Searches for Supersymmetry at ATLAS

Alberto Cervelli, on Behalf of ATLAS collaboration
INFN Sezione Bologna

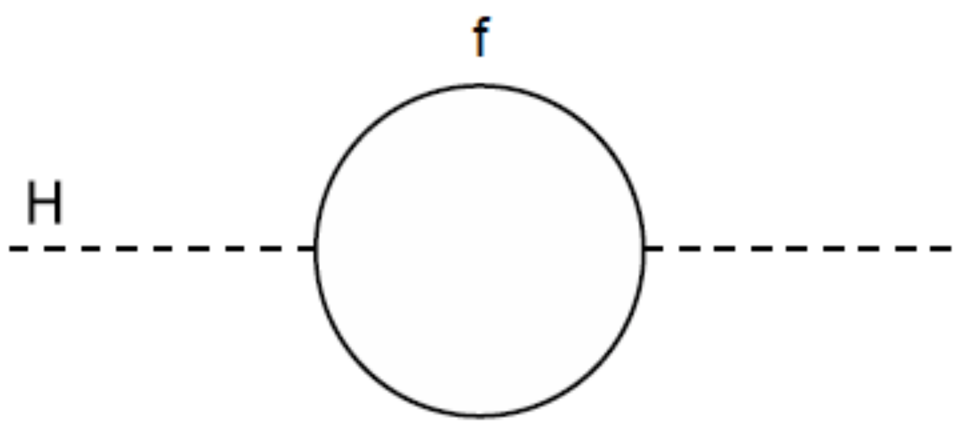
INFN
Istituto Nazionale di Fisica Nucleare

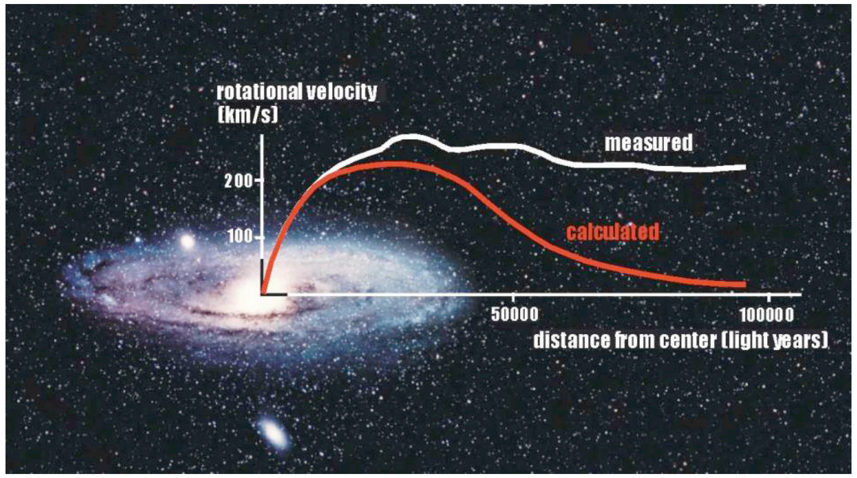
ATLAS EXPERIMENT

Why not the SM?

SM has been proven to be a very good model BUT..

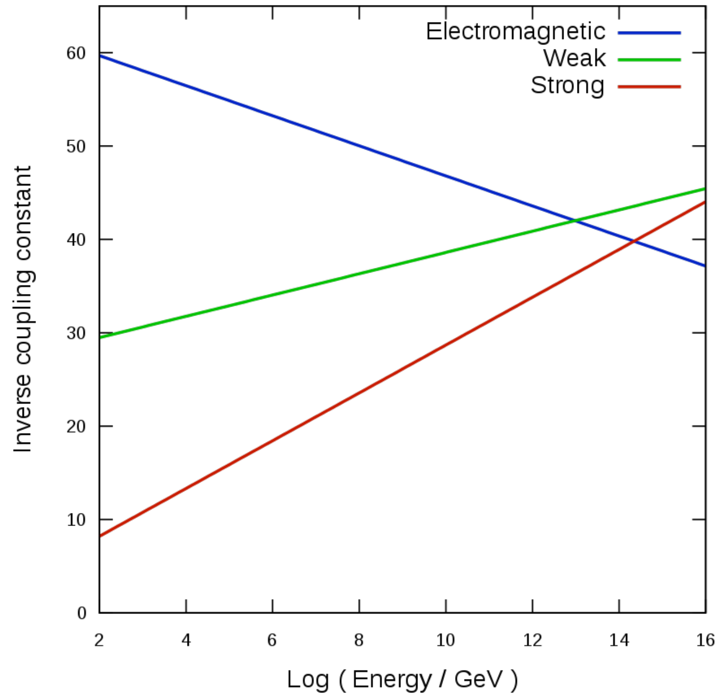
Hierarchy problem: needs incredible fine tuning for Higgs mass stability





Does not have a good candidate for Dark Matter

There is no unification of coupling constants at high energy scales



Extending the SM

Why not supersymmetry? it is a framework, many possible phenomenologies

SUSY is a time-space symmetry linking a SM particle to a SUSY partner differing by 1/2 spin unit

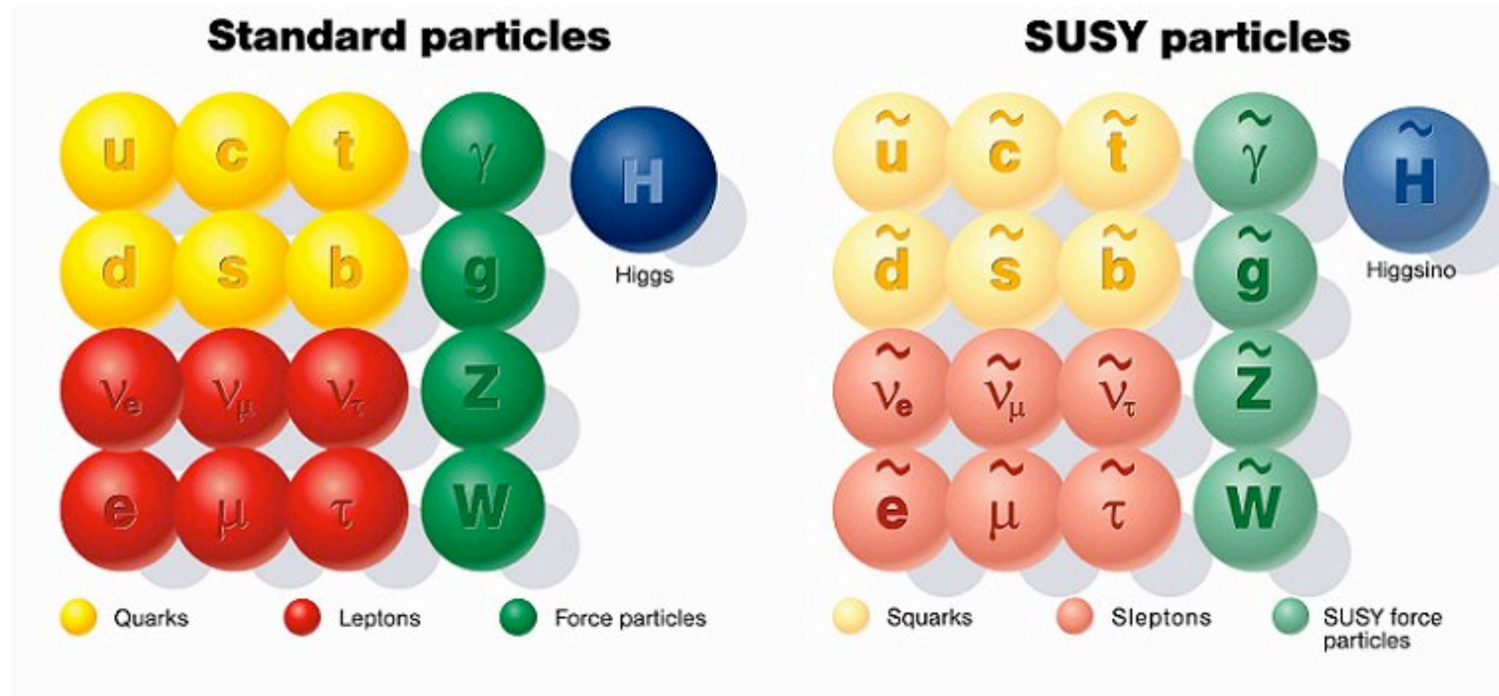
Not an exact symmetry: mass of particles≠mass of sparticles

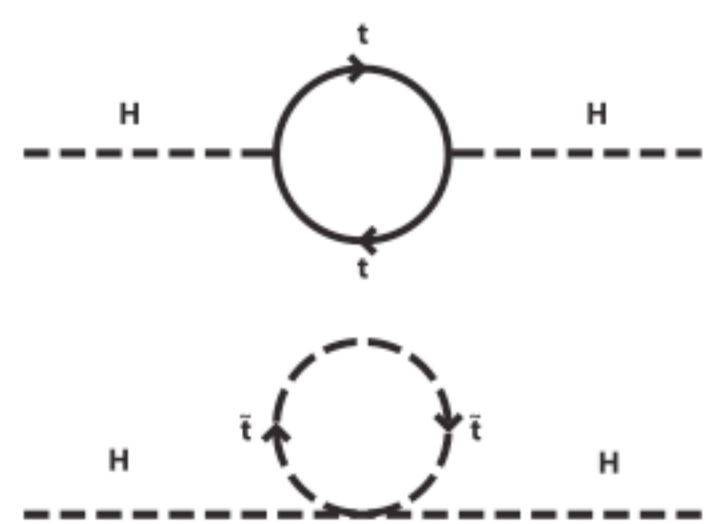
Loop corrections solve the quadratic divergence of Higgs boson mass

If R parity is conserved, SUSY LSP provide a natural Dark matter candidate

$$R : (-1)^{3(B-l)+2s}$$

+1 For SM -1 for SUSY





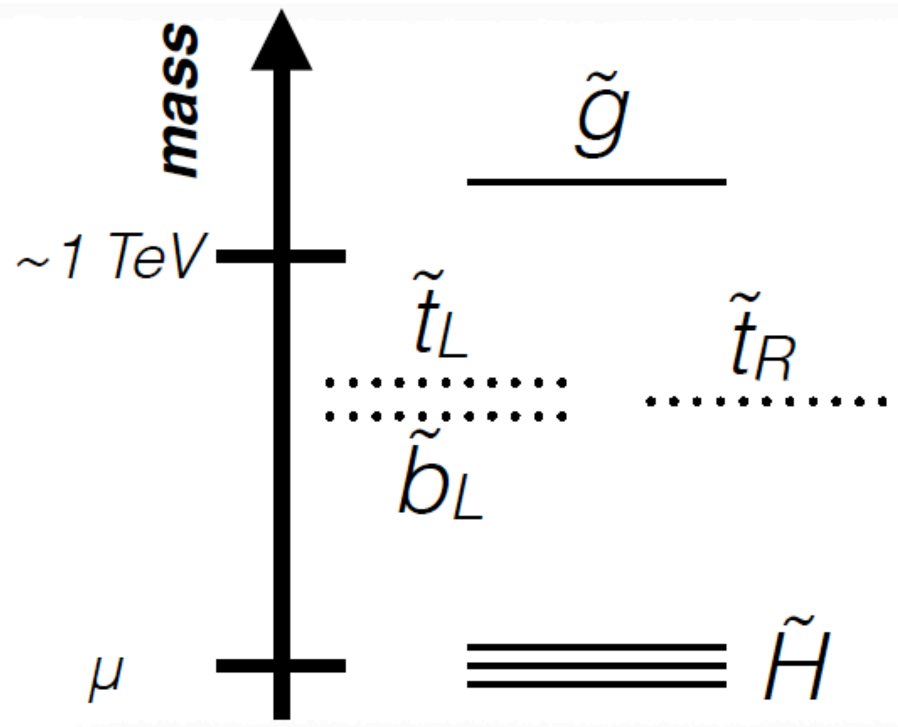
SUSY Naturalness

A possible phenomenology

Focus mainly on searches for Natural SUSY

Implication from both astronomic observation (dark matter relic density, cosmological constraints) and Particle physics (Higgs measurements)

Naturalness Phenomenology typically predict



Heavy gluinos

relatively light 3rd generation squarks

Light higgsinos

All other particles are decoupled

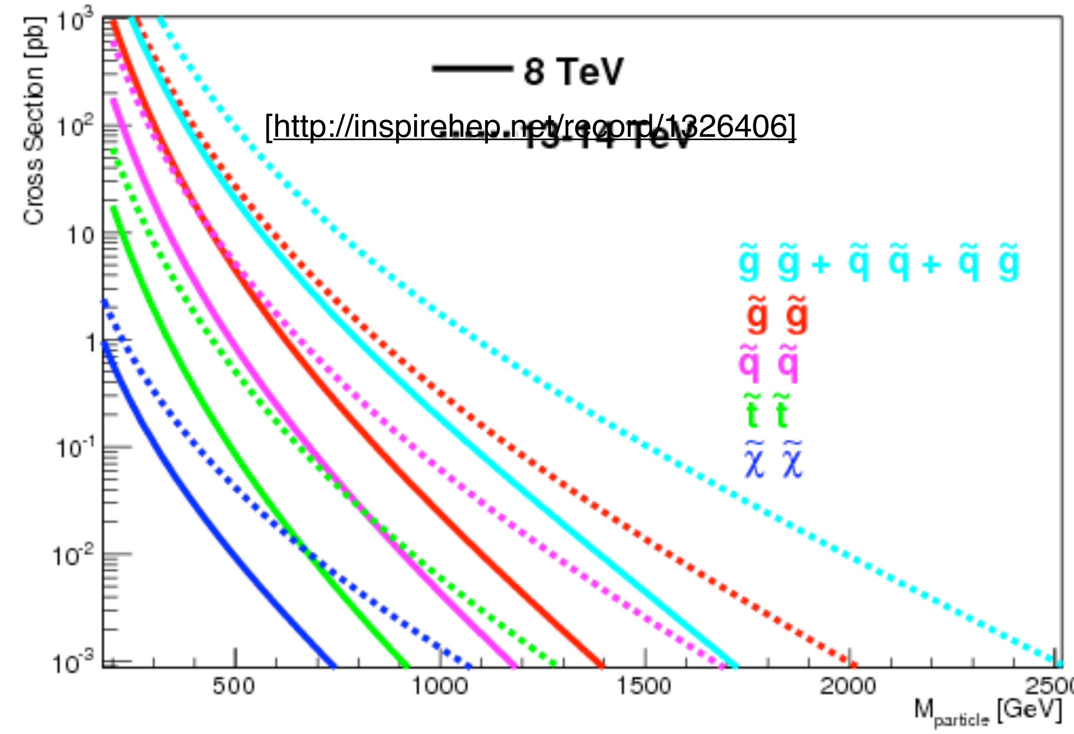
an Higgsino would be the LSP

SUSY in Run 2

Increase of cross section at 13 TeV, more sizeable for higher SUSY masses:

early data will improve gluino and 1st-2nd generation production

after 10 fb^{-1} improvement in 3rd generation and EWK production



R-parity conservation

strong/EW pair production with cascade decay to LSP

many high P_T SM particles + $\not\!\!E_T$ due to LSP escaping detection

R-parity Violation

Multi Jet/Multi leptons from LSP decays

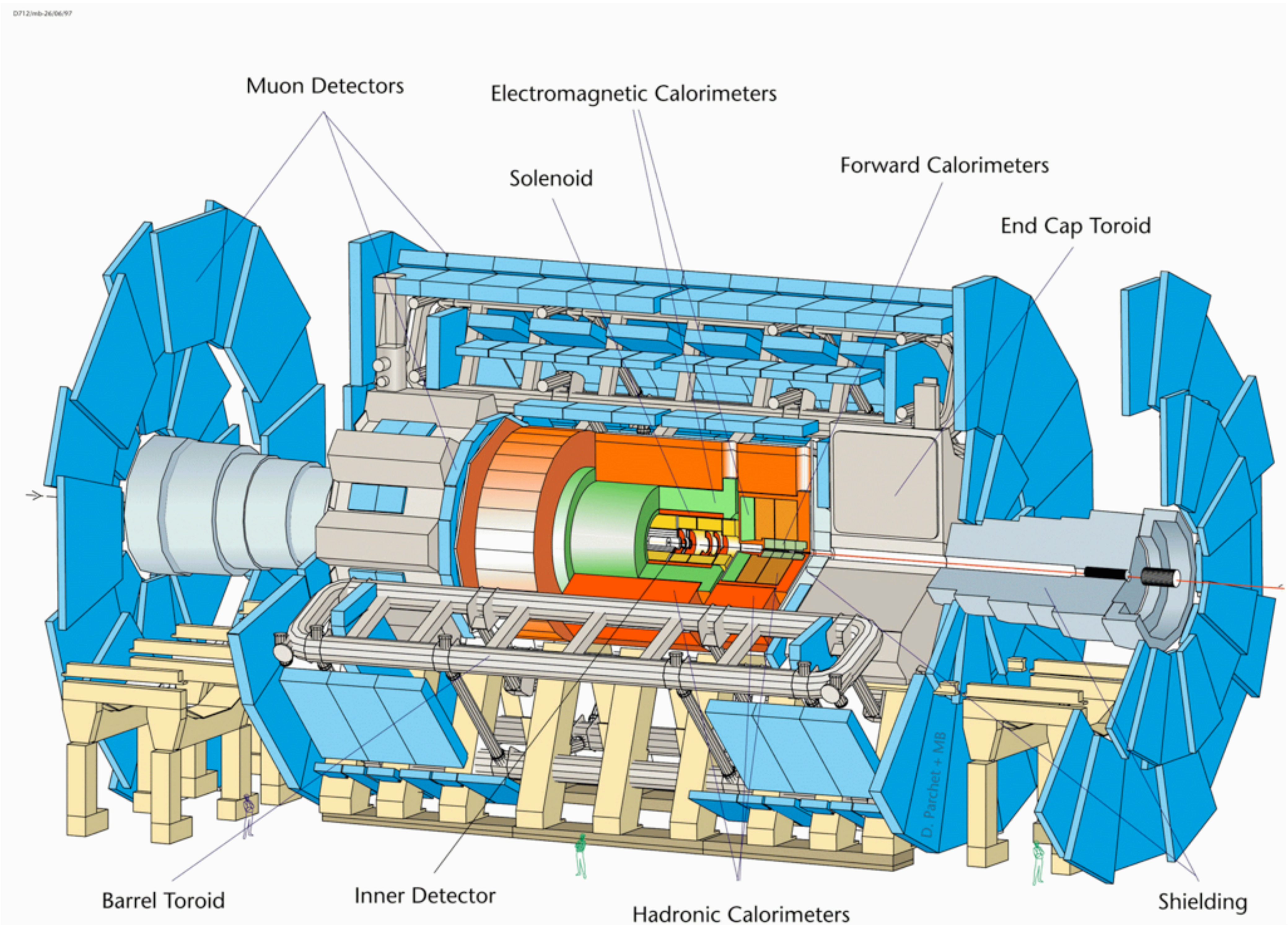
Displaced vertices due to late LSP decays

