Searches for Magnetic Monopoles and Anomalously Charged Objects with ATLAS

SUSY 2016

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Introduction

- ATLAS searches for Beyond the Standard Model phenomenon such as magnetic monopoles, and particles with high electric charges, $|z| > 1$[1]

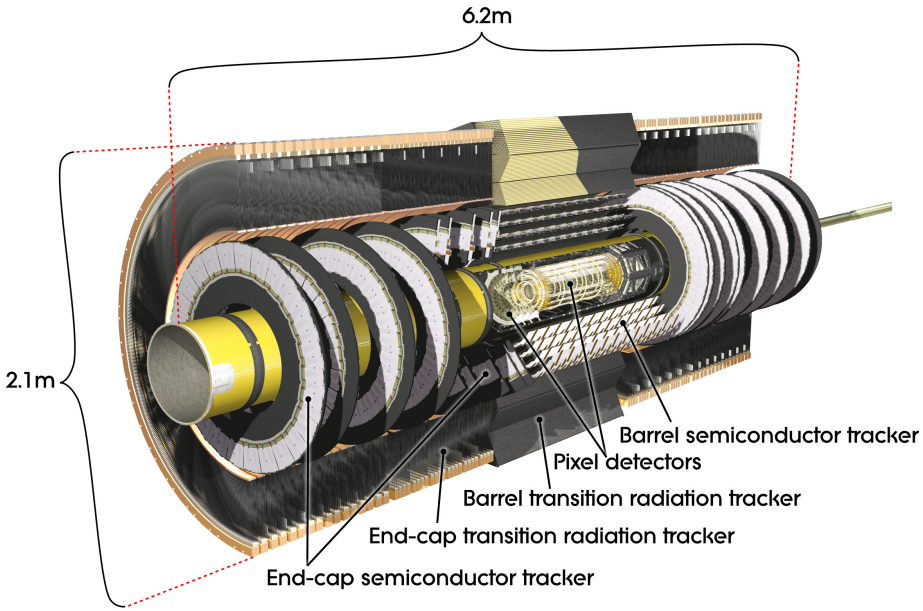
- These particles could help explain fundamental open questions:
  - charge quantisation
  - the nature of dark matter

  and can be identified as highly ionising particles (HIPs) in the ATLAS detector

- Latest results from 8 TeV pp collisions on searches for particles with magnetic and anomalous electric charge

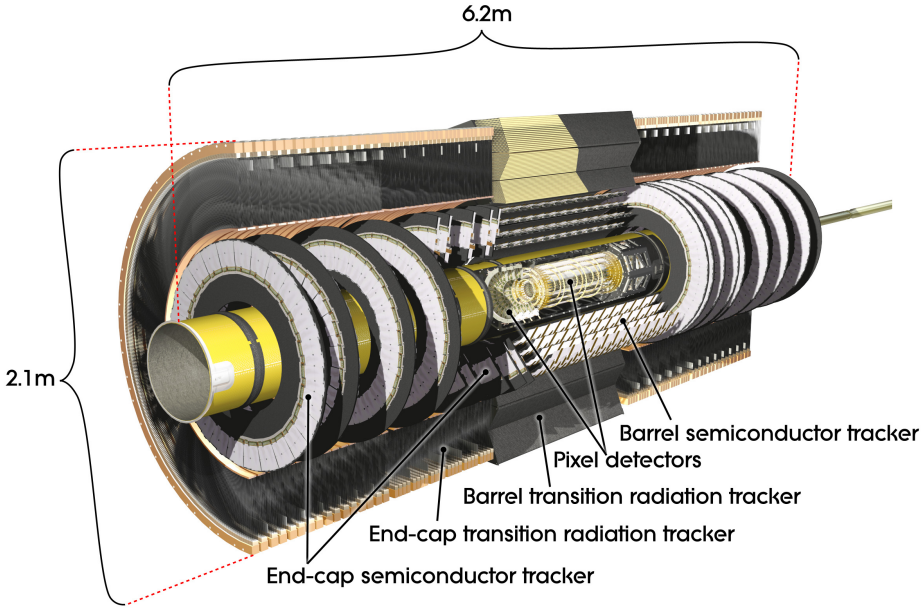
[1] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

The ATLAS inner detector



- Consists of three sub-systems: pixel, semiconductor tracker and transition radiation tracker
- Enables precise tracking of electrically charged particles

The ATLAS inner detector



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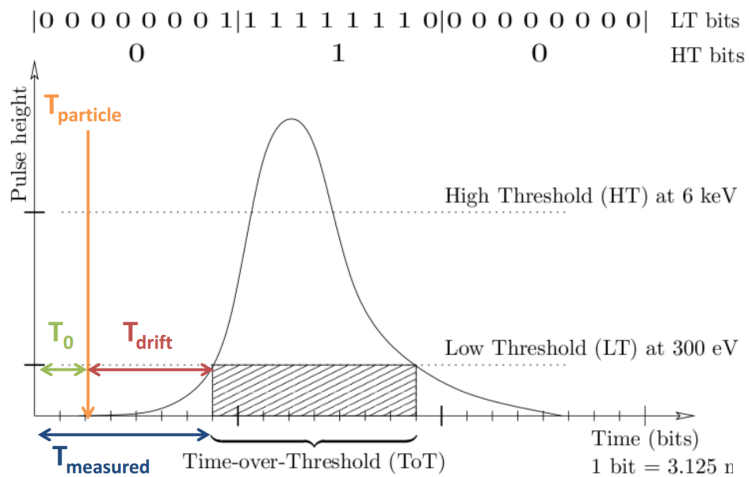
TRT readout

- Time-over-threshold measurements
- High-threshold (HT) discrimination at 6 keV



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Search for heavy long-lived multi-charged particles

Eur. Phys. J. C (2015), arXiv:1504.04188

- Searches for multi-charged ($|z|$ =2-6) particles within a mass range of 50-1000 GeV
- Several theoretical models predict such particles:
  - Almost-commutative model[2]
  - Walking techinicolor model[3]
  - Left-right symmetric model[4]
- Particles with even charge $|q| = 2ne$ could explain many dark matter experimental results[5]
- Energy loss modelled by:

$$-\frac{dE}{dx} = K\frac{Z}{A}\frac{z^2}{\beta^2}\left[\ln\frac{2m_e c^2\beta^2\gamma^2}{I} - \beta^2 - \frac{\delta}{2}\right]$$

- Defines significance of energy loss in each sub-detector as:

$$S(\mathrm{dE/dx}) = \frac{\mathrm{dE/dx_{track}} - \langle \mathrm{dE/dx_{mu}} \rangle}{\sigma(\mathrm{dE/dx_{mu}})}$$

