Recent SUSY results on long-lived particles in ATLAS

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on behalf of the ATLAS Collaboration

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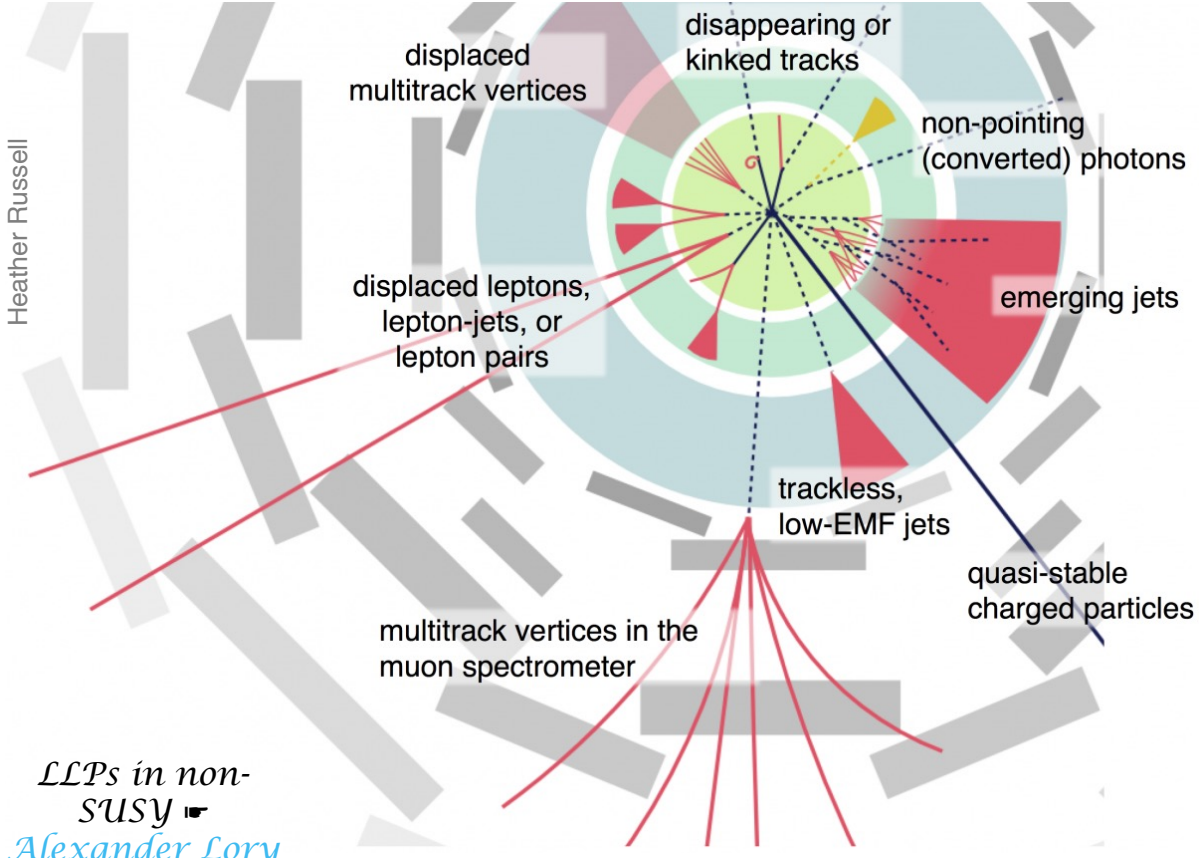
SUSY 2024

Theory meets Experiment

Lifetime frontier



LLPs in non-SUSY ☛ *Alexander Lory*

- Beyond-SM physics not appeared in searches so far
- Maybe we are not looking at the right signals
- Long-lived particles may be the answer
- Different detection techniques involving tracks, photons, leptons, jets, vertices, energy deposits …

Long-lived particles @ SUSY

- Hierarchy of mass scale
  - Split SUSY: long-lived gluinos or squarks that hadronise before decaying → **R-hadrons**
- Small coupling between sparticle and final state
  - gravitational couplings → gauge-mediated symmetry breaking (**GMSB**)
  - weak **RPV** couplings
- Mass degeneracy between sparticles
  - chargino and neutralino wino in anomaly-mediated symmetry breaking (**AMSB**)
  - compressed **higgsinos** in natural scenarios
  - stau and neutralino in **coannihilation** scenarios

