Proposal :

BSM searches with flying neutralinos decaying into electron-muon

Jean-Laurent AGRAM, Eric CONTE, Benjamin FUKS,
Arnaud GAY, Christophe GOETZMANN, Ulrich GOERLACH

Long Lived Exotica WG
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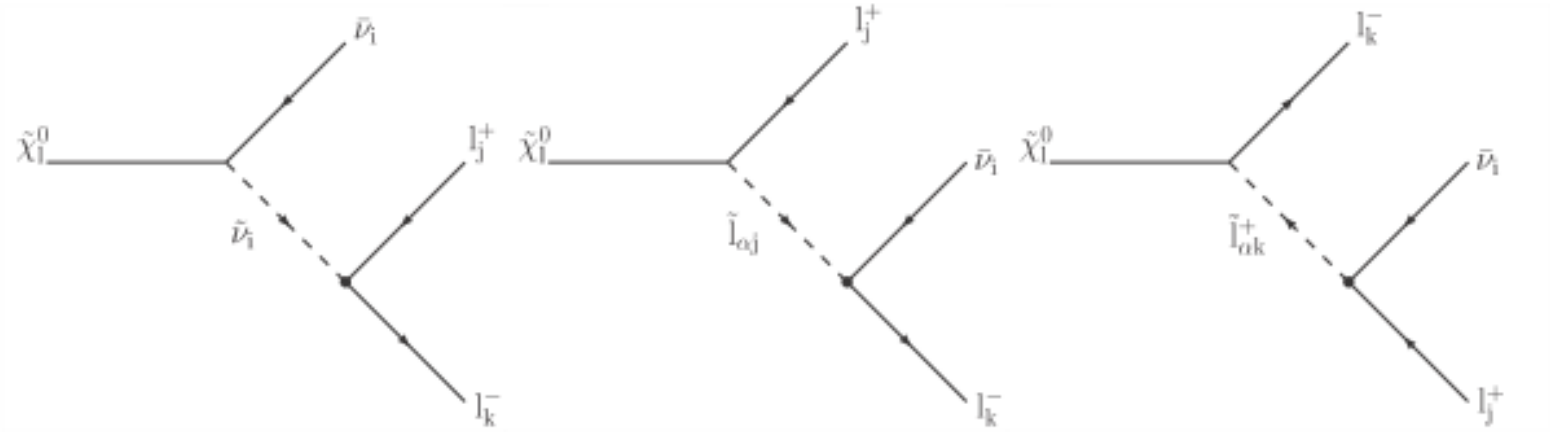
Leptonic neutralino decay

- Theoretical context : **MSSM including R-parity violation**
- R-parity violation : only λ_{ijk} trilinear couplings are considered (L violation)
- By these couplings, the LSP (neutralino 1) can decay into leptons :



- The decay products depend on the λ coupling type. Possible decay products :

$e^{\pm}e^{\mp}\nu$, $\mu^{\pm}\mu^{\mp}\nu$, $\tau^{\pm}\tau^{\mp}\nu$, $e^{\pm}\mu^{\mp}\nu$, $e^{\pm}\tau^{\mp}\nu$, $\mu^{\pm}\tau^{\mp}\nu$

Studied by
Emyr Clement and Ian Tomalin

Targeted signature

Leptonic neutralino decay

λ couplings type allowing eμ decay product :

	$\lambda_{121} = -\lambda_{211}$	$\lambda_{122} = -\lambda_{212}$	$\lambda_{132} = -\lambda_{312}$	$\lambda_{231} = -\lambda_{321}$
$\tilde{\chi}_1^0$	$e^{\pm}\mu^{\mp}\nu$	$e^{\pm}\mu^{\mp}\nu$	$e^{\pm}\mu^{\mp}\nu$	$e^{\pm}\mu^{\mp}\nu$
	$e^{\pm}e^{\mp}\nu$	$\mu^{\pm}\mu^{\mp}\nu$	$e^{\pm}\tau^{\mp}\nu$	$\mu^{\pm}\tau^{\mp}\nu$

Better sensitivity is expected with Emyr Clement & Ian Tomalin analysis

eμ analysis is relevant

Neutralino branching ratio does not depend on λ value, but essentially masses and decays.

Long-lived neutralinos

We assume one λ coupling is dominant wrt the other ones.

