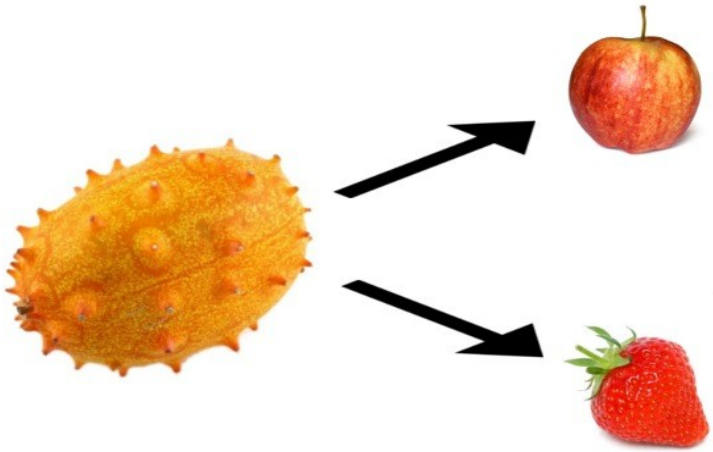
ATLAS searches for exotic decays

Philippe Mermod (University of Geneva)
on behalf of the ATLAS Colaboration

LPCC Workshop on
implications of LHC results for TeV-scale physics
CERN, 29 March 2012



Exotic particles

Weaknesses of the Standard Model:

- Unification of forces
- Dark matter
- Fine-tuning/naturalness
- Matter-antimatter asymmetry
- Three generations of quarks and leptons
- Many free parameters

SUSY?

Hidden valley?

GUT?

Compositeness?

Etc. – most models include new particles of various kinds

ATLAS exotic decay signatures covered in this talk

- **Photon + two leptons**
  - Interpreted as excited lepton
- **Two jets + two leptons (or lepton+neutrino)**
  - Interpreted as leptoquark pair
- **Two highly-displaced jets**
  - Interpreted as long-lived hidden-valley pseudoscalar pair

These are <u>benchmark models</u>.
Other interpretations are possible!

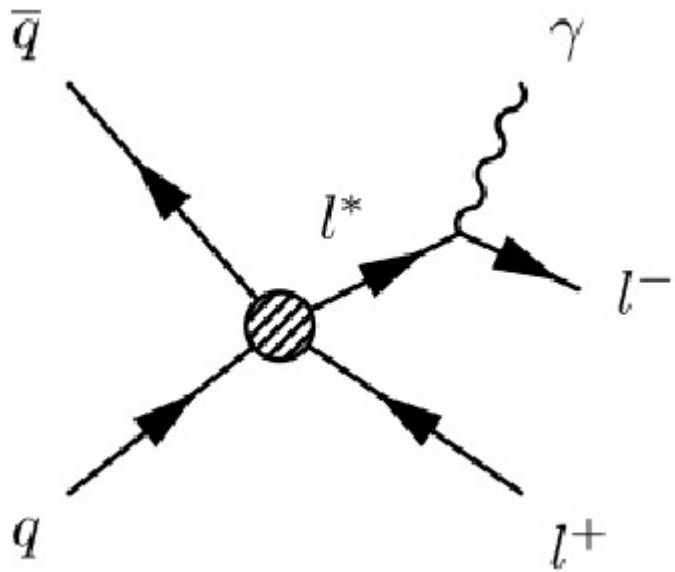
Excited leptons

Search with 2 fb^{-1} arXiv:1201.3293

Update with 5 fb^{-1} ATLAS-CONF-2012-008

Signature: one photon and two leptons (electrons or muons), with high invariant mass

Interpreted as excited (composite) lepton produced via contact interaction, decaying into lepton + γ

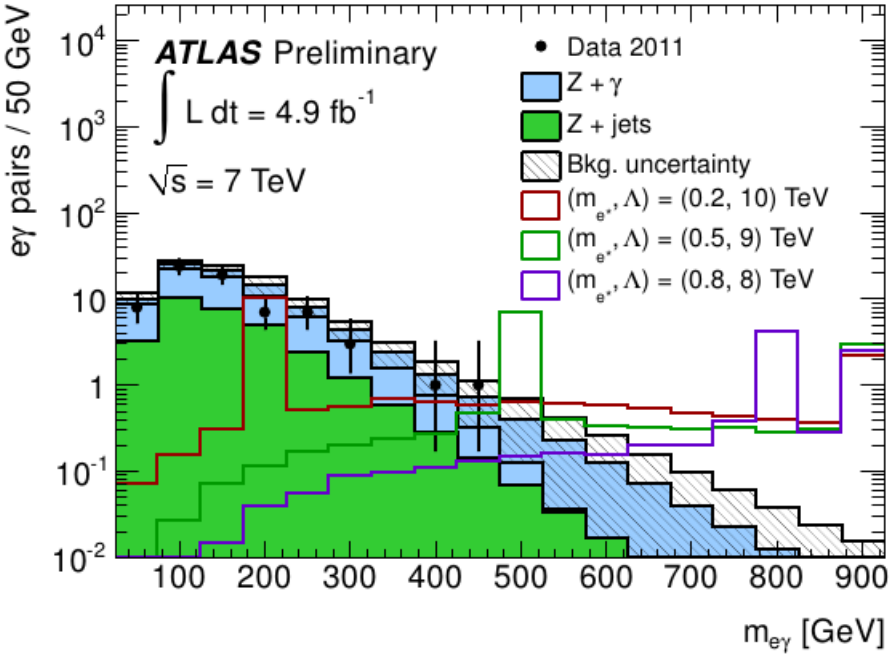


Model-dependent cross section and event kinematics

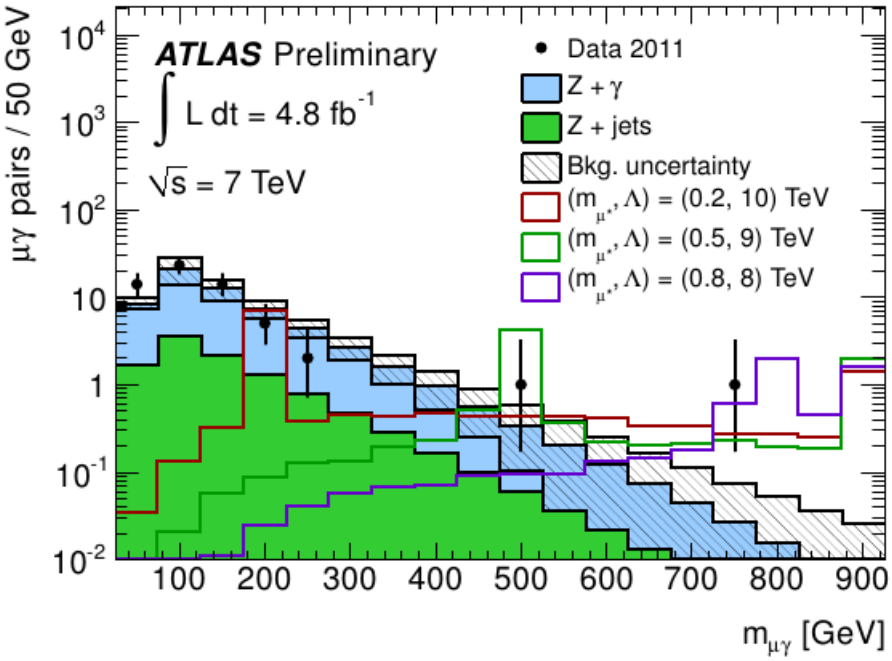
Contact-interaction model is very general, reflects our ignorance of preon dynamics

Excited leptons – two-body signature

Electron channel



Muon channel

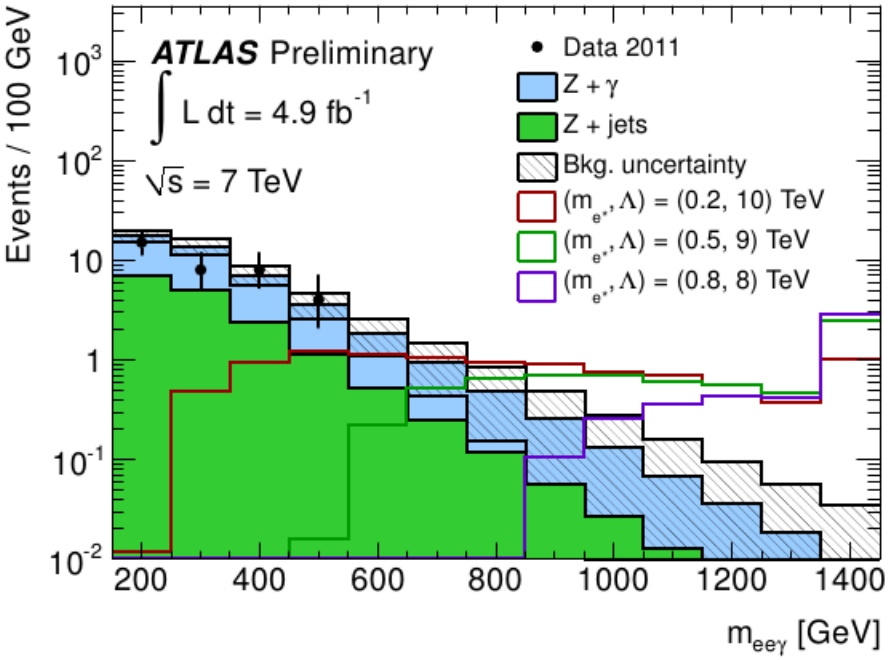


Peak in lepton-photon invariant mass

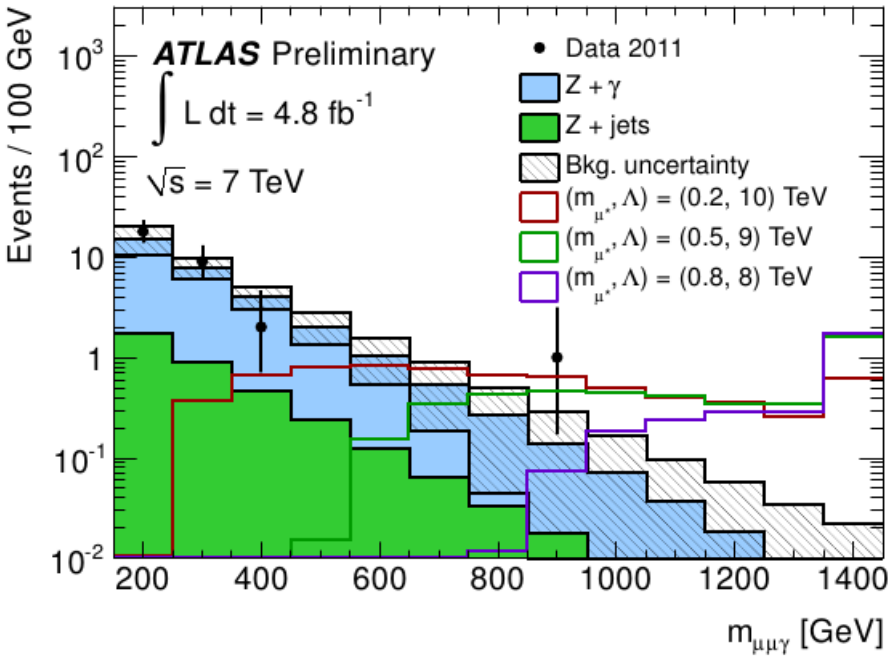
Caveat: which of the lepton to associate with l*?

