Search for Event Rate Modulation in XENON100 Electronic Recoil Data

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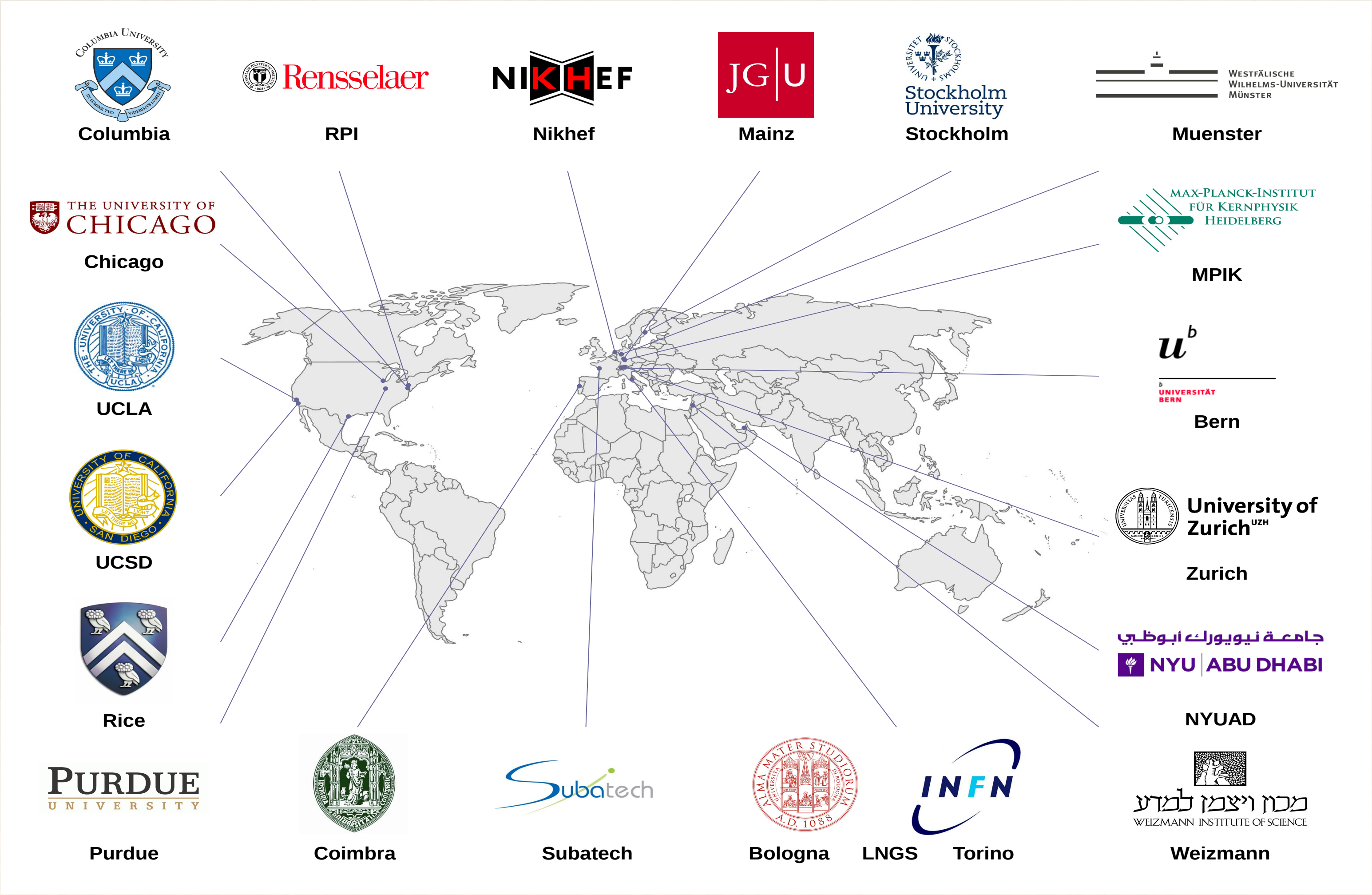
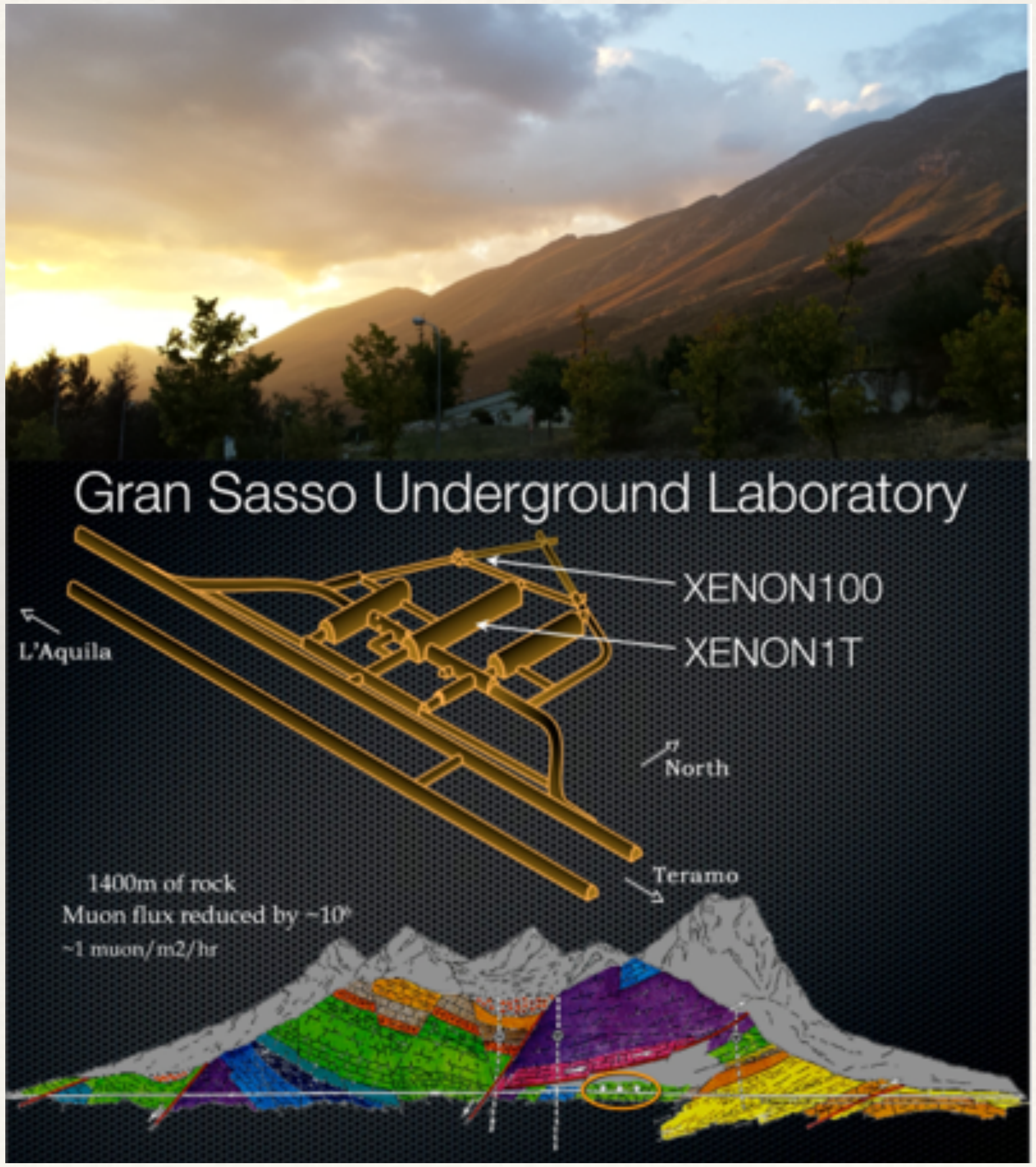
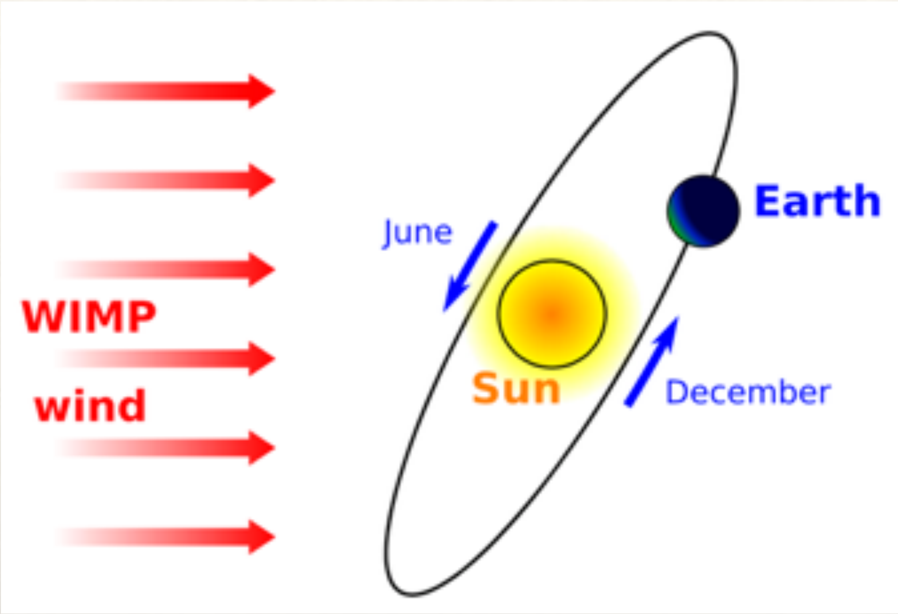
XENON Collaboration

