Delayed Electron Emission in DarkSide-50

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On Behalf of the DarkSide-50 collaboration

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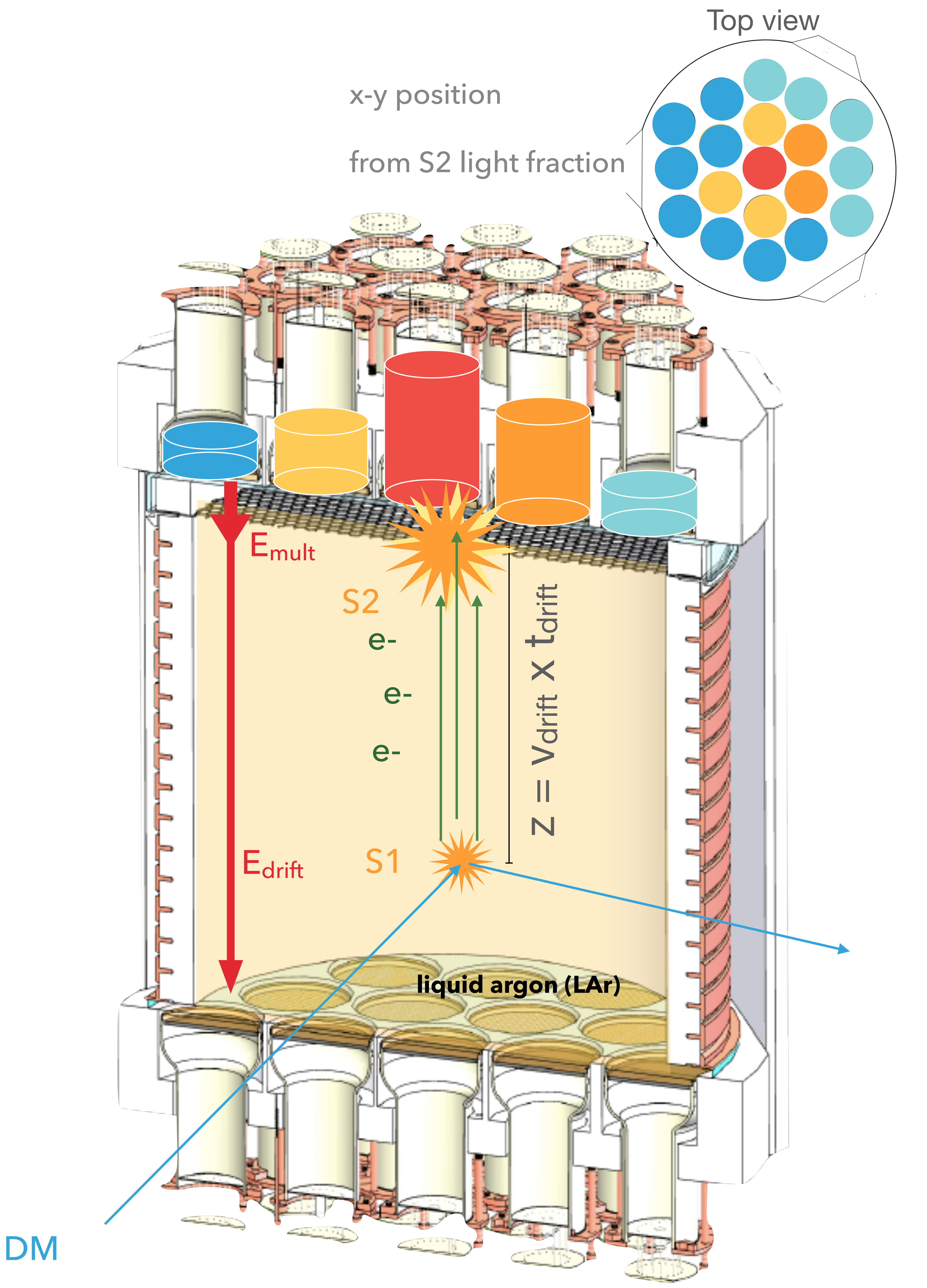
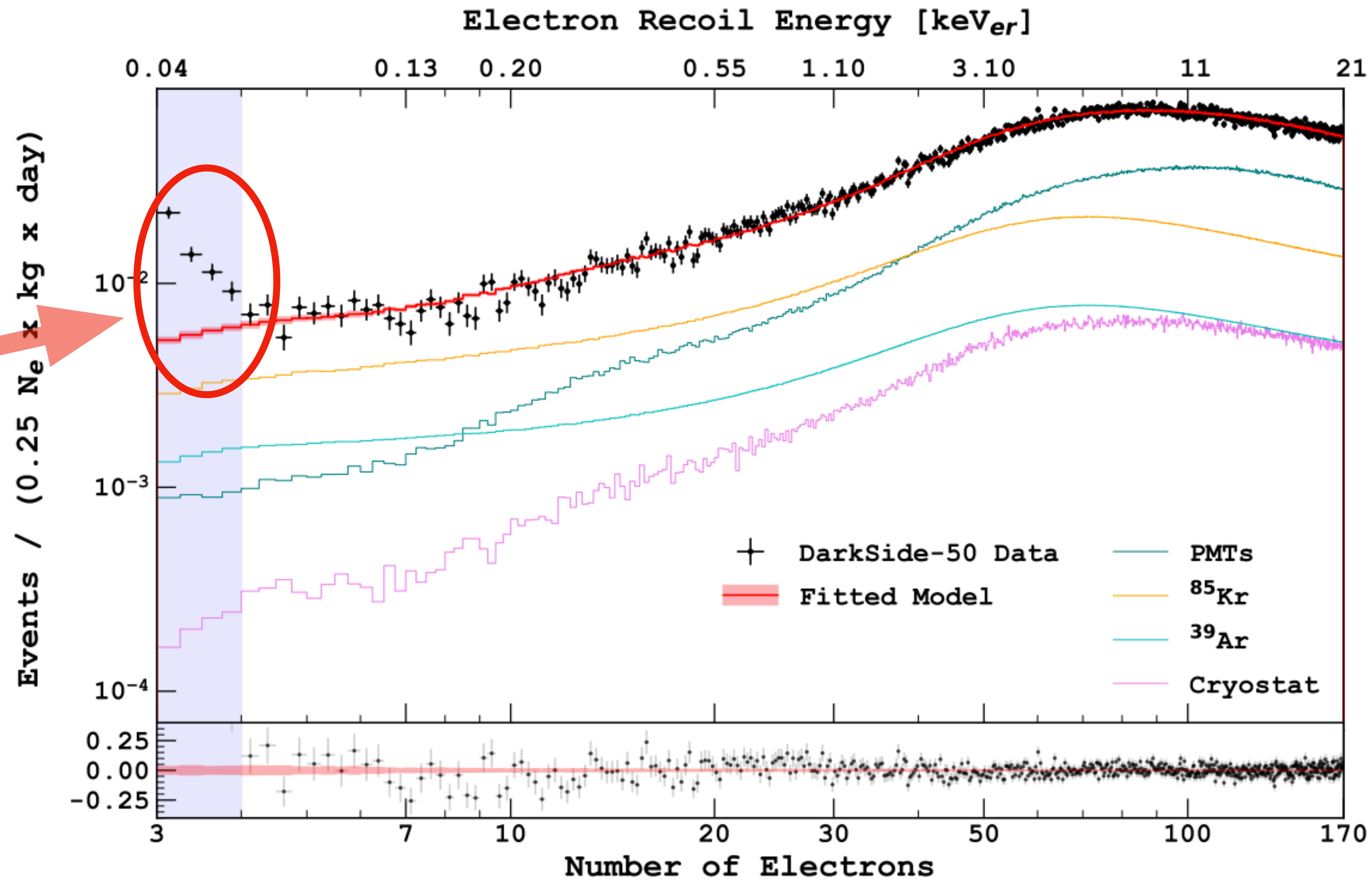
DS-50 Liquid Argon TPC

- 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.
- 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.



