

ATLAS Searches for New Physics

Matt Sullivan on behalf of the ATLAS collaboration

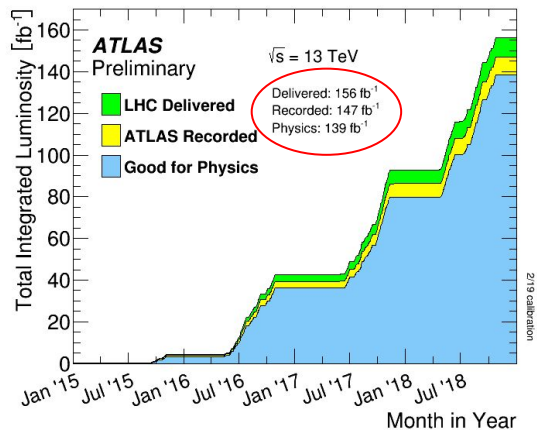
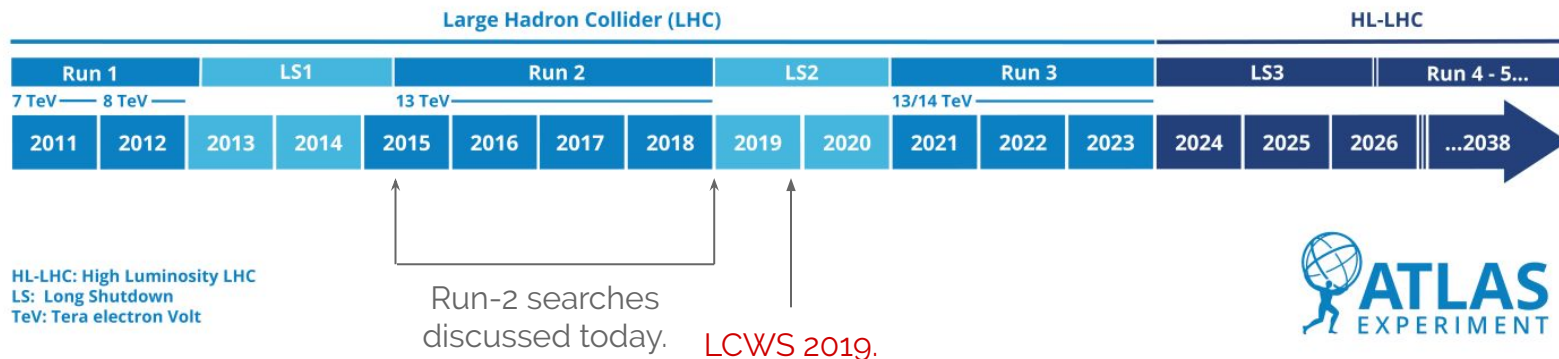
LCWS'19, Sendai

31/10/2019

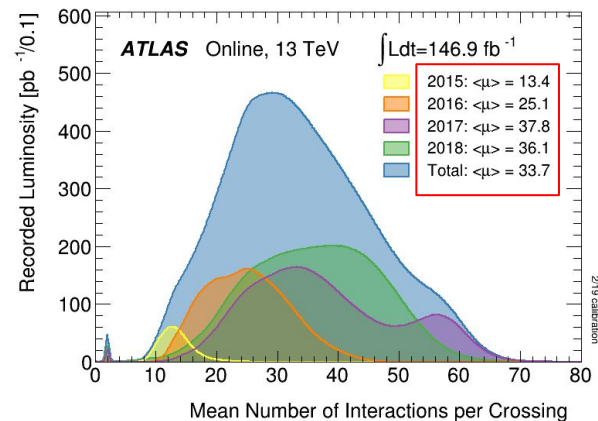
Talk contents

- ATLAS data-taking from 2015-2018
- Exotics searches:
 - Searches for heavy resonances.
- Searches for Supersymmetry:
 - Strong production, 3rd generation squarks, electroweak production.
- Searches for long-lived particles (LLPs):
 - Higgs portal dark photons.
 - Heavy Neutral Leptons.
- Searches for mediator-based Dark Matter:
 - Mono-object + MET, extended Higgs sector models.
- Summary.
- Prospects for High Luminosity LHC.

ATLAS in Run-2



- Both LHC and ATLAS performed extremely well in Run-2.
- Maintained ~94% data-taking and data-quality efficiency despite harsh pileup conditions.
- Provides huge opportunity for discovery of New Physics!**

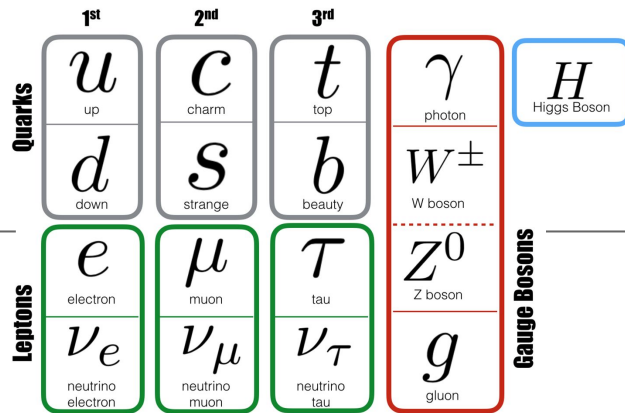


ATLAS Searches overview

- Compositeness?

- Leptoquarks?

- Heavy neutral leptons?



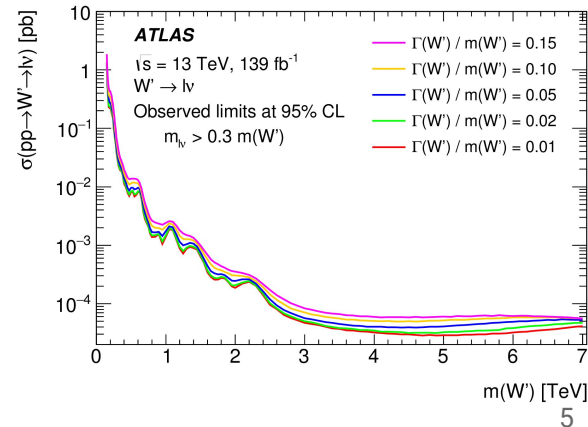
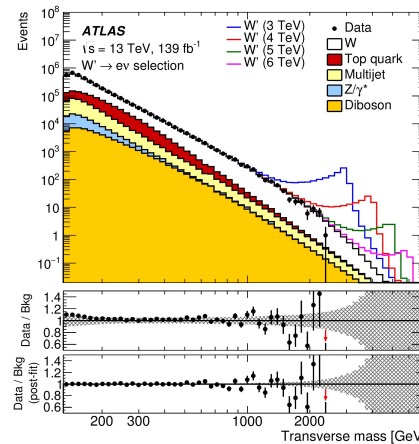
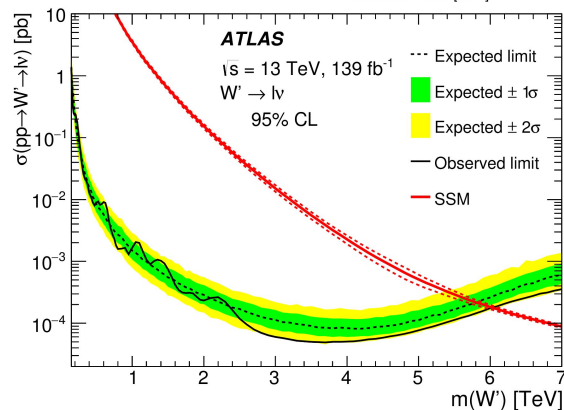
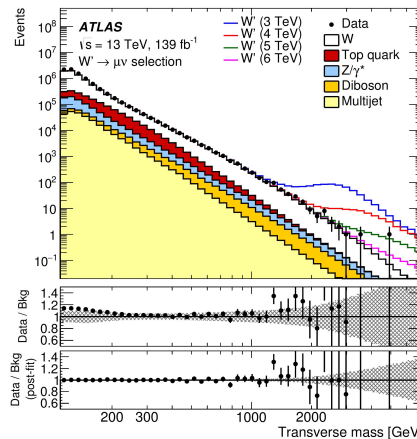
- Higgs portal to dark sector?
- Dark matter?
- Extended Higgs sector?

- Heavy gauge bosons: W'/Z' ?
- Diboson resonances?

- Gravitons?
- Dark matter?
- Supersymmetry: Hierarchy problem, DM?

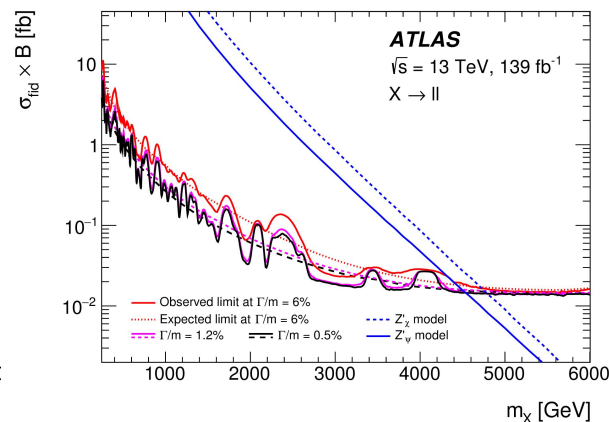
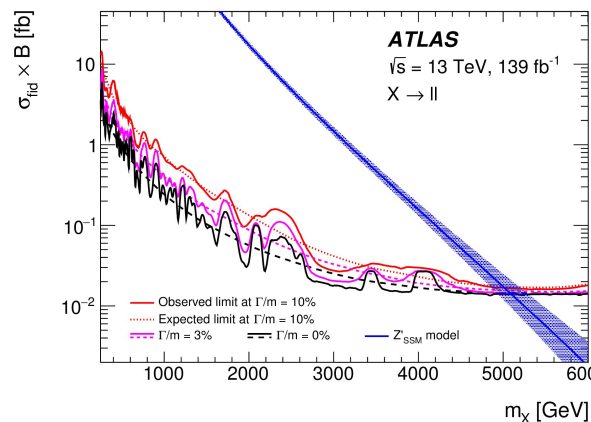
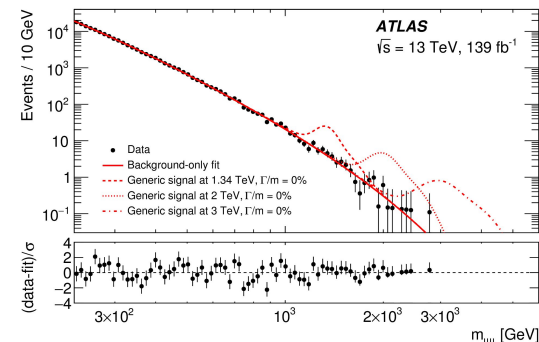
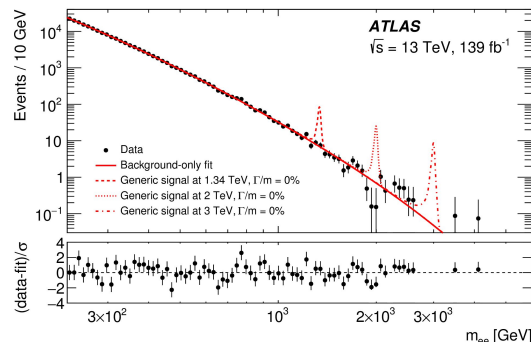
Searches for new resonances: W'

- W' predicted by many New Physics models:
 - GUT models.
 - L-R symmetry models.
 - Little Higgs models.
- Sequential Standard Model:
 - W' couples to SM leptons identically to SM W .
 - W' couplings to SM boson suppressed.
- Use MC estimate of major backgrounds, data-driven fake leptons estimate.
- **Excluded to 6 (5.1) TeV in electron (muon) channel**