~130 Scientists from 21 institutes





Annual modulation and DAMA/LIBRA



Freese *et al.*, Rev. Mod. Phys. 85, 1561 (2013)

Dark matter (DM) signal rate is expected to be annually modulating

peak phase 152 days (June 1)

A key feature to distinguish signals from overwhelming backgrounds

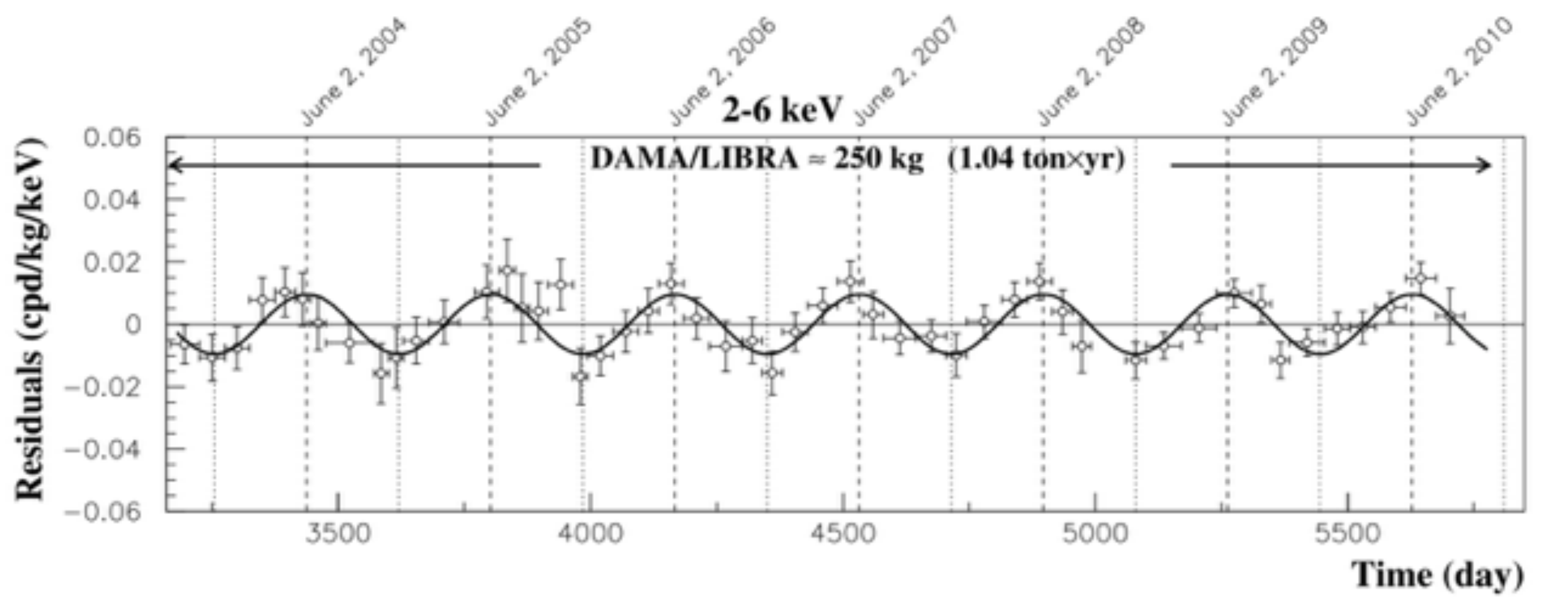
DAMA/LIBRA:

9.3 sigma significance

only for single hit

Phase (144 +- 7) days

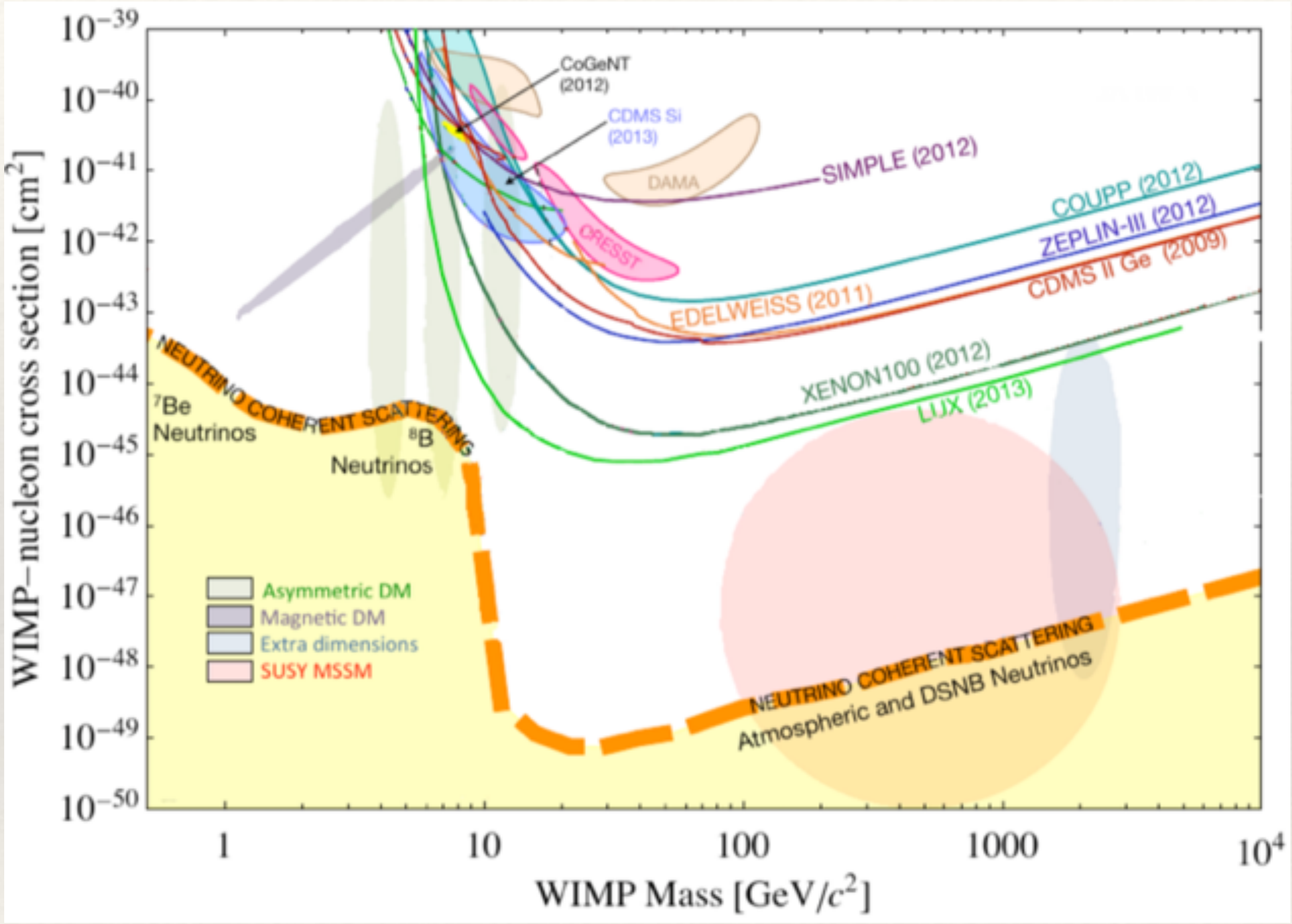
No signal above 6 keV



Bernabei *et al.*, Eur. Phys. J. C 73, 12 (2013)

