

Supersymmetry searches at the LHC

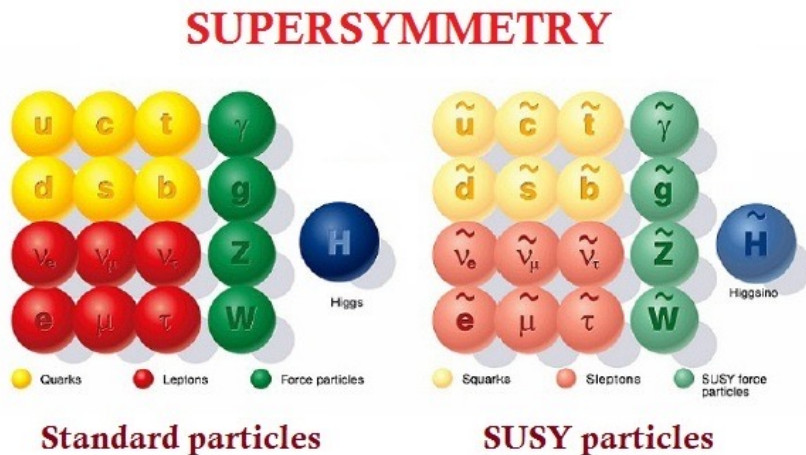
Run-2 result highlights from ATLAS and CMS

T. Cheng (Beihang University)



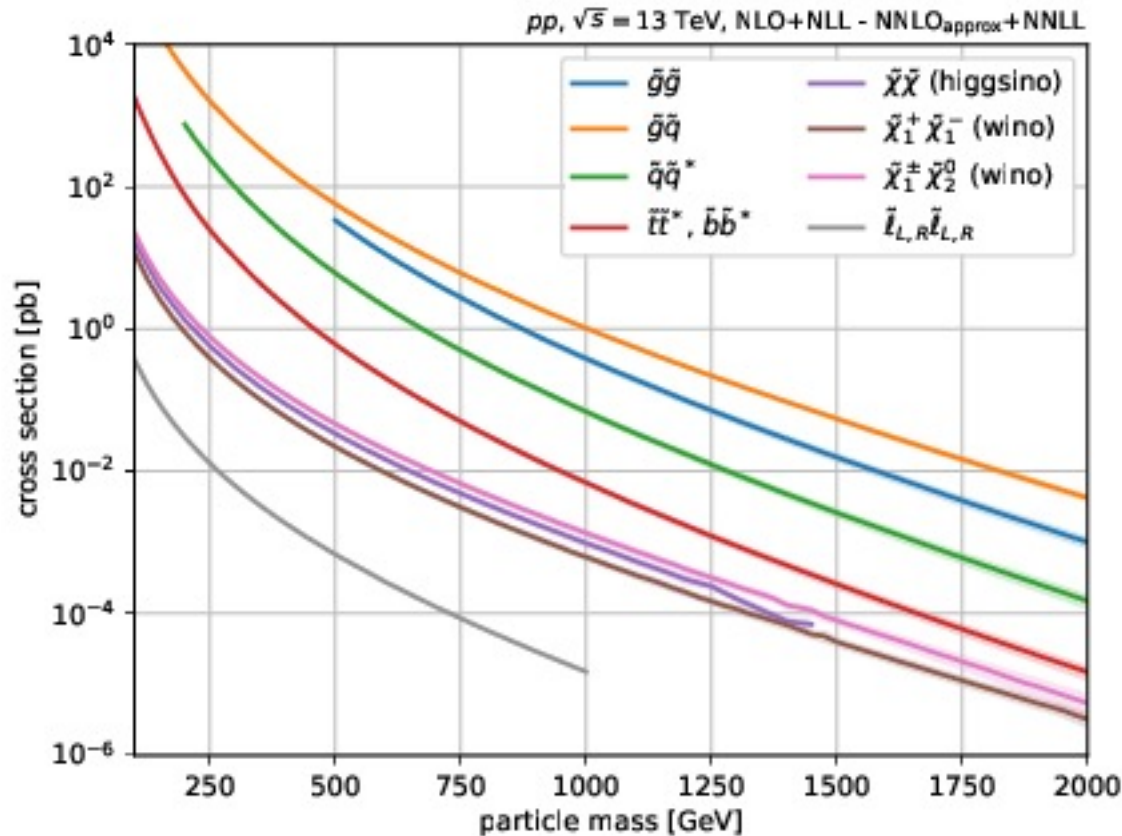
北京航空航天大学
BEIHANG UNIVERSITY

Supersymmetry



- Hierarchy problem/fine tuning
- (Precise) Grand unification
- LSP as Dark matter candidates
- Bring rich physics that may explain SM precision measurements such as muon $g-2$

Supersymmetry at the LHC



from LHC SUSY Cross Section Working Group

<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections>

Arsenal for SUSY searches at the LHC



Note:

teams in World Cup 2022 are not defeated so far
as long as they have players from Arsenal.

Arsenal for SUSY searches at the LHC

**Searches for standard model particles from
SUSY particles cascade decays**

- ☐ Signal events with large missing E_T and/or high jet/lepton multiplicities/resonances
- ☐ Decay products with life time long enough to travel through detector subsystem(s)

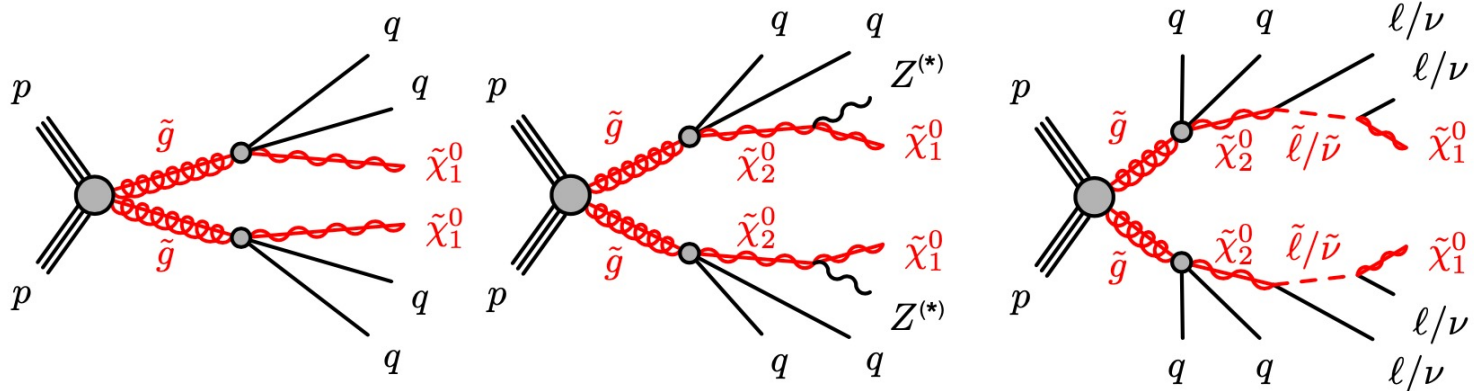
Variety of techniques enhance sensitivity

- **machine/deep learning to separate signal/background**
- **jet substructure to tag boosted heavy particle decays**
- **reconstruction with invisible particle**
- **multi-signal regions to cover different parameter space**

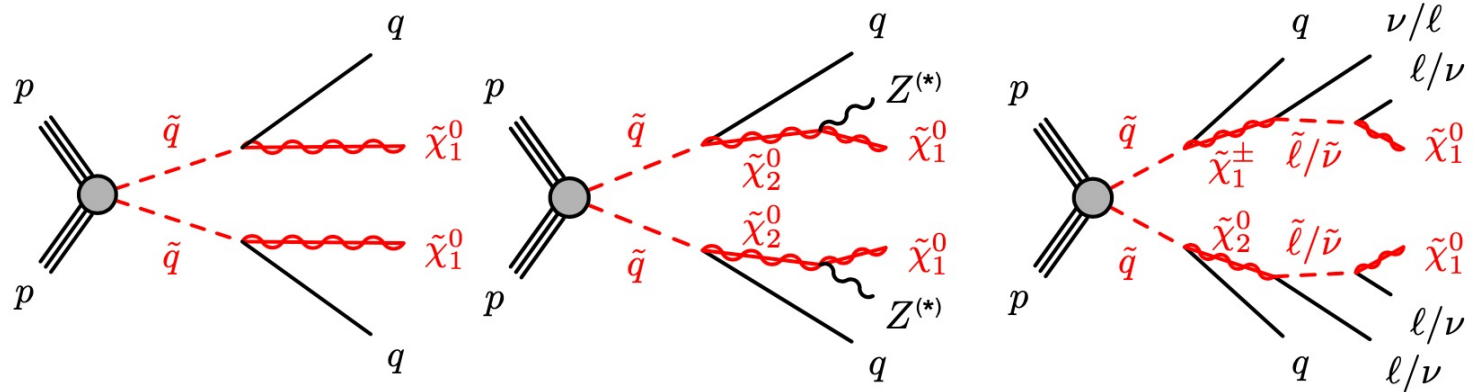
Results from Run-2 data

- ❑ Strong SUSY
- ❑ Electroweak SUSY
- ❑ SUSY searches through long-lived particle

