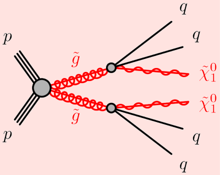
Searches for electroweak production of supersymmetry, supersymmetry in resonance production, R-parity violating signatures and events with long-lived particles with the ATLAS detector

Max Goblirsch, on behalf of the ATLAS Collaboration

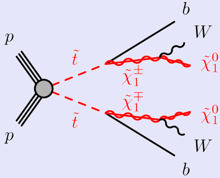
PANIC14, Hamburg, 27.08.2014

4 main search directions

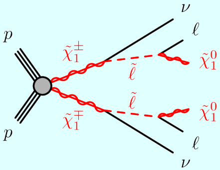
Inclusive **Strong production** of squarks and gluinos



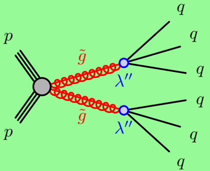
Direct production of **third generation** squarks



Electroweak production of sparticles



R-Parity violation and **Long-lived** signatures

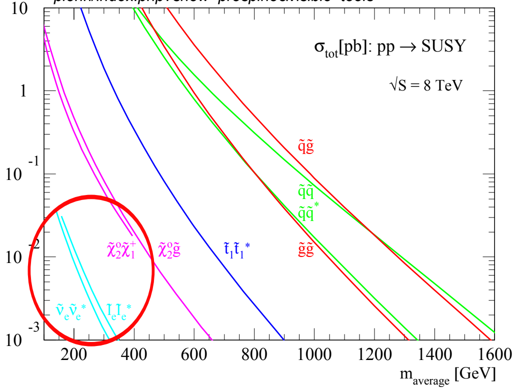


E_T^{Miss} based

Presented in Monday's BSM Session - B.Margin, G.Usai

Today

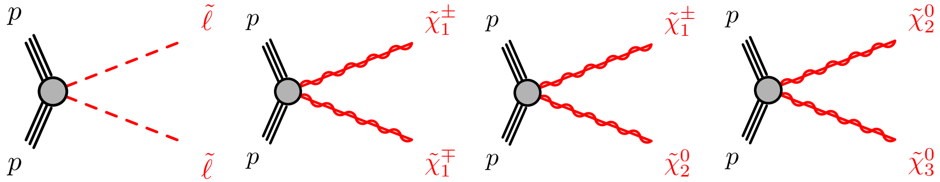
taken from http://www.thphys.uni-heidelberg.de/~plehn/index.php?show=prospino&visible=tools



- Weak production can be dominant in case of heavy squarks/gluinos
- Potential for **lepton-rich** final states

→ **Search strategy**: Leptons + E_T^{Miss}

- ATLAS: Set of complementary R-Parity conserving (RPC) Electroweak (EW) searches



Look at final states with up to four charged leptons

1 lepton + $b\bar{b}$ + E_T^{Miss}	ATLAS-CONF-2013-093	08/2013
2 leptons (e,μ) + E_T^{Miss}	JHEP05 (2014) 071	03/2014
2 leptons (τ) + E_T^{Miss}	arXiv:1407.0350 (Submitted to JHEP)	07/2014
3 leptons + E_T^{Miss}	JHEP 04 (2014)169	02/2014
4 leptons	arXiv:1405.5086 (Accepted by PRD)	05/2014

Use a **Common strategy** - allows for combination of results

Guiding principle: Keep analyses **orthogonal** and use **consistent** strategies

Categorize **SM background** based on origin of leptons:

- **Real** leptons: from the hard interaction (e.g. $Z \to \ell\ell$)
- **Fake** leptons: misidentifications or secondary decays (e.g. $b \to \mu\nu c$)
- Separate two types of background:

Irreducible	**Reducible**
• Only real leptons • Estimate using MC simulation	• Fake leptons • Estimate using the data

In both cases, **Validate** against the data in signal-depleted **Validation regions**

Define multiple **Signal regions**

- Optimize using benchmark signal models

Common set of signal models to optimize and interpret searches

- **Simplified Models**

→ One process, 100% BR, decoupled sparticles, . . .