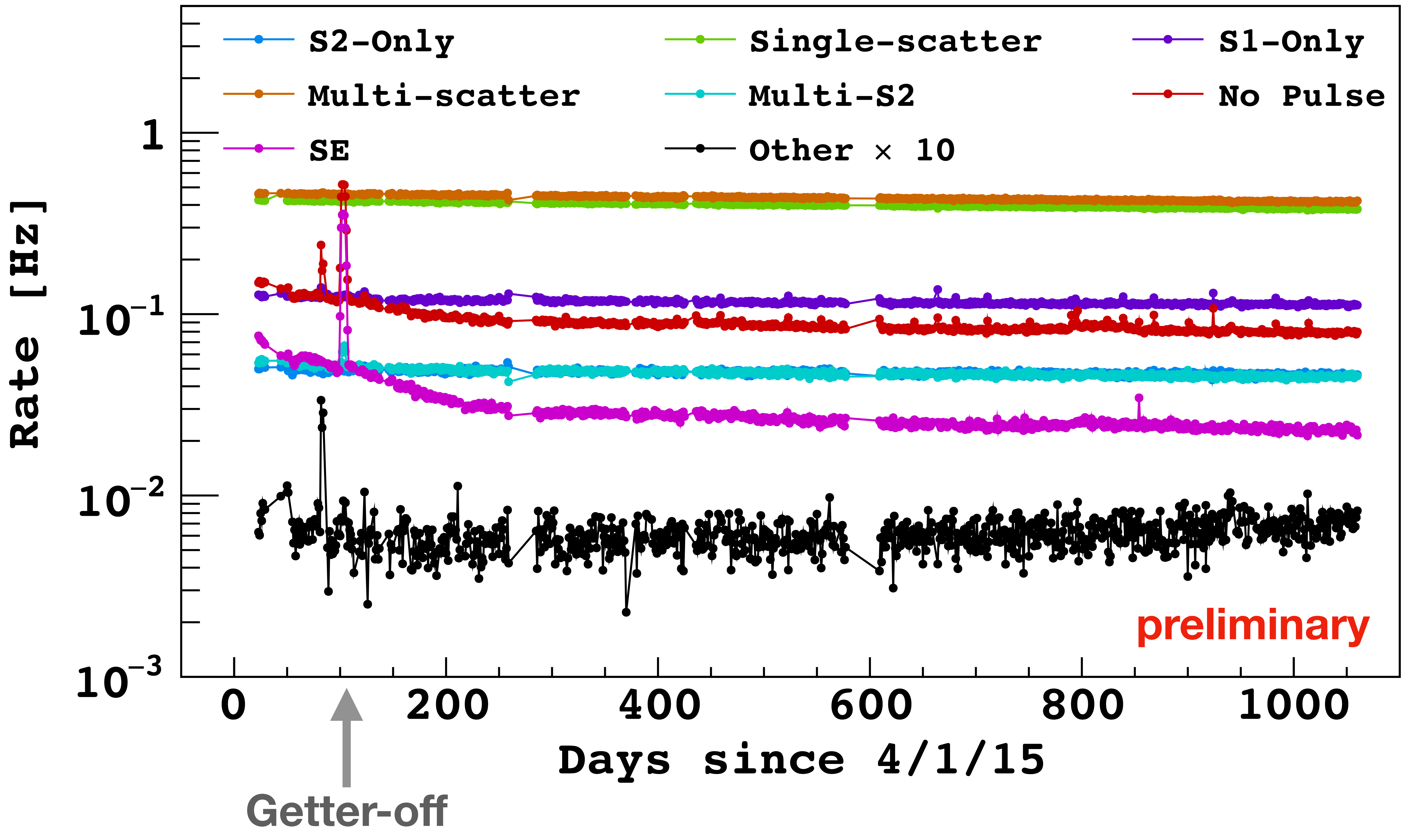
Low Energy Backgrounds

- S2 only analysis: gas pocket amplification of 23 PE/e^-
- We observe an excess of events with < 4 electrons, limiting DM search sensitivity.
- Purpose of this study: Understand this observed low energy, **spurious electron (SE)** background.



https://arxiv.org/abs/2207.11966

Event Rate

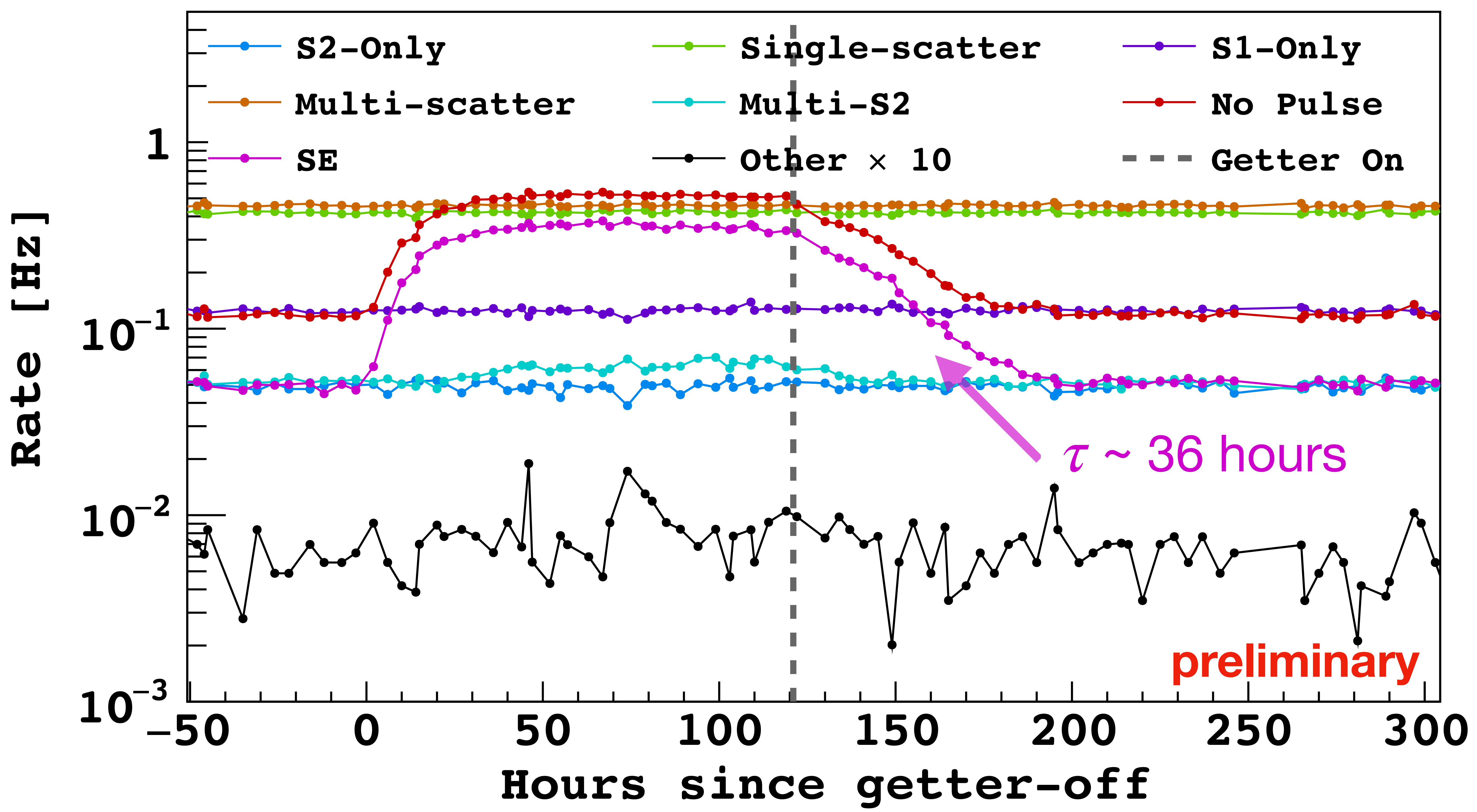


Two slopes observed in SE rate (before/after 200 days)

Event categorization:

- ***Multi scatter***: γ events, random pileup (S1 + multiple S2)
- ***Single scatter***: Normal events (S1 + S2)
- ***S1 only***: Cherenkov, surface events (no/small S2)
- ***No pulse***: Triggered, but pulse finder failed (noise triggers, low N_{e-} events near TPC edges).
- ***S2 only***: No/small S1, $N_{e-} \geq 4$ (low energy events)
- ***Multi S2***: Multi scatters where S1 and the first S2 pileup (due to low t_{drift})
- ***SE*****:** Single S2 with $N_{e-} < 4$
- ***Other*****:** All the rest, 1 mHz (<0.1% of all events), e.g., event with S2 + S1 + …

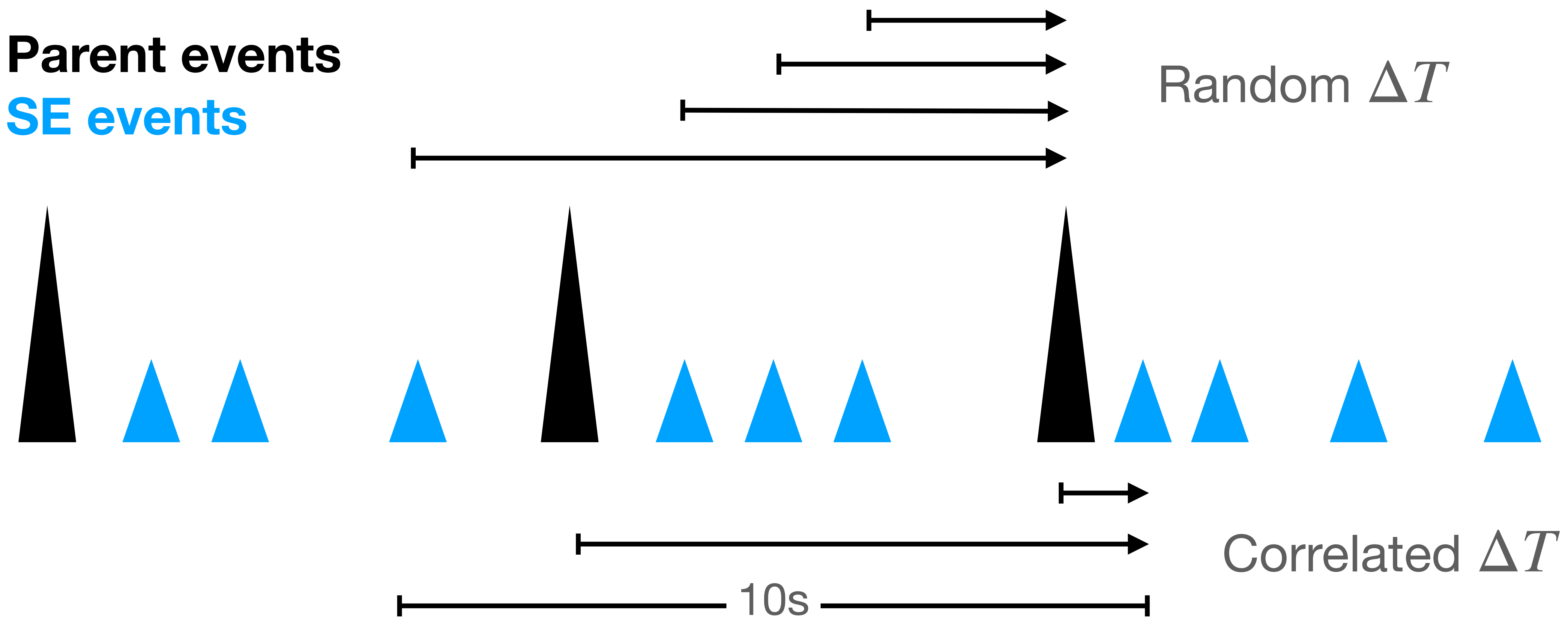
Getter-off Period



- No increase is observed in S2 only events ($N_{e-} \geq 4$).
- Increase in SE and no-pulse rate (corresponding to unidentified SEs) suggests a link to impurities.
- Time constant after getter reinstalled: ~36 hours

Temporal Correlations

- **Parent Events:** S1 > 1000 PE, t_{drift} defined, xy-position reconstructed
- **Correlated Population:** Pairs of SEs and preceding parents within a 10s window
- **Uncorrelated Population:** Pairs of SEs and subsequent parents within a 10s window

