Investigating the isolated S1 backgrounds in the LUX-ZEPLIN (LZ) experiment

20th Patras workshop on Axions, WIMPS and WISPS

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on behalf of the LZ collaboration

IMPERIAL

The LUX-ZEPLIN (LZ) experiment

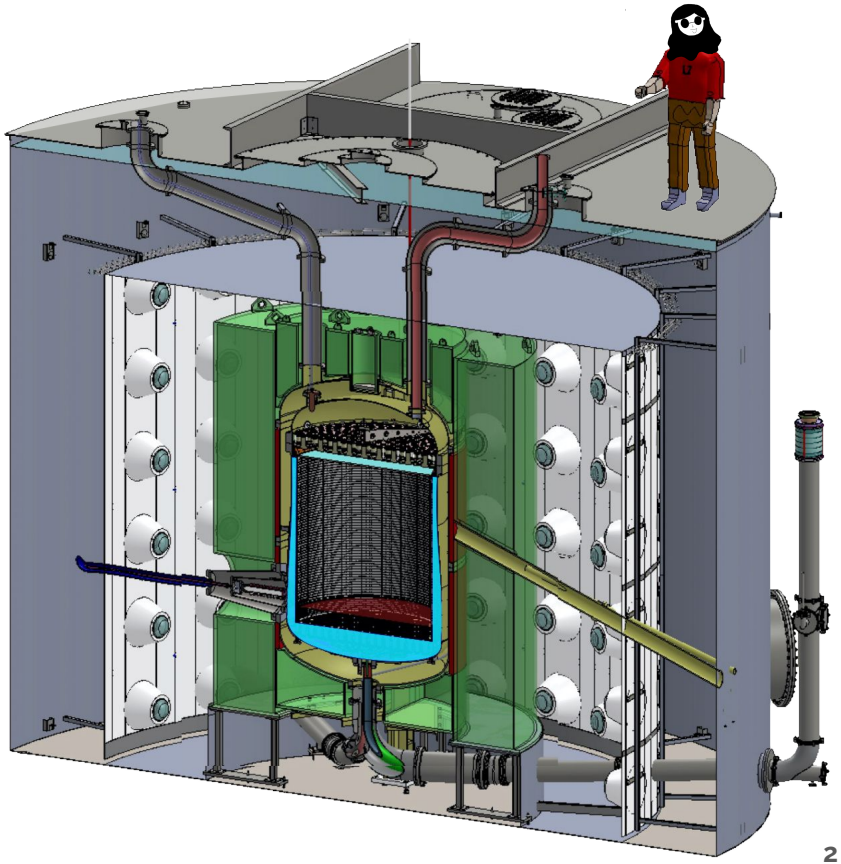
LZ is a dual-phase time projection chamber (TPC) featuring 7 tonnes of liquid xenon (active mass), instrumented with 494 3-inch-diameter PMTs (Hamamatsu R11410-22).

The aim is to detect dark matter particle interactions within its active target.

The LXe Skin and the Outer Detector surround the TPC, serving as veto systems.

When a particle interacts in the TPC, we read two different signals:

1. **S1 signal** → primary scintillation signal (VUV photons) from excitation in the liquid.
2. **S2 signal** → secondary scintillation (also VUV photons) as ionisation electrons get extracted into the gas phase.



