SUSY or not, what is the evidence? Status and perspectives of collider searches – Part IIC

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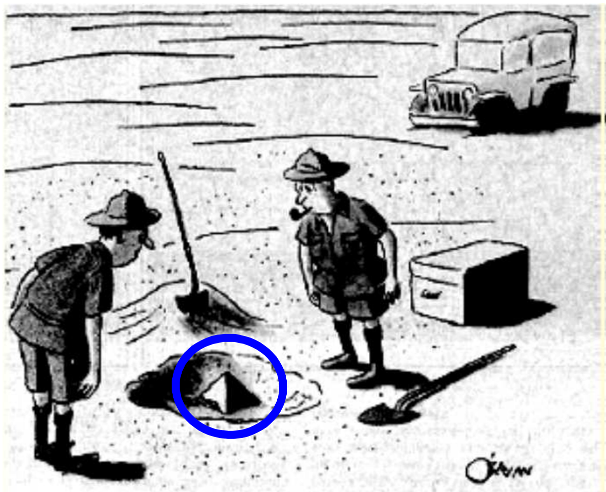
Lectures at Niels Bohr Institute



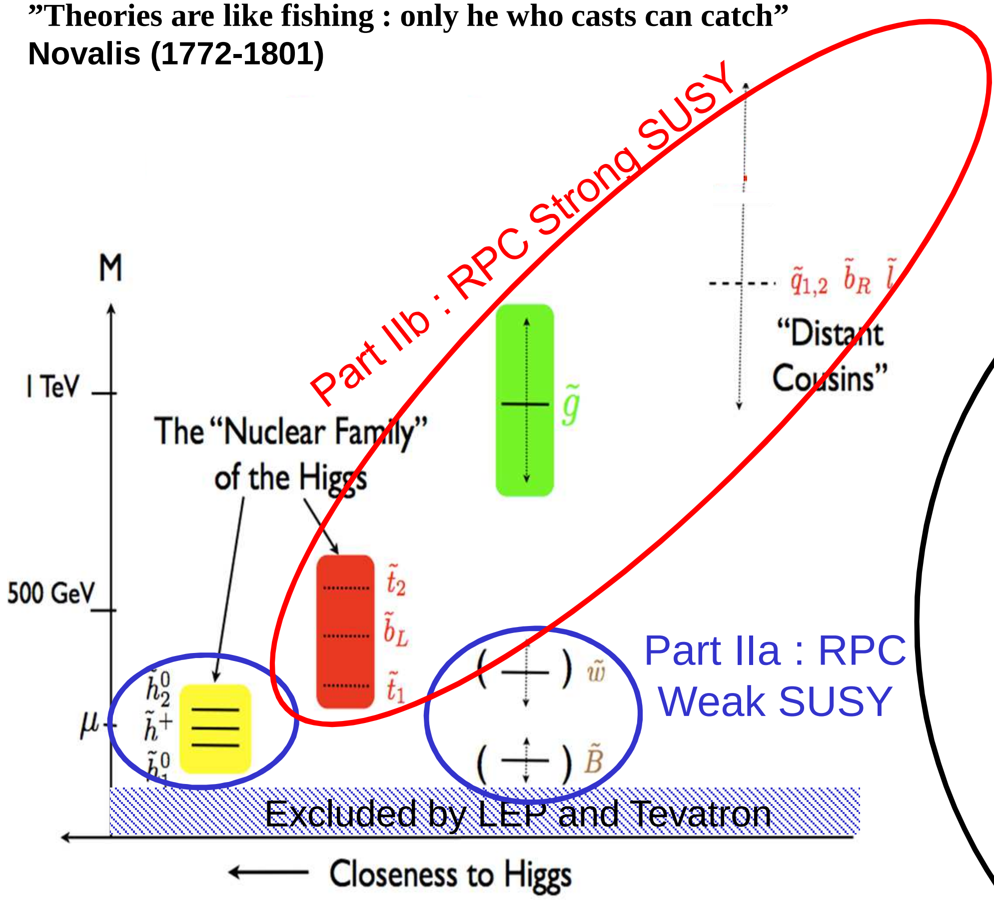
"This could be the discovery of the century. Depending, of course, on how far down it goes"

Part II (3 lectures + 2 exercises)
Direct SUSY searches at LHC

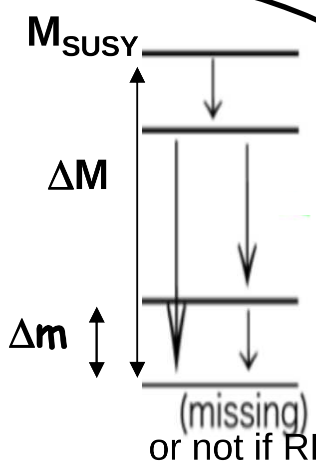
W 30-Oct	Th 31-Oct	Fr 01-Nov
--	Lecture IIA **Exercise 1**	Lecture IIC **Exercise 2**
Lecture IA Lecture IB	**Exercise 1** Lecture IIB	**Exercise 2** Lecture III

Lecture Part II

"Theories are like fishing : only he who casts can catch"
Novalis (1772-1801)



Part IIc: R-Parity Violated, Long-Lived Particles, beyond MSSM



1. Low Δ**m**, tiny RPV, weak coupling to $\tilde{G}$
   Long Lived or meta-stable sparticles
2. 'Sizeable' RPV
   Multileptons, No Z, jet resonances, LFV
3. MSSM Extensions?
   Scalar Gluon
4. Un-natural SUSY ?

Lecture Part IIc

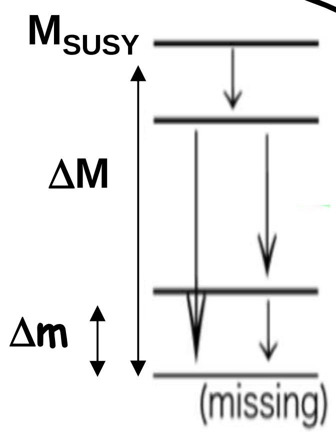
Theory Unknowns:

1- SUSY Breaking (**SUGRA, GMSB, AMSB**)

2- RPC (Lecture IIa,b) vs RPV (**here**)

3- **Open** or **compressed** spectra

Part IIc: R-Parity Violated, Long-Lived Particles, beyond MSSM



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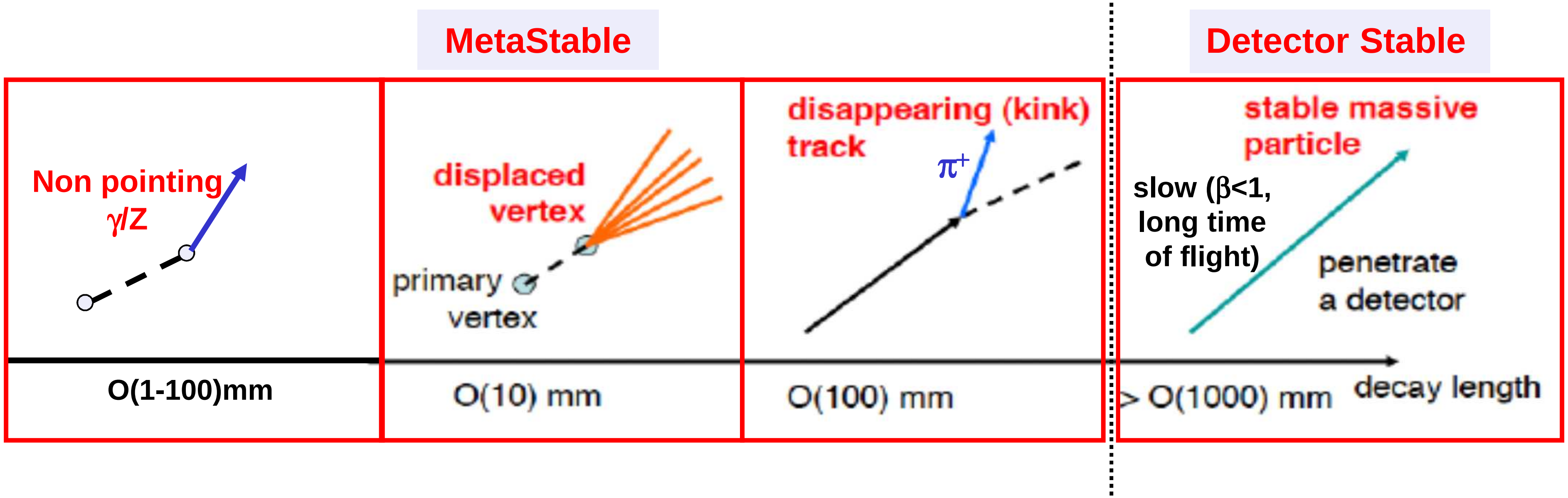
4. Un-natural SUSY ?

Long-Lived Particles

- **Apart from LSP other particle could be long-lived :**
  1. Very weak coupling with $\tilde{G}$=LSP [GMSB] : ➔ Non pointing γ or Z
  2. Lifetime proportional to $\lambda^{-2}, \lambda'^{-2}, \lambda''^{-2}$ [R-Parity violation] ➔ Displaced vertex if $\lambda, \lambda', \lambda'' \sim 0(10^{-5})$
  3. Low mass difference, e.g $\Delta M(\tilde{\chi}_1^+ - \tilde{\chi}_1^0) \sim 100$ MeV [AMSB] ➔ Low **p** emitted, kinked track
  4. Stable Massive Particle (mix of 1 and 3) ➔ Stable R-hadron ($\tilde{g}$ or $\tilde{q}$), sleptons



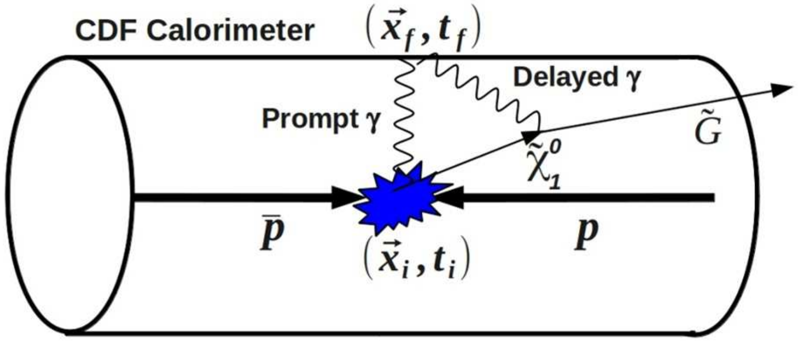
A huge effort to cover all possible signatures

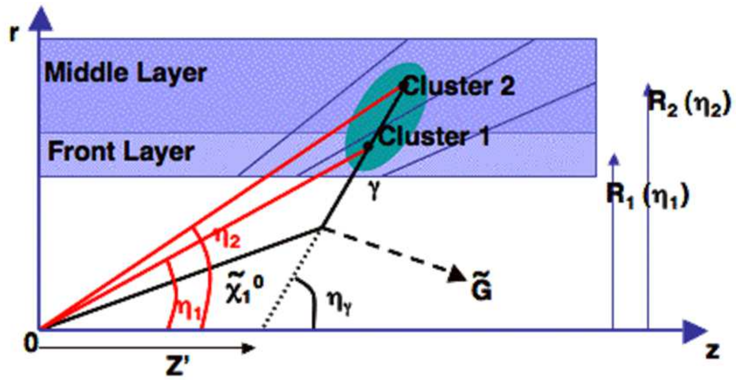
Metastable Particles (1)

1207.0627, 1212.1838, 1304.6310

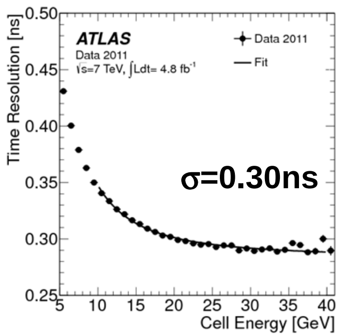
❑ Non pointing photon could have several signatures

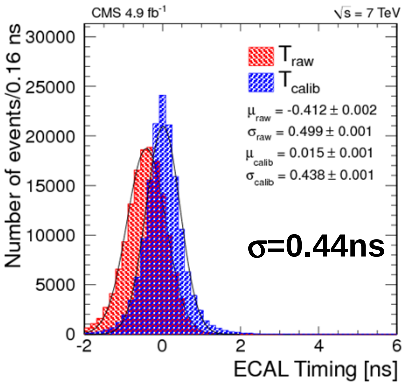
- For all studies assume strong production, GMSB and NLSP bino-like = $\chi_1^0 \rightarrow \gamma G$





Late Timing arrival in the EM calorimeter (t_γ)
➔ Need excellent calorimeter timing reso.





No pointing to the primary vertex

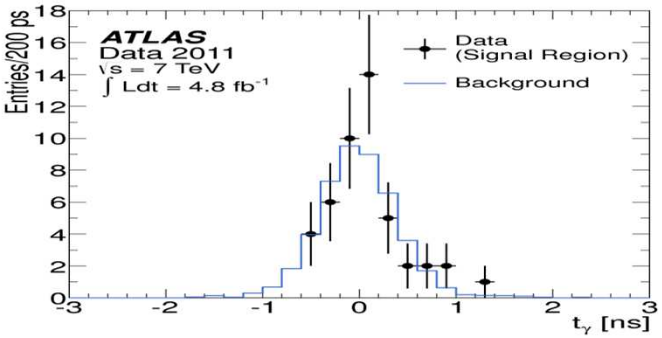
1. Stand-alone pointing capabilities of the calorimeter → $\tau(\chi_1^{+/-}) < 50$ ns
2. Impact parameter of the converted photons → $\tau(\chi_1^{+/-}) < 1$ ns

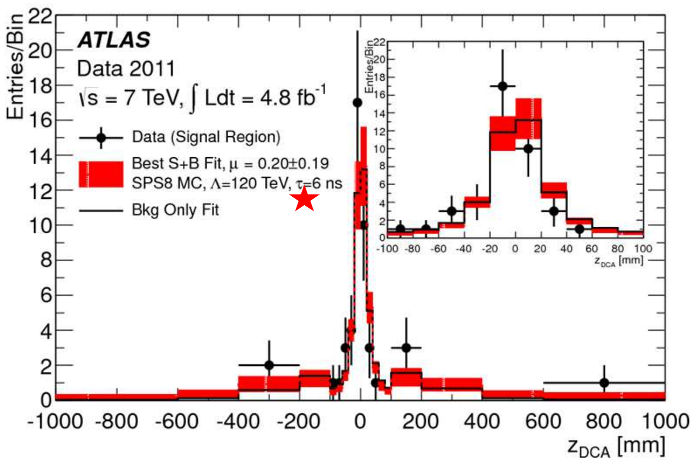
Metastable Particles (1)

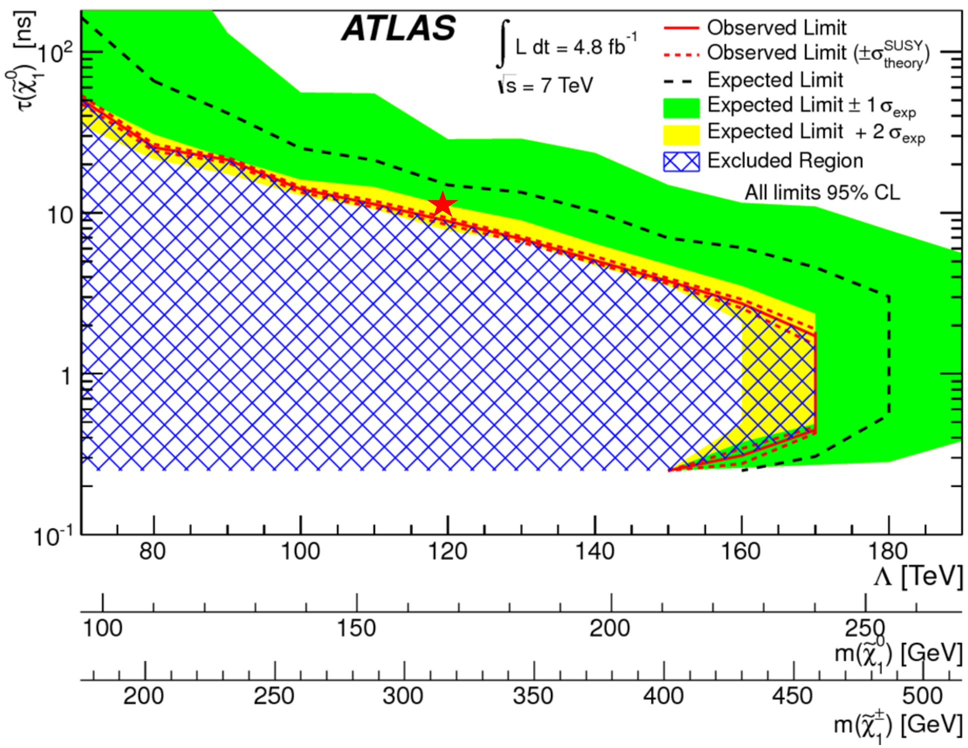
1304.6310

❑ Non pointing photon : some details about ATLAS study

- 2 photons (1 tight isolated + 1loose) with E_T (γ) > 50 GeV and MET > 75 GeV
- Timing arrival in the EM calorimeter (t_γ) and stand-alone pointing capabilities (z)





