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Improved use of MTD time in vertex reconstruction

CMS Collaboration

Abstract

An update on Mip Timing Detector (MTD) reconstruction performance is provided, focusing on the handling of uncertainties. The contribution to track time uncertainty coming from particle time of flight uncertainty σ_{TOF} has been evaluated and compared to MTD uncertainty. Mass assignment uncertainty is handled by the updated vertex time estimation algorithm, whose performance is shown. All plots have been obtained on a $t\bar{t}$ + 200 pile up sample.

Improved use of MTD time in vertex reconstruction

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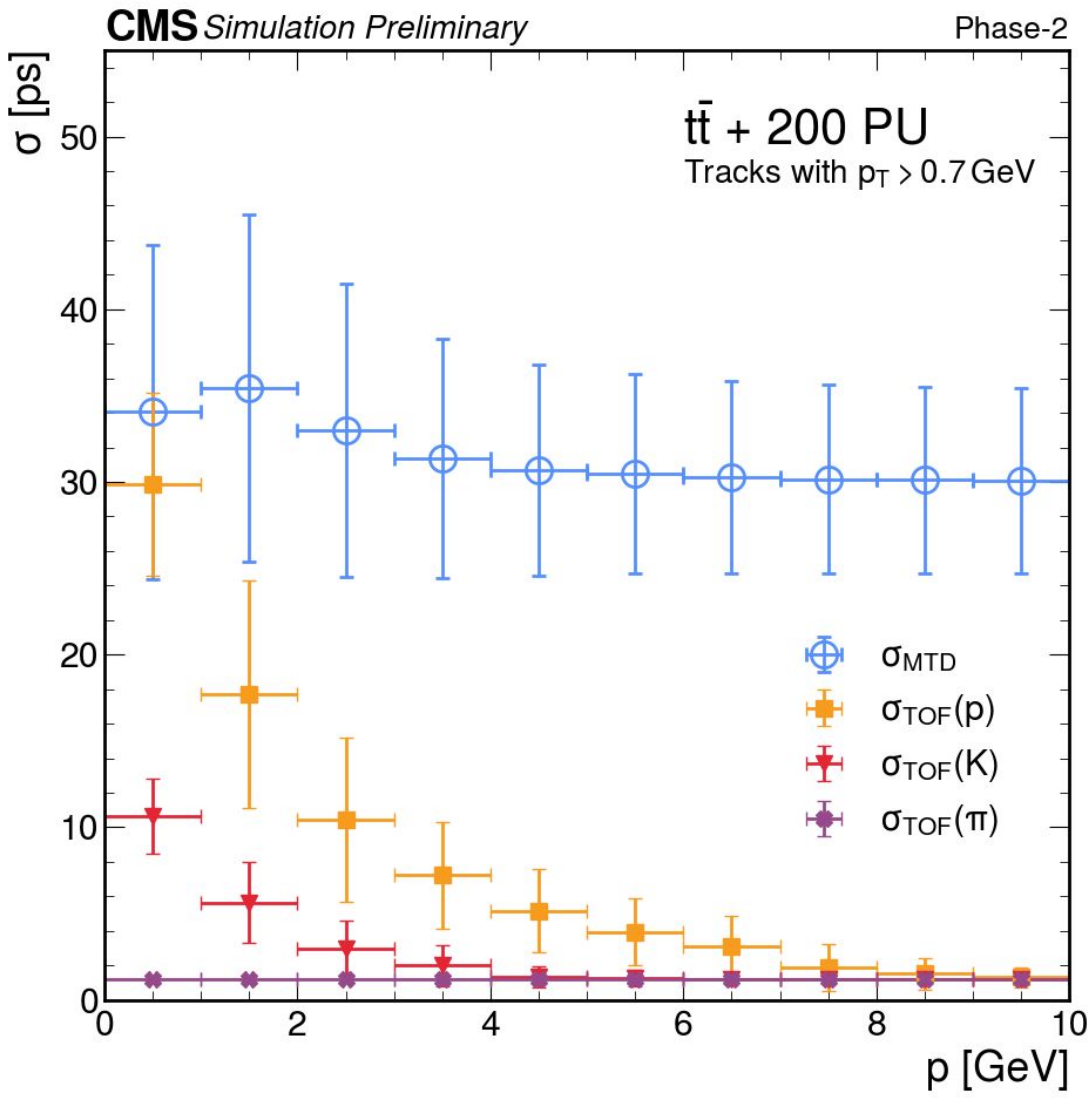
An update on **Mip Timing Detector (MTD)**[1] **reconstruction performance** is provided after the latest developments, focusing on the handling of **uncertainties**.