Long lived particles

Sparticles with long lifetimes due to mass degeneracy, small couplings

Secondary vertexes, mainly detector driven

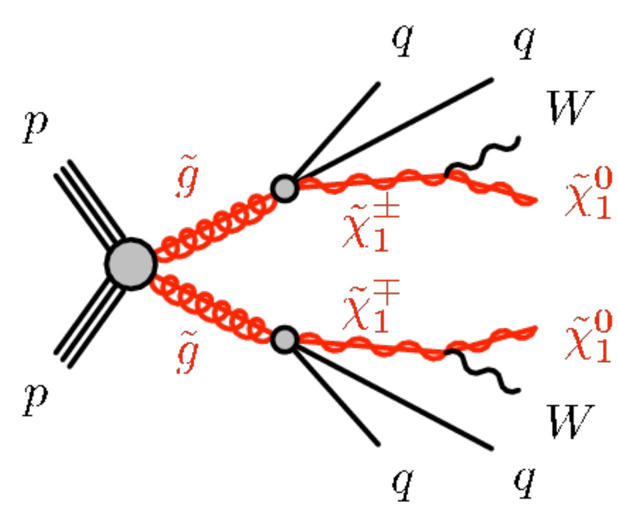
ATLAS detector



How we look for SUSY

Pick a signal model
Typically use a simplified model for signal optimization:
-assumes 100% BR along the decay cascade
-limits the number of free parameters
-easy to present results to the community
lately reinterpretation for full models may be pursued

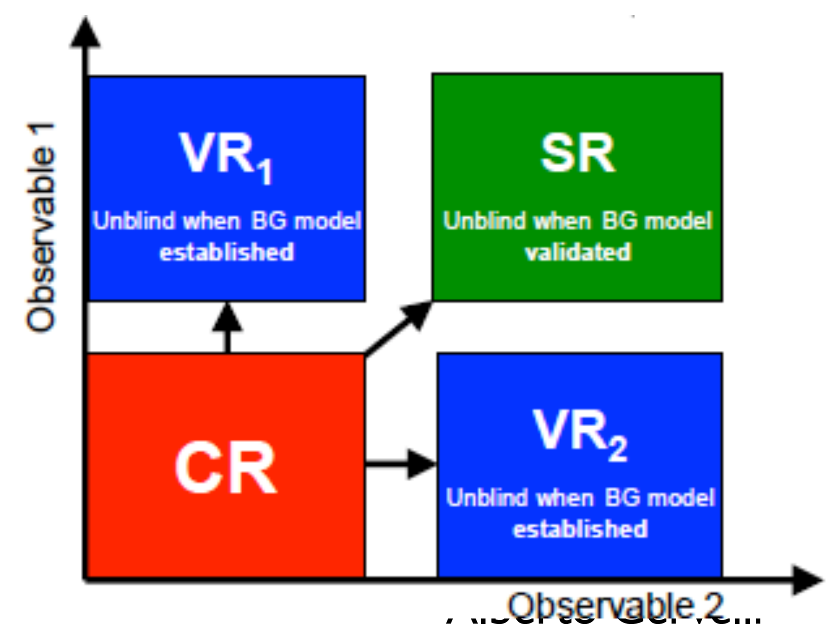
Search optimization:
Discovery: Typically inclusive cut and count analysis in SR
Exclusion: more elaborate methods such as MVA, shape fits..



Irreducible Backgrounds
- Dominant processes:
  - MC normalised to data in process-enhanced control regions (CRs)
  - Extrapolation to validation regions (VRs) & SRs
- Subdominant processes: Pure MC predictions

Reducible Backgrounds
- Fake $E_{T,miss}$, fake leptons backgrounds: Pure data-driven estimates
- Validation in VRs

Combined Fit
- Simultaneous fit of all components in CRs (and SRs for exclusion)



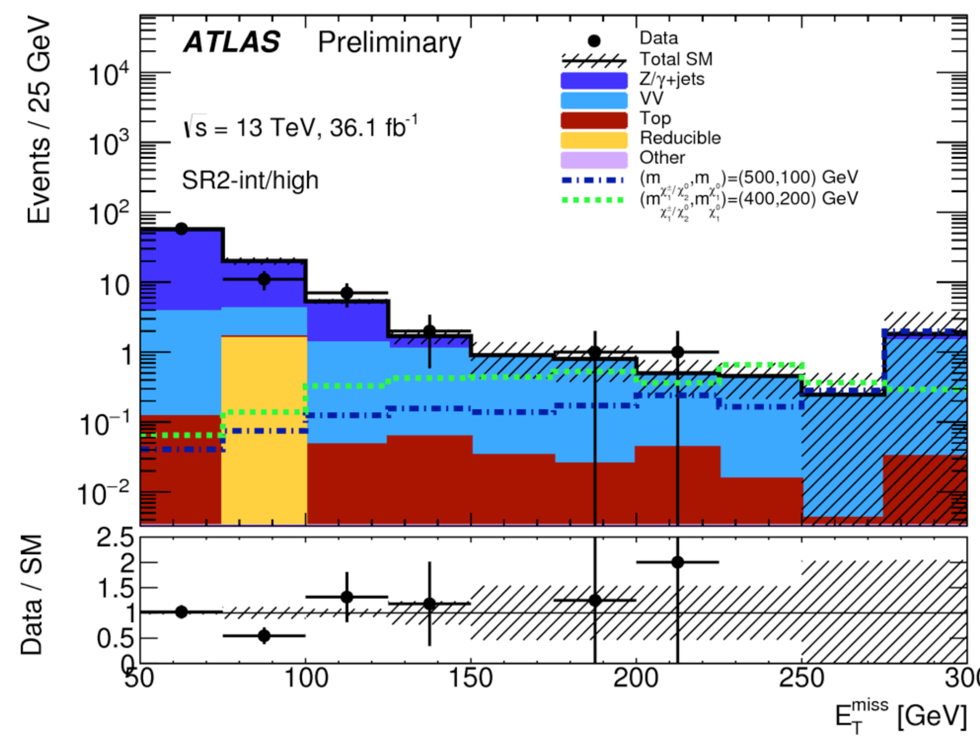
Discriminating Variables

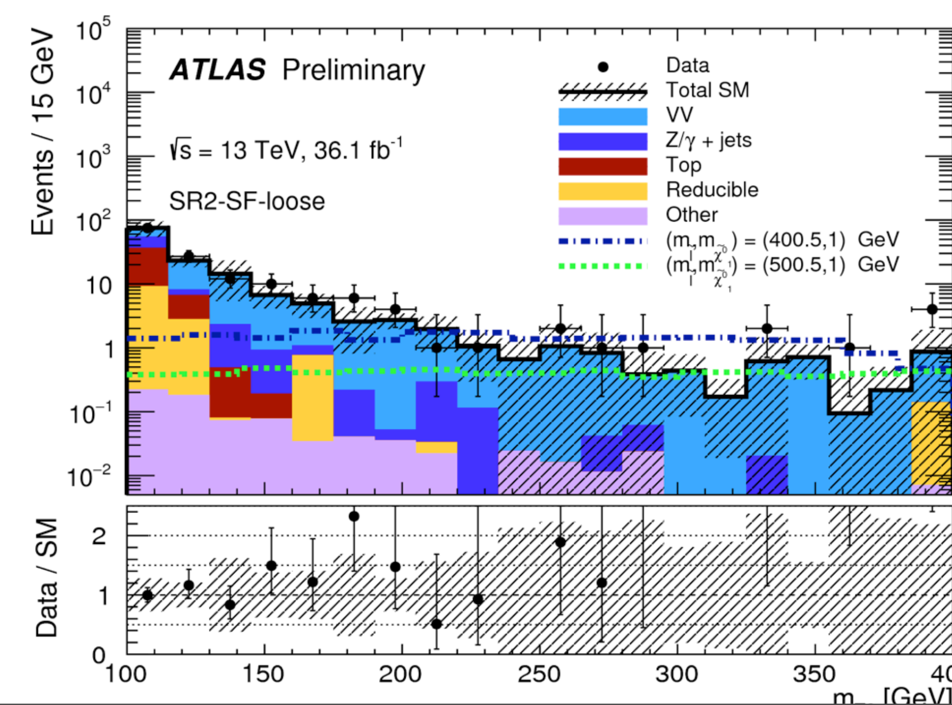
complexity

- Reconstructed object multiplicities, momenta, energies, e.g. $N_{jet/b\text{-}tag/\ell/\gamma}$, p_T, $E_{T,miss}$, …
- Scale variables, e.g. $m_{eff} = \Sigma p_T + E_{T,miss}$,
- Angular variables, e.g. **min $\Delta\Phi$**(jet, $E_{T,miss}$), …
- Mass variables, e.g. $m_{\ell\ell}$, $m_T^{b/\ell/j}$, $\Sigma m_{fat\text{-}jet}$, …
- Event shape variables, e.g. **Aplanarity**, …
- Hypothesis-based event variables e.g. m_{T2}, …

⋮

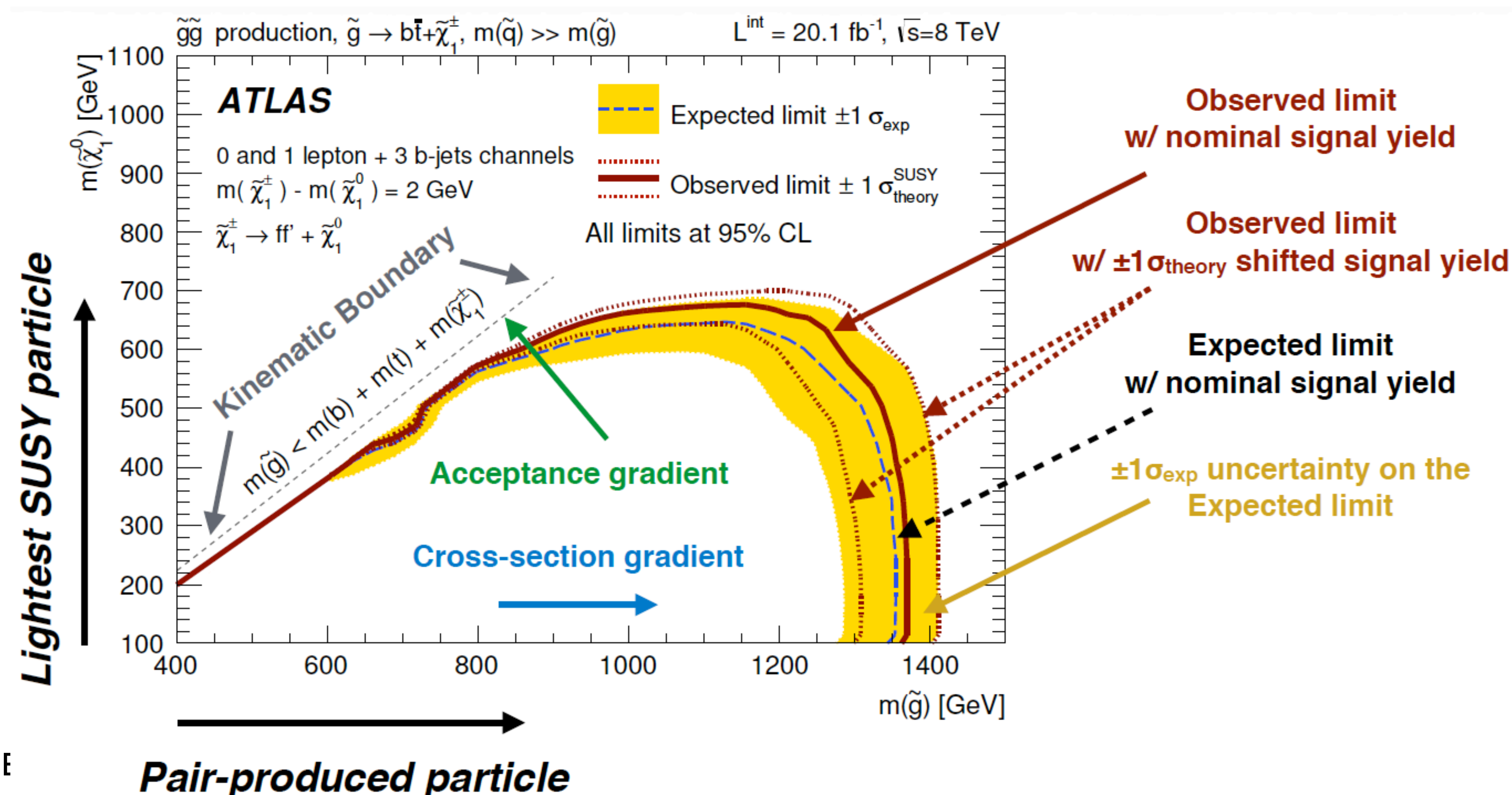
- More complex methods, e.g. new **recursive jigsaw reconstruction** [arxiv:1607.08307], …





Interpretation of results

Results typically presented in 2D slices of SUSY particle masses
Consistency between signal and bkg is evaluated for the point of the plane as a p-value
Model dependent limits are set on production cross sections



Results with full dataset

Inclusive searches
0L 2-6Jets ATLAS-CONF-2017-022
0L 7-11 Jets ATLAS-CONF-2017-033
multi b-jets ATLAS-CONF-2017-021
SS/3L + jets arXiv:1706.03731

3rd Generation
stop 0L ATLAS-CONF-2017-020
stop 1L with DM+HF ATLAS-CONF-2017-037
Stop 2L ATLAS-CONF-2017-034
2b+MET ATLAS-CONF-2017-038
Stop in Z/h arXiv:1706.03986

EWK production
EWK 2/3L ATLAS-CONF-2017-039
EWK di-tau ATLAS-CONF-2017-035

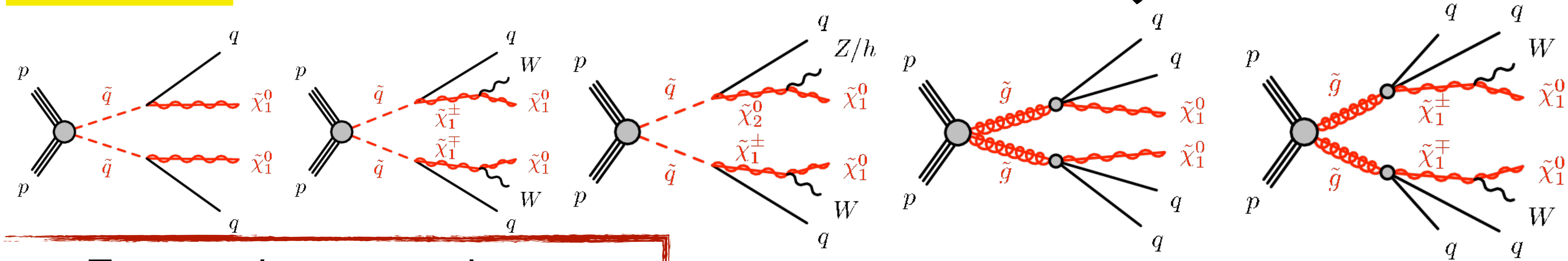
RPV/Long lived particles
stop B-L ATLAS-CONF-2017-036
stop 2x2 ATLAS-CONF-2017-025
displaced vertices +MET ATLAS-CONF-2017-026
disappearing tracks ATLAS-CONF-2017-017
RPV 1L arXiv:1706.03731

In this talk only a sample for each category will be presented, highlighted in the list, togeteher with summary