2 J.Phys. A39 (2006) 9657, arXiv:hep-th/0509213

3 Phys.Rev.D71:051901,2005, arXiv:hep-ph/0405209

4 Phys. Rev. D 11 566 (1975)

5 Mod.Phys.Lett. A26 2823 (2011), arXiv:1111.2838

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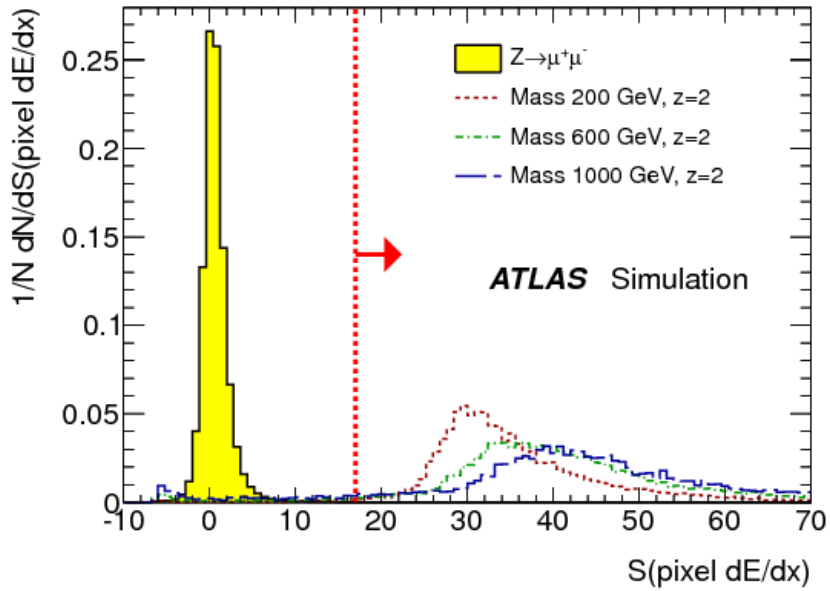
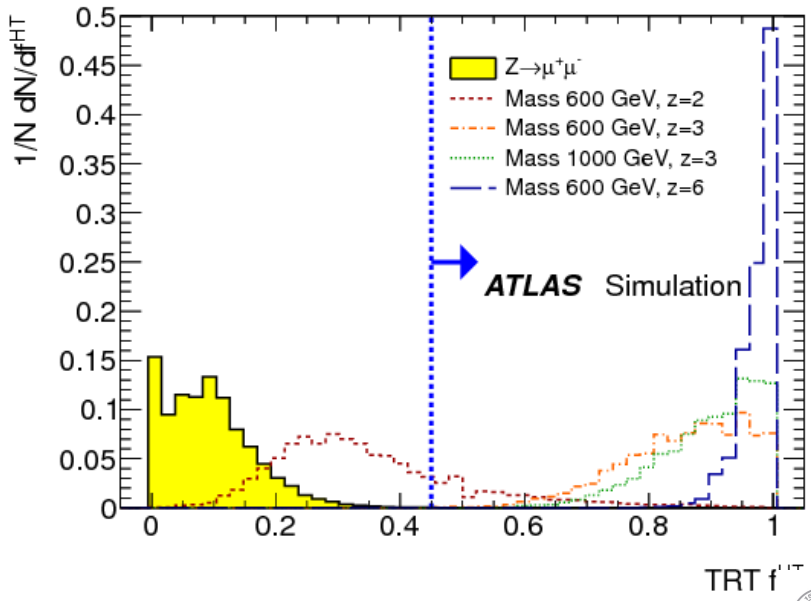
Selections of long-lived multi-charged particles

- Expected to have high ionisation coupled with muon-like signatures
- Event selections with two triggers:
  - Single-muon with $p_T/z>36$ GeV: sensitive $\beta>0.6$
  - $E_T^{Miss}>80$ GeV: recovers up to 10% of events
- Identification based on energy loss in Pixel, TRT and MDT, and track-associated fraction of TRT high-threshold hits f^{HT} on track
- Candidate track selection:
  - For $|z|=2$, high dE/dx significance in pixel is required
  - For $|z|>2$, large fraction f^{HT} is required





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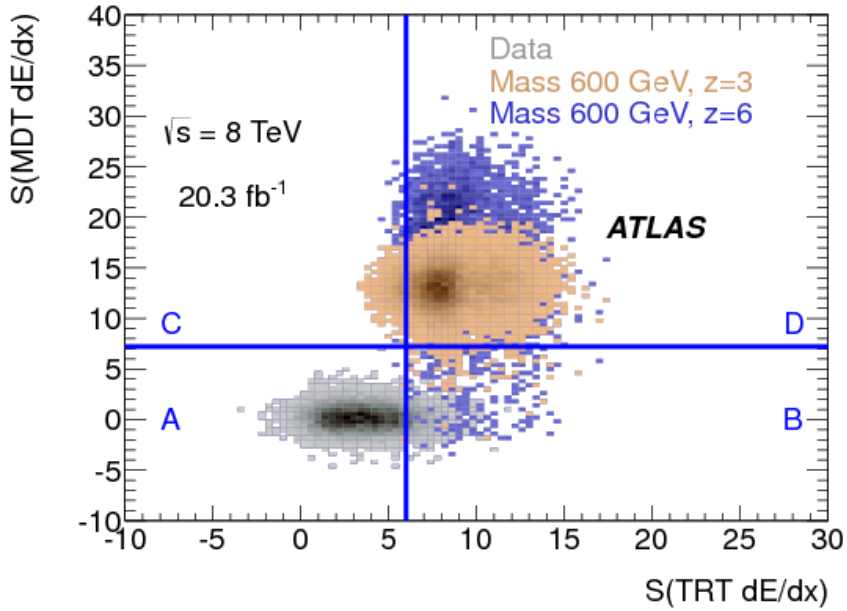
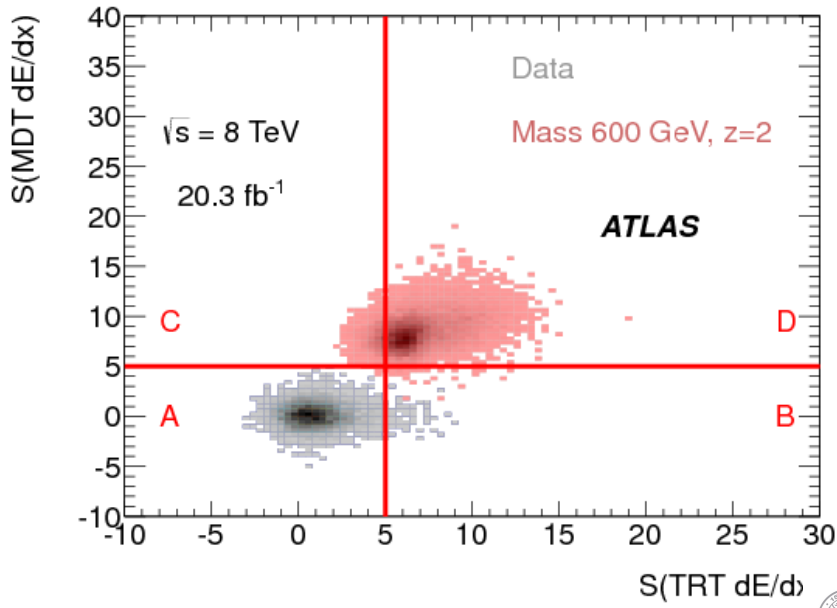
Results from long-lived multi-charged particles search

