SYSTEMATIC UNCERTAINTIES
IN
DIRECT DARK MATTER SEARCHES

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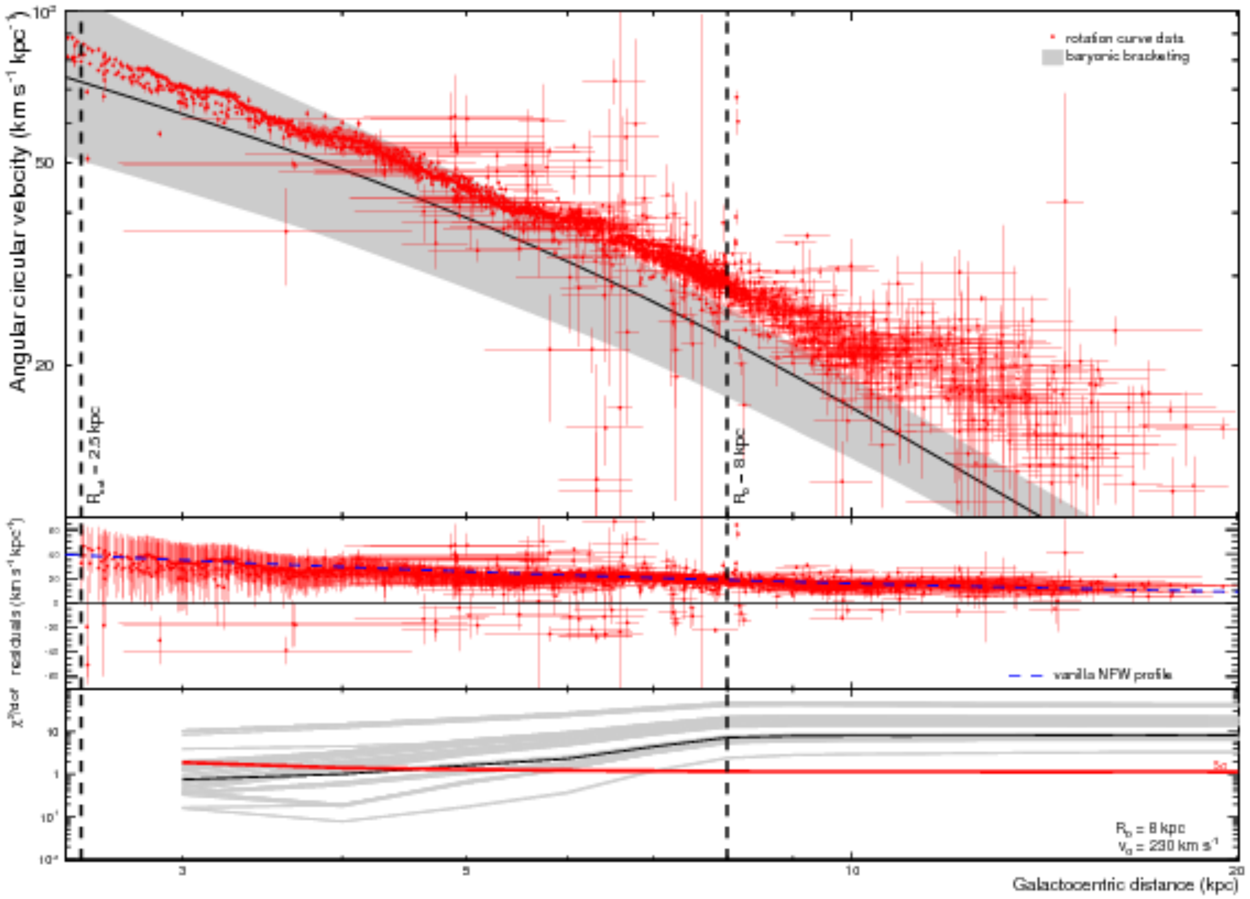
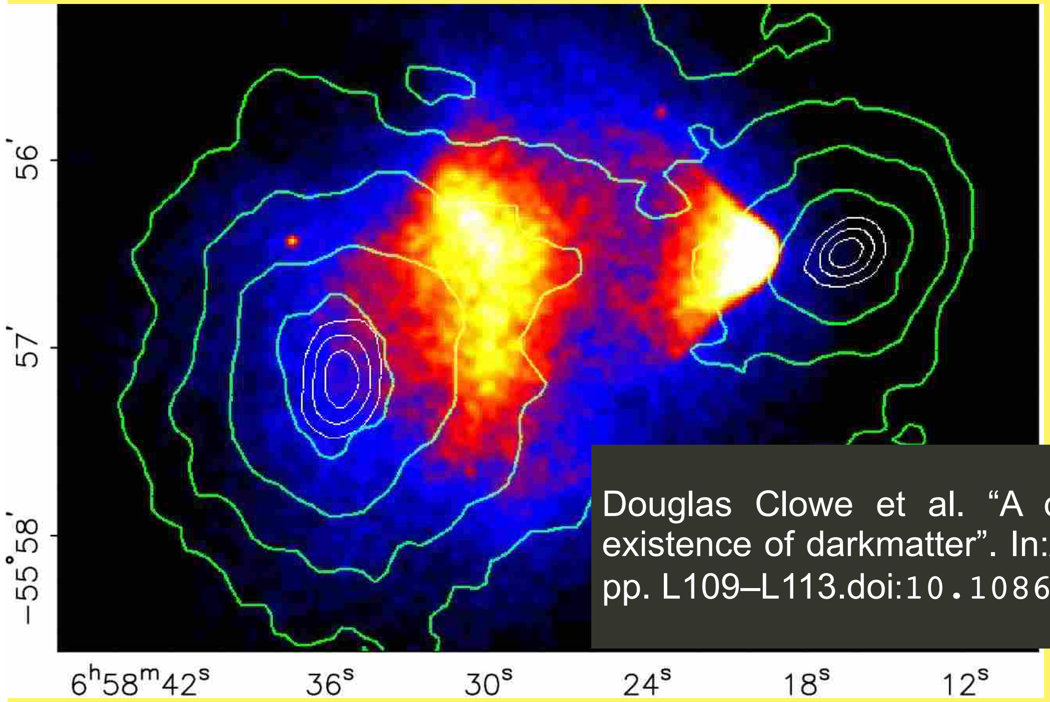
PHYSTAT-SYSTEMATICS

DARK MATTER

- Cosmological and dynamical evidence are all consistent with ordinary matter being only a small part (15% or so) of matter in the universe
- Cluster mergers/collisions point towards a particle nature
- The dark matter density at the Sun's distance from the Galactic Centre is estimated around $0.3\ \mathrm{GeV}/c^2/\mathrm{cm}^3$

Fabio Iocco, Miguel Pato, and Gianfranco Bertone. "Evidence for darkmatter in the inner Milky Way". In:Nature Phys.11 (2015), pp. 245–248.doi:10.1038/nphys3237.

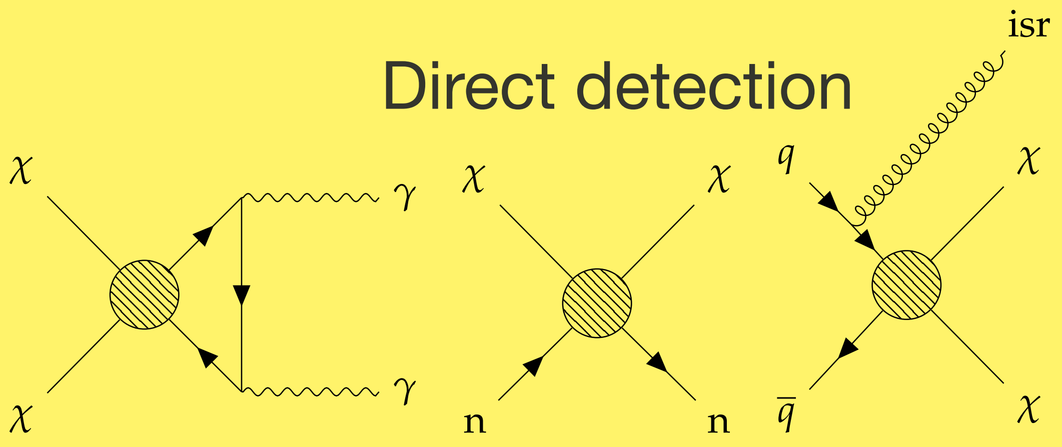


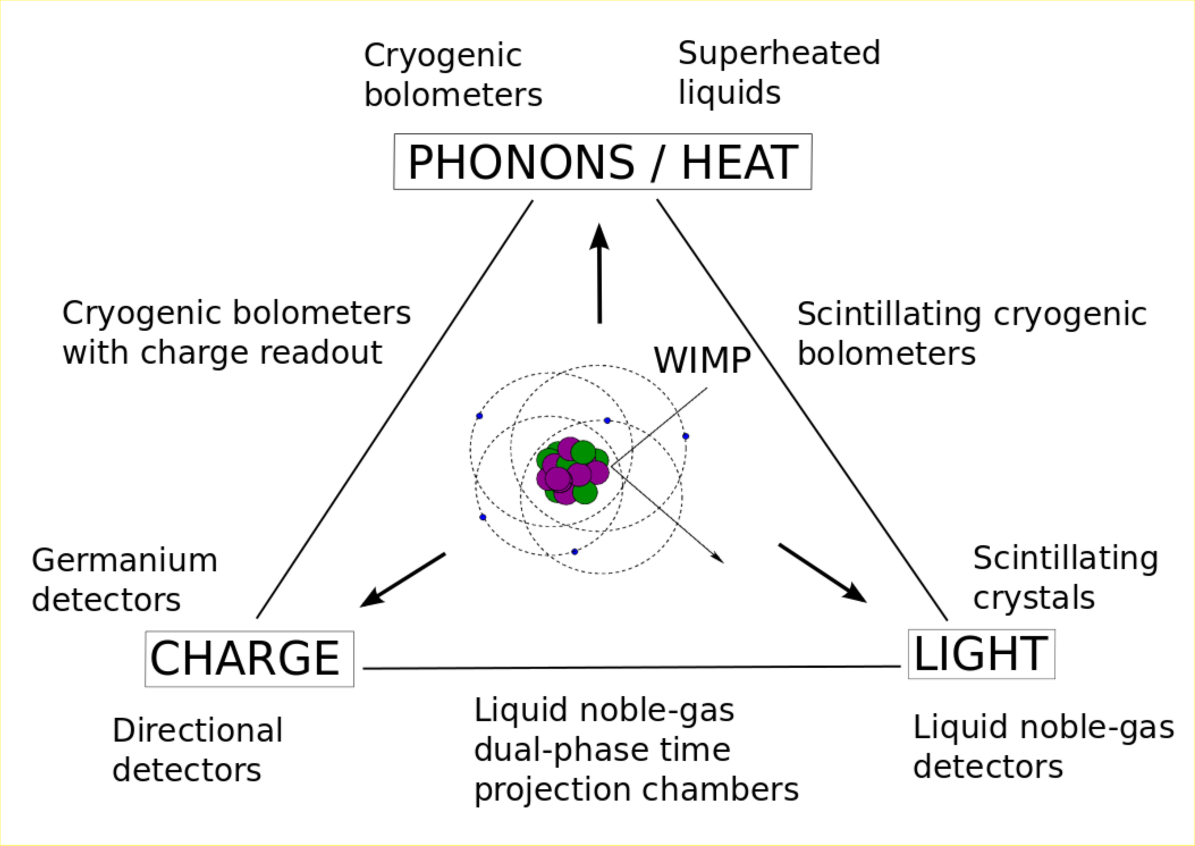


Douglas Clowe et al. "A direct empirical proof of the existence of darkmatter". In:Astrophys. J. Lett.648 (2006), pp. L109–L113.doi:`10.1086/508162`.

DIRECT DETECTION

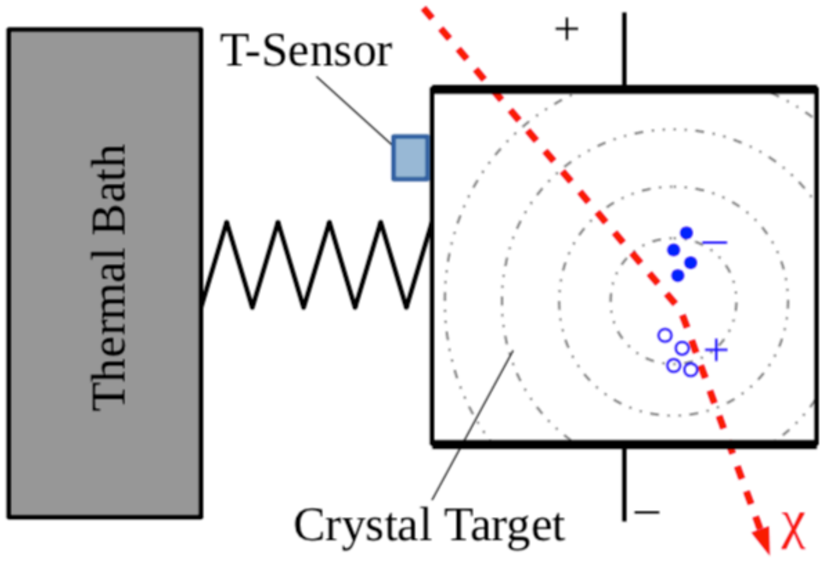
- Searches for dark matter particles interacting directly with a dark matter detector
- Energy deposited in the detector target is deposited into:
  - Phonons (in crystals) or heat
  - Ionisation / charge
  - Scintillation light
- Using more than one observable can allow some degree of discrimination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



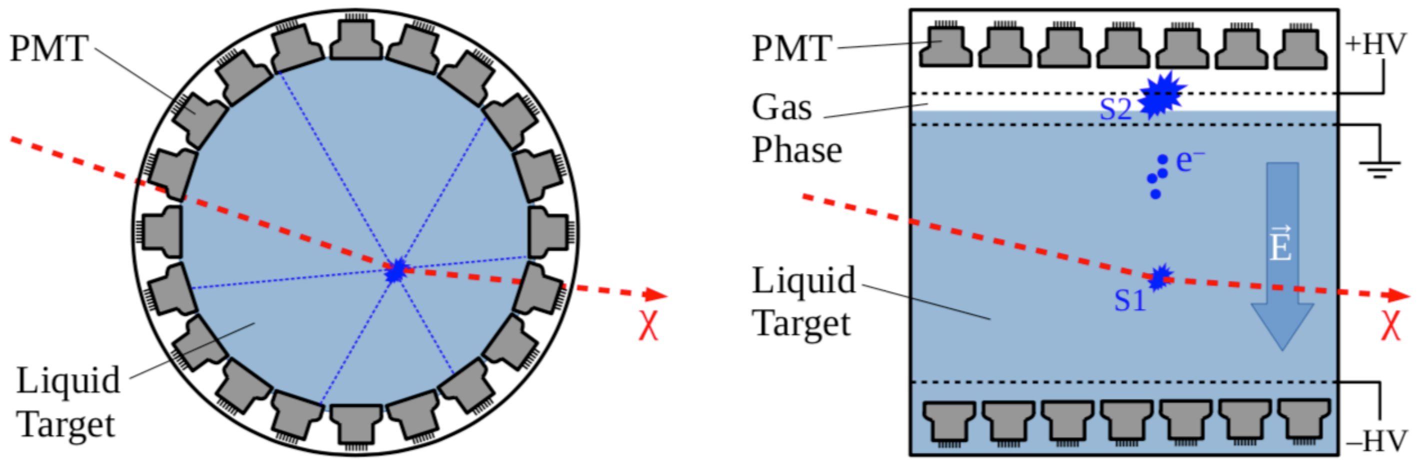


Teresa Marrodán Undagoitia and Ludwig Rauch. “Dark matter direct-detection experiments”. In: J. Phys. G43.1 (2016), p. 013001. DOI: 10.1088/0954-3899/43/1/013001.