The list of the latest ATLAS SUSY results can be found here
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

0L + MET <6 jets

ATLAS-CONF-2017-022



Two complementary selection strategies:

24 SR using Effective mass ($m_{eff}=P_T(Jets)^2+E_T^2$) selection:
2-3 jets for direct squark decays
4-5 jets for direct gluino decays
5-6 jets for gluino/squark decays via $\chi^{\pm}$
2 large jets for boosted gluino squarks via $\chi^{\pm}$

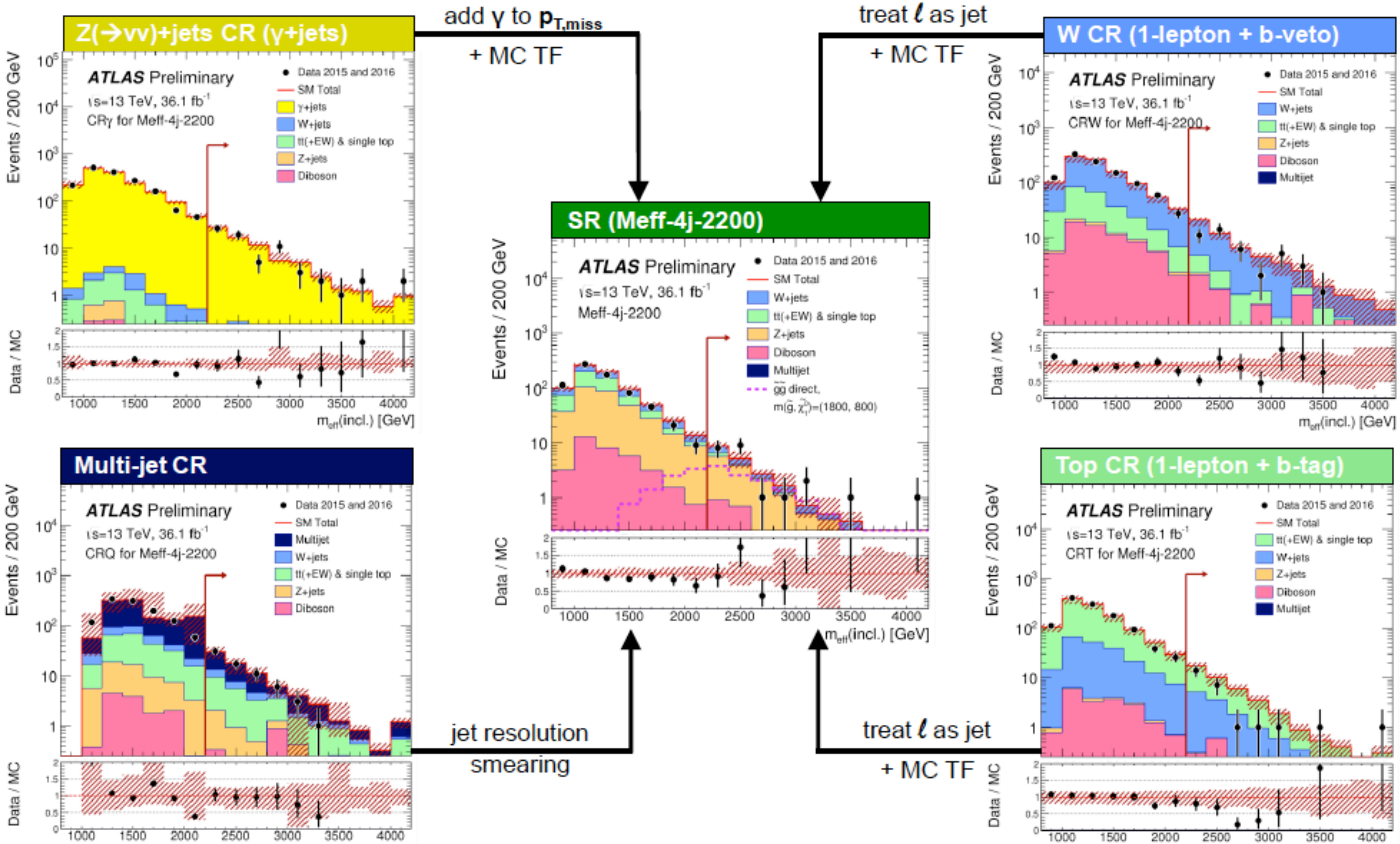
Good performance for high mass splittings

19 inclusive SR using. Recursive Jigsaw:

assumes specific decay chains to assign 4-momenta to invisible particles the kinematics of the event
Compute the kinematic variables in the reference frame of intermediate particles

Good performance for low mass splittings

Background estimation

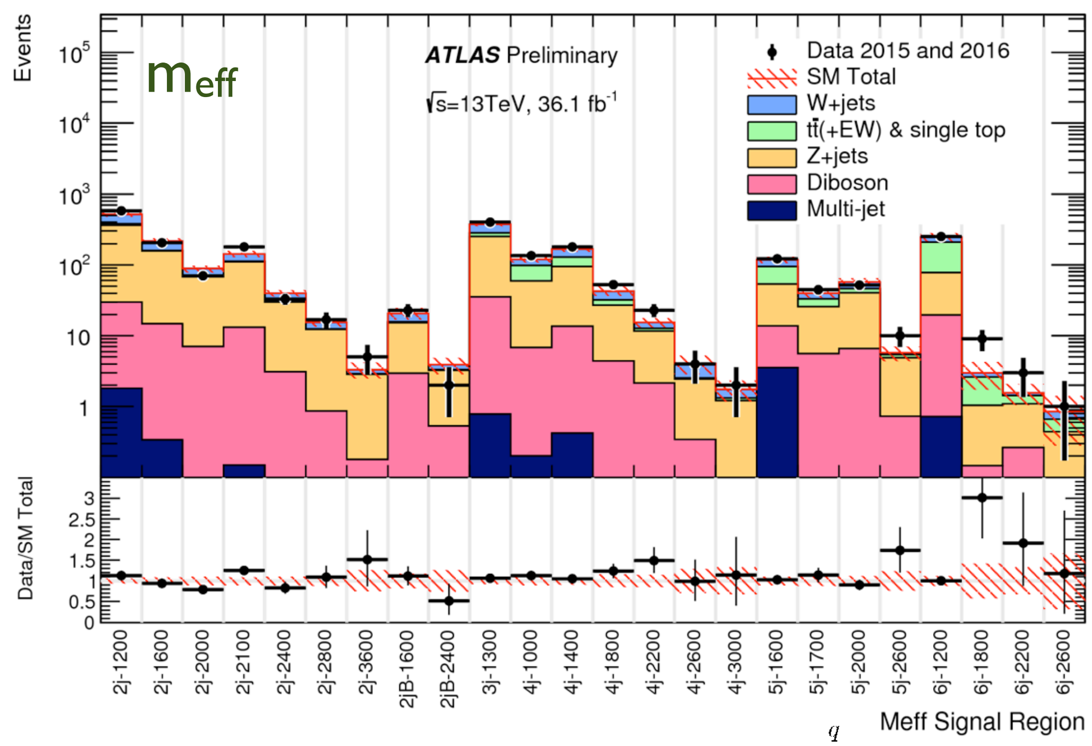


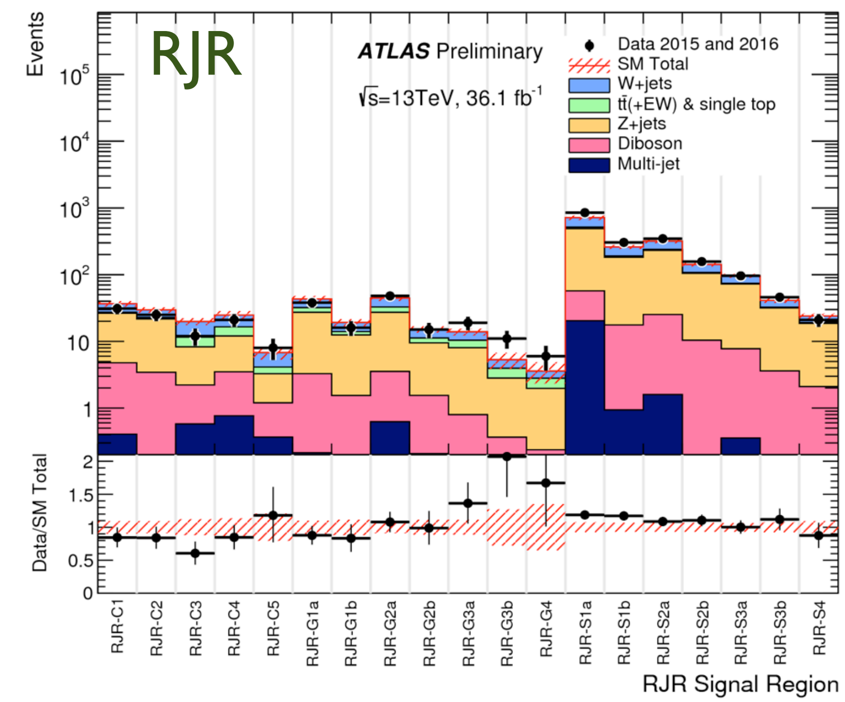
0L + MET <6 jets

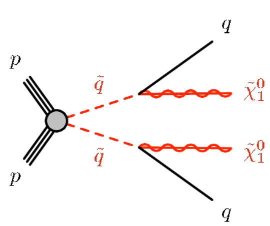
ATLAS-CONF-2017-022

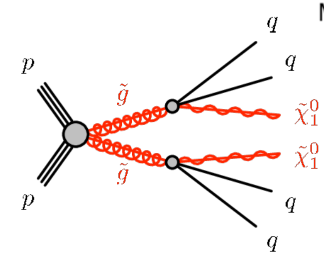
No signal excess found in 43 signal regions

