Where is sWaldo?

Searching for sTops amongst the SM crowd with the ***ATLAS*** Detector

arXiv [hep-ex]1407.0583

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Motivation

A minimal SUSY solution to the hierarchy problem requires light stops

Gospel Church Choir Cats Cat Art By Tarafly

There is no (approximate) symmetry to protect the Higgs mass from Quantum Corrections

Naively, the mass receives quadratic corrections to highest mass scale

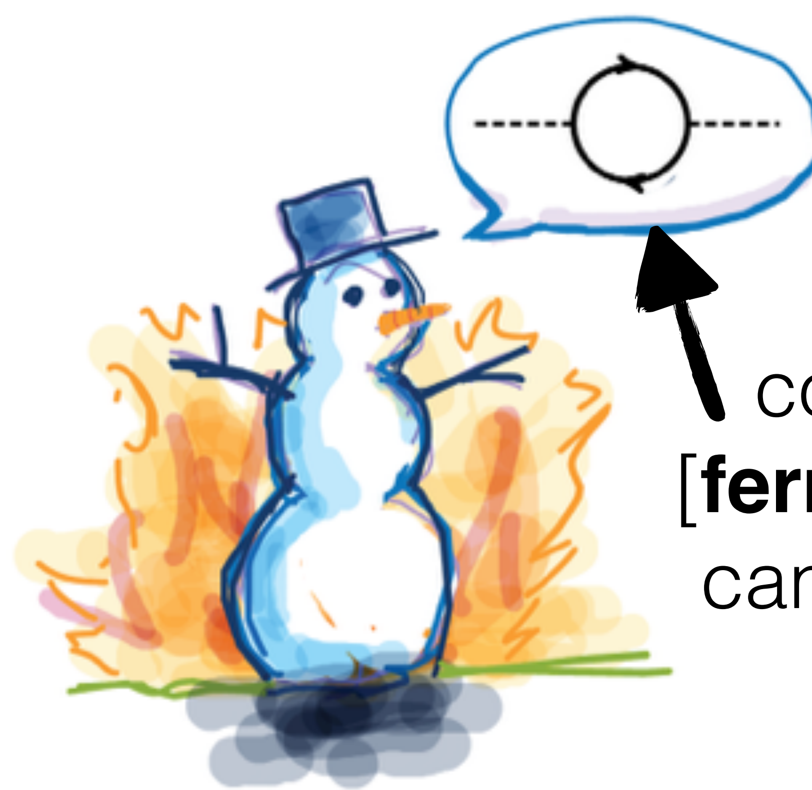
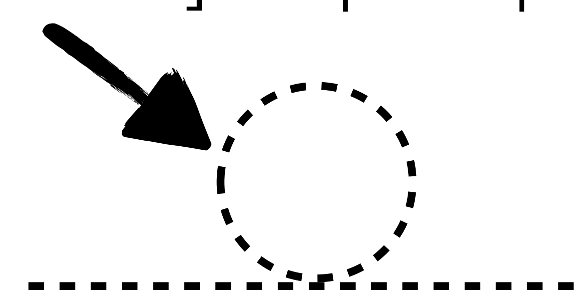


Image from Flip Tanedo (Quantum Diaries)

The largest (quantum) contribution comes from the [**fermionic**] top quark loop - can cancel with [**scaler**] stop loops



S for ***SU****per****SY****mmetry*

The parameter space of natural SUSY is huge

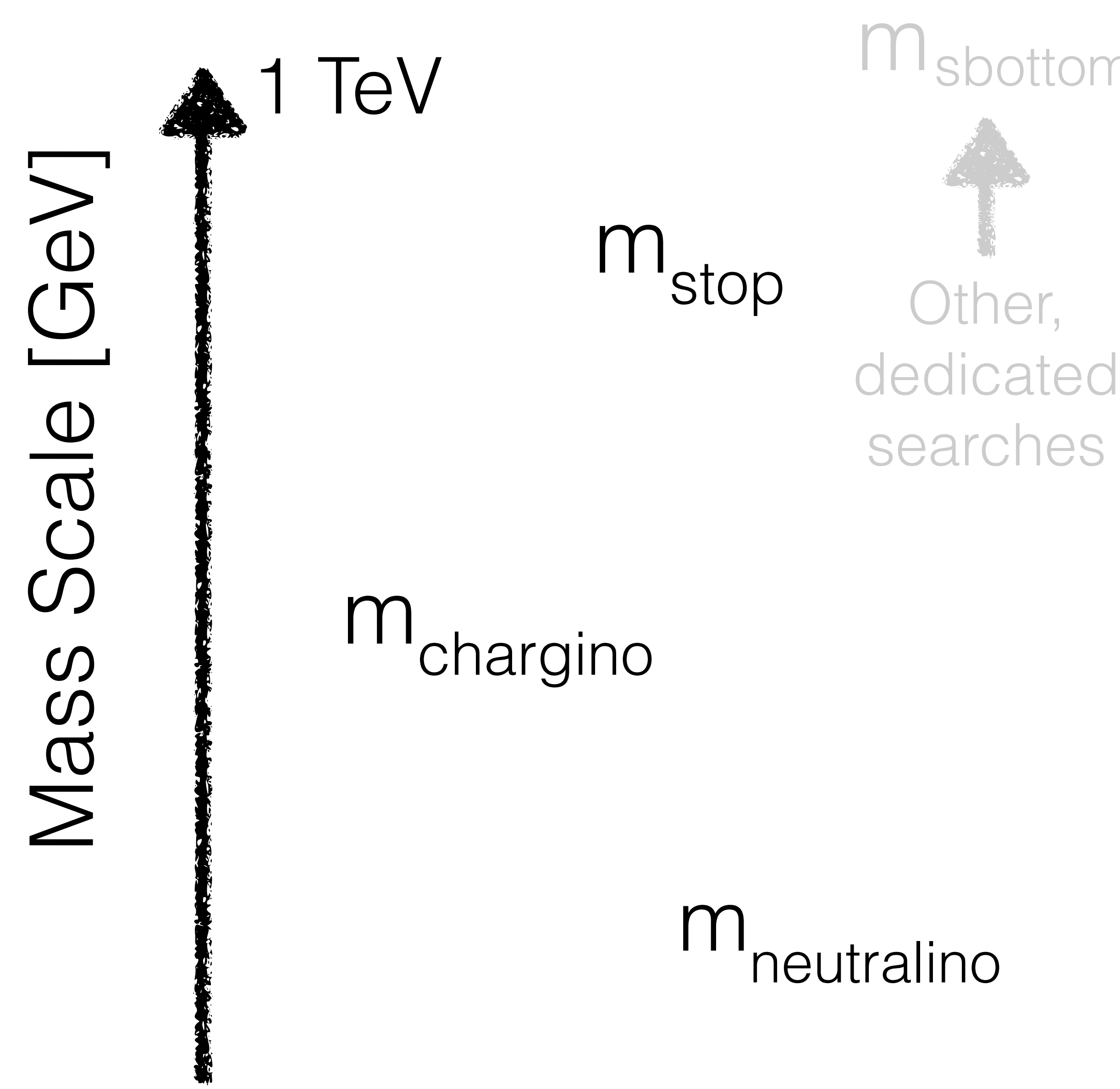
Technically, natural SUSY is a framework, not a model

The Minimal Supersymmetric SM has o(100) parameters

Simplifying assumptions

1. *R*-parity conservation
2. stop is the only light squark
3. lightest neutralino is the LSP

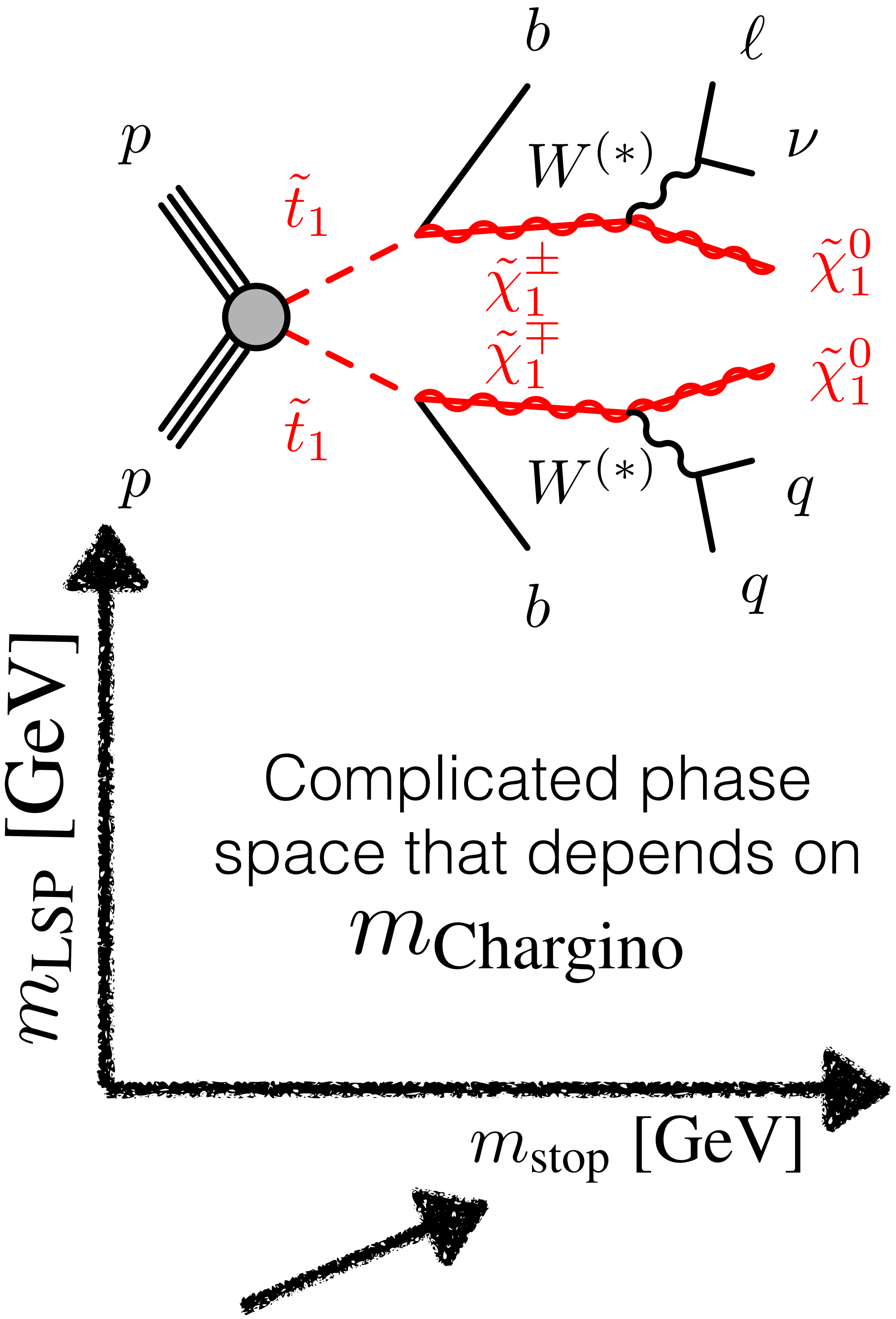
Three important parameters:



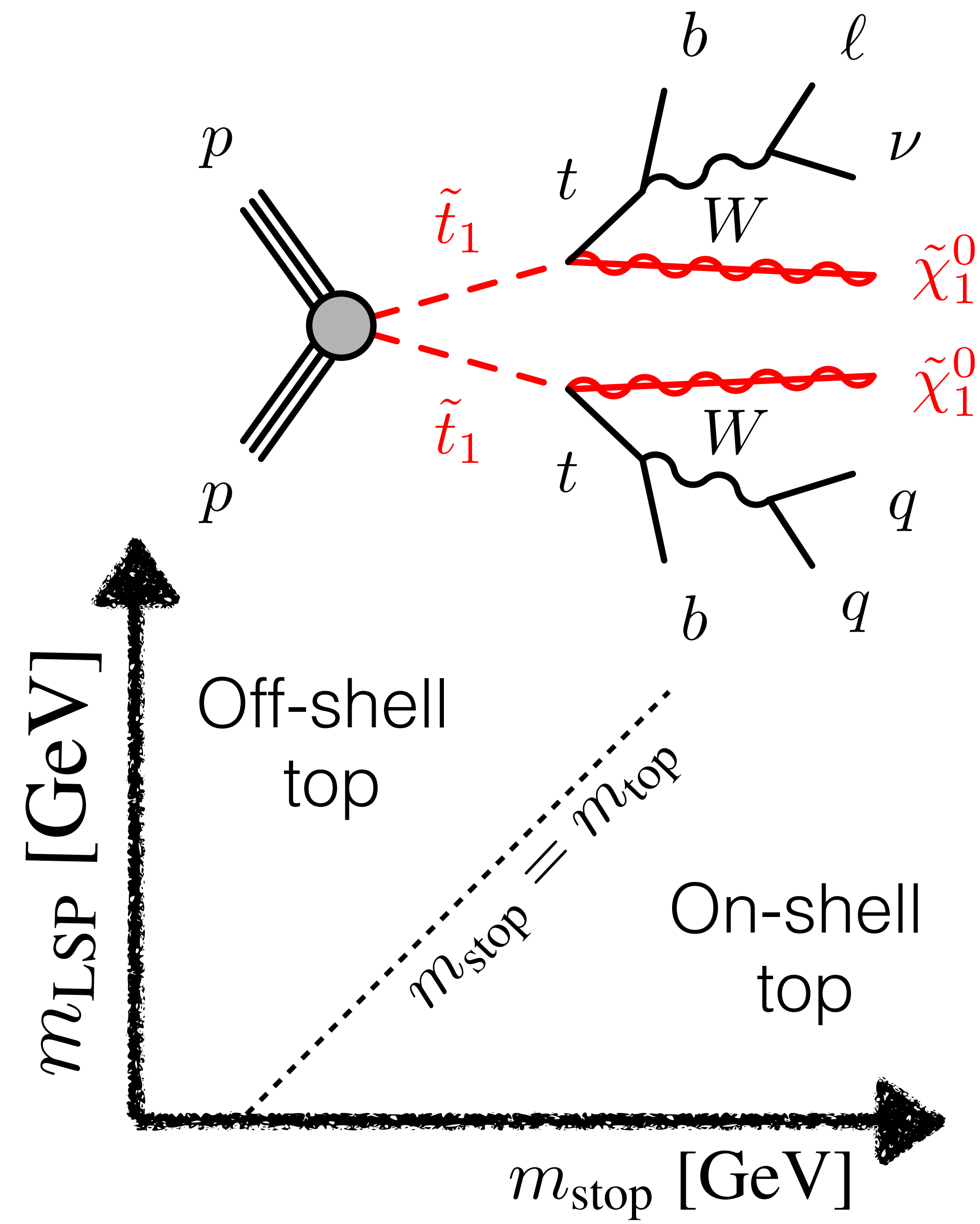
Dark Matter?

Target Models

We use simplified models: Leading order processes with 100% branching ratios



Most important parameter - sets the cross section

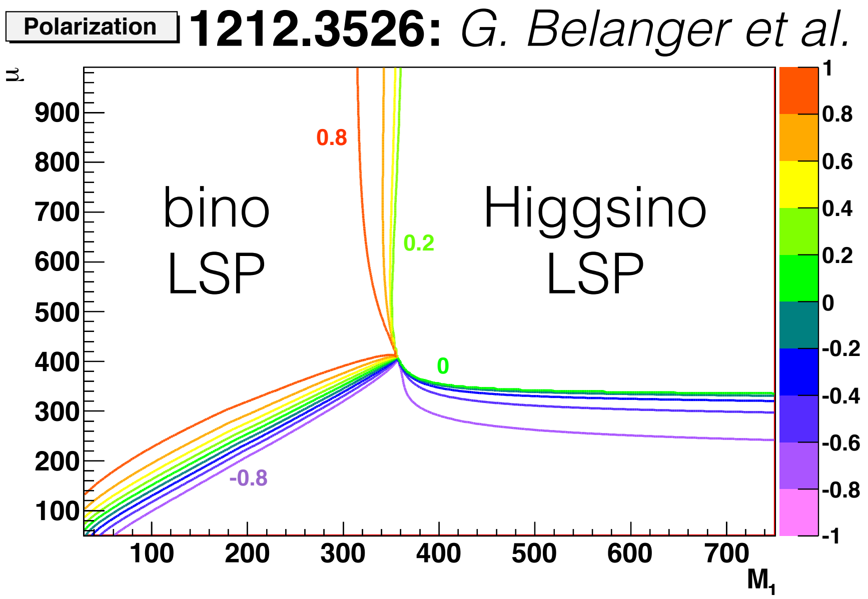


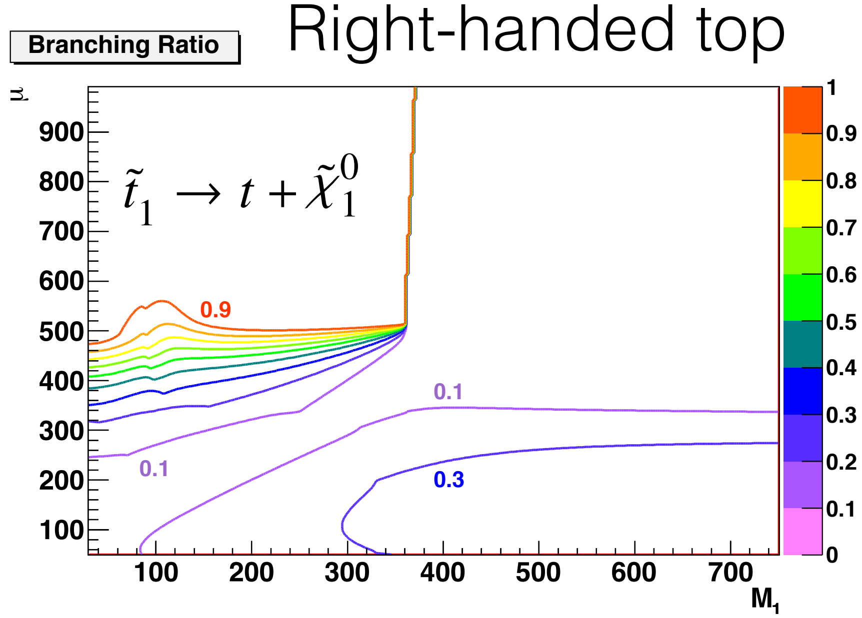
Stop is (mostly) right-handed and the neutralino is (mostly) bino

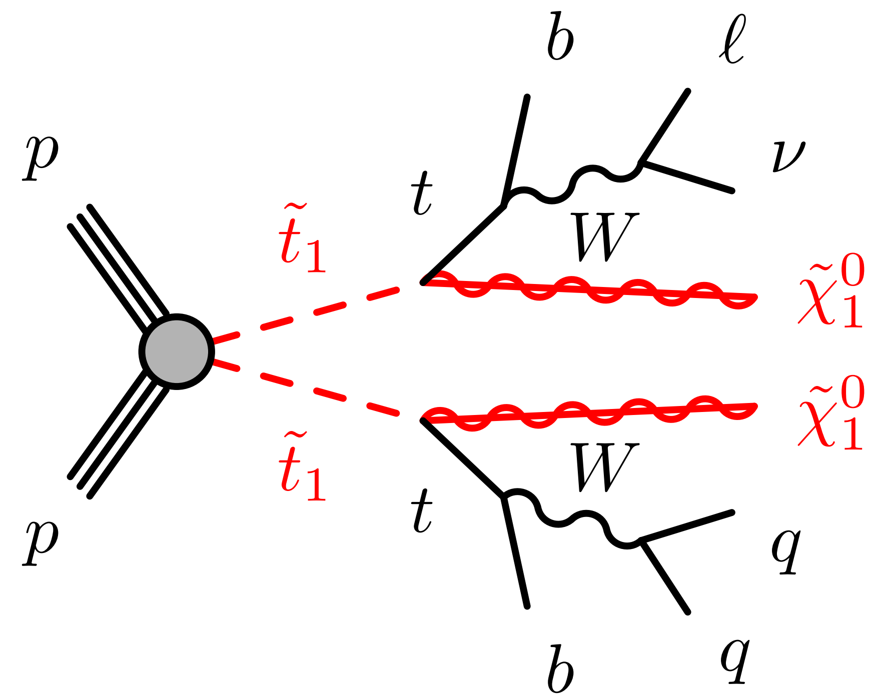
How ‘realistic’ is simple?

There are regions of the MSSM with near unity branching ratios

1212.3526: *G. Belanger et al.* Right-handed top



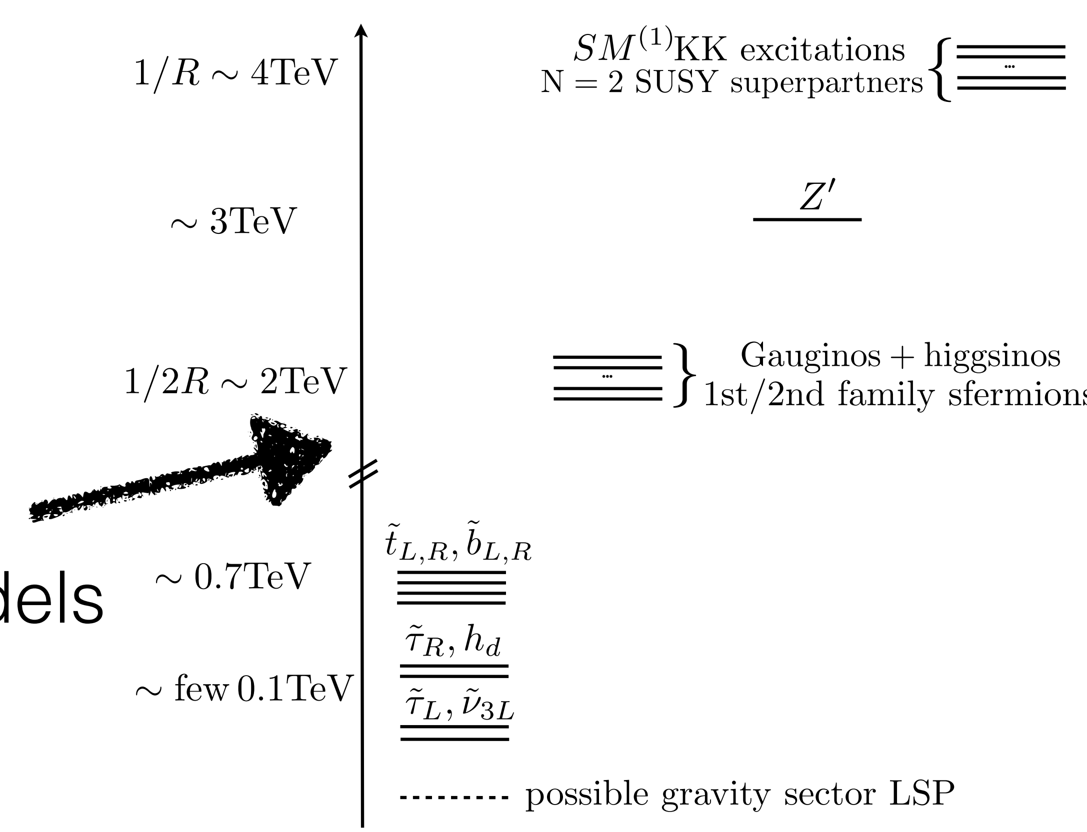




The neutralino field content is important in part for the top polarization

→ impacts acceptance through the momentum of the top decay products

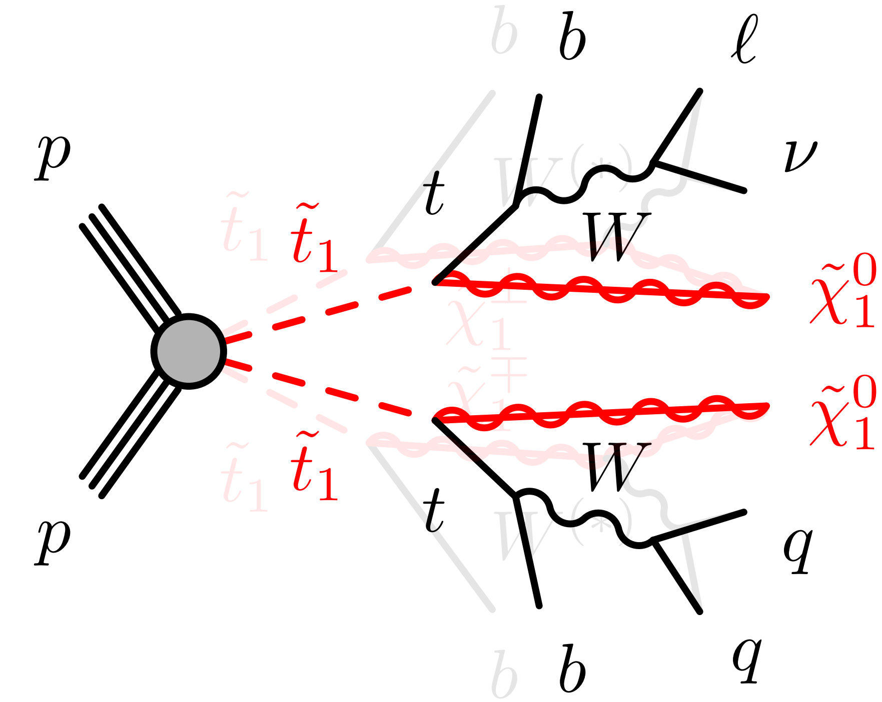
1404.7554: *S. Dimopoulos, K. Howe, and J. March-Russell*



Another motivation: *Maximally Natural SUSY*; gluinos are heavy and it look likes simplified models

This is not the MSSM!

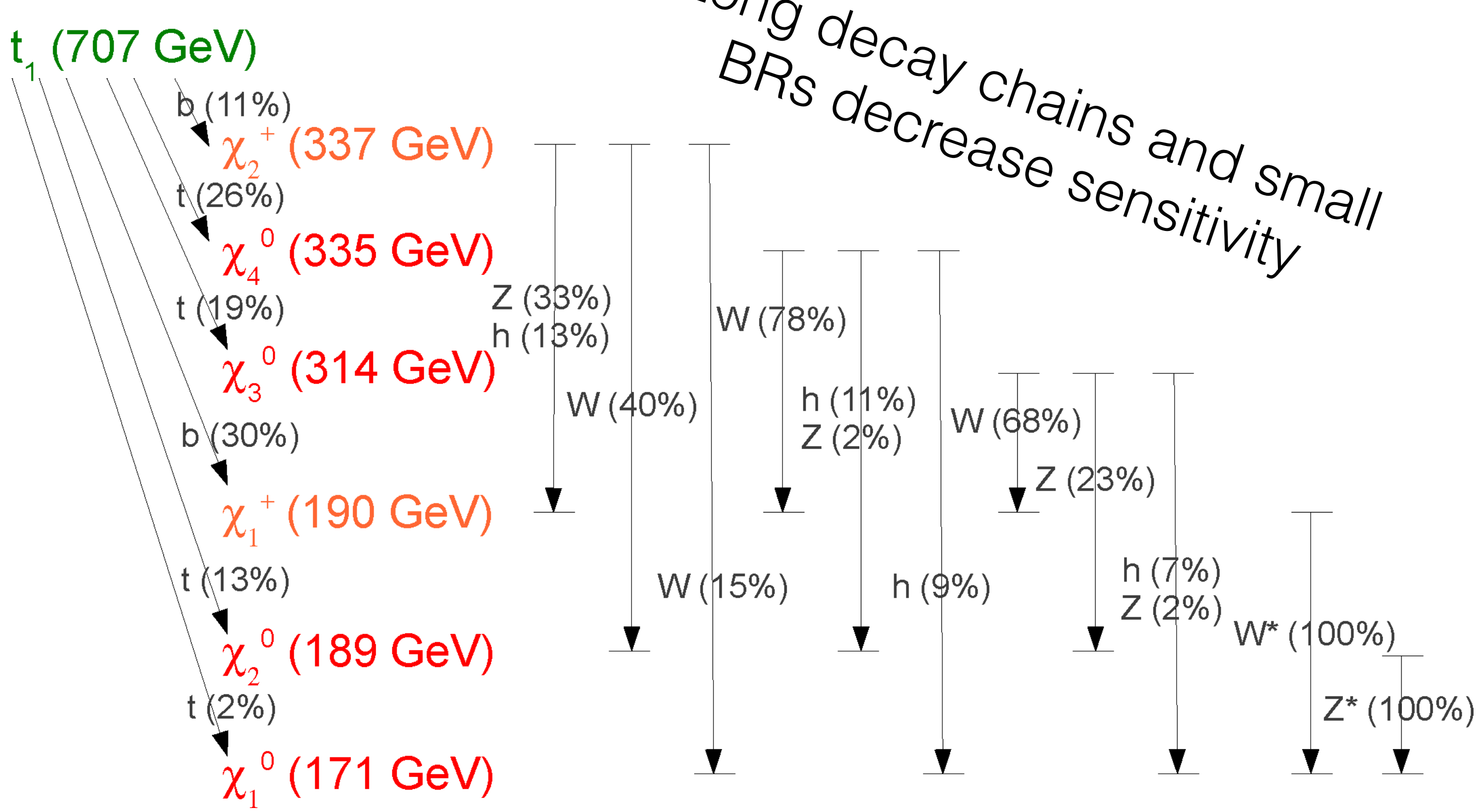
Not happy with simple?



We will also consider *asymmetric* decays where

BR(b+chargino) + BR(t+LSP) = 1
but *BR(b+chargino) < 1 & BR(t+LSP) < 1*

We also will study the impact of the stop mixing (impacts top polarization and acceptance)



Long decay chains and small BRs decrease sensitivity

Still not happy?

Just for you, we also considered a scan in the pMSSM*

(R-parity conserving MSSM subject to experimentally motivated constraints - 19 parameters)

1307.8444: *Authors listed (*)*

*Thanks to the work of M. Cahill-Rowley, J.L. Hewett, A. Ismail, and T.G. Rizzo

Search Strategy

1 lepton channel: optimal mix of cross section and background rejection

(1) **Preselection**

-Reach the trigger plateau

-Remove most multijet events

(2) **Discriminating Variables**

-Robust techniques to isolate the signal

Many designed specifically for this search

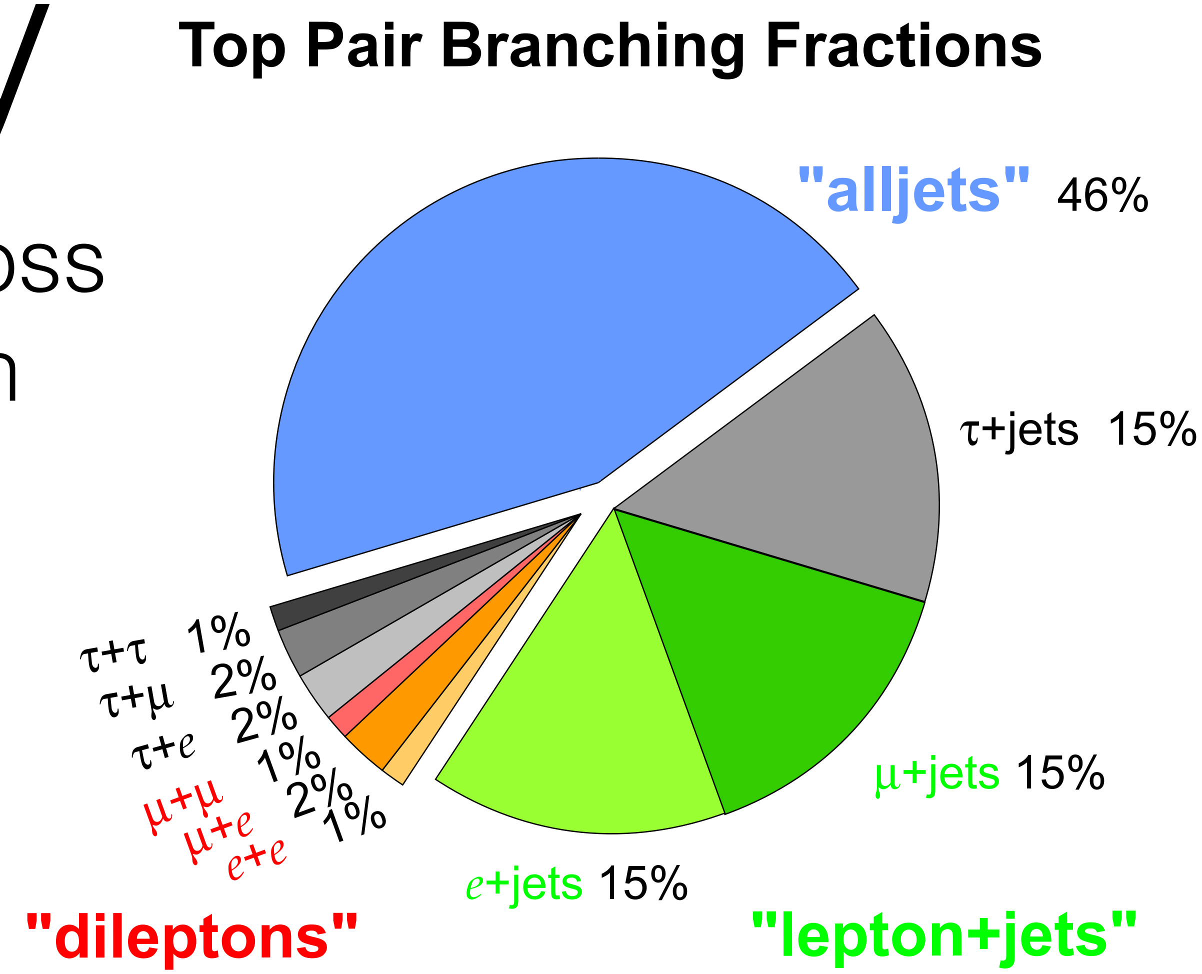
-Combine variables to form signal regions (SRs)

(3) **Background estimation**

-For the dominant backgrounds, define control regions (CRs)

-Estimate systematic uncertainties

(4) **Results**



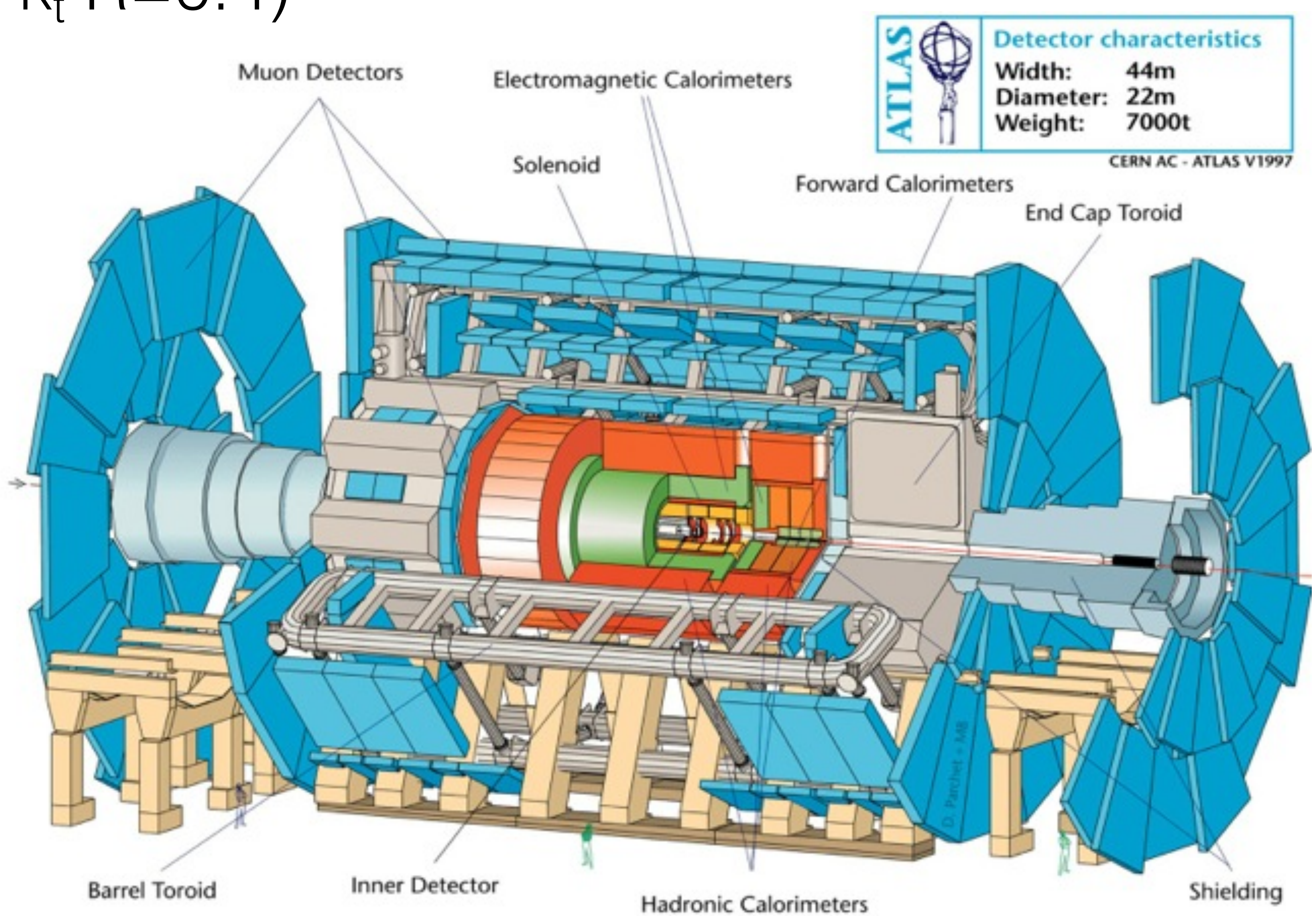
Credit: D0 Collaboration: http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/

Preselection

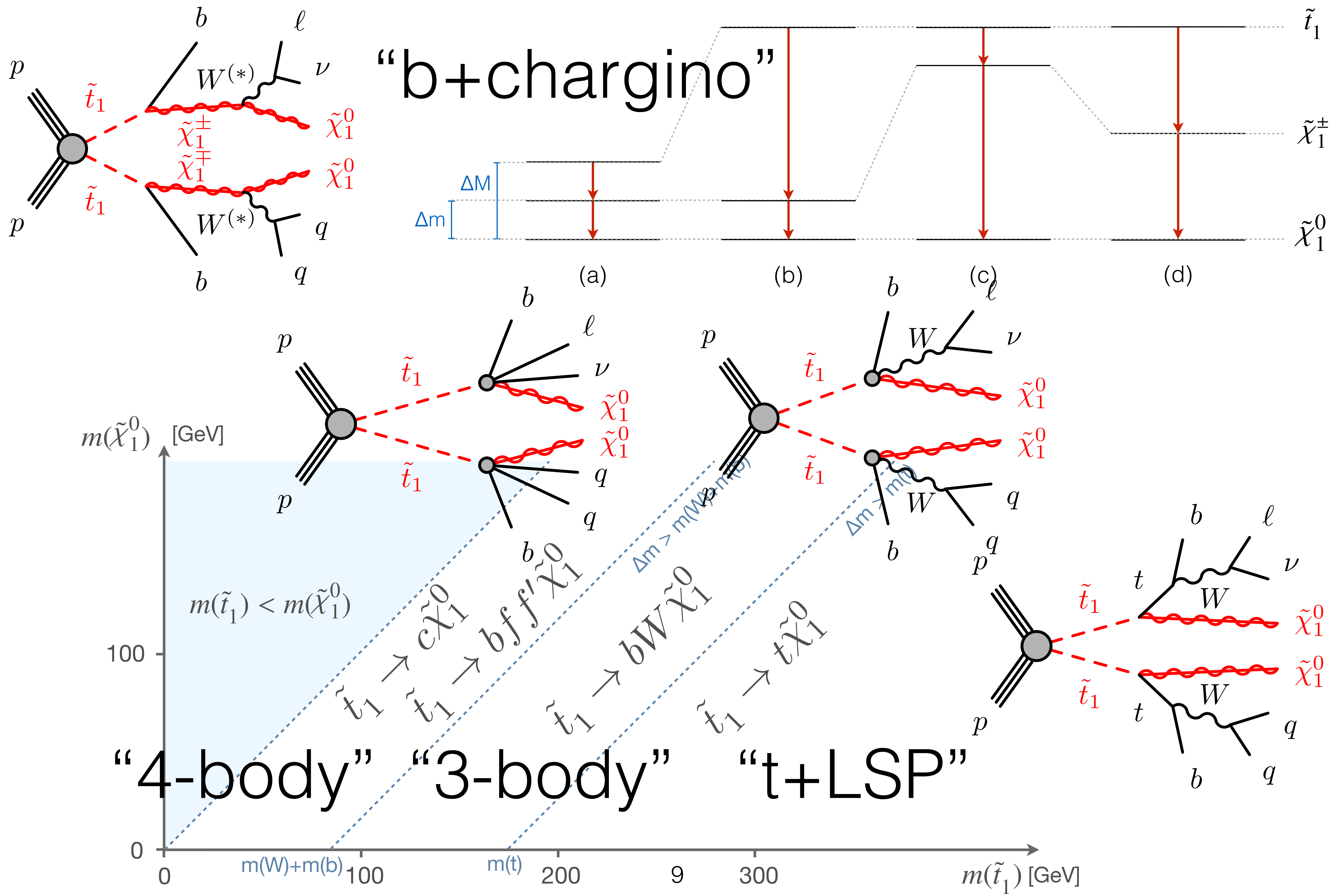
Trigger: (Single Isolated *e* or μ) or E_T^{miss}

> 24 GeV @ HLT   > 80 GeV @ HLT

- E_T^{miss} > 100 GeV
- Exactly one isolated *e* or μ with p_T > 25 GeV
- No other *e* or μ with p_T > 10 GeV
- At least one b-jet @ 70% efficiency
- At least four jets (anti-k_t R=0.4)