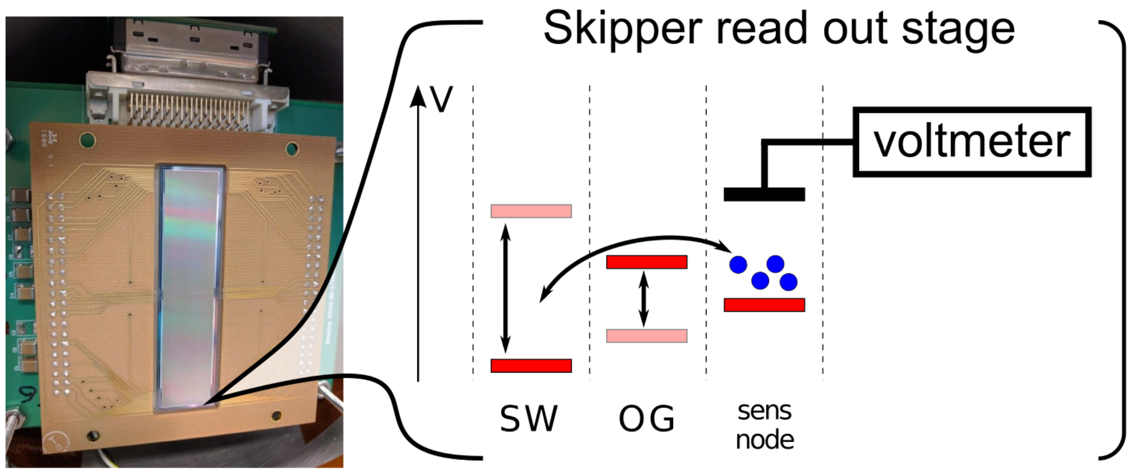
DETECTOR TECHNOLOGY EXAMPLES



CRYOGENIC DETECTOR: HEAT & IONISATION

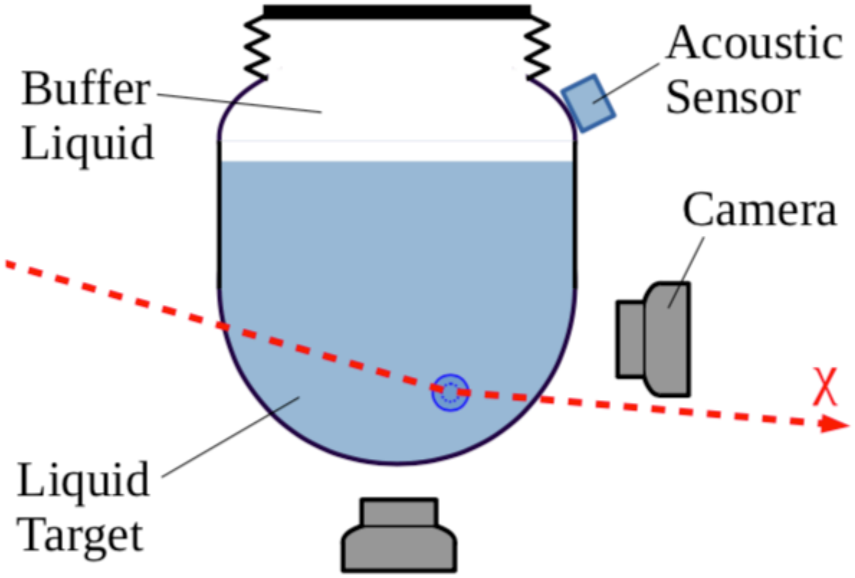


LIQUID NOBLE GAS 1- AND 2-PHASE TPCS



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 https://sensei-skipper.github.io/#SkipperCCD

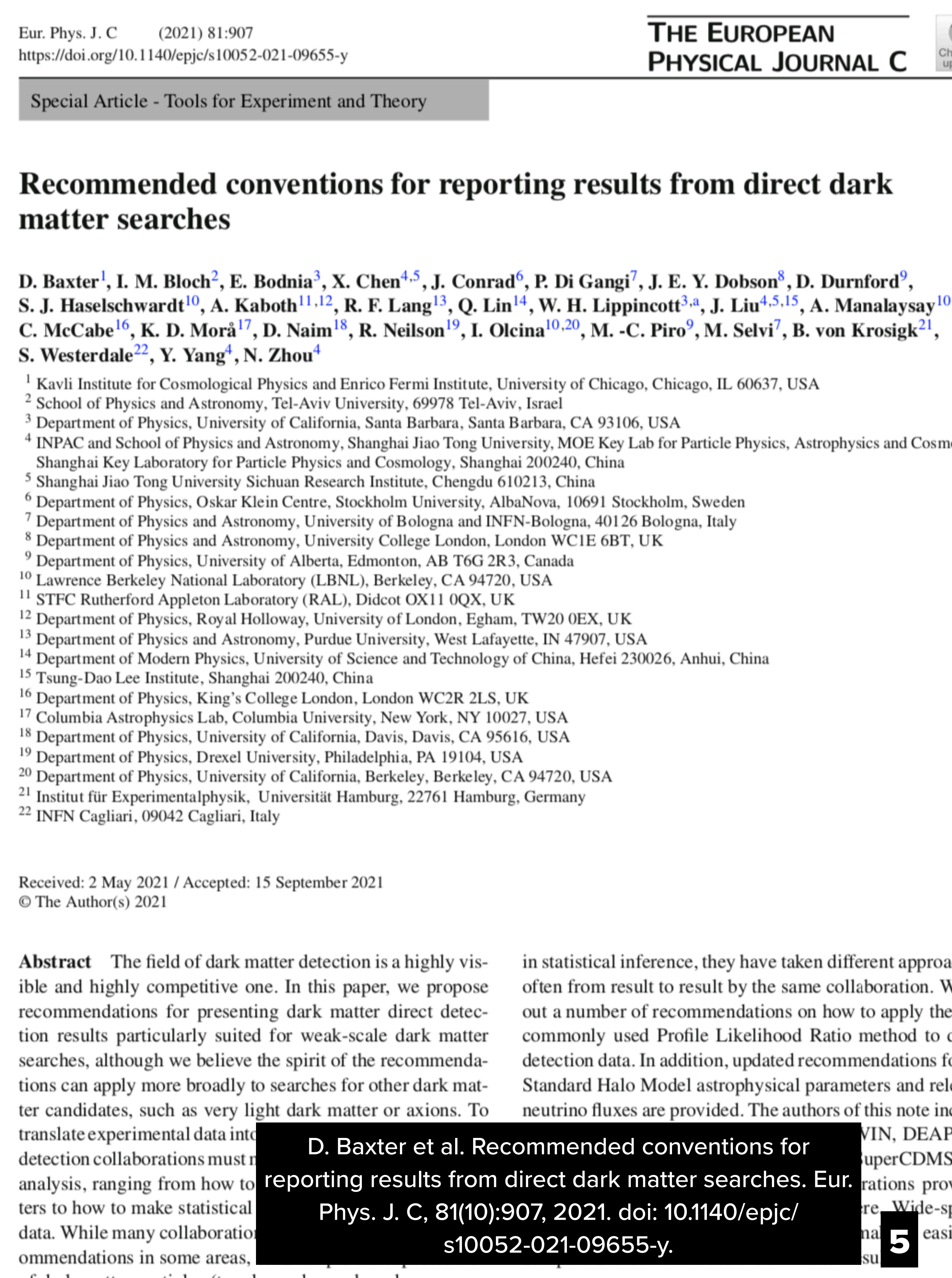


BUBBLE CHAMBER

GENERAL RECOMMENDATIONS

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

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



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

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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 int
detection collaborations must r
analysis, ranging from how to
ters to how to make statistical
data. While many collaboratio
ommendations in some areas,

in statistical inference, they have taken different approa
often from result to result by the same collaboration. W
out a number of recommendations on how to apply the
commonly used Profile Likelihood Ratio method to c
detection data. In addition, updated recommendations fo
Standard Halo Model astrophysical parameters and rel
neutrino fluxes are provided. The authors of this note inc
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D. Baxter et al. Recommended conventions for reporting results from direct dark matter searches. Eur. Phys. J. C, 81(10):907, 2021. doi: 10.1140/epjc/s10052-021-09655-y.

LIKELIHOODS

SEARCH DATA **CALIBRATION** **OTHER MEASUREMENTS /CONSTRAINTS**

$$\mathscr{L}(s, \vec{\theta}_s, \vec{\theta}_b) = \mathscr{L}_{\text{sci}}(s, \vec{\theta}_s, \vec{\theta}_b) \times \mathscr{L}_{\text{cal}}(\vec{\theta}_b) \times \mathscr{L}_{\text{anc}}(\vec{\theta}_b)$$

COUNTING

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

ON-OFF LIKELIHOODS

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

BINNED LIKELIHOODS

$$\mathscr{L}_{\text{sci}}(s, \vec{\theta}_s, \vec{\theta}_b) = \prod_{i=1}^{N_s} \left[\text{Poisson}(N_i \,|\, \mu_{b,i}(\vec{\theta}_b) + \mu_{s,i}(s, \vec{\theta}_s, \vec{\theta}_b)) \right]$$

UNBINNED LIKELIHOODS

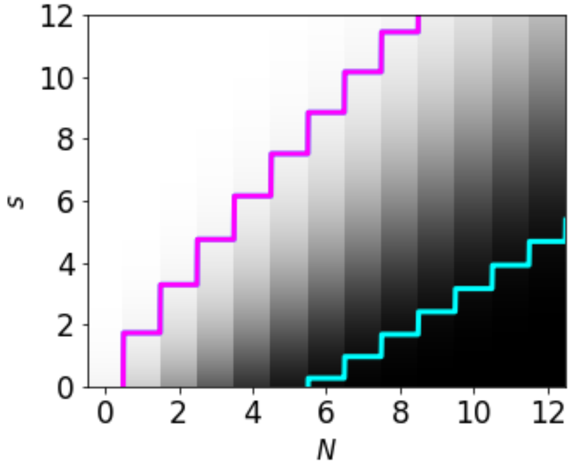
$$\mathscr{L}_{\text{sci}}(s, \vec{\theta}_s, \vec{\theta}_b) = \text{Poisson}(N_{\text{sci}} \,|\, \mu_b(\vec{\theta}_b) + \mu_s(s, \vec{\theta}_s, \vec{\theta}_b)) \times \prod_{i=1}^{N_s} \left[\frac{\mu_s}{\mu_s + \mu_b} f_s(\vec{x}_i \,|\, s, \vec{\theta}_s, \vec{\theta}_b) + \frac{\mu_b}{\mu_s + \mu_b} f_b(\vec{x}_i \,|\, \vec{\theta}_b) \right]$$

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

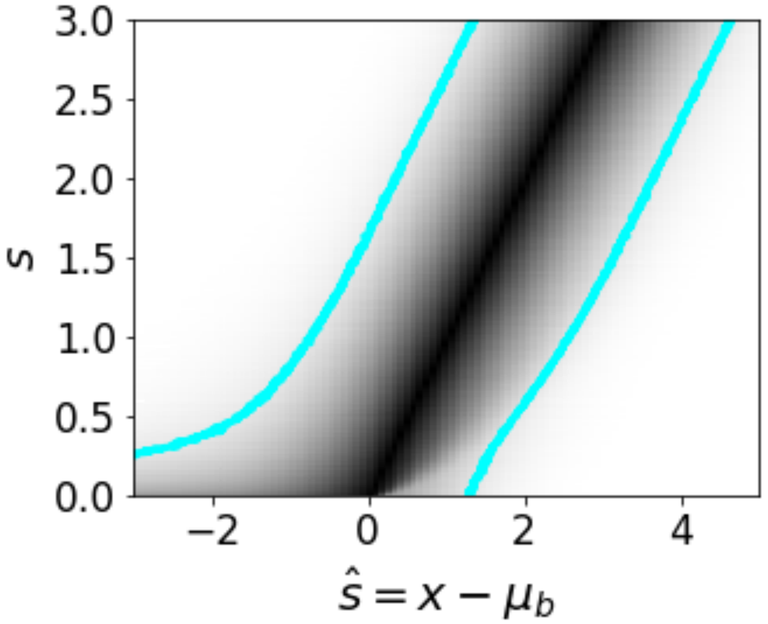
INFERENCE PROCEDURES

POISSON UPPER LIMITS (WITH OR WITHOUT PROFILING)

UPPER-LIMIT-ONLY

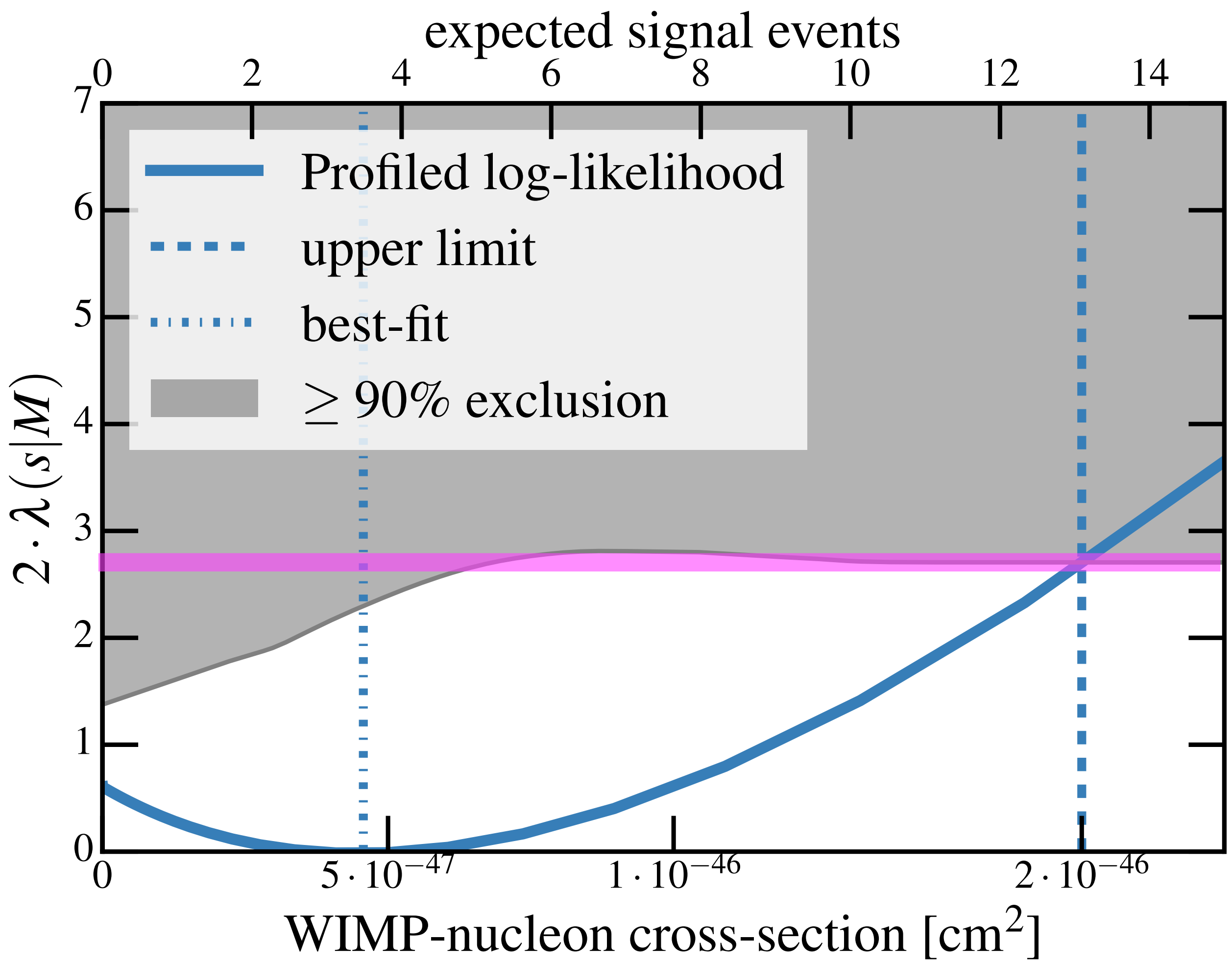


FELDMAN-COUSINS/ UNIFIED INTERVALS



ASYMPTOTIC LOG-LIKELIHOOD PROFILING

NON-ASYMPTOTIC TOY-MC CALIBRATED TEST STATISTIC DISTRIBUTIONS

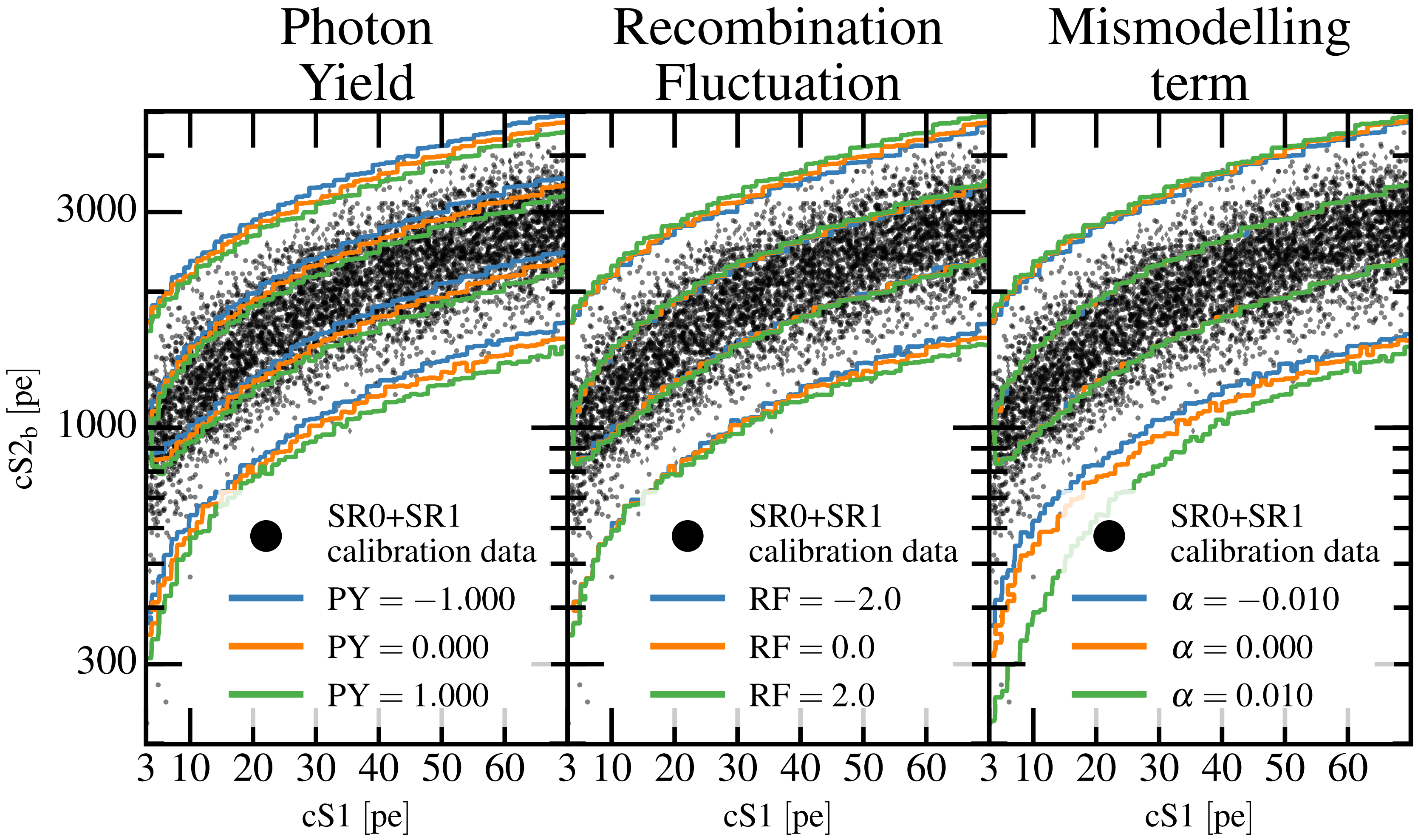


+METHODS FOR MISSING BACKGROUND MODELS (SEE LATER)

TECHNICAL ASIDE 1: SHAPE AND RATE?

$$\mathscr{L}_{\mathrm{sci}}(s, \vec{\theta}_s, \vec{\theta}_b) = \mathrm{Poisson}(N_{\mathrm{sci}} \,|\, \mu_b(\vec{\theta}_b) + \mu_s(s, \vec{\theta}_s, \vec{\theta}_b)) \times \prod_{i=1}^{N_s} \left[\frac{\mu_s}{\mu_s + \mu_b} f_s(\vec{x}_i \,|\, s, \vec{\theta}_s, \vec{\theta}_b) + \frac{\mu_b}{\mu_s + \mu_b} f_b(\vec{x}_i \,|\, \vec{\theta}_b) \right]$$

