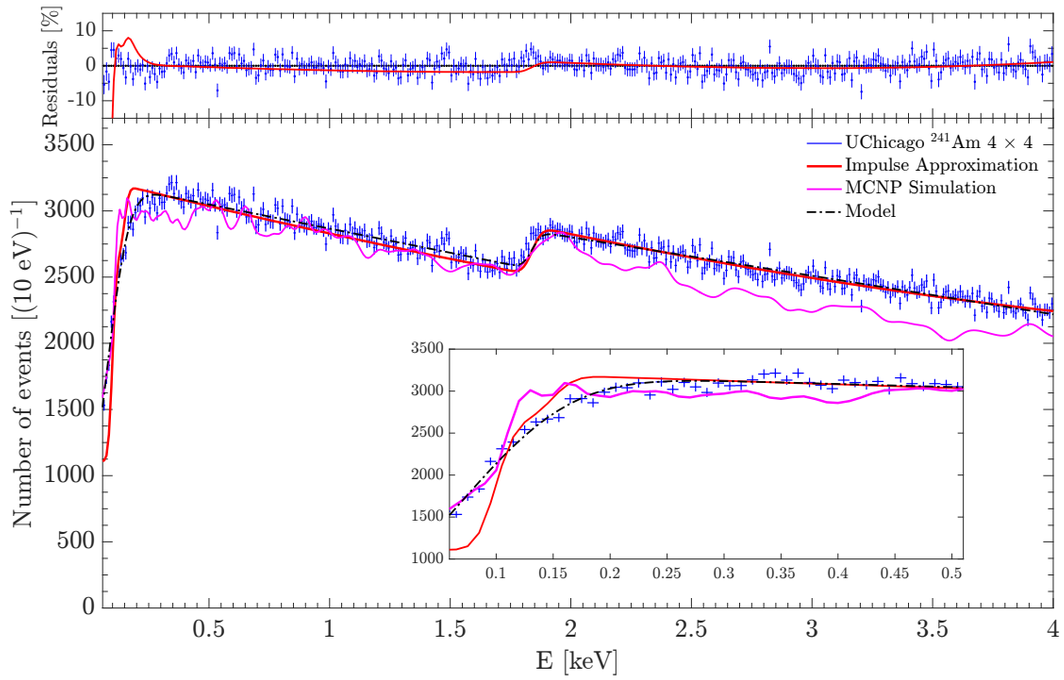
- DAMIC40: Intermediate step to confirm progress in background, improvement of operations.
- April 2016 - January 2017:
  Installation of 6-7 working CCDs
  (4k x 4k => ~40g of mass)
  - replaced copper box and modules
  - replaced of parts of the shielding with ancient lead (Roman lead from Modane)
  - cleaning and etching
- Already **6 kg.day with 5-15 d.r.u.**



STATUS: DETECTOR CALIBRATION AND SIMULATION

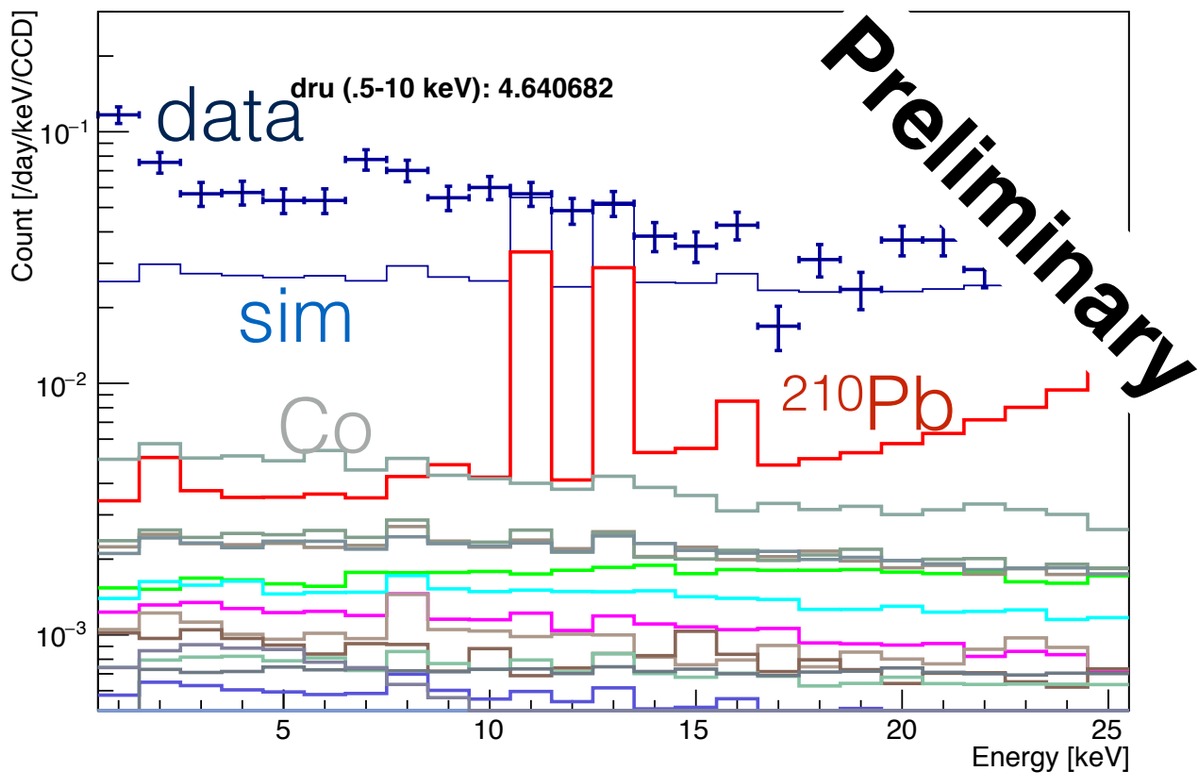
Compton spectrum measurement

(arXiv:1706.06053 Phys.Rev. D96 (2017) no.4, 042002)



- Low E Compton, final bkg
- DM search with spectral discrimination
- Spectrum measurement down to 60 eVee of the Compton spectrum
- New model produced

