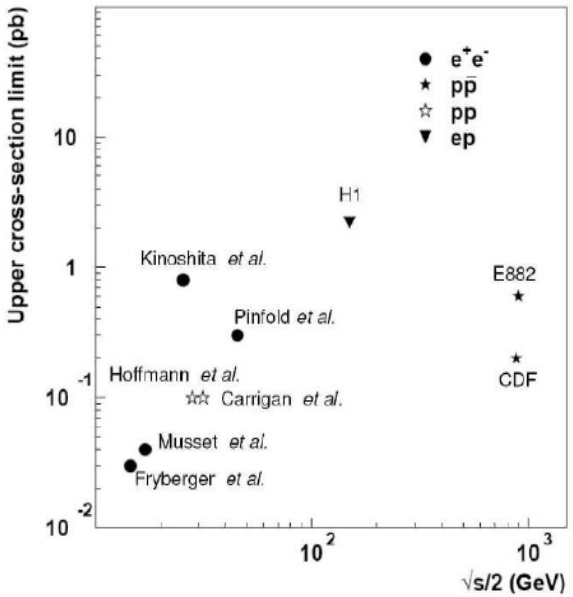
Long Lived Highly Ionizing Particles

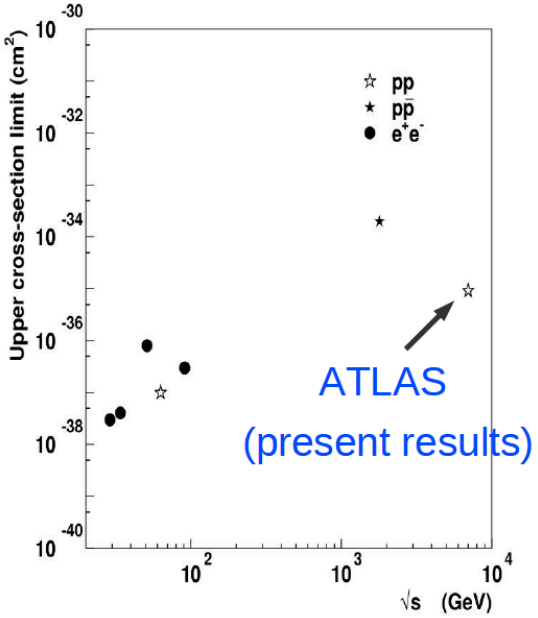
Ana Firan
Southern Methodist University
on behalf of ATLAS collaboration

