Dark matter searches with Xenon100

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On behalf of the XENON collaboration
Laboratori Nazionali del Gran Sasso

Xe
XENON
Dark Matter Project

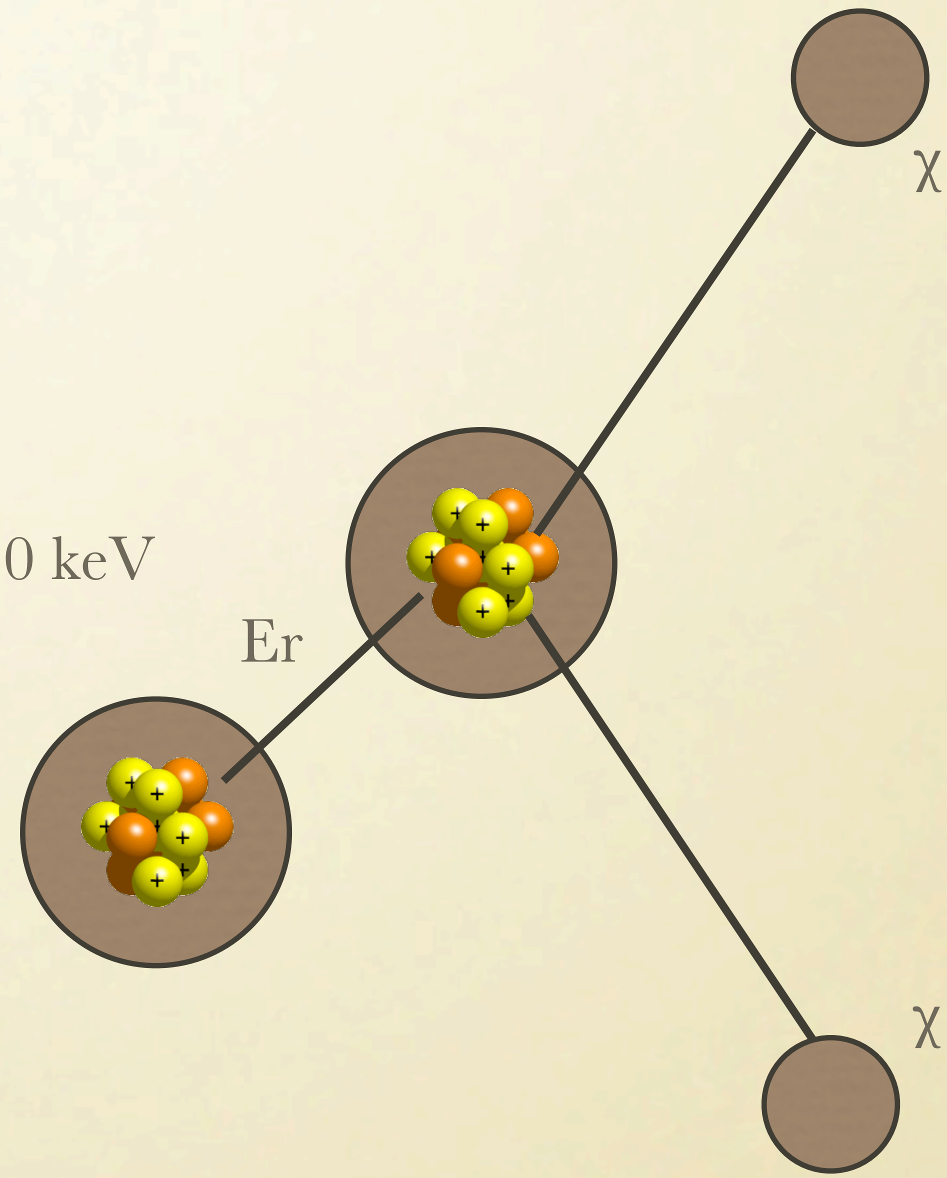
Direct WIMP searches

WIMPs interact with nucleus!

WIMP may interact with cross sections of $< 2 \times 10^{-45}$ cm^2

Observable quantities

$$E_R = \frac{q^2}{2m_N} = \frac{\mu^2\nu^2}{m_N}(1 - \cos\theta)$$ < 50 keV



q = momentum transfer

m_N = target nucleus mass

μ = reduced mass

$$\mu = \frac{m_\chi m_N}{m_\chi + m_N}$$

ν = mean WIMP-velocity on respect to the target

θ = scattering angle in the center of mass

Direct WIMP search: the backgrounds

- cross-sections ($<2 \times 10^{-45}$ cm^2)
- without background
  - ✓ Sensitivity ≈ M x t
- with background
  - ✓ Sensitivity ≈ $(M \times t)^{1/2}$
- until limited by systematics

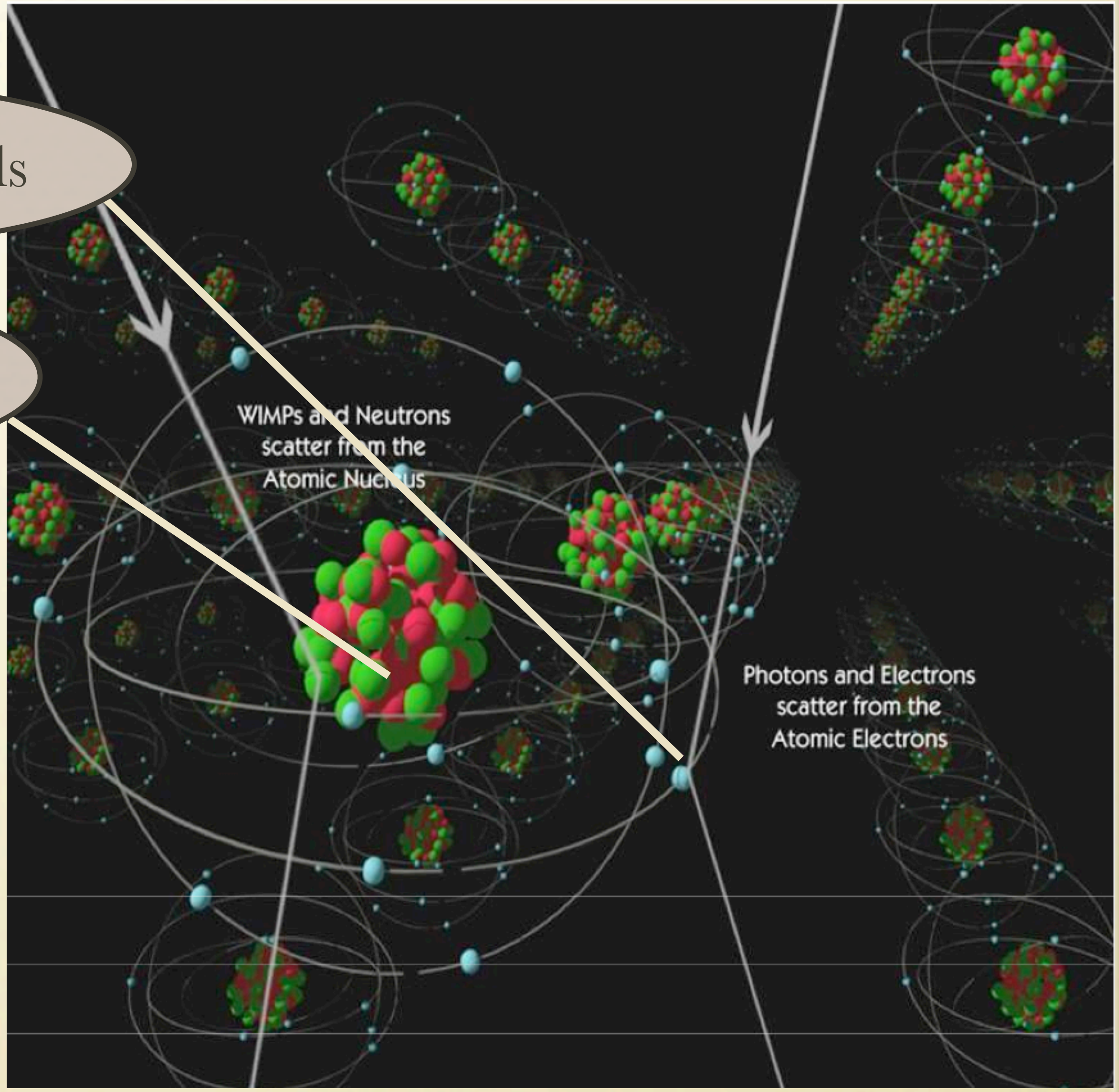
NATURE:

α, β, γ, n, μ

SIGNALS:

Electronic recoils

Nuclear recoils



SOURCES:

Artificially produced radionuclides
(^{85}Kr, ^{137}Cs) - Gamma

Cosmogenic radionuclides
(^{60}Co) - Gamma

Natural primordial radionuclides
(^{238}U, ^{232}Th, ^{40}K) - Gamma and Neutrons

Cosmic muons - Neutrons

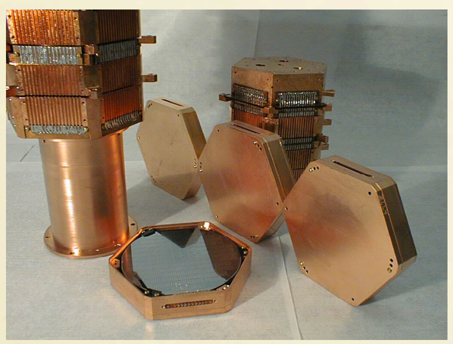
Direct WIMP search: the approaches

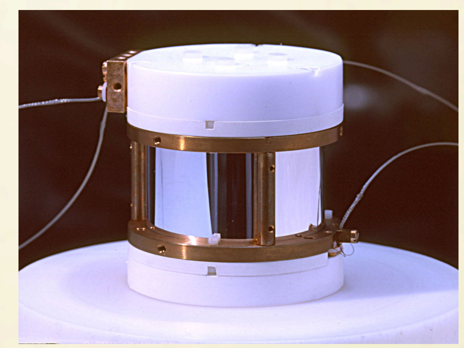
COUPP, PICASSO, SIMPLE

CDMS
EDELWEISS

Heat

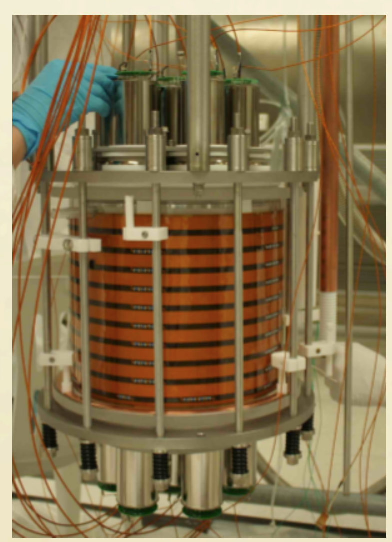
CRESST
ROSEBUD





E_R

Charge



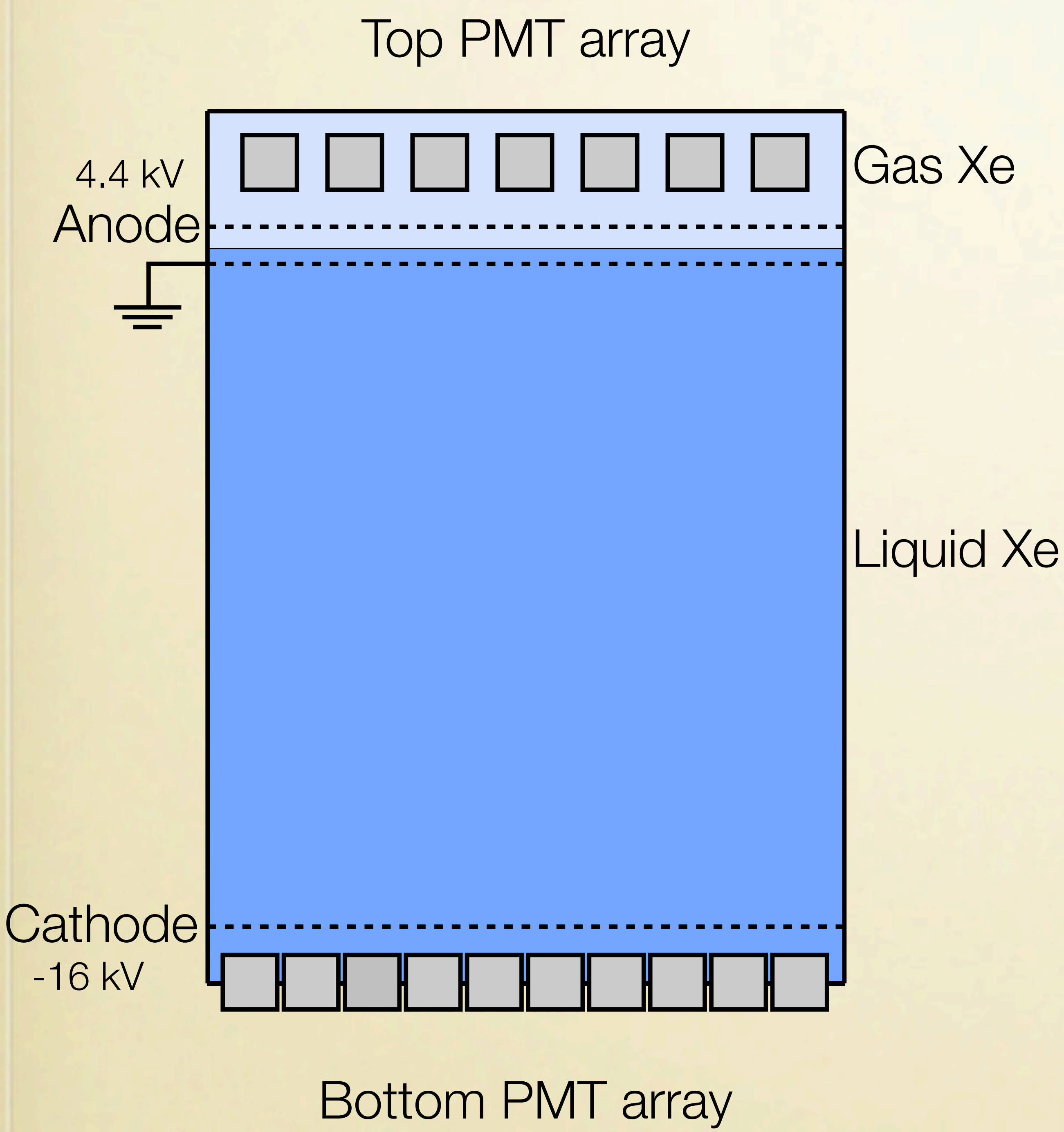
Light

CoGeNT
Texono
CDEX
DMTPC
DRIFT
MIMAC
Newage

DAMA/LIBRA
XMASS
DEAP
CLEAN
KIMS
DM-Ice

ZEPLIN, LUX, XENON,
ArDM, DarkSide, Panda-X

THE 2-PHASE TPC APPROACH



- Primary scintillation signal (S1)
- Electrons drift over 30 cm max distance
- Electrons are extracted and accelerated generating secondary scintillation signal (S2) - very localized on the top array => XY positioning
- The time difference between the two signals gives information on event position in z

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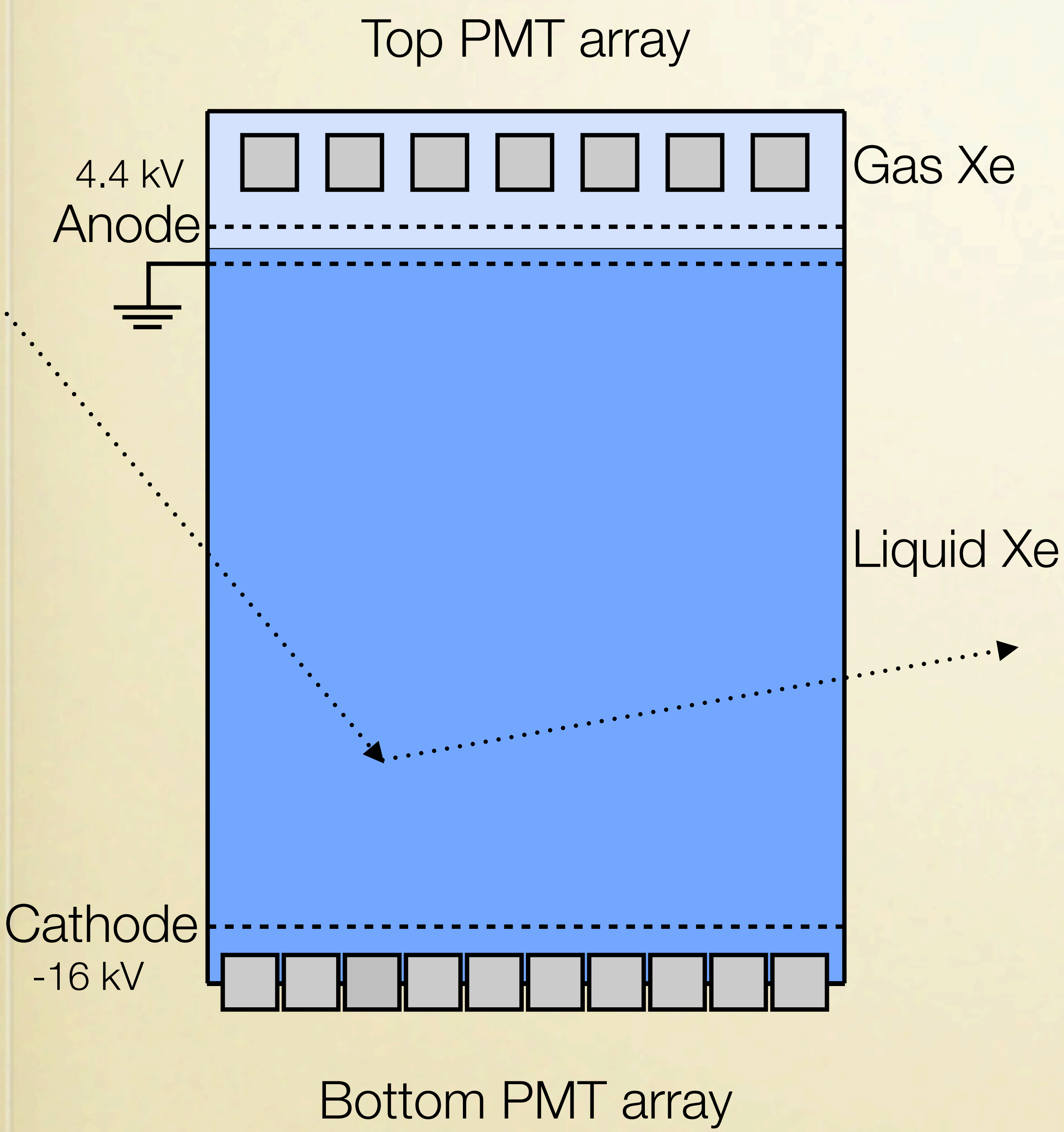

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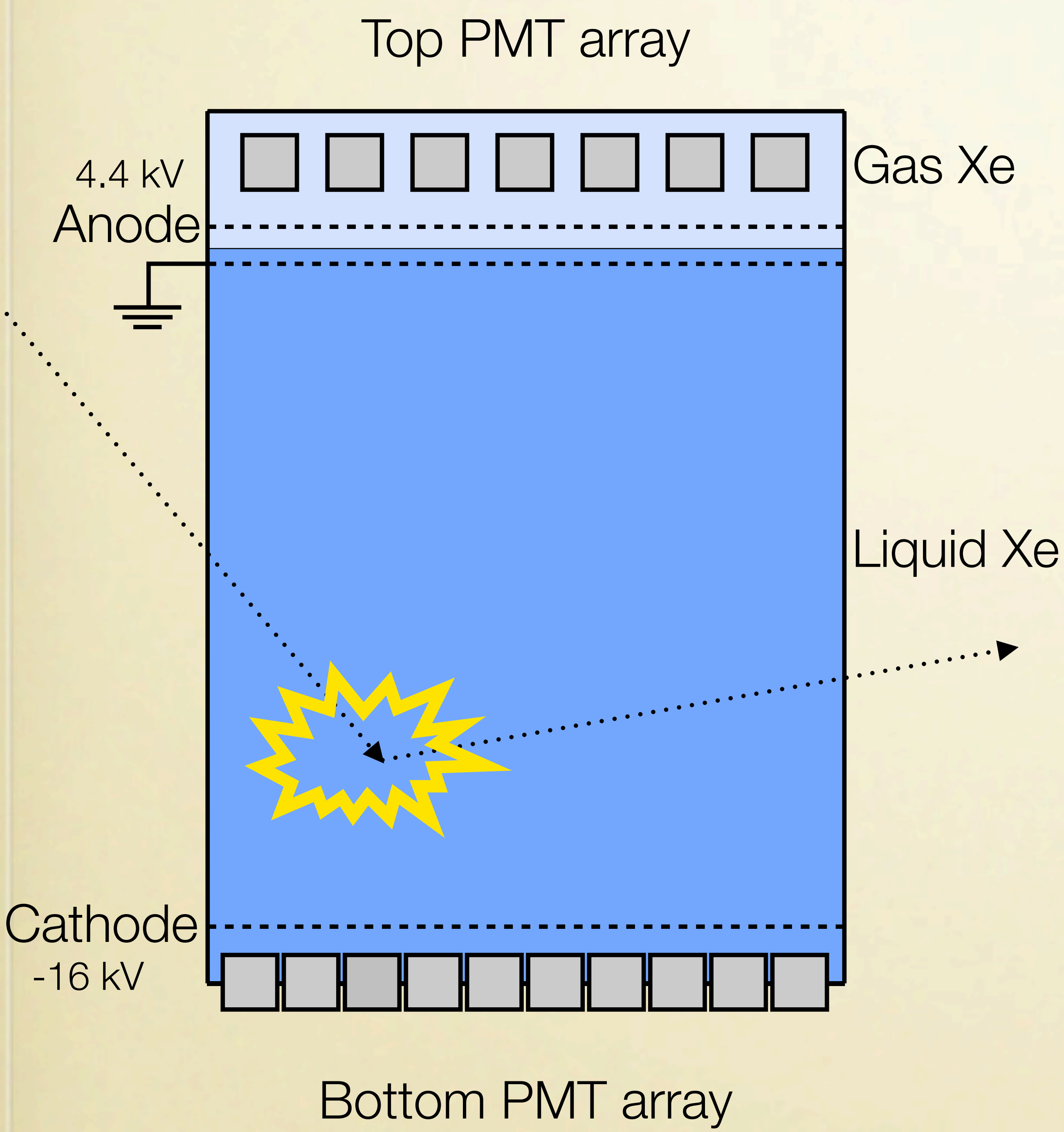

