Triggering on Long Lived Neutral Particles in ATLAS

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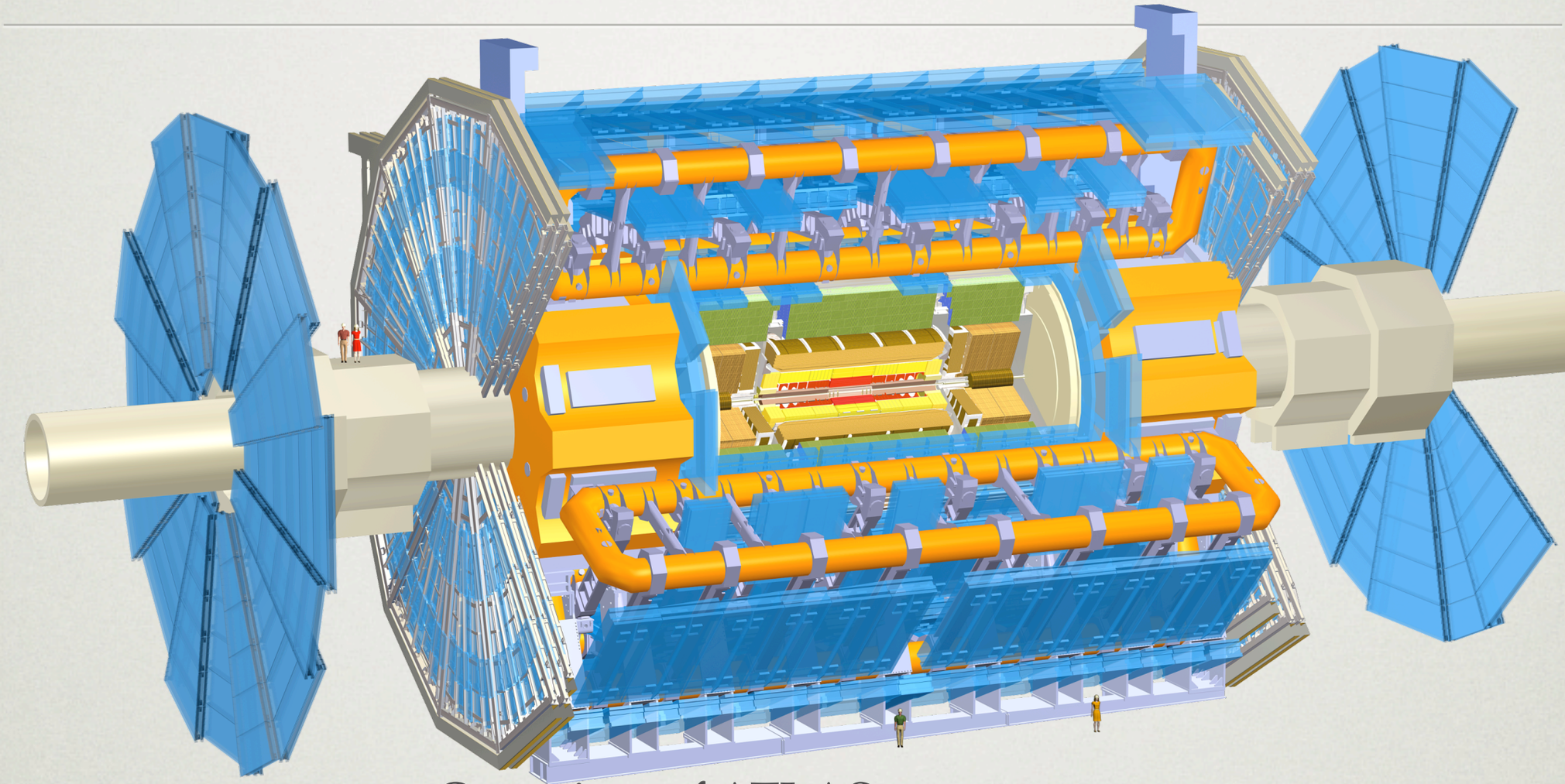
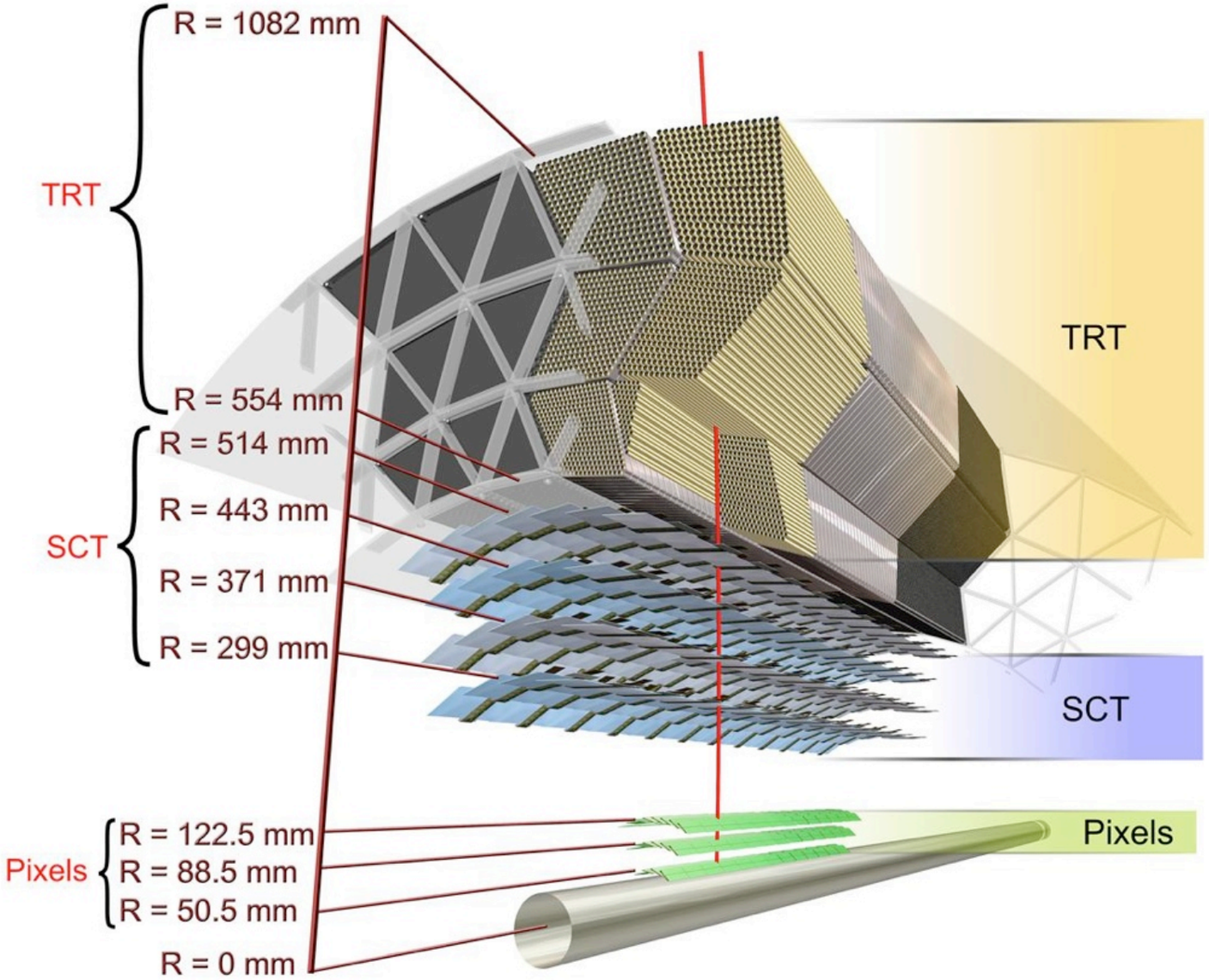
Outline



- Overview of ATLAS
- Long-lived particles
- Signatures of displaced decays to jets
  - Decays in the Muon Spectrometer
  - Decays in the Calorimeter
  - Decays in the Inner Detector

ATLAS
INNER DETECTOR



2T magnetic field

3 Pixel Layers (5cm - 12cm)

4 Silicon Layers (30cm - 51cm)

50cm of Transition Radiation Tracker (TRT) straw tubes (55cm - 110cm)

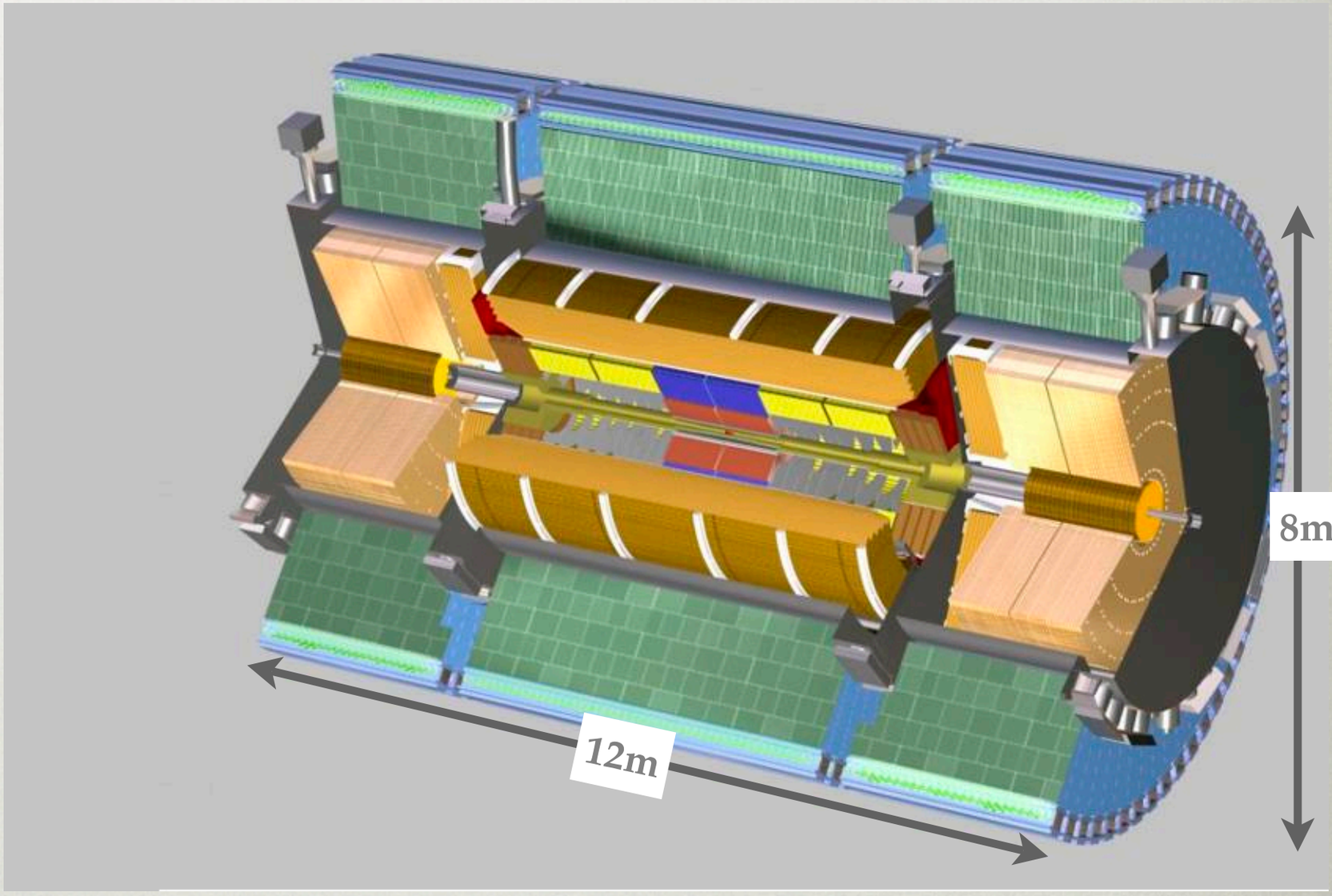
ATLAS
Calorimeters

Electromagnetic Calorimeter (ECAL)

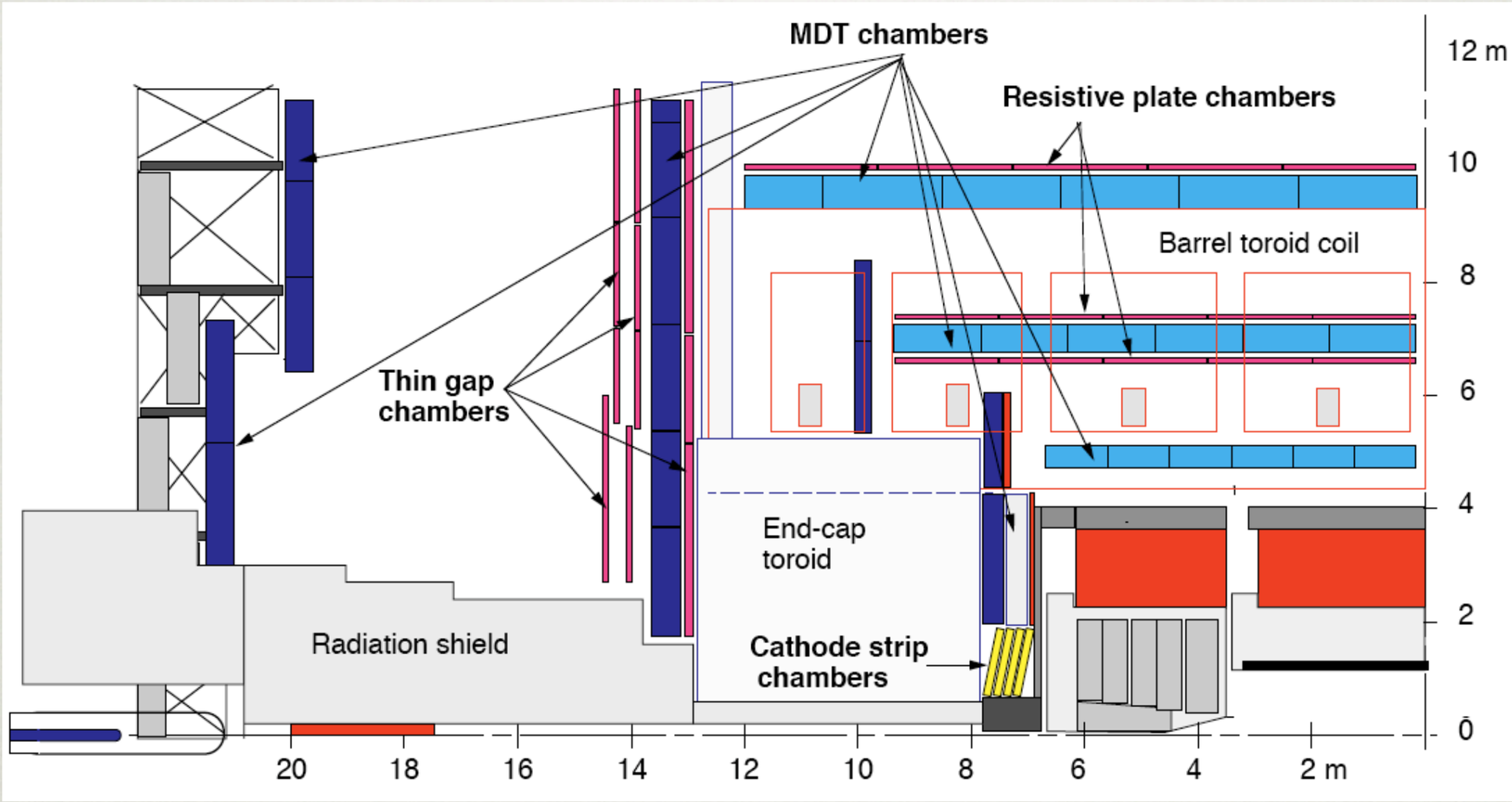
- Lead accordion with with liquid argon scintillator