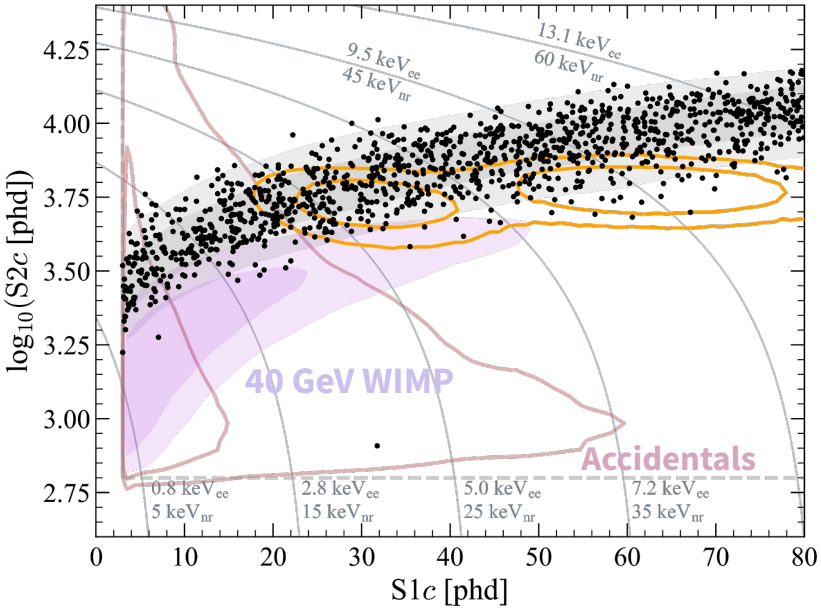
Accidental coincidence background

One of the main backgrounds which affects our sensitivity to light particles are **events originating from the accidental pairing of isolated S1 and isolated S2 pulses**.

Knowing the origin of isolated pulses:

1. Helps mitigate the accidental event background in current science searches
2. Will help design future detectors!

Image taken from[1]



Challenges: very small S1s are hard to study because they have no robust spatial reconstruction.

[1] Figure taken from Dark Matter Search Results from 4.2 Tonne-Years of Exposure of the LUX-ZEPLIN (LZ) Experiment, LZ collaboration, 2024

The DPE effect telling us about photon wavelength

The analysis method is based on **photon waveform analysis** leveraging the **double photonelectron (DPE) effect** which is observed at VUV wavelengths in these PMTs.

DPE

Generally: 1 photon detected→ 1 photoelectron

VUV light: 1 photon detected can produce 2 (or 3) "photo"-electrons

LZ PMTs: ~20% DPE probability [2]
Our estimator of photons detected is not photoelectrons ("phe") but rather a "phd" quantity which includes DPE

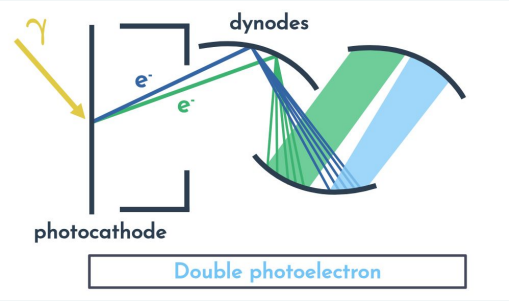
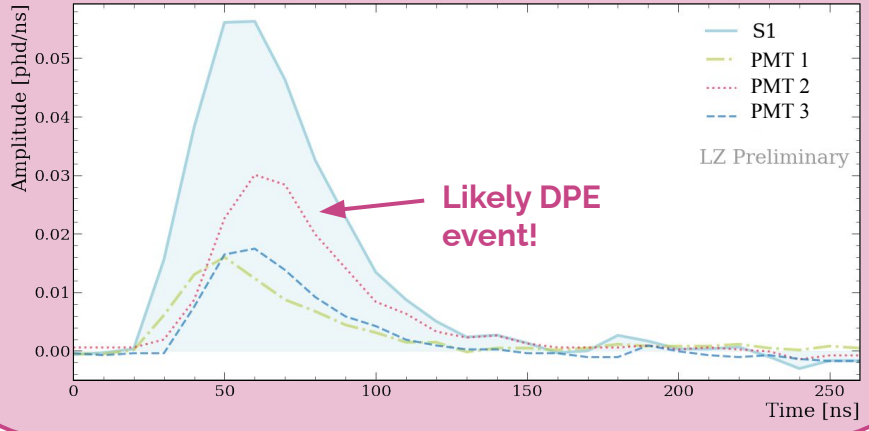


Image taken from [3]

Studying the mean response to single photons within the S1:

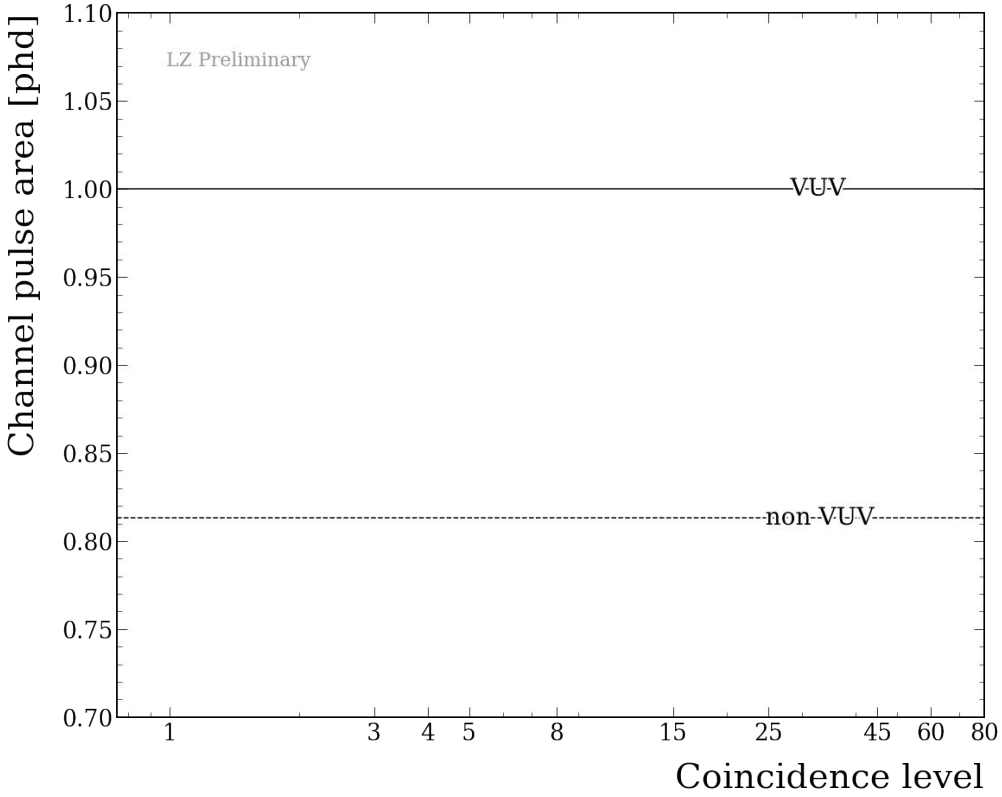
- VUV? Likely coming from xenon processes → pulse area normalised to 1.0 phd.
- Non VUV? Likely not coming from xenon processes → average pulse area at 0.82 phd



[2] Response of photomultiplier tubes to xenon scintillation light,, B. López Paredes et al, 2018
[3]Low-Energy Signals in the LUX-ZEPLIN (LZ) Experiment and Spectral Measurements of Xenon Luminescence [PhD thesis], A. Baker, 2024

The DPE effect telling us about photon wavelength - results

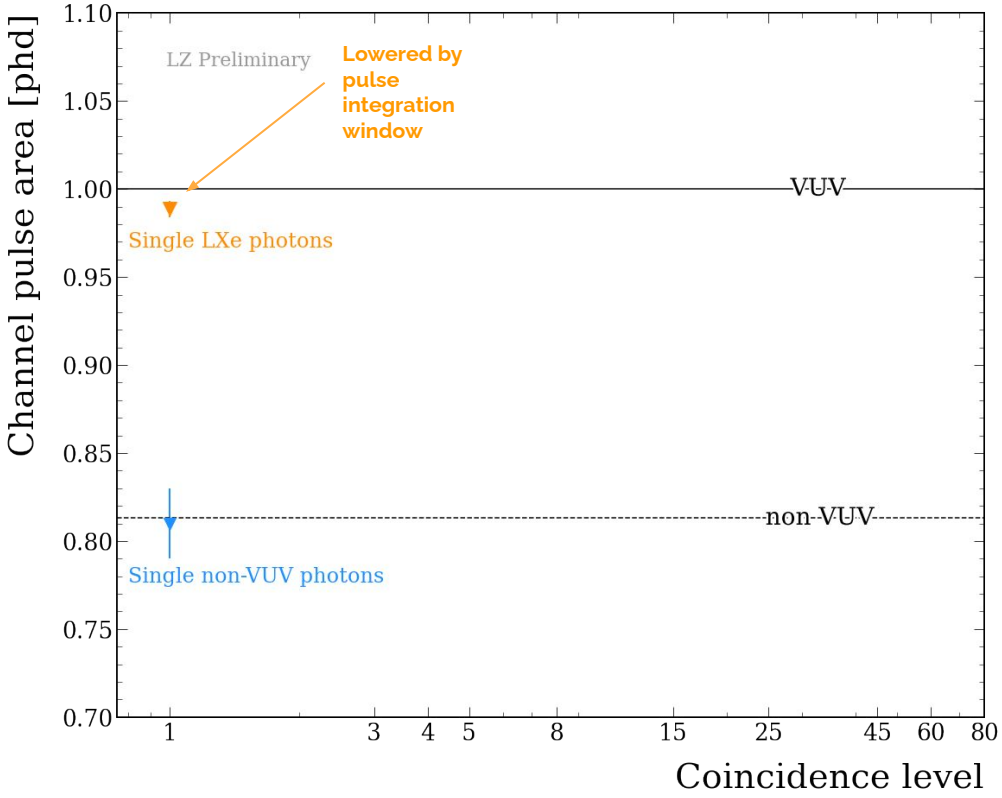
Using WS2024 science run data (220 live days) and corresponding calibration campaigns



