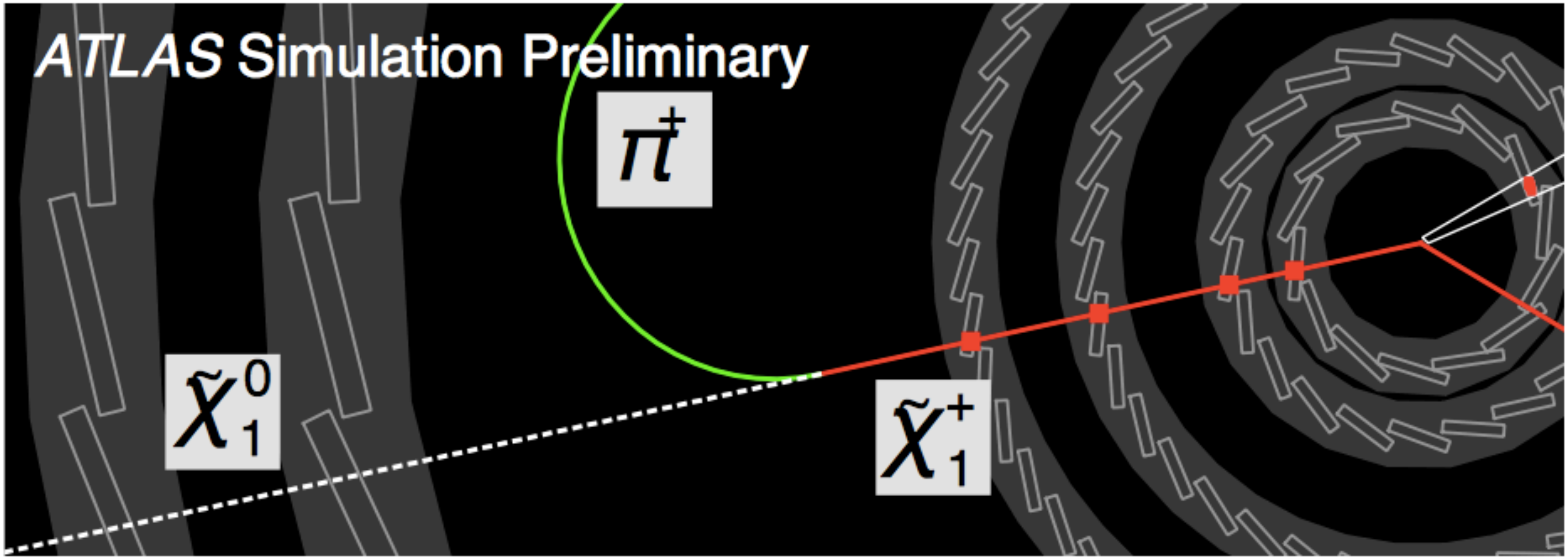
Track Triggering using Silicon Detectors



Ashutosh V. Kotwal
Duke University

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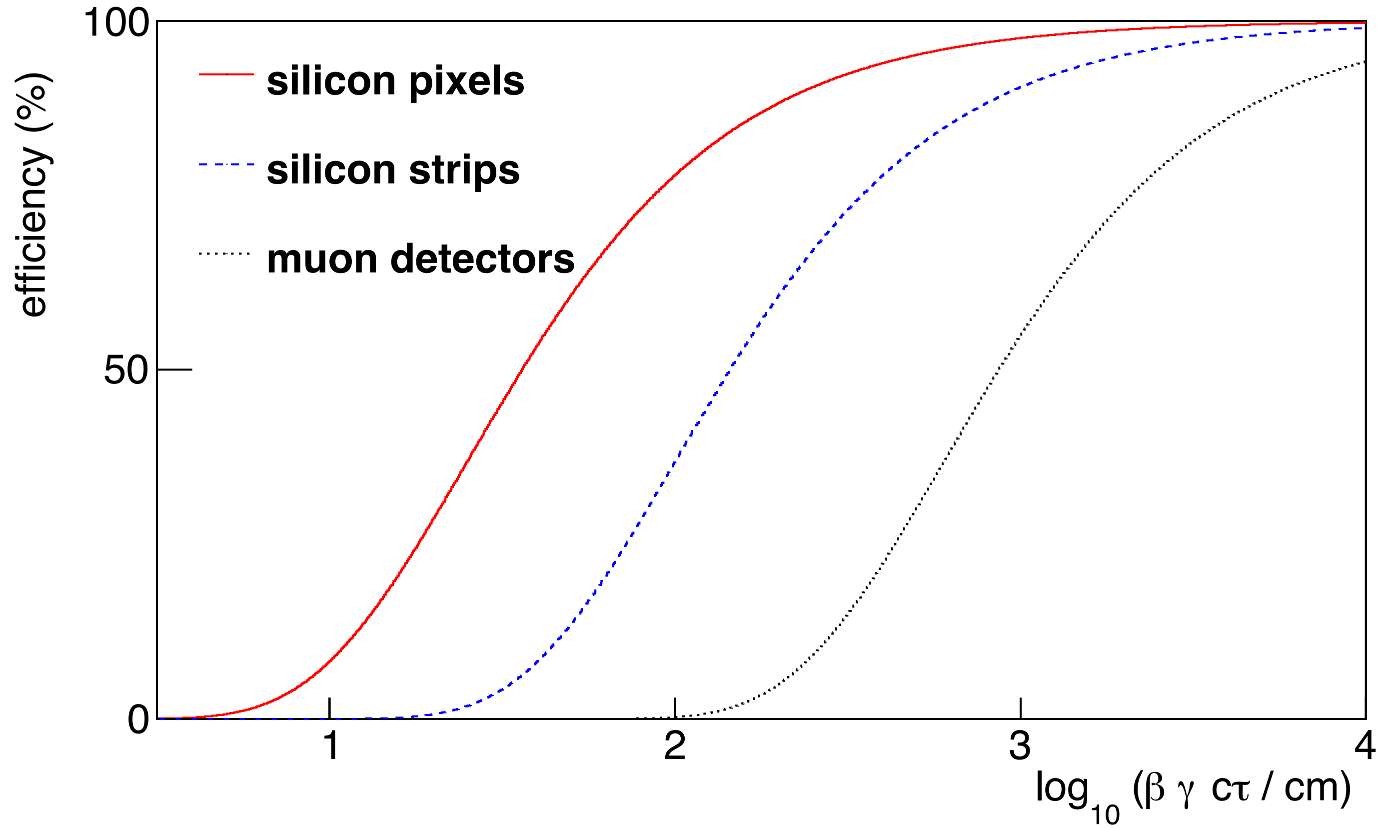
Snowmass 22, U. of Washington, Seattle

