Delayed Electron Emission in DarkSide-50

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on behalf of the DarkSide-50 collaboration
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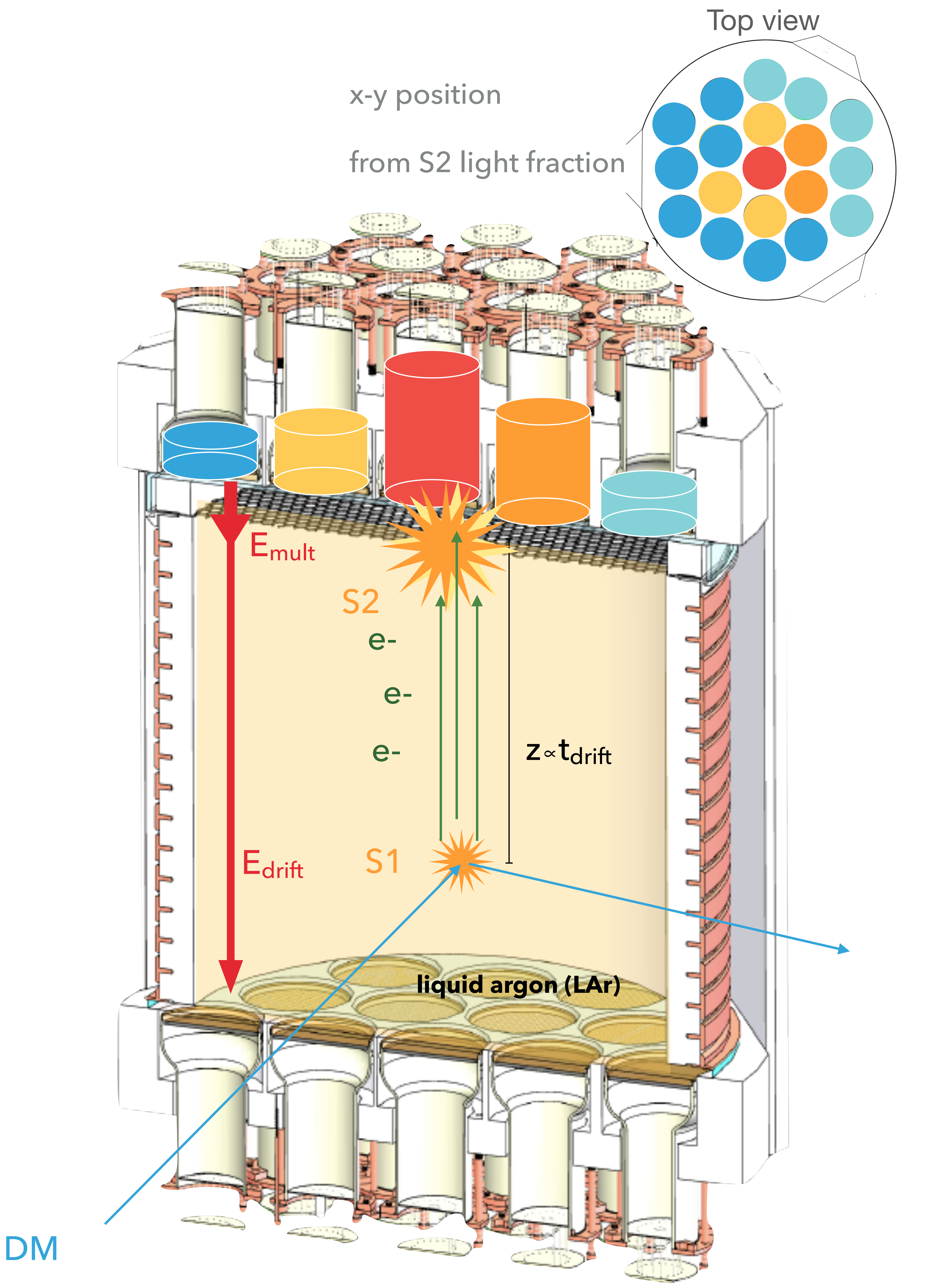
DS-50 Liquid Argon TPC

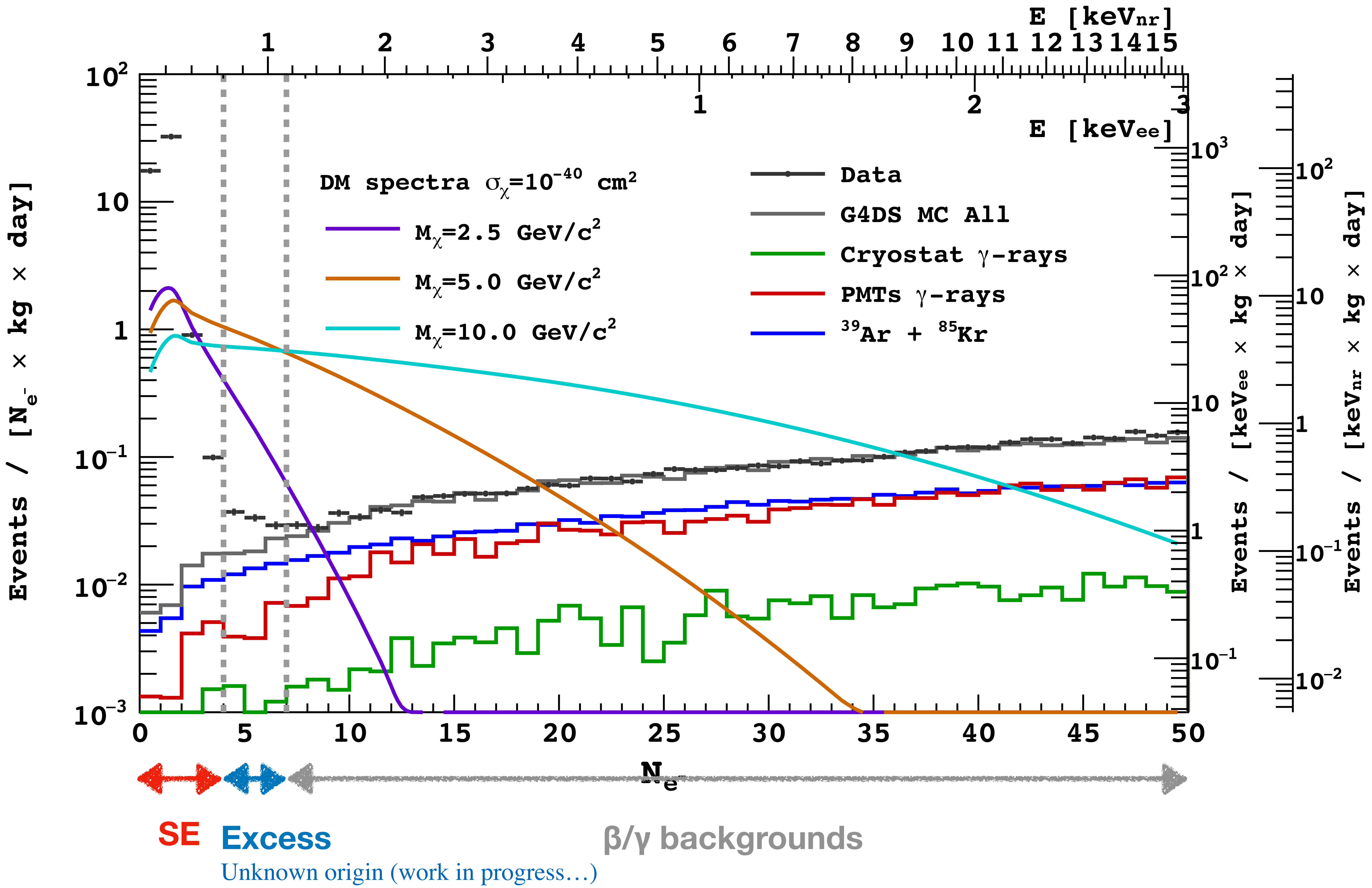
- Double-phase liquid argon TPC (see Physics Letters B 743, 456 (2015)).
- Readout S1 and S2 signals with PMTs.
- Trigger on two PMTs coincidence (0.6 PE) within 100 ns.
- Drift field is 200 V/cm.
- Multiplication field is ~5.6 kV/cm (at the x-y center) and 4.2 kV/cm (at the edge).
- Cathode and anode 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 filed of 2.8-3.7 kV/cm
- 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