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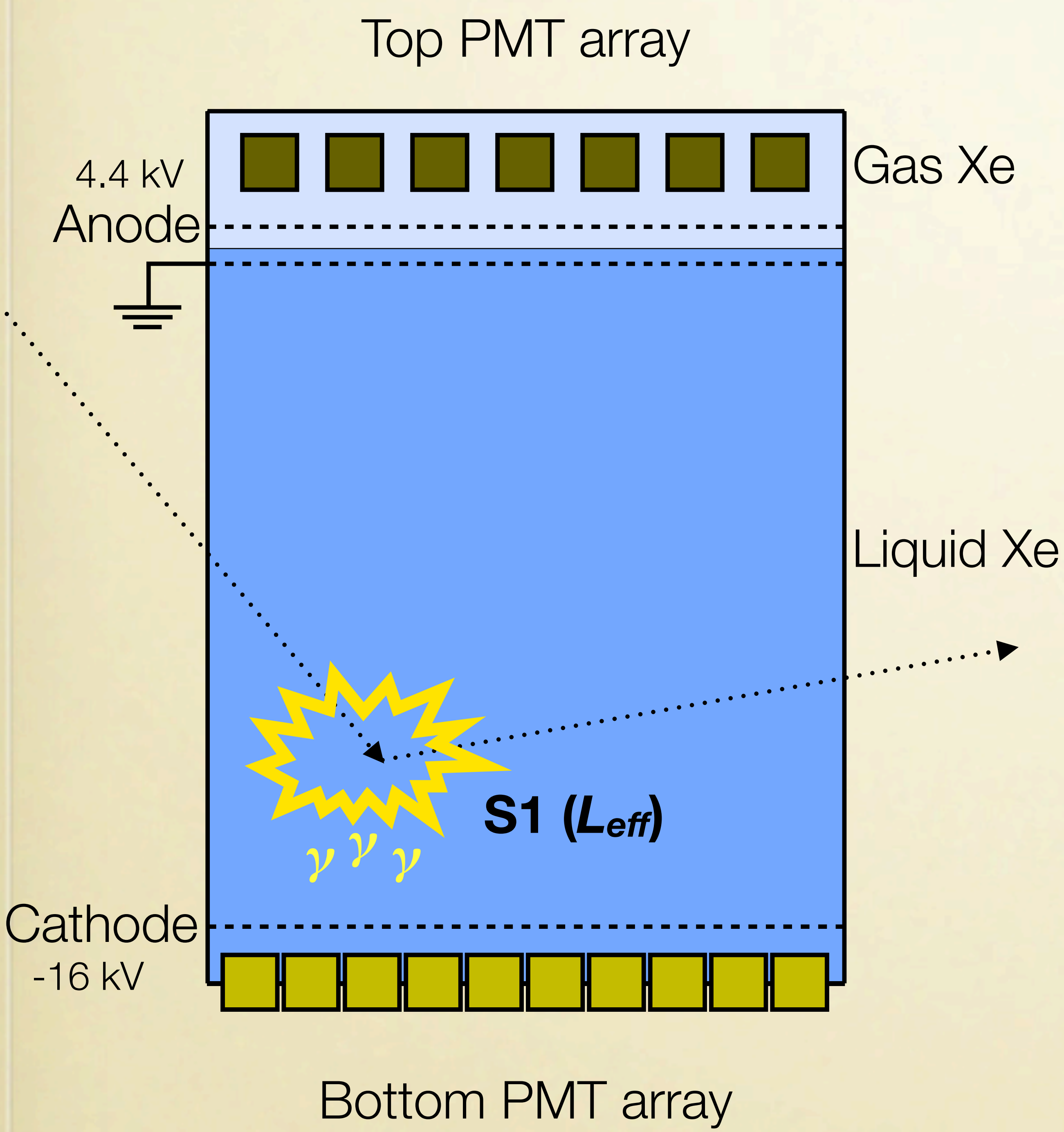

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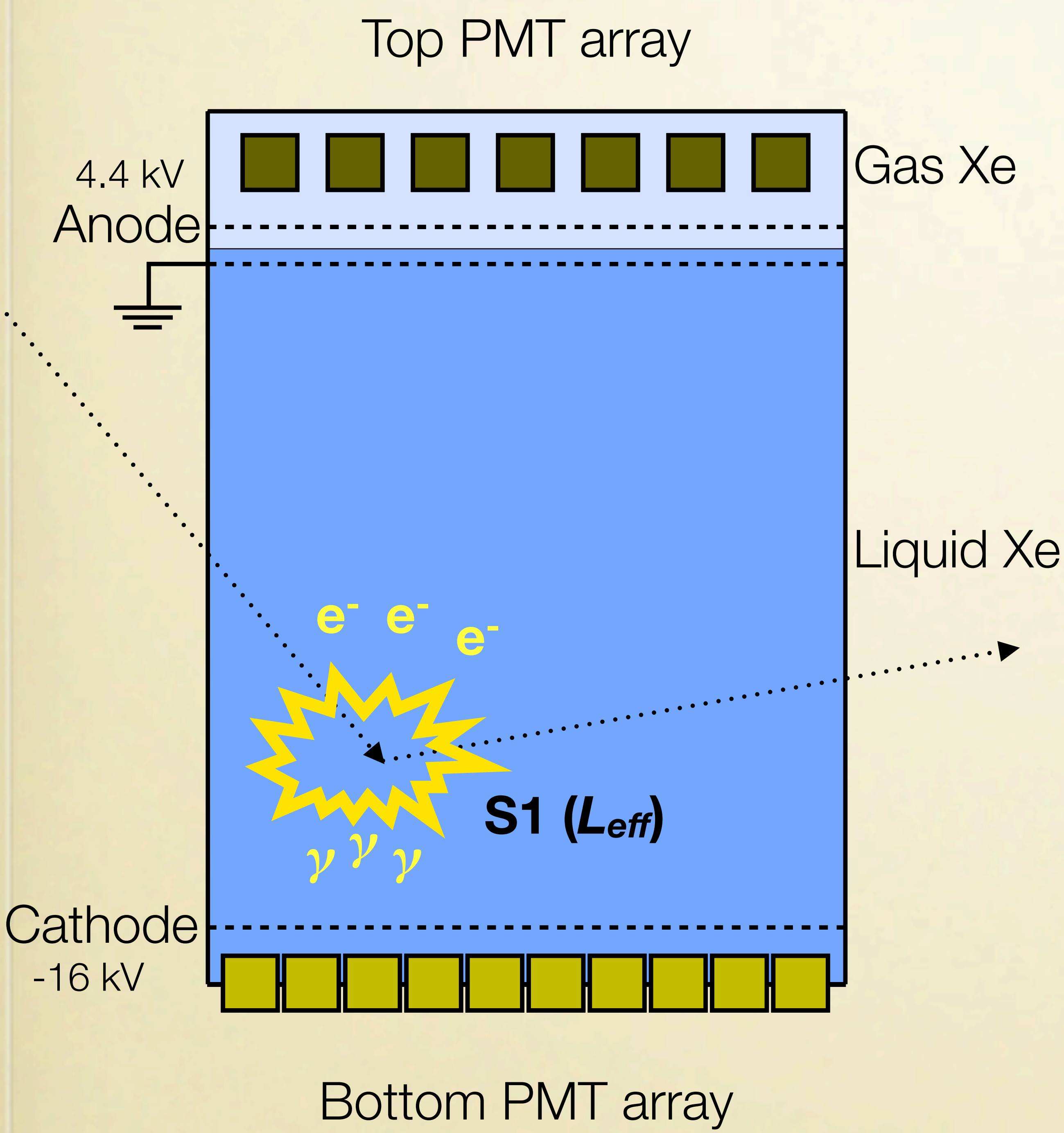

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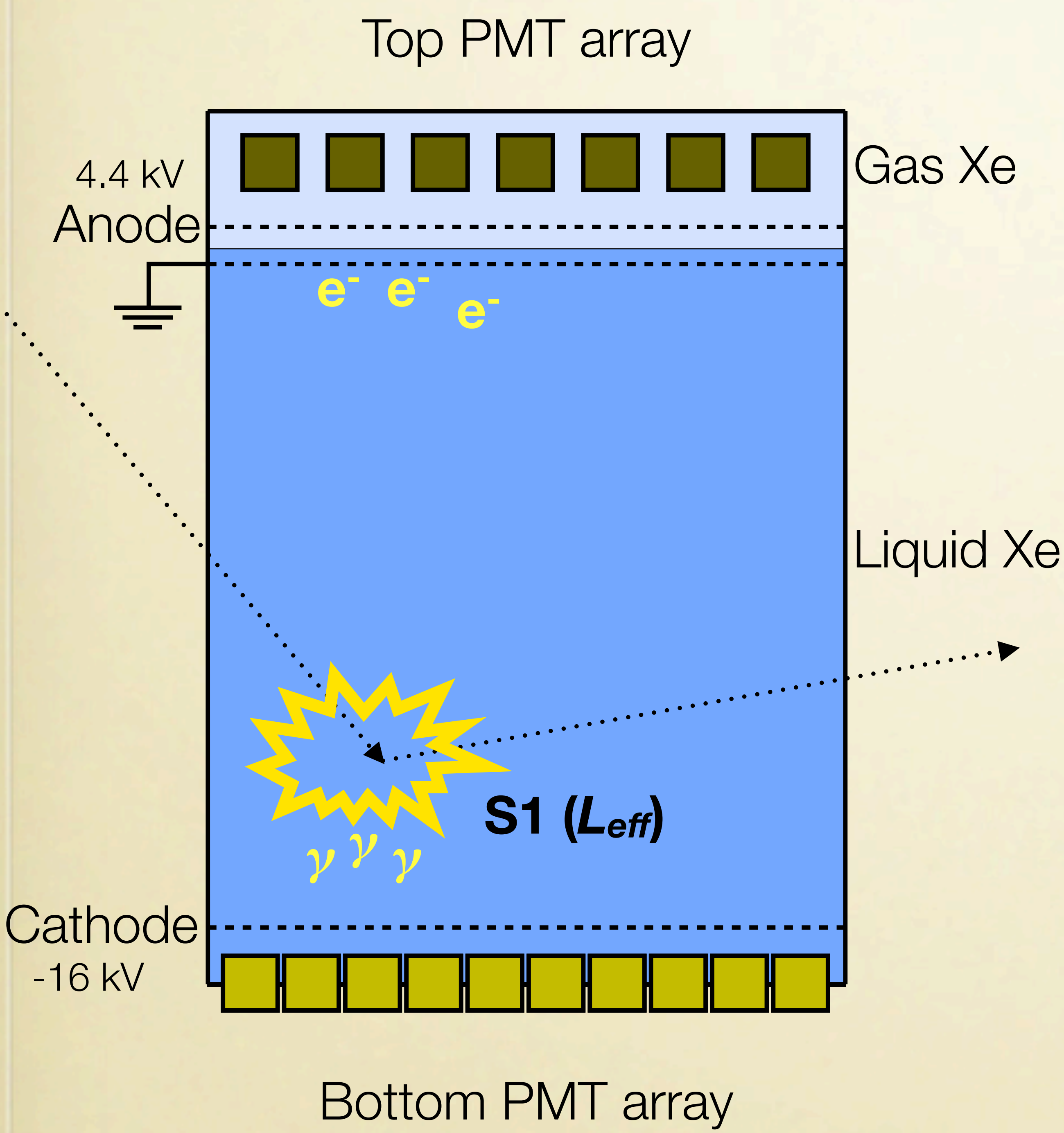

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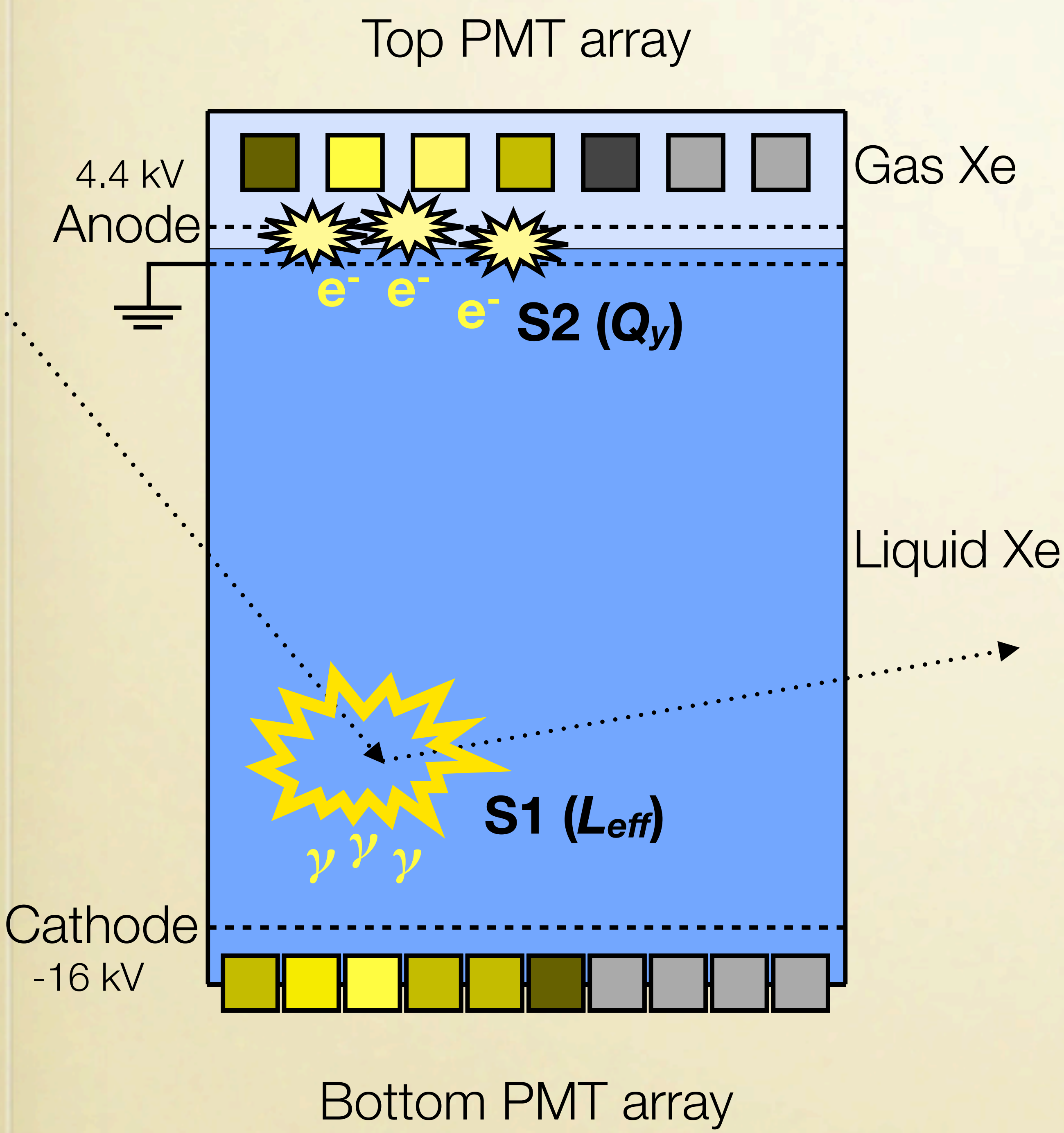

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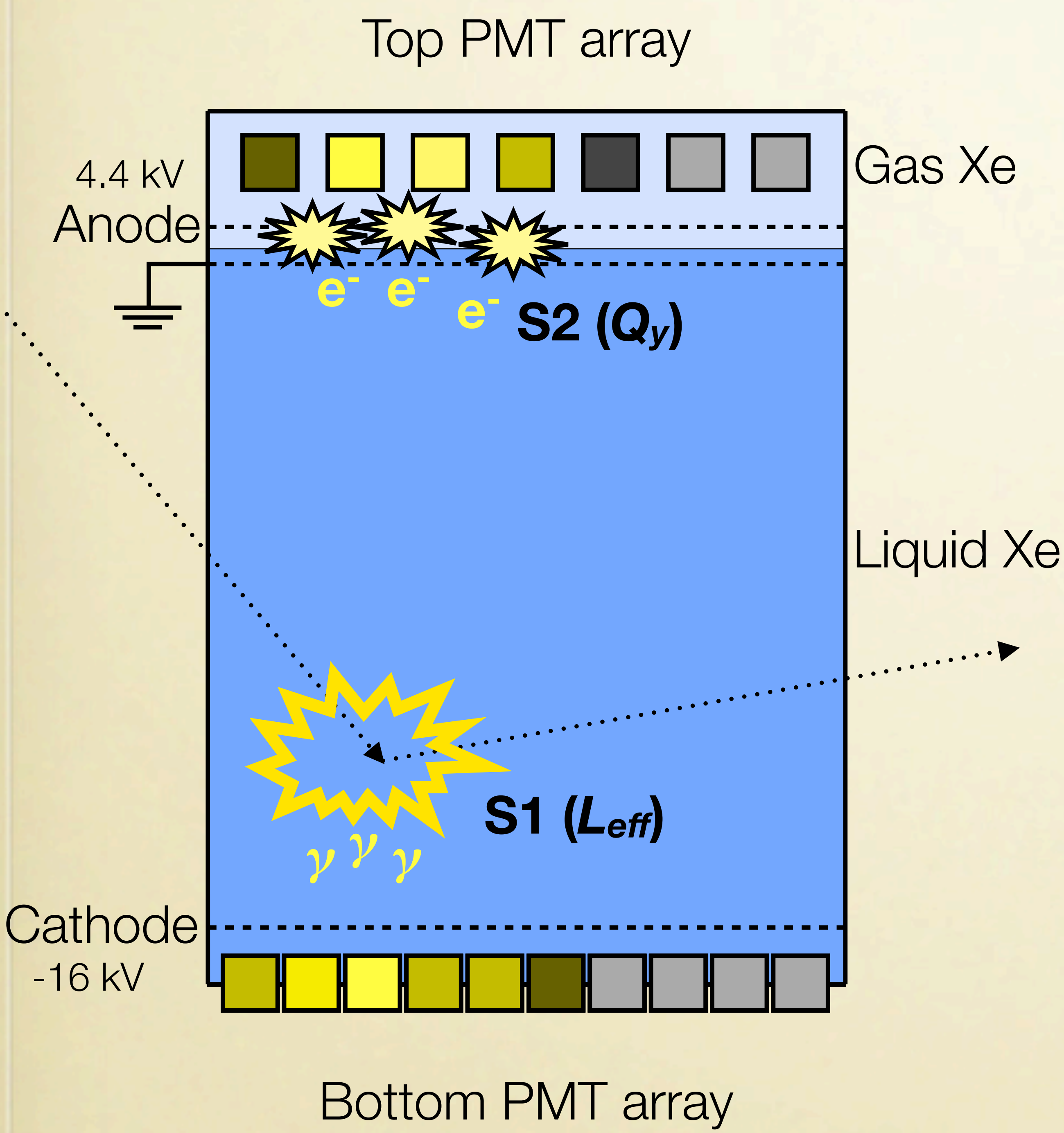

