^{85}Kr Delayed Coincidence in LUX

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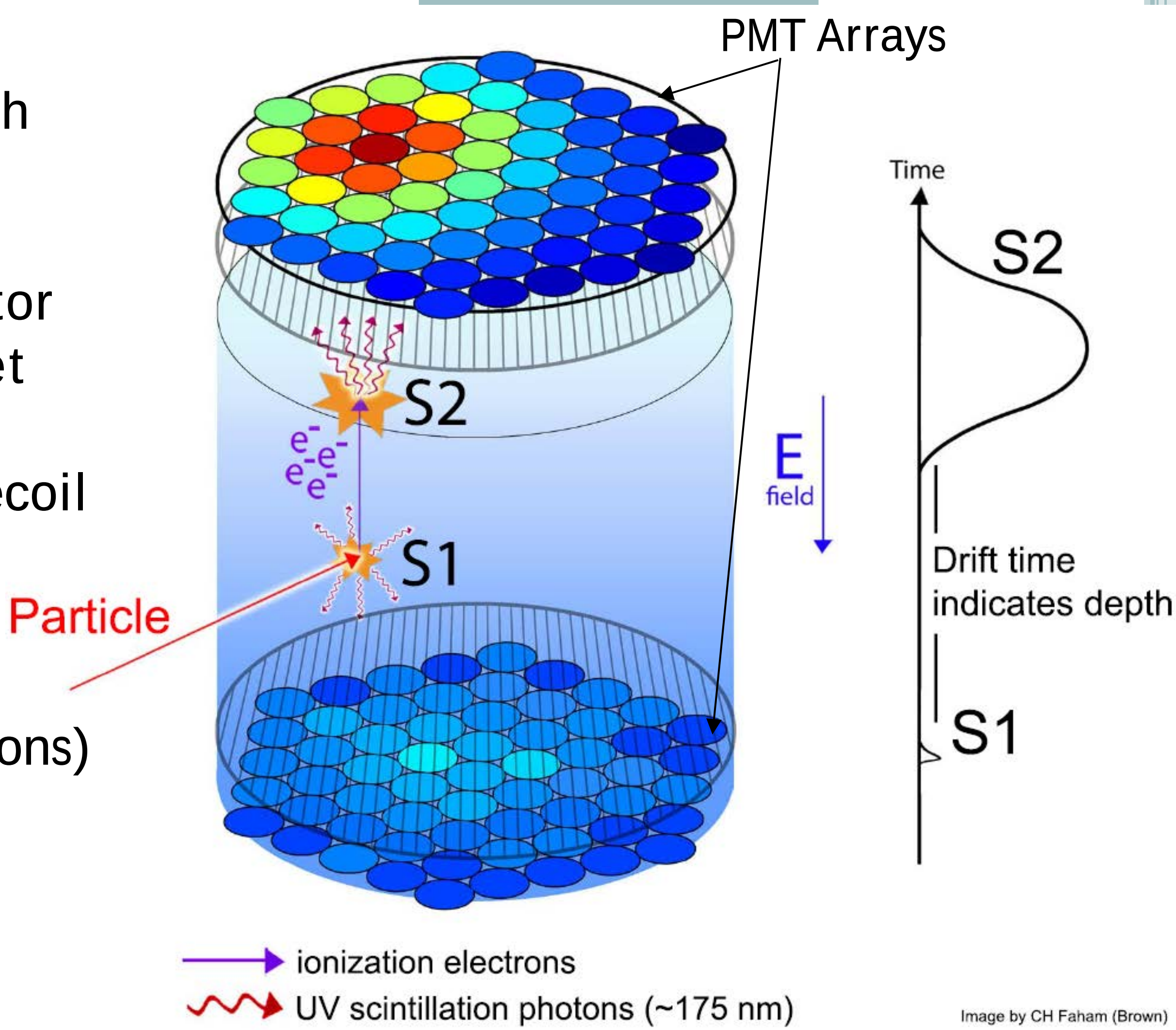
Royal Holloway

LUX Detector

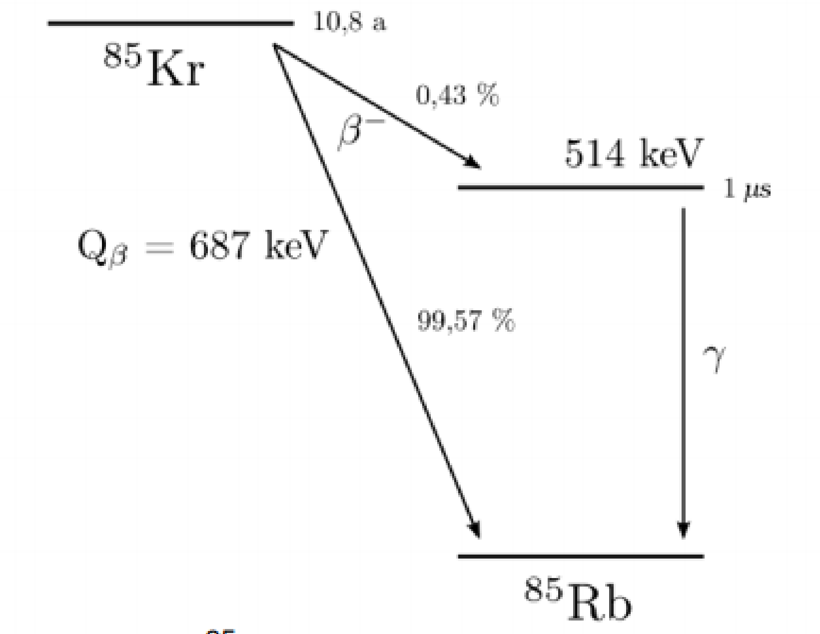
- Direct dark matter search
  - See L. Reichhart talk
- Dual-phase xenon detector
  - 250 kg active Xe target
- WIMP signal is nuclear recoil
  - Energy a few keV
- Backgrounds from:
  - Nuclear recoils (neutrons)
  - Electronic recoils (electrons/photons)
- 99.6% electronic recoil discrimination.



