L1-track triggers for ATLAS in the HL-LHC

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Outline

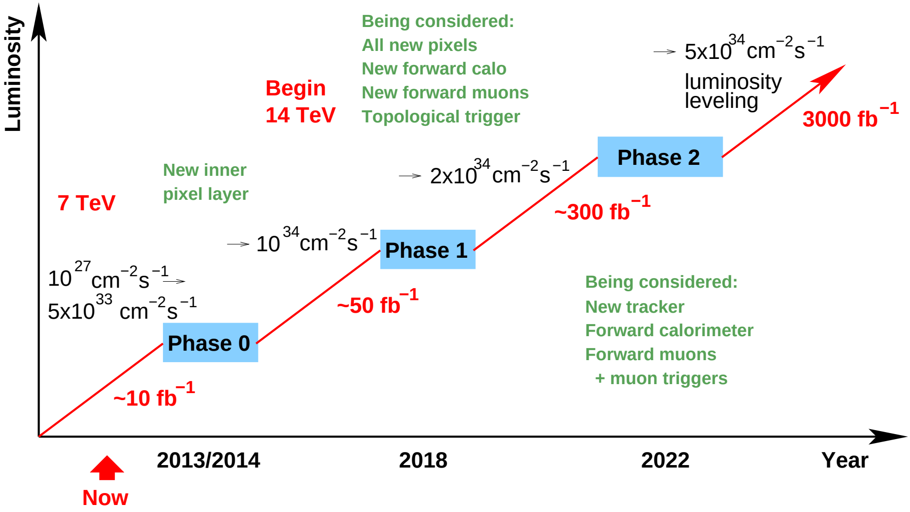
Context of trigger issues in the HL-LHC

- Comments on the HL-LHC design parameters
- The current ATLAS trigger system
- Known (or unknown) trigger issues for HL-LHC
  - Planning for the unknown

Two track trigger options

- Intro to the issues: why is this so hard?
- Self-seeded: p_{T} filtering
- Region of interest seeded: spatial filtering
- Current status
- Comparison of the Methods

HL-LHC: High Luminosity LHC



- Original design luminosity of detectors is $1 \times 10^{34}\ \mathrm{cm}^{-2}s^{-1}$

HL-LHC Parameters

Proceedings of Chamonix Workshop 2011

- Luminosity leveling at $5 \times 10^{34}\ \mathrm{cm}^{-2} s^{-1}$
- Nominal bunch spacing 25ns but it could be 50ns
- Collisions per crossing

$$N_{\mathrm{collisions\ per\ crossing}} = \sigma\, \mathcal{L}\, \Delta t_{\mathrm{bunch}}$$

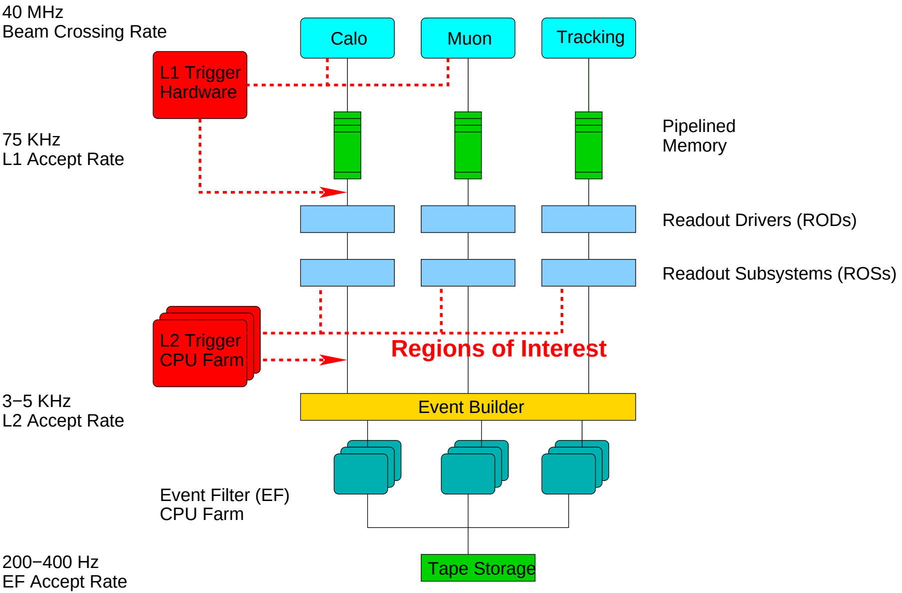
- This means $\approx$ 100 for 25 ns and $\approx$ 200 for 50 ns
- The design parameters planned in 2010 considered $10^{35}\ \mathrm{cm}^{-2} s^{-1}$(no leveling), 25-50 ns, and up to 400 collision per crossing
- LHC luminosity has ramped up faster than expected, more performance could mean more pressure on the trigger