Excited leptons – three-body signature

Electron channel



Muon channel



→ Use llγ invariant mass

Excited leptons – backgrounds

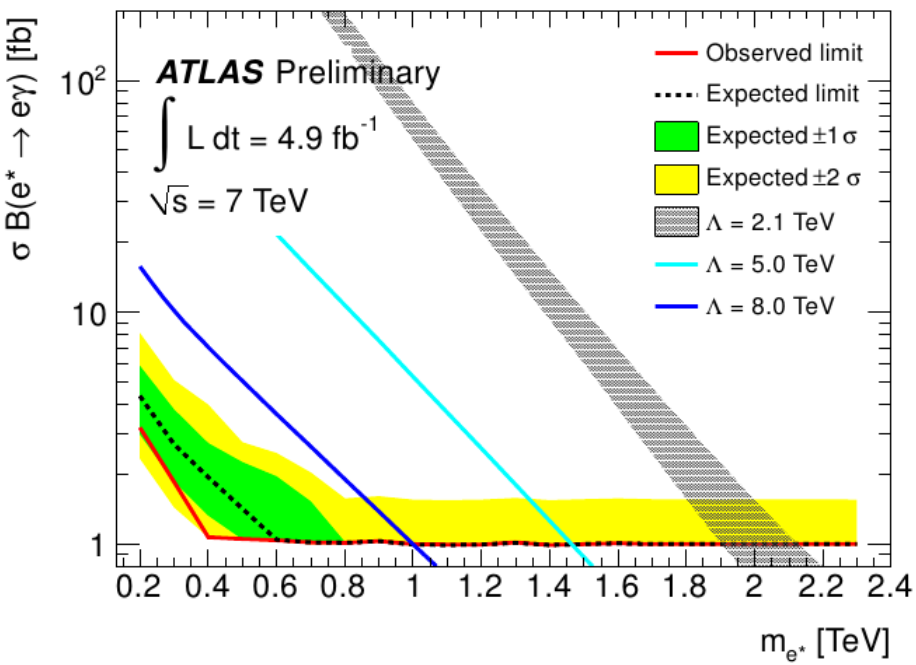
DY+γ and DY+jets backgrounds normalised to data in Control region of low dilepton invariant mass:

Region [GeV]	$Z+\gamma$	$Z+$jets	other	data
$m_{ee} < 110$	195 ± 2	115 ± 16	4.9 ± 0.6	315
$m_{ee} > 110$	32 ± 1	13 ± 3	4.5 ± 0.6	43
$m_{\mu\mu} < 110$	148 ± 2	101 ± 13	4.6 ± 0.6	254
$m_{\mu\mu} > 110$	20 ± 1	2.6 ± 0.9	0.4 ± 0.4	30

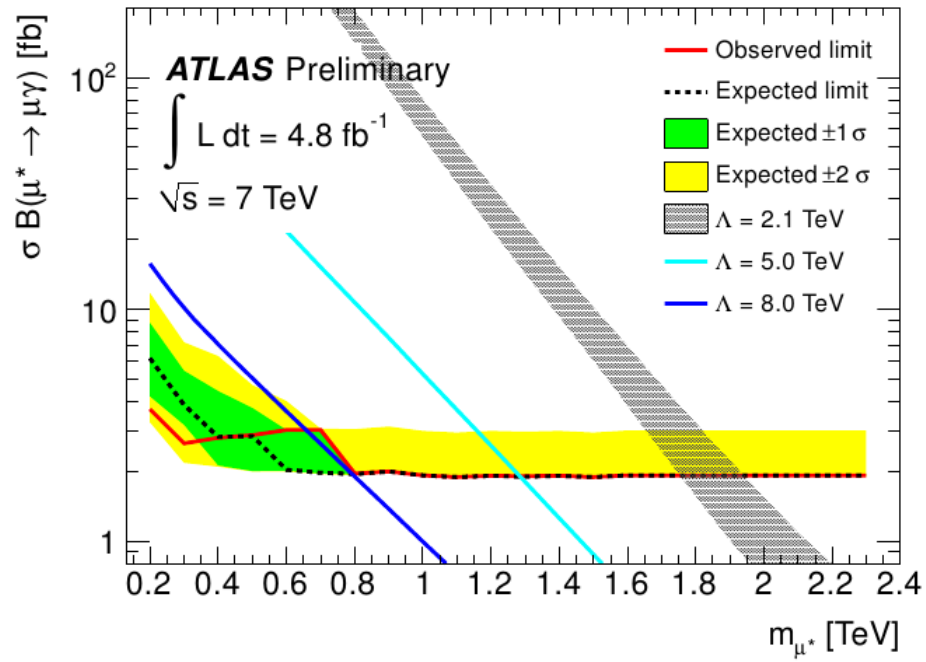
Data yields in signal region consistent with background expectations

Excited leptons – results

Electron channel



Muon channel



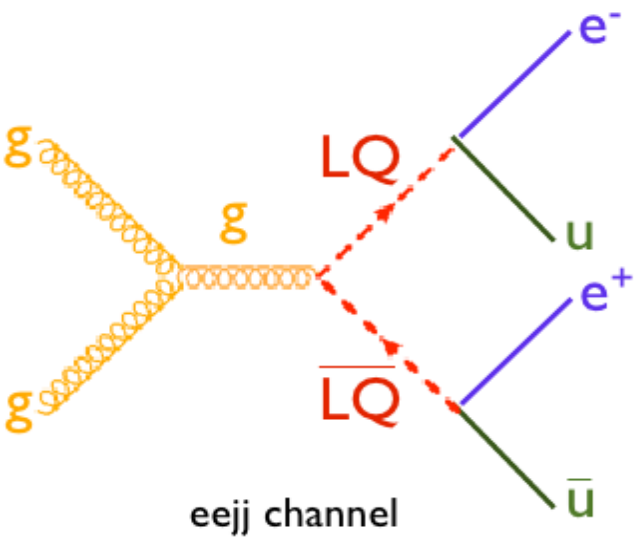
Cross section times BR limits as functions of excited lepton mass, compared with contact-interaction predictions with various compositeness scales Λ

Leptoquarks

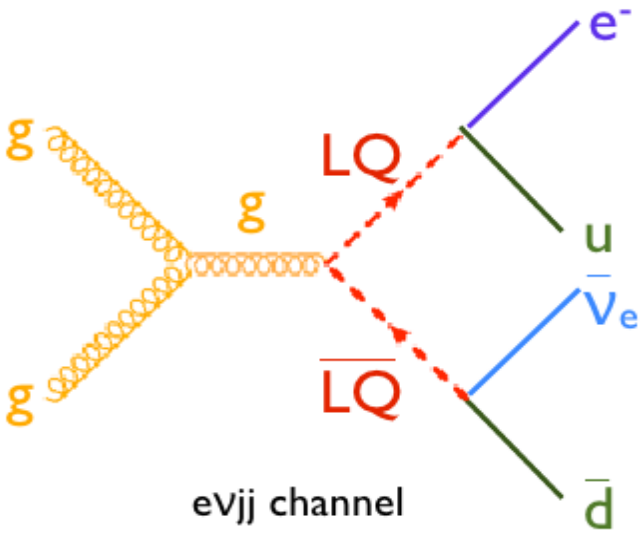
First generation: LQ → ej Phys. Lett. B709, 158 (2012)
Second generation: LQ → μj arXiv:1203.3172

Signature: two jets and two leptons OR two jets and one lepton and MET, with high invariant mass of jet-jet and lepton-lepton combinations

Interpreted as pair production of scalar colour triplets carrying both L and B numbers (leptoquarks)



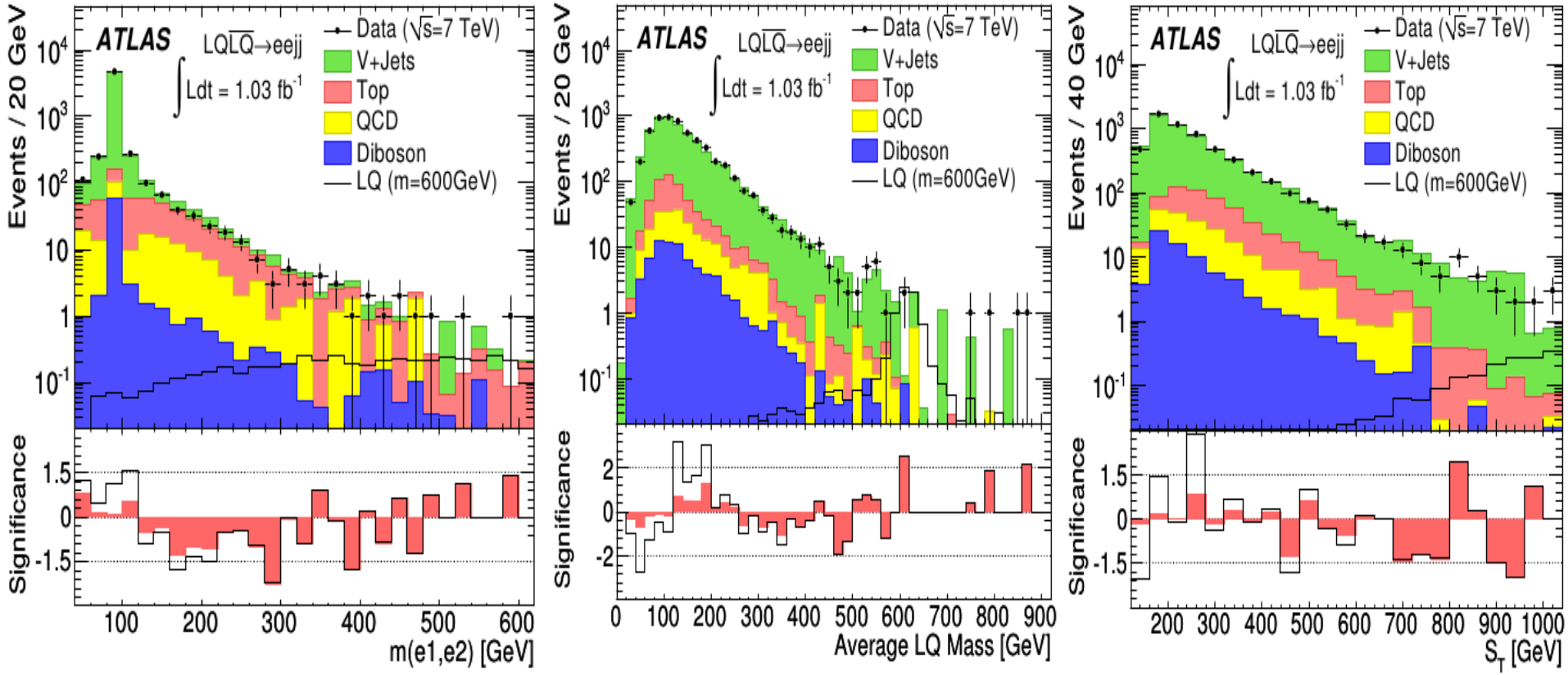
eejj channel



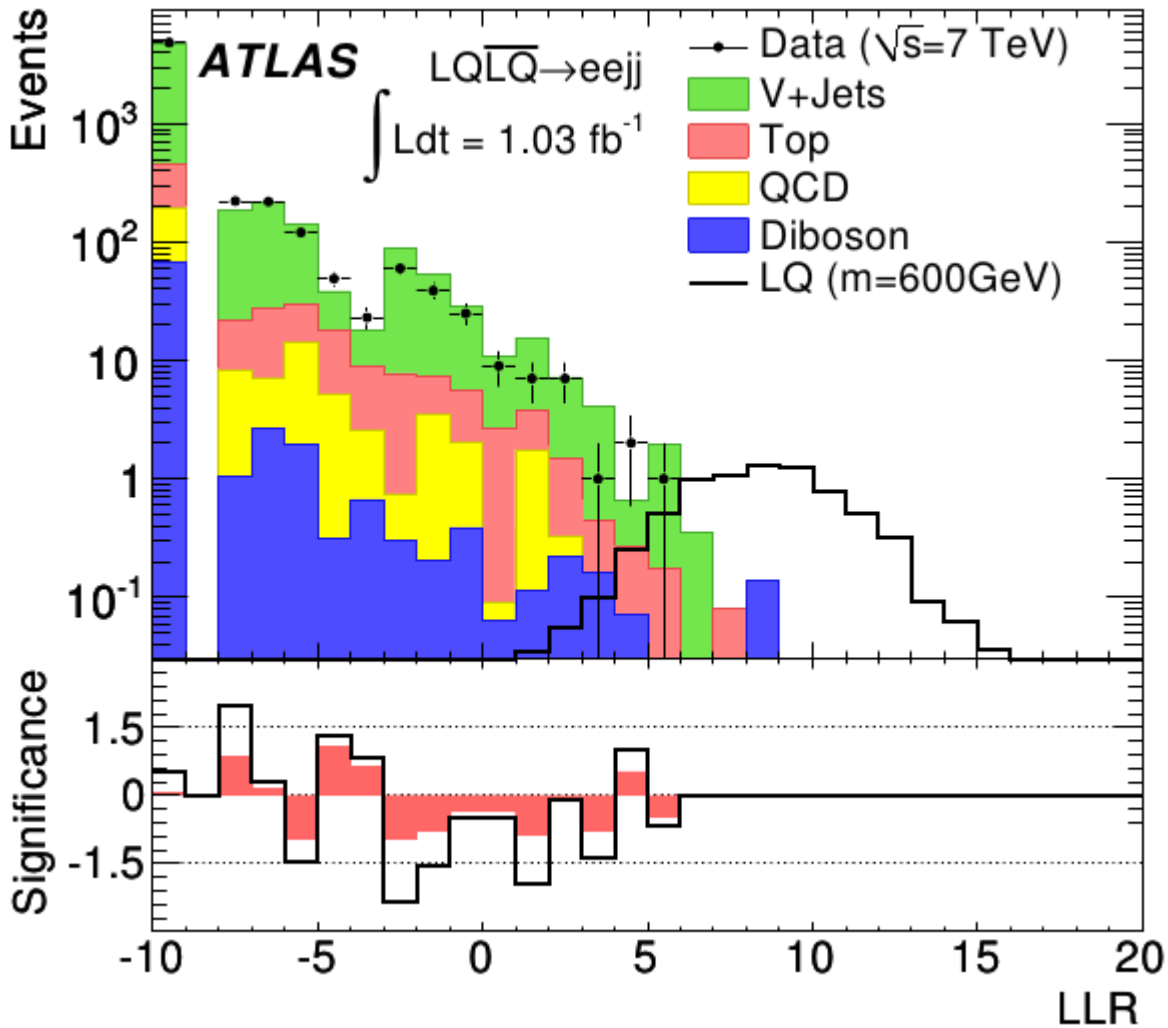
eνjj channel

Leptoquarks – selection

- Two leptons and two jets with ET>30 GeV each
- Three discriminating variables:
  - Invariant mass of the leptons
  - LQ (lepton+jet) invariant mass
  - ST (sum of all ET)