Strong SUSY searches



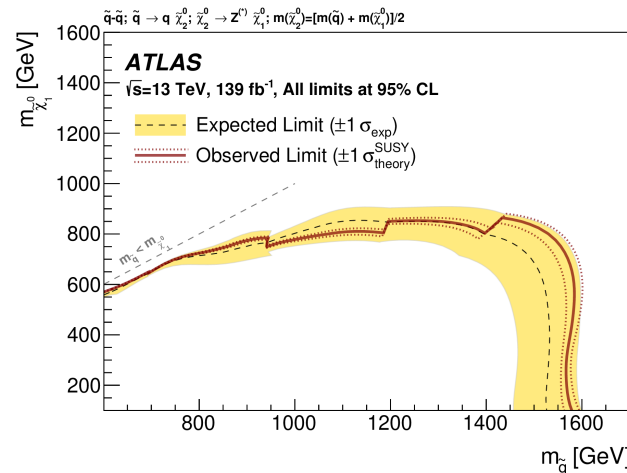
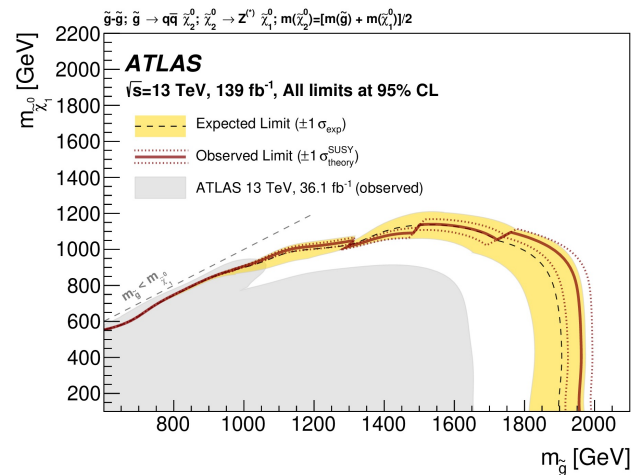
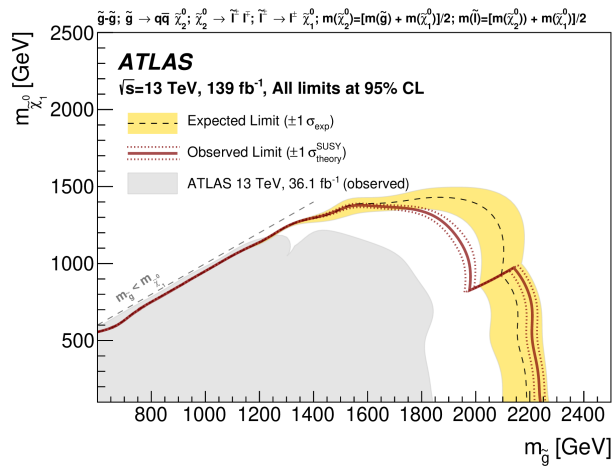
Pair production of gluino/squark pair and its cascade decay



Final state with jets (and leptons), missing E_T

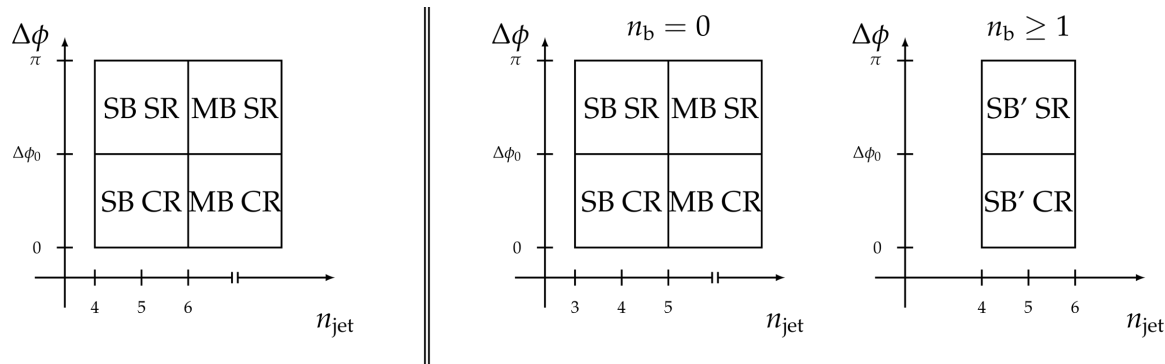
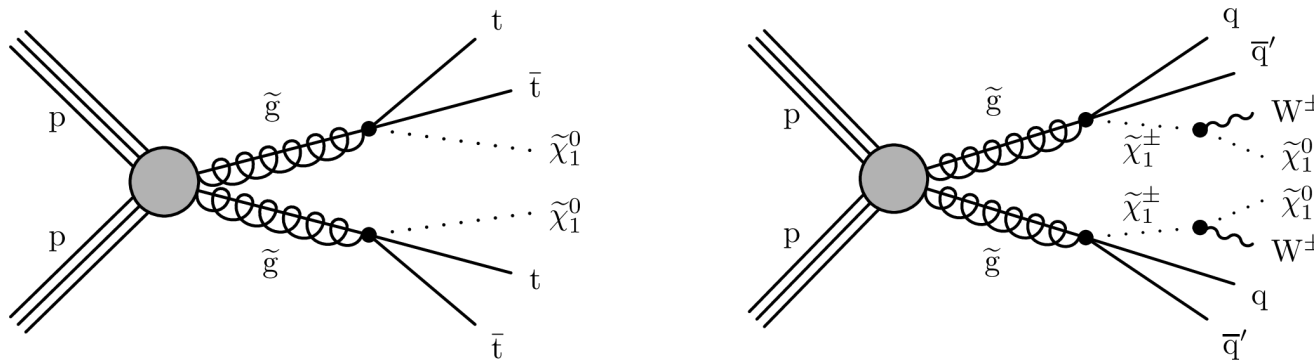
Strong SUSY searches

Strong search SRs for the $\tilde{g}$ -to- $\tilde{\ell}$, $\tilde{g}$ -to- $Z^{(*)}$, and $\tilde{q}$ - $Z^{(*)}$



arXiv:2204.13072

Strong SUSY searches

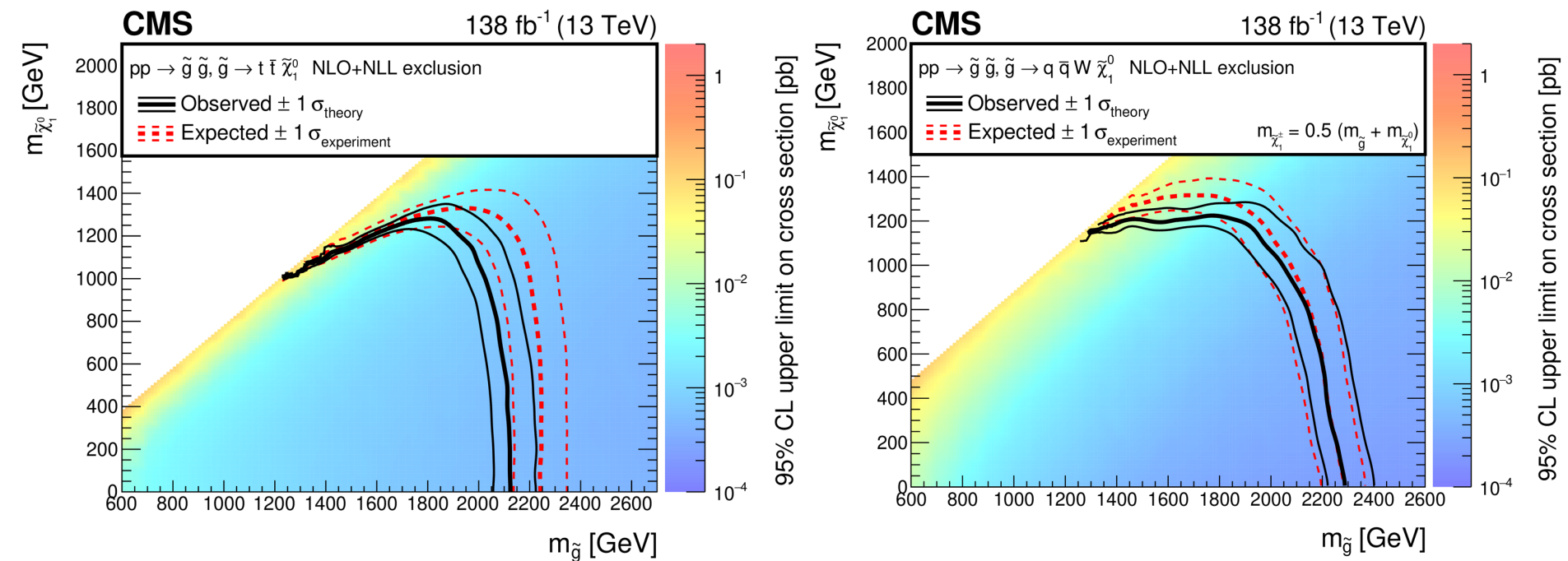


arXiv:2211.08476

MB : main band

- **Signal signatures with multi-b and zero-b categories**
- **Data driven background $\Delta\phi$ and n_{jets} for background estimation**