SRs target particular regions of phase space

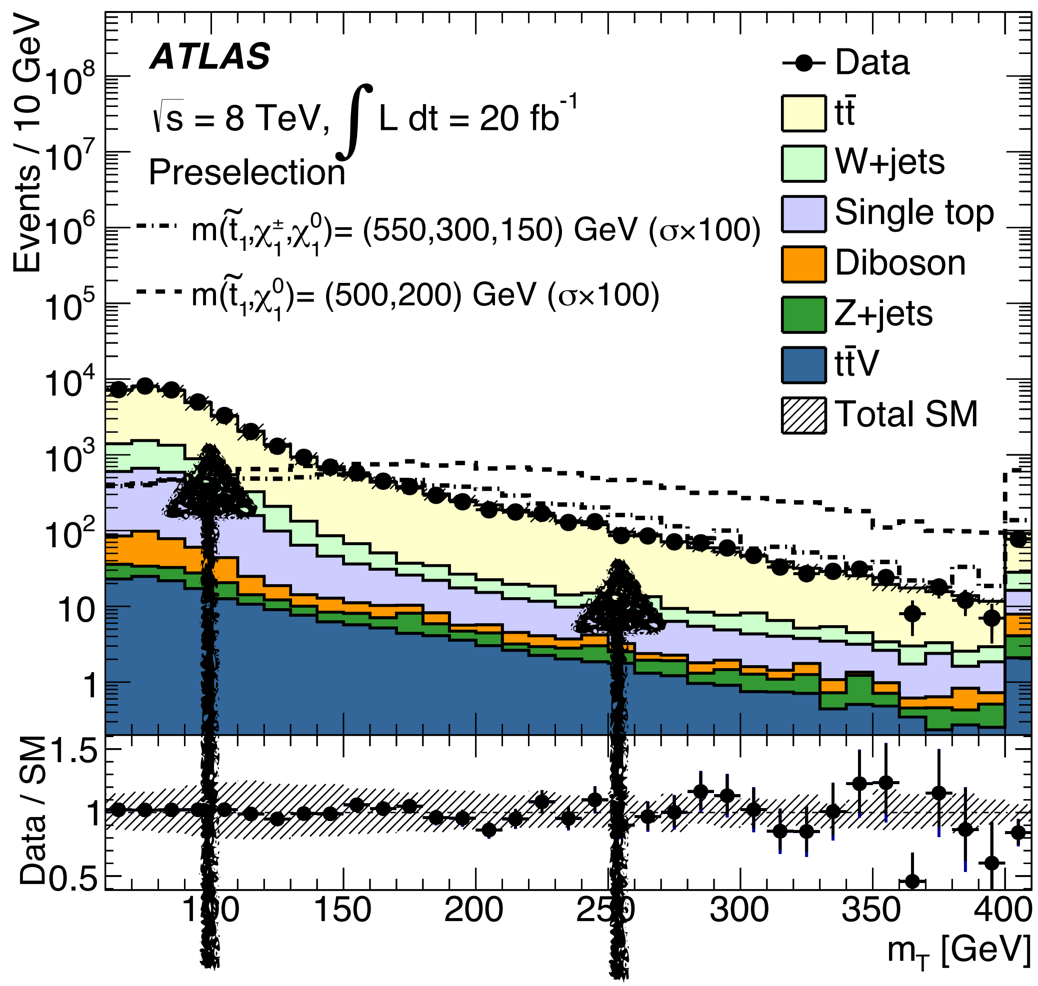


Two main discriminating variables

Transverse Mass

$$m_{\mathrm{T}} = \sqrt{2 \cdot p_{\mathrm{T}}^{\ell} \cdot E_{\mathrm{T}}^{\mathrm{miss}} \left(1 - \cos \Delta\phi(\vec{\ell}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\right)}.$$

For semileptonic $t\bar{t}$, $m_{\mathrm{T}} \leq m_W$

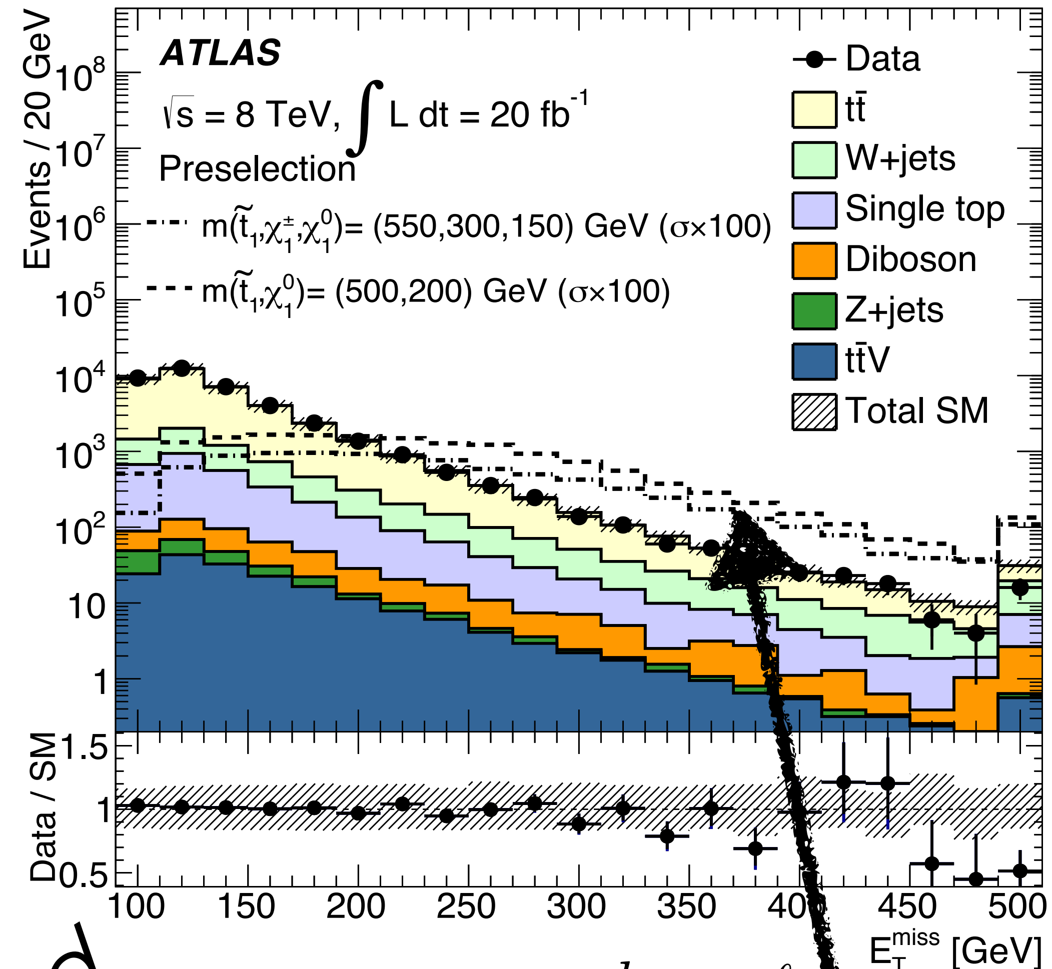


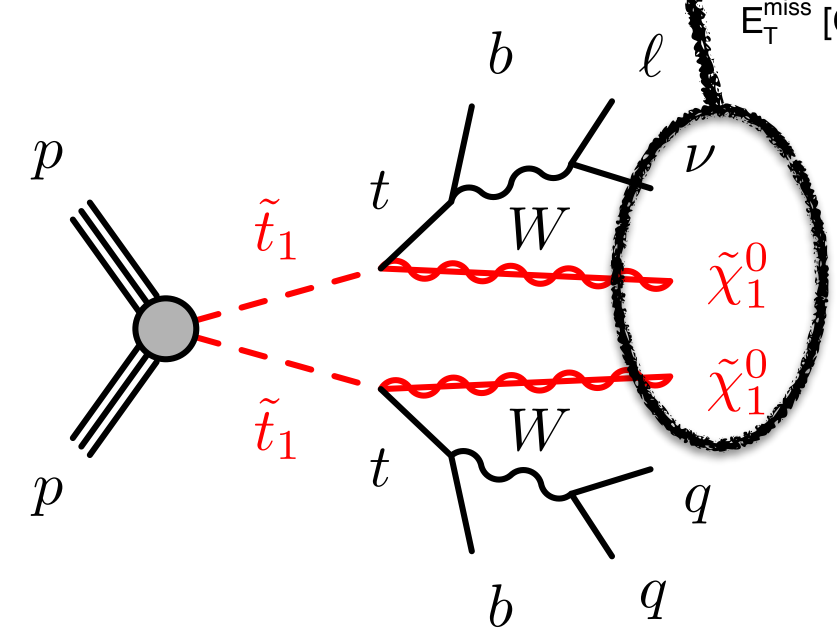
1L top 2L top

Even though our signal has 1L, after m_T, background mostly 2L

Nearly uncorrelated

E_T^{miss}





Main Backgrounds:

(dileptonic) $t\bar{t}$

W+jets

There is an m_{T2} for you!

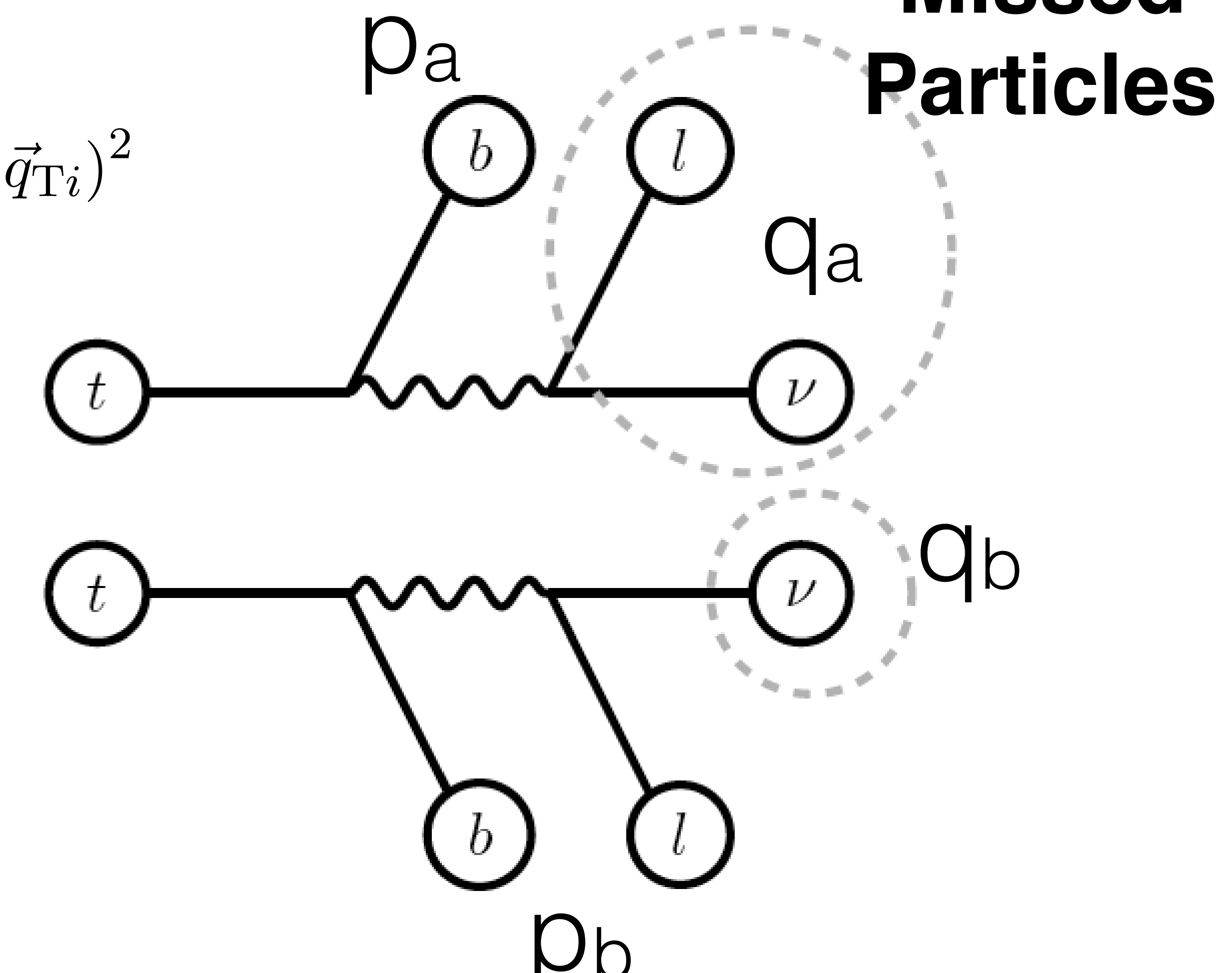
Transverse mass is a powerful variable because it takes advantage of the targeted topology

There is a class of variables which generalize the transverse mass to multiple invisible particles

$$m_{\mathrm{T2}} \equiv \min_{\vec{q}_{\mathrm{T}a}+\vec{q}_{\mathrm{T}b}=\vec{p}_{\mathrm{T}}^{\mathrm{miss}}} \{\max(m_{\mathrm{T}a}, m_{\mathrm{T}b})\},$$

$$m_{\mathrm{T}i}^2 = \left(\sqrt{p_{\mathrm{T}i}^2 + m_{p_i}^2} + \sqrt{q_{\mathrm{T}i}^2 + m_{q_i}^2}\right)^2 - (\vec{p}_{\mathrm{T}i} + \vec{q}_{\mathrm{T}i})^2$$

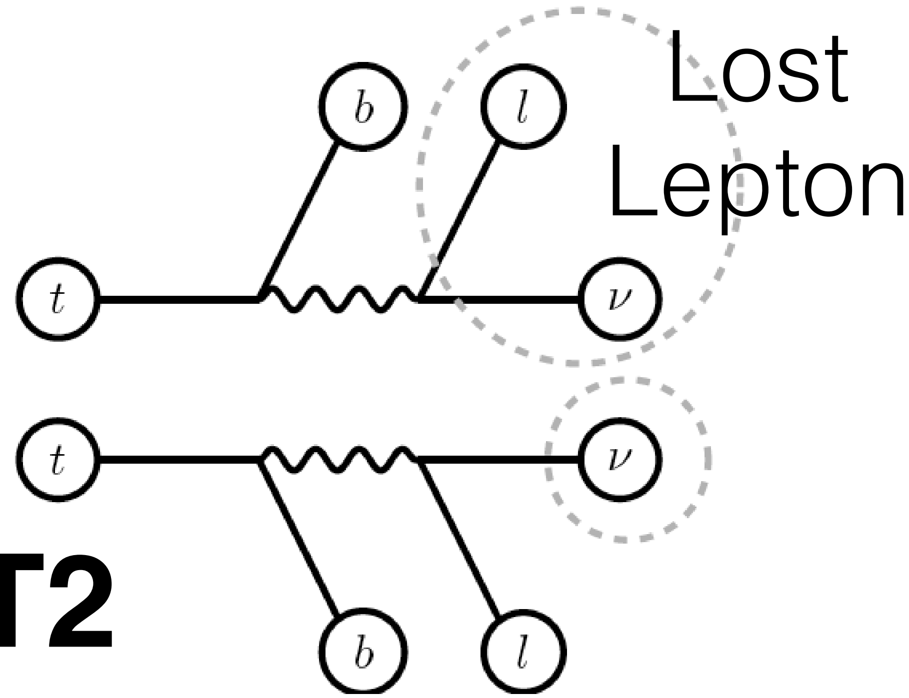
(usual transverse mass)



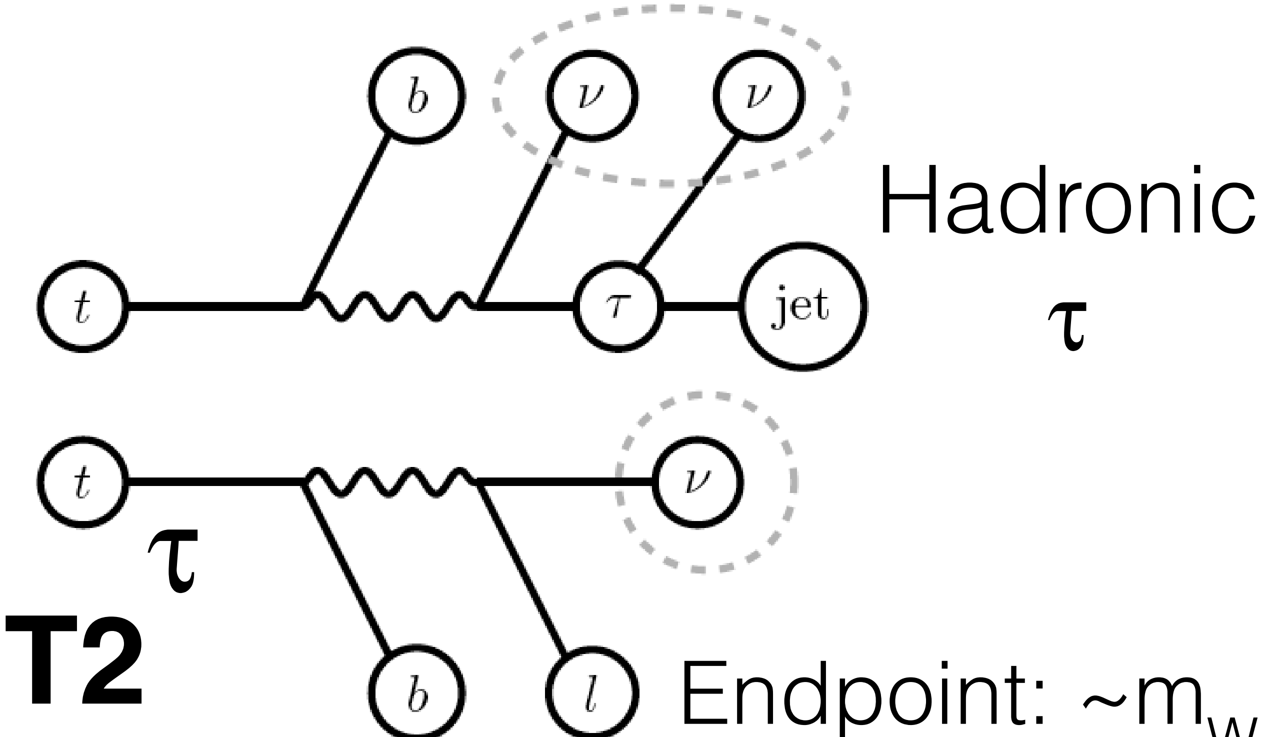
With the appropriate choices of m_{q_i}, these variables have endpoints for the background

m_{T2} for the stop 1L search

*After E_T^{miss} and m_T requirements, dominant background has **two** leptons*

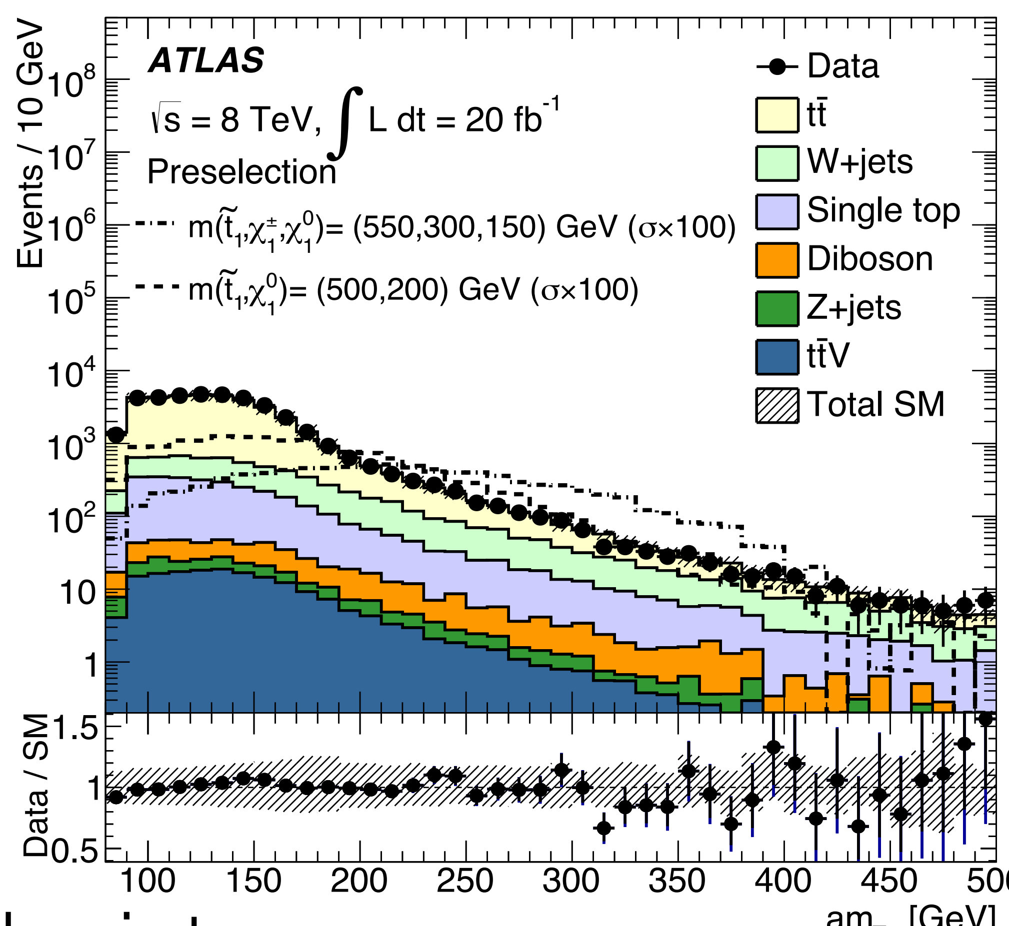


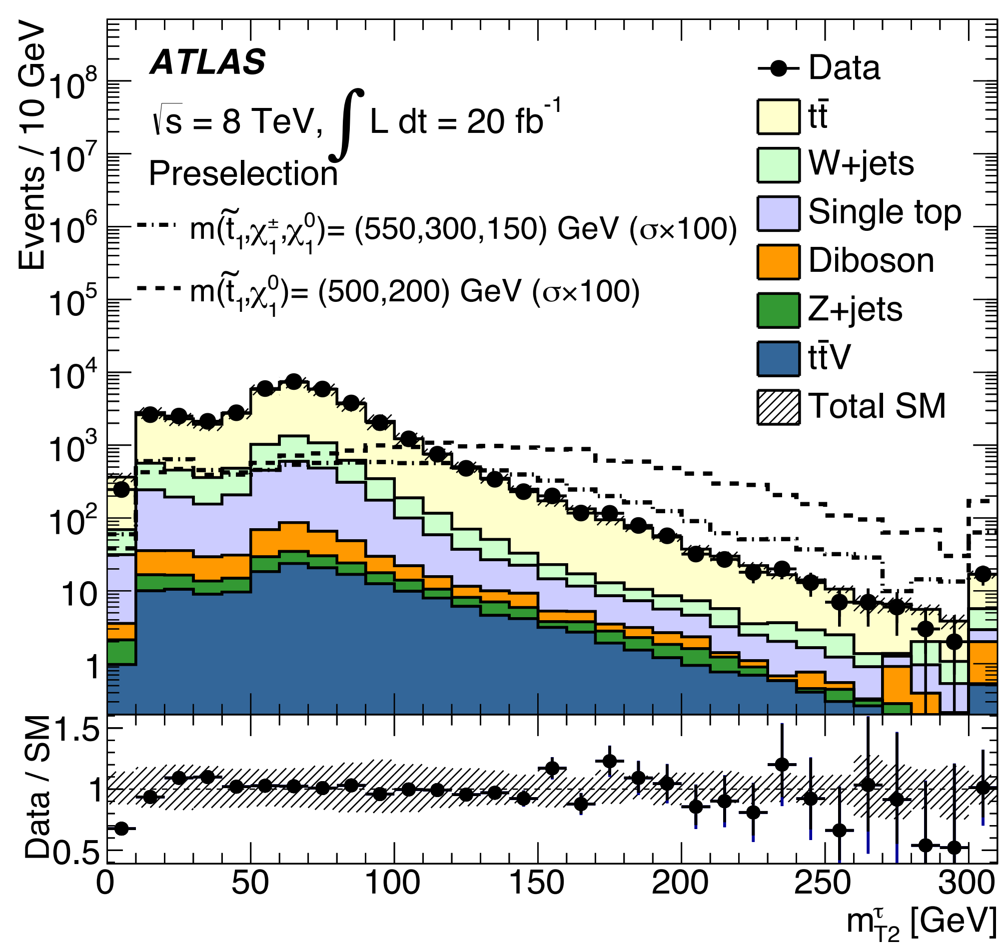
am_{T2}



m_{T2}^{τ}

Endpoint: ~m_W





Endpoint: ~m_{top}

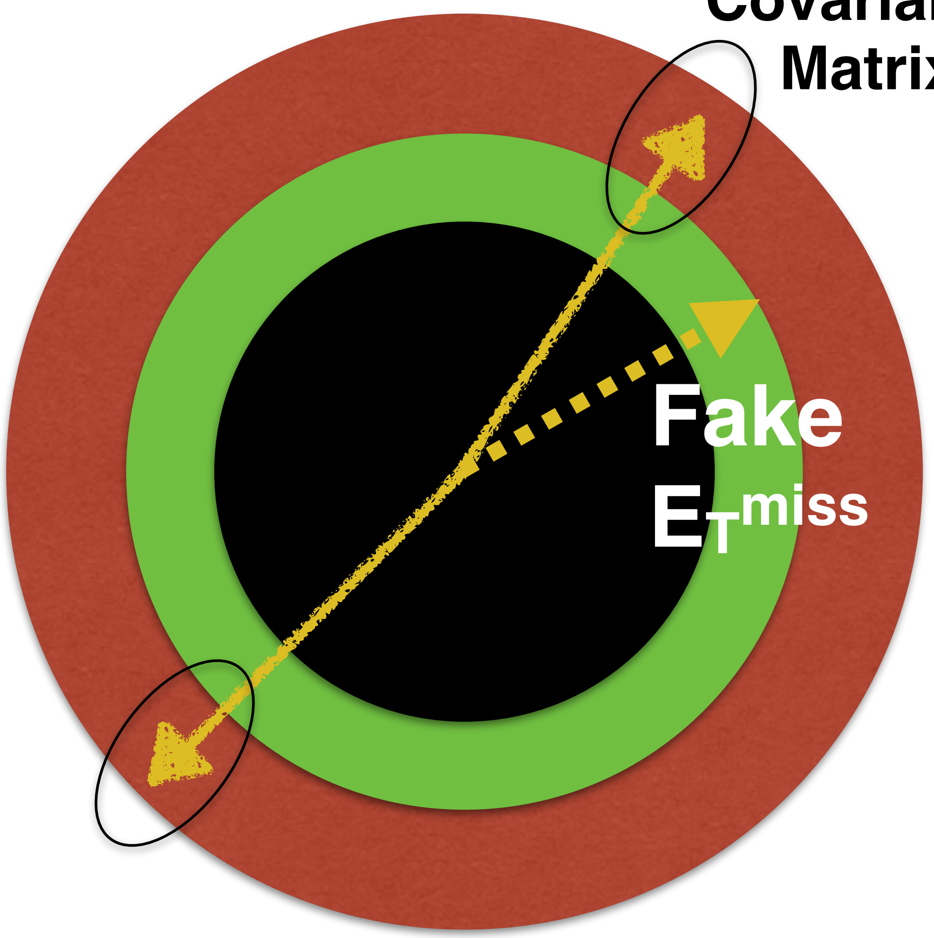
Including Resolution Information: *Significance Variables*

Mis-measurement can induce large E_T^{miss}

This motivated the *E_T^{miss} significance*:

$$E_T^{miss}/Uncertainty(E_T^{miss})$$

It is common to approximate the uncertainty as ~ 0.5 x $\sqrt{H_T}$



We can improve this by using known η and p_T dependent resolution functions for jets

$$H_{\mathrm{T,sig}}^{\mathrm{miss}} = \frac{|\vec{H}_{\mathrm{T}}^{\mathrm{miss}}| - M}{\sigma_{|\vec{H}_{\mathrm{T}}^{\mathrm{miss}}|}},$$

where H_T^{miss} is the vector sum of all measured identified objects

-Shameless self promotion-

Generalizes to any kinematic variable

See 1303.7009 (*BN and C. G. Lester*)

Many other discriminating variables have been developed to suppress the two lepton background

Hadronic Top Mass

-dileptonic $t\bar{t}$ has no hadronic top -

$$m_{\text{had-top}} = \text{argmin}_{m_{bjj}} \left\{ \frac{(m_{bjj} - m_{\text{top}})^2}{\sigma^2_{m_{bjj}}} + \frac{(m_{jj} - m_{\text{W}})^2}{\sigma^2_{m_{jj}}} \right\}$$

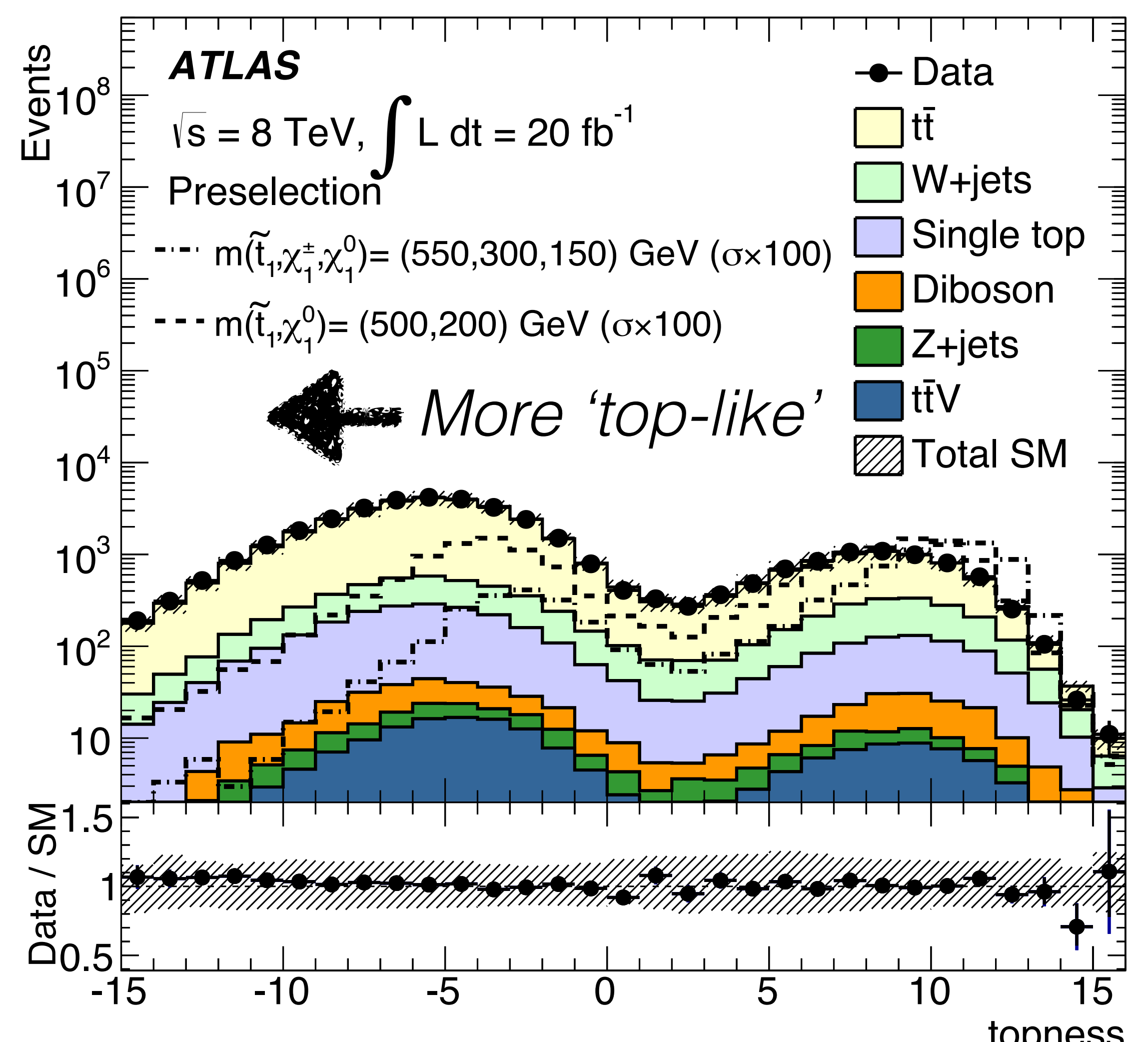
Topness **1212.4495:** *M. Graesser and J. Shelton*

One lost lepton; reconstruct the event by minimizing a χ^2 kinematic compatibility with the dileptonic hypothesis

Hadronic Taus: reconstruct and veto

τ candidates: 1-3 tracks & Q_τ x $Q_{\text{lepton}} < 0$

A BDT based on track and calo orientations for rejecting QCD jets



topness = $\ln(\min(\chi^2))$

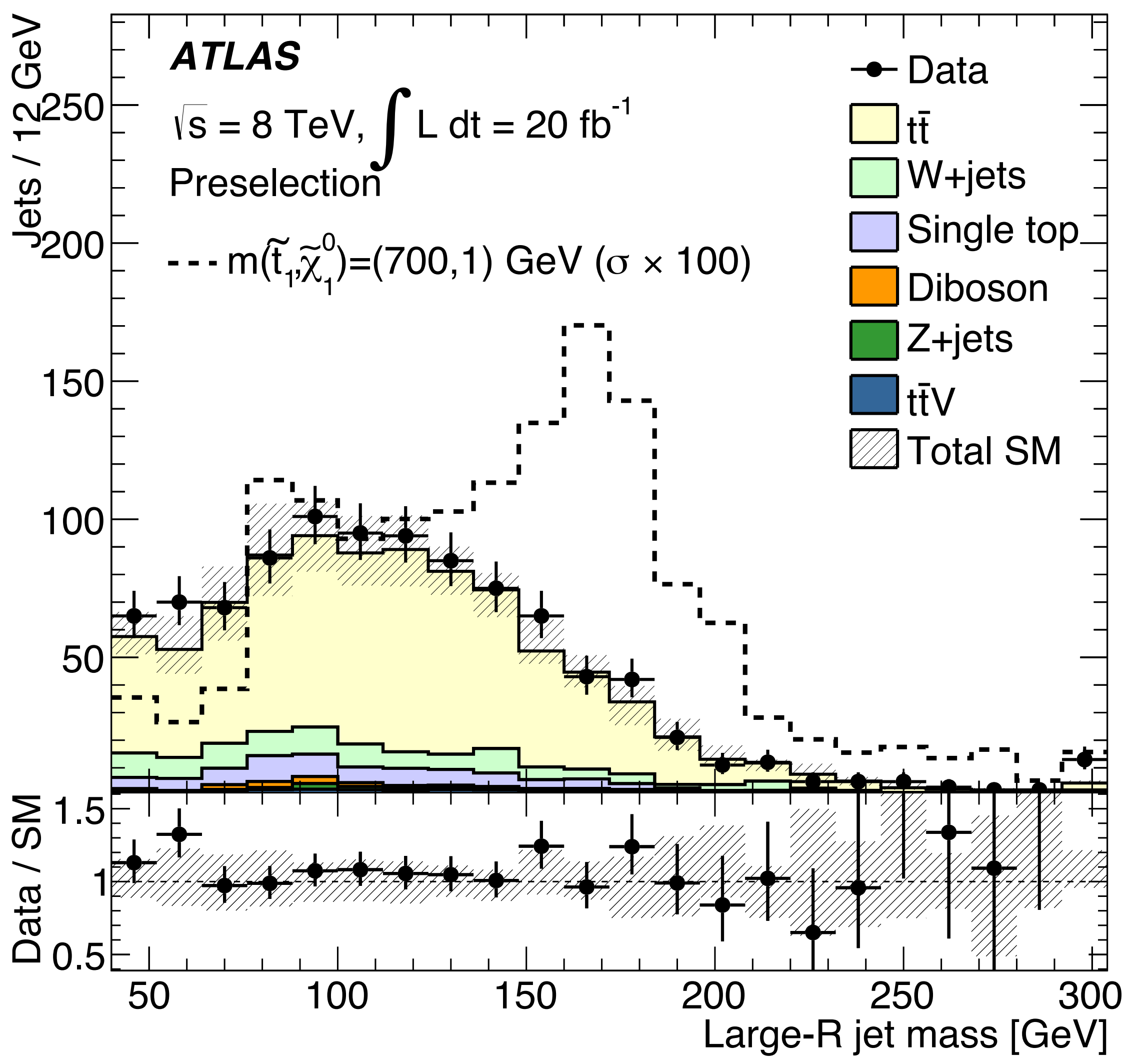
Isolated Tracks Q_{track} x $Q_{\text{lepton}} < 0$

Reject events with a well-isolated Hard Scatter (HS) track with $p_T > 10$ GeV

Isolation: no HS tracks with $p_T > 3$ GeV in $\Delta R < 0.4$

High stop mass = Boosted Tops

Hadronic Top Mass breaks down

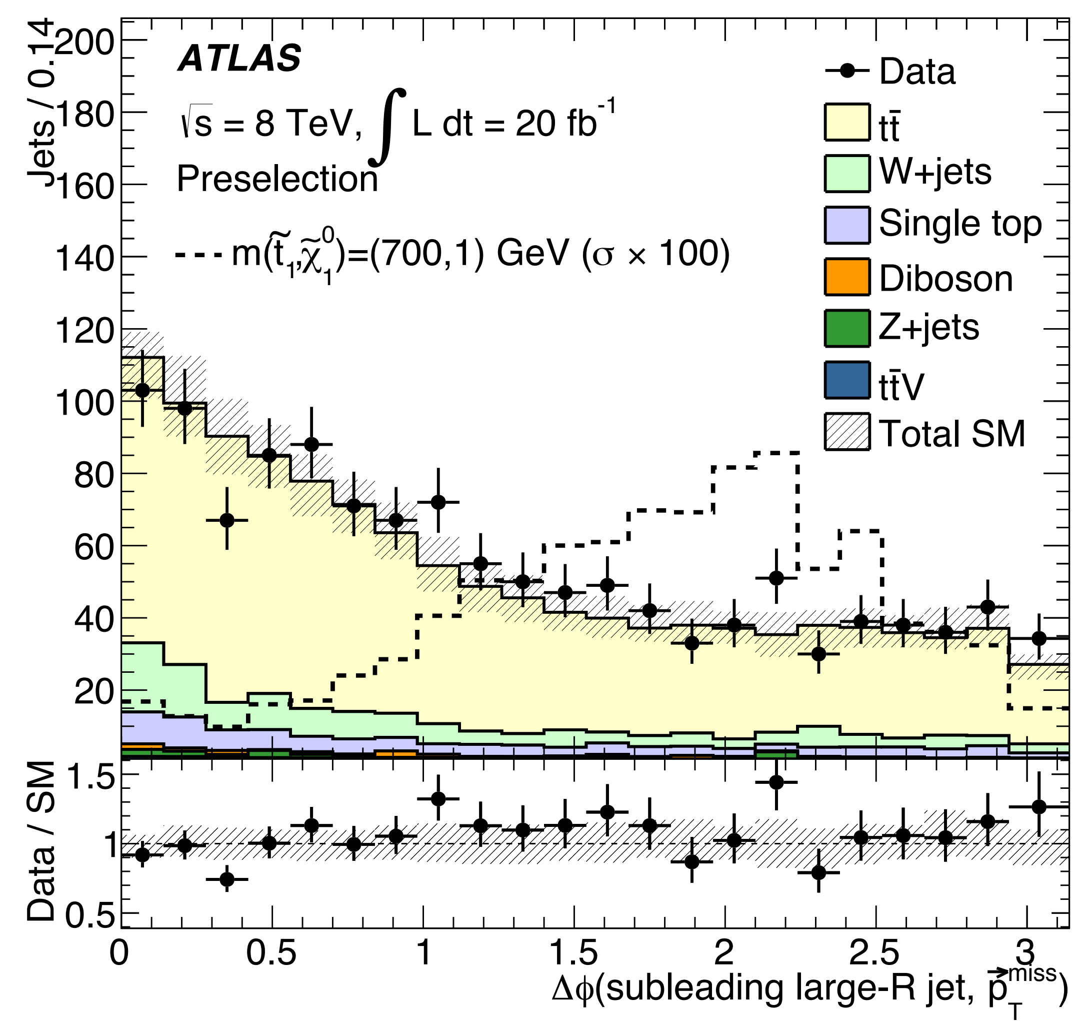


Use R = 1.0 anti-k_t trimmed **jet mass** (f_{cut} = 0.05 R_{sub} = 0.3) for a powerful hadronic top mass discriminant

When the p_T of the tops is high enough, jets begin to merge

$\Delta R \sim 2m/p_T$

For $p_T^{top} \sim m_{stop}/2$, $\Delta R \sim 1$ for $m_{stop} \sim 700$ GeV



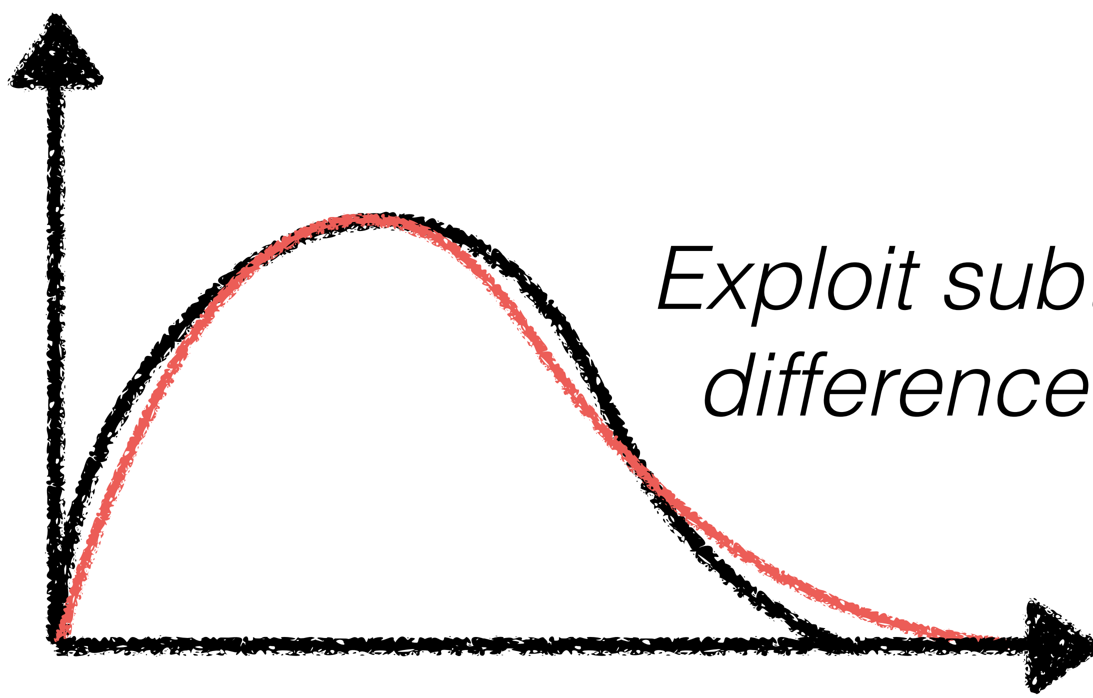
The direction of the large radius jets is also powerful

