Simulations and background estimates for the DAMIC-M experiment

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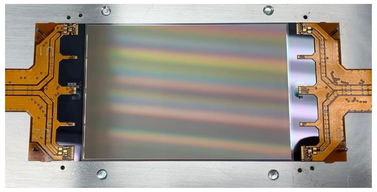
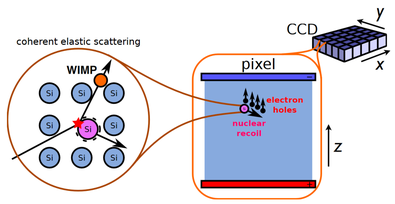
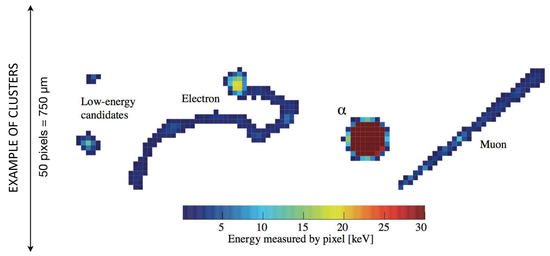
DAMIC-M: Dark Matter in CCDs at Modane

Near-future experiment aiming to search for low-mass dark matter particles through their interactions with the silicon nucleus and electrons in the bulk of charge coupled devices (CCDs).
Location: Laboratoire Souterrain de Modane (LSM), France, under 1700 m of rock.





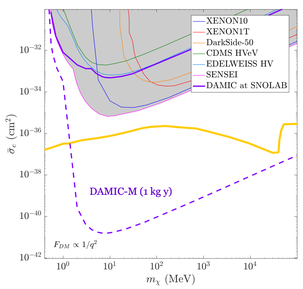
Left: tested 6k x 4k pixels CCD wire bounded to a kapton cable. Right: Principle of a dark matter detection in a CCD. A WIMP scatters with a silicon nucleus or electron producing ionization in the CCD bulk. The charge carriers are then drifted along the z-direction and collected at the CCD pixel gates [1].



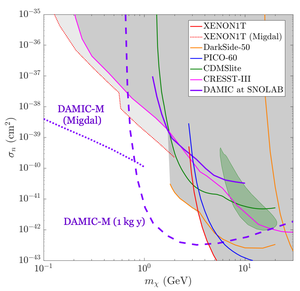
DAMIC-M unique 3D spatial resolution allows for particle identifications and background rejection in the CCD bulk [1].

DAMIC-M NOVELTIES

- Mass: 1 kg — 200 CCDs, 6k x 1 k pixels, 0.675 mm thick
- Sub-electron resolution [2]
- Background rate: ~0.1 d.r.u — MAJOR CHALLENGE



DAMIC-M will be sensitive to WIMPS with masses in the range 1-10 GeV (right) and it will be leading the search of MeV-scale DM candidates in the hidden sector (left) and eV-scale hidden photon.



Geant4 simulations are being exploited to optimize the detector design and to drive the material selection and handling.

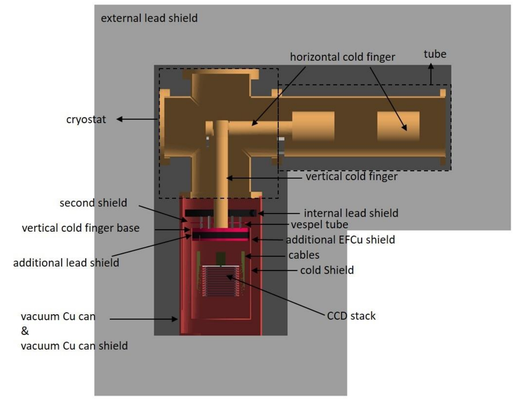
Simulations tools

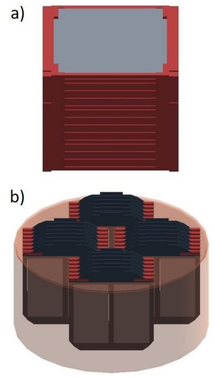
Geant4 Code:
simulations of the physics processes undergone by a particle passing through the experimental setup

WADERS (SoftWAre for Dark matter ExpeRiments with Skippers):

- Detector response: CCD pixelization, dark current, electronic noise, pixel saturation and continuous readout
- Cluster reconstruction: minimum energy threshold, clusterization

Detector design





Left: latest simulated detector design. The thickness of the external lead shield is 20 cm. The electro-formed copper components are shown in red, while the OFHC copper ones in yellow. Right: zoom on different CCD stacks. a) Horizontal CCD stack. b) Vertical CCD stack. The gray parts are the CCDs, the red parts the copper holders

Background simulations

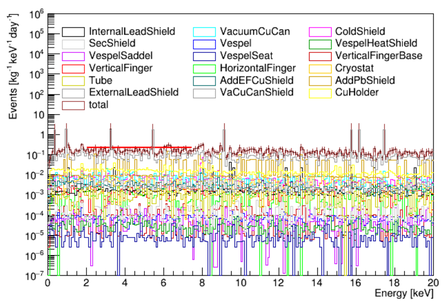
Radioactive isotopes uniformly simulated in the bulk of the detector components.

