The Abdus Salam
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2263-20

Beyond the Standard Model: Results with the 7 TeV LHC Collision Data

19 - 23 September 2011

Search for New Long-Lived Particles with the ATLAS Detector

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Searches for long-lived particles with the ATLAS Detector

Philippe Mermod (University of Oxford),
on behalf of the **ATLAS Collaboration**

BSMLHC Conference

Trieste, 21 September 2011

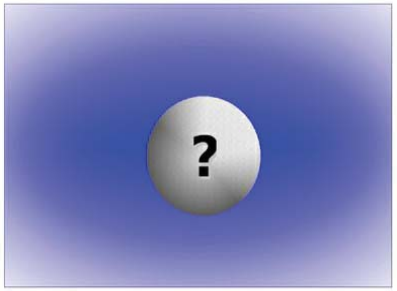
Long-lived particles

New physics are expected at the TeV scale

- Type of ”new physics” unknown

Particle quantum numbers / properties

- mass, colour/electric/magnetic charge
- couplings, decay topologies
- cover as broad a range as possible



Long-lived particle searches performed with ATLAS:

(up to 37 pb^{-1} of 7 TeV data)

Decaying

- Displaced vertices
- Out-of-time decays

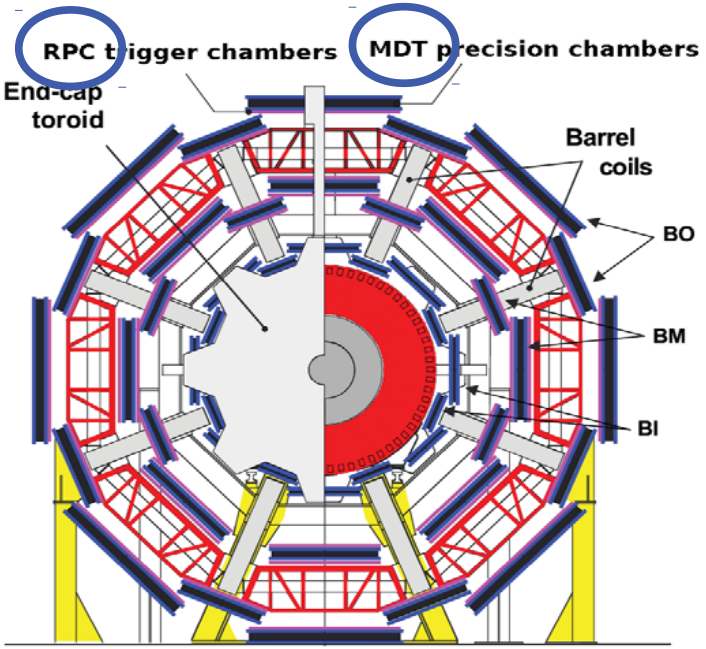
Non-decaying

- Penetrating, slow ID+Calo
- Penetrating, slow MuSp
- Stopping, highly ionising

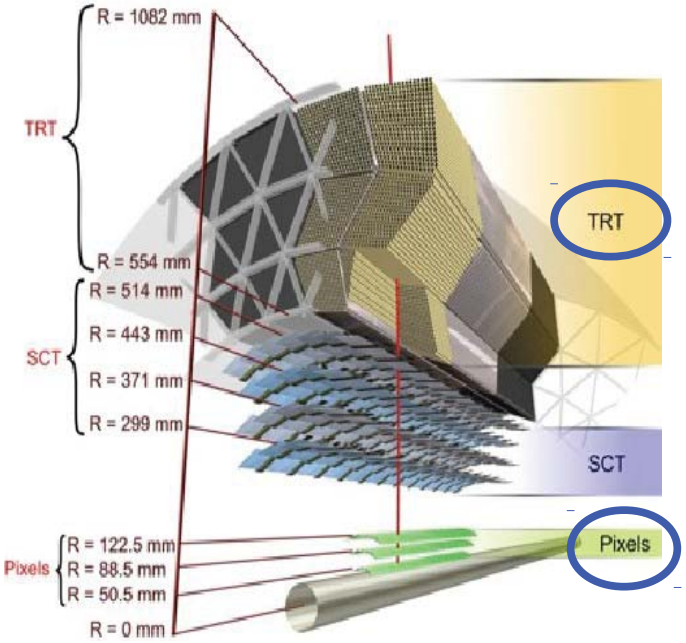
ATLAS subdetectors

- Long-lived particles often require non-standard reconstruction
- Timing is often an issue

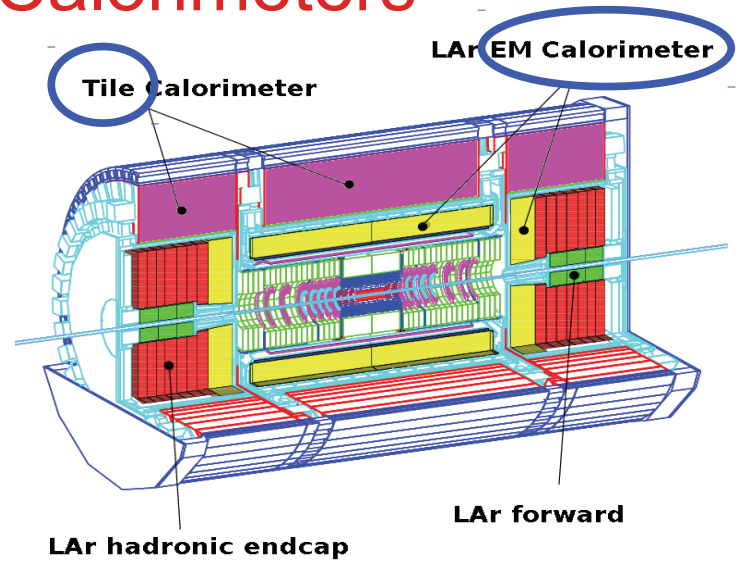
Muon Spectrometer (MuSp)



Inner Detector (ID)



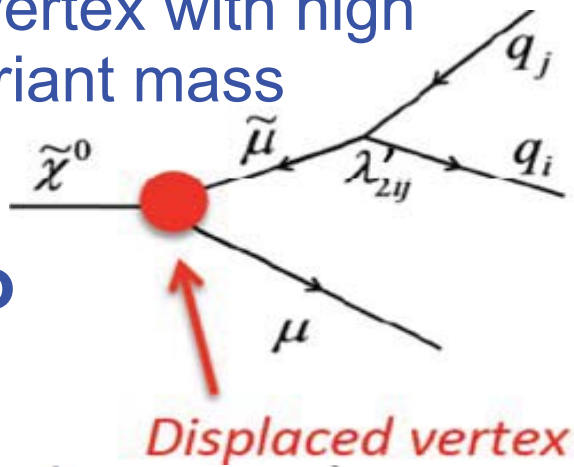
Calorimeters



Displaced vertices – introduction

Generic signature: muon (p_T > 45 GeV) and secondary vertex from tracks, with

- Large impact parameter, no hit prior to vertex
- $|z| < 300$ mm
- $r < 180$ mm → within ATLAS pixel detector
- Search for displaced (> 4 mm) vertex with high track mutiplicity and high invariant mass



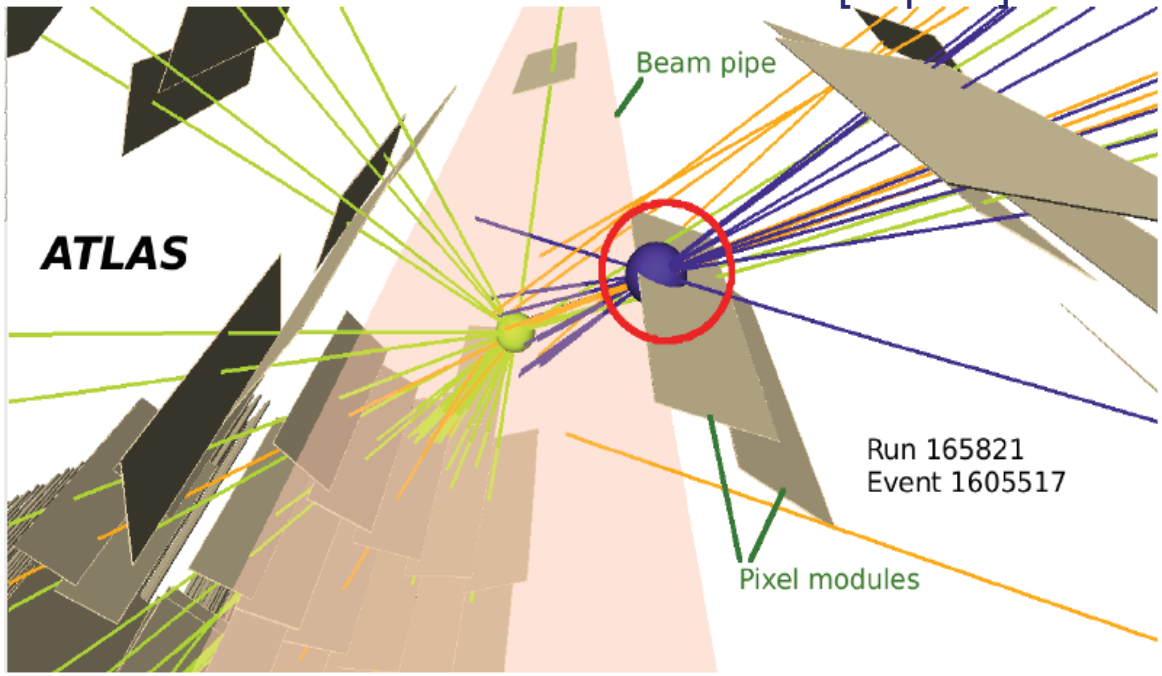
Intepreted in RPV SUSY scenario

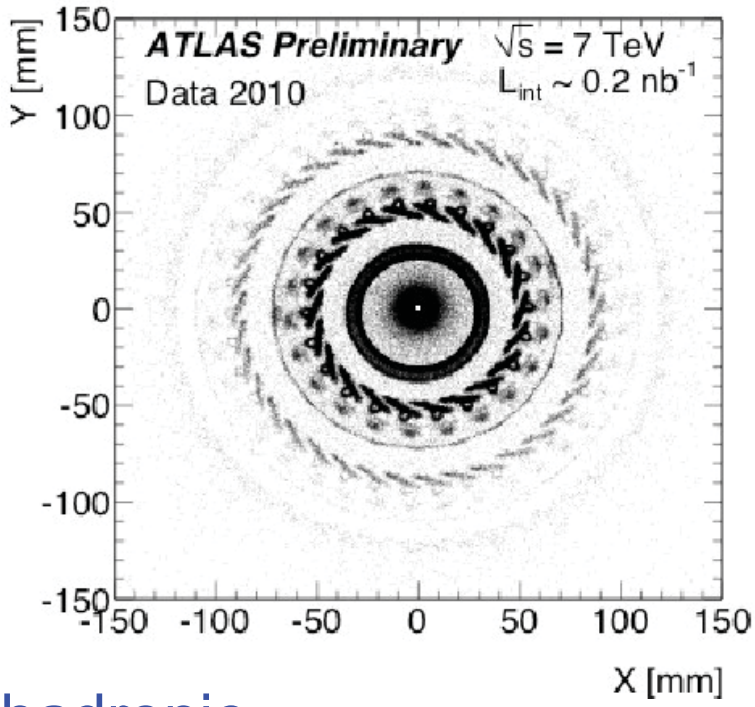
with non-zero λ' → L-violating

$$W_{\mathrm{RPV}} = \sum_i \mu_i L_i H_u + \sum_{i,j,k} \left(\frac{1}{2} \lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \frac{1}{2} \lambda''_{ijk} U_i^c D_j^c D_k^c \right)$$

