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Searches for displaced jets and long-lived particles with ATLAS

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on behalf of the ATLAS Collaboration

- Introduction
- Non-ponting photons
- Displaced vertices
- Out-of-time jets
- Low-β and highly ionizing tracks
- Conclusions

Introduction

Physics beyond SM may appear in the form of long-lived particles (LLPs) with cτ >~1 mm.

Examples

SUSY:

- Semi-stable slepton (in GMSB models)
- Semi-stable $\tilde{g}$ or $\tilde{q}$ in RPV SUSY
- Quasi-degenerate chargino-neutralino masses

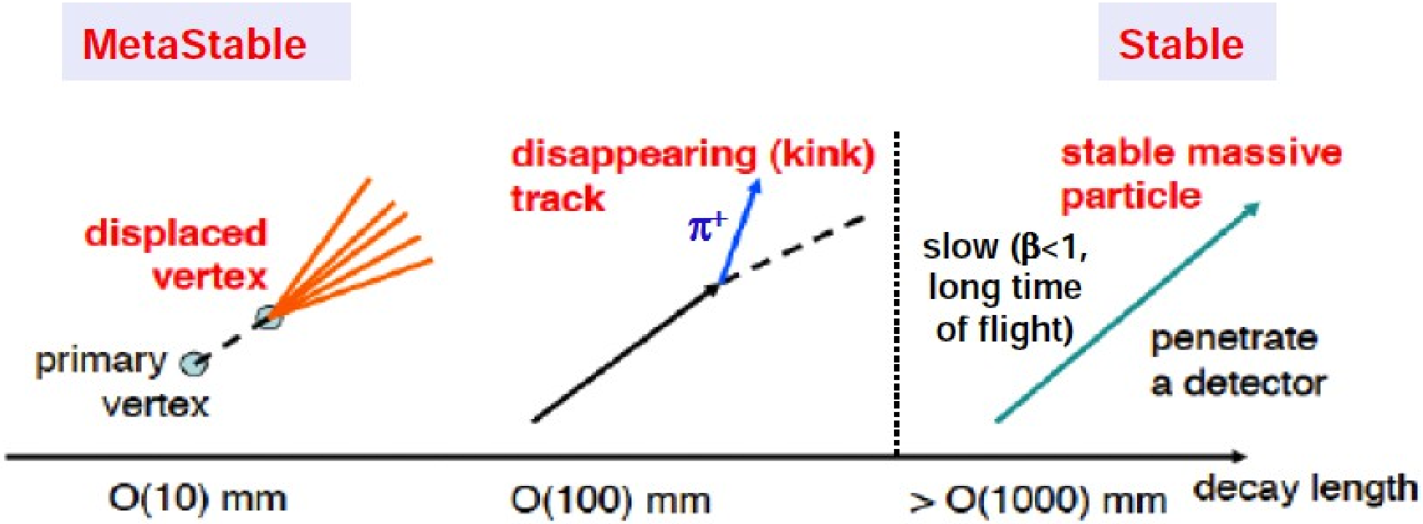
Non-SUSY:

- “Hidden Sector” models
- Magnetic monopoles ...

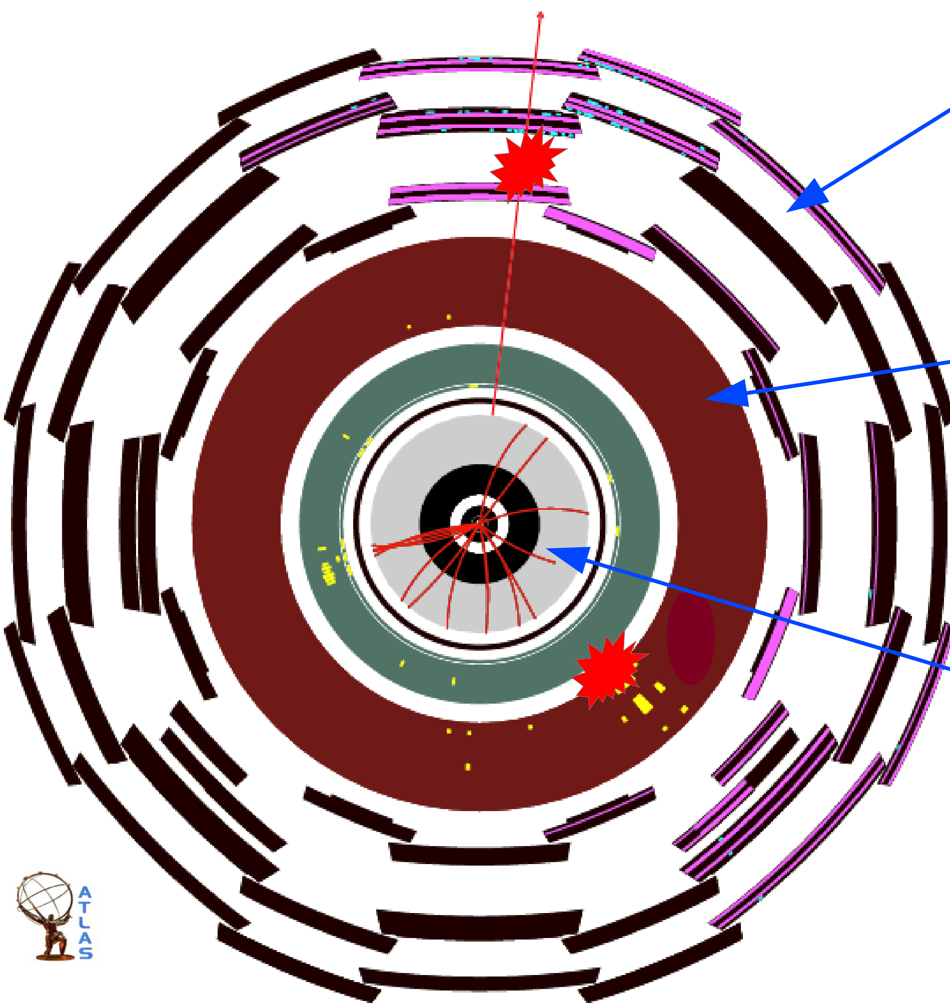
- Collider detectors not optimized for identifying (and measuring) LLPs

- Unusual signatures :
  - displaced decay vertices
  - disappearing tracks (talk by W. Ehrenfeld)
  - slow / highly-ionizing tracks
  - delayed activity

- Ongoing effort to push ATLAS performance



Long-lived particles in ATLAS



- Muon System (MS):
  - Displaced vertex reconstruction
  - Time-of-flight
    (drift tubes (MDT), RPC)
  - dE/dx (MDT)
- Calorimeters:
  - Jets with large had/EM fraction
  - Out-of-time jets
  - dE/dx
  - Time-of-flight :
    (liquid argon (LAr), Tile calorimeter)
  - Non-pointing photons (LAr)
- Inner detector (ID):
  - Displaced vertex reconstruction
  - Disappearing tracks
  - dE/dx
    (Pixels, straw tubes (TRT))

Simulated event with two displaced decays (✸)

Non-pointing photons

- Gauge-Mediated SUSY Breaking (GMSB):
  LSP=gravitino, if NLSP is neutralino then

  $\chi^0_1 \to \gamma \tilde{G}$

  Signature: 2 photons + missing-E_T
  Limit less stringent for long-lived $\tilde{\chi}^0_1$

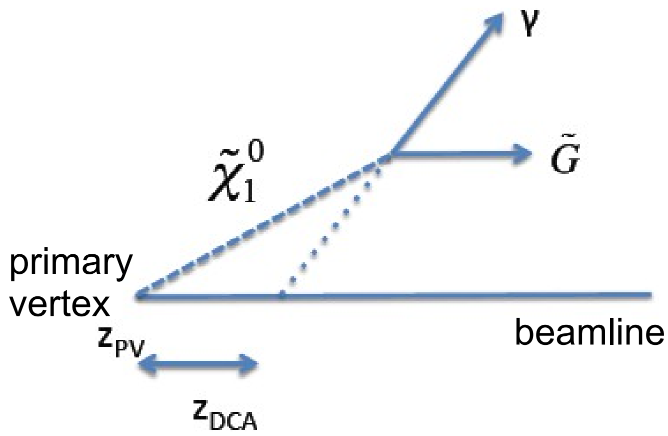
- If $\tau(\tilde{\chi}^0_1)$ ~ 0.25-50 ns : photons are non-poniting (and delayed)

- ATLAS analysis on 7 TeV data, L=4.8 fb^{-1}
  (PRD 88, 012001 (2013))

  Exploits ATLAS LAr EM calorimeter :

  - longitudinal segmentation, fine eta strips : good resolution on photon z_{DCA};

  - arrival time resolution of ~0.29 ns (0.22 ns from pp collison spread) used as a cross check.



Selection:

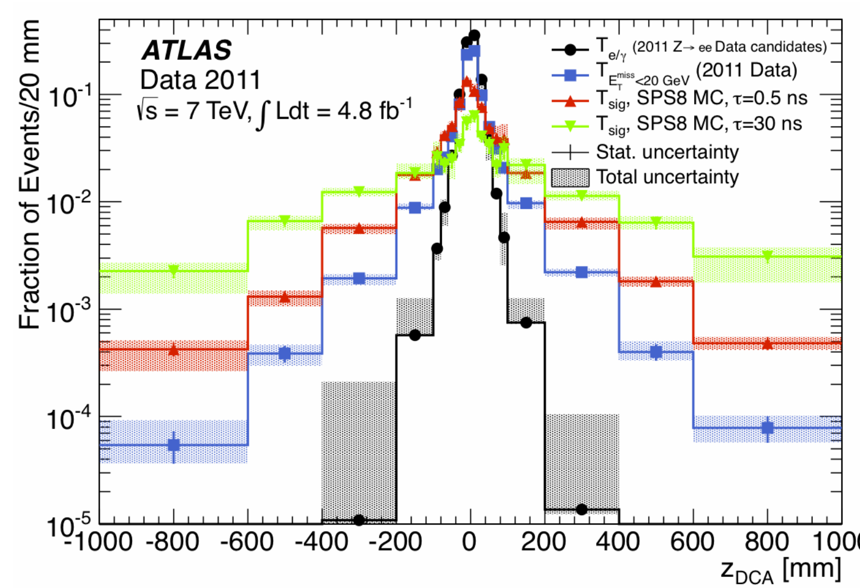
- 2 isolated γ, p_T>50 GeV , $|\eta|$<2.37 (+no cracks)

