



# The Shape of Light Stops

arXiv:1205.5805

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Fermilab Theory Seminar
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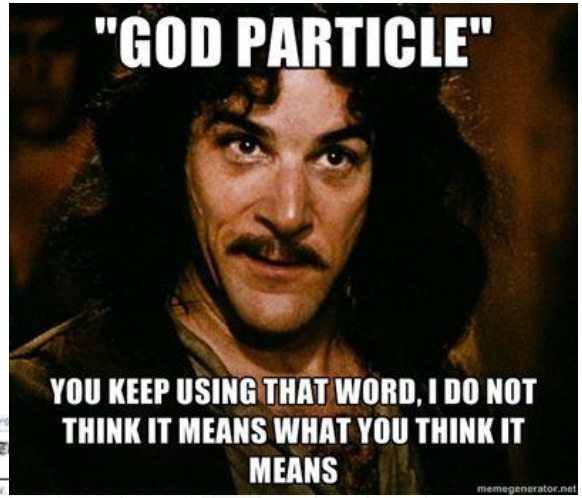
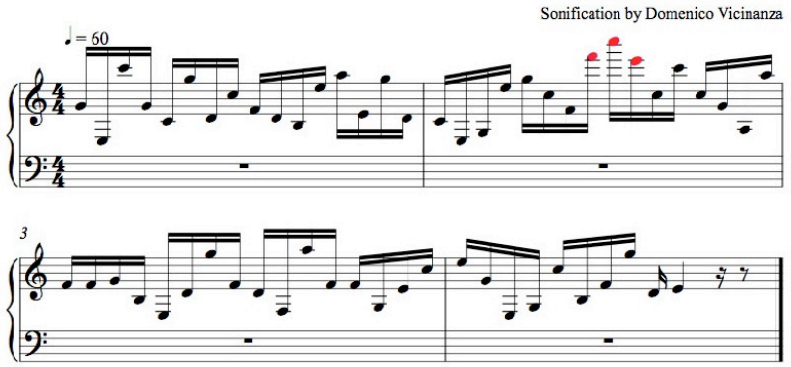
# It's been a good year for particle physics

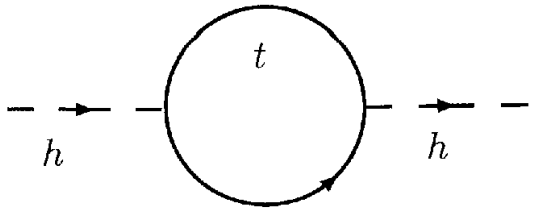




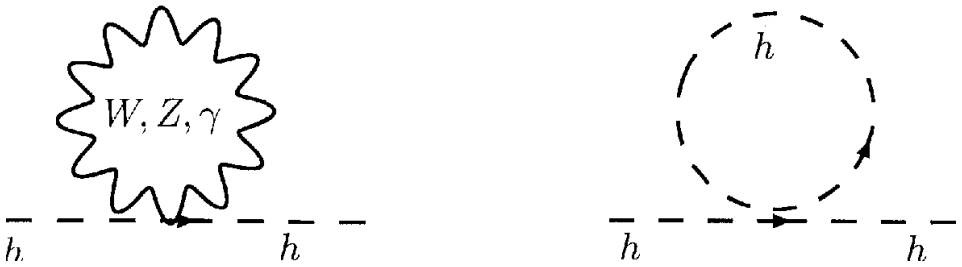





# But the Higgs comes with some baggage...




$$-\frac{3}{8\pi^2}y_t^2\Lambda^2 \sim -(2\ \mathrm{TeV})^2$$




$$\frac{1}{16\pi^2}\lambda^2\Lambda^2 \sim (500\ \mathrm{GeV})^2$$

$$\frac{1}{16\pi^2}g^2\Lambda^2 \sim (700\ \mathrm{GeV})^2$$

$$m_H^2 = m_{\mathrm{tree}}^2 + \Delta m_H^2$$

fine-tuning

↕

"hierarchy problem"

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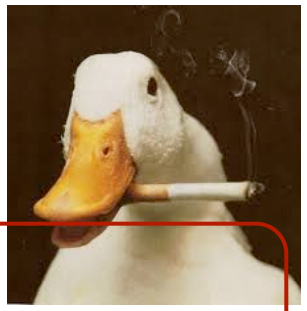

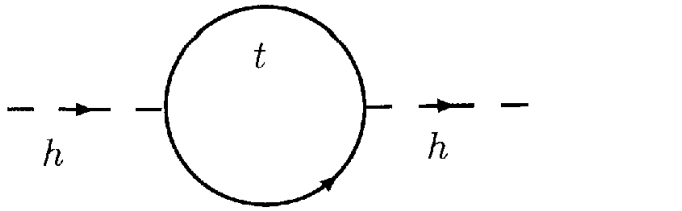


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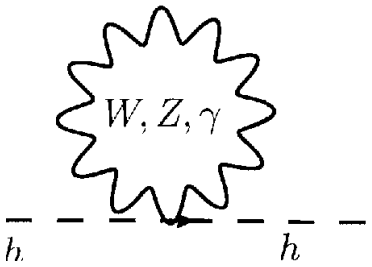


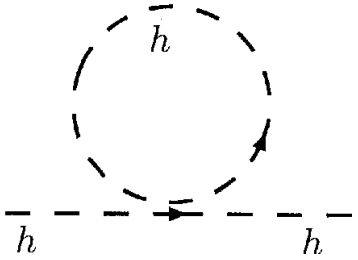


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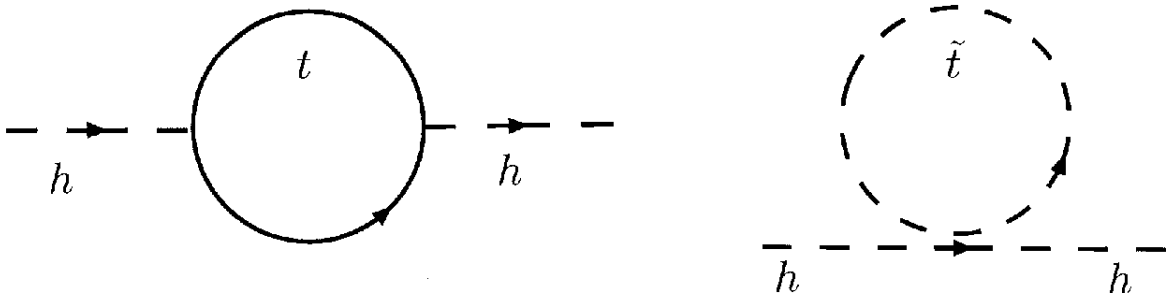
# Enter SUSY

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fermion loop

$$\Delta m_H^{1-\mathrm{loop}} = F(m_1, m_2, \theta_t)$$

scalar loop comes in with opposite sign!

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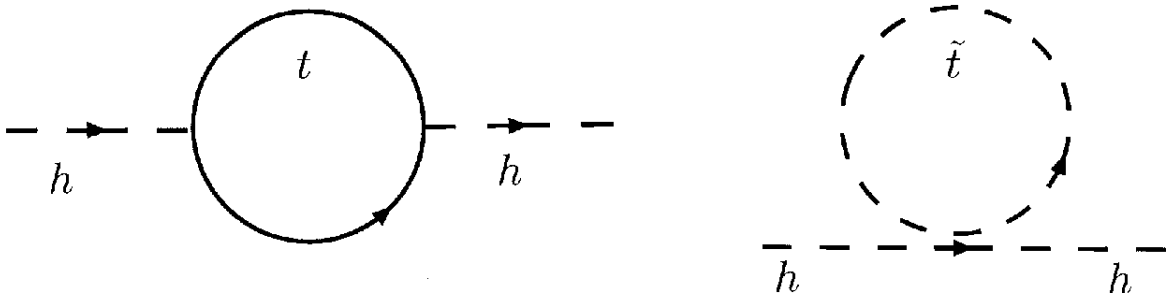


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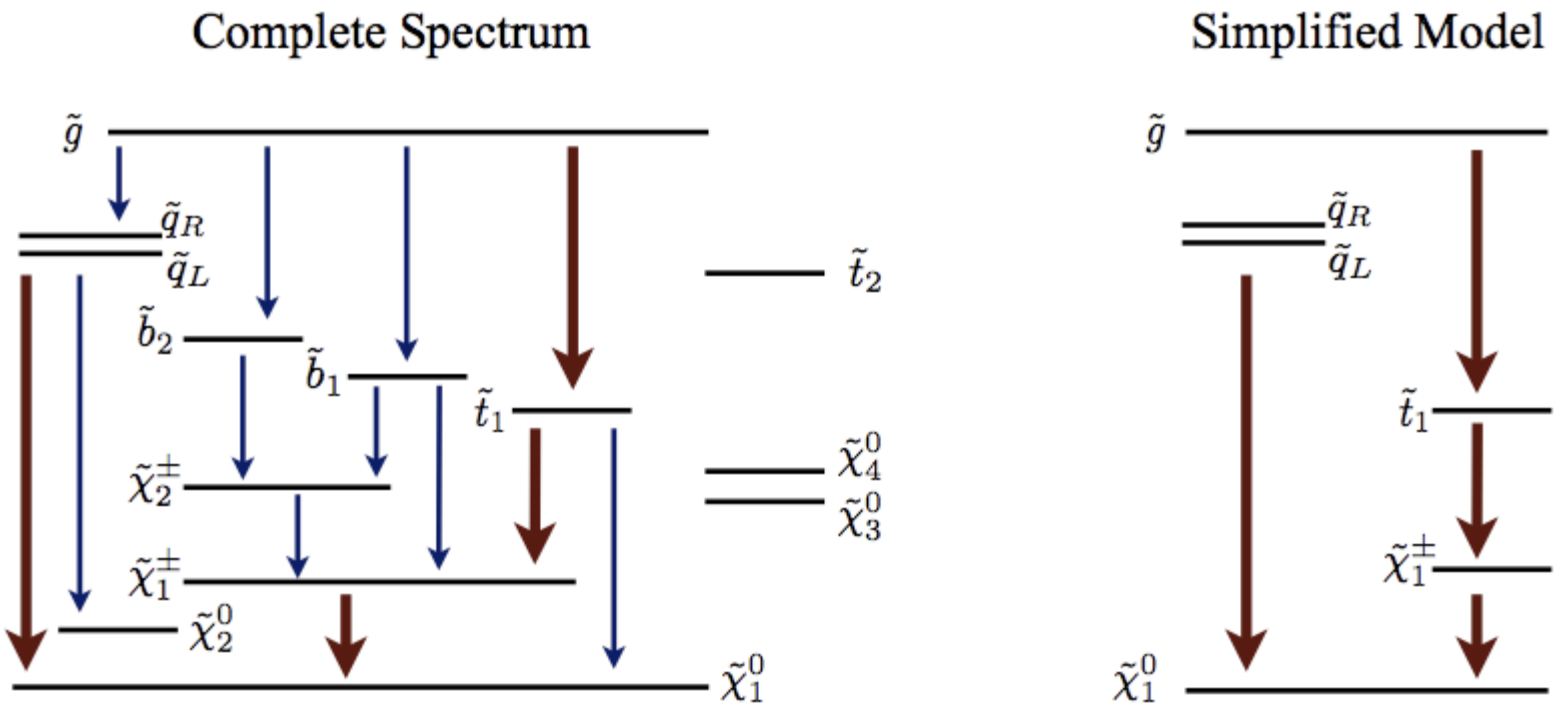
Once again, to avoid large degree of tuning we expect the top partner to be near the mass of the top.

# Simplified Models

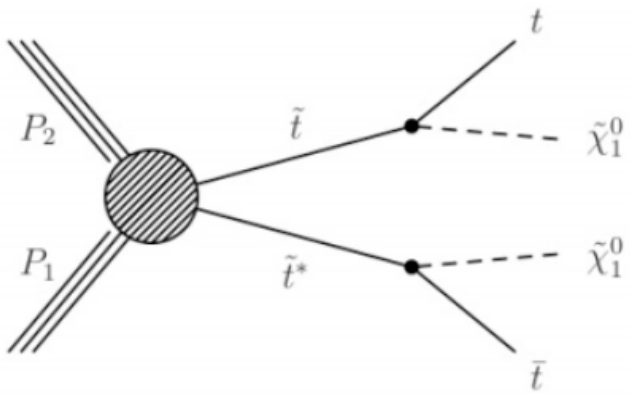



M. Lisanti

# Simplified Models

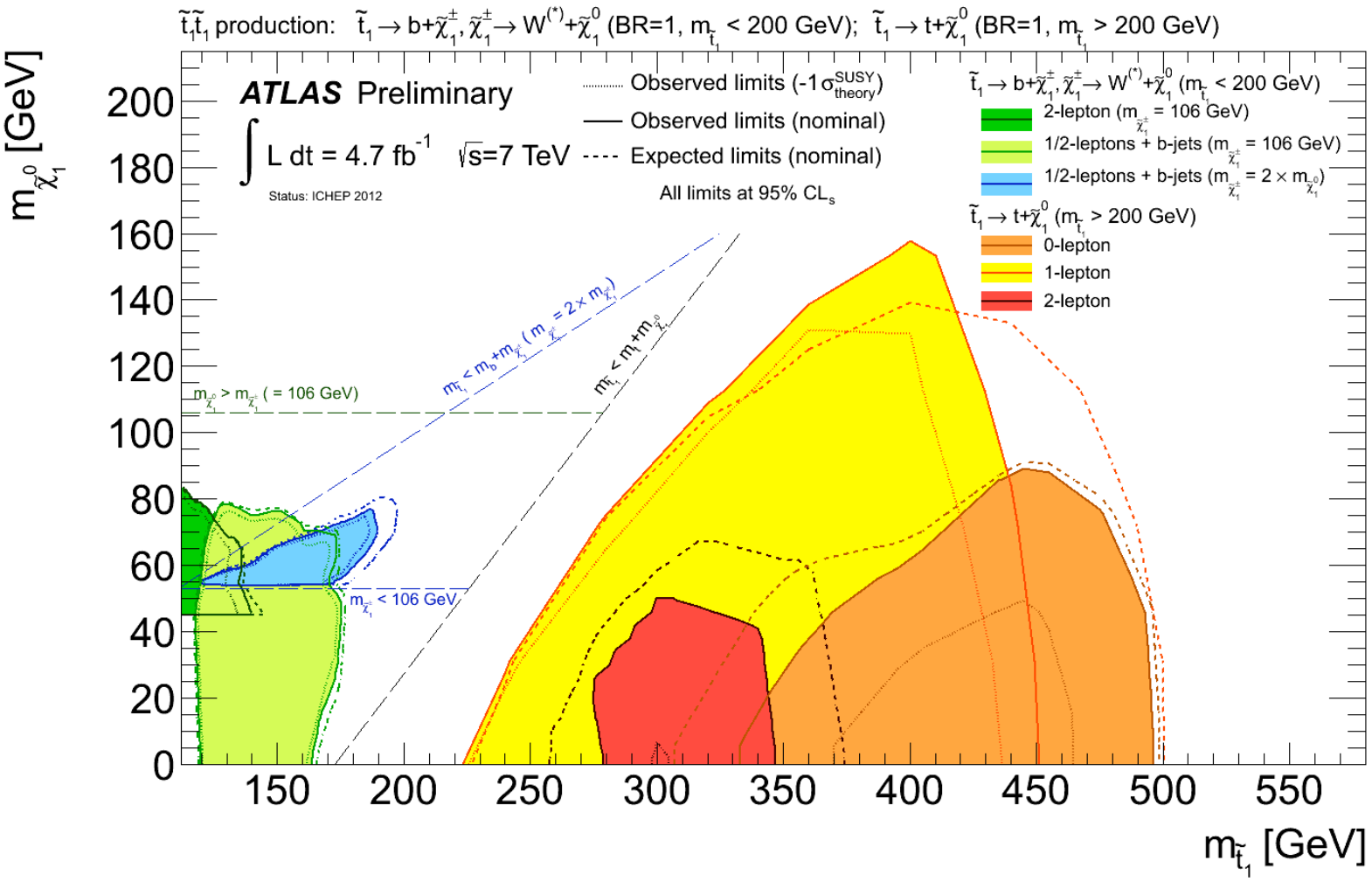
- remove complications from model-dependent details
- focus only on the kinematics
- organize theories with common signatures into a single category
- gives a more complete picture of parameter space

# direct stop production




- pair produce stop
- consider: $\tilde{t} \rightarrow t\chi^0$, most generic
- signature: top-pair + MET

