EWKino Production and Long-Lived particles at LHC

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Rencontres de Moriond EW Session
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Outline

- Strategy and results on 2011-12 data at ATLAS and CMS for:
  - **SUSY Electroweakino searches**
    - Prompt decays
    - Typical signature:
      - Large MET + multi-leptons
      - Large MET + jets/photons
  - **Long-Lived Particles searches**
    - Decays throughout the detectors depending on the different lifetimes
    - Typical signatures:
      - Displaced vertexes and jets
      - Disappearing or kinked tracks
      - Non-pointing objects
- Summary and Outlook

Magic Potion for EKWino

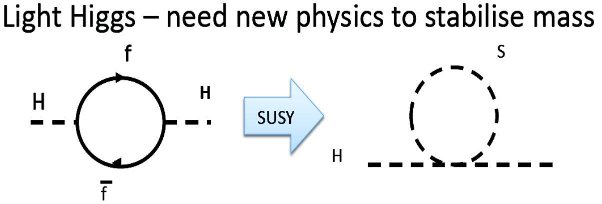
- ✓ Good lepton identification
- ✓ Good jet reconstruction
- ✓ MET

Magic Potion for LLP

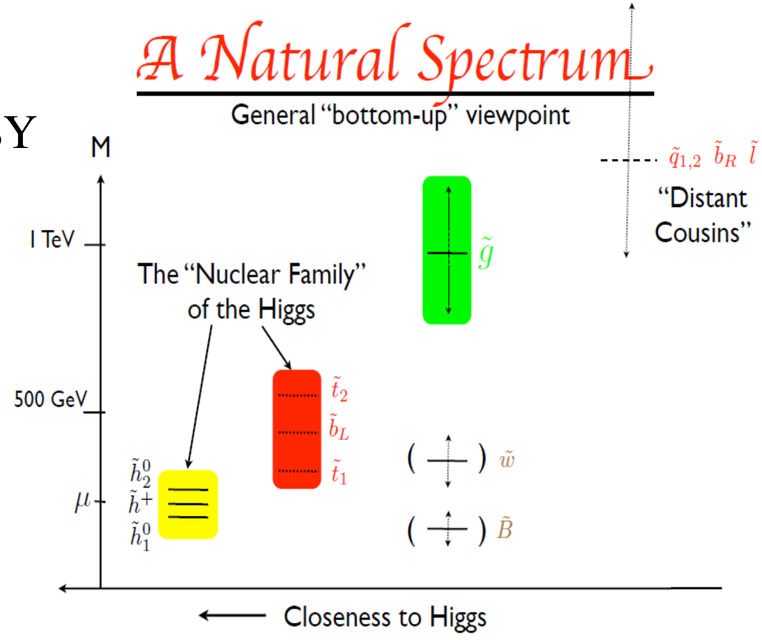
- ✓ Good vertex identification
- ✓ Good jet reconstruction
- ✓ Good track reconstruction

Why EWKino Production?

- The discovered new boson seems consistent with the SM Higgs boson, but now we are faced with an old problem: **fine tuning**



- Supersymmetry (SUSY) is a favorite solution
  - Stabilizes Higgs mass boson,
  - Offers a dark matter candidate,
  - allows unification of gauge couplings
- **No evidence of events with large hadronic activities and MET**, both ATLAS and CMS have excluded SUSY colored production up to TeV scale:
  - squarks & gluinos too heavy to be produced at 8 TeV?
- **Minimal SUSY Model** (protects Higgs mass) still motivates **searches for scalar top/bottom quark & light gauginos/higgsinos at EW scale.**
  - For example in "natural SUSY"
  - σ ($\chi^0_2\chi^\pm_1$ @300GeV) ~ 0.1 pb, σ (sleptons @200GeV) ~ 0.008 pb



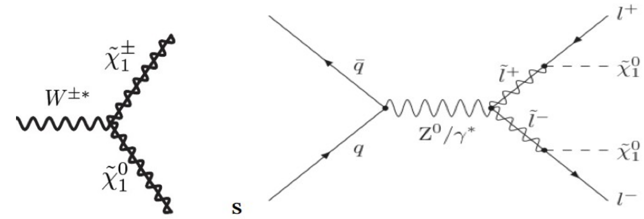
EWKino Signatures

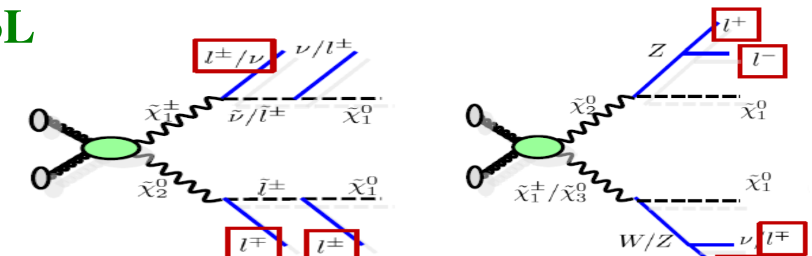
- **Direct Searches of Chargino /Neutralino and sleptons**
  - **Searches for charginos and sleptons in the 2L**
    - 2 leptons + MET (ATLAS @ 7 TeV PLB 718 (2013) 879, CMS @ 8TeV SUS-12-022)
  - **Searches for charginos and sleptons in the 3L**
    - 3 leptons + MET
- **Prompt R-Parity Violation (RPV)**
  - **Searches for charginos and sleptons in the 4L (RPV)**
    - 4 leptons + MET
  - **R-parity violation (RPV) at production and decay, sneutrino (LFV)RPV**
    - Pairs of e-τ, τ-μ, e-μ (arXiv:1212.1272)

$$R=(-1)^{(L+3B+2J)} \quad \text{where} \quad \begin{cases} L = \text{leptonic number} \\ B = \text{baryonic number} \\ J = \text{spin} \end{cases}$$

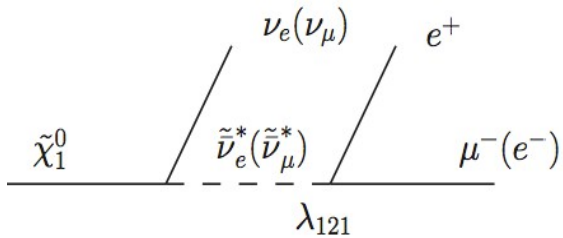
R = -1 for sparticles

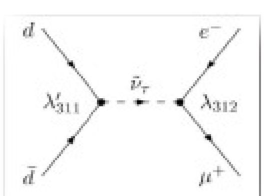
R = +1 for SM particles





Decays to sleptons   Decays to W/Z



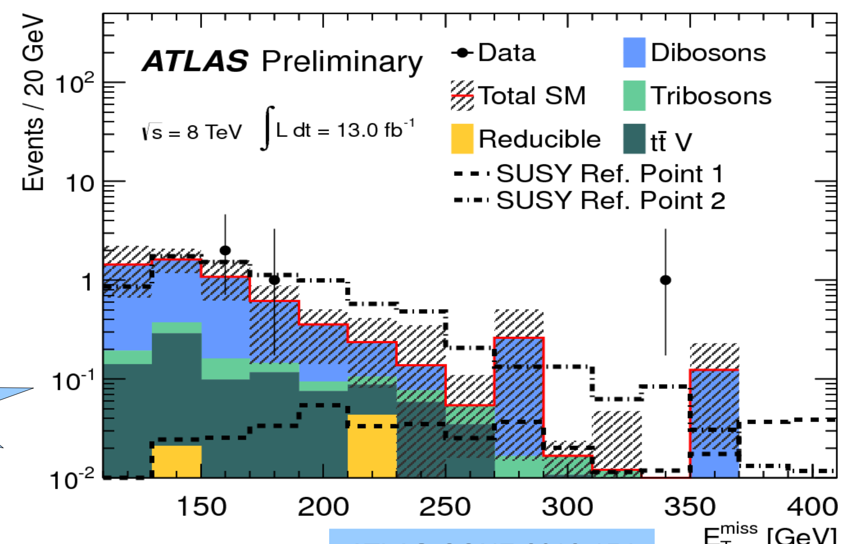


Direct Chargino/Neutralino Searches: 3 Leptons

- Charginos up to ~100 GeV in mass are excluded by LEP experiments.
- Typical signature: **three leptons + MET**
  - Large Missing Transverse momentum expected from neutralinos (LSP) in the decay chain
  - Different Signal Regions
    - ATLAS: 2 orthogonal signal regions (SR), Z-depleted (2 subregions), Z-enriched, w/o bjets
    - CMS: many signal regions, w/o Z, H_T, MET, leptons multiplicity
- **Low Rate but better Background Control due to the leptons in the final state**
  - ZW, ZZ, top, heavy flavour decays, Z+jet

Events in SR with Z-enriched

8TeV



ATLAS-CONF-2012-154

Direct Chargino/Neutralino Searches: 3 Leptons

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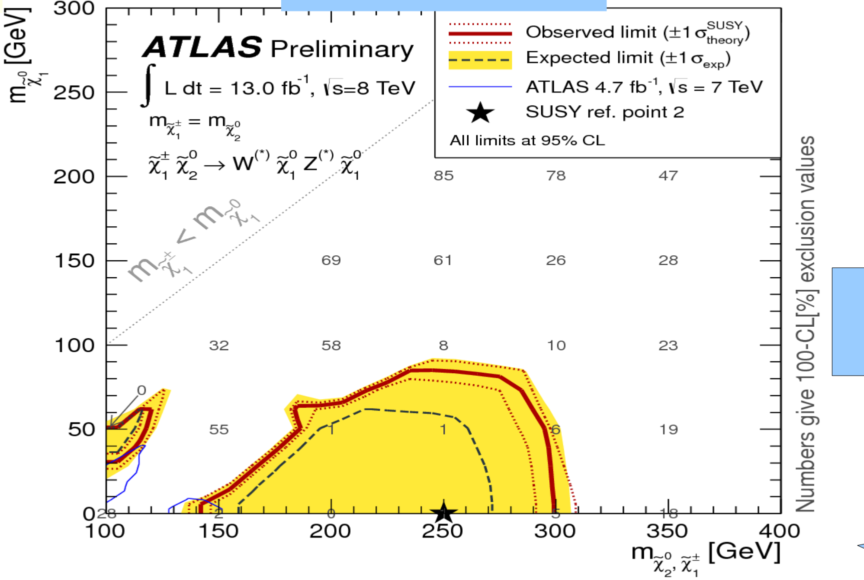
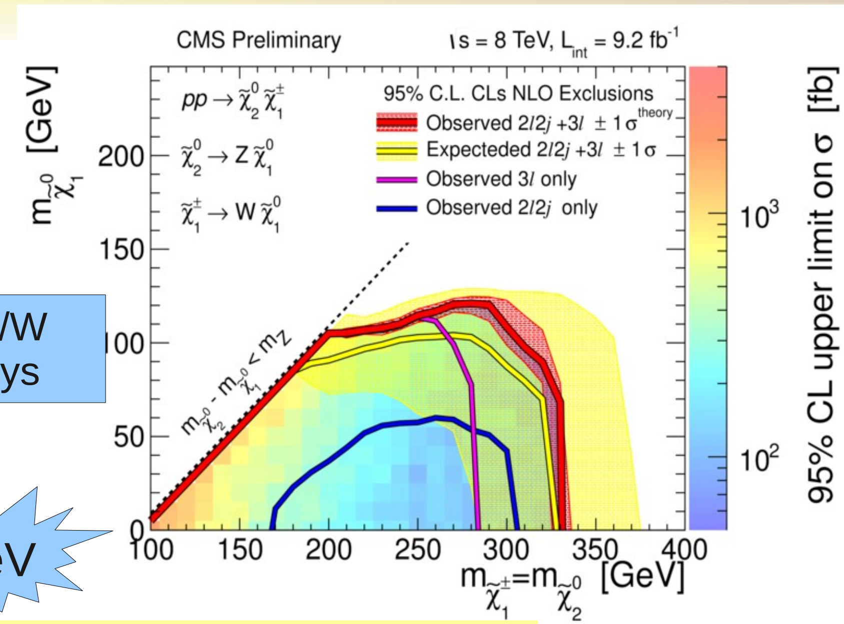


Via Z/W decays

8TeV



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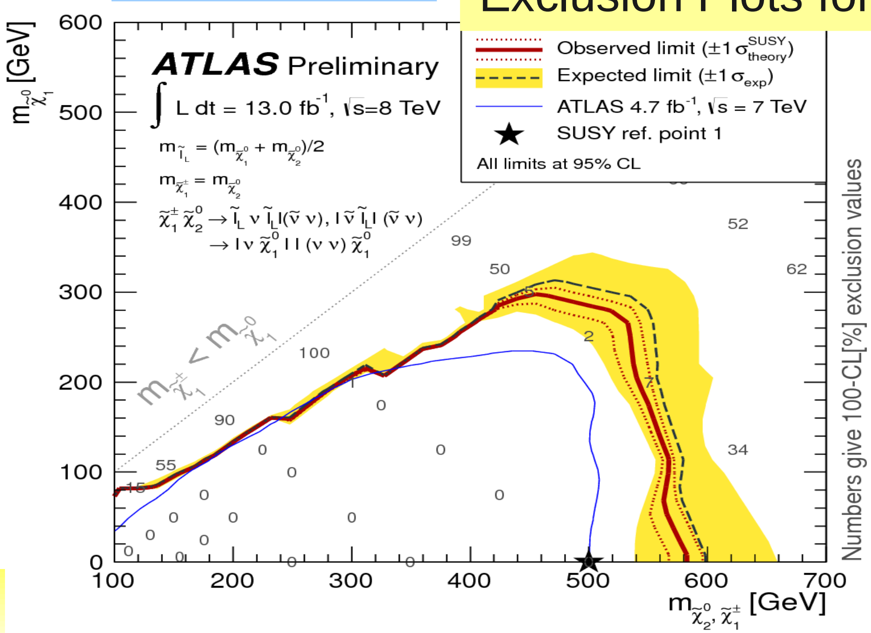
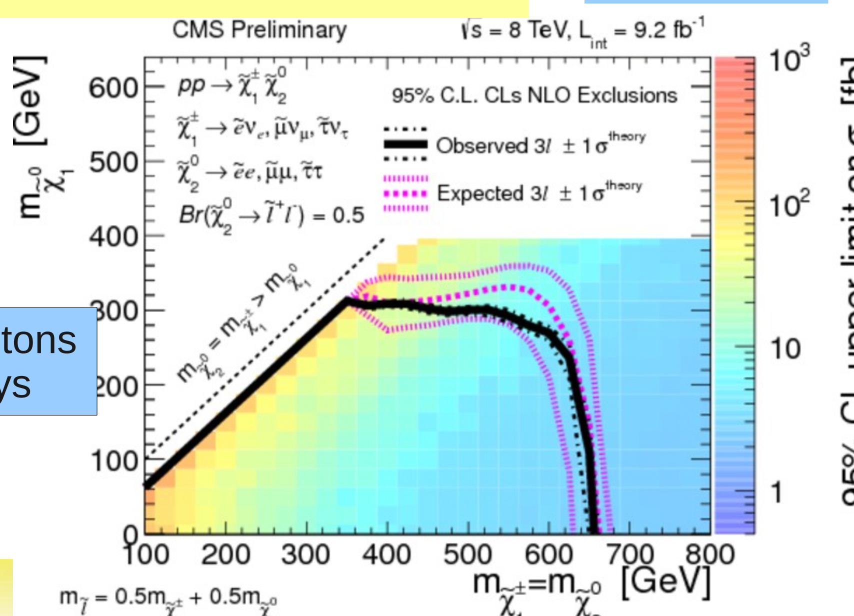
Exclusion Plots for Chargino/Neutralino masses

PAS-SUS-12-022



Via sleptons decays



Prompt R-Parity Violation (RPV)

- **RPV decays of the LSP in leptons: 4 leptons +MET**
  - Few signal regions in CMS (on/off Z, S_T,MET)
  - 2 signal regions in ATLAS:
    - Z-veto and MET>50 GeV
    - Z-veto and meff>300 GeV

Gluino m > 1.3 TeV
Slepton m > 450 GeV
Sneutrino m > 410 GeV
Chargino m > 710 GeV