Seems to be a convincing evidence, HOWEVER…

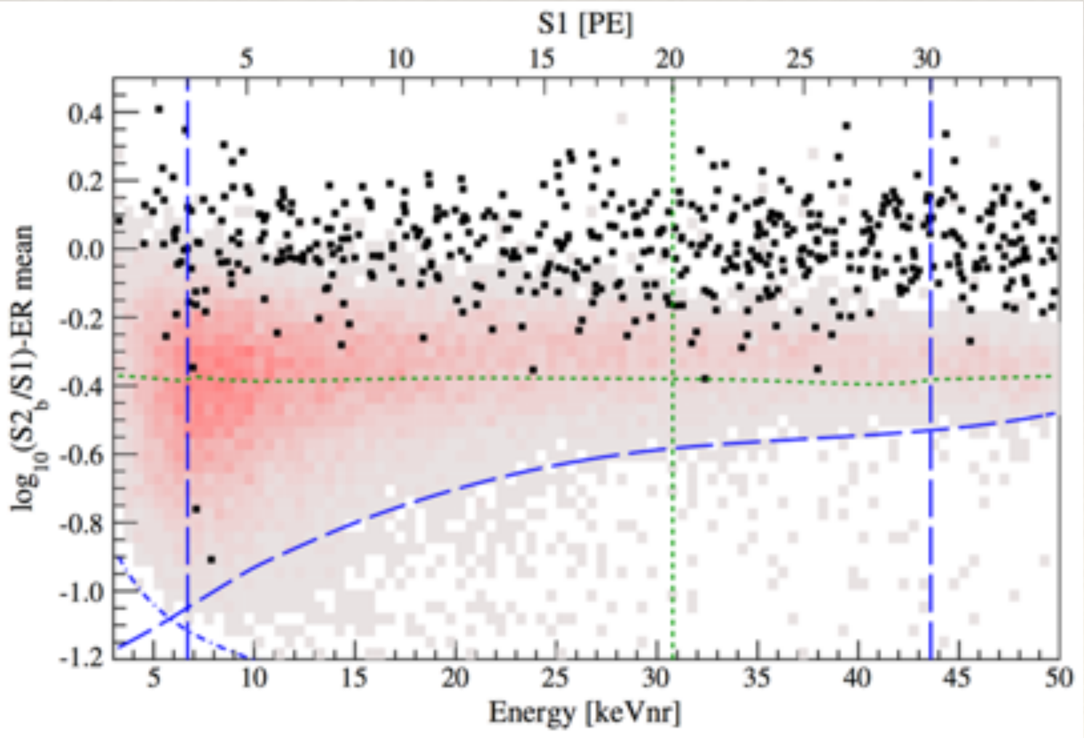
Nuclear Recoil Interpretation



Nuclear recoil interpretations of DAMA/LIBRA modulation have been challenged by several more sensitive experiments with background rejection power

How about Leptophilic DM?

- DAMA/LIBRA annual modulation can be interpreted as signals from Leptophilic DM models
- We tested three representative models in XENON100 using the electronic recoil data:
- 1, DM-electron scattering through axial-vector coupling
- 2, Mirror DM model
- 3, Luminous DM model

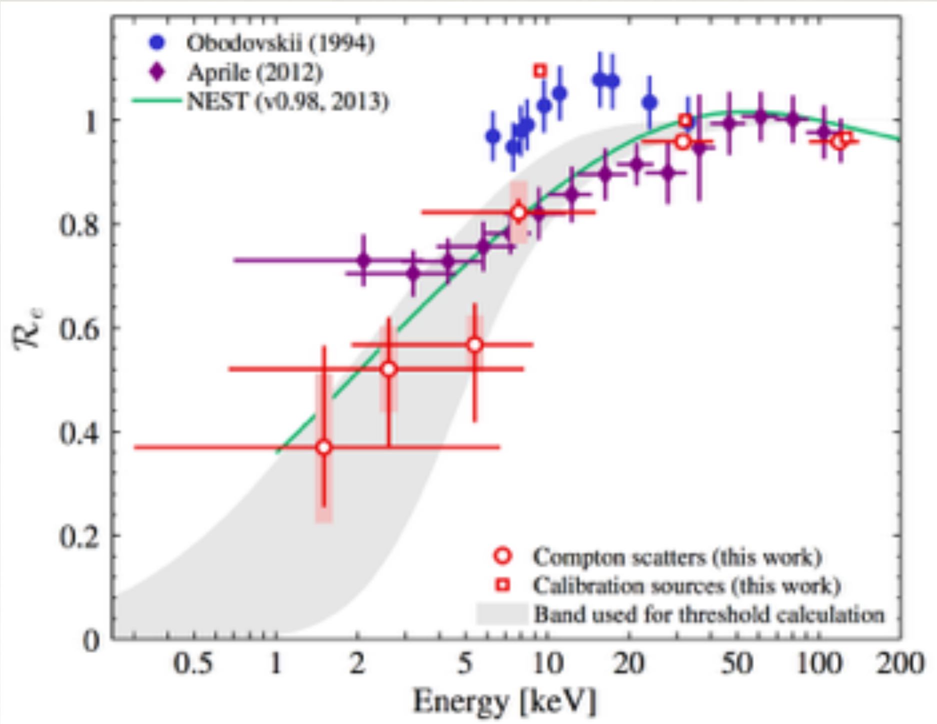


Light Response in XENON100

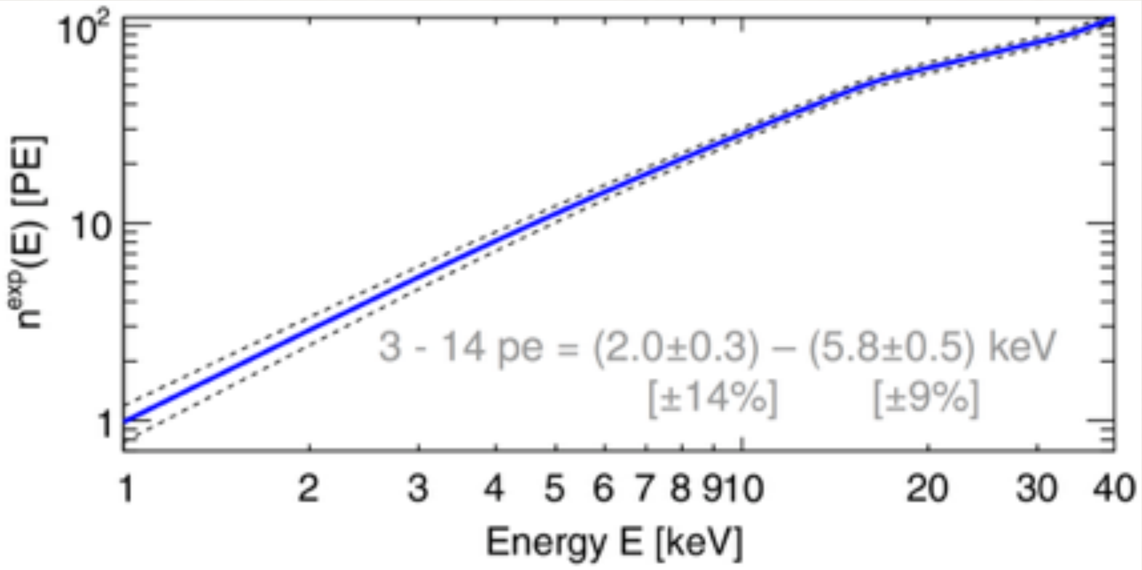
light response is determined with low energy measurements interpolated by NEST v0.98, uncertainties are from NEST and spread of measurements

Szydagis et al., J. Instrum. 6, P10002 (2011)

DAMA/LIBRA 2-6 keV Electronic recoil (ER) corresponds to 3-14 PE in XENON100



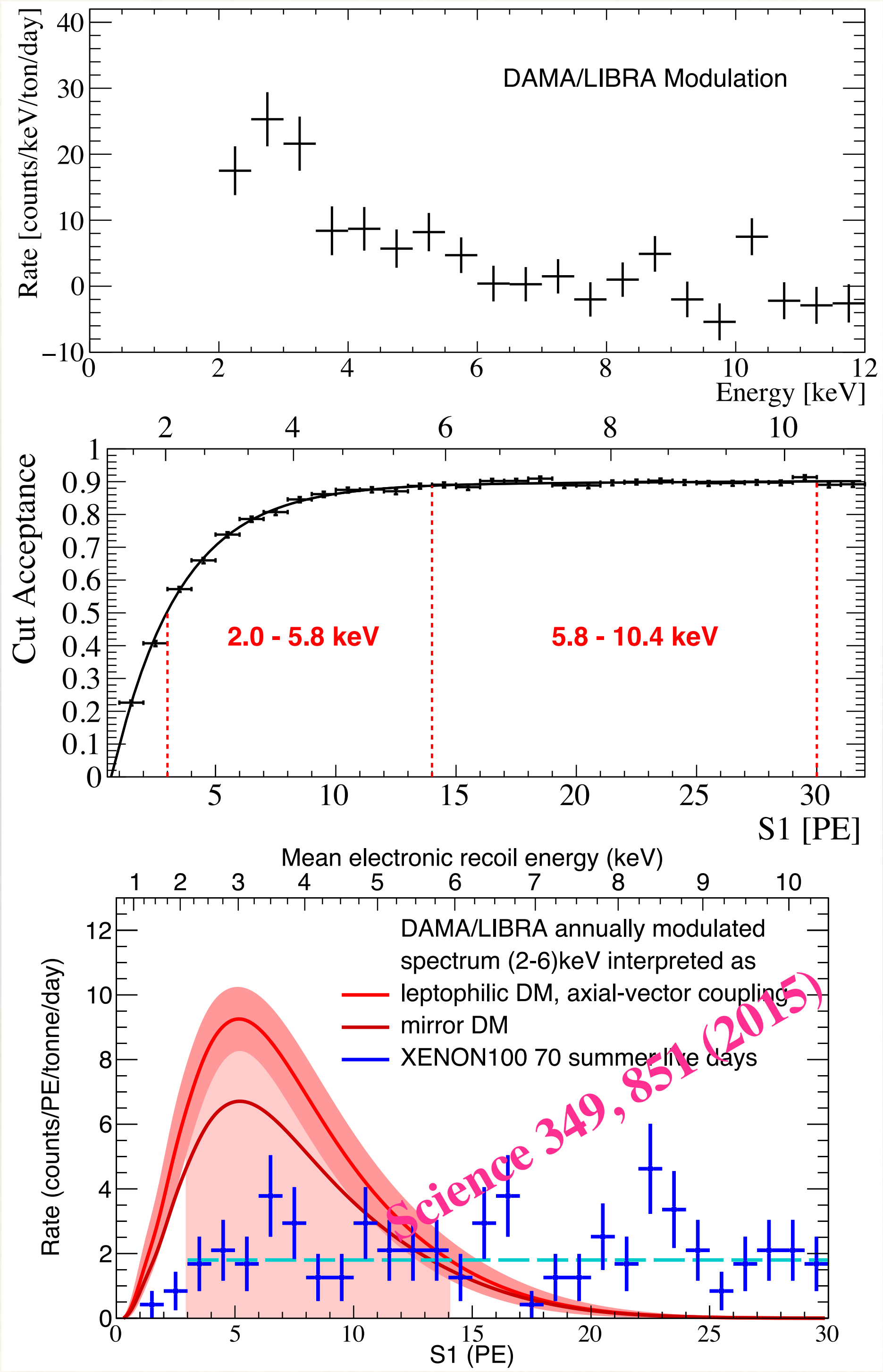
Baudis *et al*., Phys. Rev. D 87, 115015 (2013)



