Search for charged long-lived heavy particles with the ATLAS experiment at the LHC

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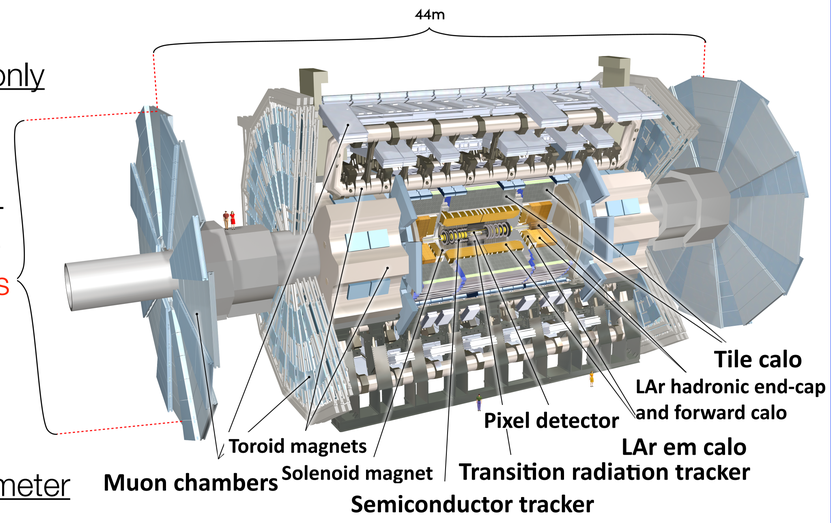
Theoretical motivations & Searches at ATLAS

- Heavy long-lived particles (LLPs) predicted by several extensions of the Standard Model: in particular **SUSY** models foresee: Phys. Rept., 438 (2007) 1
  - **meta-stable sleptons** ($\tilde{\tau}$ in Gauge-Mediated SUSY Breaking, GMSB)
  - **coloured meta-stable squarks** ($\tilde{q}$) **and gluinos** ($\tilde{g}$), which can hadronize with a light SM quark system, or with a gluon → **R-hadrons**, which may:
    - be singly charged, doubly charged, or neutral
    - change their electric charge by nuclear scattering processes with the detector material
    - decay with a finite lifetime
- Heavy LLPs produced at the LHC as massive → moving with **β<1**
  - anomalous energy deposition ***dE/dx***
  - **time-of-flight**
  - **μ-likeness**
- Searches at **ATLAS**:
  1. Inner Detector (ID)-only
  2. ID+Calorimeters (μ-agnostic)

     → meta-stable (not reaching farther sub-detectors) or stable R-hadrons (becoming neutral)
  3. Full-detector

     → stable R-hadrons
  4. ID + Muon Spectrometer (MS) → sleptons



Data & Monte Carlo simulated samples

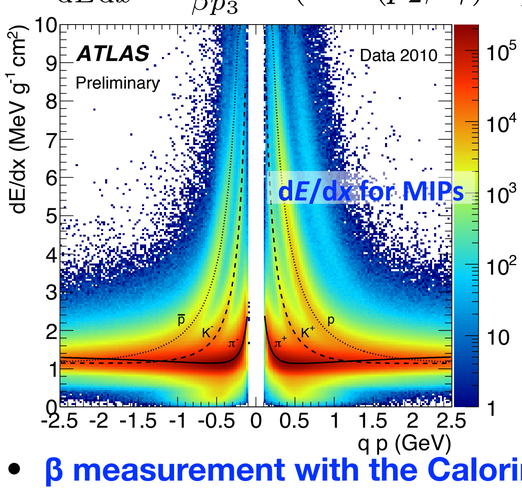
- **4.7 fb^{-1}** of *pp* collision data collected in 2011 (**$\sqrt{s}$ = 7 TeV**)
- **GMSB samples** (**122.2<*m*($\tilde{\tau}$)<465 GeV**)
- **R-hadron samples** (**200<*m*($\tilde{g}$)<1500 GeV**, **200<m($\tilde{q}$)<1000 GeV**, 10% gluino-ball fraction. Samples with variable lifetimes: τ=2ns,10ns)

