DM searches with **DAMIC** (**DA**rk **M**atter **I**n **C**CD)

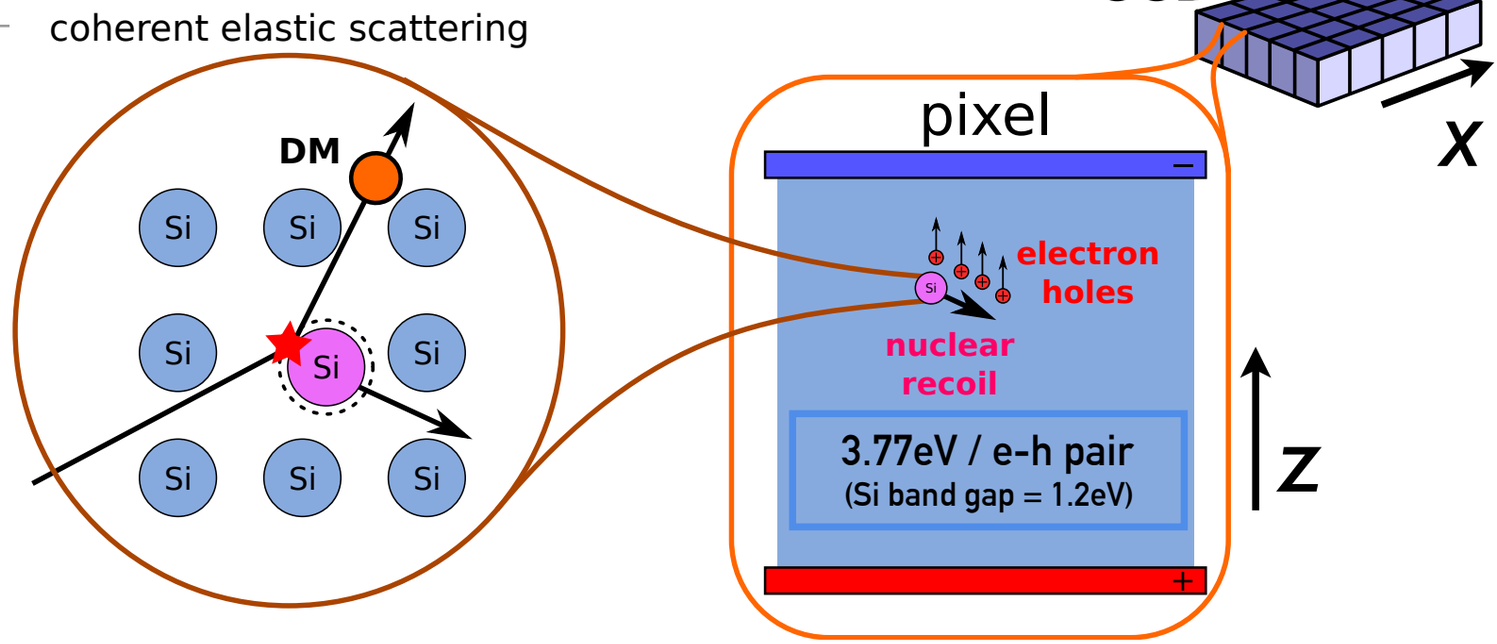
Romain Gaïor for the DAMIC collaboration

PALS meeting 25-27 september 2019 (Paris)

Why CCD ???

Threshold

- kinematic matching
- Si band gap = 1.2 eV
  (*compared with ~10eV in liq. noble gas*)
- low readout noise (currently ~2 e-)

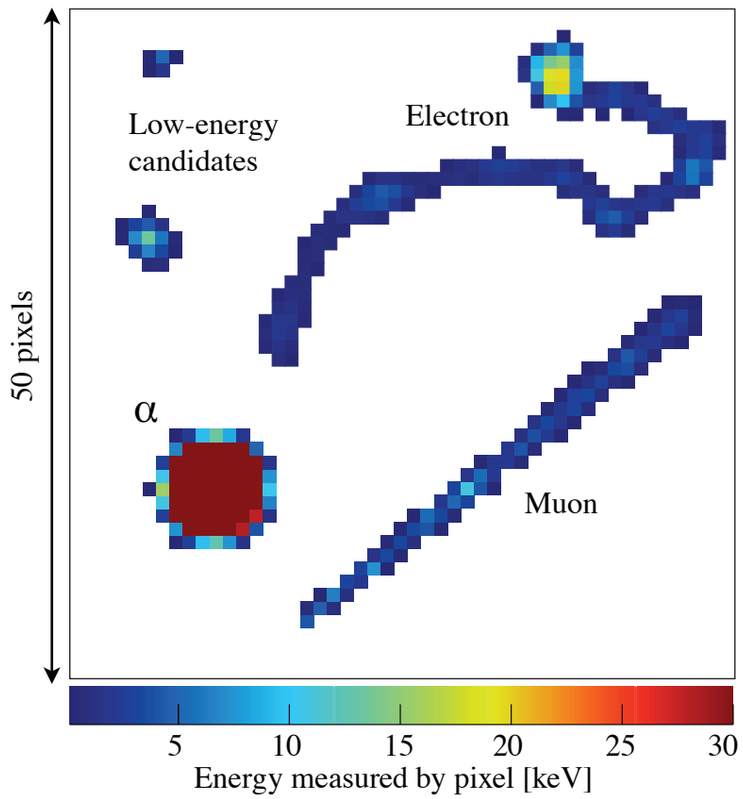


Mass

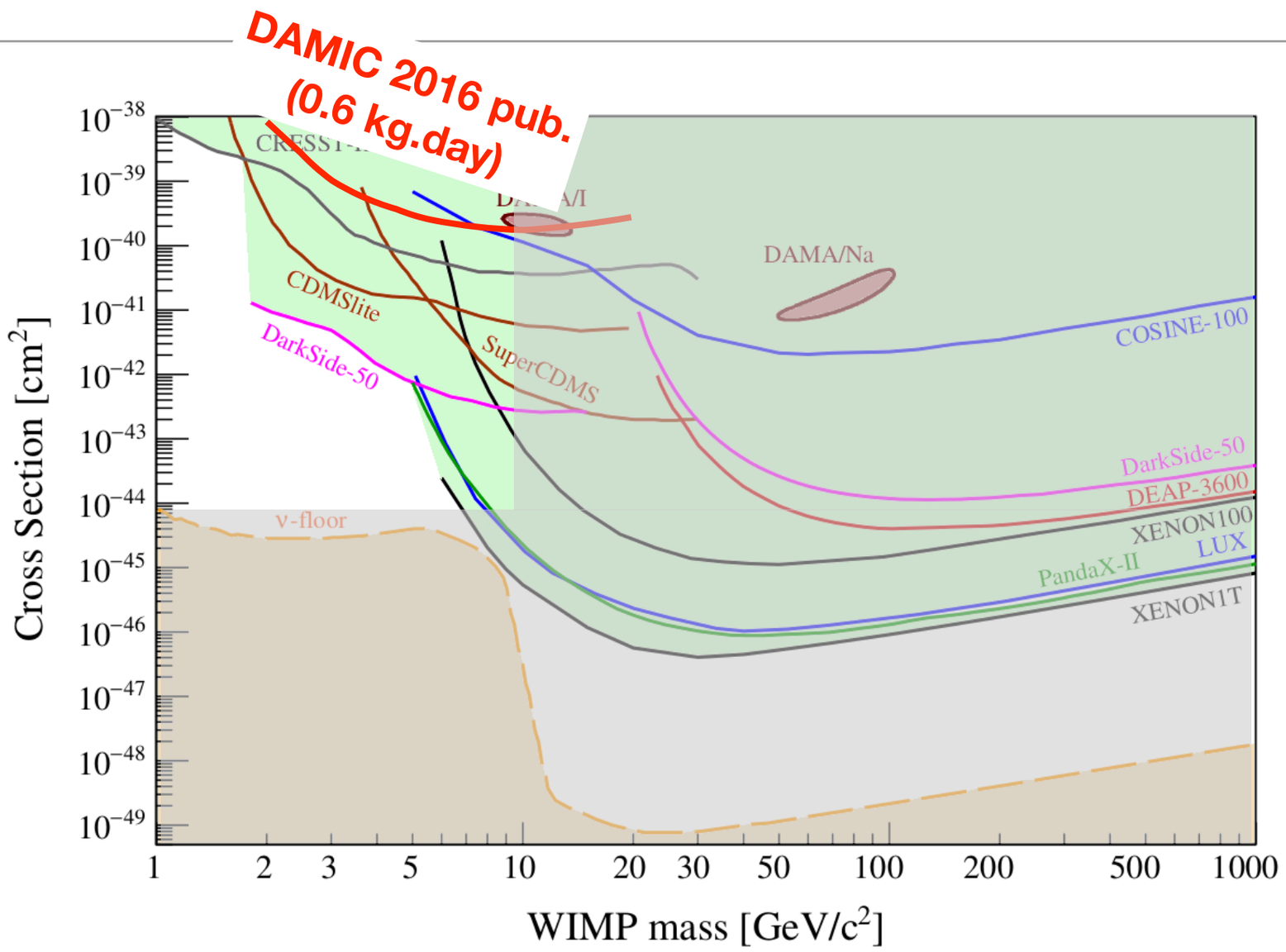
- Thick CCD
  current technology ~ 675 um
  ~ O(10g) a CCD
- detector of O(100g - 1kg)

Background

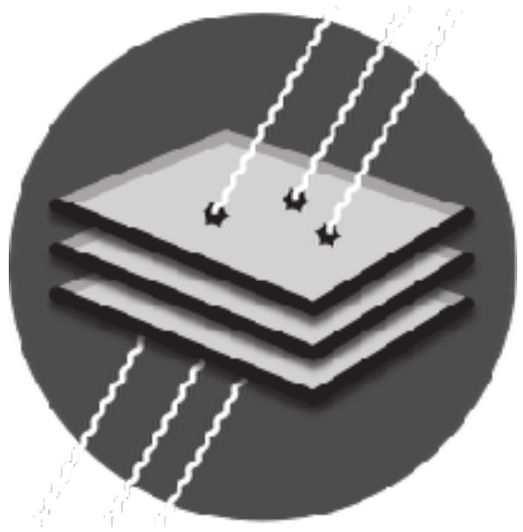
- High granularity
  3D information
- One intrinsic radio isotope



DAMIC goals

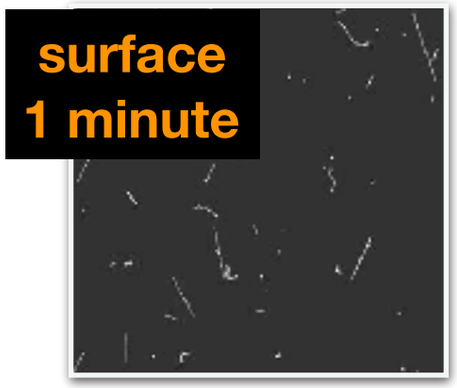


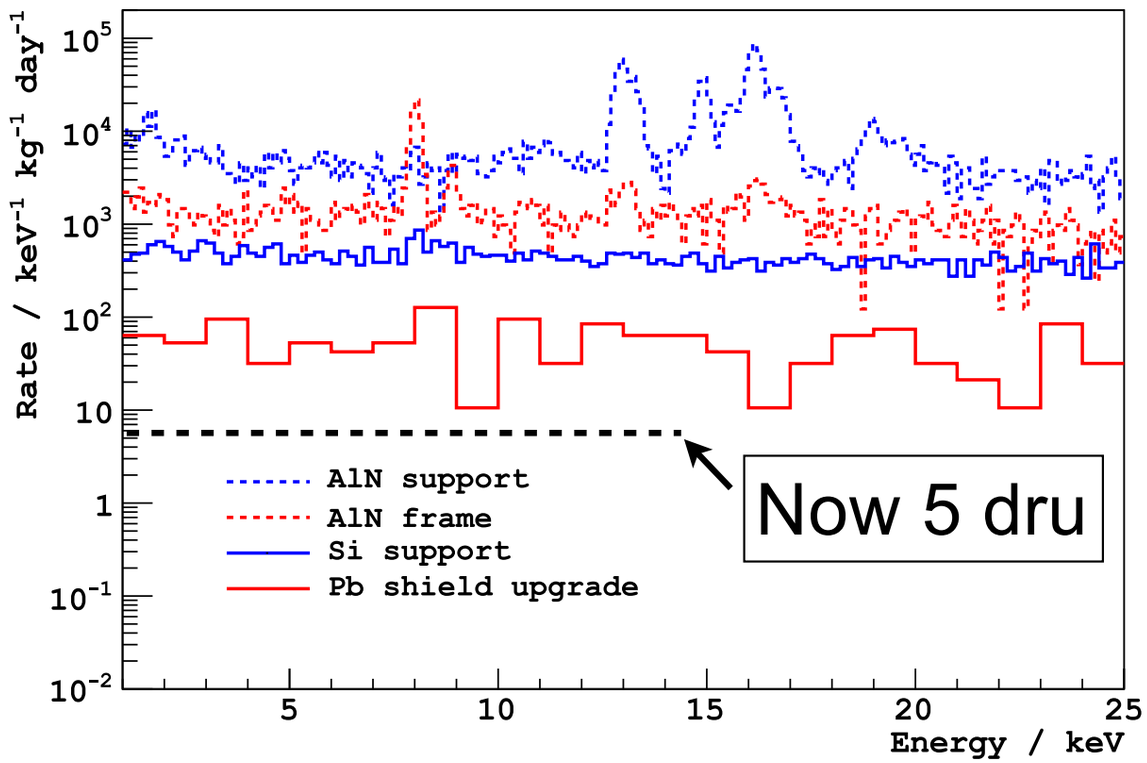
- WIMP search: **1-10 GeV/c^2** (so called light WIMP)
- Light DM (MeV scale) through DM-electron scattering

