Long-lived particle searches by ATLAS and CMS

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on behalf of the ATLAS and CMS collaborations

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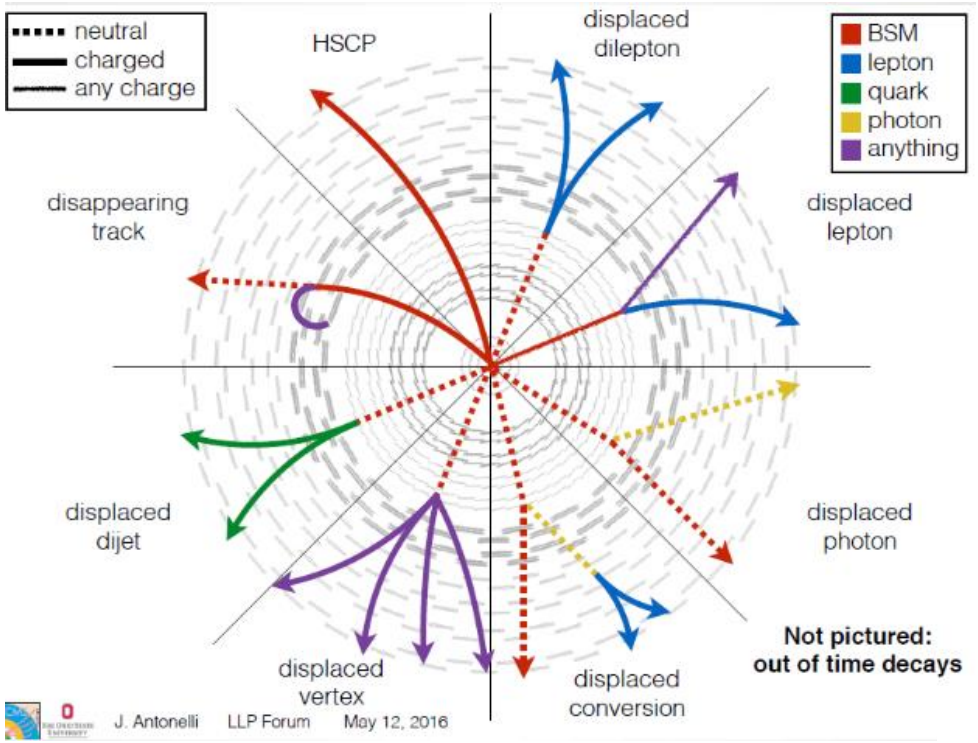
LLP signatures

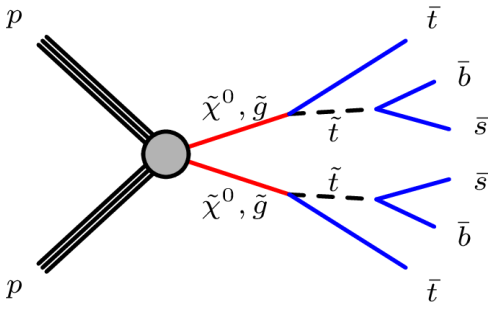
- Theoretical motivations:
- No new physics beyond Standard Model (SM) observed looking for promptly decaying new particles
- Several scenarios predict new long-lived particle (LLP) production : R-parity violating supersymmetry, split SUSY, anomaly mediated supersymmetry breaking model or also hidden valley models
- A wider parameter space of physics beyond the Standard Model could be probed

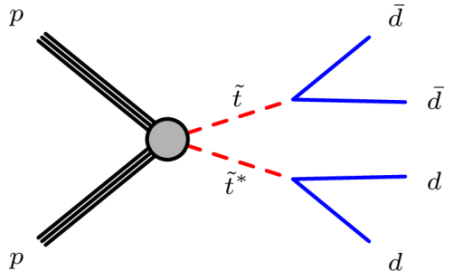
- New experimental signatures:
- Long lifetimes: starting from picoseconds … up to days or even more
- Anomalous loss of energy (dE/dx)
- Time of flight in the muon system
- (…)



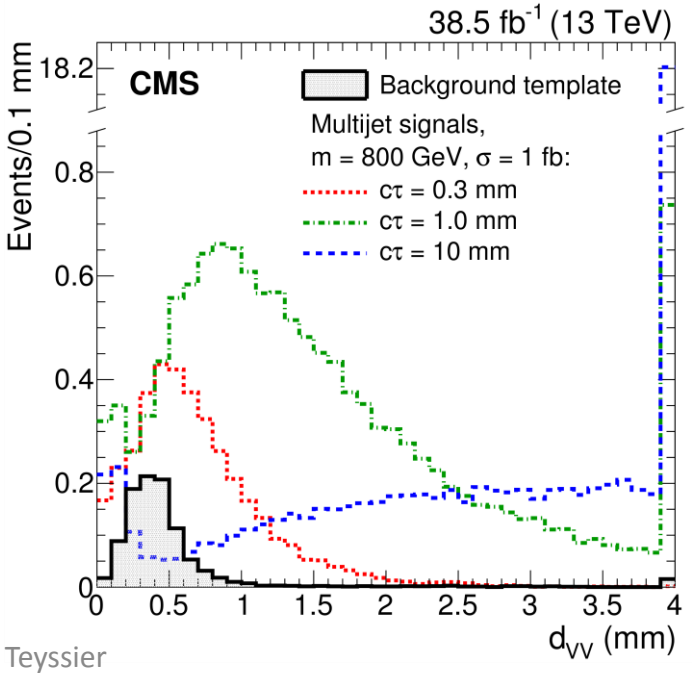
Displaced vertices

- Search for displaced vertices in CMS (CMS-EXO-17-018 ; CERN-EP-2018-203):
- Predicted in many BSM scenarios
- In the case of RPV SUSY, long-lived particles will be neutralinos, gluinos (l) or top squarks (r)





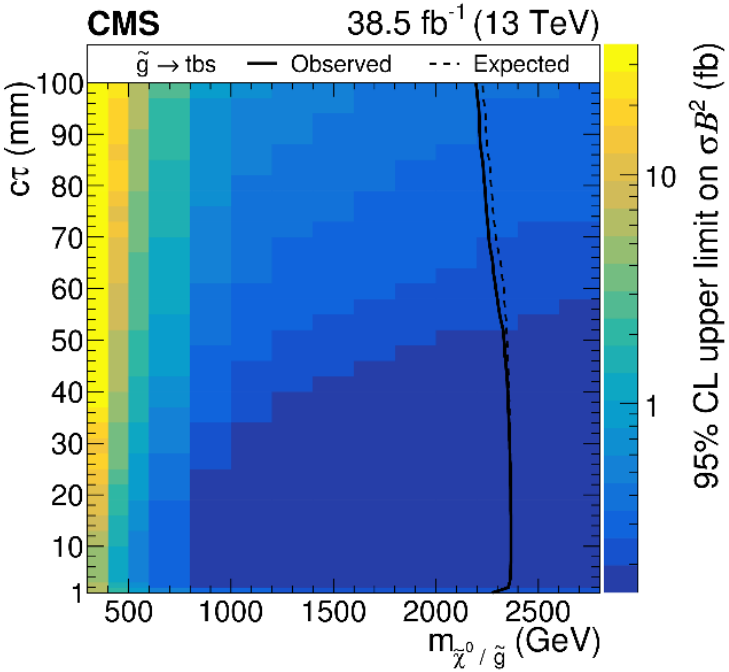
- Experimental signature : two displaced vertices shifted from beam axis (SM background : single vertex and near beam axis)
- d_{vv} : distance between vertices in the orthogonal plane to the beam axis for simulated multijet signals