The DPE effect telling us about photon wavelength - results

Using WS2024 science run data (220 live days) and corresponding calibration campaigns

1. Single photon population: **VUV** and **non-VUV**

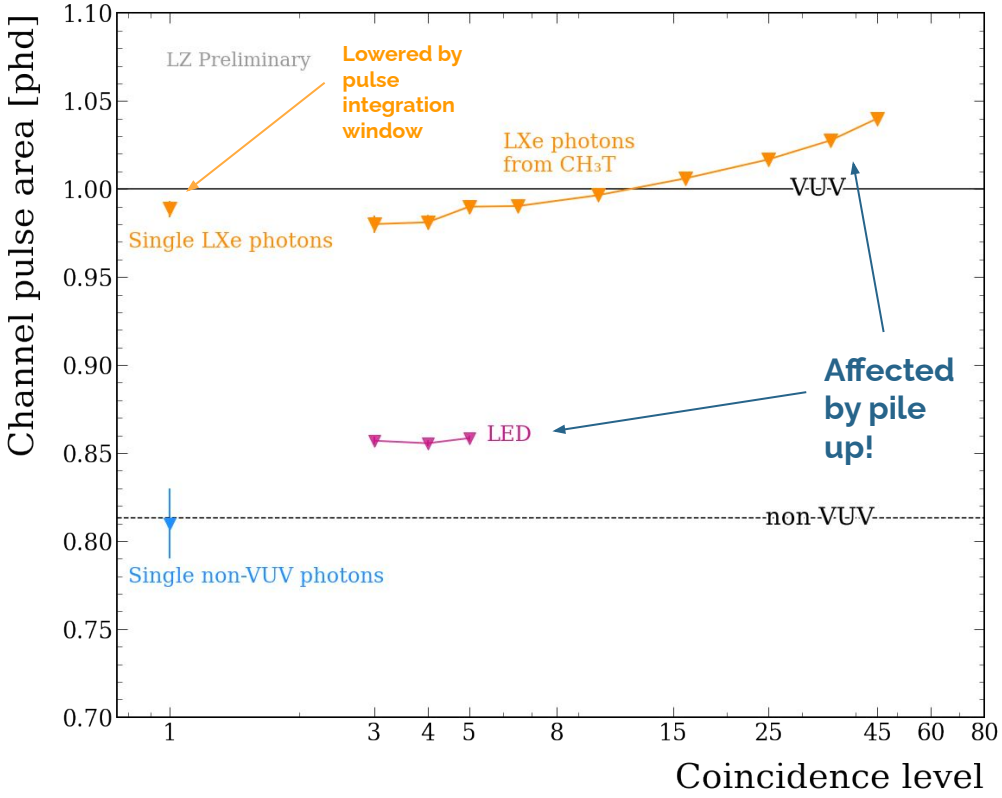


The DPE effect telling us about photon wavelength - results

Using WS2024 science run data (220 live days) and corresponding calibration campaigns