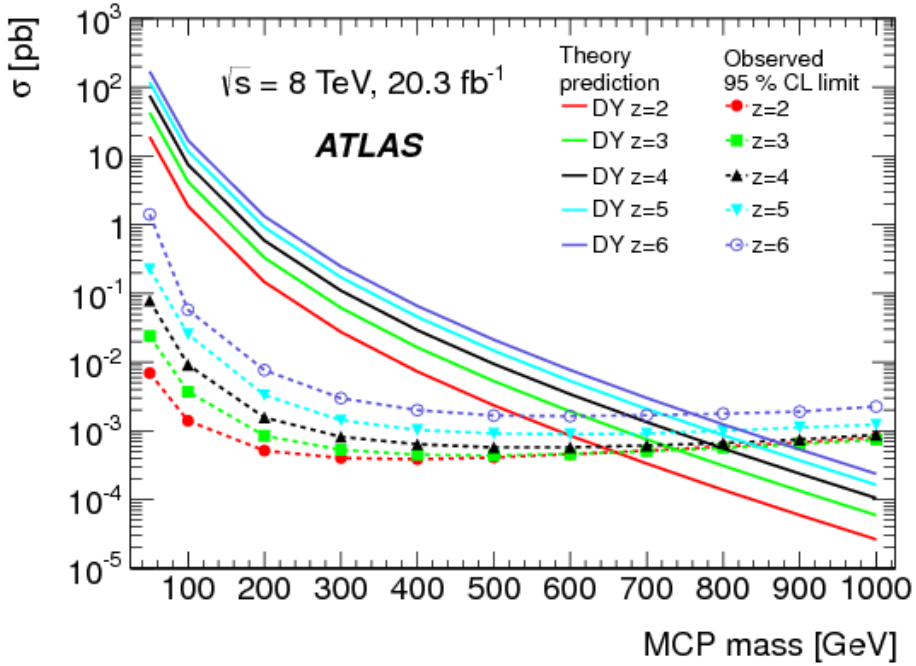
- The final discriminants are the significance of dE/dx in the TRT and MDT
- Background estimation using the data-driven ABCD method
- Zero candidates observed in the signal region





Results from long-lived multi-charged particles search

- The CLs method was used to set upper cross-section limits on Drell-Yan pair-produced multi-charged particles at 95% confidence level
- Array of mass exclusions obtained for wide ranges of tested masses



Mass exclusion regions [GeV]				
$\|z\|$=2	$\|z\|$=3	$\|z\|$=4	$\|z\|$=5	$\|z\|$=6
50-660	50-740	50-780	50-785	50-760

Searches for magnetic monopoles and highly electrically charged objects

Phys. Rev. D 93, 052009 (2016)

- **Magnetic monopoles**: Stable particles with only magnetic charge, g, postulated in several theories:
  - By Dirac[6] as a natural consquence of electric charge quantisation

    $$g = ng_D; g_D = \frac{e}{2\alpha} \approx 68.5e$$

  - Schwinger predicts[7], $g = 2ng_D$
  - GUT models by t'Hooft[8] and Polyakov[9] masses 10^{11}-10^{13} GeV
  - Electroweak models[10] masses of 4-7 TeV and g=2g_D
- Energy loss (-dE/dx) modelled by:

  $$K\frac{Z}{A}g^2\left[\ln\frac{2m_e c^2\beta^2\gamma^2}{I} + \frac{k(g)}{2} - \frac{1}{2} - \frac{\delta}{2} - B(g)\right]$$

- Magnetic charges probed: $0.5 \leq |g| \leq 2.0 g_D$

- **Highly electrically charged objects**:
  - Q-balls
  - Dyons
  - Strange quark matter
  - Micro black hole remnants
- Charges probed: $10 < |z| < 60$

No assumption on particle spin: could be fermions or bosons

6 Proc. Roy. Soc. Lond. A133 (1931) 60–72

7 Phys. Rev. 144 (1966)

8 Nucl. Phys. B79 (1974) 276–284

9 JETP Lett. 20 (1974) 194–195

10 Phys. Lett. B391 (1997) 360–365

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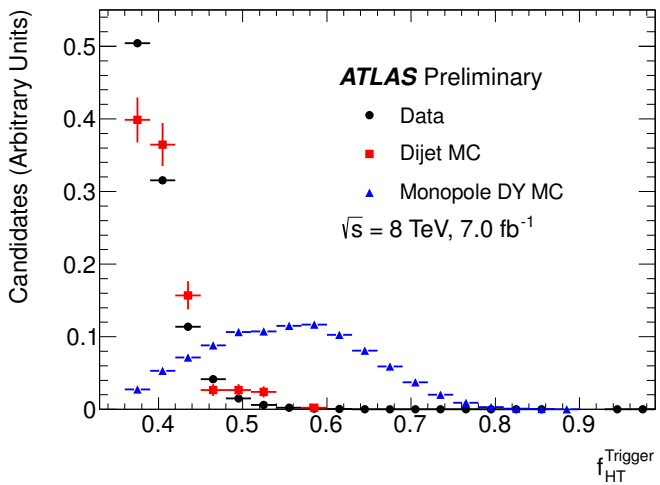
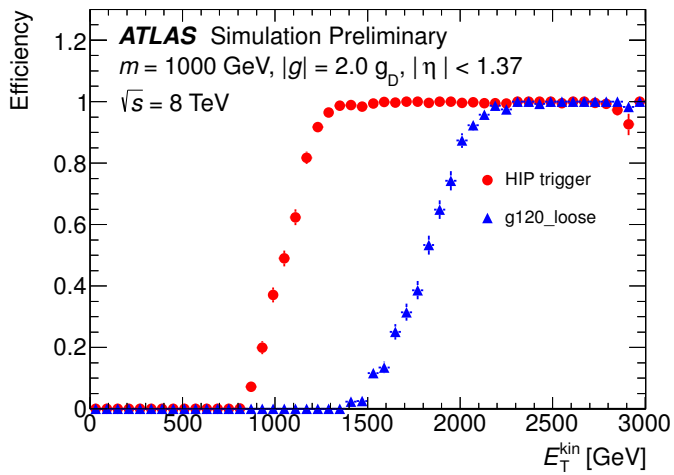
Highly ionising particle (HIP) trigger

