Searches for Long-lived Particles and Lepton-jets with the ATLAS Detector

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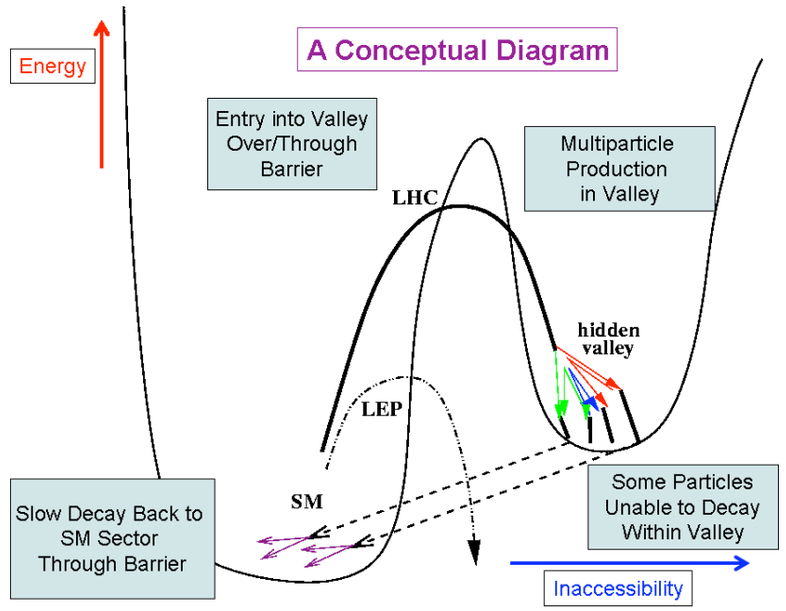
INTRODUCTION

A number of New Physics models predict long-lived particles:

Hidden Valley scenarios - final states include lepton-jets, displaced vertices

Long-lived multi-charged particles (Dyons, Q-balls) - highly ionizing signatures



Supersymmetry models (see talk by M. King):

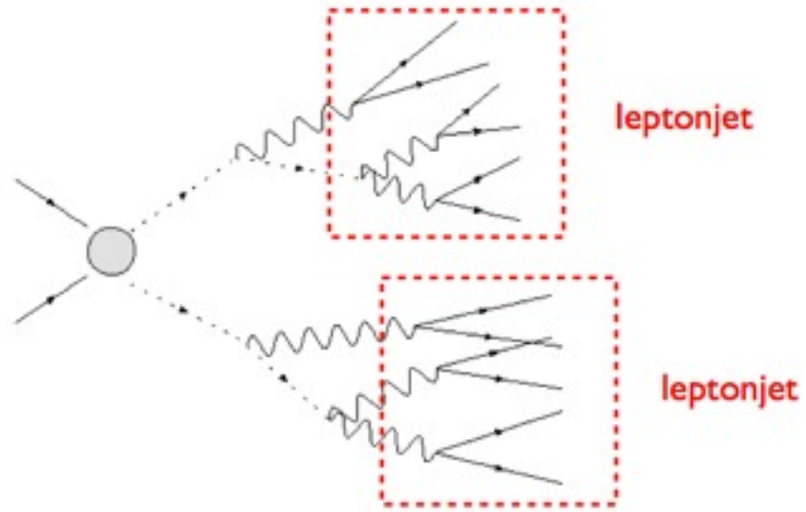
- **R-parity violating SUSY** - displaced vertices
- **AMSB direct chargino production** - 'disappearing' tracks
- **Gauge-mediated SUSY breaking (GMSB)** - long-lived sleptons and R-hadrons

Interesting final states - require custom object reconstruction

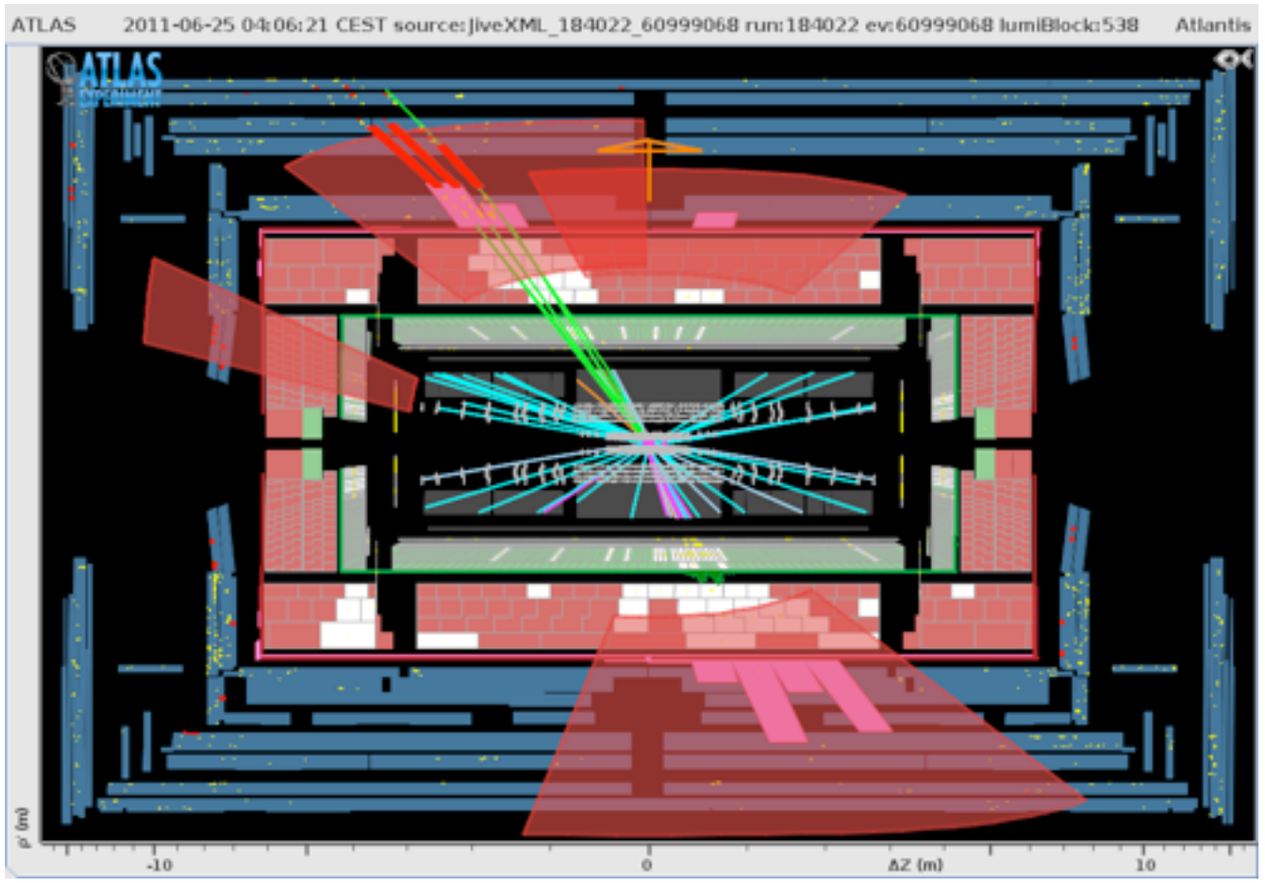
LEPTON JET SEARCHES

Hidden Valley models with a light gauge boson at the GeV scale

- Motivated by observed e^+/e^- excess
- Dark sector particles decay to highly collimated group of electrons/muons/taus (lepton-jets)
- Lepton-jets can be prompt/displaced



- Higgs, Z' can have rare decays to hidden sector

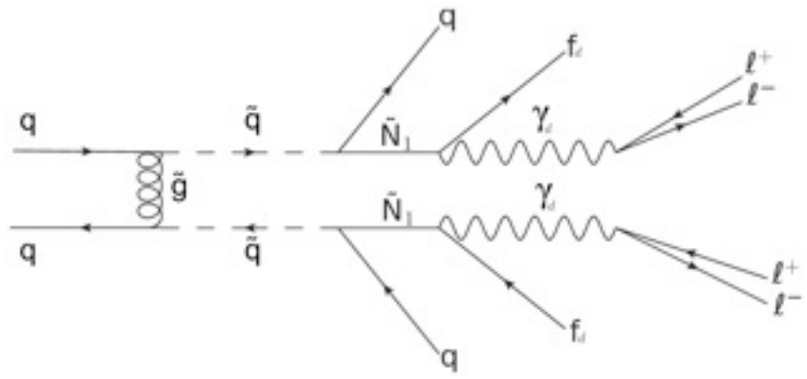


Event display with candidate muon-jet

SEARCHES FOR PROMPT LEPTON JETS

Models with SM+SUSY+dark sector:

- Certain dark sector particles can mediate decays between SUSY and SM groups
- Here, squarks decay to a cascade of dark photons (γ_d), which then decay into lepton-jets
- Other dark sector particles can also radiate γ_d



Signatures considered:

- Single muon-jet with 4 or more muons
- Pairs of muon-jets with at least two muons each
- Pairs of electron-jets with at least two electrons each

SEARCHES FOR PROMPT LEPTON JETS

Electron-jets

Electron-jet reconstruction:

Too closely collimated for standard e^- reco algorithms

Built from EM clusters with $E_T > 10$GeV and $|\eta| < 2.47$

Require two tracks from IP with $p_T > 10$ GeV, within $\Delta R < 0.1$ of cluster

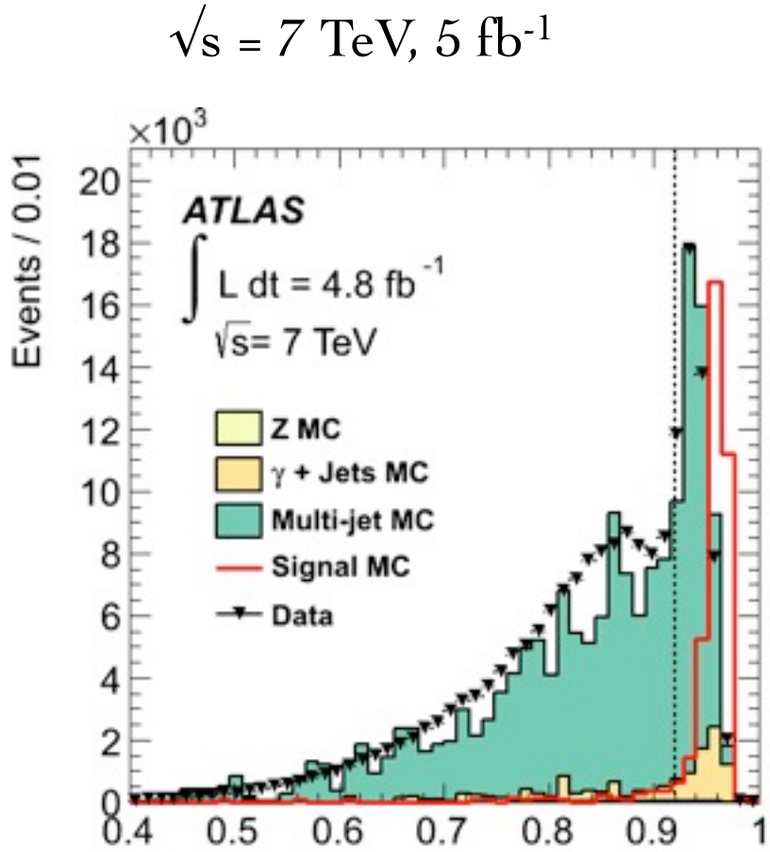
Background - mainly multi-jet processes, photon+jets

Electron-jet channel - discriminants:

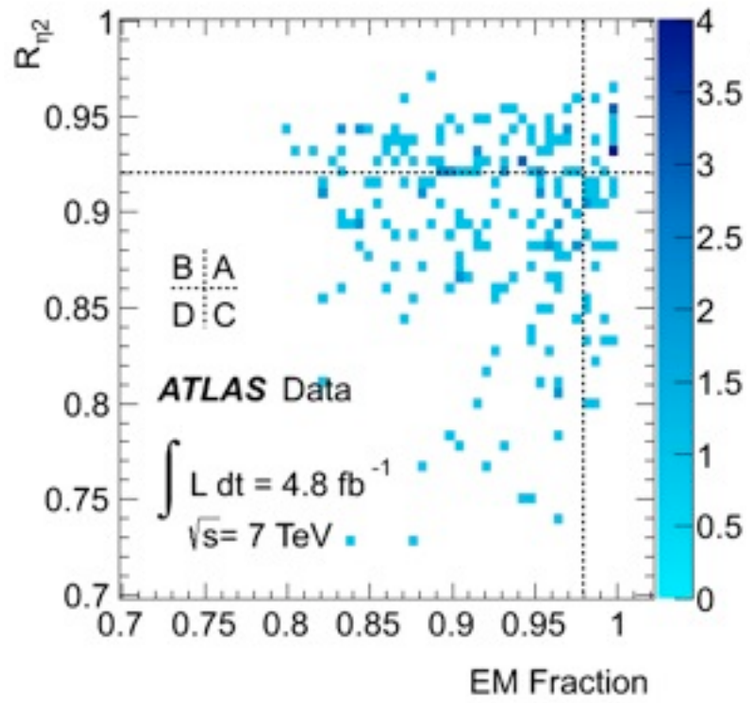
$R_{\eta 2}$ - cluster energy concentration

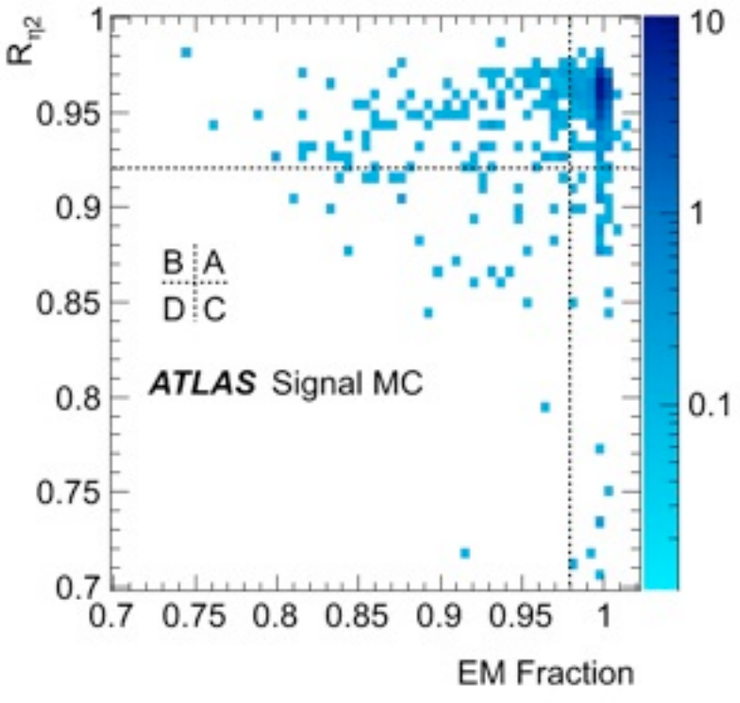
Electron-jet EM fraction

PLB 79, 599
http://arxiv.org/abs/1212.5409



Signal region - A





SEARCHES FOR PROMPT LEPTON JETS

Muon-jets

Muon-jet reconstruction:

Seed by highest p_T μ, add muons within $\Delta R = 0.1$

Single muon-jet - require μ p_T > 19, 16, 14 GeV for first three muons, μ p_T > 4 GeV for remaining muons

Double muon-jet - require μ p_T > 11 GeV

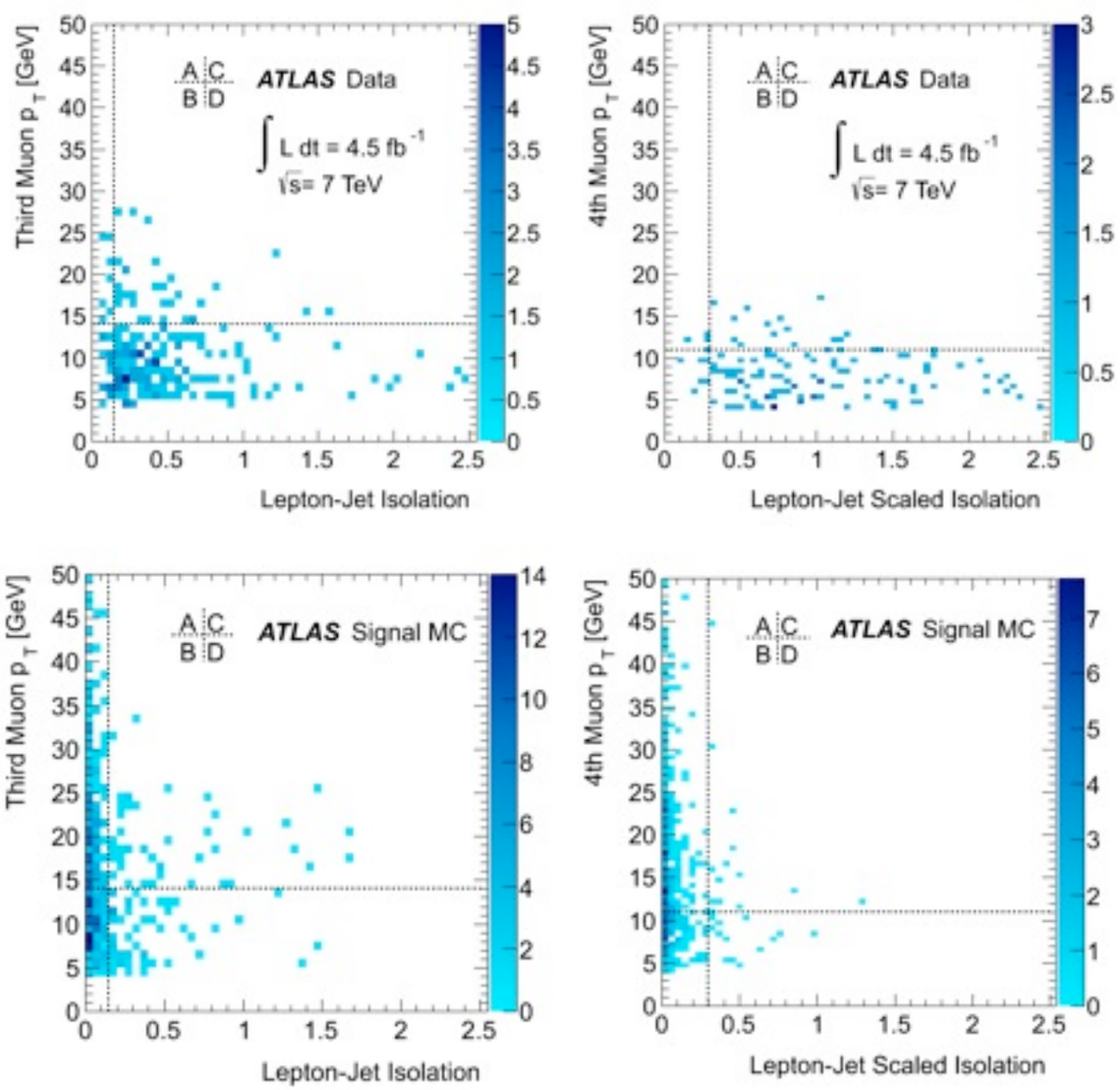
Background - decay of low mass states

Use a scaled isolation variable - sum of calorimeter deposits within $\Delta R = 0.3$ of muons, divided by muon-jet p_T