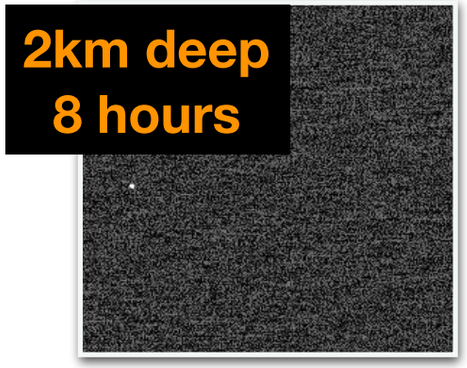


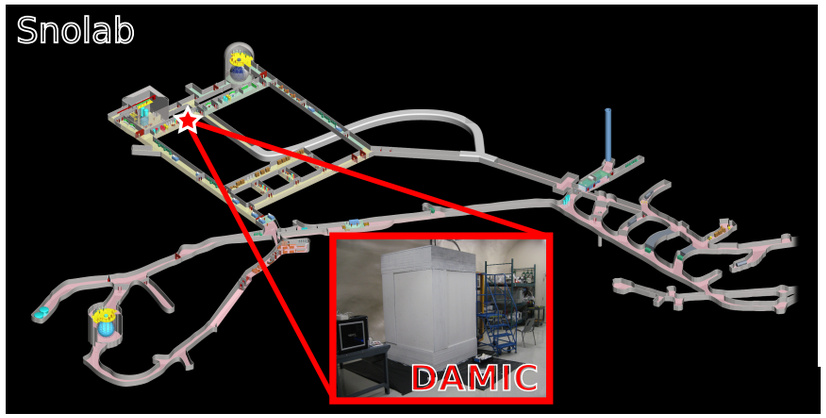
DAMIC at SNOLAB: 2012 - now

DAMIC at SNOLAB





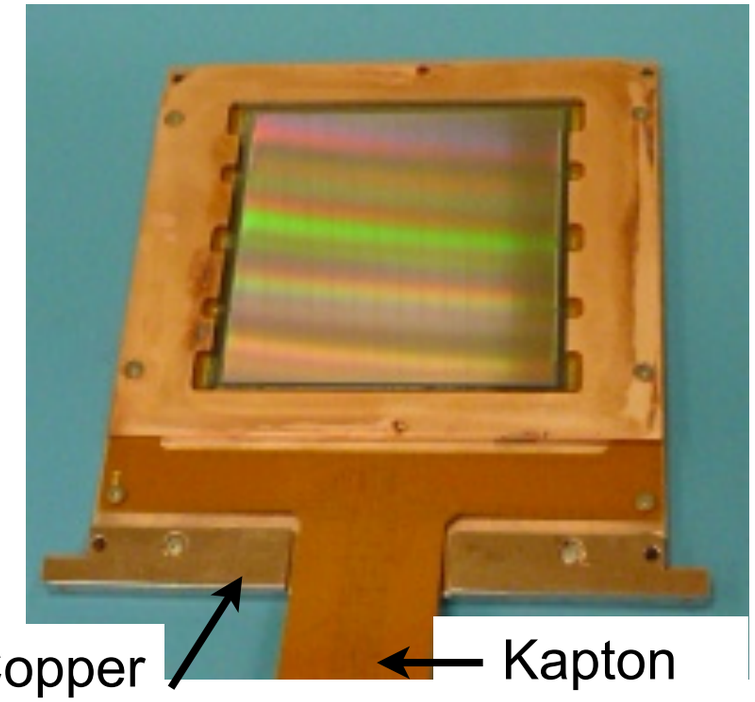


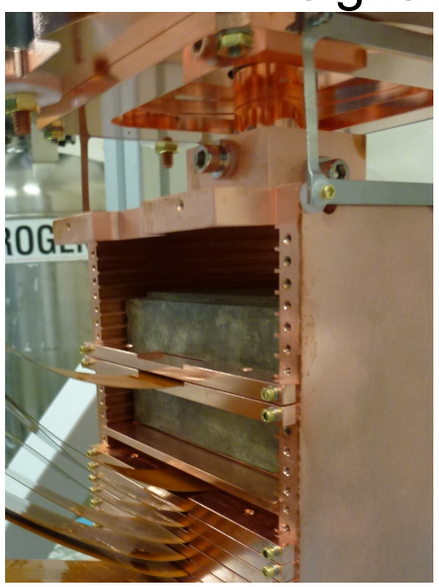


- In a (active) mine **2km** (6000m.w.e.) below surface (1μ / m^2 / 3 days)
  https://www.youtube.com/watch?v=sZPLcv-ASwc

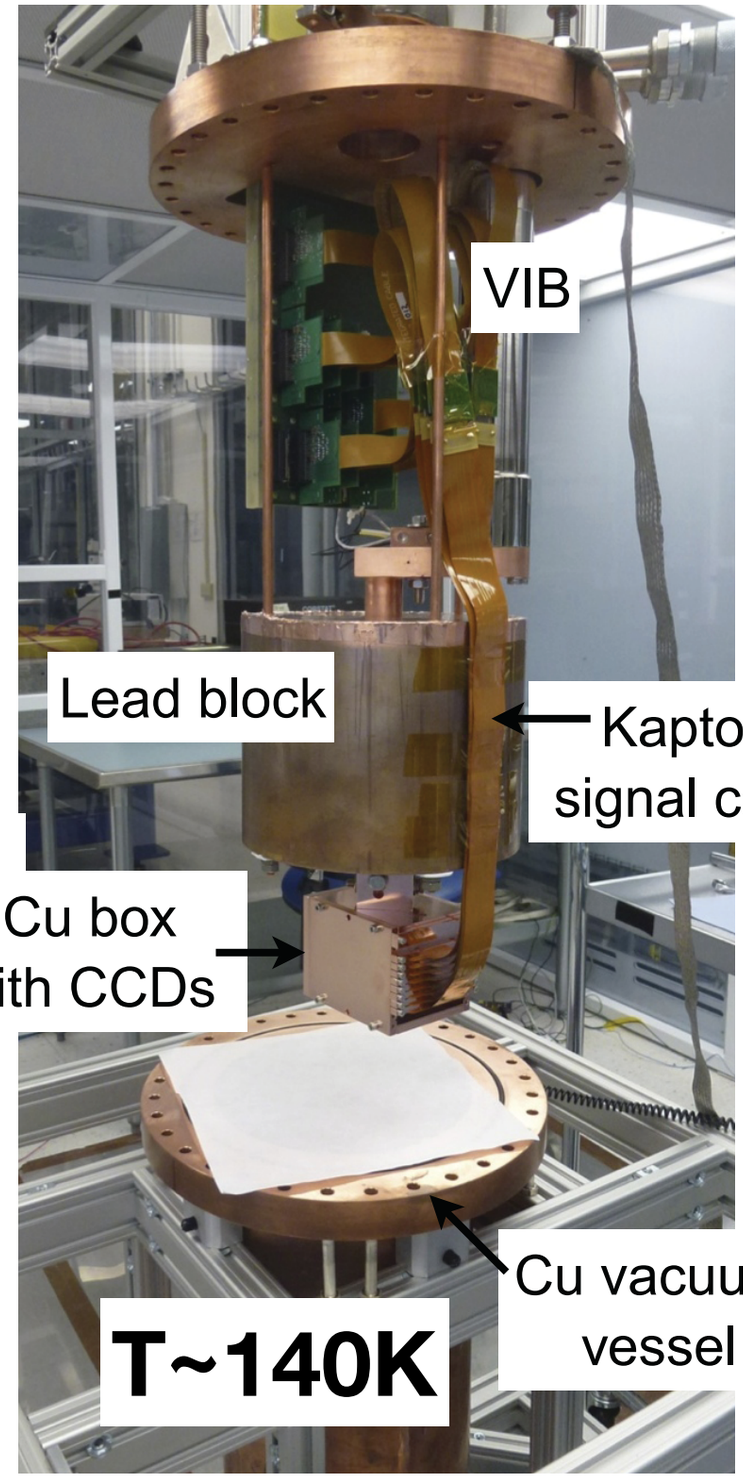
- Many improvements over the years in **background mitigation**

DAMIC detector



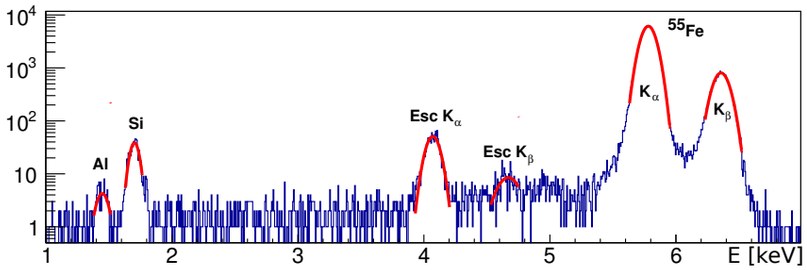


7 CCDs ~ 40g



Performances

Calibration

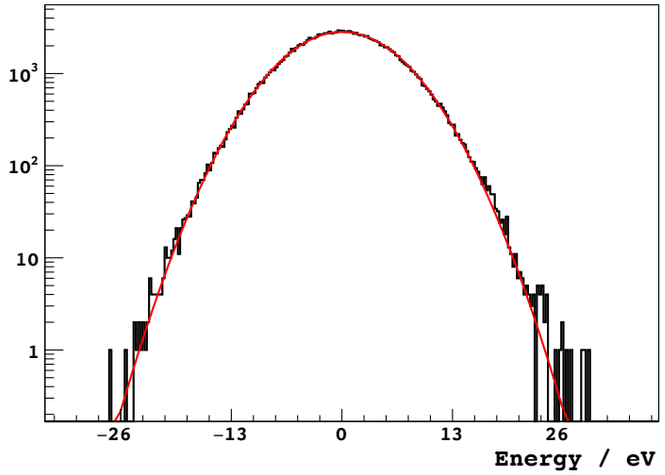


- ionisation in Si
  - fluorescence line (down to 1keV)
  - LED (40eV - 80 eV)
  - Compton spectrum
  - **Linearity** <5%

- Nuclear recoil:
  -**Quenching factor measured** in Si down to $60eV_{ee}$
  - Deviation from Lindard model

Compton:arXiv:1706.06053 Phys.Rev. D96 (2017) no.4, 042002
NR: IOP June 2017 Vol 12 P06014; Phys. Rev. D 94, 082007,

Noise



- Readout: Dual Slope integration with integration time of 40µs

- Image processing (equalisation + correlated noise suppression)

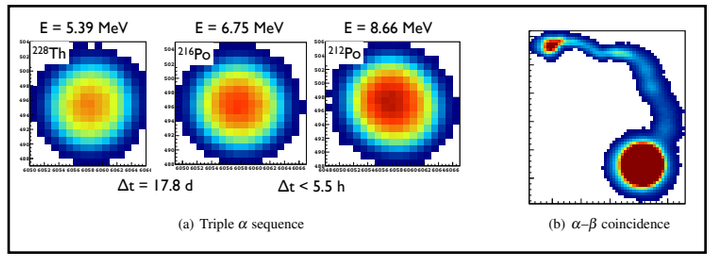
- Mask to remove « hot » pixels

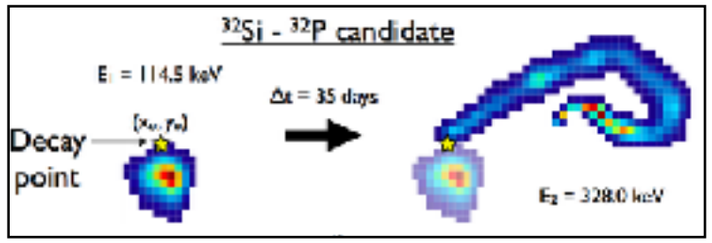
- noise ~ **1.6e**

- **low leakage current**: O(10) e- / mm2 / d

Processing + mask: *arXiv:1607.07410 Phys. Rev. D 94, 082006 (2016).*

Background





- Background mitigation thanks to material choices

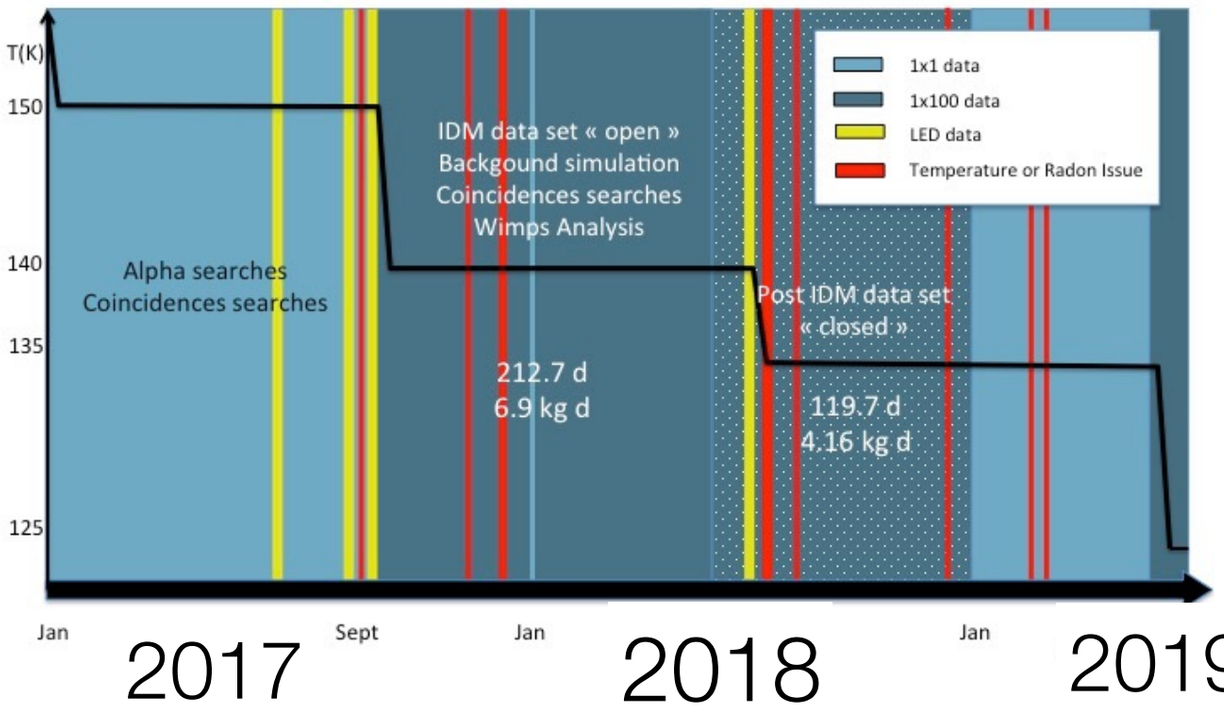
- **Identification of chain:**
  Spatial correlation + energy resolution
  - U238, Th232
    (< 5 / kg / d and < 15 /kg/d)
  - Pb210 < 35 / kg / d
  - Si32: 80 (+-110/65) / kg / d

