Searching for Long Lived Neutral Particles in the ATLAS Hadronic Calorimeter

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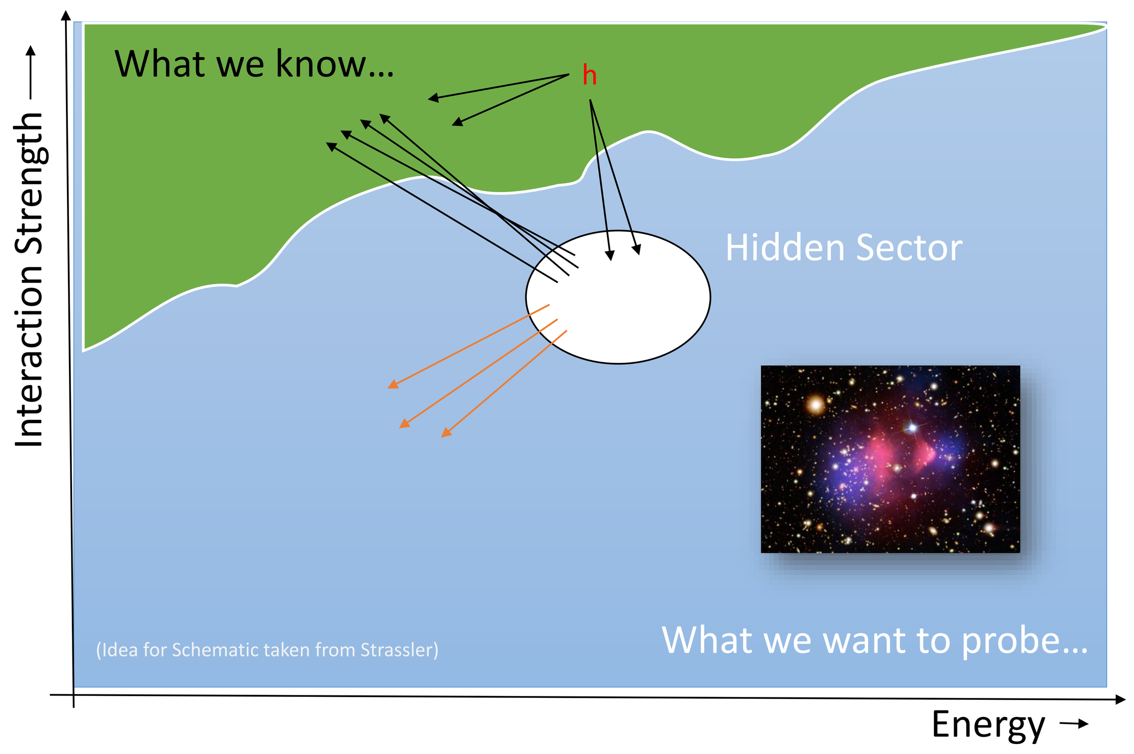
Abstract: The ATLAS detector is sensitive to the decay of neutral, weakly interacting, long-lived particles. Such decays can leave unique, detectable, signatures. This poster concentrates on preliminary results from a search for decays in the hadronic calorimeter in Run II: the search strategy looks for hadronic-only-calorimeter jets that have little or no tracks pointing at them. Many models can contain final states like this: Stealth SUSY, Baryogenesis, and a simple hidden sector scalar that decays to heavy fermion jets. Performance of the ATLAS Calorimeter Ratio trigger along with tools and preliminary results are shown.



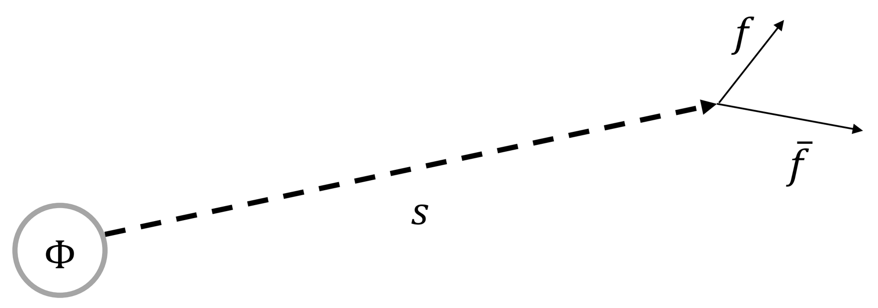
The search for hidden sectors and rare Higgs decays is motivated by our knowledge that the Standard Model is not complete. In particular it is missing Dark Matter. A hidden sector is one possible place to hide it!