- ATLAS trigger system: three tiered
- Specialised Level-2 HIP trigger
- Level-1: Hardware triggers select events with $E_T \geq 18$ GeV in the electromagnetic calorimeter (ECAL) and $E_T < 1$ GeV in hadronic calorimeter
- Level-2: Selections based on ECAL associated hits in a wedge of $\Delta\phi = \pm 0.015$; Discriminants: fraction and number of HT TRT hits

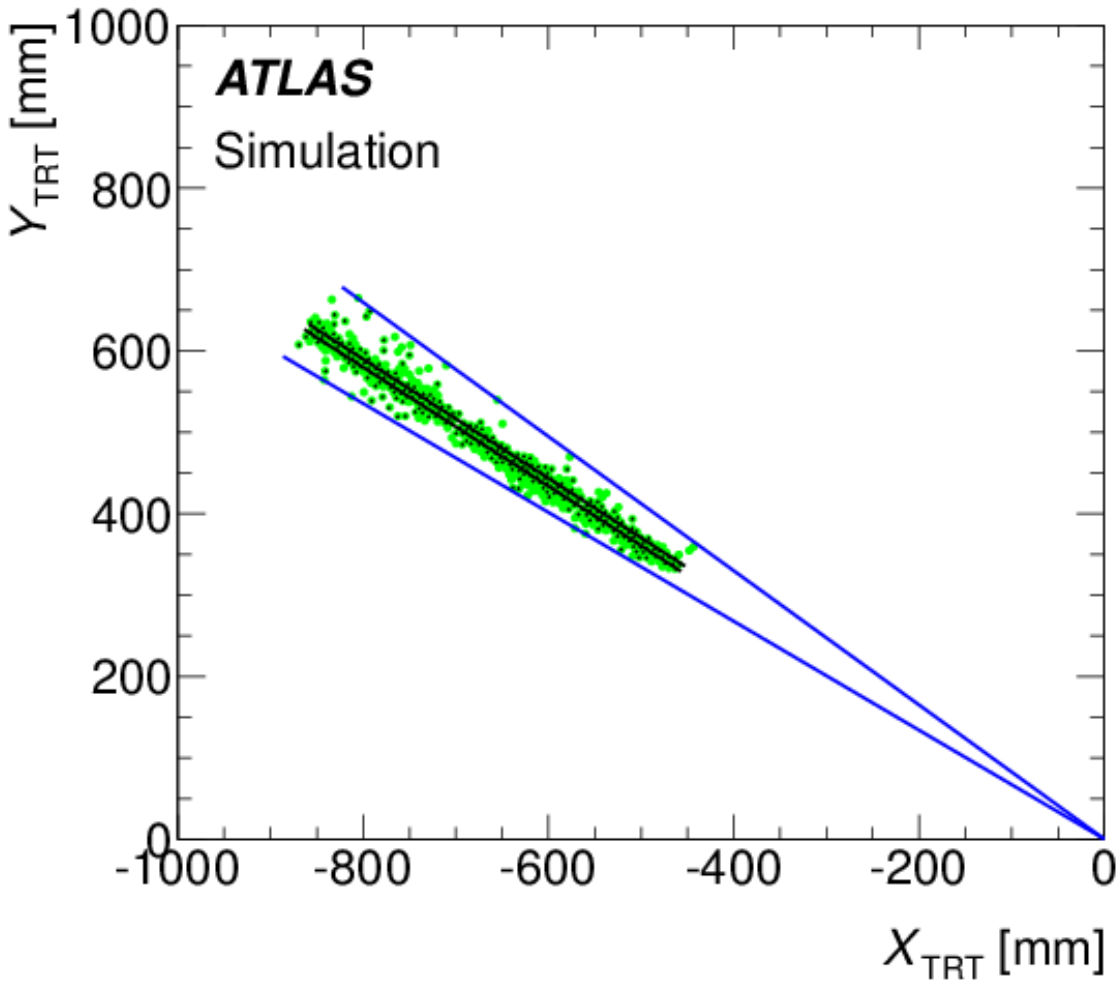
- Collected luminosity: 7.0 fb^{-1}
- HIP trigger efficiency turn-on determined by Level-1 trigger acceptance
- ATLAS sensitive to monopoles with $|g| > 1.0 g_D$ for the first time