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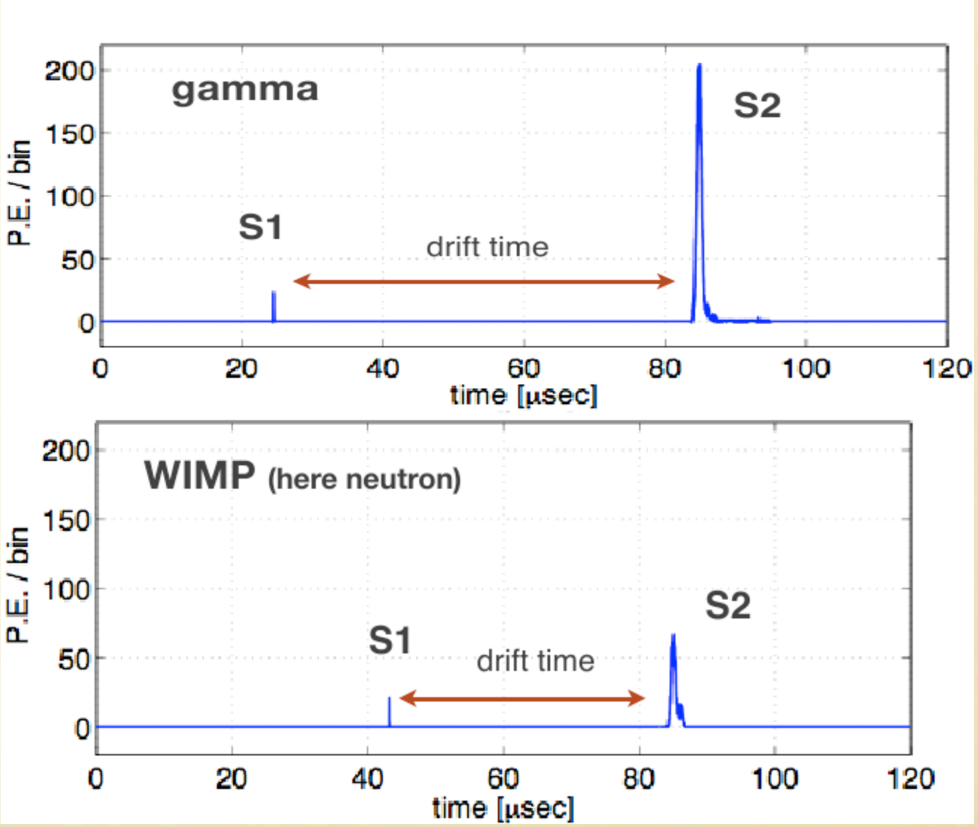
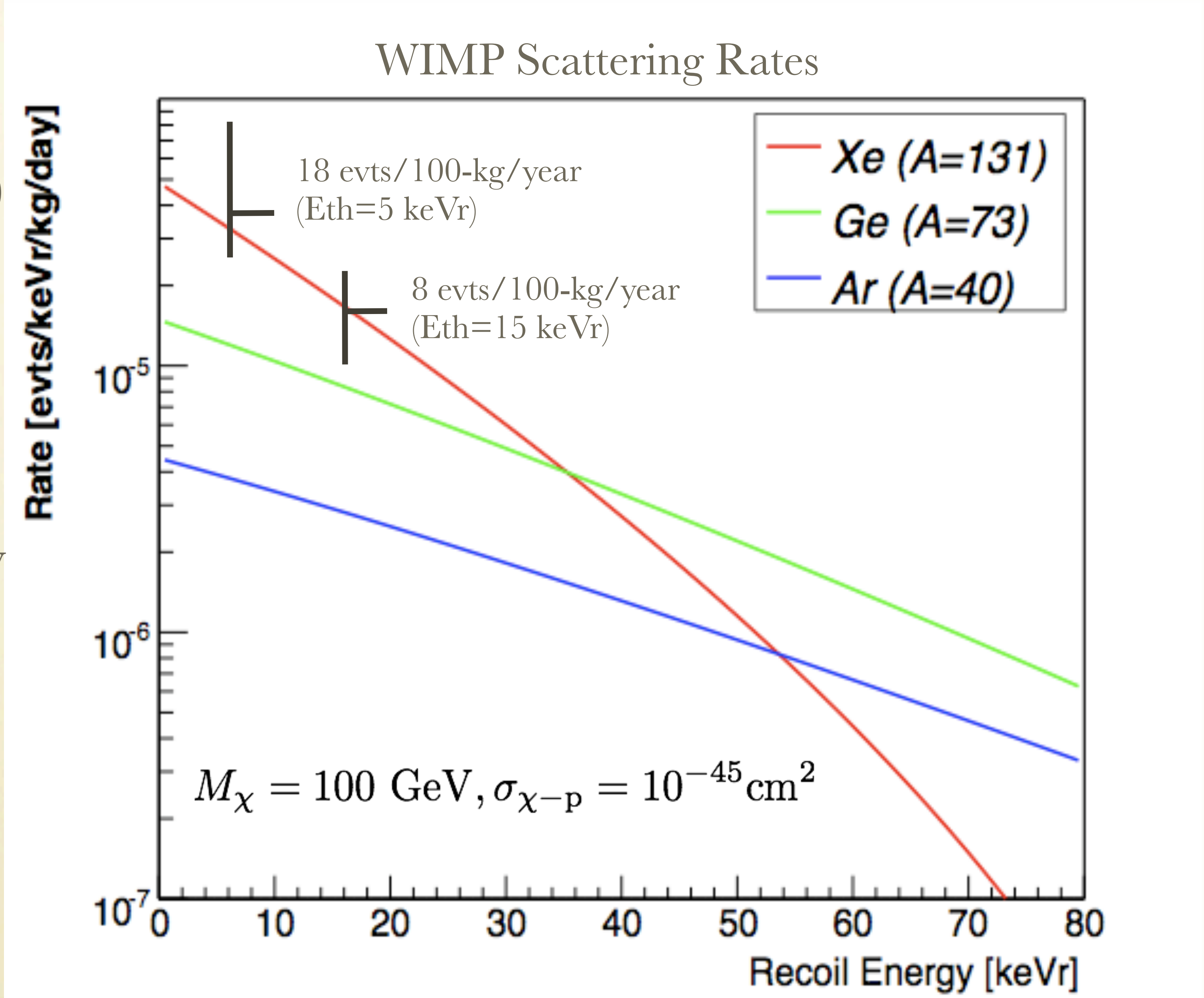


XENON100: why Liquid Xenon?

- large mass (ton scale)
- easy cryogenics (-100 °C)
- low energy threshold
  - a few keV
- A~131 (good for SI σ ~ A^2)
- ~50% odd isotopes (SD)
- background suppression
  - good self shielding features (ρ~3 g/cm^3 Z=54)
  - low intrinsic radioactivity
  - gamma background discrimination
  - position sensitive
    - TPC mode



XENON100: NR Energy scale

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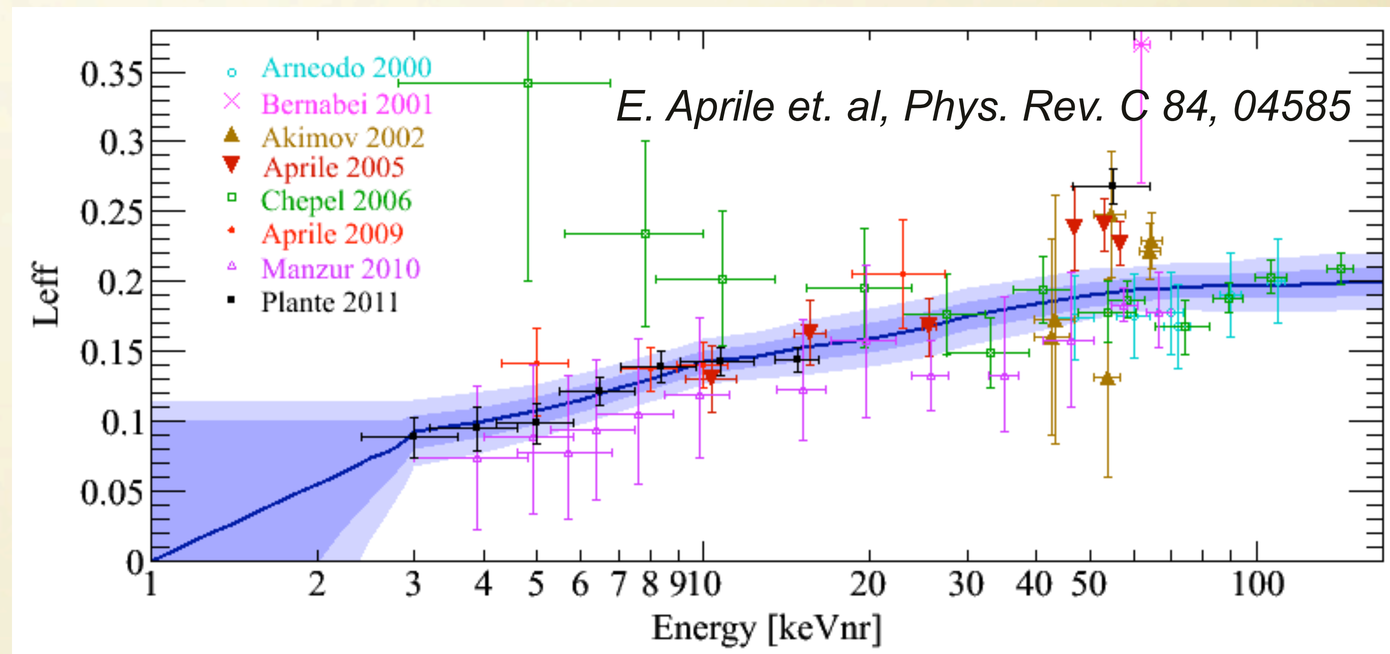
We use a global fit of the available data to compute the quenching factor for nuclear recoils

Ongoing efforts to measure this quantity with a better precision

In XENON100 [3-20] PE ~ [6.6-30.5]keVr



Scintillation light quenching due to the electric field

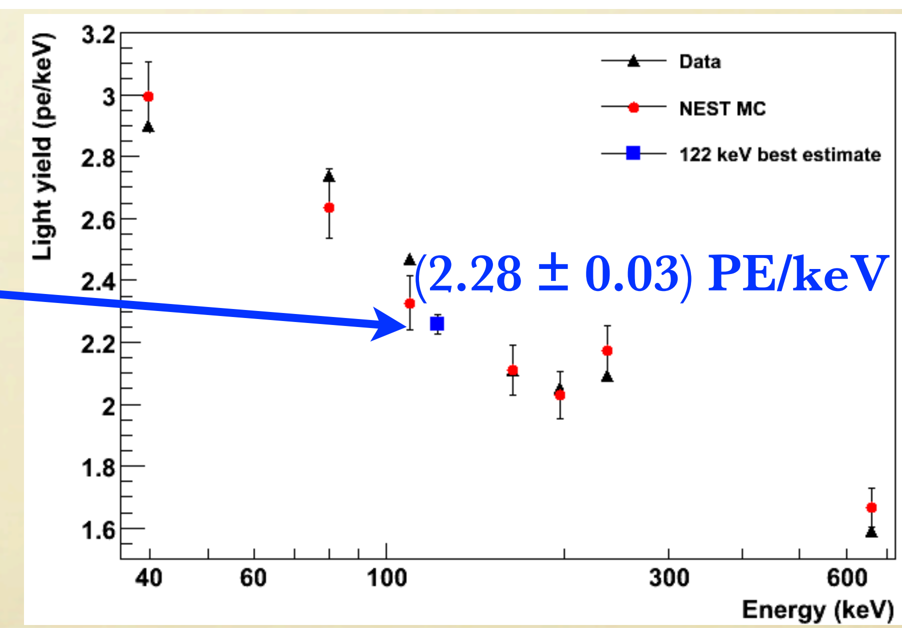
measured S1 signal in p.e.

$$E_{nr} = \frac{S1}{L_y L_{eff}} \cdot \frac{S_e}{S_r}$$

Light yield @ 122 keV

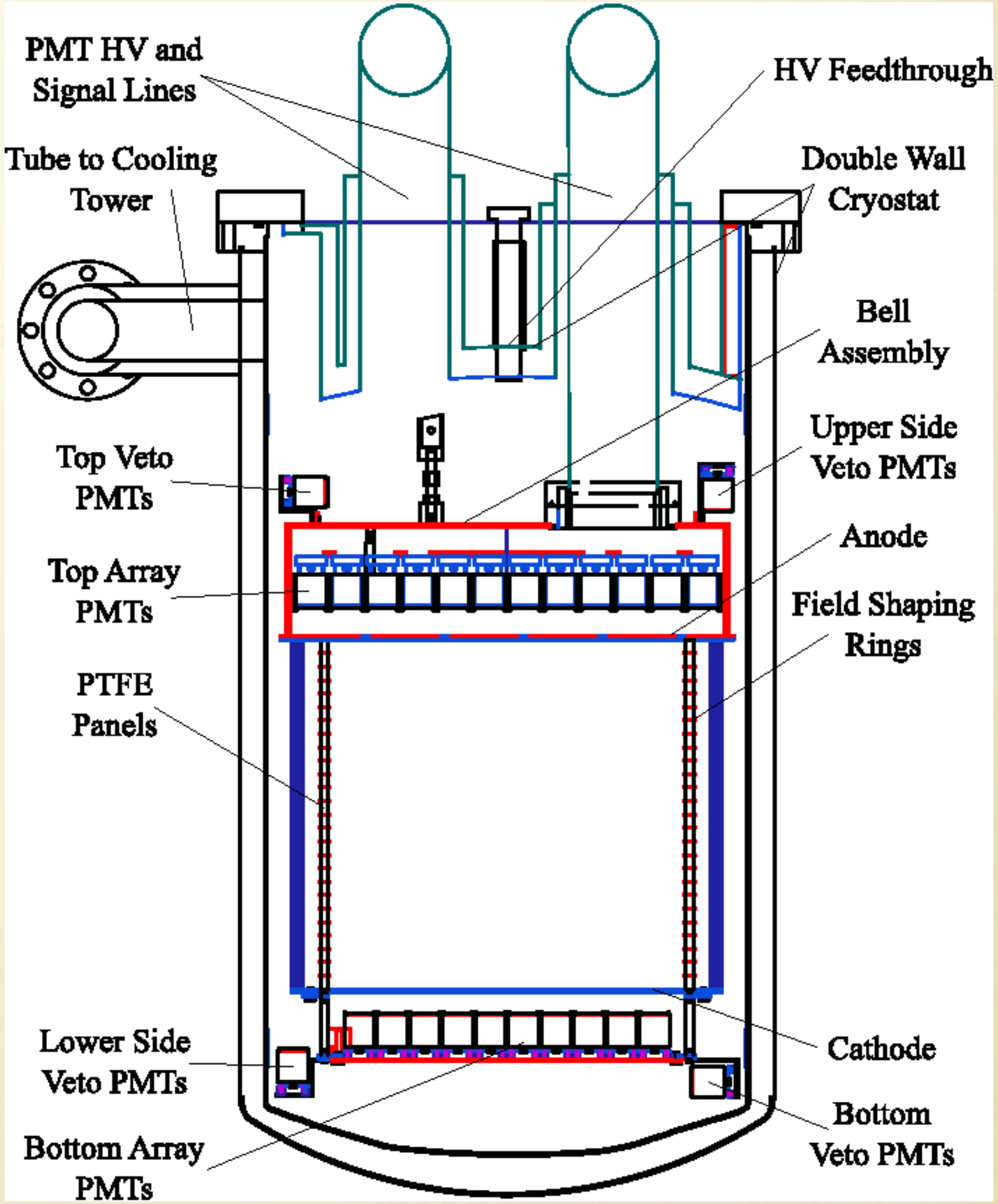
Scintillation efficiency at 0 field

Scintillation light quenching due to the electric field



XENON100: DESIGN

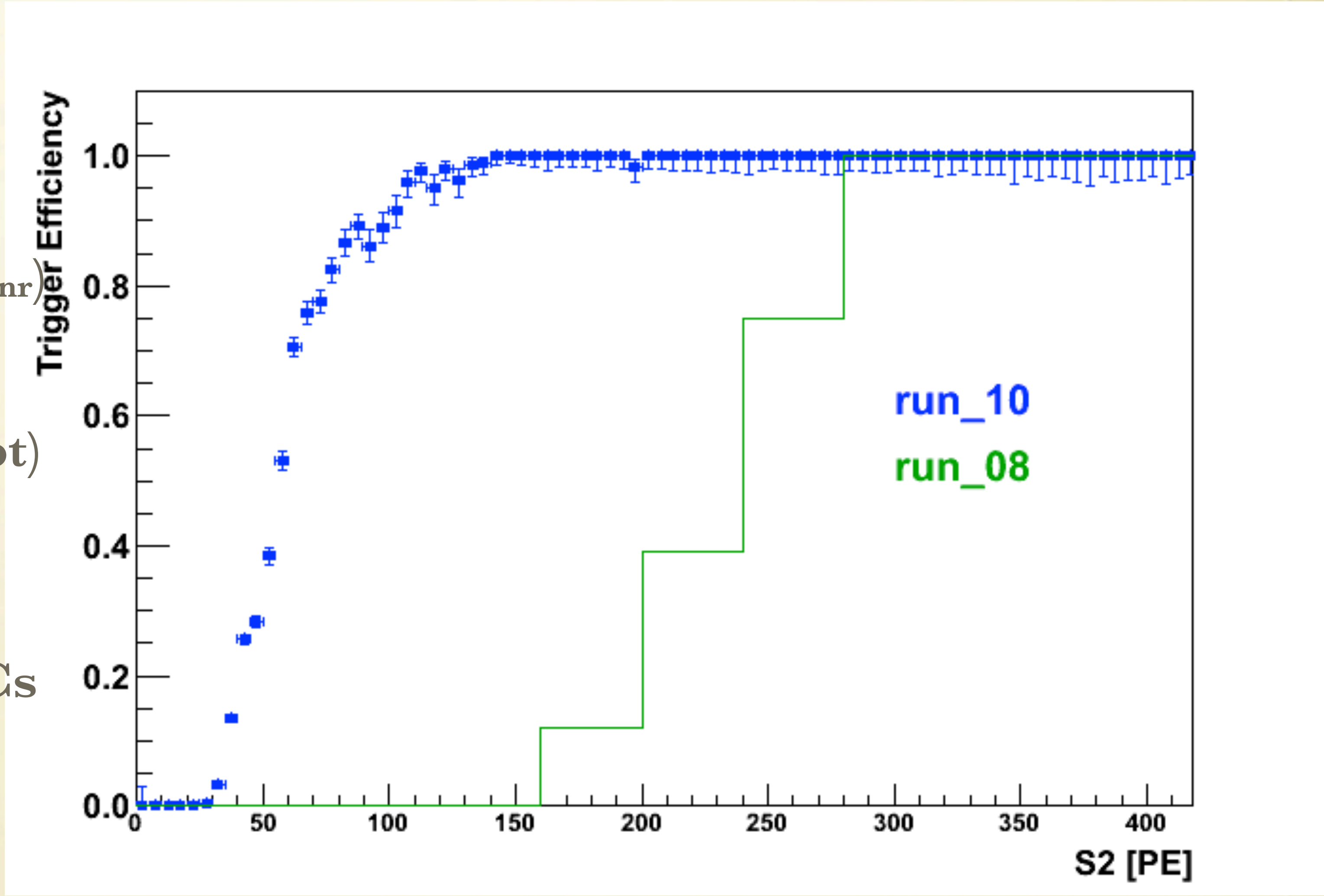
- ~161 kg total / ~62 kg target LXe (15 cm radius , 30 cm drift)
- All detector materials selected for low radioactivity - *Astropart. Phys. 35, 43-49 (2011)*
- Active LXe veto
- Improved shield (H_2O, Pb,Poly,Cu,N2 purge)
- New high QE (>32%@175nm) low activity 1" R8520 PMTs (total 242 PMTs)
- Cryocooler and feed-through outside the shield
- The Xenon is continuously recirculated and purified (in gas phase) through a hot getter (SAES) at a flow rate of ~ 10 SLPM
- Cooling power is provided by a Pulse Tube Refrigerator (160W)
- Prior to the start of the run the LXe is purified from Kr down to ppt