1. Pixel dE/dx + hadronic calo ToF
   R-hadrons, GMSB
   ATLAS-CONF-2023-044
2. dE/dx+ToF reinterpretation
   AMSB
   ATL-PHYS-PUB-2024-009
3. Micro-displaced dimuon
   GMSB
   Phys. Lett. B 846 (2023) 138172
4. Diphoton & dielectron
   GMSB
   Phys. Rev. D 108 (2023) 012012
5. Di-tau reinterpretation
   RPV
   ATL-PHYS-PUB-2024-007

Pixel dE/dx + ToF (1)

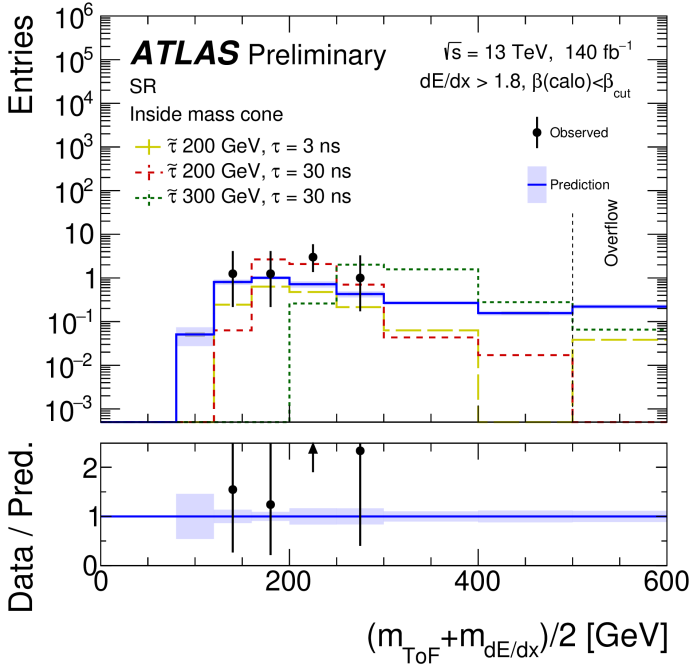
ATLAS-CONF-2023-044

- Targeting singly charged, massive, slow particles: ***m* > 100 GeV, *τ* > 3 ns**
- Based on particle-mass from two *independent* determinations of $\beta\gamma$
  - $\beta\gamma_{dE/dx}$: Bethe-Bloch relation from specific ionisation loss (dE/dx) measured in pixel detector
  - $\beta\gamma_{ToF}$: time of flight (ToF) measured in hadronic calorimeter
- Improves 2022 search, where 3.3σ excess was observed [JHEP 06 (2023) 158]
- Background
  - SM processes with high-p_T tracks, large dE/dx from Landau-distribution tails of MIPs and low-β_{ToF} by ToF mismeasurements
  - fully data-driven background estimation

$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{max}}{I^2} - \beta^2 - \frac{\delta}{2}\right]$$

