Triggering on Long-lived Neutral Particles in ATLAS

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Outline

- Motivating Long-lived Neutral Particles
- Signature Driven ATLAS Triggers for LLNP
- Understanding Backgrounds to these Triggers
- Looking forward

Motivation

The need for designated long-lived particle triggers and why Hidden Valley serves as a strong platform for their implementation.

The Need for Long-lived Triggers

Theoretical Motivations

- Many BSM theories include the possibility of the Higgs decay to long-lived neutral particles:
  - gauge-mediated SUSY extensions of the MSSM
  - MSSM with R-parity violation
  - inelastic dark matter
  - Hidden Valley

Experimental Motivations

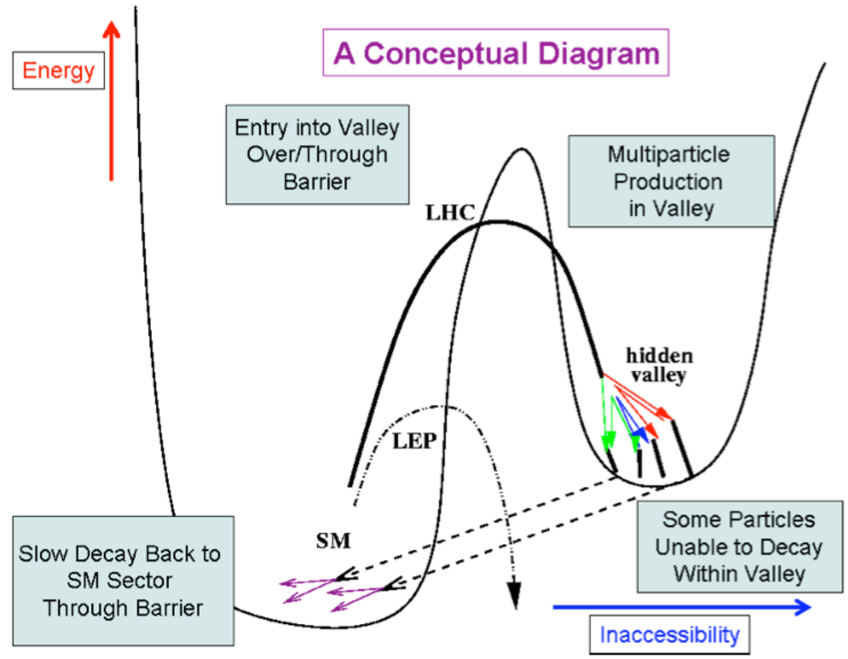
- Prescale
  - Limited computing resources require significant sacrifice of events
  - ATLAS only activates many single jet triggers < 1/10000 events in 2011.
  - What we keep are mostly events with high p_T jets and high jet multiplicity.
- IP-Centric Objects
  - Most objects reconstructed by ATLAS assume that they come from the IP.
  - A muon in ATLAS requires the matching of ID track to MS track.

The Need for Long-lived Triggers

Choosing a Benchmark Model

- In order to serve the purpose of designing triggers for the detector we want one with:
  - Many models
  - Wide range of final states
  - Wide range of particle lifetimes
  - Various production mechanisms

- Hidden Valley
  - A hidden sector accessible through LHC energies.
  - Has no lifetime prediction—particles can be prompt or live long enough to travel into the detector volume.
  - Some particles may decay (slowly) back to SM particles.



M. Strassler and K. Zurek, Phys. Lett. B651 (2007) 374

Hidden Valley

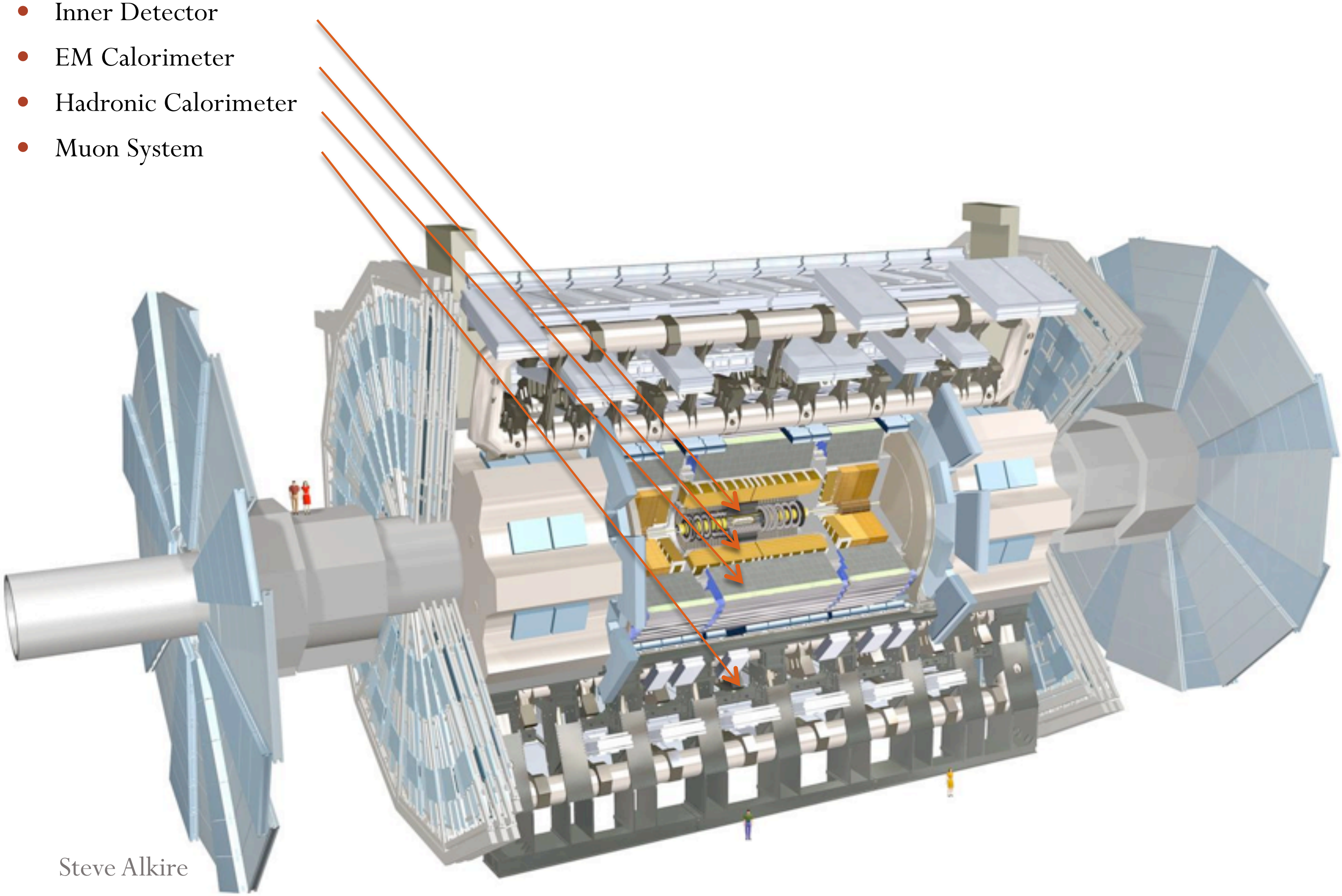
The Benchmark Model for Long-lived Neutral Particle Trigger Design

- Benchmark model (Strassler, Zurek): $h \to 2\pi_v \to 2b2\bar{b}$
  - Long-lived π_v decays to b jets
  - m_h = 140 GeV
  - m_{π_v} = 40 GeV
  - π_v have long lifetime on detector scale
  - Source: ATL-PHYS-PUB-2009-082
  - Source: M. Strassler and K. Zurek, Phys. Lett. B651 (2007) 374

Hidden Valley

The Benchmark Model for Long-lived Neutral Particle Trigger Design

- π_v can decay anywhere within the ATLAS detector:
  - Inner Detector
  - EM Calorimeter
  - Hadronic Calorimeter
  - Muon System