# Experimental results: ICHEP2012



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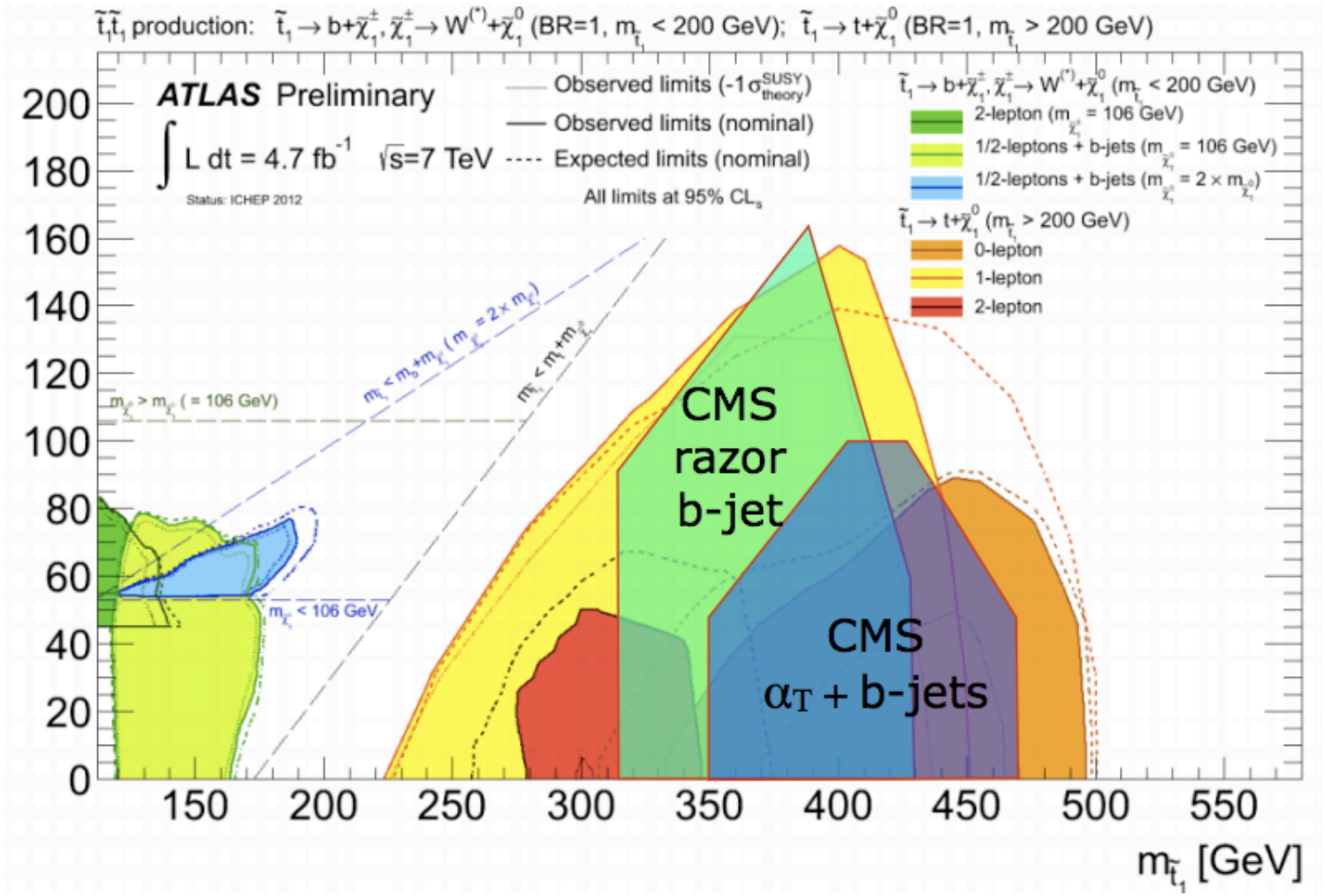
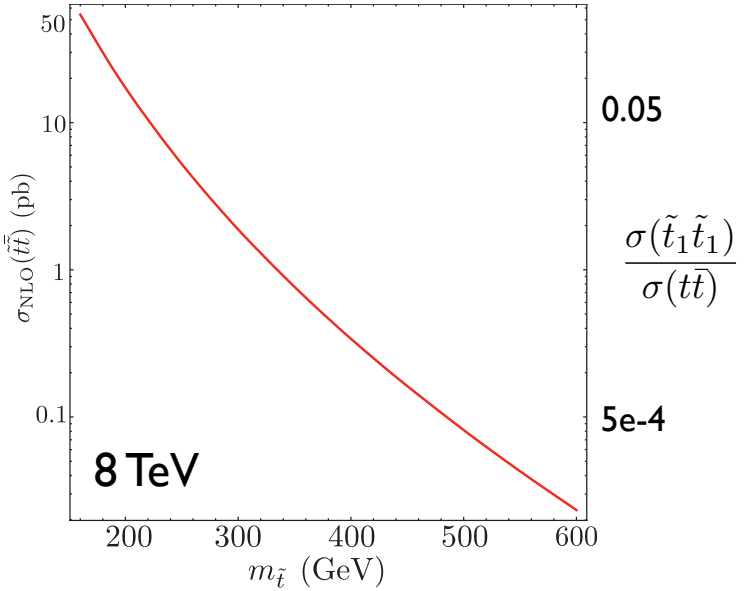


# direct stop production

- unfortunately, looks very similar to top-pair production, especially if stop and top masses are near degenerate
- pessimistic point of view: not possible to distinguish between the two
- small signal cross-section



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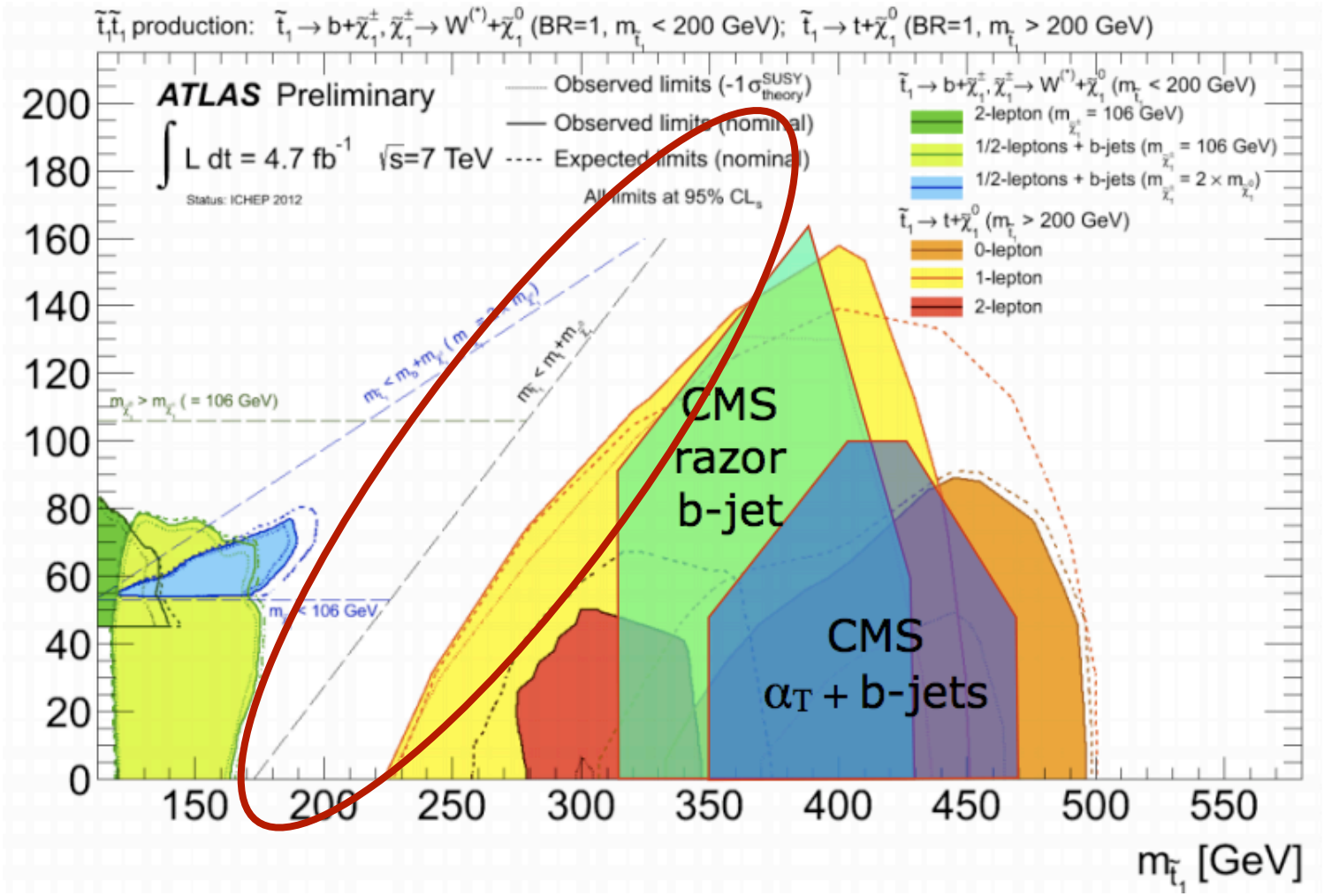

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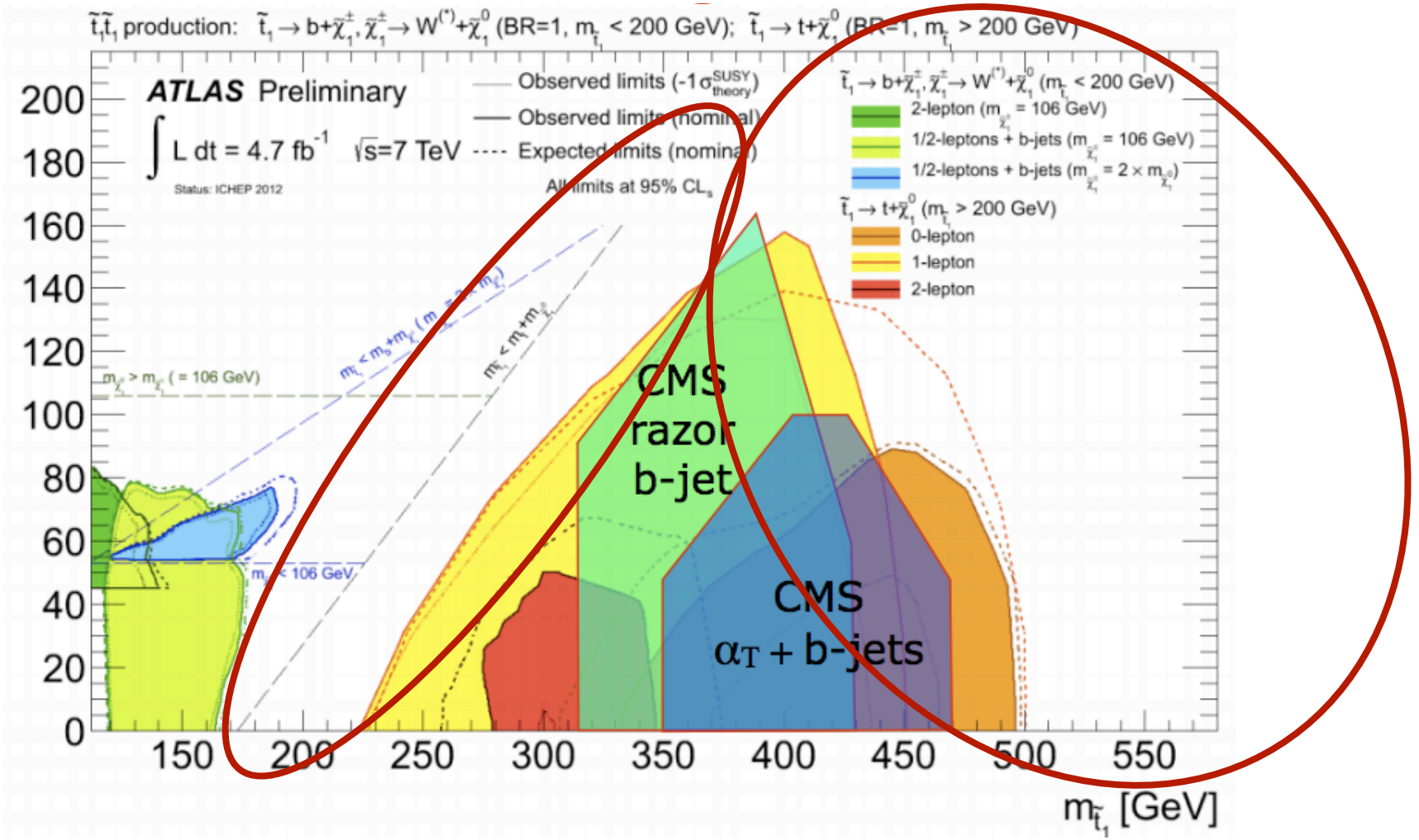

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  - count number of observed events (B)
  - take as signal (S) the difference between B and the predicted value

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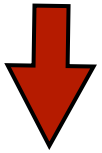


5% systematics

$$S/\sqrt{B + 0.05B^2} \sim 2$$

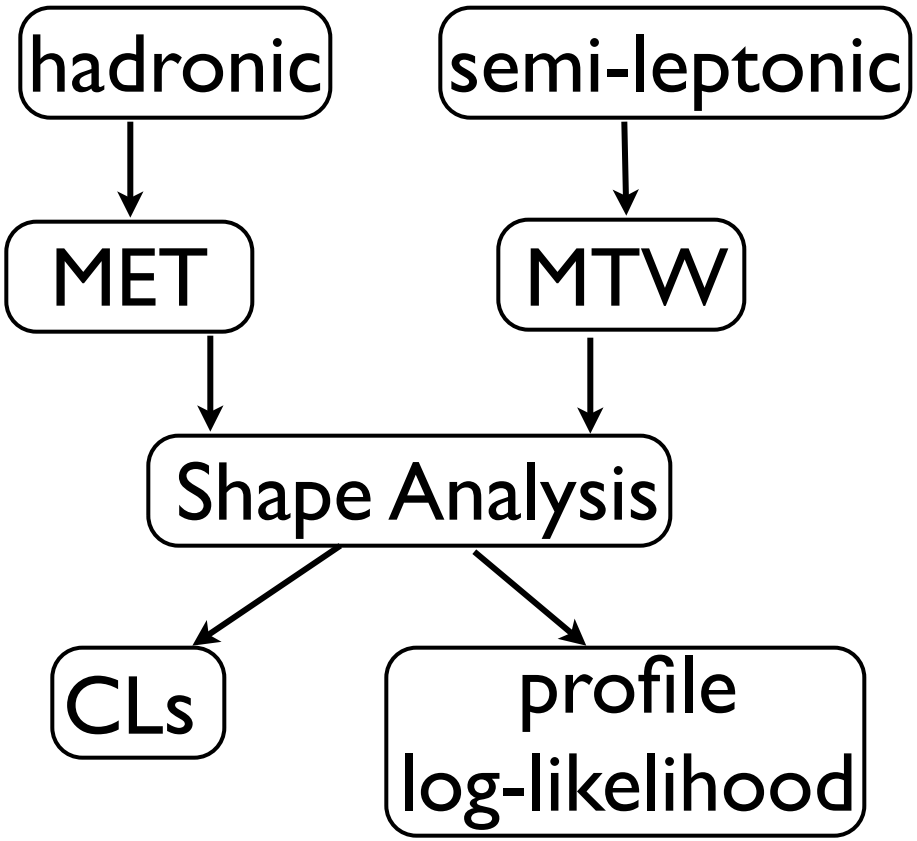
# Two important points

- MET is a measure of missing momentum, not missing energy. Both stops and tops have significant decay widths. Thus, the resulting intrinsic differences in MET are magnified by boosted kinematics at the LHC.
- Even small differences in MET spectra can be detected using a shape analysis.

- experimental analyses have in general stayed away from modeling the shape of MET distributions
- however, both ATLAS and CMS have shown the ability to understand MET distributions
- poster child: Razor analysis -- demonstrates usefulness of modeling MET-based observables
- Tevatron: W mass measurement

# How to find stops

choose your trigger:



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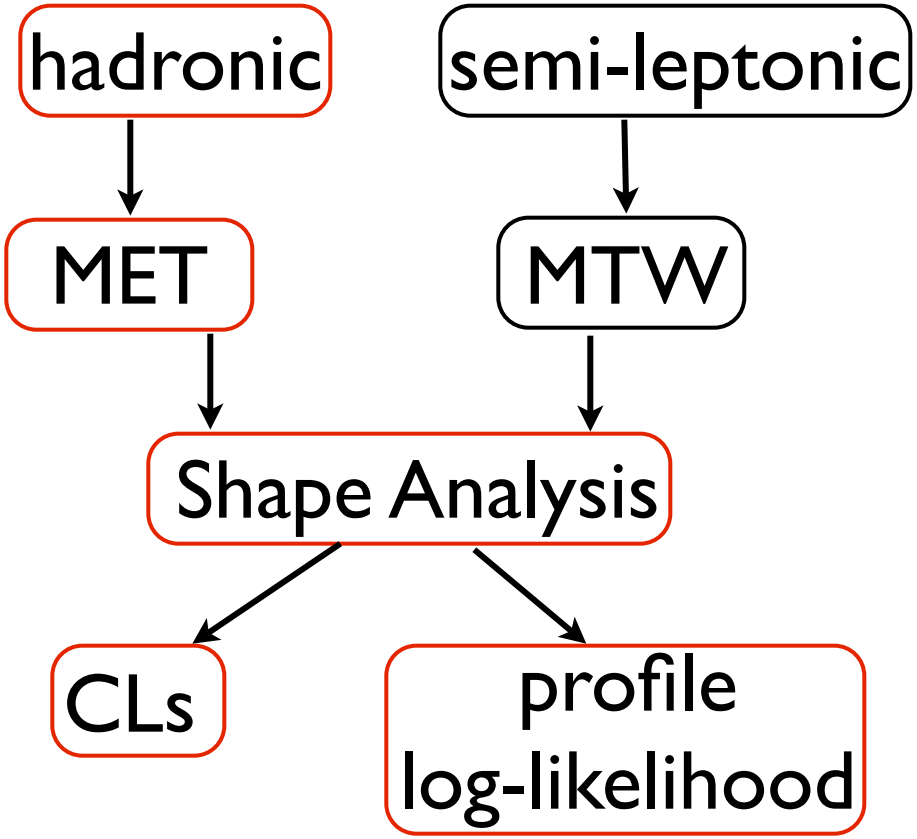


