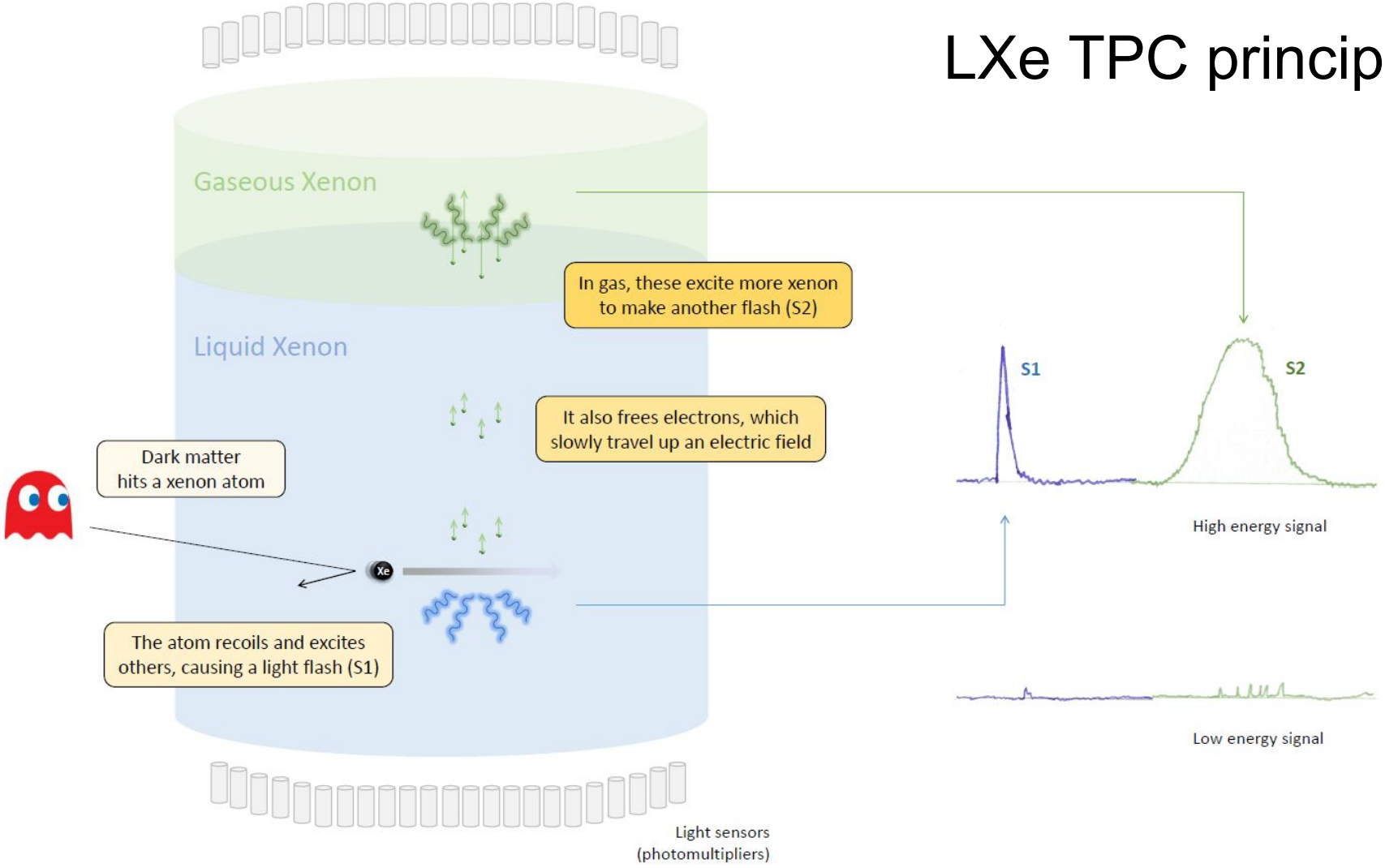
XENON1T: The analysis challenge

Jelle Aalbers
Nikhef & GRAPPA
University of Amsterdam
jaalbers@nikhef.nl

On behalf of the XENON collaboration

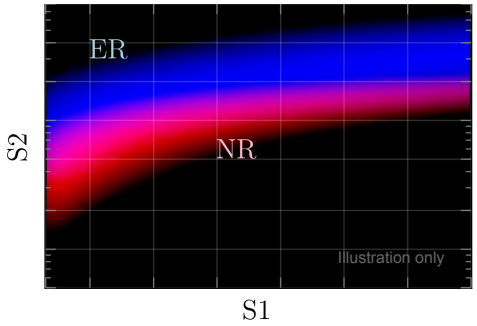
TAUP 2017

LXe TPC principle



Backgrounds

	Extrinsic	Intrinsic
Electronic recoil	Radiogenic γ, β	^{222}Rn progeny (β) ^{85}Kr (β) ν-electron scattering ^{136}Xe ββ
Nuclear recoil	Radiogenic neutrons Cosmogenic (μ-induced) n	Coherent ν-nucleus sc.

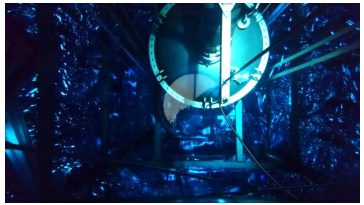


S1/S2 discrimination

^{85}Kr distillation

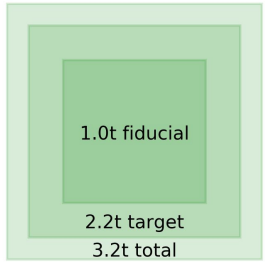
[arxiv:1612.04284]

Gran Sasso mountain
3.6 km water eq.



Instrumented water shield
10m high, 10m diam.

