Baryon and Lepton number violation at colliders (experiment)

Evelyn Thomson

University of Pennsylvania

Snowmass Rare Processes and Precision Measurements

Kickoff meeting for RF4 on BLV

July 6-8, 2020

Goals for Workshop

- Review and discuss status of this field
  - R-parity violating (RPV) SUSY models evade the stringent limits from missing-energy-based searches, and remain excellent candidates for low-scale SUSY
  - Several recent searches by ATLAS and CMS with 2015-18 data
  - European strategy did not include any projections for RPV signatures
- Support Snowmass process, with letters of intent April 1 – August 31 2020
  - ➢ Development of RPV benchmarks and summary plots
  - ➢ Comparison of rare process measurements to collider reach
  - ➢ Coordinate with the Energy Frontier BSM model-specific explorations working group EF08

Recent conference talks

Recent Experimental Results

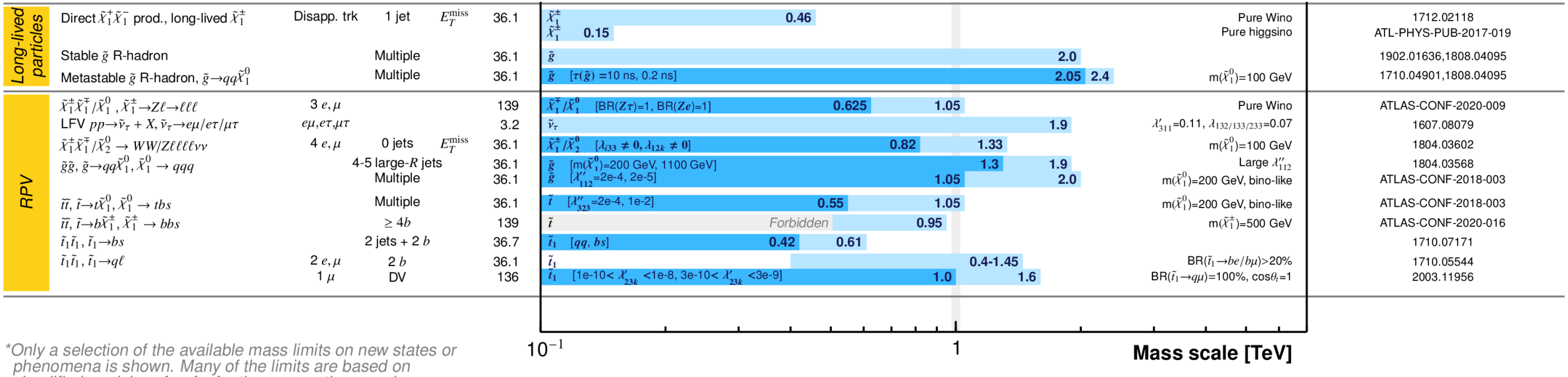
- LHCP 2020 by Ian Dyckes (Penn)
- BLV 2019 by Rebecca Carney (SLAC)
- SUSY 2019 by Javier Montejo Berlingen (DESY)
- LHCP 2019 by Kelvin Mei (Princeton)

- Report on the Physics at the HL-LHC, and Perspectives for the HE-LHC CERN-2019-007

Possible topics

- RPV SUSY multijets
  - Gluino with LSP neutralino decay
- Low mass neutralino RPV decay
  - UDD to 3 jets
  - Trigger level analyses for low mass
- B-L MSSM
  - Wino LSP RPV decay
  - Bino LSP RPV decay
- Your ideas?

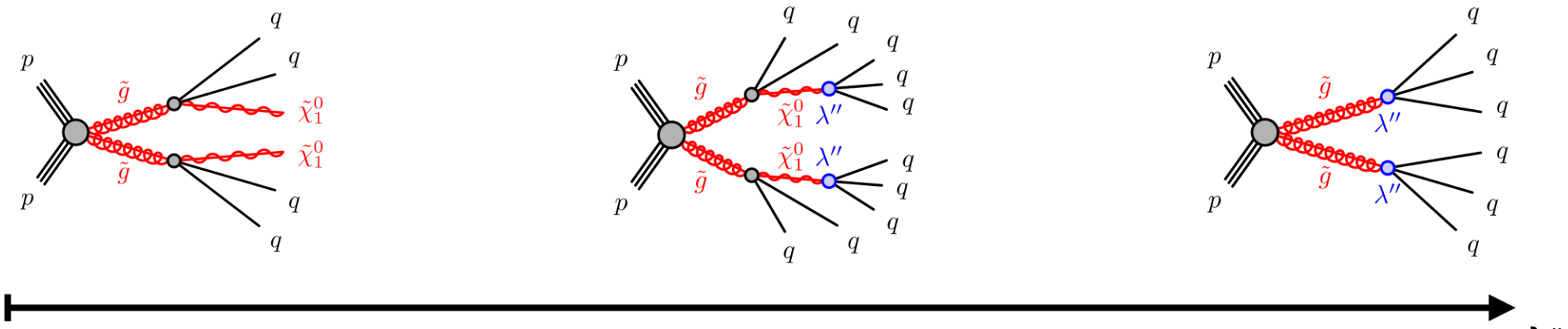
RPV/LLP summary



*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

Gluino pair production

Larry Lee
(Harvard)



Zero RPV coupling
= RPC case

Moderate coupling:
Diagrams still dominated
by gauge couplings

LSP at end of RPC decay
chain then **decays**
(potentially displaced)

Large coupling:
Direct decays if RPV
coupling dominates
over RPC vertices

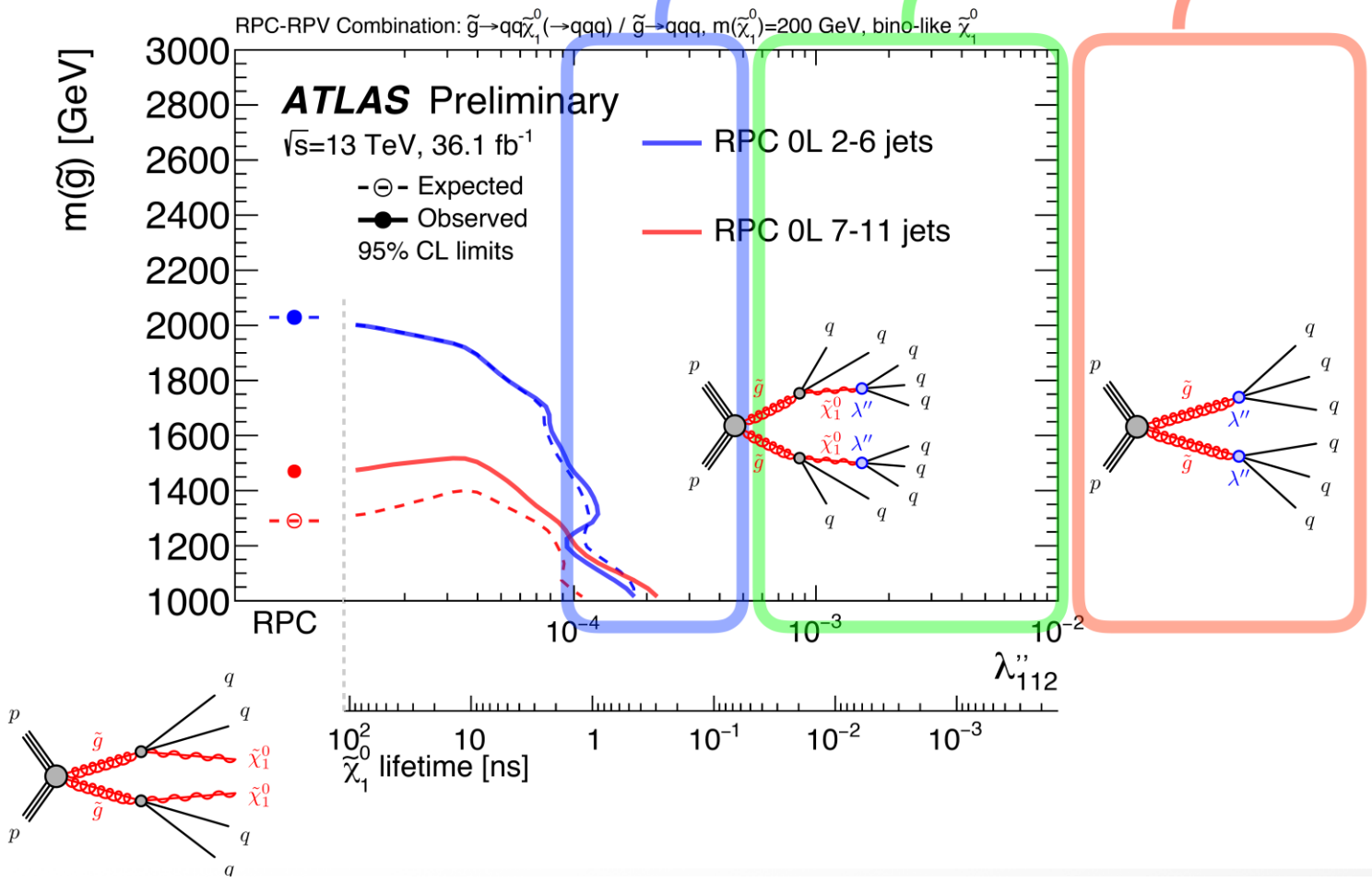
Gluino pair production

Larry Lee
(Harvard)

Displaced Vertex Sweet Spot - See Emily's talk

Covered by RPV multijet search - not yet reinterpreted

No ATLAS sensitivity since Run-1! (~1 TeV)



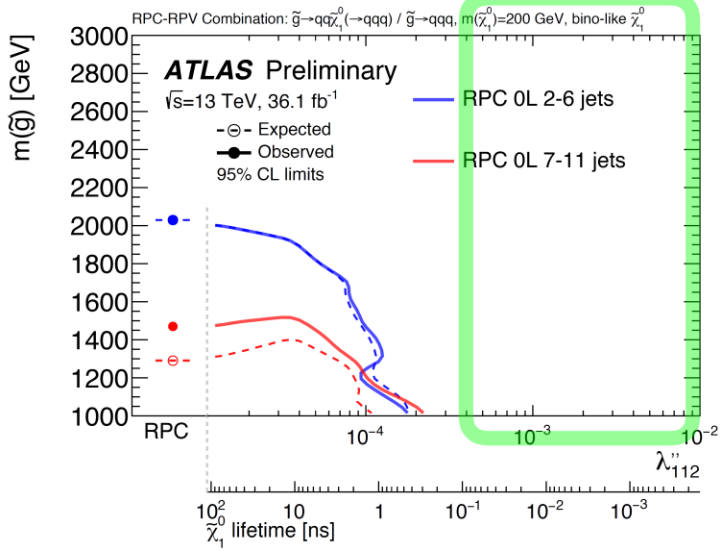
∃ **n-n̄** constraints in this plane, but very model dependent + only affect 11k (udx) couplings.