For SM, second top is leptonic, which is close to the p_T^{miss}

Compressed Spectra: Low E_T^{miss}

Signal Resembles the Background

Recover sensitivity by fitting the ***shapes*** of kinematic variables



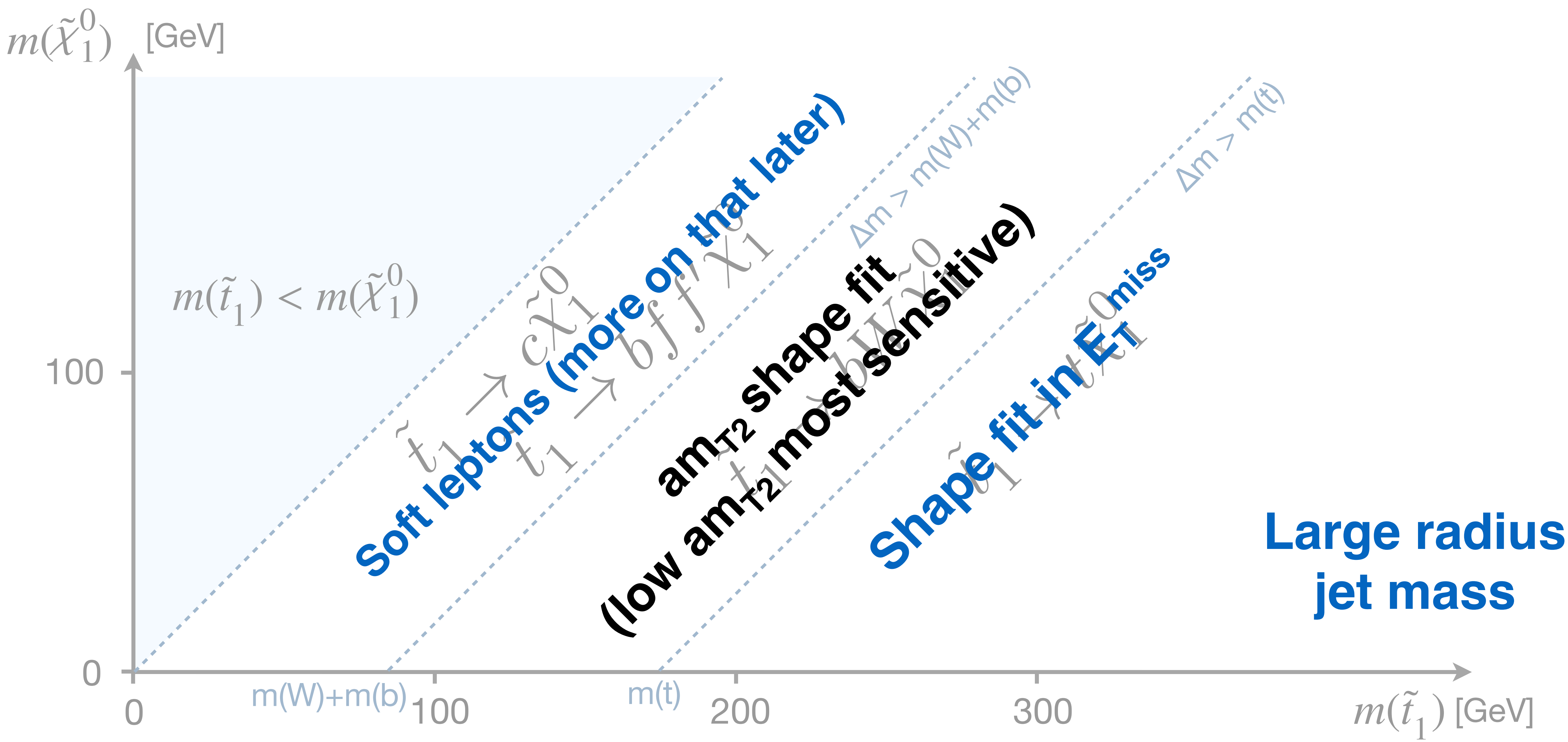
Exploit subtle differences

Bin the relevant distribution(s) with bins chosen to have a distribution of S/B

We have used 2D shape fits using $\mathbf{m_T}$ and one of $\mathbf{E_T^{miss}}$ or $\mathbf{am_{T2}}$

t+Neutralino SRs

A highlight; for more details see the paper

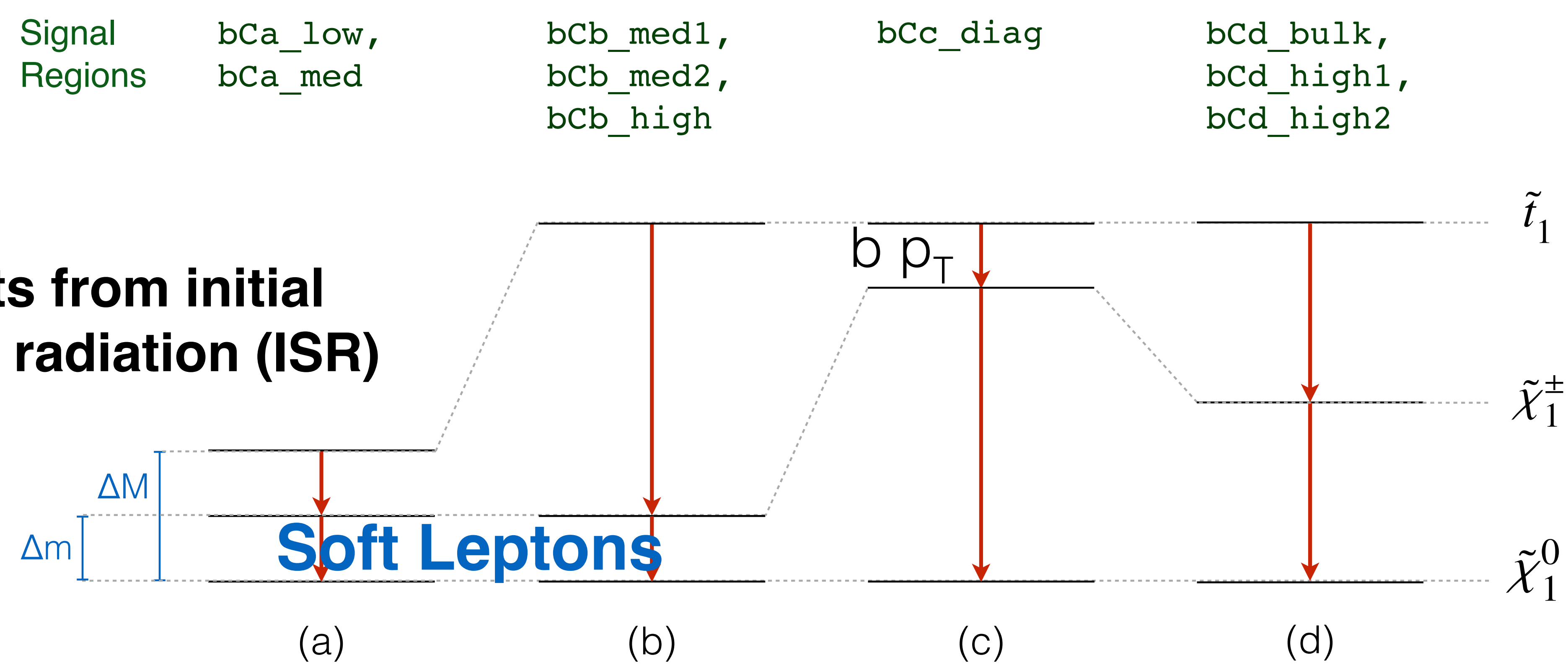


Tighter Kinematic Selection ➡

b+Chargino SRs

A highlight; for more details see the paper

veto b-jets



Multiple High p_T b-jets

Tight Kinematic Selection

Large m_{bb}

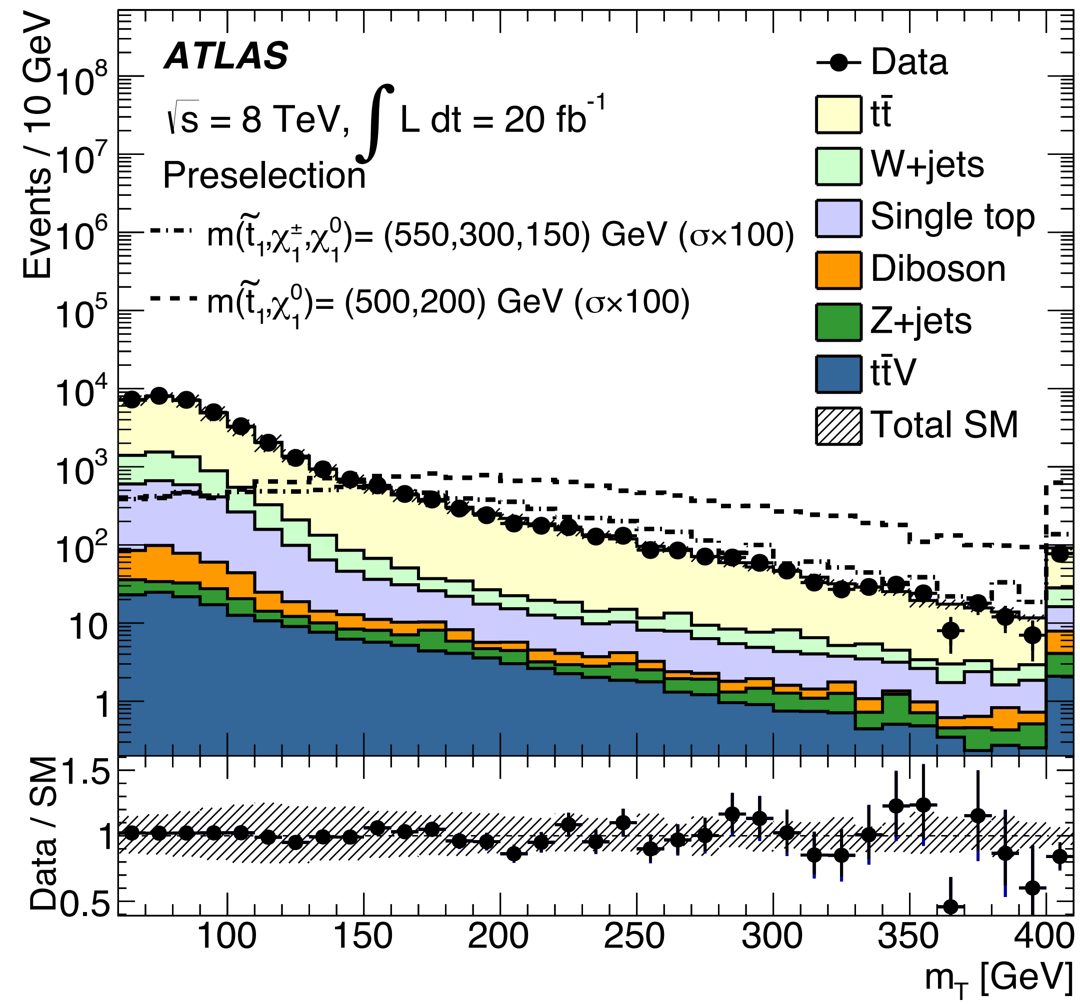
For low chargino-neutralino mass splitting, use ***soft leptons***: $p_T > 6(7)$ GeV for e(μ)

Additionally, a shape fit in am_{T2} has an inclusive sensitivity

Background Estimation

Background Estimation

Every SR has two dedicated Control Regions (CRs) *for data-driven estimates of the dominant backgrounds*



Top CR: invert

$m_T < m_W$

W+jets CR: invert

$m_T < m_W$

b-veto instead of b-tag

QCD multijets estimated in the data by loosening lepton isolation

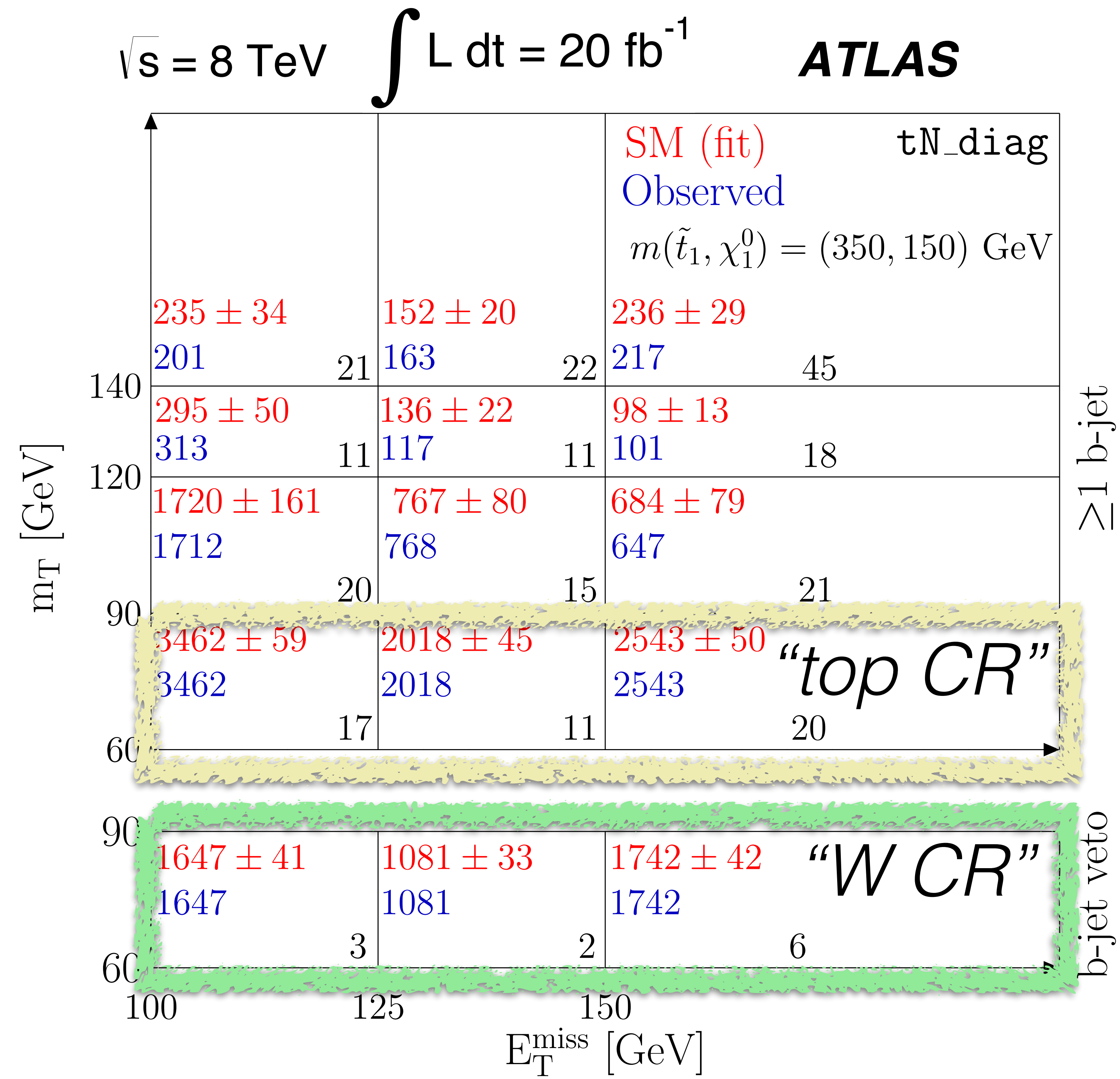
Shape Fits: Background Integrated into Fit

Every shape fit has regions which 'act' like CRs

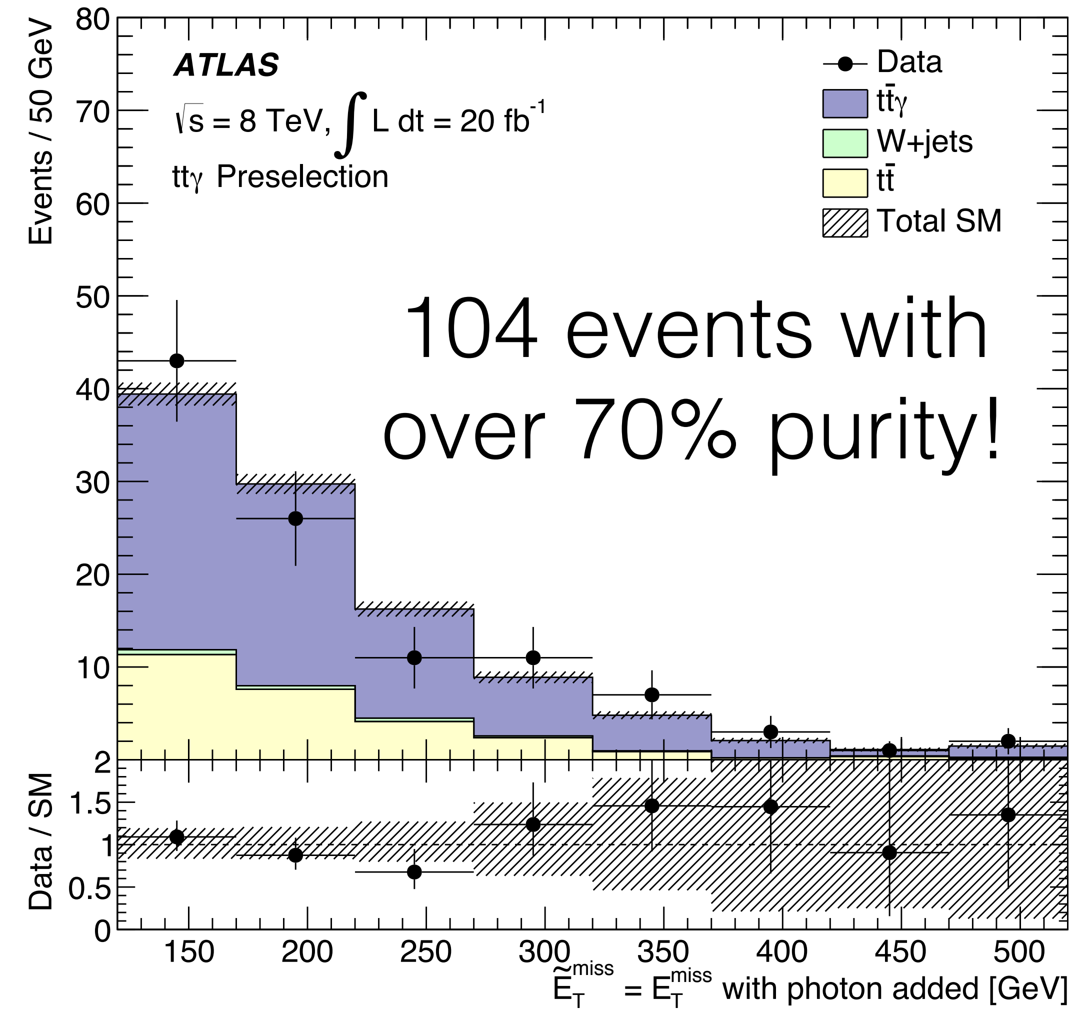
In the fit, they are treated like all other bins

Can normalize per E_T^{miss} bin to maximize sensitivity

(Trade off syst for stat uncertainty)

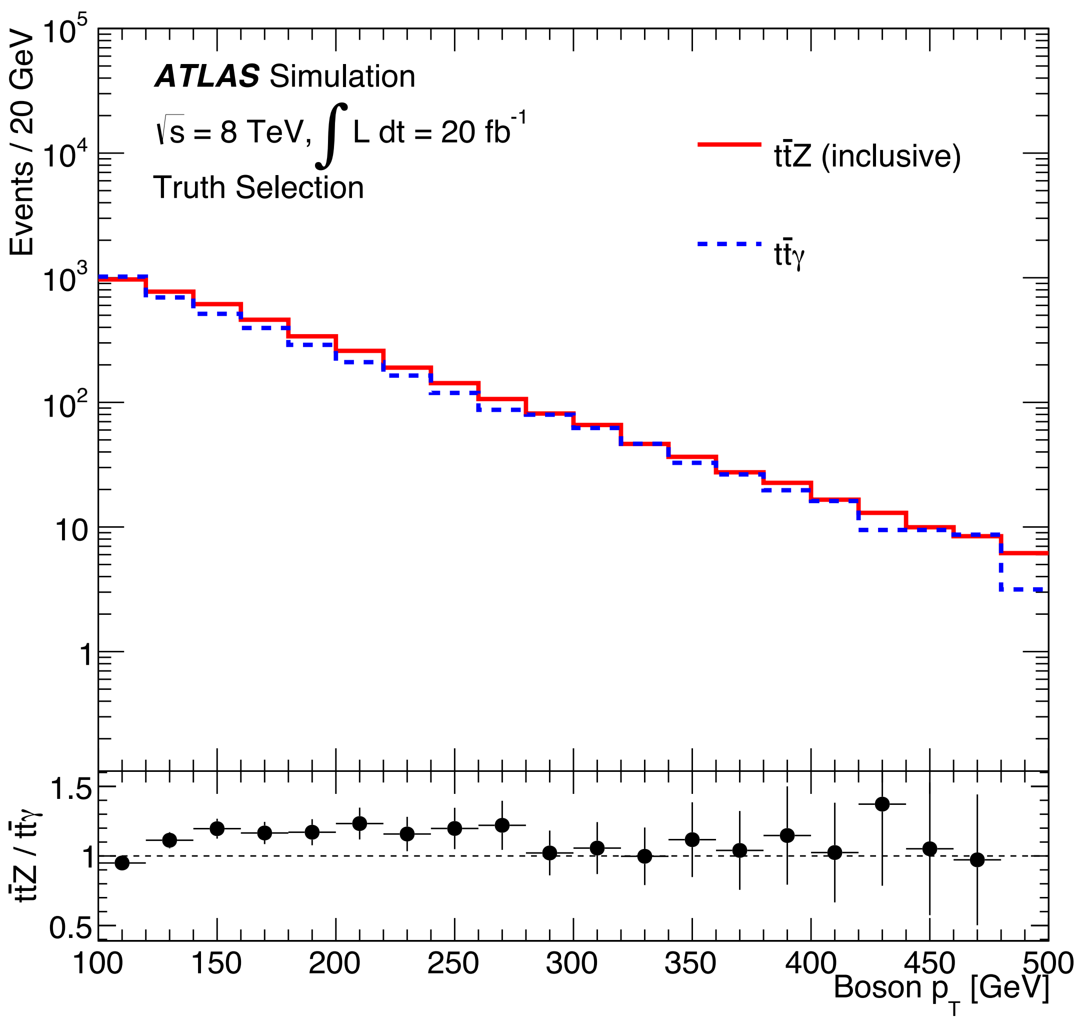


Data-Driven Validation: $t\bar{t}Z(\rightarrow \nu\bar{\nu})$ from $t\bar{t}\gamma$



Except for neutrinos and their mass, the Feynman diagrams are identical

At high p_T, boson mass irrelevant so the yield of one can predict the other

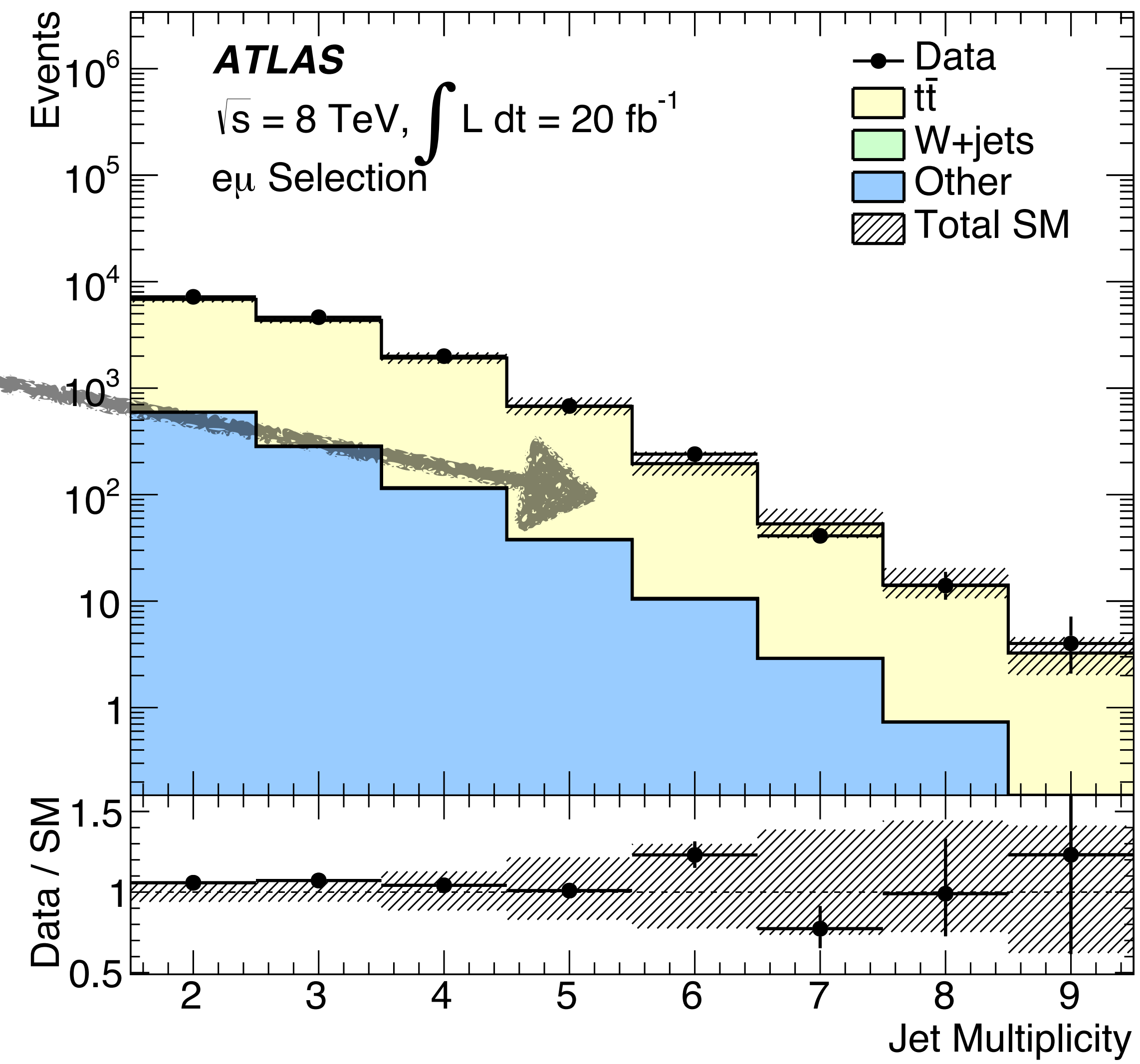


Define new m_T and E_T^{miss} variables with the photon treated as invisible

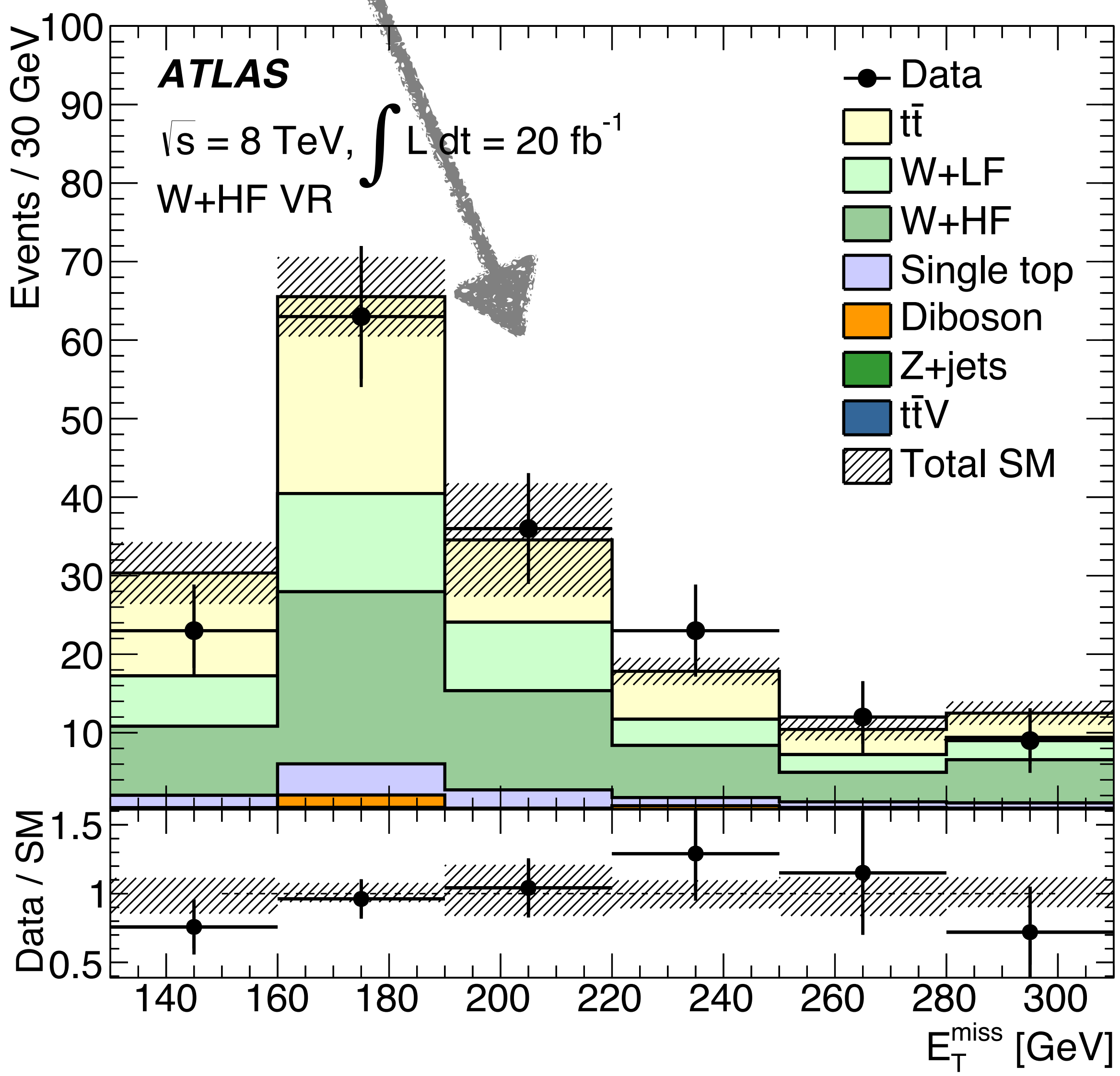
Many theoretical and experimental uncertainties should cancel in the extrapolation to the SR

Additional Validation

Beyond LO radiation in dilepton top events



W+Heavy Flavour
Jet veto + m_{bb} < 80 GeV



Additional checks with taus and isolated tracks show generally good modeling of the data

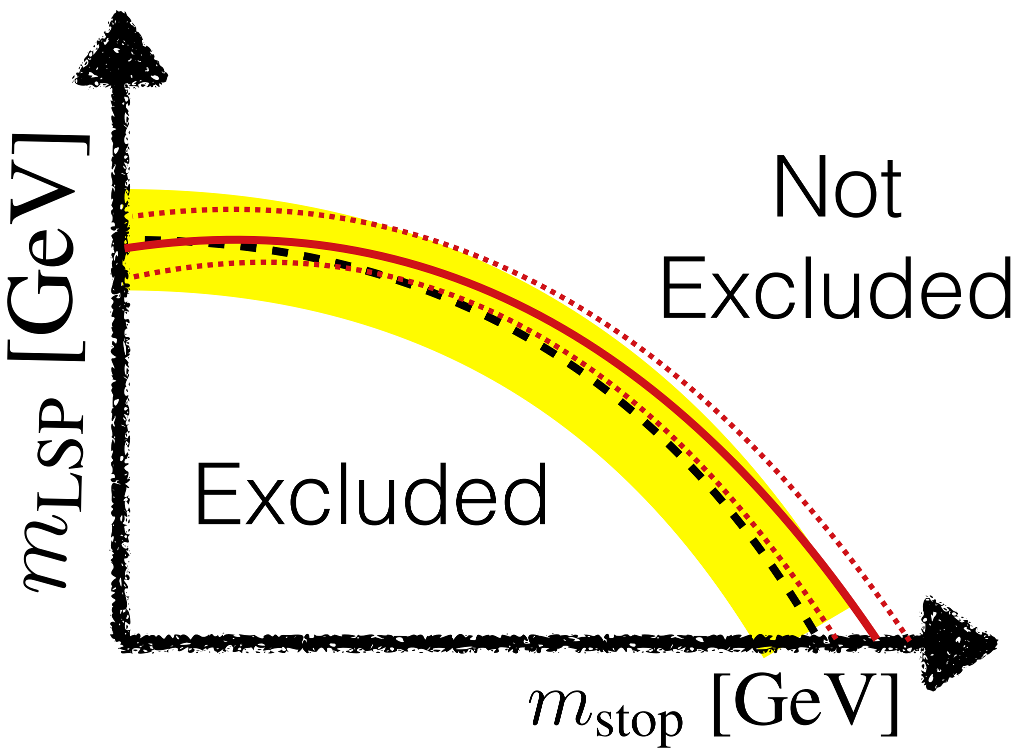
Results

<u>95% Confidence Level</u>

Reminder for reading exclusion plots

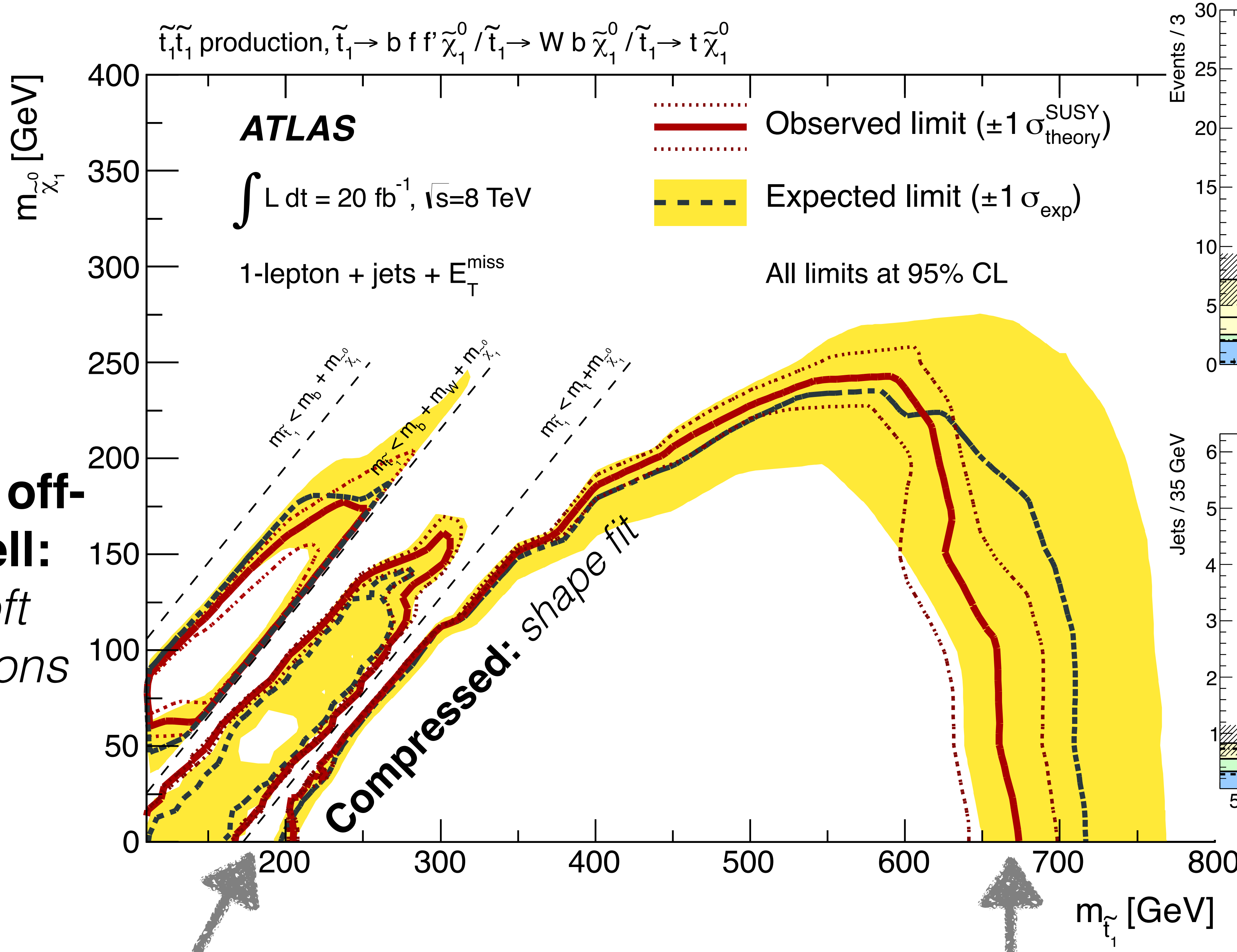
Line: Observed Limit
Band: Signal Theory Uncertainties

