A search for light dark matter in XENON10 data

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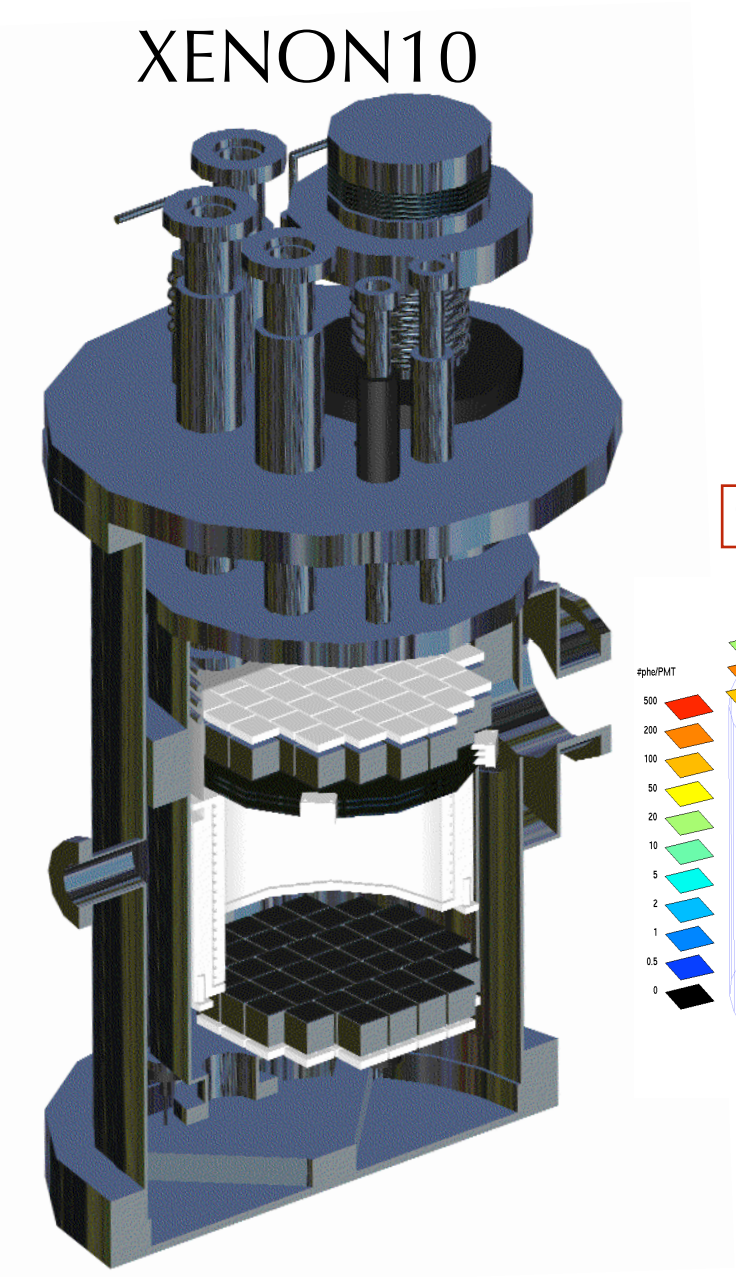
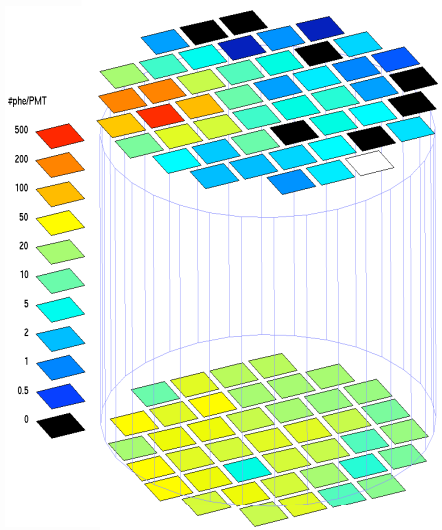
12th International Conference on Topics in Astroparticle and Underground Physics

New analysis of old (previously unreported) data

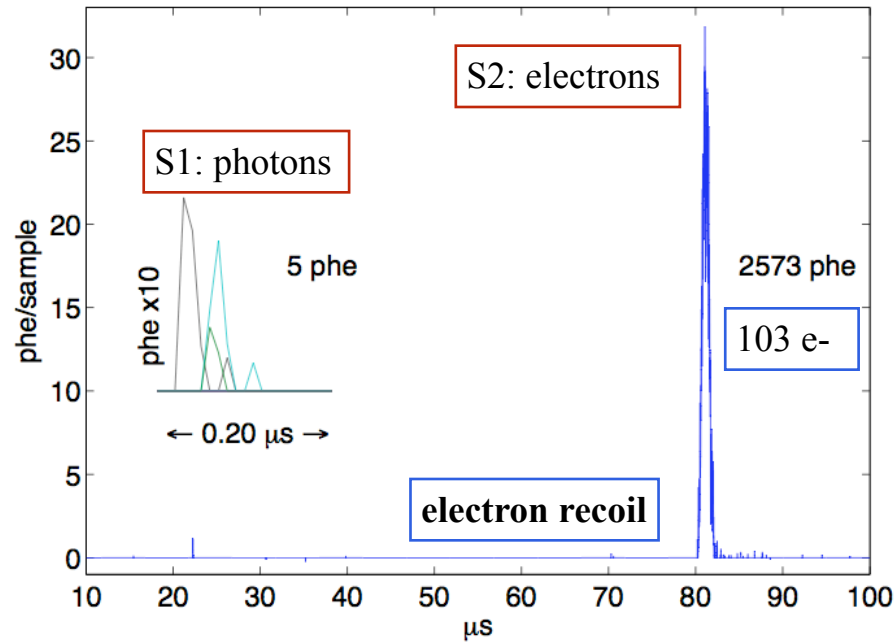
XENON10

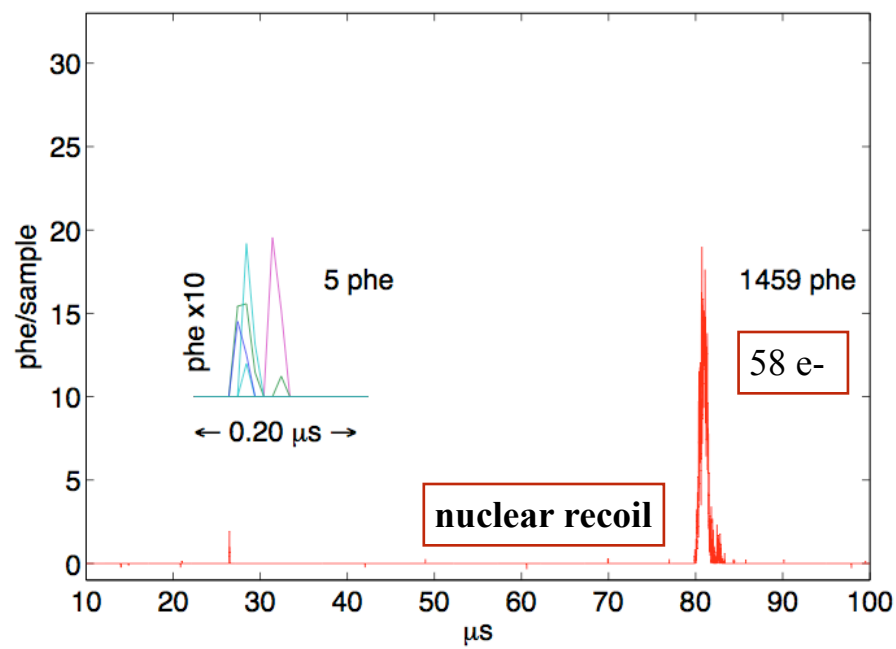


S2 hit pattern => (x,y)