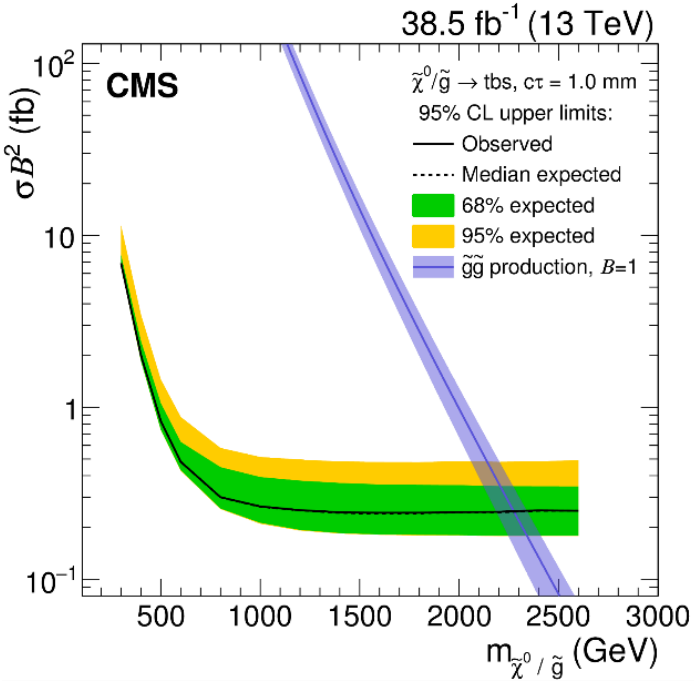


Displaced vertices

Observed 95% CL upper limits on $\sigma\beta^2$ for the multijet signal as a function of mass and mean proper decay length

- Background template is constructed using control sample
- Systematics uncertainties mainly coming from vertex reconstruction (in overall 24% on signal efficiency)



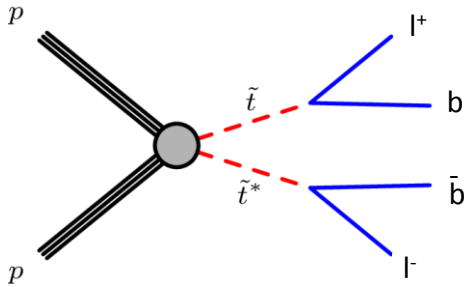


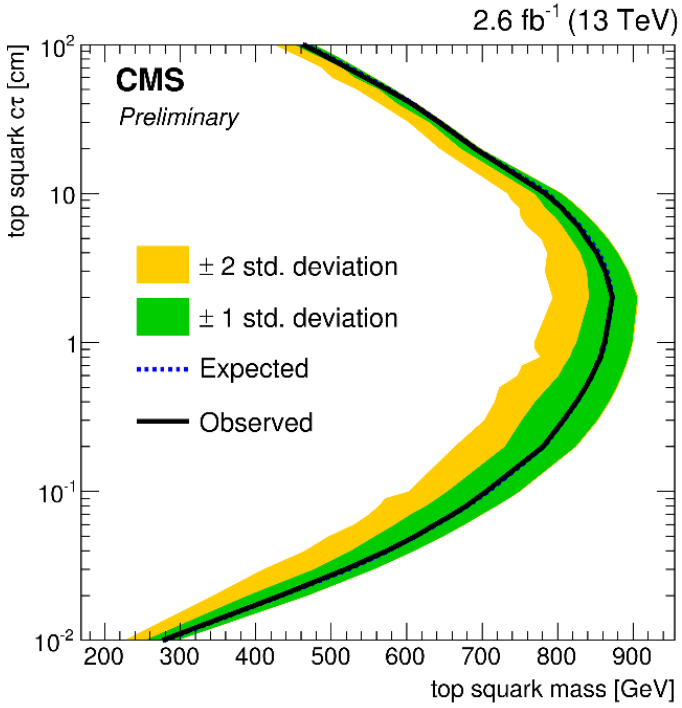
- Observed and expected 95% CL upper limits on $\sigma\beta^2$ for a fixed $c\tau$ value of 1.0 mm, for multijet signal
- $\sigma\beta^2$ ~0.3 fb excluded for masses between 800 and 2600 GeV and mean proper decay lengths between 1 and 40 mm

Similar analysis performed in ATLAS: *Phys. Rev. D 97 (2018) 052012*

Displaced leptons

- Search for displaced leptons in CMS (CMS-PAS-EXO-16-022):
- A search for displaced leptons in the e-mu channel was performed in CMS using first 13 TeV data
- The typical signature results in a transverse impact parameter in the range 100 µm up to 10cm
- For instance in displaced SUSY model, including R-parity violating terms, gives an LSP that can decay into SM particles: pair of top squarks production

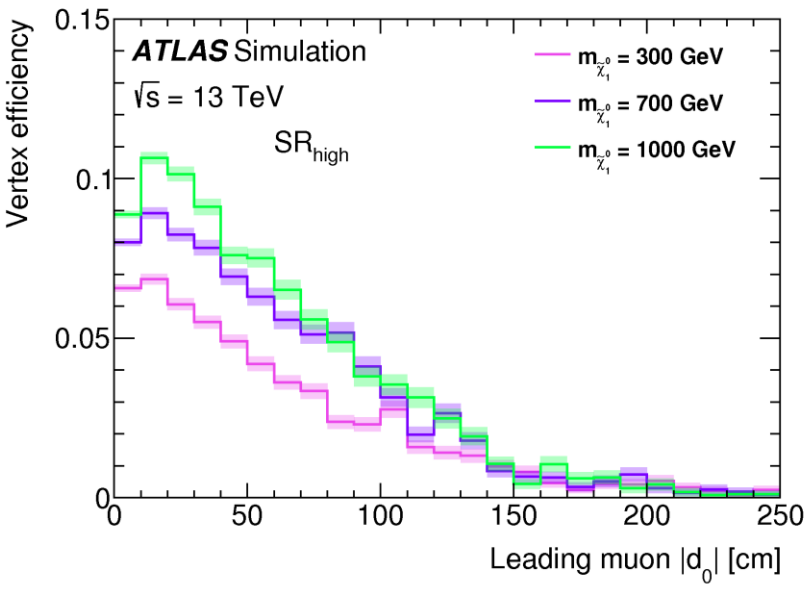


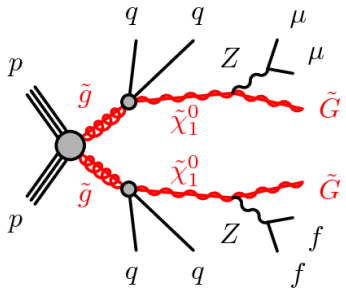


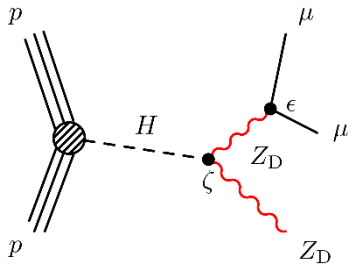
- Dedicated trigger to target displaced e-µ pairs
- For a lifetime hypothesis of 2cm/c, top squarks excluded up to 870 GeV