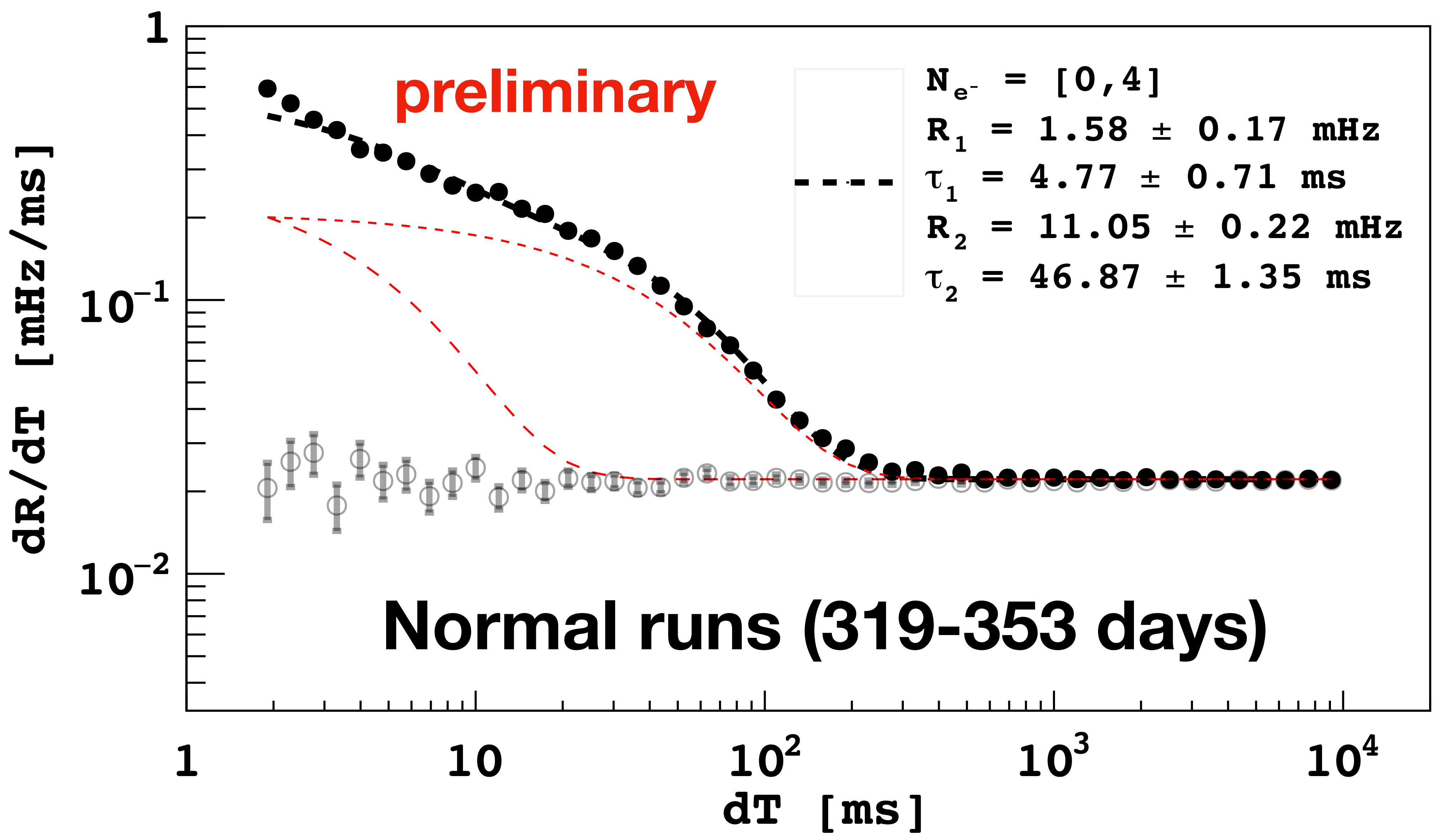


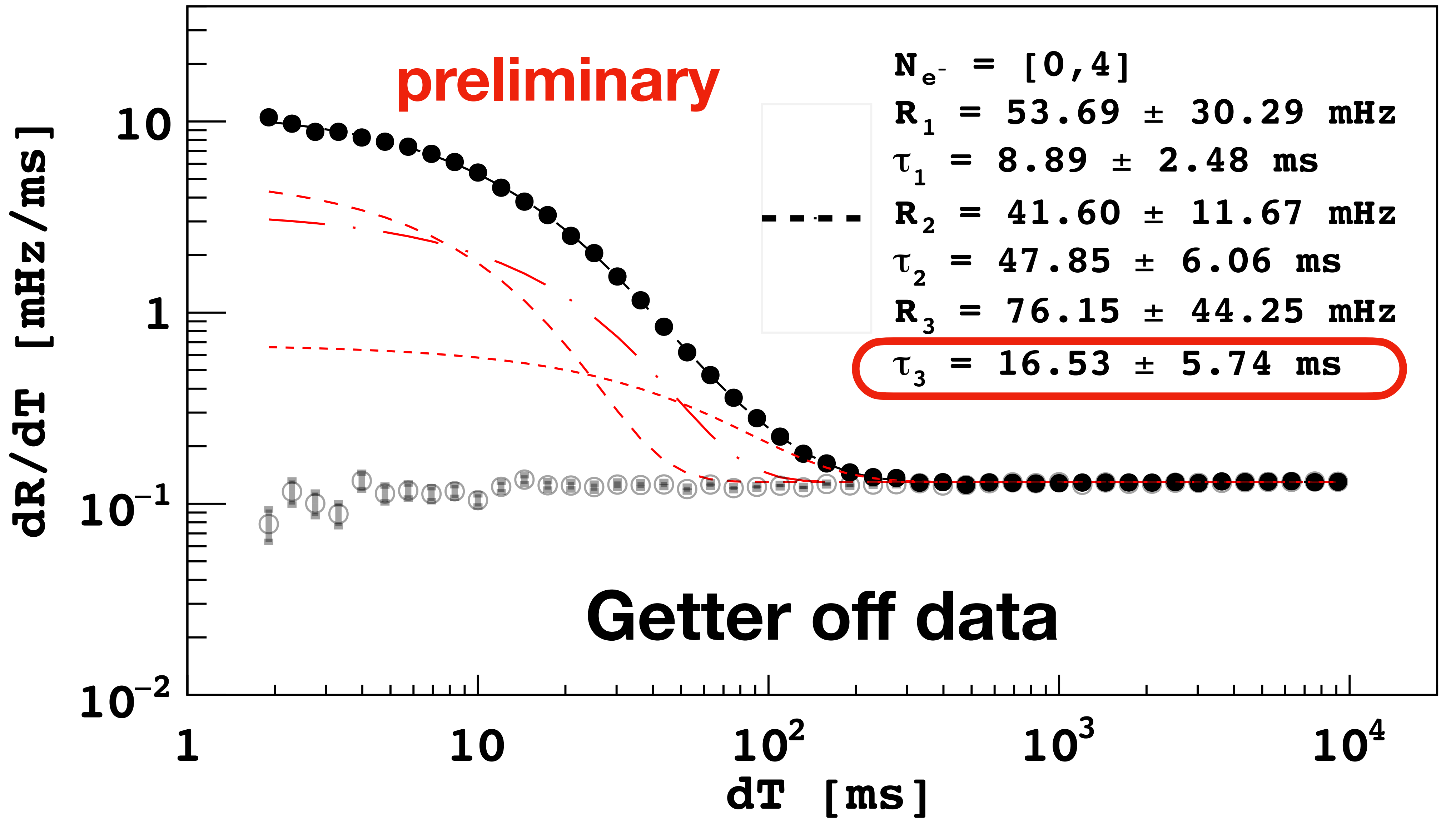
Temporal Correlations

- Normal runs are well-described by two exponentials.

$$f(t) = \frac{R_1}{\tau_1} e^{-\frac{t}{\tau_1}} + \frac{R_2}{\tau_2} e^{-\frac{t}{\tau_2}} + C$$

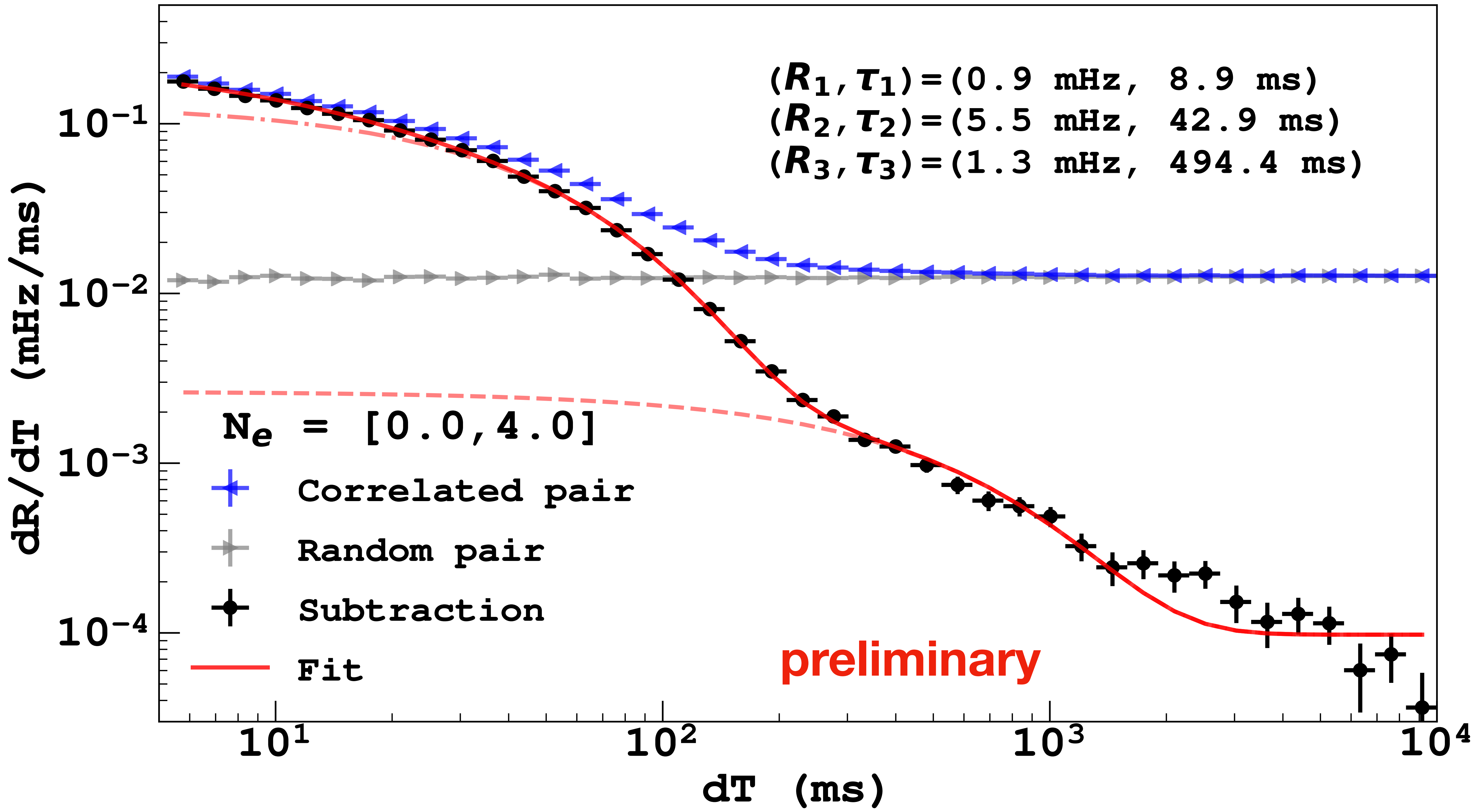
- Third ~16 ms component appears during getter-off runs.