- Assuming R-parity conserved production, the cross-section is independent from λ.
- Neutralino branching ratios are independent from λ.

→ Only neutralino width, and therefore its decay length, depend on λ.

Searching for long-lived neutralinos could allow to probe low values of λ.

Current (indirect) limits on these couplings : 0.03 – 0.05

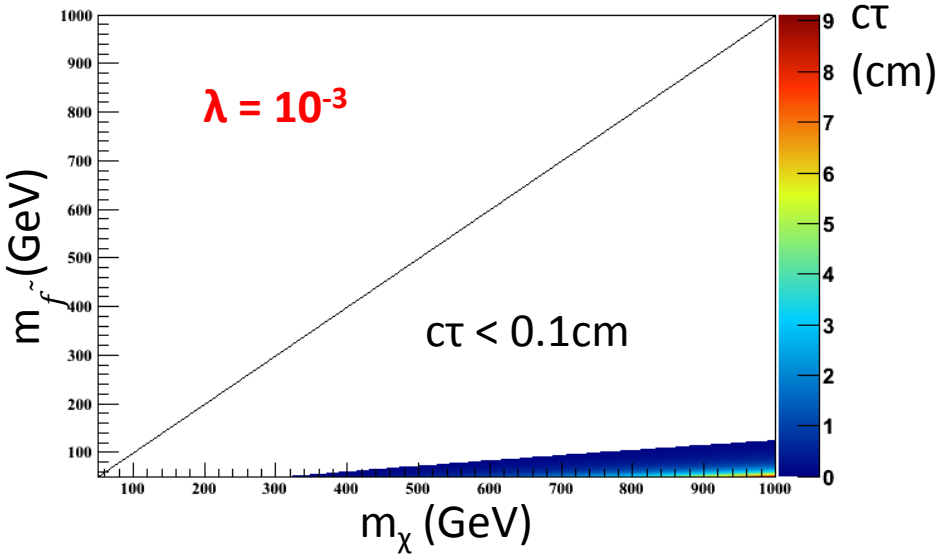
Y. Kao, T. Takeuchi, *Single-Coupling Bounds on R-parity violating Supersymmetry: an update*, 2009, arXiv:0910.4980

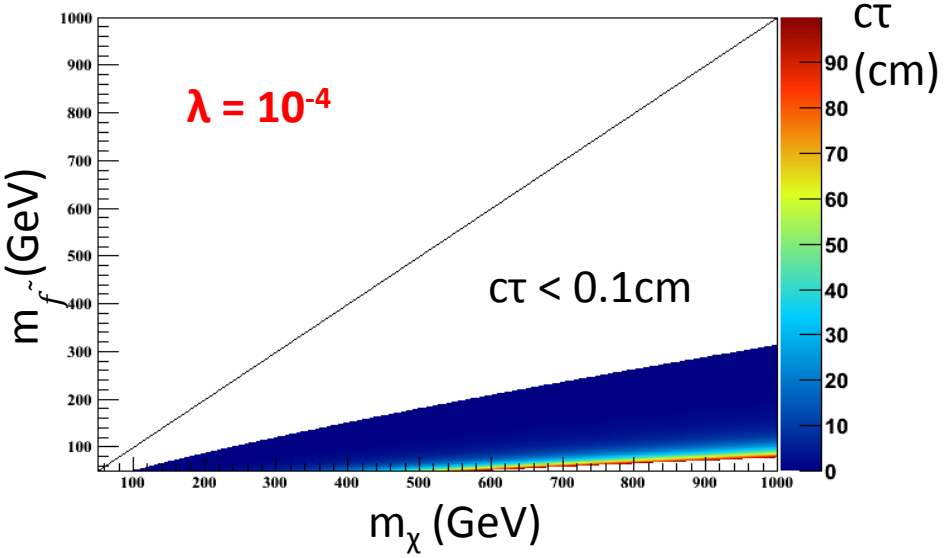
Formula for computing the decay length (narrow width approximation) :