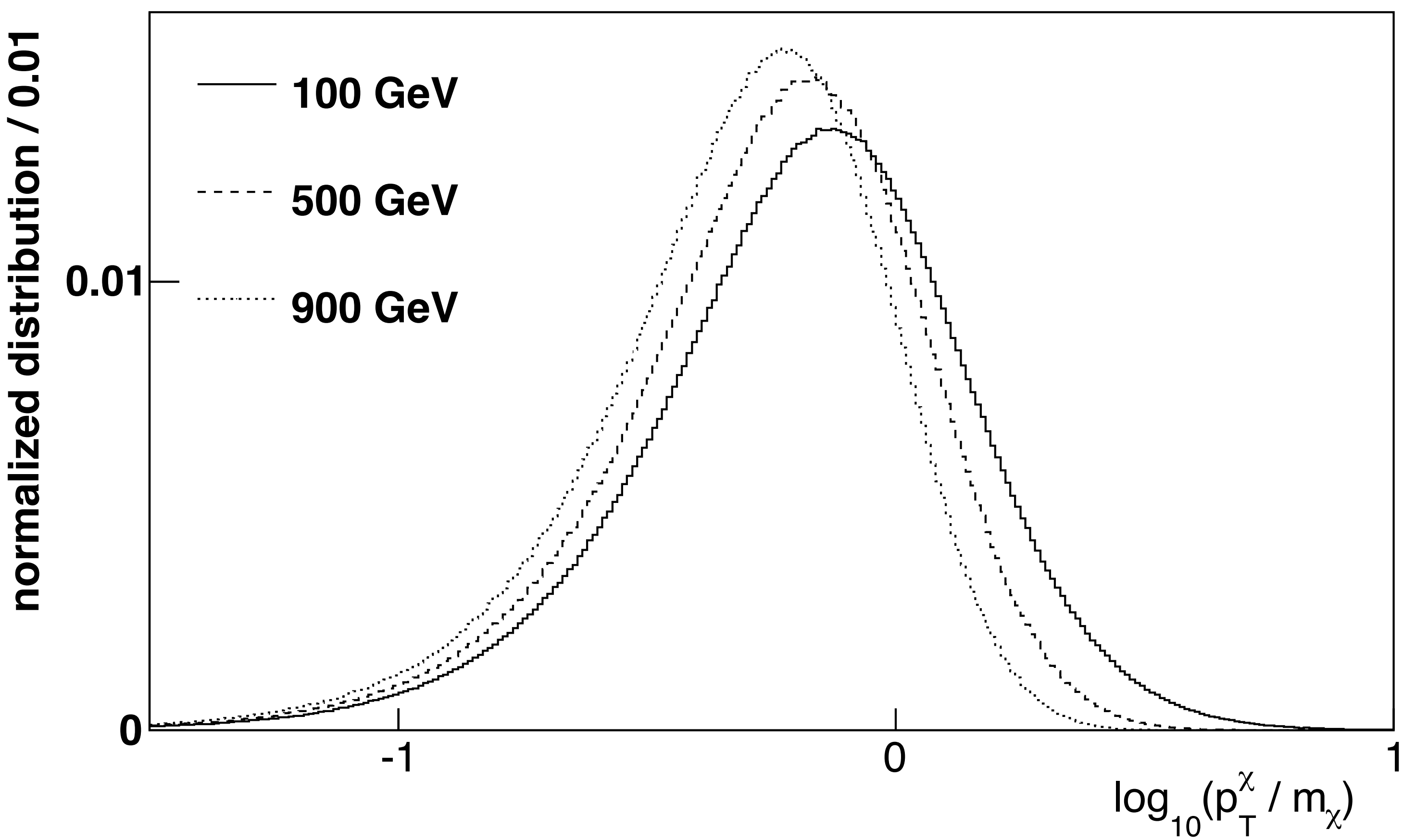
Track Triggering using Pixels

- 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



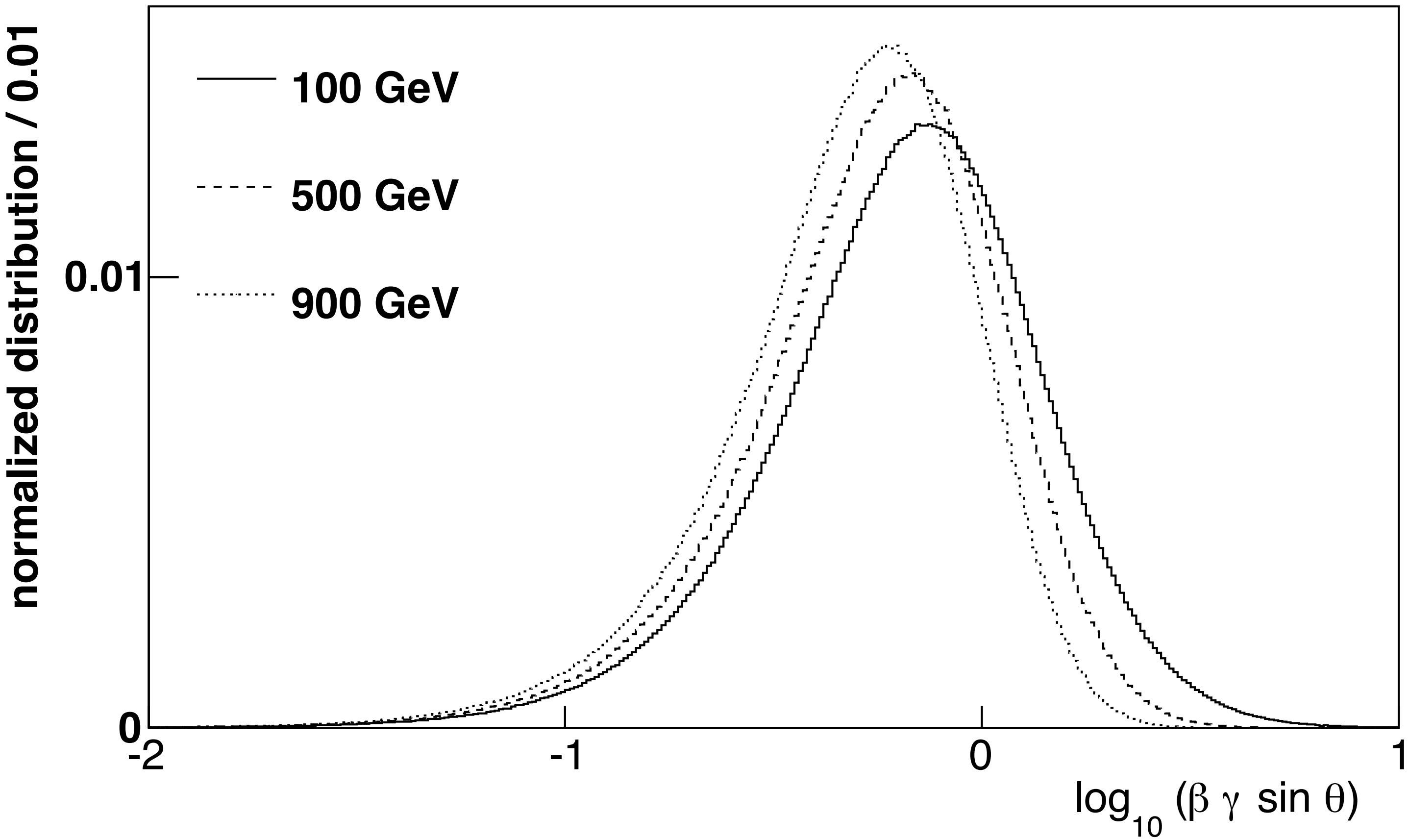