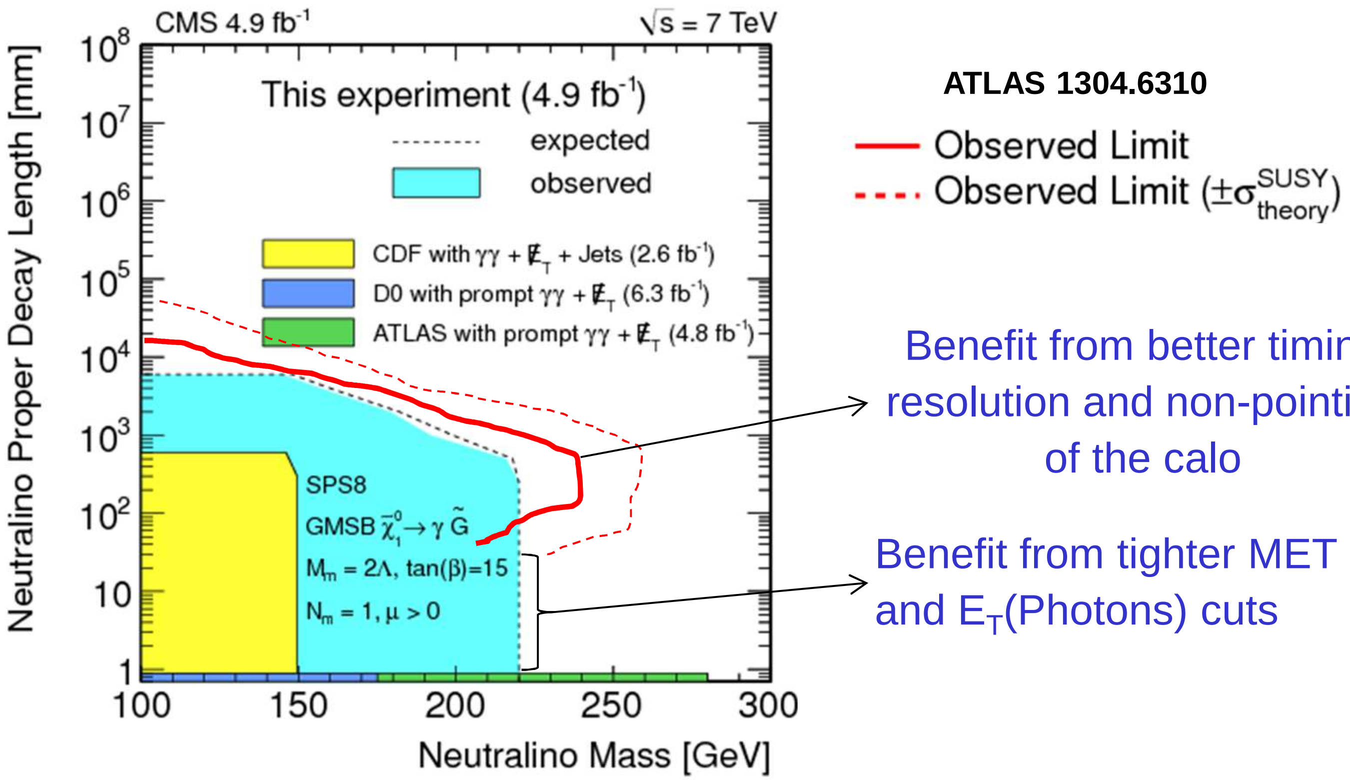


Metastable Particles (1)

1207.0627, 1212.1838, 1304.6310

❑ Non pointing photon : Summary

- Merging all analyses in one plot



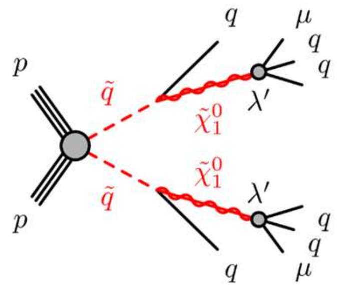
Complementary approaches

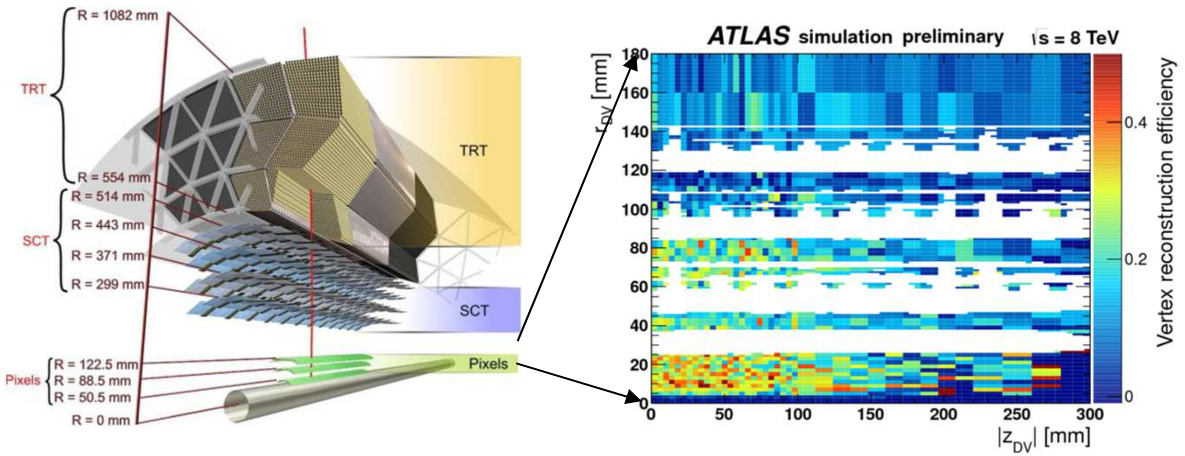
Metastable Particles (2)

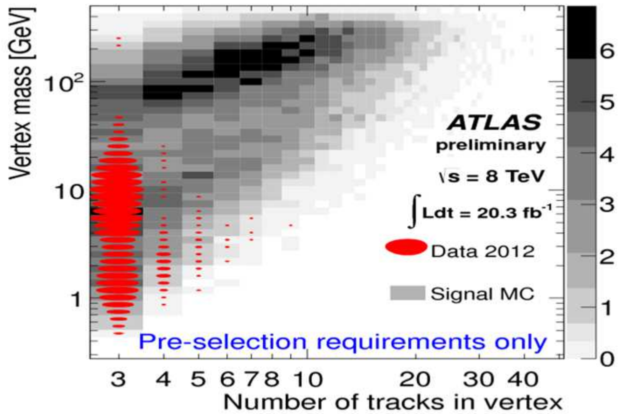
1210.7451

❑ High mass displaced vertex with 4 tracks and a muon

- Assume RPV with $\lambda'_{2ij}\neq 0$
- Design a background-free analysis in M_{vertex} – N_{track} plane
- Build up a dedicated tracking to increase signal efficiency







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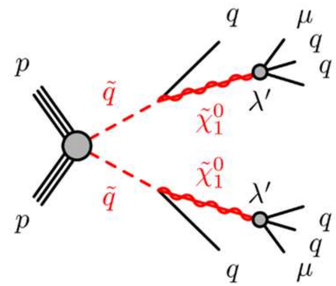
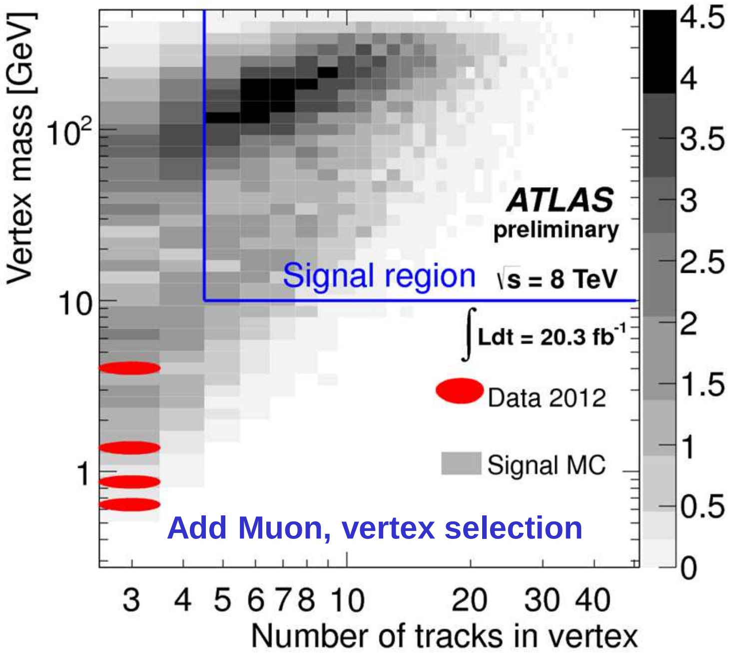
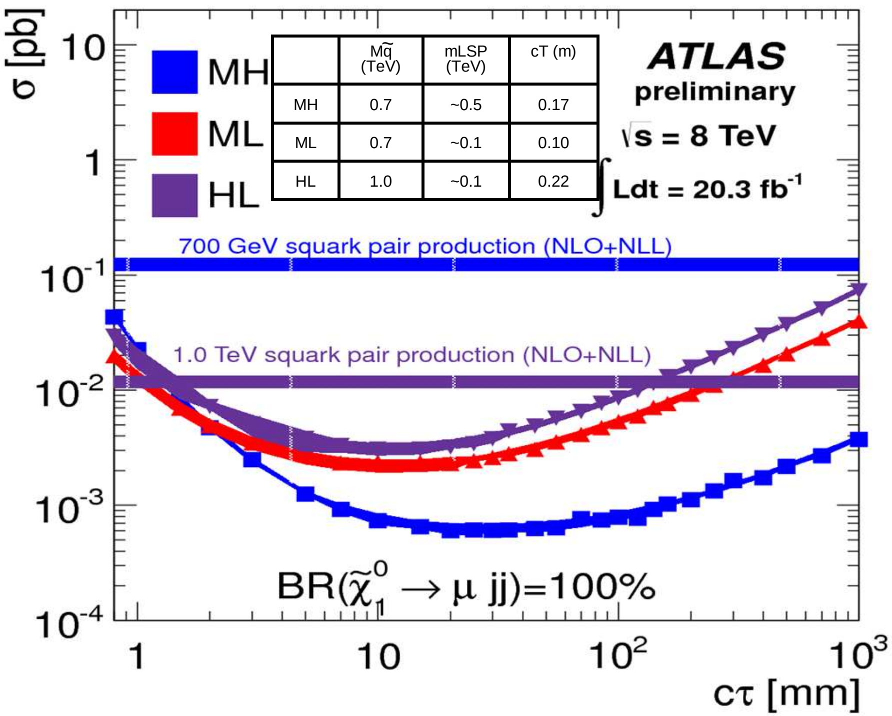






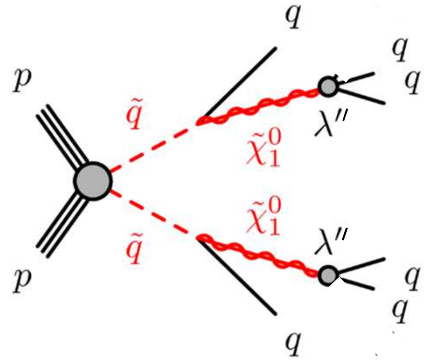
*q=1rst, 2nd gene mass degeneracy

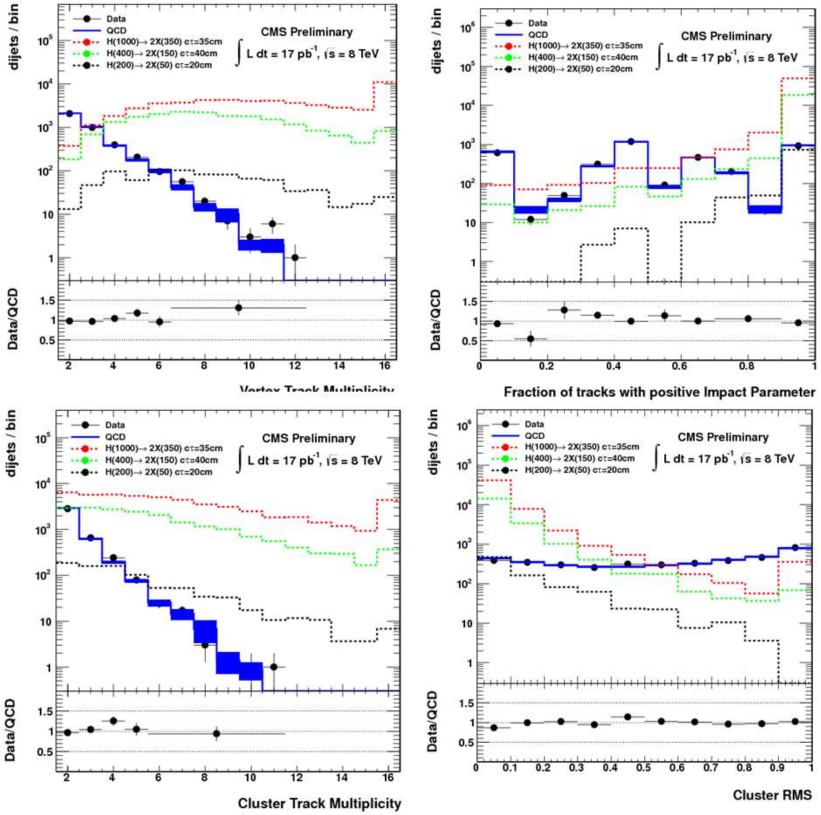
Metastable Particles (3)

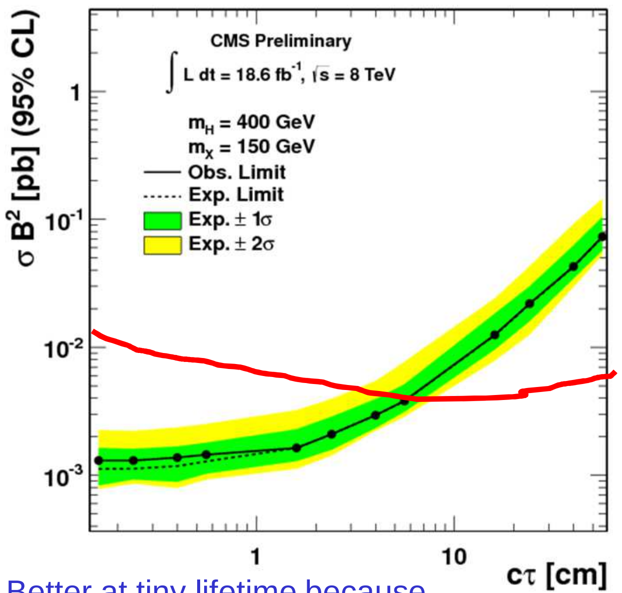
EXO-12-038

❑ High mass displaced vertex with 2 jets

- Originally developped for H→χχ→4j with displaced χ
- Use both tracker and calorimeter







Harder at high lifetime because use the calo.

ML Model

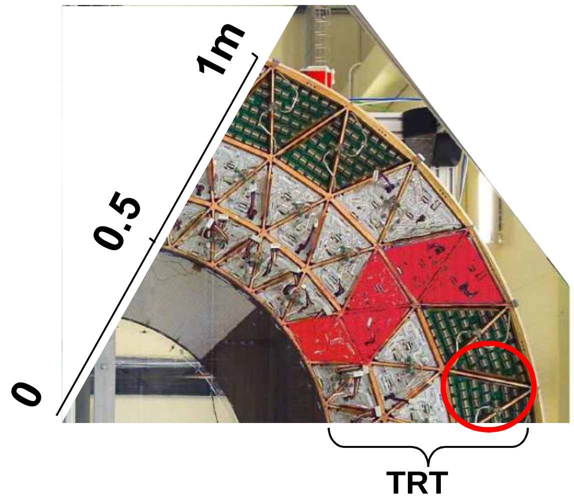
Better at tiny lifetime because combine calo + tracker.