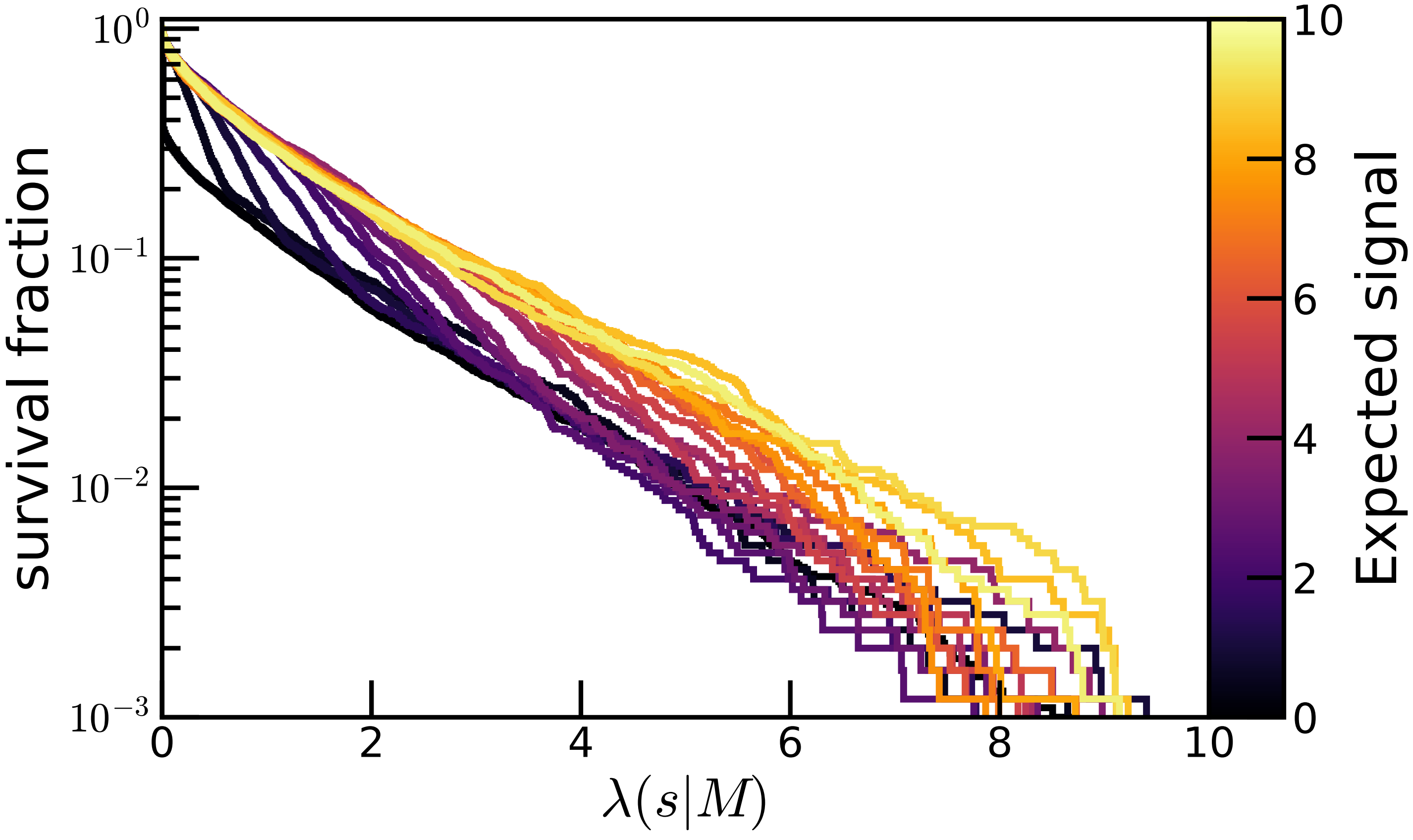
- More complicated models of the background and signals are often computed via sampling the distribution
- To have a continuous nuisance parameter, “template morphing"-- linear interpolation between some points in parameter space is often used
- Since this is computationally tricky, there will often be a divide between "rate parameters”-- those that only affect expectation values, and therefore are “easy” and "shape parameters”— those that require modifying the PDF of one or more signal/ background model



TECHNICAL ASIDE 2: NUISANCE PARAMETERS IN TOYMCS

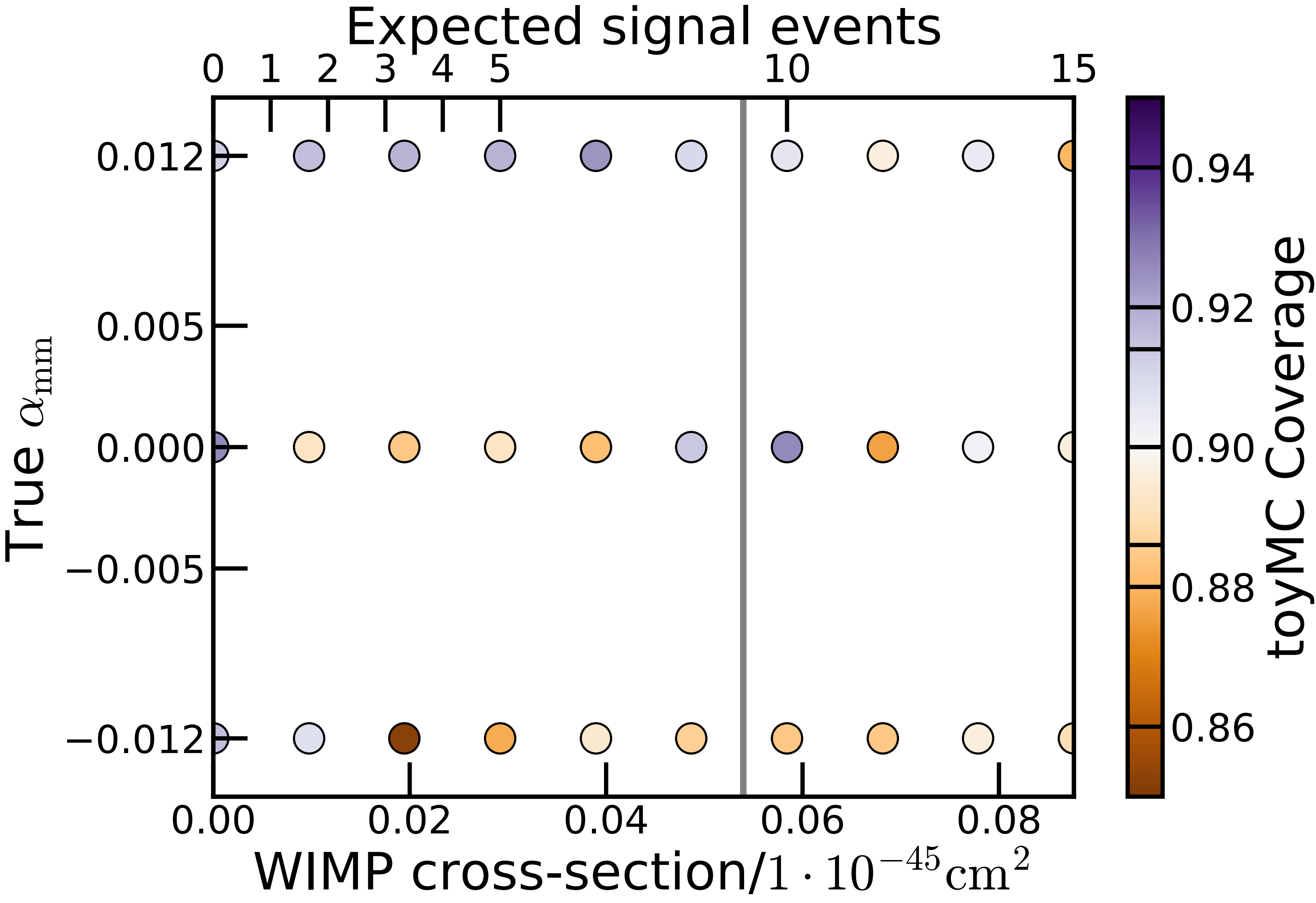
$$\mathscr{L}(s, \vec{\theta}_s, \vec{\theta}_b) = \mathscr{L}_{\mathrm{sci}}(s, \vec{\theta}_s, \vec{\theta}_b) \times \mathscr{L}_{\mathrm{cal}}(\vec{\theta}_b) \times \mathscr{L}_{\mathrm{anc}}(\vec{\theta}_b)$$

- the toy simulations needed to compute the test statistic distribution include randomising all measured parameters
  - including calibration measurements and ancillary measurement terms
- Simulations done for a set of signal strengths, and usually also for a range of signal shapes (varying mass or similar parameters)
- However, no firm procedure exists for nuisance parameters
  - Fix them to best-fit values and be certain you are not using the true values?
  - Randomise them according to uncertainty risks double-counting uncertainties



TECHNICAL ASIDE 2: NUISANCE PARAMETERS IN TOYMCS

- **XENON used the best-fit values of nuisance parameters**
- **In the latest XENON WIMP search, the robustness of this construction to mis-measuring nuisance parameters was also estimated (right)—changing the value to +-0.012 yielded a percentage point change in coverage**
- **For comparison, the best-fit value was -0.004**



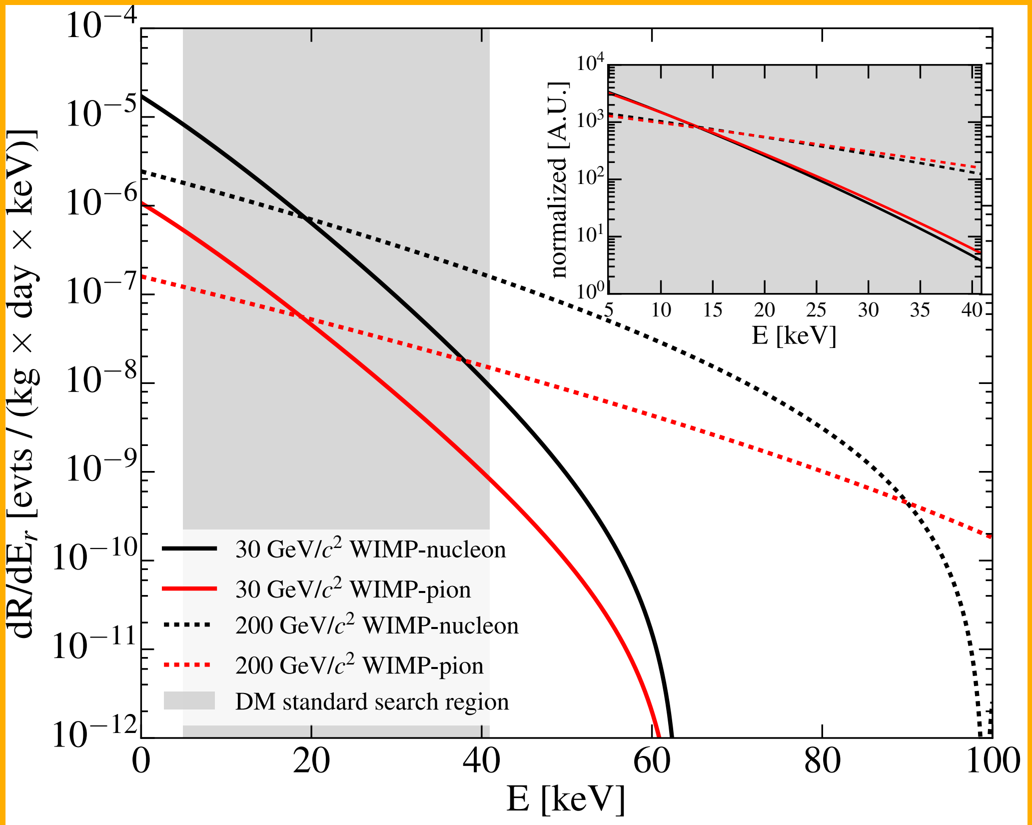
E. Aprile et. al (XENON). XENON1T dark matter data analysis: Signal and background models and statistical inference. Phys. Rev. D, 99(11):112009, 2019. doi: 10.1103/Phys- RevD.99.112009.

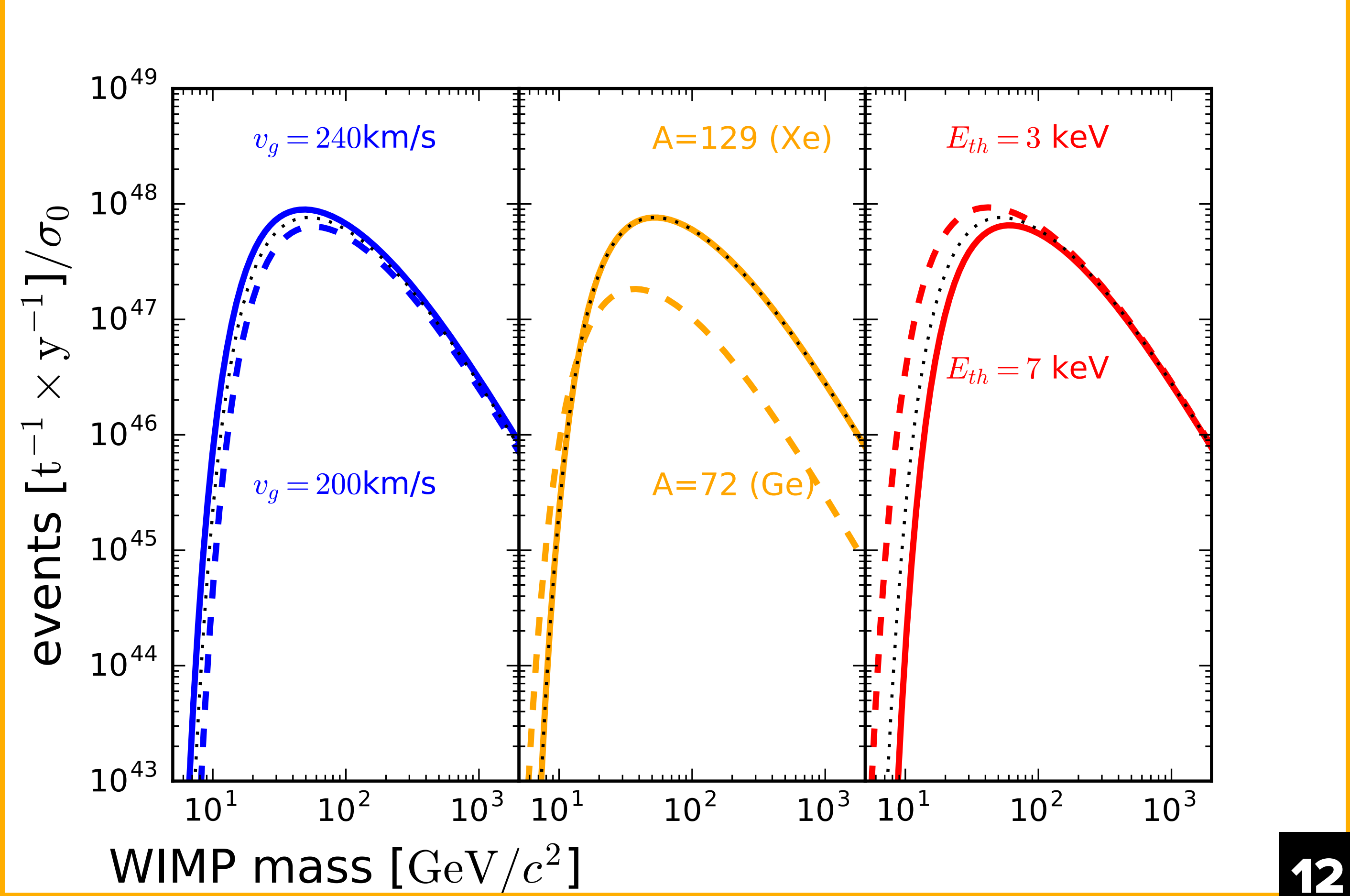
SIGNAL UNCERTAINTIES

DETECTING WIMP DARK MATTER

- The dark matter density at the Sun's distance from the Galactic Centre is about 0.3 GeV/c²
- At galactic velocities, a WIMP with typical weak-scale (GeV-TeV) would deposit some keV of nuclear recoil energy
- For a Maxwell velocity distribution the typical recoil spectrum is an exponential decreasing with recoil energy
- Note that the spectrum is rather flat— changes in model assumption will mostly change the rate
- For low recoil energies, the WIMP scatters on the entire nucleus— coherent scattering boosts the rate by a factor A²
- Transferred energy is maximised when the target nucleus and the WIMP have the same mass

XENON collaboration. "First results on the scalar WIMP-pion coupling, using the XENON1T experiment." Physical review letters 122.7 (2019): 071301.





COMPONENTS OF THE SIGNAL EXPECTATION

- Astrophysical uncertainties:
  - Velocity distribution of dark matter $f(\overrightarrow{v})$
  - Local density of dark matter ρ_0
- Particle properties of dark matter
  - Mass M_D
  - dark matter interaction cross-section $\frac{d\sigma}{dq^2}$
- Nuclear form-factors $F(E)$
- Currently, experiments will almost always fix these parameters to nominal values or functions instead of varying them.