Decays that remain in the Hidden Sector: These appear as missing E_T in a detector like ATLAS. Other searches look for those.

Decays back to the SM: If these are regular prompt particles they could be very difficult to find. But what if they have **lifetime**? What if they travel some distance before decaying?

Benchmark Model

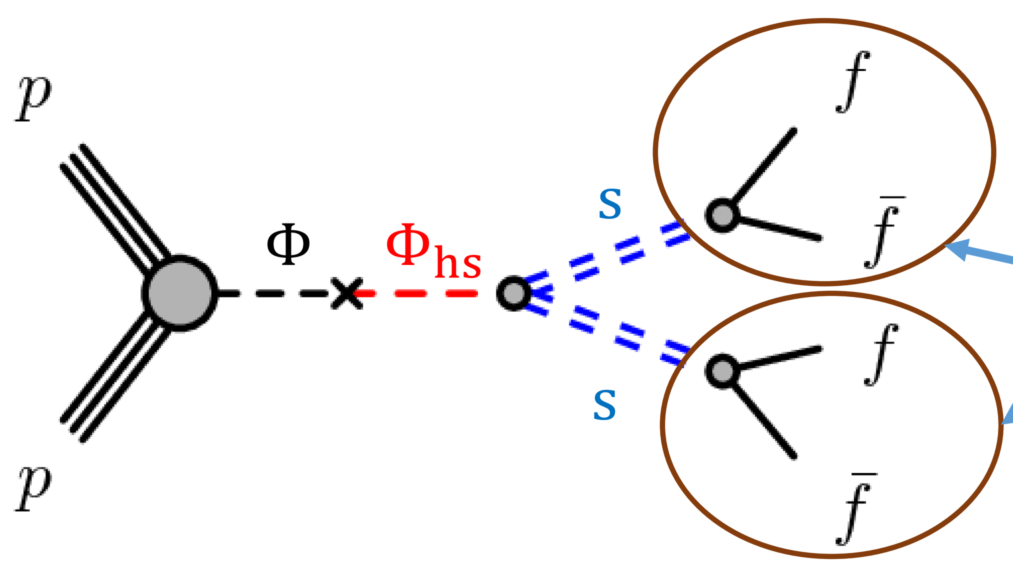
A **scalar** in the SM that mixes with a **scalar** (Φ) in the hidden sector. Depending on the HS kinematics, it can decay to some **HS scalar** (s). After some time, s decays back to SM particles. It prefers **heavy fermions**, primarily $s \to b\bar{b}$.



There is no reason the Φ can't be the Higgs, turning this into a search for exotic Higgs decays.

Lepton-Jets m_s too small to decay to quarks (see arXiv:1409.0746)
Hadronic-Jets m_s large enough