[https://arxiv.org/abs/1406.2374]

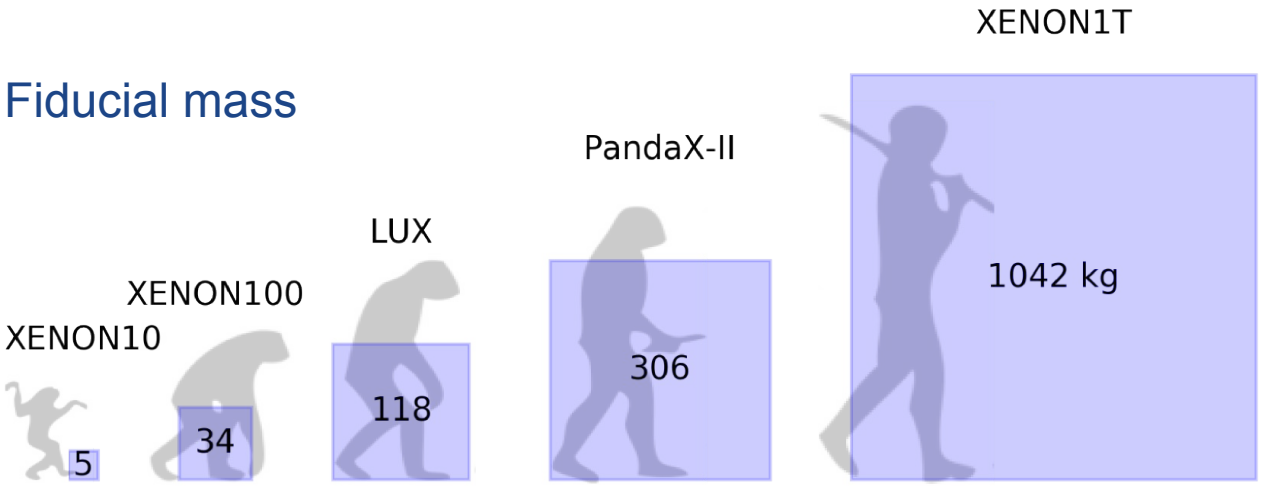


LXe self-shielding

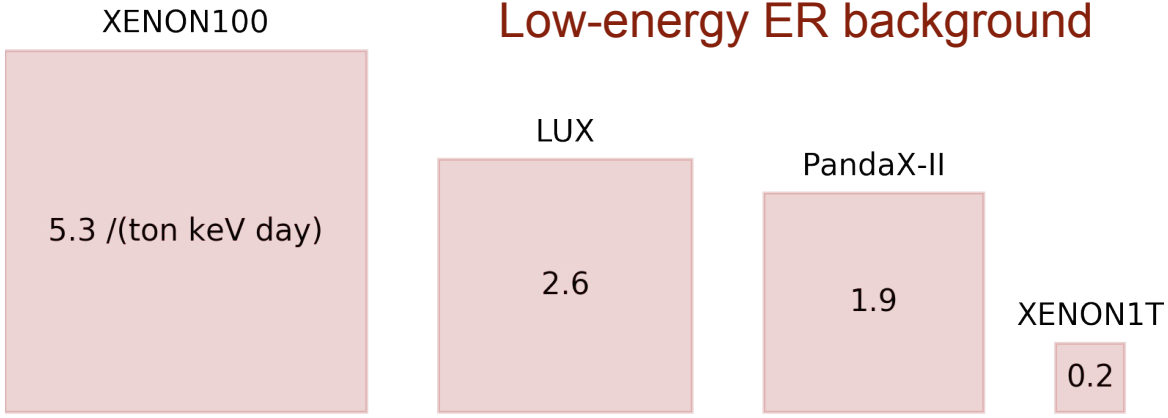
XENON1T

The next step in evolution

Fiducial mass



Low-energy ER background

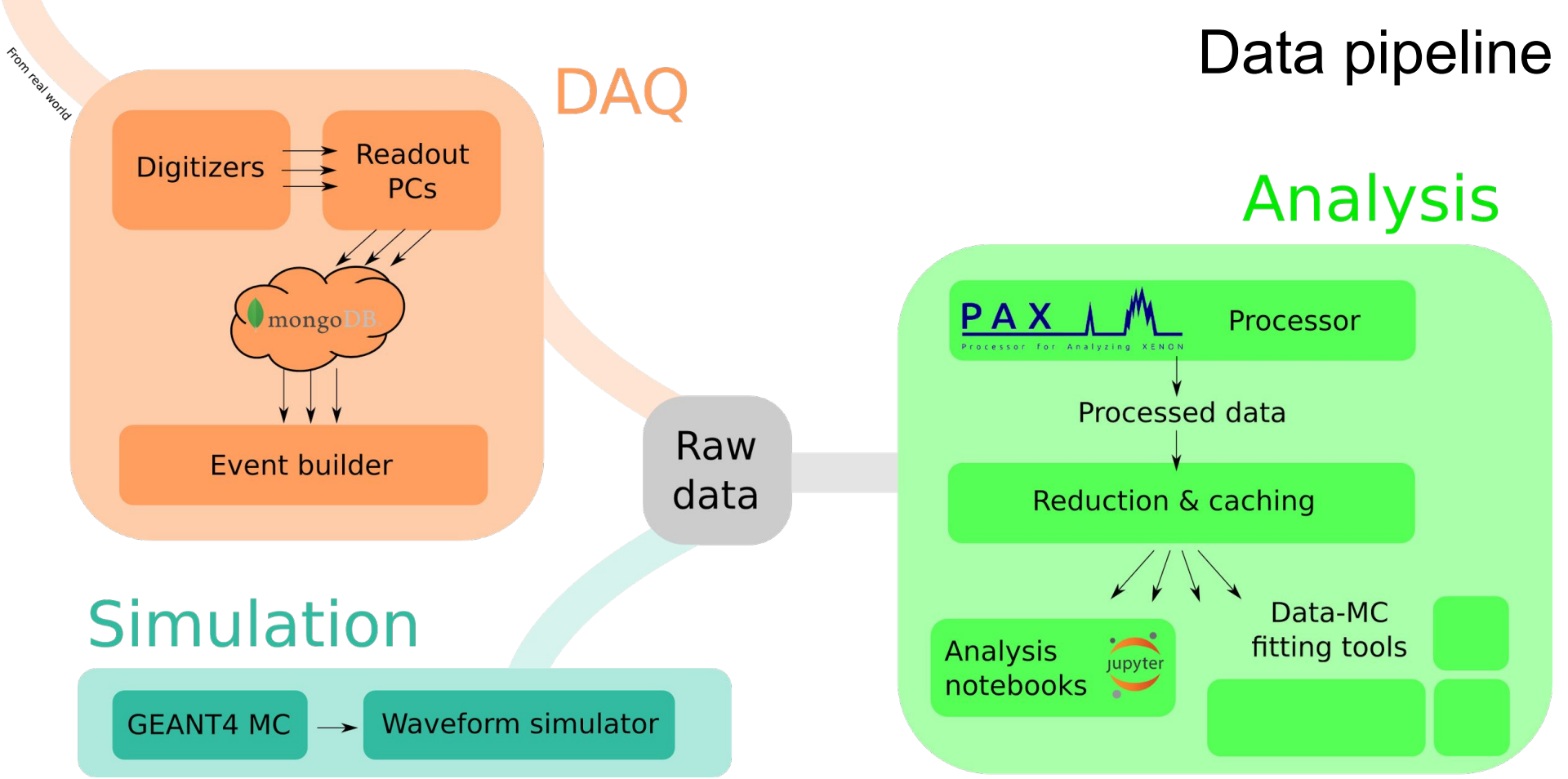


First science run: 34.2 live-days [arxiv:1705.06655]

For information on detector support systems, science run conditions and stability, see Manfred Lindner's plenary talk on Thursday.

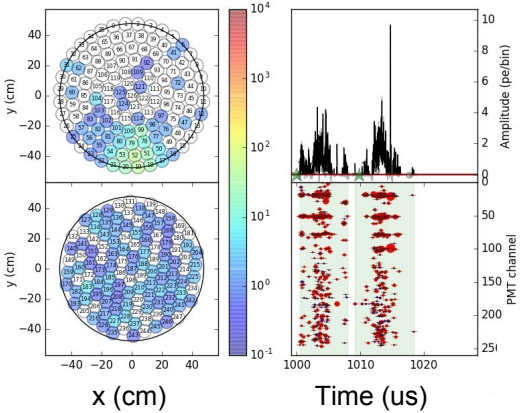
Fine print: Most experiments have different runs, often each with different fiducial volumes and background levels. LUX has a position-dependent likelihood, so there is more than one relevant background level in their fiducial volume(s). On this slide keV should be read as keV electronic recoil equivalent (keVee). XENON10's fiducial