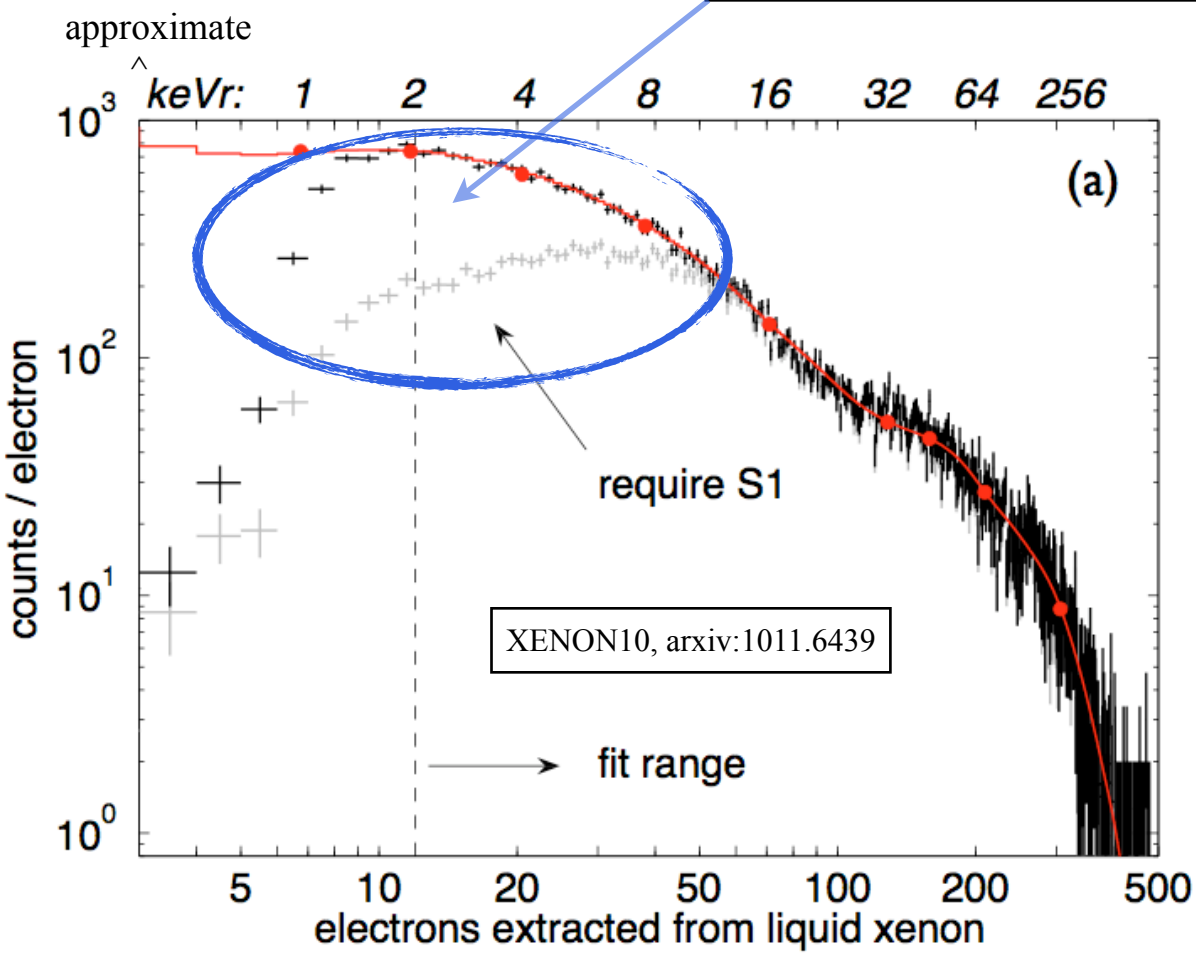
$t_{S2} - t_{S1} \Rightarrow z$





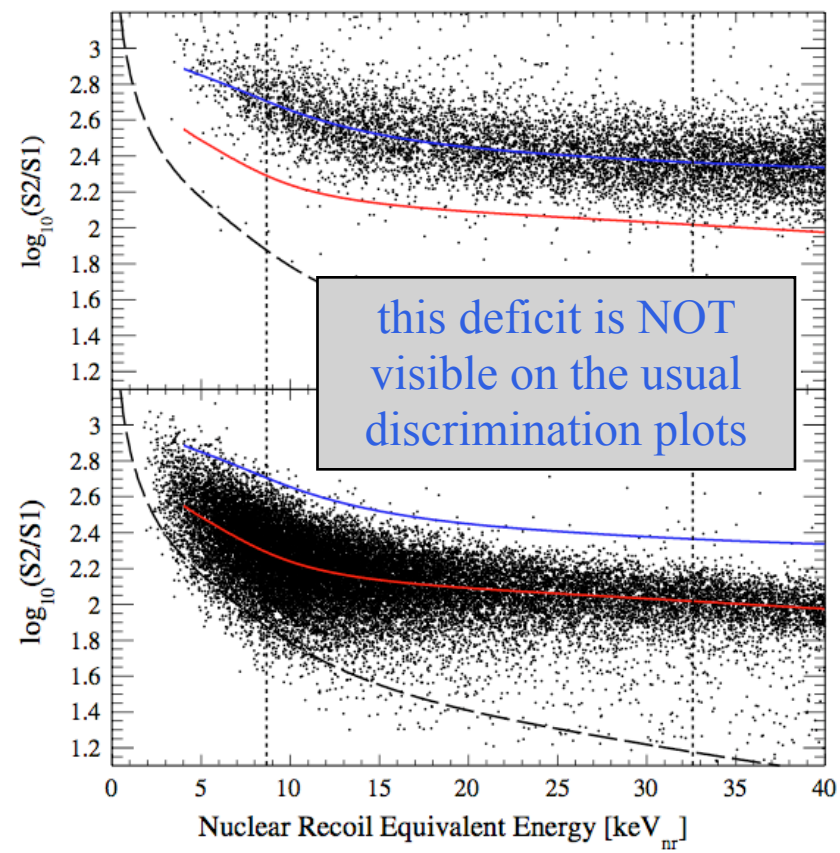
Motivation for this work

"wasted" nuclear recoil response



XENON10, arxiv:1011.6439

XENON100, Phys. Rev. Lett. **105** 131302 (2011)