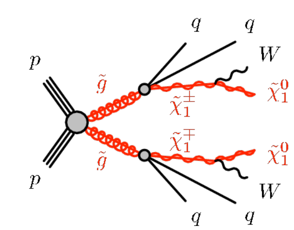
L=36fb^{-1}

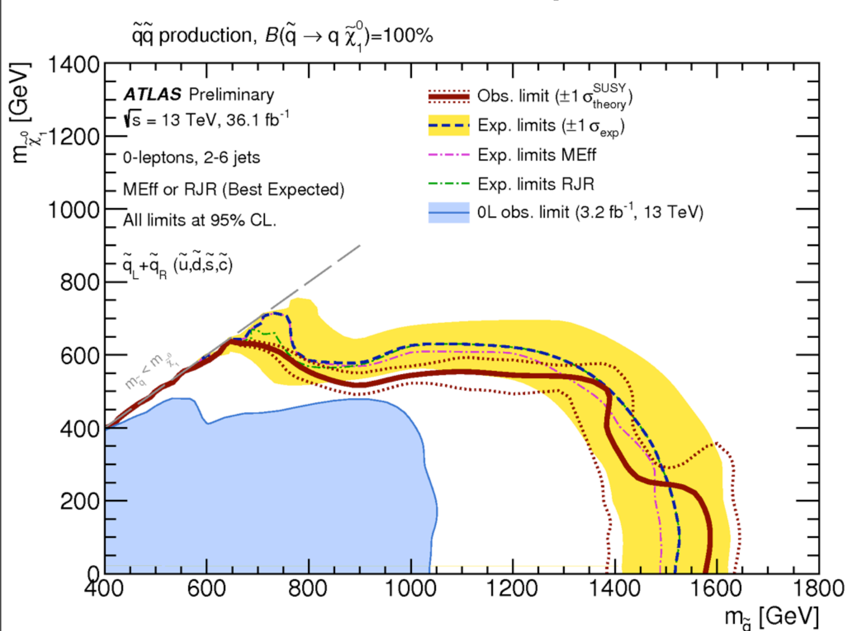


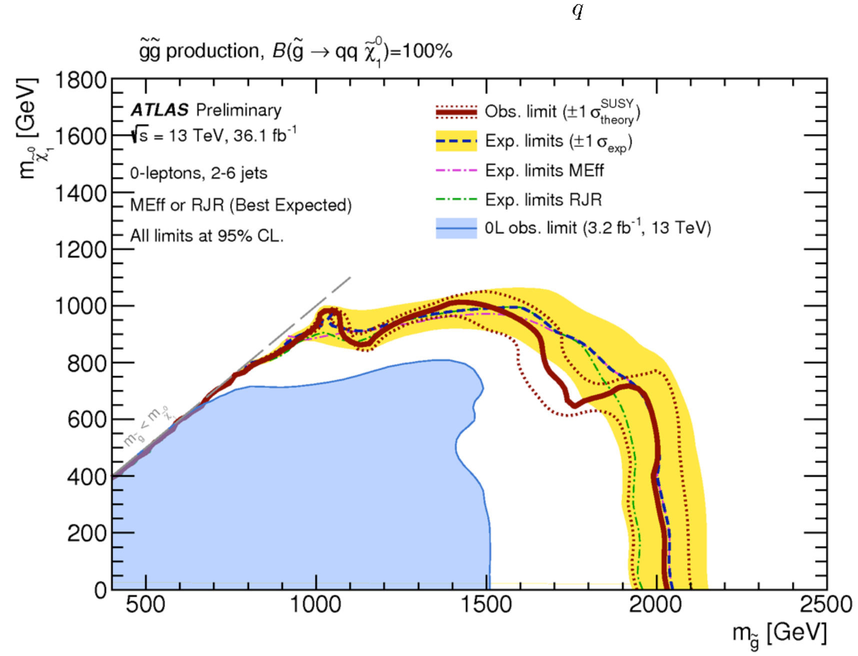


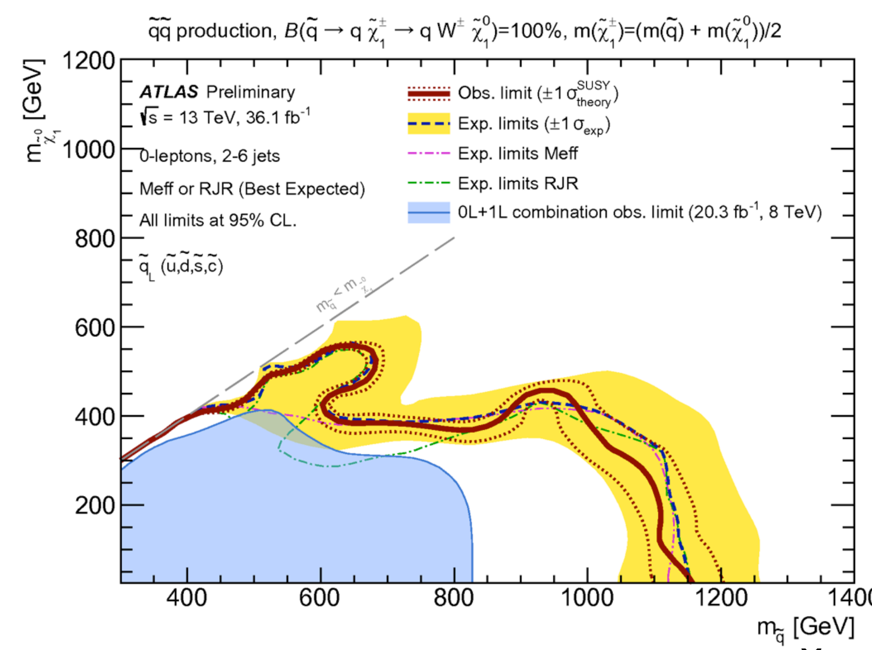






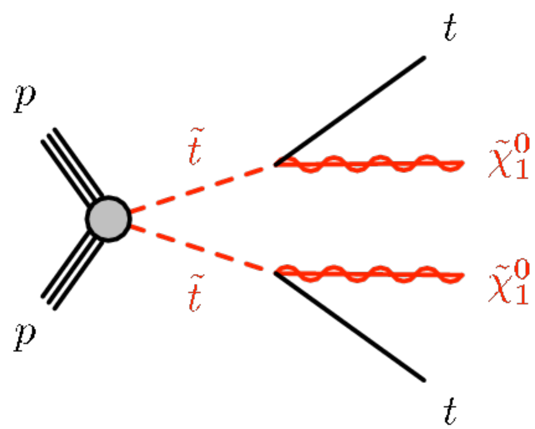


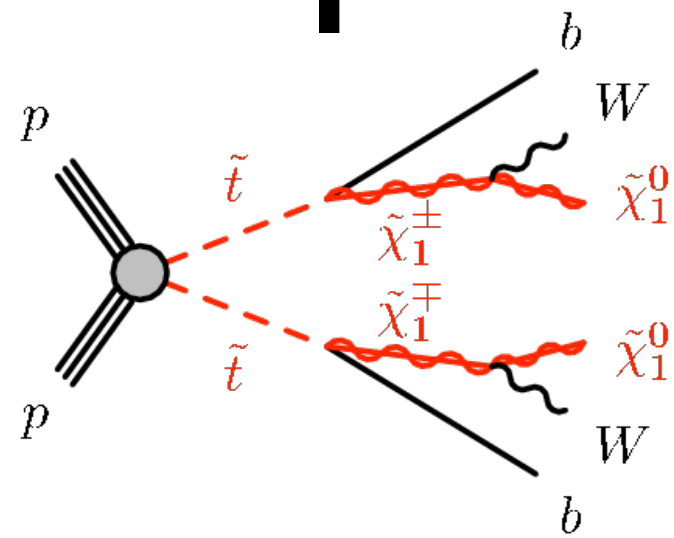


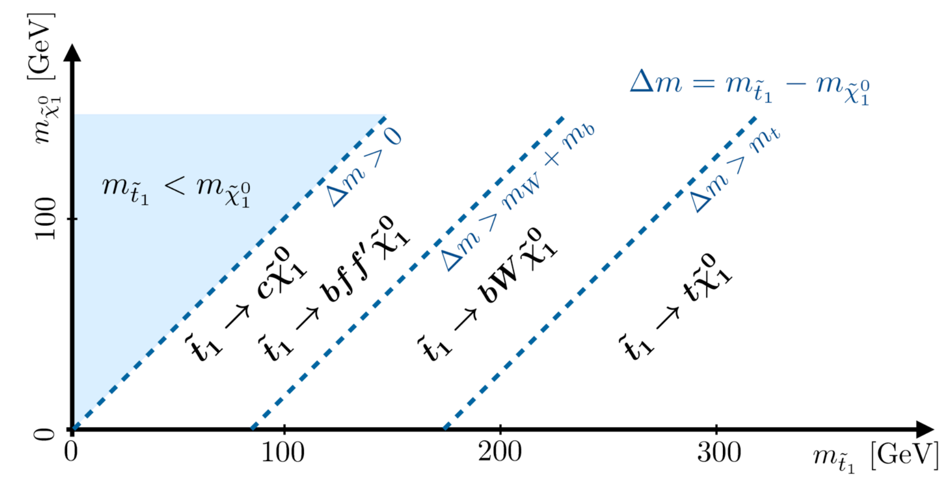


stop 1lepton

ATLAS-CONF-2017-037



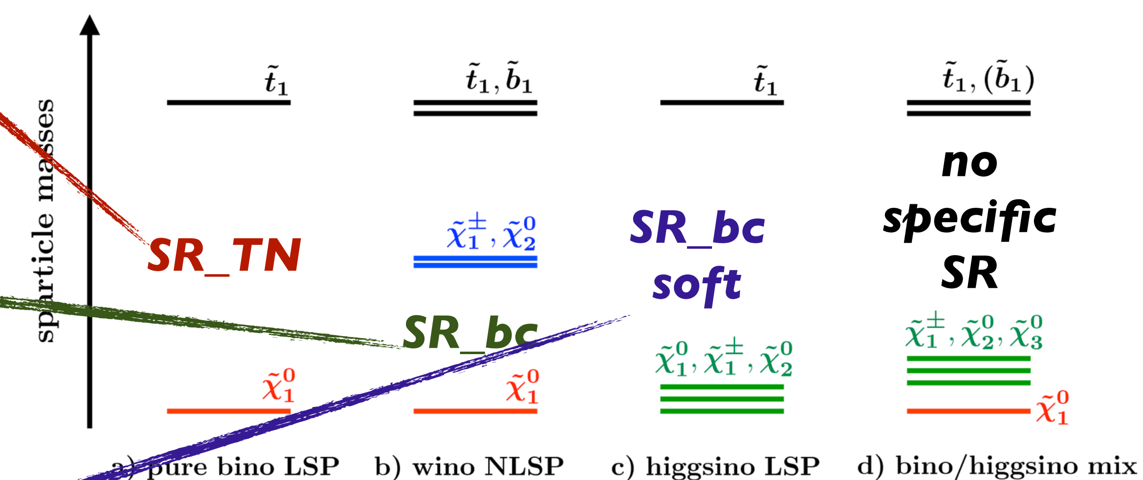




Hadronic top fully reconstructed
E_T^{miss} shape fit
Multivariate techniques for compressed spectra (BDT, RJR)

Different decay chains depending on masses, and different models require different SR

W boson fully reconstructed from jets

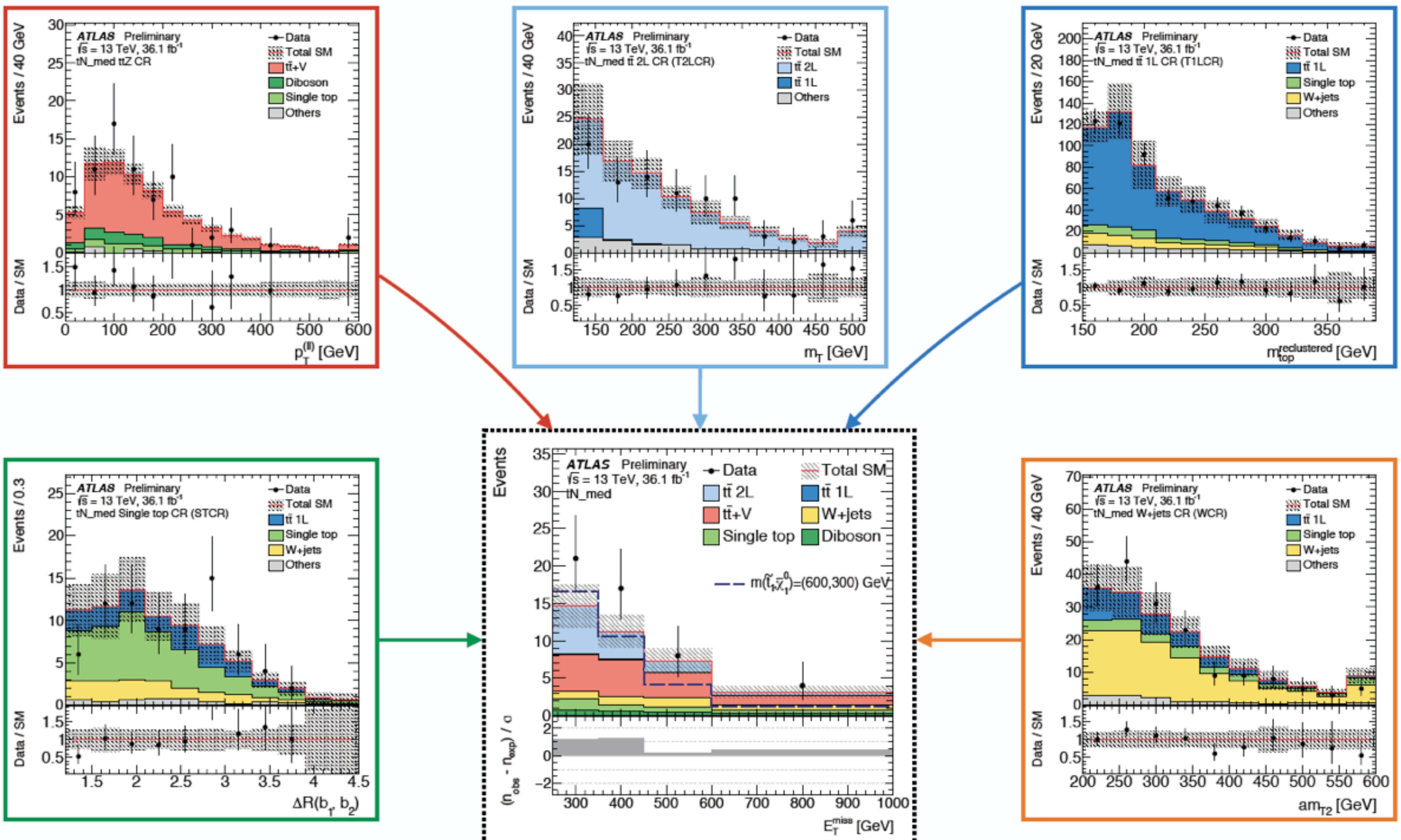


Soft spectrum: ISR jet required for boosting the system shape fit in both E_T^{miss} and lepton P_T

