Track Triggers for ATLAS

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10. Terascale Detector Workshop

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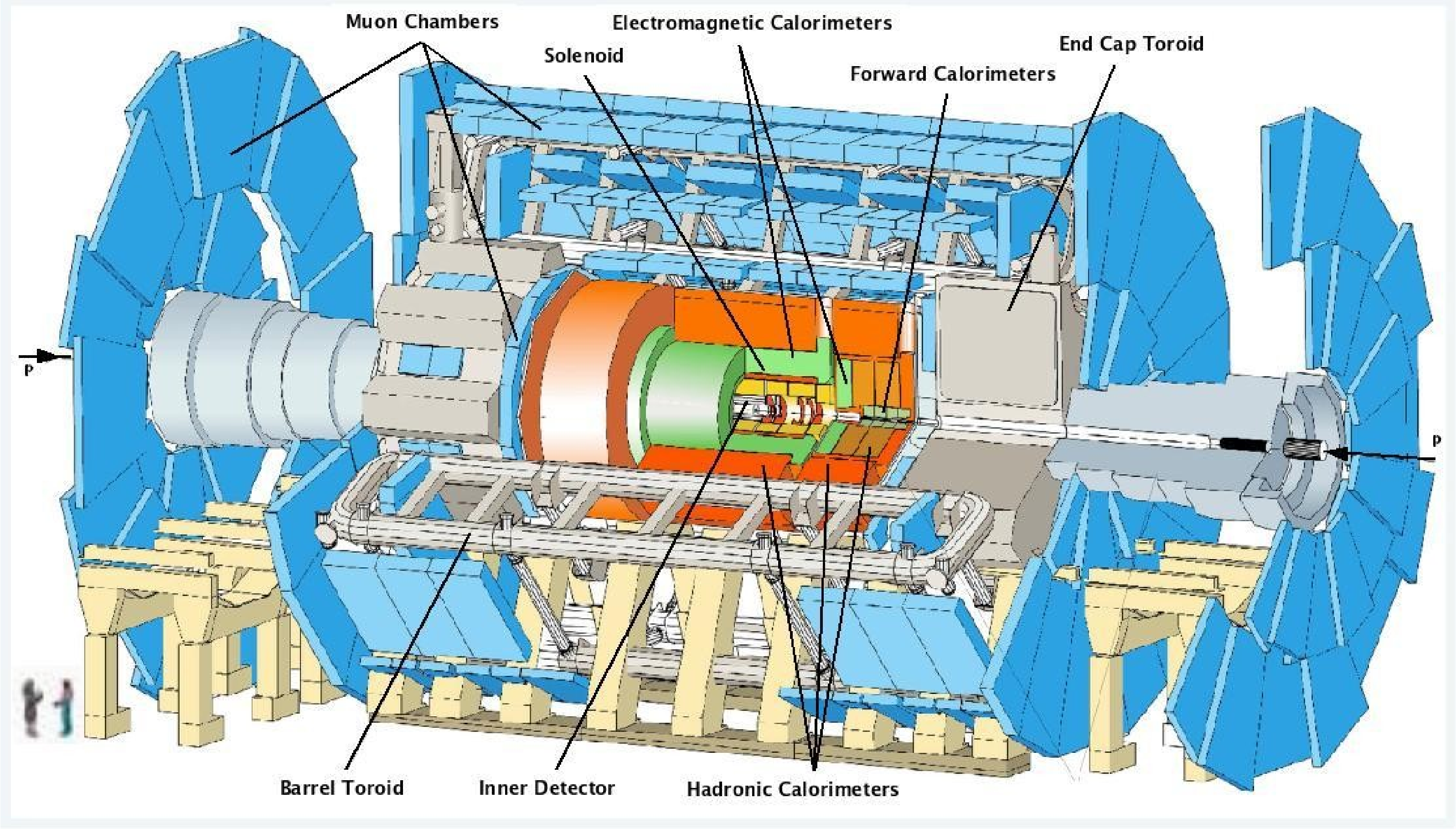
from https://www.enterprisedb.com/blog/3-ways-reduce-it-complexity-digital-transformation

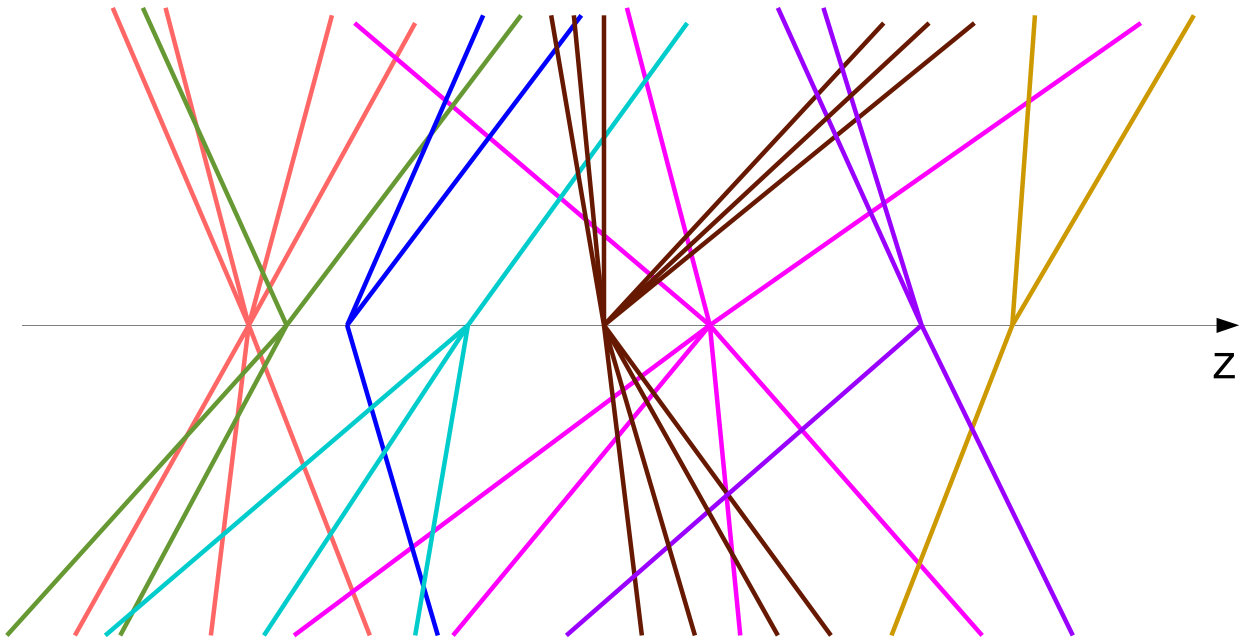
ATLAS Detector and HW-Triggers

- Calorimeter triggers: → **energy** distribution and rough particle ID
- Muon triggers: → **muon** identification and momentum
- No track triggers: → no **momentum, origin** and **separation** of charged particles



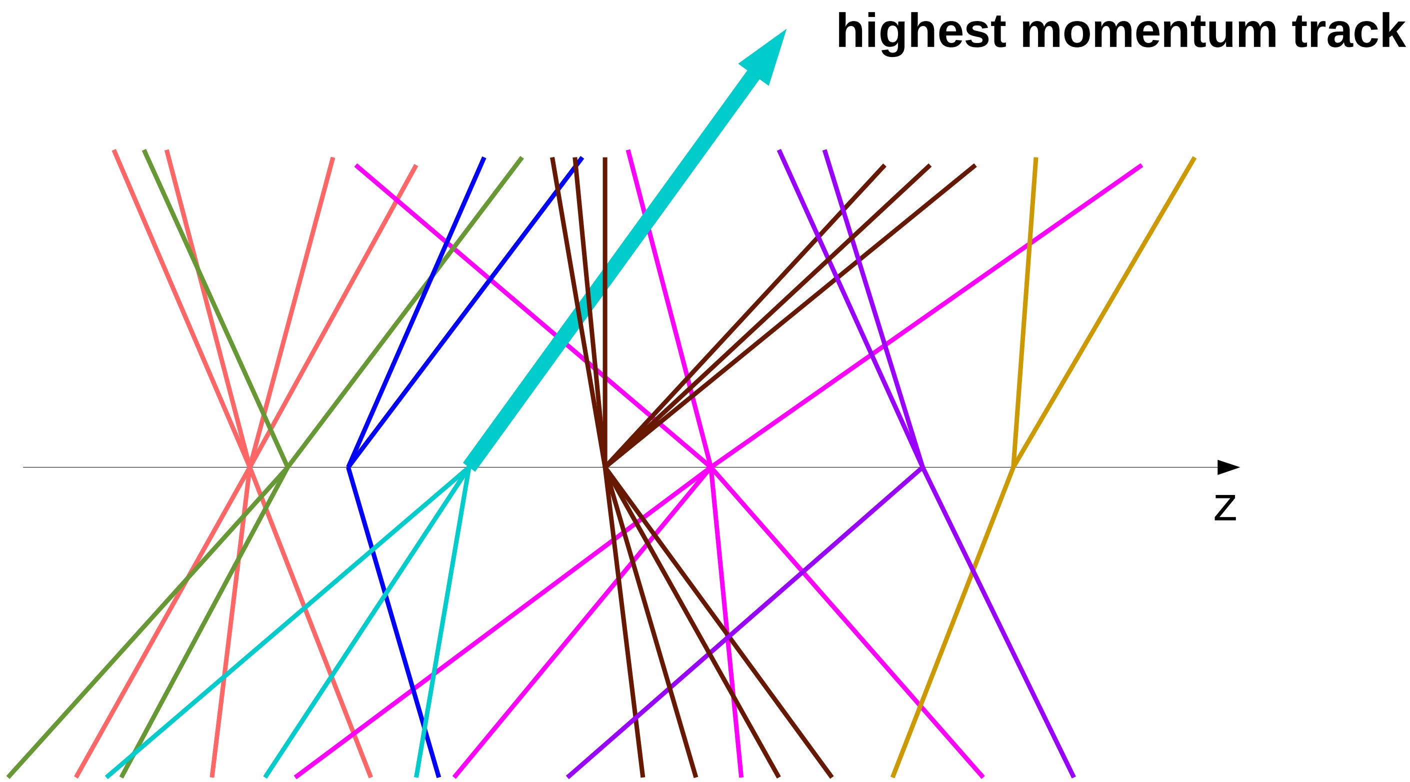
Motivation for Track Triggers @ Hadron Colliders (with high pileup)

event pileup:



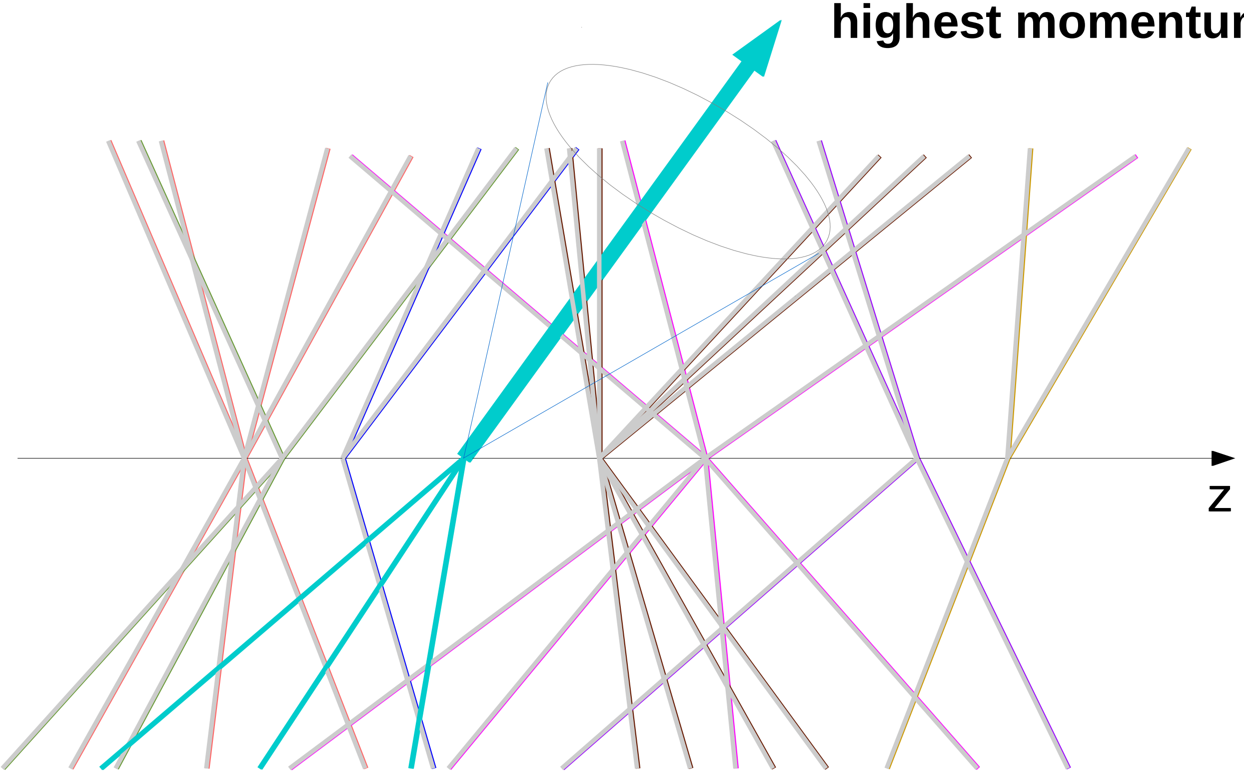
Motivation for Track Triggers @ Hadron Colliders (with high pileup)

- Isolated high-momentum track trigger:



Motivation for Track Triggers @ Hadron Colliders (with high pileup)

- Isolated high-momentum track trigger:



→ typical signature for e, μ, τ

Motivation for Track Triggers @ Hadron Colliders (with high pileup)

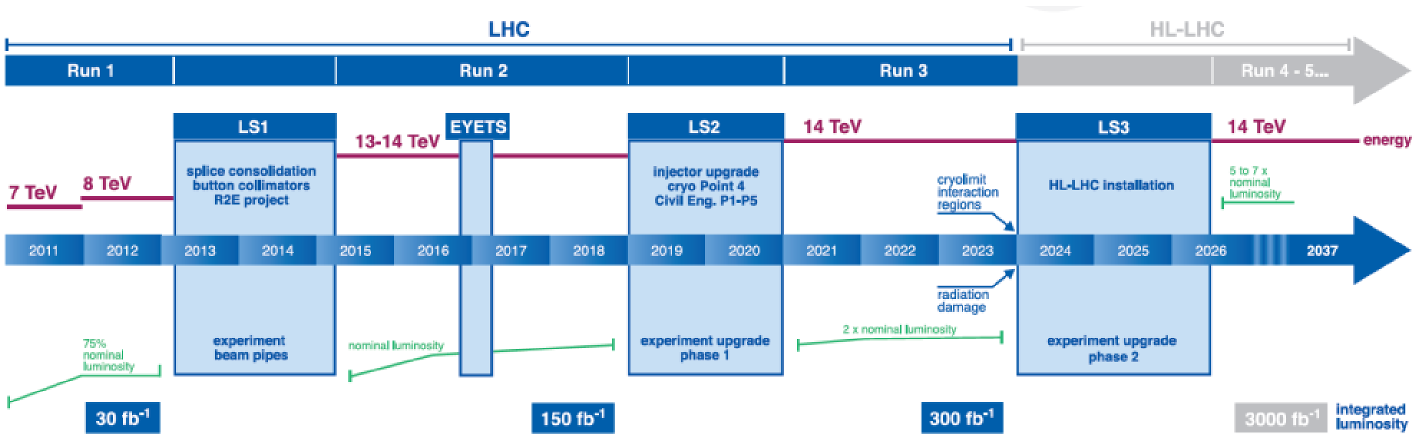
track triggers can provide useful information about:

- particle momentum
- particle direction
- origin (primary vertex, secondary vertex)
- particle counting
- particle isolation (→ lepton identification)
- particle identification (in combination with other triggers)

