Searches for long-lived particles with the ATLAS detector

Andy Haas
New York University

on behalf of the ATLAS collaboration

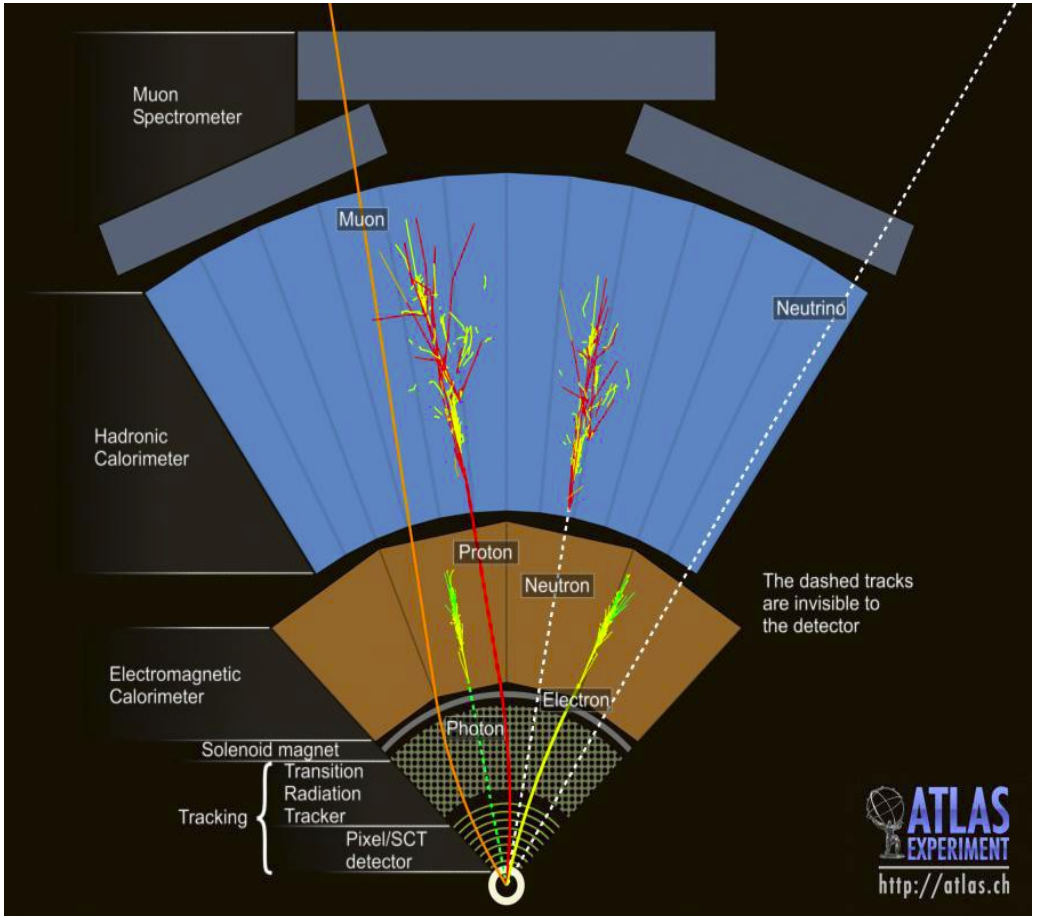
ICHEP 2012
Melbourne, Australia

July 4 – 11, 2012

Introduction

Many signatures of long-lived particles!

- Decays in inner tracker / outer tracker / calorimeter / muon system
- Slow (timing in calorimeter / muon)
- Large dE/dx and ionization (pixel/TRT)
- Stopping / decaying out-of-time



Require special triggers, data processing, reconstruction algorithms, background estimates, and simulations!

Recent Searches (2011 data)

- Displaced vertex in inner tracker (+muon) **arxiv/1109.2242**
- **Kinked / disappearing track in outer tracker**
- 

Long-lived particles → lepton-jets in muon system
- 

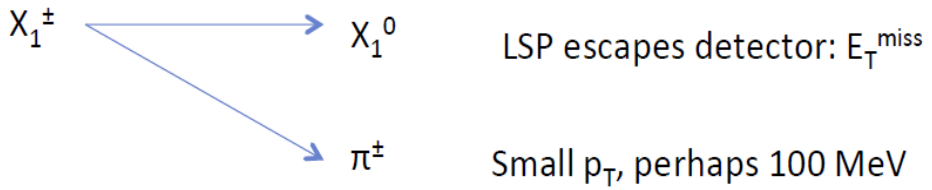
Slow, highly ionizing particles
- 

Very-highly-charged particles (monopoles)
- Stopped particles decaying to jets in the calorimeter in empty bunch crossings **arxiv/1201.5595**

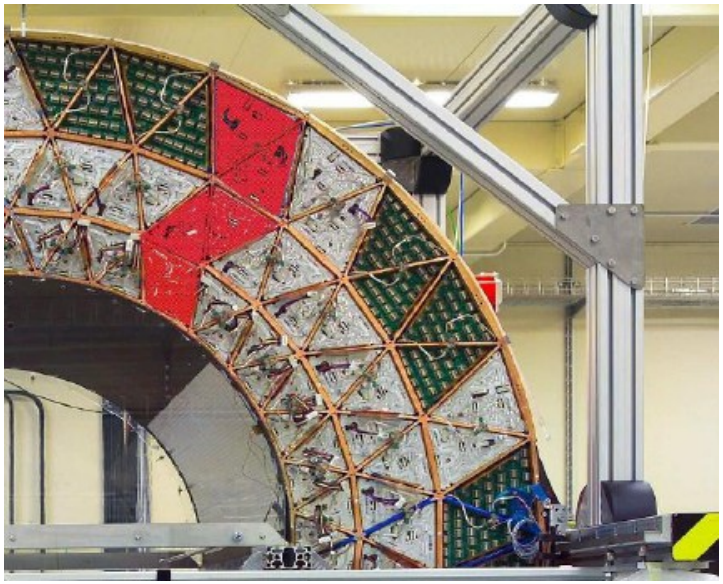
Lifetime ↓

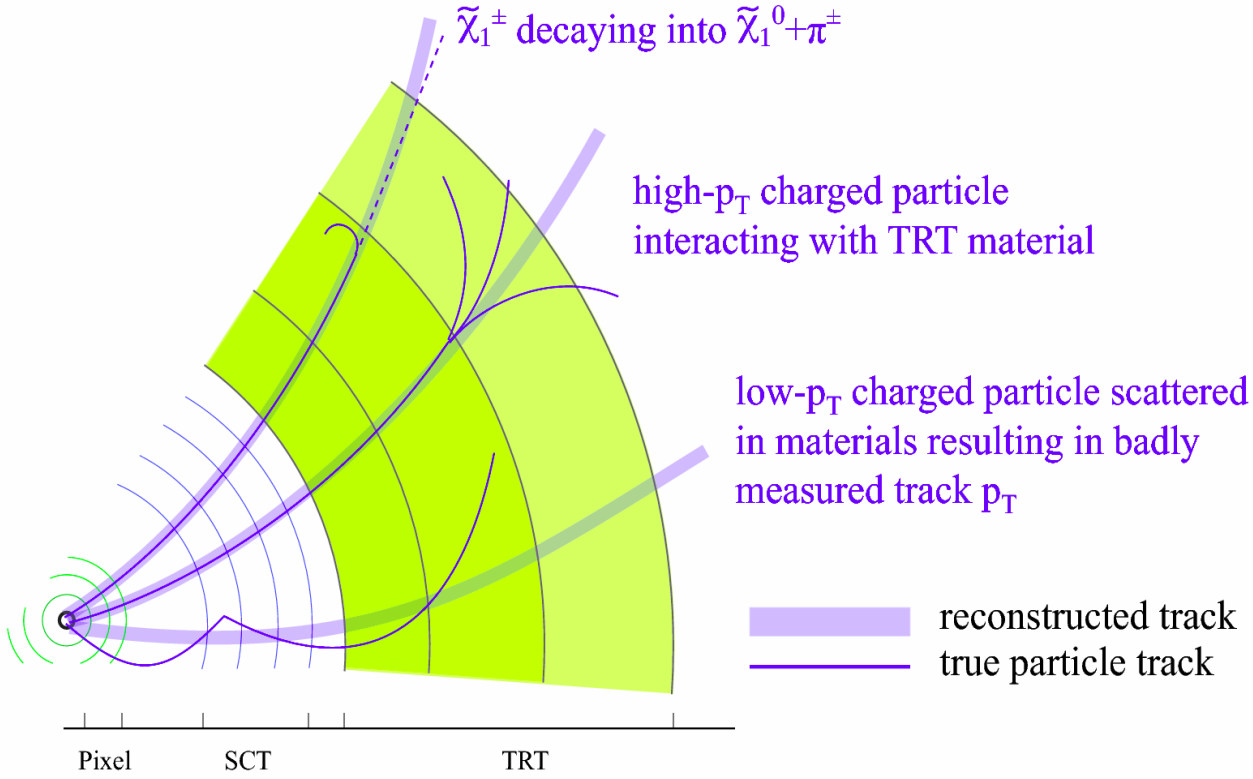
Kinked / disappearing track

- Nearly mass-degenerate chargino and neutralino
  - Often realized in AMSB
  - Long-lived chargino