Line: Expected Limit
Band: All other Uncertainties

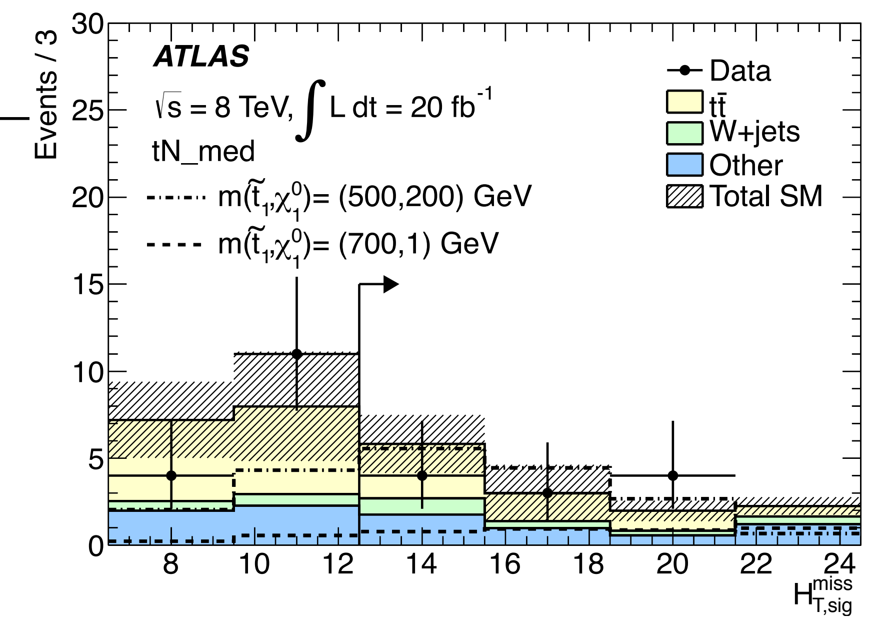


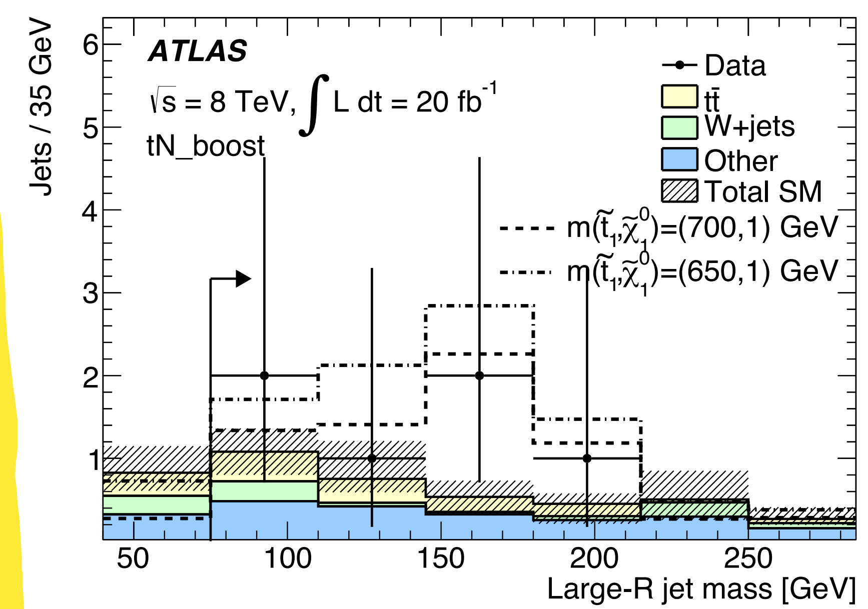
Sets the cross section

t+Neutralino Results



Very off-shell:
soft leptons



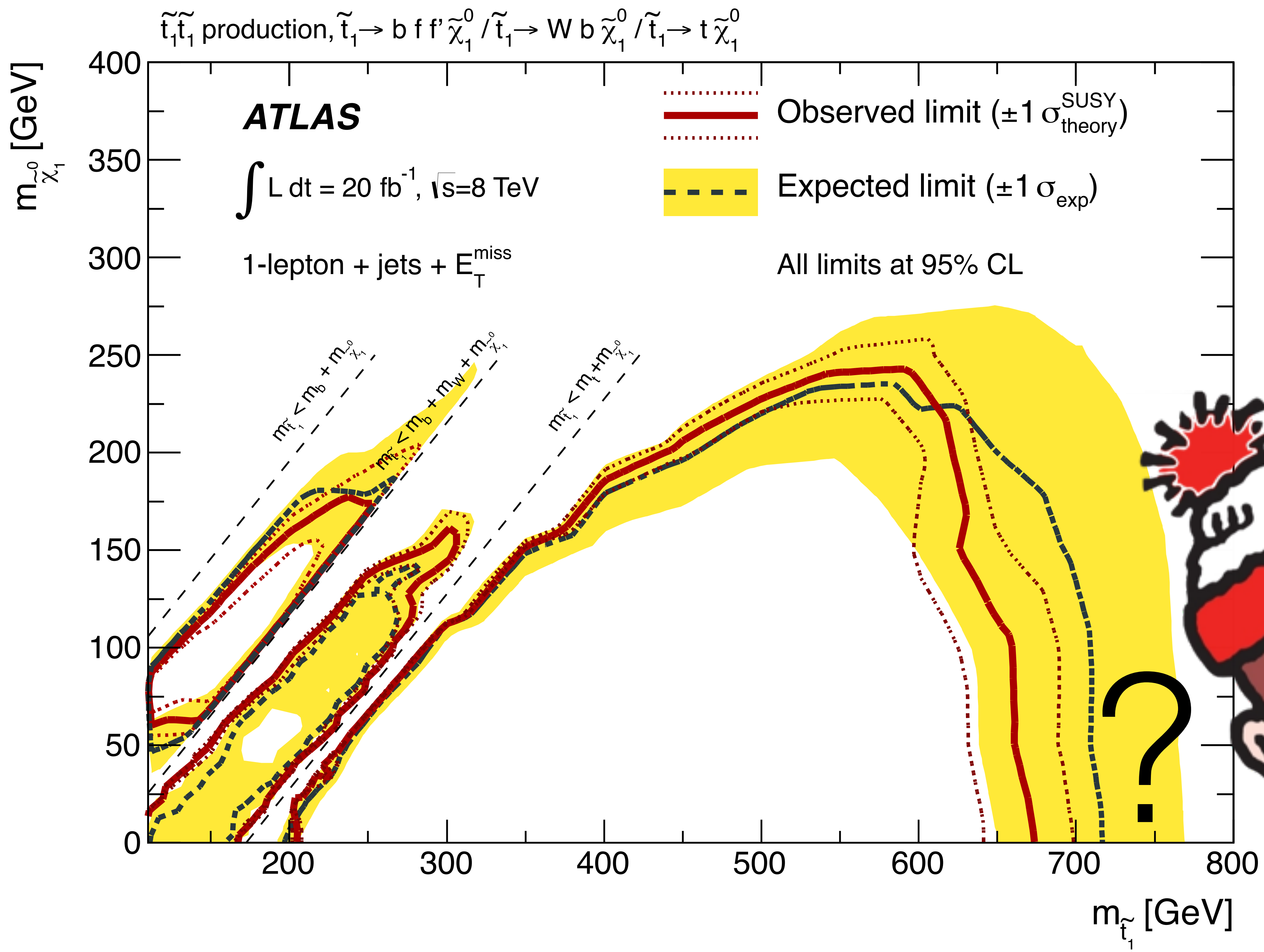


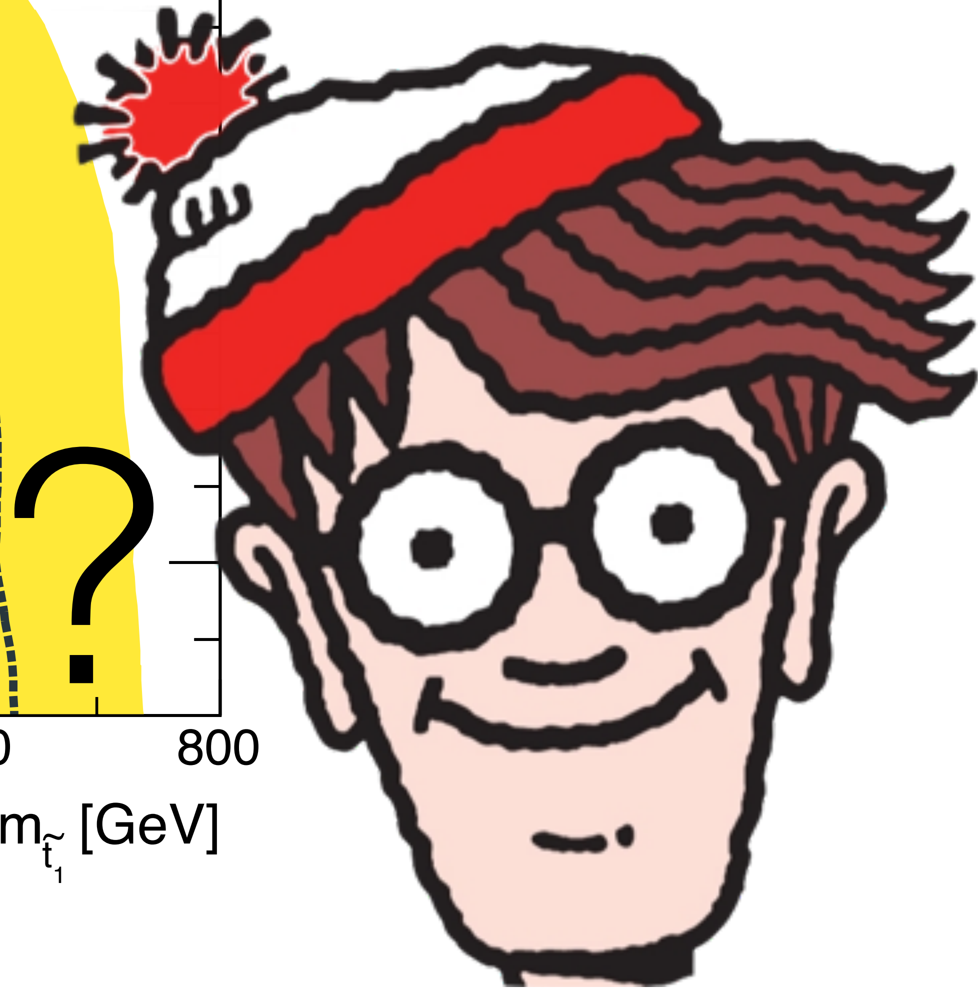
Boosted top:
large R jets

'Stealth Stop'
Difficult to reach with direct searches

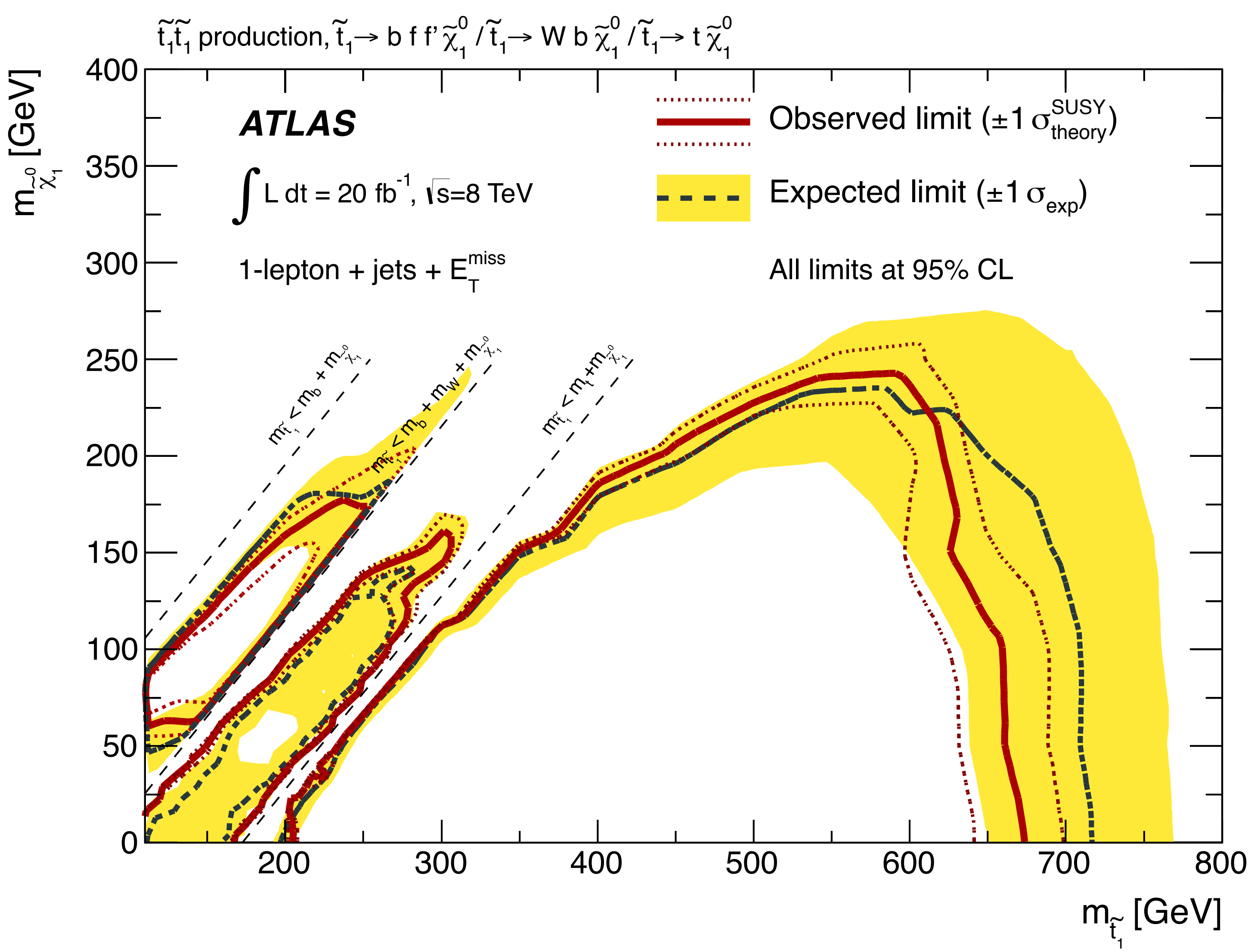
Reach limited by cross section:
10^{-5} x top cross section

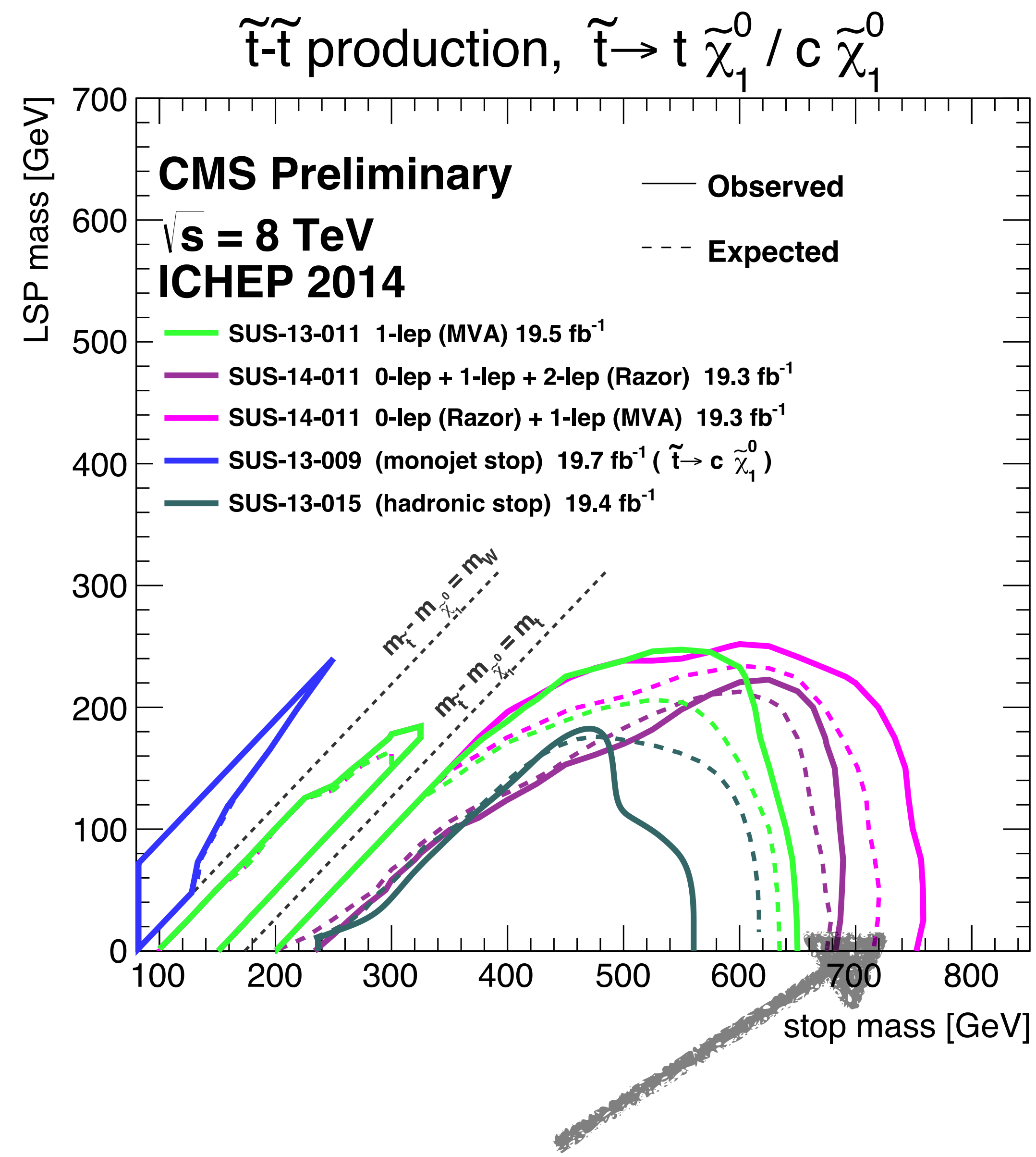
t+Neutralino Results





t+Neutralino Results

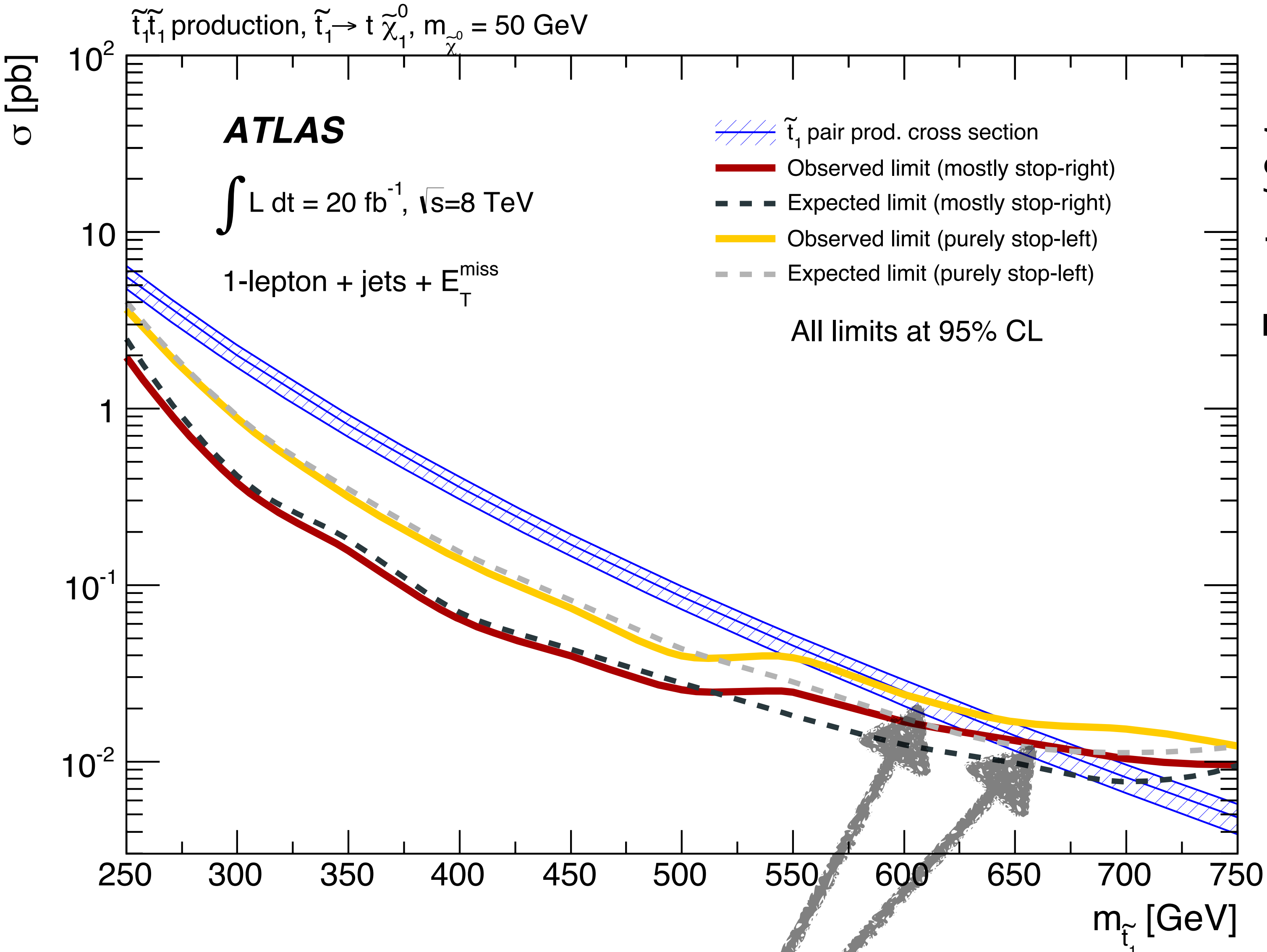




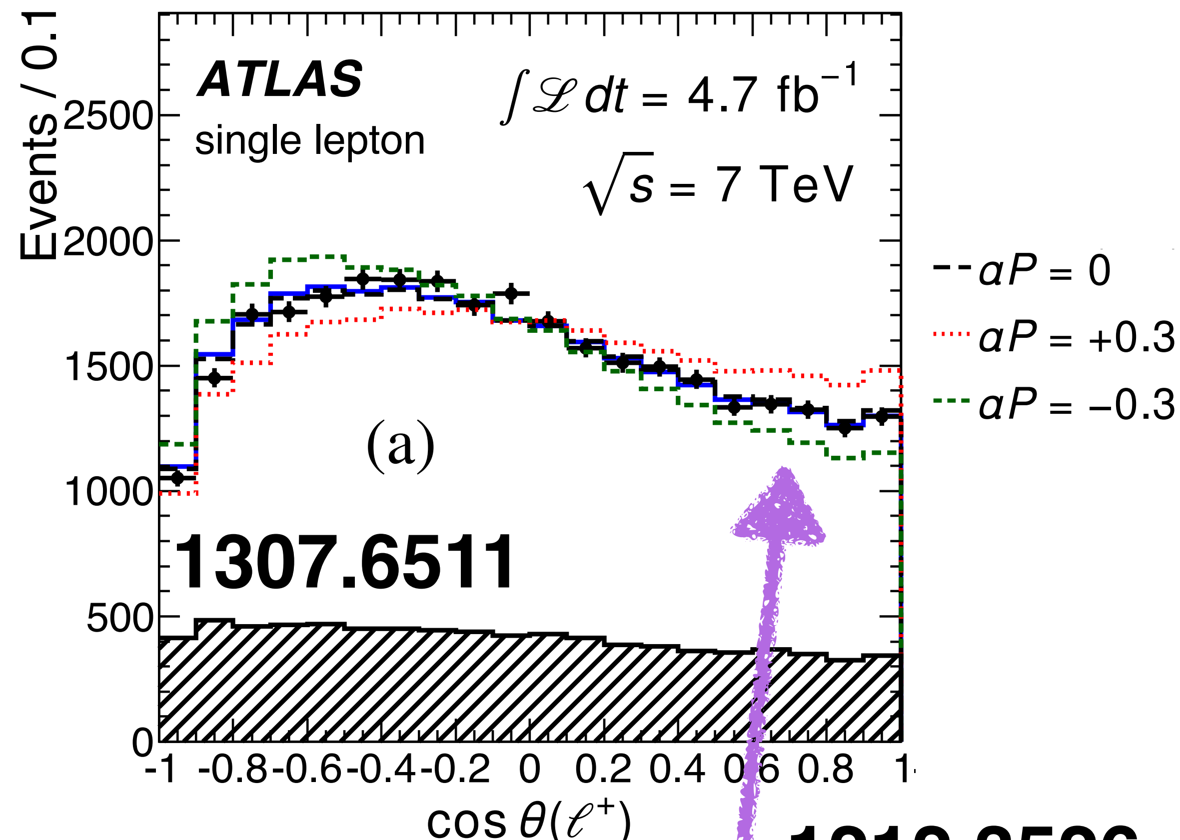
*Probably not; **CMS** sees a deficit where we see an excess*

Stop Mixing

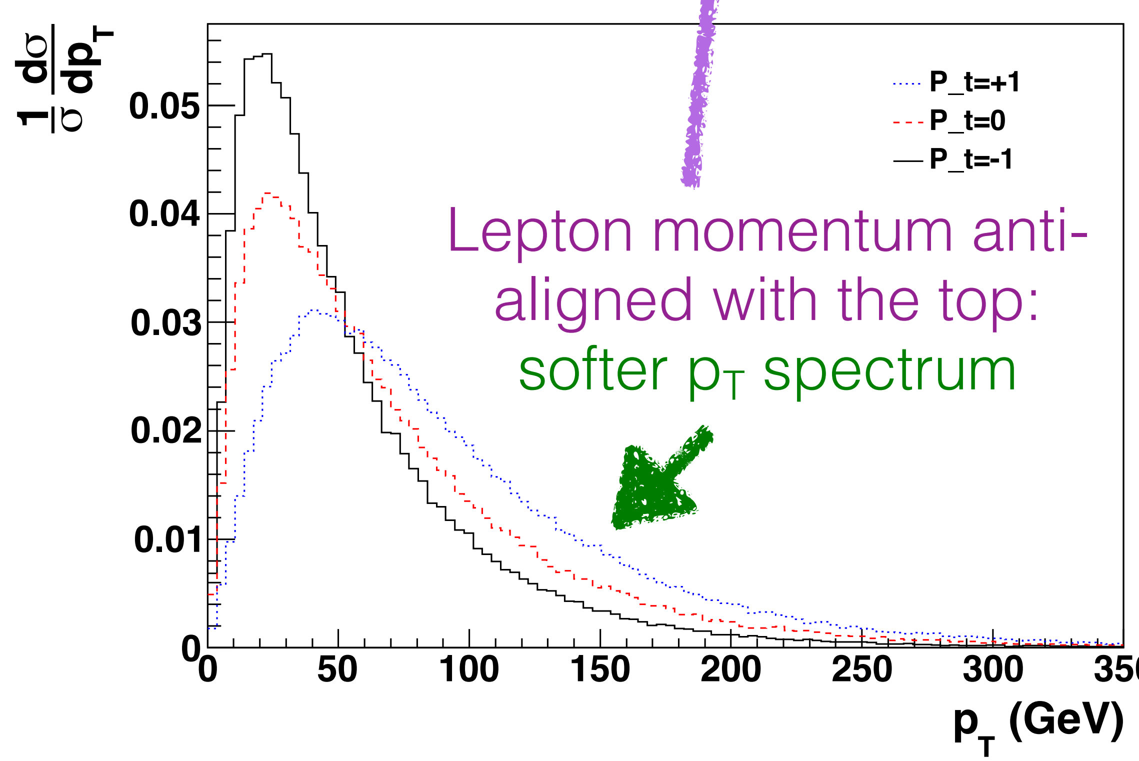
Nominal mixing: ~70% stop right $P_t \sim +1$



For a left handed stop, $P_t < 0$



1212.3526



Lepton momentum anti-aligned with the top: softer p_T spectrum

~ 50 GeV weaker limits for the left-handed stop

(true for a range of neutralino mass hypotheses)

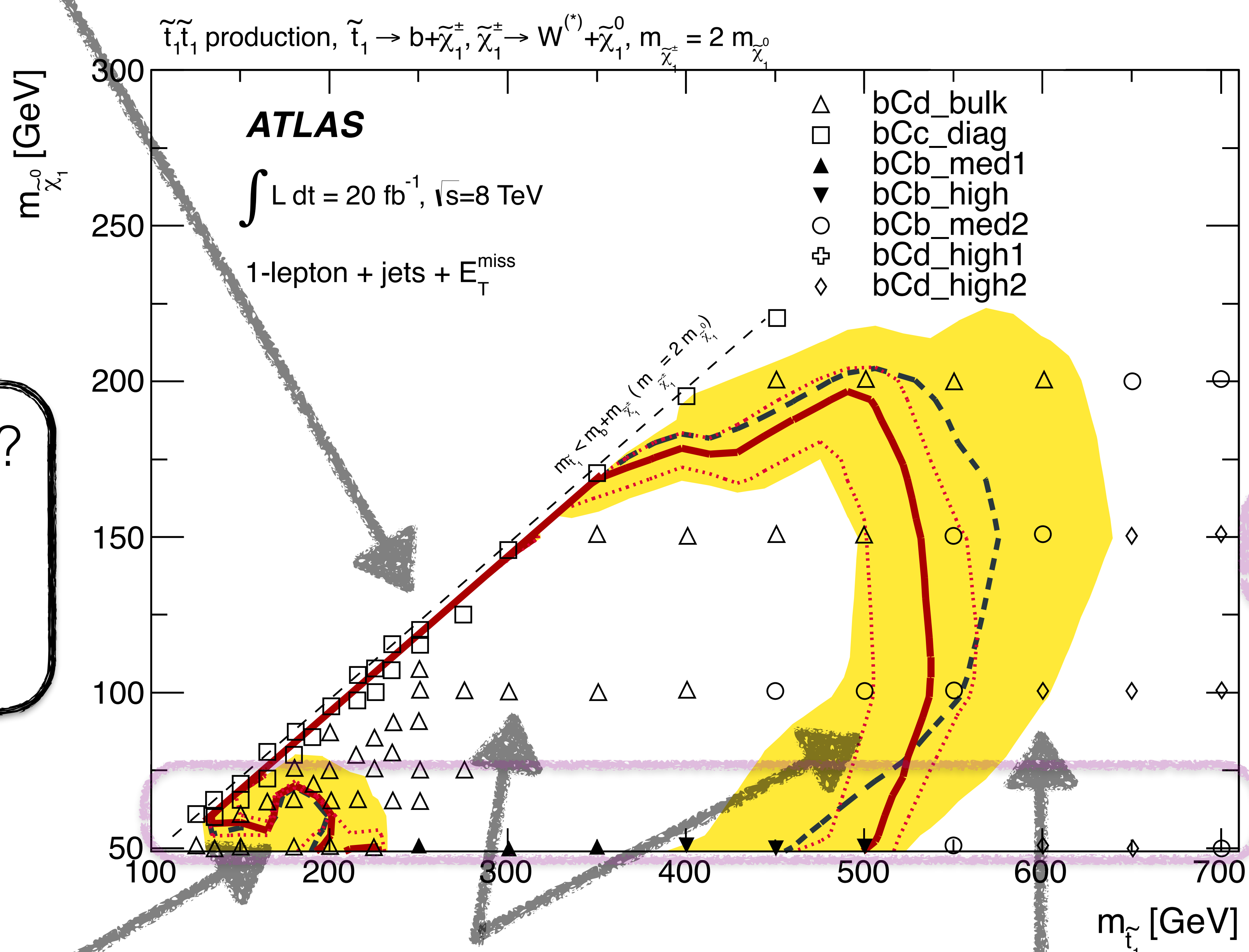
b+Chargino Results

To show 2D exclusions, need a hypothesis on $m_{chargino} = f(m_{neutralino}, m_{stop})$

One common form is f(x,y)=2x
(*Gaugino Universality*)

Soft b-jet p_T spectrum
3 jets (ISR) and veto b-jets

Why m_{LSP} > 50 GeV?
LEP limit for charginos is ~ 100 GeV



W off-shell

$m_{stop} \sim m_{top}$
W off-shell, chargino acts as 'W'
Looks like SM top!

Exploit Kinematic **Shapes**
Fit in m_T and am_{T2}

Hard b-jet p_T spectrum
Require 2 b-jets with high p_T
Tight am_{T2} threshold

b+Chargino Results

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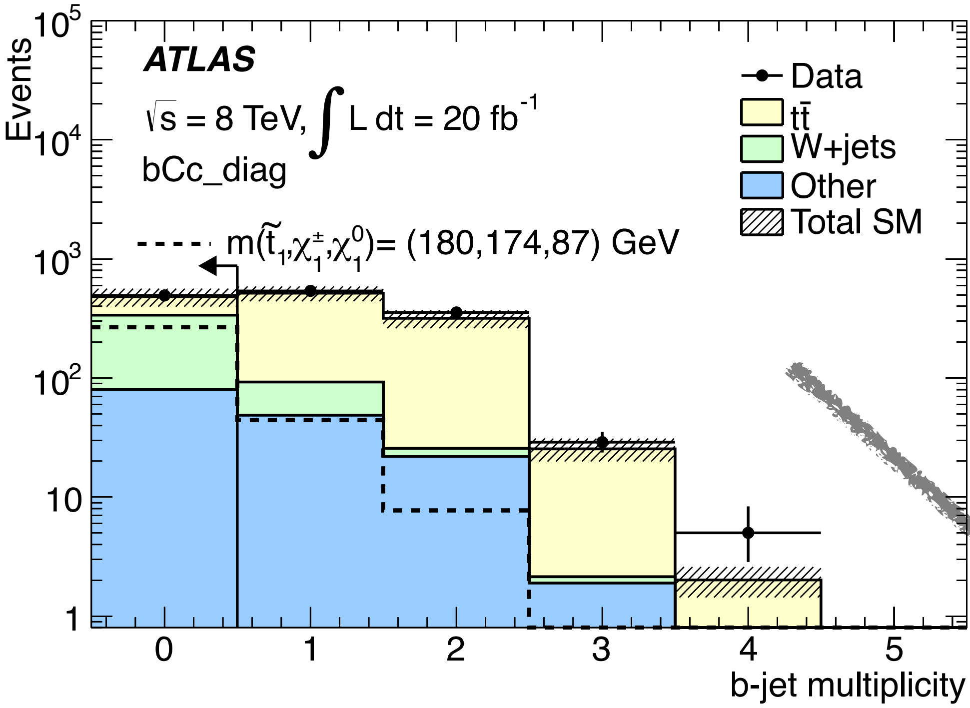
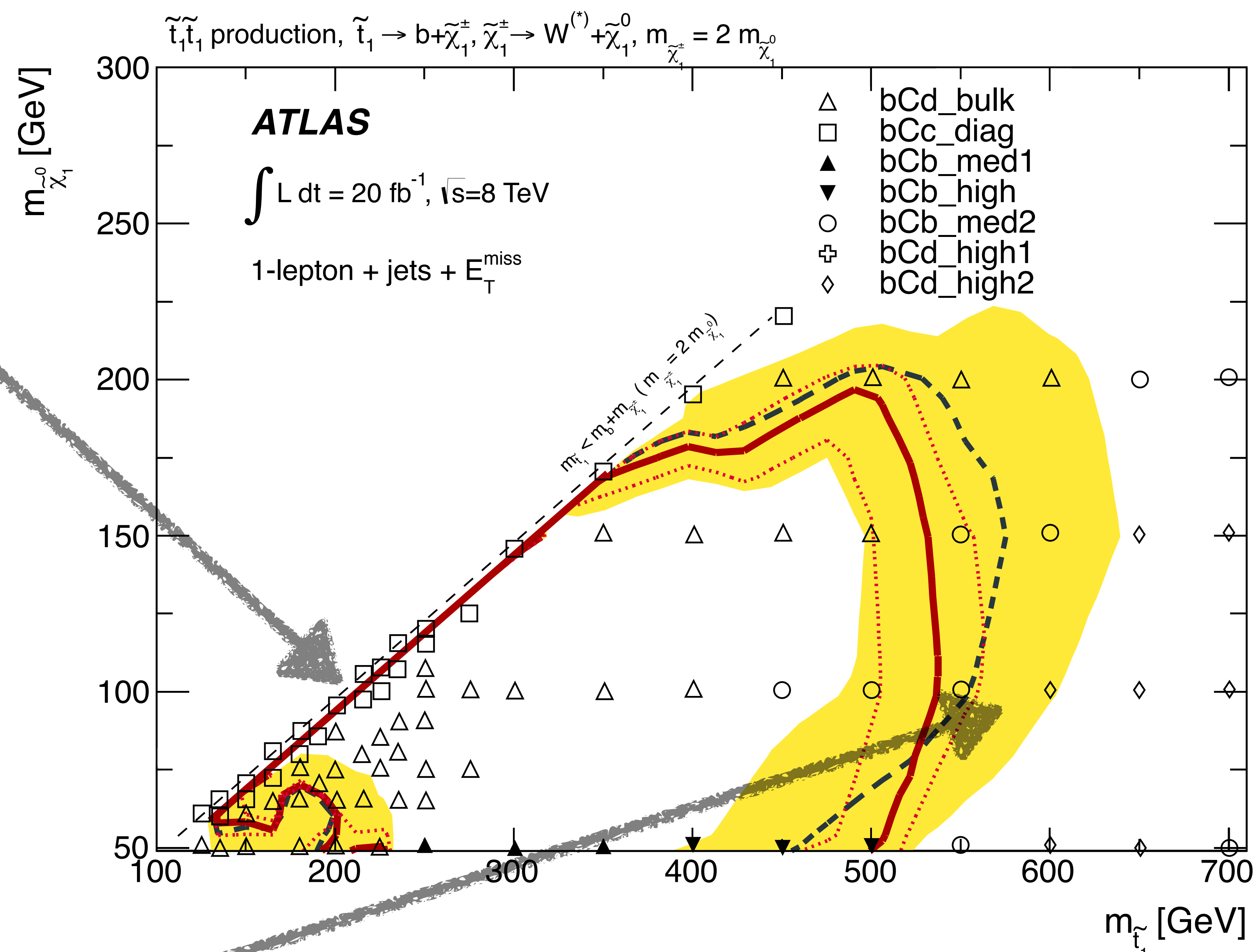
Soft b-jet p_T spectrum

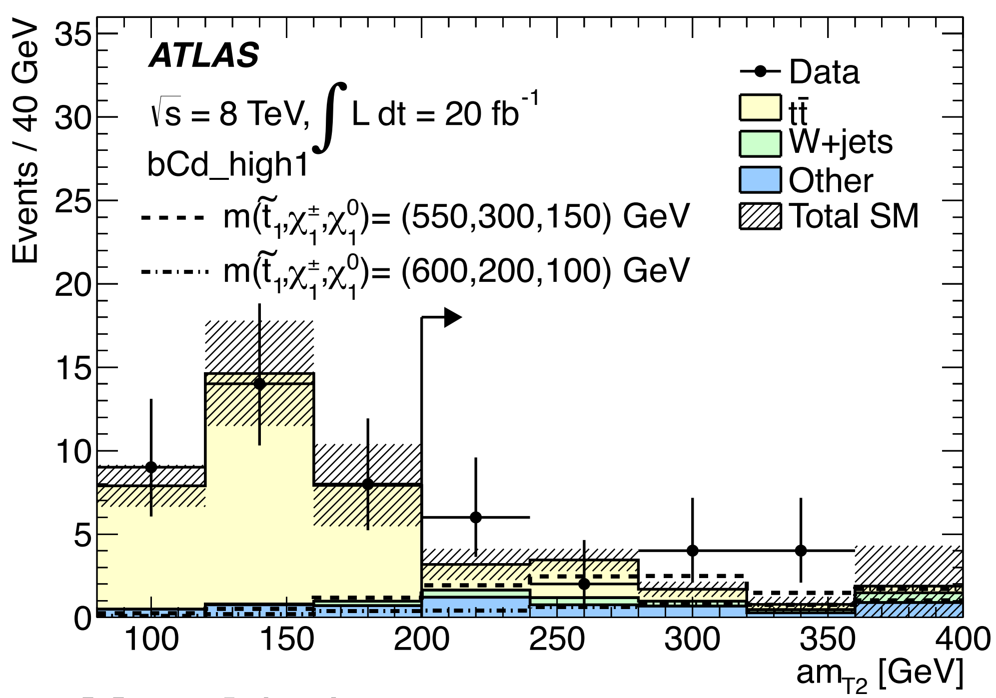
3 jets and veto b-jets



One common form is f(x,y)=2x

(*Gaugino Universality*)





Hard b-jet p_T spectrum

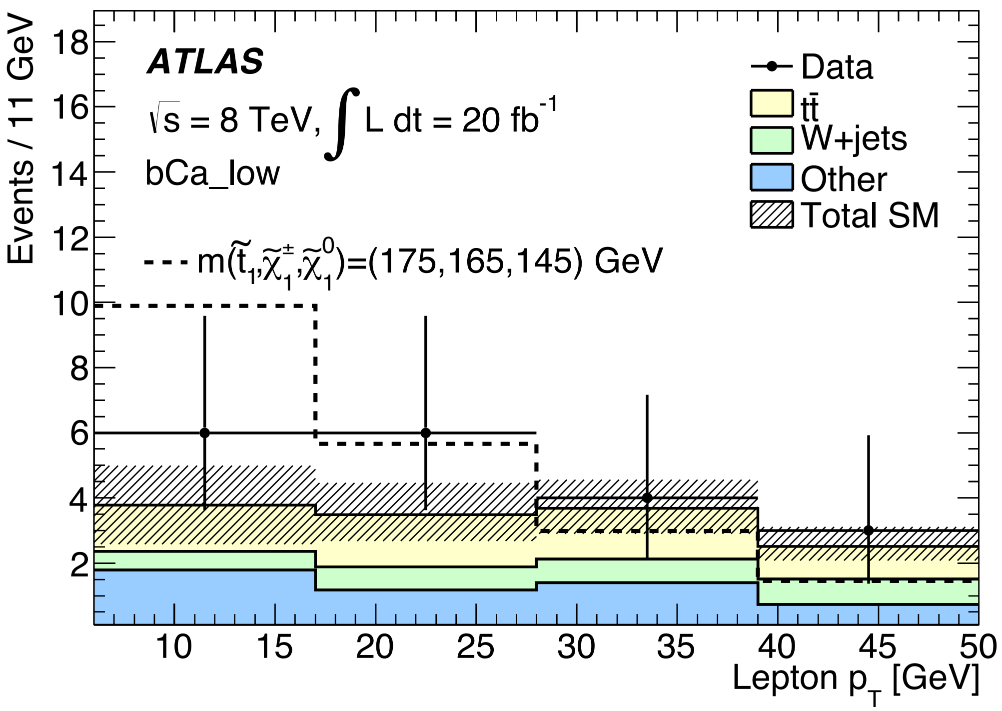
Tight am_{T2} threshold

b+Chargino Results

To show 2D exclusions, need a hypothesis on $m_{chargino} = f(m_{neutralino}, m_{stop})$

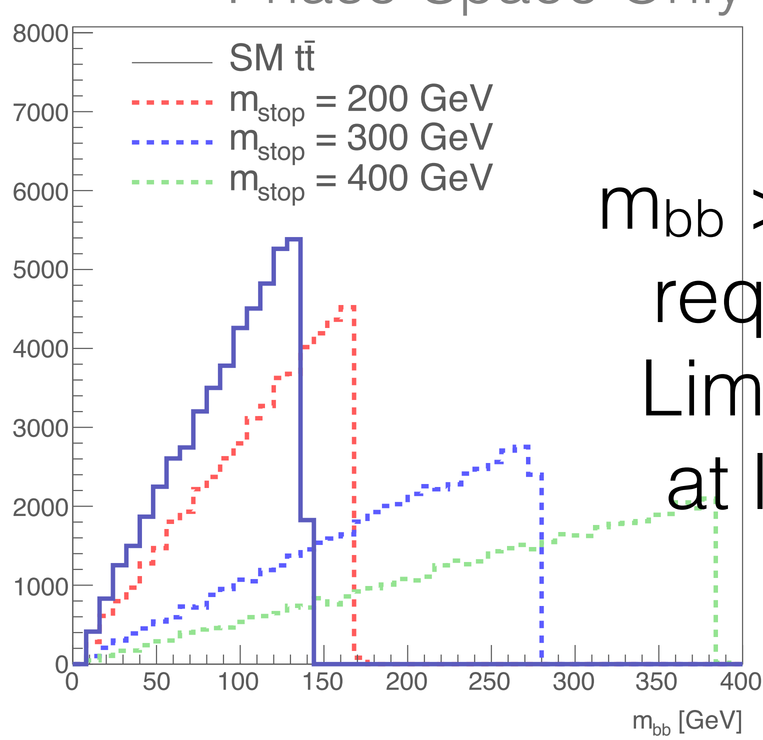
Another choice, f(x,y)=150 GeV
(*why 150? Because > LEP limit*)

[Many other choices for f in backup]