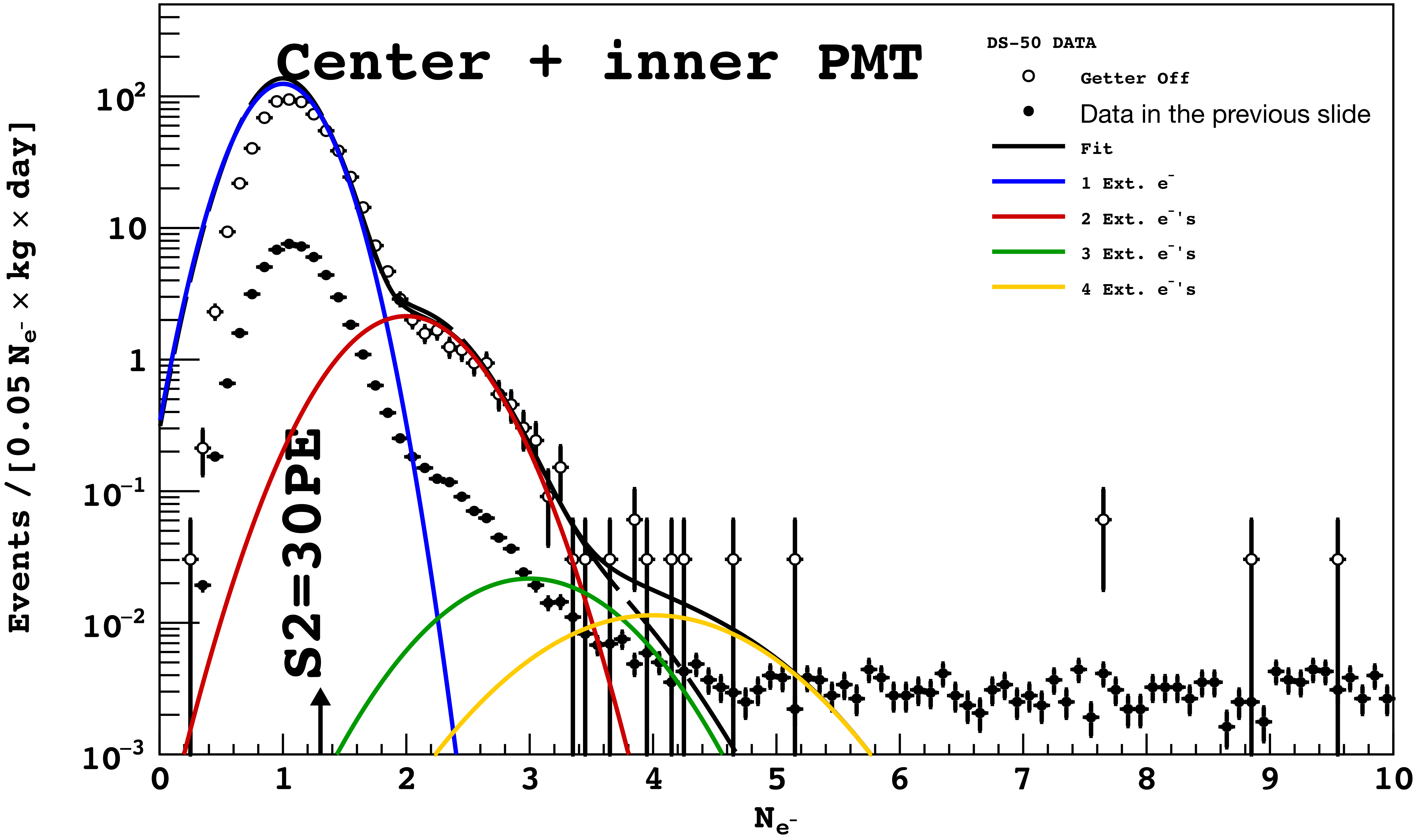
PRL 121, 081307 (2018)

- The analysis threshold was determined by the high rate 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



Zoom into the SE range

- Accounting for trigger efficiency, SE rates are consistent with Poisson statistics.
- That indicates two or more electrons events are pileup of single electrons.
- "Getter off" runs (open circle) saw increased rate of SE events.



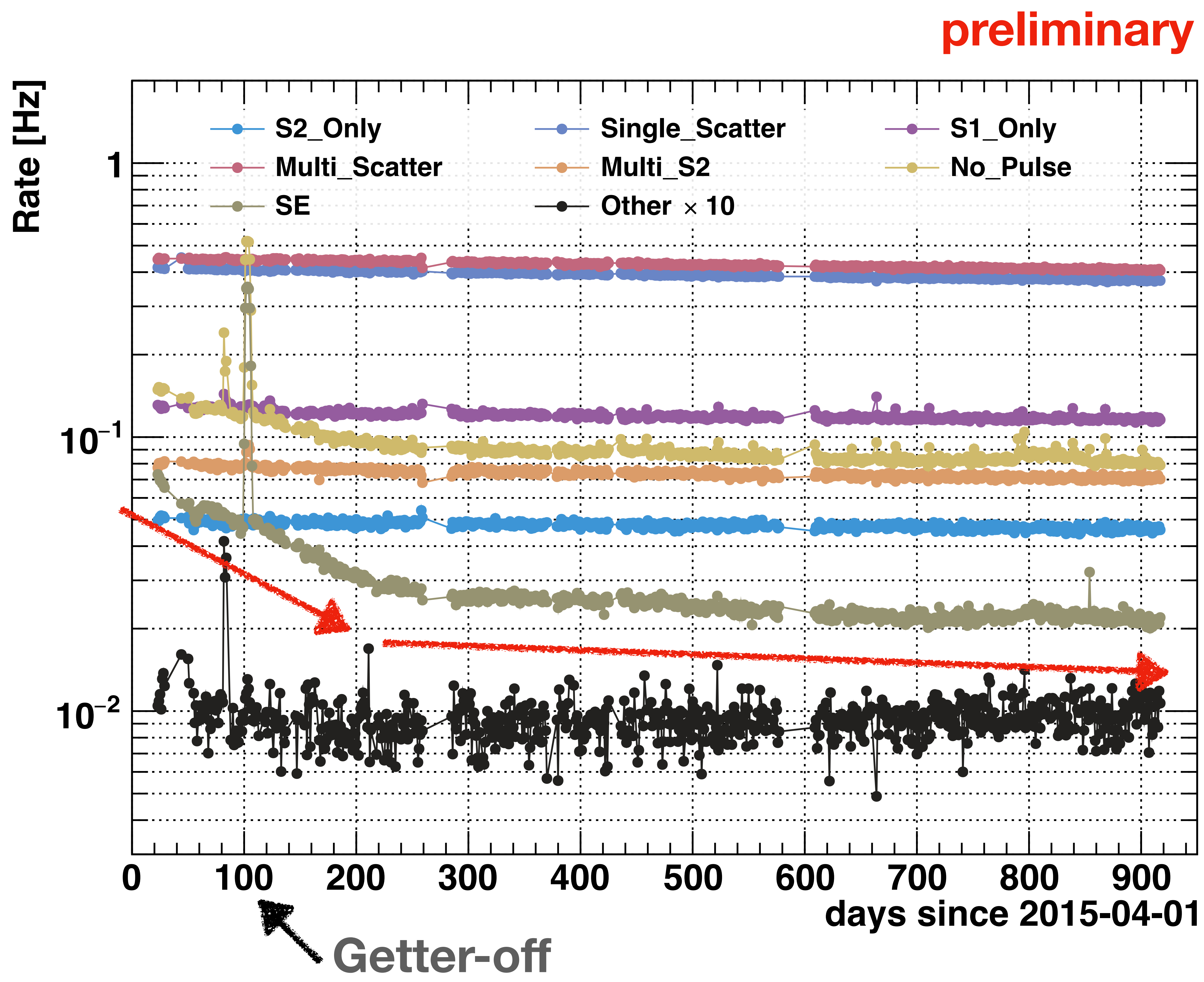
Category of few electron signals in DS-50

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

- ***Photo-ionization*** (within the acquisition window) see arXiv:2107.08015 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)
P. Sorensen and K. Kamdin JINST 13 P02032 (2018)
E Aprile et al. J. Phys. G: Nucl. Part. Phys. 41 035201 (2014)
Santos, E. et al. J. High Energ. Phys. 2011, 115