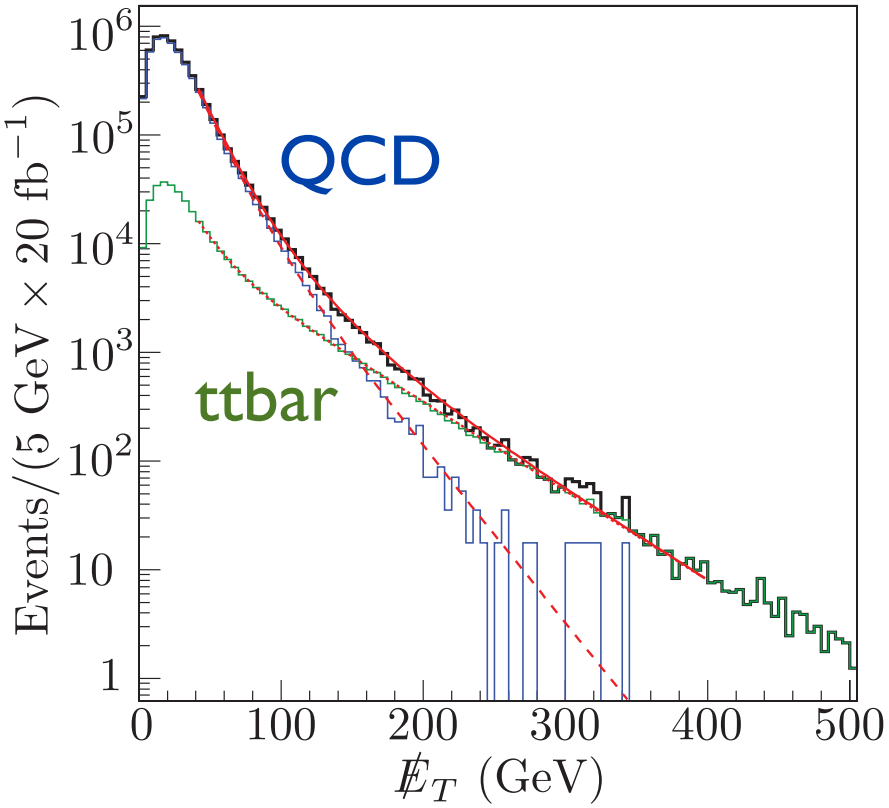

but will show results from semi-leptonic channel, too

# Hadronic stops: MET

2 jets with pT > 80 GeV
+2 more jets pT > 50 GeV
+2 b-tags (1 loose, 1 tight)
lepton veto

main backgrounds: QCD and ttbar

# Hadronic stops: MET

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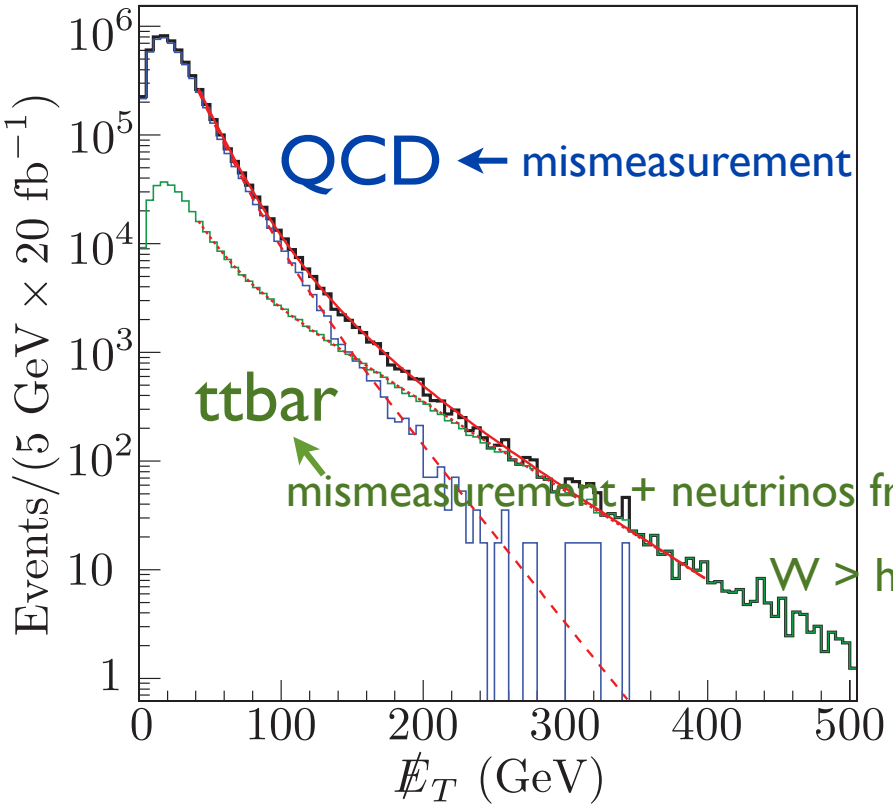


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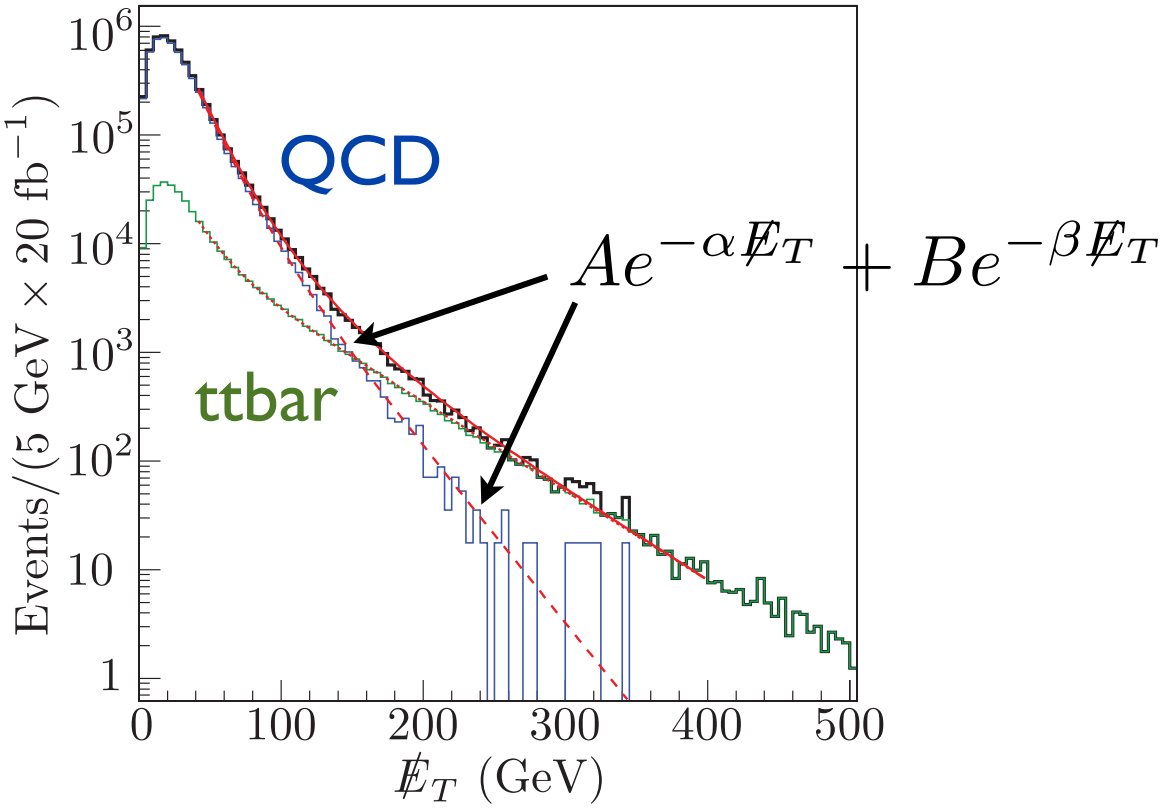


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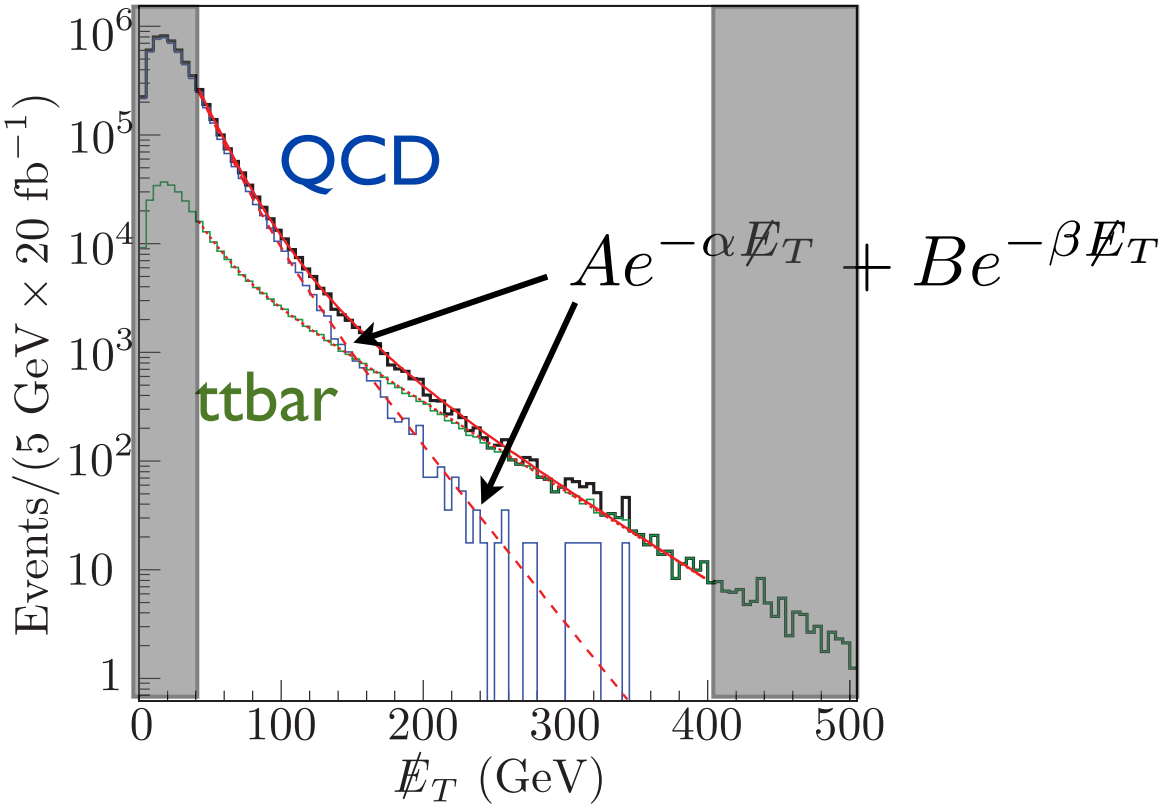


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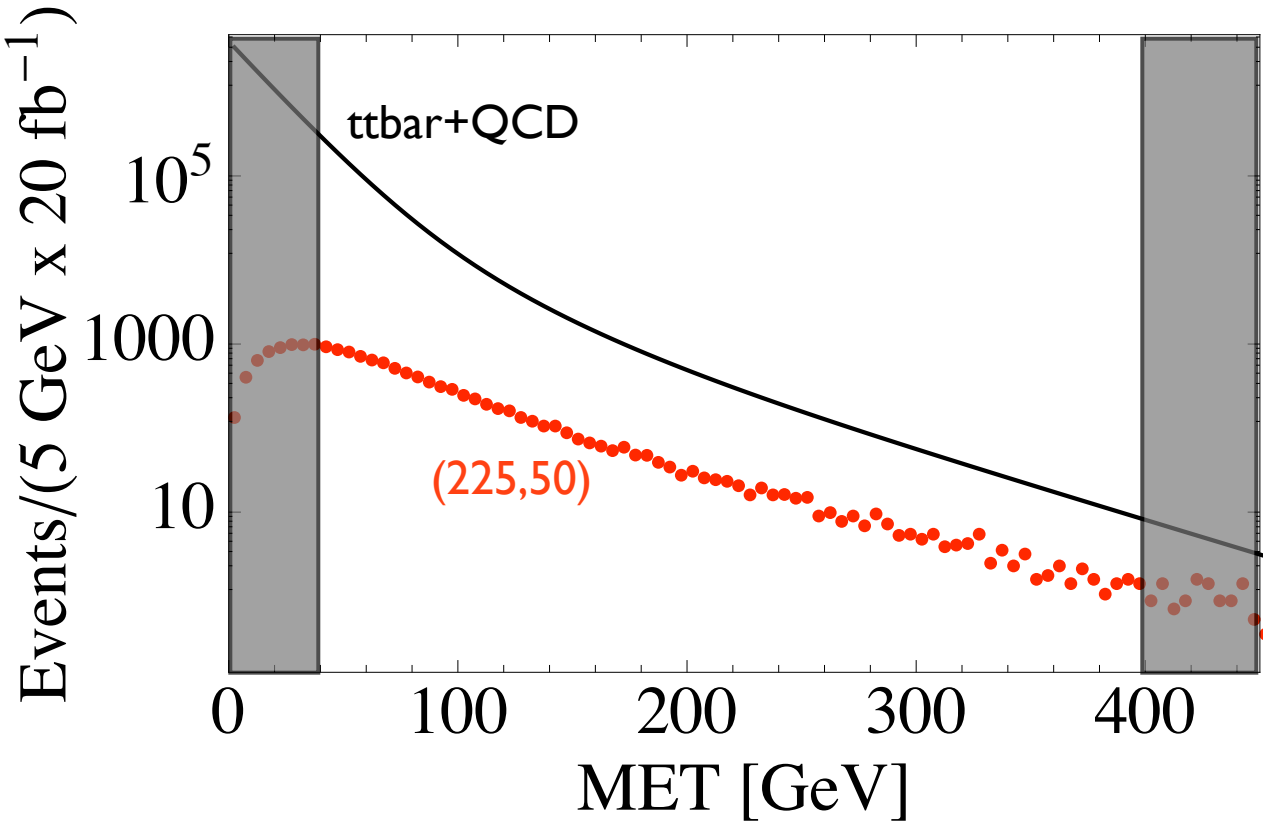
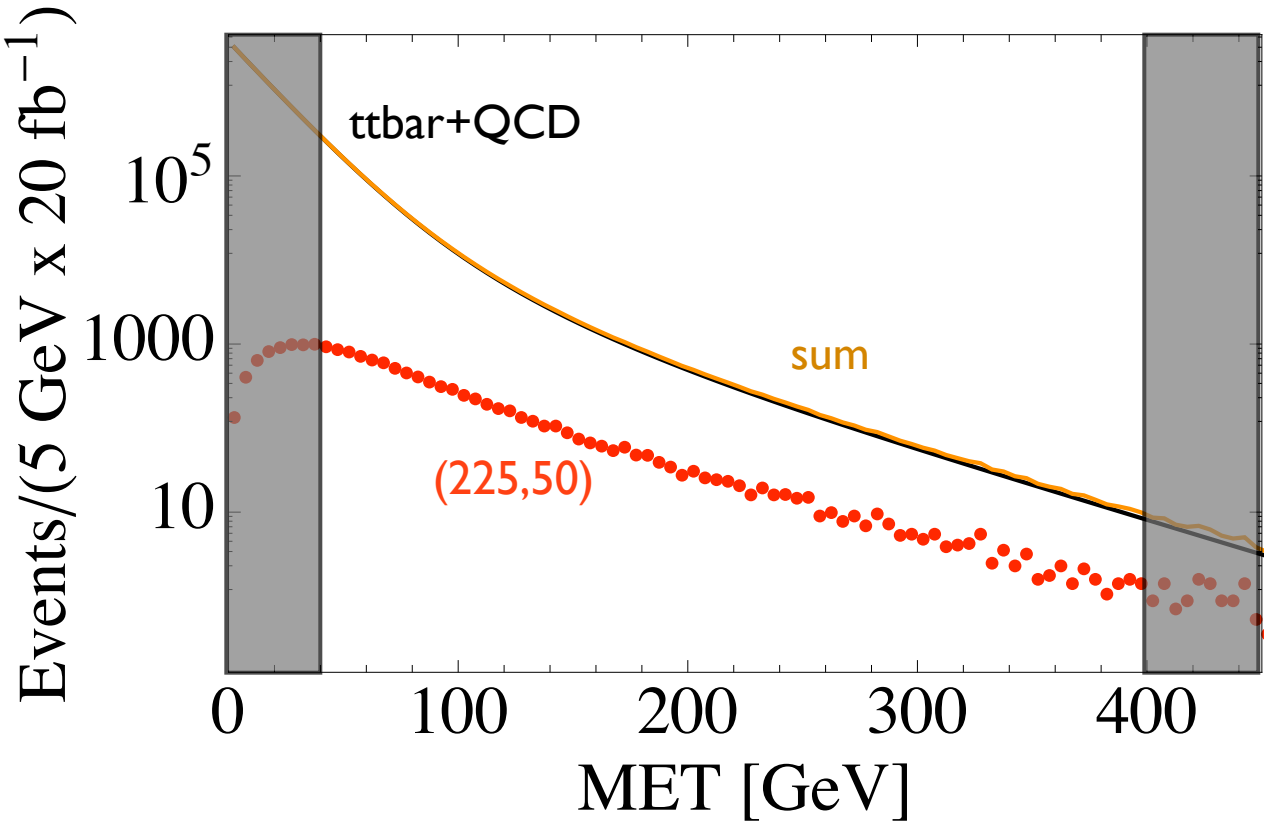

Events/(5 GeV x 20 fb$^{-1}$)
$10^5$
1000
10
ttbar+QCD
(225,50)
0
100
200
300
400
MET [GeV]


Events/(5 GeV x 20 fb$^{-1}$)
$10^5$
1000
10
ttbar+QCD
sum
(225,50)
0
100
200
300
400
MET [GeV]

# Interlude: Statistics

- the crux of our analysis is to make a statistically significant distinction between signal and background
- how do we quantify this difference?

