Update on Delayed Electron Emission in DarkSide-50

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on behalf of the DarkSide-50 collaboration

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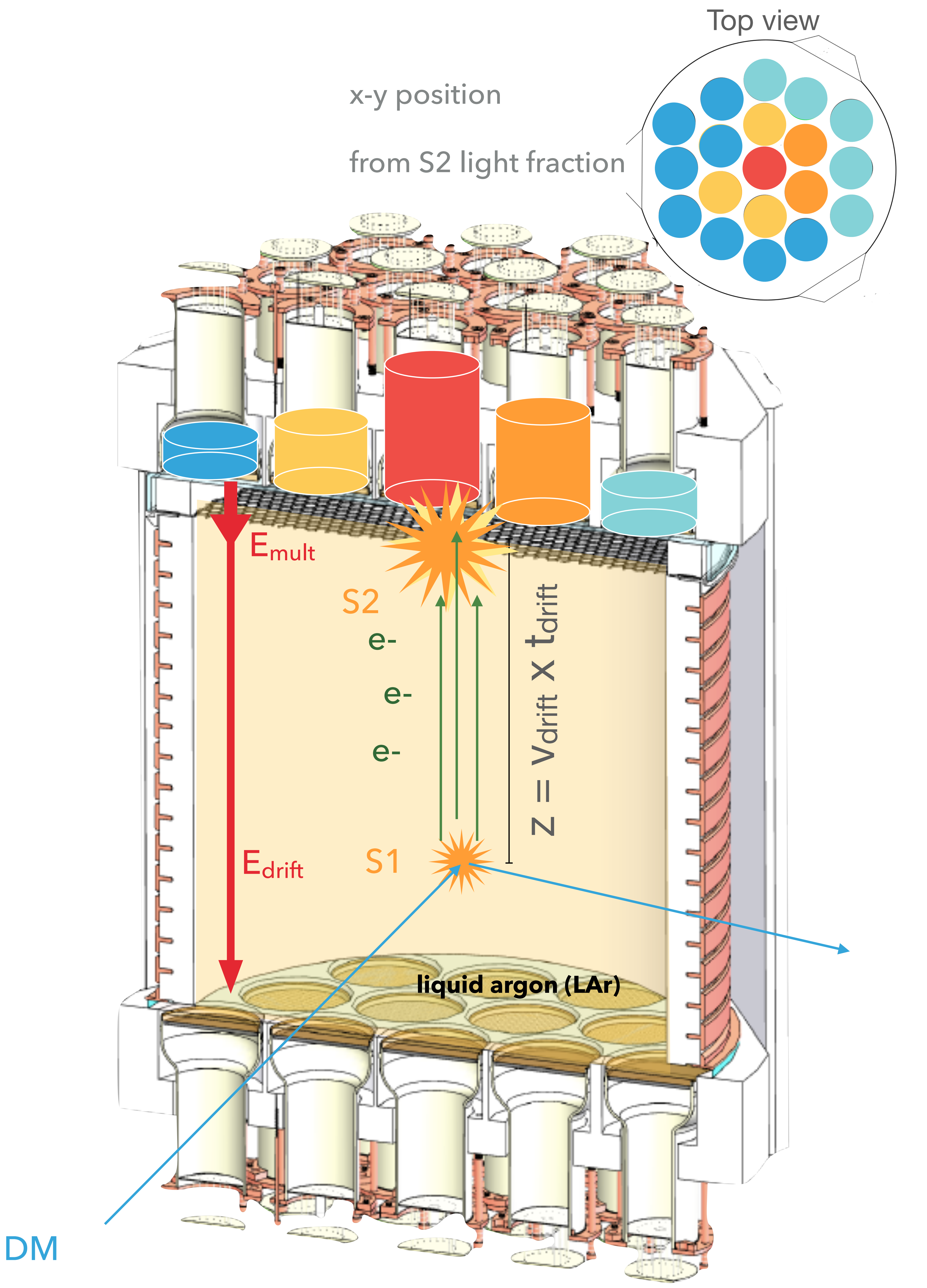
LIDINE 2022

DS-50 Liquid Argon TPC

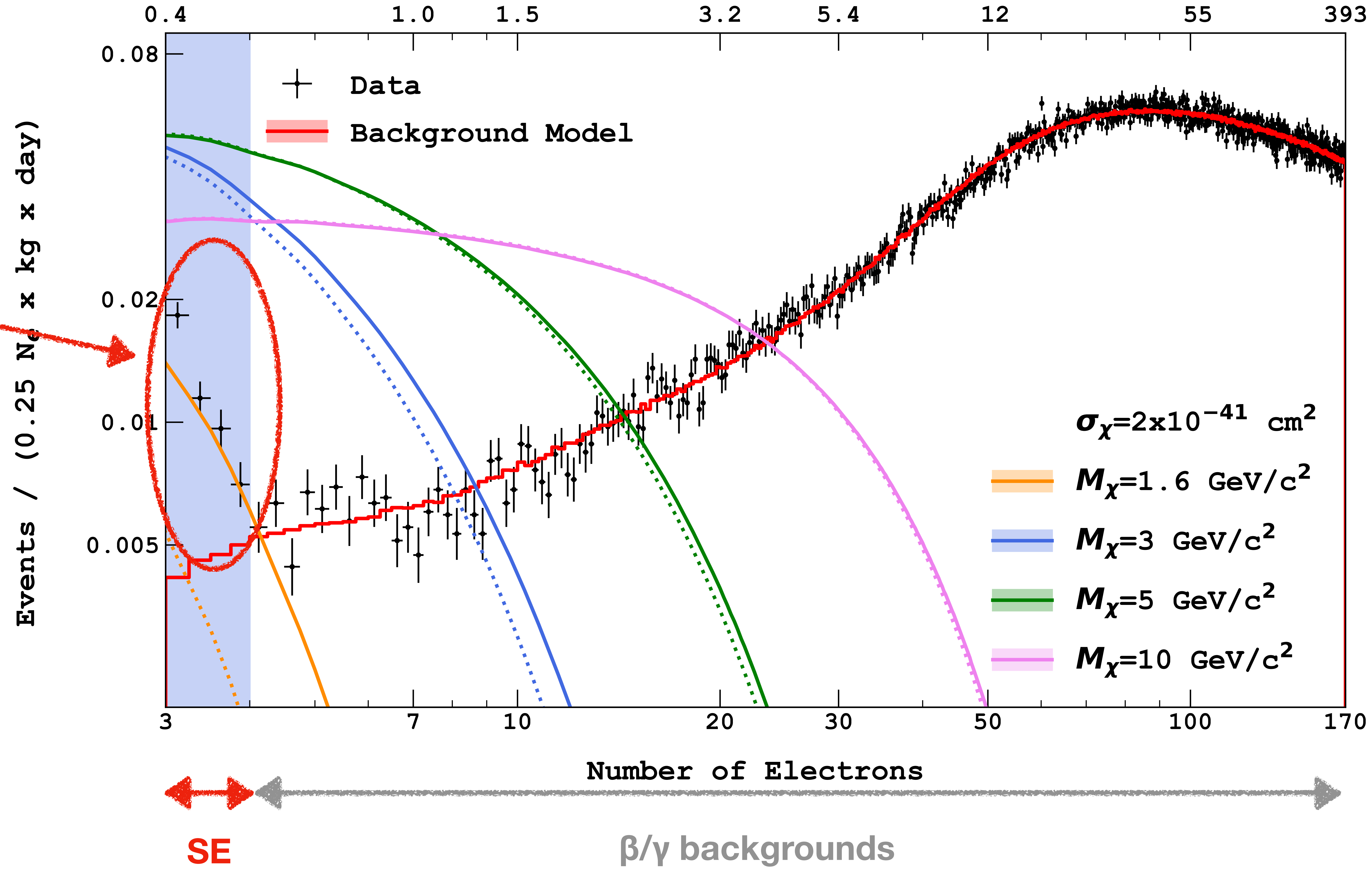
- Double-phase liquid argon TPC (see Physics Letters B 743, 456 (2015)).
- Readout **S1 and S2 light signals with PMTs.**
- Trigger on two PMTs coincidence (0.6 PE) within 100 ns.
- Drift field is 200 V/cm.
- Electroluminescence field is ~5.6 kV/cm (at the x-y center) and 4.2 kV/cm (at the edge).
- Cathode and anode consist of ITO coated on fused silica instead of wires unlike in the Xenon TPC.
- The hexagonal meshed grid at 5 mm below the liquid surface to apply the extraction field of 2.8-3.7 kV/cm (due to deformation of anode).
- **Argon is purified in gas phase by a hot getter and a Rn trap**, then directly brought back in the TPC from a condenser.