low-energy ER background was 600 events/(ton keV day). The "march of progress" is a misleading caricature of the rich and branching evolution of the great apes. Any resemblance between the ape-men and scientists working in the field is purely accidental.

Data pipeline



[https://github.com/XENON1T]

Processor & simulator calibration

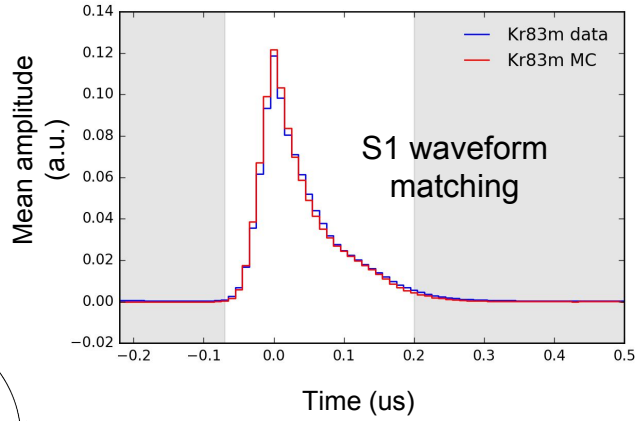


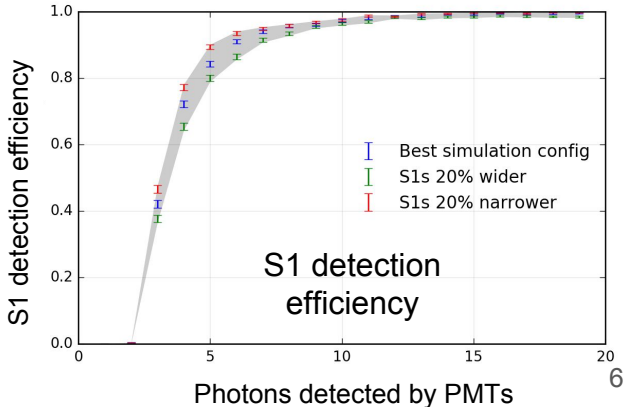
Measure simulator / data agreement

Improve simulator

Measure performance on simulated data

Improve processor





Keeping the cycle virtuous:

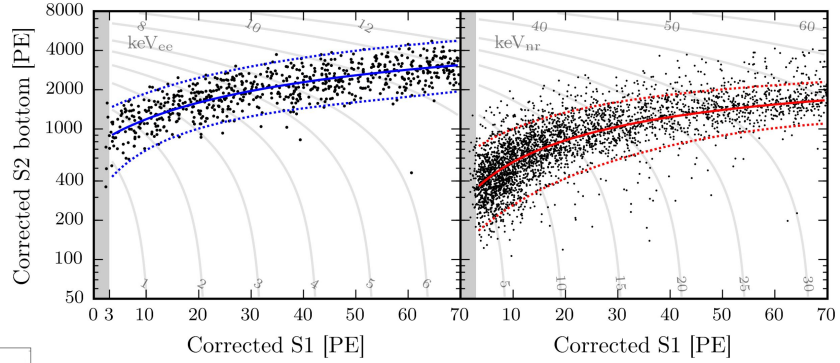
- Humans examine processed events
- Simulator contains (mostly) physical models
- Simulator injects statistical variation, processor must be generic

Processor and simulator: [https://github.com/XENON1T/pax]