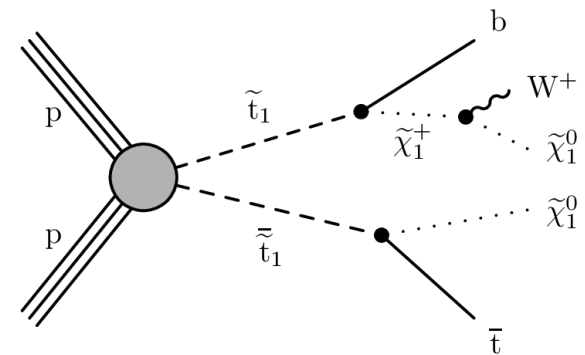
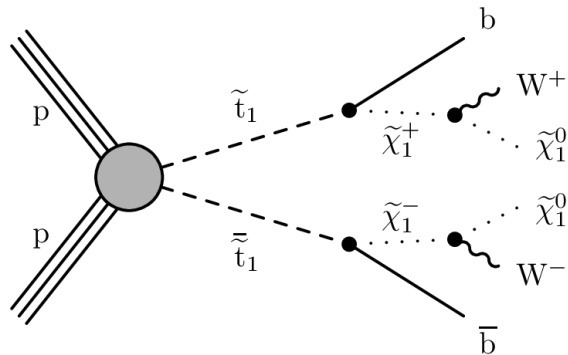
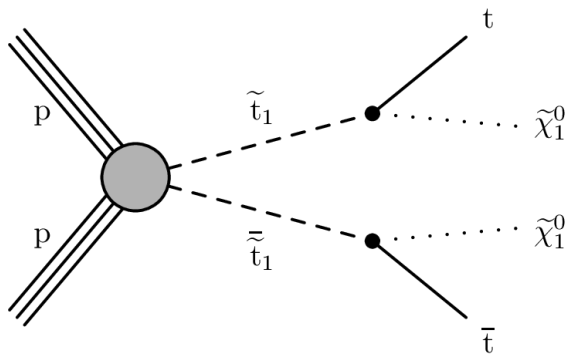
Strong SUSY searches



arXiv:2211.08476

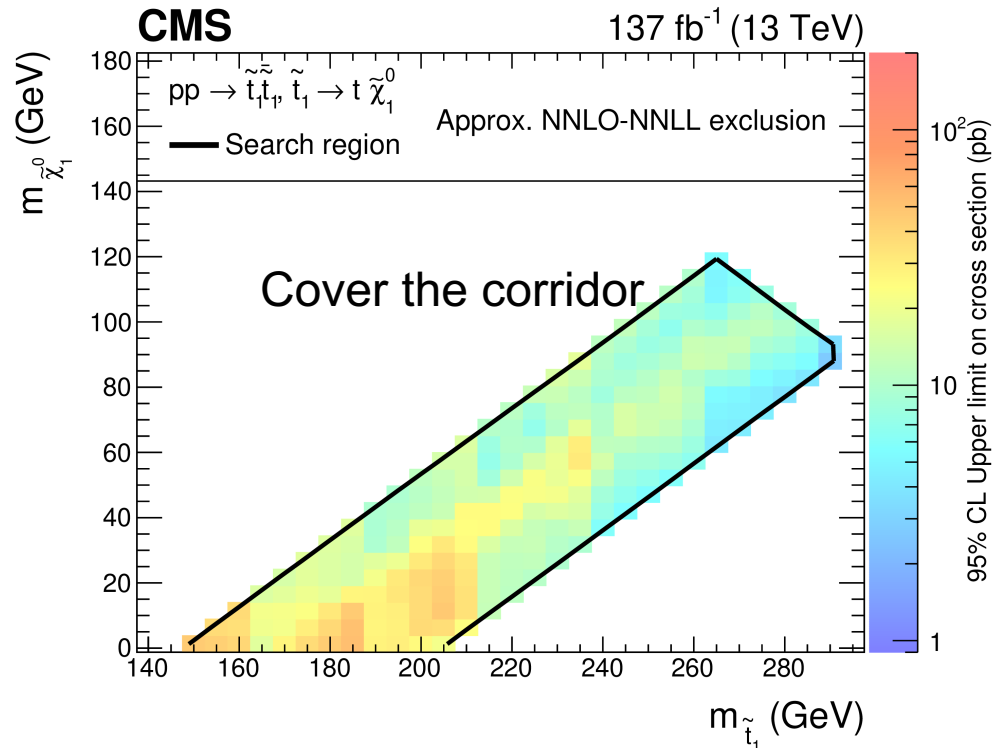
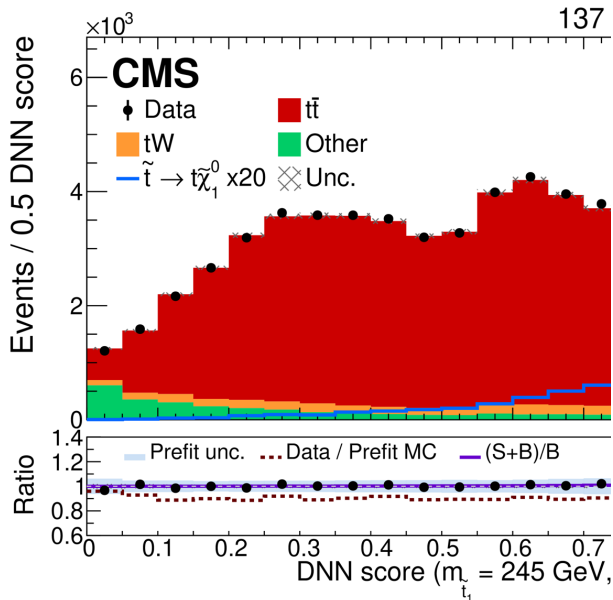
Strong SUSY : third-generation s-top

- ❑ Centrally relevant to *naturalness* problem
- ❑ Lightest squark in natural SUSY scenarios
- ❑ More difficult to probe in compressed (low $\Delta m(\tilde{t}, \tilde{\chi}^0)$) spectra