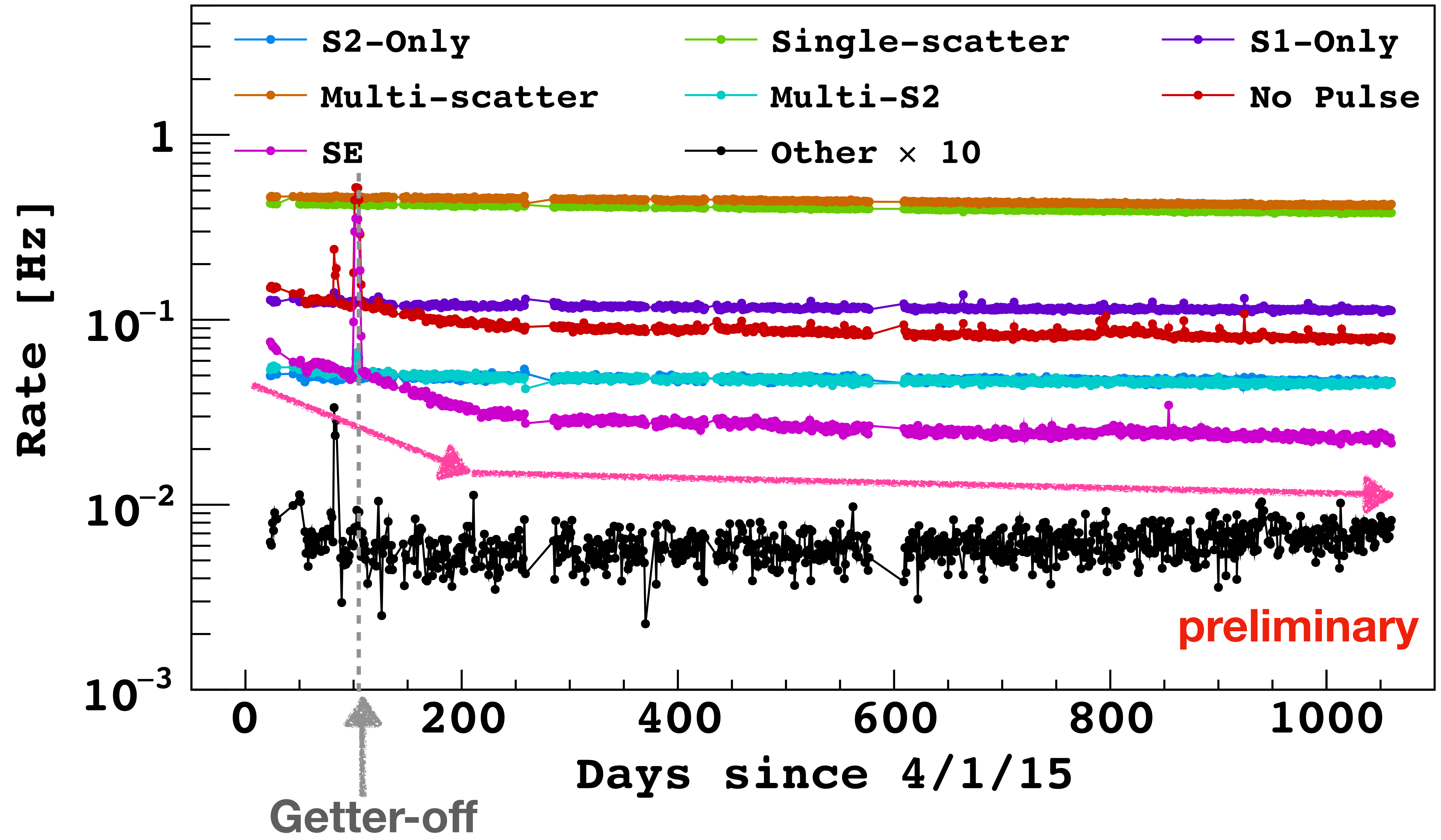
Low Energy Backgrounds in DS-50

- The analysis threshold was determined by the excessive number of events at 1-4 Ne.
- Limits our sensitivity to lower WIMP mass range.
- Need to understand the few-electrons events, so called, spurious electrons (SE) events

arXiv:2207.11966
(new low mass analysis)



Time Evolution of events in DS-50



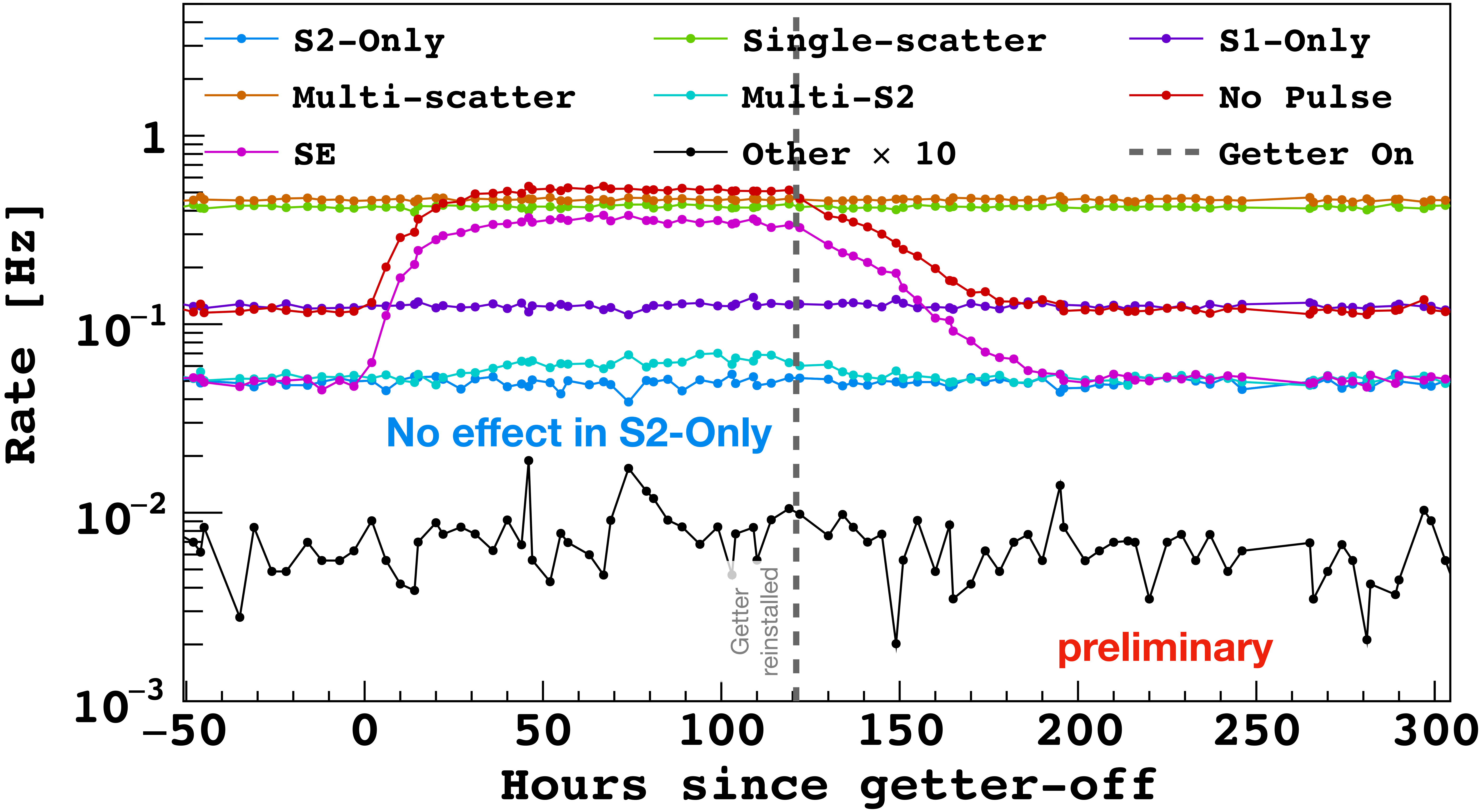
Pulse identification by pulse shape and pulse size

Event categorization based on the pulse id's and their temporal order

- *Multi scatter*: gamma events, random pileups
- *Single scatter*: normal events (S1+S2)
- *S1 only*: events don't have S2 or S2 too small (Cherenkov, wall effect, events in holes)
- *No pulse*: triggered, but pulse finder cannot find pulse including low Ne events that happen at the edge of the TPC.
- *S2 only*: events don't have S1, or S1 too small for pulse finder (only Ne≥4)
- *Multi S2*: multi scatters with S1 and the first S2 pileup (due to low t_drift)
- ***SE*: one S2-like pulse with Ne<4** Focus of this talk!
- *Other*: all the rest, 10^{-3} Hz (<0.1% of all events), for example, event with S2 + S1 + …

- Time evolution of each category from the underground Ar filling date (2015/04/01)
- Except *SE* and *No Pulse*, the rates are relatively flat. **Stable operation over years!!**
- **In *SE* and *No Pulse*, two slopes: until 200 days and rest.**
- Getter-off runs are from 99 to108 days.

Getter Off runs



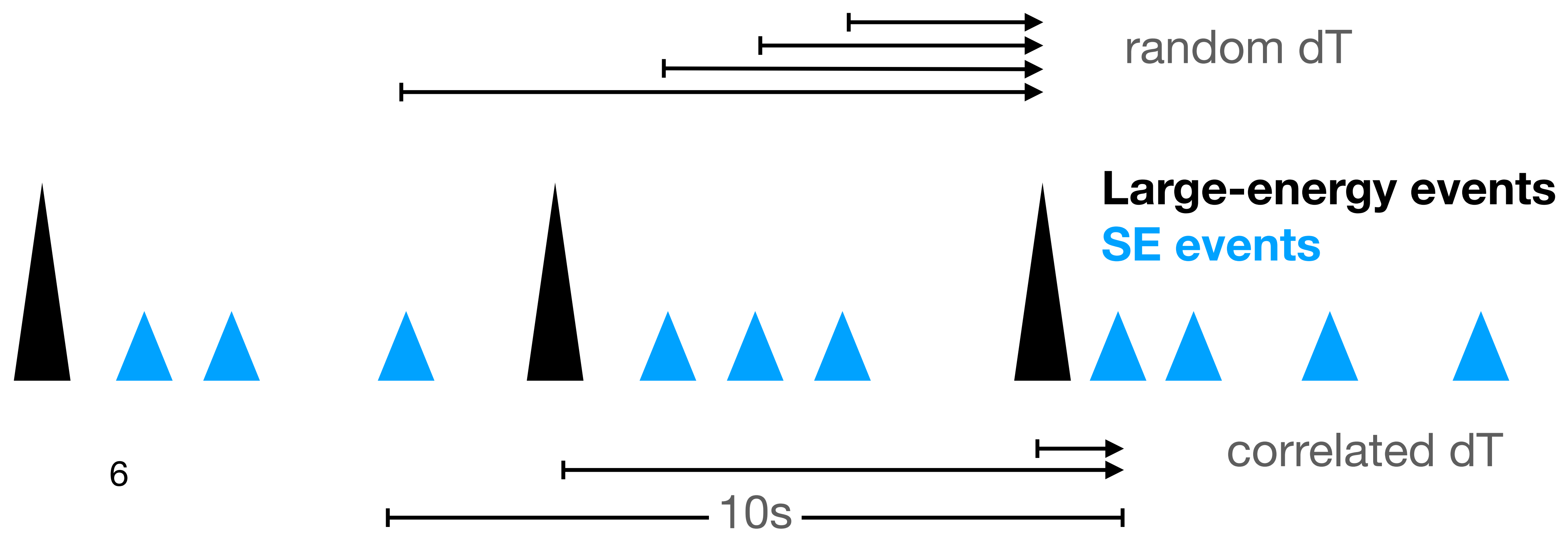
- For maintenance, the hot getter in the argon gas circulation system was bypassed for about 5 days (120 hours).
- An increase in rates of one-pulse events with a short livetime and small signal size.
- The elevated event rate was back to normal in 4 days after reinstallation of the getter.

- The increase in rates were seen only in *SE* and *No Pulse*. -> **Not affect above Ne>4**.
- The decrease rate of the extra events had a time constant of 36 hours
- The rate increased in 2 days and stable until the getter was included.
- This suggests that **impurities introduced by the absence of the getter are responsible for *SE* events** (and *SE* events too small to be found by the pulse finder, ie. *No Pulse*).