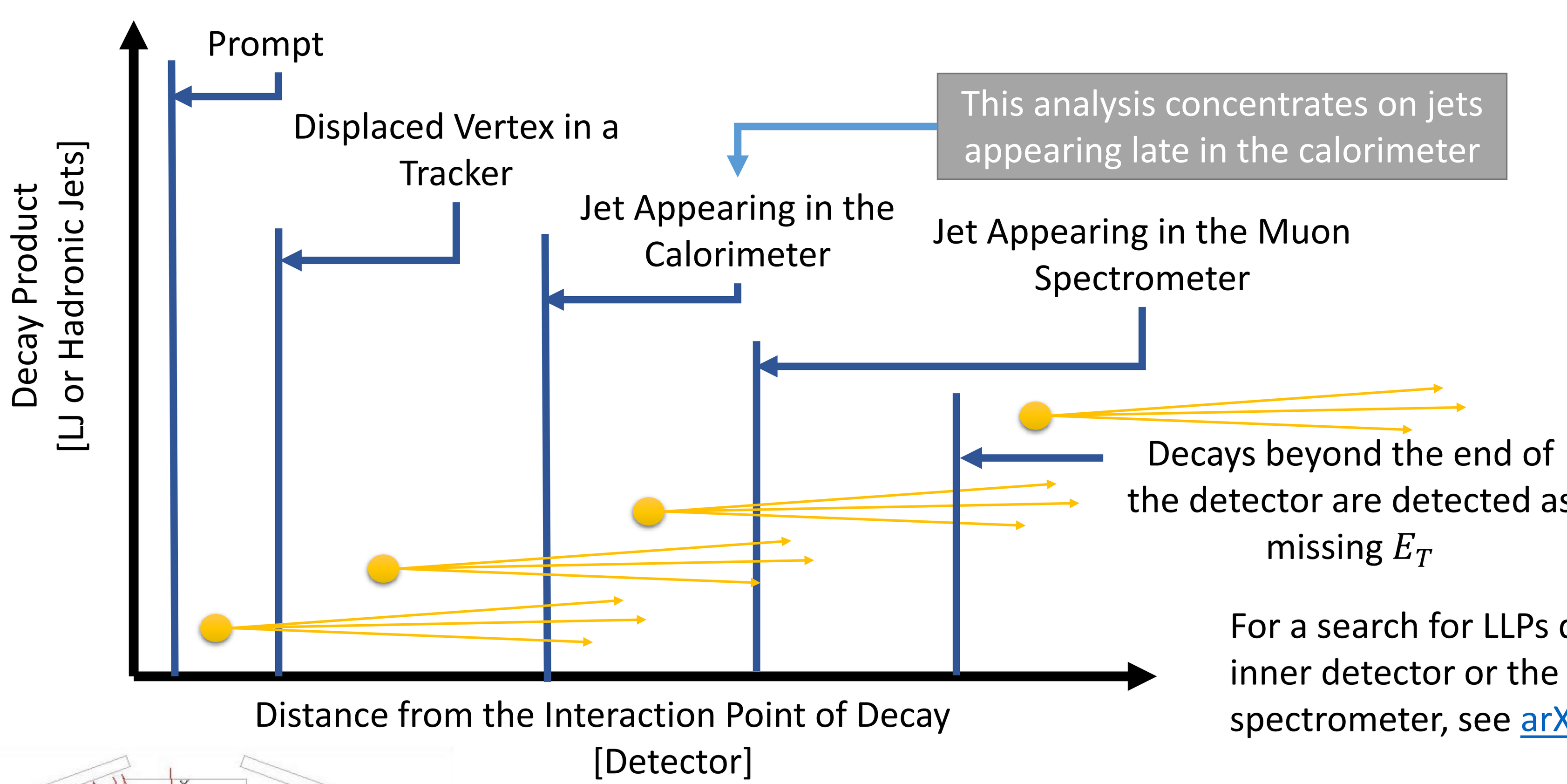
There are some **limits on the lifetimes** of these particles: previous searches at colliders, and there can be further restraints depending on how you account for Dark Matter. But the lifetimes restrictions are weak enough that we **search for all lifetimes**.



