Triplet Track Trigger for Future Hadron Collider Experiments

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Abstract

For the post High Luminosity LHC era, several accelerator projects are under study. The hadron-hadron based Future Circular Collider(FCC-hh) is one such project with the goal to collide proton beams at $\sqrt{s}$ =100 TeV at a bunch crossing rate of 25 ns. Some of the major challenges that the FCC-experiments have to tackle are the very large number of **pile-up events(∼1000)** and the data processing, namely the reduction of the huge data rate of ∼2 PB/s whilst keeping the signal efficiencies high. Therefore, smart triggering concepts that not only allow for a significant reduction of pileup and rate, but also provide high signal acceptance and purity are needed.
In this poster, one such concept of the triplet track trigger (TTT) based on monolithic CMOS technology is introduced for a generic detector geometry. Tracking and trigger performance studies are presented for a full-scale triplet pixel detector in an FCC-like detector environment and it is shown that a significant pile-up, and thus data rate reduction is achievable at the very **first trigger level**.

Physics Motivation

- High **precision measurement** of Higgs boson properties and Standard Model tests, e.g. Higgs couplings.
- Increase the discovery reach with very high energies to search for **New Physics** beyond the Standard Model (BSM).
- Search for **rare processes** with high sensitivity, e.g. $HH, t\bar{t}H, VBF$.

Challenges

- High pile-up (∼ 1000)
  - → high complexity
  - → many ambiguities
- DAQ and Computing
  - → very high data rate of ∼ 2 PB/s at 40 MHz BX
  - → limited data storage rate

Concept of Triplet Track Trigger (TTT)

Track Trigger: event selection based on track information.

Triplet Track Trigger: a generic detector concept to trigger all processes at the electroweak scale & to search for physics BSM.

- Three closely stacked, highly granular pixel layers allow for an easy reconstruction of **triplet tracks**.
- Layers placed at large radius (> 40 cm) along with beamline constraint allow for **very good momentum determination**.
- Pixel precision allows for **precise z-vertex** determination.
- Pile-up suppressed **track-jets** can be reconstructed on trigger level → highly relevent for **multi-jet signatures**, e.g.$hh \to 4b$.

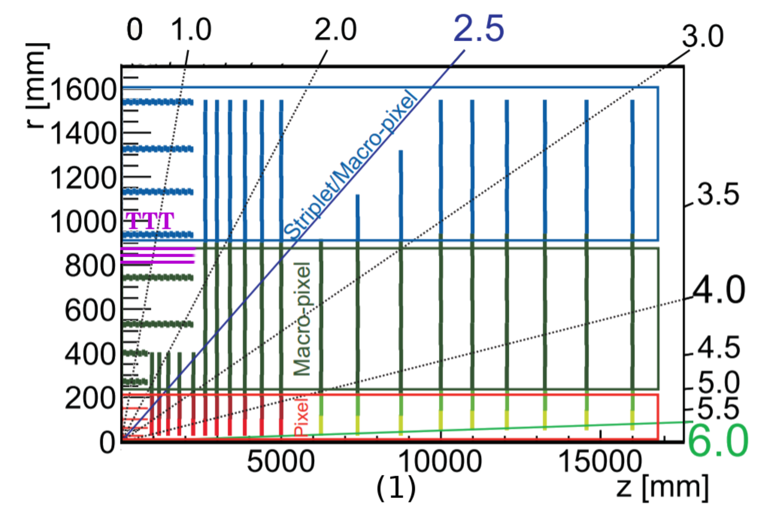
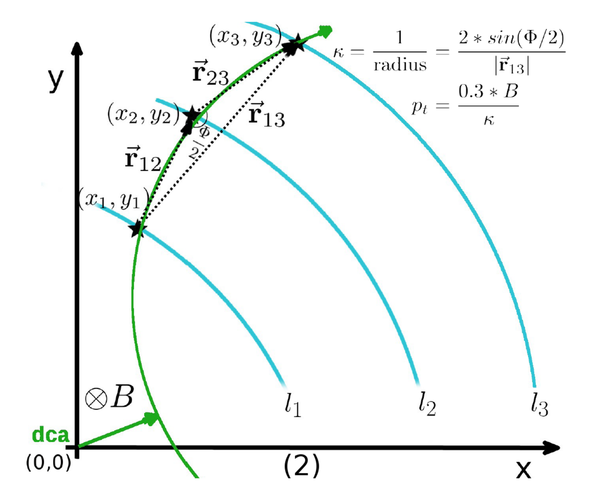
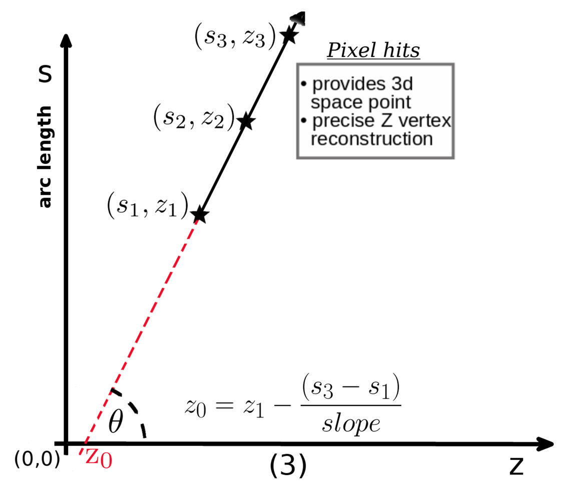