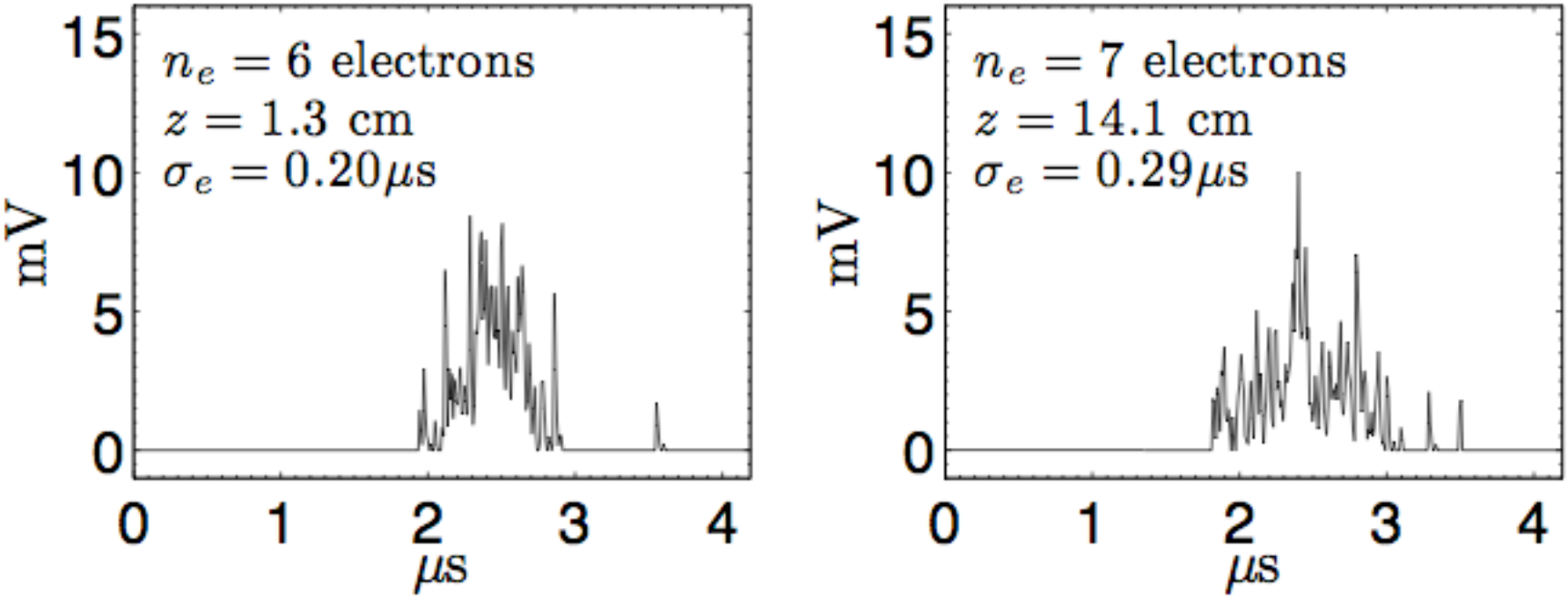


this deficit is NOT visible on the usual discrimination plots

nuclear recoil calibration data in XENON10

Motivation II. electron signal is robust

Typical low-energy single-scatter nuclear recoil signals in XENON10



nuclear recoil energy E_{nr}	quanta created in xenon (photon or electron)	quanta in photomultipliers
1.4 keV (S1) 1.4 keV (S2)	5 photons 5 electrons	0 photoelectrons 125 photoelectrons
8 keV (S1) 8 keV (S2)	48 photons 34 electrons	4 photoelectrons 850 photoelectrons

Search for light dark matter: results

XENON10, Phys. Rev. Lett. **107** 051301 (2011)

- **electron (S2) signal only**
- No discrimination
- (x,y) vertex reconstruction
- minimal software selection

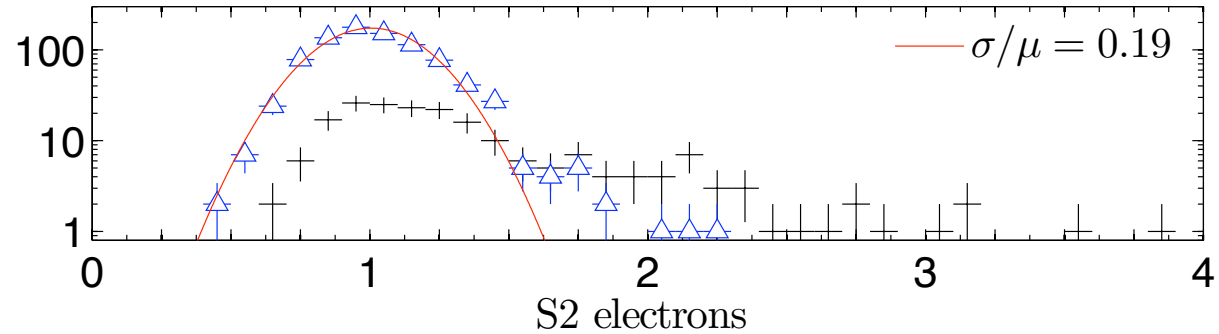
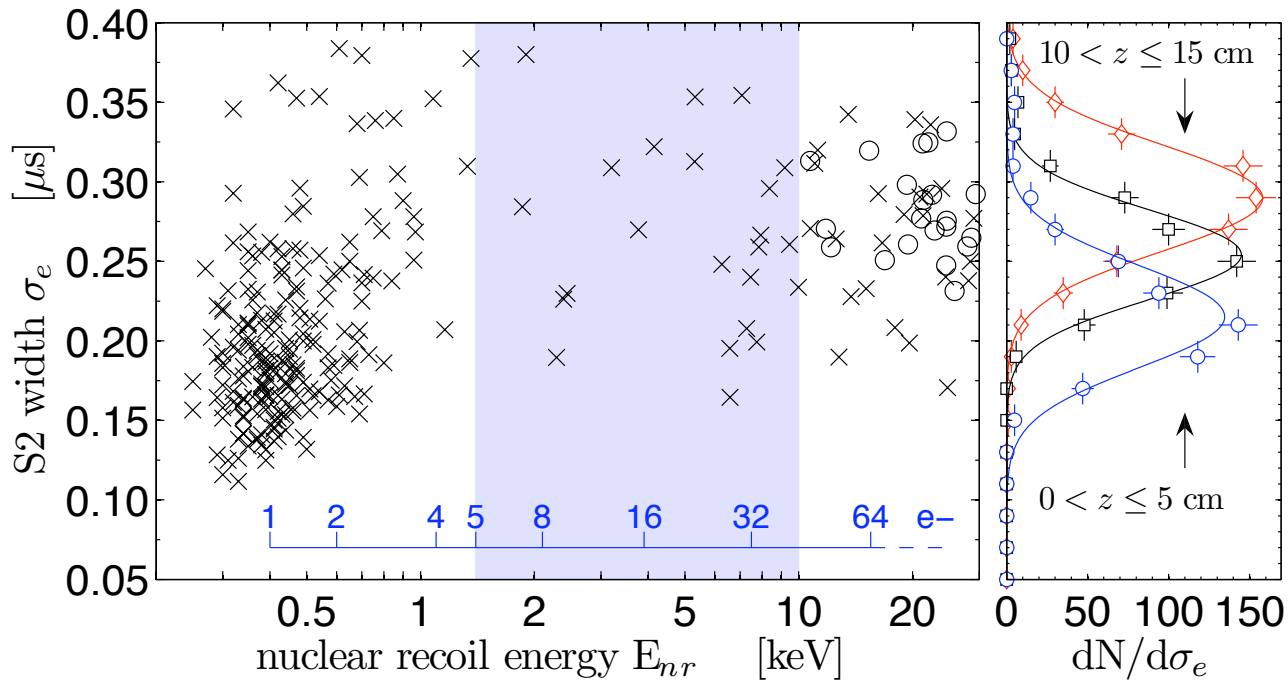


TABLE I. Summary of cuts applied to 15 kg days of dark matter search data, corresponding acceptance for nuclear recoils ε_c and number of events remaining in the range $1.4 < E_{nr} \leq 10$ keV.

