MTD time calibration

Timing days
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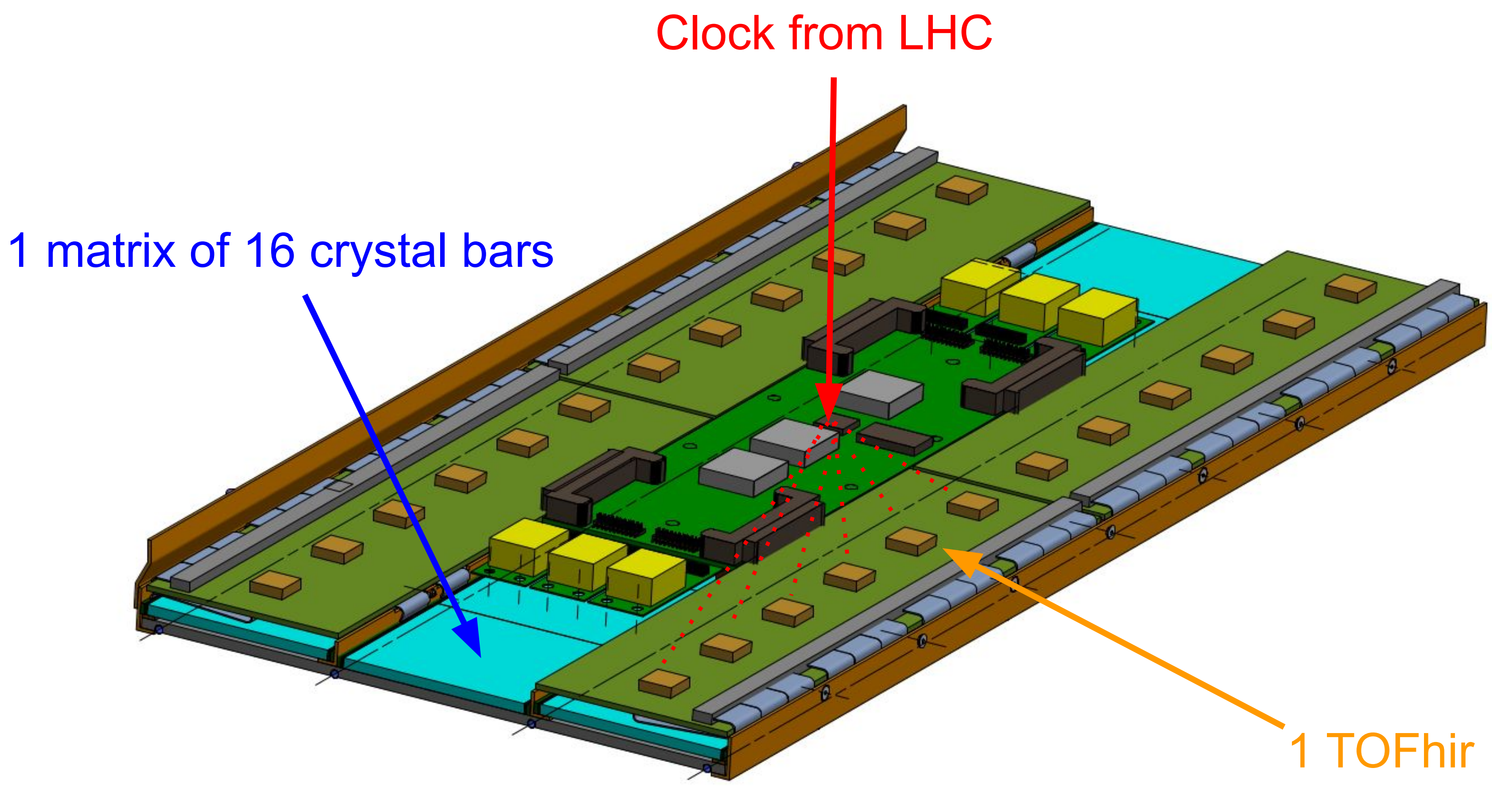
Importance of the time calibration