Time Evolution of events in DS-50



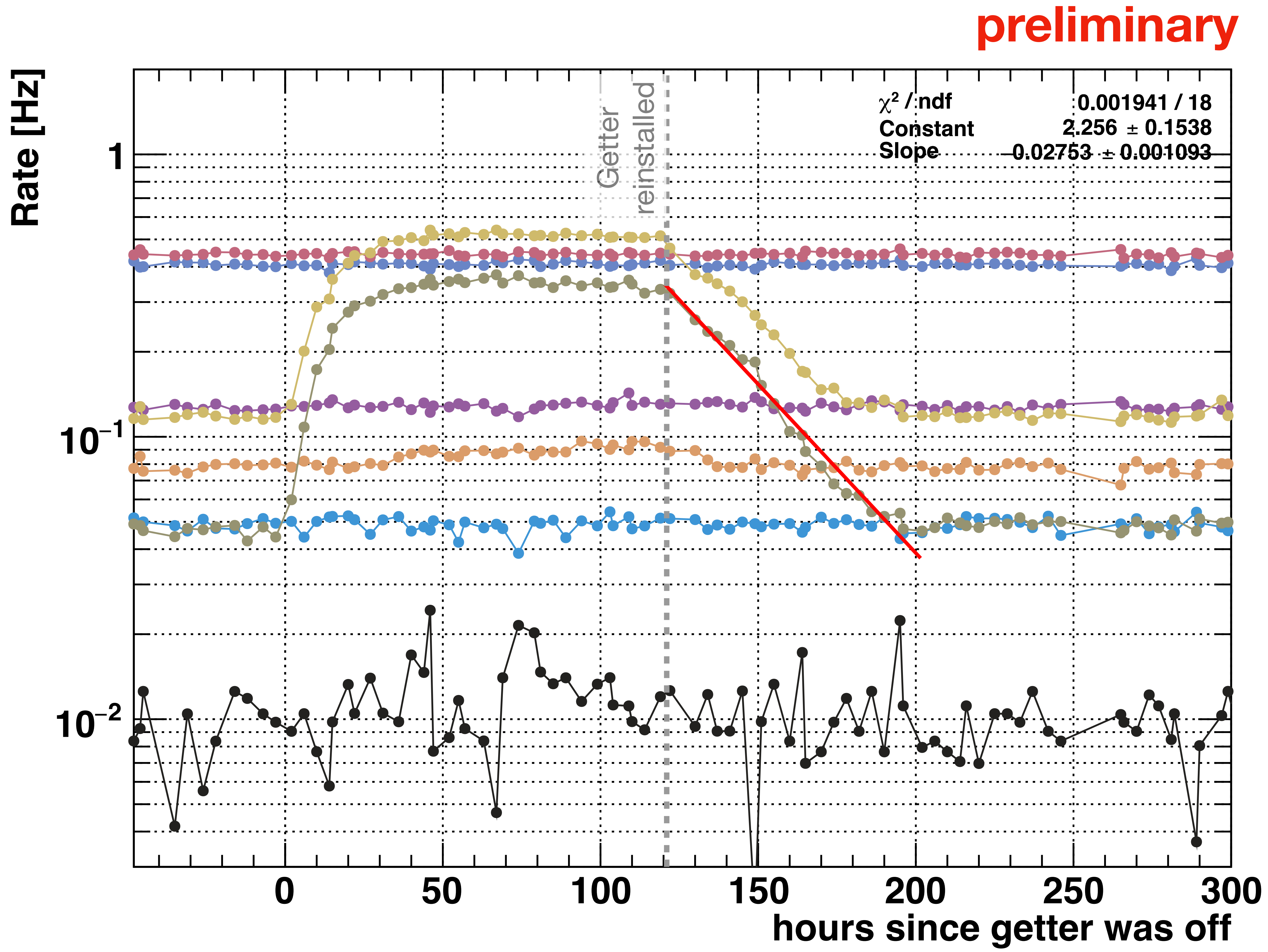
Pulse identification by pulse shape and pulse size

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

- *No pulse*: triggered, but pulse finder cannot find pulse including low Ne events that happen at the edge of the TPC.
- *S1 only*: events don't have S2 or S2 too small (Cherenkov, wall effect, events in holes)
- *Single scatter*: normal events (S1+S2)
- *Multi scatter*: gamma events, random pileups
- *S2 only*: events don't have S1, or S1 too small for pulse finder (only Ne≥4)
- *SE*: *S2 only*, but Ne<4, most of them are delayed electrons
- *Multi S2*: Multi scatters with S1 and the first S2 pileup (due to low t_drift)
- *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



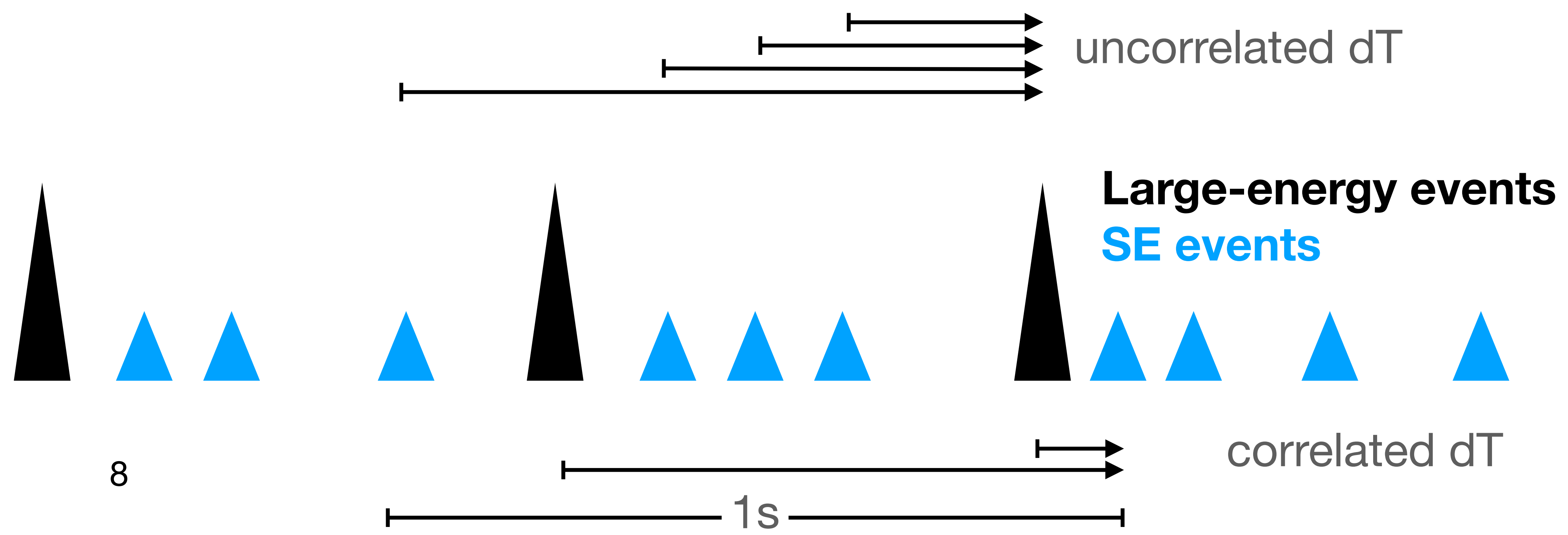
- For maintenance, the hot getter in the argon gas circulation system was removed for about 5 days.
- We noticed an increase in event rates with one pulse.
- Those events had a short livetime and small signal size.
- The elevated event rate was back to normal in 4 days after reinstallation of the getter.

- The increase in rates were seen only in *SE* and *No Pulse*.
- 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 re-installed.
- 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