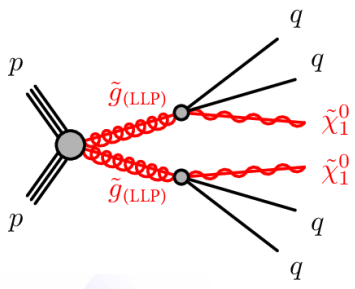
Bethe-Bloch formula

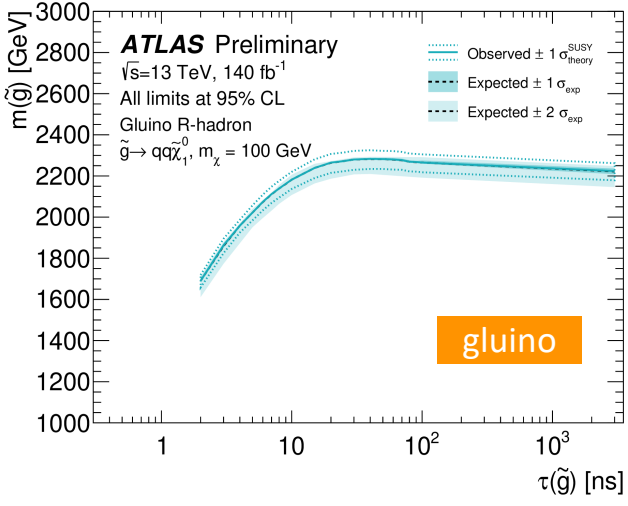
$$m = \frac{p}{\beta\gamma}$$

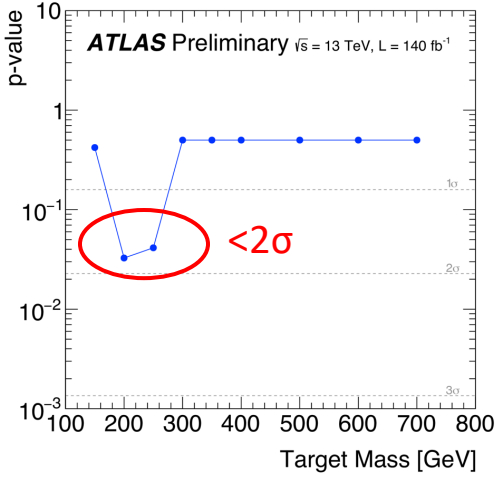


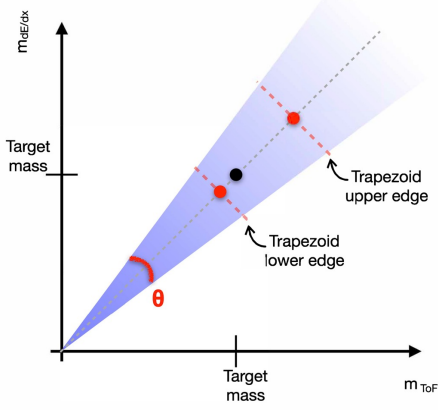
Pixel dE/dx + ToF (II)

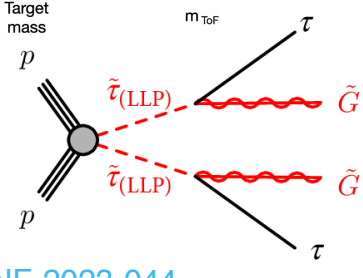
- Agreement with SM expectation
  - observed 9 events in SR
  - expected 5.1±0.5 background events
- If restricted to 22° cone
  - 6 events observed
  - 3.7±0.4 events expected