Temporal Correlations

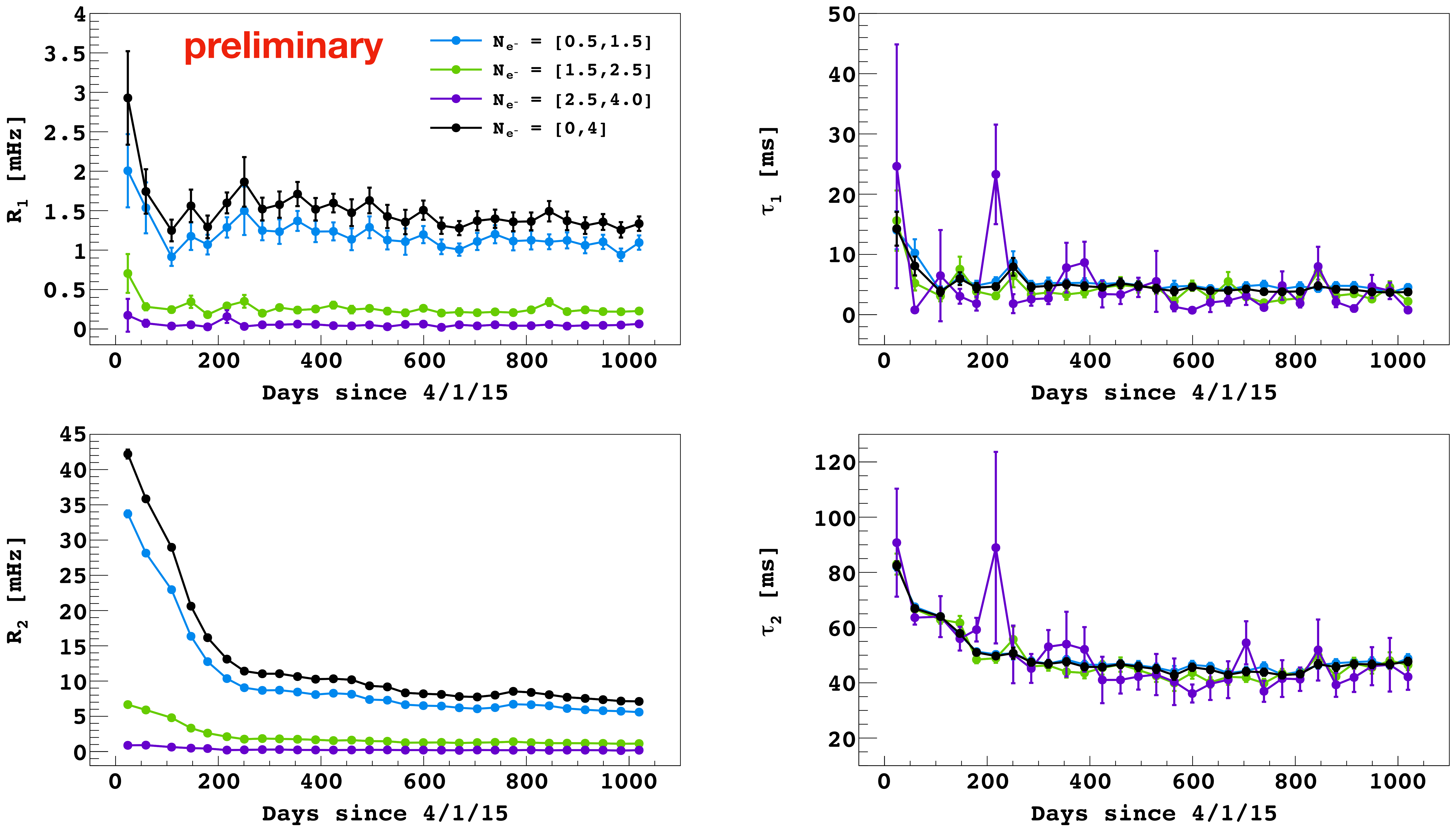
An additional long-lived component?



- With higher statistics (full 500 days), we see an additional ~500 ms component.
- Evolution of this component does not appear to change over time.

Temporal Correlations

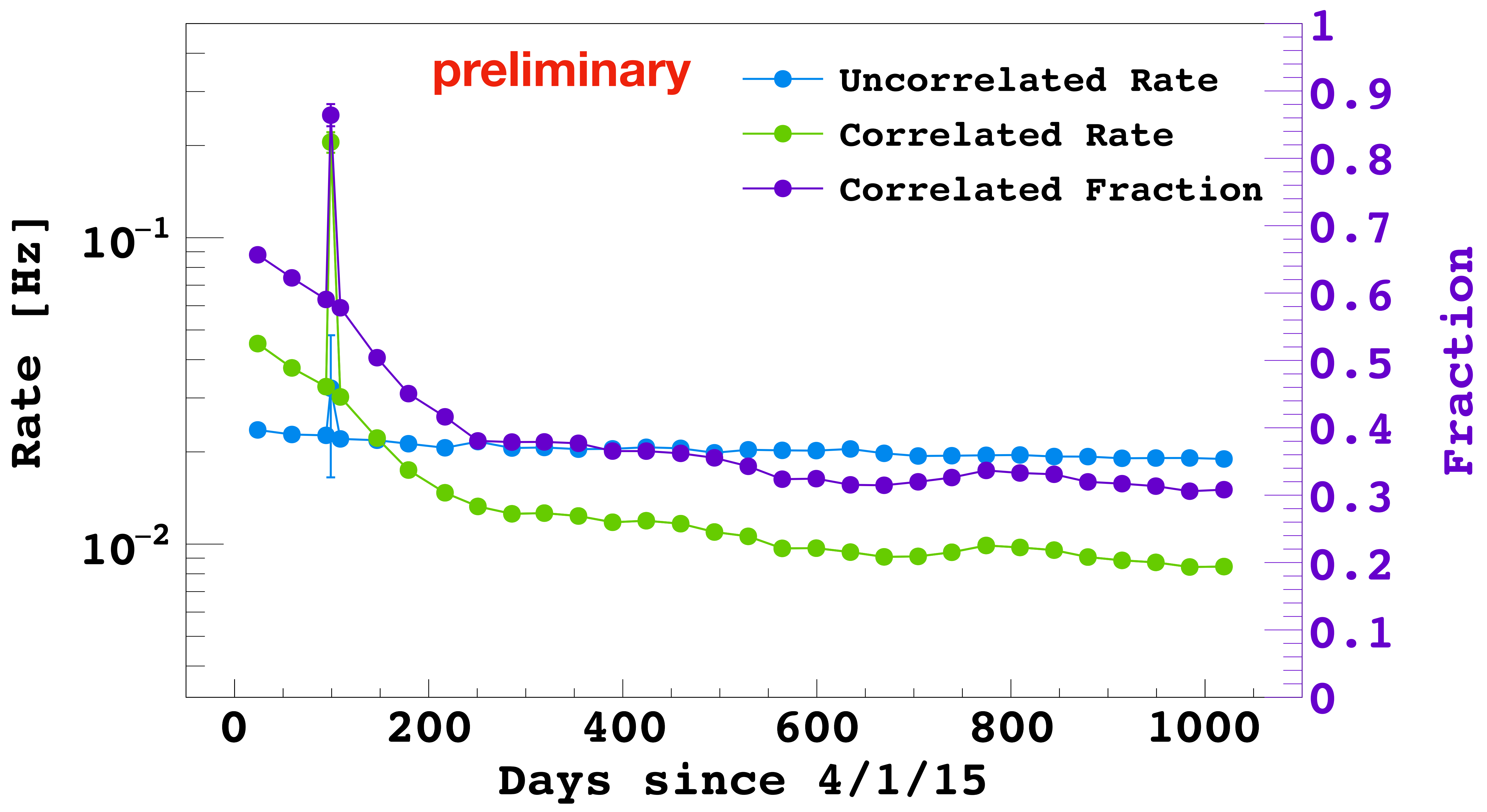
Evolution over Time



- Runs grouped into 35-day intervals.
- R_1 and τ_1 remain roughly constant over time (τ_1~ 4 ms).
- R_2 and τ_2 decrease over first 200 days (τ_2~ 85 ms, 50 ms).
- Little difference between SEs in various N_{e-} bins.