Hidden Valley

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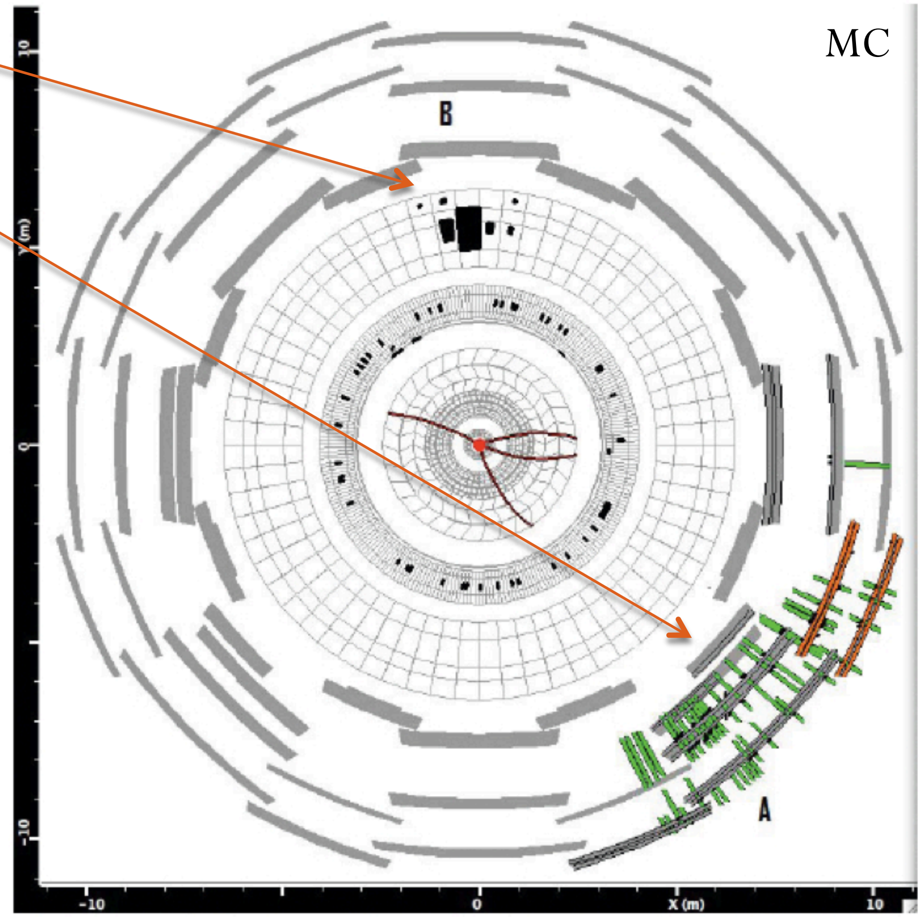
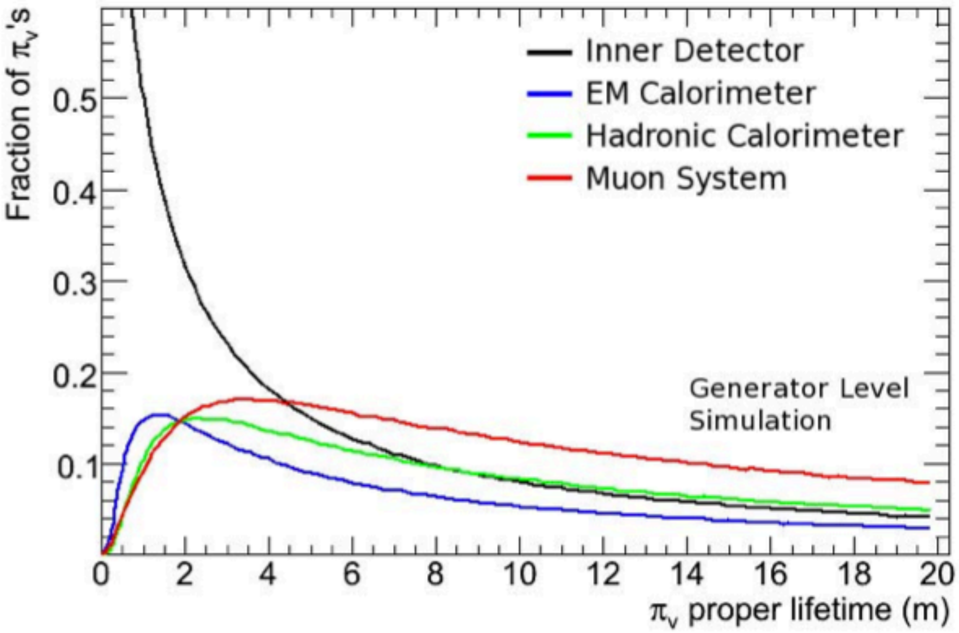


- In each case the decay is isolated from the IP
  - This forms the basis for our trigger design.

Hidden Valley Benchmark MC Simulation

Long-lived π_v Decay

- MC simulation: gg $h \rightarrow 2\pi_v \rightarrow 2b2\bar{b}$
  - $M_h = 140$ GeV/c^2
  - $M_{v\pi} = 40$ GeV/c^2
  - Proper lifetime c $\tau = 1.5$ m.
- Fraction of π_v decaying in each region of the detector as a function of proper lifetime.
  - Proper lifetime chosen to give roughly equal number of decays in EM Calorimeter, Hadronic Calorimeter, and Muon System.
  - Largest fraction of π_v decay in the Inner Detector.



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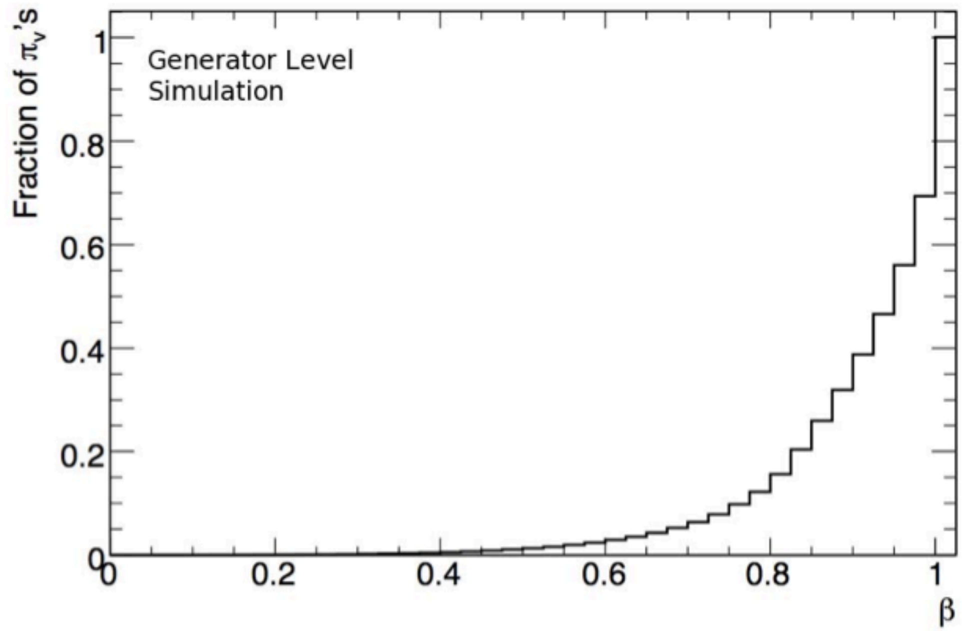
  - Proper lifetime c $\tau = 1.5$ m.
- Distribution of β of π_v.
  - Chosen kinematics give π_v timing similar to minimum ionizing particles.
  - Detector inefficiency due to timing a secondary issue with range of values for which triggers have been designed.
  - $M_h = 120$ to140 GeV/c^2
  - $M_{v\pi} = 20$ to 40 GeV/c^2