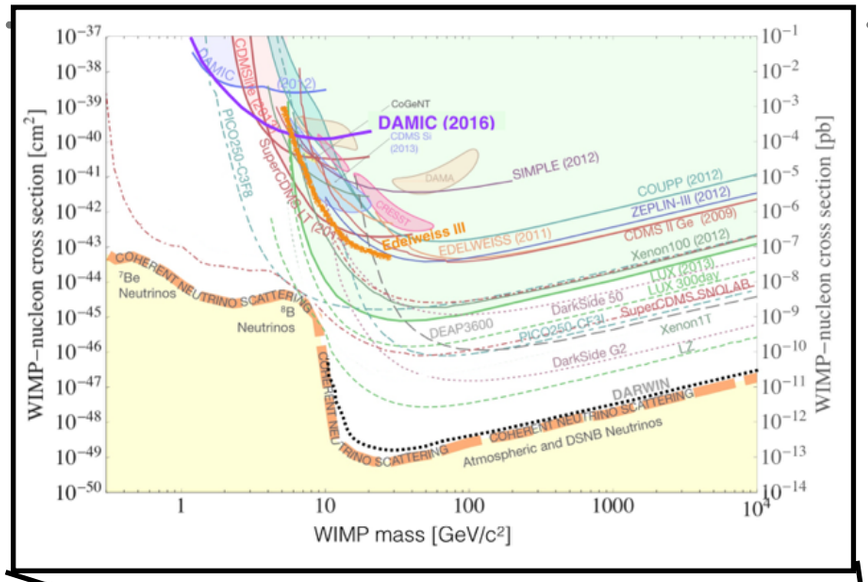
Simulations

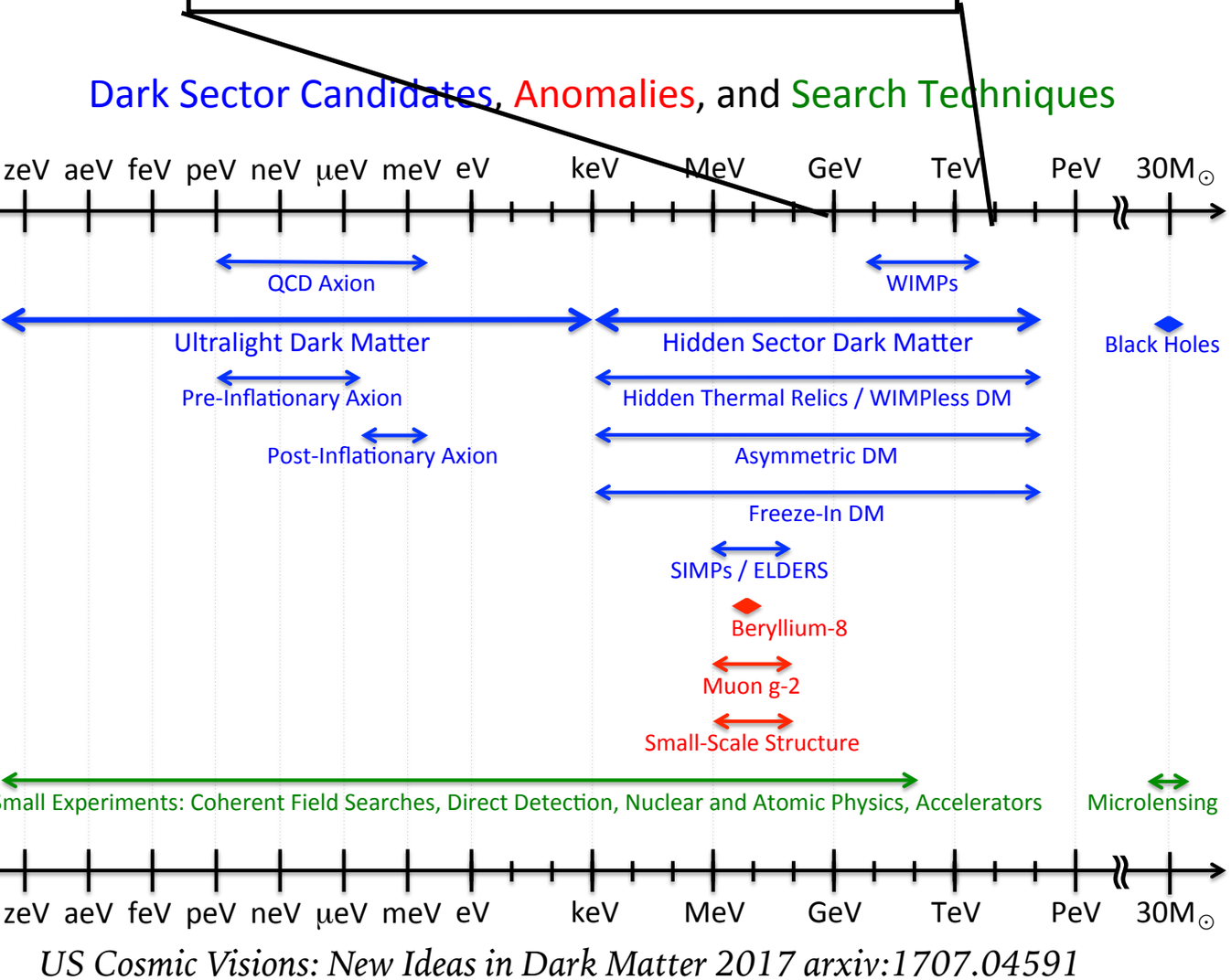


- G4 Full detector simulation —>Optimise shielding and cleaning
- Input the screening result
- Ongoing simulation and analysis
- Next step: fit spectrum with floating concentration

FUTURE PLANS

DAMIC FUTURE





US Cosmic Visions: New Ideas in Dark Matter 2017 arxiv:1707.04591

Physics goals

- ~GeV WIMPs nuclear recoil:
- Hidden sector DM: electronic recoil

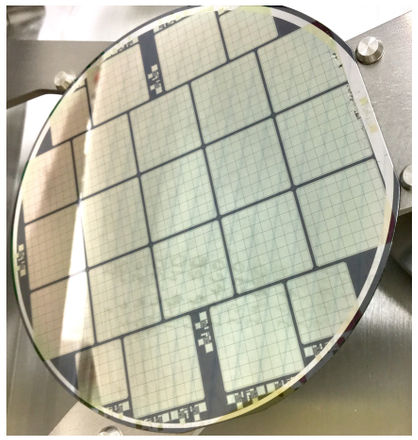
Experimental parameter to improve

- target mass to **kg scale**
- background ~ **0.1 d.r.u.**
- detector threshold down to ~**2e⁻ threshold** (resolution and E threshold)

TARGET MASS & BACKGROUND REDUCTION

Mass: ~ 1kg

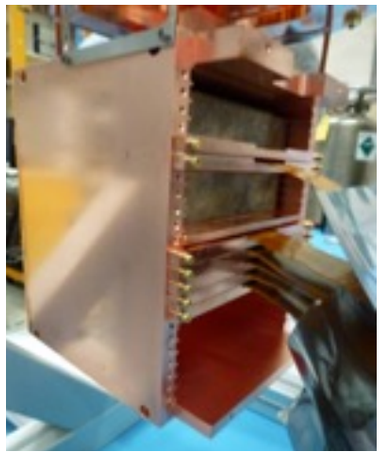
(current ~ 40 g)



- current mass: 5.8g /CCD
- goal: increase CCD mass 3X (1kg=>~50CCDs)
  - ~1mm with same fabrication process
    ~ few mm thickness might be possible
  - larger format :4k x 4x —> 6k x 6k

