Use of time information in the High Granularity Calorimeter at the CMS experiment

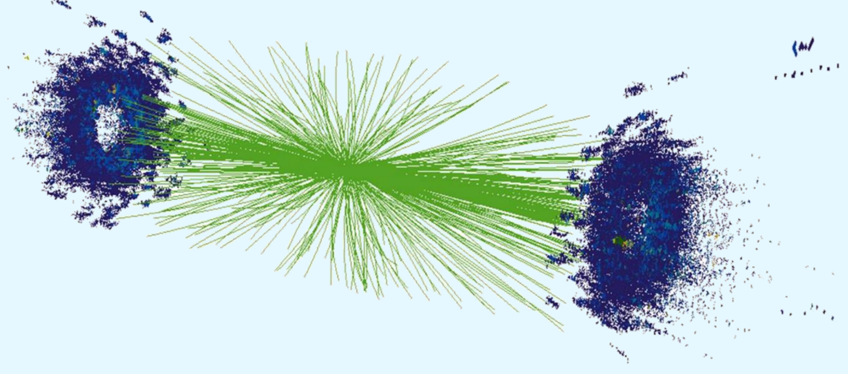
Aurora Perego on behalf of the CMS Collaboration

aurora.perego@cern.ch

CALOR 2024 Tsukuba

HL – LHC challenge

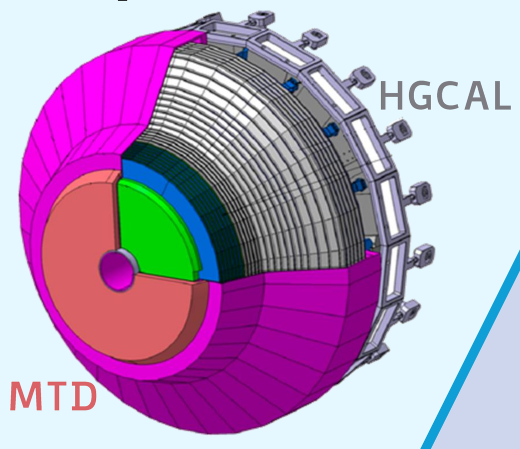
- Substantial upgrade for the **High Luminosity** Phase of **LHC** to extend its physics capabilities
- **Higher luminosity** (up to 7.5 $\cdot 10^{34}$ cm^{-2} s^{-1}) and **pileup** (up to 200), a higher **radiation** environment, and an increase in the **event complexity**
- Extensive detectors and software **upgrades** to cope with these conditions



Event display of $t\bar{t}$ in PU200 showing the tracks and the hits in the High Granularity Calorimeter of CMS