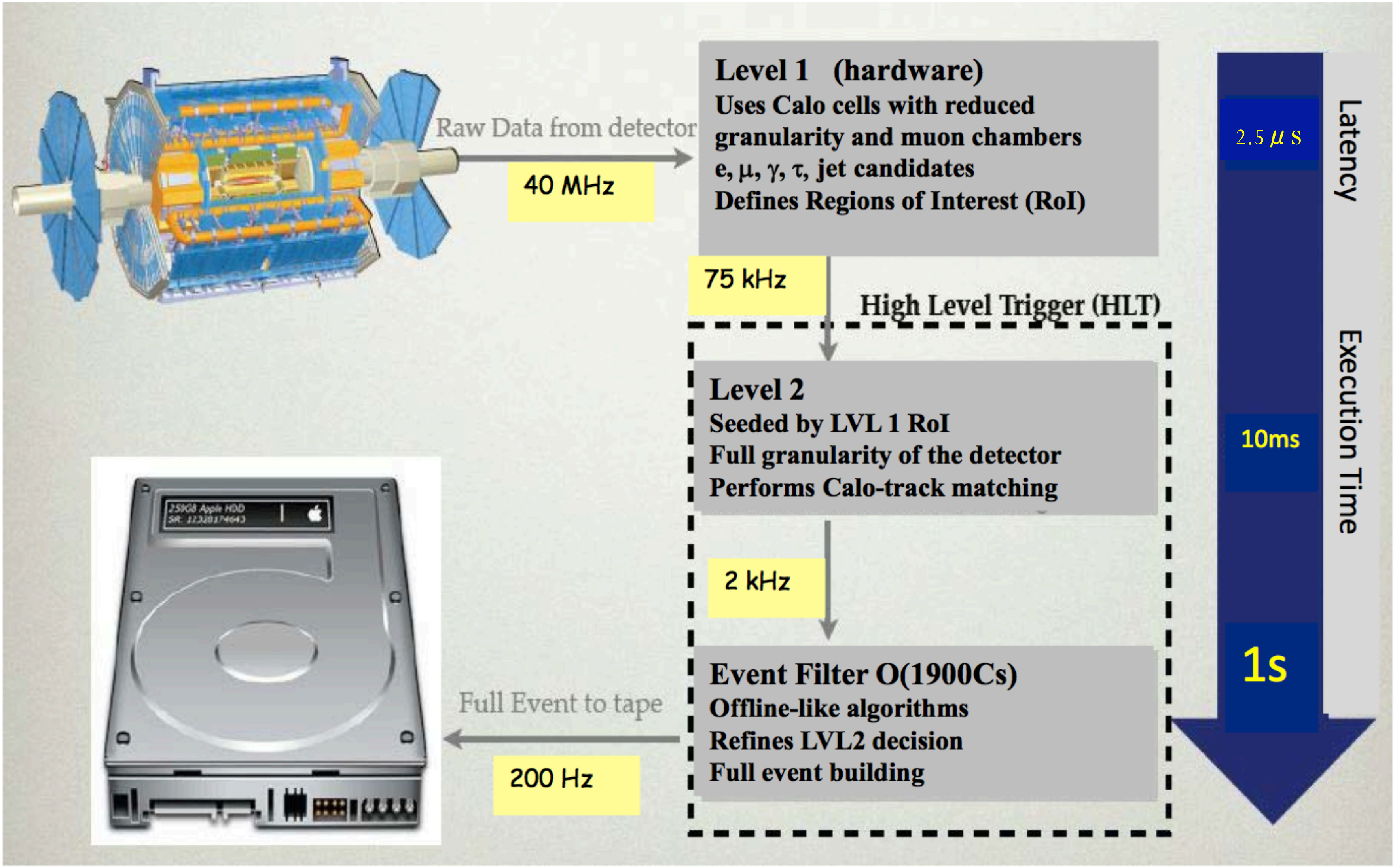


The Triggers

3 triggers to cover a wide range of detector.

Trigger Flow in ATLAS

A quick overview of data rate reduction



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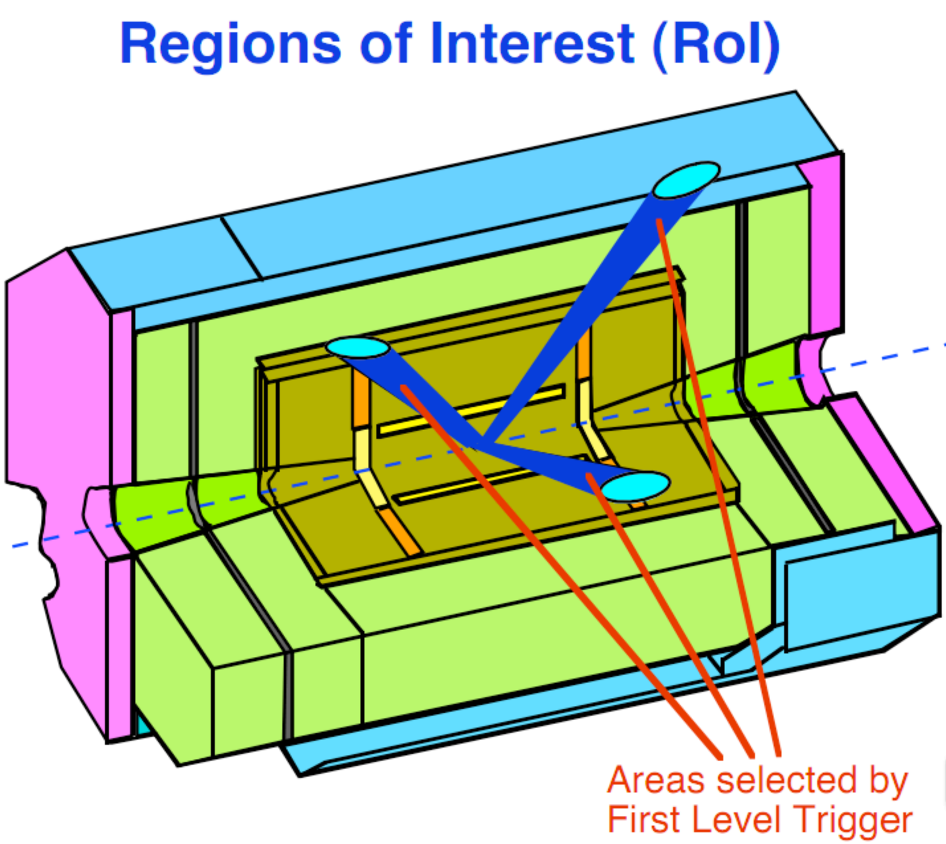
ATLAS Trigger Hierarchy

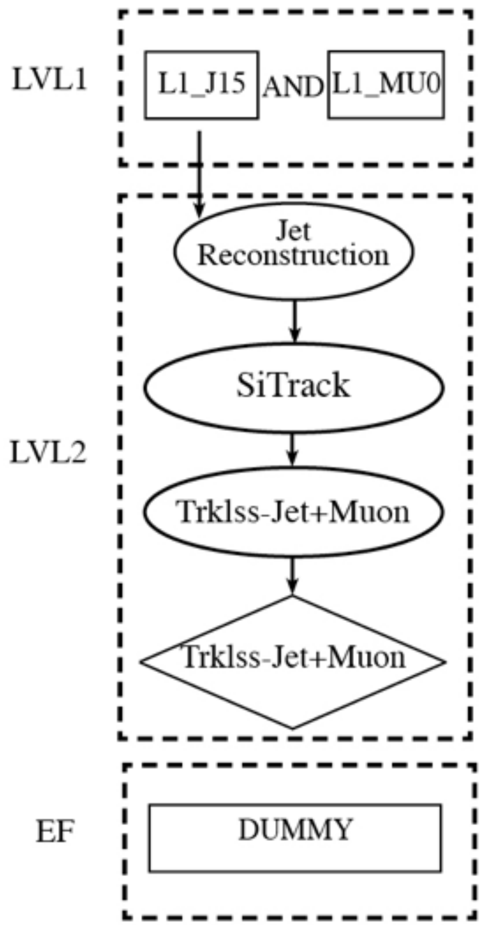
Increased processing time allows increased quality of reconstructed objects.

- Level 1
  - Coarse Calorimeter and Muon Spectrometer granularity.
  - No Inner Detector tracking.
  - Identifies Regions of Interest (RoI).
- Level 2
  - Full detector granularity in RoIs only.
  - Full tracking in RoI and all tracks are required to connect to the Interaction Point (IP).
  - Only one muon per RoI is reconstructed.
- Event Filter
  - Objects reconstructed with entire detector data.
  - Better Jet E_T resolution.
  - Better muon p_T resolution.
  - Further offline-like cuts introduced to limit write out frequency to roughly 200 Hz.