Hadronic Calorimeter (HCAL)

Iron with plastic scintillator



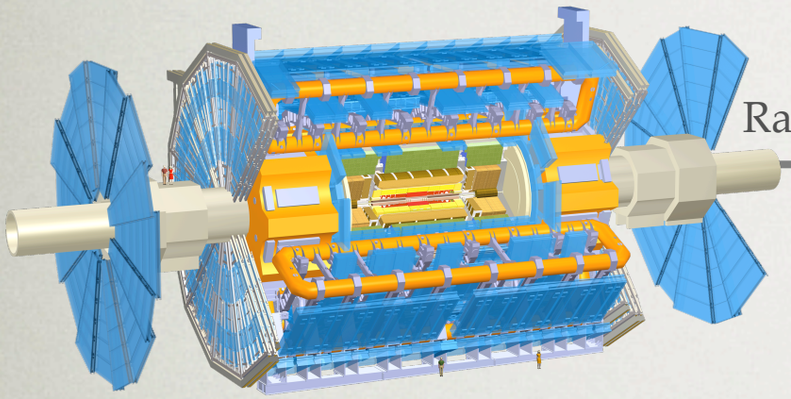
ATLAS
Muon Spectrometer



Three Layers of Drift Tubes

RPC (TGC) trigger chambers in the Barrel (Endcap)

ATLAS TRIGGER SYSTEM



Raw Data from detector

40 MHz

Level 1 (hardware):
Uses Calo cells and Muon chambers with reduced granularity.
e/γ, μ, τ, jet candidates
Defines Regions of Interest (RoI)

75 kHz

High Level Trigger (HLT)

Level 2 O(500PCs):
Seeded by LVL1 RoI
Full granularity of the detector
Performs calo-track matching

1-2 kHz

Event Filter O(1900PCs):
Offline-like algorithms
Refines LVL2 decision
Full event building

Full Event to tape

100-200 Hz

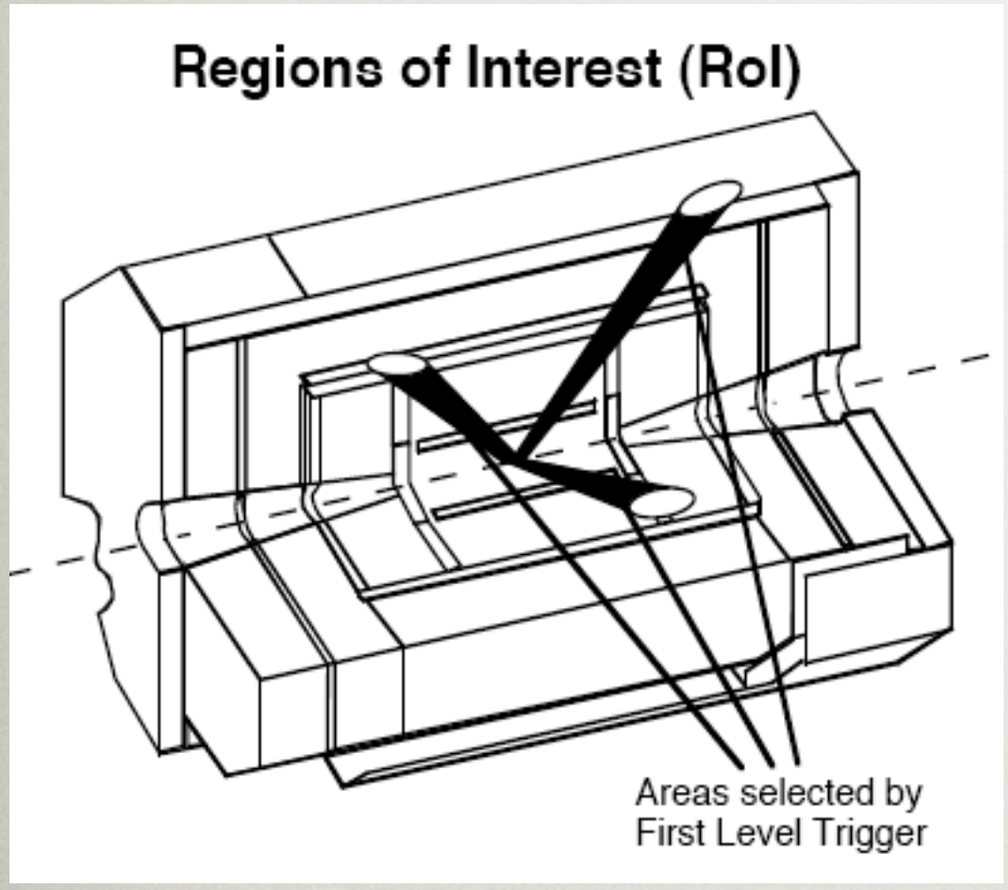
2μs

10ms

1s

Execution Time

ATLAS Trigger

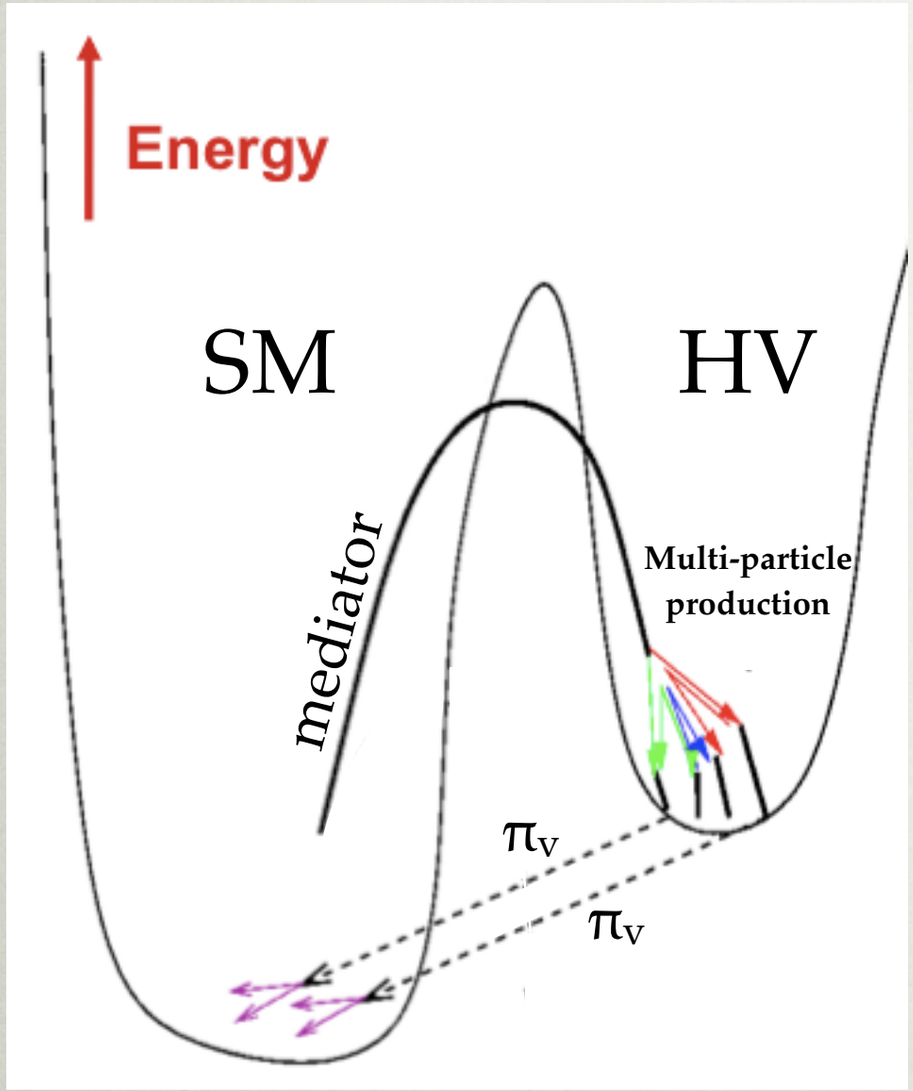


- Level 1:
  - Course granularity of Calorimeter and Muon System
  - No tracking
  - Identifies Region of Interest (RoI) to be processed at Level 2
- Level 2:
  - Full granularity inside of the RoI
  - Tracking available, all tracks required to connect to the IP
  - Only 1 track reconstructed per muon RoI

Long Lived Particles

- Many models predict particles that are NEUTRAL and LONG-LIVED
  - gauge mediated SUSY, RPV SUSY, inelastic dark matter, split SUSY, hidden valley, exciting dark matter (XDM), Asymmetric Dark Matter (ADM)
- To investigate ATLAS's ability to detect (and trigger on) long-lived neutral particles, we have simulated a Hidden Valley model

Hidden Valley† Models

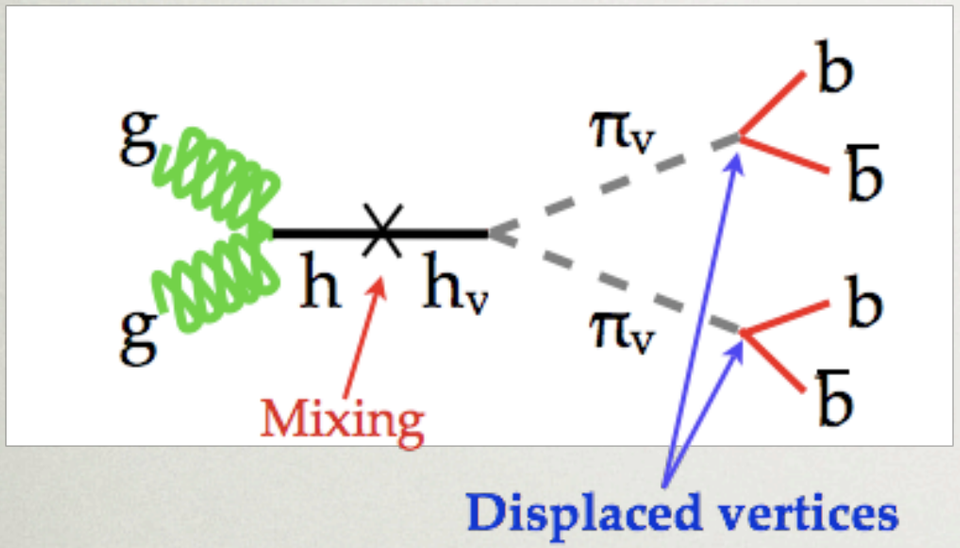


- "Hidden Valley" (HV) models are a general class of these models
- Hidden Valley and SM only communicate through mediator particles (**higgs**, Z', neutralino, ...)
- All valley-particles (v-particles) are NEUTRAL under the SM
- The lightest v-particles, "v-pions" (π_v's) are stable in the v-sector, but can decay back to the SM with long lifetimes

† M. Strassler, K. Zurek Echoes of a Hidden Valley at Hadron Colliders
Phys. Lett. B651 (2007) 374
Arkani-Hamed, et al. LHC signals for a SuperUnified Theory of Dark Matter
arXiv:0810.0713

HIGGS DECAY TO LONG-LIVED PARTICLES

- Using benchmark model of Higgs decaying to non-interacting pseudo-scalars† (π_v)



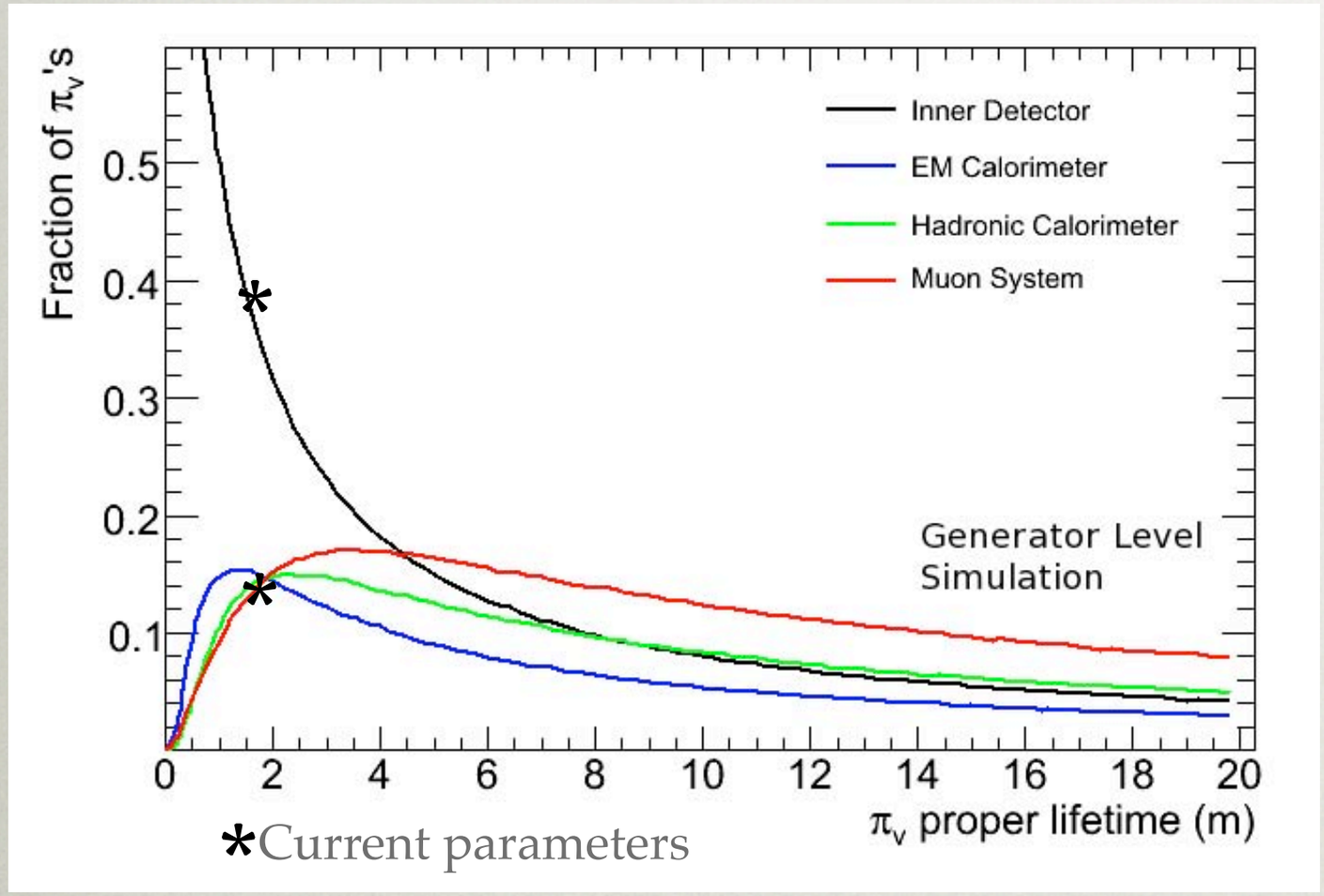
- π_v is NEUTRAL under the SM and long-lived