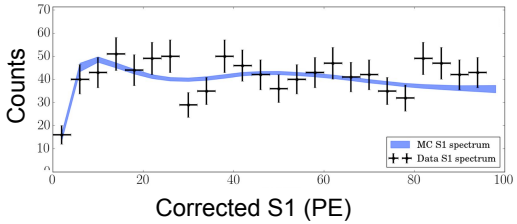
Detector response

Not shown:
(x,y,z) calibration with internal ^{83m}Kr source
Absolute signal yield (g1, g2) calibration

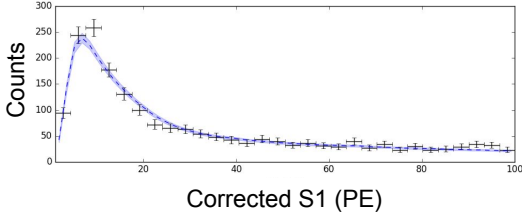
ER Calibration
Internal ^{220}Rn source

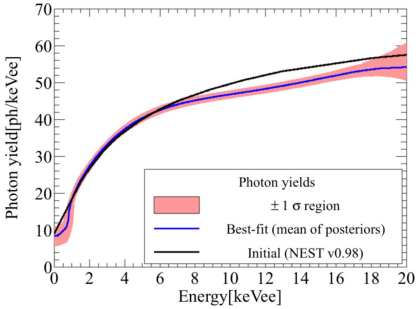


NR Calibration
External ^{241}AmBe source

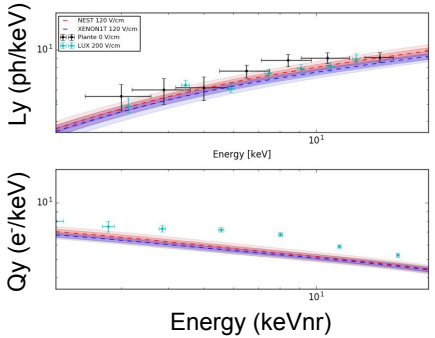


Model fits data





Fit matches literature

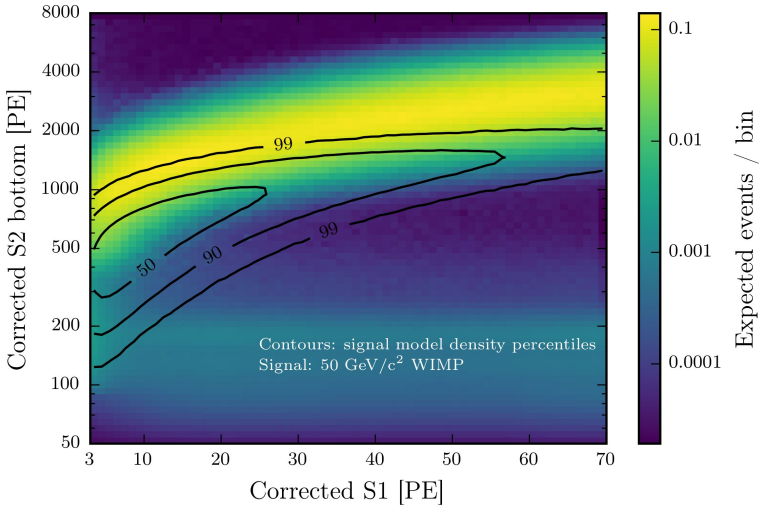


Red: prior (NEST)
Blue: posterior

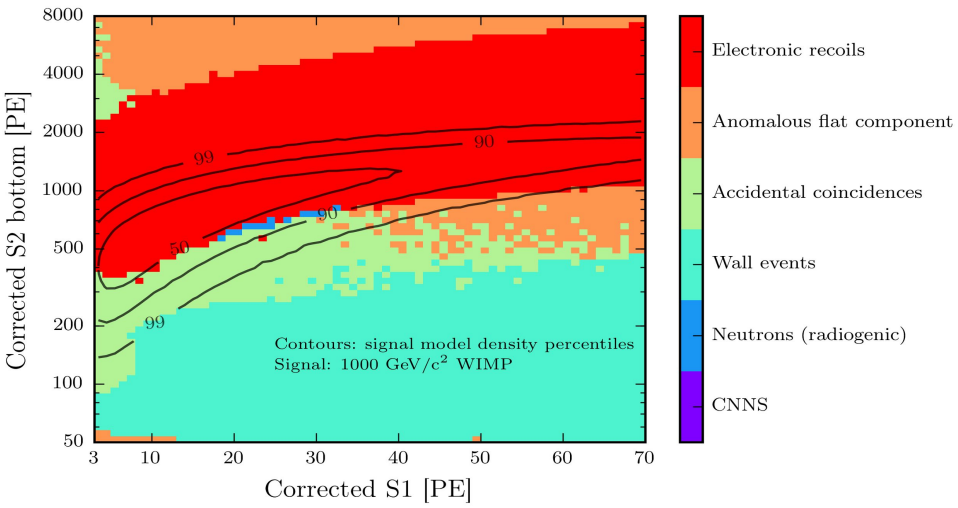
Data points:
external
measurements
(not XENON1T)