Signatures of HIPs in ATLAS

High fraction of TRT HT hits f_{HT}



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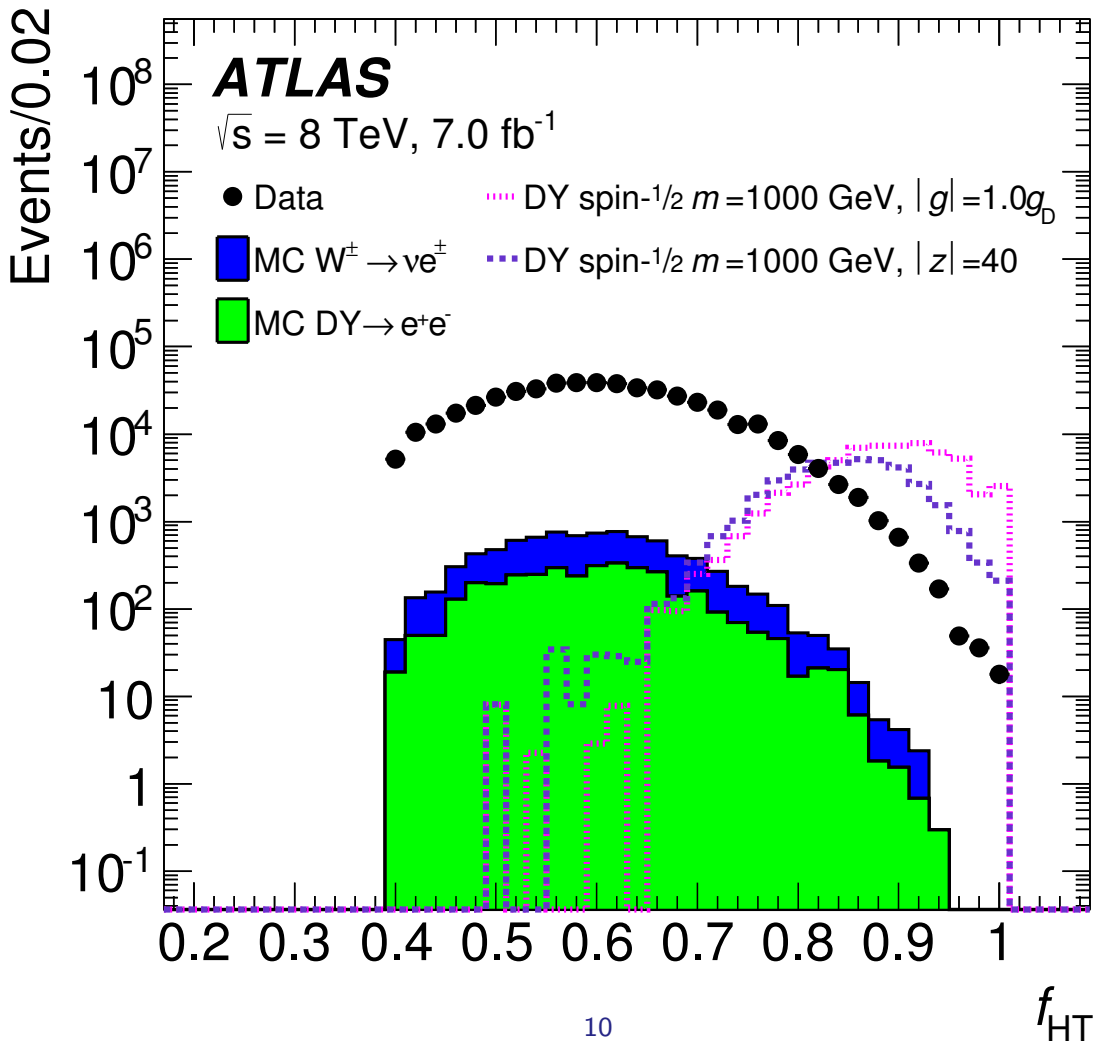
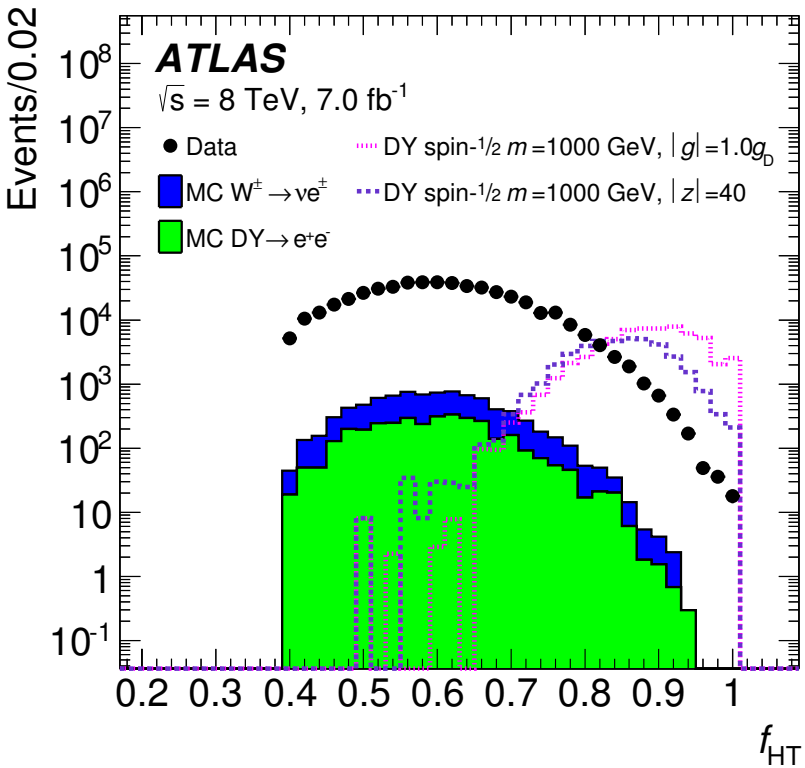


