

... and it's not dead yet

Searching SUSY with ATLAS

Steffen Schaepe



Searching SUSY in 8 Steps

- Find interesting model

Searching SUSY in 8 Steps

- Find interesting model
- Find selections to isolate your model

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Searching SUSY in 8 Steps

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- Look into data

Searching SUSY in 8 Steps

- Find interesting model
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- Figure out what the SM would look like
- Estimate how little you know about the SM
- Look into data
- Find nothing

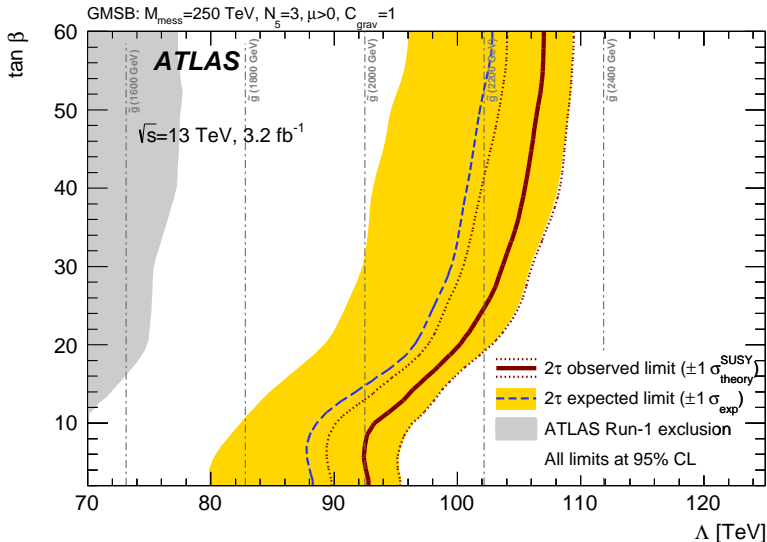
Searching SUSY in 8 Steps

- Find interesting model
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- Look into data
- Find nothing
- Draw fancy picture

Searching SUSY in 8 Steps

- Find interesting model
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- Look into data
- Find nothing
- Draw fancy picture
- (Optional) Repeat with more data

Typical Result



published in EPJC (2016) 76:683



Let's take one step back

What Is SUSY?

How To Search For SUSY?

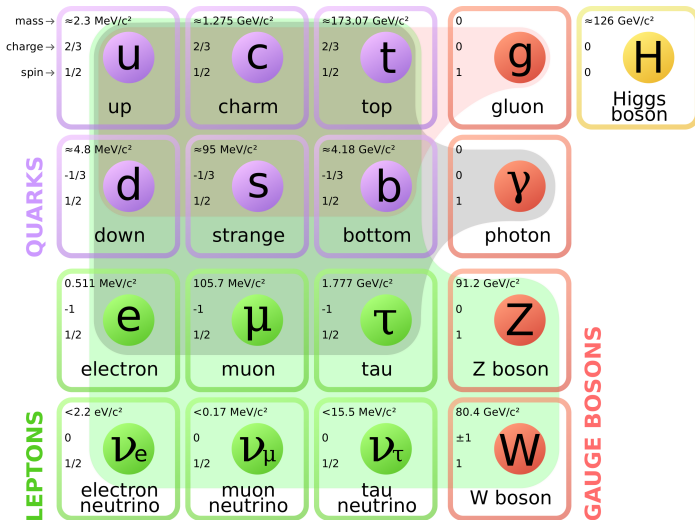
What Can We Learn From That?

Recent ATLAS SUSY Results

... And Why It's Still Not Dead!

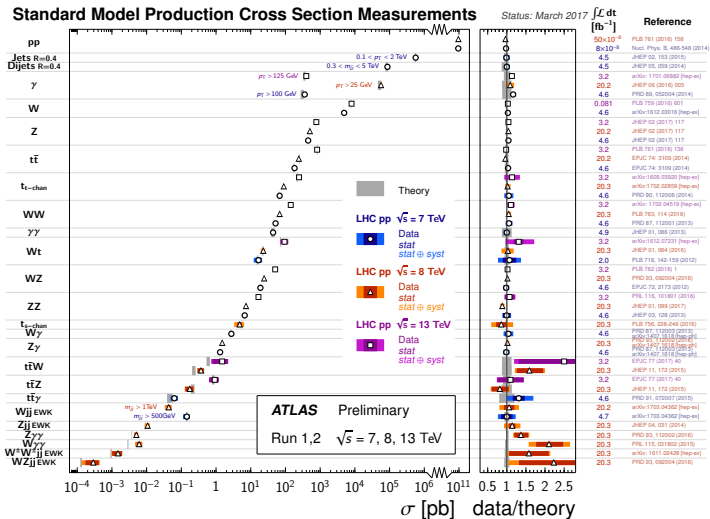
What Is SUSY?

The Standard Model (SM)



from commons.wikimedia.org

The Standard Model (SM)



atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SM



Big Questions of the 21st Century

- **Dark Matter?**
- **Dark Energy?**
- **Unification of Forces?**
- **Matter-Antimatter Symmetry?**
- **Light Higgs?**

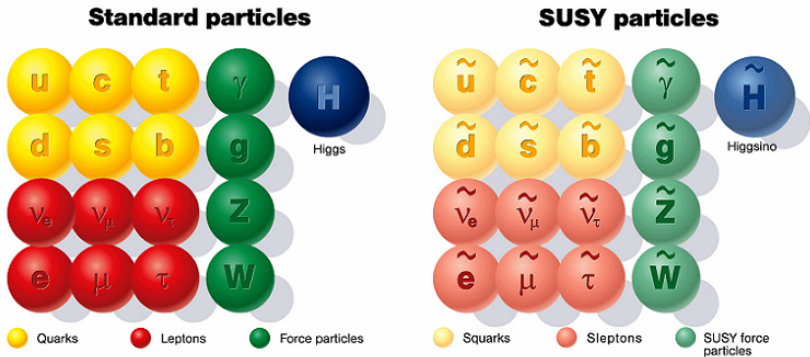
⇒ Have to be answered by particle physics!

Big Questions of the 21st Century

- **Dark Matter?** **SUSY!**
- **Dark Energy?**
- **Unification of Forces?** **SUSY!**
- **Matter-Antimatter Symmetry?** **SUSY?**
- **Light Higgs?** **SUSY!**

⇒ Have to be answered by particle physics!

Supersymmetry (SUSY)



- Copy of all SM particles with different spins
- All other properties identical
- No new parameters!

Broken SUSY (The MSSM)

- SUSY not seen so far \Rightarrow Has to be broken!
- We have no clue how SUSY breaking happens
- Write down all possible ways of SUSY breaking (within mathematical constraints)
 - \Rightarrow 105 new parameters
 - \Rightarrow B, L and flavor conservation violation
 - \Rightarrow Neither predictive nor testable

Protecting Symmetries

Introduce R-parity to restore SM symmetries
⇒ There is a SUSY quantum number!