Main backgrounds: W+jets, t tbar production

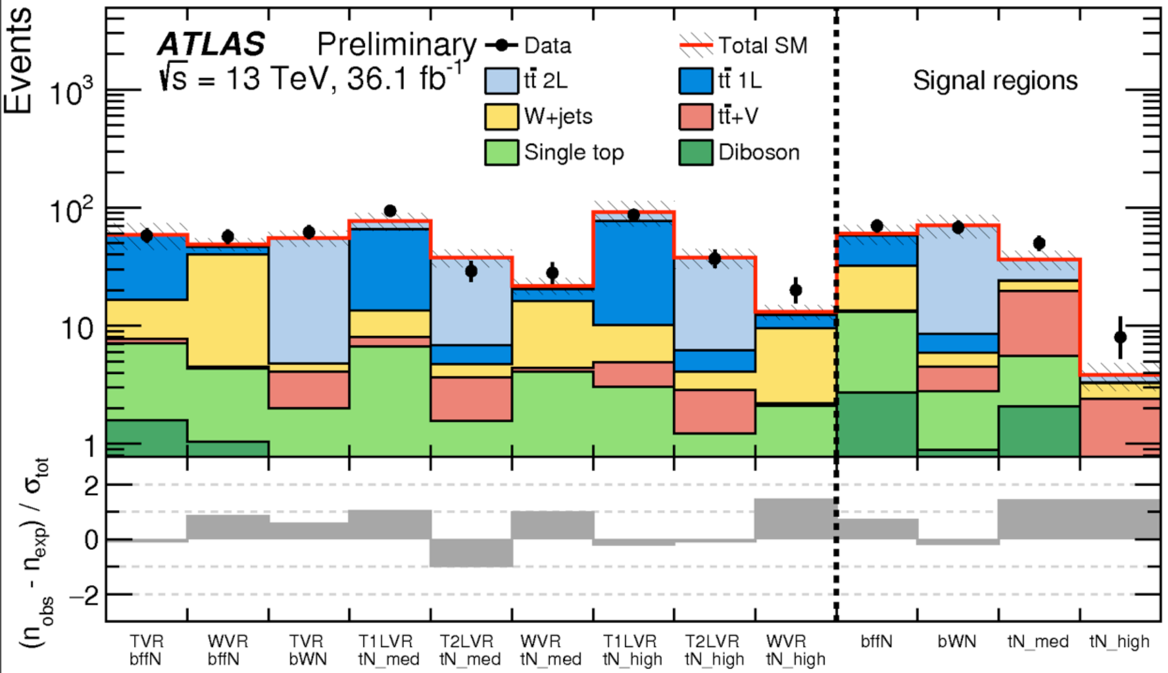
stop 1 lepton

16 SR: main discriminants m_T, E_T, p_T^W
Background estimated in up to 5 CR and validated in VR for each SR

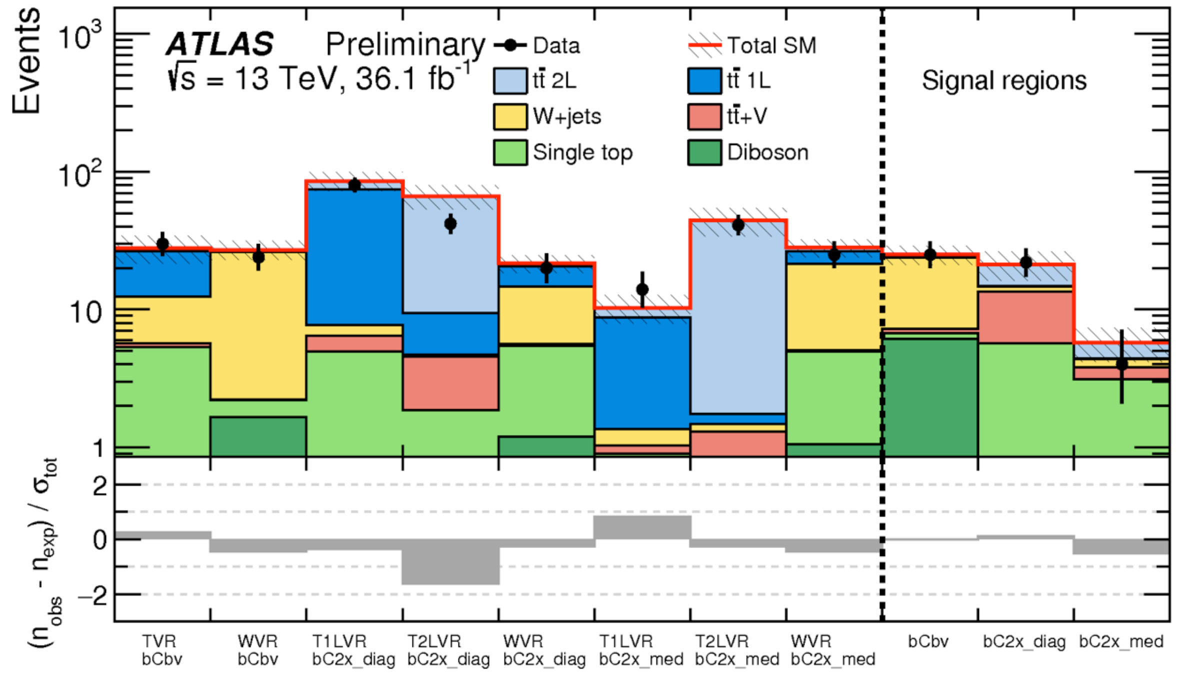


Stop 1l: results

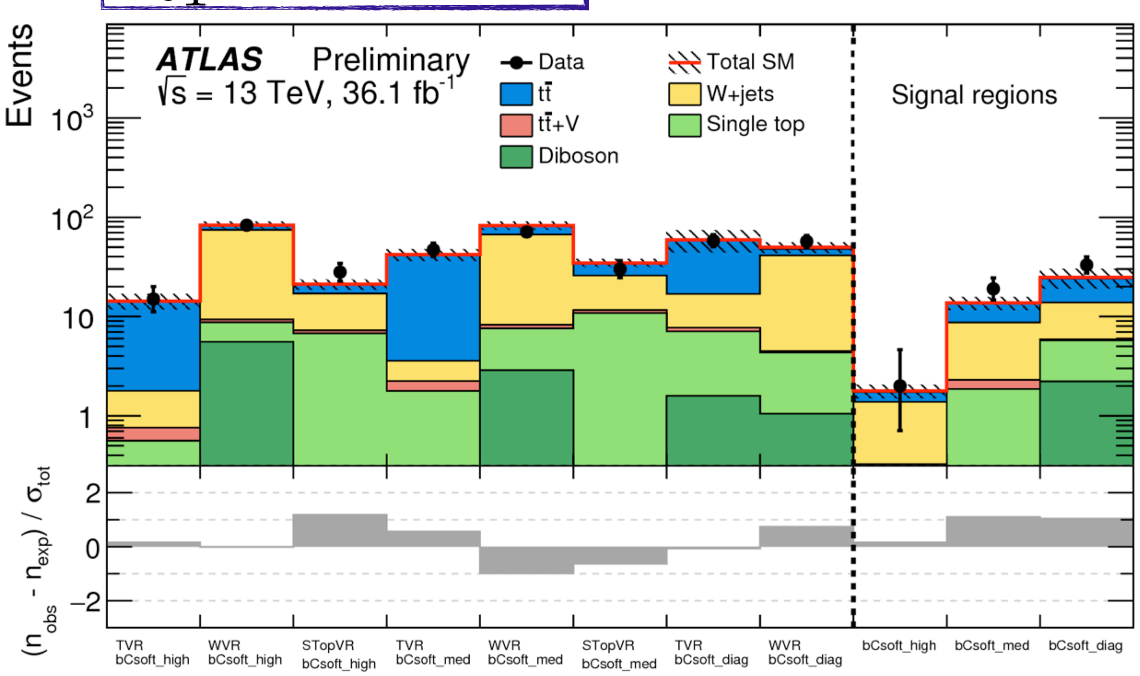
$t\tilde{\chi}_1^0$



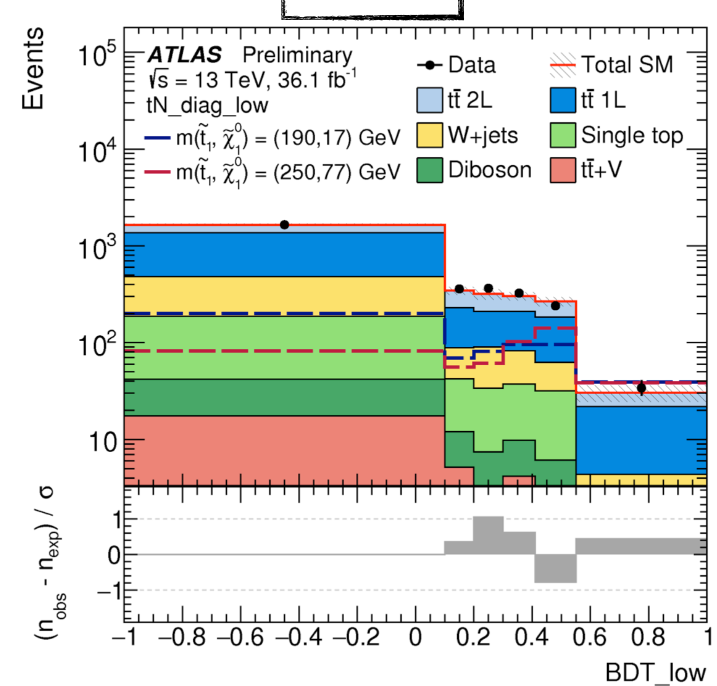
$b\tilde{\chi}_1^{\pm}$



$b\tilde{\chi}_1^{\pm}$ soft lepton



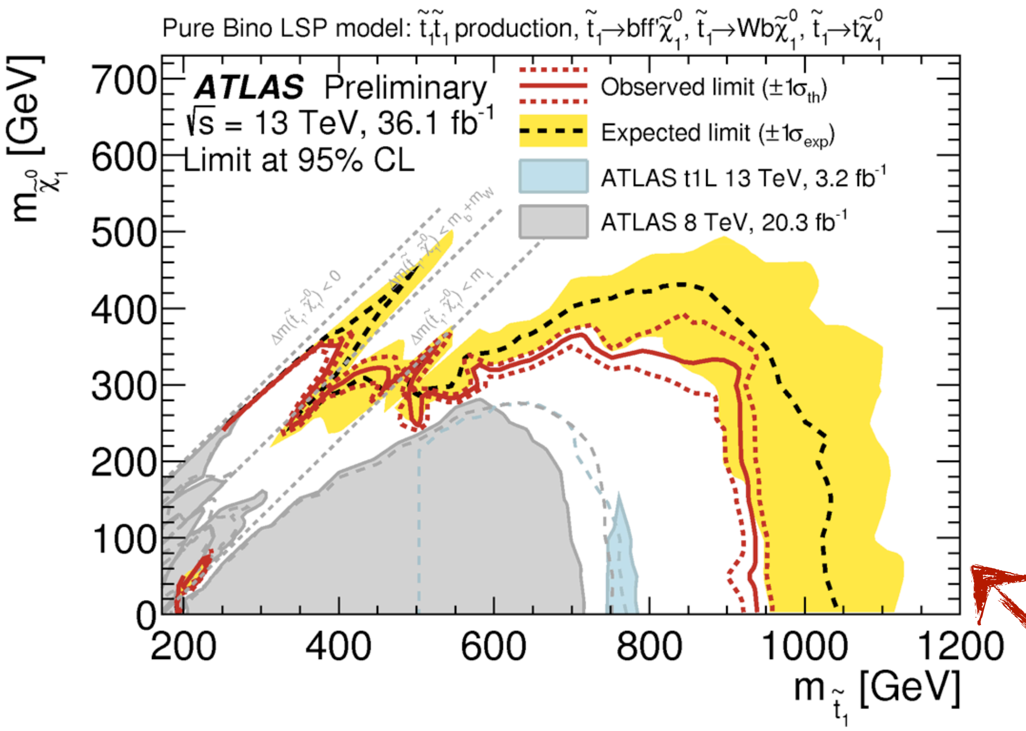
BDT

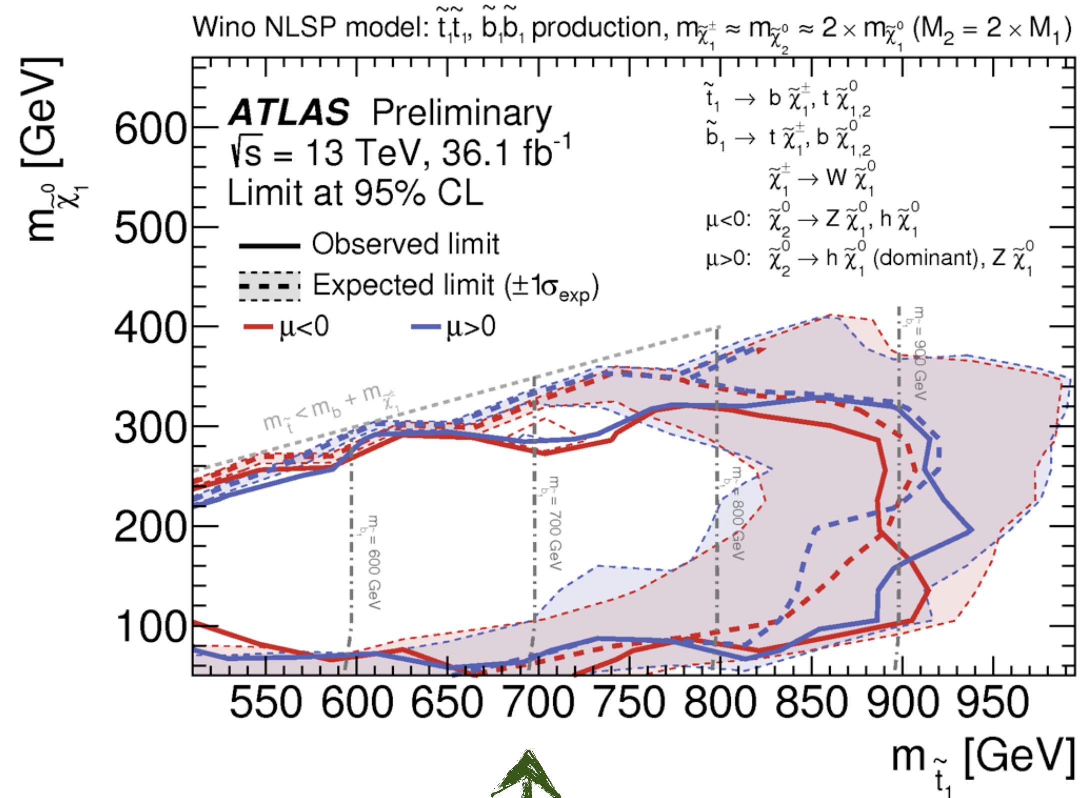


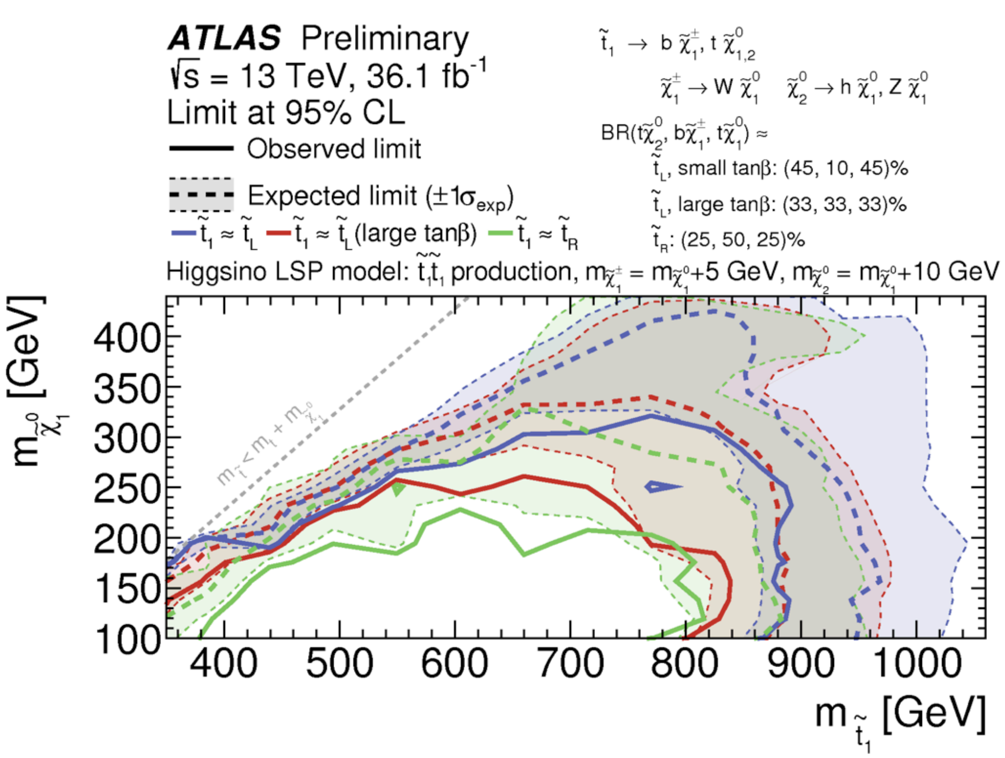
No signal excess found

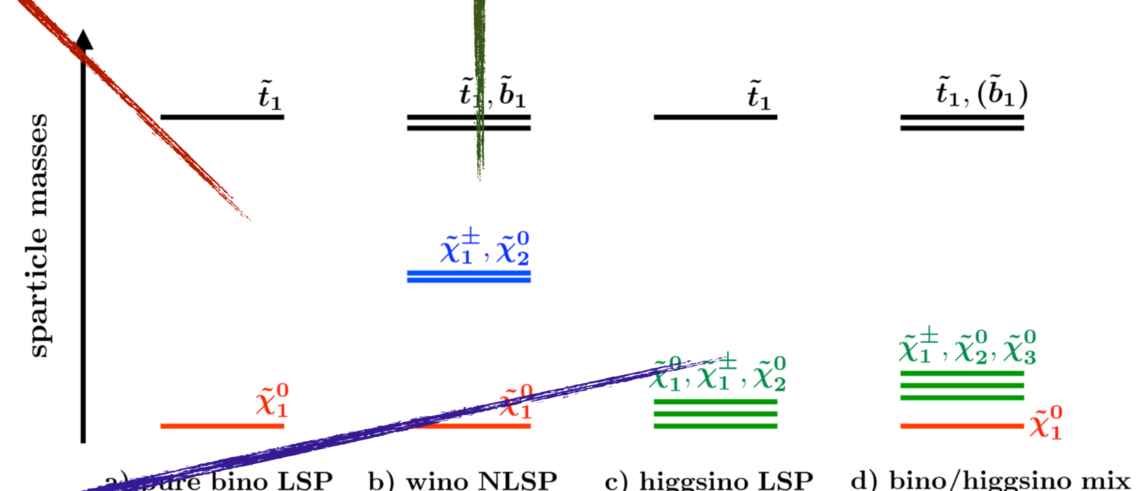
stop 1l: interpretation

ATLAS-CONF-2017-037



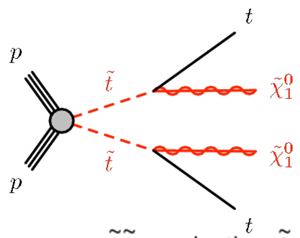




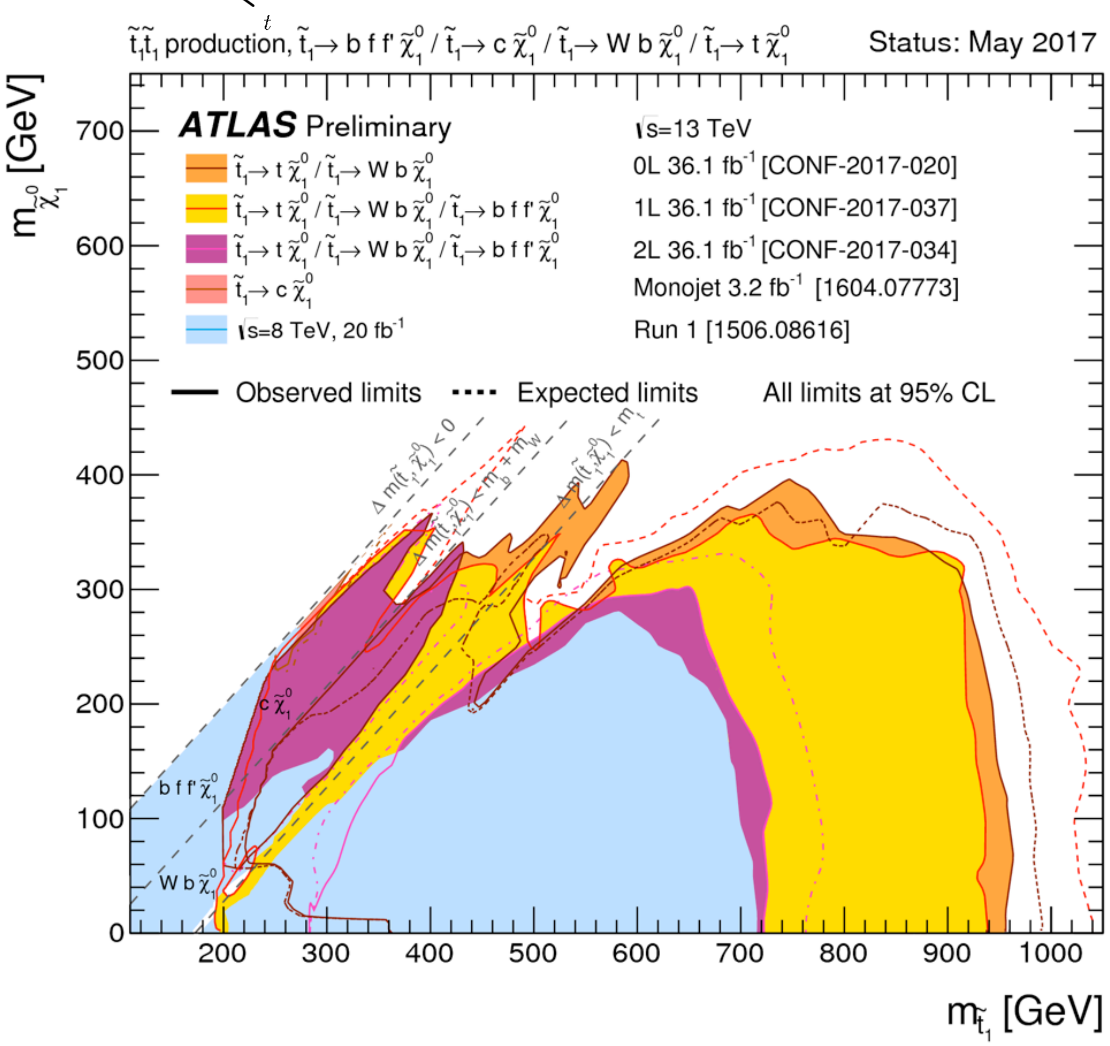


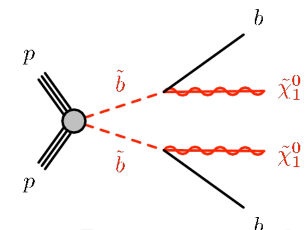
Alberto Cervelli
INFN Bologna

Summary of 3rd Gen

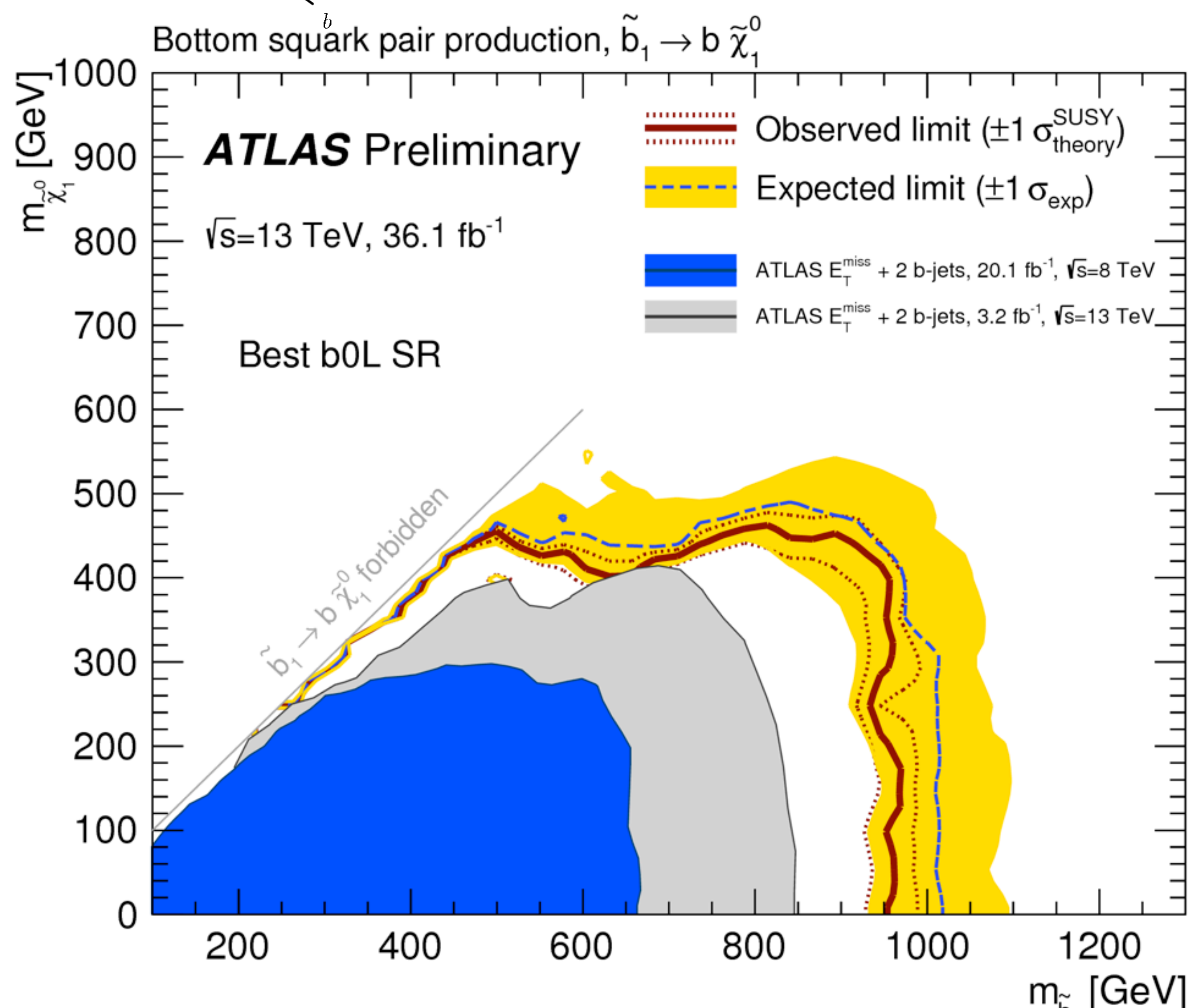


Stop with bino LSP: improved sensitivity for mass splittings of ~m_t and <m_W



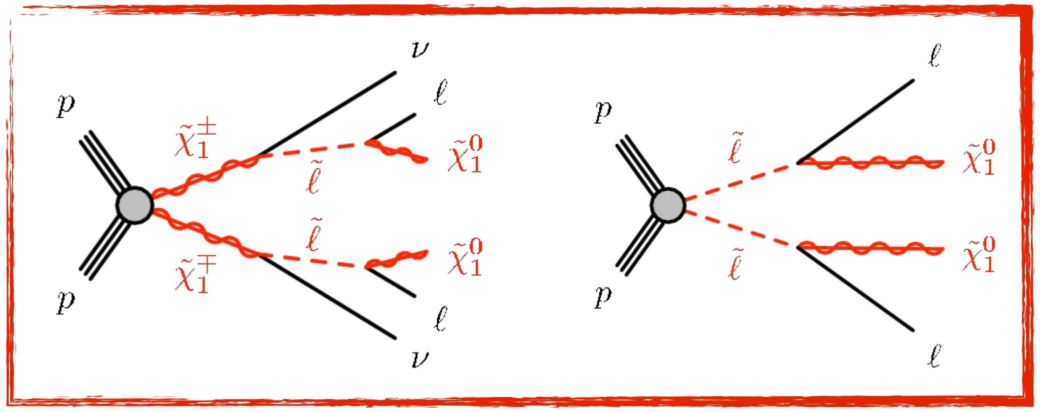