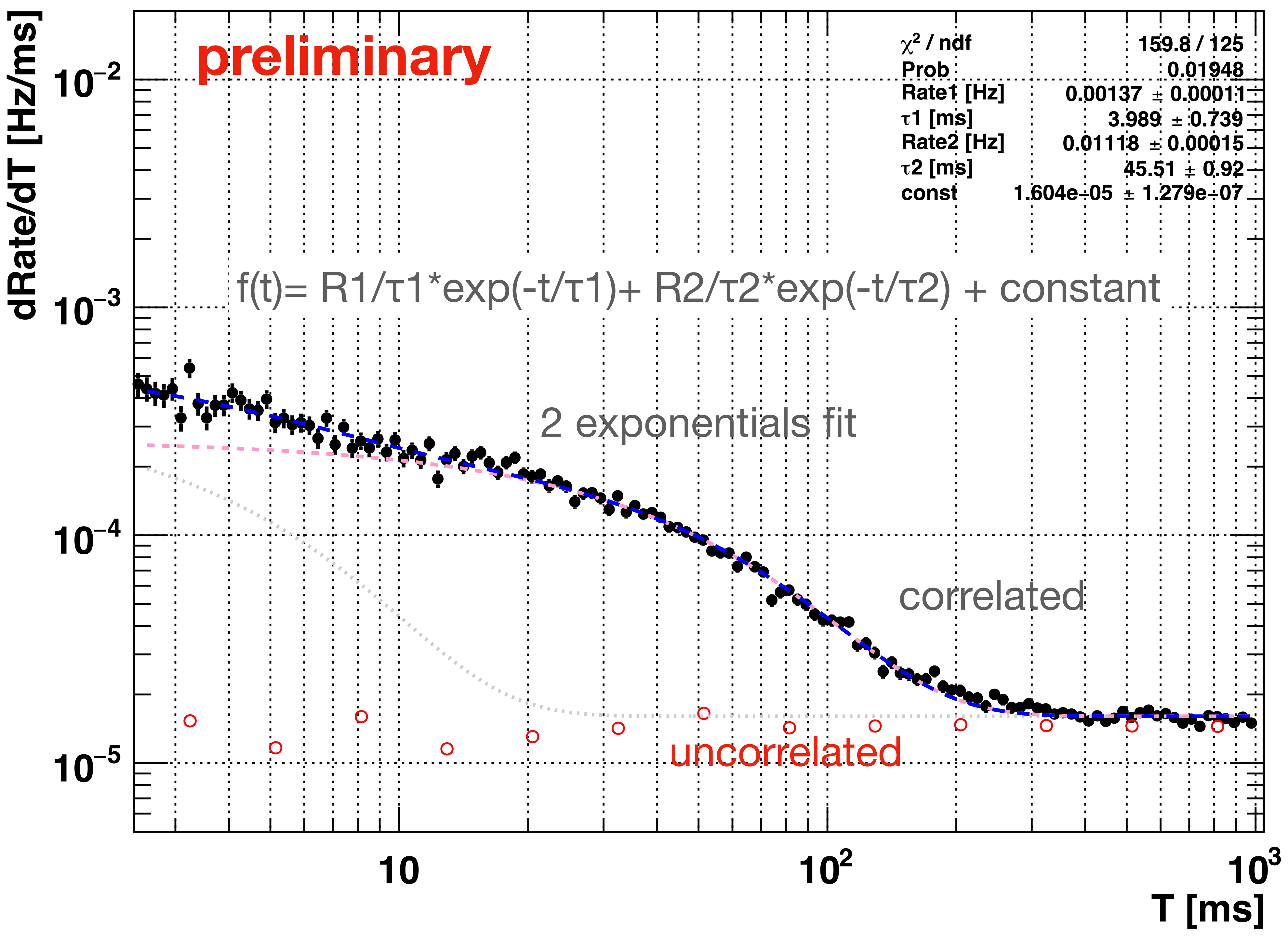
Time evolution of the time correlation

- 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 1s from the *SE*.
  - uncorrelated *ΔT*: for each identified large event, fill time difference from all preceding *SE* events within 1s from the large event.
- uncorrelated *ΔT* helpings modeling the uncorrelated fraction that is present in the correlated *ΔT*

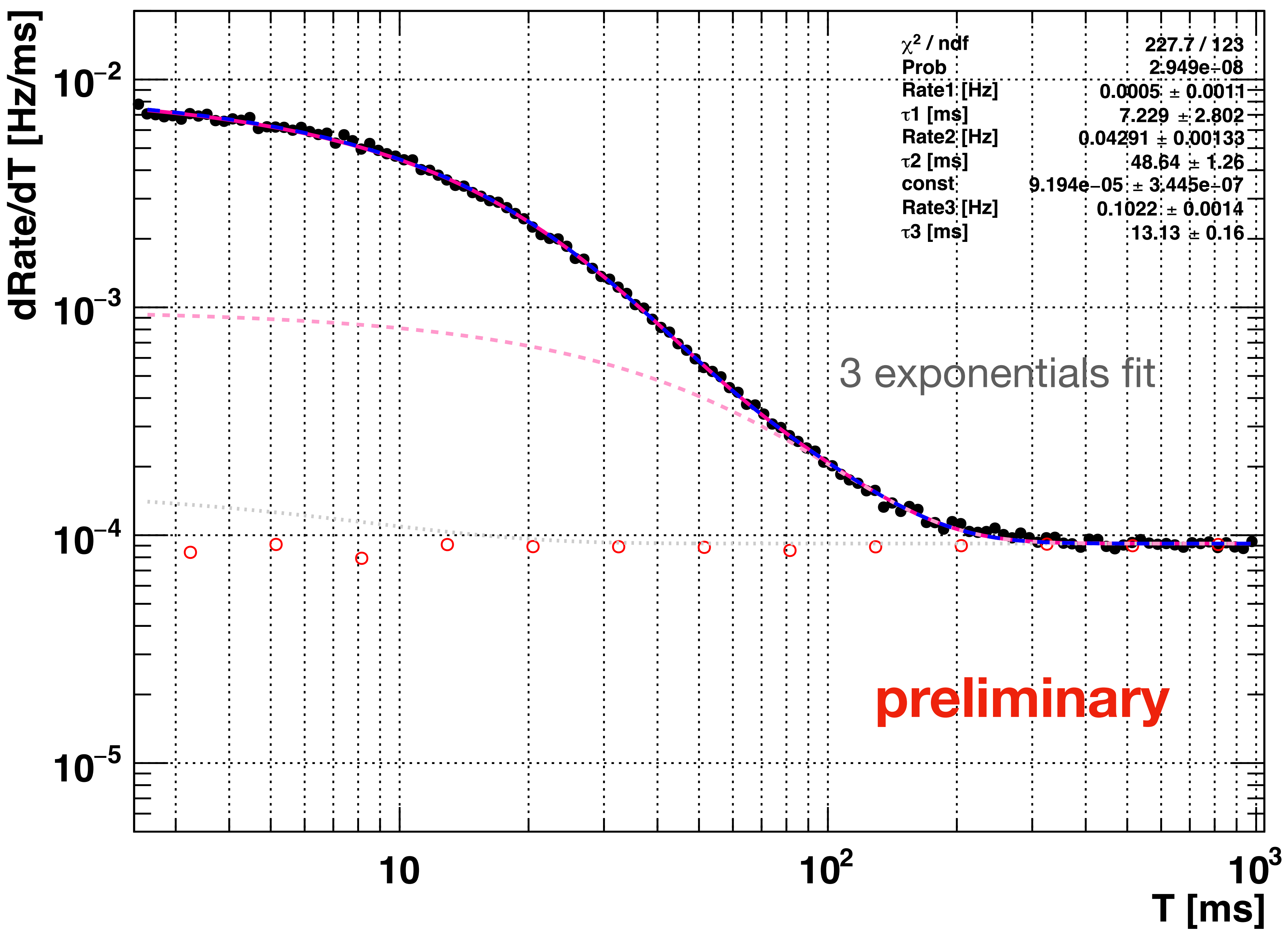


Time correlation

Normal runs (300-320 days)