- **p**henomenological **MSSM** (pMSSM)

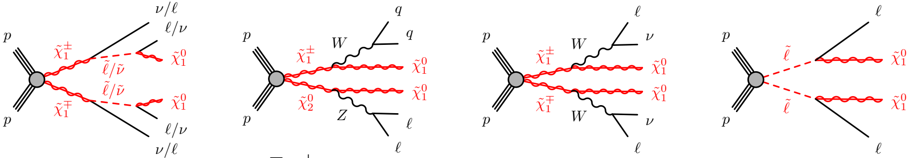
→ 19 Parameters, motivated by experimental constraints

- **Gauge Mediated** models

→ Gravitino LSP

The 2-Lepton (e,μ) search (JHEP05 (2014) 071)

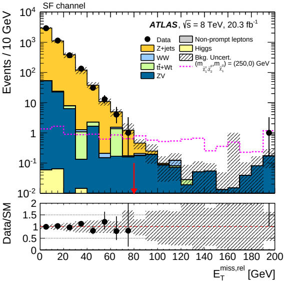
2 Leptons: sensitive to wide range of EW production mechanisms

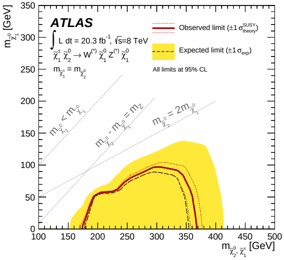


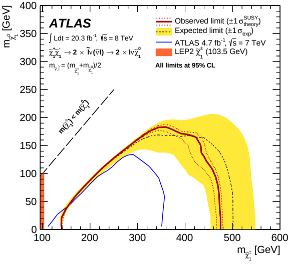
- Target production of $\tilde{\chi}_1^{\mp}\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2^0\tilde{\chi}_1^{\pm}$ or slepton pairs
- Signature: 2 leptons (e,μ) + $E_{\mathrm{T}}^{\mathrm{miss}}$

Main backgrounds:

- For Z veto: WW, top (MC, normalized to data)
- For Z request: VZ (MC), Z+jets (data driven 'jet smearing' method)

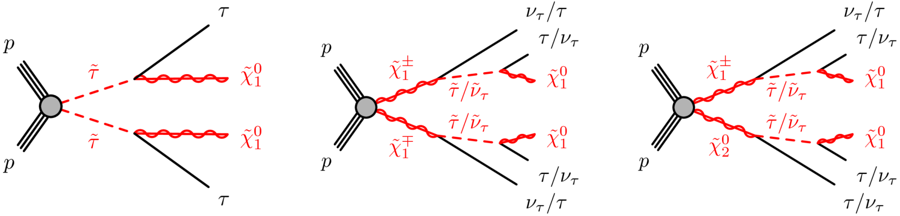






The 2 τ-Lepton analysis $\leftarrow$ **New!** arXiv:1407.0350

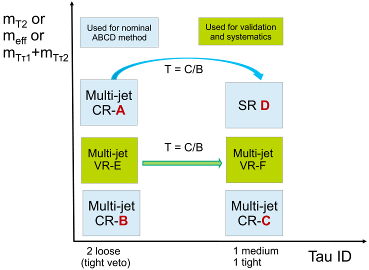
Particularily challengenging - hadronic decays of the τ



- 2 opposite charge hadronic τ decays

$\rightarrow$ Complement 2L analysis

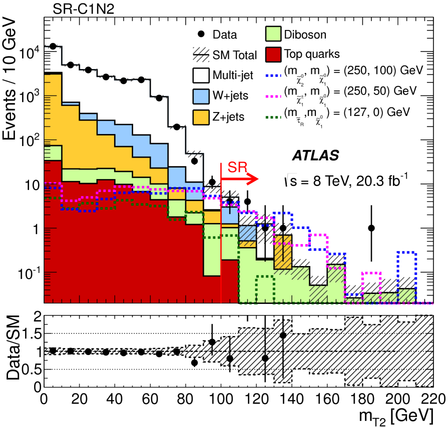
- Compared to 2L: Important role of Jets misidentified as tau decays (fake leptons)
- Multijets: 2 fakes - **ABCD** method
- W+jets: 1 fake - MC simulation, normalized to the data in control region