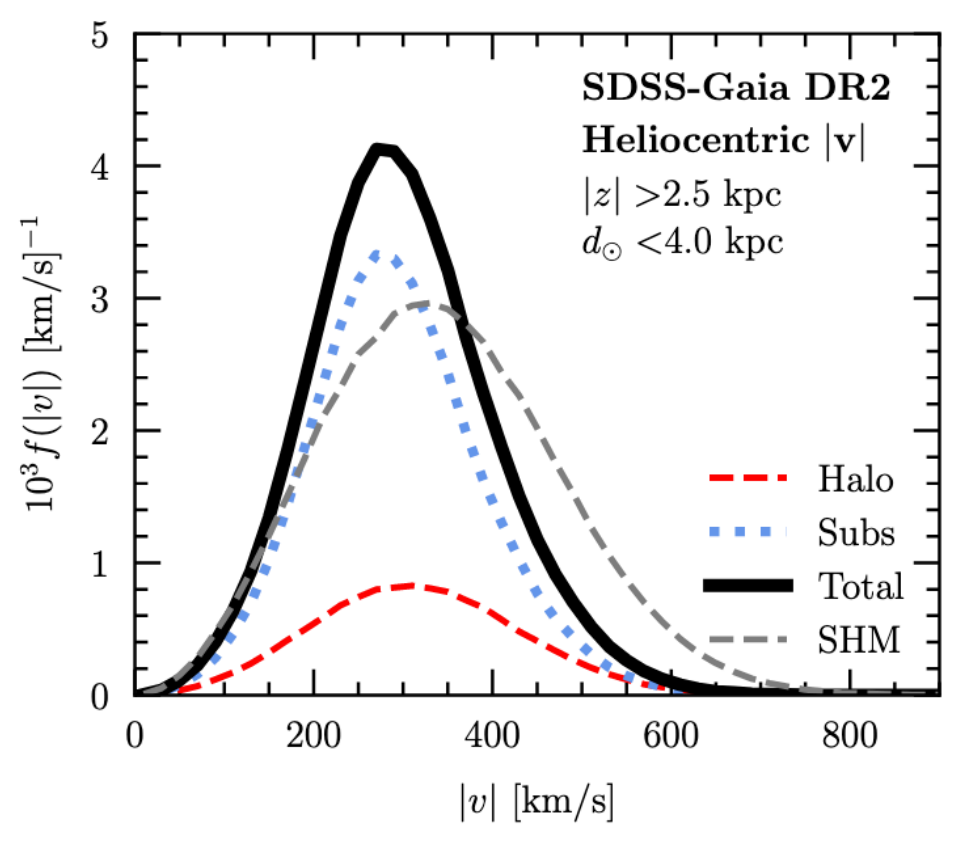
$$\frac{dR}{dE} = \frac{\rho_0}{M_D M_T} \int v f(\overrightarrow{v}) \frac{M_T}{2\mu^2 v^2} \sigma_0 F^2(E) d^3\overrightarrow{v}$$

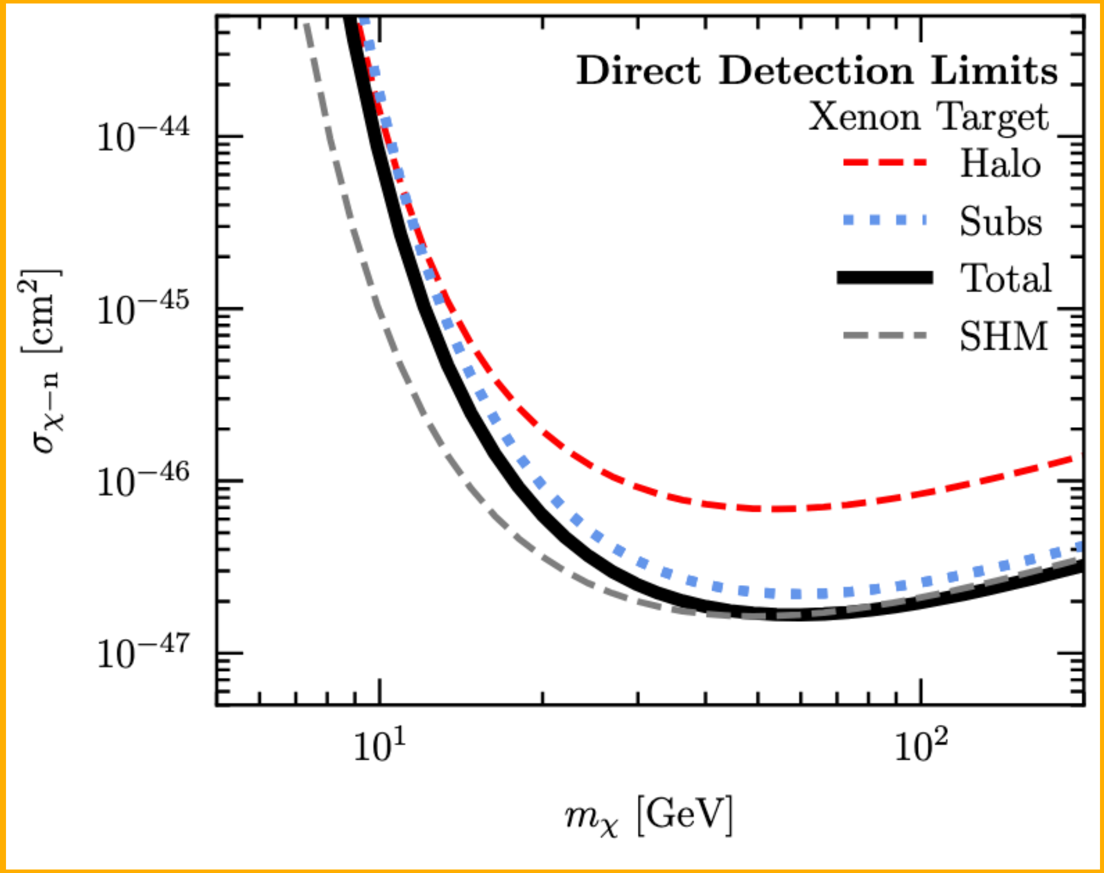
J.D. Lewin and P.F. Smith. Review of mathematics, numerical factors, and corrections for dark matter experiments based on elastic nuclear recoil. Astroparticle Physics, 6 (1):87–112, 1996. ISSN 0927-6505. doi: https://doi.org/10.1016/S0927-6505(96)00047-3.

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

DARK MATTER DISTRIBUTIONS

- The dark matter distribution when reporting results is typically chosen to be a Maxwell-Boltzmann truncated by the Galactic escape velocity with fixed parameters
- Uncertainties in these parameters,
- In particular the presence of substructures in the dark matter distribution that are either co-rotating with the sun (as a dark disk) or have much higher velocities (such as a stream or clump of dark matter after a sub halo merger) can significantly depress or enhance the expected signal, respectively

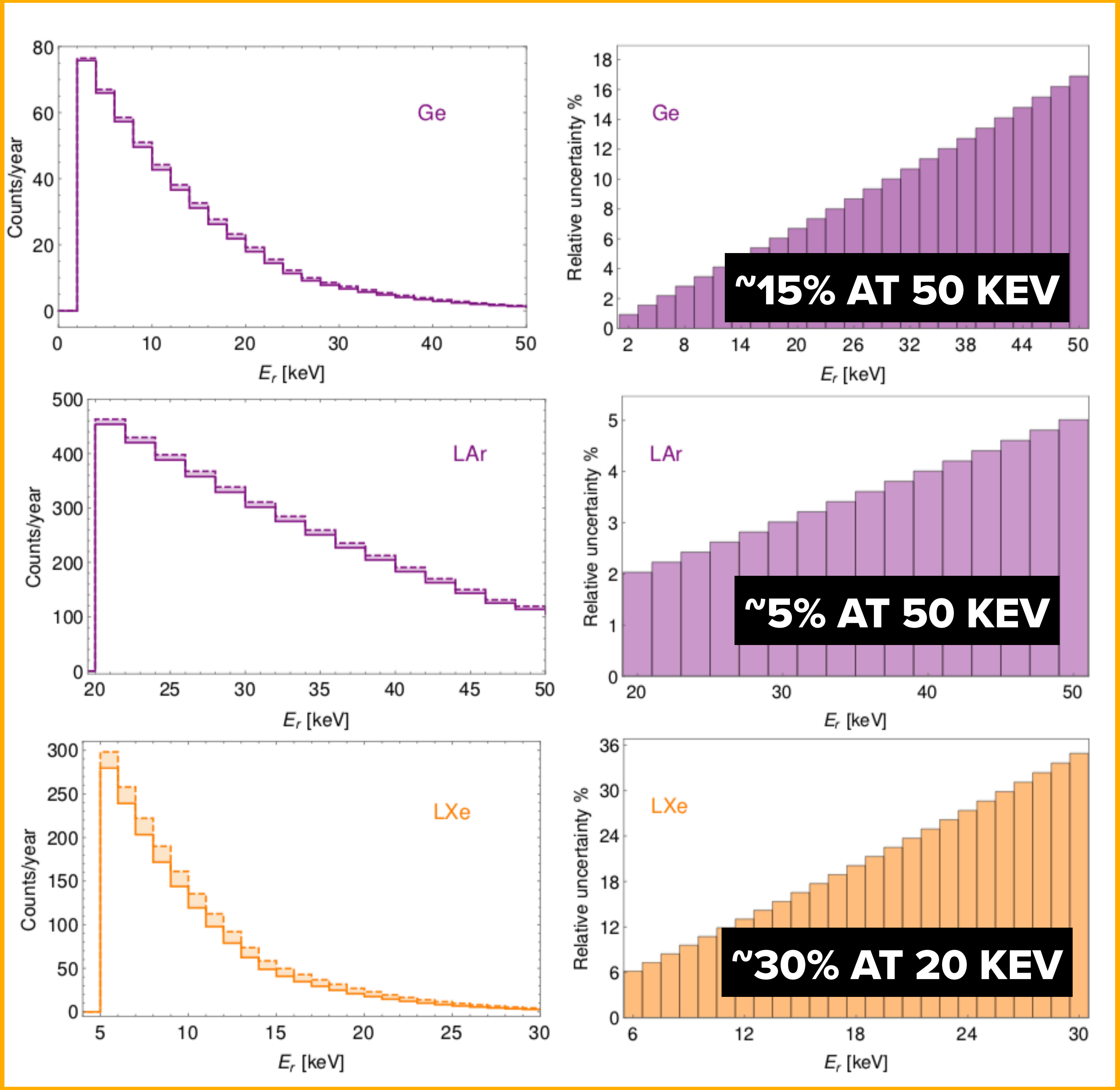




Lina Necib, Mariangela Lisanti, and Vasily Belokurov. In- ferred Evidence For Dark Matter Kinematic Substructure with SDSS-Gaia. 7 2018. doi: 10.3847/1538- 4357/ab095b.

NUCLEAR STRUCTURE

- At low energies, dark matter (or neutrinos) interact coherently with the entire nucleus— this leads to a coherent A^2 enhancement for spin-independent interactions
- The effect of the nuclear structure on the interaction probability is quantified with the nuclear form factor
- These form factor become more uncertain with higher energies.
- Standard dark matter interactions may therefore not be affected, but alternate models where the dark matter is boosted will be more strongly affected.



~15% AT 50 KEV

~5% AT 50 KEV

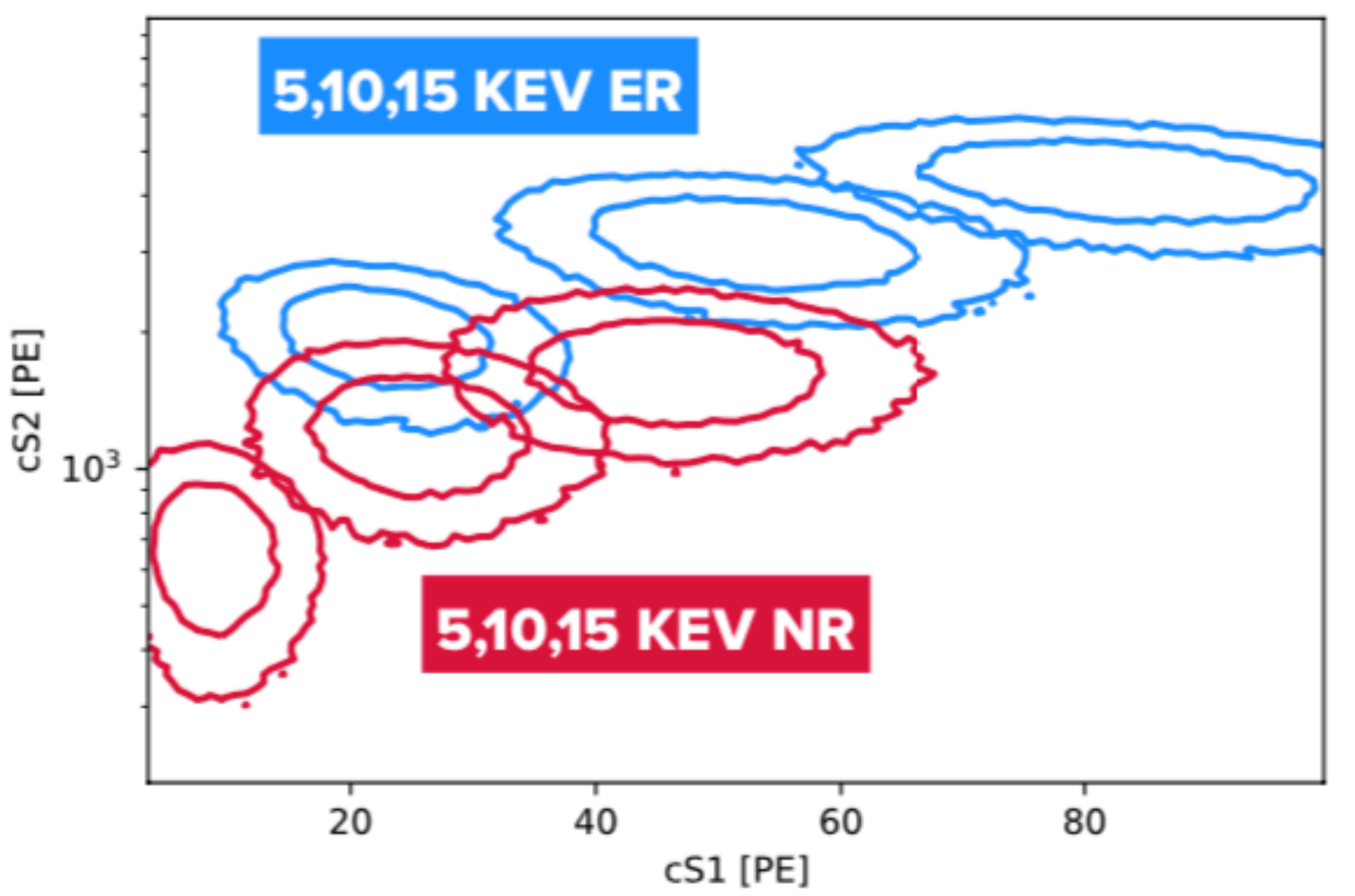
~30% AT 20 KEV

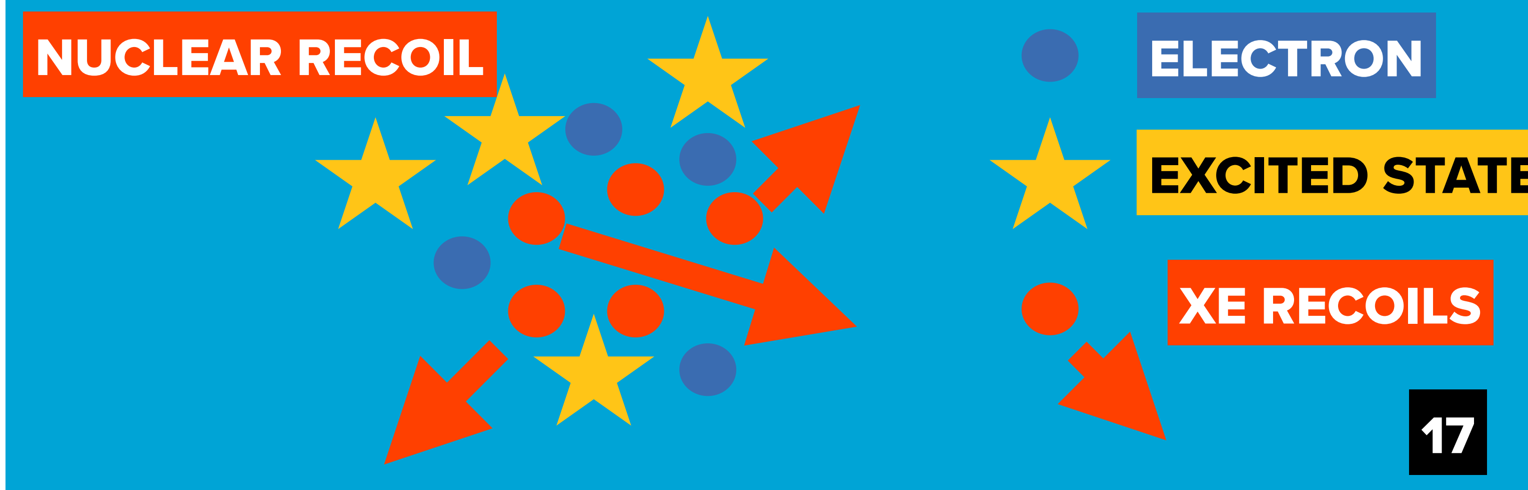
D. Aristizabal Sierra, Jiajun Liao, and D. Marfatia. Impact of form factor uncertainties on interpretations of coherent elastic neutrino-nucleus scattering data. Journal of High Energy Physics, 2019(6), Jun 2019. ISSN 1029-8479. doi: 10.1007/jhep06(2019)141

UNCERTAIN DETECTOR PARAMETERS

EXAMPLE: LIQUID XENON RESPONSE

- Energy deposited in liquid xenon results in:
    - VuV scintillation light, released on ~10ns timescales: S1
    - ionisation, which we measure after a drift period: an S2
    - heat/atomic motion— not detected
- Nuclear recoils (NRs)
    - Energy (about 80%) is lost to heat
    - Higher light-to-charge ratio
- Recoils on electrons (ERs)
    - A recoiling electron deposits little or no energy as heat
    - A larger portion of the energy as ionization