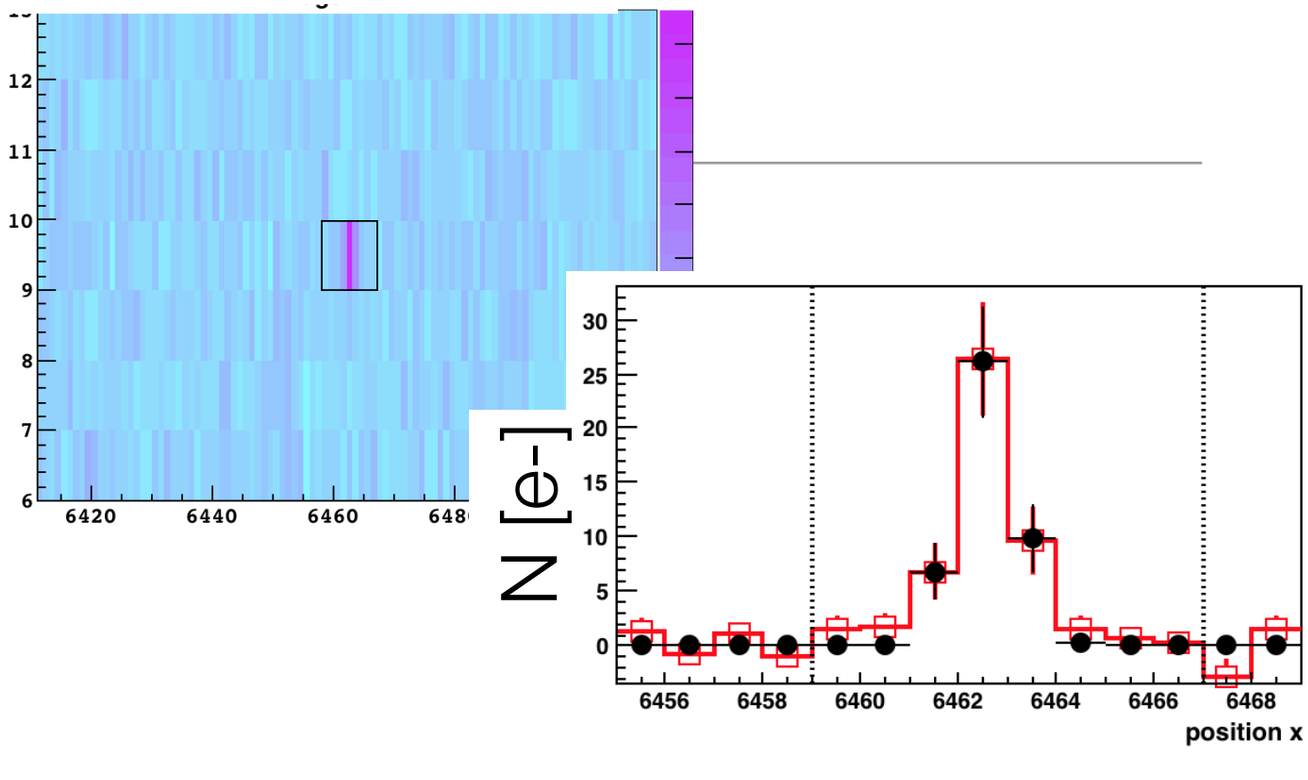
- **Surface background rejection**

- Update coming soon

Background : *arXiv:1506.02562 JINST 10 (2016) no.08, P08014*

WIMP search





Data set

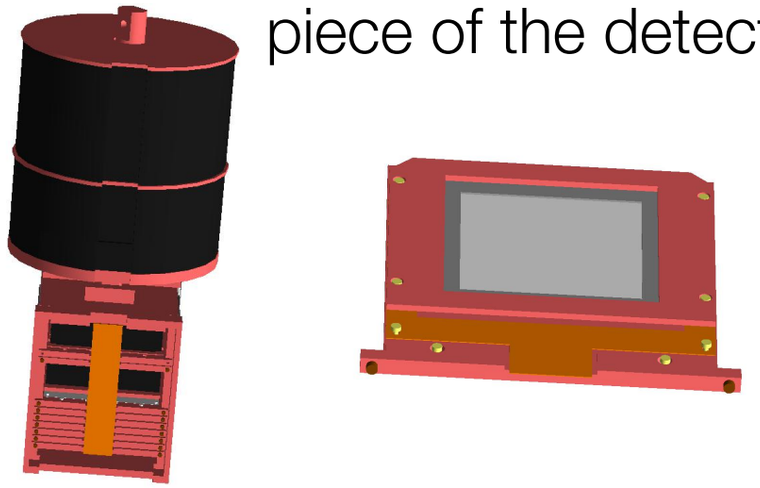
- **1x100 binning** (15 x1500um pixels)
- Data set of 864x7 images (8h or 24h exposure)
- Low radon && Low leakage current && quality cuts
- **~11 kg.day**
  (previous publication 0.6 kg.day:
  arXiv:1607.07410 Phys. Rev. D 94, 082006 (2016))

Analysis steps

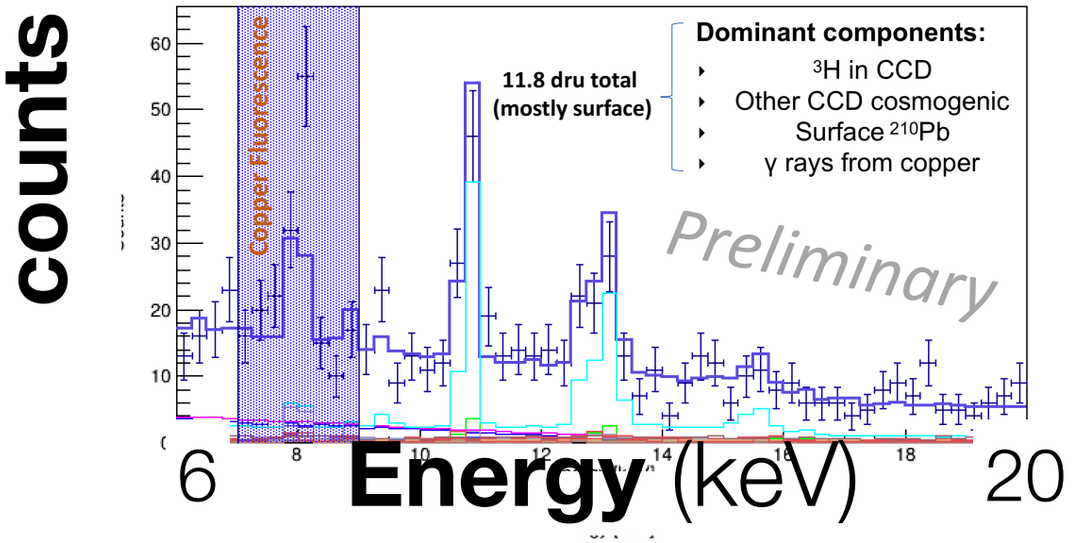
- Search for low energy deposition (~50ev - 10keV)
- Geant4 Simulation of the radioactive contaminations
- Build a background model in a test region
- Compare data / model in region of interest —> Discovery (or limits…)

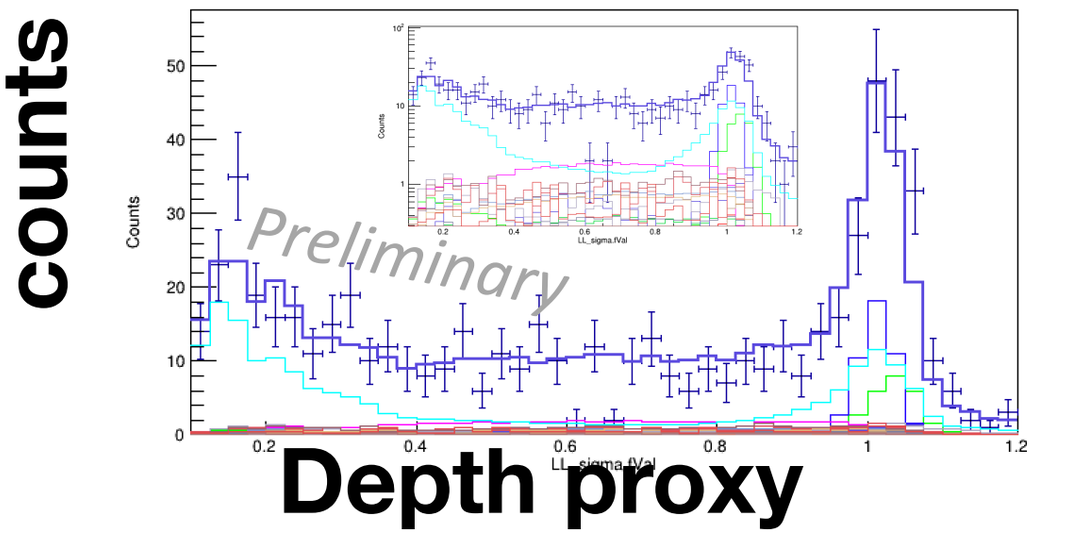
Background model

1 **GEANT4 Simulation** of relevant decay chains in each piece of the detector

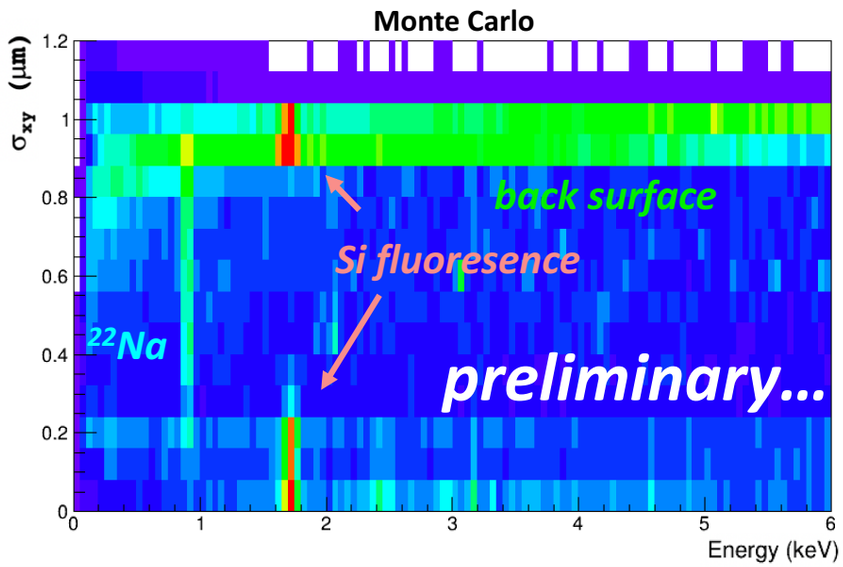


2 **2D fit** in the plane Energy-Depth at **E > 6keV** (constrained with assay value)