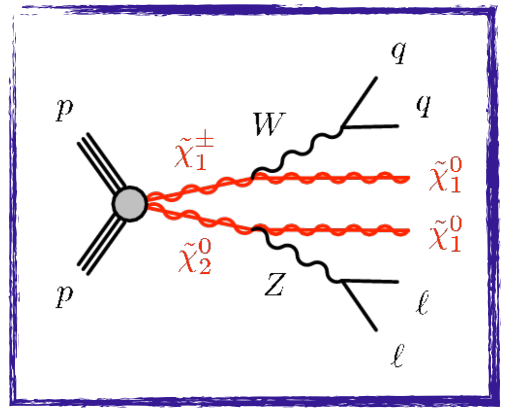
Sbottom: improved sensitivity in all the mass regions

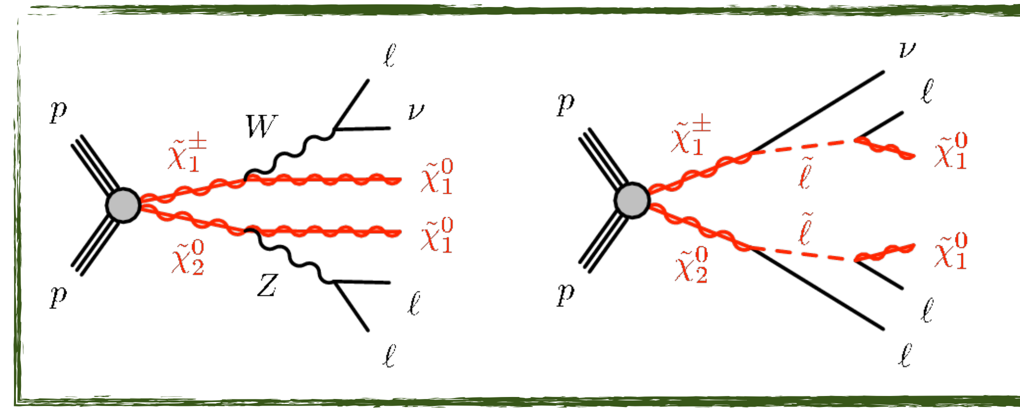


ATLAS-CONF-2017-039

2/3 leptons







Electro Weak production: Gaugino or slepton production, decaying via leptons or bosons
3 different channels/Signal regions. All channels have a large missing E_T

2l+0jets: targets chargino pair production, decaying via sleptons

Main discriminating variables: M_{T2}, invariant mass of dilepton pair.

2l+Jets: target chargino-neutralino production, decaying via gauge bosons

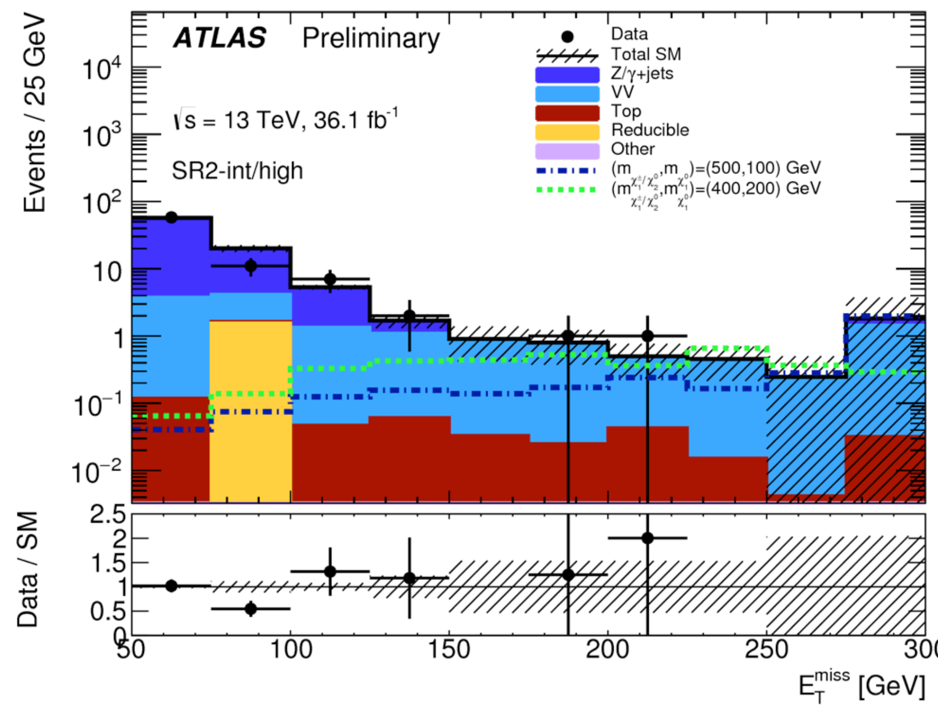
Look for 2 leptons, both opposite and same sign.

3 leptons: targets chargino-neutralino decaying both trough gauginos or sleptons

2/3 L: backgrounds

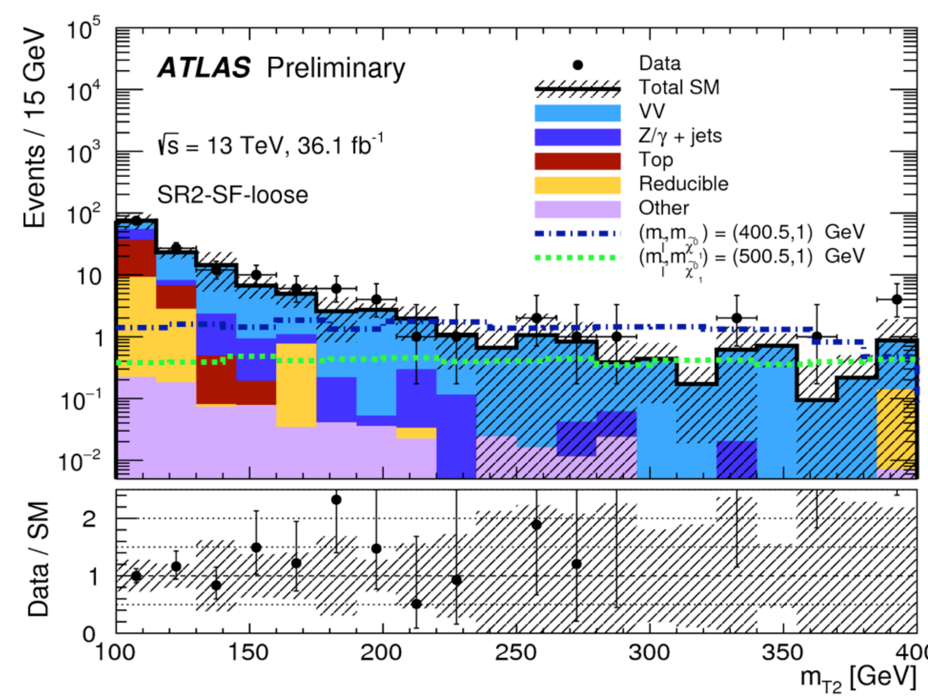
Different backgrounds and CR for different channels.

2l+0jets: top pair and VV estimated from dedicated CR
2l+Jets: Z+jets obtained from data using orthogonal γ+jets
3 leptons: top pair, VV, and single top from dedicated CR, Z+jets obtained from Data