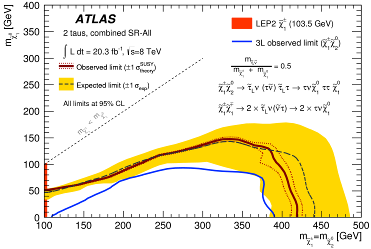


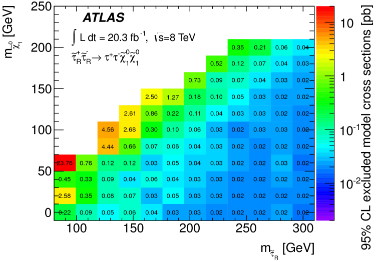
The 2 τ-Lepton analysis $\leftarrow$ **New!** arXiv:1407.0350

- Observe no significant excess with respect to SM expectation

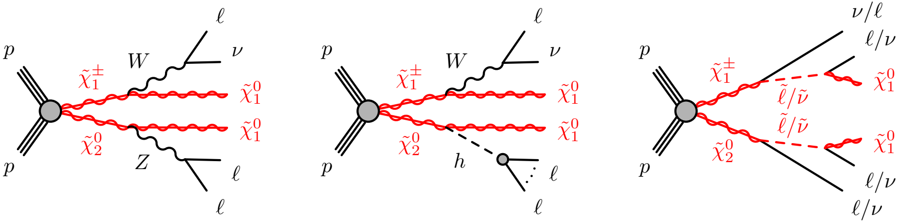
$\rightarrow$ Set exclusion limits



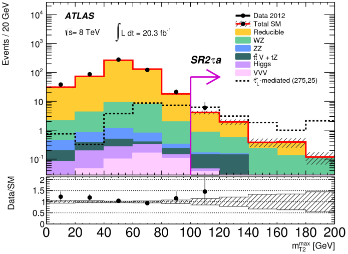




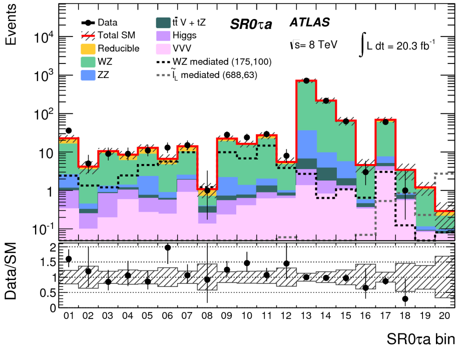
Add another lepton! Combine light (e,μ) leptons and hadronic τ decays in one channel

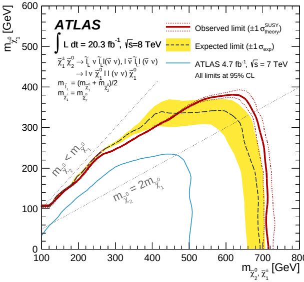


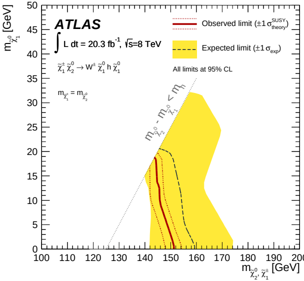
- Exactly 3 leptons (up to 2 hadronic τ decays)
- Main target: $\tilde{\chi}_2^0\tilde{\chi}_1^{\pm}$ production
- Most important standard model backgrounds:
  - WZ: Estimated using MC Simulation
  - W+jets/$t\bar{t}$ with misidentified leptons: Estimated using the data
- Signal regions for different tau lepton multiplicities (0,1,2 τ_{had})
- Role of **reducible background** increases with tau multiplicity