- ^{85}Kr is an electronic recoil background, dispersed throughout the active xenon.

^{85}Kr Properties

- $T_{1/2}$ = 10.76 years.
- Low energy part of β^- spectrum (endpoint 687 keV) gives background.
- ^{85}Kr is a small part of the Kr isotopic abundance
- Anthropogenic, in atmosphere due to nuclear fission and nuclear tests

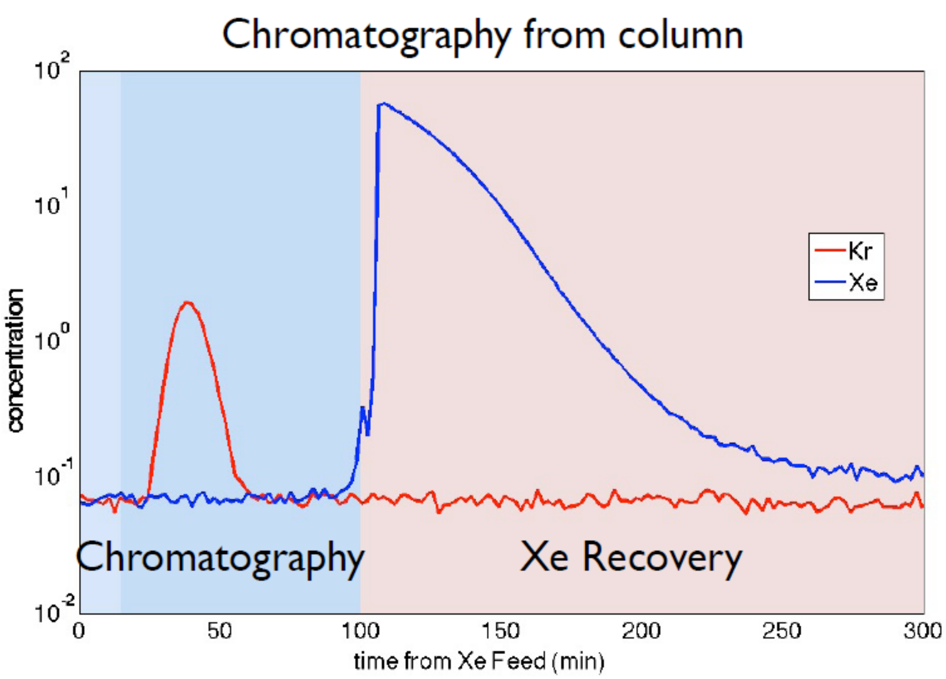


^{85}Kr decay scheme

- Commercial xenon used in LUX contained 130 ppb ^{nat}Kr/Xe (130 x10^{-9} g/g)
- Would give ~6 counts/keV/kg/day (DRU)
- Aim for ^{85}Kr background to be 0.2 mDRU – ¼ of external γ background
- Requires Kr/Xe of 5 ppt (1x10^{-12} g/g)

Kr Removal

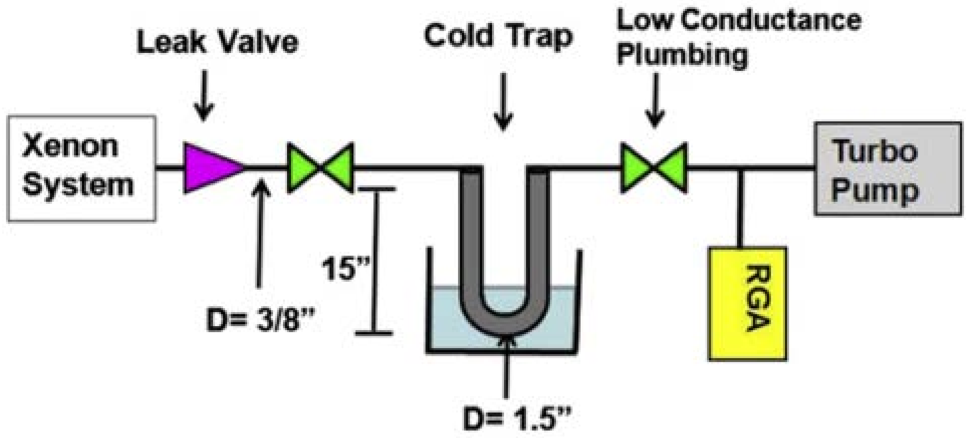
- Kr is a noble gas, not removed during the run by the chemical purifier
- Removed prior to using the xenon, chromatographic separation at CWRU
  - Bolozdynya et. al., NIM A, 579 (2007) 50–53
- Xenon is passed through a charcoal adsorption column – krypton has a shorter transit time than the xenon.