# Maximum log-likelihood

- calculate the likelihood under a given hypothesis and maximize over the nuisance parameters -- 8 parameters of the fits to background MET shapes

# Maximum log-likelihood

- calculate the likelihood under a given hypothesis and maximize over the nuisance parameters -- 8 parameters of the fits to background MET shapes
- **question**: how well can the experiments expect to do if the data they observe is due to a particular model?

# Maximum log-likelihood

- two hypotheses:
  - there is no light stop (background)
  - there is a light stop (background+signal)

# Maximum log-likelihood

- generate pseudo-data using the central values of the analytic fits to background
- fit pseudo-data using profile log-likelihood method to background and background +signal hypothesis

# Profile Likelihood

$$\log L(c_i,\sigma) = \sum_{\text{bins}} -\nu(c_i,\sigma) + n\log\left(\frac{\nu(c_i,\sigma)}{n}\right)$$
$$-\frac{1}{2}\sum_{pq}(c_p-\bar{c}_p)C^{-1}_{pg}(c_q-\bar{c}_q)$$

observed number of events in bin

predicted number of events in bin

central value of fit parameter

covariance matrix

# Profile Likelihood

- background-only hypothesis: maximize Log L over $\hat{c}_i\,,\,\hat{\sigma}$
- background+signal hypothesis: fix $\hat{\hat{\sigma}}$ to NLO prediction and maximize Log L over $\hat{\hat{c}}_i$

$$n_\sigma = \sqrt{2\log L(\hat{c}_i,\hat{\sigma}) - 2\log L(\hat{\hat{c}}_i,\sigma_{NLO})}$$

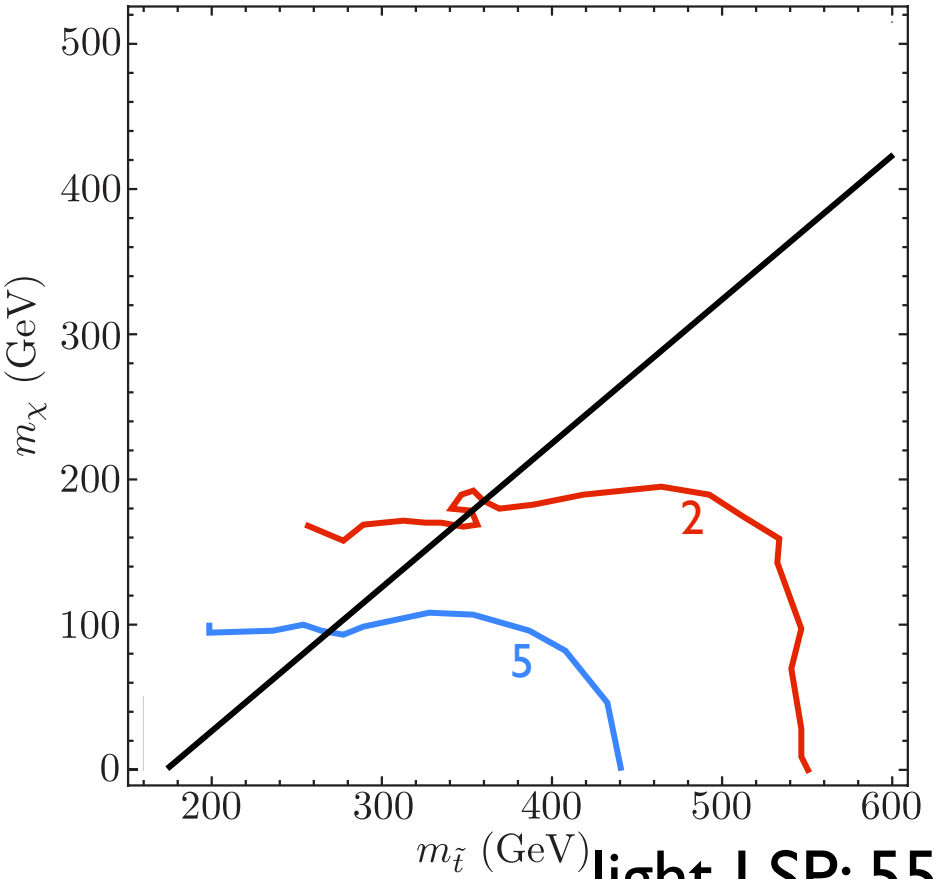
our test statistic

# Profile Likelihood

- repeat 200 times

# MET exclusion

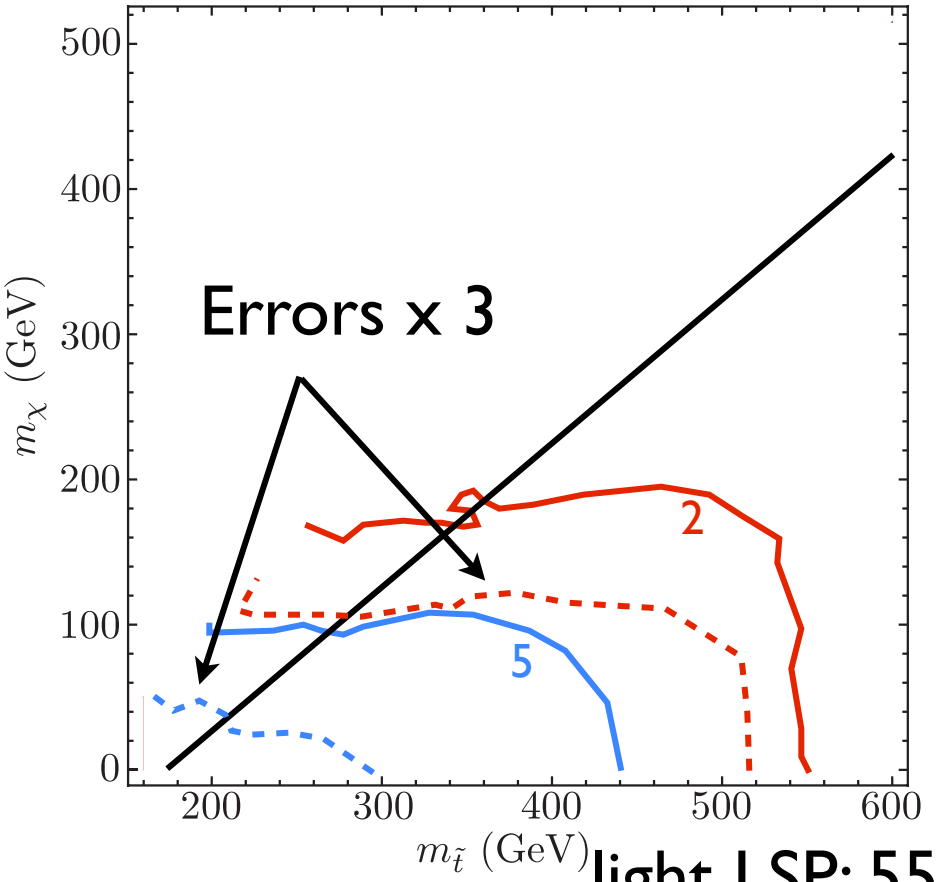
8 TeV, 20 fb-1




exclude masses up to: light LSP: 550 GeV
350 GeV

# MET exclusion

8 TeV, 20 fb-1




exclude masses up to:

light LSP: 550 GeV 520 GeV

350 GeV 280 GeV

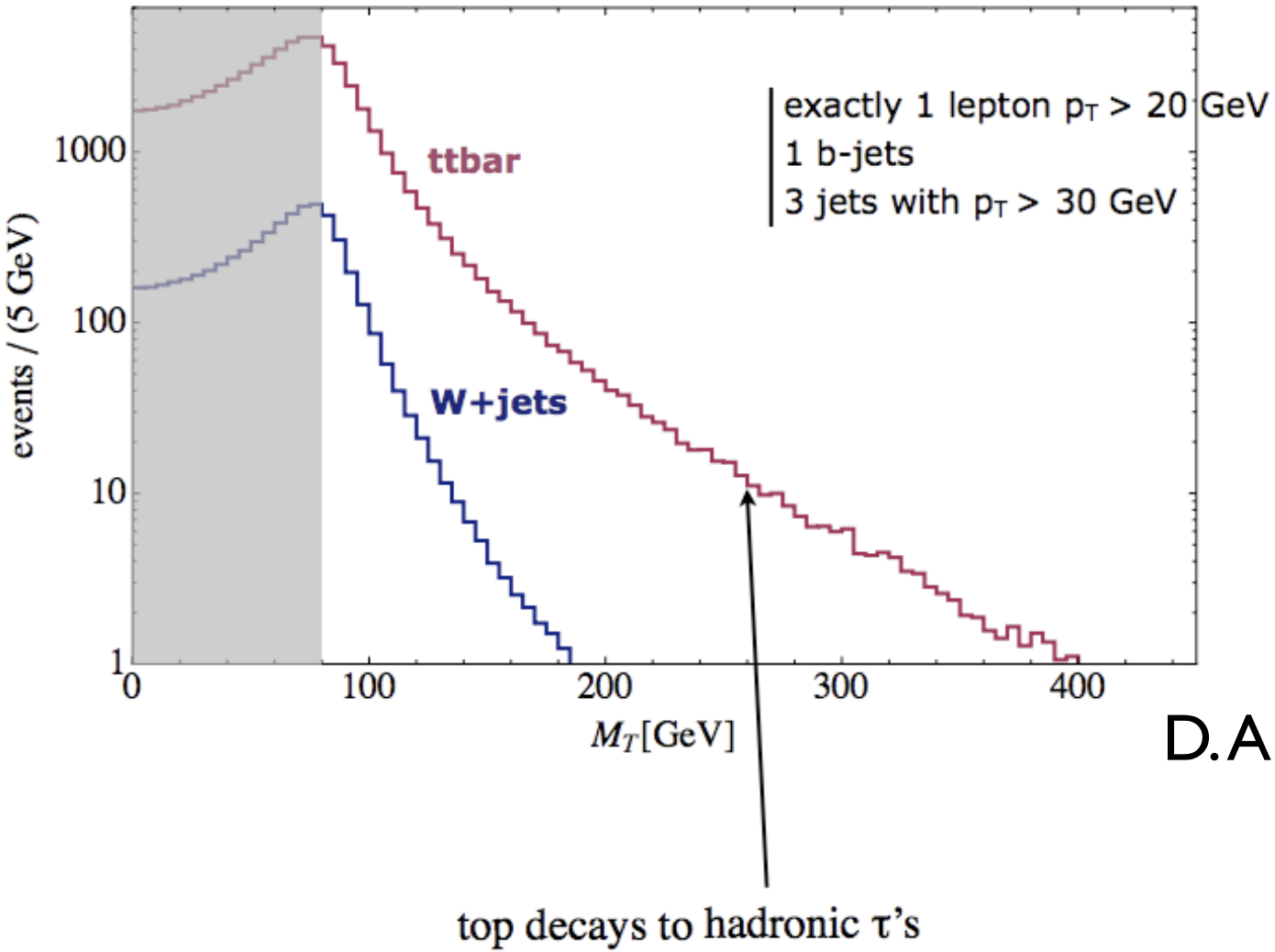
# Semi-leptonic stops: MTW

1 isolated lepton pT > 20 GeV
+at least 1 tight b-tag pT > 30 GeV
+3 or more jets pT>30 GeV

$$M_T^W = \sqrt{2(p_T^l \not{E}_T - \vec{p_T^l} \cdot \vec{\not{E}}_T)}$$

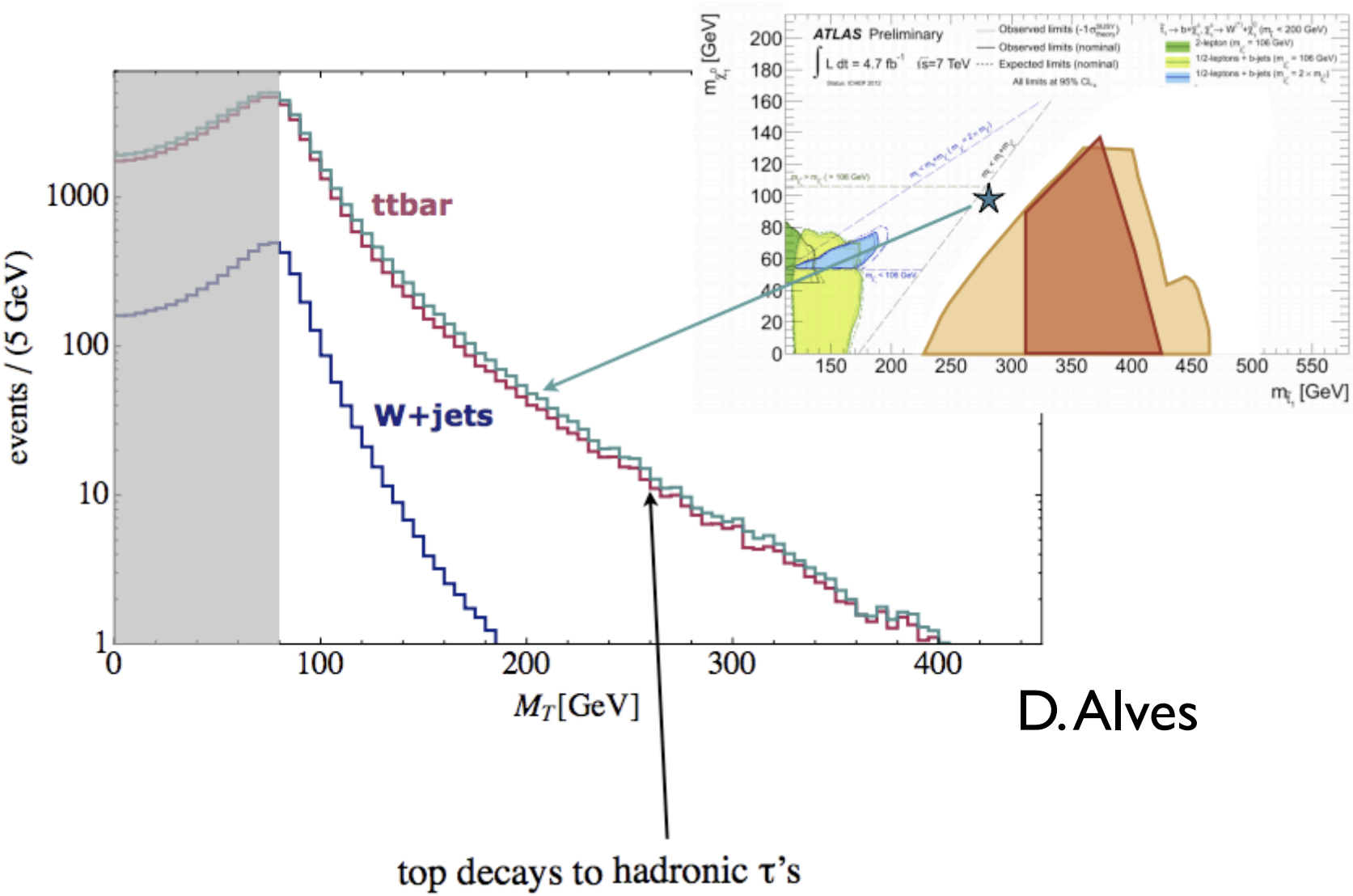
main backgrounds: ttbar and W+jets

# MTW


exactly 1 lepton $p_T$ > 20 GeV
1 b-jets
3 jets with $p_T$ > 30 GeV
ttbar
W+jets
events / (5 GeV)
1000
100
10
1
0
100
200
300
400
$M_T$[GeV]
top decays to hadronic τ's

D. Alves

# MTW


ttbar
W+jets
events / (5 GeV)
$M_T$[GeV]
top decays to hadronic τ's
ATLAS Preliminary
$\int$ L dt = 4.7 fb$^{-1}$ (s=7 TeV
Observed limits (nominal)
Expected limits (nominal)
All limits at 95% CL
$m_{\chi_1^0}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]

