



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

Joint APP/HEPP IOP Conference - 8/04/2025



Linda Di Felice,

Imperial College London,

on behalf of the LZ collaboration

IMPERIAL

The LUX-ZEPLIN (LZ) experiment

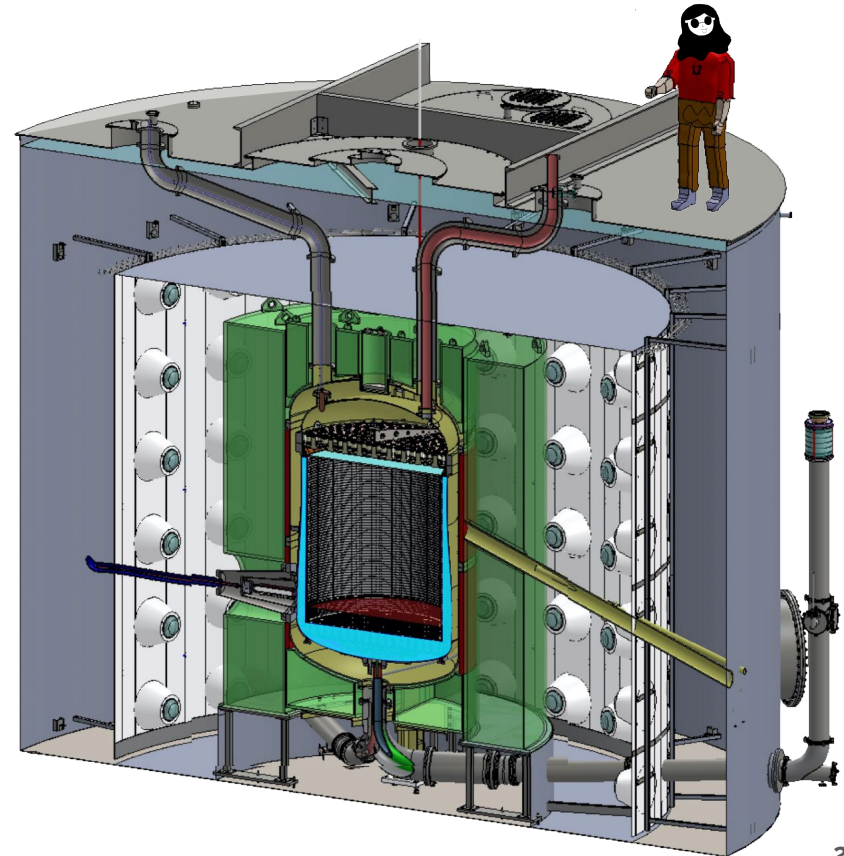
LZ is a dual-phase time projection chamber (TPC) featuring 7 tonnes of liquid xenon (active mass) instrumented with 494 3-inch-diameter PMTs (Hamamatsu R11410-22).

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

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

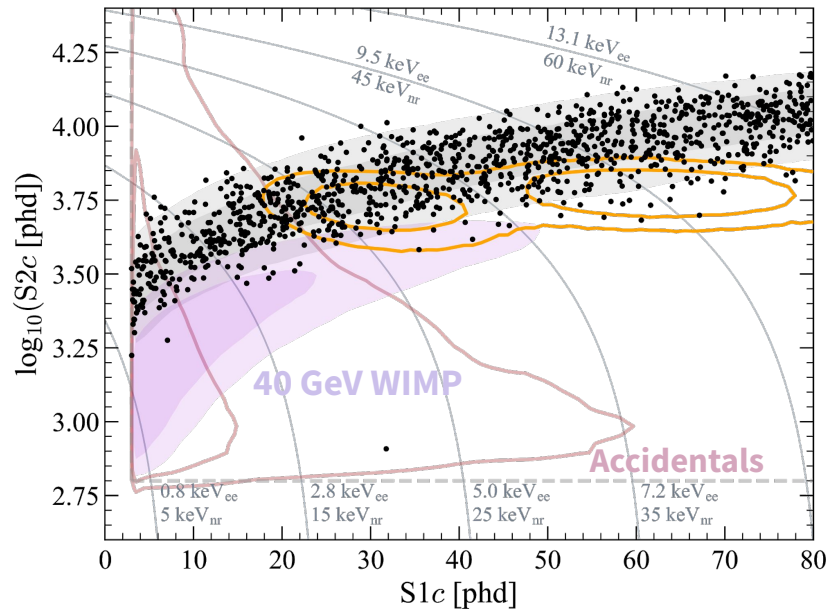
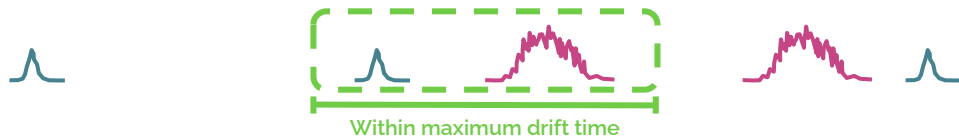
When a particle interacts in the TPC, we read two different signals:

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



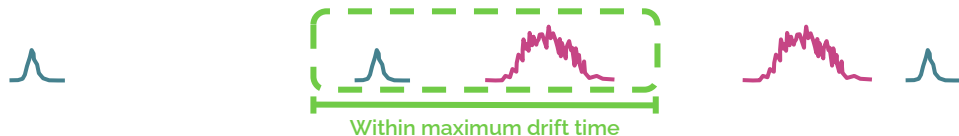
Accidental events background

One of the main background which limits our sensitivity to low particle masses are **events originating from the “accidental” pairing of isolated S1 and isolated S2 events.**



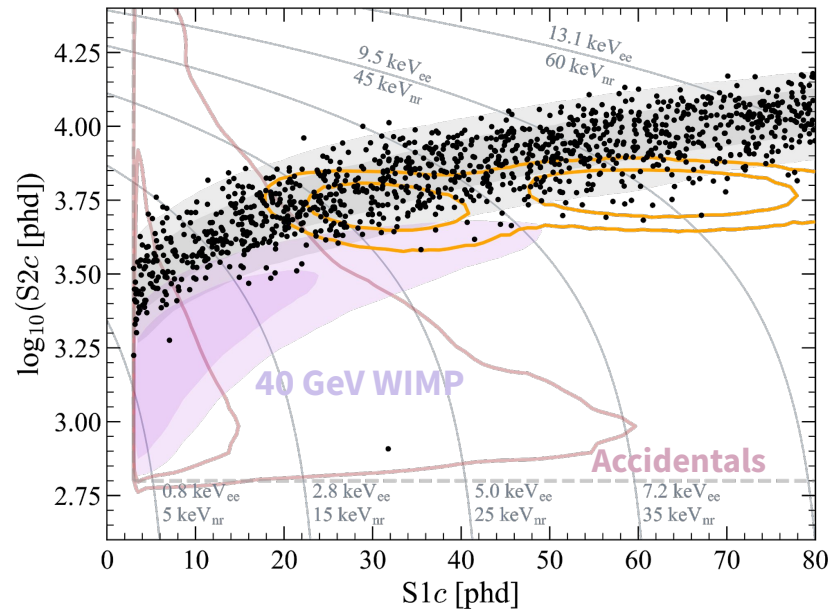
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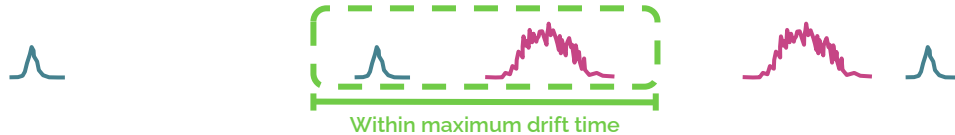
Knowing the origin of isolated pulses:

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



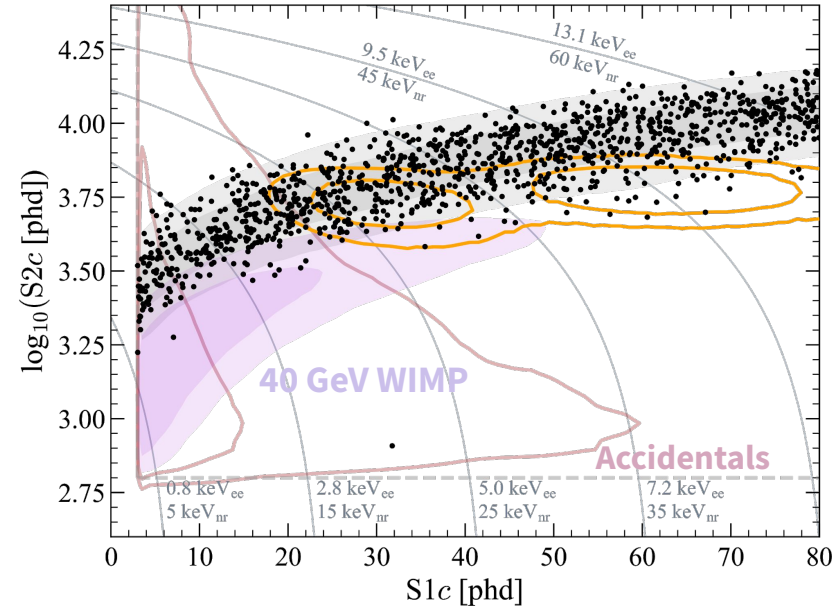
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Challenges: very small S1s are hard to study because they have no robust spatial reconstruction.