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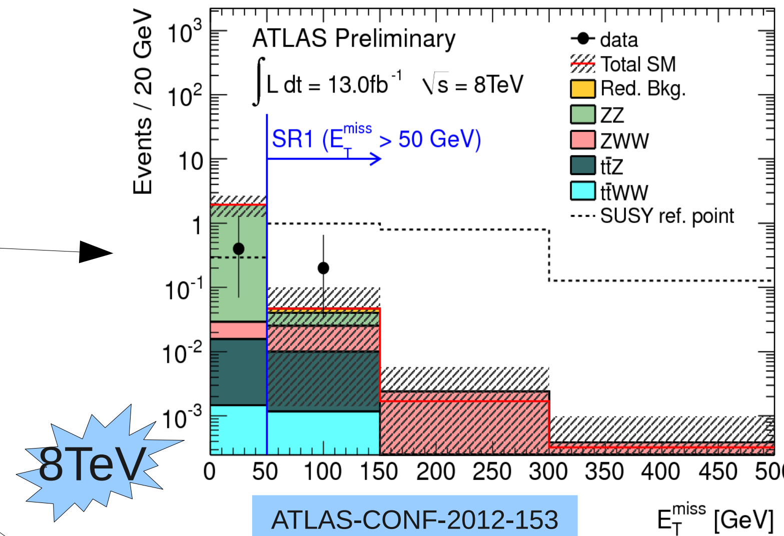

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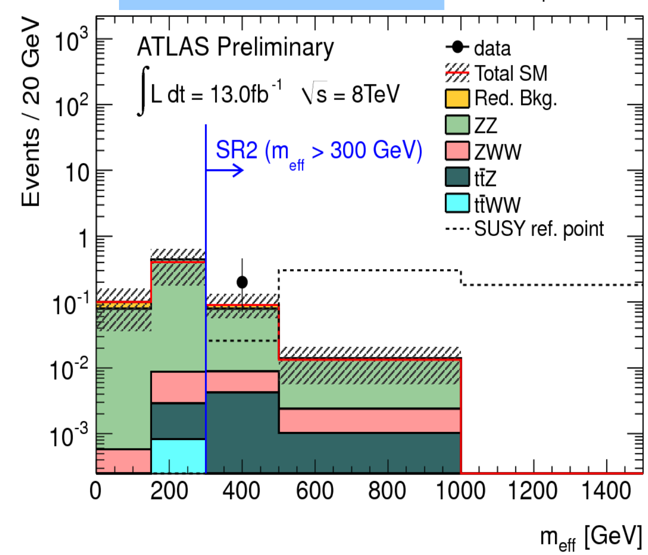
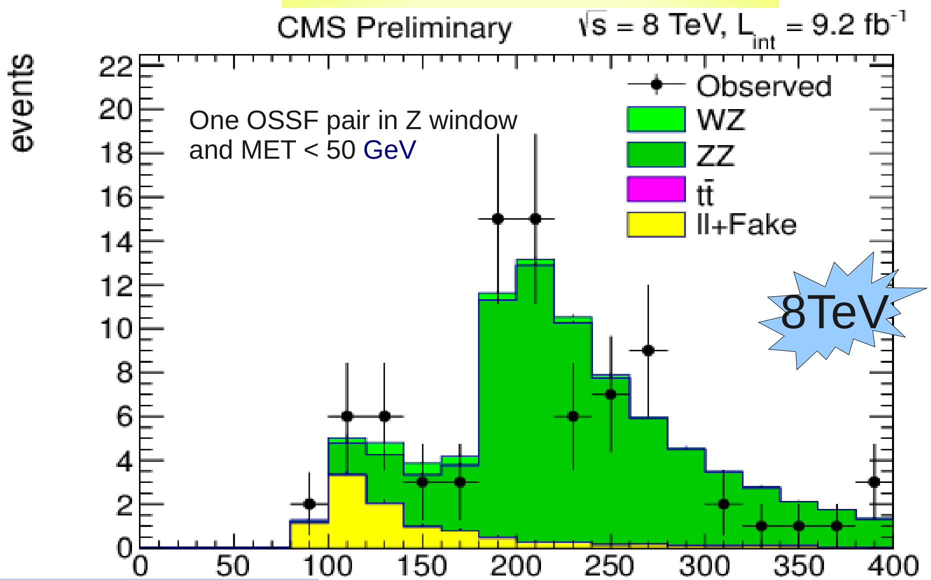


$$meff = E_T^{miss} + \sum_{\mu}(p_T^{\mu}) + \sum_{e}(E_T^{e}) + \sum_{j}(E_T^{j})$$

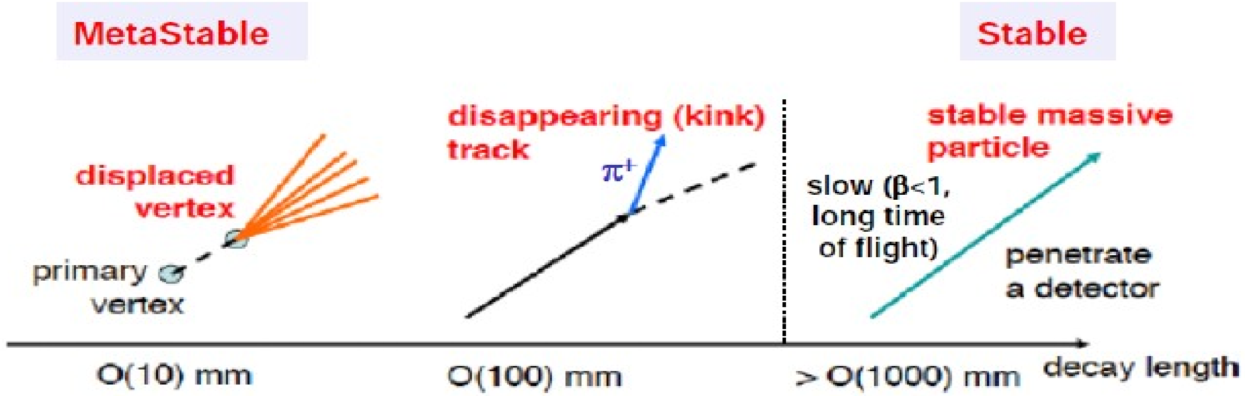


PAS-SUS-12-027

Long-Lived Particles

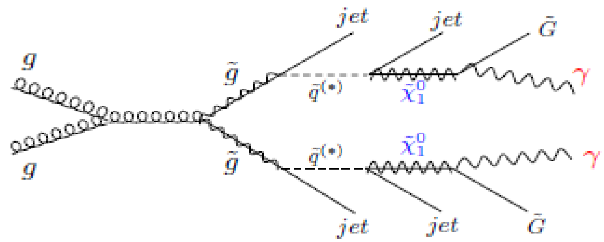
Several new physics models could give raise to new, massive particles with long-lifetime.

- **Long-lived charginos** in AMSB model: disappearing tracks
- If very heavy squarks mediate gluinos decay (strong virtuality): **Long-lived gluinos** → **R-hadrons** (eg. Split SUSY)
- If NLSP-gravitino GMSB couplings are weak: **long-lived sleptons**
- **R-Parity Violation (RPV) LSP decay:** Displaced vertex (PLB 719 (2013) 280)
- **Higgs decay to hidden-sector neutral particles:** lepton-jets and displaced vertex

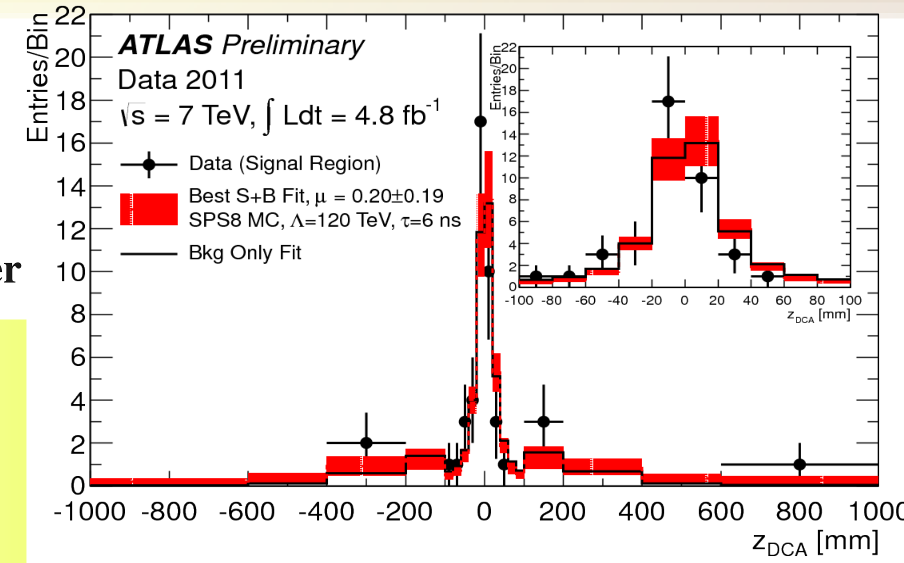


M.Verducci

GMSB with gravitino as LSP: non pointing photons



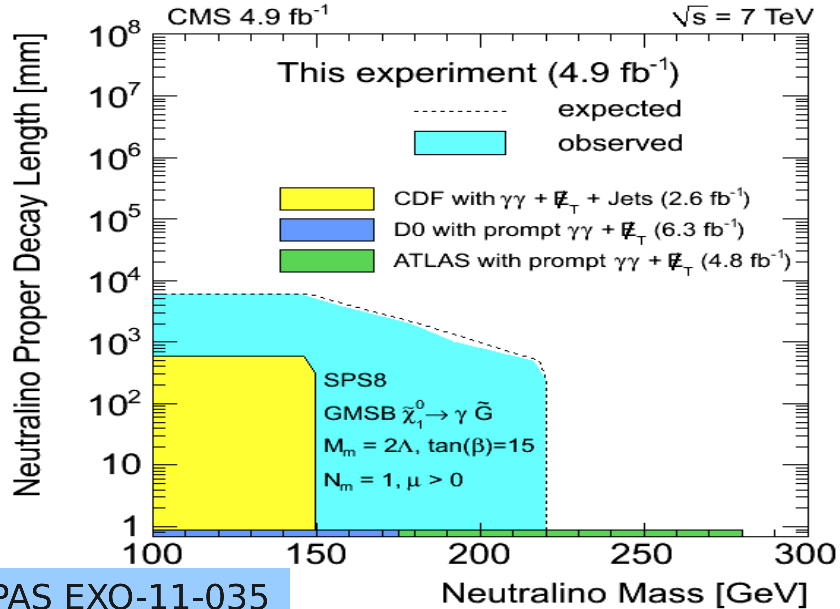
Flight direction and time of flight from Calorimeter



ATLAS-CONF-2013-1226

CMS: $m(\chi^0_1) > 220$ GeV (for $c\tau < 500$ mm), on the proper decay length of the lightest neutralino, $c\tau > 6000$ mm (for $m(\chi^0_1) < 150$ GeV) excuded at the 95% CL

ATLAS: for Λ=120 TeV, $\tau < 8.7$ ns are excluded at 95% CLs, the expected limit would exclude $\tau < 14.6$ ns.



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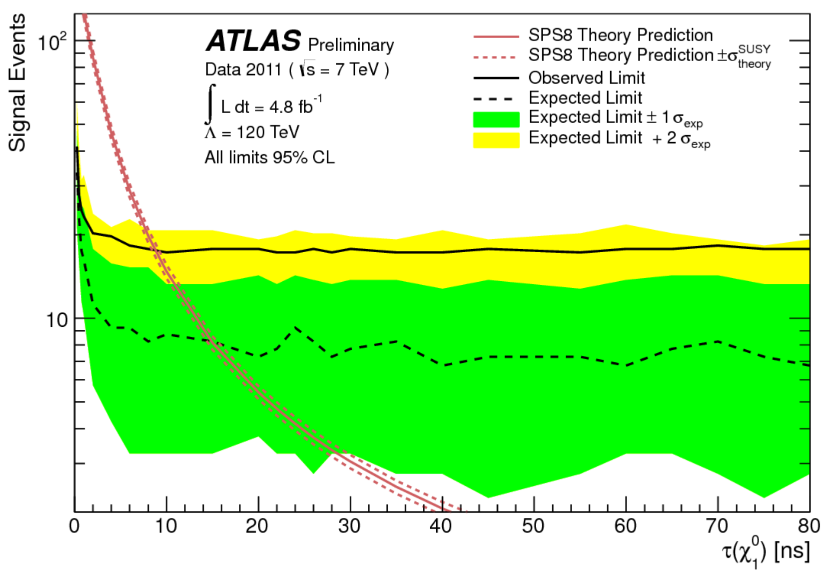
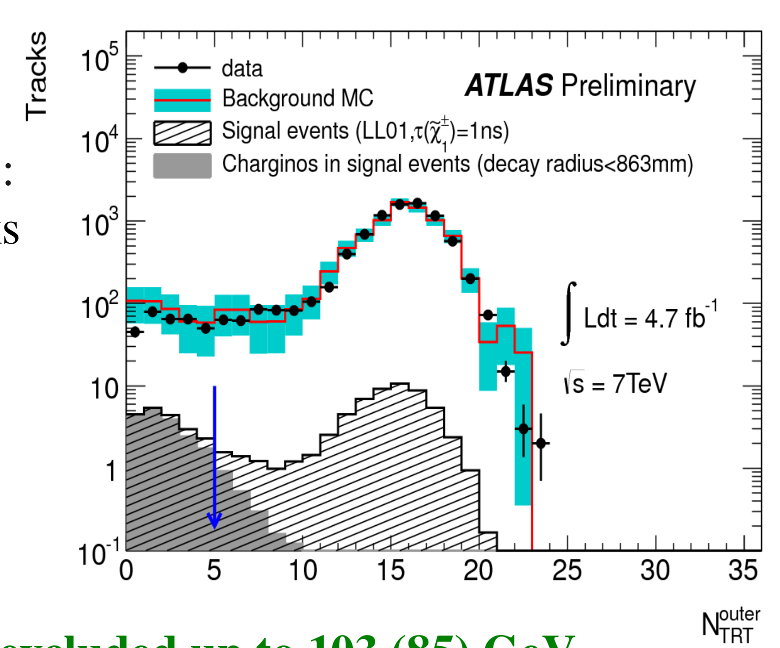


Some Results: AMSB in ATLAS

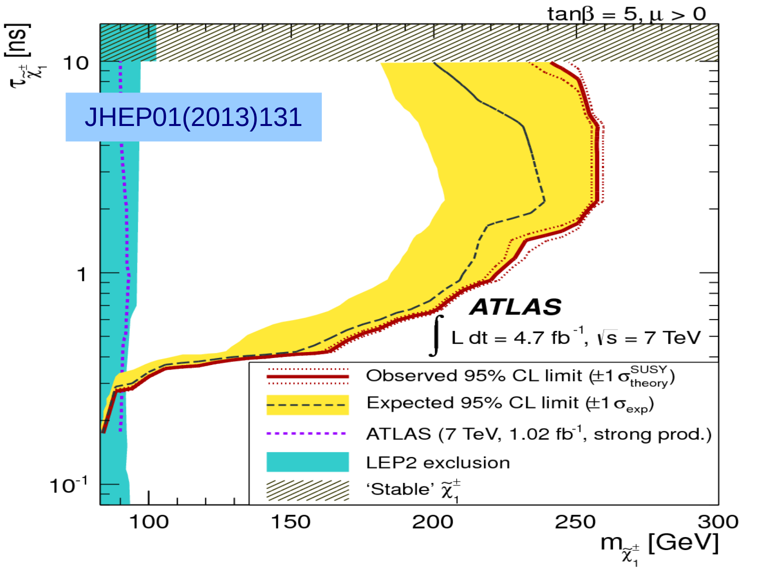
- **Long-Lived (LL) particles in R-Parity Conserved scenarios (RPC):**
  - If ΔM(chargino-neutralino) ≈ 100 MeV (AMSB):
    Long-lived charginos → disappearing tracks
  - Resulting final state:
    - High p_T jet + large MET
    - High p_T disappearing track (or “kinked” track)
    - Isolated tracks that stop in outer part of the tracker