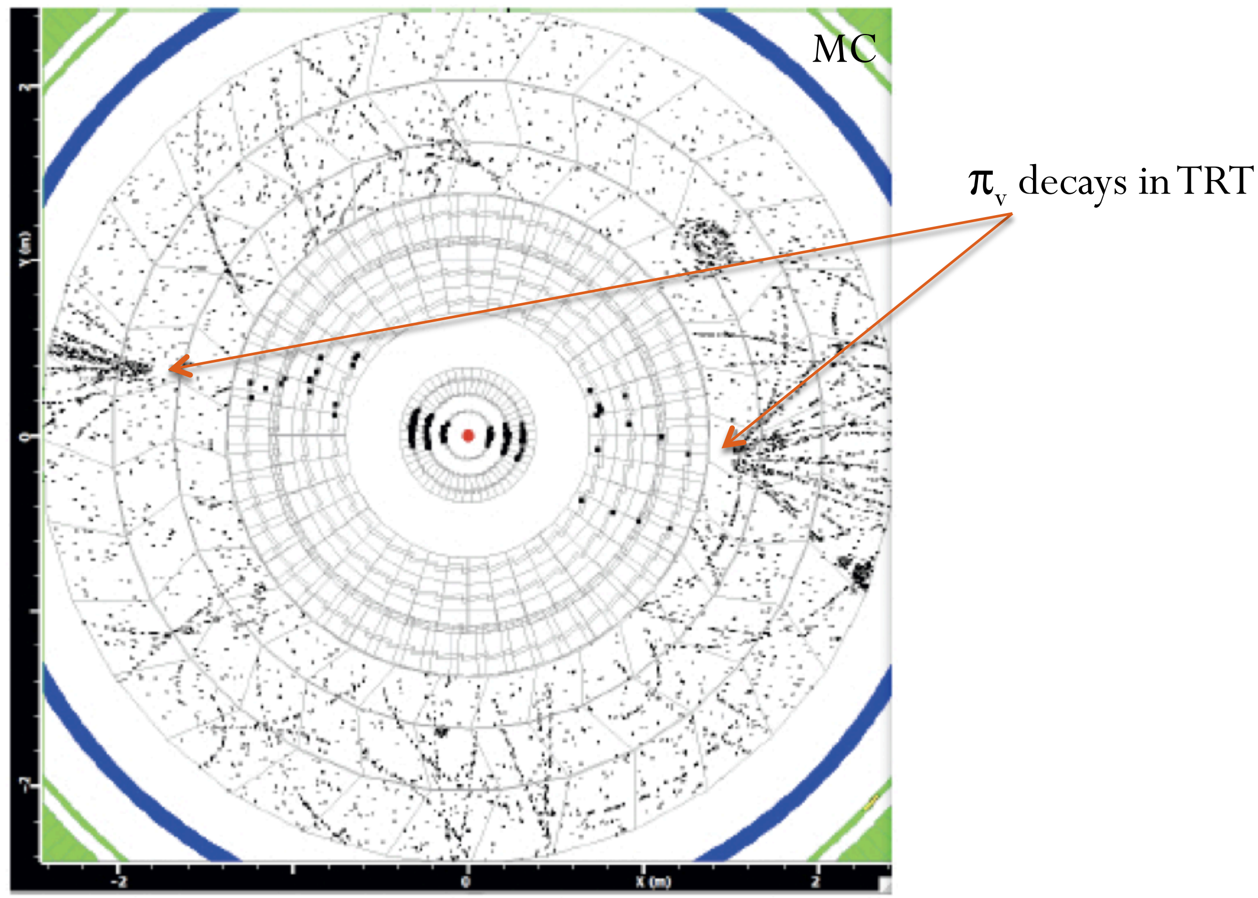


HV Triggers

Trackless Jet Trigger

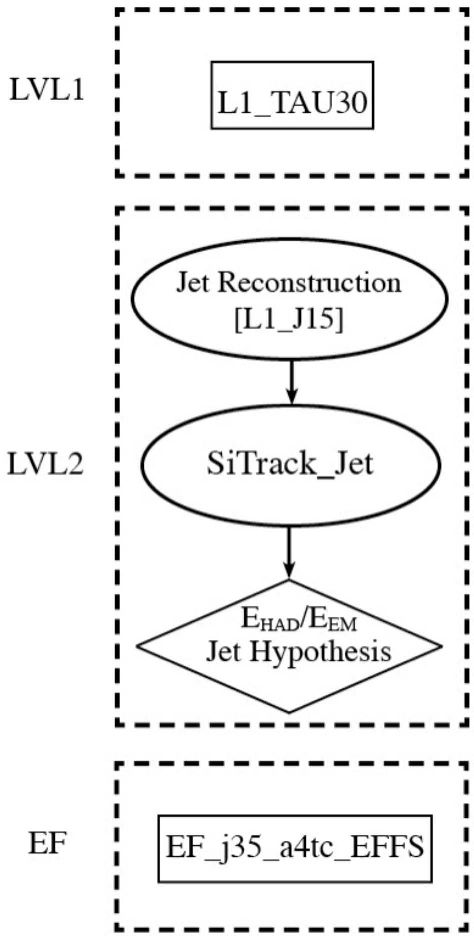


- Looks for jets which have poorly reconstructed tracks.
- 0 ID L2 tracks in jet cone ($\eta \times \phi < 0.2$) with $p_T > 1$ GeV/c.
- Muon in jet cone ($\eta \times \phi < 0.4$)
- $E_T > 30$ GeV