- 238U & 232Th chains
- Cosmogenic isotopes in Cu
- K40 & Rb87

For each isotope:

$$\text{background rate} = n_{clusters} \frac{n_{bins} \cdot A_{iso} \cdot m_{vol}}{\Delta E \cdot N_{decays} \cdot M_{detector}}$$

A_{iso}: isotope activity [decay/kg/day]
m_{vol}: mass of simulated volume [kg]
N_{decays}: number simulated events
$M_{detector}$: mass sensitive detector [kg]
$\Delta E/n_{bins}$: bin width [keV]
$n_{clusters}$: number of clusters in a given bin



Total cluster energy spectrum and contribution of the individual components. The horizontal CCD stack design was used. The cosmogenic activation of the electro-formed components is not included. The high peaks in the total energy spectrum are due to Bi210 from the external lead shield. The red line is the result of a linear fit to a constant between 2 - 7.5 keV. The fit gives the total background rate.

References

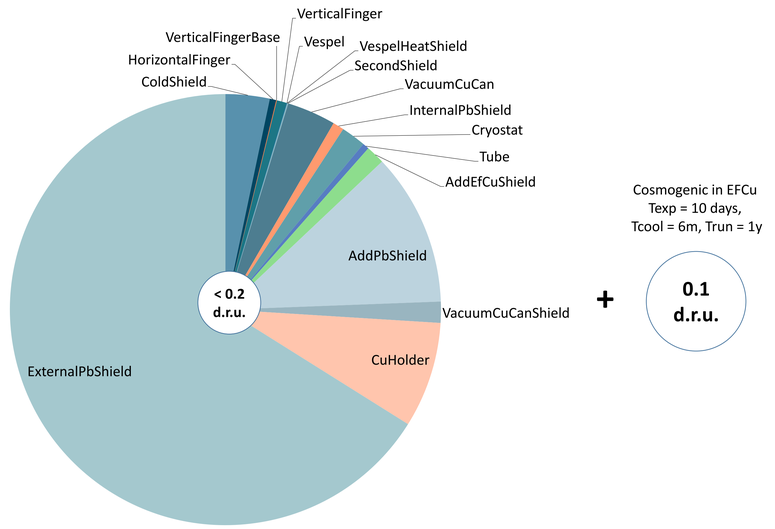
[1] A. Aguilar-Arevalo et al. [DAMIC], JINST **10** (2015) no.08, P08014, [arXiv:1506.02562].
[2] J. Tiffenberg et al.[SENSEI],Phys. Rev. Lett. **119** (2017) no.13, 131802, [arXiv:1706.00028]
[3] P. Privitera for the DAMIC-M collaboration, in proceedings of TAUP Conference (2019)
[4] S. Knapen, J. Kozaczuk and T. Lin, [arXiv:2011.09496].

Results

Copper holder and cables: major background contributors.

The external lead shield contribution is an upper limit. Measurements of the isotopes' activities are required.

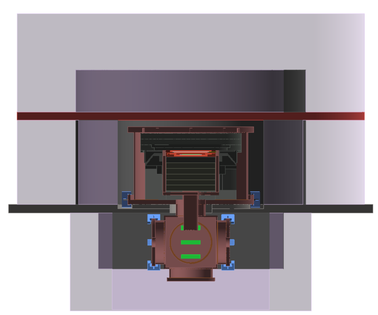
Substantial contribution from cosmogenic activation of EF copper. Control and reduction of the exposure time to cosmic rays is crucial.



Contribution to the background rate of each detector component. The horizontal CCD stack design was used. The total background rate is less than 0.3 decays/kg/keV/day [d.r.u.]. Texp: exposure time to cosmic rays, Tcool: time spent underground before data taking, Trun: experiment running time. For the OFHC Cu components: Texp = 3 m, Tcool = 6 m, Trun = 1 y.

Outlook

- Precise measurements of radiogenic isotope activities in all materials. A screening campaign is scheduled.
- Detector storage and handling underground.
- Finalized DAMIC-M detector design and simulations coming soon.
- A prototype (Low Background Chamber, LBC) will be installed at LSM in 2021 for detector study in low background environment and preliminary physics results. Validity of simulations may be tested in an unexplored low energy region.



Low Background Chamber design.