- In order to achieve 4D track reconstruction → MTD channels synchronization required to be of few ps
- Absolute synchronization wrt LHC clock is not fundamental
  - Event reconstruction relies on relative time between tracks within the same bunch crossing
- What to calibrate exactly?
  - relative time shift of single channels
  - relative shifts of the Readout Units
  - Time dependence vs position for BTL
  - Time dependence vs layer for ETL

BTL Readout Unit

- 1 channel := 1 SiPM → 2 channels per crystal bar
- Readout Unit
  - 24 TOFhir chips
  - 384 crystals → 768 channels
- Clock from LHC to each Readout Unit → distributed to each TOFhir



Time reconstruction

- Time of the track is measured as:

In BTL use the time of the 2 SiPMs at bar sides (anticorrelated)
$c_1 \times (t_L - \Delta t_{SYNCL}) + c_2 \times (t_R - \Delta t_{SYNCR})$ - TOF

In ETL use the time of the 2 detector layers (indipendent)
$c_1 \times (t_{lay1} - \Delta t_{SYNC1}) + c_2 \times (t_{lay2} - \Delta t_{SYNC2})$ - TOF

to be calibrated

- Main contributions are :

$$t_{TRK} = t_{VTX} + TOF + t_{DET} + \Delta t_{SYNC\ RU} + \Delta t_{SYNC\ CH}$$

t_{VTX} = time of the vertex

t_{DET} = detection time

In BTL
scintillation +
light propagation in the bar +
electronics

In ETL
charge drift in silicon +
electronics

$\Delta t_{SYNC\ RU}$ = sync time of the Readout Unit ← to be calibrated

$\Delta t_{SYNC\ CH}$ = sync time of the single crystal ← to be calibrated

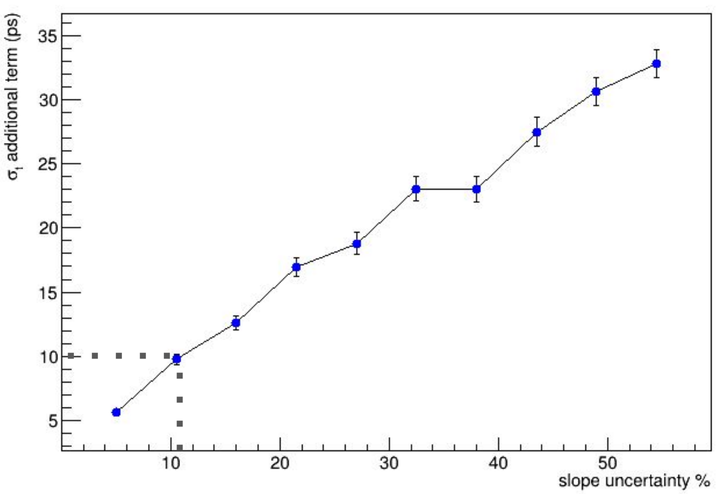
Min bias events for the calibration

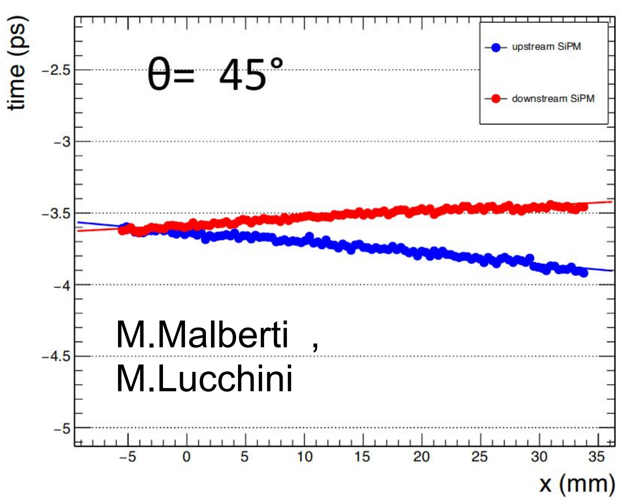
- For the calibration use all the tracks collected by the HLT
- Number of tracks is fundamental to achieve the target precision
- Assuming:
  - 1 kHz HLT rate
  - 5% occupancy per channel to be conservative (more likely 8%)
  - 23 s lumisections