Getter off data

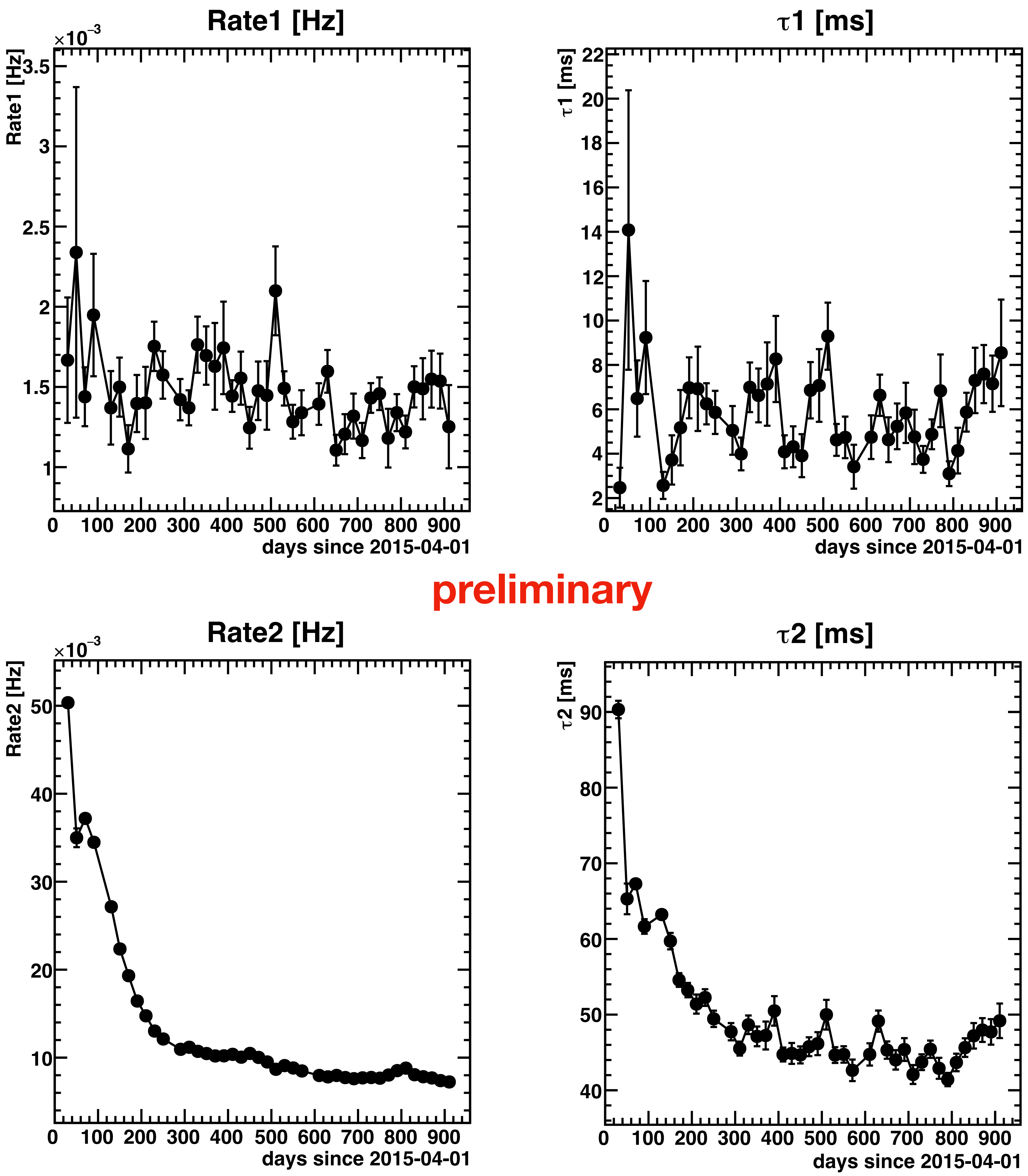


- At least two exponentials are necessary. Not power law unlike in Xenon based TPC.

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

- **In getter off data, an additional time constant of 13 ms appeared** and three exponentials are used.

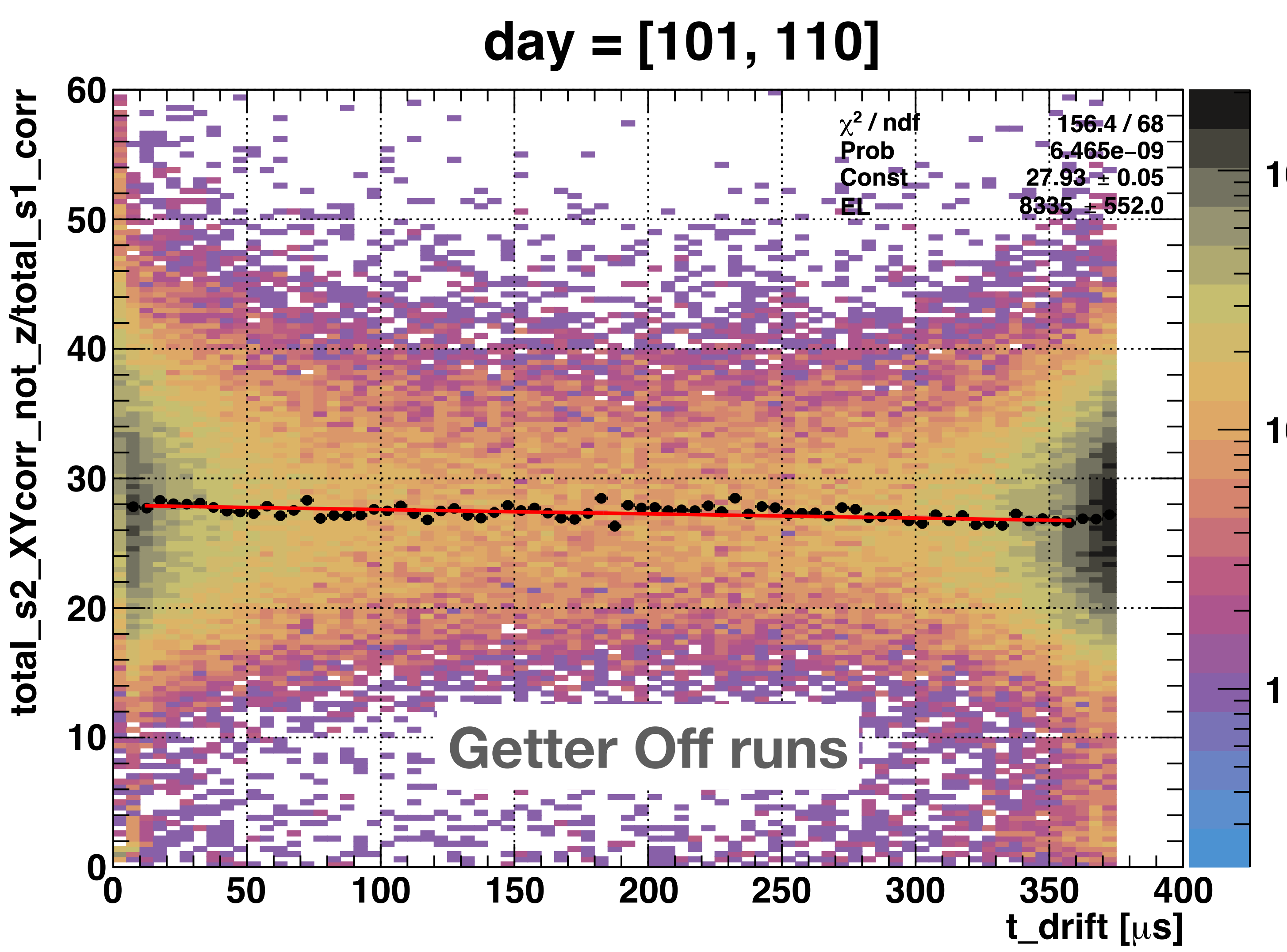
Time Evolution of Time Correlation



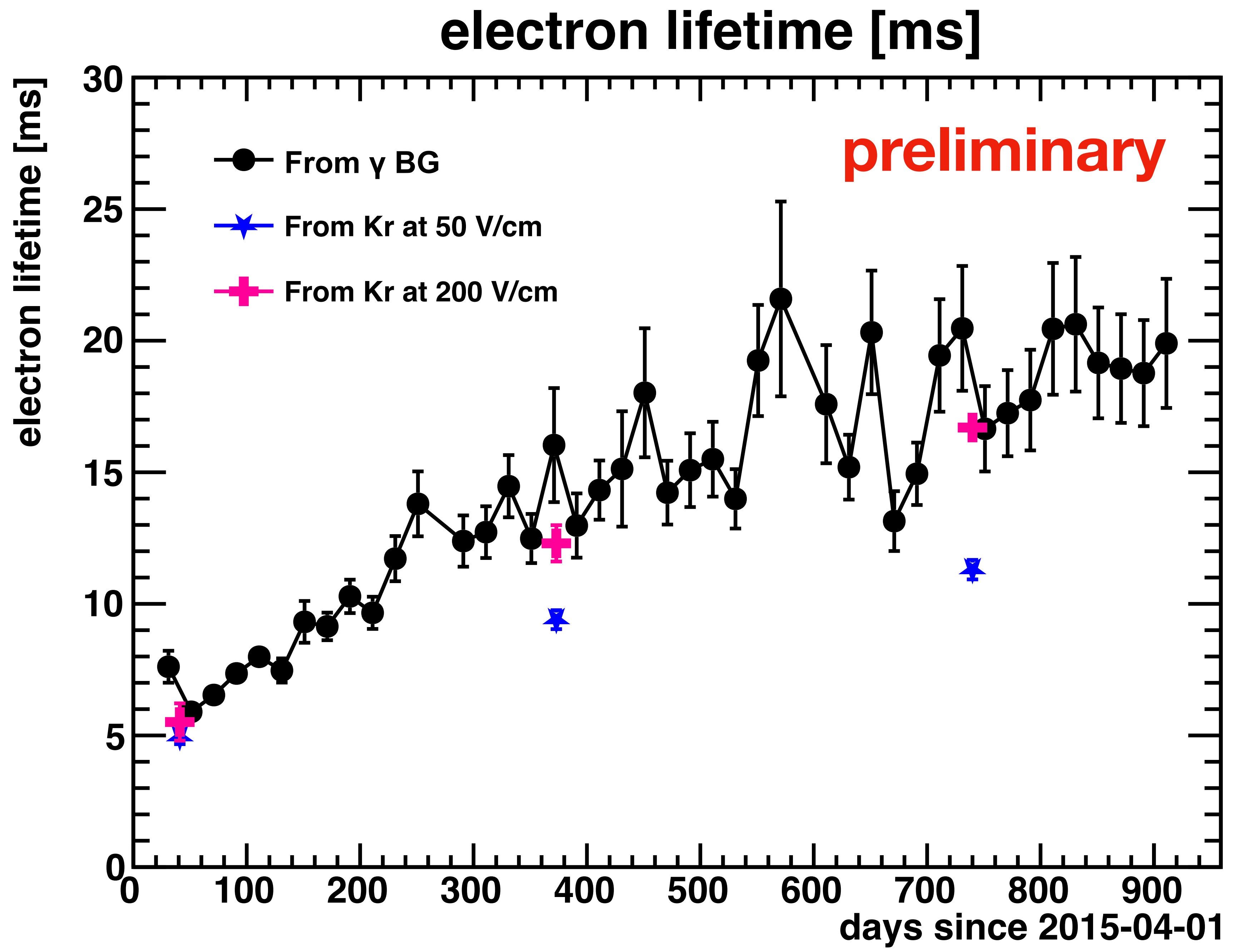
- Rate of the ~5 ms (τ1) component seems flat over time, ~1.5 mHz.
- Rate and time constant of the longer time constant (τ2) component decreased within the first 200 days.
- R_1 plus R_2 represent the correlated rates in SE events.
- We can explain 40% of the SE rate being correlated with well identified preceding events. Work underway to better quantify this.

