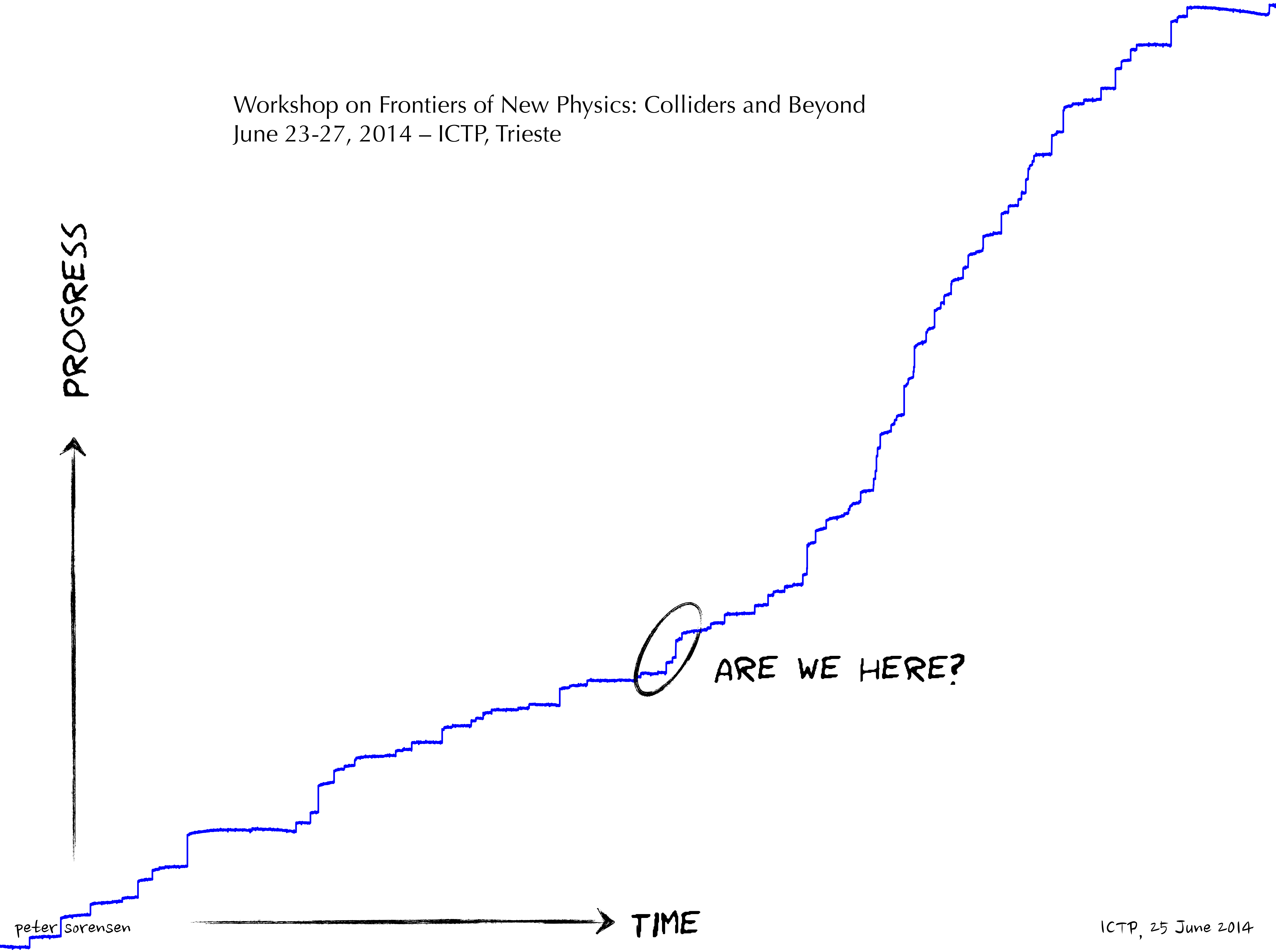
ARE WE READY FOR DIRECT DETECTION DISCOVERY?

Workshop on Frontiers of New Physics: Colliders and Beyond
June 23-27, 2014 – ICTP, Trieste



peter sorensen

ICTP, 25 June 2014

PREAMBLE

- LUX is on track to increase sensitivity by about x5
- several new LUX analyses in progress...

- LZ is on track to deliver direct detection sensitivity as exhibited in the Snowmass document arXiv:1310.8327

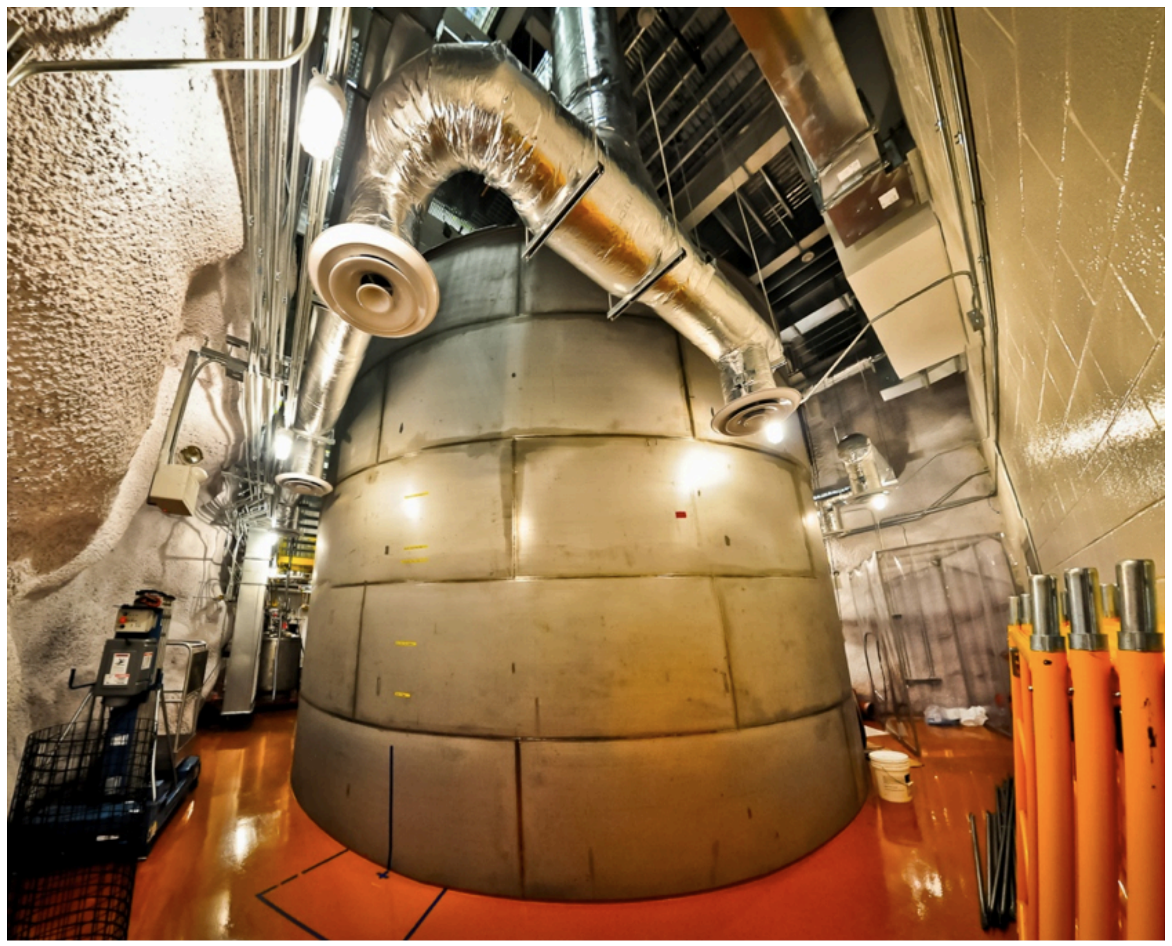
- This is not a LUX or LZ talk

BUT FOR CONTEXT, THE LUX/LZ INSTALLATION


somewhere in the Black Hills of South Dakota: SURF

- Generic DM signal expectation is O(keV) energy deposition
- Interaction rate unknown
- Control and understanding of backgrounds is paramount

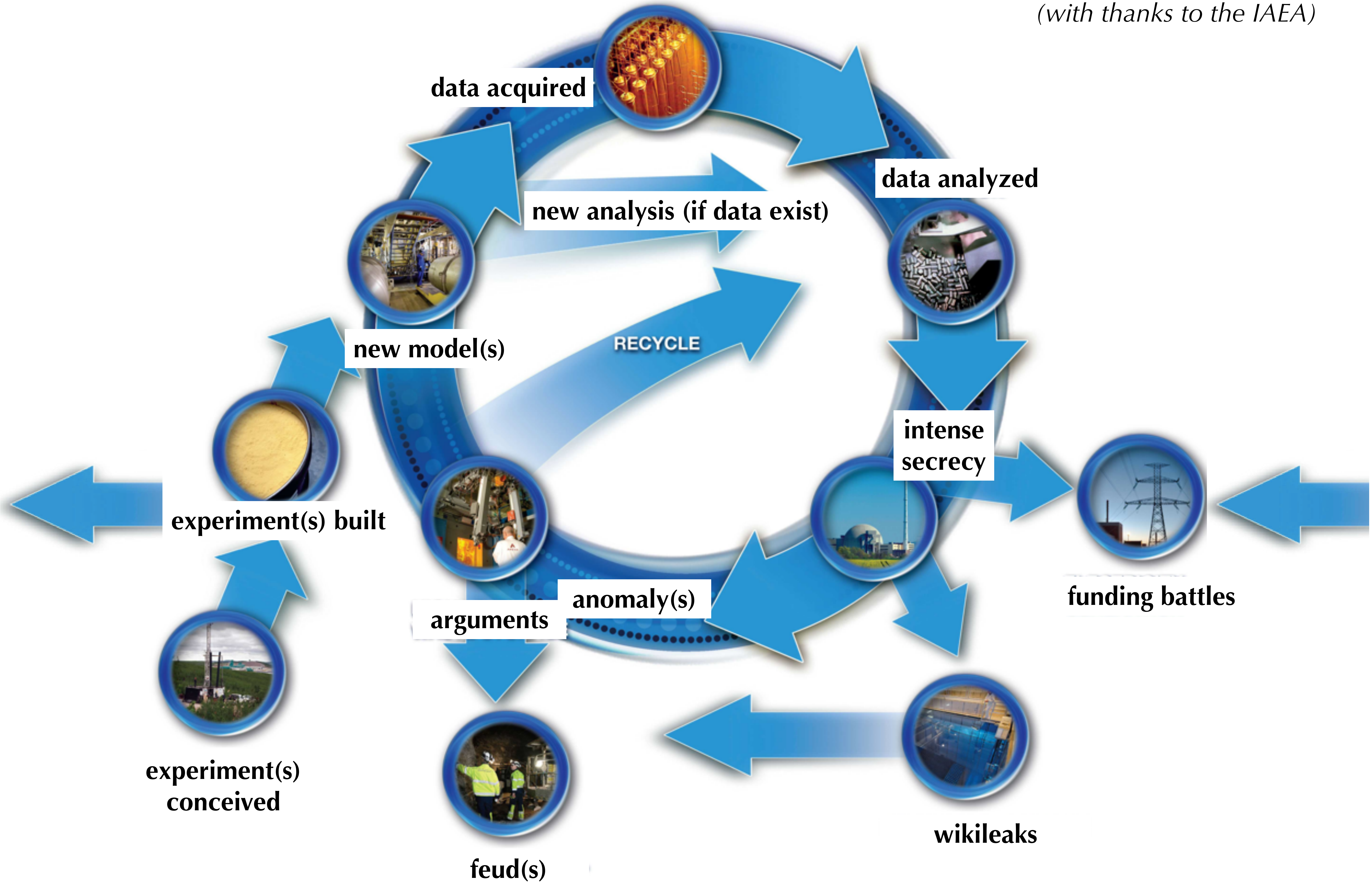
1492 meters below (4300 mwe)



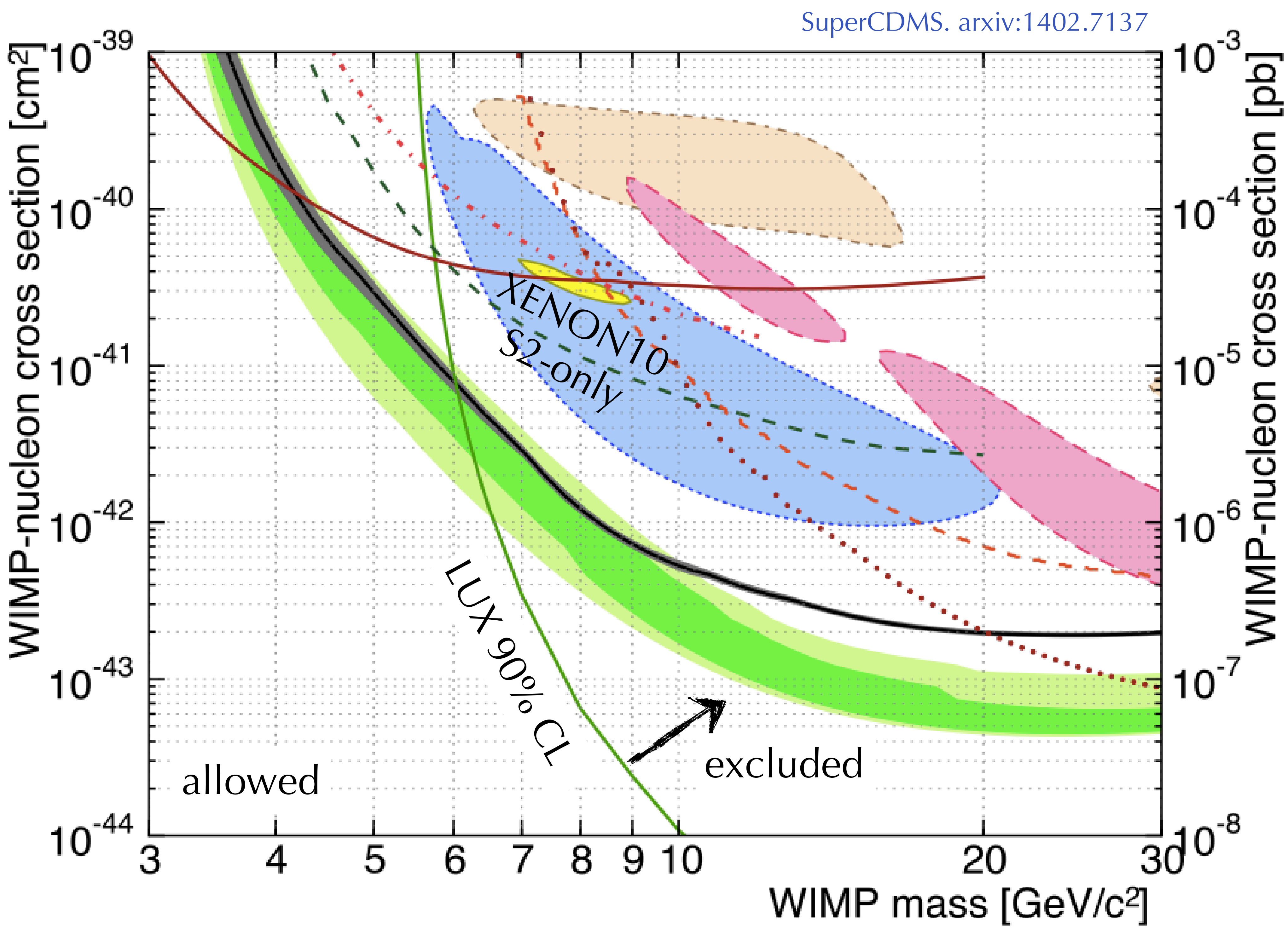
LUX in its castle (NB plenty of room for LZ)

THE DM DIRECT DETECTION FUEL CYCLE

(with thanks to the IAEA)