SMU

Phenomenology Symposium, 9-11 May 2011

Motivation





M. Fairbairn, et al., Phys. Rep. 438 (1) (2007)
http://arxiv.org/pdf/hep-ph/0611040

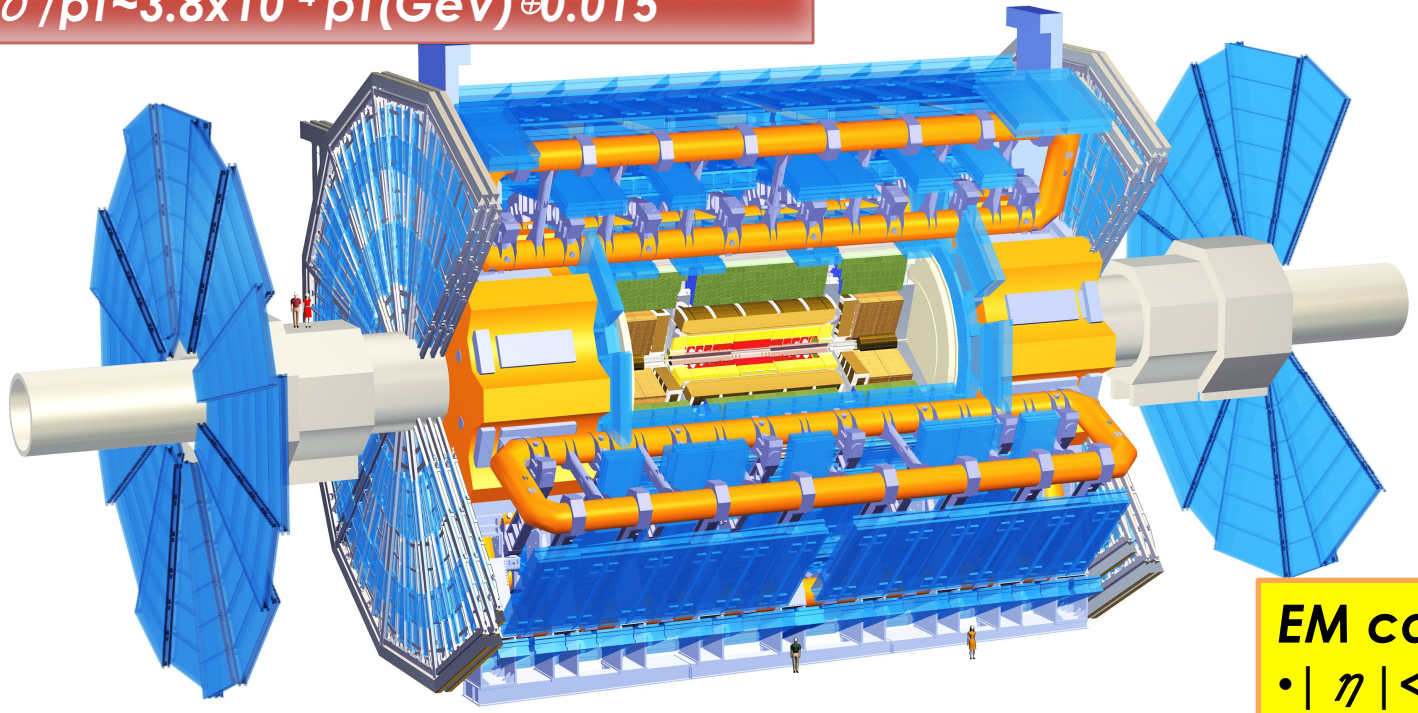
- Examples of particles that give rise to highly ionizing particle signatures (HIP) are Q-balls, black hole remnants, magnetic monopoles, and dyons.
- Recent collider searches performed at LEP and Tevatron.
- "Search for massive long-lived highly ionising particles" (HIP):

Phys.Lett.B, 698, 353-370(2011), http://arxiv.org/abs/1102.0459

A Toroidal LHC ApparatuS

Inner Detector:
- $|\eta|<2.5$
- *Precise tracking and vertexing*
- $\sigma/pT \sim 3.8 \times 10^{-4}\, pT(GeV) \oplus 0.015$