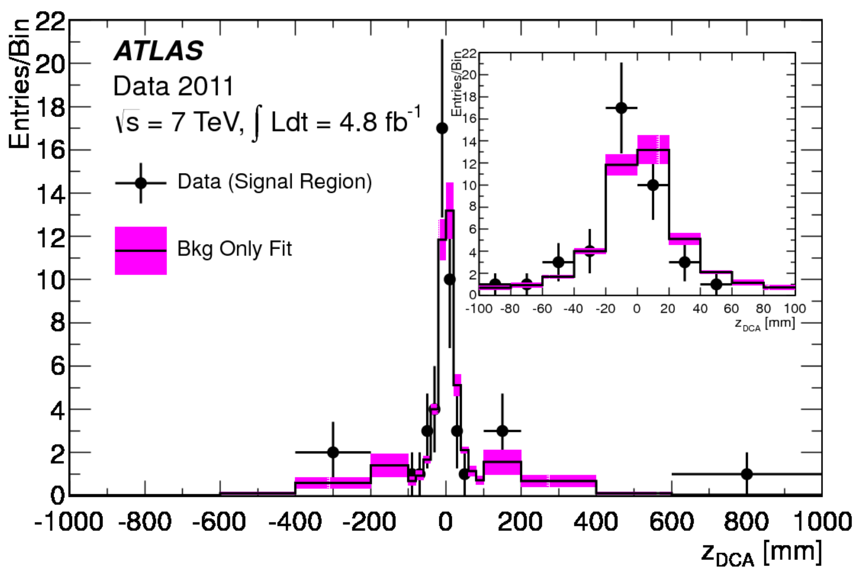
- one γ with Tight and one with Loose ID criteria

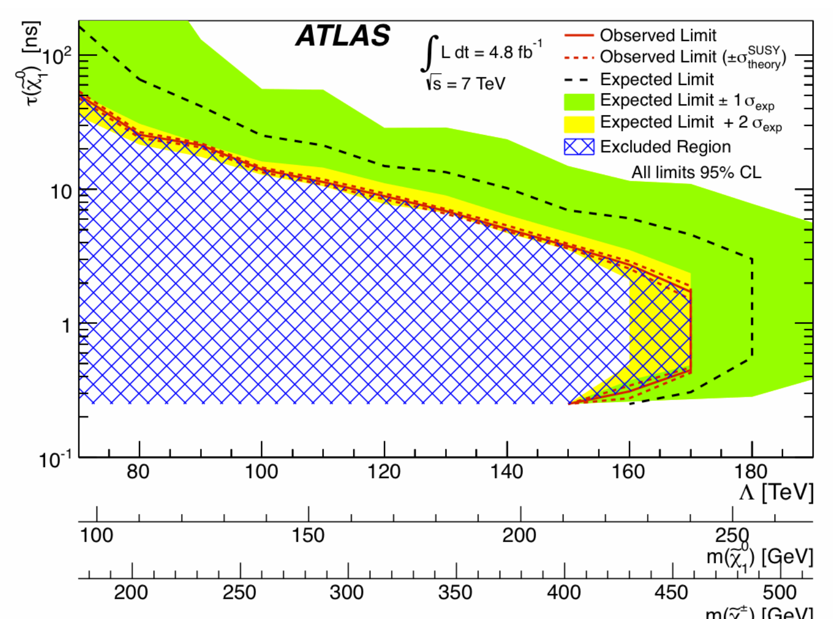
- *missing-E_T>75* GeV

Non-pointing photons, results

- Z_{DCA} measured for Loose ID candidate (less bias)
- Fit using background (+signal) templates
  - True photons, use electrons from Z->ee
  - Fake photons: sample with *Missing-E_T*<20 GeV
- Reasonable data-bkg agreement,
  fit with signal gives best signal strenght of
  μ=0.20+-0.19 for τ=6 ns
- Limit on "snowmass SPS8" point with variable mass scale Λ and $\tau(\tilde{\chi}^0_1)$

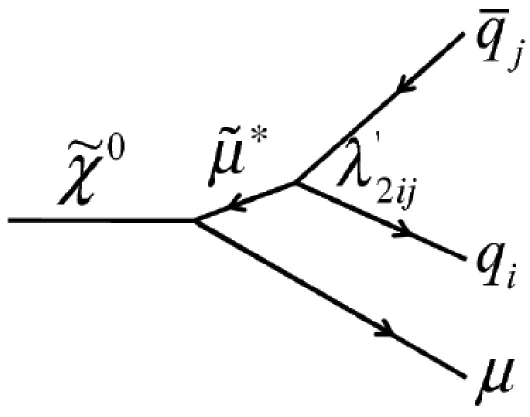


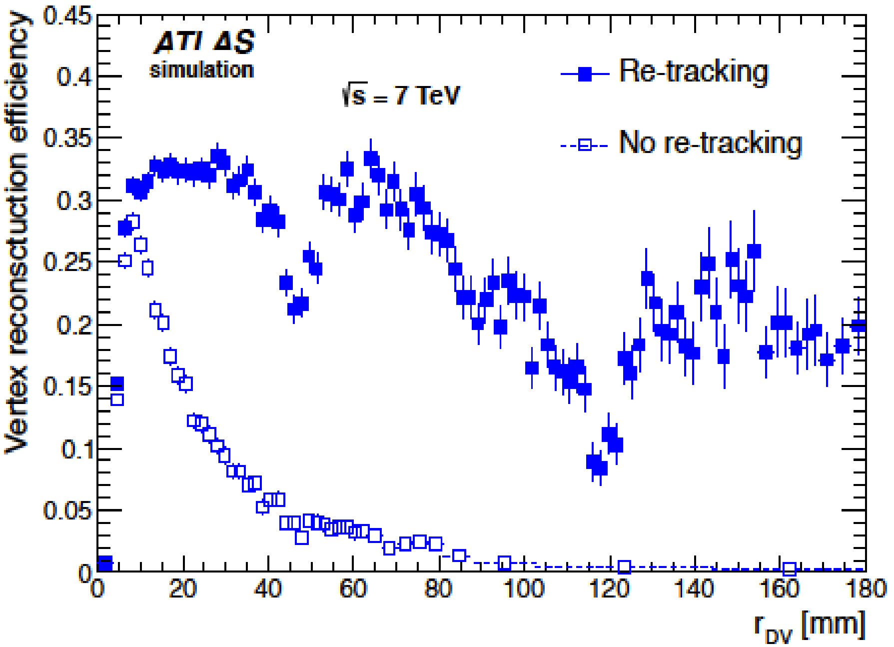




Displaced-vertex plus μ

- In R-parity violating models the lightest neutralino could decay via λ'_{2ij} with cτ ~O(1-1000 mm)
- Signature: μ + displaced vertex (DV) inside the inner detector (ID)
- ATLAS analysis of 7 TeV data $L=4.4\ fb^{-1}$ (PLB 719 (2013) 280)
- Dedicated reconstrution of tracks not pointing to the interaction region and DVs inside the ID volume
- Selection:
  - $p_T(\mu)>50$ GeV (combined ID+MS)
  - DV : 4< radius <180 mm,
  - veto on regions with ID material.
- Backgrounds:
  - combinatorial
  - interactions with gas

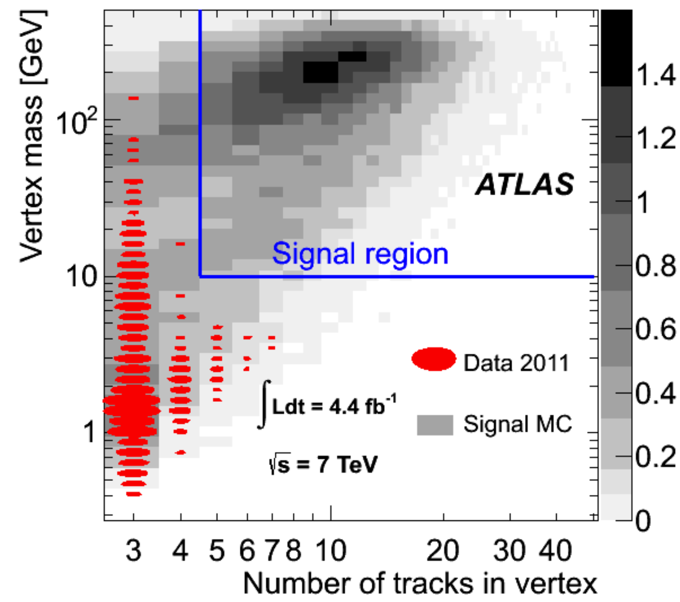




Displaced-vertex plus μ, results

Cut on track multiplicity and DV mass

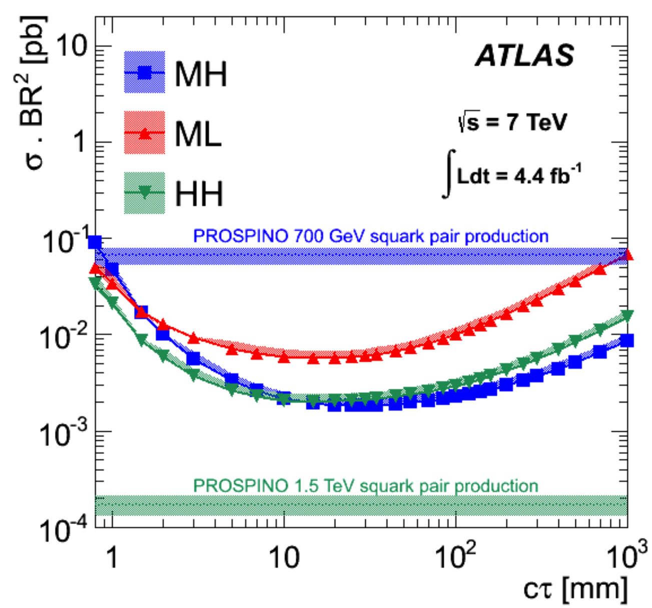
Observed events
Data: 0
Exp. bkg: $(4^{+60}_{-4})\times10^{-2}$



- 3 samples generated with Pythia for 3 combinations of $m_{\tilde{q}}$ and m_{χ^0}

- Limit on $\sigma \times B^2(\tilde{q} \to q\ \chi^0)$ as a function of $c\tau(\chi^0)$