SUSY particles can only be
produced in pairs



The lightest SUSY particle
(LSP) is stable



LSP must be neutral and at
max weakly interacting



Dark Matter candidate

Simplifying SUSY

Number of parameters has to be reduced to get usable predictions



Assume some breaking mechanism



“Phenomenological Models”



Full spectrum of particles, Realistic couplings and BRs



Limited set of “High Scale Parameters”



Ignore everything but a few particles



“Simplified Models”

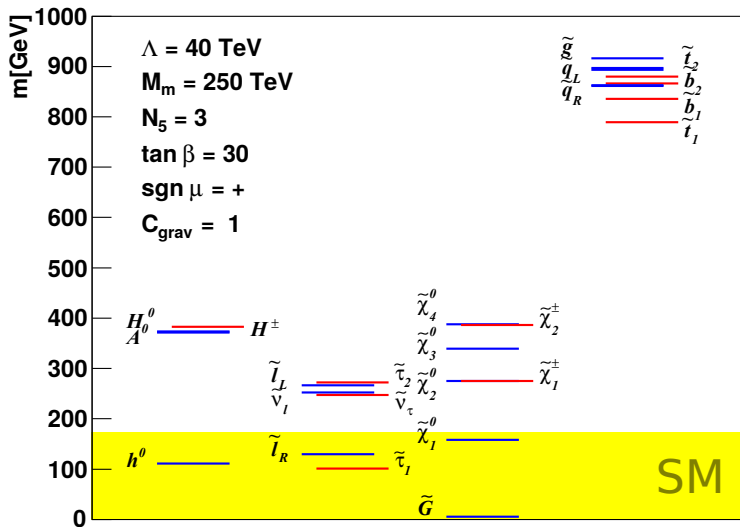


Limited Spectrum with strong assumptions and 100% BRs



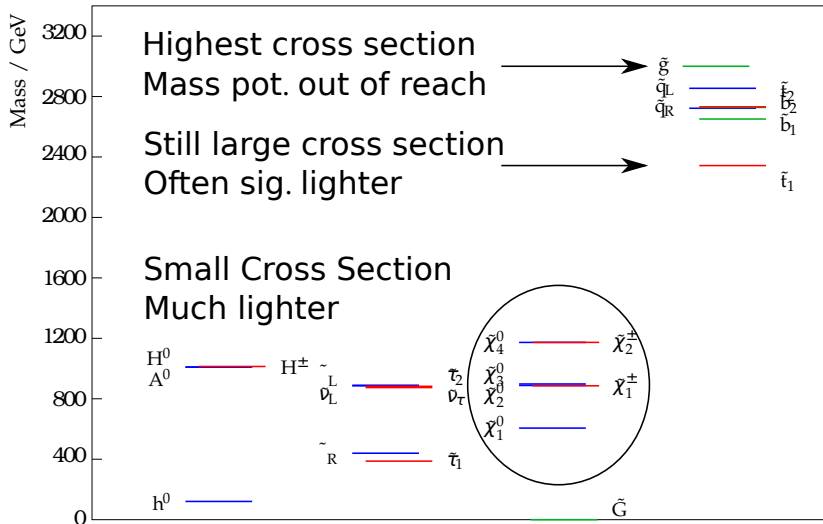
Masses of particles as parameters

Phenomenological Model

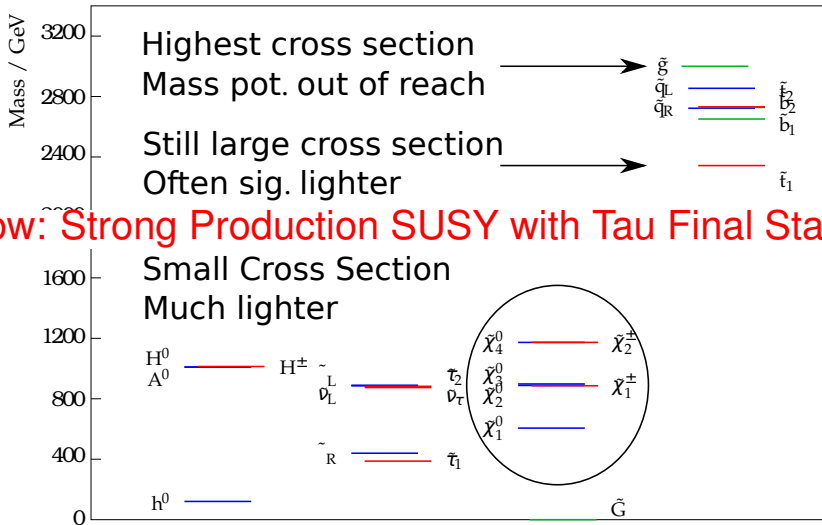


How To Search For SUSY?

Categorization



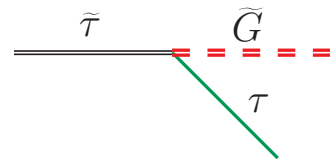
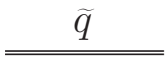
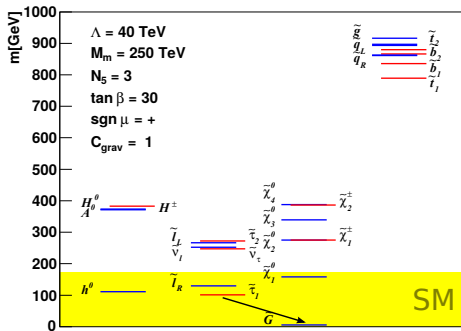
Categorization



Now: Strong Production SUSY with Tau Final States

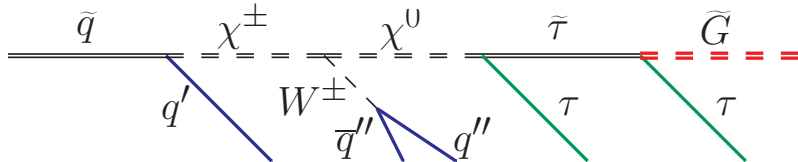
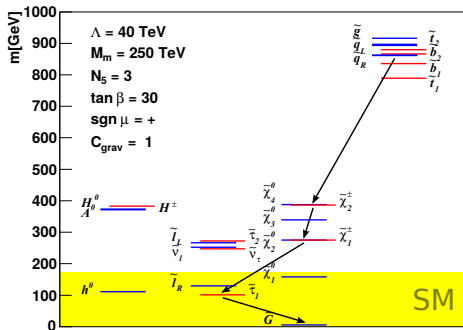
Phenomenological Model

- Invisible particles
- Tau from last decay step

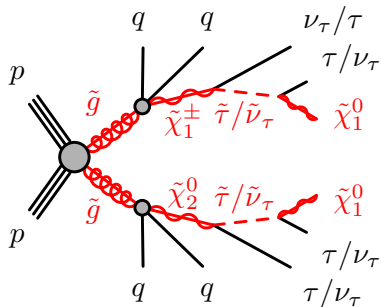


Phenomenological Model

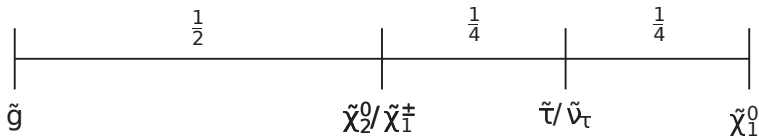
- **Invisible particles** leading to missing transverse energy \cancel{E}_T
- Multiple **taus**
- Multiple **quarks and/or gluons** in the cascade