Displaced leptons

- Search for displaced muon vertices in ATLAS (arXiv:1808.03057):
- The ATLAS muon spectrometer allows the search for muon displaced vertices in a large volume, few cm up to few m from the interacting point, corresponding to LLP masses between 20 GeV and 1100 GeV
- Several BSM scenarios can produce such displaced muon vertices, general gauge-mediated supersymmetry (left) as well as dark-sector gauge boson model (weakly interacting with SM matter via coupling to the Higgs field, right):



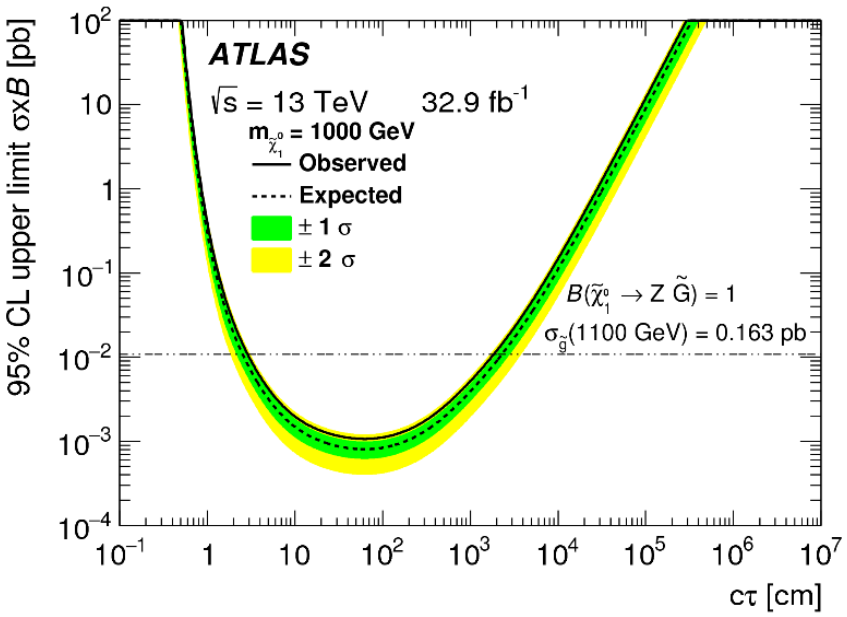




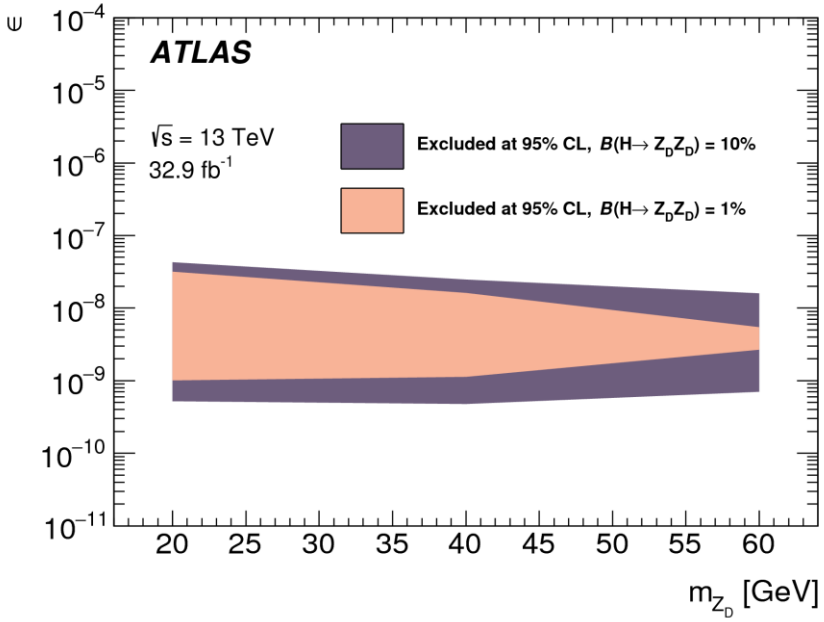
(Z_D = "dark photon")

Background contributions (cosmic muons, fake muons or pion/kaon decays) estimated using control regions and inverting some cuts in the offline analysis

Displaced leptons



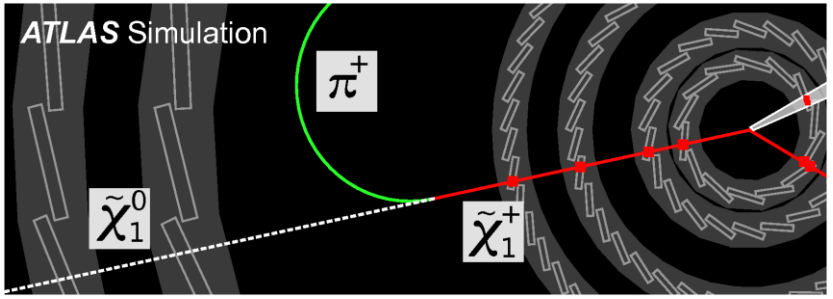
- Upper cross-section limit (long-lived particle mass = 1000 GeV)



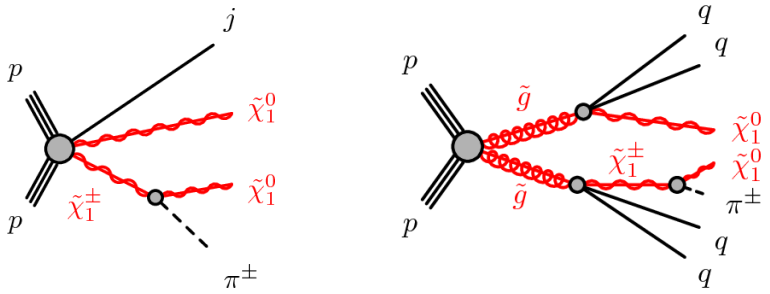
- Exclusion region in the plane ϵ (kinetic mixing parameter) versus Z_D mass, with different assumptions of the BR(H → Z_D Z_D)
- Values of ϵ of the order 10^{-8} excluded for Z_D masses in the range 20 GeV to 60 GeV

Disappearing tracks

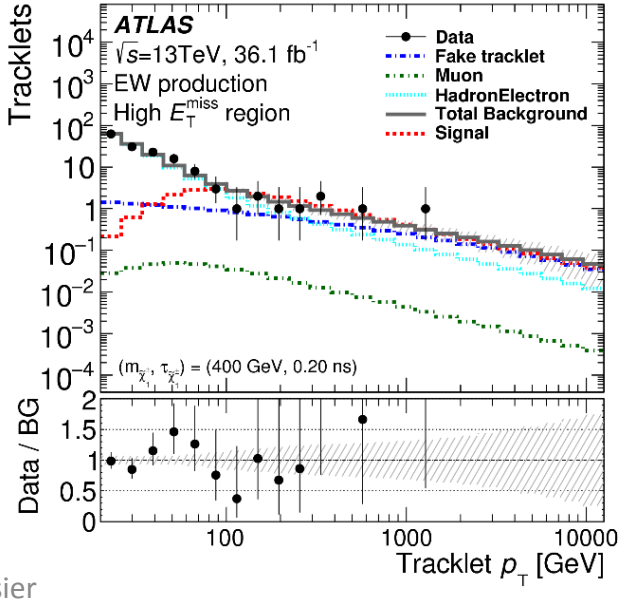
- Disappearing tracks as a signature of new long-lived particles in ATLAS (JHEP 06 (2018) 022):
- For instance anomaly-mediated supersymmetry breaking (AMSB) scenarios predict a chargino life-time around 1 ns
- The long-lived chargino decays into a pion (low momentum, not reconstructed) and the lightest supersymmetric particle (LSP), one neutralino:



- Electroweak (left) or strong production (right):

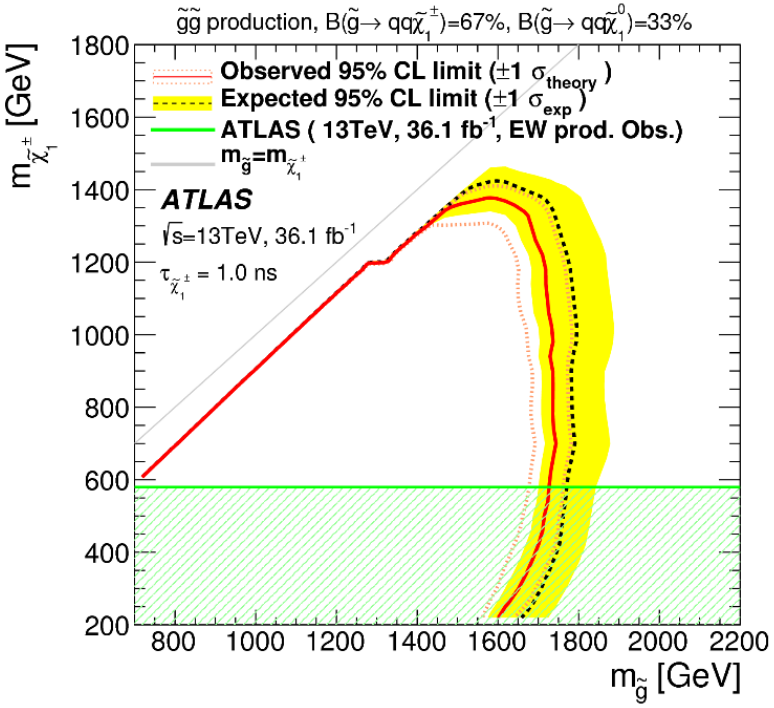


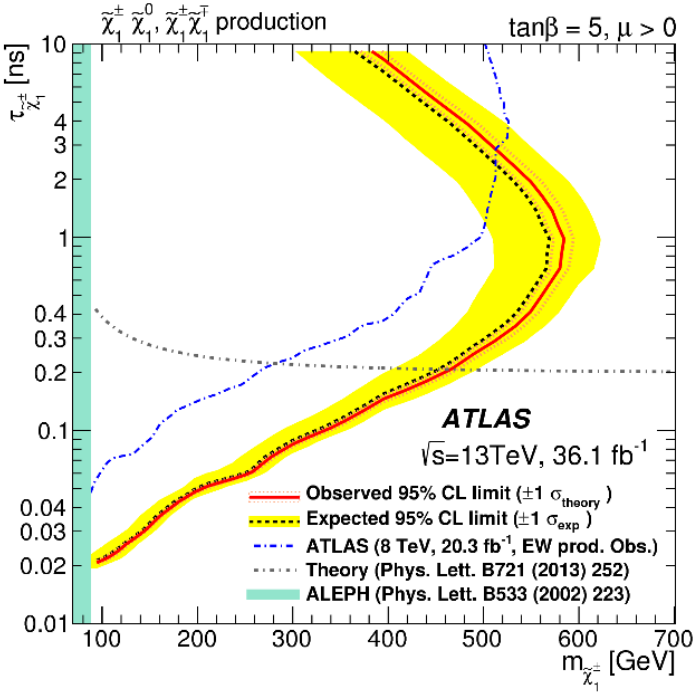
- Experimental signature: pixel track ("tracklet") *without associated hits in the rest of the silicon tracker* (= disappearing track), large missing transverse momentum and also high energetic jets



Disappearing tracks

- 95% CL electroweak channel exclusion limits in the plane chargino lifetime and mass, using 2015 and 2016 data



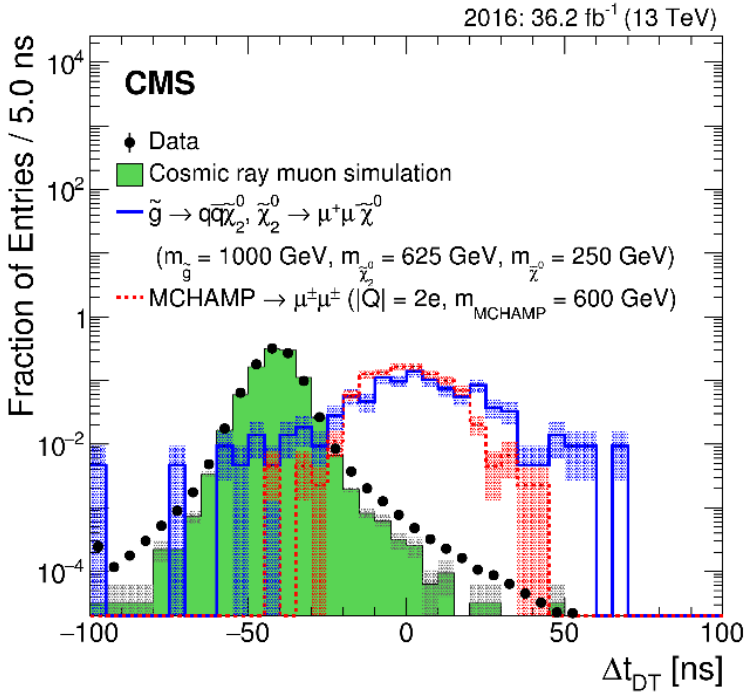


- 95% CL exclusion limit in the strong channel in the plane chargino-gluino masses, using chargino lifetime assumption of 1 ns and a compressed spectra hypothesis (mass difference lower than 200 GeV)

