DMFortFactor

A Fast and Accessible Program for Computing WIMP-Nucleus-Scattering Event-Rates

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DMFortFactor: a Fortran code to compute WIMP-nucleus form factors in an EFT framework

- Our code is **hundreds to thousands of times faster** than `DMFormFactor` [2][3], the only published code for computing these nuclear form factors
- Written in Modern Fortran, with a Python wrapper
- Capability to compute multiple relevant quantities

[2] Fitzpatrick, Haxton, Katz, Lubbers, Xu, "The effective field theory of dark matter direct detection", JCAP02(2013)004

[3] Anand, Fitzpatrick, Haxton, "Weakly interacting massive particle-nucleus elastic scattering response", PRC 89, 065501 (2014)

Direct detection of dark matter is an ongoing area of research

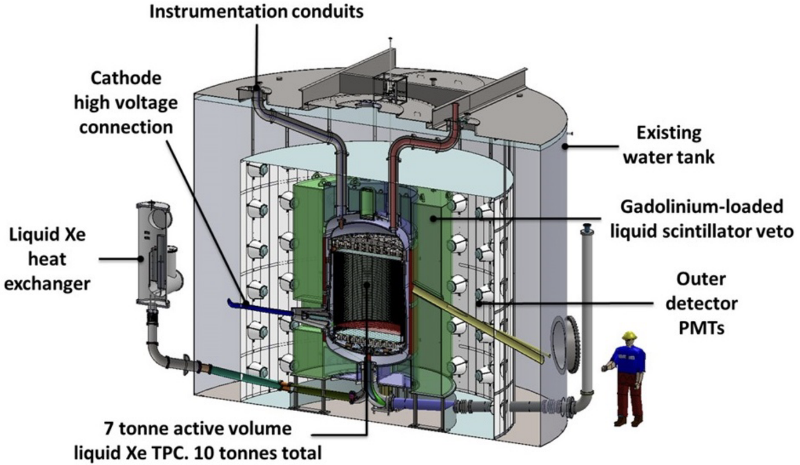


Figure: The LZ detector, which is being built at the Sanford Underground Research Facility and run by the DOE, Lawrence Berkeley Lab [arXiv:1703.09144v1]

Waiting for the right nuclear recoil

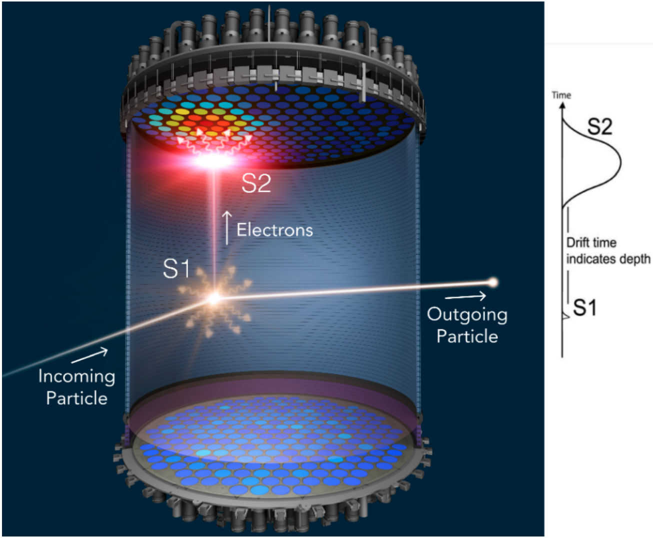


Figure: The LZ detector is waiting for a weak interaction between a WIMP and a Xenon nucleus [arXiv:1703.09144v1]

The observed event-rate sets limits on the theoretical interaction strength

- A theoretical prediction for the event rate comes from Effective Field Theory (EFT)
- Ingredients:
  1. Nuclear wave function (actually, one-body density matrices) in a H.O. basis
  2. An EFT Lagrangian cast as a Hamiltonian

$$\mathcal{H} = \sum_{x=p,n} \sum_{i=1,15} c_i^x \mathcal{O}_i \tag{1}$$

  3. A WIMP velocity distribution
- The 15 nucleon couplings $\mathcal{O}_i$ are combinations of

$$i\frac{\vec{q}}{m_N},\ \vec{v}^{\perp},\ \vec{S}_{\chi},\ \vec{S}_N. \tag{2}$$

The event rate (or lack thereof) sets limits on the theoretical interaction strength

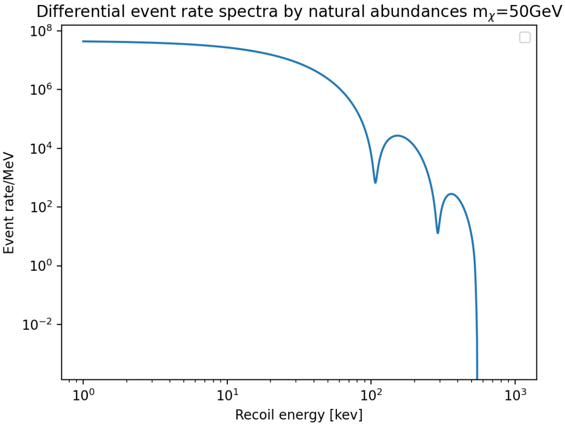


Figure: Predicted direct-dection event rate given 50 GeV WIMPs and simple coupling to protons with $c_1^p = 1$.