- Look for high-pt track missing hits in the outer tracking layer





Kinked / disappearing track

- Trigger:

  1 jet with pt>75 GeV
  MET > 55 GeV

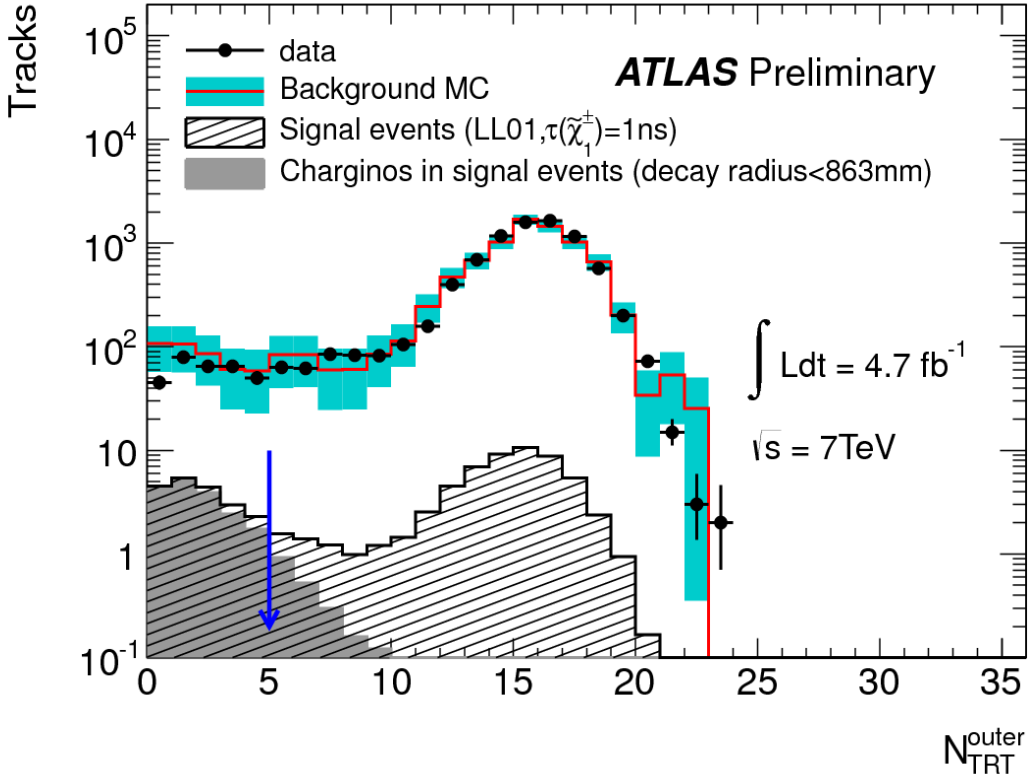
- Offline:

  3 jets with pt>130,60,60 GeV
  MET>130 GeV
  Lepton veto

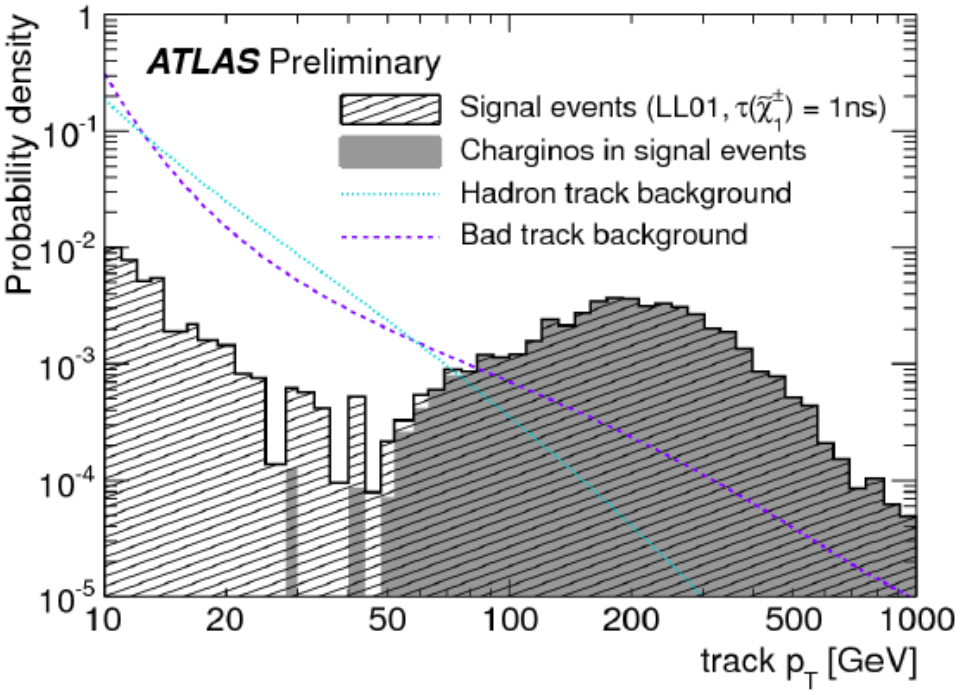
  Track pt>10 GeV

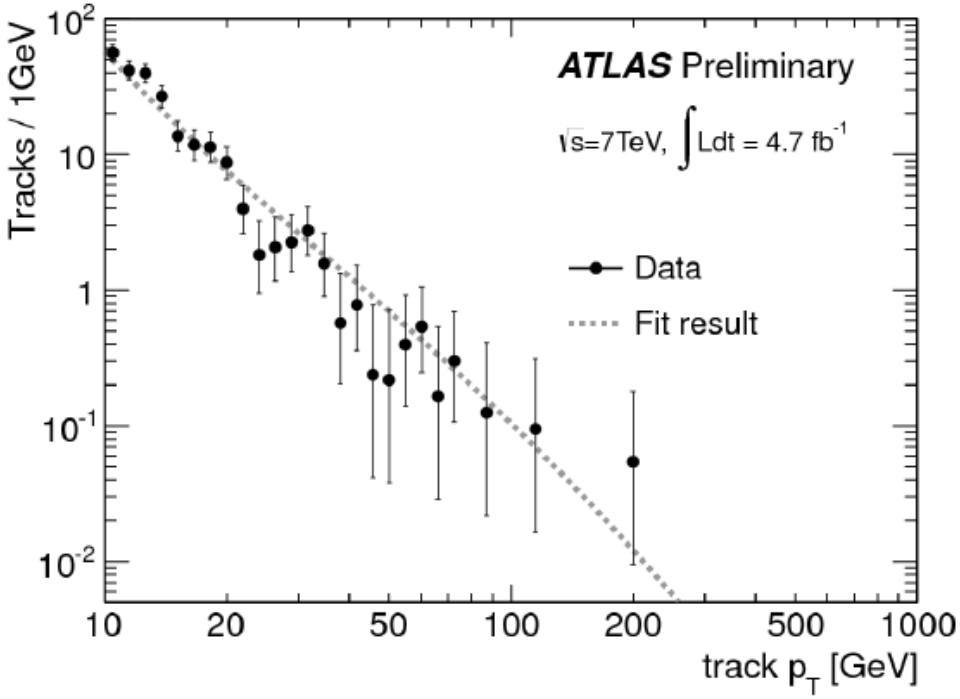
  Isolated from other tracks (dR>0.1)

  <5 hits in the outer TRT layer



Kinked / disappearing track: pT shapes





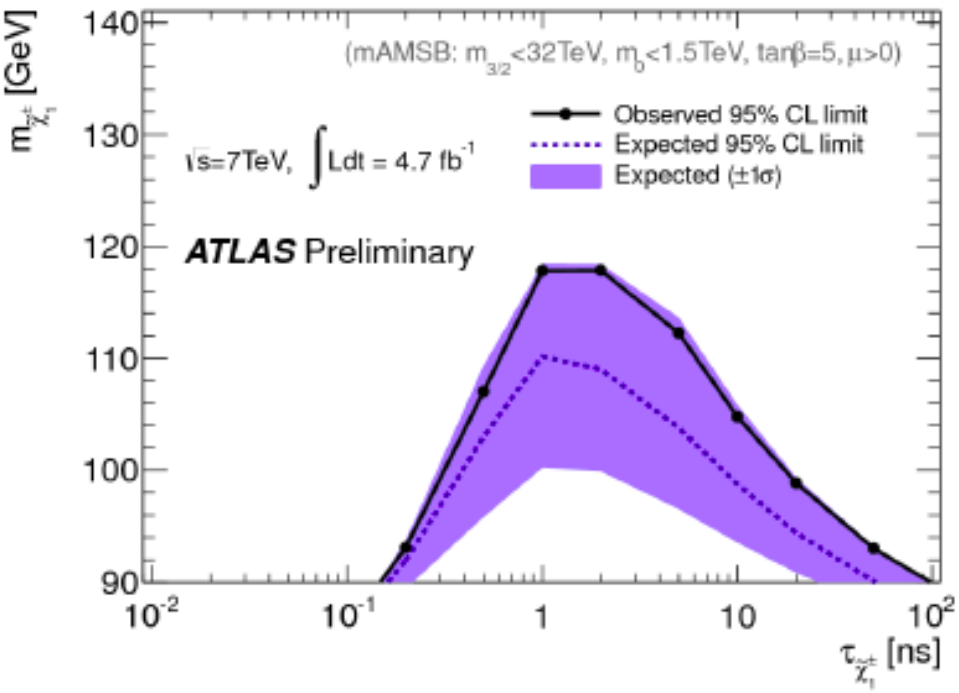
The 3 templates are fit to data:

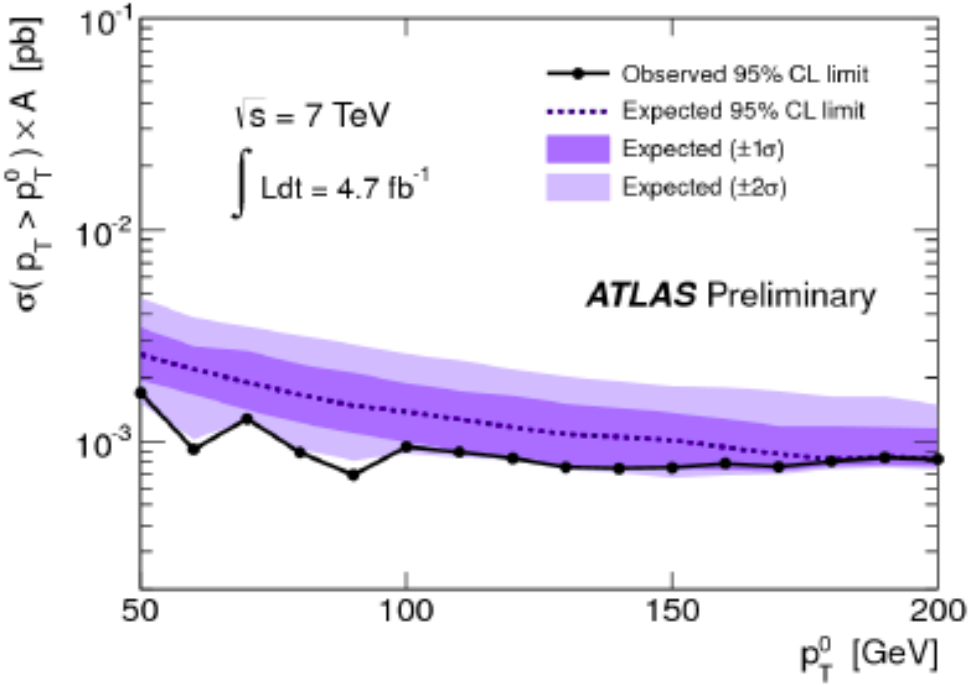
- The two background templates are fit for $p_T > 10$ GeV
- The signal template is included in the fit for $p_T > 50$ GeV

data and background fit
best fit has zero contribution from signal template

304 events in 4.7/fb of 2011 data

Kinked / disappearing track: Limits





Limit for the mass
Previous LEP2 limit: $X_1^\pm > 92$ GeV (for any lifetime)

limit on production of truncated tracks

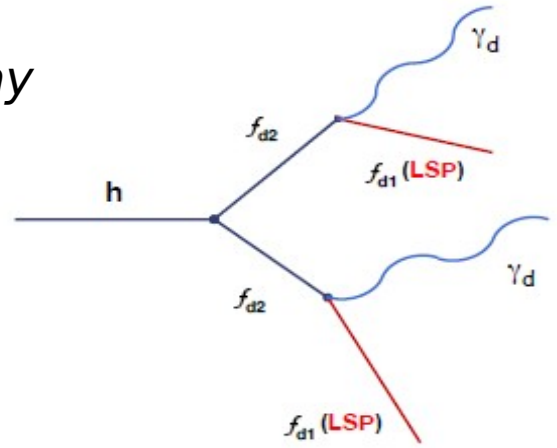
ATLAS: $\chi_1^+ > 118$ GeV (@1 ns)

primary uncertainty is the theoretical cross section (27%)
backgrounds are data driven and so have very small uncertainty

ATLAS-CONF-2012-034

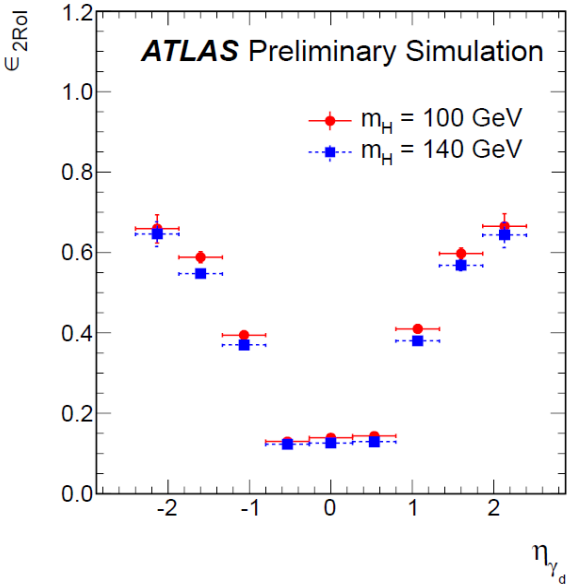
Long-lived particles → lepton-jets in muon system

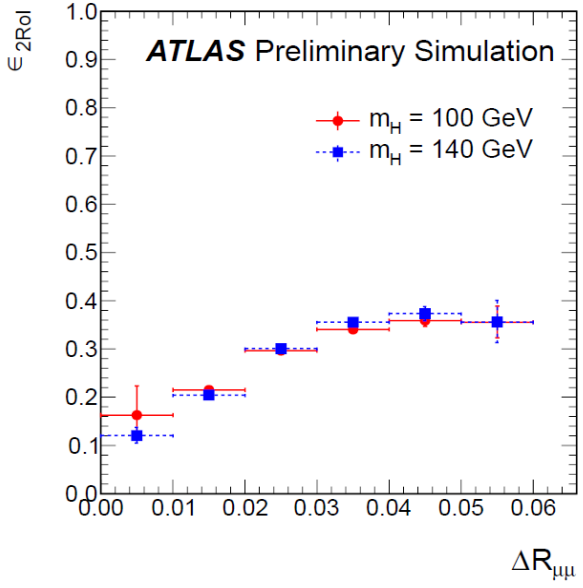
- "Lepton-jet":
  collimated group of electrons, muons, pions from decay to a new, light hidden-sector particles ("dark-photon")



- Trigger: 3 muons in MS, pt>6 GeV
  - Efficiency ~ 30% (relative to offline)
    - Need a dark photon to give <u>2 L1 trigger muon regions</u>
    - Compare to J/ψ data for systematic

Higgs mass (GeV)	m_{fd2} (GeV)	m_{fd1} (GeV)	γ_d mass (GeV) (GeV)	cτ (mm)
100.	5.0	2.0	0.4	47
140.	5.0	2.0	0.4	36





For dark-photon mass of 0.4 GeV:
BR(e,mu,pi)=0.45,0.45,0.1
~20% have two muon-jets

1.94 /fb of 2011 7 TeV pp data used

ATLAS-CONF-2012-112
(to appear soon…)

Long-lived particles → lepton-jets in muon system

- Muon jet reconstruction
  - Cluster muons using dR=0.2 cone
  - Require ≥2 OS muons per muon-jet

- Require ≥2 muon-jets

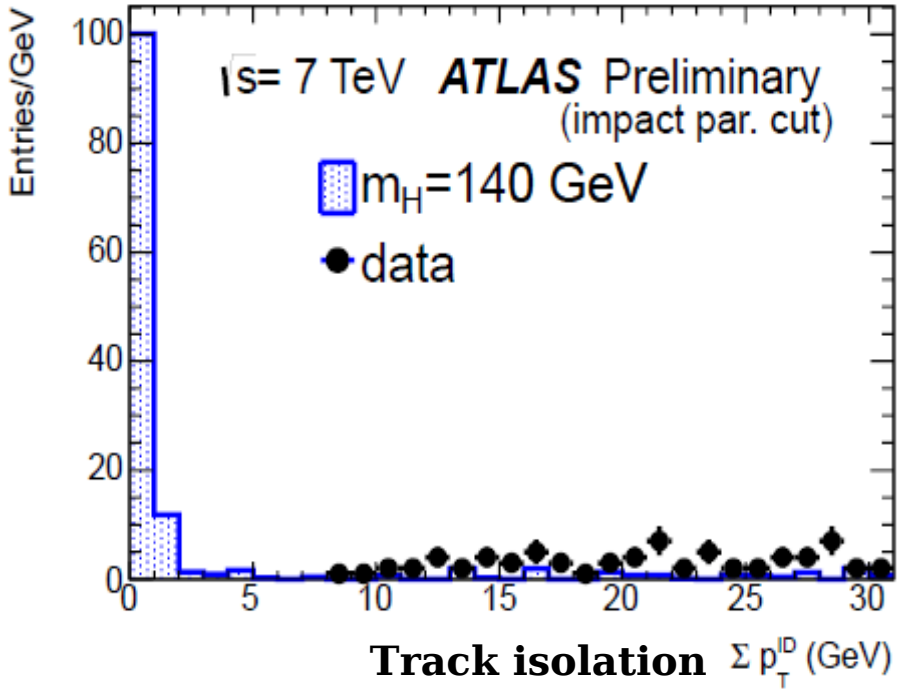
Calorimeter isolation in hollow cone 0.2<dR<0.4 around muon-jet < 5 GeV