HL-LHC Parameters

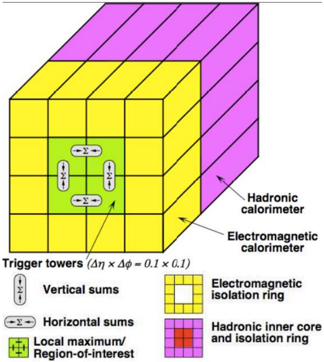
Impact of bunch spacing:

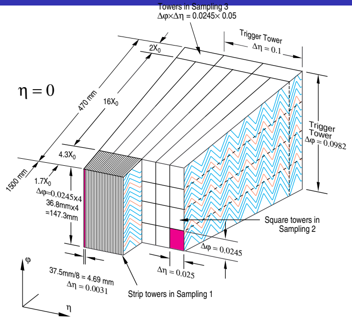
- smaller spacing means less *in time* pile-up
- smaller spacing means event based buffers/queues fill faster
  - hit-based buffers are roughly the same
- smaller spacing means more crossings, so we keep a smaller fraction
  - with a 40 MHz crossing rate and a 400 Hz final output rate, the trigger supression has to be 10^{-5}
  - with a 20 MHz crossing rate and a 400 Hz final output rate, the trigger supression has to be 5×10^{-4}

The current ATLAS trigger system



The current calorimeter trigger: vertical view





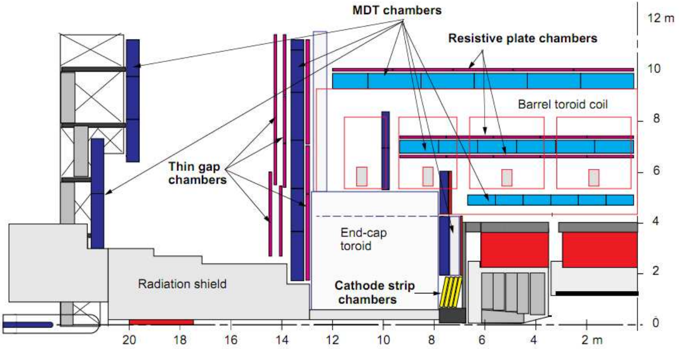
L1 trigger

- analog sums over 0.1×0.1 towers
  - EM and HAD separated (can cut on EM/HAD)
  - Isolation possible

HLT: L2 and EF trigger

- Uses full granularity and same digitization as offline
- Track shower matching
- Detailed shower shape cuts
- EF reclusters jets
- Sharper turn-on curves

The current muon trigger: vertical view



L1 trigger

- Faster Resistive Plate (RPC) and Thin Gap (TGC) Chambers
- Hardware pattern recognition

HLT: L2 and EF trigger

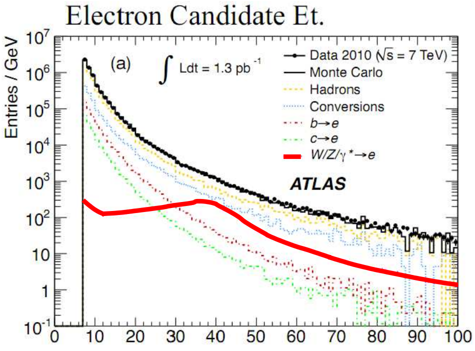
- Use slower more precise monitored drift tubes (MDT)
- Combine with inner detector tracking
- L2 simple B-field model
- EF use full offline software

Increase in overall rates

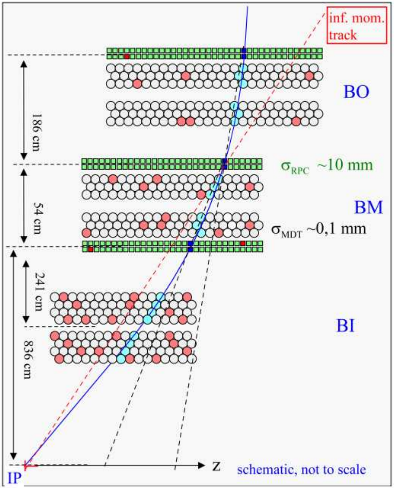
L1 Trigger	ATLAS TDR $1\times10^{34}\mathrm{cm}^{-2}s^{-1}$	Extrapolated to $5\times10^{34}\mathrm{cm}^{-2}s^{-1}$
e/γ, $p_\mathrm{T} > 30$ GeV (calo isolated)	22 KHz	110 KHz
$2 \times e/\gamma$, $p_\mathrm{T} > 20$ GeV (calo isolated)	5 KHz	25 KHz
μ, $p_\mathrm{T} > 20$ GeV	3.9 KHz	20 KHz