1. Single photon population: **VUV** and **non-VUV**

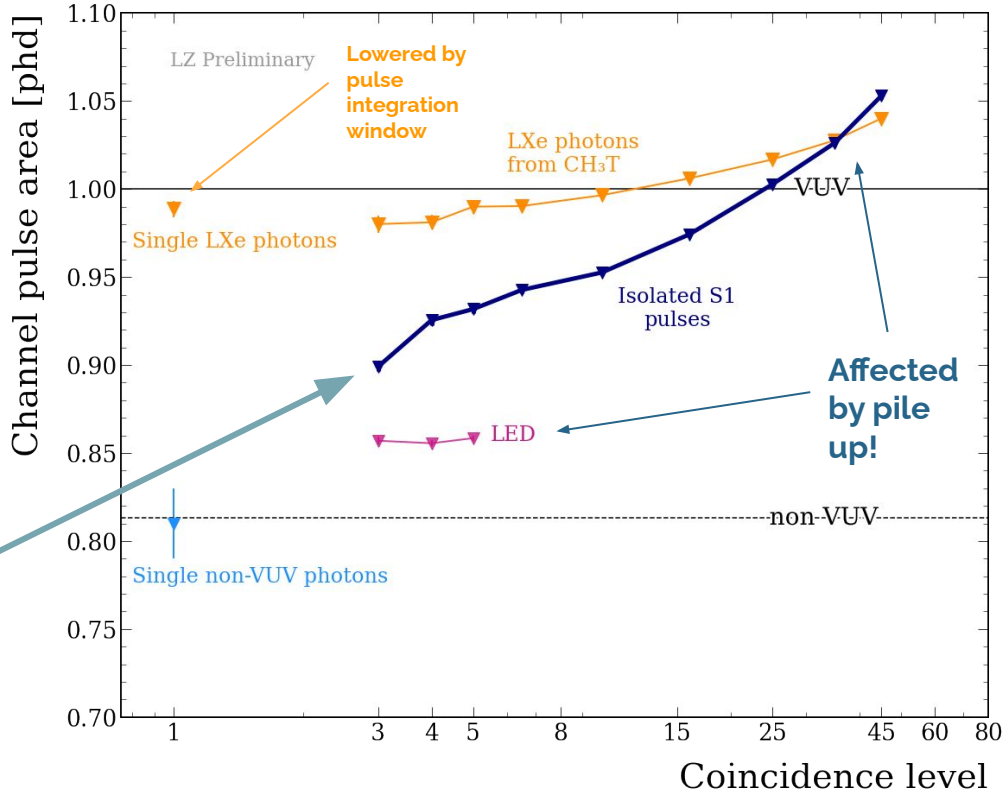
2. Calibrations across PMT coincidence levels (**VUV** and **non-VUV**)



The DPE effect telling us about photon wavelength - results

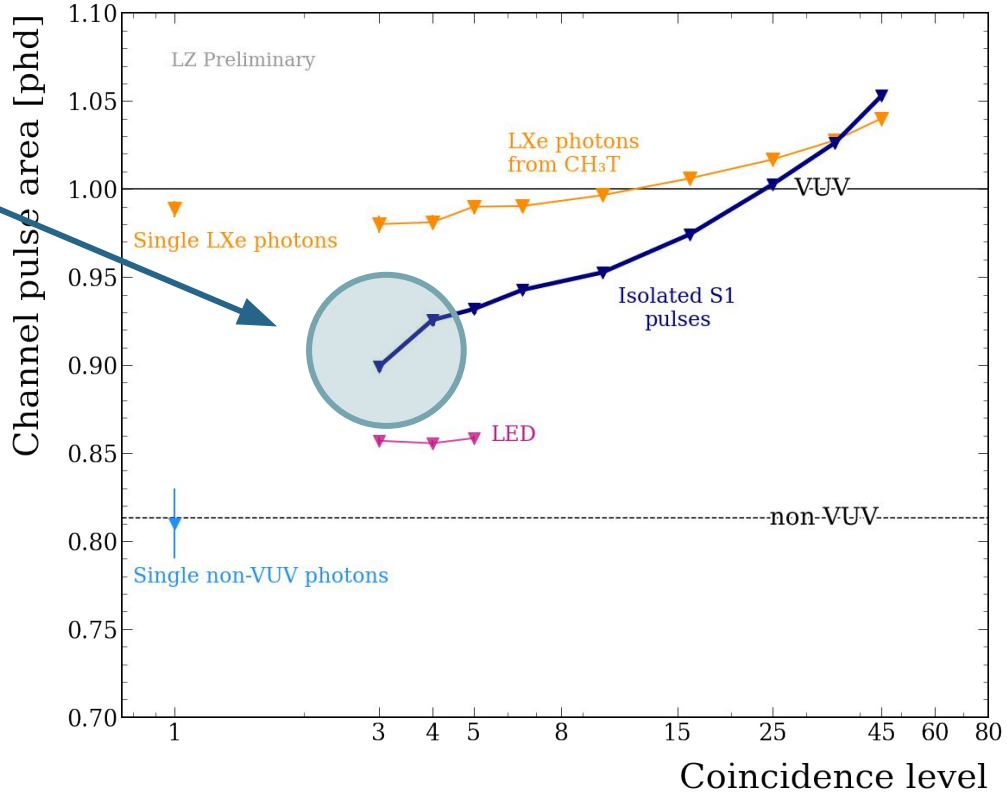
Using WS2024 science run data (220 live days) and corresponding calibration campaigns