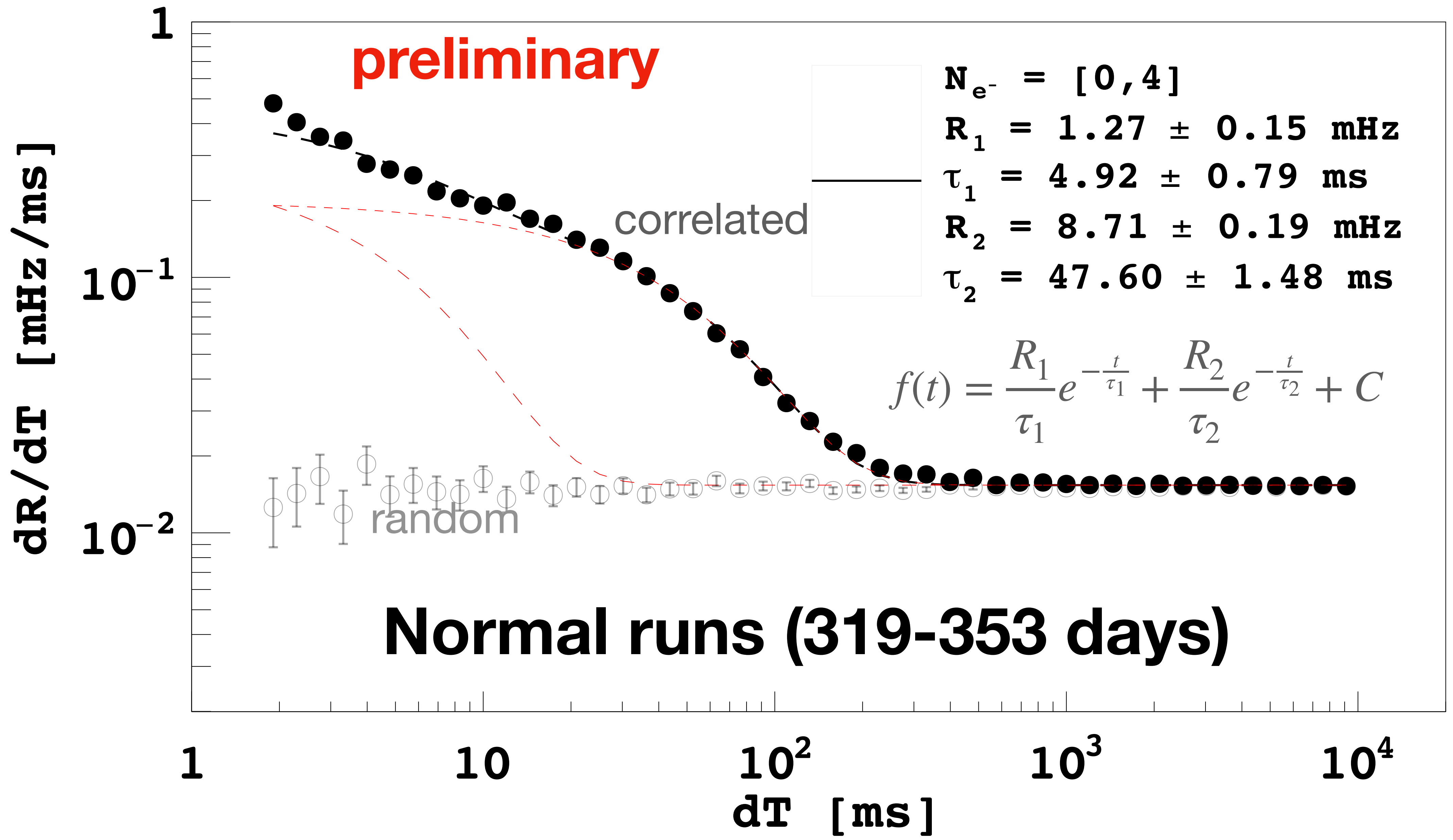
Time correlation of SE with large-energy events

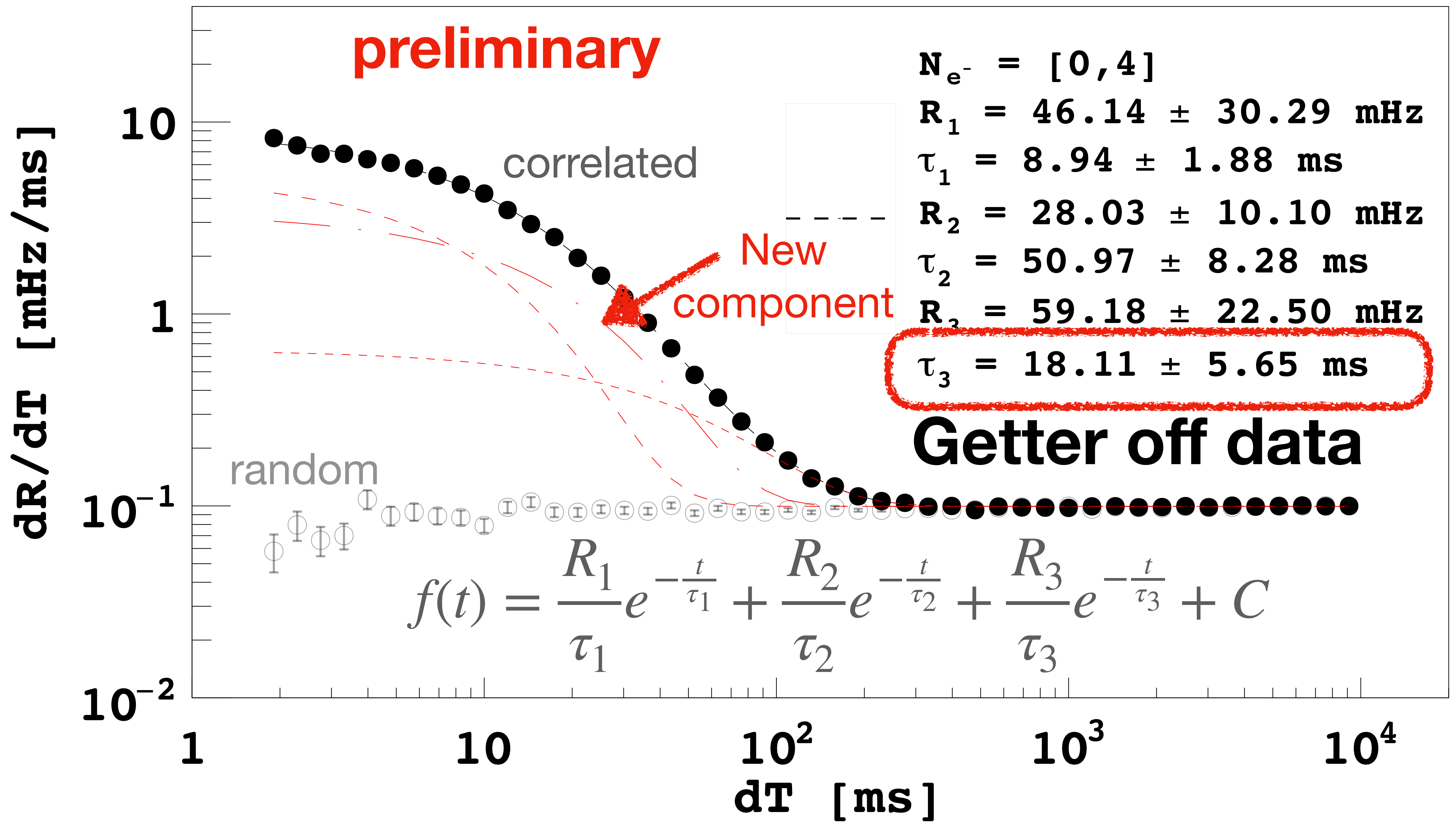
Time evolution of the time correlation

- large-energy events (parent events): S1>1000PE, t_drift defined (at least two pulses), and x-y position reconstructed.
- Register trigger time of events for large events and *SE* separately.
    - correlated ΔT: for each identified *SE*, fill time difference from all preceding large events within 10s from the *SE*.
    - random ΔT: for each identified large event, fill time difference from all preceding *SE* events within 10s from the large event.
- Random ΔT helpings modeling the uncorrelated fraction that is present in the correlated ΔT



Time correlation

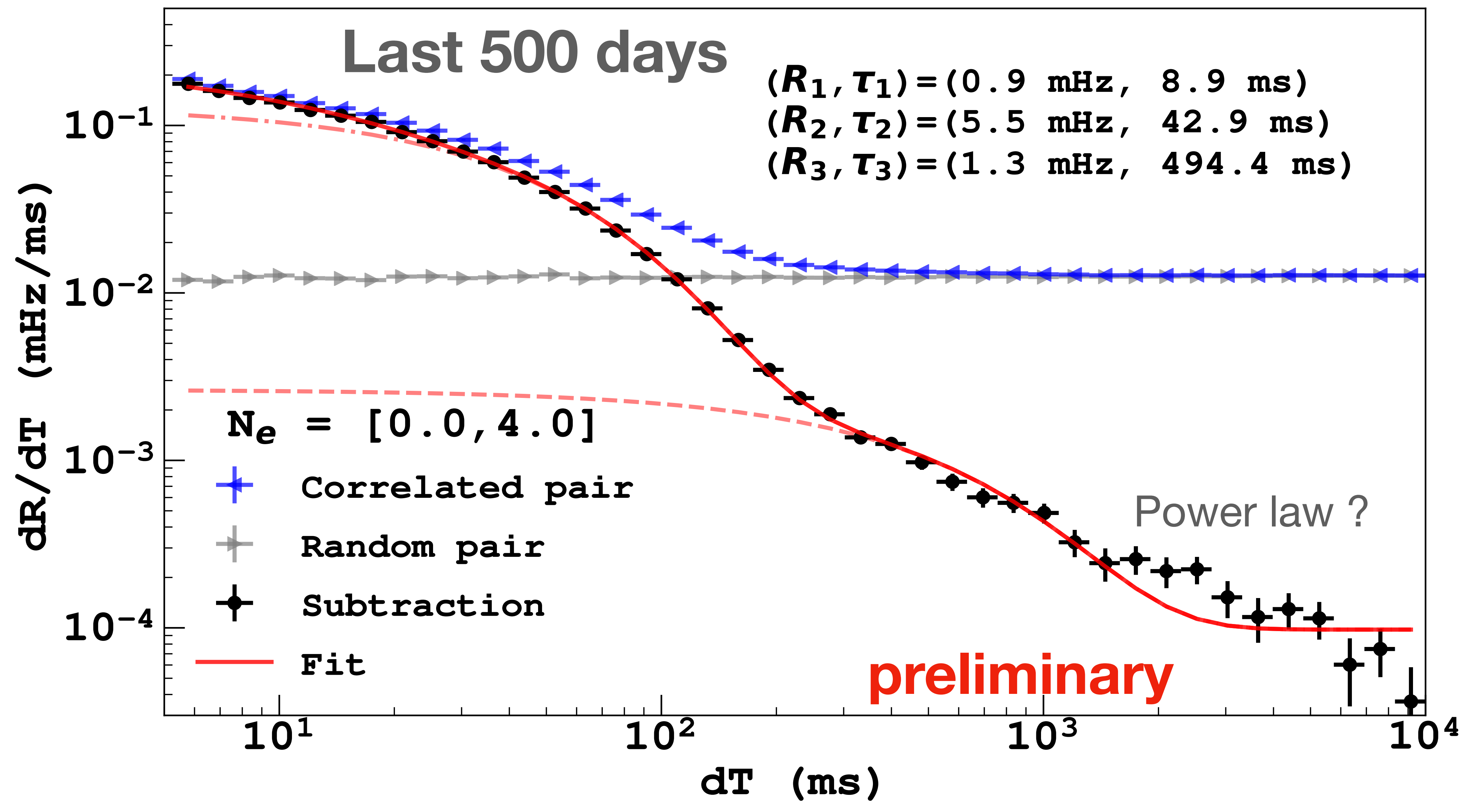




- At least two exponentials are necessary. Not power law unlike in Xenon based TPC.