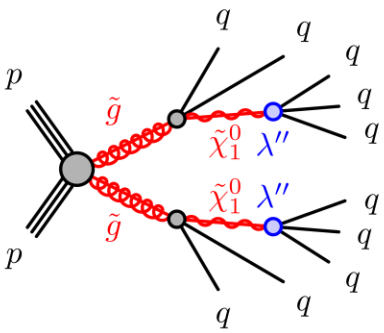
Plot could equally be 2jk (cxx) and limit gone

Gluino pair production

Covered by multijet?
Not yet reinterpreted…

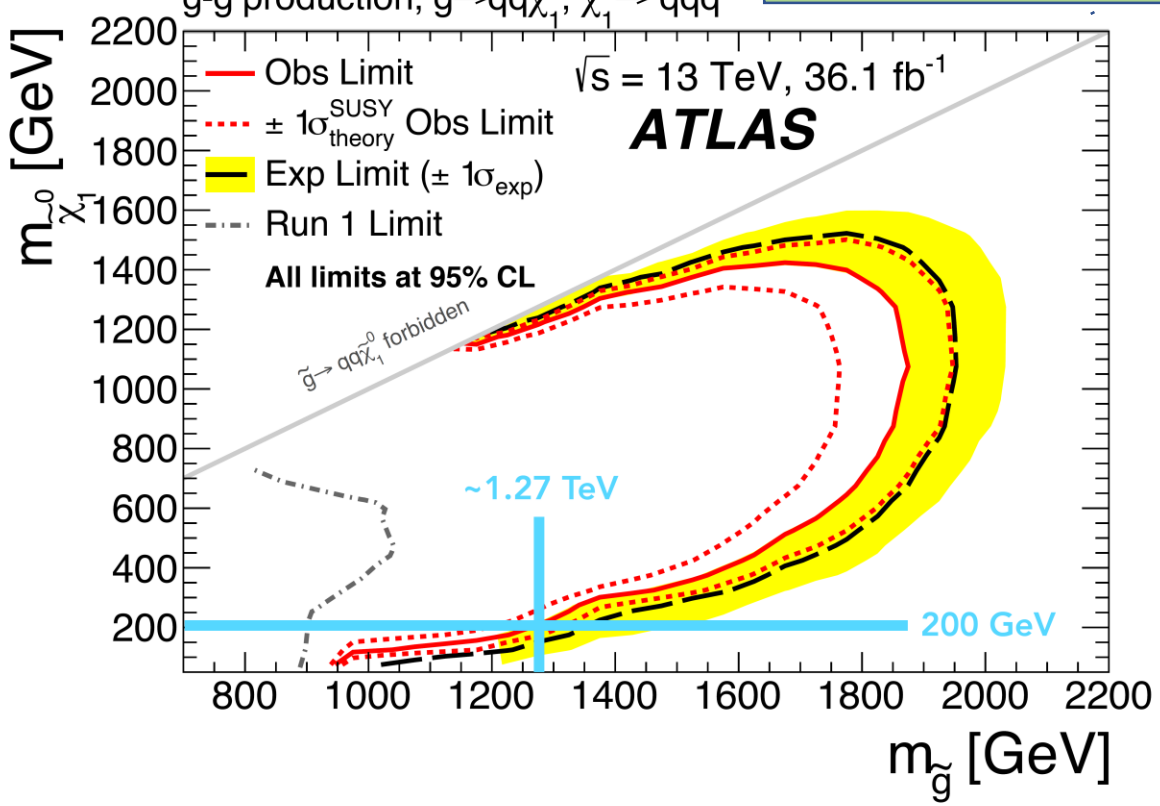
Larry Lee
(Harvard)