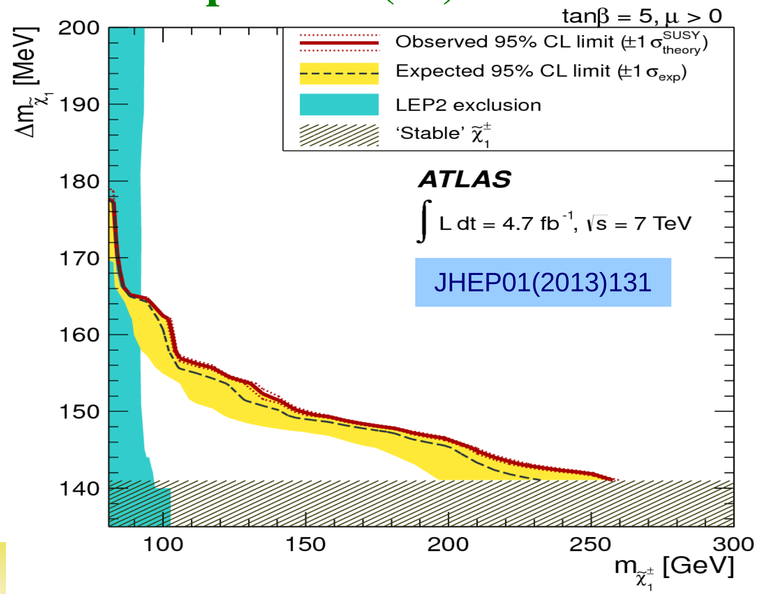
$$pp \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_1^{0} j, \quad pp \rightarrow \tilde{\chi}_1^{+}\tilde{\chi}_1^{-} j$$

$\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^{0}\pi^{\pm}$ branching ratio set to 100%



AMSB : 160 (170) MeV → chargino mass excluded up to 103 (85) GeV

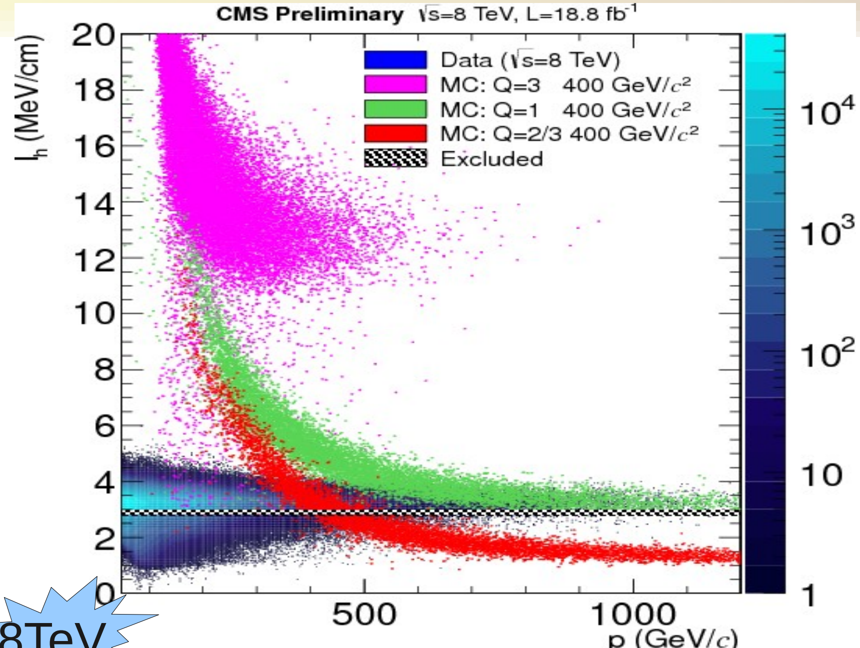




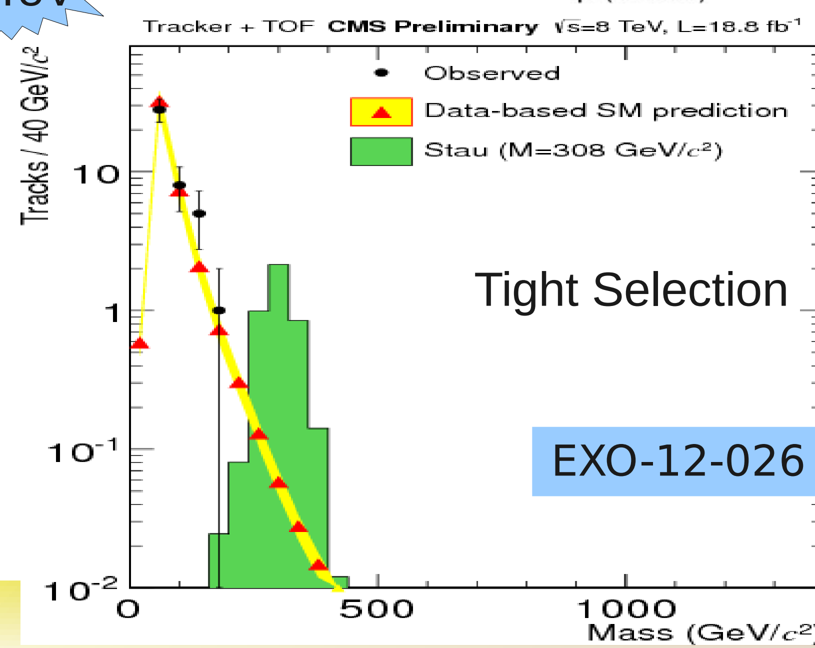
Some Results: R-hadrons in CMS I

Mass of Heavy stable charged particles (HSCPs)

- **Tracker only**
  - Sensitive to any HSCP produced prompt
  - Uses dE/dX in tracker to separate signal from BKG
- **Muon Only**
  - Sensitive to any HSCP crossing muon detector
  - Uses TOF to separate signal from BKG
  - $\beta^{-1} = 1 + (c\,\delta_t) | L$
- **Tracker+TOF**
  - uses both (for HSCP crossing the detector)

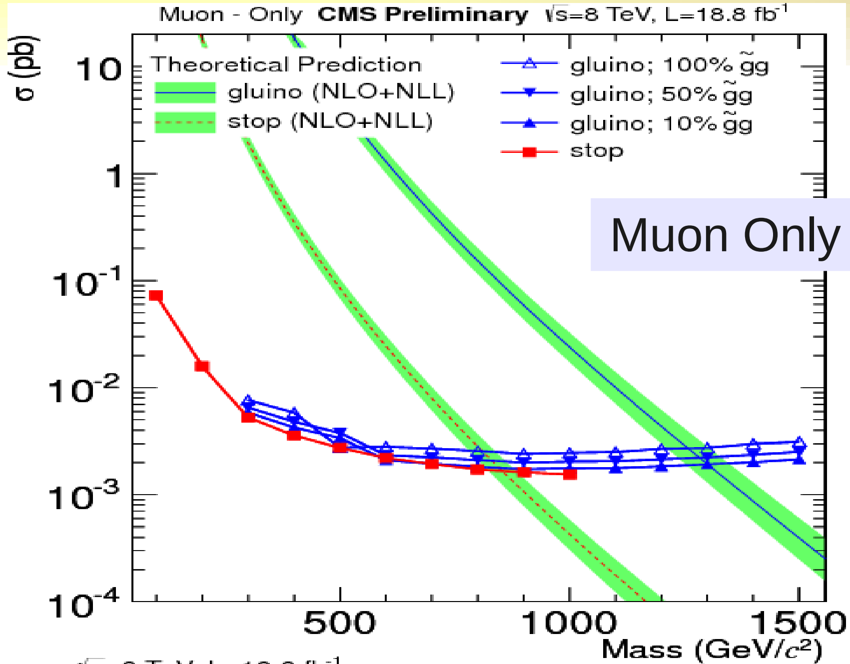


8TeV



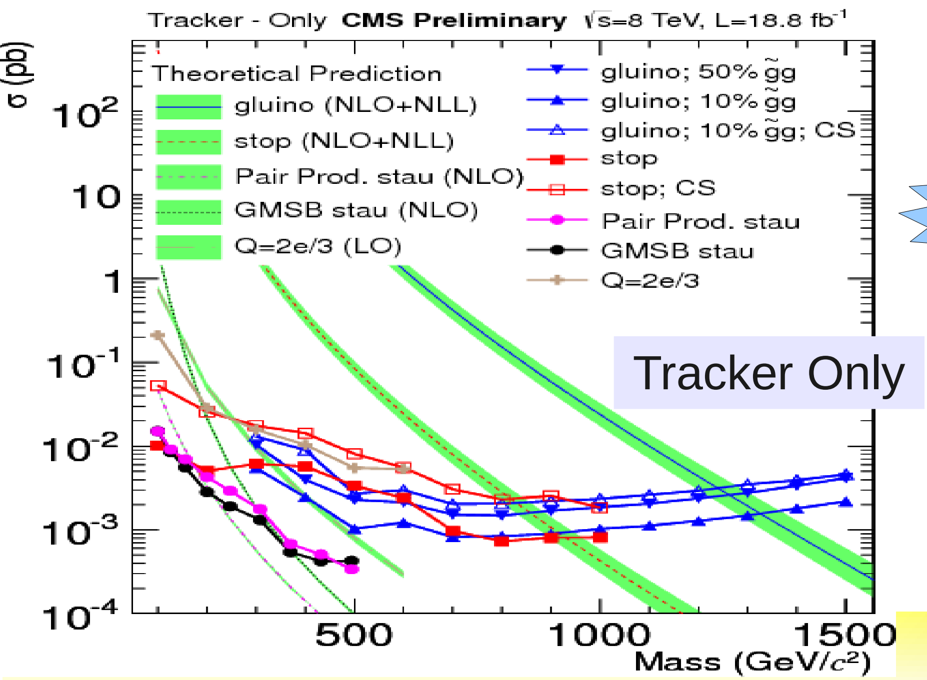
@ATLAS: R hadrons and stable sleptons http://arxiv.org/abs/1211.1597

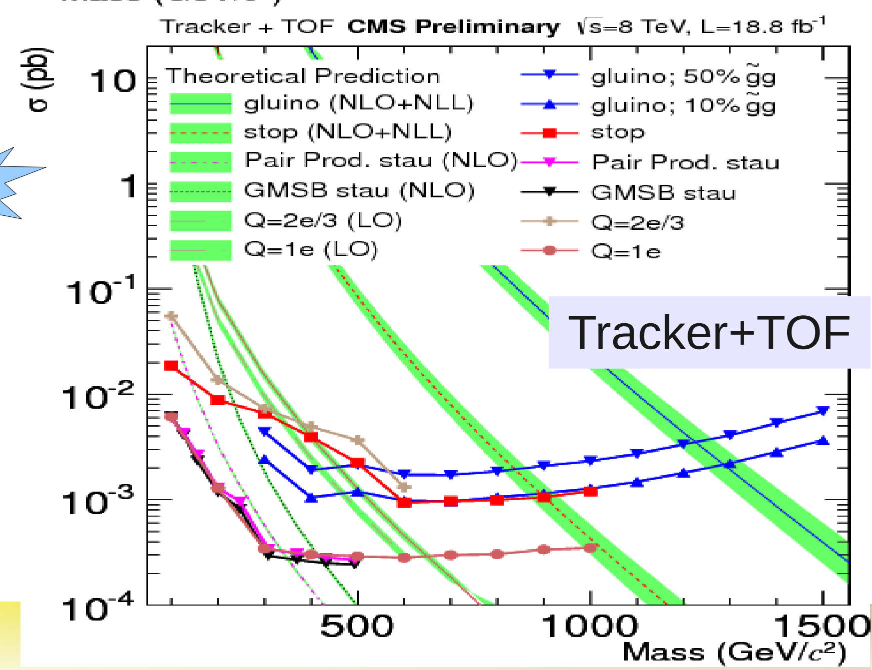
Some Results: R-hadrons in CMS II



EXO-12-026

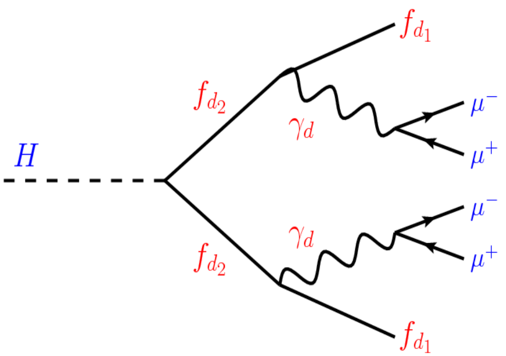
8TeV



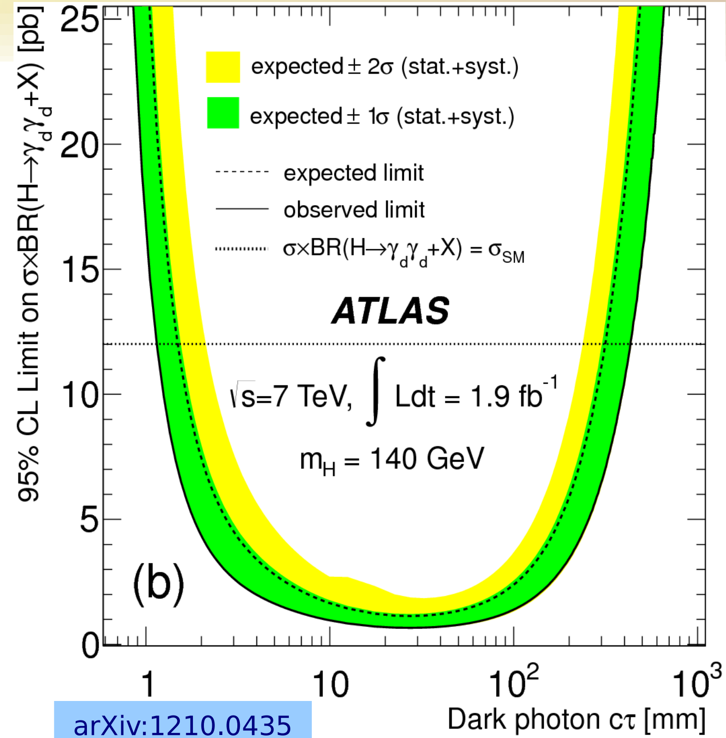


Some Results: Hidden Sectors

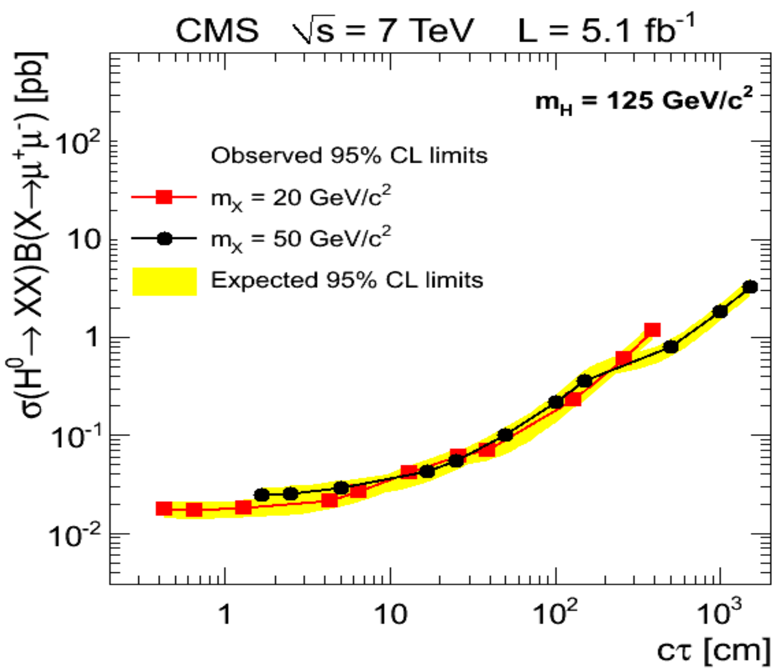
Lepton-jets: collimated group of electrons, muons or pions from decay of light hidden-sector particles (dark-photons)



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



arXiv:1210.0435



arXiv:1211.2472

Long Lived neutral X Boson

$H^0 \rightarrow XX \rightarrow$ 2e (2mu)

Decay in the ID: two displaced leptons

The limit is set on 0.7 -10 fb, for any X Boson mass(20-235 GeV) with 0.1<cτ<200 cm

Summary and Outlook

- Several SUSY and Exotics Models predict interesting signatures.
  - EWKino new particles
  - Long-lived particles
- Most of these searches are really challenging! They need a full understanding of the detectors and “non-standard” analysis techniques.
- So far, there is no evidence of new physics in any search in either of the experiments...
- Most of the analysis are being updated and improved with 2012 data
- Expect updates soon!

Back up

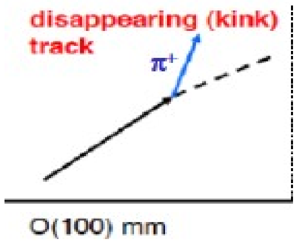
Long-Lived Particles I

Many physics models predict new massive particles with a long lifetime.