Background model

Total background model

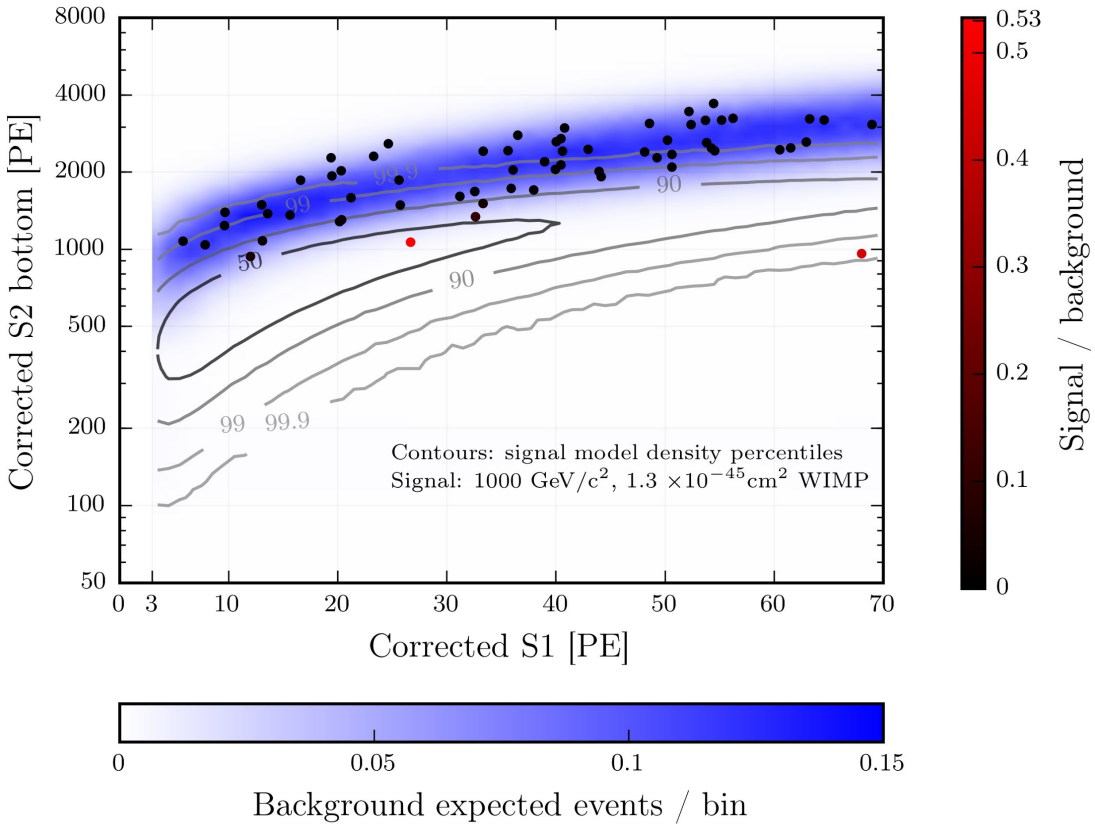


Dominant background component map



ERs are the most significant background (for > 10 GeV WIMPs)
Wall events are below the ER band, but too low S2 to hurt much
Anomalous component extremely small (~ 0.1 events expected)

Dark matter search



Two interesting events :

- 27 PE : at -2.4σ (99.2th percentile) of the ER background.
- 68 PE: probably unmodeled backgr.

Background-only (no WIMPs) still best fit at all WIMP masses.

Signal model shown here is exactly at our published 90% C.L. limit.

Statistical interpretation by extended unbinned profile likelihood ratio test:

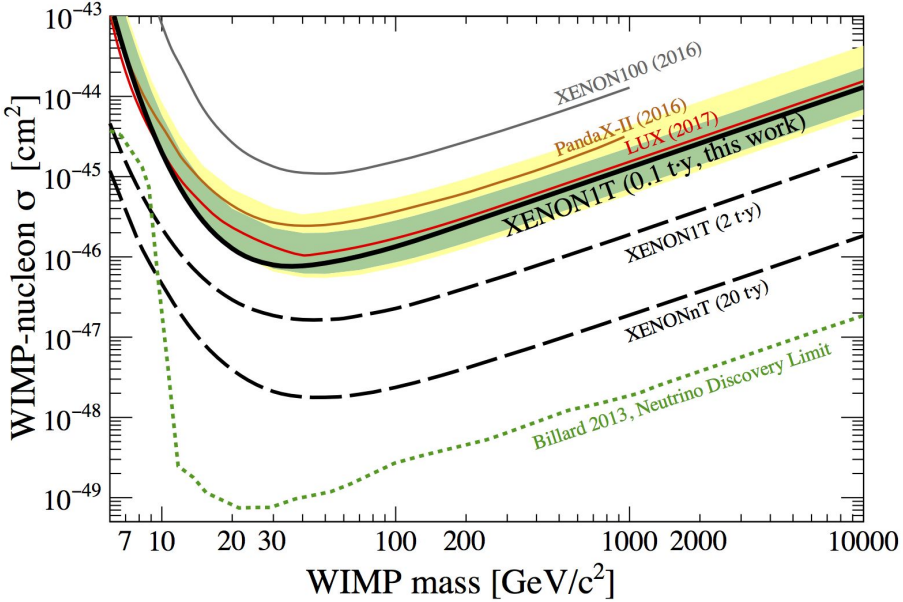
$$\log L = -\mu + \sum_{i}^{\text{events}} \log \left(\sum_{j}^{\text{sources}} \mu^{(j)} \text{pdf}^{j}(\text{event } i) \right)$$

Uncertainties are nuisance parameters:

- Background component rates
- ER and NR band shape

Inference software: [https://github.com/JelleAalbers/blueice]

Result and outlook



[arxiv:1705.06655]

Rare event search: huge statistical uncertainty
1σ band spans a factor 4

Choices could have led to a different limit (reason for blinding):

- using cS2 total instead of bottom
- removing 68 PE outlier
- statistical details: power constraint vs CLs, likelihood ratio distribution approximations

XENON1T is the largest LXe TPC, with the lowest-ever low-energy background.