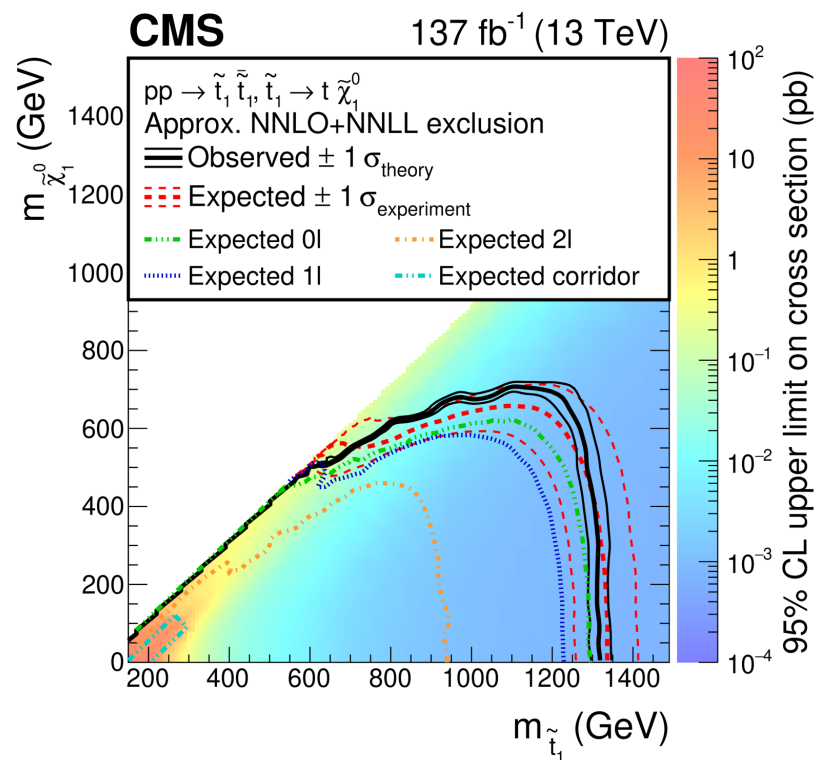


Strong SUSY : third-generation s-top

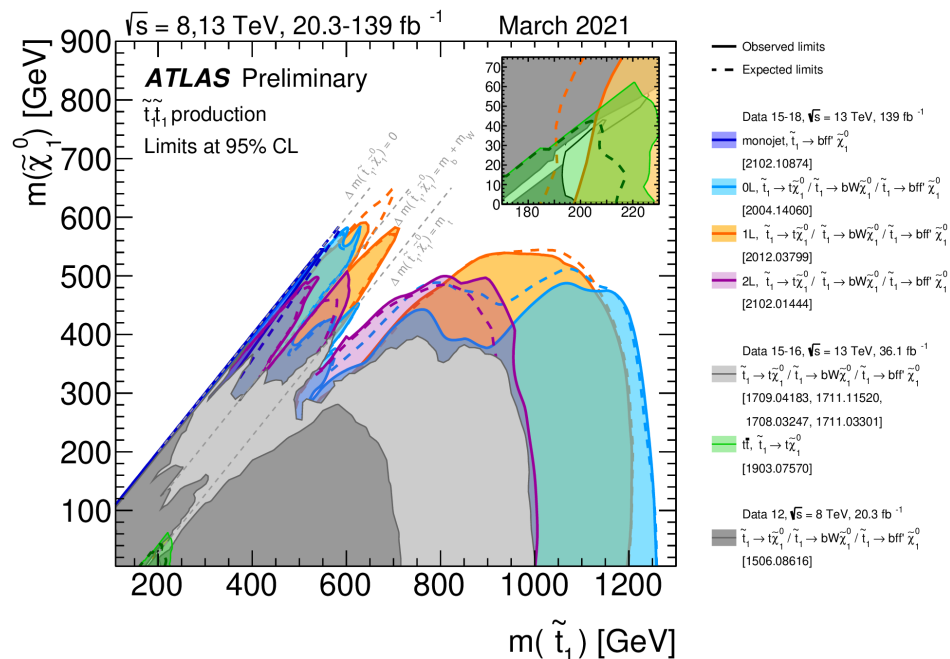
- Dedicated search with parametric DNN to discriminate signal from $t\bar{t}$ background in which the top squark and neutralino masses are introduced in the training.
- In this way, a specific model for each signal point training a single DNN is achieved.



Strong SUSY searches : third-generation s-top



Eur. Phys. J. C 81 (2021) 970



<https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults>

R-parity violation and stealth SUSY

❑ RPV SUSY

Additional interaction terms that do not conserve B or L

LSP is not stable i.e. can decay to SM particles

❑ **Stealth SUSY** : models with hidden sector

❑ S-fermion and scalar are very close in mass as SUSY is broken softly in hidden sector

❑ Top squark could decay through this hidden sector into SM particles

Challenges:

- **Low MET** → largely unexplored phase space but also large SM background
- **High jet multiplicity** → hard to model, need data-driven estimates

ATLAS Eur. Phys. J. C 81 (2021) 1023

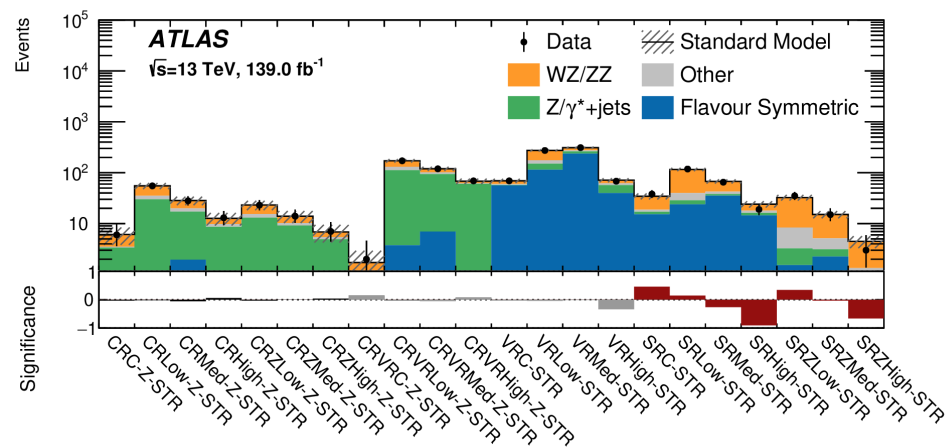
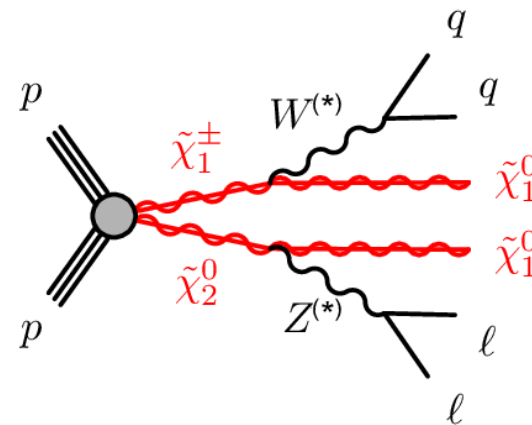
CMS Phys. Rev. D 104, 032006 (2021)

Electroweak SUSY searches

- ❑ Direct production of **charginos** and **neutralino**: mixed states of W, Z e H bosons superpartners
- ❑ Direct production of **sleptons**: leptons superpartners
- ❑ **Small cross section** compared to strong production, portion of the phase space not explore yet has **challenging signature**

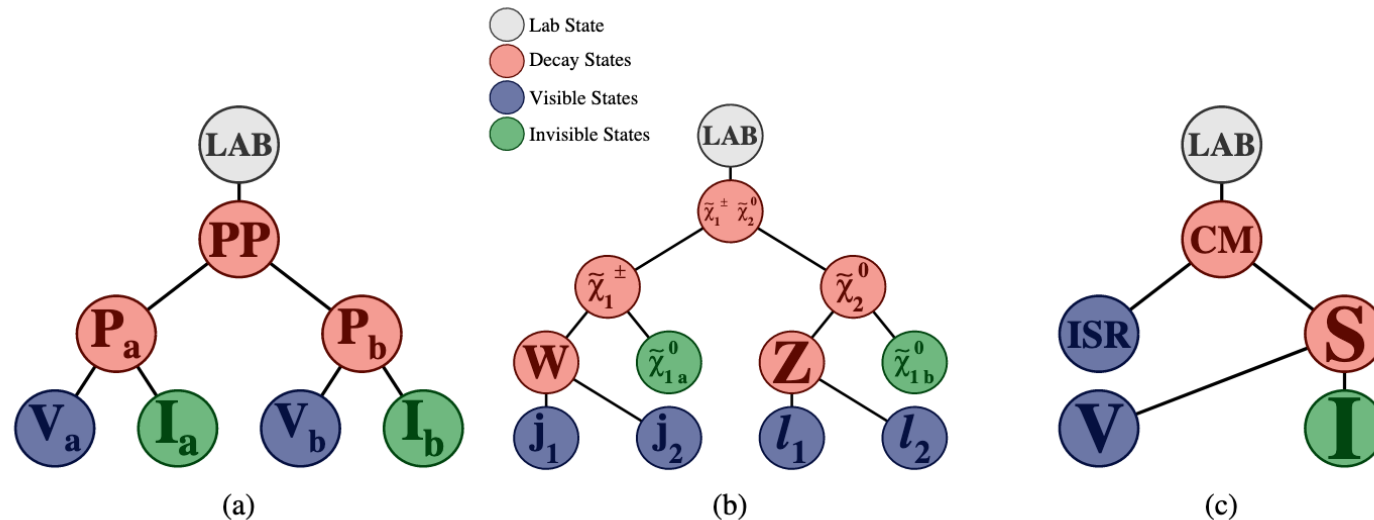
Electroweak SUSY : chargino/neutralino

- Final state with two leptons,
at least 2 jets and missing E_T
- Recursive jigsaw reconstruction
is used to estimate the invisible
particle's momenta
- Control region validate the
background estimation in signal
region : no signal evidence