- **Long-Lived (LL) particles in R-Parity Conserved scenarios (RPC)**[(*)]:
  - If ΔM(chargino-neutralino) ≈ 100 MeV (e.g. Anomaly-Mediated-SUSY-breaking AMSB): Long-lived charginos → disappearing tracks

    $pp \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_1^{0}j, \quad pp \rightarrow \tilde{\chi}_1^{+}\tilde{\chi}_1^{-}j$

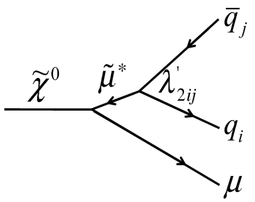
    $\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^{0}\pi^{\pm}$ branching ratio set to 100%
  - Resulting final state:
    - High p_T jet + large MET
    - High p_T disappearing track (or "kinked" track)
    - Isolated tracks that stop in outer part of the tracker



- **If very heavy squarks mediate gluino's decay (strong virtuality):**
  - Long-lived gluinos → R-hadrons (colored sparticles hadronised into long-lived bound states R-hadrons)
- **If very heavy squark is stop:** Stopped R-hadrons
- If **NLSP-gravitino then GMSB (Gauge-mediate-Susy-breaking) couplings are weak**: long-lived sleptons

Long-Lived Particles II

- **Neutral massive particles**
  - **R-Parity Violated (RPV) LSP decay: Displaced vertex**
    - lifetimes of order a few picoseconds so could decay within the inner tracking detector, giving rise to displaced vertices
    - For example: muon+jets topology, i.e. from RPV neutralinos decay with a non-zero (but small) λ'_{211} coupling
      - Presence of a muon useful for triggering and background rejection
      - High track multiplicity helps vertex reconstruction

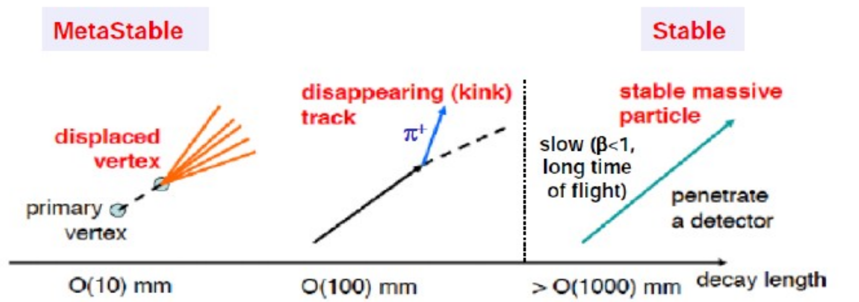


- **Hidden sectors**(*)**:**
  - **Higgs decay to hidden-sector neutral particles:**
    - look for **displaced vertices at larger radii:**near outer radius of hadronic calorimeter or in the Muon Spectrometer (MS), **specially developed trigger algorithm**, and specialized tracking and vertexing, to reconstruct vertices in MS.
  - **Higgs decay to hidden-sector fermions**
    - Decay to a (potentially long-lived) **neutral hidden-sector particle γ_d and a stable hidden sector fermion:** those escape detection, and decay of **γ_d could give rise to collimated pairs of leptons**

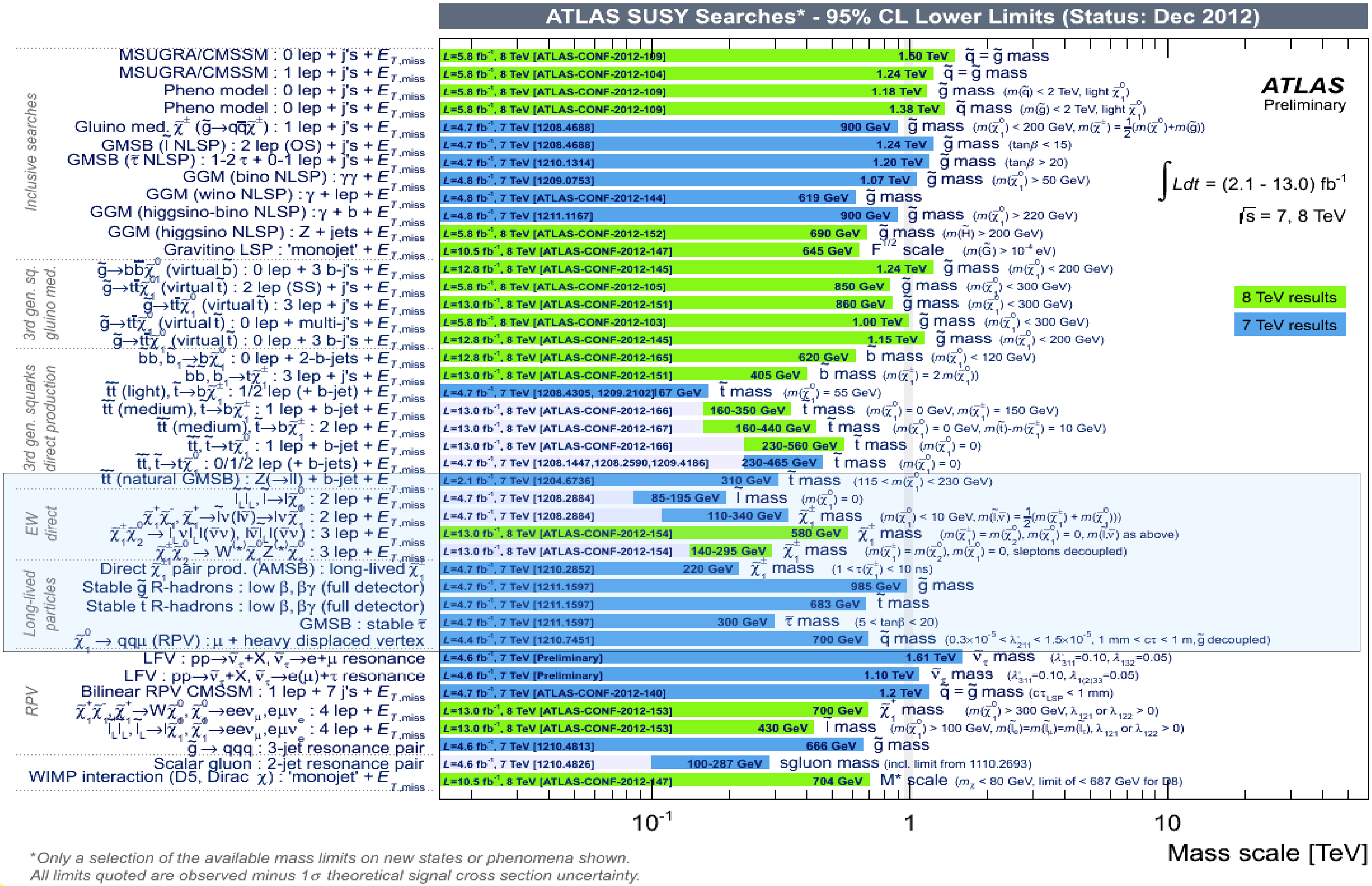
Detector Signatures

Many Signatures throughout the detector: Inner tracker, Calorimeter, Muon System

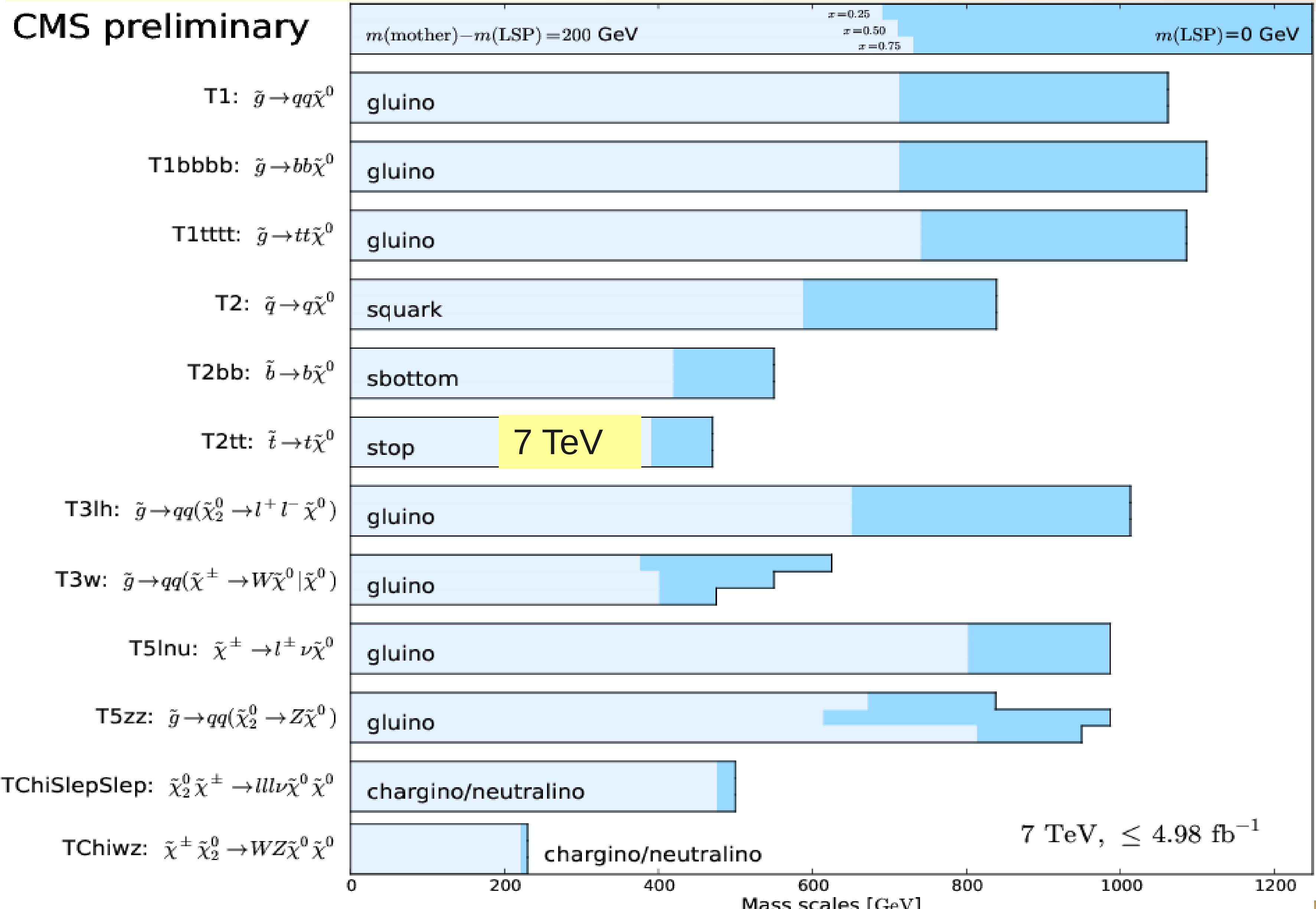
- **Inner Detector ID (RPV, AMSB,...):**
  - **Detect kinked or disappearing tracks: ID, alternative tracking fits**
- **$c\tau \geq$detector, stable massive particles (SMP), R-hadrons**
  - **Neutral and weak interactions → MET**
  - **Charged w/o strong interactions → directly measurements**
  - **Massive → β<1**
    - Mass measured by using dE/dx in different detectors, p from Inner tracker and Muon System, time-of-flight in calorimeters and Muon System
- **Decays in calorimeters or Muon System (HV sector, displaced leptons-jets,...):**
  - **Altenative Vertexing in Calorimeter and Muon System**



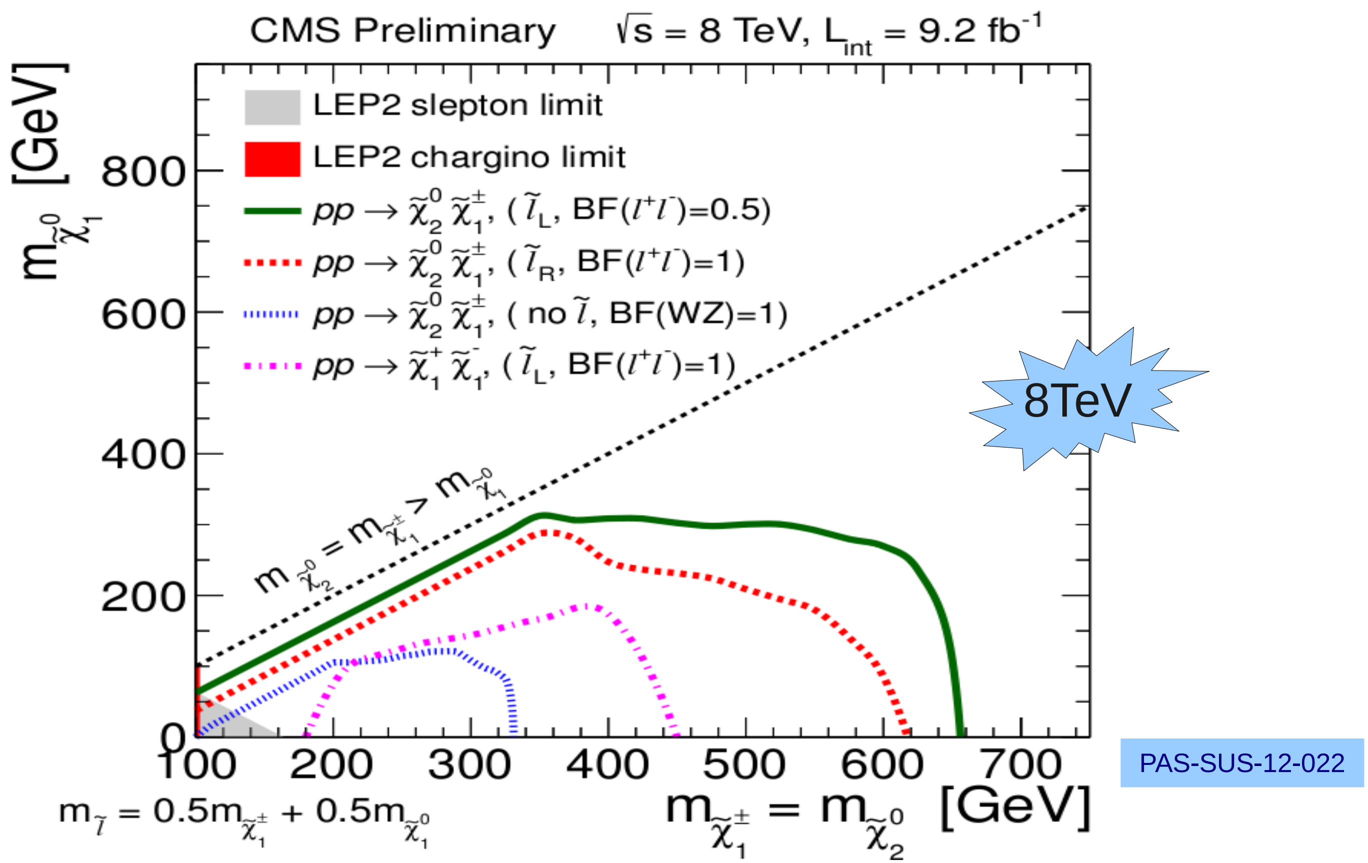
Overall Results: ATLAS



Overall Results: CMS



CMS Results: chargino-neutralino production



Summary of results for chargino-neutralino production with decays to left-handed sleptons, right-handed sleptons, or direct decays to vector bosons, and chargino-pair production. Where applicable, the xe` value used to calculate the slepton mass is 0.5.