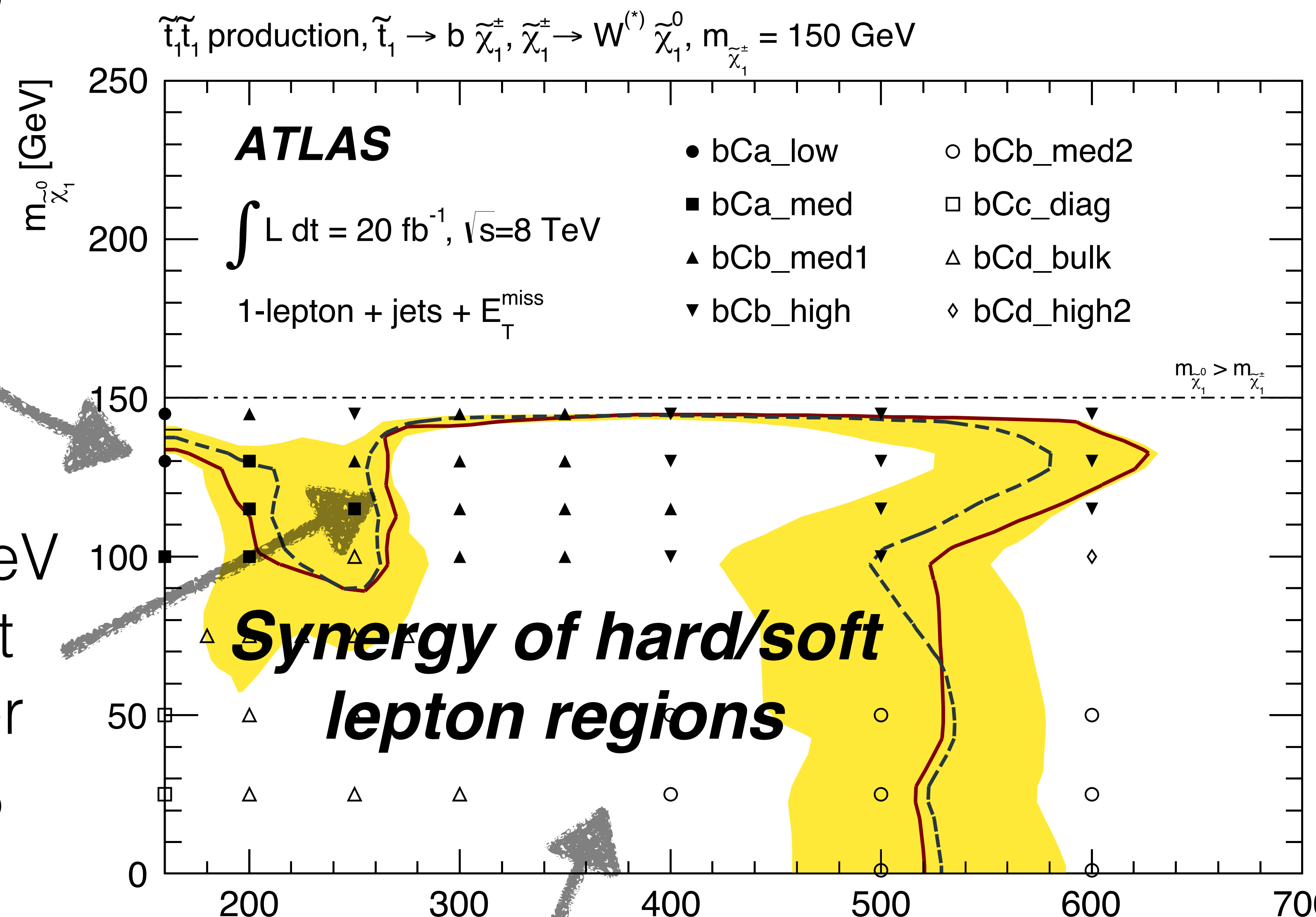


bCa_low/med use ISR in the selection and so limited to lower cross sections (stop masses)

Phase-Space Only



m_{bb} > 150 GeV requirement
Limits power at low m_{stop}



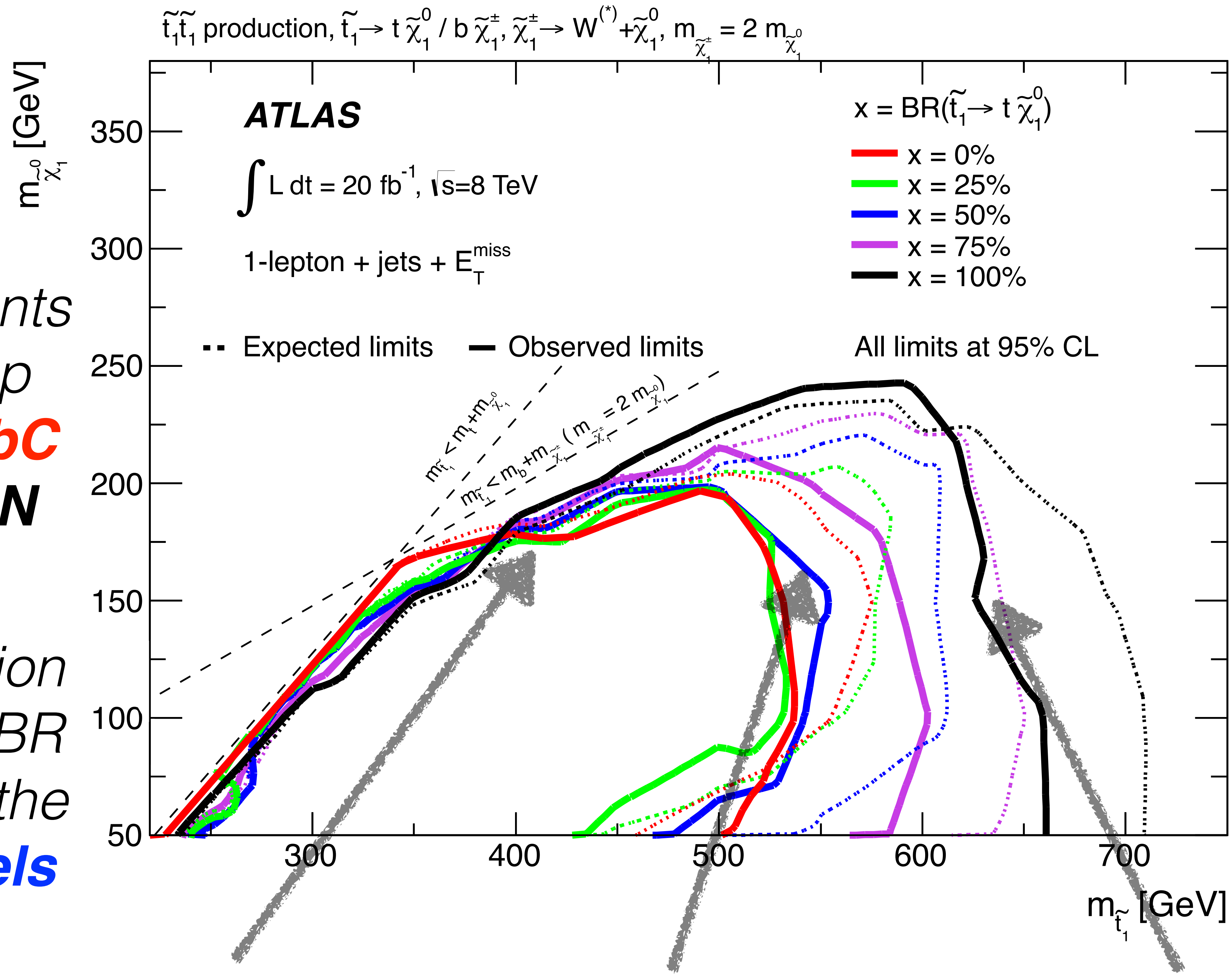
Shape Fits in m_T and am_{T2}

Results: Mixed Decays

Gaugino Universality:
$m_{chargino} = 2 \times m_{LSP}$

Generate events with one stop decaying to ***bC*** *and one to* ***tN***

A superposition of the 100% BR models give the ***mixed models***



Continuous exclusion between simplified models

Results: pMSSM

M. Cahill-Rowley, J.L. Hewett, A. Ismail, and T.G. Rizzo produced a large scan of the 19 parameter pMSSM

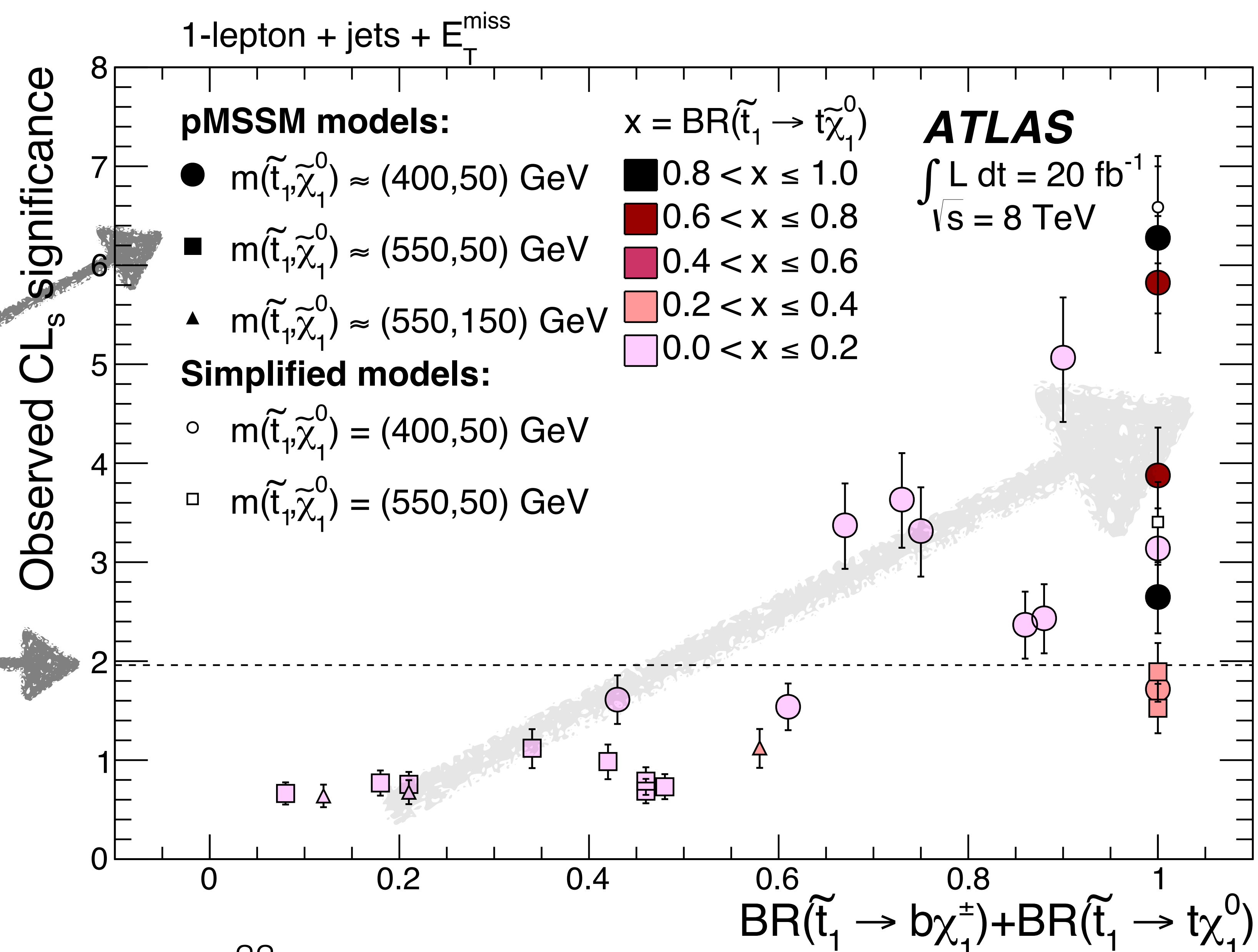
Models required to get m_h~125 GeV, saturate the DM relic density and have low FT.

~10k models with a neutralino LSP

We take a subset of 27 in three small mass ranges

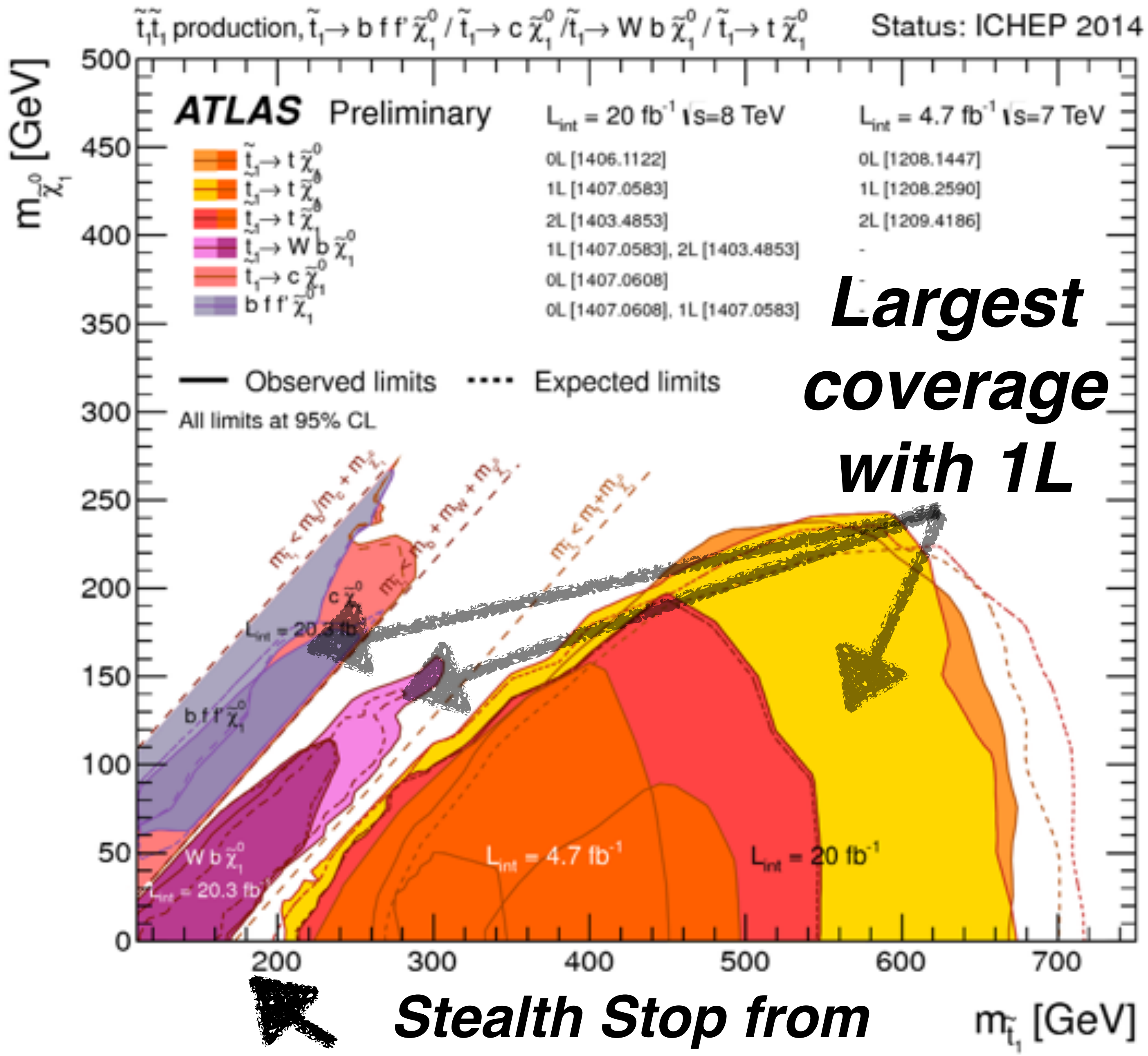
Excluded at 95% CL

Less 'simplified', less sensitivity

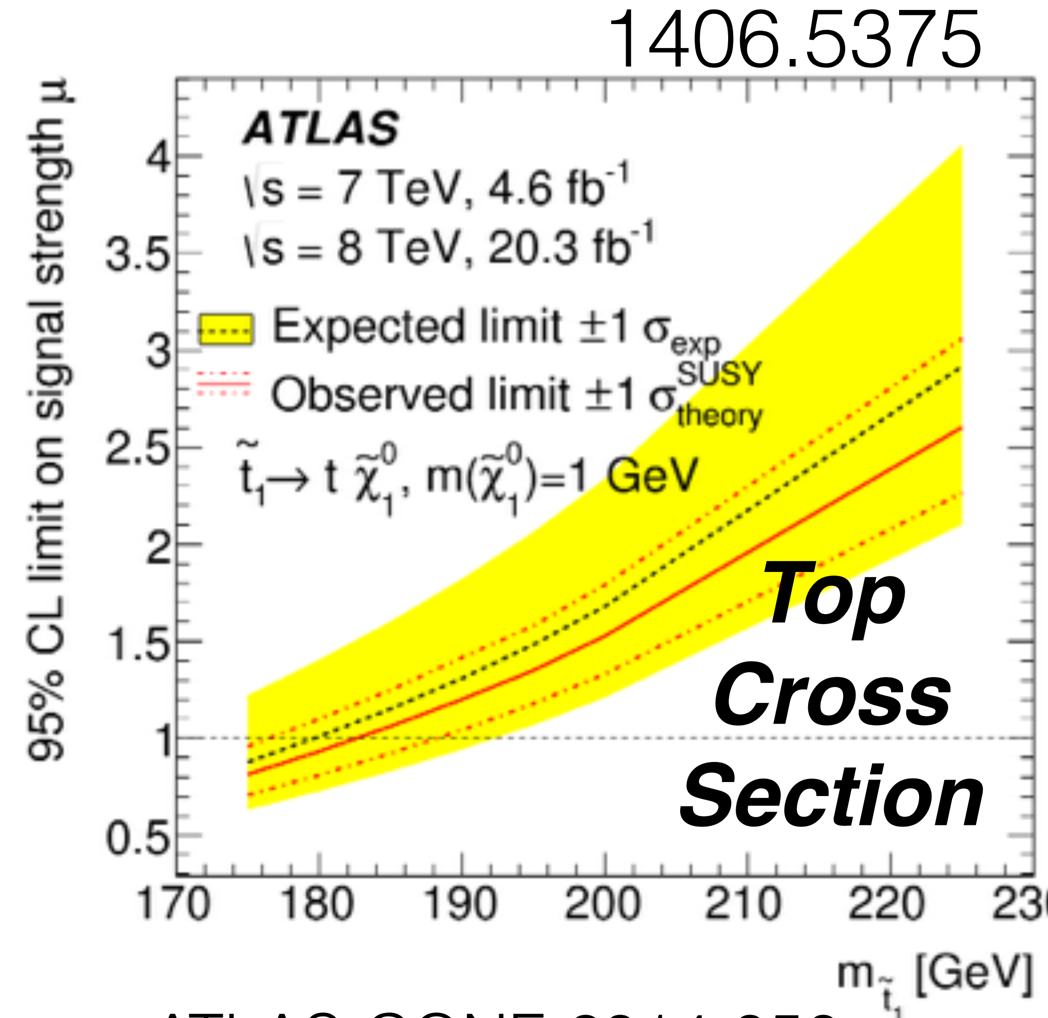


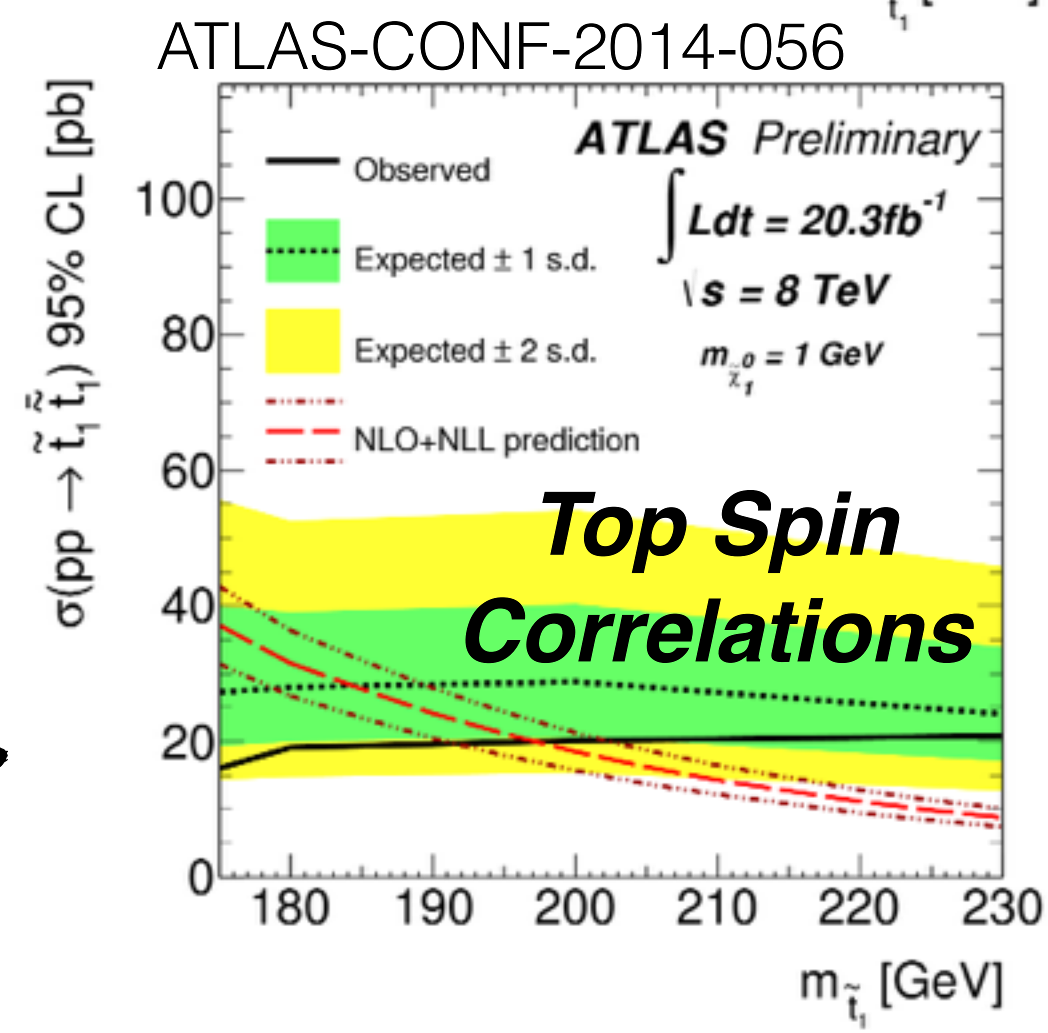
8 TeV ***ATLAS*** Stop Summary

ATLAS has a comprehensive program in direct stop searches



Stealth Stop from Top Properties



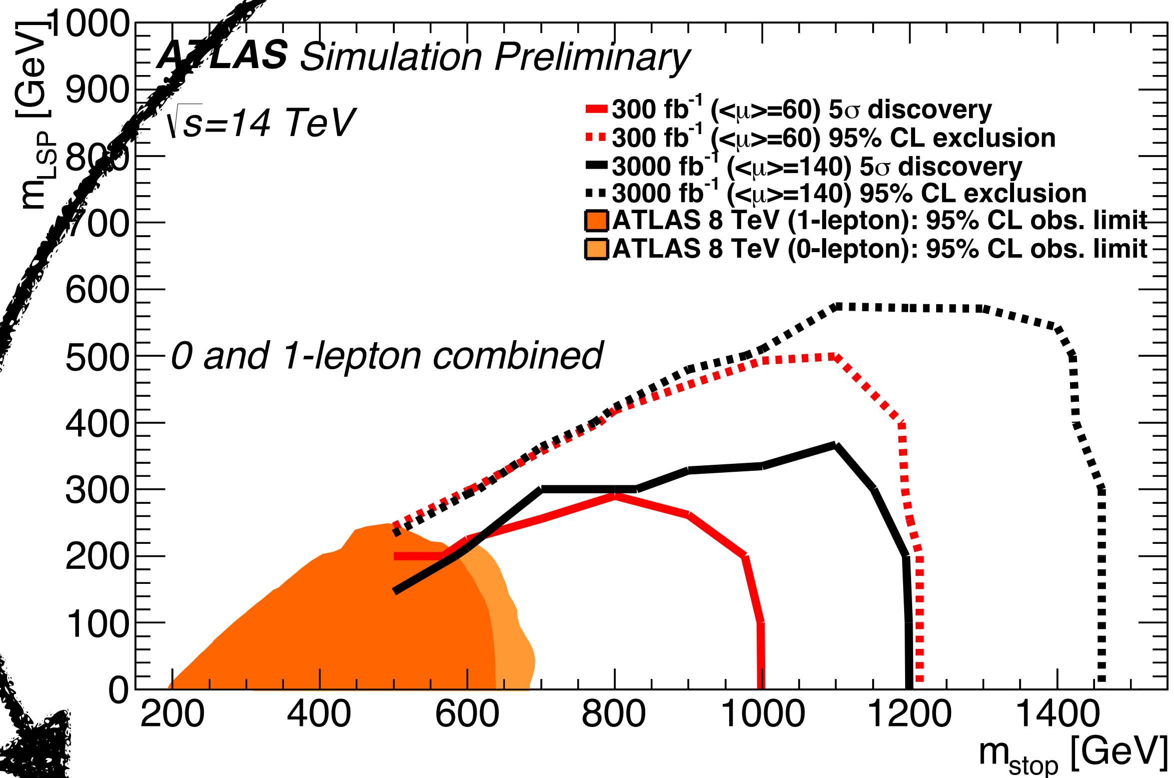


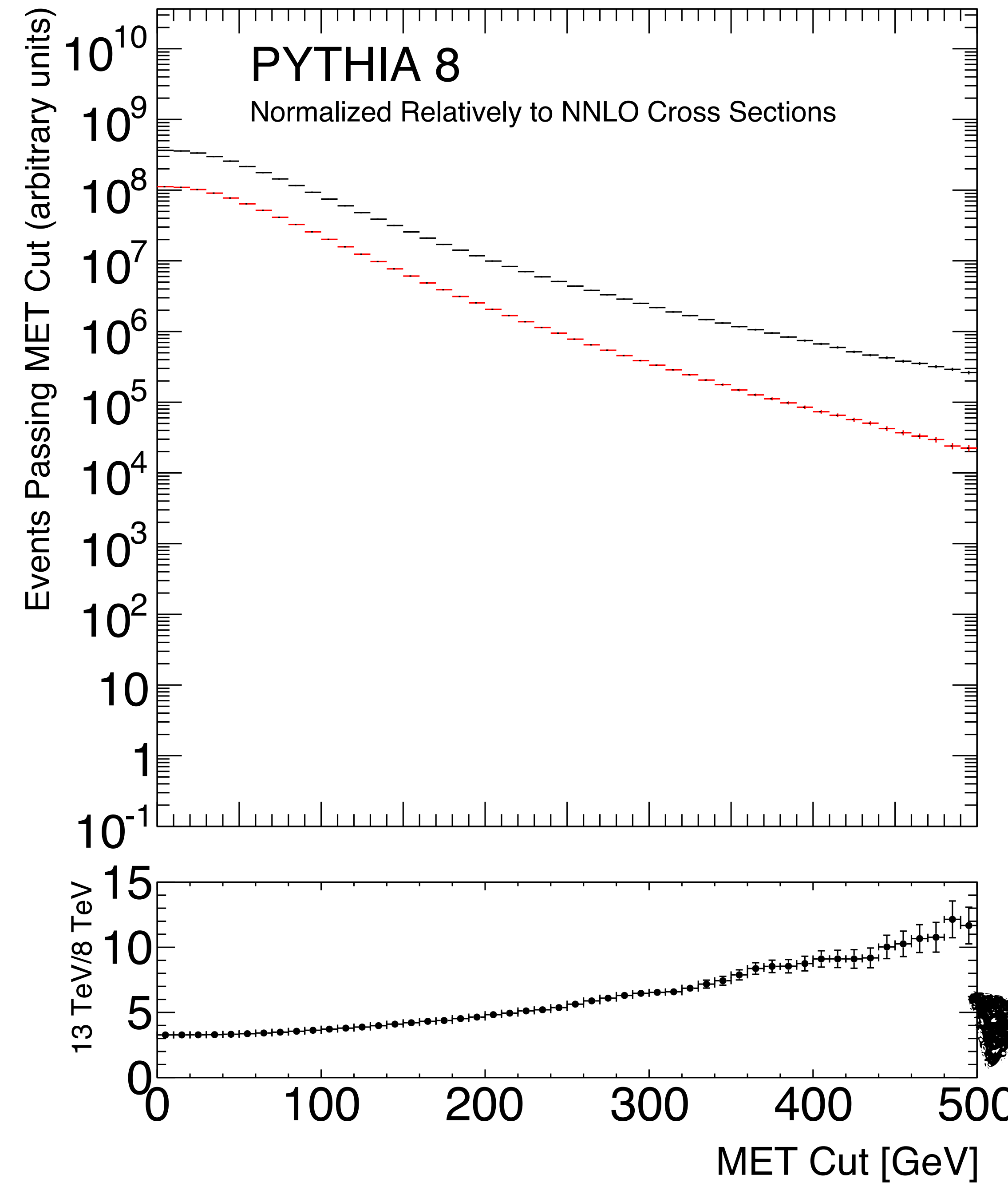
Can the stop hide from a bias in $m_{top}^{measured}$?
See ***1410.7025****: T. Eifert & BN*

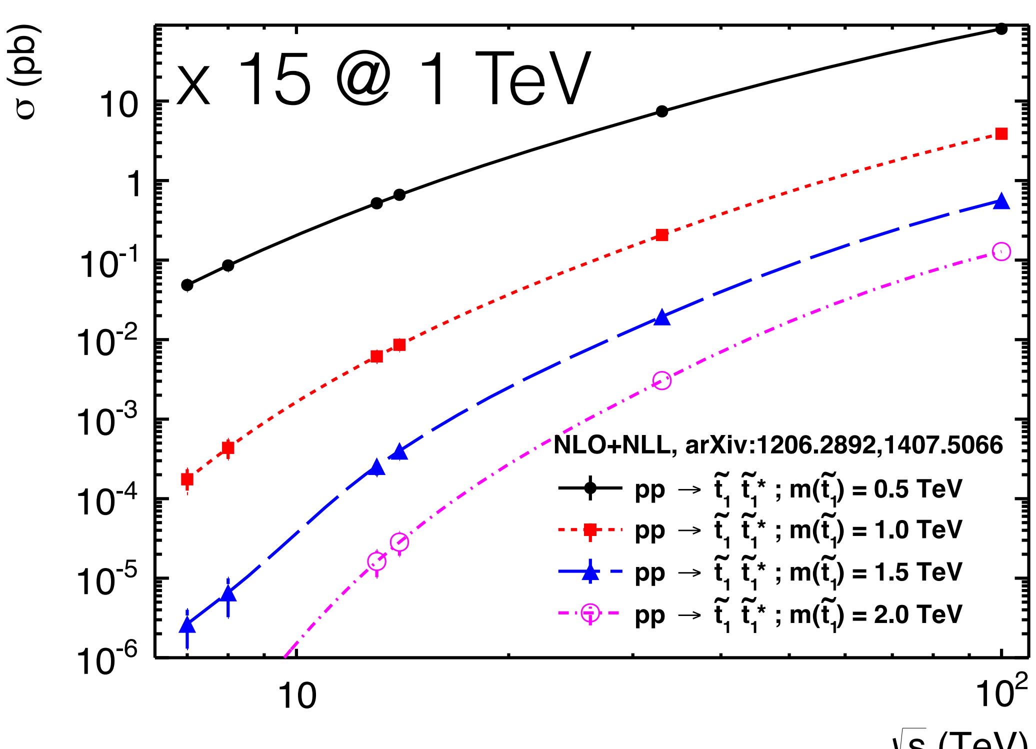
Prospects for 14 TeV

At the higher stop masses, we will gain from higher **cross sections** and **more data**

ATL-PHYS-PUB-2013-011



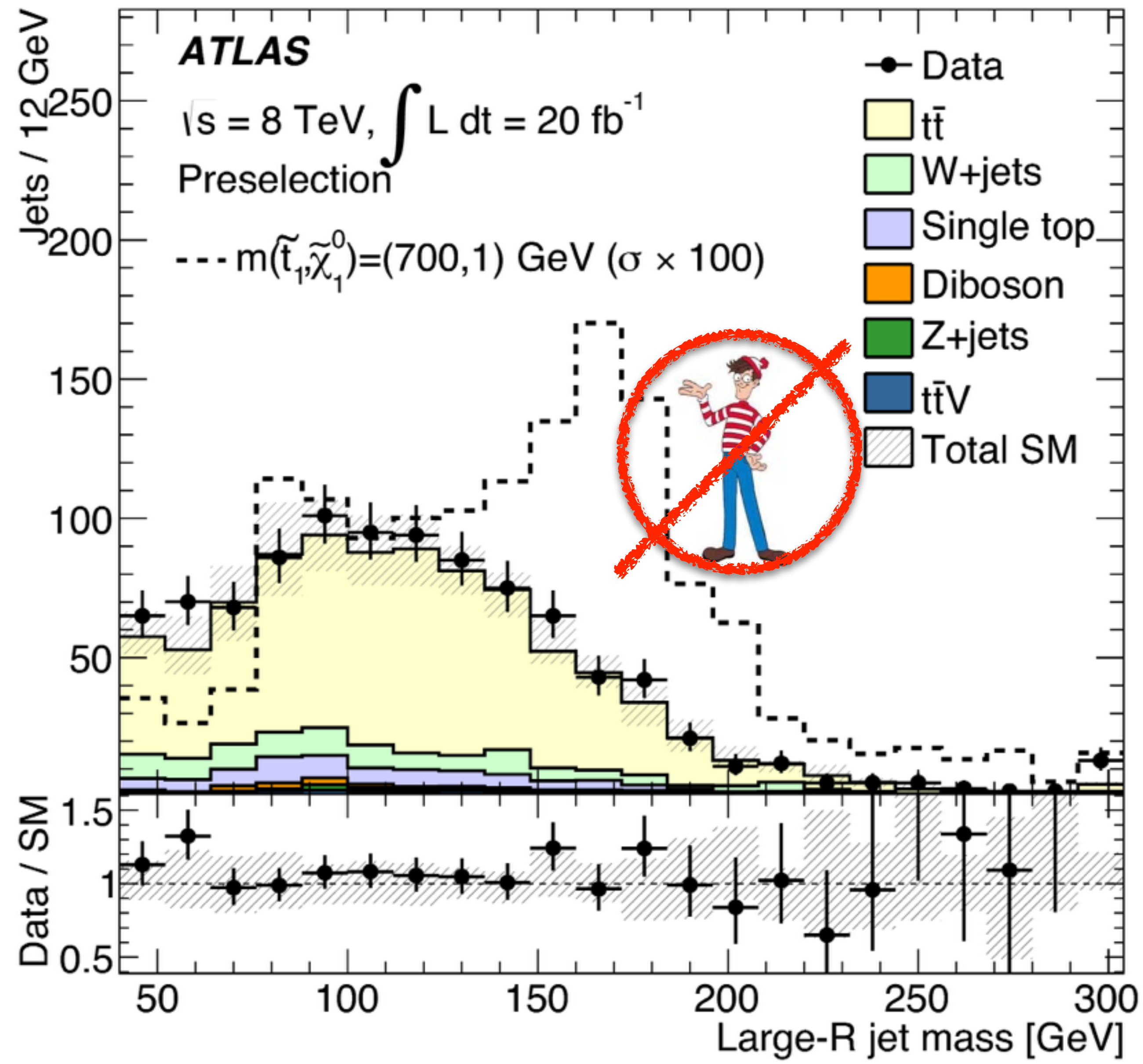




There will be new challenges, as the **top cross section** also increases; objects are more **boosted** and formerly **subdominant backgrounds** are now important

Conclusions

We have searched extensively for a natural stop using the 8 TeV ***ATLAS*** *dataset*



We have developed many new techniques to search for stops in the range ~200-700 GeV

Many regions of simplified and not-so-simplified parameter space excluded

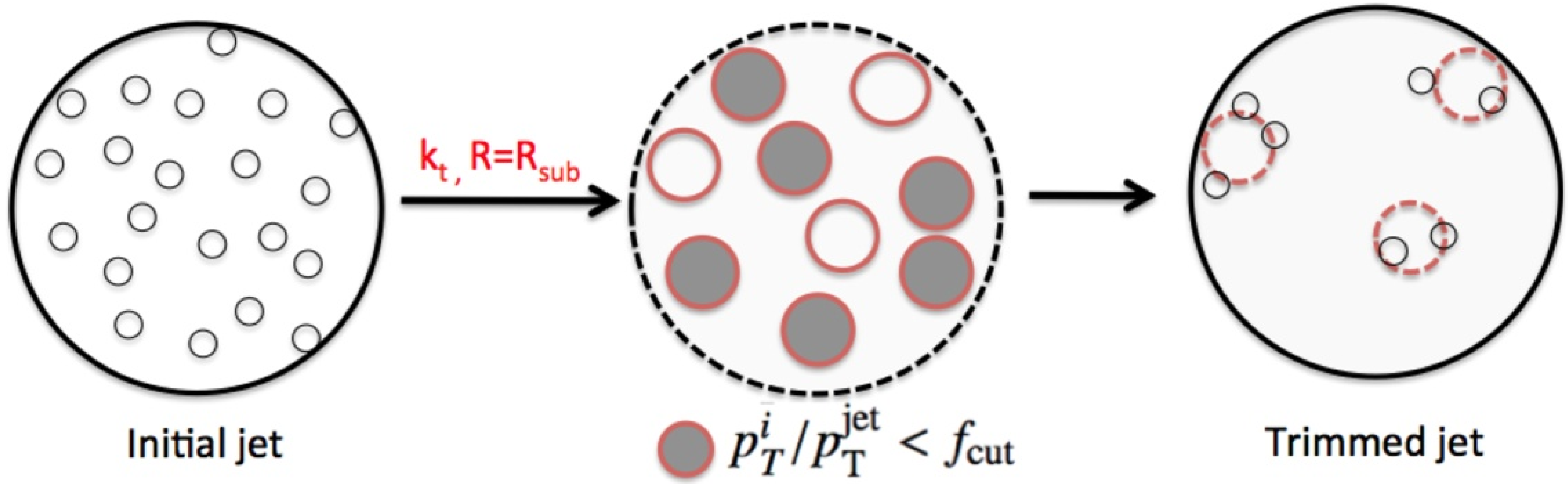
No evidence* (yet) of SUSY → *Stay tuned for 13 TeV results next year!*

*For a meta-analysis of LHC SUSY searches, see **1410.2270**: *BN & T. Rudelius*

BACKUP

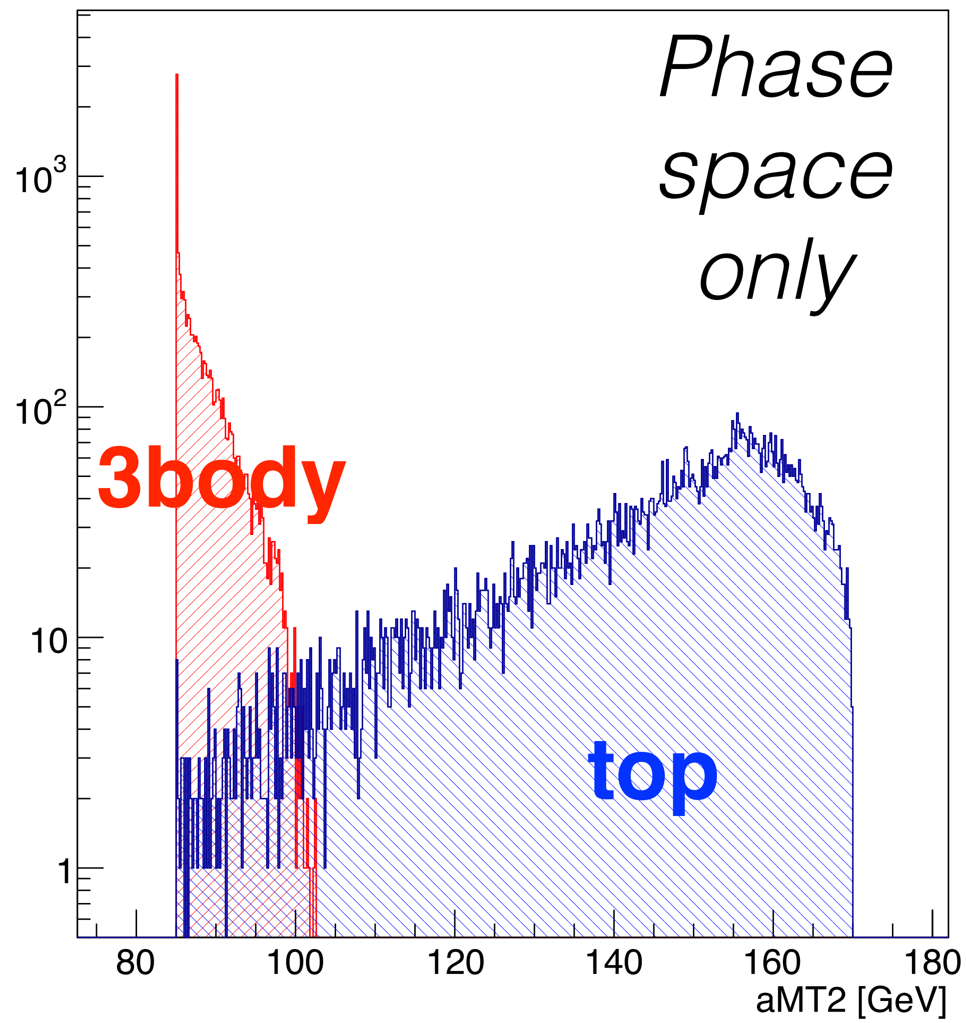
Large Radius Jets

1306.4945

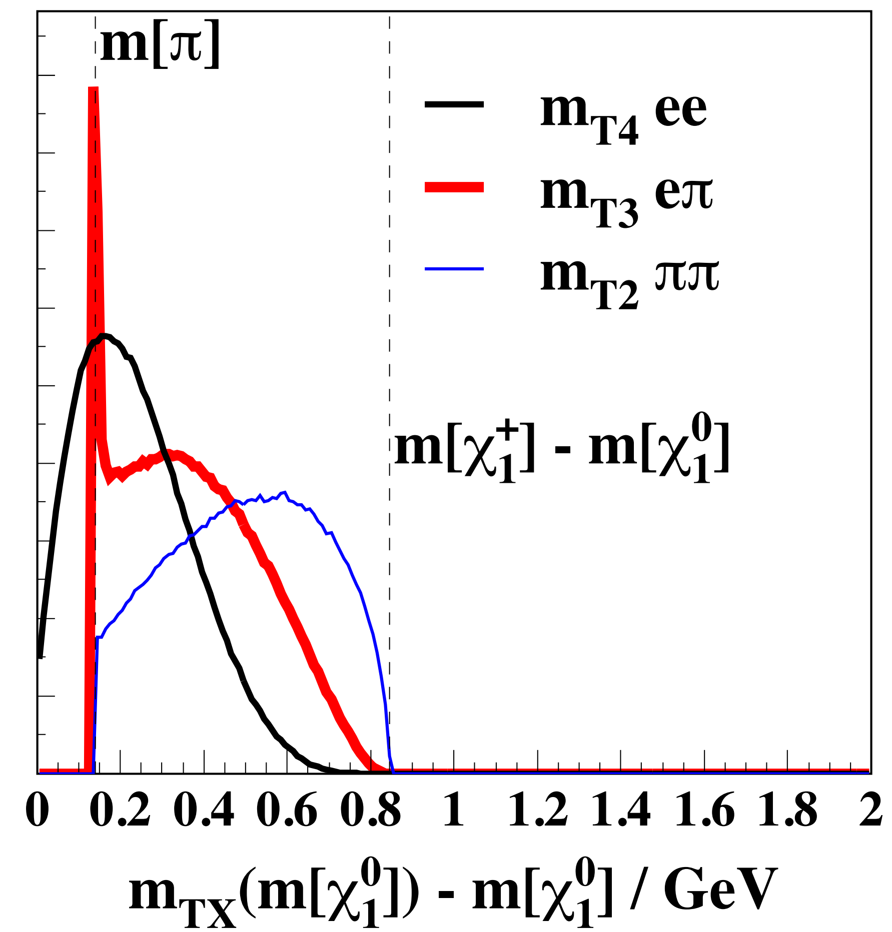


Jet mass squared = sum of the constituent 4-vectors, squared

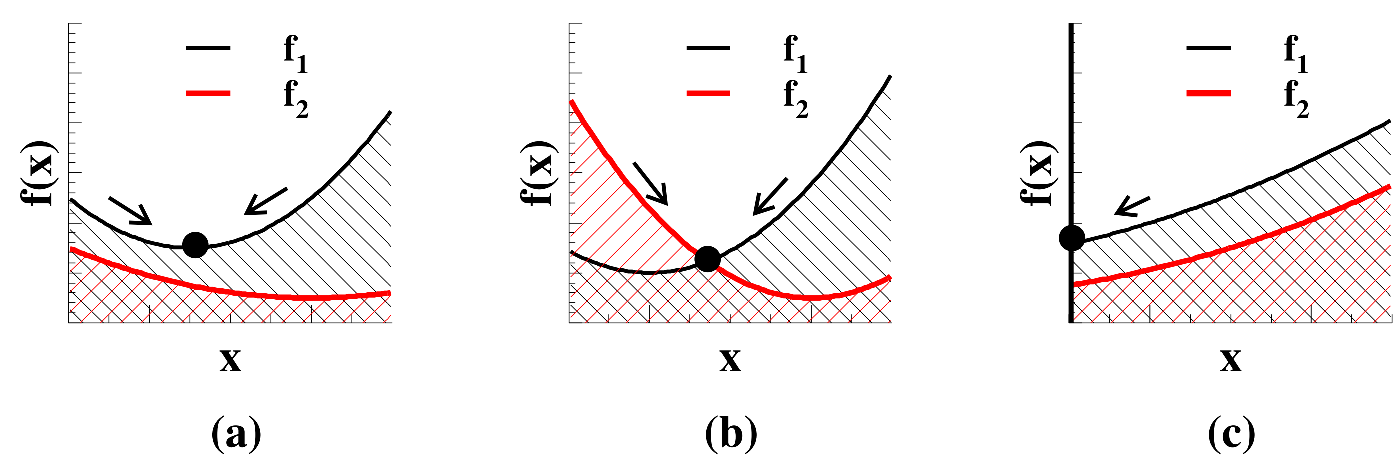
Why low am_{T2} for 3body?