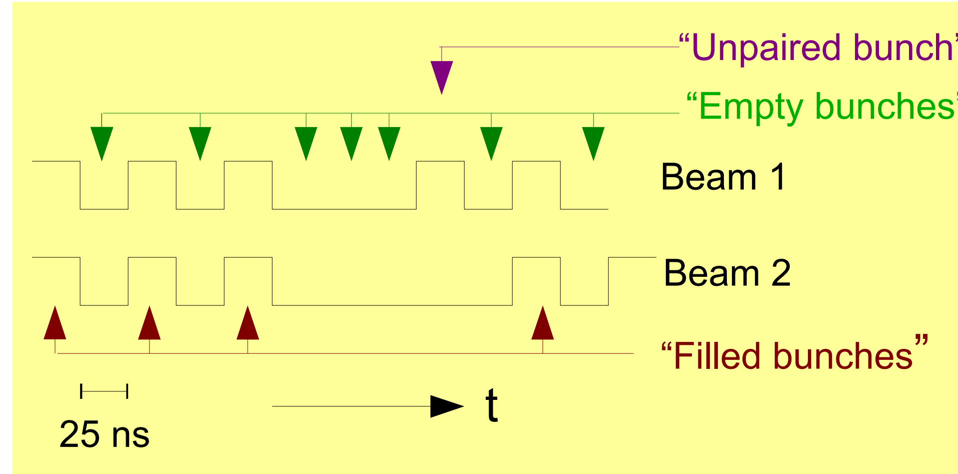
- Excluded squarks with M<700 GeV

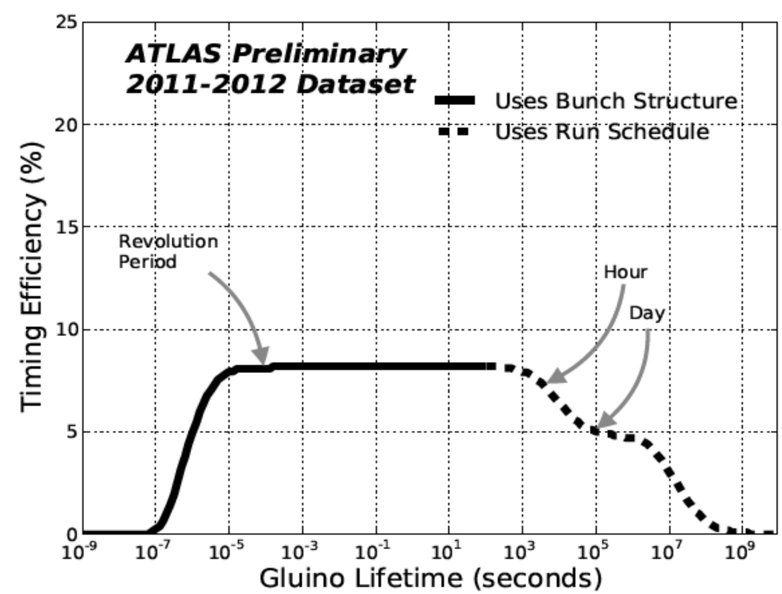


Sample	$m_{\tilde{q}}$ [GeV]	σ [fb]	$m_{\tilde{\chi}_1^0}$ [GeV]	$\langle\gamma\beta\rangle_{\tilde{\chi}_1^0}$	$c\tau_{MC}$ [mm]	λ'_{211} $\times10^{-5}$
MH	700	66.4	494	1.0	78	0.3
ML	700	66.4	108	3.1	101	1.5
HH	1500	0.2	494	1.9	82	1.5

Out-of-time jets (stopped $\tilde{g}$)

- New analysis of full 2011 + 2012 data (ATLAS-CONF-2013-057): L=5.3 fb^{-1}(@7 TeV) + 22.9 fb^{-1} (@8 TeV)
- R-parity violating (RPV) SUSY $\tilde{g}$ or $\tilde{q}$ can be semi-stable and hadronize into a R-hadron
- massive R-hadrons could loose energy by ionization and hadronic interaction and come to rest inside ATLAS and decay at a later time.
- Search looking at jets delayed with respect to the p-p collisions
- Special triggers looking at jets (p_T>*50* GeV) and *missing*-E_T (>*50 GeV*) in "empty bunches":
  Total live time = 515.1 hours
- Cosmic-enriched sample based on lower luminosity periods in first half of 2011



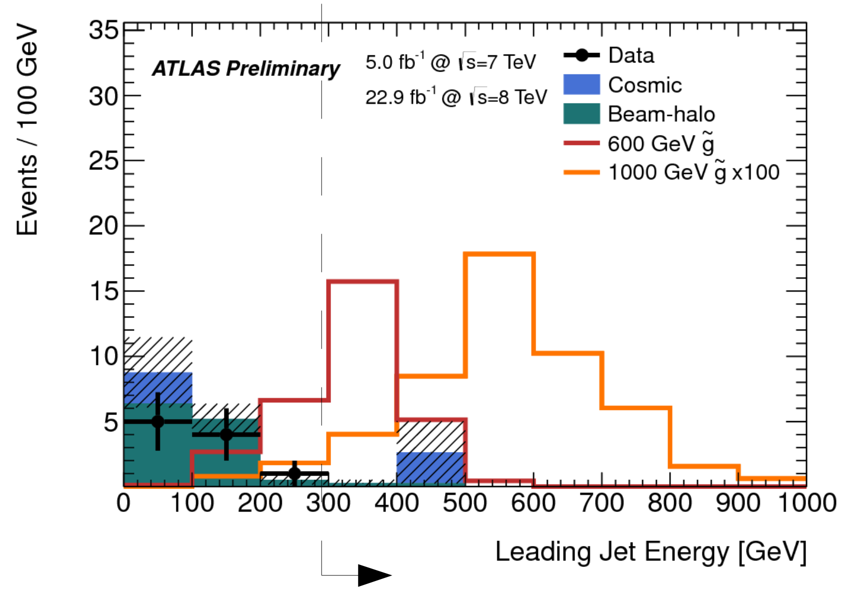


Out-of-time jets: selection

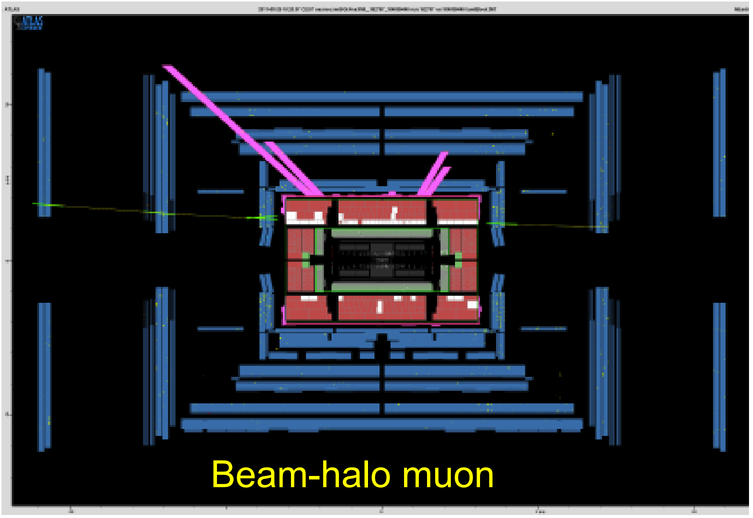
- Sensitivity to R-hadron lifetime
  100 ns < cτ < ~100 days

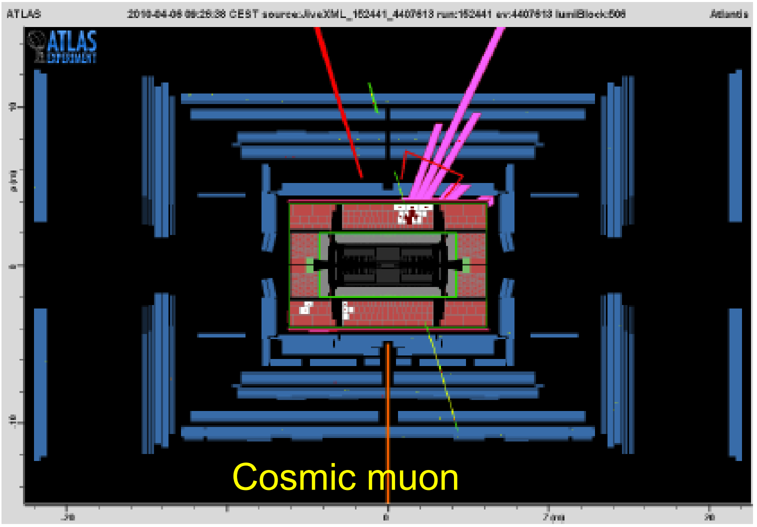
- Main backgrounds:
  - Cosmics, estimated from low-luminosity sample;
  - Beam-halo muons, estimated from "unpaired" bunches.

- Selection:
  - $|\eta_{jet}|<1.2$
  - Jet "cleaning" cuts
  - muon segment veto
  - $E_{jet}>100$, 300 GeV



Events before muon veto →

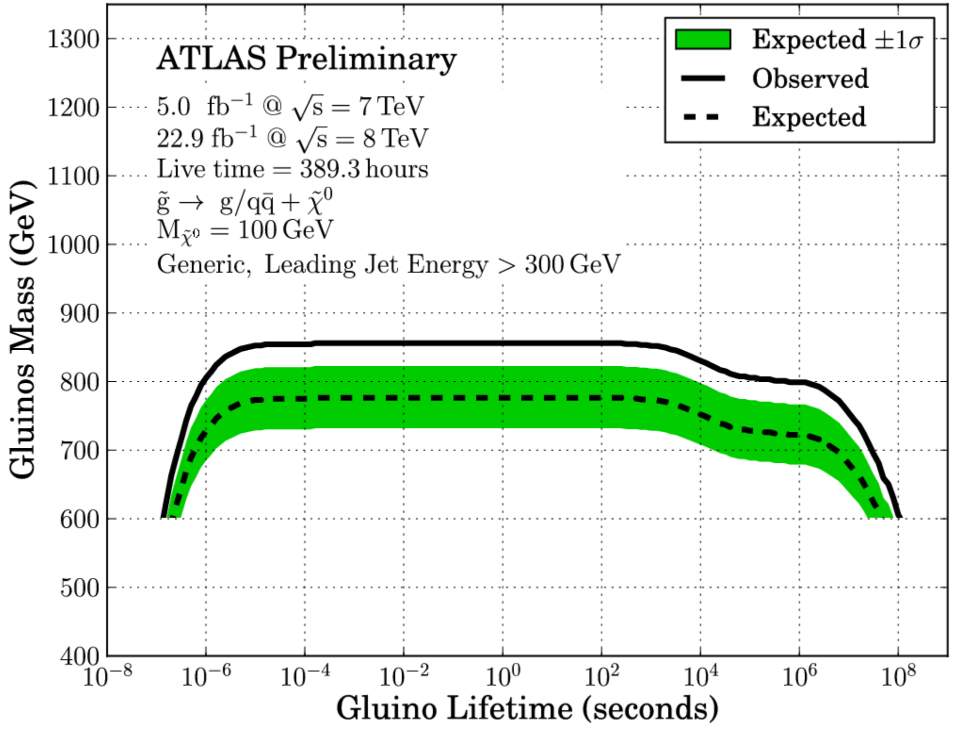




Out-of-time jets: results

- Data consistent with bkg: limits
- Limits on RPV SUSY with long-lived gluino
- Signal efficiency using Pythia with different decay modes, neutralino mass scan: 100 GeV < $M_{\tilde{\chi}1}$ < ($M_{\tilde{g}}$-100 GeV)
- Three different interaction models for R-hadrons giving stopping fractions from 5.2% to 12.2%
- 10 μs -1000 s plateau, excluded: $M_{\tilde{g}}$ < 572 - 857 GeV (generic model) O (100 GeV) worse with other models