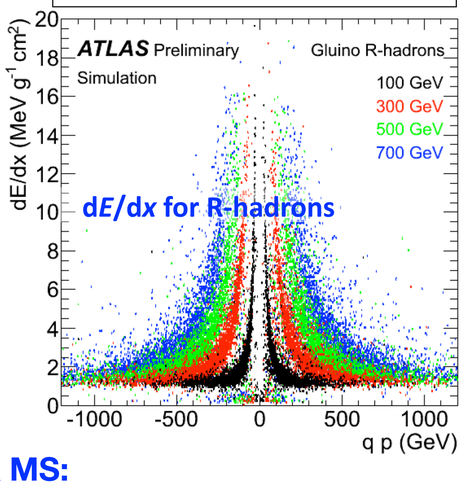
Mass & β measurements

- **Mass measurement with the Pixel Detector:**
  - masses of slow charged particles measured using only ID information
  - d*E*/d*x* and *p* fitted to an empirical Bethe-Bloch function, to deduce mass

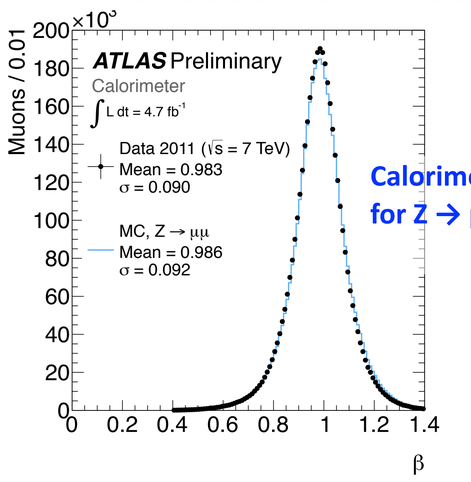
$$\mathcal{M}_{dEdx} = \frac{p_1}{\beta p_3} \ln\left(1 + (p_2 \beta\gamma)^{p_5}\right) - p_4$$

ATLAS-CONF-2011-016 (2011)

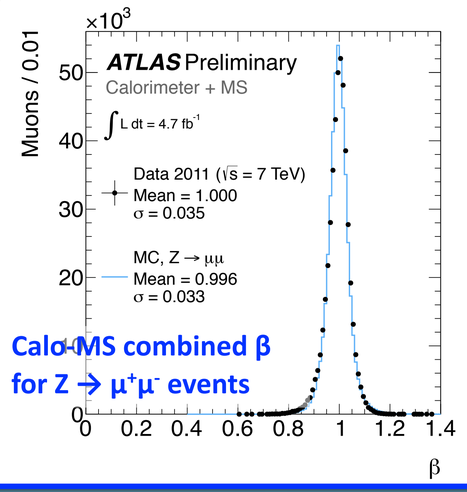




- **β measurement with the Calorimeters & MS:**
  - Tile & LAr Calorimeters: resolution ~2ns at 1 GeV → able to distinguish between highly relativistic particles and slow LLPs
  - MS: β measurement mainly by monitored drift-tube chambers (for slow LLPs combined track re-fit including ID and MS)



Calorimeter β for Z → μ$^+$μ$^-$ events



Calo-MS combined β for Z → μ$^+$μ$^-$ events

Event selection

Different selections for different searches:

- **sleptons** (typical eff. 24%):
  - **single μ** trigger (eff. ~85%)
  1. loose selection (2 LLP candidates):
     - p_T > 50 GeV
     - veto for Z invariant mass (±10 GeV)
     - combined β < 0.95
  2. tight selection (1 LLP candidate):
     - p_T > 70 GeV
     - β consistent at 2σ among at least 2 different sub-detectors
     - cut on $m_\beta = p/\gamma\beta$ (depending on slepton mass)
- **R-hadrons**:
  - missing transverse energy E_T^{miss} trigger, with 60-70 GeV threshold (eff. ~15%)
  1. full-detector and μ-agnostic (typical eff. 11%)
     - 140 GeV < p < 3.5 TeV
     - isolated from jets and other tracks
     - combined (or calo) β
     - βγ < 1.5-2.0, β < 0.8-0.9
  2. ID-only (typical eff. 6%)
     - p_T > 50 GeV, p > 100 GeV
     - more severe isolation requirement
     - offline E_T^{miss} > 85 GeV
     - veto for electrons
     - d*E*/d*x* > 1.8 + f(η) (accounting for d*E*/d*x* residual dependence on η)