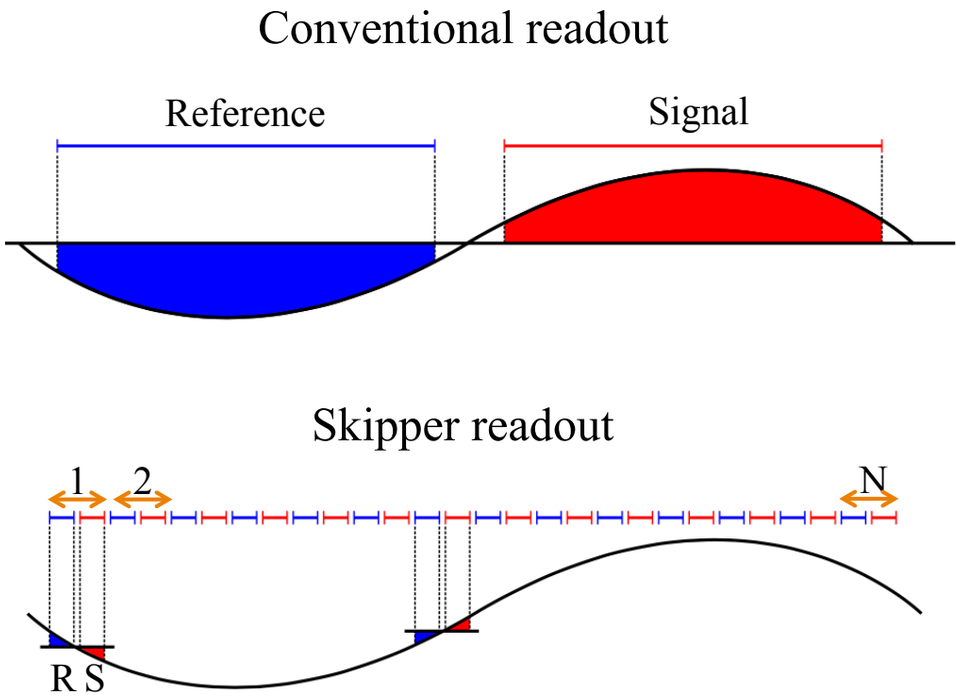
background: ~0.1 d.r.u

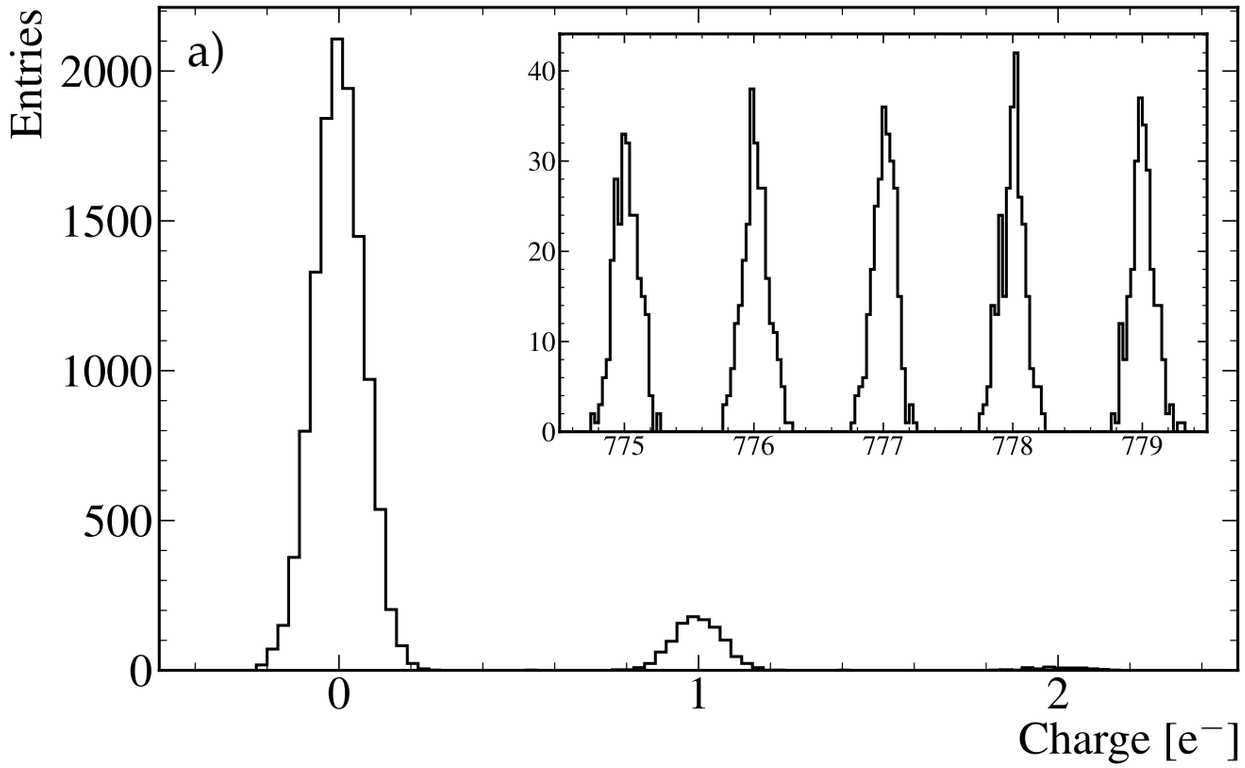
(current ~ 5 d.r.u. / EDELWEISS < 1)



- Lots of effort and experience gained
- keep activation low (Cu / Si)
  - track the Si and Cu
  - electroformed Cu
- Chain identification (a plus w.r.t. other exp.)