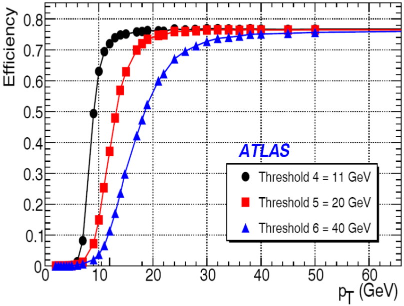
if e $p_\mathrm{T} > 30$ GeV, we lose a lot of physics (most of the *W* decays)

We need cleaner leptons, especially electrons at L1



The muon resolution problem

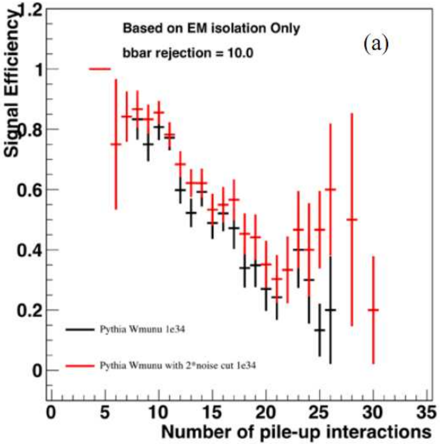


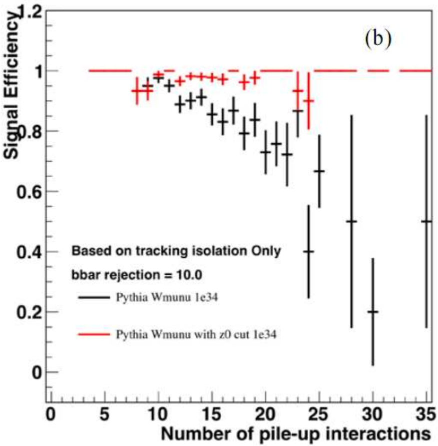


- L1 muon resolution not good enough to cut harder than 20 GeV
  - Only reduce rate by 2× going from 20 GeV to 40 GeV
- Single muon trigger would be in jeopardy

There are possible upgrades to the muon chamber themselves to address some of these problems (talk by Robert Richter).

Degradation of Calorimeter Isolation





- Calorimeter isolation will degrade in efficiency as pile-up increases
- Track isolation with a *z*-vertex cut is roughly insensitive to pile-up

Figures taken from FTK proposal (proposed fast track processor for L2)

Motivation Summary

Issues

- Overall rates are large: mostly jets misidentified as X
- Muon resolution limits the largest possible p_{T} cut
- Calorimeter isolation degrades, track isolation could help
- Missing energy degrades (less useful in combinations)
- Effects on jets?

Motivations for a track-trigger

- Improve muon resolution
- Track-shower matching
- Track isolation: e, μ, τ, γ
- Could tracks even be useful for jets?
- b-tagging?

Flexibility: We are planning Columbus' second voyage before we have full news of the first