Kinematics of Drell-Yan Production

- 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

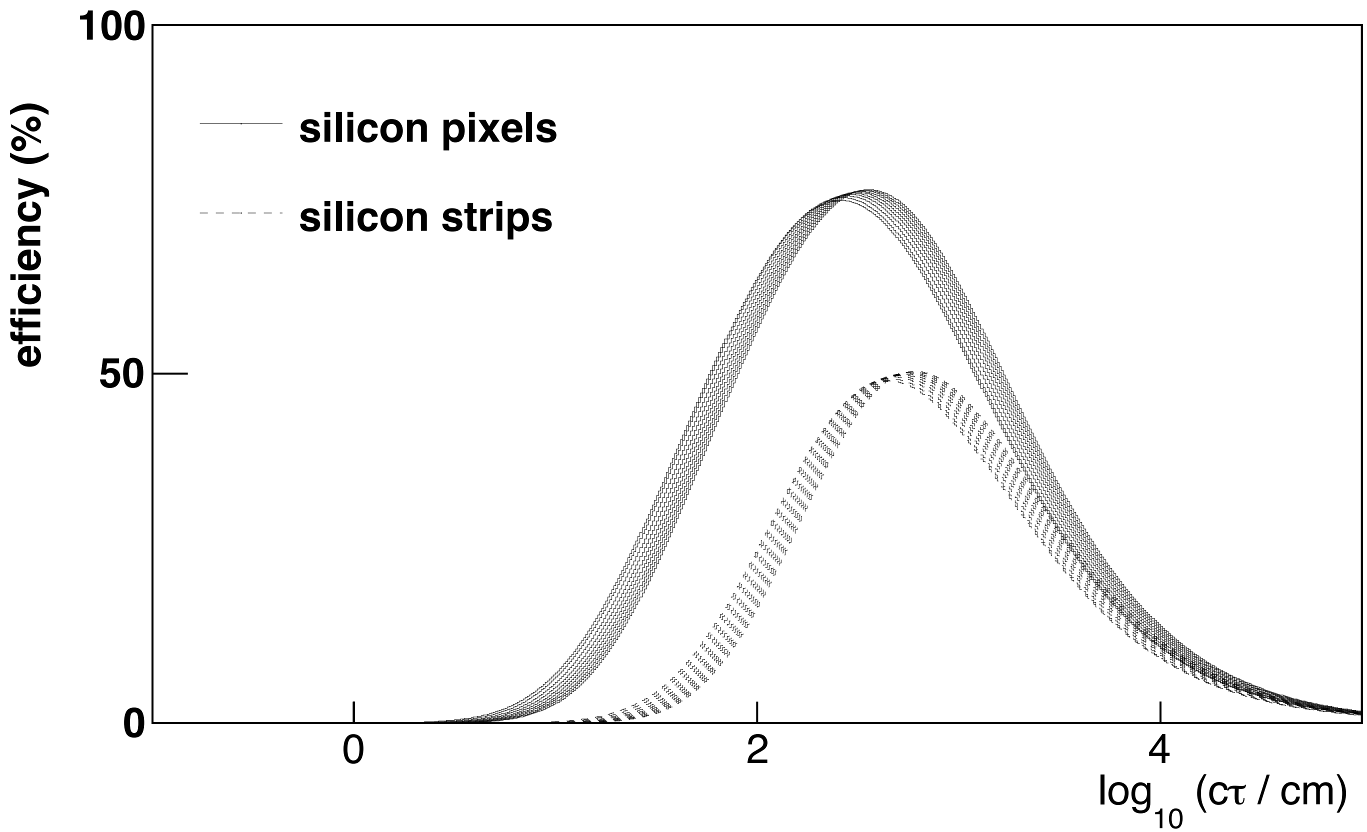
- Typical boost and life-time dilation factor near unity