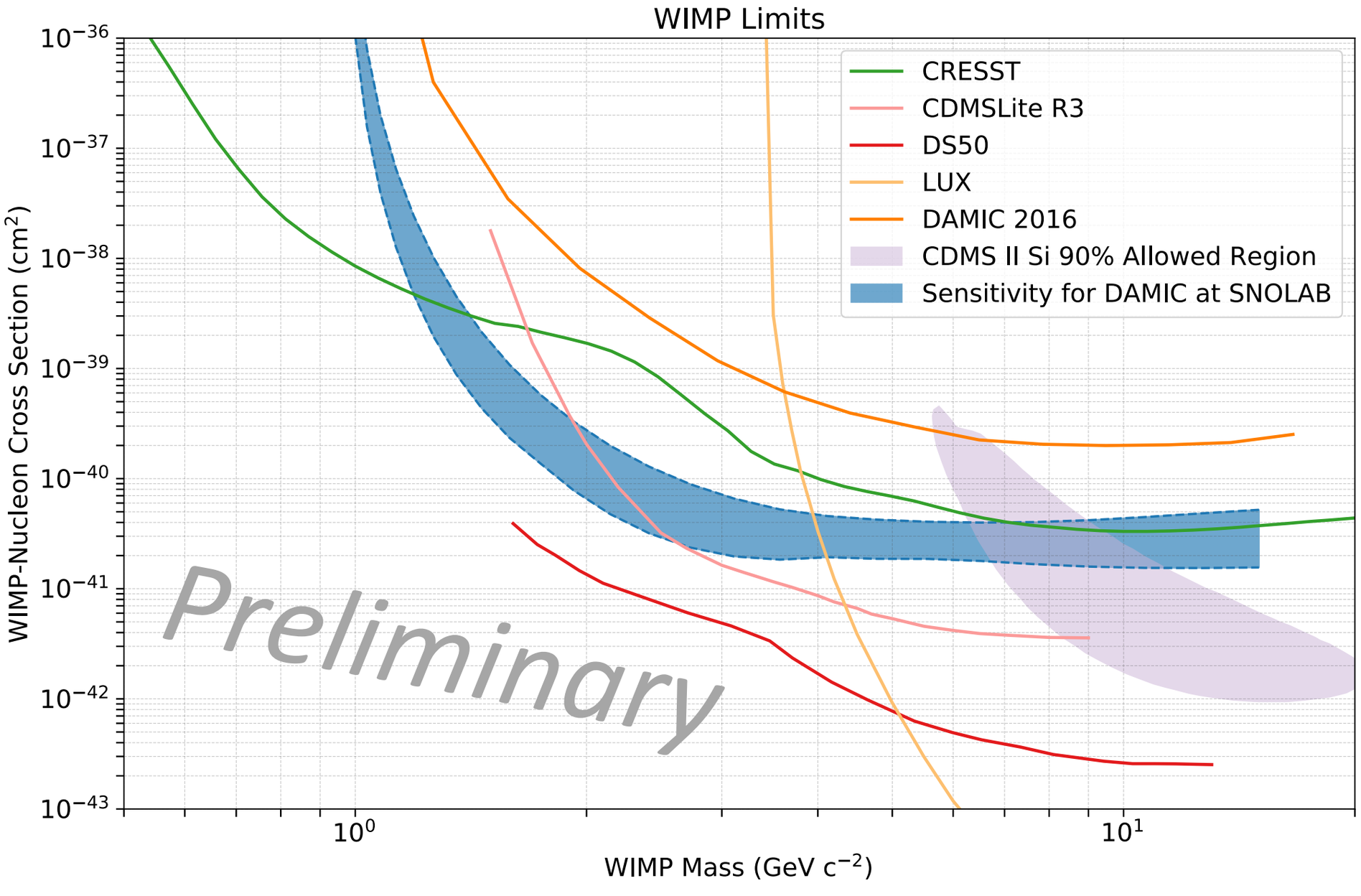




3 Background Model **in ROI**



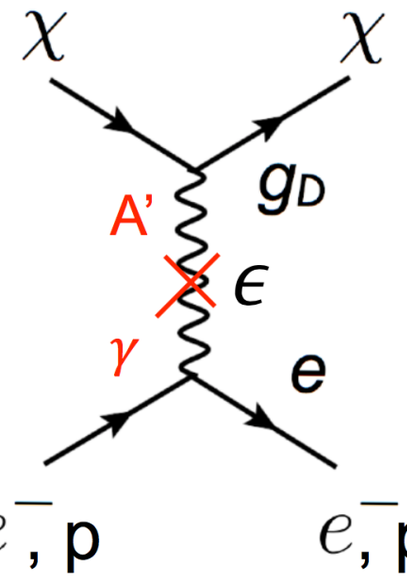
Sensitivity to WIMP with 11kg.day



Light dark matter - DM-e scattering

- Light dark matter (keV- GeV) appear in hidden sector scenarios

- elastic scattering with e- or absorption of dark photon
  —> Deposited energy large enough to directly ionise atom
  (in crystal excite from valence to conduction band)



Simulation in DAMIC detector

- indefinite momentum and band structure—> need specific treatment
  see arxiv:1509.01598 (Essig et al)

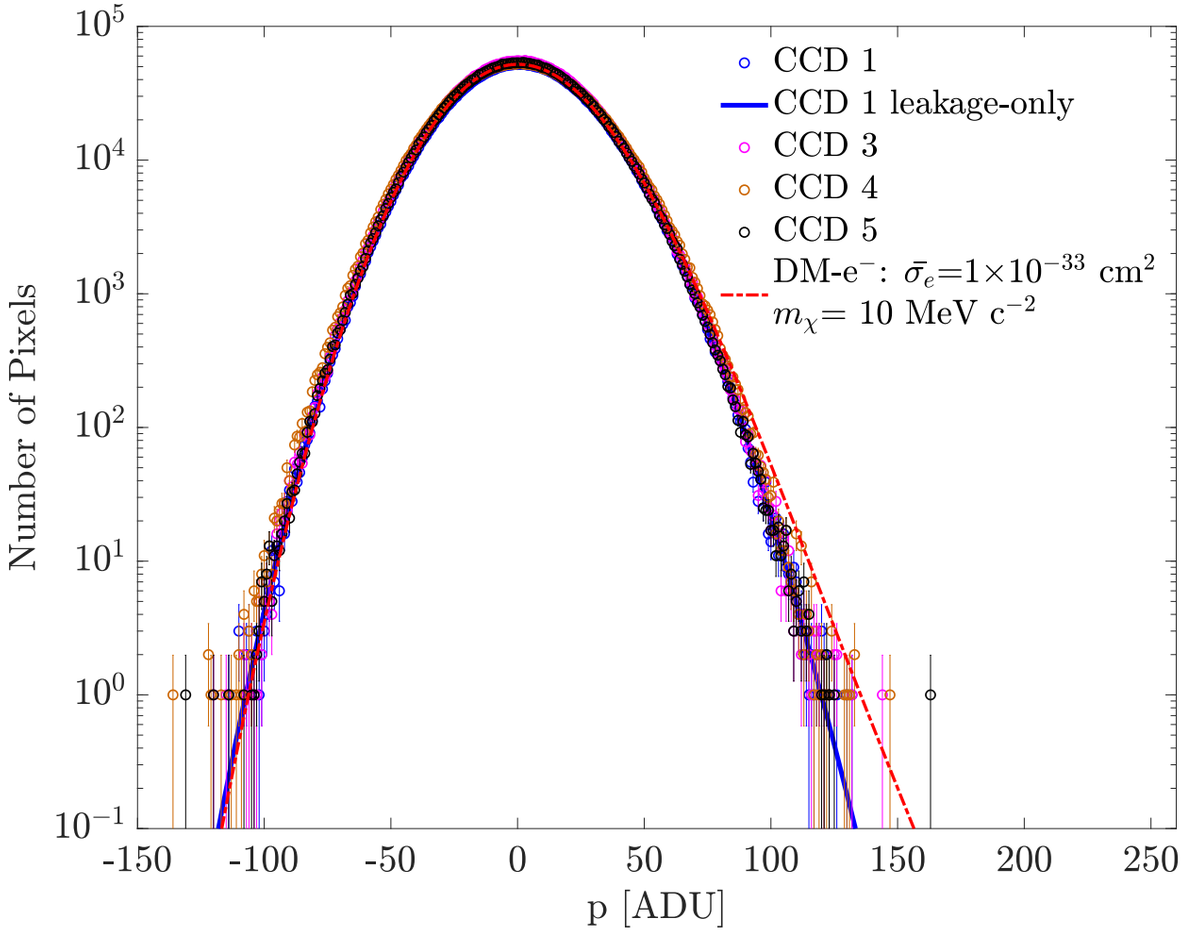
DM flux parameters *crystal form factor*

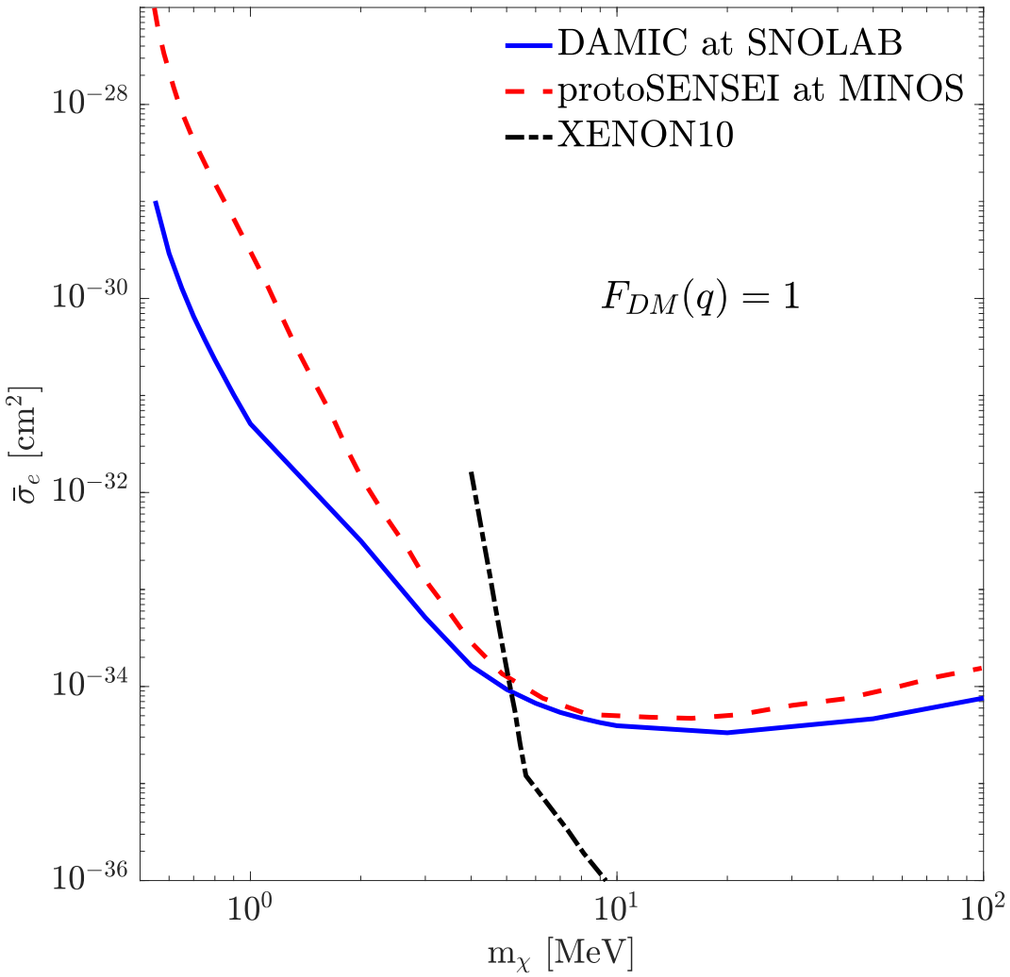
$$\frac{dR}{dE_e} \propto \bar{\sigma}_e \int \frac{dq}{q^2}\, \eta(m_\chi, q, E_e) |F_{DM}(q)|^2 |f_c(q, E_e)|^2$$

reference X section

$F_{DM} = (\alpha m_e)/q^n \ \{n = 0, 1, 2\}$
depends on interaction

DAMIC DM-electron limits: arXiv:1907.12628

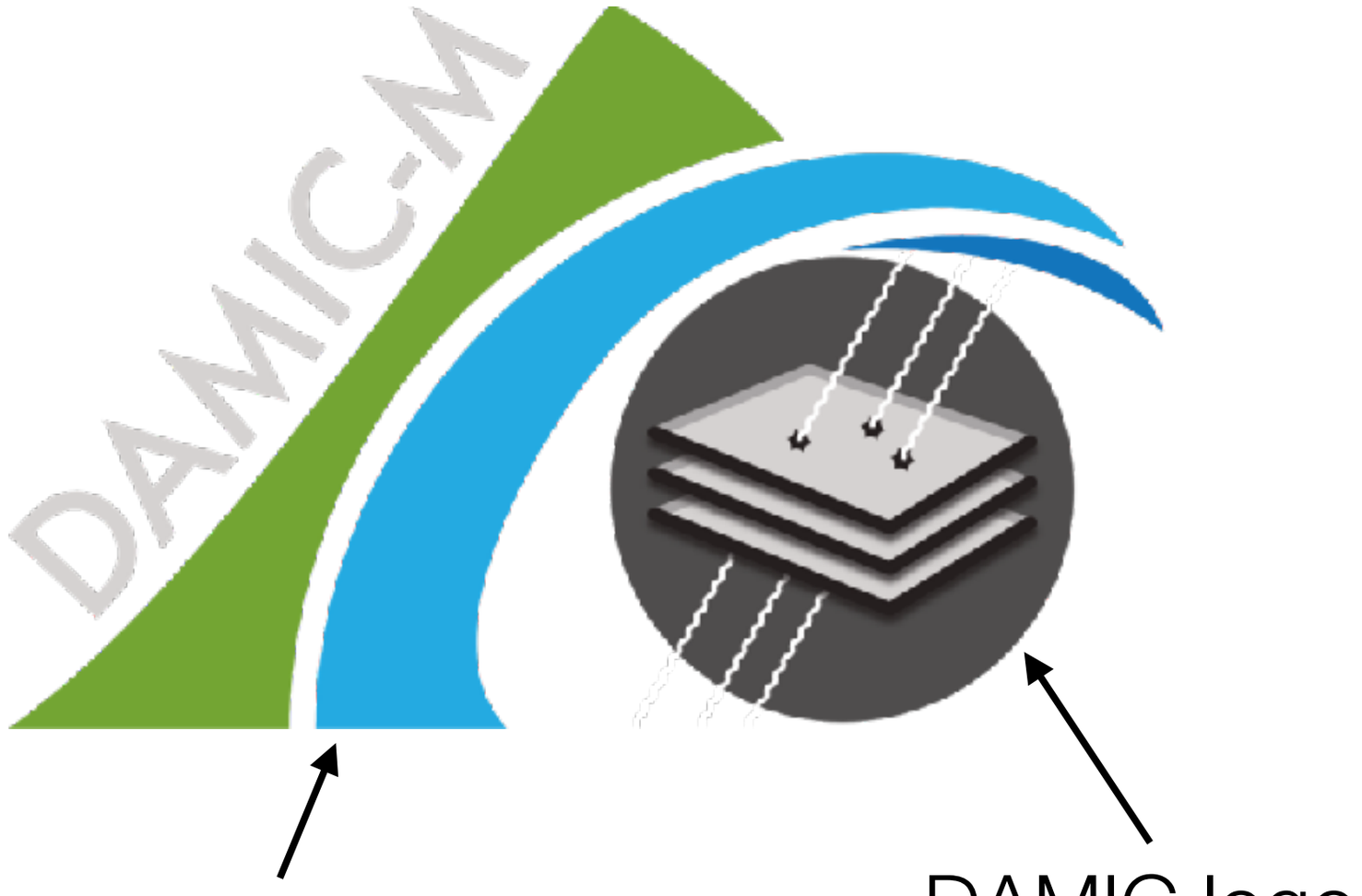




- **Selection of images** with the lowest leakage current (1-3 e- / mm2 / day)
- **Fit the pixel distribution** with electronics, leakage current, signal components
- **extract limit** on σ_e (for various interaction assomptions)