	Cut description	ε_c	N_{evts}
1.	event localization $r < 3$ cm	1.00[a]	125
2.	signal-to-noise	>0.94	58
3.	single scatter (single $S2$)	>0.99	38
4.	$\pm 3\sigma$ nuclear recoil band	>0.99	23

[a]Limits effective target mass to 1.2 kg.



Aside: z coordinate from electron diffusion

Sorensen, Nucl. Instr. Meth. A **635** 41 (2011)

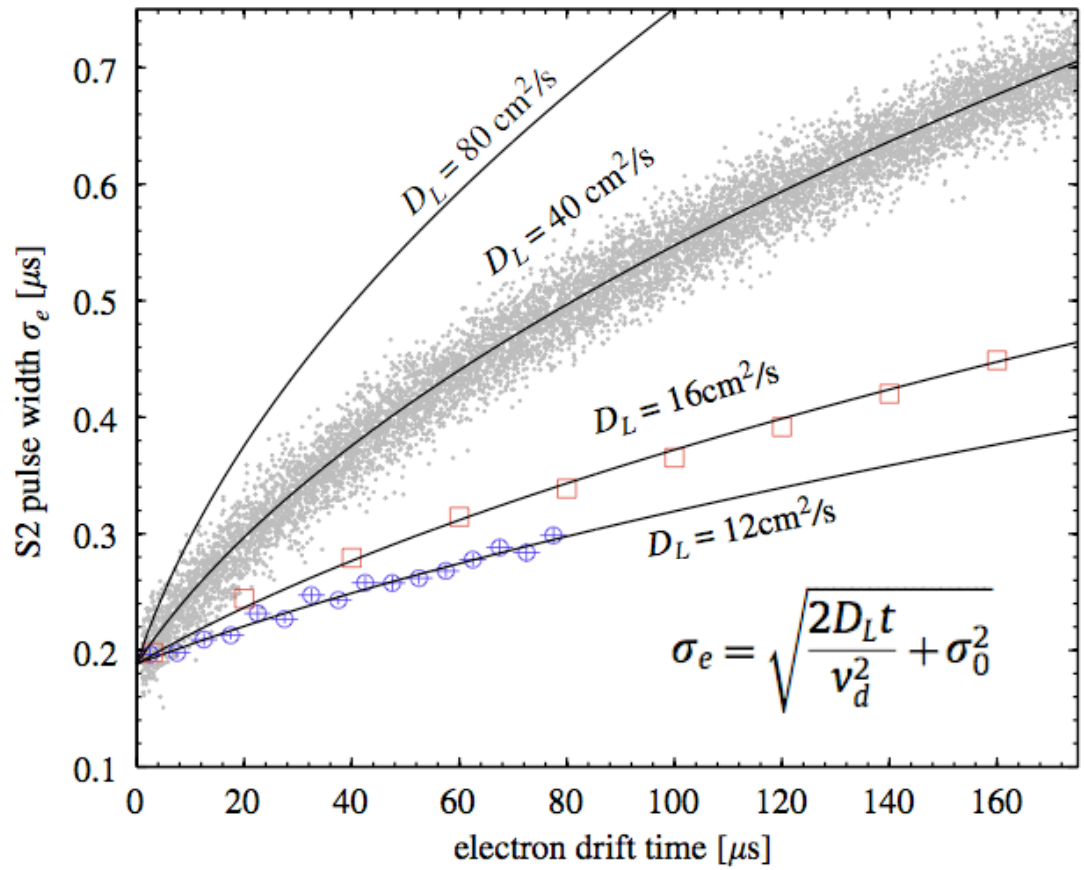
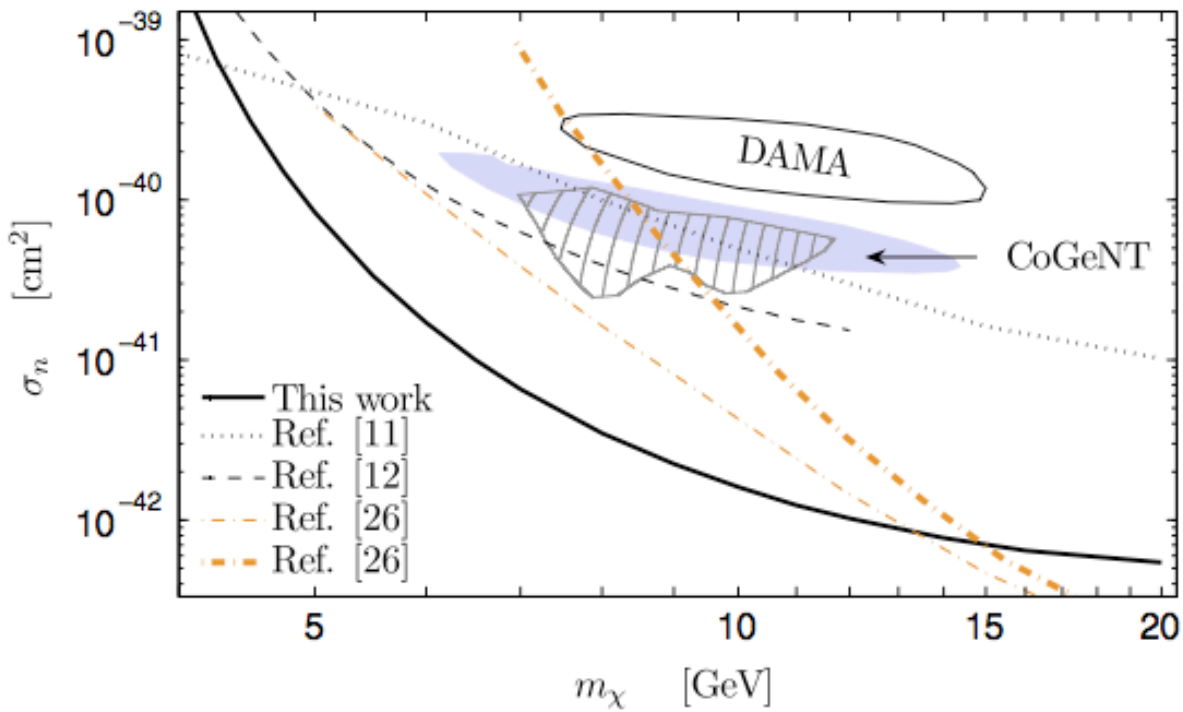


Fig. 2. Width of S2 pulses as a function of drift time through liquid xenon. Measurements from XENON10 [9] at E_d=730 V/cm and v_d=0.188 cm/µs (circles, 1σ error smaller than data points) and XENON100 [20] at E_d=530 V/cm and v_d=0.174 cm/µs (squares). The total drift distance was 15 and 30.6 cm, respectively. D_L was obtained from a fit of Eq. (5) in each case. The predicted width vs. drift time for two larger values of D_L are shown, assuming $\sigma_0 = 0.19$ µs and $v_d = 0.174$ cm/µs. A simulated distribution of events with Gaussian width $\sigma = 0.02$ µs is shown for D_L=40 cm^2/s.