D. Alves

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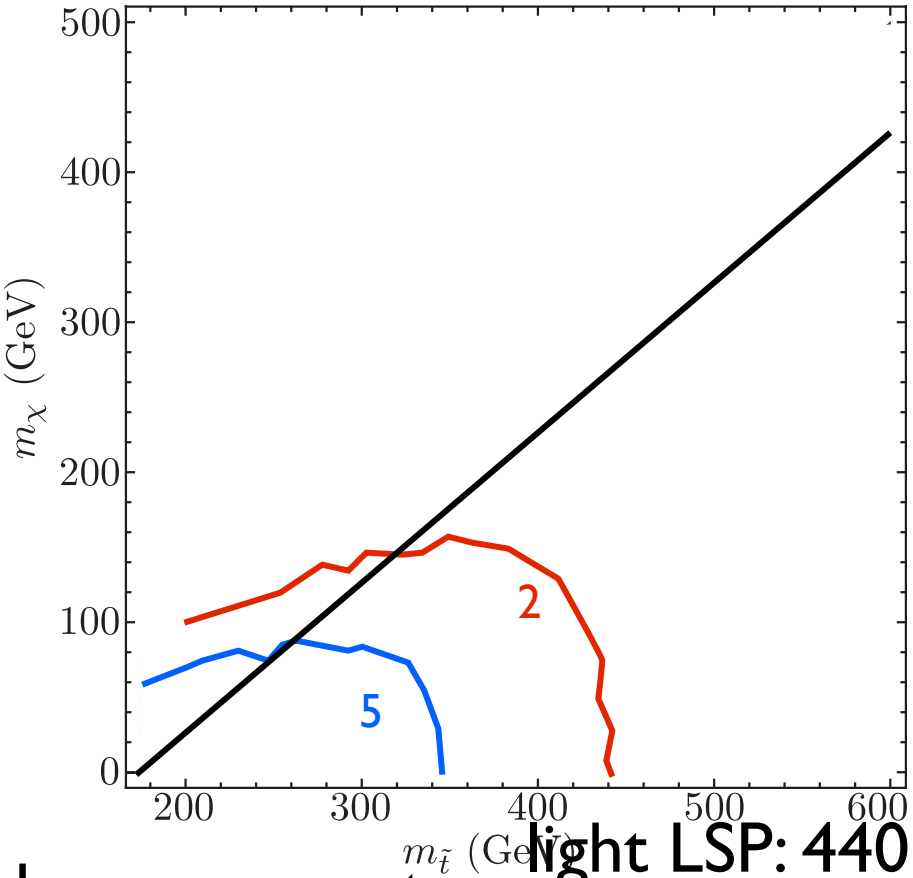
8 TeV, 20 fb-1




exclude masses up to: light LSP: 440 GeV
320 GeV

# MTW exclusion

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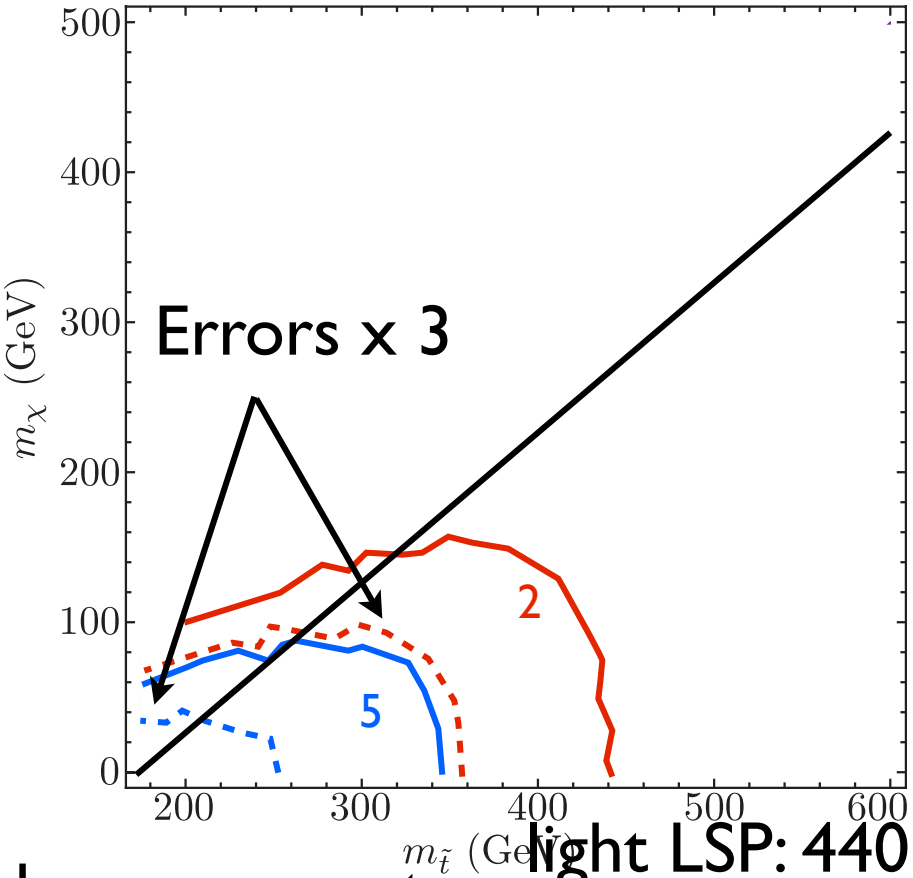
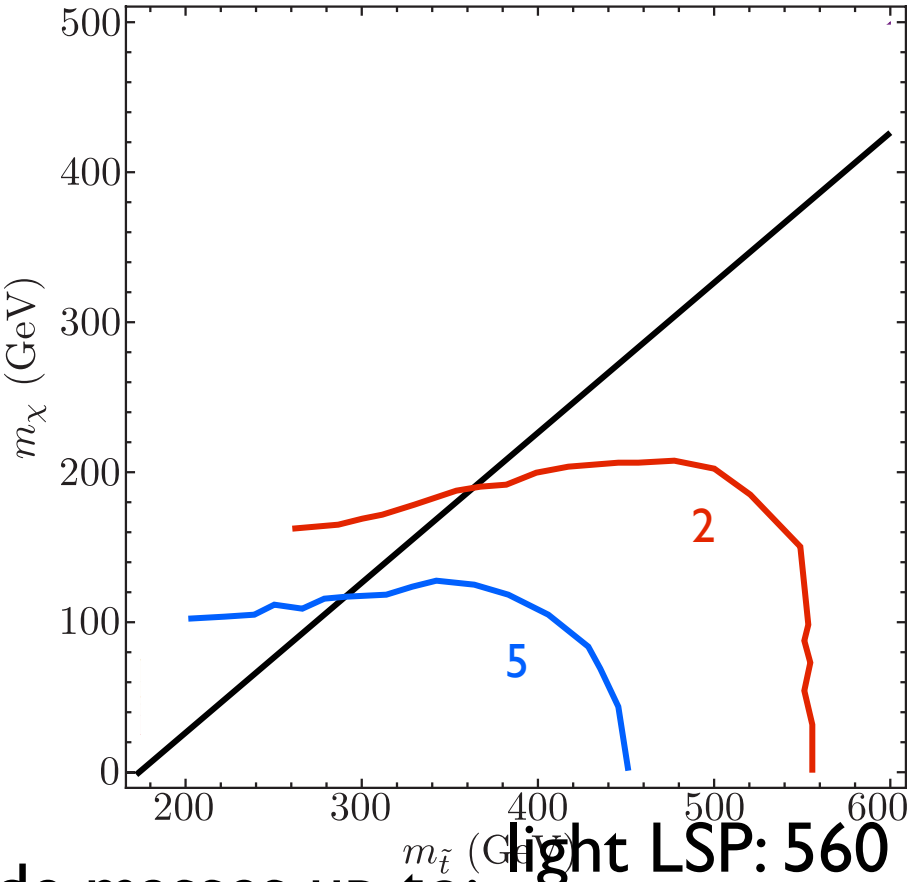



exclude masses up to: light LSP: 440 GeV 360 GeV

320 GeV 270 GeV

# Combined exclusion

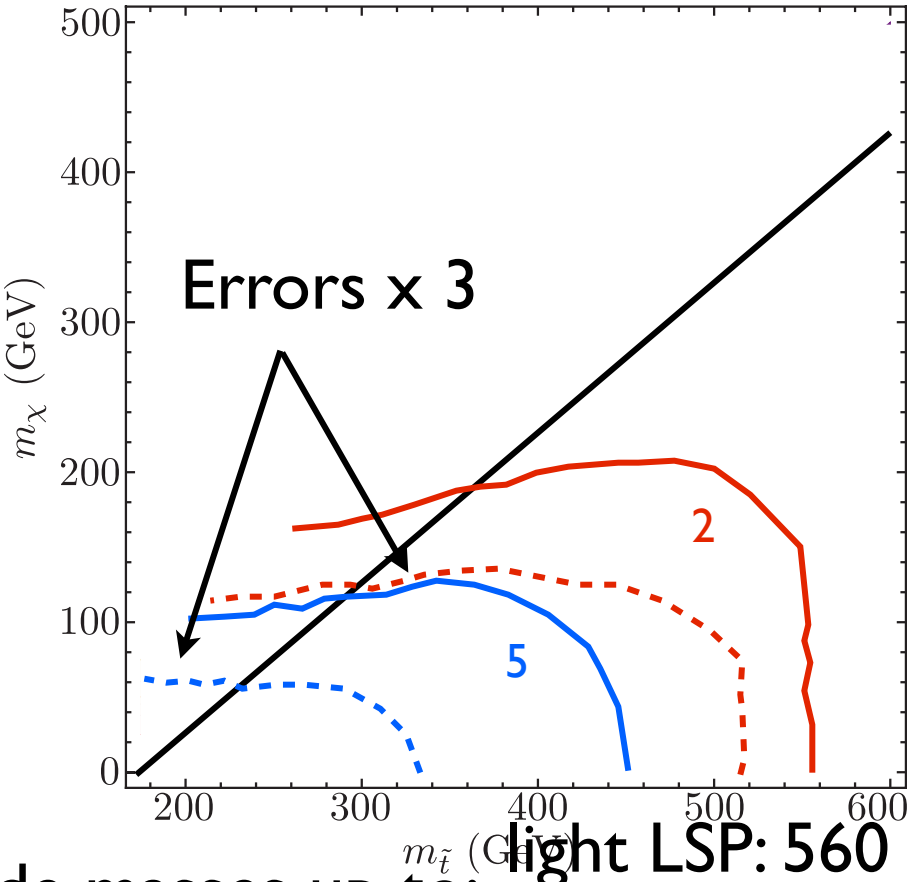
8 TeV, 20 fb-1




exclude masses up to: light LSP: 560 GeV
360 GeV

# Combined exclusion

8 TeV, 20 fb-1



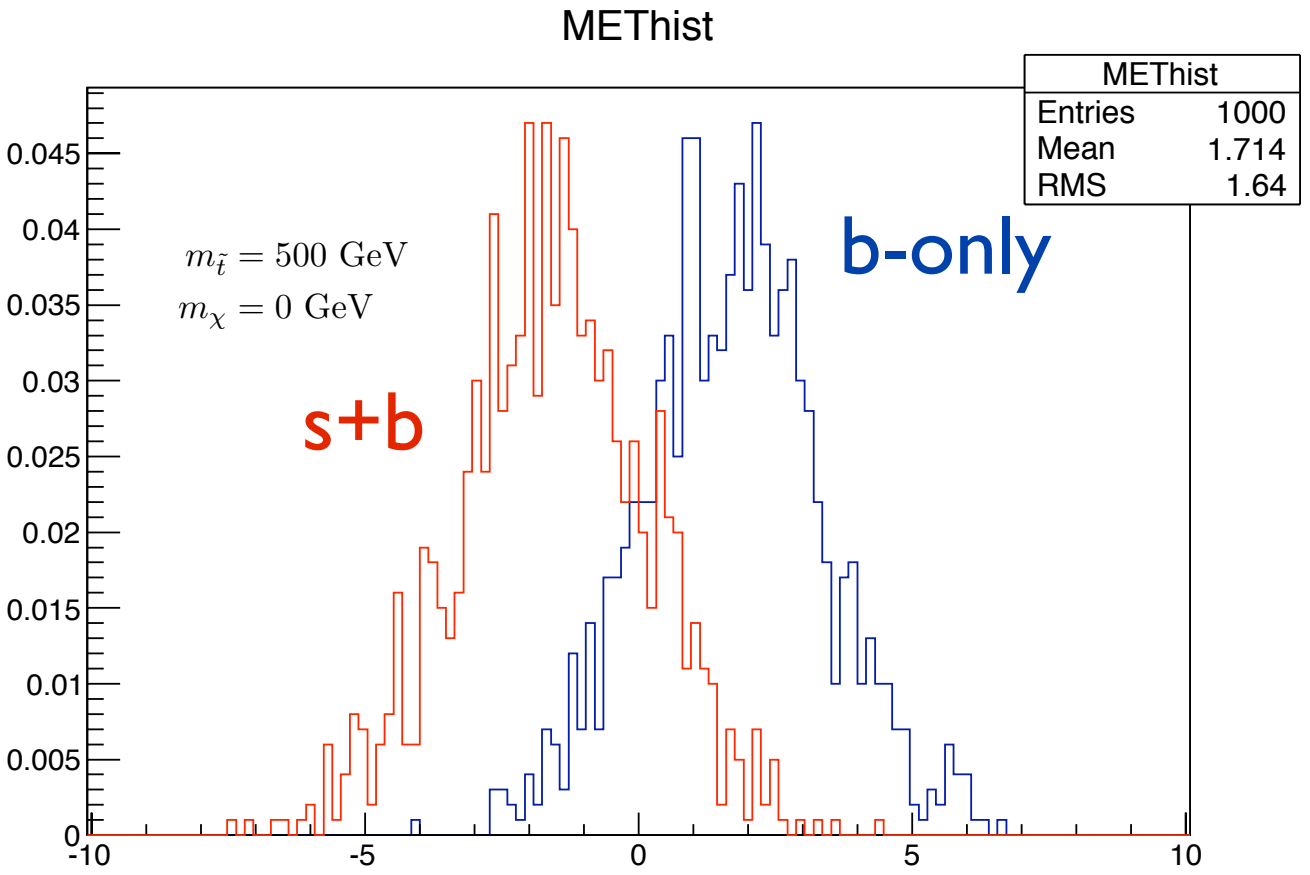

exclude masses up to: light LSP: 560 GeV 520 GeV

360 GeV 300 GeV

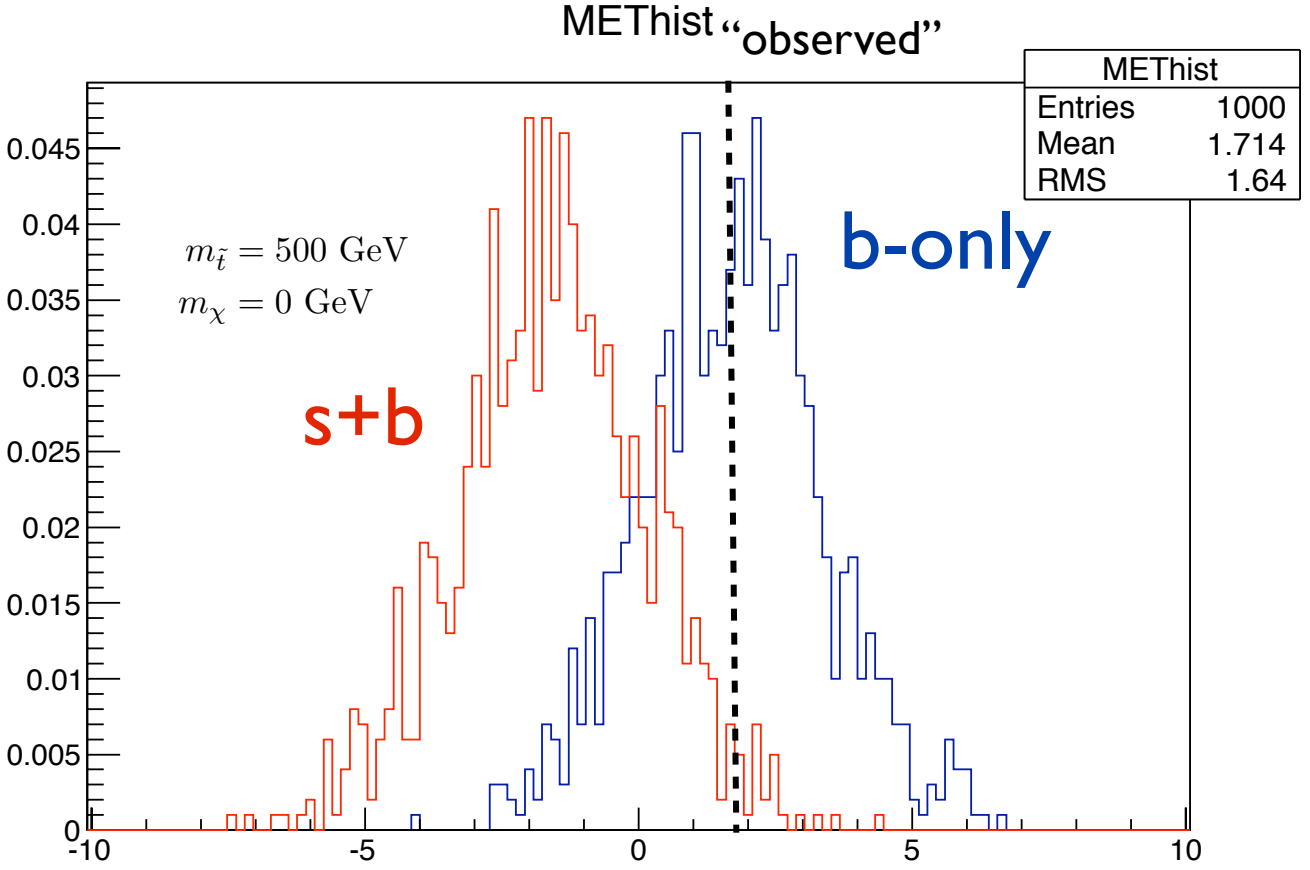
# CLs

- What if you are looking at a case of low sensitivity?
  - potentially exclude hypotheses to which one has limited sensitivity -- "spurious exclusion"
- looked only along degeneracy line
- generate $10^4$ pseudo-experiments for each hypothesis

# CLs


METhist
METhist
Entries 1000
Mean 1.714
RMS 1.64
$m_{\tilde{t}} = 500$ GeV
$m_{\chi} = 0$ GeV
s+b
b-only
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-10
-5
0
5
10

# CLs


METhist
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s+b
b-only
"observed"
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-10
-5
0
5
10