- Small-radius tracking increases acceptance for metastable charged particles substantially

Efficiency *versus* proper lifetime

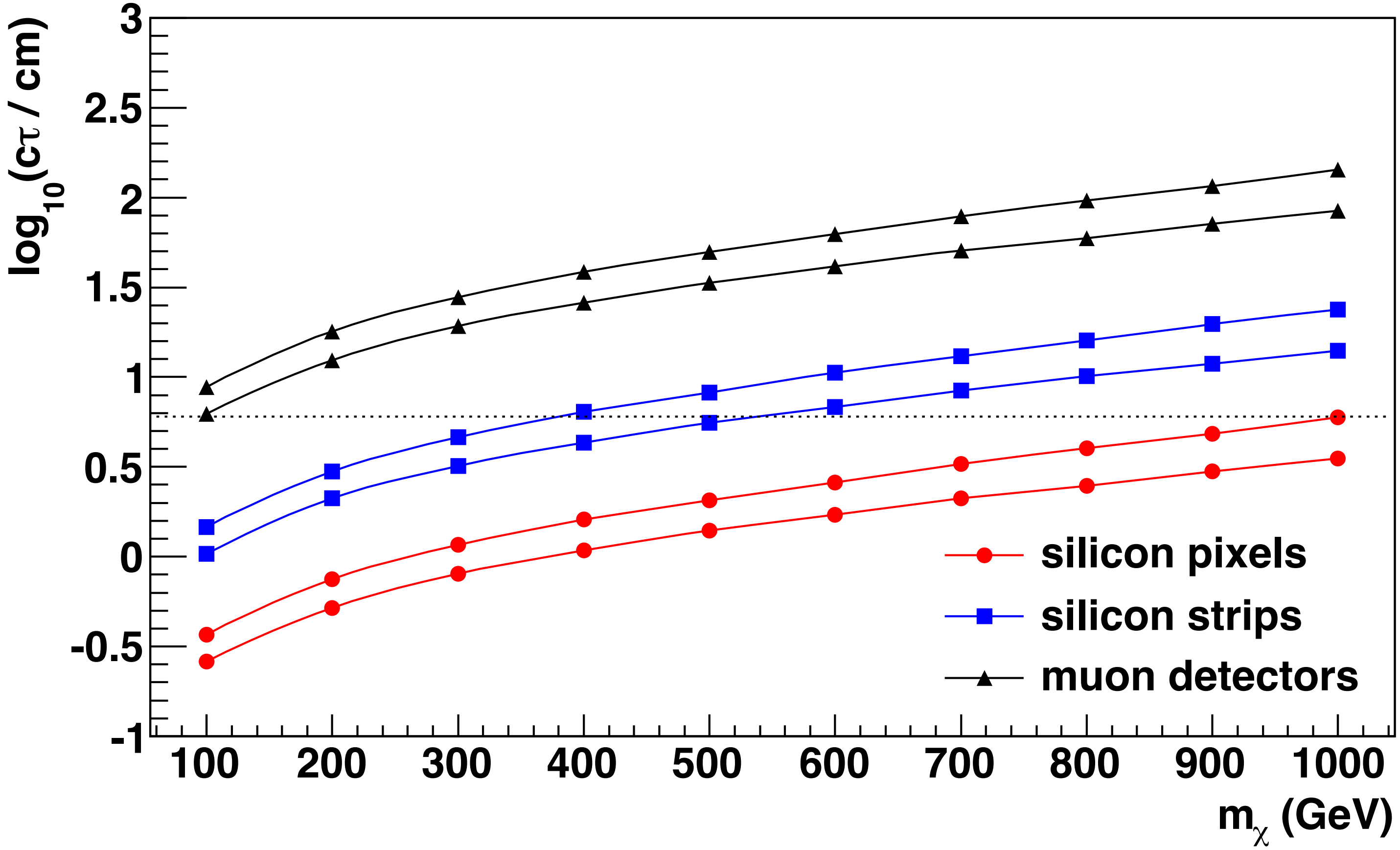
- Small-radius tracking increases acceptance for metastable charged particles substantially, relative to muon trigger, in an interesting range of proper lifetime



- Conclusion insensitive to charged-particle mass (varied between 100 GeV and 900 GeV above)