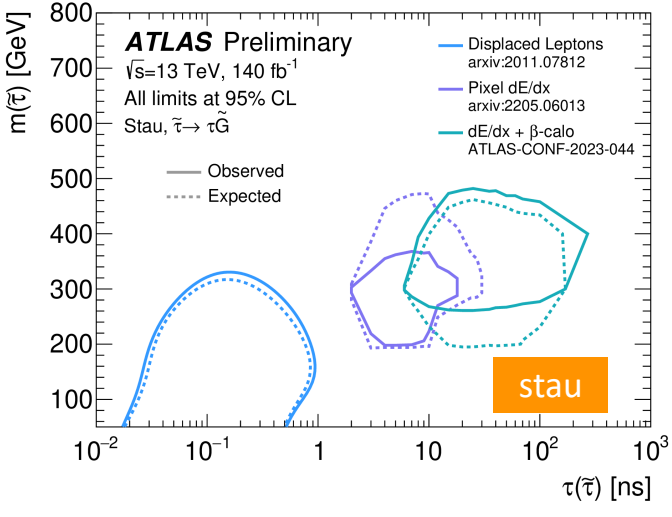






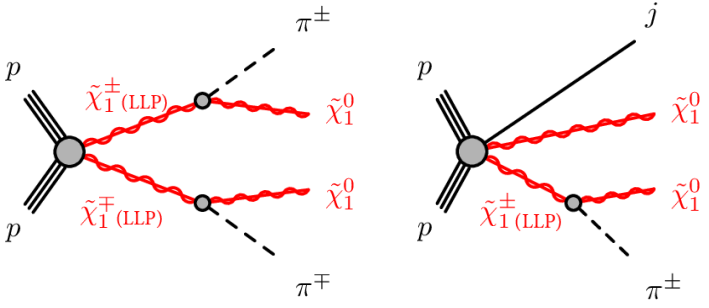


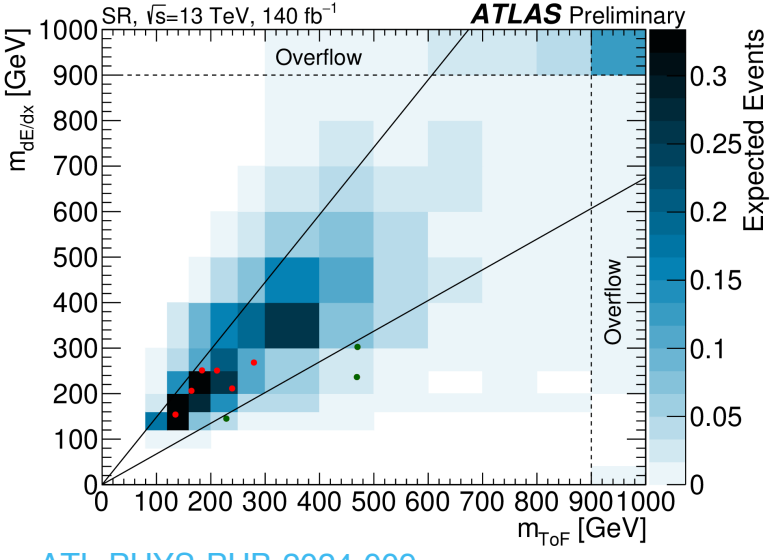
ATLAS-CONF-2023-044



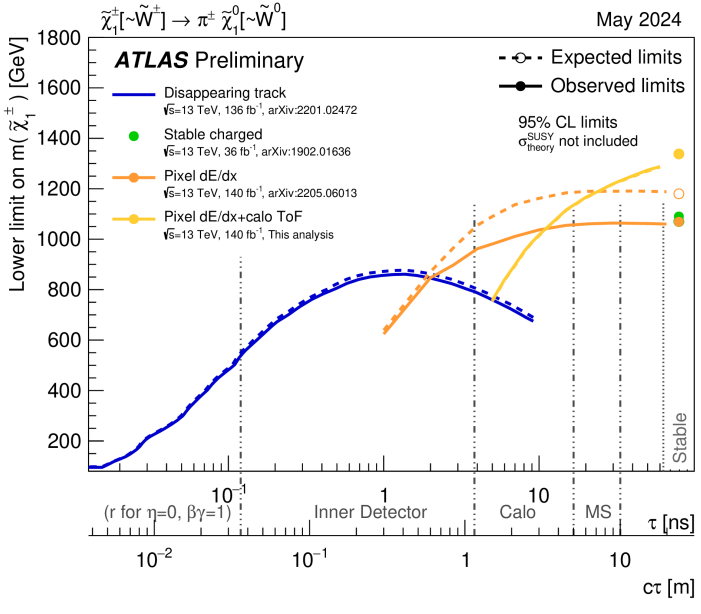
Pixel dE/dx + ToF – chargino reinterpretation

- Chargino signal models complementary to gluino and stau signal models covered in [ATLAS-CONF-2023-044]
- Long-lived ‘pure wino’ chargino in AMSB model