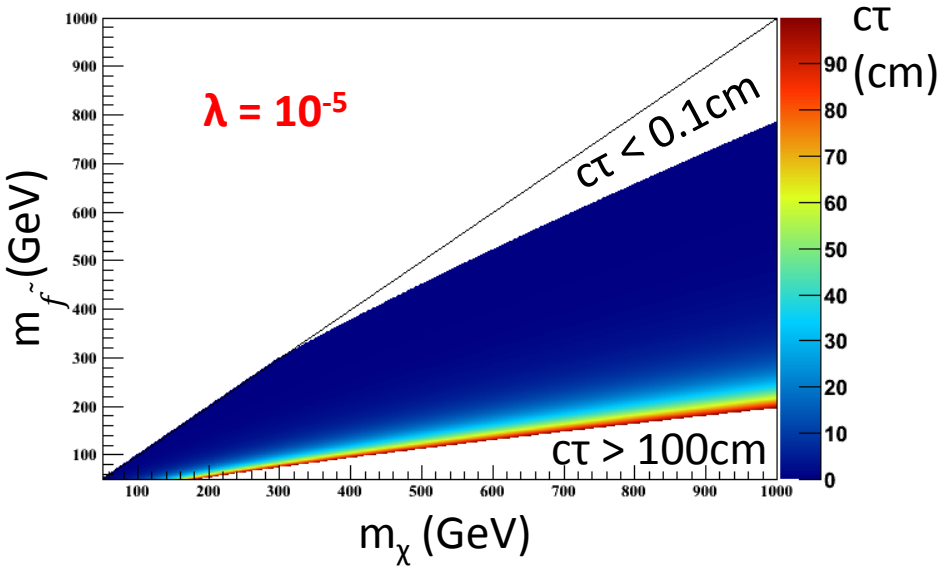
$$c\tau[cm] = \frac{0.3}{|\lambda_{ijk}|^2} \cdot \left(\frac{m_{\tilde{f}}}{100\ [GeV]}\right)^4 \cdot \left(\frac{1[GeV]}{m_{\tilde{\chi}_1}}\right)^5$$

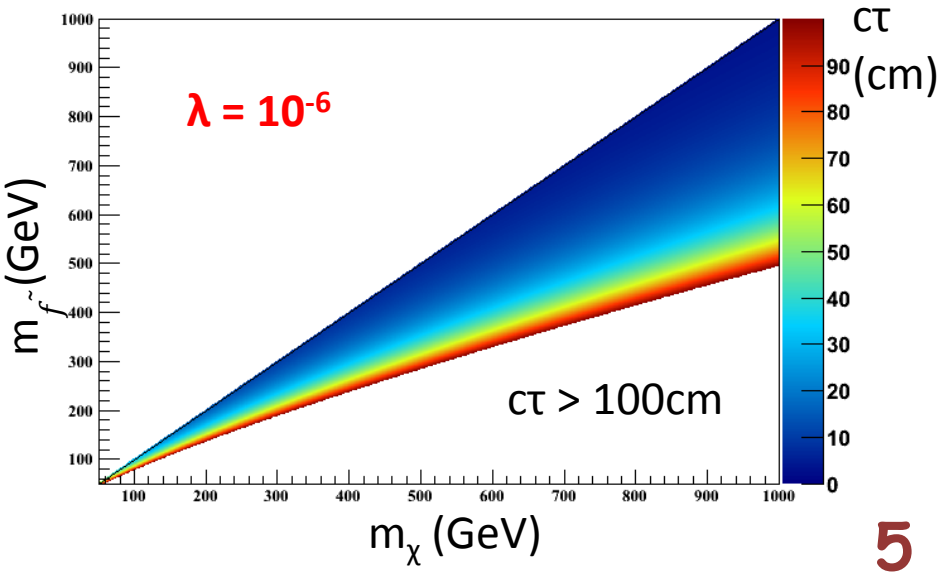
R. Barbier et al, R-parity violating supersymmetry, 2005, arXiv:hep-ph/0406039v2

Long-lived neutralinos









Neutralino production @ LHC

Production of neutralinos @ LHC :