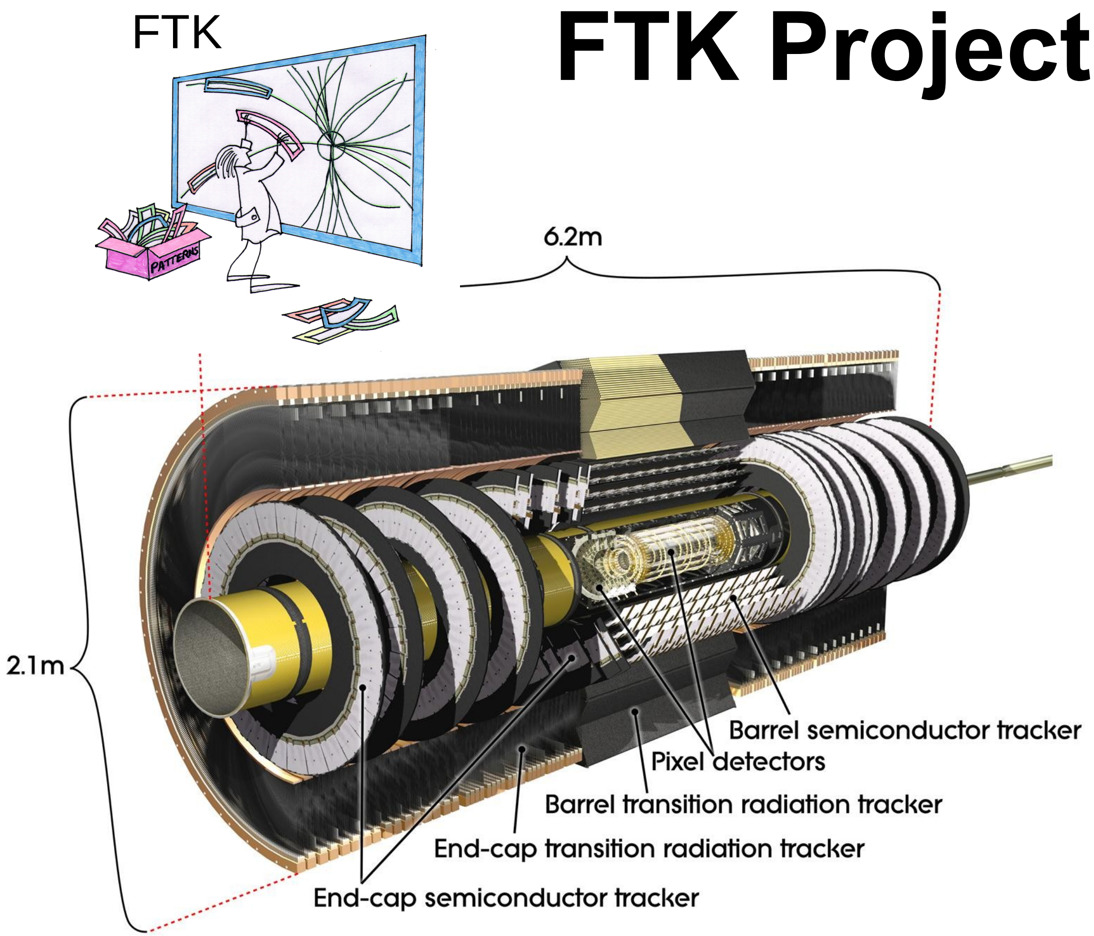
→ **complementary to calo / muon triggers**
→ **improve selectivity of trigger in general**

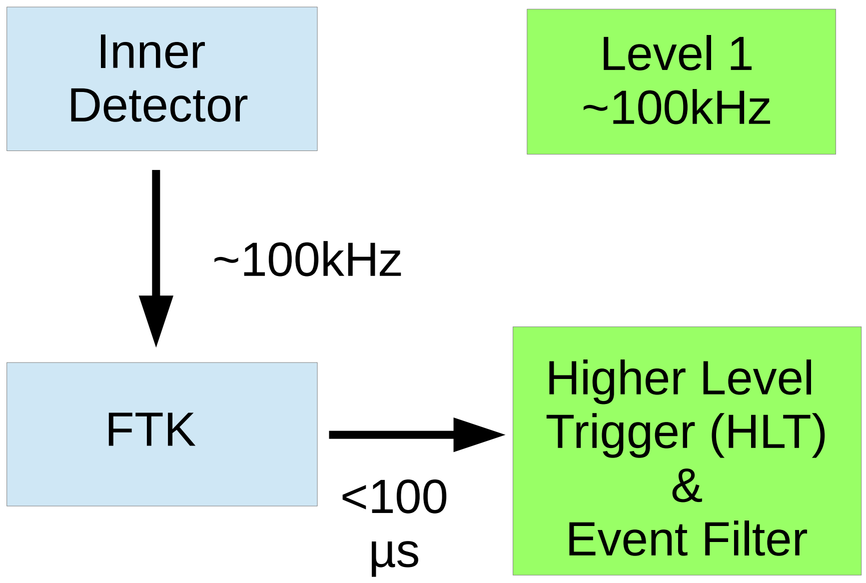
Overview ATLAS Track Triggers

- Phase I upgrade (2018)
  - **Fast TracKer Processor (FTK)** → 100kHz (being installed)
- Phase II upgrade (2025):
  - **“Regional” track trigger** (baseline) → 1 MHz (not decided)
  - **Triplet Track Trigger** (option) → 40 MHz (idea)



FTK Project → Track Processor

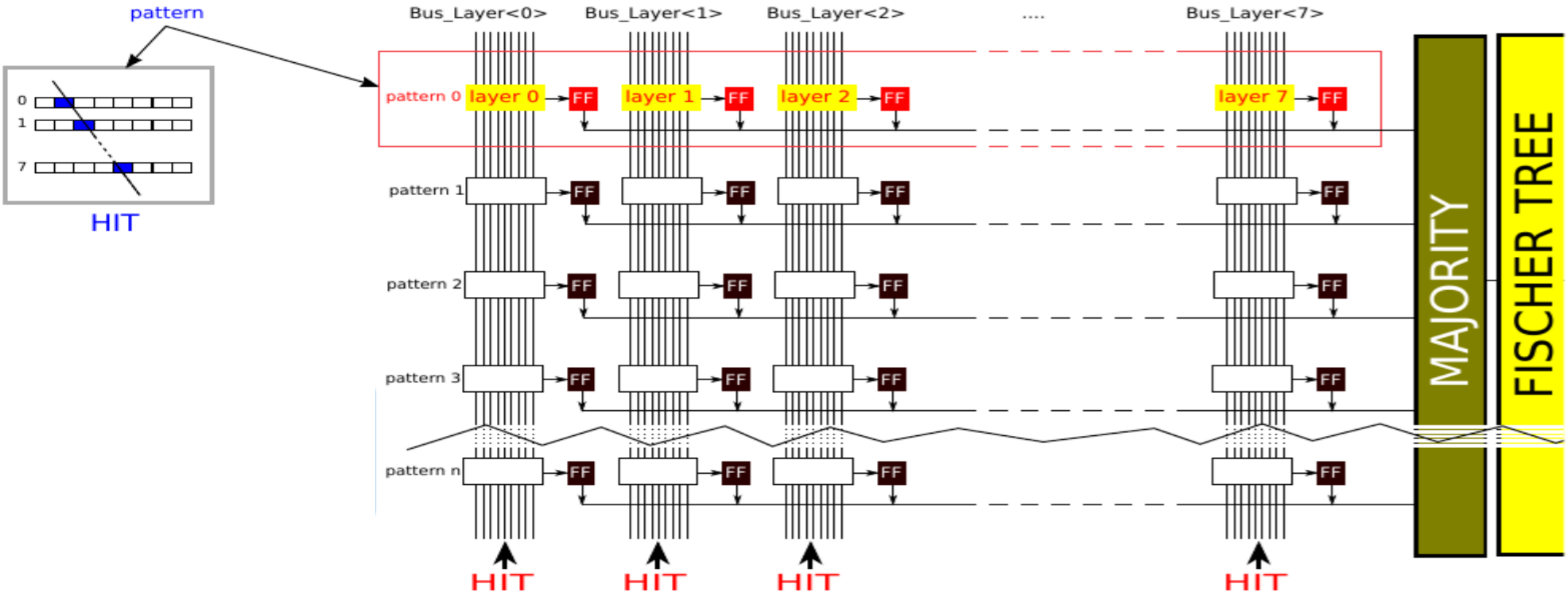




Aim & Concept

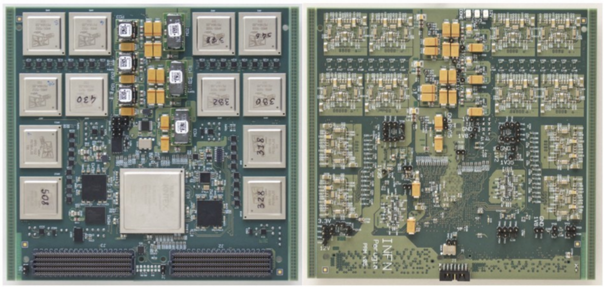
- full track reconstruction p_T>1 GeV using 8 silicon layers (pixel+strips)
- fast pattern lookup using associative memory
- linearised track fit for precise track parameters

Associative Memory



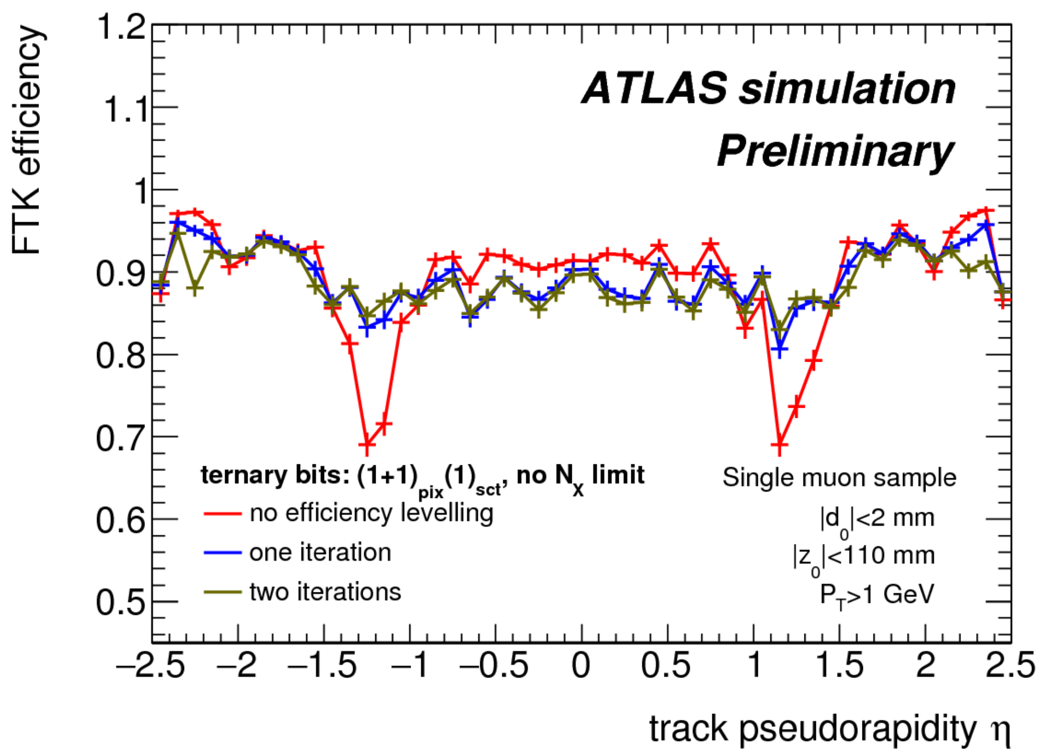
- fast matches (100 MHz)
- highly parallel
  - AMchip06: 100k patterns
  - ~10000 AMchips (pattern banks) in FTK
  - tricks like “Don’t Care bits” for variable resolution

AM Board

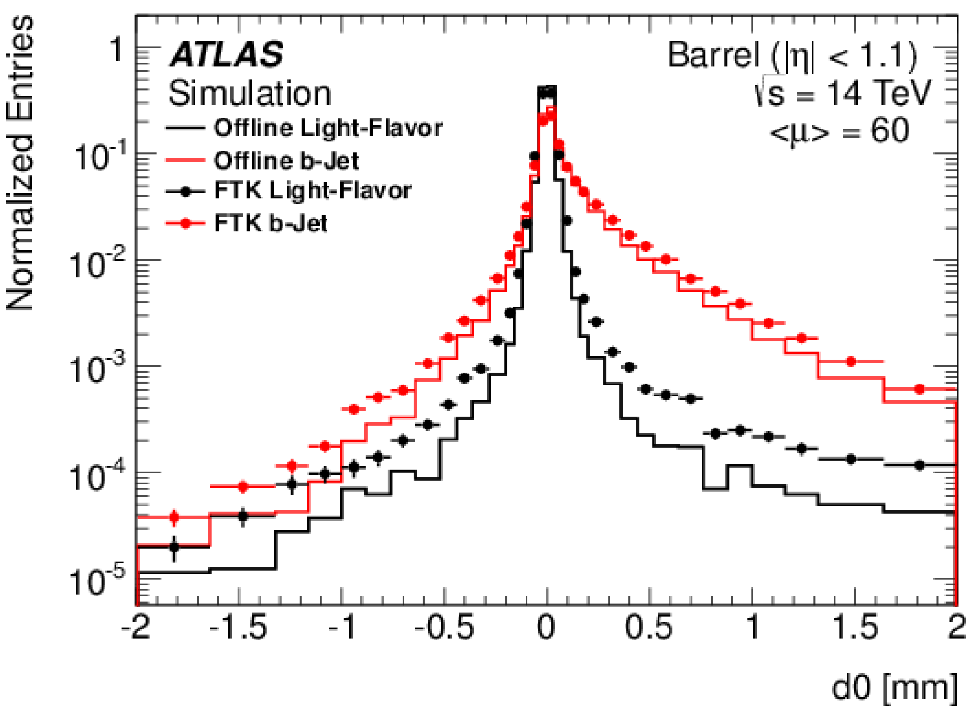


FTK Expected Performance

track reconstruction efficiency



b-tagging (FTK technical design report)

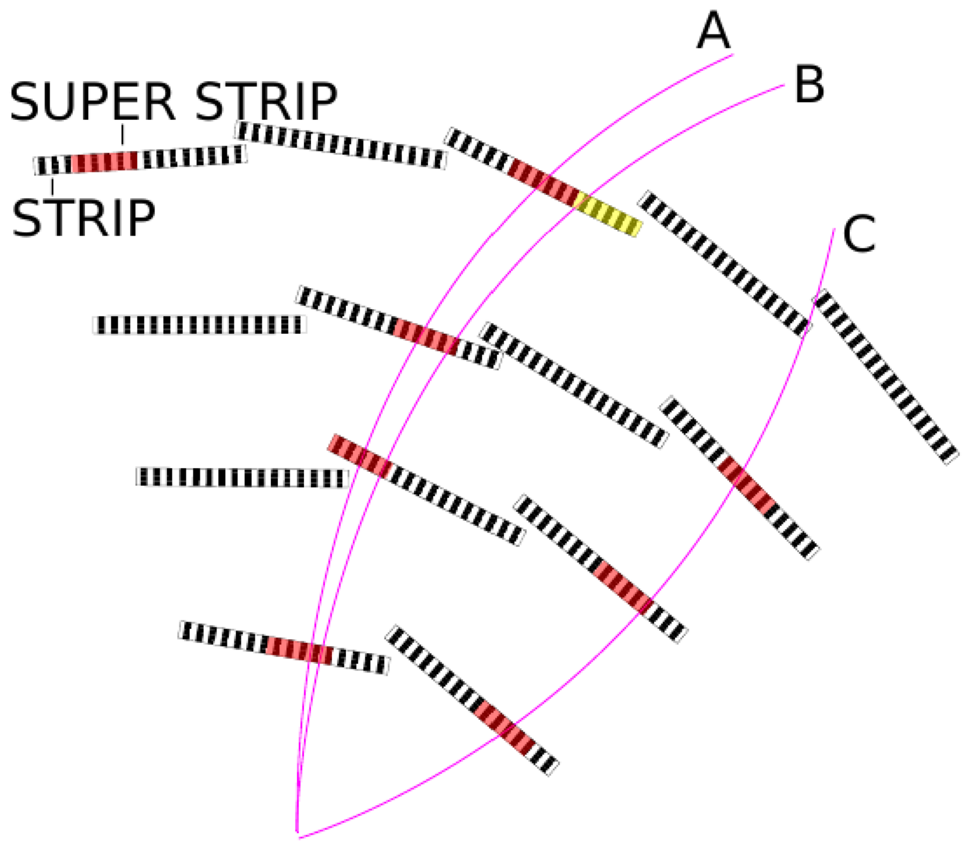


track finding efficiency depends on

- size of pattern bank
- pattern generation algorithm

FTK Limitations I

- number of (pre-calculated) patterns is limited (→ AMchip06: ~100k)
- patterns covering small phase space are neglected → inefficiency
- superstrips (-pixels) needed in order to reduce number of patterns



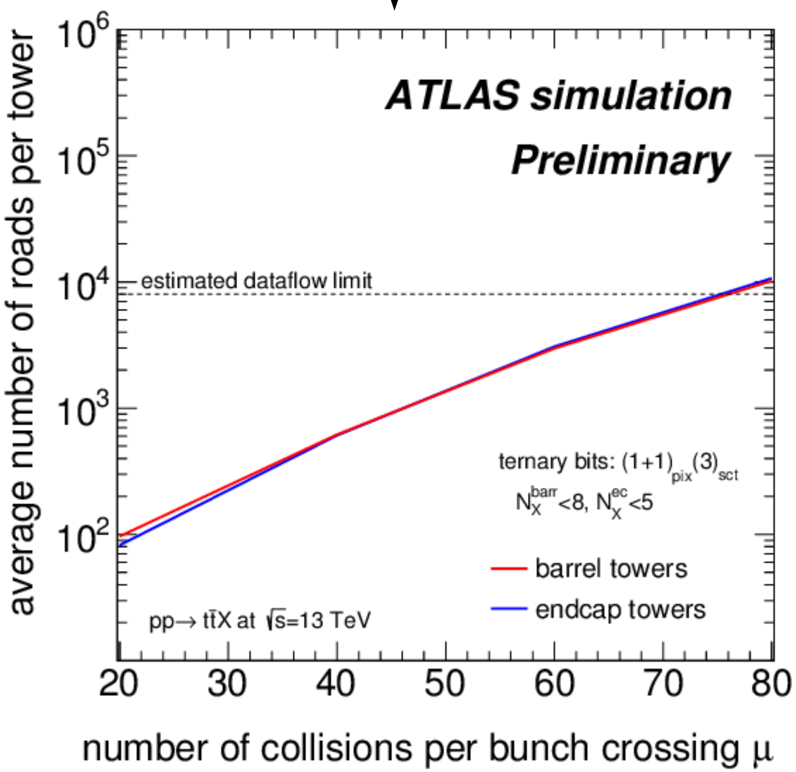
backdraws of superpixels:

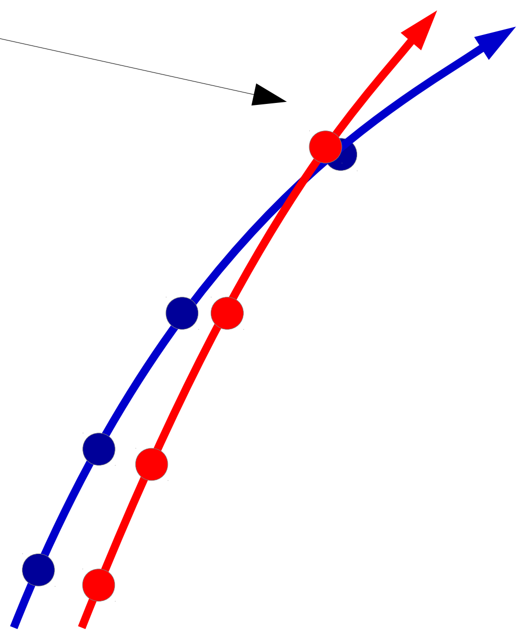
- loss of resolution
- ambiguities (e.g. A ↔ B) cannot be resolved with coarse patterns

coarse patterns need to be validated!