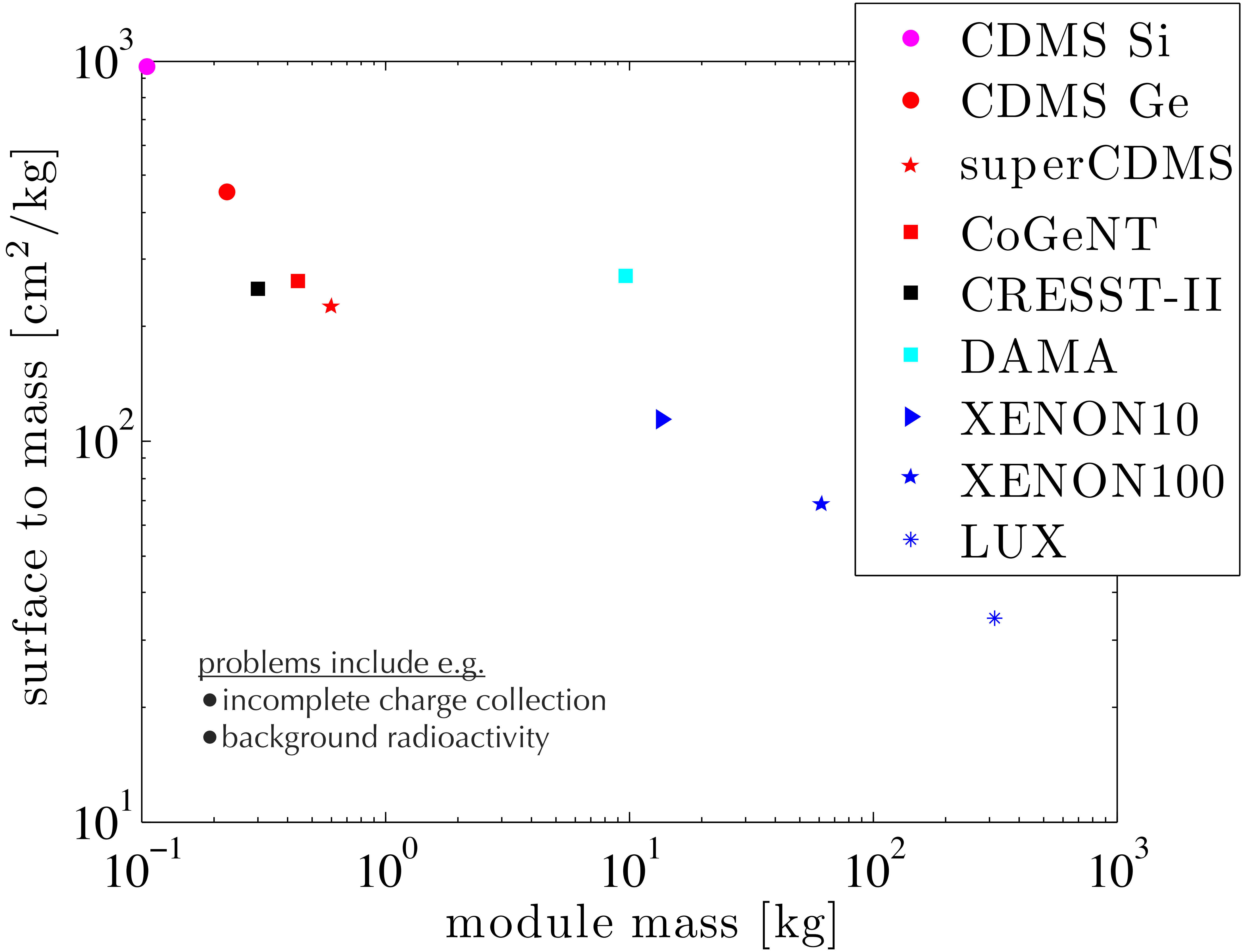


ANOMALIES IN DIRECT DETECTION



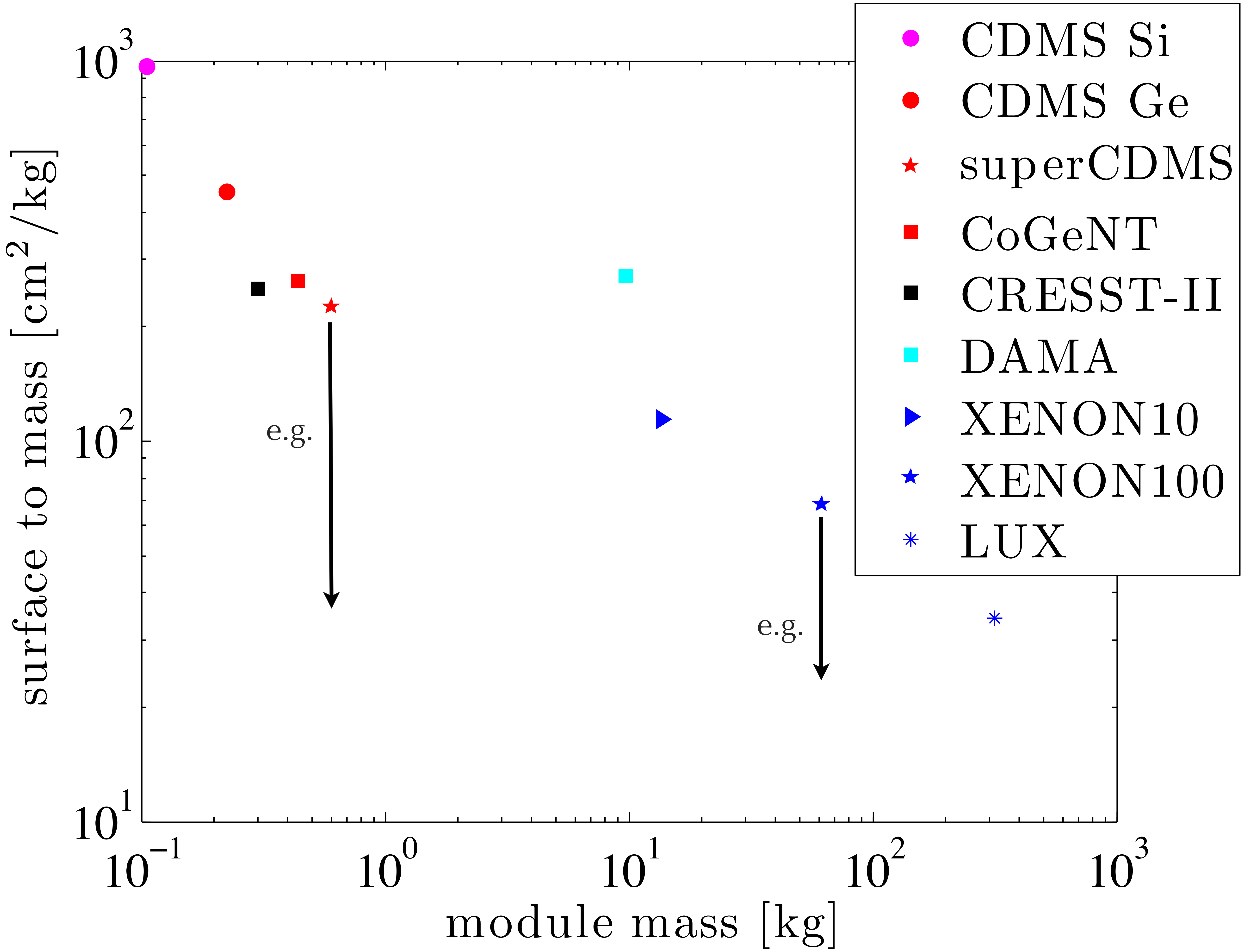
"GOD MADE THE BULK; SURFACES WERE INVENTED BY THE DEVIL"

W. Pauli



IF WE THINK OF THE Y AXIS AS A METRIC TO BE MINIMIZED

- we must account for discrimination, background rate, etc.
- arrows are only meant to be an example

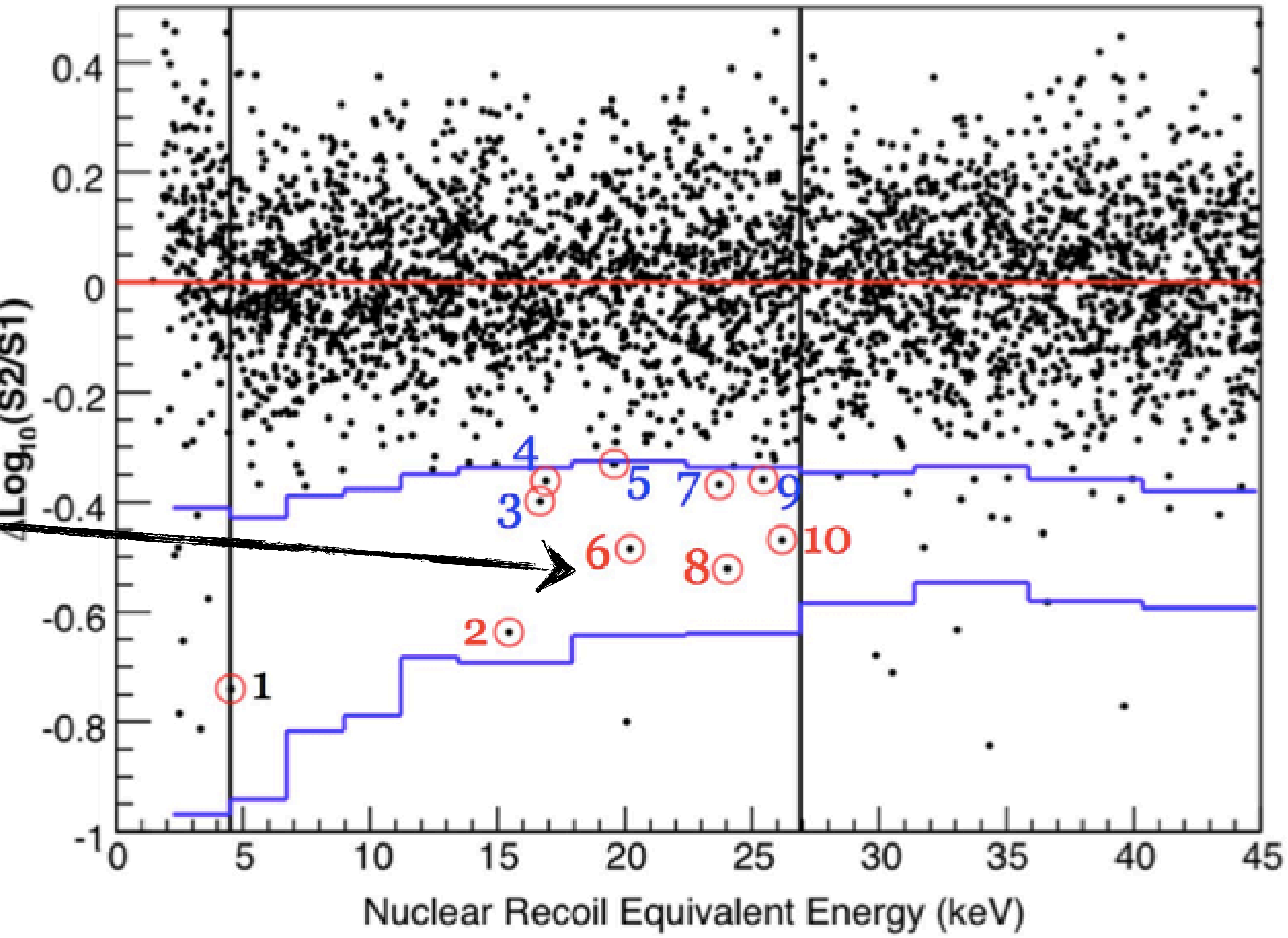


XENON10: ANOMALY NARROWLY AVERTED

WOAH! HEY NOW...

THAT LOOKS LIKE DARK MATTER!

PRL **100**, 021303 (2008) XENON10 results

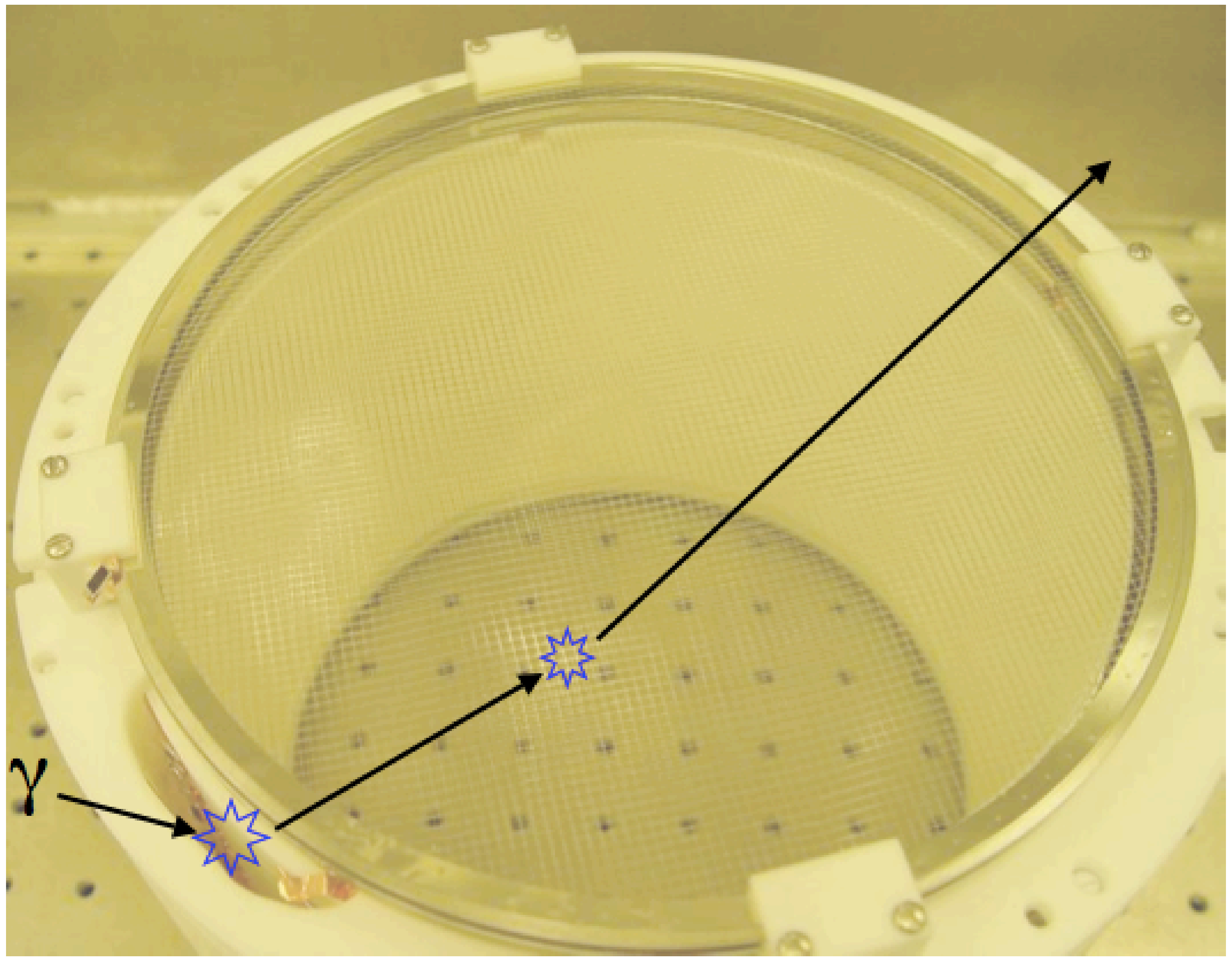


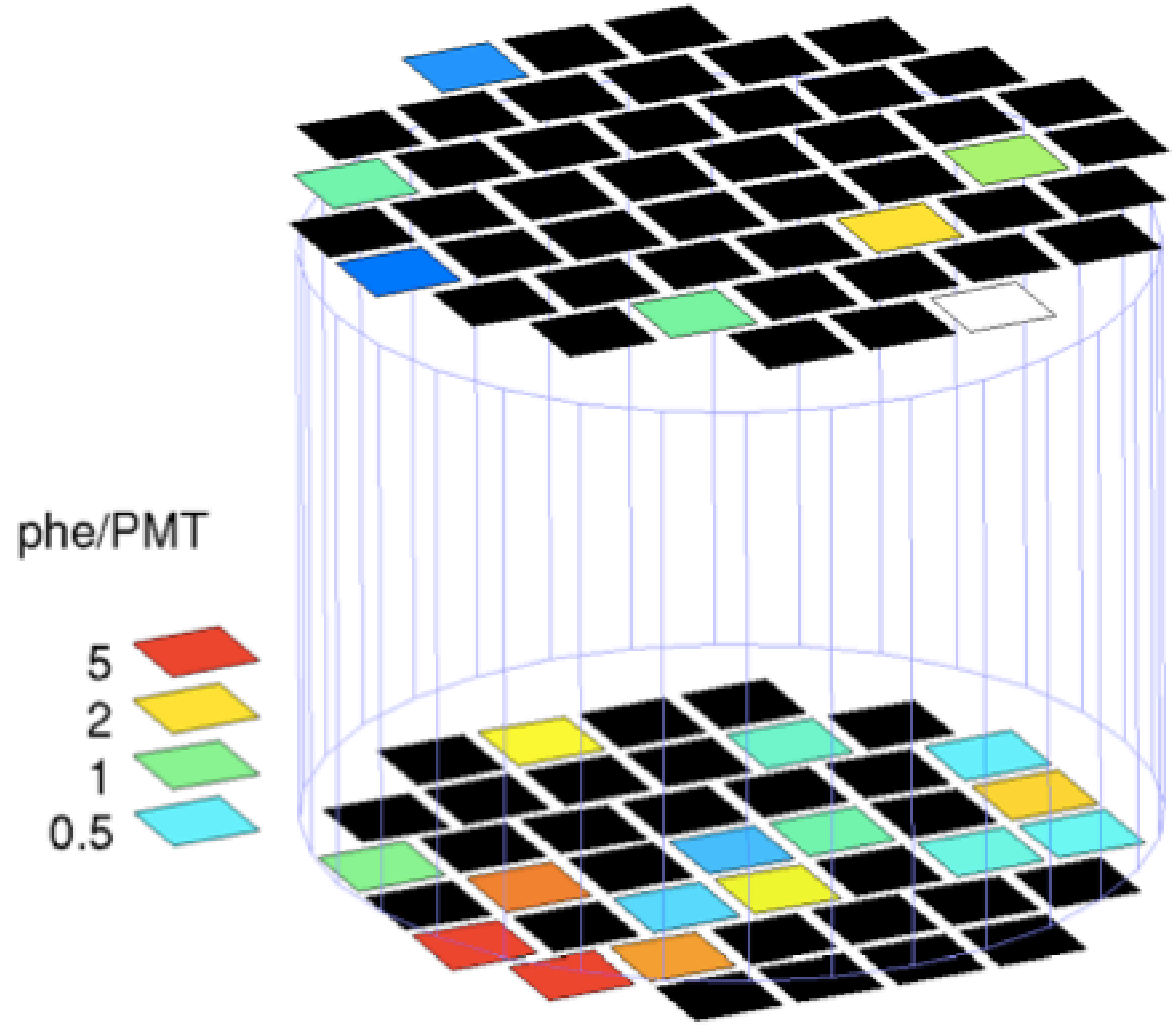
quoting from the letter:

NO. IT DOESN'T.