—> **Lowering the threshold to ~ 1 e-** would change the game…

DAMIC-M

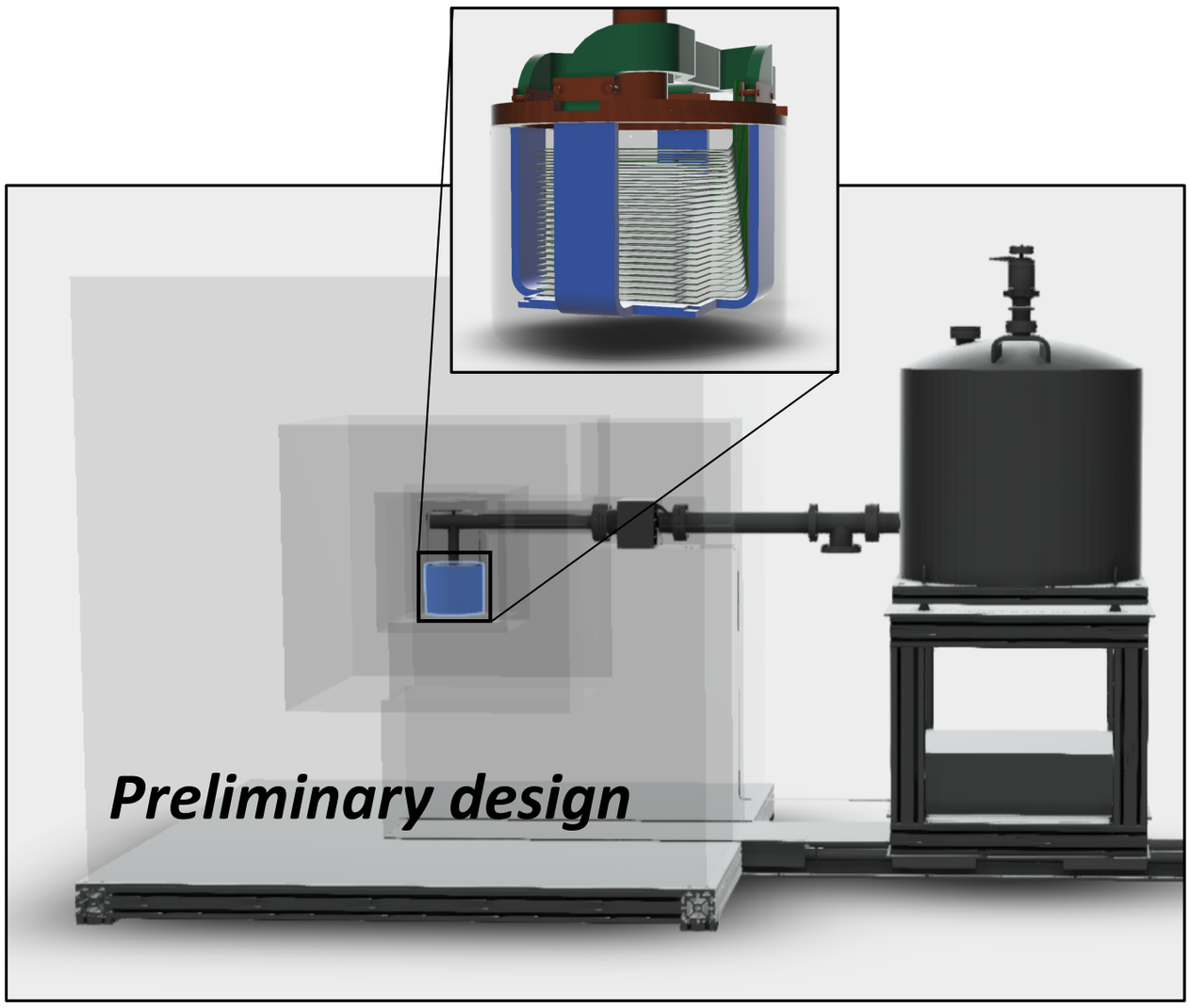


LSM logo

(Laboratoire Sous terrain de Modane)

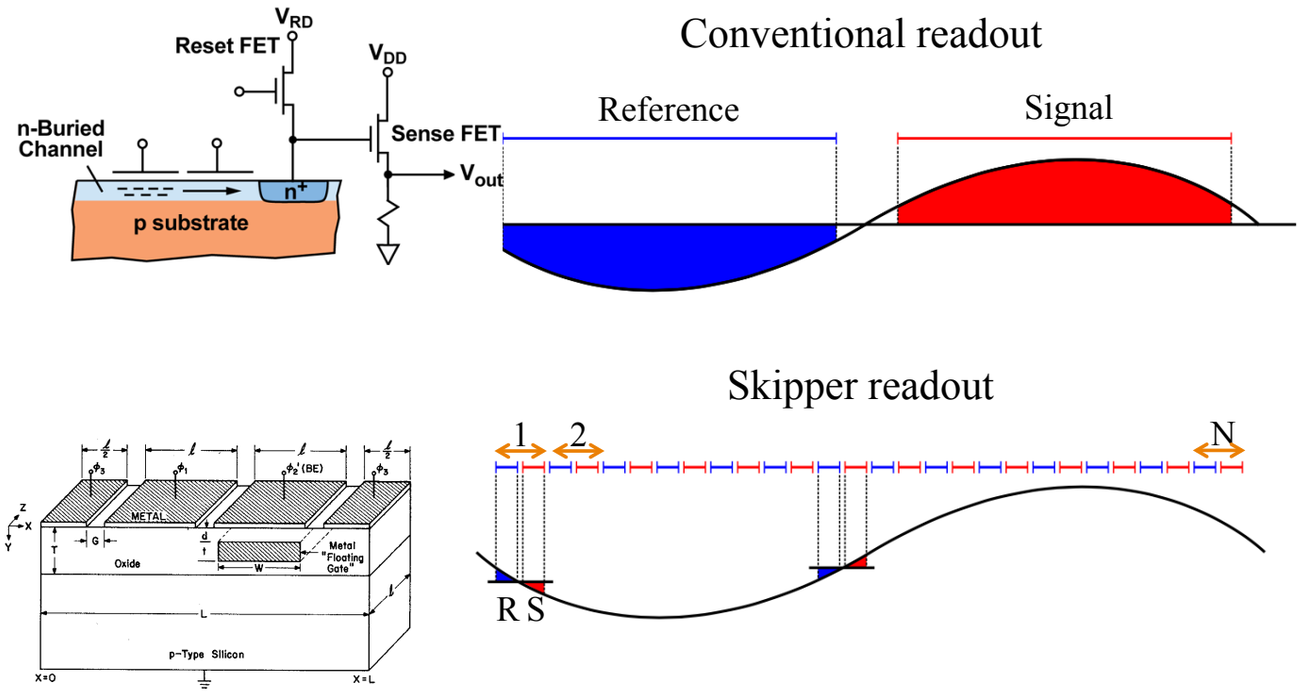
DAMIC logo

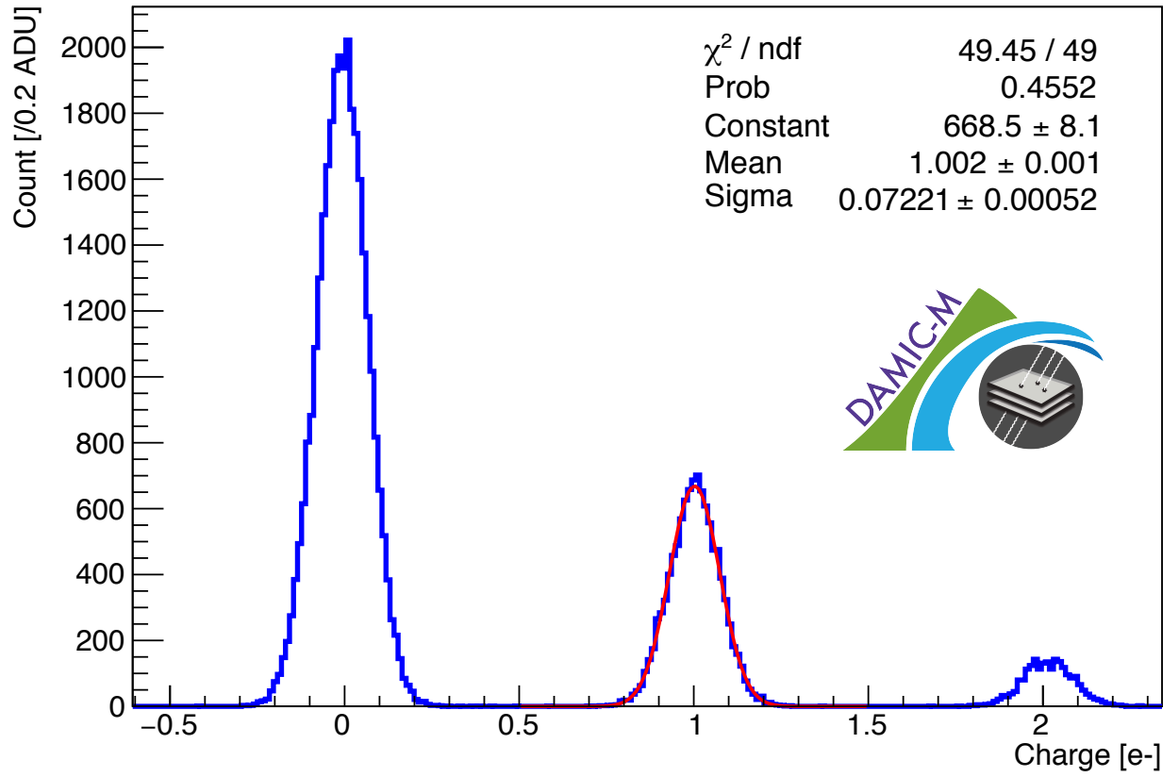
DAMIC-M in a nutshell



- Snolab —> **Modane**
- mass: 40g —> **1kg**
  more + larger CCDs
- Background: 5 —> **0.1 d.r.u**
  Very thorough component choice, gained experience
- Threshold: 10e- —> **1e-**
  Use of skipper CCD, integrated electronics