Getter off data is not included

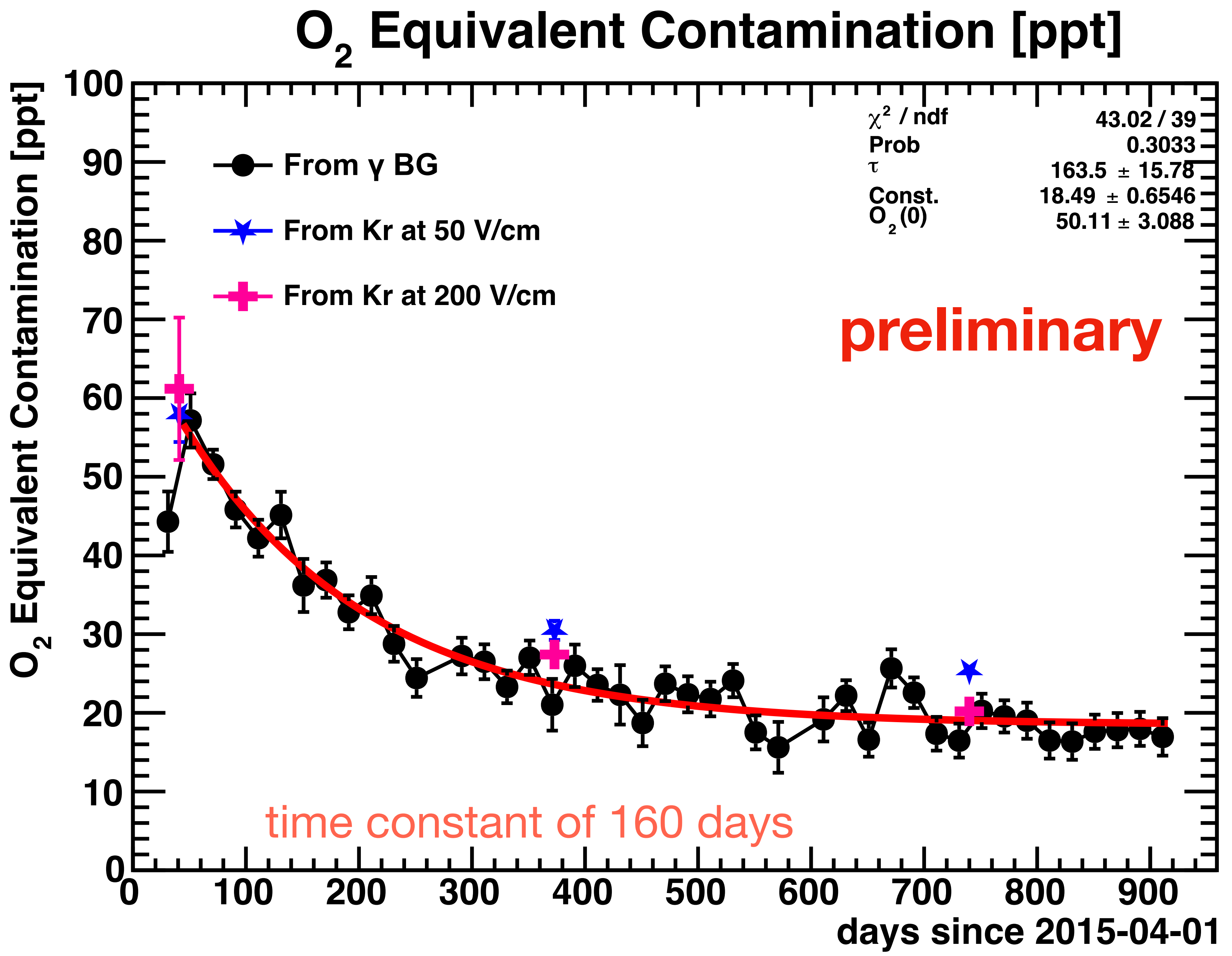
Electron lifetime



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



- The improvement trend of the electron 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 13 ms time constant in the getter off is different from the impurity causing electron lifetime degradation.**



Spacial correlation

- Pearson's correlation coefficient is used.

$$Corr(x_a, y_b) = \frac{\sigma_{x_a y_b}}{\sqrt{\sigma_{x_a}^2 \sigma_{y_b}^2}}, \text{ where}$$

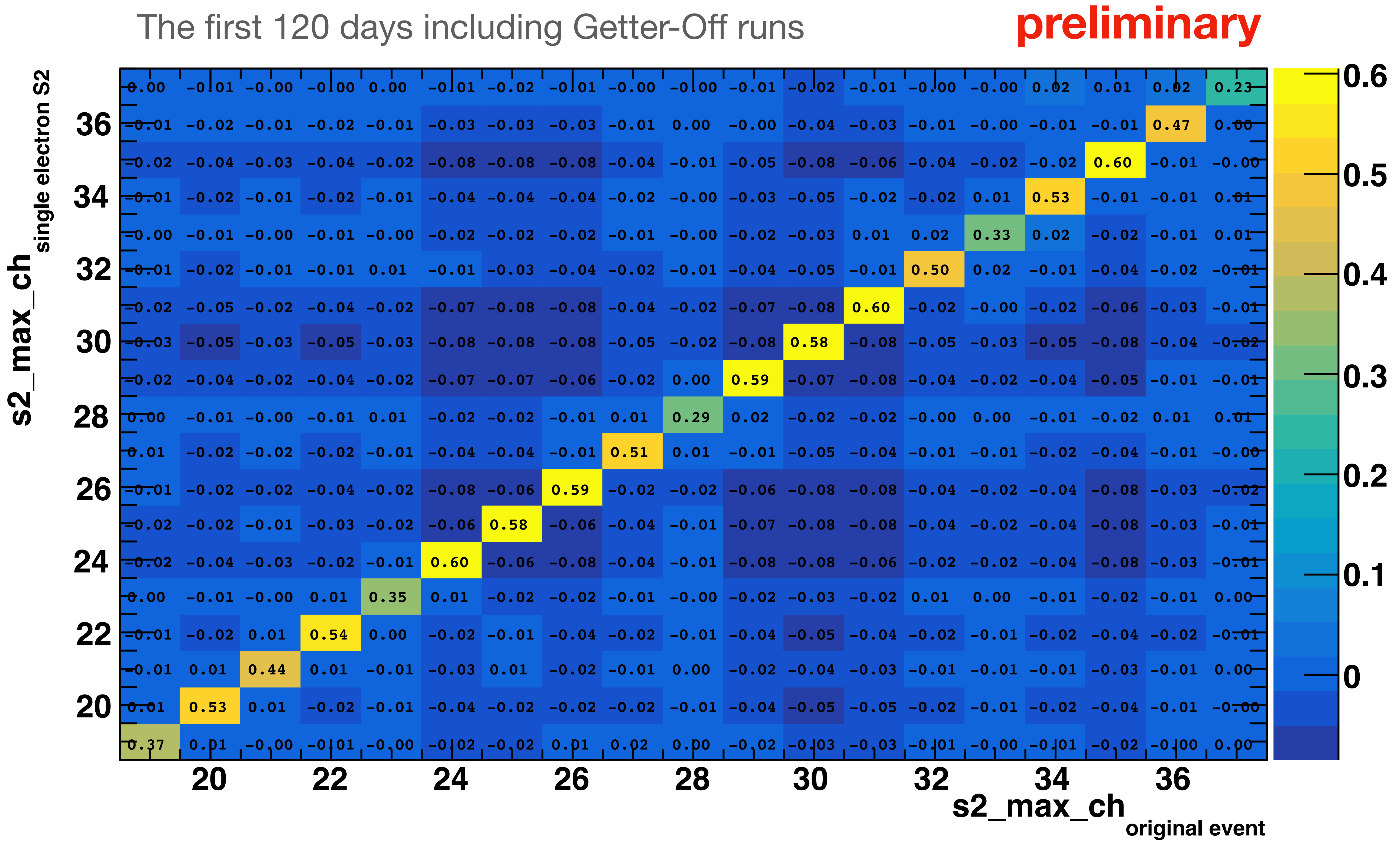
x_a (y_b) is 1 if channel a (b) is S2_max_chan in SE (parent) events.

$$\sigma_{x_a y_b} = \frac{1}{N}\sum_i^N \left(x_a^i - \langle x_a \rangle\right)\left(y_b^i - \langle y_b \rangle\right),\ \sigma_{x_a}^2 = \langle x_a \rangle, \text{ and } \sigma_{y_b}^2 = \langle y_b \rangle.$$

The mean values are used as approximation of variances since it is Poisson process.