- After this treatment:
  - 4 ± 1 ppt Kr/Xe
- ^{85}Kr Background:
  - 0.19 mDRU

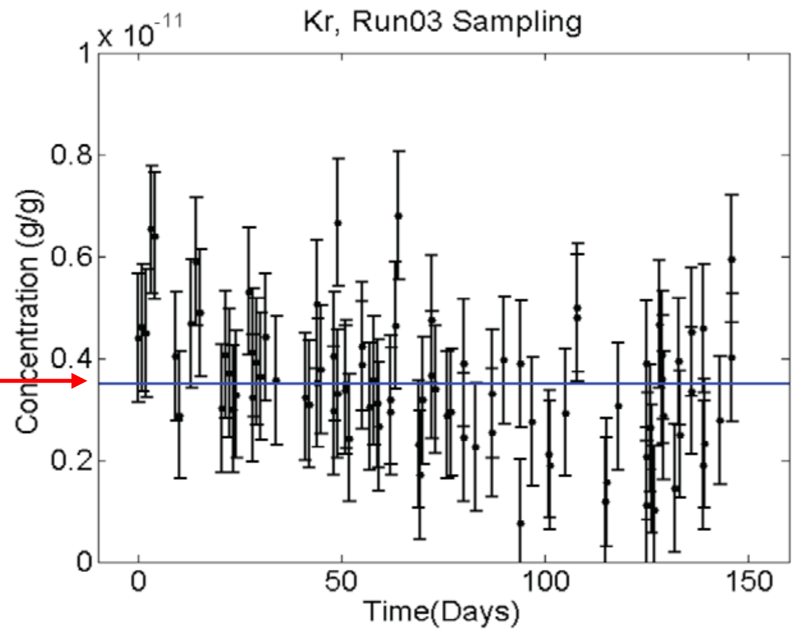
Kr Sampling

- Concentration of impurities in the xenon measured throughout WIMP run
- Sample xenon from the detector
- Measure using residual gas analyser (RGA) mass spectrometer with cold trap, developed at Maryland
  - Dobi et. al., NIM A 665 (2011) 1–6
- Cold trap freezes xenon more than the impurities (eg. N, O, Kr, Ar)
- Achieve ppt sensitivity to Kr

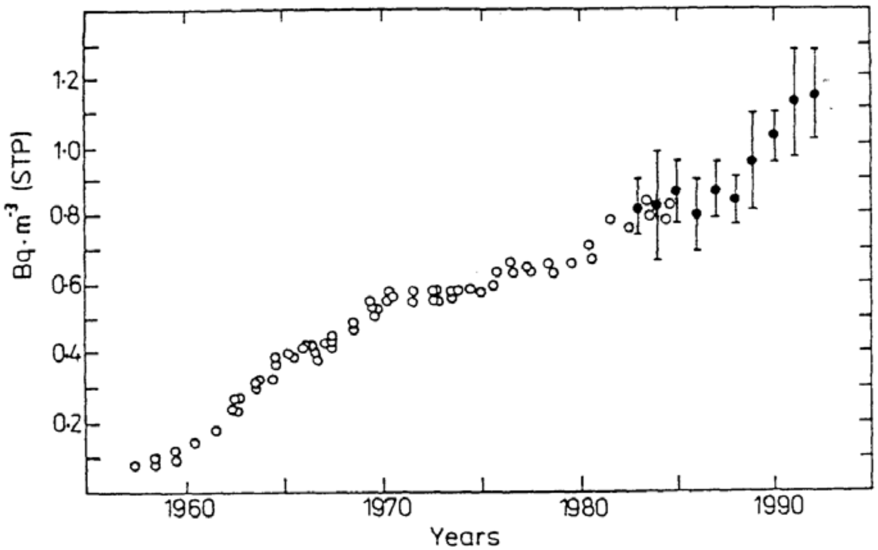


^{85}Kr Background from Sampling

1) Measure Kr/Xe ratio:
   - 3.5 ppt



2) Assume atmospheric abundance:
   - ^{85}Kr/Kr ratio: 2 x 10^{-11}



Wilhelmová, Environ. Monit. Assess., 34, (1995) 145-9

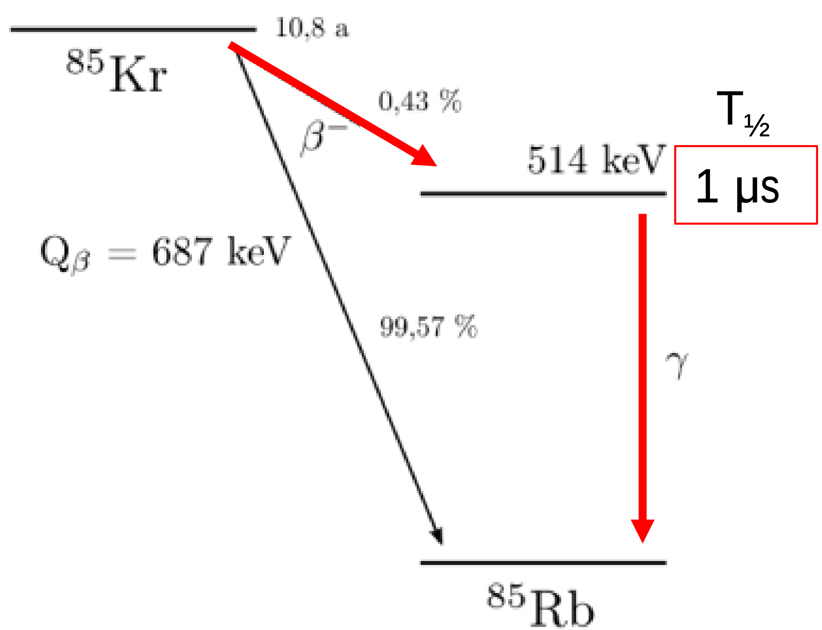
3) Calculate ^{85}Kr background:

Source	Background Rate [mDRU$_{ee}$]
γ rays	$1.8 \pm 0.2_{\rm stat} \pm 0.3_{\rm sys}$
^{127}Xe	$0.5 \pm 0.02_{\rm stat} \pm 0.1_{\rm sys}$
^{214}Pb	$0.11 - 0.22$ (0.20 expected)
^{85}Kr	$0.17 \pm 0.10_{\rm sys}$
Total predicted	$2.6 \pm 0.2_{\rm stat} \pm 0.4_{\rm sys}$
Total observed	$3.6 \pm 0.3_{\rm stat}$

arXiv:1403.1299

Direct Measurement of ^{85}Kr

- Alternatively, measure ^{85}Kr background directly from WIMP search data
- Use large subset of exposure, 118 kg fiducial mass, 70 live days



