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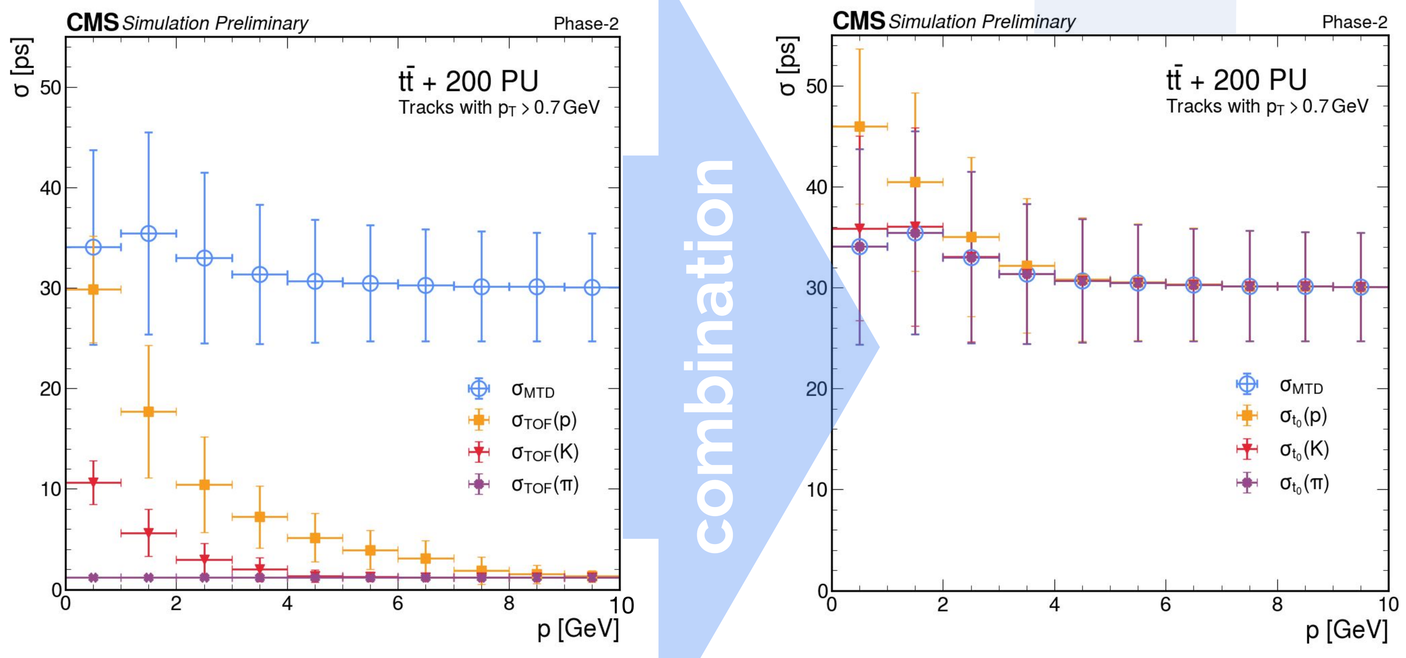
Track backpropagation

- MTD measures **time of arrival** of charged particles with a precision of **σ_{MTD} ~ 30-40 ps**.
- Given its momentum, the track is **backpropagated** to the **beamline** by computing **time of flight** (TOF) under a **given mass hypothesis**:

$$t_0(\pi, K, p) = t_{\text{MTD}} - \text{TOF}(\pi, K, p)$$

- This introduces additional **mass-dependent** source of uncertainty **σ_{TOF}**:

$$\sigma_{t_0}(\pi, K, p) = \sqrt{\sigma^2_{\text{MTD}} + \sigma^2_{\text{TOF}}(\pi, K, p)}$$



σ_{TOF} ~ $\mathcal{O}$ (10 ps) comparable to **$\sigma(t_{MTD})$** for **heavy**, **low momentum** particles (protons with p < 2 GeV).