- Again, no excess above the SM background
- Interpretation in simplified and pMSSM models





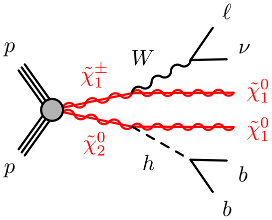


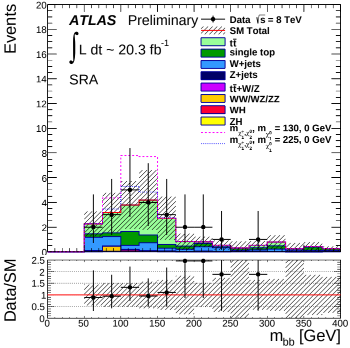
The 1-Lepton analysis (ATLAS-CONF-2013-093)

A specialized search for Higgs-mediated decays

- Target $\tilde{\chi}_2^0 \tilde{\chi}_1^\pm$ production
- $\tilde{\chi}_2^0$ decay via Higgs emission
- Final state:1 lepton, 2 b-Jets and $E_{\mathrm{T}}^{\mathrm{miss}}$
- Background mainly from W and top

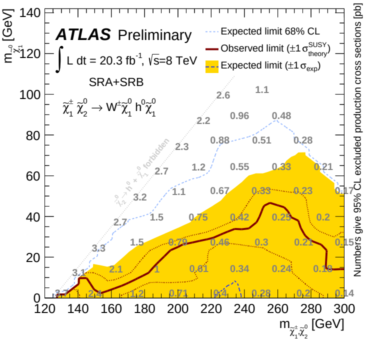
→ Estimation: Combined fit to the data (using MC templates)





Observe no excess

→ Set limits in simplified model

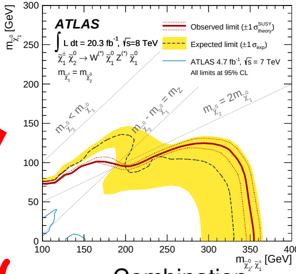


- **Combine** the 2L and 3L results

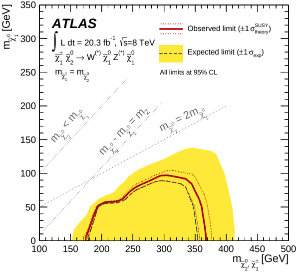
→ Maximize sensitivity to $\tilde{\chi}_2^0\tilde{\chi}_1^\pm$ decays via WZ

- Improve by more than 50 GeV in $m(\tilde{\chi}_2^0/\tilde{\chi}_1^\pm)$

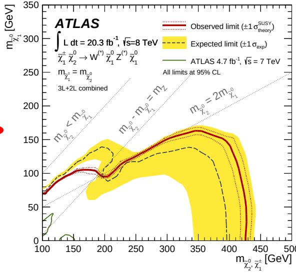
3L limit



2L limit



Combination

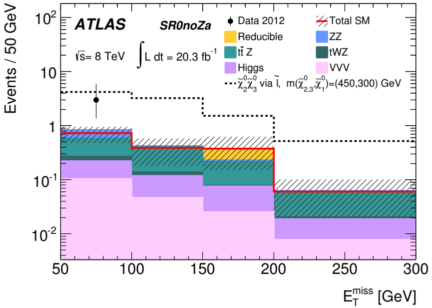


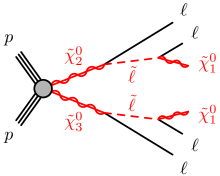
Add *another* lepton - sensitive to Neutralino pair production

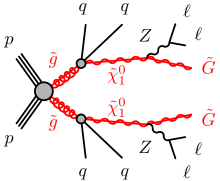
- **Signal regions** with 0/1/2 τ_{had}
- also sensitive to **GGM** with wino-like NLSP

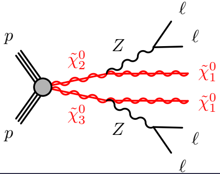
Background estimation consistent with electroweak searches

