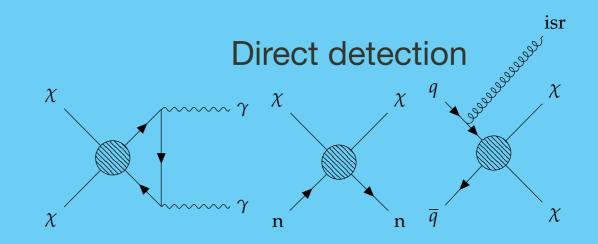
# RECASTABLE DIRECT DARK MATTER SEARCHES

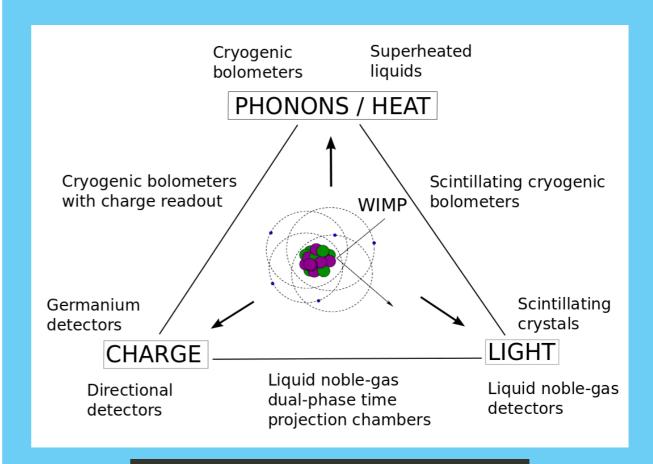
**DEC 13TH 2022** 

KNUT DUNDAS MORÅ KNUT.DUNDAS.MORAA@COLUMBIA.EDU (RE)INTERPRETATION OF LHC RESULTS FOR NEW PHYSICS

## DIRECT DETECTION

- Searches for dark matter particles interacting directly with a dark matter detector
- Energy deposited in the detector target is deposited into:
  - Phonons (in crystals) or heat
  - Ionisation / charge
  - Scintillation light
- Using more than one observable can allow some degree of discrimination between different recoil types

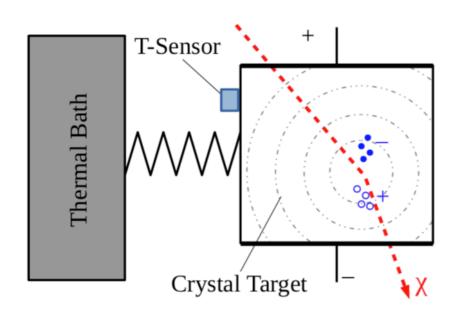


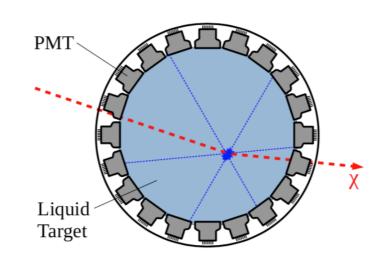


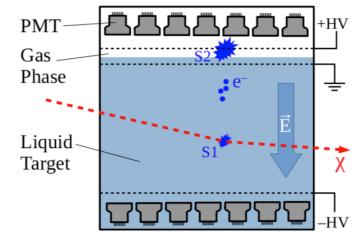
Teresa Marrodán Undagoitia and Ludwig Rauch. "Dark matter direct-detection experiments". In: J. Phys. G43.1 (2016), p. 013001. DOI: 10.1088/0954-3899/43/1/013001.

$$\frac{dR}{dE}(E,t) = \frac{\rho_0}{m_\chi \cdot m_A} \cdot \int v \cdot f(\mathbf{v},t) \cdot \frac{d\sigma}{dE}(E,v) \, d^3v$$

### **DETECTOR TECHNOLOGY EXAMPLES**

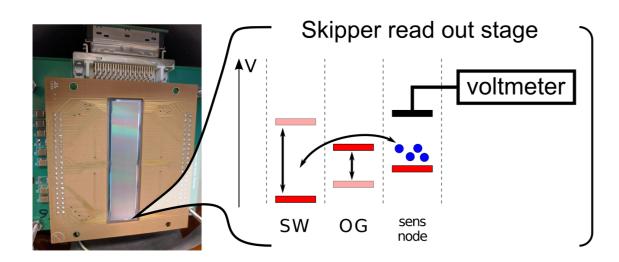






#### **LIQUID NOBLE GAS 1- AND 2-PHASE TPCS**

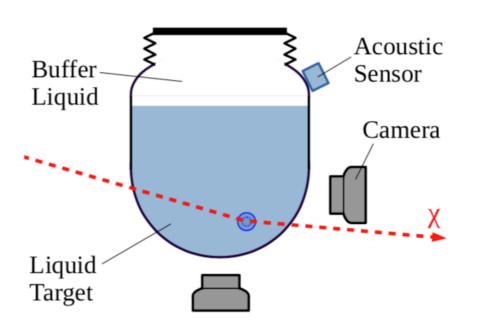
#### **CRYOGENIC DETECTOR: HEAT & IONISATION**



#### **CCD READ OUT REPEATEDLY PER-PIXEL**

Figures except SENSEI from: Marc Schumann. "Direct Detection of WIMP Dark Matter: Concepts and Status". In: J. Phys. G 46.10 (2019), p. 103003. doi: 10.1088/1361- 6471/ ab2ea5.

SENSEI illustration from <a href="https://sensei-skipper.github.io/#SkipperCCD">https://sensei-skipper.github.io/#SkipperCCD</a>

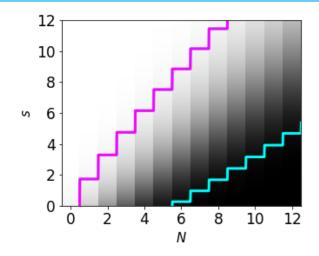


**BUBBLE CHAMBER** 

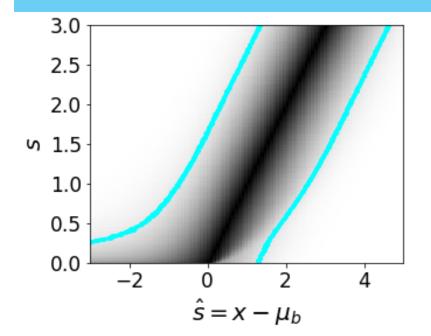
### **INFERENCE PROCEDURES**

# POISSON UPPER LIMITS (WITH OR WITHOUT PROFILING)

#### **UPPER-LIMIT-ONLY**

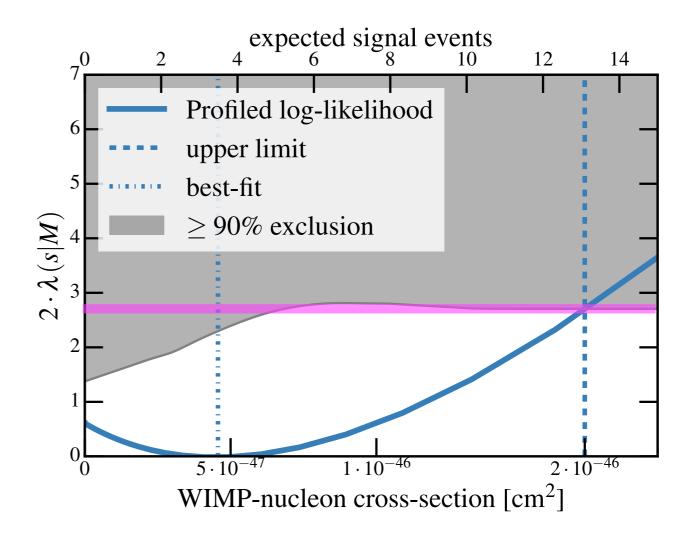


### FELDMAN-COUSINS/ UNIFIED INTERVALS



#### ASYMPTOTIC LOG-LIKELIHOOD PROFILING

# NON-ASYMPTOTIC TOY-MC CALIBRATED TEST STATISTIC DISTRIBUTIONS



+METHODS FOR MISSING BACKGROUND MODELS (SEE LATER)