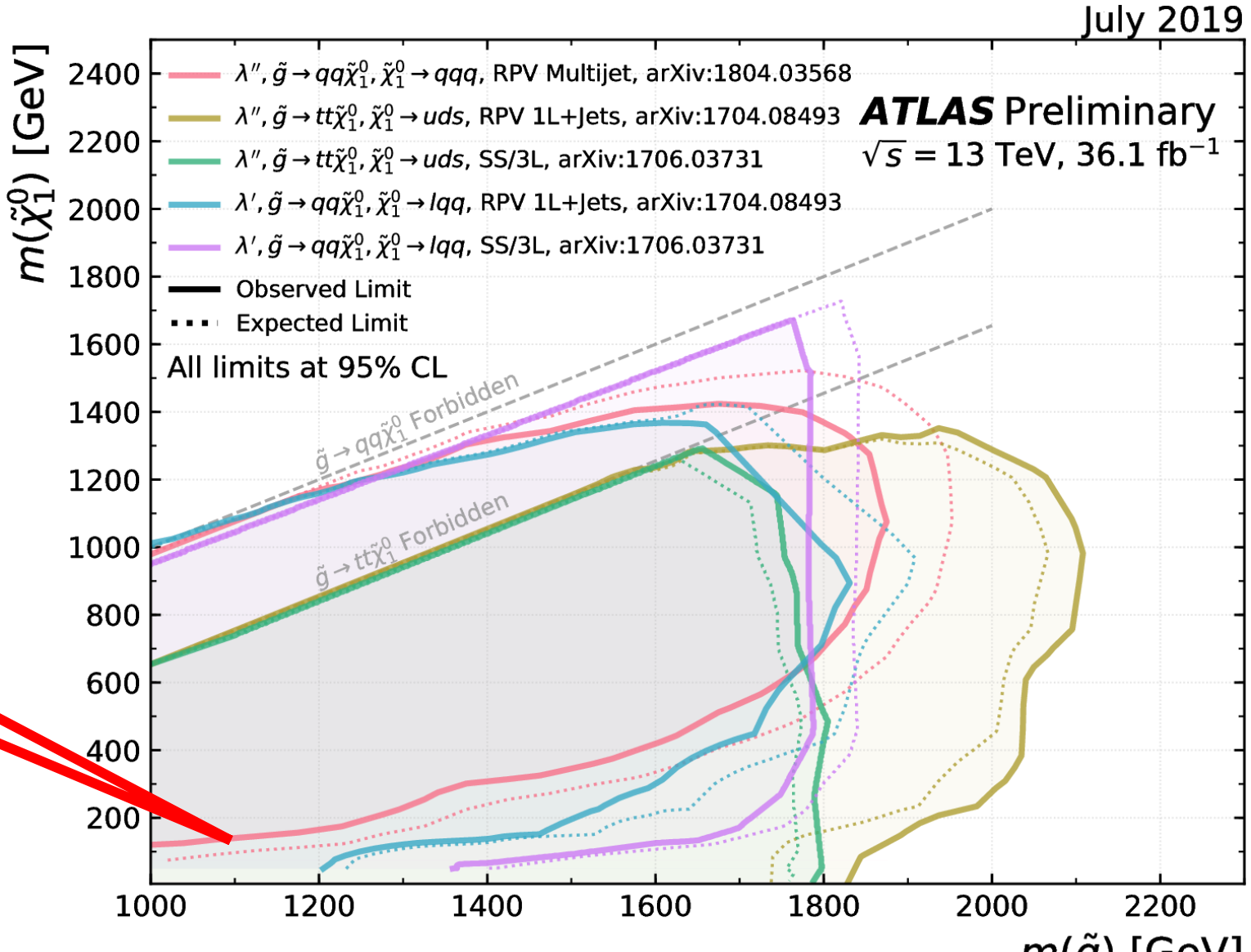
But not looking great…

Unexcluded corridor is for low mass LSP



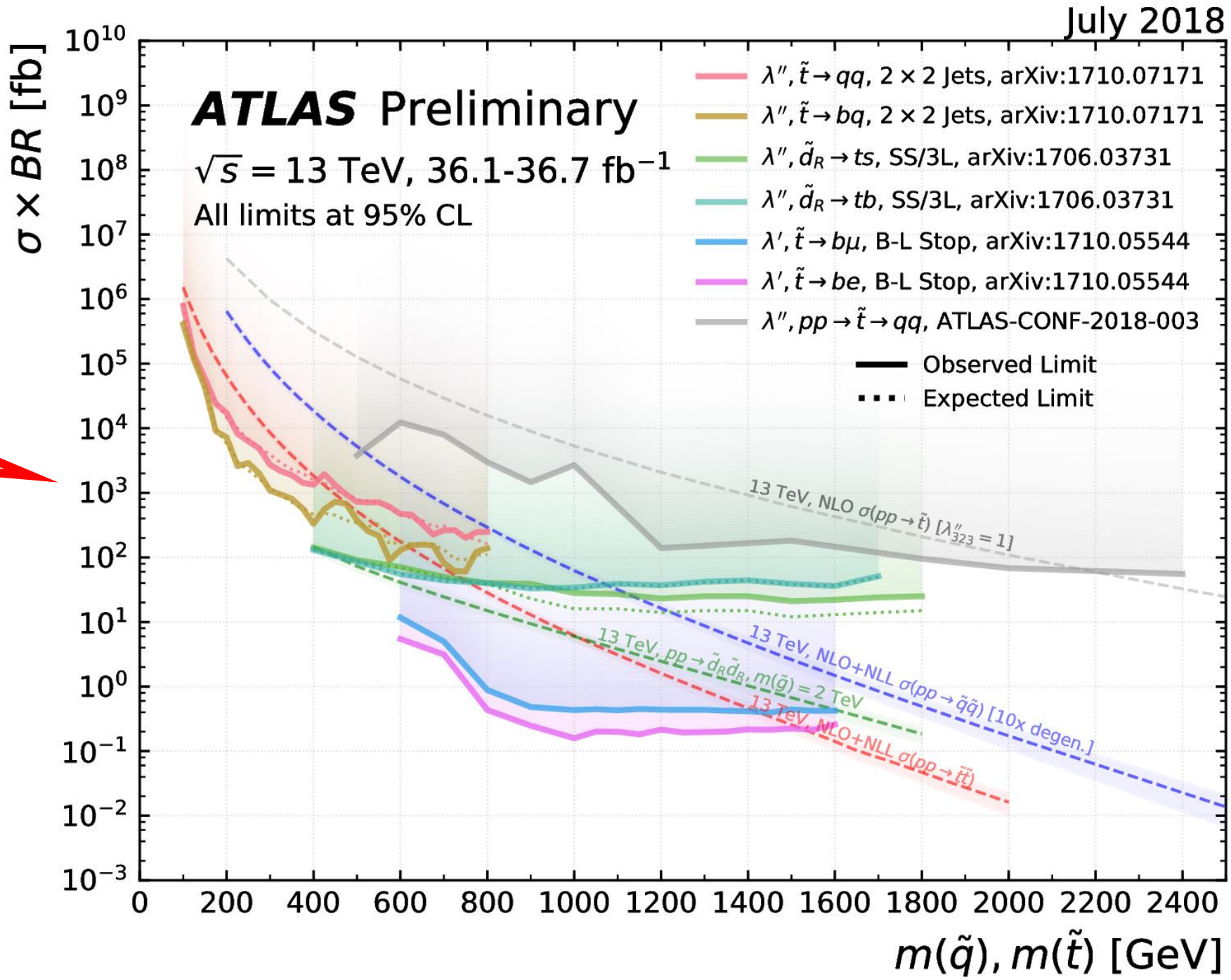
Gluino pair production with RPV decay of LSP

UDD coupling with LSP decay to 3 jets
Unexcluded corridor for low mass LSP

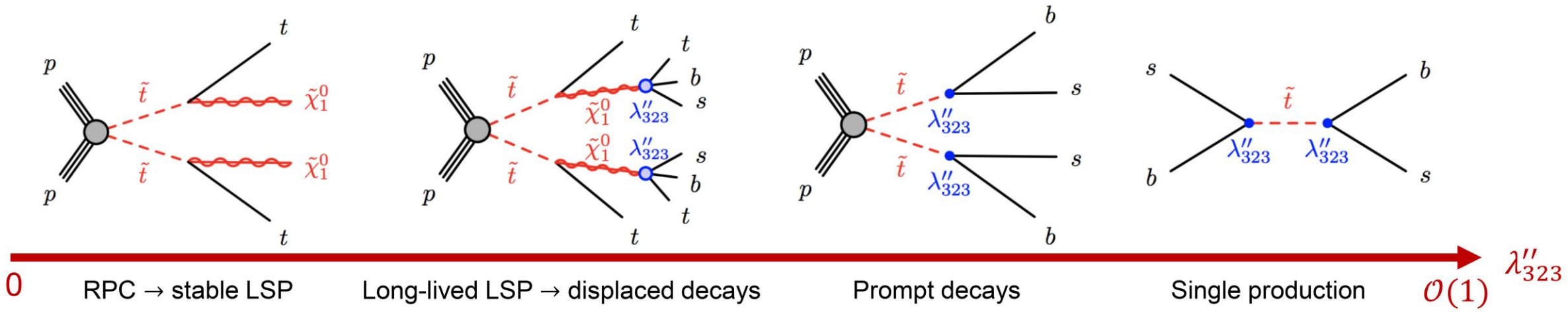


Squark decay

Need to go deep to go beyond 100% BR and large couplings



Top squark


p
p
$\tilde{t}$
$\tilde{t}$
t
t
$\tilde{\chi}_1^0$
$\tilde{\chi}_1^0$
λ''_{323}
λ''_{323}
b
s
s
b
$\mathcal{O}(1)$
λ''_{323}
0
RPC → stable LSP
Long-lived LSP → displaced decays
Prompt decays
Single production

Filling in the Gaps

Setting limits on coupling strength:

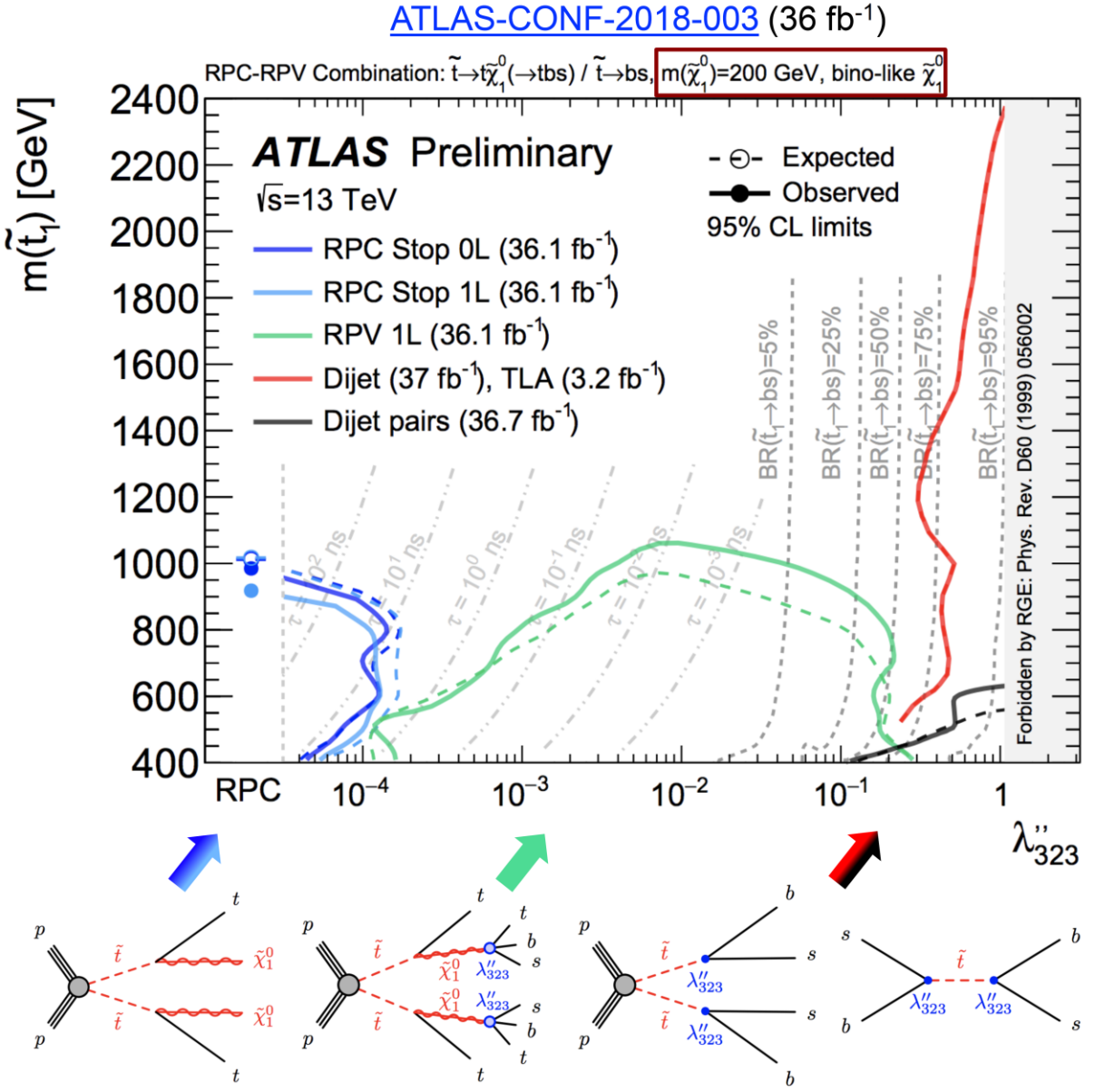
- For LL searches, can convert lifetime limits → coupling limits via an equation.
  - May depend on other parameters (virtual sparticle masses, mixings).
- For prompt searches, need reinterpretations.
  - Use RPV signals with variable coupling strengths.
  - Additional systematics for displaced signals.
- Analyses targeting RPC SUSY or other BSM may be sensitive to RPV.
  - Should reinterpret these as well!

RPV meets RPC:

- ATLAS reinterpreted prompt SUSY (RPC+RPV) and exotics searches.
  - Set limits on RPV coupling strengths in multiple models.
  - Including a stop model with a non-zero UDD coupling (λ''_{323}).

Facilitating reinterpretations:

- CMS has published simplified likelihoods for their multi-bin analyses [1].
- ATLAS has started publishing full likelihoods using pyhf [2].