Analysis method and the DPE effect

Given the poor spatial reconstruction the analysis method is based on **photon analysis** leveraging the **double photon electron (DPE) effect** which is observed at VUV wavelengths in these PMTs.

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DPE

Generally: 1 photon \rightarrow 1 photo electron

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

LZ PMTs: ~20% of having DPE

Our unit of photons measured is not photons emitted, but instead **photons detected (phd)**!

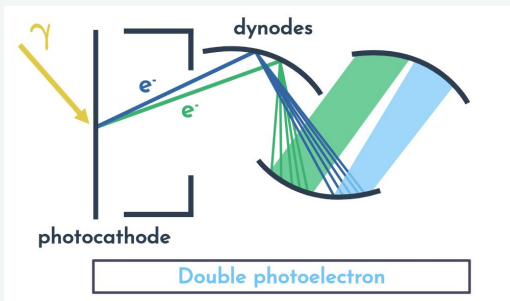


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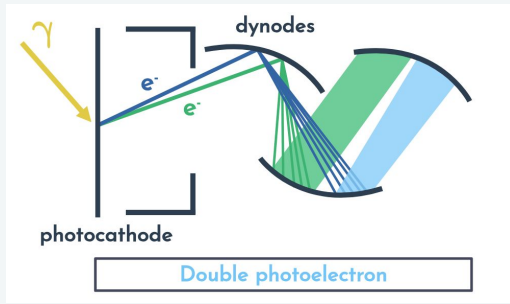
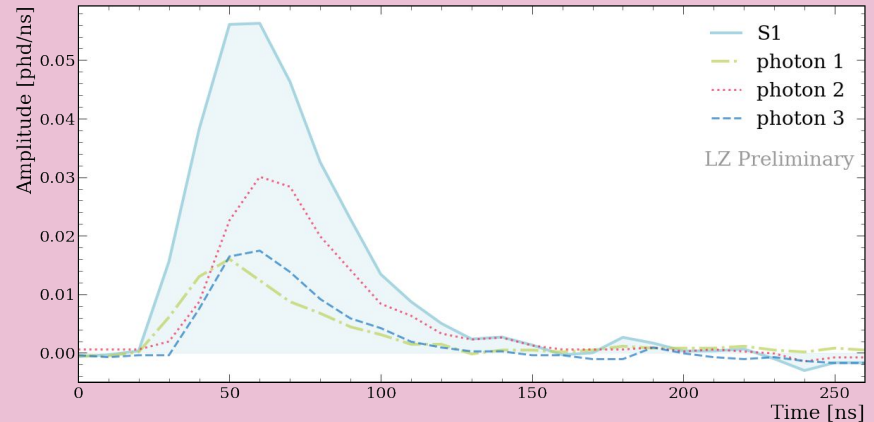


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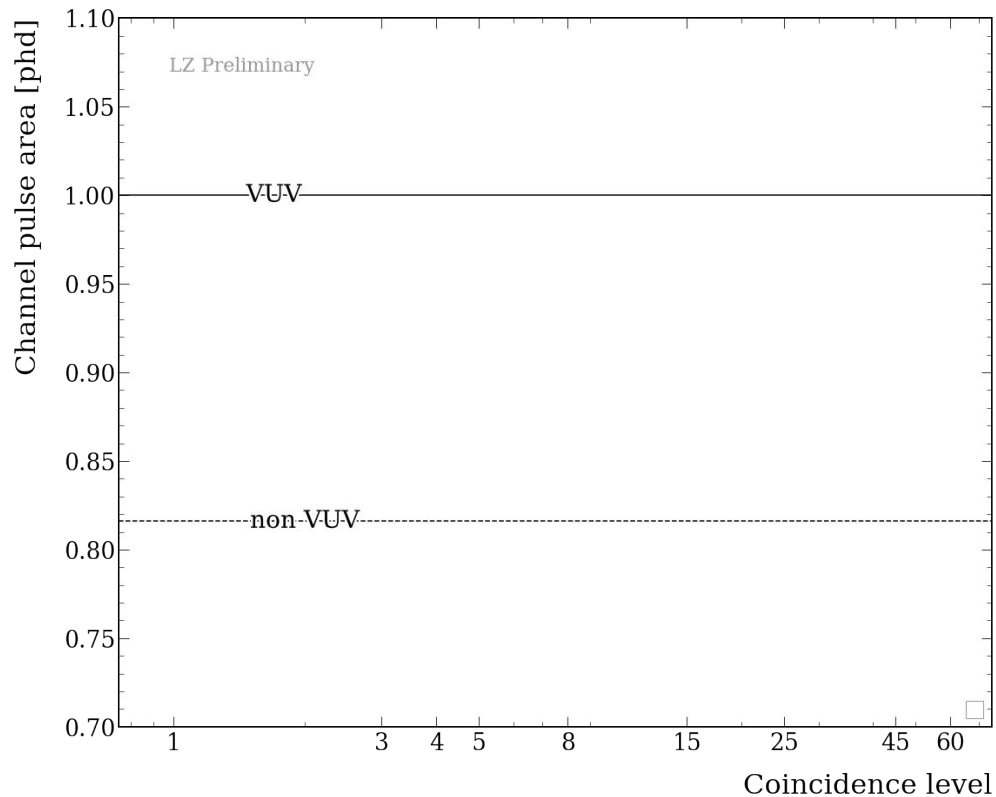
Studying the mean response of single photons within the S1:

- VUV? Likely coming from xenon processes.
- Non VUV? Likely not coming from xenon processes \rightarrow response at 0.82 photon detected



Analysis method and the DPE effect - results

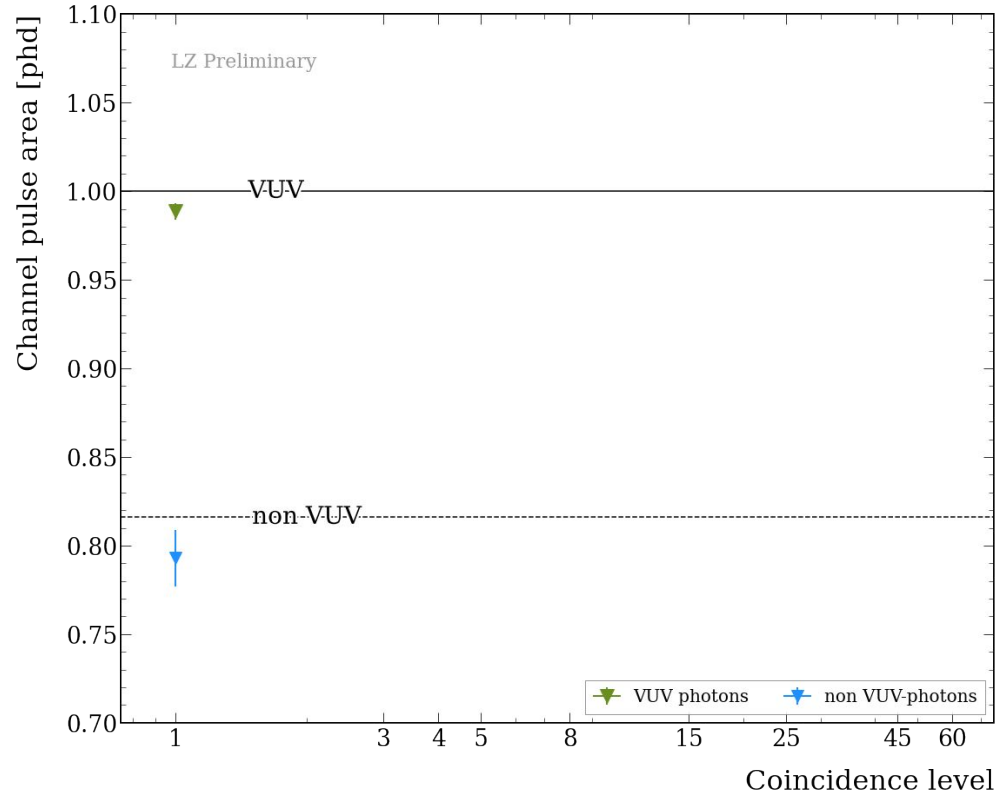
Using WS2024 science run data (220 live days) and corresponding calibration campaigns