- We use 2 samples to study trigger strategies for this process:
  - Ideal sample (signal only)
  - Signal with pileup
    - pileup for $L=10^{32}cm^{-2}s^{-1}$
    - 4.1 collisions/crossing
    - 450ns bunch spacing
- Parameters:
  - $E_{CM} = 10$ TeV
  - $m_h = 140$ GeV
  - $m_{\pi v} = 40$ GeV
  - $c\tau_{\pi v} = 1500$ mm (arbitrary choice)
- Events simulated using PYTHIA

† see: M. Strassler & K. Zurek, Phys Lett B 661 (2008) 263-267
S. Chang et al. arXiv:hep-ph/0511250
L. Carpenter et al. arXiv:hep-ph/0607204

Decay Positions

Hidden Valley events are characterized by highly displaced decays leading to jets appearing throughout the volume of ATLAS



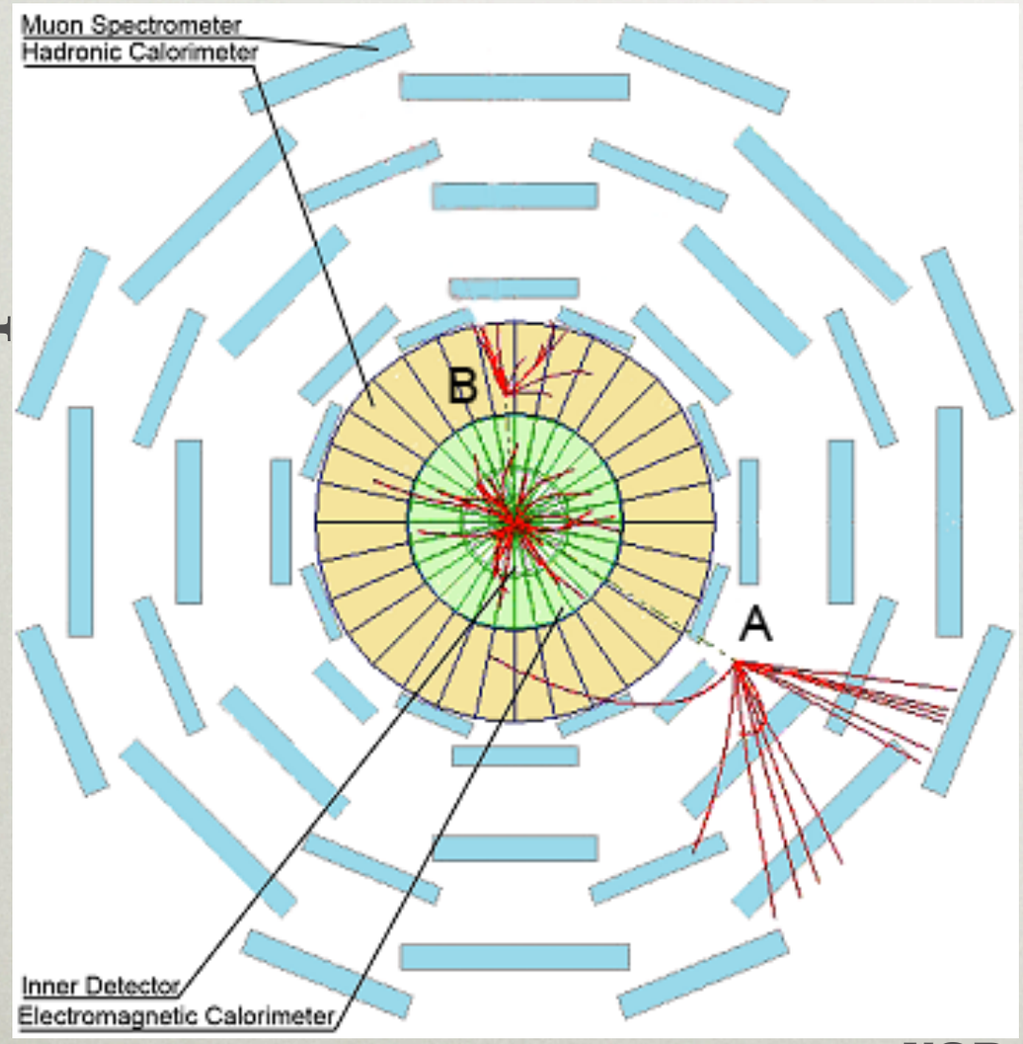
*Current parameters

- Probability for π_v from gg fusion to decay in the 4 detector regions vs $c\tau$ for $|\eta| < 2.5$ (Inner Detector coverage)
- Event Signatures are different for each of the regions
  - Inner Detector
  - EM Calorimeter
  - Hadronic Calorimeter
  - End of HCAL to 1rst muon trigger plane

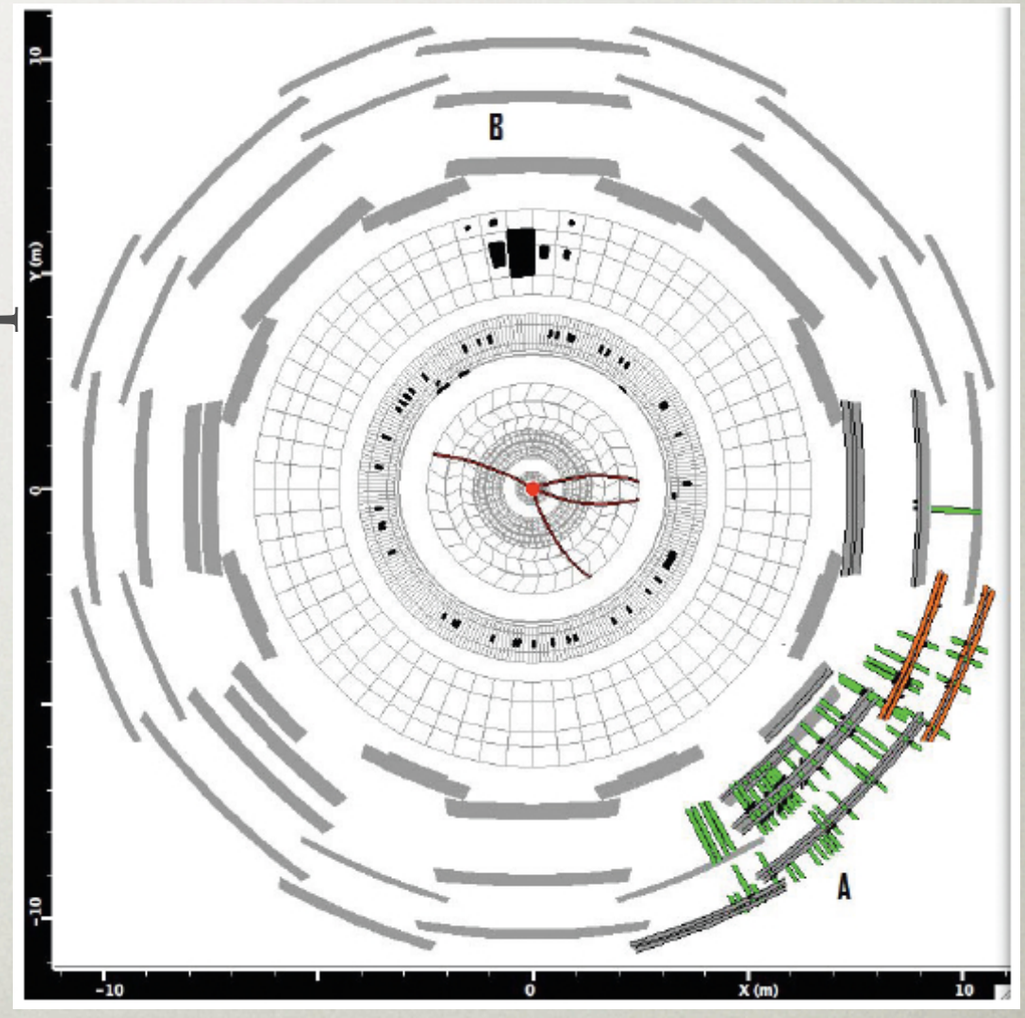
HIGGS DECAY TO LONG-LIVED PARTICLES

- Event with one π_v decay in the Muon System (A) and another π_v decay in the Hadronic Calorimeter (B)

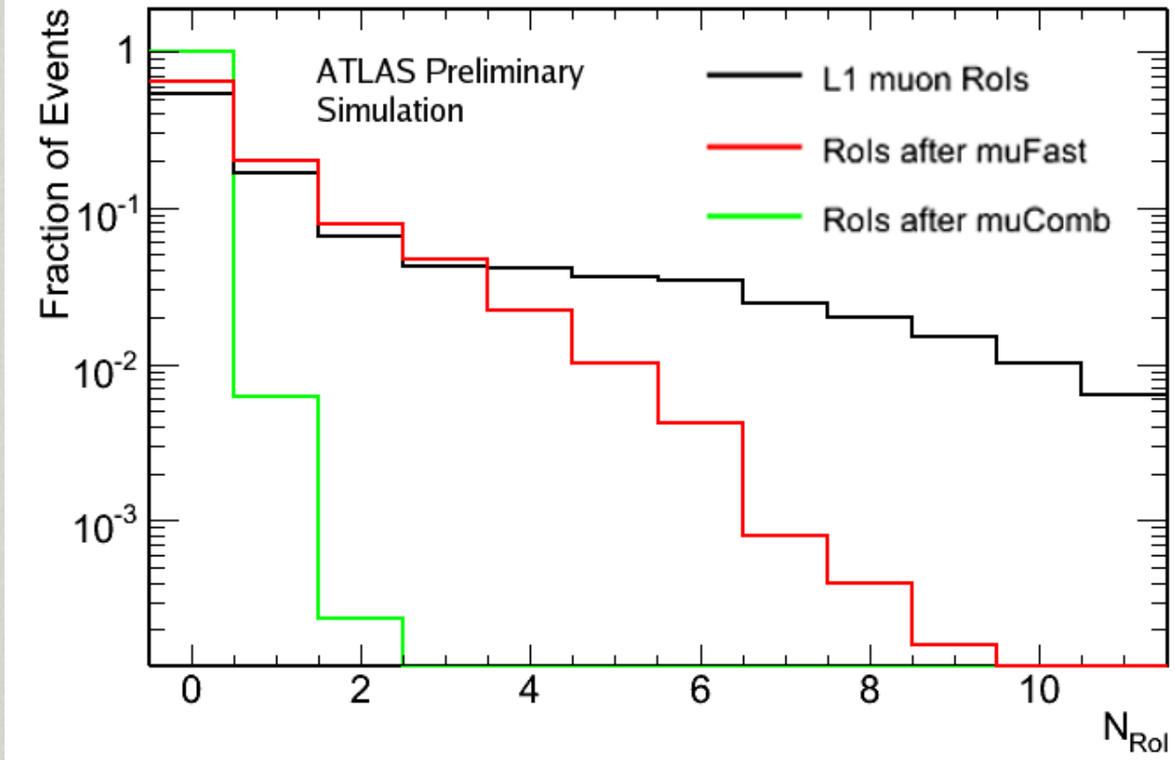
PYTHIA output



ATLAS output



Standard ATLAS Triggers



- ATLAS Level-2 muon trigger has 2 stages:
  - Stand-Alone tracking (muFast)
  - Matching with an ID track (muComb)

- Jet triggers: Events with Higgs decays to π_v's are characterized by several low E_T jets
  - Low energy jets are rejected by the Level-2 trigger due to large QCD backgrounds

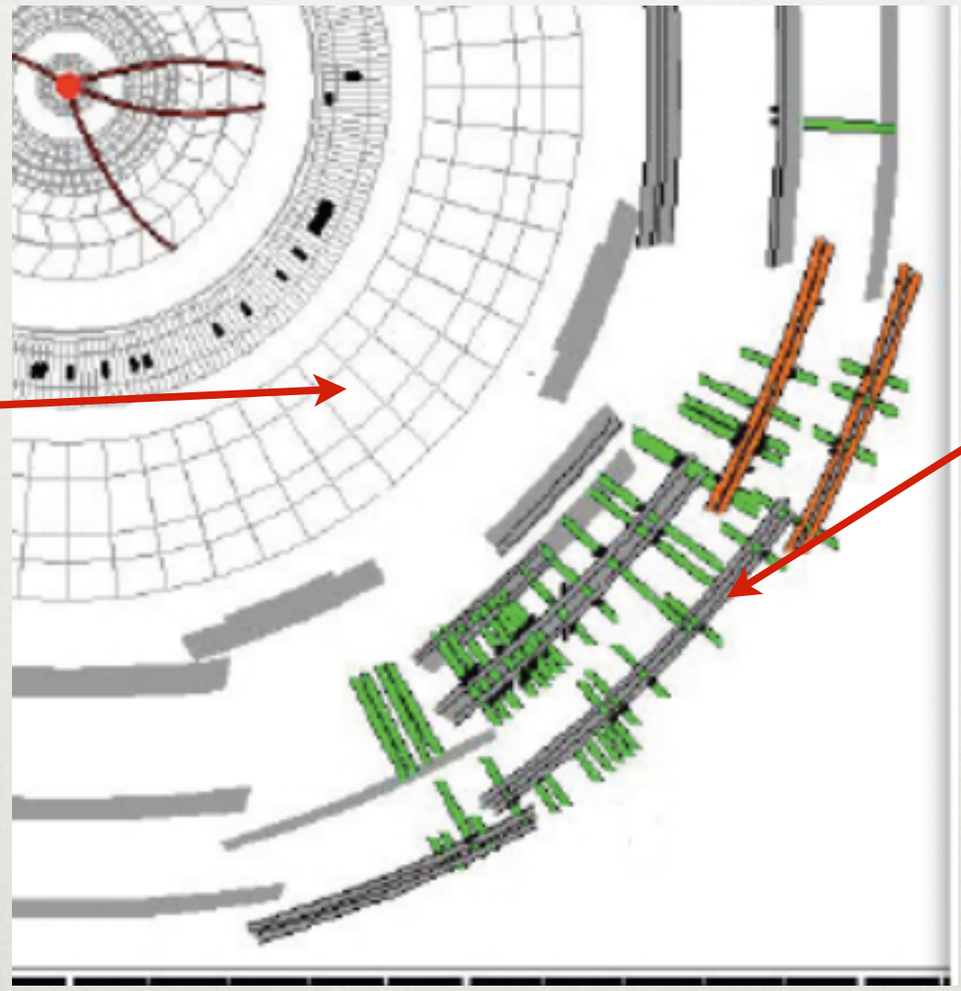
Standard ATLAS Triggers

- Standard ATLAS triggers are Interaction Point (IP) centric
- Neutral states decaying far from the IP lead to many challenges for the trigger:
  - Muons from displaced vertices do not have reconstructed tracks in the inner detector and fail the standard ATLAS level-2 muon trigger
  - Jets from late decays may not have normal energy deposition and could punch through
  - Depending on where the decay occurs (Inner Detector, Calorimeter, Muon Spectrometer), different approaches are required