- High lepton multiplicity: low level of background









Dominant backgrounds:

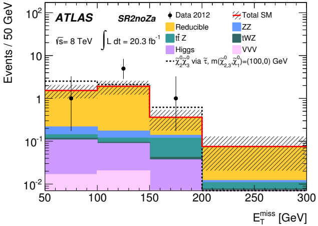
- Irreducible component dominant for 0τ

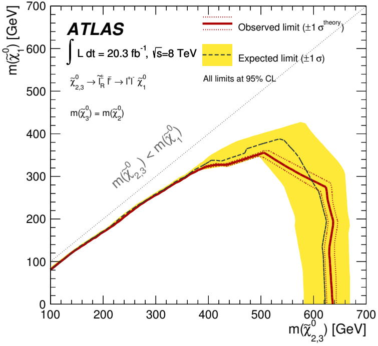
$\rightarrow$ ZZ, VVV, $t\bar{t}Z$, Higgs (from MC)

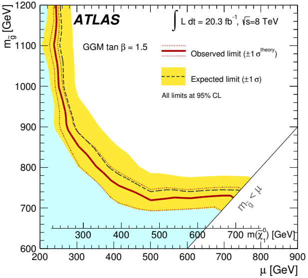
- Reducible component dominant for $1\text{-}2\tau$

$\rightarrow$ Z+jets, $t\bar{t}$, WZ (data driven)

Observe **no excess** - place limits!

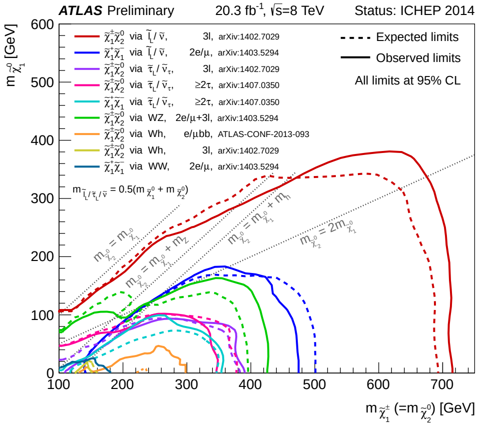


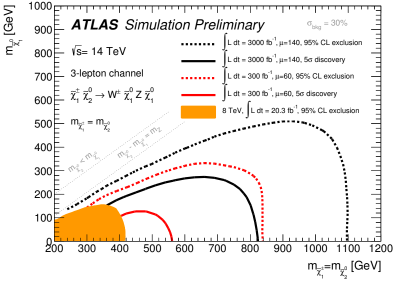




Combination of channels: Cover **wide range of decay mechanisms** for the main electroweak processes

Still **room for improvement** in future runs!





Potential search reach of the 3L search with L = 300 / 3000 fb^{-1} → ATL-PHYS-PUB-2014-010

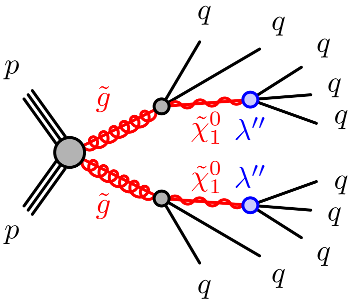
What else can we look for?

We can add superpotential terms that violate either lepton or baryon number without destabilizing the proton

$$W_{\Delta B,L} = \underbrace{\lambda_{ijk} L_i L_j \bar{E}_k}_{\text{"}LLE\text{"}} + \underbrace{\lambda'_{ijk} L_i Q_j \bar{D}_k}_{\text{"}LQD\text{"}} + \kappa_i L_i H_d + \underbrace{\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k}_{\text{"}UDD\text{"}}$$

These terms lead to **R-Parity violation** (RPV)

- Potential mechanism for generating neutrino masses
- LSP can decay into standard model particles
- High multiplicity final states
- Not necessarily any missing transverse momentum