CMS upgrades

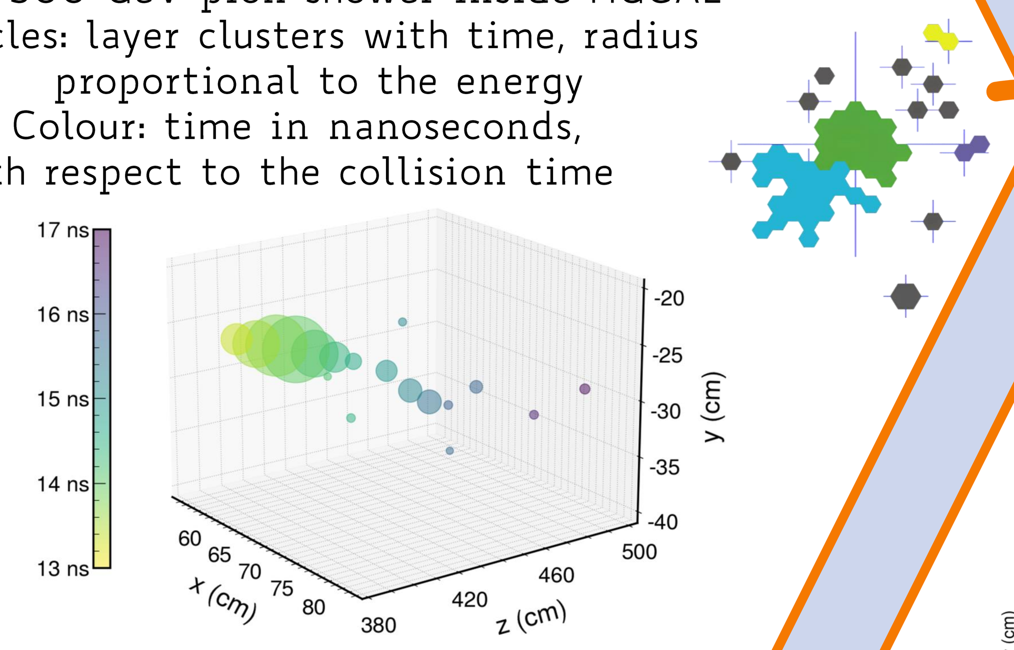
- New strategy: introduction of sub-detectors for **precise time measurements**
- Collision vertices within a bunch crossing ($\sigma_t \simeq 200$ ps) can be distinguished → pileup mitigation
- New **MIP Timing Detector** (MTD): resolution of 30-40 ps for charged particles
- **ECAL barrel** new electronics: 30 ps for showers > 50 GeV
- Current endcap calorimeters replaced by the **High Granularity Calorimeter** (HGCAL): timing information at single-hit level, resolution < 30 ps for layer clusters with p_T > 5 GeV [1] [2]



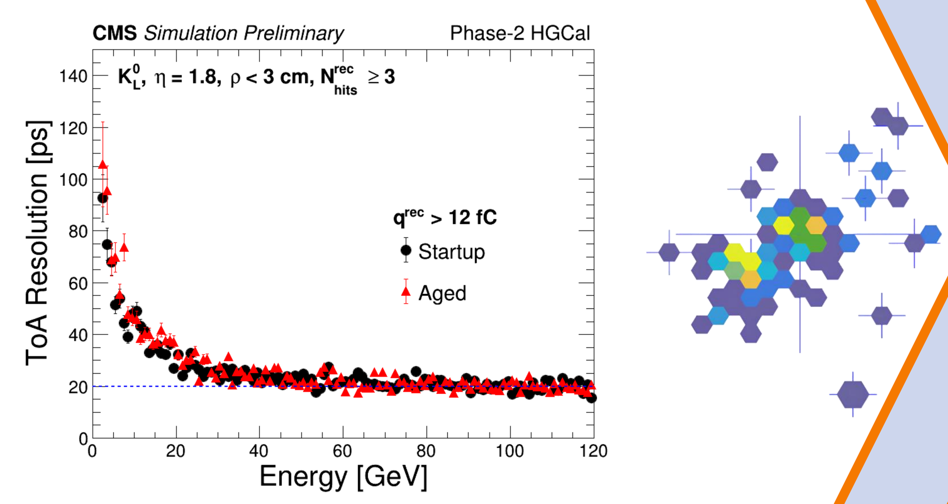
- Required ≥ 3 hits with ToA to compute the **layer cluster time**
- **Average** of the **hits time** weighted with their resolution
- Predefined **time window** containing the highest density of hits considered

Below: **time development** of a 500 GeV pion shower inside HGCAL

- Circles: layer clusters with time, radius proportional to the energy
- Colour: time in nanoseconds, with respect to the collision time