ELECTRONICS: SKIPPER CCD

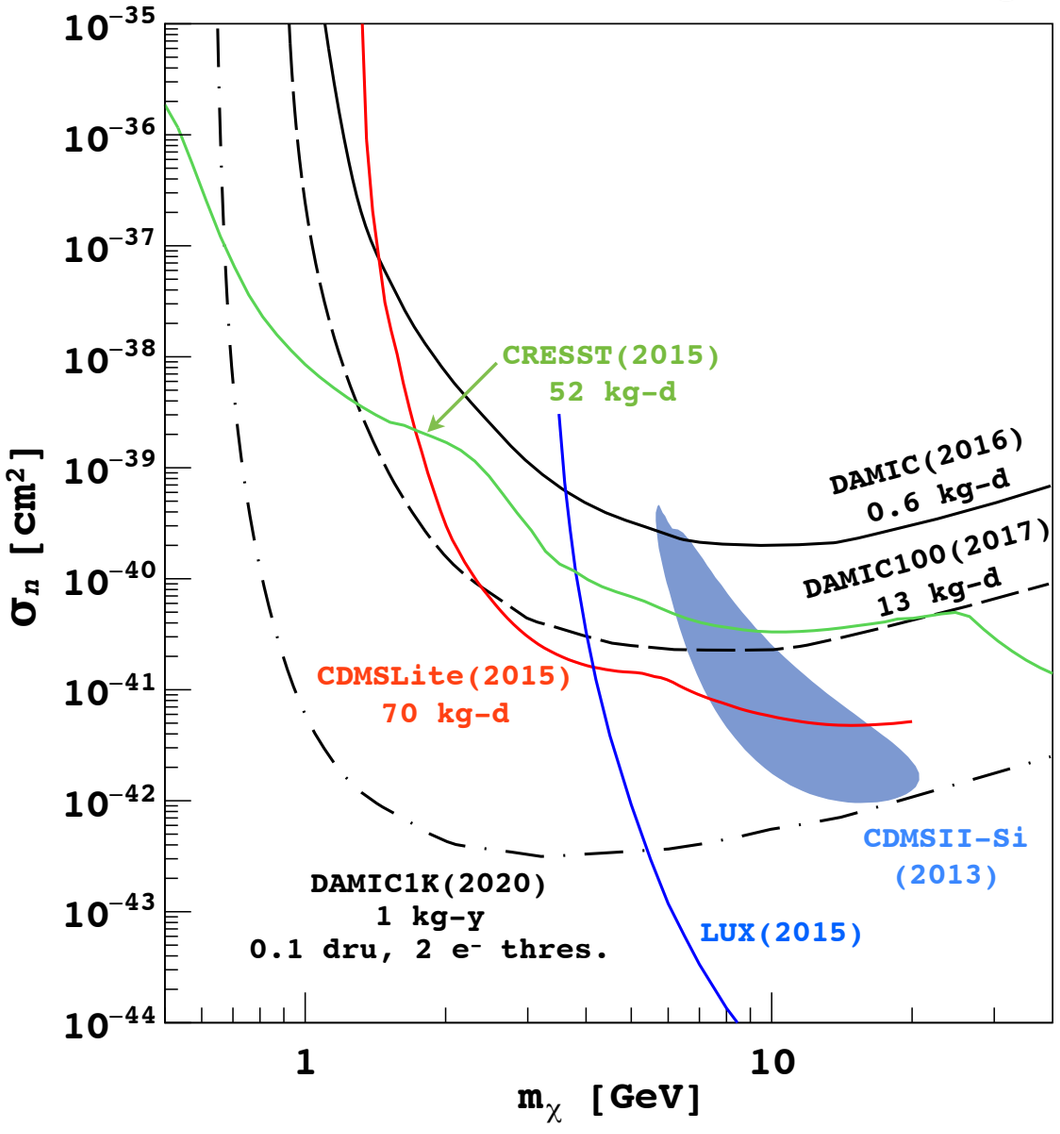




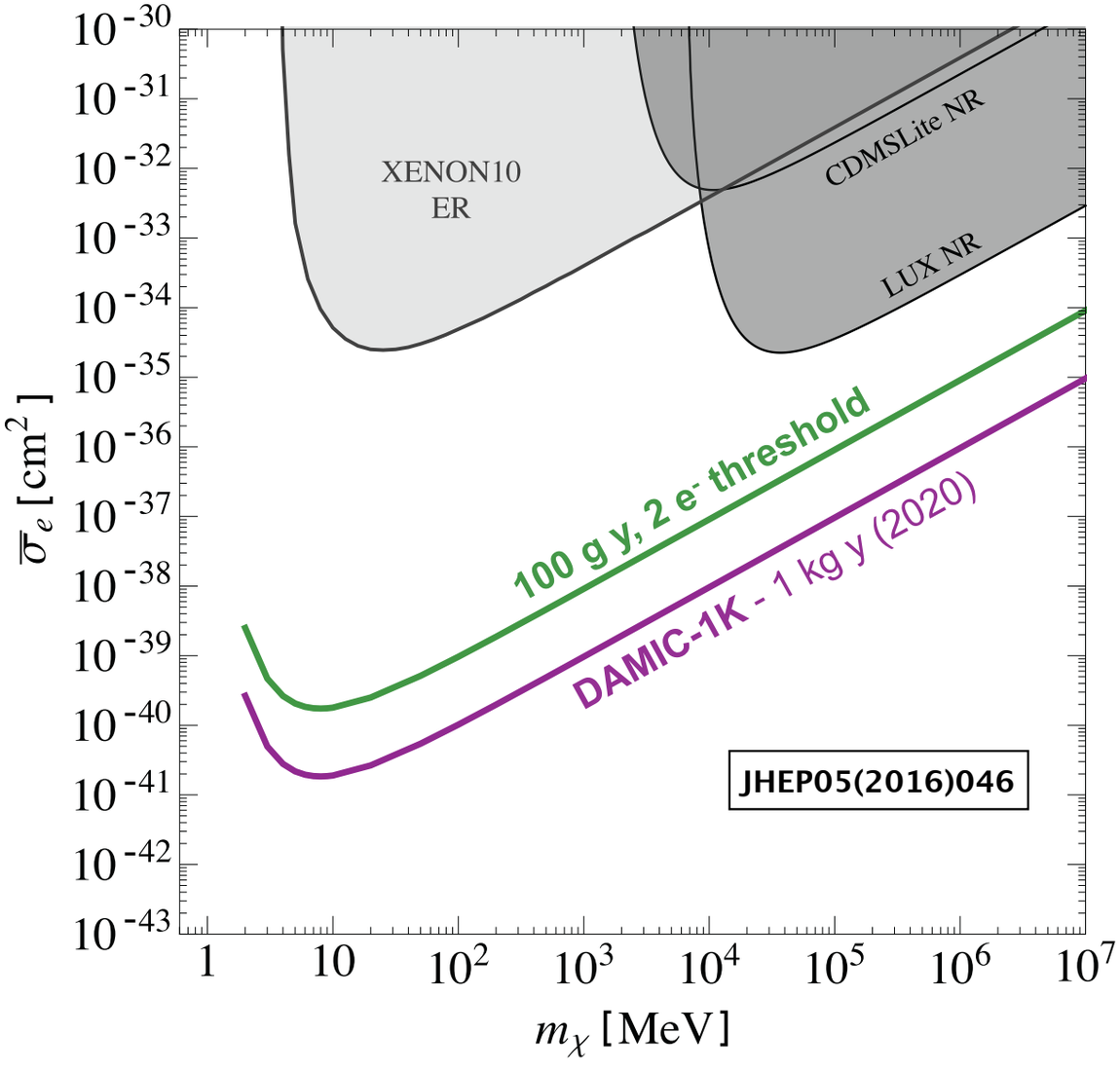
- Skipper CCD is an innovative technique (cf SENSEI project *arXiv:1706.00028*)
  Non destructive multiple uncorrelated readings
- resolution < 0.1 e- can be achieved (0.2 e- is a good compromise for read out time)
- Allow for the single e- measurement
- dark current limiting but very low in Si: **2e- threshold possible**

DAMIC POTENTIAL SENSITIVITY

DM-nucleus SI coherent scattering



DM-e Scattering via Ultra-light Dark Photon



- Competitive limits on ~GeV WIMP interaction