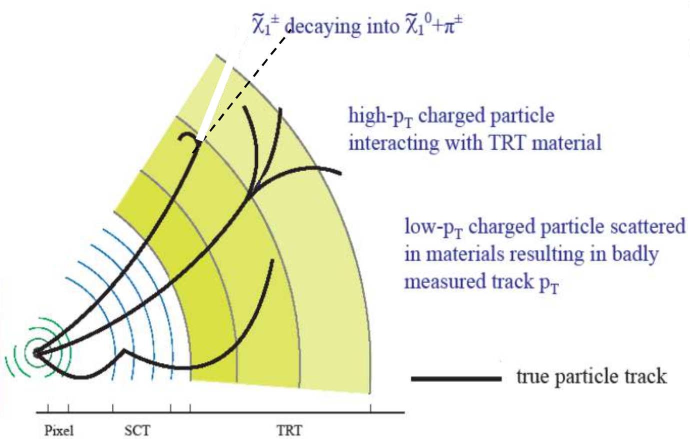
Metastable Particles (4)

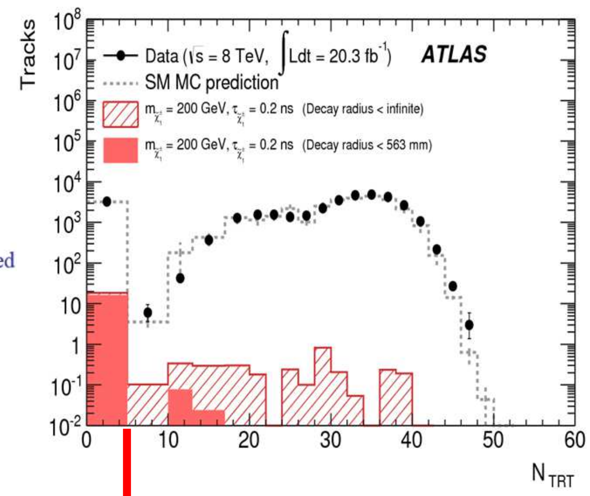
1310.3675

❑ Direct production of a metastable $\chi_1^{\pm}$ *

- Motivated by AMSB, but model independent results
  - ✓ $\chi_1^{\pm} \rightarrow$ soft π^{+} + χ_1^{0} : Disapearing track in the TRT
- Remove background : N_{TRT} + highest p_T isolated track







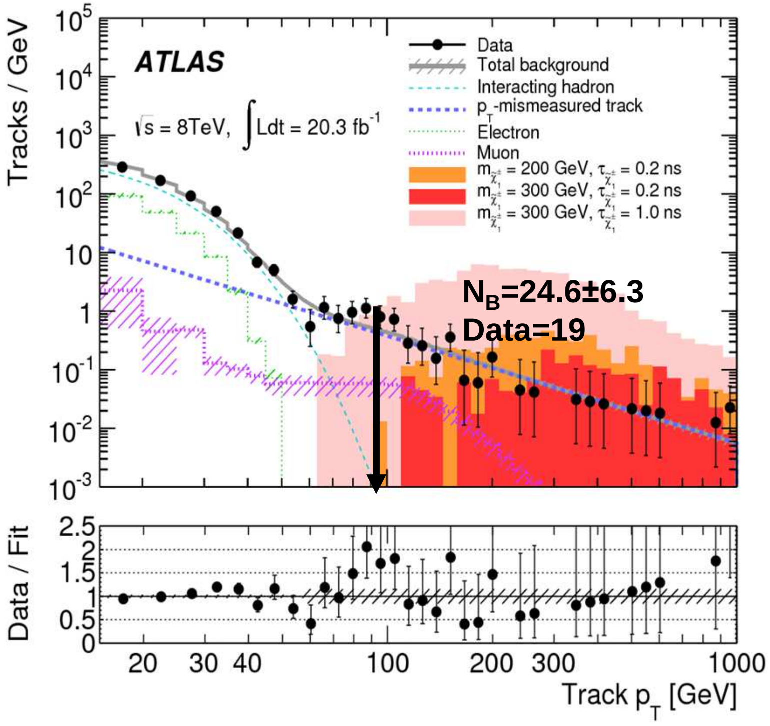
Truncated tracks | Normal tracks

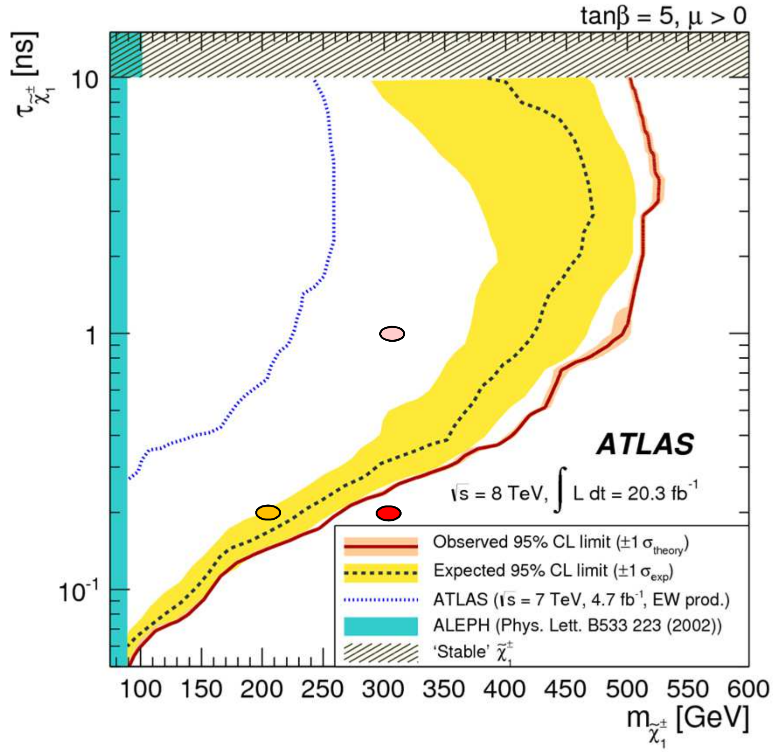
* σ (C1N1,C1C1) ~ 15/ 1pb for m=100/200 GeV

Metastable Particles (4)

1310.3675

❑ Direct production of a metastable $\chi_1^{\pm}$





A good candidate for minimum unnatural SUSY model

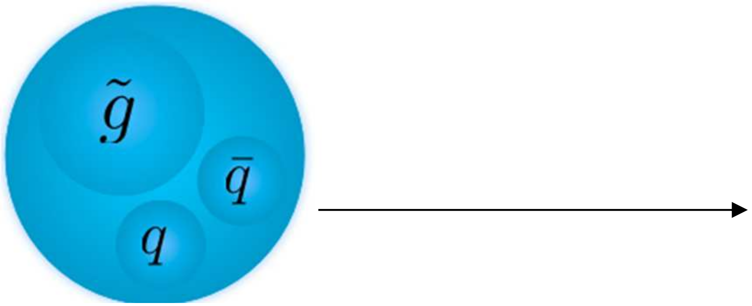
Detector-Stable Particles (1)

hep-ph/0611040

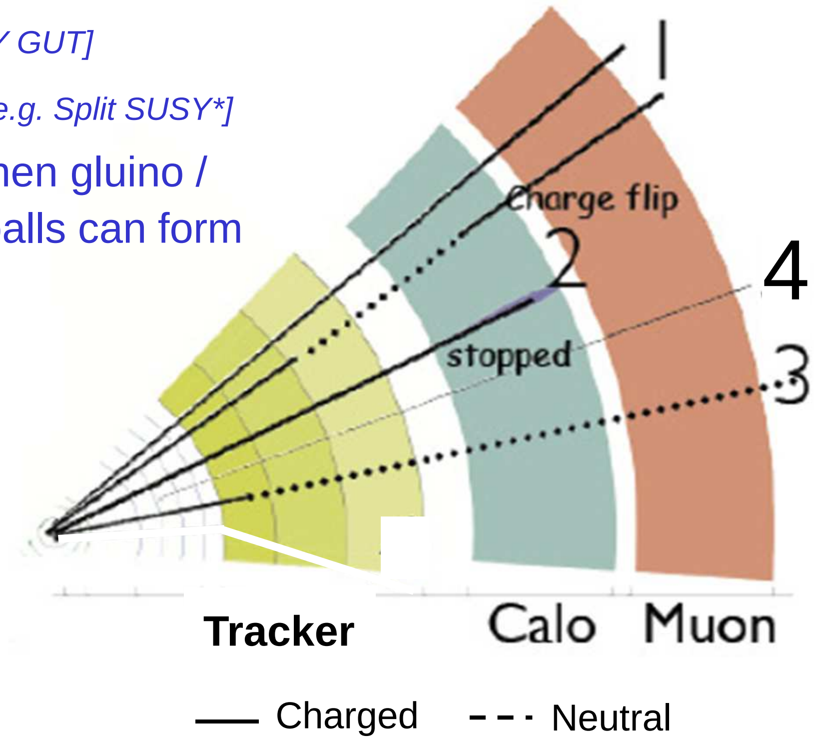
❑ 3 main possibilities for colored particles :

1. Gluino is the LSP *[SUSY GUT extension]*
2. Very weak coupling of NLSP=$\tilde{\mathbf{g}}$ with $\tilde{G}$=LSP *[SUSY GUT]*
3. Squarks decoupled or $\Delta m(\tilde{\mathbf{g}}/\tilde{\mathbf{q}}-\tilde{\chi}_1^0)$~O(100) MeV *[e.g. Split SUSY*]*

➔ If lifetime > hadronization time scale ~O(10^{-24})s then gluino / squark (especially $\tilde{t}_1$ and $\tilde{b}_L$) R-hadrons or gluinoballs can form



- Detector Stable
- Highly ionising particle
- Slow moving (non-relativistic)
- Can change sign



**Decay to LSP is suppressed because of very high mass virtual squarks*

Detector-Stable Particles (2)

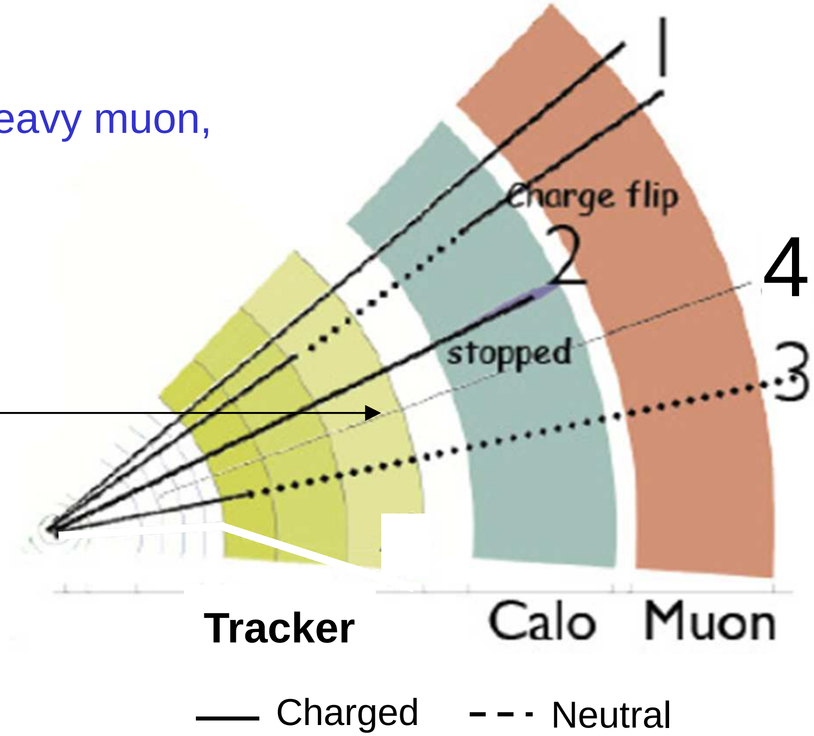
hep-ph/0611040

❑ 3 main possibilities for non-colored particles :

1. Slepton is the LSP
2. Very weak coupling of NLSP=$\tilde{l}$ with $\tilde{G}$=LSP
3. Low mass difference $\Delta M(\tilde{l} - \tilde{\chi}_1^0)$~100 MeV

➔ Long-lived sleptons (mainly τ_1) manifest as a heavy muon, charged and penetrating

- Detector Stable
- Highly ionising particle
- Slow moving (non-relativistic)



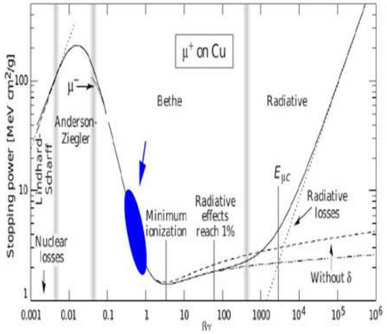
Later called LLP (also find SMP, CHAMP, …)

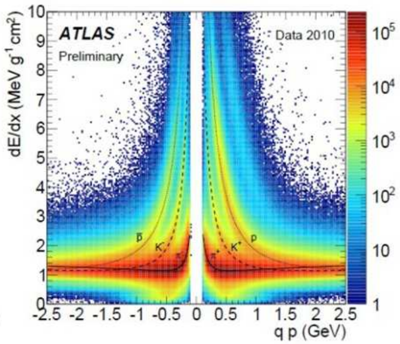
Detector-Stable Particles (3)

1211.1597, ATLAS-2013-058

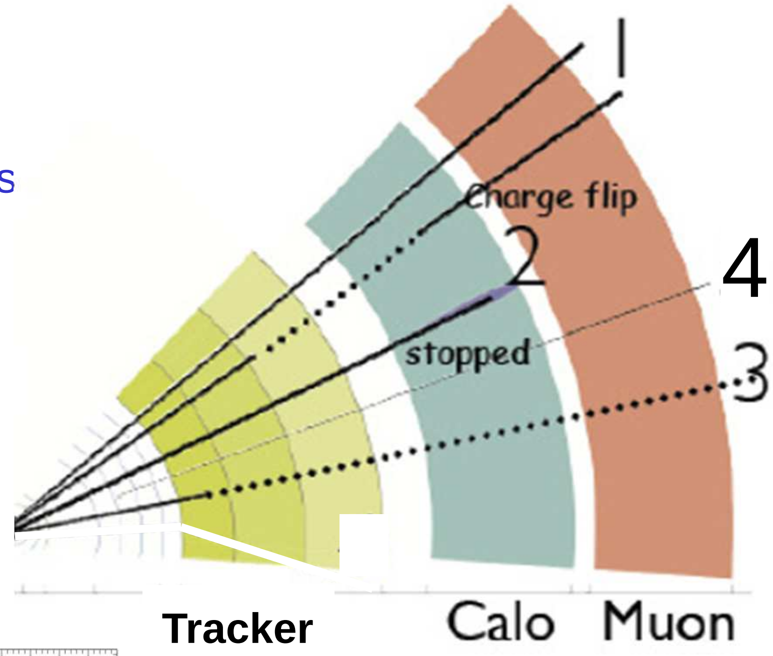
❑ Striking signature → Reconstruct mass

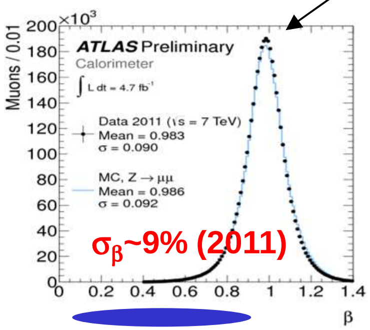
1. Start from one (or two) high pT isolated track → p
2. Measure βγ (invert Bethe-Bloch) from **Si-track** clusters

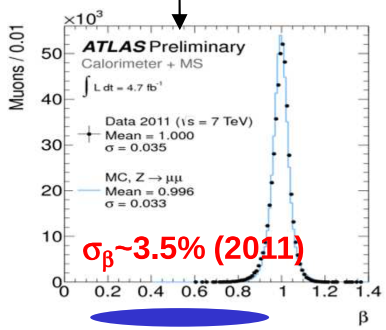


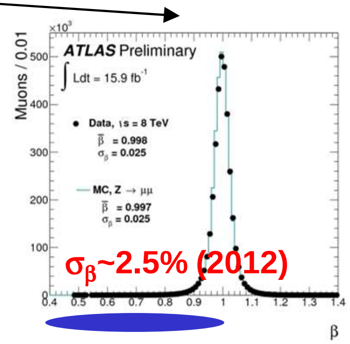


3. Measure β (**calo** or **calo+Muon Spectrometer**)









Signal

➔ Add the 2 or 3 information together and compute $M = p/\beta\gamma$

Detector-Stable Particles (4)

1211.1597, ATLAS-2013-058

❑ Event selection

($\tilde{g}$+q$\bar{q}$, g+qqq, $\tilde{b}/\tilde{t}$ + $\bar{q}$, qq) + ISR — Heavy Muon

Requirements	R-hadrons (ID-only)	Stable R-hadrons (ID+calo-only)	Stable R-hadrons (Full Detector)	Stable Sleptons (Full detector, 2 cand.)
Particle Type	Metastable or Charged→Neutral	Charged→Neutral	Charged	Charged
Trigger	MET turn-on			Slow β
Track quality	d0, z0, n (ID-hits)			
Track kinematics	pT>50, p>100 GeV			pT>50 GeV
β Consistency between detectors	No	Yes		
β < [m(g, q, l) dependent]	No	0.8-0.9		0.95
βγ> [m(g, q, l) dependent]	MIP	1.5-2.0		No
M_β range (TeV)	No	0.2-1.1 ; 3.0		0.1-0.3
$M_{\beta\gamma}$ range (TeV)		0.2-1.1 ; 3.0		No
Signal Efficiency (%)	6 [m(g)=900 GeV]	7 [m(g)=900 GeV]	11 [m(g)=900 GeV]	20
Systematics (%)	6 (S), 13 (B)	12 (S), 15 (B)	12 (S), 15 (B)	6 (S), 8-21 (B)

Optimised (β consistency through M_β range rows)

- Background type : high pT muons (tracks) with mis-measured β (dE/dx)
- Background estimate: generate mass spectrum from S/B<<1 → p-templates + β (βγ)-PDF templates
- Signal: Different interaction models, gluino ball fractions (10%, 50 %, 100%).