Neutralinos produced in cascade decays

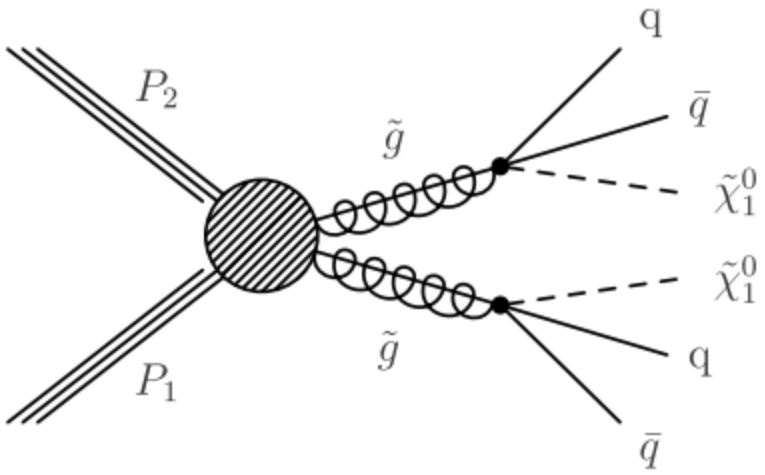
hadronic environment

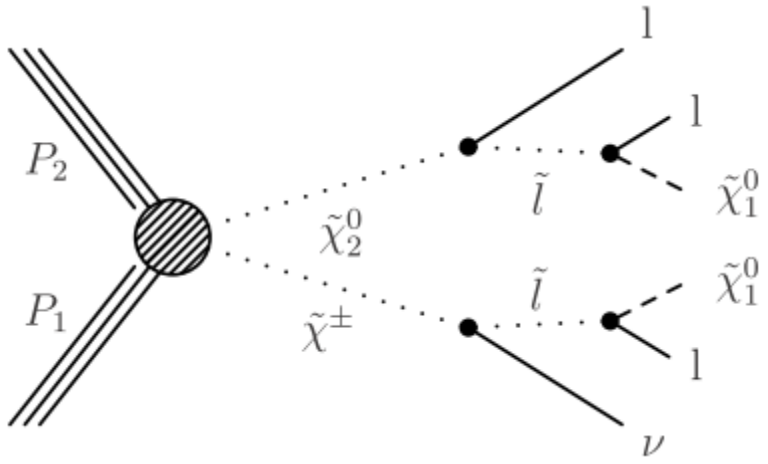
$$p\,p \rightarrow \tilde{g}\,\tilde{g}$$
$$p\,p \rightarrow \tilde{q}\,\tilde{q}$$
$$p\,p \rightarrow \tilde{q}\,\bar{\tilde{q}}$$
$$p\,p \rightarrow \tilde{q}\,\tilde{g}$$

$$p\,p \rightarrow \tilde{\chi}_i^0\,\tilde{\chi}_j^0$$
$$p\,p \rightarrow \tilde{\chi}_i^0\,\tilde{\chi}_j^{\pm}$$
$$p\,p \rightarrow \tilde{\chi}_i^{\pm}\,\tilde{\chi}_j^{\pm}$$
$$p\,p \rightarrow \tilde{\chi}_i^{\pm}\,\tilde{\chi}_j^{\mp}$$

Neutralinos produced directly (or almost)

leptonic environment





Examples extracted from PAS SUS-11-016

Neutralino production @ LHC

Production of neutralinos @ LHC :

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Neutralinos produced directly (or almost)

leptonic environment

R-parity violated contributions in the production are small and can be neglected.
→ At least 2 neutralinos are expected.

We will require that one of the neutralino decays in electron-muon by one of the couplings : **121, 122, 132, 231**. Possible final states :

$e\mu ee$ $e\mu\mu\mu$ $e\mu e\tau$ $e\mu\mu\tau$ $e\mu e\mu$

Analysis strategy

Collaboration work with people of the *displaced fermions* group, especially Emyr Clement and Ian Tomalin already involved in a neutralino decay analysis.

Search strategy :

- Events containing 2 neutralinos with **one decaying in e + μ** ; the **other one in e/μ + X**

→ **Inclusive search** : asking for one displaced vertex eμ (decay length > about 1cm)

Trigger strategy :

Event final states containing **2 non-pointing electrons** or/and **2 non-pointing muons** :

- Possibility to use one trigger path created for H→XX with X a long-lived invisible particle (CMS AN 11-486 & AN 11-112) :
  - Double electron case : **HLT_DoublePhoton43_HEVT** (H/E < 5%)
  - Double muon case : **HLT_L2DoubleMu23_NoVertex_2Cha_Angle2p5**

- Possibility to use triggers devoted to Higgs analyses for the double electron case :
  HLT_PhotonX_Cuts1_PhotonY_Cuts2 with low threshold on E_T

Analysis strategy

Reconstruction of displaced vertices eμ :

- Using the common framework developed by the *displaced fermions* group.
- Extending the existing tools to the reconstruction of eμ-vertices.
- We hope this new tool could be implemented in the existing framework and can be used for future analyses.