➢ The expected number of min bias events is
  - ~ 10^3 evts / channel / ls
  - ~ 10^4 evts / channel / 200 s
  - ~ $2 \cdot 10^4$ evts / Readout Unit / 1 s

Calibration of c_1 and c_2 for BTL

- $slope_1$ and $slope_2$ describes the dependence of t_1 and t_2 from impact point, along φ direction (φ-geometry)
- $slope_1$ and $slope_2$ can be measured fitting t_1 and t_2 vs extrapolated impact point
  - test beam show dependence on MIP impact angle → on p_T
- $c_1 = slope_1 / (slope_1 + slope_2)$ and $c_2 = slope_2 / (slope_1 + slope_2)$
- Required precision on slope is at least ~ 11%
- Ongoing studies with CMS simulation to estimate the expected precision on the slope in p_T bins





Relation between c_1 and c_2 calibration and Δt_{SYNC}

- In a perfect world for each lumisection:
  1. Calibrate the slopes → compute c_1 and c_2
  2. Calibrate Δt_{SYNC} on top of it
- BUT in order to achieve a sufficient precision on the slopes (~11%) more than a lumisection is required (from preliminary results ~10^2-10^3 lumisection)
- Slopes expected to be stable in a time scale of ~ week (constant MTD conditions)
- Proposed method: split Δt_{SYNC} in the 2 contributions Δt_{SYNC1} and Δt_{SYNC2}
  1. Calibrate separately Δt_{SYNC1} and Δt_{SYNC2} per lumisection
  2. Calibrate the slopes on top of it per 10^2-10^3 lumisections

Calibration of Δt_{SYNC} for BTL

- Measure the time distribution of the tracks and compare it to the bunch crossing nominal time
- Using min bias data of a lumisection: ~10^3 events / ch / ls
- Time spread of the beamspot ~ 200 ps RMS

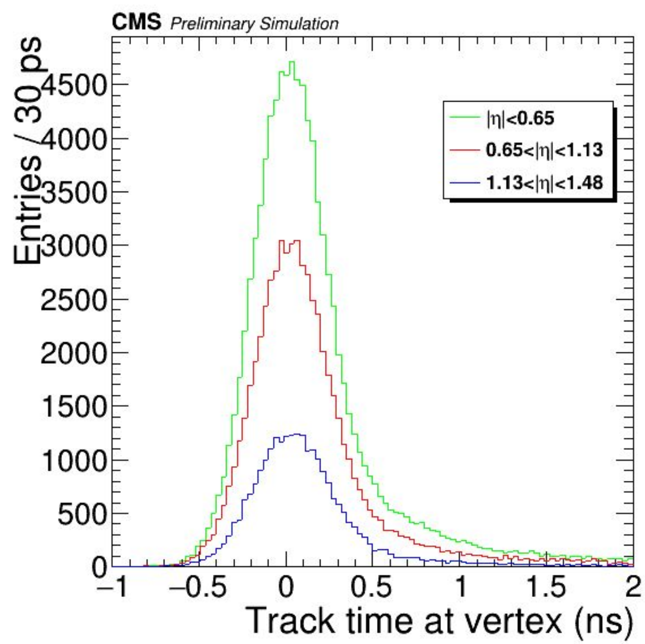
- **If independent calibration of $SiPM_{LEFT}$ and $SiPM_{RIGHT}$**
  - ⊕ Spread due to light propagation in the bar =
    = 50 mm * 6 ps/mm / sqrt(12) = 108 ps
  - ○ Single SiPM time resolution = 40 ps
  - ➢ **Exp. precision** = (200 ⊕ 87 ⊕ 40) ps / sqrt(1000) = **7.3 ps**

- **If calibration only of $c_1 \times t_{LEFT} + c_2 \times t_{RIGHT}$ with $c_1 = c_2 = ½$**
  - ○ Sensor time resolution = 30 ps
  - ➢ **Exp. precision** = (200 ⊕ 30) ps / sqrt(1000) = **6.4 ps**

- Values obtained neglecting the impact of the TOF back-propagation
  - ○ Use simulation to estimate the precision of the method