Leading jet energy (GeV)	Muon veto	Number of events: Cosmic	Beam-halo	Total background	Observed
50	No	4820 ± 570	900 ± 130	5720 ± 590	5396
50	Yes	2.1 ± 3.6	12.1 ± 3.2	14.2 ± 4.0	10
100	Yes	0.4 ± 2.7	6.0 ± 1.8	6.4 ± 2.9	5
300	Yes	2.4 ± 2.4	0.54 ± 0.40	2.9 ± 2.4	0



Displaced vertices from Hidden Sectors

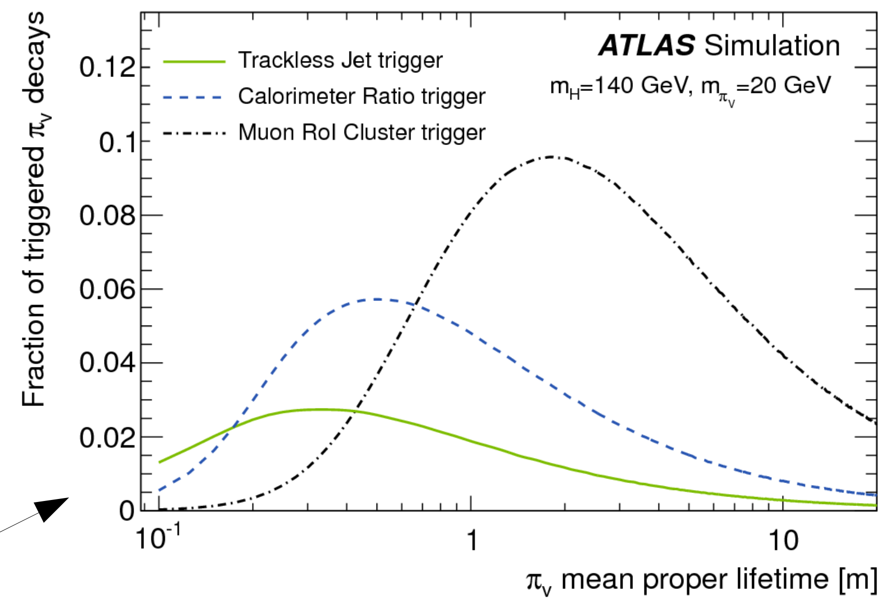
Models with a "Hidden Sector" coupled to SM via heavy mediators (Higgs, Z',...) or gravity.

May decay with displaced vertices,
1 mm < cτ < 10 m

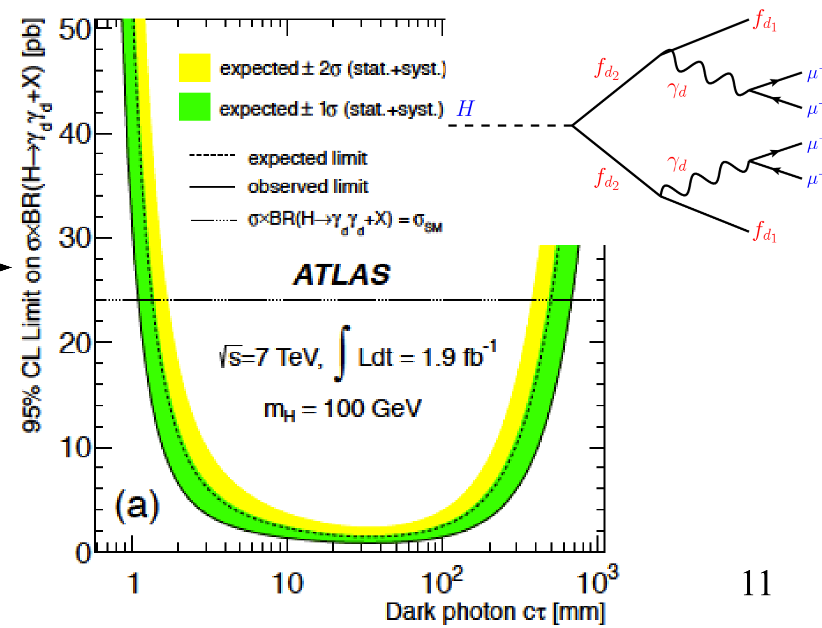
Two models considered (7 TeV analyses) :

1) Higgs decay into long-lived heavy scalars
$H \rightarrow \pi_v \pi_v$: with late π_v decay in $f\bar{f}$ (mainly $b\bar{b}$)
(PRL 108 (2012) 251801)
- Dedicated triggers (arXiv:1305.2284 acc. by JINST)
- Vertex reconstruction inside the MS

Trigger efficiency for π_v



2) Higgs decay into dark fermions and dark photons
$H \rightarrow 2\, f_{d2}$, $f_{d2} \rightarrow LSP + \gamma_d$ with late γ_d decays in two leptons.
(PLB 721 (2013) 32)
- Search of "lepton jets" (2 collimated muons) without matched ID tracks



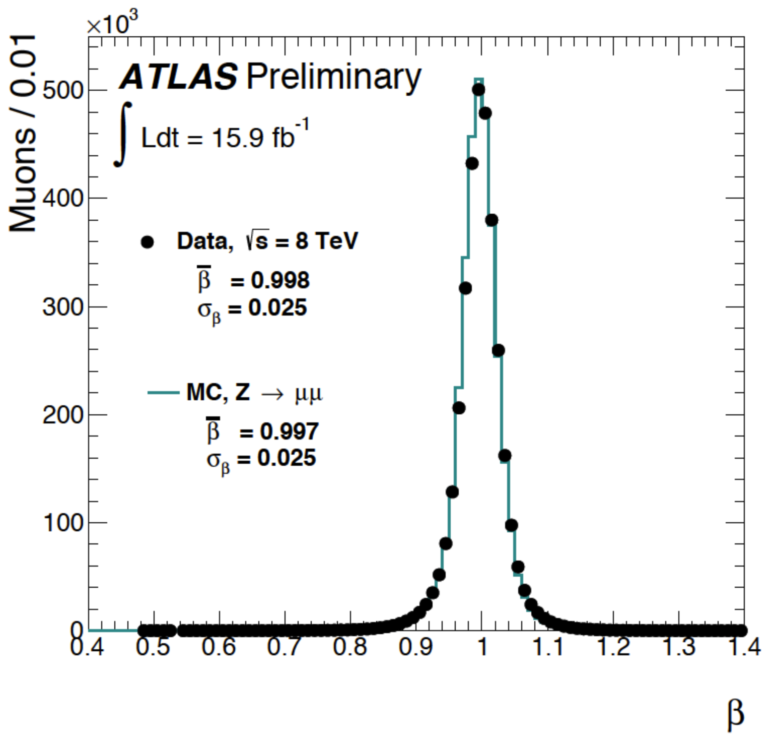
All in agreement with expected backgrounds.

Long-lived Particles: sleptons

- Heavy charged LLPs with $c\tau \geq O(1\ m)$ could traverse the ATLAS detector like a "heavy muon"
- Signatures:
  time-of-flight: low-β
  high ionization: large dE/dx
- Search optimized for two possibilities:

  1) GMSB models with long-lived sleptons most sensitivity from β measurement

  2) R-hadrons could neutralize or decay before reaching the muon system: exploit calorimeters and dE/dx in the pixels
- 7 TeV analysis (PLB 720 (2013) 277) slepton search updated with 8 TeV data, L=16 fb^{-1} (ATLAS-CONF-2013-058) [see poster by E. Musto]



β measured combining
- muon spectrometer (MDT, RPC)
- calorimeter (LAr, Tile)

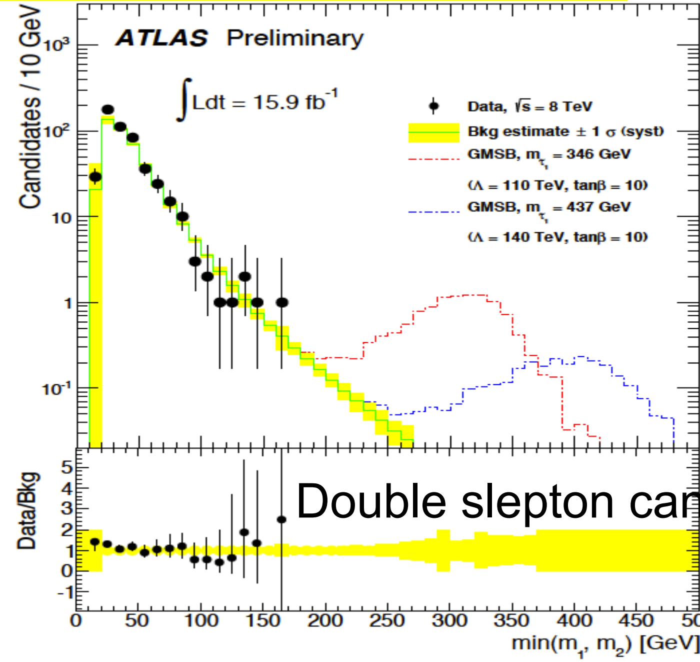
Tested on Z->μμ
Resolution: 0.025

Long-lived sleptons, results

Selection:

- Muon trigger
- Z->μμ and cosmic veto
- two candidates with p_T>50 GeV, |η|<2.5
- good β measurement
- consistency of MS, Calo and pixel dE/dx