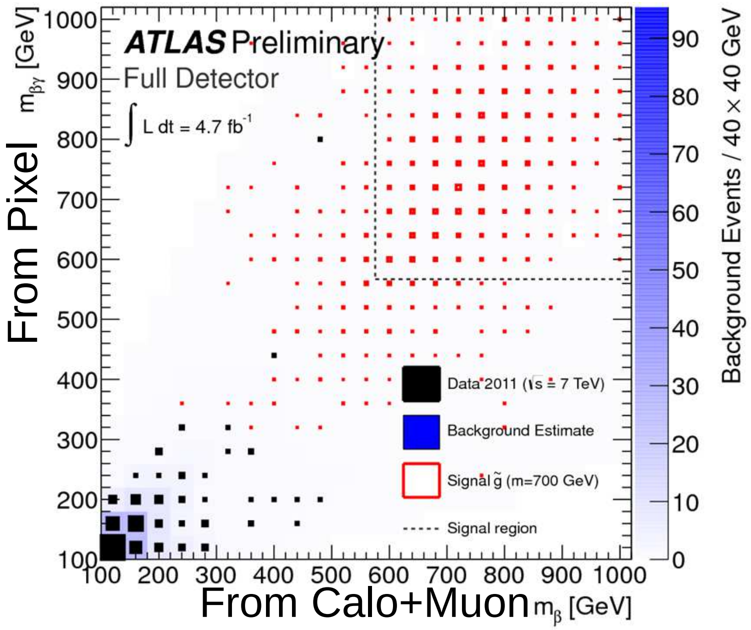
Detector-Stable Particles (5)

1211.1597, ATLAS-2013-058

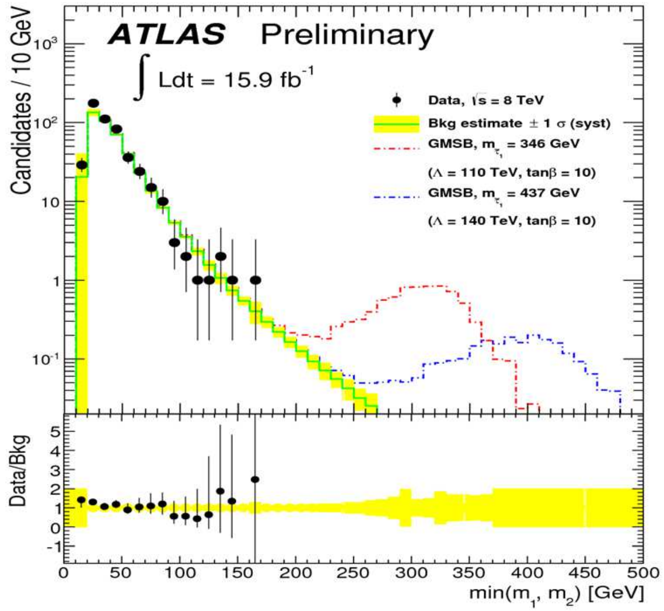
❑ Mass distributions

- Cut and count in mass ranges.
- Background free analyses

R-hadrons: Full detector



Slepton searches (2 candidates)



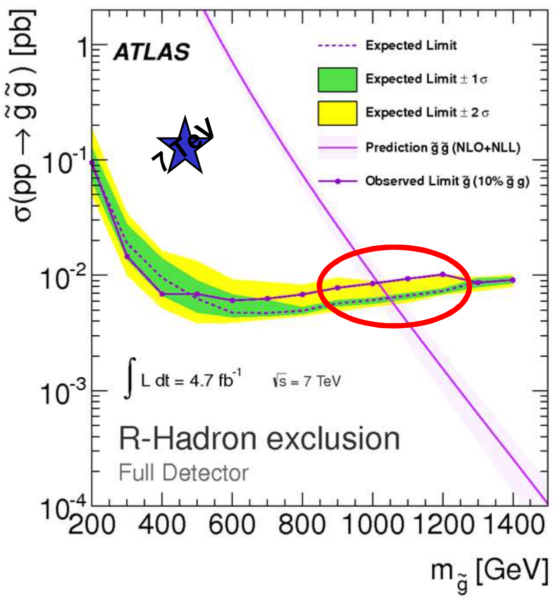
Detector-Stable Particles (6)

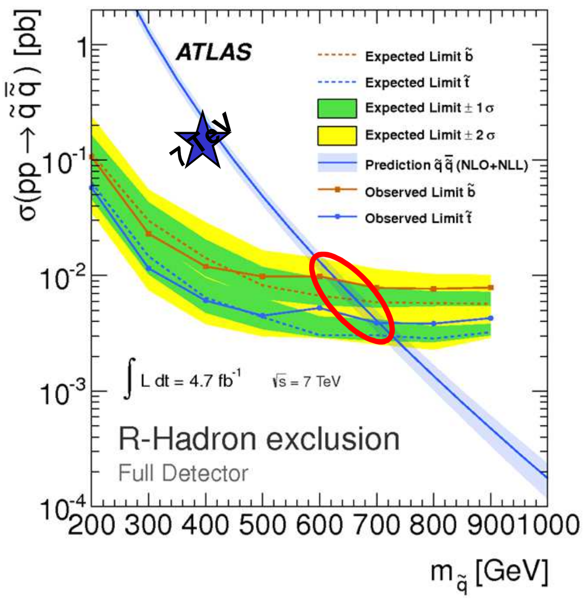
1211.1597, ATLAS-2013-058

❑ Model independent limits

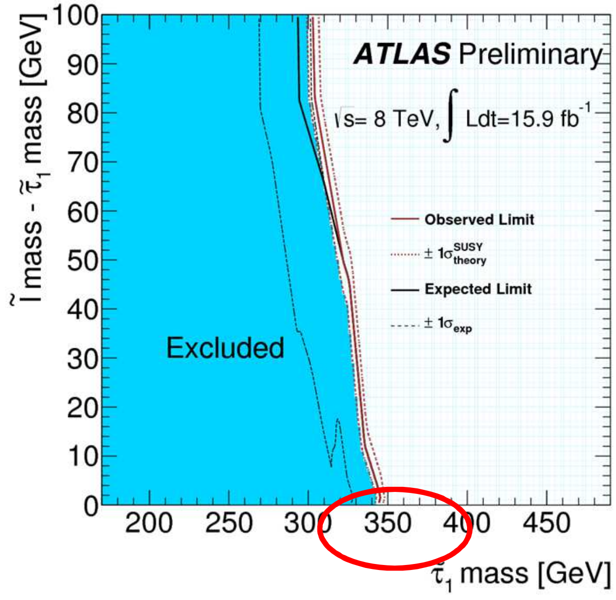
- Just rely on the MSSM production cross-section

R-hadrons: Full detector





Slepton searches (2 candidates)



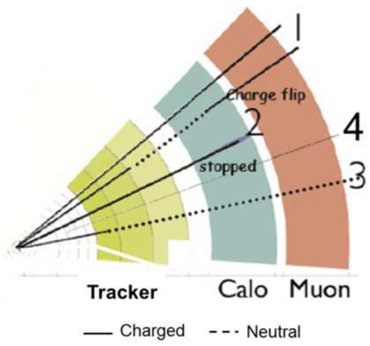
Generally stronger limits than prompt SUSY searches

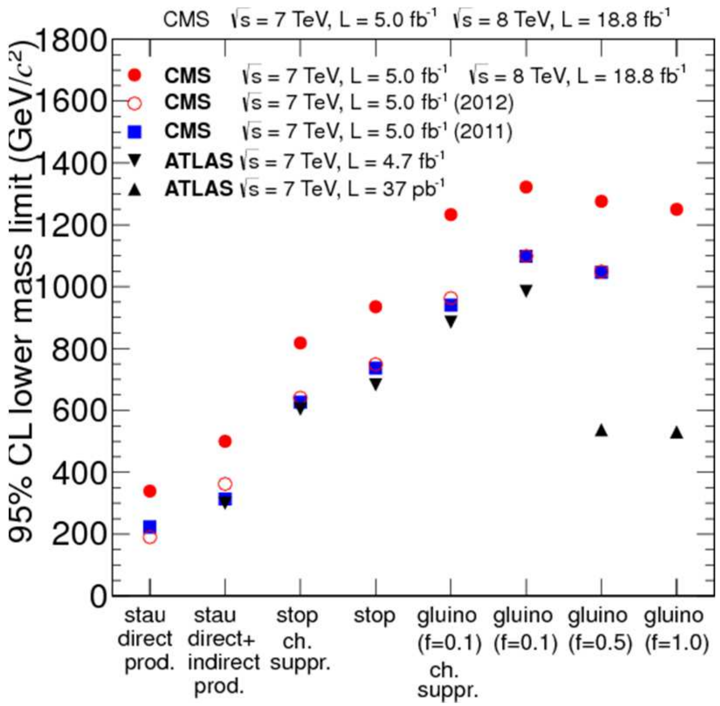
Detector-Stable Particles (7)

1305.0491

❑ Comparison with CMS results

- Not rely on calorimetry information: Tracker, Tracker+Muon and Muon-only
  - ✓ Weakly affect the limits but exclude some scenarios for R-hadrons
- Have analysed the full statistics → stronger limits



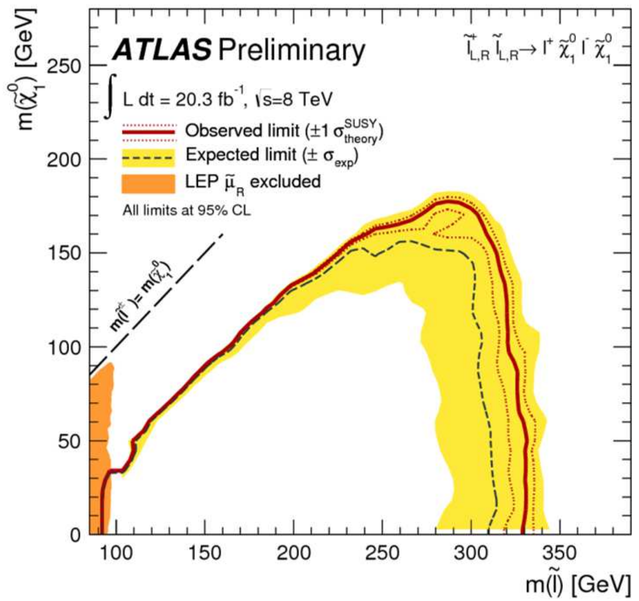


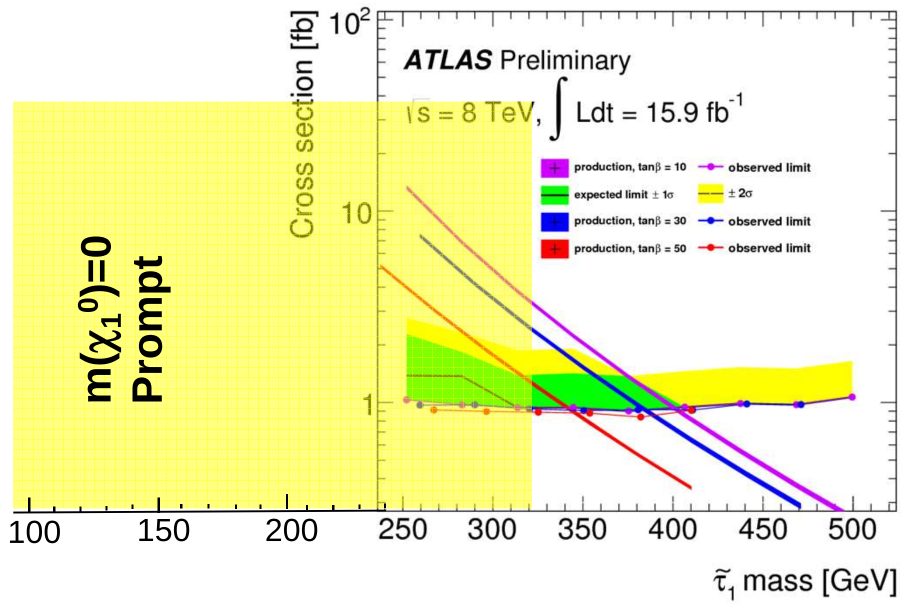
Detector-Stable Particles (8)

❑ Comparison with prompt searches

Slepton searches
(2 prompt candidates)

Slepton searches
(2 LLP candidates)





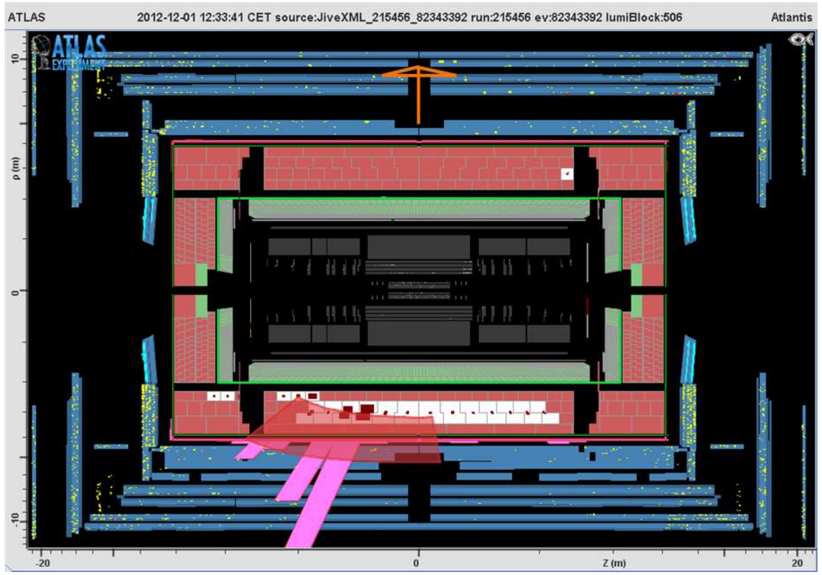
➔ Intermediate region (metastable slepton, i.e. displaced vertex w 1lepton) not covered

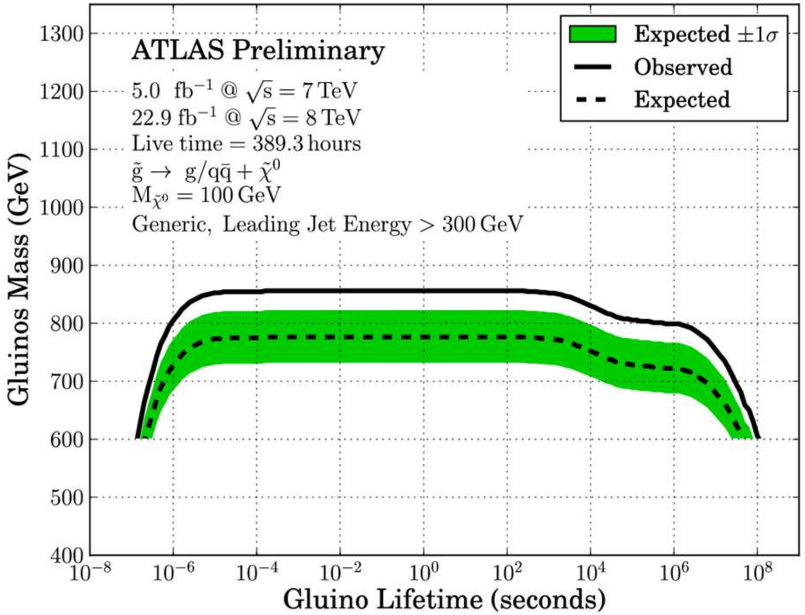
Detector-Stable Particles (9)

ATLAS-CONF-2013-057

❑ R-hadrons can also stop in the calo and decay later

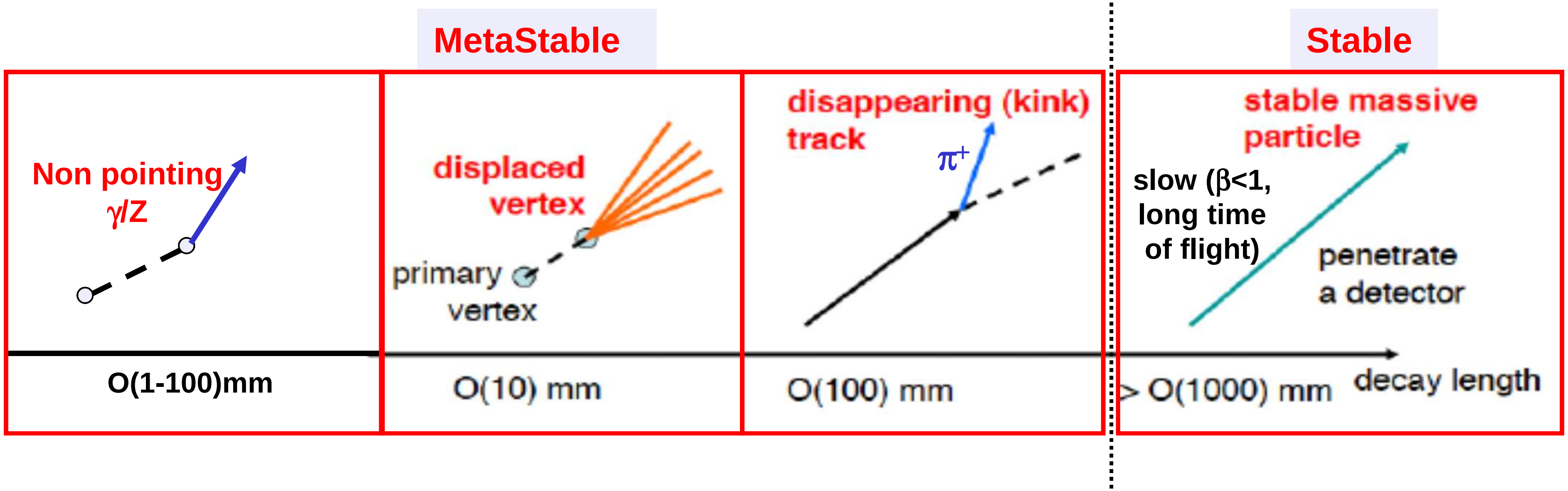
- In Split SUSY (unnatural model), the stopped gluino only particle reachable at LHC
- High energetic jets in absence of collisions
- Background = calorimeter noise, cosmics and beam halo not SM !