FTK Limitations II

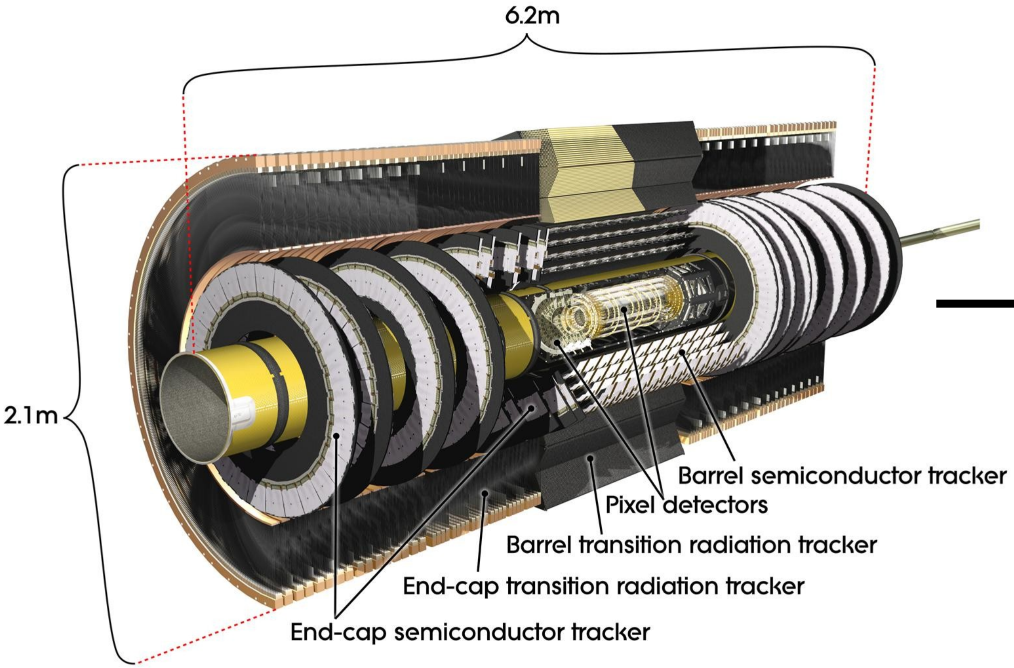
- to regain precision: refine hit positions and fit track candidates (DSPs)
- resolve ambiguities ("hit warrior")
  - time consuming
  - data flow limitations

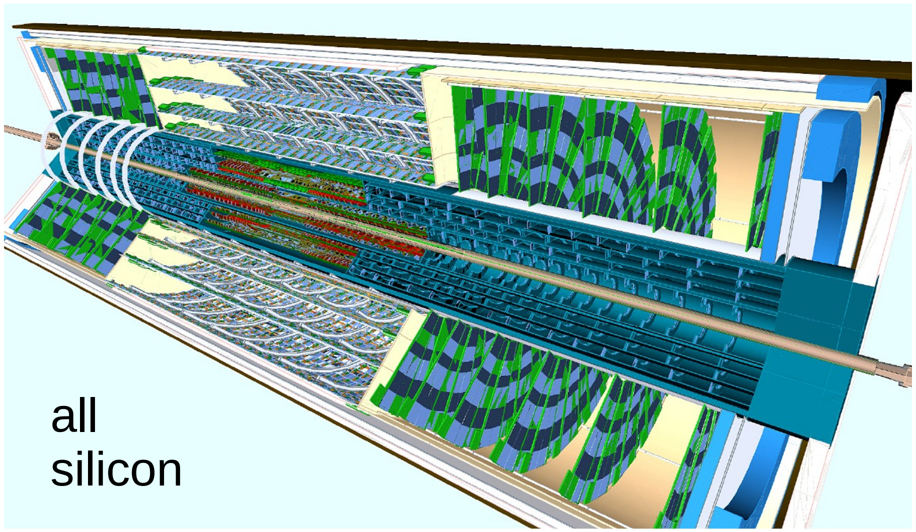




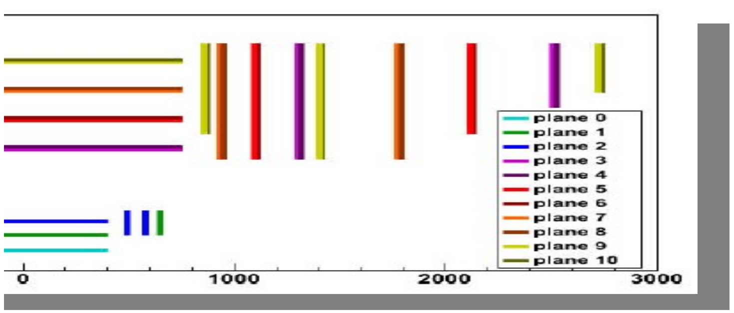
→ needs to be upgrade for HL-LHC upgrade