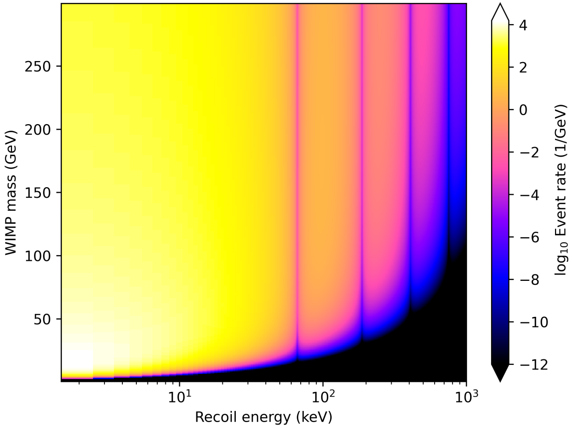
Timing

Runtime (seconds)		
Nonzero coefficients	c_1^n	All
DMFormFactor[4]	20,000	20,000
DMFortFactor (serial)	1.7	100
DMFortFactor (parallel x4)	0.5	30

Table: Program execution time for an event-rate calculation of ^{131}Xe with 1000 recoil energies with $m_\chi = 150$ GeV.

[4] arXiv:1308.6288, arXiv:1203.3542

Timing benchmark: Differential eventrate spectra for 300 possible WIMP masses



Code	Runtime
DMFormFactor	70 days (predicted)
DMFortFactor	10 minutes

[Easy to use] Use the Python wrapper to compute WIMP-nucleus scattering-event rates

```
'''
Use dmfortfactor to compute the differential event
rate spectra for Xe-131 assuming a WIMP mass of 50 GeV
and isovector coupling to operator-3.
'''
import dmfortfactor as dm
control_dict = {"wimpmass" : 50.0}
c_v = np.zeros(15)
c_v[2] = 0.0048 # Set the EFT coupling
Erkev, ER = dm.EventrateSpectra(
              Z = 54,
              N = 77,
              dres = "../dres/xe131gcn",
              controlwords = control_dict,
              cvvec = c_v)
```

[Easy to export] Generation of tabulated nuclear form factors for codes like WimPyDD

$$W_i^{x,x'}(q) = \sum_J \sum_{a,b} \rho_J^x(a,b)\rho_J^{x'}(a,b) \langle a||\mathcal{W}_J^{(f),x}||b\rangle \langle a||\mathcal{W}_J^{(f),x'}||b\rangle$$

Columnated plain text for `m` momentum values q

```
q_1  W_1^00 W_2^00 ... W_8^00 W_1^10 ... W_8^11
q_2  W_1^00 W_2^00 ... W_8^00 W_1^10 ... W_8^11
...
q_m  W_1^00 W_2^00 ... W_8^00 W_1^10 ... W_8^11
```

[Easy to import] Python function for nuclear form factors for codes like WimPyDD (arXiv:2106.06207)

```python
'''
Use dmfortfactor to generate form factors for Xe-131
and return a Python function for later use
'''
cwords = {
        "wimpmass" : 150.0,
        "usemomentum": 1}
Wfunc = dm.NucFormFactor(
        Z = 54,
        N = 77,
        dres = "../dres/xe131gcn",
        controlwords = cwords,
        ermin = 0.001,
        ermax = 10.0,
        erstep = 0.001)
```

[Easy to import] Python function for nuclear form factors for codes like WimPyDD

A function of momentum transfer q, and returns the $(8, 2, 2)$ array of form factors needed for WimPyDD

```
[python console] >>> Wfunc(q=0.001)
```

```
[[[ 1.62248e+03  2.78451e-02]
  [ 5.92199e-03 -3.54404e+02]]
 [[-2.61310e+02 -2.61411e-02]
  [-8.93270e-03  5.70787e+01]]
 [[-2.61310e+02 -2.61411e-02]
  [-8.93270e-03  7.84651e+01]]
 [[ 4.20853e+01  2.45414e-02]
  [ 1.34741e-02 -1.26372e+01]]
 [[ 7.74174e+01  1.39266e-02]
  [ 7.00767e-02 -4.41734e-02]]
 [[-1.71453e+01 -1.30745e-02]
  [-6.05964e-02  4.14702e-02]]
 [[-1.71453e+01 -1.30745e-02]
  [-6.05964e-02  3.81975e-02]]
 [[ 3.80365e+00  1.22745e-02]
  [ 5.23987e-02 -3.58599e-02]]]
```

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- **Publication in preparation for** *Computer Physics Communications*

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