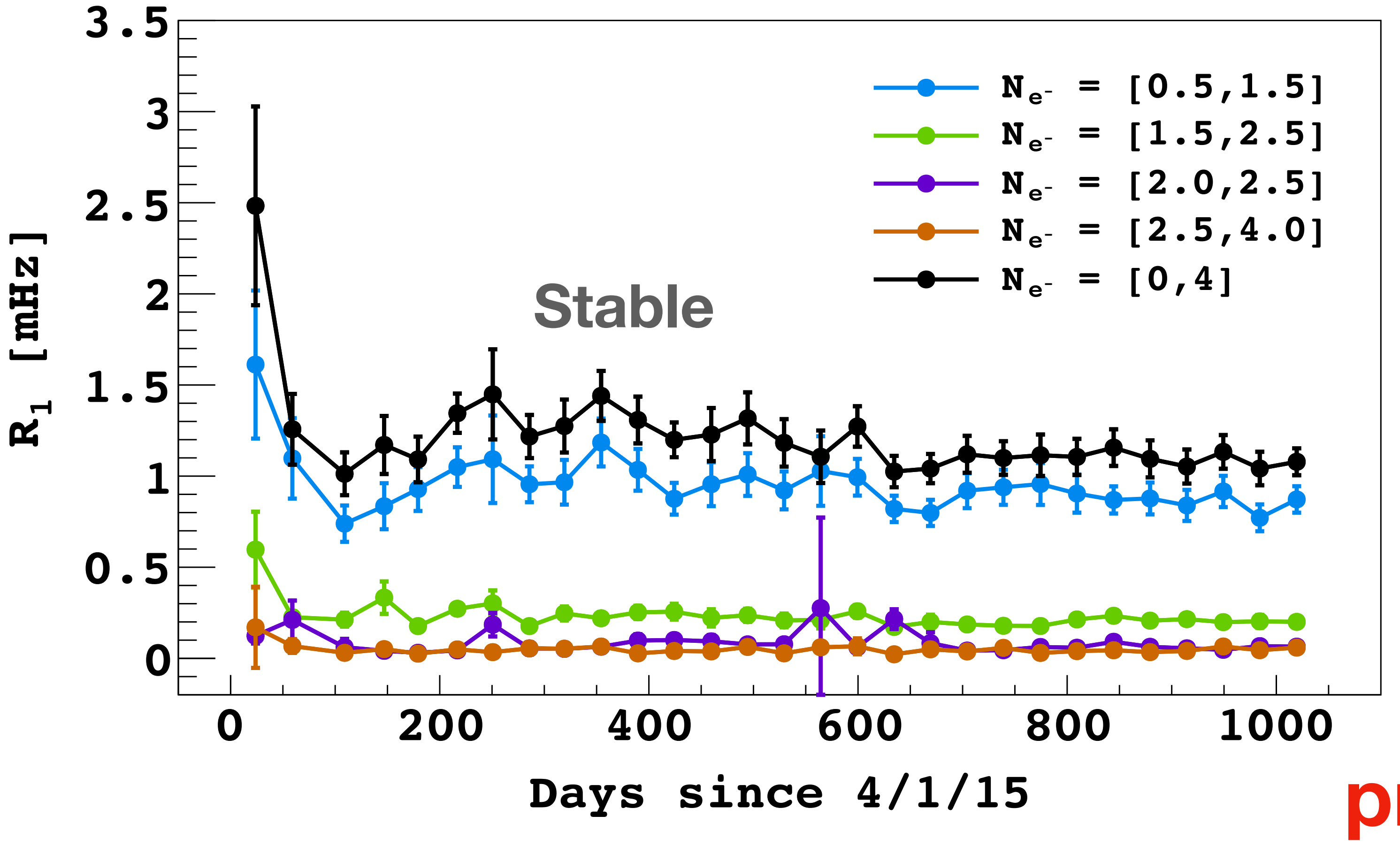
D.S. Akerib et al. Phys. Rev. D 102, 092004 (2020)

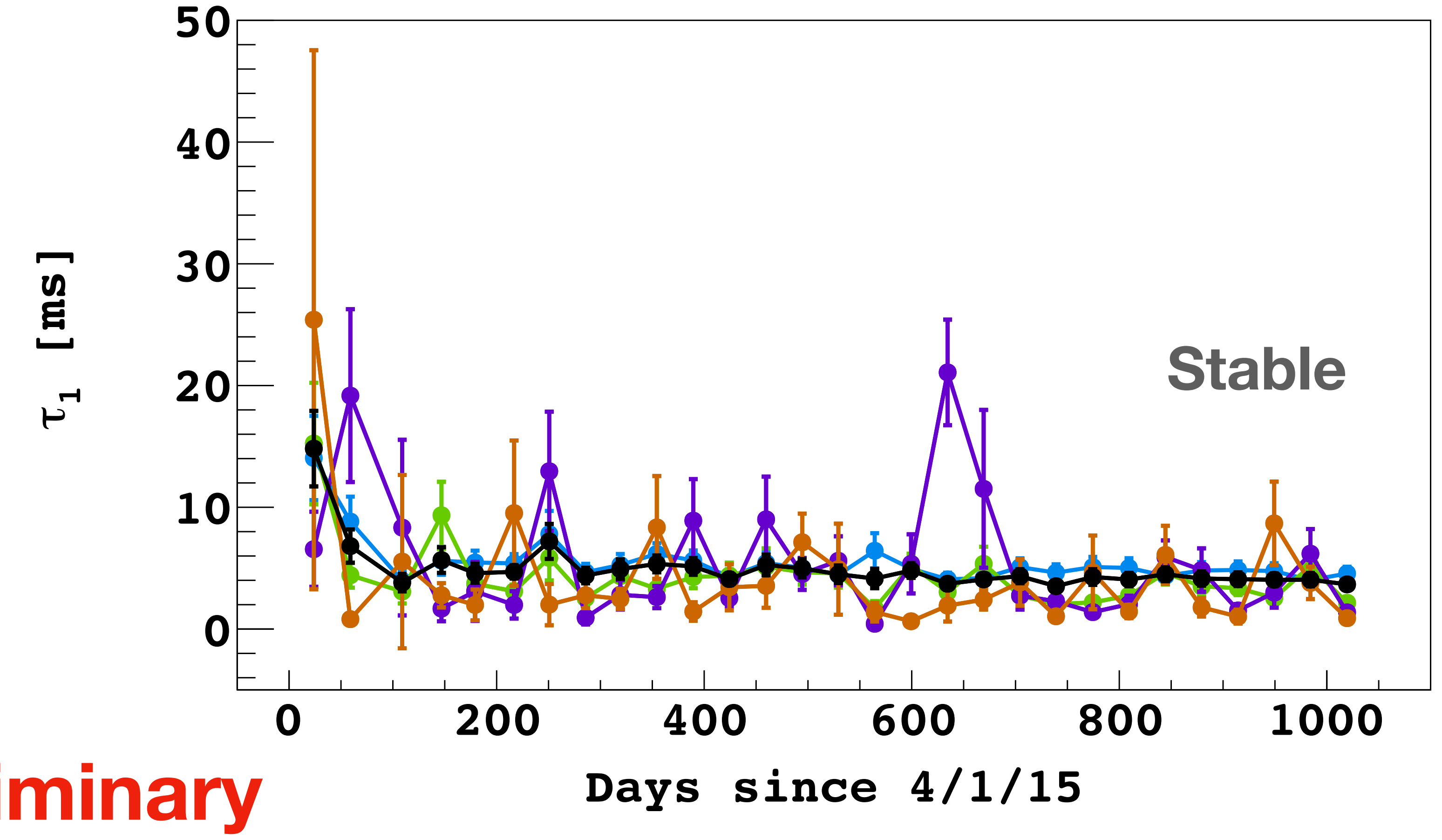
- **In getter off data, an additional time constant τ_3 of 18 ms appeared** and three exponentials are used.



- High statistics analysis of data belonging to a 500 d time period reveals **other components beyond the simple two exponential model.**