This coefficient is 0 if there is no correlation, 1 for perfect correlation and -1 for perfect anti-correlation.

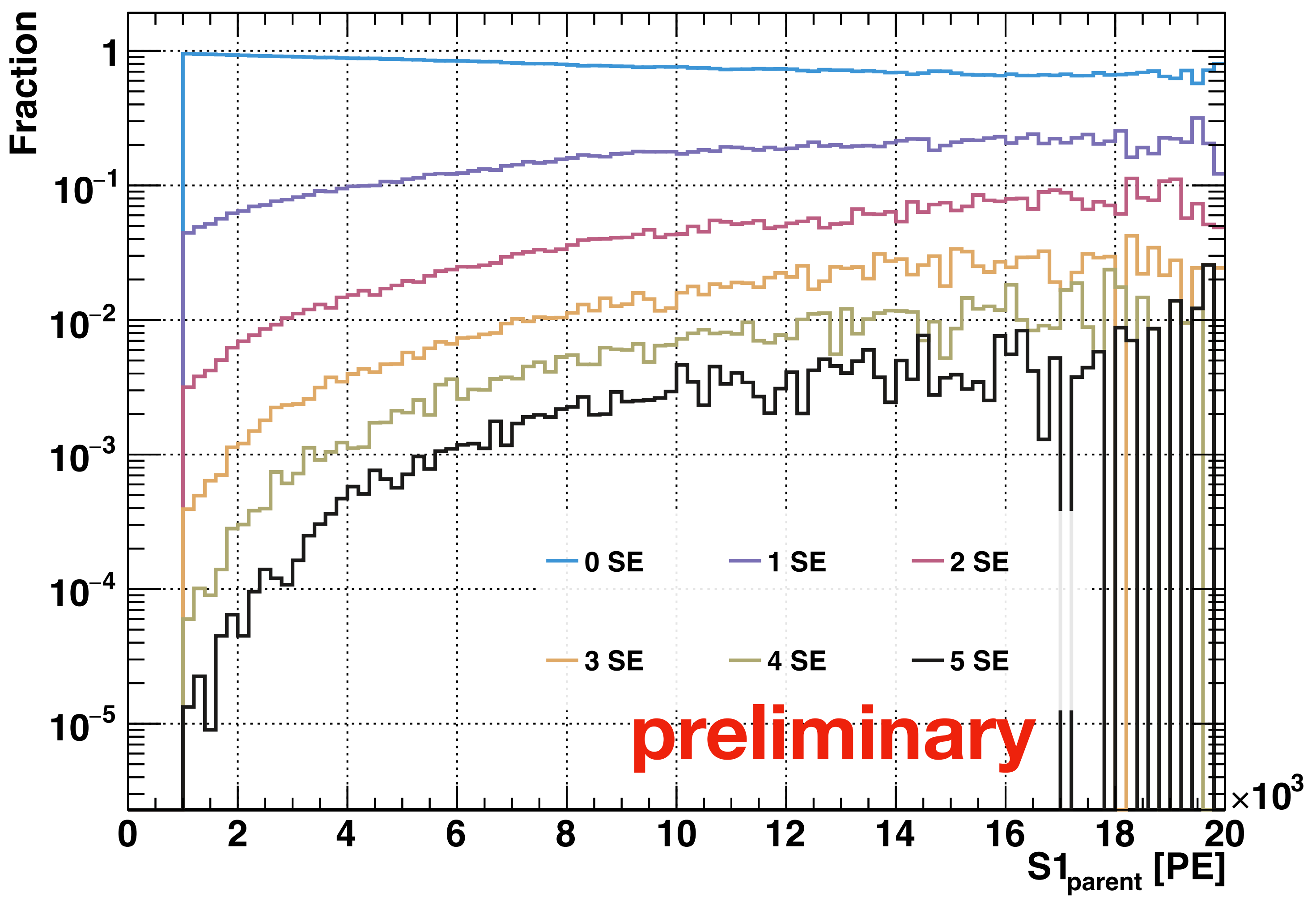
- Only single scatter parent events (well-defined event positions) are used
- Only SE events <200ms from single scatter parent events are used.
- The correlation coefficients are about (0.60/0.51/0.34) at (center, middle, edge) PMTs.
- **Strong correlations** are observed between S2_Max_chan of SE and its parent events. The correlation with other channels are basically 0, no correlation.



Correlation w/ Parent’s energy and z-position

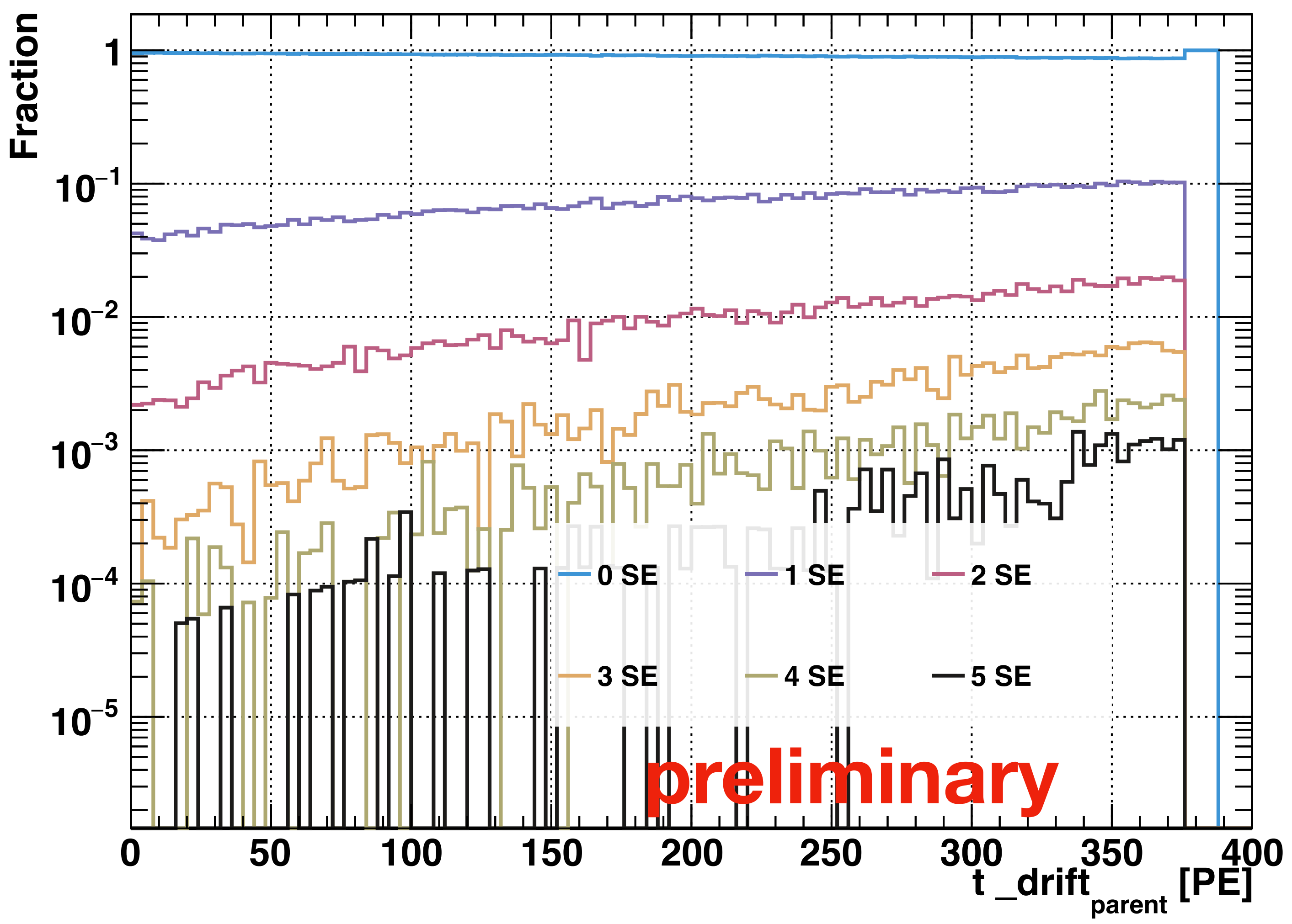
- For all parent events, count how many SE events follow until next parent event.
- The fraction of parent events with no SE events, one SE event, two SE events, so on, is calculated as a function of parent S1.
- **Large energy events create more SE events.**

The first 120 days including Getter-Off runs



- Only single scatter events as parent 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.**
- This is consistent with the expected behavior of the correlated events, which originates from the charge released in previous interactions drifting along the field and being trapped along the route.