Length : ~ 46 m
Diameter : ~ 24 m
Weight : ~ 7000 tons

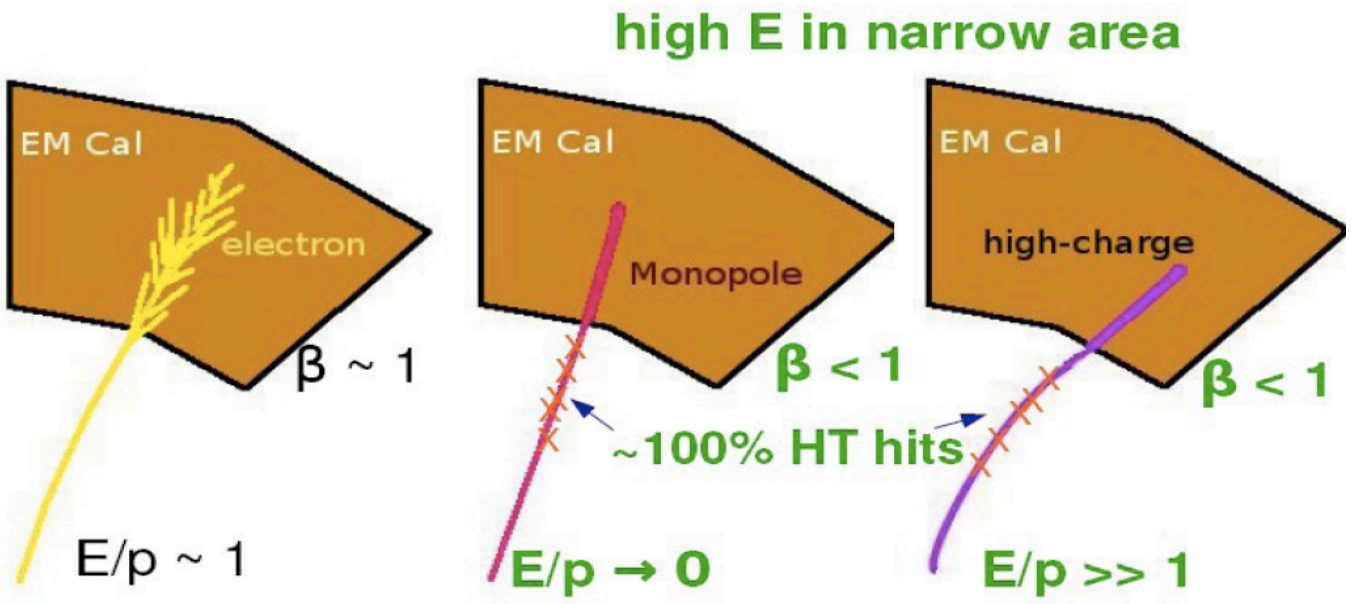


EM calorimeter:
- $|\eta|<3.2$
- *Resolution* $\sigma/E \sim 10\%/\sqrt{E}$

HAD calorimeter
- $|\eta|<5$
- *Central:* $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$
- *Forward:* $\sigma/E \sim 90\%/\sqrt{E} \oplus 0.07$

Muon Spectrometer
- $|\eta|<2.7$
- *Momentum Resolution<10%*
- *up to* $E_{\mu} \sim 1TeV$

Signature



•Due to large mass, HIPs are characterized by their non-relativistic speeds, as well as, high electric charge.

•Large amounts of energy loss through ionisation (no bremsstrahlung).

•In ATLAS: leave tracks in inner tracking detector, matched to narrow shower in Electromagnetic Calorimeter.

Signal selection

Accessible parameter space:

- $|q| \geq 6e$ bound determined by $E_T > 10$ GeV trigger threshold.

- $|q| \leq 17e$ bound determined by delta electrons and electron recombination.

- mass ≤ 1000 GeV bound determined by trigger timing constraints.

- life time larger than 100 ns (if the particle decays earlier in the calorimeter it would not meet the narrow shower requirement)

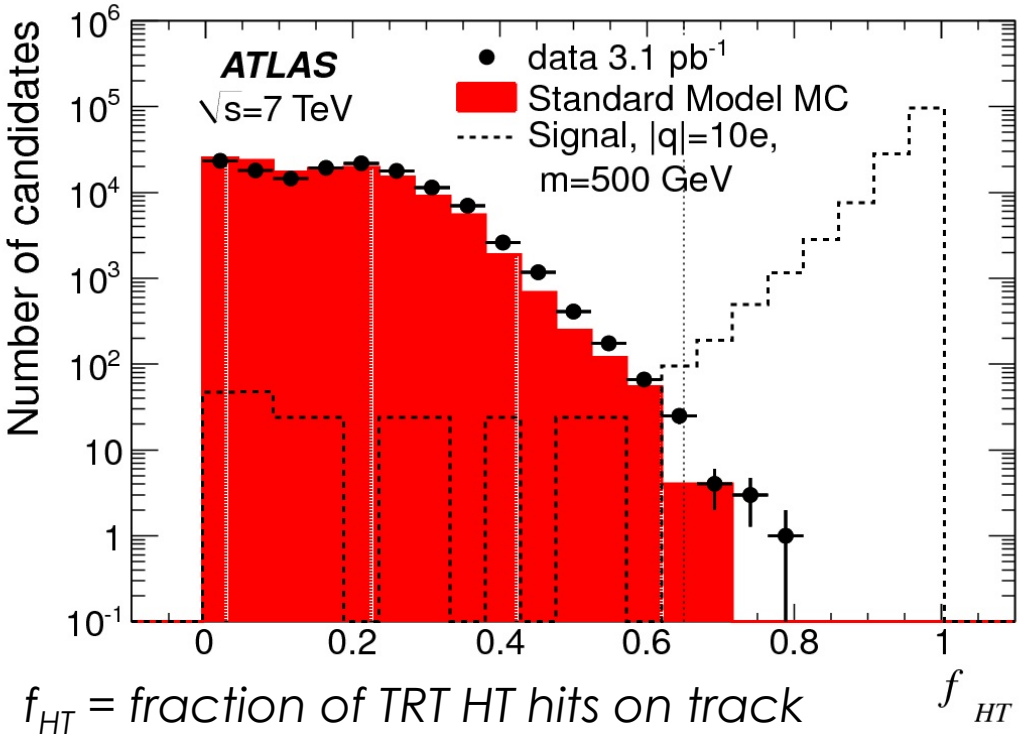
- Not sensible to particles caring magnetic charge