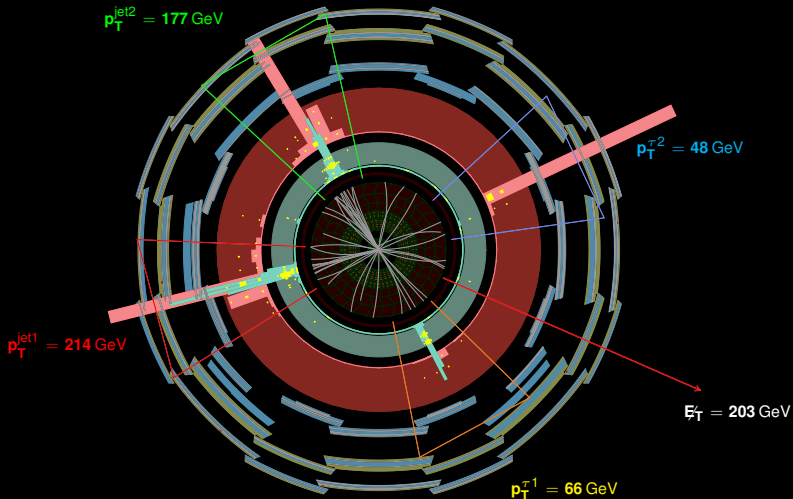
Simplified Model



- Essentially one decay
- $m_{\tilde{g}}$ and $m_{\tilde{\chi}_1^0}$ as free parameters
- Masses of $\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ and $\tilde{\tau}/\tilde{\nu}_\tau$ degenerate
- Masses of intermediate particles fixed



