Triplet Track Trigger for Future High Rate Experiments

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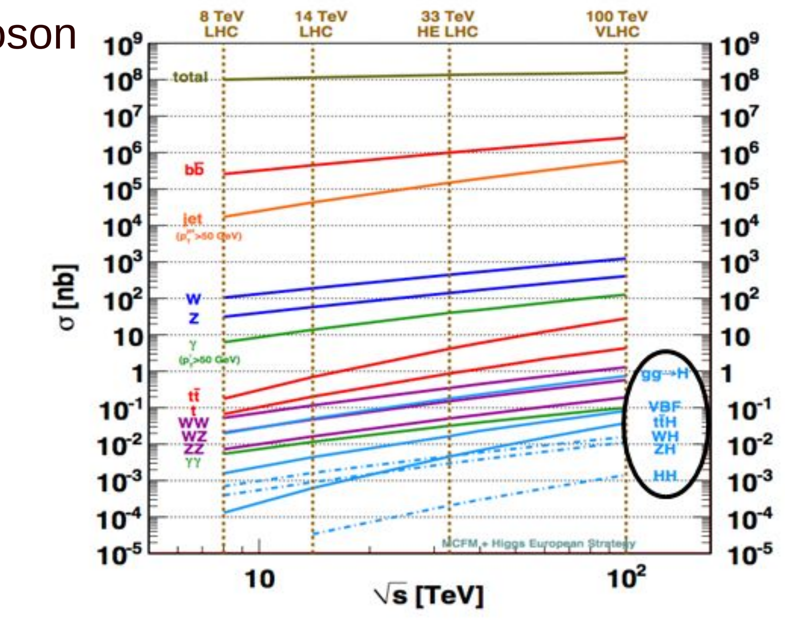
Abstract:

For the post High Luminosity LHC era several accelerator projects are under study with the aim to increase the discovery potential for new physics at both the high energy and intensity frontier. The hadron-hadron based Future Circular Collider (FCC-hh) is one such project with the goal to collide proton-proton beams at $\sqrt{s}$ ~100TeV with a bunch crossing rate of 25ns. 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 1 - 2 PBytes/s whilst keeping the signal efficiencies high. Therefore, we need smart triggering concepts that not only allow for a significant reduction of pile-up and rate but also provide high signal acceptance and purity. One such concept is the triplet track trigger based on monolithic pixel sensors, which is presented for a generic detector geometry. It is demonstrated that the triplet pixel layer design allows for a very simple and fast track reconstruction, providing excellent track reconstruction efficiencies and very high purity at the same time. Based on a full Geant4 simulation tracking performance studies are presented for a full-scale triplet pixel detector, i.e. three closely spaced pixel layers at sufficiently large radius, in a FCC like detector environment. Results obtained for different triplet layer design parameters are compared.

Physics motivation:

- High precision measurement of Higgs boson properties and Standard Model tests, e.g. Higgs couplings
- Fully explore the TeV energy scale to search for New Physics beyond the Standard Model
- Search for rare processes with high sensitivity

Total cross section as a function of centre of mass energy



Challenges:

- High pile-up (~1000)
  → higher complexity
  → many ambiguities
- DAQ and Computing
  → high input data rate (~ 1-2 PBytes/s @40MHz BX)
  → full data rate cannot be stored

High selectivity and efficient pile-up suppression required at the earliest possible stage in the trigger.

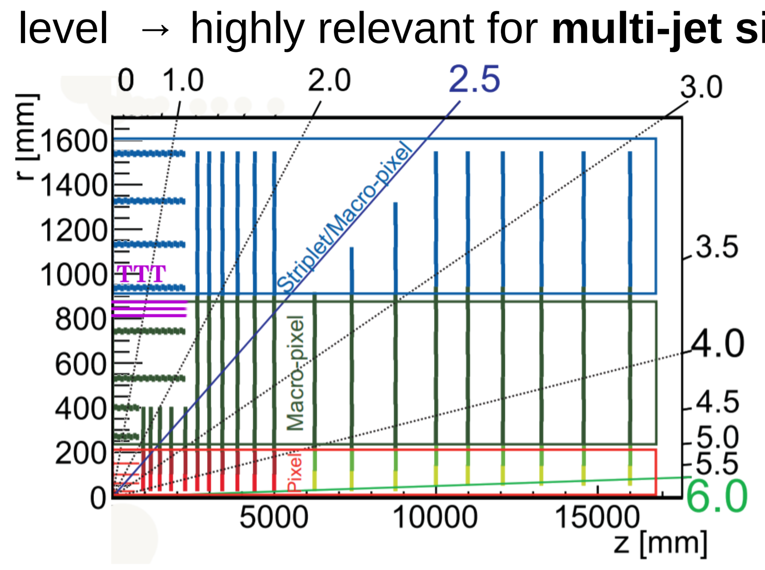
Triplet Track trigger (TTT) concept:

To trigger all processes at the electroweak scale and to look for new physics BSM we propose a generic detector concept: three closely stacked detector layers consisting of highly granular monolithic active pixel sensors at large radii > 40cm

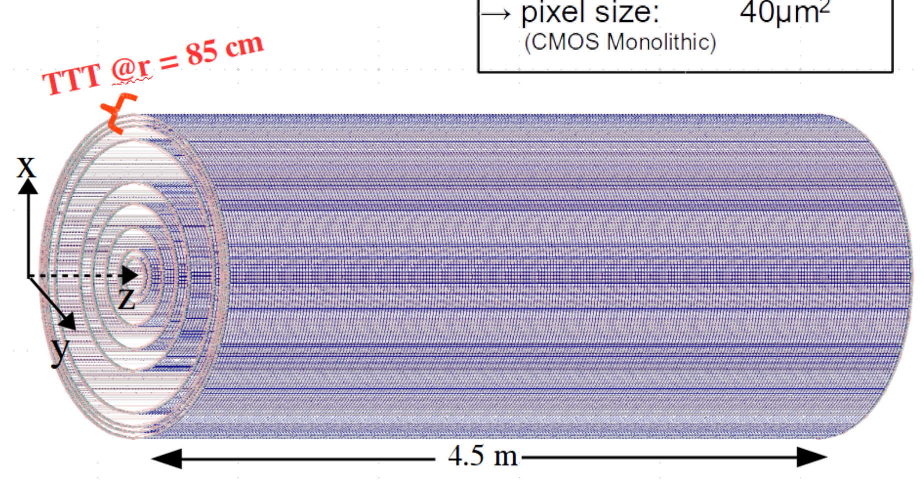
- stacked pixel layers allow for an easy reconstruction of **triplet tracks**
- beam line constraint allows for **very good momentum** determination
- pixel precision allows for **precise z-vertex** determination
- pile-up suppressed **track-jets** can be reconstructed on trigger level → highly relevant for **multi-jet signatures** (e.g. hh→4b)

TTT Geometry Specifications in Geant4:

→ radius:	85cm
→ barrel:	450cm
→ gap sizes:	2, 4, 5 cm
→ x/X_0 per layer:	2%
→ pixel size: (CMOS Monolithic)	40μm²



TTT for FCC - hh tracker

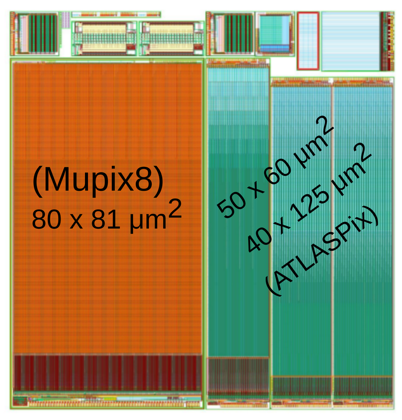


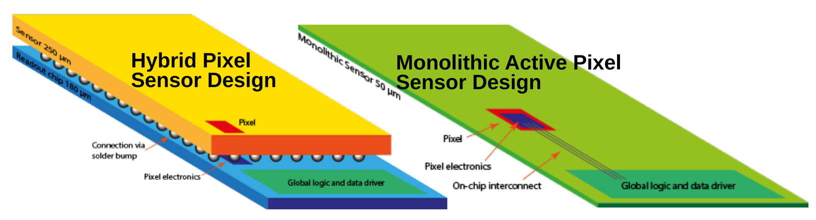
Monolithic Active Pixel Sensors (MAPS):

Unlike the hybrid pixel sensors, MAPS combine the sensor and the readout electronics in a single chip.

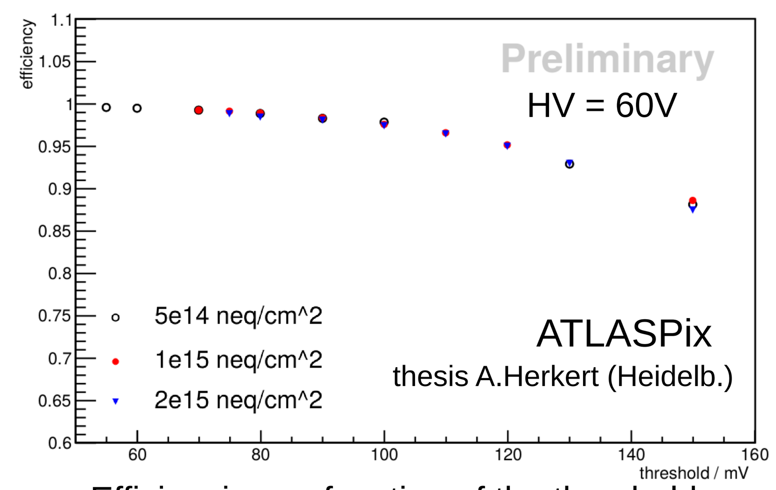
- commercial CMOS process → cost effective
- no hybridisation → less material, easier handling
- possibility to instrument large area of pixel detectors
- HV-MAPS have proven to be radiation hard
- HV-MAPS allow for higher particle rates

First large area HV-MAPS prototype





Hybrid pixel sensor Vs Monolithic pixel sensor



Efficiencies as function of the threshold Voltages for different neutron fluences .