The contribution to track time uncertainty coming from particle **time of flight uncertainty** σ_{TOF} has been evaluated and compared to MTD uncertainty.
Mass assignment uncertainty is now also better handled by the **updated vertex time estimation algorithm**, whose performance is shown.

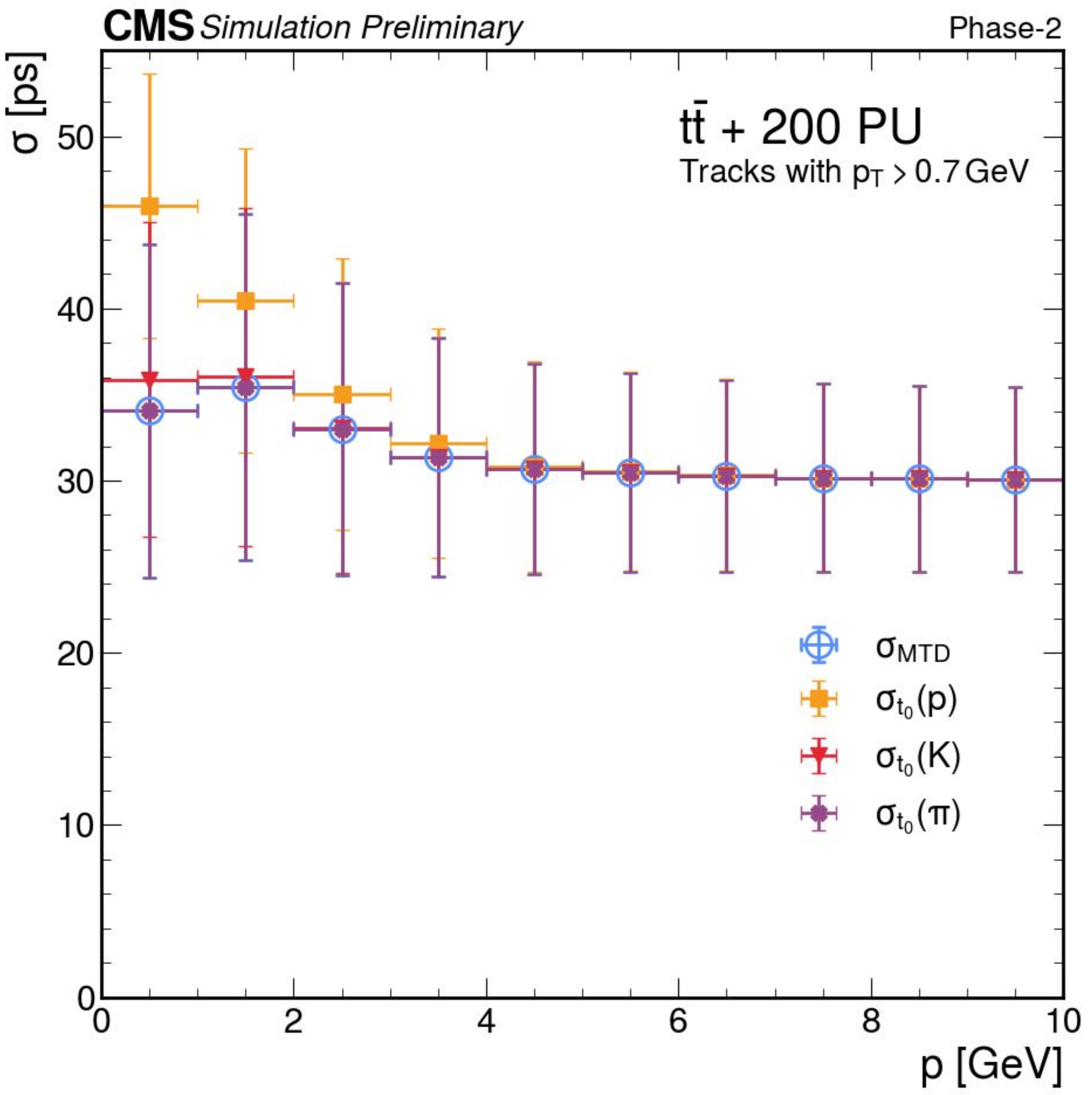
All plots have been obtained on a $t\bar{t}$ + 200 pile up (PU) sample.