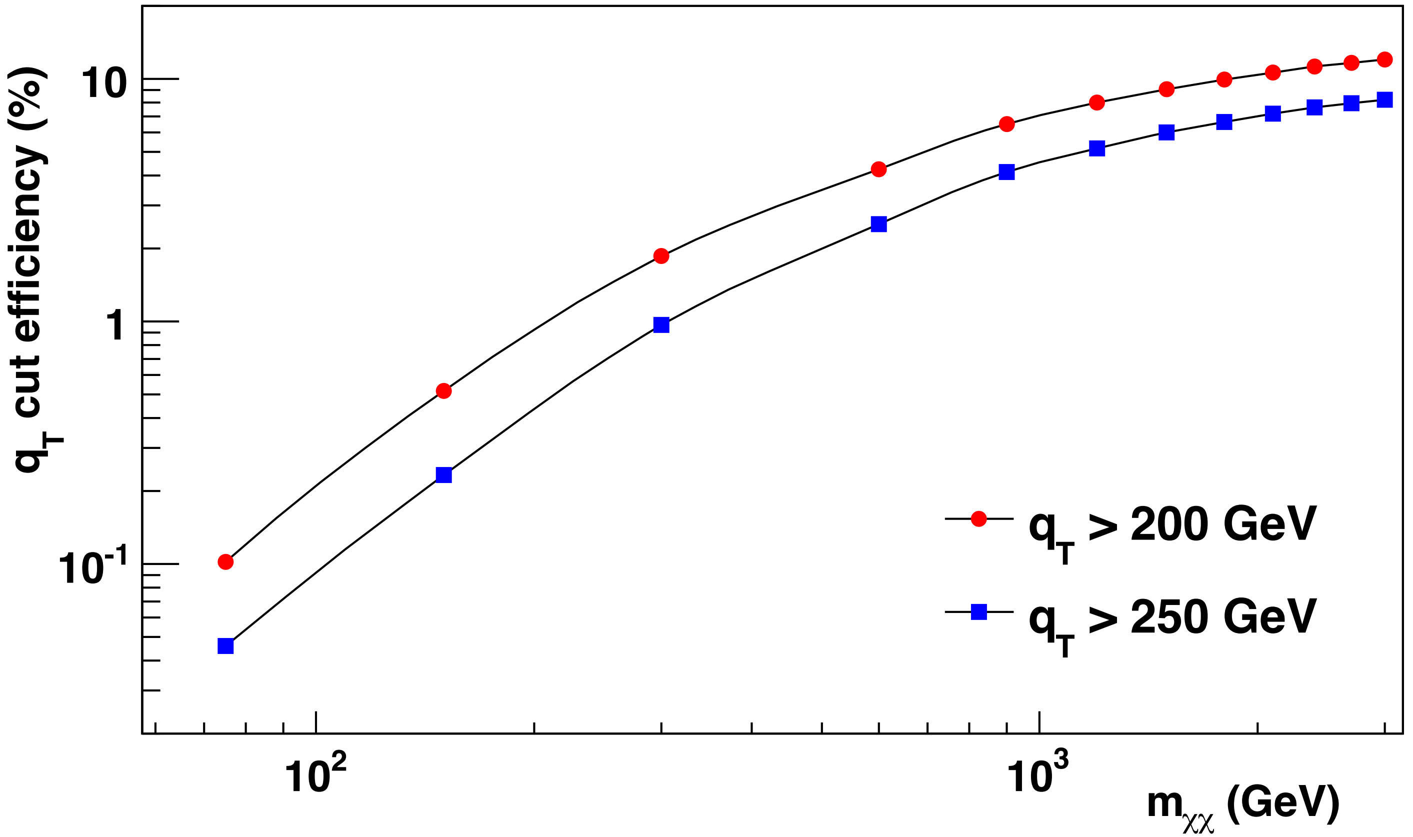
Discovery Reach @ HL-LHC (3 ab^{-1})

- Pure wino scenario in SUSY as a source of neutralino dark matter
  - Almost degenerate chargino and neutralino yields chargino proper decay distance ~ 6 cm [Low & Wang, *JHEP* 1408, (2014) 161]
  - Signal event yields of 1000 events (upper curves) and 100 events (lower curves)



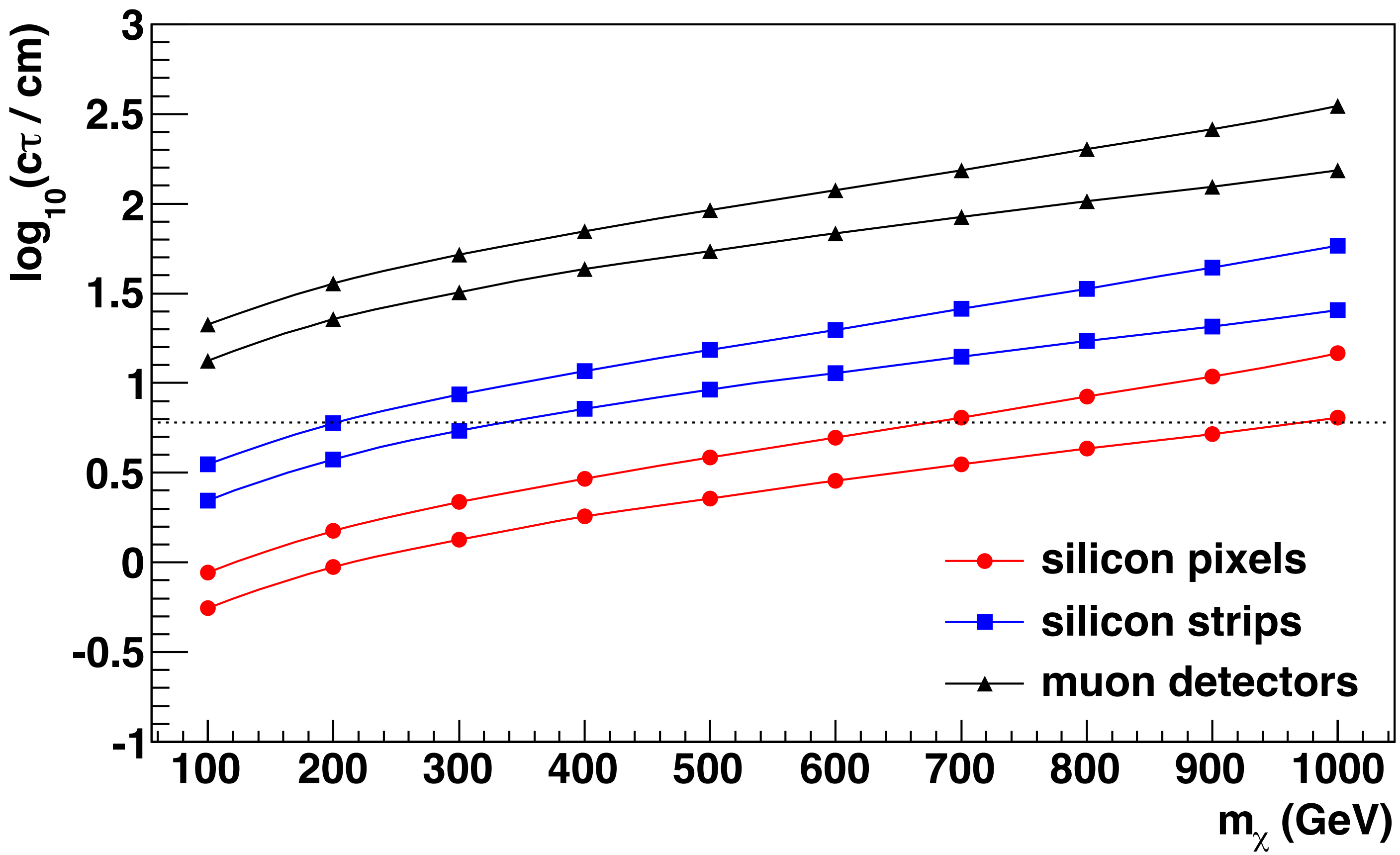
Comparison to triggering on Initial State Radiation