arXiv:0304226



3body more sensitive to the unbalanced solution



pMSSM Models

Mass [GeV]						Branching ratio $\tilde{t}_1 \to$						
$\tilde{t}_1$	$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$	$\tilde{\chi}_3^0$	$\tilde{\chi}_1^\pm$	$\tilde{\chi}_2^\pm$	$t\tilde{\chi}_1^0$	$t\tilde{\chi}_2^0$	$t\tilde{\chi}_3^0$	$b\tilde{\chi}_1^\pm$	$b\tilde{\chi}_2^\pm$	$[T_{11}]^2$	$[N_{11}]^2$
404	40	221	230	220	1073	0.09	0.01	0.09	0.81	0.00	0.53	0.96
404	44	324	445	325	471	0.16	0.00	0.00	0.84	0.00	0.98	0.99
407	46	368	372	367	1515	0.74	0.00	0.00	0.26	0.00	0.02	0.98
408	49	187	207	188	376	0.02	0.31	0.23	0.41	0.04	0.97	0.95
409	39	211	212	206	1768	0.05	0.24	0.02	0.68	0.00	0.56	0.95
409	49	180	190	179	795	0.02	0.22	0.17	0.59	0.00	0.99	0.94
410	40	232	253	234	427	0.11	0.25	0.00	0.64	0.00	0.96	0.97
410	43	387	396	386	889	0.88	0.00	0.00	0.12	0.00	0.01	0.99
413	42	197	367	197	385	0.03	0.10	0.00	0.85	0.02	0.95	0.98
413	45	373	406	374	508	0.32	0.00	0.00	0.68	0.00	0.99	0.99
414	45	194	440	195	453	0.03	0.14	0.00	0.83	0.00	0.96	0.99
416	45	394	397	393	1975	0.90	0.00	0.00	0.10	0.00	0.99	0.99
417	46	333	350	335	573	0.65	0.00	0.00	0.35	0.00	0.96	0.98
418	39	206	209	202	1779	0.09	0.05	0.28	0.59	0.00	0.47	0.95
546	46	292	310	292	520	0.02	0.28	0.24	0.44	0.01	0.98	0.98
547	46	346	374	346	500	0.12	0.49	0.00	0.22	0.16	0.93	0.98
550	40	225	235	225	760	0.02	0.28	0.24	0.46	0.00	0.98	0.96
551	43	351	366	351	621	0.07	0.38	0.21	0.35	0.00	0.98	0.99
552	41	249	275	252	420	0.02	0.20	0.21	0.44	0.13	0.98	0.97
552	42	332	337	331	1496	0.05	0.47	0.35	0.13	0.00	0.99	0.98
552	43	346	350	344	1501	0.08	0.27	0.52	0.13	0.00	0.97	0.98
552	43	385	397	385	731	0.36	0.00	0.00	0.64	0.00	0.97	0.99
554	44	439	445	439	1007	0.21	0.00	0.00	0.79	0.00	0.99	0.99
555	47	279	287	280	933	0.04	0.54	0.38	0.04	0.00	0.97	0.97
553	147	169	444	168	455	0.31	0.12	0.00	0.27	0.30	0.07	0.93
554	151	195	207	191	1969	0.09	0.35	0.43	0.12	0.00	0.88	0.68
546	154	210	213	200	434	0.07	0.40	0.34	0.05	0.14	0.86	0.70

Table 1. Properties of the 27 selected pMSSM models. The table contains the masses of the stop, of neutralinos and of the charginos, the branching ratios of the stop decays, the $\tilde{t}_\mathrm{L}$ content of the $\tilde{t}_1$ ($[T_{11}]^2$, with T being the stop mixing matrix) and the bino content of the χ_1^0 ($[N_{11}]^2$, with N being the neutralino mixing matrix).

Soft Lepton Selections

	bCa_low	bCa_med	bCb_med1	bCb_high
Preselection	soft-lepton preselection, cf. table 3.			
Lepton	$= 1$ soft lepton		$= 1$ soft lepton with $p_T < 25$ GeV	
Jets	≥ 2 with $p_T > 180, 25$ GeV	≥ 3 with $p_T > 180, 25, 25$ GeV	≥ 2 with $p_T > 60, 60$ GeV	
Jet veto	–		$H_{T,2} < 50$ GeV	–
***b*-tagging**	$\geq 1b$-tag amongst sub-leading jets (70% eff.)		Leading two jets b-tagged (60% eff.)	
***b*-veto**	1^{st} jet not b-tagged (70% eff.)		–	
m_{bb}	–		> 150 GeV	
E_T^{miss}	> 370 GeV	> 300 GeV	> 150 GeV	> 250 GeV
E_T^{miss}/m_{eff}	> 0.35	> 0.3	–	
m_T	> 90 GeV	> 100 GeV	–	
Exclusion setup: shape-fit				
	4 bins in lepton p_T range [6(7), 50] GeV		6 bins in am_{T2} range [0, 500]GeV	
Discovery setup				
	lepton $p_T < 25$ GeV		$am_{T2} > 170$ GeV	$am_{T2} > 200$ GeV

b+Chargino Lepton Selections

	bCb_med2	bCc_diag	bCd_bulk	bCd_high1	bCd_high2
Preselection	Default preselection criteria, cf. table 3.				
Lepton	= 1 lepton	= 1 lepton with $\lvert\eta(\ell)\rvert < 1.2$	= 1 lepton		
Jets	≥ 4 with $p_{\mathrm{T}} > 80, 60, 40, 25\,\mathrm{GeV}$	≥ 3 with $p_{\mathrm{T}} > 80, 40, 30\,\mathrm{GeV}$	≥ 4 with $p_{\mathrm{T}} > 80, 60, 40, 25\,\mathrm{GeV}$		≥ 4 with $p_{\mathrm{T}} > 80, 80, 40, 25\,\mathrm{GeV}$
***b*-tagging / veto**	≥ 2 (80% eff.) with $p_{\mathrm{T}} > 140, 75\,\mathrm{GeV}$	$= 0$ (70% eff.) with $p_{\mathrm{T}} > 25\,\mathrm{GeV}$	≥ 1 (70% eff.) with $p_{\mathrm{T}} > 25\,\mathrm{GeV}$	≥ 2 (80% eff.) with $p_{\mathrm{T}} > 75, 75\,\mathrm{GeV}$	≥ 2 (80% eff.) with $p_{\mathrm{T}} > 170, 80\,\mathrm{GeV}$
$E_{\mathrm{T}}^{\mathrm{miss}}$	$> 170\,\mathrm{GeV}$	$> 140\,\mathrm{GeV}$	$> 150\,\mathrm{GeV}$		$> 160\,\mathrm{GeV}$
m_{T}	$> 60\,\mathrm{GeV}$	$> 120\,\mathrm{GeV}$	$> 60\,\mathrm{GeV}$	$> 120\,\mathrm{GeV}$	
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$	$> 6\ \mathrm{GeV}^{1/2}$	$> 5\ \mathrm{GeV}^{1/2}$	$> 7\ \mathrm{GeV}^{1/2}$	$> 9\ \mathrm{GeV}^{1/2}$	$> 8\ \mathrm{GeV}^{1/2}$
am_{T2}	$> 80\,\mathrm{GeV}$	–	$> 80\,\mathrm{GeV}$	$> 200\,\mathrm{GeV}$	$> 250\,\mathrm{GeV}$
Track, τ-veto	track & loose τ-veto	–	track & loose τ-veto		
$\Delta R(j_1, \ell)$	–	$\in [0.8, 2.4]$	–		
$\Delta\phi(\mathrm{jet}, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})$	> 0.8 (1st and 2nd jet)	> 2.0 (1st jet), > 0.8 (2nd jet)	> 0.8 (1st and 2nd jet)		
Exclusion setup	shape-fit in m_{T} and am_{T2}, cf. figure 9.	cut-and-count	shape-fit in m_{T} and am_{T2}, cf. figure 9.	cut-and-count	
Discovery setup	test signal-sensitive bins.	cut-and-count	test signal-sensitive bins.	cut-and-count	

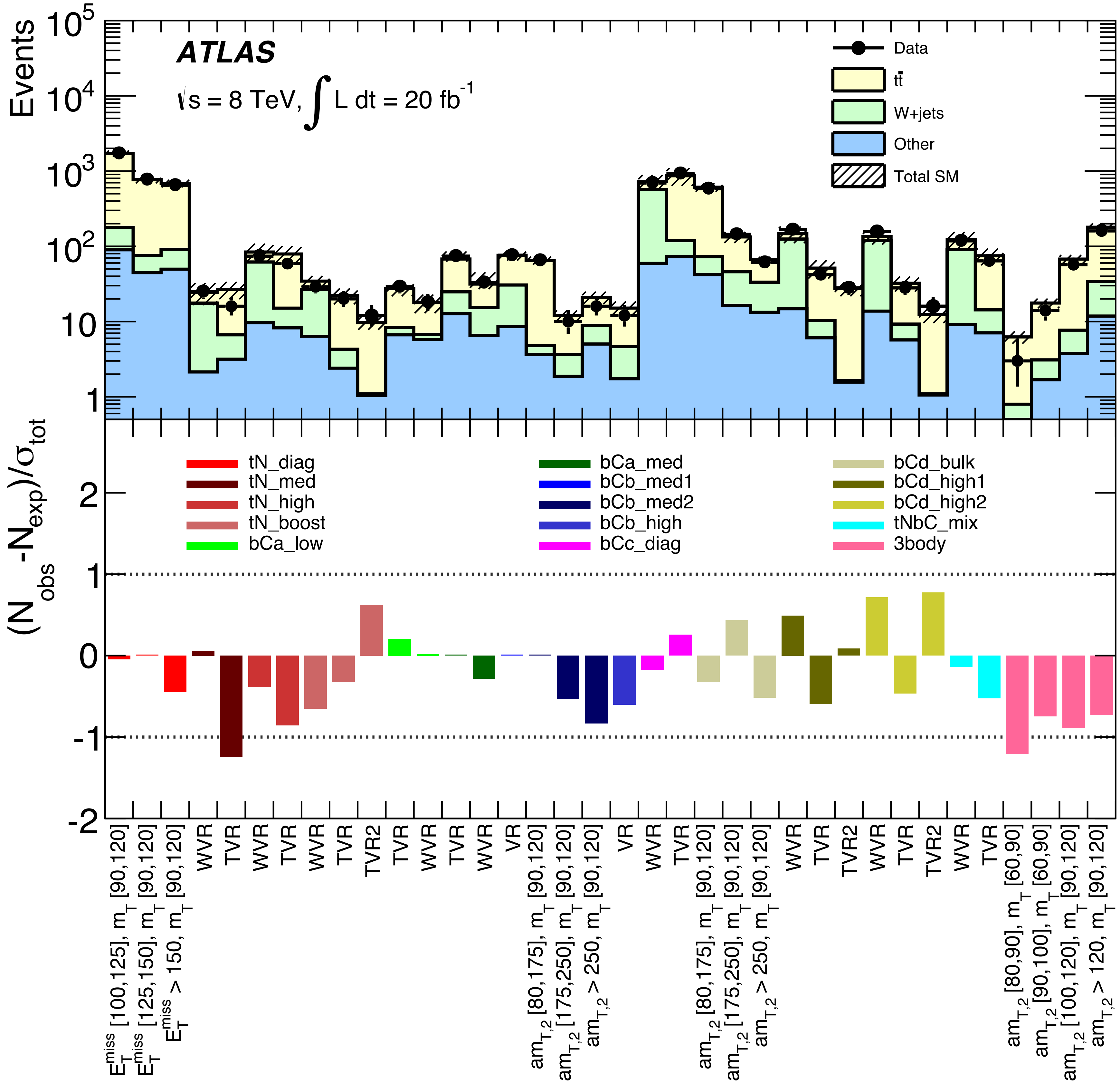
3body and Mixed SRs

	tNbC_mix	3body
Preselection	Default preselection criteria, cf. table 3.	
Lepton	$= 1$ lepton	
Jets	≥ 4 jets with $p_{\mathrm{T}} > 80, 70, 50, 25\,\mathrm{GeV}$	≥ 4 jets with $p_{\mathrm{T}} > 80, 25, 25, 25\,\mathrm{GeV}$
***b*-tagging**	≥ 1 b-tag (70% eff.) with $p_{\mathrm{T}} > 60\,\mathrm{GeV}$	≥ 1 b-tag (70% eff.) with $p_{\mathrm{T}} > 25\,\mathrm{GeV}$
$E_{\mathrm{T}}^{\mathrm{miss}}$	$> 270\,\mathrm{GeV}$	$> 150\,\mathrm{GeV}$
m_{T}	$> 130\,\mathrm{GeV}$	$> 60\,\mathrm{GeV}$
am_{T2}	$> 190\,\mathrm{GeV}$	$> 80\,\mathrm{GeV}$
topness	> 2	–
$\boldsymbol{m_{jjj}}$	$< 360\,\mathrm{GeV}$	–
$\boldsymbol{E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}}$	$> 9\ \mathrm{GeV}^{1/2}$	$> 5\ \mathrm{GeV}^{1/2}$
$\boldsymbol{\tau}$**-veto**	loose	
$\boldsymbol{\Delta\phi(\mathrm{jet}_i, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})}$	> 0.6 $(i = 1, 2)$	> 0.2 $(i = 1, 2)$
$\boldsymbol{\Delta\phi(\ell, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})}$	> 0.6	> 1.2
$\boldsymbol{\Delta R(\ell, \mathrm{jet}_i)}$	< 2.75 $(i = 1)$	> 1.2 $(i = 1)$, > 2.0 $(i = 2)$
$\boldsymbol{\Delta R(\ell, b\text{-jet})}$	< 3.0	–
Exclusion setup	cut-and-count	shape-fit in m_{T} and am_{T2}, cf. figure 6.
Discovery setup	cut-and-count	test signal-sensitive bins one-by-one.

top+Neutralino SRs

	tN_diag	tN_med	tN_high	tN_boost
Preselection	Default preselection criteria, cf. table 3.			
Lepton	= 1 lepton			
Jets	≥ 4 with $p_{\mathrm{T}} >$ $60, 60, 40, 25\,\mathrm{GeV}$	≥ 4 with $p_{\mathrm{T}} >$ $80, 60, 40, 25\,\mathrm{GeV}$	≥ 4 with $p_{\mathrm{T}} >$ $100, 80, 40, 25\,\mathrm{GeV}$	≥ 4 with $p_{\mathrm{T}} >$ $75, 65, 40, 25\,\mathrm{GeV}$
***b*-tagging**	≥ 1 *b*-tag (70% eff.) amongst four selected jets			
large-*R* jet	–			≥ 1, $p_{\mathrm{T}} > 270\,\mathrm{GeV}$ and $m > 75\,\mathrm{GeV}$
$\Delta\phi(\mathrm{jet}_2^{\text{large-}R}, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}})$	–			> 0.85
$E_{\mathrm{T}}^{\mathrm{miss}}$	$> 100\,\mathrm{GeV}$	$> 200\,\mathrm{GeV}$	$> 320\,\mathrm{GeV}$	$> 315\,\mathrm{GeV}$
m_{T}	$> 60\,\mathrm{GeV}$	$> 140\,\mathrm{GeV}$	$> 200\,\mathrm{GeV}$	$> 175\,\mathrm{GeV}$
am_{T2}	–	$> 170\,\mathrm{GeV}$	$> 170\,\mathrm{GeV}$	$> 145\,\mathrm{GeV}$
m_{T2}^{τ}	–	–	$> 120\,\mathrm{GeV}$	–
topness	–	–	–	> 7
$m_{\mathrm{had-top}}$	$\in [130,\ 205]\,\mathrm{GeV}$	$\in [130,\ 195]\,\mathrm{GeV}$	$\in [130,\ 250]\,\mathrm{GeV}$	
τ-veto	tight	–	–	modified, see text.
$\Delta R(b\text{-jet}, \ell)$	< 2.5	–	< 3	< 2.6
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}}$	$> 5\ \mathrm{GeV}^{1/2}$	–		
$H_{\mathrm{T,sig}}^{\mathrm{miss}}$	–	> 12.5		> 10
$\Delta\phi(\mathrm{jet}_i, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}})$	> 0.8 $(i = 1, 2)$	> 0.8 $(i = 2)$	–	$> 0.5, 0.3$ $(i = 1, 2)$
Exclusion setup	shape-fit in m_{T} and $E_{\mathrm{T}}^{\mathrm{miss}}$, cf. figure 6.	cut-and-count		
Discovery setup	test signal-sensitive bins one-by-one.	cut-and-count		

Validation Regions



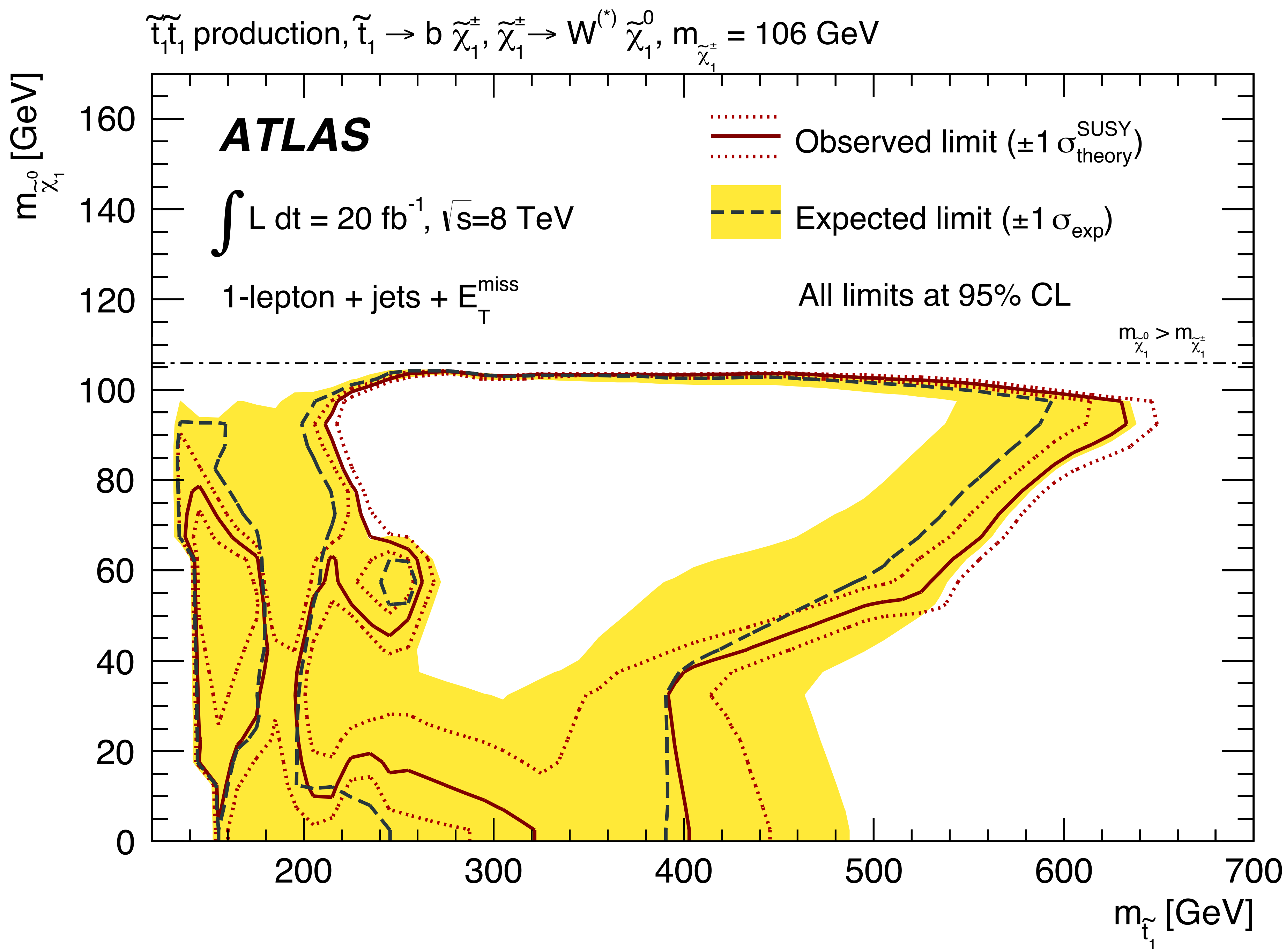
Results

Region	Obs.	Exp. bkg.	p_0	$N_{\rm non-SM}$ Obs.	$N_{\rm non-SM}$ Exp.	$\sigma_{\rm vis}$ [fb] Obs.	$\sigma_{\rm vis}$ [fb] Exp.
tN_med	12	13.0 ± 2.2	≥ 0.5	8.5	9.2	0.4	0.5
tN_high	5	5.0 ± 1.0	≥ 0.5	6.0	6.0	0.3	0.3
tN_boost	5	3.3 ± 0.7	0.17	7.0	5.3	0.3	0.3
bCa_low	11	6.5 ± 1.4	0.08	12.2	7.8	0.61	0.92
bCa_med	20	17 ± 4	0.33	14.4	12.3	0.72	0.68
bCb_med1	41	32 ± 5	0.12	23.5	16.0	1.17	0.88
bCb_high	7	9.8 ± 1.6	≥ 0.5	6.5	7.9	0.32	0.22
bCc_diag	493	470 ± 50	0.27	110.6	95.1	5.4	4.7
bCd_high1	16	11.0 ± 1.5	0.09	13.2	8.5	0.7	0.4
bCd_high2	5	4.4 ± 0.8	0.36	6.3	5.7	0.3	0.3
tNbC_mix	10	7.2 ± 1.0	0.13	9.7	7.0	0.5	0.3
tN_diag							
$125 < E_{\rm T}^{\rm miss} < 150$ GeV, $120 < m_{\rm T} < 140$ GeV	117	136 ± 22	≥ 0.5	42.1	55.7	2.1	2.7
$125 < E_{\rm T}^{\rm miss} < 150$ GeV, $m_{\rm T} > 140$ GeV	163	152 ± 20	0.35	55.4	47.8	2.7	2.4
$E_{\rm T}^{\rm miss} > 150$ GeV, $120 < m_{\rm T} < 140$ GeV	101	98 ± 13	0.43	36.1	33.9	1.8	1.7
$E_{\rm T}^{\rm miss} > 150$ GeV, $m_{\rm T} > 140$ GeV	217	236 ± 29	≥ 0.5	58.7	71.4	2.9	3.5
bCb_med2							
$175 < am_{\rm T2} < 250$ GeV, $90 < m_{\rm T} < 120$ GeV	10	12.1 ± 2.0	≥ 0.5	7.3	8.8	0.4	0.4
$175 < am_{\rm T2} < 250$ GeV, $m_{\rm T} > 120$ GeV	10	7.4 ± 1.4	0.10	9.7	7.3	0.5	0.4
$am_{\rm T2} > 250$ GeV, $90 < m_{\rm T} < 120$ GeV	16	21 ± 4	≥ 0.5	9.3	12.3	0.5	0.6
$am_{\rm T2} > 250$ GeV, $m_{\rm T} > 120$ GeV	9	9.1 ± 1.6	≥ 0.5	7.7	7.8	0.4	0.4
bCd_bulk							
$175 < am_{\rm T2} < 250$ GeV, $90 < m_{\rm T} < 120$ GeV	144	133 ± 22	0.29	36.1	33.9	1.8	1.7
$175 < am_{\rm T2} < 250$ GeV, $m_{\rm T} > 120$ GeV	78	73 ± 8	0.34	58.7	71.4	2.9	3.5
$am_{\rm T2} > 250$ GeV, $90 < m_{\rm T} < 120$ GeV	61	66 ± 6	≥ 0.5	17.5	20.9	0.9	1.0
$am_{\rm T2} > 250$ GeV, $m_{\rm T} > 120$ GeV	29	26.5 ± 2.6	0.34	14.8	12.6	0.7	0.6
3body							
$80 < am_{\rm T2} < 90$ GeV, $90 < m_{\rm T} < 120$ GeV	12	16.9 ± 2.8	≥ 0.5	7.3	9.9	0.4	0.5
$80 < am_{\rm T2} < 90$ GeV, $m_{\rm T} > 120$ GeV	8	8.4 ± 2.2	≥ 0.5	7.9	7.8	0.4	0.4
$90 < am_{\rm T2} < 100$ GeV, $90 < m_{\rm T} < 120$ GeV	29	35 ± 4	≥ 0.5	11.7	14.7	0.6	0.7
$90 < am_{\rm T2} < 100$ GeV, $m_{\rm T} > 120$ GeV	22	29 ± 5	≥ 0.5	55.4	47.8	2.7	2.4

b+Chargino Results

To show 2D exclusions, need a hypothesis on $m_{chargino} = f(m_{neutralino}, m_{stop})$

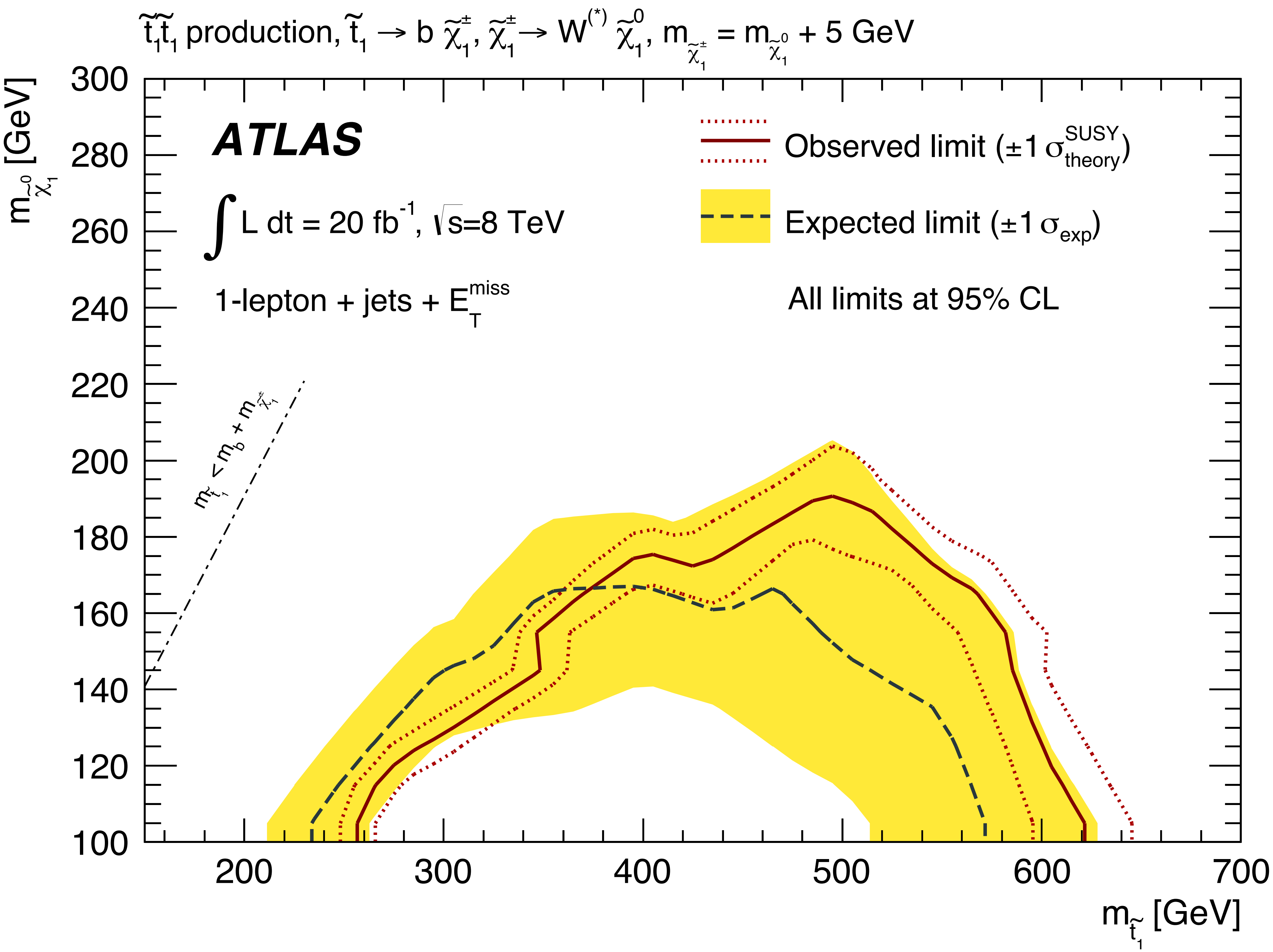
Another choice, f(x,y)=106 GeV
(*why 106? Because ~ LEP limit*)



b+Chargino Results

To show 2D exclusions, need a hypothesis on $m_{chargino} = f(m_{neutralino}, m_{stop})$

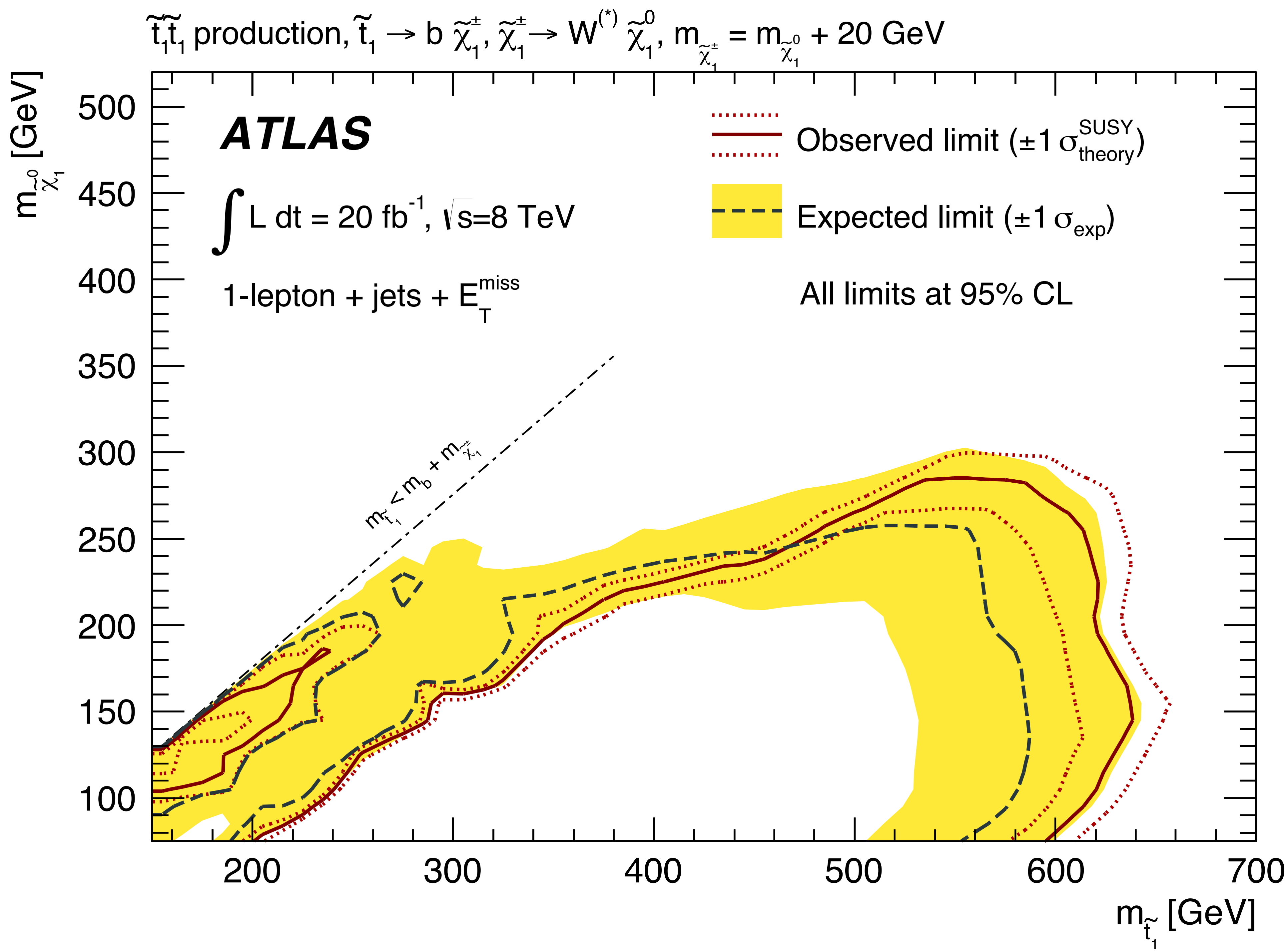
Another choice, f(x,y)=x+5 GeV



b+Chargino Results

To show 2D exclusions, need a hypothesis on $m_{chargino} = f(m_{neutralino}, m_{stop})$

Another choice, f(x,y)=x+20 GeV

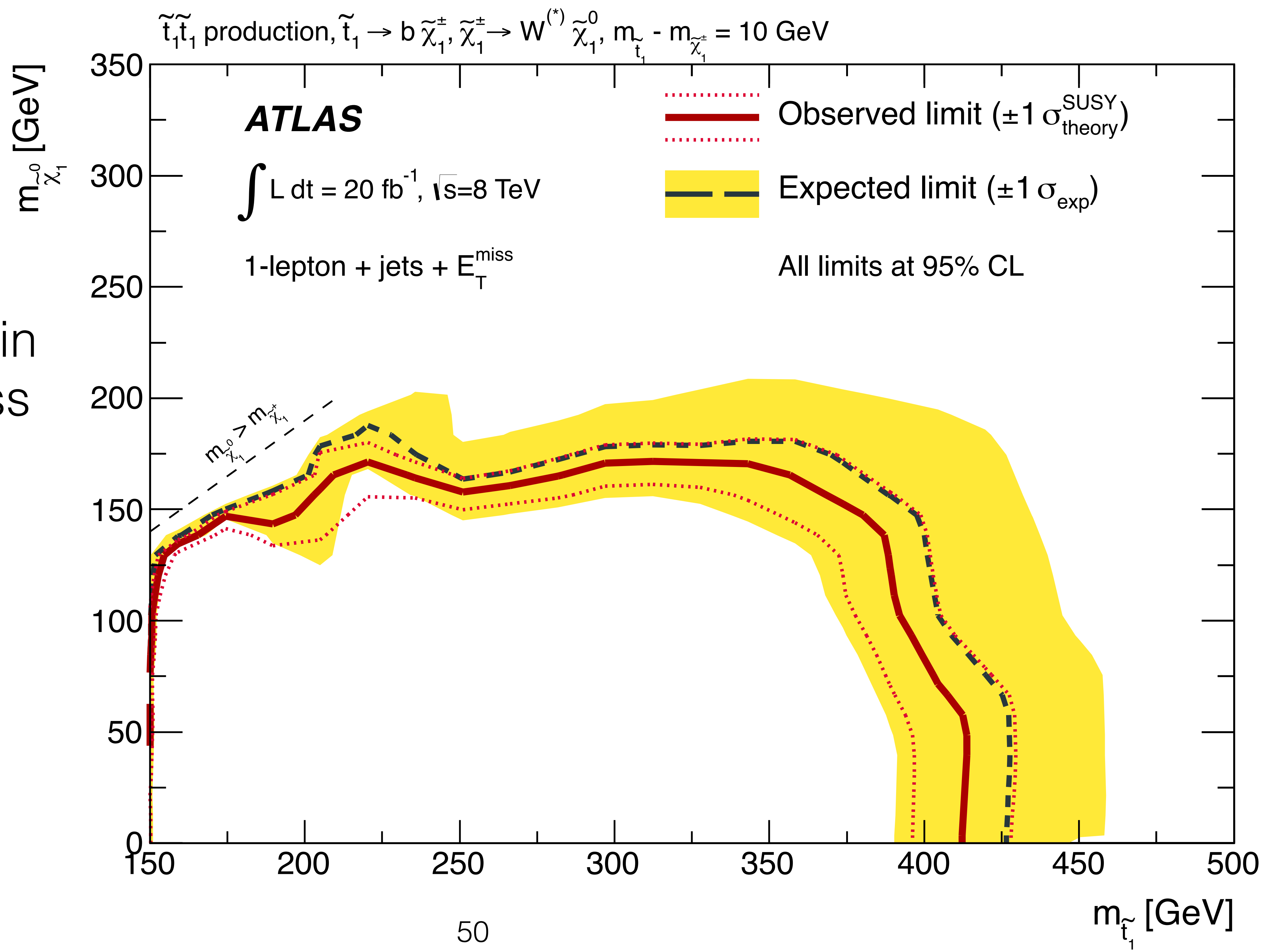


b+Chargino Results

To show 2D exclusions, need a hypothesis on $m_{chargino} = f(m_{neutralino}, m_{stop})$

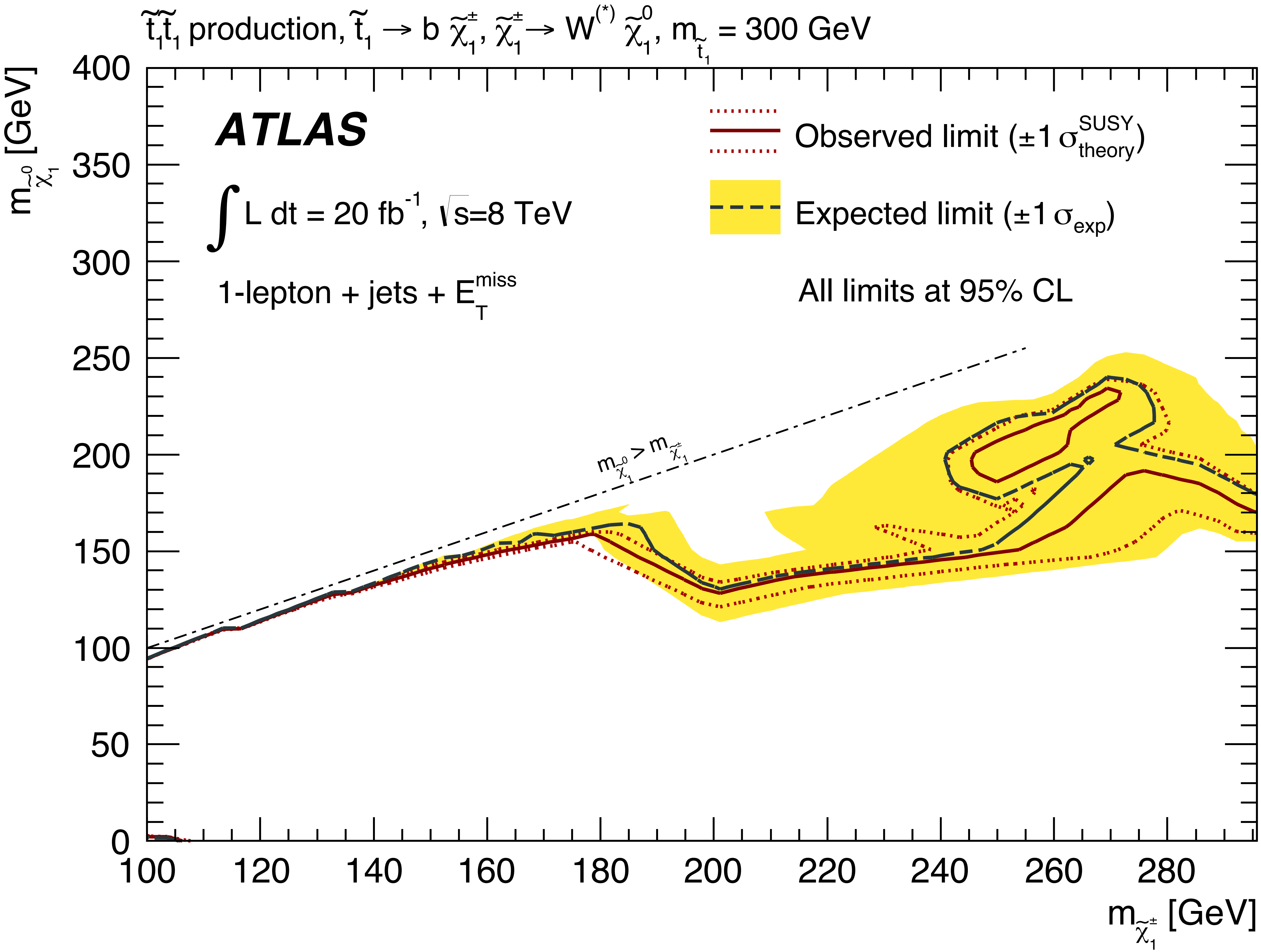
Another choice, f(x,y)=y-10 GeV

Can this explain the WW excess (and other excesses)? see arXiv: 1406.0858



b+Chargino Results

m_{stop} = 300 GeV

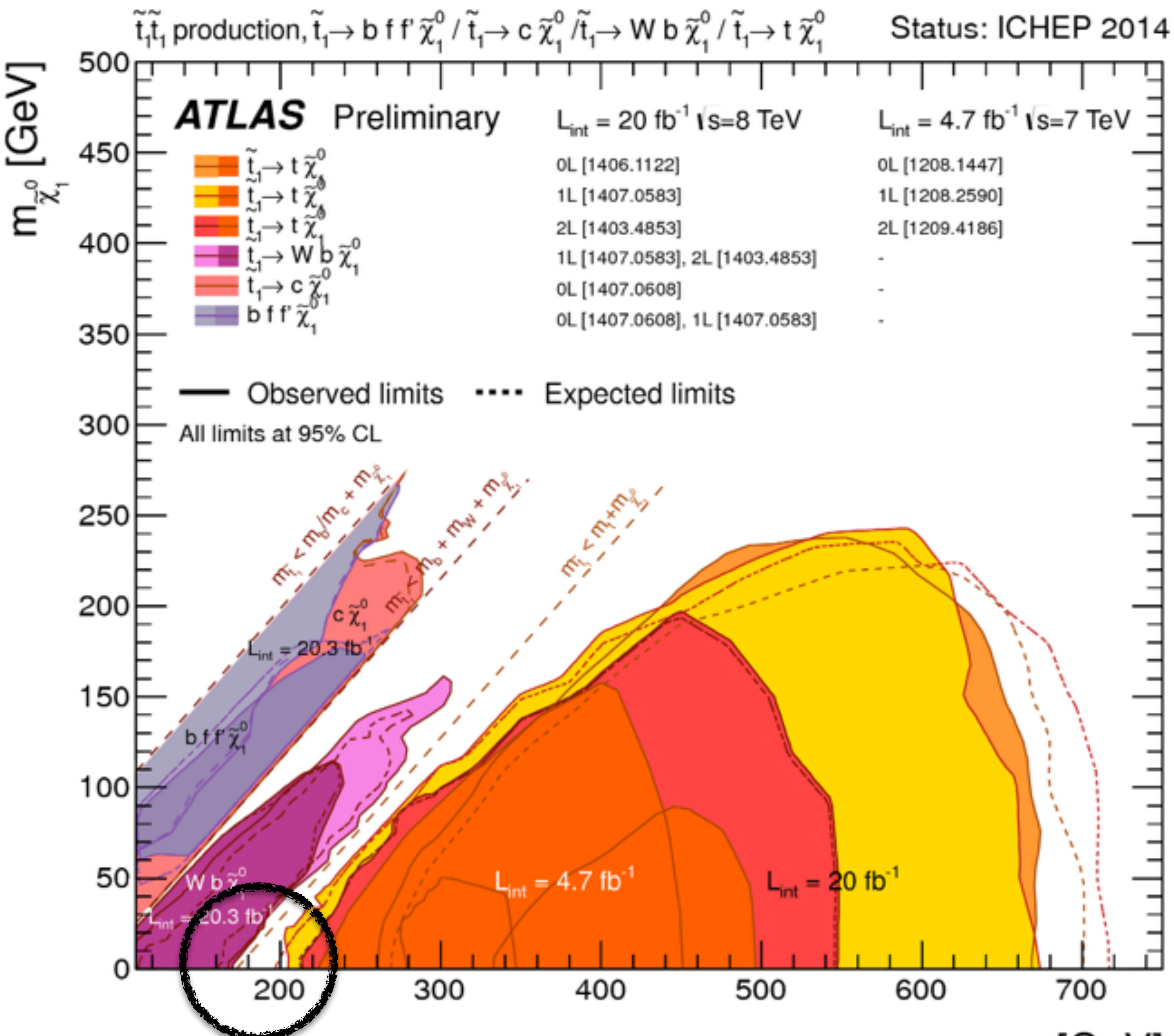


A Sneaky Light Stop

Till Eifert (CERN) and BN

arXiv:1410.7025

The stealth stop is difficult: looks like the SM!