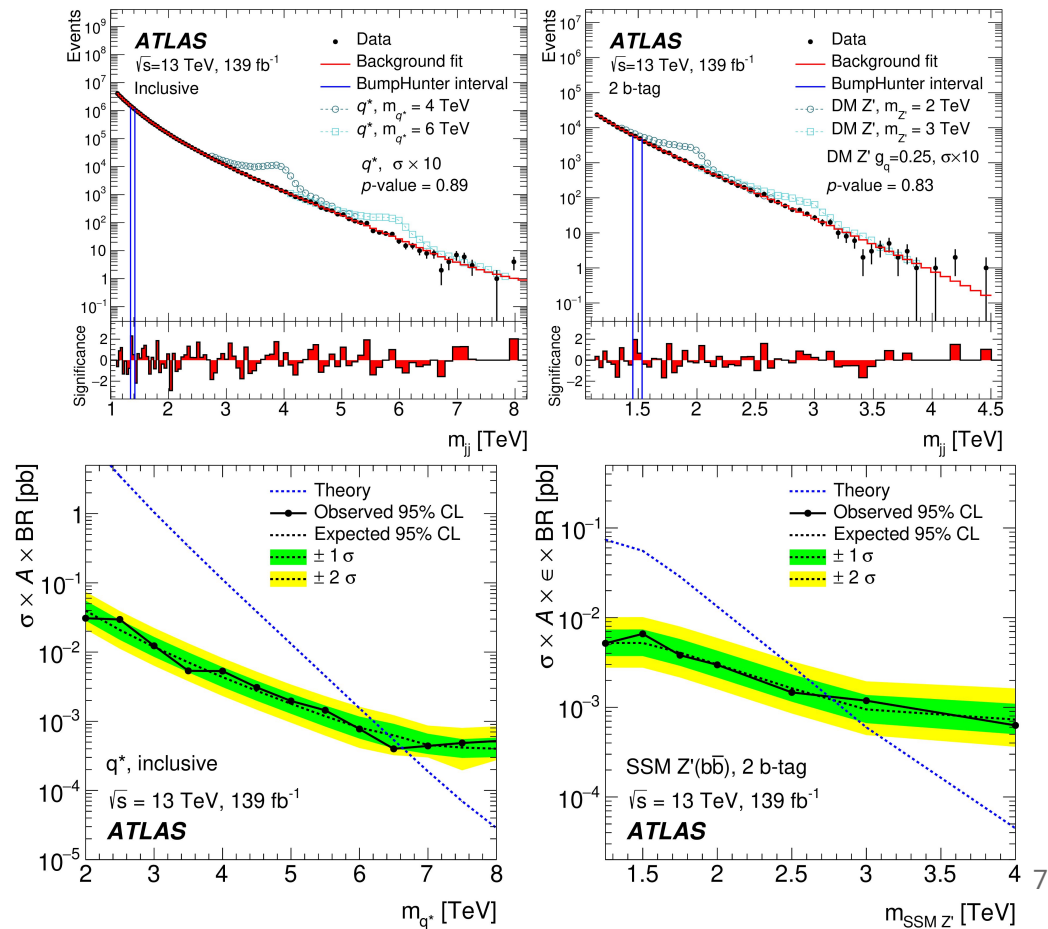
Searches for new resonances: Z'

- Searches for new heavy gauge boson: Z' .
- Z' predicted by many New Physics models:
 - SSM Z' .
 - GUT Z'_X or Z'_ψ
 - New SU(2) triplet: Z'_{HVT}
- **New:** search for signals on smoothly-falling background-fit from data.
- No significant deviation from SM - interpretations:
 - **Z' (SSM) excluded to 5.1 TeV**
 - **Z'_ψ excluded to 4.5 TeV**



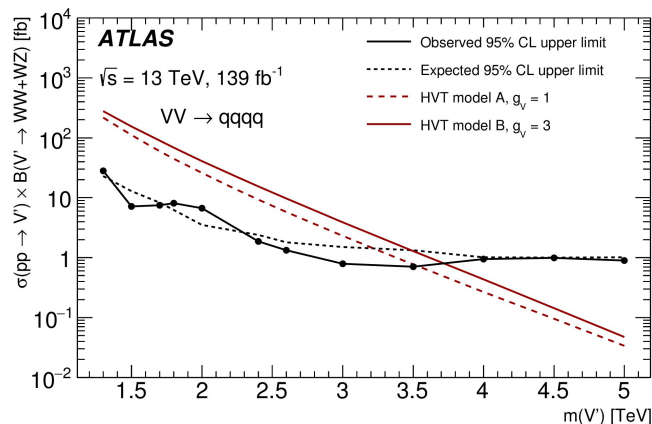
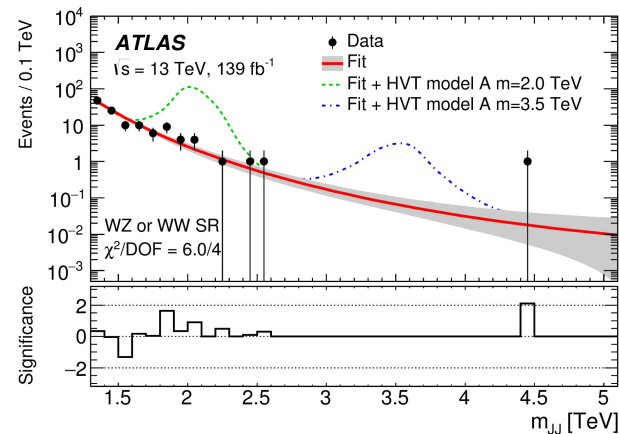
Searches for new resonances: dijets

- Searches for heavy dijet + di b-jet resonances:
 - Excited quarks (q^*) in models of compositeness.
 - Test generic Gaussian signal shapes.
 - SSM Z' + DM Z' mediator (bb).
- Search for resonant signal over smoothly-falling QCD background fit from data.
- Interpretations:
 - Excited quarks (q^*) excluded upto 6.7 TeV.**
 - SSM Z' (bb) excluded upto 2.7 TeV.**
 - DM Z' mediator upto 2.9 TeV.**



Searches for new resonances: $X \rightarrow VV$

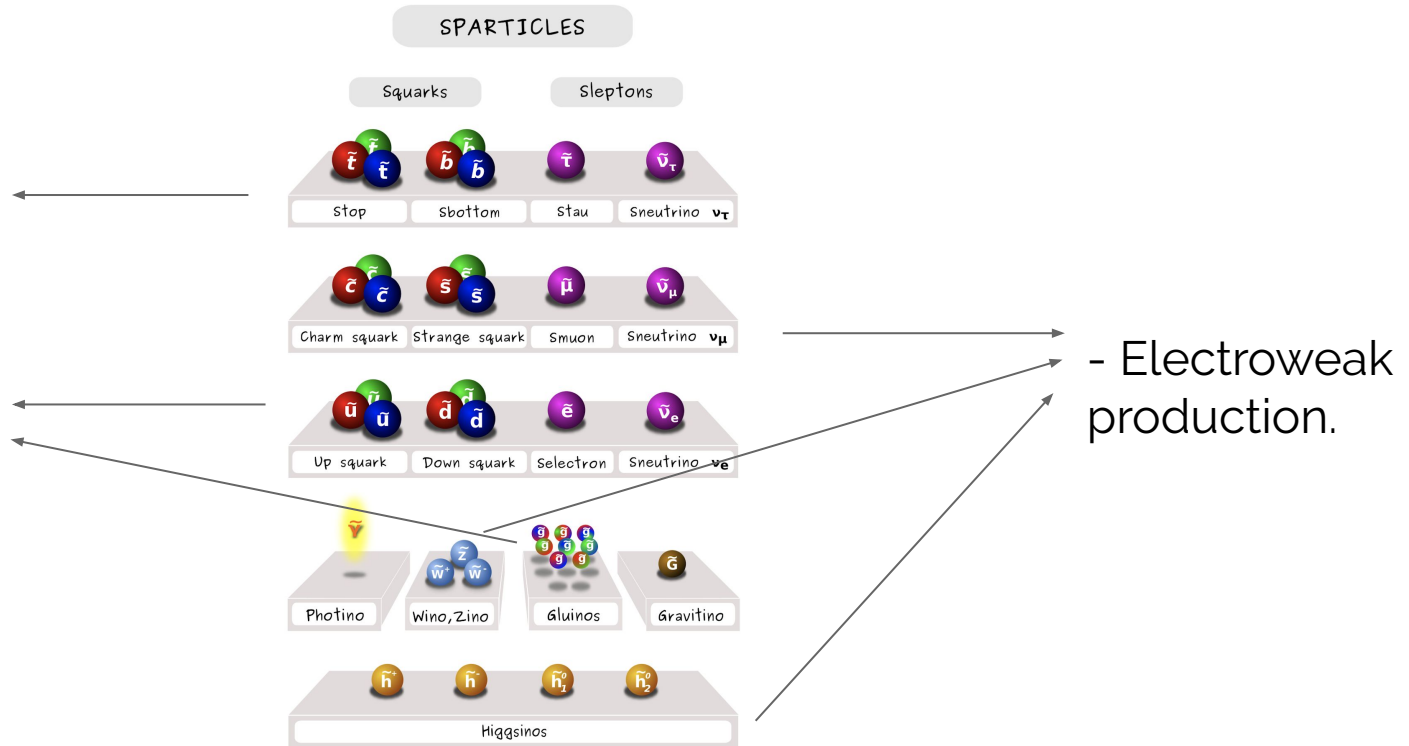
- Resonance decaying to VV pair ($V = W, Z$).
 - Here showing only all-hadronic final states.
- Interpretations:
 - Spin-0 radion.
 - Spin-1 Heavy Vector Triplet.
 - Spin-2 Graviton.
- Search for resonant signals on smoothly-falling background-fit from data.
- No significant deviation from SM
 - interpretations:
 - **HVT model: Excluded upto 3.8 TeV.**
 - **Graviton: Excluded upto 1.8 TeV.**



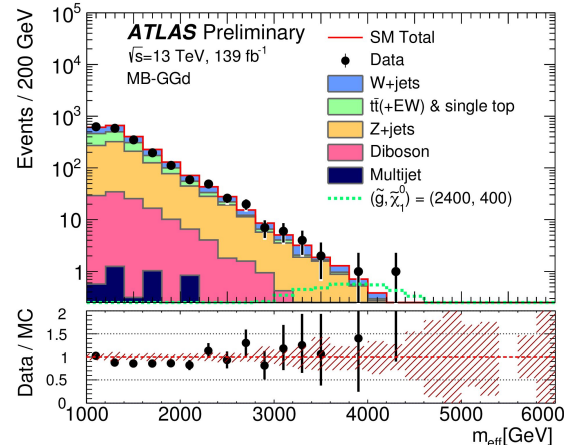
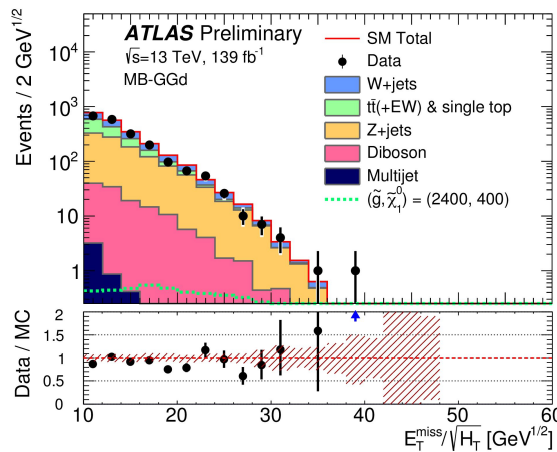
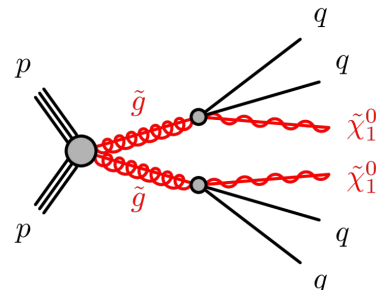
ATLAS Supersymmetry searches: Program structure

- 3rd generation searches.