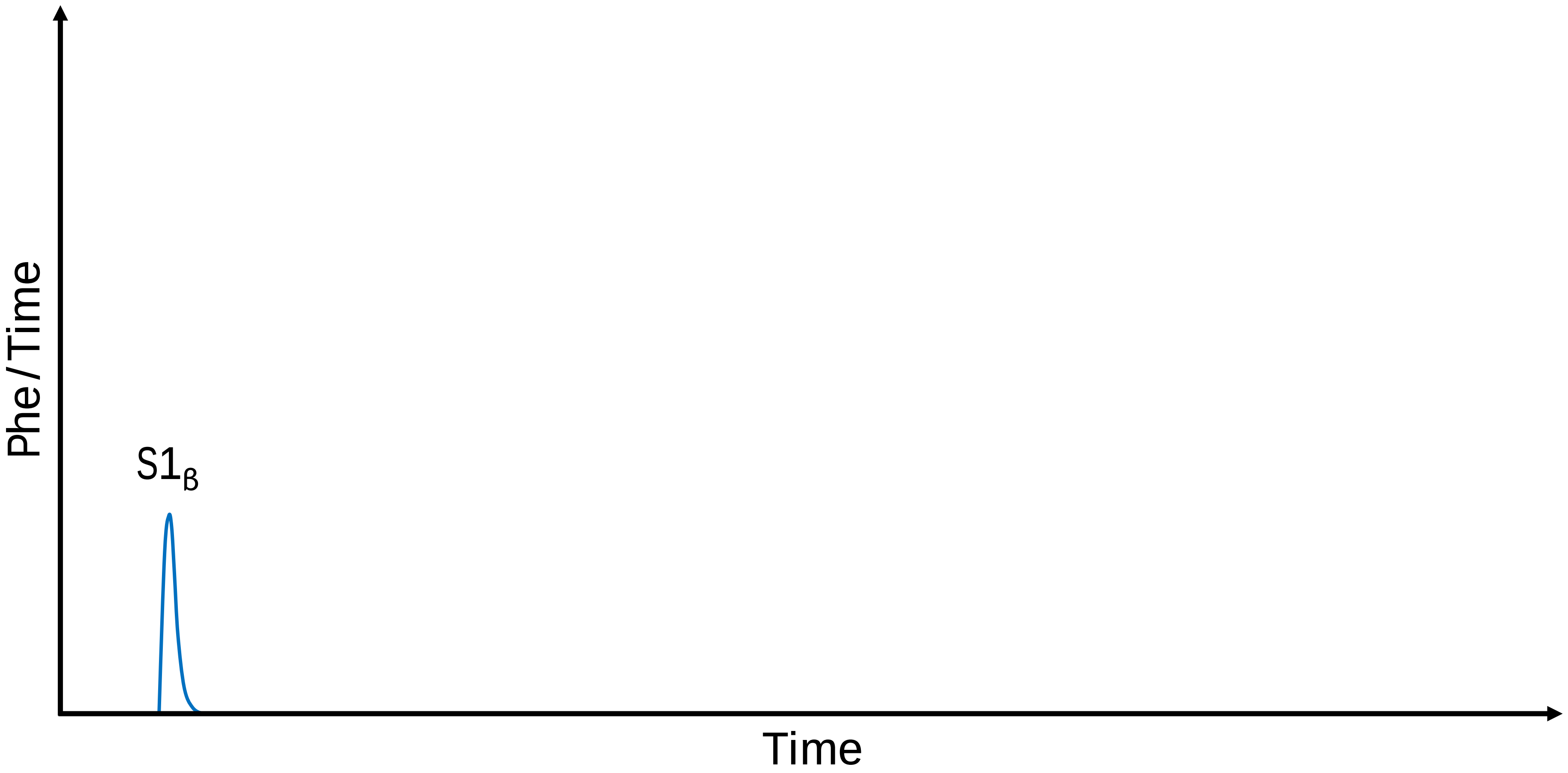
^{85}Kr decay scheme

- Rare decay of ^{85}Kr
  - Branching ratio 0.434 %
- Based on sampling measurement, expect only a few decays
- But, distinct signal:
  - 173 keV endpoint β^- decay
  - Followed by 514 keV γ-ray

- Find events with two S1s: one from β^- ($S1_\beta$) and one from γ-ray ($S1_\gamma$)
- Select events based on energy, location and time delay between the S1s