Event Nos. 2, 6, 8, and 10 are not favored as evidence for WIMPs for three main reasons. First, they are all clustered in the lower part of the fiducial volume (see Fig. 2) where anomalous events happen more frequently, as discussed above. Second, the anomalous $S1$ hit pattern cut discussed earlier for the primary blind analysis was designed to be very conservative. An independent secondary blind analysis performed in parallel with the primary analysis used a more stringent cut to identify anomalous hit patterns in $S1$ and rejected three (Nos. 6, 8, and 10) of these four candidate events. Third, the expected nuclear-recoil spectrum for both neutrons and WIMPs falls exponentially with energy, whereas the candidate events appear preferentially at higher energy.

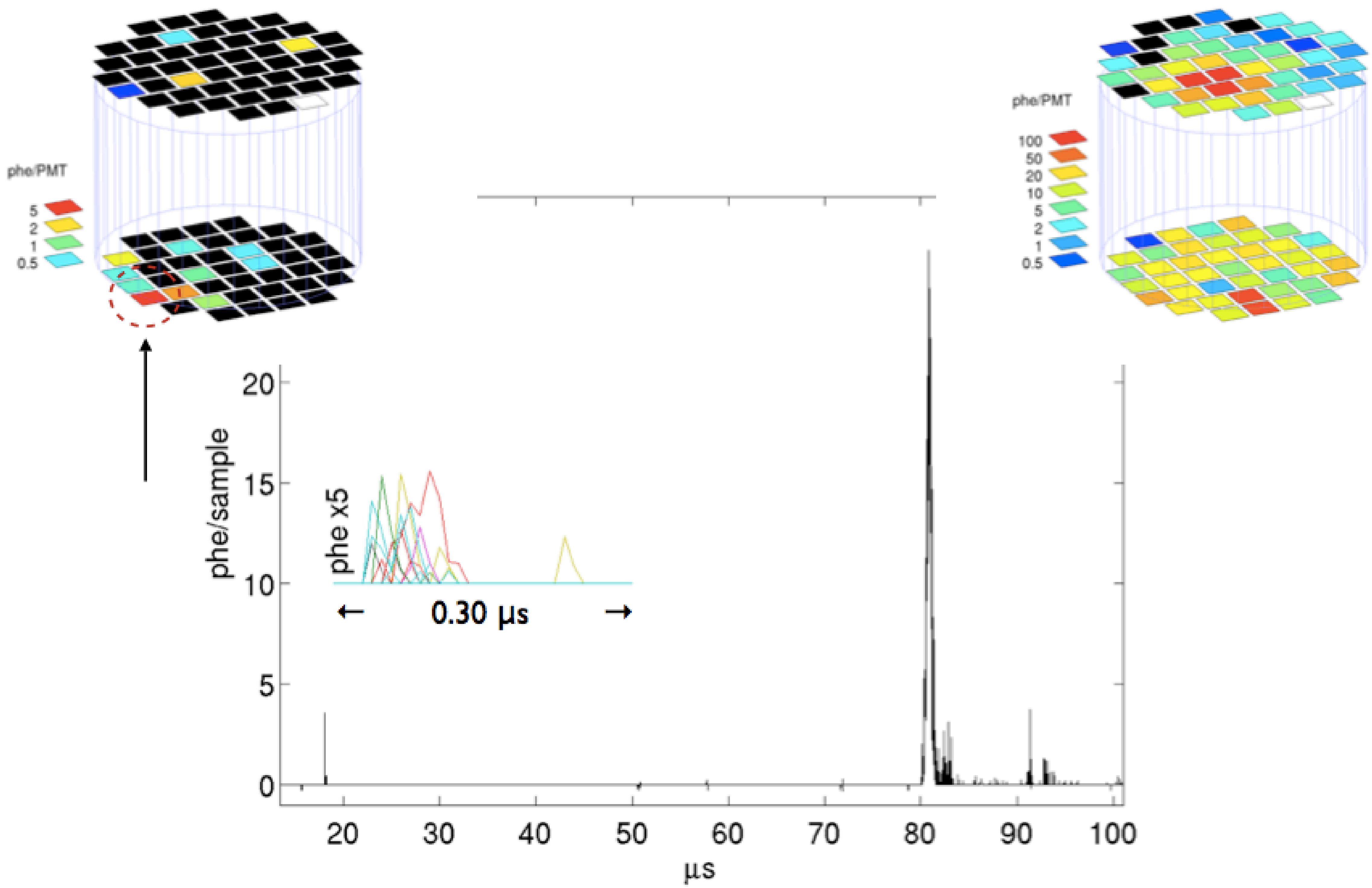
TOPOLOGIES AND RARE EVENTS





- inevitable field ring resistors for voltage division packaged in a sub-optimal way
- allowed for multiple scatters to be tagged as single scatters, because
  - the pocket surrounding the divider was charge insensitive, and
  - not optically isolated
- I predicted this pathology and developed a successful software cut, prior to XENON10 results release
  - why didn't we use it?
- LUX got ahead of this curve with a fully encapsulated divider

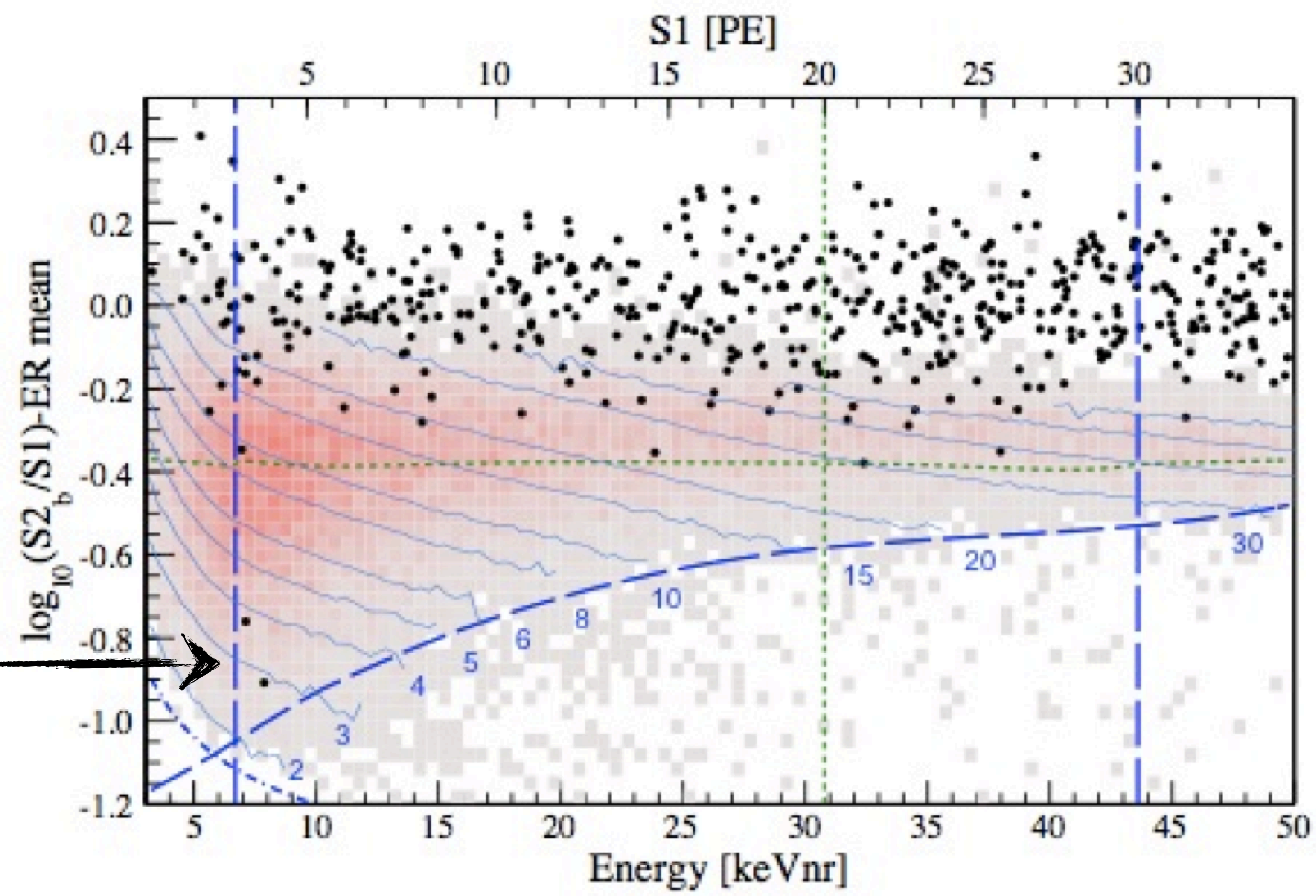
DETAILED STUDY OF PHOTOMULTIPLIER HITPATTERNS



- event record shows a **clean single scatter** in the center of the detector
- S2/S1 is consistent with nuclear recoil
- it is not a nuclear recoil... and it is not the only example
- ***the entire calling card is contained in a single pixel***

THE XENON100 "ANOMALY"

most of the ~3 keV signal is below S1 threshold, down here



measured quantity

corrected energy (keV)

simple, S1-only energy (keV)

WOAH! HEY NOW...

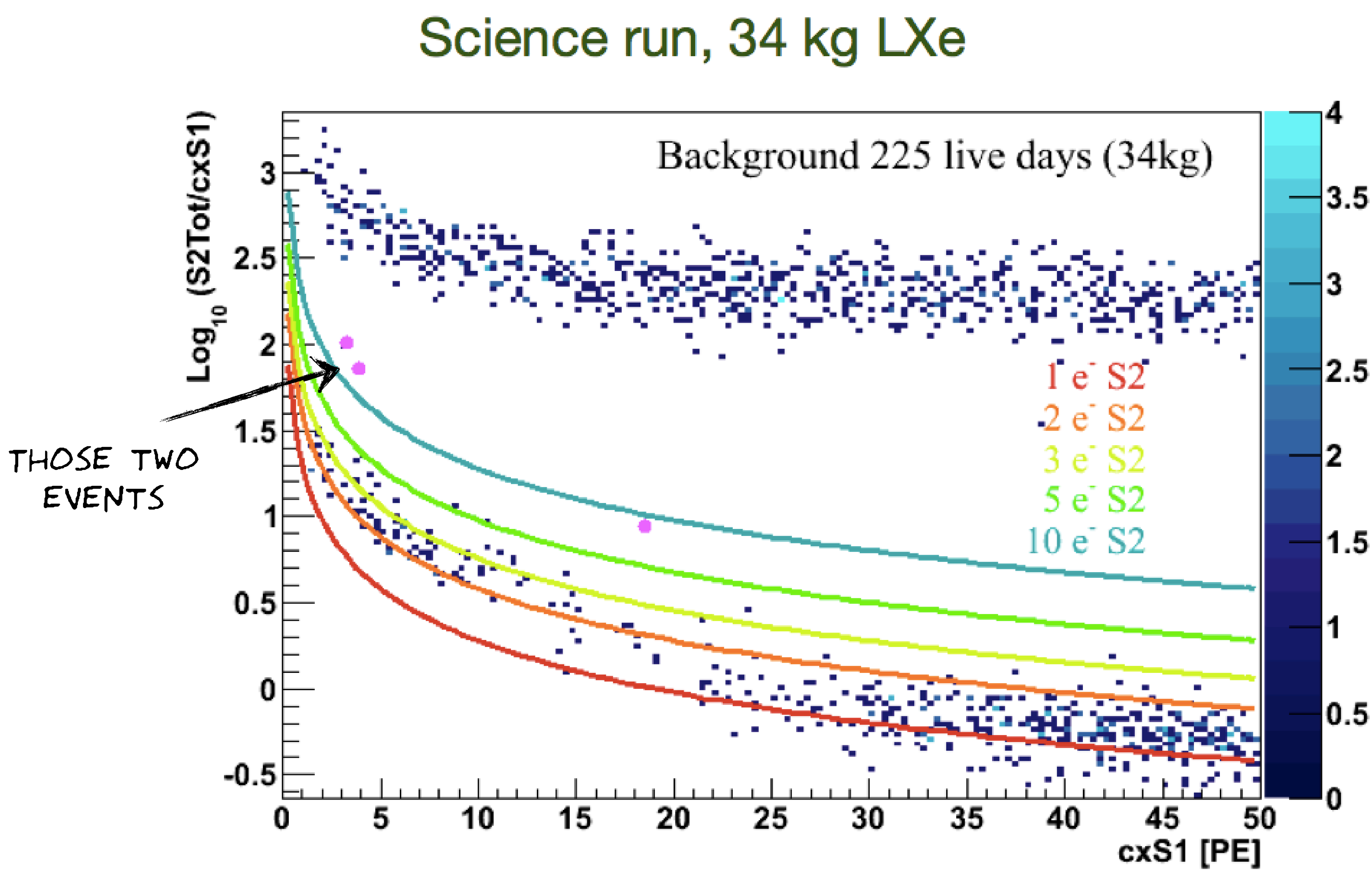
THAT LOOKS LIKE DARK MATTER!