$$\mathscr{L}(s, \overrightarrow{\theta_s}, \overrightarrow{\theta_b}) = \mathscr{L}_{\text{sci}}(s, \overrightarrow{\theta_s}, \overrightarrow{\theta_b}) \times \mathscr{L}_{\text{cal}}(\overrightarrow{\theta_b}) \times \mathscr{L}_{\text{anc}}(\overrightarrow{\theta_b})$$

COUNTING

$$\mathscr{L}_{\text{sci}}(s, \overrightarrow{\theta}_s, \overrightarrow{\theta}_b) =$$

Poisson
$$(N_{\text{sci}} | \mu_b(\vec{\theta}_b) + \mu_s(s, \overrightarrow{\theta}_s, \vec{\theta}_b))$$

**ON-OFF** 

LIKELIHOODS 
$$\mathscr{L}_{sci}(s, \overrightarrow{\theta}_s, \overrightarrow{\theta}_b) =$$

Poisson
$$(N_{\text{sci}} | \mu_b(\vec{\theta}_b) + \mu_s(s, \vec{\theta}_s, \vec{\theta}_b)) \times$$
  
Poisson $(N_{\text{cal}} | \alpha \times \mu_b(\vec{\theta}_b))$ 

BINNED LIKELIHOODS

$$\mathcal{L}_{\text{sci}}(s, \overrightarrow{\theta_s}, \overrightarrow{\theta_b}) = \prod_{i=1}^{N_s} \left[ \text{Poisson}(N_i | \mu_{b,i}(\overrightarrow{\theta_b}) + \mu_{s,i}(s, \overrightarrow{\theta_s}, \overrightarrow{\theta_b})) \right]$$

LIKELIHOODS

$$\mathcal{L}_{\text{sci}}(s, \overrightarrow{\theta_s}, \overrightarrow{\theta_b}) = \text{Poisson}(N_{\text{sci}} | \mu_b(\overrightarrow{\theta_b}) + \mu_s(s, \overrightarrow{\theta_s}, \overrightarrow{\theta_b})) \times \prod_{i=1}^{N_s} \left[ \frac{\mu_s}{\mu_s + \mu_b} f_s(\overrightarrow{x_i} | s, \overrightarrow{\theta_s}, \overrightarrow{\theta_b}) + \frac{\mu_b}{\mu_s + \mu_b} f_b(\overrightarrow{x_i} | \overrightarrow{\theta_b}) \right]$$

 $\mathscr{L}_{\mathrm{cal}}(\vec{ heta}_b)$  typically on the same form, while  $\mathscr{L}_{\mathrm{anc}}(\vec{ heta}_b)$  contains ancillary measurements— often Gaussian terms like  $\operatorname{Gaussian}(\hat{\theta}_i | \theta_i, \sigma_{\theta_i})$  but sometimes more complex functions, e.g. with correlations or with a different likelihood shape

# RECOMMENDATIONS

Whitepaper this year, written in particular for high-mass (  $> 10 \text{ GeV}/c^2$ ) dark matter searches.

- Recommends profile likelihood with toyMCs
- Fixed set of signal models
- Recommended set of astrophysical models

A similar effort is underway for low-threshold detectors

Eur. Phys. J. C (2021) 81:907 https://doi.org/10.1140/epjc/s10052-021-09655-y THE EUROPEAN PHYSICAL JOURNAL C

Special Article - Tools for Experiment and Theory

#### Recommended conventions for reporting results from direct dark matter searches

D. Baxter<sup>1</sup>, I. M. Bloch<sup>2</sup>, E. Bodnia<sup>3</sup>, X. Chen<sup>4,5</sup>, J. Conrad<sup>6</sup>, P. Di Gangi<sup>7</sup>, J. E. Y. Dobson<sup>8</sup>, D. Durnford<sup>9</sup>, S. J. Haselschwardt<sup>10</sup>, A. Kaboth<sup>11,12</sup>, R. F. Lang<sup>13</sup>, Q. Lin<sup>14</sup>, W. H. Lippincott<sup>3,a</sup>, J. Liu<sup>4,5,15</sup>, A. Manalaysay<sup>10</sup> C. McCabe<sup>16</sup>, K. D. Morå<sup>17</sup>, D. Naim<sup>18</sup>, R. Neilson<sup>19</sup>, I. Olcina<sup>10,20</sup>, M. -C. Piro<sup>9</sup>, M. Selvi<sup>7</sup>, B. von Krosigk<sup>21</sup>, S. Westerdale<sup>22</sup>, Y. Yang<sup>4</sup>, N. Zhou<sup>4</sup>

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- <sup>9</sup> Department of Physics, University of Alberta, Edmonton, AB T6G 2R3, Canada
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- <sup>11</sup> STFC Rutherford Appleton Laboratory (RAL), Didcot OX11 0QX, UK
- <sup>12</sup> Department of Physics, Royal Holloway, University of London, Egham, TW20 0EX, UK
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Received: 2 May 2021 / Accepted: 15 September 2021 © The Author(s) 2021

**Abstract** The field of dark matter detection is a highly visible and highly competitive one. In this paper, we propose recommendations for presenting dark matter direct detection results particularly suited for weak-scale dark matter searches, although we believe the spirit of the recommendations can apply more broadly to searches for other dark matter candidates, such as very light dark matter or axions. To

translate experimental data into detection collaborations must n ters to how to make statistical data. While many collaboration ommendations in some areas,

in statistical inference, they have taken different approa often from result to result by the same collaboration. V out a number of recommendations on how to apply the commonly used Profile Likelihood Ratio method to detection data. In addition, updated recommendations for Standard Halo Model astrophysical parameters and rel neutrino fluxes are provided. The authors of this note in

D. Baxter et al. Recommended conventions for analysis, ranging from how to reporting results from direct dark matter searches. Eur. rations pro Phys. J. C, 81(10):907, 2021. doi: 10.1140/epjc/ s10052-021-09655-y.

uperCDMS

VIN, DEAF

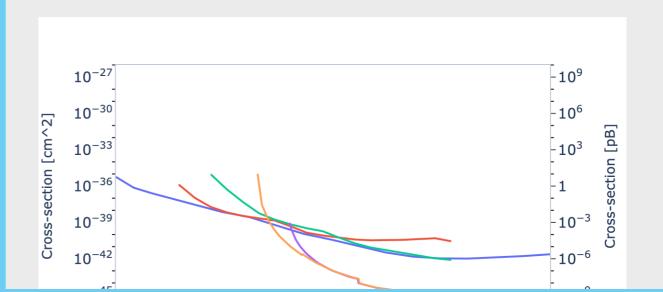
# DARK MATTER DATA CENTER

- Collects public datasets
  - CRESST,
  - XENON
  - **ANAIS**
  - Three more upcoming
- Online jupyter notebooks and visualisation to explore data
- **Funded by ORIGINS Excellence Cluster**

With the ORIGINS Dark Matter Data Center we want to fully leverage the potential of open science to bring together observations from different experiments, the implications of different models and all the associated software. At the DMDC we aim at increasing accessibility to scientific process and knowledge, open data and open source software: key ingredients for the nourishing of open science (From "Open Data to Open Science" Earth and Space Science doi:10.1029/2020EA001562), by offering a repository for experimental data, models and code. The Dark Matter Data Center supports data comparison, combination and interpretation using clear and reproducible methodologies, easing the usability of this data, enabling one to make the most out of it. Our sights are set on sharing knowledge in all its relevant forms: data, methodologies and software with the ultimate goal of offering a consistent and unified view of the field in all its facets.