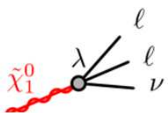
$M_{\tilde{g}} < 800$ GeV ($M_{\chi 0}$ =100 GeV) excluded for 1 ms < t < 300 hours

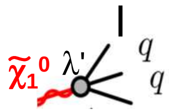
Conclusion on Long-Lived Particles

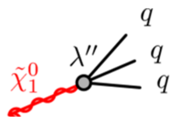


- Very well motived and could explain the absence of signal in standard SUSY searches
- Huge number of possibilites (not yet all covered)
- Striking signatures of BSM not present in the SM
  → generally detector-oriented, background-free
  → Limits on SUSY particles generally stronger

RPV







$$W = W_{MSSM} + \underbrace{\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k}_{\text{Lepton Number Violation (LFV)}} + \kappa_i L_i H_u + \underbrace{\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k}_{\text{Baryon Number Violation (BNV)}}$$

- Add **48** new Yukawa couplings and **96** complex parameters
- Proton decay only forbids simultaneous violation of lepton and baryon number
  - ✓ … but not one **or** the other
- Allow the LSP to decay
- Can change other sparticle decay

➔ Considerable change in the final states

RPV (1)

❑ R-parity violating search at LHC

$$W = W_{MSSM} + \underbrace{\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k}_{\text{Lepton Number Violation (LFV)}} + \kappa_i L_i H_u + \underbrace{\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k}_{\text{Baryon Number Violation (BNV)}}$$

From H. Dreiner

	Signature	Model
1)	4 charged leptons: $e^+e^+\mu^-\mu^-$	χ_1^0–LSP, $LL\bar{E}$, $\tilde{\tau}$–LSP, $LL\bar{E}$
2)	2 leptons, 2 taus: $e^+e^+\tau^-\tau^-$	χ_1^0–LSP, $LL\bar{E}$, $\tilde{\tau}$–LSP, $LQ\bar{D}$
3)	6 jets or 2 w/ substructure	χ_1^0–LSP, $\bar{U}\bar{D}\bar{D}$
4)	like-sign dileptons + jets	χ_1^0–LSP, $LQ\bar{D}$
5)	dilepton resonance	$LL\bar{E} \otimes LQ\bar{D}$
6)	mono lepton	$LL\bar{E} \otimes LQ\bar{D}$
7)	dijet resonance	pure $LQ\bar{D}$
8)	like sign ditau's $\tau^-\tau^-$ + 6jets	$\tilde{\tau}$–LSP, $LQ\bar{D}$

Multilepton production (including taus)

Resonances (2jets, 2x2 jets, 2x3 jets, eμ, eτ, mτ)

Note: Absence of Z and Importance of taus

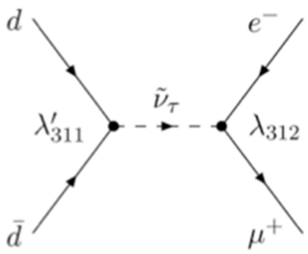
➔ Generally: lower background (no LFV nor BNV in SM) and MET than RPC

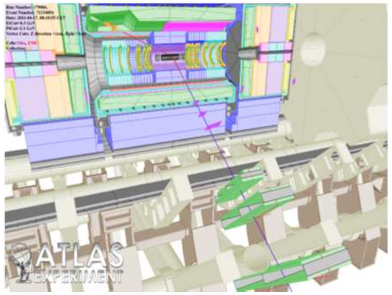
RPV (2)

1212.1272

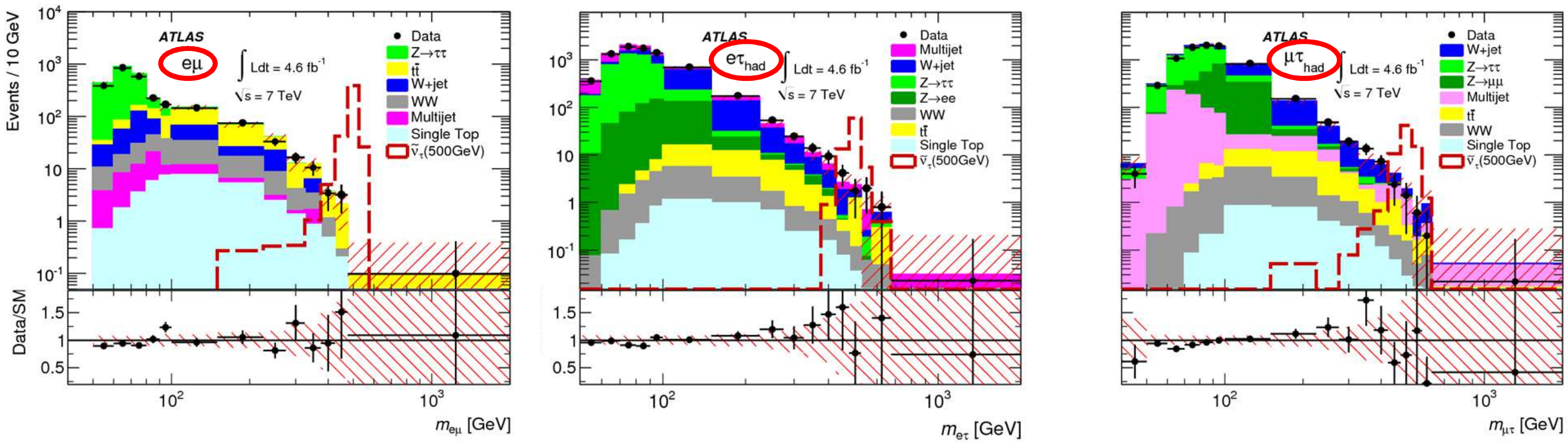
❑ Lepton flavor violation in the production / decay

- λ'_{311}, $\lambda_{i32} \neq 0$ and pp $\rightarrow \tilde{\nu}_\tau \rightarrow e\mu$, $e\tau$, $\mu\tau$ resonance $W = W_{MSSM} + \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \kappa_i L_i H_u + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$





$\Delta\phi$ (e, μ)~π , MET=132 GeV, no Jet !

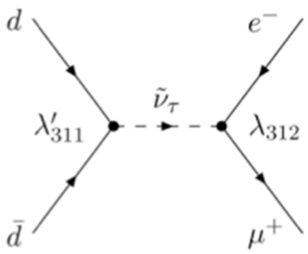


RPV (3)

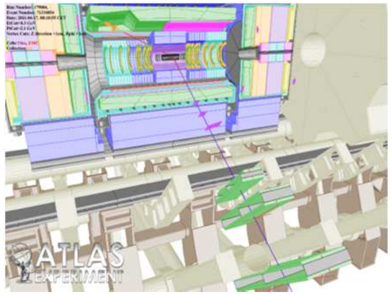
1212.1272

Limits on RPV couplings

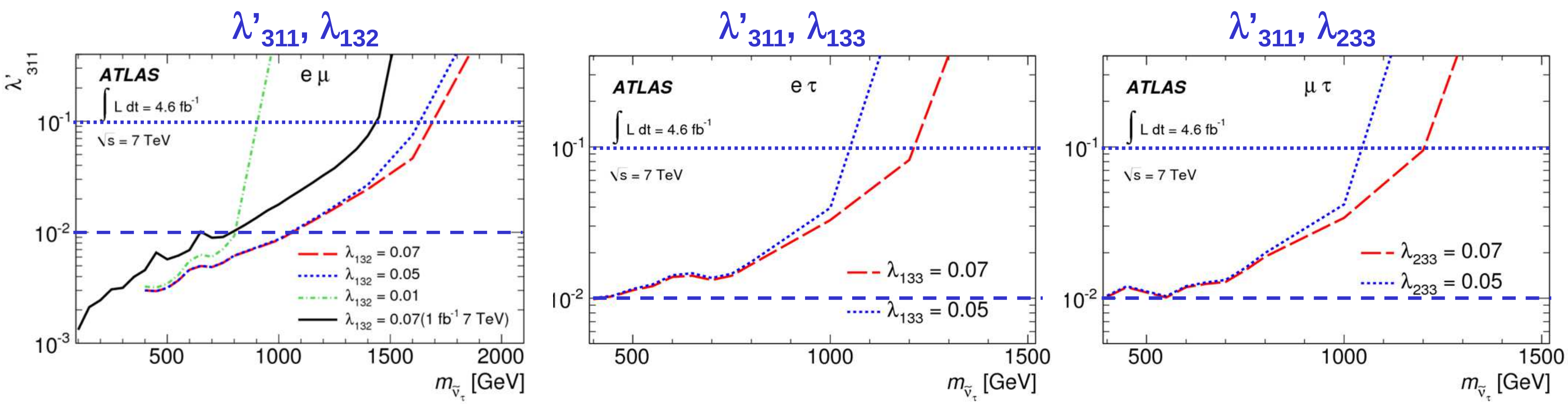
- λ'_{311}, $\lambda_{i32} \neq 0$ and pp $\rightarrow \tilde{\nu}_\tau \rightarrow e\mu$, $e\tau$, $\mu\tau$ resonance $W = W_{MSSM} + \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \kappa_i L_i H_u + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$



Only production mode



$\Delta\phi$ (e, μ)~π , MET=132 GeV, no Jet !



Can not go beyond 10^{-2} for λ'_{311}, λ_{132} for $m(\nu_\tau)$<1 TeV

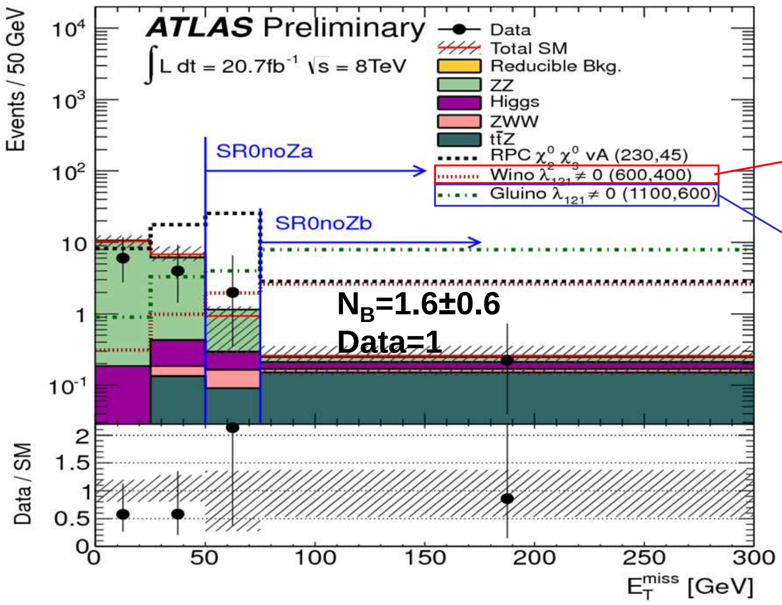
RPV (4)

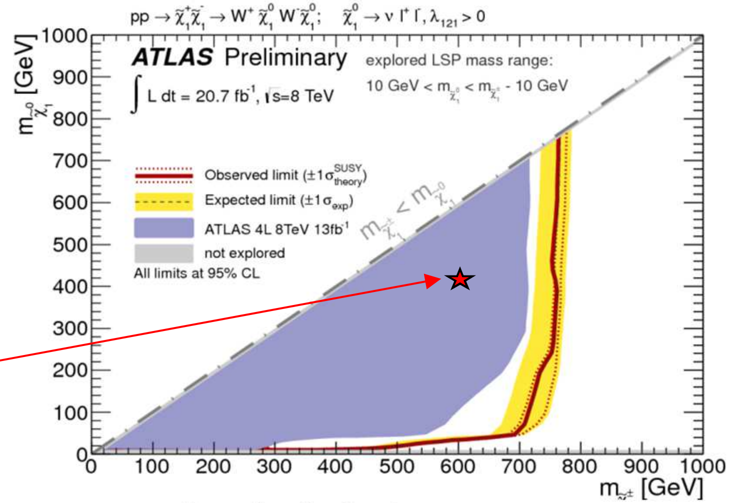
ATLAS-CONF-2013-036, CMS-PAS-SUS-13-010

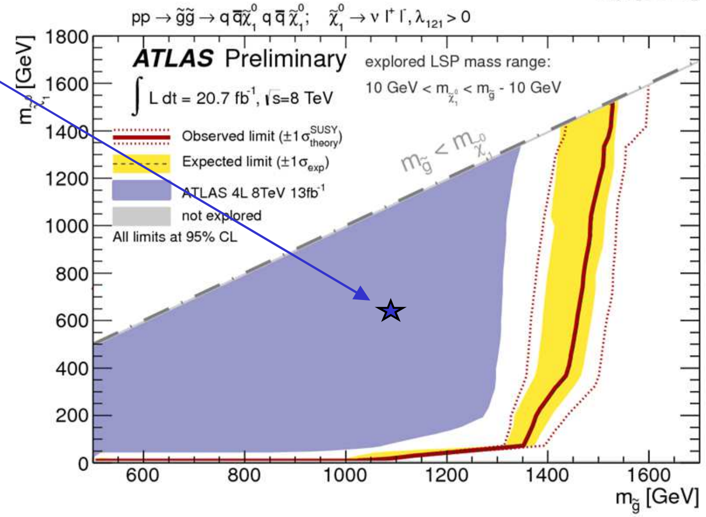
❑ Lepton Flavor Violation (no Z)

- χ_1^0 LSP, $\lambda_{121} \neq 0$ implies $\chi_1^0 \rightarrow e\mu\nu$
- pp $\rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow W\tilde{\chi}_1^0 W\tilde{\chi}_1^0 \rightarrow$ 4-5-6l (+ jets)+MET
  pp $\rightarrow \tilde{g}\tilde{g} \rightarrow qq'\tilde{\chi}_1^0 qq'\tilde{\chi}_1^0 \rightarrow$ =4l +jets +MET

$$W = W_{MSSM} + \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \kappa_i L_i H_u + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$







Very strong limits for direct chargino production (reminder: no limit in RPC)

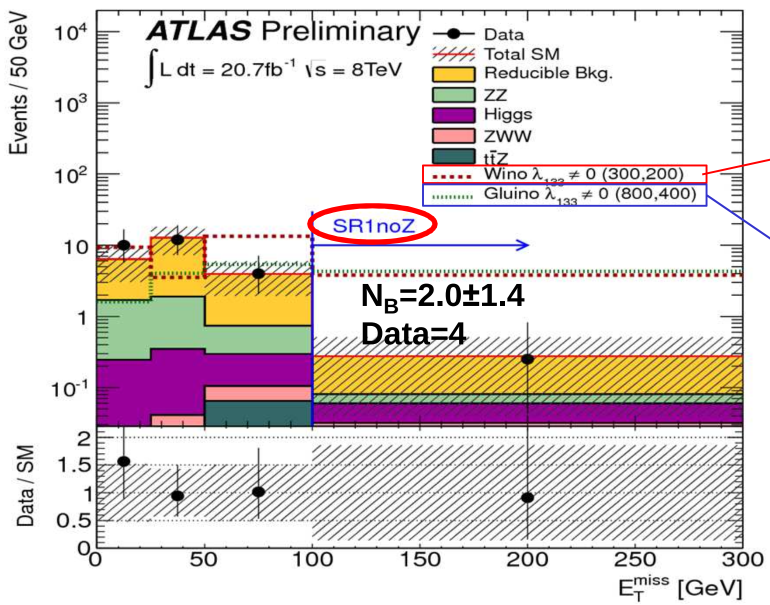
RPV (5)

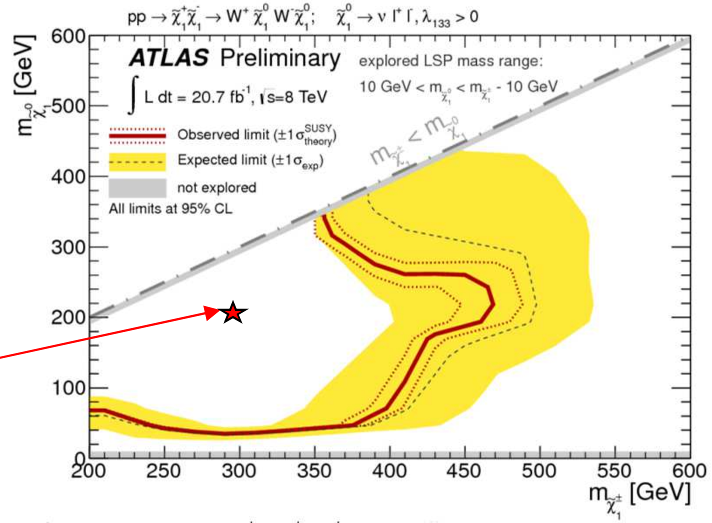
ATLAS-CONF-2013-036, CMS-PAS-SUS-13-010

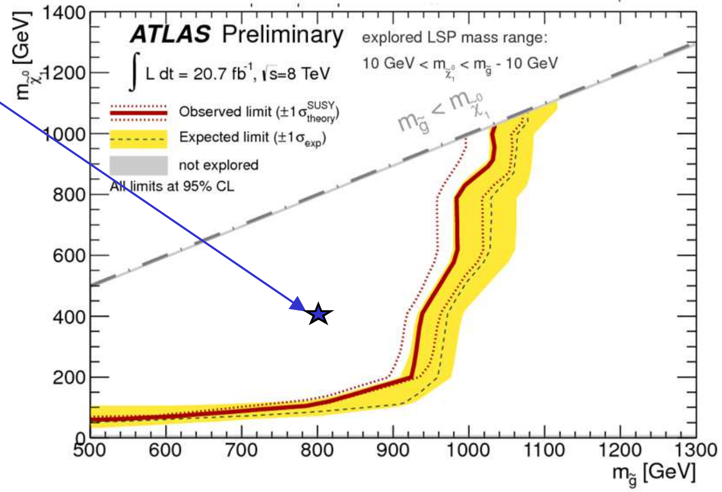
$$W = W_{MSSM} + \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \kappa_i L_i H_u + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

❑ Lepton Flavor Violation (no Z)

- χ_1^0 LSP, $\lambda_{133} \neq 0$ implies $\chi_1^0 \rightarrow \tau\tau\nu$ / $e\tau\nu$
- pp $\rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow W\tilde{\chi}_1^0 W\tilde{\chi}_1^0 \rightarrow$ 4-5-6l (+ jets)+MET
  pp $\rightarrow \tilde{g}\tilde{g} \rightarrow qq'\tilde{\chi}_1^0 qq'\tilde{\chi}_1^0 \rightarrow$ =4l +jets +MET







Limits weaken when considering taus.