Vertex reconstruction

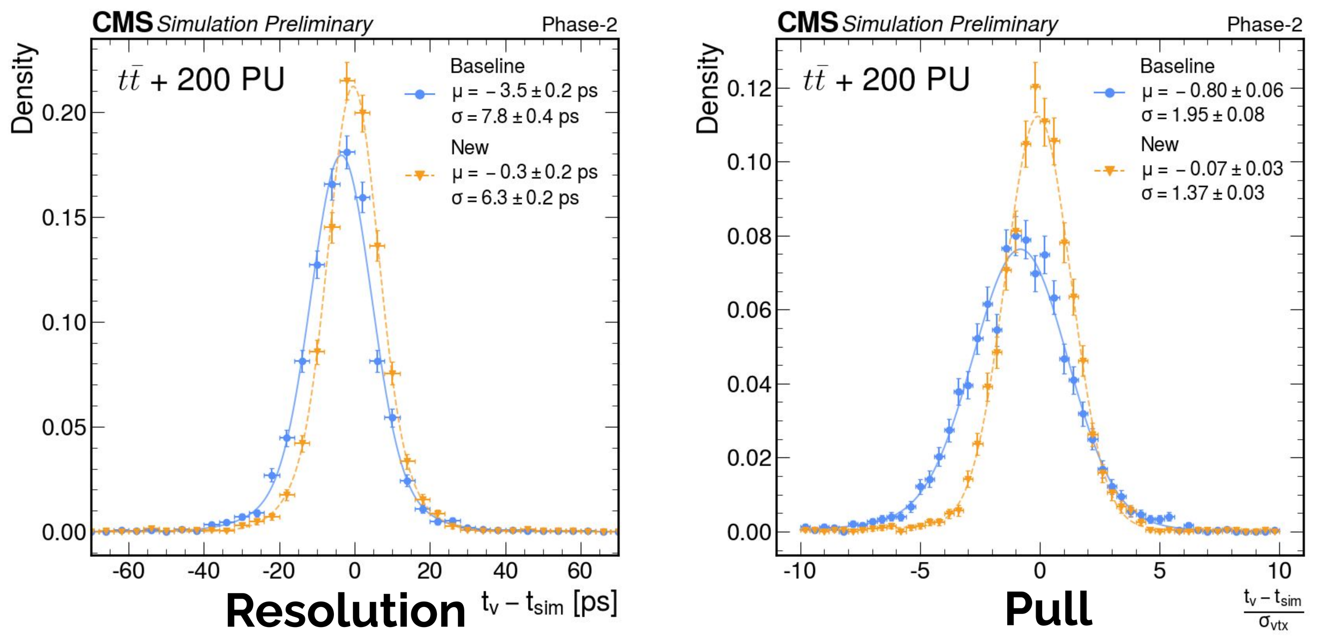
- Tracks are **clustered** to construct **vertices** given **beamline times** and **positions**.
- **However, how do we deal with track mass assignment?**
  - **Baseline**: take the *most likely* hypothesis; compute t_v as weighted average:

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

  - **New**: consider *all* mass hypotheses (hp) weighted by compatibility with candidate vertex); t_v from **deterministic annealing** on appropriate cost function, hence, at last iteration n:

$$t_v = \frac{\sum_{\text{tracks},i} \sum_{\text{hp}} w_i(\text{hp})\, t_{0,i}(\text{hp})}{\sum_i \sum_{\text{hp}} w_i(\text{hp})} \quad \text{with } w_i(\text{hp}) = \frac{\alpha_{\text{hp}} \exp\left(-\chi^2_{i,\text{hp}}\right)}{Z} \times w_i^{3D} \times \frac{1}{\sigma^2_{t_0,i}(\text{hp})}$$

prior probability; $\chi^2_{i,\text{hp}} = \frac{(t_{0,i}(\text{hp}) - t_v^{(n-1)})^2}{\sigma^2_{t_{0,i}}(\text{hp})}$; normalization