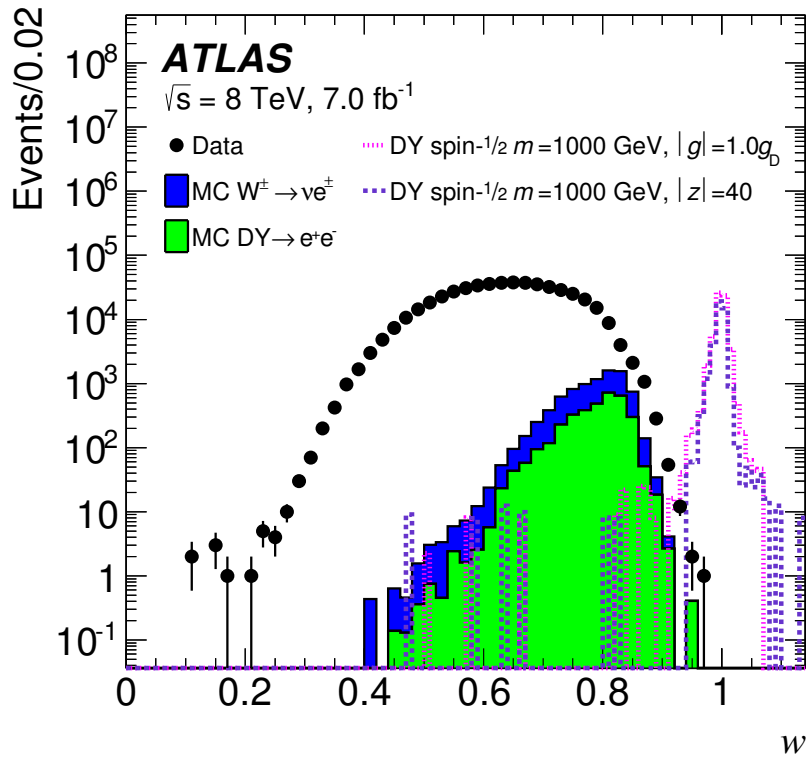
Signatures of HIPs in ATLAS

High fraction of TRT HT hits f_{HT}

Lateral dispersion, $w = \frac{\sum_{layers} w_i}{N_{layers}}$

$$w_i = \frac{\sum_{cells\ \ in\ \ layer\ \ i} E_j}{E_i^{total}}$$





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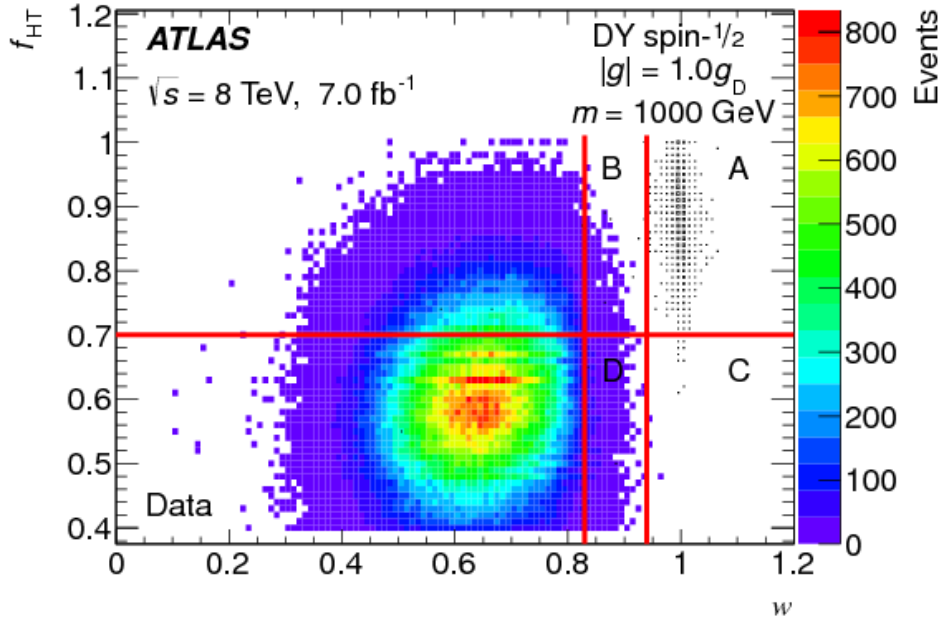
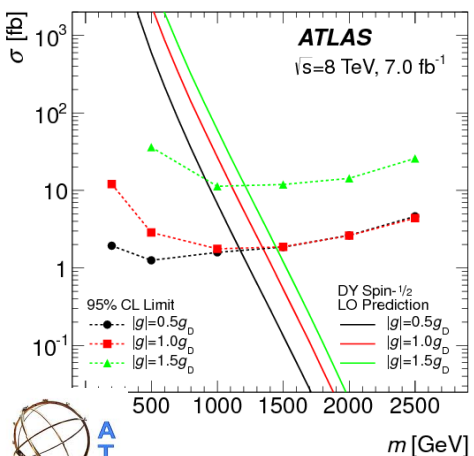
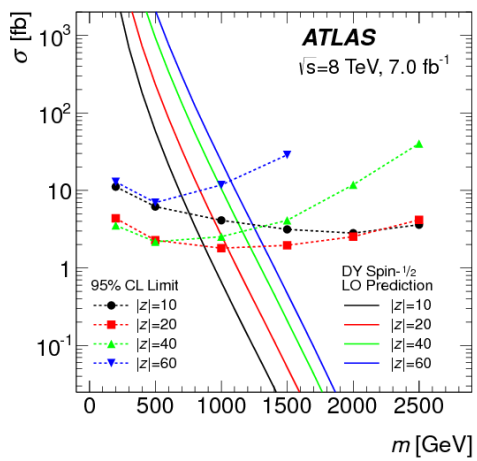
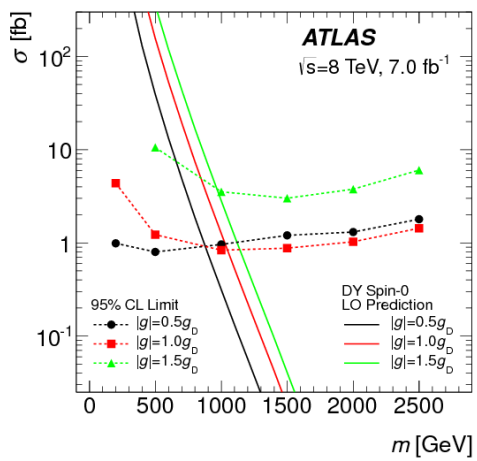
Results

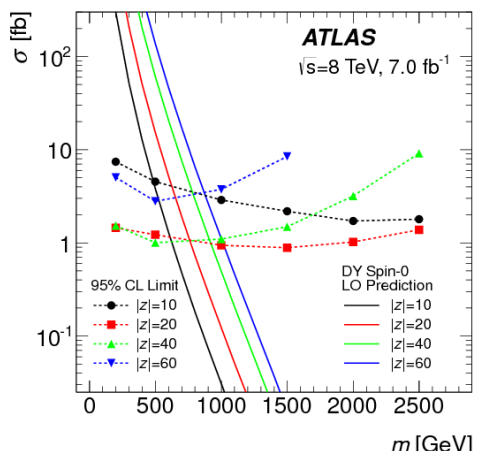
- Background estimation: ABCD method
- No observed candidates in the signal region
- Model independent upper cross-section limits set to 0.5 fb for HIPs in fiducial regions of high and uniform event selection efficiency
- Assuming pair production model: upper cross-section limits and lower mass limits set at 95% confidence level
- Spin-0 results extrapolated from spin-$\frac{1}{2}$











Conclusions

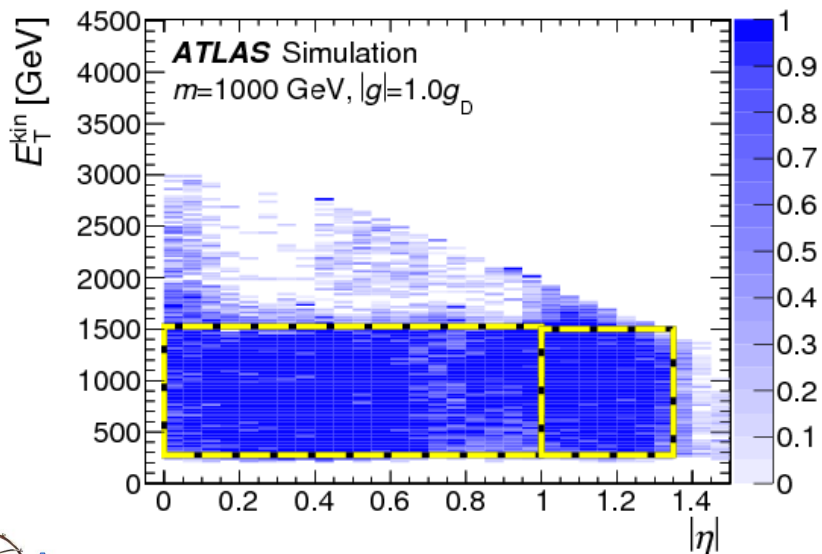
- ATLAS performed searches for magnetic monopoles and particles with electric charges greater than 1 using the LHC *pp* collusion data from Run-1
- Both analyses exploit the inner detector features of identifying expected high-ionisation signatures
- Searches set upper cross-section limits and lower mass limits in the absence of any observed events
- Discovery of such particles will show evidence of physics beyond the Standard Model and are actively being searched even in the Run-2 data