Event Topology

Sketch of event – not to scale



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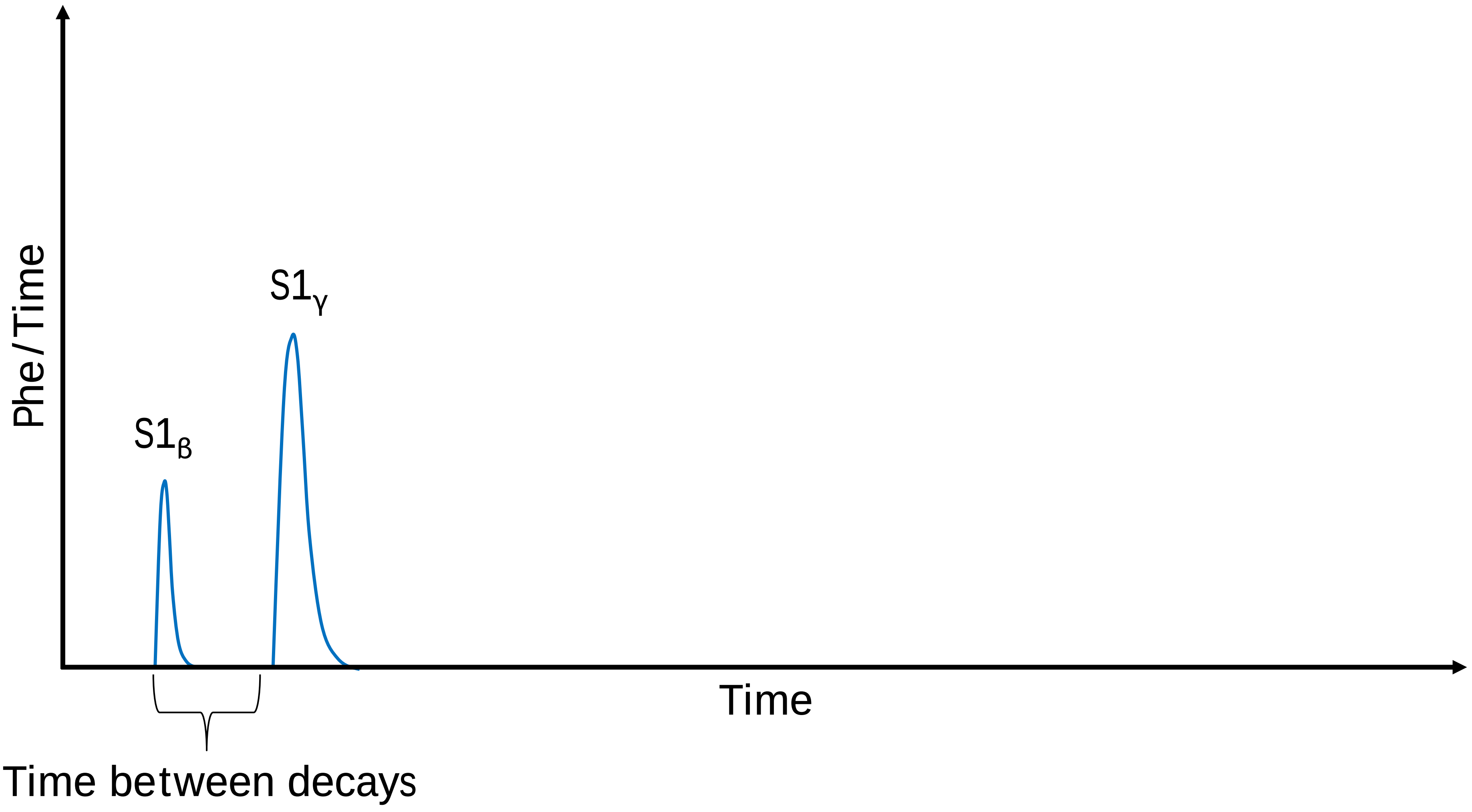

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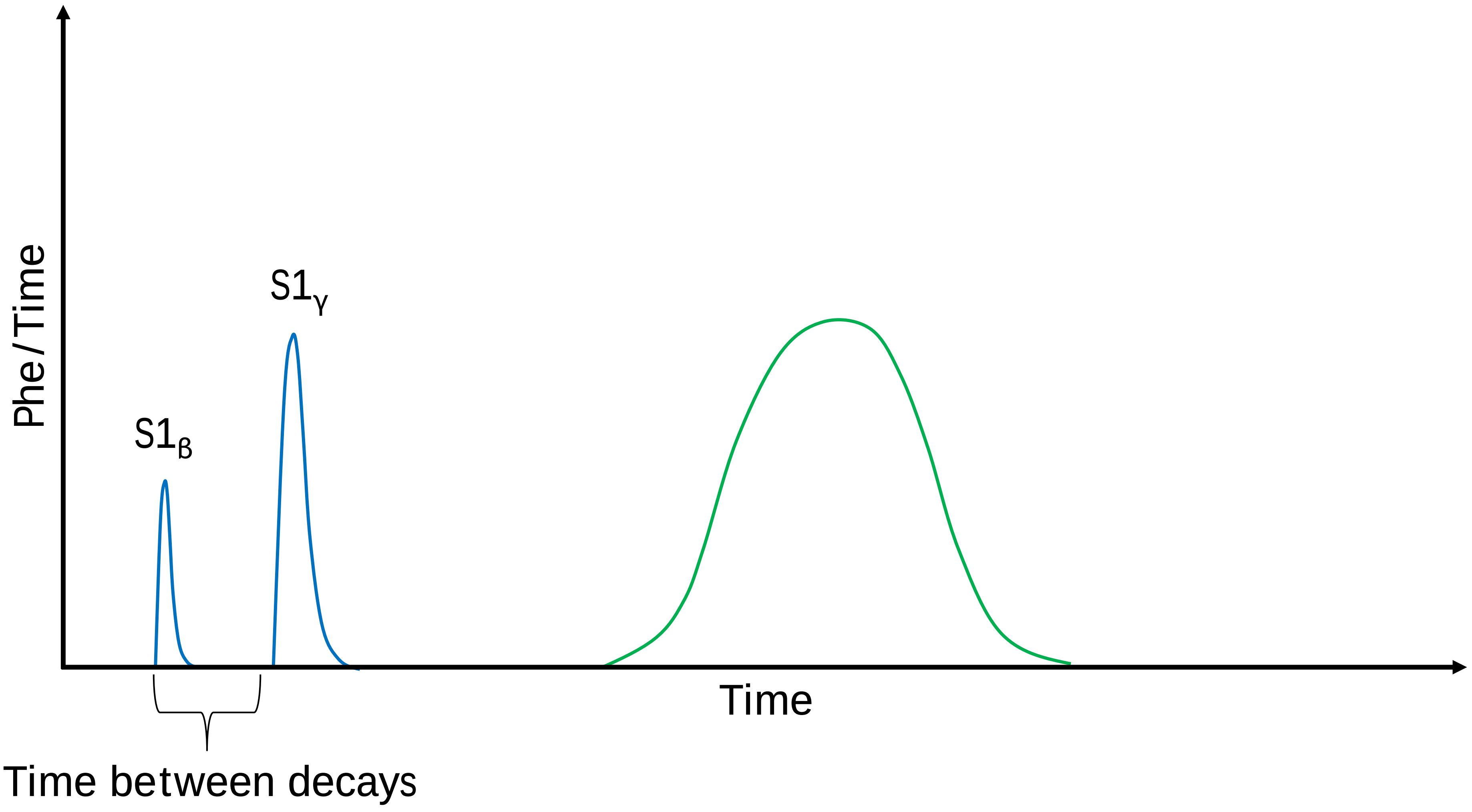