Leptoquarks – likelihood ratio



All three variables shown on previous slide are used to construct:

$LLR = \log(L_s/L_B)$

Leptoquarks – backgrounds for LLR>0

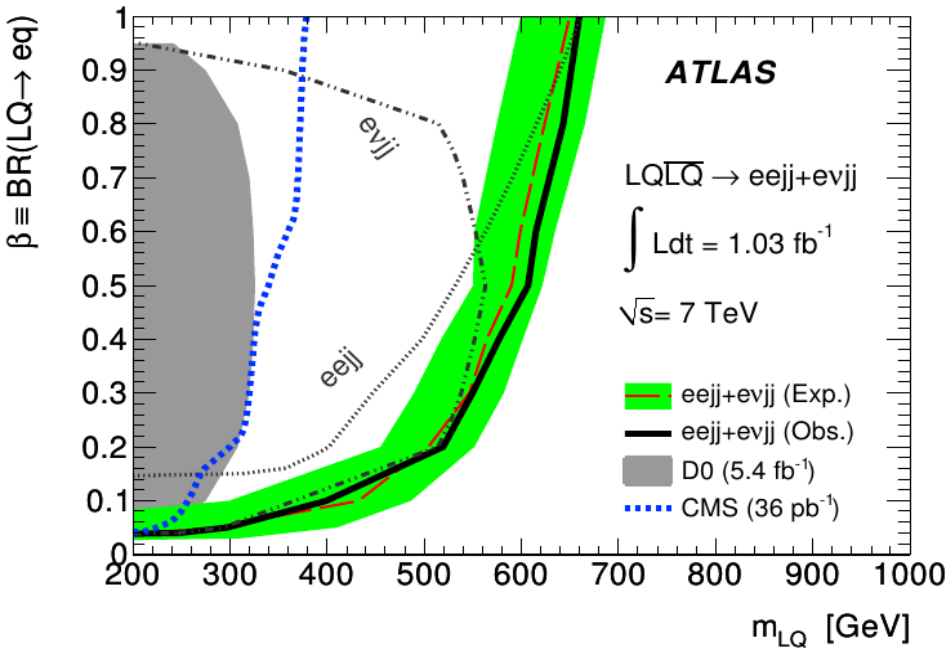
Source	$eejj$ Channel		$e\nu jj$ Channel	
	400 GeV	600 GeV	400 GeV	600 GeV
W+jets	—	—	1500 ± 670	670 ± 210
Z+jets	98 ± 53	26 ± 14	45 ± 41	18 ± 19
$t\bar{t}$	15 ± 9	4.6 ± 2.2	430 ± 180	150 ± 38
Single t	1.4 ± 0.9	0.7 ± 0.4	53 ± 19	23 ± 4
Dibosons	1.5 ± 0.8	0.7 ± 0.3	25 ± 11	11 ± 2
MJ	9.2 ± 4.5	2.3 ± 1.5	170 ± 35	75 ± 15
Total	120 ± 55	34 ± 14	2200 ± 690	950 ± 220
Data	82	22	2207	900
LQ	120 ± 8	7.5 ± 0.5	69 ± 4	4.5 ± 0.2

Backgrounds normalised to data in control regions

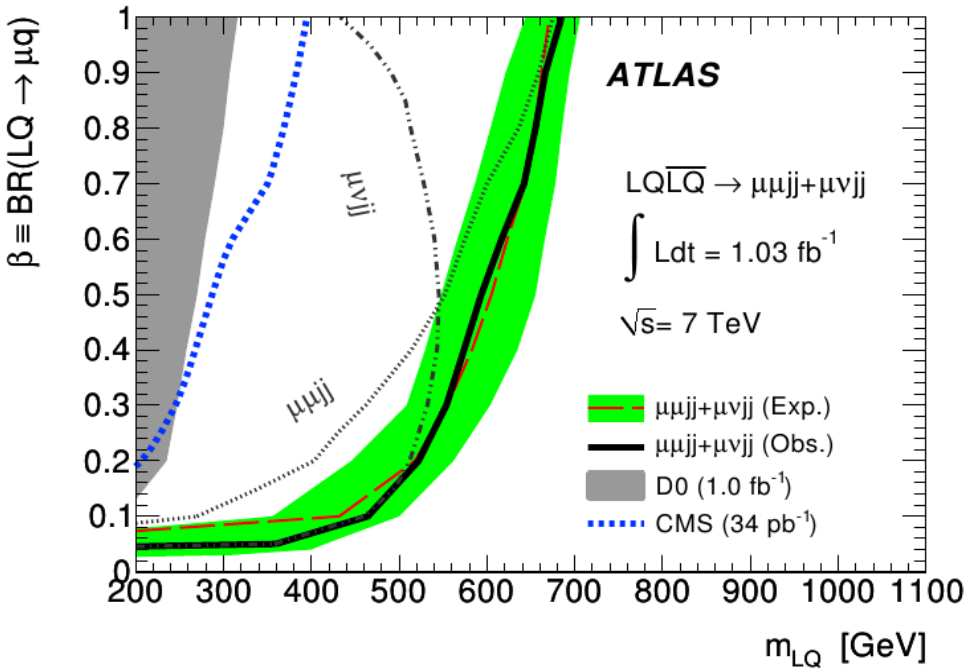
Dominant systematics from extrapolation of the background distribution to signal region

Leptoquarks – results

First generation (electron channel)



Second generation (muon channel)

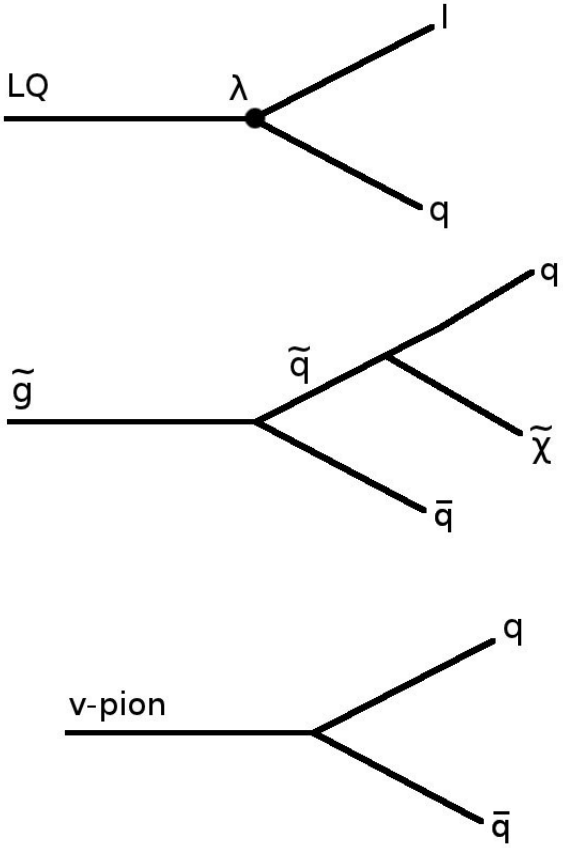


Combination of lljj and lνjj channels for electrons/muons allow to exclude first/second generation leptoquarks with masses up to 690 GeV

Displaced jets from long-lived neutral particles

- What if Leptoquark Yukawa coupling λ is very small?
  - LQ R-hadrons
- Slit-SUSY scenario
  - Gluino R-hadrons
- Hidden valley
  - v-hadrons
- RPV SUSY, etc...
- **Long-lived particles**

can give displaced decays!

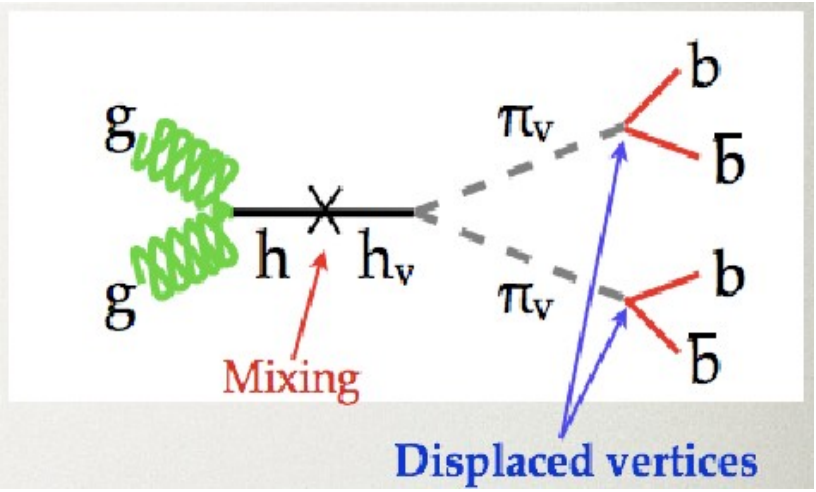


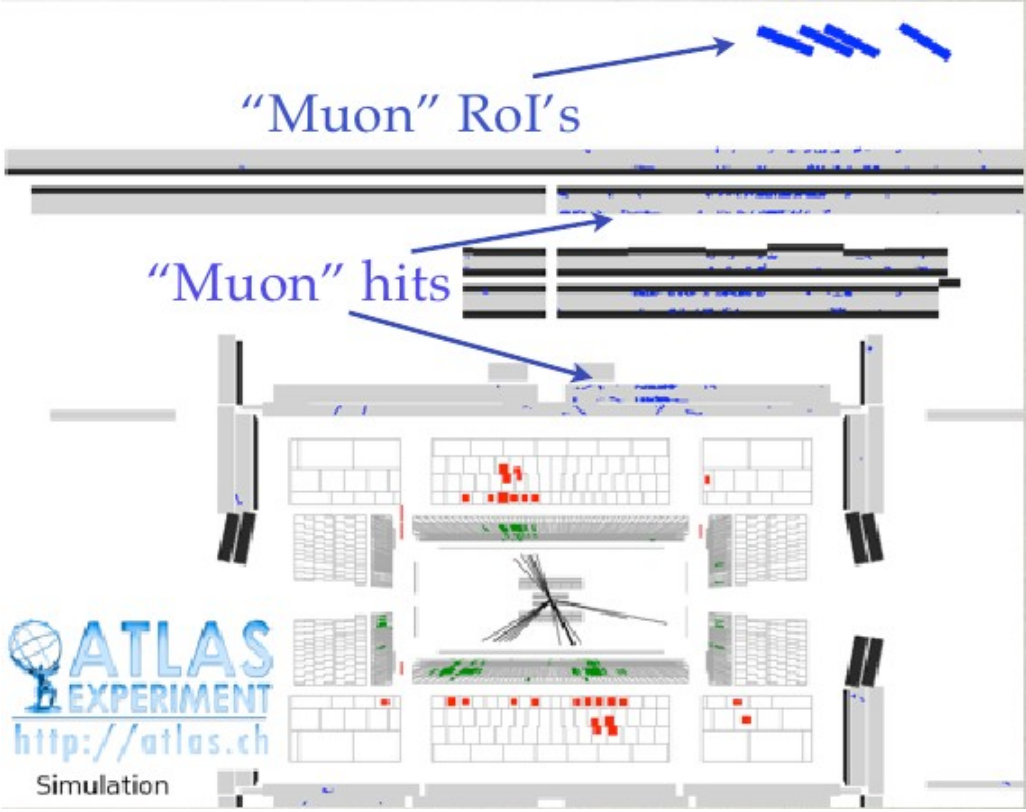
Highly displaced jets (4 to 7 m)

arXiv:1203.1303

Signature: two highly-displaced vertices from muon hits, with calorimeter and inner track isolation

