STOP SIGNS AT THE LHC

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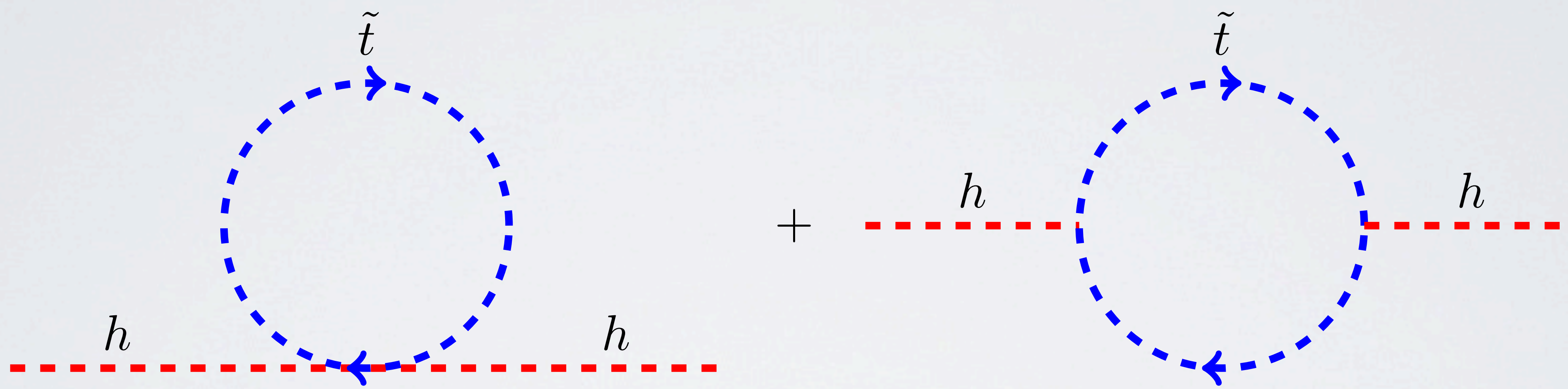
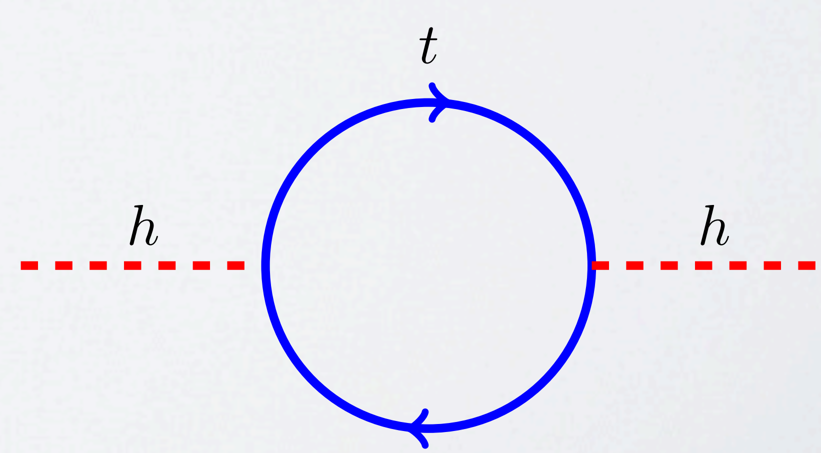
Harvard University

At the Chicago LHC Workshop, May 2, 2012

SUPERSYMMETRY AND THE HIGGS MASS



Different-spin pieces combine to cancel large corrections.



DICHOTOMY

Higgs at 125 GeV

Beyond MSSM,
natural

MSSM with
heavy scalars

robust experimental connection

Stop search;
Higgs sector
(rates, decays)

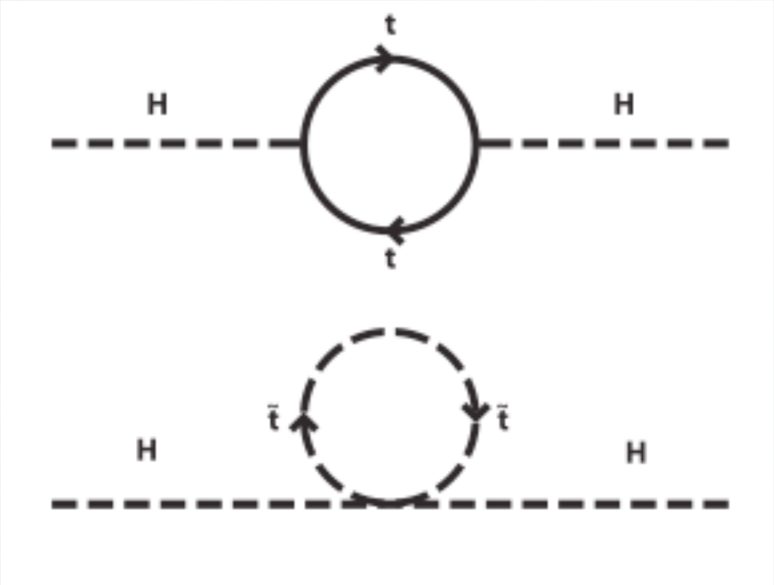
Models?
(NMSSM, D-terms,
compositeness....)