Temporal Correlations

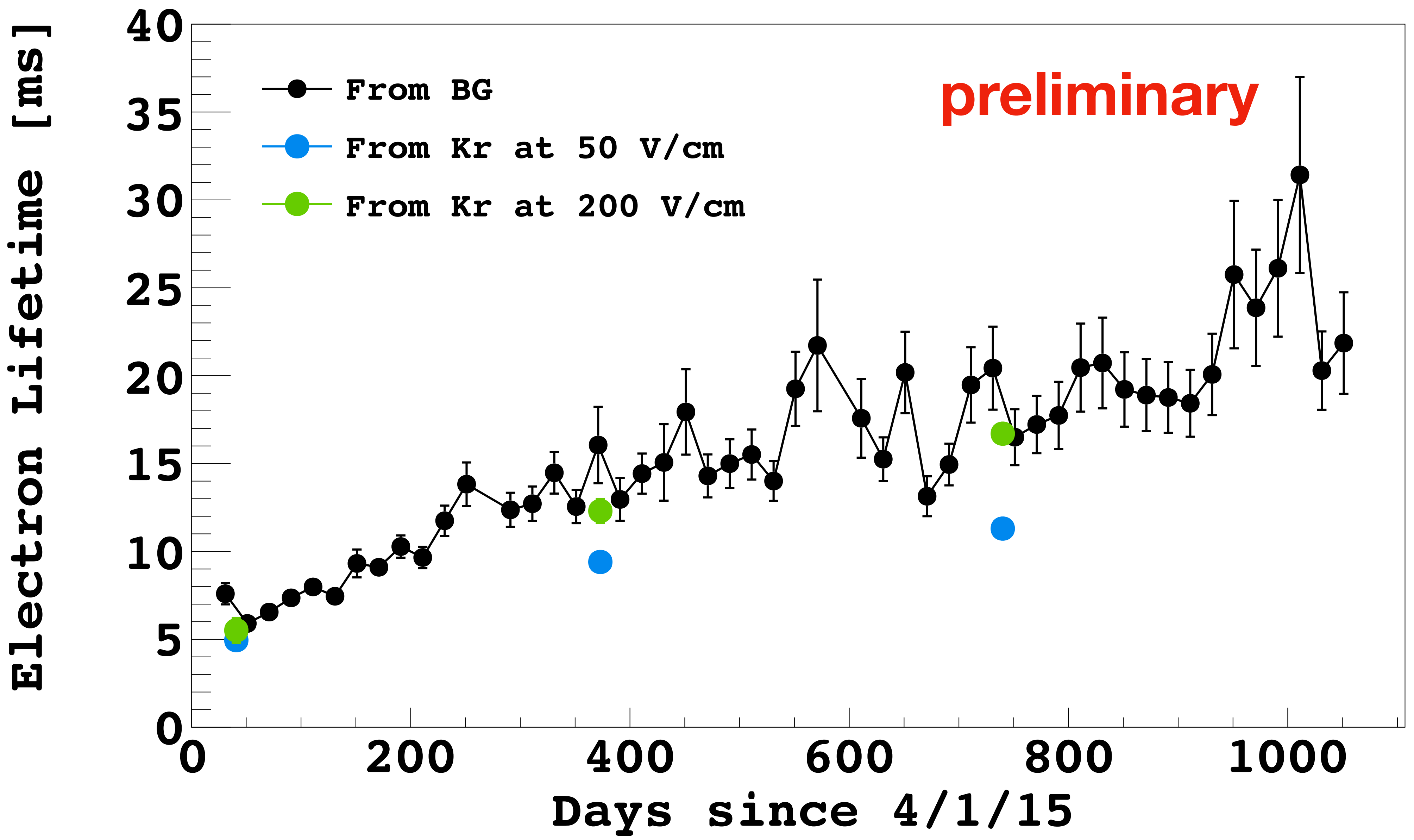
Evolution over Time

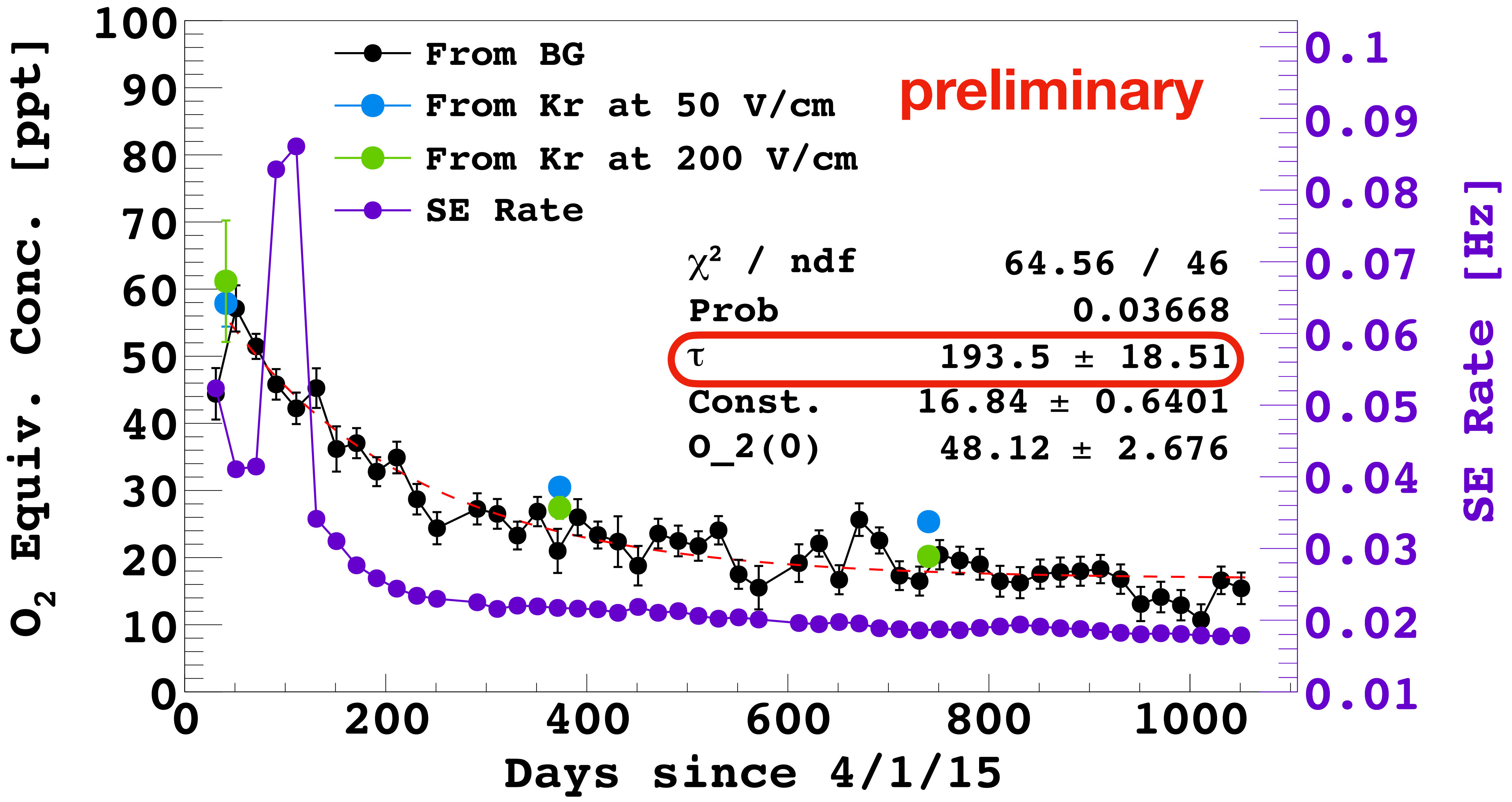


- Sum of R_1 and R_2 gives total correlated rate.
- "Uncorrelated" Rate: Total SE rate $-\ (R_1 + R_2)$.
- We can explain 40% to 70% of the SE rate through correlations to parent events.
- Remaining events may correspond to misidentified correlated SEs, or true uncorrelated events.

Electron Lifetime

- Electron drift-lifetime is evaluated using physics data and calibration data at 200 and 50 V/cm.
- No degradation in electron lifetime observed in getter-off runs: **impurity causing the 16 ms time constant (τ_3) in getter-off runs is different from the impurity causing electron lifetime degradation.**
- Time constant of O_2 concentration agrees in order with change in SE rate, but does not show distinguishable trends before/after 200 days.