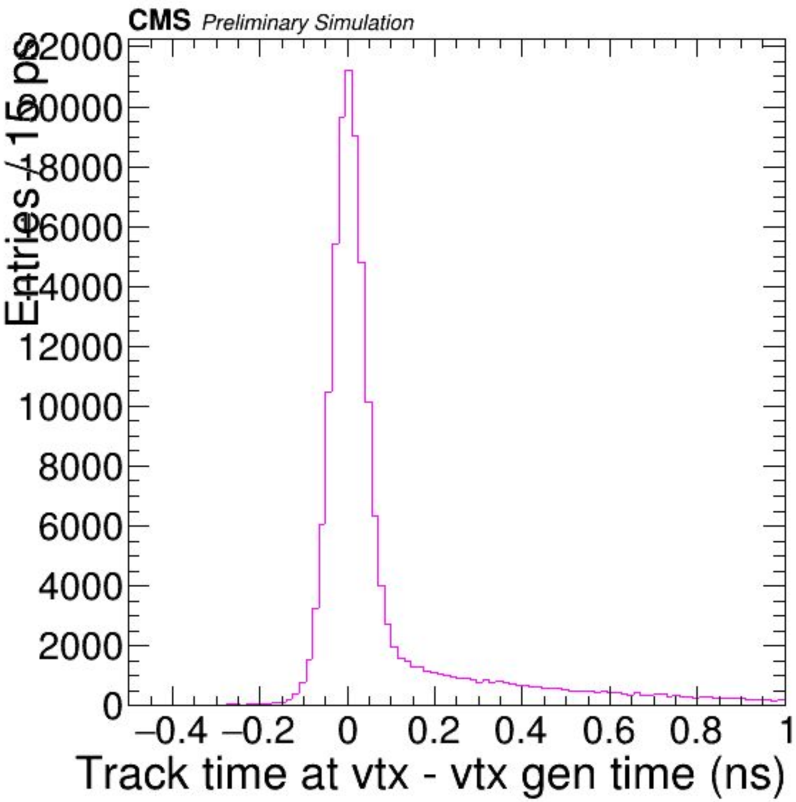
Simulation setup

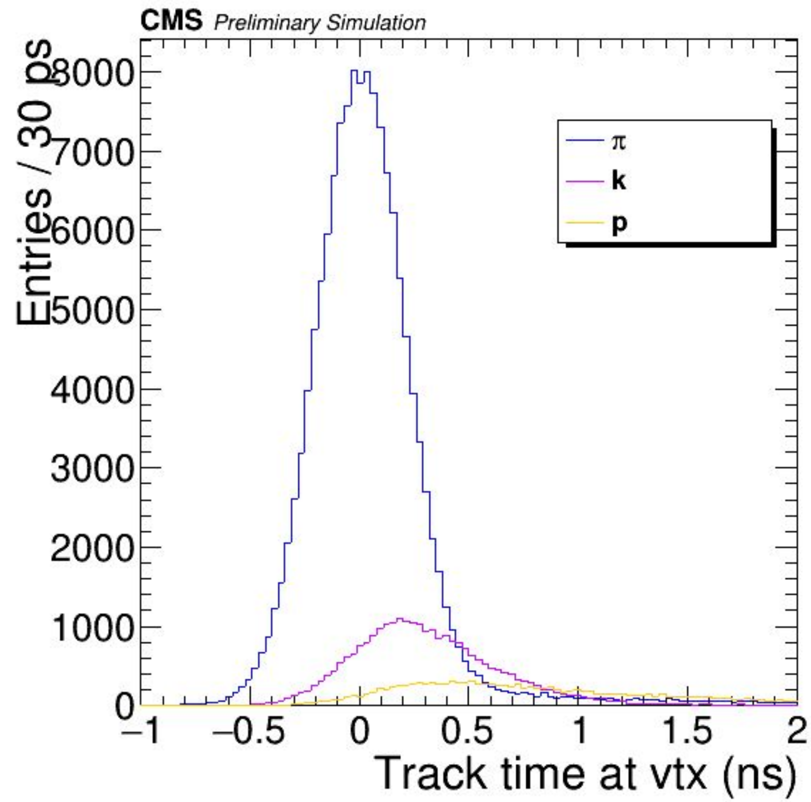
- Simulate min-bias events using CMSSW with phi-geometry, 0-pileup
- For each track use the time of the crystal with the largest energy deposit
- Limited number of simulated events
  - Not possible to calibrate separately each bar/SiPM
  - Take the time distribution in different η-regions and use a MC toy to generate the required number of events
- Once back-propagated, time distribution is independent from η
  - Dominated by beamspot spread
  - Correlation at different η due to tracks coming from the same vertex