Non prompt background estimated from data

Error on background estimation ~20-50%

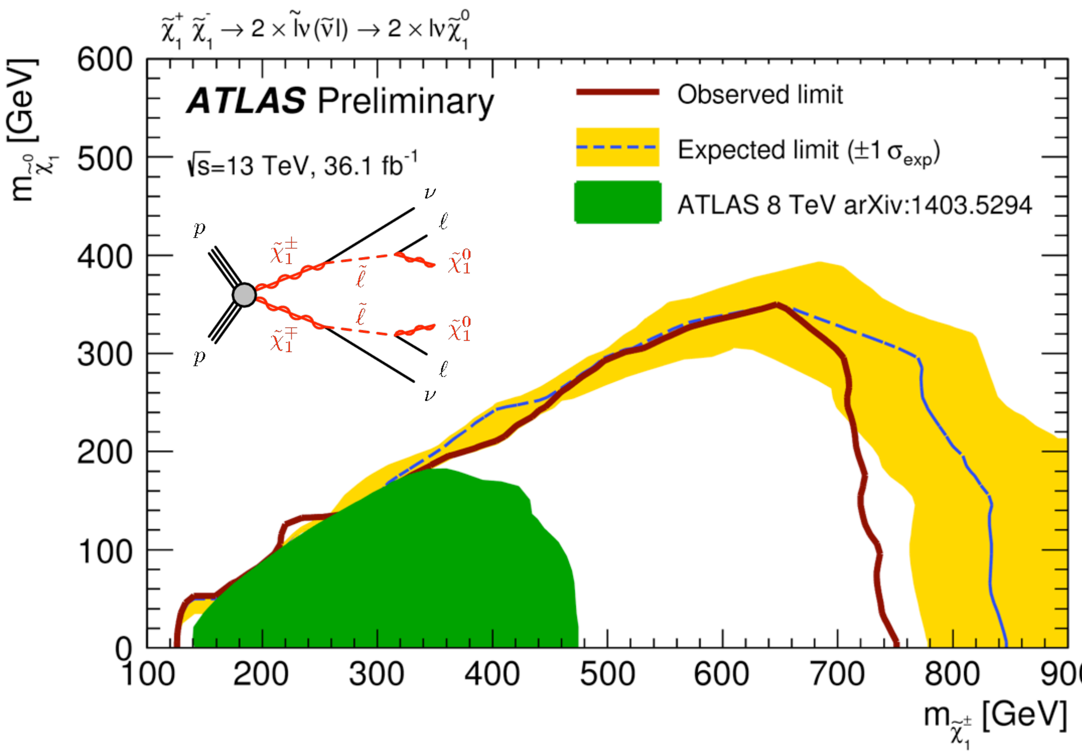


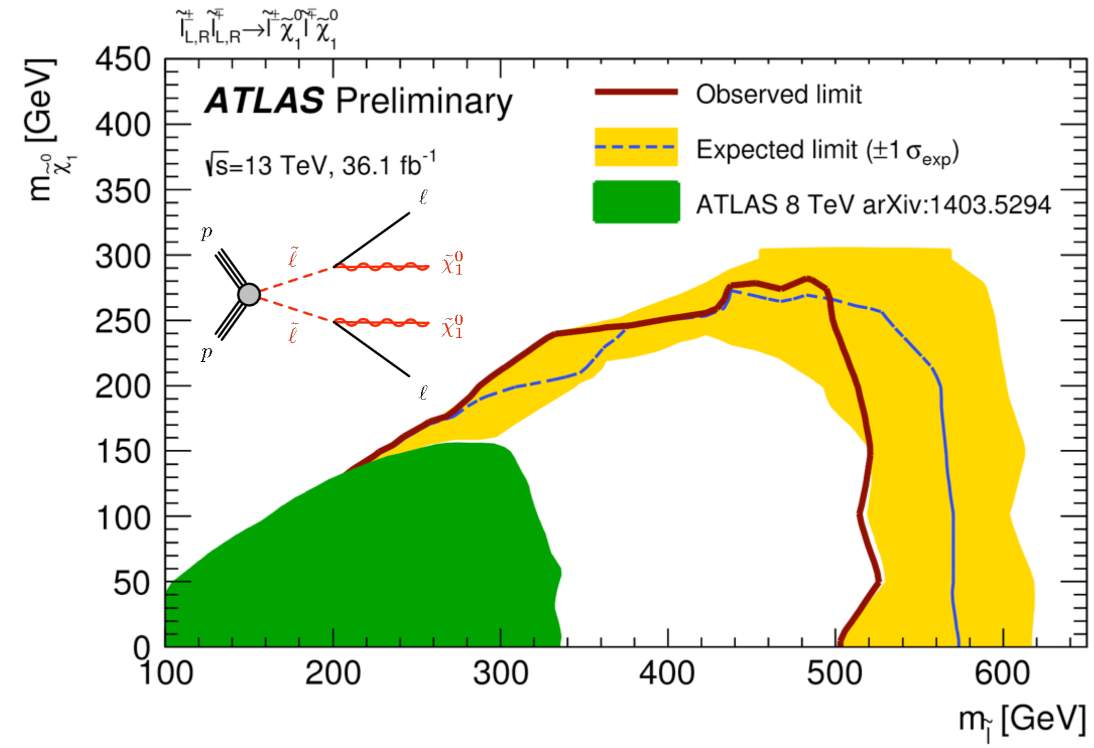
2/3 leptons

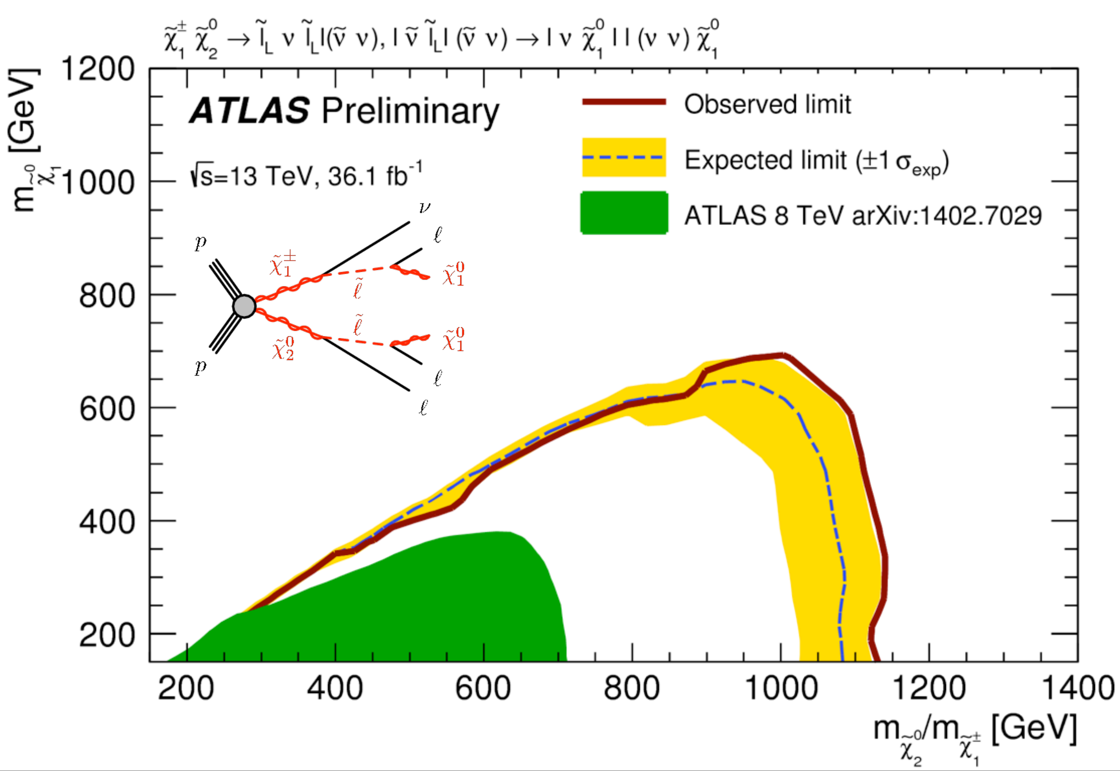
No signal excess found

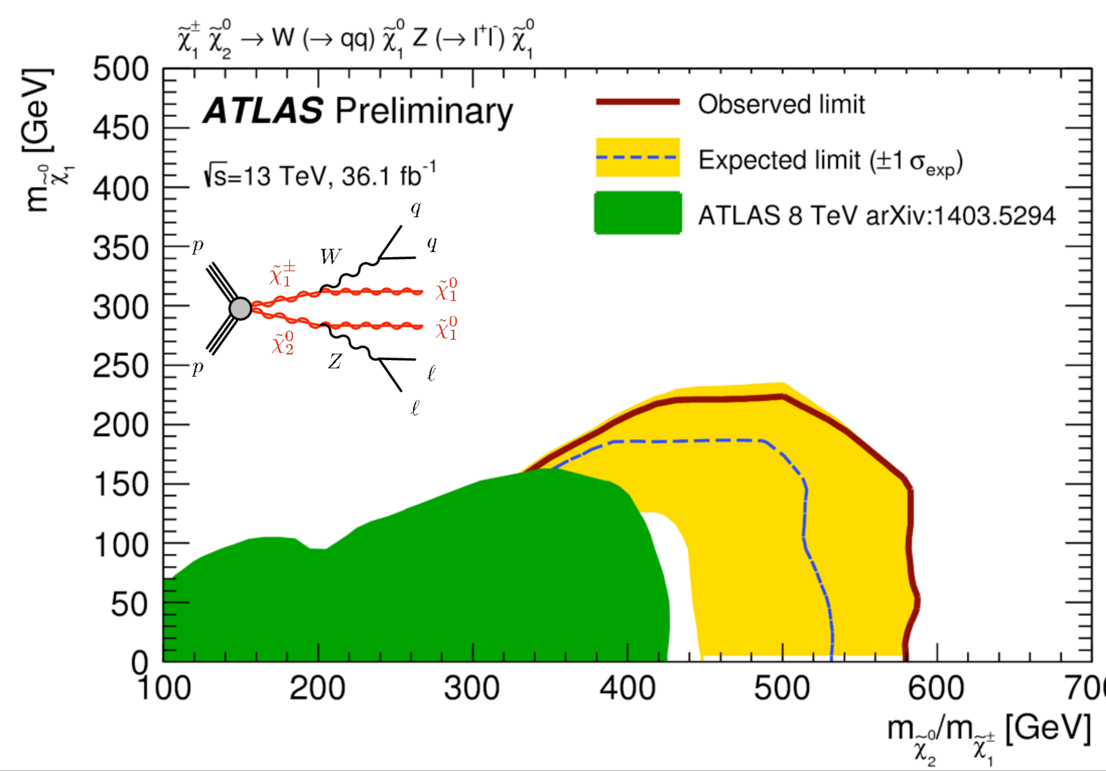
L=36fb^{-1}

ATLAS-CONF-2017-039





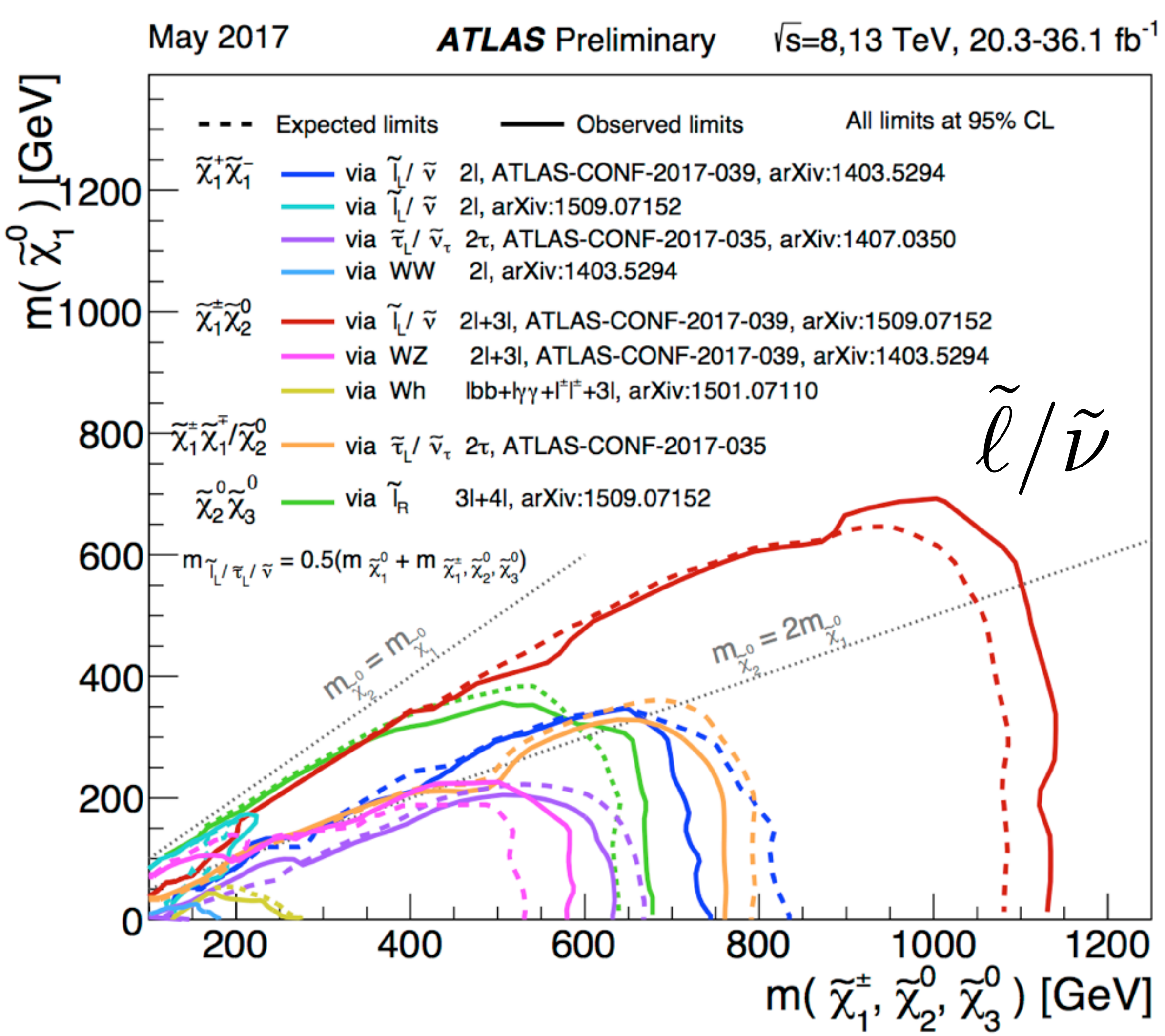


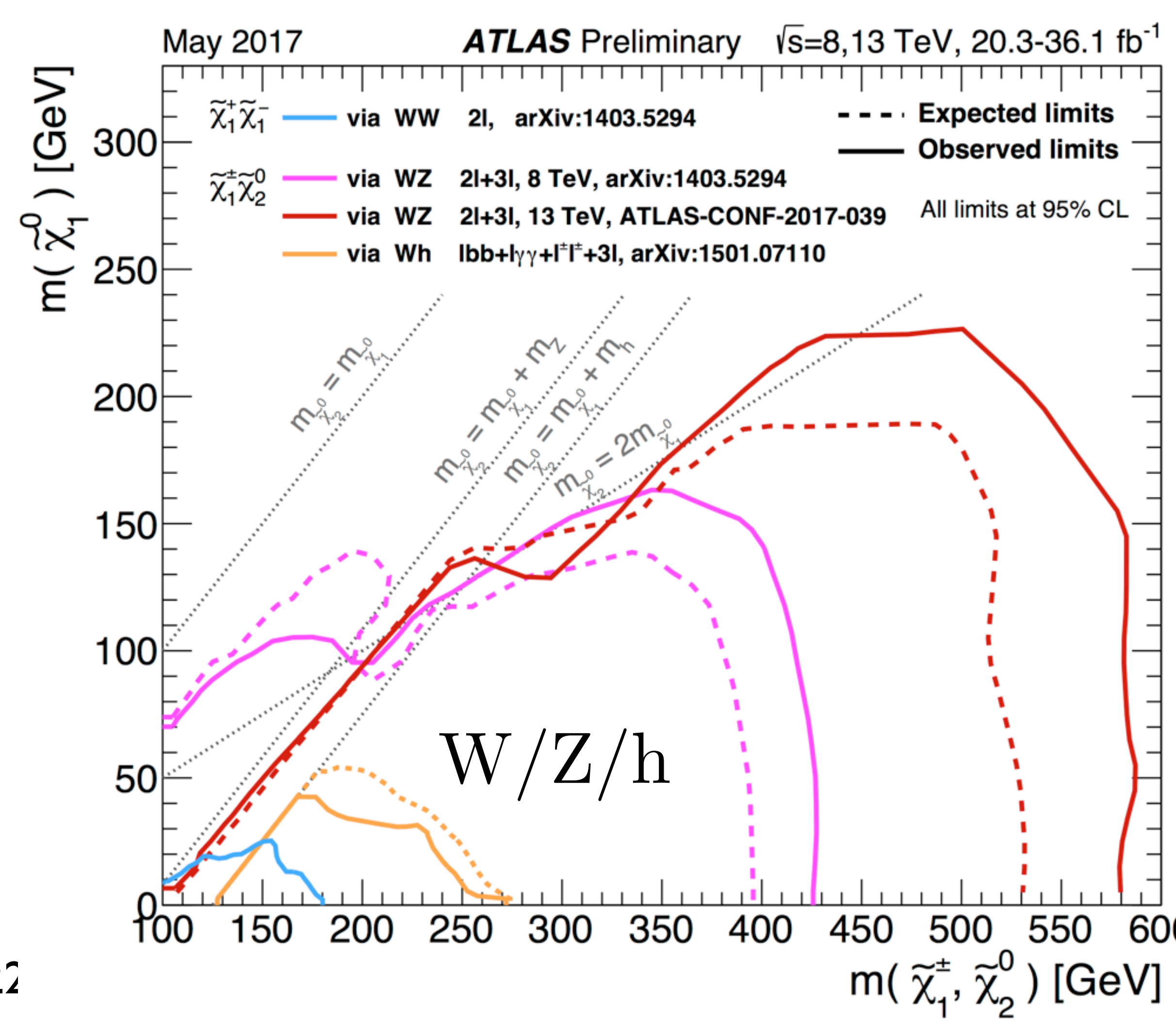


Summary of EWK

Decays via sleptons:
Sensitivity exceeding 1TeV for chargino and heavier neutralinos

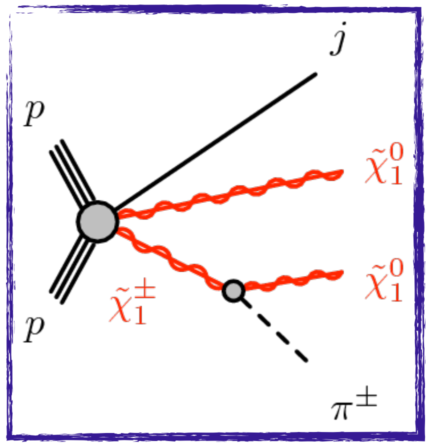
Decays via W/Z/h bosons:
sensitivity up to 600 GeV for chargino and heavier neutralinos

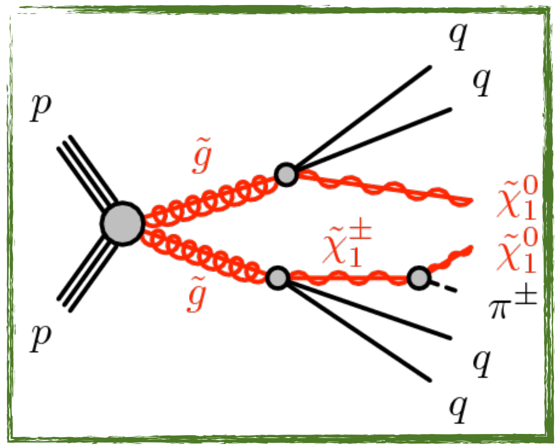


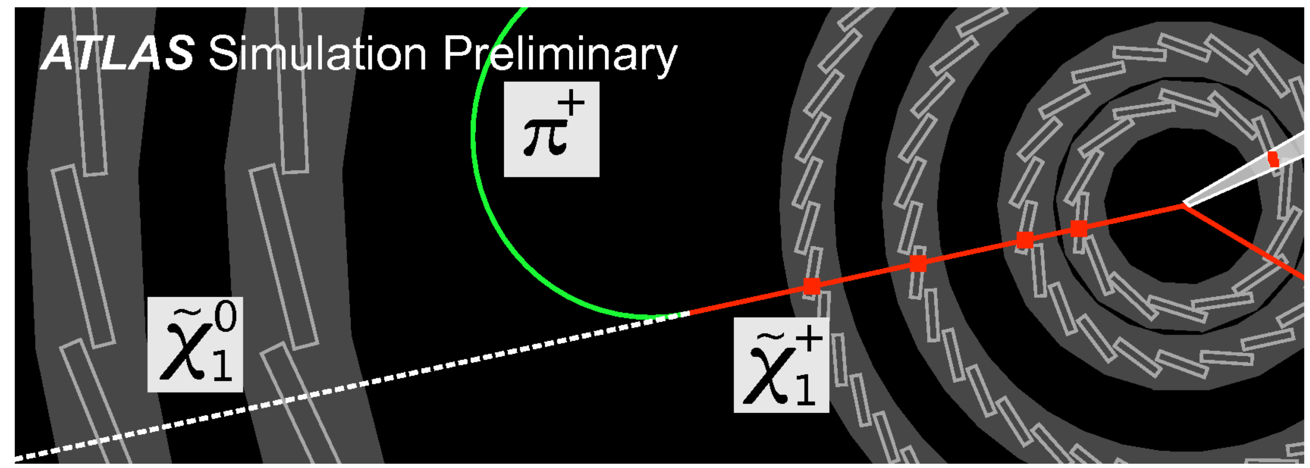


Disappearing Tracks

ATLAS-CONF-2017-017







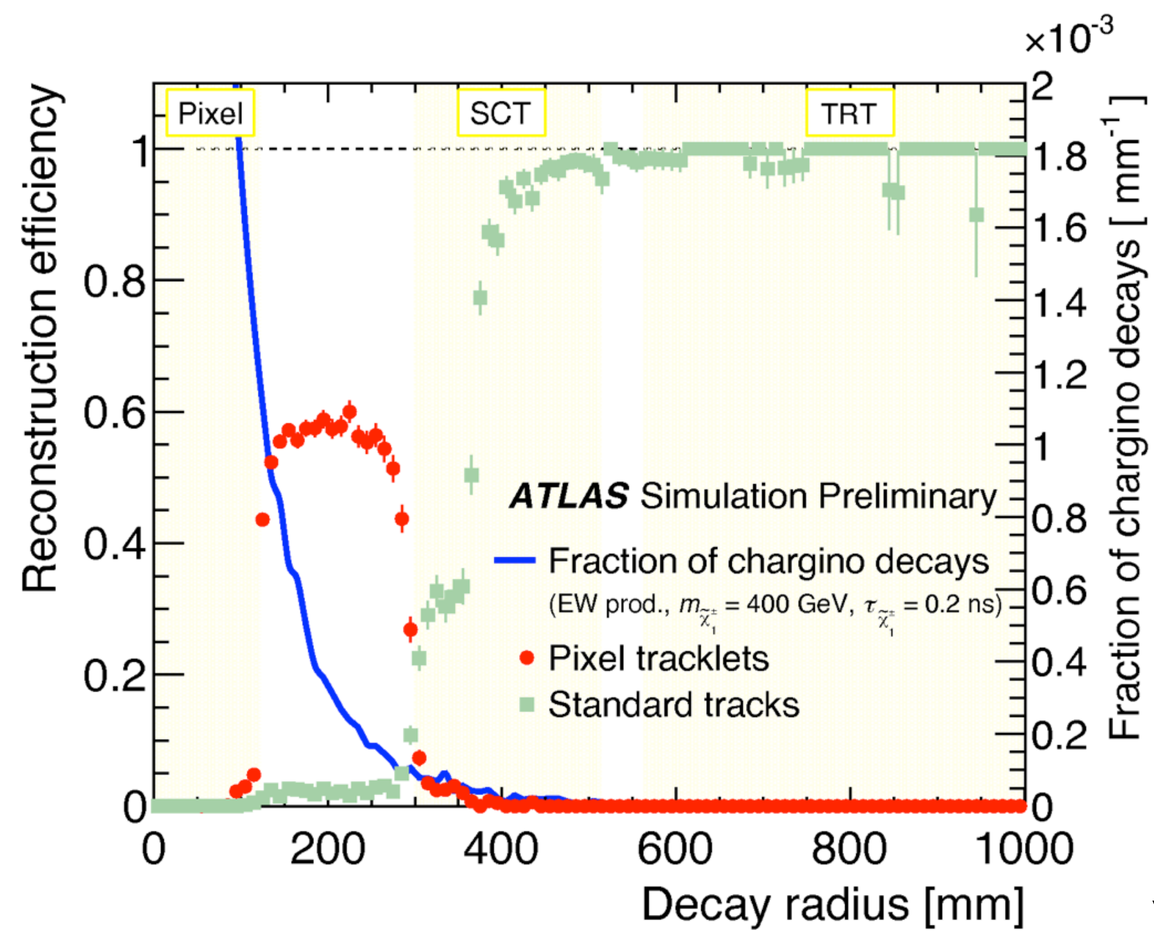
Detector driven analysis.