XENON100, Phys. Rev. Lett. **109** 181301 (2012)
with energy scale overlaid from
PS, Phys. Rev. D **86** 101301 (2012)

quoting from the letter:

> region of interest. The majority of ER background events is Gaussian distributed in the discrimination parameter space, with a few events leaking anomalously into the NR band. These anomalous events can be due to double scatters with one energy deposition inside the TPC and another one in a charge insensitive region, such that the prompt *S*1 signal from the two scatters is combined with only one charge signal *S*2. Following the observed distribution in

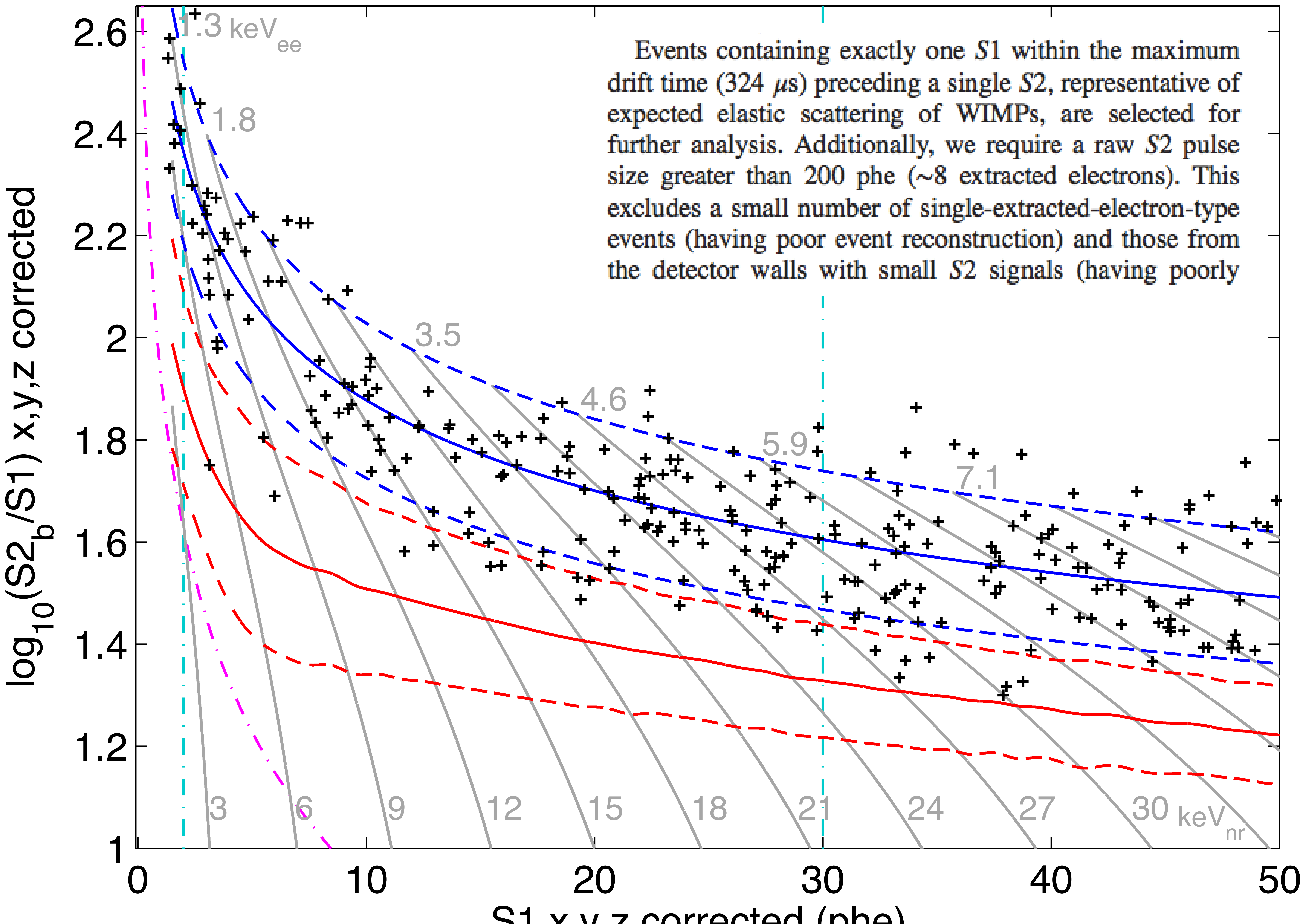
PLENTY MORE "DARK MATTER" EVENTS BELOW THE BOX



plot from L. Baudis, LBL seminar April 30, 2013

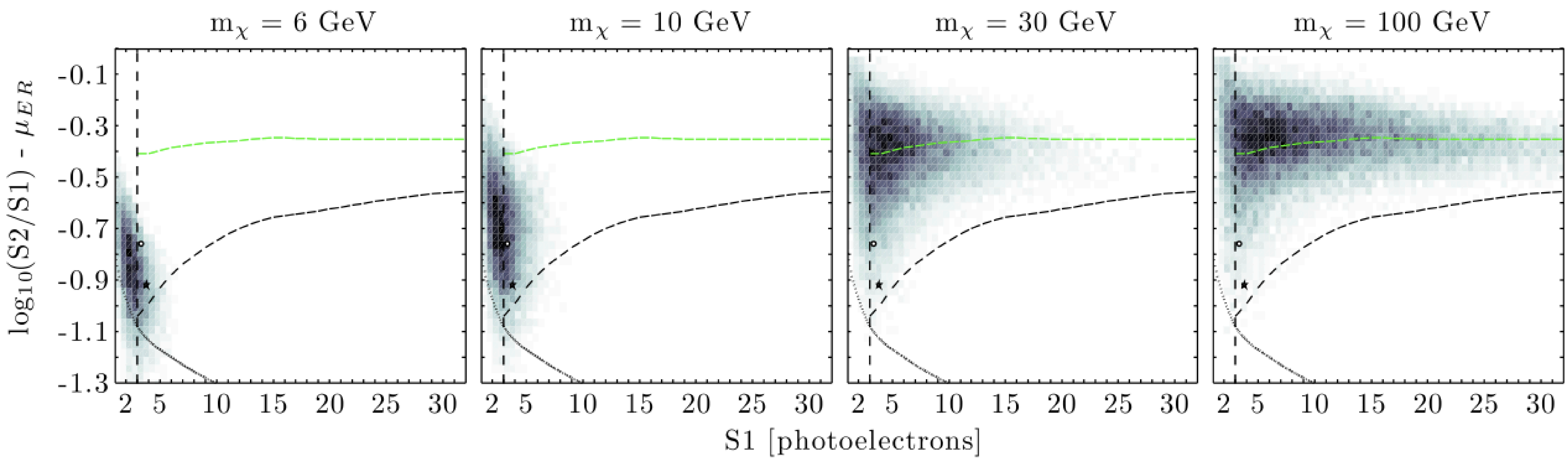
- The two events appear to be on the tail of a known background distribution
- Probably the same "electron train" background described in arXiv:1104.3088

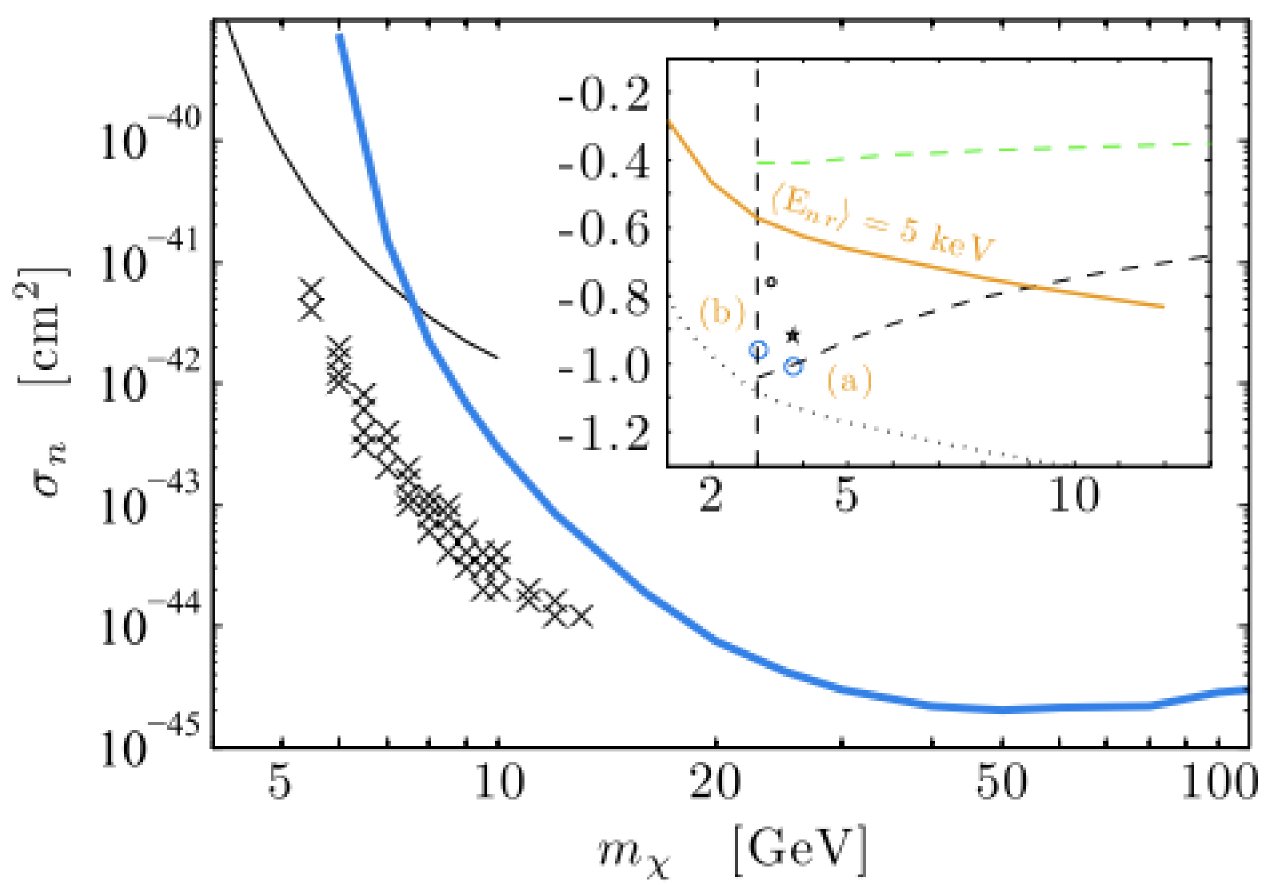
LUX: ~8 ELECTRON THRESHOLD



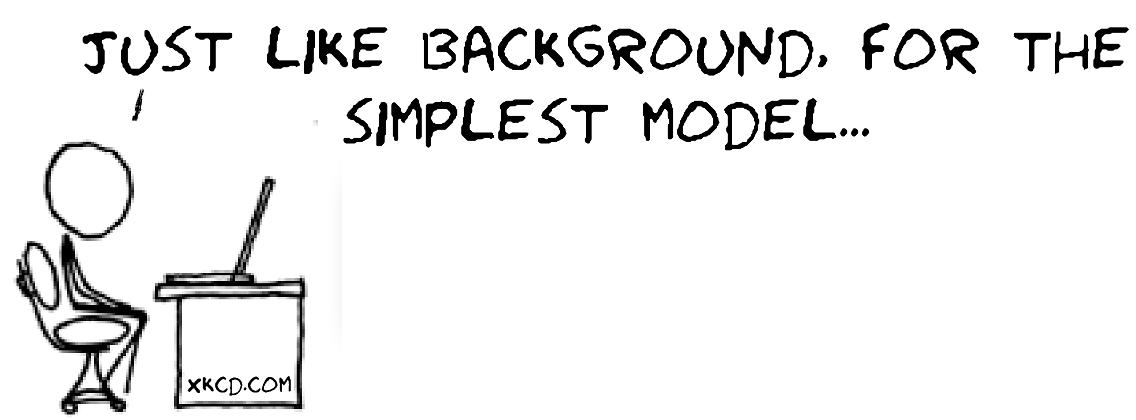
- state of the art => walking the edge of event misidentification
- in contrast to other dark matter search technologies, liquid xenon TPCs are on the safe side of that edge (i.e. not drawing blobs in σ-m parameter space)
- ~~or, perhaps we've just missed a detection~~

WHAT MIGHT A FIRST DETECTION LOOK LIKE?





PS, Phys. Rev. D **86** 101301 (2012)



- **every increase in search sensitivity will be accompanied by new detector-induced background pathologies**

- analysis blinding techniques do NOT really address this

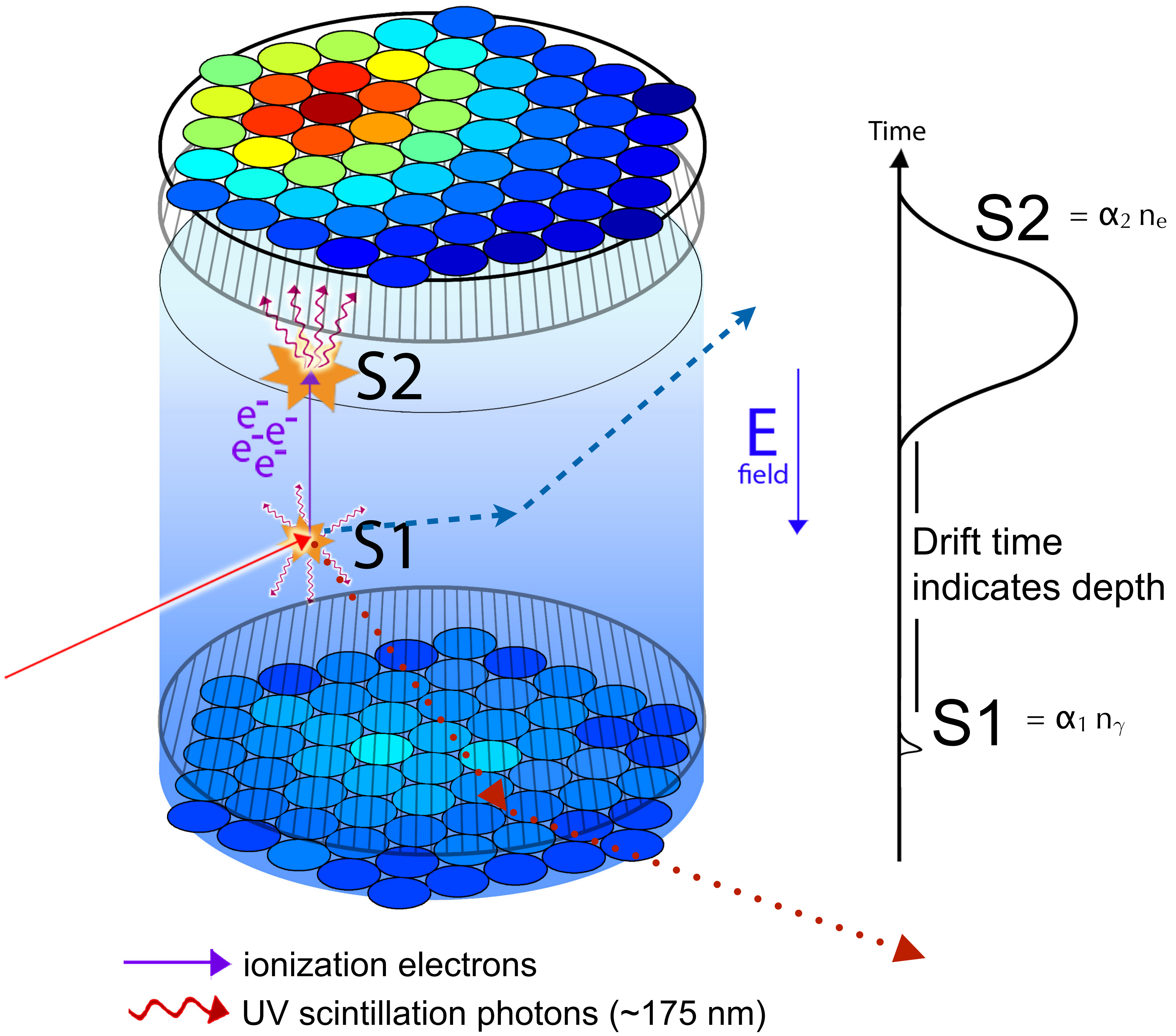
- ***"life just goes on and on, getting harder and harder..."***

The Rolling Stones

WHAT DO WE KNOW FOR EACH EVENT?