XENON10 vanilla, elastic DM sensitivity

XENON10, Phys. Rev. Lett. **107** 051301 (2011)



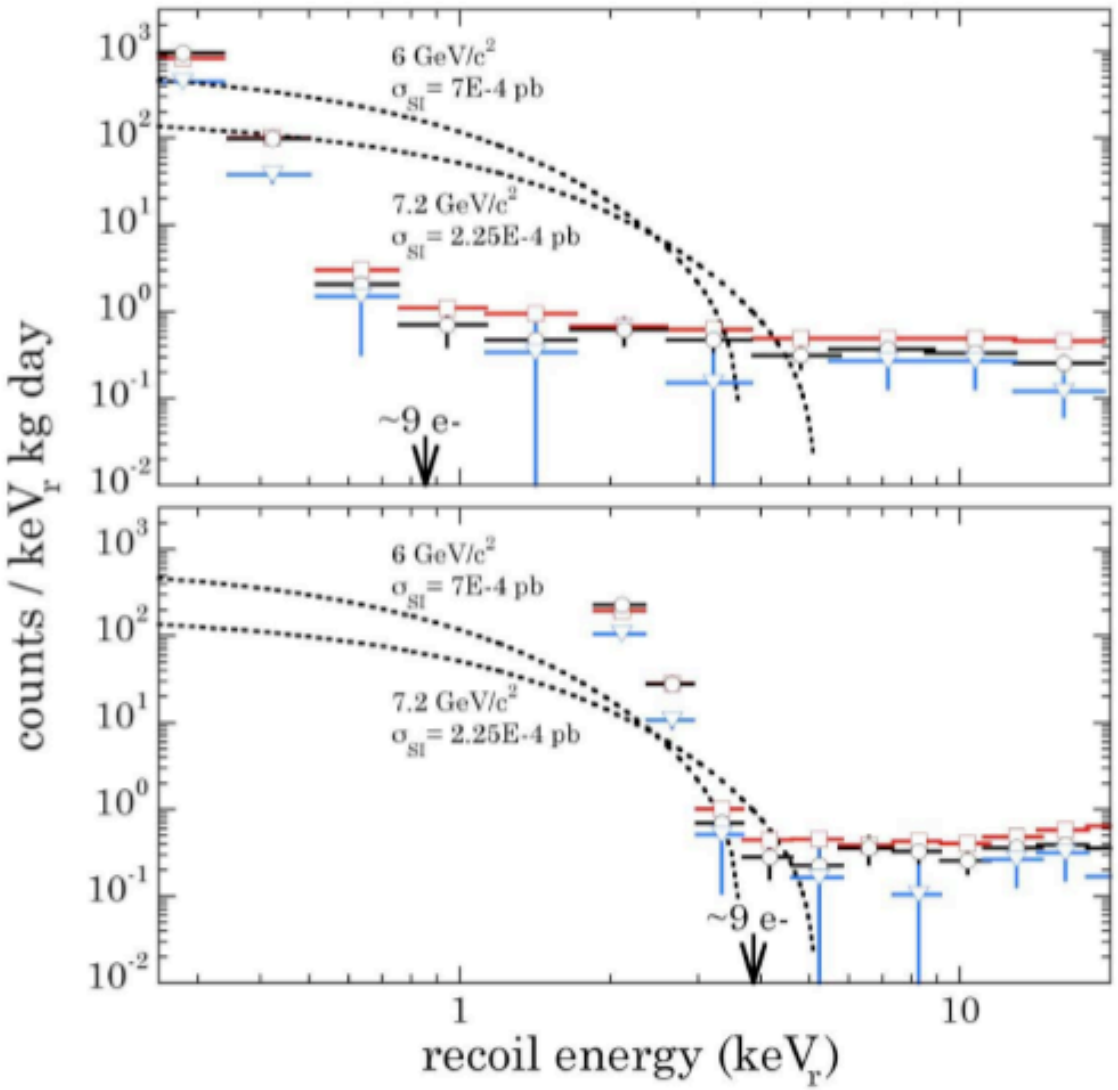
see also e.g.

Fox, Liu & Weiner, Phys. Rev. D **83** 103514 (2011)

FIG. 3 (color online). Curves indicate 90% C.L. exclusion limits on spin-independent σ_n for elastic dark matter scattering, obtained by CDMS (dotted [11], and dashed [12]) and XENON100 (dash-dot [23]). The region consistent with assumption of a positive detection by CoGeNT is shown (hatched) [2], and (shaded) [4]; the latter assumes a 30% exponential background. Also shown is the 3σ allowed region for the DAMA annual modulation signal (solid contour) [43].

Criticism of this result

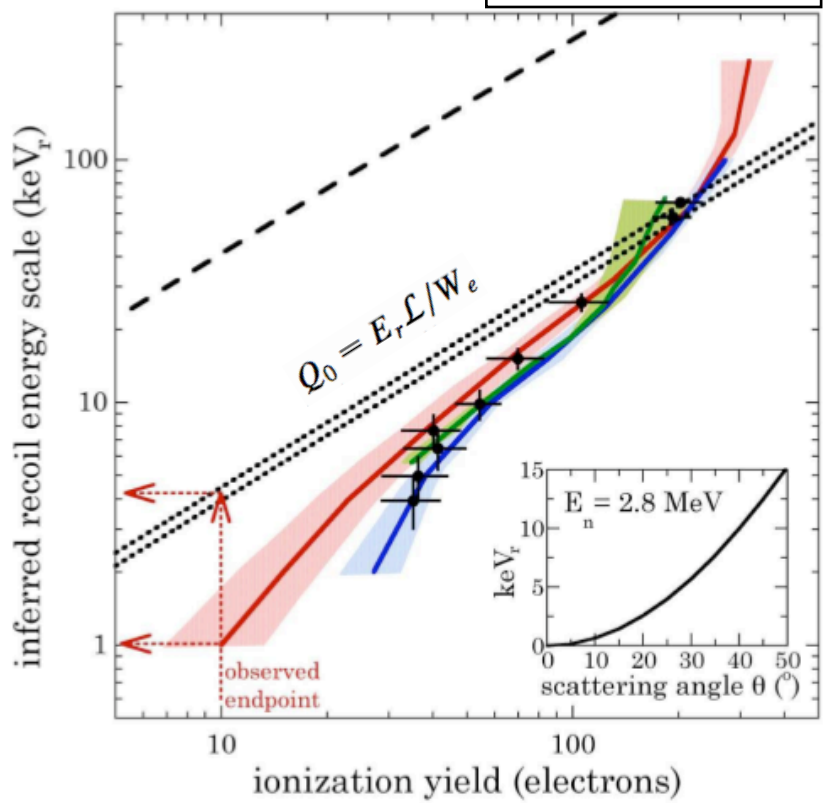
Collar, arxiv:1010.5187 with data from XENON10, arxiv:1011.6439



incorrect

^Interpretation of measurements in xenon

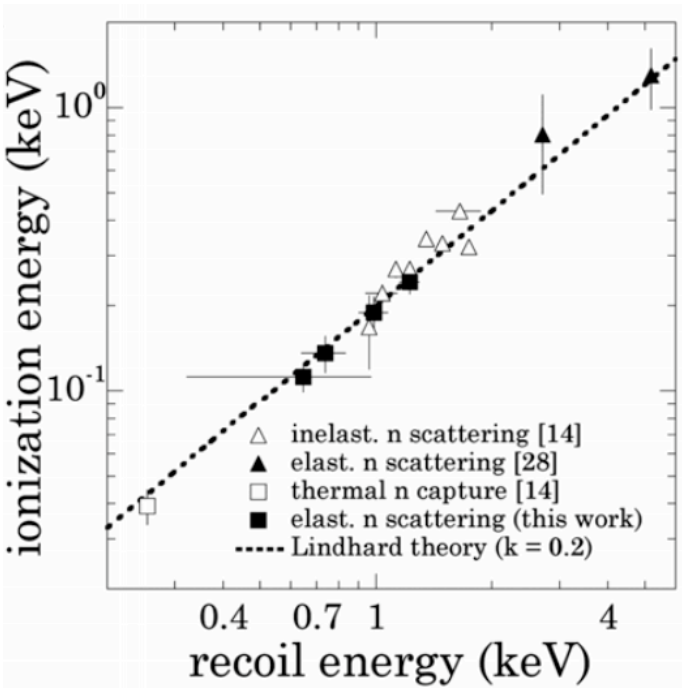
Collar, arxiv:1010.5187



dotted lines based on **incorrect** formalism from
Aprile *et al.* Phys Rev. Lett **97** 021302 (2006)

Nuclear recoil energy and Lindhard

Measurements in germanium



Barbeau, Collar and Tench, JCAP **09** 009 (2007)

Mat. Fys. Medd. Dan. Vid. Selsk. **33,** no. 10 (1963)

More precisely, for an incoming particle of energy E we ask for that part η of the total energy loss, E, which is ultimately given to electrons, and that part ν, which is ultimately left in atomic motion.