ATL-PHYS-PUB-2024-009

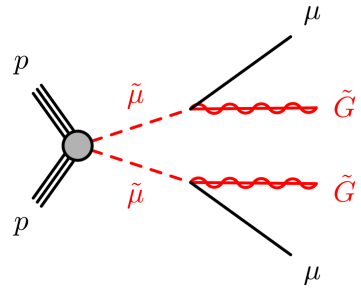


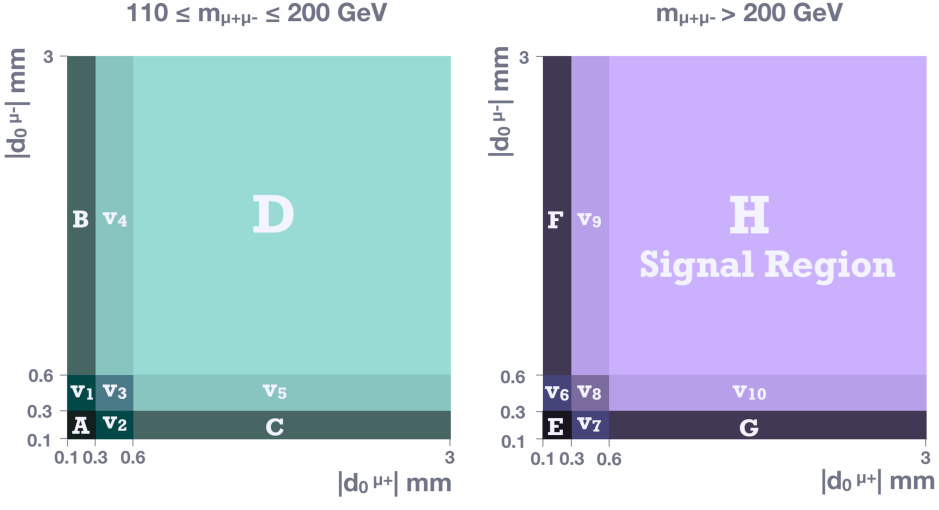
Compressed higgsinos ☛ *Jeff Shahinian*

Dimuon with small displacement

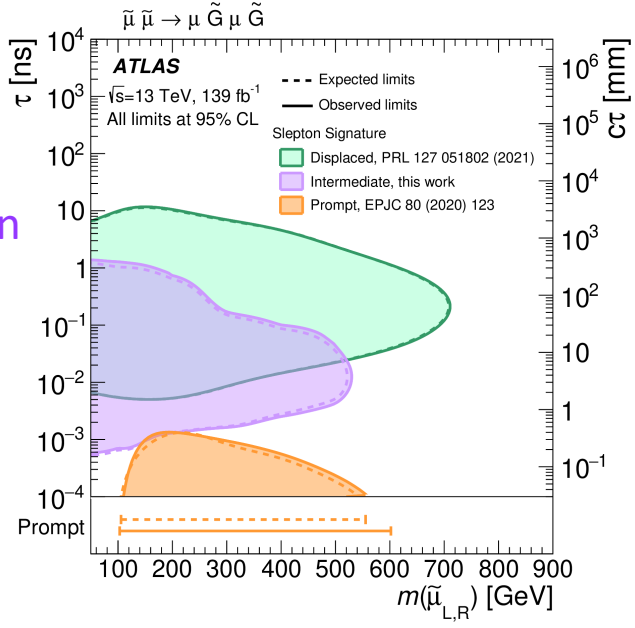
Phys. Lett. B 846 (2023) 138172

- Search for $\mu^+\mu^-$ from smuon decays with $\mathcal{O}$(mm) impact parameter & large $m(\mu^+\mu^-)$
- Motivated by GMSB models; small coupling to LSP
- Dominant SM background: semileptonic B-hadron decays
- Extended ABCD method to estimate background





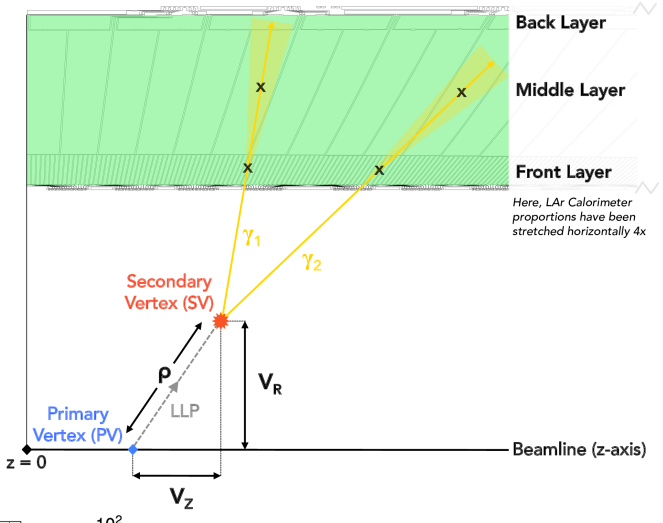
Closes smuon lifetime gap of previous searches