Aprile *et al*., Phys. Rev. D 90, 062009 (2014)

DAMA/LIBRA Comparison

- DAMA/LIBRA rate converted to XENON100 spectrum assuming leptophilic DM model, axial vector coupling
- Energy response, resolution and cut acceptance applied
- Compare XENON100 average rate with DAMA/LIBRA modulation amplitude
- Constraints on DM interpretation of DAMA/LIBRA (assuming 100% modulation):
- WIMPs-electron scattering 4.4-sigma
- Mirror dark matter model 3.6-sigma
- Luminous dark matter model 4.6-sigma

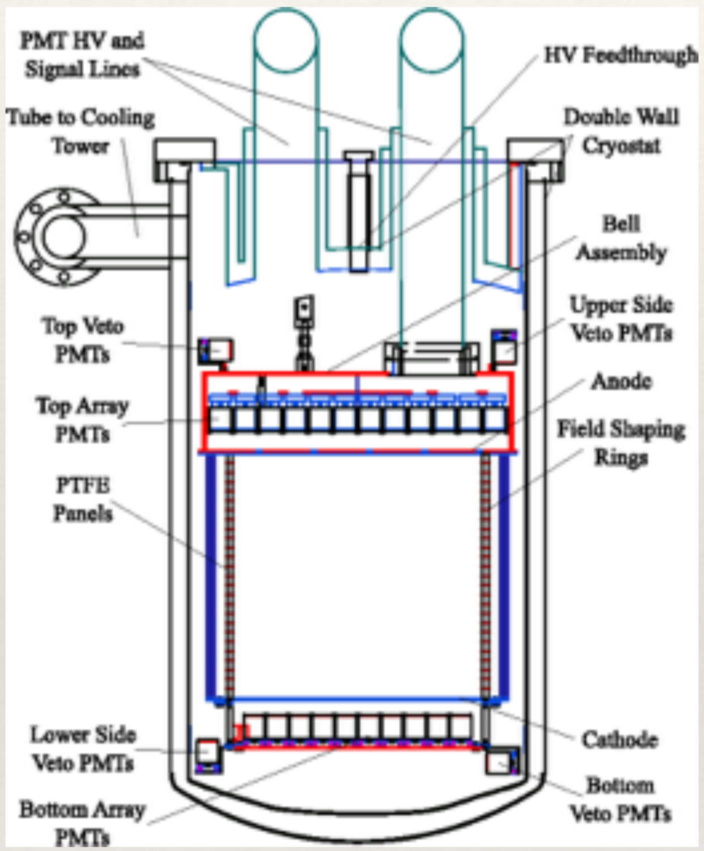


Search for Modulations

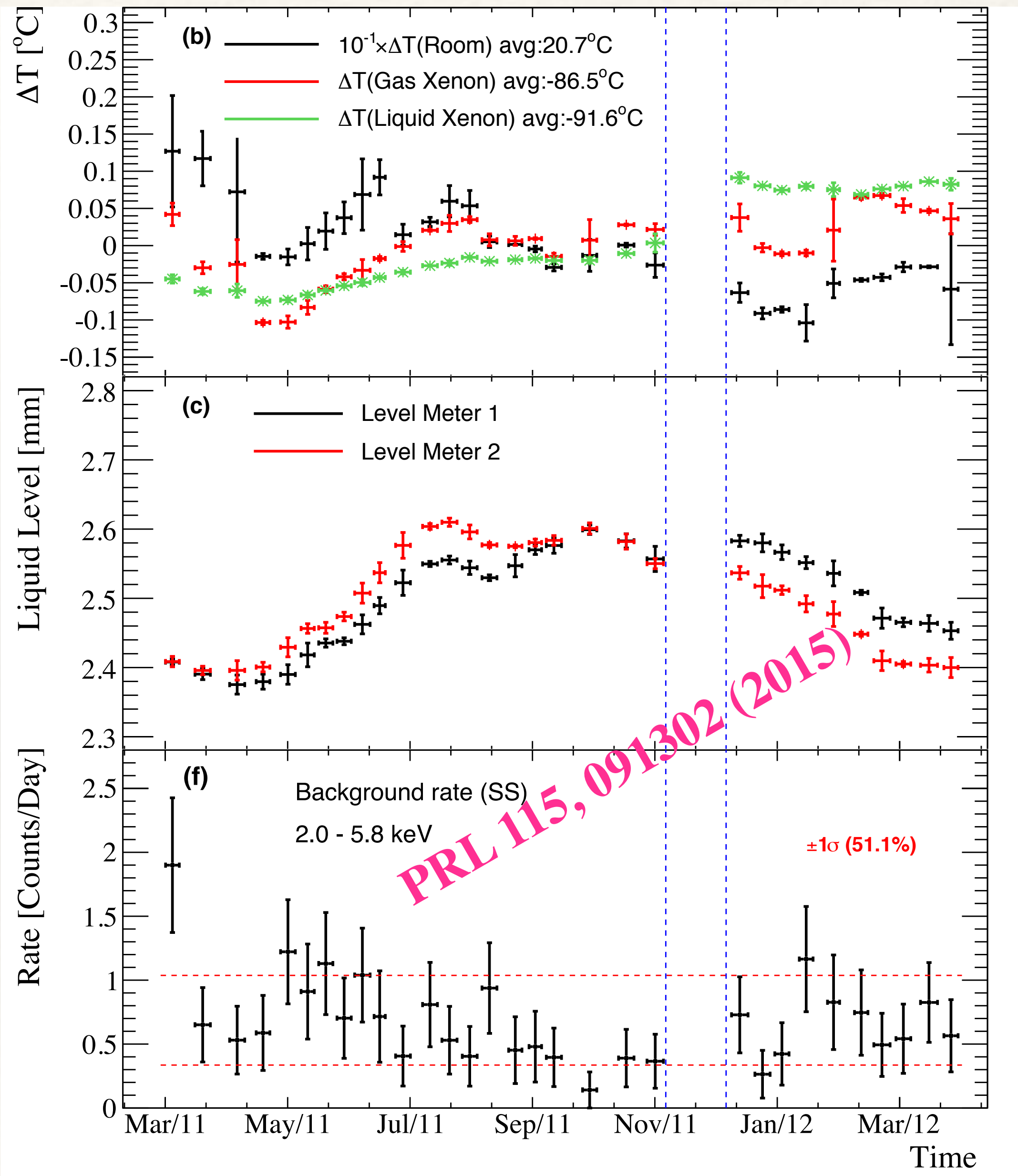
- The first LXe TPC with more than one year of stable running conditions
- The first modulation search for DM at Gran Sasso Lab after DAMA/LIBRA
- Demonstration for future XENON modulation searches
- Search for leptophilic DM signals
- Require good understand the stability of detector and backgrounds

Stability of the Detector

Aprile *et al.*, Astropart. Phys., 35, 573-590 (2012)



- Detector pressor (2)
- Room pressor
- LXe temperature (4)
- PTR temperature
- Room temperature
- Purification flow rate
- LXe levels (2)
- PMT gain
- Radon level (2)