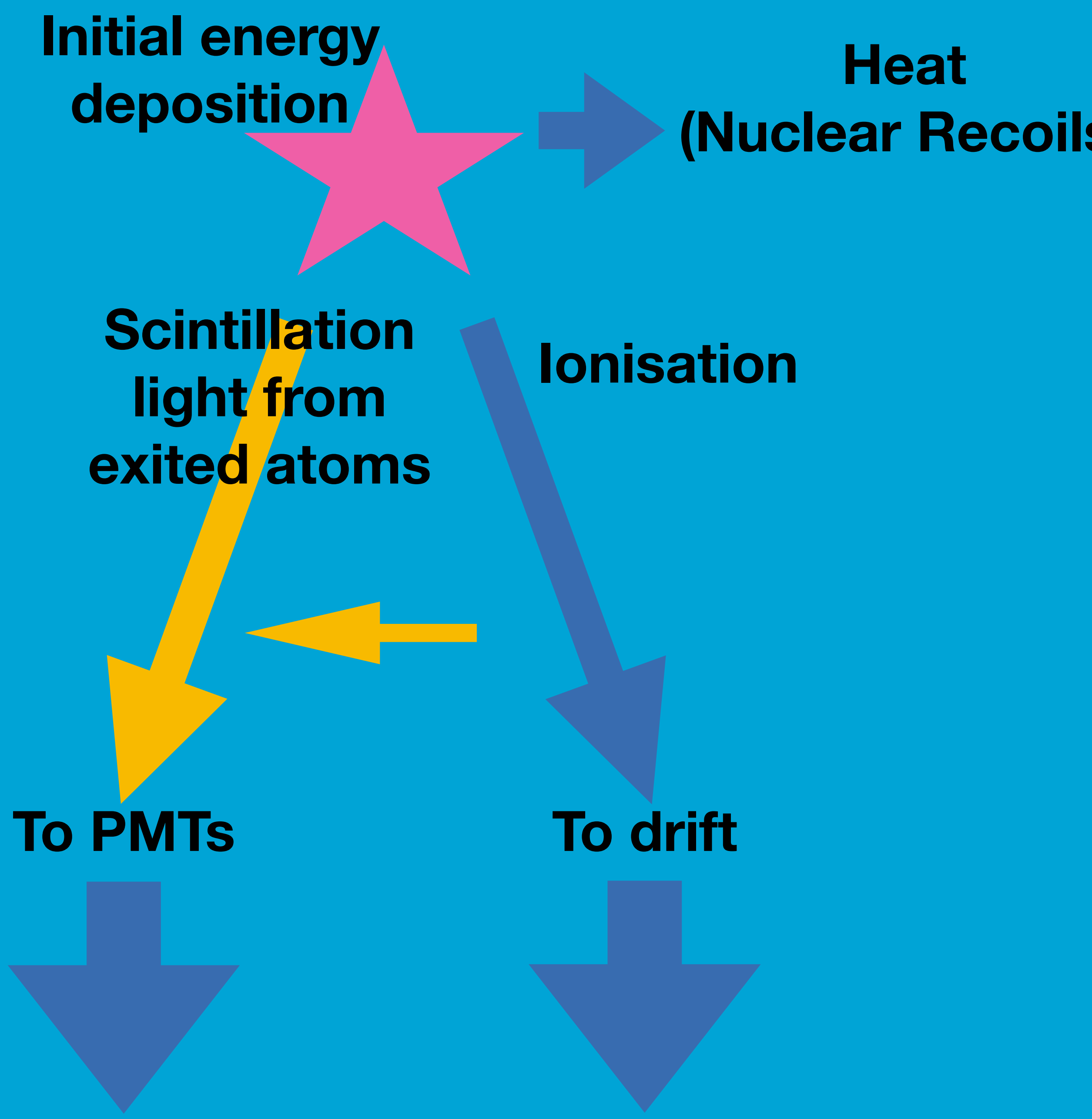




LXE RESPONSE MODELS

- Going from an initial interaction to scintillation photons and drifting electrons requires modelling a range of uncertain parameters as first-principle measures are not available.
- Often, these parameters are best constrained by (combinations of) smaller, dedicated experiments or dedicated calibrations
- The Noble Element Simulation Technique (NEST) framework aims to model the process from interaction to observables and fit it to sixteen (as of 2020) sets of data of varying energy and electric field
- In total, 9 parameterisation values fitted to available data using a Metropolis-Hastings MCMC

PARAMETERS:
PARTICLE/INTERACTION TYPE,
DEPOSITED ENERGY
ELECTRIC FIELD

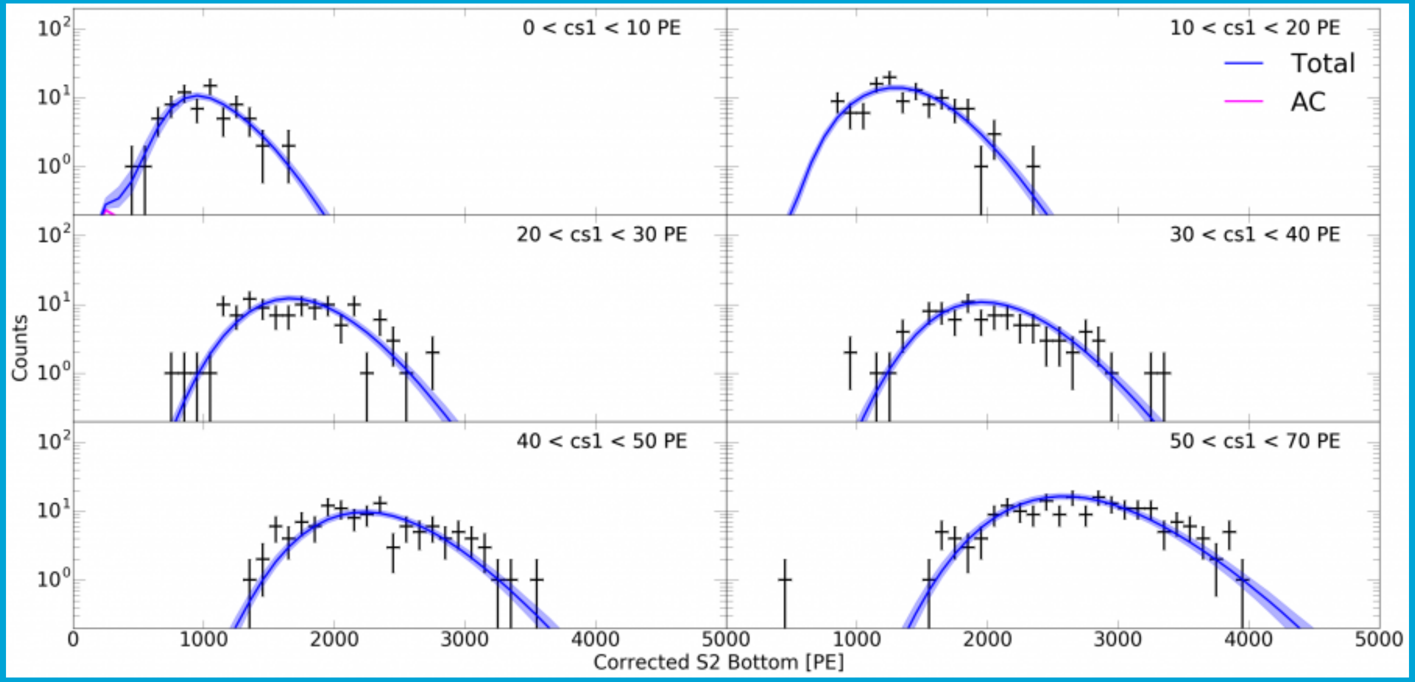


Lenardo et al (NEST) A global analysis of light and charge yields in liquid xenon. IEEE Transactions on Nuclear Sci- ence, 62(6):3387–3396, Dec 2015. ISSN 1558-1578. doi: 10.1109/tns.2015.2481322.

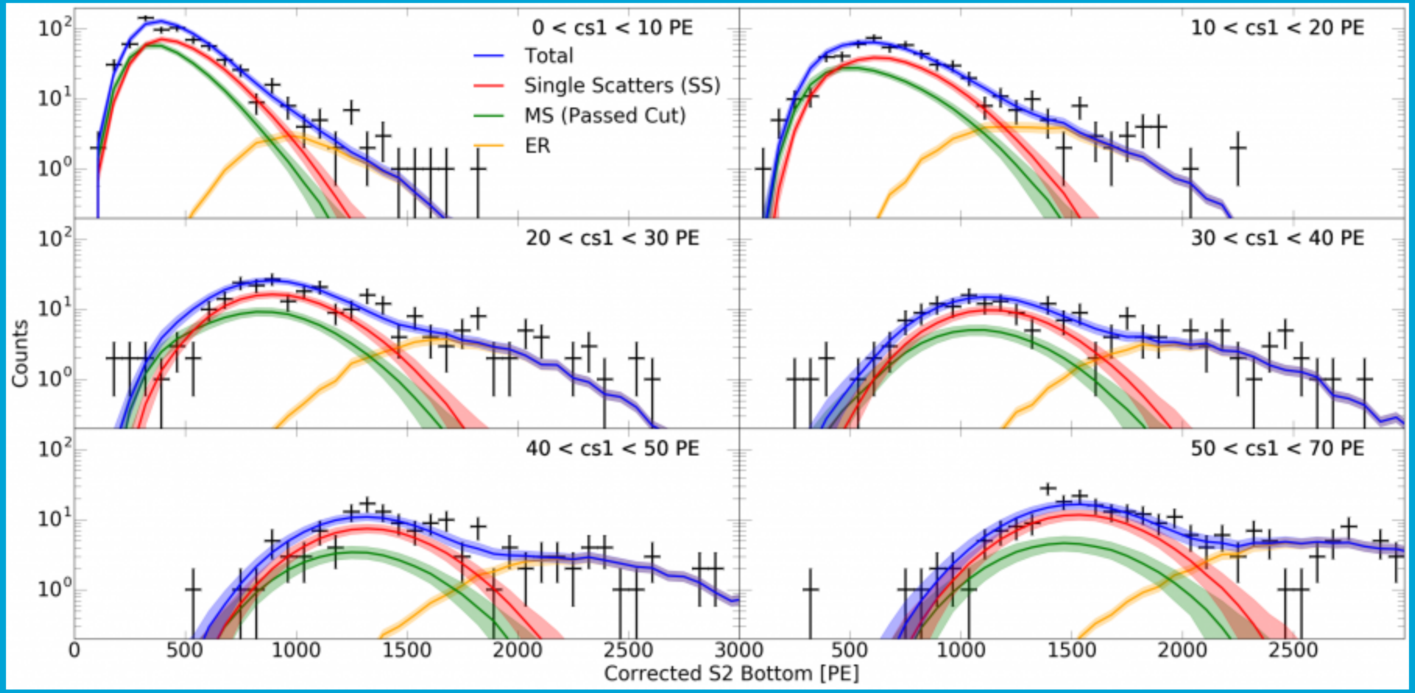
USING RESPONSE MODELS

- Experiments sometimes use NEST out of the box, but as there are a range of detector effects to account for, will in the very least
    - compare the NEST+detector model with calibration
    - or perform a re-fit with NEST
- As an example, LUX uses NEST to compute yields, but tunes values to calibrations of electronic and nuclear recoils , and modifies the parameterisation for electronic recoils
- XENON employs a model similar to NEST fitting both response parameters and detector parameters to ER and NR calibrations.
- In both cases, it is not possible to propagate all uncertainties to the final inference procedure, some parameters considered important are selected

ER FIT IN XENON1T



NR FIT IN XENON1T

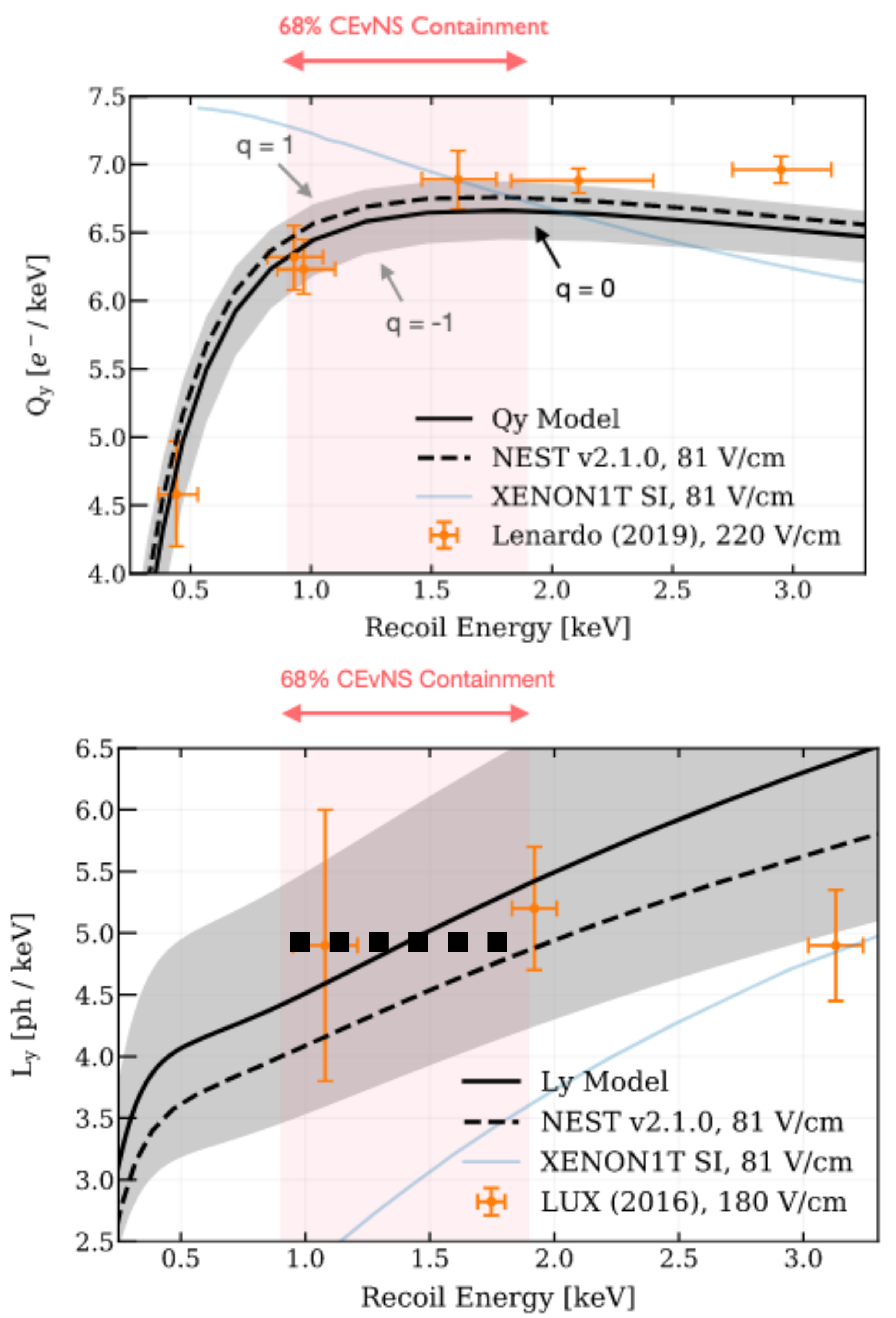


Akerib, D. S. et. al (LUX). Calibration, event reconstruction, data analysis, and limit calculation for the LUX dark matter experiment. Phys. Rev. D, 97(10):102008, 2018. doi: 10.1103/PhysRevD.97.102008.

E. Aprile et. al (XENON). XENON1T dark matter data analysis: Signal and background models and statistical inference. Phys. Rev. D, 99(11):112009, 2019. doi: 10.1103/Phys- RevD.99.112009.

SEARCHING FOR SOLAR NEUTRINOS

- Solar neutrinos are expected to be an important background for WIMP masses around $6\mathrm{GeV}/c^2$
- A XENON signal used the NEST charge and light yield functions (for nuclear recoils), but included only measurements that were taken in the low-energy region close to the ROI when constraining each parameter.
- Since the solar neutrinos the analysis could detect were distributed in a relatively narrow region, it turned out that both parameters primarily affect the signal expectation
  - Replacing the Ly curve with a uniform value did also not change the expected observed spectrum
  - Using this allowed the analysis to compute a three-dimensional confidence volume



E. Aprile et. al (XENON). Search for Coherent Elastic Scattering of Solar ^{8}B Neutrinos in the XENON1T Dark Matter Experiment. Phys. Rev. Lett., 126:091301, 2021. doi: 10.1103/PhysRevLett.126.091301.

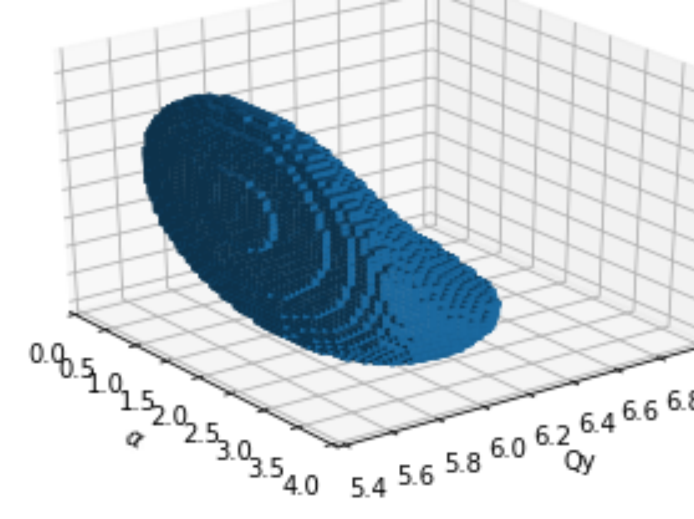
CONSTRUCTING 3D CONFIDENCE VOLUME

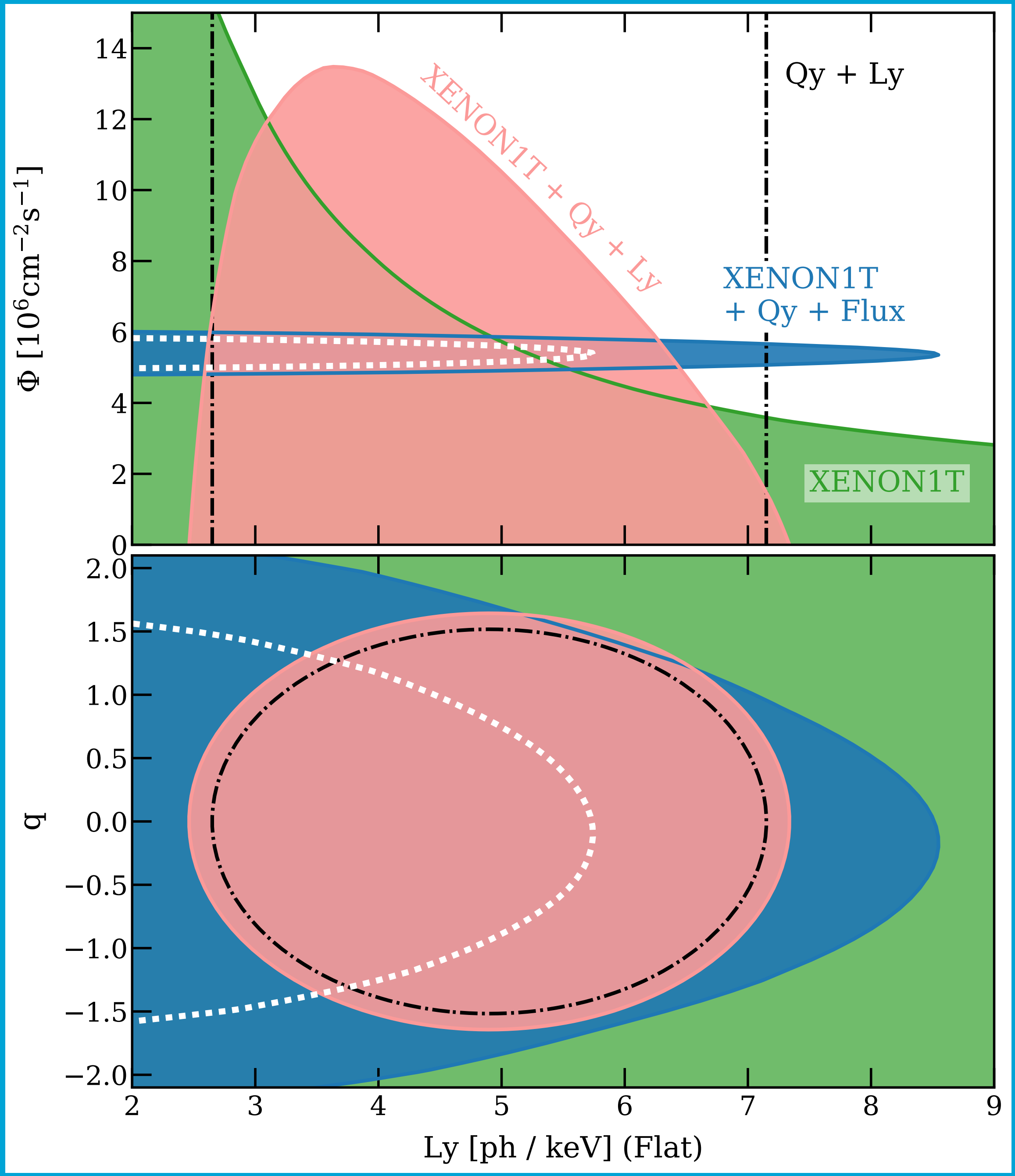
FOR EACH SIGNAL EXPECTATION $\mu_{\mathrm{CE}\nu\mathrm{NS}}$