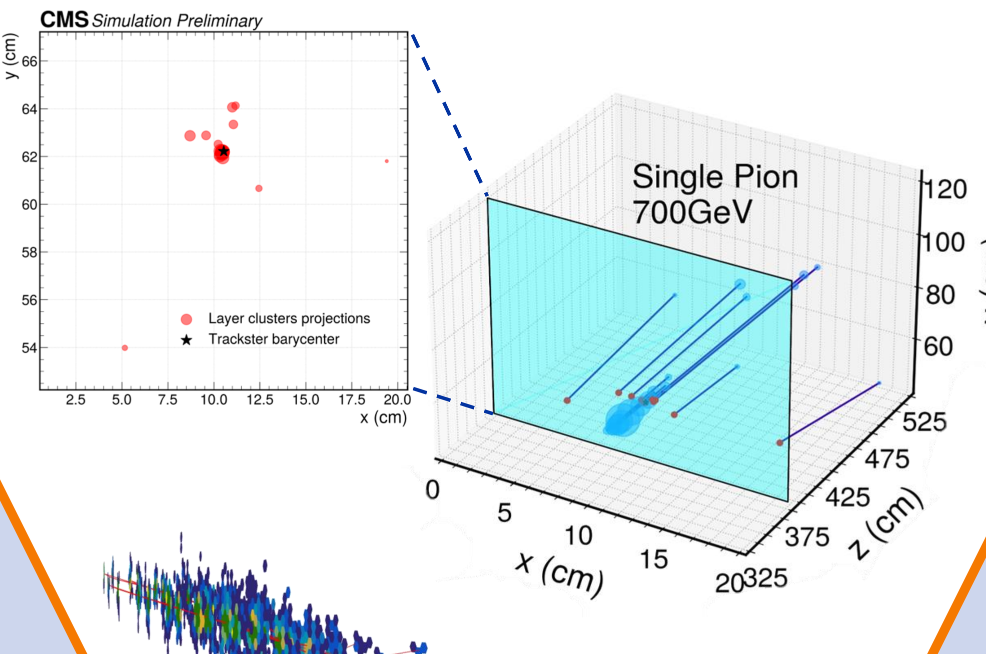


- Particle crossing a sensor in HGCAL and leaving a **charge above threshold** has a **time of arrival** (ToA) measured with a time-to-digital converter
- Time is **local** in HGCAL
- resolution based on S/N ratio and $\propto 1/Energy$



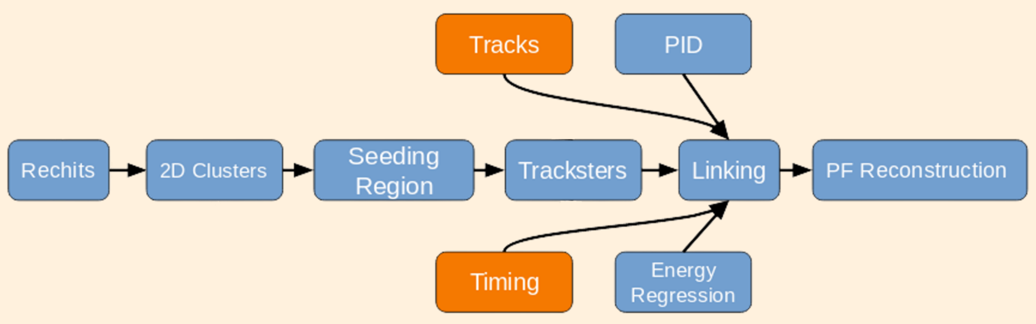
Time resolution of K_L^0 showers (hits within 3 cm from shower axis), as a function of the K_L^0 energy, ToA threshold of 12 fC, at startup (black) and aged (3 ab^{-1}, red) conditions [5]

- Layer clusters **projected** in a straight line towards the origin onto the trackster barycenter x-y **plane** (light-blue plane below)
- Layer cluster times **propagated** at the **speed** of **light** to this plane, **averaged** weighted with the time resolution



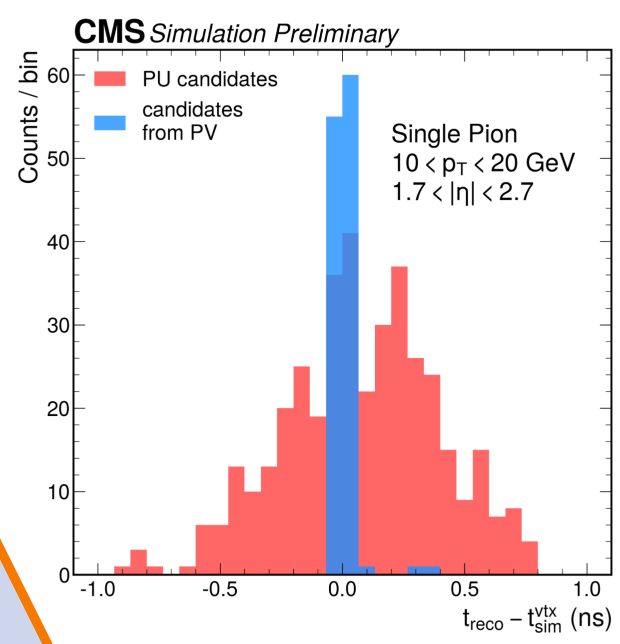
The Iterative Clustering (TICL)