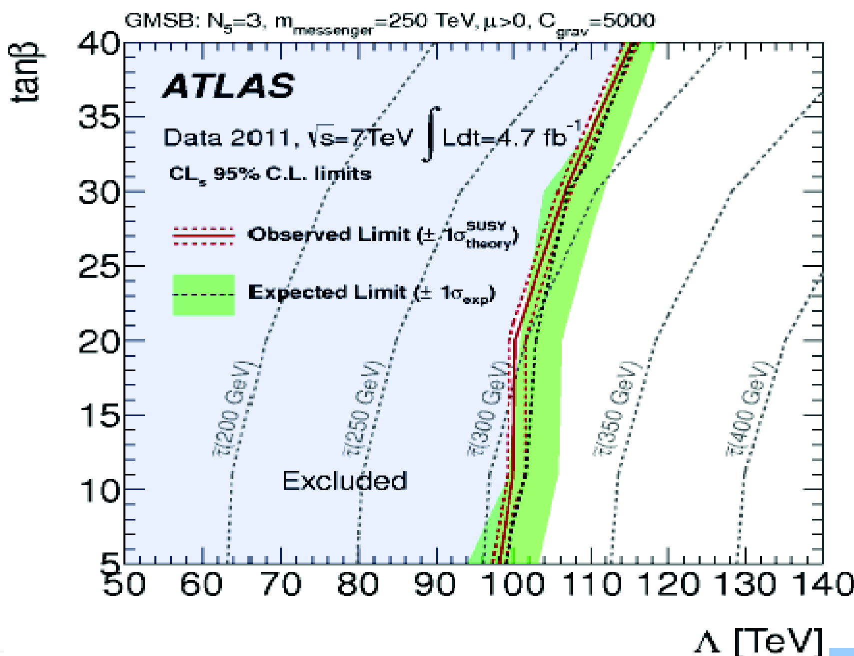
Some Results: Stau

No excess above background expectation

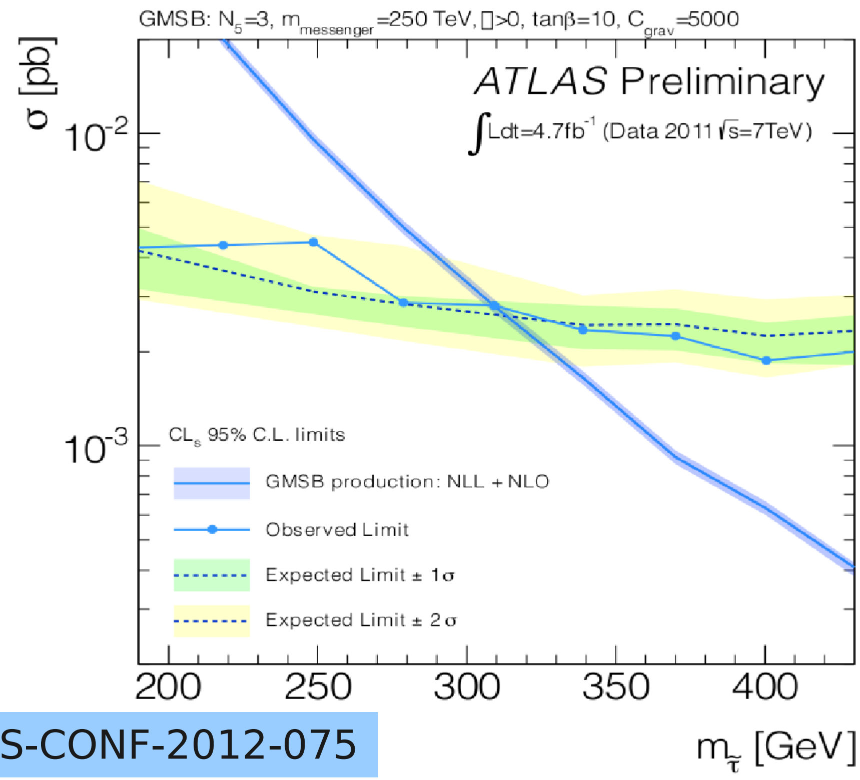
Constraints in tanβ vs Λ in GMSB scenario

Direct sleptons production dominate around limit

SMP = GMSB stau



Stau : excluded m(stau) < 300GeV for tanβ =5-20



ATLAS-CONF-2012-075

Direct Search of Neutralino and Chargino

Experimental constraints from LEP and Tevatron:

Charginos up to ~100 GeV in mass are excluded by LEP experiments. Chargino mass <138 GeV is excluded by 3 leptons+MET study at Tevatron.

Neutralino is a mix of neutral gauginos and Higgsinos: Bino,Zino,H^0

4-fermion states:
χ_1^0 light $\chi^0_{2,3,4}$ heavy

Chargino is mix of charged gauginos and Higgsinos: Winos,$H^\pm$

2-fermion states:
$\chi^\pm_1$ light $\chi^\pm_2$ heavy

RPC and RPV models, the lightest neutralino (chargino) is stable and all supersymmetric cascade-decays end up decaying into this particle which leaves the detector unseen and its existence can only be inferred by looking for unbalanced momentum in a detector.

Natural SUSY

- Natural SUSY requires lightest neutralino and chargino (and 3rd quark generation) to be close to ~O(100)GeV, while squarks and gluinos above TeV.
- R-Parity= $(-1)^{2S}(-1)^{3B+L}$
  - R-Parity Conserved RPC:
    - Makes lightest sparticles LSP stable allowing it to be dark matter candidate
    - LSP produced in pairs
    - Large MET
  - R-Parity Violated RPV:
    - Lightest sparticles LSP decay in SM particles (not stable)
- LSP: Neutralinos and Charginos
  - Higgsino, Winos, Zino, Bino (Gauginos) mixture

Search results for 3 leptons: ATLAS & CMS

M_T (GeV)	E_T^{miss} (GeV)	$M_{\ell\ell} < 75$ GeV		75 GeV $< M_{\ell\ell} <$ 105 GeV		$M_{\ell\ell} > 105$ GeV	
		total bkg	observed	total bkg	observed	total bkg	observed
> 160	50 – 100	2.1 ± 0.5	4	3.3 ± 0.5	3	1.2 ± 0.7	0
	100 – 150	1.7 ± 0.4	0	1.8 ± 0.2	1	1.1 ± 0.7	1
	150 – 200	0.8 ± 0.3	1	0.63 ± 0.16	1	0.26 ± 0.18	0
	> 200	0.25 ± 0.20	0	0.58 ± 0.19	1	0.18 ± 0.14	0
120 – 160	50 – 100	3.5 ± 0.5	3	10.0 ± 0.6	11	1.30 ± 0.19	0
	100 – 150	1.1 ± 0.3	0	1.5 ± 0.2	0	0.17 ± 0.05	2
	150 – 200	0.15 ± 0.16	0	0.4 ± 0.4	1	0.12 ± 0.10	0
	> 200	0.11 ± 0.05	0	0.17 ± 0.10	1	0.08 ± 0.09	0
0 – 120	50 – 100	53 ± 5	63	382 ± 15	377	19.0 ± 1.7	22
	100 – 150	6.6 ± 1.0	5	63 ± 3	61	4.0 ± 0.6	6
	150 – 200	1.4 ± 0.3	1	16.0 ± 0.9	13	0.9 ± 0.3	2
	> 200	0.54 ± 0.17	1	9.5 ± 0.6	3	0.43 ± 0.08	2

$$meff = E_T^{miss} + \sum_\mu (p_T^\mu) + \sum_e (E_T^e) + \sum_j (E_T^j)$$

CMS

PAS-SUS-12-022

ATLAS-CONF-2012-153

ATLAS

$$m_T = \sqrt{(2 * E_T * p_T^l * (1 - \cos(\Delta\phi_{l,MET})))}$$

Selection	SR1a	SR1b	SR2
Targeted $\tilde{\chi}_2^0$ decay	$\tilde{l}^{(*)}$ or Z^*		on-shell Z
$\|m_{SFOS} - m_Z\|$	> 10 GeV		< 10 GeV
Number of b-jets	0		any
E_T^{miss}	> 75 GeV		> 120 GeV
m_T	any	> 110 GeV	> 110 GeV
p_T of leptons	> 10 GeV	> 30 GeV	> 10 GeV

Selection	SR1a	SR1b	SR2
$t\bar{t}$+V	0.62 ± 0.28	0.13 ± 0.07	0.9 ± 0.4
triboson	3.0 ± 3.0	0.7 ± 0.7	0.34 ± 0.34
ZZ	2.0 ± 0.7	0.30 ± 0.23	0.10 ± 0.10
WZ (normalised)	34 ± 4	1.2 ± 0.6	4.7 ± 0.8
Reducible Bkg.	10 ± 6	0.8 ± 0.4	$0.012^{+1.6}_{-0.012}$
Total Bkg.	50 ± 8	3.1 ± 1.0	$6.1^{+2.0}_{-1.2}$
Data	48	4	4
SUSY Ref. Point 1	13.9 ± 1.0	11.4 ± 0.9	0.5 ± 0.1
SUSY Ref. Point 2	0.9 ± 0.1	0.3 ± 0.1	8.0 ± 0.6
Visible σ (exp)	< 1.5 fb	< 0.4 fb	< 0.5 fb
Visible σ (obs)	< 1.3 fb	< 0.5 fb	< 0.4 fb

Search results >3 leptons: ATLAS & CMS

CMS

PAS-SUS-12-022

E_T^{miss} (GeV)	Observed	Total Bkg
1 OSSF, 0 τ		
0–30	0	$3.94 \pm 0.32 \pm 1.32$
30–50	1	$0.71 \pm 0.10 \pm 0.18$
50–100	1	$0.74 \pm 0.09 \pm 0.17$
> 100	0	$0.36 \pm 0.04 \pm 0.12$
1 OSSF, 1 τ		
0–30	13	$11.33 \pm 0.51 \pm 2.44$
30–50	4	$5.50 \pm 0.20 \pm 0.73$
50–100	6	$4.93 \pm 0.17 \pm 0.55$
> 100	1	$1.62 \pm 0.09 \pm 0.19$
2 OSSF, 0 τ		
0–30	69	$68.52 \pm 1.04 \pm 20.18$
30–50	9	$9.31 \pm 0.32 \pm 3.08$
50–100	1	$1.67 \pm 0.14 \pm 0.56$
> 100	0	$0.31 \pm 0.03 \pm 0.12$

ATLAS-CONF-2012-154

Selection	SR1	SR2	VR1	VR2	VR3
Number of leptons	≥ 4	≥ 4	3	≥ 4	≥ 4
SFOS pair	–	–	SFOS-veto	SFOS requirement	–
Z-candidate	Z-veto	Z-veto	Z-veto	Z requirement	Z-veto
E_T^{miss}/GeV	> 50	–	> 50	–	< 50
m_{eff}/GeV	–	> 300	–	–	< 300

ATLAS

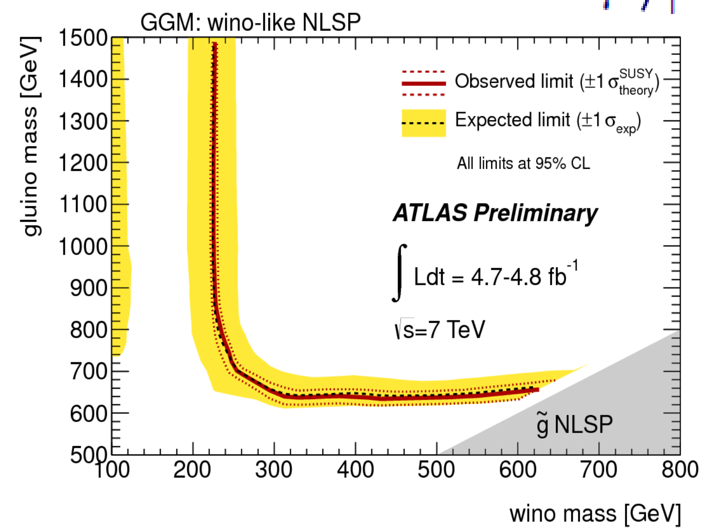
Selection	SR1	SR2
ZZ	$0.07^{+0.22}_{-0.07}$	$1.0^{+0.4}_{-0.4}$
ZWW	$0.10^{+0.10}_{-0.10}$	$0.09^{+0.09}_{-0.09}$
$t\bar{t}Z$	$0.045^{+0.028}_{-0.028}$	$0.06^{+0.04}_{-0.04}$
$t\bar{t}WW$	$(6^{+6}_{-5})\times10^{-3}$	$(3.3^{+4.8}_{-3.3})\times10^{-3}$
Irreducible Bkg.	$0.22^{+0.27}_{-0.21}$	$1.1^{+0.5}_{-0.4}$
Reducible Bkg.	$0.028^{+0.107}_{-0.028}$	$0.10^{+0.14}_{-0.10}$
Total Bkg.	$0.25^{+0.29}_{-0.25}$	$1.2^{+0.5}_{-0.4}$
Data	1	2
p_0-value (σ)	0.037 (1.8)	0.16 (1.0)
σ_{vis} (exp)	< 0.28 fb	< 0.28 fb
σ_{vis} (obs)	< 0.34 fb	< 0.38 fb

Gauge-mediated SUSY breaking (gravitino as LSP)

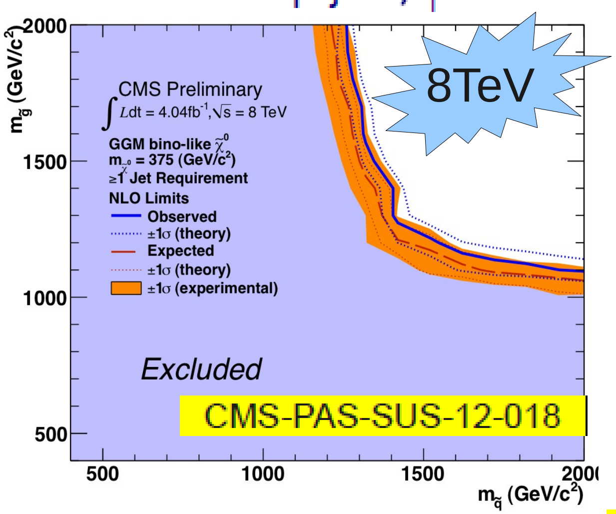
- Gauge-mediated SUSY breaking where NLSP is Neutralino, decay will depend on Higgsino/bino/wino mixture
  - Wino-like $\tilde{\chi}^0 \rightarrow \gamma/Z + \tilde{G}$, $\tilde{\chi}^+ \rightarrow W + \tilde{G}$
  - Higgsino-like $\tilde{\chi}^0 \rightarrow h/Z + \tilde{G}$
  - Bino-like $\tilde{\chi}^0 \rightarrow h/Z + \tilde{G}$