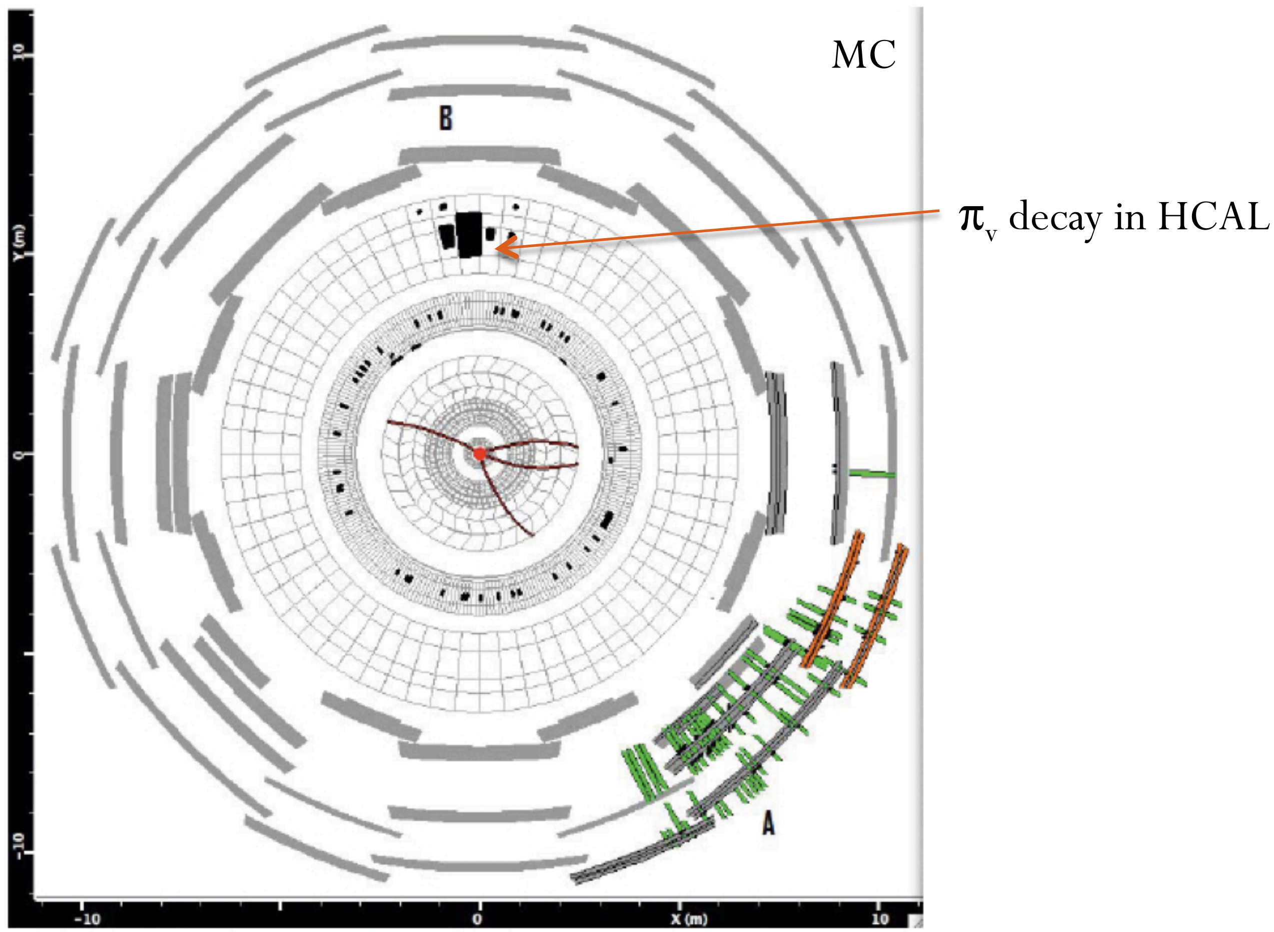


HV Triggers

Calorimeter Energy Ratio Trigger

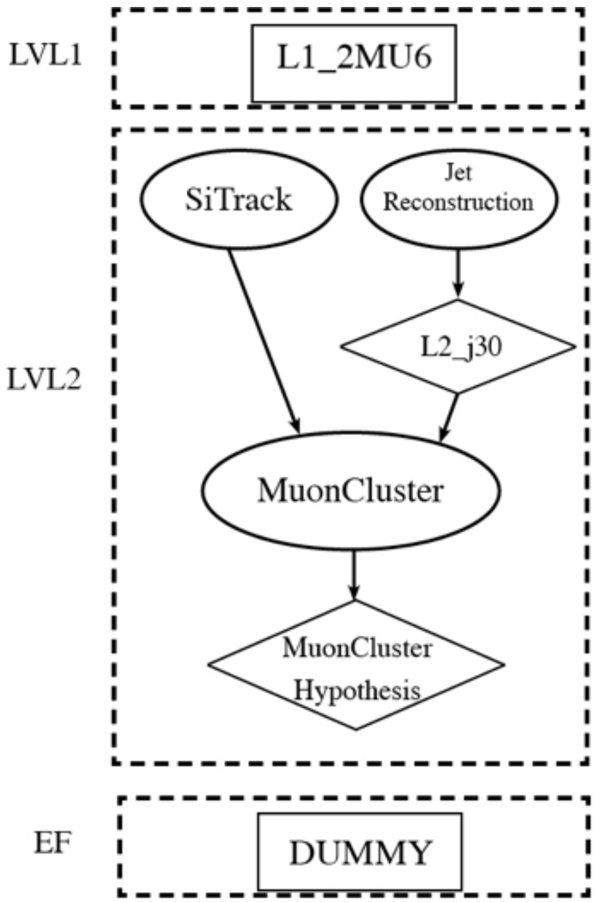


- Looks for jets with little energy in the EM calorimeter.
- $\log_{10}(E_{HAD}/E_{EM}) > 1$
- No ID tracks with $p_T > 1$ GeV/c in ($\eta \times \phi < 0.2$)
- $E_T > 35$ GeV



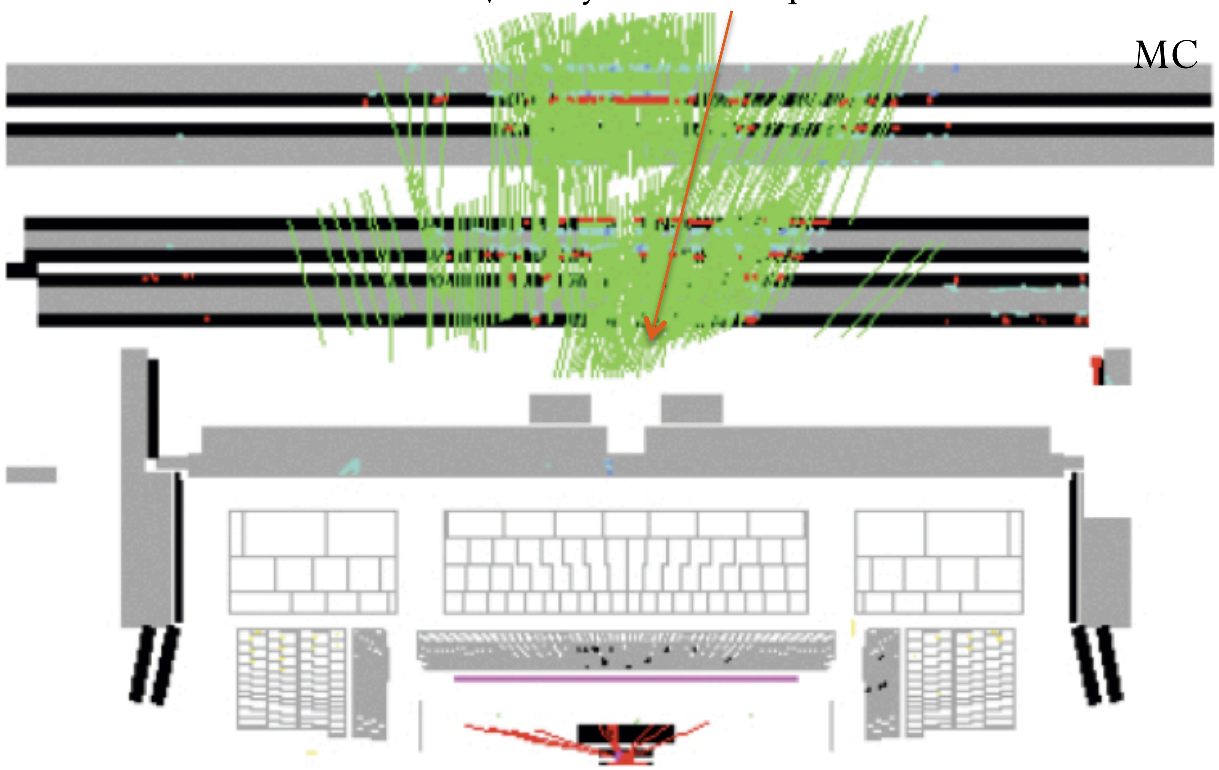
HV Triggers

Muon RoI Cluster Trigger



- > 3 muon RoIs in region (η x ϕ of 0.4)
- No jet E_T > 30 GeV in (η x ϕ < 0.4) cone around cluster centroid.
- No ID tracks with p_T > 1 GeV/c in (η x ϕ < 0.2)
- | η | < 1.0

π_v decay in Muon Spectrometer



Trigger Efficiency

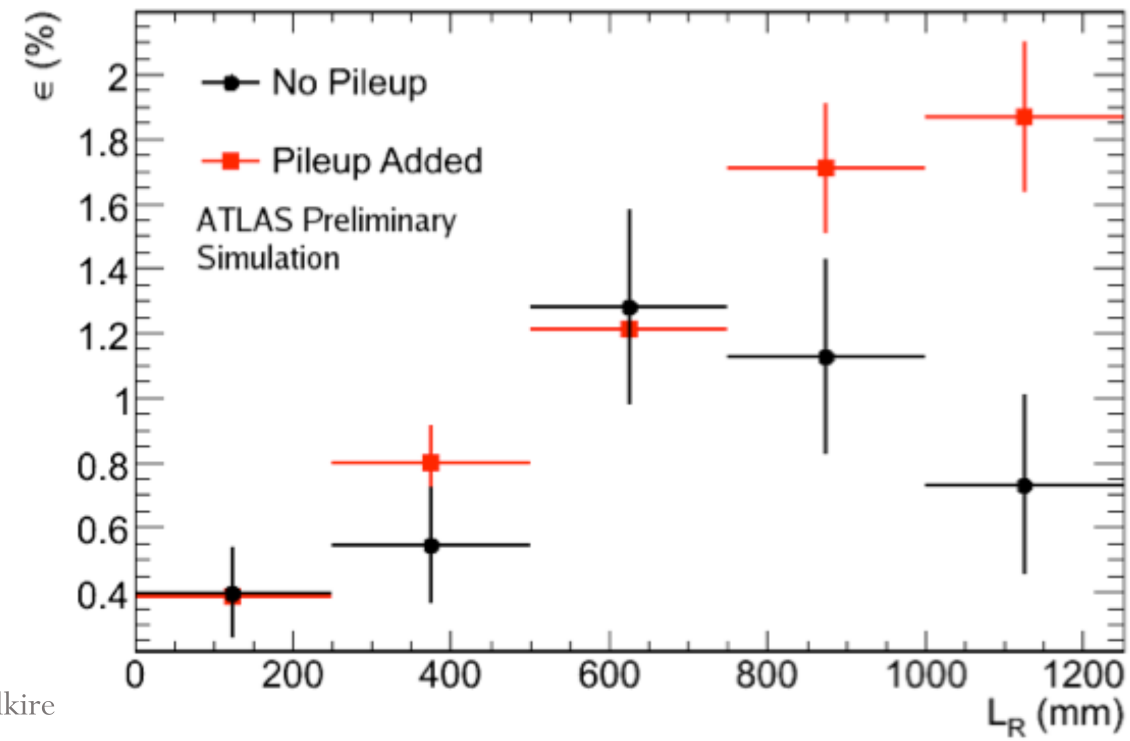
Efficiency of triggers depend on proper lifetime of π_v.