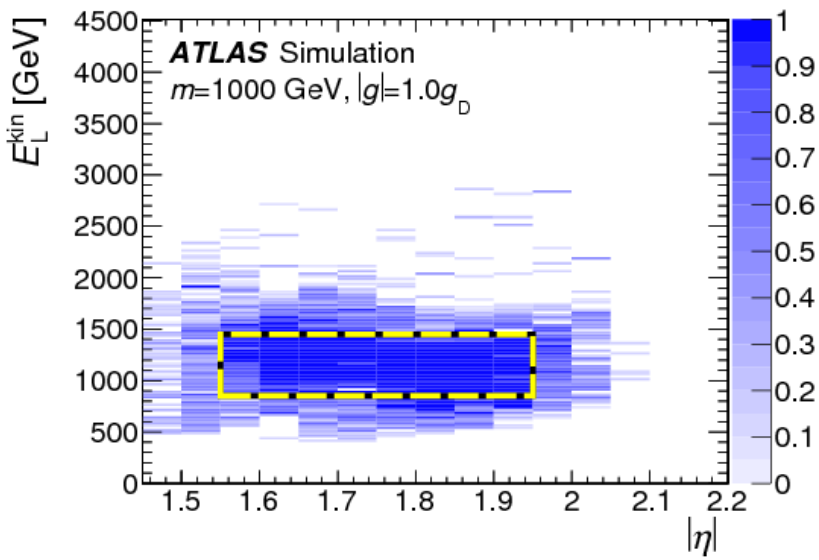
BACKUP

Monopole & HECOs: Model-independent searches

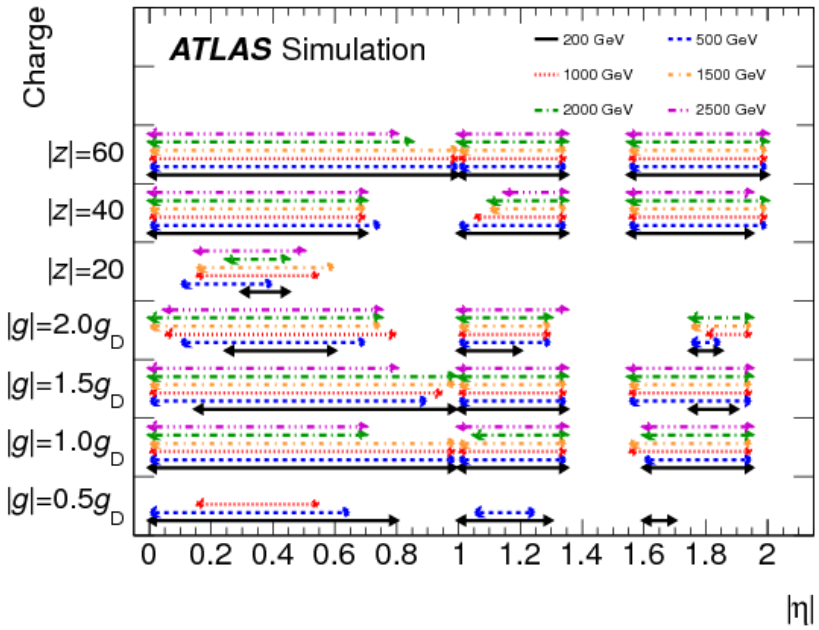
Non-pertubative nature of HIP coupling to the photon results in uncertainty in production models

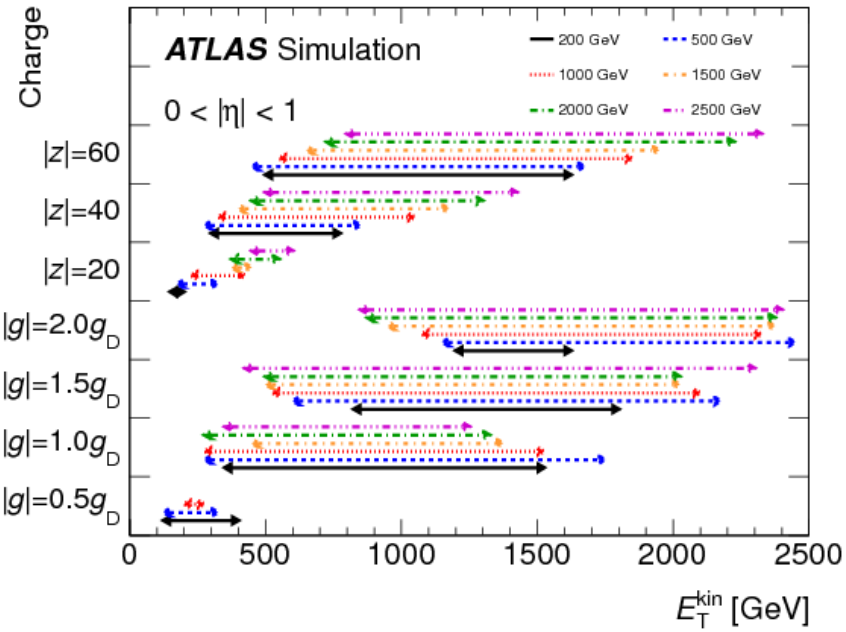
- HIP acceptance for specific mass and charge depends largely on kinetic energy and material passed
- Efficiency maps in E_{kin} and η were used to find regions where the average efficiency taken over all bins $\epsilon_{avg} > 0.9$
- Limits were set with respect to these regions, which can be combined with the kinematics of a specific model