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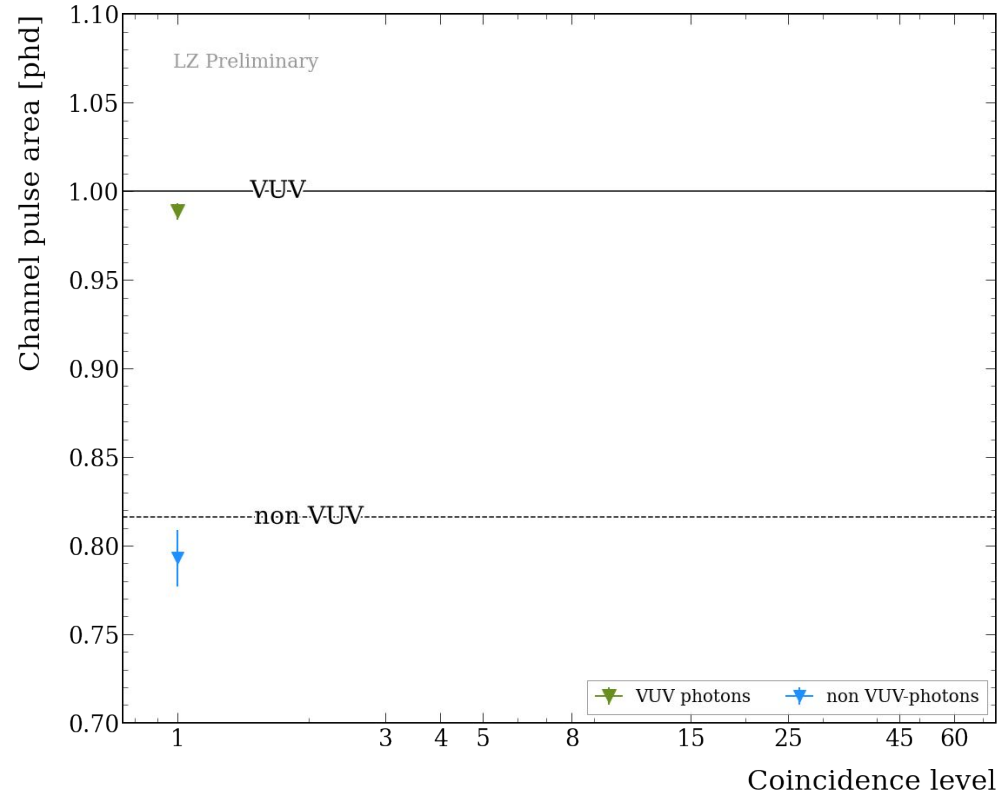
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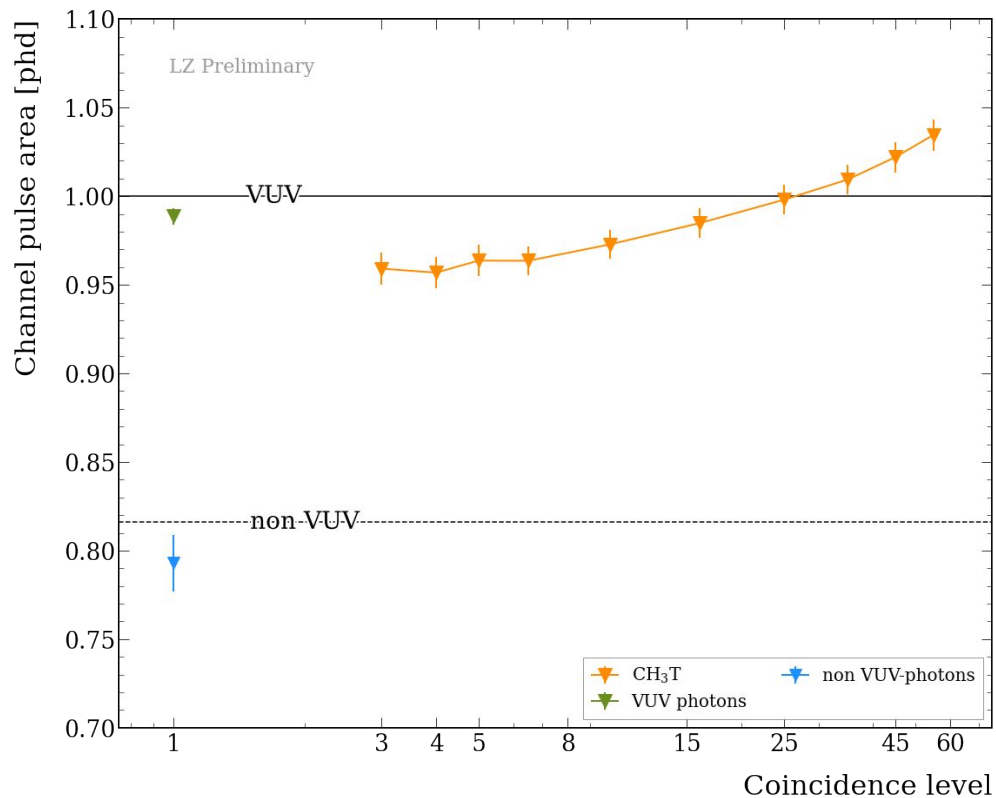
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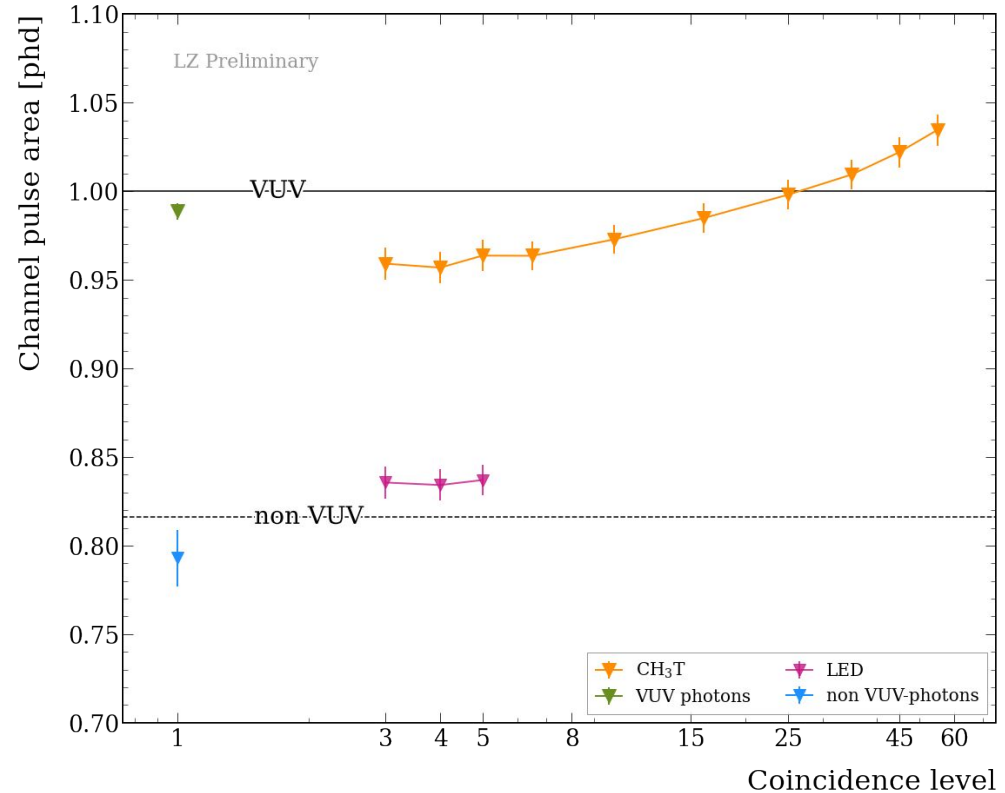
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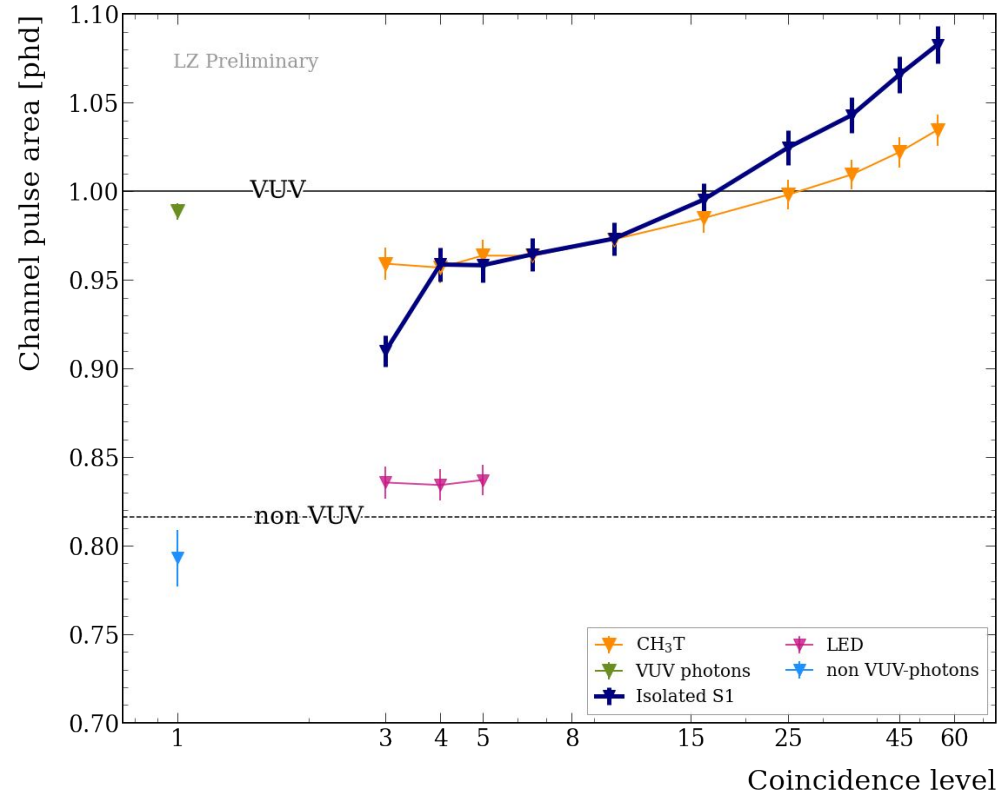