Future:

- XENON1T: > 100 live-days already taken
- XENONnT: ~5 ton fiducial upgrade, ~2019

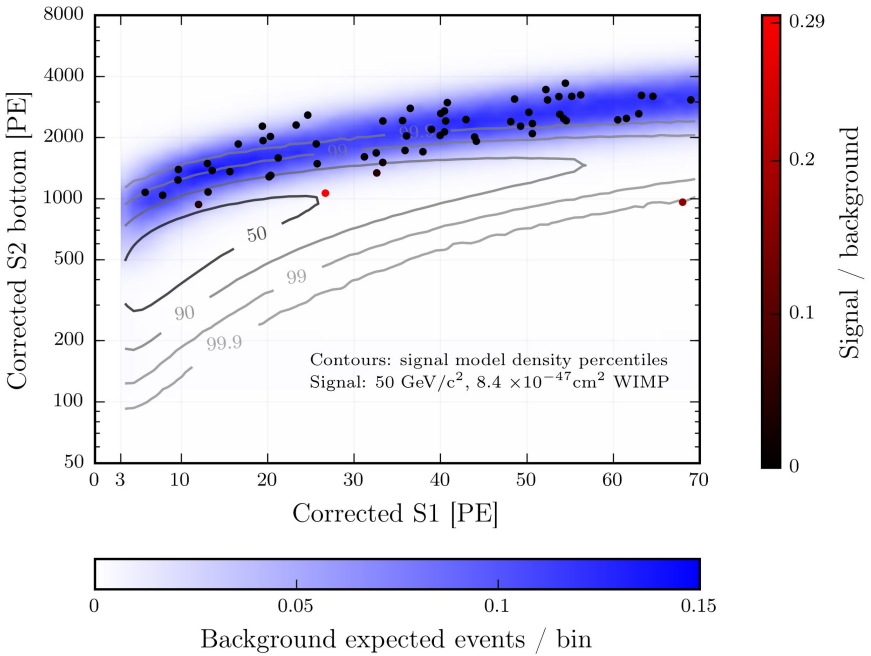
Don't miss other XENON-related talks at TAUP:

- Alex Fieguth (Today, 14:45 Neutrino session): *Double electron capture results*
- Rafael Lang (Tue. 16:45 DM session): *The DARWIN Observatory*
- Manfred Lindner (Thursday Plenary): *XENON1T status and first results*