#### Overview

- Explore Data
- Publish Data
- Publish Code
- Simulate and Compare



#### **Available Datas**

Click on a Collabor datasets it has ma

- CRESST
- XENON
- ANAIS

#### Available softwa

#### Submit data or s

#### Simulate

Simulate event rat experiments with Soon!)

https://www.origins-cluster.de/odsl/dark-matterdata-center

# REINTERPRETABLE RESULTS

Effective Field Theory results: A large number of results to cover theory-space

Maximum-Gap methods: one dimension, can provide upper limits

Data Releases: allows you to construct your own likelihood

Likelihood Releases: gives you a collaboration-provided likelihood definition

# EFFECTIVE FIELD THEORY RESULTS

- Effective field theories of direct detection provides a full set of possible recoil spectra
  - Nonrelativistic EFTs can give a complete set of Galilean-invariant operators
  - However, other sets of operators can better preserve the connection with high-energy interactions, for example Chiral EFTs that expand the QCD lagrangian
- In either case, any specific theory will predict a mixture of many operators, and you must either find which will dominate the spectrum, or match your recoil spectrum to the nearest available EFT spectrum and use that limit appropriately scaled
- Benefits: get the full likelihood that the collaboration uses

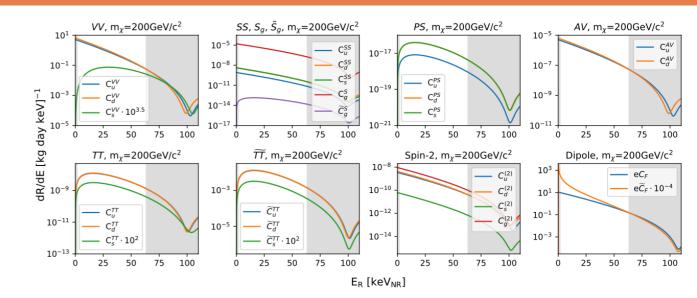


Figure 1. Differential rate spectra for the ChEFT operators investigated in this work, divided according to the interaction type. They are obtained by setting each Wilson coefficient to 1 and  $\Lambda=1\,\text{TeV}$ . The shaded region marks the energy range where the signal acceptance is below 10%. For some spectra, the coefficients were multiplied by a factor written in the legend for plotting purposes.

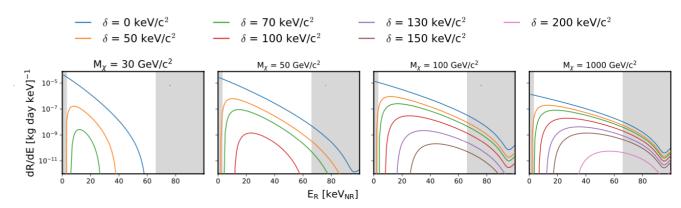
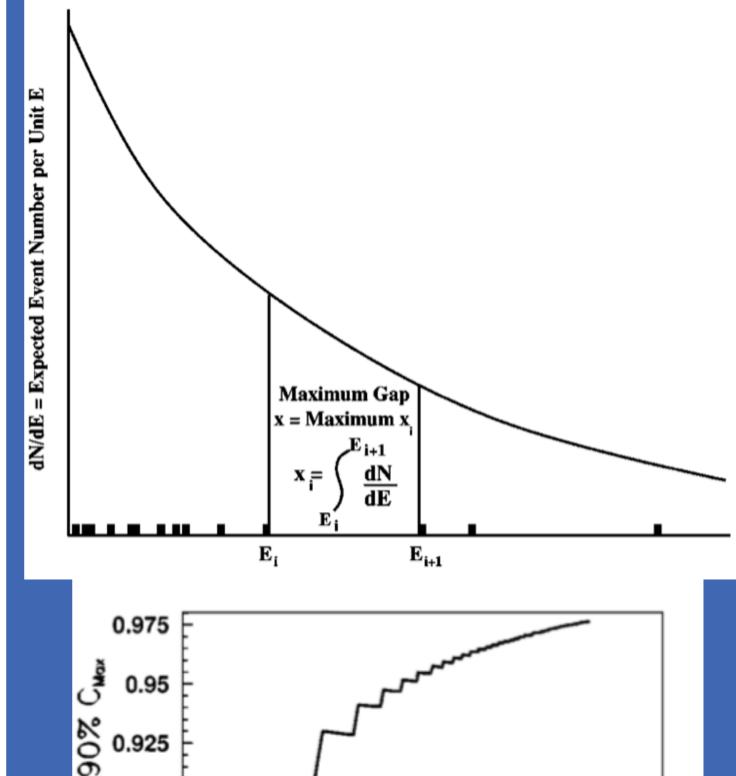
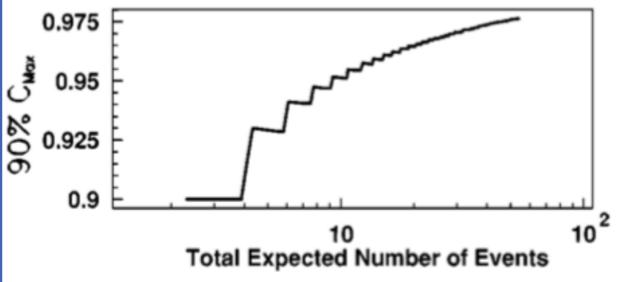


Figure 2. Differential rate spectra for a few representative iDM models investigated in this work. The grey area indicates the region where the detection efficiency is below 10%. The parameter space explored was selected to include models peaked within the selected energy region.

### **UPPER LIMITS WITH UNKNOWN BACKGROUNDS**

- If the signal distribution is known along some variable, the maximum gap/optimal interval method can incorporate this, even in the presence of an unknown background
- Find the space between observed events containing the largest signal expectation, and find the largest signal compatible with this largest "gap".
- The method can be extended as "optimum interval" where you search for the largest interval containing 0,1,2 etc events
- threshold for the best interval test statistic found via toyMC methods





S. Yellin. Finding an upper limit in the presence of an unknown background. Physical Review D, 66(3), Aug 2002. ISSN 1089-4918. doi: 10.1103/physrevd.66.032005.