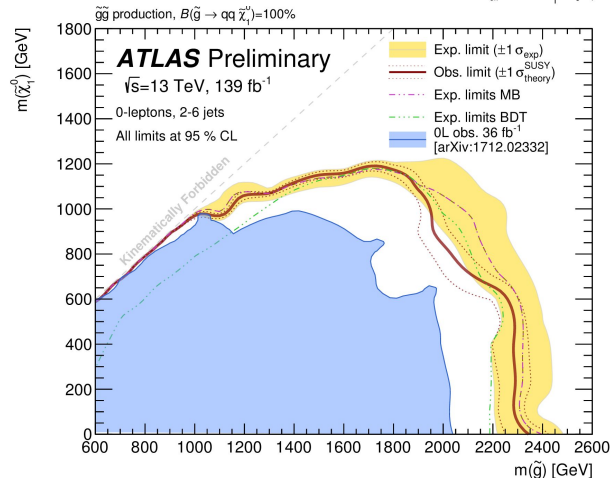
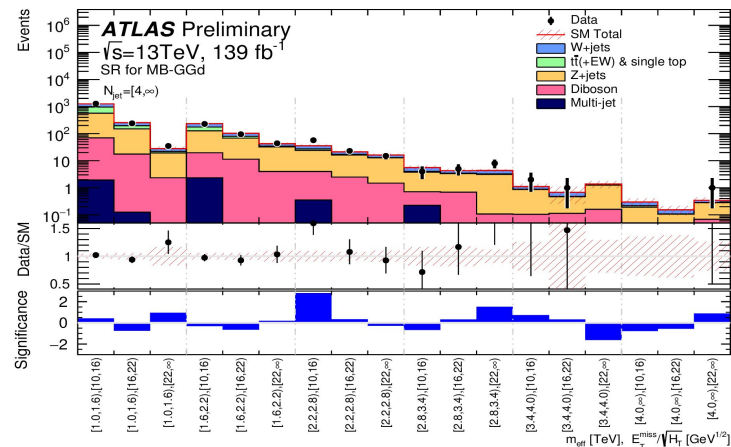
- Strong production.



- SUSY searches well motivated by open SM questions:
 - Hierarchy problem.
 - Dark matter.
- Strong production dominant SUSY production process at LHC:
 - 3-4 orders of magnitude higher than electroweak processes.
- Searches for squarks and gluinos:
 - High jet multiplicities.
 - Large E_T^{Miss} .
 - Lepton veto.



- Many signal regions targeting different scenarios:
 - Gluino-pair, squark-pair, gluino-squark production.
 - Cut-based and boosted decision tree (BDT)-based analyses.
- No significant excesses observed:
 - Direct gluino exclusion: 2.35 TeV**
 - Direct squark exclusion: 1.94 TeV**

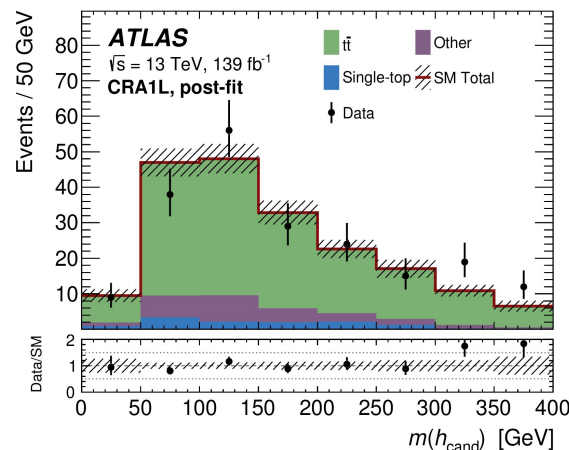
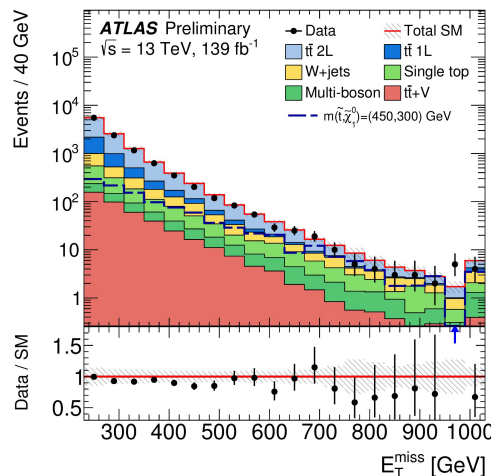
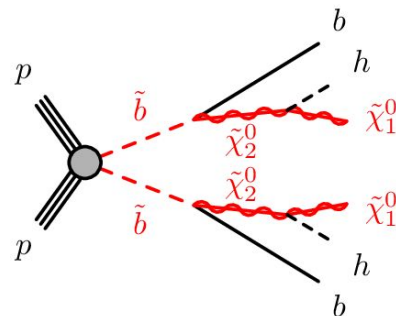
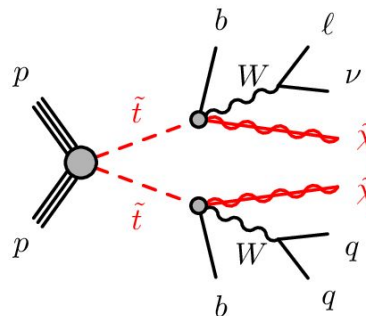


Searches for SUSY: 3rd generation squarks

ATLAS-CONF-2019-017

ArXiv 1908.03122

- 3rd generation squarks:
 - 'Stop', 'Sbottom'.
 - Expected to be 'light' due to naturalness arguments.
 - Important for resolving hierarchy problem!
 - Relative lightness of 3rd gen squarks = expected large yields at LHC.
- Stop search:
 - Targeting 'compressed' scenarios: $m(\text{stop}) - m(\tilde{\chi}_1^0) < m(\text{top})$.
- Sbottom search:
 - Target events with high b-jet multiplicities.
 - HEPData: [Link](#)
 - Likelihood for reinterpretation: [ATL-PHYS-PUB-2019-029](#)

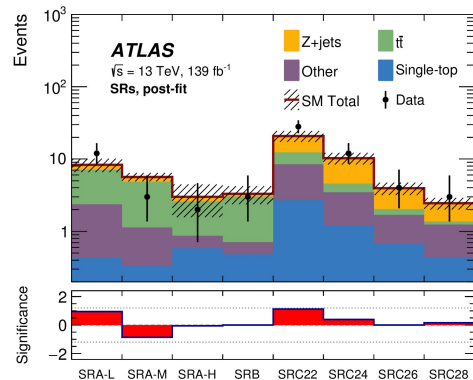
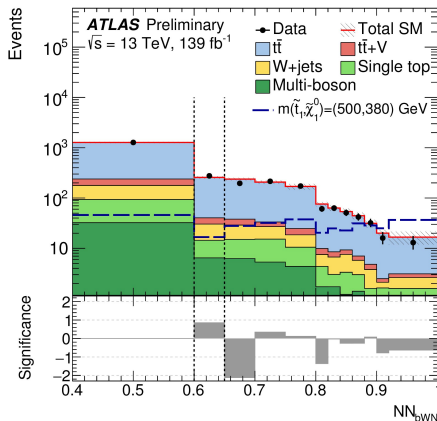


Searches for SUSY: 3rd generation squarks

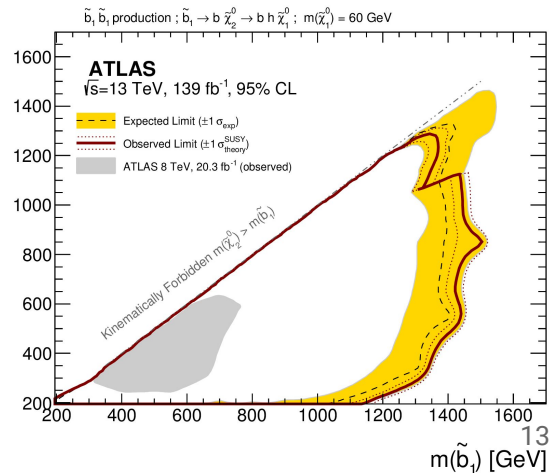
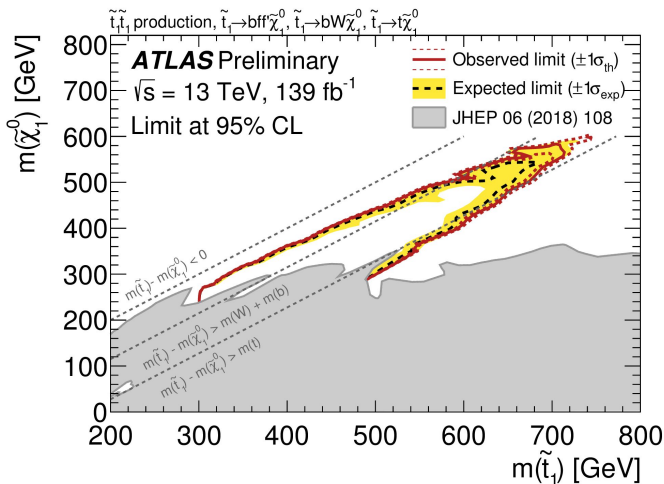
ATLAS-CONF-2019-017

ArXiv 1908.03122

- Stop search:
 - Targeting 'compressed' scenarios: $m(\text{stop}) - m(N_1) < m(\text{top})$.
 - **Stop squark excluded upto 720 GeV for 580 GeV N_1 .**

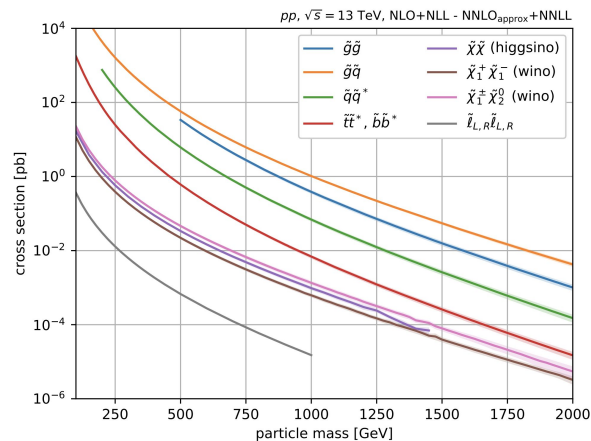
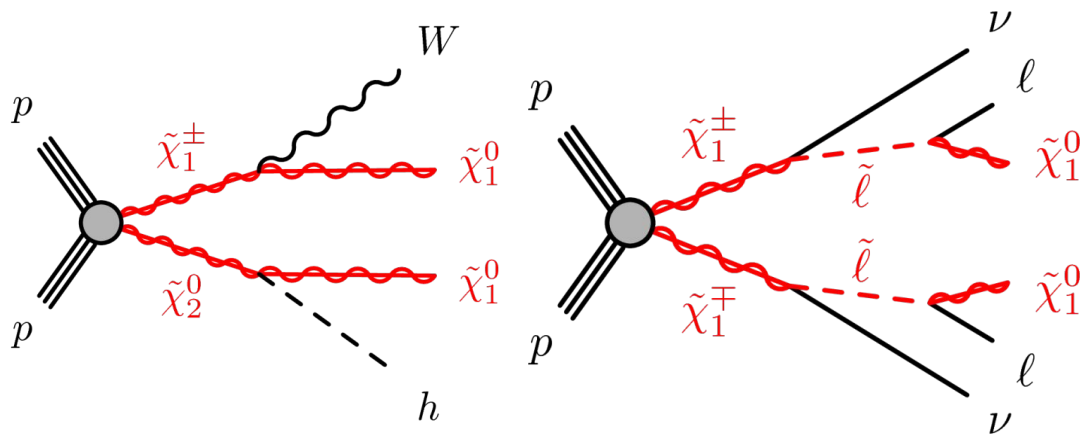