Displaced vertices – material interactions

arXiv:1109.2242 [hep-ex]





Background vertices dominantly from hadronic interactions with detector material

- typically low mass, but coinciding track at large angle can result in high mass vertex

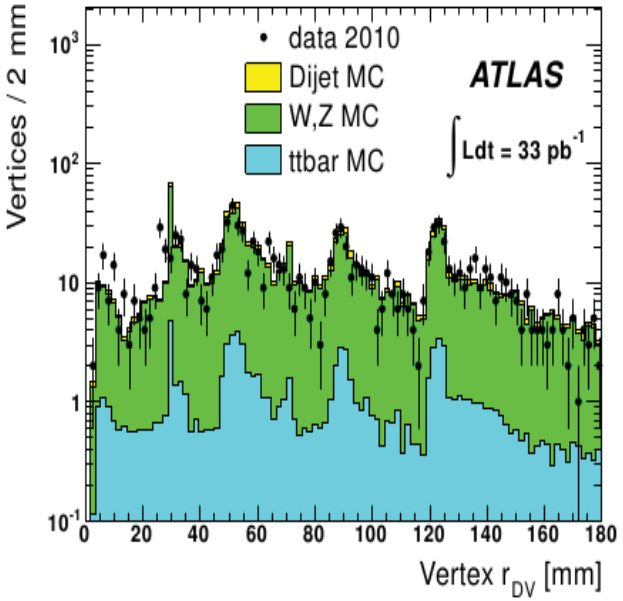
→ Veto vertex position with material map from 2010 data

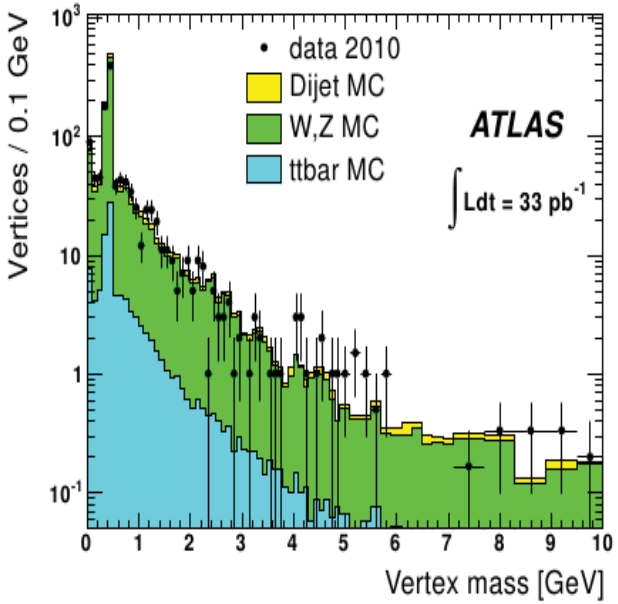
Displaced vertices – simulation vs. data

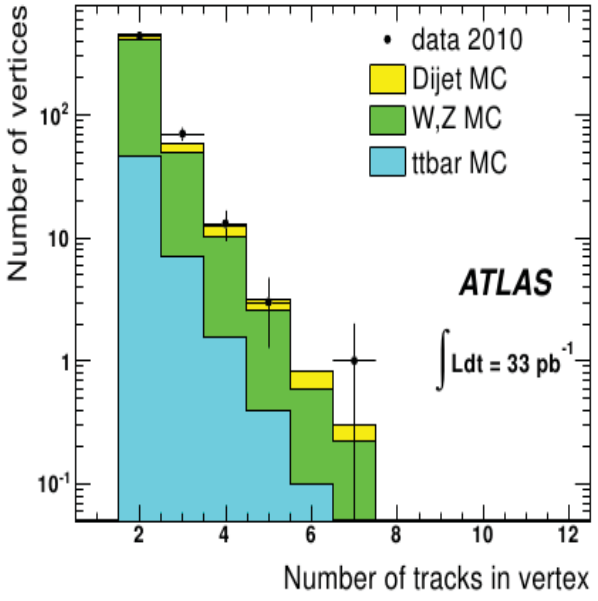
Loose selection for data/MC comparison

- Allow vertices with two tracks
- Low vertex mass (< 10 GeV)
- No material veto

arXiv:1109.2242 [hep-ex]



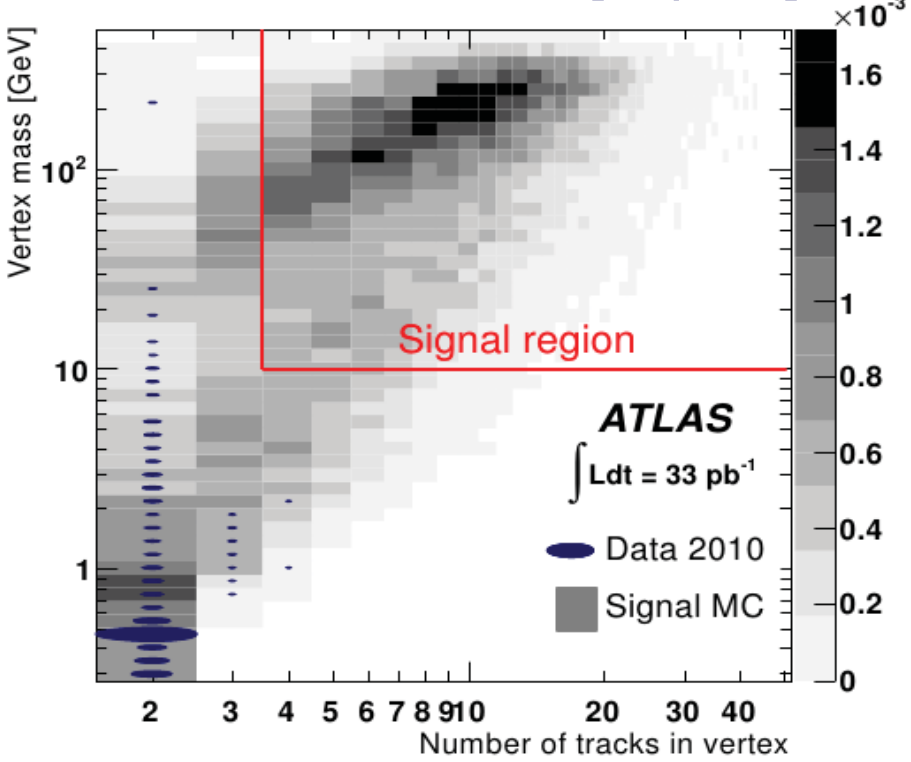


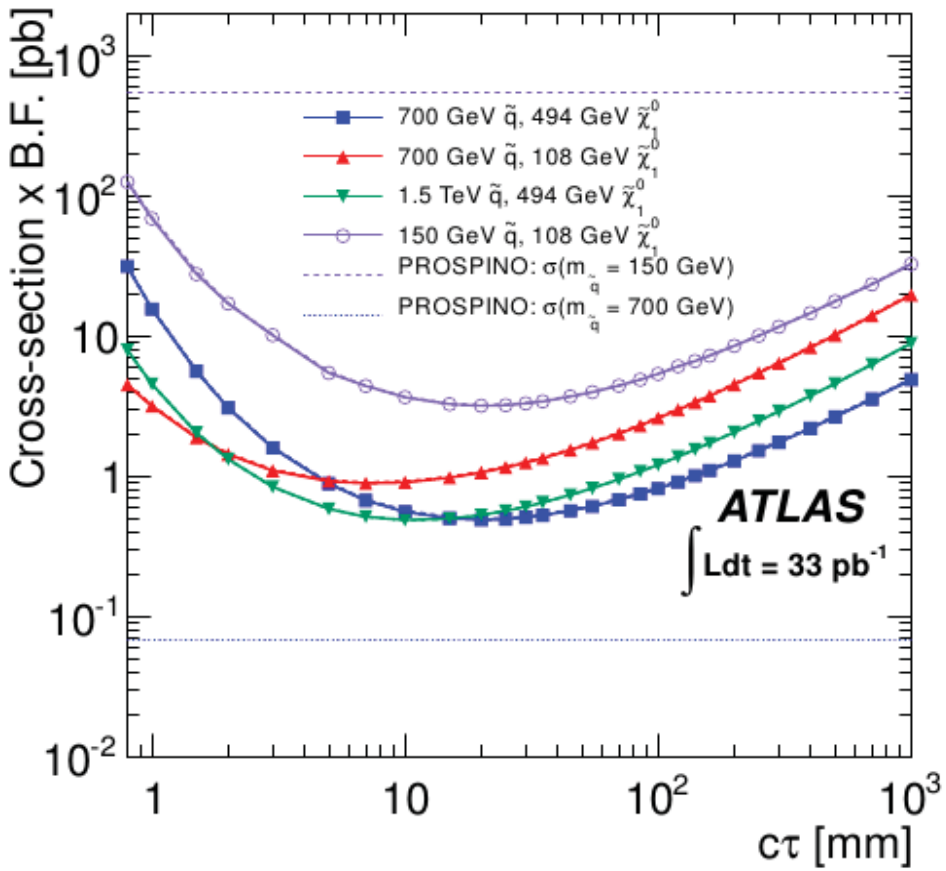


→ excellent agreement in shape and yield

Displaced vertices – results

arXiv:1109.2242 [hep-ex]





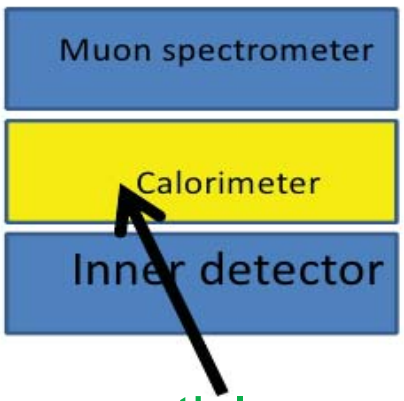
No events in signal region

- Tiny backgrounds

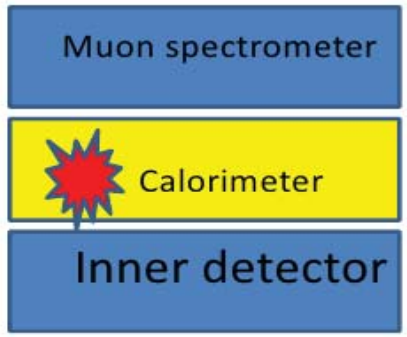
Upper limits at 95% c.l. as function of mean decay length for different SUSY mass splitting scenarios