[Submitted on 17 May 2019 (v1), last revised 6 Apr 2020 (this version, v3)]

#### Description of CRESST-III Data

CRESST Collaboration: A. H. Abdelhameed, G. Angloher, P. Bauer, A. Bento, E. Bertoldo, C. Bucci, L. Canonica, A. D'Addabbo, X. Defay, S. Di Lorenzo, A. Erb, F. v. Feilitzsch, S. Fichtinger, N. Ferreiro Iachellini, A. Fuss, P. Gorla, D. Hauff, J. Jochum, A. Kinast, H. Kluck, H. Kraus, A. Langenkämper, M. Mancuso, V. Mokina, E. Mondragon, A. Münster, M. Olmi, T. Ortmann, C. Pagliarone, L. Pattavina, F. Petricca, W. Potzel, F. Pröbst, F. Reindl, J. Rothe, K. Schäffner, J. Schieck, V. Schipperges, D. Schmiedmayer, S. Schönert, C. Schwertner, M. Stahlberg, L. Stodolsky, C. Strandhagen, R. Strauss, C. Türkoglu, I. Usherov, M. Willers, V. Zema

DUWIIIUau.

- PDF
- Other formats

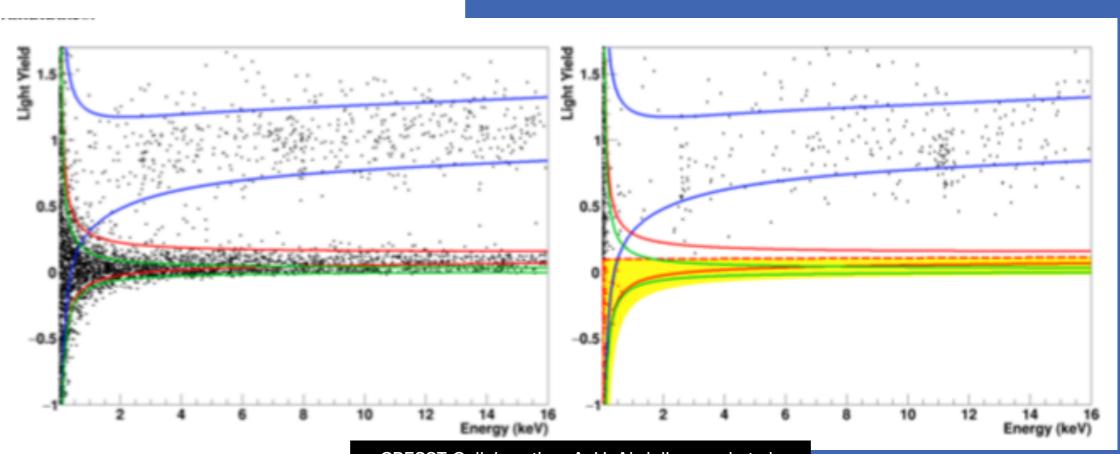
(license)

#### Ancillary files (details):

- C3P1\_DetA\_AR.dat
- C3P1\_DetA\_DataRelease\_SD.xy
- C3P1\_DetA\_DataRelease\_Sl.xy
- C3P1\_DetA\_cuteff.dat
- C3P1\_DetA\_eff\_AR\_Ca.dat
   (3 additional files not shown)

Current browse context: astro-ph.CO

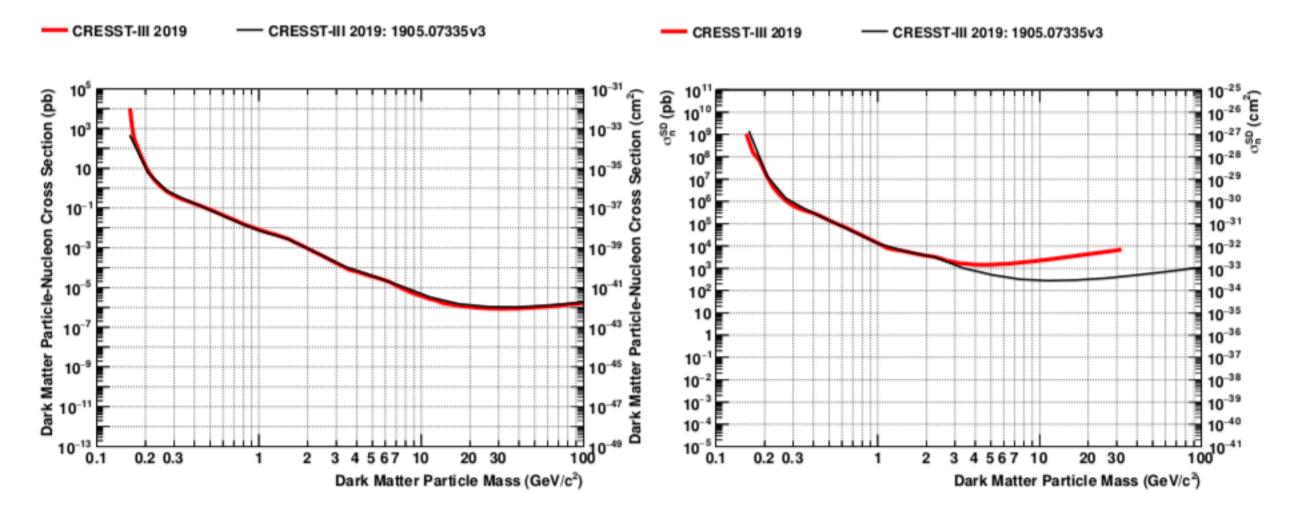
< prev | next >



 Model for p(E<sub>reco</sub>| p<sub>model</sub>(E) provided, with datafile for the efficiency, data-points:

$$\widetilde{p}(E_{reco}) = \Theta(E_{reco} - E_{thr,reco}) \cdot \widetilde{\varepsilon} \cdot \varepsilon_{x,Acc}(E_{reco}) \cdot \int_{0}^{\infty} p_{\text{model}}(E) \cdot \mathcal{N}(E_{reco} - E, \sigma_{p}^{2}) dE$$

 At high mass, the normal approximation to the detector resolution fails, but results are otherwise very similar to the main CRESST-III results for both spin-dependent and dependent:

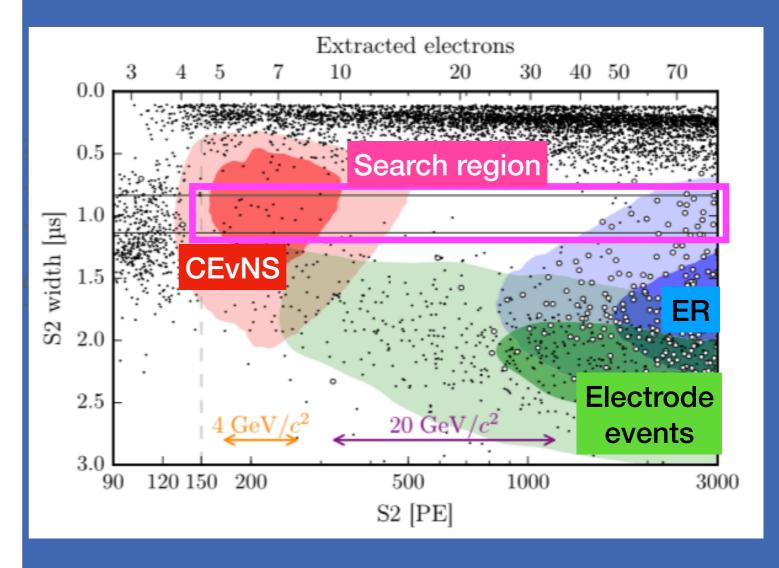


CRESST Collaboration, A. H. Abdelhameed et al., "Description of CRESST-III Data," arXiv:1905.07335

### **XENON1T IONISATION-ONLY ANALYSIS**

- An analysis requiring only an ionisation signal (no scintillation flash)
  - **Event depth resolution** deteriorates
  - Incomplete background model
- A 30% portion of the data is used to choose optimal ROIs for each signal model considered
- limits on elastic recoils down to 3 GeV/c2

Aprile, E. et al. (XENON collaboration), Phys. Rev. Lett. 123, 251801 (2019) https://github.com/XENON1T/s2only\_data\_release http://doi.org/10.5281/zenodo.4075018



#### §2. Compute the energy spectrum

If you are a phenomenologist, insert your amazing dark matter candid

For this example, we will use a 4 GeV/c^2 spin-independent elasti reference cross-section, we'll use 1 zb or 10-45cm^2.