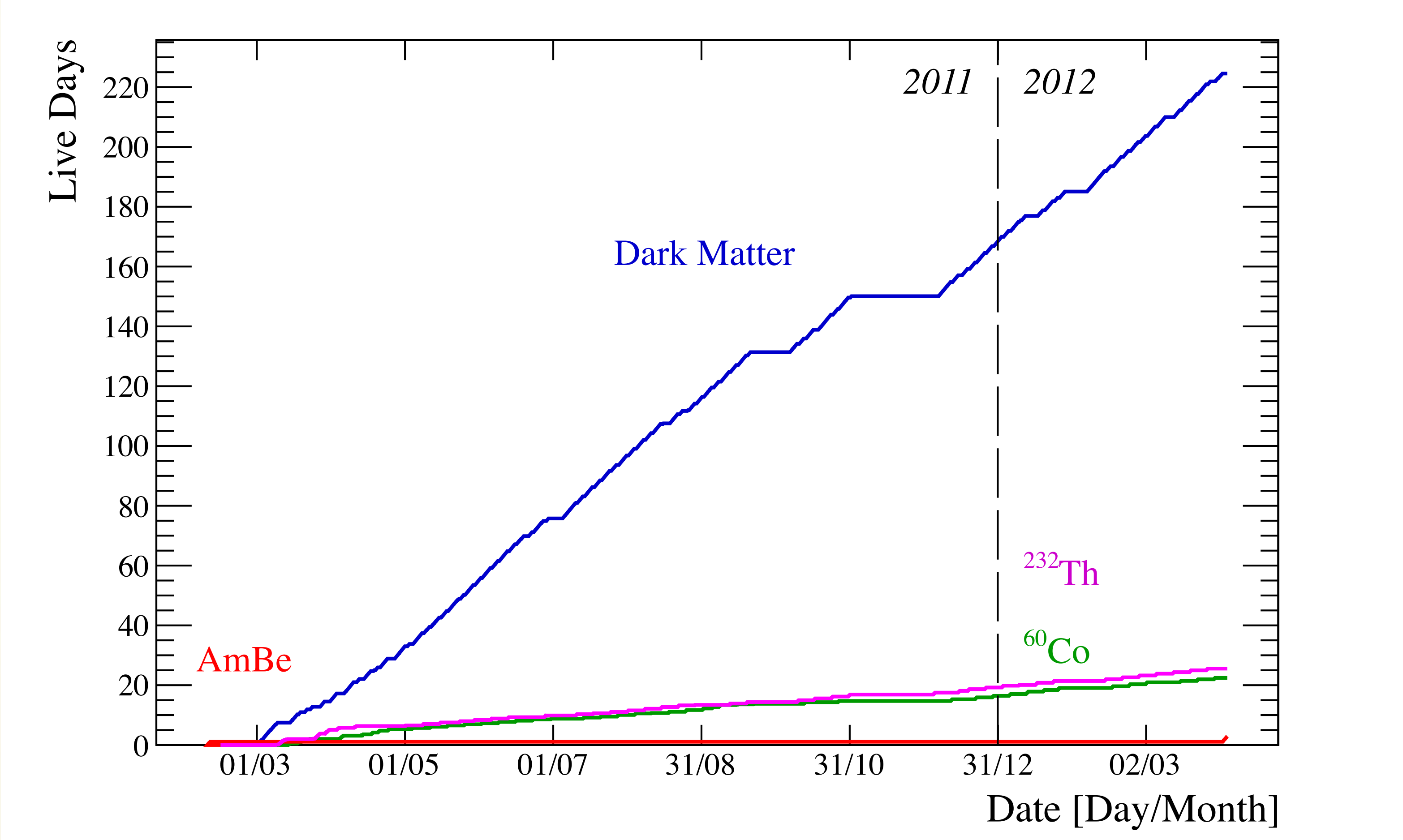
Astropart. Phys. 35, 43-49 (2011)

XENON100: IMPROVEMENTS

- More than double exposure
- Lower threshold:
  - S2 > 150 PE and S1 > 3 PE (6.6 keV_{nr})
- Reduced noise and improved cuts to identify/reject “noisy” events
- Reduced Kr/Xe contamination (19 ppt)
- More calibration data:
  - 35x more ER calibration
  - AmBe before and after the run
- Electron lifetime monitored with ^{137}Cs source increasing from 375 to 610 μs

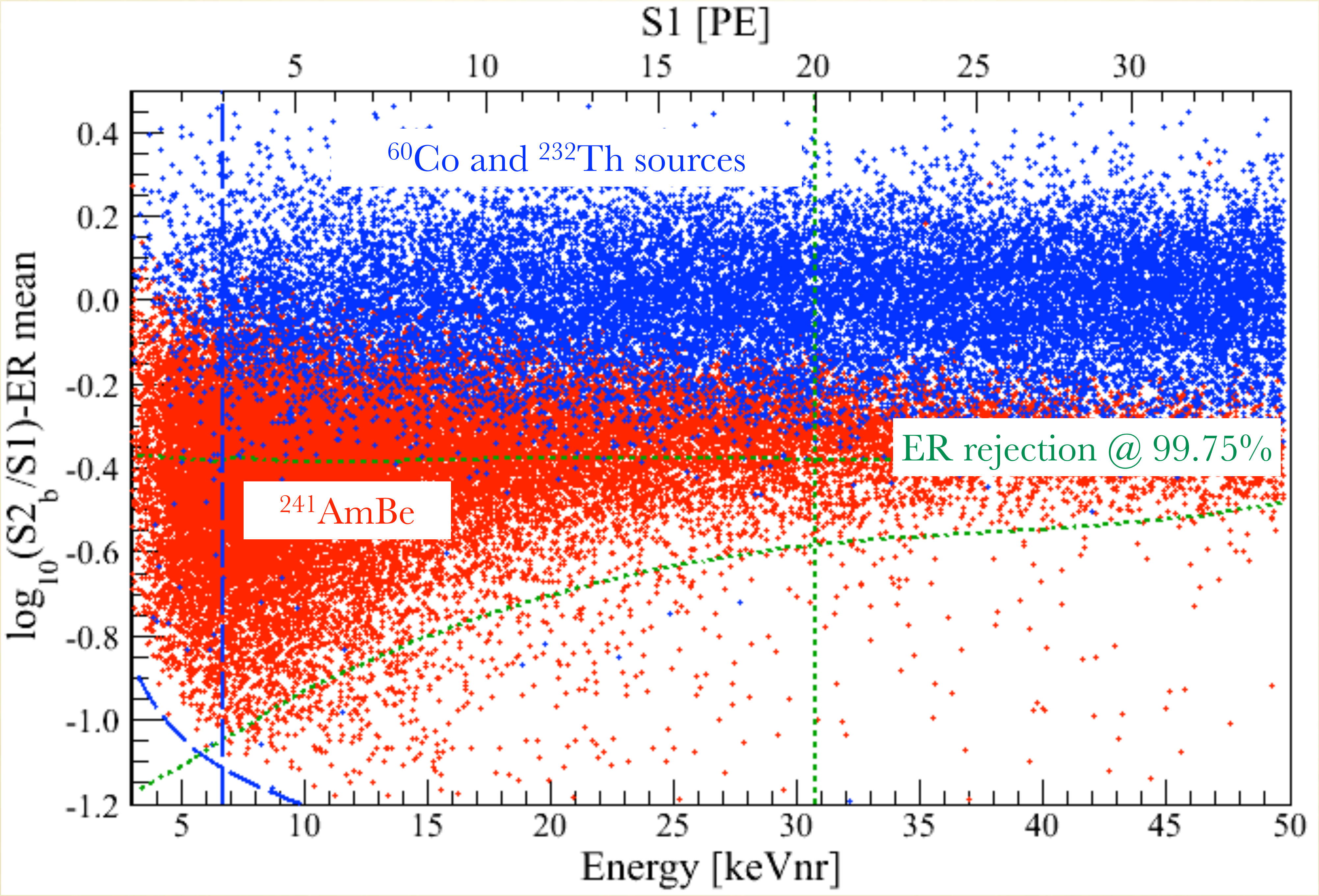


XENON100: 2011-2012 DATA TAKING



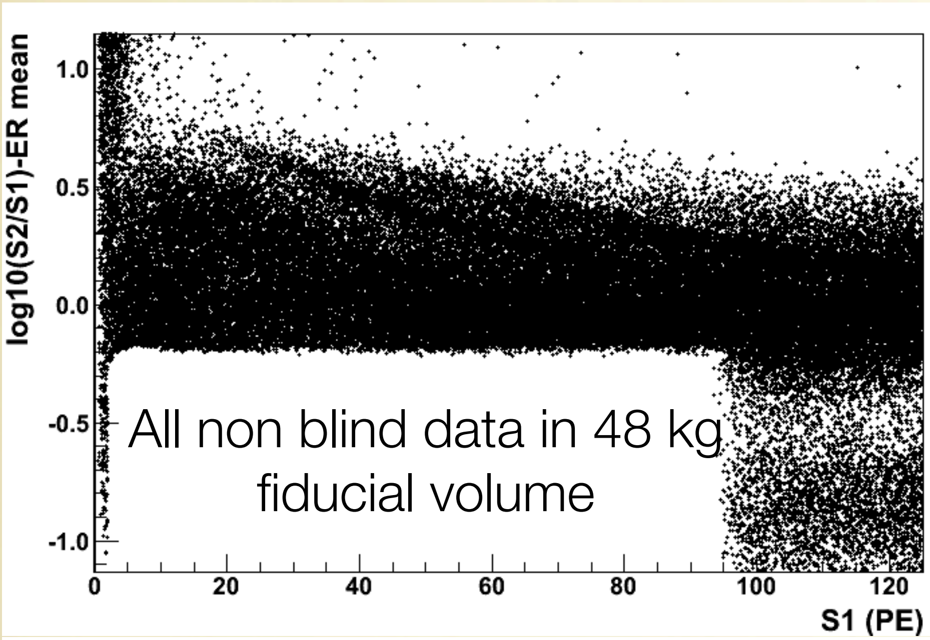
- Data taking: Feb. 28, 2011 to March 31, 2012
- Excellent stability of the detector parameters: T variation < 0.16% and P variation < 0.7%
- Data following maintenance periods removed from analysis
  => 224.6 live days of dark matter data
- Longest run of a liquid xenon detector

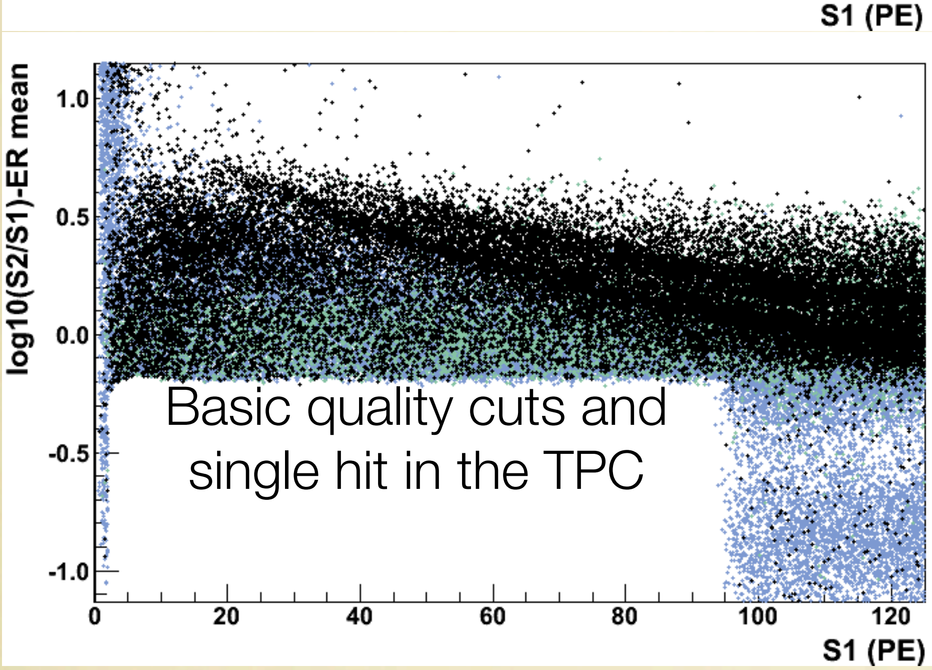
XENON100: CALIBRATION

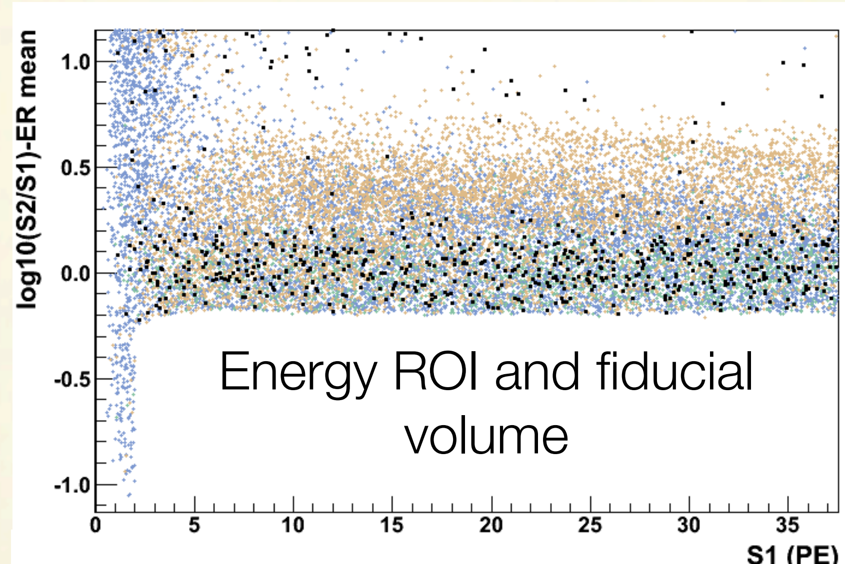


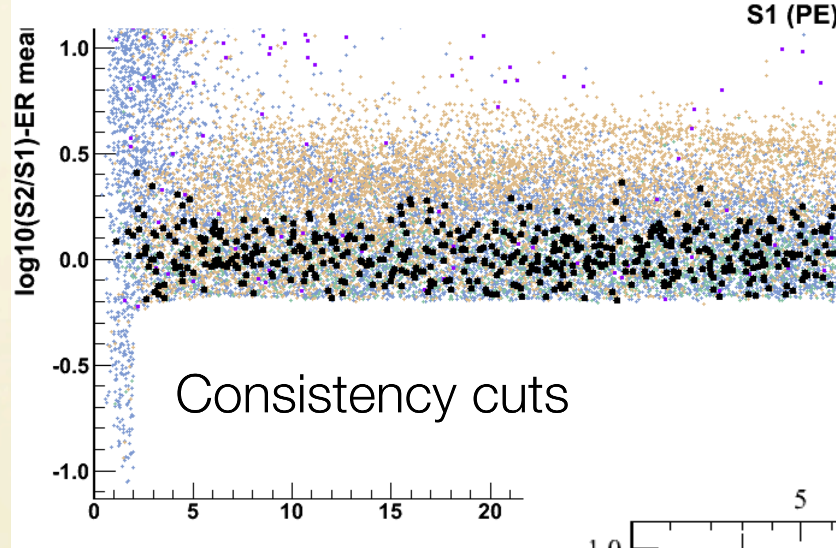
E. Aprile et al. (XENON100), arXiv:1207.3458

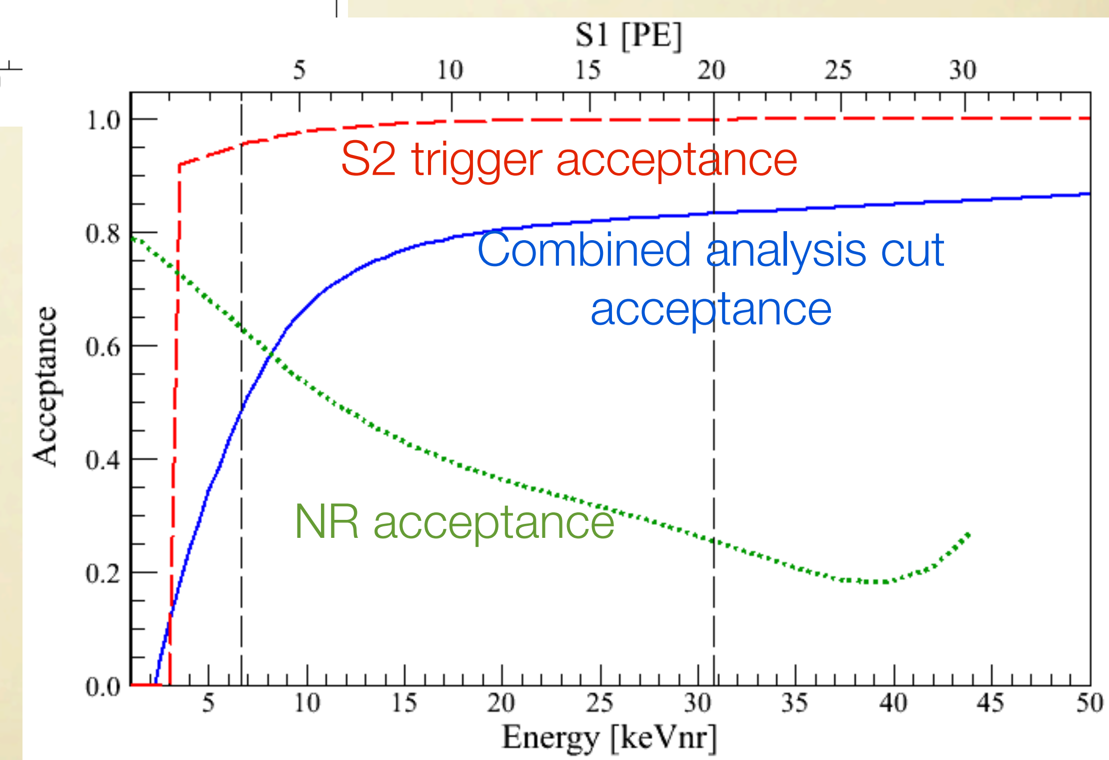
XENON100: Analysis









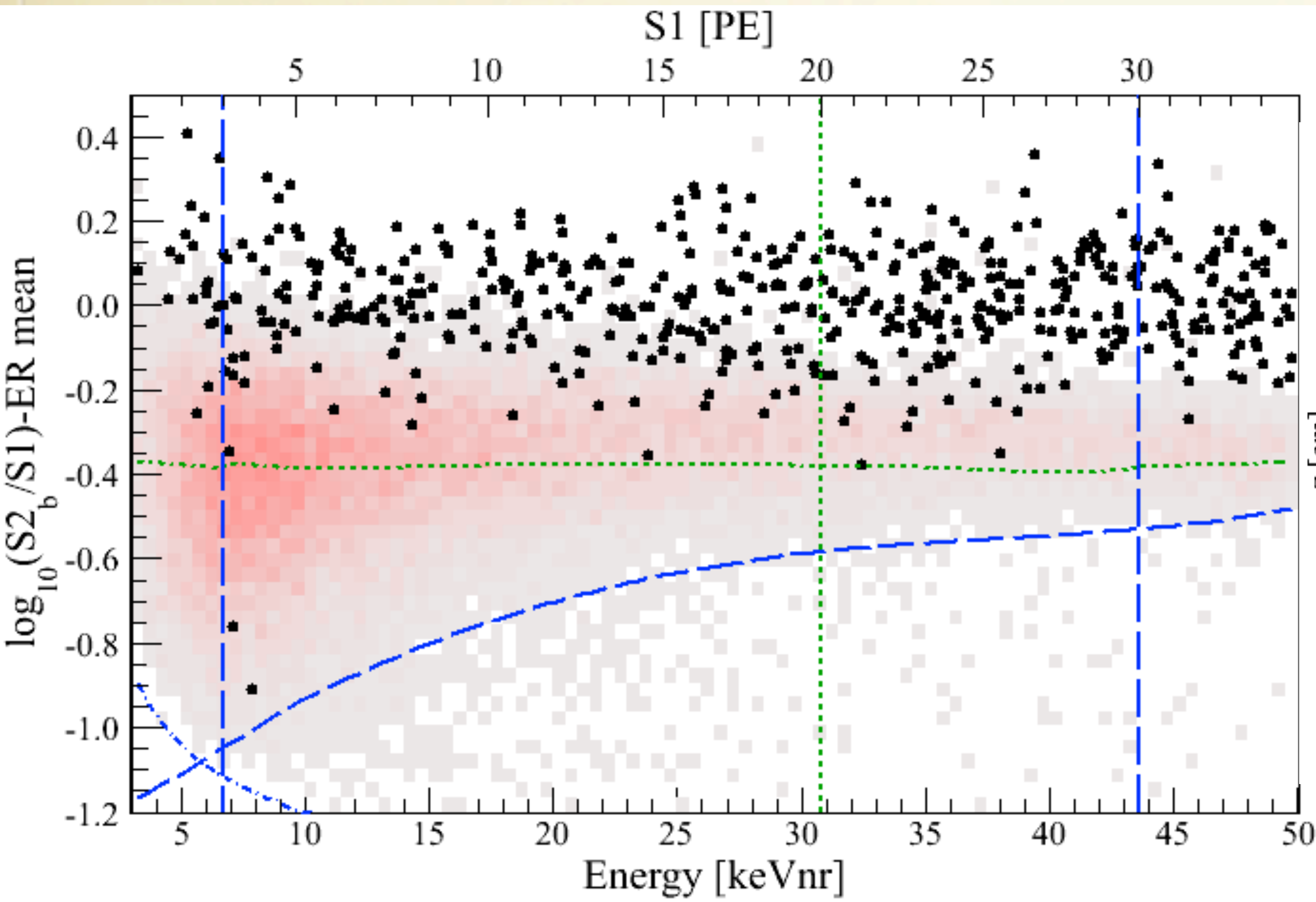


Details on the analysis:

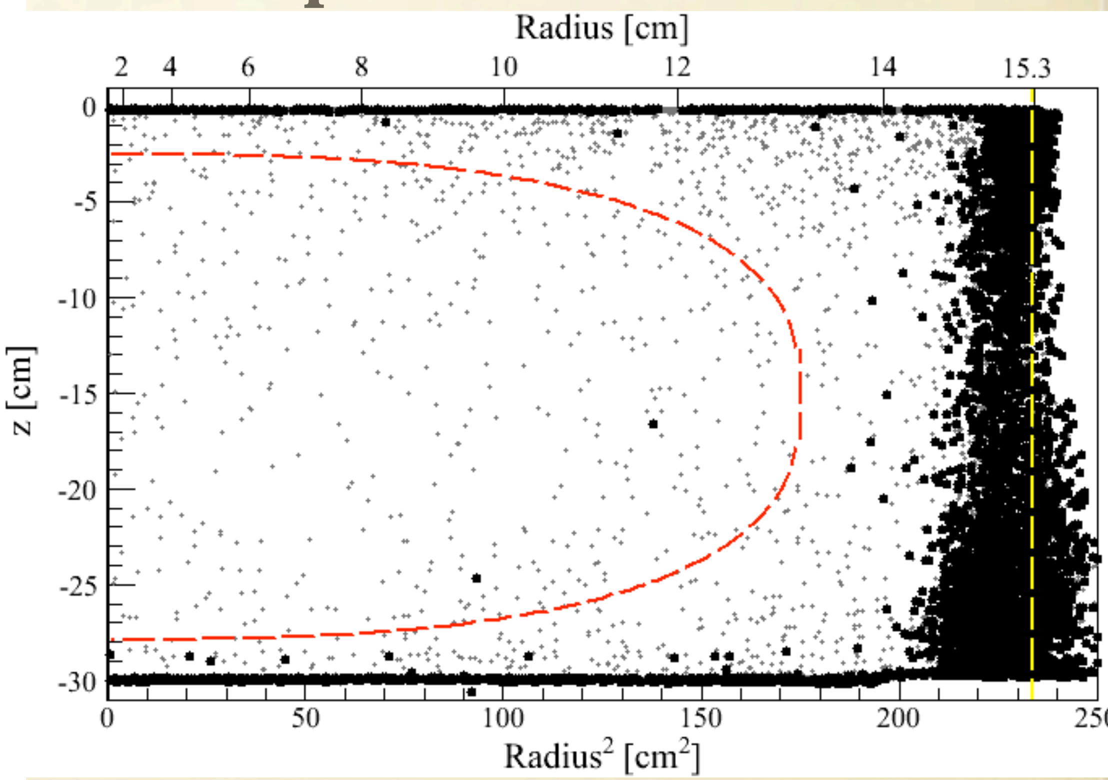
E. Aprile et al. (XENON100), arXiv:1207.3458

XENON100: RESULTS

E. Aprile et al., Phys. Rev. Lett. 109 (2012) 181301



The power of fiducialization



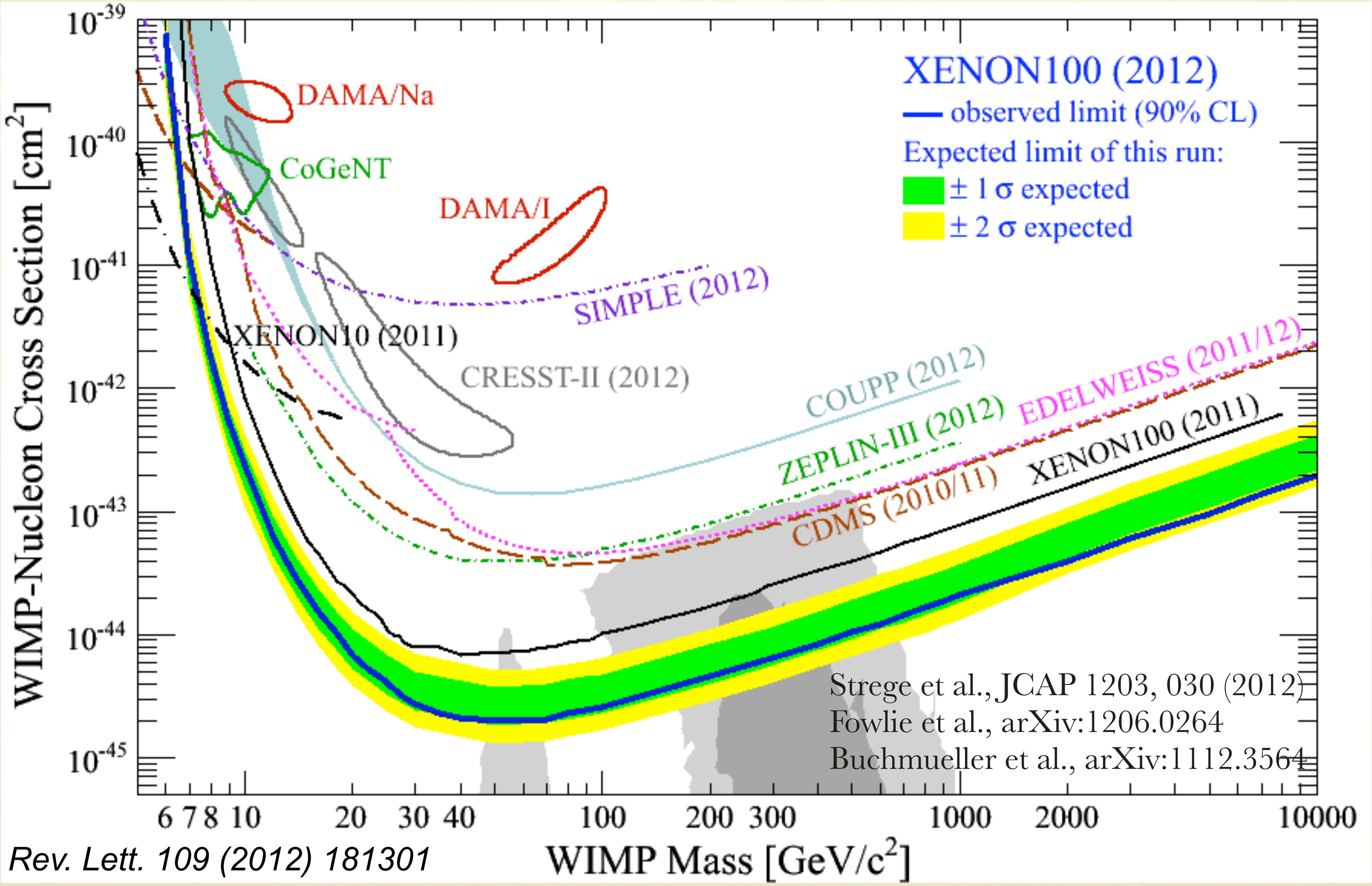
34 kg fiducial volume

- 2 events observed with 1.0 ± 0.2 events expected
- 26.4% probability of upward background fluctuation
- No significant excess due to signal seen in XENON100 data

XENON100: Spin Independent limits

- 2011/2012 data taking: 224.6 days x 34 kg exposure
- Dark matter isothermal halo: maxwellian velocity distribution v_c = 220 km/s, Galactic escape velocity v_{esc} = 544 km/s, local density of $\rho = 0.3$ GeV/cm^3
- Limits extracted via Profile Likelihood method

MOST STRINGENT LIMIT TO DATE



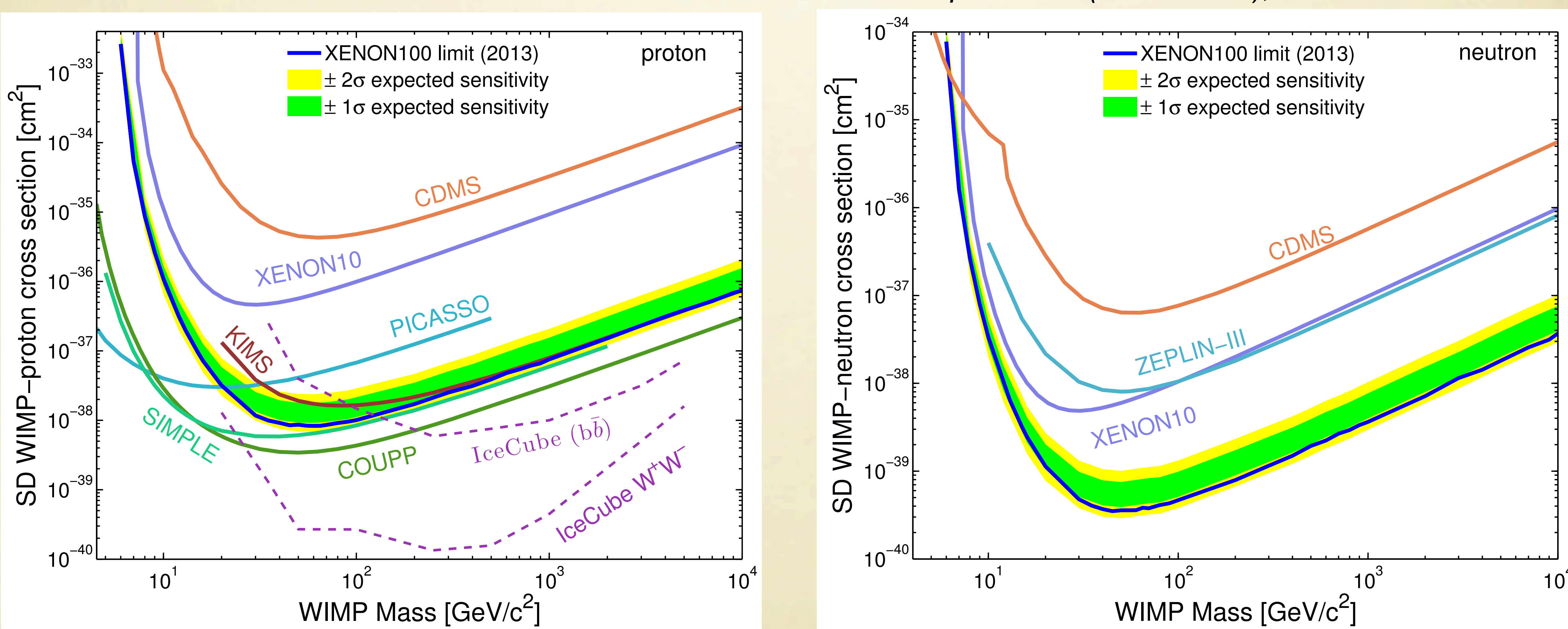
E. Aprile et al., Phys. Rev. Lett. 109 (2012) 181301

σ = 2.0 x 10-45 cm2, Mχ = 55 GeV/c2 (90% CL)

XENON100: Spin Dependent limits

- ~ 50% non-zero spin nuclei (129Xe (1/2) and 131Xe (3/2))
- competitive proton-only limit
- leading neutron-only limit

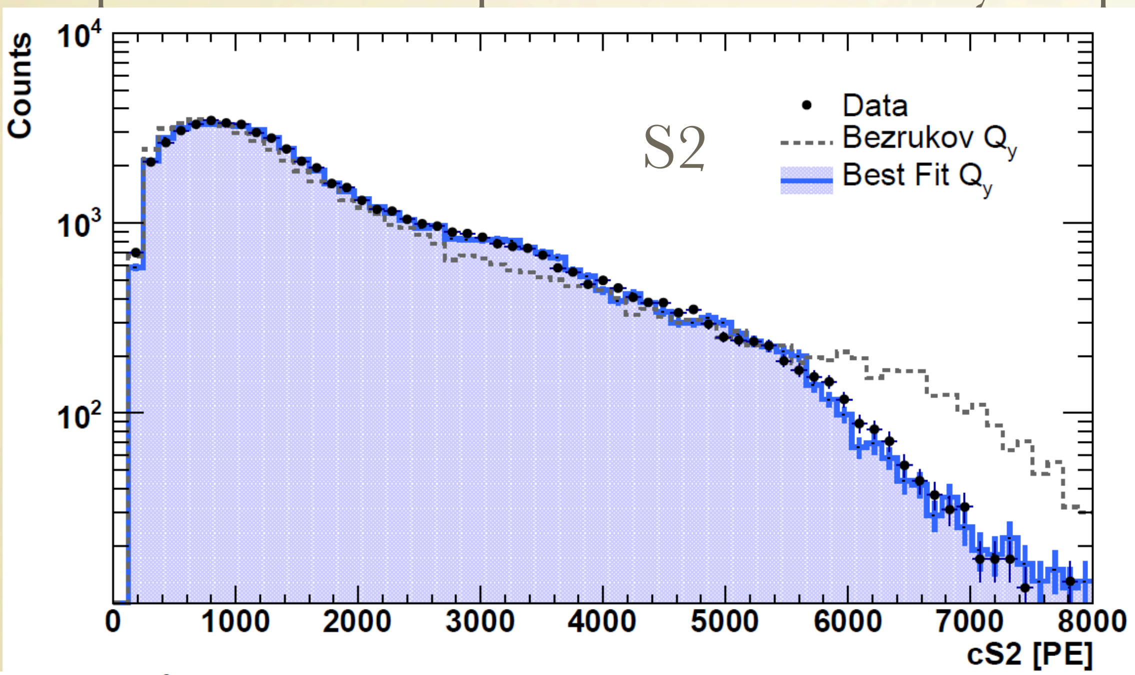
E. Aprile et al. (XENON100), arXiv:1301.6620

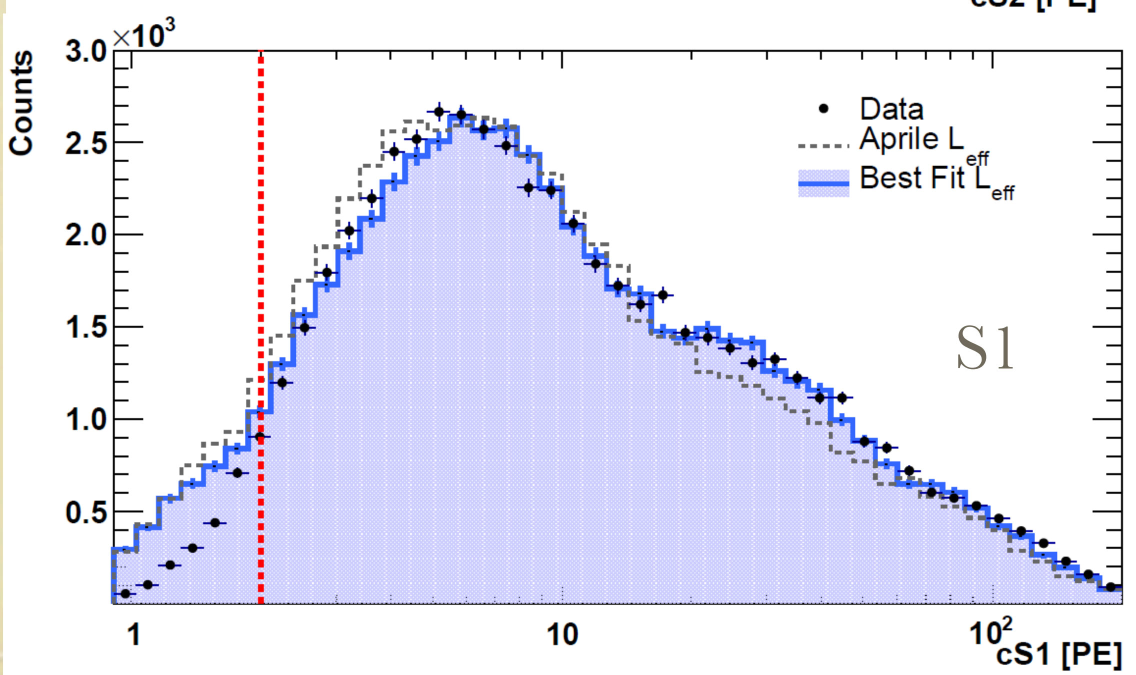


XENON100: Control on systematics

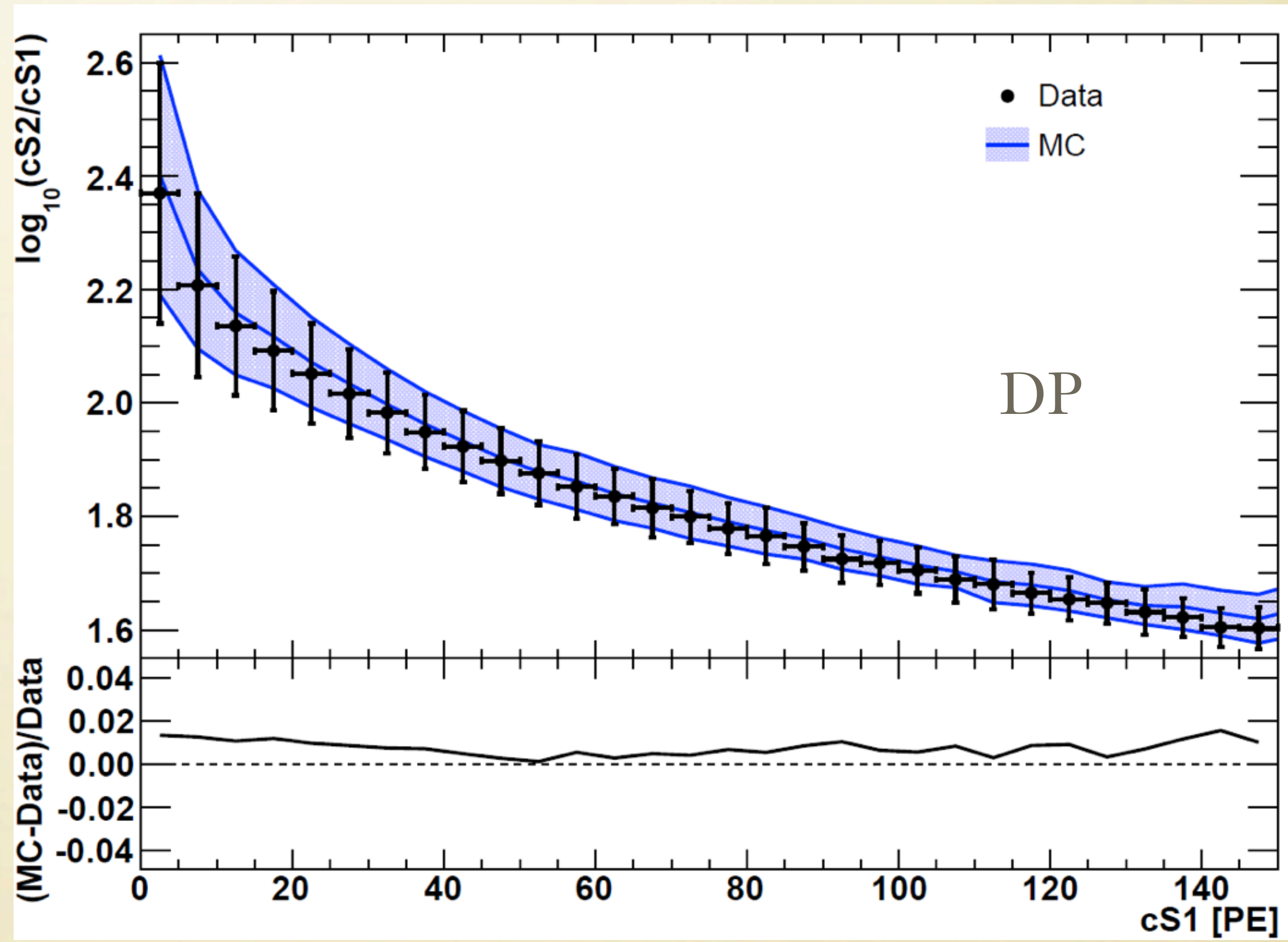
AmBe calibration

- Absolute (no scaling) data - Monte Carlo matching at % level down to 3 keV_{nr}
- simulation of both scintillation (S1) and ionization (S2) signals
- reproduce both spectra and 2D analysis space (DP)





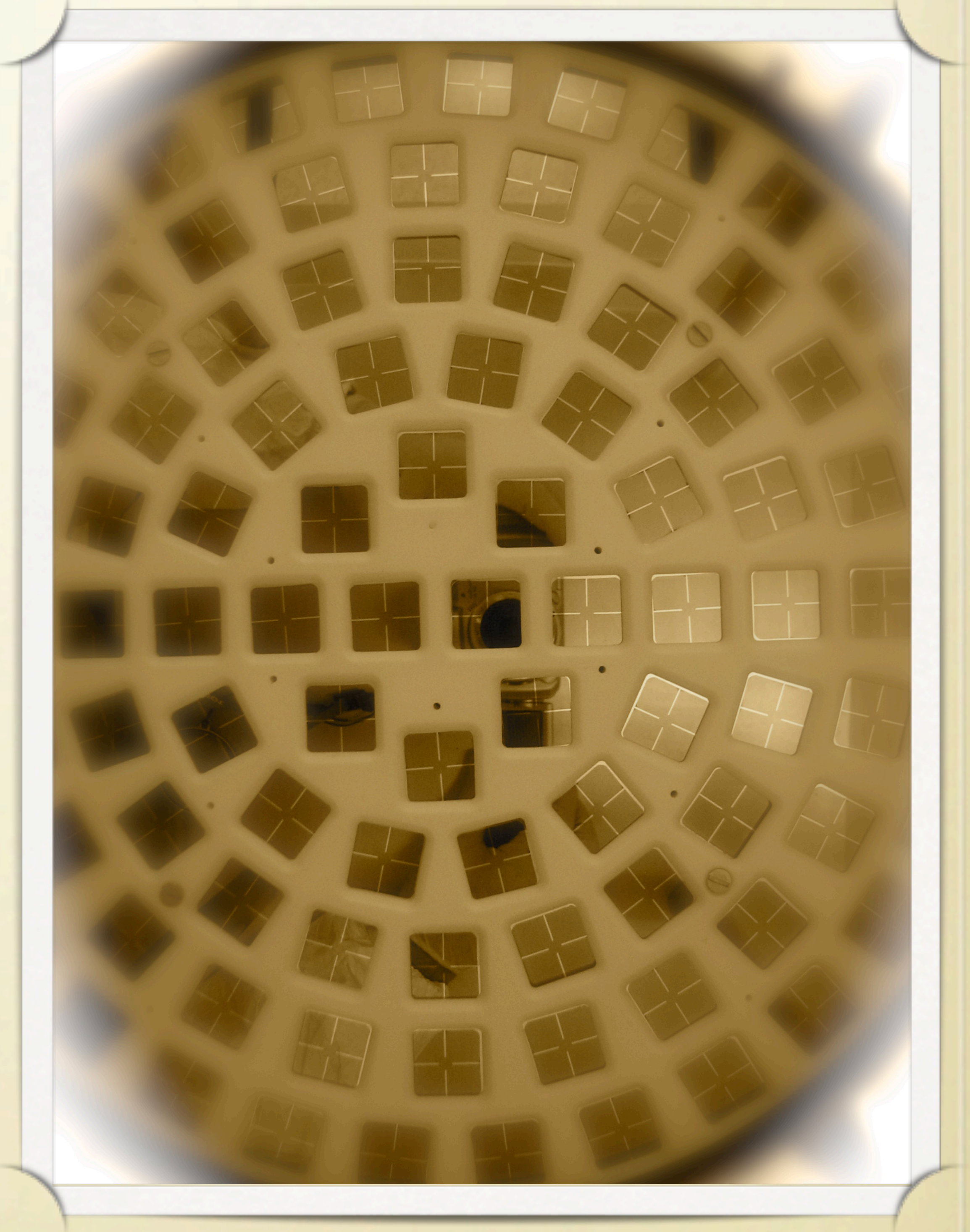
E. Aprile et al. (XENON100), arXiv:1304.1427