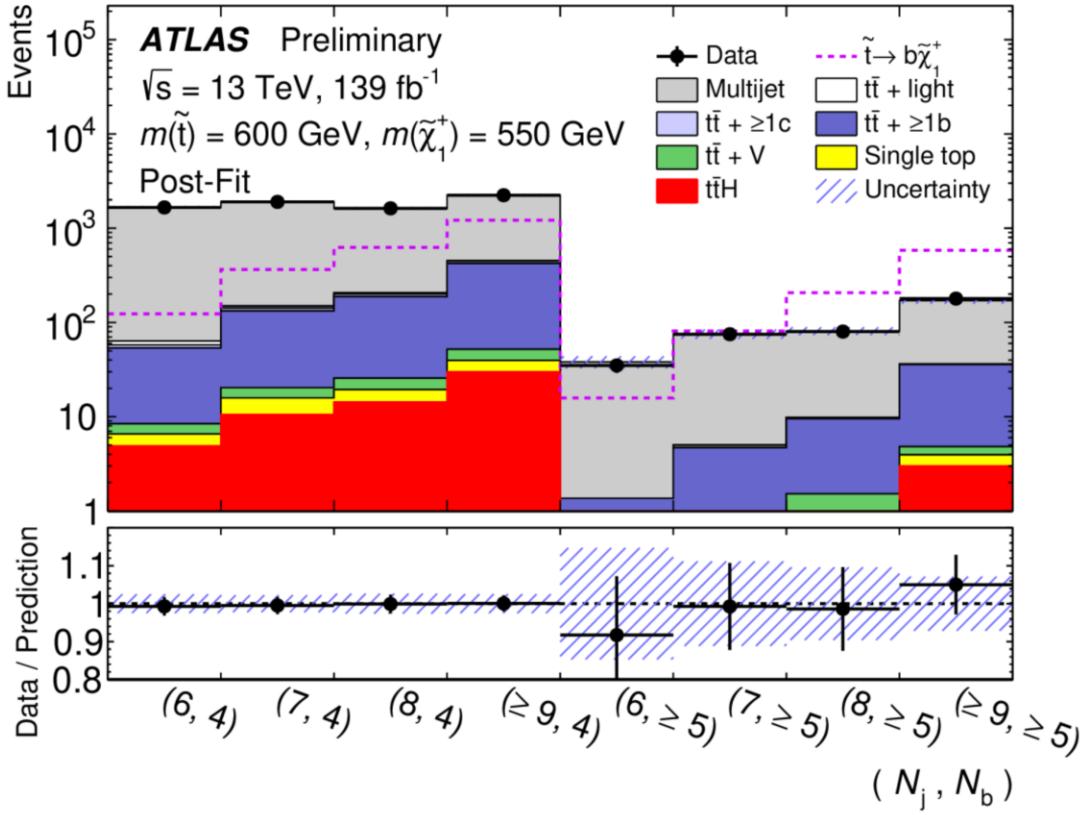
Search for BSM phenomena in events with large b-jet multiplicities

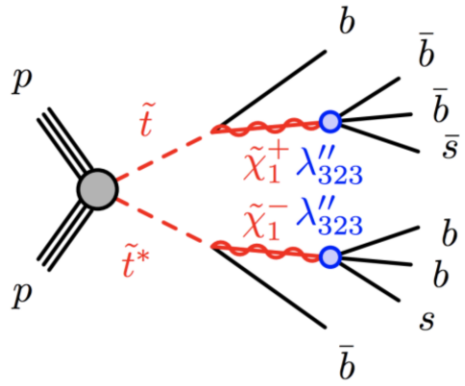
ATLAS-CONF-2020-016

Light stop & higgsino LSPs → natural

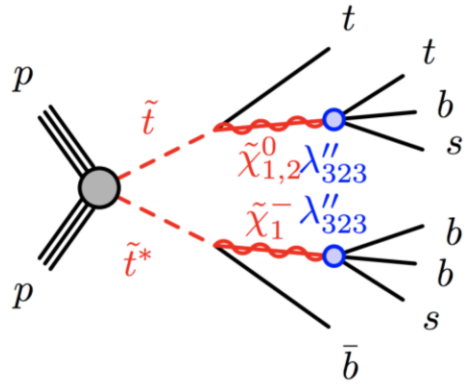
Final State:

- Large b-jet multiplicity, no leptons, and low $E_{\mathrm{T}}^{\mathrm{miss}}$.
  - First LHC search in this final state.





$\mathrm{BR}(\tilde{t} \to b\,\tilde{\chi}_1^{\pm}) = 100\%$



$\mathrm{BR}(\tilde{t} \to b\,\tilde{\chi}_1^{\pm}) = 50\%$

$\mathrm{BR}(\tilde{t} \to t\,\tilde{\chi}_{1,2}^{0}) = 50\%$

Benchmark RPV models:

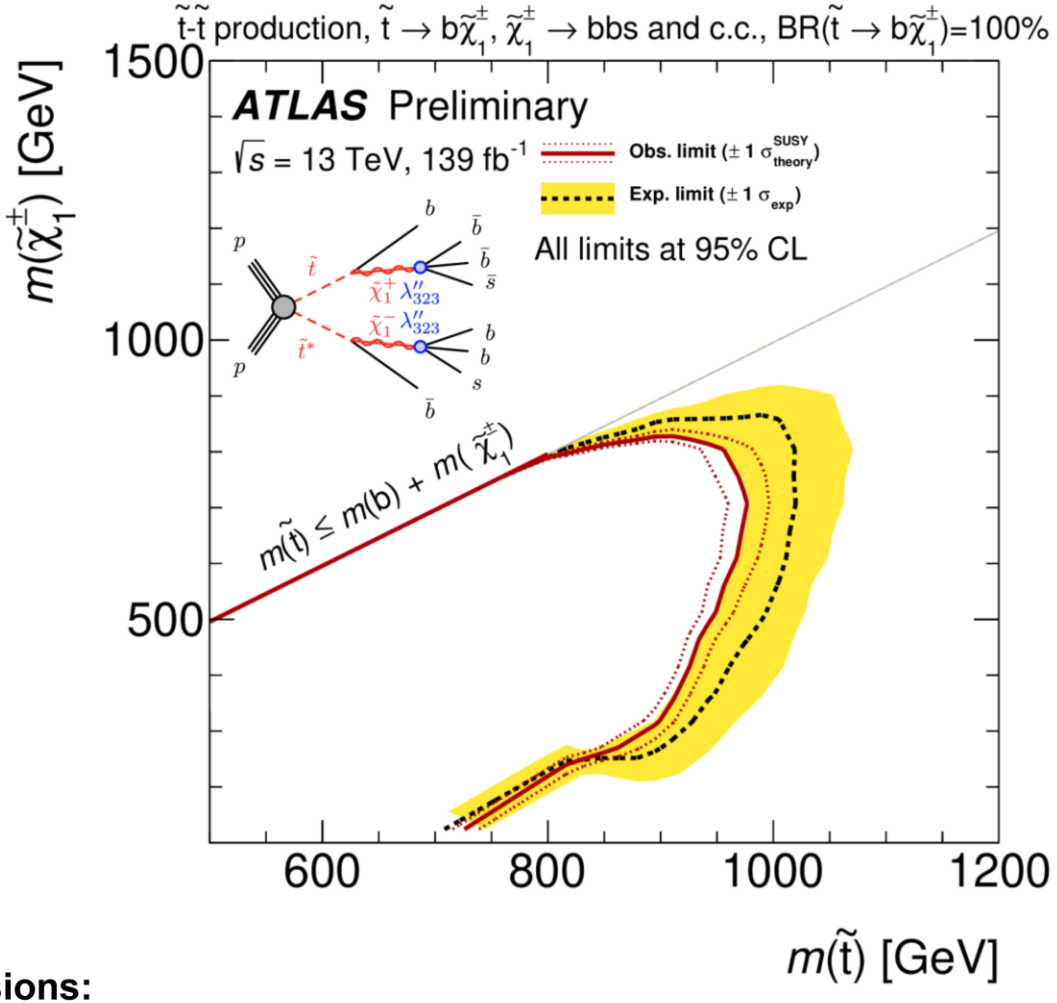
- Stop pair production with different available decay paths.
- Charginos and neutralinos decay via UDD RPV coupling (λ''_{323}).

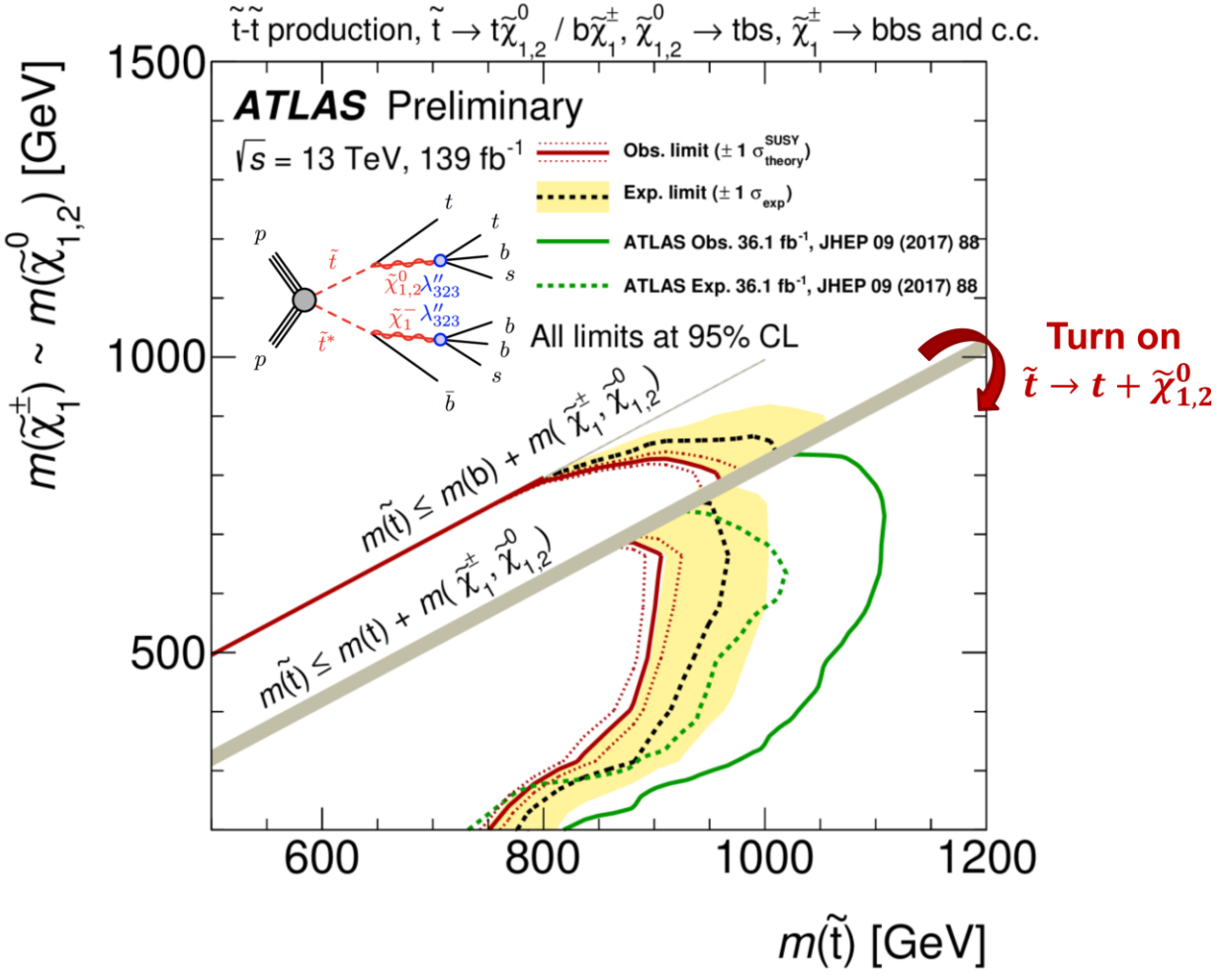
SR Strategy:

- Simultaneously fit 8 orthogonal SRs, binned in N_j and N_b.