#### [n [3]: import wimprates as wr reference cross section = 1e-45 # cm^2 rate pertonneyearkev = wr.rate wimp std( es=energy\_kev, sigma nucleon=reference cross section) plt.plot(energy kev, rate pertonneyearkev, drawstyl plt.xlabel("Nuclear recoil energy [keV]") plt.ylabel("Expected recoils / (tonne year keV)") plt.yscale('log') plt.xscale('log' plt.xlim(0.4, 10) Dut[3]: (0.4, 10)

#### §4. ROI choice and limit setting

You now need to choose an S2 region of interest (ROI) for comparison with data. You have several options

- 2A: We list many ROIs in the limit datafiles, for different WIMP masses, models, compare your model's response to one of these reference models, see which matches best, and use its
- you do, do NOT just choose the ROI that gives you the best results! We chose our ROIs be

You now want to count the expected number of events in the ROI. Since we have guite a few S2 bins, a naiv

mask = (s2\_roi[0] <= s2\_bin\_centers) & (s2\_bin\_centers <= s2\_roi[1]) expected events = rate final[mask].sum() expected events

#### But feel free to interpolate/integrate

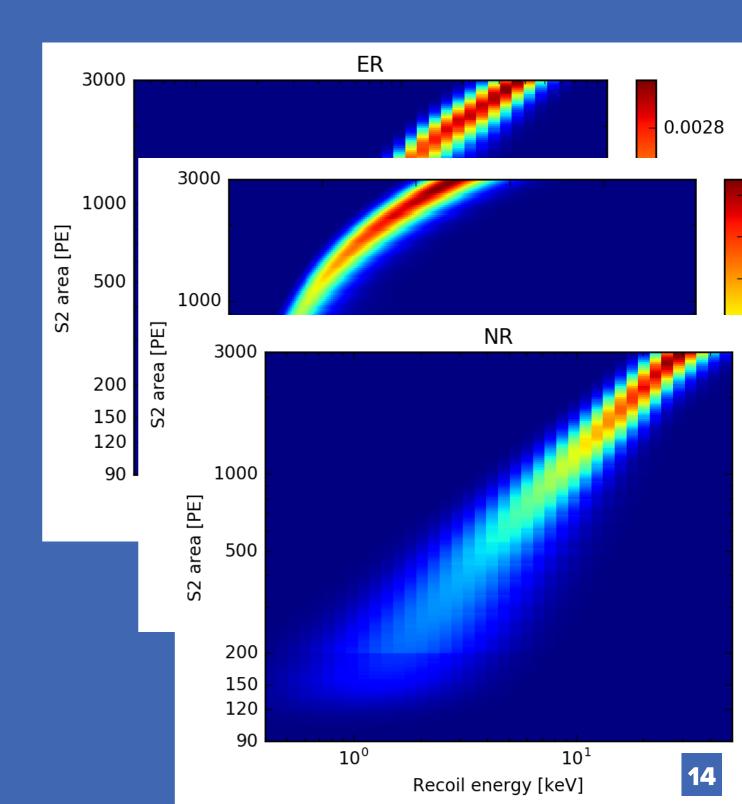
= interpolate.interpld(s2\_bin\_centers, rate\_final / s2\_bin\_widths) expected\_events, integration\_error = integrate.quad(f, \*s2\_roi, epsabs=1e-6)

print(expected\_events, integration\_error/expected\_events)

# XENONIT IONISATION-ONLY ANALYSIS

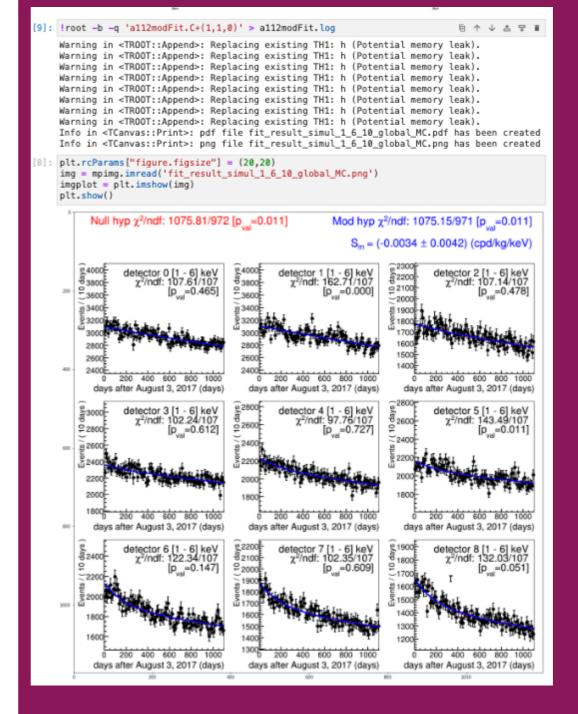
- The analysis includes a data release with
  - Data coordinates (training and science dataset)
  - detector response matrices (right) for electronic and nuclear recoils
  - the partial background model
  - Jupyter notebook to compute upper limits using the ROIs optimised for the signal models considered in the paper

Aprile, E. et al. (XENON collaboration), Phys. Rev. Lett. 123, 251801 (2019) https://github.com/XENON1T/s2only\_data\_release http://doi.org/10.5281/zenodo.4075018



# **ANAIS DATA RELEASE**

- ANAIS searches for an annual modulation signal with NaI scintillators (similar to those used by DAMA/LIBRA)
- Observables: energy and phase
- With  $315~kg \times y$  exposure, they record a  $\sim 3\sigma$  tension with the DAMA signal
- The released data includes
  - data for each of 9 detectors,
  - efficiency
  - live time
  - simulated data
- And a ROOT routine to fit the data



ANAIS Collaboration and the open data center: Dataset for Annual modulation results from three-year exposure of ANAIS-112, <a href="https://www.origins-cluster.de/odsl/dark-matter-data-center/available-datasets/anais">https://www.origins-cluster.de/odsl/dark-matter-data-center/available-datasets/anais</a>

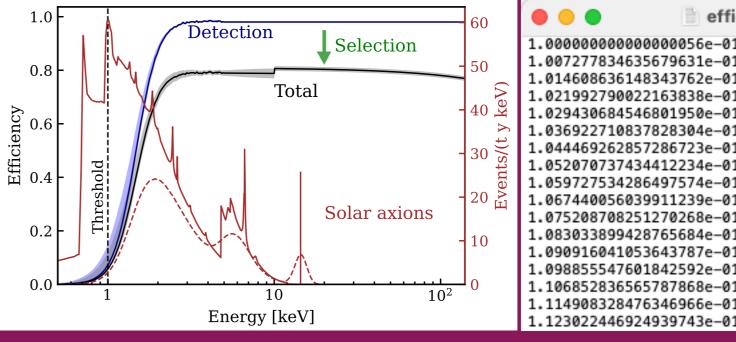
https://gitlab.mpcdf.mpg.de/dmdc/anais/anais112/