- Can exploit e- recoil as well and explore hidden sector

CONCLUSION

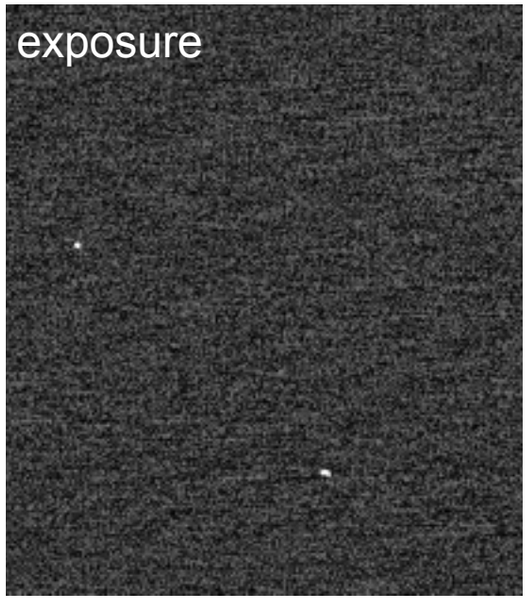
- CCD is an efficient DM detector for low mass WIMP
  - stable operation
  - very good energy & spatial resolution

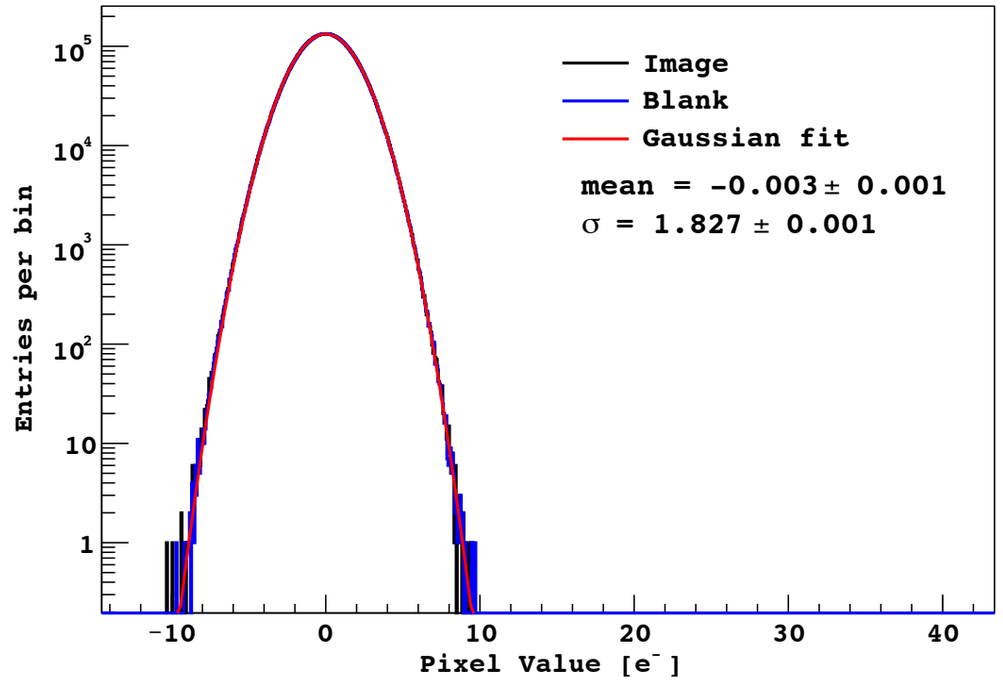
- After a phase of development / bkg reduction DAMIC has released competitive limits (0.6kg day exposure)
  - Currently upgrading to DAMIC40

- Broad potential for next upgrade:
  - physics goal: ~GeV WIMP **and** Light DM
  - work on CCD fab. , read out electronics, process/transport handling