Mass: $m=p/\beta\gamma$



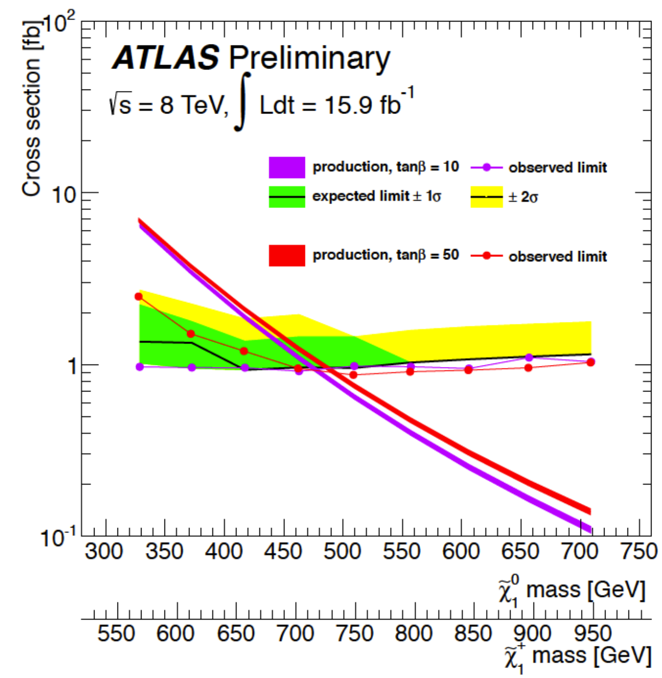
Double slepton candidates

- no candidate pair observed with $\min(m_1,m_2)$>250 GeV

- Limits on GMSB model:

(GMSB: N_5=3, $m_{messenger}$=250 TeV, μ>0, tanβ=10, C_{grav}=5000)

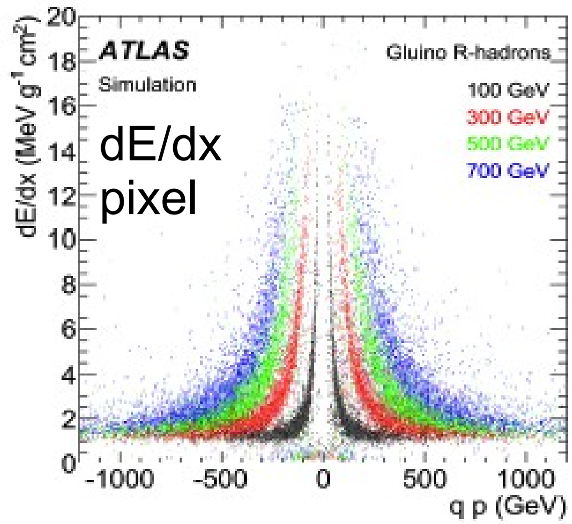
direct production of χ^0_1, χ^+_1 decaying into sleptons excluded for :
$M\chi^0_1$<475-490 GeV (dep. on tanβ)
(about 200 GeV higher for χ^+_1)

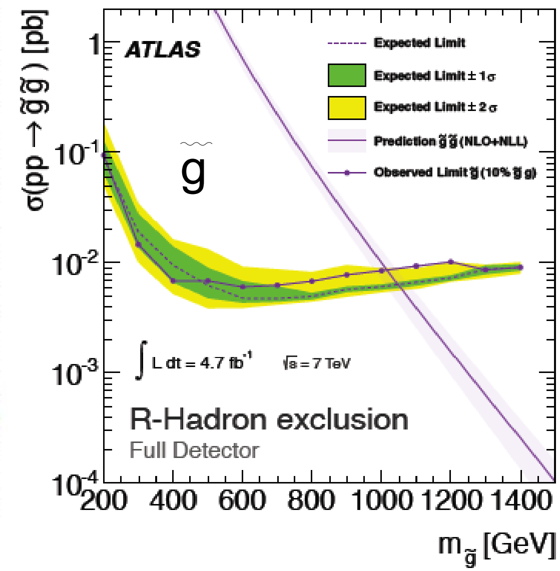


Highly ionizing LLPs

- RPV R-hadron (PLB 720 (2013) 277): combination of pixel dE/dx and ToF

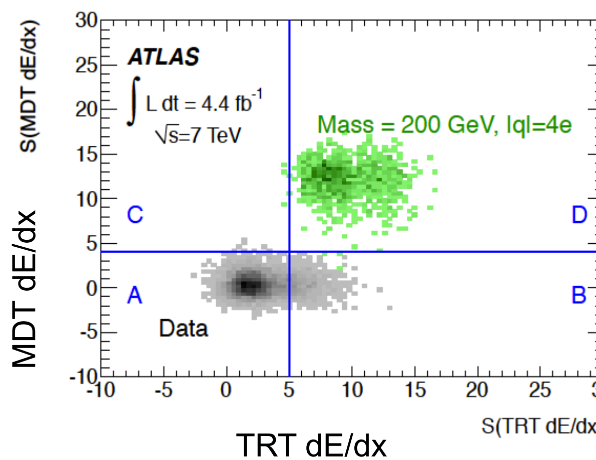
  Excluded: $M_{\tilde{g}}$< 985 GeV



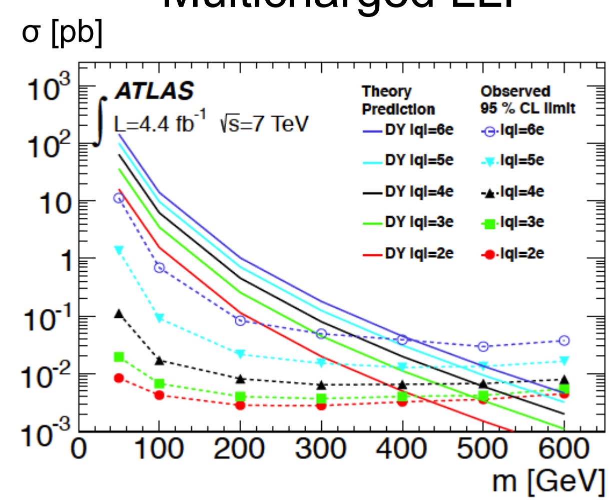


- Multicharged particles (PLB 722, 305 (2013))
  dE/dx measured in Pixel, TRT, MDTs

  DY production
  Excluded: M< ~400 GeV



Multicharged LLP



- Magnetic Monopoles (PRL 109 (2012) 261803)
  dE/dx in calorimeters and TRT

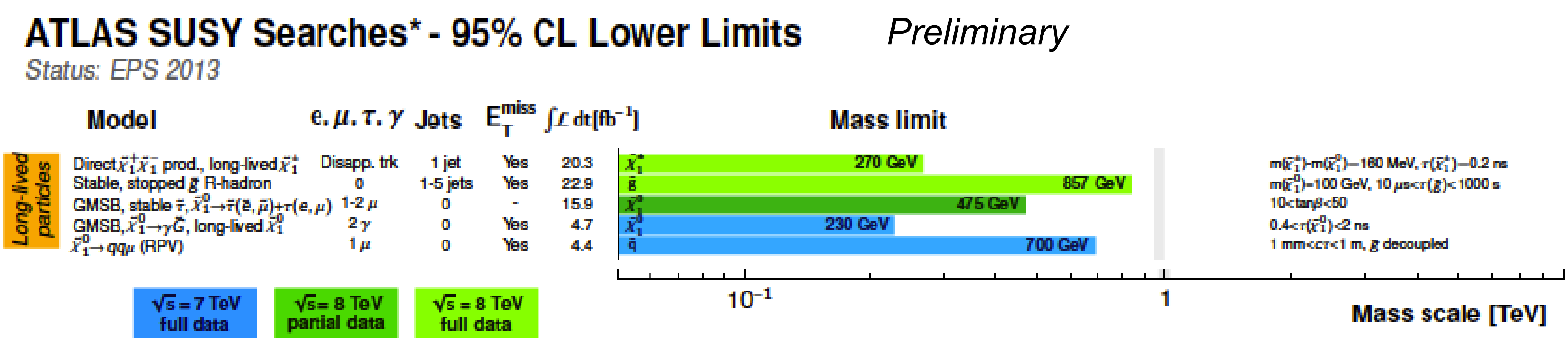
  Excluded: σ >16-145 fb
  (for 200<m<1200 GeV)

Conclusions

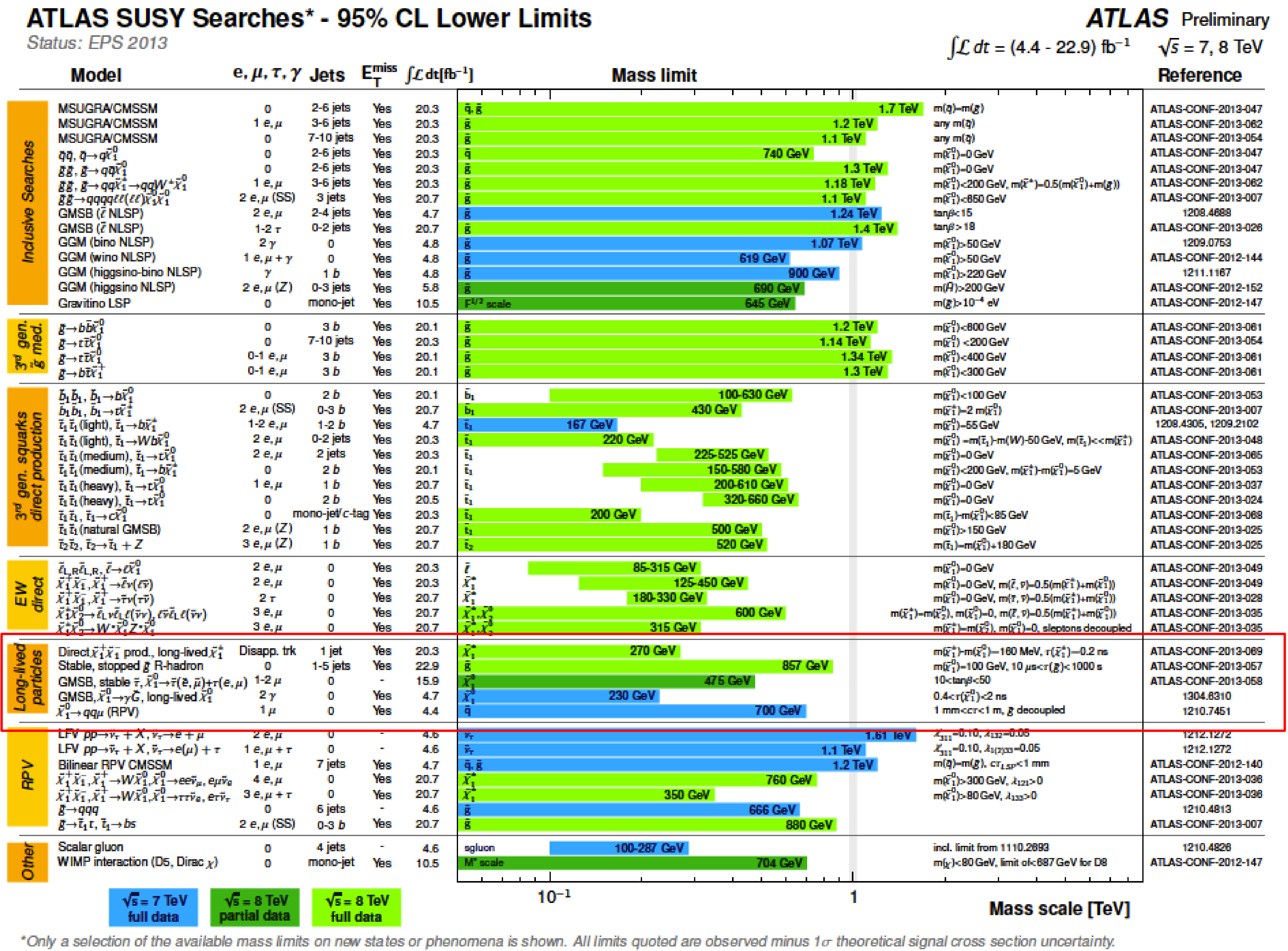
- Continuous effort to push the ATLAS capability to detect LLPs, developing dedicated triggers, reconstruction algorithms etc.