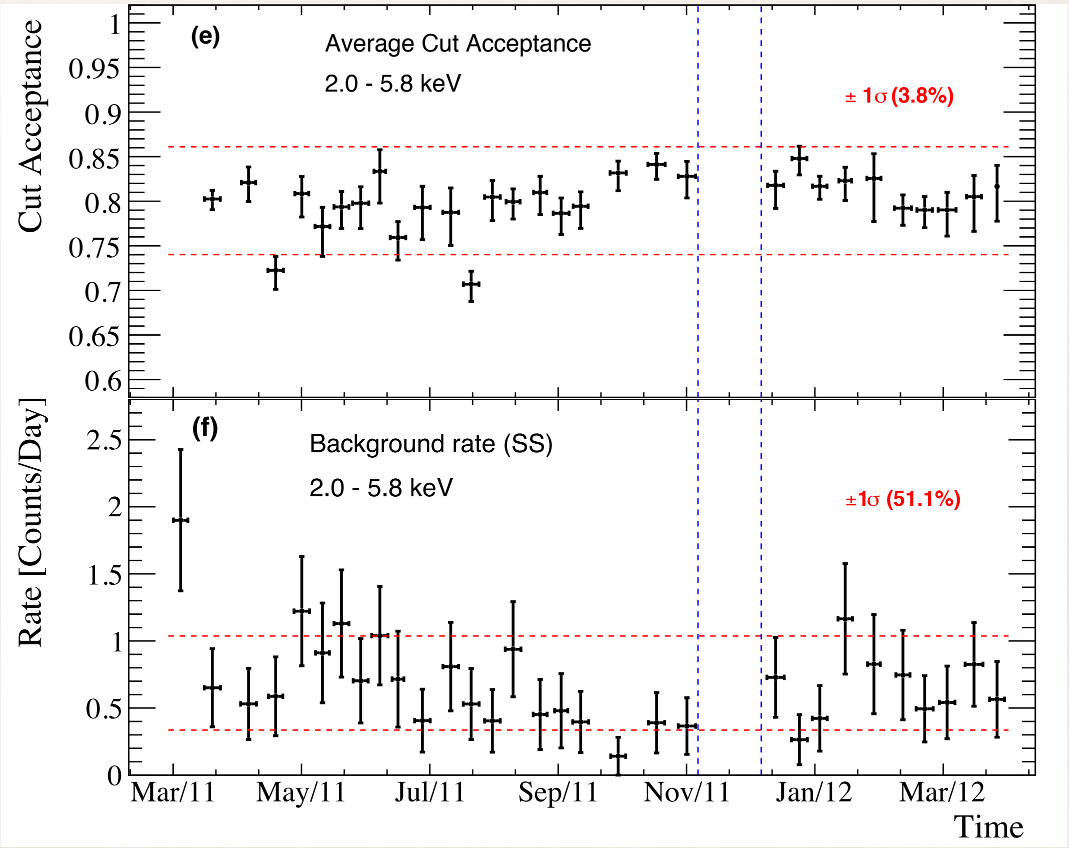
Very tiny absolute variations

No correlations with ER rate

No significant impact on ER rate!

Stability of Cut Acceptance

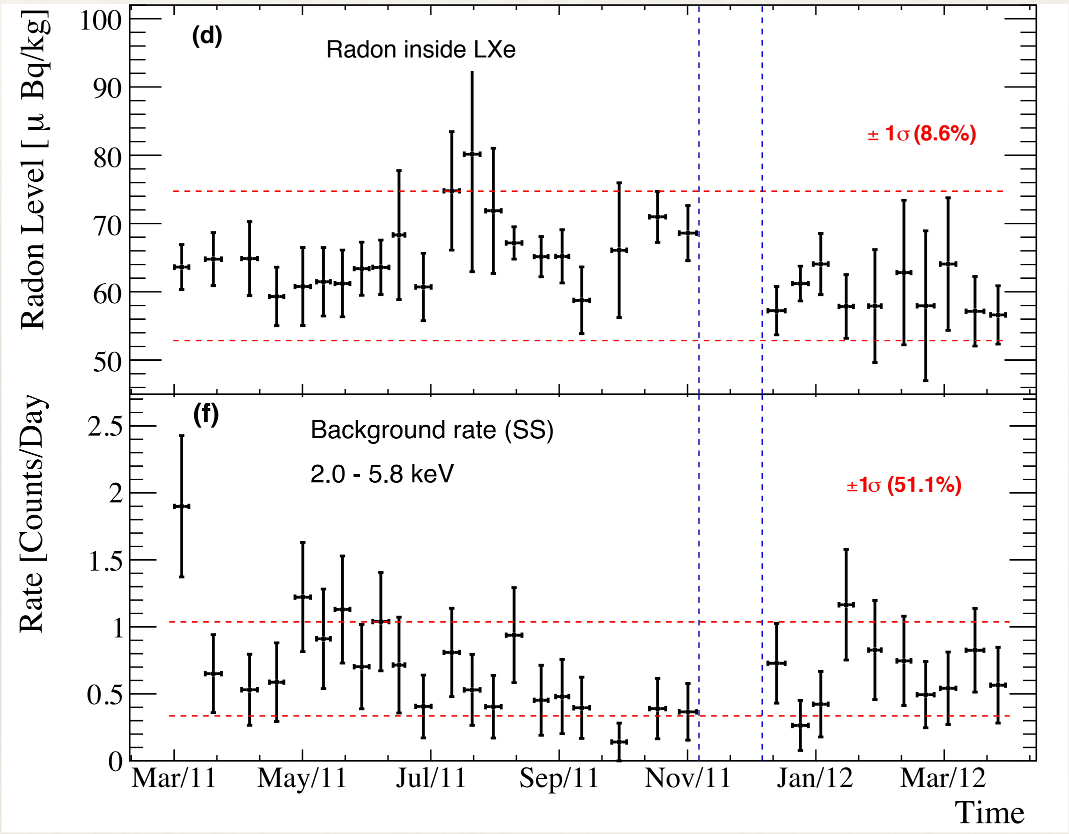
- Stability of cut acceptance is derived from weekly ER calibrations sources
- The acceptance variation further accounts for the variation of the detector parameters like LXe level.
- The dips of acceptance are due to increment of noise level.
- The fluctuation of acceptance is taken into account for the event rate modulation analysis.



PRL 115, 091302 (2015)

Stability of Backgrounds

- Co60 ($T_{1/2} = 5.3$ year) gamma background is time dependent, but the absolute contribution is negligible.
- Radon and krypton background concentration are time dependent due to tiny air leak
- Radon contributes to the overall background by less than 20%. Hence the absolute contribution to fluctuation is negligible.
- No correlation between radon and ER rate.
- Krypton concentration varies in time due to air leak. The size of its variation is taken into account.



Profile Likelihood Analysis

Cut acceptance

constant background

Event Rate: $\longrightarrow$ $$f(t) = \epsilon(t)\left(C + Kt + A\cos\left(2\pi\frac{(t-\phi)}{P}\right)\right)$$

krypton variation
due to air leak

modulation

$$\mathcal{L} = \left(\prod_{i=1}^{n} \tilde{f}(t_i)\right) \text{Poiss}\left(n|N_{\text{exp}}(E)\right) \mathcal{L}_\epsilon \mathcal{L}_K \mathcal{L}_E$$ $\longleftarrow$ energy response