Scalar sum pt of tracks in dR<0.4 cone around each muon-jet < 3 GeV

dphi>2 for two muon-jet

d0<200mm and |z0|<270mm w.r.t. PV (remove cosmic background)

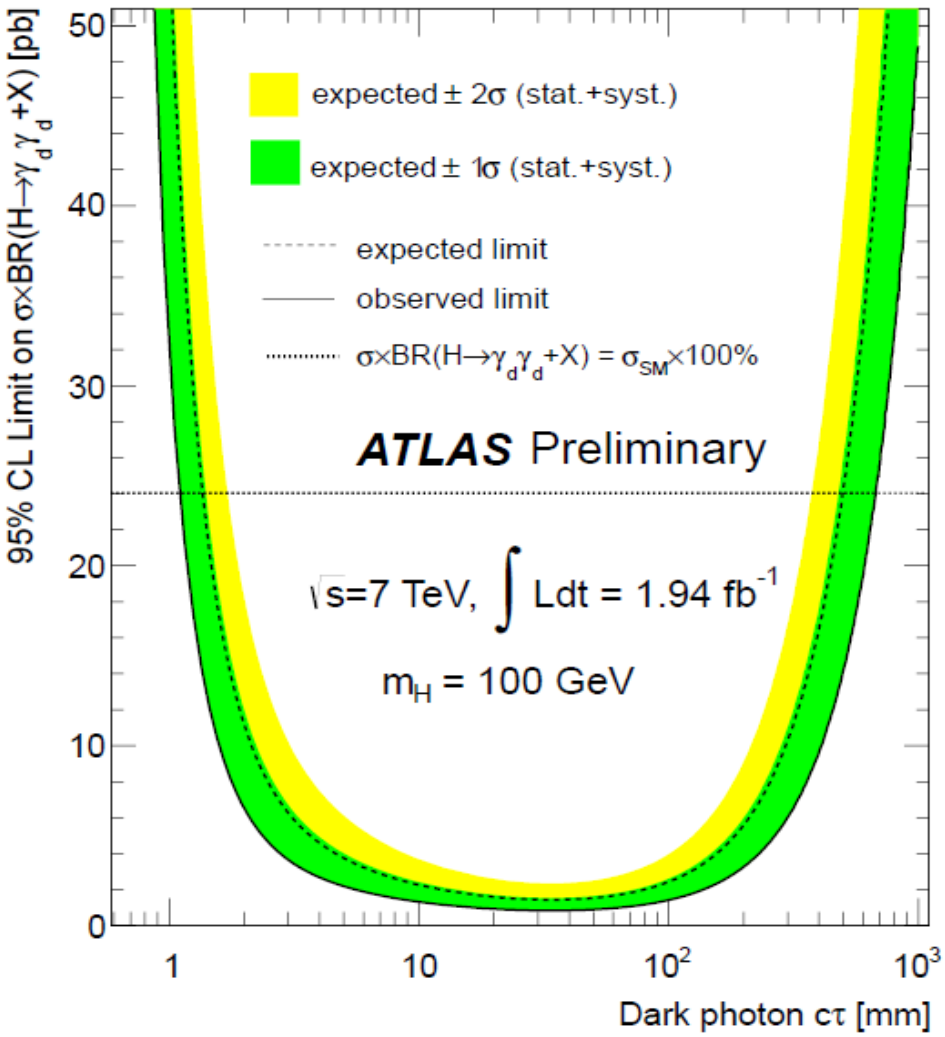
sample	2MJ	Final Selection
Cosmics	3.0 ± 2.1	$0^{+1.64}_{-0}$
multi − jet		$0.059\pm0.015^{+0.66}_{-0.059}$
Total background		$0.059^{+1.64\ +0.66}_{-0.015-0.059}$
m_{Higgs} =100 GeV	$135\pm11^{+29}_{-21}$	$75\pm9^{+16}_{-12}$
m_{Higgs} =140 GeV	$90\pm9^{+17}_{-13}$	$48\pm7^{+9}_{-7}$
DATA	871	0



Long-lived particles → lepton-jets in muon system

- Set limits on signal vs. dark-photon decay length

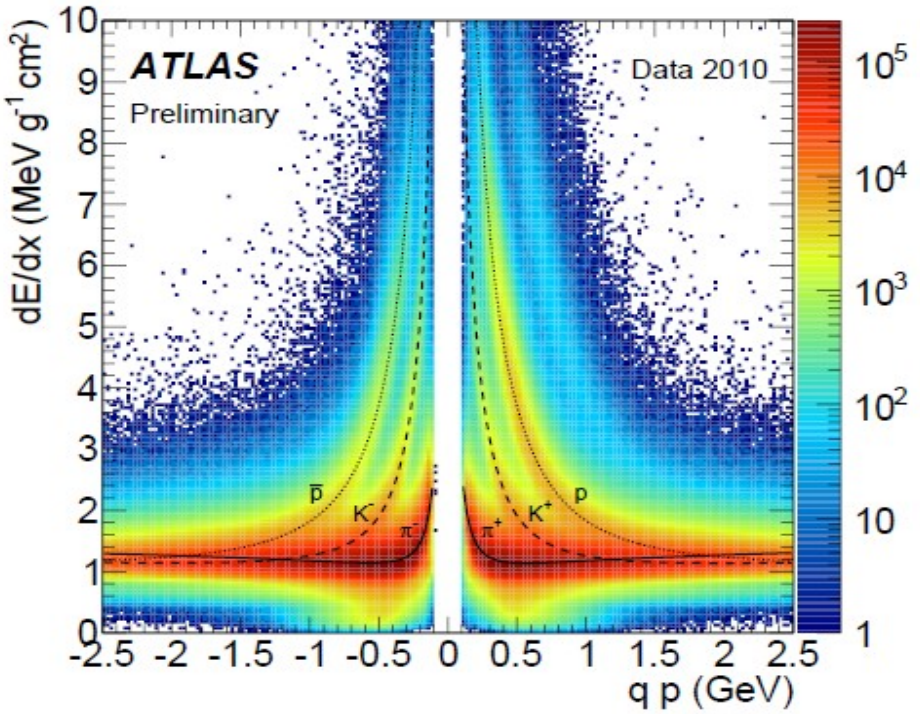
  (weak dependence on m_H)



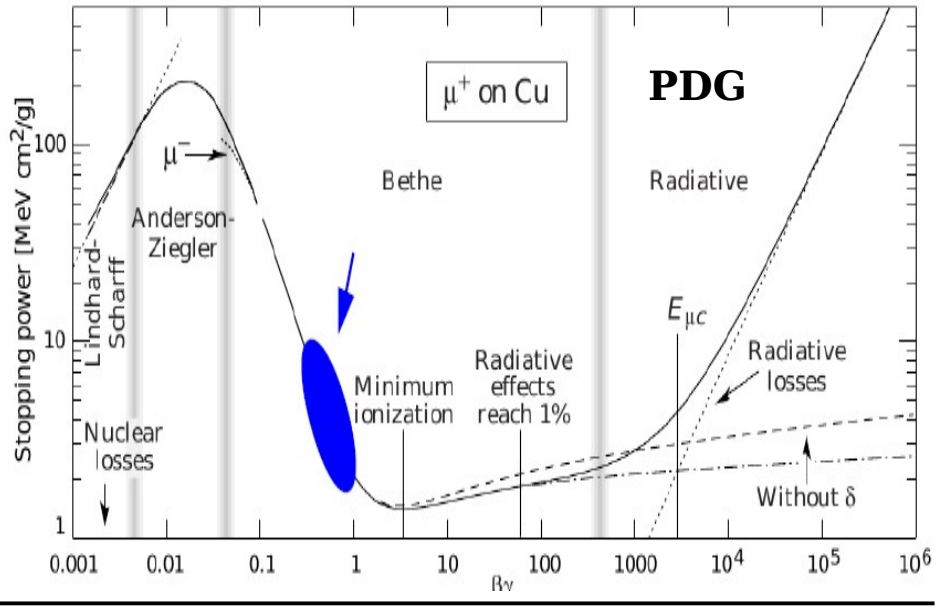
Exclude γ_d proper decay lengths ~1 – 500 mm for 100% BR($H \rightarrow \gamma_d \gamma_d$)