Need SIGNATURE DRIVEN TRIGGERS

Decays in the muon system

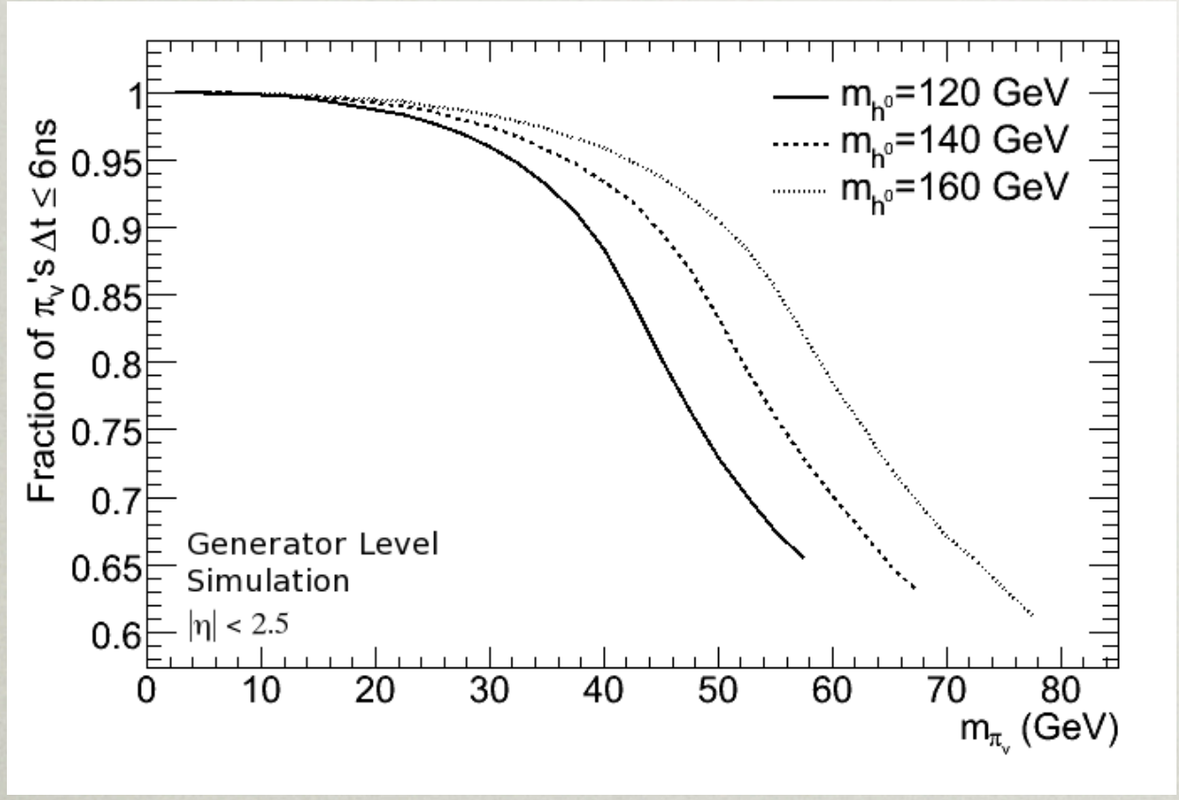
- Little/No energy deposited in the calorimeter

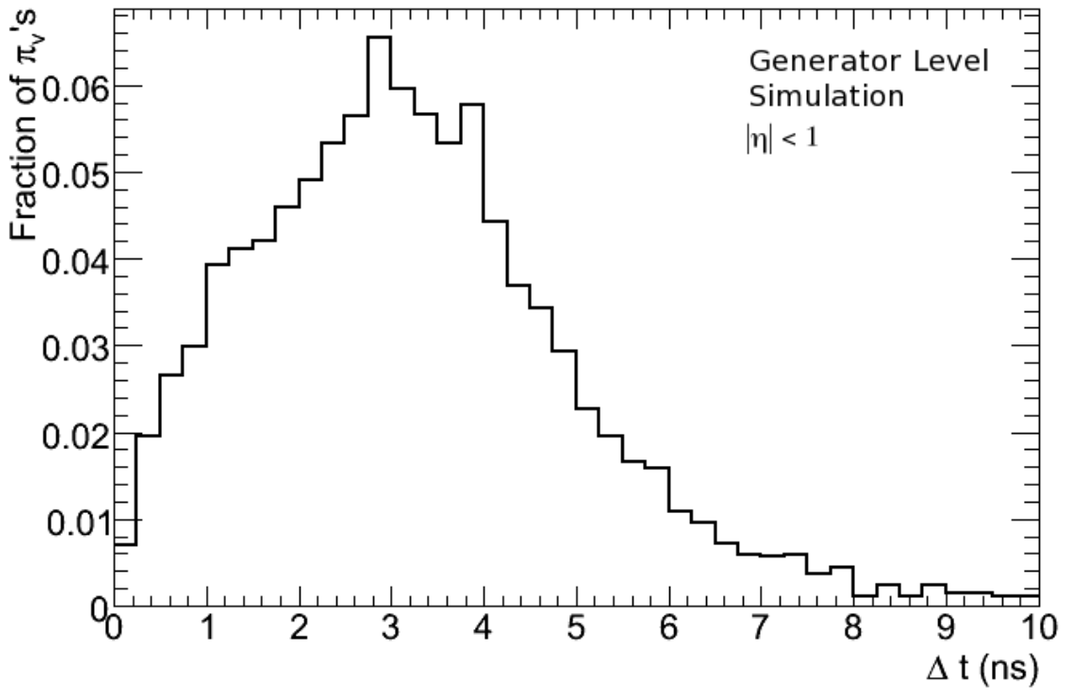


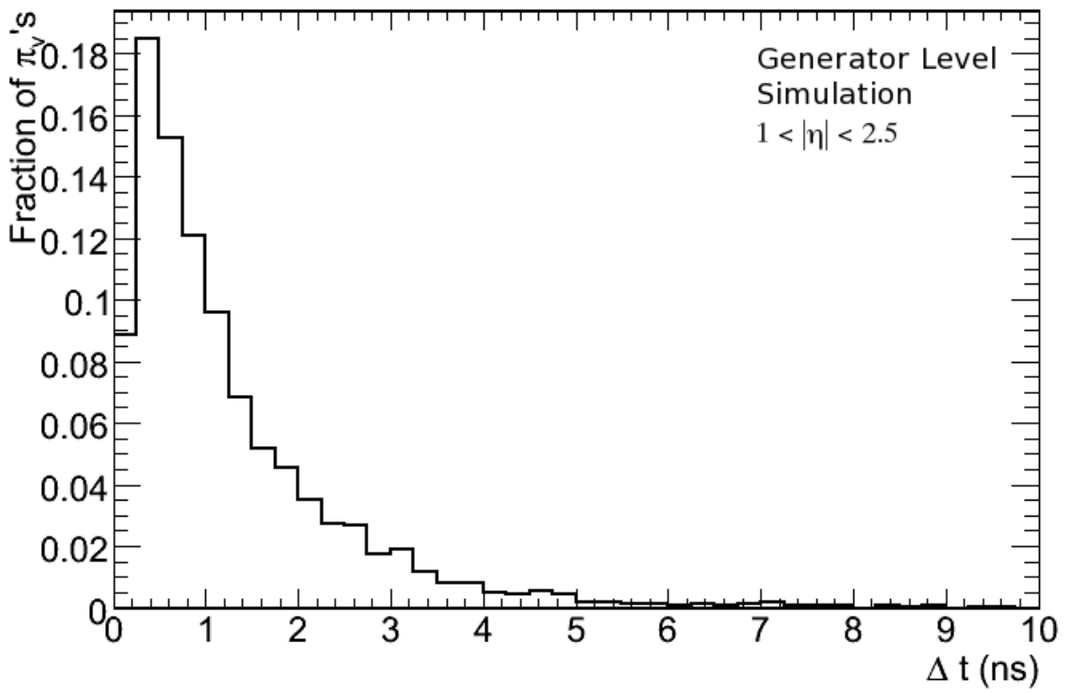
- Decays in the muon system are characterized by a large number of charged tracks and a cluster of "muon" RoIs

Trigger Timing
Decays in the Muon System

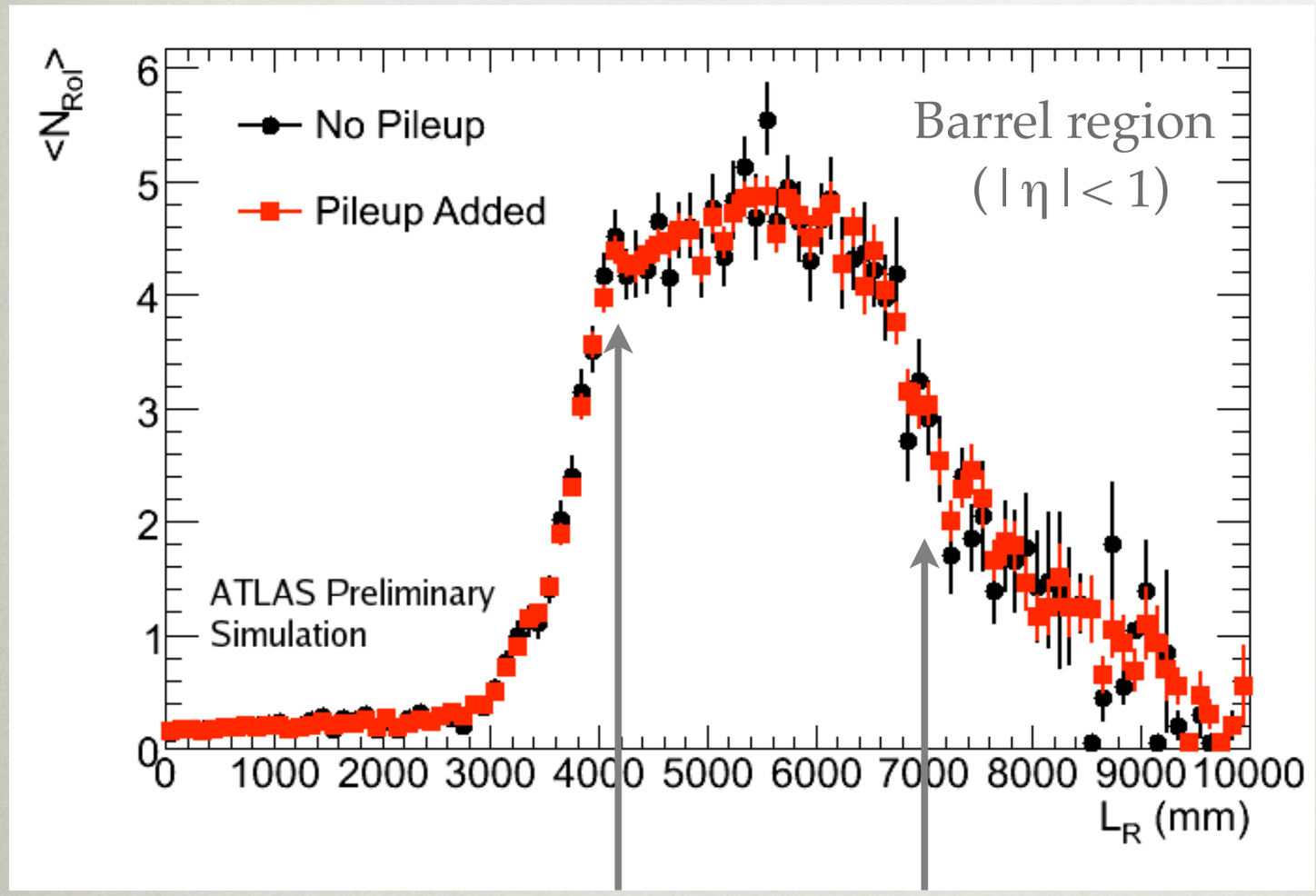
- Trigger will delayed by the arrival time difference, Δt, between the π_v and a $\beta=1$ particle
- From H8 test beam, window of 100% BCID efficiency is $\Delta t < 6$ ns
- Probability for the π_v to associated with the correct bunch crossing is $> 90\%$ for $m_{\pi_v} < m_h/3$





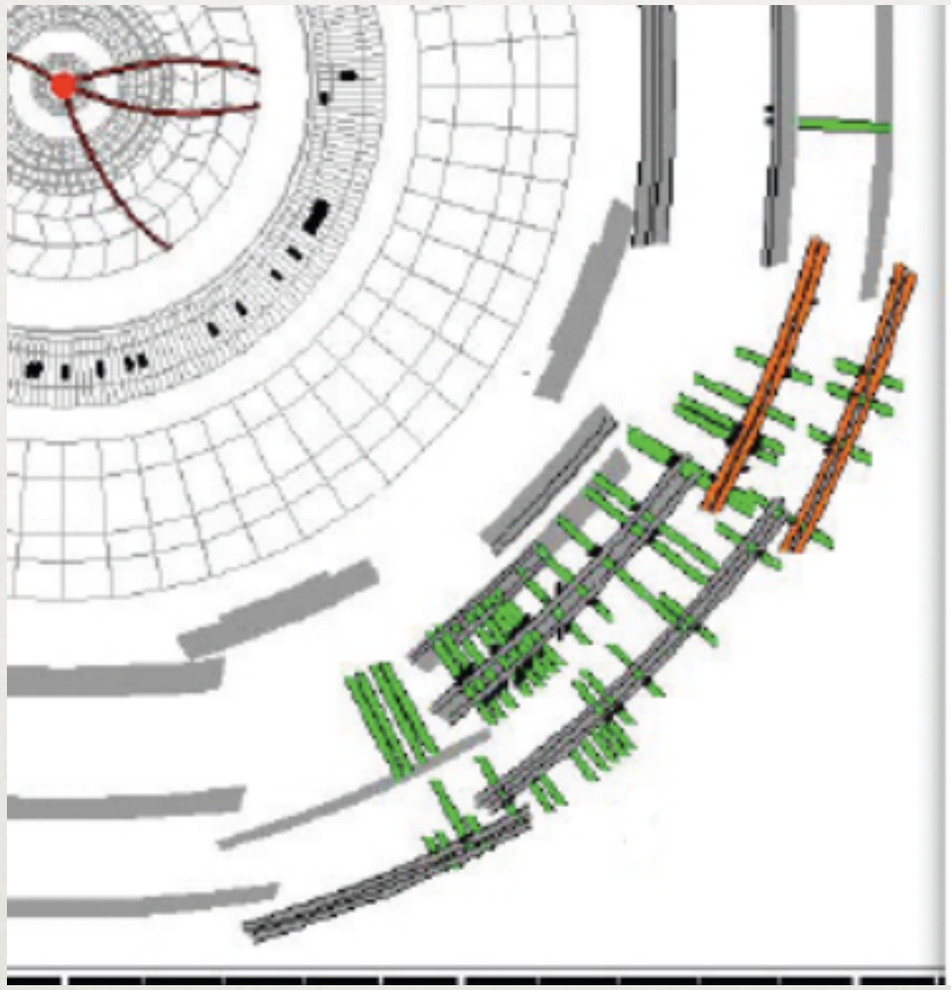


Decays in the muon system



- Average number of L1 muon RoIs contained in a cone of $\Delta R=0.4$ centered around the π_v line of flight versus the π_v radial decay distance
- For π_v decays between the Hadronic Calorimeter (4m) and 1rst trigger plane (7m), the event is characterized by greater than 3 L1 muon RoIs in a small (η,φ) region