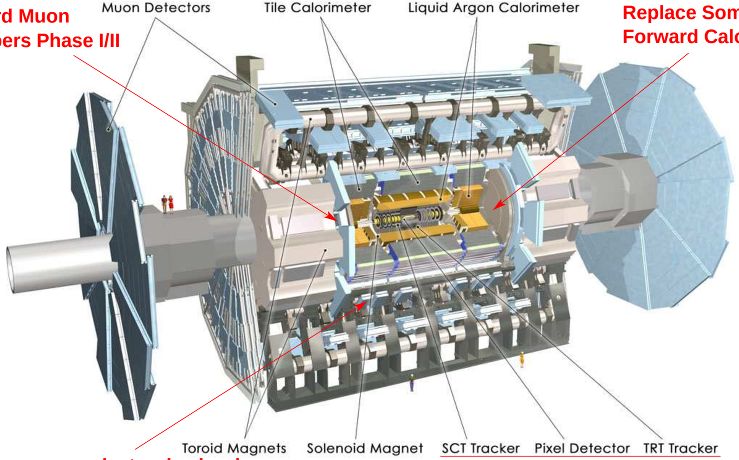
Overview of Upgrade

Overview of the upgrade: Phase 2

Replace Innermost Forward Muon Chambers Phase I/II

Replace Calorimeter Electronics

Replace Some Forward Calorimeters

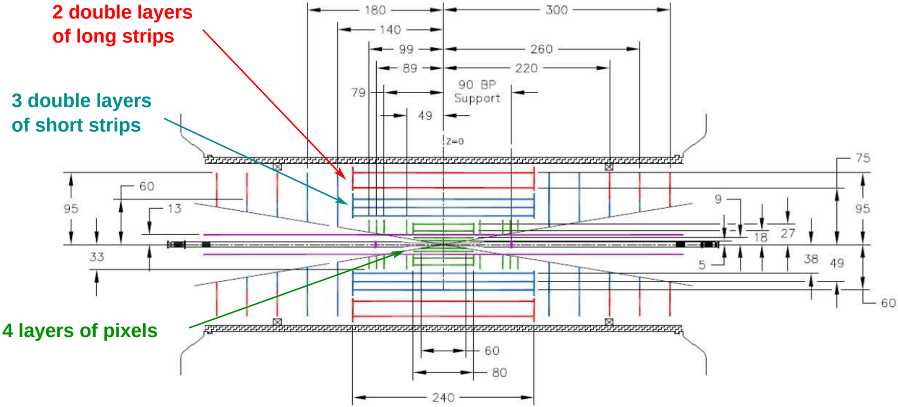


Some muon electronics hard to reach/upgrade

Replace All Trackers

Tracker Upgrade

Current Strawman Layout



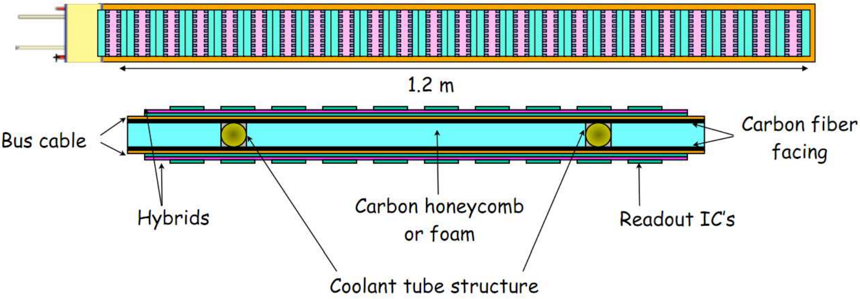
Pattern recognition / fake track supression are important design criteria

Strips are configured with one-side having a low-angle stereo

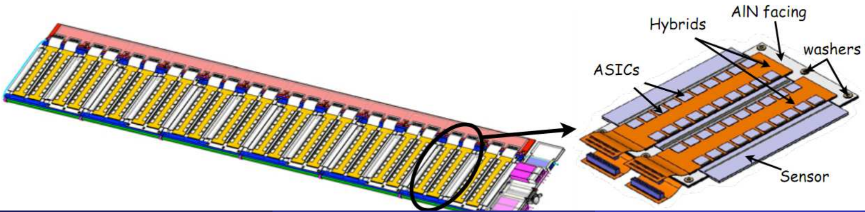
... and of course minimize material

Strip construction

Stave: integrated bus, cooling, and support



Double-sided Super modules: modular construction



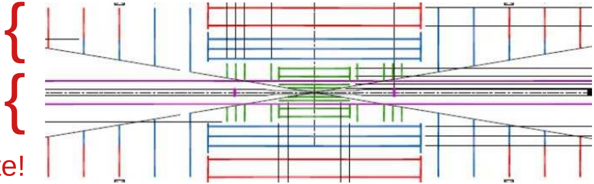
Track Triggering Options

Track Trigger Challenges

Strips: $\approx$ 45 million

Pixels: $\approx$ 400 million

40 MHz beam crossing rate!



Data flow

- Before the track trigger, the plan was to read out $\approx$100 KHz of full events
- Doubling the rate roughly doubles the power, which means the material in the power distribution and the cooling.
- Reading out the full detector at 20 (or 40) MHz is a non-starter
- $\Rightarrow$ **Need a filter to reduce the data flow**