Massive, slow, highly-ionizing tracks

- Look for high-pt tracks
- Measure *velocity* of track using
  - dE/dx in pixel detector (invert Bethe-Block)
    - dE/dx in TRT and calorimeters not used yet
  - Timing in calorimeter and muon systems



- Main background: mis-measured timing or dE/dx
  - Estimated using data in control regions with low S/B (lower pt cut or on Z peak)



Massive, slow, highly-ionizing tracks

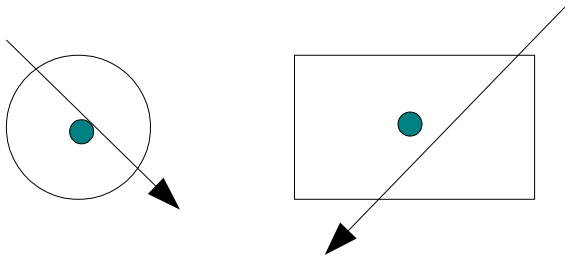
- Three searches:
  - 1) optimized for colorless particles (stau)
    - charged through whole detector → inner track + calorimeter + muon
  - 2) motivated by colored particles (R-hadrons)
    - may become neutral in calorimeter → inner track + calorimeter
  - 3) motivated by shorter lifetime particles
    - may decay before leaving tracker → short pixel+SCT track only

Triggers:

- Single muon, pT>18 GeV
  - Not sensitive to very slow particles (later bunch crossing)
  - ~90% efficient for staus
- MET > 60-70 GeV (EM-scale)
  - Sensitive to very slow particles
  - 15-40% efficient for R-hadrons

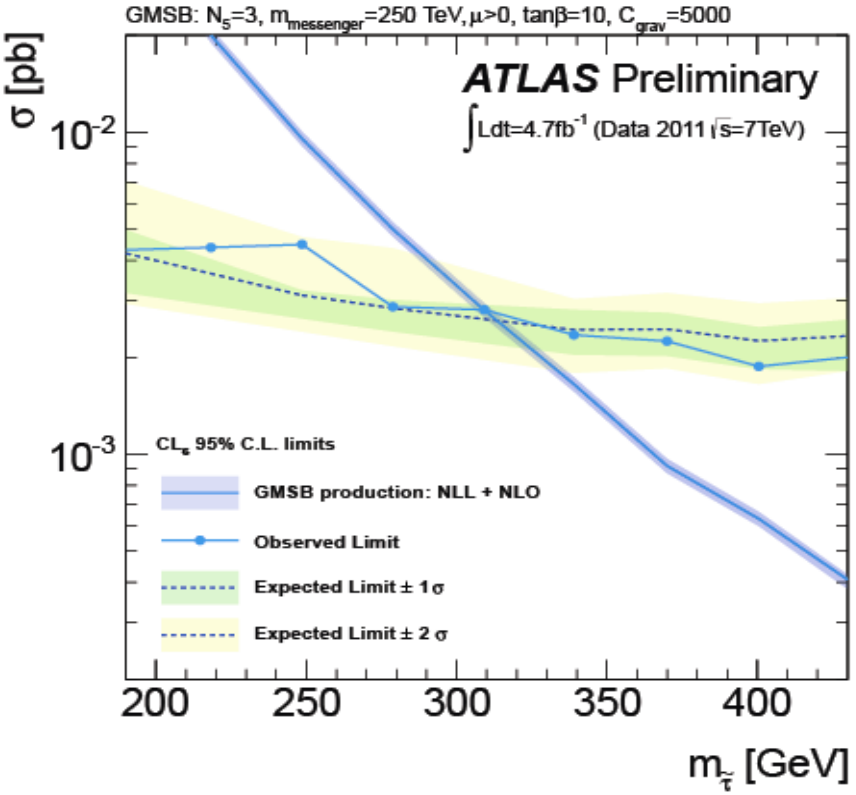
Cosmic rejection:

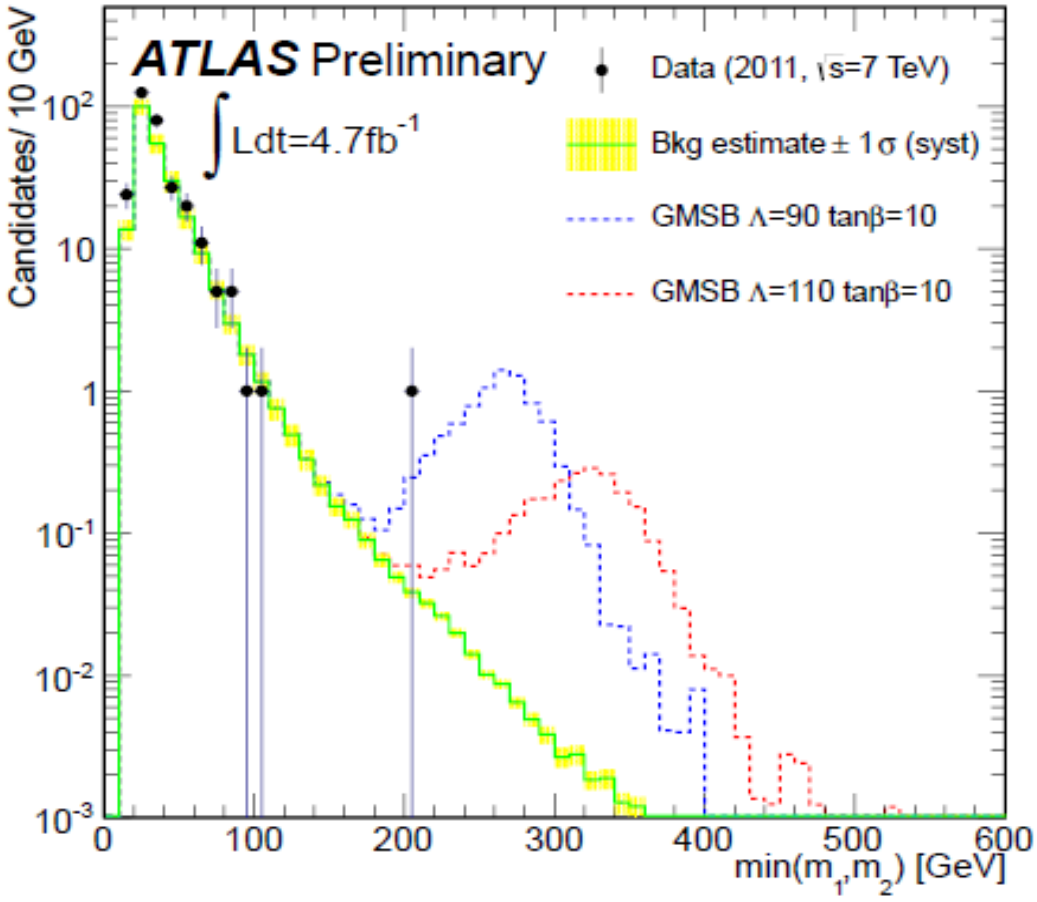
- Cut on distance of track to PV in 2D-IP and z
- Reject back-to-back tracks in phi or eta



Slepton (stau) search

- Two-track channel
  - Looser track selection
  - pT>50 GeV
  - Anti-Z-mass cut (+-10 GeV)
  - Cut on velocity





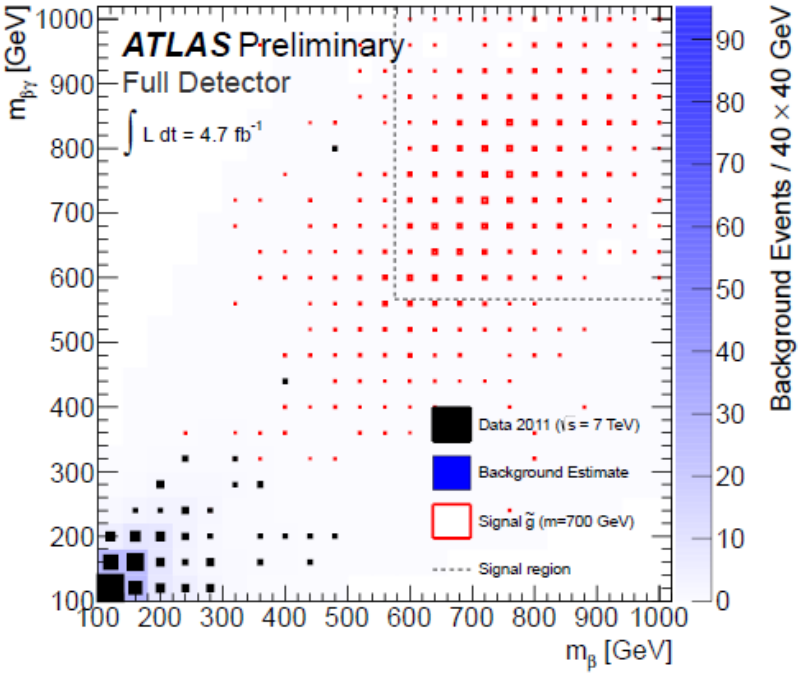
m(stau)>310 GeV (tanB in 5-20)
pair-produced stable leptons > 297 GeV