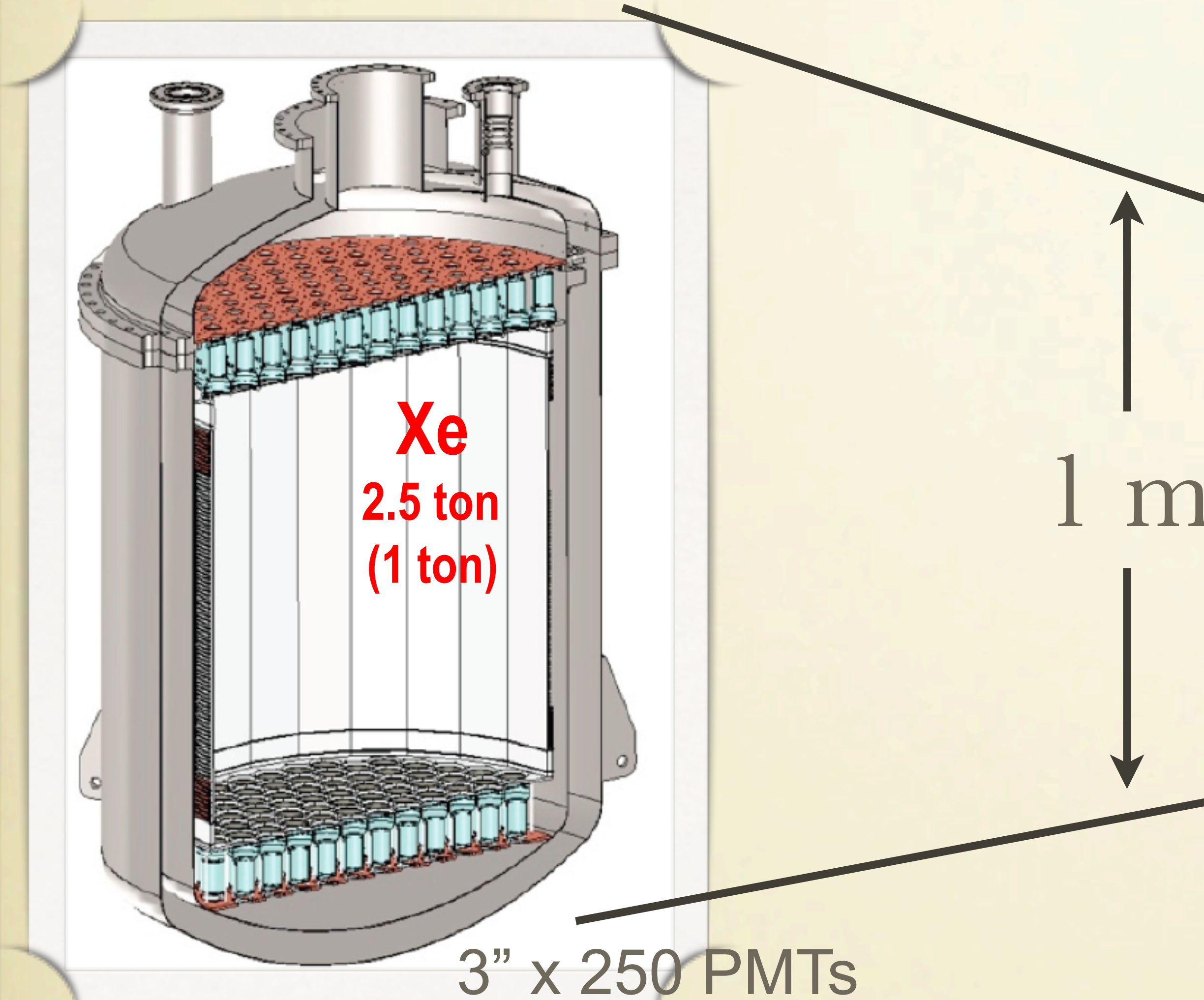
XENON100: WHAT IS GOING ON?

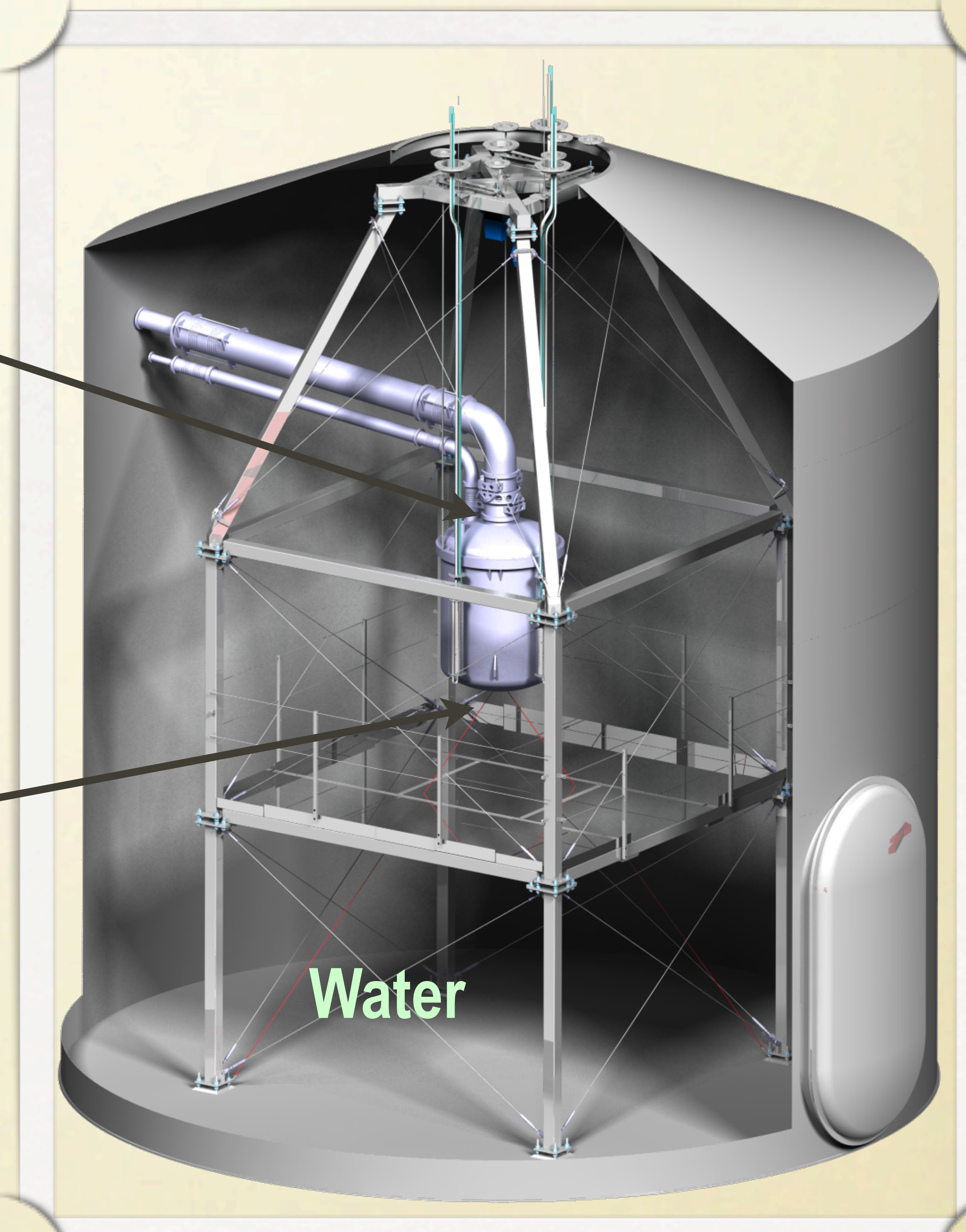
- Monte Carlo study of Nuclear Recoil background
- Detector response to single electron
- Annual modulation in low-energy ER
- Axion and super-WIMPs search
- Light dark matter with S2 only analysis
- 2D analysis with S1 and S2 energy scales combined and WIMP simulation

- Meanwhile XENON100 is still running and a new AmBe calibration just finished for the current run_12
- But we need to move forward



XENON1T



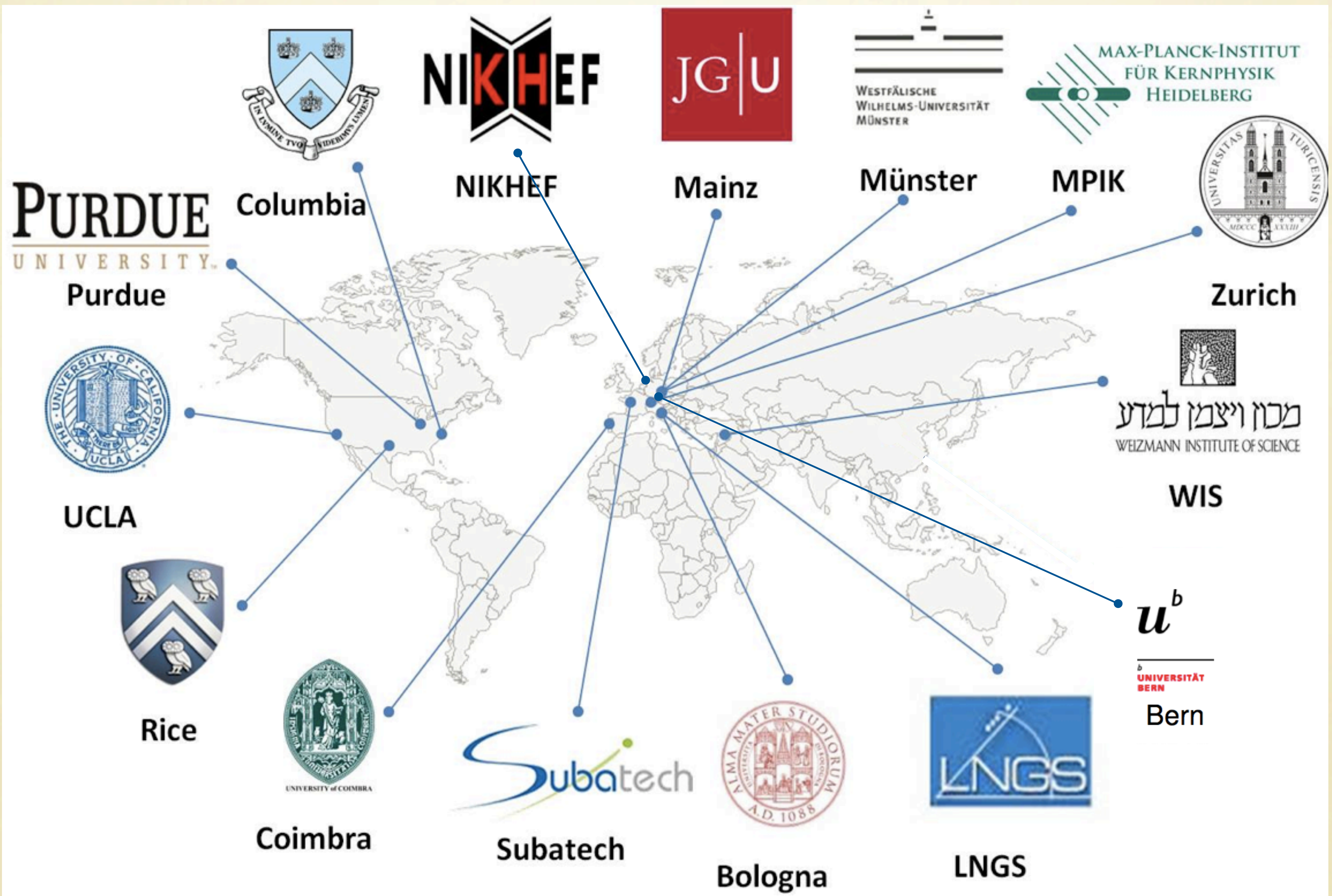


- ~ 40 x XENON100 sensitive mass
- 100 x less background than XENON100
- > 3 x longer drift and larger radius than XENON100
- toughest challenges:
  - intrinsic contamination - < 0.5 ppt Kr and < 1 μBq/kg of ^{222}Rn
  - -100 kV on cathode (-16 for XENON100)
  - recirculation and purification

Watch out! It's coming...

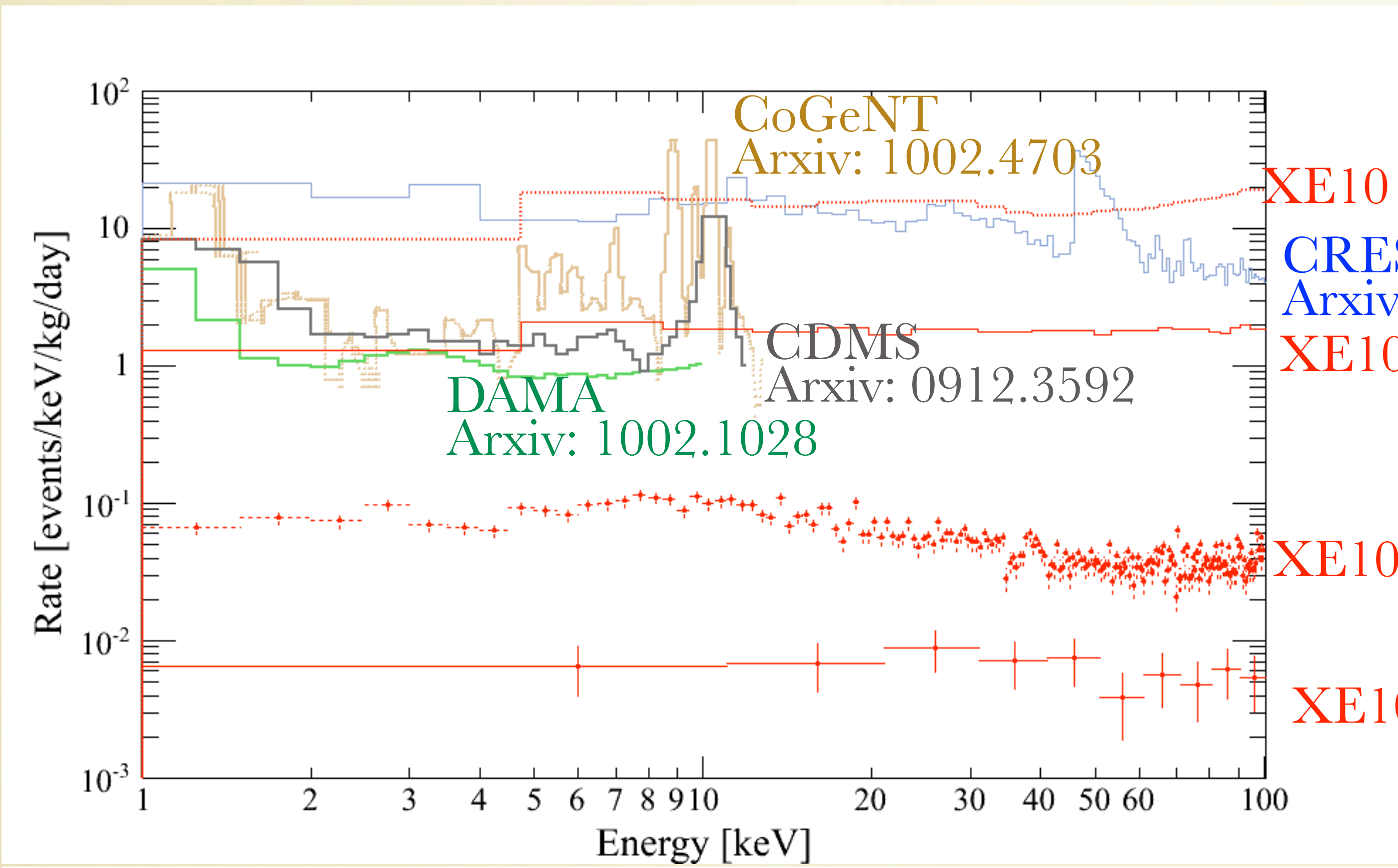
Xe
XENON
Dark Matter Project

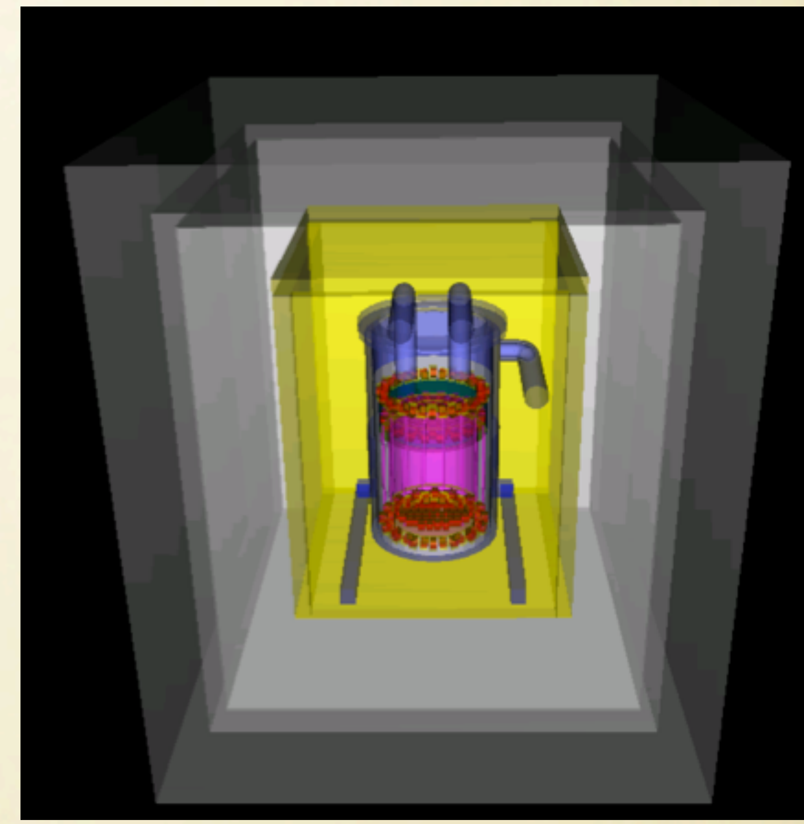
The XENON Collaboration

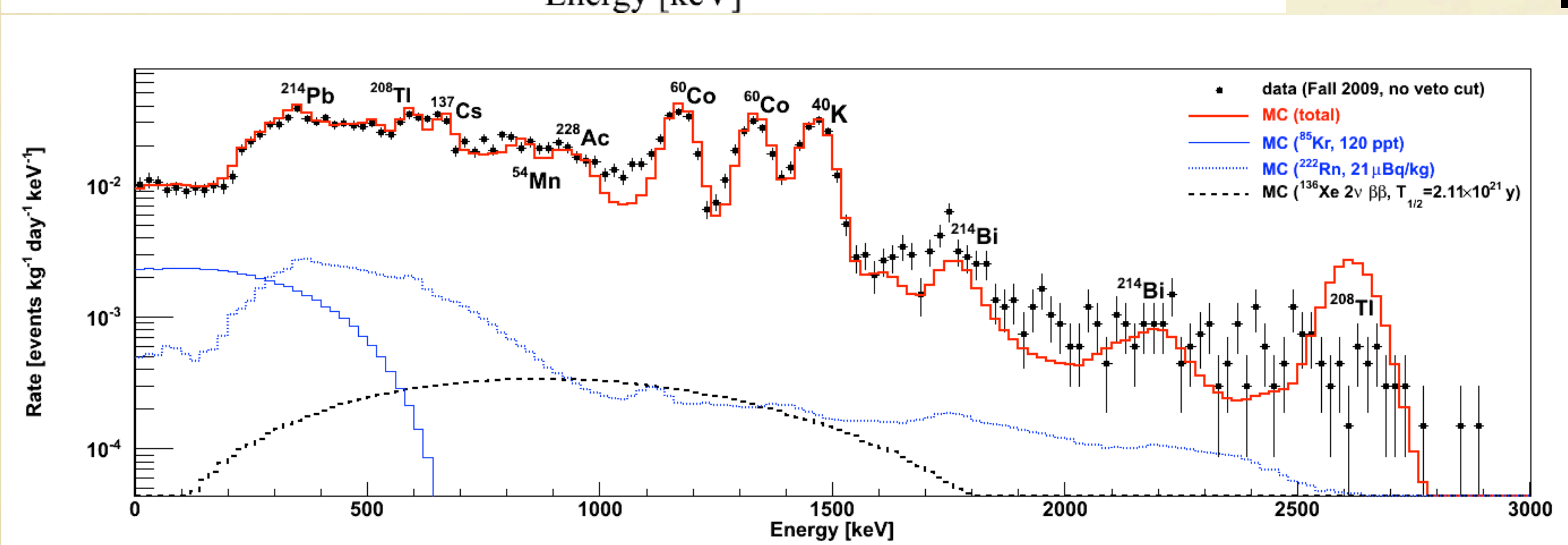


XENON100: BACKGROUND

Lowest background dark matter detector







Phys. Rev. D 83, 082001 (2011)