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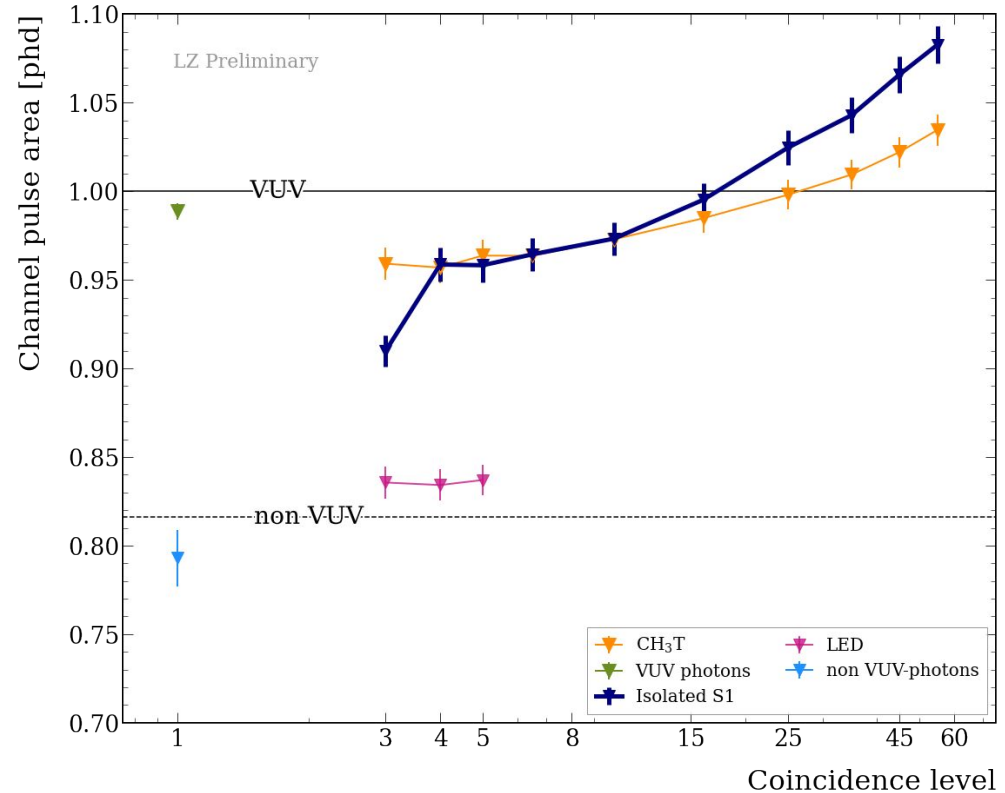
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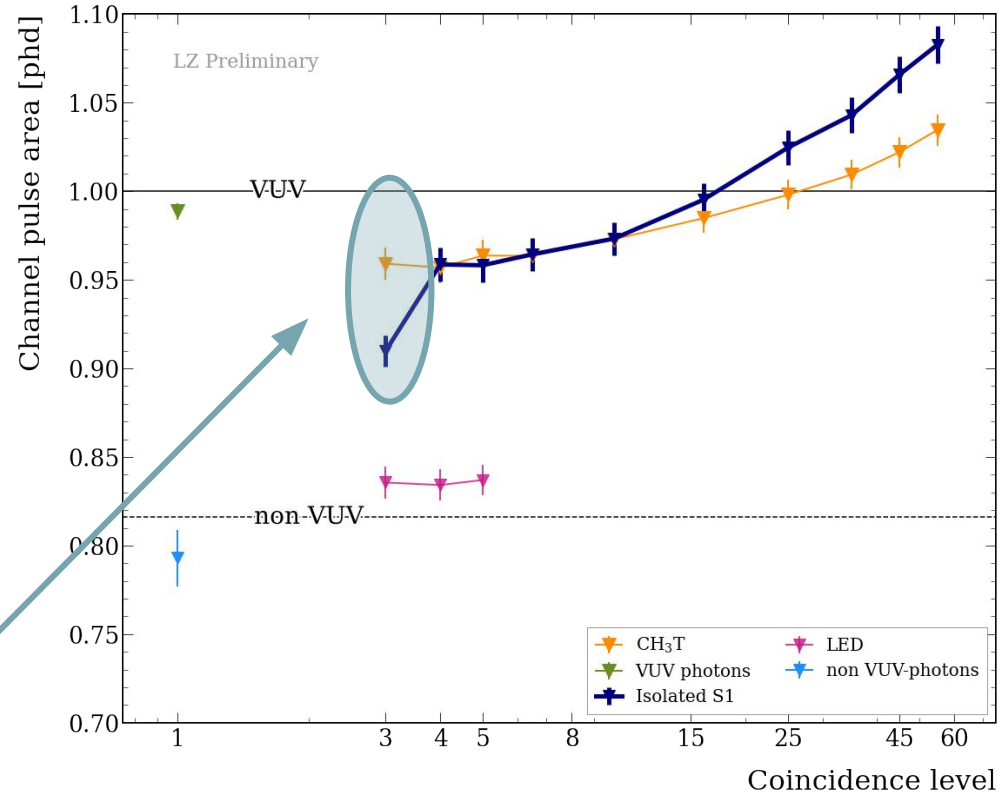
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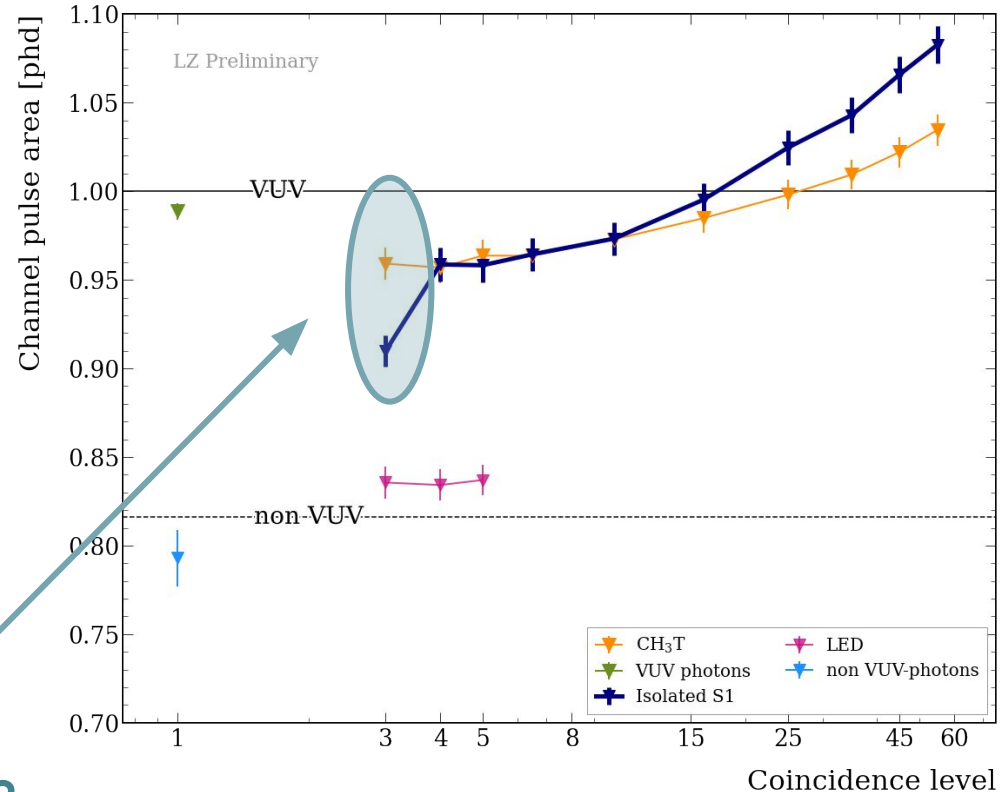
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What can be the cause of this?