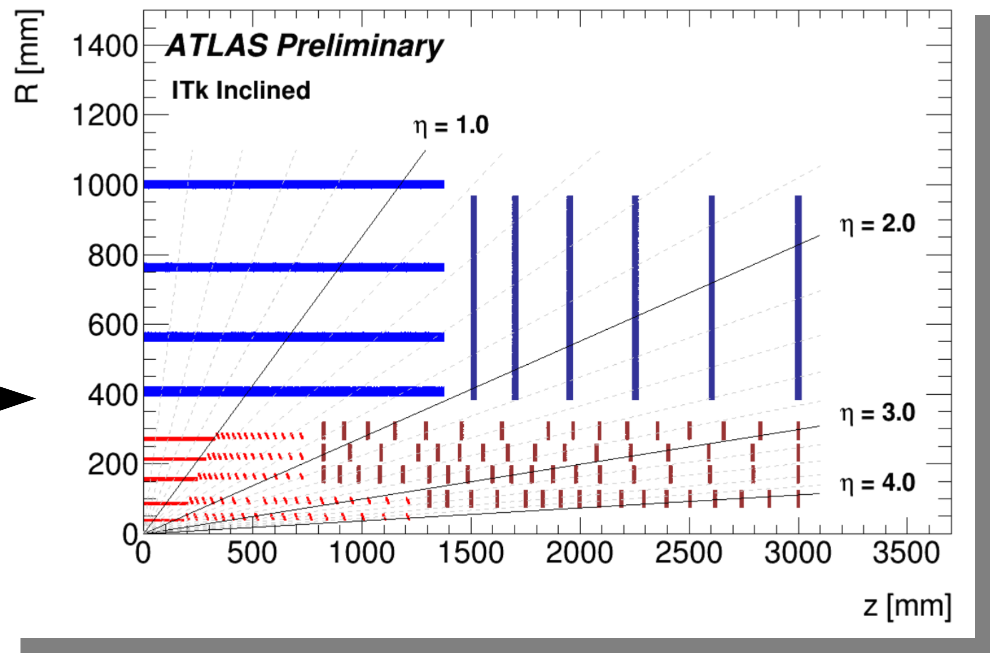
HL-LHC Phase II Upgrade



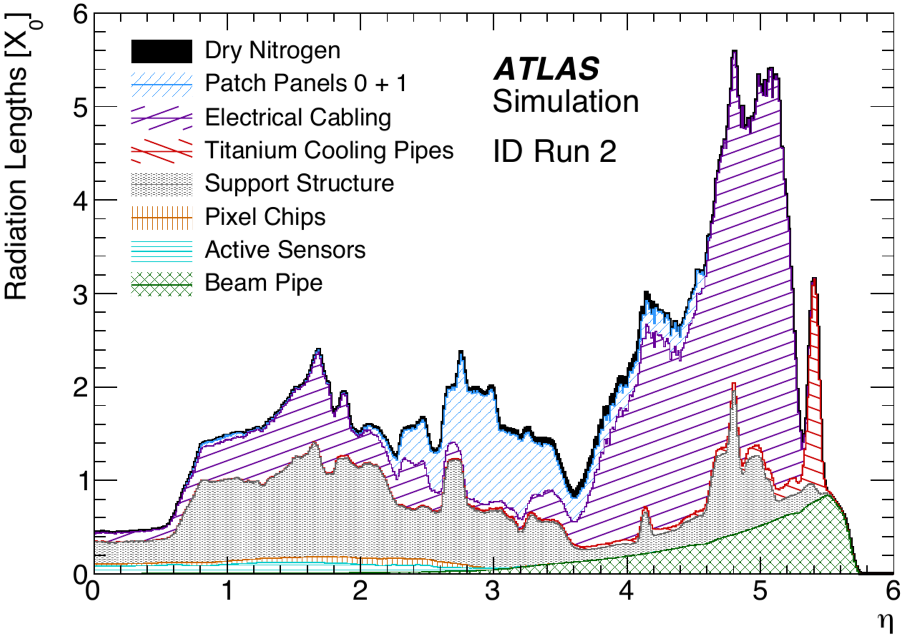


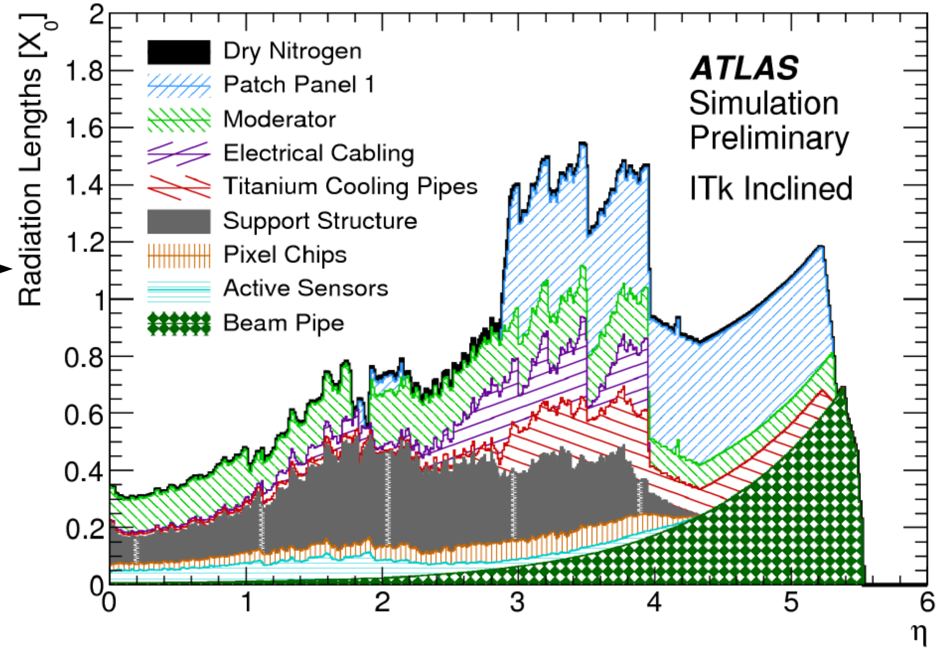
current silicon detector



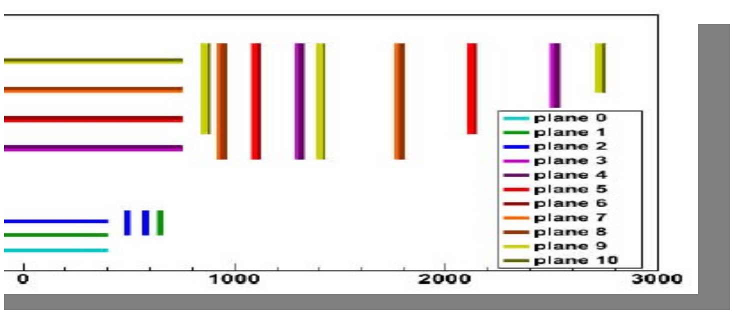


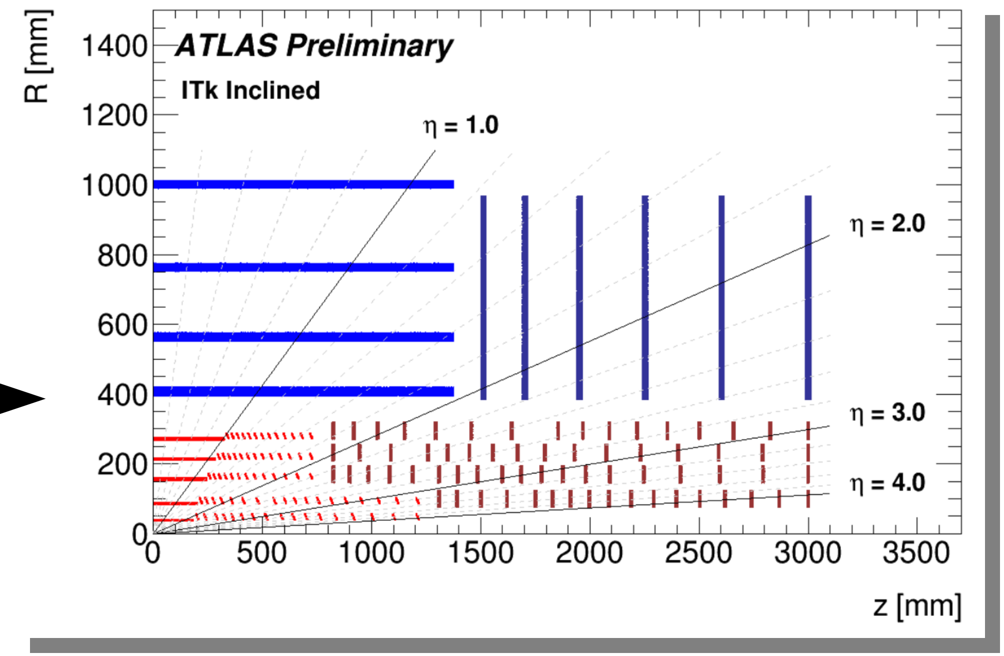
HL-LHC Phase II Upgrade



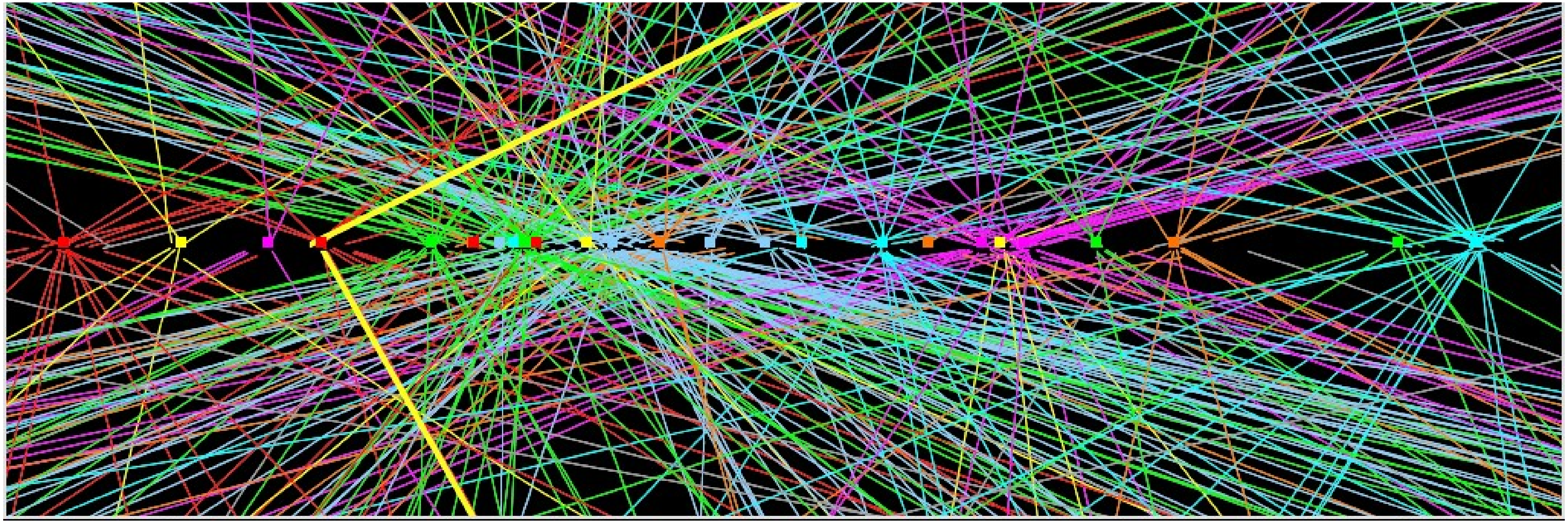


current silicon detector





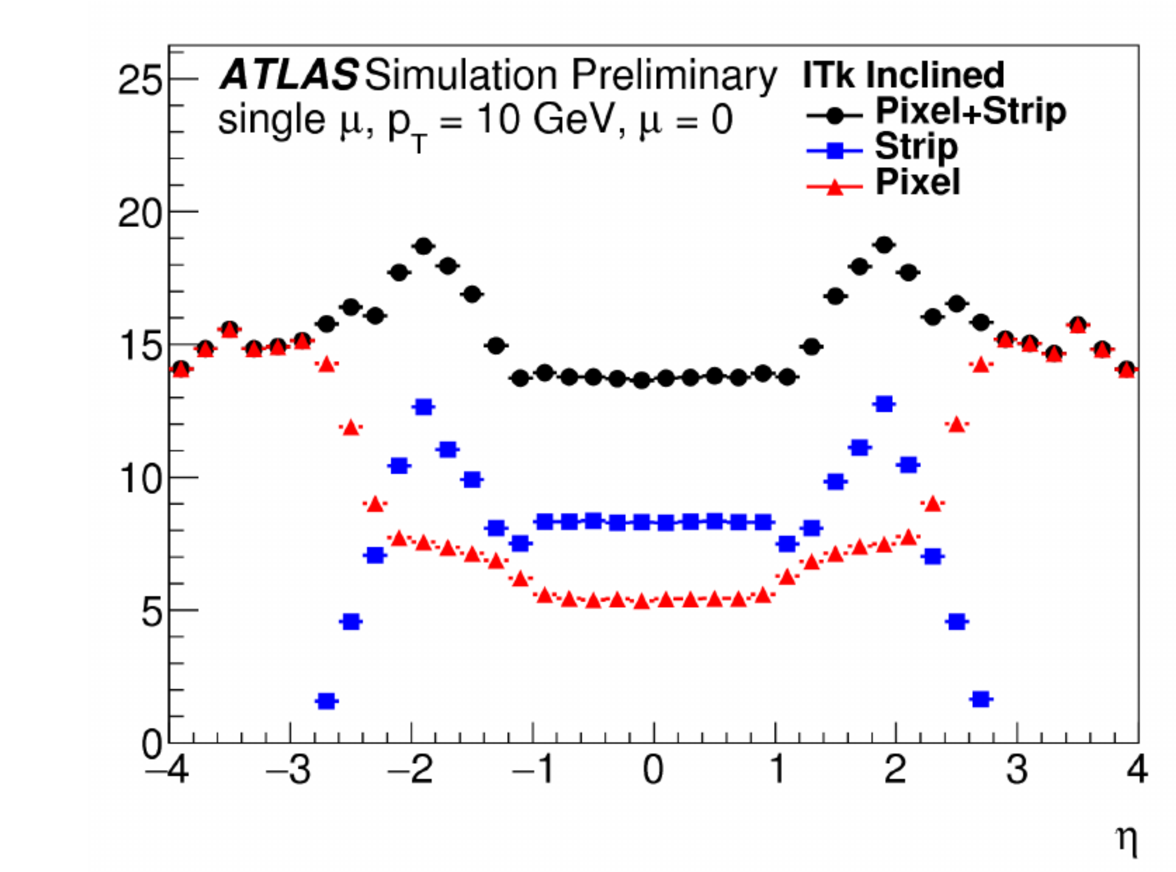
Pileup at HL-LHC

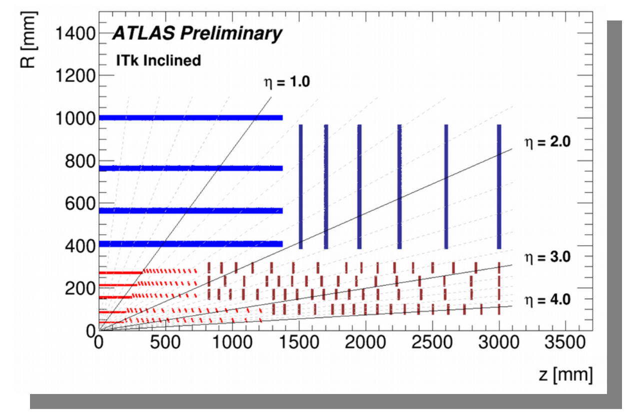


- 5 times more luminosity
  - → significantly higher data rate
- up to 200 pileup events
  - → tracking becomes even more important

HL-LHC: extremely challenging environment for track trigger!

Track Trigger Challenges for Phase II

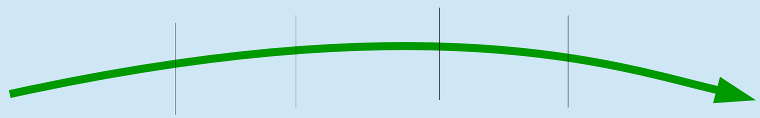




→ 14-19 tracking layers

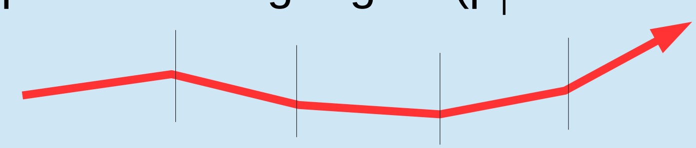
pattern lookup?

Hit uncertainty region ($p_T > 10$ GeV/c):



$$N_{patterns} \propto N_{layer}^2$$

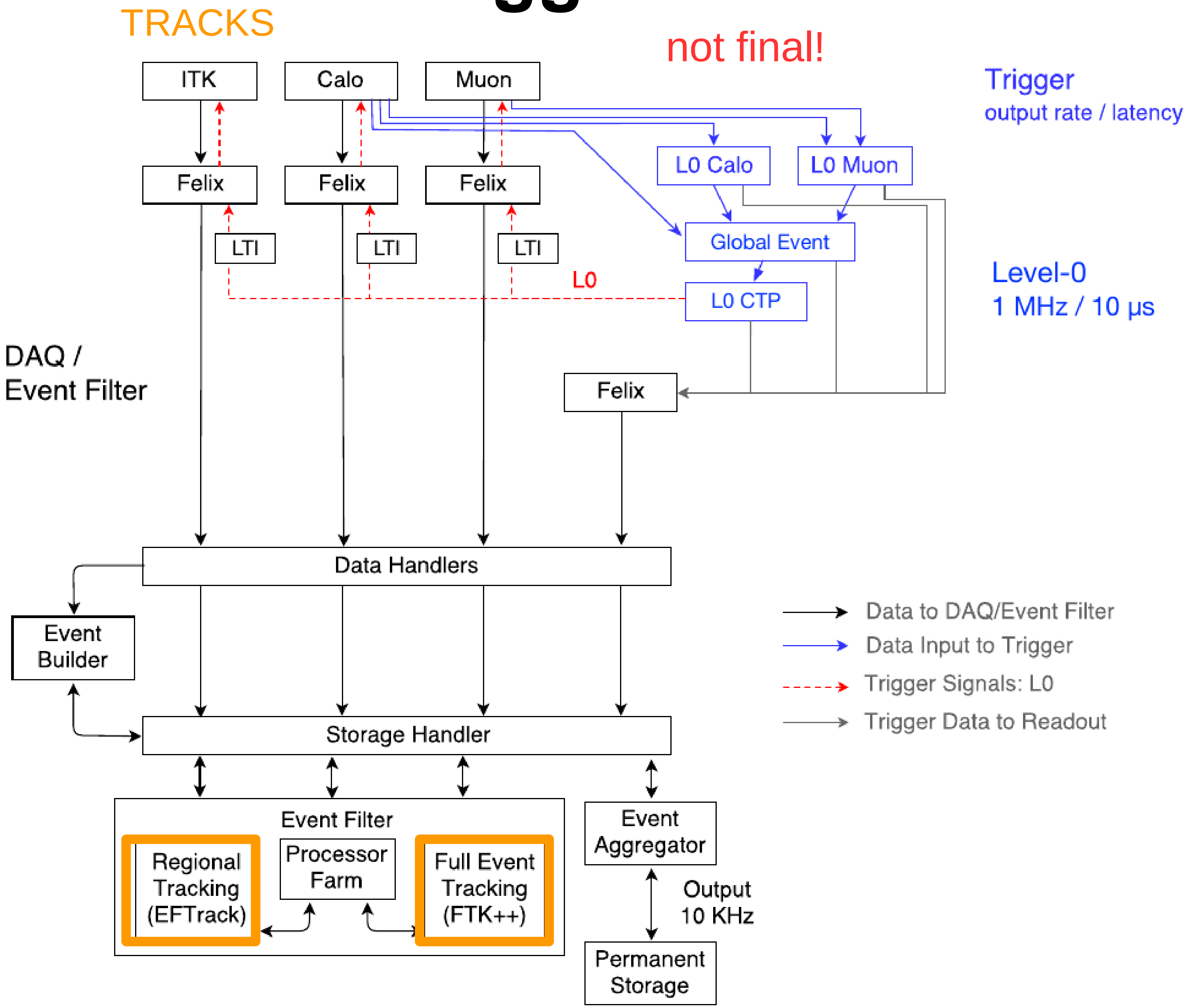
Multiple Scattering region ($p_T < 10$ GeV/c):



$$N_{patterns} \propto X^{2\,N_{layer}}$$

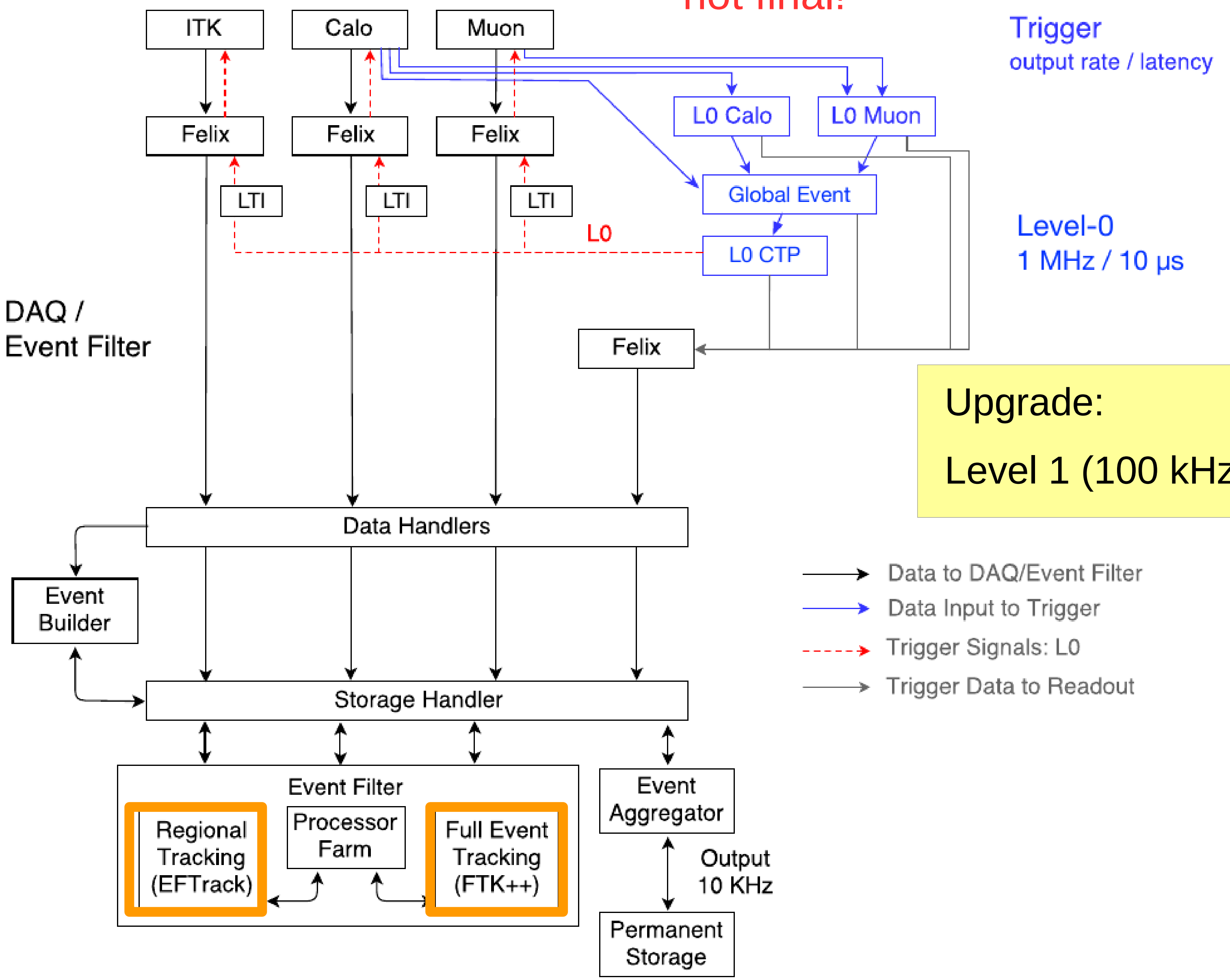
→ use reduced number of layers

ATLAS Baseline Phase-II Readout + Trigger Architecture



ATLAS Baseline Phase-II Readout + Trigger Architecture

not final!



