Triplet Track Trigger for Future Hadron Collider Experiments

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Future Circular Collider

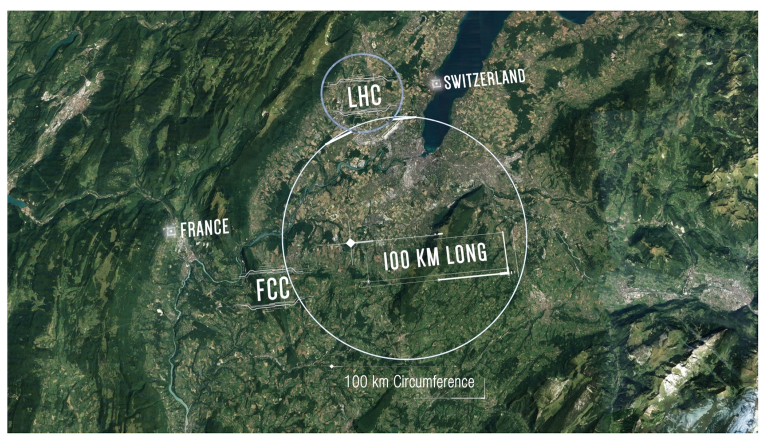


Figure 1: schematic map of the 100km long FCC tunnel, Image: CERN

The hadron-hadron based **Future Circular Collider (FCC-hh)** is a project under study with the goal to collide proton beams at $\sqrt{s}$ =**100 TeV** at a bunch crossing rate of **25 ns**.

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

Challenges

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

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.

Concept and Goal of Triplet Track Trigger (TTT)

- Three closely stacked detector layers
  $\rightarrow$ easy reconstruction of **triplet tracks**
- Layers placed at large radius ($> 40\,\text{cm}$), beamline constraint
  $\rightarrow$ **very good momentum determination**
- Highly granular pixels (CMOS monolithic)
  $\rightarrow$ **precise z-vertex** determination
- Pile-up suppressed **track-jets** at trigger level
  $\rightarrow$ highly relevent for **multi-jet signatures**, e.g.$hh \rightarrow 4b$

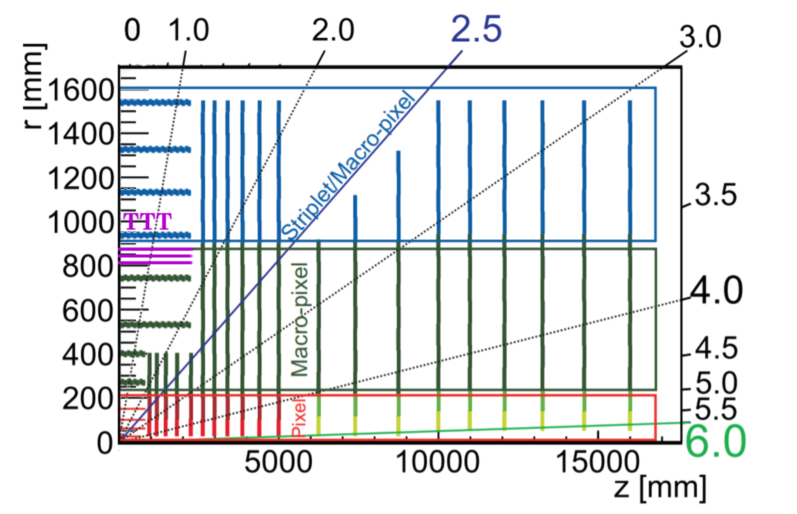
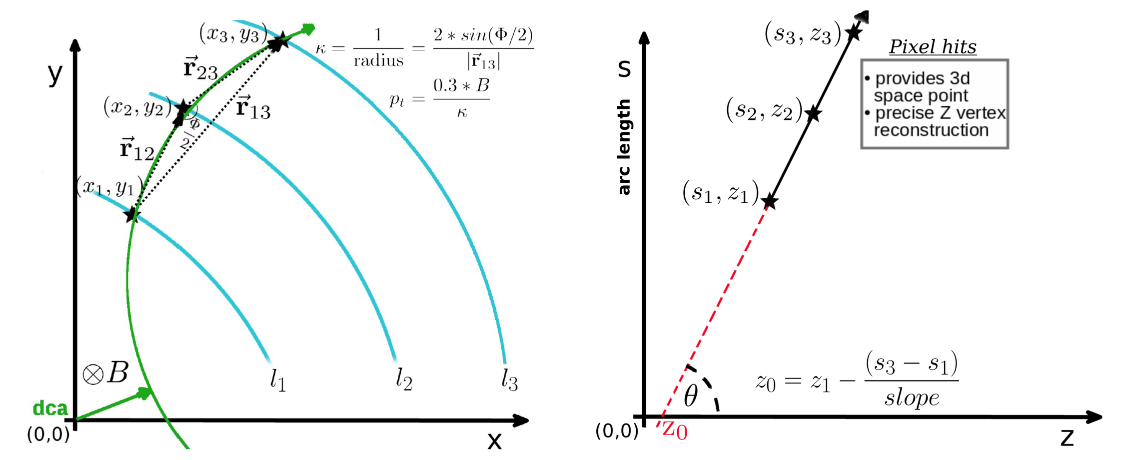