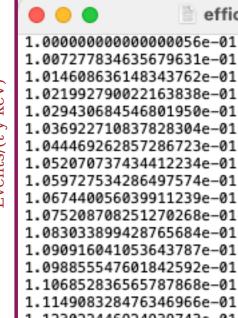
ANAIS Collaboration: Annual modulation results from three-year exposure of ANAIS-112, Phys. Rev. D **103 (2021)**, 102005, DOI: 10.1103/PhysRevD.103.102005

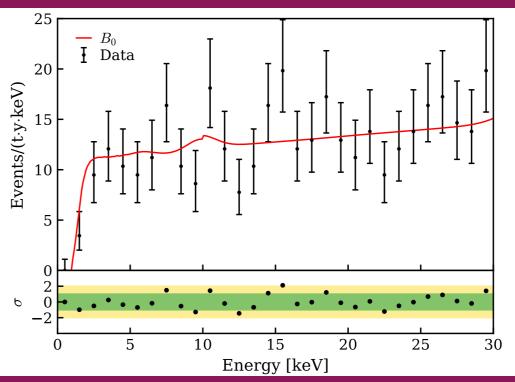
### **XENONNT ELECTRONIC RECOIL SPECTRUM**

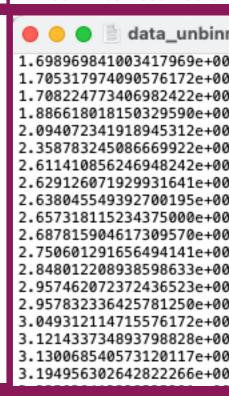
- In addition to WIMP searches, IXe TPCs are sensitive to signatures of dark photons, axions and other particles that would leave an electronic recoil signature in the 1 keV - 100 keV range.
- A peak observed by XENON1T at 2.7 keV has been excluded by XENONnT— for both results, the data has been made public to allow recasts
- Released data on Zenodo contains the necessary ingredients to compute the likelihood:
  - **Detector efficiency**
  - **Background model**
  - **Event energies**

#### https://xenonexperiment.org/public-data/







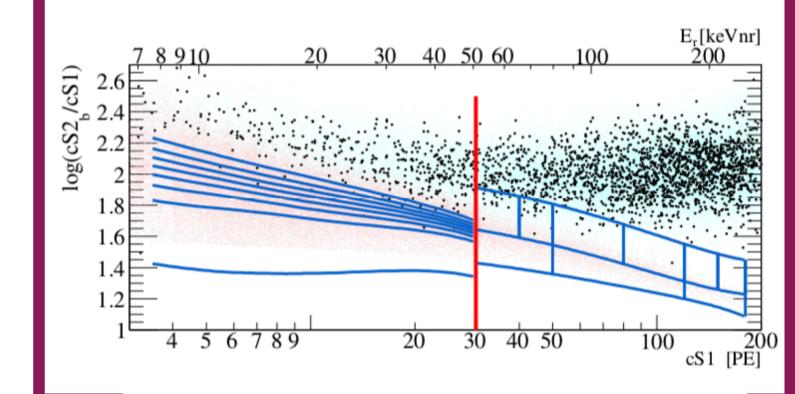


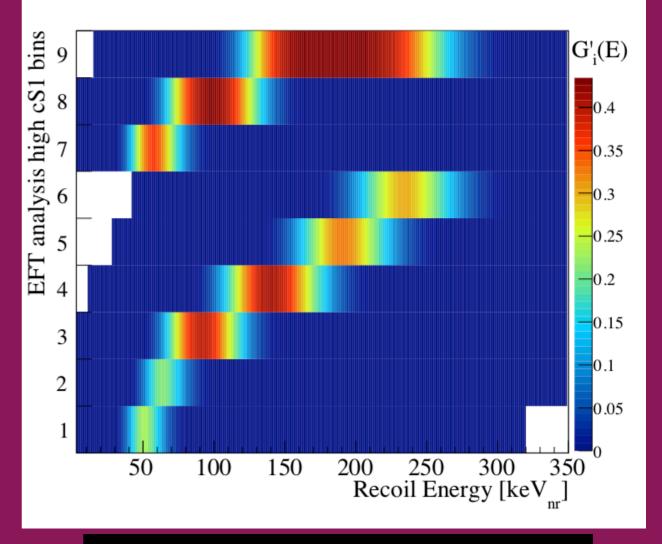
XENON Collaboration: Excess Electronic Recoil Events in XENON1T, Phys.Rev.D 102 (2020) 7, 072004, DOI: 10.1103/PhysRevD.102.072004

XENON Collaboration: Search for New Physics in Electronic Recoil Data from XENONnT, Phys.Rev.Lett. 129 (2022) 16, 161805, DOI: 10.1103/ PhysRevLett.129.161805

# PARTITIONING ANALYSIS SPACE

- High-energy nuclear search published alongside EFT results for low (cS1<30PE) recoil energy</li>
- If inelastic recoils are allowed, the number of free signal parameters became intractable 28 allowed EFT couplings, plus a WIMP mass and mass splitting
- 9 bins with event numbers, expected background, provided for a set of points in S1/S2 space
- The expected signal in each bin is given with the transfer probability matrix between true recoil energy and bin number. The transfer matrix is provided for a range of nuisance parameters

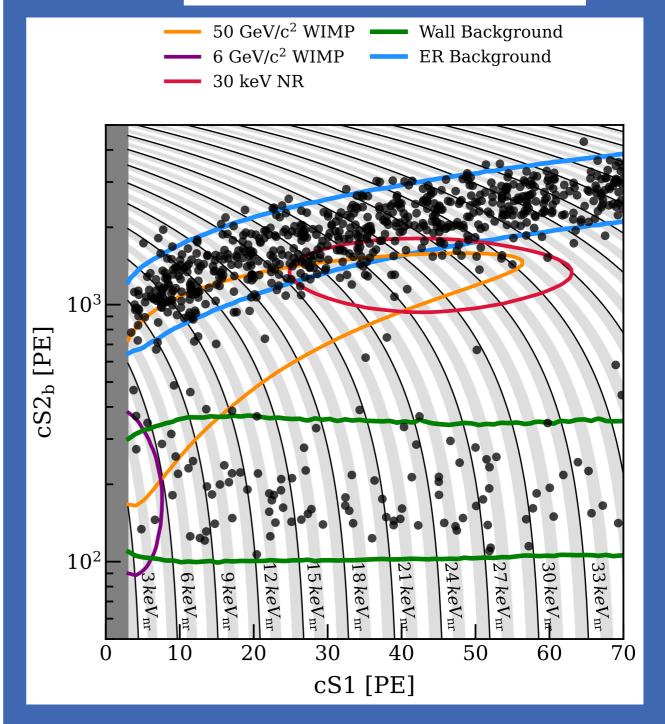




# XENON1T: FAST APPROXIMATE XENON1T LIKELIHOOD

- Discriminating between signal and background in IXe TPCs uses several observables (S1, S2 and often spatial dimensions or categories)
- Data reported in sub-volumes of the detector such as in the table of the original result paper can only give a rough indication of the upper limit
- The calculation is also rather slow—  $\sim 30~\mathrm{s}$  for one upper limit for XENON1T.
- Taking inspiration from FERMI results and the XENON100 EFT paper, XENON has published an approximate likelihood for WIMPs (and other NR signatures)