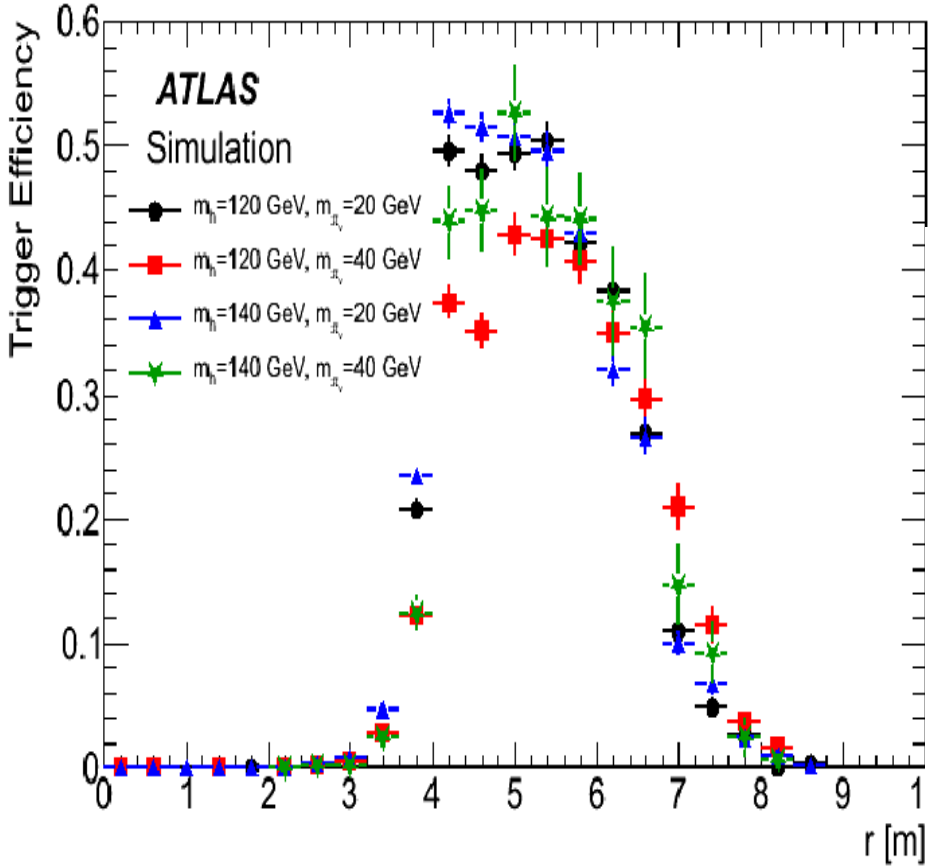
Interpreted in hidden valley scenario with long-lived v-pions decaying mainly to bb



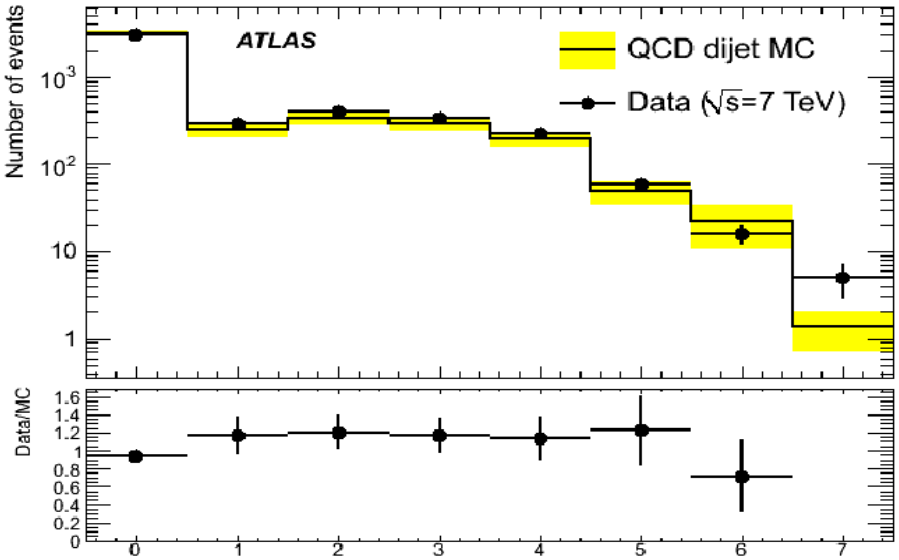


Highly displaced jets – dedicated, signature-driven trigger

- At least three muon RoIs in a ΔR=0.4 cone in barrel
- Calorimeter and track isolation



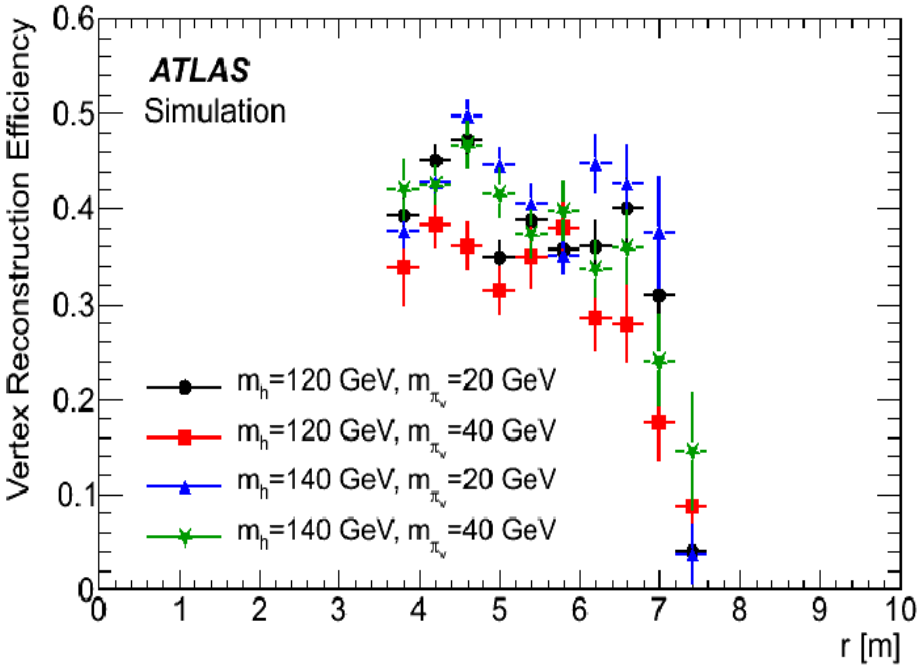
Performance studied using punch-through jets in data

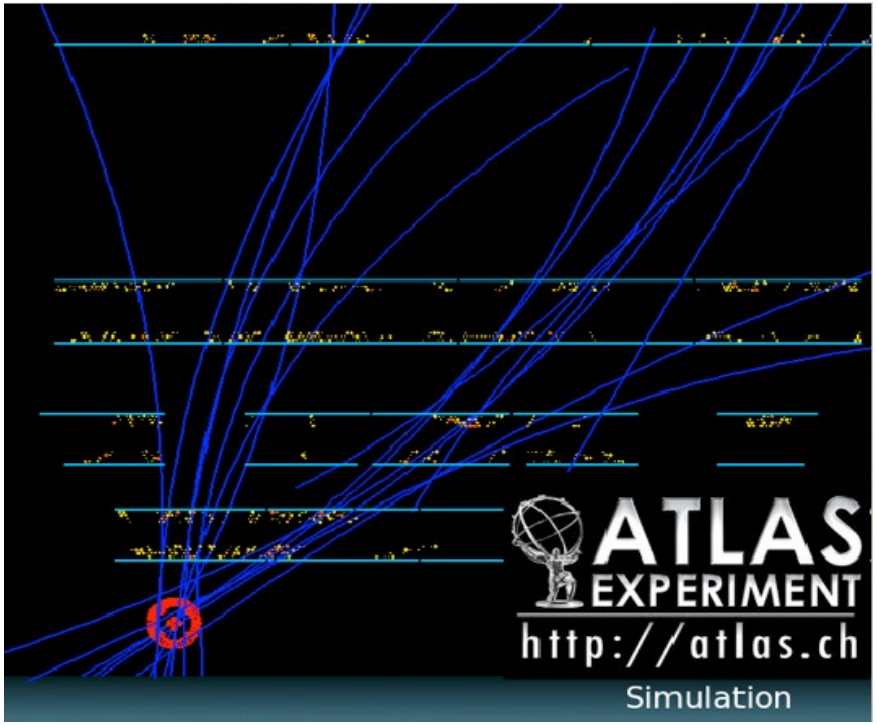


Number of muon RoIs

Highly displaced jets – reconstruction

Efficiency in signal:

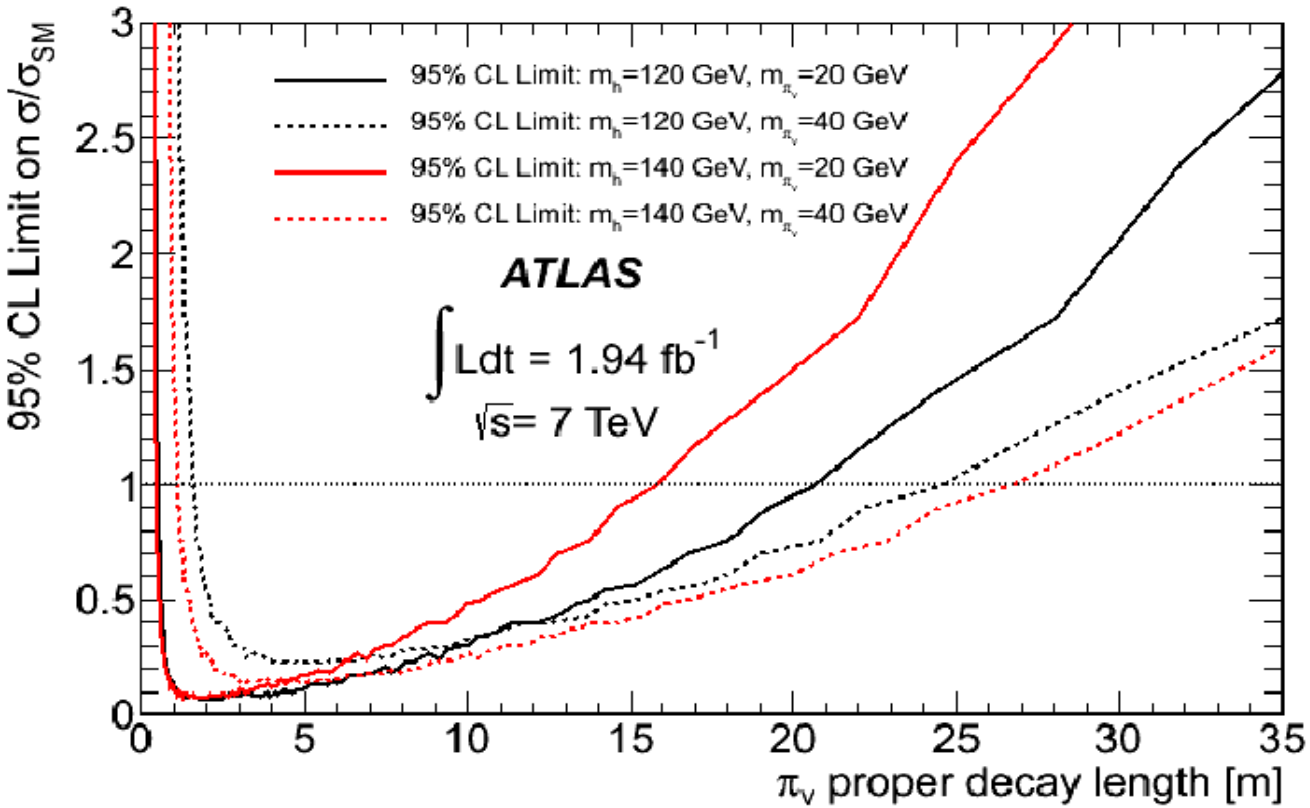




Efficiency in punch-through jets:

Number of MDT hits	QCD dijet Monte Carlo	Data
$300 \leq N_{MDT} < 400$	10.1±2.2 %	9.1±0.5 %
$400 \leq N_{MDT} < 500$	9.2±2.8 %	10.5±0.7 %
$500 \leq N_{MDT} < 600$	13.1±5.4 %	13.0±0.9 %
$N_{MDT} \geq 600$	16.5±4.5 %	16.7±0.7 %

Highly displaced jets – results



0 observed, 0 expected from data-driven background estimate

Upper limits at 95% c.l. as function of <u>proper</u> decay length for different Higgs and hidden valley mass splitting scenarios

Long-lived exotics: work in progress

Displaced decays

- Displaced leptons
  - Collimated (lepton-jets)
  - Non-collimated
- Displaced jets with minimal additional requirements
  - Low EM fraction trigger
  - Trackless jet trigger
  - B-jet trigger
  - Goal is to cover all possible lifetimes

Non-decaying

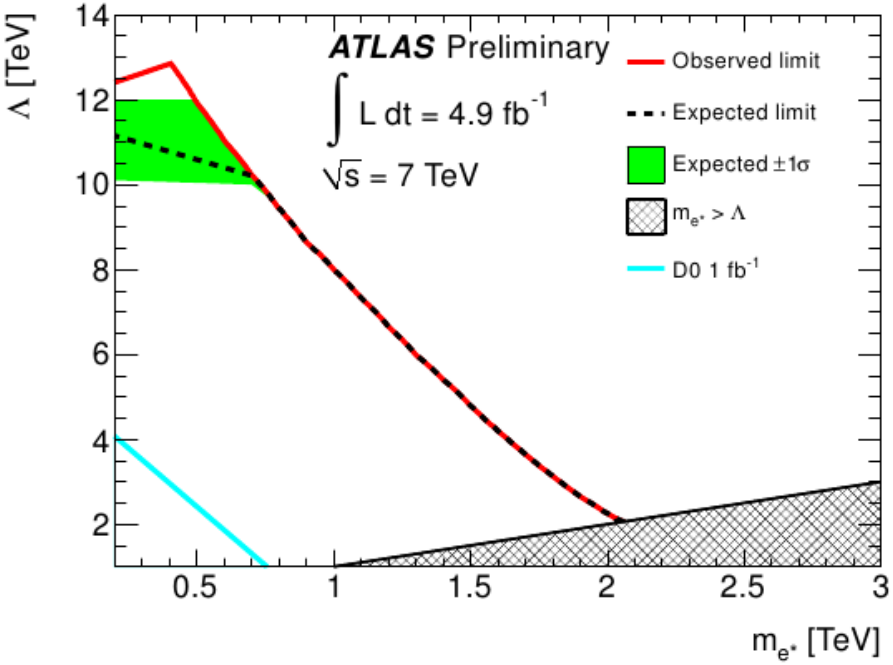
- Magnetic monopoles – first results coming soon!
- Multiply-charged particles (|q| = 2 – 6e)

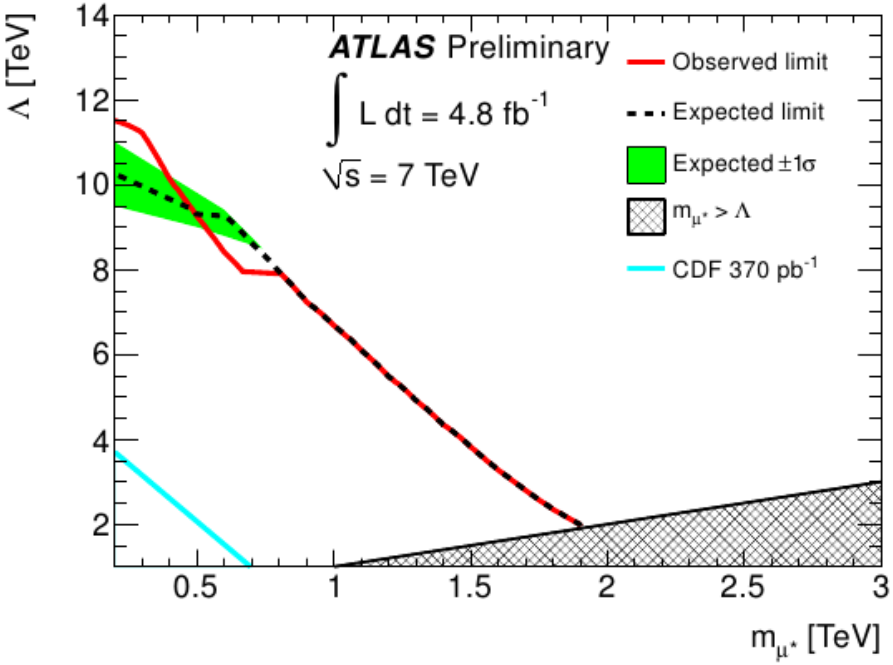
Summary

- Many signatures of new decaying particles are investigated in ATLAS. Among those, three were presented in this talk:
  - $ll^* \rightarrow ll\gamma$ (5 fb^{-1})
  - $LQ \rightarrow lq$ (1 fb^{-1})
  - Long-lived $\rightarrow qq$ (2 fb^{-1})
- Masses are constrained up to the TeV scale!

Extra slides

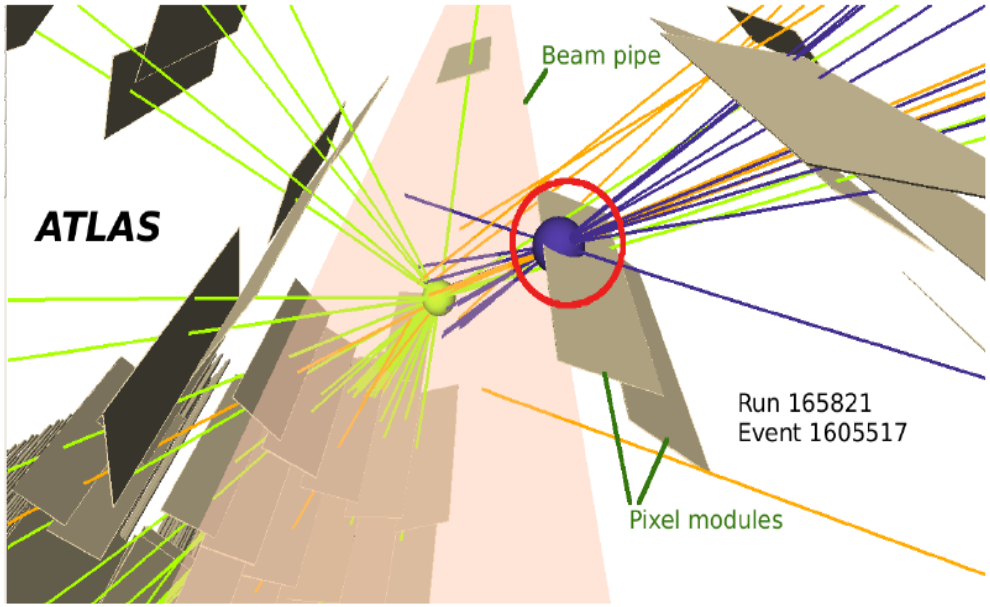
Excited leptons – model-dependent limits



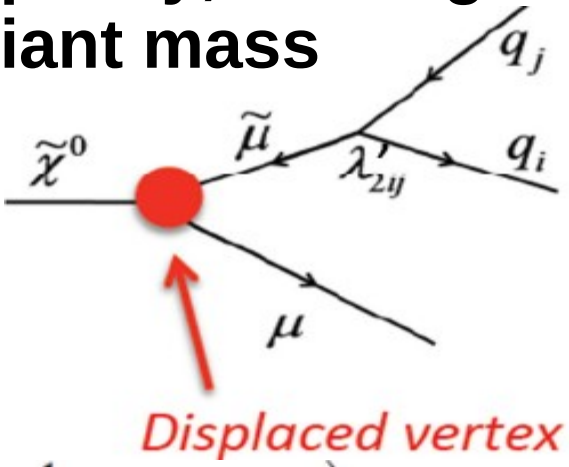


ATLAS displaced jets in inner detector (decay after up to 18 cm)

arXiv:1109.2242 [hep-ex]



Signature: muon and secondary vertex from tracks, with large impact parameter, high track multiplicity, and high invariant mass



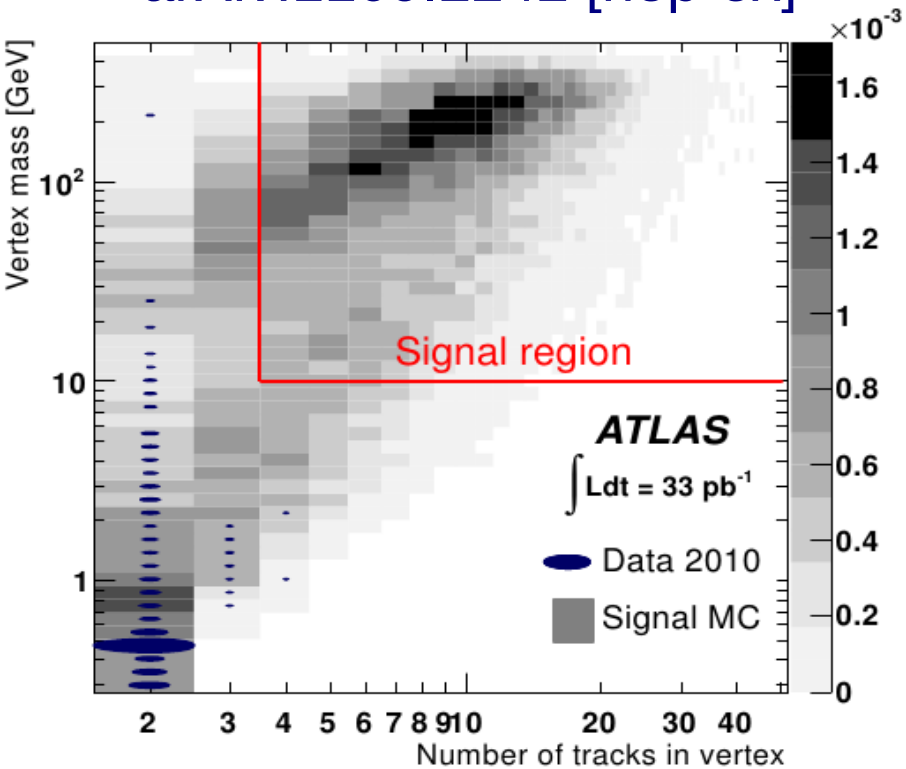
Intepreted in RPV SUSY scenario

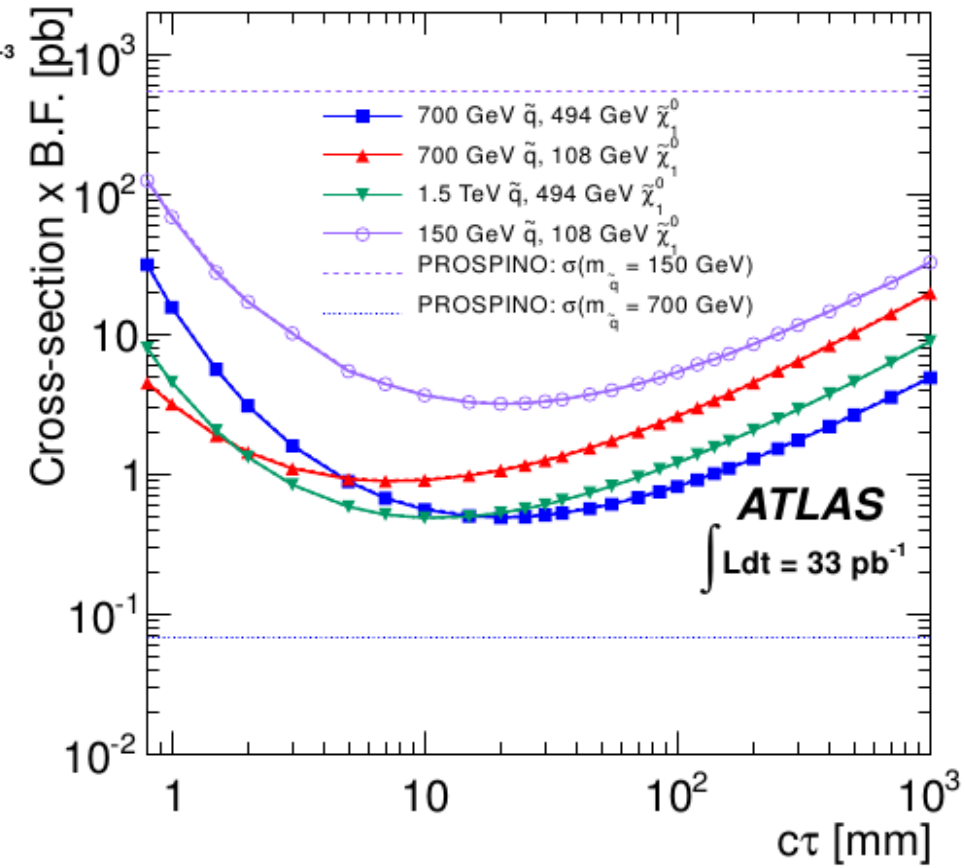
with non-zero λ' → L-violating

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

Displaced jets in inner detector – results

arXiv:1109.2242 [hep-ex]