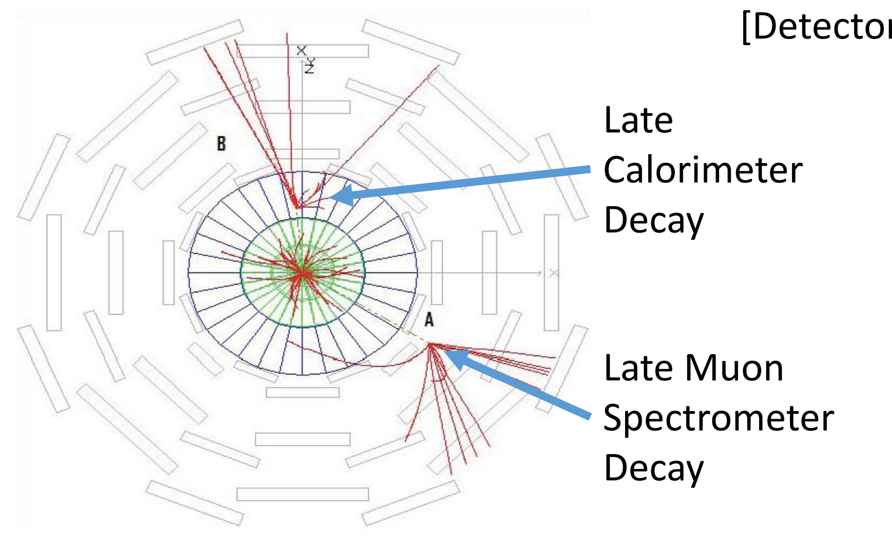
Topology is 4 heavy fermions, almost always b quarks, appearing somewhere in the detector. Depending on kinematics and the detector where they appear, the $f\bar{f}$ pair won't always be resolvable as individual objects.

Detector Signature

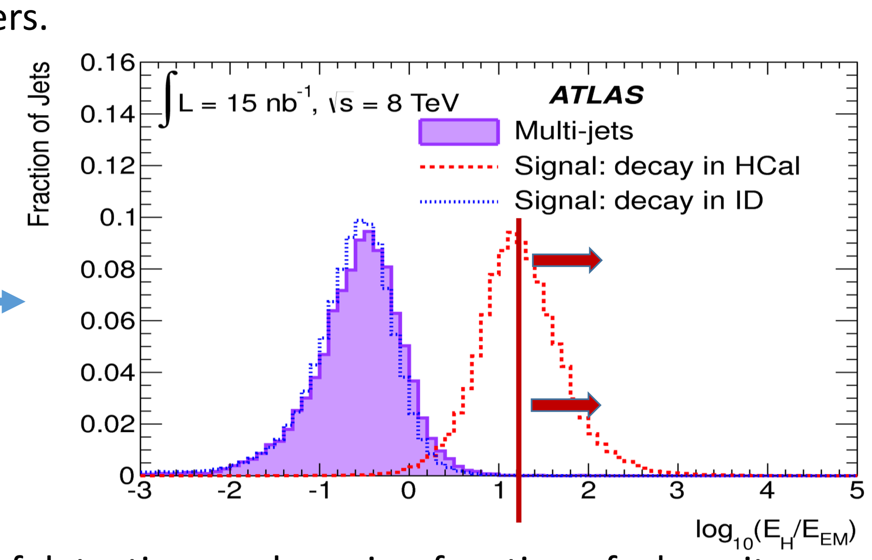
The detector signature is unique. However it depends dramatically on where in the detector the decay occurs. Separate algorithms (and triggers) must be developed for each detector region.

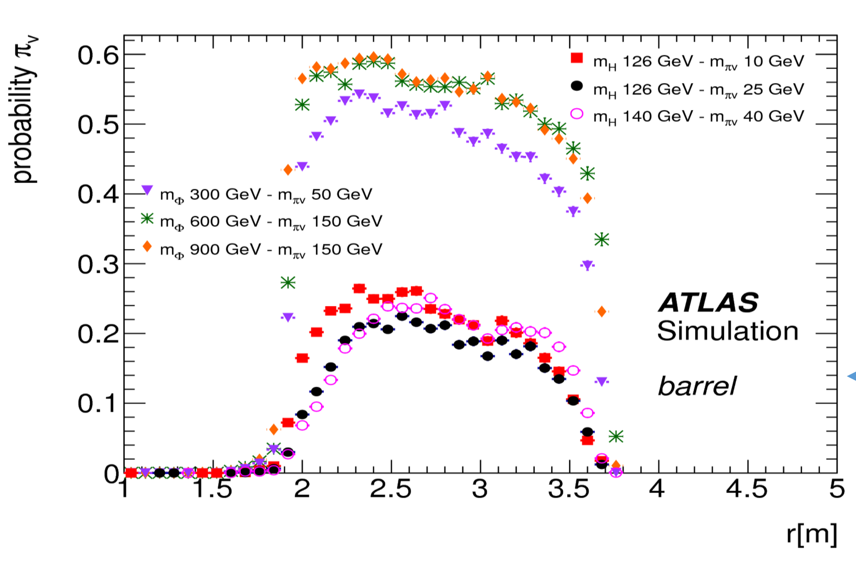


For a search for LLPs decaying in the inner detector or the muon spectrometer, see arXiv:1504.03634