observed number
of events

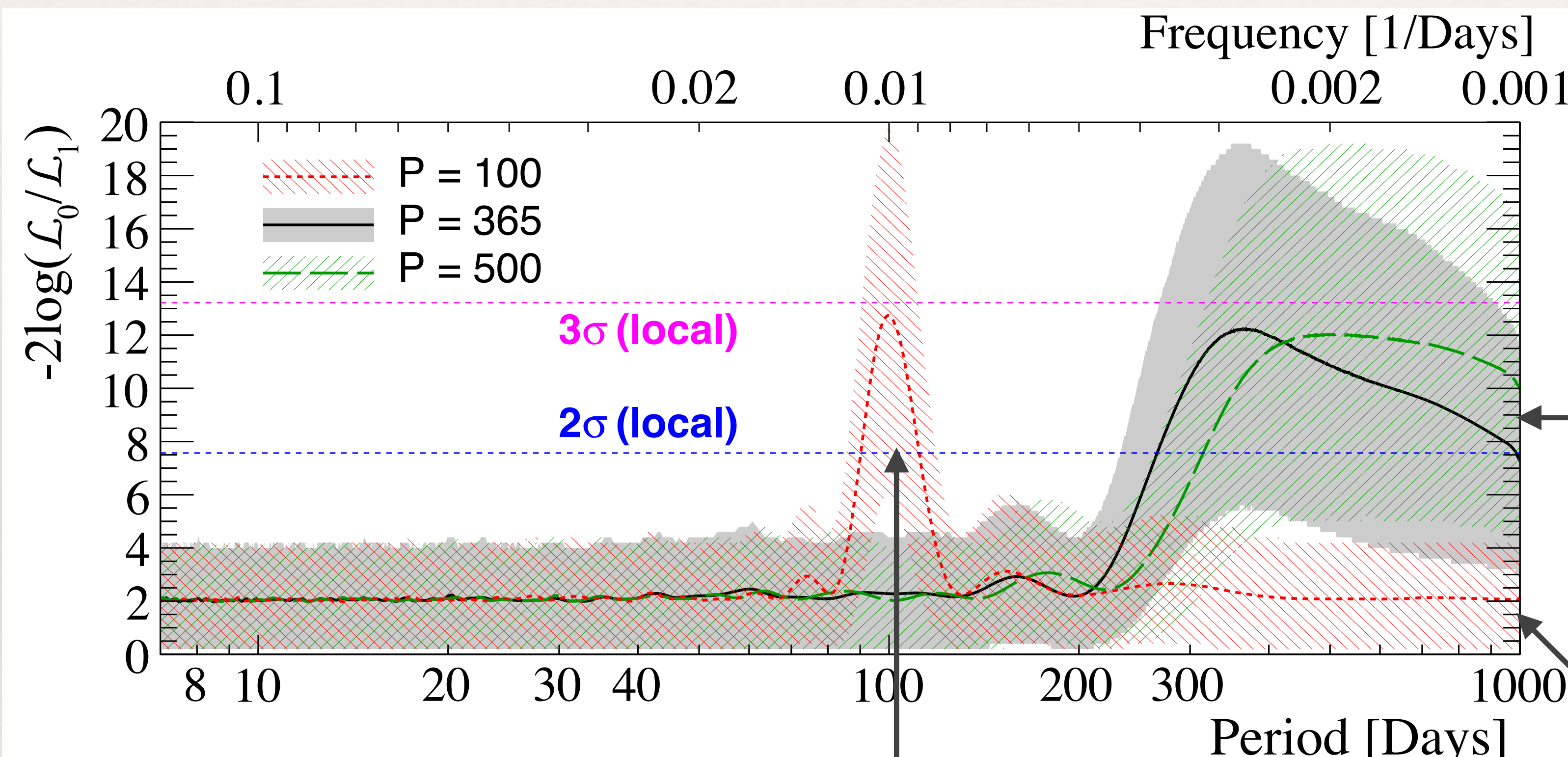
Constraints

We performed an unbinned **profile likelihood** analysis to search for modulation signal

Discovery Potential

Simulated modulation signals

A=2.7 events/(keV · tonne · day) ~ best fit value for P=365.25 days



PRL 115, 091302 (2015)

Characteristic plateau

no resolution on period

no rise at large period

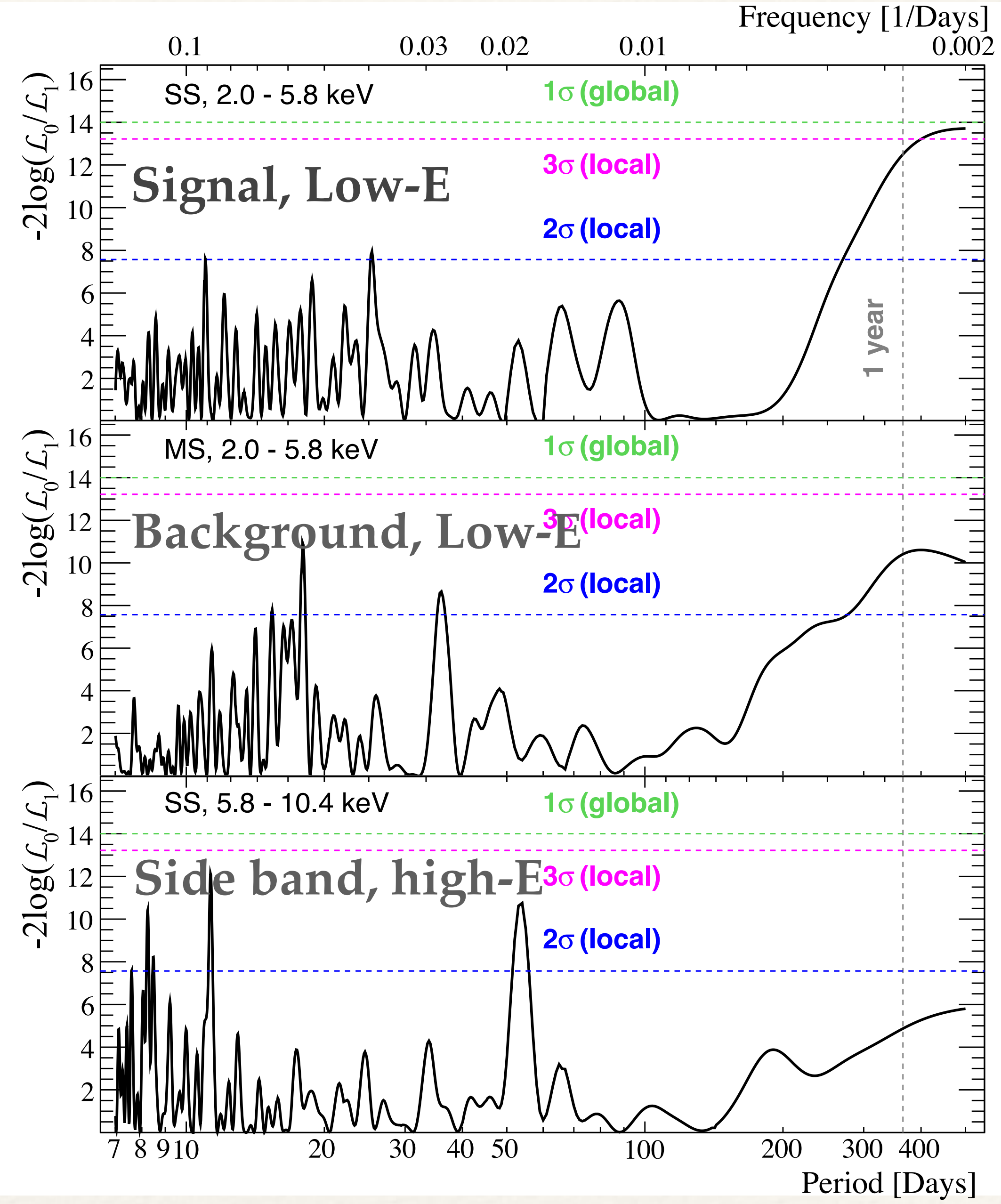
good resolution on period

Average significance of 3 sigma assuming ~25% DAMA/LIBRA modulation

The data is only sensitive to modulation with period < 500 days

Modulation Search Results

- No evident peak crossing the 1-sigma global significance threshold!
- SS in the Low-E (2.0-5.8 keV) range shows increasing significance at long period region. 2.8-sigma local significance at one year period
- MS background only control sample in Low-E range shows similar power spectrum as SS. This disfavors an WIMPs interpretation of the SS spectrum
- SS in high-E (5.8-10.4 keV) does not show high significance at long period region

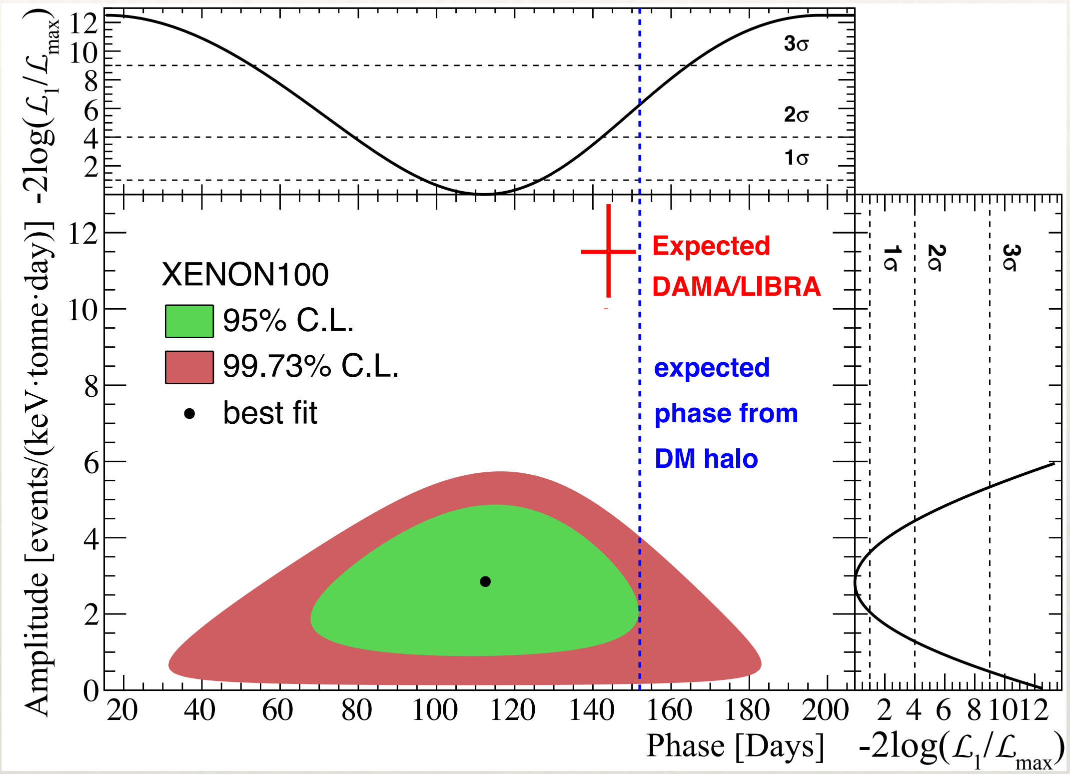


PRL 115, 091302 (2015)