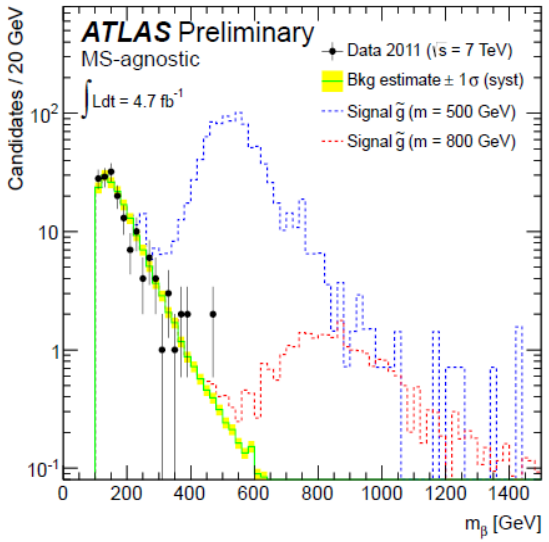
Also interpreted in GMSB parameter space

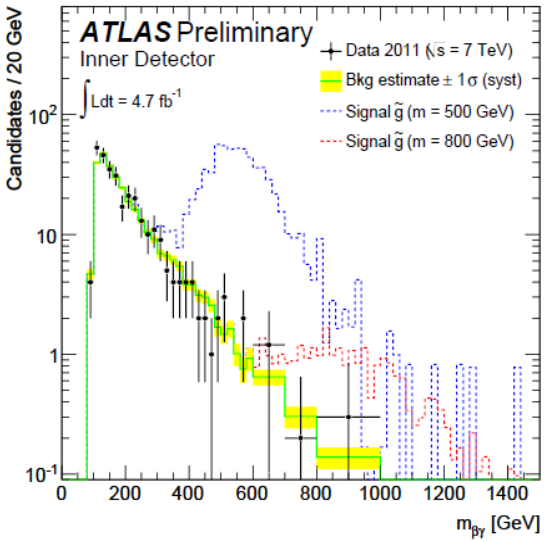
ATLAS-CONF-2012-075

R-hadron search

- Only a single-track selection is used, since efficiency is smaller
  - Checks are made for double candidates
- Track pT>140 GeV (50 GeV for short-track-only analysis)
- Isolation from jets (ET>40 GeV, dR<0.3)
  Isolation from tracks (pT>10 GeV, dR<0.25)
  - pT>1 GeV, dR<0.25 for short-track-only analysis





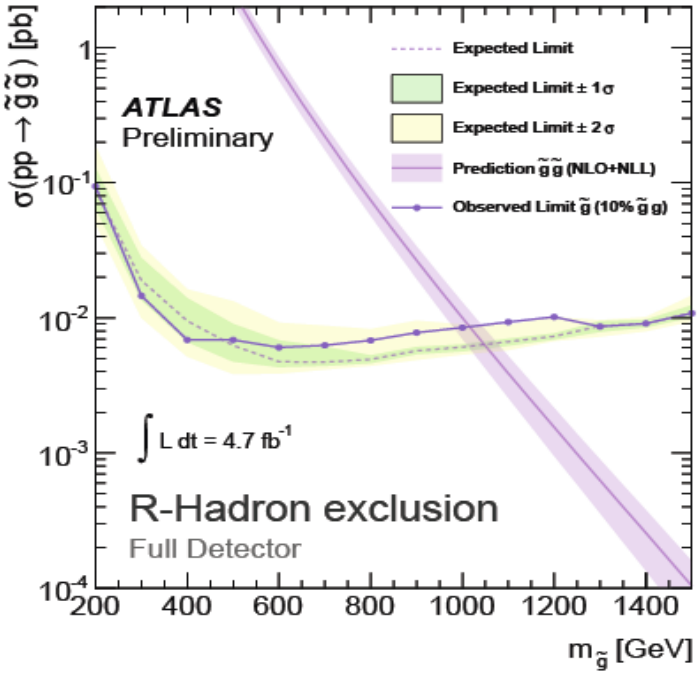


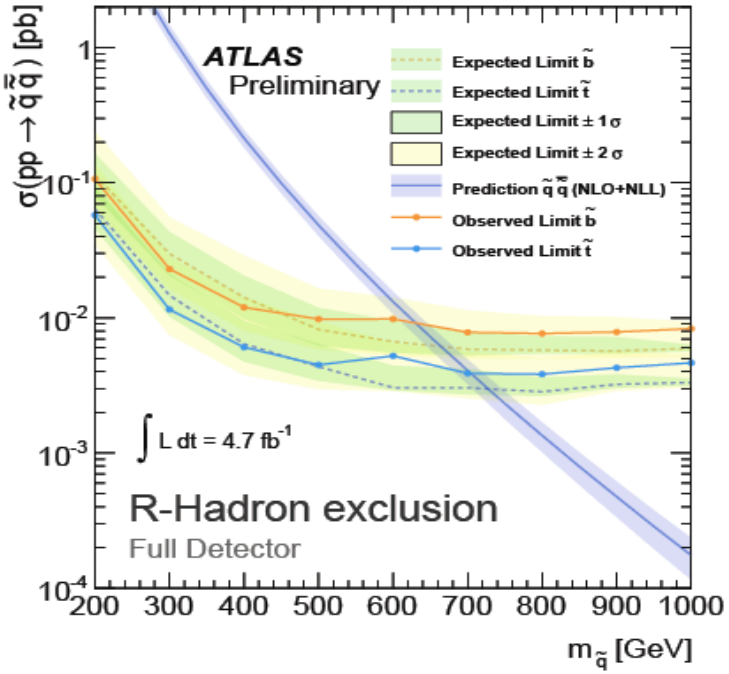
R-hadron search results

- Cuts on velocity from pixel / calorimeter / muon system

- Limits in the 3 analyses (95% C.L.): **ATLAS-CONF-2012-075**

	gluino	stop	sbottom
Full detector	985	683	612
Track+calorimeter	989	657	618
Track only	940	604	576



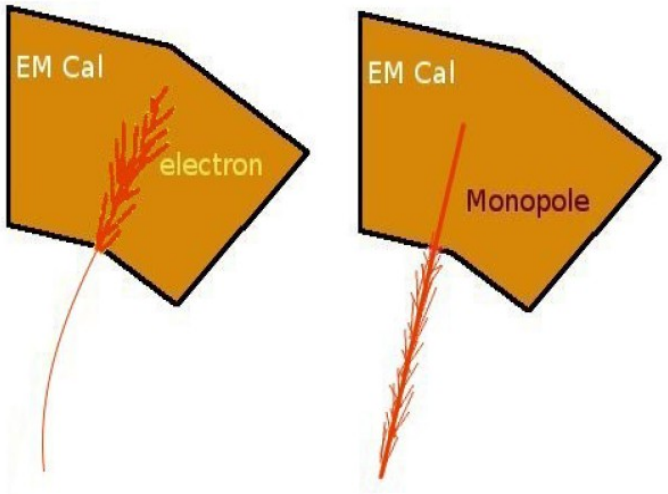


Very-highly-charged particles (monopoles)

- Pair-produced, heavy, highly charged, anomalous bending in B-field
  - Full monopole detector simulation

$$\frac{ge}{\hbar c} = \frac{1}{2} \Rightarrow \frac{g}{e} = \frac{1}{2\alpha_e} \approx 68.5$$

- Large energy cluster in EM calorimeter
  - Many high-ionization hits in the TRT along road from primary vertex to EM energy cluster