Trigger Efficiency

Trackless Jet

- Low efficiency in range of decay of radius 0 to 1200 mm.
  - Efficiency takes a heavy hit from requiring a muon within the jet cone.
  - Muon requirement is necessary in order to reduce QCD background at trigger level.

Efficiency of Trackless Jet trigger in the barrel.

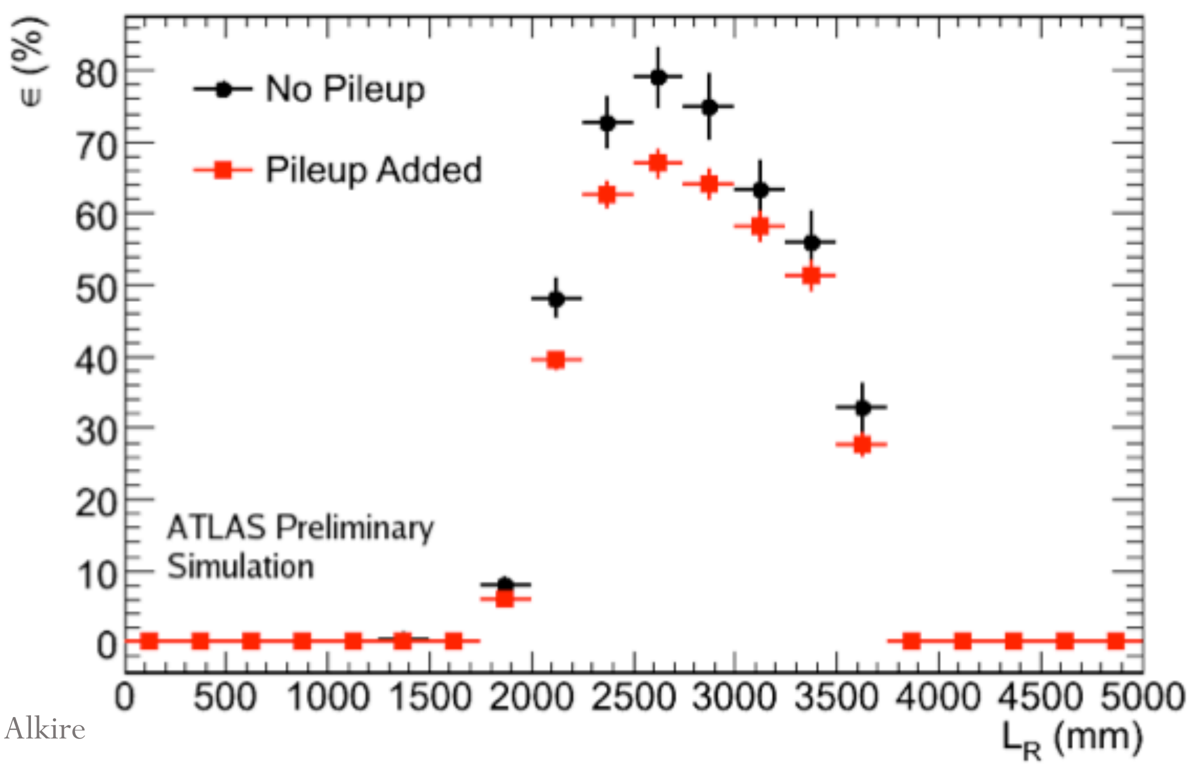


Trigger Efficiency

Calorimeter Energy Ratio Trigger

- Highly efficient for the limited range of radius of decay from 2500 mm to 3500 mm.
  - Picks up decays in the outer extent of the EM calorimeter and in the Hadronic Calorimeter.
- Sees reduction in efficiency with the addition of pileup.
  - Pileup increases the likelihood of additional energy deposition in the EM Calorimeter within the jet cone.
  - Thus reducing the value of $\log_{10}(E_{HAD}/E_{EM})$

Efficiency of Cal Energy Ratio trigger in the barrel.

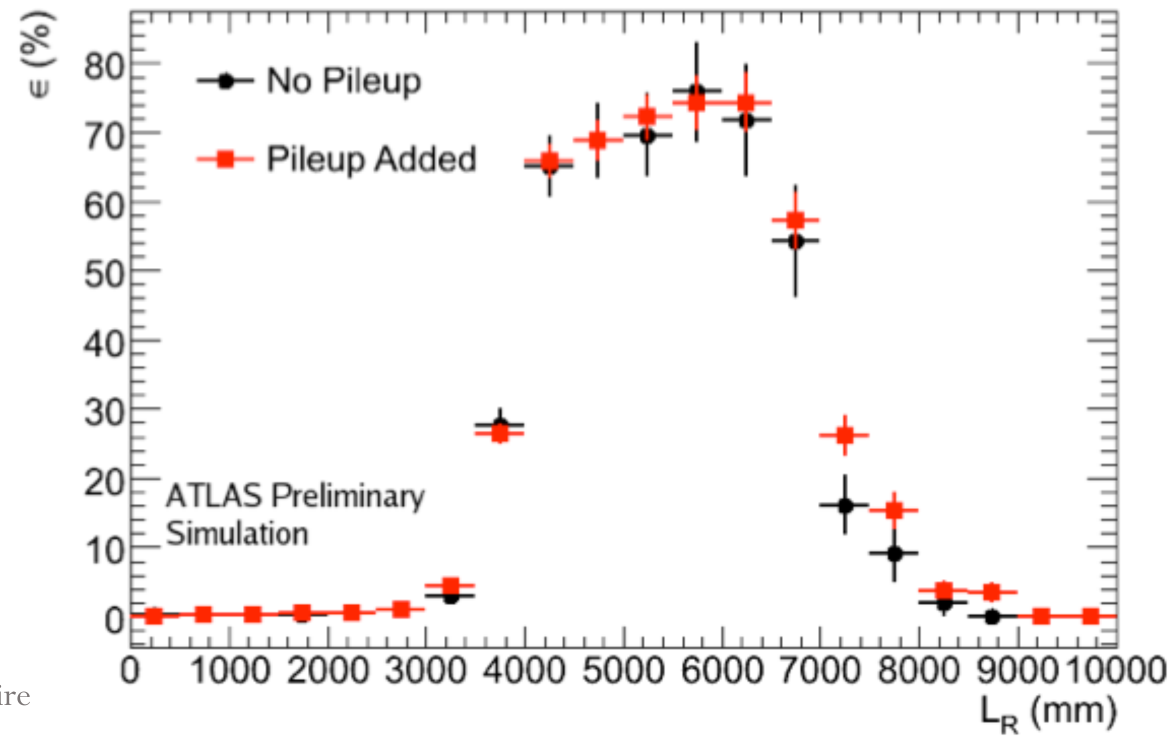


Trigger Efficiency

RoI Cluster Trigger

- Highly efficient for limited range of decay radius 4m to 7m.
  - This range roughly reflects the region between the end of the Hadronic Calorimeter and the first muon trigger plane.
- Little difference seen with the addition of pileup to the MC simulation.
  - This is expected, as the detector is designed to stop all but muons from reaching the MS.