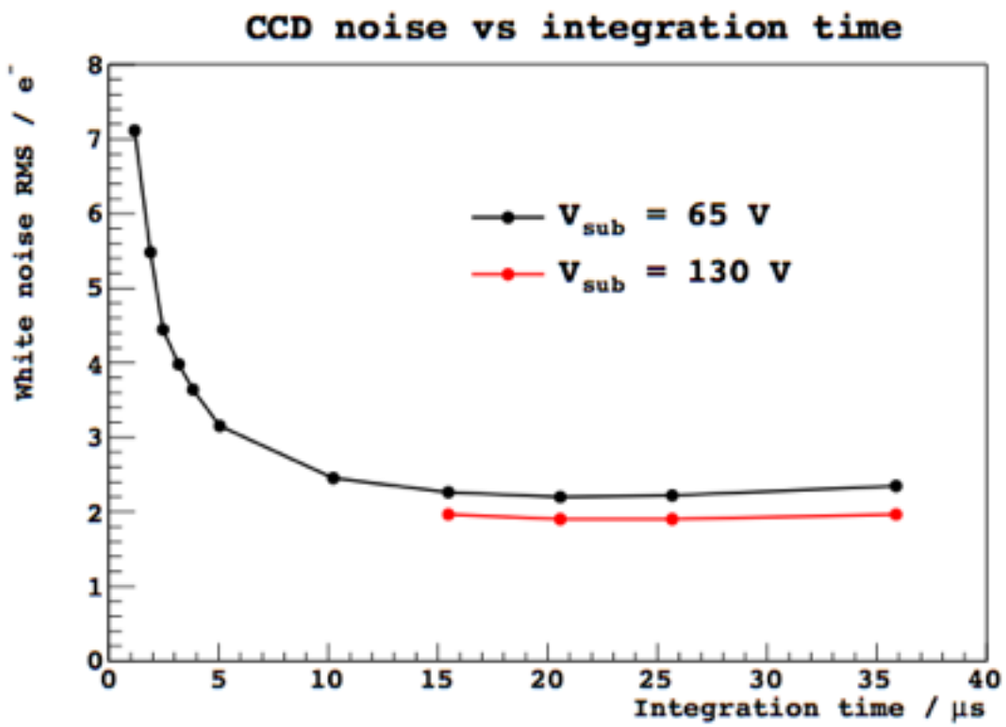
THANKS FOR YOUR ATTENTION

READ OUT NOISE

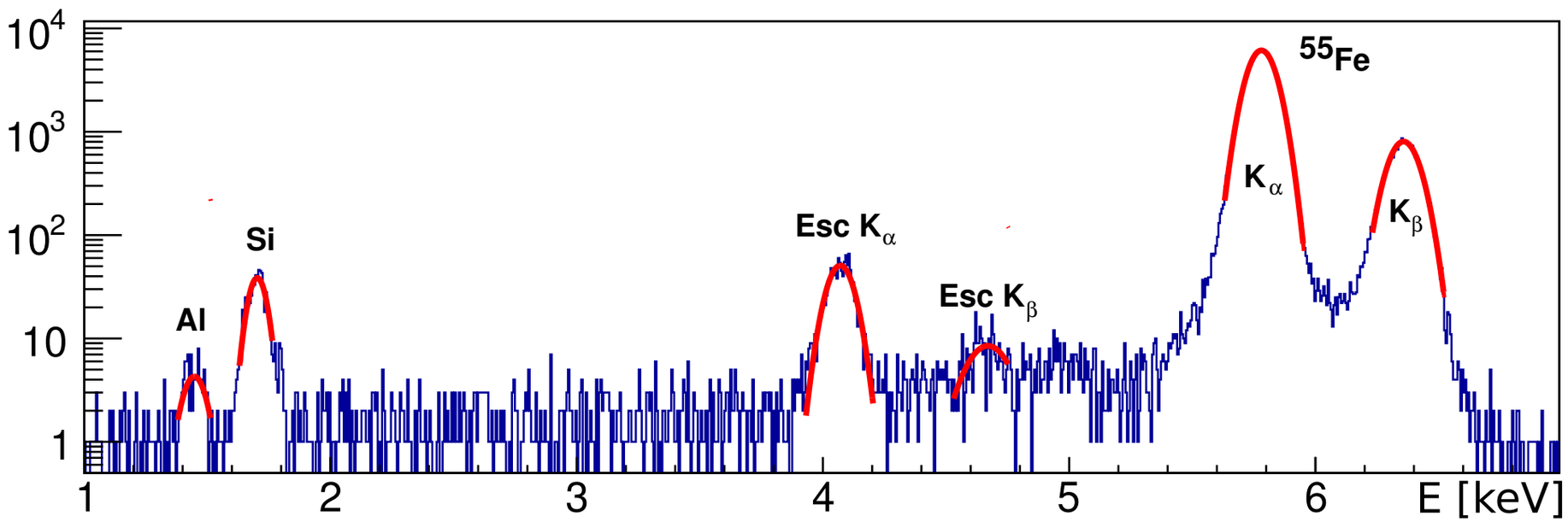


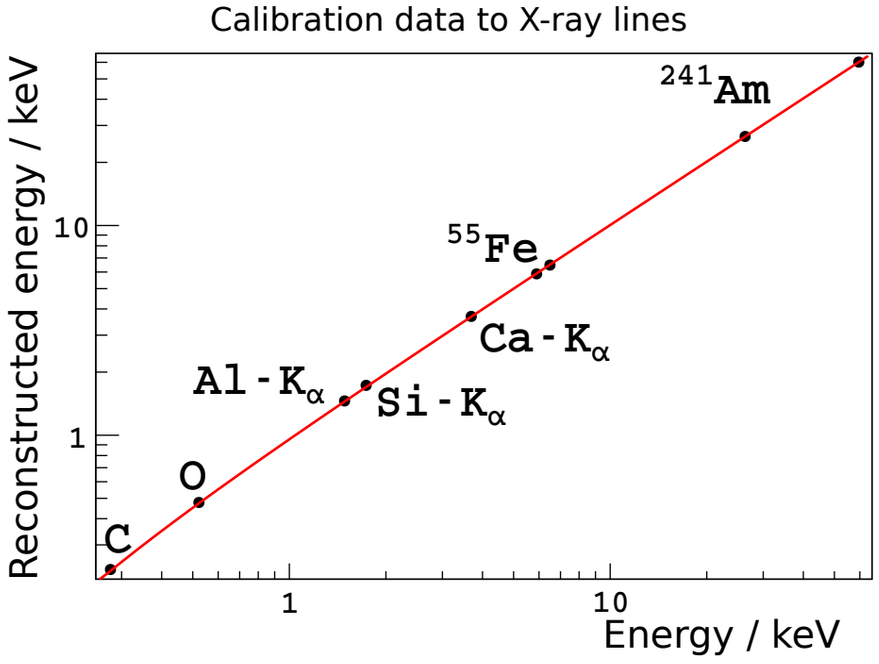


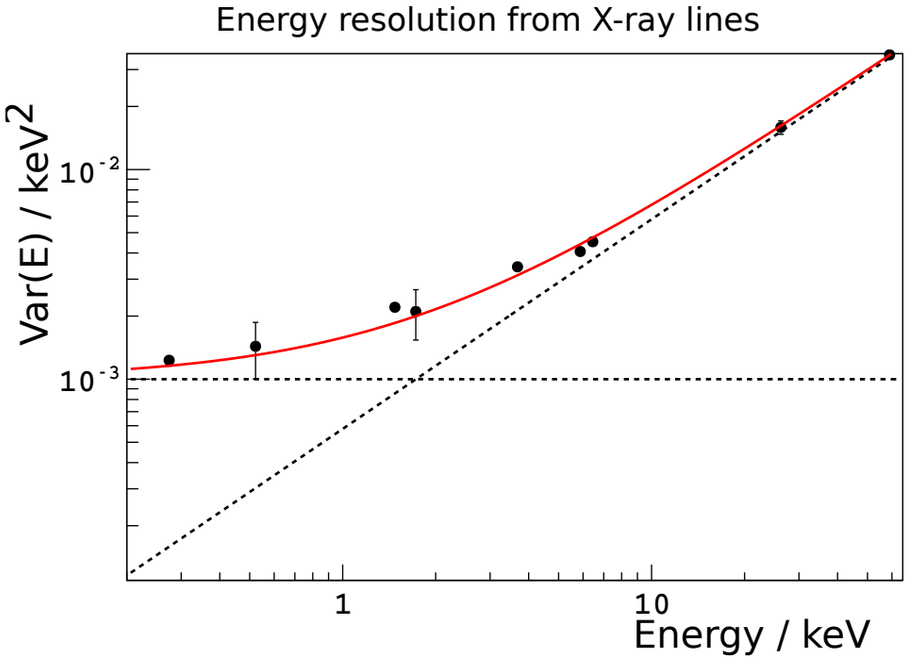
- noise limited by read out
  - improved by CDS (Correlated Double Sampling)
  - limited to 2e- with the current electronics