Study these models using **dedicated searches** and **reinterpretations** of searches for R-Parity conserving decays

Long-lived decays of supersymmetric particles are possible in several frameworks, including

- Weak **R-Parity violating** couplings
- **Gauge Mediated SUSY breaking**(GMSB) with a weakly coupling Gravitino LSP
- highly **degenerate/compressed spectra**

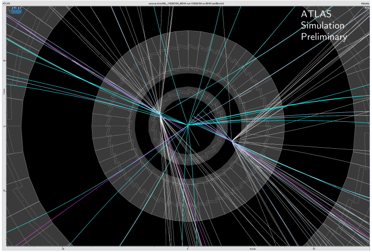
Also may include decays of **composite states**

- Long lived Gluinos or squarks may **hadronize** before decaying

$\rightarrow$ **R-hadrons** consisting of sparticle and colored SM particles

Depending on the **lifetime**, search channels include

- Displaced vertices
- Leptons/Photons pointing away from primary vertex
- Disappearing or kinked tracks
- Delayed decays of stopped massive particles
- Stable massive charged particles
- RPC searches (escaping particles $\rightarrow E_T^{Miss}$)



Overview: Recent ATLAS results based on the 2012 dataset

Three main categories:

Reinterpretation of existing analyses

Metastable Gluinos	ATLAS-CONF-2014-037	07/2014
$\rightarrow$ Monday - B. Martin		

Searches for RPV signatures

4 leptons (LLE)	arXiv:1405.5086 (Accepted by PRD)	05/2014
Multijets (UDD)	ATLAS-CONF-2013-091	08/2013
Displaced vertices (LQD)	ATLAS-CONF-2013-092	08/2013

long-lived RPV

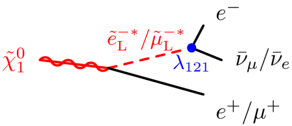
Long-lived particle searches

Displaced vertices (LQD)	ATLAS-CONF-2013-092	08/2013
Stopped R-hadrons	Phys. Rev. D 88, 112003 (2013)	10/2013
Disappearing tracks	Phys. Rev. D 88, 112006 (2013)	10/2013
Long lived sleptons	ATLAS-CONF-2013-058	06/2013

Multipurpose search - go beyond EW production and study **LLE RPV**!

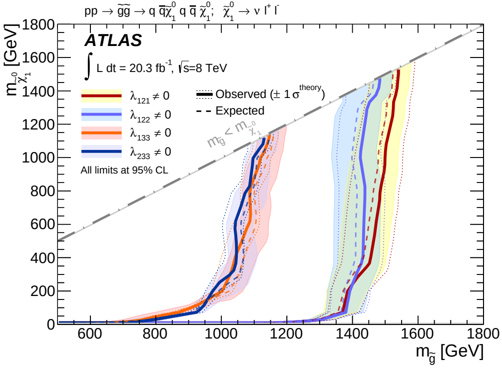
- Neutralino decays into 2 charged leptons and a neutrino

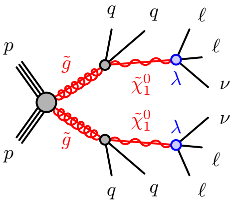
$\rightarrow$ **4 charged leptons** (flavours determined by λ_{ijk} choice)

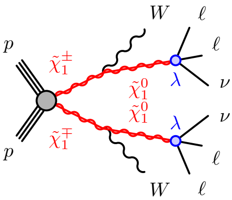


RPV Signal selection via **Z-Veto** and **Effective mass**

$$m_{eff} = \sum_{\text{Leptons,Jets}} p_T + E_T^{\text{Miss}}$$





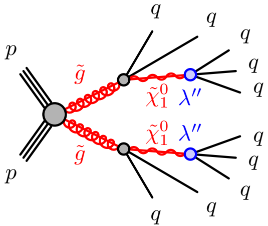


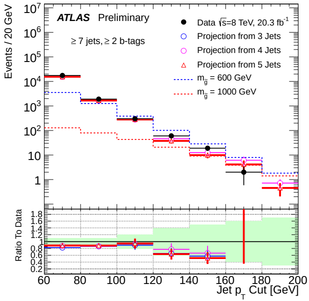
RPV Multijets (ATLAS-CONF-2013-091)