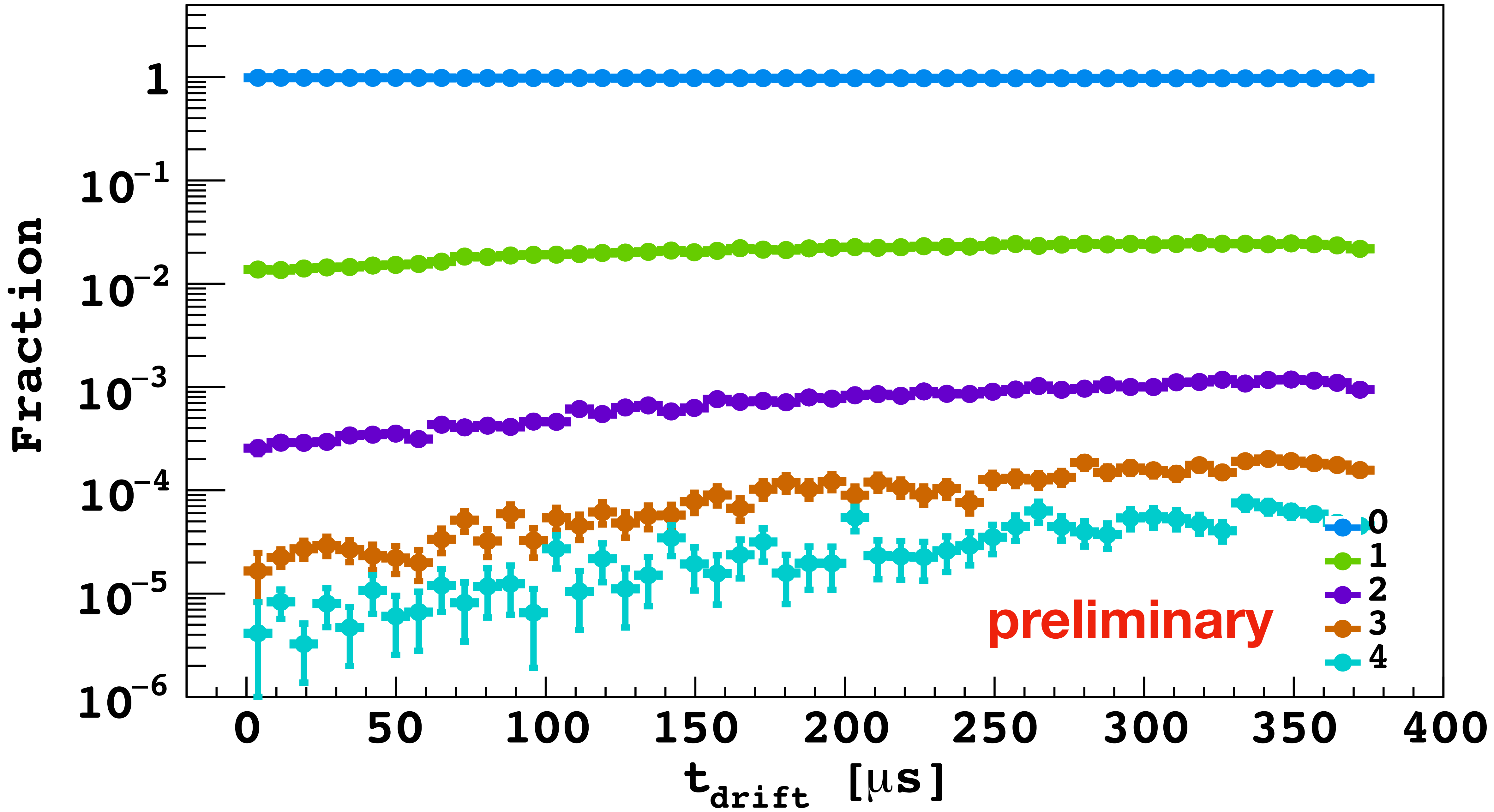


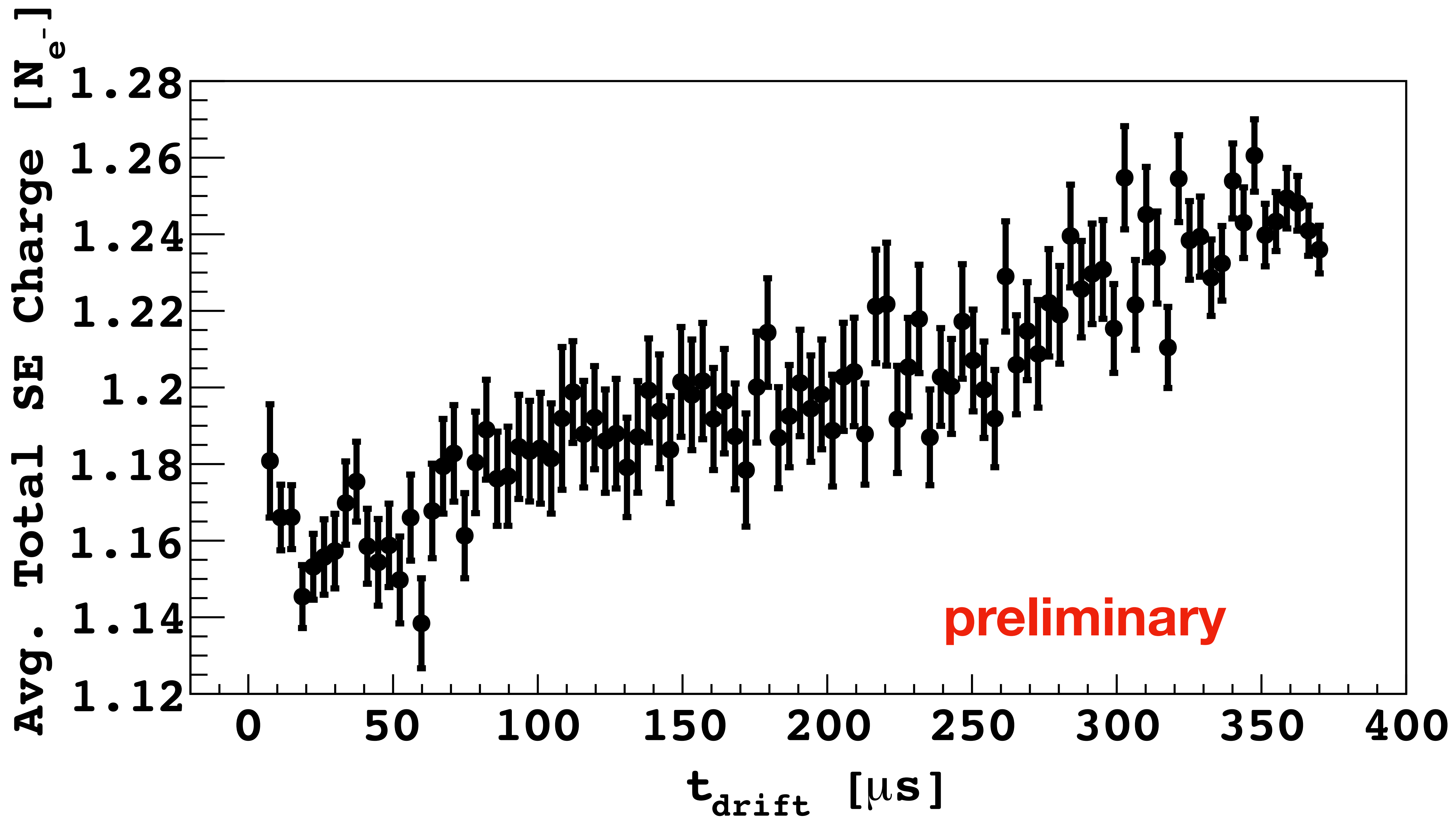


Spatial Correlations

Correlations in t_{drift} (z-position)

- Parents are restricted to single-scatter events, to ensure well-defined z-position.
- Clear linear relationship with z-position of parent: **Longer drift time increases probability of electron capture.**
- Consistent with the hypothesis that SEs are drifting electrons released from impurities.