DAMA/LIBRA Comparison (2D)

- The phase (112+-15) days (April 22) is not consistent with the standard halo model (June 2) at 2.6-sigma
- The amplitude of is also too small (only ~25%) compared with the expected DAMA/LIBRA modulation signal in XENON100.
- The DM interpretation of DAMA/LIBRA annual modulation as being due to WIMPs electron scattering through axial vector coupling is disfavored at 4.8-sigma from a PL analysis

PRL 115, 091302 (2015)



$$A = (2.7 \pm 0.8) \quad \text{events}/(\text{keV} \cdot \text{tonne} \cdot \text{day}),$$

$$C = (5.5 \pm 0.6) \quad \text{events}/(\text{keV} \cdot \text{tonne} \cdot \text{day}),$$

$$\phi = (112 \pm 15) \text{ days}$$

$$DAMA/LIBRA(expected) = 11.5 \pm 1.2stat \pm 0.7syst$$

Summary

- The first stable LXe TPC sufficient for modulation searches.
- No significant modulation is found in the XENON100 electronic recoil data.
- The increasing significances at long period in both SS and MS samples does not favor a dark matter interpretation
- Leptophilic DM models to interpret DAMA/LIBRA modulation have been challenged by XENON100
- WIMPs-electron scattering 4.4-sigma
- Mirror dark matter model 3.6-sigma
- Luminous dark matter model 4.6-sigma
- More data is ready for modulation searches.

Science 349, 851 (2015)

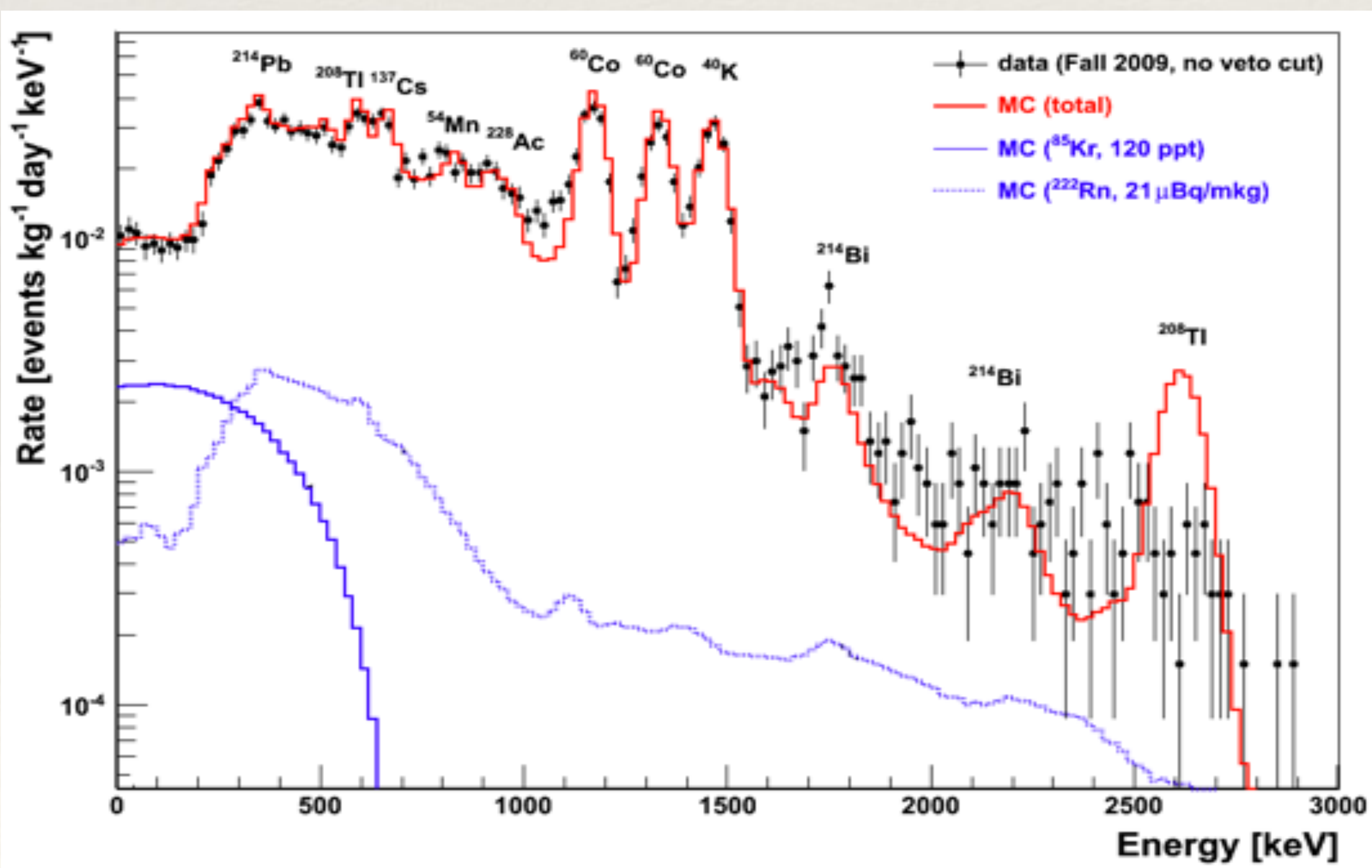
PRL 115, 091302 (2015)

XENON100 ER background

Very good data/MC absolute matching inside fiducial volume!!!

Radioactivity from screening values, no turning!

E. Aprile et al. (XENON100), Phys. Rev. D83, 082001 (2011)

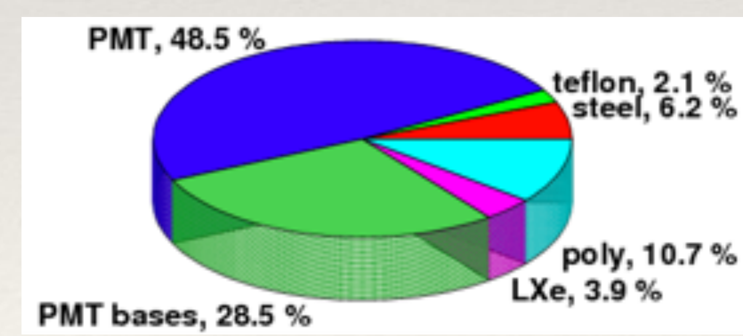


ER background:

Beta decay from krypton

Beta decay from radon

Gammas from materials



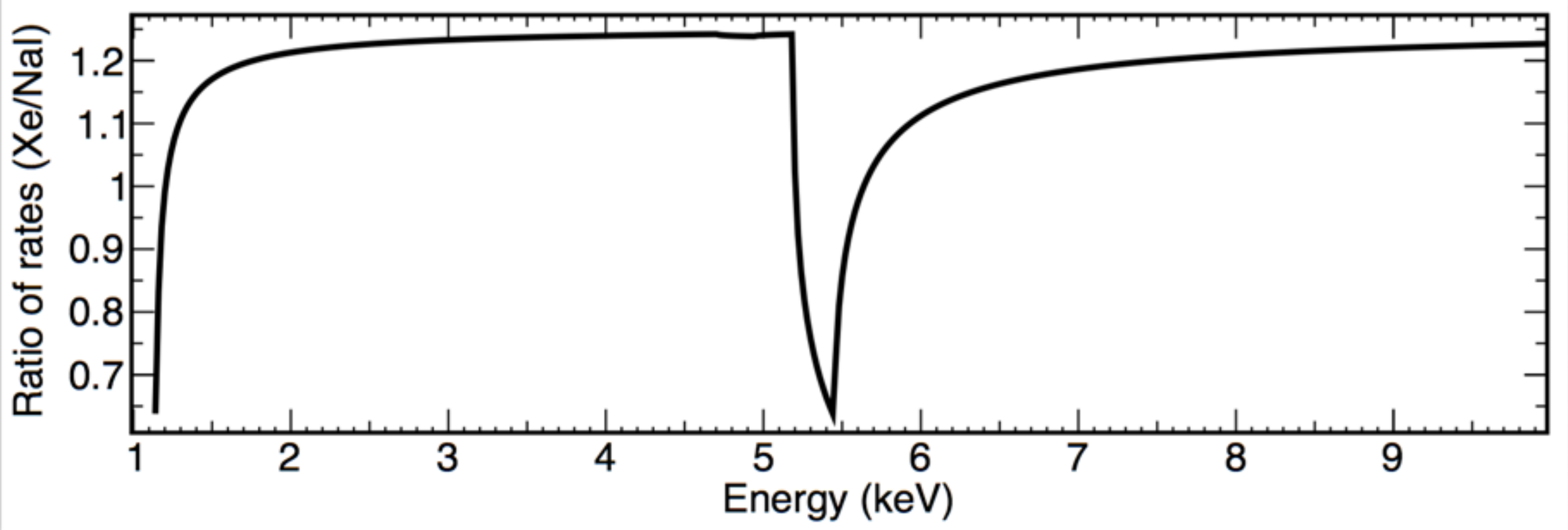
Need XENON1T to suppress PMT background

WIMP-electron scattering

Requirement: no loop-induced nuclear recoil - axial vector interaction

Advantage: natural model with coupling to electrons

Disadvantage: bad spectrum match with DAMA/LIBRA



Kopp et.al, PRD 80, 083502 (2009)