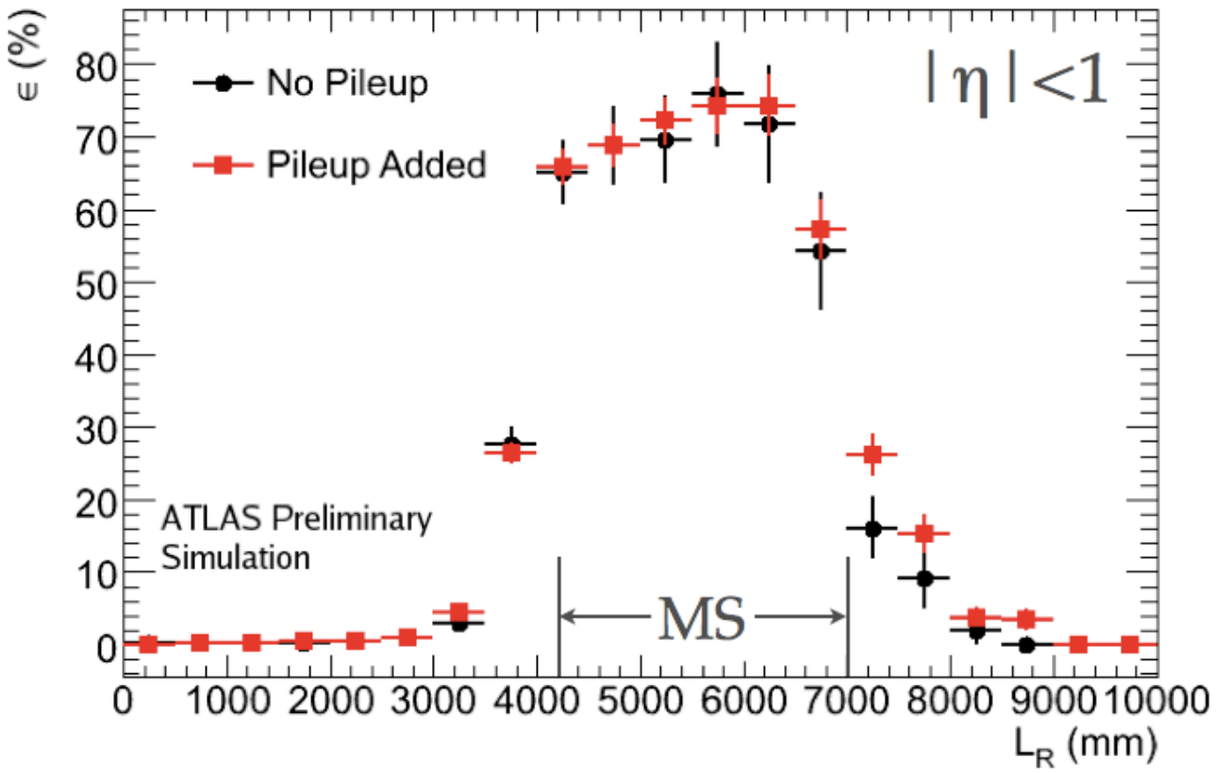
Decays in the muon system



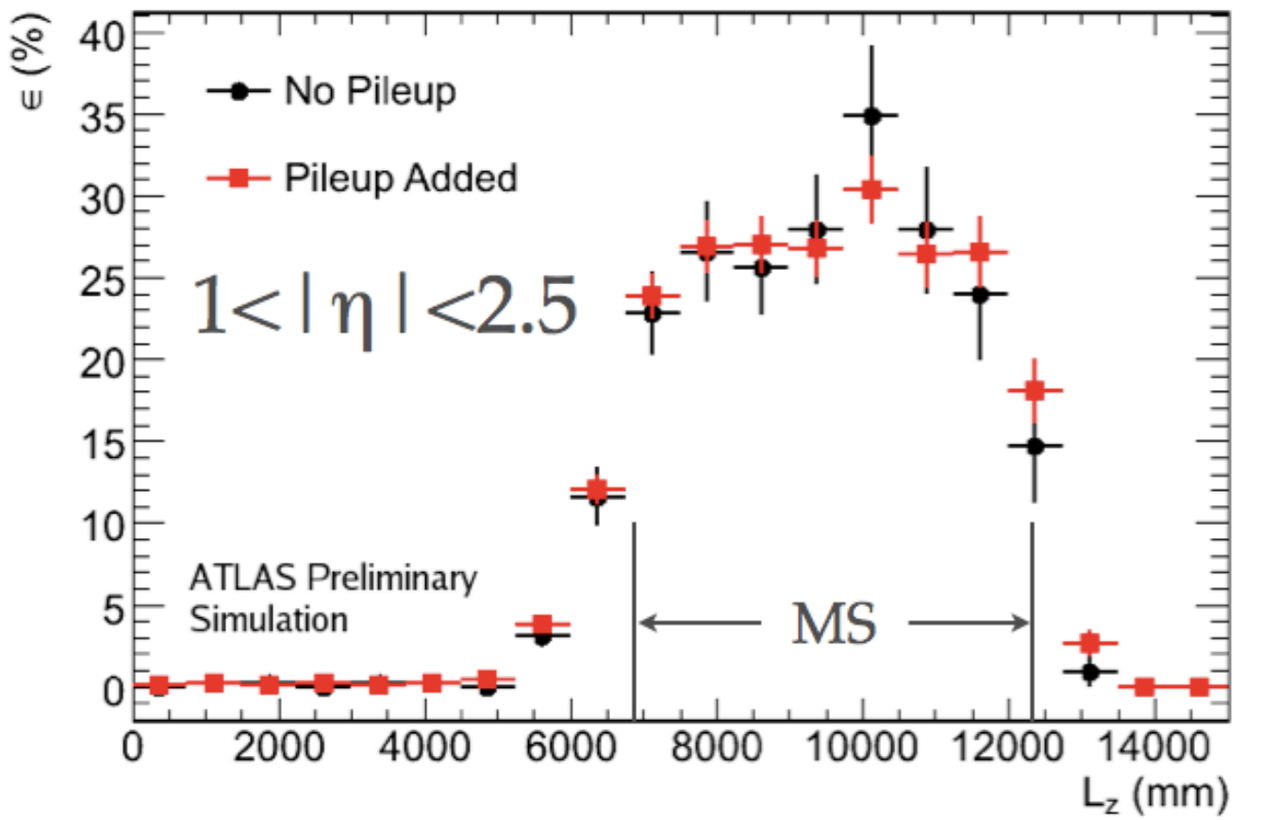
- We define a Level 2 trigger using these signatures as:
  - A cluster (≥3) of Level 1 muon RoIs
  - Isolation wrt jets and Inner Detector tracks

Decays in the muon system

Efficiency for Triggering

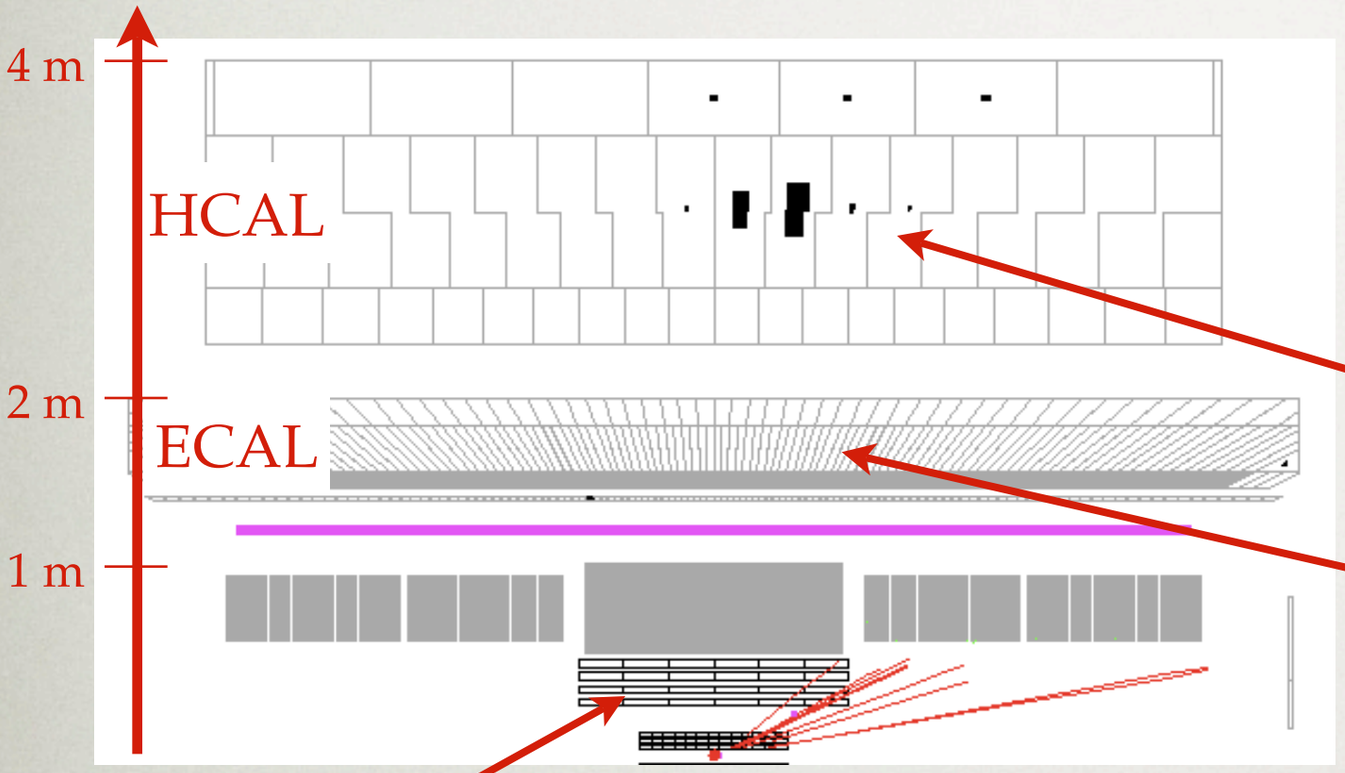


>70% Efficient for decays in the Barrel Muon Spectrometer

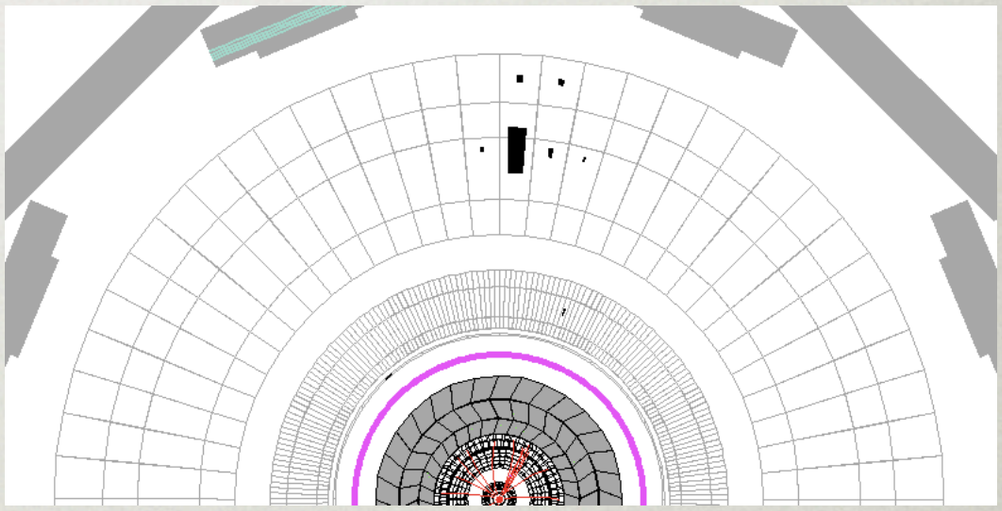


Efficiency is still high (25%) in the endcap region where UE and pileup can spoil the isolation requirements