Upgrade:

Level 1 (100 kHz) → **Level 0 (1 MHz)**

ATLAS Baseline Phase-II Readout + Trigger Architecture

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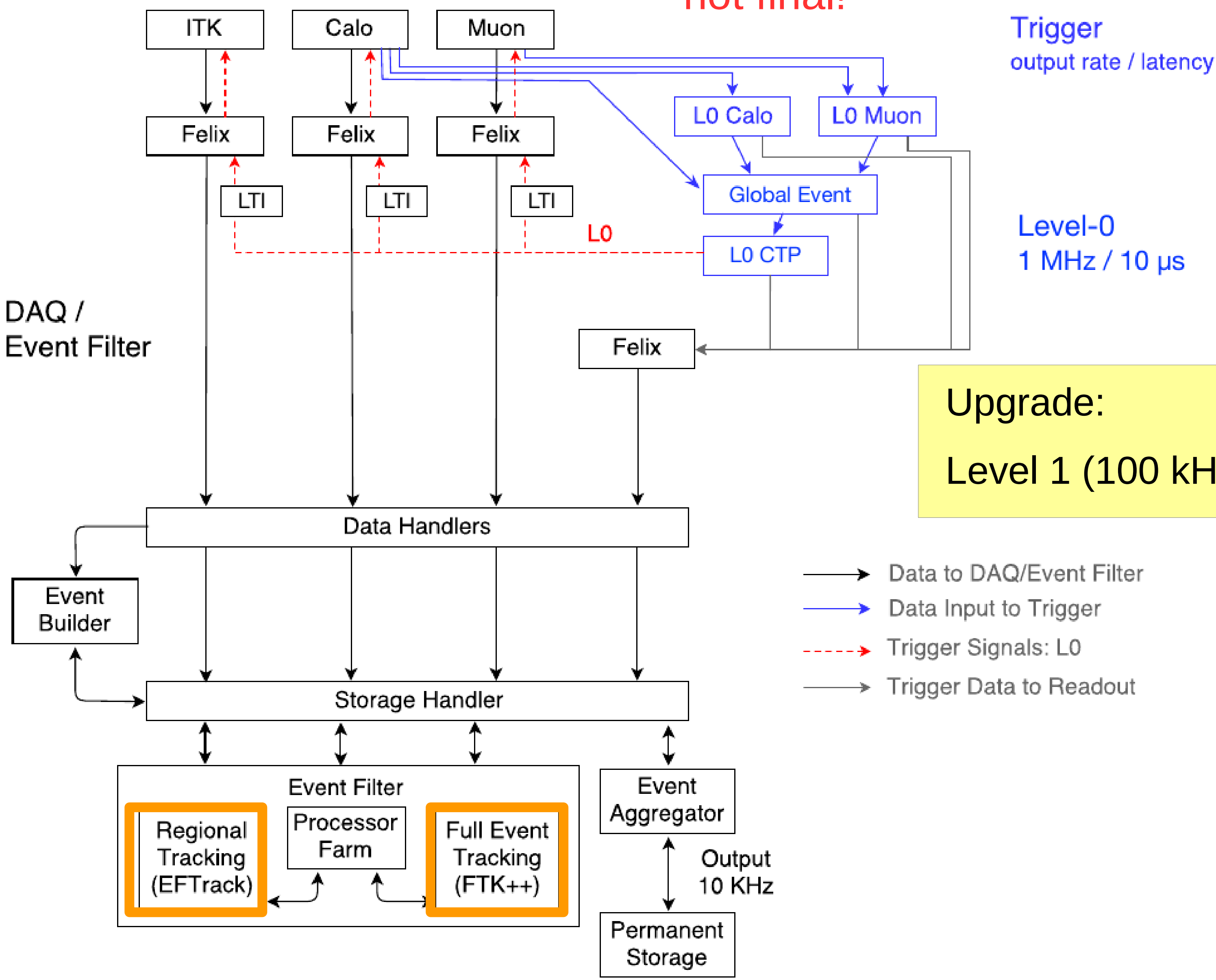

No Track-Trigger @ Level 0

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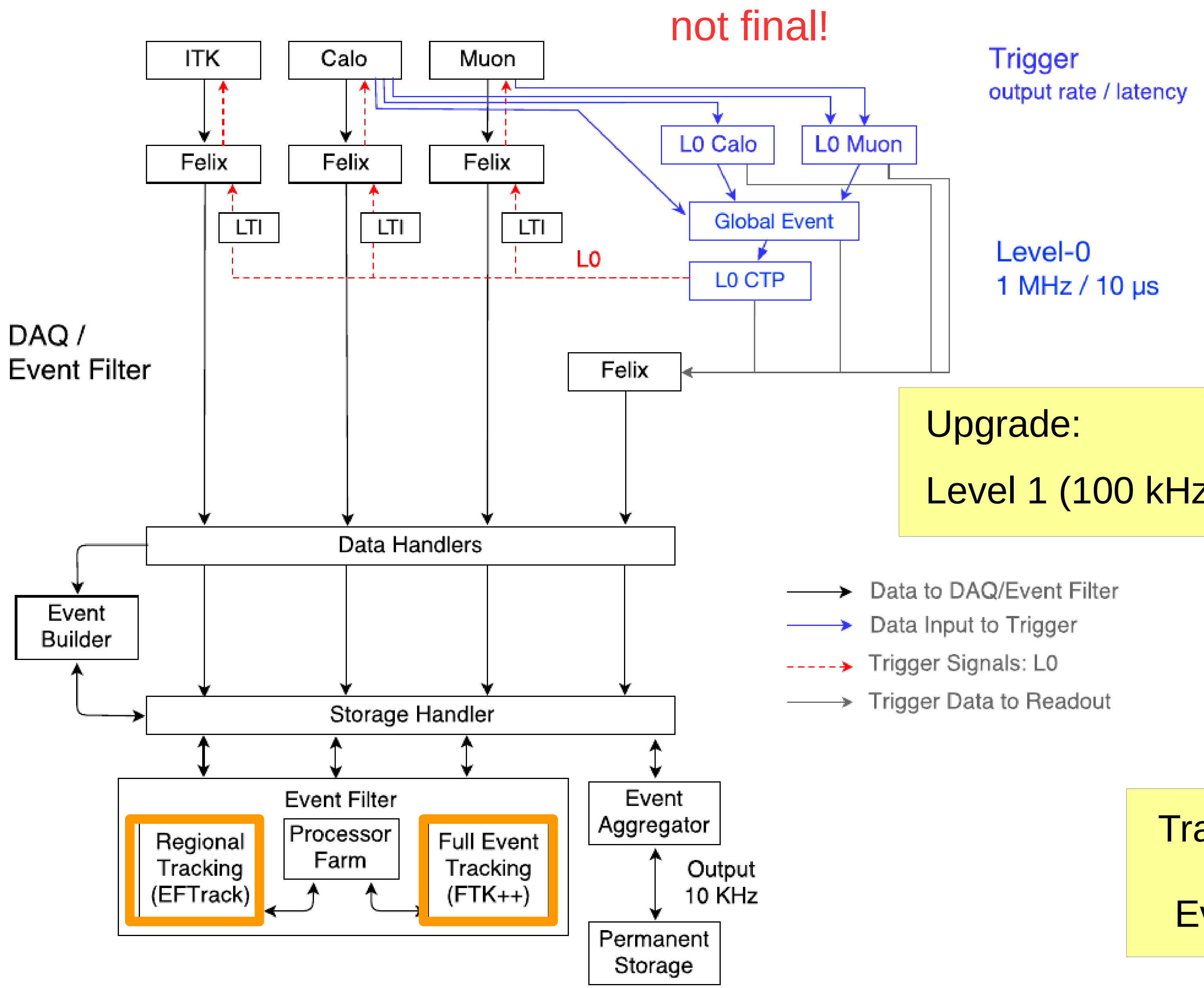
ATLAS Baseline Phase-II Readout + Trigger Architecture



No Track-Trigger @ Level 0

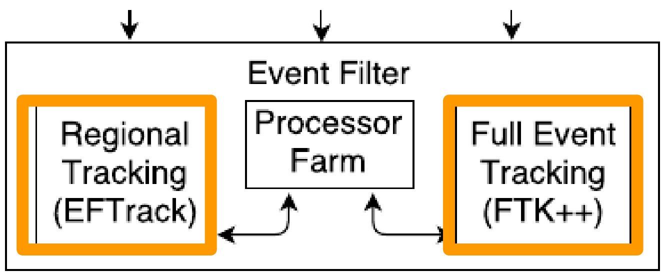
Upgrade:

Level 1 (100 kHz) → **Level 0 (1 MHz)**

Track-Trigger @ Event Filter

Common Track Trigger HW based on FTK Concept with AMs?

being investigated by ATLAS:



Two systems but same HW:

- FTK++: Full tracking at 100 kHz
- EFTrack: Tracking with 1 MHz in Regions of Interest (10% of ITK)
- (L1Track): Tracking with 4 MHz in Regions of Interest (10% of ITK)

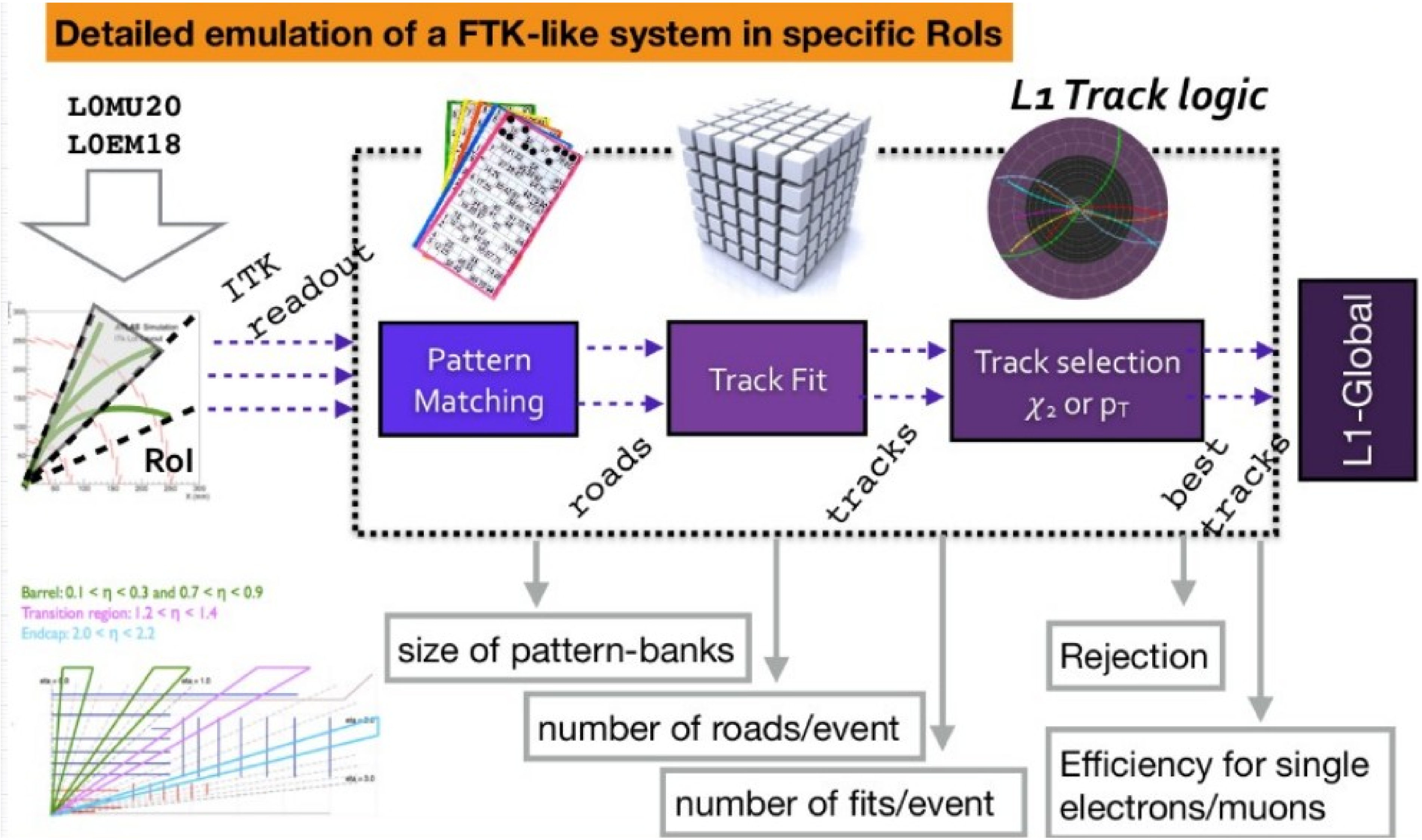
Remark: L1Track requires dedicated L0/L1 readout architecture

very preliminary!

	FTK++	EFTrack	(L1Track)
Input Rate	100 kHz	1 MHz (ROI)	4 MHz (ROI)
p_T^{min} (GeV/c)	>1.0	>2.0	>4.0
#patterns (billion)	5	2.5	2.5
2nd fitting stage	yes	no	no

development of improved AMchip2020 → ~ 400k patterns per chip (250 MHz)

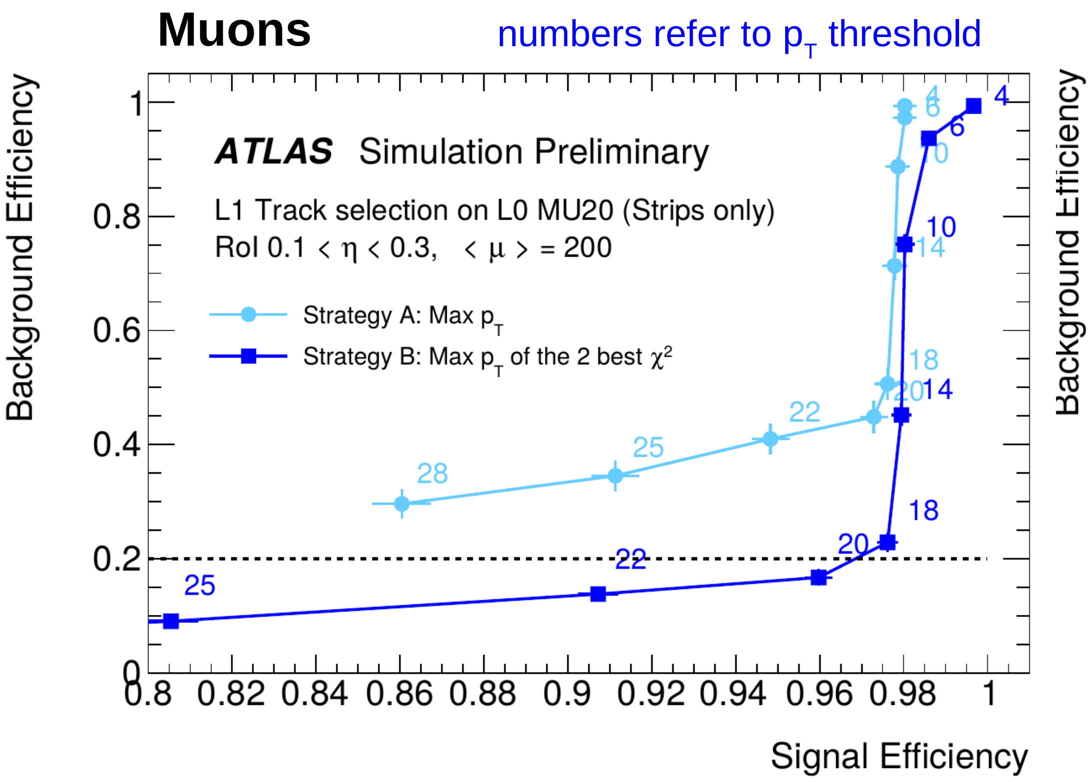
ATLAS Track Trigger Emulation

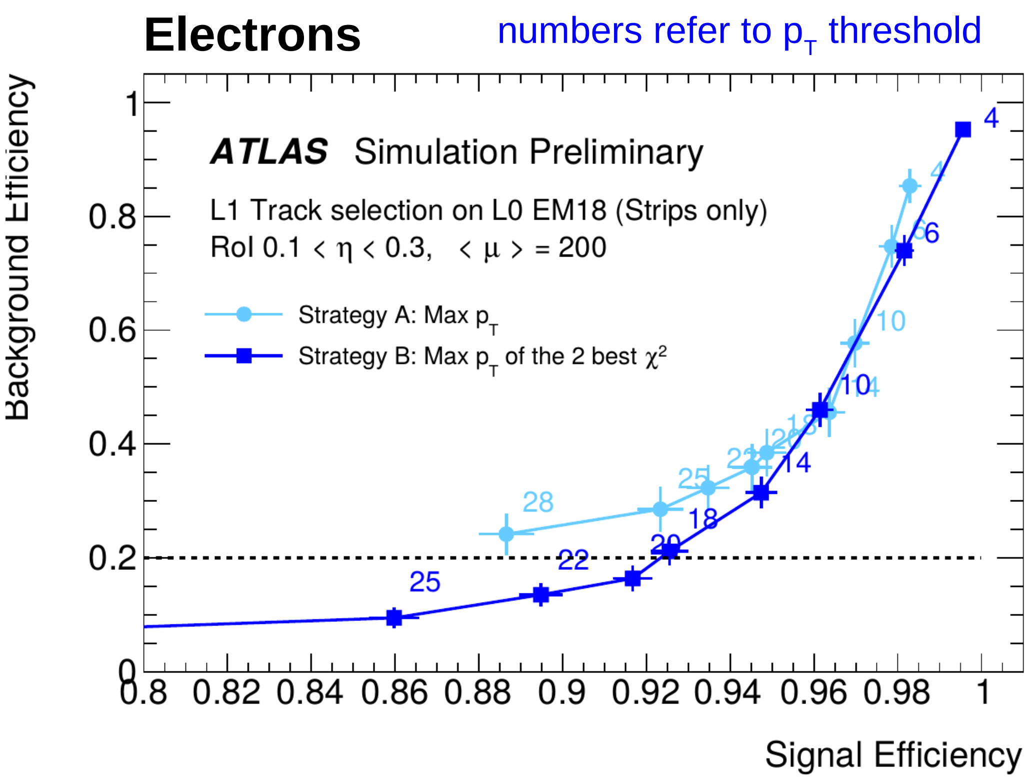


Simulation Results of AM-based Track Trigger

→ Muon (MIP) track finding and fitting efficiency ~99%

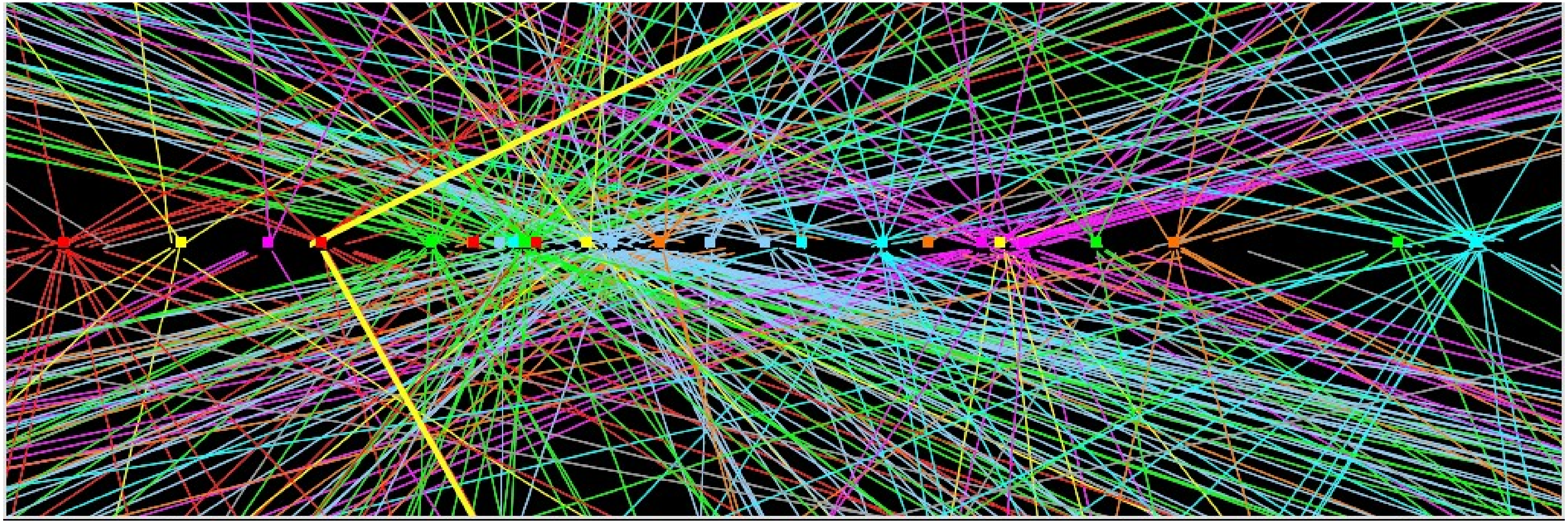
Rejection and Efficiency of Muons and Electrons triggered by Level 0:





→ factor 5-10 rejection of minimum bias background

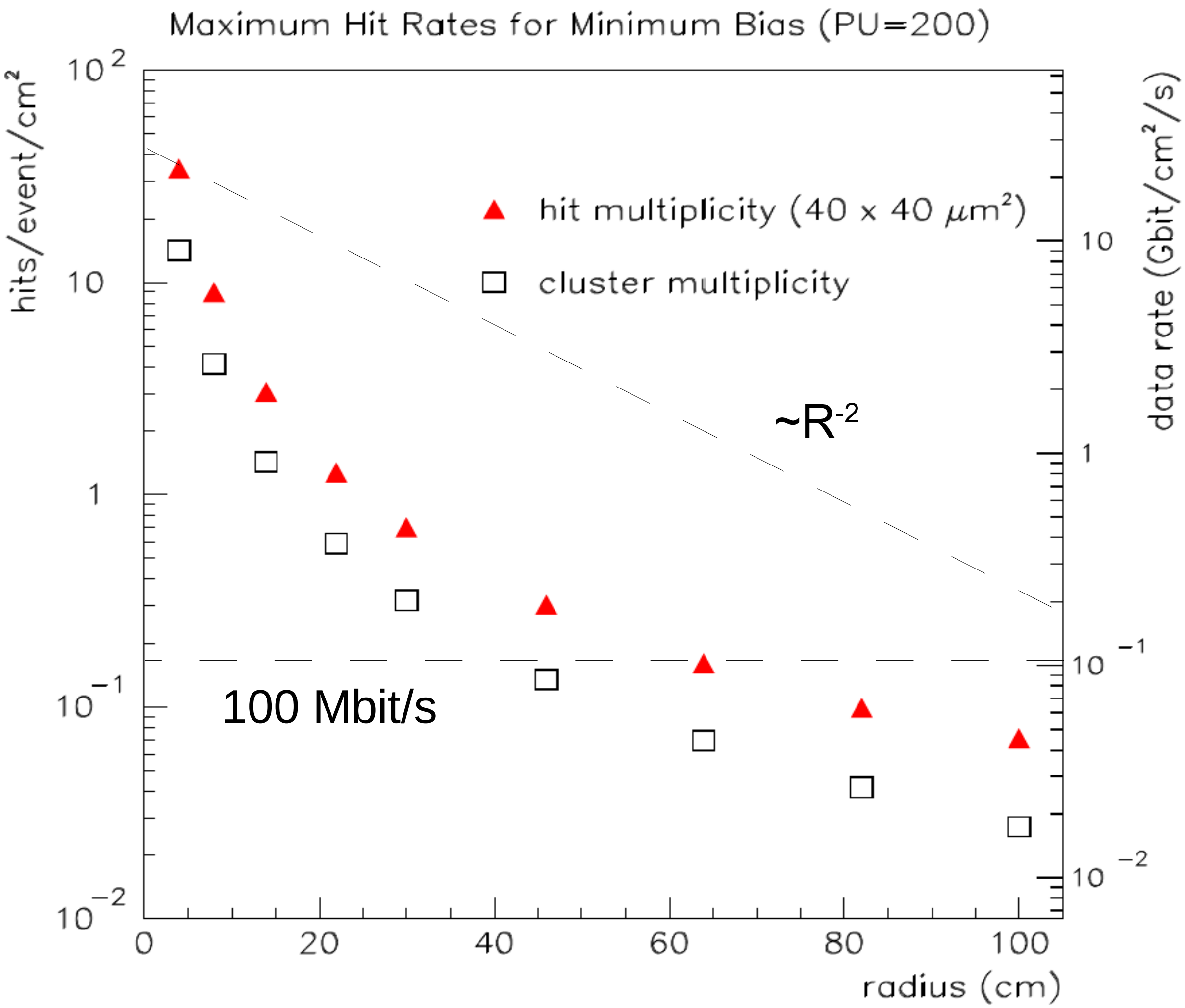
Why not reconstruct all tracks at 40 MHz?



The Bandwidth Problem

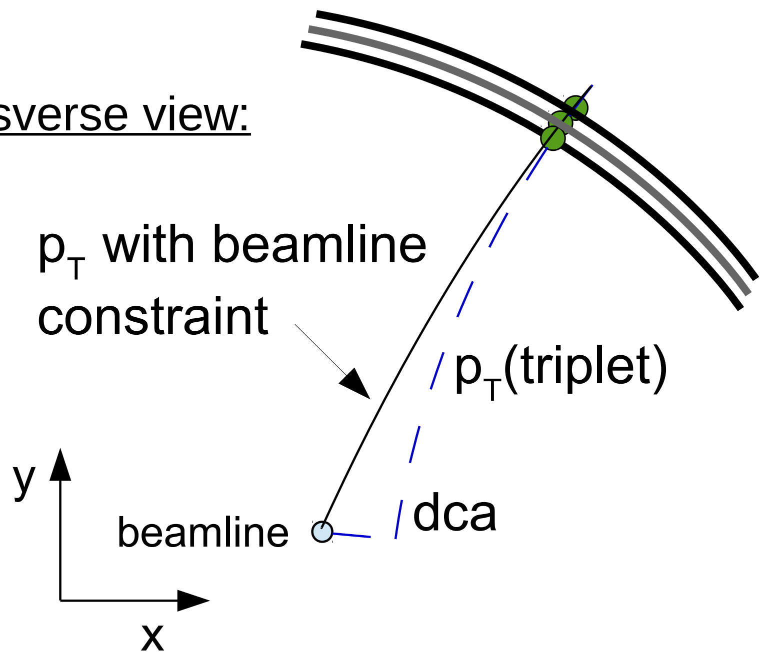
- Readout of **all hits** for every bunch crossing only feasible for large radii

ATLAS detector for HL-LHC

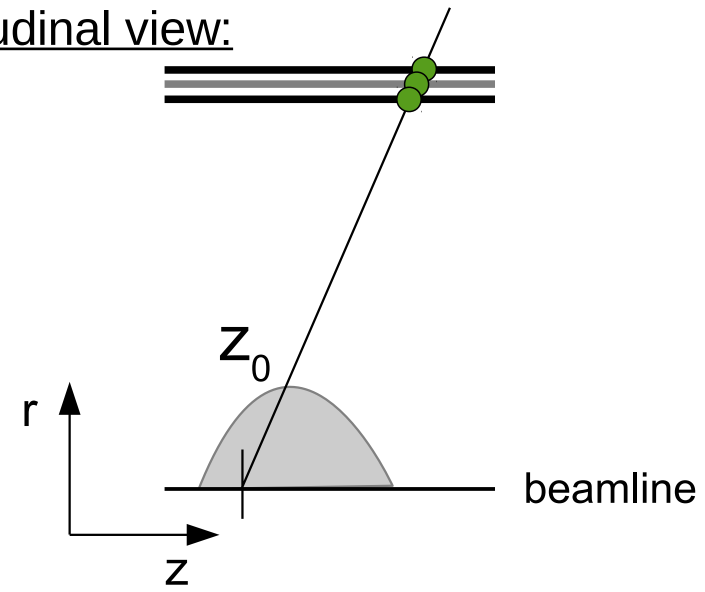


Minimum Number of Tracking Layers?

transverse view:



longitudinal view:



- with beamline constraint → 2 layers
- w/o beamline constraint → 3 layers (some redundancy included!)

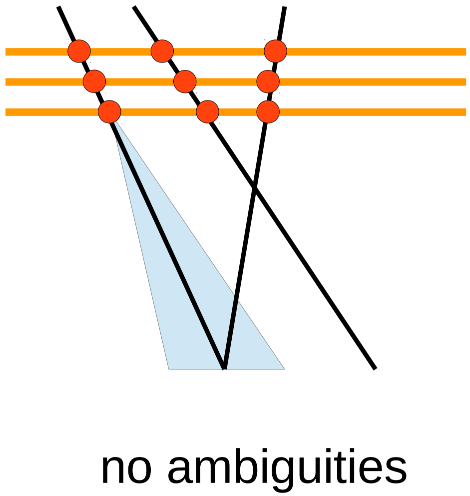
Optimal Distance Between Tracking Layers?

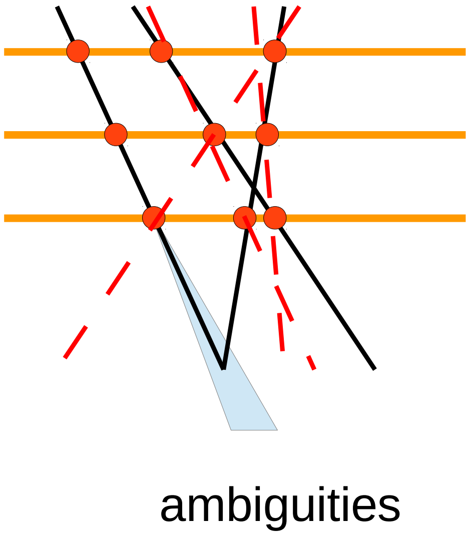
Large gap between layers:

- reduction of extrapolation uncertainties
- increase of ambiguities (fake tracks)

Small gap between tracking layers

- increase of extrapolation uncertainties
- reduction of ambiguities (fake tracks)





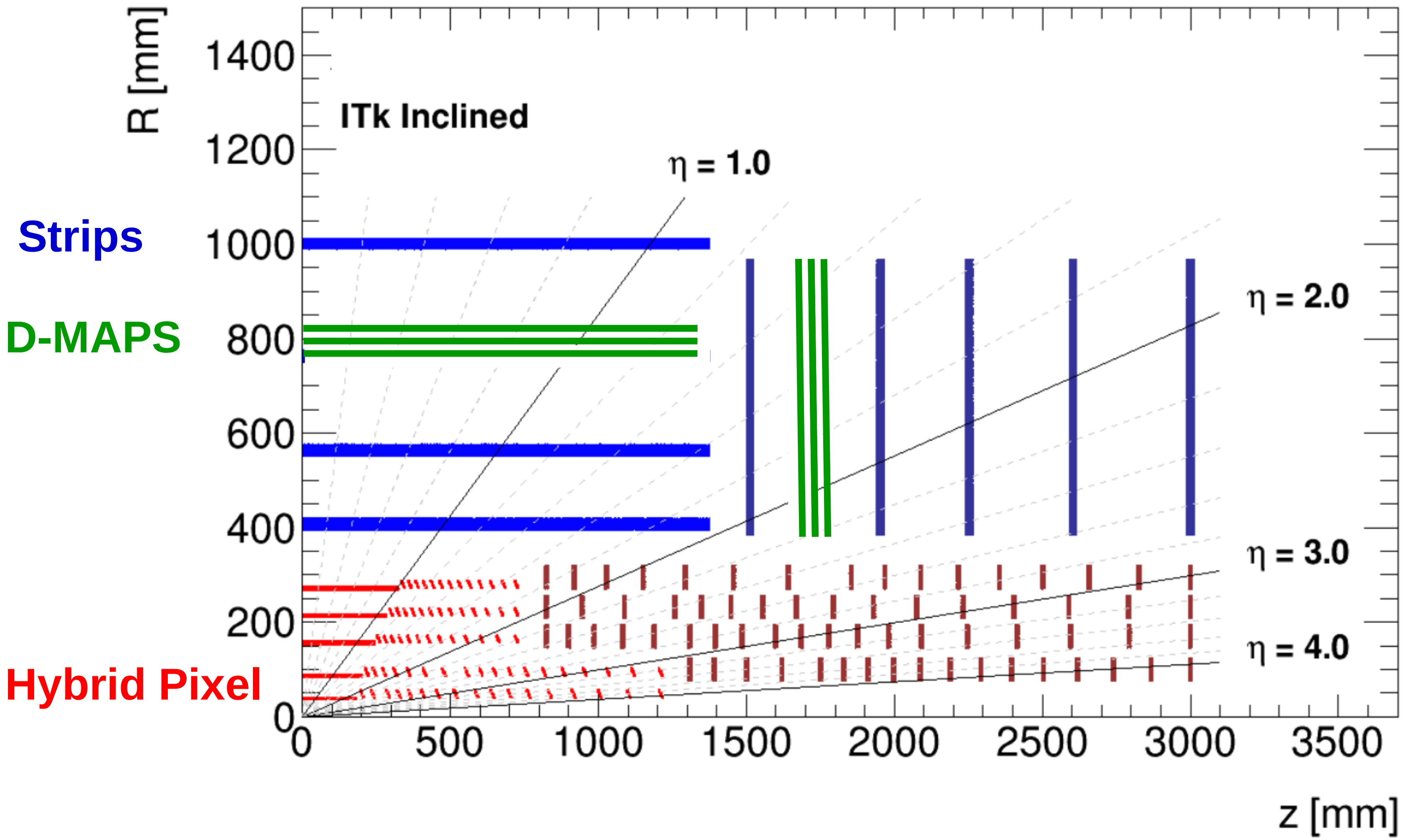
- optimal tracking layer distance ~2-4 cm
- hits line up on almost straight lines → easy reco