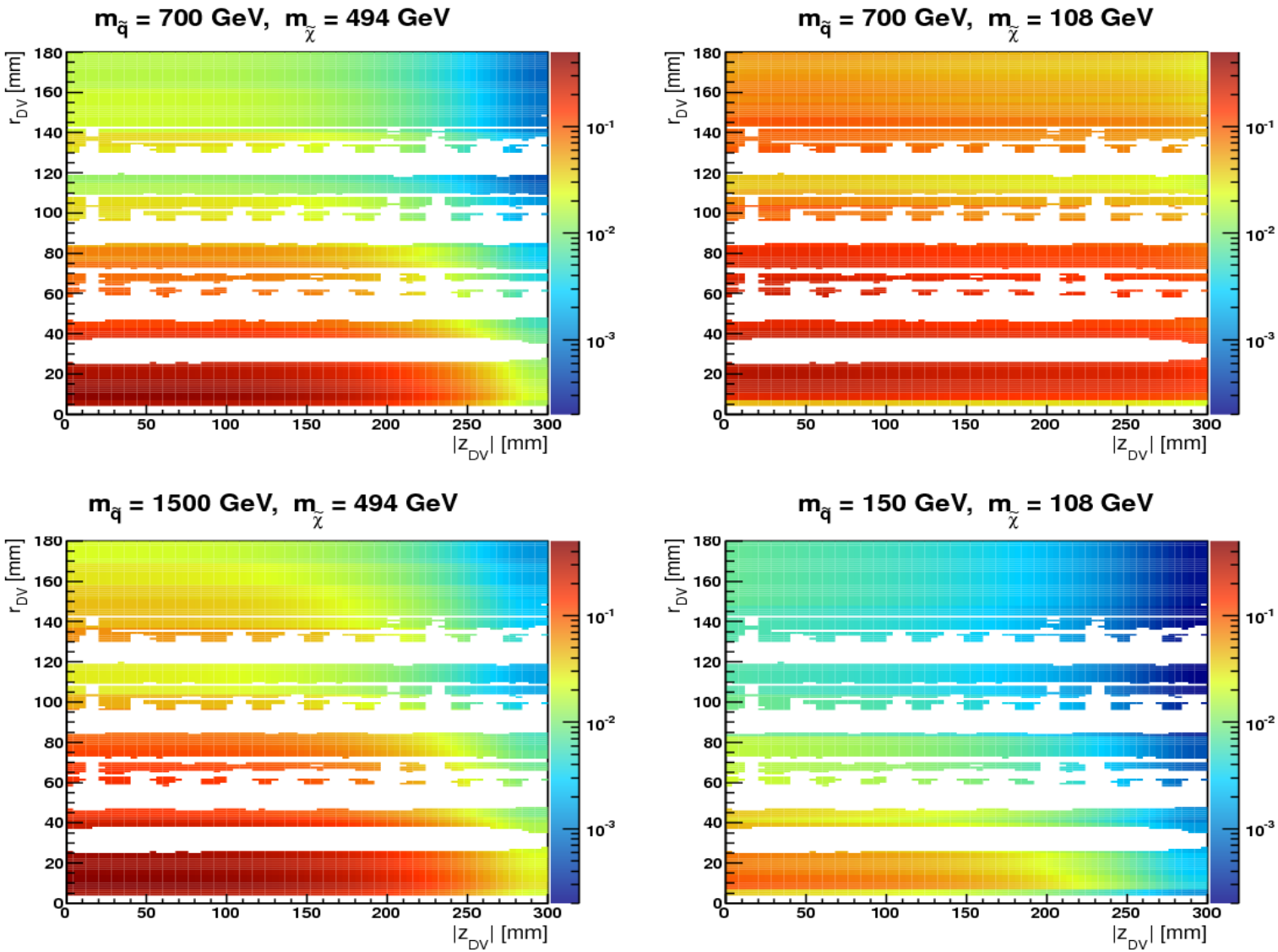




No events in signal region (tiny backgrounds after vetoing on material interactions)

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

Displaced vertices – efficiencies



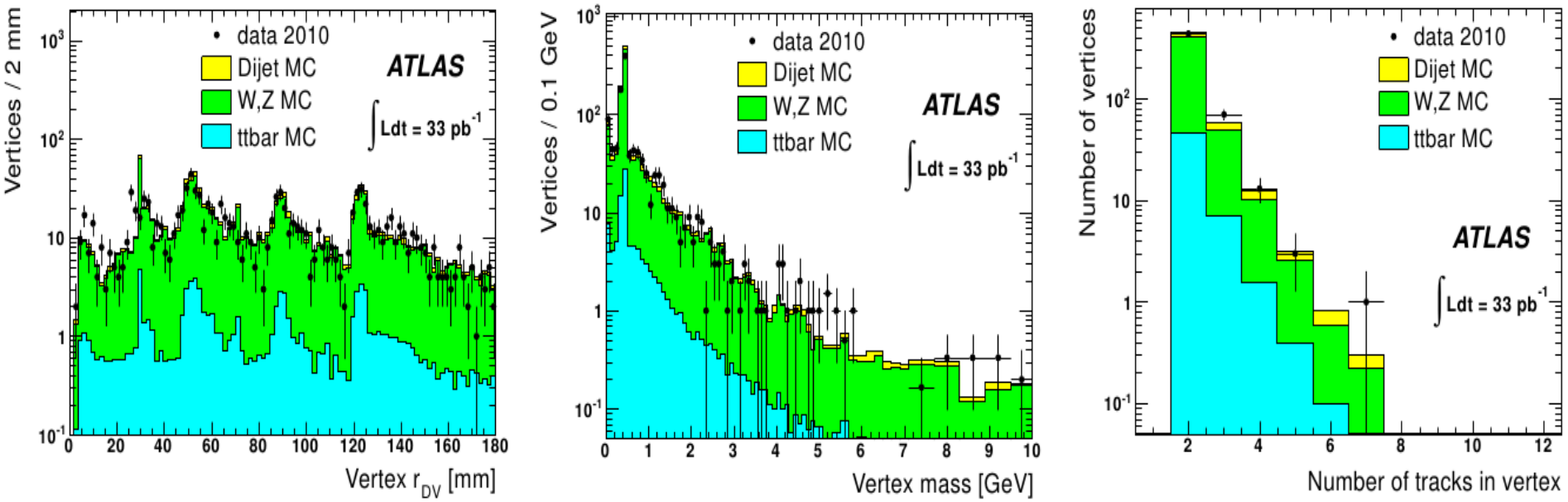
***ATLAS** simulation*
preliminary

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]



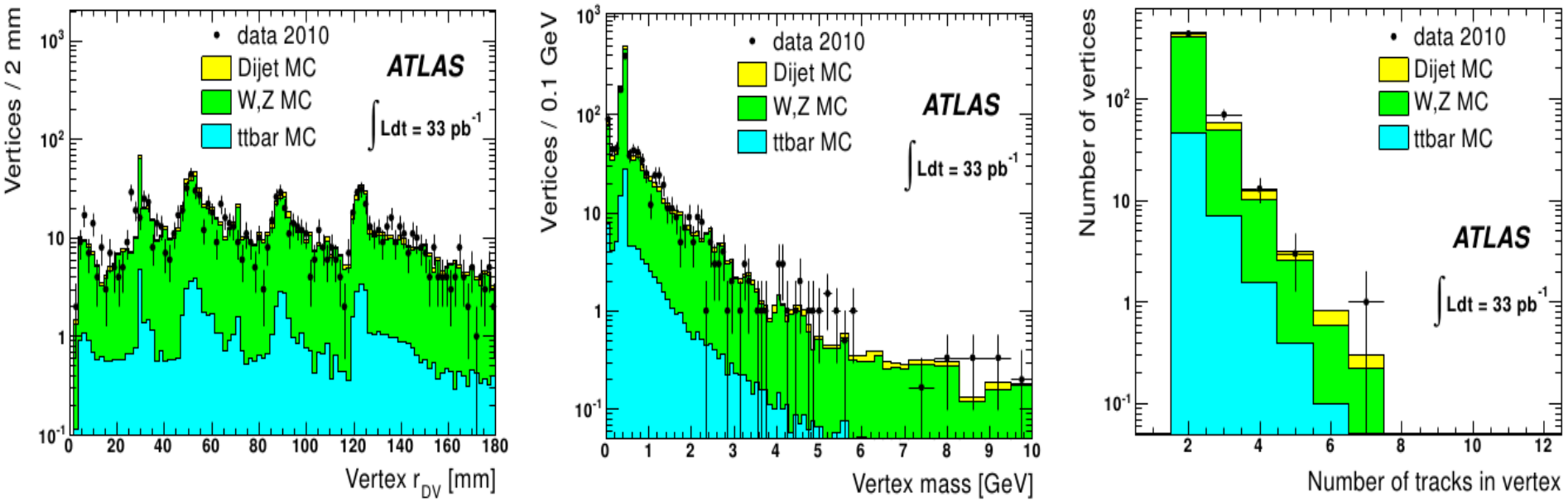
→ excellent agreement in shape and yield

Displaced vertices – simulation vs. data

Loose selection for data/MC comparison

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

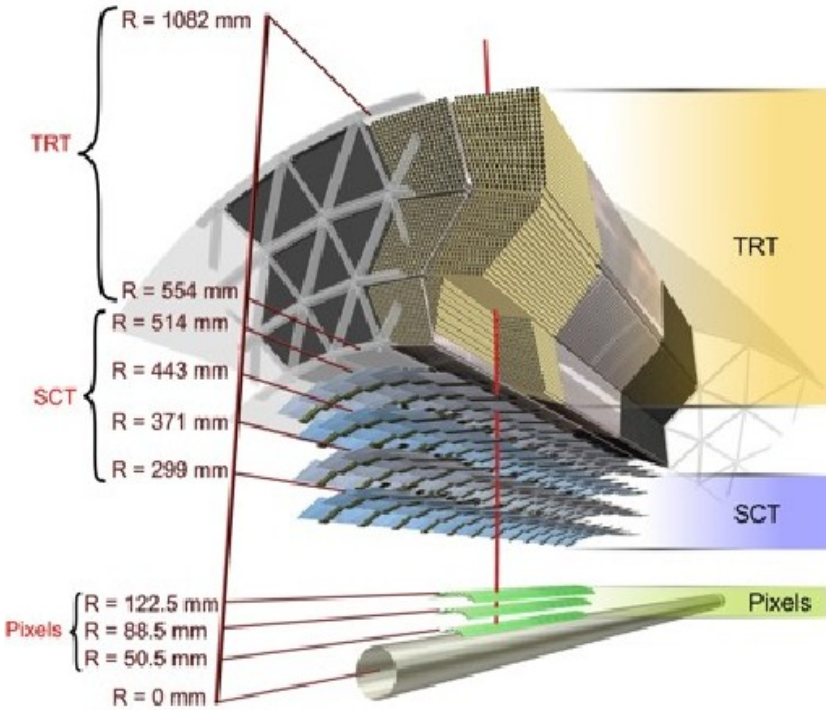
arXiv:1109.2242 [hep-ex]



→ excellent agreement in shape and yield

ATLAS disappearing tracks (70 to 90 cm)