Investigating the origin of the 3-fold

Key clue:

3-fold coincidence events (rate of 0.55 Hz in WS2024) are contaminated by a significant amount of non-VUV photons.

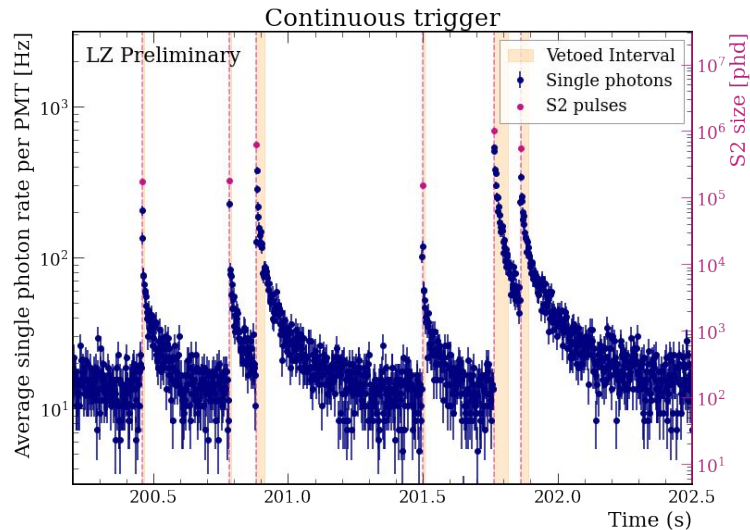
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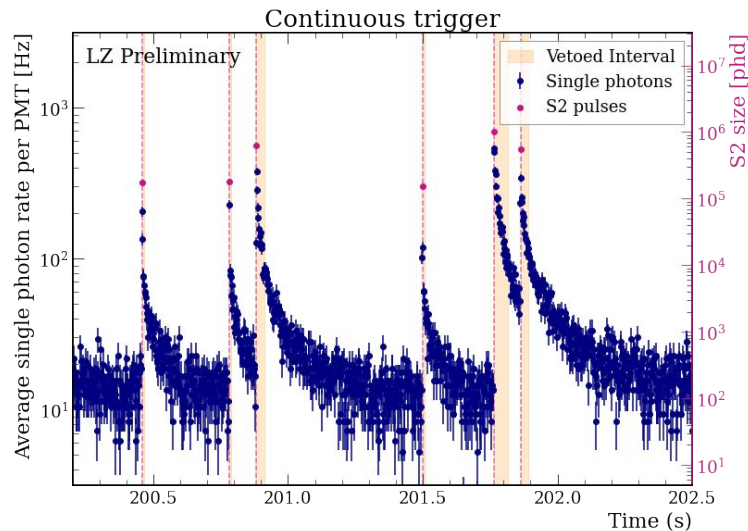
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Using poissonian statistics can recover what is the probability of obtaining a 3-fold S1 based on a rate of uncorrelated single photon. Knowing my dataset livetime I can then evaluate the number of pile up S1s I get.



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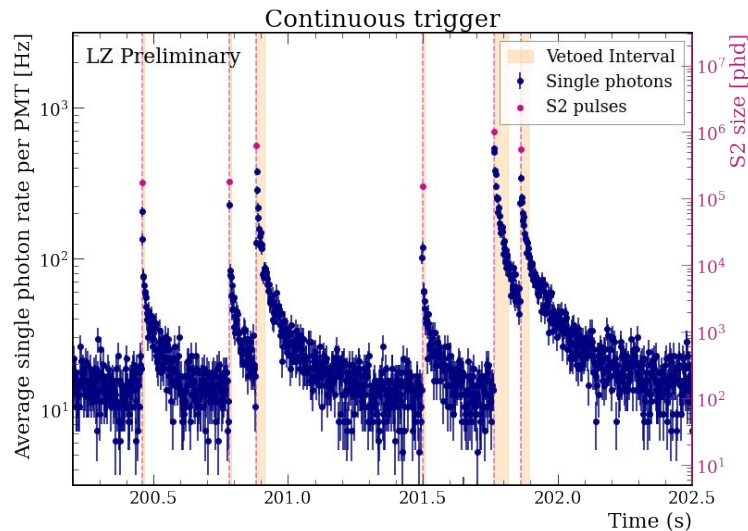


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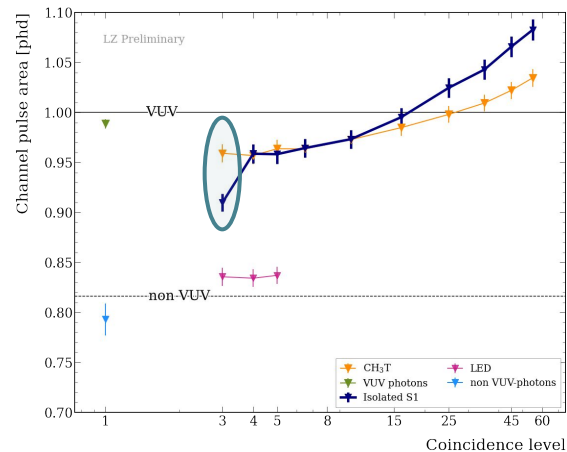


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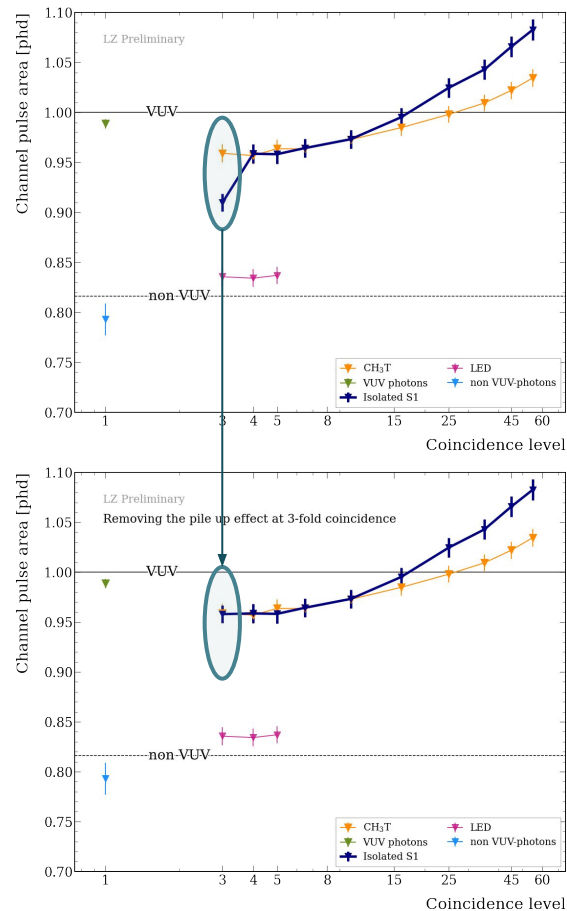


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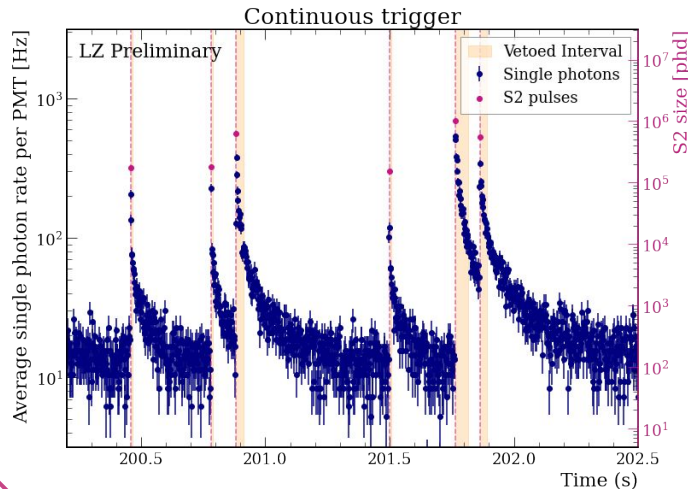


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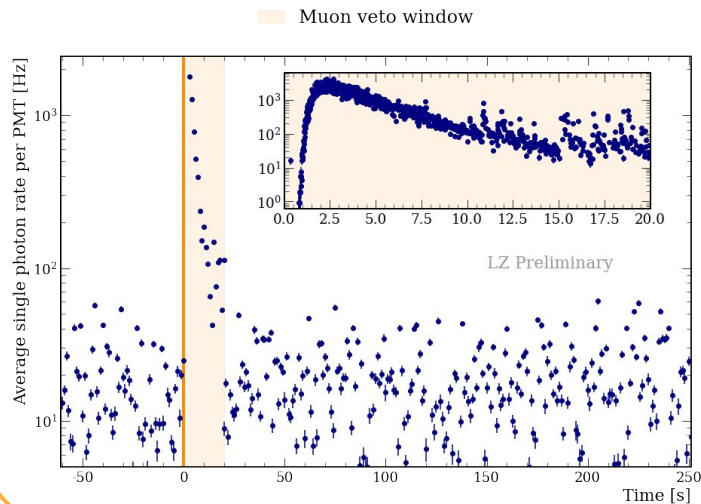
A **large S2** produces several VUV photons (low irradiation):