Example Event

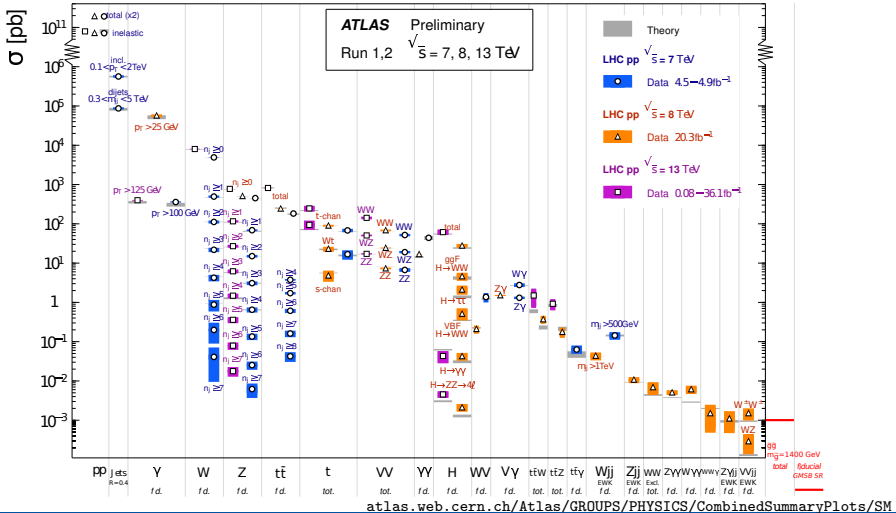


atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2011-18

Backgrounds

Standard Model Production Cross Section Measurements

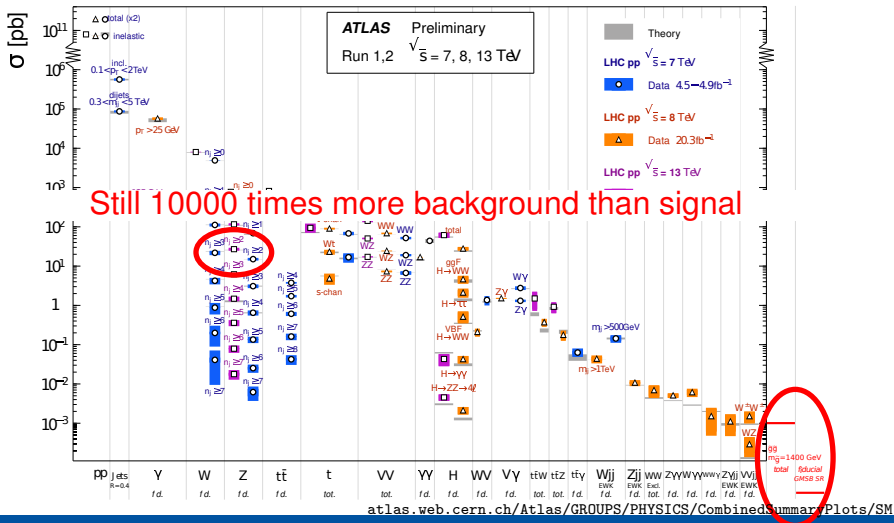
Status: May 2017



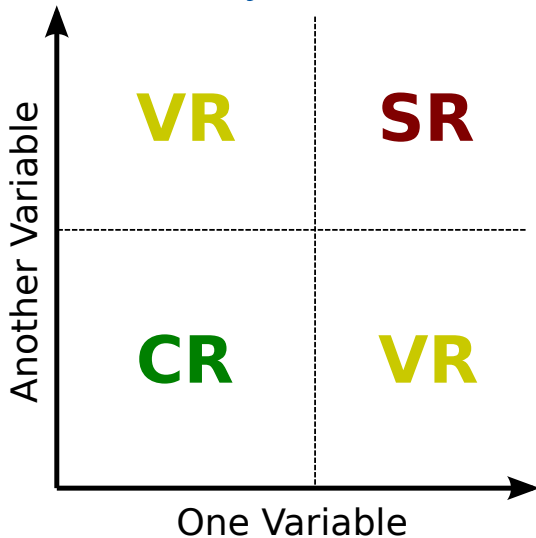
Backgrounds

Standard Model Production Cross Section Measurements

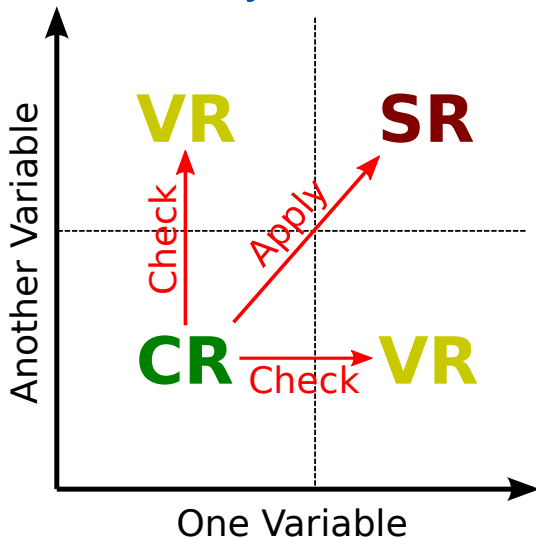
Status: May 2017



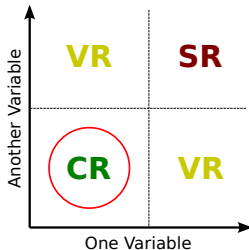
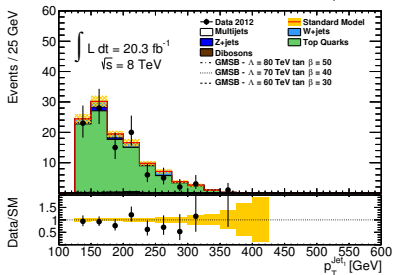
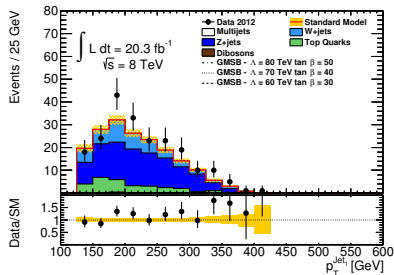
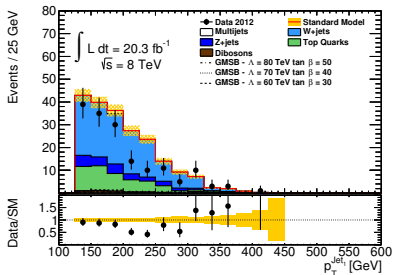
Data Driven Analysis



Data Driven Analysis

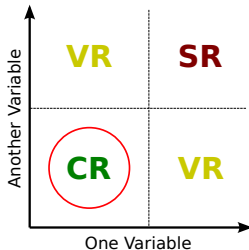
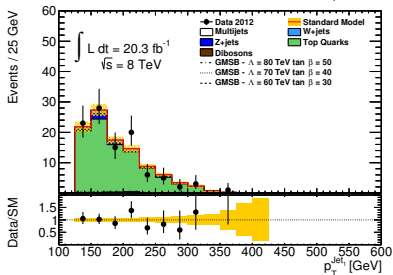
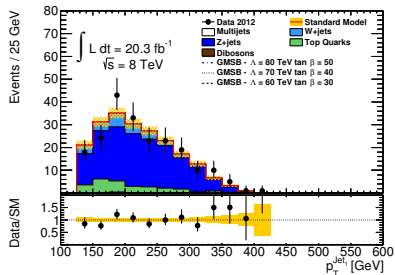
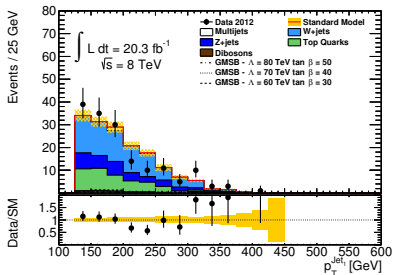


Backgrounds



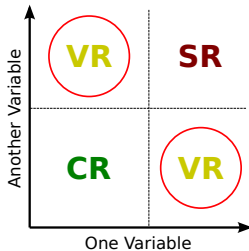
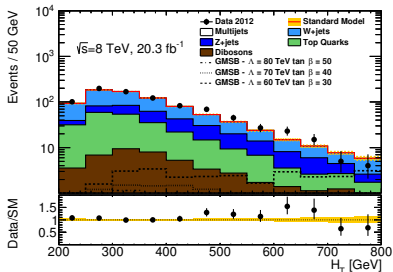
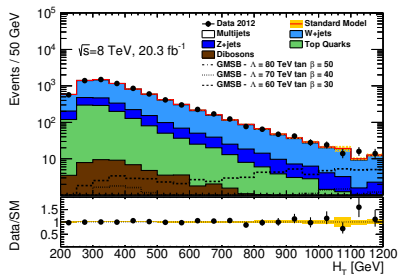
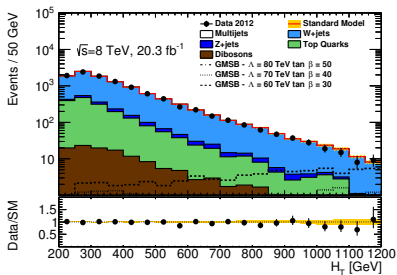
S.S., Dissertation, <http://hss.ulb.uni-bonn.de/2016/4238/4238.htm>

Backgrounds



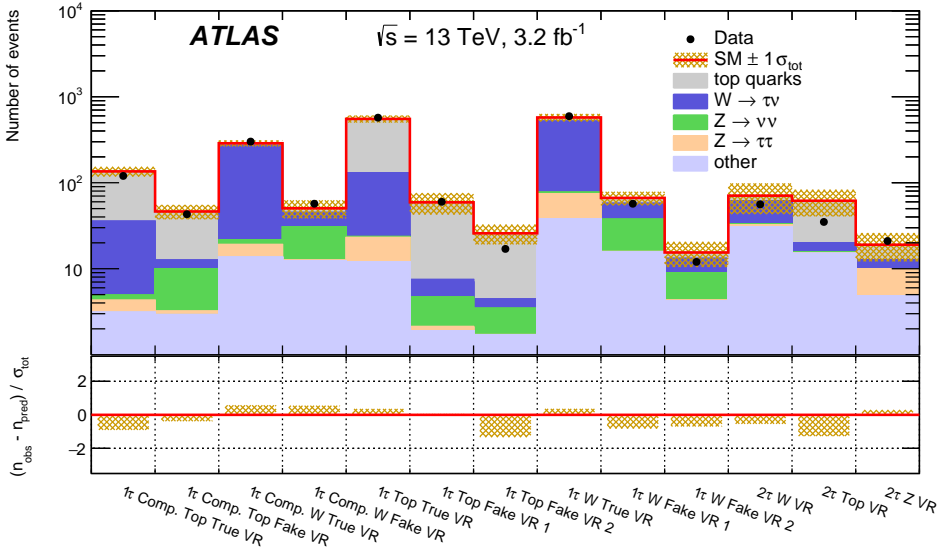
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Validation