Figure 1: Triplet Track Trigger (TTT) for FCC-hh central tracker placed at a radius of ∼ 85 cm (shown in purple). CMOS Monolithic Active Pixel Sensors are used as its active detector element.

Triplet Track Reconstruction Algorithm

A charged particle's trajectory in a uniform magnetic field **B**: a circle in the x-y plane & a straight line in the s-z plane.





Transverse momentum determination of a charged particle in the transverse plane (Figure 2) and z-vertex in the longitudinal plane (Figure 3) without the beamline constraint

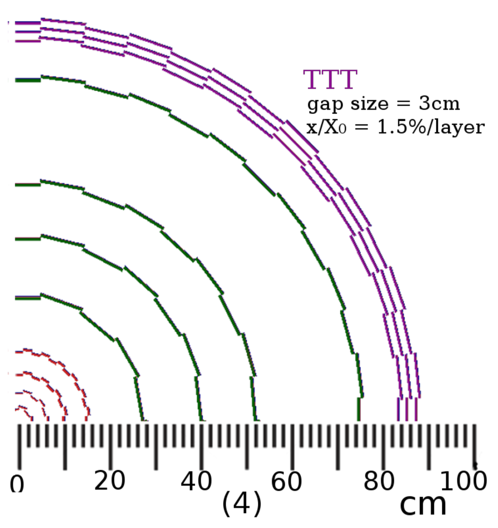
1. **Triplet hit selection**: A search window in the $\Delta z - \Delta\phi$ is defined to search for triplet candidates. Hit combinatorial problem is largely reduced at this stage (stacked triplet layers).
2. **Track Reconstruction**: Two independent methods are used to determine the track parameters in the x-y and s-z plane with hit coordinates measured in,
   - all the three layers, l_1, l_2 & l_3, see Figures 2-3. As $\frac{\sigma p_t}{p_t} \propto \frac{p_t}{B*L} \implies p_t$ is not so precise[a]
   - l_1 & l_3 alone where a pseudo hit (0,0) is used as the third hit[b]. Large $L \implies p_t$ is very precise.
3. **Triplet Validation**: A significant number of wrongly reconstructed tracks are rejected by applying a consistency check on the curvature values determined using the two methods in 2.

Very simple and fast!
Can be implemented in hardware, e.g. in an FPGA, at the very first level of a trigger system

[a] L is the length of the lever arm determining the curvature κ and hence p_t.
[b] It is assumed that the particles originate from the beamline (0,0), called as the beamline constraint

Performance studies of the TTT for FCC-hh

Full Geant4 detector simulation



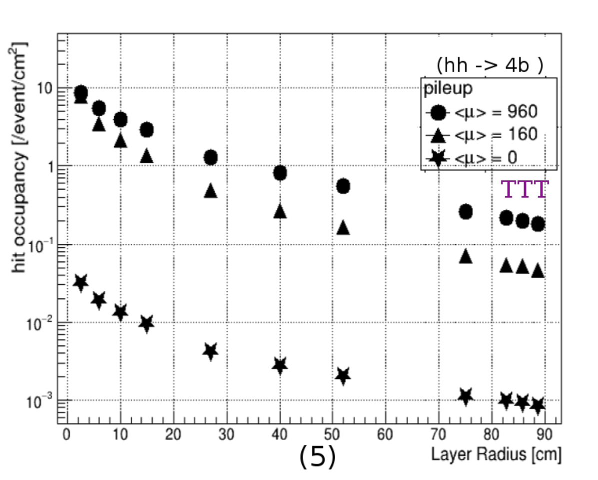
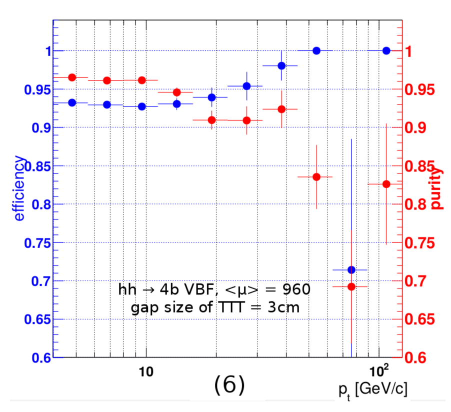