Out-of-time decays – introduction

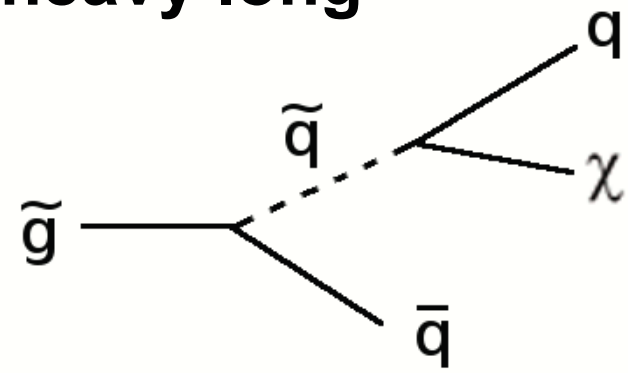
Generic signature: look for hadronic decays happening in the calorimeters in events without collisions → stopped heavy long-lived particle

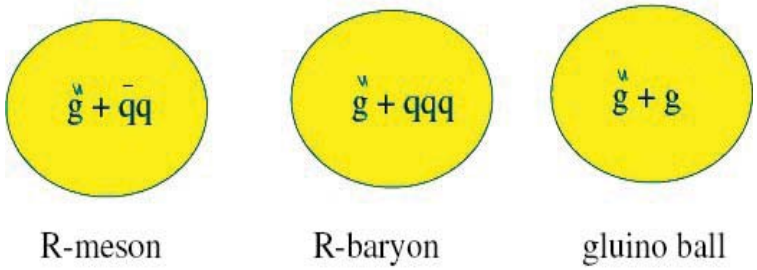


Slow particle stops in calorimeter



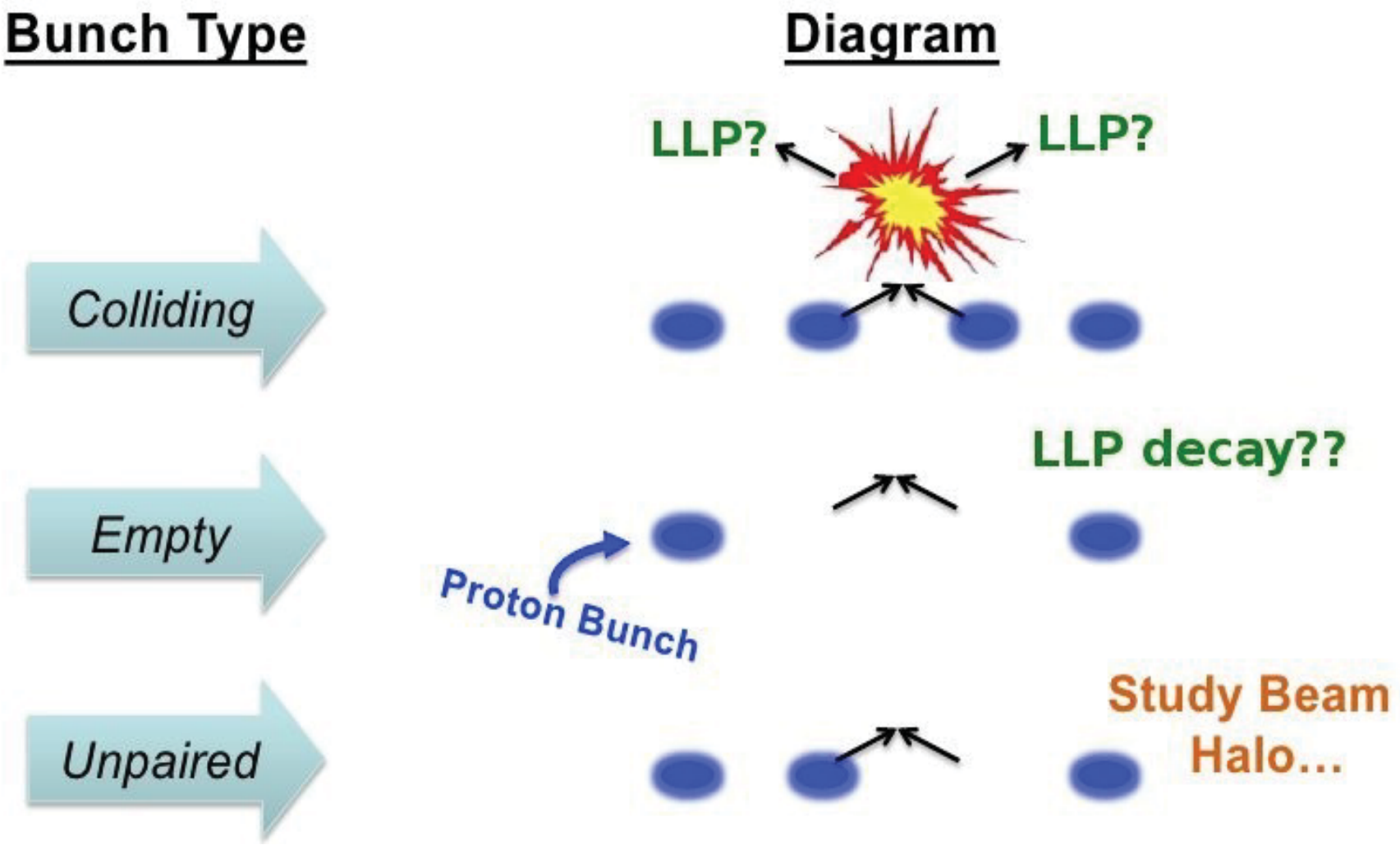
much later...



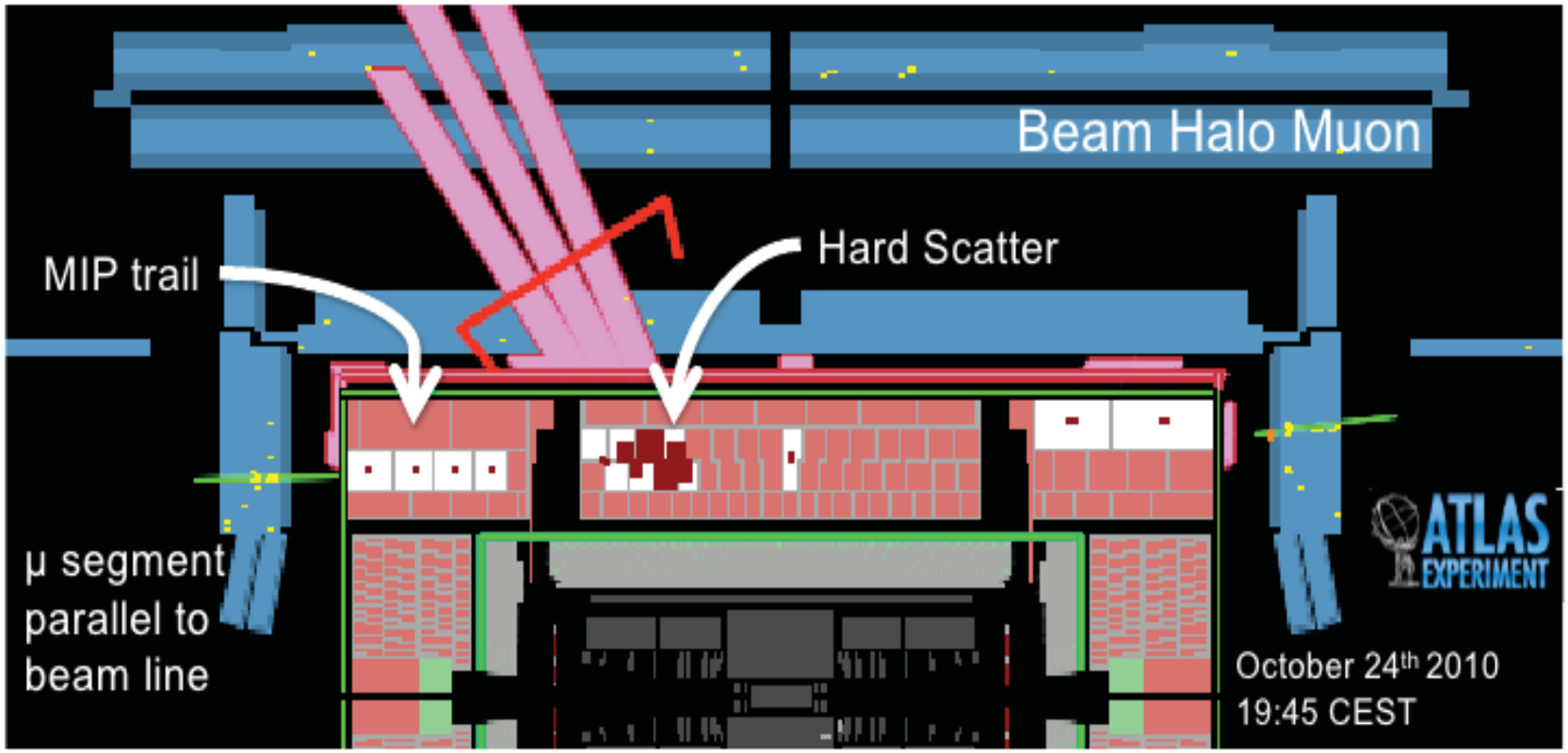


Intepreted in Split-SUSY scenario with metastable gluino (high squark mass) → late-decaying R-hadrons