Triplet Track Reconstruction Algorithm:

1. **Triplet hit selection:** A search window in the Δz-Δφ is defined to search for triplet candidates. Hit combinatorial problem is largely reduced already at this stage (stacked triplet layers), compared to conventional tracker designs.
2. **Track reconstruction:** Track parameters are reconstructed using the hit positions measured in the 1st and 3rd layer as input assumping that the particle originates from the beamline (0,0) as shown in fig (a)
3. **Triplet Validation:** A consistency check is done by validating the middle hit position w.r.t the 1st and the 3rd hit. This step allows significant fake rejection and ensures a very high track purity.

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

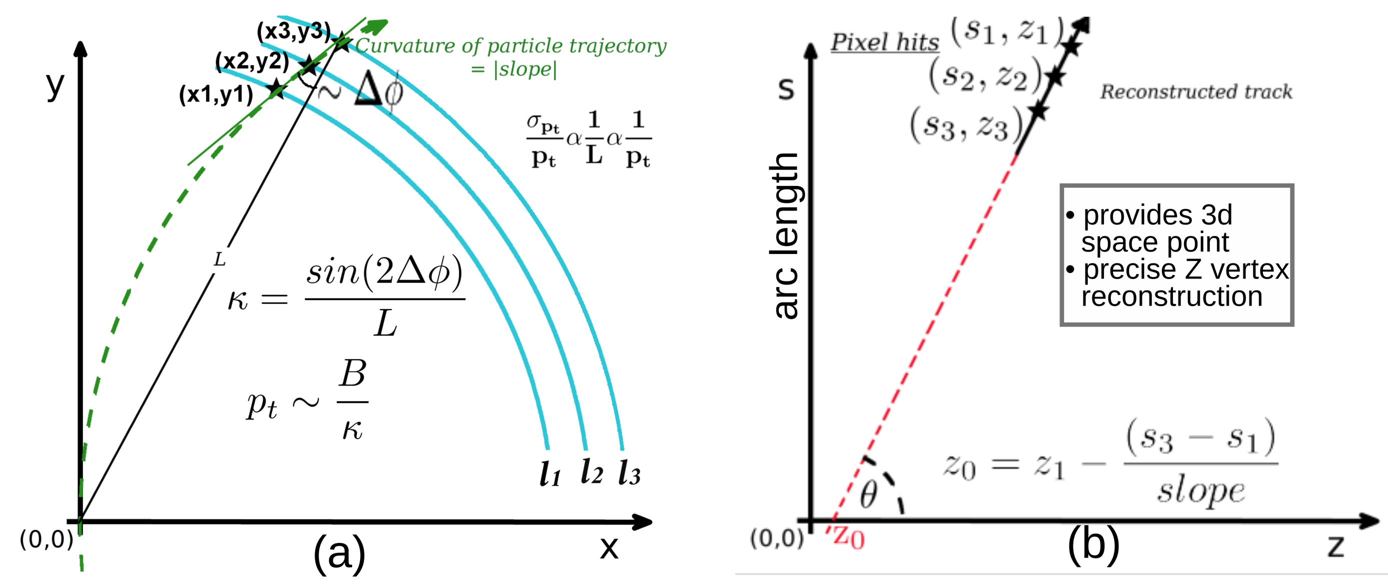


fig (a) reconstruction of a charged particle's track in the transverse plane, in a constant magnetic field B. Transverse momentum of this track can be calculated simply by measuring the slope of a line joining the hits in the three layers.
fig(b) z-vertex reconstruction of this track

Results:

- Physics channel: hh → 4b
- TTT can reconstruct tracks with an efficiency > 95%.
- Momentum resolution of better than 1% @10GeV/c is achievable using TTT with gap size > 20mm
- z0 resolution of sub-mm precision possible using TTT @85cm → will allow significant pile-up reduction
- Track purity degrades more rapidly with the gap size of the TTT with increasing pile-up