Time Evolution of Time Correlation





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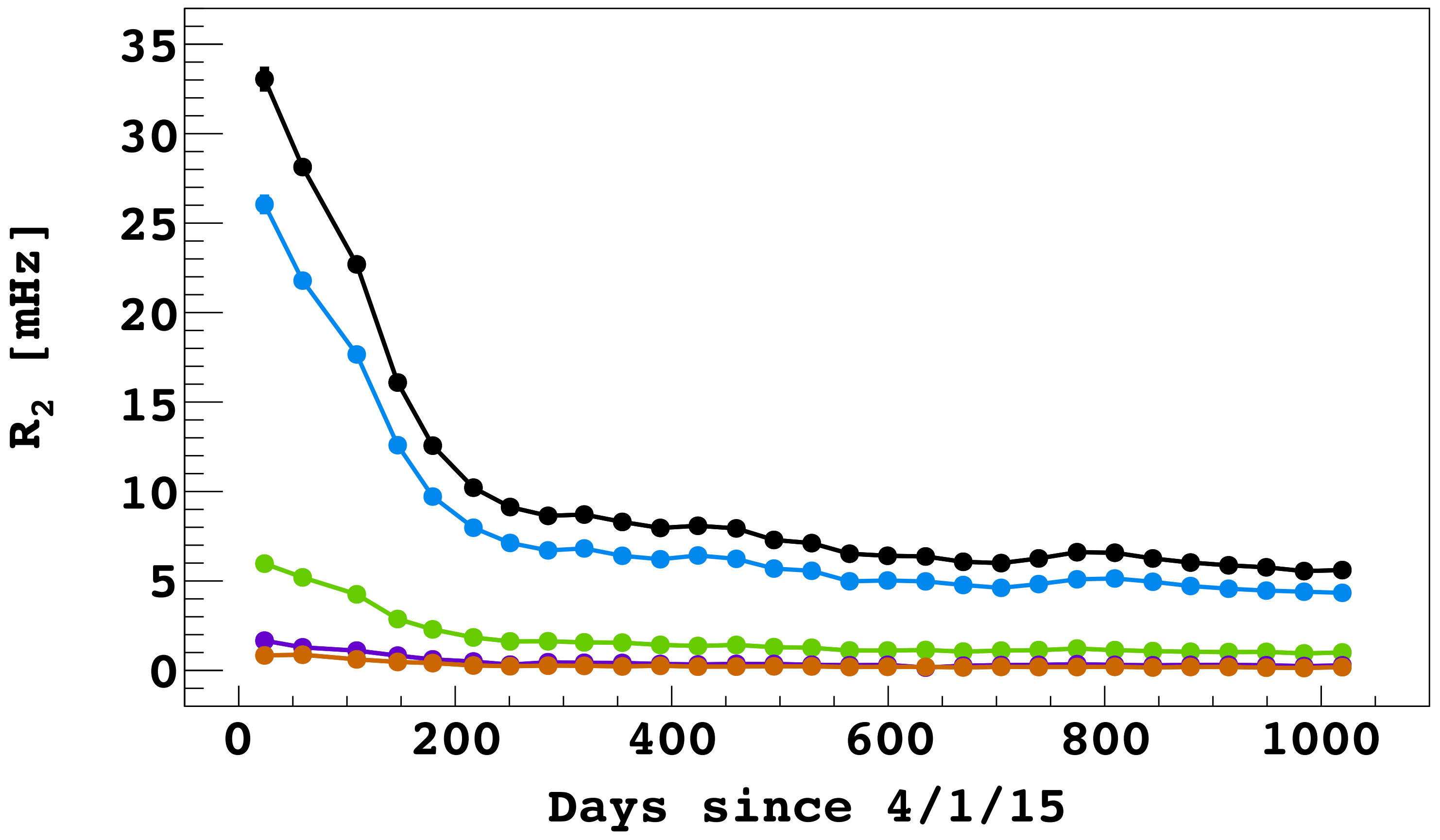
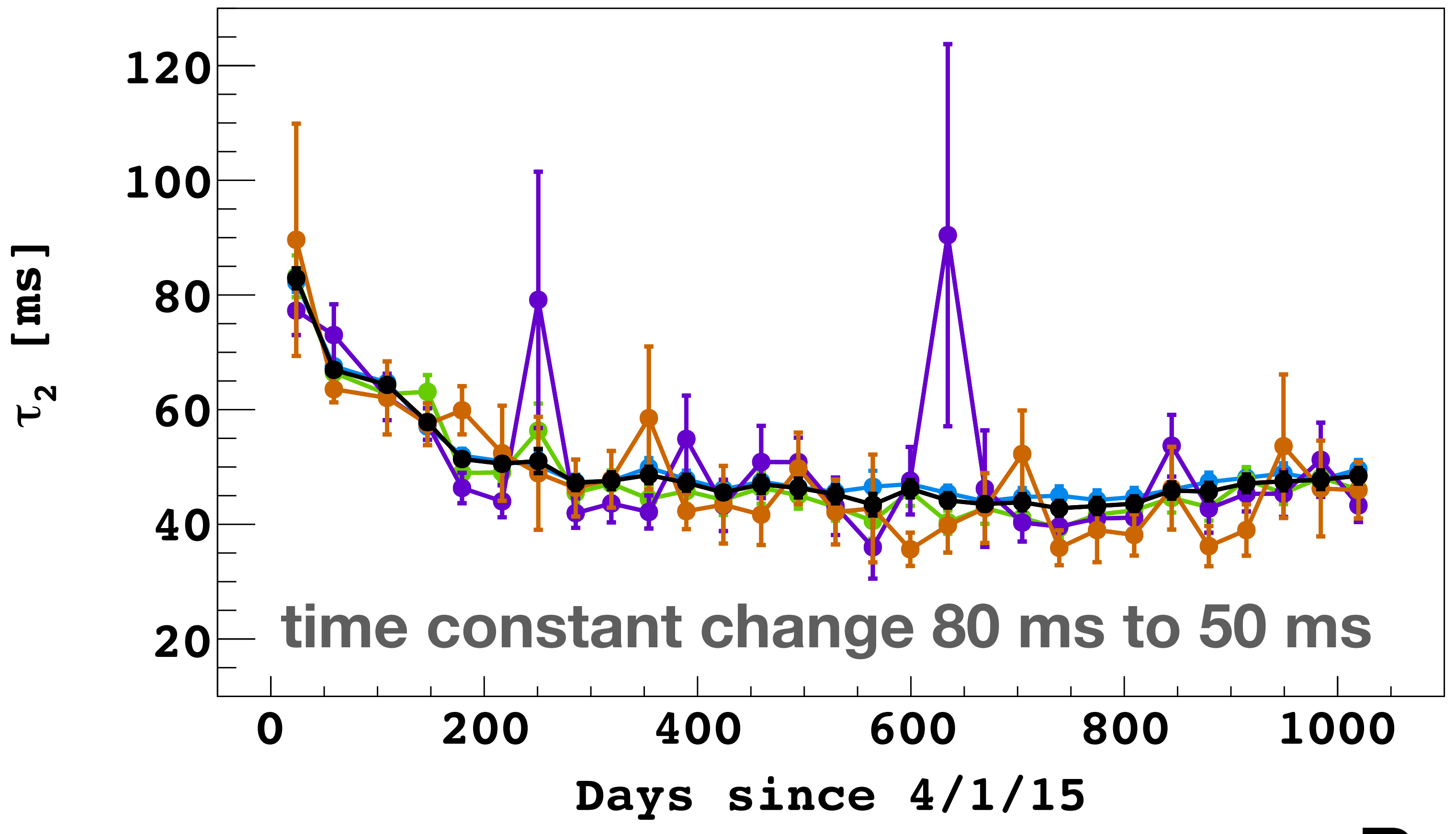
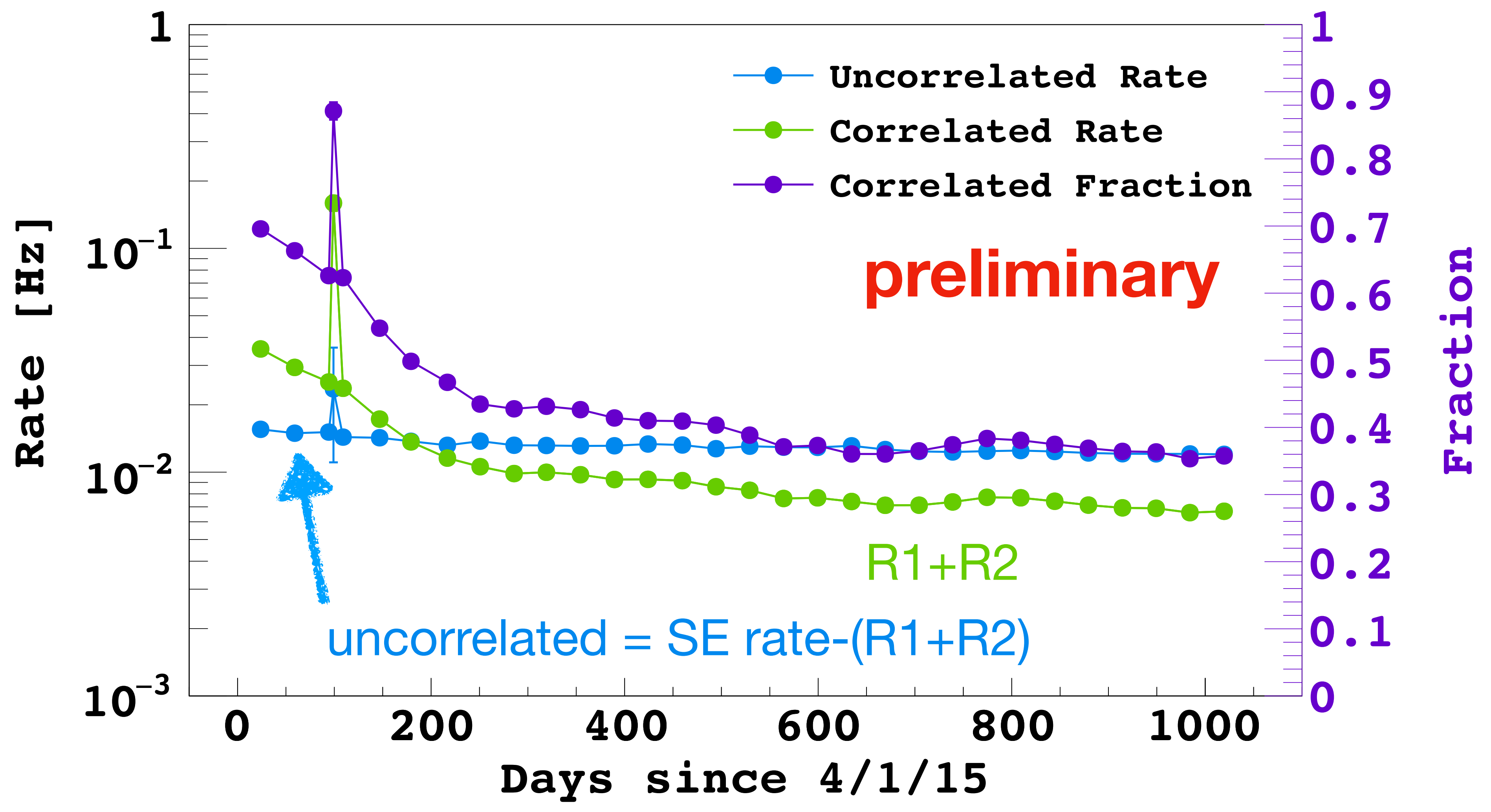