Shape of the distribution

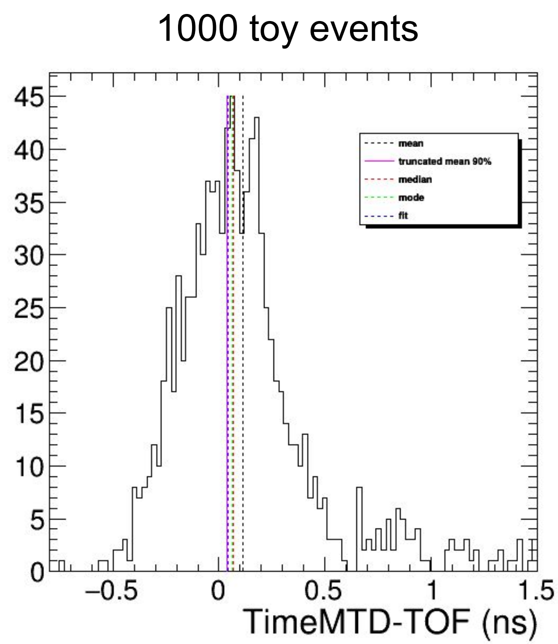
- Right tail in distribution due to *π*-mass hypothesis for *p* and *k* in back-propagation procedure