The presence of HIP can be found by measuring:

- f_{HT} – *Fraction of TRT hits on the track which* pass high-threshold (high-ionization hits)

- *w1, w2 – Fraction of energy deposited outside 3* most energetic cells first and second layers of the EM calorimeter

Signal selection – Inner Detector



f_{HT} = fraction of TRT HT hits on track

Signal:

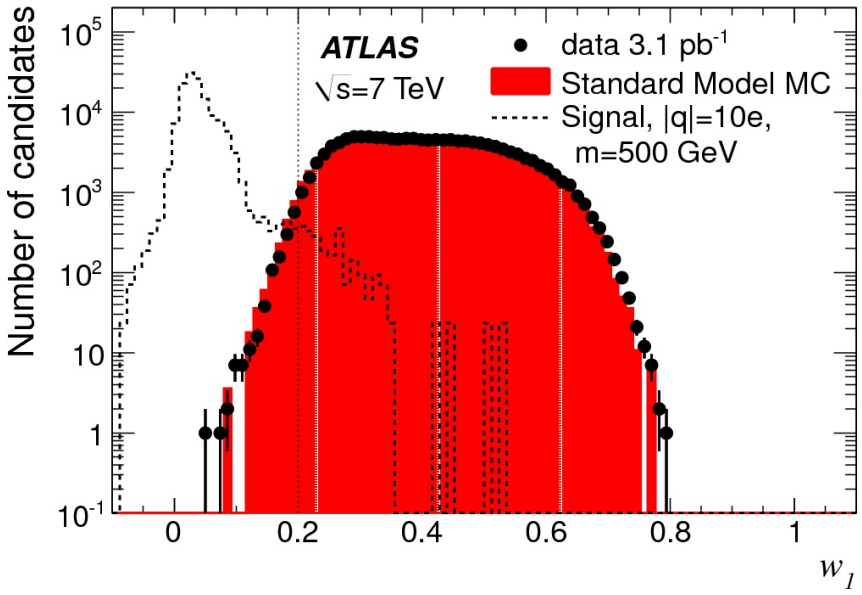
•Produced with the PYTHIA Monte Carlo generator with Drell-Yan kinematics (heavy fermion pairs)

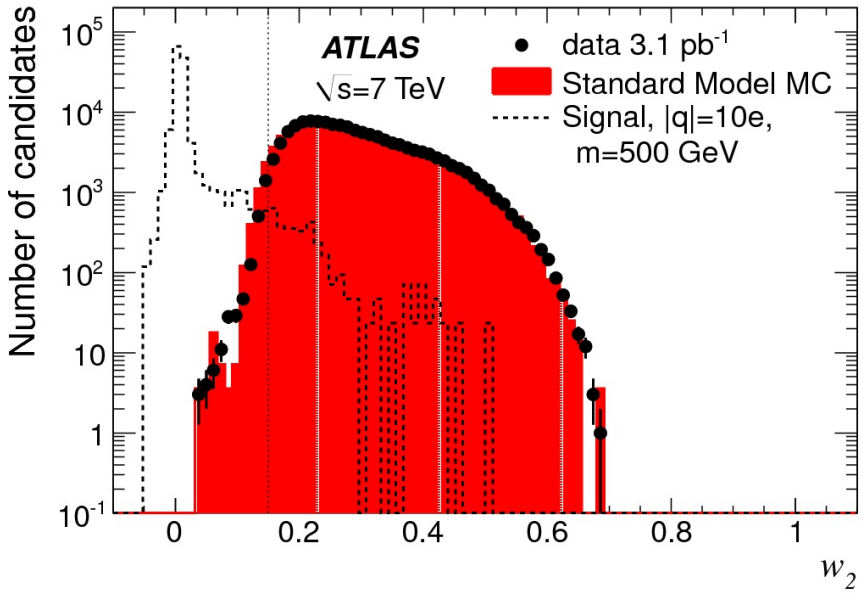
Standard model Monte Carlo:

•Consists mainly of QCD events in which the hard subprocess is a strong 2-to-2 process.