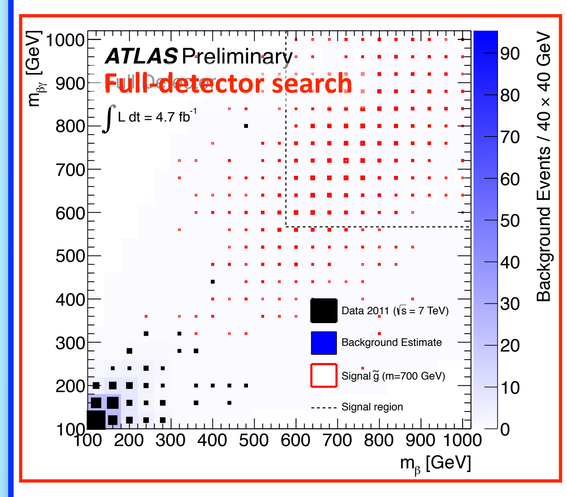
Background estimation

- After selection, background is mainly due to high-p_T μ with mis-measured β
- **Data-driven approach** to build high-statistics random samples

Systematic uncertainties

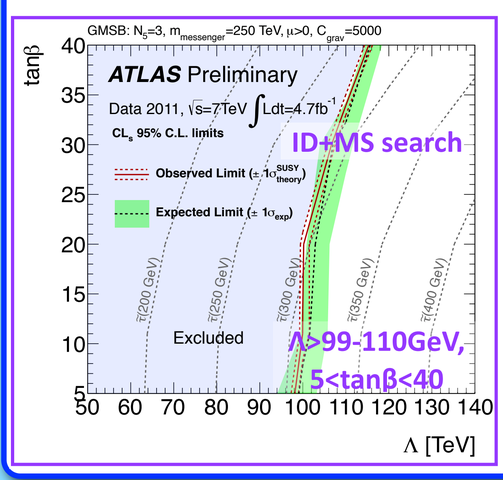
1. Theoretical cross-sections (NLO+NLL): **5%**; **15-30%**
2. Signal efficiency: systematic discrepancies between data and simulation in trigger efficiency, momentum resolution, β and d*E*/d*x* calibrations, E_T^{miss} scale; QCD uncertainties. **4-6%**; **11-13%**
3. Background estimation: variations of distributions, statistics. **10.5-12.5%**; **15-20%**
4. Luminosity: **3.9%**

Results

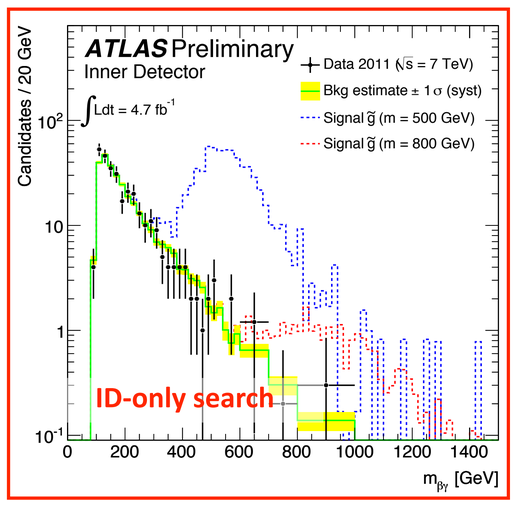


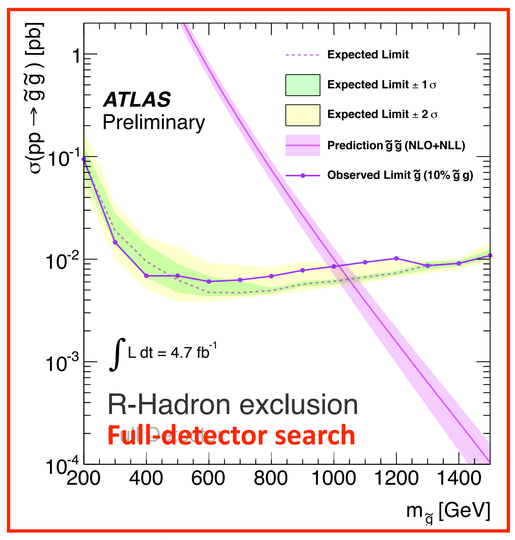
	Full-detector	μ-agnostic	ID-only
m($\tilde{g}$)	> 985 GeV	> 989 GeV	> 940 GeV
m($\tilde{t}$)	> 683 GeV	> 657 GeV	> 604 GeV
m($\tilde{b}$)	> 612 GeV	> 618 GeV	> 576 GeV

m(GMSB $\tilde{\tau}$)	> 300 - 268 GeV, 5<tanβ<40
m(directly produced sleptons)	> 278 GeV, 5<tanβ<40



- No indication of signal above the expected background is observed
- Cross-section limits at 95% confidence level





- Extension of ATLAS previous limits thanks to increased luminosity, and more refined data analysis

Phys.Lett. B701 (2011) 1; ibid. B703 (2011) 428

- Complementary to searches for SUSY particles decaying immediately