- Sbottom search:
 - Target two scenarios: $m(N_2) - m(N_1) = 130 \text{ GeV}$ and $m(N_1) = 60 \text{ GeV}$.
 - **Sbottom squark excluded upto 1500 GeV.**



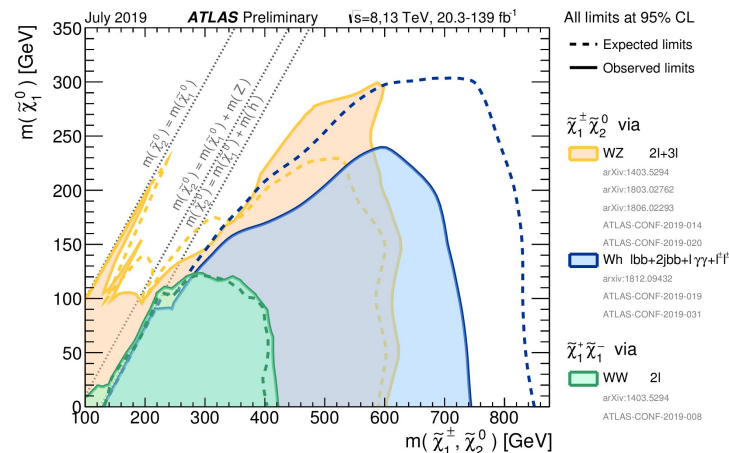
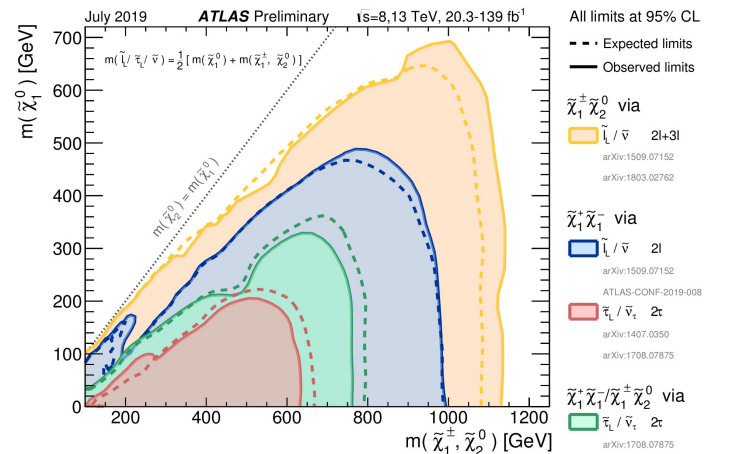
Searches for SUSY: electroweak production

- EWK SUSY:
 - Dominant production process if strong SUSY sector decoupled.
 - Naturalness arguments result in Higgsino masses \sim electroweak scale.
 - Stable LSP is important DM candidate.
- Huge Run-2 dataset:
 - EWK SUSY production cross-section orders magnitude lower than strong production.
 - Unprecedented opportunity to probe low cross-section EWK SUSY processes!



Searches for SUSY: electroweak production

- Wide search program:
 - Chargino-neutralino pair-production.
 - Chargino-chargino pair-production.
 - Decays via SM gauge bosons and direct sleptons.
- As of yet, no significant excesses:
 - Stringent limits set on decays via direct sleptons: **> 1 TeV!**
 - Limits on decays via SM gauge bosons see vast improvements in Run-2: ***C1N2 → Wh excluded upto 740 GeV.***

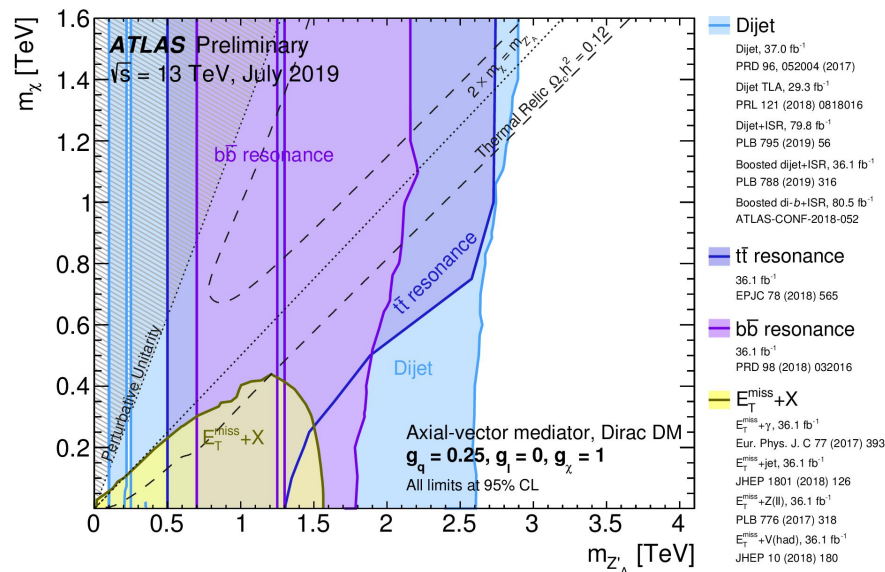
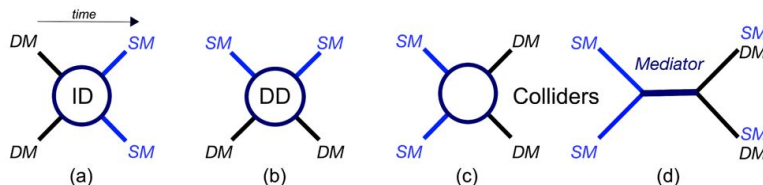
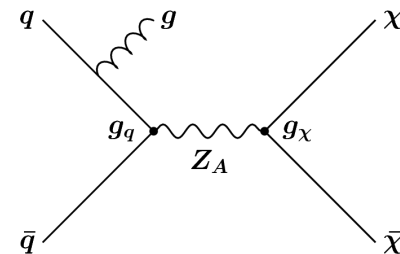
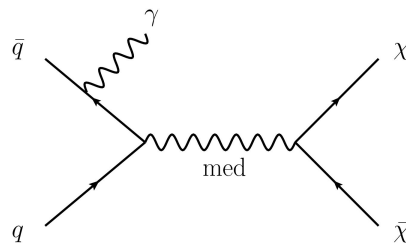


Searches for DM: mono-object + MET

Eur. Phys. J. C 77 (2017) 393

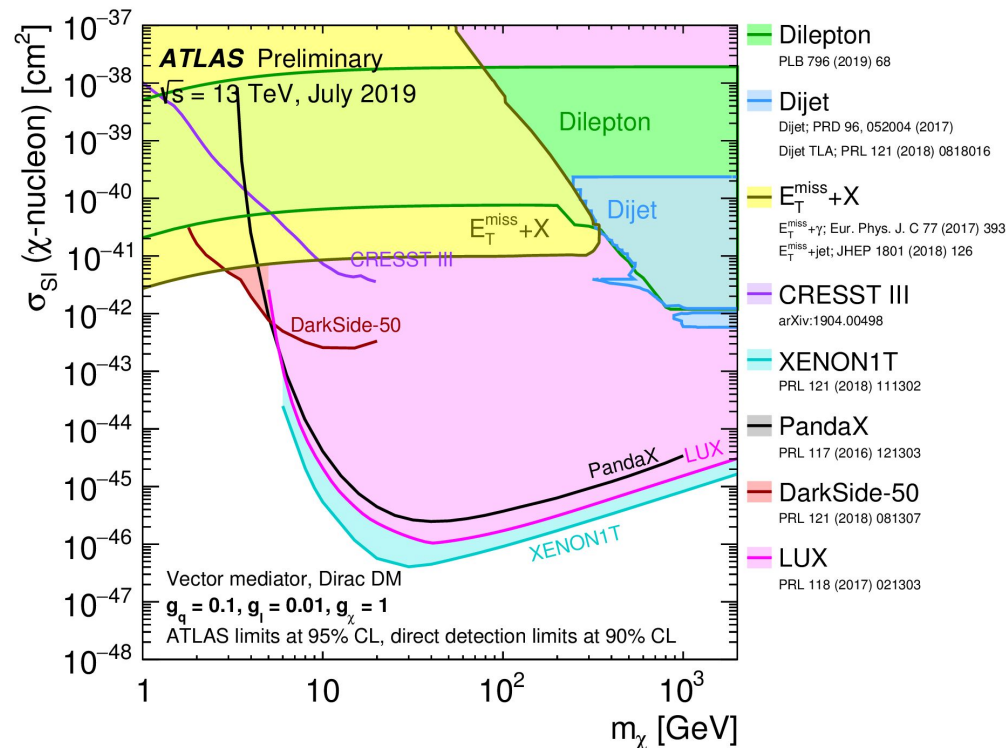
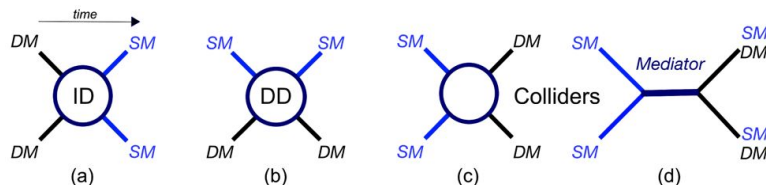
JHEP 01 (2018) 126

- 'Classic' DM search:
 - Visible object recoiling against MET.
 - Mediator-based interaction of SM and DM.
- Many search channels:
 - γ , jets, W, Z...
 - Axial-vector mediator (Z_A).