S.S., Dissertation, <http://hss.ulb.uni-bonn.de/2016/4238/4238.htm>

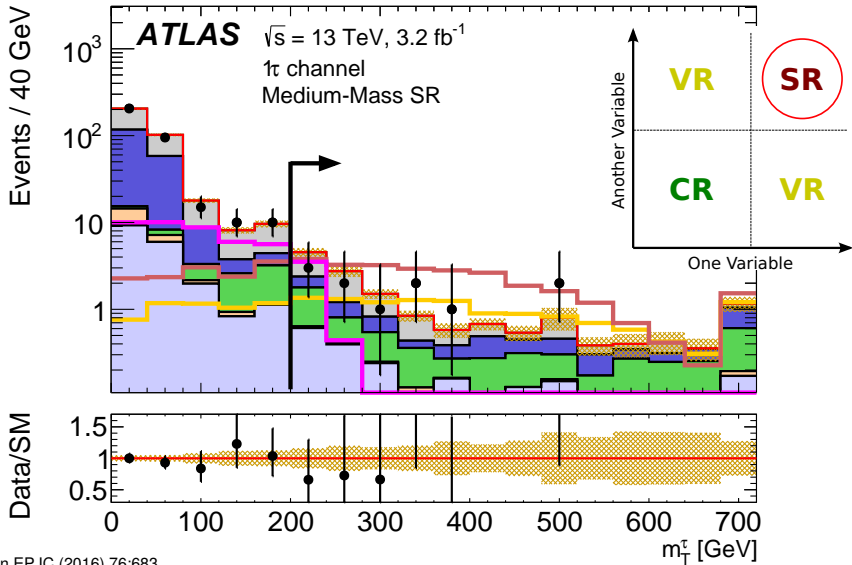
Validation



published in EPJC (2016) 76:683



Results

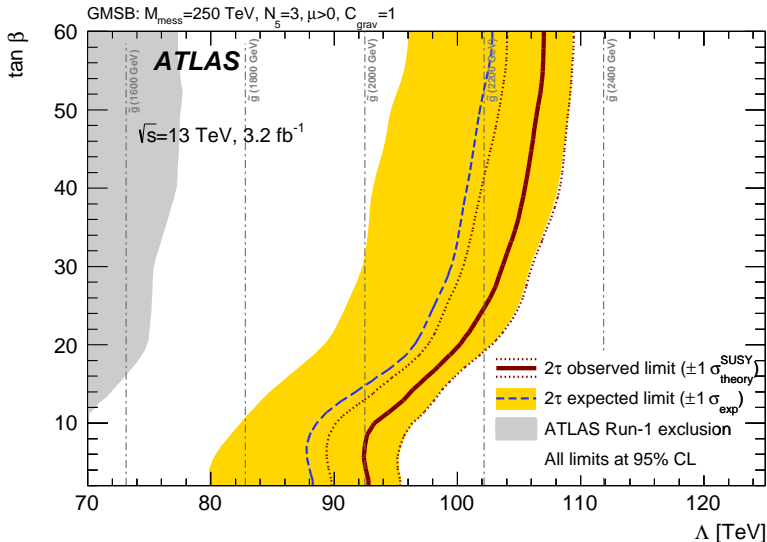


published in EPJC (2016) 76:683

Nothing Found!

What Can We Learn From That?

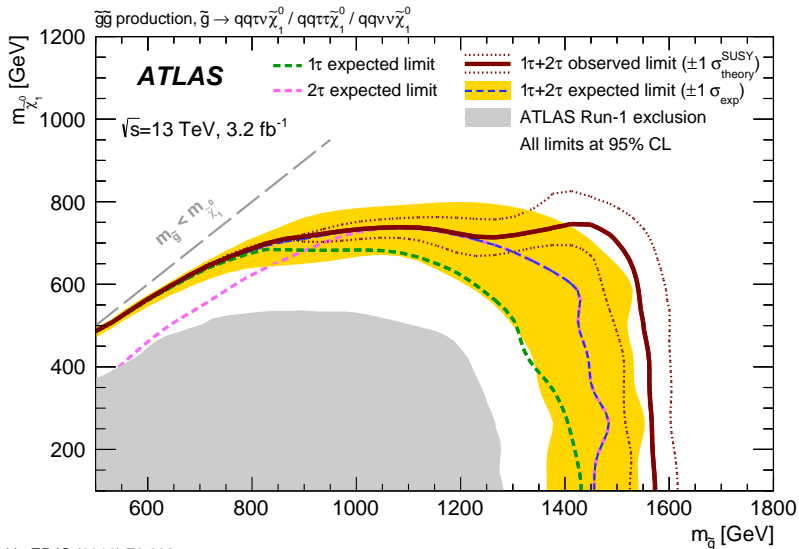
Limits on Model Parameters



published in EPJC (2016) 76:683



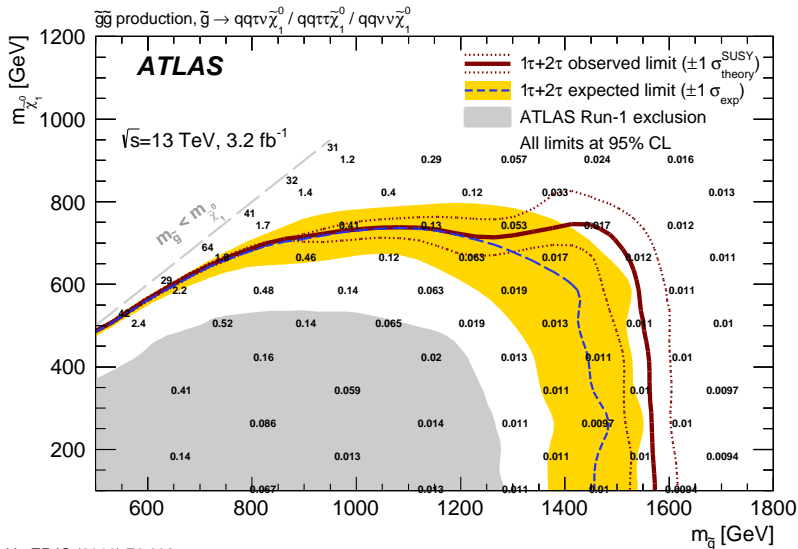
Limits on Masses



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Limits on Cross Sections



Model Independent Limits

1τ channel	Compressed SR	Medium-Mass SR	High-Mass SR
Data	47	11	1
Total background	49.2 ± 6.2	15.0 ± 2.4	5.7 ± 1.2
$S_{\text{obs}}^{95} (S_{\text{exp}}^{95})$	$16.7 (18.4^{+6.9}_{-5.0})$	$7.5 (9.7^{+3.5}_{-2.5})$	$3.8 (6.1^{+2.1}_{-1.5})$
$\langle \sigma_{\text{vis}} \rangle_{\text{obs}}^{95}$ [fb]	5.19	2.34	1.17
CL_B	0.41	0.23	0.02

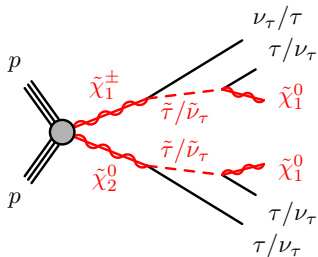
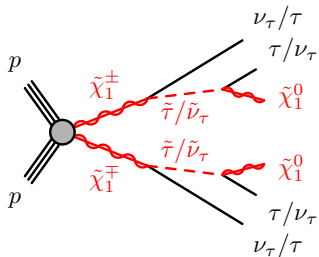
2τ channel	Compressed SR	High-Mass SR	GMSB SR
Data	4	0	0
Total background	4.2 ± 3.0	3.2 ± 1.2	0.69 ± 0.24
$S_{\text{obs}}^{95} (S_{\text{exp}}^{95})$	$8.2 (8.0^{+2.1}_{-2.0})$	$3.4 (4.8^{+1.4}_{-1.0})$	$3.4 (3.7^{+0.5}_{-0.2})$
$\langle \sigma_{\text{vis}} \rangle_{\text{obs}}^{95}$ [fb]	2.55	1.07	1.07
CL_B	0.53	0.12	0.53