- 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
  - Ideally, trigger electronics should be on-detector
    - self-triggering “smart 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

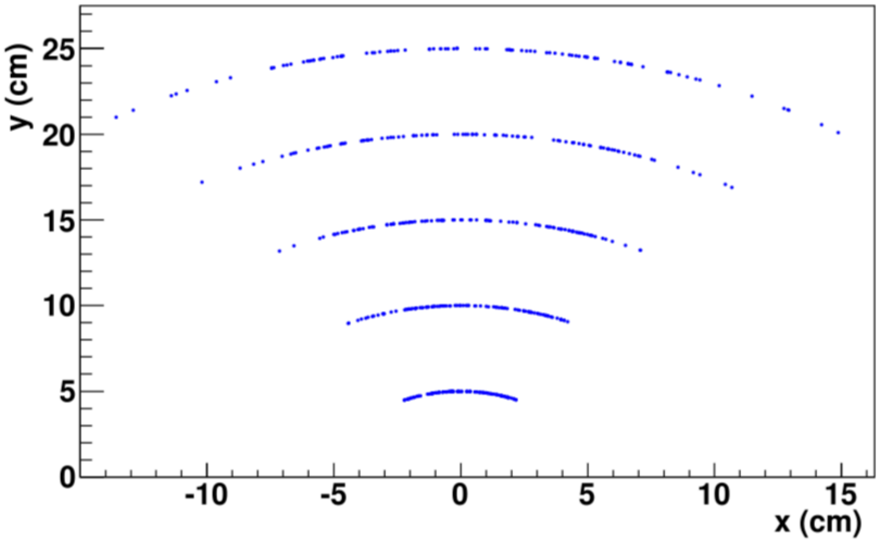
- Modular design of each processing unit that can be replicated in FPGAs
- Exploit parallel processing capability
- Effectively running a huge number of “threads” in parallel

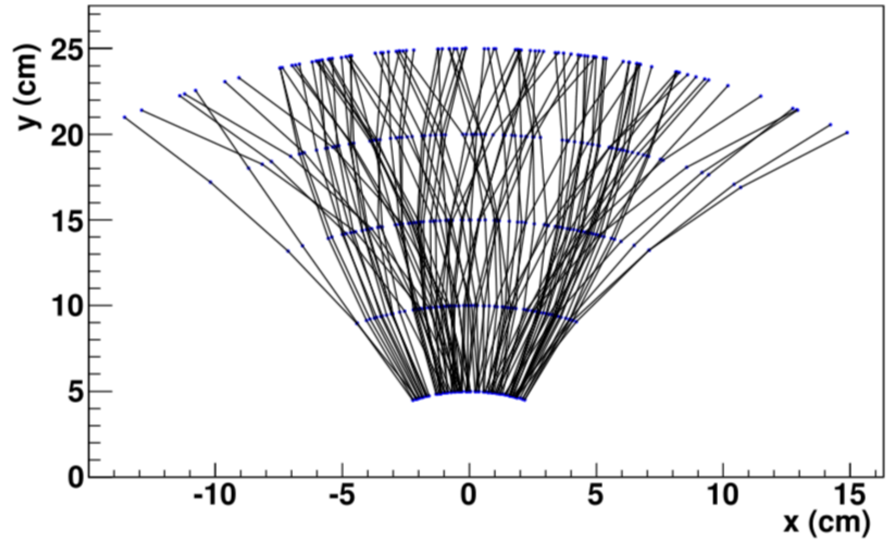
Algorithm emulated in software

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

Track Reconstruction

- Discussion of concept published:
- AVK, "*A fast method for particle tracking and triggering using small-radius silicon detectors*", Nucl. Inst. Meth. Phys. Res. A 957 (2020) 163427





- Each hit processed by a specialized computing circuit
- Trajectories sorted by smoothness locally
- Information sharing between nodes to find smoothest trajectory globally