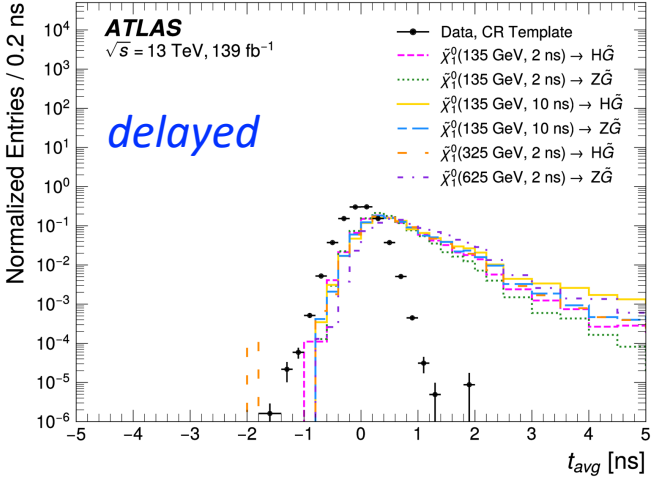


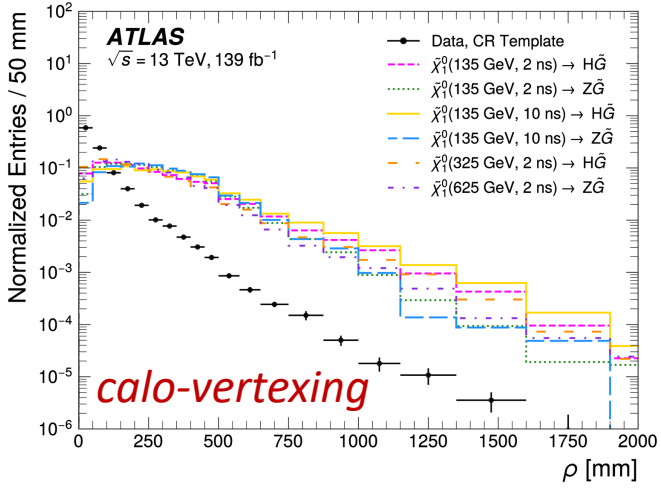
Diphoton and dielectron (1)

- First search for displaced *H/Z* production from neutral LLP decay
- Decay modes: $H \rightarrow \gamma\gamma$ and $Z \rightarrow ee$
- Based on precision spatial and timing capabilities of LAr EM calorimeter (ECAL)
- EM objects reconstructed using only ECAL *without* distinguishing between diphotons and dielectrons
  - delayed
  - nonpointing
- Large MET, too