GENERATE TOY DATASETS AND COMPUTE $\lambda_{\mathrm{XENON1T}}(\mu_{\mathrm{CE}\nu\mathrm{NS}})$

FOR EACH ϕ, Q_y, L_y, COMPUTE $\mu_{\mathrm{CE}\nu\mathrm{NS}}(\phi, Q_y, L_y)$, AND USE THE TOYS CORRESPONDING TO THIS EXPECTATION VALUE

AND ADD EACH TOY-SIMULATION $\lambda_{\mathrm{XENON1T}}(\mu_{\mathrm{CE}\nu\mathrm{NS}})$ AND A RANDOM χ^2_n-VARIABLE TO GET $\Lambda(\phi, Q_y, L_y)$

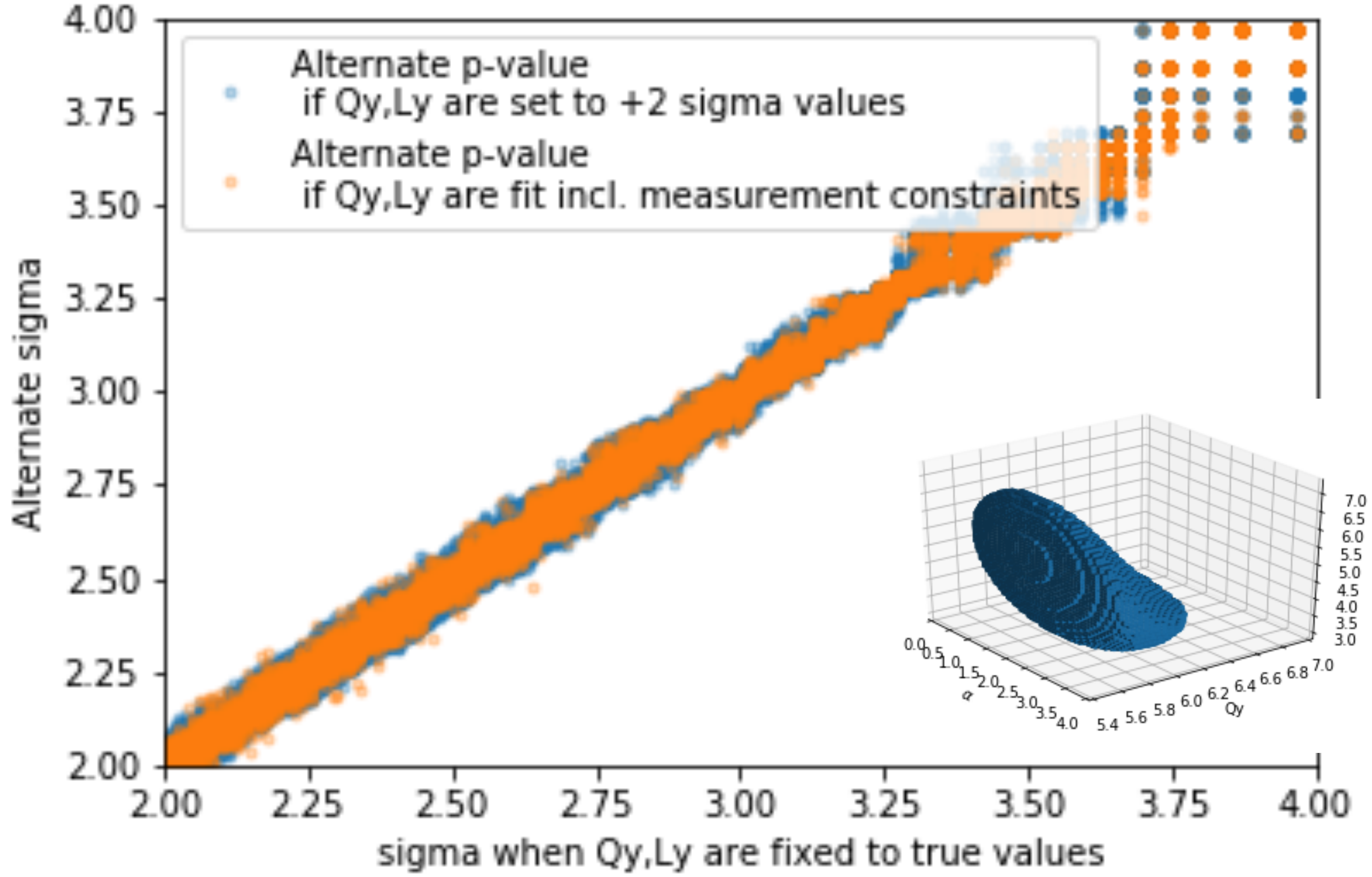


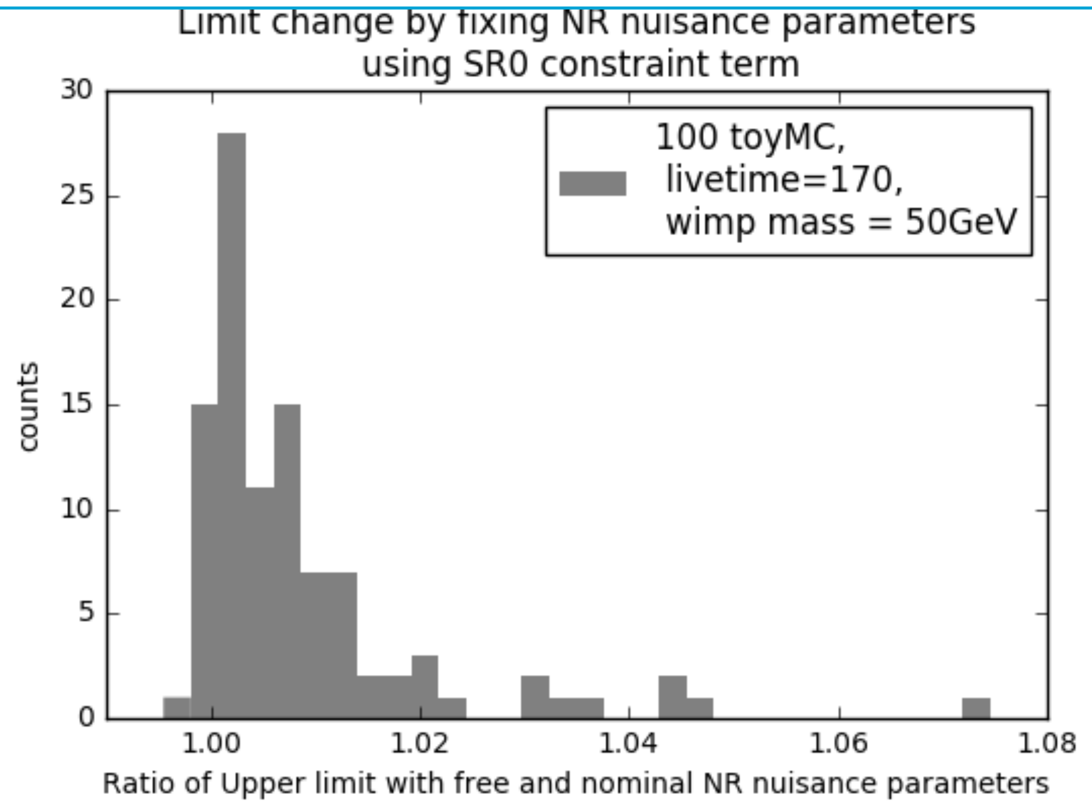


E. Aprile et. al (XENON). Search for Coherent Elastic Scattering of Solar ^{8}B Neutrinos in the XENON1T Dark Matter Experiment. Phys. Rev. Lett., 126:091301, 2021. doi: 10.1103/PhysRevLett.126.091301.

FOLLOW-UP QUESTION: WHAT PARAMETERS MAY BE IGNORED?

- We are rarely (never) able to include every possible uncertainty in our inference frameworks
  - And it is not likely that every parameter is important
- Need ways to decide which parameters are unimportant enough
- To my knowledge, no standards or consistency in how these questions are treated.
- To the right, two toy investigations in XENON1T— signal shape parameters often have very little impact on confidence intervals





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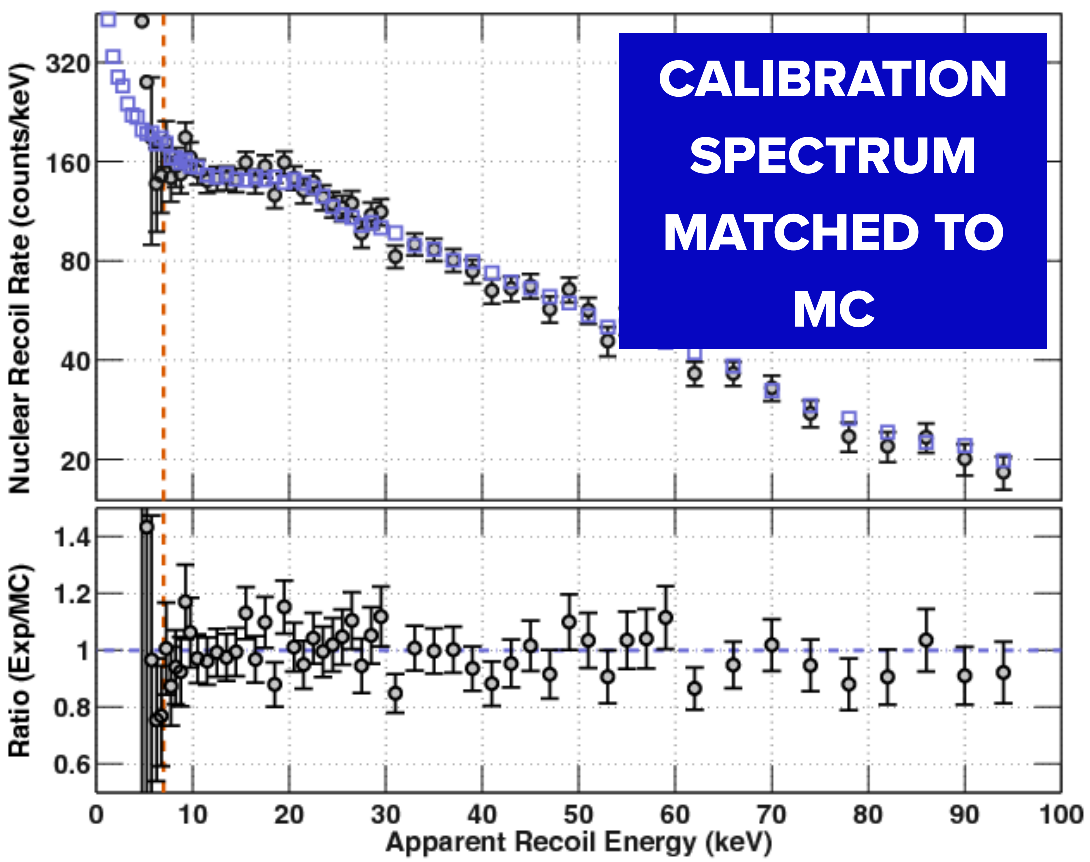
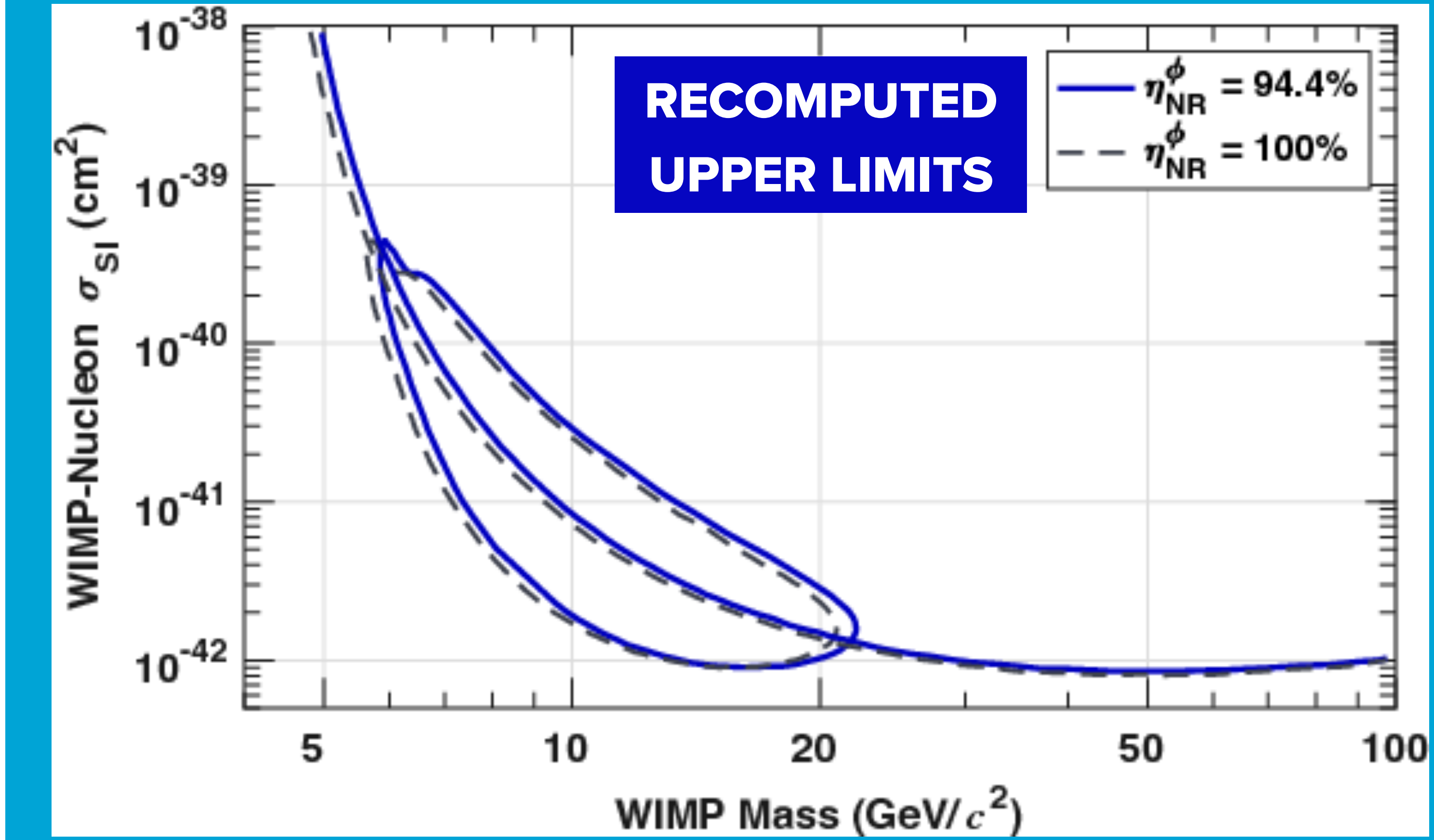
E. Aprile et. al (XENON). Dark Matter Search Results from a One Ton-Year Exposure of XENON1T. Phys. Rev. Lett., 121(11):111302, 2018. doi: 10.1103/Phys- RevLett.121.111302.

SUPERCDMS ENERGY CALIBRATION

- Some neutron calibration sources yield a very WIMP-like spectrum—steeply falling in energy and with only wide features.
- Connecting this spectral shape to an energy scale is therefore a challenge, in particular if you wish to compare with other experiments
- Full detector simulation matched to the $^{252}\mathrm{Cf}$ calibration data provided the expected energy deposition distribution, and matching this to the data yields an estimated relative phonon collection efficiency of $95.2^{+0.9}_{-0.7}\,\%$
- The change in yield from the previously assumed 100% shifts most limits a bit, in particular for lower masses.