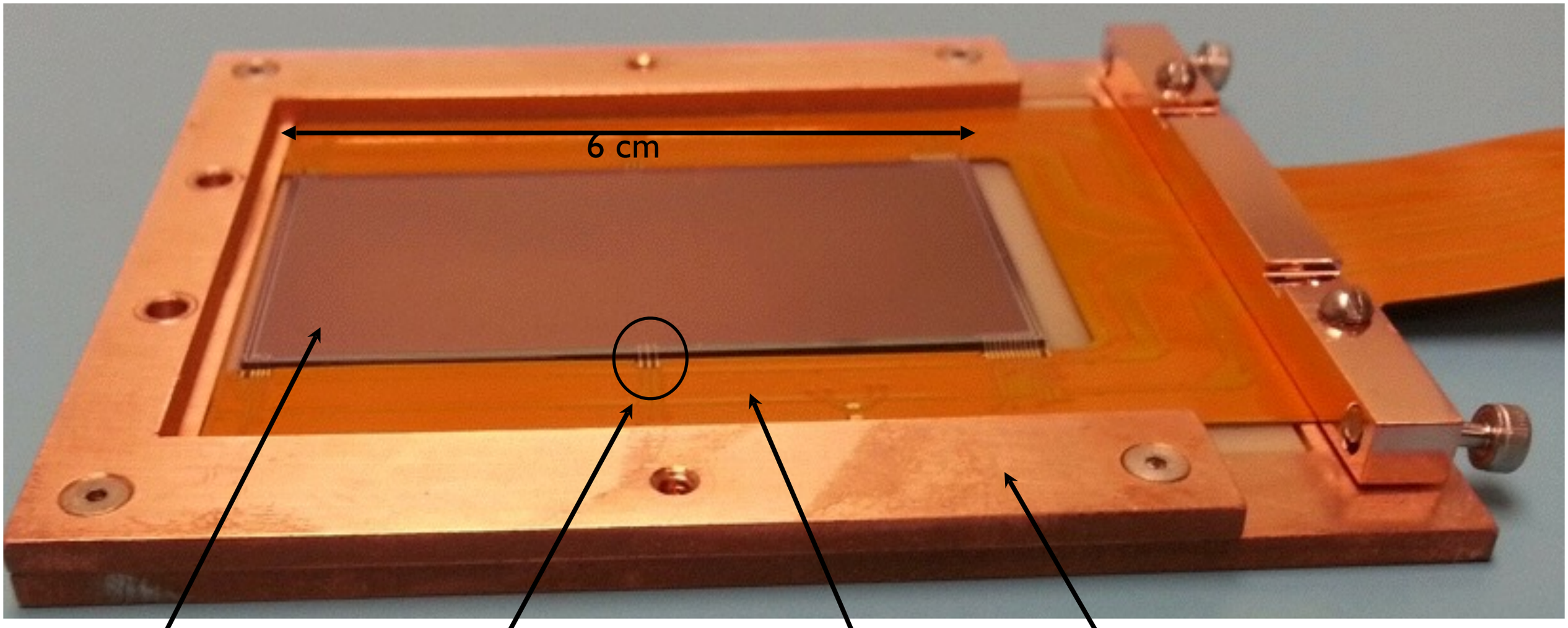
ENERGY LINEARITY



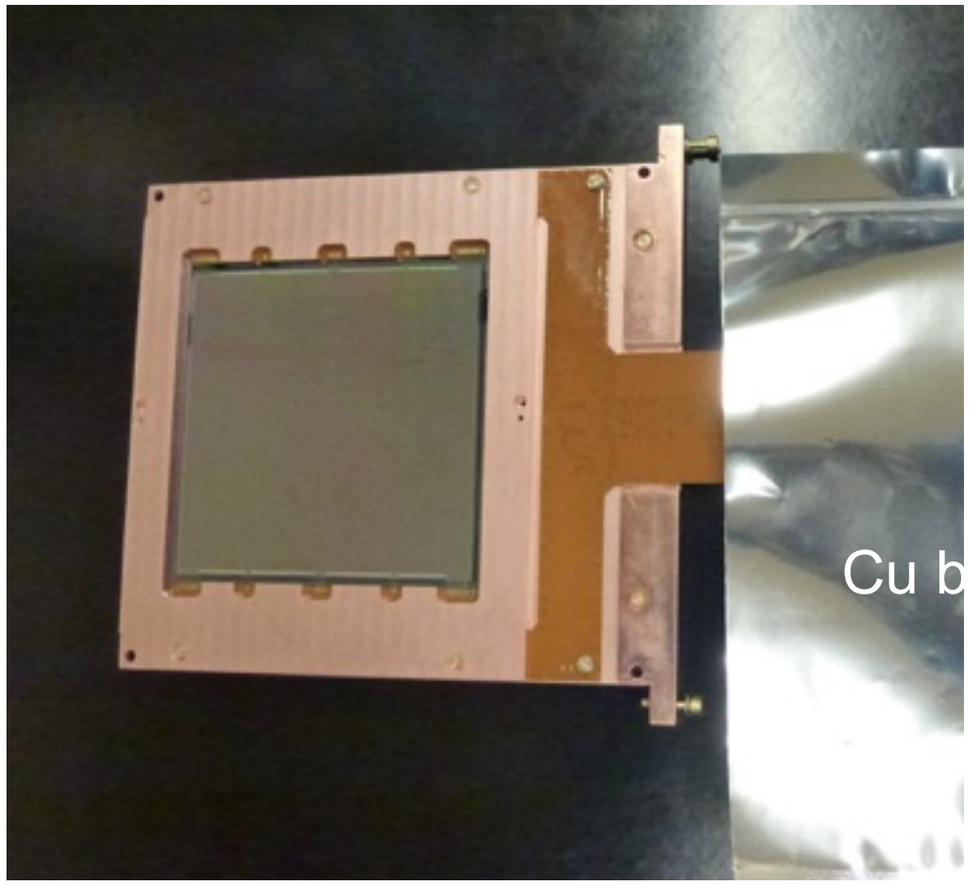




CCD


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

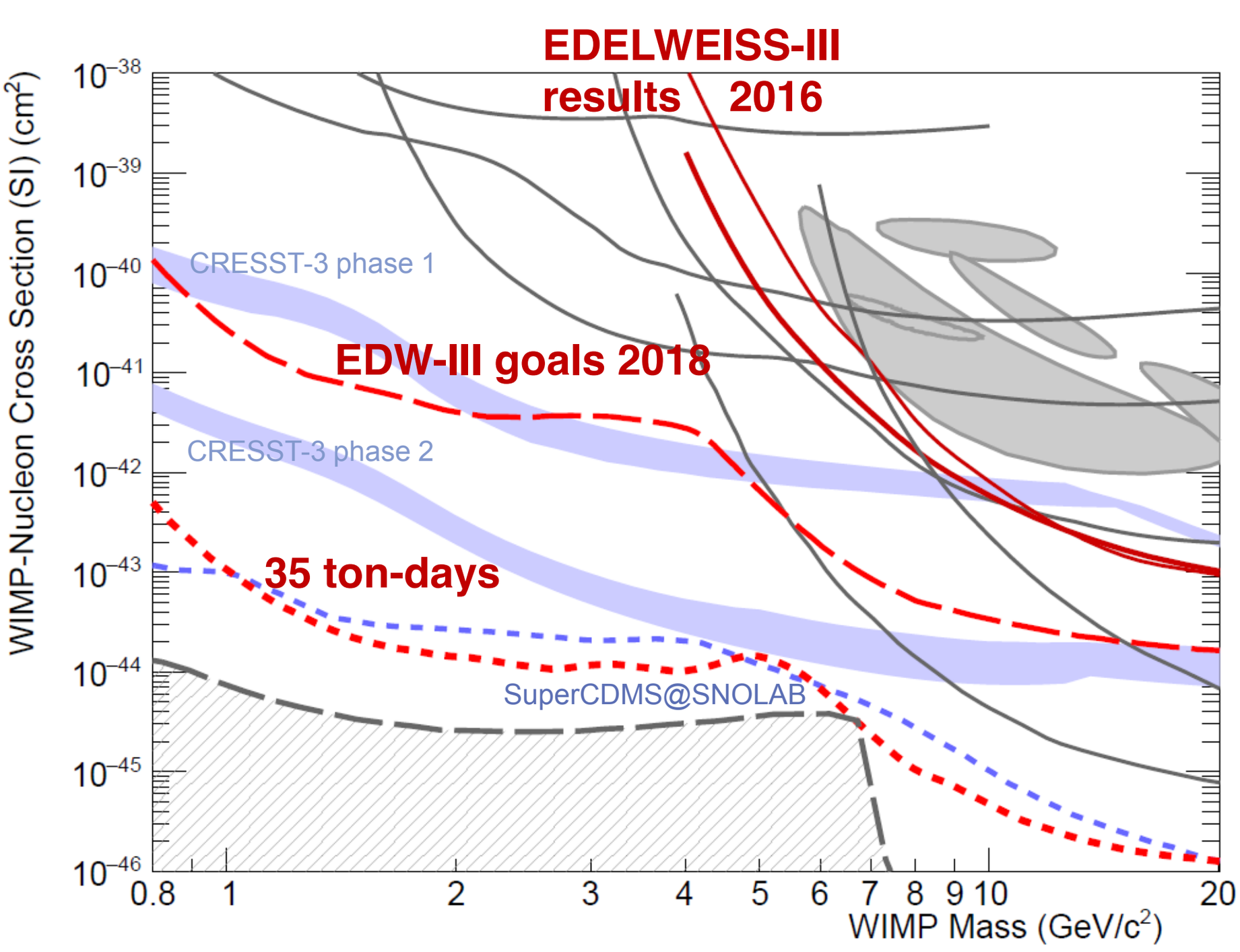
CCD



Radiogenic bkg

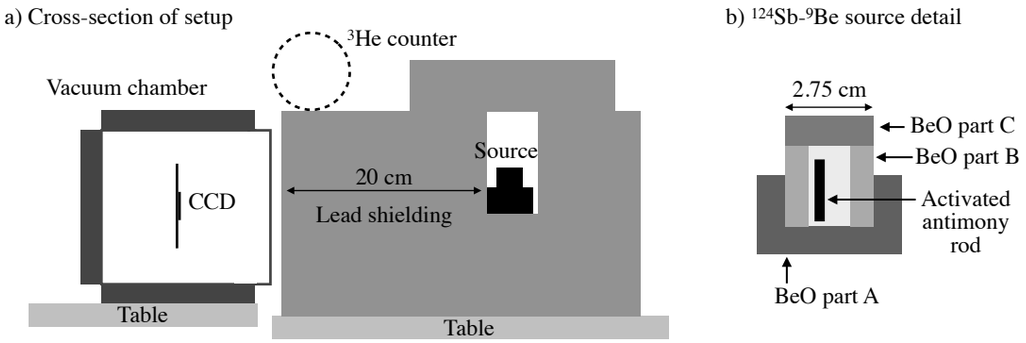
Analysis method	Isotope(s)	Tracer for	Bulk rate $kg^{-1}\,d^{-1}$	Surface rate $cm^{-2}\,d^{-1}$
α spectroscopy	^{210}Po	^{210}Pb	<37	0.011 ± 0.004, 0.078 ± 0.010
	$^{234}U + {}^{230}Th + {}^{226}Ra$	^{238}U	<5 (4 ppt)	–
	^{224}Ra–^{220}Ra–^{216}Po	^{232}Th	<15 (43 ppt)	–
β spatial coincidence	^{32}Si–^{32}P	^{32}Si	80^{+110}_{-65}	–
	^{210}Pb–^{210}Bi	^{210}Pb	<33	–