Track Reconstruction using Pixels

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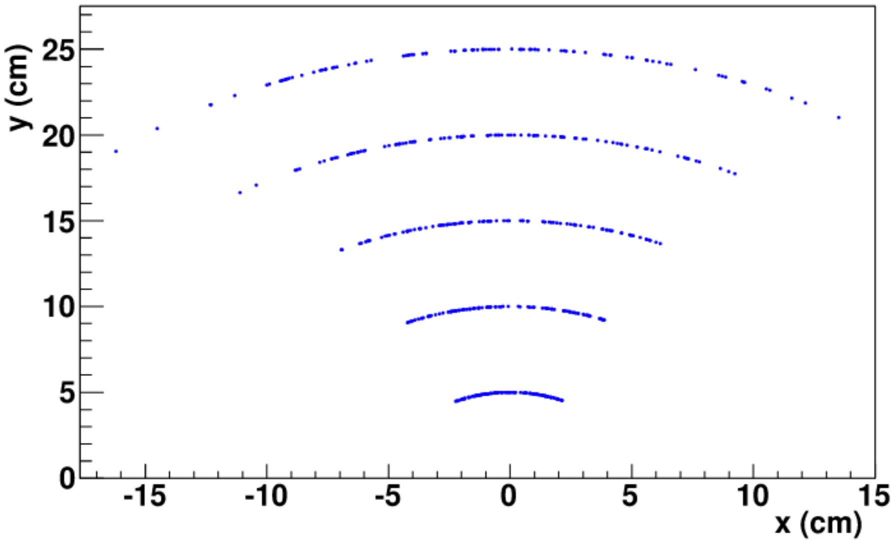
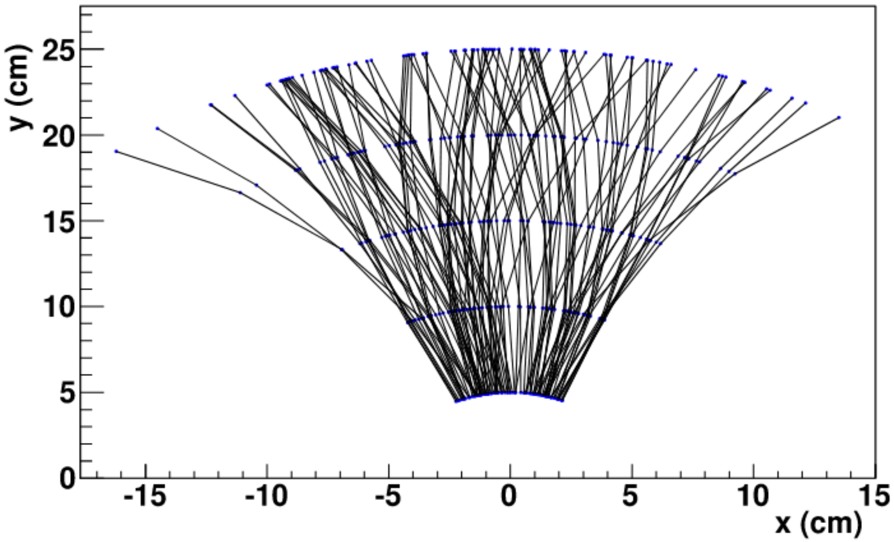