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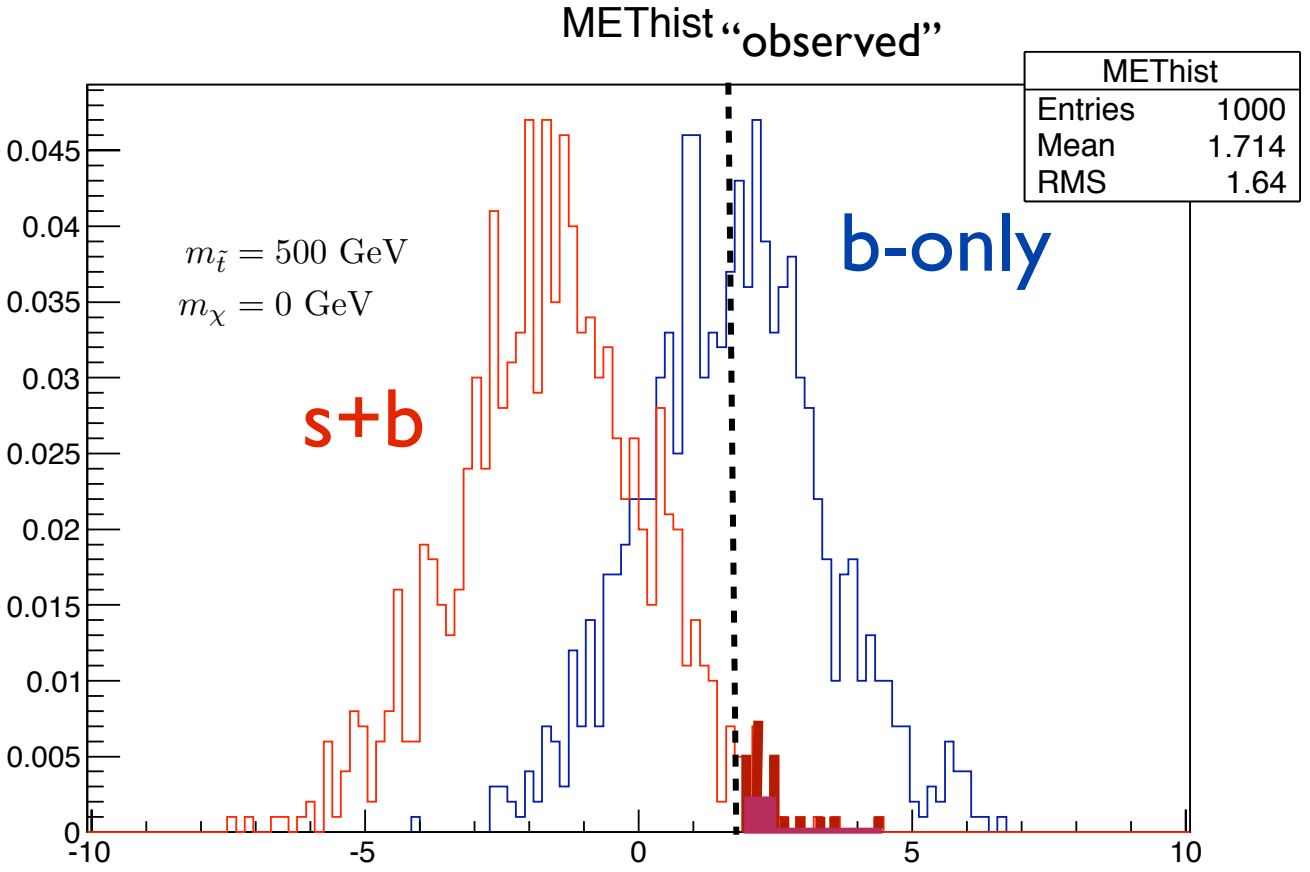
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0.015
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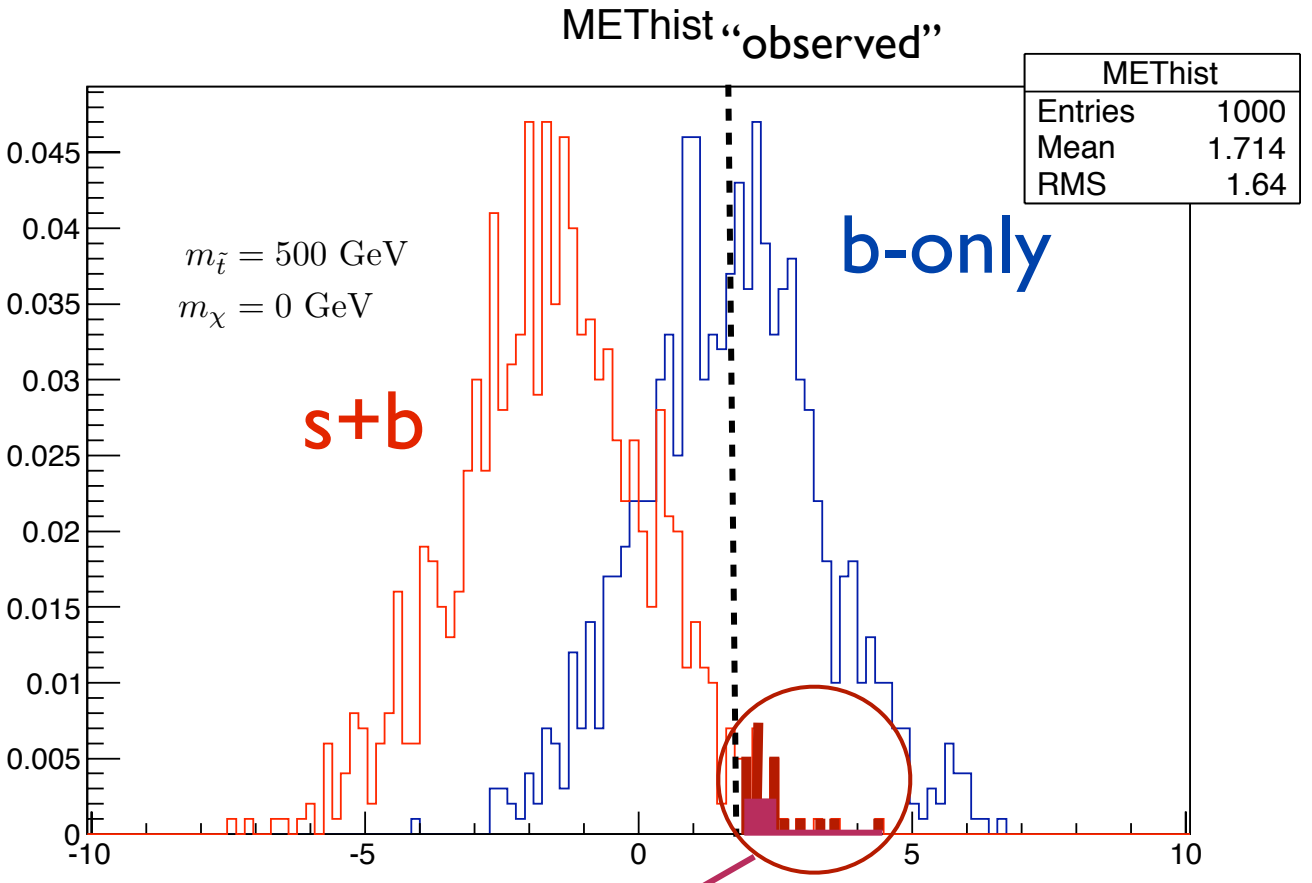
0
-10
-5
0
5
10

# CLs




$$CL_s = \frac{CL_{s+b}}{CL_b} \rightarrow 0.5$$

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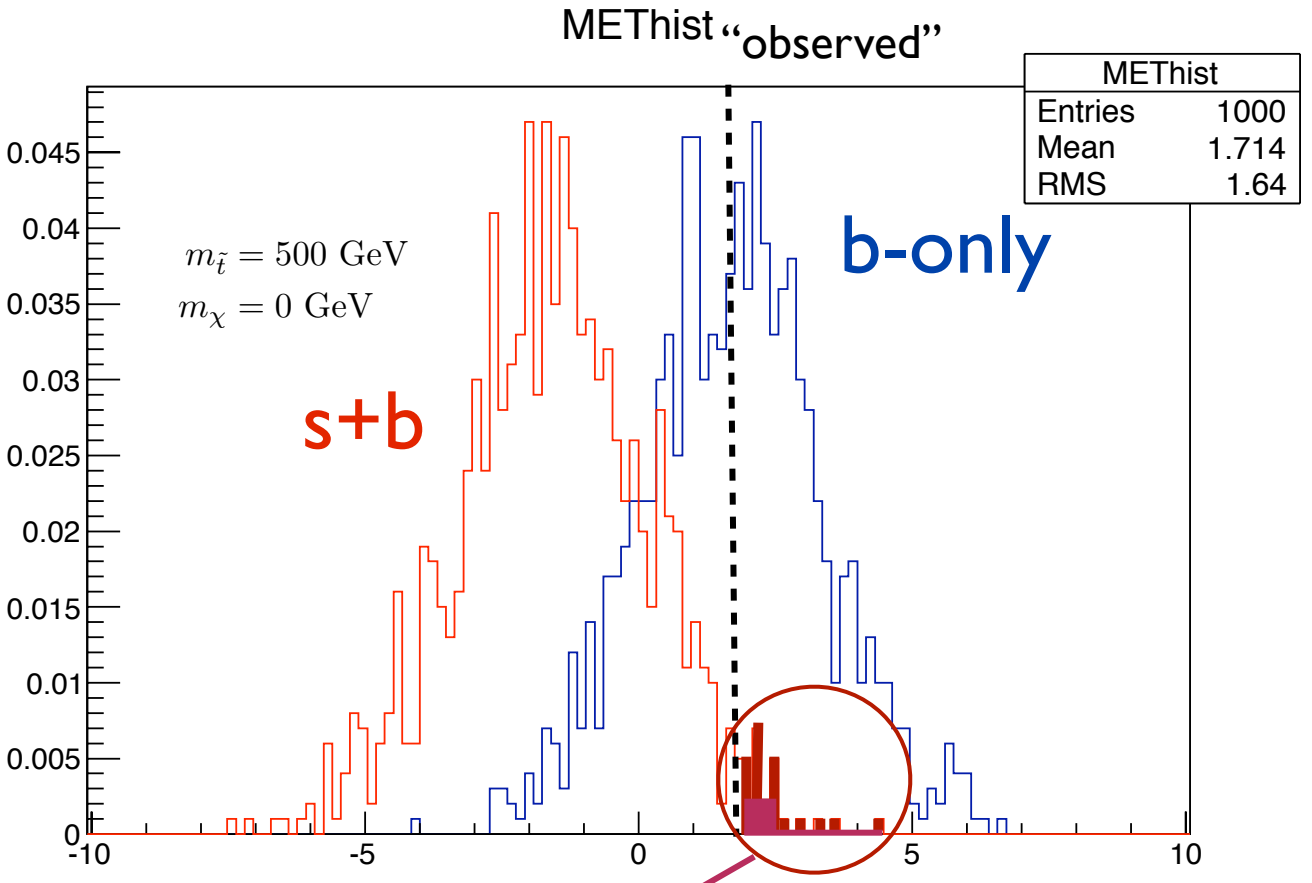
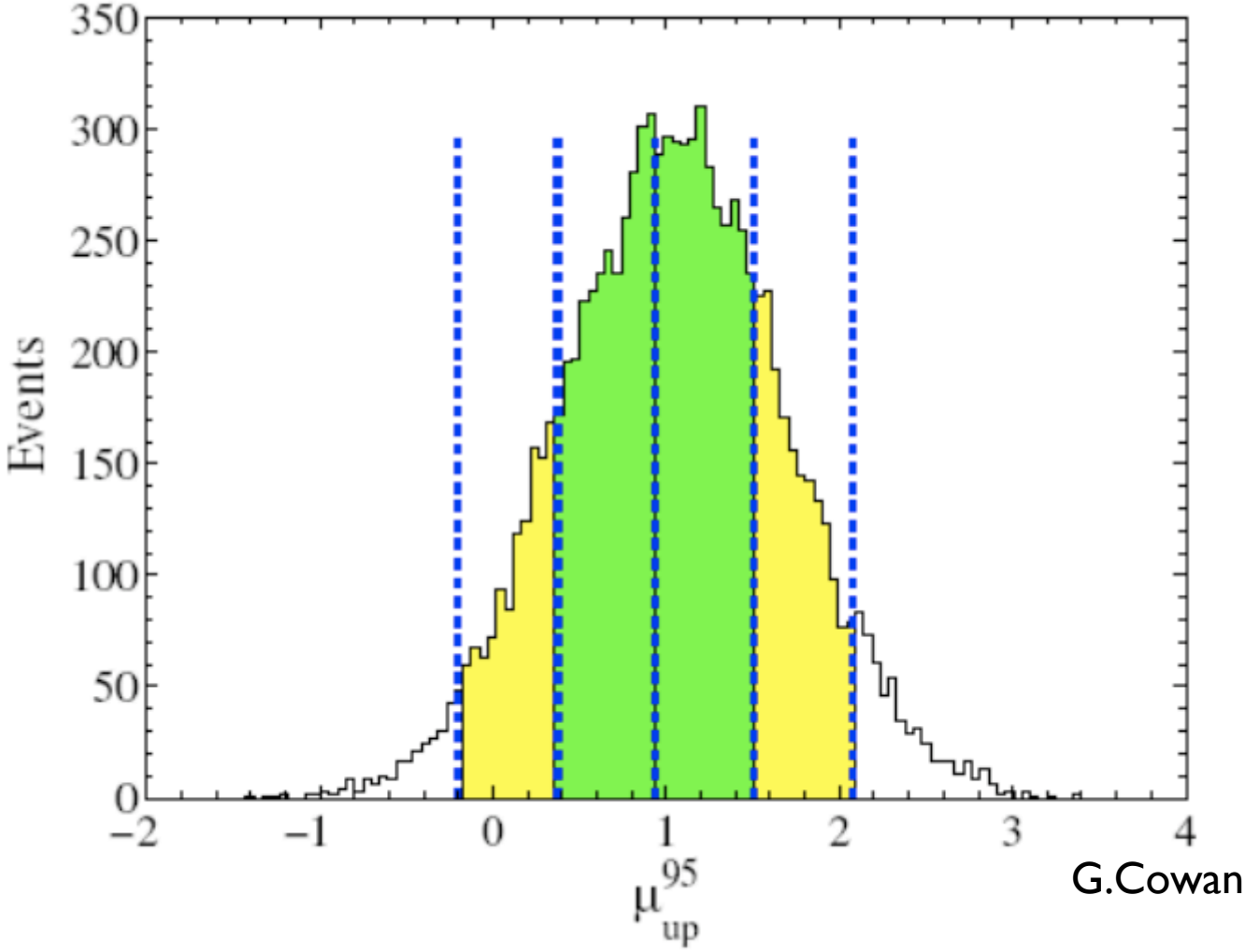