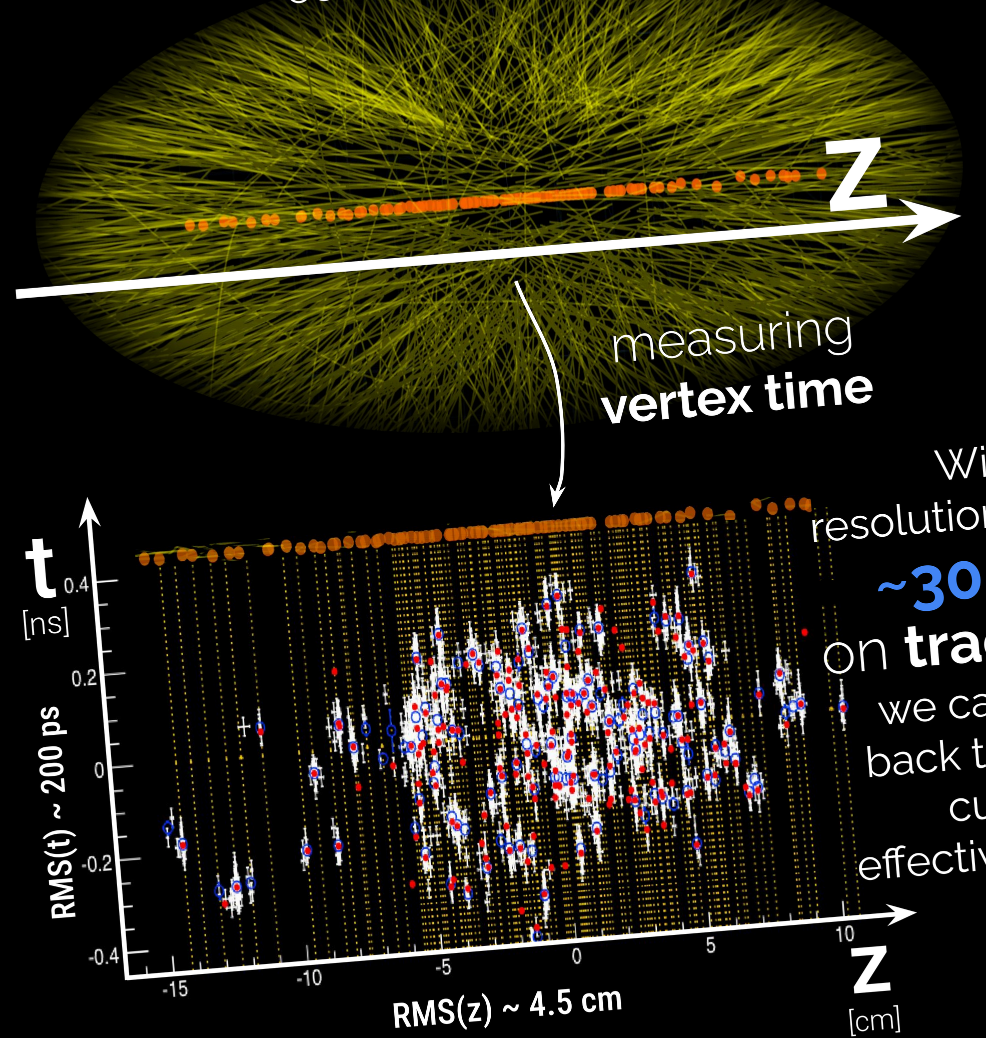


New vertex time algorithm improves both **resolution** (now about **6 ps**) and **bias** (now compatible with 0), as well as reducing pull width.

References: [1] CMS-TDR-020, "A MIP Timing Detector for the CMS Phase-2 Upgrade"; [2] CMS-DP-2022-025, "Update of the MTD physics case"; [3] CMS-DP-2024/048, "Improved use of MTD time in vertex reconstruction"

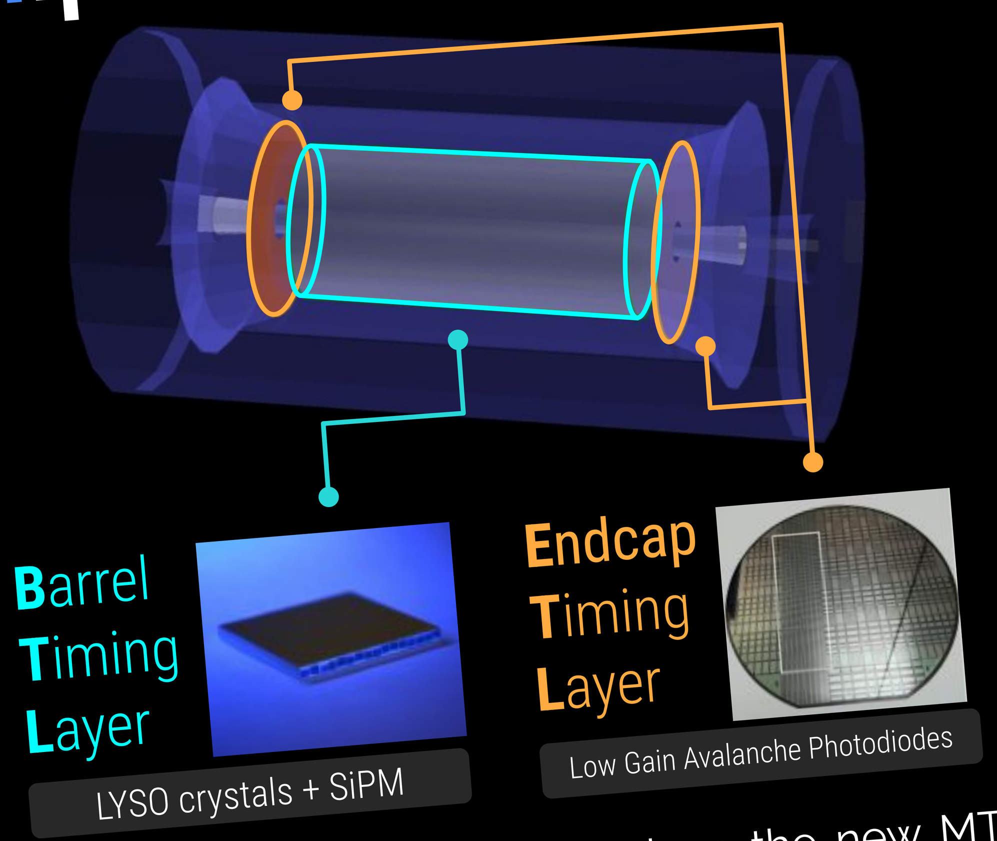
TOWARDS A PRECISE MEASUREMENT OF PARTICLES TIME-OF-FLIGHT WITH THE

During the High-Luminosity phase of LHC, we expect approximately **200 simultaneous interactions** per collision (**pileup, PU**)