1. Single photon population: **VUV** and **non-VUV**
2. Calibrations across PMT coincidence levels (**VUV** and **non-VUV**)
3. **Isolated S1s**:
   a. Non-VUV contamination
   b. **At threshold**: steeper drop, stronger contamination!



Non-VUV contamination of isolated S1s

At the standard 3-fold threshold of LZ 24% of the isolated S1 is found to be coming from the pile up of non-VUV photons occurring after γ interactions in the detector!



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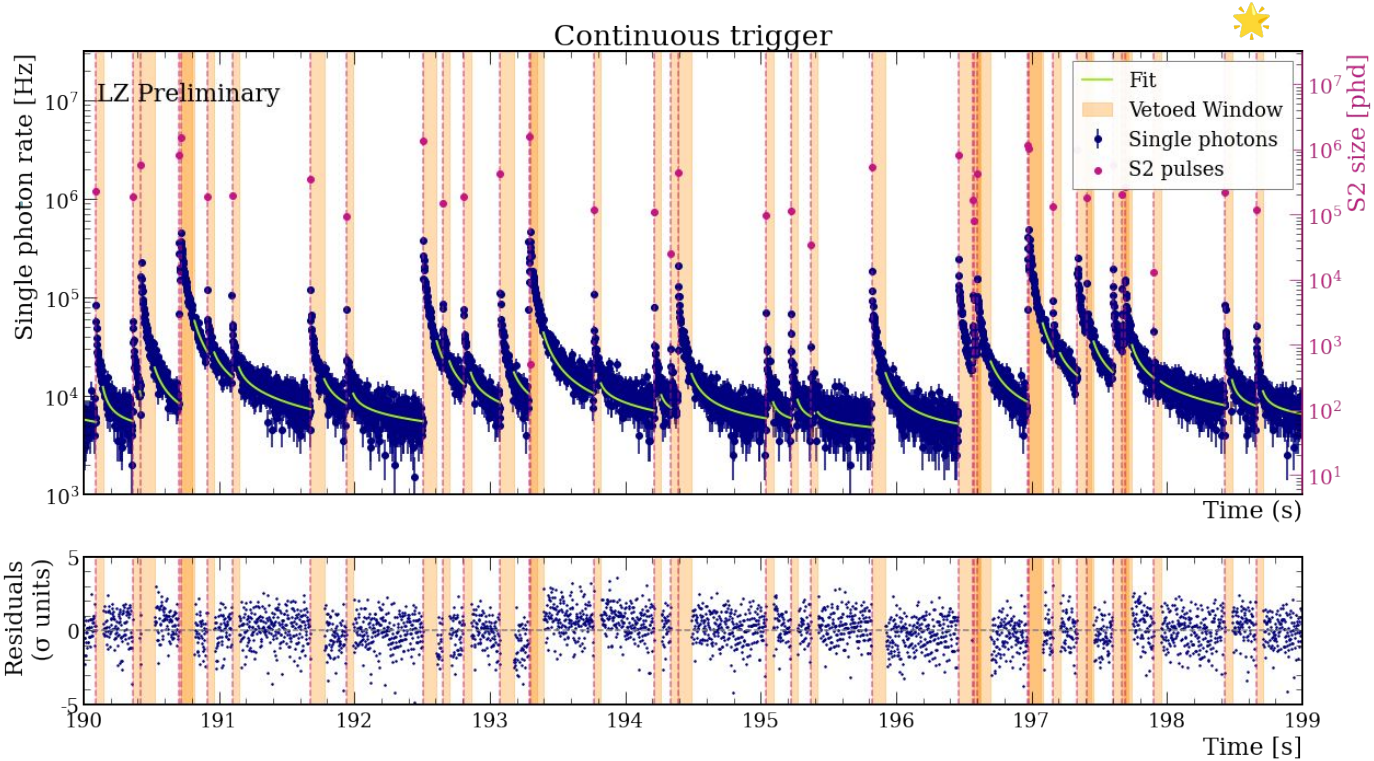