- **Modular** software **framework** integrated in CMSSW (CMS software)
- **Reconstructs particle showers** in **HGCAL** from single hits to final particle candidates and their properties [3]



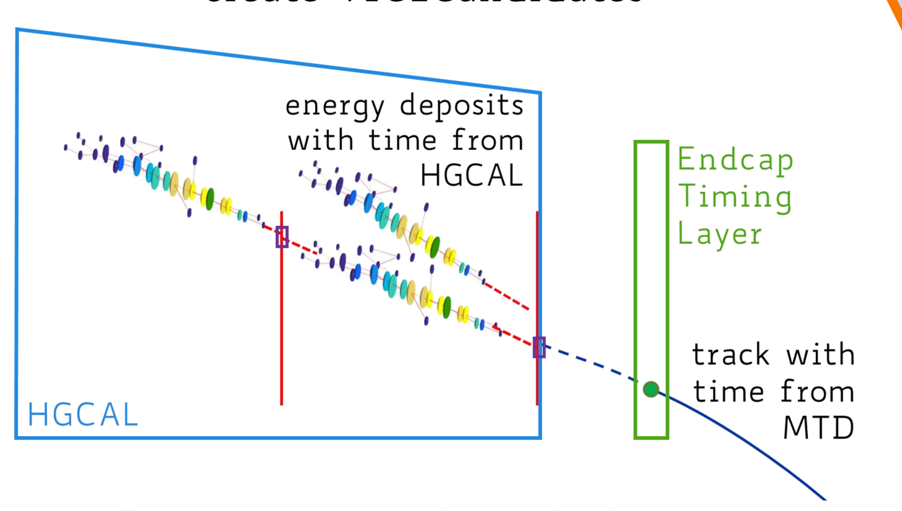
- Hit clustering on each HGCAL layer with **CLUE** [4] to create 2D clusters (layer clusters)
- **Pattern recognition** and **linking** across full detector to create 3D clusters (tracksters)
- Linking with tracks, energy regression and particle identification to obtain the **final candidates** (input to Particle flow interpretation)

- **TICLCandidate time: trackster**(s) time **propagated** back to the point of closest approach to the **beam spot** along the track (or straight line if no track)
- **TICLCandidate** time and **MTD time combined** at **vertex** if both available



- TICLCandidates time compared to simulated vertex time, restricted to charged particles
- Distribution of candidates from pileup vertices matches time spread of the beam spot

Trackster-to-trackster and **track- to-trackster** linking to create TICLCandidates

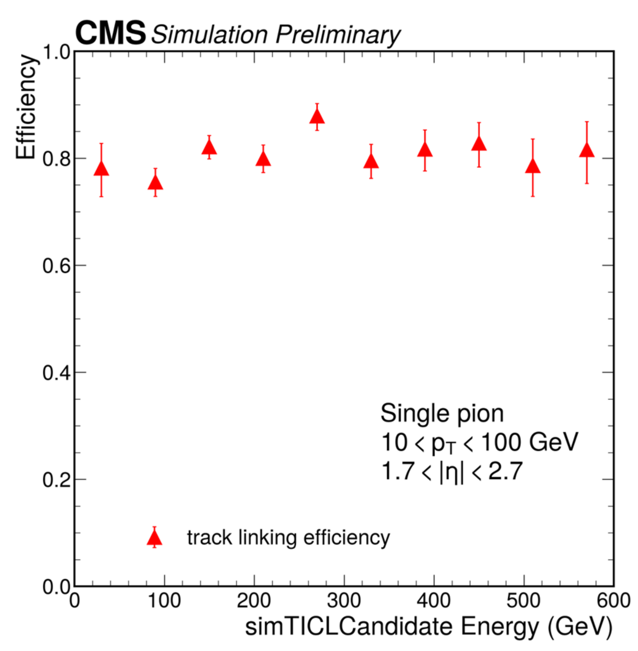


In track-to-trackster linking:

- **geometric**, **energy**, and **time compatibility**
- time compatibility: comparing **track time** from MTD with **local HGCAL time**, projecting times onto each other at the speed of light requiring a 3σ compatibility, with

$$\sigma = \sqrt{\sigma^2_{MTD} + \sigma^2_{HGCAL}}$$

Linking efficiency of a **track** with the correct **trackster** as a function of the simulated particle energy



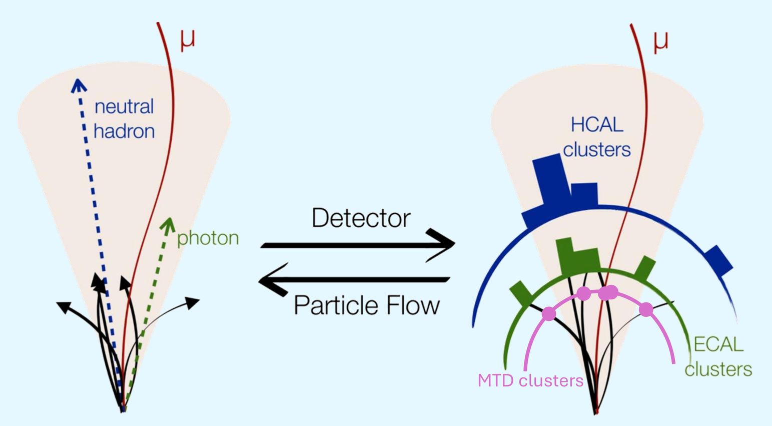
Efficiency: tracks correctly linked over tracks that should have been linked, i.e., reconstructed and passing cuts used in linking algorithm

Conclusion

Timing information provided by HGCAL can be used in **CMS event reconstruction**:

- description of how **time** is **assigned** to each object for every step of **TICL**
- use of timing information in track-to-trackster linking to **reduce pileup** contamination

HGCAL and MTD time combination opens the possibility to perform a **time-aware global event description** in CMS



Future studies

- Use time information in **trackster-to-trackster** linking
- Better exploit time information in track linking and in **global event description**
- Use this work as the starting point for similar studies on **future colliders** detectors

References

[1] CMS Collaboration. "The Phase-2 Upgrade of the CMS Endcap Calorimeter." CERN, Tech Report No. CERN-LHCC-2017-023, CMS-TDR-019, Geneva, 2017, url: https://cds.cern.ch/record/2293646

[2] Lobanov, Artur; CMS Collaboration. "Precision timing calorimetry with the CMS HGCAL." JINST, vol. 15, no. 07, 2020, url: https://cds.cern.ch/record/2723431

[3] Pantaleo, Felice, and Rovere, Marco; CMS Collaboration. "The Iterative Clustering framework for the CMS HGCAL Reconstruction." CERN, Tech Report No. CMS-CR-2022-037, Geneva, 2023, url: https://cds.cern.ch/record/2806234

[4] Rovere, Marco et al. "CLUE: A Fast Parallel Clustering Algorithm for High Granularity Calorimeters in High-Energy Physics." Frontiers in Big Data, vol. 3, 2020, url: https://cds.cern.ch/record/2709269

[5] CMS Collaboration. "Impact of Time-to-Digital converter thresholds on the precision of HGCAL timing." 2024, url: https://cds.cern.ch/record/2886420

20th International Conference on Calorimetry, Tsukuba, Japan — 20 - 24 May 2024