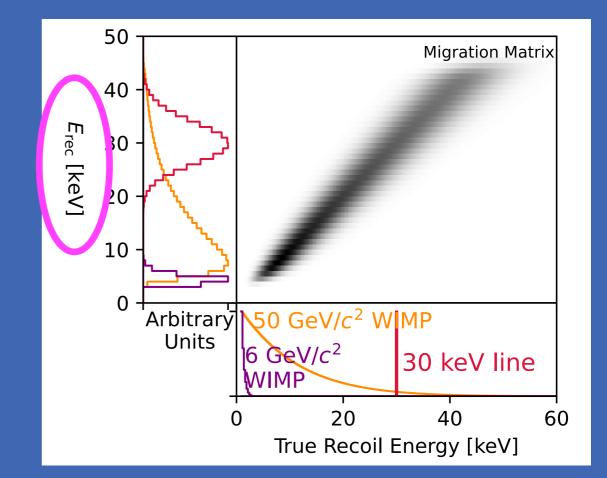
Mass (ton)	1.3	1.3	0.9	0.65
$(cS1, cS2_b)$	Full	Reference	Reference	Reference
ER Neutron CE\(\nu\)NS AC Surface	$627 \pm 18 \\ 1.43 \pm 0.66 \\ 0.05 \pm 0.01 \\ 0.47^{+0.27}_{-0.00} \\ 106 \pm 8$	$\boldsymbol{0.77 \pm 0.35}$	$\begin{array}{c} 1.12 \pm 0.21 \\ 0.41 \pm 0.19 \\ 0.02 \\ 0.06^{+0.03}_{-0.00} \\ 0.02 \end{array}$	
Total BG WIMP <sub>best-fit</sub> Data	735 ± 20 3.56 739	$7.36 \pm 0.61$ $1.70$ $14$	$1.62 \pm 0.28 \\ 1.16$	$0.80 \pm 0.14$ $0.83$

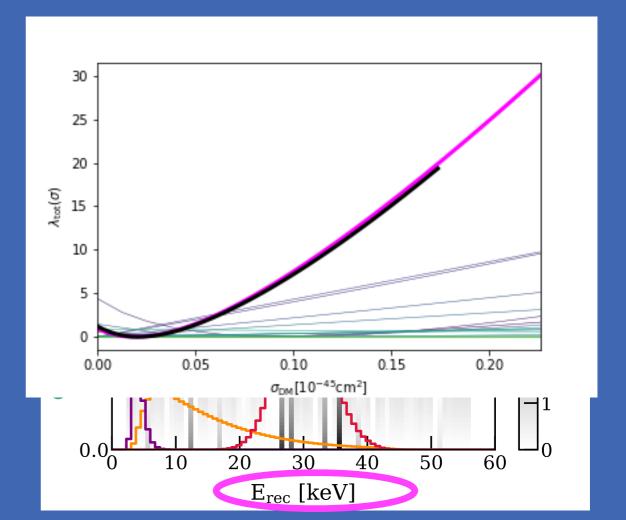


# FAST APPROXIMATE XENON1T LIKELIHOOD

- Key idea: compute profiled likelihoods in bins of reconstructed energy as function of the signal expectation in that bin
- A migration matrix gives you the expected number of events for each reconstructed energy bin r— which you can then look up the profiled likelihood in that bin
- The total approximate loglikelihood is the sum of the contributions from each bin





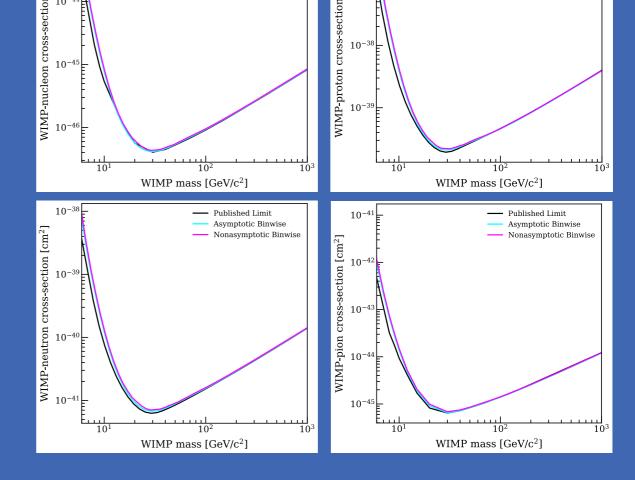


## FAST LIKELIHOODS

- Approximations:
  - All models are assumed to be constant within each reconstructed energy bin
  - Nuisance parameters (except the mismodelling term) are set to their best-fit values.
  - Each reconstructed bin is profiled separately
  - Asymptotic results are mostly used
- Bias and spread with respect to the full likelihood is checked for a range of signal spectra away from the spectrum, they are slightly conservative with < 20 % spread.</p>

XENONCollaboration, XENON1T approximate binwise data release (2022). <a href="https://zenodo.org/record/7255651#.Y5OTAC9w1fE">https://zenodo.org/record/7255651#.Y5OTAC9w1fE</a>

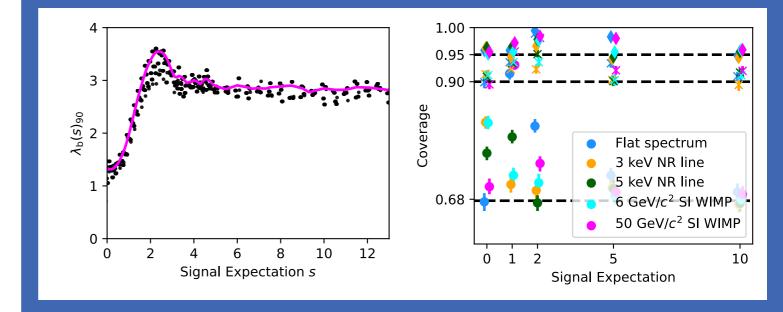
XENON. An approximate likelihood for nuclear recoil searches with XENON1T data. Eur. Phys. J. C, 82:989, 2022. doi: 10.1140/epjc/s10052-022-10913-w

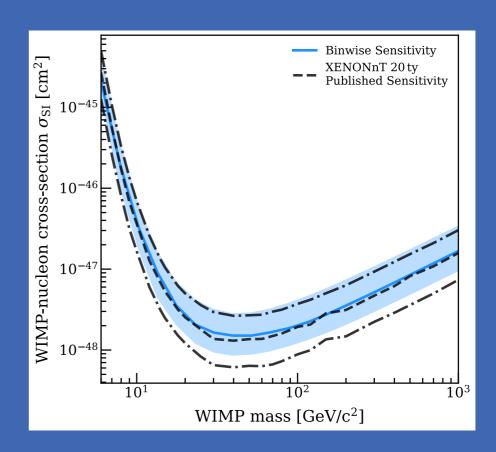


	n = 80  Bins	
Flat Spectrum	$1.01^{+0.07}_{-0.05}$	
NR Lines		
3 keV	$1.04^{+0.29}_{-0.15}$	
5 keV	$1.11^{+0.19}_{-0.13}$	
7 keV	$1.13_{-0.12}^{+0.16}$	
10 keV	$1.11^{+0.14}_{-0.11}$	
20 keV	$1.04_{-0.08}^{+0.12}$	
30 keV	$1.03^{+0.10}_{-0.08}$	
SI WIMP signals		
$6~{ m GeV}/c^2$	$1.02^{+0.31}_{-0.19}$	
$10~{ m GeV}/c^2$	$1.06^{+0.19}_{-0.14}$	
$50~{ m GeV}/c^2$	$1.06^{+0.09}_{-0.07}$	
$100~{ m GeV}/c^2$	$1.06^{+0.09}_{-0.06}$	