- ~10% will be detected by the PMTs
- Some of the remaining photons will be absorbed by the PTFE



A **muon event** produces many more VUV photons (high irradiation):

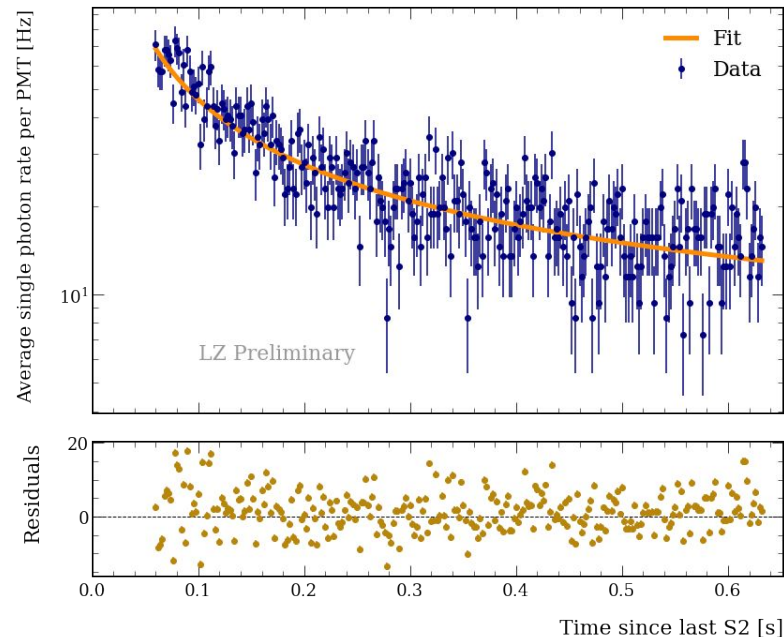
- Long and uniform irradiation of the TPC
- Higher activity recorded up to 20s after muon events



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- When the UV irradiation is low (i.e. **large S2**) → power law behaviour dominates



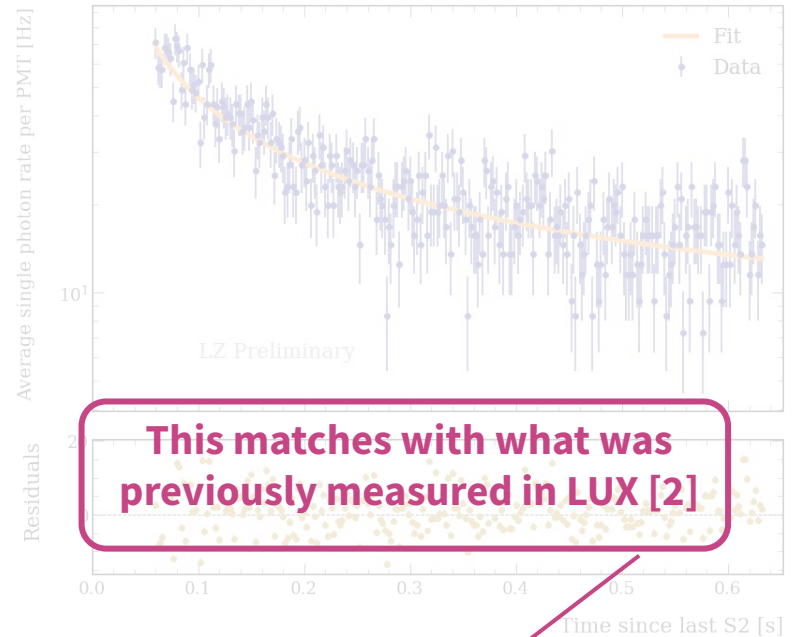
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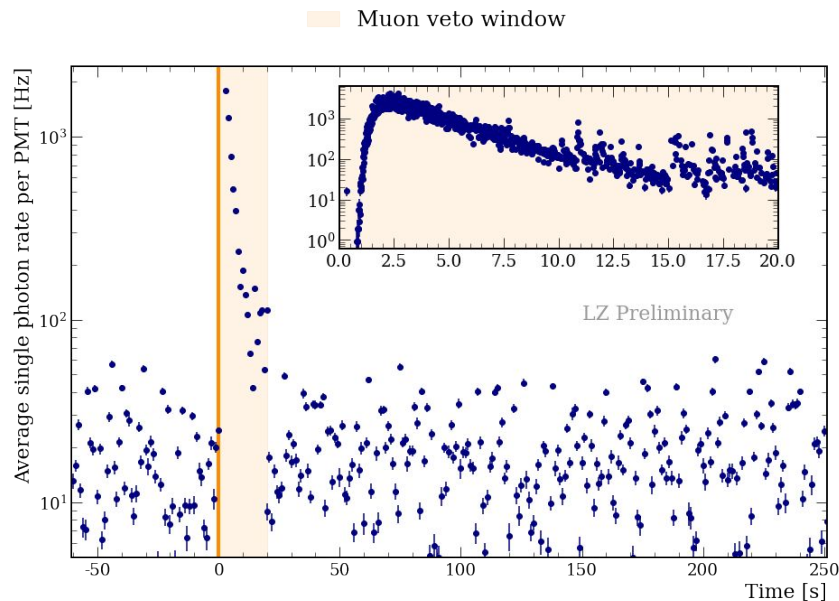
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 - Direct de-excitation to the ground state [3]



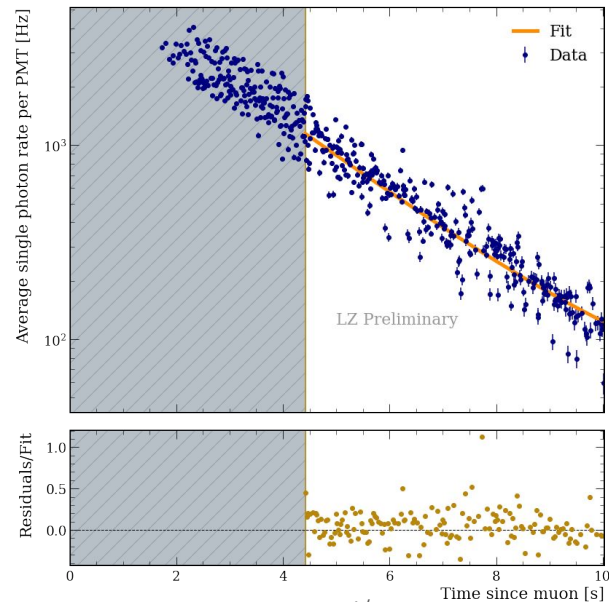
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Fit model $\propto e^{-t/\tau} + c$

Results: $\tau = 2.3 \pm 0.2 \text{ s}$

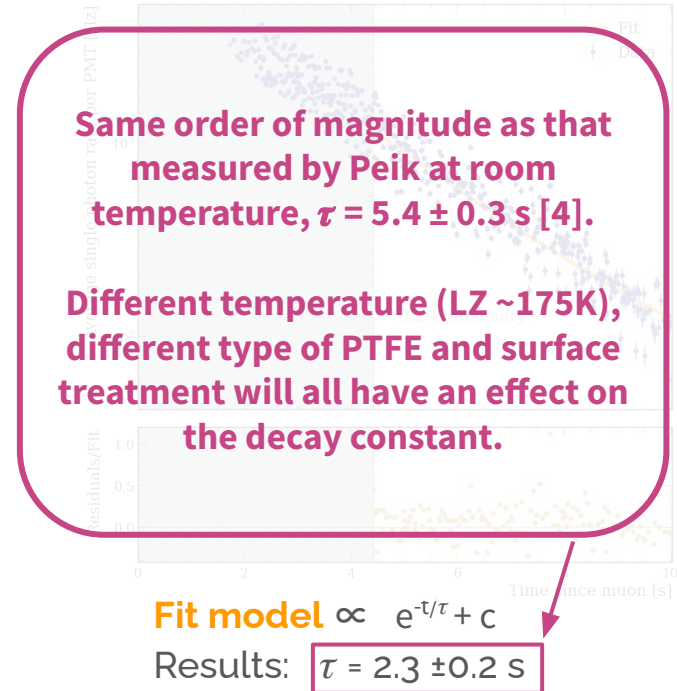
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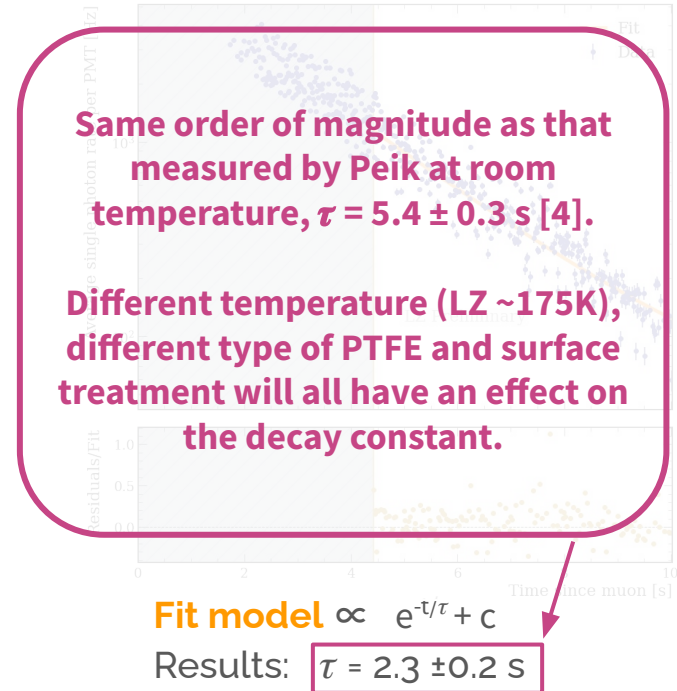
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Currently studying competing effects due to migration of carriers.