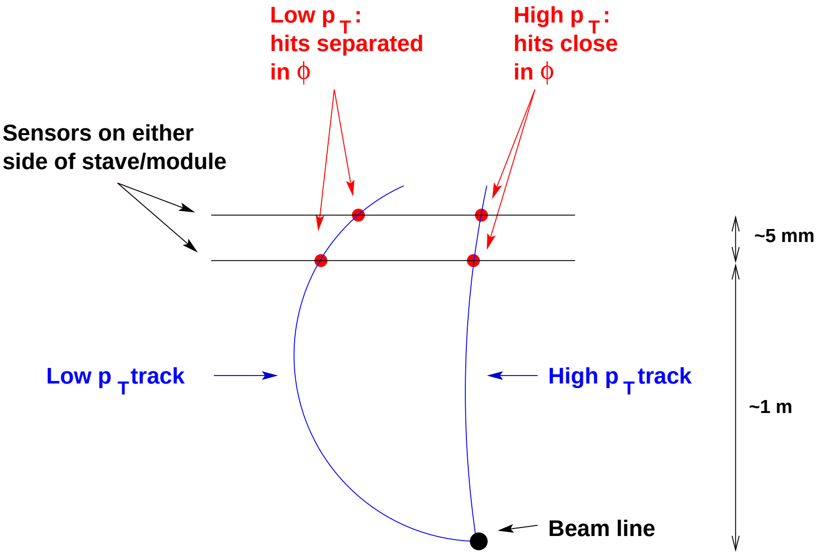
Two options:

1) Filtering on p_{T}
2) Filtering on Region

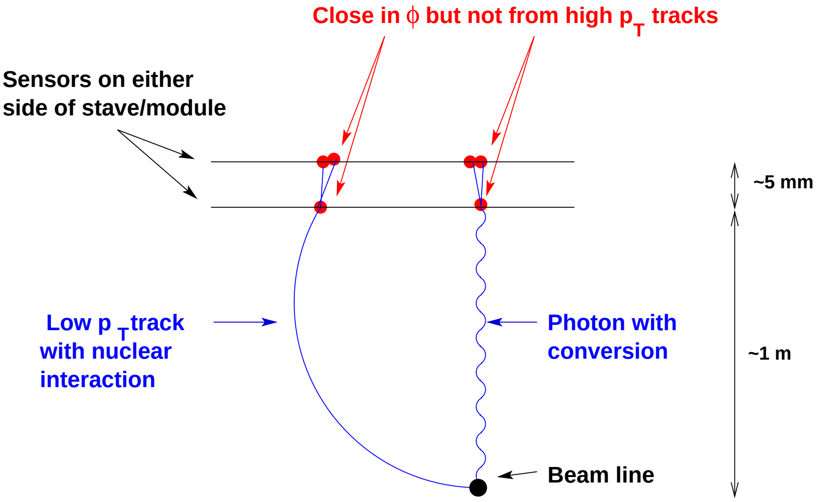
Filtering on p_{T}: Unseeded/Doublet Method

Reducing the data flow, Option 1: Filtering on p_T

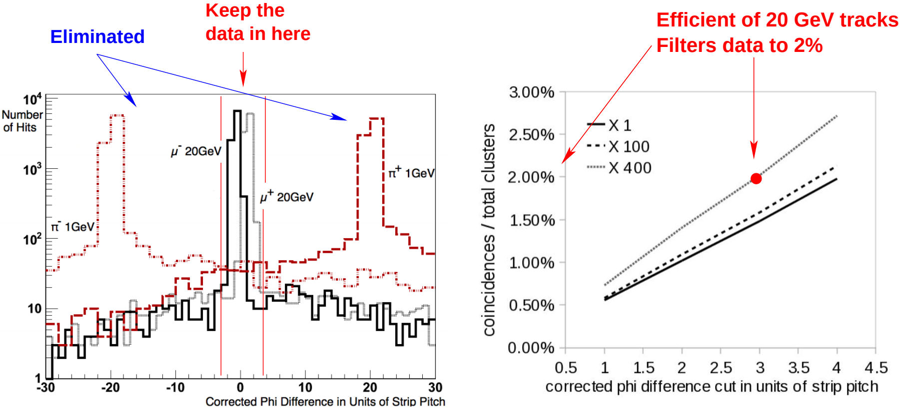
"Unseeded"/Doublet Method



Other sources of doublet coincidences



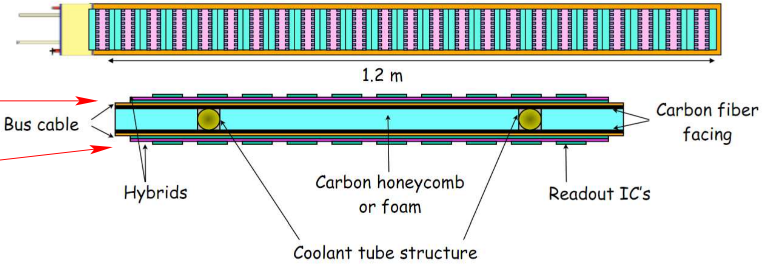
The Data Reduction

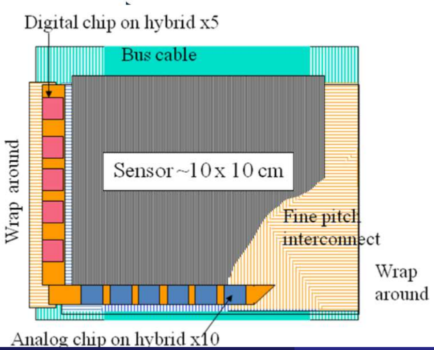


- Two-trigger layers at 0.80 m and 1m roughly doubles to total bandwidth
- Total bandwidth for outer layer with doublet readout is comparable to an inner layer without
- Must eliminate stereo angle for outer layers