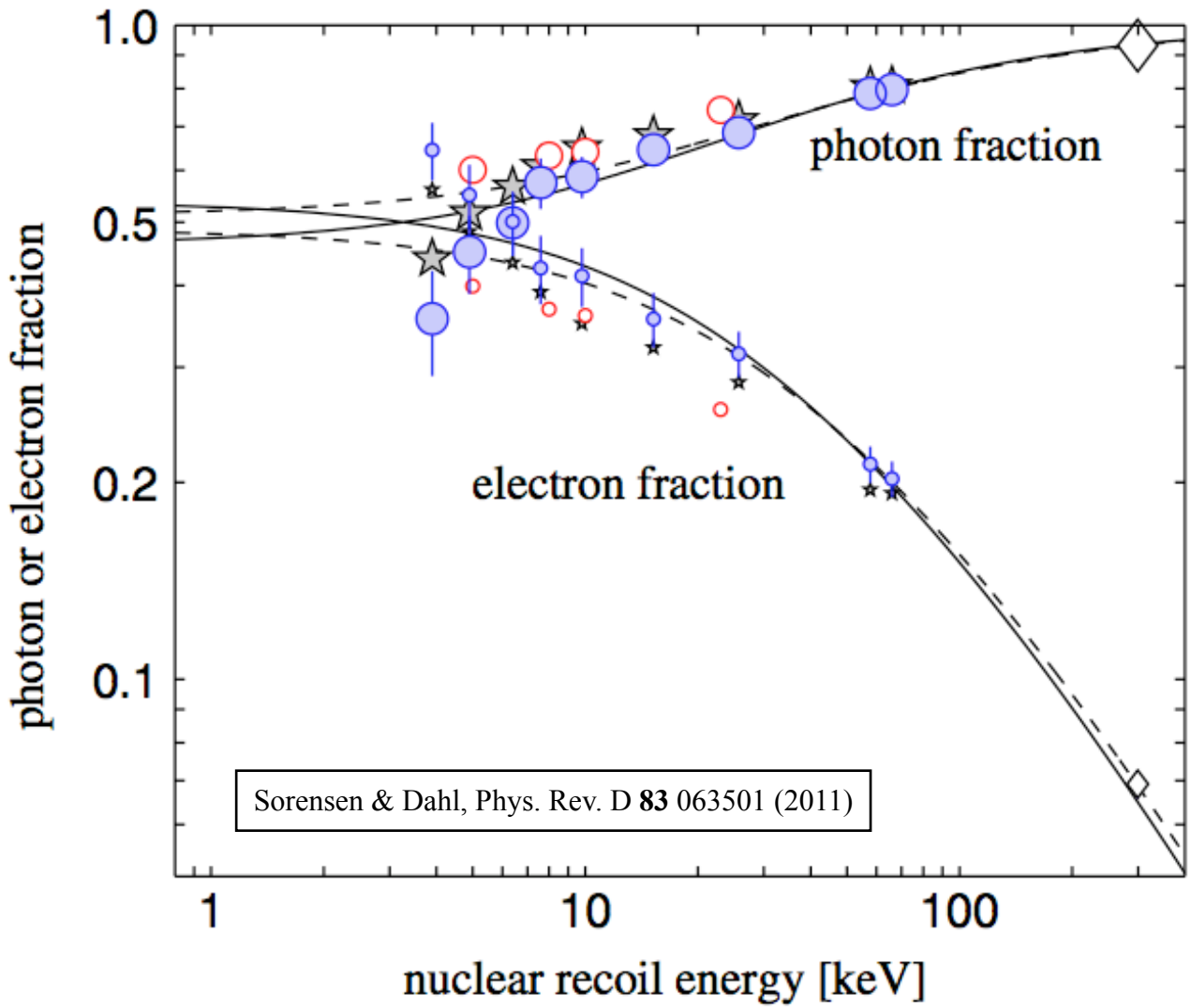
$$\left(\frac{d\varepsilon}{d\varrho}\right)_e \cdot \bar{\nu}'(\varepsilon) = \int_0^{\varepsilon^2} \frac{dt}{2\,t^{3/2}} \cdot f(t^{1/2}) \left\{ \bar{\nu}\left(\varepsilon - \frac{t}{\varepsilon}\right) - \bar{\nu}(\varepsilon) + \bar{\nu}\left(\frac{t}{\varepsilon}\right) \right\}$$

solve above integro-differential equation, obtain dashed curve shown at right

Lindhard theory should apply equally well to germanium and xenon (and other media)...

SO. what's the problem?

E_{nr} partitions into photons and electrons



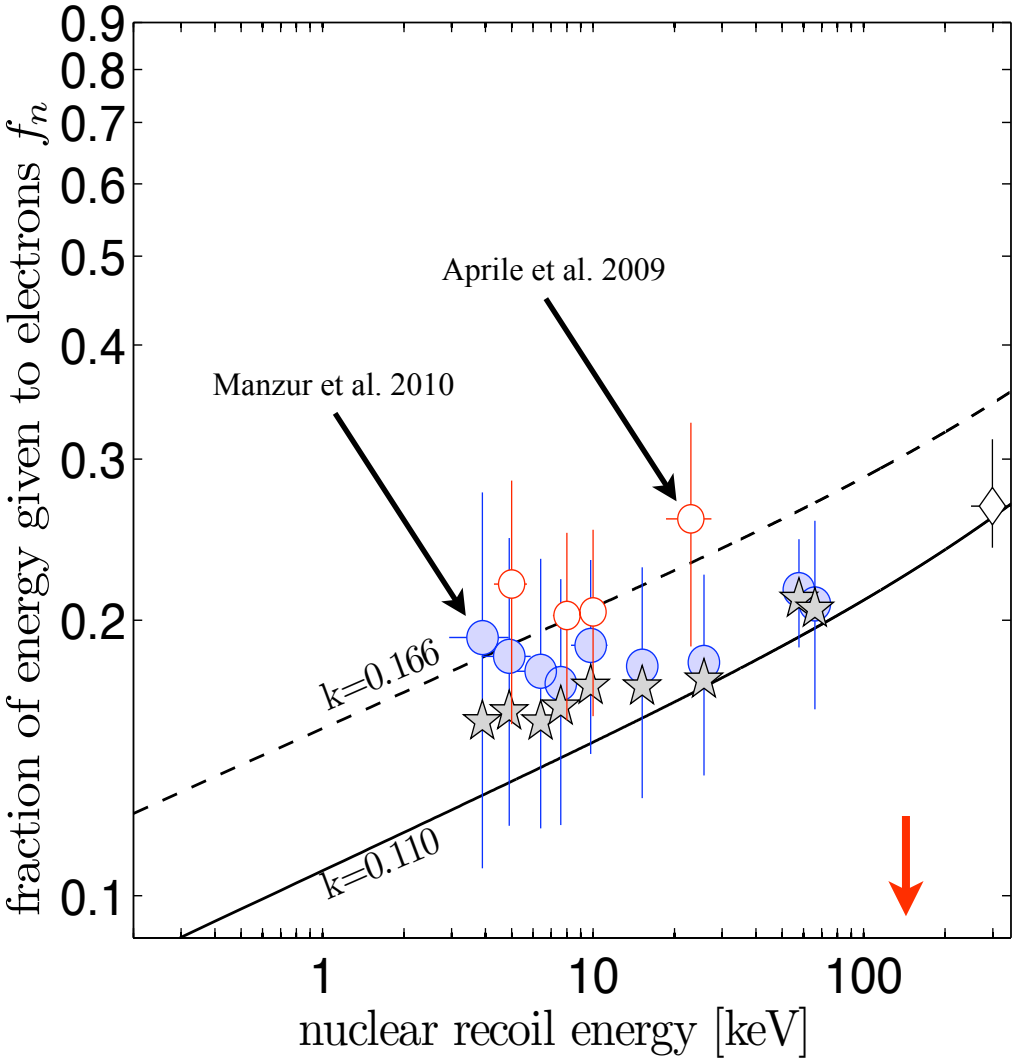
Lindhard theory applies to *"the total energy loss which is ultimately given to electrons"* i.e. the total number of quanta:

$$E_{\mathrm{nr}} = \epsilon(n_\gamma + n_e)/f_n$$

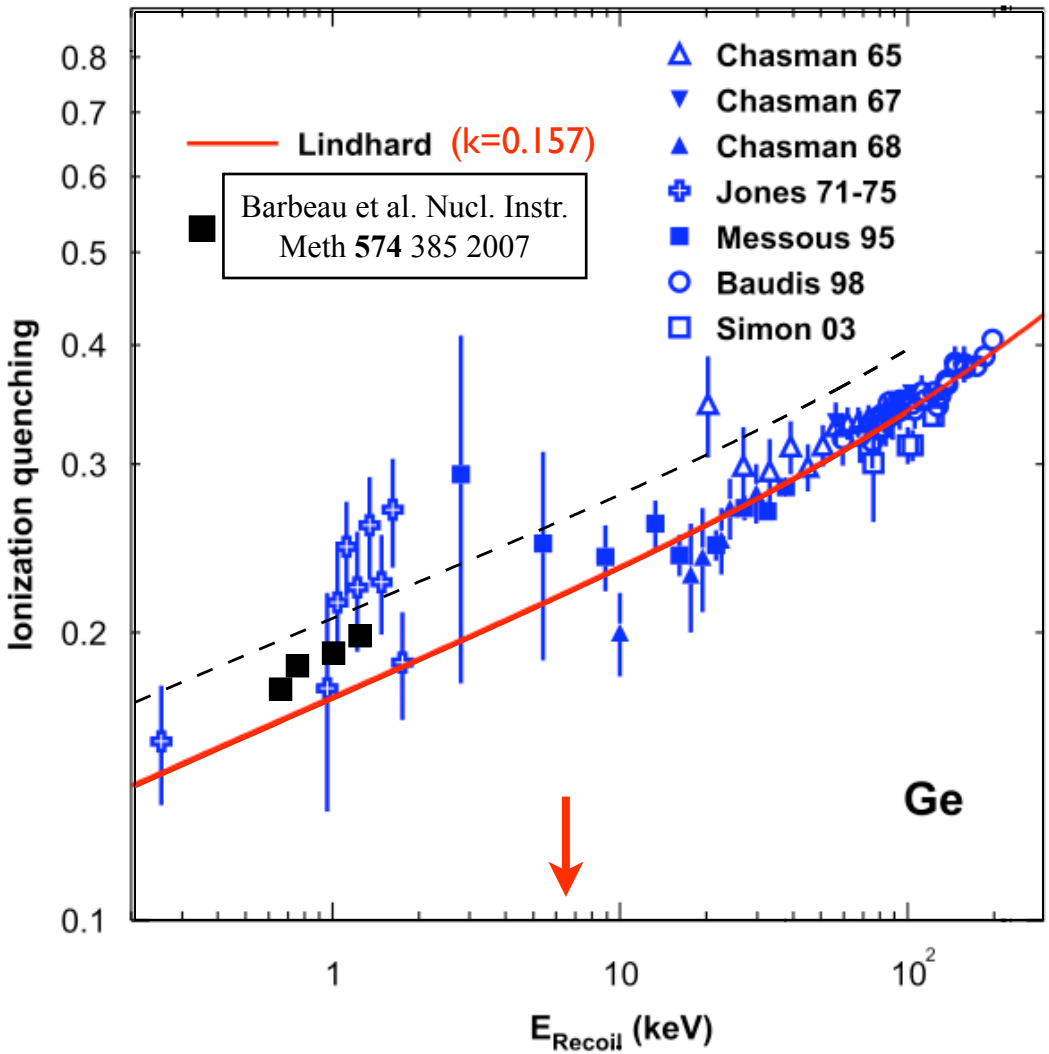
(in germanium, the above equation holds with n_γ=0)