Search for BSM phenomena in events with large b-jet multiplicities

ATLAS-CONF-2020-016

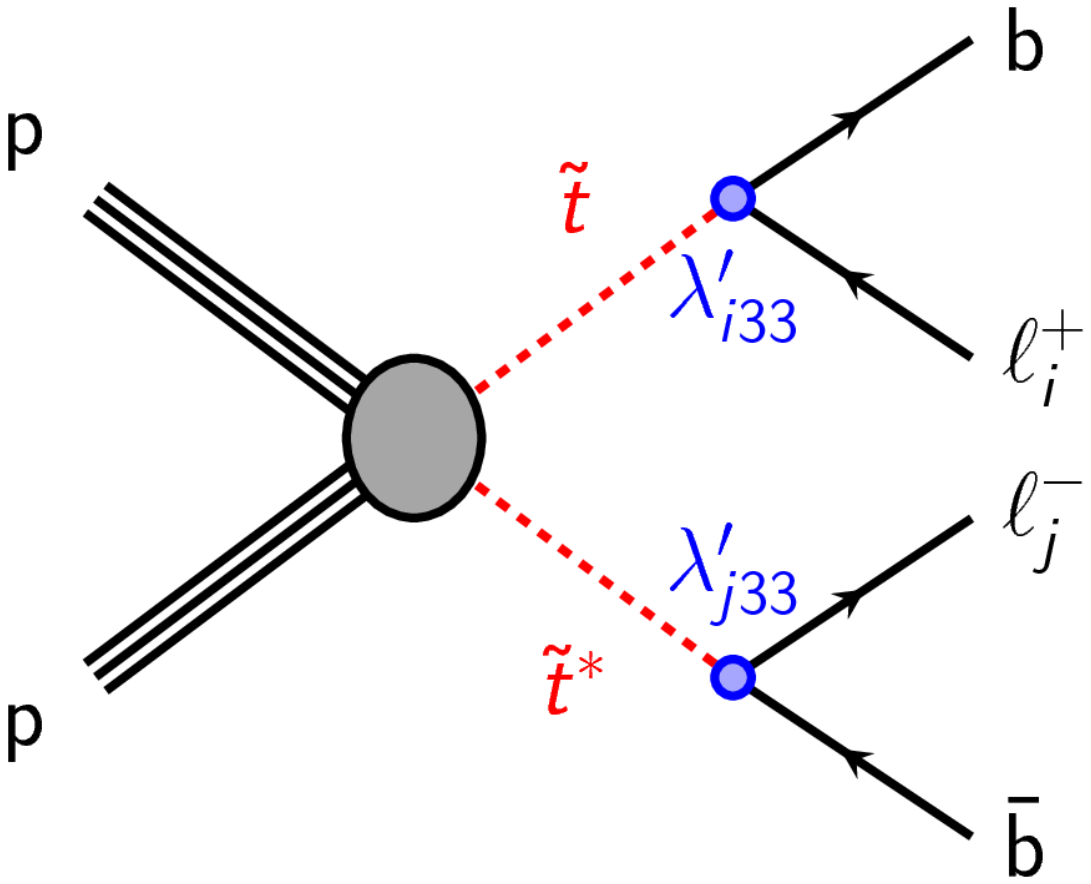




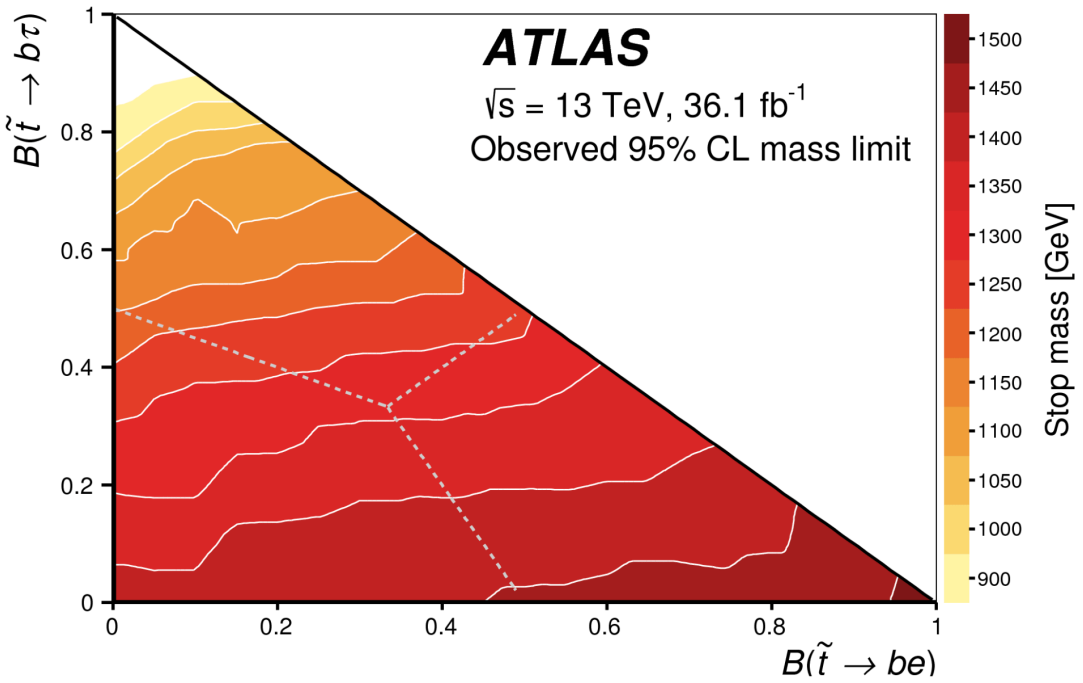
Exclusions:

- No observed excess over background prediction.
- Exclude stop masses up to 950 GeV in these models.

B-L MSSM scalar top

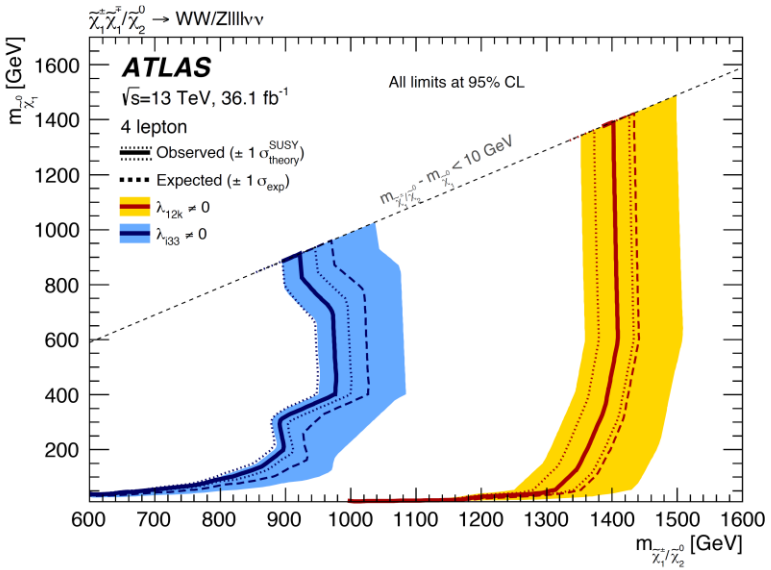


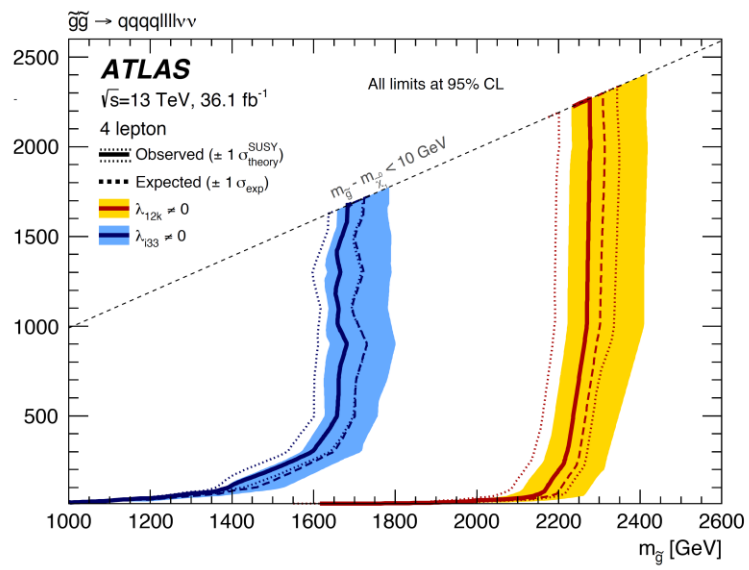
Leptoquark searches on the corners
100% to e, mu, tau