The communicating between the two sides

Need to get from here to here





- Local correlator for each 10cm module
- Only doublets passing the $\Delta\phi$ strip cut are sent to the end stave

Latency

Rough Latency Estimate

Digitization collecting signals and correlating	$\approx$100 ns
Hit Transmission sending the data from the detector to the electronics cavern	$\approx$500 ns
Track Linking content addressable memory (CAM) or FPGAs	$\lesssim$ 500 ns

$\Rightarrow$ Produce tracks in order 1μs

This is in time to fit into the L1 latency of the current system

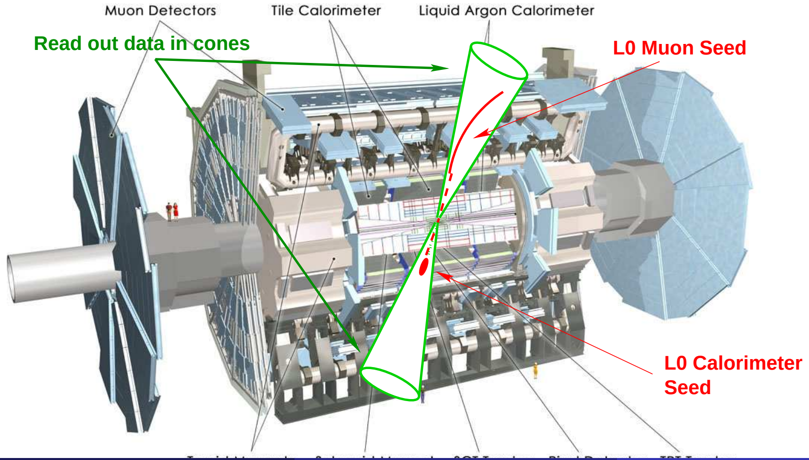
No conflict with existing hardware

Filtering on Region: Two-level trigger

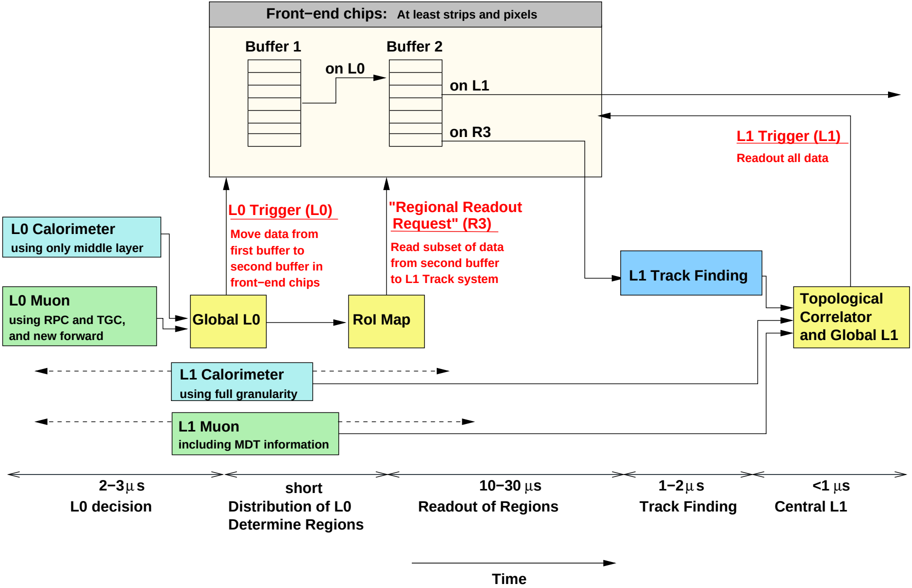
Reducing the data flow, Option 2: Filtering on Region

Two-level trigger: L0 and L1

- **L0** uses calorimeter and muon system to define regions of interest (RoIs)
- **L1** extracts tracking for just RoIs from detector front-ends