- Most analyses based on 7 TeV 2011 data, first results from 8 TeV and combined 7+8 TeV

- No hint of signal found, limits on :
  - GMSB: $\tilde{\chi}^0_1 \to \gamma \tilde{G}$, (semi-)stable sleptons
  - RPV: $\tilde{\chi}^0_1 \to \mu q \bar{q}$, (semi-)stable $\tilde{g}$ or $\tilde{q}$ R-hadrons
  - Hidden sector models
  - Multicharged particles, monopoles

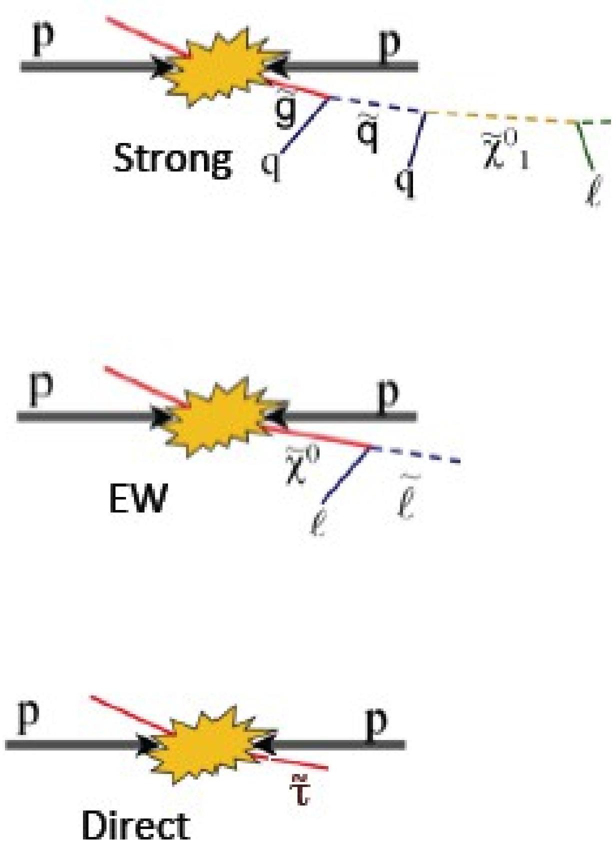


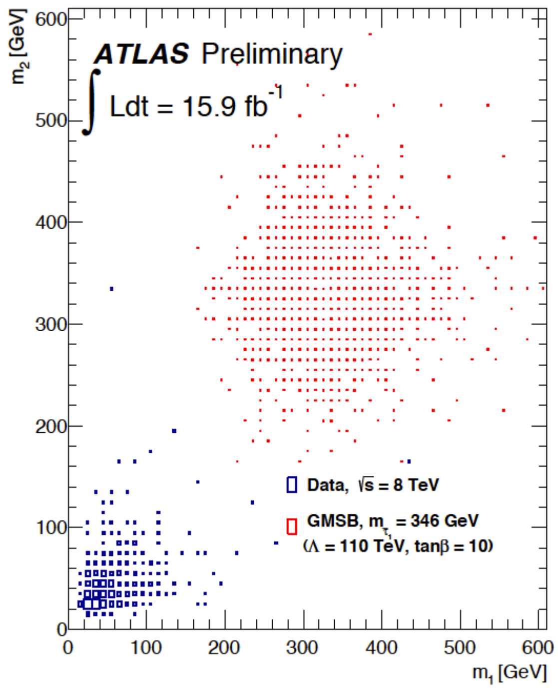
BACKUP SLIDES


ATLAS SUSY Searches* - 95% CL Lower Limits
Status: EPS 2013
ATLAS Preliminary
$\int \mathcal{L}\,dt = (4.4 - 22.9)$ fb^{-1} $\sqrt{s} = 7, 8$ TeV
Model | e, μ, τ, γ | Jets | E_T^{miss} | $\int \mathcal{L}\,dt$[fb^{-1}] | Mass limit | Reference
Inclusive Searches
MSUGRA/CMSSM | 0 | 2-6 jets | Yes | 20.3 | $\tilde{q}, \tilde{g}$ 1.7 TeV | $m(\tilde{q})=m(\tilde{g})$ | ATLAS-CONF-2013-047
MSUGRA/CMSSM | 1 e, μ | 3-6 jets | Yes | 20.3 | $\tilde{g}$ 1.2 TeV | any $m(\tilde{q})$ | ATLAS-CONF-2013-062
MSUGRA/CMSSM | 0 | 7-10 jets | Yes | 20.3 | $\tilde{g}$ 1.1 TeV | any $m(\tilde{q})$ | ATLAS-CONF-2013-054
$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$ | 0 | 2-6 jets | Yes | 20.3 | $\tilde{q}$ 740 GeV | $m(\tilde{\chi}_1^0)$=0 GeV | ATLAS-CONF-2013-047
$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$ | 0 | 2-6 jets | Yes | 20.3 | $\tilde{g}$ 1.3 TeV | $m(\tilde{\chi}_1^0)$=0 GeV | ATLAS-CONF-2013-047
$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$ | 1 e, μ | 3-6 jets | Yes | 20.3 | $\tilde{g}$ 1.18 TeV | $m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}^\pm)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$ | ATLAS-CONF-2013-062
$\tilde{g}\tilde{g}\to qqqq\ell\ell(\ell\ell)\tilde{\chi}_1^0\tilde{\chi}_1^0$ | 2 e, μ (SS) | 3 jets | Yes | 20.7 | $\tilde{g}$ 1.1 TeV | $m(\tilde{\chi}_1^0)$<650 GeV | ATLAS-CONF-2013-007
GMSB ($\tilde{\ell}$ NLSP) | 2 e, μ | 2-4 jets | Yes | 4.7 | $\tilde{g}$ 1.24 TeV | $\tan\beta$<15 | 1208.4688
GMSB ($\tilde{\ell}$ NLSP) | 1-2 τ | 0-2 jets | Yes | 20.7 | $\tilde{g}$ 1.4 TeV | $\tan\beta$>18 | ATLAS-CONF-2013-026
GGM (bino NLSP) | 2 γ | 0 | Yes | 4.8 | $\tilde{g}$ 1.07 TeV | $m(\tilde{\chi}_1^0)$>50 GeV | 1209.0753
GGM (wino NLSP) | 1 $e, \mu + \gamma$ | 0 | Yes | 4.8 | $\tilde{g}$ 619 GeV | $m(\tilde{\chi}_1^0)$>50 GeV | ATLAS-CONF-2012-144
GGM (higgsino-bino NLSP) | γ | 1 b | Yes | 4.8 | $\tilde{g}$ 900 GeV | $m(\tilde{\chi}_1^0)$>220 GeV | 1211.1167
GGM (higgsino NLSP) | 2 e, μ (Z) | 0-3 jets | Yes | 5.8 | $\tilde{g}$ 690 GeV | $m(\tilde{H})$>200 GeV | ATLAS-CONF-2012-152
Gravitino LSP | 0 | mono-jet | Yes | 10.5 | $F^{1/2}$ scale 645 GeV | $m(\tilde{G})>10^{-4}$ eV | ATLAS-CONF-2012-147
3rd gen. $\tilde{g}$ med.
$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$ | 0 | 3 b | Yes | 20.1 | $\tilde{g}$ 1.2 TeV | $m(\tilde{\chi}_1^0)$<600 GeV | ATLAS-CONF-2013-061
$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$ | 0 | 7-10 jets | Yes | 20.3 | $\tilde{g}$ 1.14 TeV | $m(\tilde{\chi}_1^0)$ <200 GeV | ATLAS-CONF-2013-054
$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$ | 0-1 e, μ | 3 b | Yes | 20.1 | $\tilde{g}$ 1.34 TeV | $m(\tilde{\chi}_1^0)$<400 GeV | ATLAS-CONF-2013-061
$\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$ | 0-1 e, μ | 3 b | Yes | 20.1 | $\tilde{g}$ 1.3 TeV | $m(\tilde{\chi}_1^0)$<300 GeV | ATLAS-CONF-2013-061
3rd gen. squarks direct production
$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$ | 0 | 2 b | Yes | 20.1 | $\tilde{b}_1$ 100-630 GeV | $m(\tilde{\chi}_1^0)$<100 GeV | ATLAS-CONF-2013-053
$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^\pm$ | 2 e, μ (SS) | 0-3 b | Yes | 20.7 | $\tilde{b}_1$ 430 GeV | $m(\tilde{\chi}_1^\pm)$=2 $m(\tilde{\chi}_1^0)$ | ATLAS-CONF-2013-007
$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$ | 1-2 e, μ | 1-2 b | Yes | 4.7 | $\tilde{t}_1$ 167 GeV | $m(\tilde{\chi}_1^0)$=55 GeV | 1208.4305, 1209.2102
$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to Wb\tilde{\chi}_1^0$ | 2 e, μ | 0-2 jets | Yes | 20.3 | $\tilde{t}_1$ 220 GeV | $m(\tilde{\chi}_1^0)=m(\tilde{t}_1)-m(W)$-50 GeV, $m(\tilde{t}_1)<<m(\tilde{\chi}_1^\pm)$ | ATLAS-CONF-2013-048
$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to t\tilde{\chi}_1^0$ | 2 e, μ | 2 jets | Yes | 20.3 | $\tilde{t}_1$ 225-525 GeV | $m(\tilde{\chi}_1^0)$=0 GeV | ATLAS-CONF-2013-065
$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$ | 0 | 2 b | Yes | 20.1 | $\tilde{t}_1$ 150-580 GeV | $m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}_1^\pm)-m(\tilde{\chi}_1^0)$=5 GeV | ATLAS-CONF-2013-053
$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$ | 1 e, μ | 1 b | Yes | 20.7 | $\tilde{t}_1$ 200-610 GeV | $m(\tilde{\chi}_1^0)$=0 GeV | ATLAS-CONF-2013-037
$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$ | 0 | 2 b | Yes | 20.5 | $\tilde{t}_1$ 320-660 GeV | $m(\tilde{\chi}_1^0)$=0 GeV | ATLAS-CONF-2013-024
$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$ | 0 | mono-jet/c-tag | Yes | 20.3 | $\tilde{t}_1$ 200 GeV | $m(\tilde{t}_1)-m(\tilde{\chi}_1^0)$<85 GeV | ATLAS-CONF-2013-068
$\tilde{t}_1\tilde{t}_1$(natural GMSB) | 2 e, μ (Z) | 1 b | Yes | 20.7 | $\tilde{t}_1$ 500 GeV | $m(\tilde{\chi}_1^0)$>150 GeV | ATLAS-CONF-2013-025
$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1 + Z$ | 3 e, μ (Z) | 1 b | Yes | 20.7 | $\tilde{t}_2$ 520 GeV | $m(\tilde{t}_1)=m(\tilde{\chi}_1^0)$+180 GeV | ATLAS-CONF-2013-025
EW direct
$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$ | 2 e, μ | 0 | Yes | 20.3 | $\tilde{\ell}$ 85-315 GeV | $m(\tilde{\chi}_1^0)$=0 GeV | ATLAS-CONF-2013-049
$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$ | 2 e, μ | 0 | Yes | 20.3 | $\tilde{\chi}_1^\pm$ 125-450 GeV | $m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$ | ATLAS-CONF-2013-049
$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$ | 2 τ | 0 | Yes | 20.7 | $\tilde{\chi}_1^\pm$ 180-330 GeV | $m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$ | ATLAS-CONF-2013-028
$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$ | 3 e, μ | 0 | Yes | 20.7 | $\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 600 GeV | $m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$ | ATLAS-CONF-2013-035
$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W^*\tilde{\chi}_1^0 Z^*\tilde{\chi}_1^0$ | 3 e, μ | 0 | Yes | 20.7 | $\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ 315 GeV | $m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled | ATLAS-CONF-2013-035
Long-lived particles
Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$ | Disapp. trk | 1 jet | Yes | 20.3 | $\tilde{\chi}_1^\pm$ 270 GeV | $m(\tilde{\chi}_1^\pm)-m(\tilde{\chi}_1^0)$=160 MeV, $\tau(\tilde{\chi}_1^\pm)$=0.2 ns | ATLAS-CONF-2013-069
Stable, stopped $\tilde{g}$ R-hadron | 0 | 1-5 jets | Yes | 22.9 | $\tilde{g}$ 857 GeV | $m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s | ATLAS-CONF-2013-057
GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$ | 1-2 μ | 0 | - | 15.9 | $\tilde{\chi}_1^0$ 475 GeV | 10<$\tan\beta$<50 | ATLAS-CONF-2013-058
GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$ | 2 γ | 0 | Yes | 4.7 | $\tilde{\chi}_1^0$ 230 GeV | 0.4<$\tau(\tilde{\chi}_1^0)$<2 ns | 1304.6310
$\tilde{\chi}_1^0\to qq\mu$ (RPV) | 1 μ | 0 | Yes | 4.4 | $\tilde{q}$ 700 GeV | 1 mm<$c\tau$<1 m, $\tilde{g}$ decoupled | 1210.7451
RPV
LFV $pp\to\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\to e + \mu$ | 2 e, μ | 0 | - | 4.6 | $\tilde{\nu}_\tau$ 1.61 TeV | λ'_{311}=0.10, λ_{132}=0.05 | 1212.1272
LFV $pp\to\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\to e(\mu) + \tau$ | 1 $e, \mu + \tau$ | 0 | - | 4.6 | $\tilde{\nu}_\tau$ 1.1 TeV | λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05 | 1212.1272
Bilinear RPV CMSSM | 1 e, μ | 7 jets | Yes | 4.7 | $\tilde{q}, \tilde{g}$ 1.2 TeV | $m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}$<1 mm | ATLAS-CONF-2012-140
$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$ | 4 e, μ | 0 | Yes | 20.7 | $\tilde{\chi}_1^\pm$ 760 GeV | $m(\tilde{\chi}_1^0)$>300 GeV, λ_{121}>0 | ATLAS-CONF-2013-036
$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$ | 3 $e, \mu + \tau$ | 0 | Yes | 20.7 | $\tilde{\chi}_1^\pm$ 350 GeV | $m(\tilde{\chi}_1^0)$>80 GeV, λ_{133}>0 | ATLAS-CONF-2013-036
$\tilde{g}\to qqq$ | 0 | 6 jets | - | 4.6 | $\tilde{g}$ 666 GeV | | 1210.4813
$\tilde{g}\to\tilde{t}_1 t, \tilde{t}_1\to bs$ | 2 e, μ (SS) | 0-3 b | Yes | 20.7 | $\tilde{g}$ 880 GeV | | ATLAS-CONF-2013-007
Other
Scalar gluon | 0 | 4 jets | - | 4.6 | sgluon 100-287 GeV | incl. limit from 1110.2693 | 1210.4826
WIMP interaction (D5, Dirac χ) | 0 | mono-jet | Yes | 10.5 | M* scale 704 GeV | $m(\chi)$<80 GeV, limit of<687 GeV for D8 | ATLAS-CONF-2012-147
10^{-1}
1
Mass scale [TeV]
$\sqrt{s}$ = 7 TeV full data
$\sqrt{s}$ = 8 TeV partial data
$\sqrt{s}$ = 8 TeV full data
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