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Recent ATLAS SUSY Results

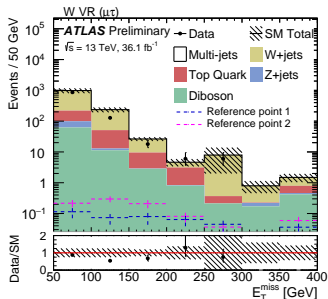
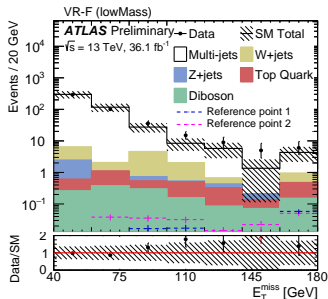
Elektroweak 2τ



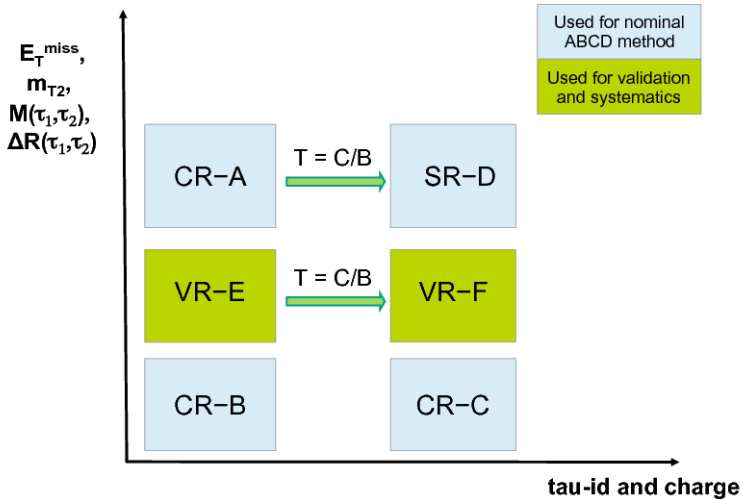
- First tau-search published with full 2015+2016 dataset
- Targets events with two hadronic OS τ leptons
- ATLAS-CONF-2017-035

Elektroweak 2τ

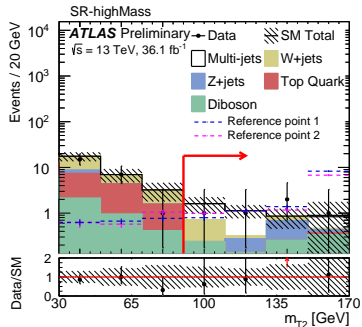
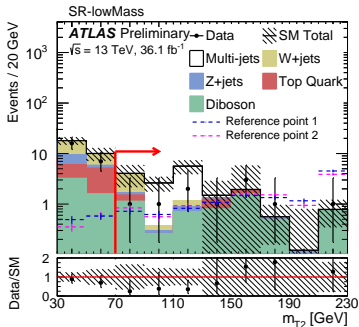
- Dominant backgrounds: diboson, multijets and W +jets
- Multijets estimated purely from data, W +jets data-driven



Elektroweak 2τ



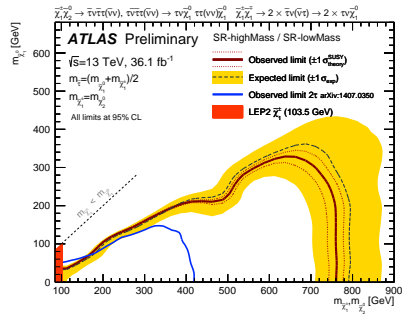
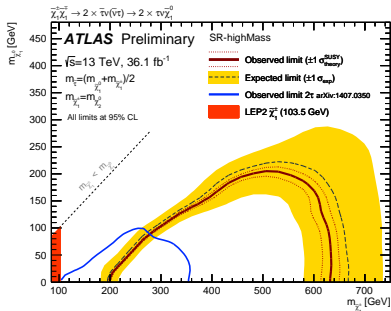
Elektroweak 2τ



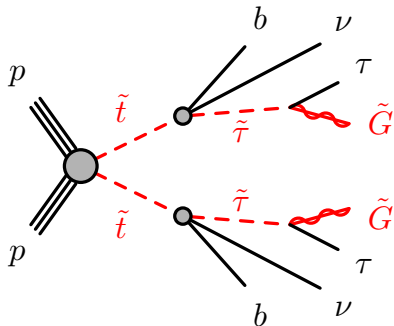
- Two SRs based on various mass variables, \cancel{E}_T and p_T^τ
- No Excess observed in any SR

Elektroweak 2τ

- Limits substantially improve previous results
- Extension to direct $\tilde{\tau}$ production planned

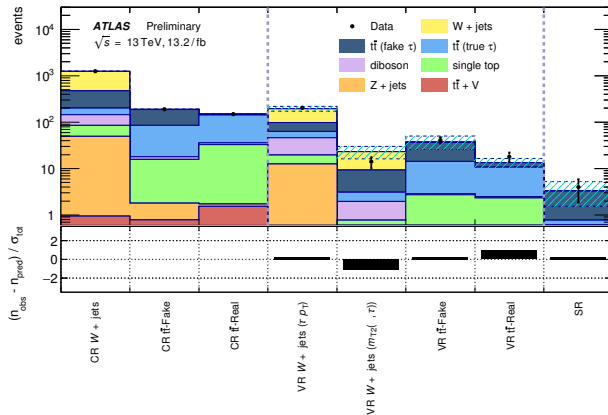


Stop-Stau



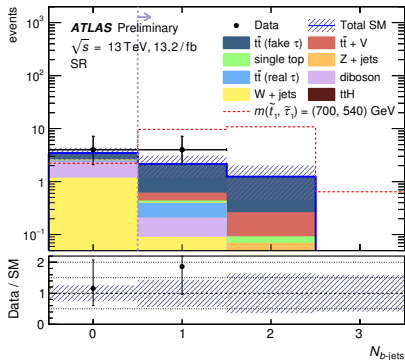
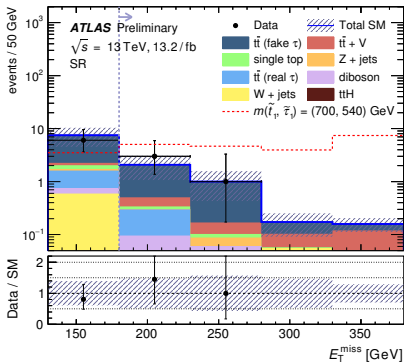
- Based on 13.2 fb^{-1} of 13 TeV data
- Signal model inspired by gauge-mediated SUSY
- Targets events with one hadronic τ and one light lepton
- Dominant background: $t\bar{t}$ with a fake τ
- ATLAS-CONF-2016-048