ATLAS-CONF-2012-144

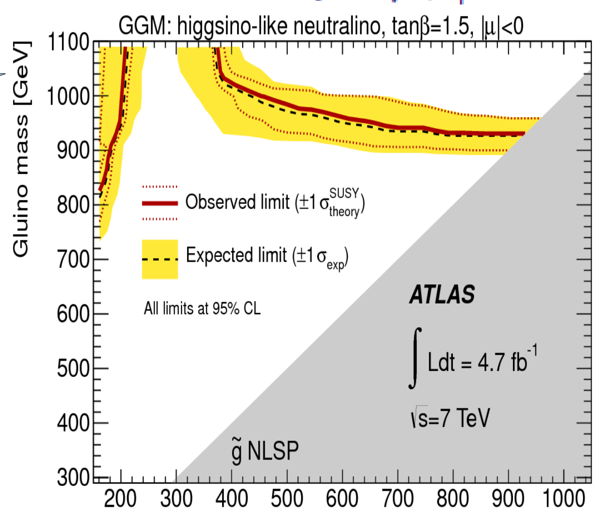
ATLAS: $\ell+\gamma+\not{E}_T$



CMS: 2γ+jet+$\not{E}_T$

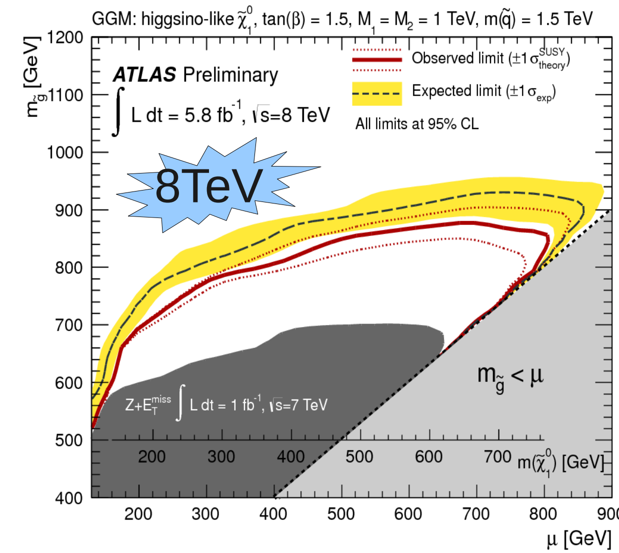


ATLAS: b-jet+γ+$\not{E}_T$



ArXiv:1211.1167

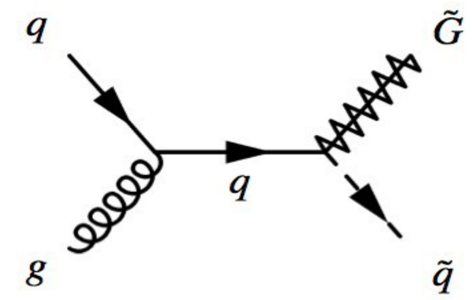
ATLAS: Z+$\not{E}_T$+jets

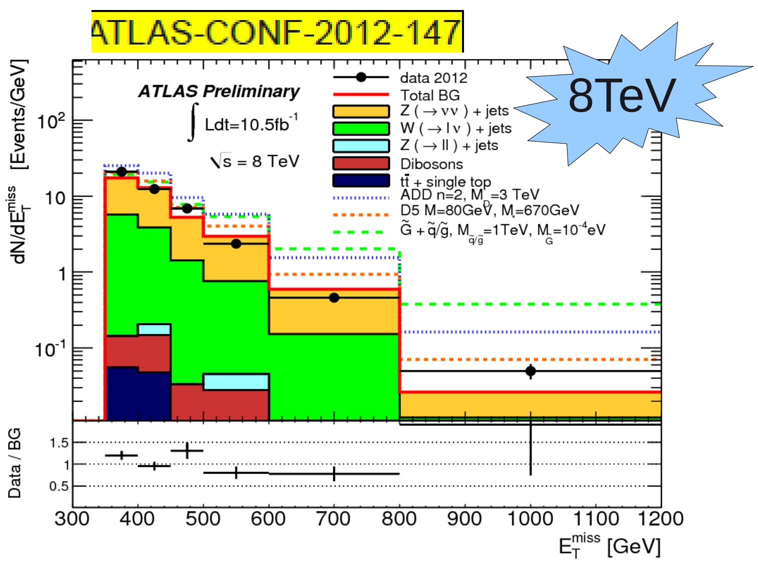


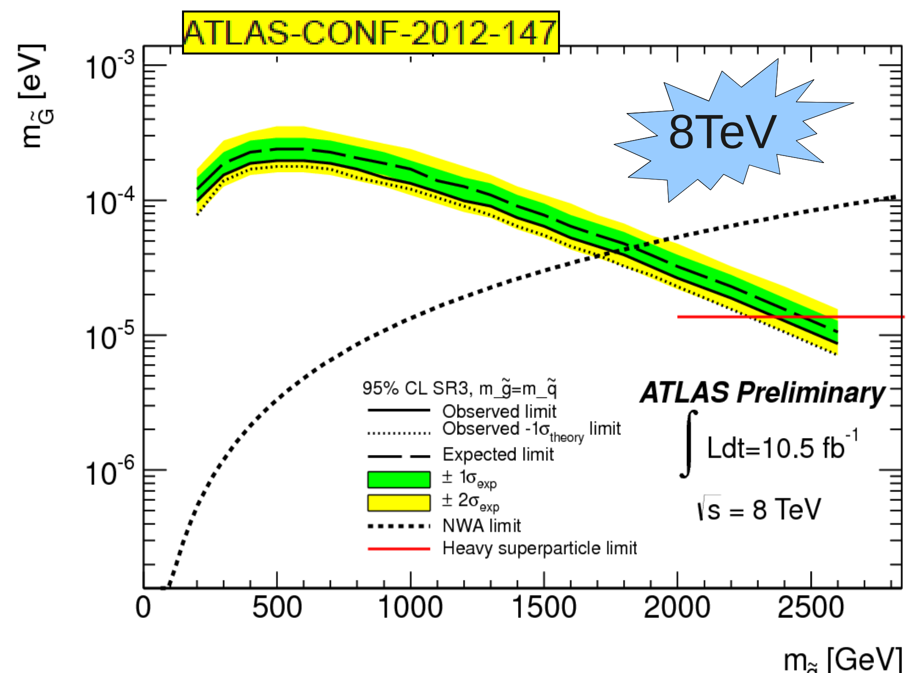
ATLAS-CONF-2012-152

Limit on Gravitino Mass

- Mono-jet analysis
  - Limit on direct gravitino squark/gluino production
  - Limit on $m_{\tilde{G}}$ using
    - $\sigma \sim 1/m_{\tilde{G}}^2$
  - Limits assume
    - BF($\tilde{q} \rightarrow q\tilde{G}$)=100%

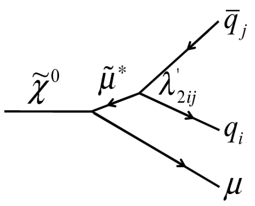






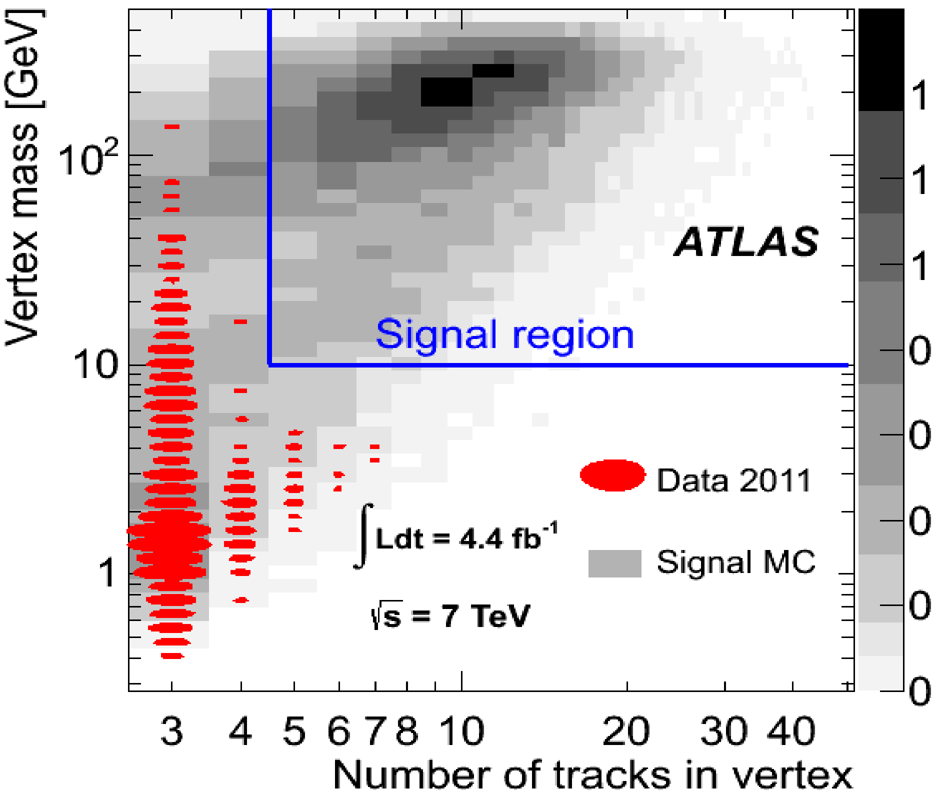
(RPV) LSP decay: Displaced vertex

- muon+jets topology, i.e. from RPV neutralinos decay with a non-zero (but small) λ'_{211} coupling
  - Presence of a muon useful for triggering and background rejection
  - High track multiplicity helps vertex reconstruction



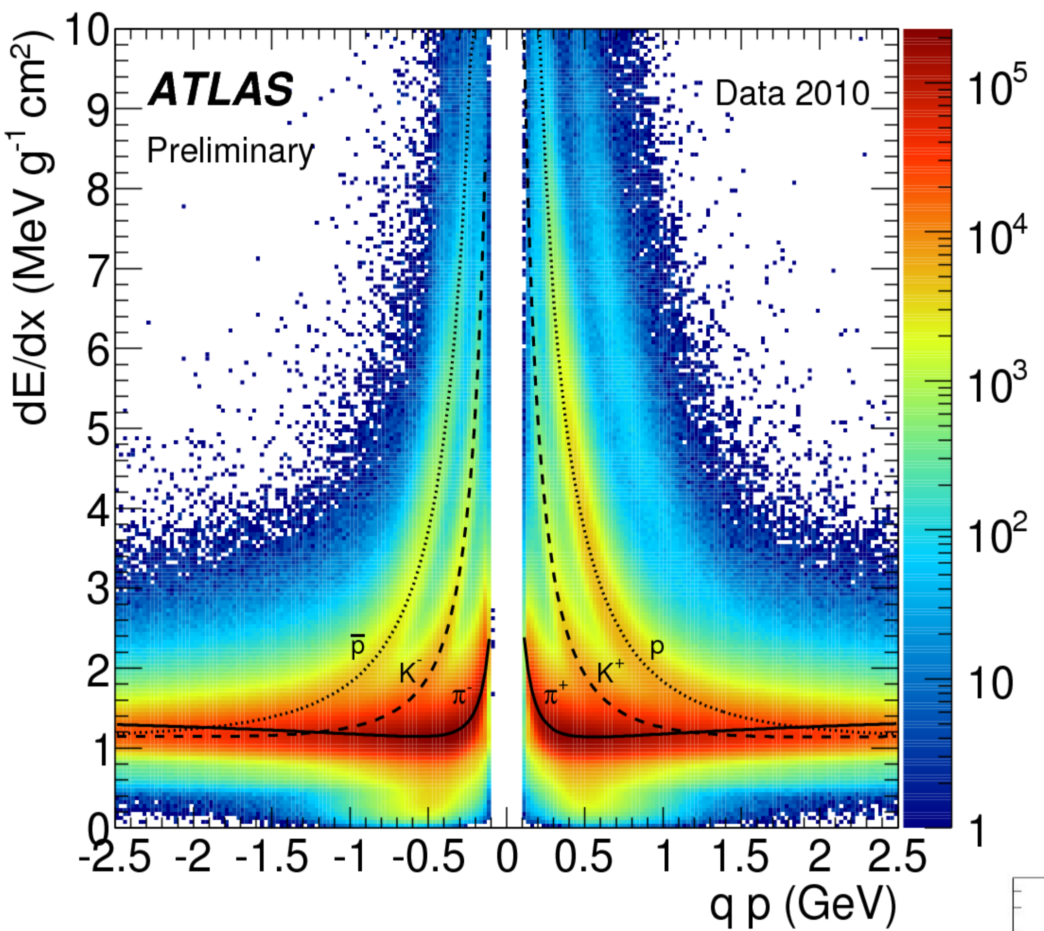
Two sources of background vertices considered:

- Purely random combinations of tracks inside the beampipe (where vacuum is good, but track density is high).
- High-mass tail of distribution of real vertices from hadronic interactions with gas molecules.



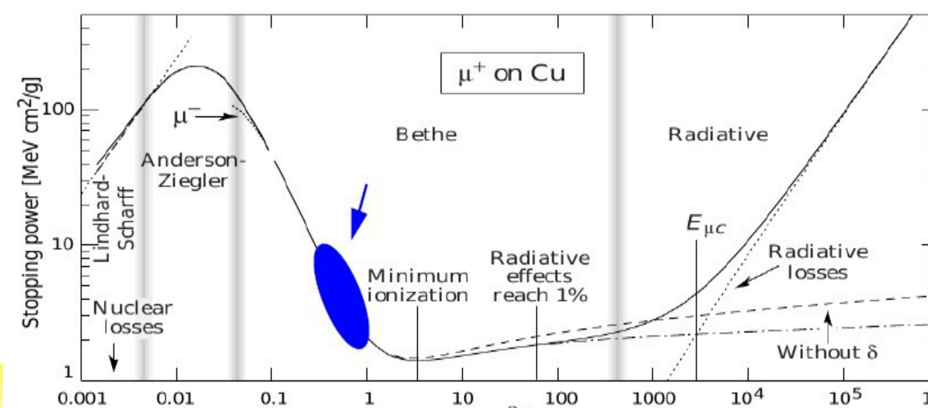
Zero vertices passing selection requirements observed in 4.4 fb-1 data sample

dE/dx measurements



- Pixel detector can measure ionization energy loss dE/dx via charge deposited (calculated from Time-over-Threshold)
- TRT can also measure dE/dx via Time-over-Threshold
- Measure velocity of track using:
  - dE/dx in pixel detector (invert Bethe-Block)
  - Main background: mis-measured timing or dE/dx

Main background are high-p_T muons with mismeasured β.



M.Verducci

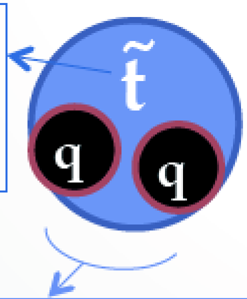
SMP I

- SMPs predicted in SUSY several other BSM scenarios
- Stable → cτ ≥ size of detector
- Produced with β<1
- *Within SUSY:*
  - $\tilde{l}$ and $\tilde{\chi}^{+}$
  - $\tilde{q}$/$\tilde{g}$ (bound states)

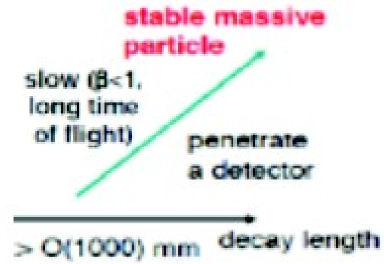
Colored sparticles can hadronise into long-lived bound hadronic states

R-hadrons

Heavy parton carrying most of the momentum



Light quark system (LQS)



SMP	LSP	Scenario	Conditions
$\tilde{\tau}_1$	$\tilde{\chi}_1^0$	MSSM	$\tilde{\tau}_1$ mass (determined by $m^2_{\tilde{\tau}_{L,R}}$, μ, $\tan\beta$, and A_τ) close to $\tilde{\chi}_1^0$ mass.
	$\tilde{G}$	GMSB	Large N, small M, and/or large $\tan\beta$.
		$\tilde{g}$MSB	No detailed phenomenology studies, see [23].
		SUGRA	Supergravity with a gravitino LSP, see [24].
	$\tilde{\tau}_1$	MSSM	Small $m_{\tilde{\tau}_{L,R}}$ and/or large $\tan\beta$ and/or very large A_τ.
		AMSB	Small m_0, large $\tan\beta$.
		$\tilde{g}$MSB	Generic in minimal models.
$\tilde{\ell}_{s1}$	$\tilde{G}$	GMSB	$\tilde{\tau}_1$ NLSP (see above). $\tilde{e}_1$ and $\tilde{\mu}_1$ co-NLSP and also SMP for small $\tan\beta$ and μ.
	$\tilde{\tau}_1$	$\tilde{g}$MSB	$\tilde{e}_1$ and $\tilde{\mu}_1$ co-LSP and also SMP when stau mixing small.
$\tilde{\chi}_1^+$	$\tilde{\chi}_1^0$	MSSM	$m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0} \lesssim m_{\pi^+}$. Very large $M_{1,2} \gtrsim 2$ TeV $\gg |\mu|$ (Higgsino region) or non-universal gaugino masses $M_1 \gtrsim 4M_2$, with the latter condition relaxed to $M_1 \gtrsim M_2$ for $M_2 \ll |\mu|$. Natural in O-II models, where simultaneously also the $\tilde{g}$ can be long-lived near $\delta_{GS} = -3$.
		AMSB	$M_1 > M_2$ natural. m_0 not too small. See MSSM above.
$\tilde{g}$	$\tilde{\chi}_1^0$	MSSM	Very large $m^2_{\tilde{q}} \gg M_3$, e.g. split SUSY.
	$\tilde{G}$	GMSB	SUSY GUT extensions [25–27].
	$\tilde{g}$	MSSM	Very small $M_3 \ll M_{1,2}$, O-II models near $\delta_{GS} = -3$.
		GMSB	SUSY GUT extensions [25–29].
$\tilde{t}_1$	$\tilde{\chi}_1^0$	MSSM	Non-universal squark and gaugino masses. Small $m^2_{\tilde{q}}$ and M_3, small $\tan\beta$, large A_t.
$\tilde{b}_1$			Small $m^2_{\tilde{q}}$ and M_3, large $\tan\beta$ and/or large $A_b \gg A_t$.

Table 1
Brief overview of possible SUSY SMP states considered in the literature. Classified by SMP, LSP, scenario, and typical conditions for this case to materialise in the given scenario.