Searches for DM: direct detection comparison

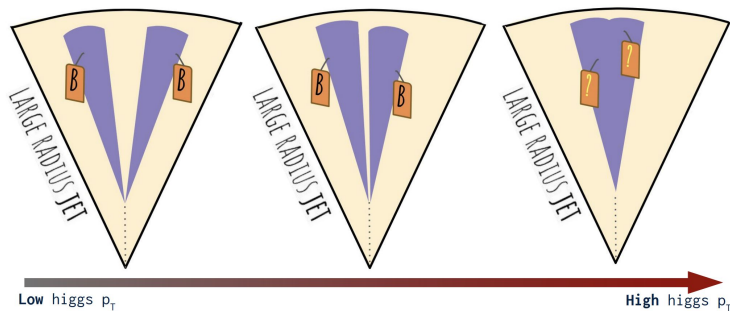
- Comparisons of inferred limits with limits from direct detection experiments.
- Plots show limit on spin-independent WIMP-nucleon scattering cross-section.
- ATLAS excludes large regions of DM phase space - complementary with direct detection.
 - *Caveat: specific model parameter choices!*



Searches for DM: extended Higgs sector models

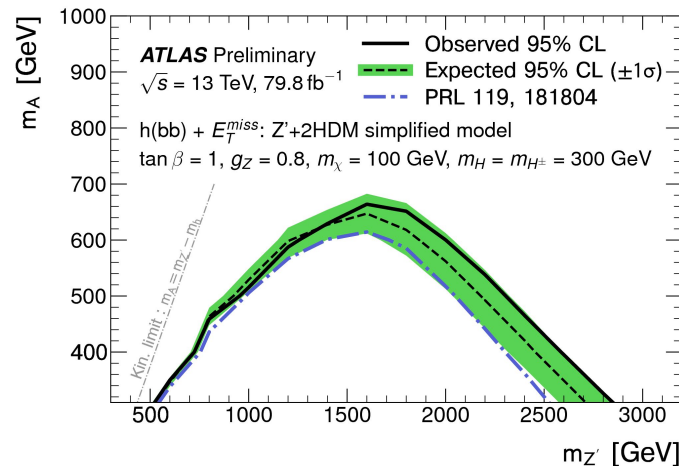
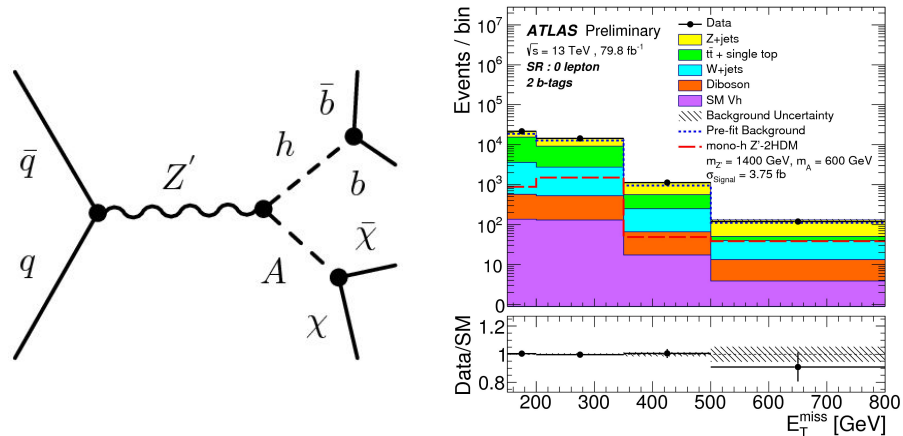
ATLAS-CONF-2018-039

- Two Higgs Doublet model (2HDM+Z):
 - Extra Higgs doublet + additional mediator for DM - richer phenomenology.
 - Lightest CP-even state = SM Higgs.
- Exploit new methods in Run-2:
 - Use variable-radius track jets to resolve jets with small angular separation.



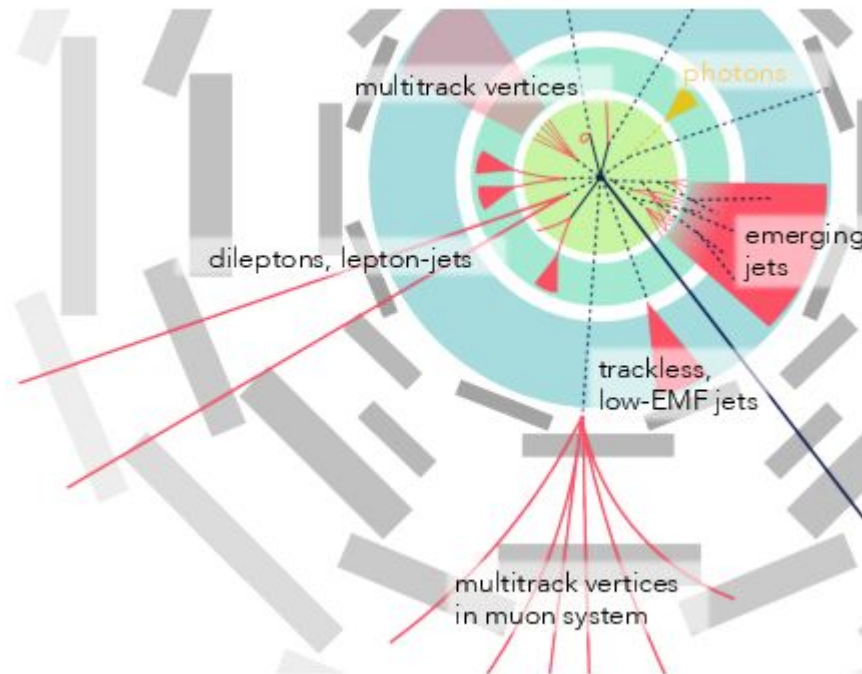
S Paredes Saenz, IOP 2019

- 2HDM+Z': **excluded up to 2.8 TeV.**



Searches for long-lived particles: overview

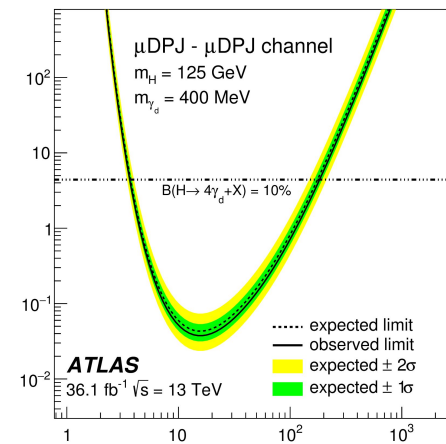
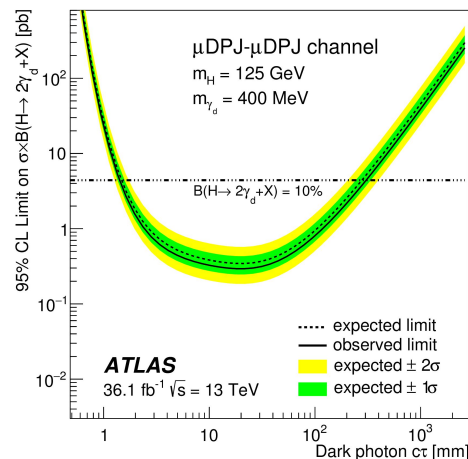
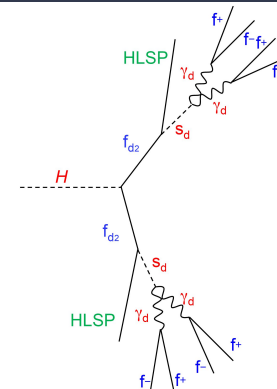
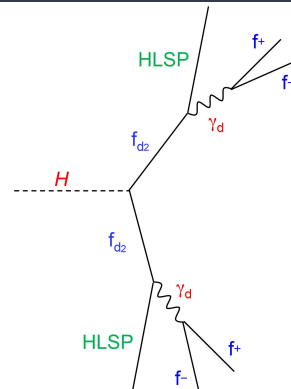
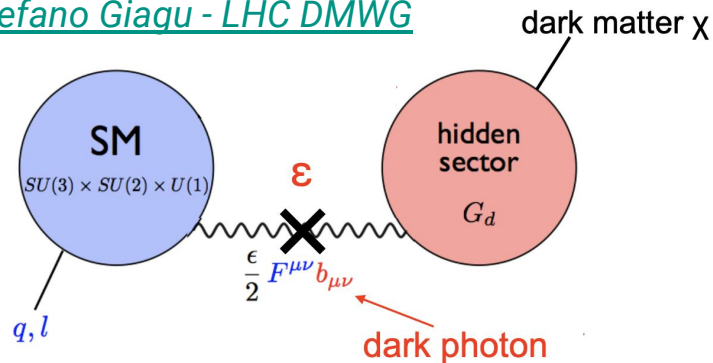
- Example signature of long-lived particles (LLPs):
 - Displacement of objects from primary vertex.
 - Depending on lifetime, can decay in tracker, calorimeter or muon system.
- Lifetime determined by mass and mixing with decay products.
- Signatures-based searches:
 - Model-specific LLP searches developed targeting specific signatures.



Searches for LLPs: dark photons

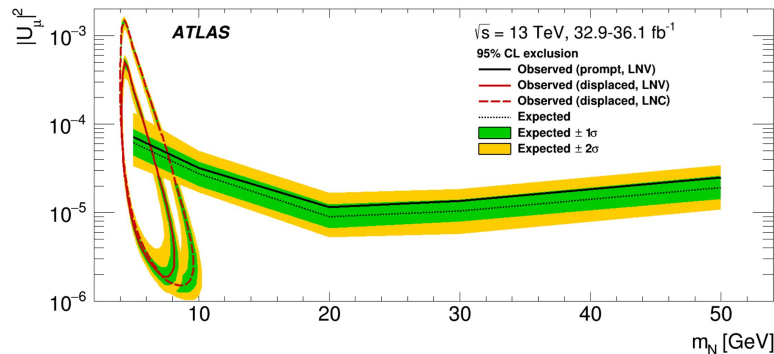
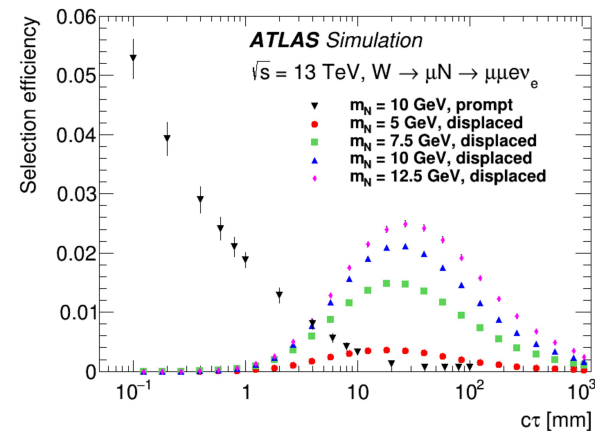
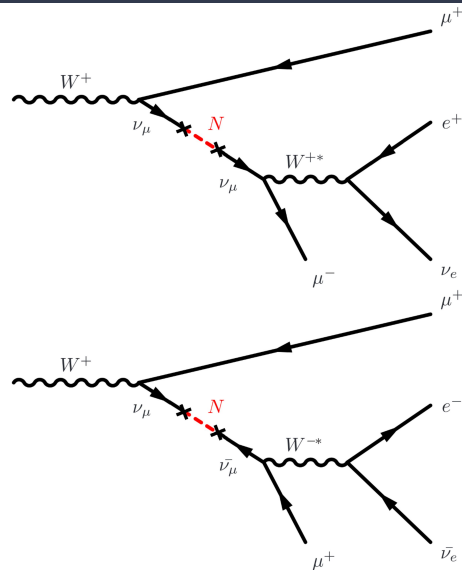
- Dark sector:
 - Postulated extension to SM - dark fermions, dark photons...
 - Higgs can be portal to dark sector with branching ratio upto 10% not excluded for exotic decays.
- Dark photons:
 - Lifetime can be long if small mixing between SM photon and dark photon.
 - Signature: no tracks in Inner Detector!

Stefano Gagu - LHC DMWG



Searches for LLPs: heavy neutral leptons

- Massive neutrinos:
 - RH Majorana neutrino (HNL) \rightarrow see-saw mechanism.
 - HNLs could explain SM neutrino masses, matter-antimatter asymmetry, and is a DM candidate.
- HNL-neutrino mixing:
 - Small mixing required, resulting in long-lived HNLs.
 - Signatures: prompt and displaced.
- No evidence for HNLs observed:
 - Displaced signatures: excluded coupling strength to 1.5×10^{-6}**
 - Prompt signatures: excluded coupling strength to 1.1×10^{-5}**



Summary plots: Exotics

- Exotics searches cover plethora of models!
 - Summary plot shows a selection of the full search program.
- 4 full Run-2 dataset analyses shown today:
 - W' , Z' , dijet resonances, diboson resonances..
- Dark photon, HNL and DM searches done with partial Run-2 datasets.
- No evidence of New Physics in the data so far.
- Stringent limits set across wide parameter space.