Decays in the Hcal

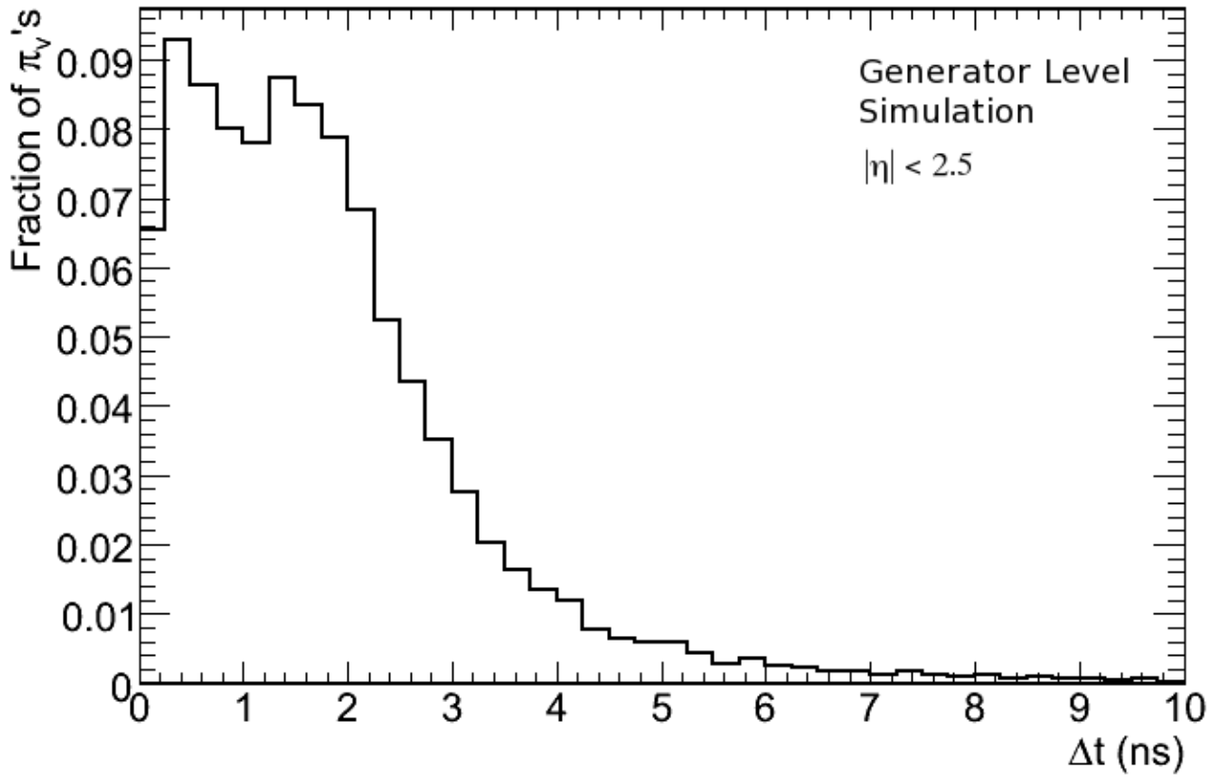


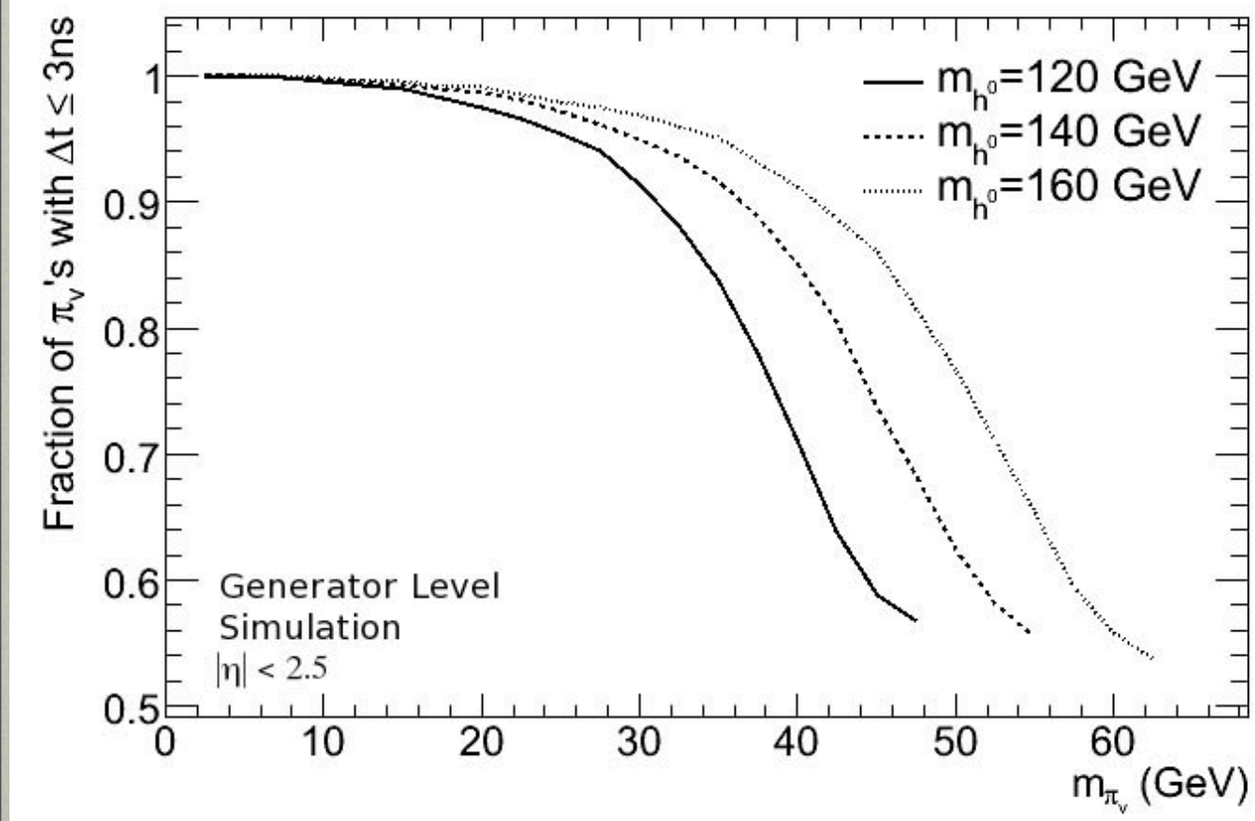
- Decays in the Hadronic Calorimeter (HCAL) are characterized by narrow jets with:
  - Large deposit of energy in the HCAL
  - No energy in the ECAL
  - Jets with no reconstructed tracks (with $p_T > 1$ GeV) in the Inner Detector



Trigger Timing
Decays in the Calorimeter

- Current simulation of calorimeter trigger correctly handles signals from late decays
- For time shifts of $\Delta t \leq 3$ ns, the effect on E_T is $< 1\%$ at Level-2

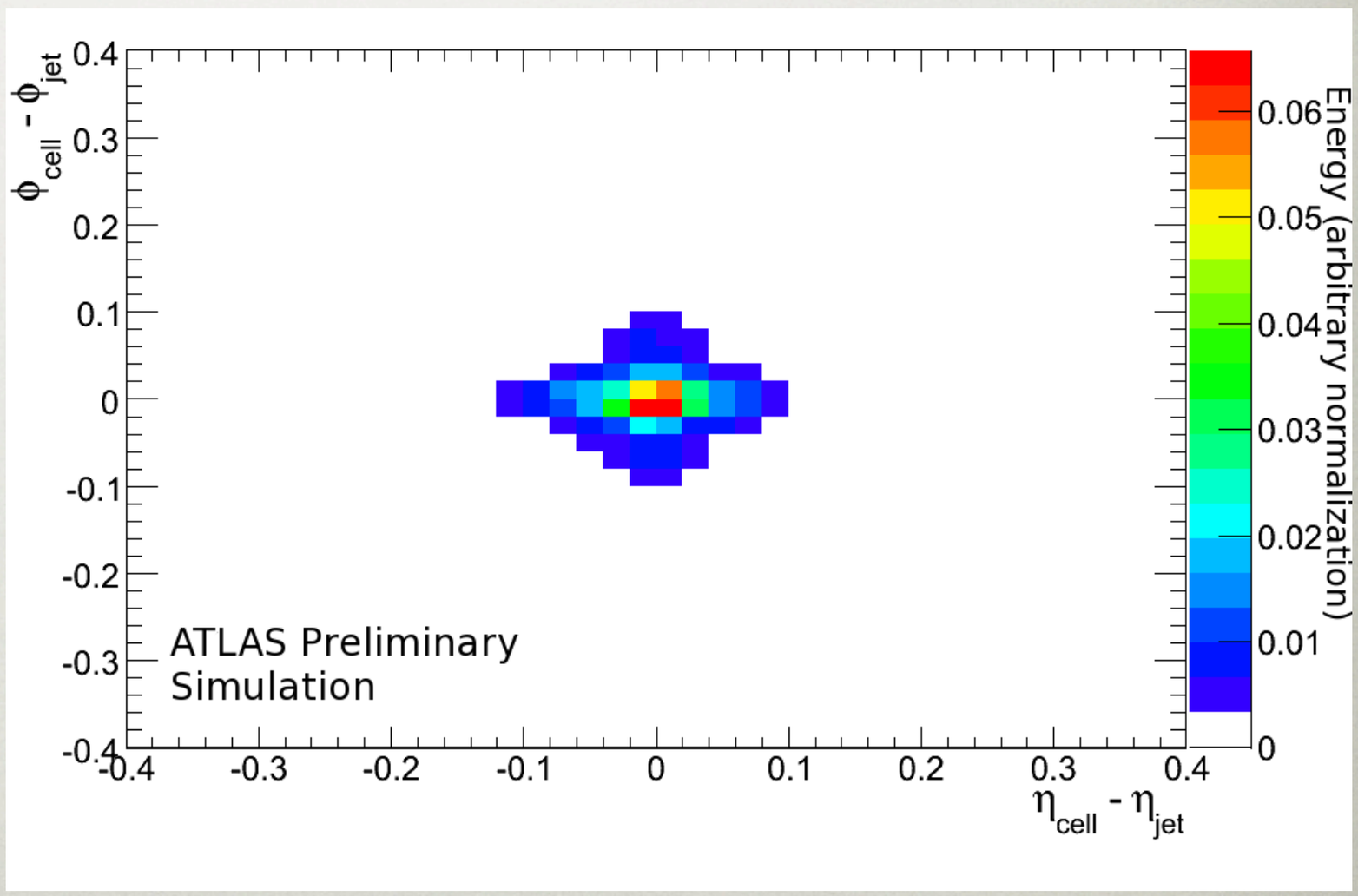




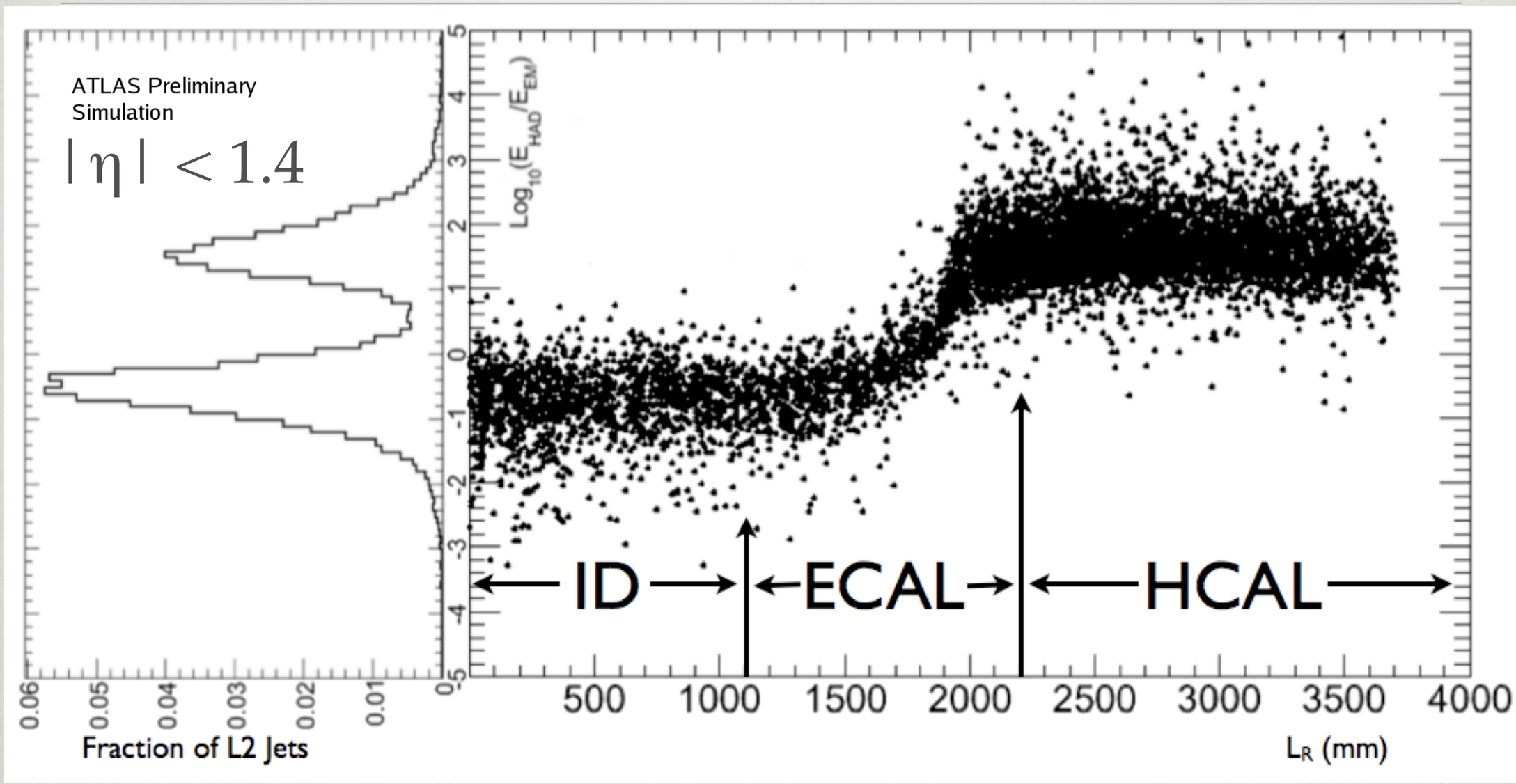
- Can correct the energy measurements for late (> 3ns) decays by fitting the calorimeter line shape during offline processing

Decays in the Hcal

- Jets from decays in the HCAL produce very narrow jets
  - Energy is contained in a cone of $\Delta R = 0.1$ as compared to standard jets of size 0.4
- The narrow jet allows us to use a Level-1 τ trigger to select these decays

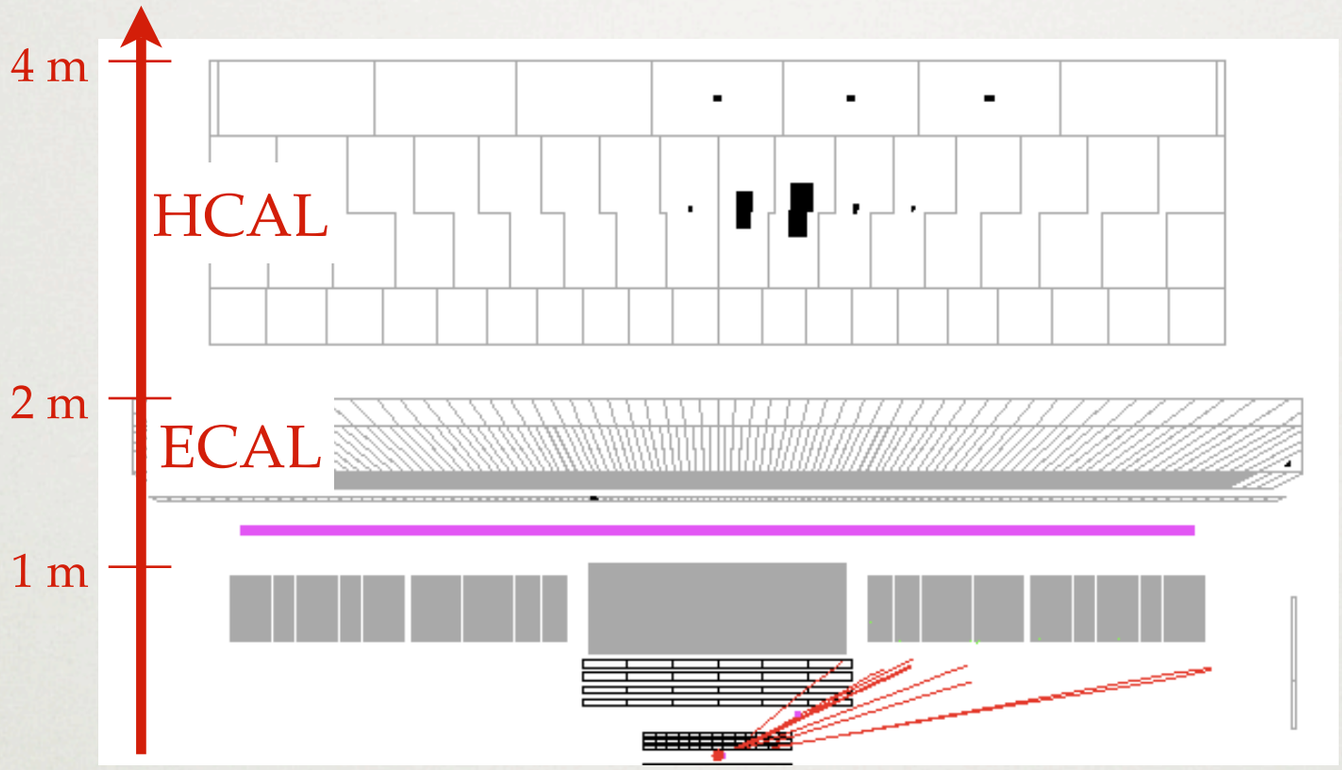


Decays in the Hcal



- Jets originating inside the ID/ECAL have the "standard" $\mathrm{Log}_{10}(E_{HAD}/E_{EM})$ ~-1
- Jets from π_v's decaying in the HCAL have $\mathrm{Log}_{10}(E_{HAD}/E_{EM})$ ~1.5