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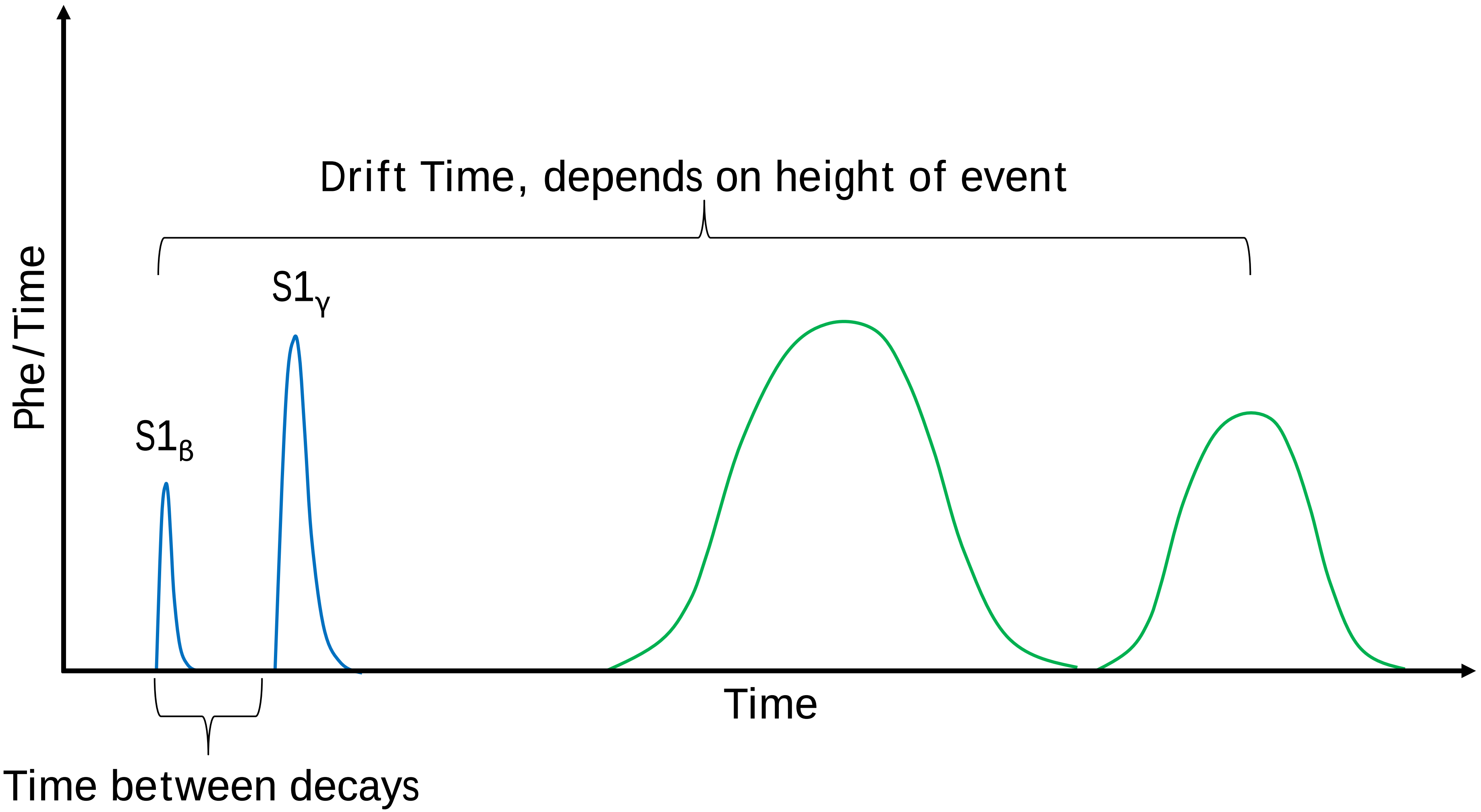