Similar analysis performed in CMS: *JHEP 08 (2018) 016*

Stopped LLP

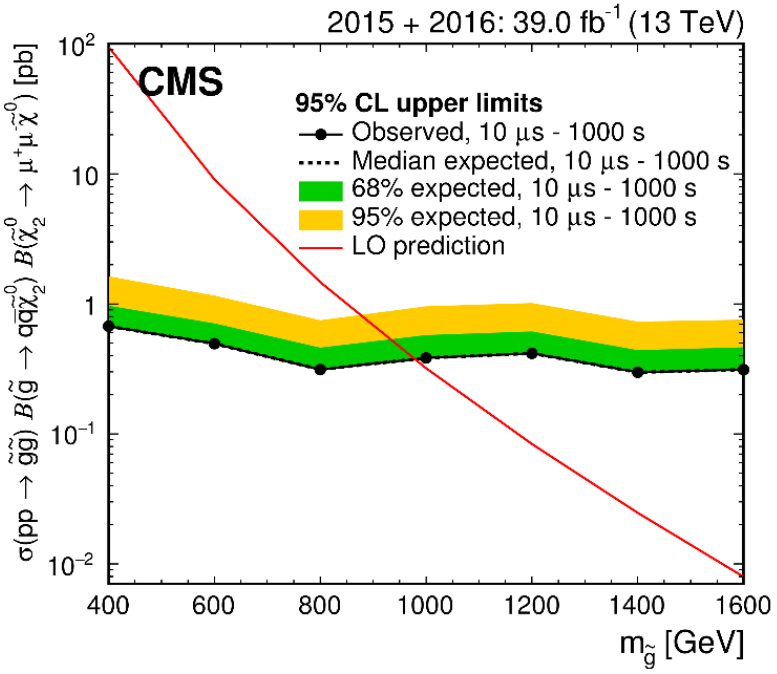
- Decays of stopped exotic long-lived particles in CMS (*JHEP 05 (2018) 127*):
- A search for heavy exotic LLP was performed, looking for lifetimes between 100 ns up to 10 days
- Nuclear interactions and/or ionisation can stop completely heavy LLP
- out-of-collision time used to discriminate these decays, using dedicated trigger to select events away by more than 50ns from the pp collisions
- Experimental signature: large energy deposit in calorimeters or displaced muon tracks

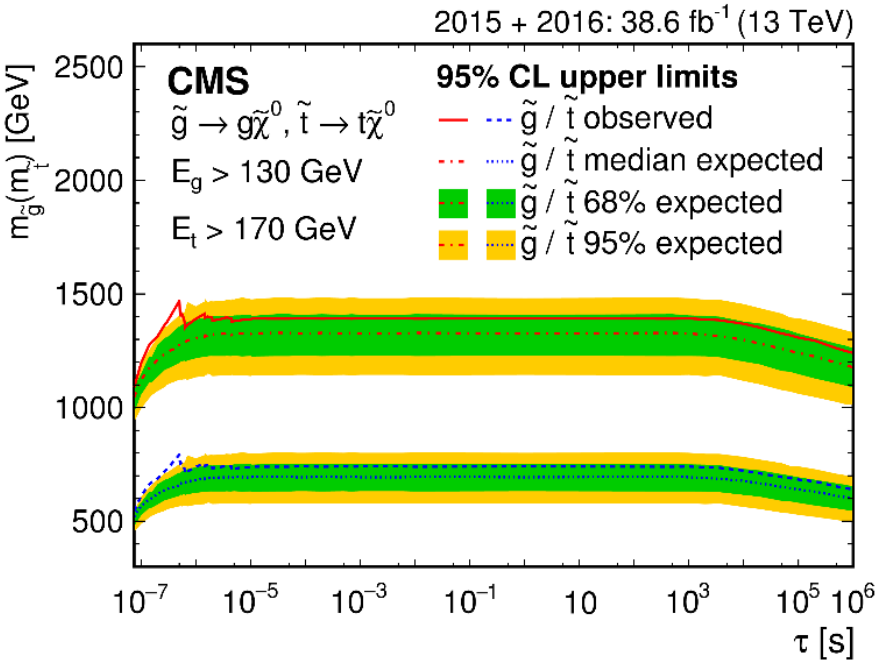


- Specific cosmic runs with these dedicated triggers were taken several days after the beams stopped to get a control sample
- Main backgrounds are the cosmic muons, beam halo and hadronic calorimeter noise
- Split SUSY model: two candidates as LLP (gluino and/or top squarks) and BSM scenarios predict some doubly-charged LLP, that could decay into a pair of same-sign muons

Stopped LLP

- Calorimeter search results: lifetimes between 10 μs and 1000 s excluded for $m_{\tilde{g}} < 1385$ GeV and $m_{\tilde{t}} < 744$ GeV



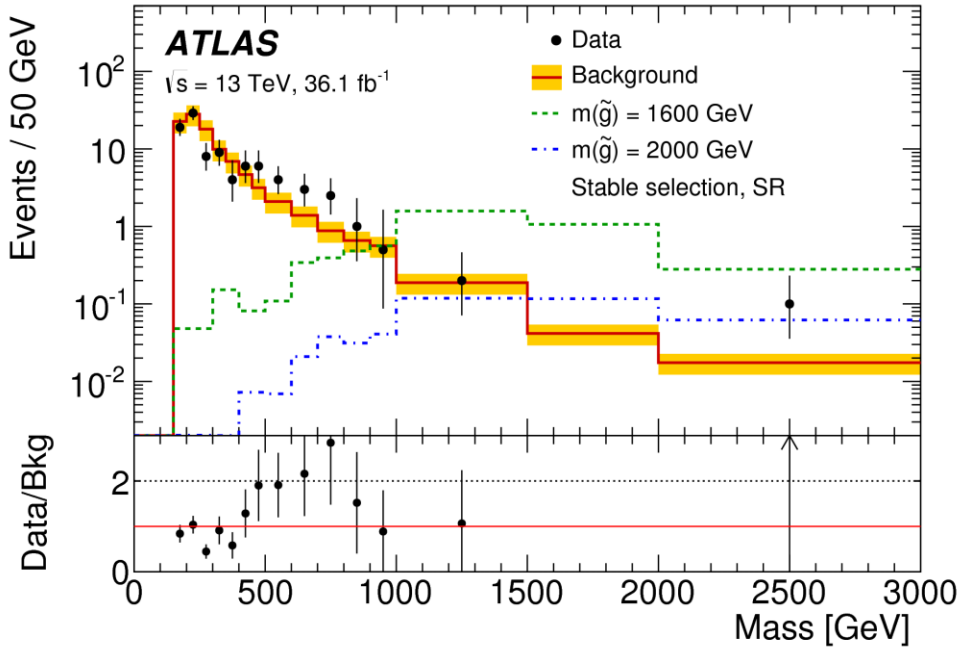


- Muon pairs search results: gluino mass excluded between 400 and 980 GeV for cτ in the range 10 μs and 1000 s

Similar analysis performed in ATLAS: *Phys. Lett. B 743 (2015) 15*

Heavy charged LLP

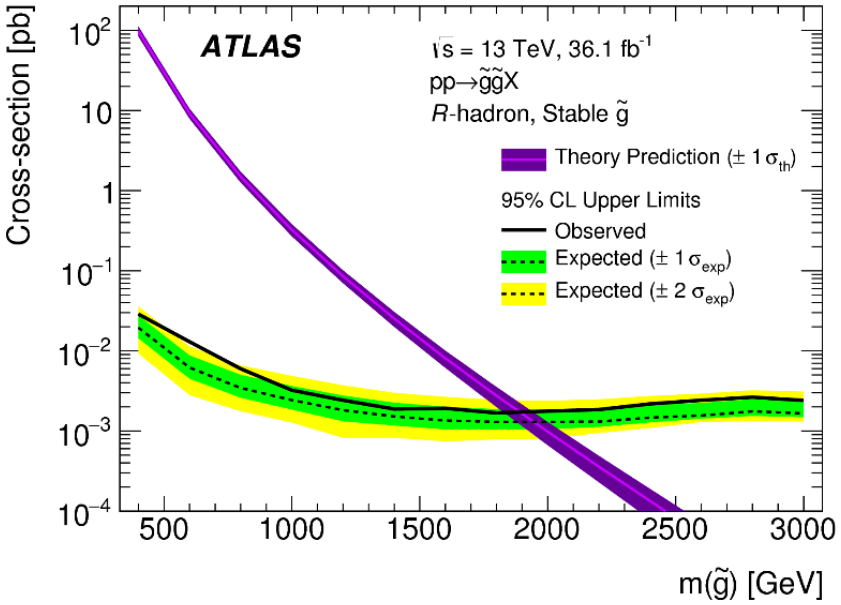
- Search for heavy stable charged particles in ATLAS (arXiv:1808.04095):
- Several SUSY models (split SUSY, AMSB) predict the production of R-hadrons, composite colourless states of a gluino together with SM quarks or gluon
- Heavy charged long-lived particles are supposed to travel well below c, giving higher ionisation than SM particles