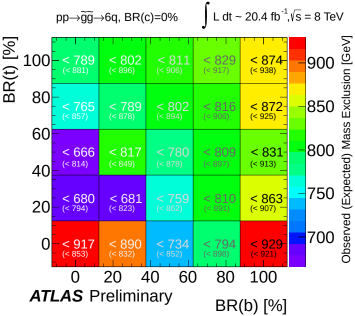
Talked a lot of leptons so far - what about some jets?

- Target the B violating $\lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k$ *term*
- **Signal discrimination** using Jet multiplicity, momenta, b-tagging
- Need to understand **QCD Multijet Background**

$\rightarrow$ data driven with MC transfer factors







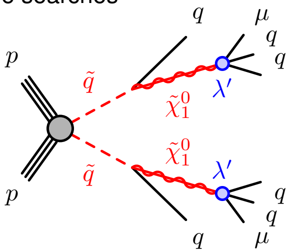
RPV searches can also be long-lived particle searches

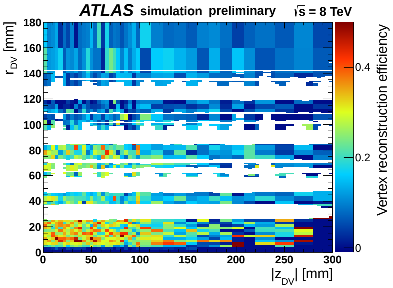
Target a **weak**, L violating $\lambda'_{2jk} L_2 Q_j \bar{D}_k$ RPV coupling

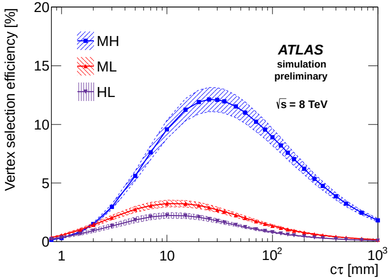
- Delayed Neutralino decays into quarks and a muon

→ For decays inside the tracking volume: **Displaced multi-track vertex** with an **associated muon**

- **Challenge:** Reconstruct highly displaced vertices
- But: **Negligible** SM Background



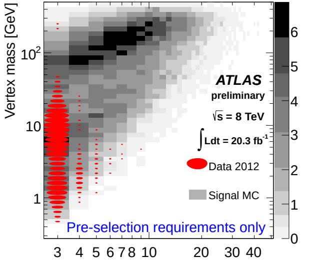


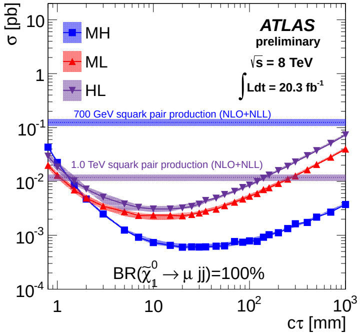


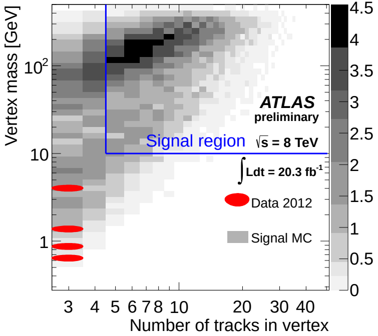
Signal selection: Displaced vertices with at least **5 tracks** and a mass of more than 10GeV, associated to a muon