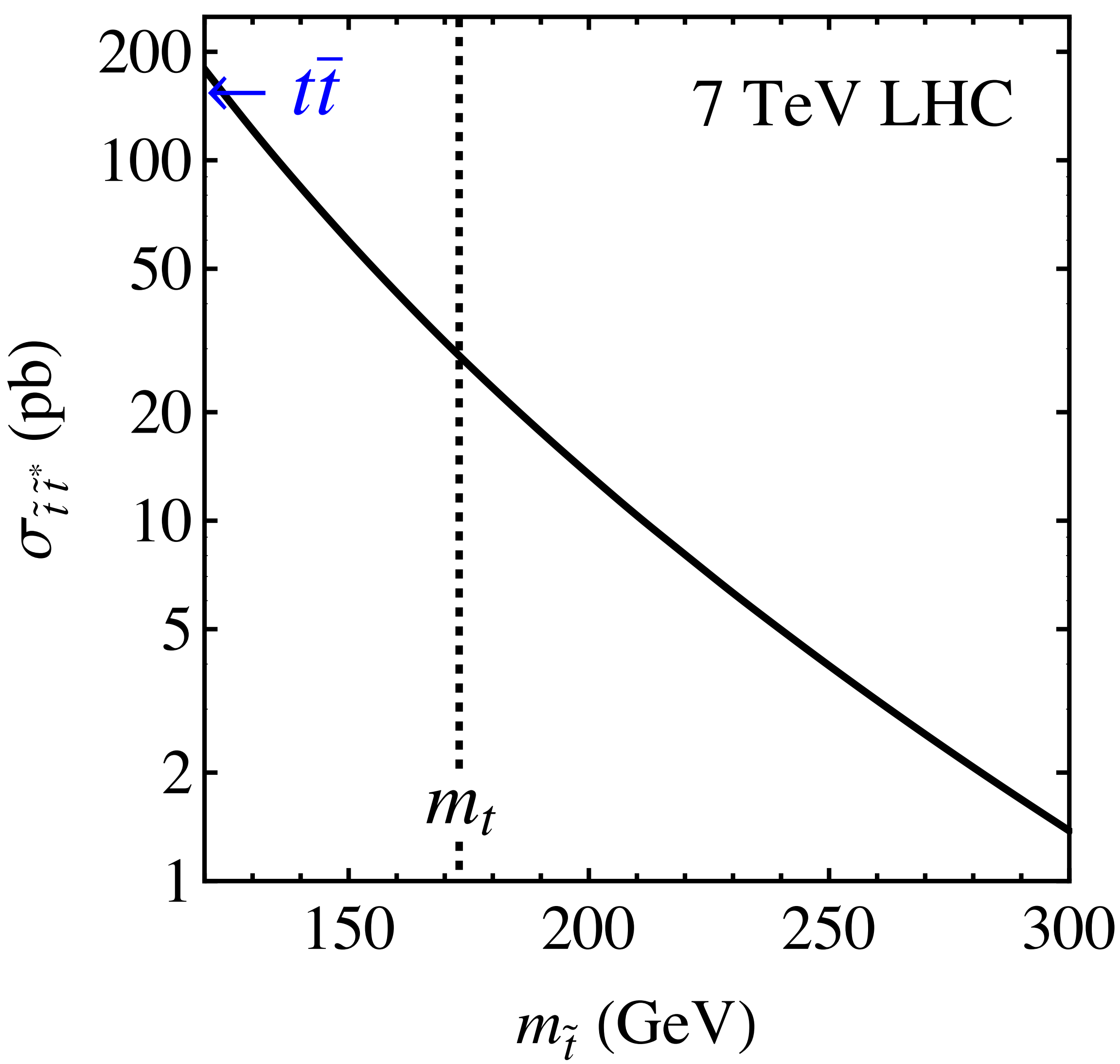


$m_{stop} \sim m_{top}$

The stealth stop is difficult: looks like the SM!

One way forward: Precision top quark properties to complement direct searches

1106.0030



SUSY σ set by the stop mass

Cross Section

σ_{SUSY}~10% x σ_{SM}

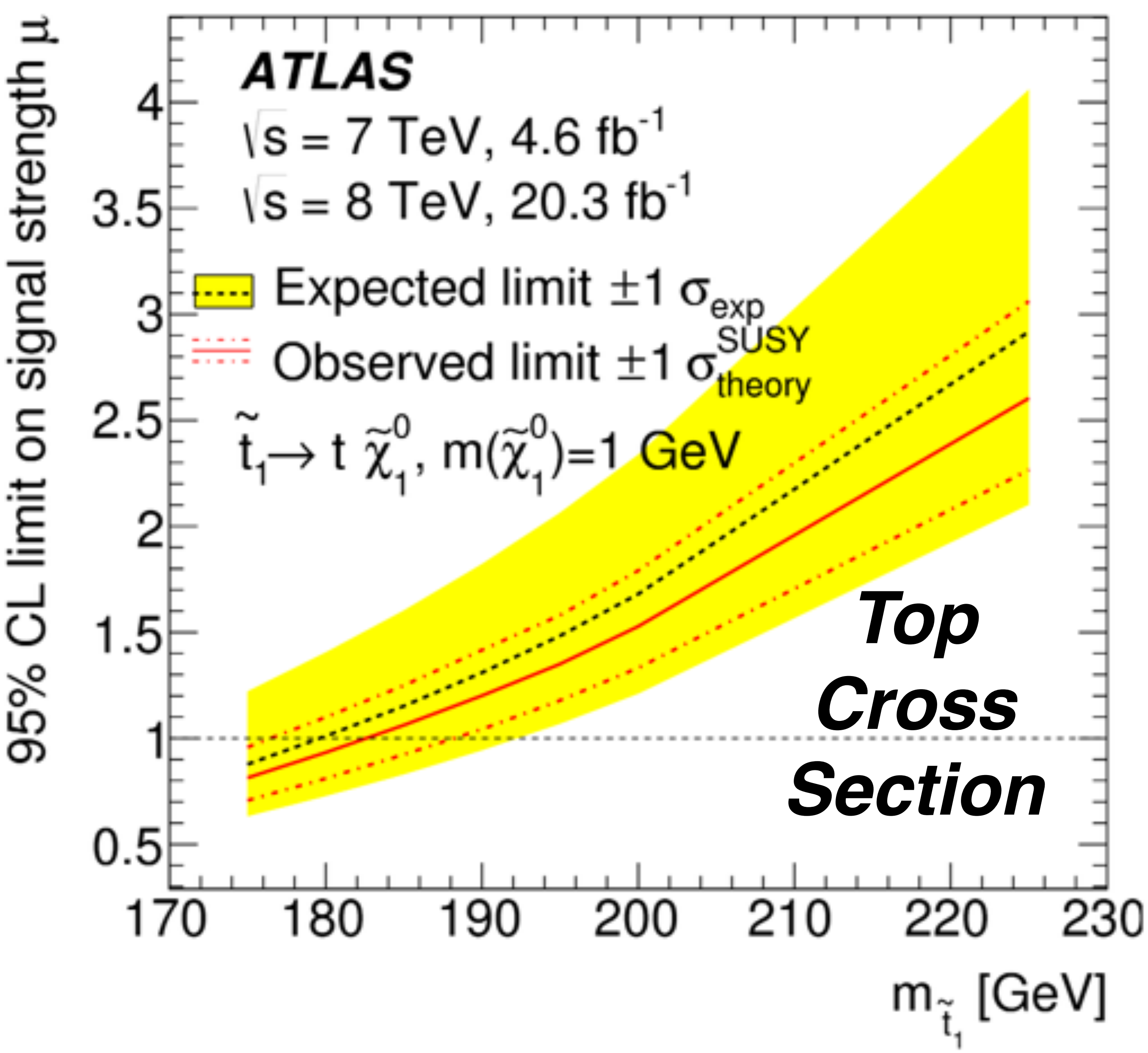
Current experimental precision ~ 4%

Angular Distributions

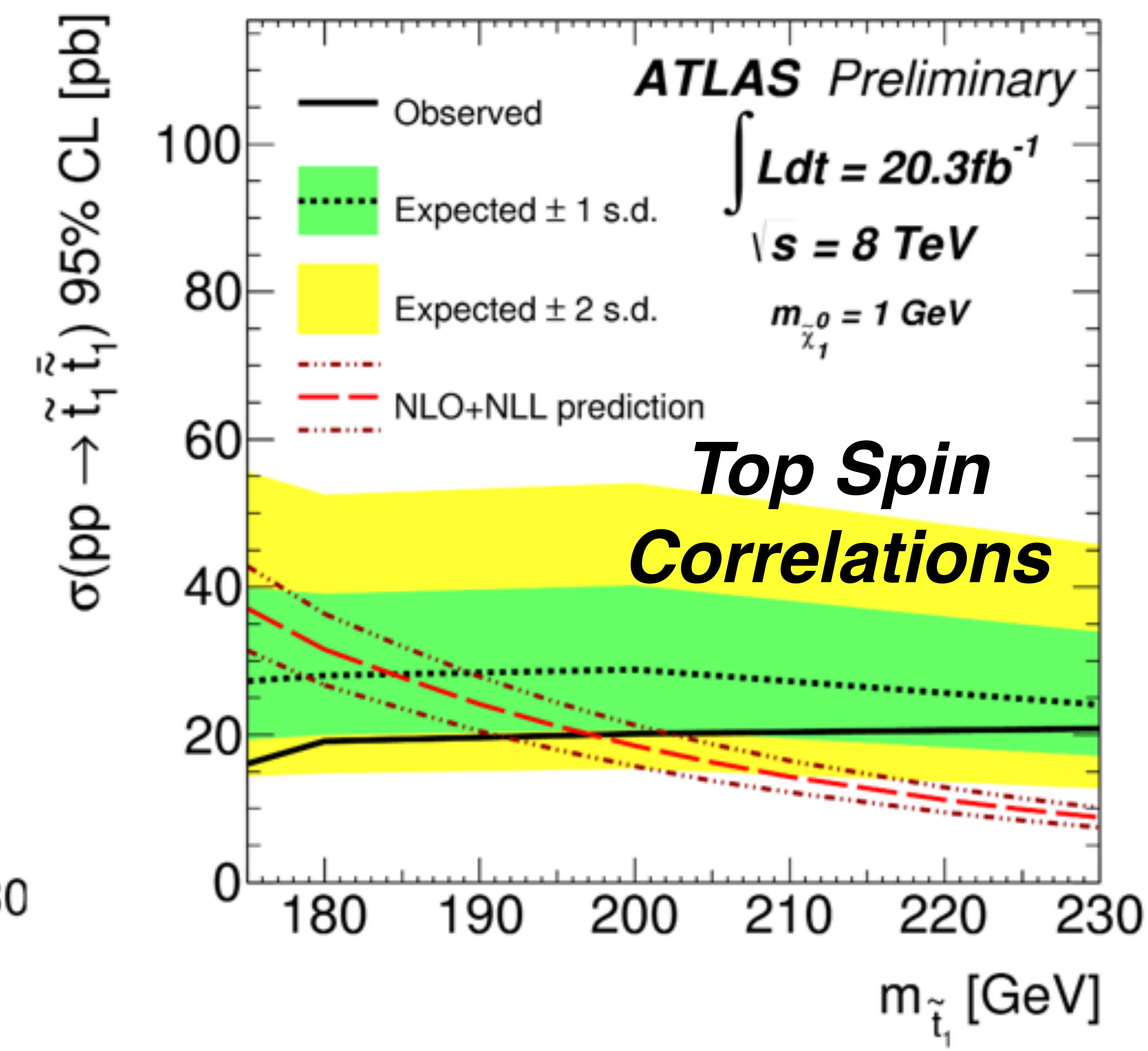
Stop is a scalar; top can be polarized

ATLAS is leading the community on this front: measurements in both cases are used to constrain light stops

1406.5375



ATLAS-CONF-2014-056



$m_{stop} \sim m_{top}$ excluded

Important Assumption: *m_{top} is known*

If there are light stops, they could bias the top mass measurement

The top mass is a parameter of the SM Lagrangian, so we can't use this to find stops

But the cross section prediction depends strongly on the mass!

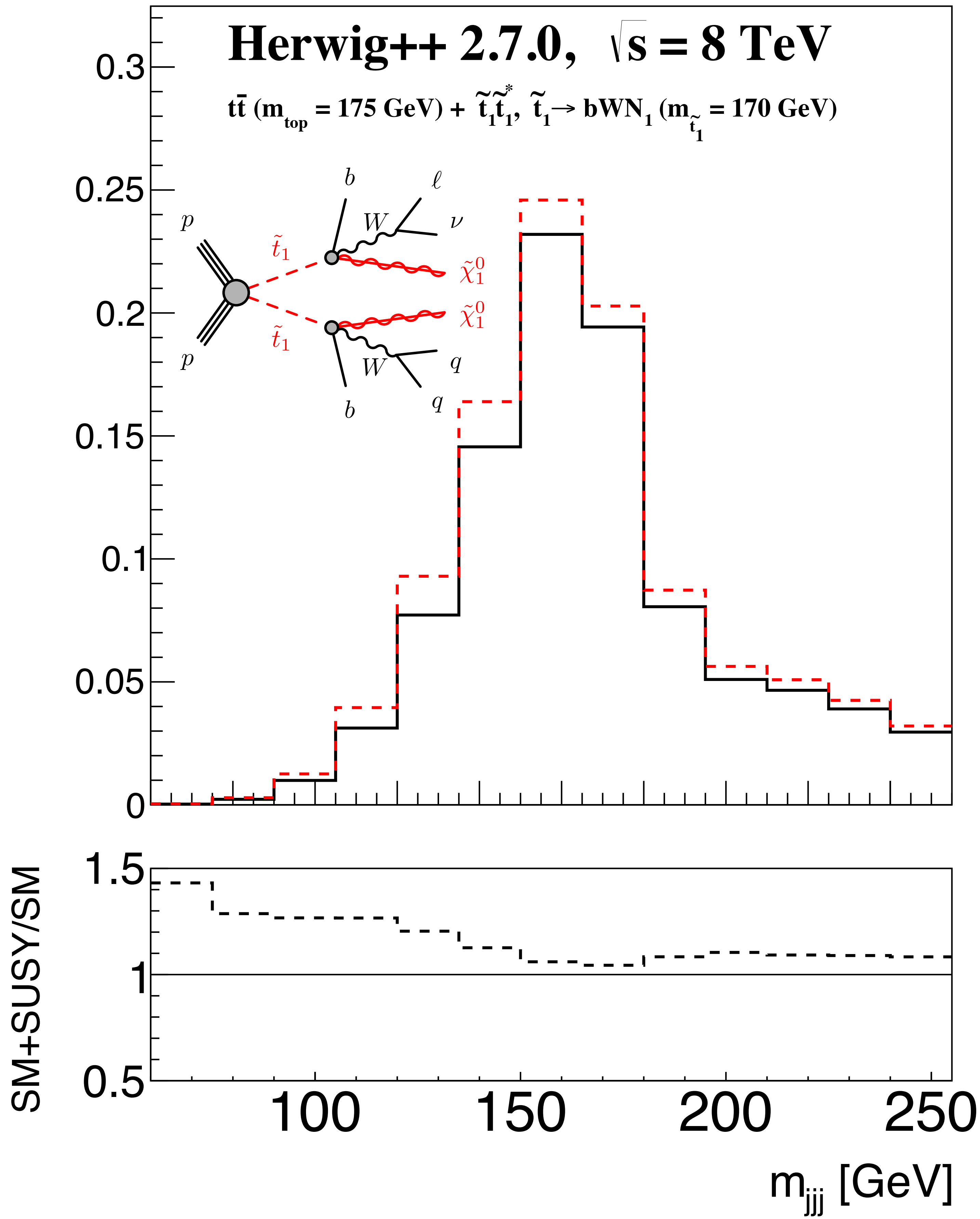
1410.7025: T. Eifert & BN

Light stops can bias the top mass measurements in such a way as to be ***sneaky****:*

1) $m_{top}^{measured} < m_{top}^{truth}$

2) $\sigma_{top}^{measured} > \sigma_{top}^{truth}$

3) $\sigma_{top}^{measured} \sim \sigma_{top}^{truth} + \sigma_{SUSY}$



Feynman Diagrams from 1407.0583

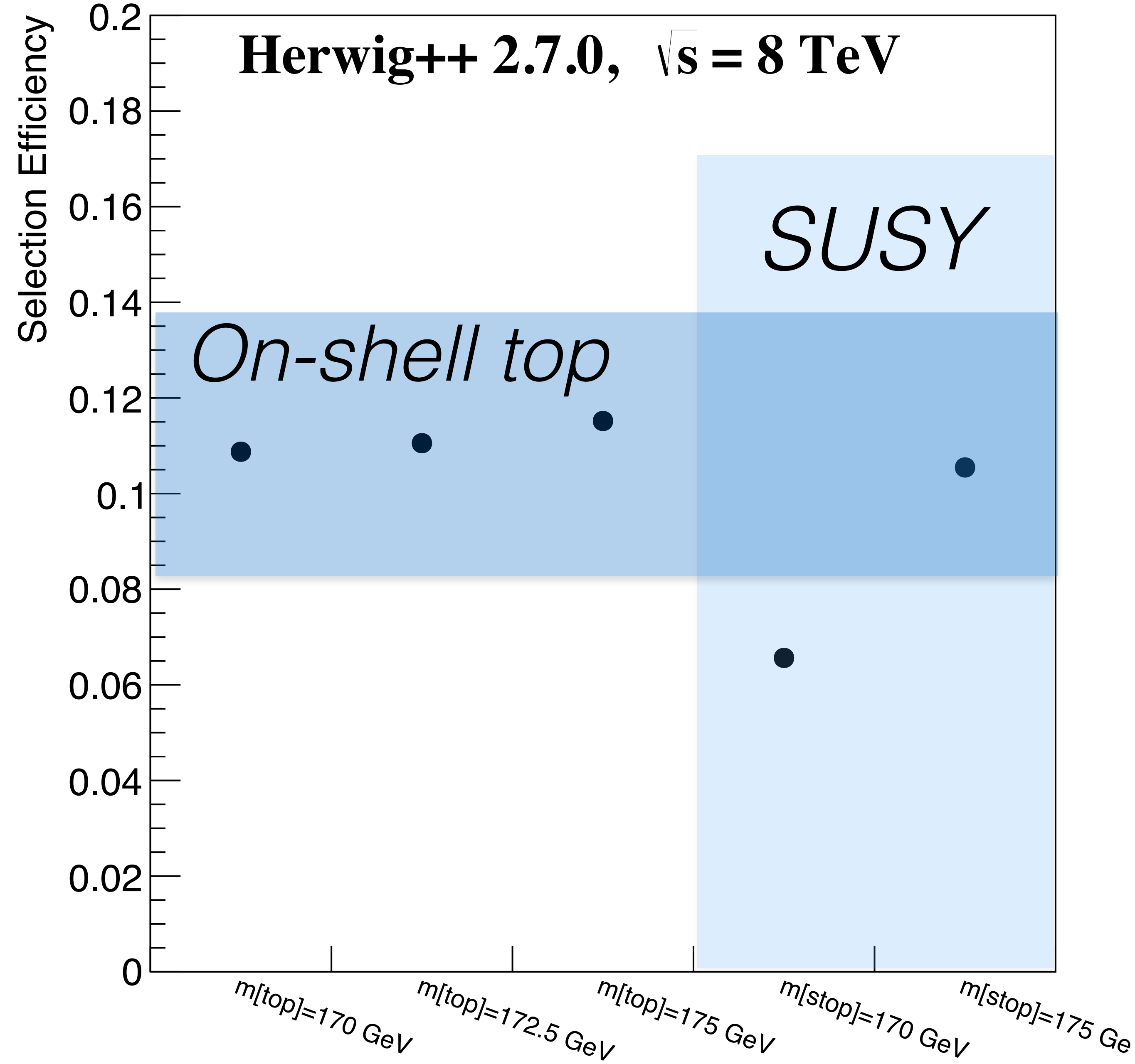
*To quantify the existence of **sneaky** stops, we simulate SM and SUSY events*

Herwig++ nominal
Madgraph+Herwig as a cross-check

We perform a simple mass measurement, using a χ^2 to create a m_{jjj} observable

$$\chi^2 = \frac{(m_{j_1 j_2 b_1} - m_{b_2 l \nu})^2}{(20\ \mathrm{GeV})^2} + \frac{(m_{j_1 j_2} - m_W)^2}{(10\ \mathrm{GeV})^2},$$

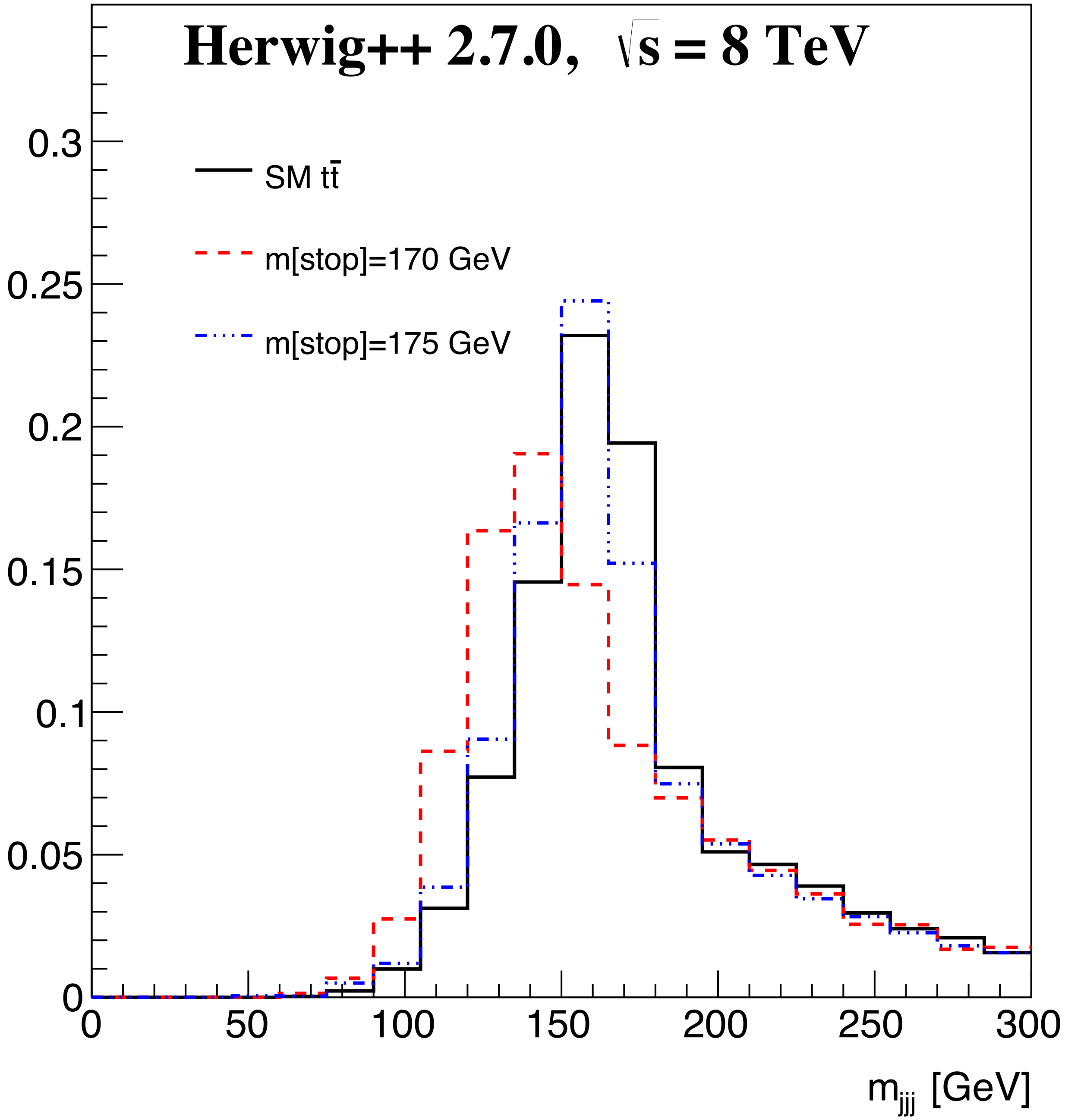
1410.7025: T. Eifert & BN

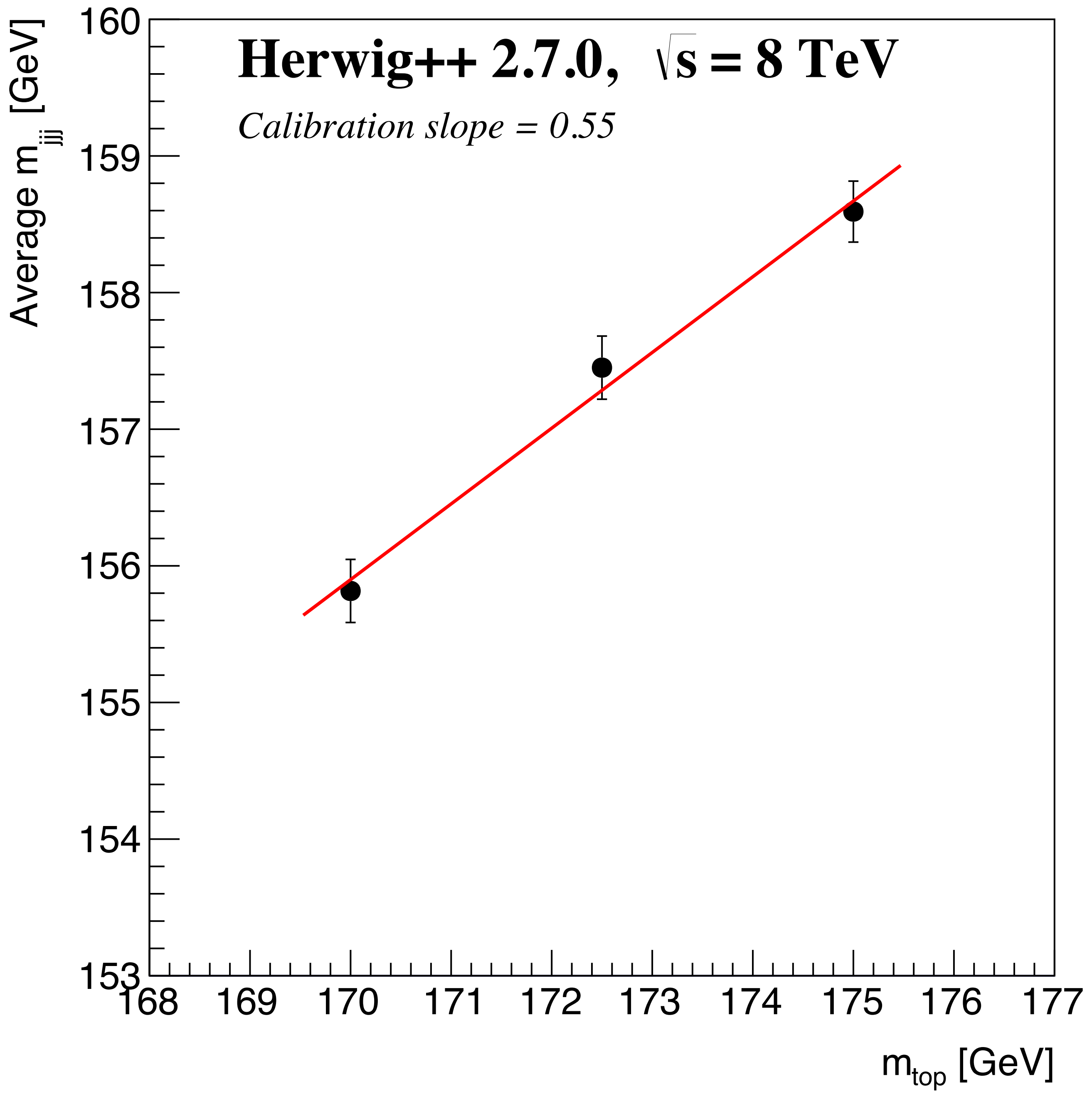


Choose semileptonic events with jets/leptons above a p_T threshold

Mass sensitive observable: $\langle m_{jjj} \rangle = f(m_{top})$

1410.7025: T. Eifert & BN

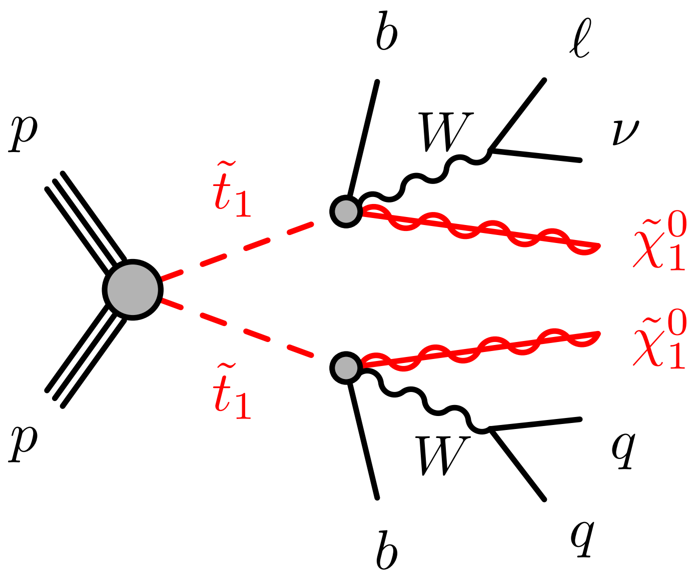




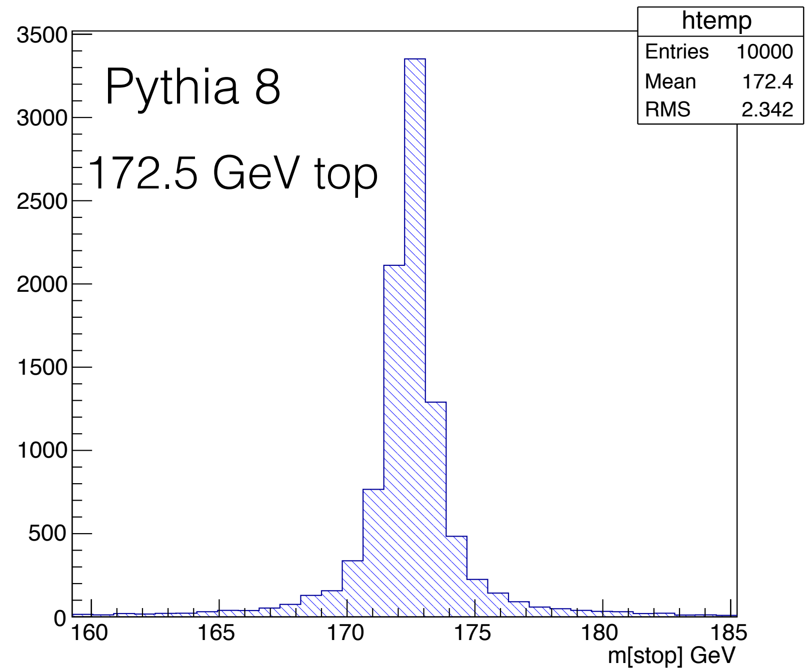
‘Measure’ $\langle m_{jjj} \rangle$ and then invert f to infer m_{top}

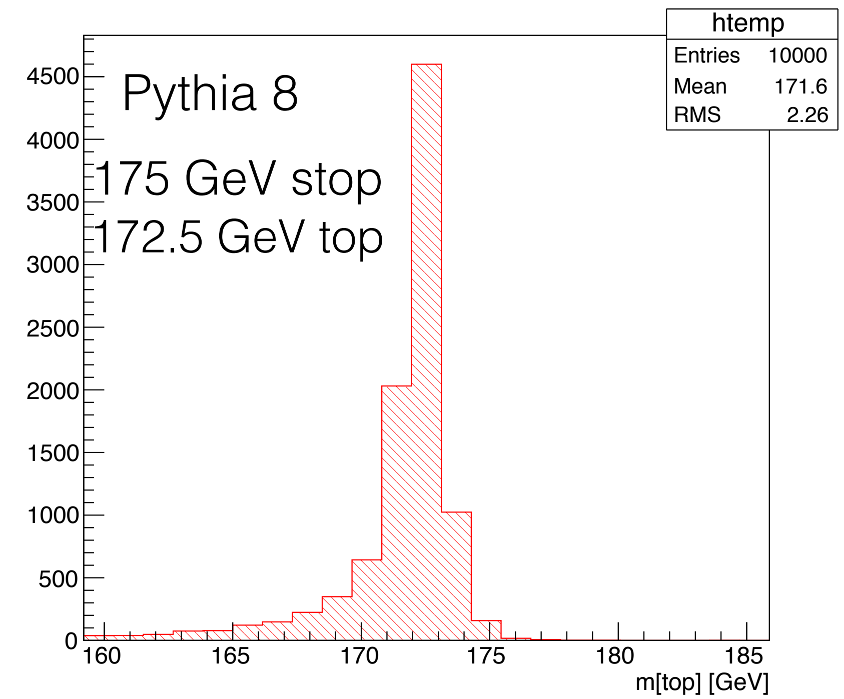
cross-checked with a simple template fit

Origin of (Negative) Biases



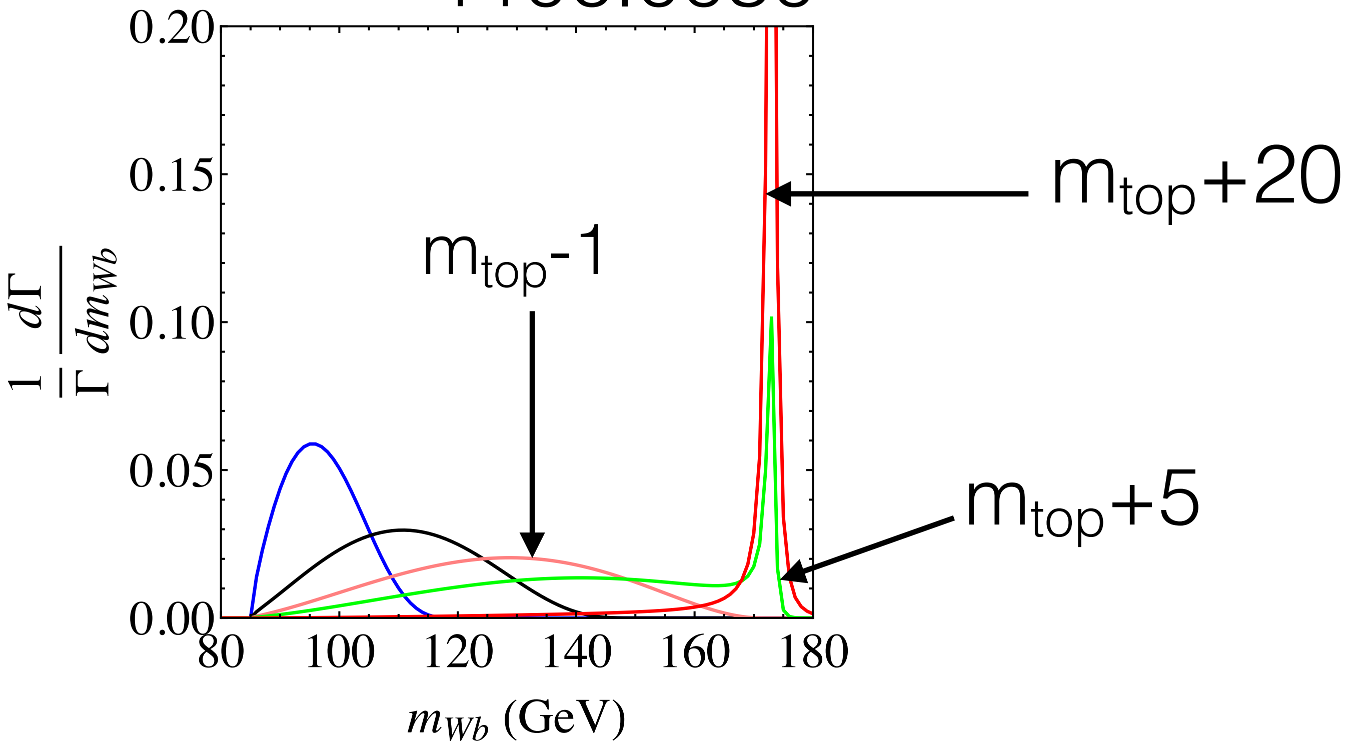
For resonant tops, the BW is sculpted from the finite top/stop widths