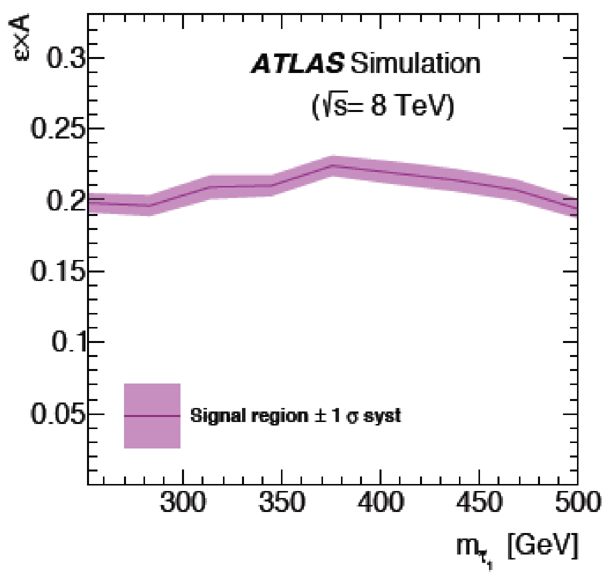
Additional LLP slepton plots

Slepton production modes





Slepton efficiency

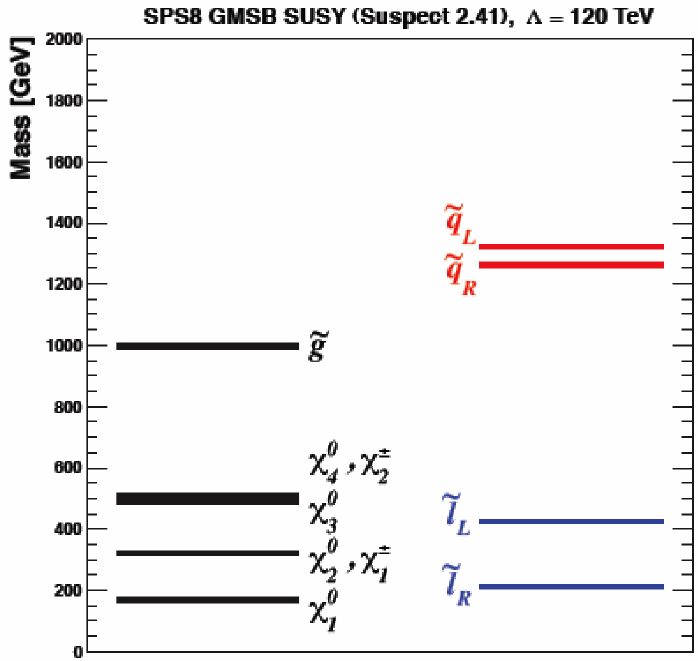


Benchmark Model: SPS8 line of the mGMSB model

- We take minimal GMSB as a reference low-scale SUSY breaking model.
- MSSM masses originate from SM gauges interactions, so masses are proportional to the gauge couplings carried. The parameter Λ= F/M sets the overall mass scale.
- For $N_{mes} = 1$ (e.g. in SPS8), χ_1^0 is NLSP and primarily decays via $\chi_1^0 \longrightarrow \gamma\tilde{G}$

SPS8

$$M_m = 2\Lambda$$
$$N_m = 1$$
$$\tan\beta = 15$$
$$\mu > 0$$



$$m_{\tilde{G}} = \frac{F}{\sqrt{3}M_p} \approx 2.4 \left(\frac{\sqrt{F}}{100 \text{ TeV}}\right)^2 \text{ eV}$$

- F also sets the rate by which the NLSP decays into a SM particle and the gravitino.
  - **For sufficiently large F the decay can be non-prompt.**

NLSP Decay Rate

$$\Gamma(\tilde{X} \to X\tilde{G}) = \frac{\kappa m_{\tilde{X}}^5}{16\pi F^2}\left(1 - \frac{m_X^2}{m_{\tilde{X}}^2}\right)^4$$