•Contributions from heavy quarks and vector boson production are included.

Signal selection
Electromagnetic Calorimeter

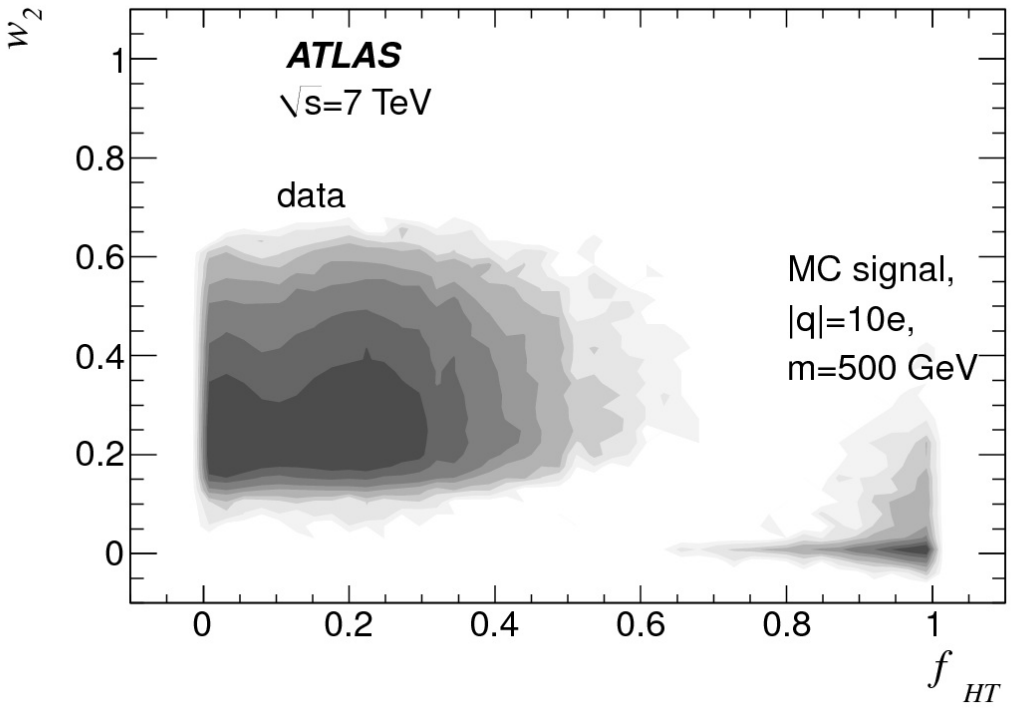




***w1 = fraction of cluster energy not contained in three* most energetic cells in EM layer 1**

***w2 = fraction of cluster energy not contained in three* most energetic cells in EM layer 2**

Signal selection



Selection cuts applied:

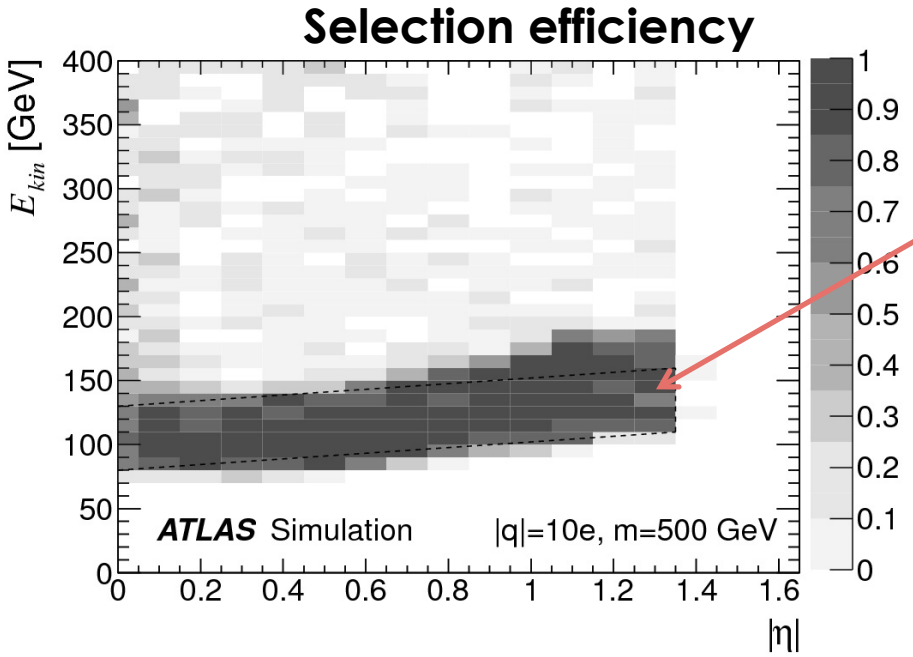
- $f_{HT} > 0.65$
- $w1 < 0.20$
- $w2 < 0.15$