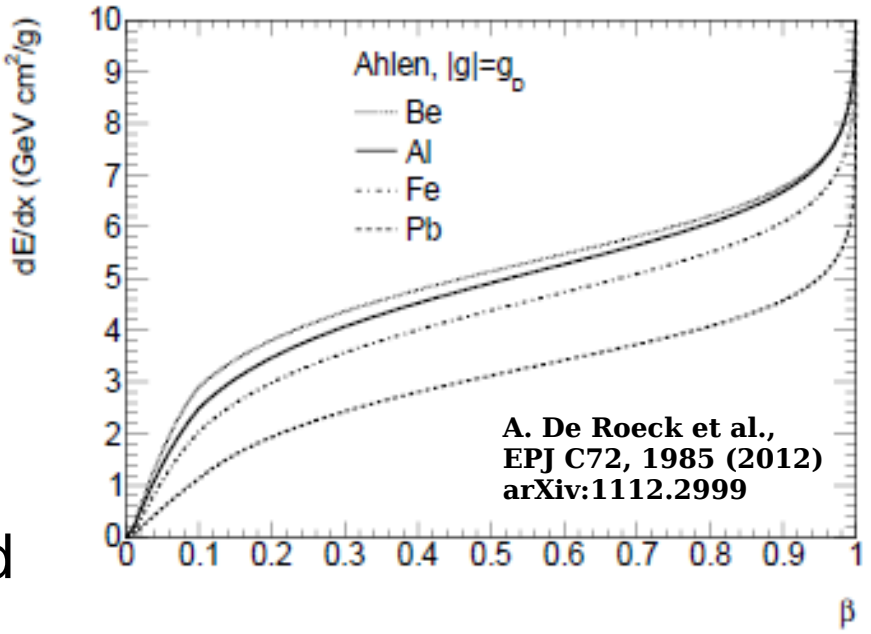
- Trigger on ET>60 GeV EM calorimeter cluster
  - Working on special triggers based on TRT high-threshold hits

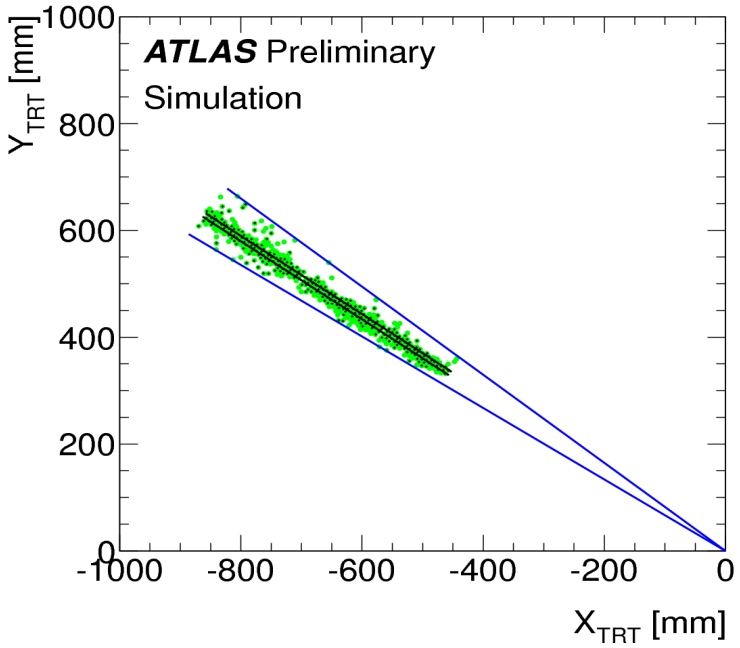
    ET>65 GeV *central* EM calorimeter cluster offline

ATLAS-CONF-2012-062

Very-highly-charged particles (monopoles)

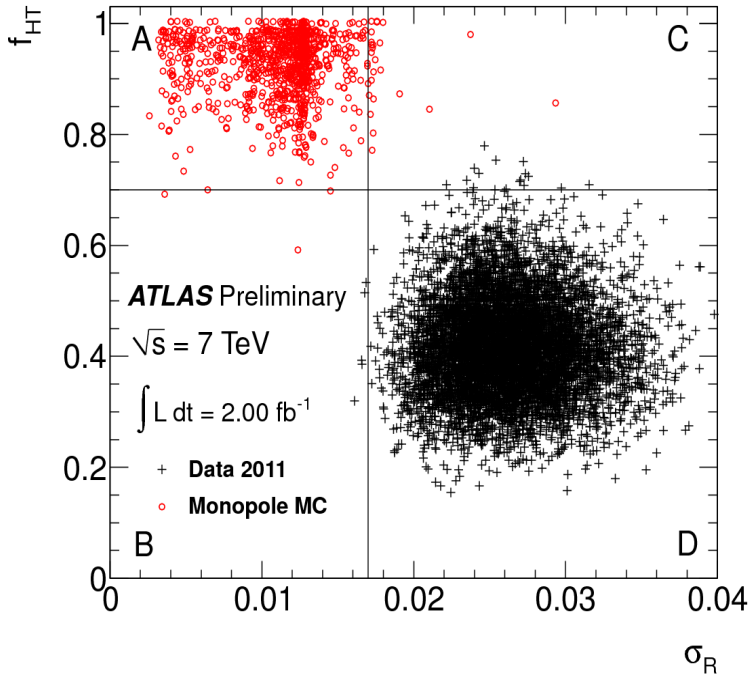
- Very large ionization from large electromagnetic coupling
  - High threshold hit in TRT has >6000 eV in straw
  - >200 eV for low-threshold
- Large number of δ-rays → wide road
  - $|\Delta\varphi|<0.05$ radians for pre-selection
  - Optimized road defined for final selection
- Require at least 20 high-threshold TRT hits in the track road
  - 20% of the TRT hits must also be high-threshold

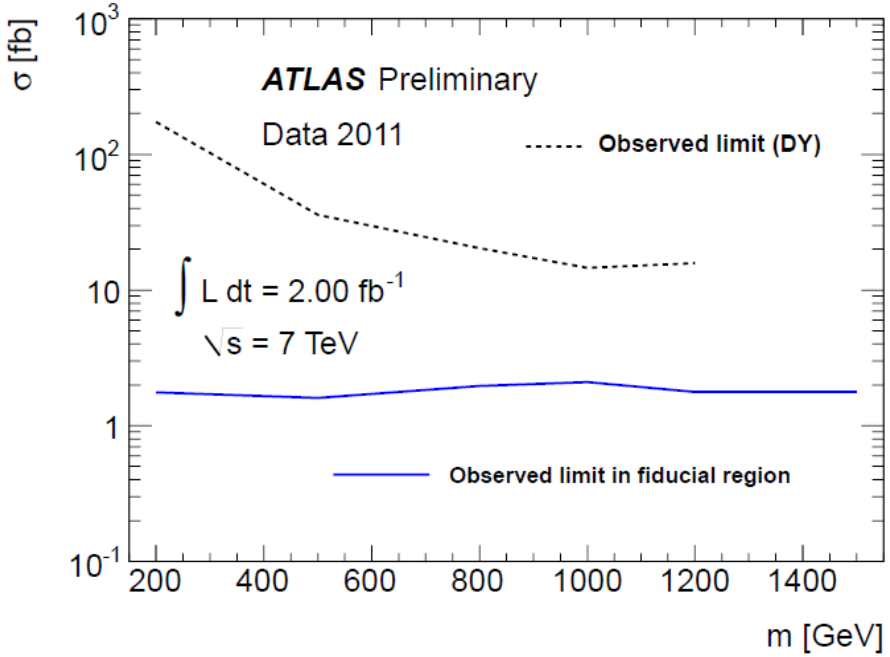


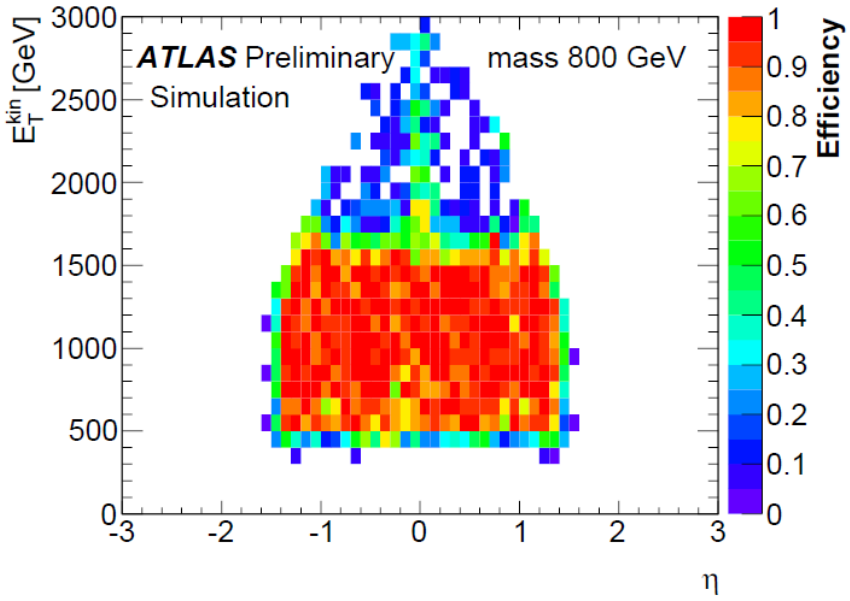


Very-highly-charged particles (monopoles)

- Expect *narrower* EM shower for monopoles compared to e / γ
  - Much less Bremsstrahlung and pair-production
- Data-driven ABCD background: 0.011 ± 0.007 events
- No event observed in signal region