🌟 These enhanced photon rates likely come from detector material fluorescence, ask me about it (or see my poster!).

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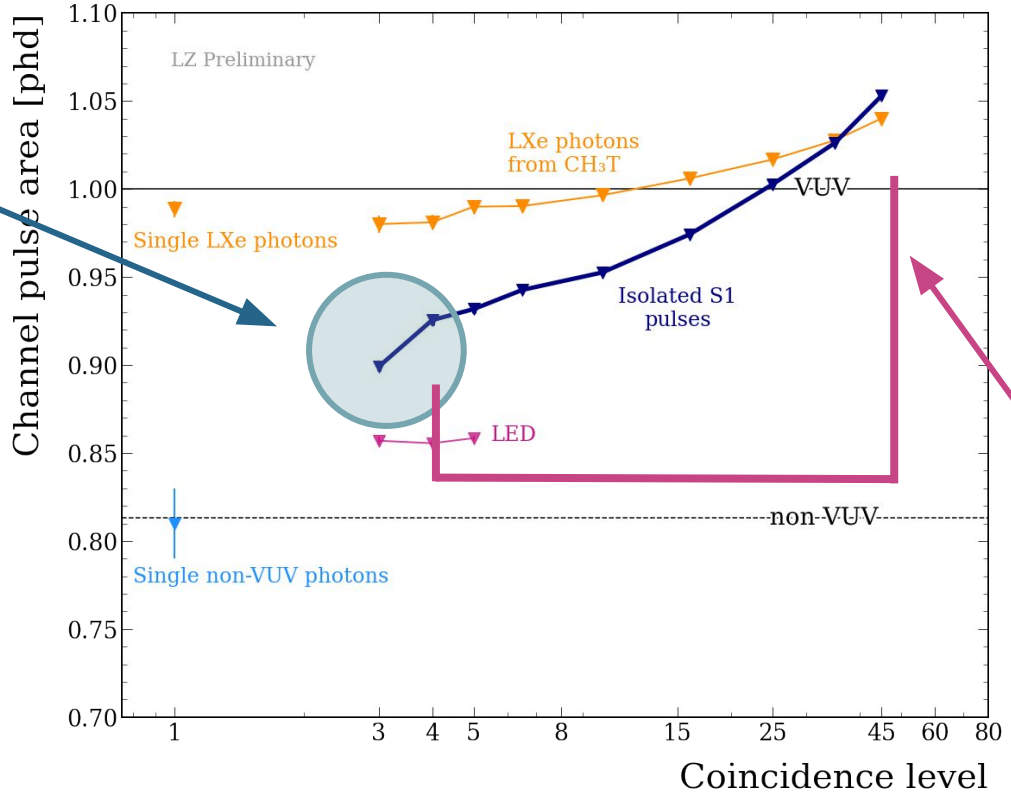

Several scenarios were tested; Cherenkov radiation leaking through the TPC walls (from PTFE) remains a leading possibility, though inconclusive for now!

Conclusion

Motivation for the work:

Studying the origin of isolated S1s is very important to mitigate the accidental backgrounds in current science searches but also to steer the design of future detectors.

Results:

- **Isolated S1 are significantly contaminated by non-VUV light** → still investigating the source!
- **~24% of the events at the dark matter threshold come from the pile up of non-VUV single photons** → the enhanced photon rates are due to detector's material photoluminescence!

Thank you!

Find me at my poster for discussion and more questions!

LZ (LUX-ZEPLIN) Collaboration, 38 Institutions

250 scientists, engineers, and technical staff

@lzdarkmatter

https://lz.lbl.gov/

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