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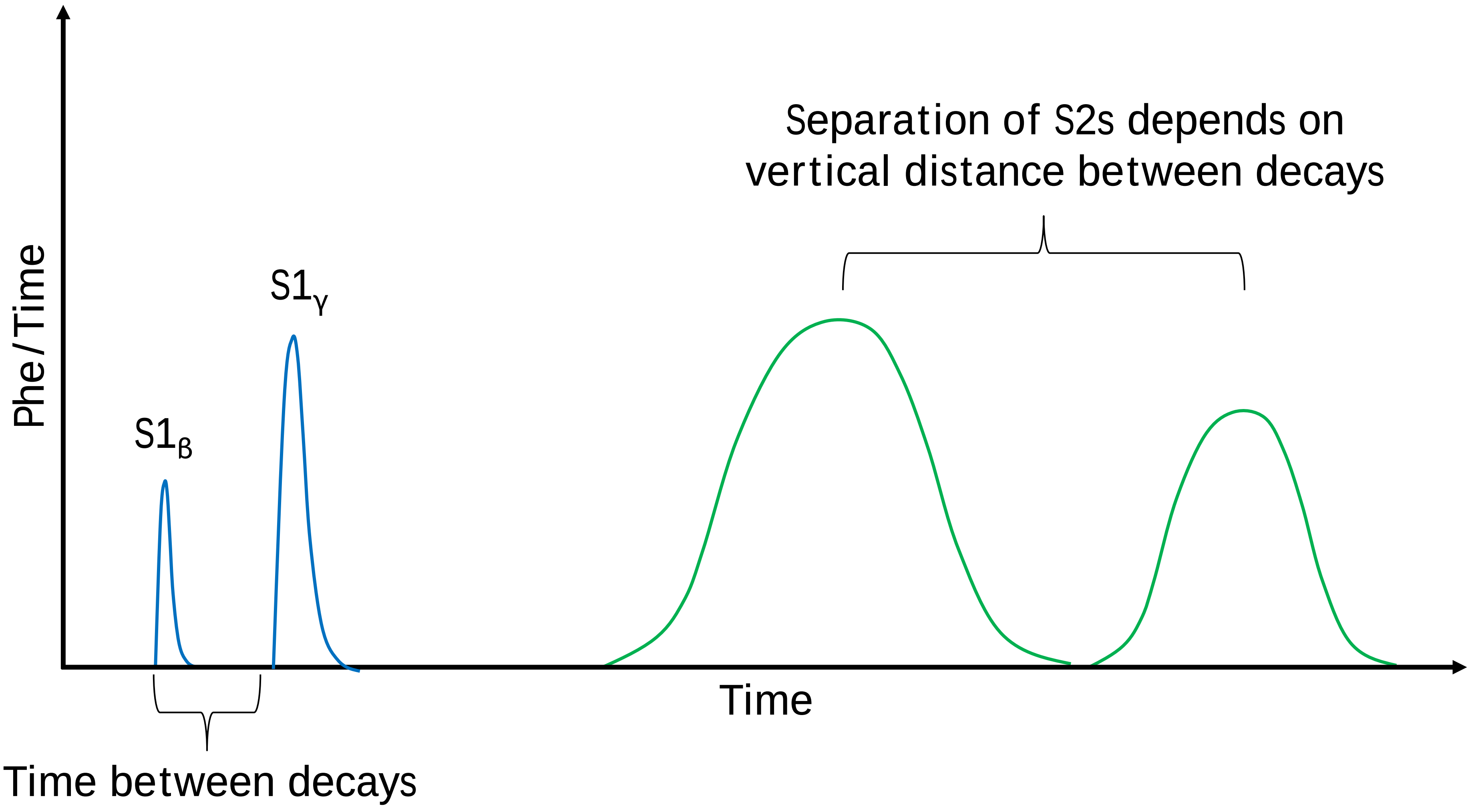

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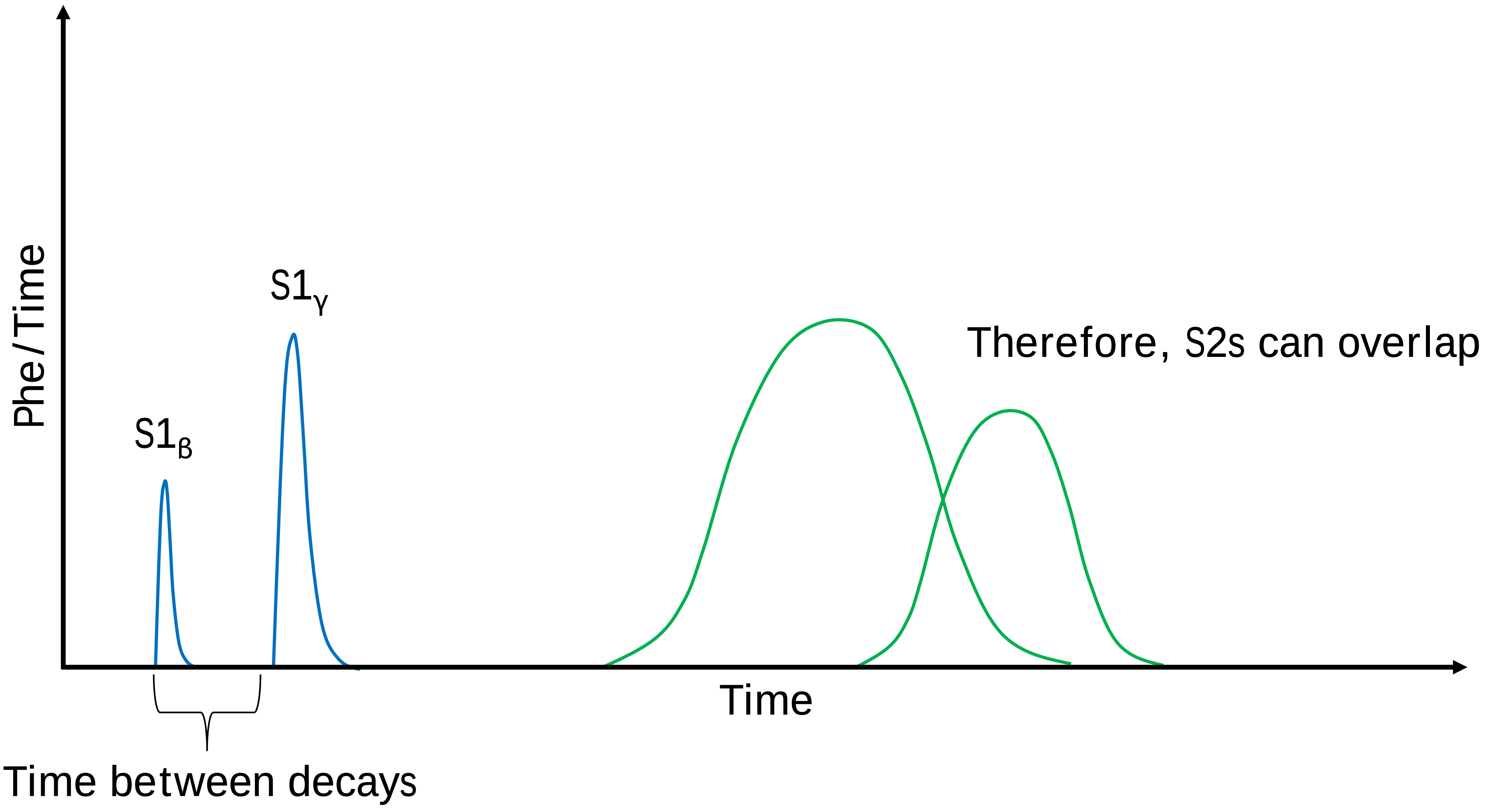