WARNING

THE FOLLOWING SLIDES CONTAIN CONTENT
THAT SOME MAY FIND DISTURBING
AND THAT ARE NOT SUITABLE FOR
SOME AUDIENCE

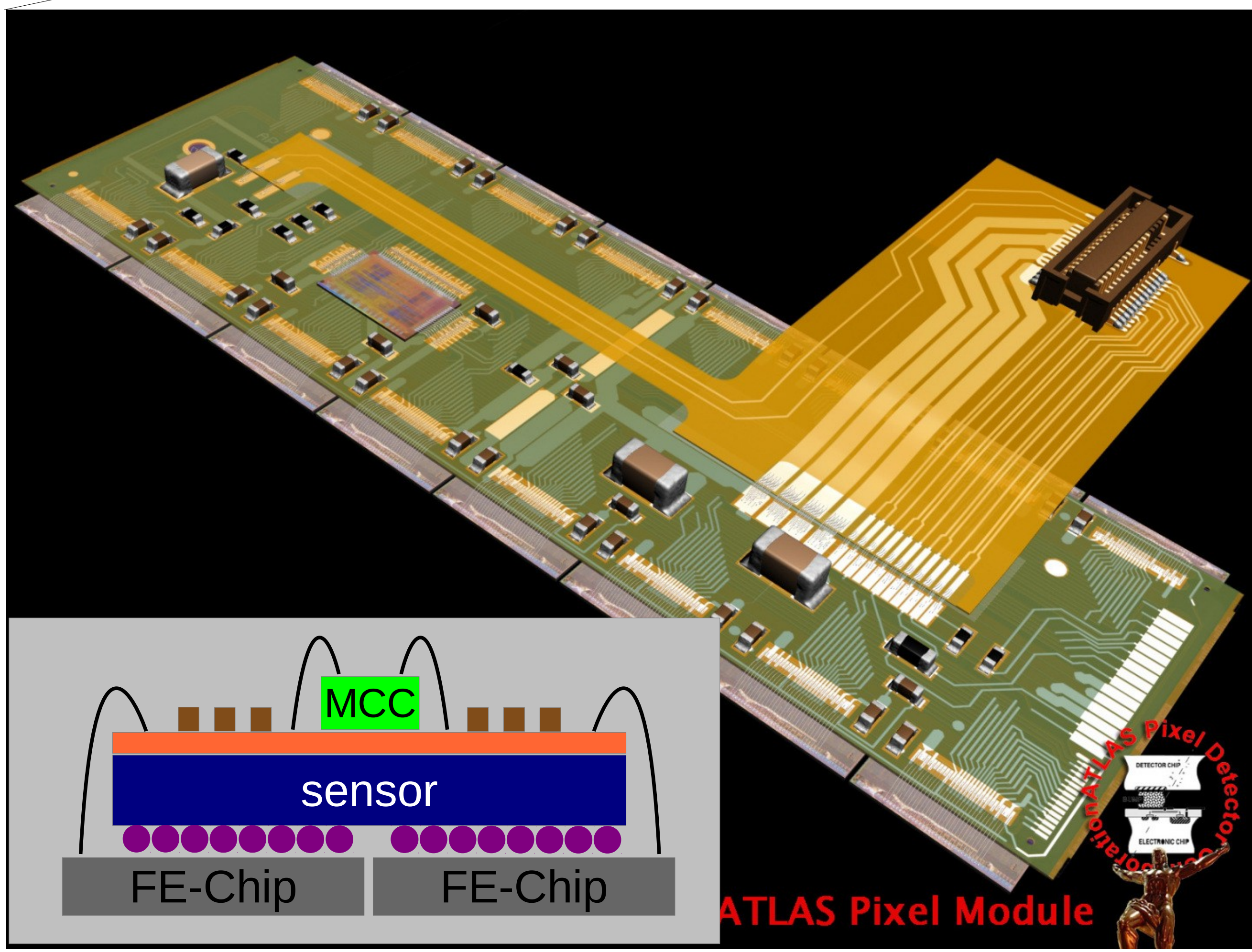
ACCORDINGLY,
VIEWER DISCRETION IS ADVISED

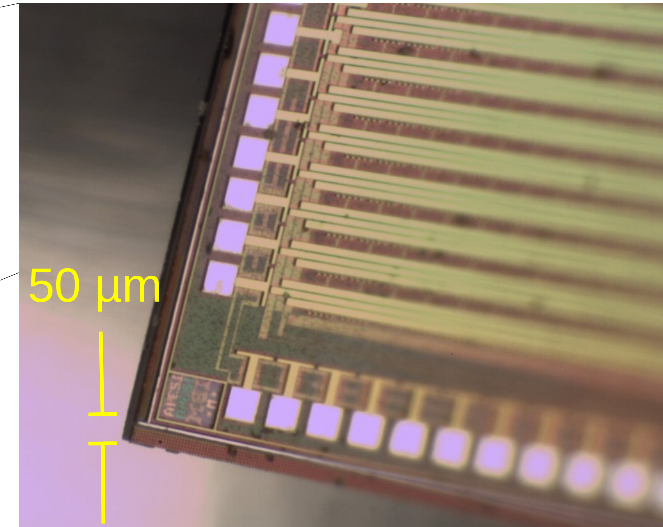
Alternative 40 MHz Track Trigger (L0TT)



D-MAPS = Depleted Monolithic Active Pixel Sensors

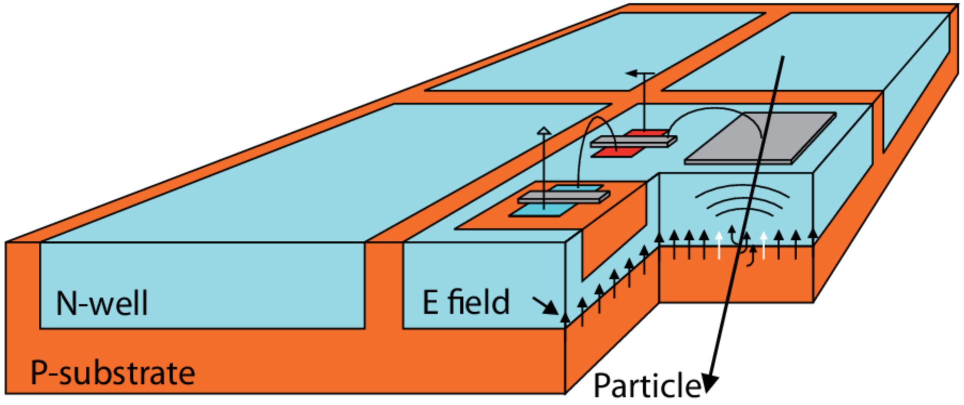
Hybrid Pixel versus Monolithic Pixel Chip

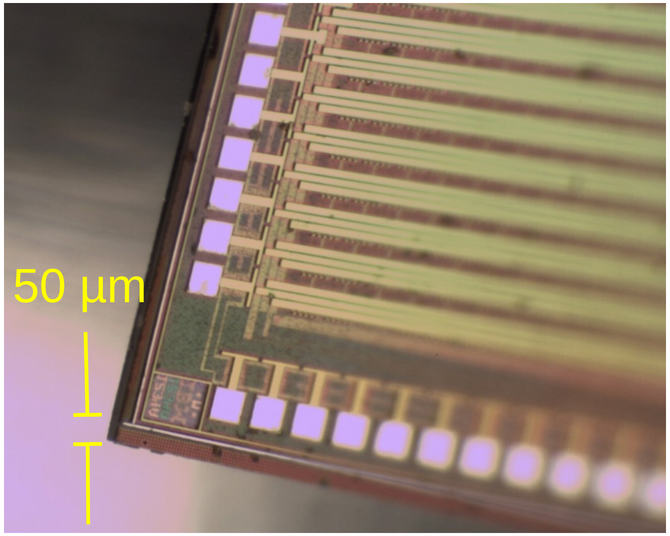




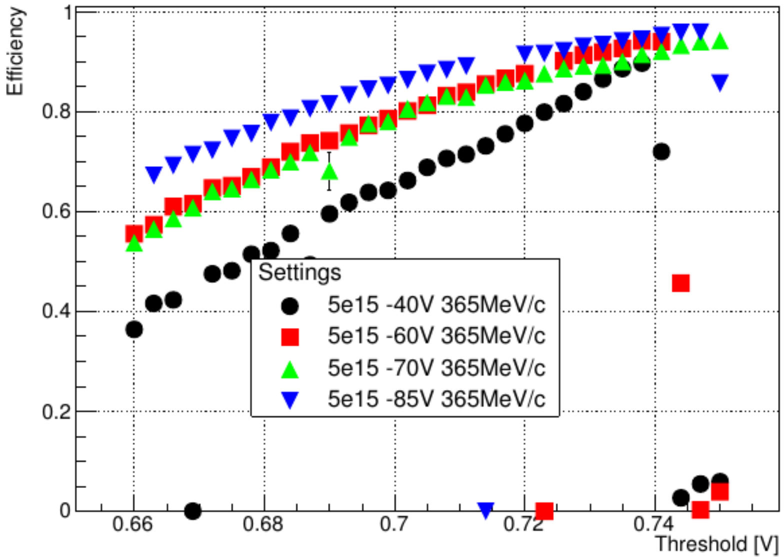
High Voltage Monolithic Pixel Chips

Ivan Perić, NIMA 582 (2007) 876



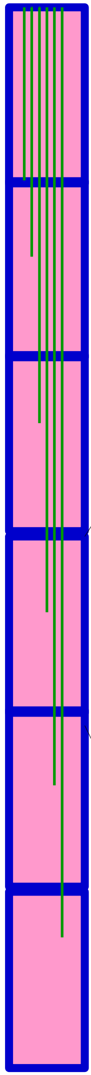


Mupix7 (AMS 180 HV-CMOS)
neutron irradiated

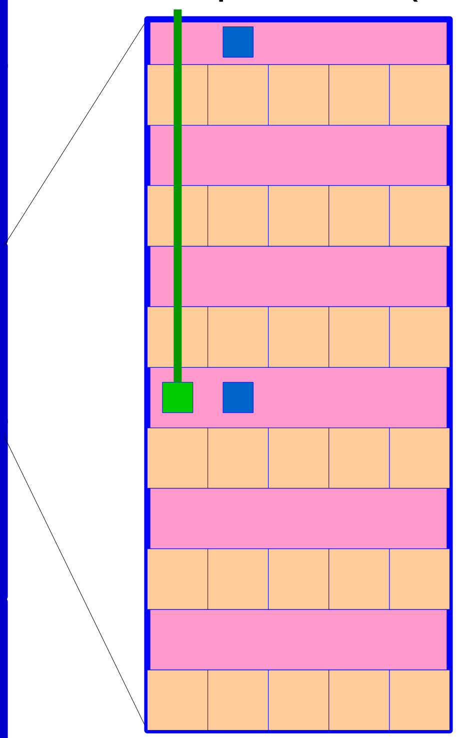


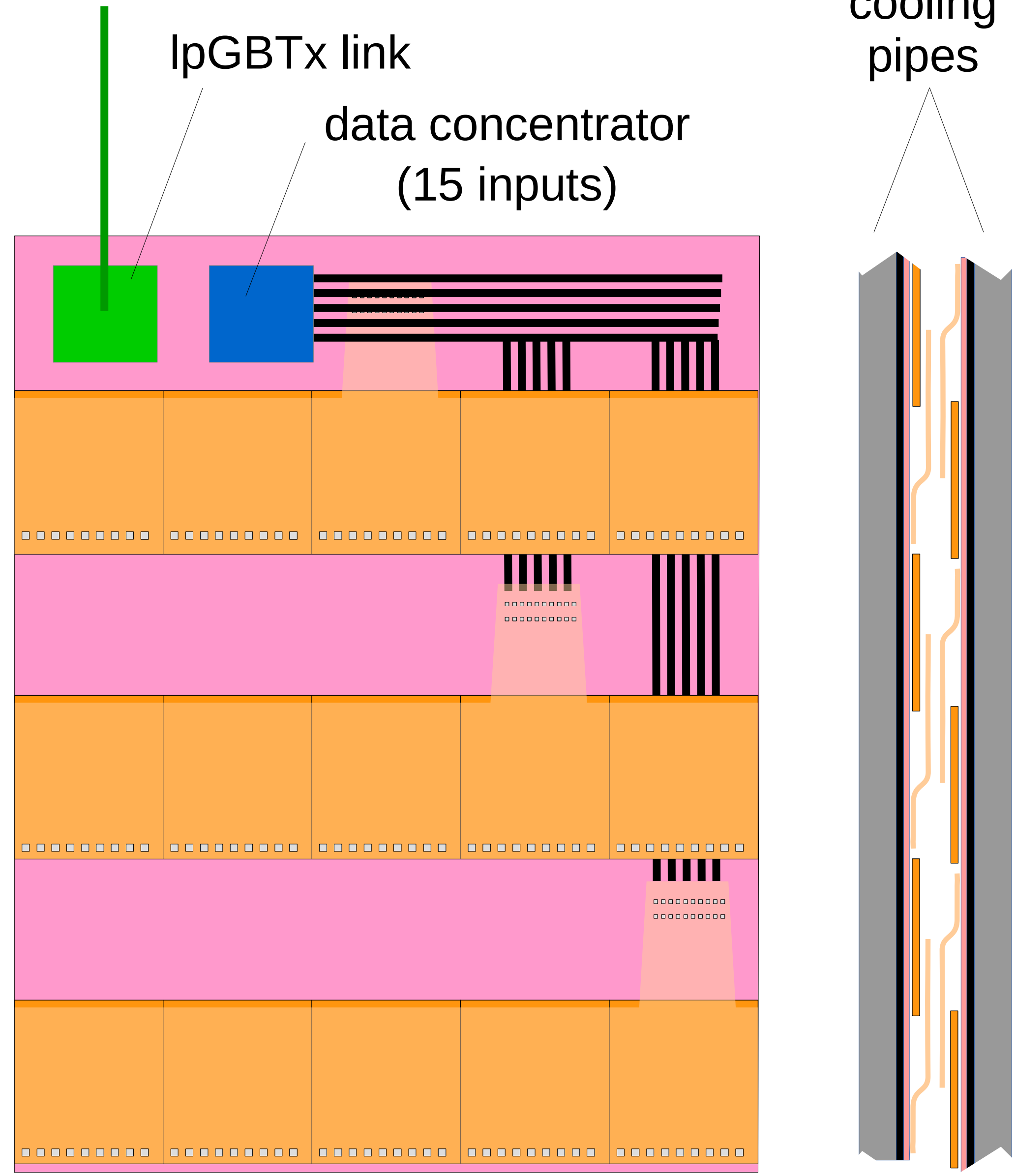
- **no composite - no interconnects**
- **simplified design (ASIC)**
- **sparsified readout (zero suppressed)**
- **fast signals**
- **low noise**
- **thin sensor!**
- **fast serial output**
- **continuous readout → trigger**
- **radiation hard!**

Possible Design of HV-MAPS stave

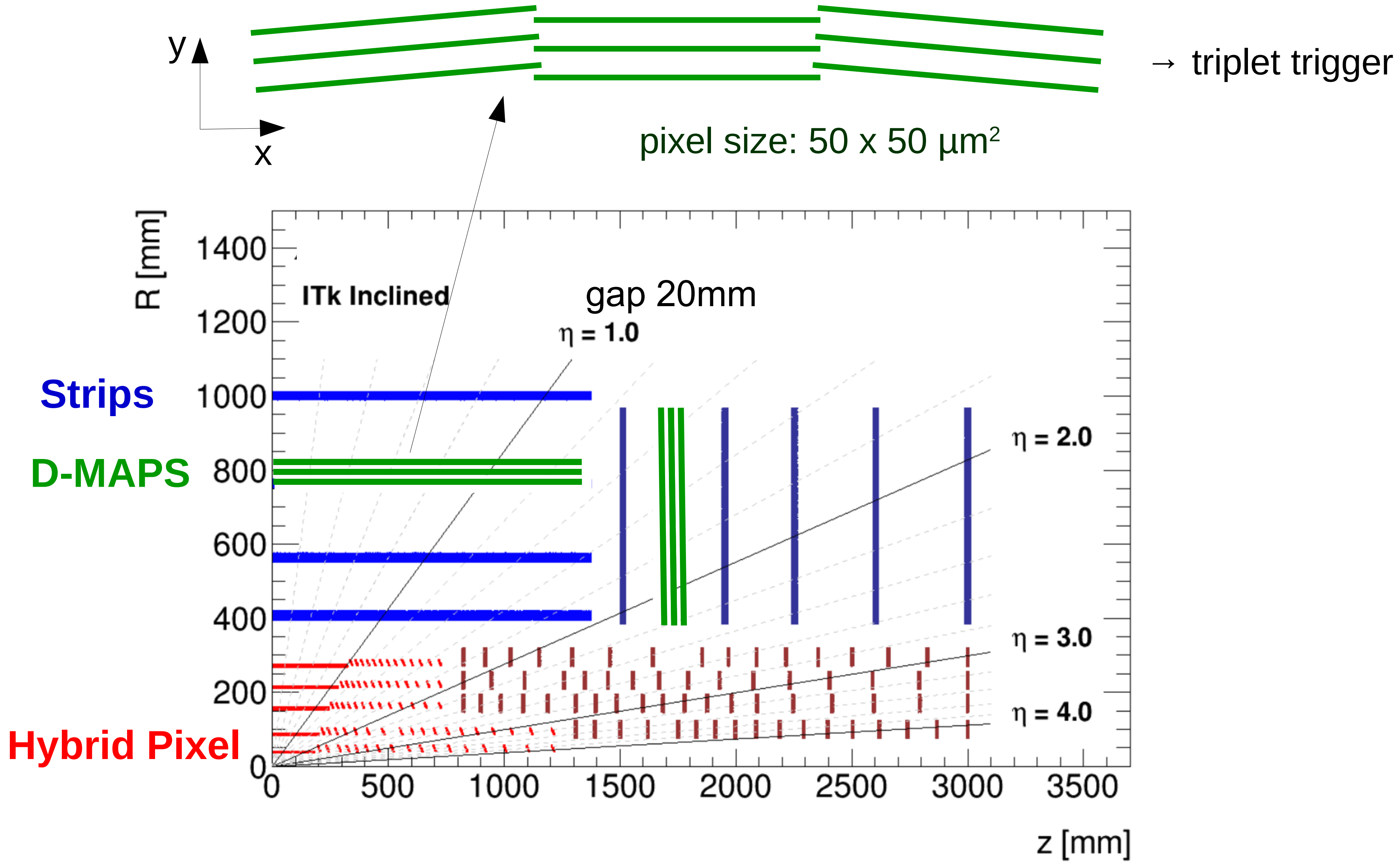


<u>Double Group</u>
2x power groups
2x 15 reticles
2x data concentrator
data rate: 6Gbps (cluster)
1x optical link (1 spare?)