Data-driven background estimation (ABCD method):

Exploits lack of correlation between selection variables f_{HT}, $w1$, $w2$

- **Result: 0.019 ± 0.005 expected background events**

Signal selection efficiency



Acceptance Kinematic Region

- **At least one single particle in detector range $|\eta| < 1.35$ which stops in the second or third layer of the EM calorimeter**
- **High selection efficiency**

$\|q\|$	m [GeV]	E_{kin}^{min} $(\eta = 0)$	E_{kin}^{min} $(\|\eta\| = 1.35)$	E_{kin}^{max} $(\eta = 0)$
10e	200	50	80	90
10e	500	80	110	130
10e	1000	110	150	180

- **The selection efficiency in this region (E_{kin}, η) is flat within 10%.**
- ***This allows to set model-independent limits***

Signal selection efficiency

Expected fractions of HIP candidates passing the final selection, assuming they are produced inside the acceptance regions

m [GeV]	$\|q\| = 6e$	$\|q\| = 10e$	$\|q\| = 17e$
200	0.822 ± 0.026	0.820 ± 0.015	0.484 ± 0.012
500	0.868 ± 0.021	0.856 ± 0.014	0.617 ± 0.011
1000	0.558 ± 0.019	0.858 ± 0.012	0.700 ± 0.012

Expected fractions of signal events passing the final selection, assuming Drell–Yan kinematics

m [GeV]	$\|q\| = 6e$	$\|q\| = 10e$	$\|q\| = 17e$
200	0.102 ± 0.002	0.175 ± 0.003	0.112 ± 0.002
500	0.150 ± 0.003	0.236 ± 0.003	0.193 ± 0.003
1000	0.133 ± 0.002	0.299 ± 0.004	0.237 ± 0.004

Results

Inclusive HIP cross section upper limits (in pb) at 95% confidence level for isolated long-lived massive particles with high electric charges produced in predefined regions of pseudorapidity and kinetic energy

m [GeV]	$\|q\| = 6e$	$\|q\| = 10e$	$\|q\| = 17e$
200	1.4	1.2	2.1
500	1.2	1.2	1.6
1000	2.2	1.2	1.5

Pair production cross section upper limits (in pb) at 95% confidence level for long-lived massive particles with high electric charges, assuming a Drell–Yan mechanism

m [GeV]	$\|q\| = 6e$	$\|q\| = 10e$	$\|q\| = 17e$
200	11.5	5.9	9.1
500	7.2	4.3	5.3
1000	9.3	3.4	4.3

Conclusions

- Upper cross- section limits between 1.2 pb and 11.5 pb have been obtained for HIPs with charges between 6e and 17e and masses between 200 GeV and 1000 GeV under two kinematic assumptions.

- These limits are the first limits on HIPs at the LHC energies.

- This is the first search sensitive to HIPs with masses > 800 GeV.

Backup slides

Systematic uncertainties

m [GeV]	$\|q\| = 6e$	$\|q\| = 10e$	$\|q\| = 17e$
200	25%	11%	9%
500	17%	10%	9%
1000	28%	10%	9%

Relative systematic uncertainties in efficiency, combining in quadrature effects like: recombination of electrons, stopping before reaching the detector, modeling of inactive EM calorimeter regions, cross-talk between EM calorimeter cells, delta electron, delayed clusters, choice of parton distribution functions.