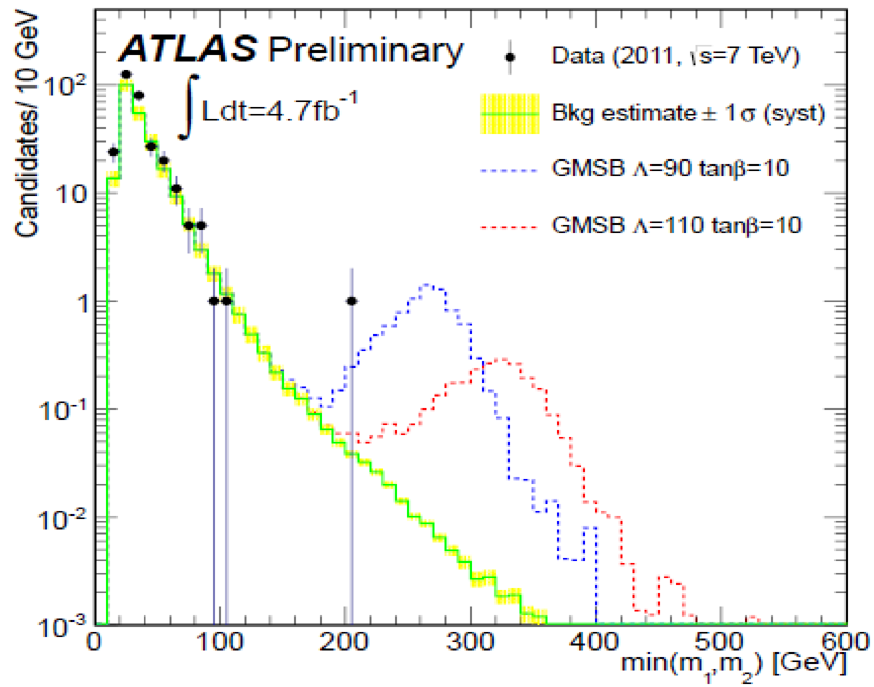
SMP II

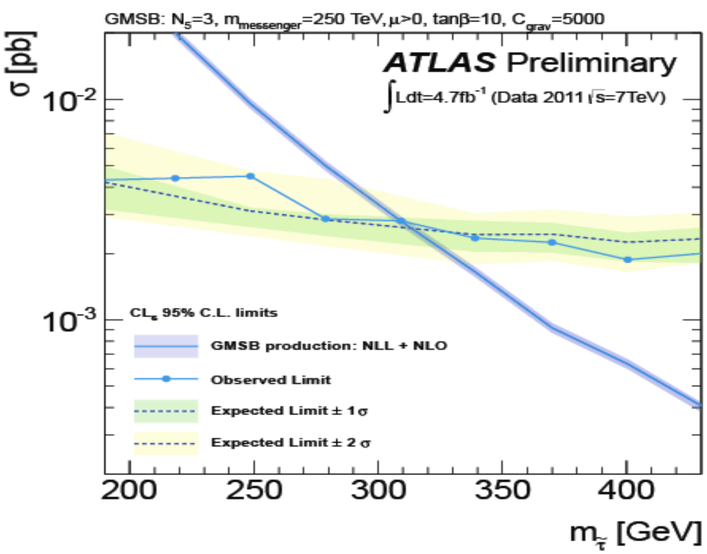
- Particles with $c\tau \geq$ size of detector:
  - If neutral and weakly interacting -- >MET
  - If charged (at any point!) or strongly interacting --> can detect them directly
  - If massive, could be produced with low velocities: $\beta < 1$
- Mass of SMPs:
  - measure charged particle momentum p in ID and MS
  - measure energy loss dE/dx in several subdetectors
    - For these analyses, use Pixel
    - dE/dx is related to relativistic boost factor $\beta\gamma$
  - measure time-of-flight in several sub-detectors
    - For these analyses, use Tile, RPC, MDT
    - Can measure velocity β

$$p=\beta\gamma m$$

Slepton (stau) search

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





m(stau)>310 GeV (tanβ in 5-20)

pair-produced stable leptons > 297 GeV

Also interpreted in GMSB parameter space

ATLAS-CONF-2012-075

R-hadrons I

- **Undergo interactions with detector material can also change charge as it moves through detector**
- If β is too low, particle might be associated with following bunch crossing by the time it gets to MS.
- Due to both these effects, efficiency for single muon trigger can be quite low
    - Checks are made for double candidates
    - Track p_T>140 GeV (50 GeV for short-track-only analysis)
    - Isolation from jets (E_T>40 GeV, dR<0.3)
    - Isolation from tracks (p_T>10 GeV, dR<0.25)
    - p_T>1 GeV, dR<0.25 for short-track-only analysis
- **Three different analyses:**
    - "Full detector"
    - "ID only"
    - "MS agnostic"

R-hadrons II

All three analyses require good quality, isolated, high momentum ID track.

- "MS agnostic":
  - MET triggers
  - calorimeter-only timing measurement
  - require ID trk p_T>140 GeV
- "ID only":
  - Offline MET cut
  - Tighter cuts on isolation and number of silicon hits

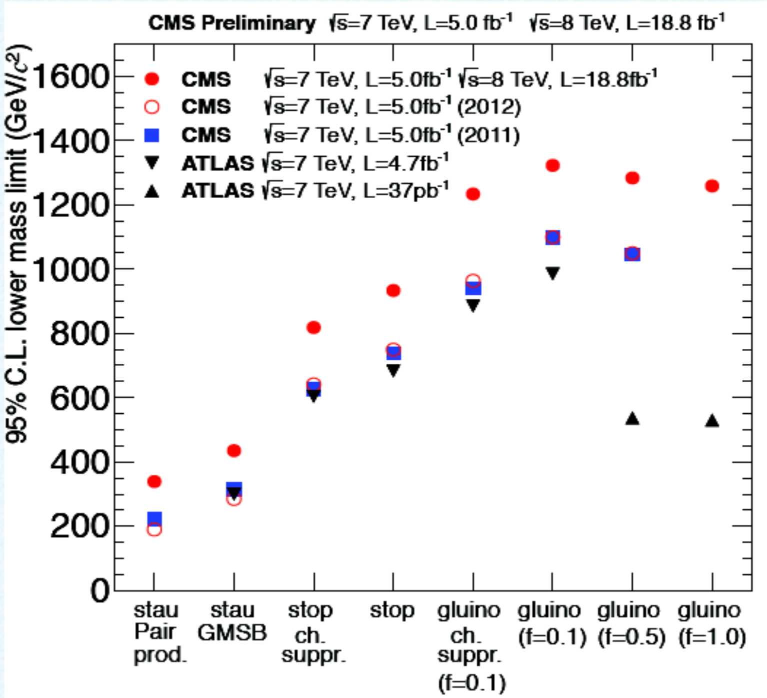
Limits in the 3 analyses (95% C.L.):

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

R-hadrons CMS

$$\beta^{-1} = 1 + \frac{c\delta_t}{L}$$

	Selection criteria				Numbers of events			
					$\sqrt{s} = 7$ TeV		$\sqrt{s} = 8$ TeV	
	p_T (GeV/c)	$I_{as}^{(\prime)}$	$1/\beta$	Mass (GeV/c^2)	Pred.	Obs.	Pred.	Obs.
tracker-only	> 70	> 0.4	-	> 0	7.1 ± 1.5	8	32.5 ± 6.5	41
				> 100	6.0 ± 1.3	7	26.0 ± 5.2	29
				> 200	0.65 ± 0.14	0	3.1 ± 0.6	3
				> 300	0.11 ± 0.02	0	0.55 ± 0.11	1
				> 400	0.030 ± 0.006	0	0.15 ± 0.03	0
tracker+TOF	> 70	> 0.125	> 1.225	> 0	8.5 ± 1.7	7	43.5 ± 8.7	42
				> 100	1.0 ± 0.2	3	5.6 ± 1.1	7
				> 200	0.11 ± 0.02	1	0.56 ± 0.11	0
				> 300	0.020 ± 0.004	0	0.090 ± 0.02	0
muon-only	> 230	-	> 1.40	-	–	–	5.6 ± 2.9	3
$\lvert Q \rvert > 1e$	-	> 0.500	> 1.200	-	0.15 ± 0.04	0	0.52 ± 0.11	1
$\lvert Q \rvert < 1e$	> 125	> 0.275	-	-	0.12 ± 0.07	0	0.99 ± 0.24	0

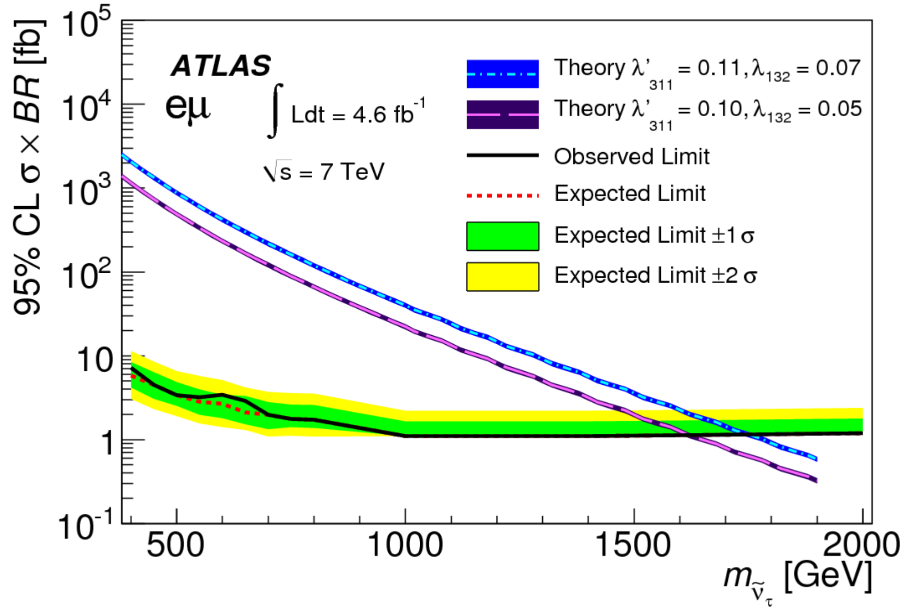


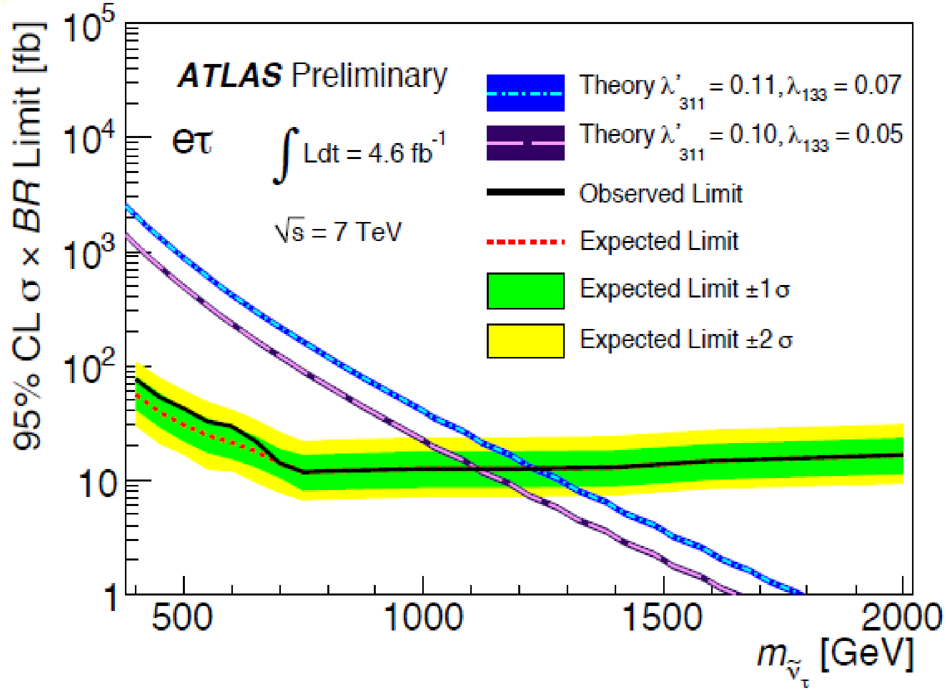
charge/unit path (fixed k=2)

$$I_h = \left(\frac{1}{N} \sum_i c_i^k \right)^{1/k} = K \frac{m^2}{p^2} + C$$

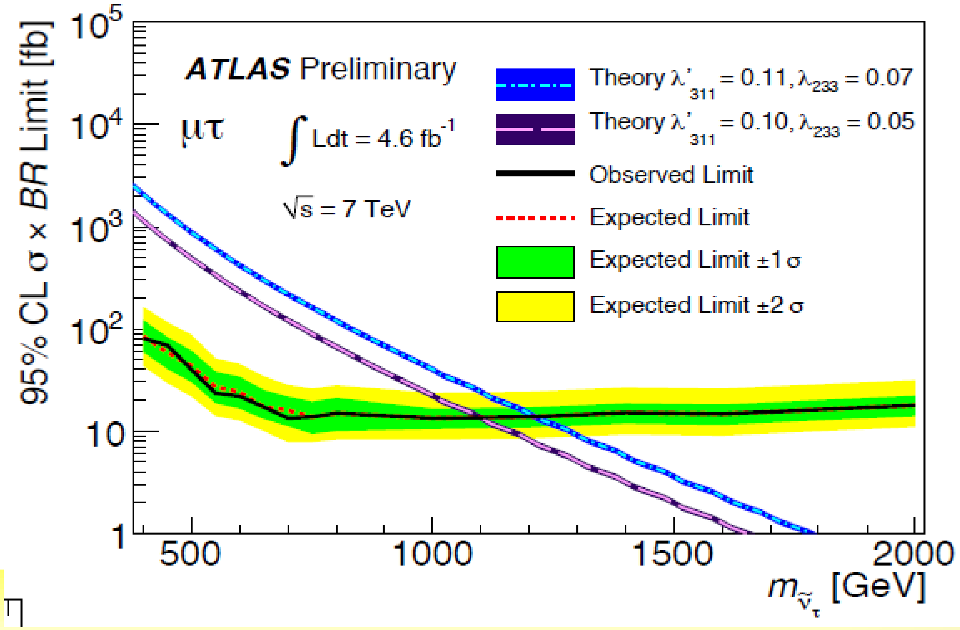
empirical coefficients

e-μ, e-τ, μ-τ Resonances





arXiv:1212.1272



Disappearing tracks: ATLAS Selection

Event selection

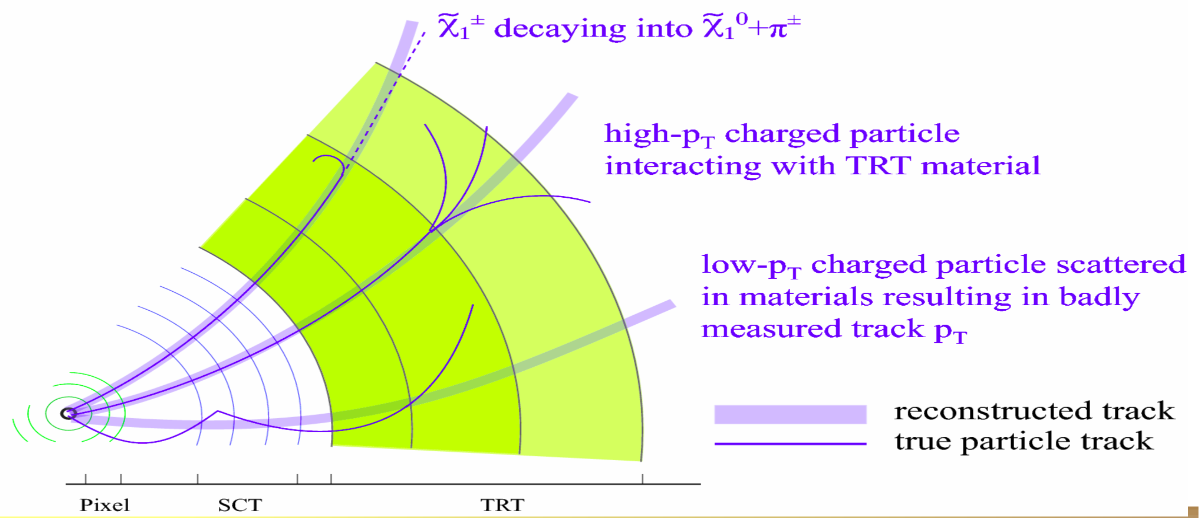
selection	Description
Trigger	EF_j55_a4tc_EFFS_xe55_medium_noMu_dphi2j30xe10
Primary vertex	Primary vertex has >= 5 tracks
Cleaning	larError = 0, jet cleaning, smart veto
Lepton veto	# of leptons = 0
# of jets	>= 1
1st jet p_T	> 90 GeV
MET	> 90 GeV
$\Delta\Phi_{\min}^{jet-MET}$	> 1.5
High p_T isolated track selection	At least 1 high p_T isolated tracks **(Pre-selection)**
Disappearing track selection	N_{TRT}(outer) <5 **(Signal region)**

High p_T isolated track definition

Selection	Description
Track p_T	> 10 GeV
|eta|	0.10 < |eta| < 0.63
N(B-layer)	>=1, if expected
N(Pixel)	>=1
N(SCT)	>=6
Isolation	NuCone10 = 0
Overlap removal	dR(leading 2jets, track) > 0.4
σ(1/p)/1/p	< 0.2