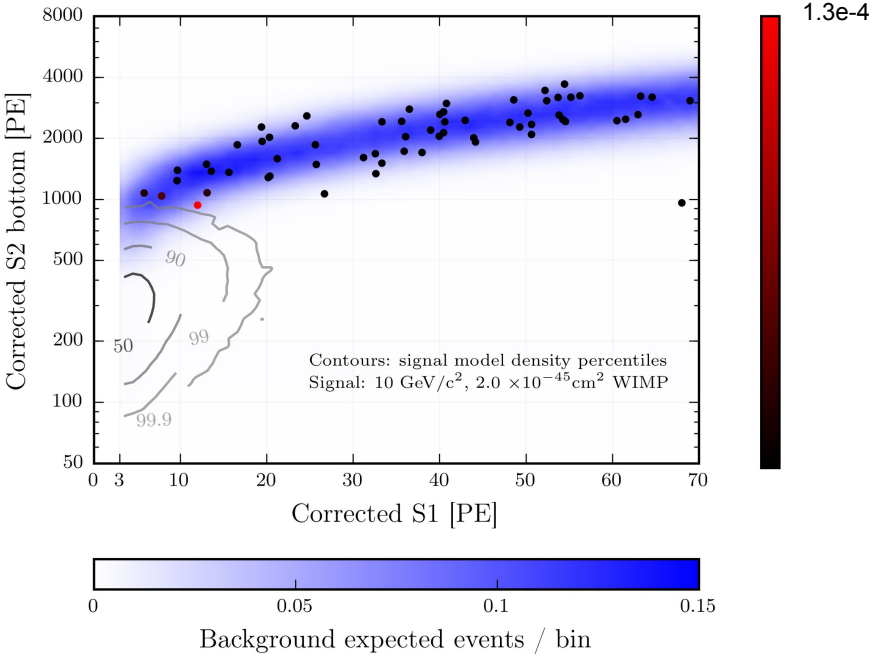
Backup slides

Lower-mass WIMPs

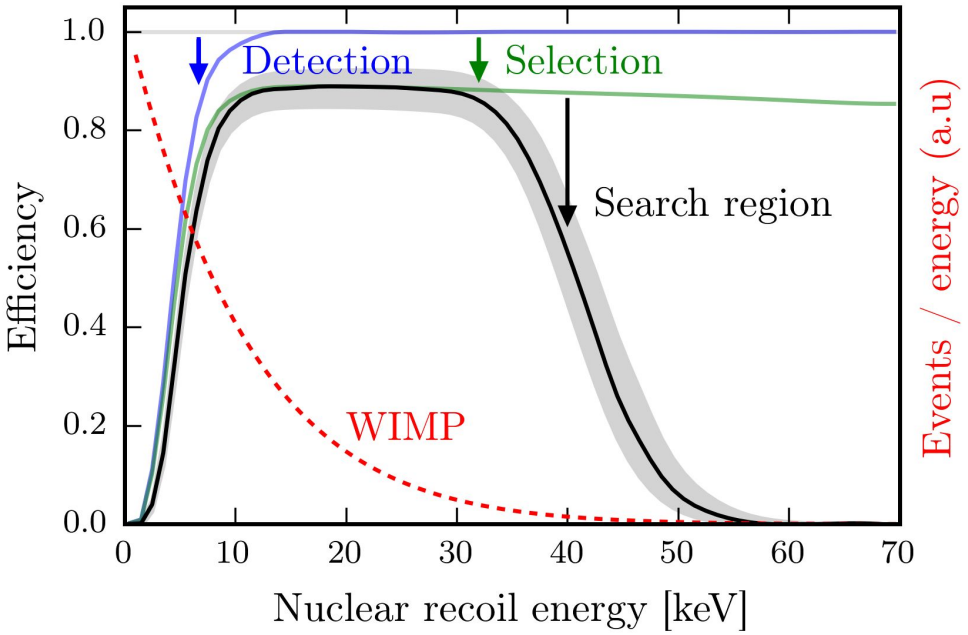
50 GeV



10 GeV

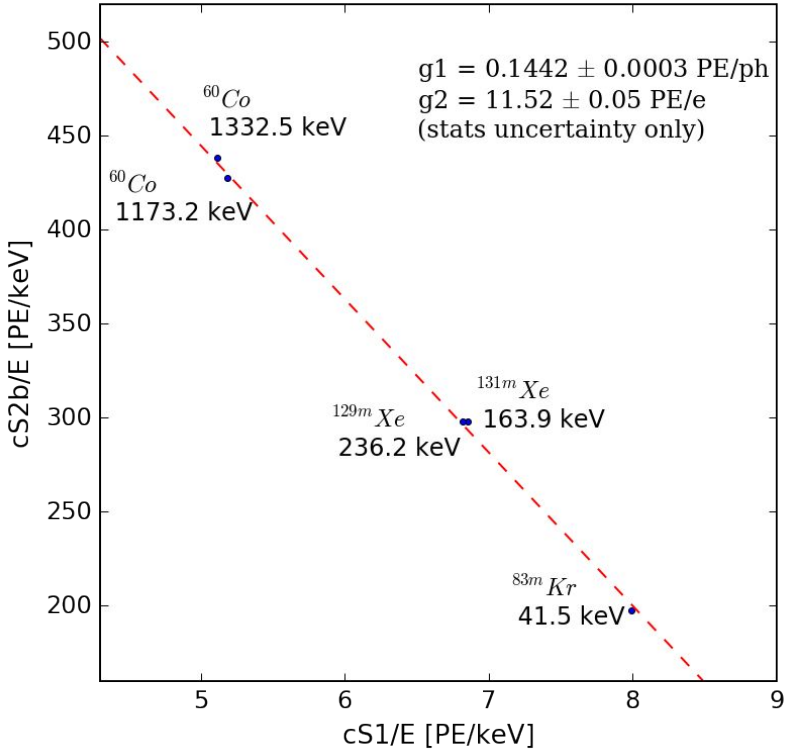


Signal efficiency

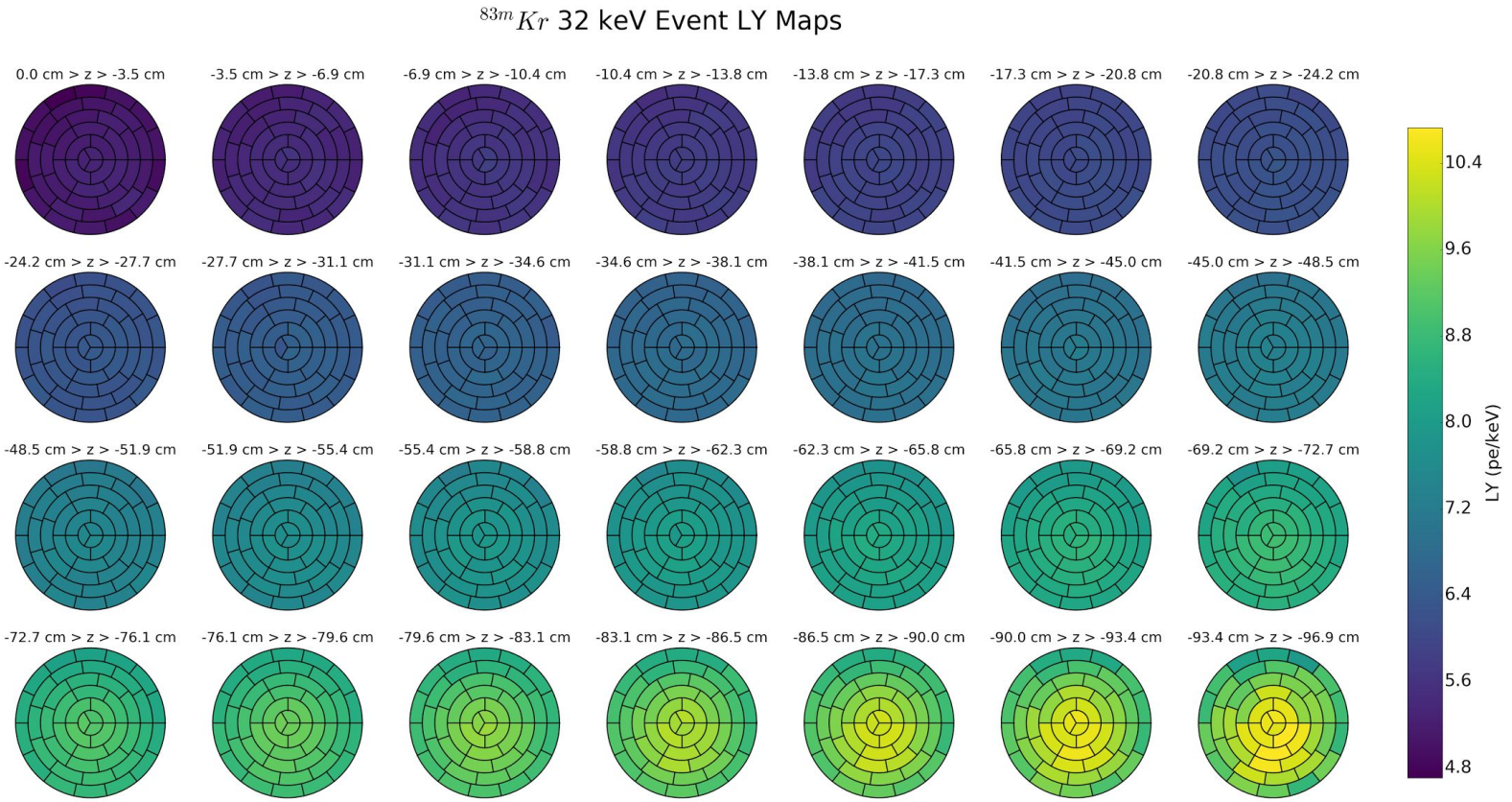


Dominant signal loss is from 3 PMT S1 coincidence requirement
Example WIMP spectrum shown here is for m = 50 GeV