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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.

Analysis methods and results:

- Leveraging the DPE effect and performing a photon analysis of the isolated S1 population I found:
 - Majority of isolated S1 comes from xenon interactions
 - ~48% of 3-fold coincidence photons come from the pile up of non-VUV single photons
- One of the hypotheses which could explain the heightened single photon rate is PTFE fluorescence. Other hypotheses are being investigated

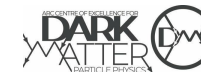
250 scientists, engineers, and technical staff

<https://lz.lbl.gov/>

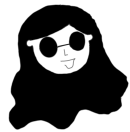
- Black Hills State University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial College London
- King's College London
- Lawrence Berkeley National Lab.
- Lawrence Livermore National Lab.
- LIP Coimbra
- Northwestern University
- Pennsylvania State University
- Royal Holloway University of London
- SLAC National Accelerator Lab.
- South Dakota School of Mines & Tech
- South Dakota Science & Technology Authority
- STFC Rutherford Appleton Lab.
- Texas A&M University
- University of Albany, SUNY
- University of Alabama
- University of Bristol
- University College London
- University of California Berkeley
- University of California Davis
- University of California Los Angeles
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- University of Liverpool
- University of Maryland
- University of Massachusetts, Amherst
- University of Michigan
- University of Oxford
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Science and
Technology
Facilities Council



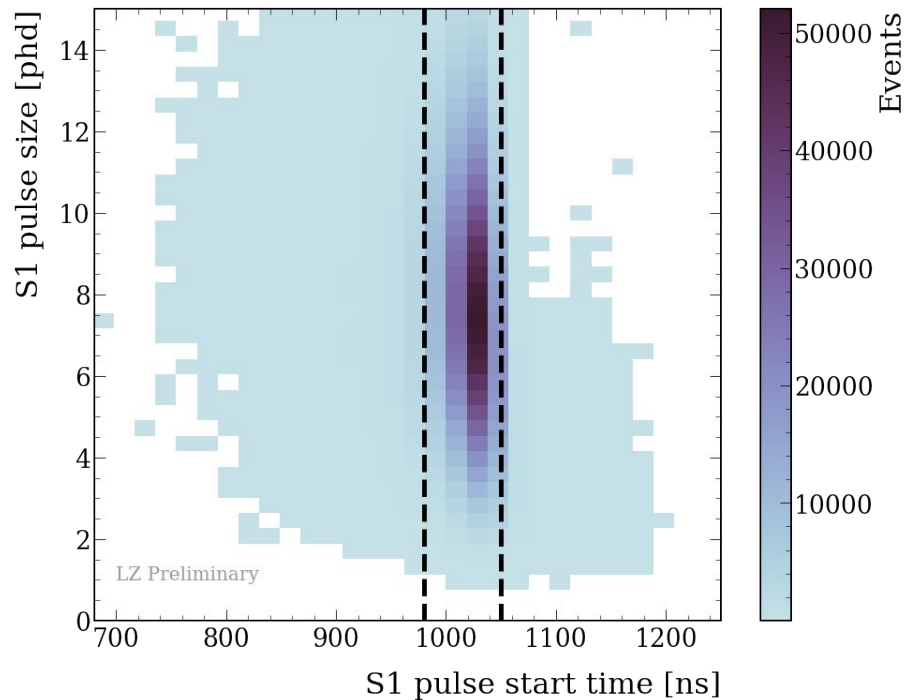
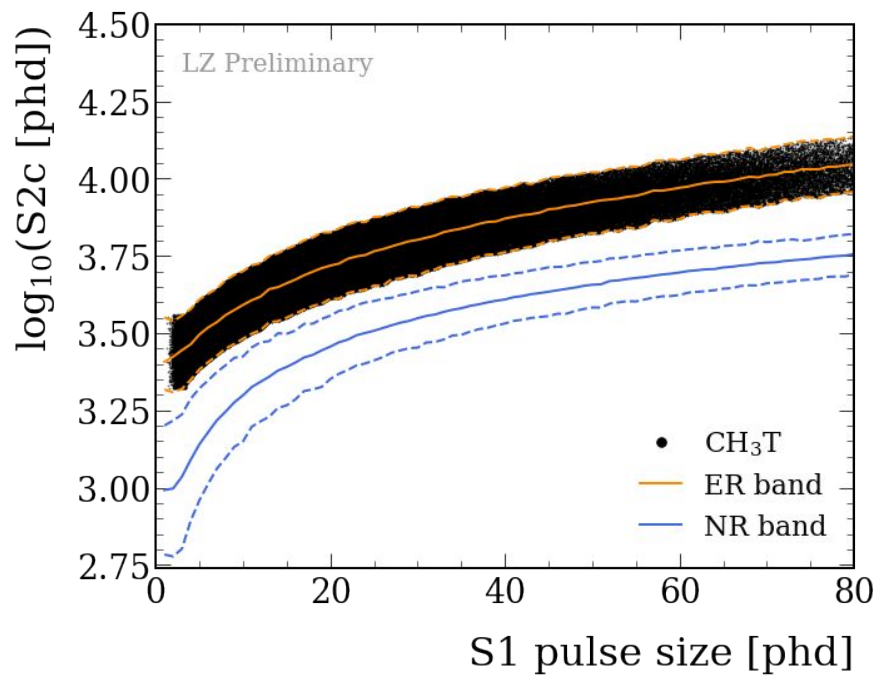
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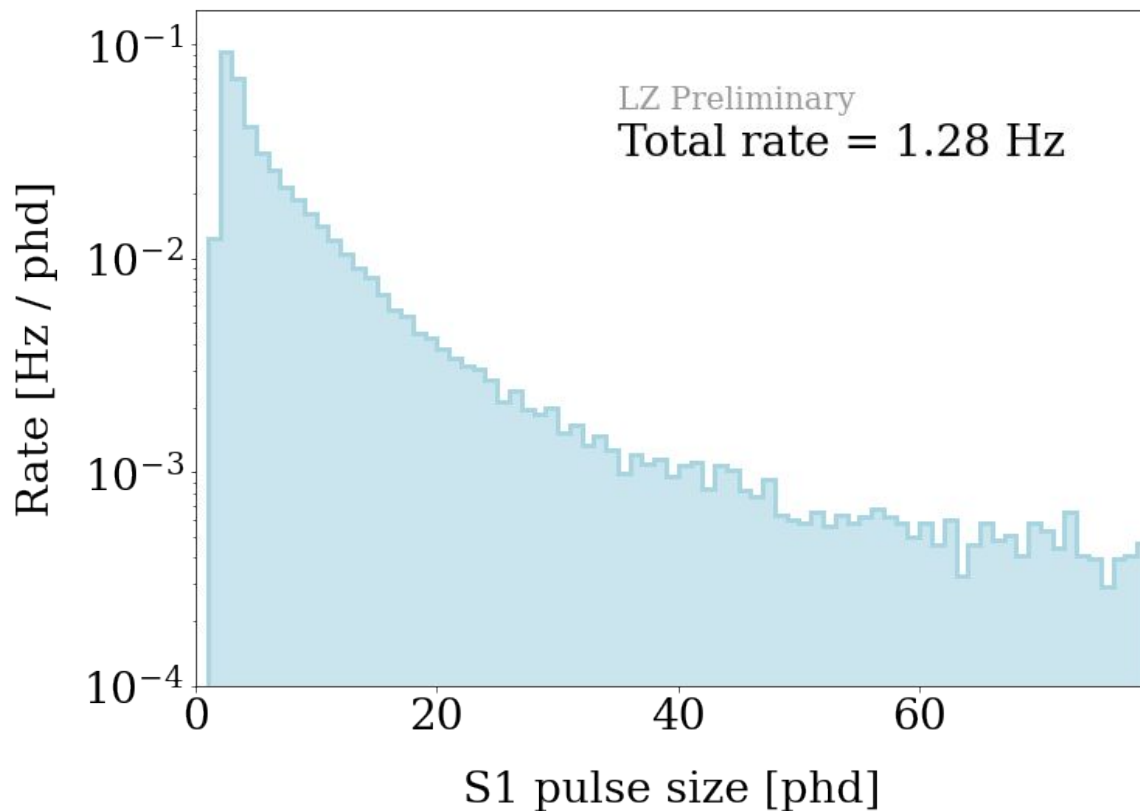
Backup slides