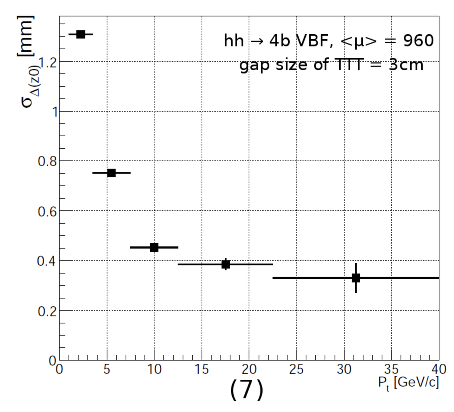
Figure 4 shows a cross-section of the castellated tracker layers implemented in Geant4 for the FCC-hh baseline detector with the TTT and Figure 5 shows the hit occupancies as a function of radius in an FCC-hh like detector environment for three different pileup configurations.

- High pile-up $\implies$ very high hit occupancies
- Full data readout considered to be possible only at radii > 40 cm (lower combinatorics)

Tracking performance

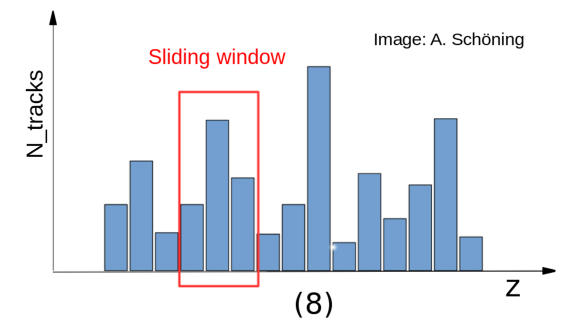
- Track reconstruction efficiencies and purities > 90% for a wide range of track p_t only with **three tracking layers**.
- The z-vertex position of tracks (z_0) is reconstructed with **sub-mm precision**, will allow significant pileup suppression and rate reduction.



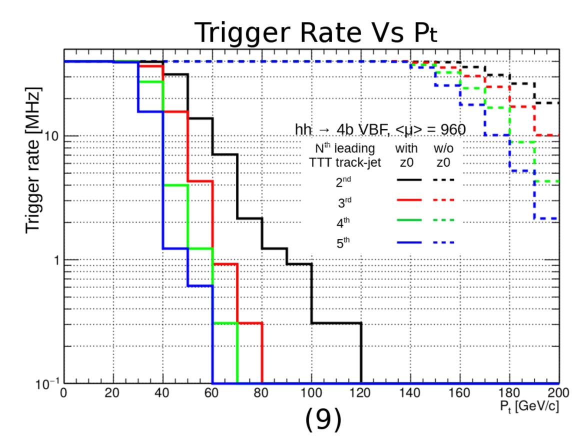


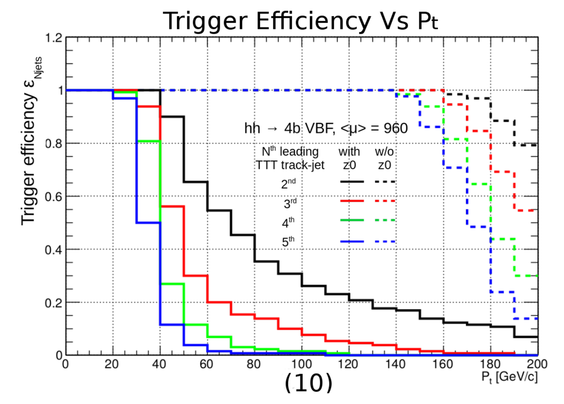
Track reconstruction efficiencies and purities as a function of transverse momentum (Figure 6) and z-vertex resolution as a function of transverse momentum (Figure 7), for $hh \to 4b$, VBF physics channel in pile-up 1000.

Trigger performance



- Small z_0 regions are defined where **jet clustering** alorithms run in **parallel**, see Figure 8.
- Consider all sliding window regions in parallel and **select maximum p_t**.





- A significant data rate reduction is achievable at the first trigger level, see Figure 9.
- The trigger criterion needs to be defined as an optimum of trigger rate and efficiency.

References

[1] M. Benedikt et al., "Future Circular Collider Study, **3**: FCC-hh CDR", CERN-ACC-2018-0058 (2018)
[2] A. Schöning,"Three-Dimensional Triplet Tracking for LHC & Future High Rate Experiments", JINST **9**, C10025 (2014) [arXiv:1408.5536]

Conclusion and Outlook

- The **TTT** concept is based on a very **simple** and **fast** track reconstruction algorithm.
- Early access to the track **vertex** allows significant **pile-up and rate reduction**.
- Performance of **triplet disc** layers in the endcap is foreseen as part of future studies.
- Should be considered for tracking in **Future high rate experiments.**