With a resolution of **~30 ps** on **tracks** we can go back to the current effective PU level

Mip Timing Detector



The CMS experiment will introduce the new MTD detector between the tracker and the electromagnetic calorimeter, measuring the **time of arrival** of **charged particles** with the required accuracy.

NEW MIP TIMING DETECTOR FOR THE CMS EXPERIMENT

PID exploited for...

Time is used for...

Food for thought

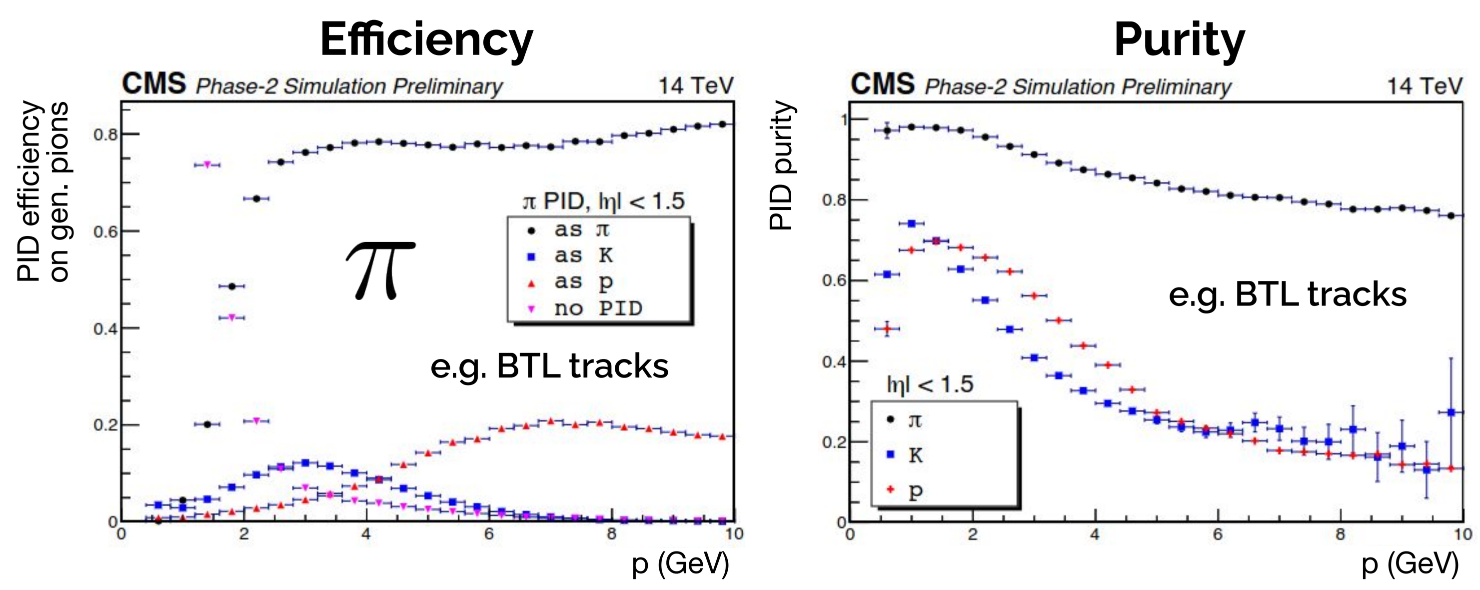
Current PID based on χ^2 **cuts**: many **possible developments**!

💡 Use variables from other detectors (e.g. particle **dE/dx** information from tracker)

💡 Pursue alternative **modern computational techniques** – possible synergy with time usage in vertex reconstruction

Particle identification (PID)

For each track, mass assignment done based on best **space-time compatibility** with the assigned **vertex time** evaluating χ^2 for **pion**, **kaon** and **proton** hypotheses:



Particle identification is **iteratively connected** to **vertex reconstruction**; with this procedure, we can reach up to **80% efficiency** and **purity** on **pions, kaons and protons**, depending on momentum.

Physics case : Heavy Stable Charged Particle (HSCP) search

MTD can directly measure **particle velocity** β. Standard Model particles are typically produced with $\beta \sim 1$; we are thus sensitive to exotic massive particles, which could be detectably slower.

x4 **signal acceptance** in a **HSCP stau** benchmark model with M = 432 GeV!