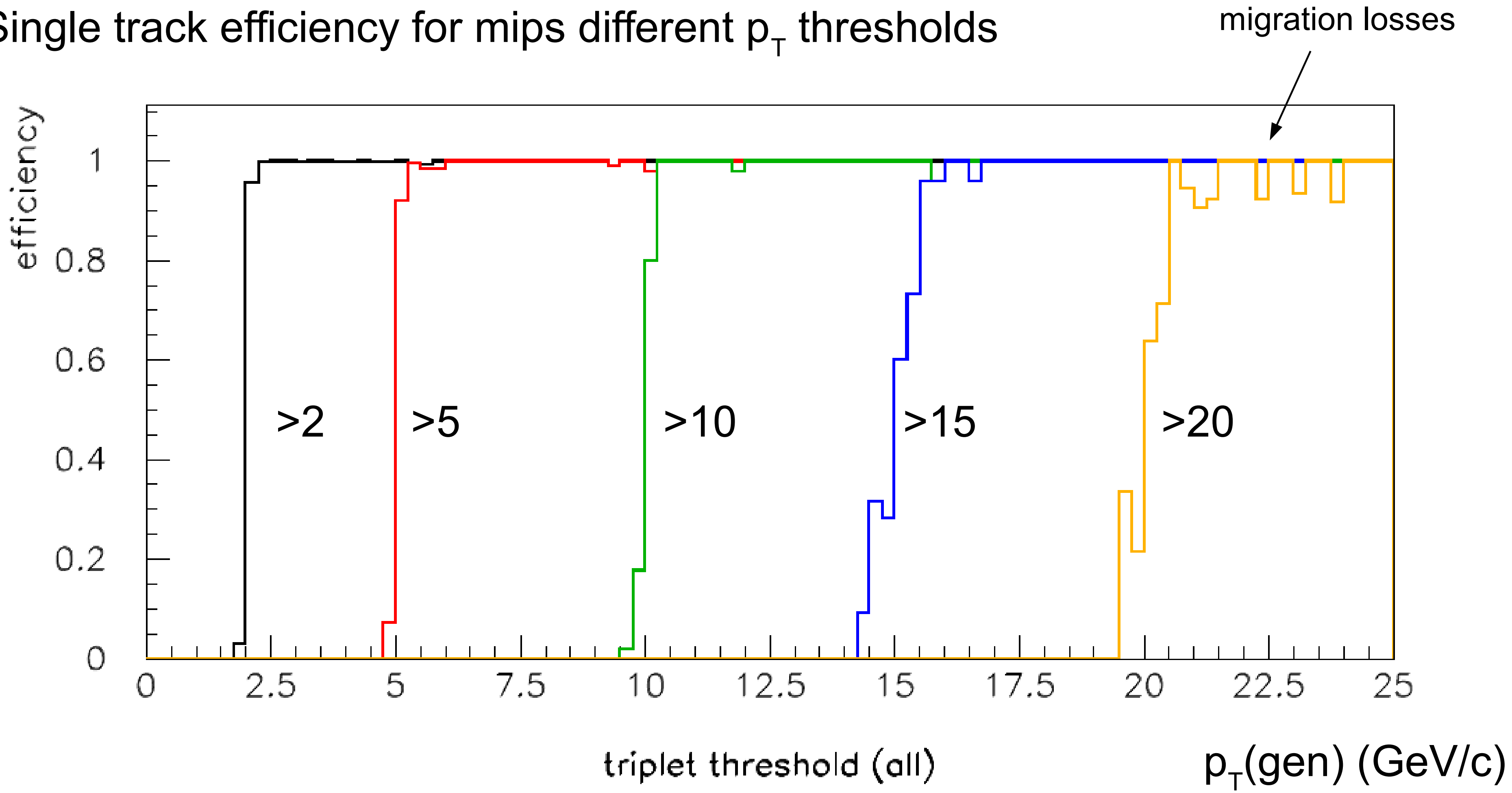
Alternative 40 MHz Track Trigger (L0TT)



D-MAPS = Depleted Monolithic Active Pixel Sensors

Track Finding Efficiency

Single track efficiency for mips different p_T thresholds

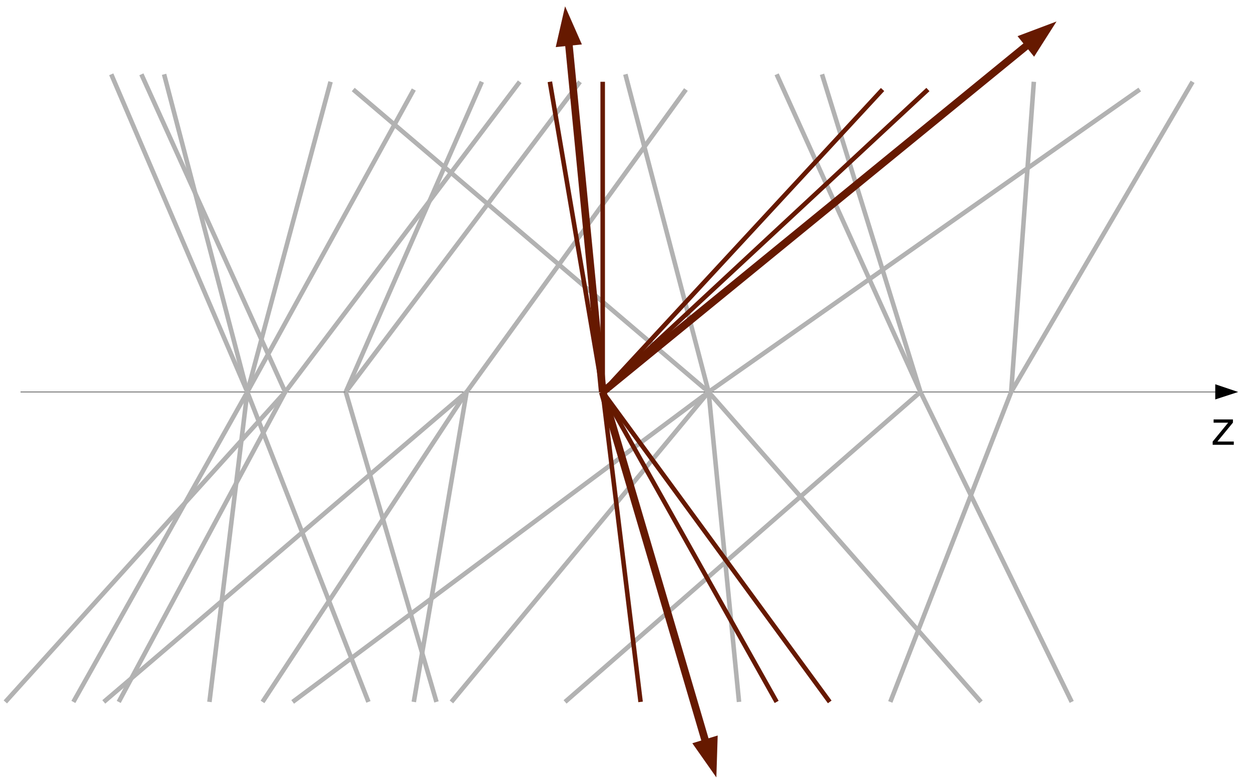


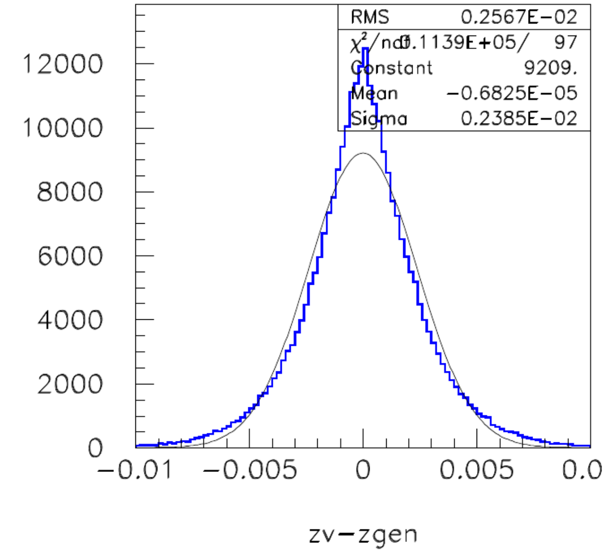
- Track reconstruction efficiency ~ 100% *
- Track purity is close to 100% (not shown)

* assuming 100% single hit efficiency

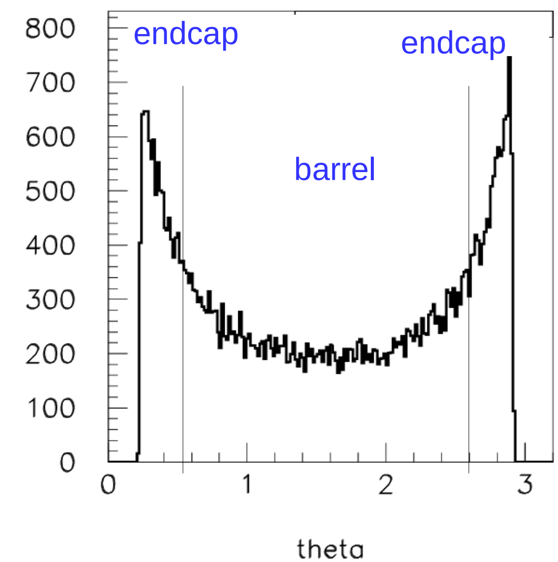
Simulated Z_0 Resolution

event vertex can be reconstruction with a resolution
of a few mm in z-direction (depends on tracker material)





$\sigma(z_0) \sim 2.5$ mm

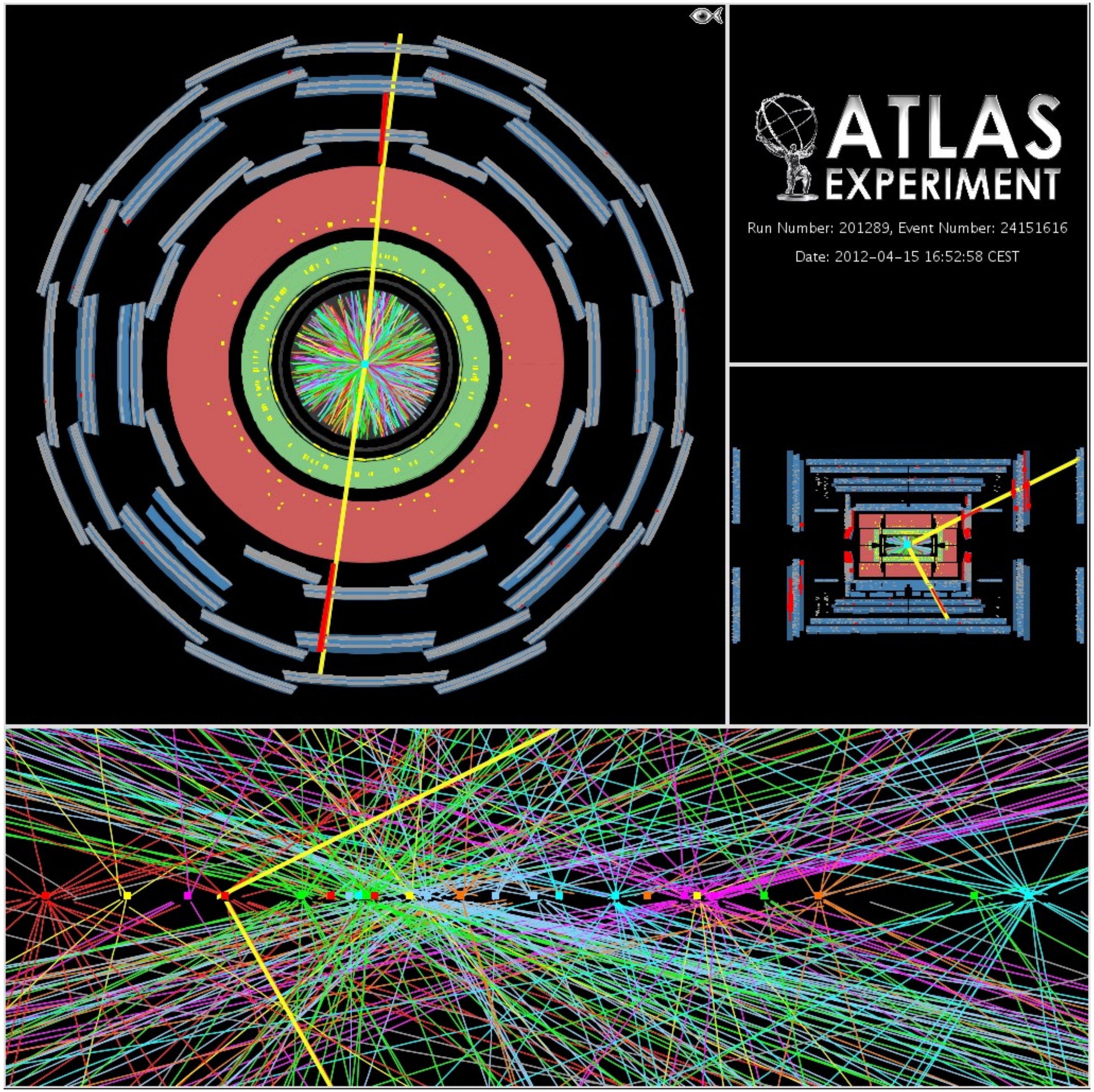


coverage up to |eta|=2.2

→ **good separation of pileup events possible!**

relevant for multi-jet triggers

Example: Simple Two Track Trigger



Summary

FTK Phase I upgrade

- full track reconstruction at 100 kHz
- being installed and fully operational in 2018

ATLAS Phase II: discussed track trigger upgrades

- FTK++: continuation of FTK concept with associative memories (baseline)
- EFTrack: similar to FTK but reconstruction at higher rate (1 MHz) in regions of interest (ROI) only

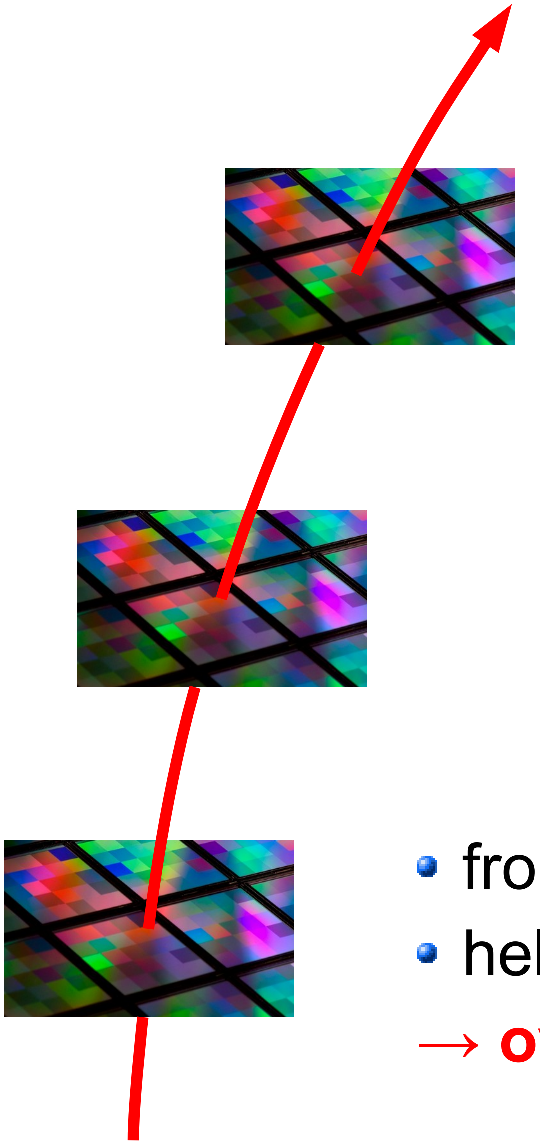
ATLAS Phase II: L0TT triplet track trigger

- not so crazy idea of instrumenting large areas with monolithic active pixel sensors for track trigger
- can reconstruct ALL tracks (p_T>1 GeV) at 40 MHz

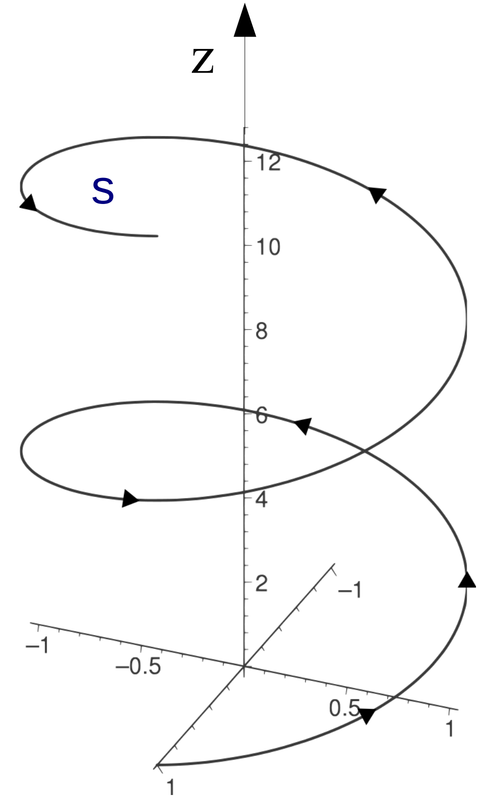
Backup

Track Parameters from Space Points

basic assumption: solenoidal magnetic field



3D tracking:
- **simple**
- **robust**



- from three planes → **9 parameters**
- helix and crossings described by **8 parameters**

→ **over-constrained fit**

Variable Pattern Matches with Don’t Care