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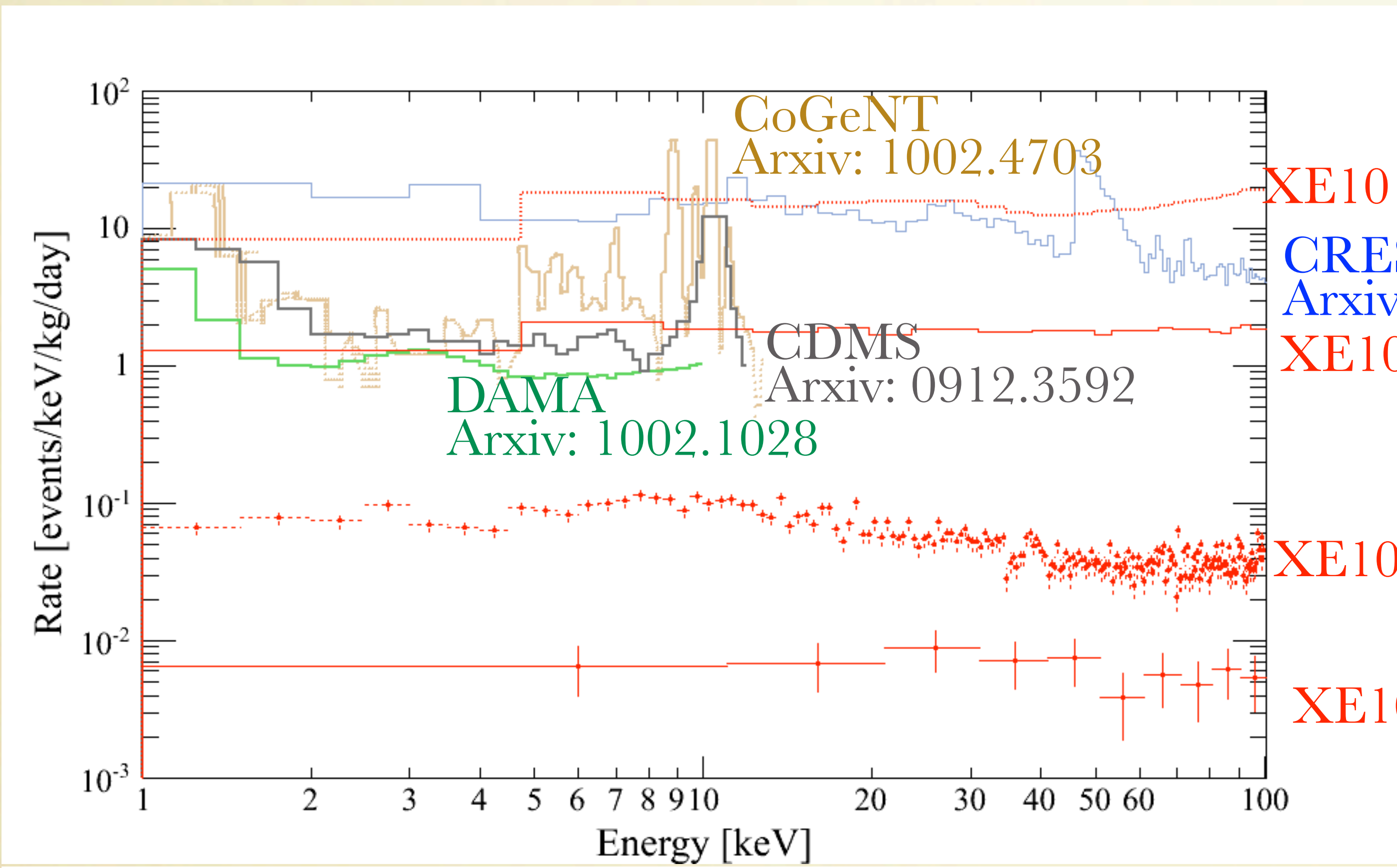
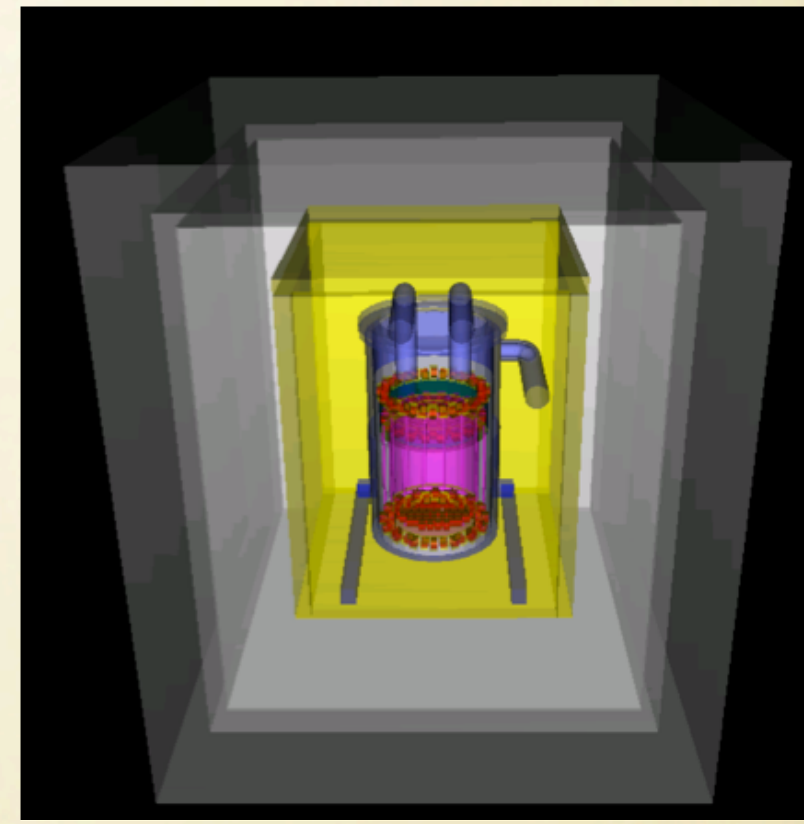
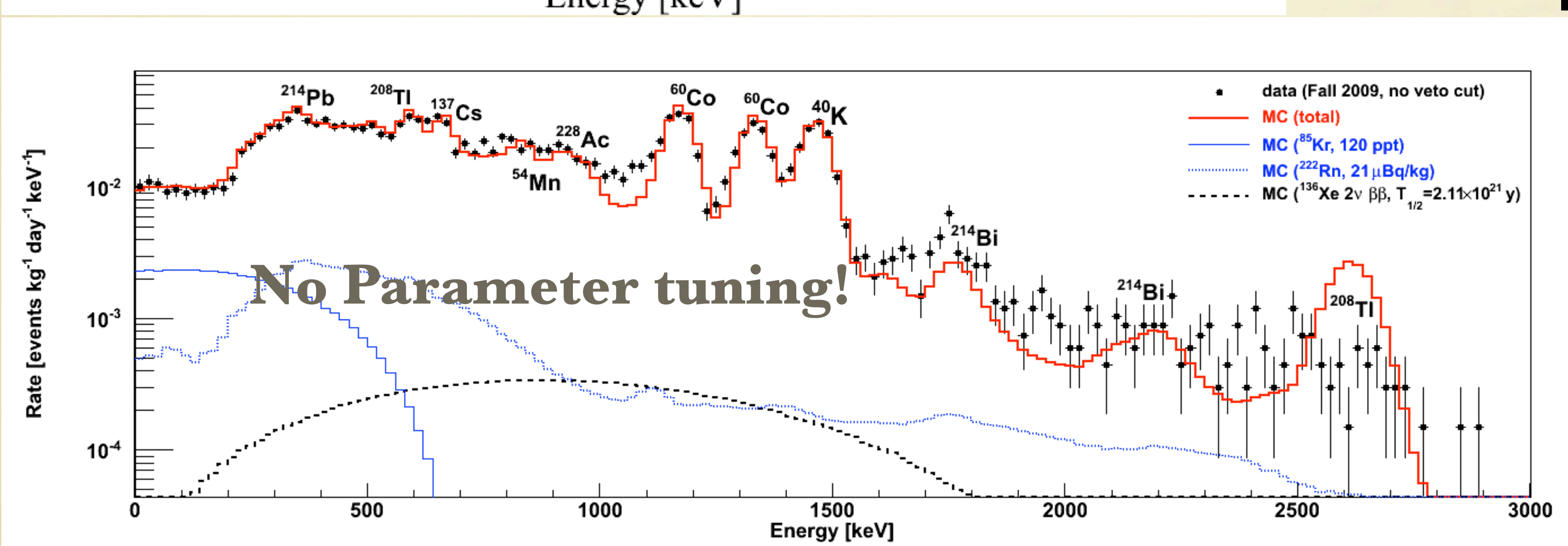
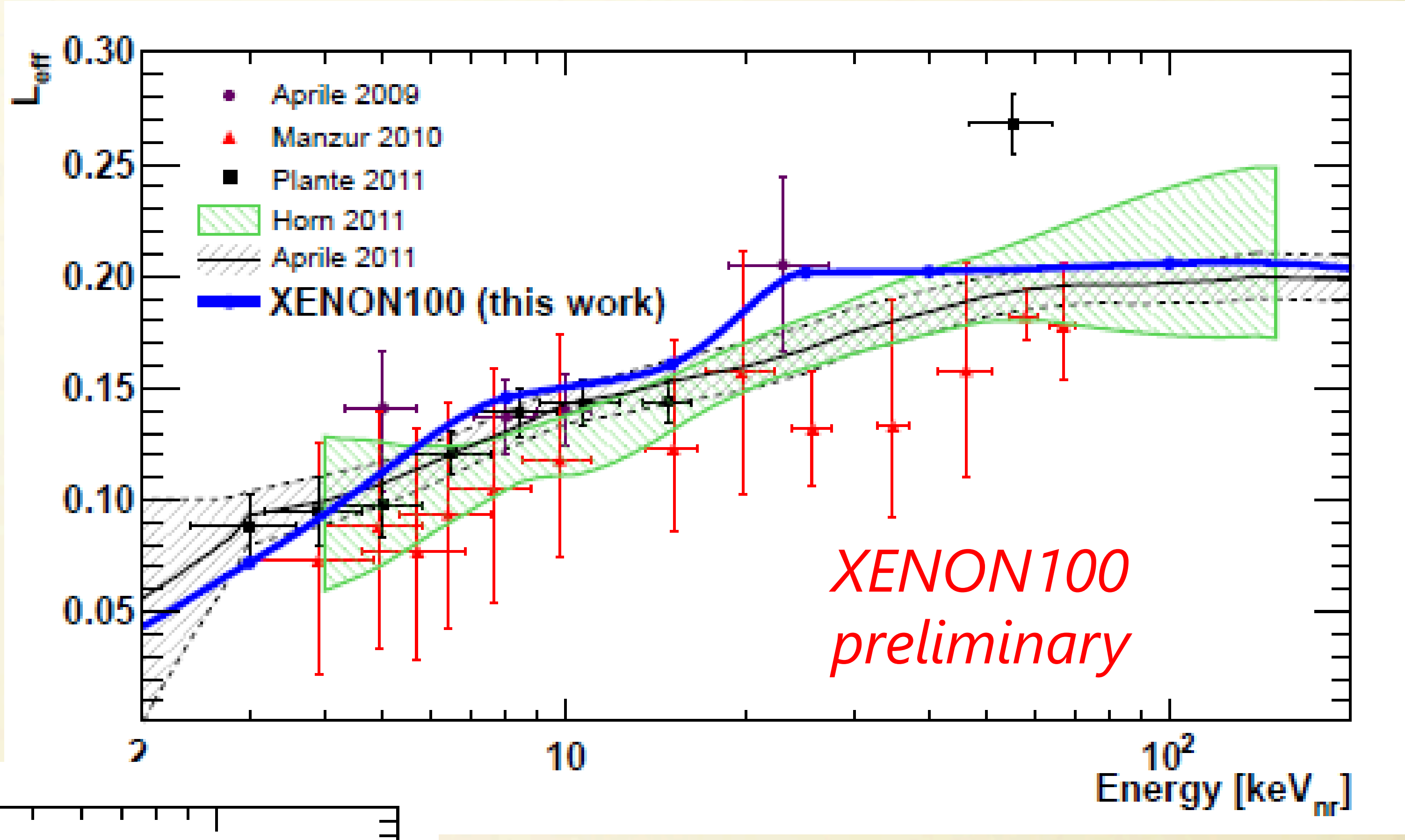


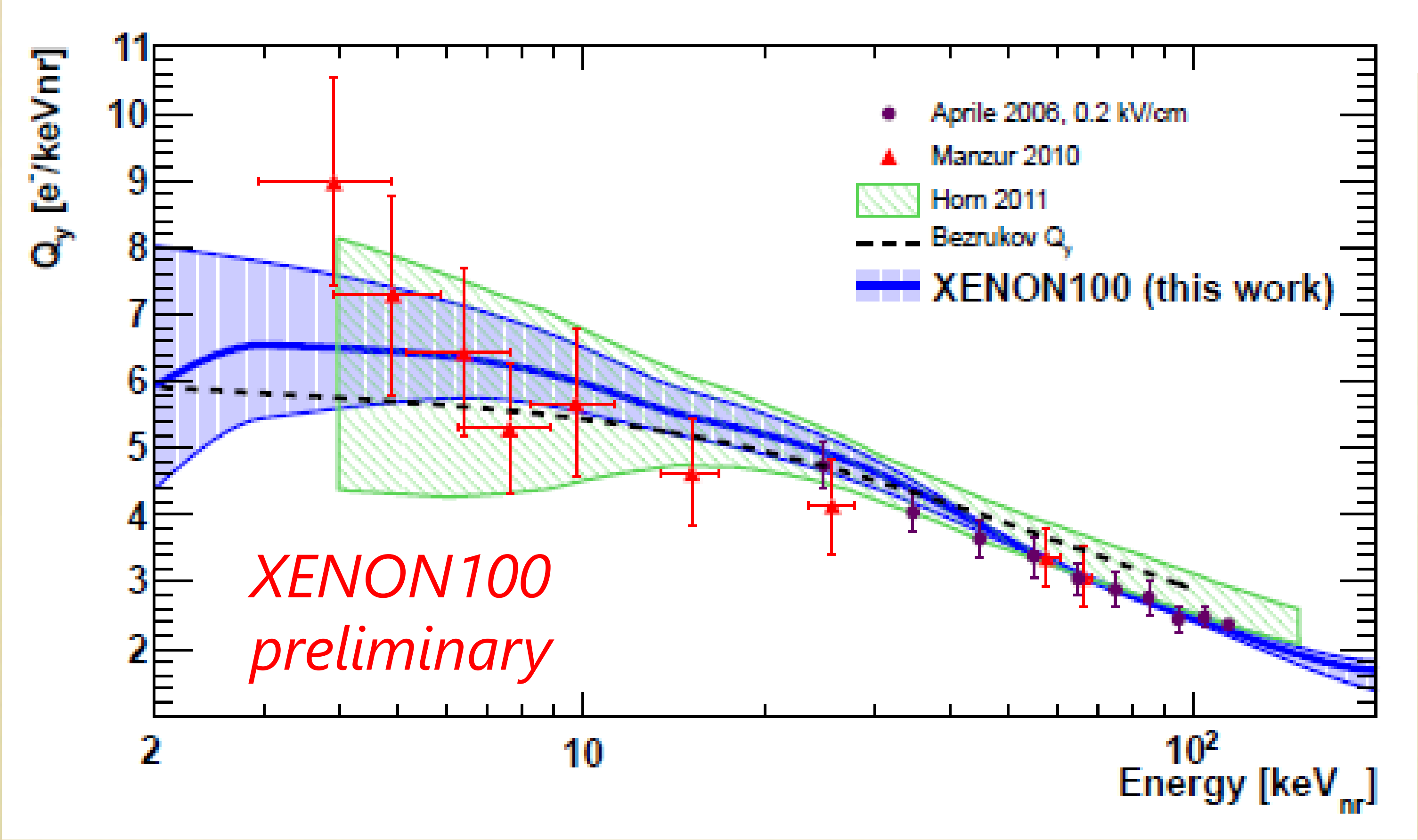




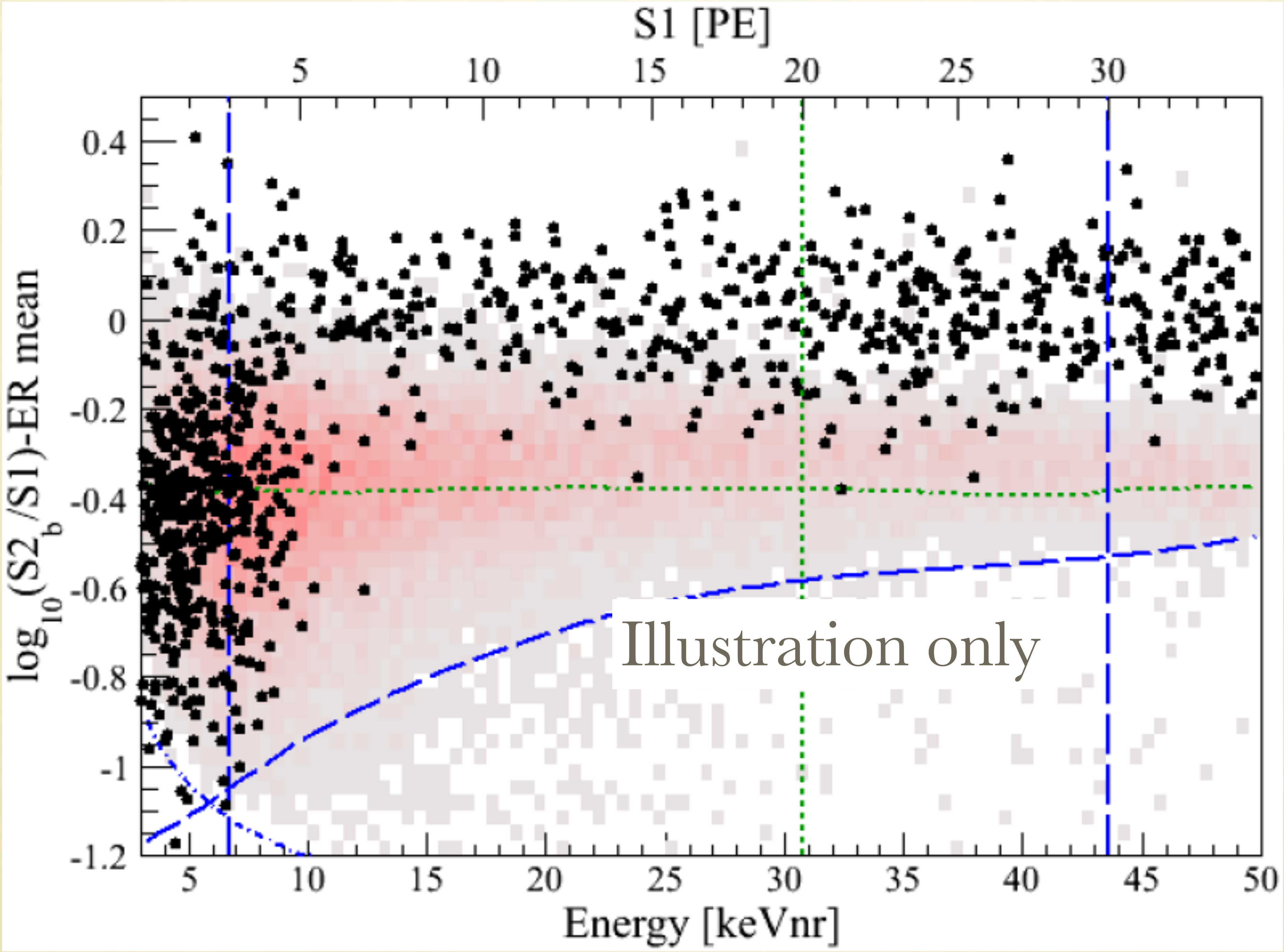
Phys. Rev. D 83, 082001 (2011)