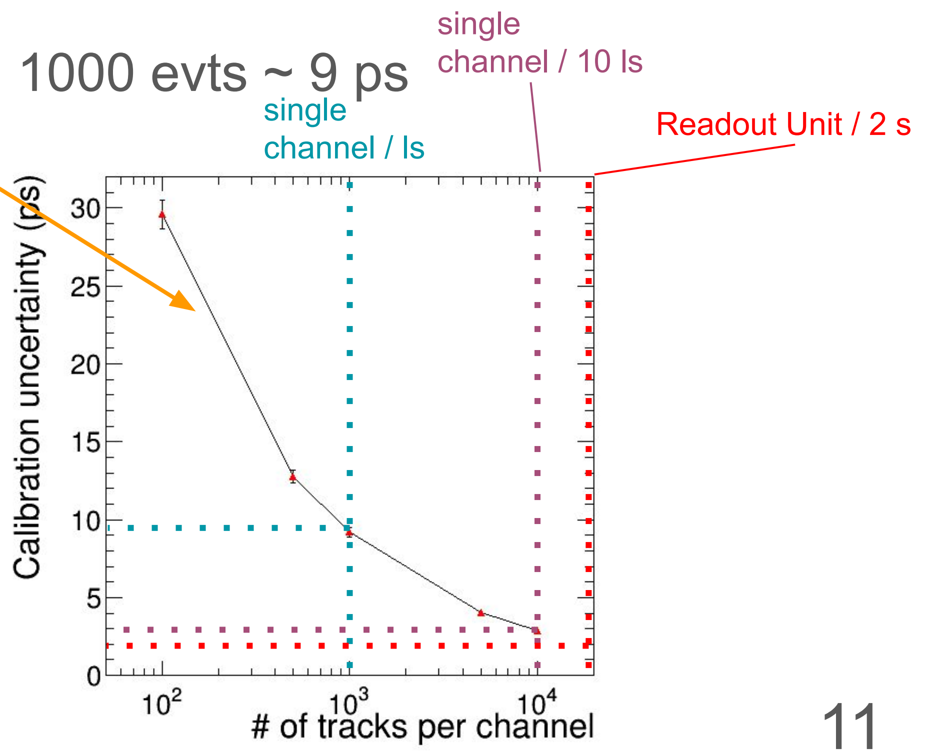




Calibration precision vs number min bias events

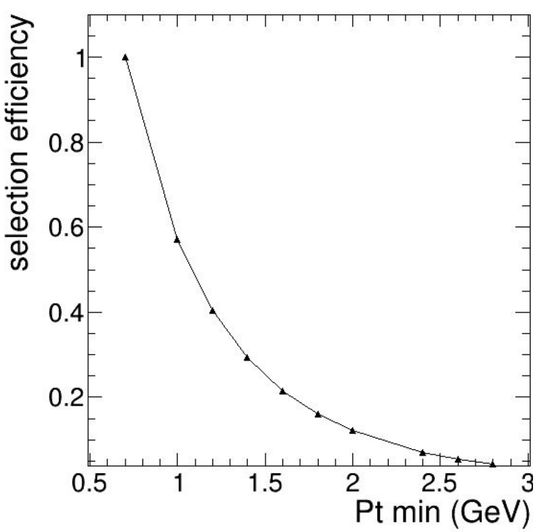
- Results for direct calibration of the bar $((t_{LEFT}+t_{RIGHT})/2)$
- Distribution is not symmetric
  - Try different estimators: mean, median, mode, gaus fit of the core, truncated mean
- Calibration uncertainty = spread between the injected time offset and the estimated time offset
- Best method: median
- Achieved precision calibrating with 1000 evts ~ 9 ps

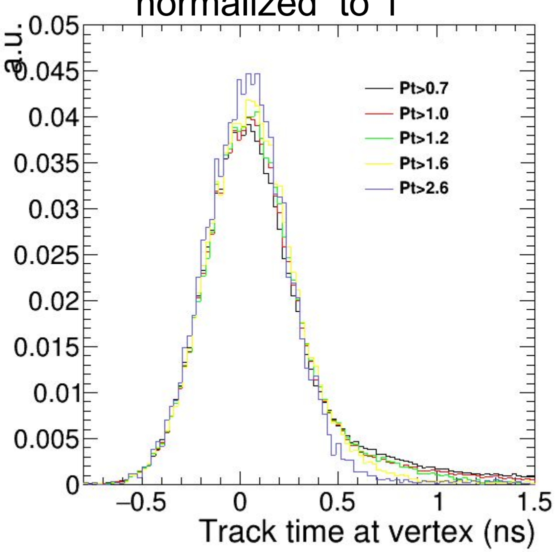


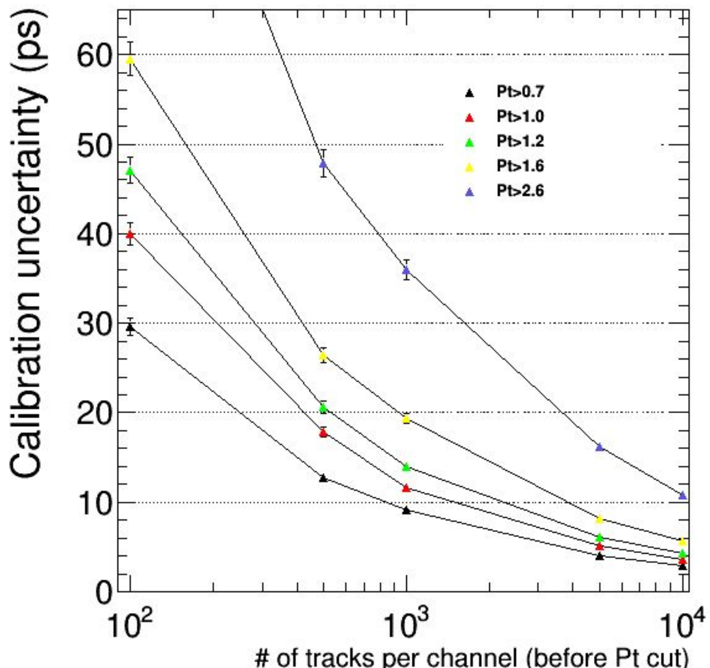


Calibration precision vs Pt cut

- The cut $Pt > Pt_{min}$:
  - Reduces the efficiency
  - Reduces the tails in the distribution due to protons and kaons
    - Visible effect only with a cut Pt>2 GeV→~10% efficiency
- The reduction of efficiency is the dominating effect
  - Best result achieved with full p_T acceptance