Calibration data selection

Selection of event from CH₃T and LED calibration campaigns

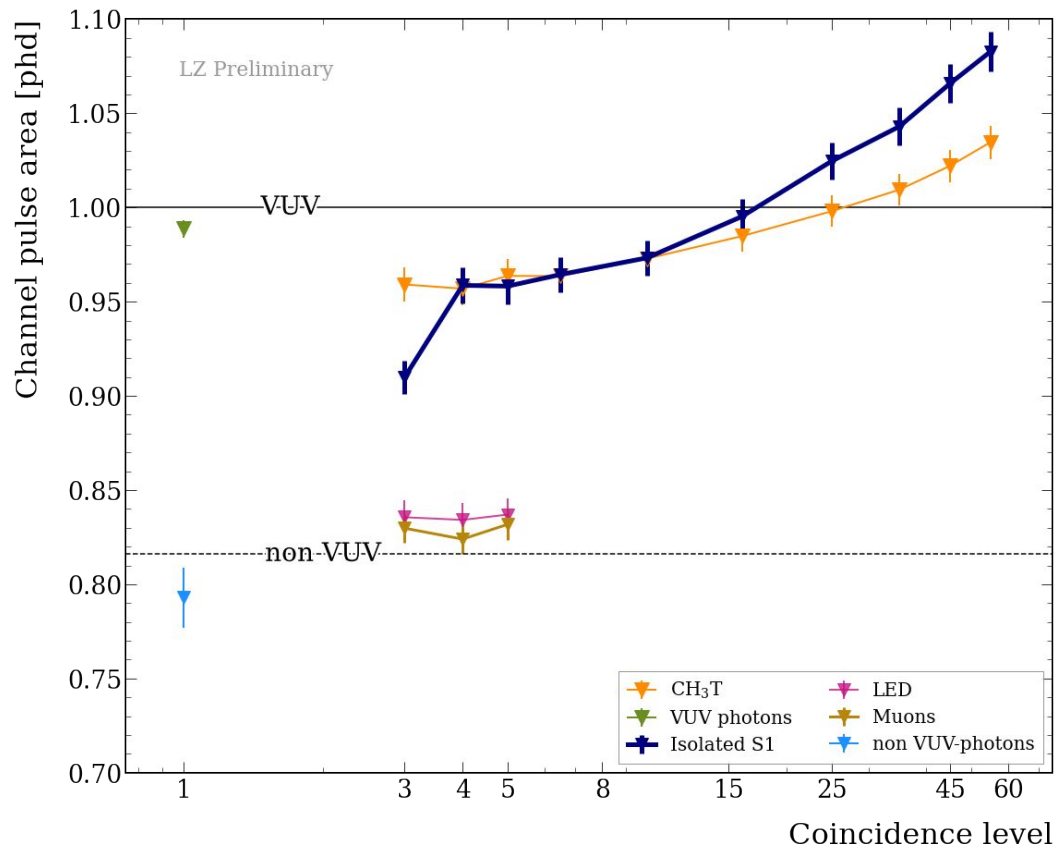


Rate of isolated S1 events in WS2024

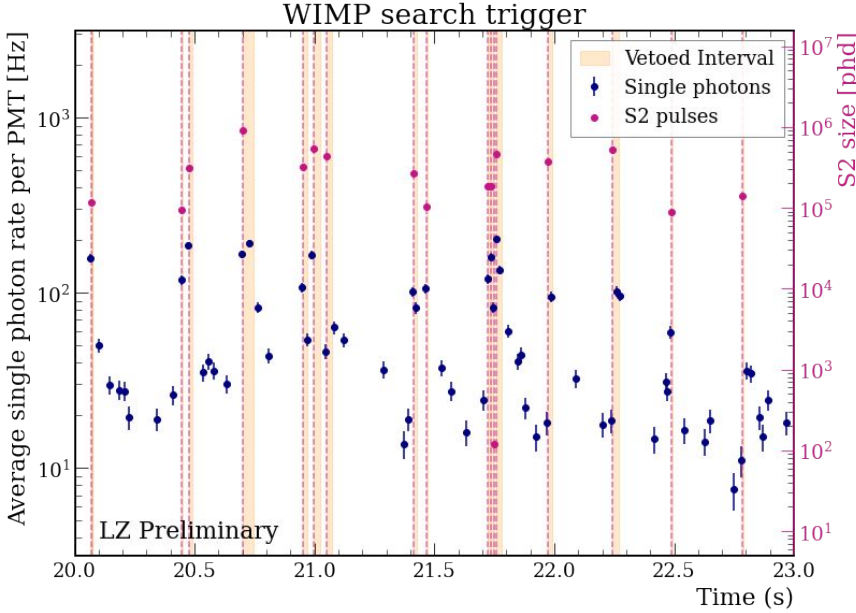
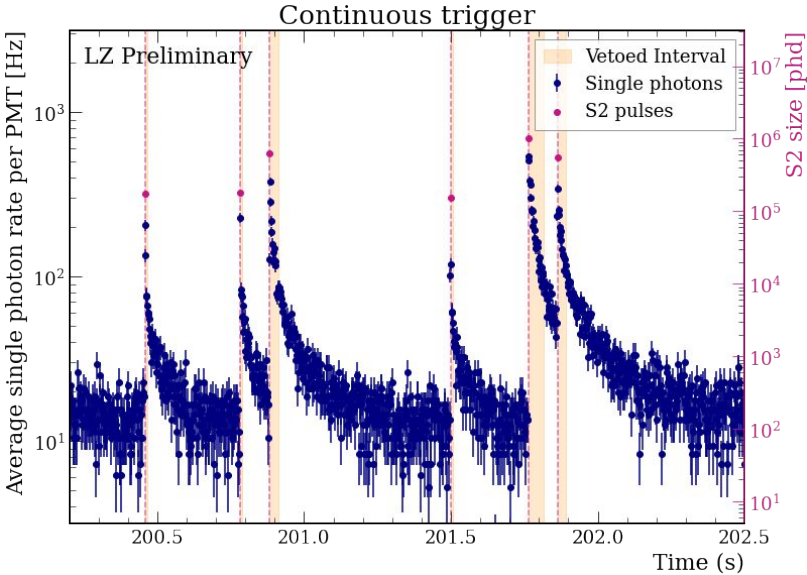


Muon pile up S1s

During a muon tail several single photons pile up to make up an S1, as predicted this falls in the **non-VUV regime**



Enhanced SPE rate in nominal trigger



Checks on the 4-fold coincidence

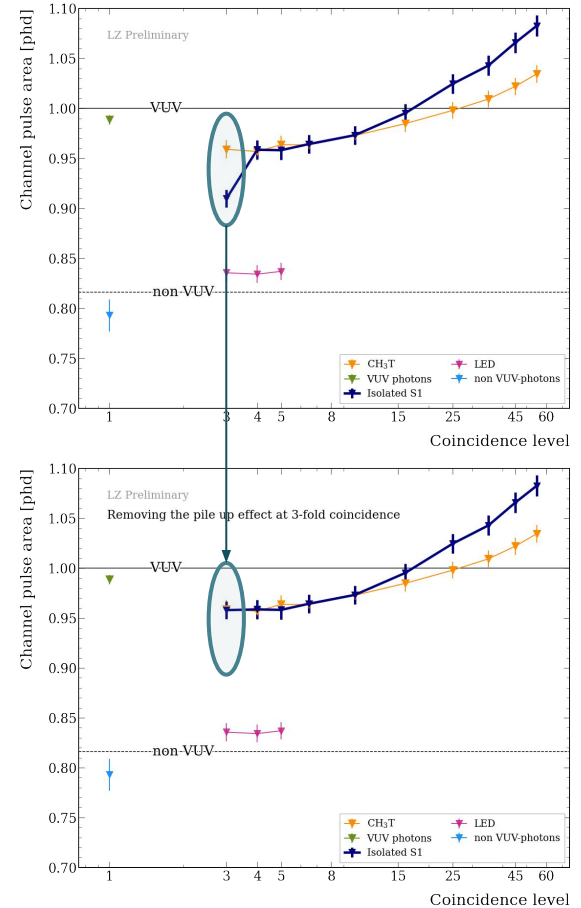
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Only 1% of the 4-fold coincidences come up from this pile up mechanism

This agrees with what observed from the isolated S1 population!



PTFE fluorescence - Peik 2007

Exponential decay with $\tau = 5.4 \pm 0.3$ s

Power law decay $\propto t^{-1}$