1. number of electrons
2. number of photons
   - leads to statistical inference of incident particle type
3. (x,y,z) with high confidence
   - but tails in reconstruction may be non-Gaussian
4. multiple ionization vertices
5. photon hit patterns on the PMTs
   - this can help pinpoint pathologies

LUX, Nucl. Instr. Meth. A 668 1 (2012)



wish list

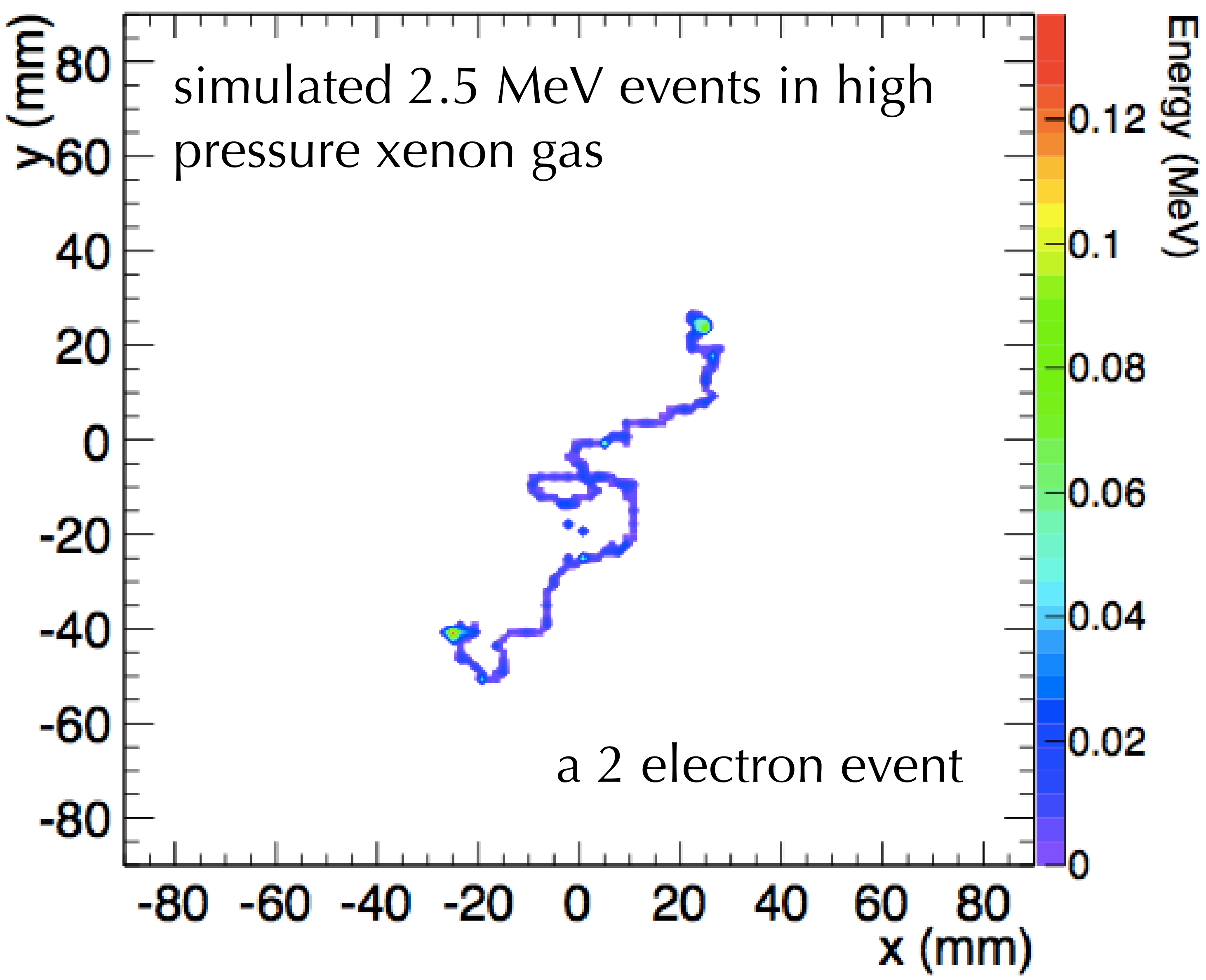
- **recoil track information?**
- **better discrimination**

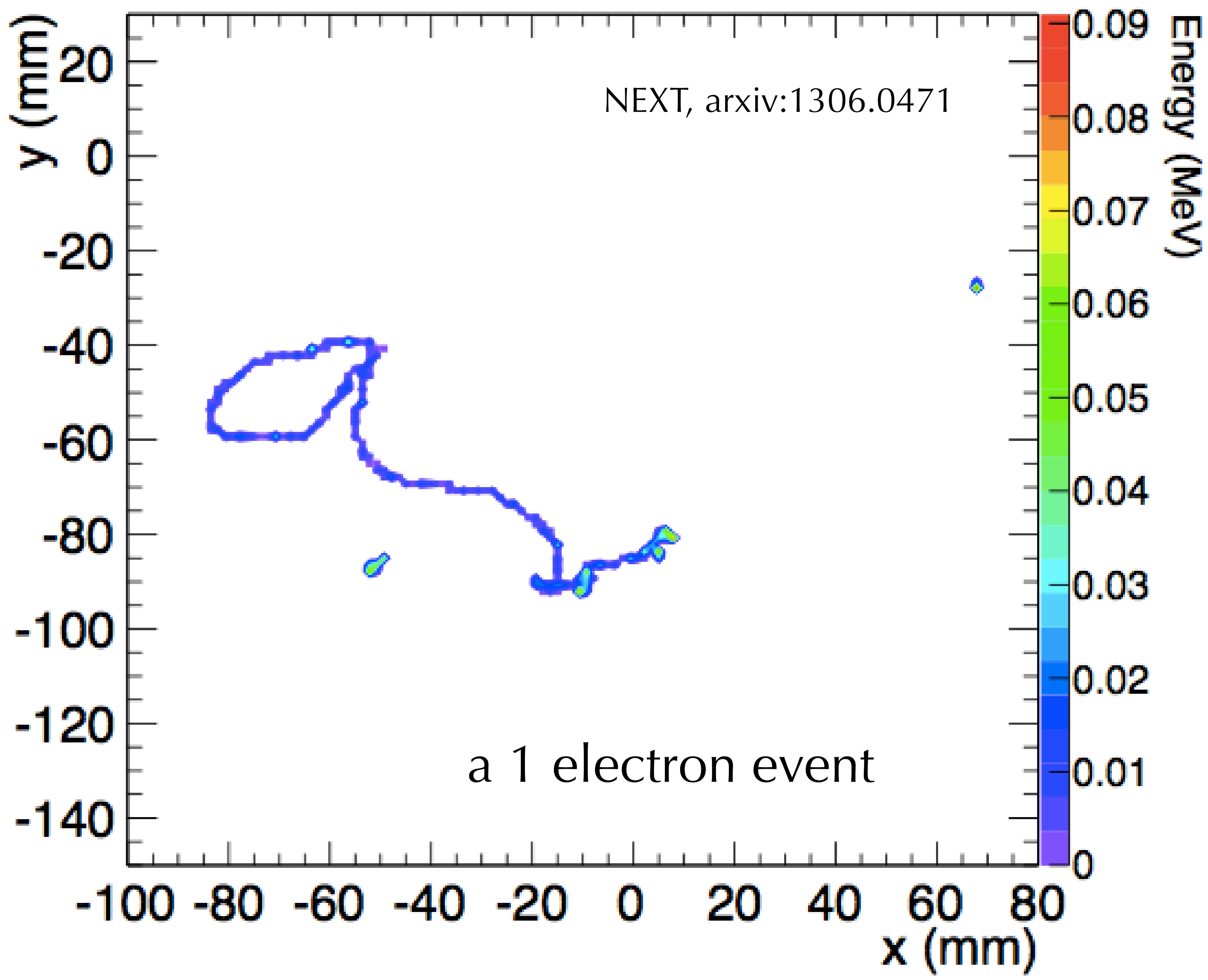
2nd vertex would result in a second S2 pulse (multiple scatter tag)

if 2nd vertex below cathode, would NOT exhibit a second S2 pulse (NO multiple scatter tag)

IS TRACK INFORMATION ACCESSIBLE?

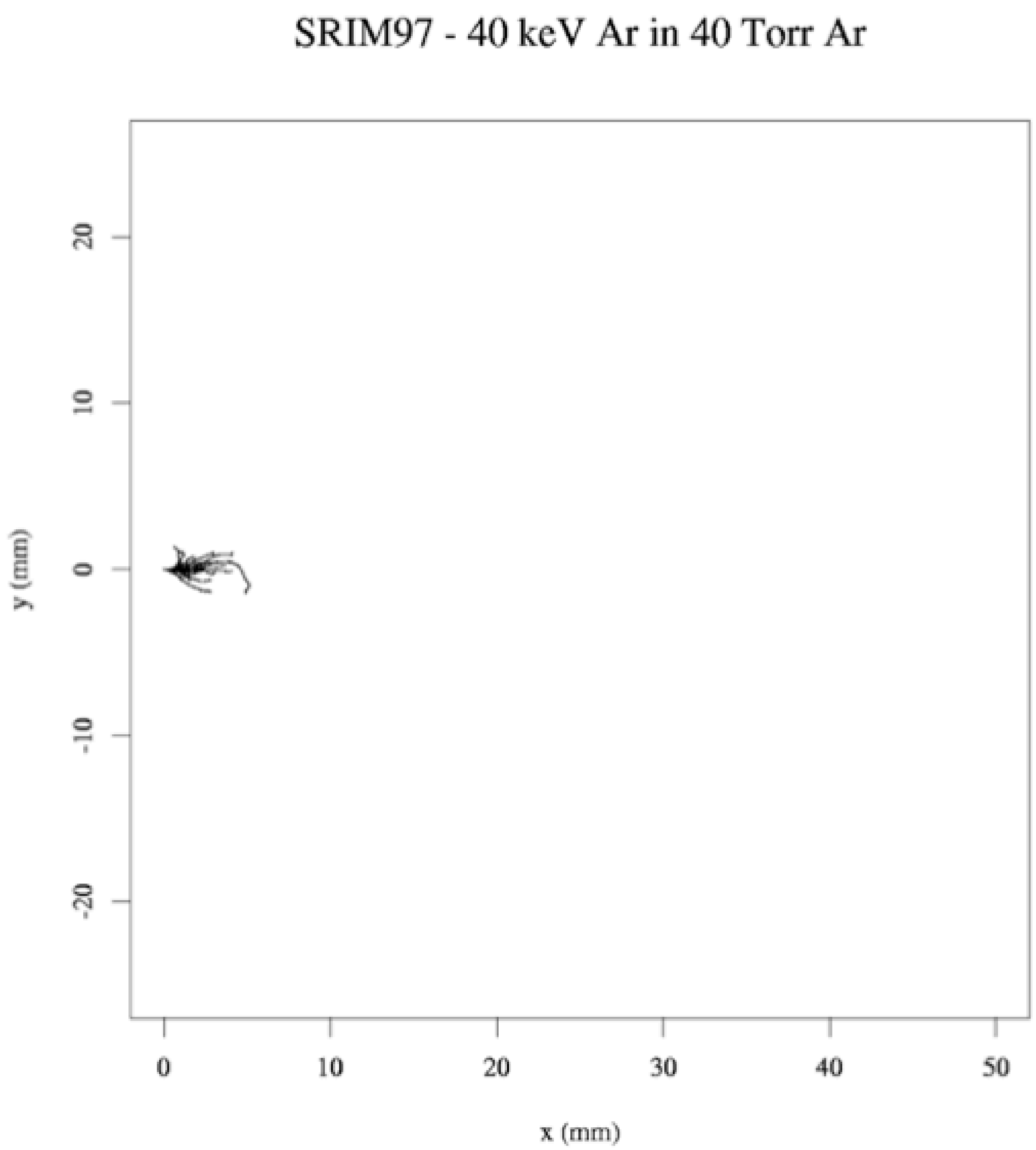
- ~keV recoiling nuclei and electrons have O(10 nm) tracks in liquid xenon

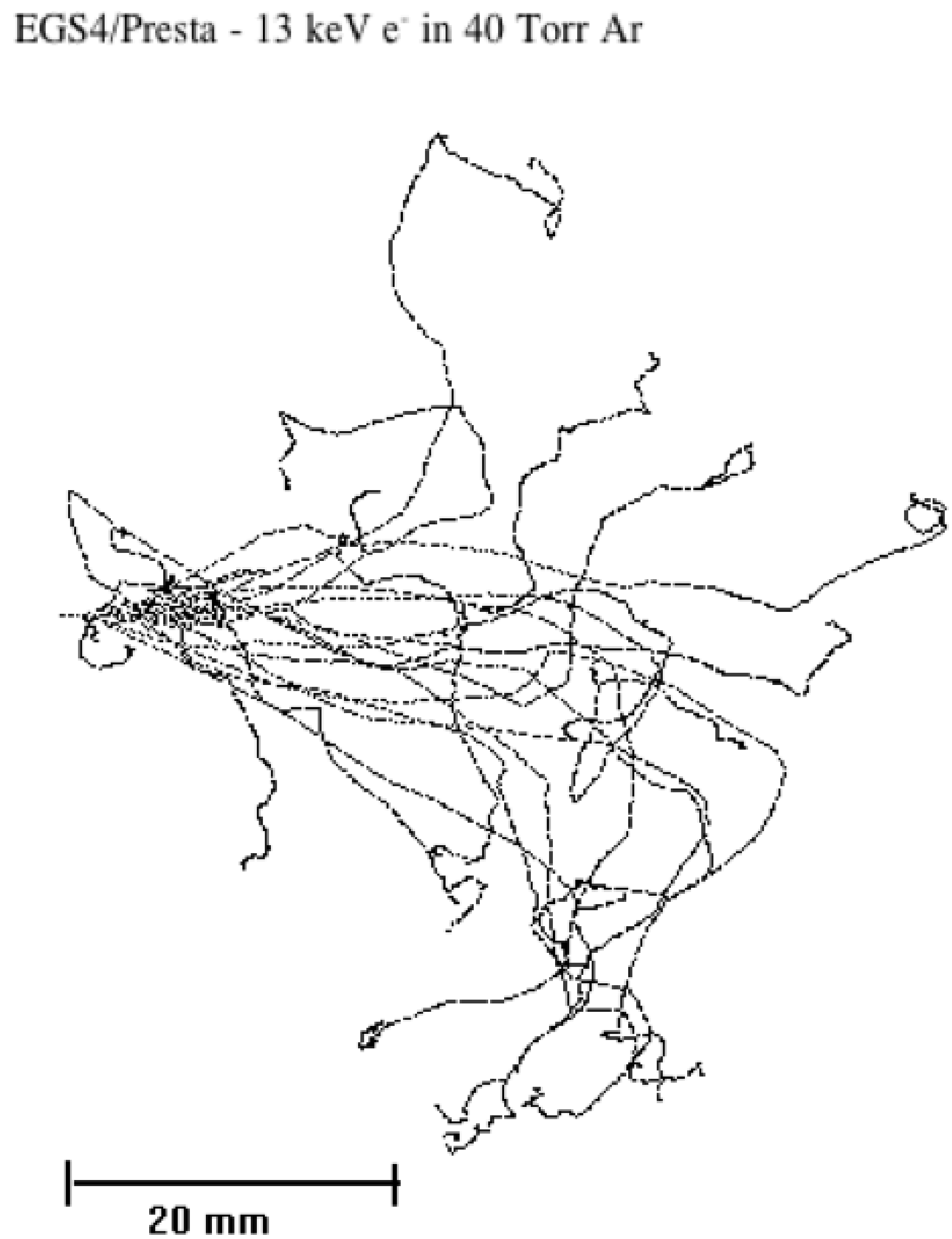




- but tracking is possible in high pressure xenon gas, where e- ranges are O(100 mm)
- keV recoiling nuclei have sub mm ranges in HPXe
- this motivates low pressure gaseous TPCs...