Out-of-time decays – strategy



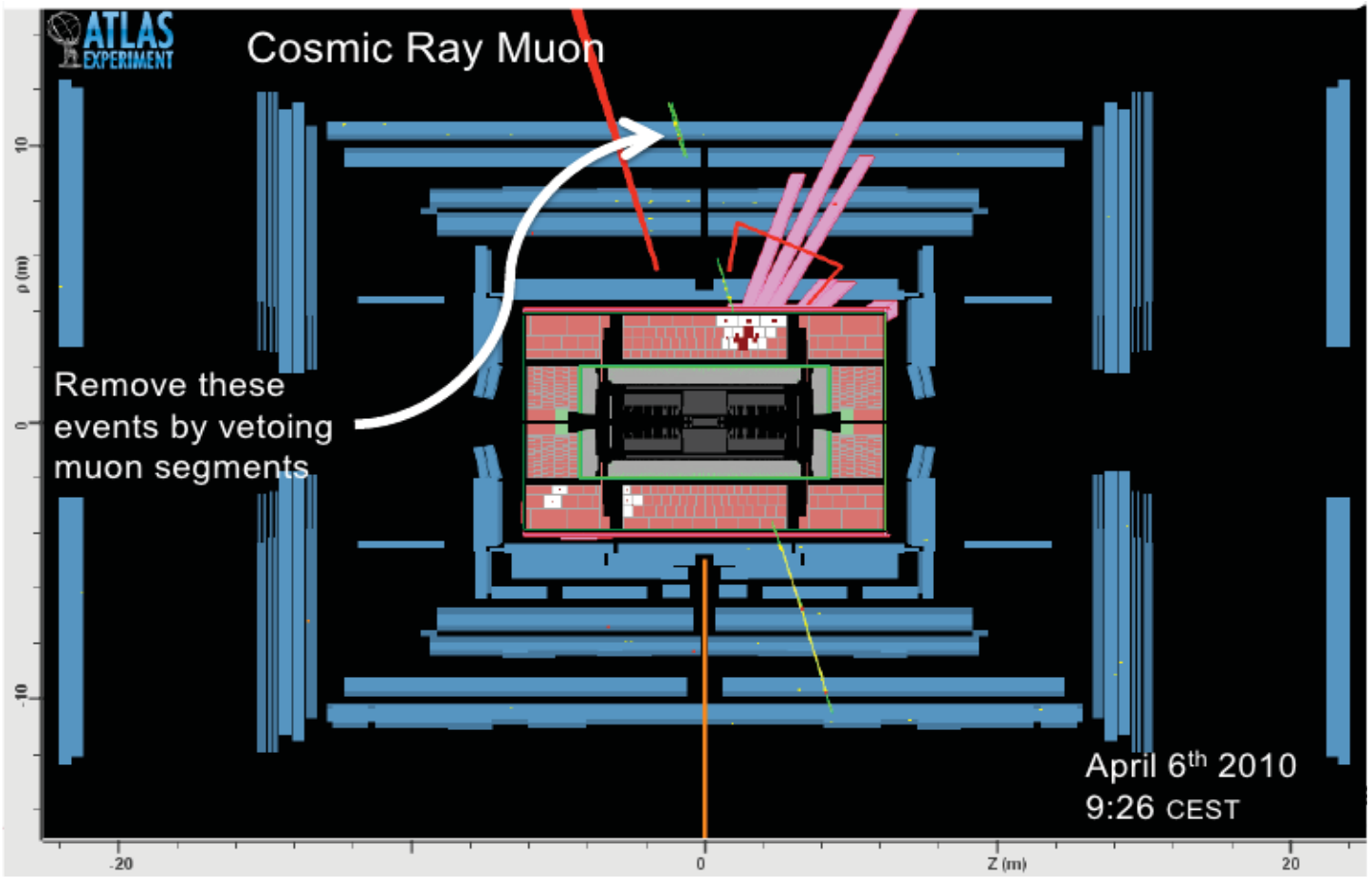
Out-of-time decays – beam halo bgd



- Scales with LHC vacuum, collimators, filling scheme etc.
- Rejected by veto on jet location and shape
- Negligible Contribution for the considered data sample, estimated from unpaired events (orthogonal sample)

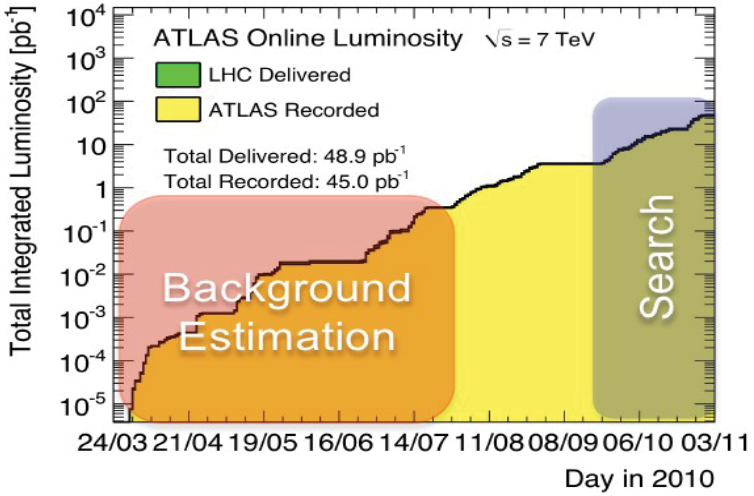
Out-of-time decays – cosmic bgd

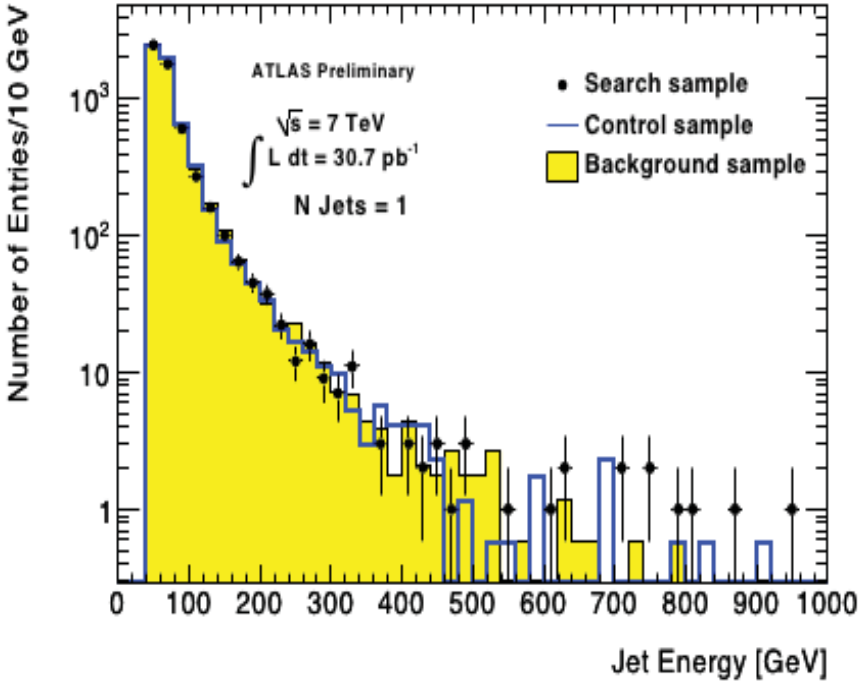
- Scales with time, not luminosity
- Rejected by veto on muon segments
- Measured with low-luminosity (~signal free) runs

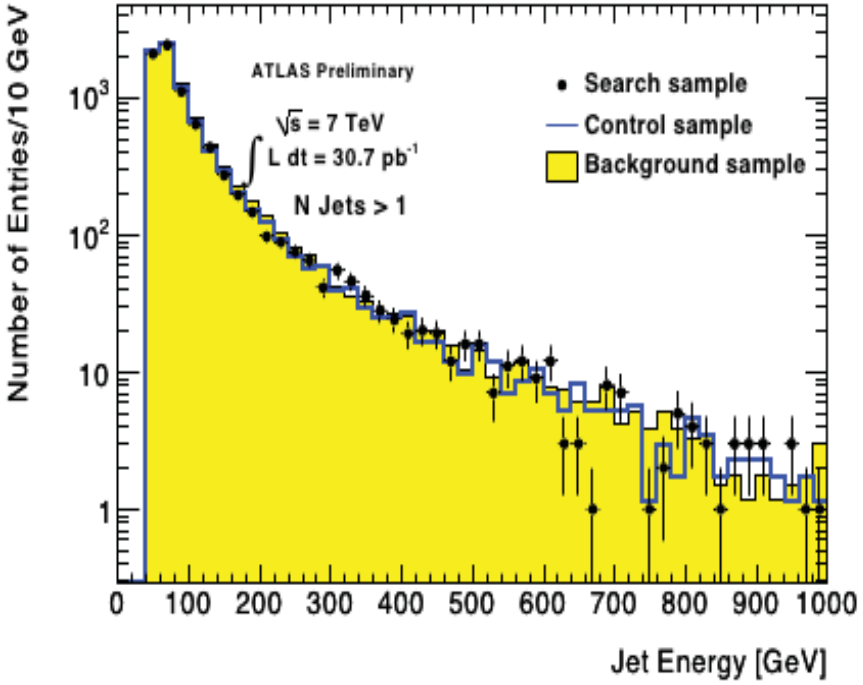


Out-of-time decays – results

- Search region: 30.7 pb^{-1}
- Excellent agreement with background sample scaled with time → dominated by cosmics





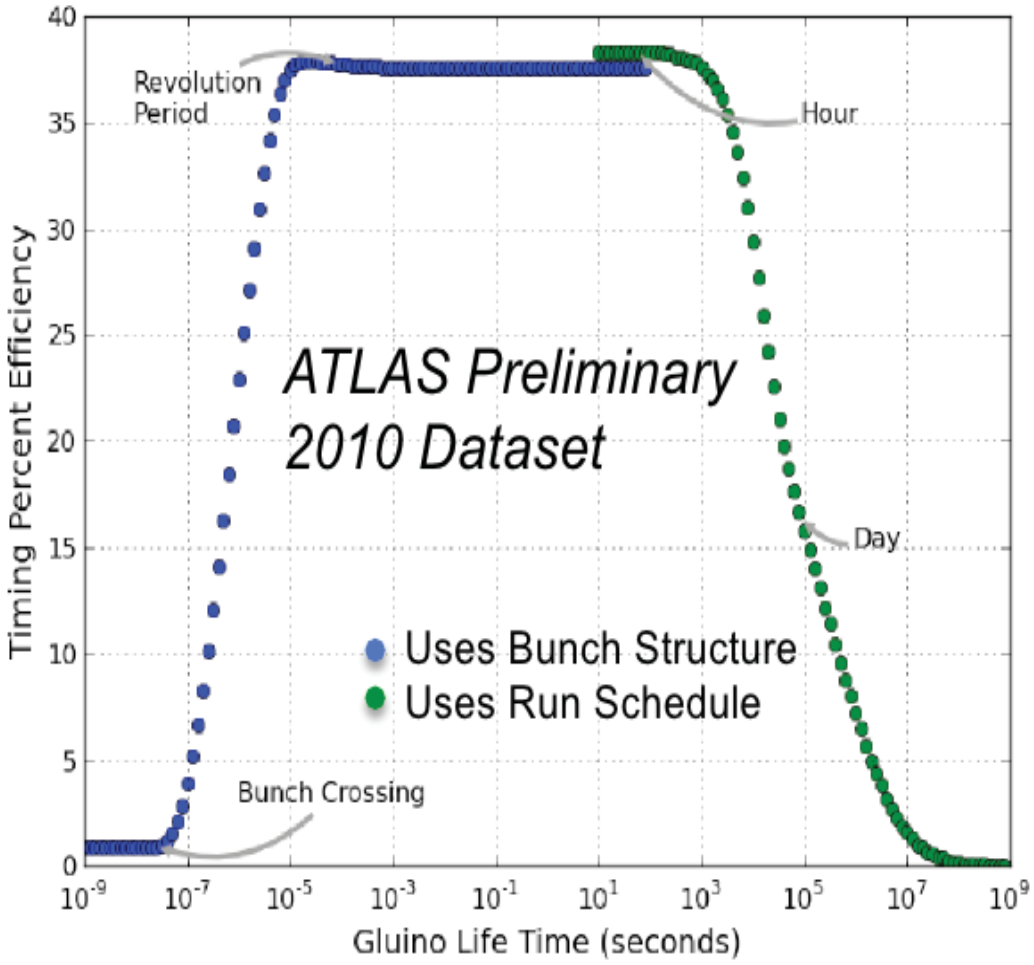


Out-of-time decays – sensitivity

Inefficiency sources:

- Stopping fraction
- Reconstruction
- Muon veto
- **Timing** → run duration and number of empty bunch crossings

37% efficiency when lifetime in range 10^{-5} – 10^{3} s

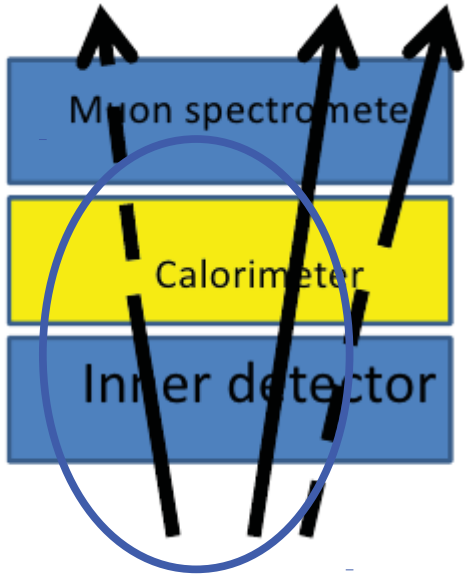


No excess → limits (not yet ready to show)

Non-decaying ID+Calo – introduction

Generic signature: track with high p_T, time delay and large dE/dx (slow-moving)

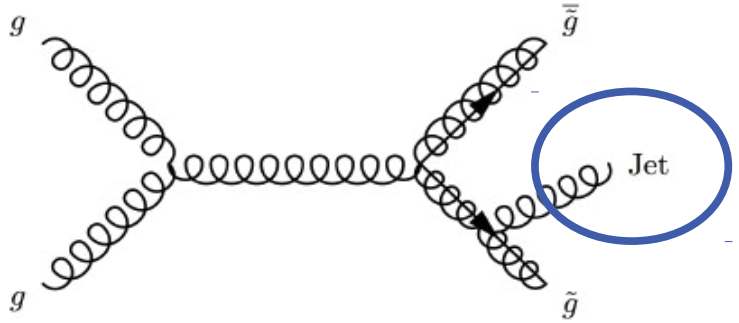
Intepreted as pair-produced massive long-lived coloured particle



- R-hadron can be dominantly neutral before ($\tilde{g}$ g) or after (charge exchange) calorimeter
- This search does not use muon spectrometer (muon-agnostic)
- Complementary MuSp-based search in a few slides...

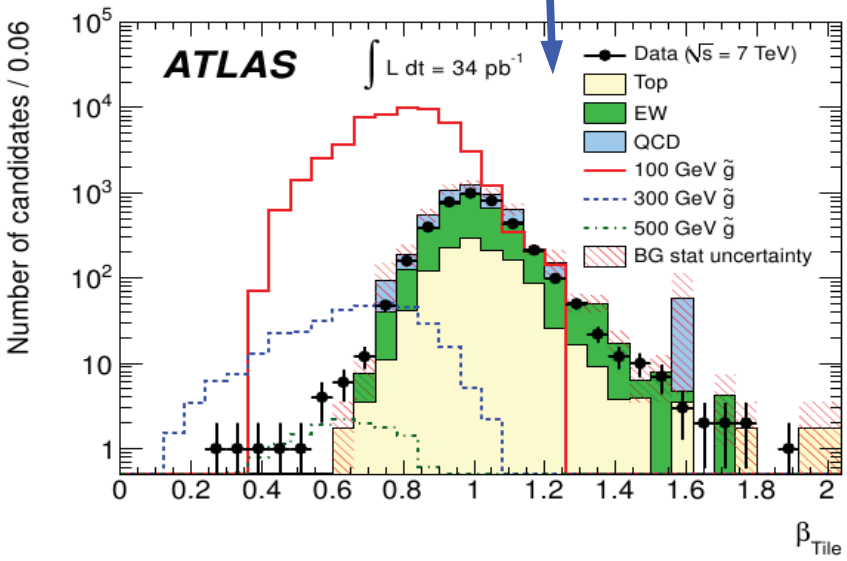
Non-decaying ID+Calo – selection

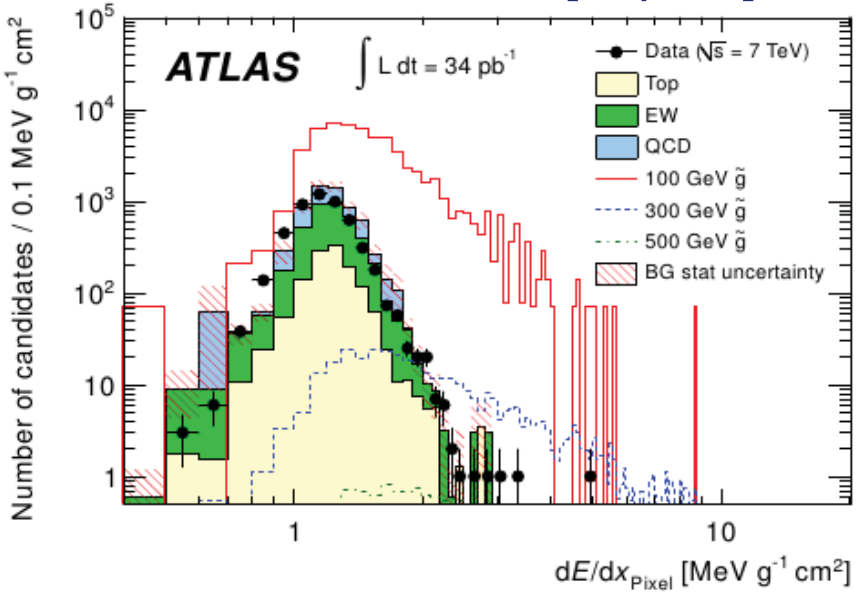
- **Preselection:**
  - E_T^{miss} > 40 GeV trigger
  - ID track with p_T > 50 GeV



- **Three complementary observables:**
  - TRT dE/dx as cross-check
  - Pixel detector dE/dx
  - Tile calorimeter β

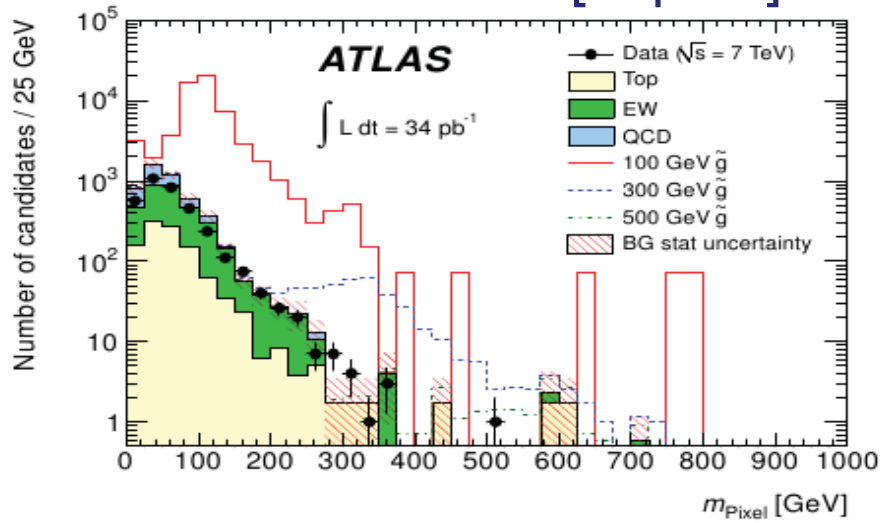
arXiv:1103.1984 [hep-ex]

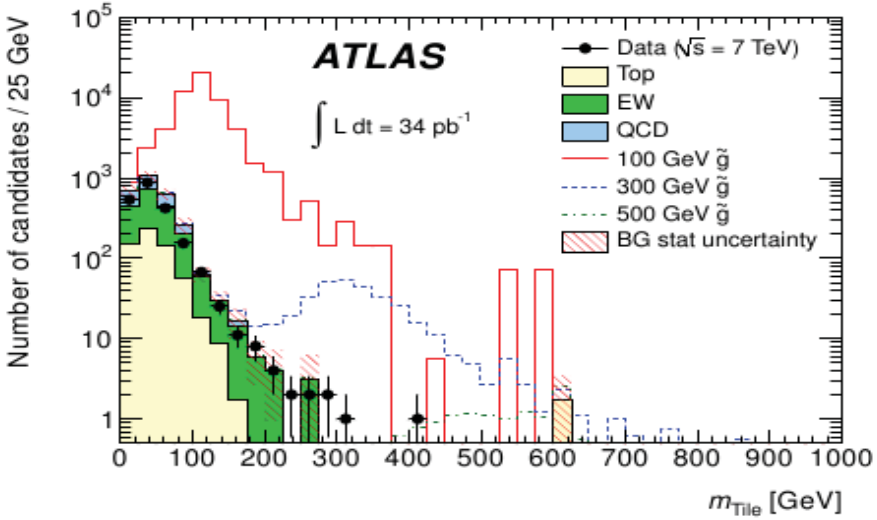


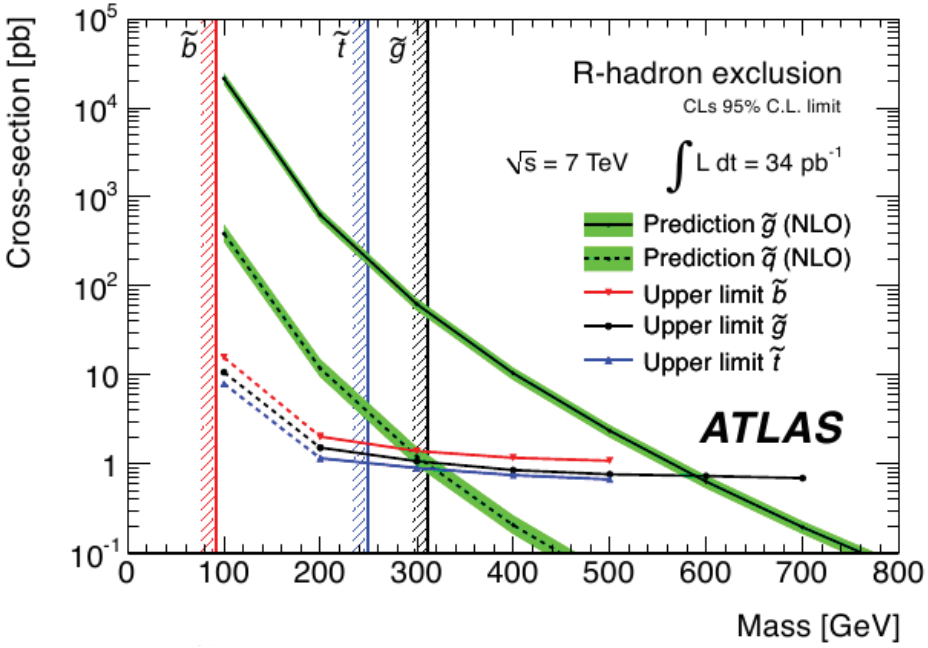


Non-decaying ID+Calo – results

arXiv:1103.1984 [hep-ex]