arXiv:2204.13072

Recursive Jigsaw reconstruction

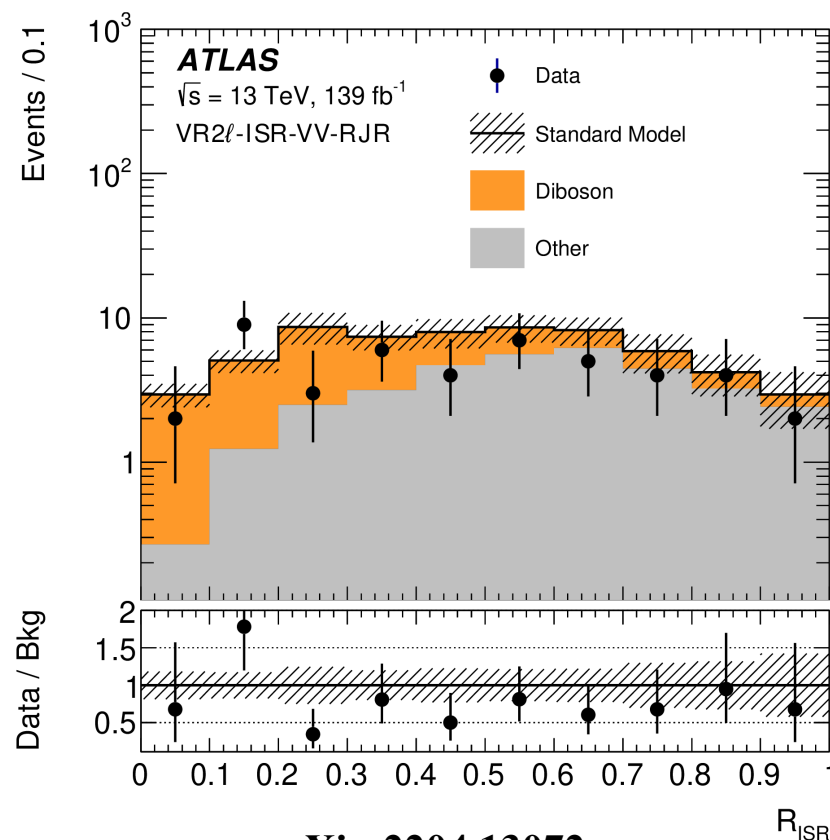
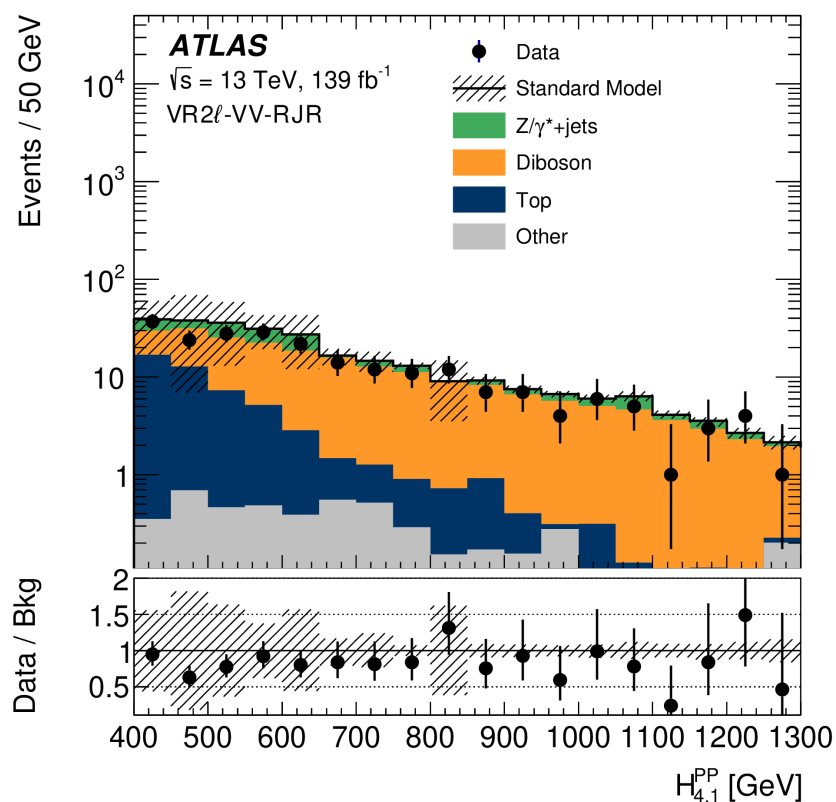


- ❑ method for decomposing per-event measured kinematic variables
- ❑ achieved by approximating the rest frames of intermediate particles
- ❑ minimize the model dependency,
mainly assumption is the canonical form of the decay tree structure

Recursive Jigsaw reconstruction

$$H_{n,m}^F = \sum_{i=1}^n |\vec{p}_{\text{vis}, i}^F| + \sum_{j=1}^m |\vec{p}_{\text{inv}, j}^F|$$

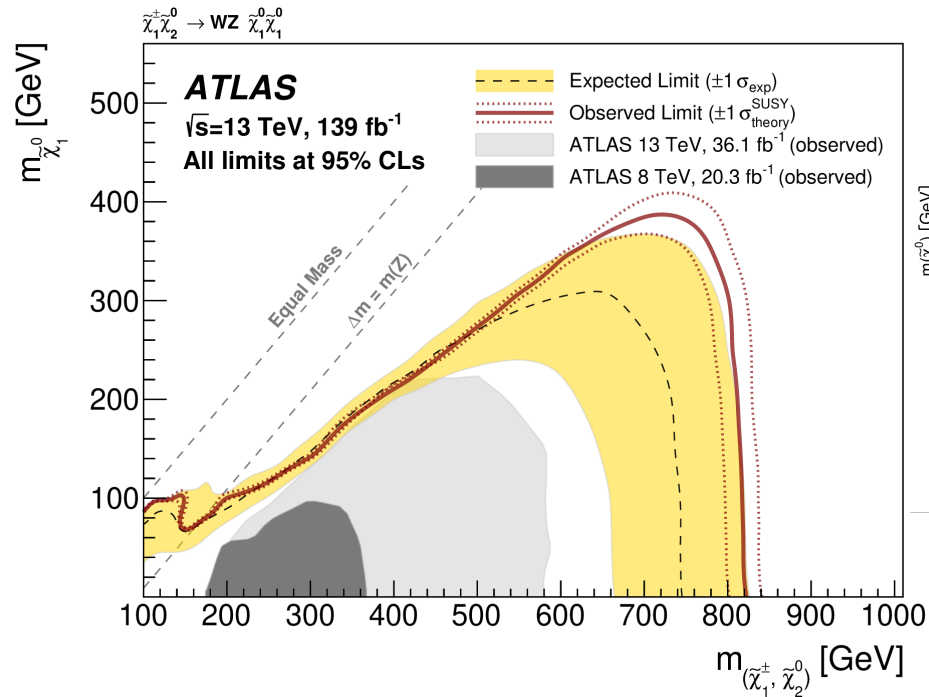
$$R_{\text{ISR}} \equiv \vec{p}_I^{\text{CM}} \cdot \hat{p}_{\text{TS}}^{\text{CM}} / p_{\text{TS}}^{\text{CM}}$$