Decays in the hadronic calorimeter will have two easily signatures:
- No or few tracks as the LLP decay occurs after the tracking detectors. We look for no tracks above 2 GeV within 0.2 of ΔR of the jet axis.
- A late decay in the EM calorimeter or in the hadronic calorimeter means a no or little energy deposited in the EM calorimeter. We use a requirement on the log of the CalRatio variable, $\log_{10}(\frac{E_H}{E_{EM}}) > 1.2$, which compares the energy deposited in the two calorimeters.





The probability of detecting a s decay is a function of where it decays in the calorimeter.
- The efficiency depends on η and the boost of the s as well. They are averaged over in the below plot.
- The shape of the efficiency curves is also a function of the proper lifetime at which the sample was generated.

Backgrounds

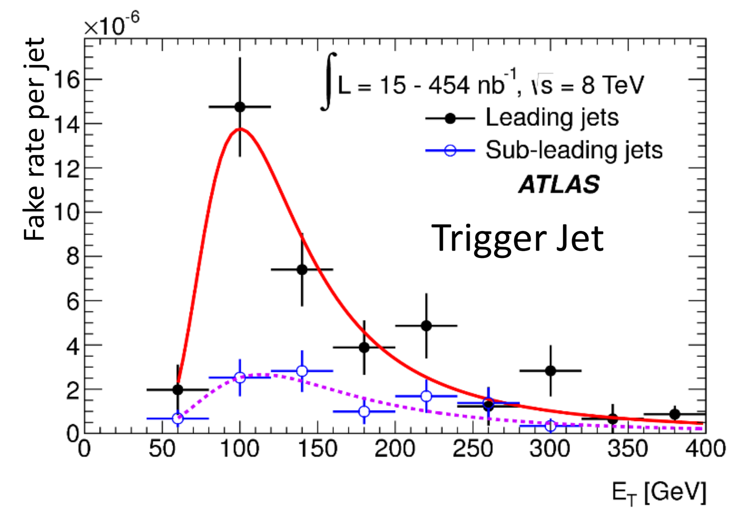
Backgrounds include multijets, cosmics, and beam-induced-background (e.g. beam-gas).
- Cosmics are removed by requiring missing $E_T < 50$ GeV,
- Beam induced background are removed by looking for beam remnants in the end-cap muon detector

The main background is QCD-like jets that have fluctuated to look like low EMF jets with no tracks.

Multijet Cross-section × Small Fake Rate = A big number

A data-driven determination of the background is the only option

Determine the fake rate for a detector jet using the tag-and-probe method.
- Use jet-triggered data (low signal probability)
- Different categories of jets have different fake rates
- Leading and sub-leading (by jet p_T)
- Trigger or non-trigger
- We are statistics limited



The background is then a sum of all the multi-jet data in our sample, with these fake rates applied to each event using simple combinatorics:

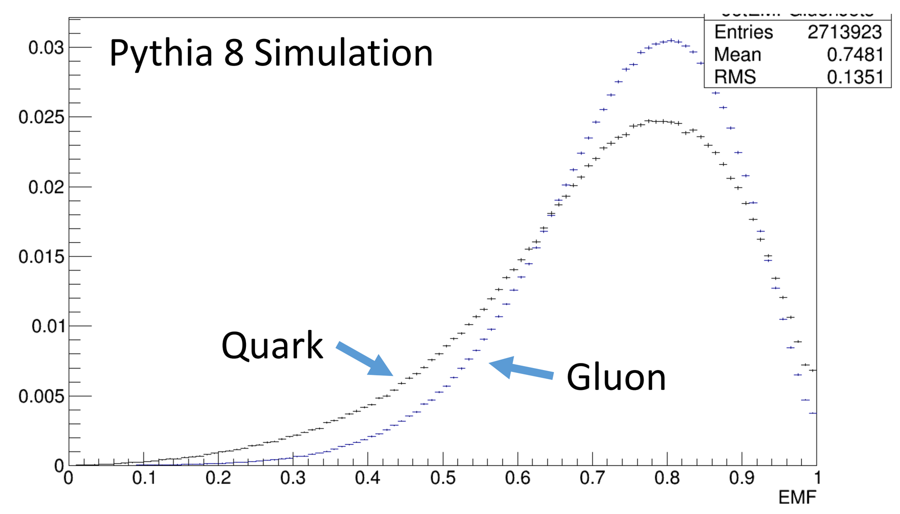
$$P_{event} = 1 - (1 - P(j_1))(1 - P(j_2))$$