Christophe is already learning to use it.

Small changes in the lepton identification :

Problem with standard reconstruction :	CMS electron reconstruction procedure is not applied for identifying non-pointing electrons (tracks coming from the last step of the iterative tracking algorithm are not used).
Current solution :	Electron are identified by ΔR-matching the general tracks with online electron. This technique cannot be used for events only selected by a double muon trigger path.
Future solution :	Electron could be identified by ΔR-matching the general tracks with offline electron object (cluster).

Analysis strategy

Theoretical model and Monte Carlo sample production :

- Some Monte Carlo samples have been already produced with Pythia by Emyr.

→ Using them for a preliminary study.

- The Strasbourg team has an expertise in model building, Monte Carlo production with FeynRules + MadGraph + Pythia and other phenomenological tools such as MadAnalysis.

→ We plan to generate and share our Monte Carlo samples.

SUSY model :

- In a first step, **cMSSM model + R-parity violation** will be considered.
  6 new parameters wrt SM : m_0, $m_{1/2}$, A_0, tanβ, sign(μ) and λ

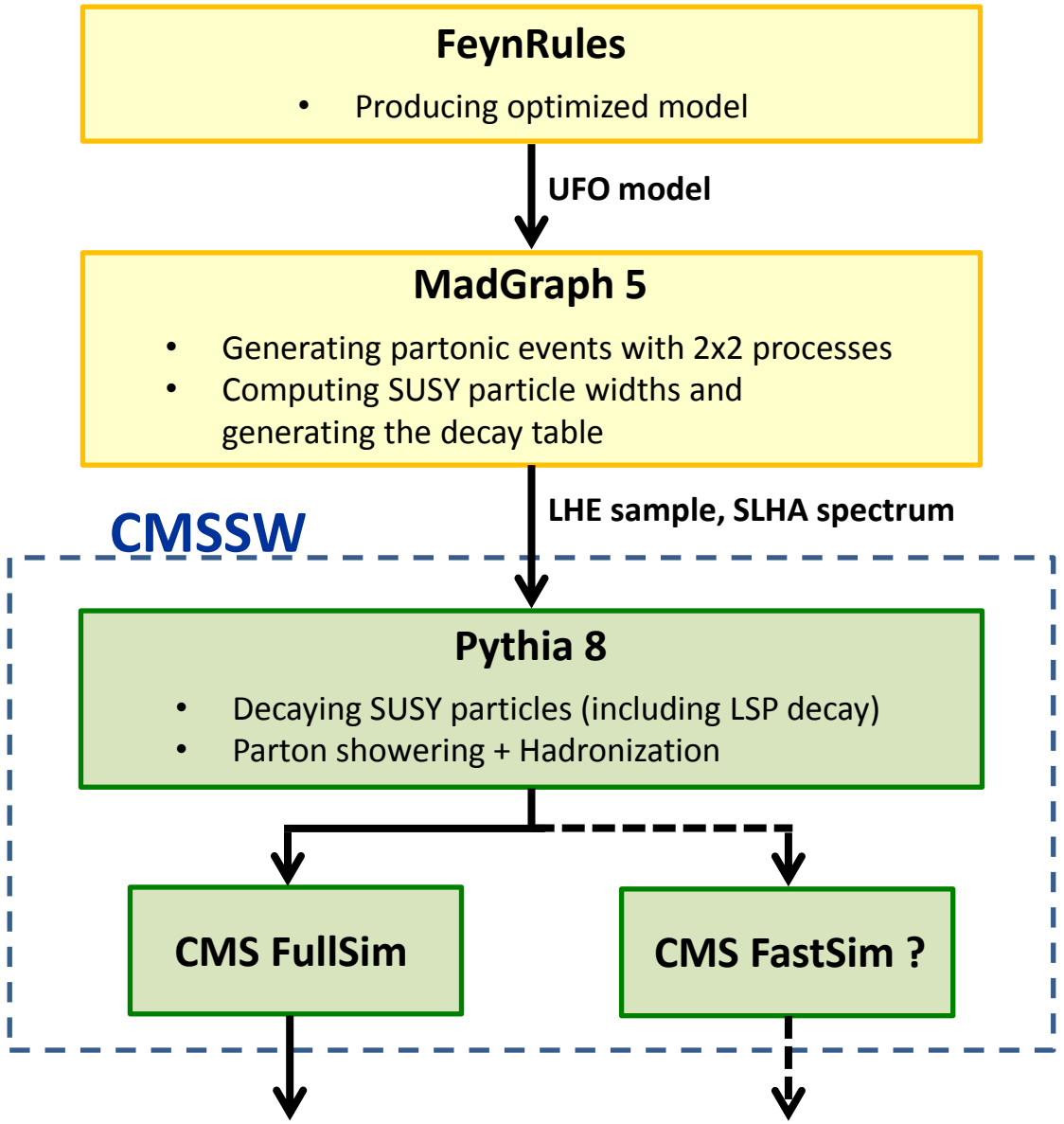
- In a second step, **pMSSM model + R-parity violation** could be studied (20 parameters)
  Additional hypothesis will be necessary to reduce the number of parameters.
  For instance: a scenario where strong superpartners will be decoupled