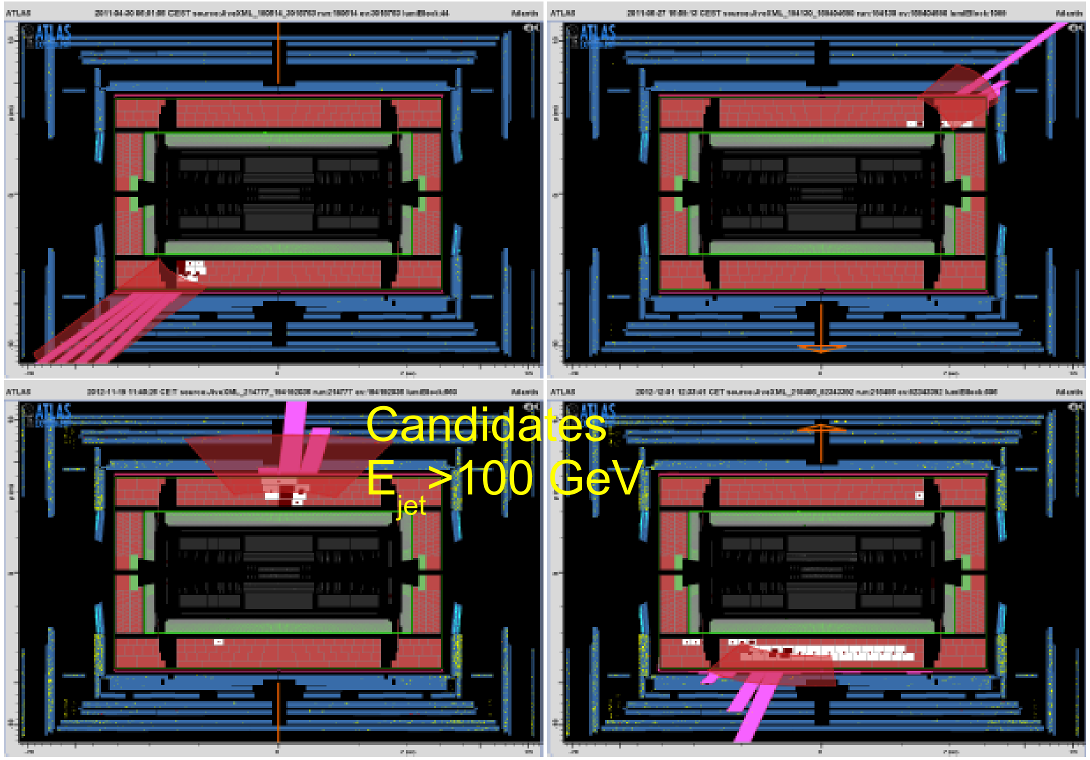
Out-of-time jets

Table 6: Bayesian lower limits on gluino mass for the various signal models considered, with gluino lifetimes in the plateau acceptance region between 10^{-5} and 10^{3} seconds.

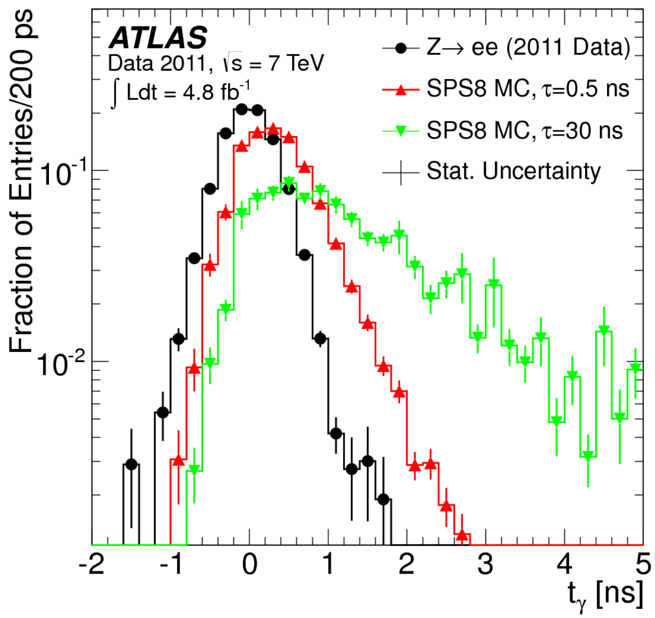
Leading jet energy (GeV)	R-hadron model	Gluino decay	Neutralino mass (GeV)	Limits on $m_{\tilde{g}}$ (GeV) Expected	Observed
100	Generic	$g/q\bar{q}+\tilde{\chi}^0$	$M_{\tilde{g}}$ − 100	549	572
100	Generic	$t\bar{t}+\tilde{\chi}^0$	$M_{\tilde{g}}$ − 380	711	723
300	Generic	$t\bar{t}+\tilde{\chi}^0$	100	722	809
300	Generic	$g/q\bar{q}+\tilde{\chi}^0$	100	763	857
300	Intermediate	$g/q\bar{q}+\tilde{\chi}^0$	100	635	722
300	Regge	$g/q\bar{q}+\tilde{\chi}^0$	100	687	788

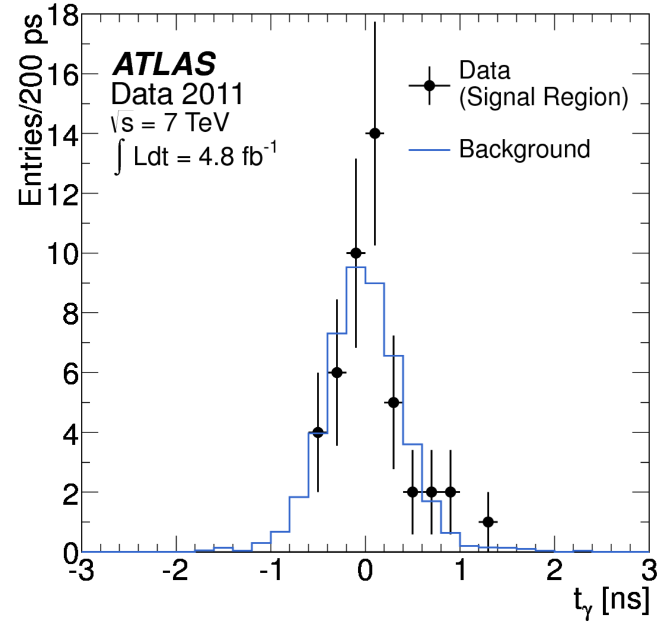
Luminosity and live time

Data period	Delivered luminosity (fb^{-1})@CM energy (TeV)	Recorded empty live time (hours)
Cosmic	0.3 @ 7	125.8
Search	5.0 @ 7 + 22.9 @ 8	389.3
Total	5.3 @ 7 + 22.9 @ 8	515.1



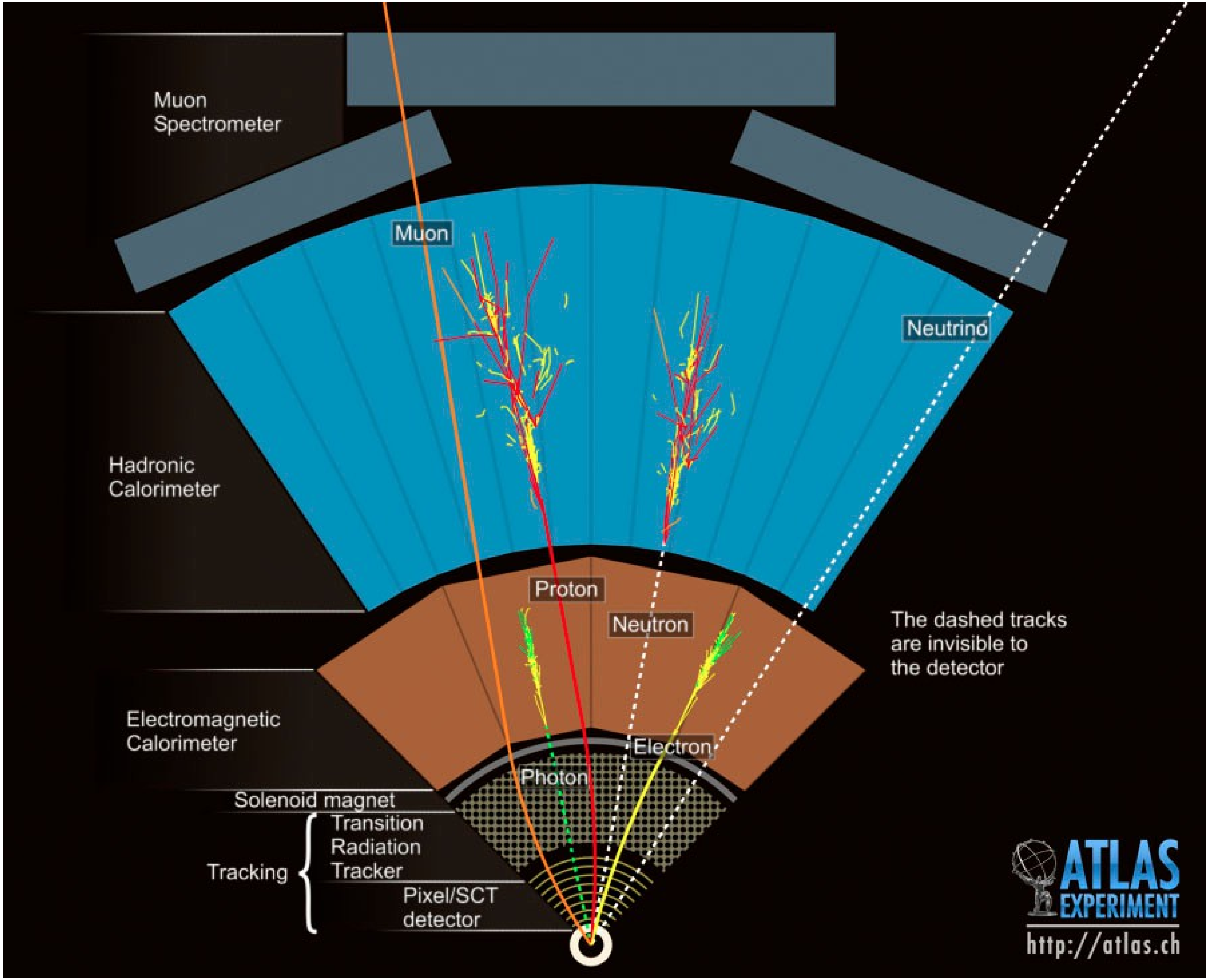
Non-pointing photons, timing, outlier events





Run	Event	E_T^{miss}	Loose Photon			Tight Photon		
Number	Number	(GeV)	E_T (GeV)	z_{DCA} (mm)	t_γ (ps)	E_T (GeV)	z_{DCA} (mm)	t_γ (ps)
186721	30399675	77.1	75.9	−274	360	72.0	22	580
187552	14929851	77.3	59.4	−262	1200	87.2	−120	240
191920	14157929	77.9	56.6	752	2	54.2	5	−200

TABLE III. Some parameters of the three "outlier" events mentioned in the text.



Muon
Spectrometer
Hadronic
Calorimeter
Electromagnetic
Calorimeter
Solenoid magnet
Tracking
Transition
Radiation
Tracker
Pixel/SCT
detector
Muon
Neutrino
Proton
Neutron
Electron
Photon
The dashed tracks
are invisible to
the detector
ATLAS
EXPERIMENT
http://atlas.ch

Vertex reconstruction in the MS

PRL 108 (2012) 251801

- Dedicated tracking in MS
  exploits low material in ATLAS MS
  - low-pt tracks (>100 MeV)
  - not pointing to the interaction
  - robust against high hit multiplicity
    (due to photon showers)