Actual combinatoric formula is a bit more complex as it includes things like only two jets allowed, that there are different probabilities for the different jets, etc.

This method only works if each jet is independent!

The main selection cuts, on CalRatio and on the number of tracks, are correlated between quarks and gluons

The correlation can be accounted for in data by running the background prediction in control regions and extrapolating the derived correction factor to the signal region. The error is statistics!



QCD Expected Background: 23.2 $\pm$ 8.0 events.

Limits

Observed: 24 Events
Expected Background: 23.5 $\pm$ 8 Events

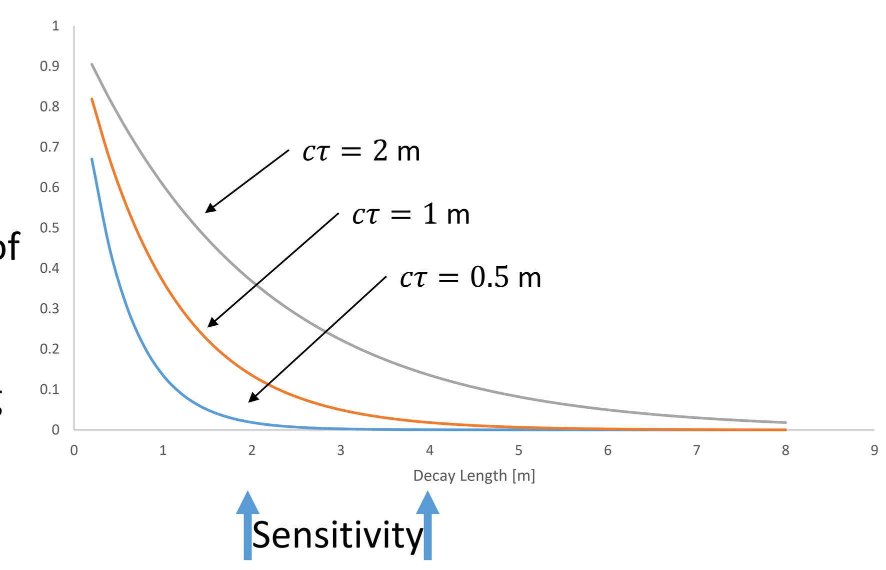
Sample m_H, m_{π_v} [GeV]	H σ [%]	JES [%]	Trigger [%]	E_T^{miss} [%]	Time Cut [%]	Total [%]
126, 10	$^{+10.4}_{-10.4}$	$^{+2.2}_{-2.7}$	±1.1	$^{+5.5}_{-2.4}$	$^{+1.6}_{-6.6}$	$^{+16.4}_{-16.7}$
126, 25	$^{+10.4}_{-10.4}$	$^{+1.5}_{-1.6}$	±1.3	$^{+3.1}_{-1.8}$	$^{+0.8}_{-3.3}$	$^{+15.6}_{-15.5}$
126, 40	$^{+10.4}_{-10.4}$	$^{+2.6}_{-6.2}$	±1.1	$^{+7.7}_{-4.6}$	$^{+1.9}_{-5.9}$	$^{+18.2}_{-16.9}$