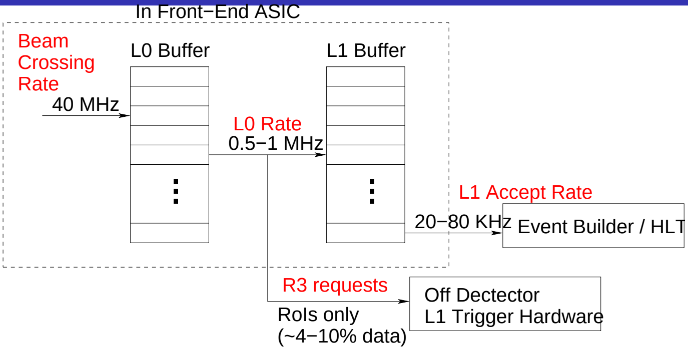


Two-buffer scheme



Note for 100 KHz, serial readout time for a module is $\approx 10\mu s$

Two-buffer scheme



Bandwidth = L1 Rate + L0 Rate $\times$ fraction of data in RoIs $\approx$ 100 KHz

e.g. L0 Rate = 500 KHz, L1 Rate = 50 KHz, RoI fraction = 10%

$$\text{L0 Latency} = \frac{\text{L0 Buffer length (in events)}}{\text{Beam Crossing rate}} \approx \frac{128}{40\text{MHz}} \approx 3.2\mu s$$

$$\text{L1 Latency} = \frac{\text{L1 Buffer length (in events)}}{\text{L0 Rate}} \approx \frac{128}{500\text{KHz}} \approx 256\mu s$$

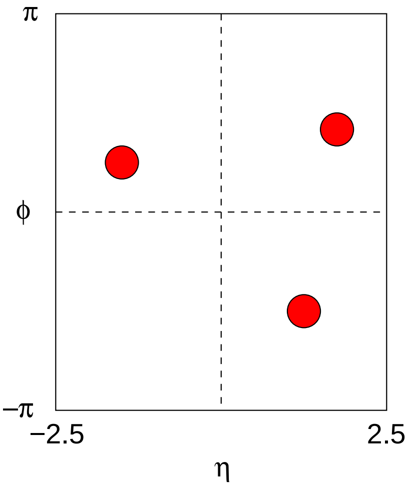
Data Reduction from Regions

Consider cones in $\eta - \phi$ space

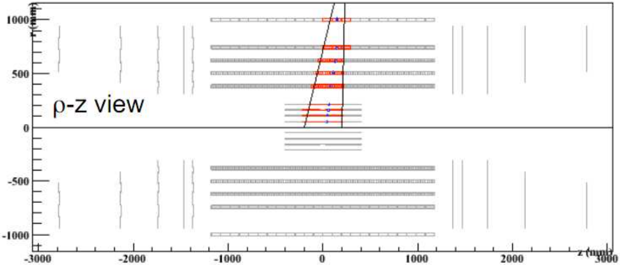
- Typical cones size used for isolation are $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2} = 0.2 - 0.4$
- Fractions of tracking volume in a cone of $\Delta R < r$ is

$$\frac{\pi r^2}{(\eta \text{ range}) \times (\phi \text{ range})}$$

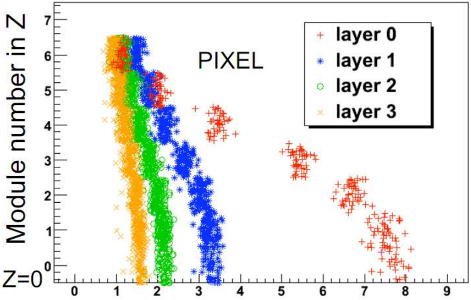
- For a cone of $\Delta R < 0.2$ this is 0.4%
- This allows for a large number of RoIs and a safety margin to fit in 10% RoI request fraction



Data Reduction from Regions



- Because of beam spot spread, RoI need to be elongated along beam direction
- Large request rate for central wafers in inner pixel layers

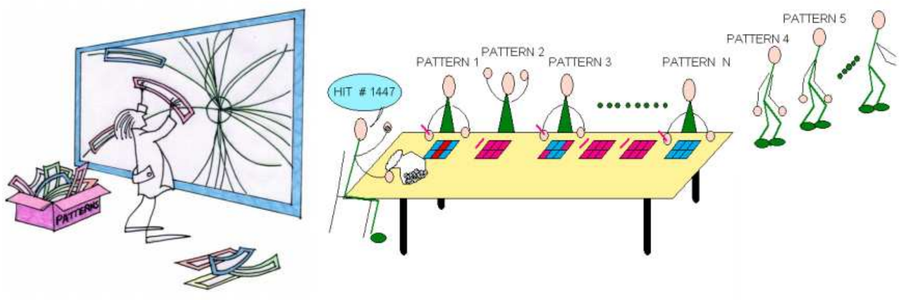


Fraction of RoIs requesting a module (in %)