RPV (6)

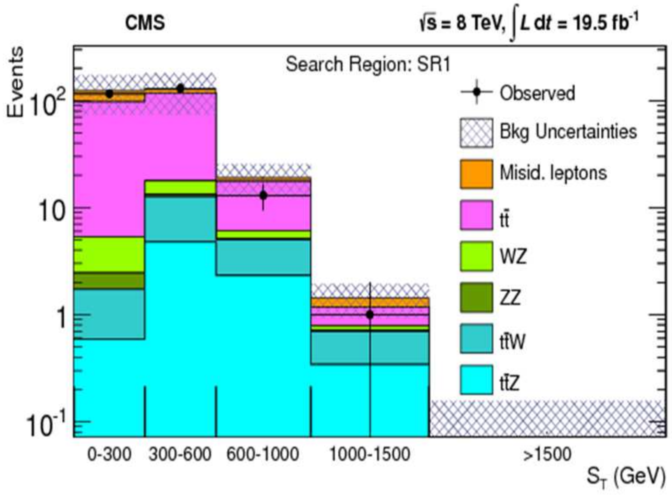
1306.6643

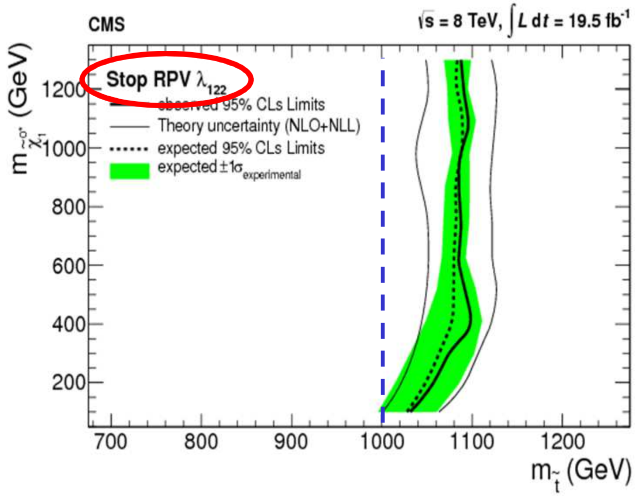
❑ Stop RPV (LFV)

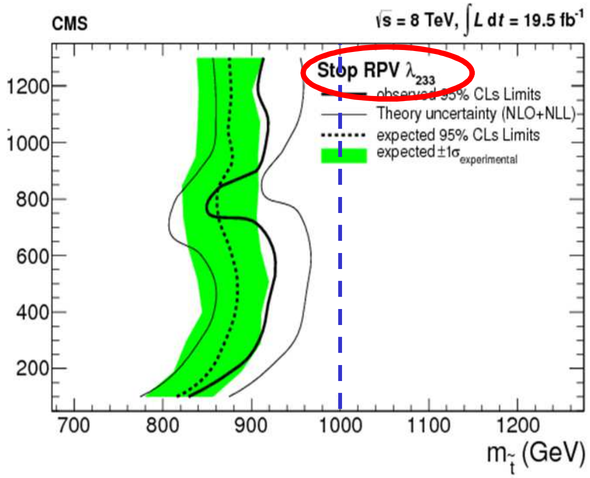
$$W = W_{MSSM} + \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \kappa_i L_i H_u + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

- χ_1^0 LSP, consider two possible combinations →
- pp → $\tilde{t}\tilde{t}$ → $t\chi_1^0 t\chi_1^0$ → >4l (+ jets)+MET
- Assume χ_1^0 bino-like

λ-term	neutralino LSP decay mode
$\lambda_{122} = -\lambda_{212}$	$\mu\mu\nu_e + \mu e\nu_\mu$
$\lambda_{233} = -\lambda_{323}$	$\tau\tau\nu_\mu + \tau\mu\nu_\tau$







Very strong limits for direct stop, w or wo taus (independent of LSP mass)

RPV (7)

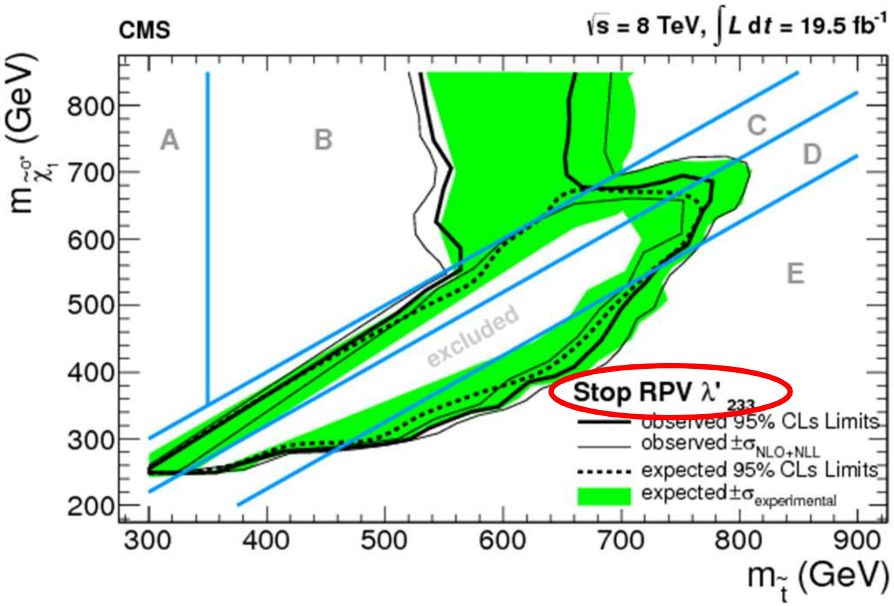
1306.6643

❑ Stop RPV (LFV)

$$W = W_{MSSM} + \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \kappa_i L_i H_u + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

- χ_1^0 LSP, consider several decay modes →
- Final states: $2\mu + 2t + 2b$
- Assume χ_1^0 bino-like

region label	kinematic region	stop decay mode(s)
A	$m_t < m_{\tilde{t}} < 2m_t, m_{\tilde{\chi}_1^0}$	$\tilde{t} \to t\nu b\bar{b}$
B	$2m_t < m_{\tilde{t}} < m_{\tilde{\chi}_1^0}$	$\tilde{t} \to t\mu t\bar{b} + t\nu b\bar{b}$
C	$m_{\tilde{\chi}_1^0} < m_{\tilde{t}} < m_W + m_{\tilde{\chi}_1^0}$	$\tilde{t} \to \ell\nu b\tilde{\chi}_1^0 + jjb\tilde{\chi}_1^0$
D	$m_W + m_{\tilde{\chi}_1^0} < m_{\tilde{t}} < m_t + m_{\tilde{\chi}_1^0}$	$\tilde{t} \to Wb\tilde{\chi}_1^0$
E	$m_t + m_{\tilde{\chi}_1^0} < m_{\tilde{t}}$	$\tilde{t} \to t\tilde{\chi}_1^0$



Weaker limits dependent of LSP mass

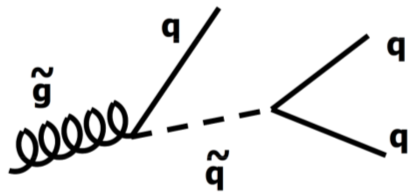
RPV (8)

ATLAS-CONF-2013-091, CMS-PAS-EXO-12-049

❑ 2x3 (2x5) jets resonance

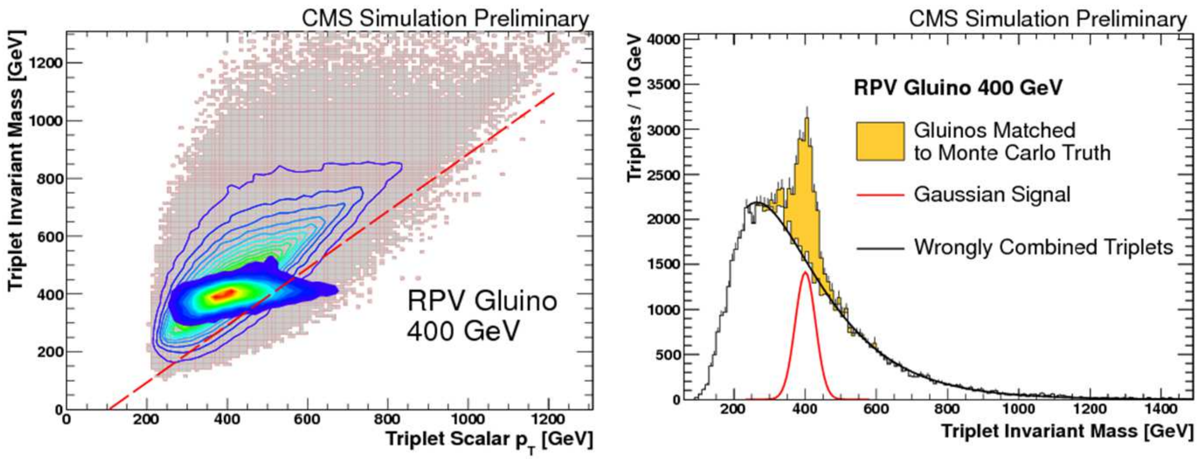
$$W = W_{MSSM} + \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \kappa_i L_i H_u + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

- Motivated by g→qqq and g→qqχ_1^0→qqqqq
- Multi-jets background data driven and differentiates 0, 1, 2 btag …
- 2 different strategies pursued by CMS and ATLAS

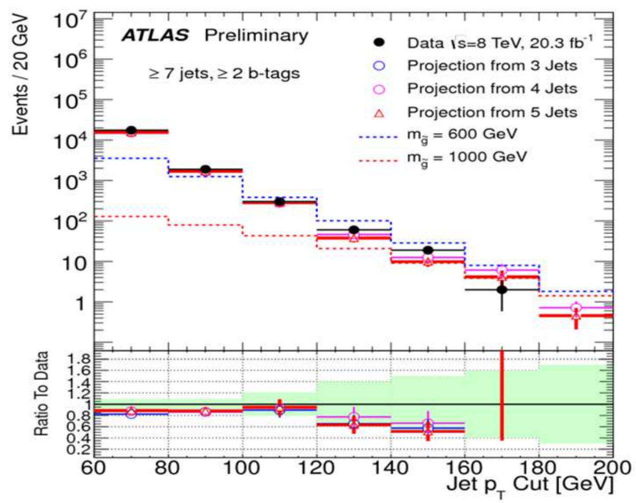


m(q̃)>>m(g̃)

Reconstruct 6jet invariant mass



Resolve 6-10jet evts with a lower p_T cut

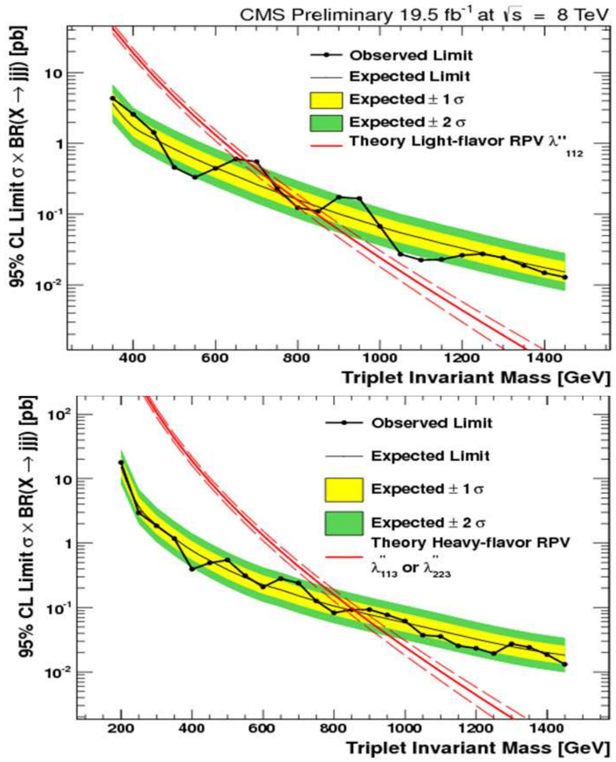


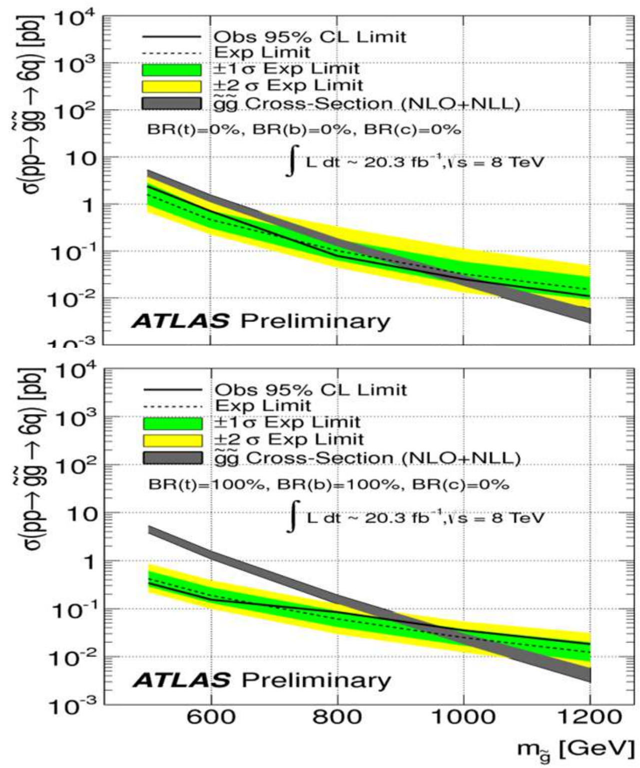
RPV (9)

ATLAS-CONF-2013-091, CMS-PAS-EXO-12-049

❑ Results for 2x3 jets resonance

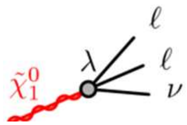
- Show for light flavor (top) and heavy flavor (bottom)

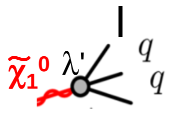


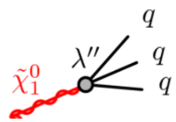


➔ Exclude Gluino masses < 1 TeV. ATLAS above CMS

Conclusion on RPV







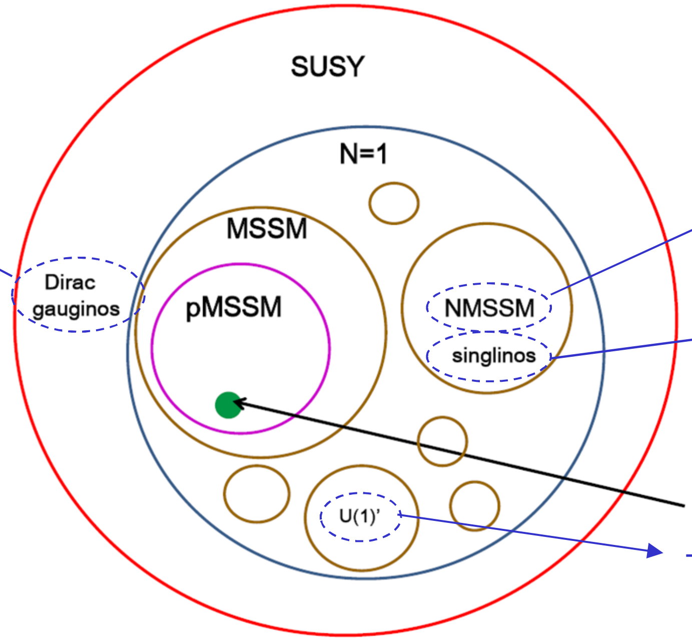
$$W = W_{MSSM} + \underbrace{\lambda_{ijk}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k}_{\text{Lepton Number Violation (LFV)}} + \kappa_i L_i H_u + \underbrace{\lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k}_{\text{Baryon Number Violation (BNV)}}$$

- Several combination of lambda tested
  - ✓ Still a large spectrum not covered (generally assume χ_1^0 LSP and decay)
- Like for Long-lived particles, generally stronger limits than for Standard SUSY (RPC)

Beyond MSSM

N=2/N=1 models [**0812.3586**] where for example gluinos are not Majorana particles. Similar if R is a continuous symmetry instead of discrete [RMSSM, **0712.2039, 0810.3919**].
➔lower σ, 2x2 jet resonance

SUSY Theory phase space



T. Rizzo (SLAC Summer Institute, 01-Aug-12)

A new scalar singlet is added [2 more Higgs and one more neutralino, **0910.1785**]
➔ Relax constraints from Higgs mass (i.e. reduce fine-tuning) and provide a solution to the μ problem

Stealth SUSY. Invisible singlet added.
➔ Relax MET cuts **[1105.513]**

Top-down. Mediation of SUSY breaking via U(1)'. [**0910.2480**]
➔ Generally predicts wino-like LSP

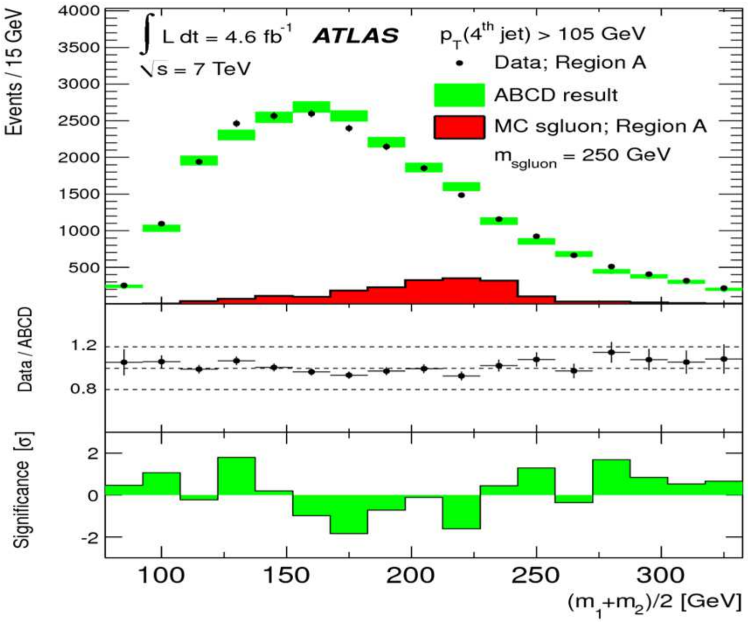
Loose simplicity, can generally evade part of the LHC limits – but not for long