Phys. Rev. D 108 (2023) 012012



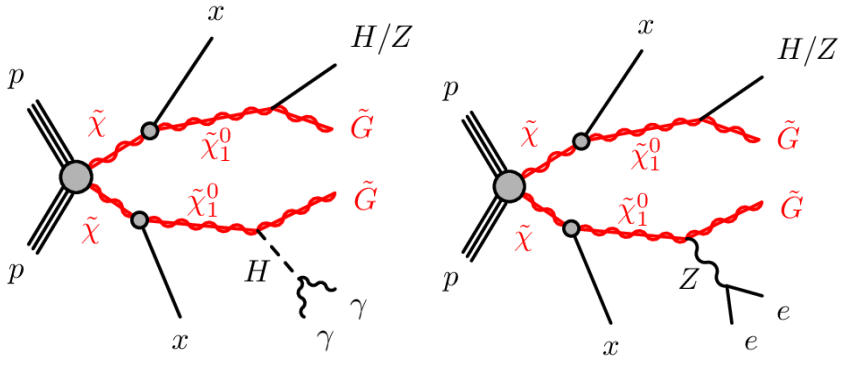


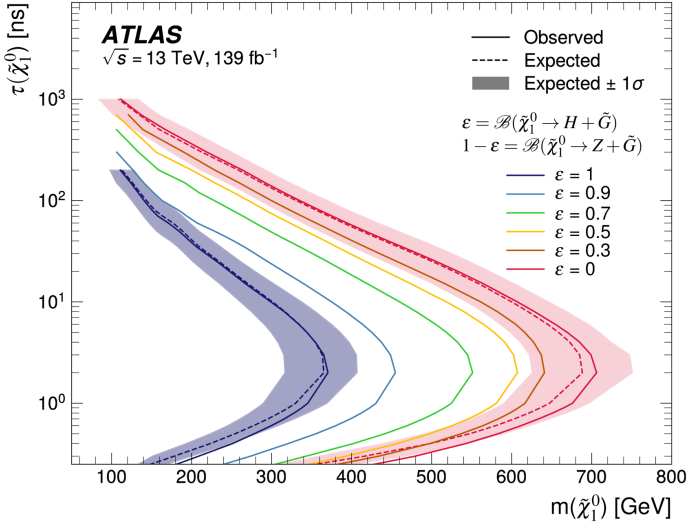


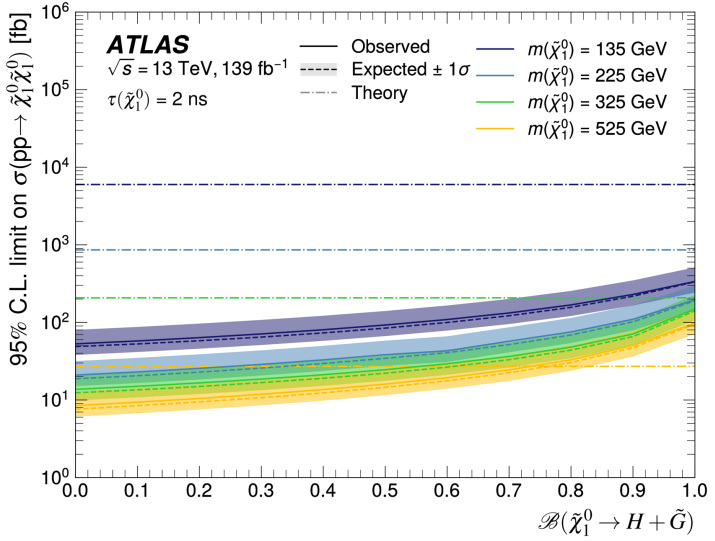
Diphoton and dielectron (II)

Phys. Rev. D 108 (2023) 012012

- No significant deviation observed in data
- GMSB model with pair-produced almost mass-degenerate higgsinos that decay to long-lived NLSP neutralinos
- For BR = 100%, $m(\tilde{\chi}_1^0)$ lower limits are set:
  - 369 GeV (Higgs)
  - 704 GeV (Z)
  - $\tau(\tilde{\chi}_1^0)$ = 2 ns → maximum sensitivity