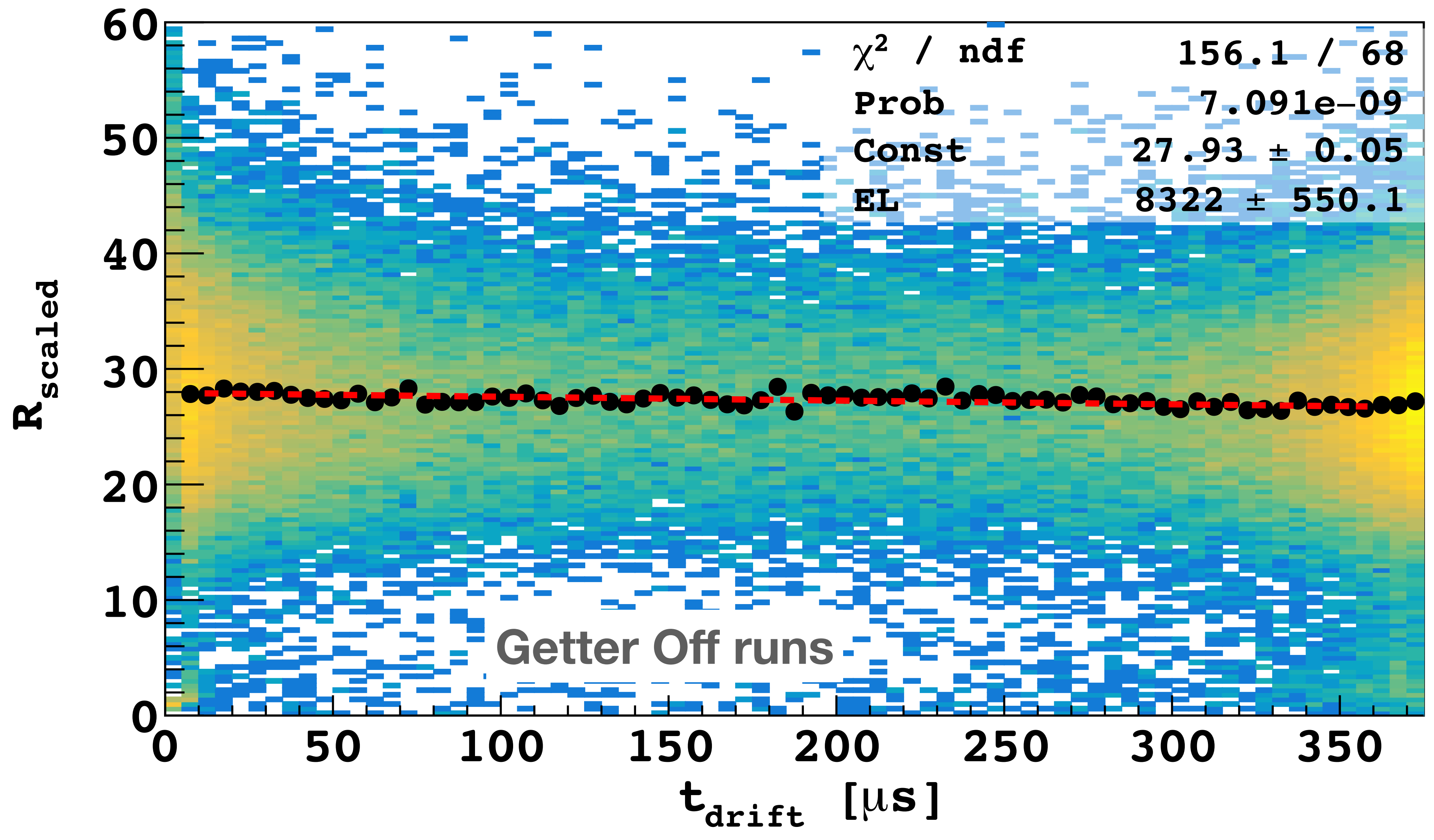
- Rate (R1) of the ~5 ms (τ1) component seems flat over time, ~1.3 mHz.
- Rate and time constant of the longer time constant (τ2) component decreased within the first 200 days.



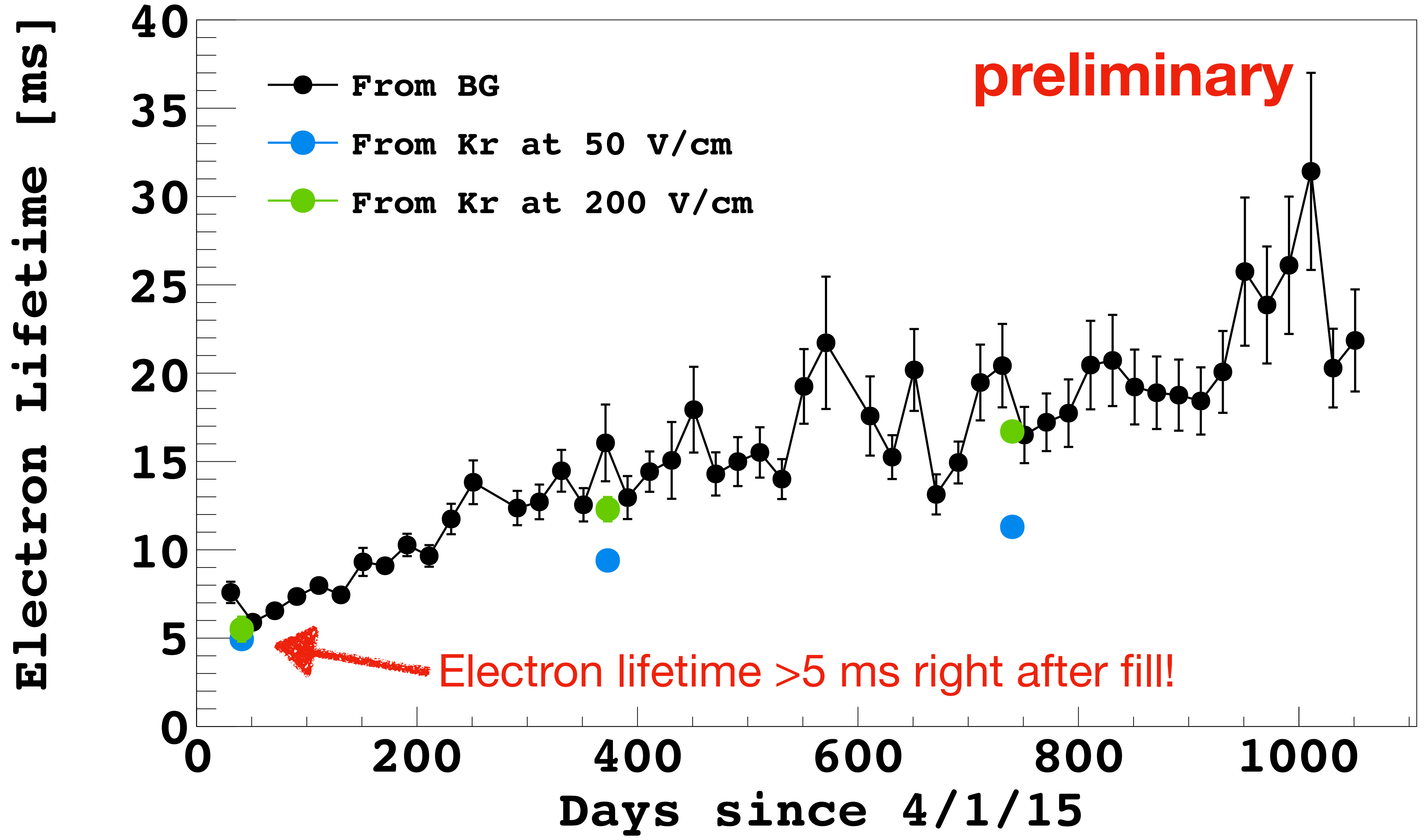
- R_1 plus R_2 represent the correlated rates in SE events.
- We can explain 40% to 70% of the SE rate being correlated with well identified preceding events.

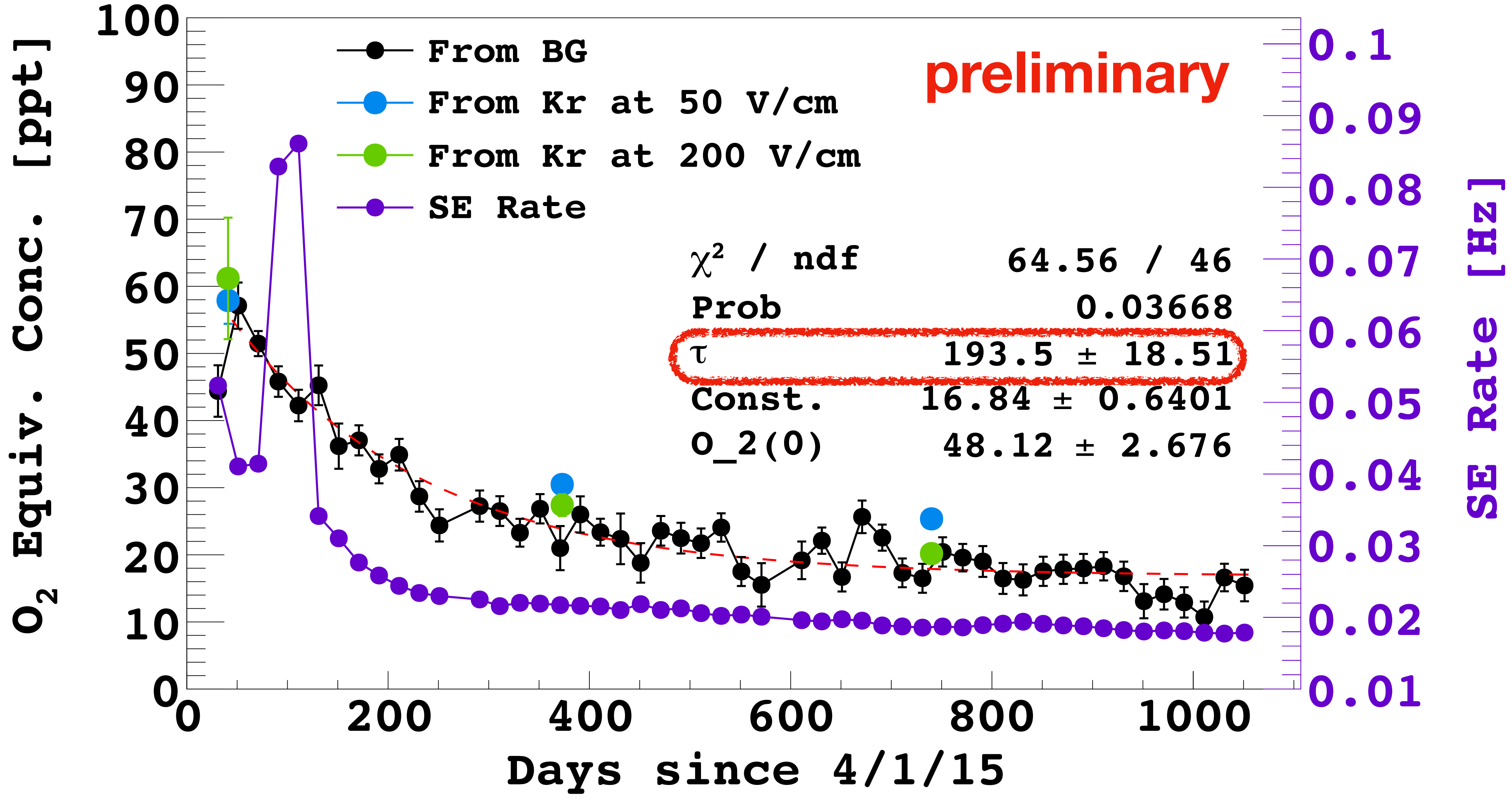
Getter off data is not included

Electron drift-lifetime



- The electron drift-lifetime is evaluated using normal data and Kr source data at 200 and 50 V/cm.