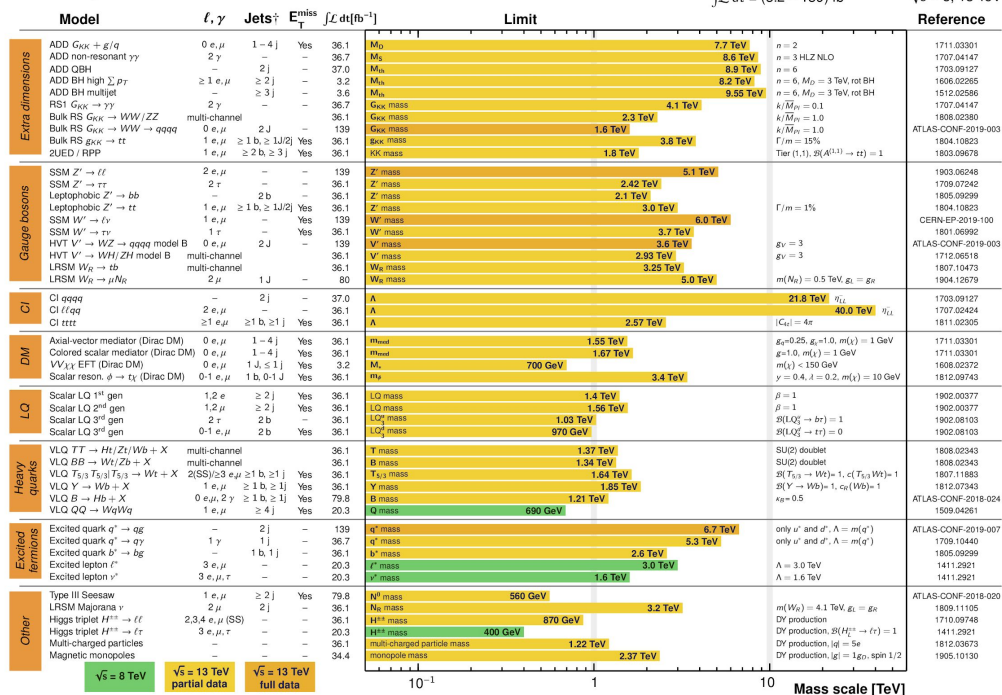
ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: May 2019

ATLAS Preliminary

$$\int \mathcal{L} dt = (3.2 - 139) \text{ fb}^{-1}$$

$$\sqrt{s} = 8, 13 \text{ TeV}$$



*Only a selection of the available mass limits on new states or phenomena is shown.

[†]Small-radius (large-radius) jets are denoted by the letter j (J).

Summary plots: SUSY

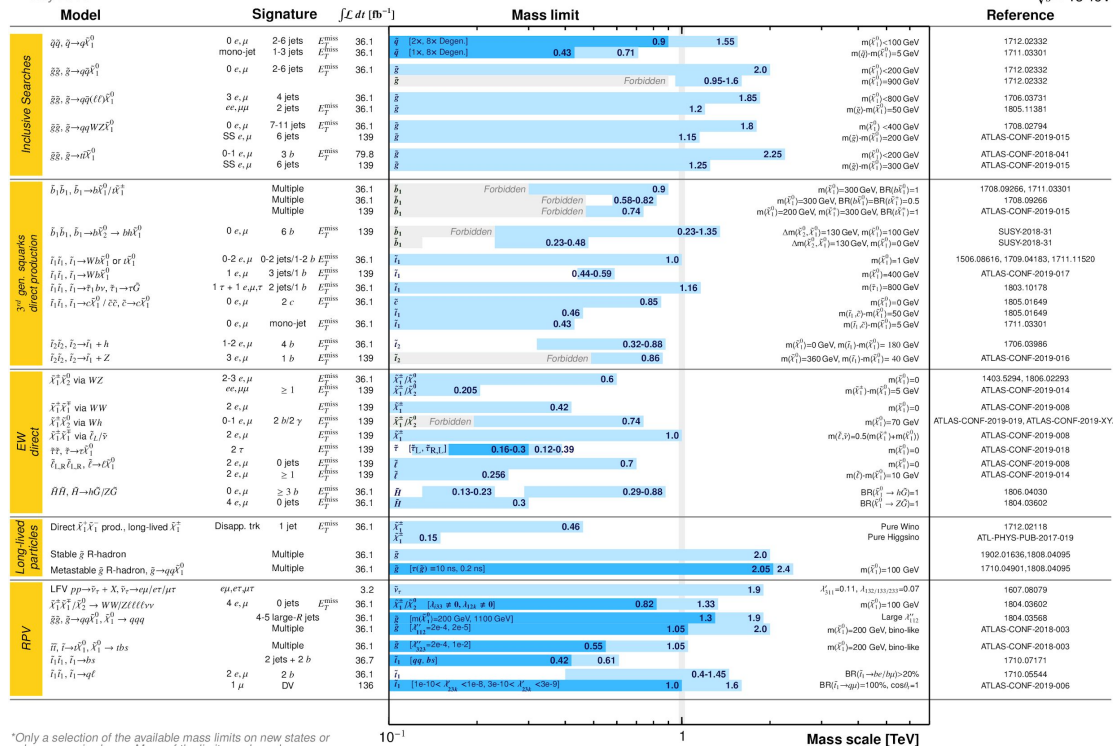
- Huge program of SUSY searches on ATLAS.
- 5 full Run-2 dataset analyses shown today:
 - Strong oL.
 - Direct stop, direct sbottom.
 - EWK C1N2 via Wh, EWK C1C1 via WW.
- No evidence of SUSY in the data so far!
- Stringent limits set in strong, 3rd gen. searches.
- EWK SUSY probed to unprecedented levels.

ATLAS SUSY Searches* - 95% CL Lower Limits

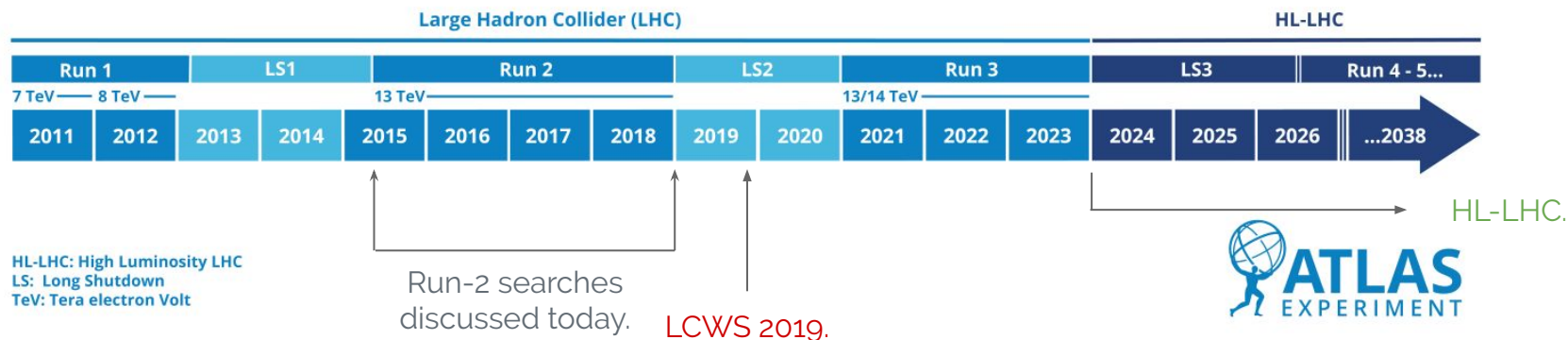
July 2019

ATLAS Preliminary

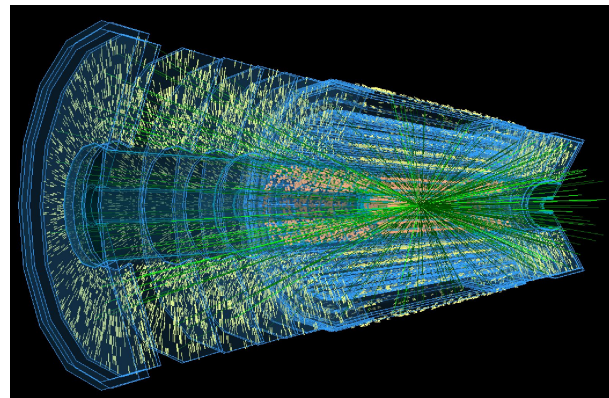
$\sqrt{s} = 13$ TeV



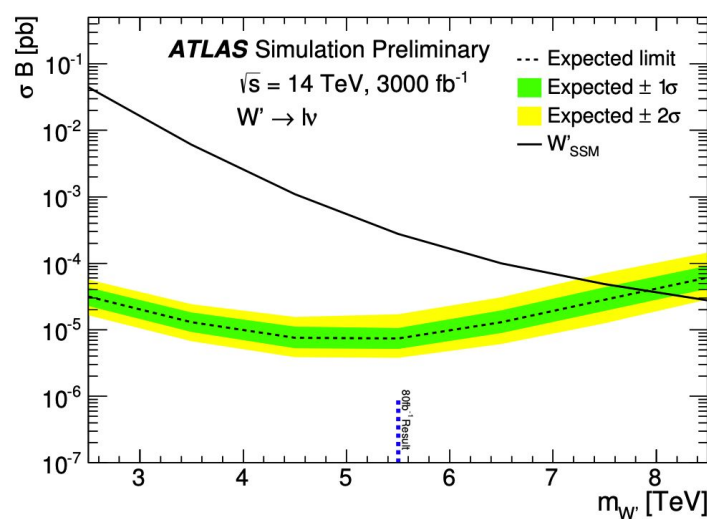
ATLAS at the High Luminosity LHC



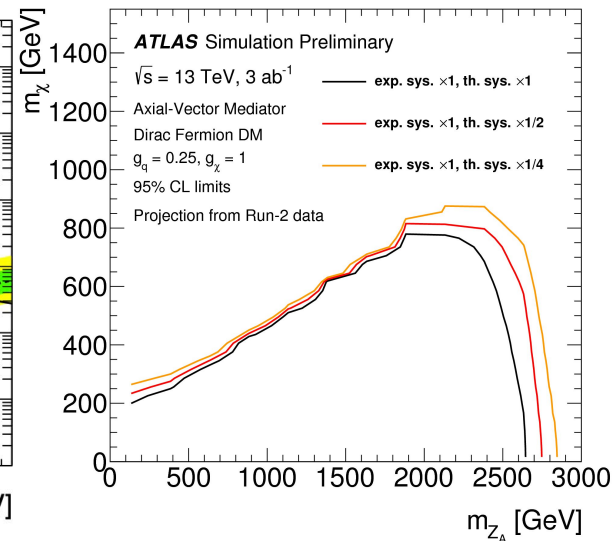
- ATLAS will face new challenges at HL-LHC.
 - Instantaneous luminosity increase x 10.
 - ~ 200 pp interactions per bunch-crossing.
- ATLAS is expected to record 3000 fb⁻¹ of data at HL-LHC!
- As part of European Strategy on Particle Physics, many HL-LHC prospects studies done.
 - Input from ATLAS, CMS, ALICE, LHCb and theorists.
 - 5 working groups: SM, Higgs, BSM, Flavour, Heavy Ion.
 - Summary TWiki: [HLHELHCWorkshop](#)



- Both W' & mono analyses will benefit from increased luminosity.
- $W' \rightarrow l\nu$:
 - Expected exclusion at HL-LHC: 7.9 TeV
 - ~ 2 TeV increase from Run-2 limit!
- Mono-jet:
 - Expected exclusion at HL-LHC: 2.52 TeV