Data consistent with SM expectation, and with data-driven background estimate

Xs limits interpreted as mass limits for pair-produced:

- $\tilde{g}$ 562-586 GeV
- $\tilde{t}$ $(\tilde{b})$ 309 (294) GeV

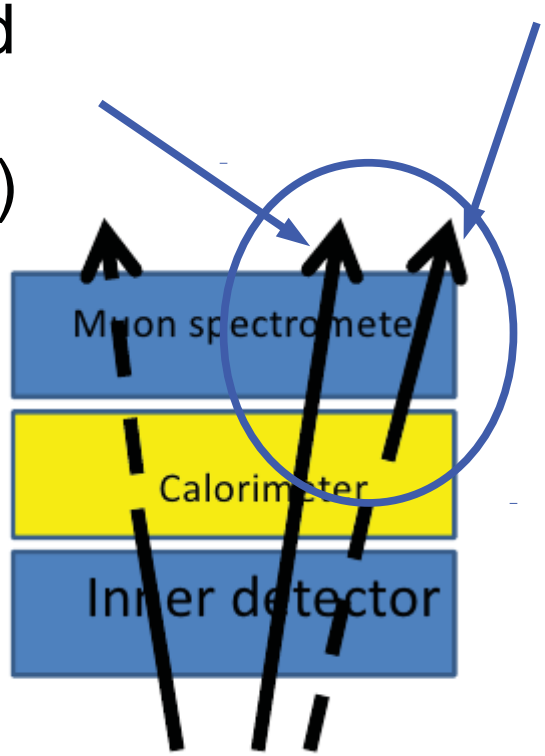
Non-decaying MuSp – introduction

Signature 1: combined ID+MuSp track, time-of-flight in MuSp+Tile

Interpreted in GMSB scenario (long-lived slepton visible throughout detector)

Signature 2: MuSp track, time-of-flight in MuSp

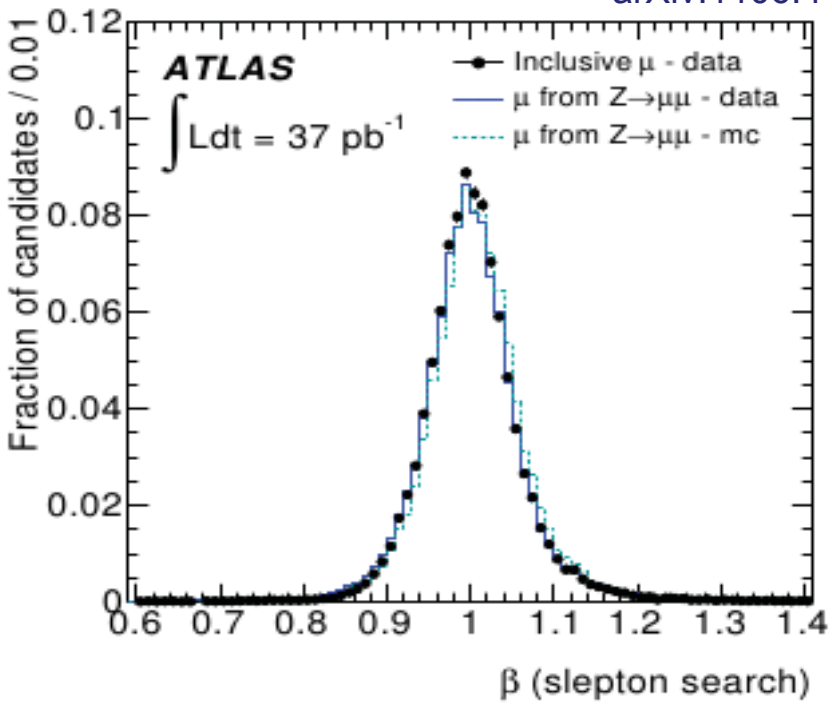
Interpreted in split-SUSY scenario (R-hadron may be charged only in MS)



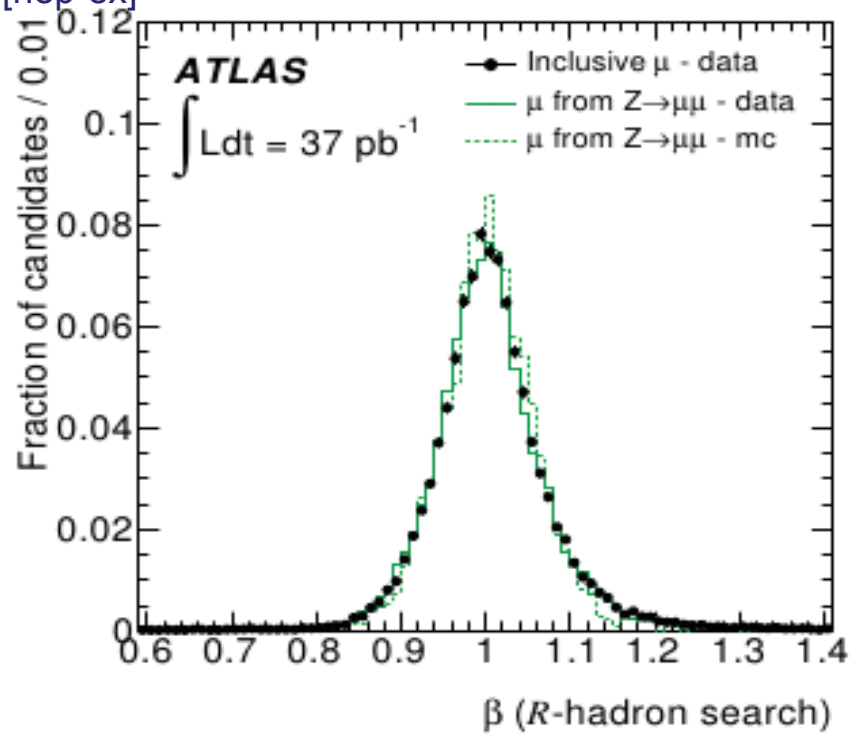
+ use muon trigger

Non-decaying MuSp – β estimators

MDT+RPC+Tile arXiv:1106.4495 [hep-ex]



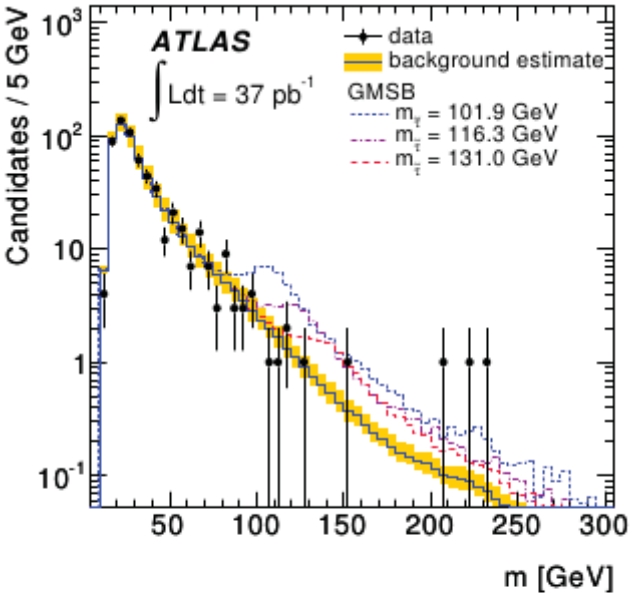
MDT+RPC (MuSp track only)

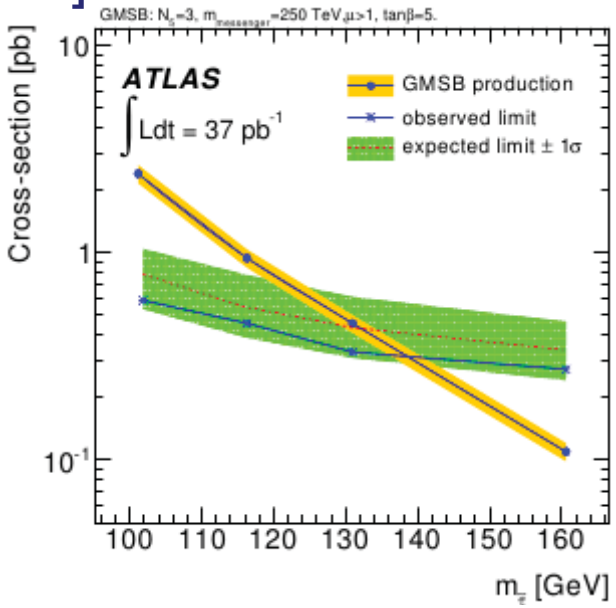


- Control samples from $Z \rightarrow \mu\mu$ to monitor intrumental backgrounds
- β resolution ~0.05

Non-decaying MuSp – results

arXiv:1106.4495 [hep-ex]