arXiv:2204.13072

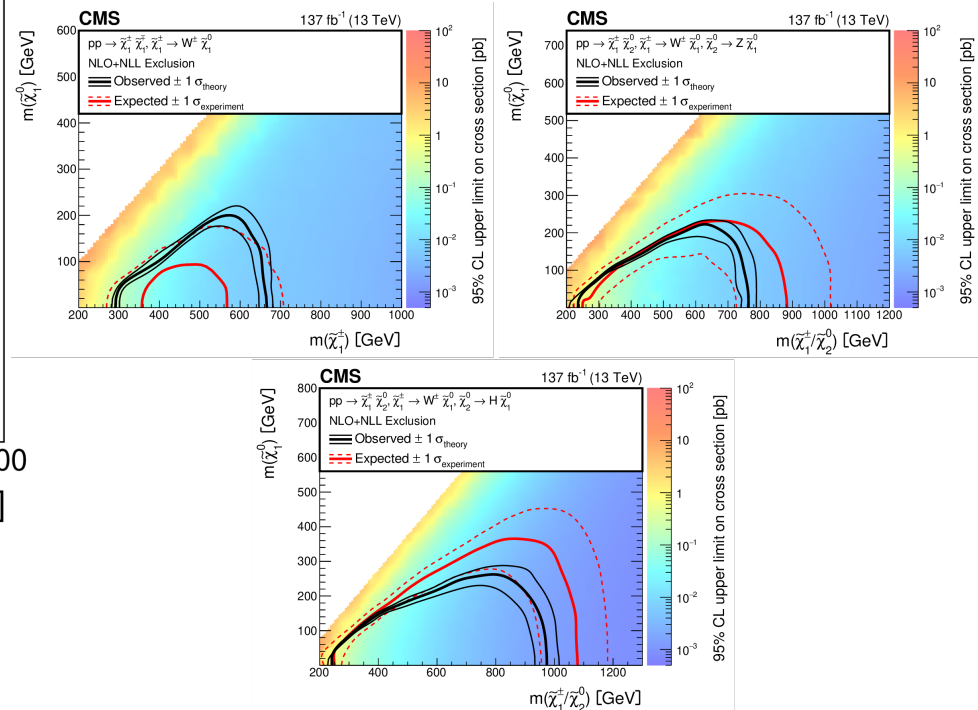
Electroweak SUSY : chargino/neutralino

WZ final state in ATLAS



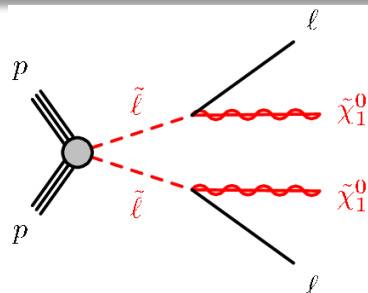
arXiv:2204.13072

WW/WZ/WH final states in CMS

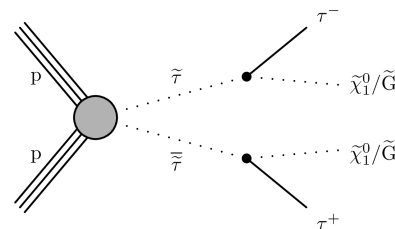


arXiv:2205.09597

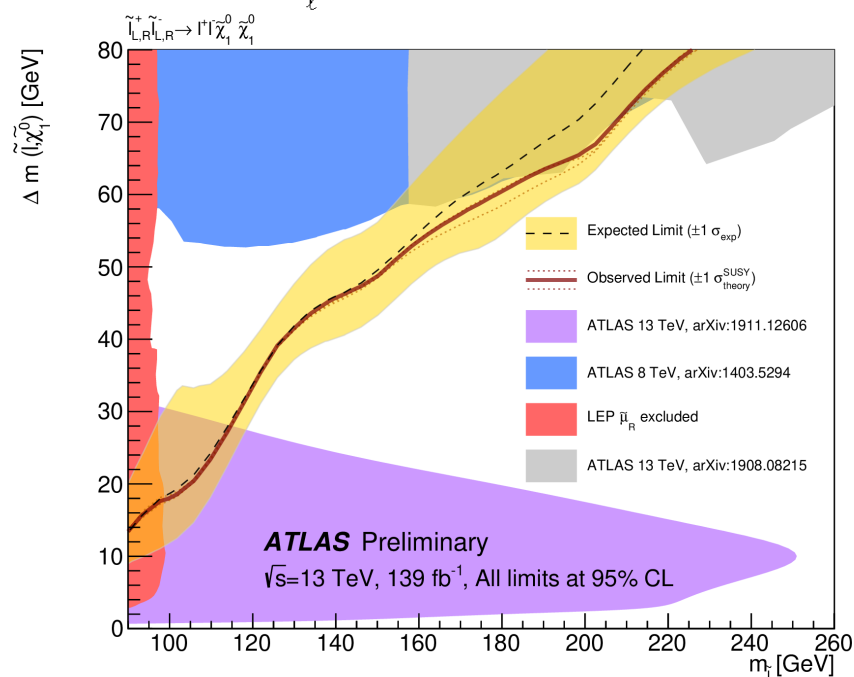
Electroweak SUSY : slepton



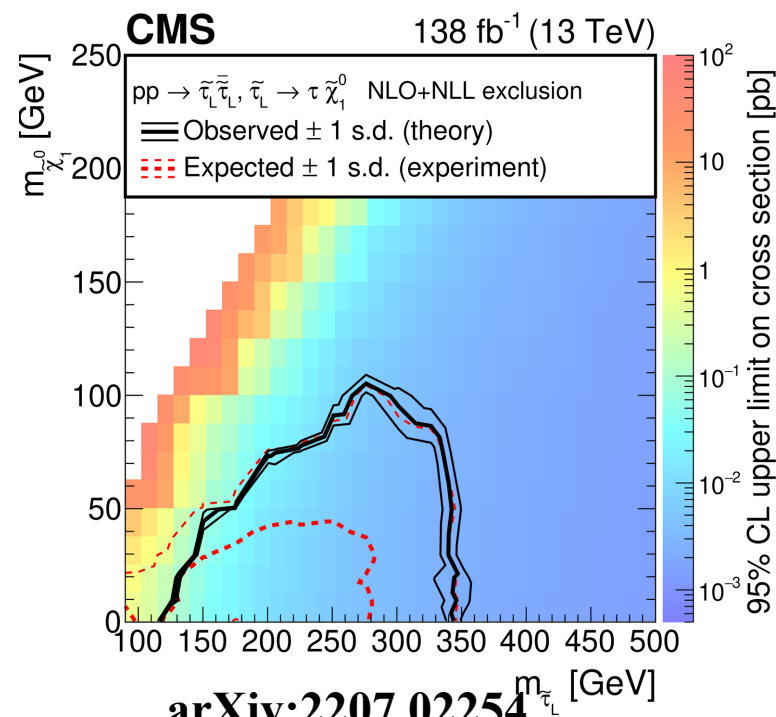
0-jet final state
with BDT selection



full hadronic tau tagger
with DNN



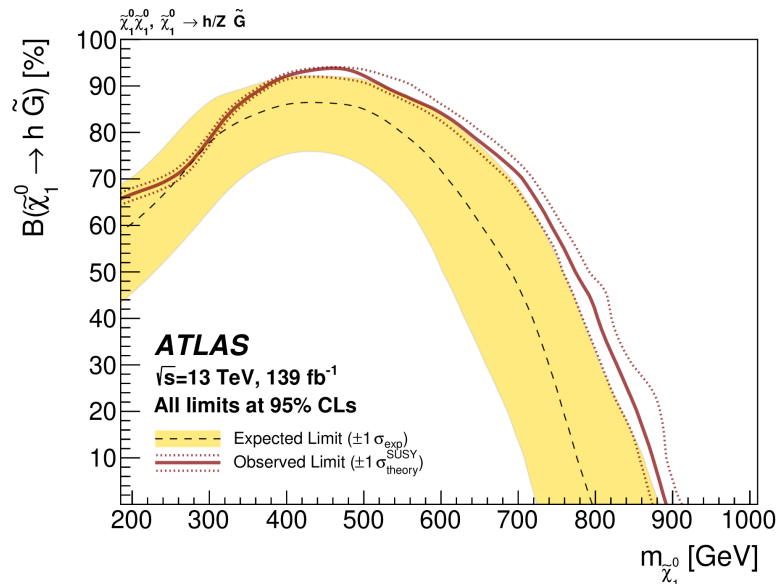
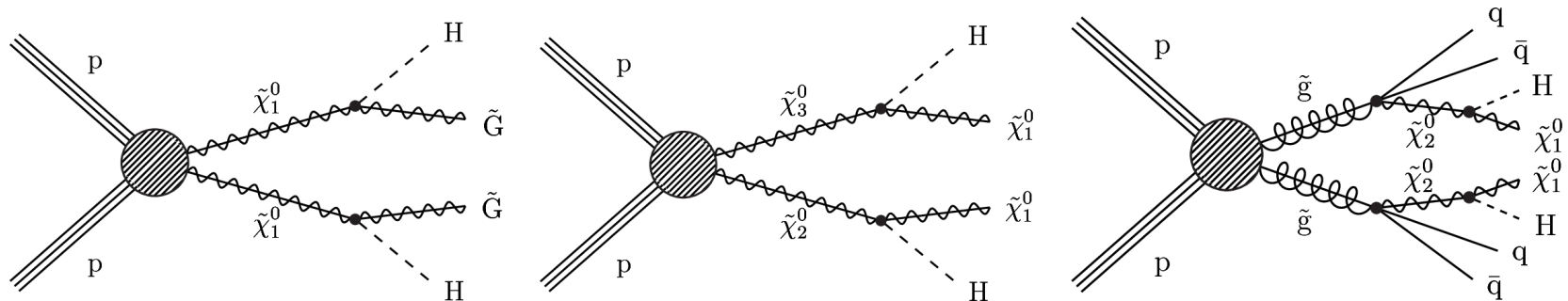
arXiv:2209.13935