CALIBRATION SPECTRUM MATCHED TO MC



RECOMPUTED UPPER LIMITS

Agnese, R. et al. (CDMS). Nuclear-Recoil Energy Scale in CDMS II Sili- con Dark-Matter Detectors. Nucl. Instrum. Meth. A, 905:71–81, 2018. doi: 10.1016/j.nima.2018.07.028

UNCERTAIN BACKGROUNDS
KNOWN

UPPER LIMITS WITH UNKNOWN BACKGROUNDS

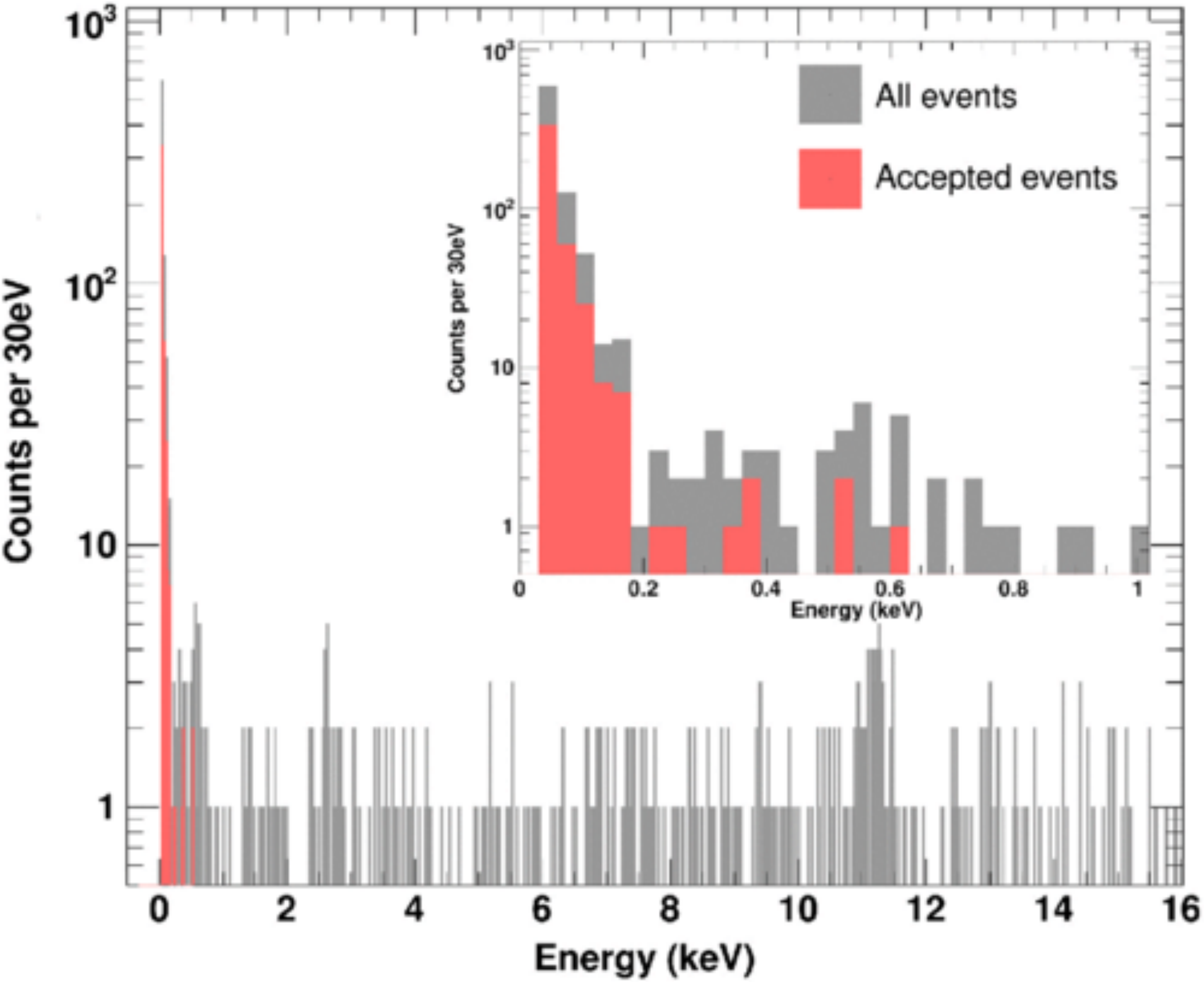
- In particular when pushing towards very low energy thresholds, unknown or partially known backgrounds are encountered

- Examples include:

    - single-electron events in DarkSide-50, possibly from electron capture/release on impurities after a preceding event

    - A low-energy population of events in CRESST-III of unknown origin, varying between detector modules

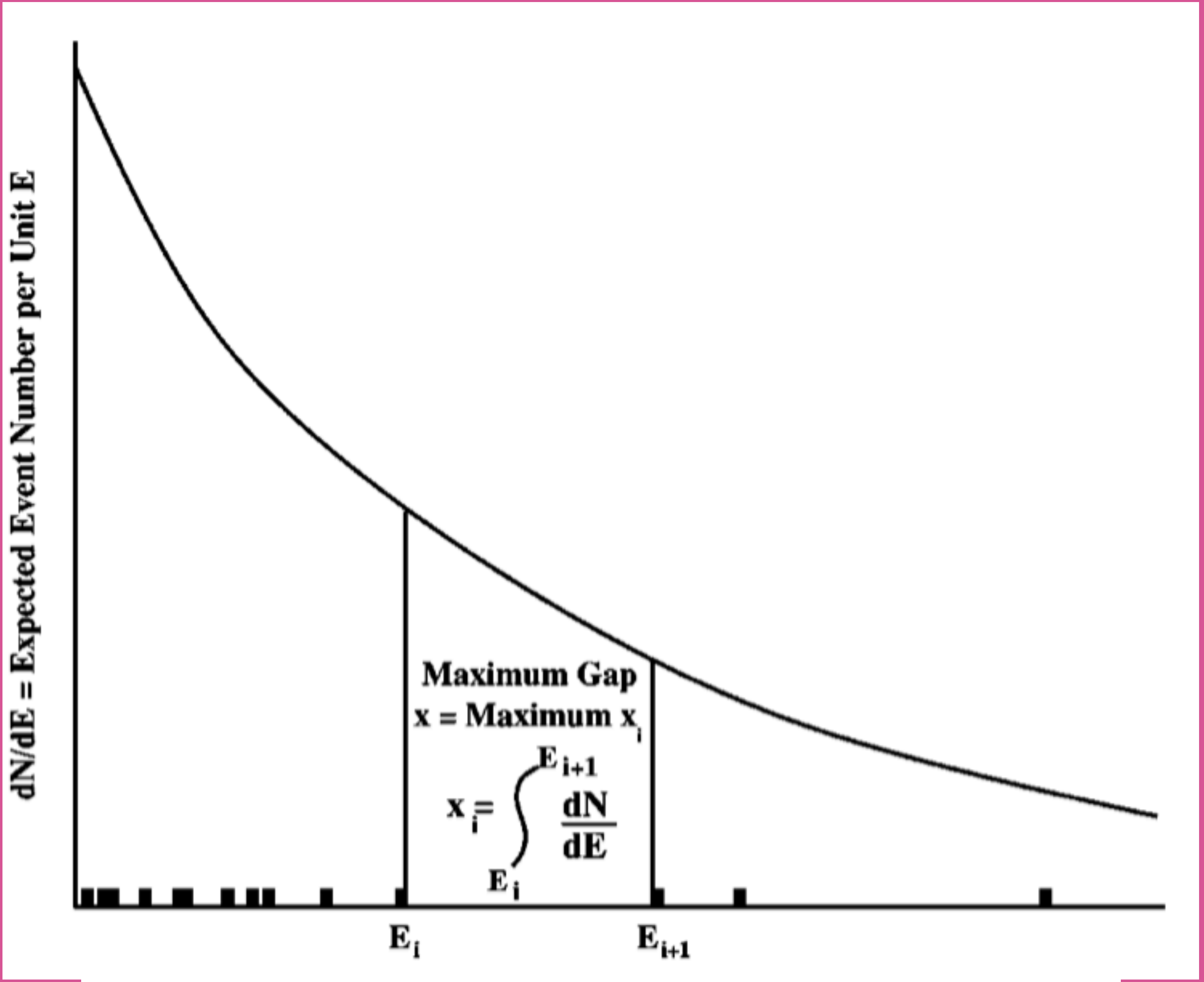
    - β-decays on electrodes creating small electron-only signals in the XENON1T ionisation-only search

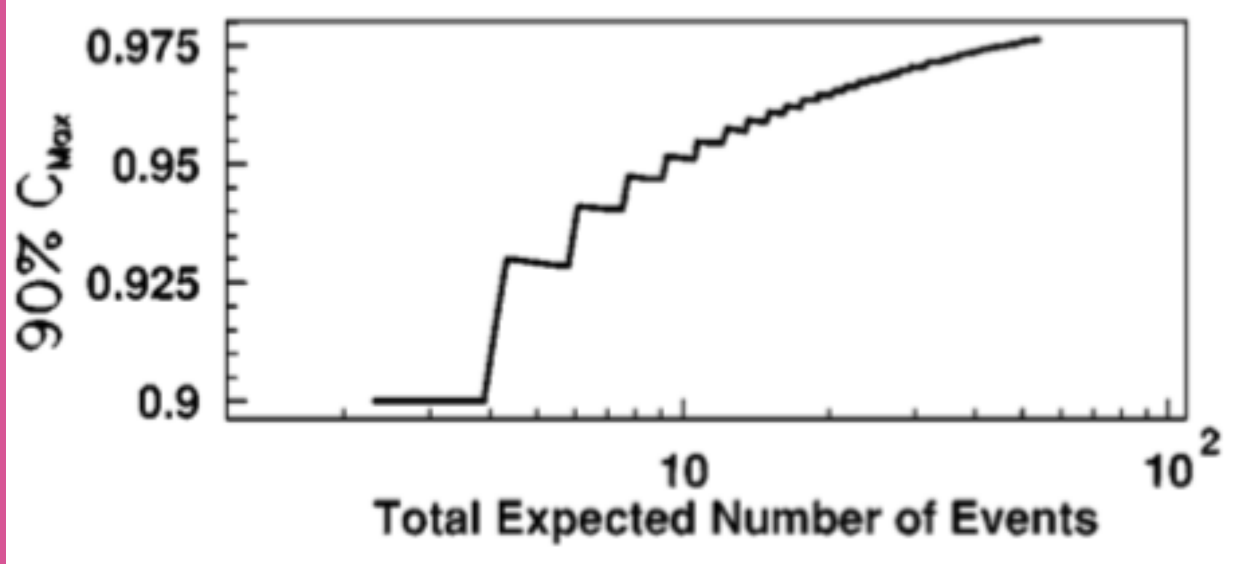


Abdelhameed, A. H. et al. (CRESST). First results from the CRESST-III low-mass dark matter program. Phys. Rev. D, 100(10):102002, 2019. doi: 10.1103/Phys- RevD.100.102002.

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



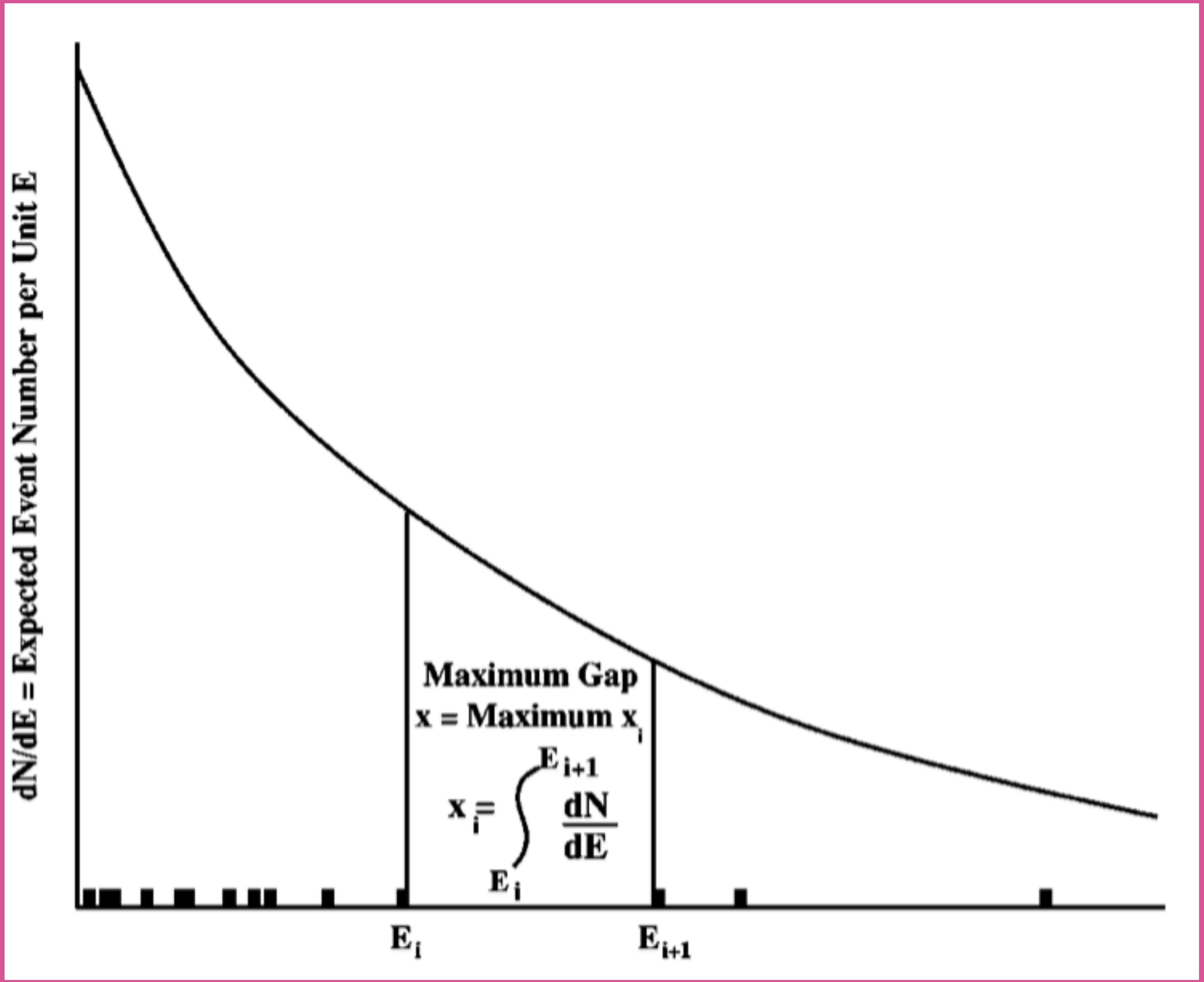


S. Yellin. Finding an upper limit in the presence of an unknown background. Physical Review D, 66(3), Aug 2002. ISSN 1089-4918. doi: 10.1103/physrevd.66.032005.

UNKNOWN BACKGROUNDS AND UNCERTAIN SIGNAL

THE CHALLENGE WITH MAX-GAP
COURTESY OF JELLE AALBERS

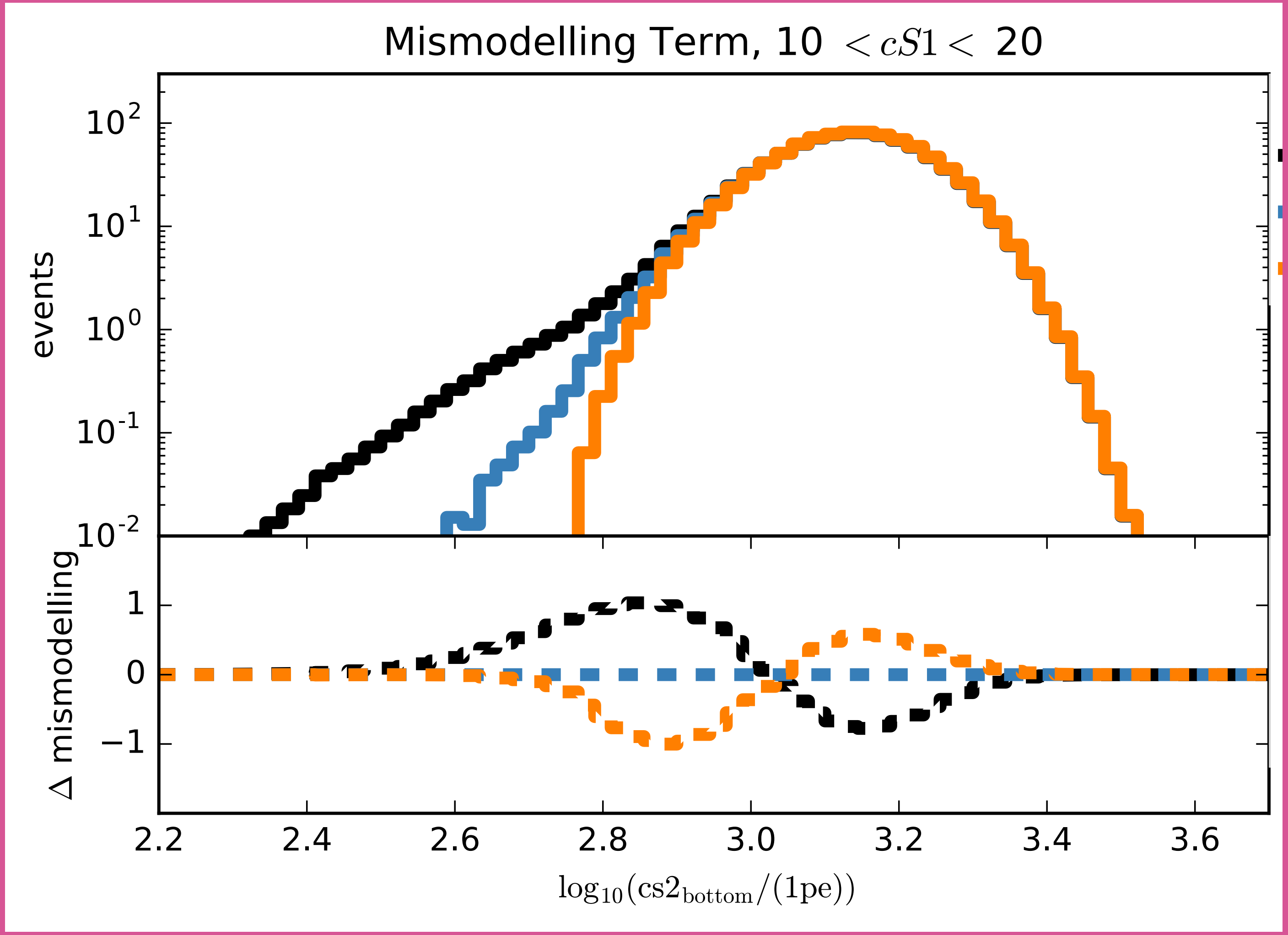
- If the signal model is also unknown, the optimum interval method becomes more challenging, as it relies on knowing the precise distribution of the signal
- If your model over- or under-estimates a signal tail, for example, your maximum gap will be biased towards the region you underestimate your signal in (if there is a signal, mind)
- This is primarily a challenge if you're using the optimum interval method with a large (100-1000s) number of events



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.