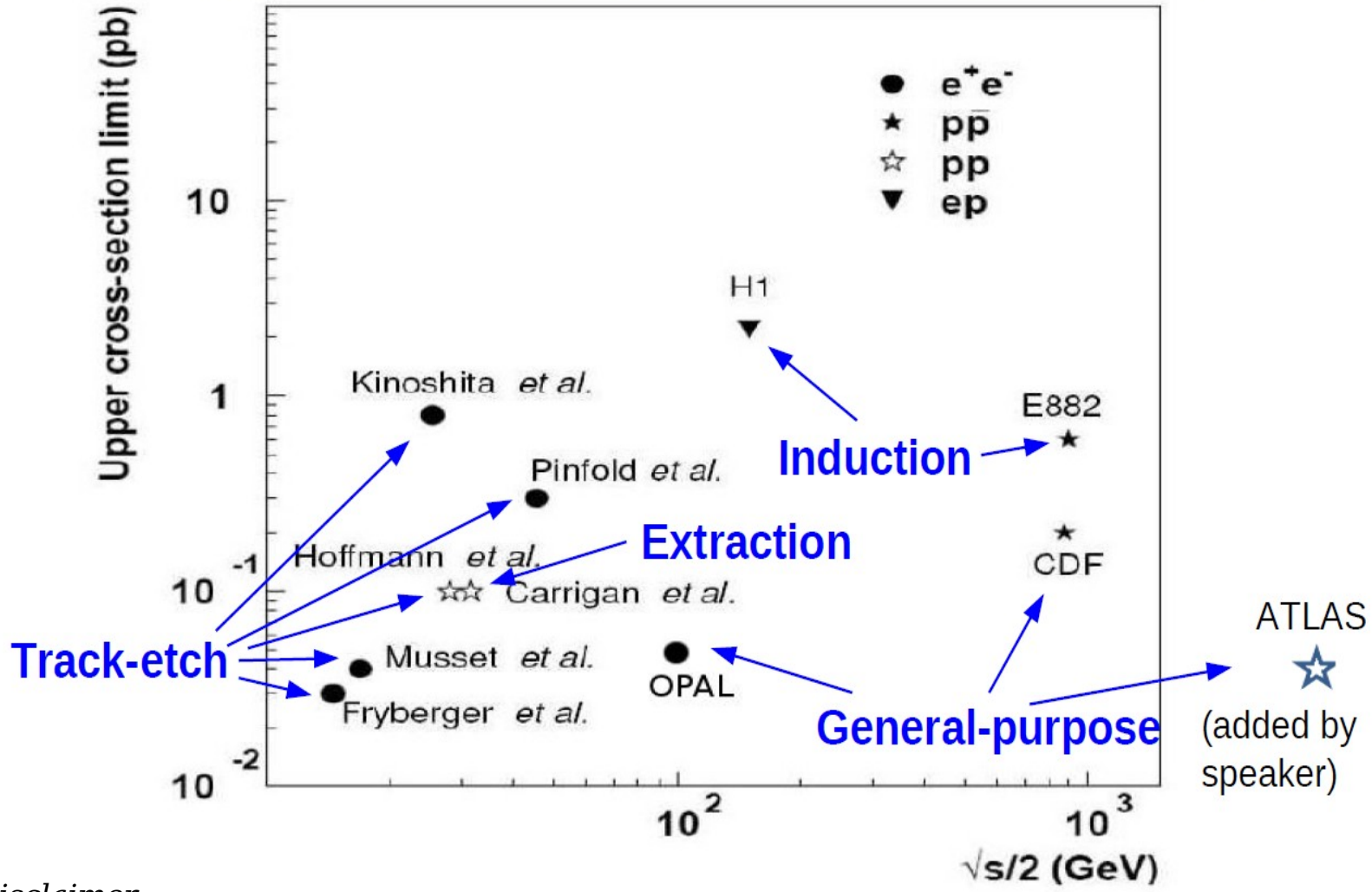






Very-highly-charged particles (monopoles)

M. Fairbairn *et al.*, Phys. Rept. 438, 1 (2007), arXiv:hep-ph/0611040



Disclaimer:

Valid only in a given mass range for a benchmark model of monopole production.
Monopole with charge equal to the Dirac charge.

First constraints on magnetic monopole production at the LHC !

Conclusions

No hints for signal yet...

We'll continue to look at new signatures and with more data in the years to come!

- Displaced vertex in inner tracker (+muon)
- **Kinked / disappearing track in outer tracker**
- 

Long-lived particles → lepton-jets in muon system
- 

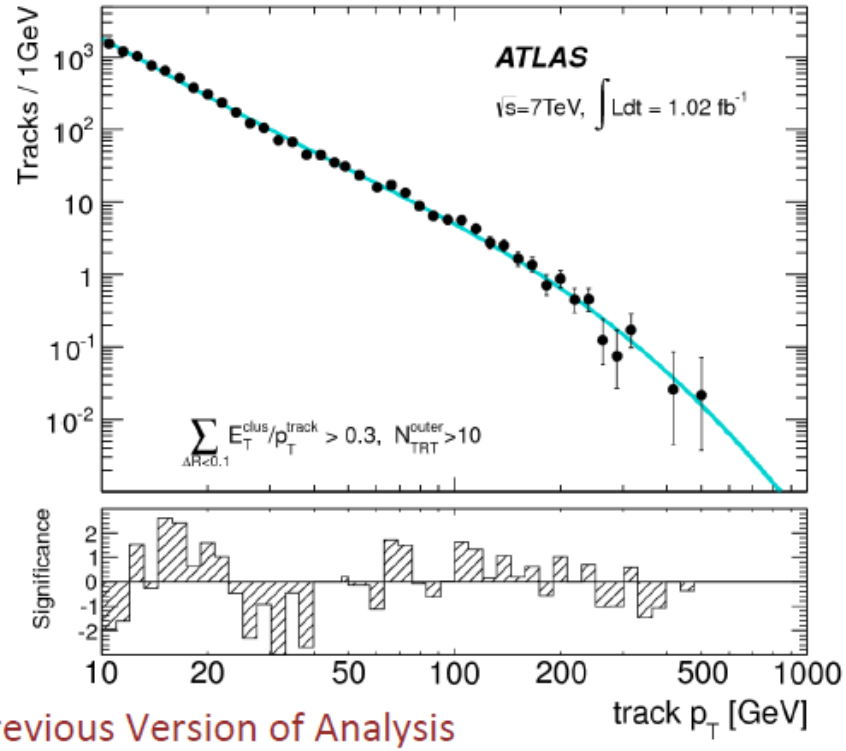
Slow, highly ionizing particles
- 

Very-highly-charged particles (monopoles)
- Stopped particles decaying to jets in the calorimeter in empty bunch crossings

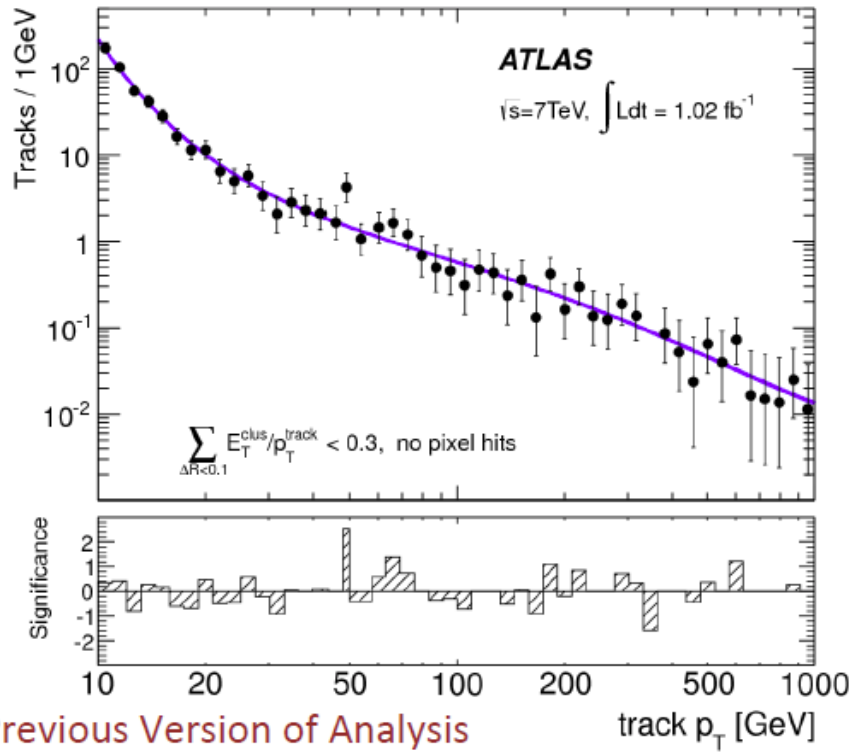
Lifetime

Backup

Disappearing track: background track pT shapes



Previous Version of Analysis



Previous Version of Analysis

shape for high p_T tracks that interact
Sample is signal-free:

$N_{TRT}^{outer} > 10.$

shape for mismeasured low p_T tracks
Sample is signal-free:

$E_T^{miss} < 100$ GeV
no pixel hits