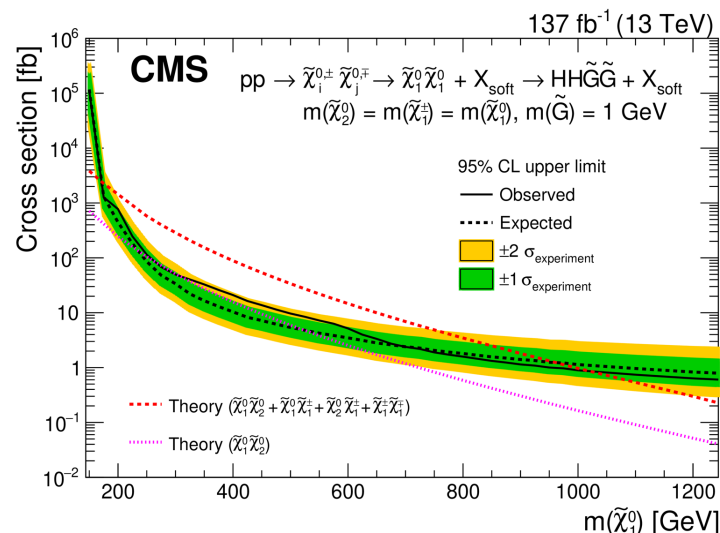
arXiv:2207.02254

Electroweak SUSY : Higgsino

Gauge Mediated SUSY breaking with higgsino NLSP



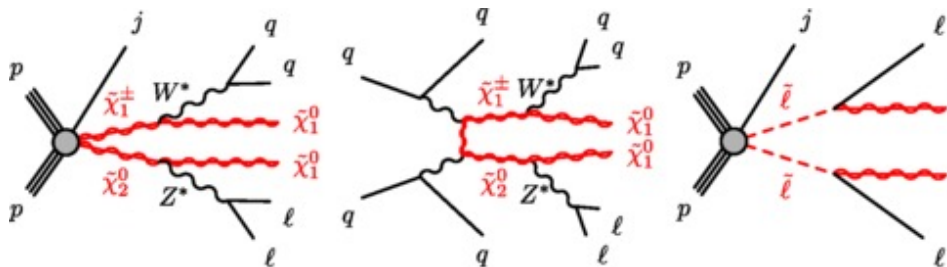
arXiv:2204.13072



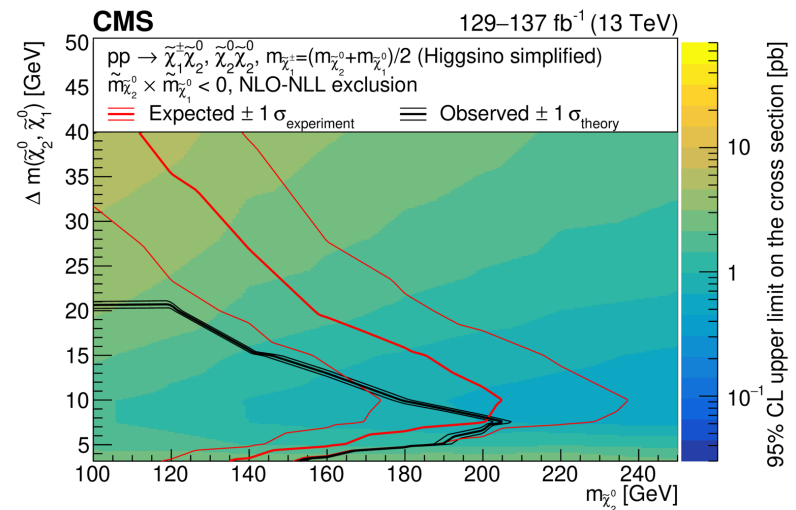
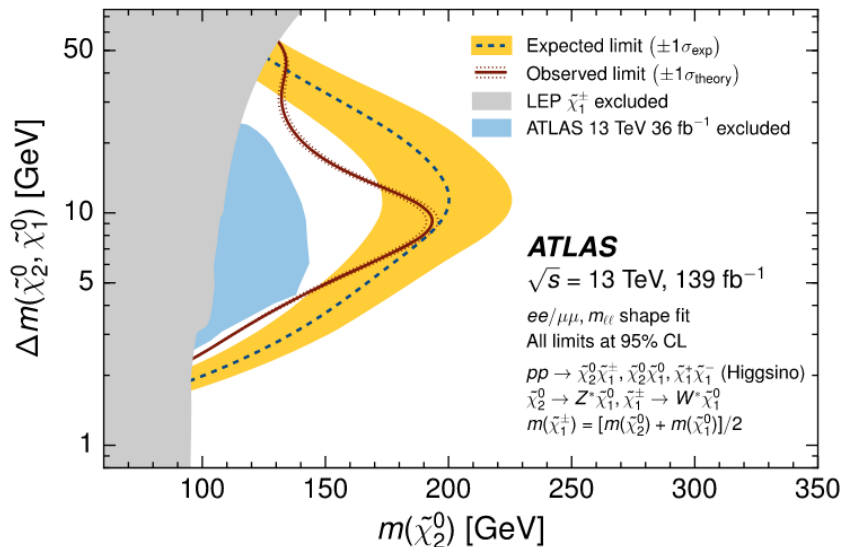
JHEP 05 (2022) 014

Electroweak SUSY : Higgsino

higgsino LSP with multi-leptons in the final state



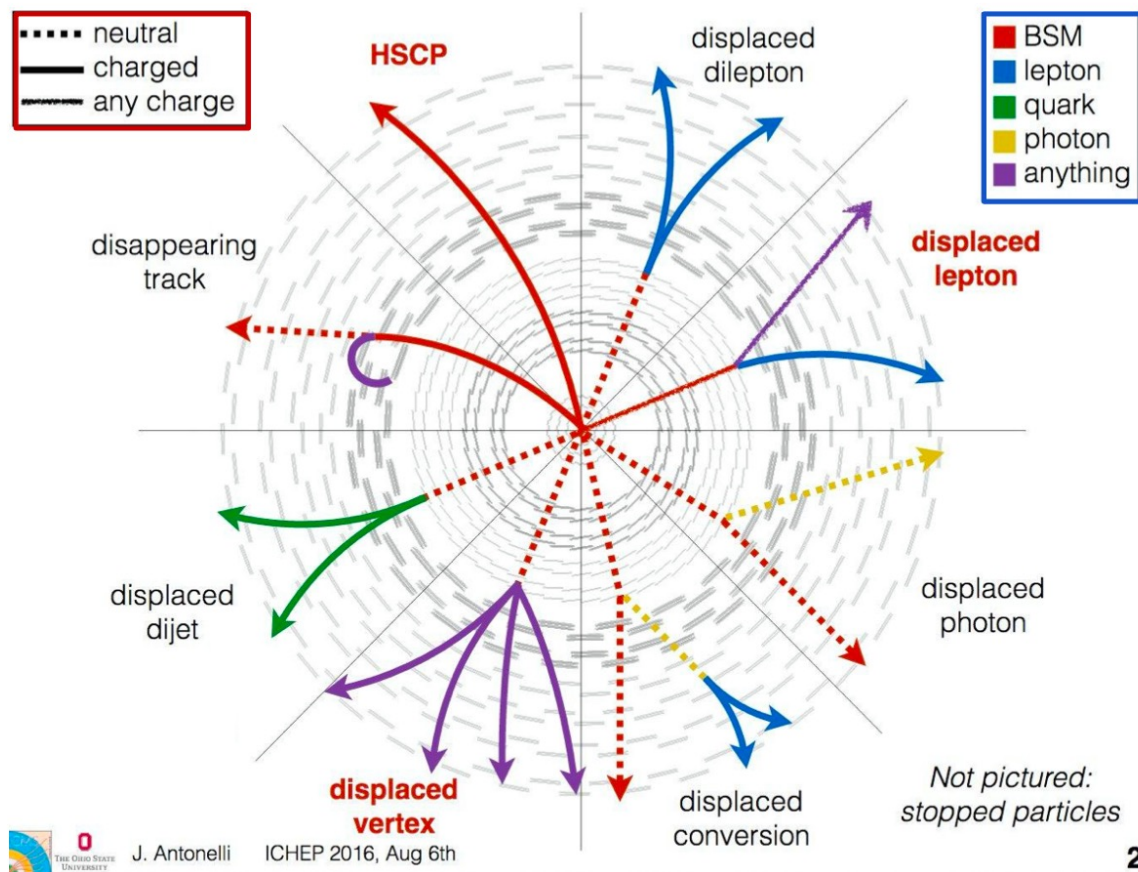
(c)