Targets models where chargino and neutralino are almost degenerate, pion not reconstructed

Two different signatures and productions:
EWK: ISR jet+$\not{E}_T$+disappearing
strong: multi jets+$\not{E}_T$+disappearing

Low mass (160 MeV) LSP may have cτ~6cm

Run 2 sensitivity improved thanks to IBL

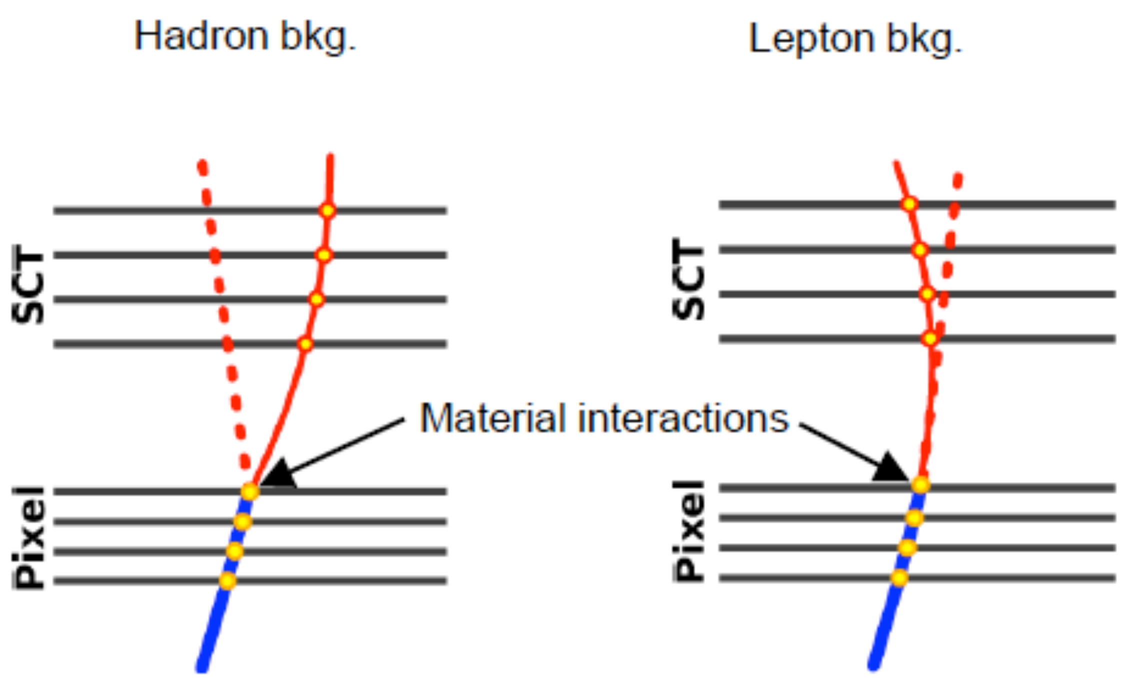


Disappearing tracks

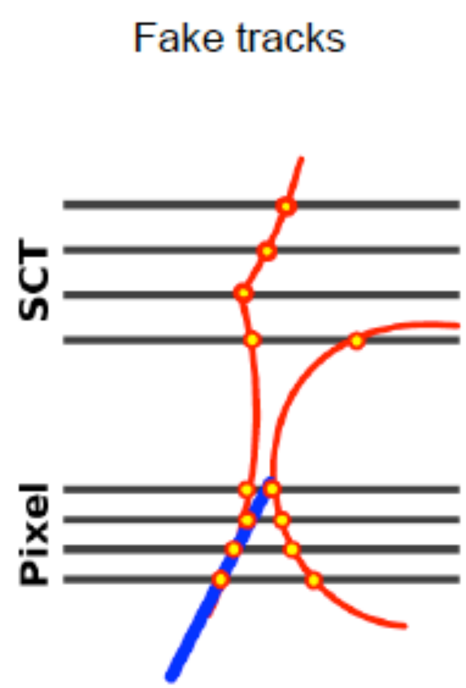
Simultaneus fit of tracklet P_T for the 3 backgrounds (+ signal)

obtained from data control samples without material interaction

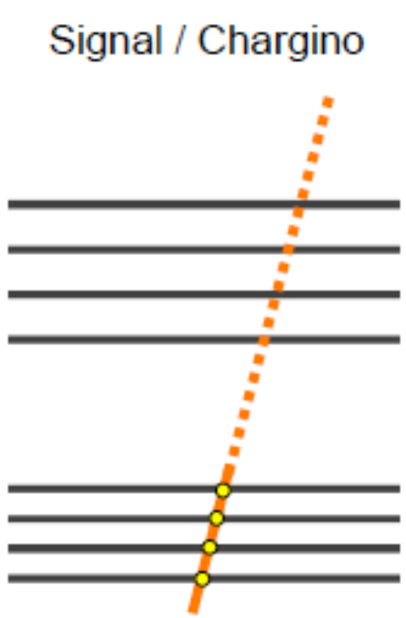
Smeared with resolution function to match the tracklet P_T spectrum



Fake track from data CR with large d_0 significance, but no missing E_T

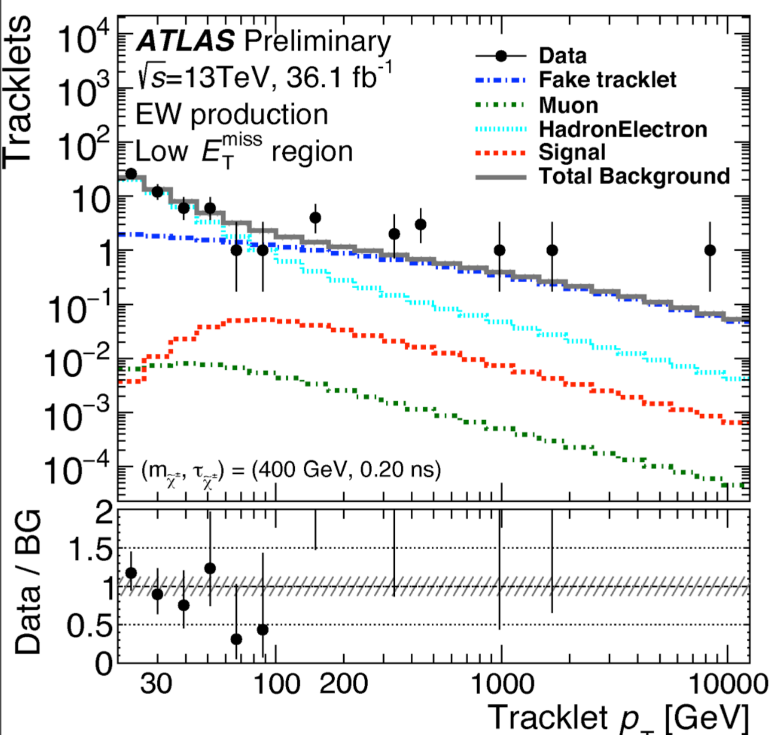


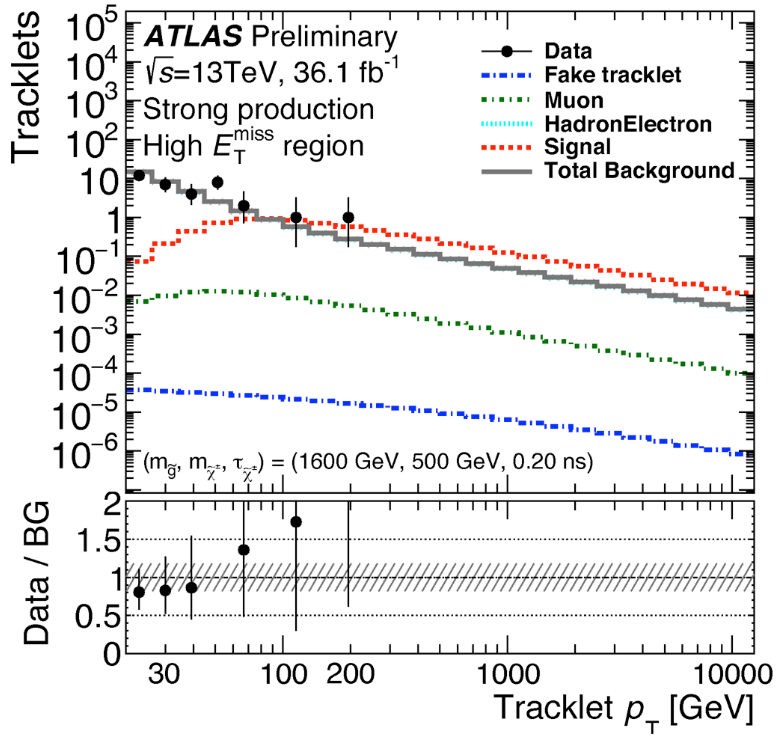
Fake track from data CR with large d_0 significance, but no missing E_T



ATLAS-CONF-2017-017

Disappearing tracks



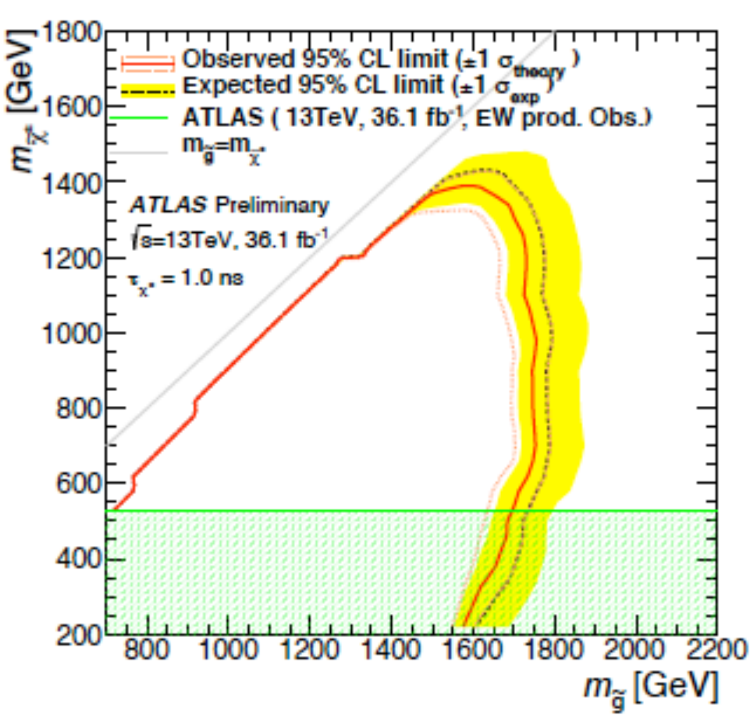


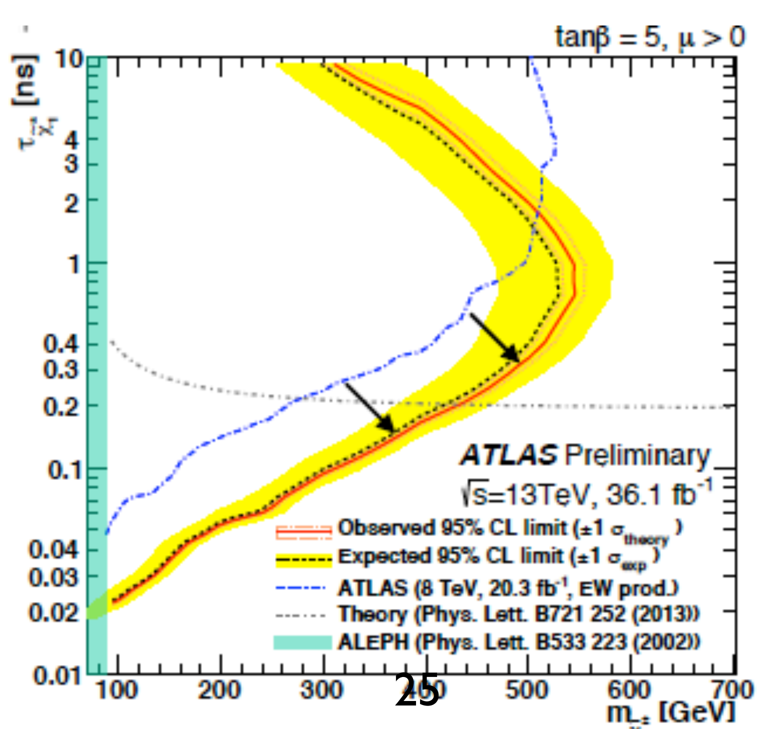
No signal excess found

For weak production large increase w.r.t Run1

Starting to be as sensitive as direct higgsino searches

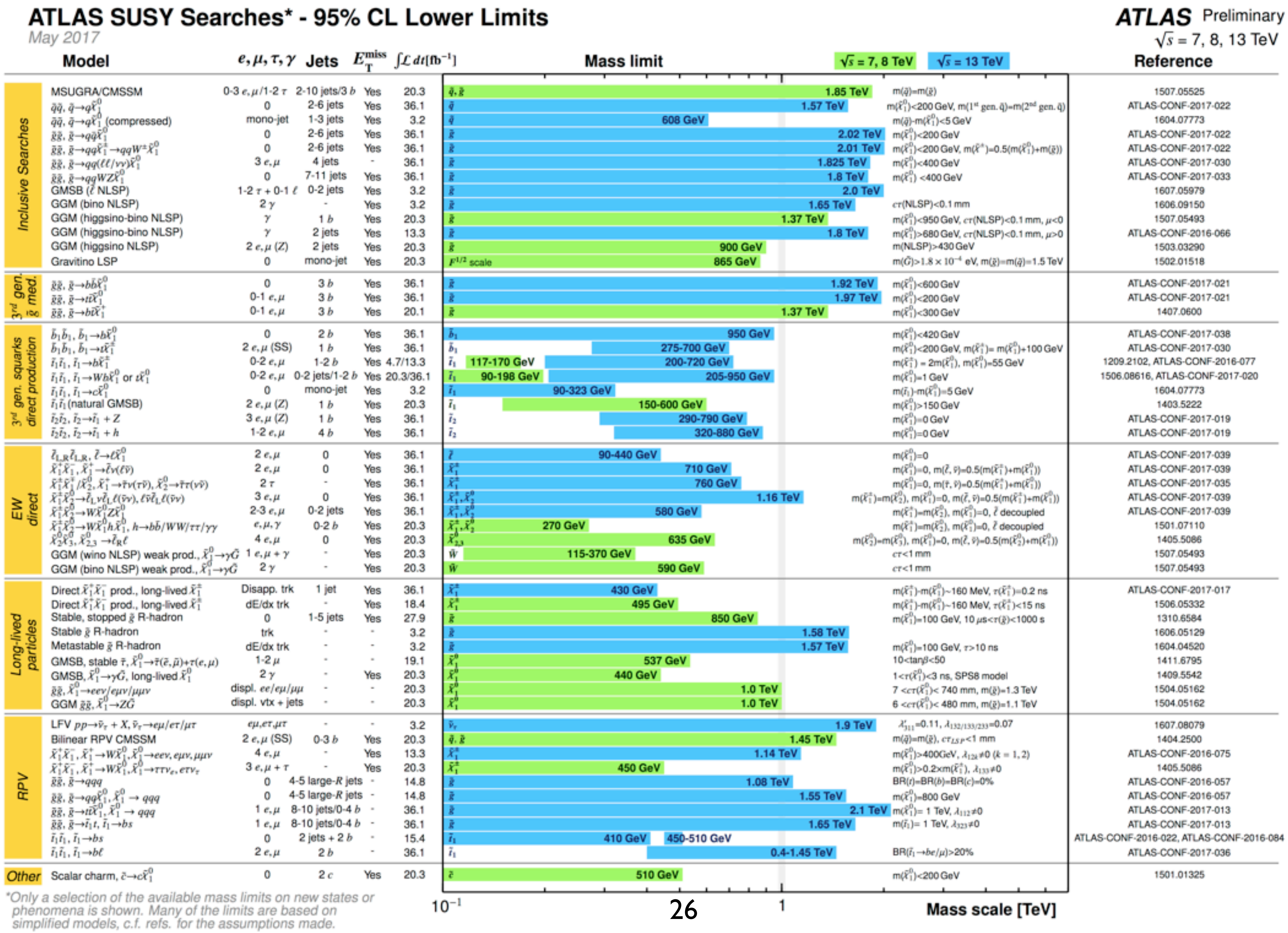
Strong production excludes up to 1.6 TeV for lifetimes under 1.1 ns





Alberto Cervelli
INFN Bologna

A broader look



Conclusions

- SUSY searches in ATLAS represent a broad spectrum of different searches and approaches, 13 results are now public with full Run2 dataset
  - Different Physics: strong production, weak production, long lived particles
  - Different techniques: multivariate, kinematic variables, detector driven approaches
- We did not see anything yet
  - Final Run2 dataset will provide more insight on SUSY, and tools are getting better and better
  - Will be able to target lower cross-sections and problematic kinematic regions for SUSY decay chains