XENON100: NR Energy scale

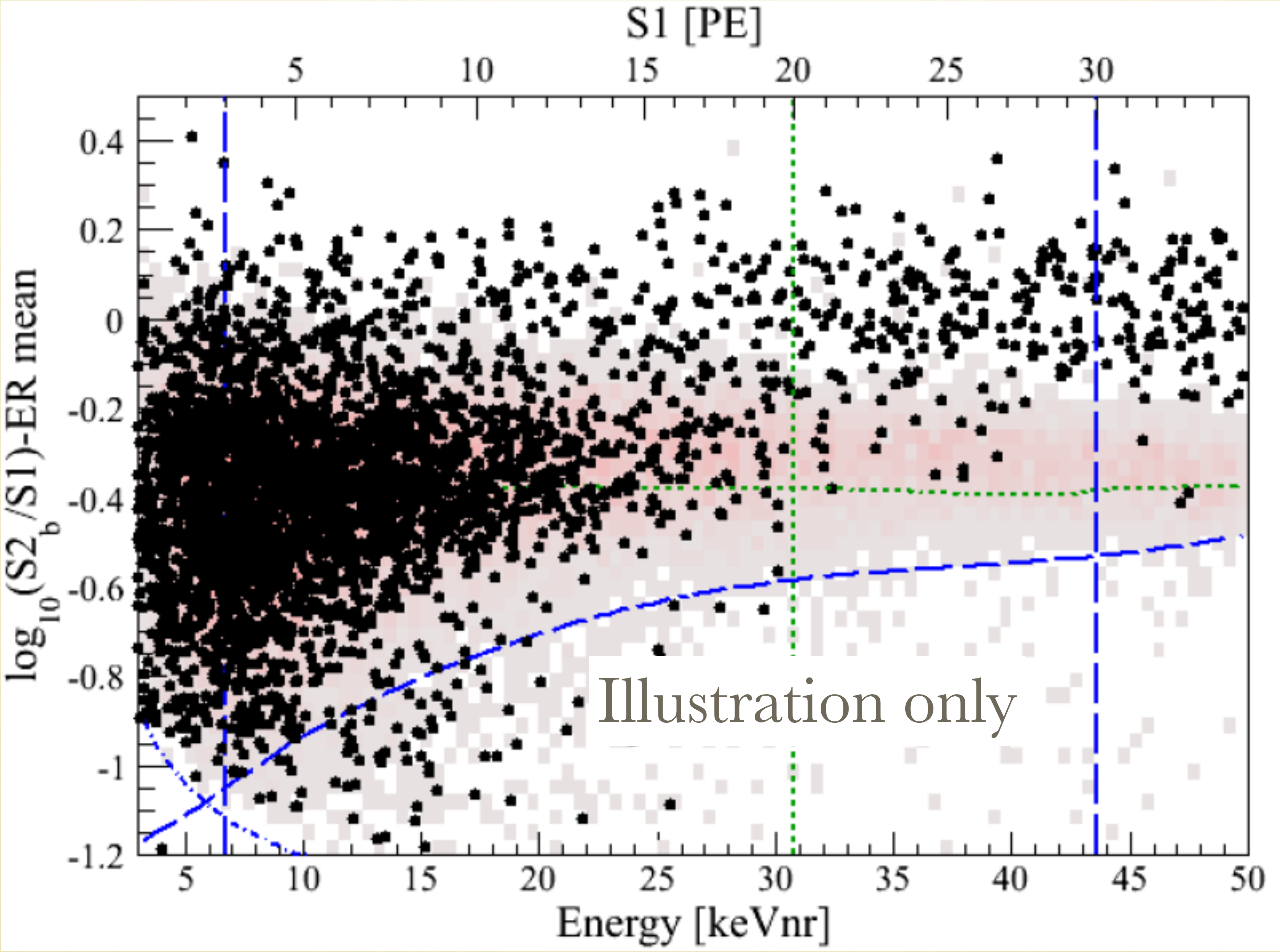




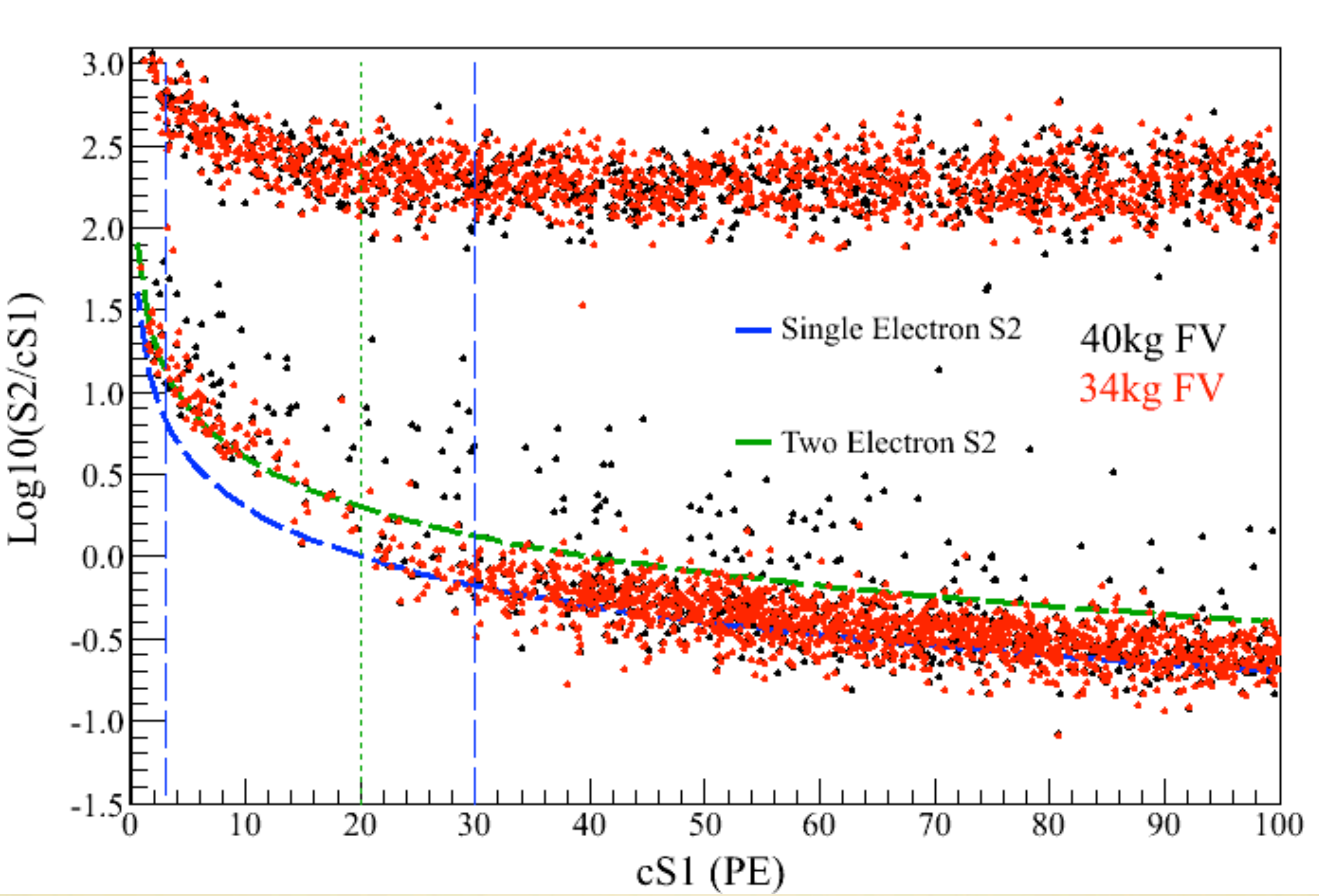
σ = 1.0 x 10^{-40} cm^2, M$_X$ = 8 GeV/c^2



σ = 1.6 x 10^{-40} cm^2, M$_\chi$ = 25 GeV/c^2



Analysis on the two candidate events

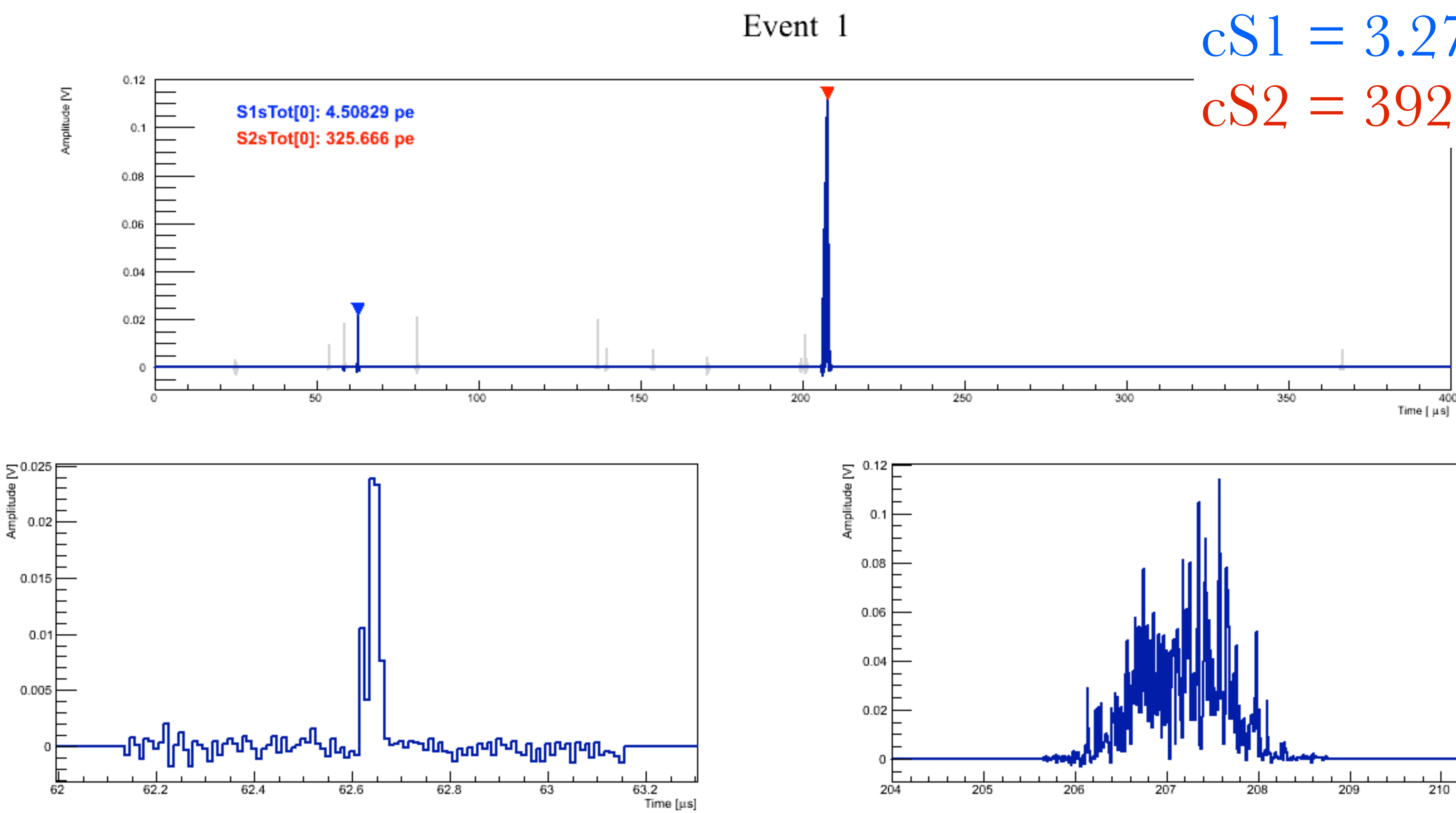


Relaxing the S2 threshold condition (S2>150 PE)

=> band of events at very low S2/S1(below signal range)

- 2 events from the tail of this band?
- further studies are required
- quantify and put into background model for the next run

Candidate event #1



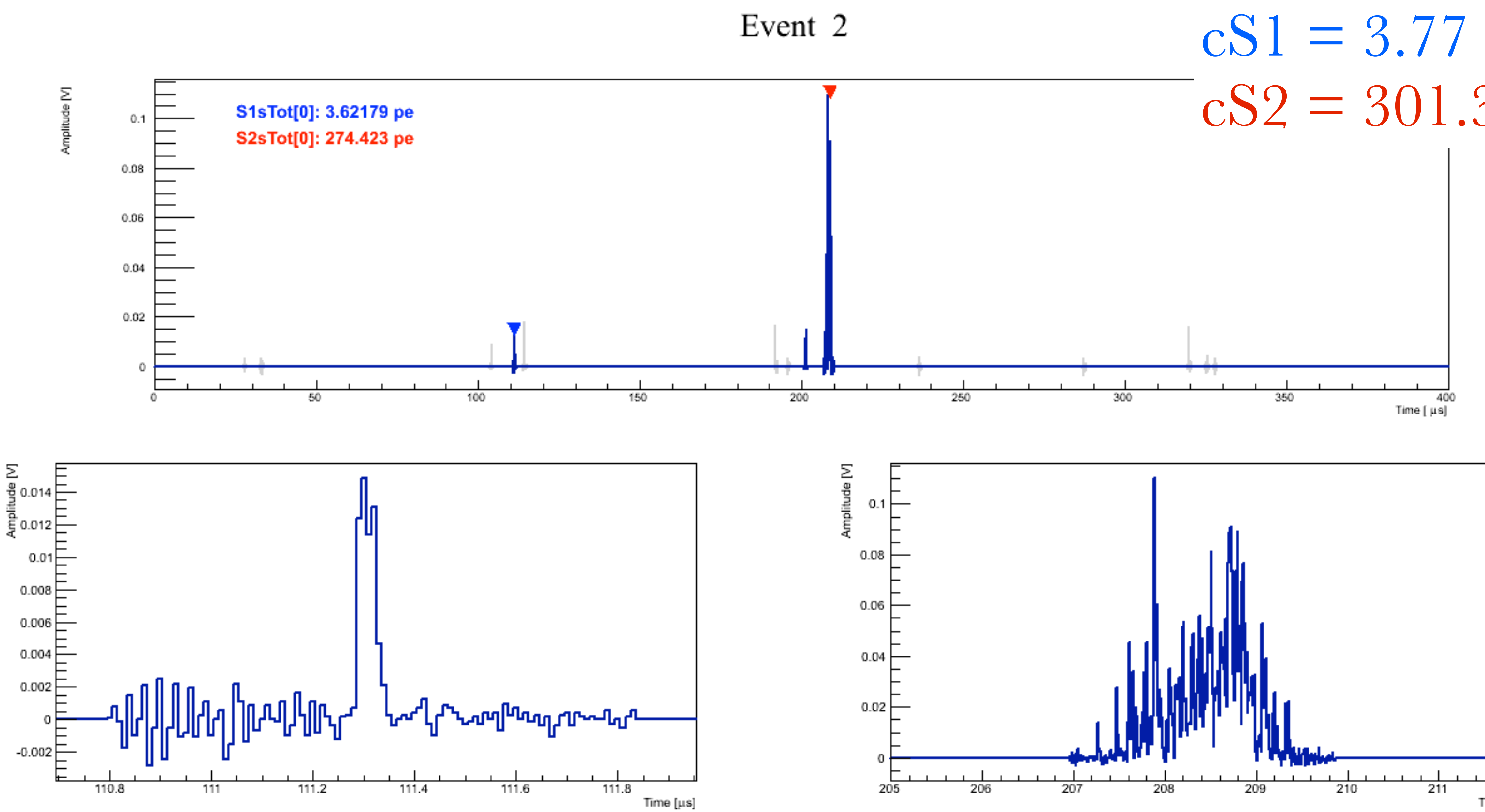
cS1 = 3.27 PE

cS2 = 392.8 PE

Candidate event #2

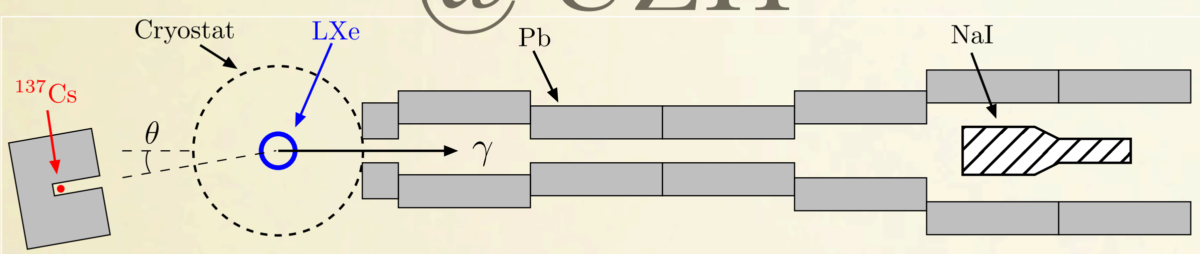
cS1 = 3.77 PE

cS2 = 301.3 PE

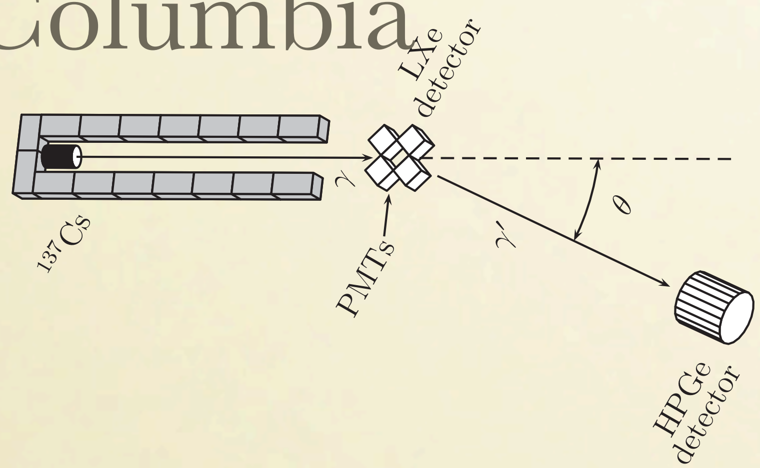


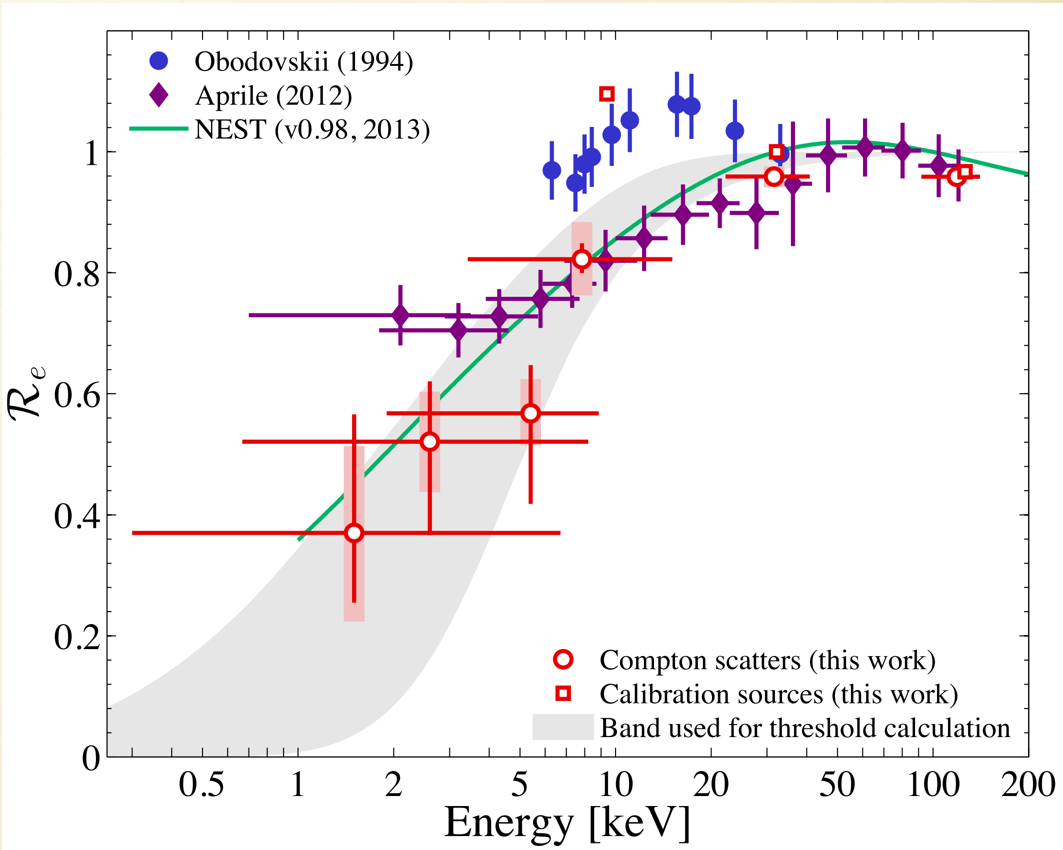
Energy scale for electronic recoils

@ UZH



@ Columbia





- Scintillation response by means of "Compton coincidence technique"
- Measuring the energy of the scattered γ ray

$$E_r = E_\gamma - \frac{E_\gamma}{1 + \frac{E_\gamma}{mc^2}(1 - cos\theta)}$$

- Two different approaches:
  - Energy: HPGe to select events with fixed recoil energies
  - Time: NaI to select events at a fixed time