Skipper CCD

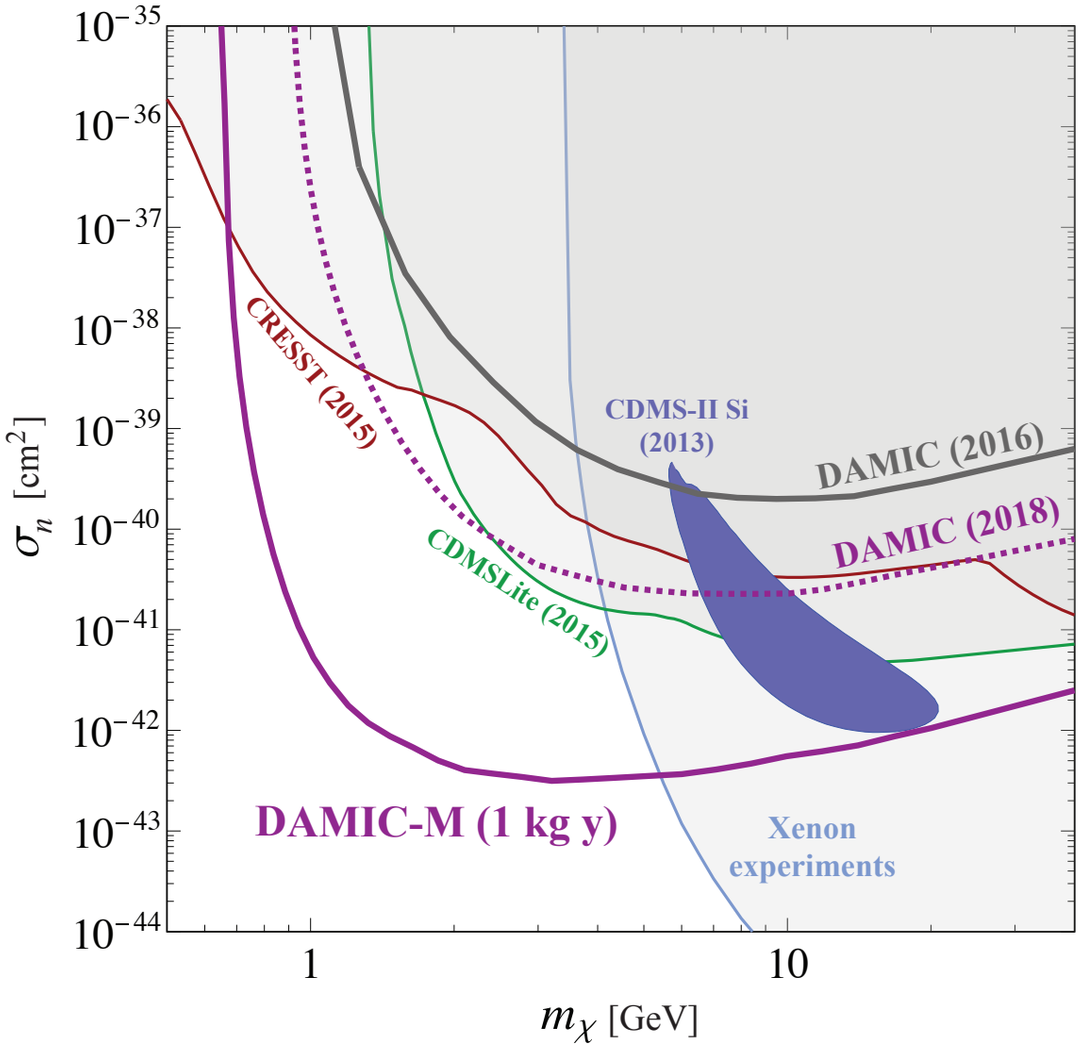




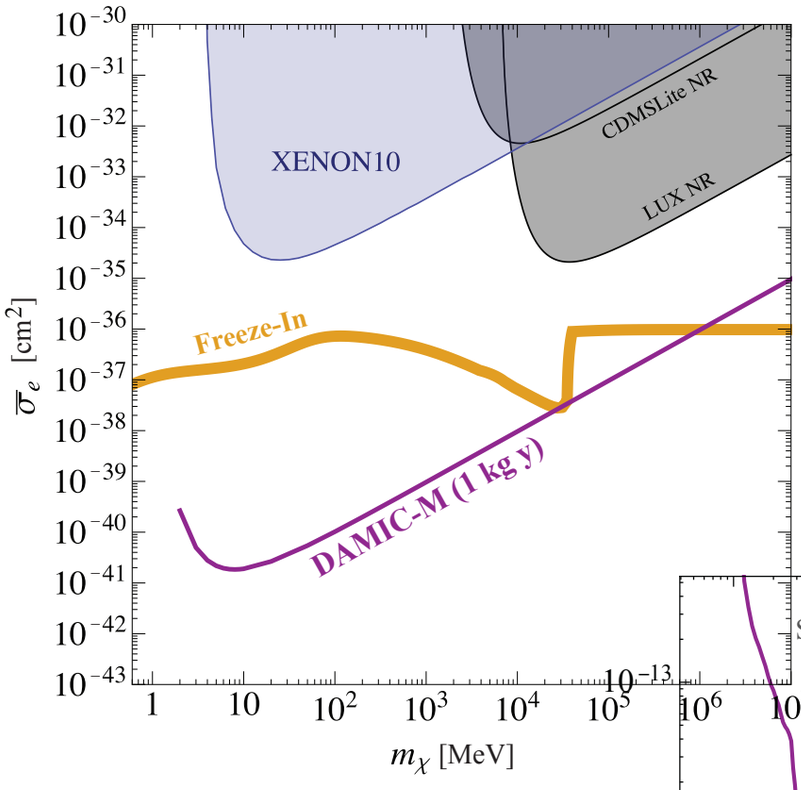
- Skipper CCD is an innovative technique (*arXiv:1706.00028*)
  Non destructive multiple uncorrelated readings
- **DAMIC-M teams have reached sub-electron resolution !**
- Improve readout noise: development of an ASIC
- dark current limiting but very low in Si: **1-2e- threshold possible**

DAMIC-M expected science performances

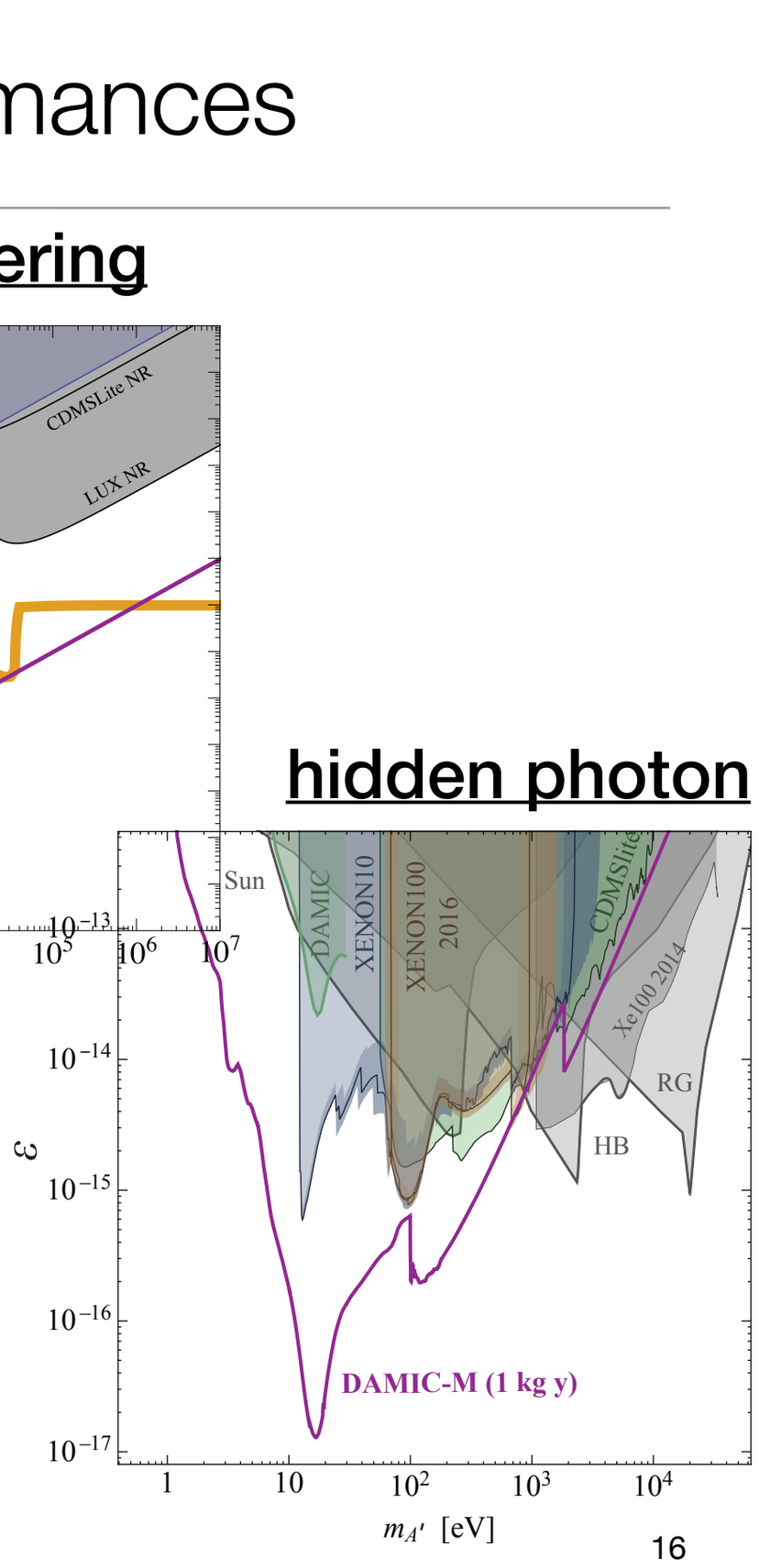
WIMPs



DM - e scattering



hidden photon



Conclusions

DAMIC:

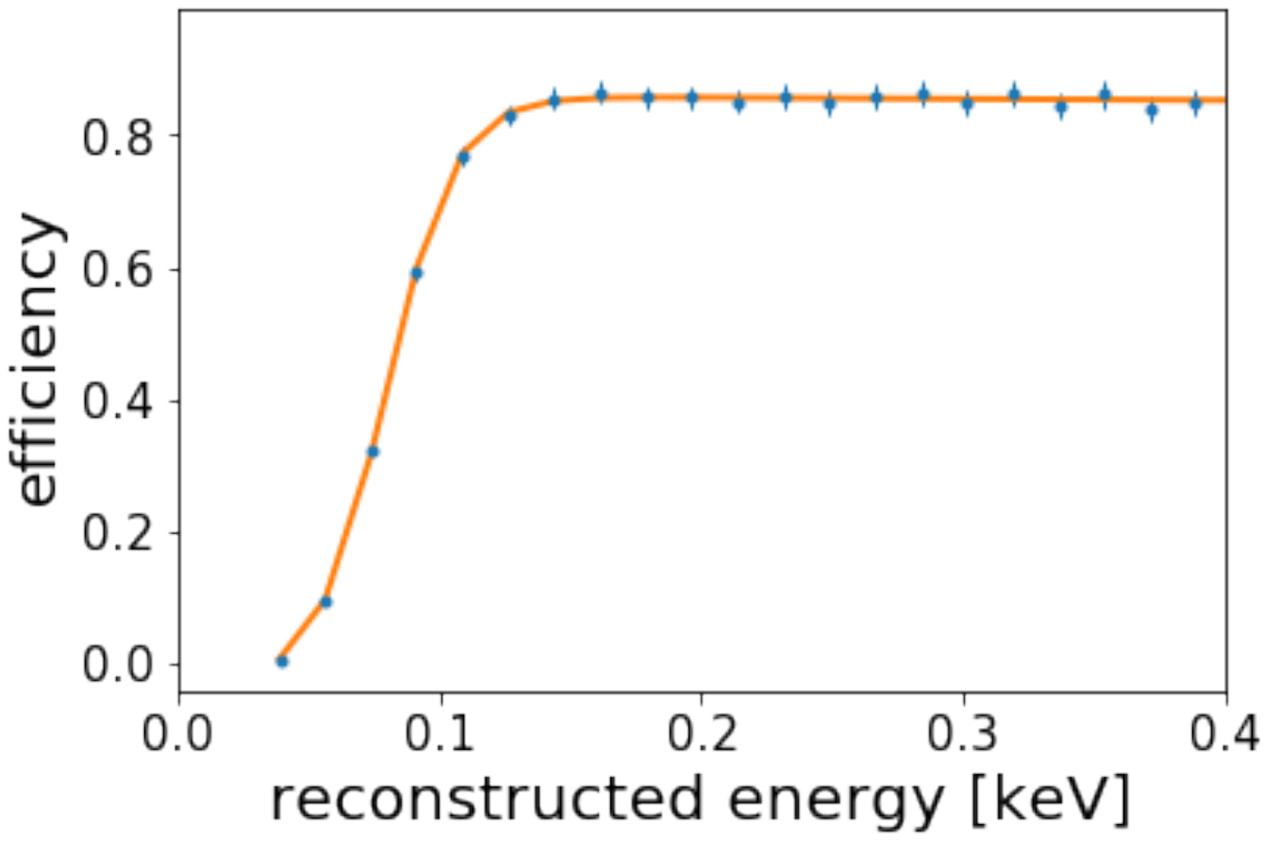
- DM-e exclusion: expected very soon publication (already on arxiv)
- Updated background model
- low mass WIMP with ~11kg.day : publication soon (months scale)

DAMIC-M

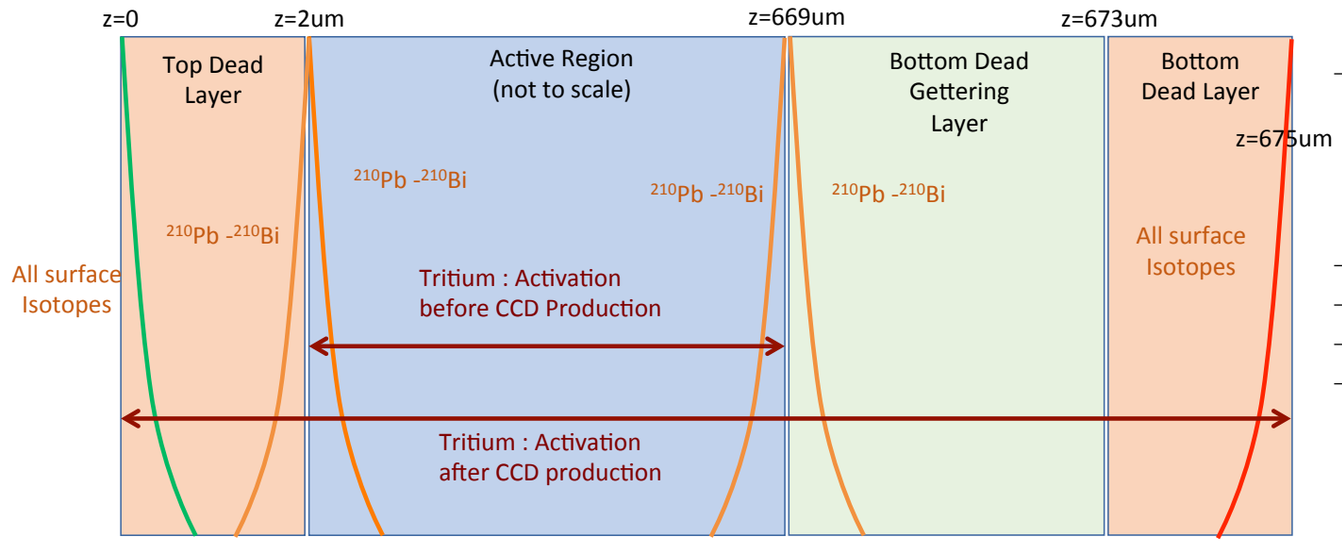
- decreased threshold, lower background, increased exposure will lead to significant science results
- very active developments:
  low background, mechanical design, electronics
- expected first « light » in 2021-2022