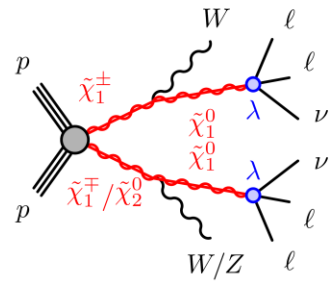


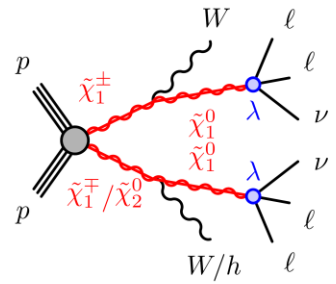
Multi-leptons, λ LLE

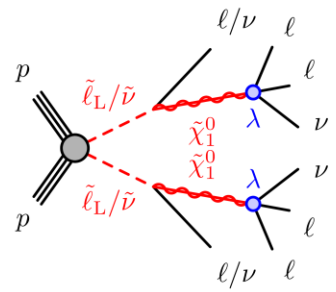
Submitted to PRD, arXiv:1804.03602

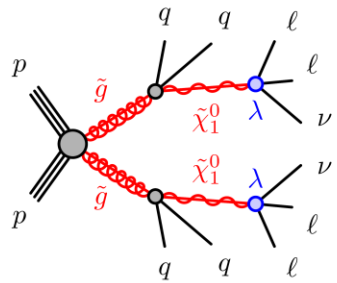








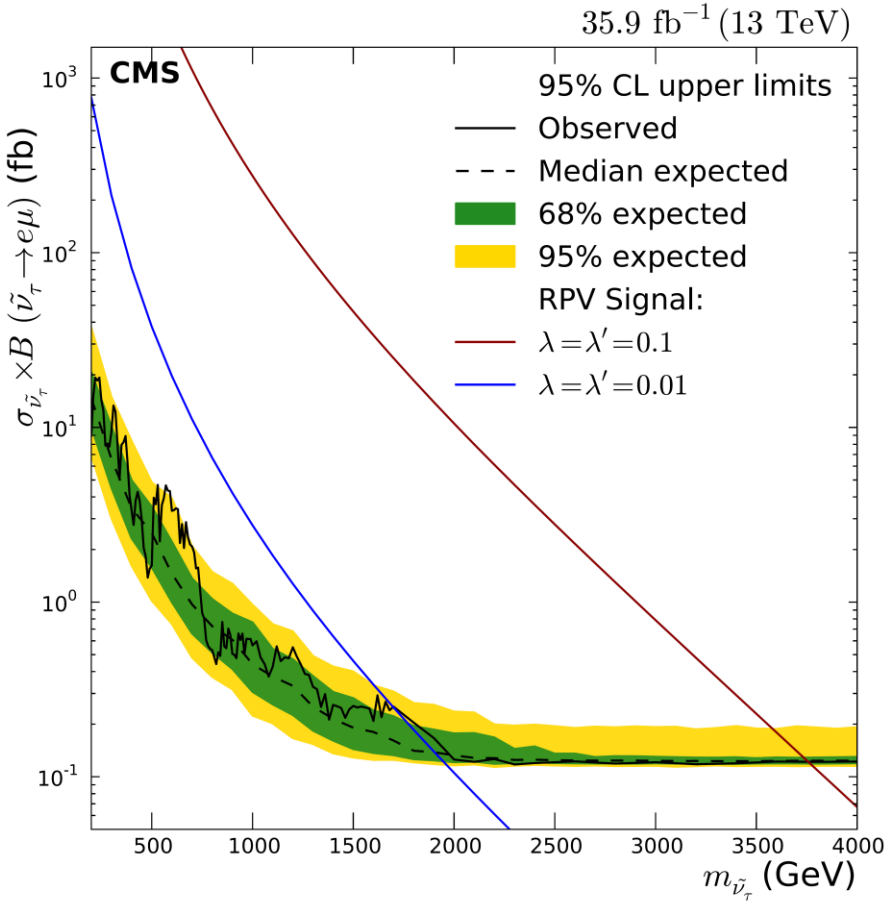


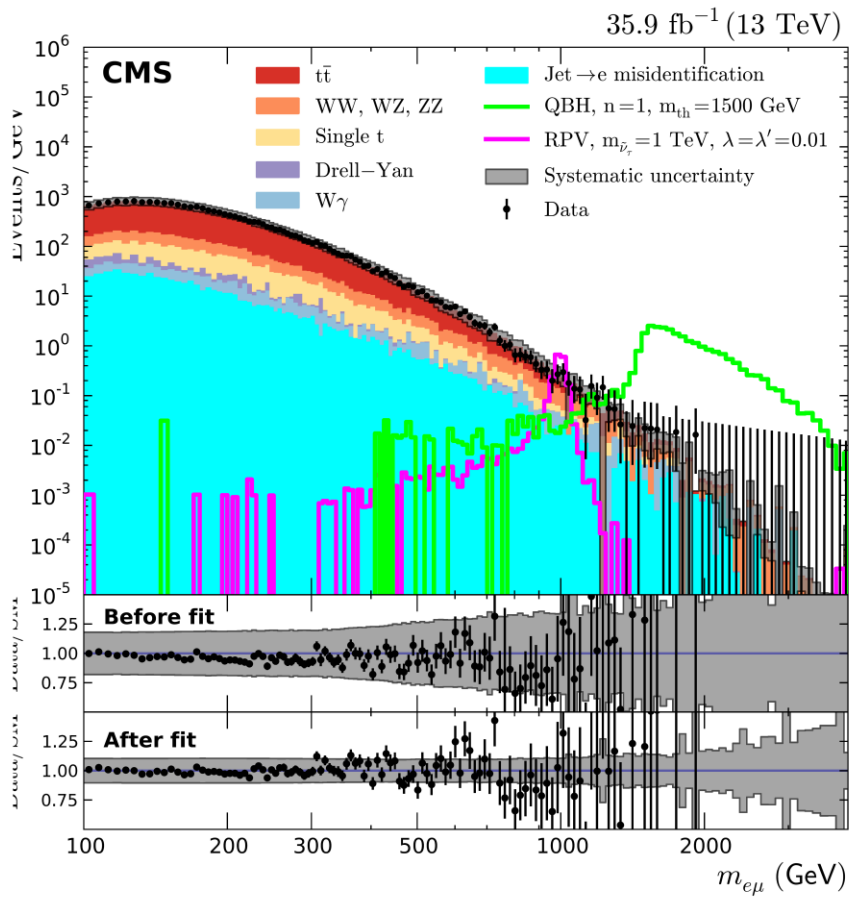


- Good example demonstrating sensitivity from conventional SUSY searches in events with neutrinos in the final state
- Final states: ≥ 4 leptons
- Exclude: wino to 1.4 TeV, slepton to 1.0 TeV and gluino up 2.3 TeV
- To avoid neutrinos in LLE couplings, need to choose the correct model

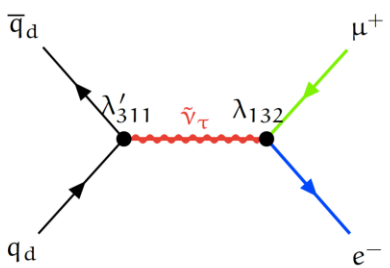
τ sneutrino → eμ, λ LLE

JHEP 04 (2018) 073





- Probe LLE couplings without MET in final states from neutrinos
- Search for LFV resonance with eμ final states
  - Sensitive also to quantum black hole and Z'
- τ sneutrinos excluded between 1.7 TeV for λ = λ' = 0.01



Trilepton resonances from chargino & neutralino pair production

ATLAS-CONF-2020-009

Model:

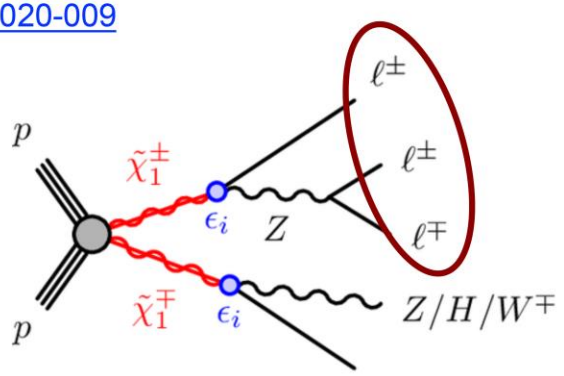
- Inspired by the $B-L$ MSSM with RPV.
  - Add $\mathrm{U}(1)_{B-L}$ symmetry to the MSSM.
  - Break spontaneously → R-parity and L-violation.

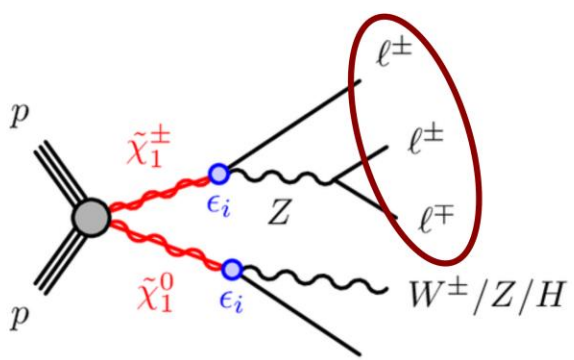
- Wino $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_1^0$ are possible LSPs in this model.
  - Decay promptly to a SM boson and a lepton/neutrino.
  - BRs to different lepton flavors related to the neutrino hierarchy.

