Track Triggering using Pixel Detectors

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26 May 2021
TIPP21, TRIUMF
Track Triggering using Pixels

• Goal: Develop an algorithm for finding high-momentum tracks using silicon pixel detectors
  – Massive stable charged particles will behave as muons and be triggered by muon system
  – Need silicon tracker-based triggering for short-lived particles

![Graph showing efficiency vs. log10(βγct/cm) for silicon pixels, silicon strips, and muon detectors.](chart.png)
Kinematics of Drell-Yan Production

- Drell-Yan pair production of massive charged particles tends to yield momenta close to mass threshold (examples below from LHC)
  - Phase-space suppression at momenta < mass
  - Parton distribution and matrix element suppression at high momenta
Kinematics of Drell-Yan Production

- Typical boost and life-time dilation factor near unity

- Small-radius tracking increases acceptance for metastable charged particles substantially
Efficiency *versus* proper lifetime

- Small-radius tracking increases acceptance for metastable charged particles substantially, relative to muon trigger, in an interesting range of proper lifetime.

- Conclusion insensitive to charged-particle mass (varied between 100 GeV and 900 GeV above)
Discovery Reach @ HL-LHC (3 ab$^{-1}$)

- Pure wino scenario in SUSY as a source of neutralino dark matter
  - Almost degenerate chargino and neutralino yields chargino proper decay distance $\sim 6$ cm [Low & Wang, JHEP 1408, (2014) 161]
  - Signal event yields of 1000 events (upper curves) and 100 events (lower curves)
Comparison to triggering on Initial State Radiation

- Substantial loss of acceptance when requiring a large transverse momentum kick ($q_T$) from initial-state QCD radiation
  - Rate suppressed by factor of 10 at high mass, and factor of 1000 at low mass
Comparison to triggering on Initial State Radiation

- Substantial loss of acceptance when requiring a large transverse momentum kick ($q_T$) from initial-state QCD radiation
  - Mass reach reduced by 200-300 GeV if using ISR trigger than a track trigger
Track Triggering using Pixels

• **Goal:** Develop an algorithm for finding high-momentum tracks using silicon pixel detectors

• **Requirements:**
  – Trigger particle with $p_T > 10$ GeV
  – Barrel detector coverage (skip forward disks)
  – No regions of interest pre-defined by other trigger objects, i.e. track trigger should be standalone
  – Latency of a few microseconds
  – To be implemented in FPGAs
  – Ideally, trigger electronics should be on-detector
    • avoid reading out the full detector for trigger processing
    • Design should be modular and segmented
Track Triggering using Pixels

Concept: use a large number of simple processing units

- Modular design of each processing unit that can be replicated in FPGAs
- Exploit massively parallel processing capability
- Effectively running a huge number of “threads” in parallel

Algorithm emulated in software

- Pileup hits from 200 collisions are parsed into two-dimensional “towers”
- Each tower is processed independently by identical circuits
Track Reconstruction using Graph Computing

- Discussion of concept published:

- Graph computing methodology - each hit processed by a graph node
- Trajectories sorted by smoothness locally
- Information sharing between nodes to find smoothest trajectory globally
Track Reconstruction using Pixels

- Discussion of concept published:

- Limitations:
  - No noise hits
  - All generated tracks with $p_T > 1$ GeV
  - Attempted full tracking in large sectors (unrealistic)
Full Reconstruction -> High $p_T$ Trigger

• Reduce tower dimensions

• Use realistic $p_T$ spectrum for pileup particles (peak ~ 250 MeV)

• Include “loopers” in the magnetic field

• Include resolution effects for ~50 micron pixels

• Trigger particle with $p_T > 10$ GeV embedded amongst low $p_T$ pileup tracks
Full Reconstruction -> High $p_T$ Trigger

Trigger particle with $p_T > 10$ GeV embedded amongst low $p_T$ pileup tracks
Results of emulation in software

- Assume 5 pixel sensor layers spaced 5 cm apart, 5...25 cm radii

- Efficiency of finding high-$p_T$ track in 200 pileup events > 99.9%

- Tracks found are robust, very small rate for wrongly-assigned hits

Next steps
- Study spurious trigger rate and FPGA implementation
Summary

• A standalone track trigger based on silicon tracking detectors has significant physics potential
  – Metastable charged particles with proper lifetime in the few mm to tens of cm range provide a motivated physics case
  – Postulated in models of dark matter

• Studies of an algorithm based on graph computing in progress
  – Parallel processing architecture
  – Search for locally smooth trajectories at each processing node
  – Iterative procedure with information exchange between nodes
  – Convergence towards globally smoothest trajectory

• Initial results suggest high track-finding efficiency > 99%
  – Evaluation of fake rate in progress
  – Feasibility of FPGA implementation to be investigated