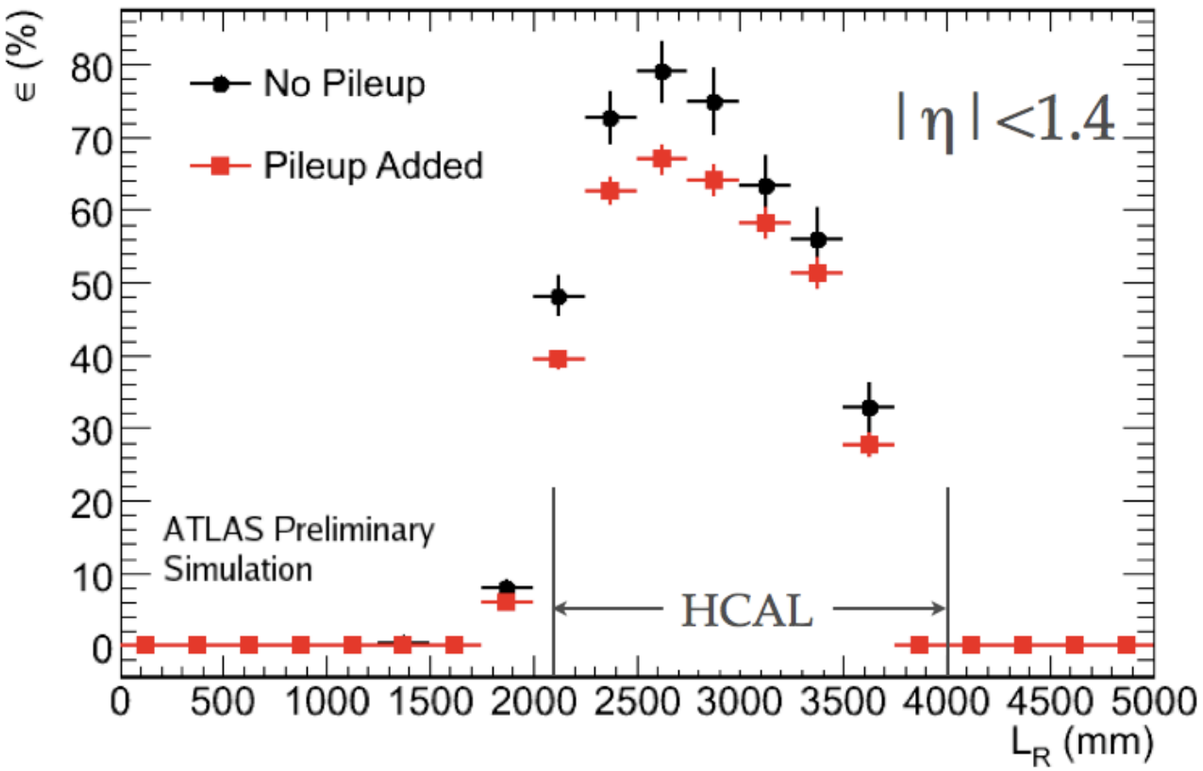
Decays in the Hcal



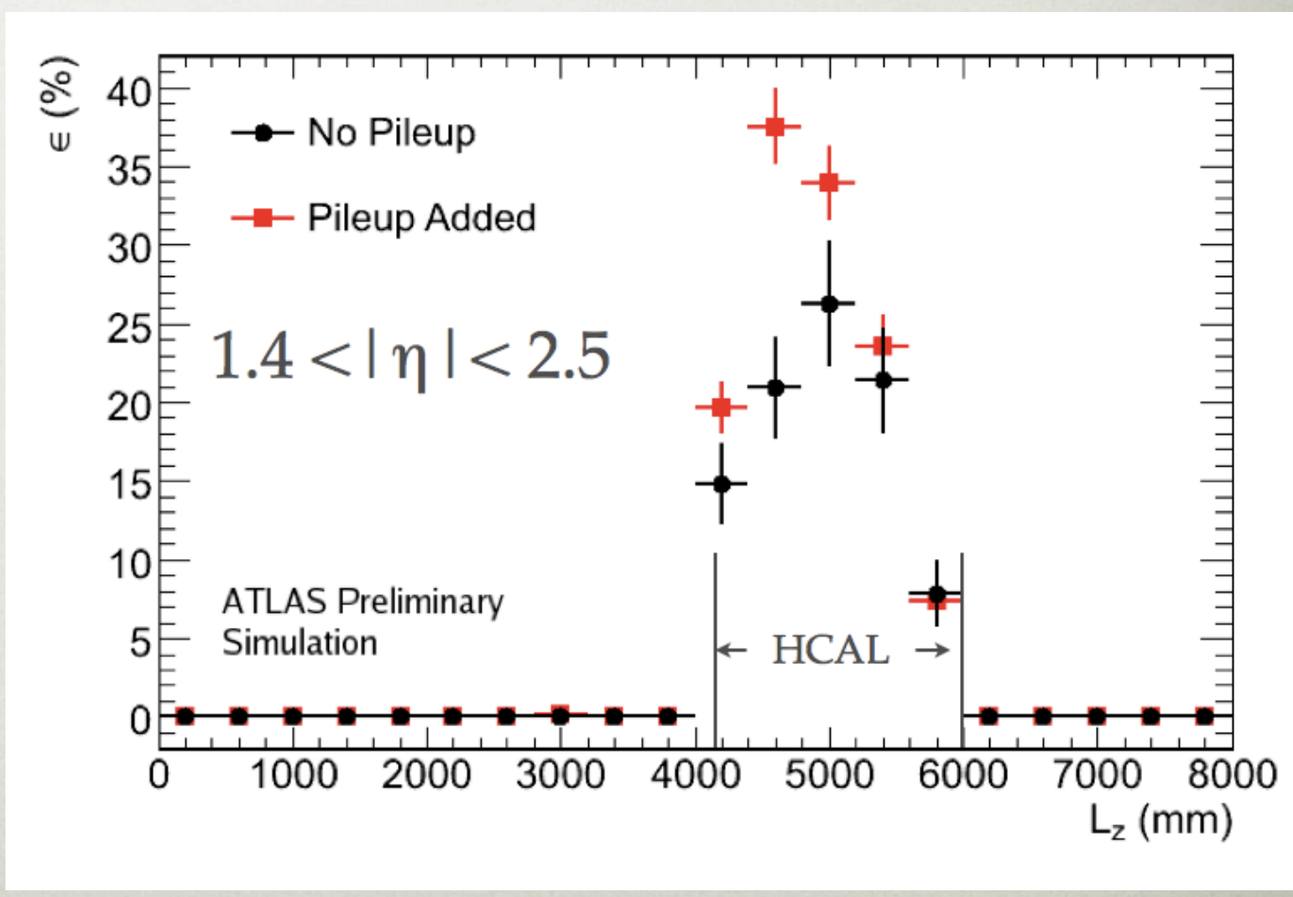
- We define a Level 2 trigger using these signatures as:
  - $\mathrm{Log}_{10}(E_{HAD}/E_{EM}) > 1$
  - Isolation wrt Inner Detector tracks

Decays in the Hcal

Efficiency for Triggering



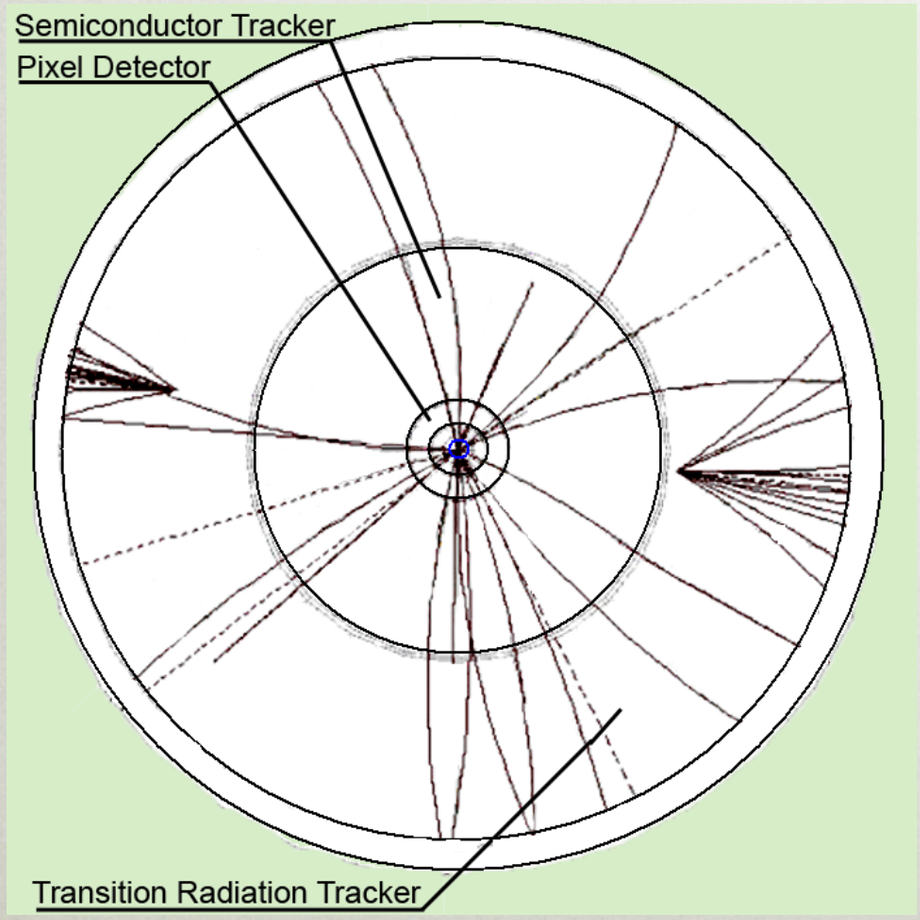
>60% Efficient for decays in the Barrel HCAL



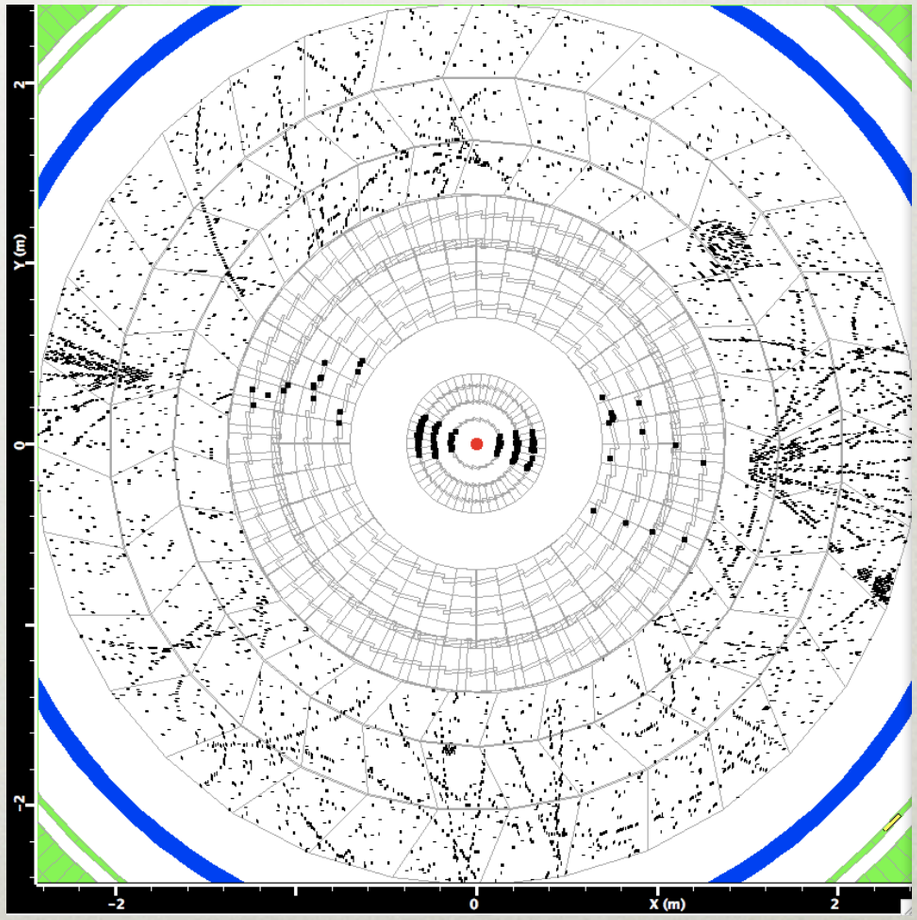
Decays in the Inner Detector

- Decays in the Inner Detector are the hardest to trigger on
- Characterized by 1-2 low energy jets that look QCD like to the trigger
- To reduce backgrounds, we require the event to pass a level 1 muon ($p_T \geq 6$ GeV) trigger