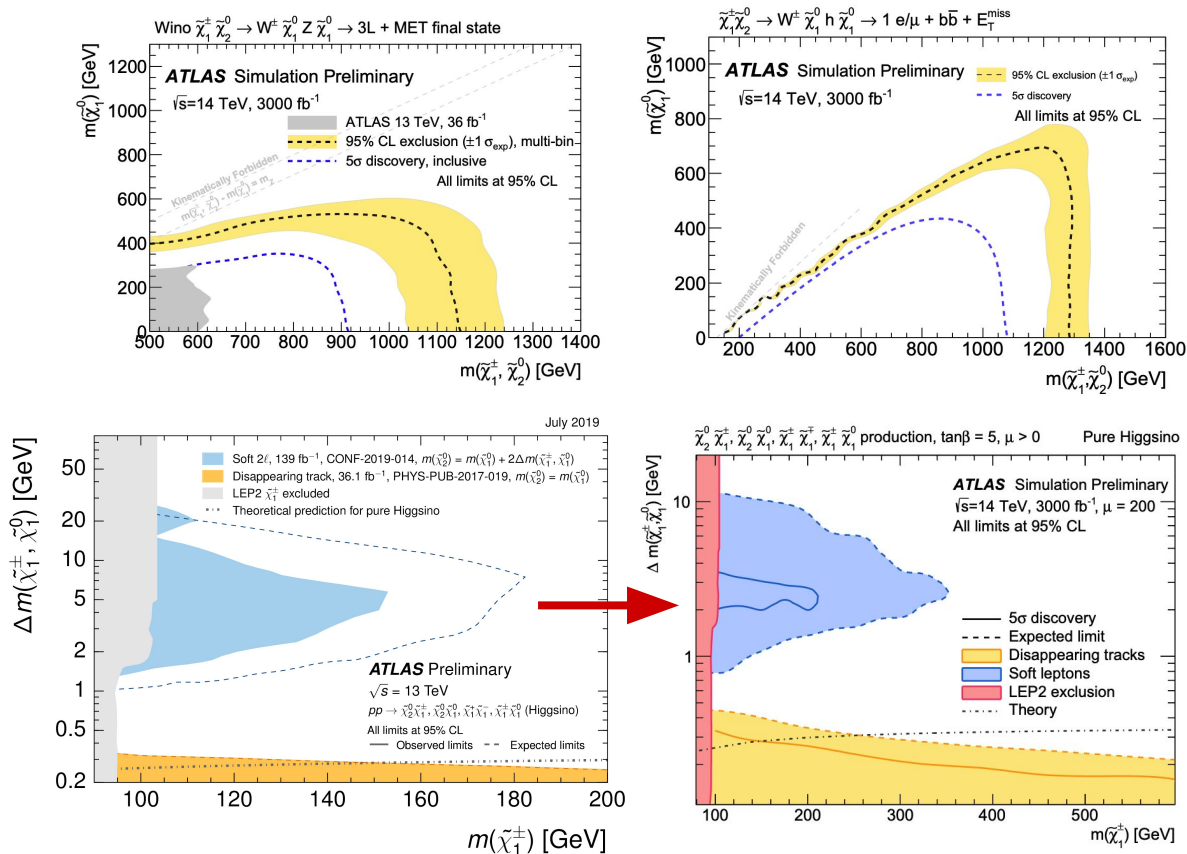


Decay	Exclusion [TeV]	Discovery [TeV]
$W'_{SSM} \rightarrow e\nu$	7.6	7.5
$W'_{SSM} \rightarrow \mu\nu$	7.3	7.1
$W'_{SSM} \rightarrow \ell\nu$	7.9	7.7



HL-LHC prospects studies: EWK SUSY

- EWK SUSY production will benefit greatly from increase in luminosity!
- Pileup and SM backgrounds challenging.
- Despite challenging conditions, HL-LHC expected to probe EWK SUSY to unprecedented levels!



Conclusions

- Huge search program, only a selection shown today:
 - **Exotics:** Heavy resonances, DM, LLPs.
 - **SUSY:** Strong, 3rd generation, EWK production.
 - **Many New Physics scenarios probed to unprecedented levels.**
- Selection of HL-LHC prospects:
 - W', EWK SUSY and mono-jet prospects shown today, many more studied for European Strategy.
 - **Vast improvements expected for large number of New Physics scenarios.**

BACKUP

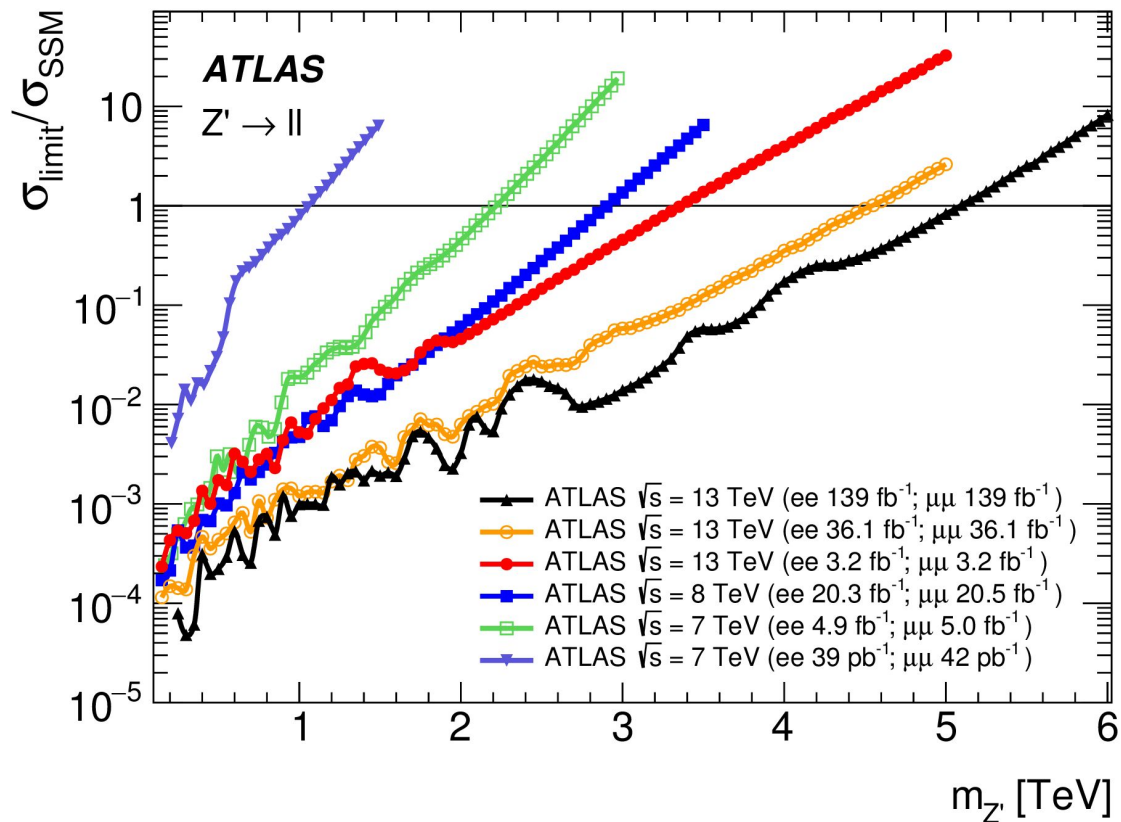
W' systematics

Source	Electron channel		Muon channel	
	Background $m_T = 2$ (6) TeV	Signal $m_T = 2$ (6) TeV	Background $m_T = 2$ (6) TeV	Signal $m_T = 2$ (6) TeV
Trigger	negl. (negl.)	negl. (negl.)	1.1% (1.0%)	1.2% (1.2%)
Lepton reconstruction and identification	4.1% (1.4%)	4.3% (4.3%)	8.9% (37%)	6.6% (38%)
Lepton momentum scale and resolution	3.9% (2.7%)	2.7% (4.5%)	12% (47%)	13% (20%)
E_T^{miss} resolution and scale	<0.5% (<0.5%)	<0.5% (<0.5%)	<0.5% (<0.5%)	<0.5% (<0.5%)
Jet energy resolution	<0.5% (<0.5%)	<0.5% (<0.5%)	<0.5% (0.6%)	<0.5% (<0.5%)
Multijet background	4.4% (420%)	N/A (N/A)	0.8% (1.5%)	N/A (N/A)
Top-quark background	0.8% (1.9%)	N/A (N/A)	0.7% (<0.5%)	N/A (N/A)
Diboson extrapolation	1.5% (47%)	N/A (N/A)	1.3% (9.7%)	N/A (N/A)
PDF choice for DY	1.0% (10%)	N/A (N/A)	<0.5% (1.0%)	N/A (N/A)
PDF variation for DY	8.1% (13%)	N/A (N/A)	7.4% (14%)	N/A (N/A)
EW corrections for DY	4.2% (4.5%)	N/A (N/A)	3.7% (7.0%)	N/A (N/A)
Luminosity	1.6% (1.1%)	1.7% (1.7%)	1.7% (1.7%)	1.7% (1.7%)
Total	12% (430%)	5.4% (6.4%)	17% (62%)	15% (43%)

Z' systematics

Uncertainty source for m_X [GeV]	Dielectron		Dimuon	
	300	5000	300	5000
Spurious signal	± 12.5 (12.0)	± 0.1 (1.0)	± 11.7 (11.0)	± 2.1 (2.2)
Lepton identification	± 1.6 (1.6)	± 5.6 (5.6)	± 1.8 (1.8)	$^{+25}_{-20} \left(\begin{smallmatrix} +25 \\ -20 \end{smallmatrix} \right)$
Isolation	± 0.3 (0.3)	± 1.1 (1.1)	± 0.4 (0.4)	± 0.4 (0.5)
Luminosity	± 1.7 (1.7)	± 1.7 (1.7)	± 1.7 (1.7)	± 1.7 (1.7)
Electron energy scale	$^{-1.7}_{-4.0} \left(\begin{smallmatrix} +1.0 \\ -1.8 \end{smallmatrix} \right)$	$^{+0.1}_{-0.4} (\pm 0.8)$	-	-
Electron energy resolution	$^{+7.9}_{-8.3} \left(\begin{smallmatrix} +1.1 \\ -0.9 \end{smallmatrix} \right)$	$^{+0.4}_{-0.9} (\pm 0.1)$	-	-
Muon ID resolution	-	-	$^{+0.8}_{-2.3} \left(\begin{smallmatrix} +0.3 \\ -0.8 \end{smallmatrix} \right)$	$^{+0.6}_{-0.4} \left(\begin{smallmatrix} +0.5 \\ -0.3 \end{smallmatrix} \right)$
Muon MS resolution	-	-	$^{+2.8}_{-3.8} \left(\begin{smallmatrix} +1.0 \\ -1.3 \end{smallmatrix} \right)$	± 2.4 (2.1)
‘Good muon’ requirement	-	-	± 0.6 (0.6)	$^{+55}_{-35} \left(\begin{smallmatrix} +55 \\ -35 \end{smallmatrix} \right)$