TRACK STRUCTURE OFFERS ADDITIONAL DISCRIMINATION

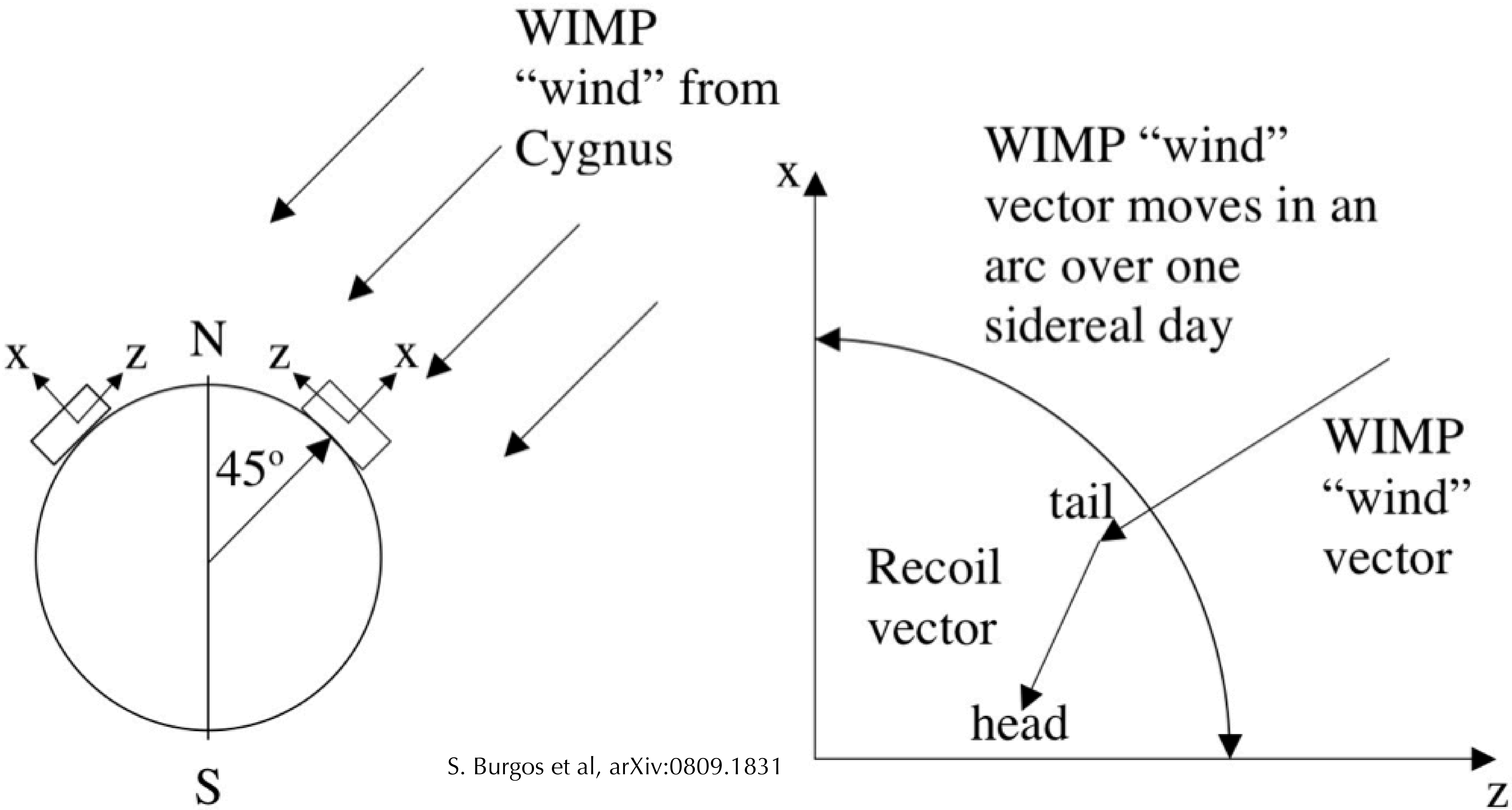




plots from D. Snowden-Ifft, IDM 2012

Measuring track structure leads to directional detection

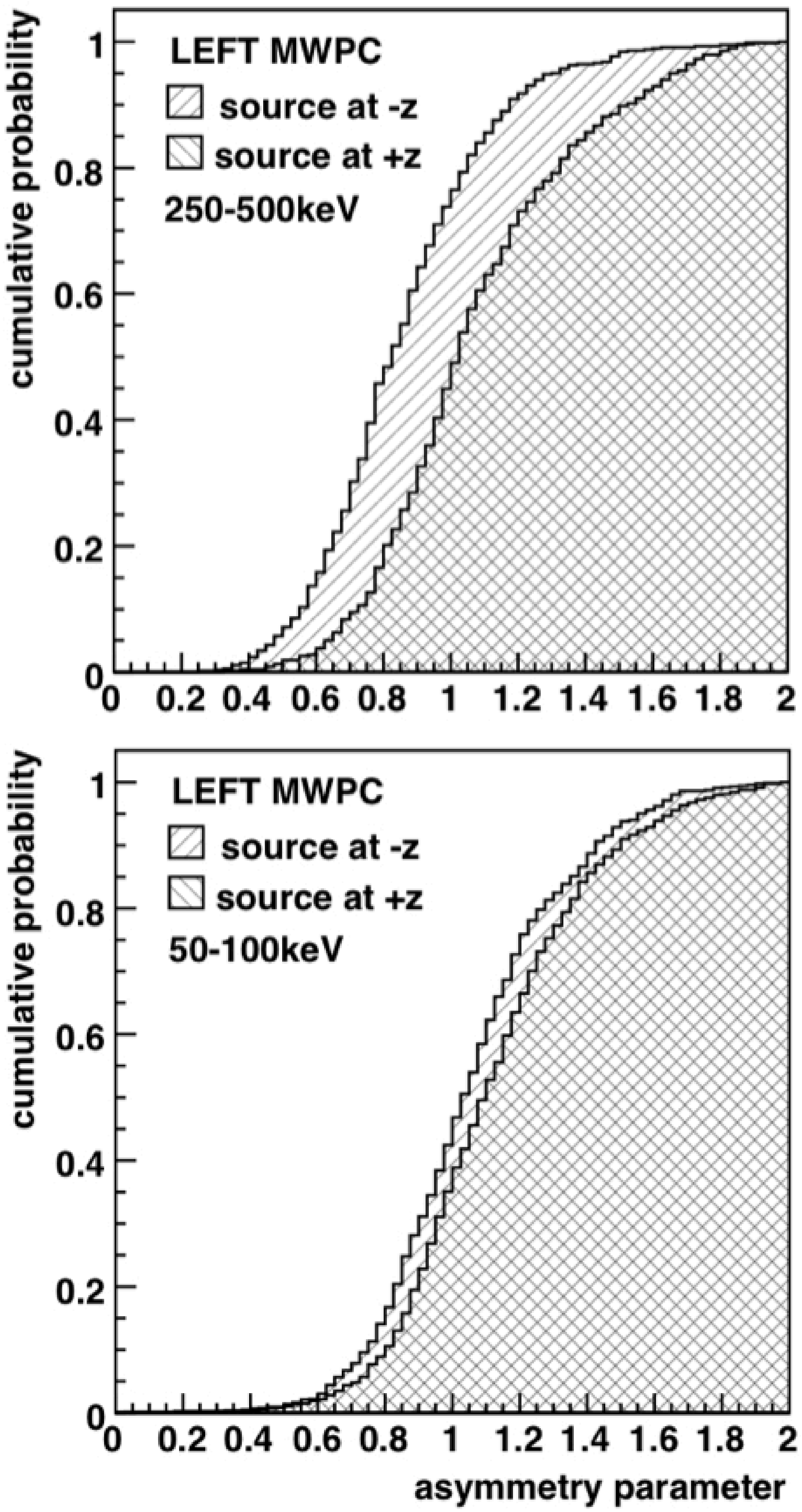
directional detection leads to CONFIDENCE!



S. Burgos et al, arXiv:0809.1831

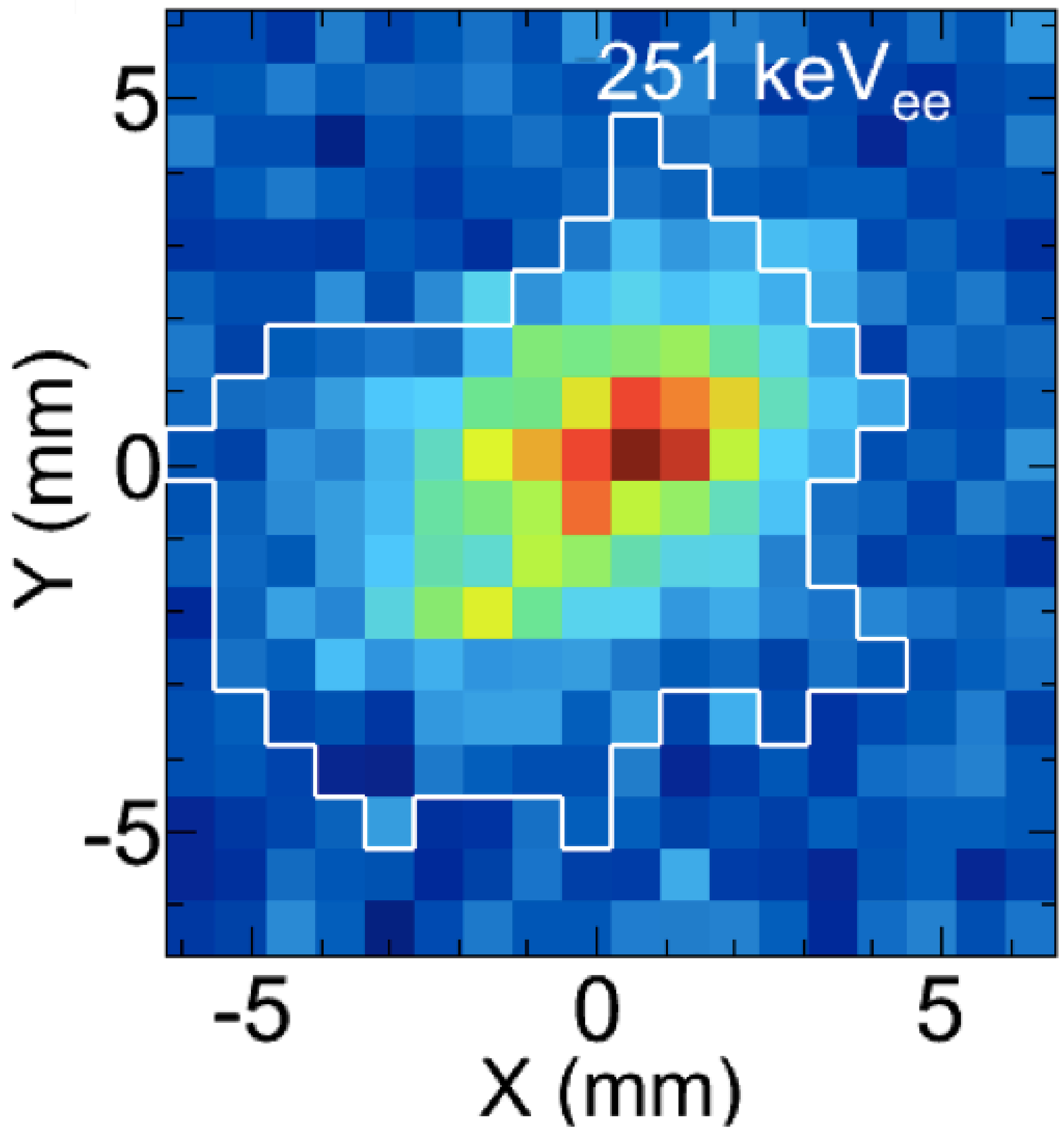
OR, AT LEAST, THAT IS THE DREAM

S. Burgos et al, arXiv:0809.1831



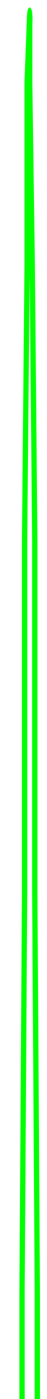
- (left)
- head-tail asymmetry in DRIFT: 40 Torr CS_2
- 0.135 kg target in 1.5 m^3 detector

- (below)
- recoil track in DMTPC: 75 Torr CF4
- 0.006 kg target in a 20 liter detector



plot from J. Battat, Aspen winter conference 2013 (a dream with a crux):

"directionality or target mass. choose one"