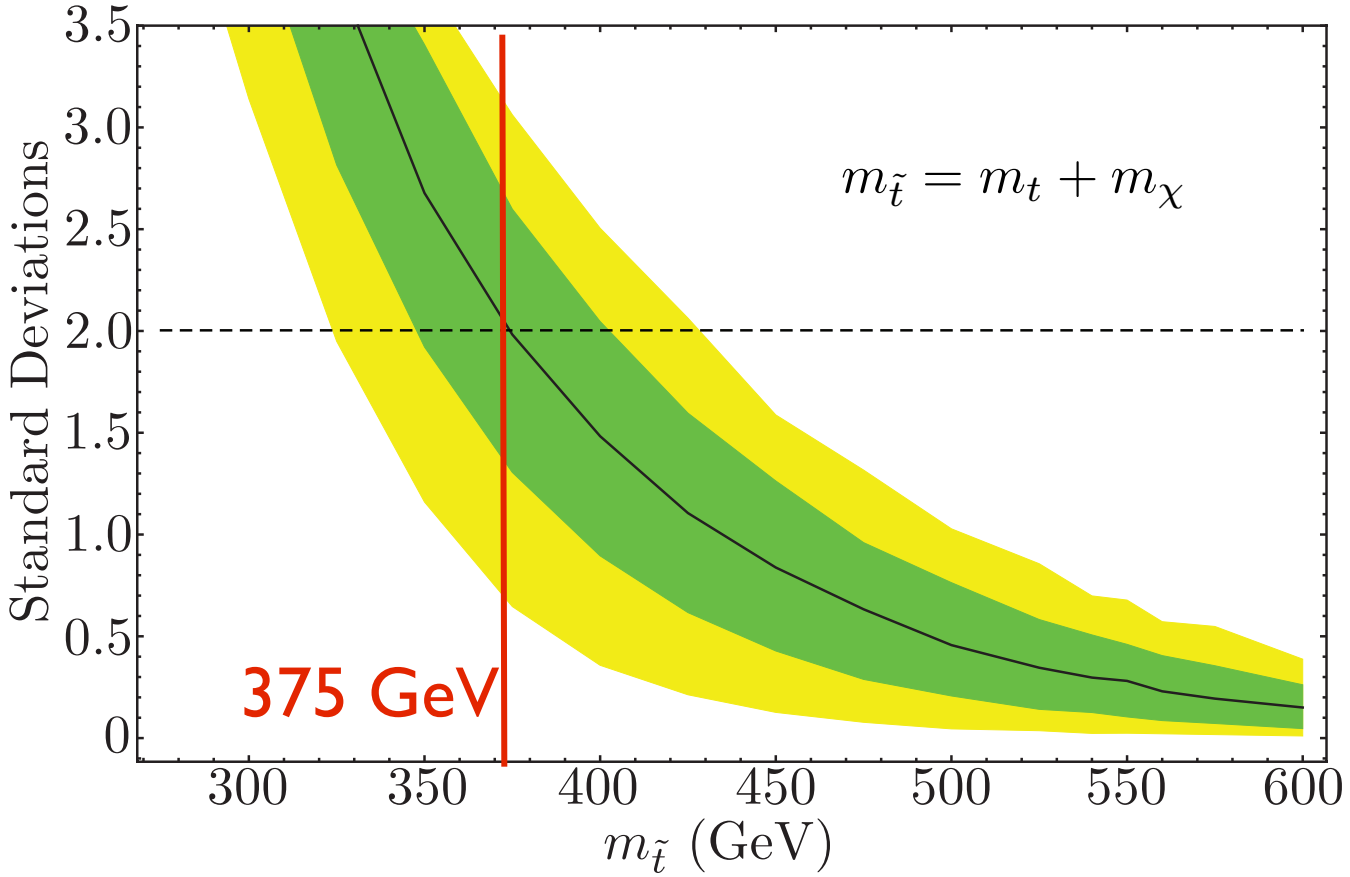

$$CL_s = \frac{CL_{s+b}}{CL_b} \rightarrow 0.5$$

Exclude at 1-CLs confidence level

# CLs



# CLs




compare to 360 GeV

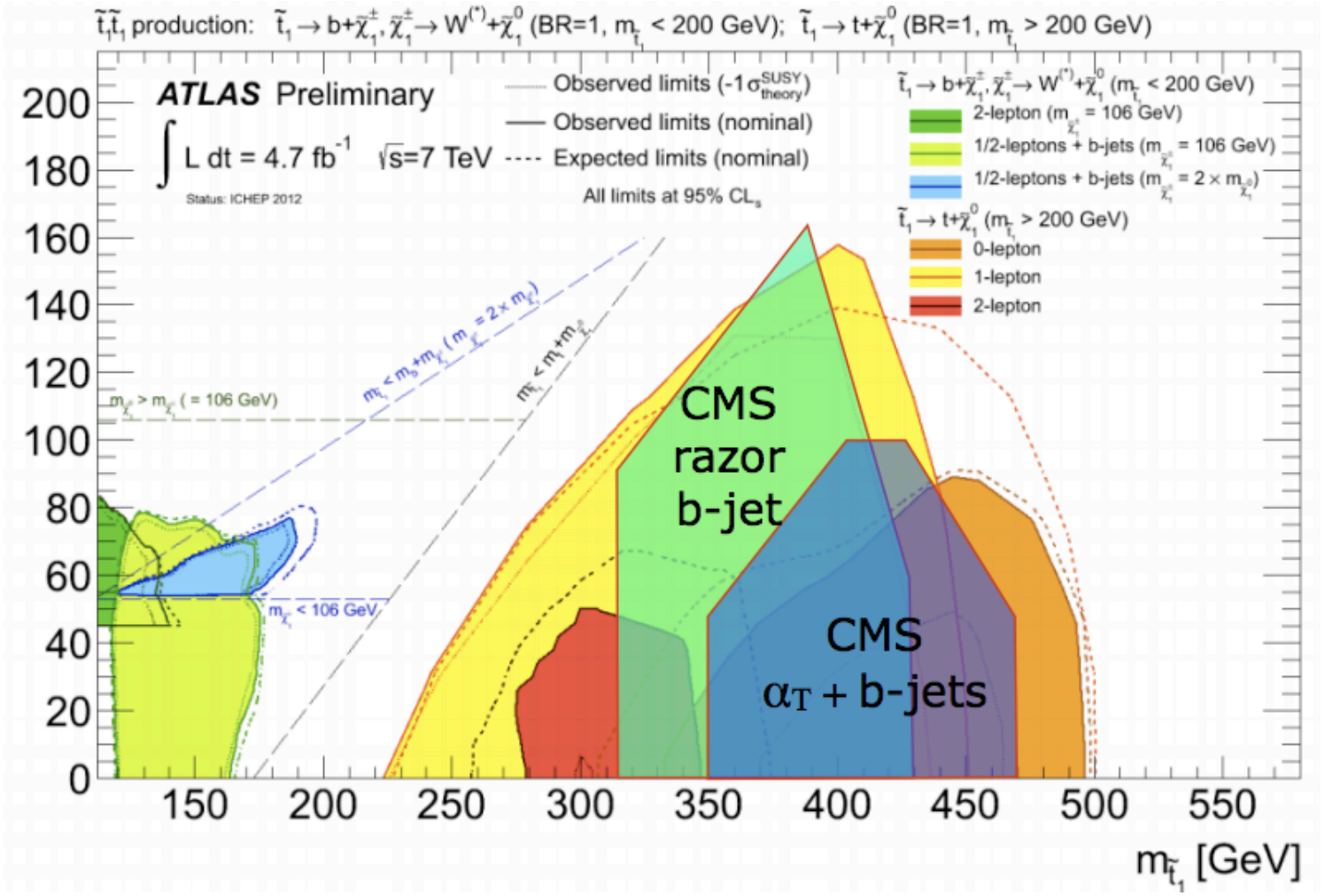
# Other recent theory works:

**kinematic variables with endpoints for background**
arXiv:1203.4813 -- Bai, Cheng, Gallichio, Gu

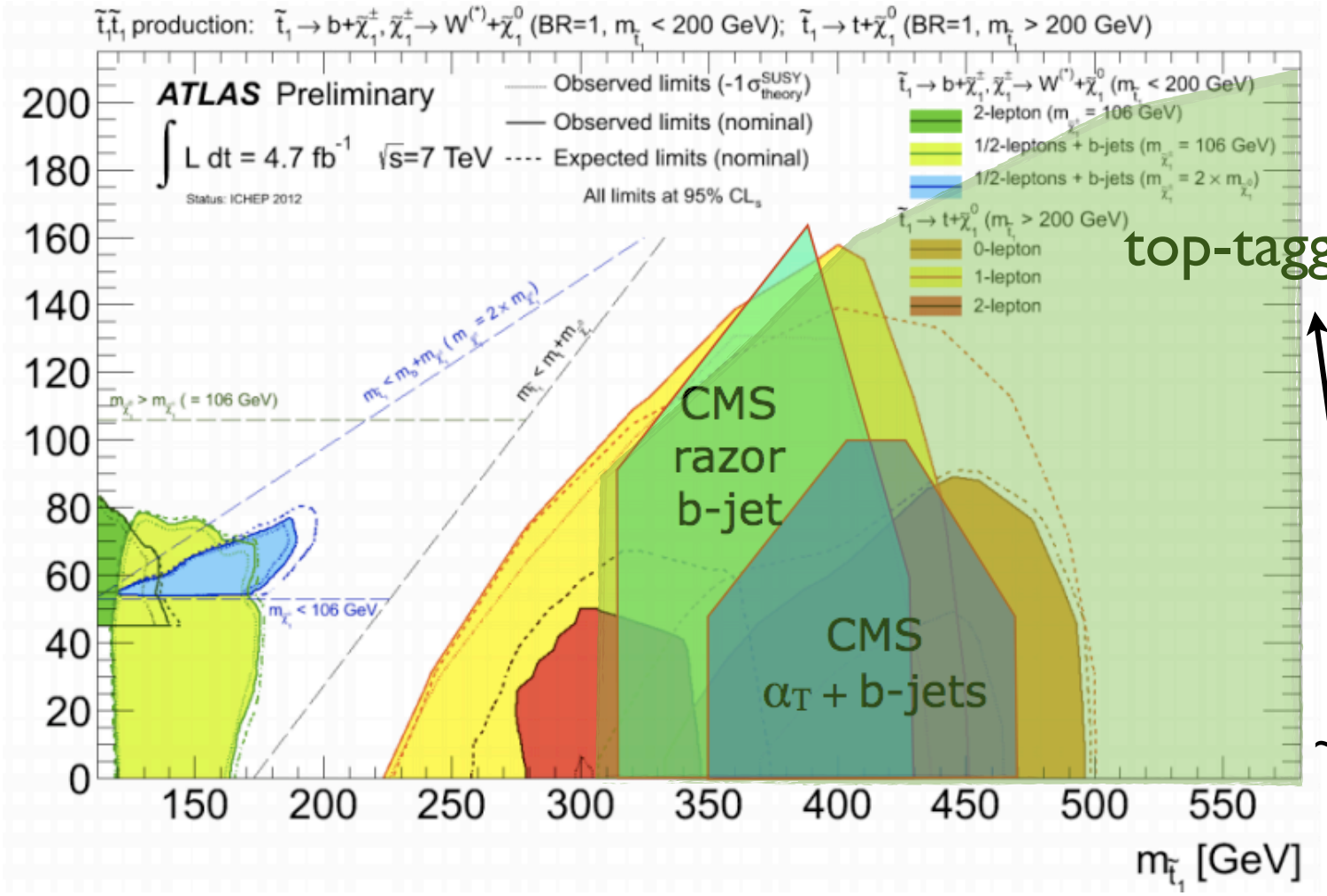
**spin correlations and rapidity gaps**
arXiv:1205.5808 -- Han, Katz, Krohn, Reece

**top-tagging boosted tops from stop decays**
arXiv:1205.2696 -- Plehn, Spannowsky, Takeuchi
arXiv:1205.5816 -- Kaplan, Rehermann, Stolarski