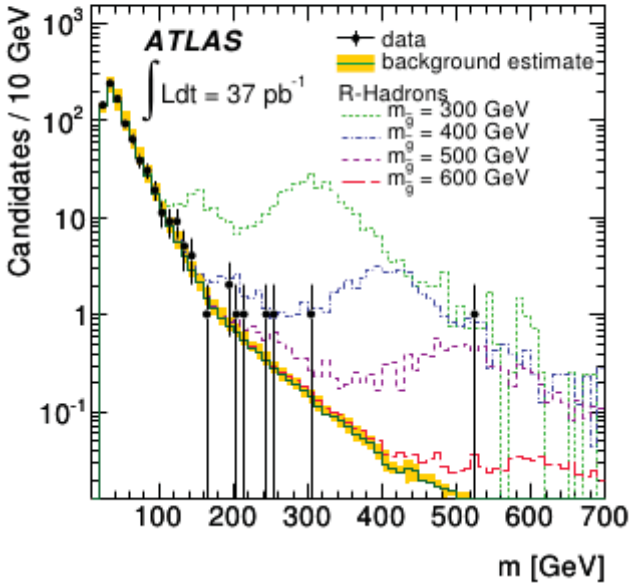


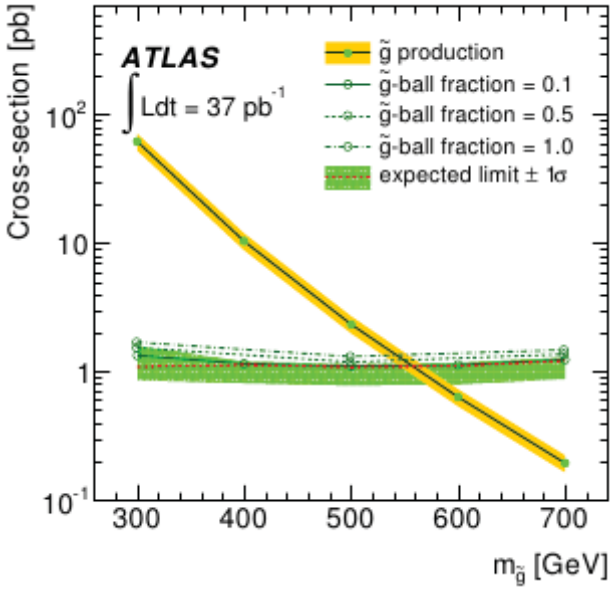
GMSB scenario

$\tilde{\ell}$ mass (95 % CL)

>136 GeV (all prod.)

> 110 GeV (EW prod.)





$\tilde{g}$ mass (95% CL)

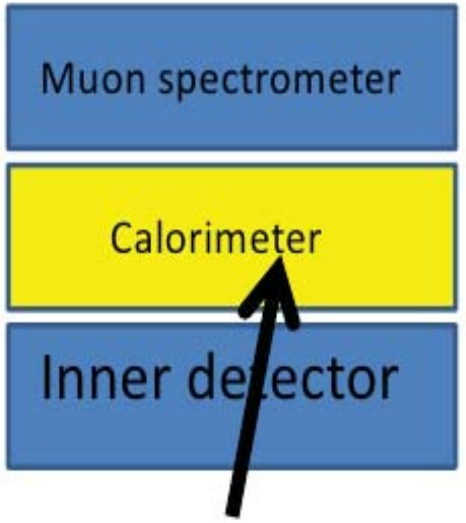
> 544 GeV ($f_{\tilde{g}g} = 0.1$)

> 537 GeV ($f_{\tilde{g}g} = 0.5$)

> 530 GeV ($f_{\tilde{g}g} = 1.0$)

Highly Ionising Particles – introduction

Generic signature: reconstructed electron with very high-ionisation track and very narrow EM cluster



Intepreted as multi-charged long-lived particle stopping in EM calorimeter

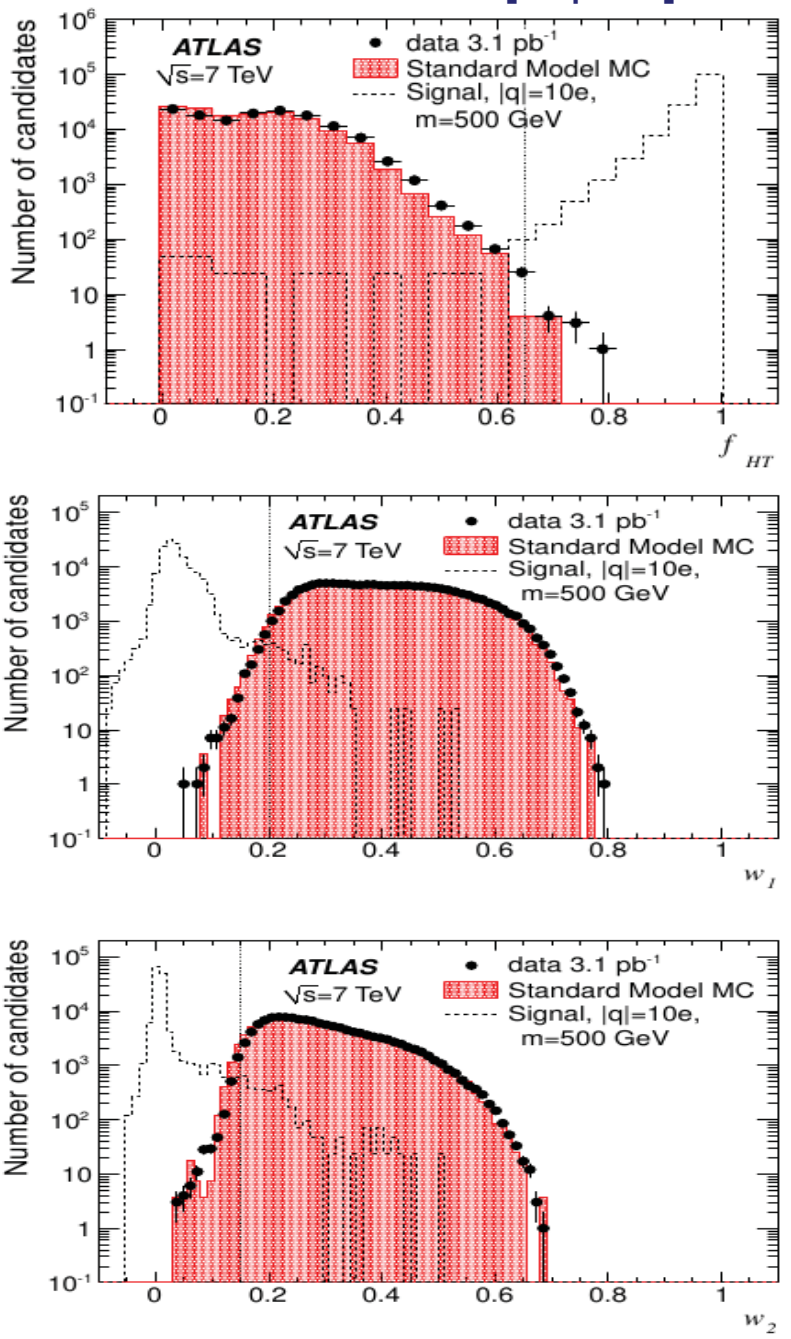
- Sensitive to electric charge in the range 6*e* – 17*e*
- *Early search* (summer 2010, 3.1 pb^{-1})
- *Blue sky search,* motivated by detector capibility rather than speculative theory

HIPs – selection

(applied to electron candidates with $|\eta| < 1.35$, $E_T > 15$ GeV)

- Independent variables:
  - fraction of TRT high-threshold hits on track
  - lateral extent of EM calorimeter energy deposition in first and second layers
- Number of selected events in data: 0
- Data-driven background estimate: 0.019 ± 0.005

arXiv:1102.0459 [hep-ex]



HIPs – cross section limits

arXiv:1102.0459 [hep-ex]

- In fiducial ranges of (η,E_{kin}) (pb, 95% c.l.)

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

Model-independent!

- For Drell-Yan fermion pair production (pb, 95% c.l.)

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

- First (and so far only) HIP search at LHC energies

Results summary

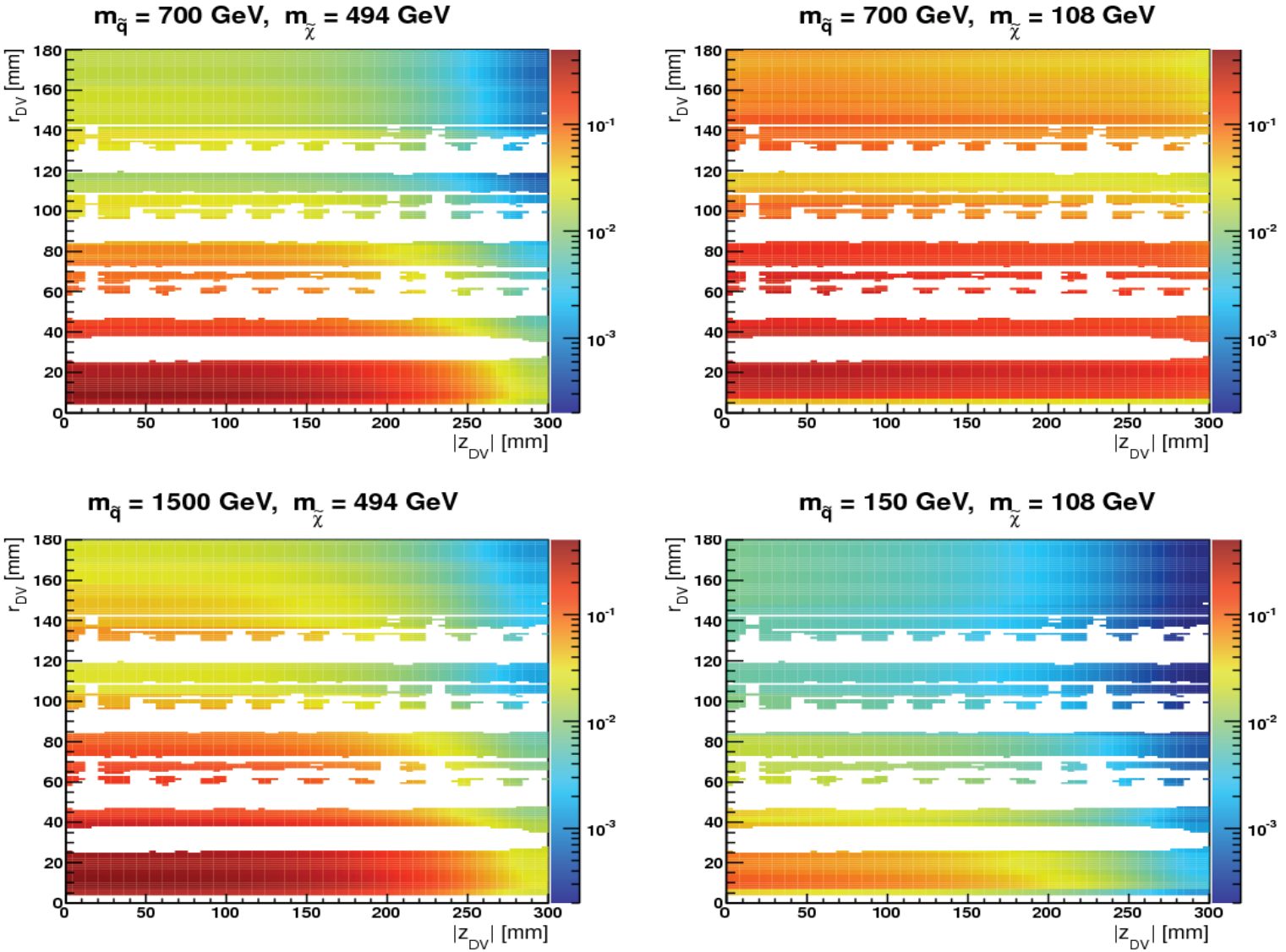
- Displaced vertices (decay after 4 – 180 mm)
  - Most stringent limits to date in the context of RPV SUSY with non-zero λ'
- Out-of-time decays (10 μs – 1000 s after stopping)
  - No excess in the data
- Slow-moving, penetrating LLPs
  - Agnostic approach: covered ID only, Muon only and ID+Muon signatures
  - Severe constrains over large mass ranges for various types of objects (lepton, triplet, octet)
- Highly ionising particles
  - Novel, model-independent search, constrains electric charges $6e \leq |q| \leq 17e$ and masses up to 1 TeV

Outlook – ATLAS work in progress

- Updates of work shown above
  - Improved analyses
  - Increased integrated luminosity (> 1 fb^{-1})
- Kinked/disappearing tracks
  - e.g. in SUSY AMSB with long-lived chargino
- Displaced jets or lepton-jets
  - e.g. from long-lived dark boson in hidden sector
- Muon candidates with anomalous dE/dx
  - e.g. from multiply or fractionally charged particles
- Many TRT HT hits in a cone around EM cluster
  - e.g. from magnetic monopoles
- And more...