PYTHIA output



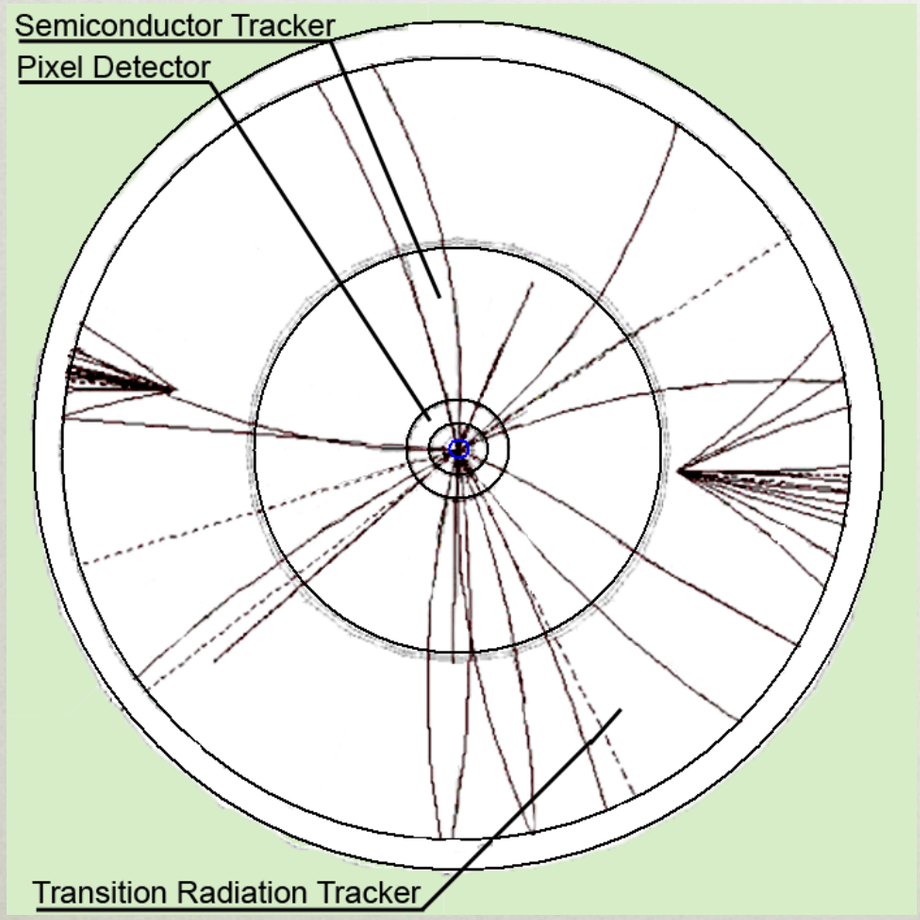
ATLAS output



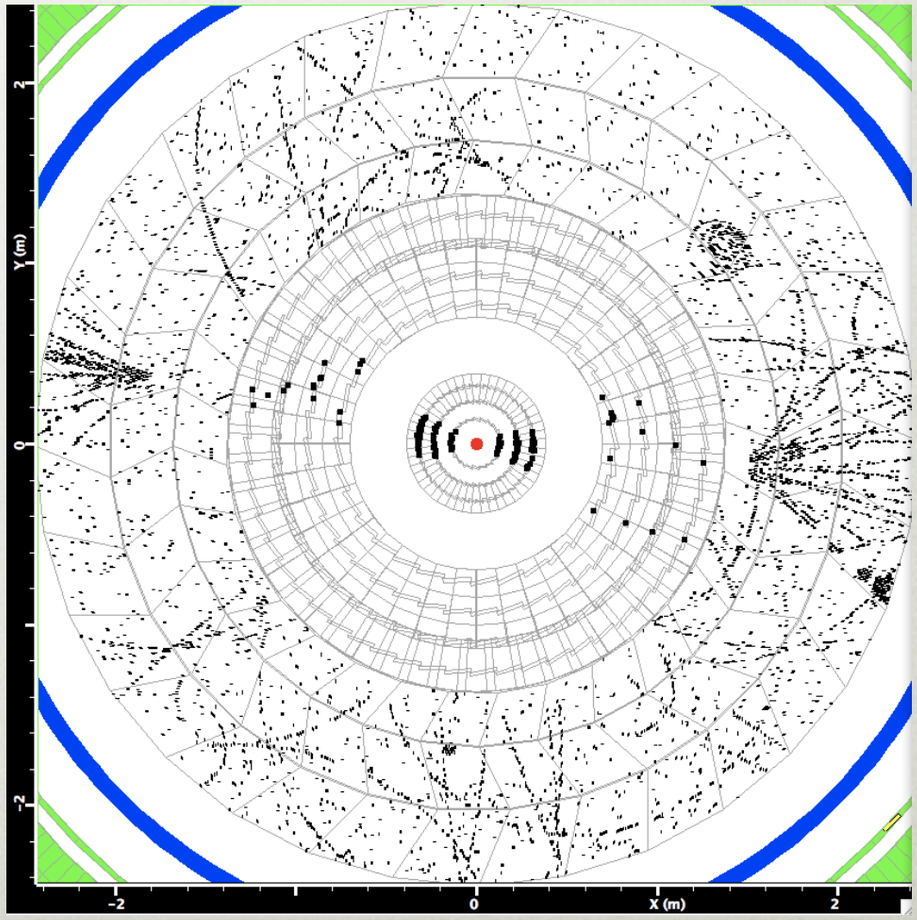
Decays in the Inner Detector

- ATLAS Level 2 tracking algorithms require hits in 4 of the first 5 tracking layers --> decays beyond r~12 cm will not have reconstructed tracks
- Displaced decays are then characterized by “trackless” jets
- Trigger object: “trackless” jet that contains a muon inside the jet cone

PYTHIA output

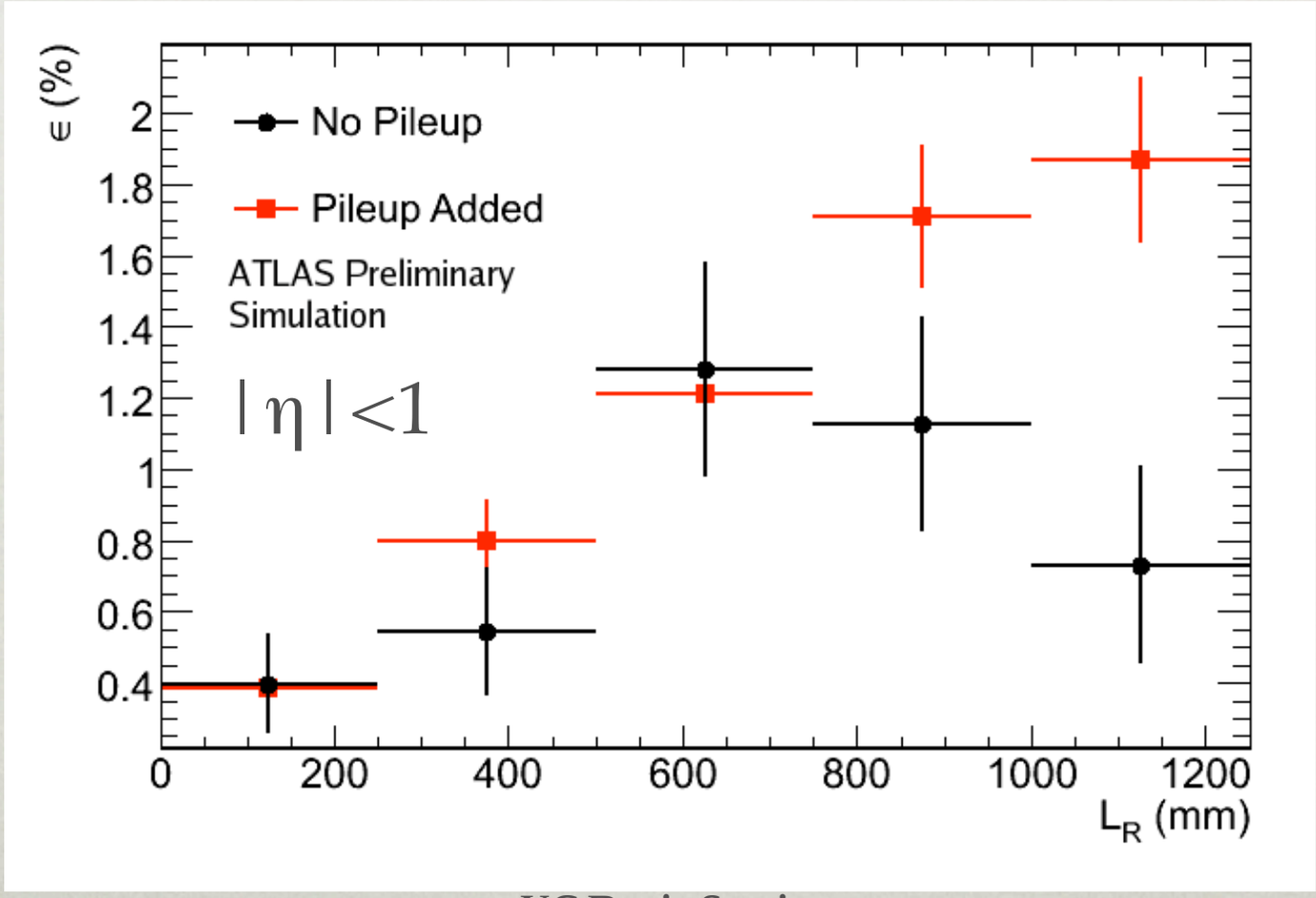


ATLAS output

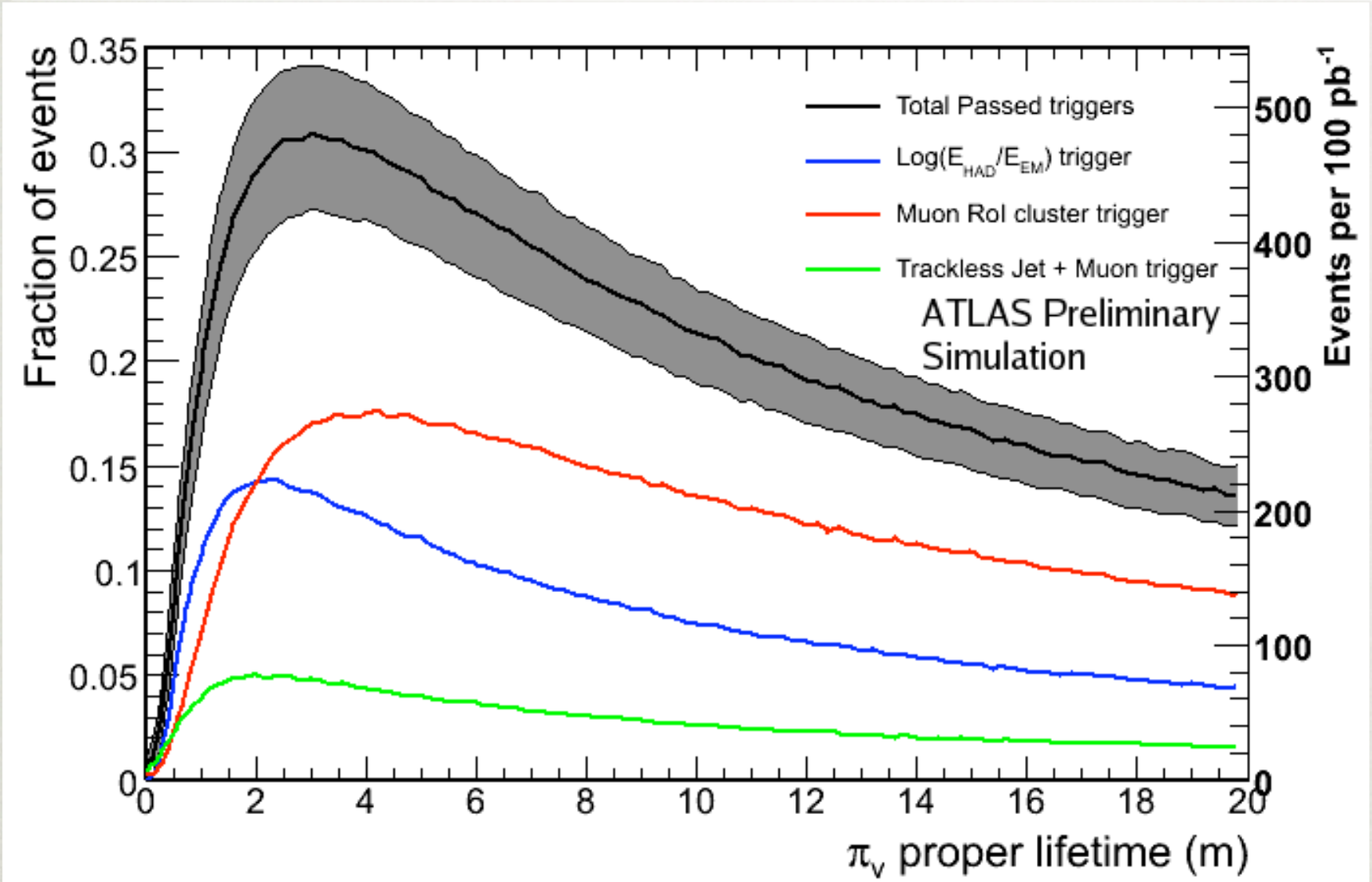


Decays in the Inner Detector

- Low absolute efficiency is due to requiring the muon in the event
- The Level 2 trigger is ~22% efficient wrt Level 1
- Work is on-going to define a more efficient trigger (possibly) using backtracking and jet substructure in the ECAL



Outlook



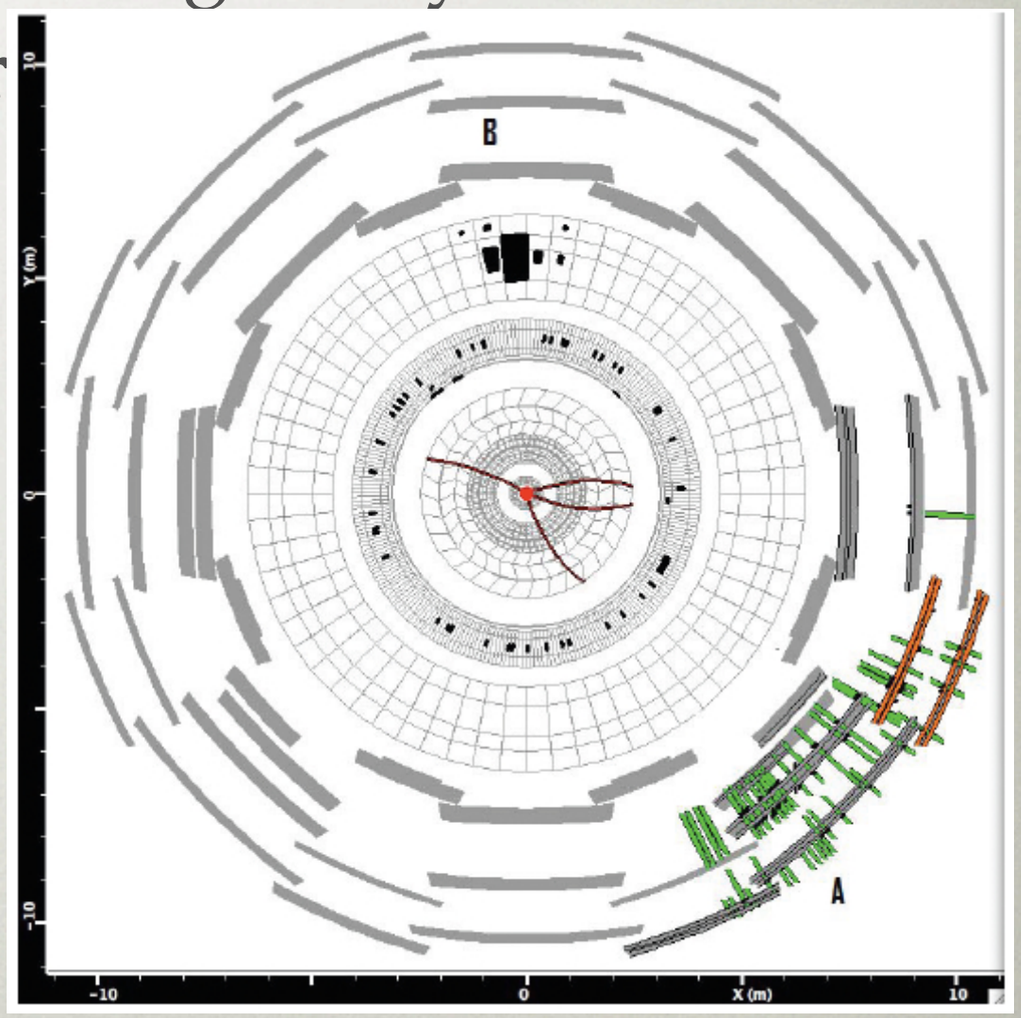
Systematics not included!

- Assuming a branching fraction of 100% and a lifetime of 1.5m (20m) we expect ~400 (200) events per 100 pb^{-1} of 10 TeV data
- Trigger algorithms have been implemented and included in the trigger menu

Cross section/event yield is calculated assuming 100% branching fraction for $h \rightarrow \pi_v \pi_v$

Conclusions

- Signature driven trigger objects have been defined for selection of long lived neutral particles decaying to jets (decays from higgs, Z', SUSY, ..., mediated events)
  - High efficiency (60-80%) for selecting decays in the HCAL and Muon Spectrometer
  - Triggers have been implemented and included in the 2009/2010 trigger menu



BACKUP

Backgrounds

- Tested trigger algorithms on 10 TeV minbias and QCD di-jet samples
  - 0 out of 3M minbias events pass the trigger
- di-jet background gives acceptable rates (at $\mathcal{L}=10^{32}$ cm^{-2} s^{-1}) for the level 2 trigger

	35 - 70 GeV		70 - 140 GeV	
Trigger	Events	Rate (Hz)	Events	Rate (Hz)
Muon Cluster	21	0.4	22	0.03
ID-jet+muon	21	0.4	71	0.10
E_{HAD}/E_{EM}	5	0.1	10	0.01