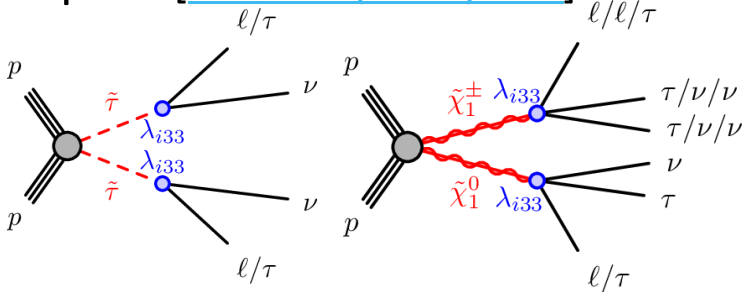


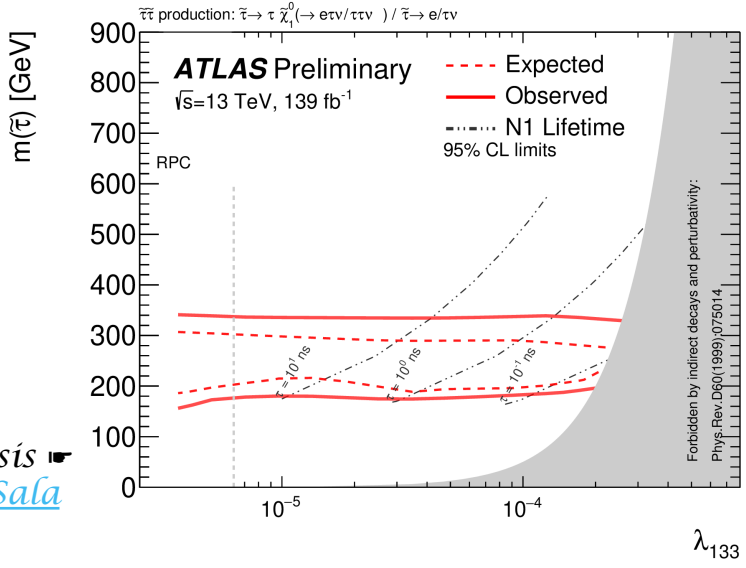


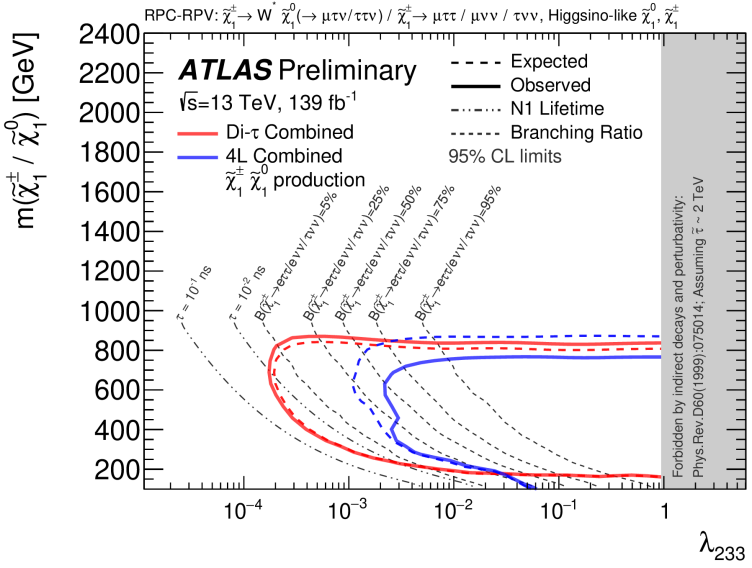
Displaced τ from RPV SUSY

ATL-PHYS-PUB-2024-007

- Reinterpretation of di-τ [JHEP 05 (2024) 150] and 4-lepton [JHEP 07 (2021) 167] analyses for *prompt* decays
- Constrains RPV with coupling strength λ_{133} and λ_{233}
- Stau and higgsino models



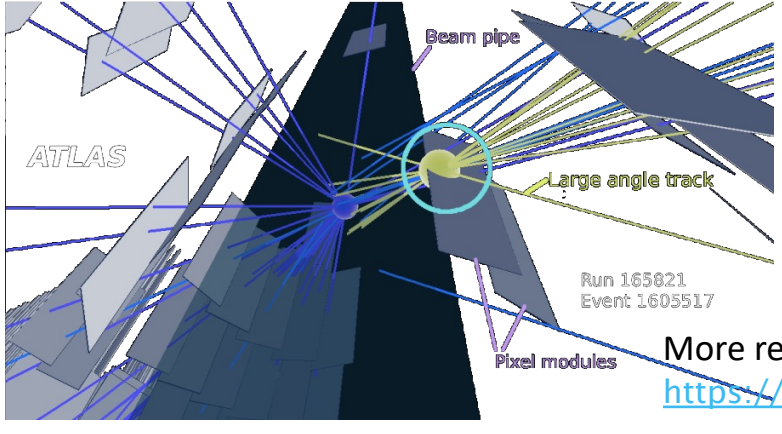




Di-tau analysis ☛ *Alessandro Sala*

Summary

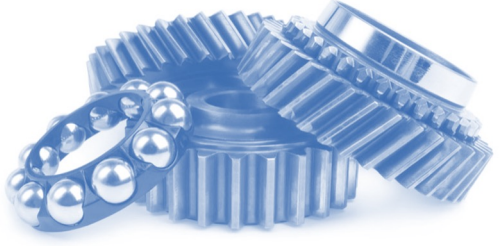
- **LLPs** might be the key for finding BSM physics, including SUSY
- Ever increasing effort at LHC experiments to discover LLPs
- Development of new tools and strategies to improve identification of LLPs, pushing detector beyond original design capabilities
- No hints of SUSY signal in LLP searches so far
- Many more results expected from Run 3 and HL-LHC



More results:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

Thank you for your attention!

Spares



R-parity violation

$$W_{\not R p} = \underbrace{\lambda_{ijk}\hat{L}_i\hat{L}_j\hat{E}^C_k + \lambda'_{ijk}\hat{L}_i\hat{Q}_j\hat{D}^C_k}_{L\text{-number violation}} + \underbrace{\epsilon_i\hat{L}_i\hat{H}_u}_{\text{bilinear terms}} + \underbrace{\lambda''_{ijk}\hat{U}^C_i\hat{D}^C_j\hat{D}^C_k}_{B\text{-number violation}}$$

R-parity conservation hinted but *not required* by proton stability

$$R = (-1)^{3(B-L)+2s}$$

$$R = \begin{cases} +1 \text{ for SM particles} \\ -1 \text{ for superpartners} \end{cases}$$

In *R*-parity violating SUSY

- LSP is ***not* stable**
- LSP may be charged and/or carry colour
- **MET** may be small (due to v's) or vanishing
- **resonant LSP reconstruction** (impossible in RPC SUSY)
- LSP may be long-lived → **displaced vertices**