Figure 2: Triplet Track Trigger (TTT) for FCC-hh central tracker placed at a radius of $\sim$ 85 cm (shown in purple).

Triplet Track Reconstruction Algorithm

A charged particle's trajectory in a uniform magnetic field **B**.



(a) (b)

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

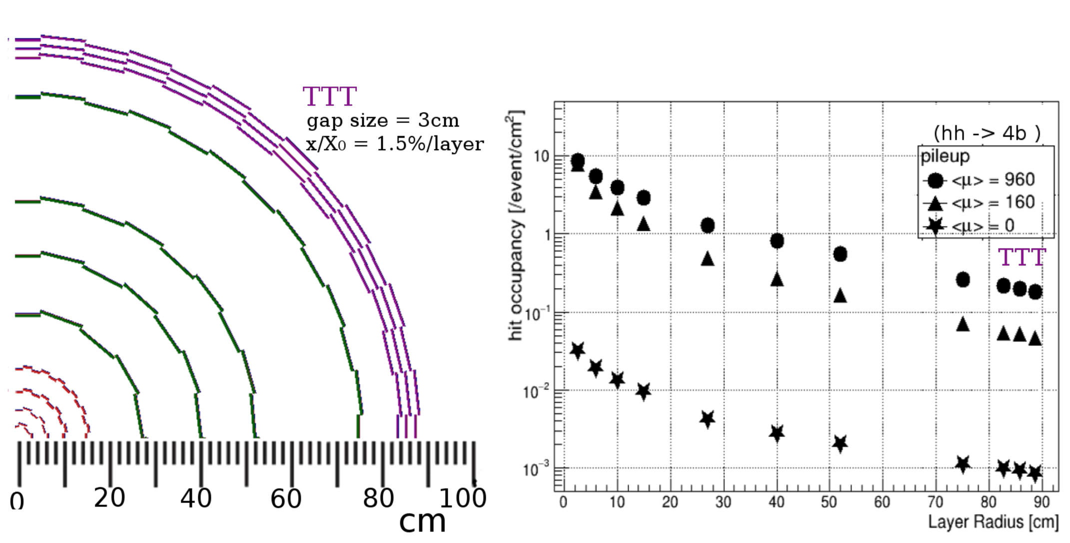
1. **Triplet hit selection**: A search window in the $\Delta z - \Delta\phi$ to search for triplet candidates. Hit combinatorial problem largely reduced at this stage (stacked triplet layers).
2. **Track Reconstruction**: Two independent methods used to determine the track parameters
   - hits from all the three layers, l_1, l_2 & l_3. As $\frac{\sigma_{p_t}}{p_t} \propto \frac{p_t}{B*L} \implies p_t$ is not so precise.
   - hits from l_1 & l_3 alone where a pseudo hit (0,0) is used as the third hit[a]. Large $L \implies p_t$ is very precise.
3. **Triplet Validation**: A significant rejection of wrongly reconstructed tracks 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] 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