Finding tracks in the data

Both methods are about getting the data out of the detector

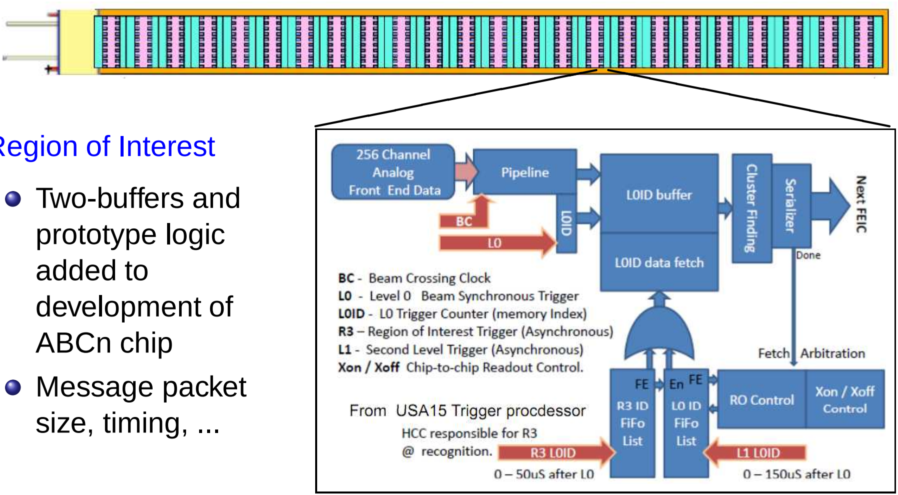
Still need to find the tracks ⇒ Content Addressable Memory (CAM)



- Technology has been used in many places : CDF SVT, H1, ...
- Current proposal for ATLAS Phase-I upgrade is a preprocessor for the level-2 trigger which gets tracks with near-offline quality at the current 75 KHz L1 output rate
- For RoIs, longer latency means other option possible (GPUs?)

Prototyping in ABCn chip: Region of Interest

ABCn = front-end shaping, digitization, and buffering chip

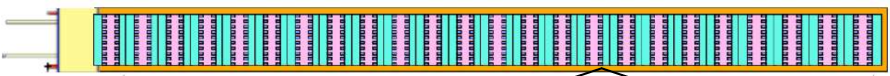


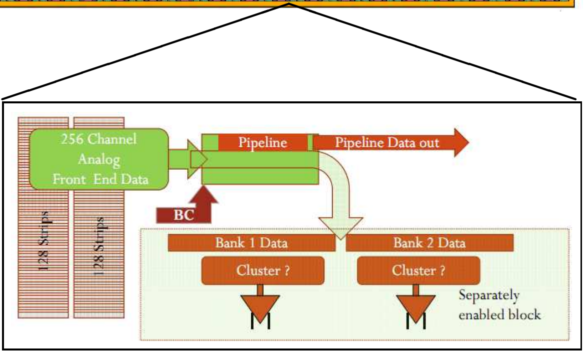
Region of Interest

- Two-buffers and prototype logic added to development of ABCn chip
- Message packet size, timing, ...

Prototyping in ABCn chip: Doublet

ABCn = front-end shaping, digitization, and buffering chip





Doublet Method

- Separate path with cluster size filtering
- Dedicated link sends out cluster information at a fixed latency after beam crossing

Comparing the methods

Doublet Method

- Delivers: High-p_T tracks for all crossings
- Latency: Could fit withing latency specifications of current system
- Effects on tracking system:
  - Requires development of fast readout chain
  - Requires removal of stereo angle on trigger-layer strips

Region of Interest Method

- Delivers: All momentum tracks in regions for selected events
  - Allows for track isolation determination
- Latency: Needs replacement of all electronics in the system
  - Almost all electronics already planned to be replaced
- Large latency allows for more processing of the other detector information
  - Inclusion of muon monitored drift tube (MDT) information
  - Inclusion of fine granularity calorimeter information
- Effects on tracking system:
  - Only affects buffers and readout logic in the front-end chips

Summary

Motivation

- Total rates with current L1 get large
- Muon resolution in current L1 insufficient to raise p_{T} threshold beyond 20 GeV
- Calorimeter isolation and Missing transverse energy will be degraded by pile-up

Methods

- Strip doublets: High-p_{T} tracks for all crossings
- Region of Interest: All momentum tracks in selected regions for selected events

Outlook

- A technical proposal is being drafted with both concepts included for further investigation