Absolute signal yield calibration

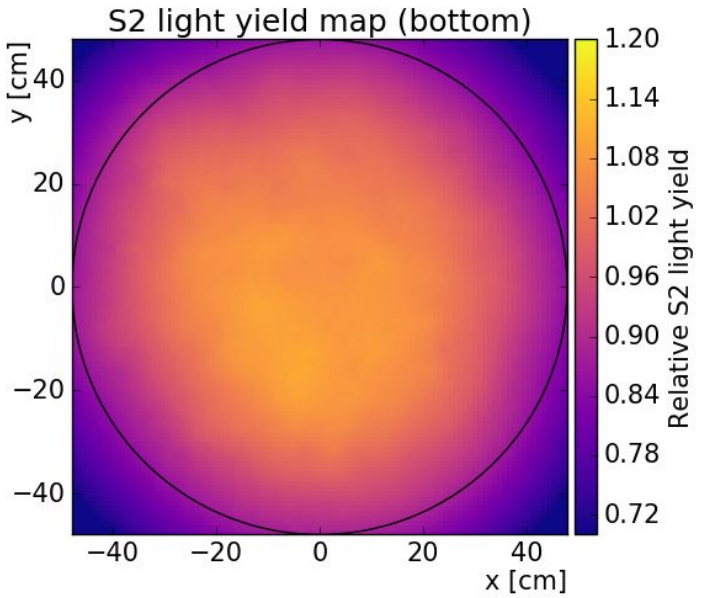


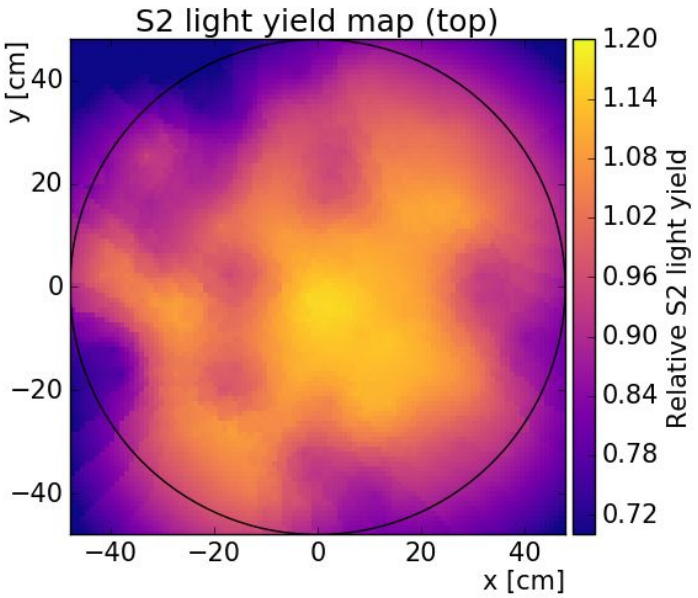
Spatial response calibration with ^{83m}Kr



Backup slide

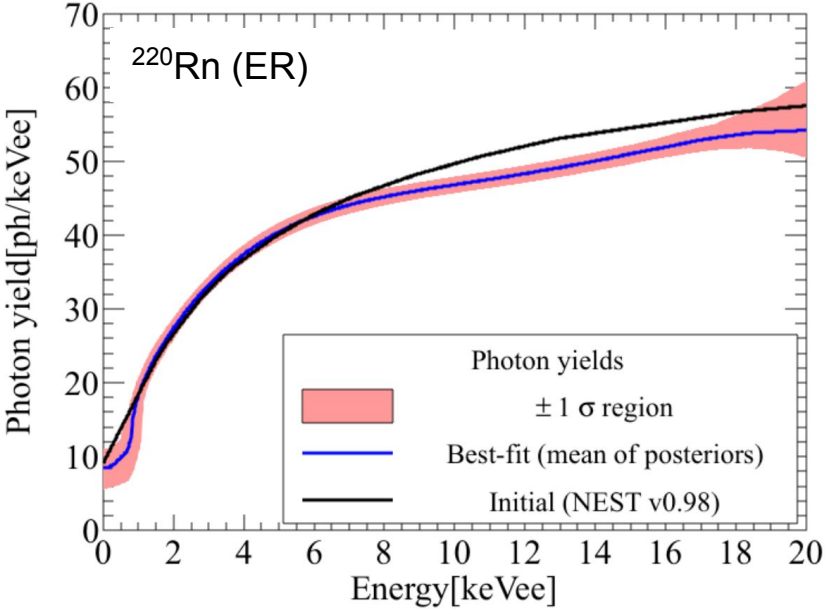
Spatial response calibration with ^{83m}Kr

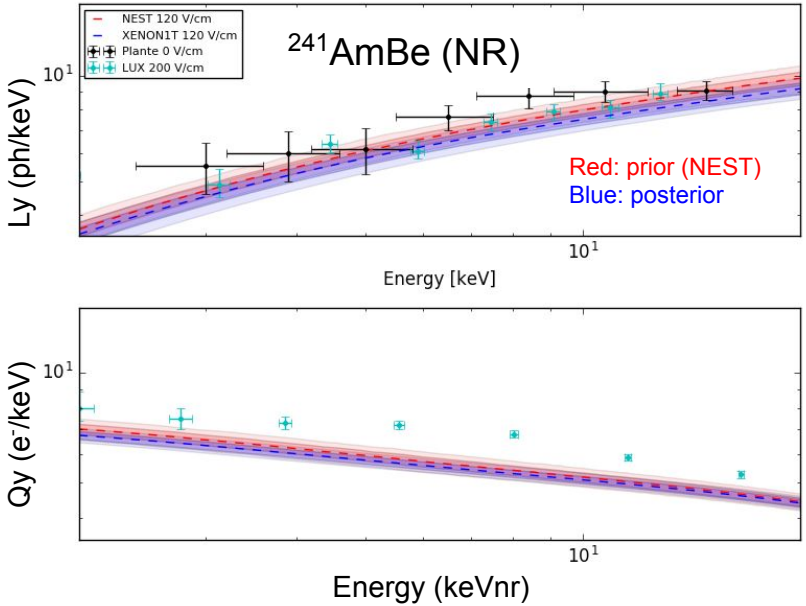




S2 response more homogeneous in bottom array: only bottom array S2 used for analysis

ER and NR fit comparison with literature





NR fit is *not* a Qy/Ly measurement: we start from tight NEST priors [https://arxiv.org/abs/1412.4417]


Xe
XENON
Matter Project