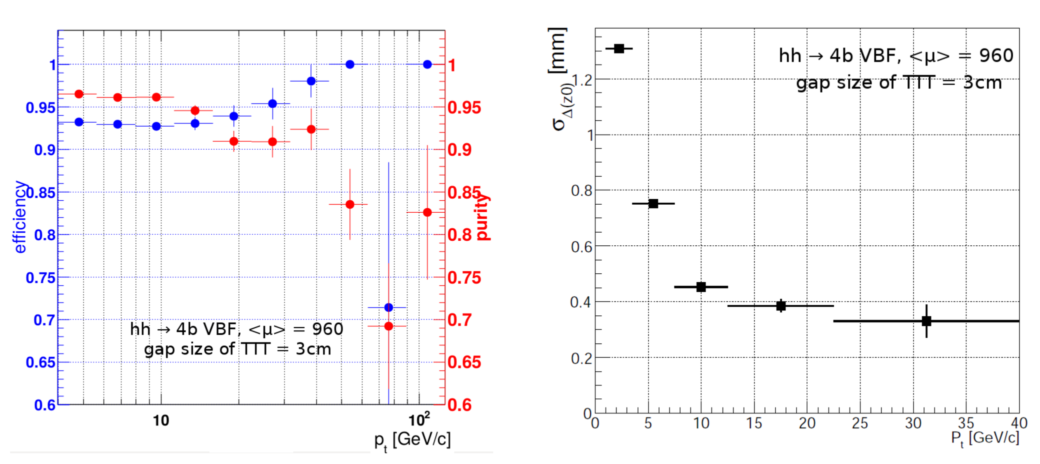
(a) (b)

Figure 4: shows a cross-section of the castellated tracker layers with the TTT implemented in Geant4 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 $> 40\,\text{cm}$ (lower combinatorics)

Tracking performance

- Track reconstruction efficiencies & purities $> 90\%$ with only **three tracking layers**.
- The z-vertex position of tracks (z_0) is reconstructed with **sub-mm precision**
  $\rightarrow$ significant pileup suppression and rate reduction.



(a) (b)

Figure 5: Track reconstruction efficiencies and purities as a function of transverse momentum (a) and z-vertex resolution as a function of transverse momentum (b), for $hh \rightarrow 4b$, VBF physics channel in pile-up 1000.

Trigger performance

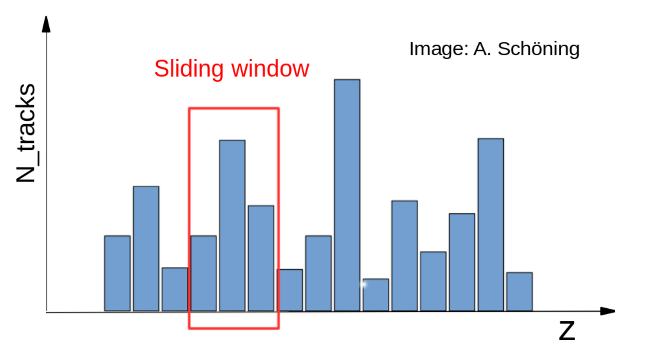
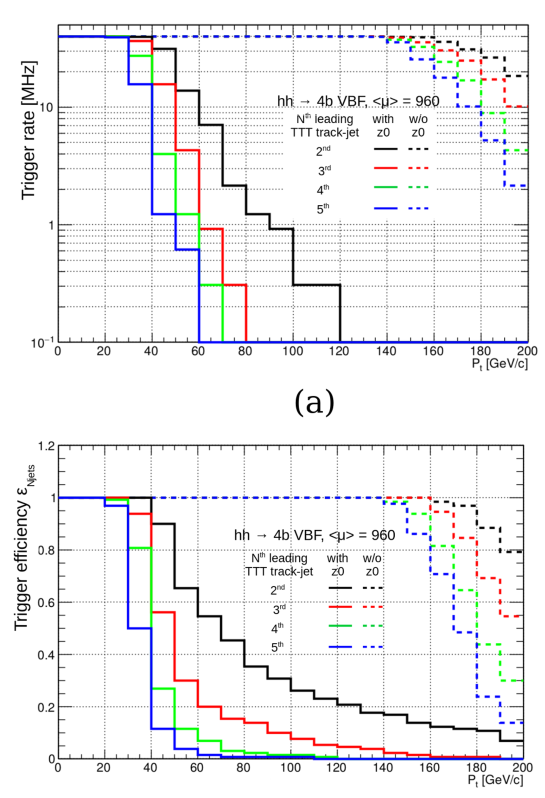


Figure 6: shows parallel jet clustering in the small z_0 regions defined along the beam axis

- All sliding window regions are considered in parallel and the **maximum track-jet $\mathbf{p_t}$ is selected.**



(a)

(b)

Figure 7: Trigger rate (a) and Trigger efficiency (b) of track-jets as a function of transverse momentum

- A significant data rate reduction is achievable at the **first trigger level**, see Figure 7a.
- Trigger criterion: optimum of trigger rate & 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.**