Analysis strategy

Monte Carlo production scheme :

Compromise between :

- Realistic and coherent generation
- Consumption of CPU resources



Available skills and manpower

Useful team skills:

CMS

- Strasbourg team has an expertise in **dileptonic** decay of top quark analysis.
- **Tracker** knowledge : hardware, track reconstruction, alignment and upgrade.
- Experience with **displaced vertices** (Arnaud GAY) .
- **Computing** skills

Pheno menology

- **Collaboration between experimentalists and theorists.**
- Model building (**FeynRules)** in particular SUSY models and effective models.
- Monte Carlo sample production (**MadGraph+Pythia**) and phenomenological investigations (**MadAnalysis**).

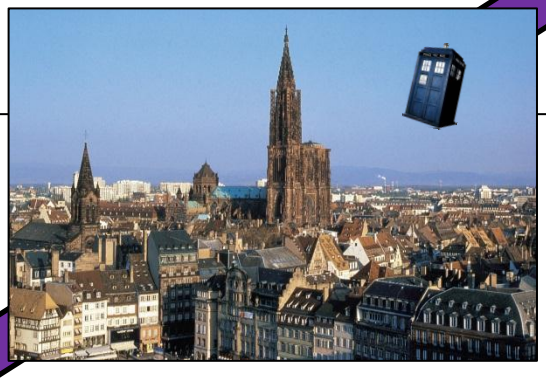
Manpower :

Christophe GOETZMANN	**PhD student**	**100%**
Arnaud GAY	**Post-doc**	**10% now, more in the coming months**
Ulrich GOERLACH	**Professor**	**10% now, more in the coming months**
Jean-Laurent AGRAM	**Junior professor**	**15% from January**
Eric CONTE	**Junior professor**	**25%**
Benjamin FUKS	**Junior professor**	**Help for MC production and results interpretation**

Summary

Possible extensions:

- Designing a trigger devoted to displaced eμ vertices for 2014/2015 data
- Leptonic neutralino decays involving taus by one λ coupling
- Hadronic-leptonic decays ($qq\mu$) by one λ' coupling



Help needed for 2012 analyses!

Possible channels (where X is long-lived):

1) Higgs -> 2X -> 2(l+l-) in Tracker (like 2011)
2) Higgs -> 2X -> 2(l+l-) with stand-alone muons
3) Higgs --> 2X --> 2(e+e-) with ECAL timing
4) 2 * Long-lived neutralino --> l l nu.
5) 2 * Long-lived neutralino --> q q mu (i.e., what ATLAS searched for)
6) Higgs -> 2X -> (bb)(mumu), where one b decays to mu.
7) Higgs -> 2X -> 2(bb), where two b decay to mu.
8) Higgs -> 2X -> 2(qq) with tracking
9) Higgs -> 2X -> 2(qq) with ECAL timing
10) Higgs -> 2X -> 2(tau tau)
11) long-lived b' (4th generation) -> t W -> b l l nu nu
12) 2 * long-lived gluino --> 2 * (q qbar neutralino)

[Emyr Clement and Ian Tomalin]