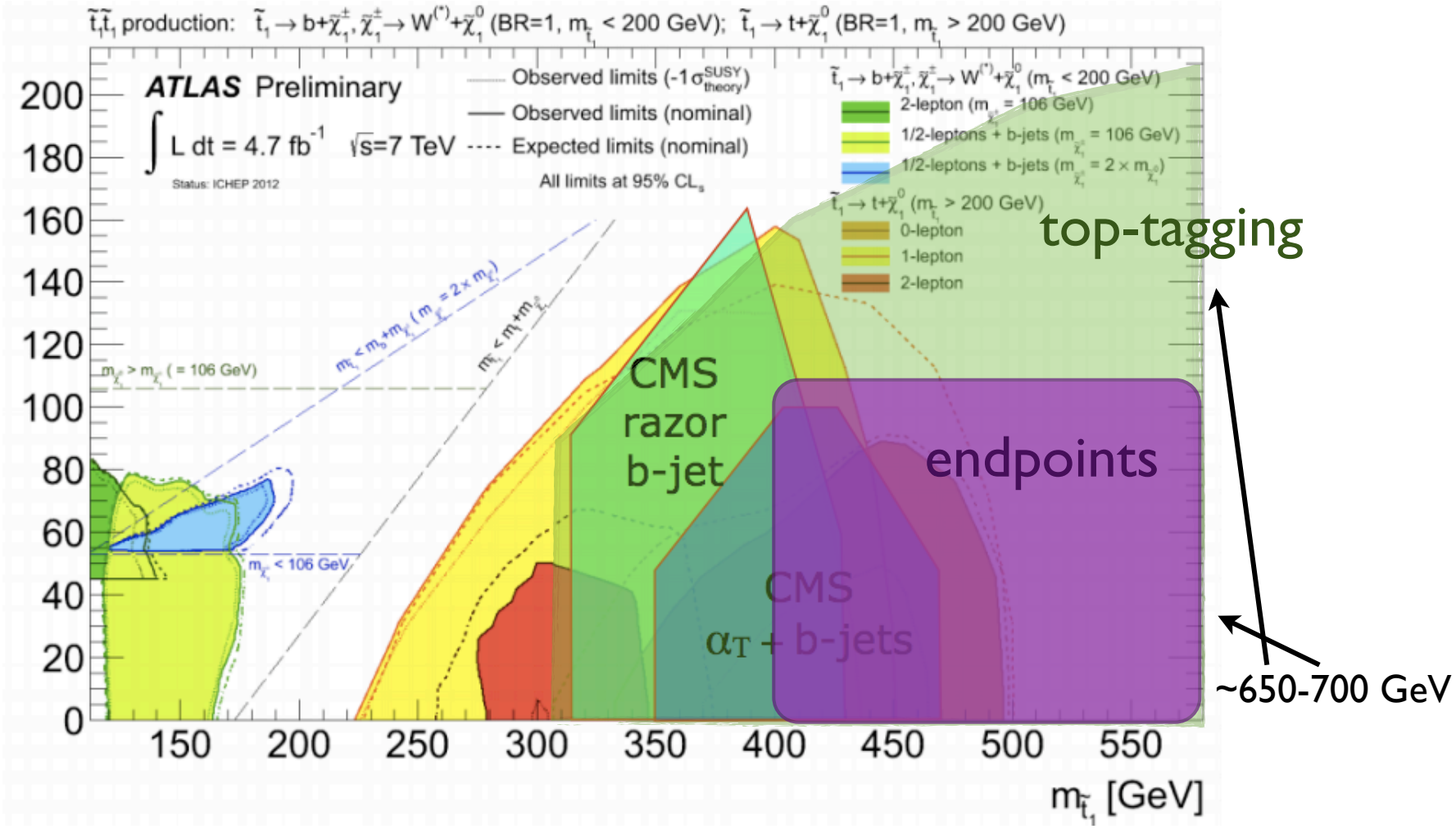
# All together now



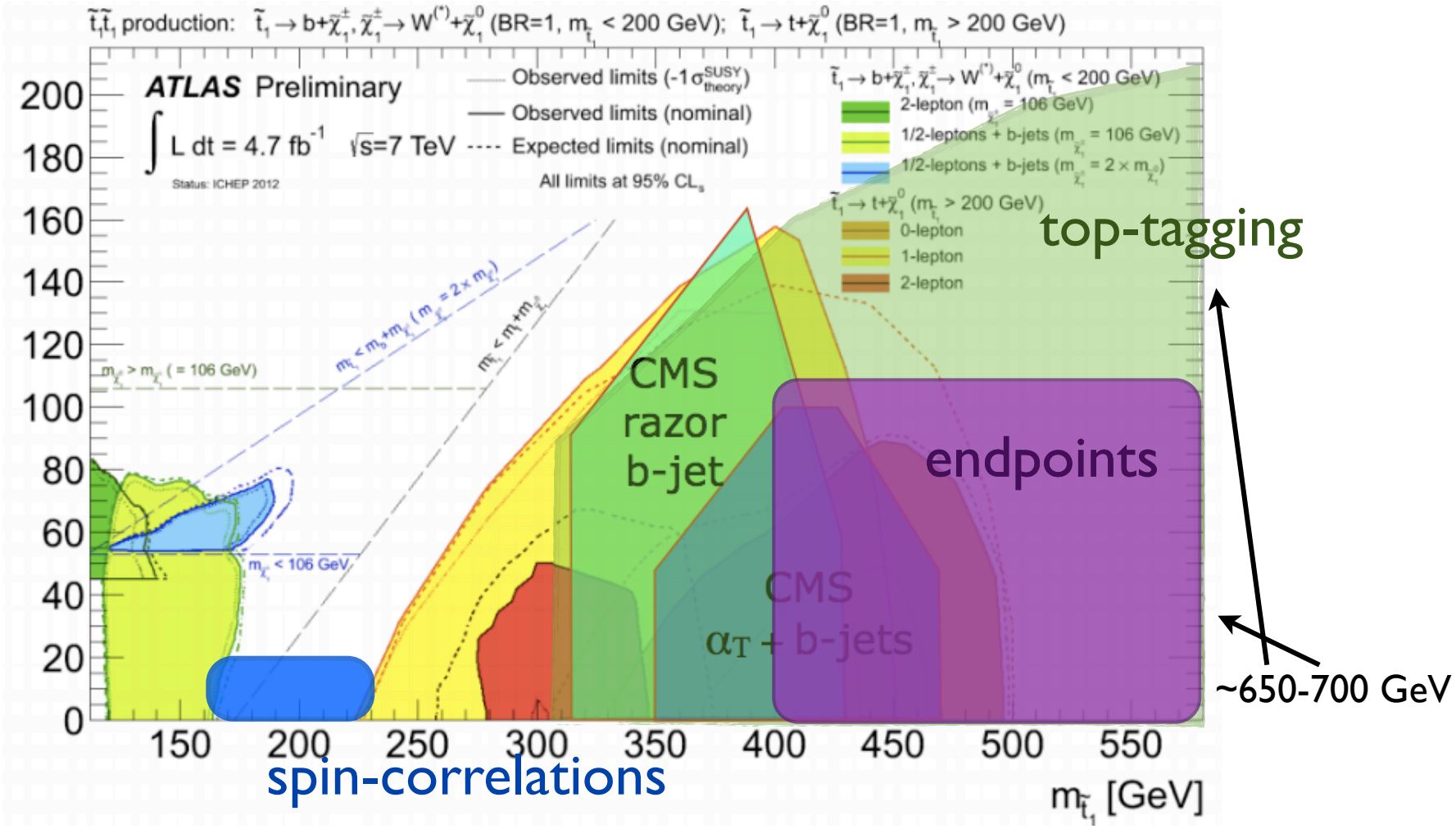
# All together now



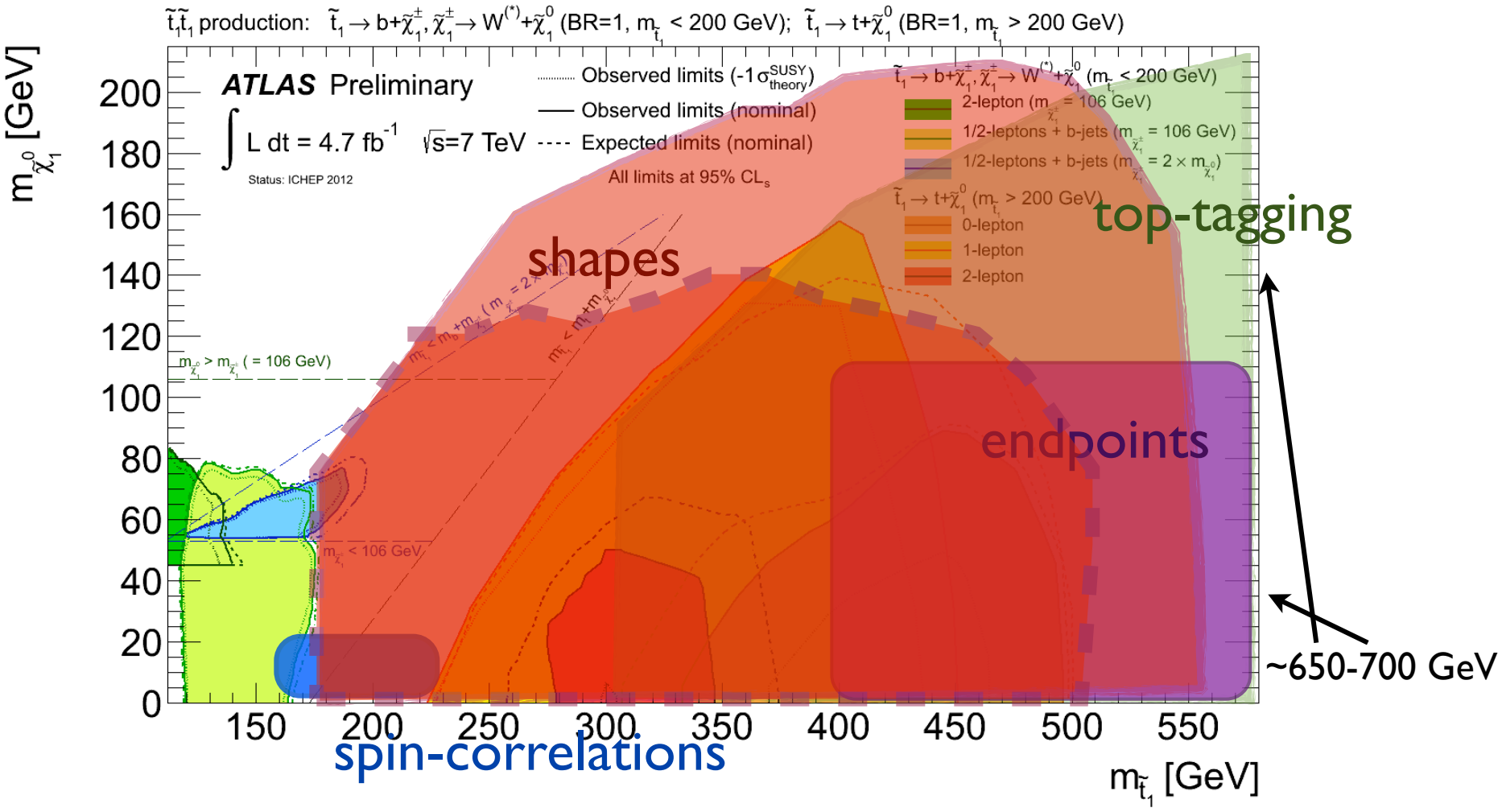
# All together now



# All together now



# All together now



# Summary

- light stops are interesting
- first results of direct stop production at LHC cover interesting regions of parameter space
- regions along the degeneracy line and at higher mass are still allowed
- shape analyses + other proposed theoretical ideas can explore these interesting regions
- worth looking at other simplified models,

  e.g. stop > bottom + chargino

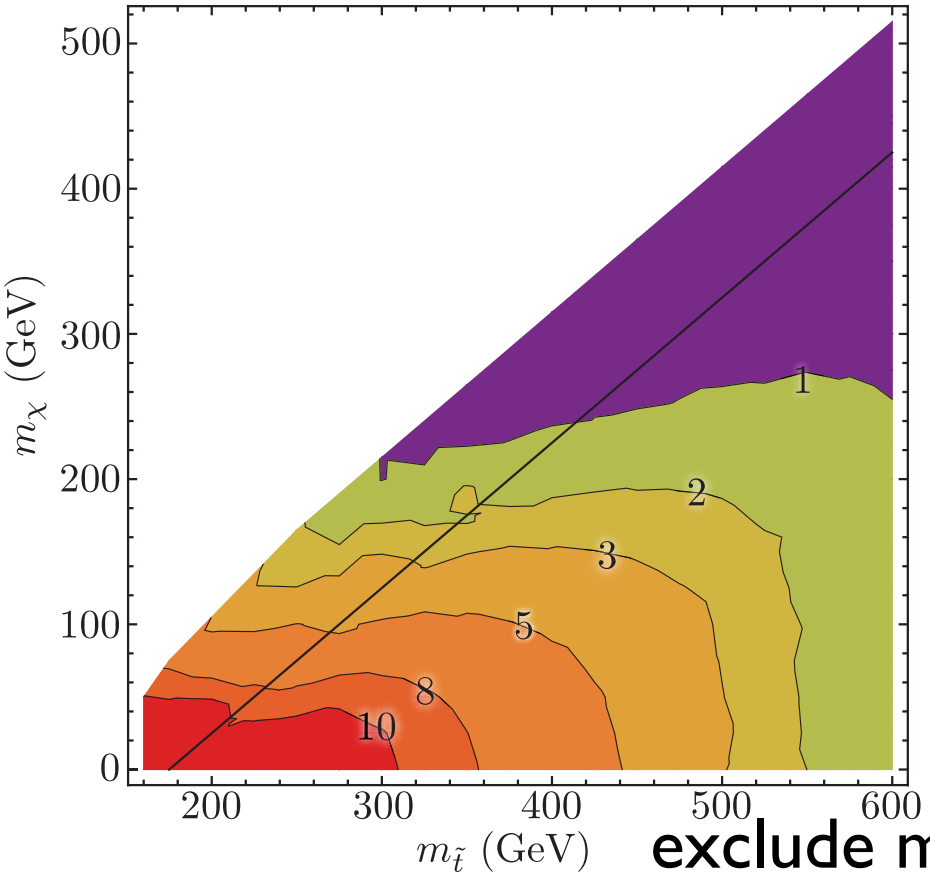
# BACKUP

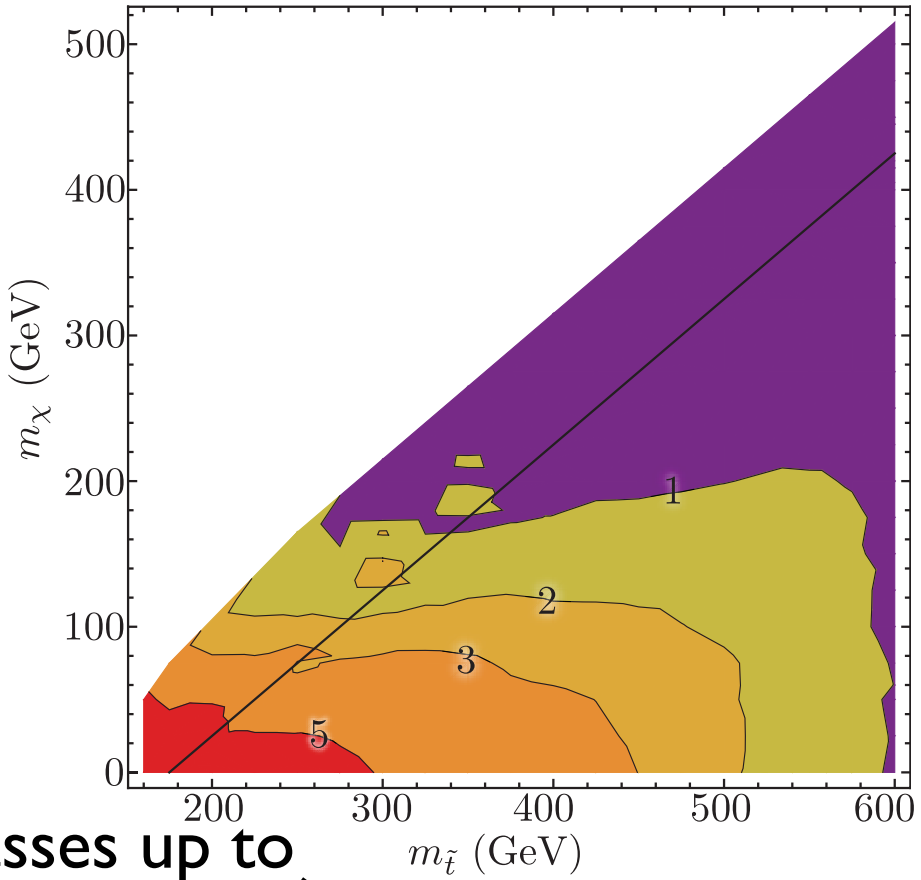
# MET

errors x 1

8 TeV, 20 fb-1

errors x 3




exclude masses up to

550 GeV

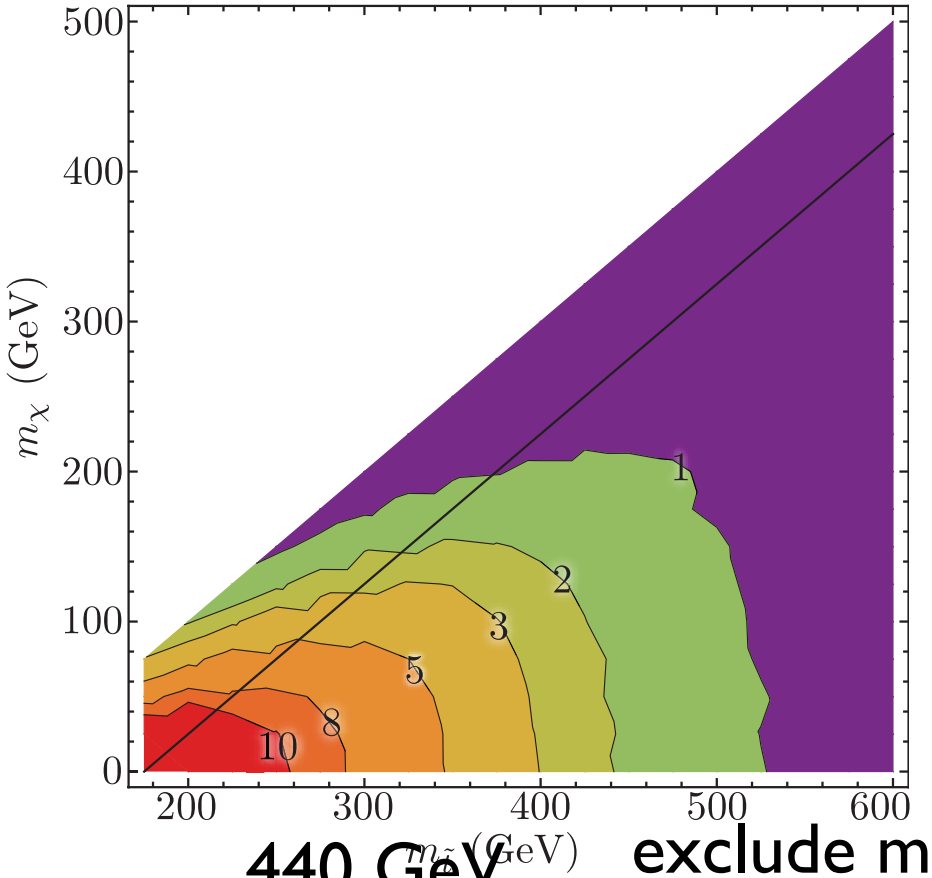
light LSP: 350 GeV

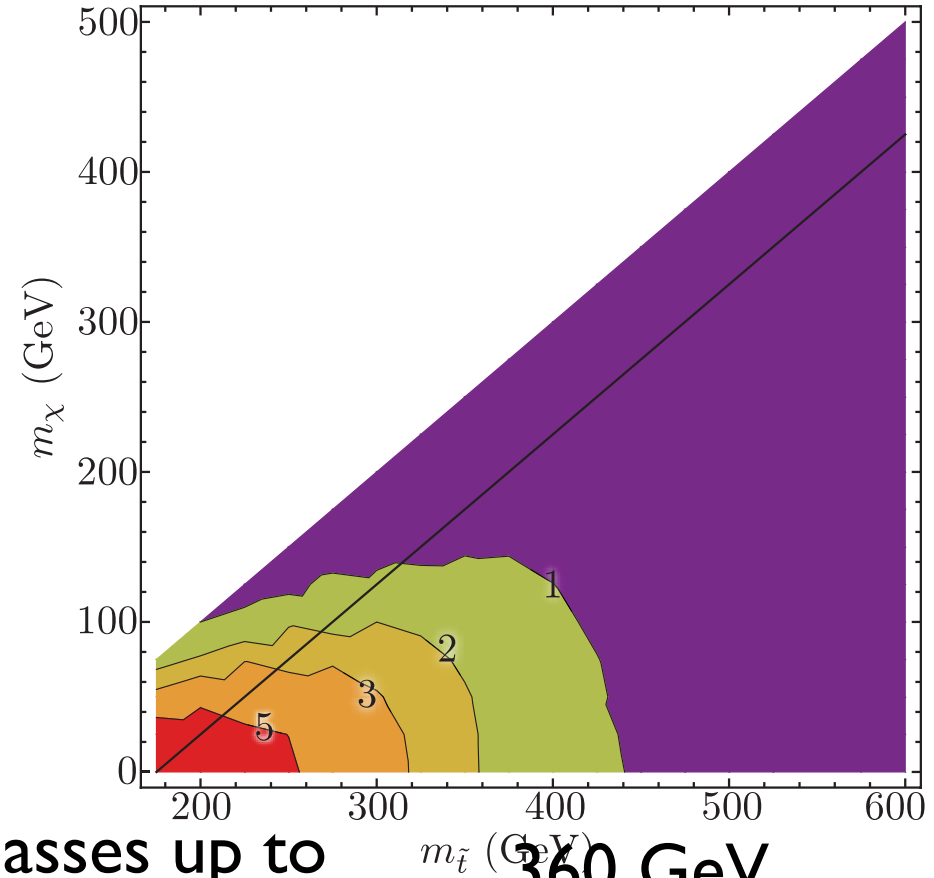
520 GeV

light LSP: 280 GeV

# MTW

errors x 1 — 8 TeV, 20 fb-1 — errors x 3



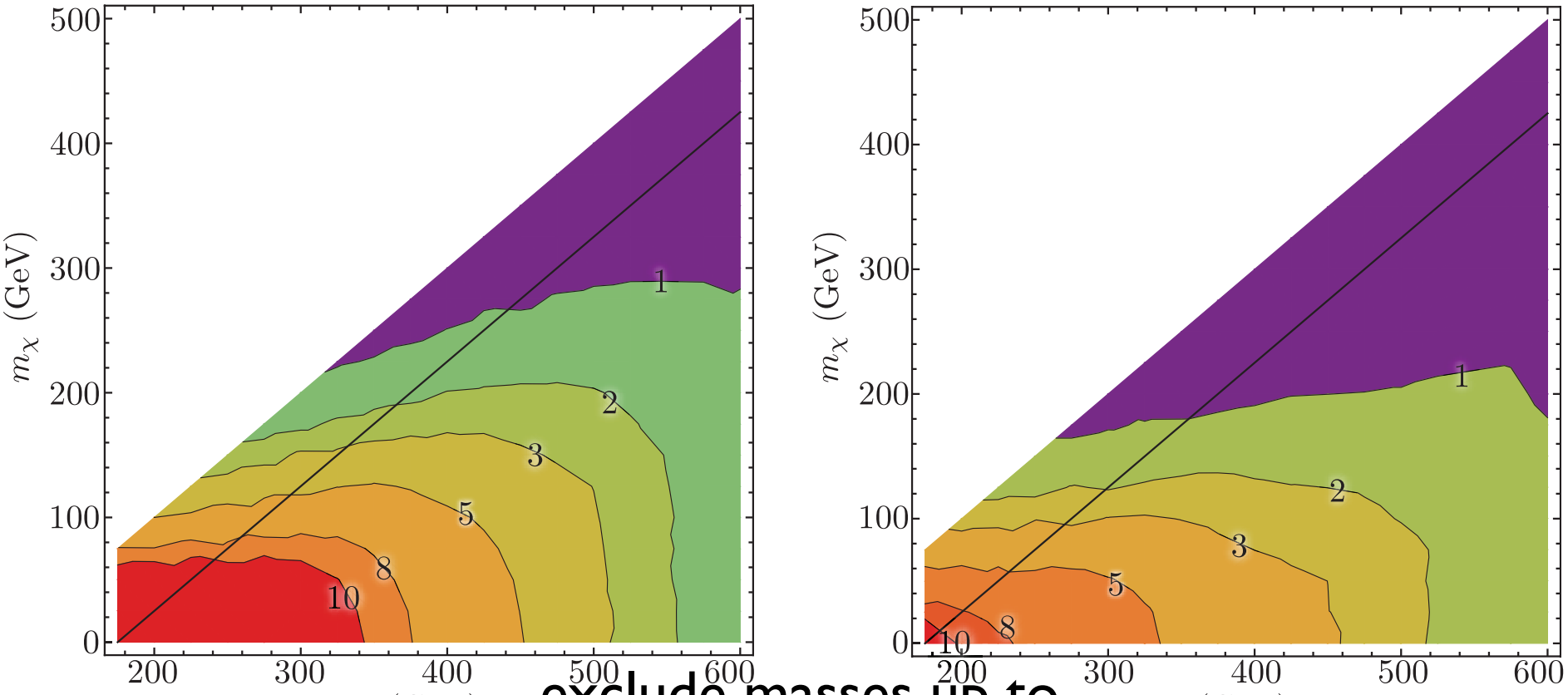

440 GeV ↙ exclude masses up to ↘ 360 GeV

light LSP: 320 GeV

light LSP: 270 GeV

# Combined

errors x 1 — 8 TeV, 20 fb-1 — errors x 3




exclude masses up to

560 GeV
light LSP: 360 GeV

520 GeV
light LSP: 300 GeV