PLB 79, 599
http://arxiv.org/abs/1212.5409

$\sqrt{s}$ = 7 TeV, 5 fb^{-1}

Single muon-jet | Double muon-jet



Signal region - A

	Electron LJ	1 Muon LJ	2 Muon LJ
Data	15	7	3
All background	15.2±2.7	3.0 ± 1.0	0.5 ± 0.3

SEARCHES FOR PROMPT LEPTON JETS

For a given coupling α_d and dark photon mass $m_{\gamma D}$, limits on cross-section times branching ratio range between 0.017 - 1.2

- Electron observed limits agree well with expectation
- Muon channels are within 2σ of SM expectations

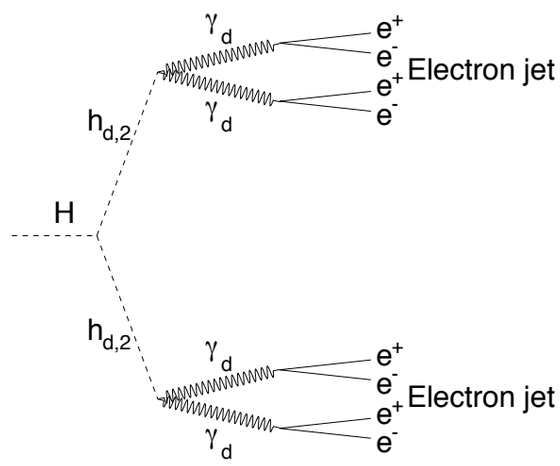
Signal Parameters		Electron LJ	1 Muon LJ	2 Muon LJ
α_d	m_{γ_D} [MeV]	Obs (Exp) pb	Obs (Exp) pb	Obs (Exp) pb
0.0	150	0.082 (0.082)	-	-
0.0	300	0.11 (0.11)	0.060 (0.035)	0.017 (0.011)
0.0	500	0.20 (0.21)	0.15 (0.090)	0.019 (0.012)
0.10	150	0.096 (0.10)	-	-
0.10	300	0.37 (0.37)	0.064 (0.036)	0.018 (0.011)
0.10	500	0.39 (0.39)	0.053 (0.035)	0.018 (0.011)
0.30	150	0.11 (0.11)	-	-
0.30	300	0.40 (0.40)	0.099 (0.055)	0.020 (0.012)
0.30	500	1.2 (1.2)	0.066 (0.043)	0.022 (0.015)

PLB 79, 599
http://arxiv.org/abs/1212.5409

W+Prompt Electron-Jets

Associated Higgs production: pp⟶WH

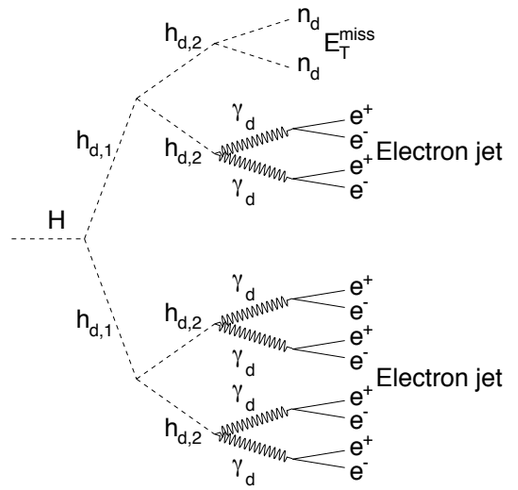
- Higgs decay to electron-jets and weakly interacting neutral particles in a two- or three-step cascade
- Hidden sector particles - dark photon γ_d, neutral stable scalar n_d, hidden scalars h_d
- γ_d can kinematically mix with the stable scalar n_d



2-step cascade

Signal Characteristics:

- Distinct two-jet topology
- Usually 4 electrons per jet



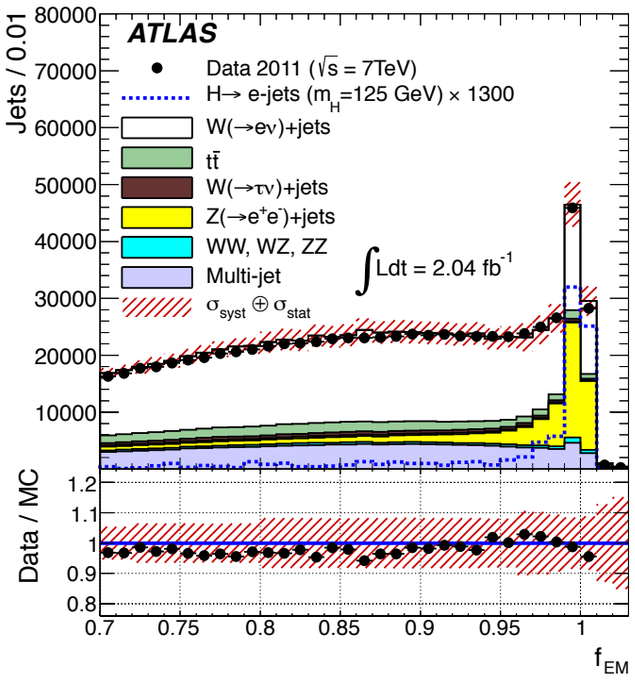
3-step cascade

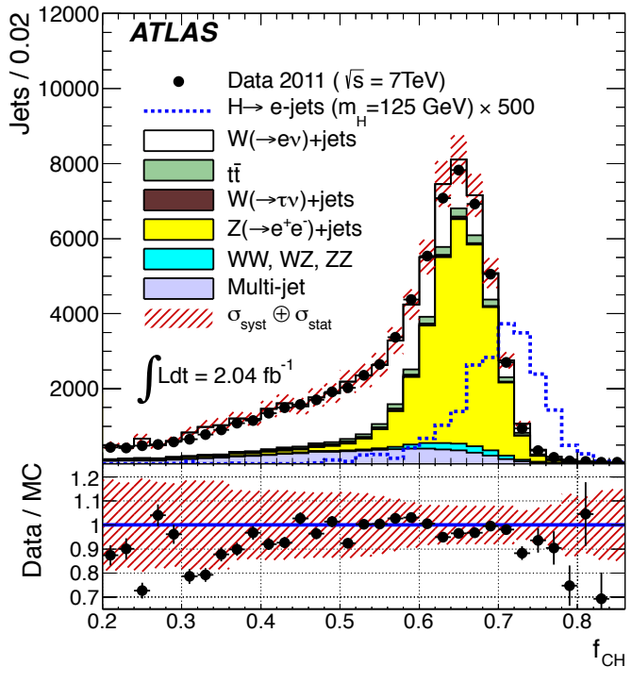
W+Prompt Electron-Jets

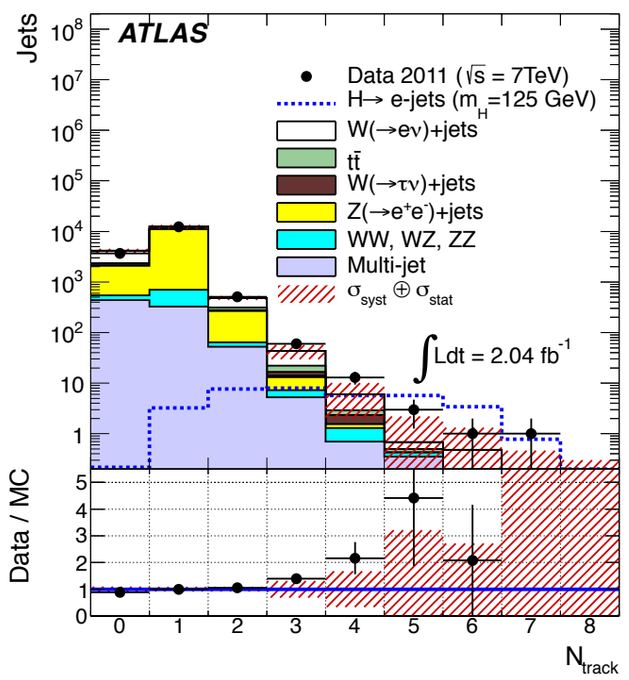
Event selection - W+electron-jet pair

- W decays to eν, μν considered
- Electron-jet constituent electrons too closely collimated for standard reconstruction algorithms
- Use discriminating variables:
  - Jet EM fraction
  - Fraction of hits with high energy deposition
  - Jet charged particle fraction