^{85}Kr Delayed Coincidence Analysis

- Cut on energy of β and γ for separated S2s
- For overlapping S2s, cut on total energy

Cut	Minimum (keV)	Maximum (keV)	Comments
β	0	190	Assumed single scatter
γ	482.9	545.1	2σ around mean
Total E	529.6	659.0	For events with one S2

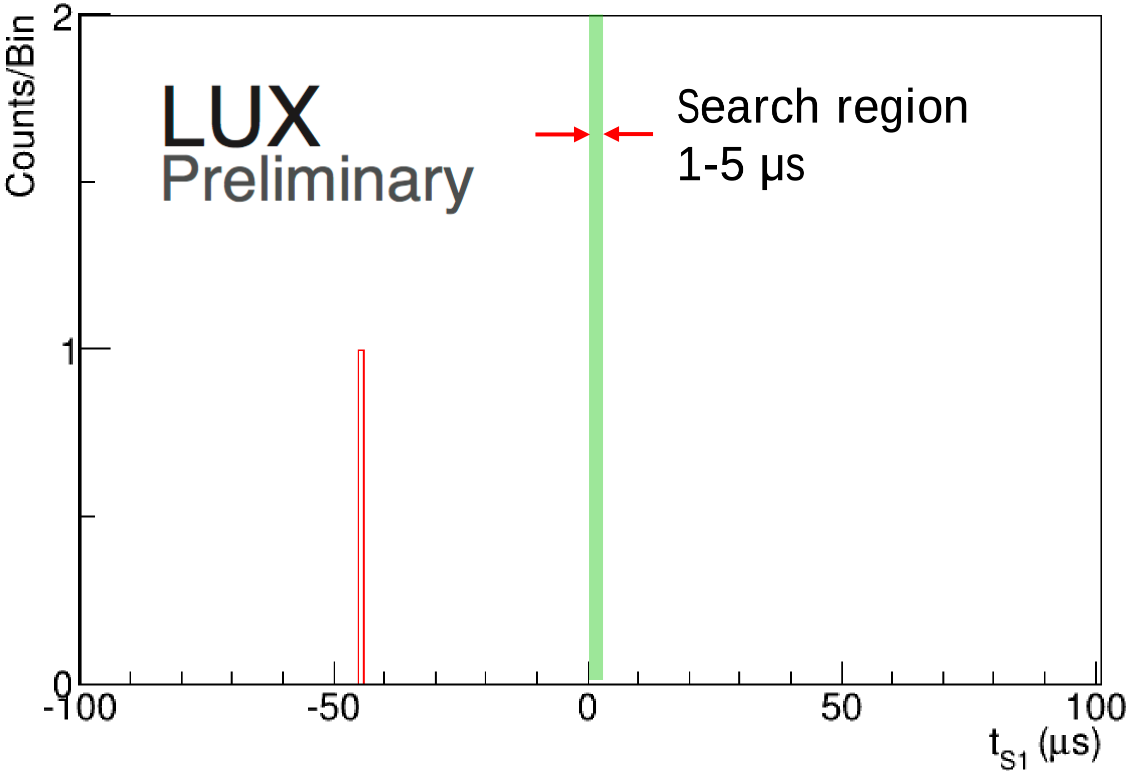
- Cut on S1 based on expected size of signal β and γ
- Other cuts are to remove different event topologies

Cut	Minimum	Maximum	Acceptance	Comments
Energy	-	-	0.95	See above
$\log_{10}(S2/S1)$	1.0	2.0	$\simeq 1$	
$S1_S$	202 phe	1067 phe	0.79	Signal loss is only from minimum cut.
$S1_L$	0 phe	3480 phe	1	Conservative 3σ upper cut
Bad S1 Area	0 phe	100 phe	$\simeq 1$	Area between the S1s
$S1_S$ RMS / Area	0	1.0 Samples/phe	1.0	Pulse width cut

- Cuts are intentionally loose to avoid removing signal

^{85}Kr Delayed Coincidence Analysis

- Define $t_{S1} = t_{\gamma} - t_{\beta}$
- Events with negative t_{S1} cannot be signal
  - Use to estimate of background from random coincidences
- Then count events in search region, from 1-5 $T_{½}$
  - Using sampling and $^{85}Kr/Kr = 2 \times 10^{-11}$ result expect 1.1 ± 0.6 events in fiducial volume after efficiency losses



- Estimate 0.04 background events in search region
  - observe 0
- 90% upper limit:
  - 2.4 β-γ decays
  - 0.37 mDRU

Conclusions

- Measured the ^{85}Kr content directly, without assuming a ^{85}Kr/Kr ratio:
  0.37 mDRU 90% upper limit

- Compared to sampling results (^{85}Kr/Kr = 2×10^{-11}):
  $0.17 \pm 0.10_{sys}$ mDRU
- The two methods are consistent
  - Confirms that ^{85}Kr background successfully mitigated, is not dominant

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- Sensitivity from this method will improve during a longer WIMP run
  - Expect ~ 3.5x more exposure