σ_{TOF} vs. σ_{MTD}



- The reconstructed track momentum uncertainty translates into an uncertainty on the **estimated time-of-flight σ_{TOF}**, and therefore on the time at the track origin. This uncertainty is computed as a function of the **track momentum *p*** under three different mass hypotheses: pion (purple), kaon (red), proton (yellow).
- This must be compared to the **estimated MTD hit time uncertainty σ_{MTD}**.
- For each momentum bin, the **mean** value and **standard deviation** of σ_{MTD} and σ_{TOF} are shown. The distributions correspond to tracks with transverse momentum $p_T > 0.7$ GeV from a $t\bar{t}$ event sample with an average pileup of 200.
- **σ_{TOF} is comparable to σ_{MTD}** at **low momenta** ($p \leq 2$ GeV) in the **proton** hypothesis.

Total track time uncertainty σ_{t_0}



- Track time at the point of closest approach to the beam line is given by $t_0(\pi, K, p) = t_{\mathrm{MTD}} - \mathrm{TOF}(\pi, K, p)$: hence, the **total track time uncertainty** is given by $\sigma_{t_0}(\pi, K, p) = \sqrt{\sigma^2_{\mathrm{MTD}} + \sigma^2_{\mathrm{TOF}}(\pi, K, p)}$.
- For each momentum bin, the **mean** value and **standard deviation** of $\sigma_{t_0}(\pi, K, p)$ are shown. The distributions correspond to tracks with transverse momentum p_T > 0.7 GeV from a $t\bar{t}$ event sample with an average pileup of 200.
- While $\sigma_{t_0}(\pi)$ **is comparable to σ_{MTD}**, an appreciable deviation due to the addition of σ_{TOF}(p) can be observed at **low momenta** (*p* ≤ 2 GeV) for $\sigma_{t_0}(p)$.
- Nonetheless, following studies confirmed the **impact of σ_{TOF}** on both **vertex reconstruction** and **particle identification** to be **marginal**.

4D vertex time reconstruction with MTD

The **vertex time** computation has been performed so far with a weighted average of track times, assuming a fixed mass hypothesis for each of them:

$$t_v = \frac{\sum_{\text{tracks},i} w_i \, t_{0,i}(\pi, K, p)}{\sum_{\text{tracks},i} w_i} \quad \text{with } w_i = \frac{1}{\sigma^2_{t_0,i}(\pi, K, p)}$$