Background - Dominated by associated production of W with hadronic jets







NJP 15, 043009
http://arxiv.org/abs/1302.4403

W+Prompt Electron-Jets

$\sqrt{s}$ = 7 TeV, 2.04 fb^{-1}

m_H = 100, 125,140 GeV, $m_{\gamma d}$ = 100, 200 MeV

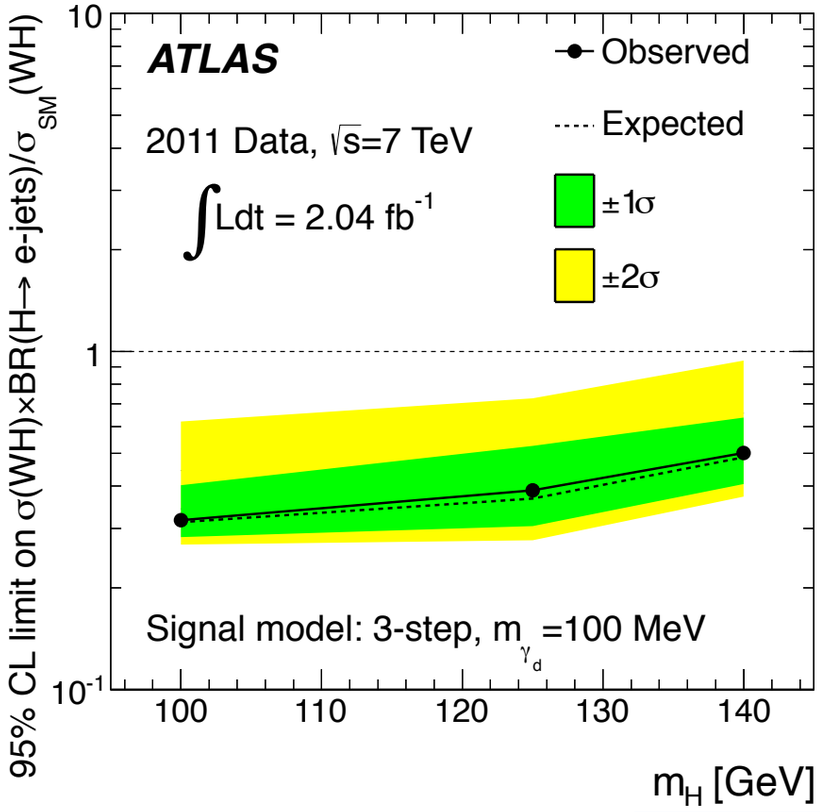
Limits set on signal strength:

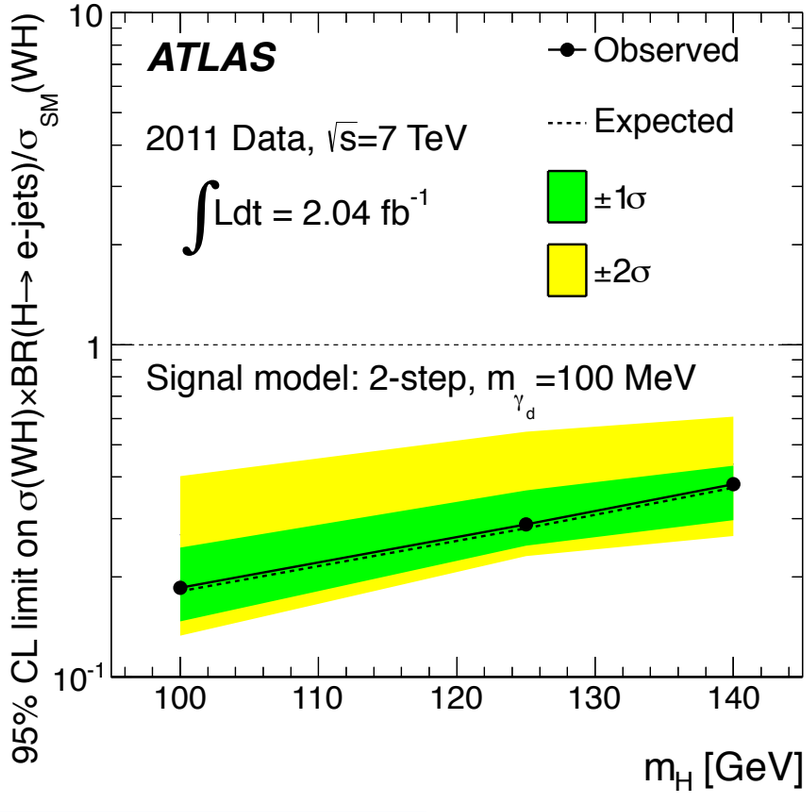
$\sigma(WH) \times BR(H \rightarrow \text{electron jets}) / \sigma_{SM}(WH)$

m_H - 125 GeV

Model	m_{γ_d} (MeV)	Observed	Expected
three-step	100	0.39	0.37
three-step	200	0.45	0.44
two-step	100	0.29	0.28
two-step	200	0.24	0.24

Higgs boson branching ratios to electron-jets are excluded between 24% and 45% for m_H = 125 GeV at 95% confidence level





NJP 15, 043009
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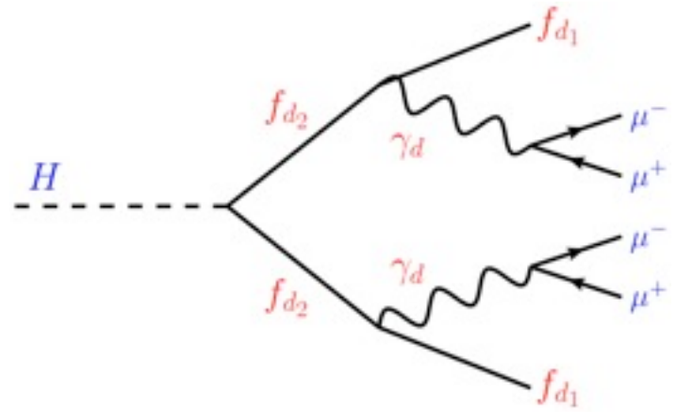
DISPLACED MUON-JETS

Model used:

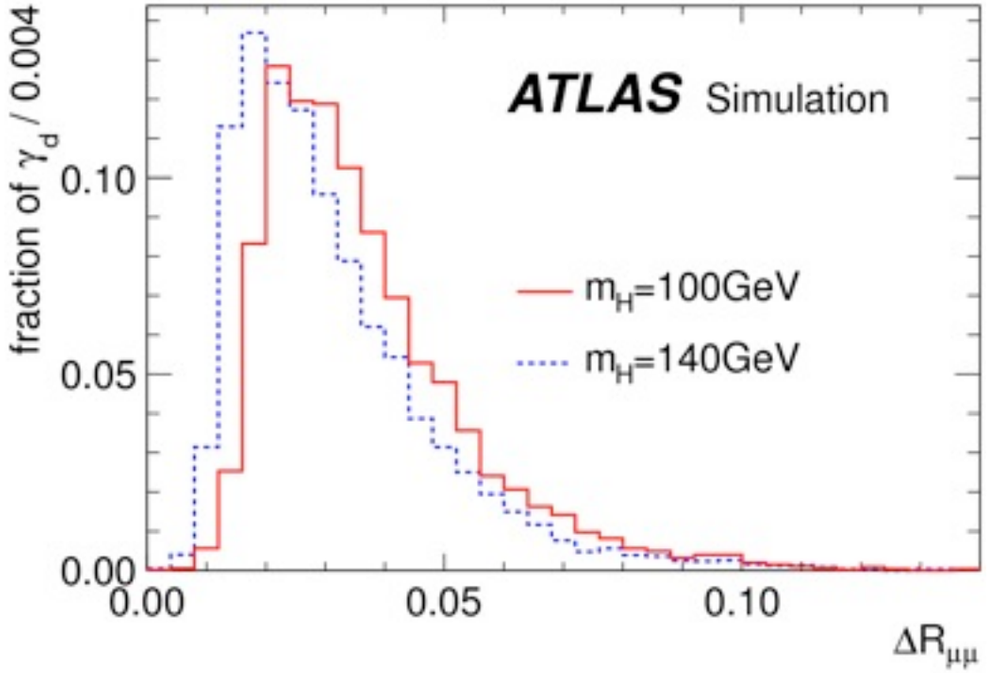
Higgs decays to hidden sector

Hidden sector particles decay to collimated muon pairs



Signal Kinematics:

- Hidden sector particles produced back-to-back in ϕ
- γ_d are highly boosted, leading to highly collimated muon-jets
- ΔR between muons usually < 0.1



PLB 721, 32
http://arxiv.org/abs/1210.0435

DISPLACED MUON-JETS

Muon-jet Reconstruction:

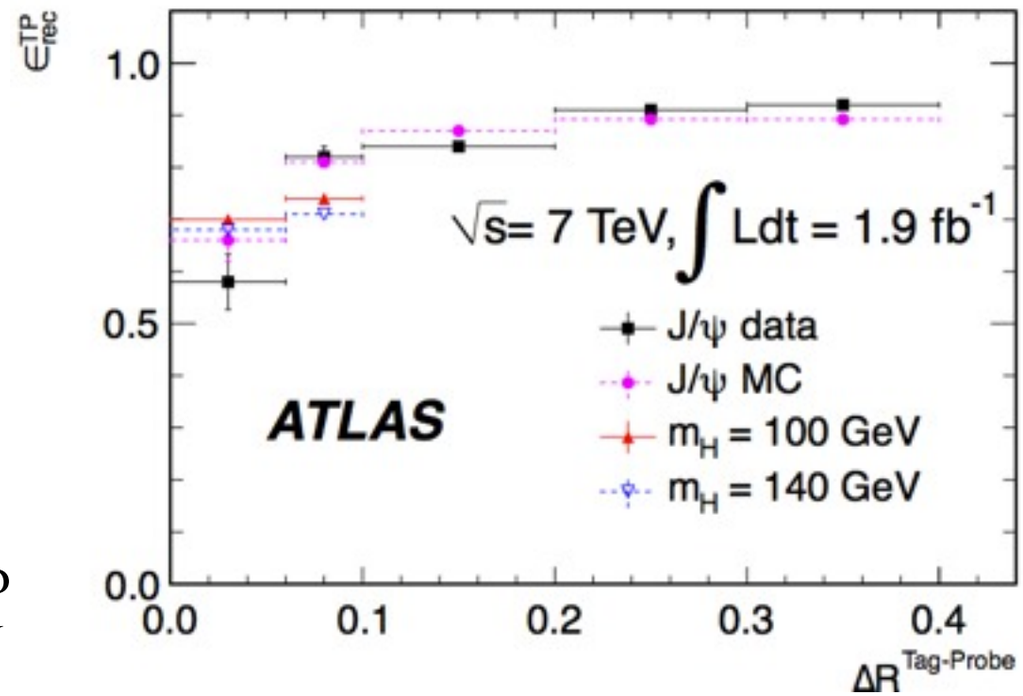
Created from muon spectrometer (MS) tracks, using a clustering algorithm ($\Delta R = 0.2$)

Calorimeter isolation around muon-jet direction required

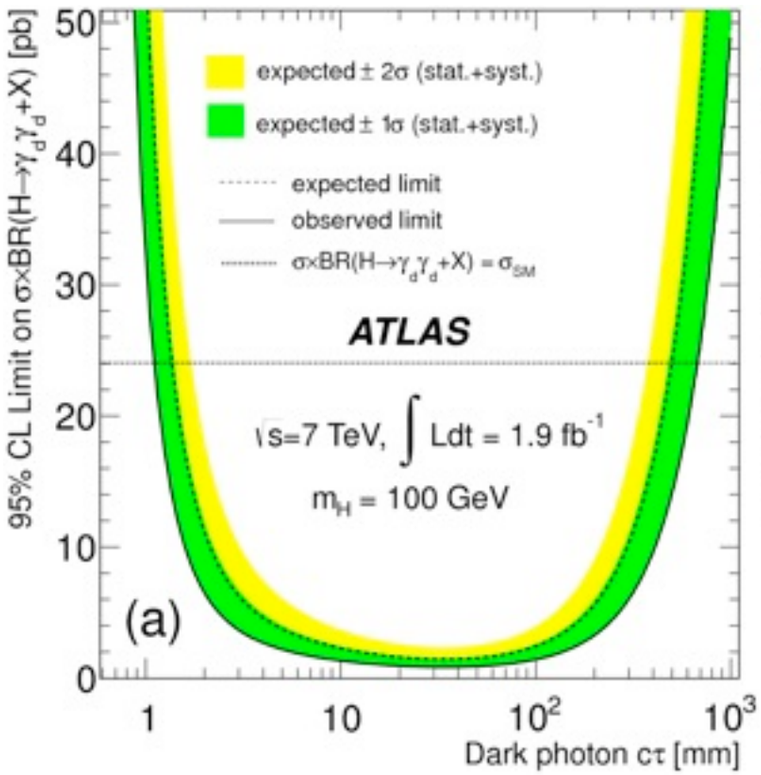
Constituent muon tracks displaced from the IP

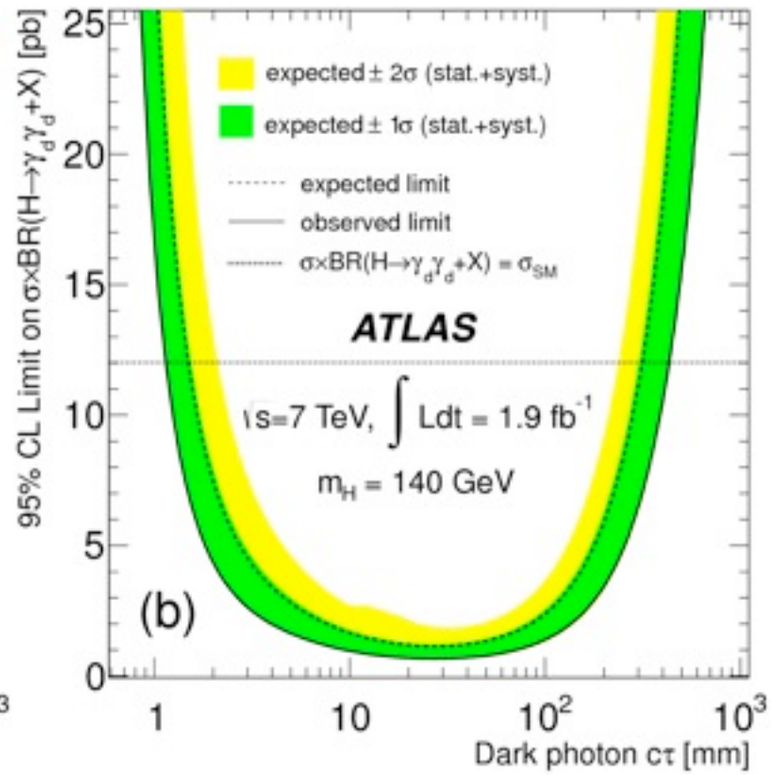
$|\Delta\phi| \geq 2$ between muon-jets

$\sqrt{s}$ = 7 TeV, 1.9 fb^{-1}



Limits are set on the cross-section time branching ratio for $H\rightarrow\gamma_d\gamma_d$, given $BR(\gamma_d\rightarrow\mu\mu)$=45% and $m_{\gamma d}$=0.4 GeV





Assuming SM production rate for 140 GeV Higgs boson, BR $(H\rightarrow\gamma_d\gamma_d)<10\%$, at 95% CL, for 7 mm $\leq c\tau \leq$ 82mm

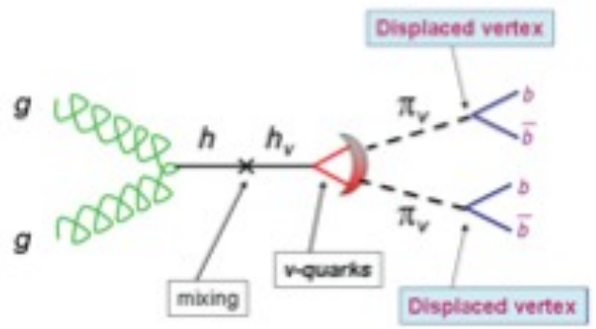
PLB 721, 32
http://arxiv.org/abs/1210.0435

DISPLACED VERTICES

A hidden sector with light particles is appended to the SM, with a mediator/ mediators between the two

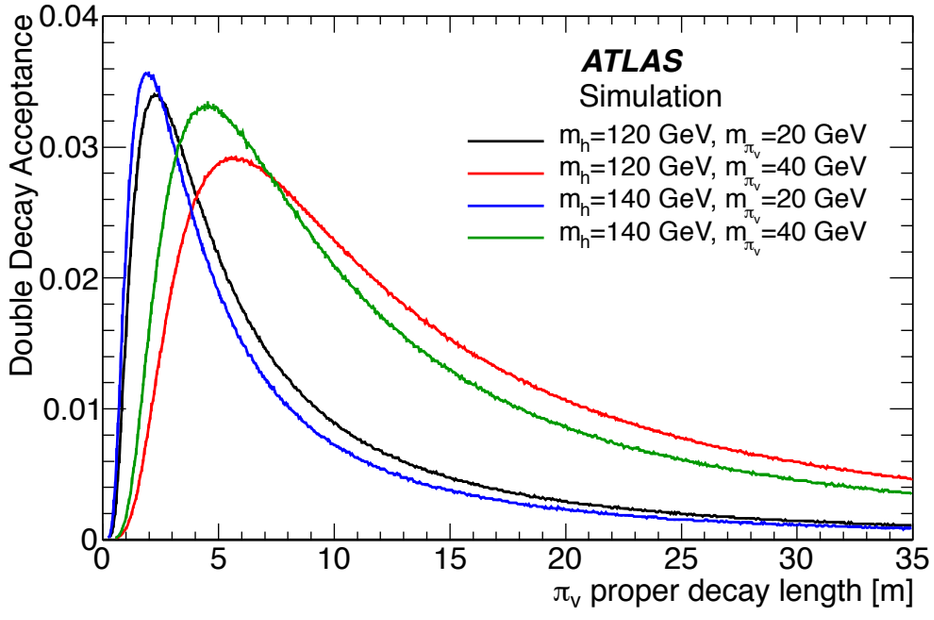
Higgs as a mediator:

- Decays to two v-quarks
- Light mass of the Higgs - two v-pions in the final state
  - v-pions decay mainly to b, anti-b pairs
  - v-pions decay throughout the detector volume



Final state characteristics:

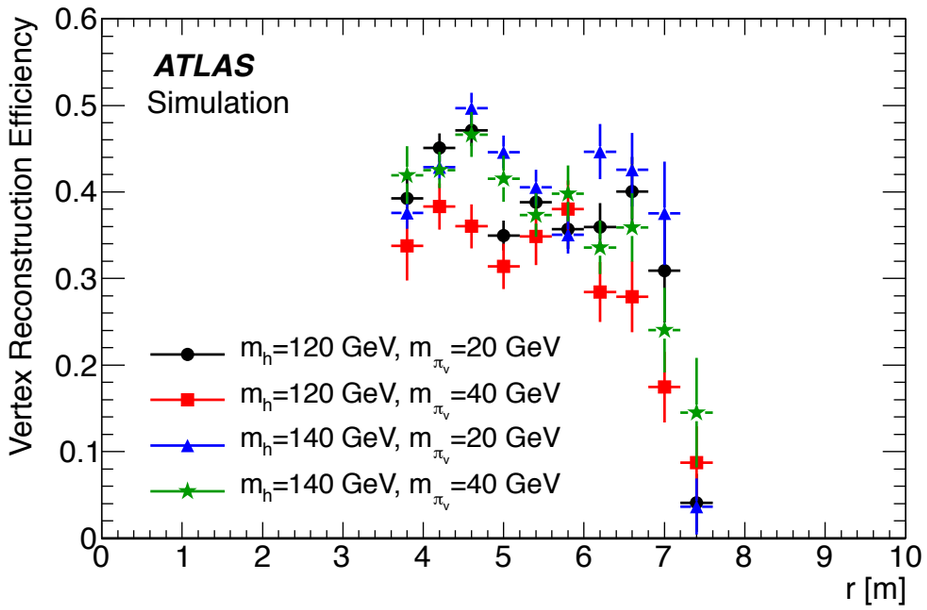
- Decays can be highly displaced
- Look for two vertices in the muon spectrometer



Displaced Vertices

Displaced vertex reconstruction:

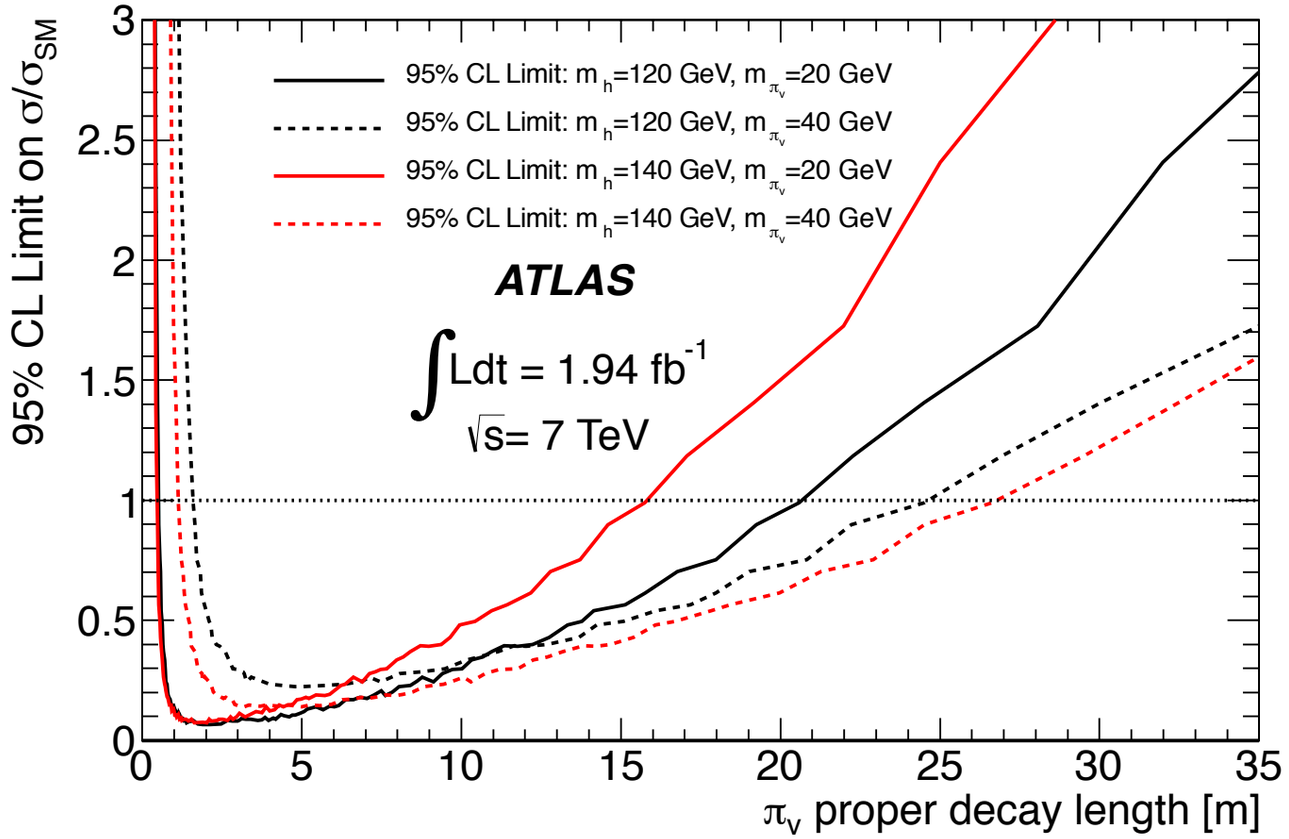
- Use the two separated multilayers in the MDT to create tracklets
- Group tracklets using a cone algorithm ($\Delta R = 0.6$)
- Vertices must have at least 3 tracklets
- Vertices must be well-isolated from high p_T tracks and jets



In the absence of an excess of events, broad ranges of v-pion proper decay lengths have been excluded:

m_{h^0} (GeV)	m_{π_v} (GeV)	Excluded Region
120	20	$0.50 < c\tau < 20.65$ m
120	40	$1.60 < c\tau < 24.65$ m
140	20	$0.45 < c\tau < 15.8$ m
140	40	$1.10 < c\tau < 26.75$ m

PRL 108 251801
http://arxiv.org/abs/1203.1303



SEARCH FOR MULTI-CHARGED PARTICLES

$\sqrt{s}$ = 7 TeV, 4.4 fb^{-1}

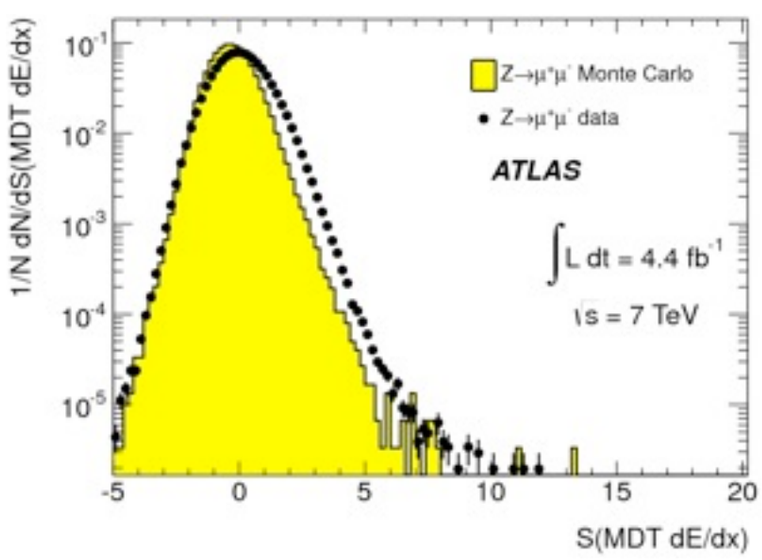
Long-lived particles with |q|>e

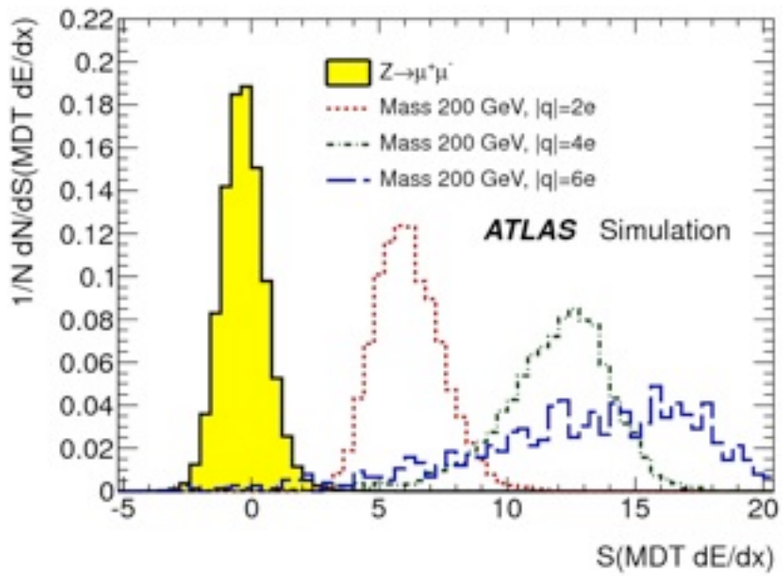
- Could have implications for dark matter formation
- Highly ionizing signature
- Walking Technicolor, AC models