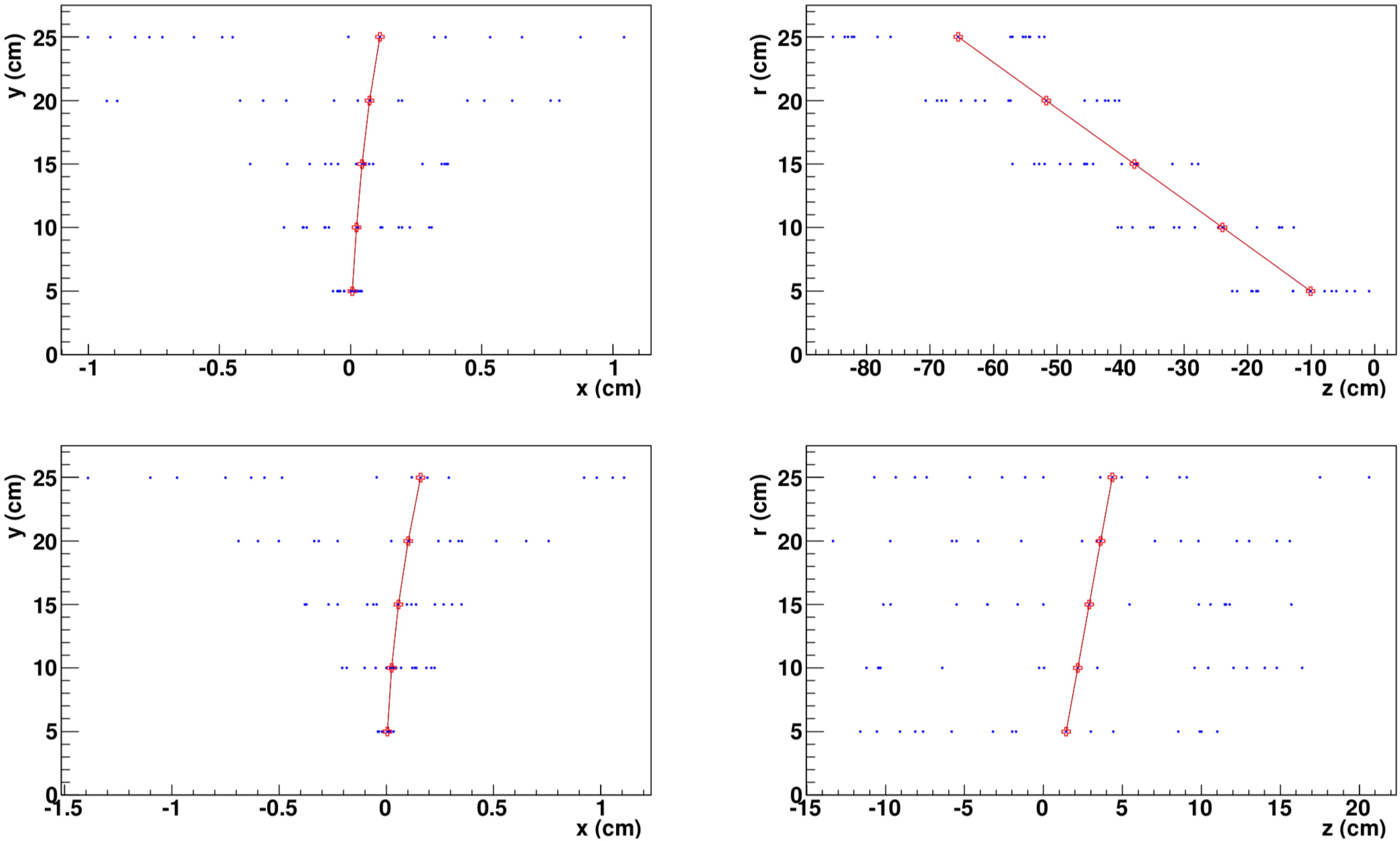


- Limitations:
  - No noise hits
  - All generated tracks with $p_T > 1$ GeV
  - Attempted full tracking in large sectors (unrealistic)

High p_T Track Trigger

- Reduce tower dimensions
- Use realistic p_T spectrum for pileup particles (peak ~ 250 MeV)
- Include "loopers" in the magnetic field and noise hits
- Include resolution effects for ~50 micron pixels
- Trigger particle with $p_T > 10$ GeV embedded amongst low p_T pileup tracks

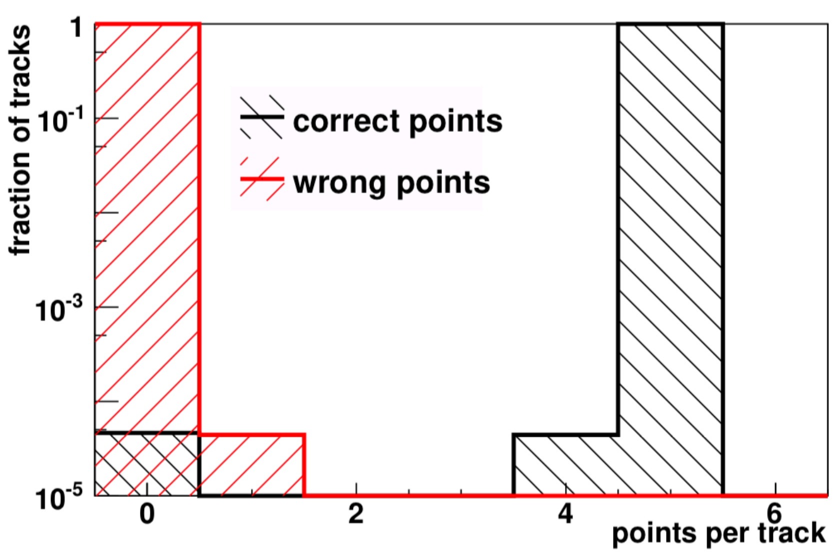
High p_T Trigger

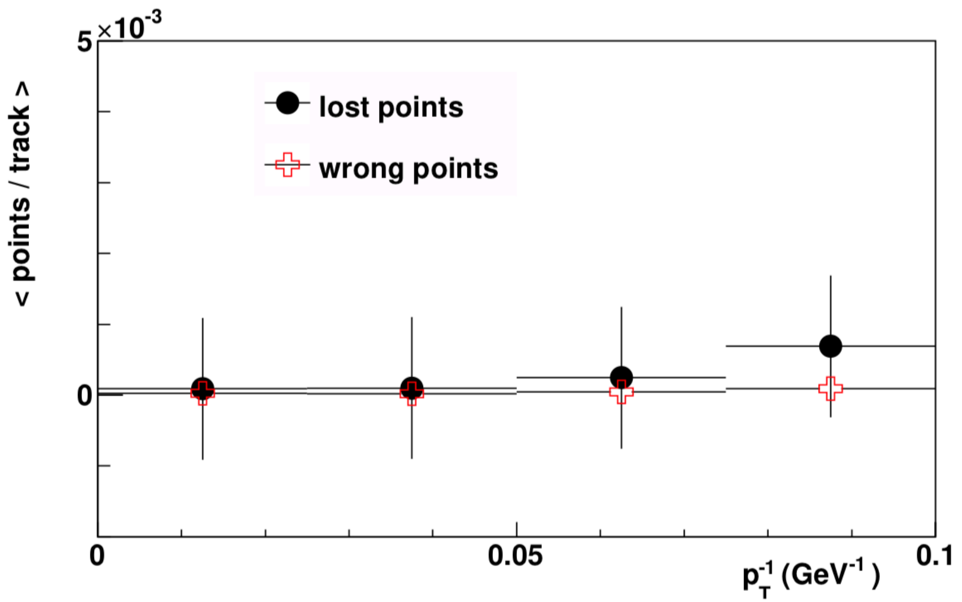


Trigger particle with $p_T > 10$ GeV embedded amongst low p_T pileup tracks

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
- Published in AVK, Scientific Reports **11**, 18543 (2021)





Next steps: study FPGA implementation

FPGA Implementation

- Basic functional units needed are algebraic operations and sorting circuits

- Studies conducted with VITIS HLS design environment from XILINX
  - Converts C code to FPGA implementation
  - Elementary integer additions execute in nanoseconds
  - Integer comparisons execute in 2 nanoseconds
  - Parallelized sorting algorithms for 10's of integers may execute in 10-20 nanoseconds

- Coding in progress to build high-level algorithm using algebra and sorting modules
  - Attempting to estimate total count of look-up tables needed and total latency
  - Study of pipelining options in progress

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 algorithm 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%
- Feasibility of FPGA implementation being investigated