Disappearing tracks: Background

- **Hadron Track**
  - The p_T Spectrum of interacting hadron tracks(Si-seed) is the same as that of non-interacting hadron tracks(Si-seed).
  - Hadron track p_T shapes are determined by inverting N_{TRT} (outer) cut and requiring hadronic
- **Electron Track**
  - Residual electron track p_T shapes (and also the numbers) are determined by multiplying electron p_T in Weν CR(data) by the probability to fail ID requirement & N_{TRT}(outer)<5

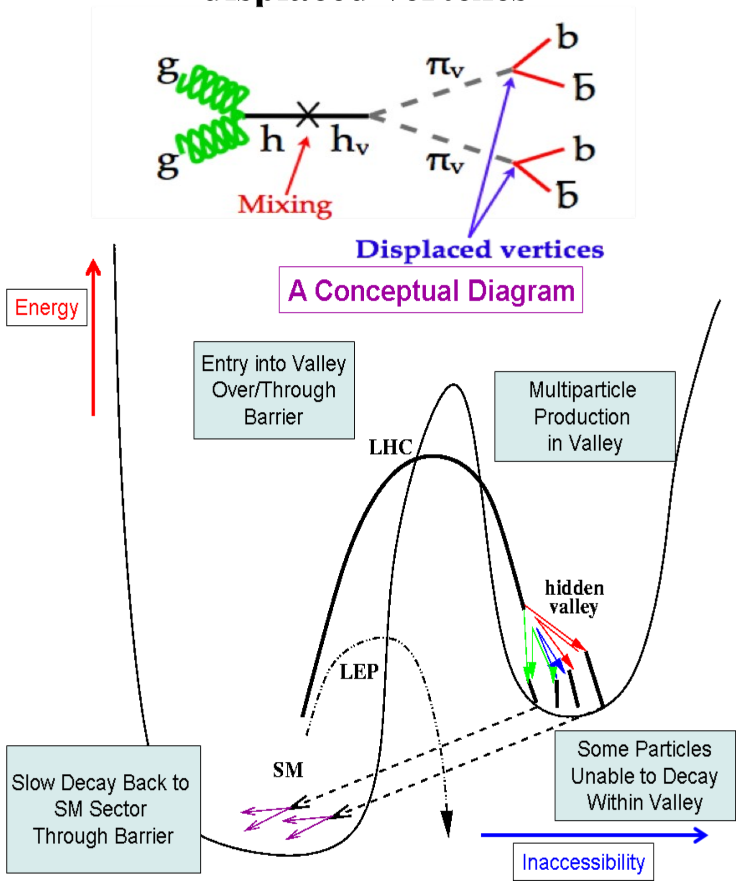


Hidden Valley ATLAS

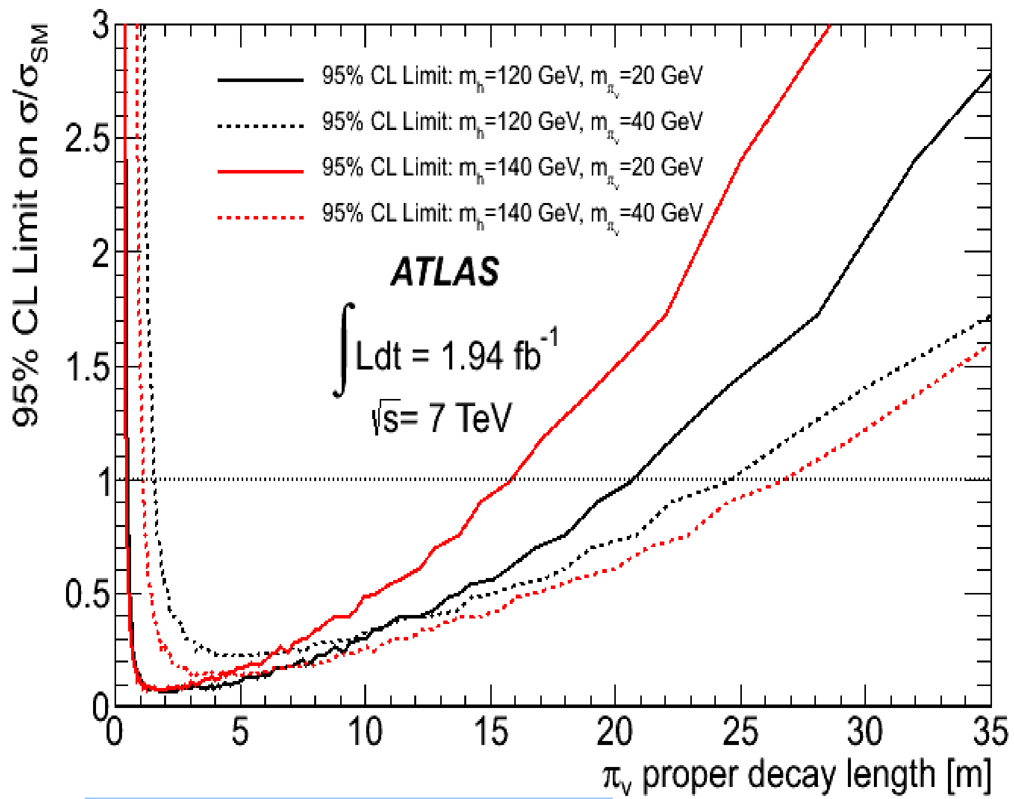
Hidden Valley Sector:

H->$\pi_v \pi_v$ ->4b

Decay in the Muon Spectrometer: muon displaced vertexes



Limit sets on vpion mass (20-40 GeV) and Higgs Mass (120-140 GeV) with 500<ct<1500cm



arXiv:1203.1303; PRL 108 (2012) 251801

Displaced Muon-Jets

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

Higgs mass (GeV)	$m_{f_{d2}}$ (GeV)	$m_{f_{d1}}$ (GeV)	γ_d mass (GeV) (GeV)	$c\tau$ (mm)
100.	5.0	2.0	0.4	47
140.	5.0	2.0	0.4	36

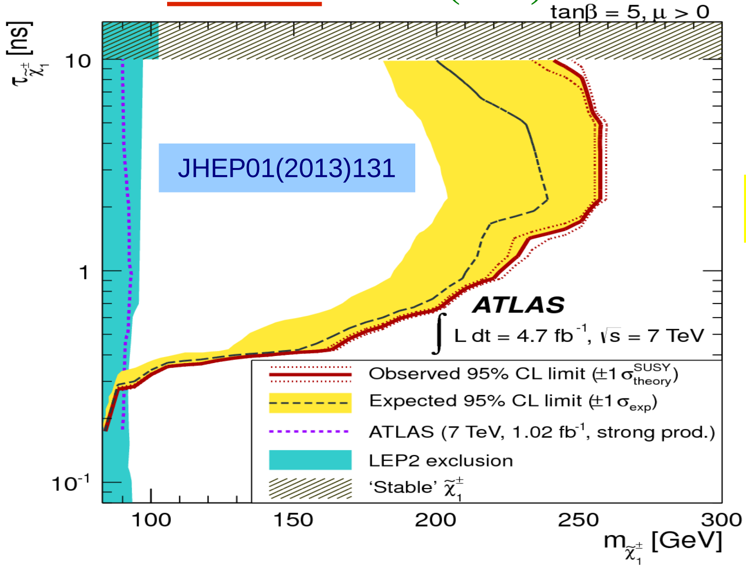
sample	2MJ	Final Selection
Cosmics	3.0±2.1	$0^{+1.64}_{-0}$
$multi-jet$		$0.059\pm0.015^{+0.66}_{-0.059}$
$Total\ background$		$0.059^{+1.64}_{-0.015}{}^{+0.66}_{-0.059}$
m_{Higgs} =100 GeV	$135\pm11^{+29}_{-21}$	$75\pm9^{+16}_{-12}$
m_{Higgs} =140 GeV	$90\pm9^{+17}_{-13}$	$48\pm7^{+9}_{-7}$
DATA	871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

Muon jet reconstruction

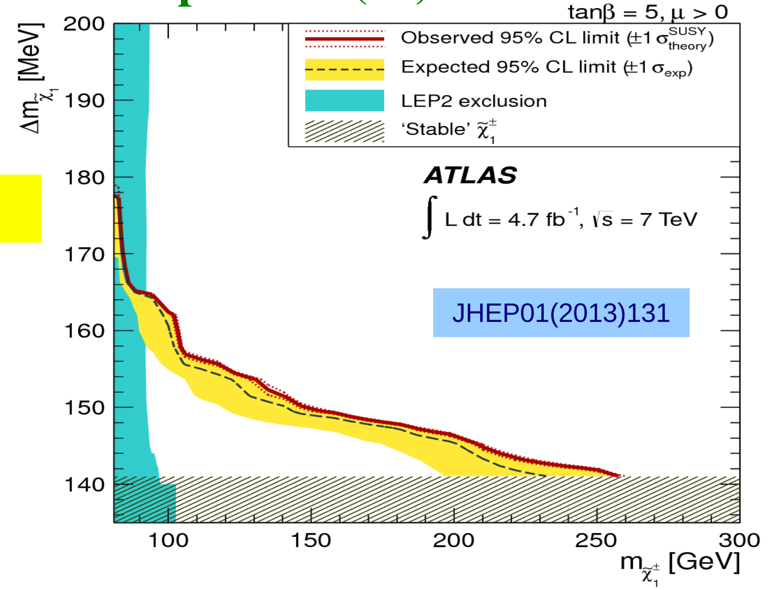
- Cluster muons using dR=0.2 cone
- Require ≥2 OS muons per muon-jet
- Require ≥2 muon-jets
  - Calorimeter isolation in hollow cone 0.2<dR<0.4 around muon-jet < 5 GeV
  - Scalar sum pt of tracks in dR<0.4 cone around each muon-jet < 3 GeV
  - dphi>2 for two muon-jet
  - d0<200mm and |z0|<270mm w.r.t. PV (remove cosmic background)

Some Results: AMSB and R-hadrons

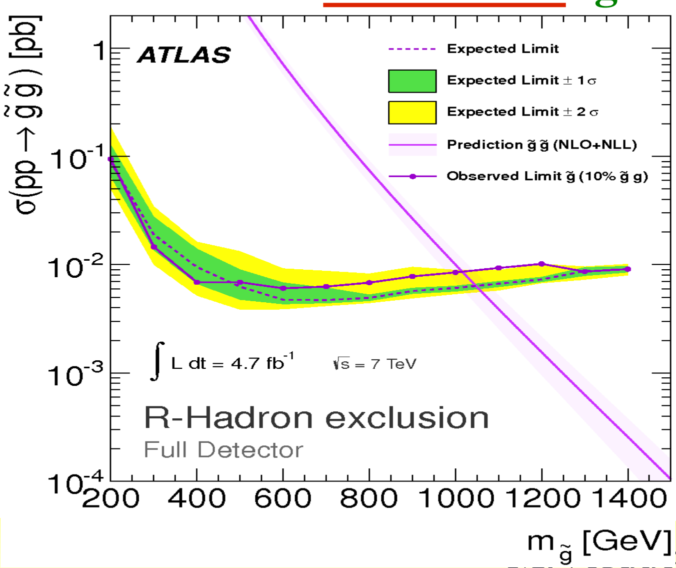
AMSB : 160 (170) MeV → chargino mass excluded up to 103 (85) GeV



2011 data 5 fb^{-1}

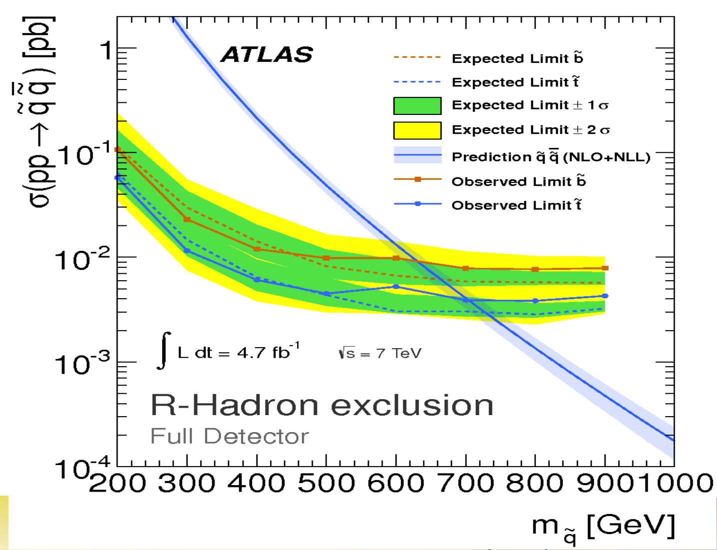


R-hadrons: gluino and squarks(stop and sbottom)

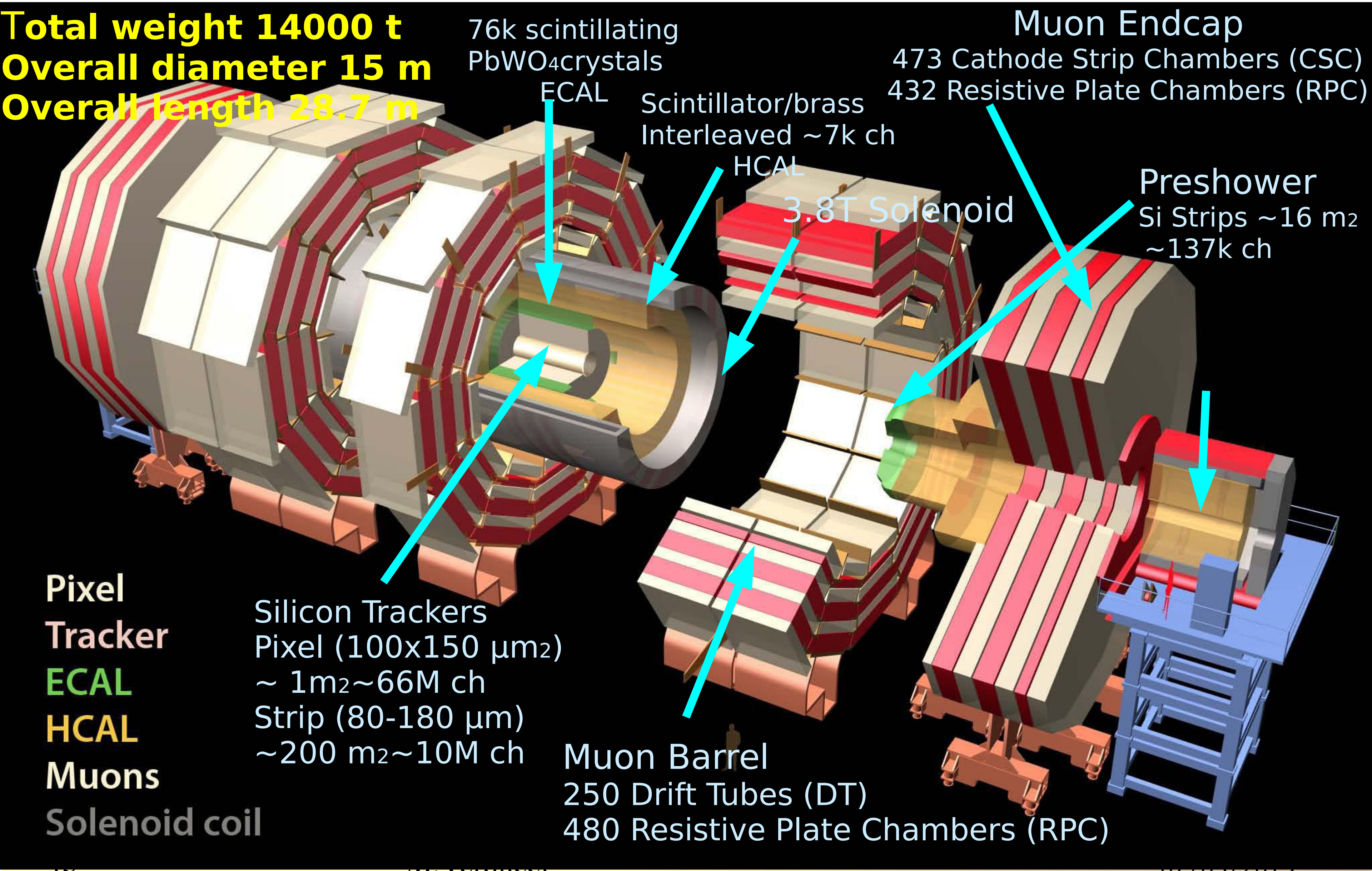


2011 data 5 fb^{-1}

arXiv:1211.1597



CMS Detector Overview



ATLAS Detector