ALLOWING FOR UNKNOWN TAILS: THE SAFEGUARD

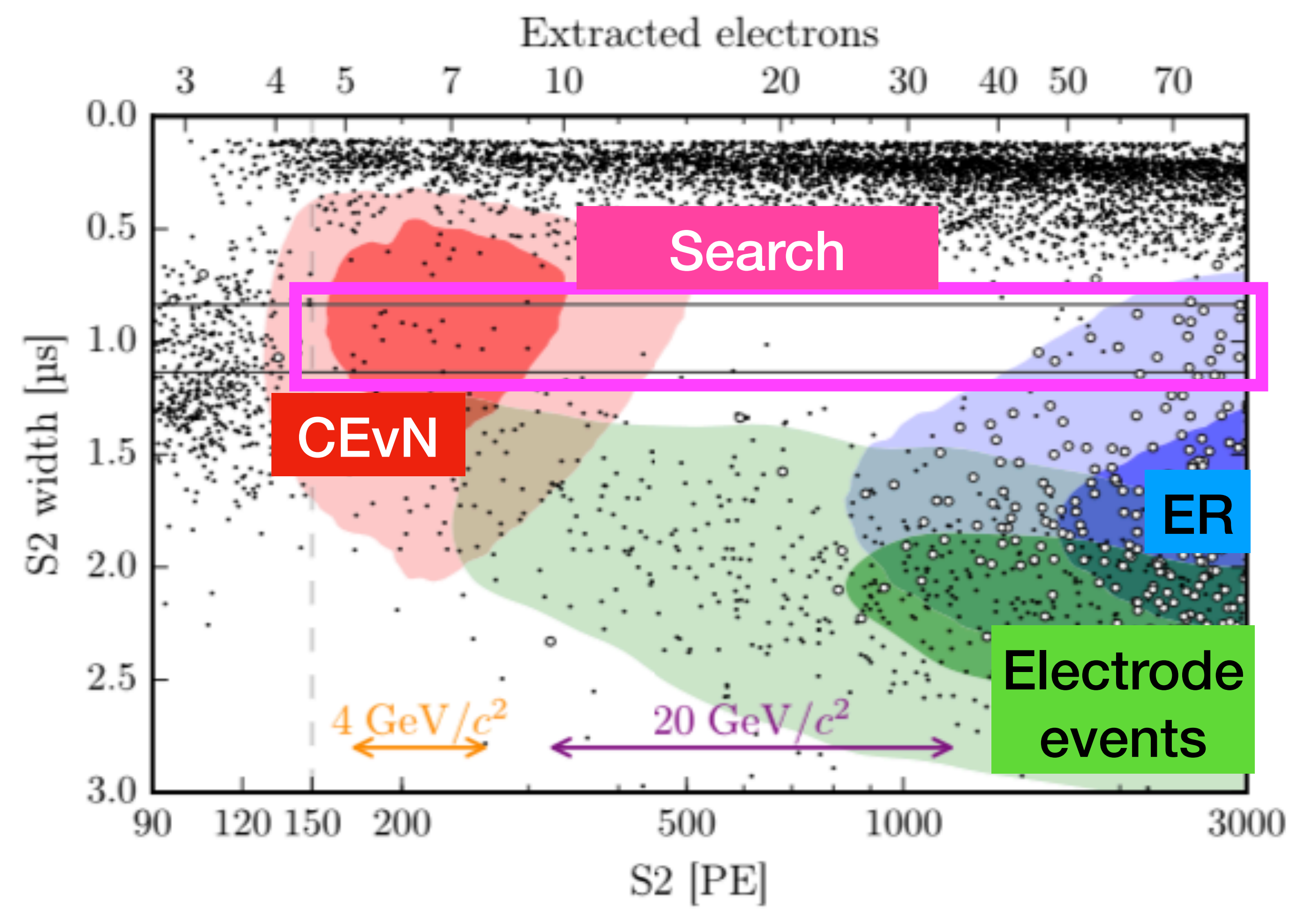
- If a significant background in the signal region comes from the tail of a larger background component, it is crucial that this tail is not over- or under-estimated.
- XENON1T used a construct similar to one employed in ATLAS, including a signal-like contamination in the background model
- This parameter was included in the final profiled likelihood, constrained by also including the ER calibration datasets.

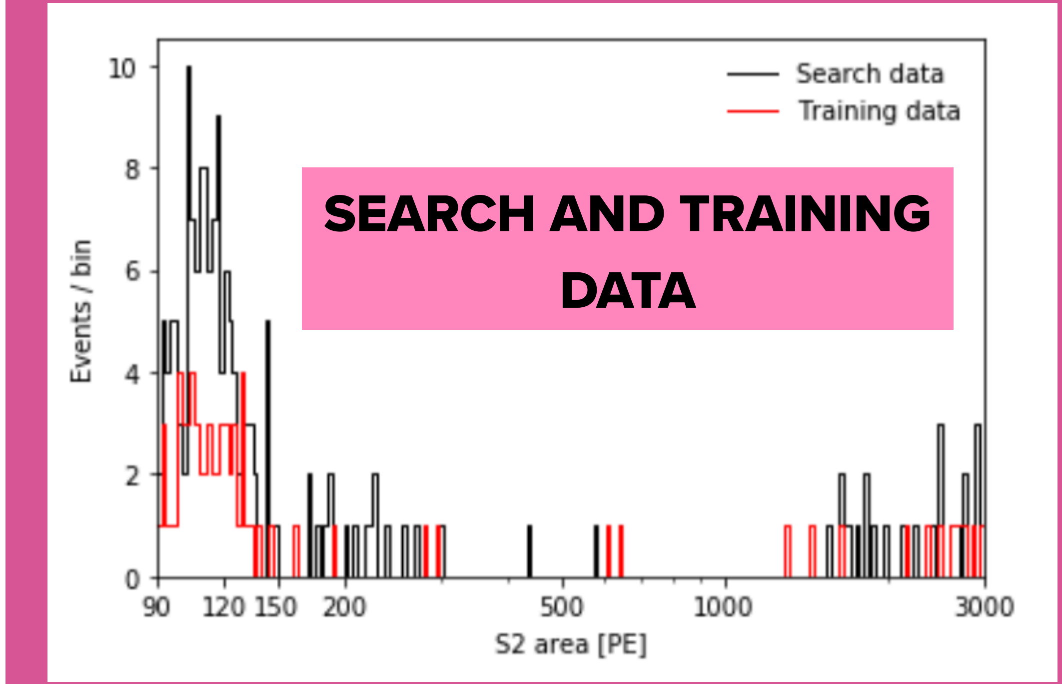


N. Priel et al. A model independent safeguard against background mismodeling for statistical inference. 2017(05):013–013, may 2017. doi: 10.1088/1475-7516/2017/05/013.

UNKNOWN BACKGROUNDS AND UNCERTAIN SIGNAL

- Not demanding a scintillation signal significantly lowers the energy threshold for liquid xenon TPCs
    - Backgrounds at this low energy are only partially characterised,
    - Signal model has significant uncertainties,
    - and the number of events are relatively high
- Instead, 30% of the data was chosen as a training set, used to select the region that yielded the best limit on the training data and disallowing it to extend beyond the 95th





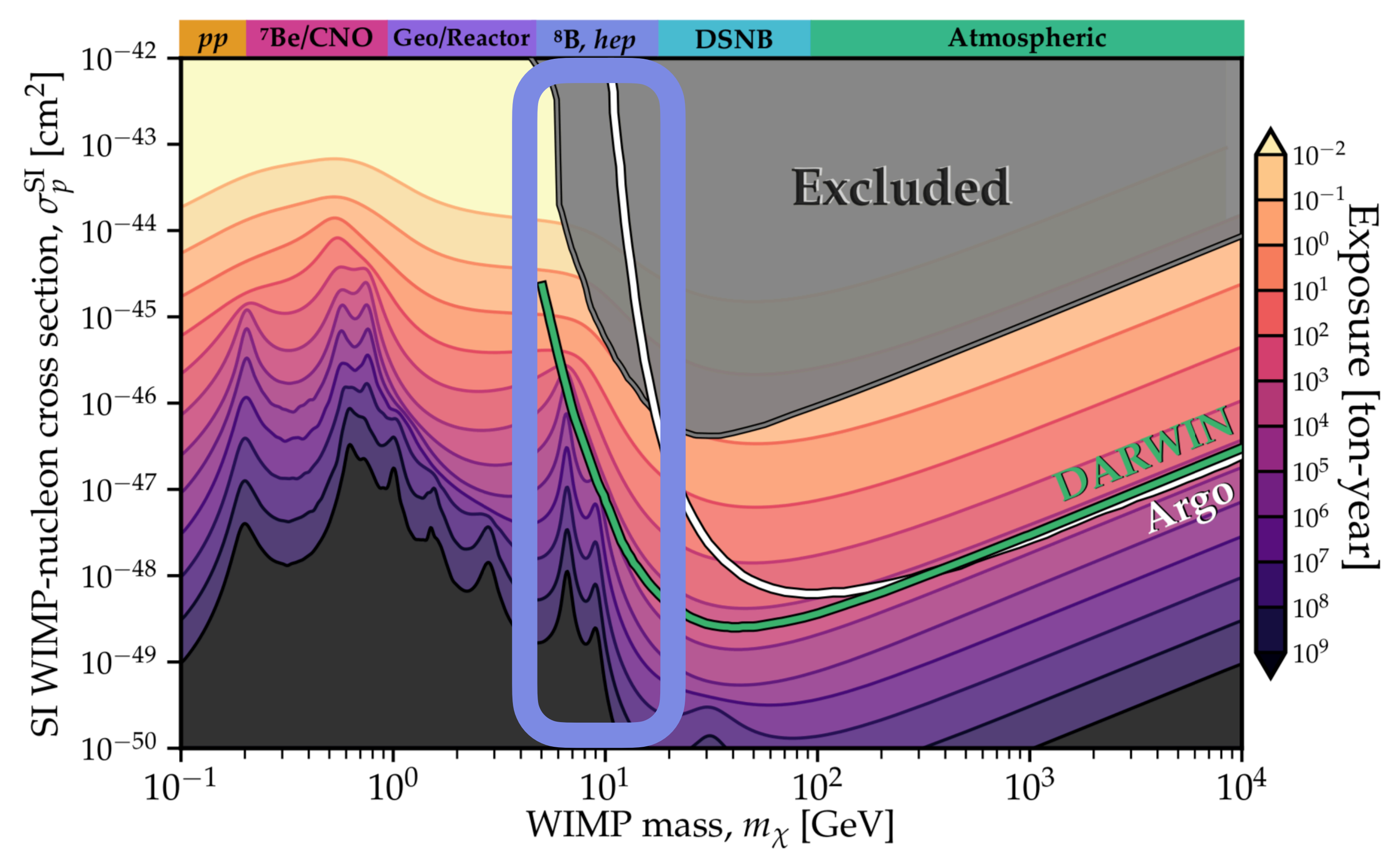
E. Aprile et. al (XENON). Light Dark Matter Search with Ionization Signals in XENON1T. Phys. Rev. Lett., 123(25):251801, 2019. doi: 10.1103/PhysRevLett.123.251801.

A FINAL BACKGROUND

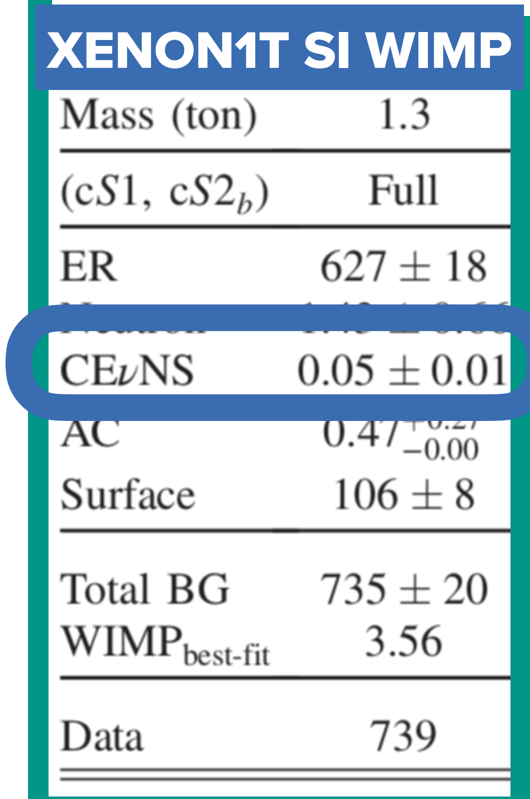
SOLAR NEUTRINOS: BACKGROUND AND SIGNAL

- Neutrinos tick all the boxes of the WIMP acronym, and astrophysical neutrinos will yield recoils indistinguishable from dark matter scattering
    - Spectral information still helps if your exposure is big enough, directional information is lost in most direct detection experiments.
- The first spectrum expected to be observed is coherent elastic scattering of solar ^{8}B neutrinos, which have a recoil spectrum nearly indistinguishable from a 6 GeV/c^2 WIMP with cross-section ~2 10^{-45} cm^2
    - Right at the lower threshold of the signals the standard WIMP search reached
- For the XENON1T spin-independent WIMP search, the expected neutrino rate was tiny

O'Hare C. A. J. "Can we overcome the neutrino floor at high masses?"
Phys.Rev.D 102 (2020) 6, 063024, DOI: 10.1103/PhysRevD.102.063024



XENON1T SI WIMP



Mass (ton)	1.3
($cS1$, $cS2_b$)	Full
ER	627 ± 18
[illegible]	[illegible]
CEνNS	0.05 ± 0.01
AC	$0.47^{+0.27}_{-0.00}$
Surface	106 ± 8
Total BG	735 ± 20
WIMP$_{\text{best-fit}}$	3.56
Data	739

AT THE NEUTRINO FLOOR, THE SENSITIVITY CHANGES AS

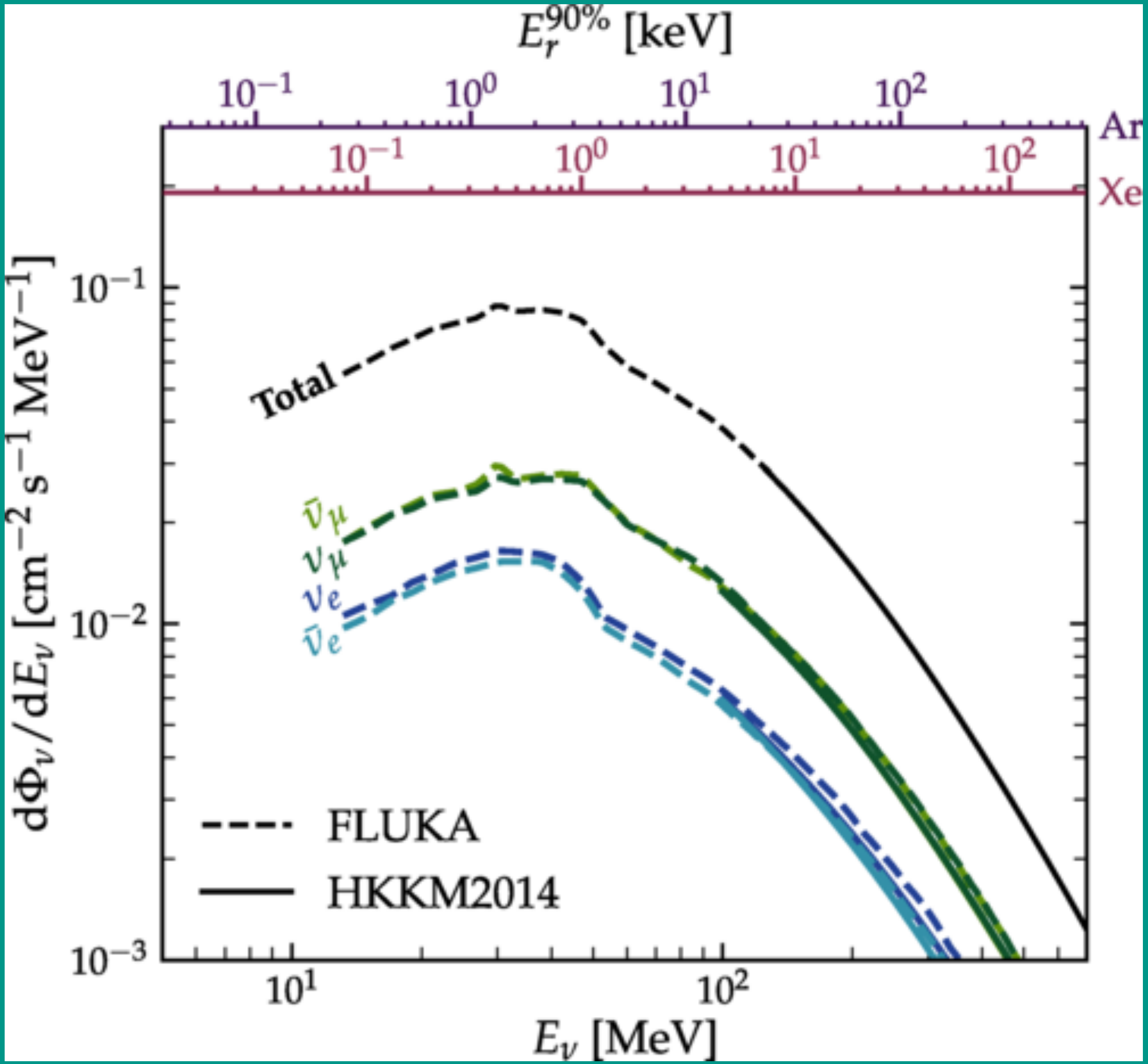
$$\sigma \propto \sqrt{\frac{1 + N\delta\phi^2}{N}}$$

WHERE N IS THE TOTAL NUMBER OF NEUTRINOS AND $\delta\phi$ IS THE RELATIVE UNCERTAINTY ON THE NEUTRINO EXPECTATION

SOLAR NEUTRINOS: BACKGROUND AND SIGNAL

- **Towards the neutrino floor/fog, the systematic uncertainty on the neutrino signal will dominate the total uncertainty of constraints**
  - **Flux uncertainties between 1-50%**
  - **Shape of the neutrino spectrum**
  - **Uncertainties in the detector response**
- **At the moment, these backgrounds are typically only modelled as a rate uncertainty (if anything), but the precise shape would be crucial for high-exposure searches**
- **Combined fits of experimental results can take advantage of that the detector target changes what WIMP spectrum the neutrinos mimic (in particular for spin-dependent interactions)**

ATMOSPHERIC NEUTRINO UNCERTAINTIES:



O'Hare C. A. J. "Can we overcome the neutrino floor at high masses?"
Phys.Rev.D 102 (2020) 6, 063024, DOI: 10.1103/PhysRevD.102.063024

F. Ruppin, J. Billard, E. Figueroa- Feliciano, and L. Strigari. Complementarity of dark matter detectors in light of the neutrino background. Phys. Rev. D, 90:083510, Oct 2014. doi: 10.1103/PhysRevD.90.083510. URL https://link.aps.org/doi/10.1103/PhysRevD.90.083510.

?S

&THANKS!