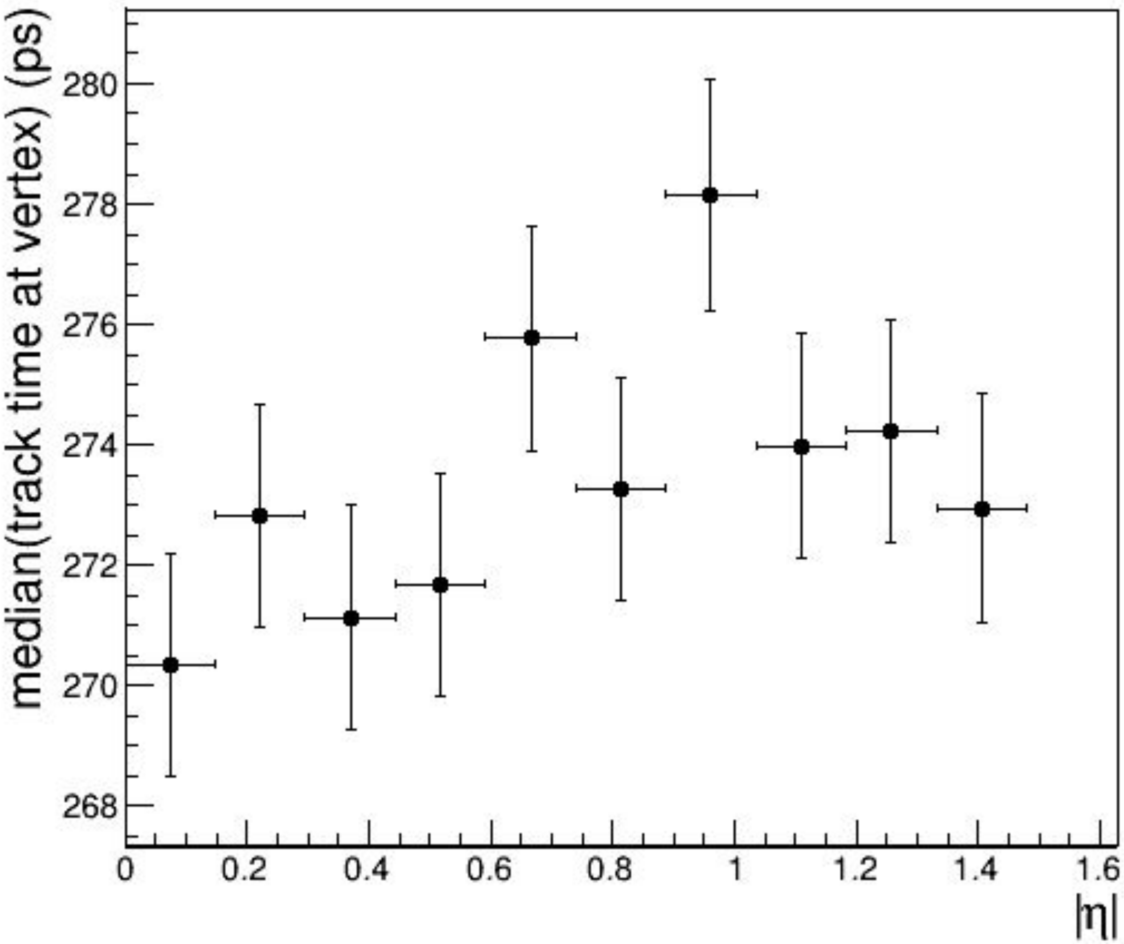
Summary

- Performed feasibility study of the MTD time calibration
  - Mainly focused on BTL calibration: can be easily generalized to ETL (studies ongoing)
  - Expected precision below 10 ps for single channel calibration and below 3 ps for Readout Unit calibration
  - Study of additional systematic effects ongoing (pileup, short period clock instabilities, in-lumisection changes)
- Calibration constants can be made available for the the Prompt reconstruction
- The MTD channel synchronization will not be a limiting factor in the MTD operation

BACKUP

Median vs η

- Median estimator is stable vs η within ~ 3-4 ps



Calibration precision using different estimators

- At large number of events the mode is not reliable due to the binning
- Template fit is better than the median but additional uncertainty expected
  - The template function does not match exactly with the distribution as assumed in the toy