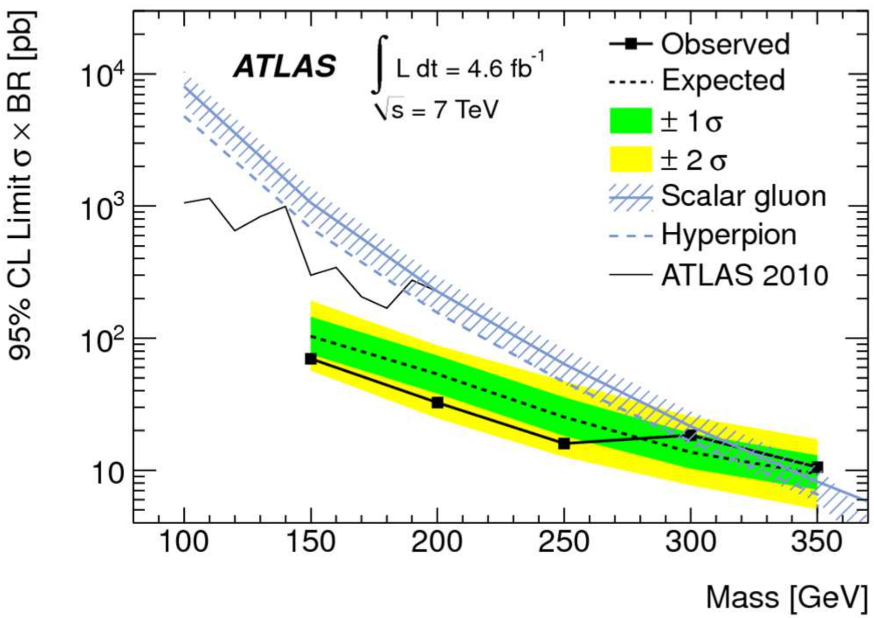
Beyond MSSM (1)

1210.4826

❑ Massive color scalars : 2x2 jets final state

- sgluon (→ gg) pair produced: 2 resonances M_1, M_2 reconstructed with ≥4 jets pT>80 GeV
- Reduce combinatorics by minimizing $|\Delta R_1 - 1| + |\Delta R_2 - 1|$





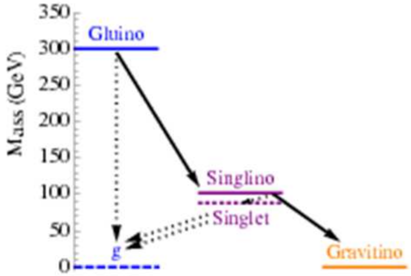
➔ Exclude scalar gluons for masses below 300 GeV

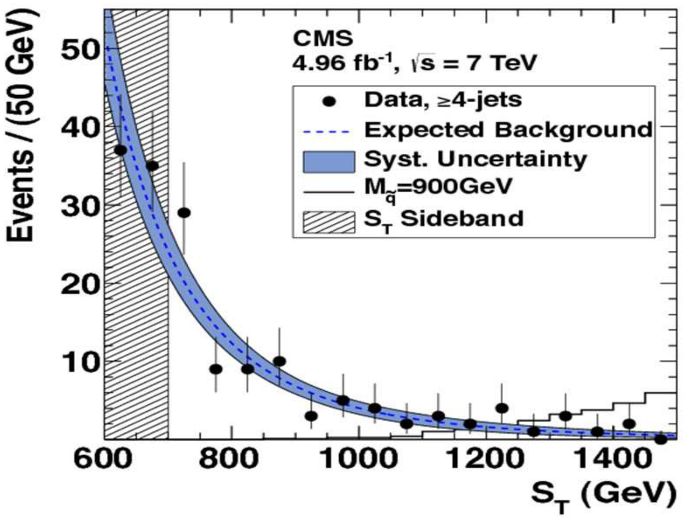
Beyond MSSM (2)

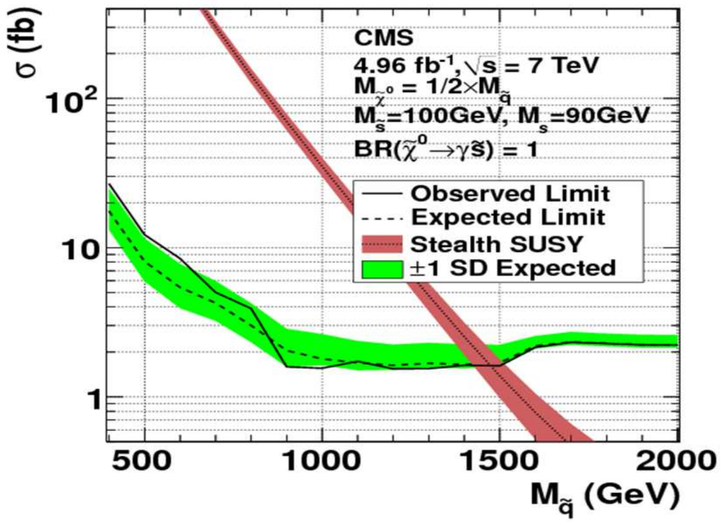
1210.2052

❑ Stealth SUSY

- There is an extra light, approximately supersymmetric multiplet
  - ✓ All sparticles connect to this R=-1 stealth particle ($\tilde{S}$)
  - ✓ Which then decay back to S its close-by superpartner
  - ✓ Reduce MET carried by gravitino but not MEff≈S_T
- CMS consider S decay via photon





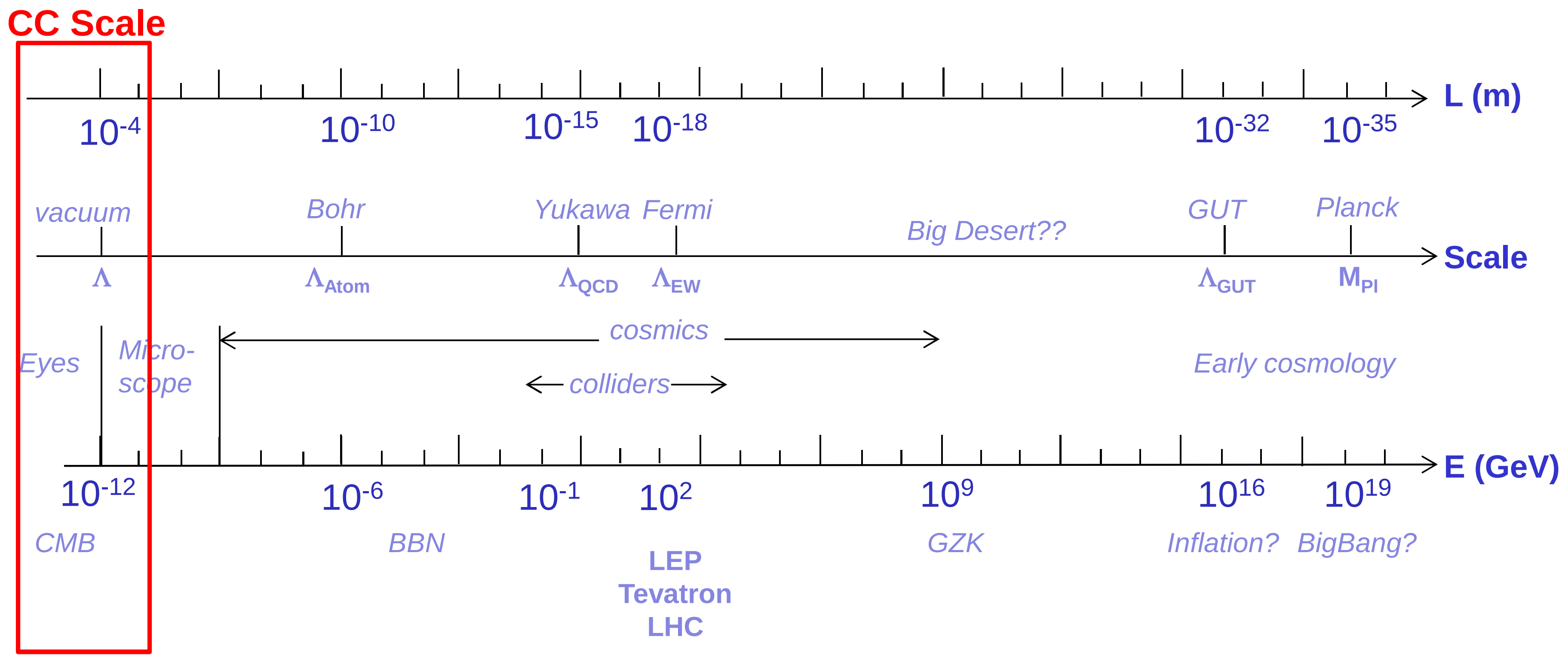


➔ New results expected for LHC run I soon

Or simply un-natural?

hep-th/0405159, hep-ph/0406088

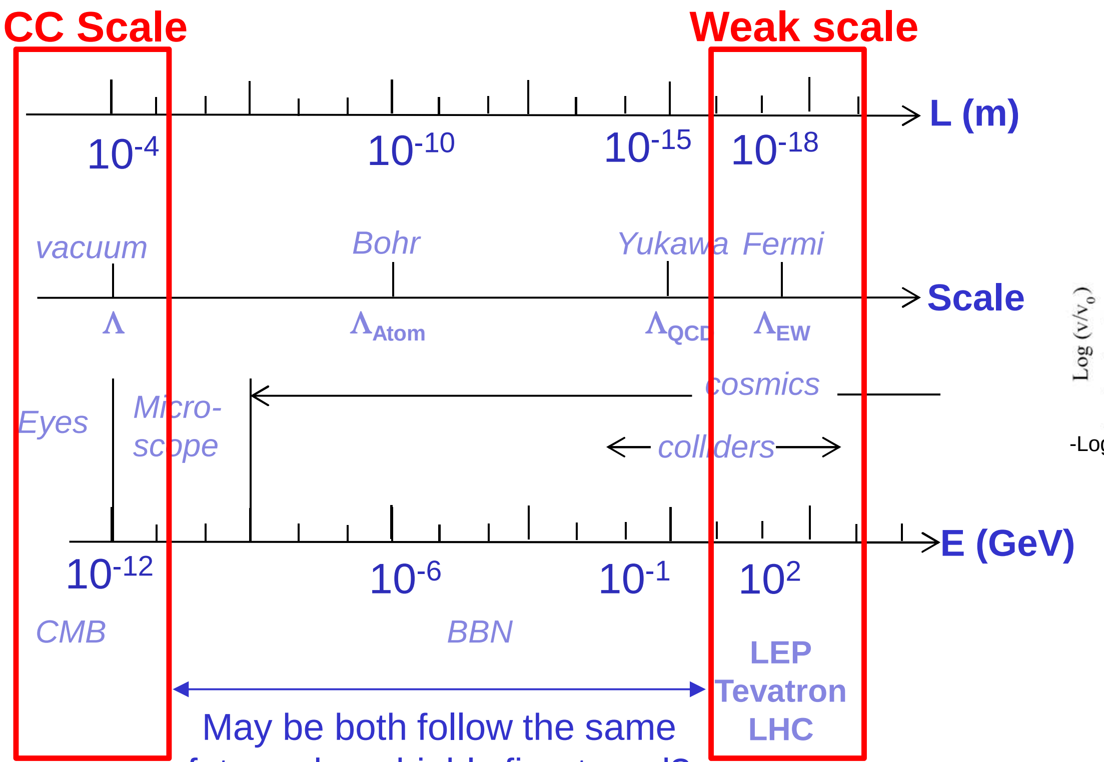
- A natural cosmo. constant (CC, Λ) implies new physics at 10^{-12} GeV
  - But present particle physics computations are valid at much higher energy
    - ✓ May be this threshold does not influence particle physics?



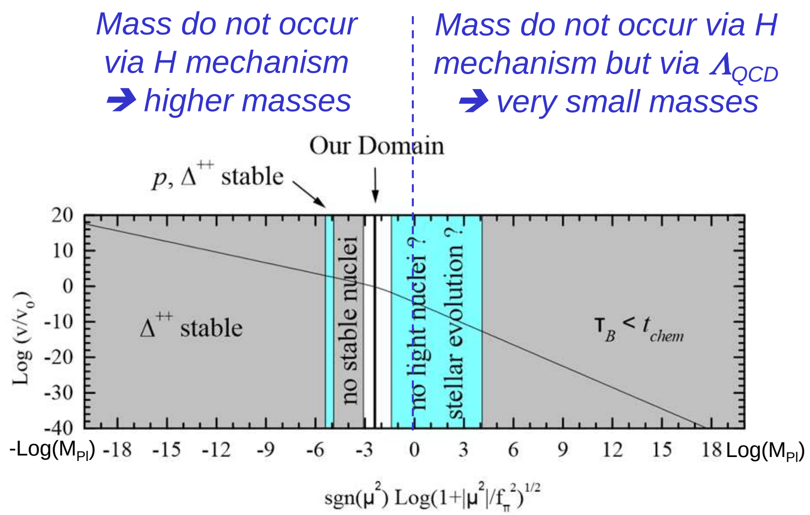
Or simply un-natural?

hep-ph/9801253

- **A natural cosmo. constant (CC, Λ) implies new physics at 10^{-12} GeV**
  - But present particle physics computations are valid at much higher energy
    - ✓ Alternately, very high fine-tuning !



May be both follow the same fate and are highly fine-tuned? (anthropic principle or multiverse space favoring critical points)



- Δ++=uuu
- p=uud
- $\mu^2=-m_H^2/2$
- f_π~0.1 GeV

- $\mu_0^2=-(89)^2$ GeV
- v_0=246 GeV
- $(m_u/m_d)_0$=0.6
- $(m_d)_0$=7 MeV*

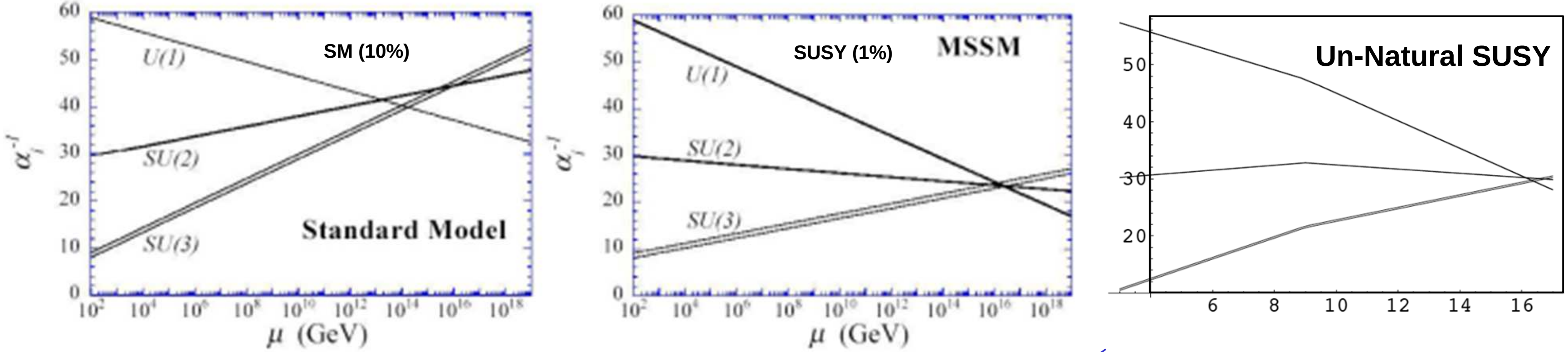
Life is driven by $m_d-m_u \propto v/v_0$

*$(m_e)_0$=0.5 MeV

Or simply un-natural?

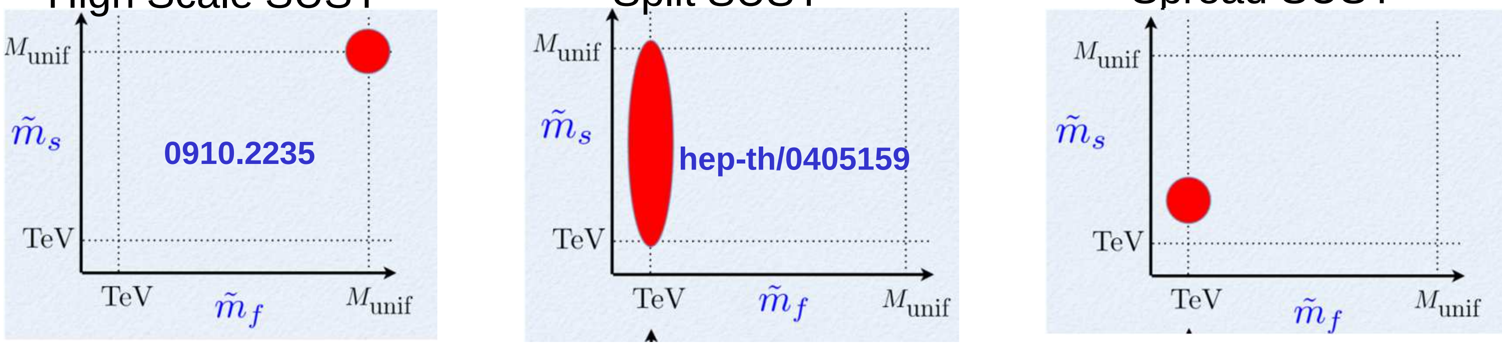
❑ Construct SUSY models forgetting hierarchy problem

- **Retains good SUSY features**: unification of forces at GUT scale and dark matter candidate



- **Remove unpleasant aspects**: m_H constraint, excessive C̸P, protection against proton decay
- Un-natural mass spectrum ➔ could still have a vestige at LHC (no guarantee)

High Scale SUSY | Split SUSY | Spread SUSY

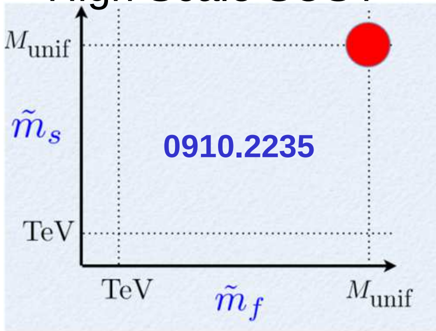


Axion Dark Matter | Gaugino/Higgsino Dark Matter (long-lived)

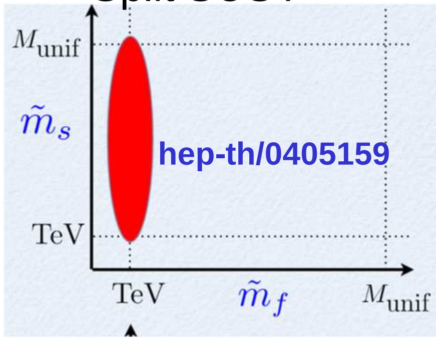
Or simply un-natural?