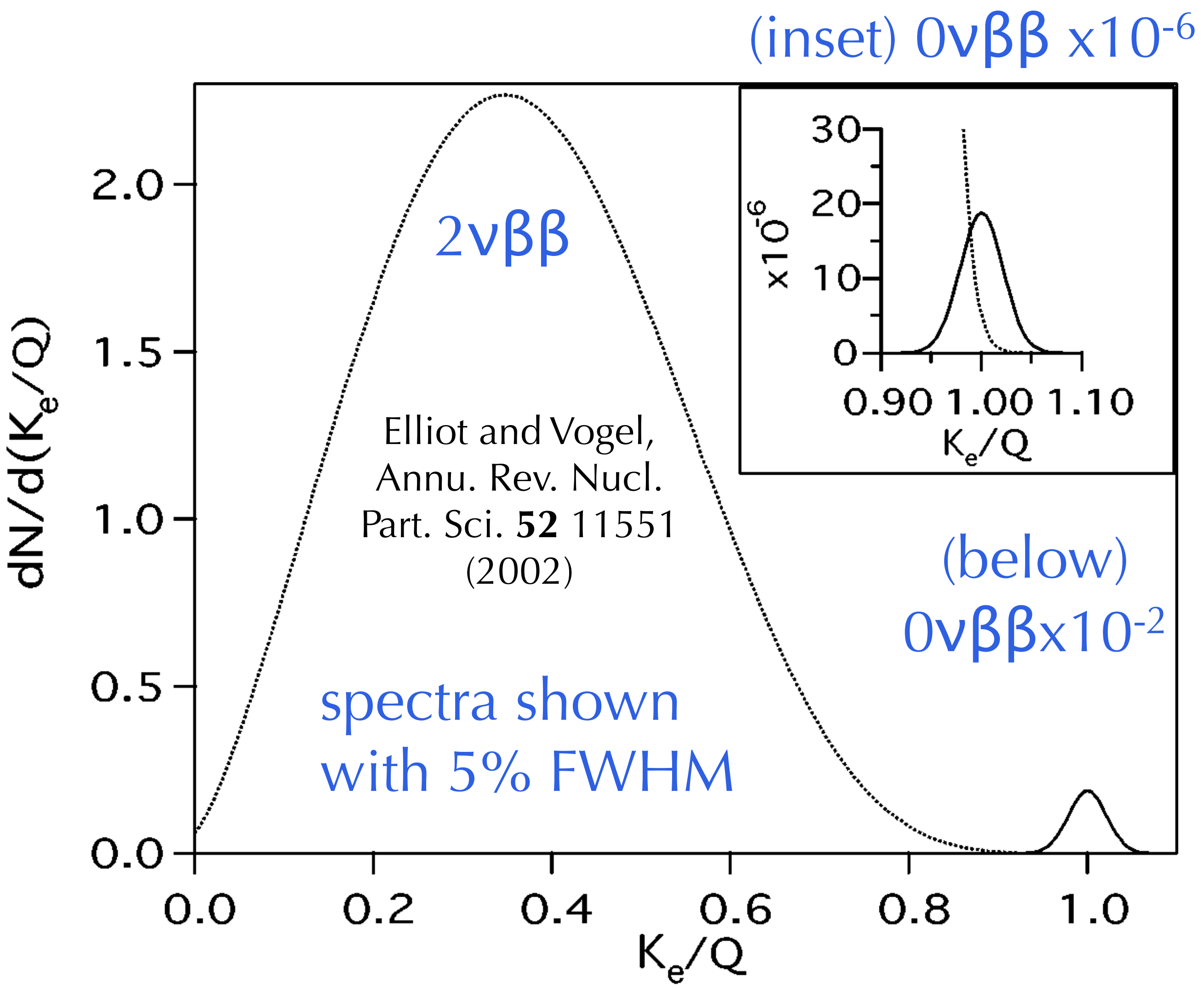


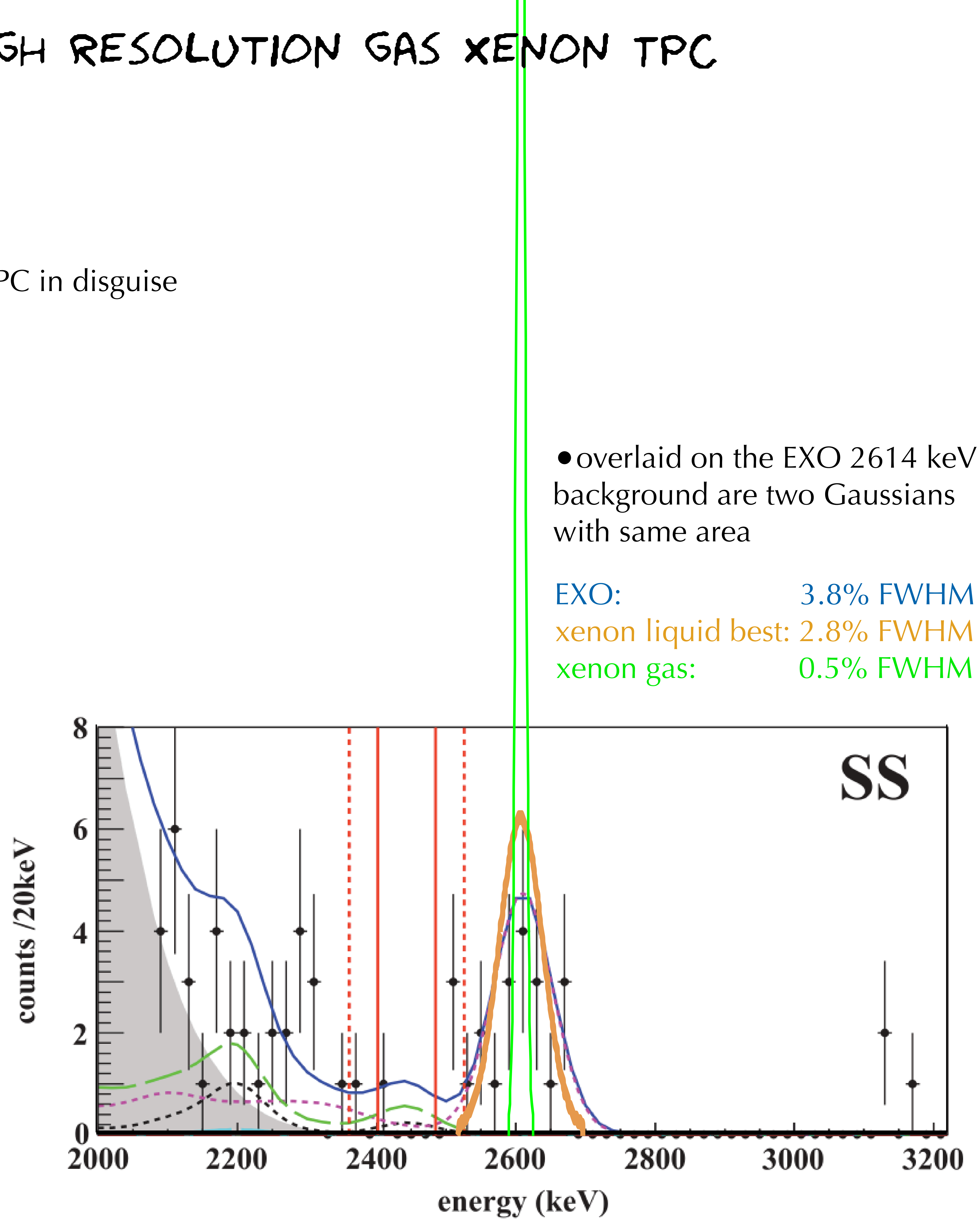
Ancient proverb

- actually a DM search track-imaging TPC in disguise

- overlaid on the EXO 2614 keV background are two Gaussians with same area

EXO: 3.8% FWHM
xenon liquid best: 2.8% FWHM
xenon gas: 0.5% FWHM

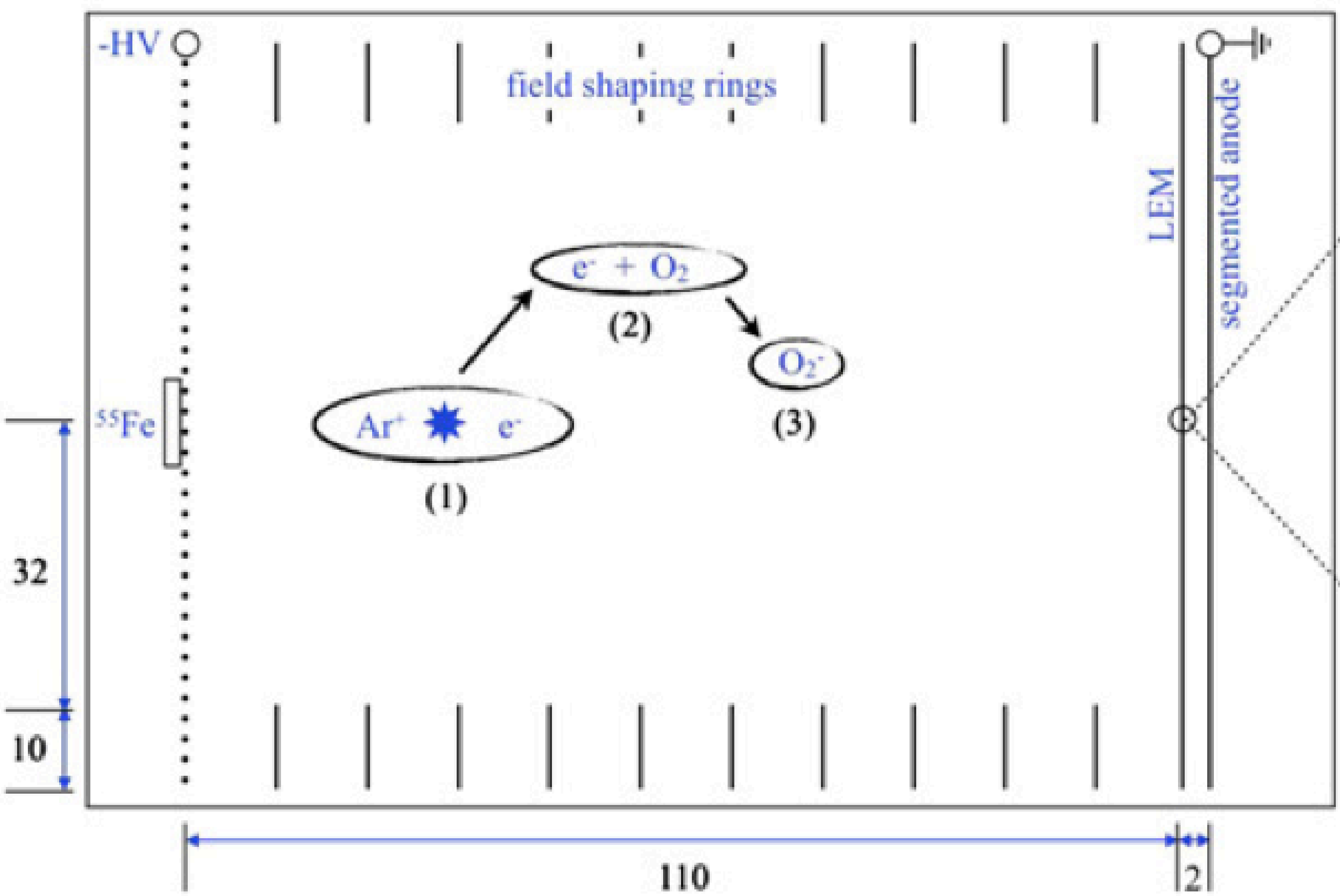


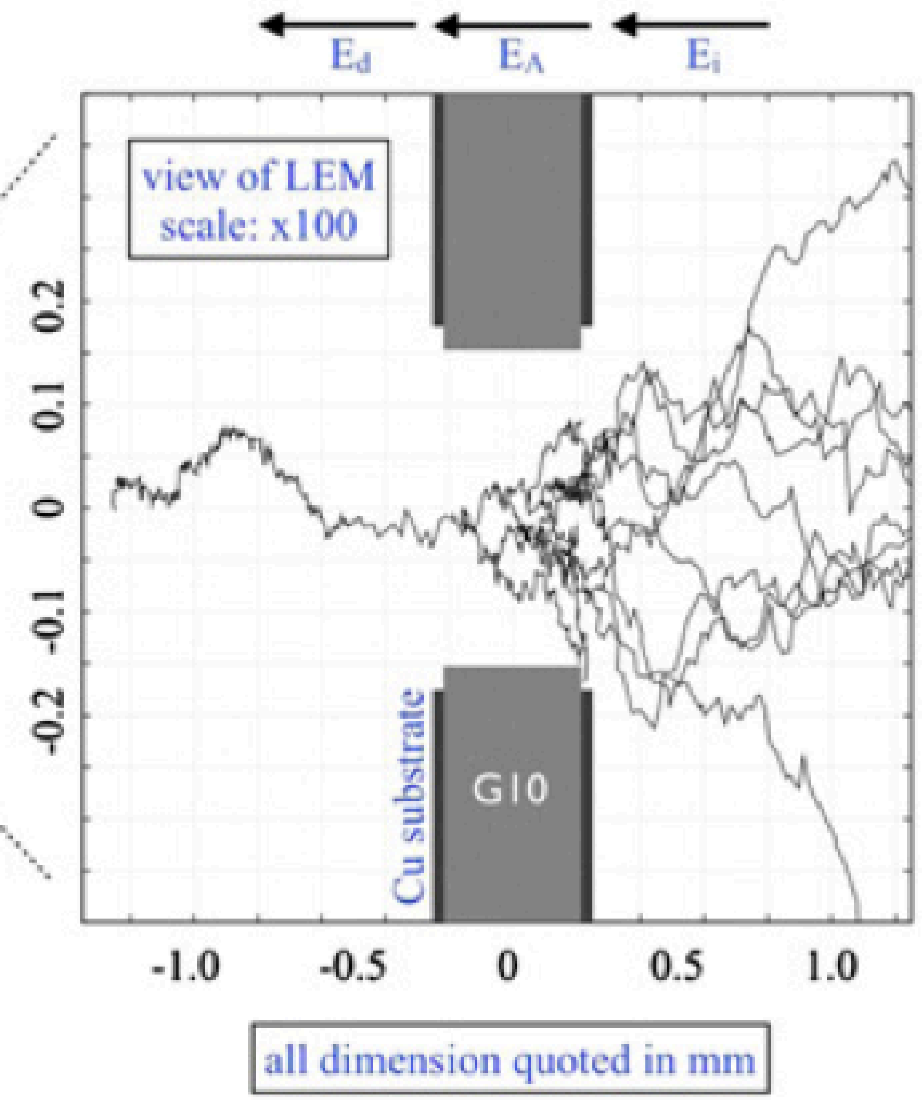


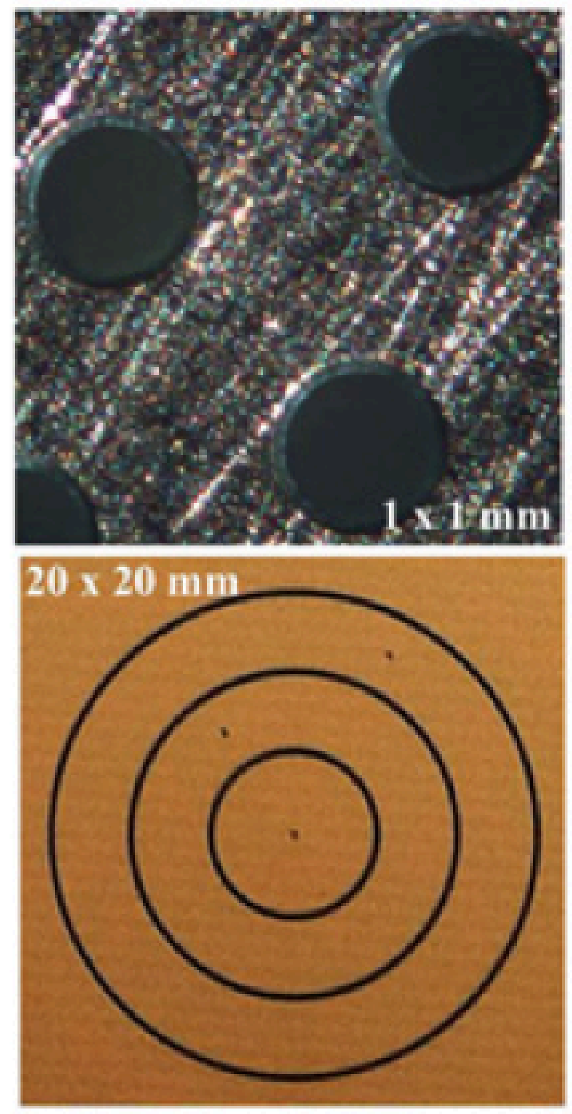
NEGATIVE ION TPC - A MEANS TO INTRINSIC RESOLUTION?

concept (1): C.J. Martoff et al., Nucl. Inst. Meth. A440, 355 (2000)
concept (2): D.R. Nygren J. Phys. Conf. Ser. 65 012003 (2007)
implementation: PS et al, Nucl. Instr. Meth. A 686 106 (2012)

- We used 0.25 bar Ar-CO_2 (70-30) as a low-cost surrogate for xenon.
- 5.9 keV ^{55}Fe x-ray source was used to study the detector performance.
- in analogy with e.g. LUX, this was an S2-only detector (but could add S1)

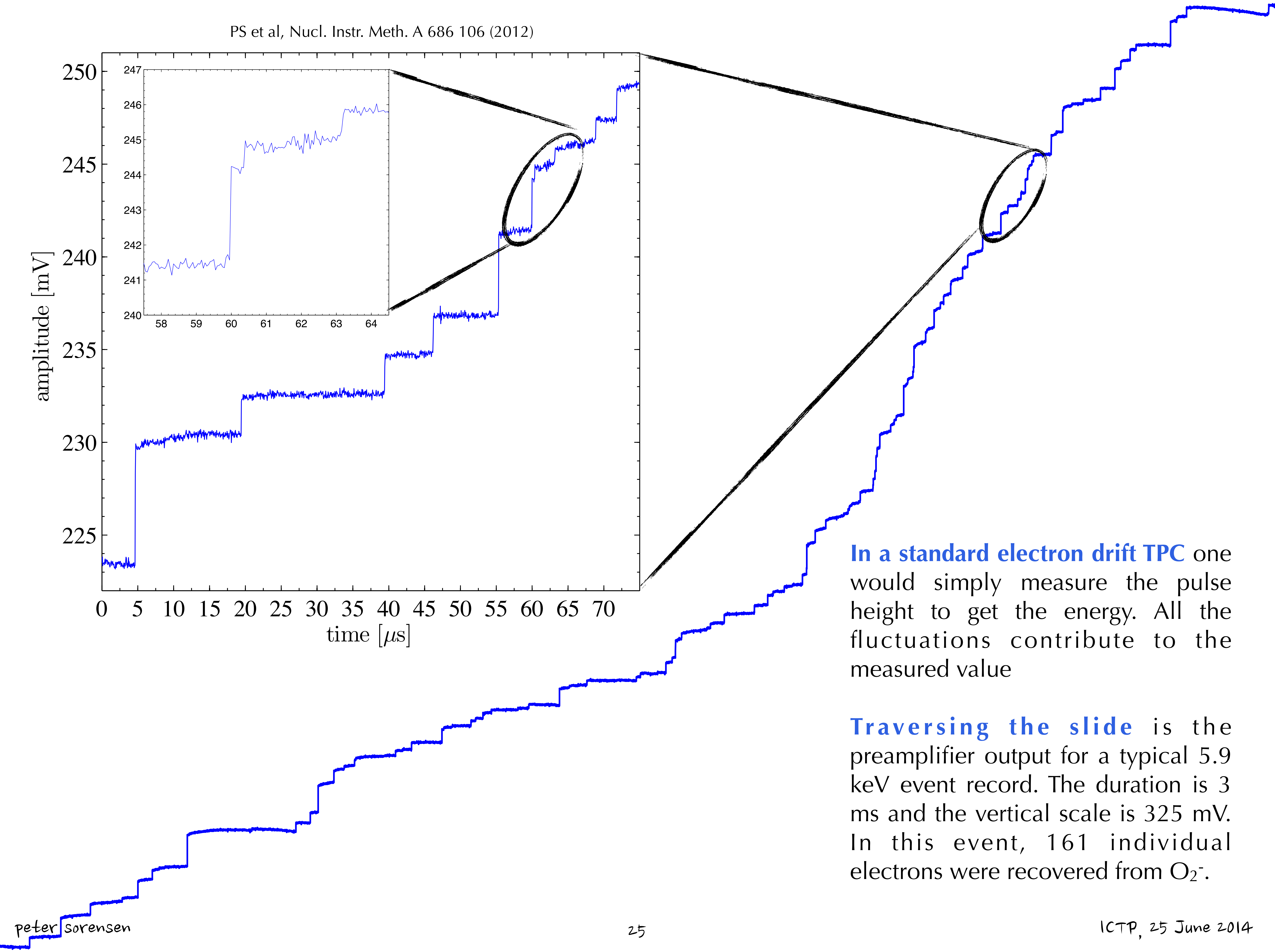






Typical 5.9 keV event in our negative ion TPC

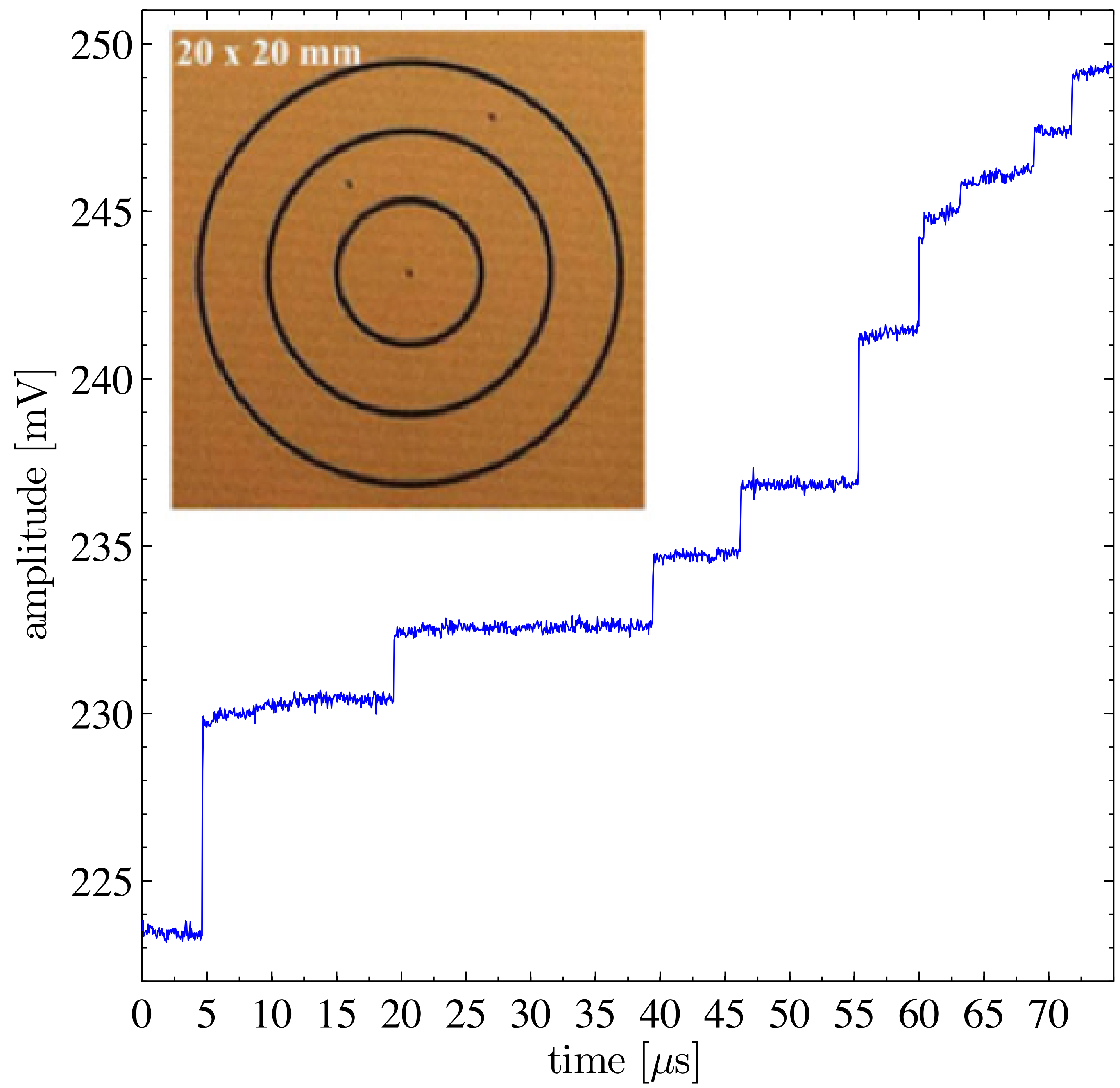
PS et al, Nucl. Instr. Meth. A 686 106 (2012)



In a standard electron drift TPC one would simply measure the pulse height to get the energy. All the fluctuations contribute to the measured value

Traversing the slide is the preamplifier output for a typical 5.9 keV event record. The duration is 3 ms and the vertical scale is 325 mV. In this event, 161 individual electrons were recovered from O_2^-.