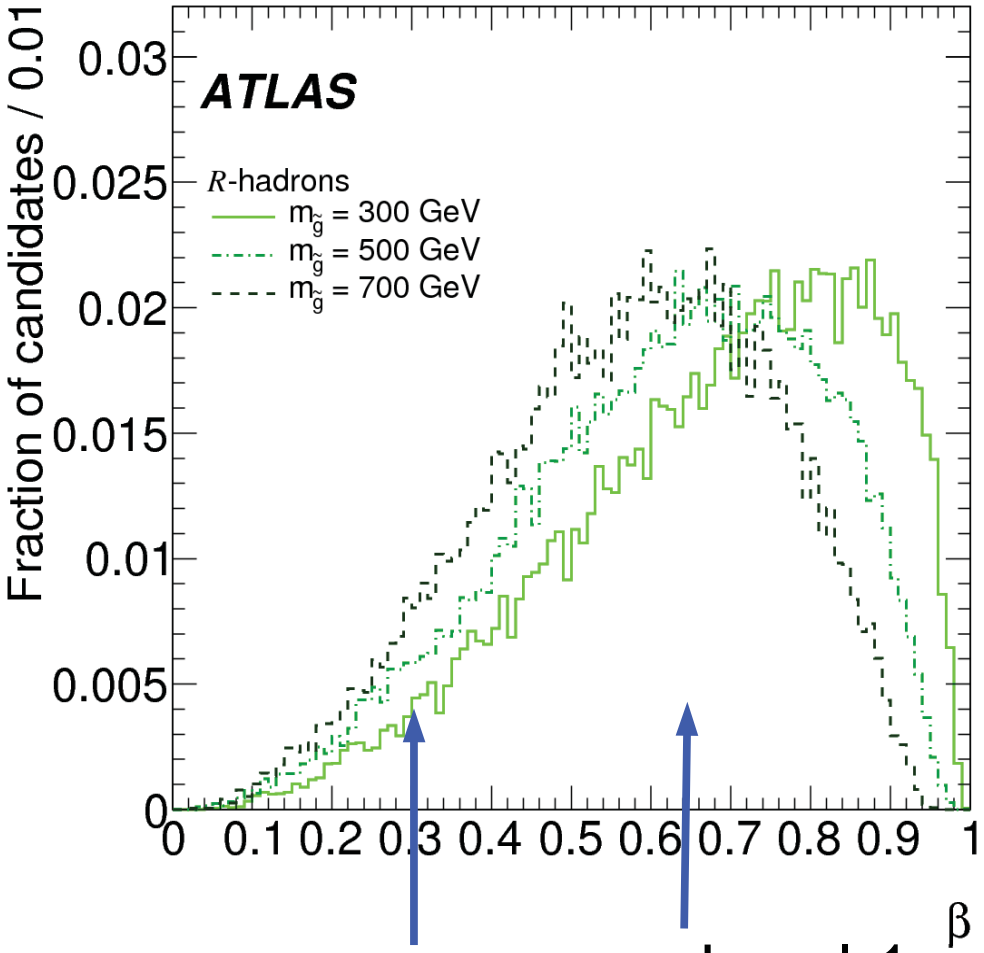
Extra slides

Displaced vertices – efficiencies



ATLAS *simulation*
preliminary

R-hadron generated β distributions



Late arrival can affect efficiency:

- Pulse integration window
- Proton bunch crossing assignment

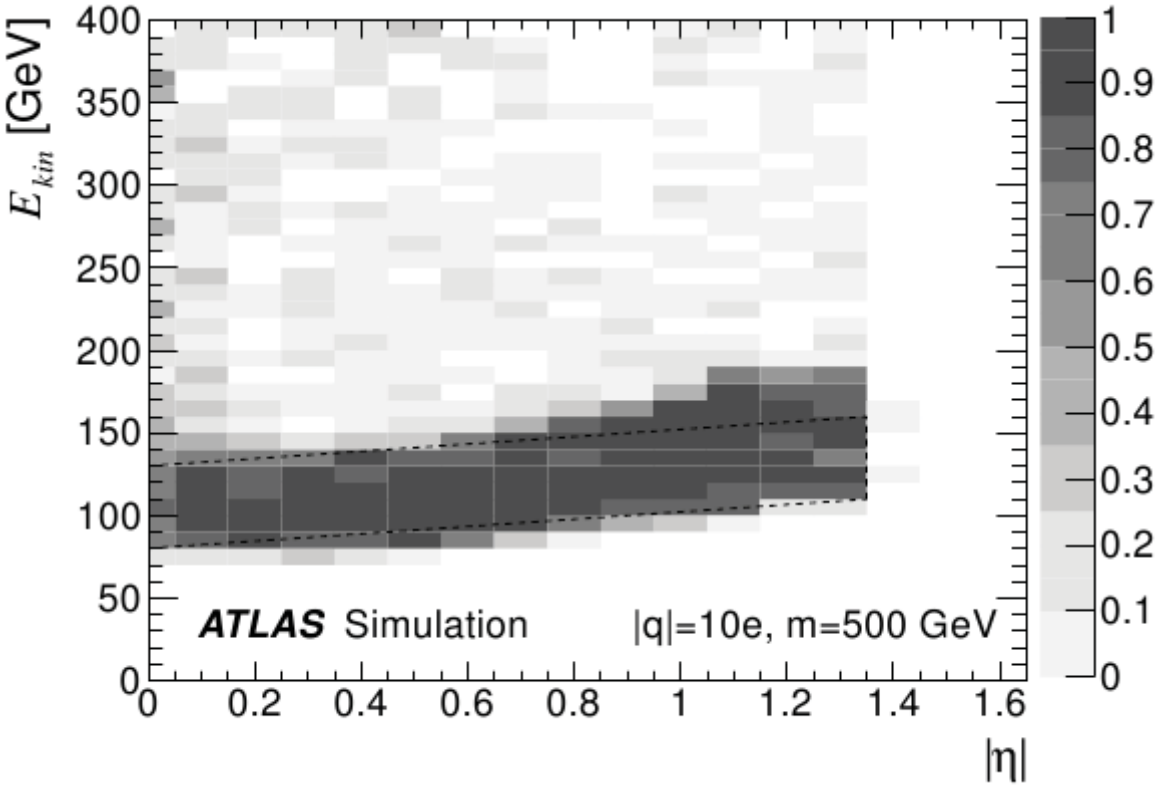
Tile measurement (MET trigger)

Level-1 muon trigger

Stopping HIPs – efficiencies

Major source of inefficiency comes from acceptance (probability to stop in second layer of EM barrel)

- Depends on model of kinematics



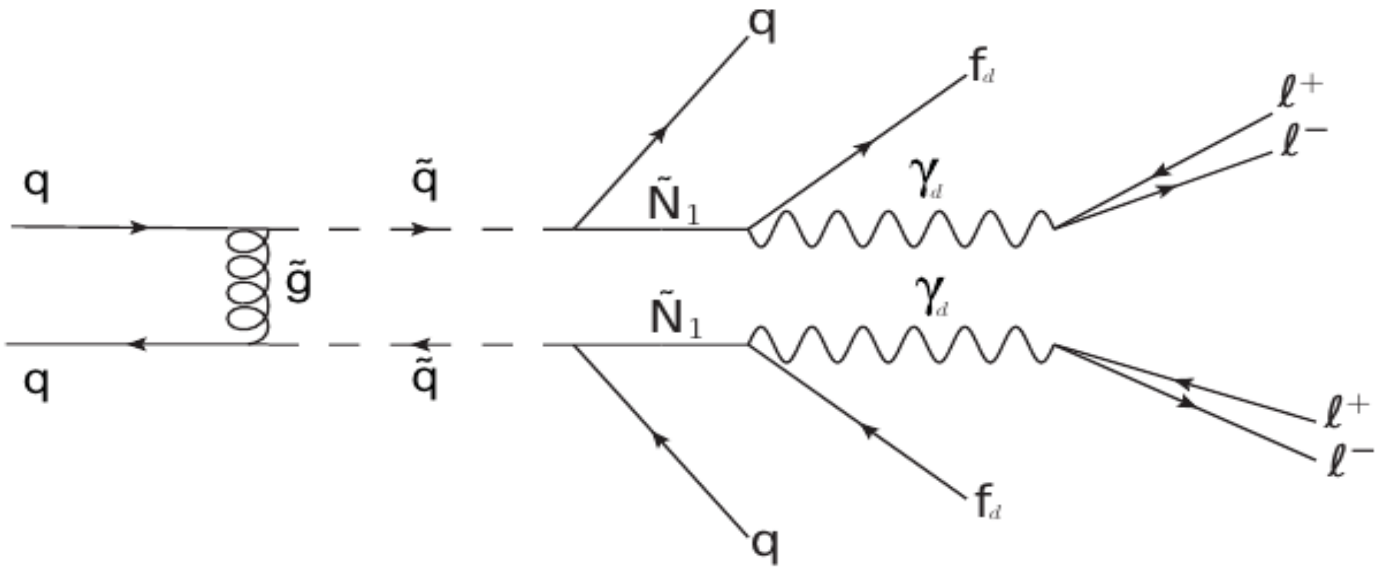
In specific kinematic ranges, signal selection efficiency estimated from MC is flat, around 80%

→ Model-independent approach

Prompt muon-jets – introduction

Generic signature: at least two isolated jets of at least two collimated muons

Intepreted in hidden-sector scenario with LSP decaying into dark photon and dark fermion



Prompt muon-jets – results