Mirror electron scattering

- Multi-component mirror models
- DM halos are composed of a multi-component plasma of mirror particles (same mass as their partners)
- Mirror electron scatters on electron through kinematically mixed coupling
- Scatter rate proportional to number of loosely bound electrons (binding energy < 1 eV)
- Constant scaling of 0.89 between XENON100 and DAMA/LIBRA

. R. Foot, Int.J.Mod.Phys. A29, 1430013 (2014)

Luminous Dark Matter

- Upper scattering inelastic dark matter scattering, the interaction rate is determined by dipole moment
- ~keV mass splitting produce X-rays
- Interaction in the earth besides the detector, and produce X-rays inside the detector
- 3.0 keV mass splitting fits well with the DAMA/LIBRA modulation

. B. Feldstein et.al, Phys.Rev. D82, 075019 (2010)

Radon Correlation Analysis

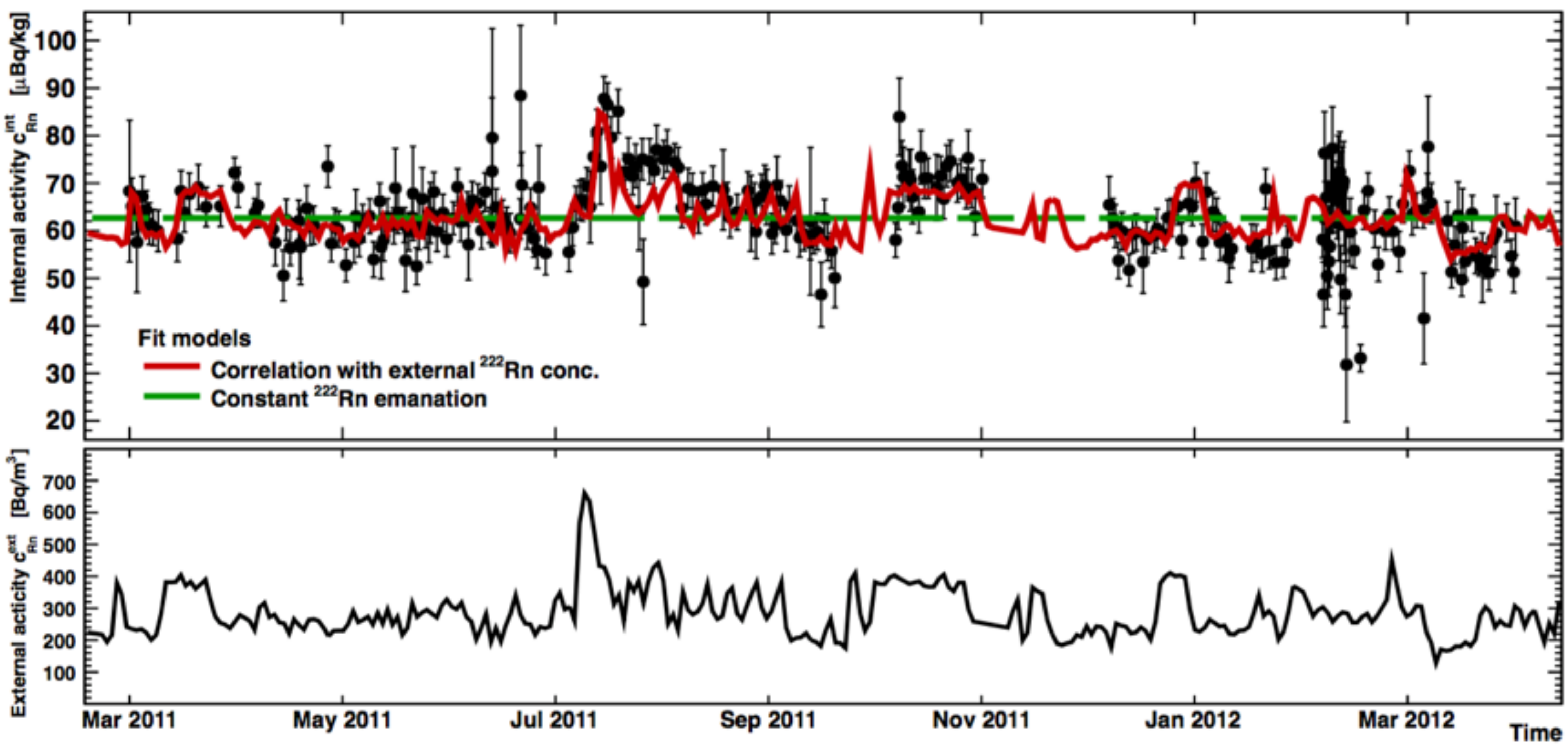


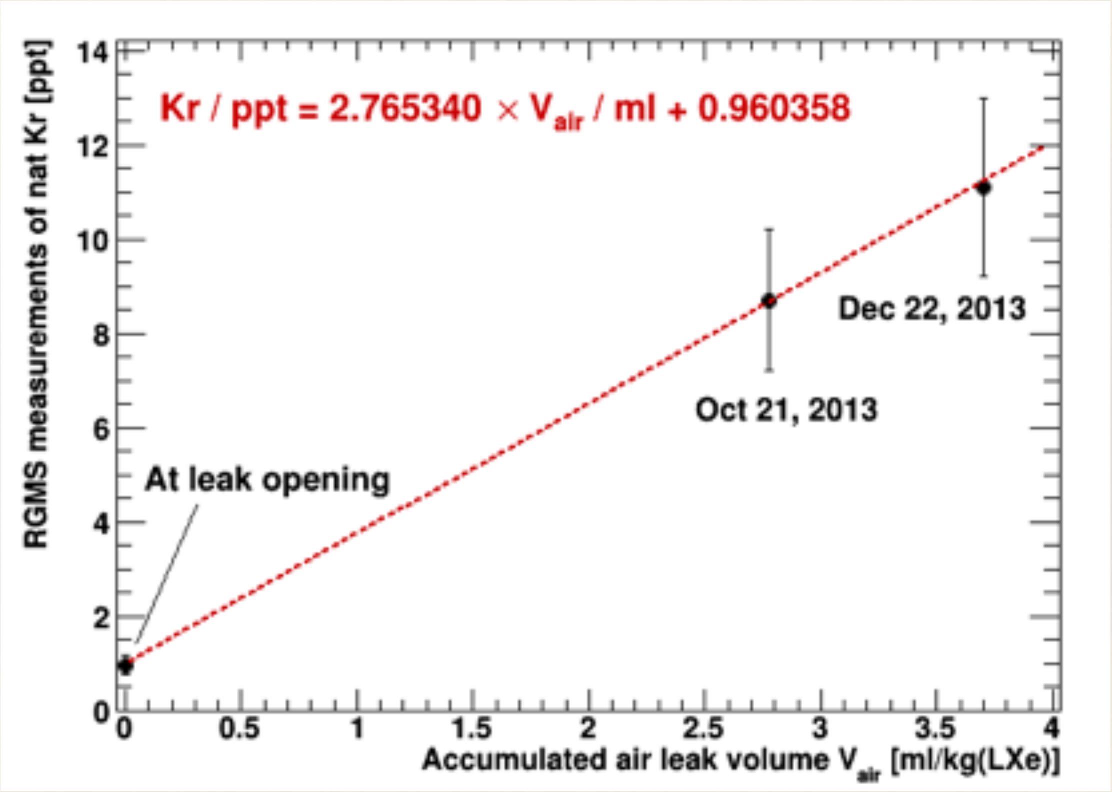
Figure 4.31: Test of hypothetical time-correlation of the internal ^{222}Rn activity (black data points, upper frame) with the outside radon decay concentration (black line, lower frame) in the ambient air at the XENON100 detector site. The best fit of the model function c_{Rn}^{int} is represented by the red line, while a constant fit to data is shown in green for comparison.

M. Weber, PhD Dissertation, University of Heidelberg (2013) www.ub.uni-heidelberg.de/archiv/15155

Calibration between radon and krypton

Leak rate is calculated from the correlation analysis between external and internal radon

three RGMS measurements of krypton across the run



Perfect linear correlation between krypton levels and air leak