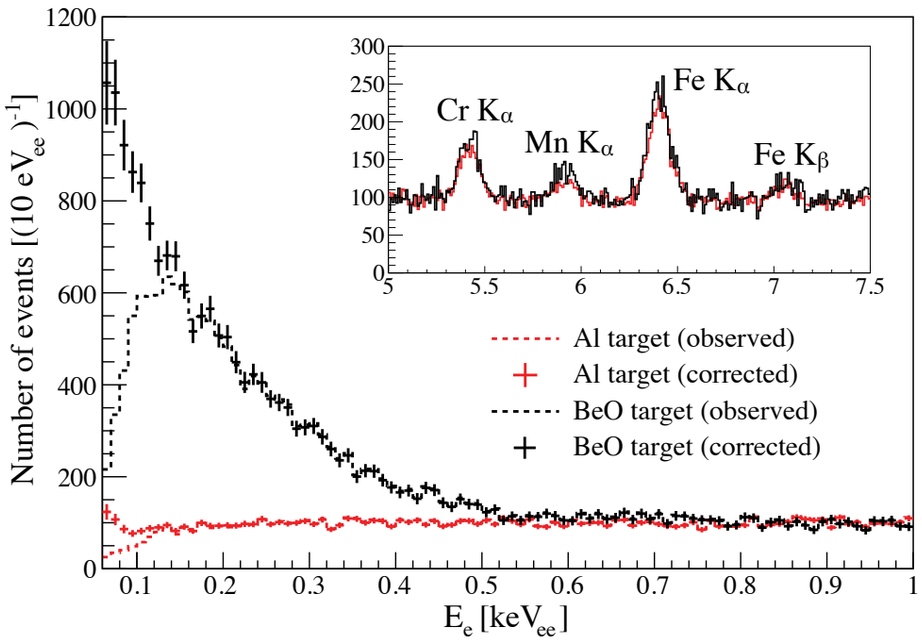
OTHER EXPERIMENTS



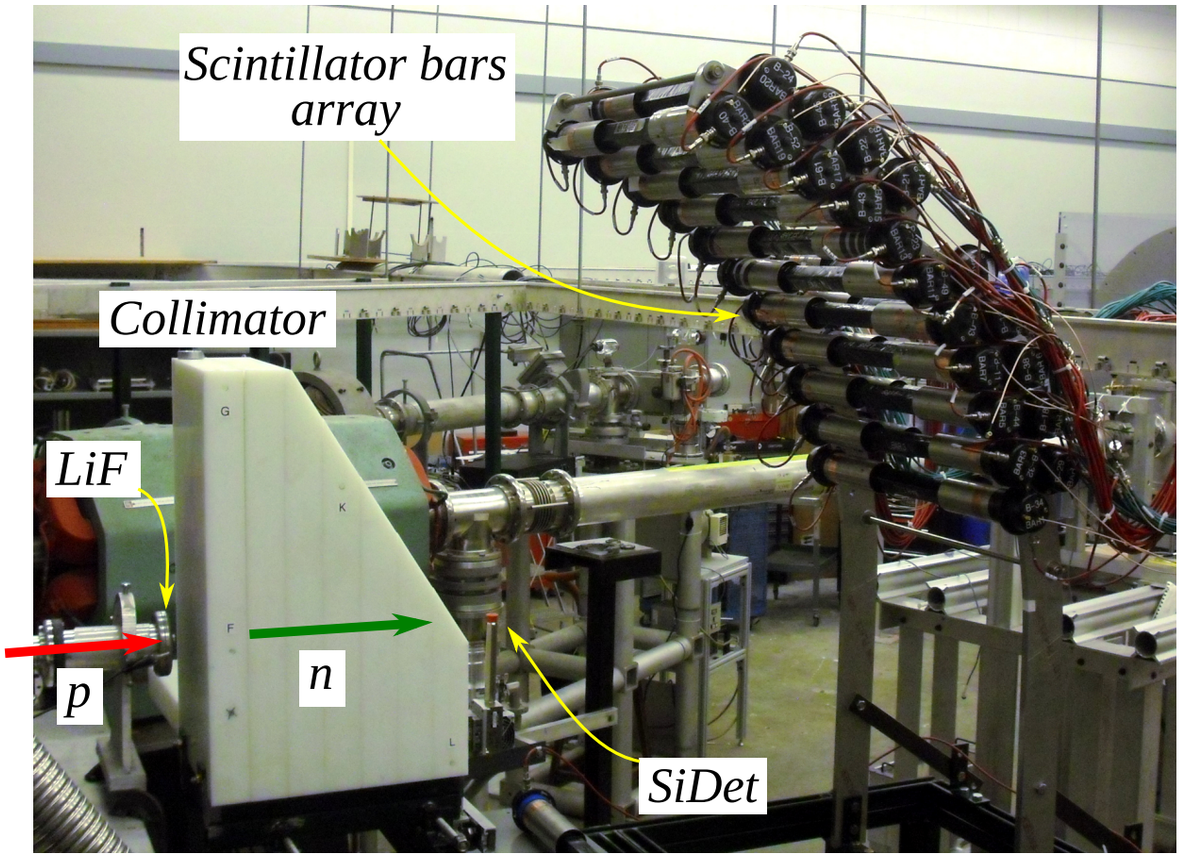
NUCLEAR RECOIL CALIBRATIONS

low E neutrons

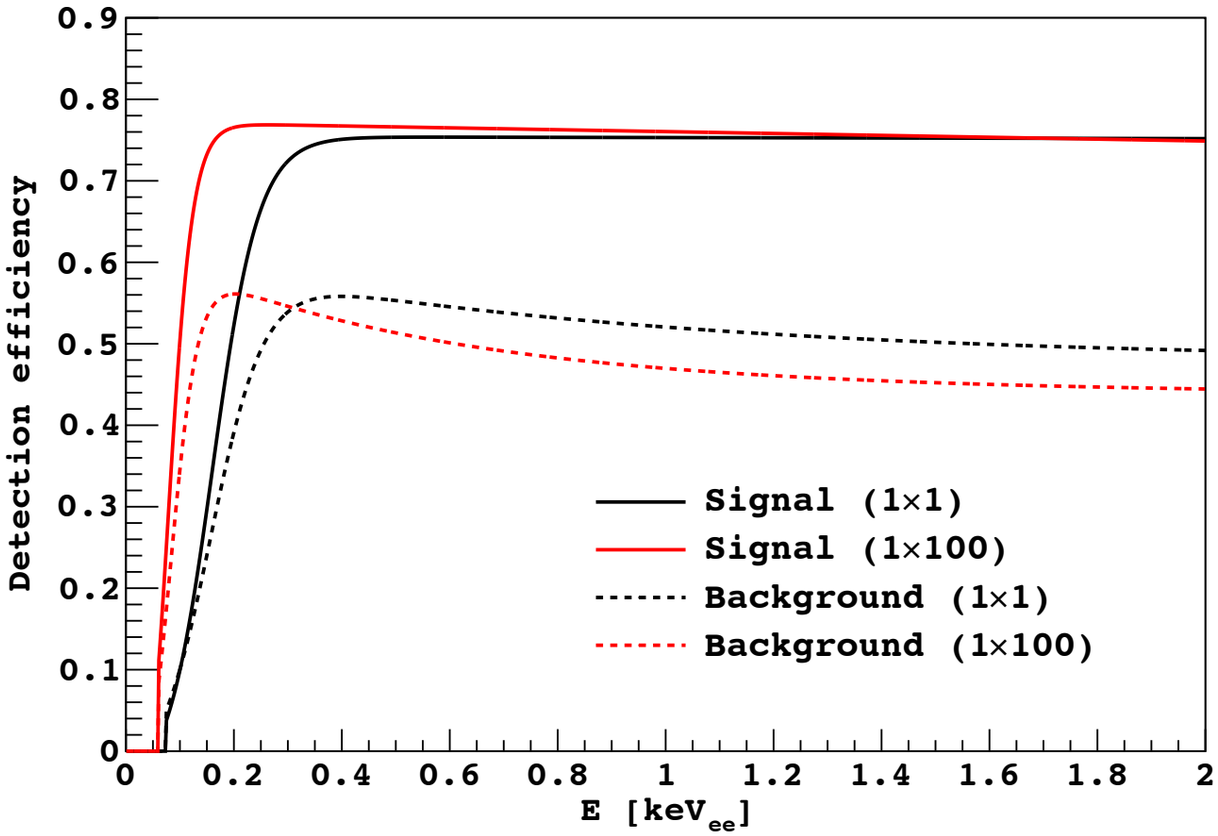




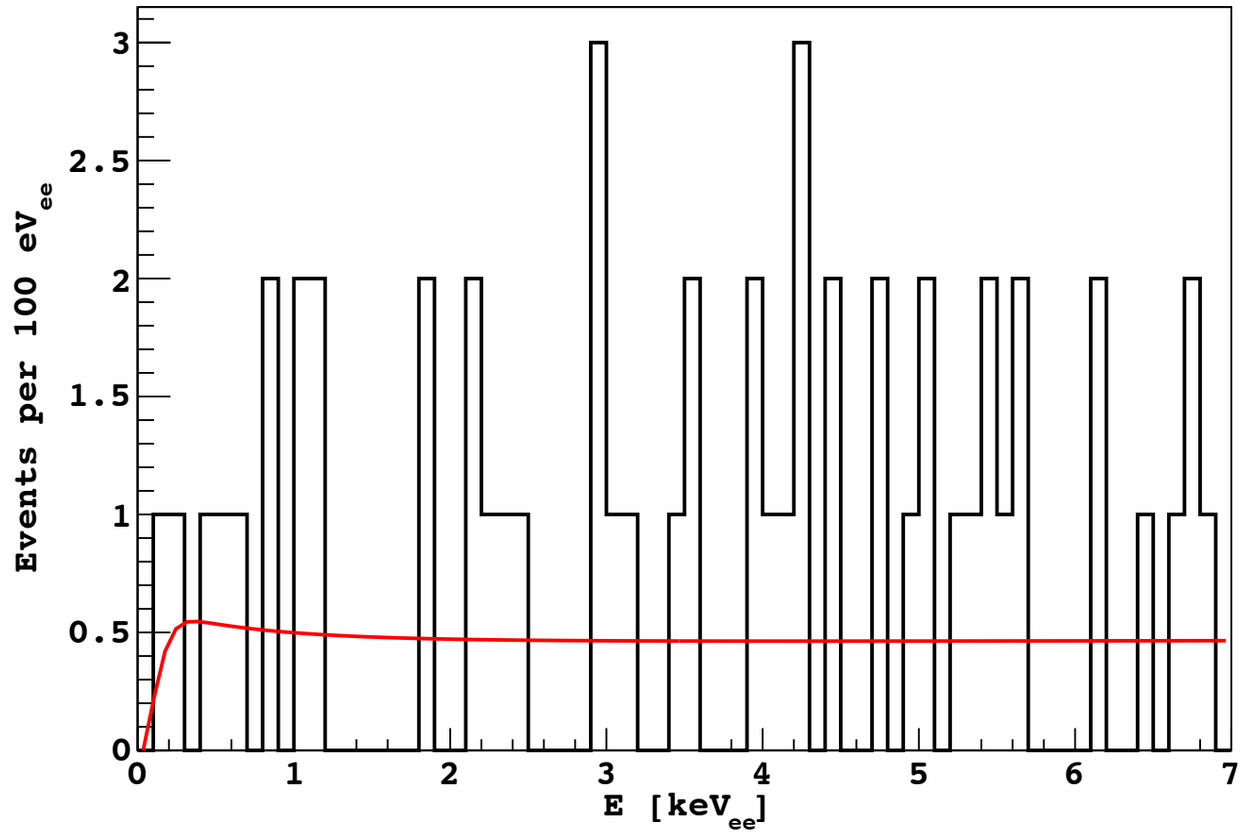
fast neutrons



WIMP Search efficiency



DM candidate spectrum



DAMIC BACKGROUND SPECTRUM