Stop-Stau



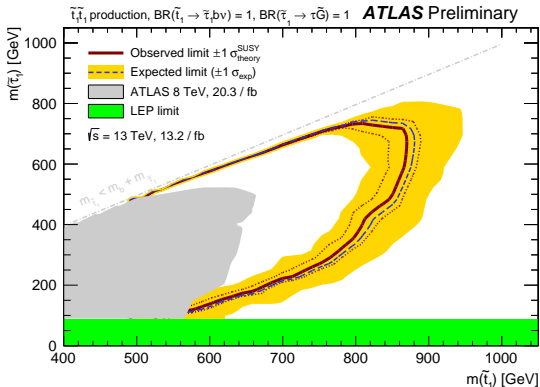
- Data-driven estimate of $t\bar{t}$ and W +jets
- Extensive validation

Stop-Stau



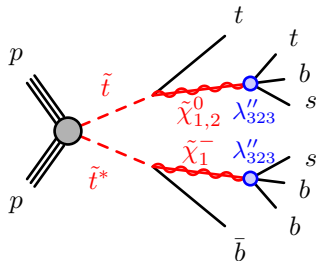
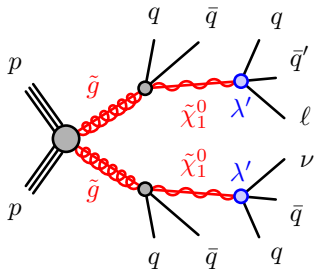
- One SR based on various mass variables, E_T^{miss} and $N_{b\text{-jet}}$

Stop-Stau



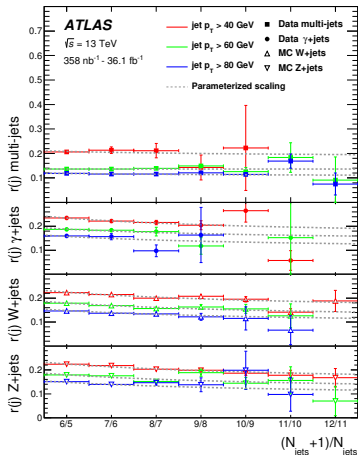
- Previous exclusion substantially improved
- Extension to full 2015+2016 dataset in preparation

$1\ell + \text{many jets}$



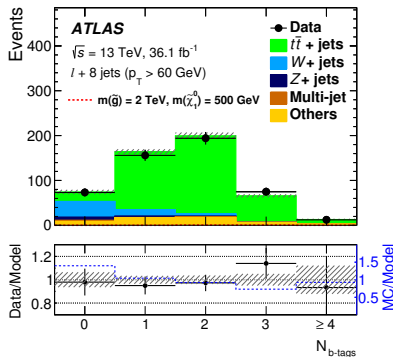
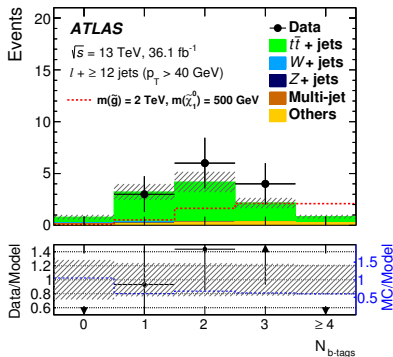
- R-parity violated \Rightarrow LSP instable \Rightarrow no \cancel{E}_T
- Signature:
 $1\ell + \geq 8 - 12 \text{ jets} + 0 / \geq 3 \text{ b-jets}$
- Very different to “normal” searches
- arXiv:1704.08493, submitted to JHEP

$1\ell + \text{many jets}$



- Background simulation difficult
- Normalize in low N_{jet} CRs
- Extrapolate from low N_{jet} to high N_{jet} slices

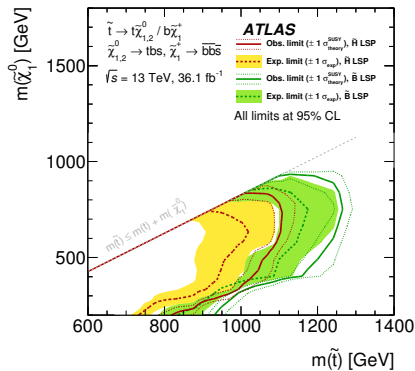
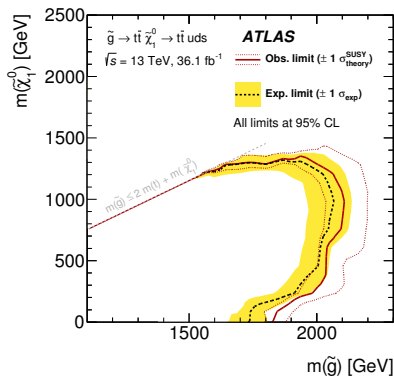
1 l + many jets



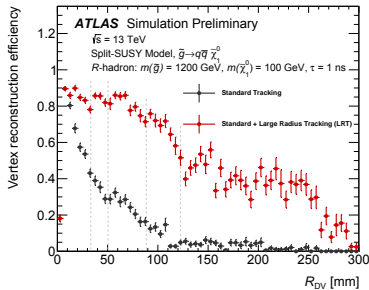
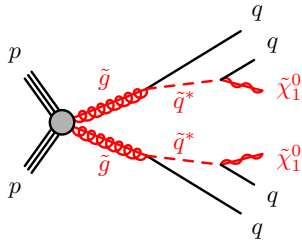
- 18 SRs binned in N_{jet} and $N_{b\text{-jet}}$ for 3 thresholds in jet- p_T
- No Excess observed in any SR

1 ℓ + many jets

- Limits in various models
- Exclusions up to $m_{\tilde{g}} > 2$ TeV

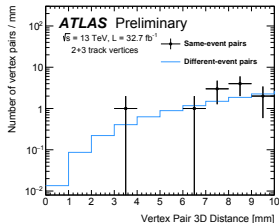
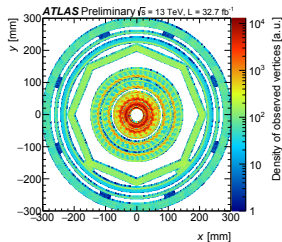


Displaced Vertices + \cancel{E}_T



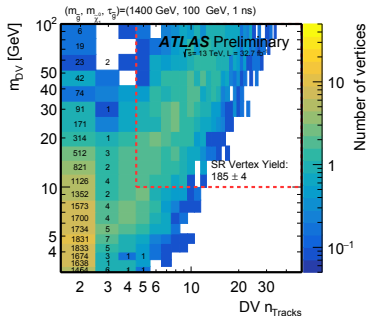
- Signature: High-mass ($m_{DV} > 10 \text{ GeV}$), multi-track ($n_{\text{track}} \geq 5$) vertices at large radii + large \cancel{E}_T
- Targets meta-stable, neutral particles
- Special tracking needed
- ATLAS-CONF-2017-026