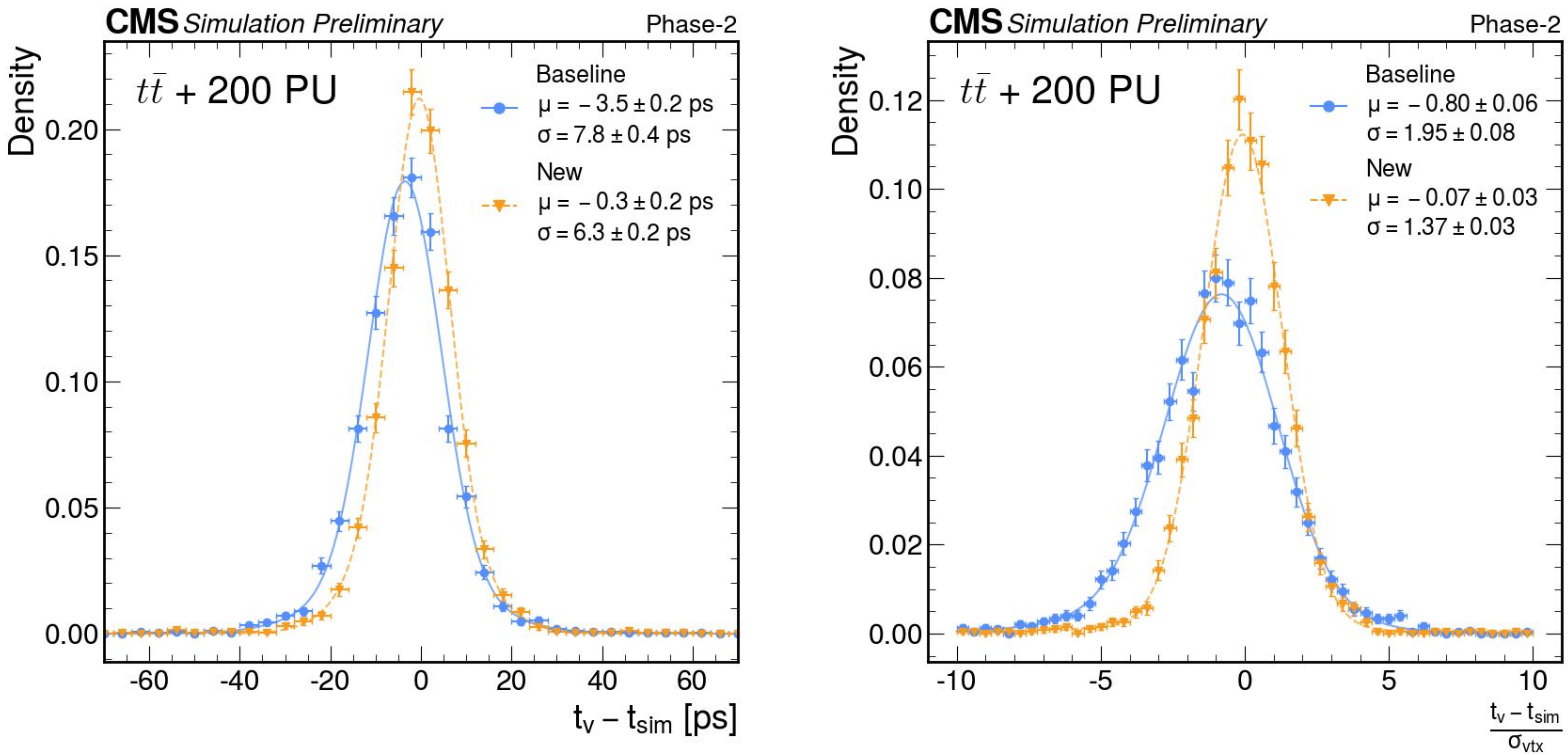
An alternative approach is proposed, based on a **Deterministic Annealing** (DA) algorithm[2], by finding the optimal t_v vertex time compatible with the vertex tracks that minimises the cost function

$$F = -T \sum_{\text{tracks},i} w_{0,i} \log\left(Z_0 + \alpha_\pi e^{-\frac{(t_{0,i}(\pi)-t_v)^2}{2T\sigma^2_{t_0,i}(\pi)}} + \alpha_K e^{-\frac{(t_{0,i}(K)-t_v)^2}{2T\sigma^2_{t_0,i}(K)}} + \alpha_p e^{-\frac{(t_{0,i}(p)-t_v)^2}{2T\sigma^2_{t_0,i}(p)}}\right)$$

where $w_{0,i}$ is the i-th track weight, $t_{0,i}(\pi, K, p)$ the track times in different mass hypotheses, each with a priori weight $\alpha_{\pi,K,p}$ (0.7, 0.2 and 0.1 used for pions, kaons and protons respectively), $\sigma_{t_0,i}(\pi, K, p)$ their respective uncertainties, T the DA initial temperature and Z_0 is the outlier-rejection constant.

This algorithm can be applied to a reconstructed vertex regardless of the use of time in its clustering and fitting. The use of the DA algorithm in the **last stage of the 4D iterative vertex reconstruction** (**New**) is compared to the use of the weighted average (**Baseline**).

4D vertex time reconstruction performance



Vertex time resolution (left) and **pull** (right) distribution for **signal** vertices in a sample of $t\bar{t}$ events with an average pileup of 200, comparing the **Baseline** approach (vertex time with weighted track time average) and the **New** one (vertex time from DA algorithm). Distributions are fit with a double Gaussian – parameters shown refer to the narrowest one. Fit parameters with and without σ_{TOF} are compatible within fit uncertainty.

References

[1] CMS Collaboration, *A MIP Timing Detector for the CMS Phase-2 Upgrade, Technical Design Report*, CERN-LHCC-2019-003 [link]

[2] K. Rose, *Deterministic Annealing for Clustering, Compression, Classification, Regression and related Optimisation Problems*, Proc. IEEE 86 (1998) 2210 [link]