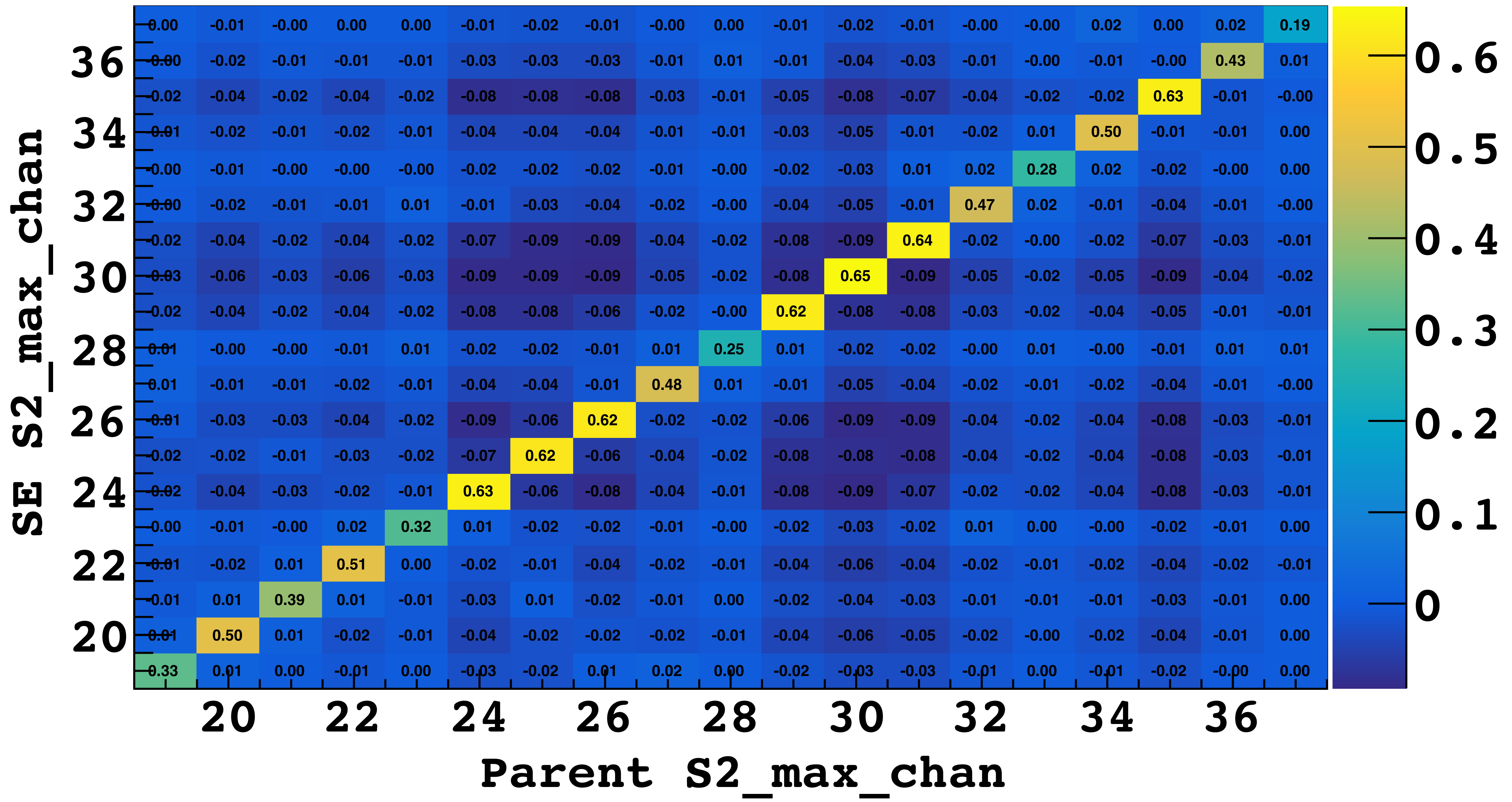


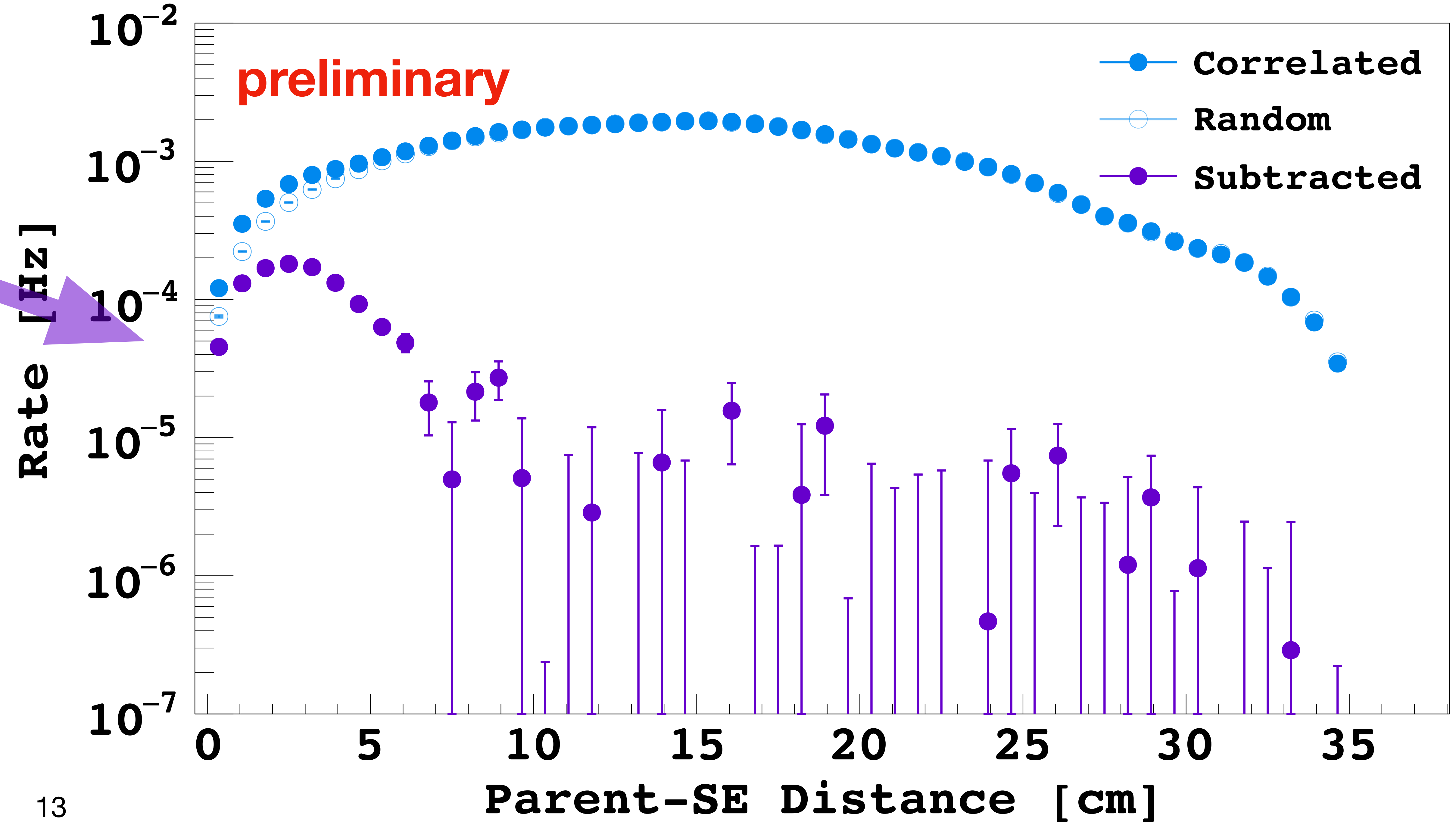


Spatial Correlations

xy-position

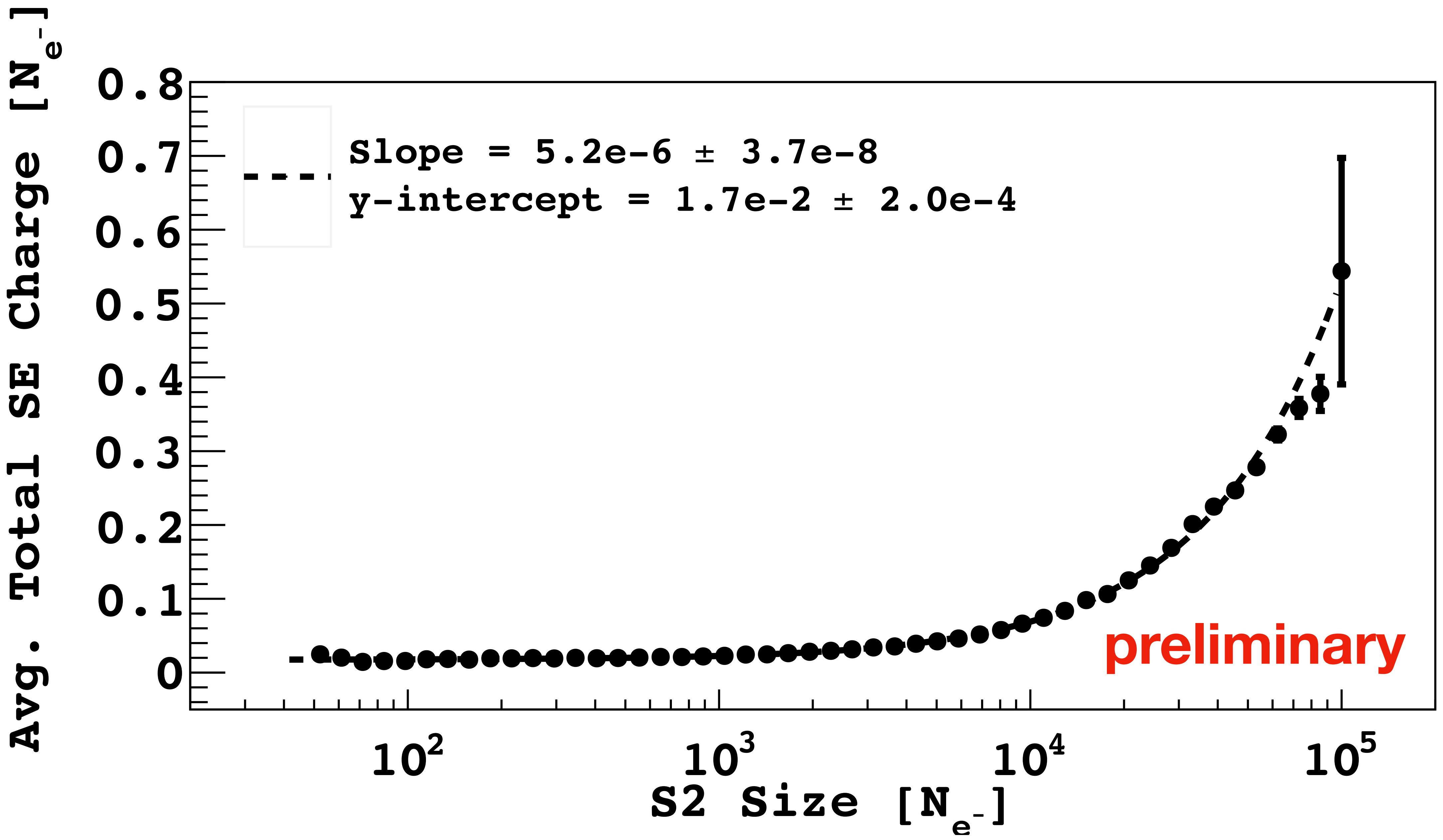
- Strong correlations are observed between S2_max_chan of SEs and parent events.
- Temporally correlated parent-SE pairs also appear spatially correlated.
- Consistent with drifting-electrons hypothesis.