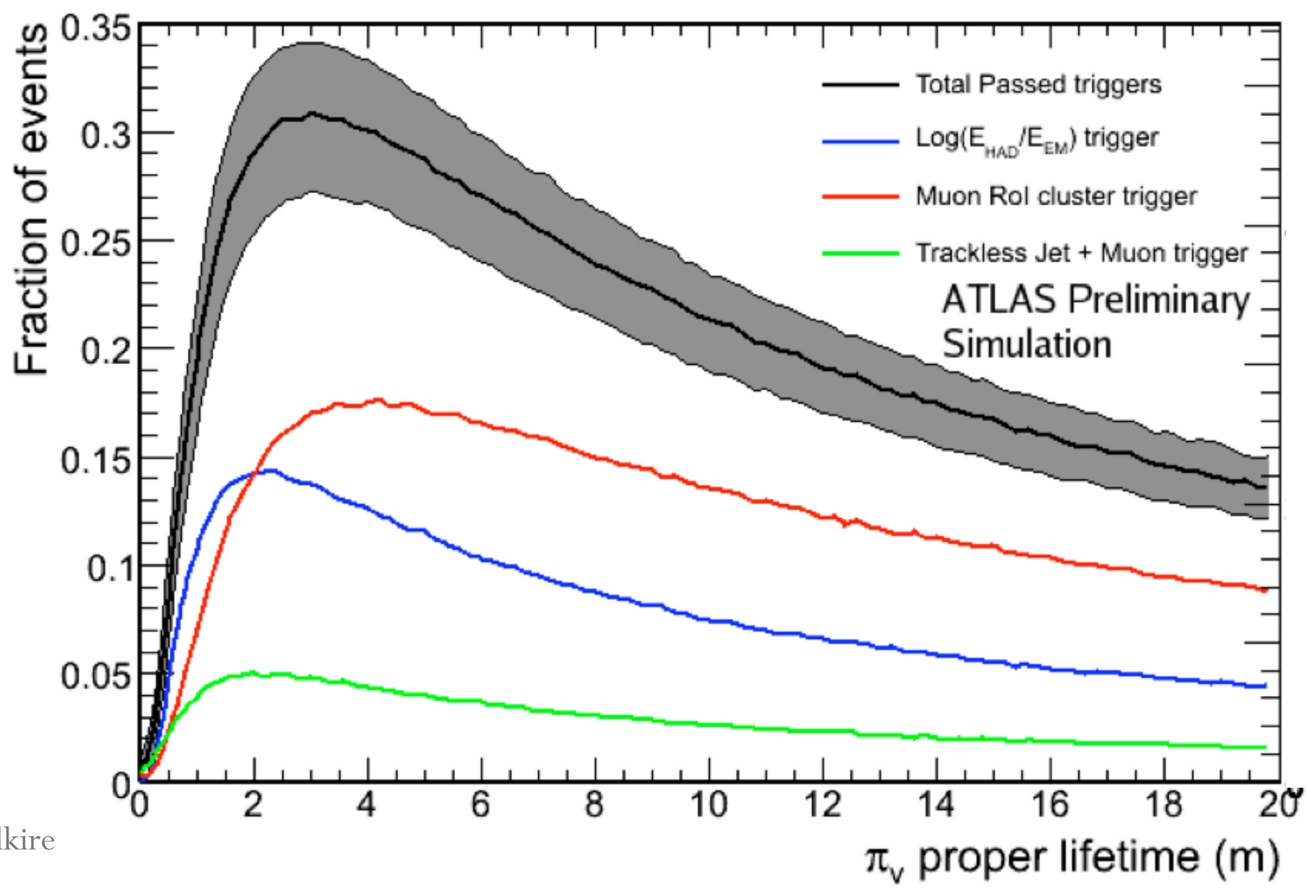
Efficiency of Muon RoI Cluster trigger in the barrel.



Trigger Efficiency

Combined performance of all 3 triggers.

- 300k events were simulated with incremental π_v proper lifetime in the range 0 to 20000 mm.
- Using the efficiency of each trigger with respect to radius of decay of the π_v shown on the previous 3 slides, the overall fraction of events passing each trigger was calculated with respect to π_v proper lifetime.
- Uncertainty bounds (grey stripe) are from uncertainty in the efficiency plots.



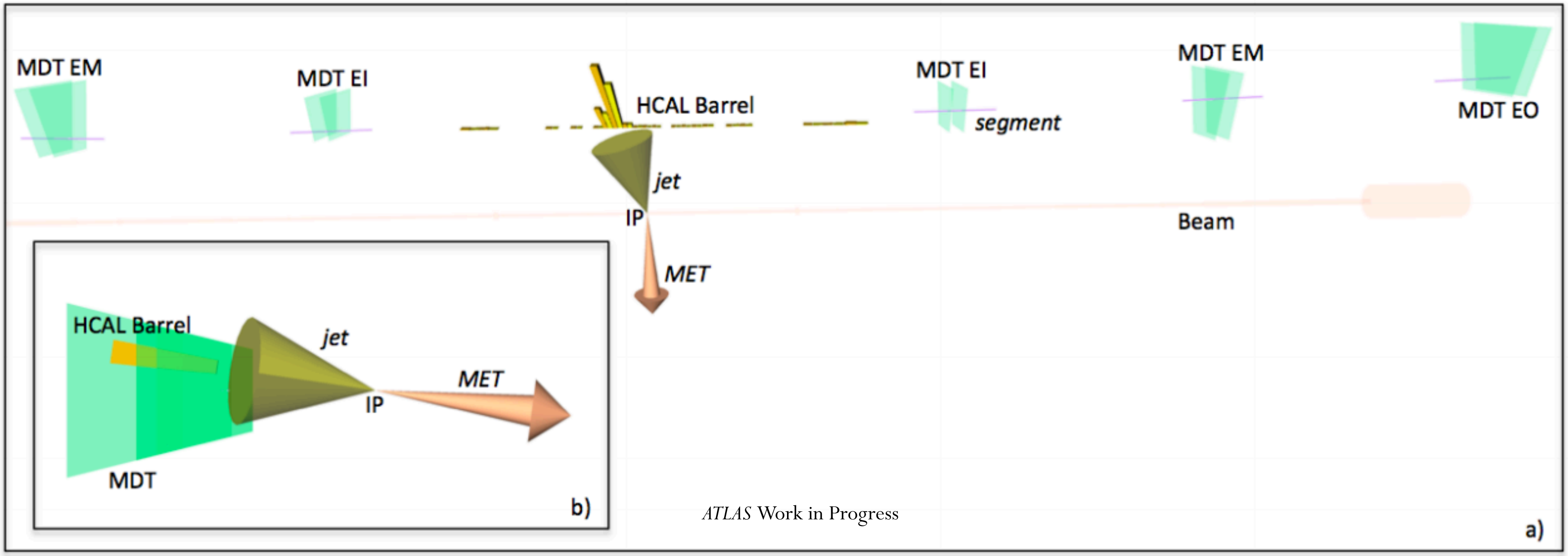
Backgrounds

Beam-induced backgrounds, QCD Dijet background, and Cosmic.

Beam-Induced Background

Reconstructed Jets From Beam Halo Bremstrahlung in Calorimeters

ATL-COM-PHYS-2011-844



- Muons travel parallel to the beam axis and bremstrahlung within the calorimeters.
- In their traversal of the detector they may leave a trail of excited calorimeter cells, reconstructed segments within the MS, and reconstructed jet objects.
- Account for 30-60% of Calorimeter Energy Ratio trigger rate in 2011 runs.
- Selection criteria have been developed in order to identify these events.
  - High purity: $\sim 1/10^5$
  - Good Efficiency: > 85%
- Rates do not exceed 1% for our Trackless Jet and Muon RoI Cluster triggers.