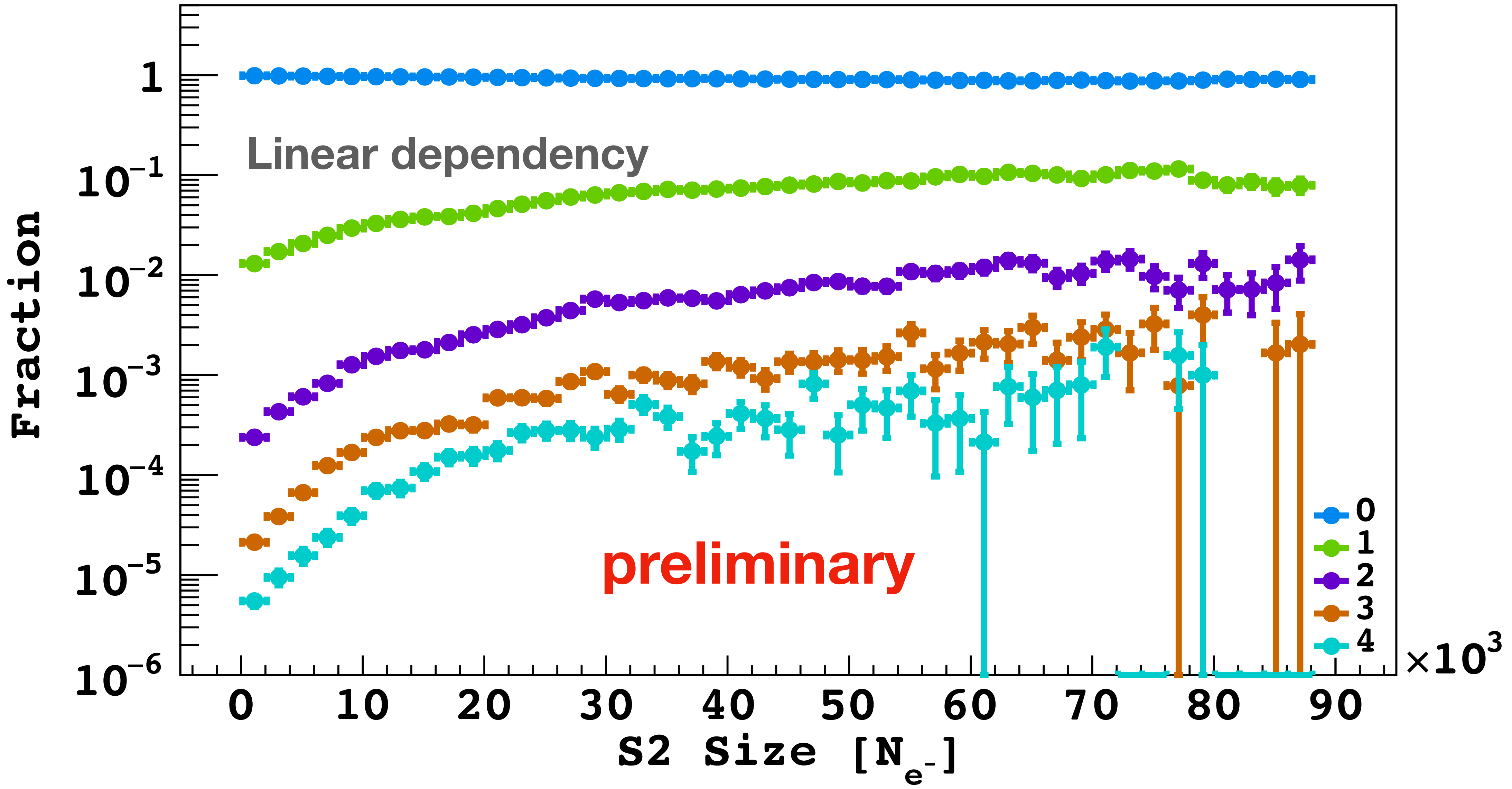




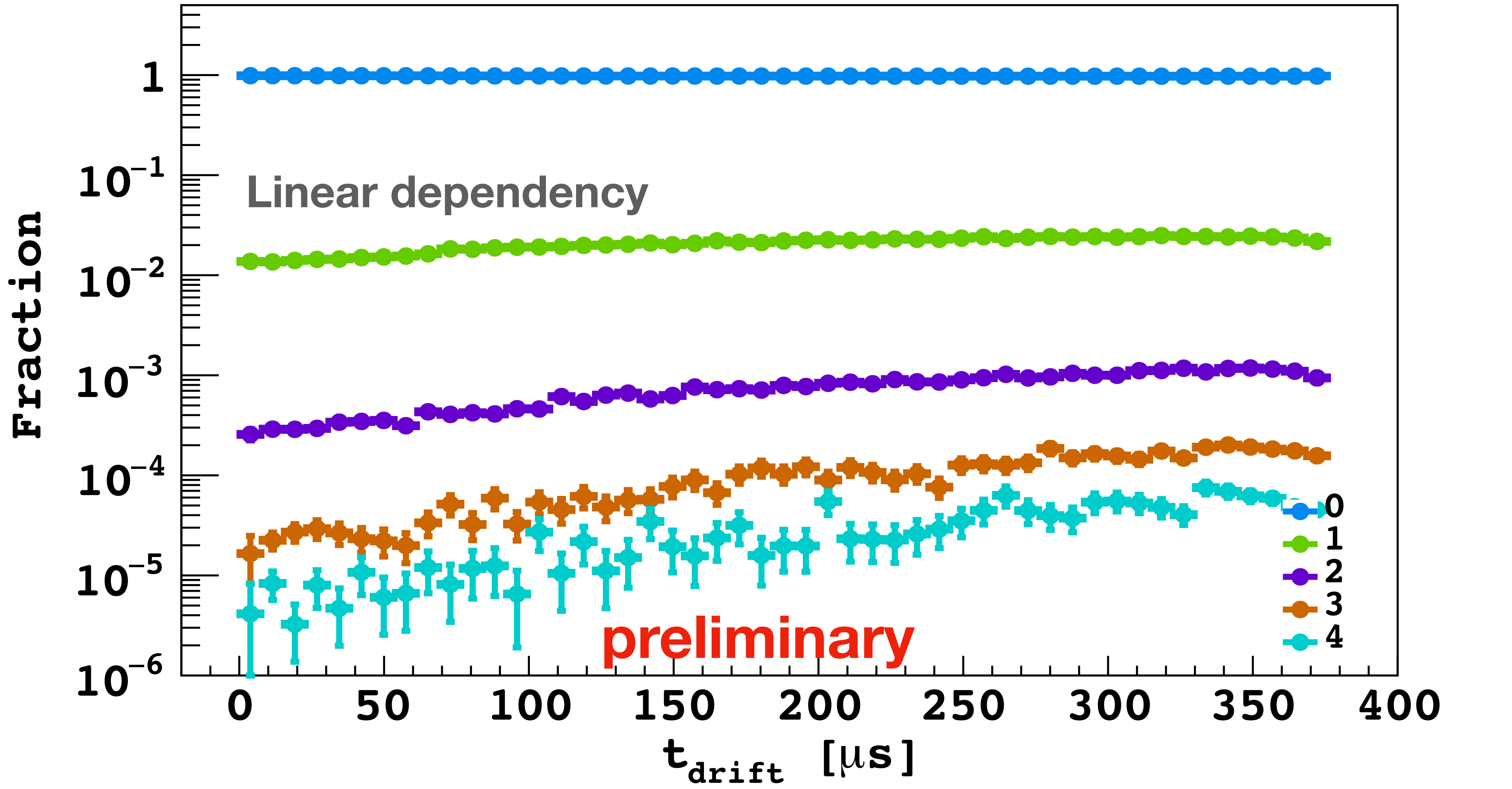
- The improvement trend of the electron drift-lifetime is similar to the trend of the longer time correlation.
- The getter off runs did **not show degradation** of electron lifetime.
- **The impurity causing 18 ms time constant (τ_3) in the getter off is different from the impurity causing electron lifetime degradation.**

Correlation with Parent's S2 and z-position

- For all parent events, count how many SE events follow until next parent event.
- The fraction of parent events with no SE events, one SE event, two SE events, so on, is calculated as a function of parent S2.
- **Large energy events create more SE events.**



- Only single-scatter parent events to have a well-defined z-position.
- Clear linear relationship with z-position of parent. -> **The longer the drift time, the higher the chance of electrons to be captured.**
- Consistent with the correlated-events hypothesis, which originates from the charge released in previous interactions drifting along the field and being trapped along the route.

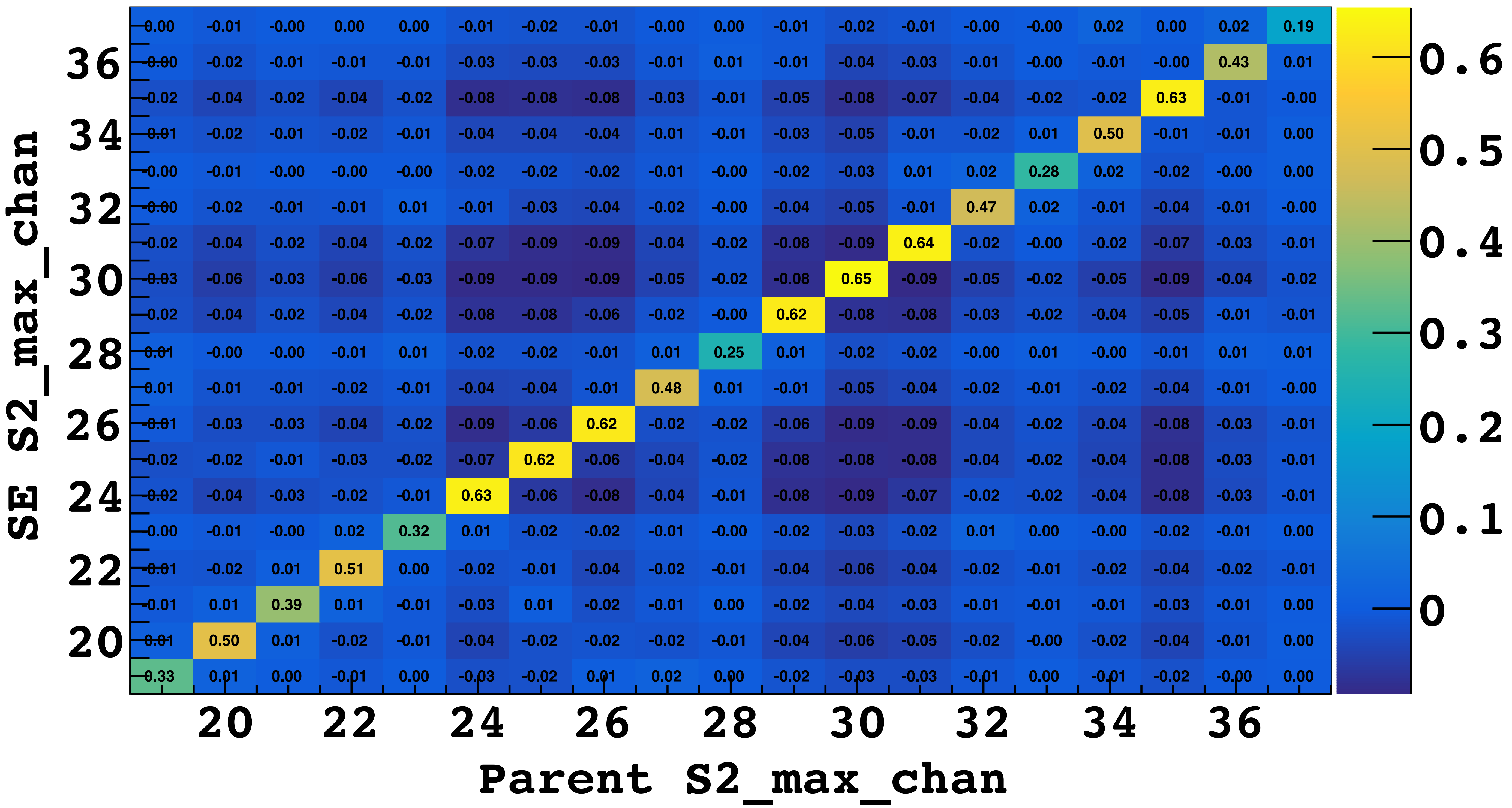


x-y correlation

- **Strong correlations** are observed between S2_Max_chan of SE and its parent events.
- The correlation with other channels is basically 0, no correlation. Pearson's correlation coefficient is used.
- **Temporary correlated pairs shows strong spatial correlation** as well.