Ionization estimators:

- Specific energy loss dE/dx
- dE/dx significance:

$$S(dE/dx) = \frac{dE/dx_{track} - < dE/dx_{\mu} >}{\sigma(dE/dx_{\mu})}$$





Monitored Drift Tubes (MDT) dE/dx:

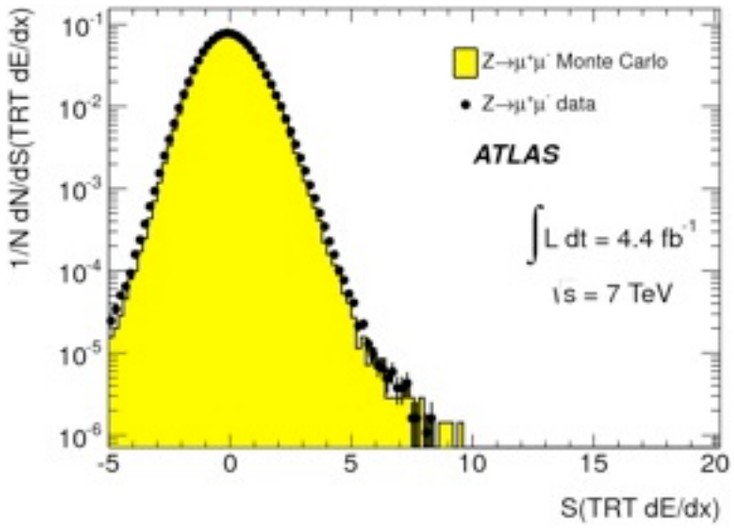
Each MDT provides signal proportional to ionization charge

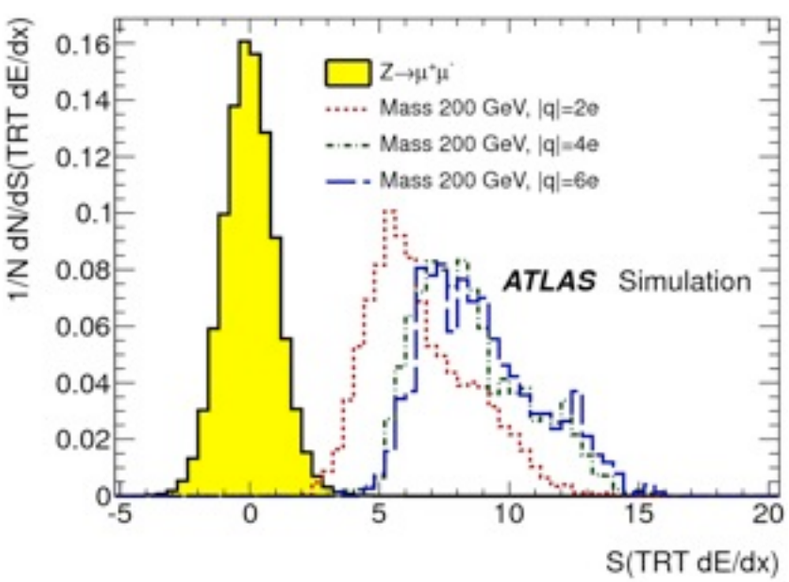
Transition Radiation Tracker (TRT) dE/dx:

Estimated by time the signal remains after a low energy deposit (200 eV) hit

Pixels dE/dx (|q| = 2e):

Measured from ionization in each pixel

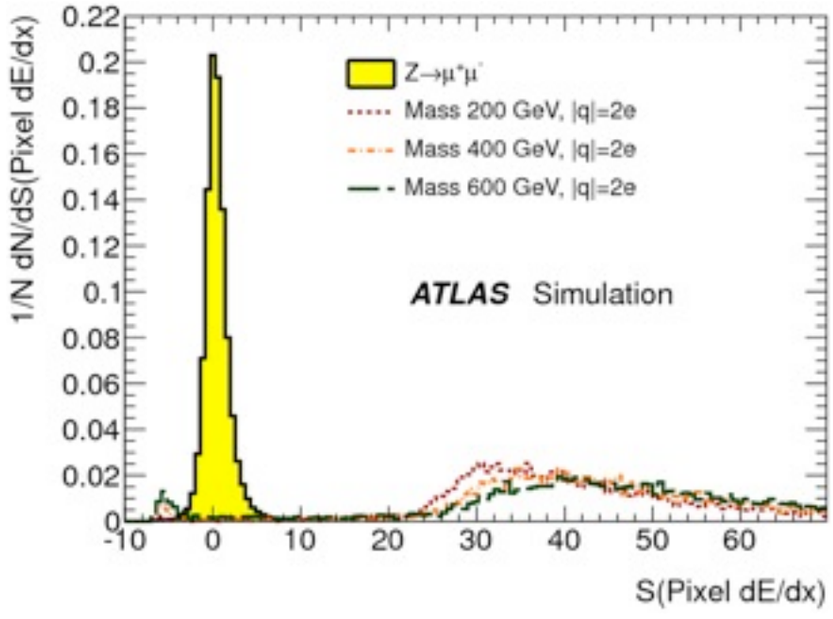




SEARCH FOR MULTI-CHARGED PARTICLES

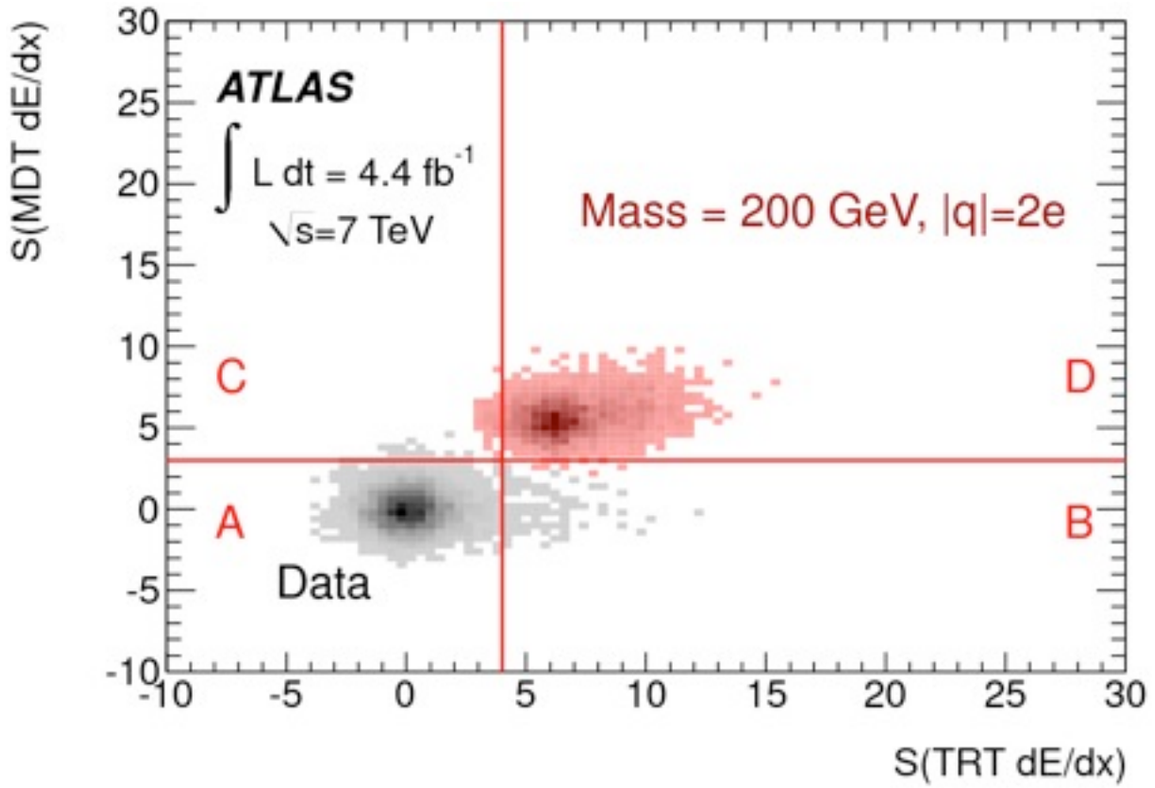
Candidate selection:

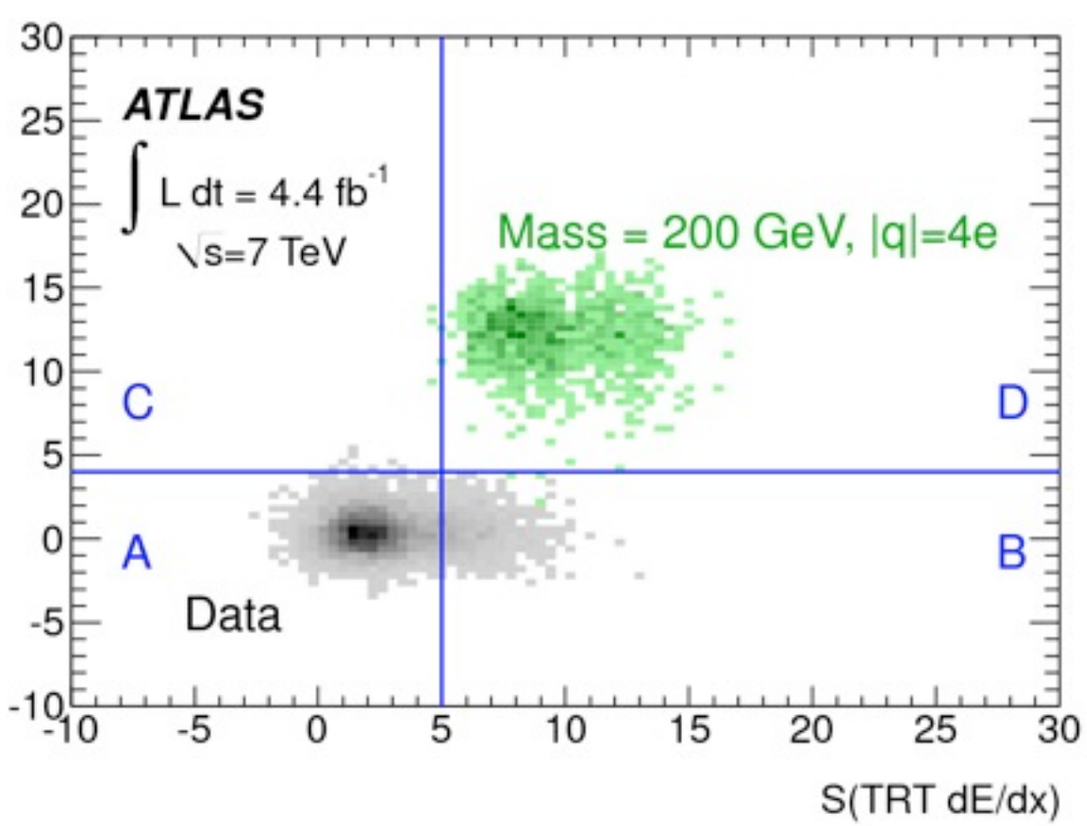
- Particles with muon system tracks - $|\eta| < 2.0$, $p_T > 20$GeV
- Pre-selection based on pixel dE/dx significance ($|q| = 2e$), fraction of hits with high energy deposits ($|q| > 2e$)



Signal regions:

- S(MDT dE/dx) > 3 and S(TRT dE/dx) > 4 for $|q| = 2e$
- S(MDT dE/dx) > 4 and S(TRT dE/dx) > 5 for $|q| > 2e$

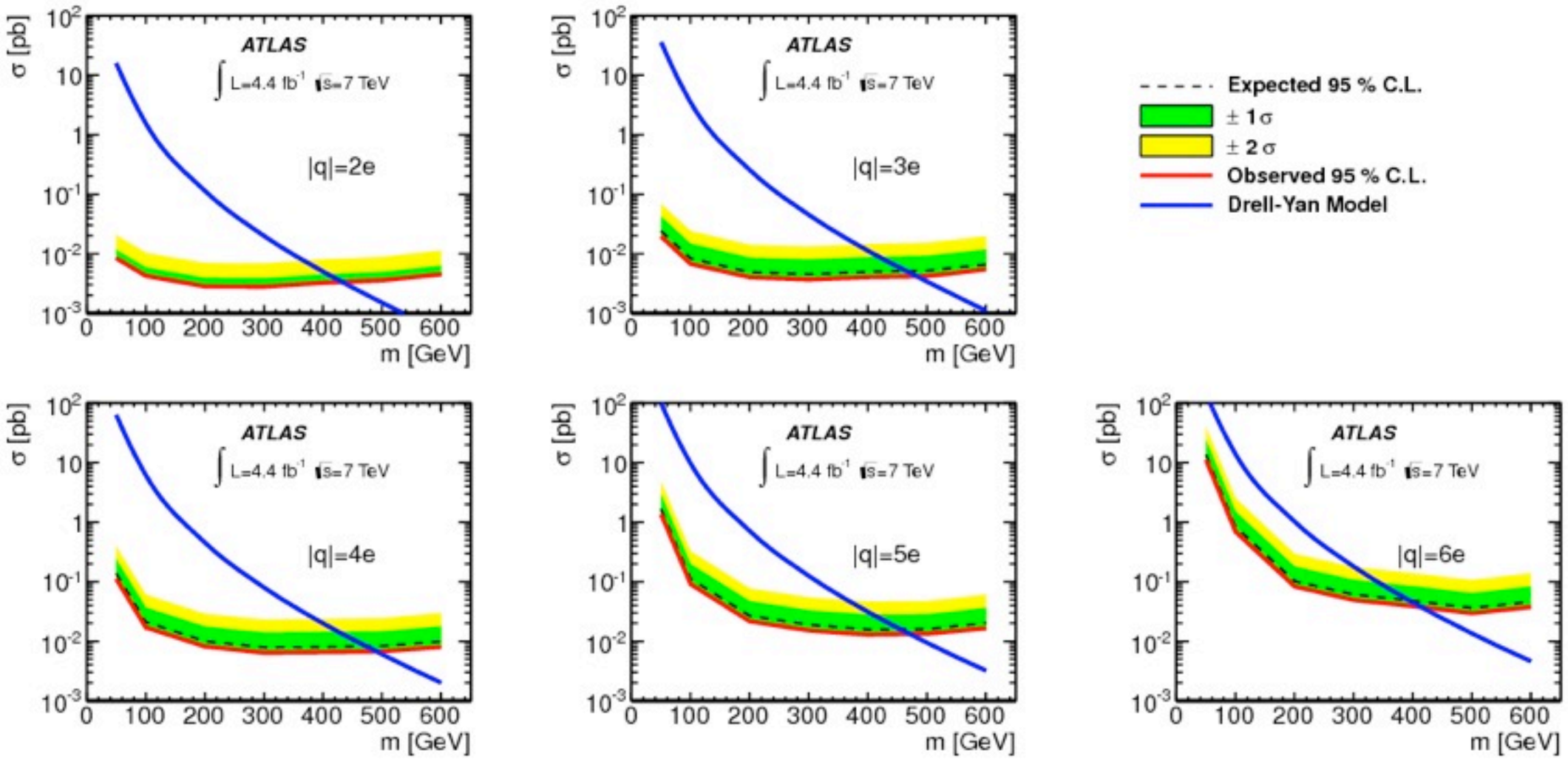




SEARCH FOR MULTI-CHARGED PARTICLES

Limits set on cross-sections as a function of mass

- Translate to mass exclusion lower limits of 50GeV to 430, 480, 490, 470, and 420 GeV respectively for charges |q|=2e, 3e, 4e, 5e, and 6e



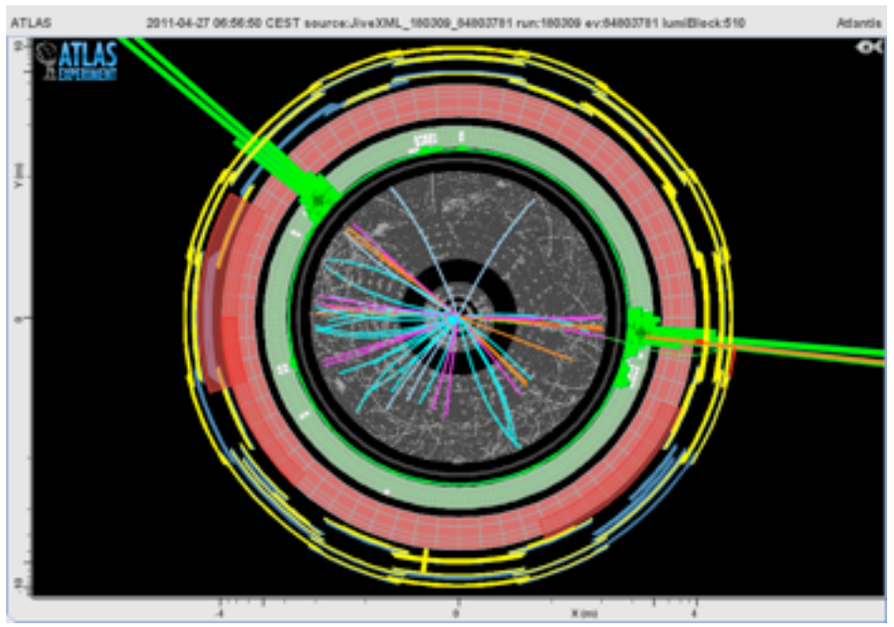
http://arxiv.org/abs/1301.5272

SUMMARY

A number of New Physics models predict the existence of long-lived particles, with interesting decay signatures

Require custom reconstruction algorithms - challenging!

These final states covers a range of theoretical models



Analyses are being updated to $\sqrt{s}$ = 8 TeV dataset, with 20 fb^{-1}

More final states being added in to searches

No new physics (yet)!

Backup

The ATLAS Detector