QCD Dijet Background at Trigger Level

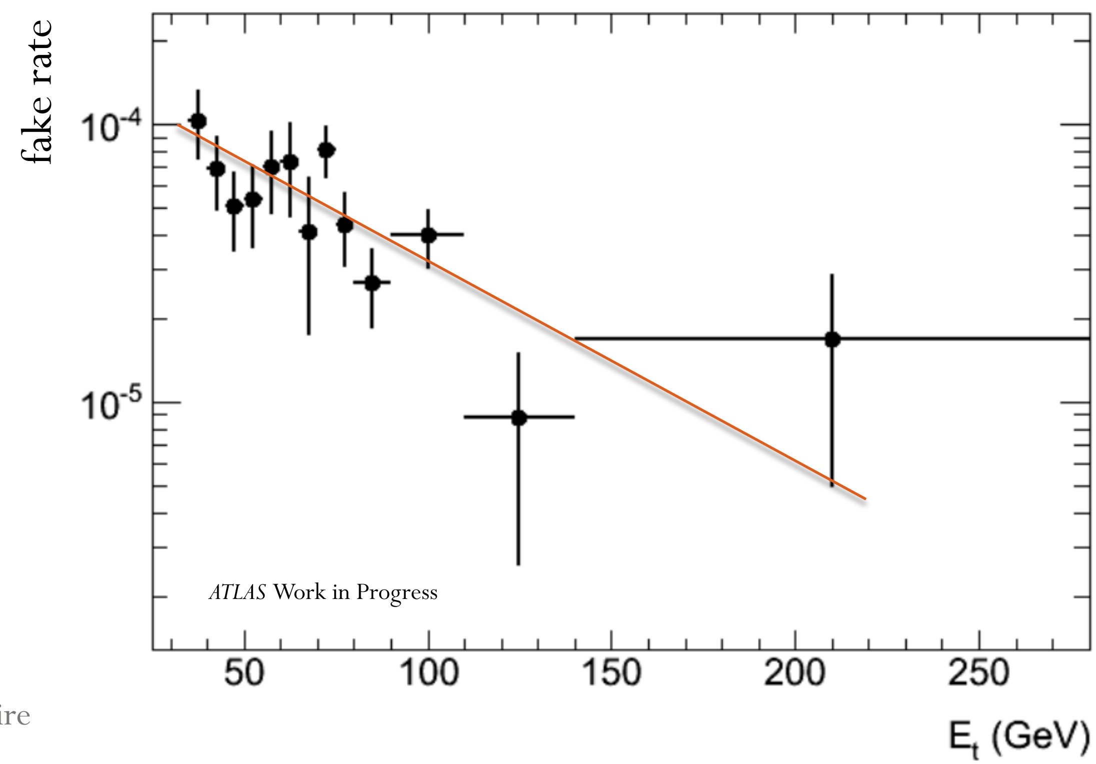
Tag and probe study using 2010 data--periods B-I, 30 pb^{-1}.

- Tag jet:
  - Seeded by a single-jet trigger
    - By using single jet triggers we do not bias the sample.
    - Statistics are low from heavy prescaling.
  - L2 jets used because prescales are based on energies calculated at L2.
  - $E_T > 25$ GeV
  - Passes Good Jet Criteria
  - $|\eta| < 2.0$
- Probe jet:
  - $d\phi$ between tag and probe > 2.6
  - $E_T > 25$ GeV

QCD Dijet Background at Trigger Level

Tag and probe study using 2010 data--periods B-I, 30 pb^{-1}.

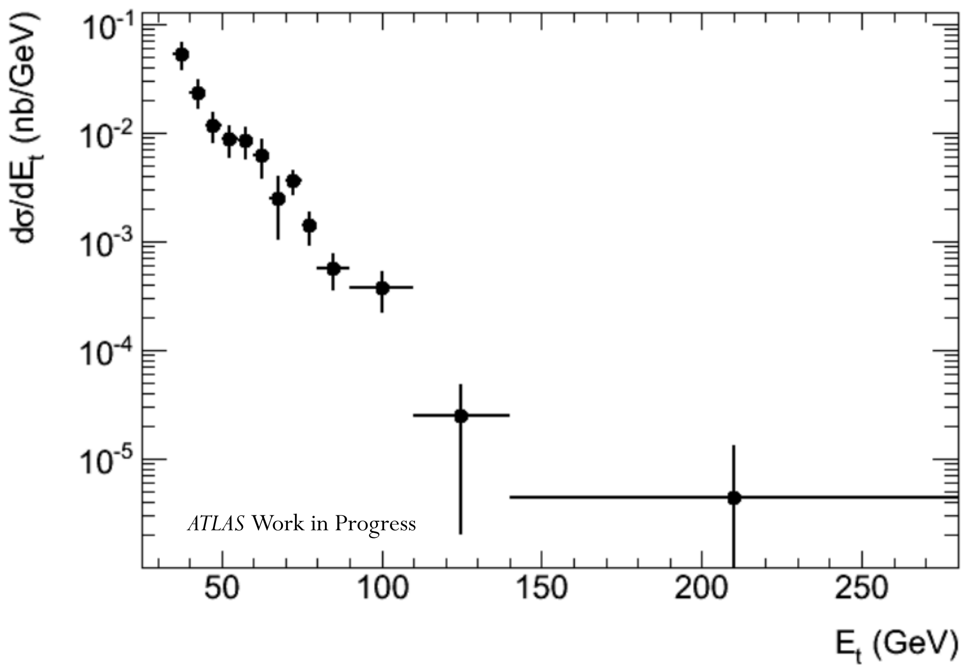
- We calculate the fake rate for probe jets passing each trigger.
- Denominator: all probe jets. Numerator: those passing the HV trigger.
- For Calorimeter Energy Ratio trigger it is shown in exclusive jet energy bins:



QCD Dijet Background at Trigger Level

Tag and probe study using 2010 data--periods B-I, 30 pb^{-1}.

- Differential cross-section of Cal Energy Ratio trigger for QCD dijets. Distributions are from previous plot and cross-section weighted Et distributions of MC J1-J5.



- Total cross-section for Cal Energy Ratio, Trackless Jet, and Muon RoI Cluster triggers based on this approach.

ATLAS Work in Progress

Trigger	Fake rate (nb)	Unc.
Cal_Energy_Ratio	0.61	0.09
Trackless_Jet	0.42	0.10
Muon_RoI_Cluster	0.003	0.002

Looking Forward

Looking Forward

Coming soon: analyses like the following, *but real*.

- Toy analysis for 2011 run, 47 pb^{-1}, compared to a benchmark MC.
- *Philosophy: use the power of 2 HV triggers—reduce your backgrounds by another 10^4.*
  - Tighten isolation cuts already used in Cal Energy Ratio trigger: 0 offline tracks, offline-based ratio, beam background rejection.
  - Require second "tightened" Cal Ratio Jet as well.

ATLAS Work in Progress

Cut	Strategy	Cut Description	Collision	MC
0		All events in sample.		*49022*
1	**Use a Cal Ratio Jet**	Event passes Cal Energy Ratio trigger.	*42503*	.
2	**and**	Beam-induced background cuts applied to Cal Energy Ratio trigger jet.	.	.
3	**tighten the**	Jet quality criteria applied to trigger jet.	.	.
4	**quality of selection.**	Offline jet satisfies $-0.1 < E_{EM}/E_{HAD} < 0.1$	.	.
5		0 reconstructed offline tracks in jet cone of $\delta R < 0.2$	.	.
6	**Use a 2^{nd} Cal Ratio Jet**	Require a second jet at least δR of .6 from the first with Et > 35 GeV.	.	.
7	**and**	Second jet has 0 reconstructed offline tracks	.	.
8	**tighten the**	Second jet satisfies $-0.1 < E_{EM}/E_{HAD} < 0.1$	.	.
9	**quality of selection.**	Beam-induced background cuts applied to second jet.	.	.
10		Jet quality criteria applied to second jet.	*6*	*281*

Conclusions

- Sorry, no limits set yet.
- 3 signature driven Long-lived neutral particle triggers are present and un-prescaled since 2010.
- We are working to understand our backgrounds and uncertainties right now.
- Stay tuned for analyses for winter conferences:
  - Combining all 3 triggers.
  - Modeling our backgrounds—QCD dijets, beam-related, cosmic.
  - Data in the fb^{-1}