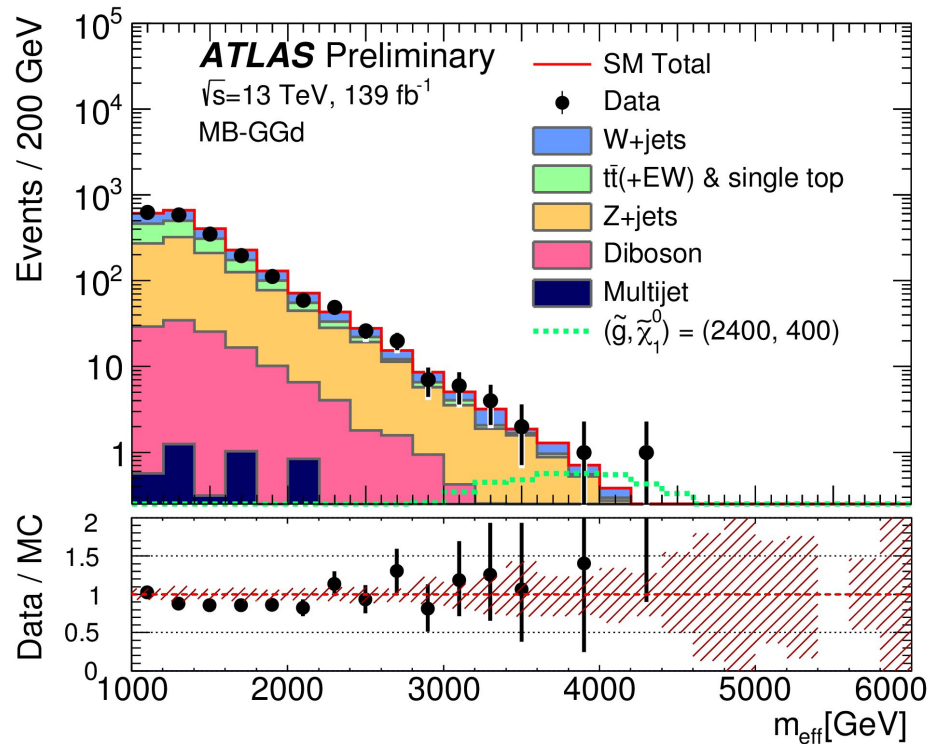
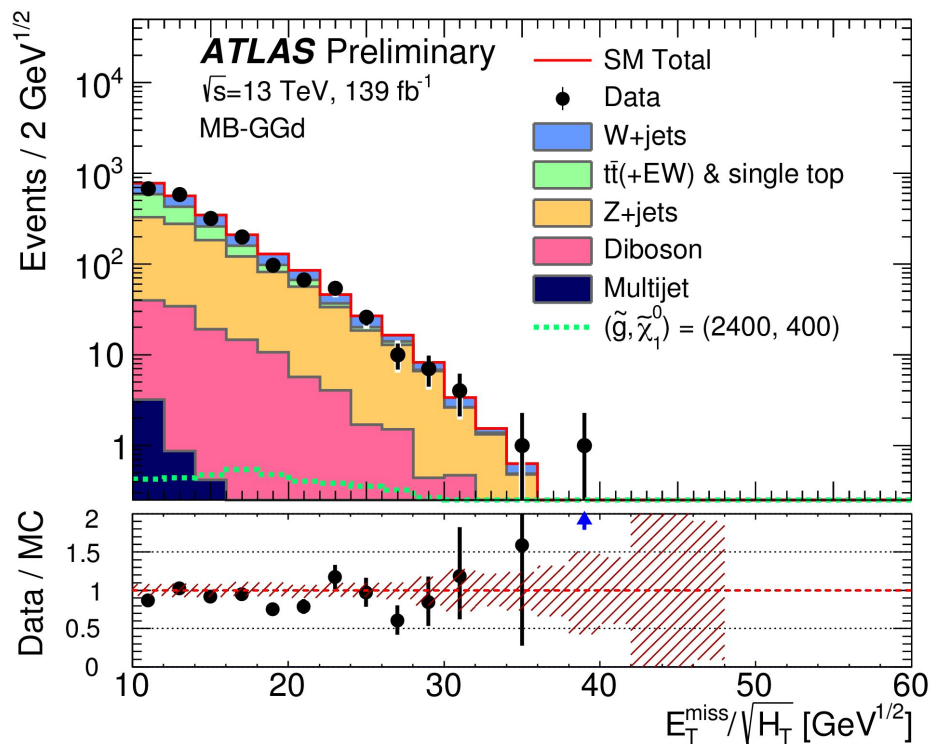
Z' limit comparison



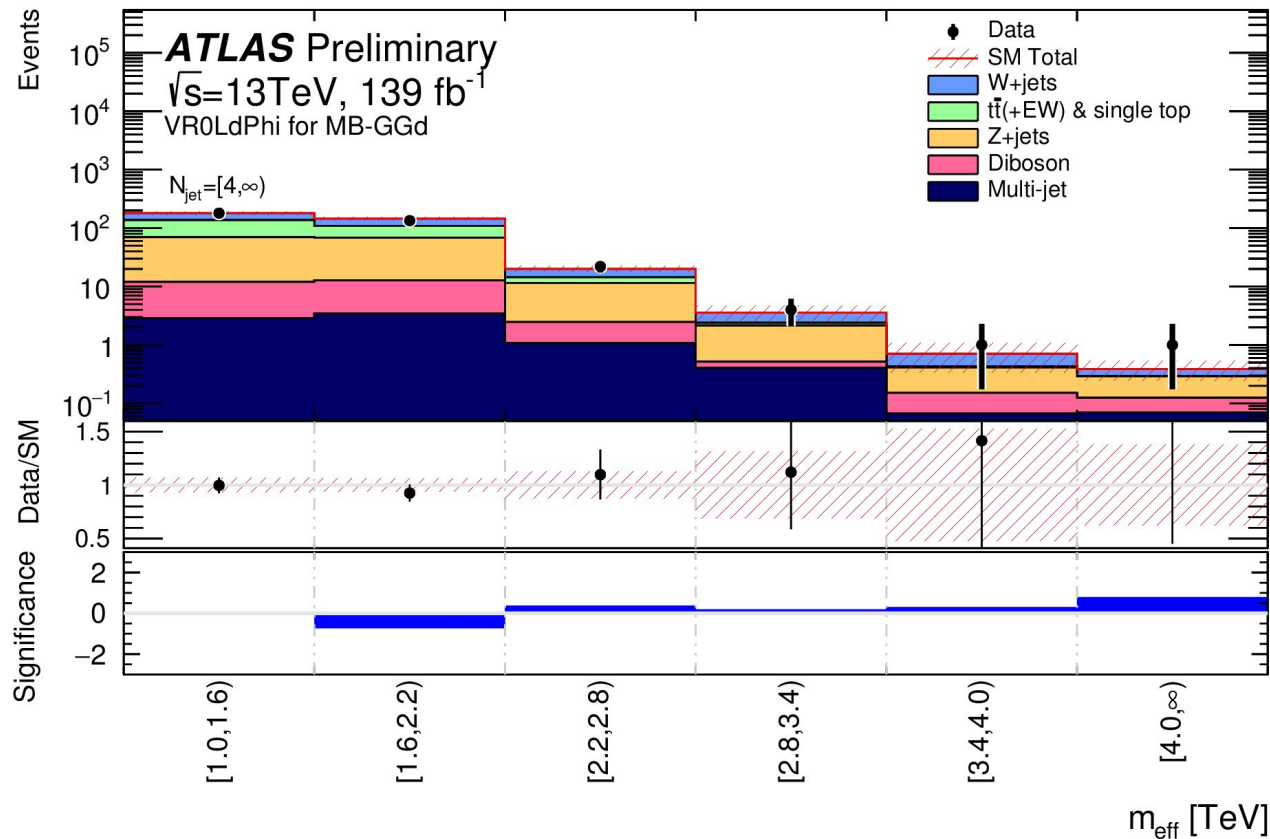
DM MET + H systematics

Source of uncert.	Impact [%]		
	(a)	(b)	(c)
<i>b</i> -tagging	4.0	8.0	10
<i>V</i> + jets modeling	3.5	6.0	5.0
Top modeling	3.7	4.8	4.5
MC statistics	1.8	5.4	4.9
SM $Vh(b\bar{b})$	0.8	3.2	2.1
Diboson modeling	0.8	1.5	1.1
Signal modeling	3.0	2.5	1.5
Luminosity	2.0	2.5	2.5
Small- <i>R</i> jets	1.4	3.0	2.0
Large- <i>R</i> jets	0.2	1.0	2.0
E_T^{miss}	1.2	1.7	1.1
Leptons	0.2	0.8	0.7
Total syst. uncert.	6.5	13	13
Statistical uncert.	2.3	20	22
Total uncertainty	7	24	25

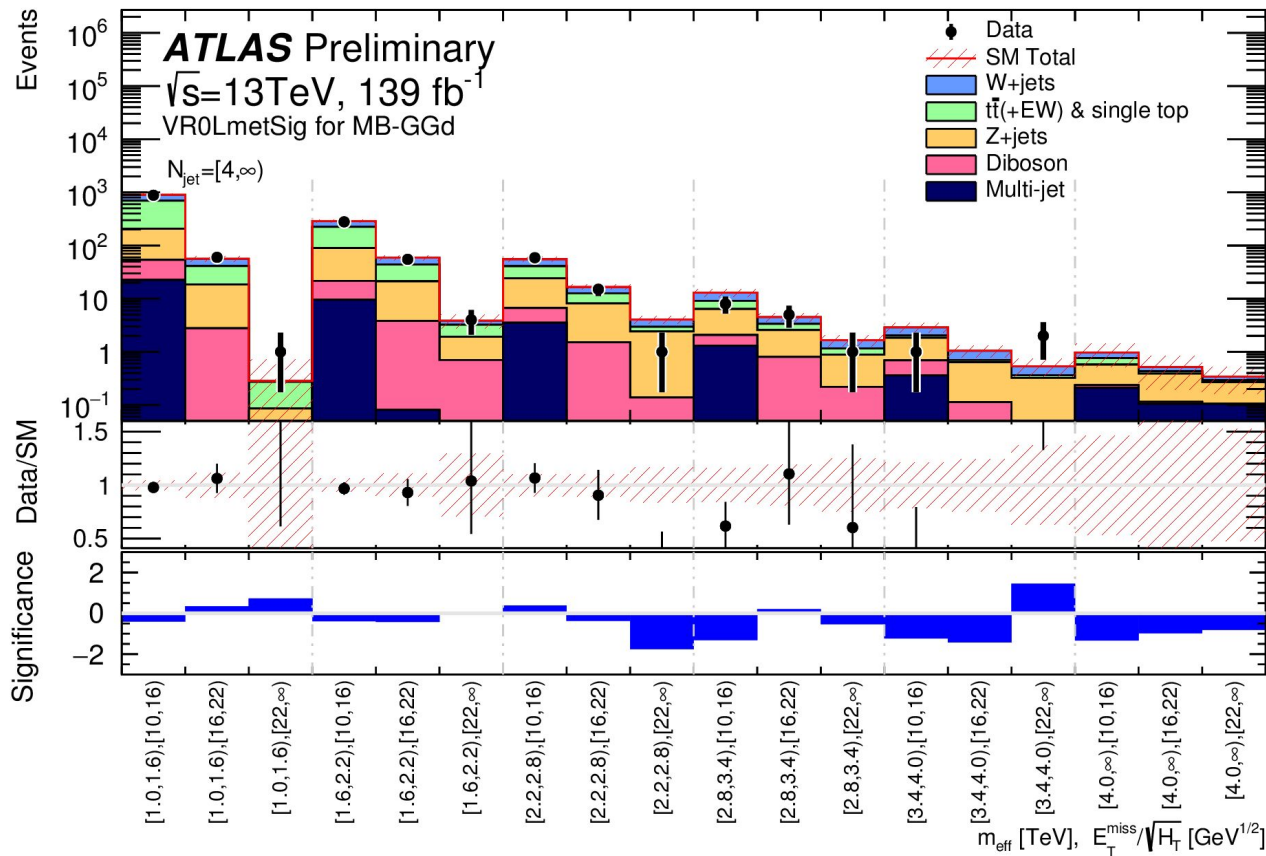
SUSY Strong oL: Pre-fit distributions



SUSY Strong oL: VRs



SUSY Strong oL: VRs



SUSY Strong oL: CRs