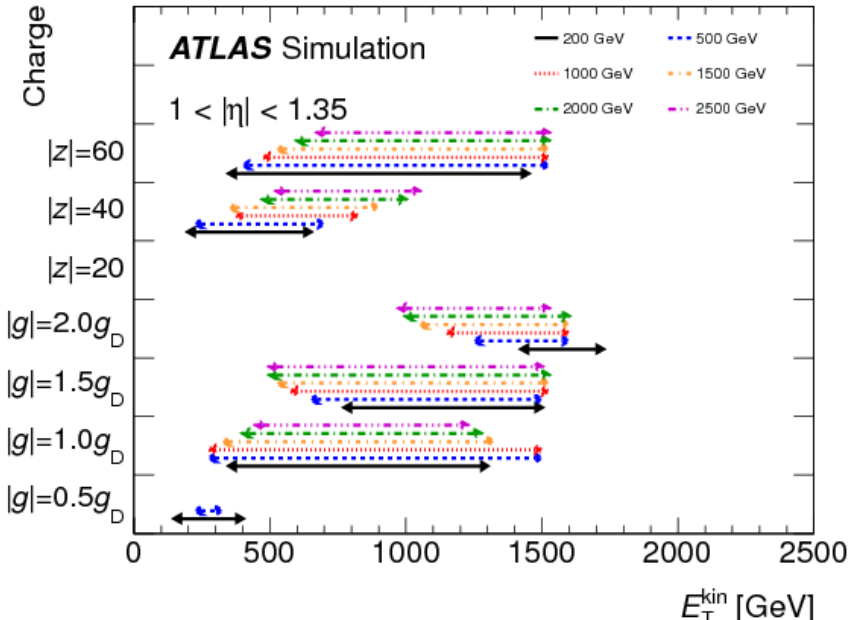


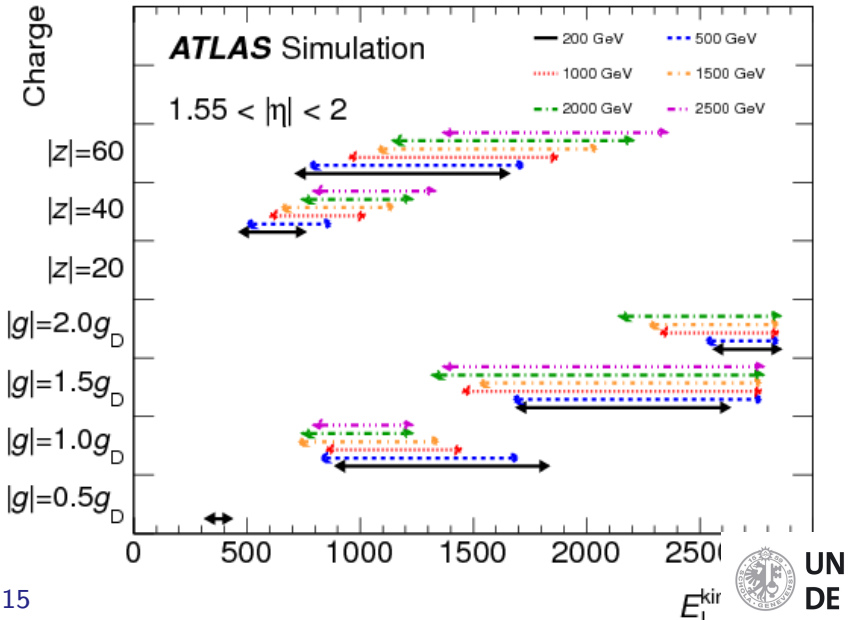


Monopoles & HECOs: Fiducial regions









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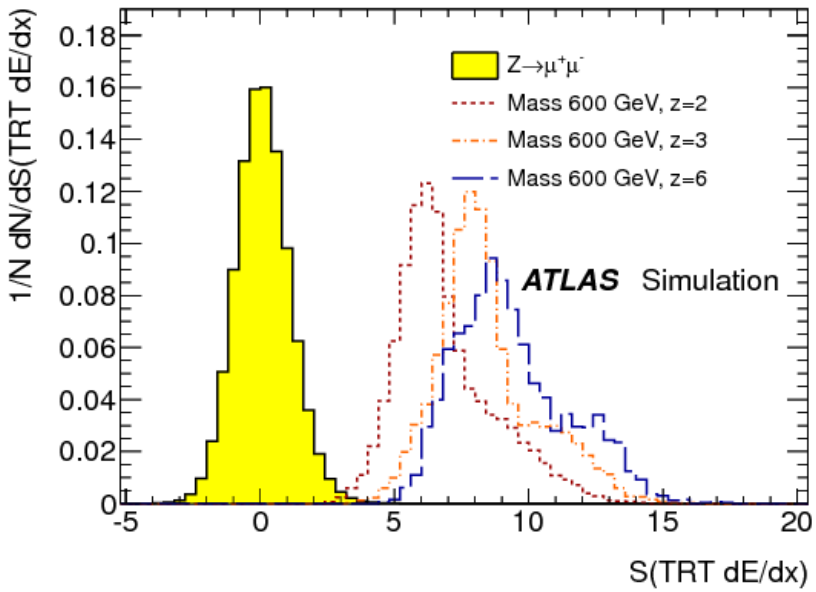
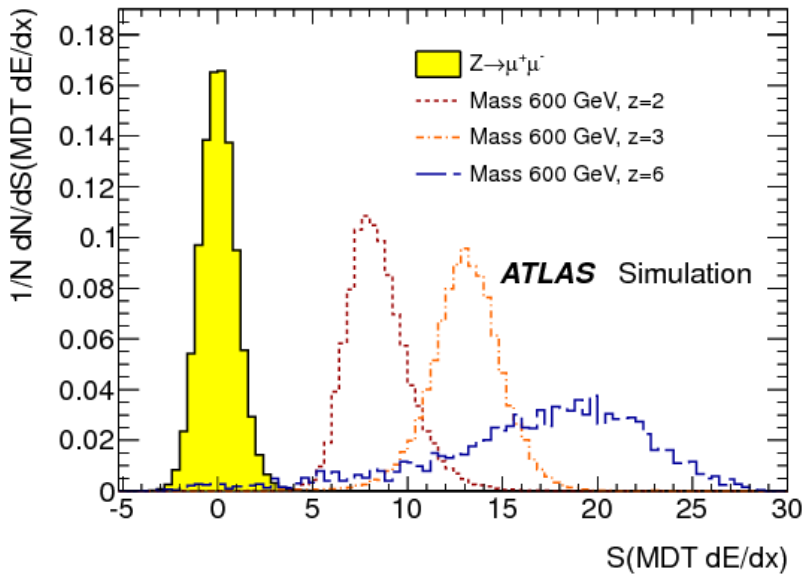
MCP: Significance of energy loss





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MCP: Analysis selections

Event selection criteria

		Trigger and event selection	Candidate track selection	Tight and final selections ($z = 2$)	Tight and final selections ($z \geq 3$)
Requirements	Single-muon trigger case	≥ 1 trigger tight muon with $p_{\mathrm{T}}/z > 36$ GeV ≥ 1 reconstructed muon with $p_{\mathrm{T}}/z > 75$ GeV	Any muon with: $N_{\mathrm{MDT\ hits}} \geq 7$ $p_{\mathrm{T}}/z > 40$ GeV $\lvert\eta\rvert < 2.0$ $N_{\mathrm{SCT\ hits}} \geq 6$ $N_{\mathrm{TRT\ hits}} \geq 10$ $\lvert d_0\rvert < 1.5$ mm $\lvert z_0 \sin\theta\rvert < 1.5$ mm no other tracks within $\Delta R < 0.01$	Event passing preselection having a muon with: $S(\text{pixel } \mathrm{d}E/\mathrm{d}x) > 17$ $S(\text{MDT } \mathrm{d}E/\mathrm{d}x) > 5$ $S(\text{TRT } \mathrm{d}E/\mathrm{d}x) > 5$	Event passing preselection having a muon with: $f^{\mathrm{HT}} > 0.45$ $S(\text{MDT } \mathrm{d}E/\mathrm{d}x) > 7.2$ $S(\text{TRT } \mathrm{d}E/\mathrm{d}x) > 6$
	$E_{\mathrm{T}}^{\mathrm{miss}}$ trigger case	trigger $E_{\mathrm{T}}^{\mathrm{miss}} > 80$ GeV ≥ 1 reconstructed muon with $p_{\mathrm{T}}/z > 60$ GeV	Any muon with: $N_{\mathrm{MDT\ hits}} \geq 7$ $p_{\mathrm{T}}/z > 30$ GeV $\lvert\eta\rvert < 2.0$ $N_{\mathrm{SCT\ hits}} \geq 6$ $N_{\mathrm{TRT\ hits}} \geq 10$ $\lvert d_0\rvert < 1.5$ mm $\lvert z_0 \sin\theta\rvert < 1.5$ mm no other tracks within $\Delta R < 0.01$		

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MCP: Efficiency trends