Signature: events with jets and MET → search for tracks which leave no hits in the outer volume of the TRT



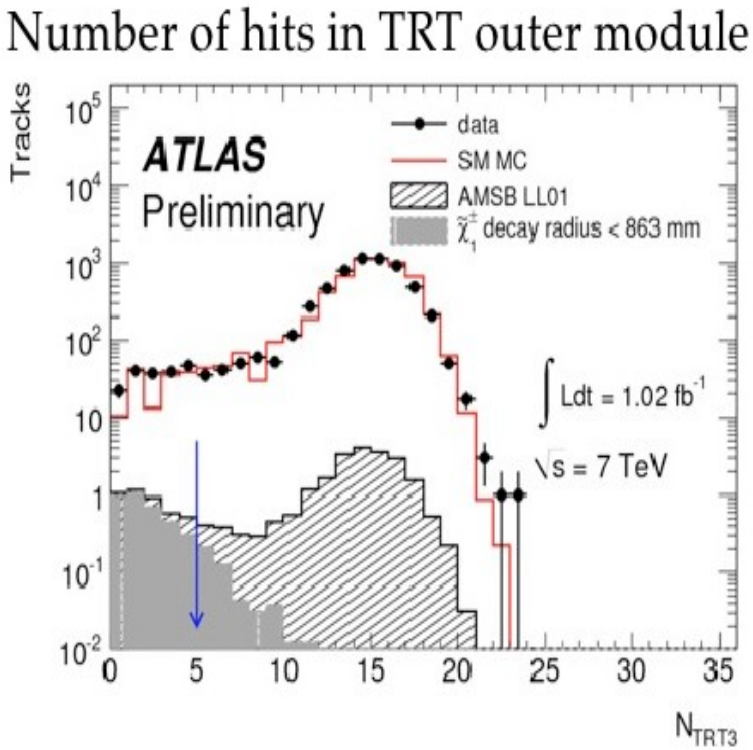
Intepreted in SUSY AMSB scenario with

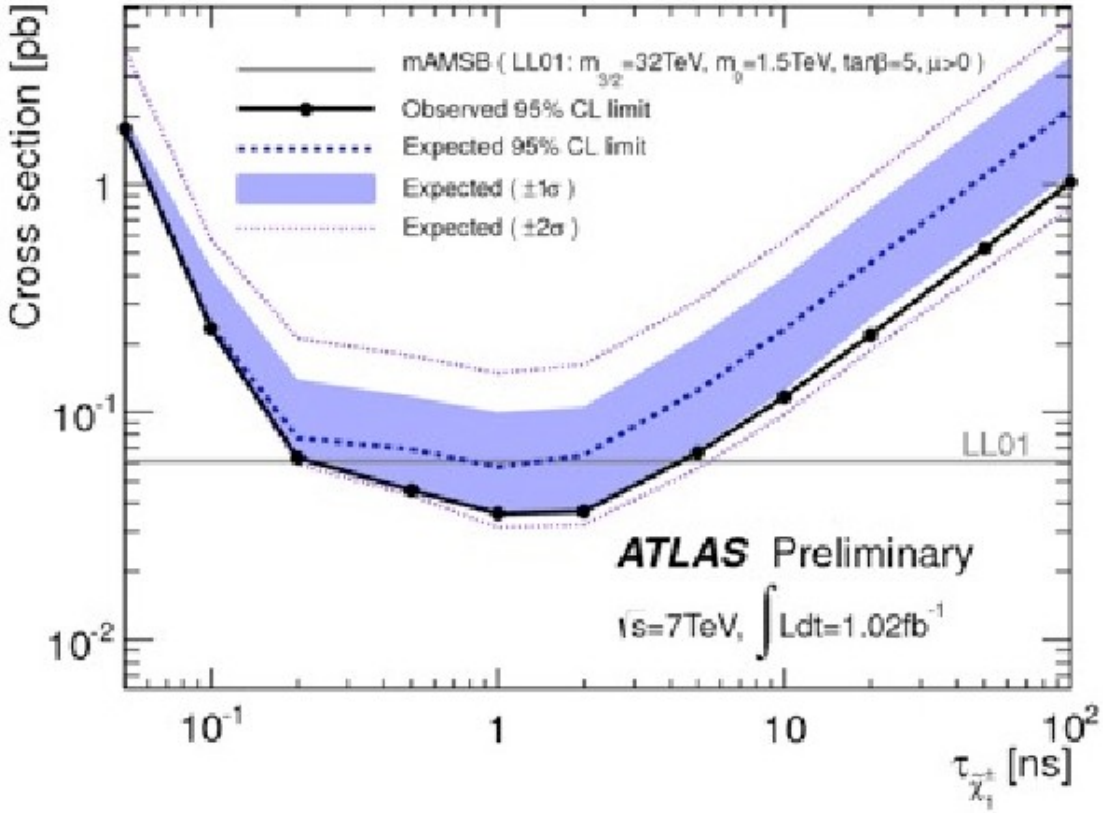
- near degenerate chargino and neutralino (long-lived chargino)
- Dominant decay:

$$\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^{0} + \pi^{\pm}$$

Soft pion (not reconstructed) → disappearing track

ATLAS disappearing tracks – preliminary results



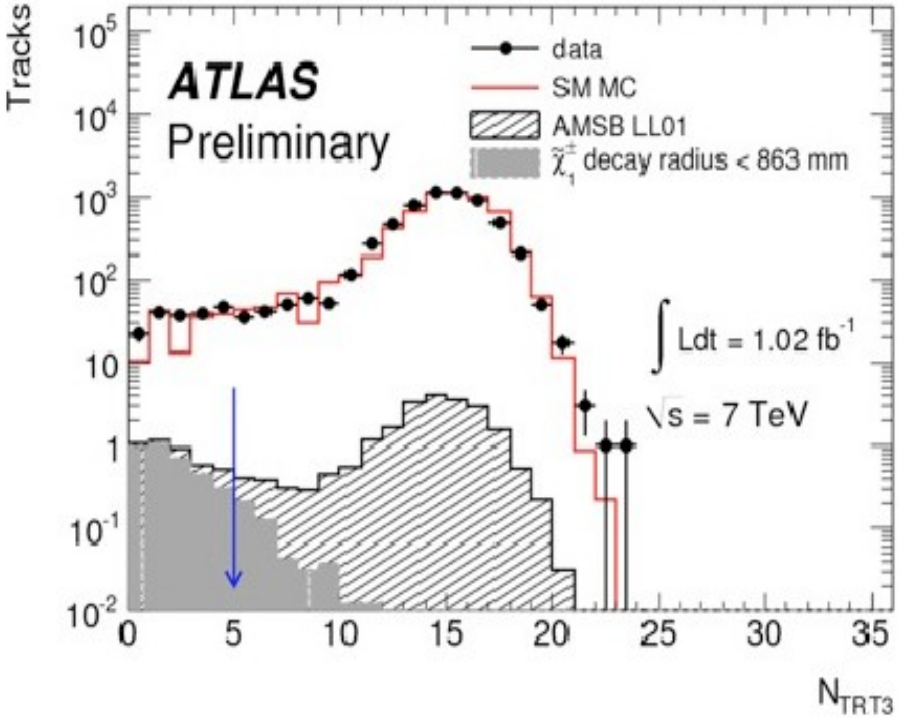


Upper limits at 95% c.l. as function of <u>proper</u> lifetime for given AMSB scenario

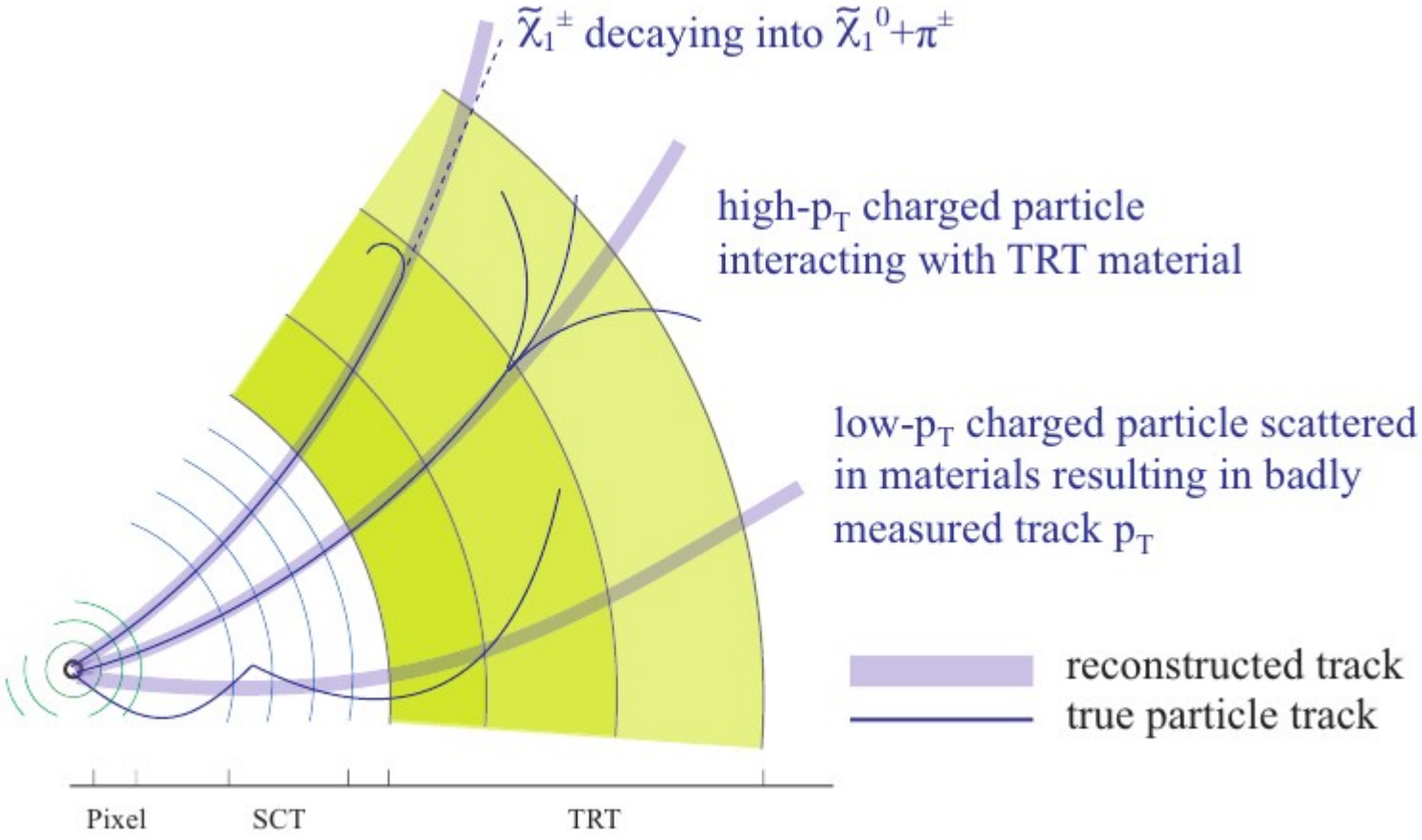
Disappearing tracks – selection

- Jet+MET trigger
- MET > 130 GeV
- 3 jets with p_T > 130, 60, 60 GeV and |η| < 3.2
- Track with:
  - p_T > 10 GeV (highest)
  - Isolated
  - |η| < 0.63
  - N(PIX) ≥ 1
  - N(SCT) ≥ 6
  - N(TRT3) < 5