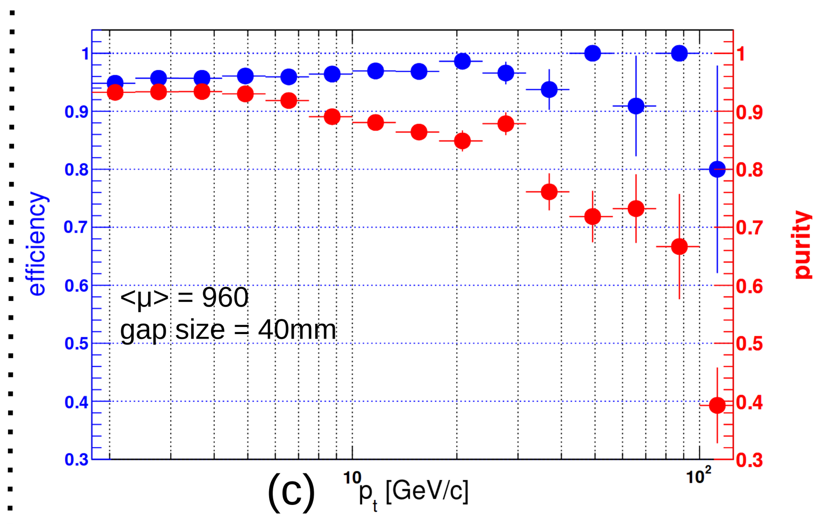
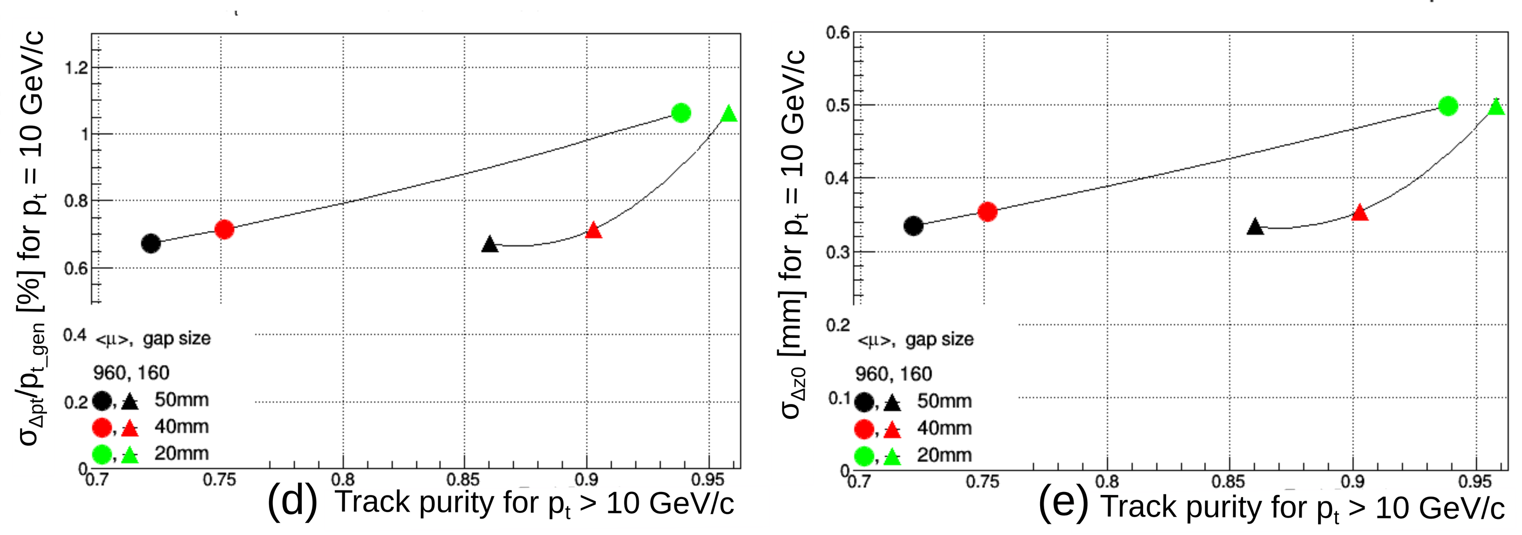


fig (c) Track reconstruction efficiency and purity in hh→4b as a function of transverse momentum in pile-up 1000



Relative p_t resolution (fig (d)) and z0 resolution (fig (e)) of single pions @10GeV/c as a function of track purity in hh → 4b for pt >10GeV/c, for three different gap sizes in pile-up 200 and 1000 resp.

Conclusion:

- MAPS open up the possibilities to construct **large area pixel detectors.**
- The concept of Triplet Track Trigger is based on a **very simple and fast** track reconstruction algorithm and will allow to reconstruct all tracks for the first trigger level → significant pile-up reduction.
- Can be considered for tracking in **Future High Rate Experiments.**

Outlook:

- Carry out track jet based studies using TTT tracks to trigger on e.g. dilepton and multi-jet channels
- Simulate and study the performance of triplet disc layers in the endcap .

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