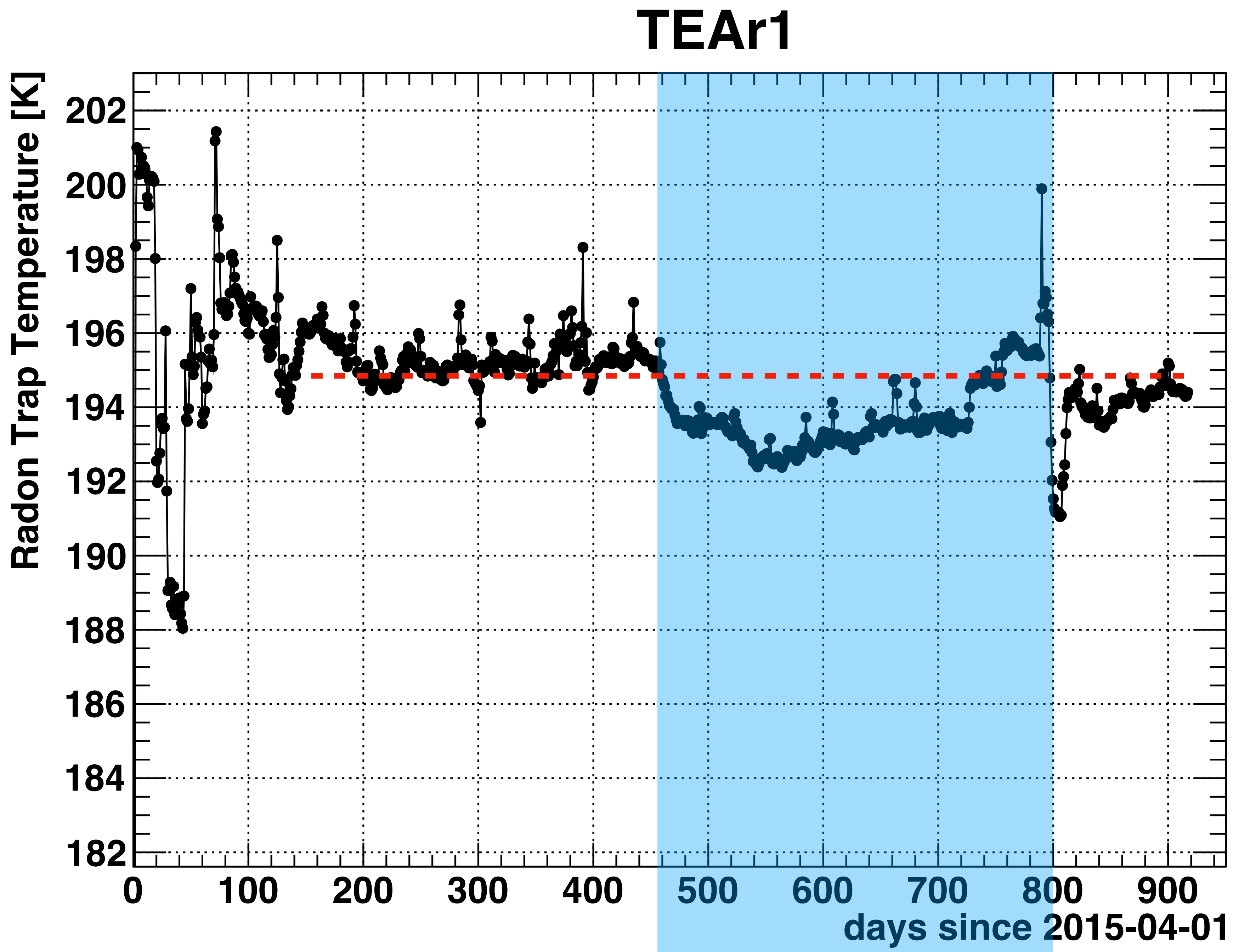
The first 120 days including Getter-Off runs

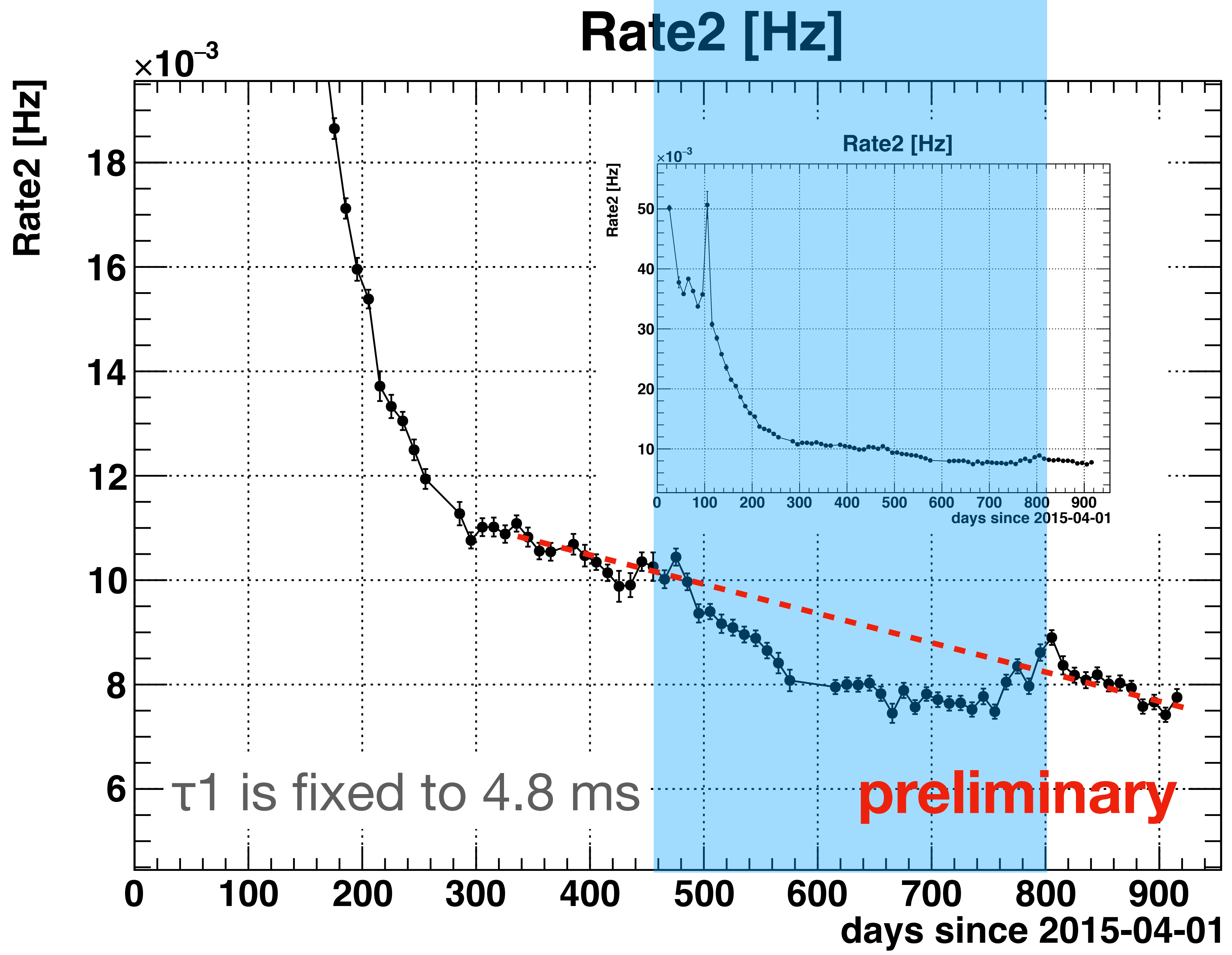


Correlation?

a hint of correlation

- Temperature in the cryostat and the Ar condenser are stable within 1 K most of the time.
- No obvious correlation with the SE rates are observed.
- When the temperature of the radon trap decreased, the rate of the slow time constant (~50 ms) also decreased.
- It might mean the radon trap captured the impurity causing the slow time constant SE.





Summary

- In DS-50 TPC, we observed 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.
- In the time correlation study, the time constants change with time: 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.
- No clear correlation with the impurity causing electron lifetime degradation.
- The SE rate decreased with a time constant of ~65 days.
- Another longer decreasing trend with time constant of ~8 years. Another impurity? or correlate with the decrease of the total event rate?
- The rate of SE shows a hint of correlation with the temperature of the Rn trap.
- The mechanism of releasing electrons from impurity is unknown.