Number of hits in TRT outer module

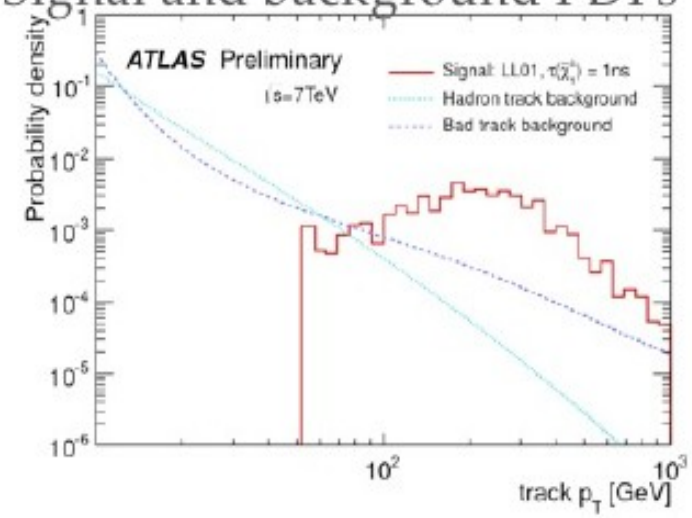


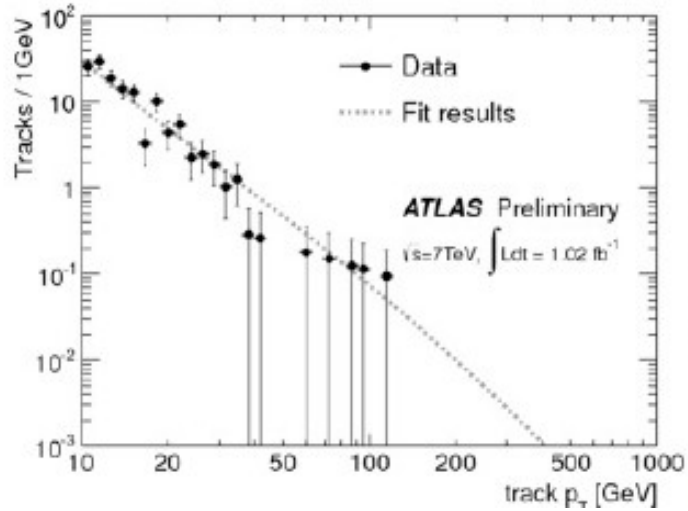
Disappearing tracks – backgrounds



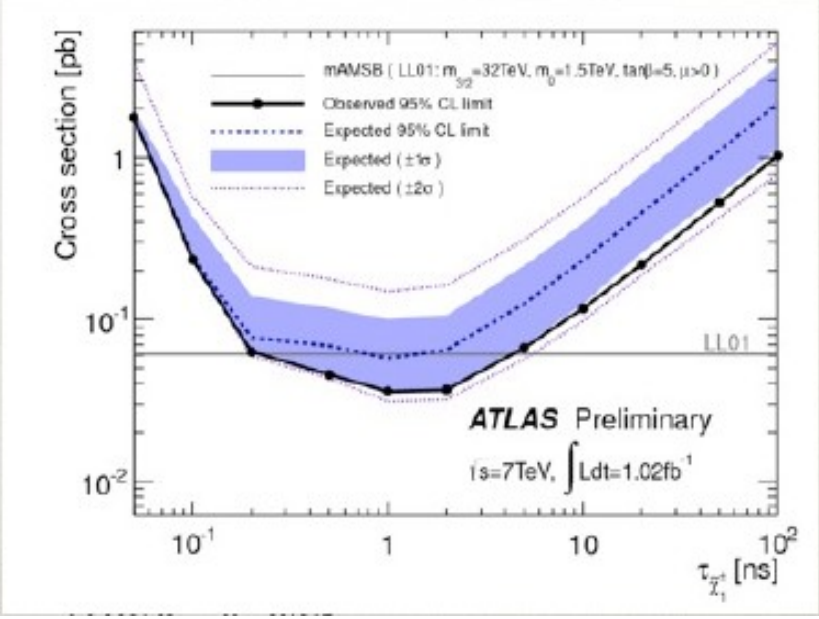
Disappearing tracks – results

Signal and background PDFs





- Background is estimated by fitting the region $10 < p_T < 50$ GeV with the background PDFs
  - Expected background with $p_T > 50$ GeV is 13 ± 1
  - Observed 5 events with $p_T > 50$ GeV
- For the mAMSB point LL01 (m_0 =1.5 TeV, $m_{3/2}$ =32 TeV, $m_{\chi^\pm}$= 90.2 GeV), $\chi^\pm$ lifetimes of $0.5 < \tau_{\chi^\pm} < 2$ ns are excluded at 95% CL

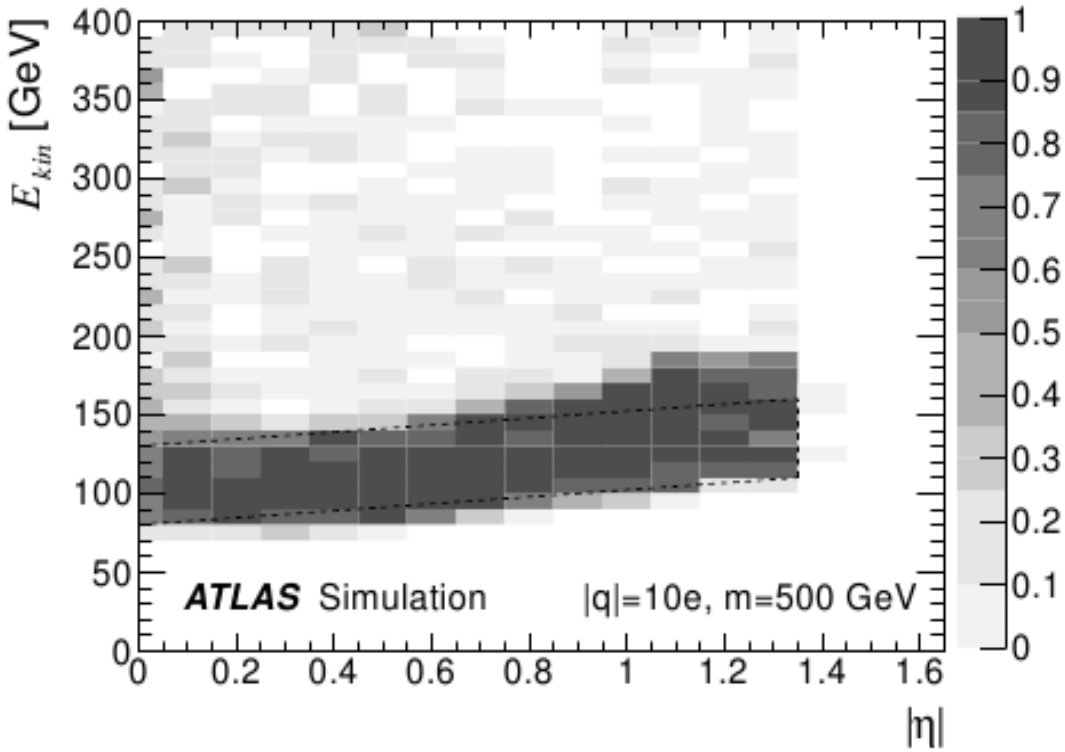


ATLAS HIP search with first data

arXiv:1102.0459v3 [hep-ex]

Signature: electron-like object with high ionization and narrow cluster

➔ Exclusion limits for electrically charged HIPs $6e \leq |z| \leq 17e$ and mass up to 1000 GeV

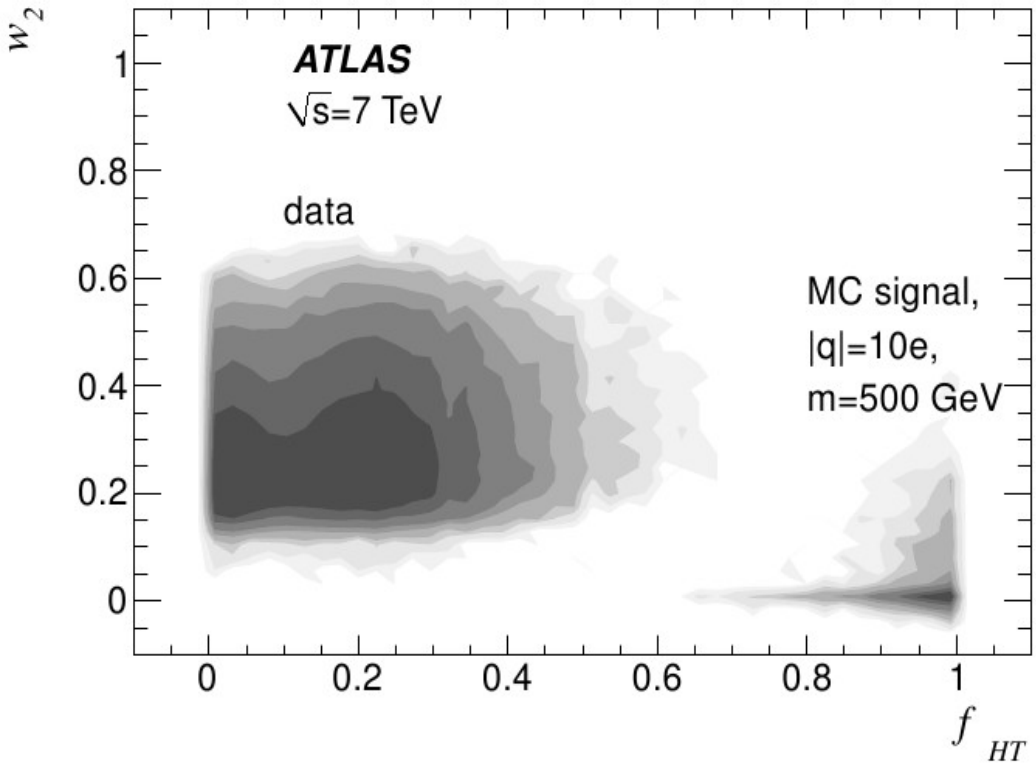


Is the search also sensitive to magnetic charges?

- $|g| < g_D/2$: too low energy in calorimeter
- $|g| \geq g_D/2$: delta electrons spoil the tracking

Answer is: no

HIPs: observables and limits



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

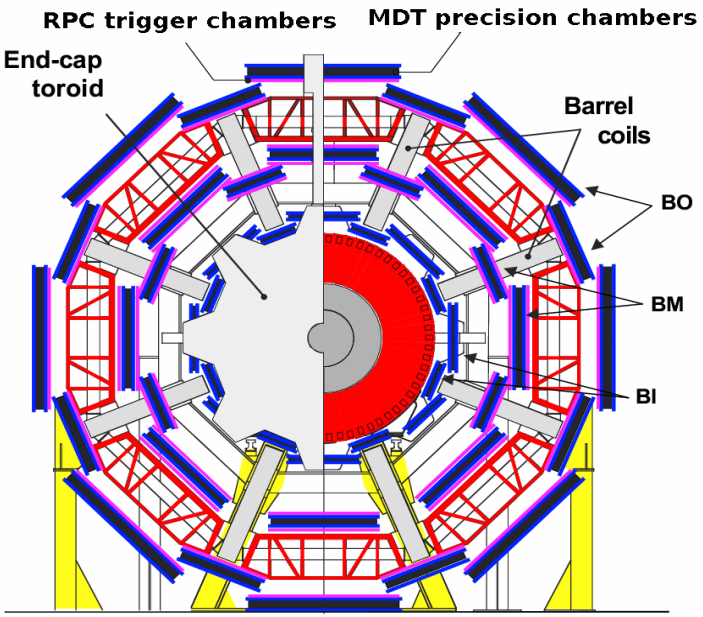
Limits (pb) in kinematic regions of good acceptance

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

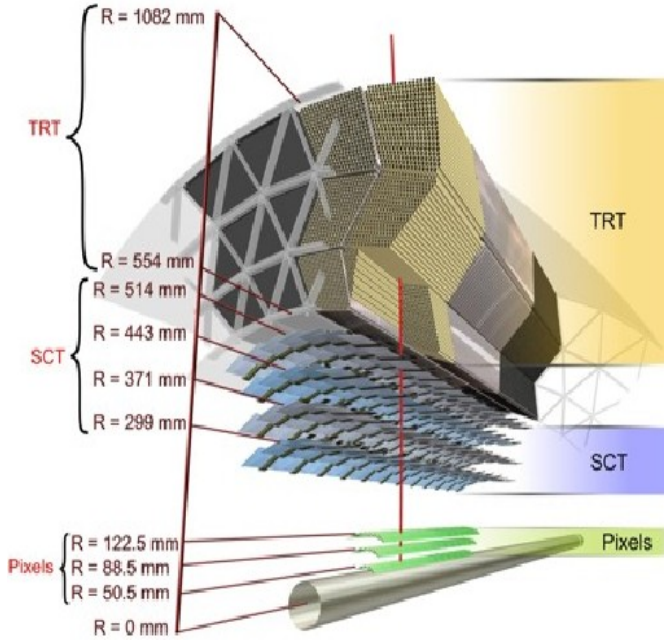
- Limits (pb) for Drell-Yan kinematics

ATLAS subdetectors

Muon Spectrometer (MuSp)



Inner Detector (ID)



Calorimeters