Note on a Simple Timing Invariant in CMS LLP Searches

September 11, 2025

Dear CMS Exotica Group,

This short note highlights a model-agnostic timing pattern for long-lived particles (LLPs). Consider the linear combination

$$X \equiv t - \alpha\, d_0,$$

where t is the reconstructed time-of-arrival (e.g., ECAL timing) and d_0 is the transverse impact parameter of the associated track or displaced vertex proxy. The empirical claim is:

$$\mathrm{Var}(X) \text{ is minimized at the same } \alpha^\star \text{ across different LLP topologies.}$$

How it can be tested with CMS Run-3 data

- **Samples:** use existing LLP-enriched selections (EXO/LLP triggers or displaced-track/vertex categories) in Run-3.
- **Reconstruction:** per-candidate t from ECAL time-of-arrival (after standard timing calibrations and path-length/TOF corrections); d_0 from tracker track or displaced-vertex fit (choose a consistent proxy when no single track is available).
- **Binning:** split by topology (displaced leptons, displaced jets, delayed photons, etc.) and by kinematics (p_T, η) to control trivial kinematic effects.
- **Fit:** for each bin, scan α and find the $\alpha^\star$ minimizing $\mathrm{Var}(t - \alpha d_0)$; propagate uncertainties with bootstrapping and include timing/tracking systematics.
- **Universality check:** test whether $\alpha^\star$ is consistent across LLP classes and bins; compare to control regions dominated by SM backgrounds (cosmics, beam-halo, out-of-time pileup).
- **Robustness:** repeat with alternative t definitions (cluster time vs. seed time) and with per-candidate β corrections (when available) to verify stability.

Why this may be important

- **Model-agnostic discriminant:** a common $\alpha^\star$ provides a simple observable for LLP selections, potentially improving S/B without assuming a specific LLP model.
- **Systematics cross-check:** universality of $\alpha^\star$ across categories is a nontrivial coherence pattern; its absence in background regions helps validate timing/tracking systematics.
- **Search reach:** if confirmed, $X = t - \alpha^\star d_0$ can be added to multivariate LLP taggers as a physically interpretable feature.

Sincerely,

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