- **Construct models forgetting hierarchy problem**
  - Un-natural mass spectrum ➔ could still have a vestige at LHC (no guarantee)

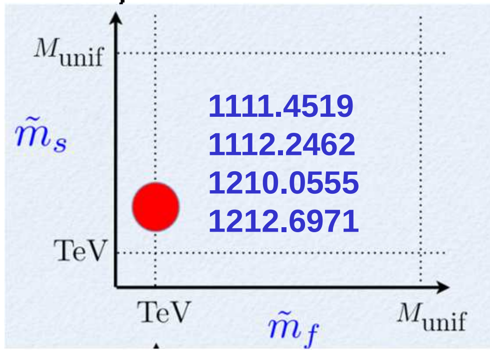
High Scale SUSY



Split SUSY

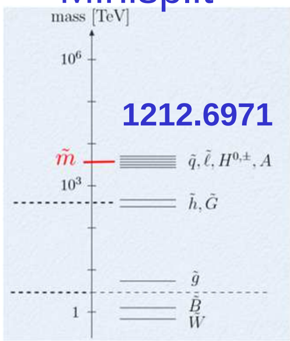


Spread SUSY

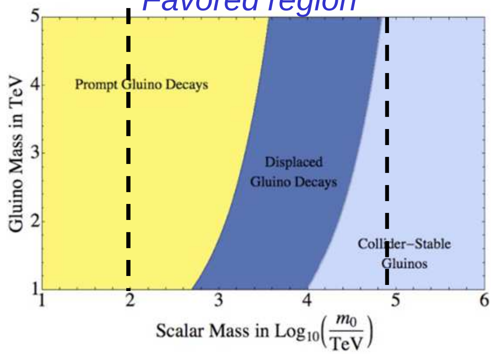


Axion Dark Matter
→ No sign at LHC

Minisplit



Favored region

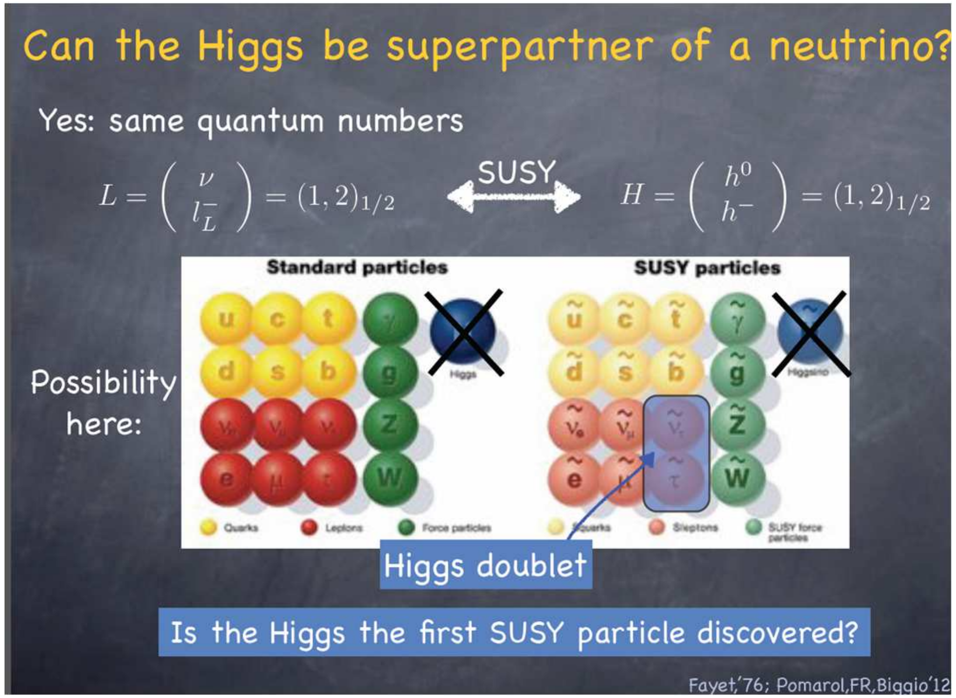


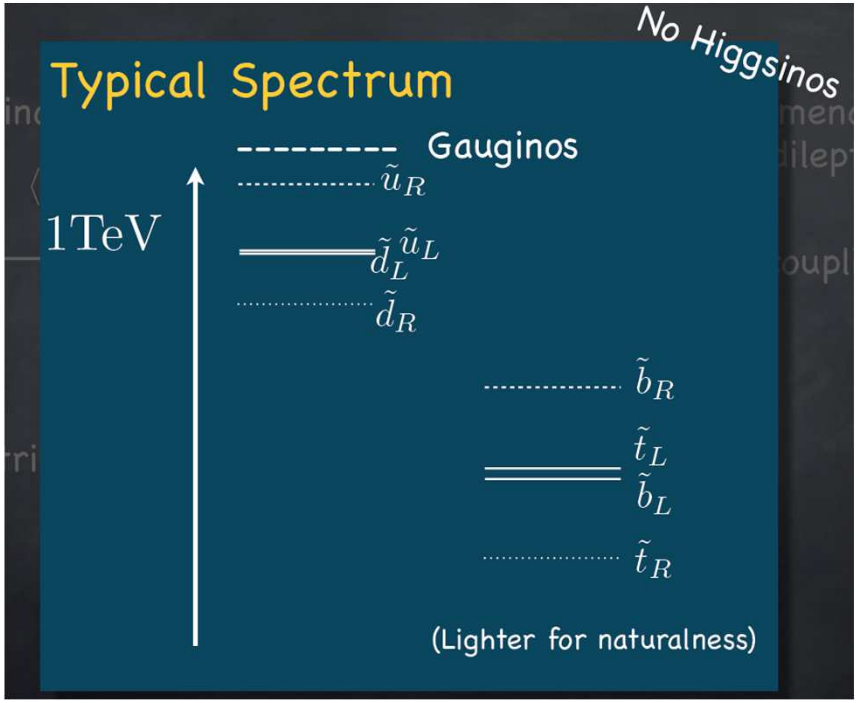
Gaugino/Higgsino Dark Matter
→ Displaced decays from gluino *(Rhadrons)* **See Before**, Wino *(disappearing tracks)* **See Before**, Higgsino *(sub-cm charged tracks)* **Not yet covered**

A final possibility !

1211.4526

- **In fact we may have already discover SUSY !!!**
  - The Higgs doublet is the superpartner of the neutrino
  - Not (yet) excluded !
  - Phenomelogical consequences: Gauginos Dirac-type, Lepton-Gaugino mixing, no LR mixing in the squark sector, no Ordinary R-parity (q̃→q̃+l), no LSP

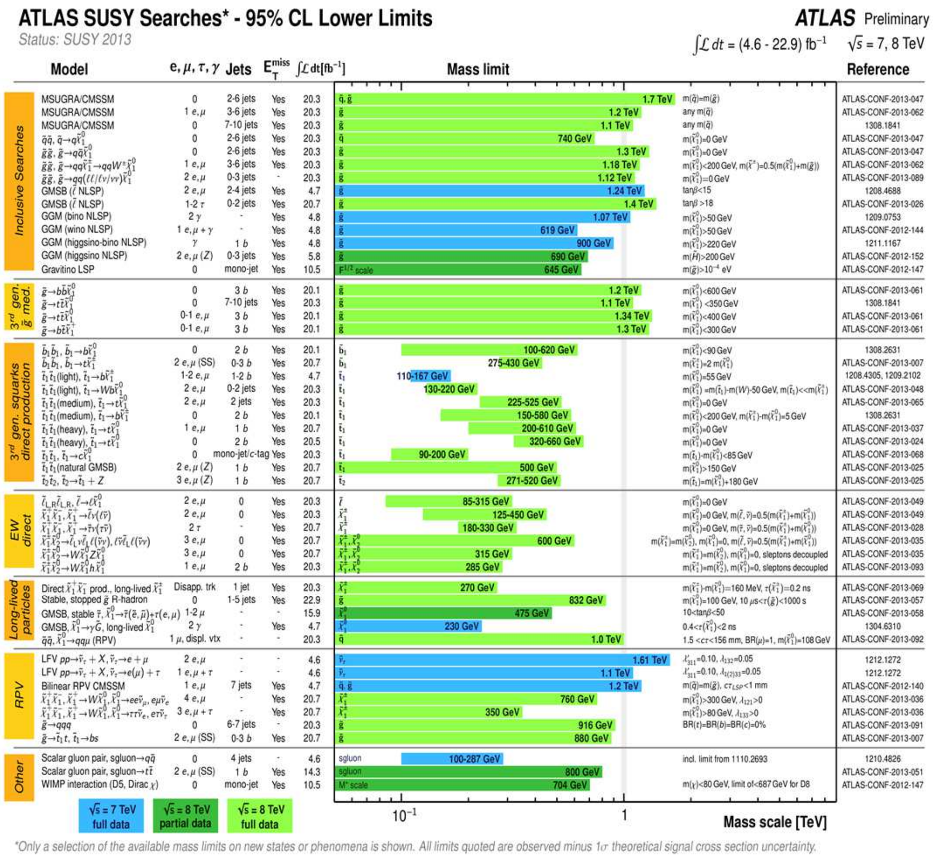


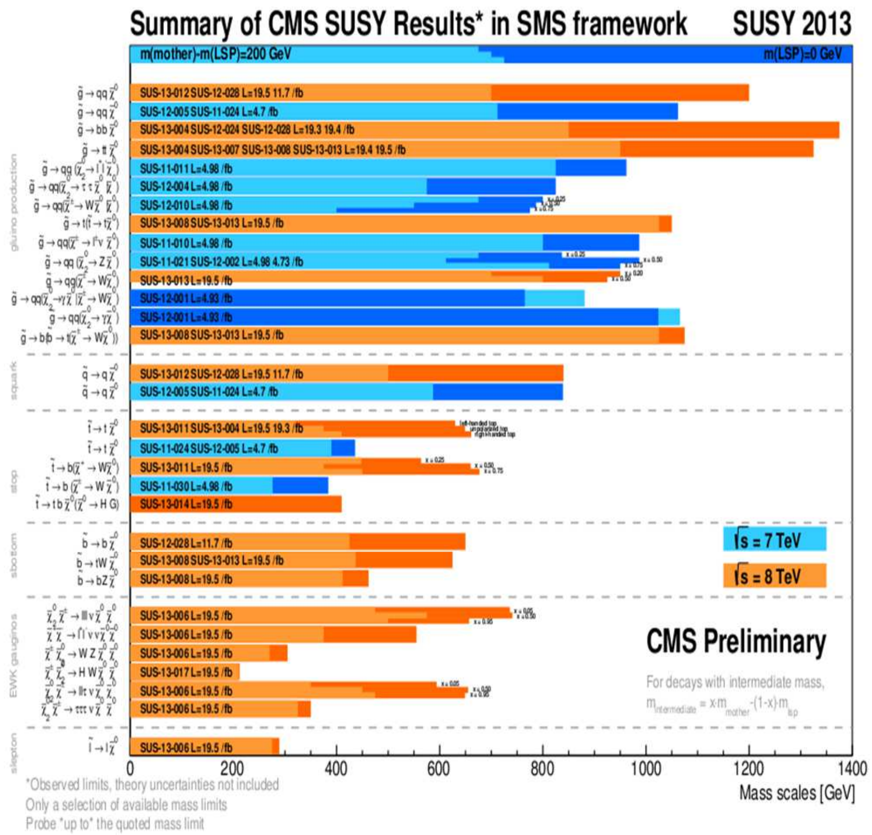


Conclusions (1)

❑ Summary on direct searches at LHC: an impressive list !

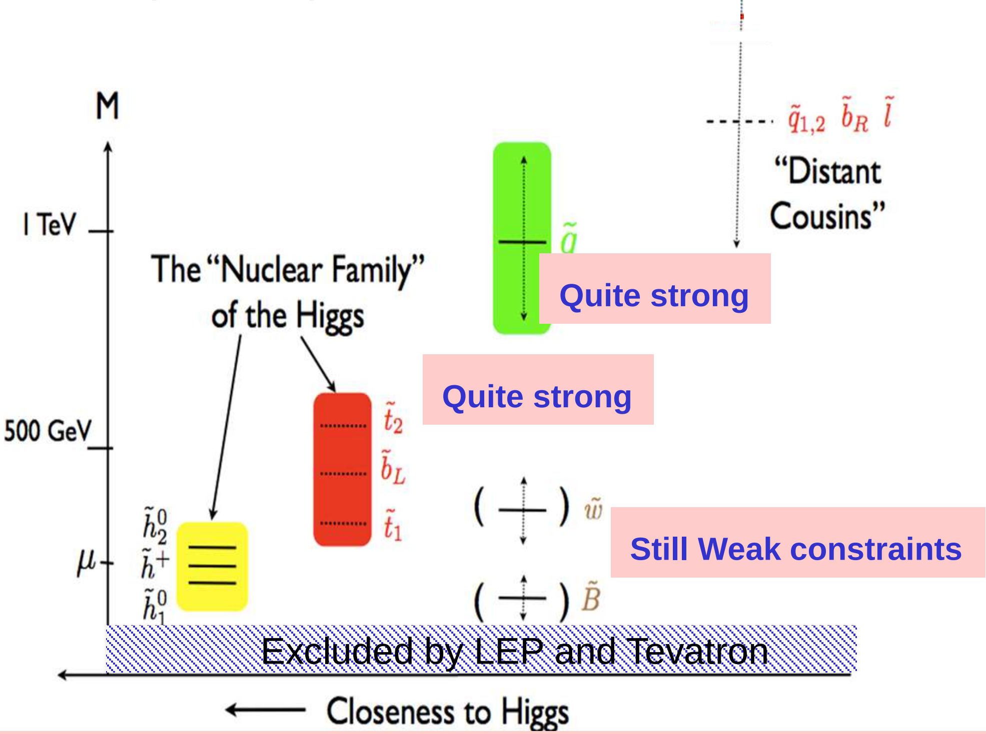
- Digest of 150 public analyses
- Getting close to the 1 TeV bound – and fine tuning ~ 0.1-1 %





Conclusions (2)

"Theories are like fishing : only he who casts can catch"
Novalis (1772-1801)



General weak points

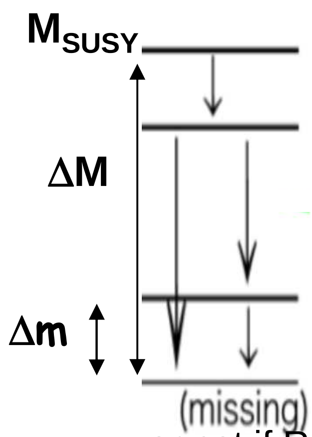
1- Compressed scenario → ISR/Monojet-like analysis, delayed trigger

2- Intricate SUSY decay chains → pMSSM systematic scan

3- A new electroweak singlet is added (relax Higgs constraints)
→not fully explored yet

4- Hard at low luminosity ($\chi_1^+\chi_1^- \rightarrow WW$), ...

Part IIc: R-Parity Violated, Long-Lived Particles, beyond MSSM



or not if RPV

1. Low Δm, tiny RPV, weak coupling to $\tilde{G}$
   Long Lived or meta-stable sparticles
2. 'Sizeable' RPV
   Multileptons, No Z, jet resonances, LFV
3. MSSM Extensions?
   Scalar Gluon
4. Un-natural SUSY ?

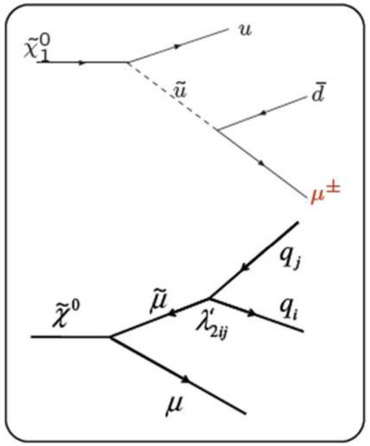
Still Many possibilities not covered

➔ SUSY Seriously cornered *(Consequences for SUSY models discussed tomorrow)*

SPARE

LSP decay

Neutralino-LSP decay



- $\tilde{\chi}_1^0$ could decay via non-zero **λ**, **λ'** couplings:

$$LL\bar{E}(\lambda):\ \ \tilde{\chi}_1^0 \to ll' + \nu$$

$$LQ\bar{D}(\lambda'):\ \ \tilde{\chi}_1^0 \to \begin{pmatrix} e,\mu,\tau \\ \nu \end{pmatrix} + 2\ \text{jets}$$

- The lifetime is proportional to $(\lambda)^{-2}$, $(\lambda')^{-2}$
  - Decay prompt for **λ**, **λ'** $\gtrsim 10^{-5}$.
  - If the RPV coupling is smaller than that (e.g. $\lesssim 10^{-7}$), *a decay vertex with a significant distance from its production point* can be seen.

- →Perform a search using a displaced vertex (DV) reconstruction technique.
  - The result presented today is based on 2010 data, non-zero λ' with muon final states.
  - More to come using 2011 full dataset covering variety of signatures:
    - Final states including e/tau