Tracking + resolution: negative ion TPC raison d'etre



The good

- counting individual quanta, so no loss of resolution from discretizing the readout array
- exquisite (x,y) reconstruction possible
- diffusion is small (drifting ions rather than electrons)
- works OK at 0.25 bar (187 Torr, a factor x5 more than DRIFT...)

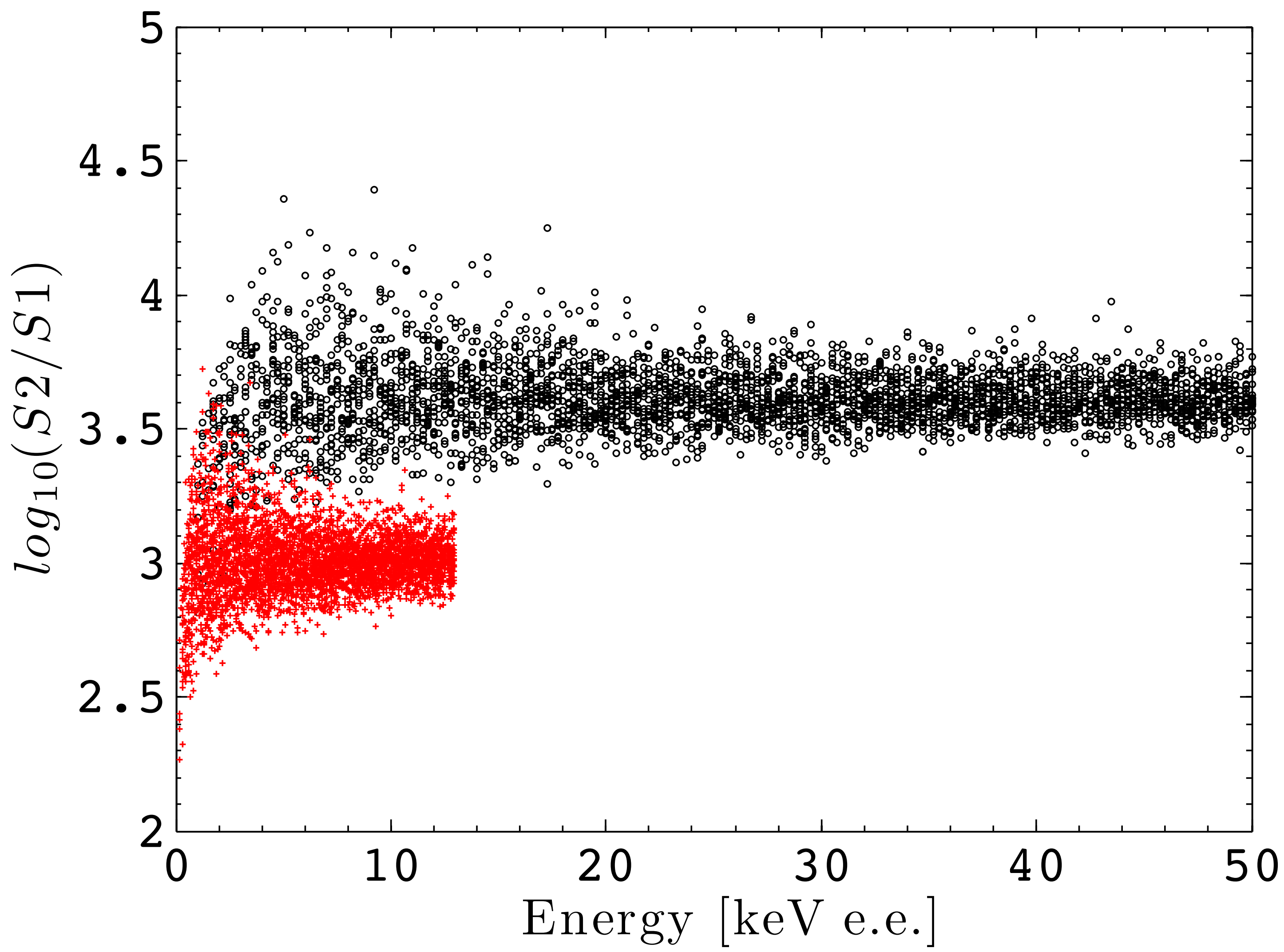
The bad

- 0.25 bar is low density
- recovery of e- from -ion does not appear to work above about ~1 bar

The unknown

- did not yet try Xe O_2 negative ion TPC

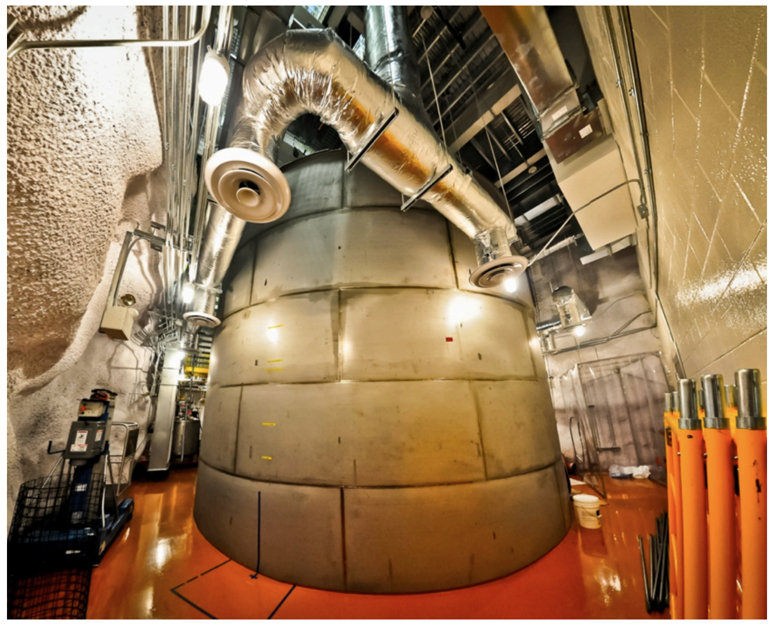
figure from D.R. Nygren, Paris TPC conference 2012



- (left) simulation of 0-50 keV ER (black) and NR (red)
- one should reasonably expect **better discrimination** from high pressure xenon gas
- several assumptions underly this plot...

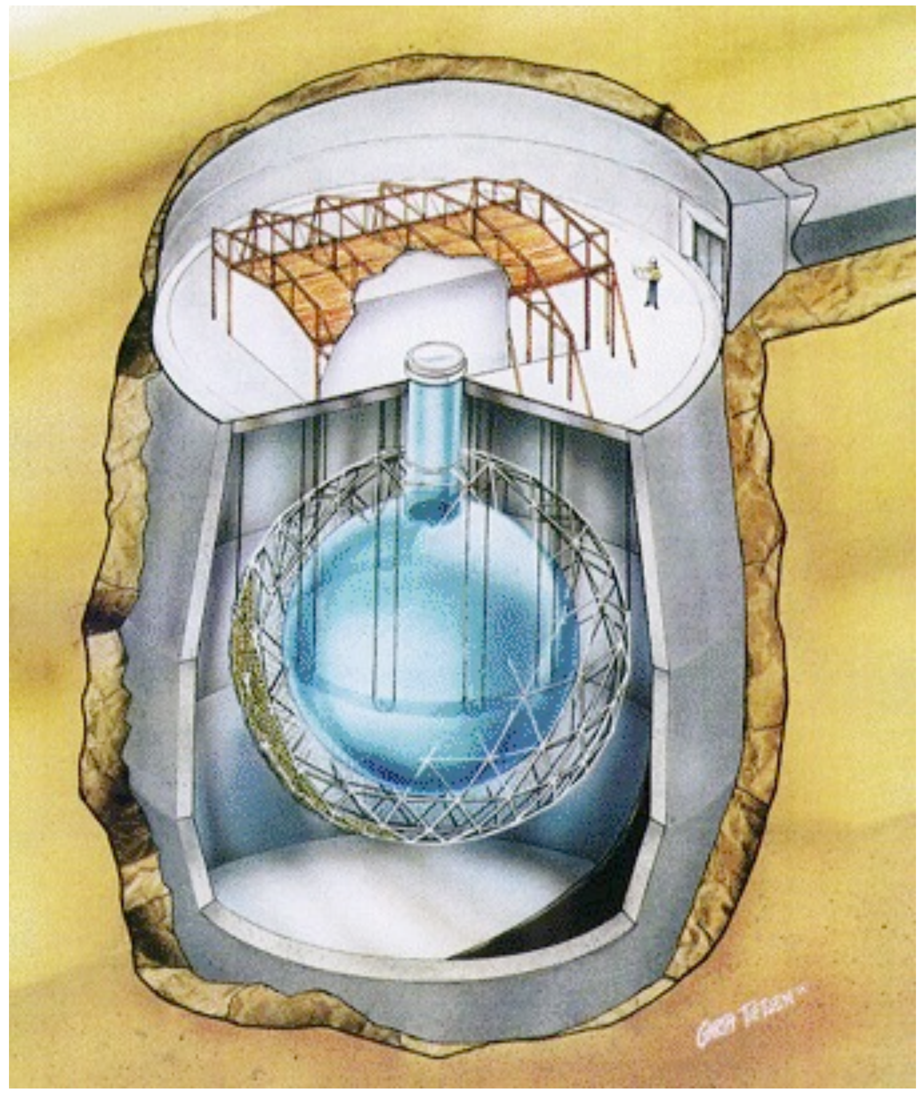
A SENSE OF SCALE

LZ, ~ 1.5m ∅ in an 8m ∅ water veto



LXe:	~7 tonne target
HPXe:	~300 kg target
1 bar Xe:	~15 kg target

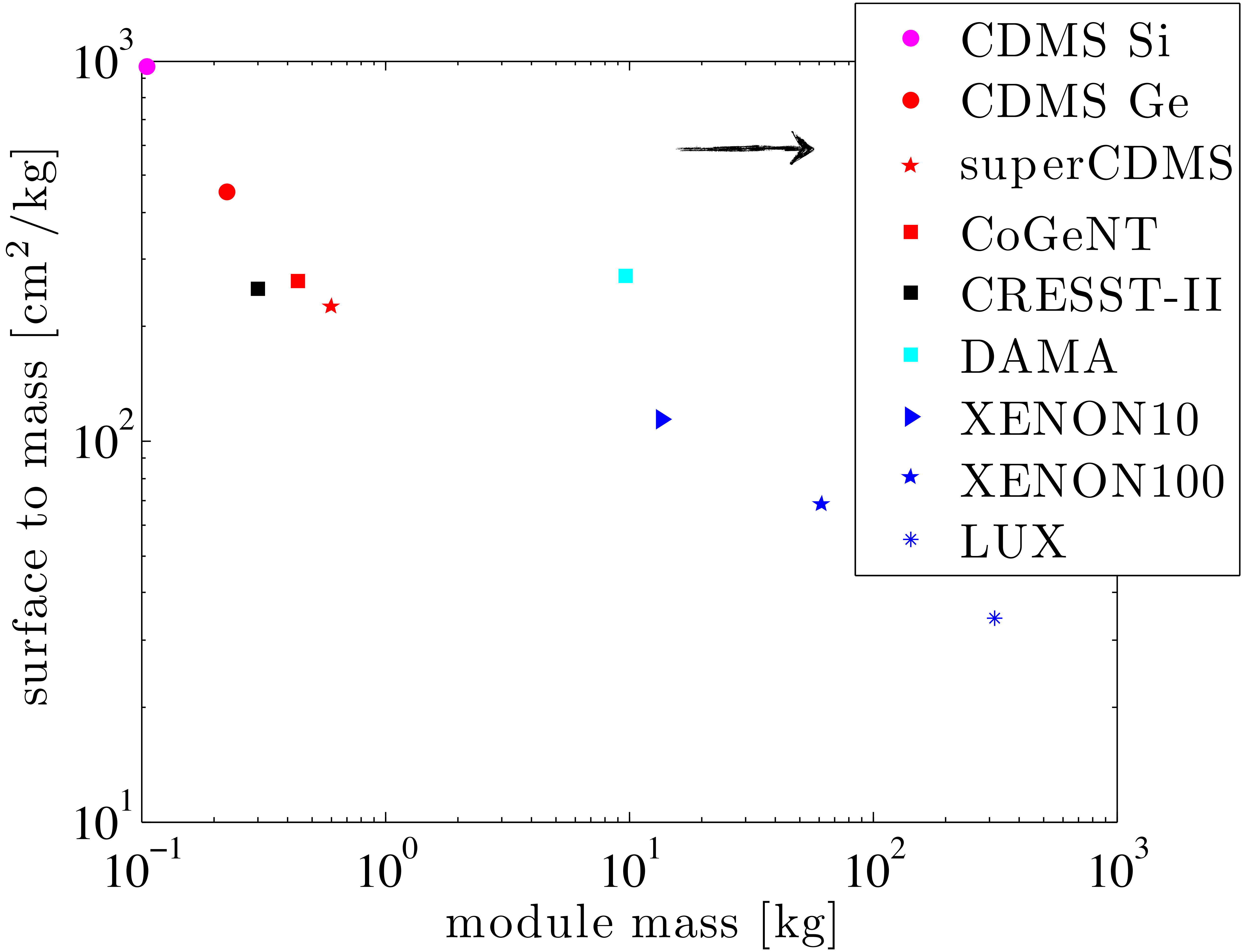
SNO, 12m ∅ in a 30m ∅ water veto



LXe:	~2.5 ktonne target
HPXe:	~90 tonne target
1 bar Xe:	~5 tonne target

WHERE WOULD A DIRECTIONAL GASEOUS TPC FALL?

- DRIFT is off scale by nearly 4 orders of magnitude!
- 15 bar xenon in a cubic meter falls at about 600 (arrow)



SO WHERE ARE WE?

- A robust direct detection of dark matter presents serious technical challeges
  - *false positive signals are easy to come by, and often difficult to reject*
  - *blinding techniques do not appear to help*
- need (but don't have) maximal event level information
- more anomalies are inevitable
  - *not necessarily a bad thing*

- **the outlook for existing experiments is still bright: need**
  - *a decent number of events (i.e. not 2, probably not 3...)*
  - *more detailed analyses of detector-induced backgrounds*

- **the outlook for directional detection is hazy**
  - *its not clear if sufficient target mass can be maintained*
  - *need to explore this*