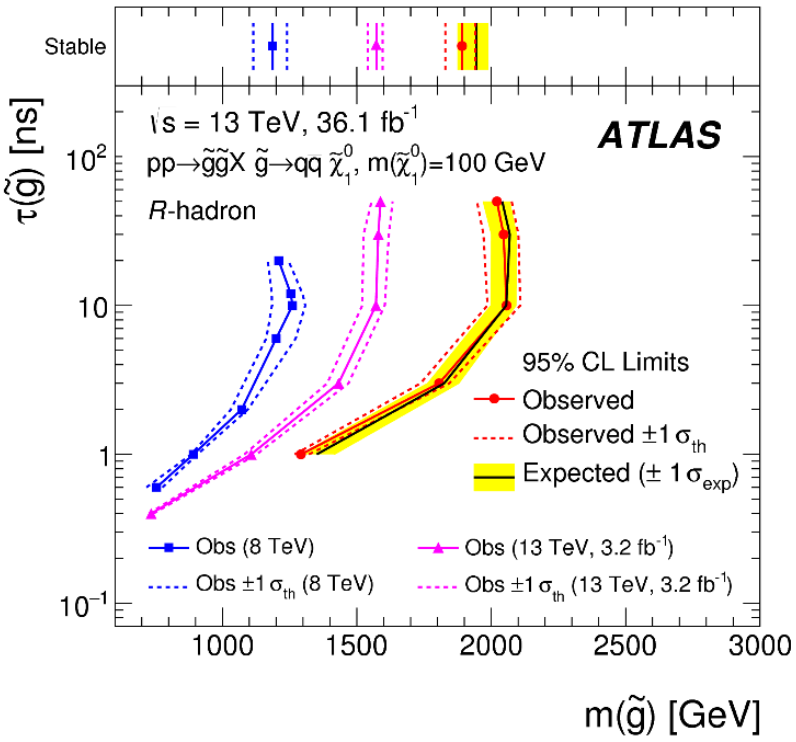


- Pixel detector is used to measure the ionisation energy loss of charged particles (dE/dx)
- For metastable R-hadrons, large transverse missing momentum from neutralinos, while stable R-hadrons will not decay inside the detector

Heavy charged LLP

- Gluino masses excluded up to 1809 GeV for stable LLP

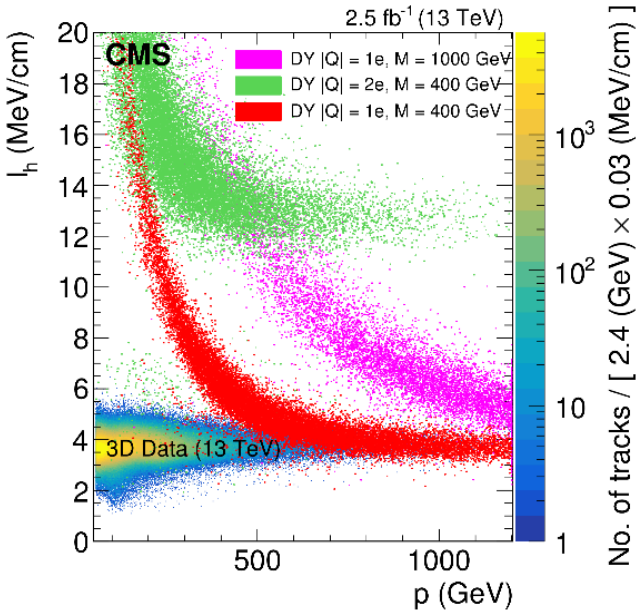




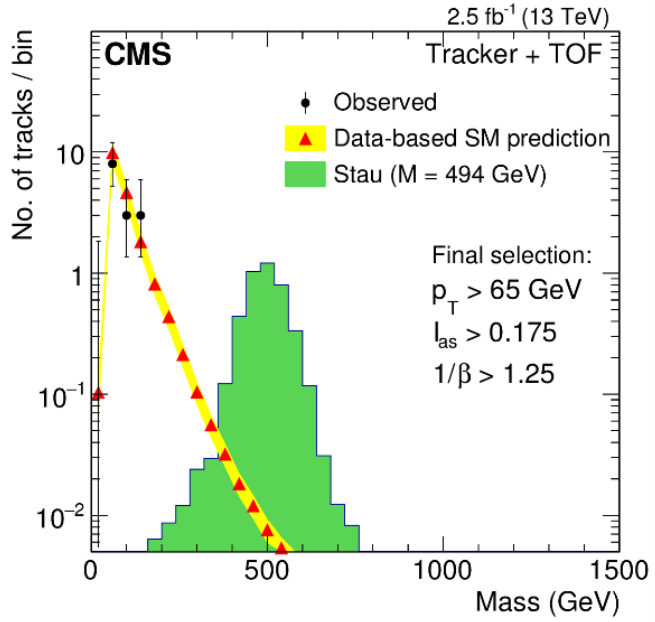
- Observed 95% CL limits on gluinos masses and lifetimes, using 8 TeV data (blue), first 13 TeV data (pink) and finally full 2015/2016 datasets (red)
- Sensitivity for shorter than 1ns lifetimes falls sharply and will be complemented by displaced vertices/disappearing tracks searches

Heavy charged LLP

- Search for heavy stable charged particles in CMS (*Phys. Rev. D 94 (2016) 112004*):
- Both tracker and muon system combined in CMS search for HSCP
- dE/dx from silicon tracker:



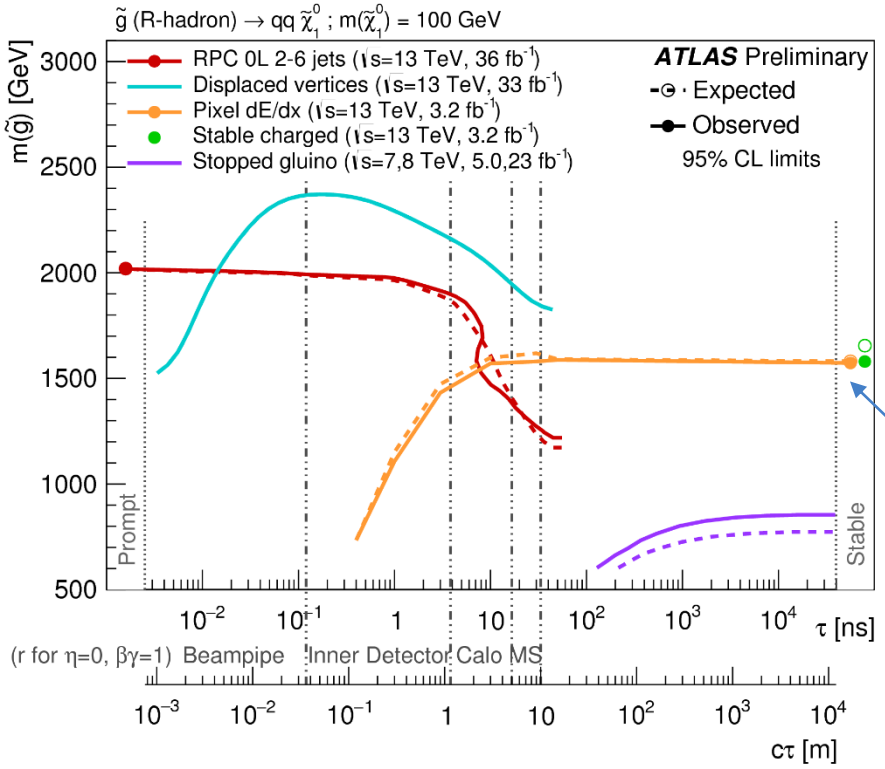
Adding the time of flight in muon system:



- New mass limits for long-lived gluinos, top squarks, tau sleptons and multiply charged LLP derived, improving Run 1 of LHC limits
- R-hadron like HSCP limits given for several gluino-gluon hadronization fractions and two different interaction models
- Gluino mass limit up to 1610 GeV

Reinterpretation

- Reinterpretation of (prompt decay) SUSY searches in ATLAS (ATLAS-CONF-2018-003)*:*
- A set of nine ATLAS SUSY searches were reinterpreted in the context of long-lived particle searches
- RPV coupling strength could be varied: LSP could be stable/long-lived particle

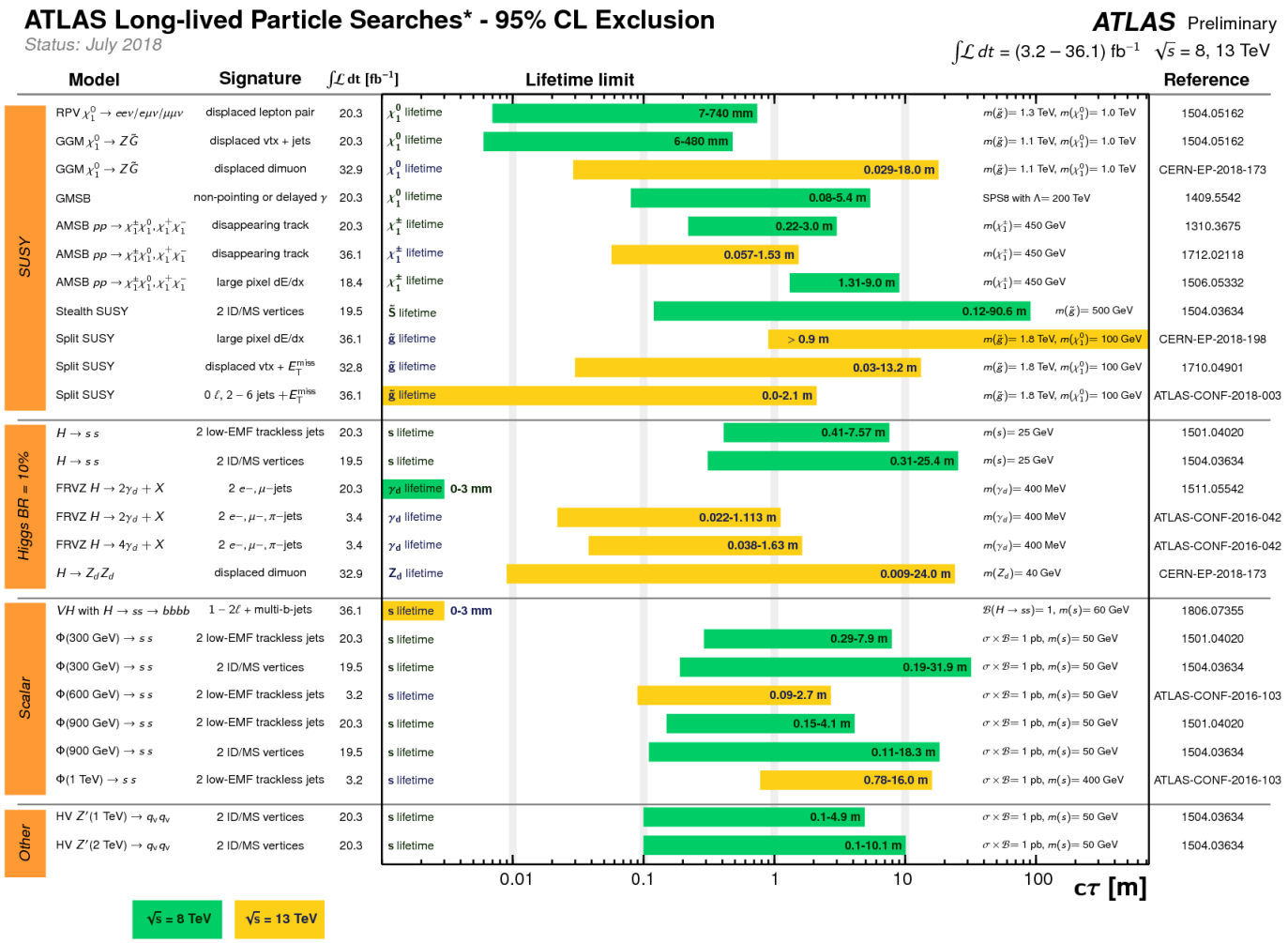


95% CL exclusion limits of R-hadron lifetimes vs. gluino mass (region under curves is excluded)

Escaping the detector

ATLAS summary

- ATLAS summary LLP searches:



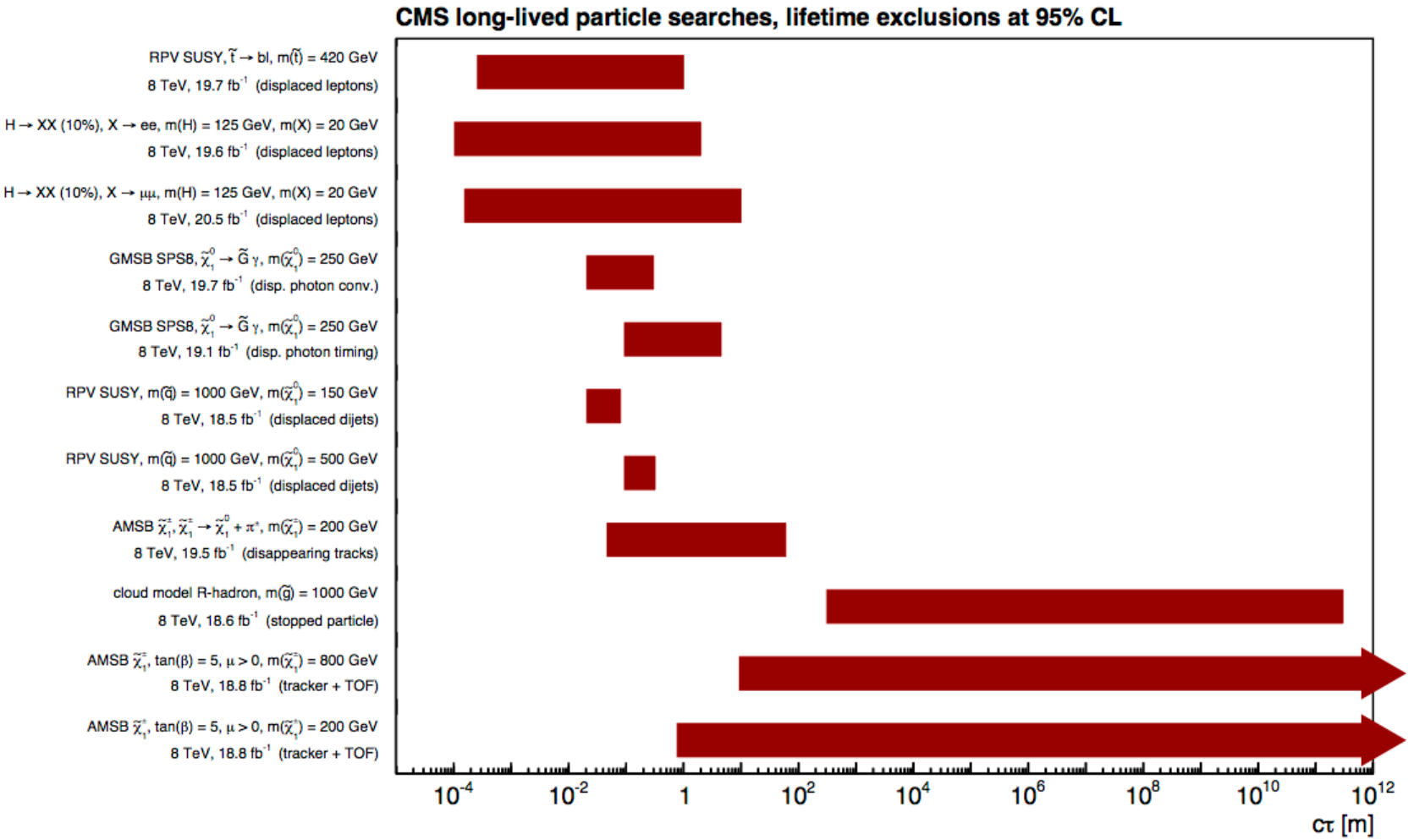
Conclusion

- Long-lived new particle searches are complementary to prompt decay searches
- A lot of new experimental signatures emerge from several theoretical scenarios
- No deviations from SM background observed
- New lower mass limits were set in different SUSY or BSM scenarios
- Several order of magnitude of LLP lifetimes probed by both ATLAS and CMS
- Sensitivity will be improved using latest run 2 of LHC data and/or next run 3 data

Backup

CMS summary

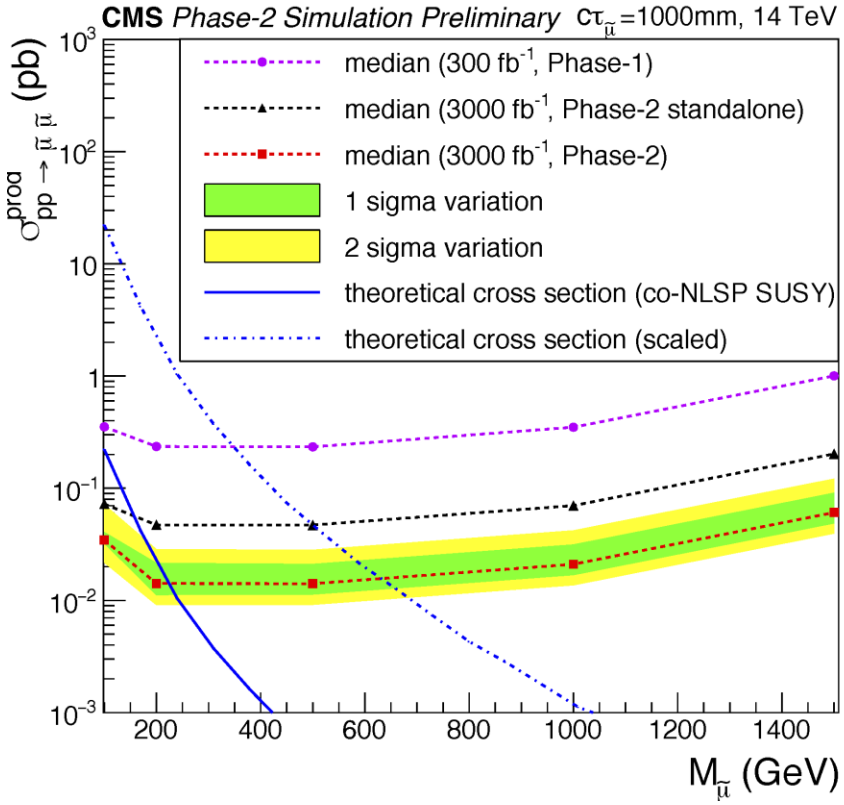
- CMS summary LLP searches:



HL-LHC

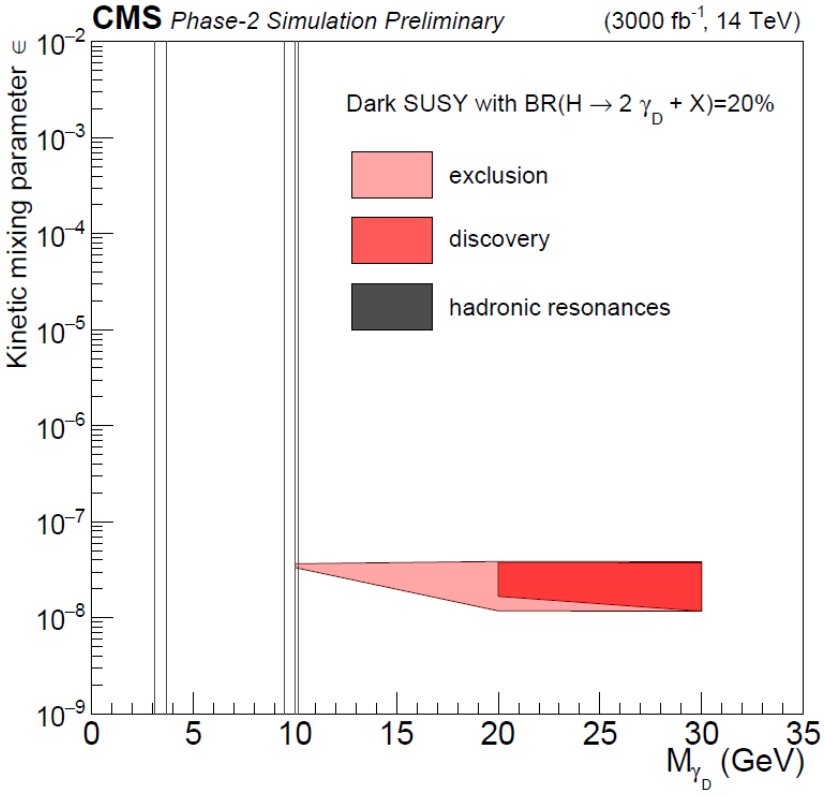
Improved sensitivity @ HL-LHC for displaced muons:

CMS-TDR-016



GMSB-SUSY smuons are LLP

FTR-18-002



Dark SUSY (dark) photons are LLP