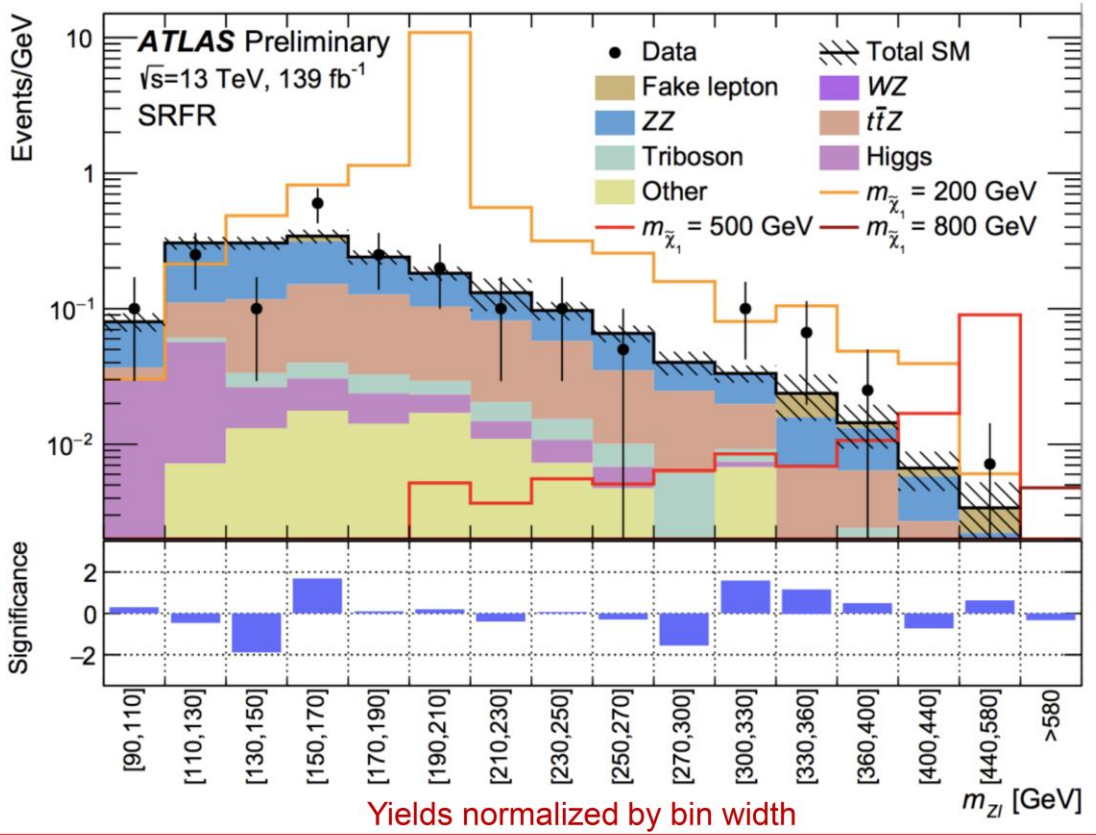
SR Strategy:

- Targets wino $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp} + \tilde{\chi}_1^{\pm}\tilde{\chi}_1^0$ production.
  - Require one $\chi_1^{\pm} \to Zl \to lll$ decay → trilepton resonance.
  - No constraints on the decay of the other $\tilde{\chi}_1^{\pm}$/ $\tilde{\chi}_1^0$.

- Attempt to reconstruct the second wino decay.
  - Number of leptons and reconstructed bosons defines 3 SRs.

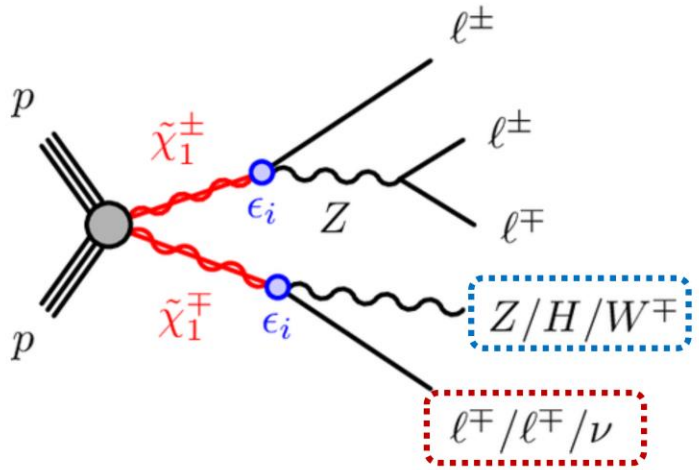


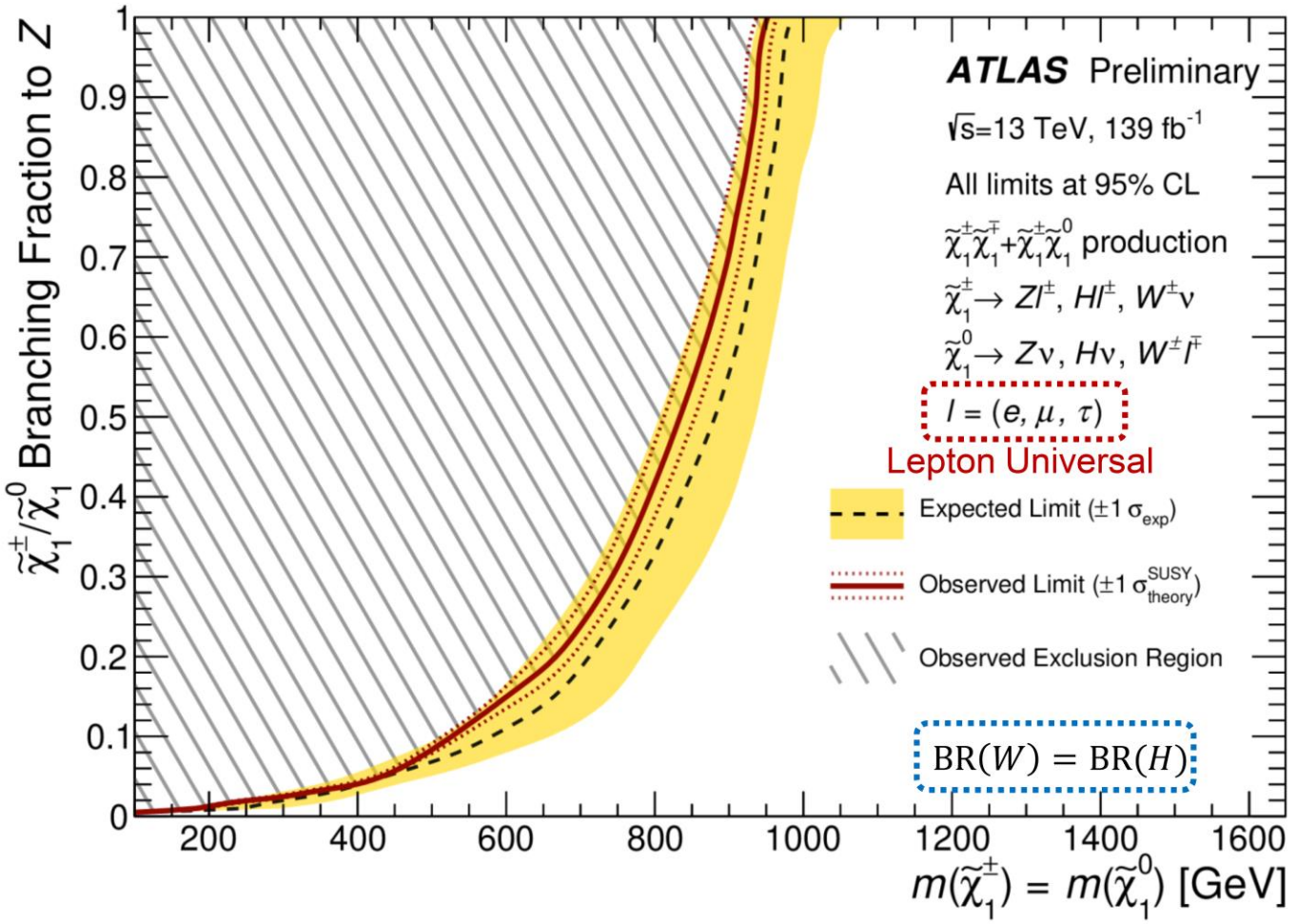




Trilepton resonances from chargino & neutralino pair production

ATLAS-CONF-2020-009





Results:

- No significant excess seen → set limits.
- Simultaneously fit the m_{Zl} distributions in the 3 SRs.
- Scan over $\tilde{\chi}_1^{\pm}$ / $\tilde{\chi}_1^{0}$ decay BRs to bosons & lepton flavors.
  - For each sampled point in lepton BR space, limits are set on wino mass as function of $\mathrm{BR}(Z)$.
- Exclude wino masses up to 950 GeV for lepton universal decays.

Searches for long-lived particles with displaced vertices and muons

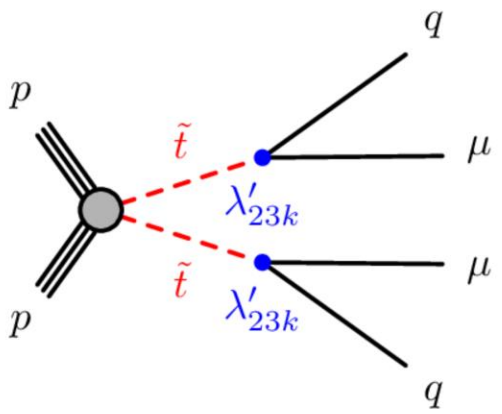
arXiv:2003.11956

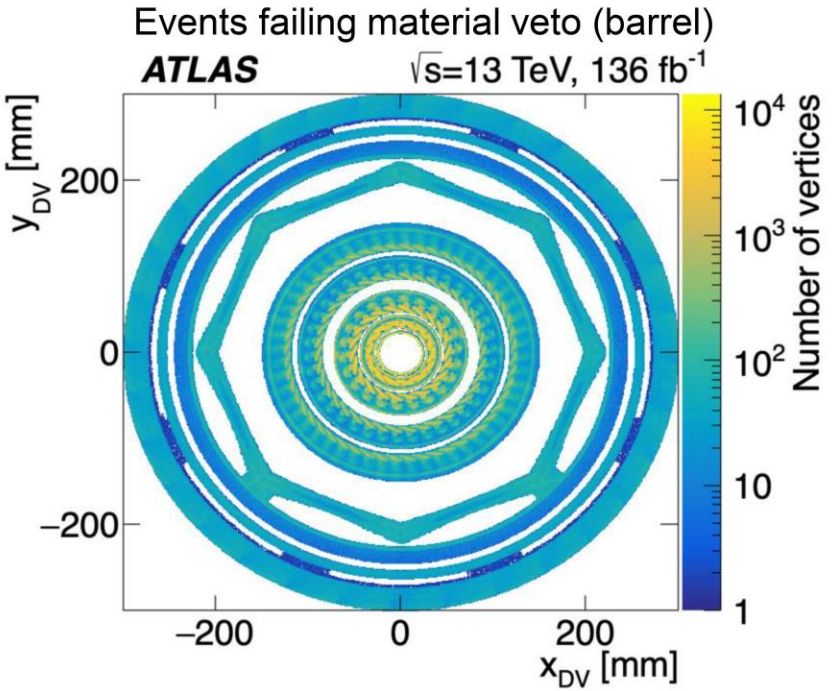
Model:

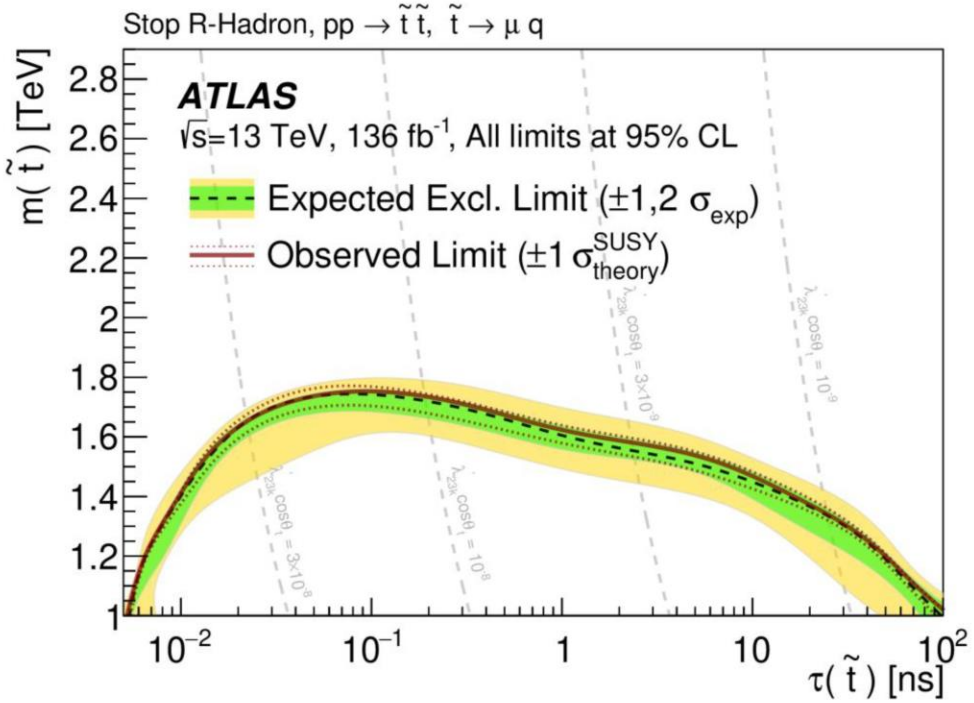
- Stop LSP decays via LQD term (λ') to muon and d/s quark.
- Small $\lambda' \rightarrow$ stop hadronizes, has displaced decay.

Signature:

- Muons with large impact parameters.
- Displaced vertices with 4 mm $< r_{\mathrm{DV}} <$ 300 mm (before the SCT).







Managing SM background:

- Veto DVs with positions consistent with the detector (active + support/services).

Results:

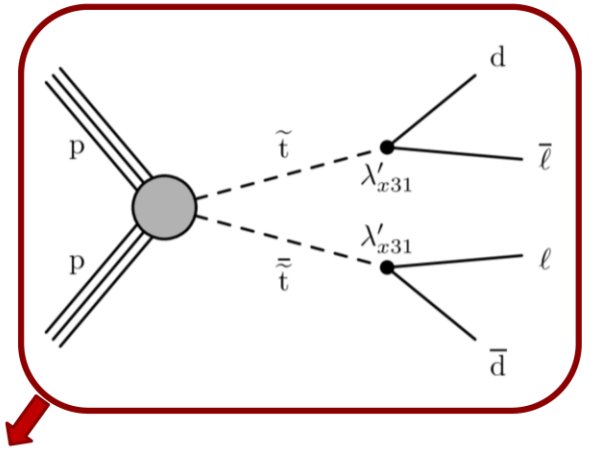
- No events above expected background.
- Set limits in the $m_{\tilde{t}}$ vs $\tau(\tilde{t})$ plane.

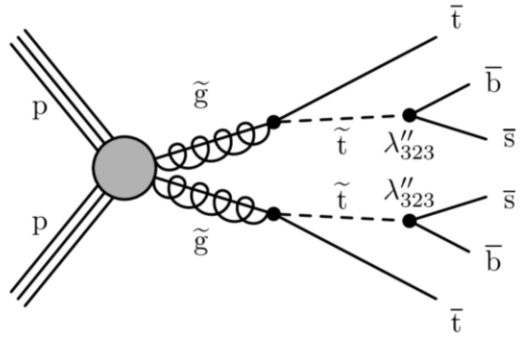
Searches for long-lived particles decaying into displaced jets

CMS-PAS-EXO-19-021

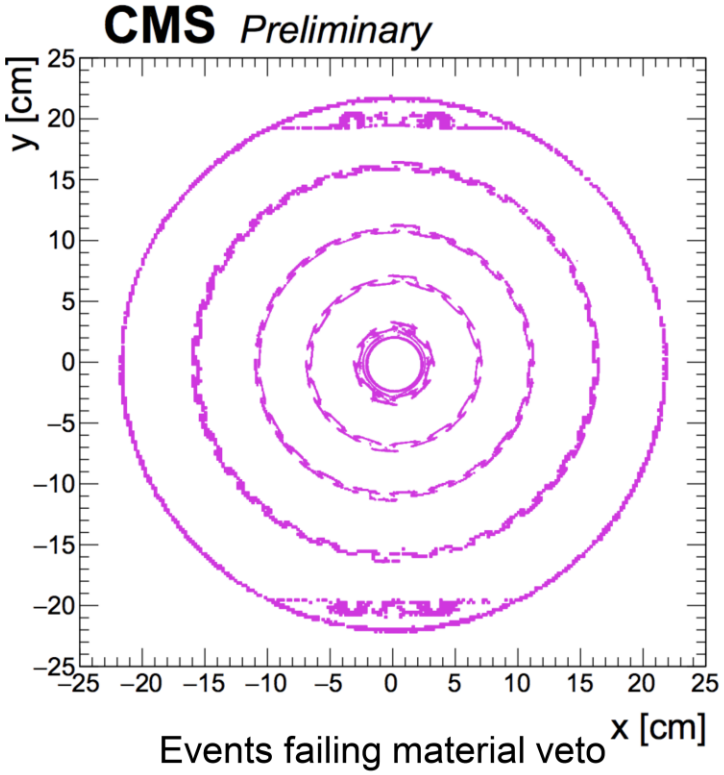
Target Models:

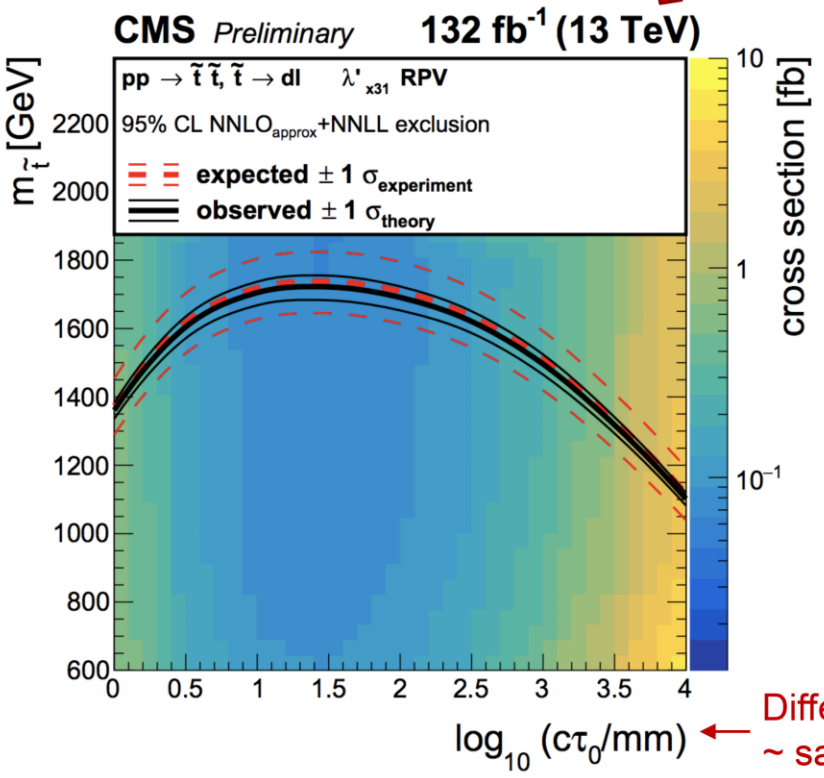
- Many BSM models with LLPs decaying to jets.
- RPV models:
  - $\tilde{t} \to l d_k$ via LQD (λ') and $\tilde{g} \to tbs$ via UDD (λ'').
  - $\tilde{t} \to dd$ via dynamical RPV coupling (η/M).





Long-lived $\tilde{g}$, off-shell $\tilde{t}$.





Different units ~ same range

Signature:

- Dijet systems matched to a displaced vertex.
  - Transverse displacements $r_{\mathrm{DV}} \lesssim 55$ cm.
  - Before outer barrel of the silicon strip tracker.

Results:

- Expected $0.75 \pm 0.44\ (\mathrm{stat}) \pm 0.39\ (\mathrm{syst})$.
- Observed 1 event with a DV with $r_{\mathrm{DV}} = 26$ cm.
  - Close to a silicon strip layer (within ~1 cm).

Discussion of possible topics

- RPV SUSY multijets
  - Gluino with LSP neutralino decay
- Low mass neutralino RPV decay
  - UDD to 3 jets
  - Trigger level analyses for low mass
- B-L MSSM
  - Wino LSP RPV decay
  - Bino LSP RPV decay

- Your ideas?

Veronika Magerl
(Freiburg)