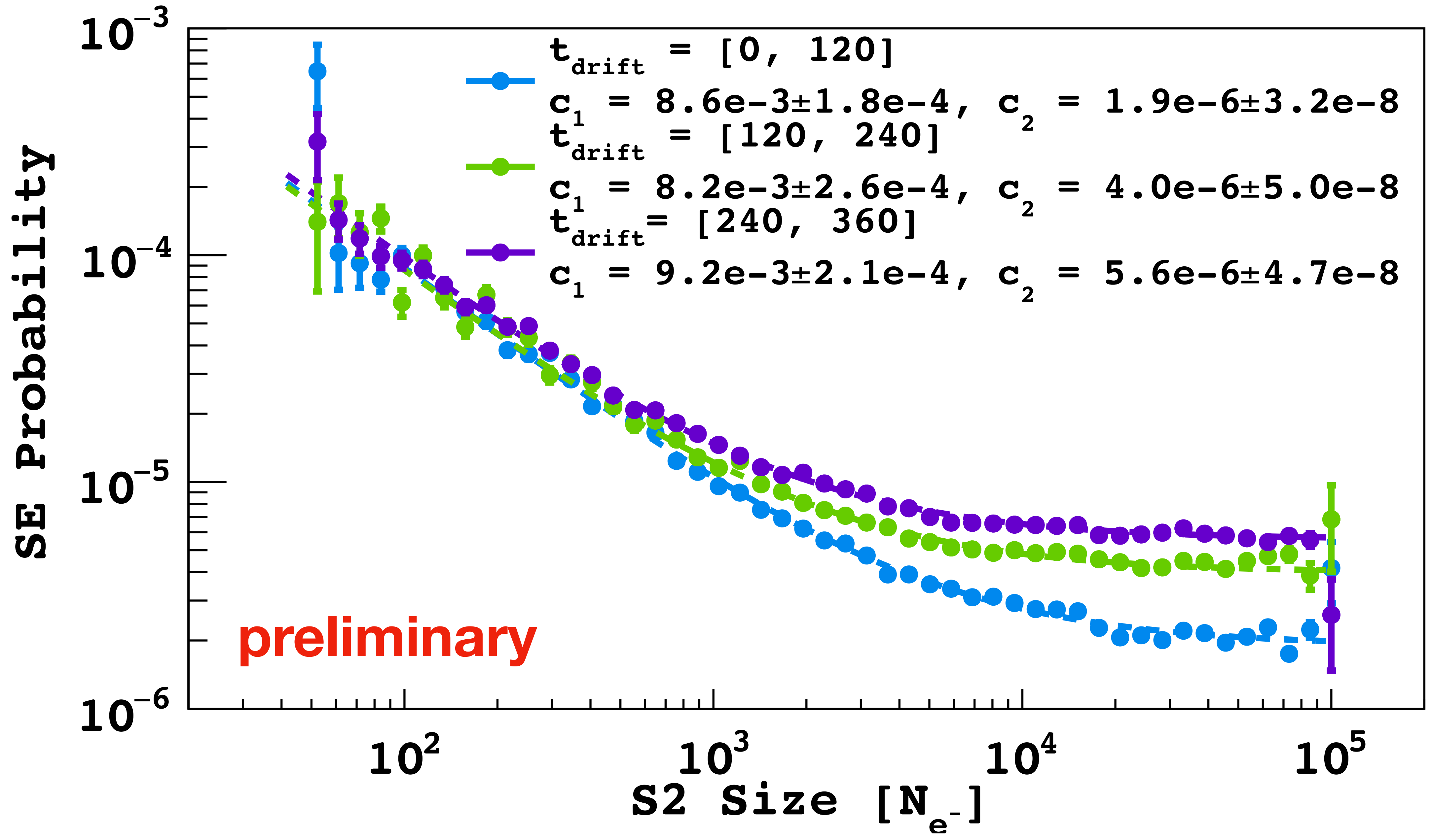




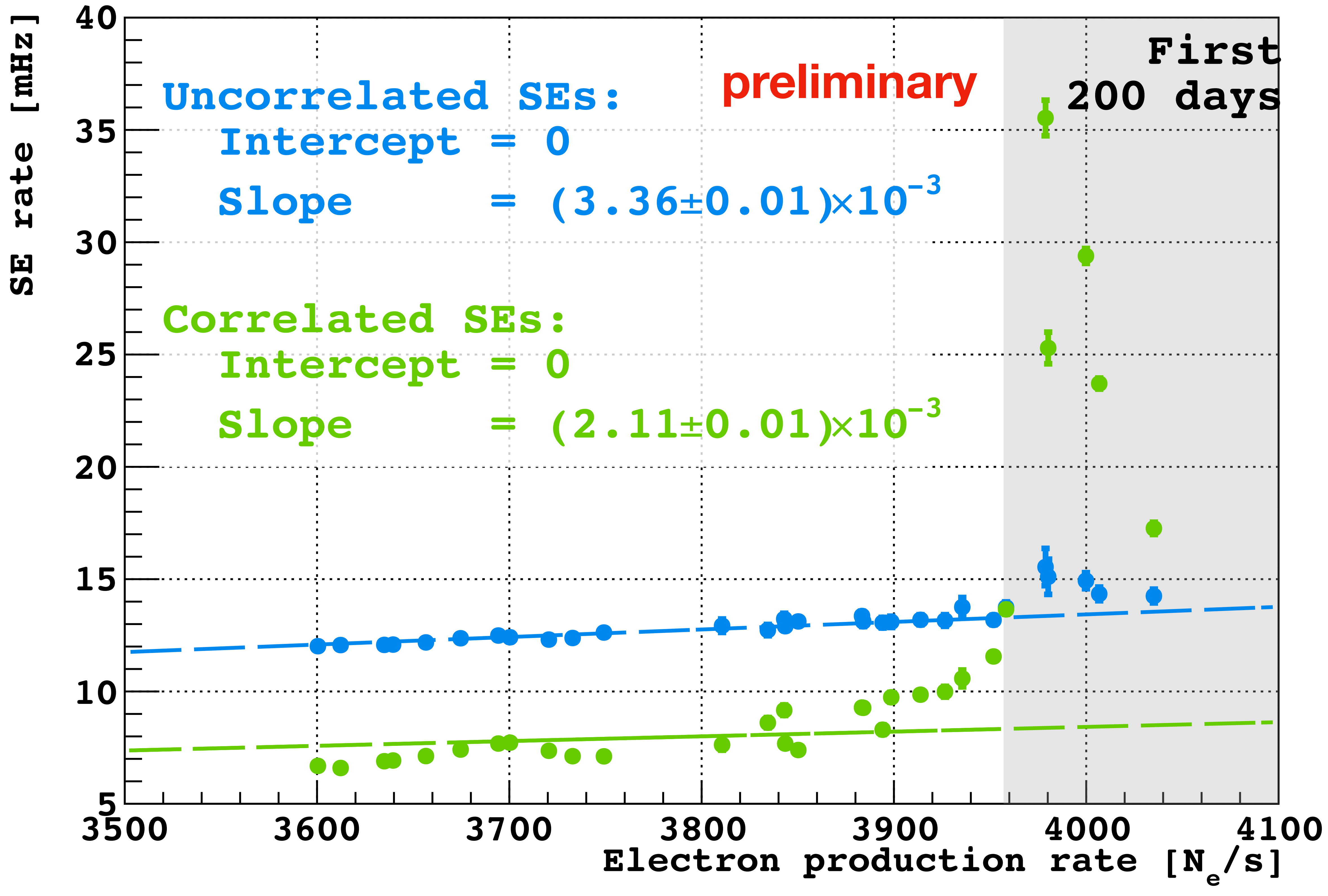
Energy Correlations

- SEs are attributed to parents by counting all SEs that follow a parent until the arrival of the next parent.
  - SE Probability: Total charge of SEs following parent / parent S2 size
- Number of SEs produced by parents increases linearly with parent energy.
- Results are consistent with presence of correlated and uncorrelated component:
  - SE Probability is fit to $\frac{c_1}{x} + c_2$
  - No t_{drift} dependence for S2 < 2000 Ne-





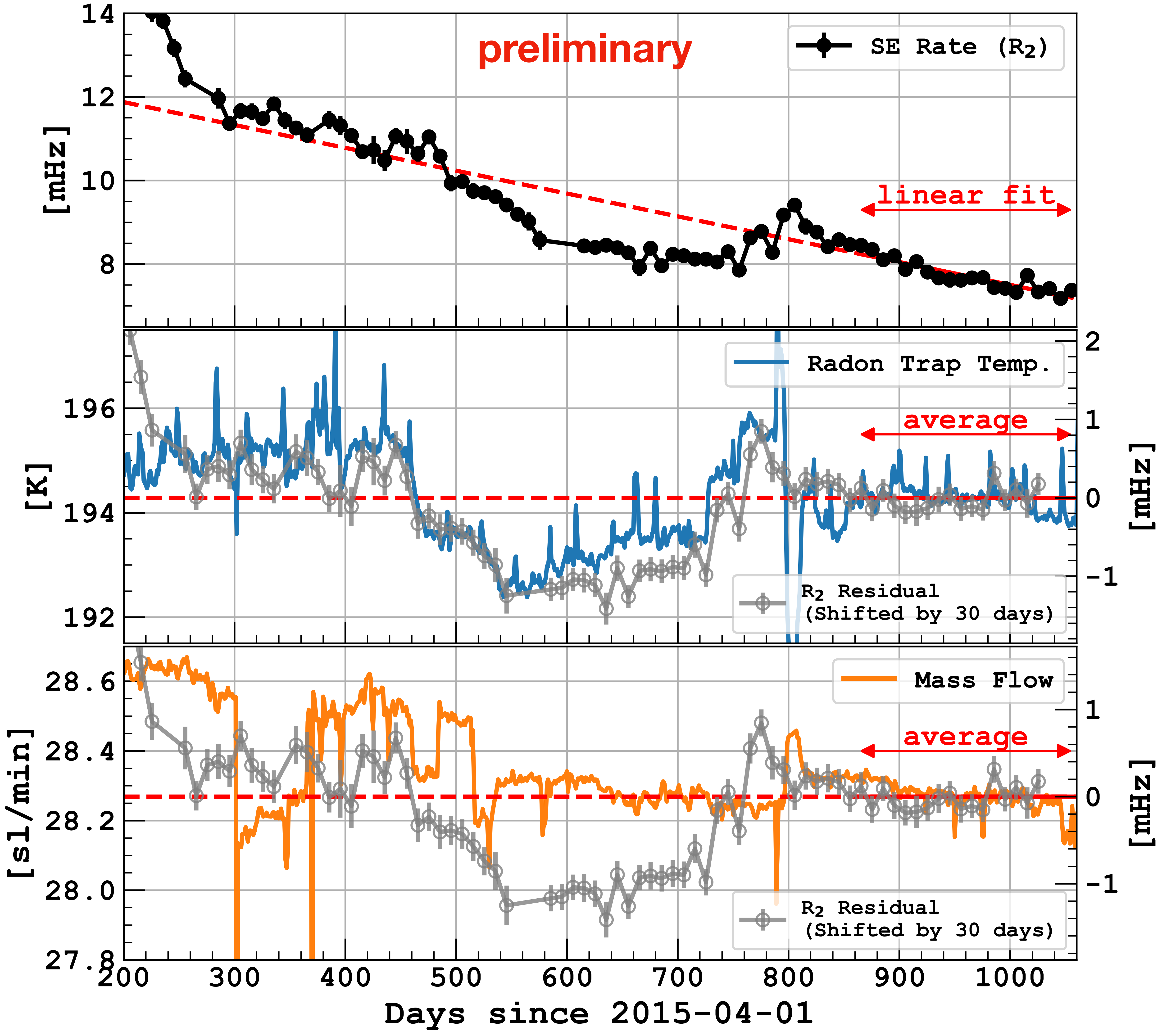
SE Rates vs. Total TPC Activity



- Both correlated ($R_1 + R_2$) and uncorrelated rates increase with overall rate of electron production.
- Suggests that uncorrelated SEs may correspond to a long-lived component where SE is not paired with parent.
- We estimate that “truly uncorrelated” SEs must have a rate < 4.5 mHz (90 % C.L.).

Correlations with Detector Parameters

- We see some evidence of a correlation between R_2 and radon trap temperature.
- No clear correlation was observed relative to other slow-control parameters.
- For most molecules, charcoal radon trap captures more molecules at lower temperatures.



Summary

- We observe strong correlations between parent events and following SE events in event positions, time, and energy.
  - Temporally correlated SEs make up 40-70% of the total SE rate.
  - Both rates of temporally correlated and uncorrelated SEs decrease as the total event rate decreases.
- We observe 3-4 different time constants: a stable ~ 4 ms short component, a longer time component that evolves from 85 to 50 ms, and an additional ~16 ms component that appears in getter-off runs. With higher statistics, a ~0.5 s component is visible.
- The rate of SEs shows a hint of correlation with the temperature of the Rn trap.