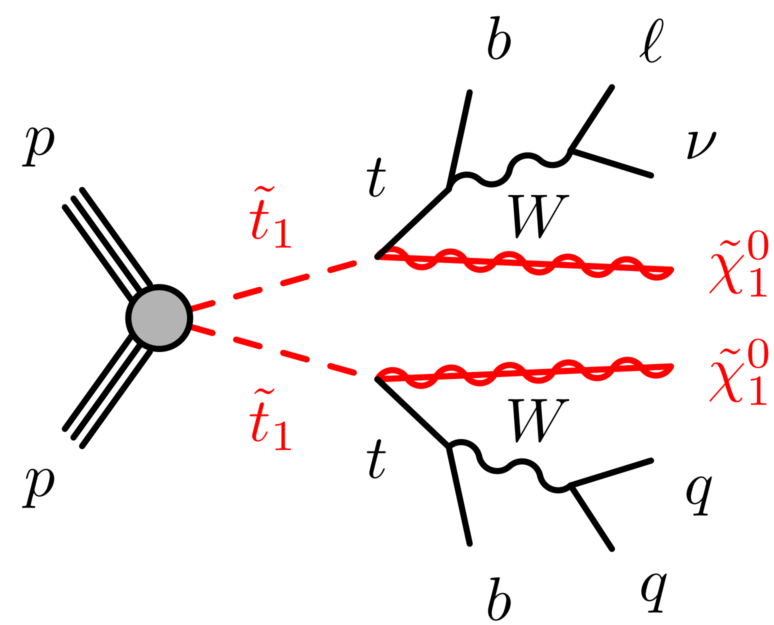




3-body phase space significantly different than for resonant tops

1106.0030

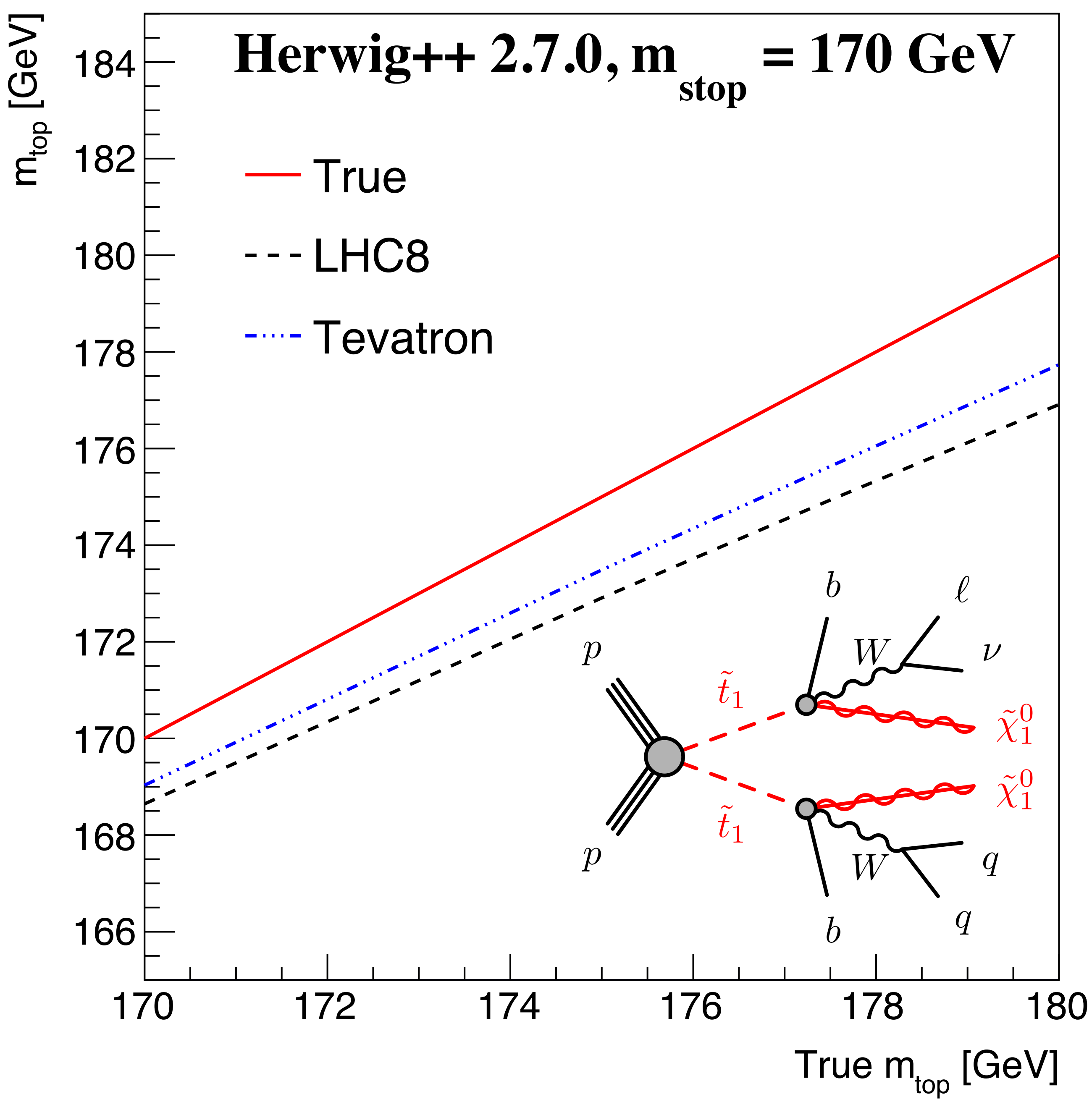


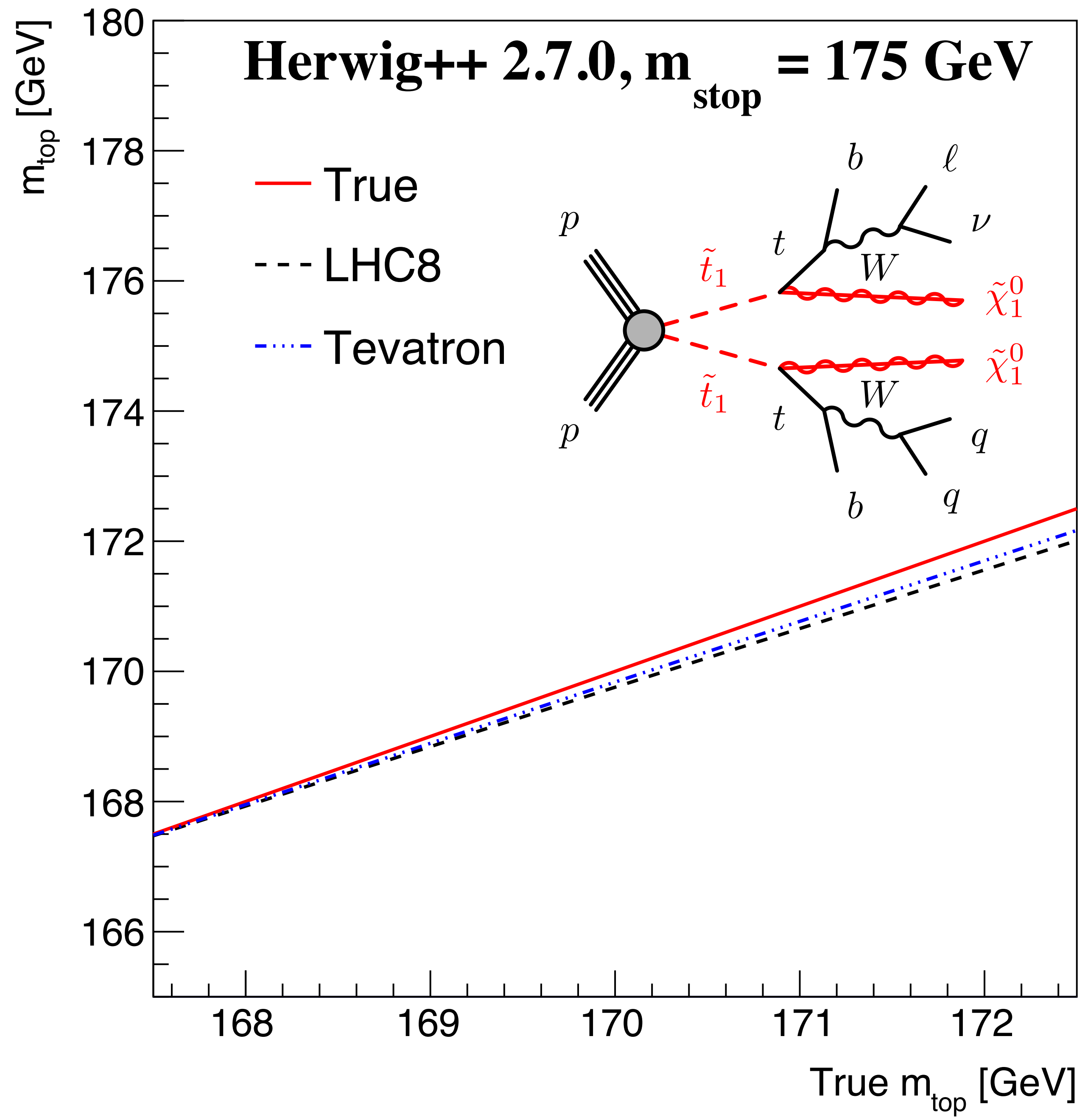


Measured Bias

1410.7025: T. Eifert & BN

For the 3-body decays, larger bias. When there is a resonant top, the bias is very small (LHC results so far are robust).

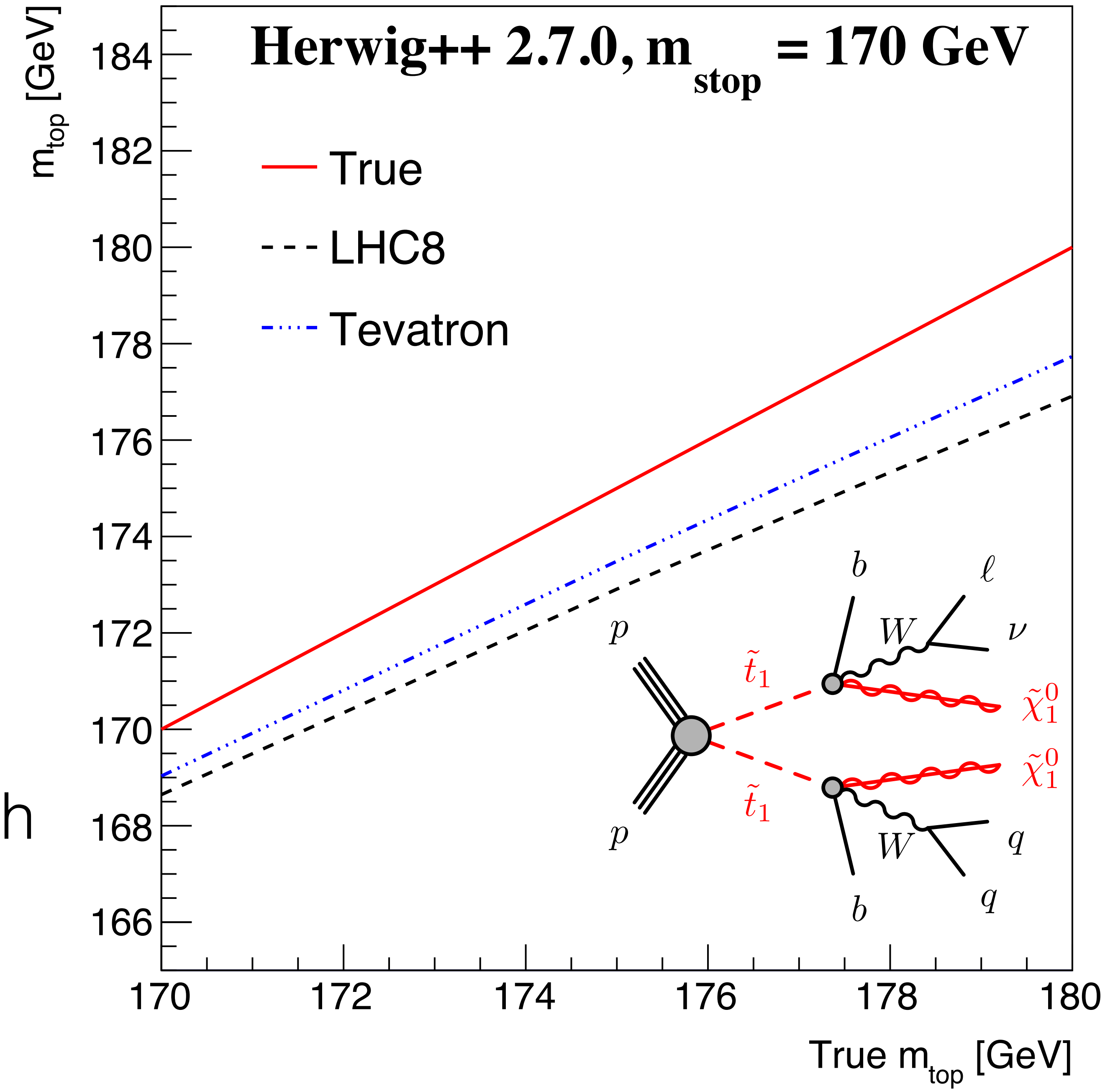




Measured Biases: 3-body

A 170 GeV stop can hide in within the current measurement uncertainty

The consistency with the measurement improves for slightly higher stop masses (not shown)



Cross Section Prediction Too High

m_{top}^{true}	$m_{top}^{measured}$		True $\sigma_{t\bar{t}}(m_{top}^{true})$		True $\sigma_{t\bar{t}}(m_{top}^{measured})$		True $\sigma_{\tilde{t}\tilde{t}^*}$		Measured $\sigma_{t\bar{t}}$	
	LHC8	Tevatron	LHC8	Tevatron	LHC8	Tevatron	LHC8	Tevatron	LHC8	Tevatron
170	168.6	169.0	271.1	8.0	279.0	8.1	42.6	0.87	295.4	8.5
172.5	170.8	171.3	251.7	7.3	264.4	7.6	42.6	0.87	276.0	7.8
175	172.9	173.5	233.8	6.8	249.7	7.2	42.6	0.87	258.1	7.3

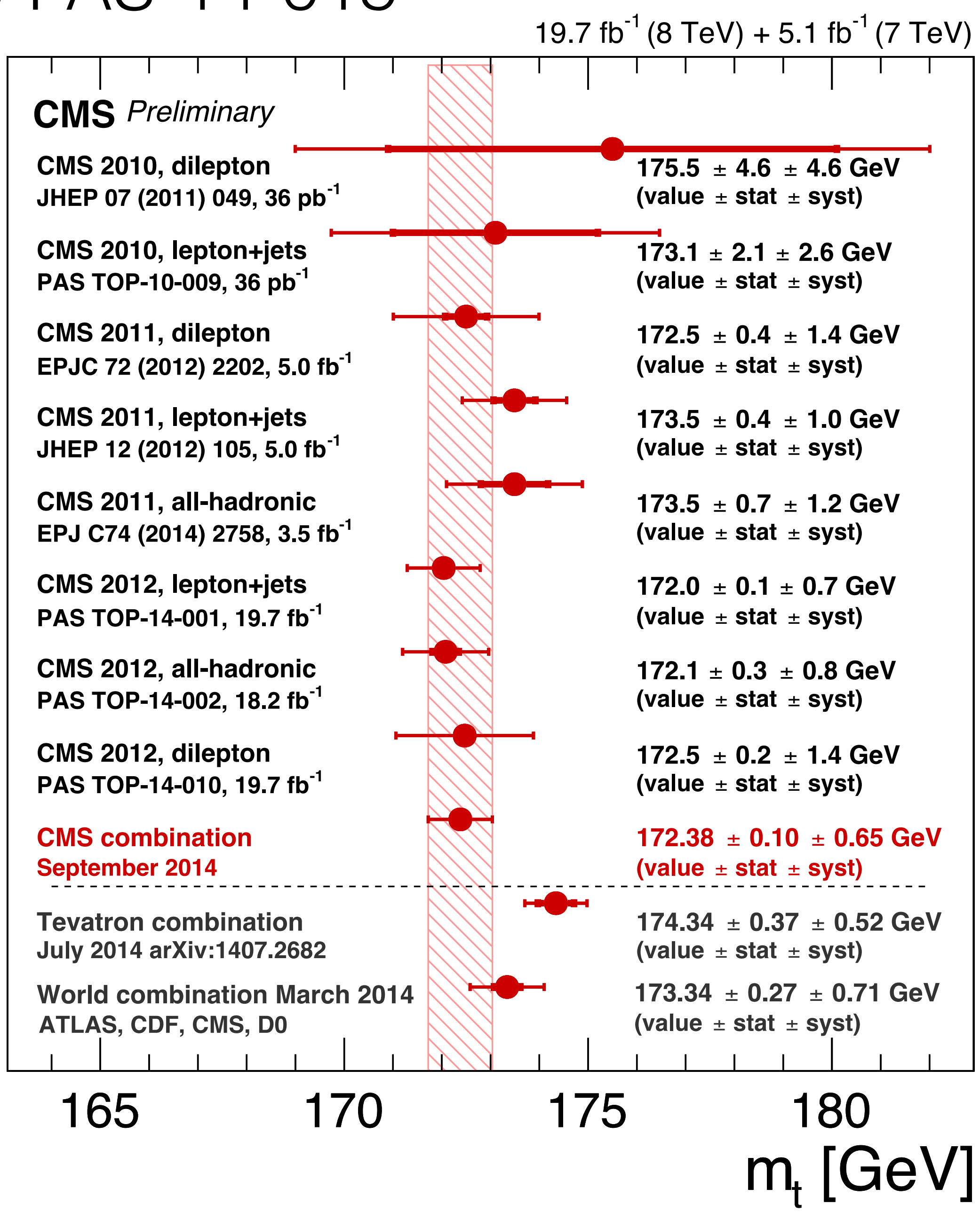
Measured Mass > True Mass

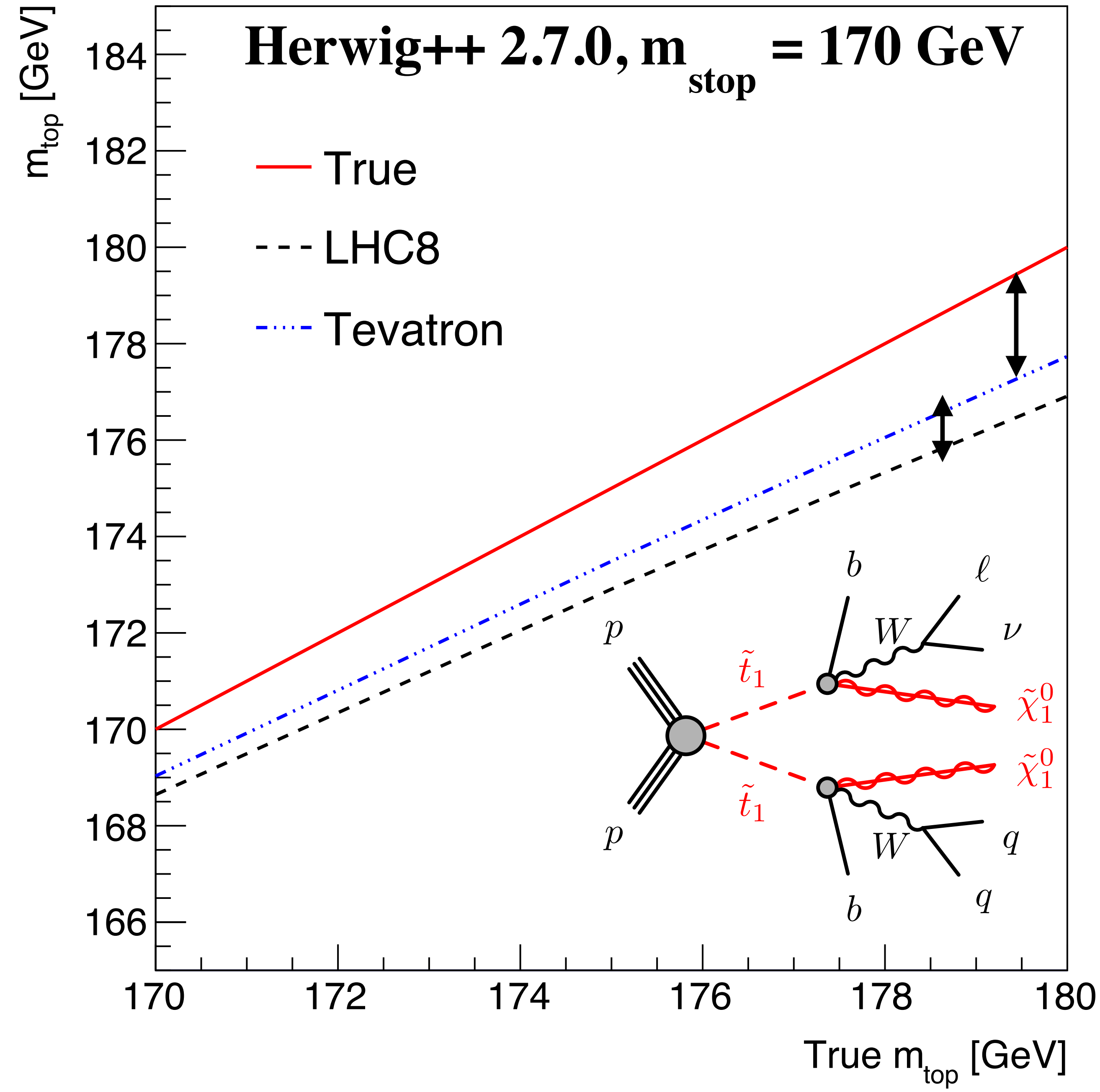
1410.7025: T. Eifert & BN

LHC vs Tevatron

Curiously, the measured Tevatron top mass is slightly higher than the LHC mass

CMS-PAS-14-015



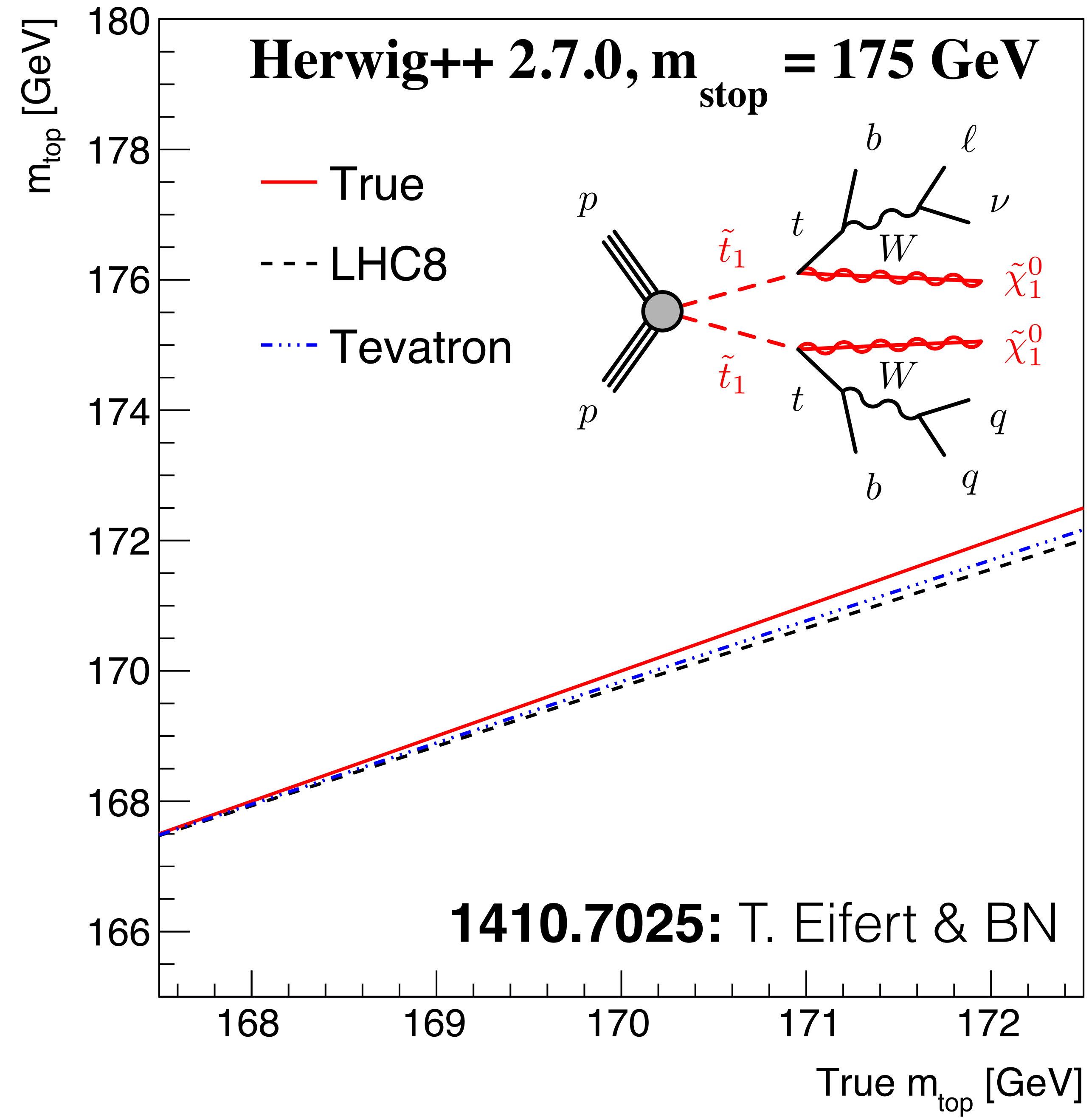


This could be explained by or provide a constraint on light stops.

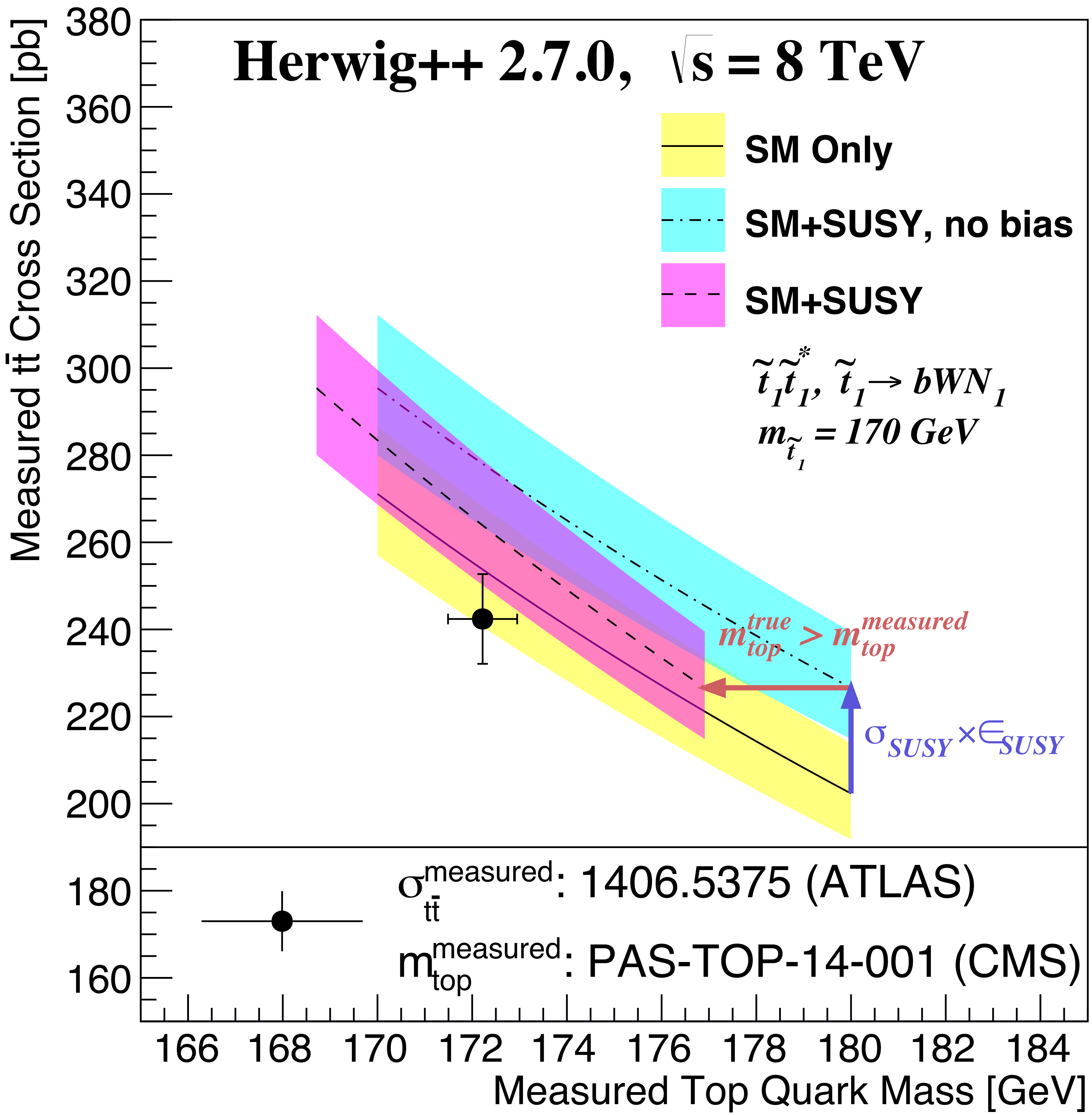
Many caveats: most importably is the fact that different (nominal) generators are used!

Measured Biases: 2-body

Unlike for the 3-body decays, the measurement is nearly unbiased with resonant tops.



m_{top}^{true}	$m_{top}^{measured}$		True $\sigma_{t\bar{t}}(m_{top}^{true})$		True $\sigma_{t\bar{t}}(m_{top}^{measured})$		True $\sigma_{\tilde{t}\tilde{t}^*}$		Measured $\sigma_{t\bar{t}}$	
	LHC8	Tevatron	LHC8	Tevatron	LHC8	Tevatron	LHC8	Tevatron	LHC8	Tevatron
170	169.8	169.8	271.1	8.0	273.7	8.0	36.8	0.70	304.8	8.6
172.5	172.0	172.2	251.7	7.3	255.4	7.4	36.8	0.70	285.4	8.0

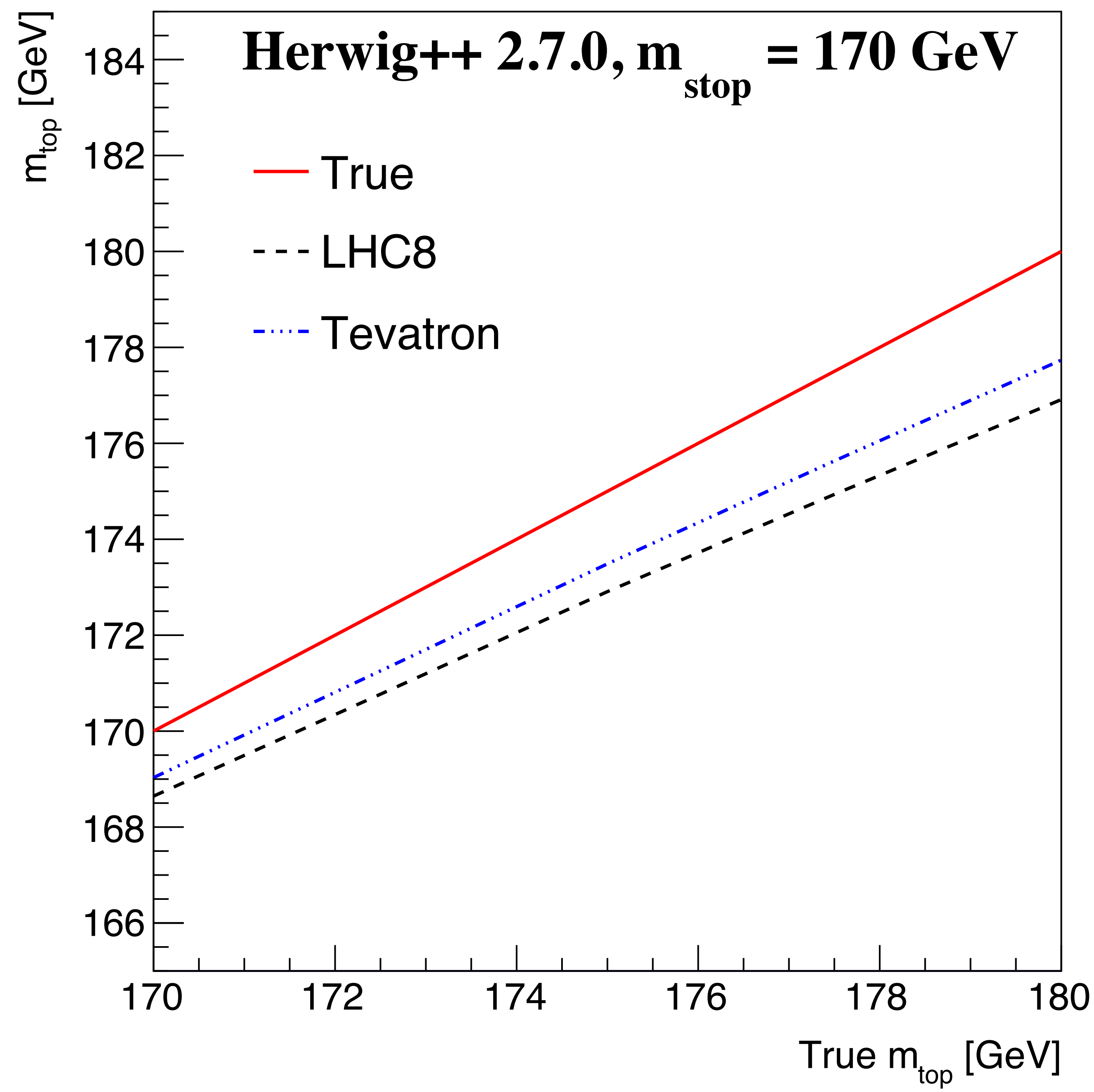


1410.7025: T. Eifert & BN

Conclusions

1410.7025: T. Eifert & BN

Searching for stealth stops will require precision top measurements



Such studies must consider the impact of biases in the top mass, in particular for 3-body decays

*Light, **sneaky**, stops may be hiding in the 8 TeV dataset!*

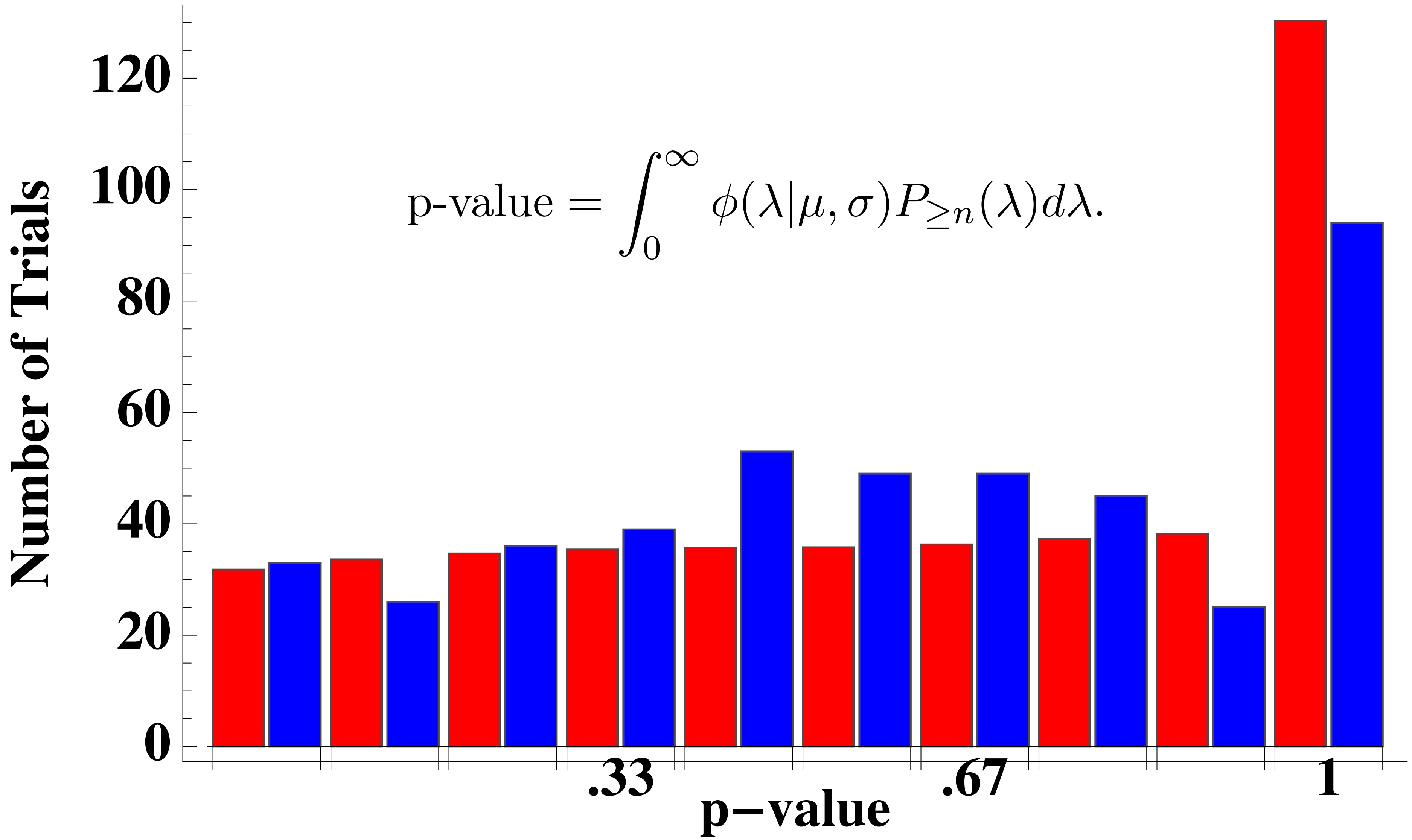
A Meta-analysis of the 8 TeV ATLAS and CMS SUSY Searches

BN and Tom Rudelius (Harvard)

arXiv:1410.2270

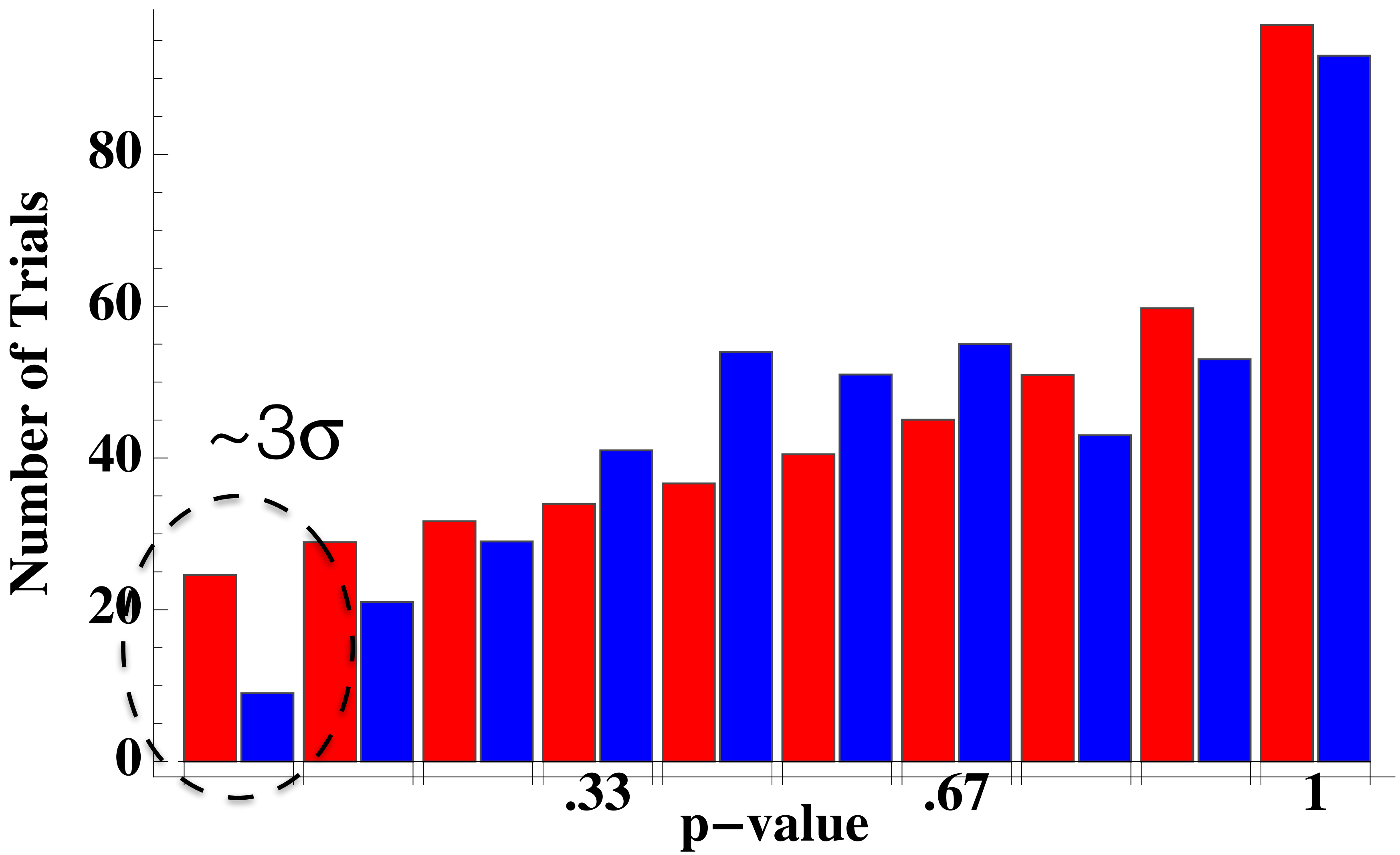
1410.2270: BN & T. Rudelius

Distribution of the 'excesses' p-values



Observed **Expected**

Distribution of the 'deficits' p-values



Observed **Expected**