# USE FOR SENSITIVITY, COVERAGE CHECK

- At low recoil energies, the signal-background discrimination is low, and lowmass WIMP limits for XENON1T were in the non-asymptotic regime
- By computing the Neyman threshold for a range of monoenergetic signals, we can find the most extreme discrimination case— we provide this threshold line to allow for nonasymptotic upper limits
- Results overcover for all tested signals
- In addition, the release includes results for the 20ty XENONnT projection paper, so that projections can be computed for arbitrary spectra





XENON. An approximate likelihood for nuclear recoil searches with XENON1T data. Eur. Phys. J. C, 82:989, 2022. doi: 10.1140/epjc/s10052-022-10913-w

XENONCollaboration, XENON1T approximate binwise data release (2022). <a href="https://zenodo.org/record/7255651#.Y5OTAC9w1fE">https://zenodo.org/record/7255651#.Y5OTAC9w1fE</a>
<a href="https://github.com/XENON1T/">https://github.com/XENON1T/</a>

xenon1t\_approximate\_nuclear\_recoil\_likelihood

# FAST LIKELIHOODS

- Data and code available via zenodo and GitHub:
  - **Migration matrix**
  - Likelihood matrix
  - python code to compute limits given an arbitrary recoil spectrum
  - XENONnT 20ty projection migration matrix and 1000 toy simulation likelihood matrices
- **–** an upper limit takes  $\sim 40 \text{ ms}$ - three orders of magnitude faster than the full computation

XENON. An approximate likelihood for nuclear recoil searches with XENON1T data. Eur. Phys. J. C, 82:989, 2022. doi: 10.1140/ epjc/s10052-022-10913-w

XENONCollaboration, XENON1T approximate binwise data release (2022). https://zenodo.org/record/7255651#.Y5OTAC9w1fE https://github.com/XENON1T/

xenon1t\_approximate\_nuclear\_recoil\_likelihood

#### Estimating the XENON1T limit for a 50 GeV WIMP

from xe\_likelihood import BinwiseInference, Spectrum

#### Step 1: define the recoil spectrum

In this case we will use the built in WIMP spectrum

spectrum\_wimp = Spectrum.from\_wimp(mass=50)

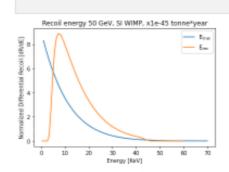
#### Step 2: Create an inference object from the XENON1T results

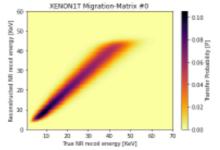
These results are distributed with the python package

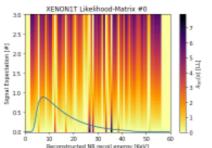
xenon inference = BinwiseInference.from xenon1t sr(spectrum=spectrum wimp)

#### Step 3: Make some plots!

xenon\_inference.plot\_spectrum(show=True) xenon\_inference.plot\_migration\_matrix(show=True) xenon\_inference.plot\_likelihood\_matrix(show=True) xenon inference.compute ul(spectrum=spectrum wimp) print(xenon\_inference.uls)







# REINTERPRETABLE RESULTS

- Many experiments now publish recastable results
- In particular if the likelihood is in one dimension many results are released either via the max gap, or as a spectrum
- Higher-threshold IXe TPC NR searches use higherdimensional likelihood, and have often only provided EFT results as a way to reinterpret their limits beyond simple counting approximations
- approximate likelihoods can yield a good approximation to these results that also gives significant performance improvements.

**Effective Field Theory results** 

Maximum-Gap methods

**Data Releases** 

Likelihood Releases

Thanks to people who answered my questions for this:

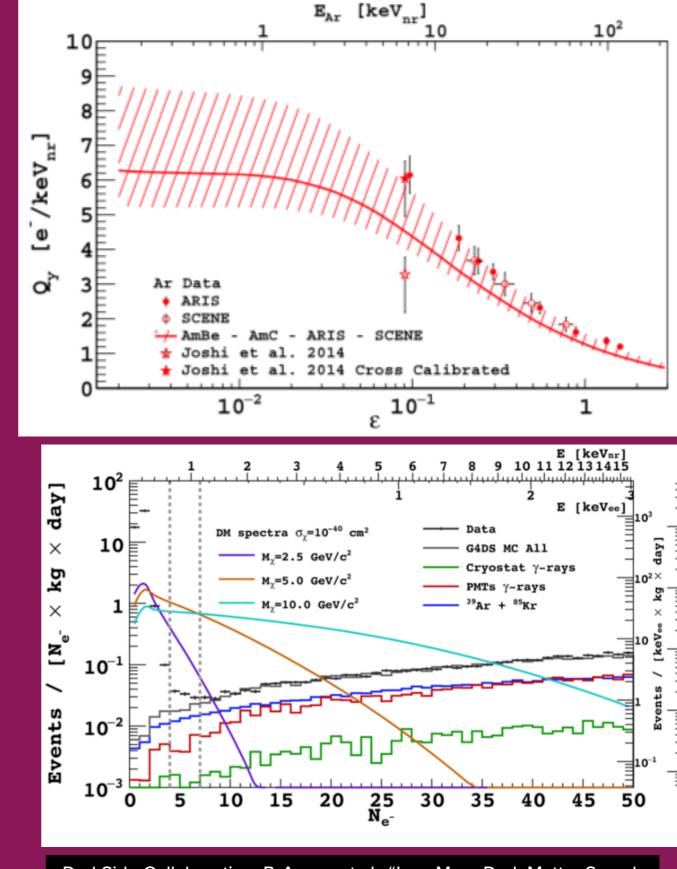
- Heerak Banerjee
- Dan Baxter
- Qing Lin
- Ibles Olcina
- Madeleine Zurowski



&THANKS!

### DARKSIDE-50 IONISATION-SEARCH

- The DarkSide-50 detector is a liquid argon dual-phase TPC with a 46 kg active target
- For a low-threshold (down to 0.6 keV NR) search, using only ionisation signals and a 6786 kg-days exposure
- upper limits computed with a binned profile likelihood
- In addition to confidence intervals on spin-independent dark matter, the paper includes the
  - Quenching model and efficiency needed to compute signal spectra in the n<sub>e-</sub> ionisation bins
  - (possibly incomplete)
     background expectation per n<sub>e-</sub> bin
  - Detection efficiency



DarkSide Collaboration, P. Agnes et al., "Low-Mass Dark Matter Search with the DarkSide-50 Experiment," Phys. Rev. Lett. 121 no. 8, (2018) 081307