- Expect 0.02 ± 0.02 background events
- Observe no signal candidates

→ Place limits as a function of the LSP decay length for several mass scenarios



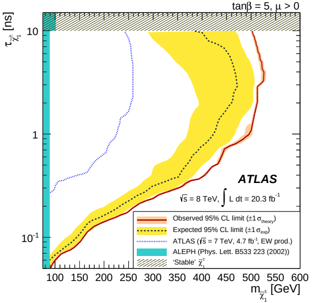




Long-lived searches need to exploit the **full potential** of the detector

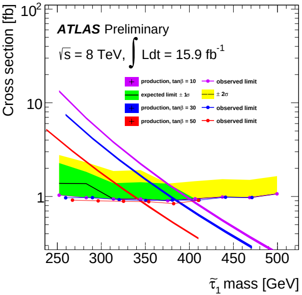
Nearly mass-degenerate scenarios (e.g. AMSB) can lead to long-lived $\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 \pi^\pm$ decays

- Signature: **Disappearing** track in the inner detector
- Main backgrounds:
  1. Hadron material ineractions
  2. Tracks with mismeasured p_T



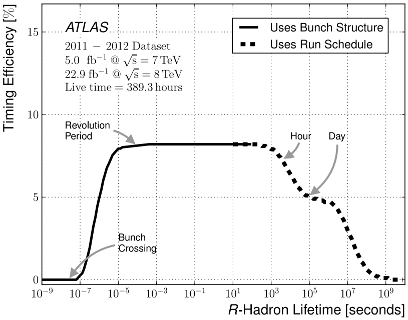
GMSB SUSY: Long-lived slepton NLSPs may traverse the whole detector

- Signature: **charged particle** track
- Signal discrimination using the **mass**, $m = p/(\beta\gamma)$
- Main background: Muons with mismeasured β



How far can we reach in lifetime sensitivity? **far!**

Target a **long-lived, stopped R-hadron** decaying **at rest** during **empty bunch crossings**



Signal selection:

- At least one **high p_T jet** in the barrel calorimeter ($|\eta| < 1.2$)
- **Missing transverse momentum** of at least $0.5 \cdot p_T^{\text{lead}}$

Backgrounds from

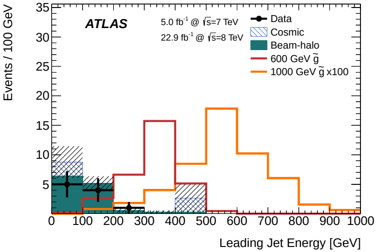
- Beam-Halo
- Cosmic rays

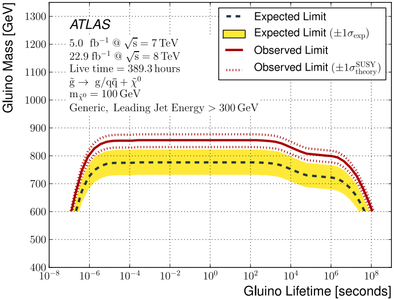
→ suppressed using a **Muon segment veto** and **Jet shapes**

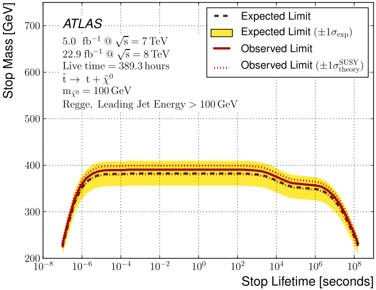
Estimation using **control datasets**:

- Beam-Halo: Unpaired bunch crossings
- Cosmic rays: Early 2011 data (low L)

- Observation in the signal region in excellent agreement with the SM prediction
- Bayesian interpretation - limits on models with gluino or stop/sbottom R-hadrons
- Investigate various interaction models







Electroweak Production: Promising for lepton-based searches

- Cover 1-4 leptons
- Consistent analysis strategy across the channels

→ Allow for **combination** of results

R-Parity Violation and **long-lived decays**:

- May lead to collider signatures not predicted by conventional RPC searches

→ Effort to cover them with dedicated analyses

Search Approaches:

- **Reinterpretations** of existing RPC analyses
- **Prompt RPV searches**

→ Typically target high multiplicity final states

- **Searches for long-lived decays**

→ Exploit the full potential of the detector

No signs of SUSY yet - stay tuned for new results!