Thanks for your attention

WIMP Analysis



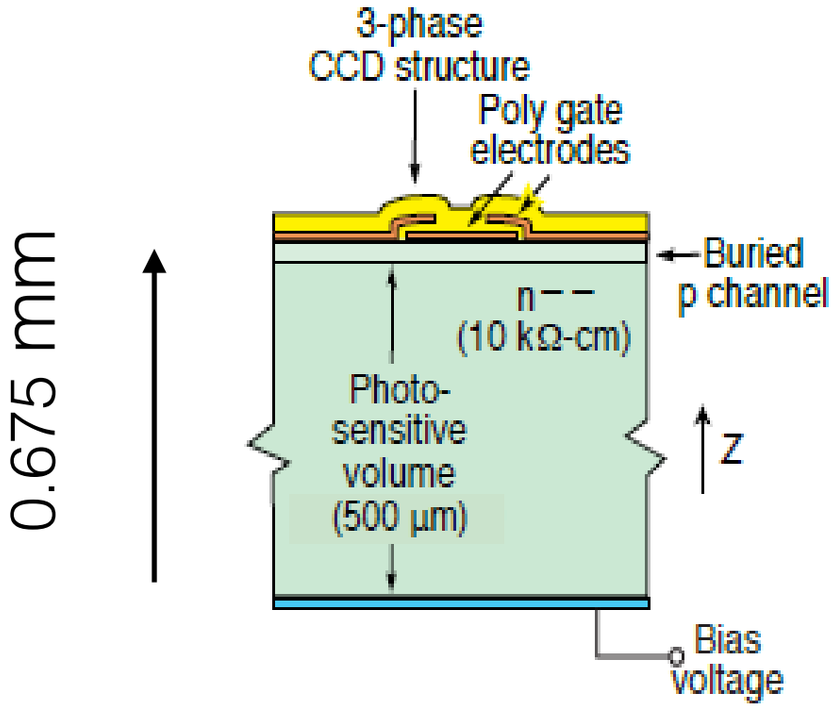
Background model



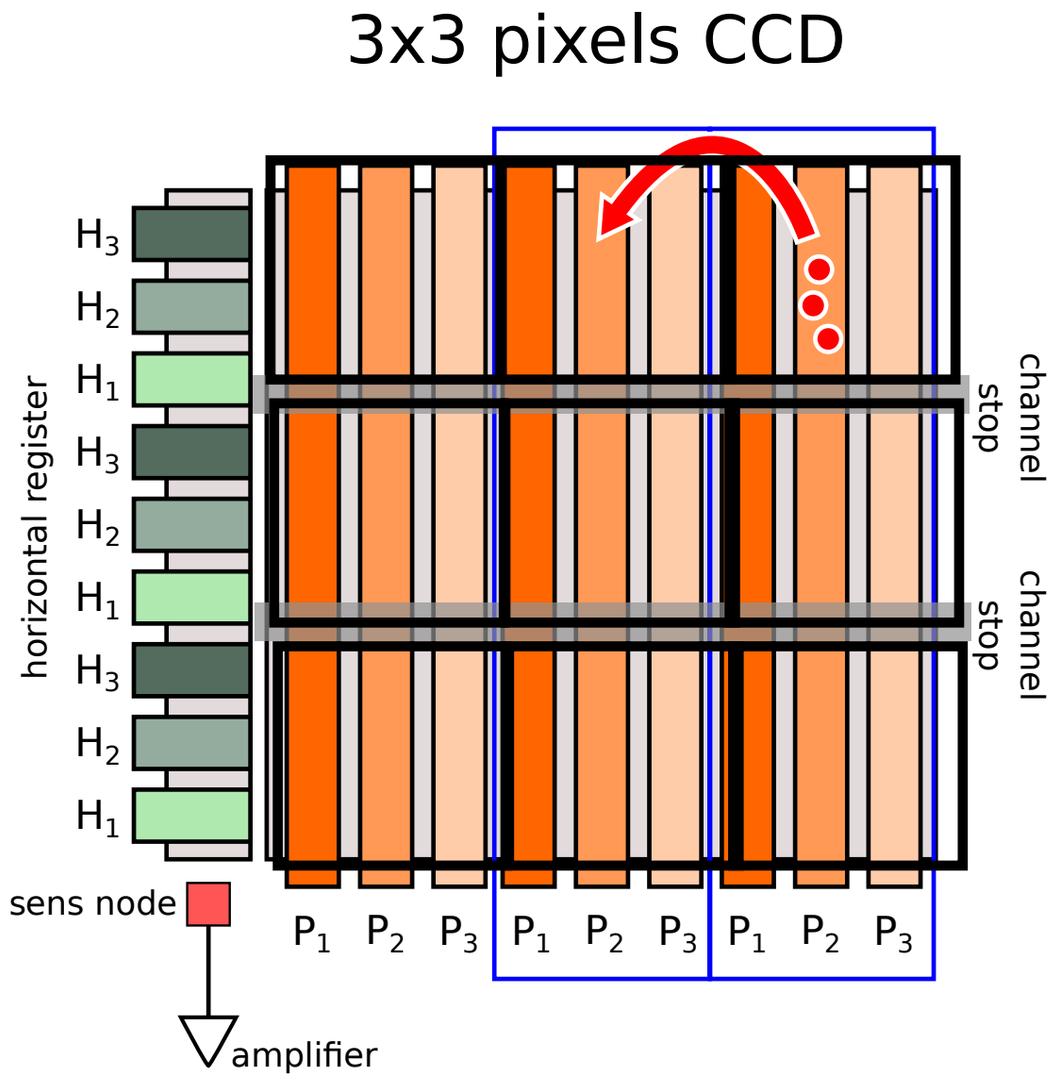
Parent Chain	Isoptopes Considered	Simulation ID	Comments
U238	Pa234	234a91z	
	Th234	234a90z	
Ra226	Pb214	214a82z	
	Bi214	214a83z	
Pb210	Pb210	210a82z	(surface and bulk)
	Bi210	210a83z	
Th232	Ac228	228a89z	
	Ra228	228a88z	
	Pb212	212a82z	
	Bi212	212a83z	0.64 BR
	Ti208	208a81z	0.36 BR
K40	K40	40a19z	
Rb87	Rb87	87a37z	
Cs137	Cs137	137a55z	
Activation	Co56	56a27z	(copper/flex/screws)
	Co57	57a27z	
	Co58	58a27z	
	Co60	60a27z	
	Fe59	59a26z	
	Mn54	54a25z	
	Sc46	46a21z	
Si32	Si32	32a14z	(silicon only)
	P32	32a15z	
H3 (Tritium)	H3	3a1z	(silicon only)
Na22	Na22	22a11z	(silicon only)

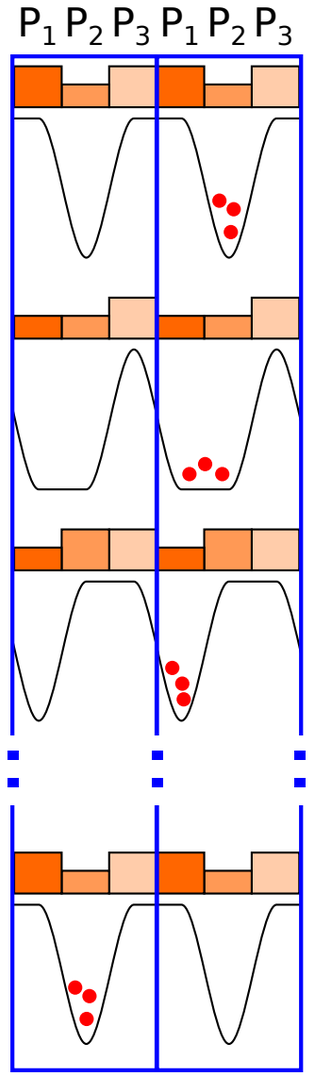
Table 11: Decay chains considered in this analysis.

DAMIC CCD



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





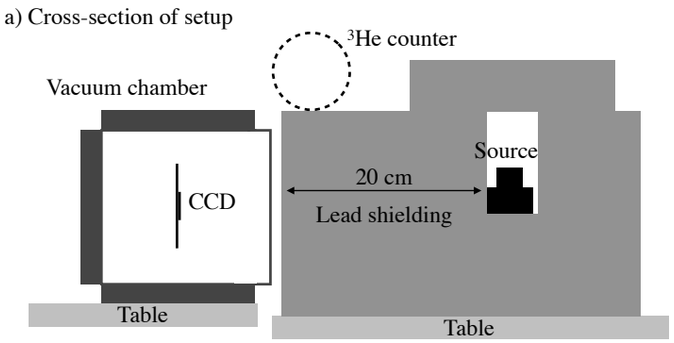
- **Thick CCD: 0.675 mm**
- **2.9g (5.8g)/ CCD**
- 8 (16) MegaPixels
- **pixel size: 15 x 15 µm**
- High resistivity: 10-20 kΩ.cm
  (low donor density—>fully depleted at 40V)
- low dark current (**10^{-3} e- /pix /day at 120K**)

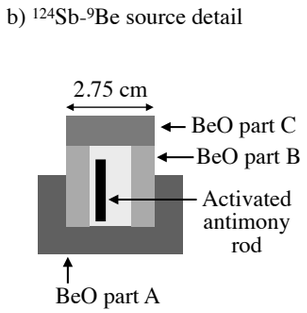
- **readout noise < 2 e-**
- readout time ~ 40us / pix