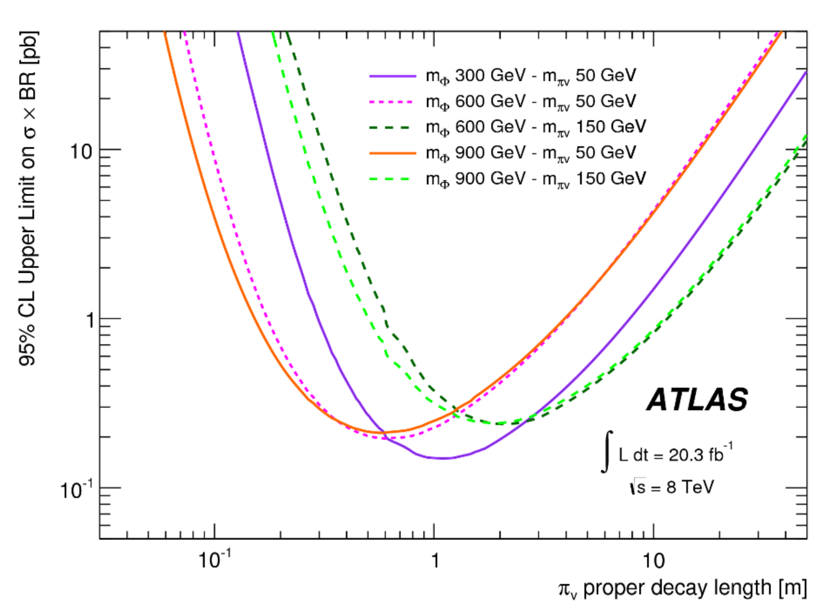
Systematic Errors for the $\Phi = 126$ GeV Samples

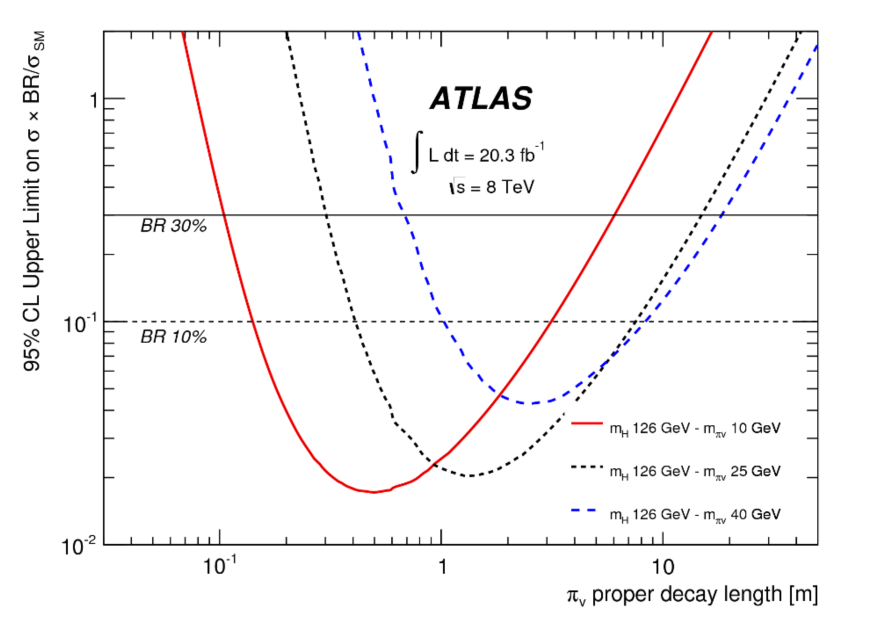
Use a simple CL_s method to set limits.

This is a limit at a single proper lifetime

We extrapolate to set limits at other lifetimes. The limit extrapolation process takes into account:
- The boost of the s and how far it will travel before decaying.
- The efficiency of the analysis as a function of decay position in the detector.
- Timing cuts that are inherent in the timing structure of the detector and further timing cuts in the analysis to help eliminate background events from cosmic rays.







Run 2 Plans

The LHC has taken a large amount of data in 2016; almost to 17 fb^{-1} as of this writing. This analysis is being extended to use this data.
- We have developed a new, more sensitive identification for displaced jets using a boosted decision tree.
- And we are experimenting with a new method to calculate the multijet background.