Lindhard theory vs experiment

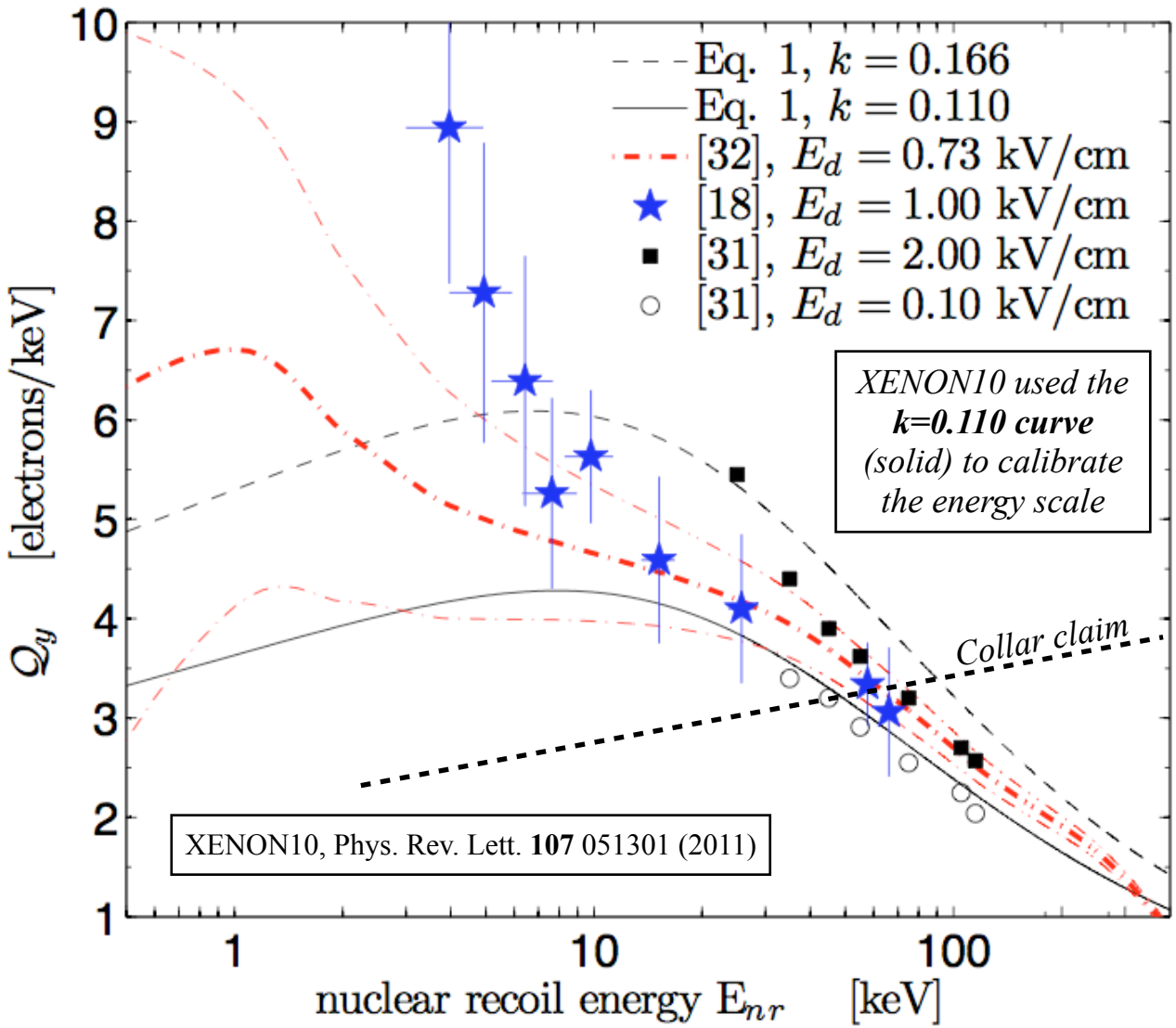
Sorensen and Dahl, Phys. Rev. D **83** 063501 (2011)



Benoit et al. Nucl. Instr. Meth **577** 558 (2007)



Ionization yield of liquid xenon



$$Q_y \equiv \frac{n_e}{E_{nr}} = \frac{1}{\xi}\ln(1+\xi)\frac{f_n(k)/\epsilon}{1+N_{ex}/N_i}$$

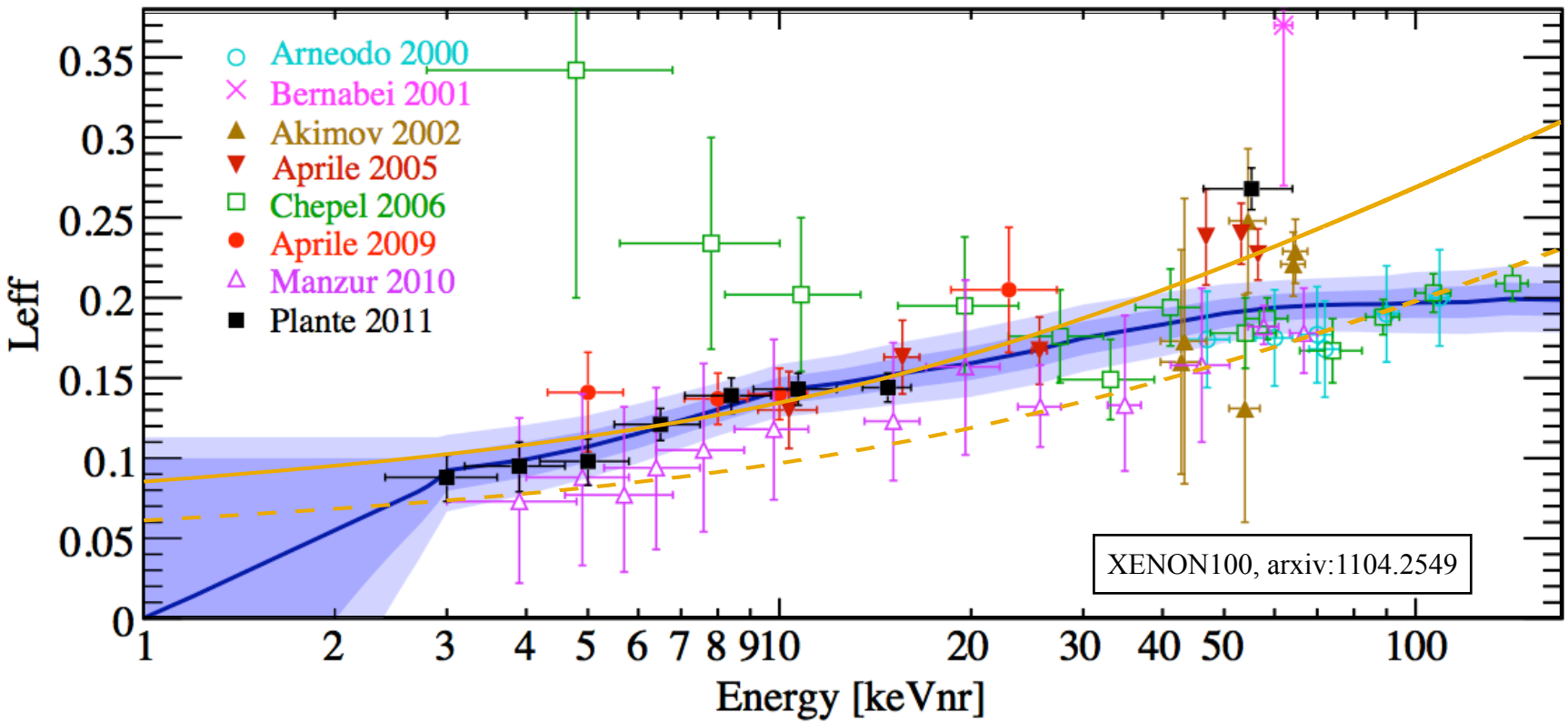
Sorensen & Dahl, Phys. Rev. D **83** 063501 (2011)

see also:

Bezrukov, Kahlhoefer & Lindner, arxiv: 1011.3990

$$E_{nr} = \epsilon(n_\gamma + n_e)/f_n$$

Experimental quantity of the year (X years running!)



Added: orange curves (solid and dashed) which correspond to Qy curves from previous slide. These were calculated from (assuming k=0.110):

$$\mathcal{L}_{\rm eff} = (1 - \mathcal{F}_e)\frac{f_n}{\epsilon}\frac{\alpha_1}{L_y}\frac{S_e}{S_n}$$

Sorensen & Dahl, Phys. Rev. D **83** 063501 (2011)

where $\mathbf{F_e}$ is the electron fraction shown in slide 11

Summary points

(0) (Vanilla) tension between XENON10 null result and CoGeNT/DAMA/CRESST

(a) based on theoretical prediction for energy scale

(b) clear need for measurements <3 keV

(1) Energy scaling soes not appear to solve this

(a) smart $ is on Lindhard theory

(b) L_{eff} and Q_y are coupled, once k is fixed

(c) in xenon, photon and electron fractions are key

(2) XENON100: O(x30) improvement in sensitivity to light dark matter (?)

(a) need to lower trigger threshold to ~1 electron

(b) reduced applied electric field should increase electron diffusion (for z coordinate reconstruction)

(3) LUX? coming soon - see talk by C. Hall, thursday parallel session.