PRD 101 (2020) 052005

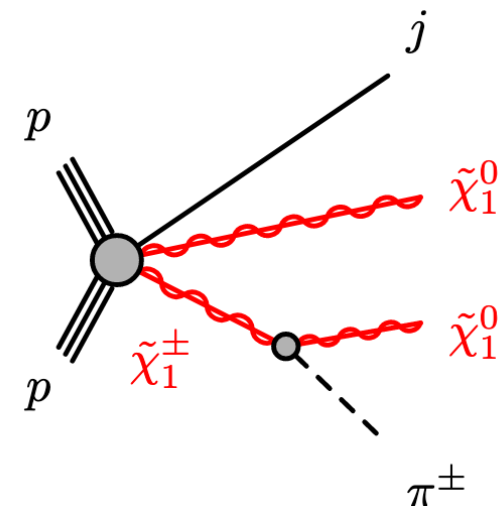
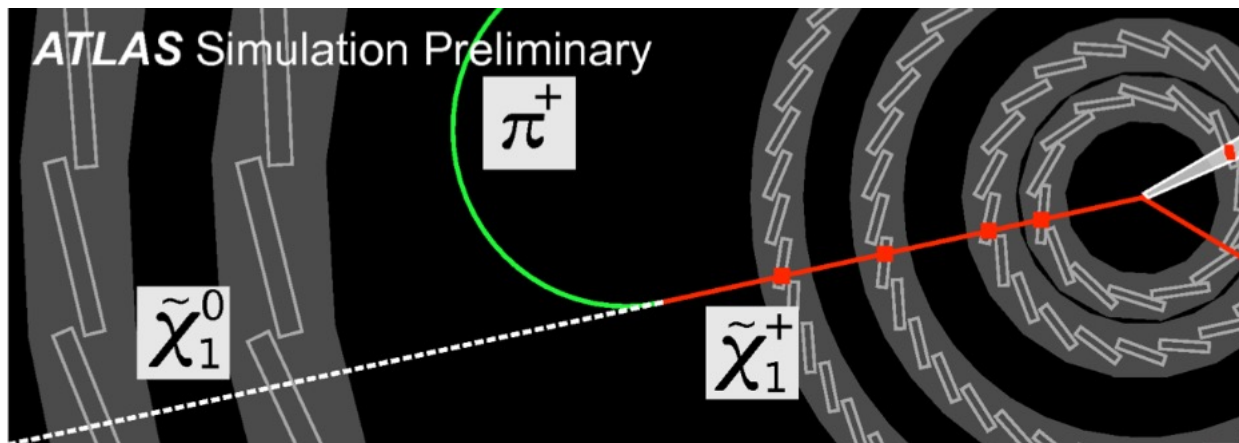
arXiv:2204.13072

SUSY through long-lived particle



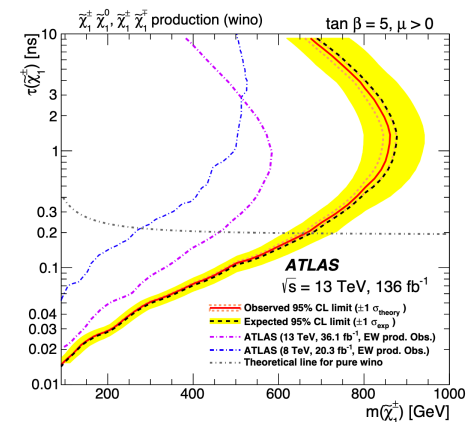
J. Antonelli ICHEP 2016

SUSY through long-lived particle



**Disappearing tracks when chargino has long life-time
(compressed mass spectrum)**

arXiv:2201.02472

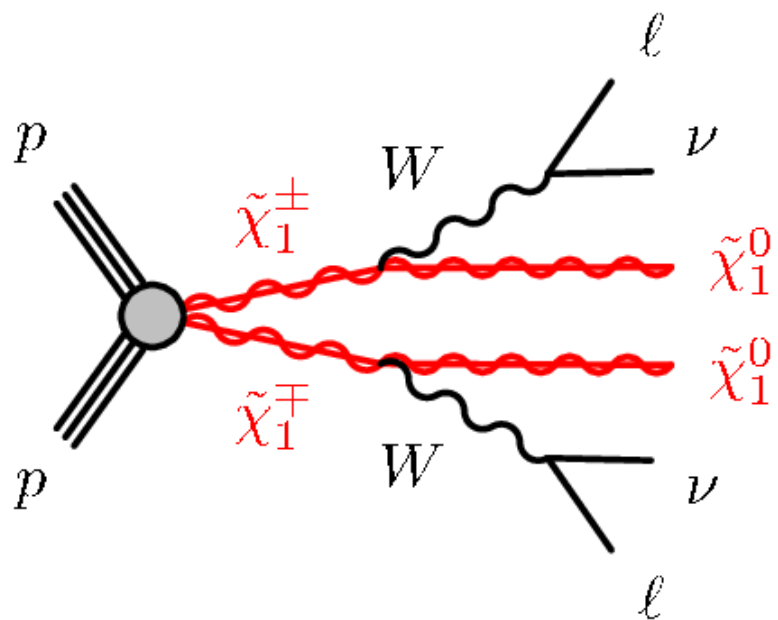


Summary

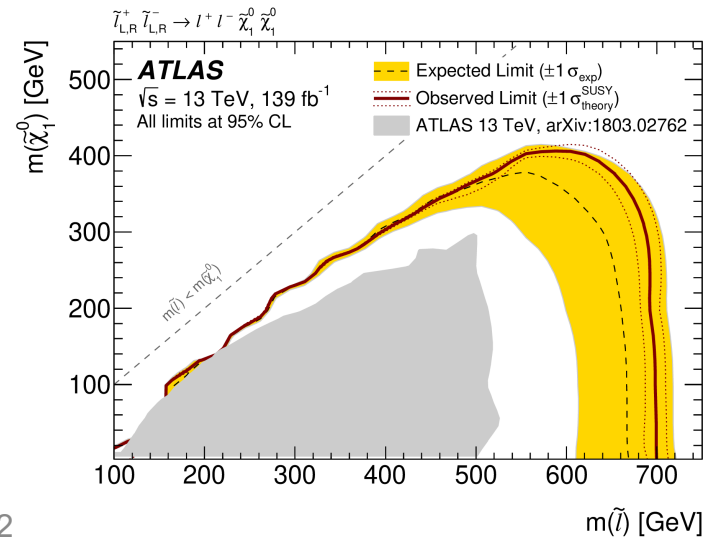
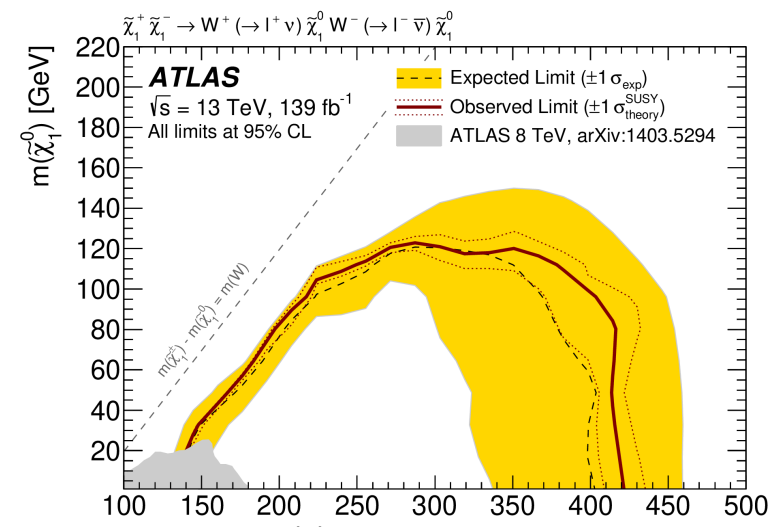
- ❑ SUSY searches are one of the most challenging scenarios at the LHC
 - ❑ Cross sections are small
 - ❑ Complicated matrix between signal scenarios (parameters/theories) and analysis scenarios(final states)
- ❑ ATLAS and CMS are **improving previous limits of** and **exploring portion of the phase space not covered before**

Backup

Electroweak SUSY : chargino/neutralino in 0jet



Eur. Phys. J. C 80 (2020) 123



Electroweak SUSY : Higgsino

Gauge Mediated SUSY breaking with higgsino NLSP