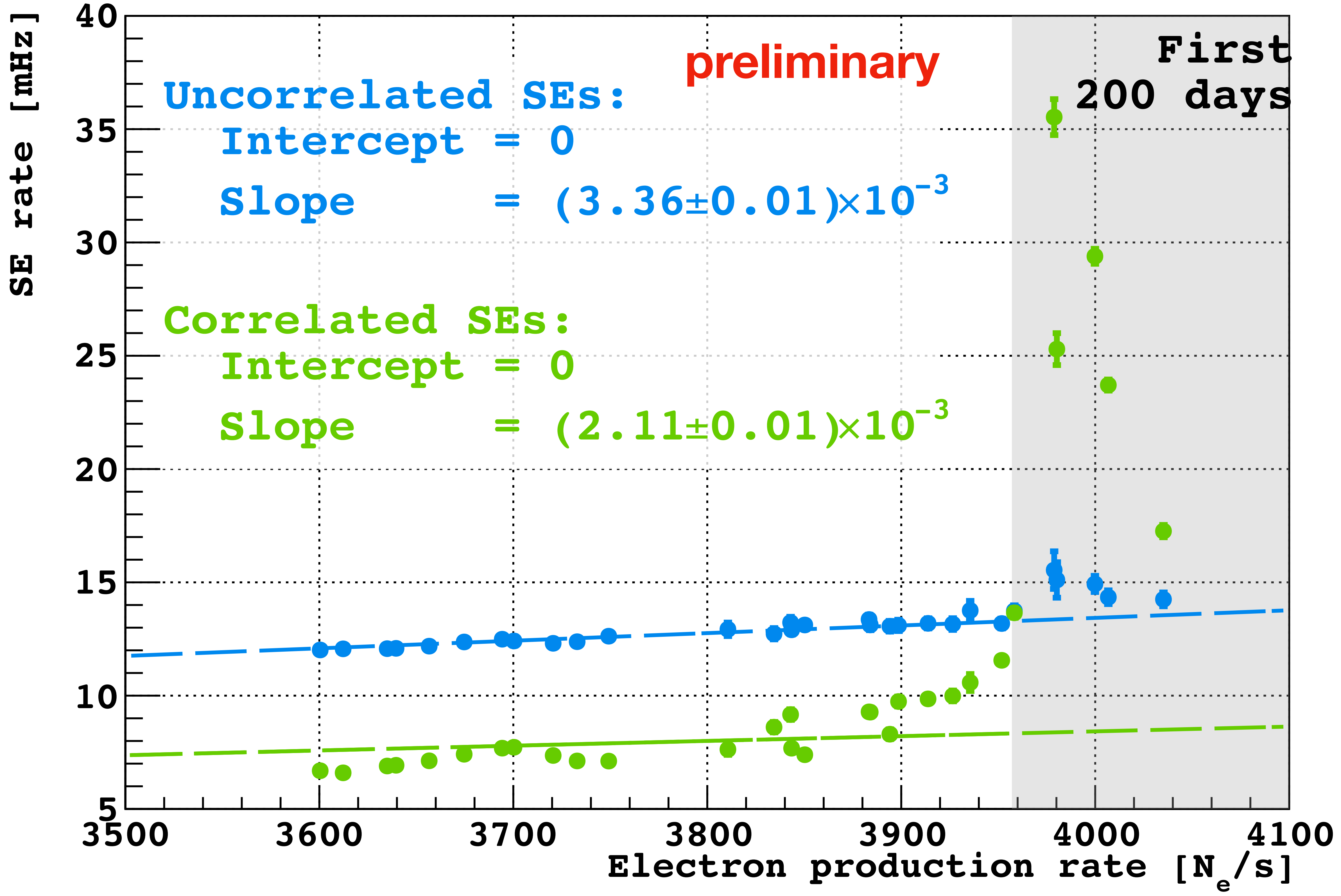
The first 120 days including Getter-Off runs

preliminary



SE rate correlation with total activity in TPC

- Both temporally correlated and uncorrelated SE rates decreased as total activity in TPC decreased.
- It suggests that **less radioactive detectors might have lower SE rate** in the future experiments.

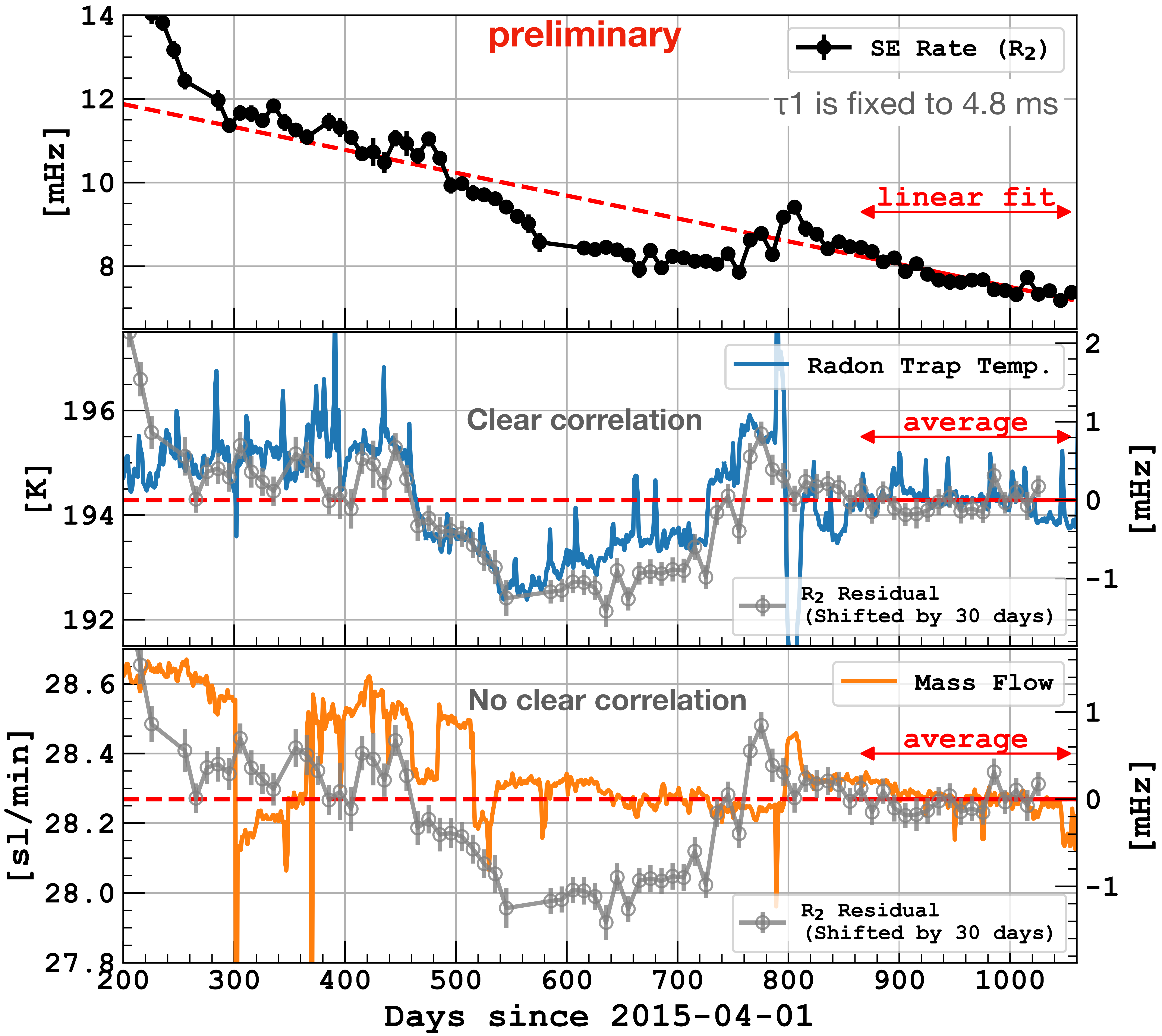


Total Activity in TPC

Correlation?

a hint of correlation

- When the temperature of **the radon trap decreased, the rate of the slow time constant R_2 (~50 ms) also decreased.**
- It might mean the radon trap captured the impurity and reduce the rate of SE w/ the slow time constant.
- Other slow control parameters showed **no obvious correlation with the SE rates**.



Dark Wave
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Summary

- In DS-50 TPC, we observed events with a few electrons emission, which set a threshold for low mass dark matter search.

- The SE event rates decrease with time constant of 36 hours for the getter off impurity, which is much shorter than the time scale of the electron lifetime improvement (~160 days). This impurity should have lower boiling temperature than Ar, such as N^2, which has boiling temperature of 77K (87K for Ar) and is one of gases removed by the hot getter.

- There are strong correlations between parent events and following SE events in event positions, time, and energy. **Temporally correlated SE make up 40-70% of total SE rate.**

- In the time correlation study, the time constants change with time in our exposure: the short component ~5 ms stable, the long component evolve from 90 to 45 ms. With getter-off, an additional component is necessary, maybe sign of different type of impurities. With higher statistics, a ~0.5 s component is visible.

- **No clear correlation with the impurity causing finite electron drift-lifetime.**

- Both rates of temporally correlated and uncorrelated SE decrease as the total event rate decrease.

- **The rate of SE shows a hint of correlation with the temperature of the Rn trap.**

Few electron signals in DS-50

Few-electron events are identified in DS-50 by pulse shape and time info relative to other pulse.

- ***Photo-ionization*** (within the acquisition window) see Astropart.Phys.2022.102704 for more details.
    - TPB/ITO photo-ionization (@ maximum drift time, 375 μs: S1or S2 echos)
    - Impurity photo-ionization? delayed electrons? (< maximum drift time)
- ***Delayed electrons*** (> the acquisition window, 440 μs, independently triggered events)

preliminary

- **Spurious electrons** (focus of this presentation)
- ***Not seen*** (or not identified) in DS-50, but reported in Xenon based TPCs
    - Release of trapped electrons at liquid surface
    - Grid emission

D.S. Akerib et al. Phys. Rev. D 102, 092004 (2020)
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