Displaced Vertices + \cancel{E}_T

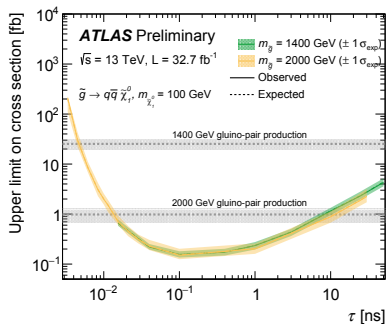


- No irreducible background
- Mainly hadronic interactions and merging of close-by vertices
- Veto events from areas of high mass density
- Study merging probability in control studies

Displaced Vertices + \cancel{E}_T



- No candidate event observed
- Stingent limits set



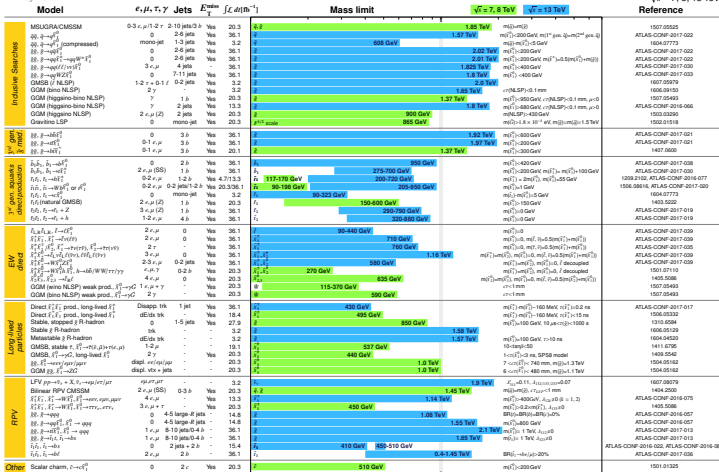
All ATLAS SUSY Results

ATLAS SUSY Searches * 95% CL Lower Limits

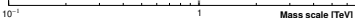
May 2017

ATLAS Preliminary

$\sqrt{s} = 7, 8, 13$ TeV



*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.



atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY



... And Why It's Still Not Dead!

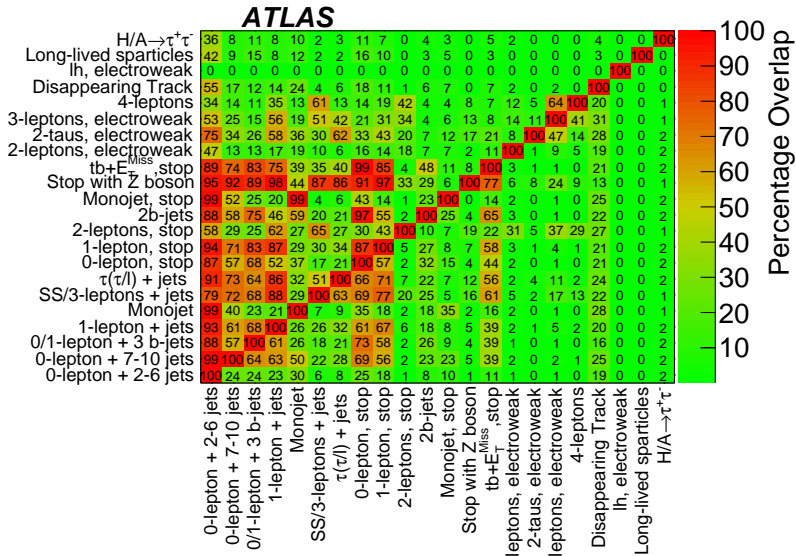
The Limits of the Limits

- All limits rely on more or less restrictive assumptions
- How “universal” are they?
- At the end of Run I, published large scale study on pMSSM (JHEP 10 (2015) 134)
- pMSSM = only minimal assumptions, 19 parameters
- 22 analyses evaluated
- > 500 Million signal points sampled

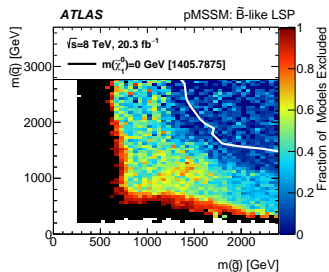
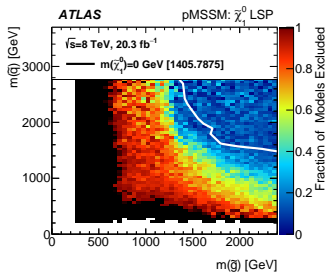
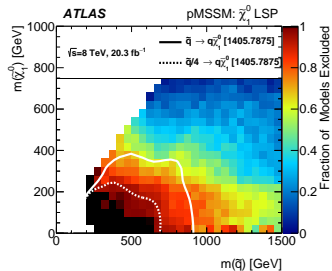
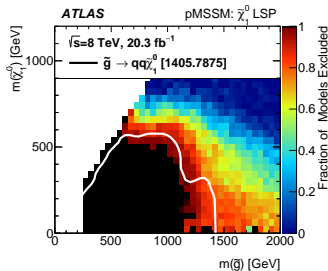
Questions

- How powerful are analyses for different final states?
- How rigid are our exclusions?
- Which type of signatures did we miss so far?

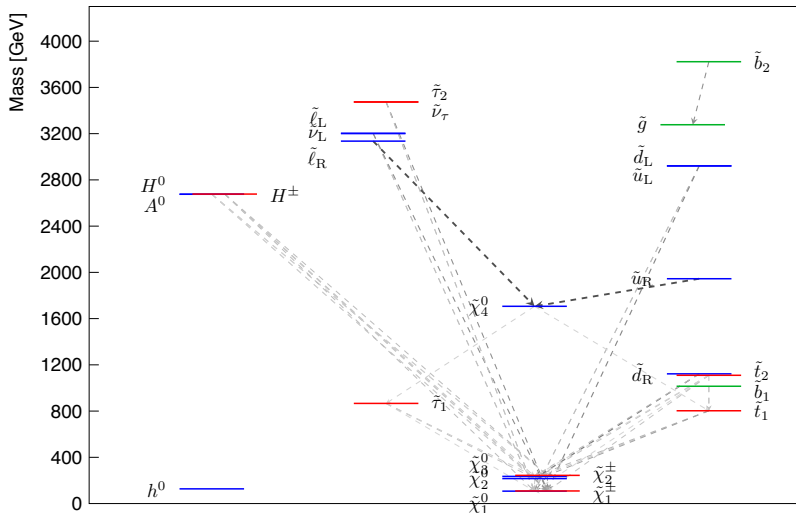
Different Analyses



Hard and Soft Limits



What We Missed



Summary

- SUSY well motivated extension of the SM
- ... that could solve some open issues
- Searching for SUSY requires looking in many corners!
- LHC and ATLAS ideal tools for searches
- No signs of SUSY observed (so far)
- More and stronger exclusions put SUSY under severe stress
- But there is still plenty of room where SUSY could be hidden!



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