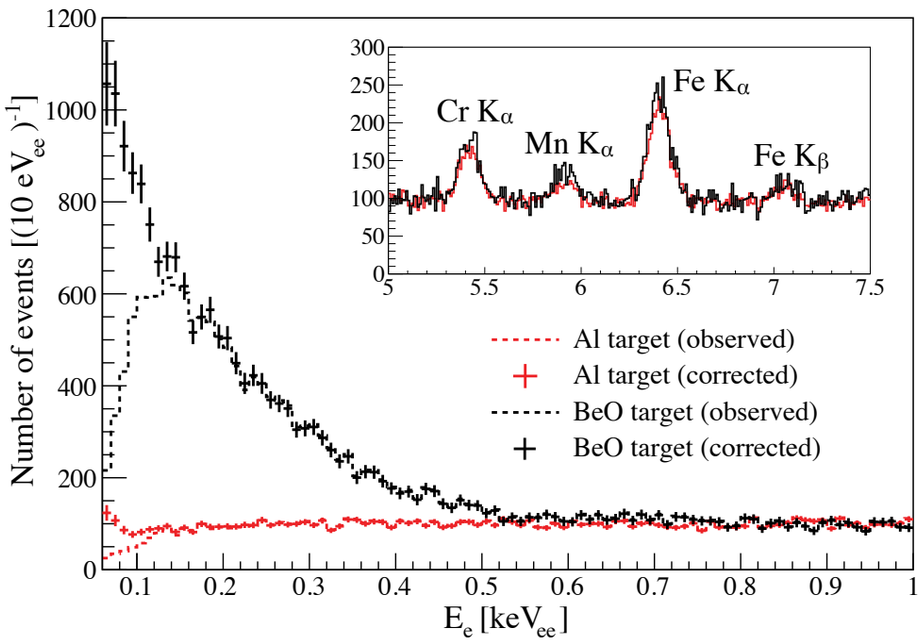
NUCLEAR RECOIL CALIBRATIONS

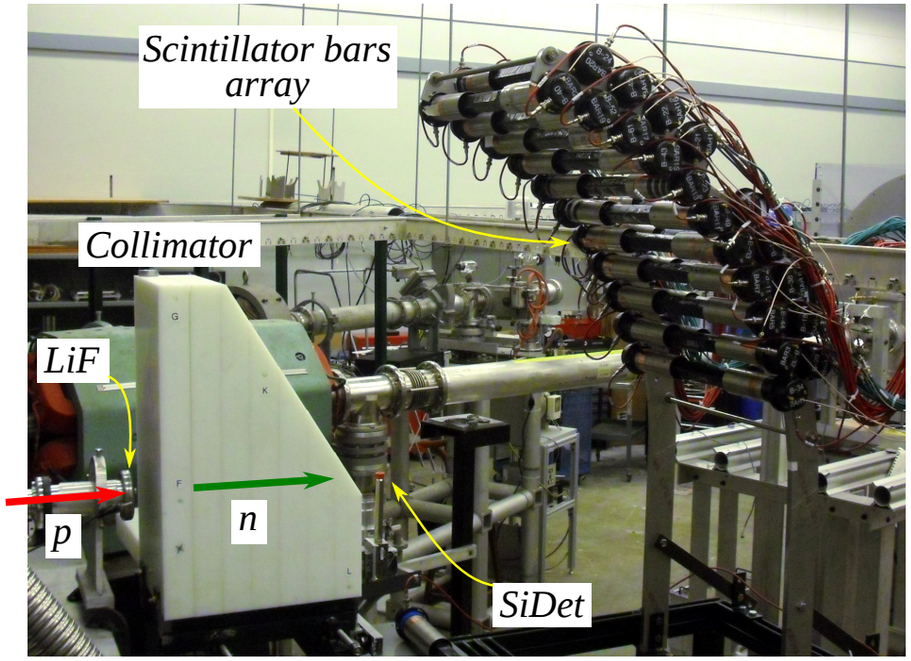
fast neutrons

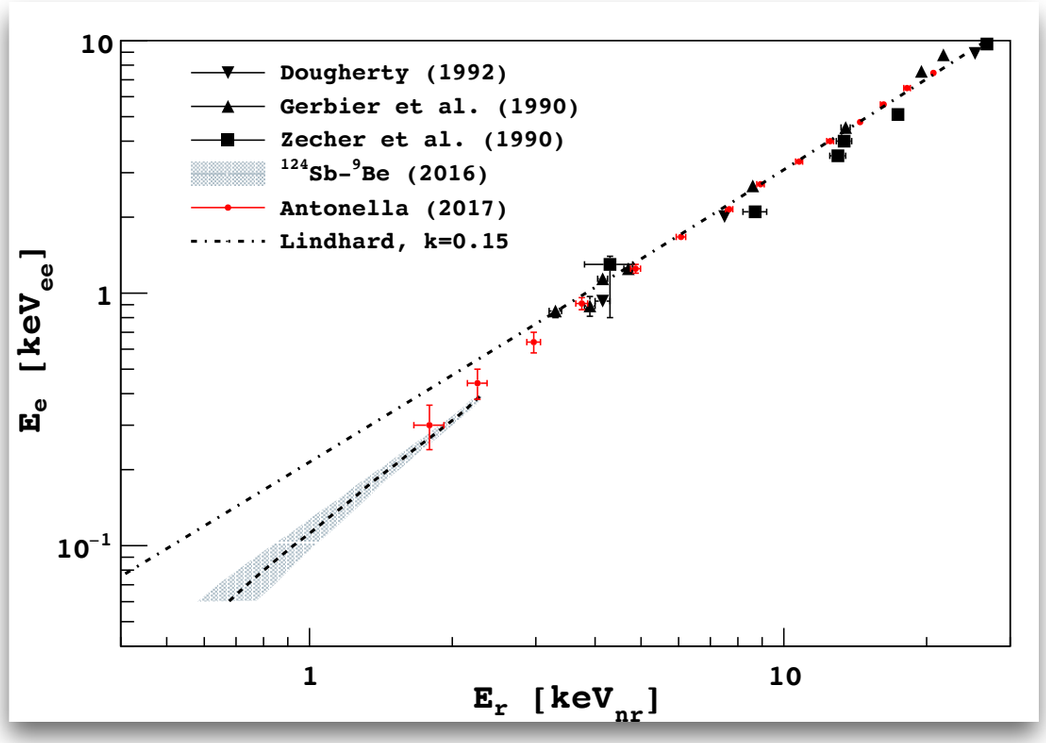
low E neutrons







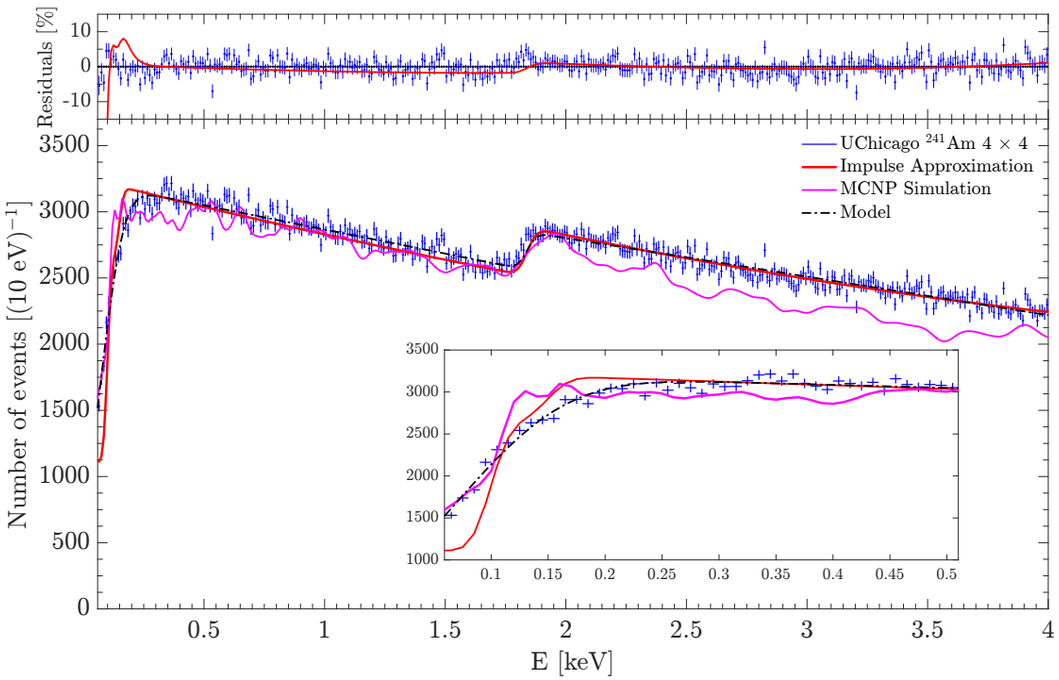


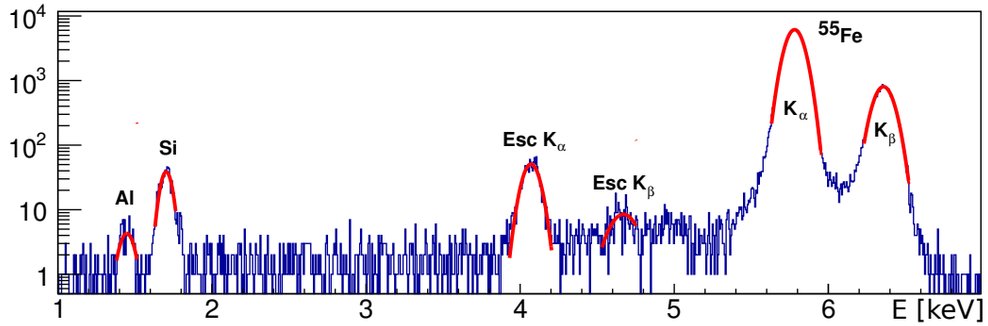


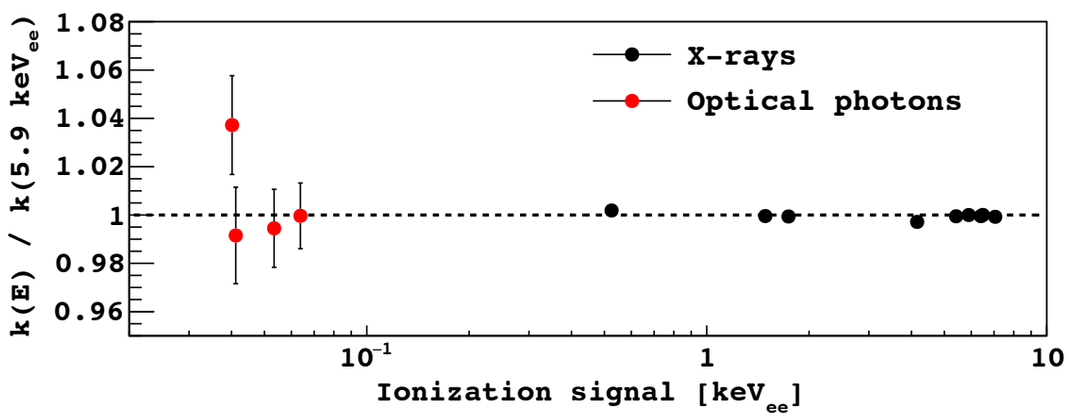
ionisation calibration

Compton spectrum measurement

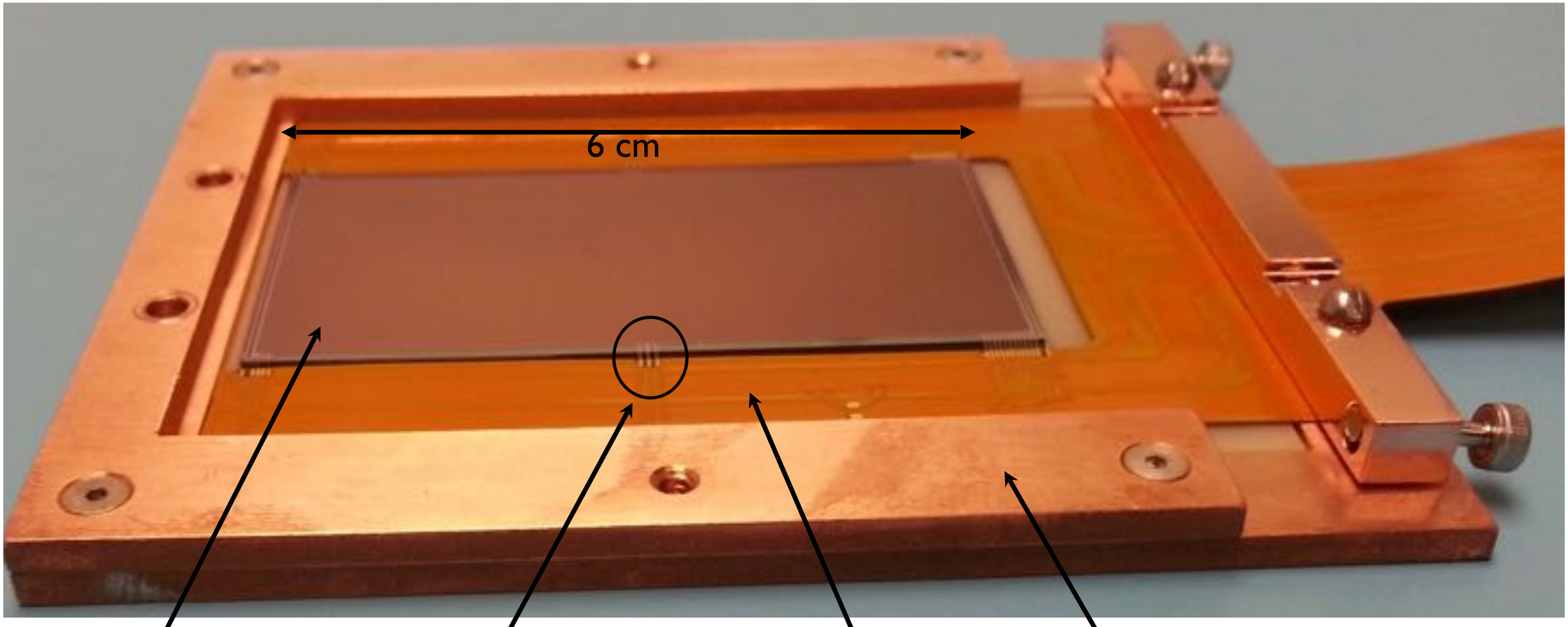
(arXiv:1706.06053 Phys.Rev. D96 (2017) no.4, 042002)





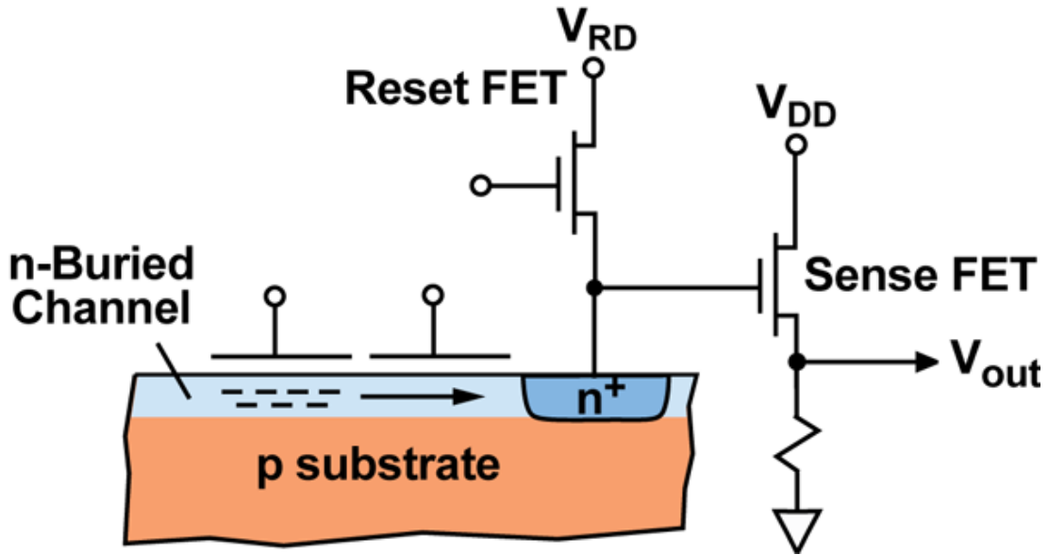


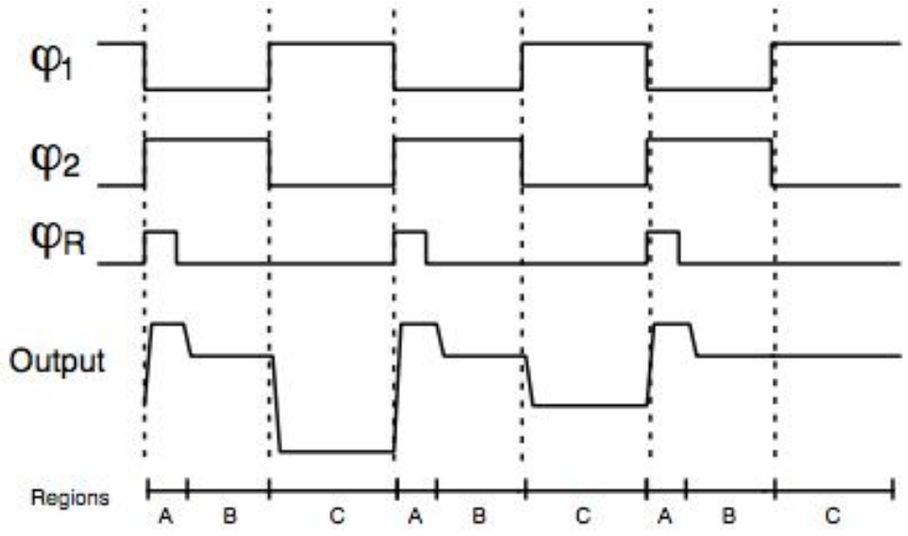
CCD


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

Skipper CCD

Regular Diffusion gate CCD





Skipper