Gluino
search

Top-down
theory

NATURAL SUSY

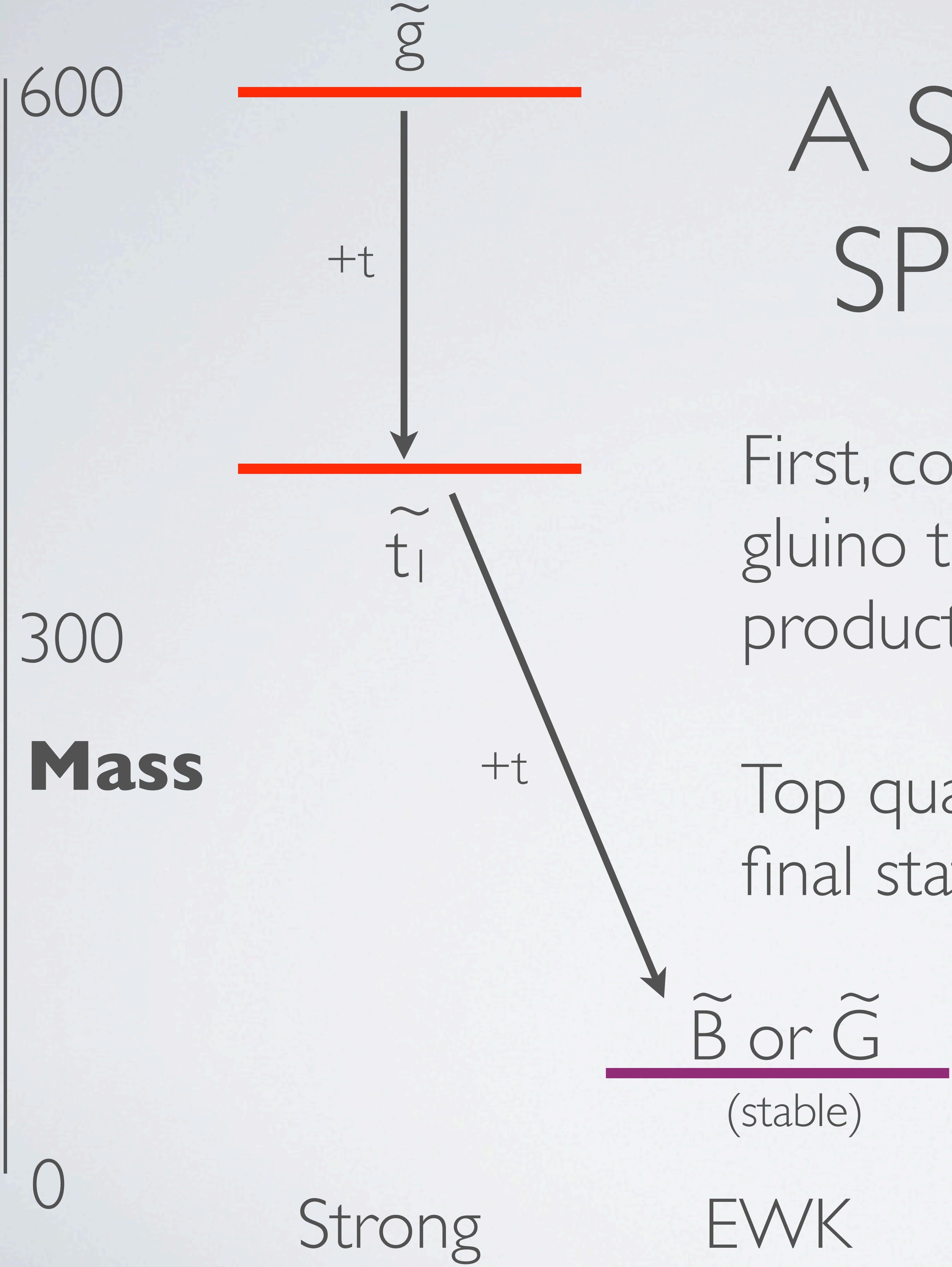
To target the natural SUSY scenario (light stops & sbottoms, heavier 1st/2nd generation), work with **simplified spectra.**



P. Meade & MR, '06

Focus on the hierarchy problem: which particles do we *need*?

The scalar top quark cancels the biggest divergence.



A SIMPLIFIED SPECTRUM

First, consider the case with a gluino to enhance production rate.

Top quarks: higher-multiplicity final state.

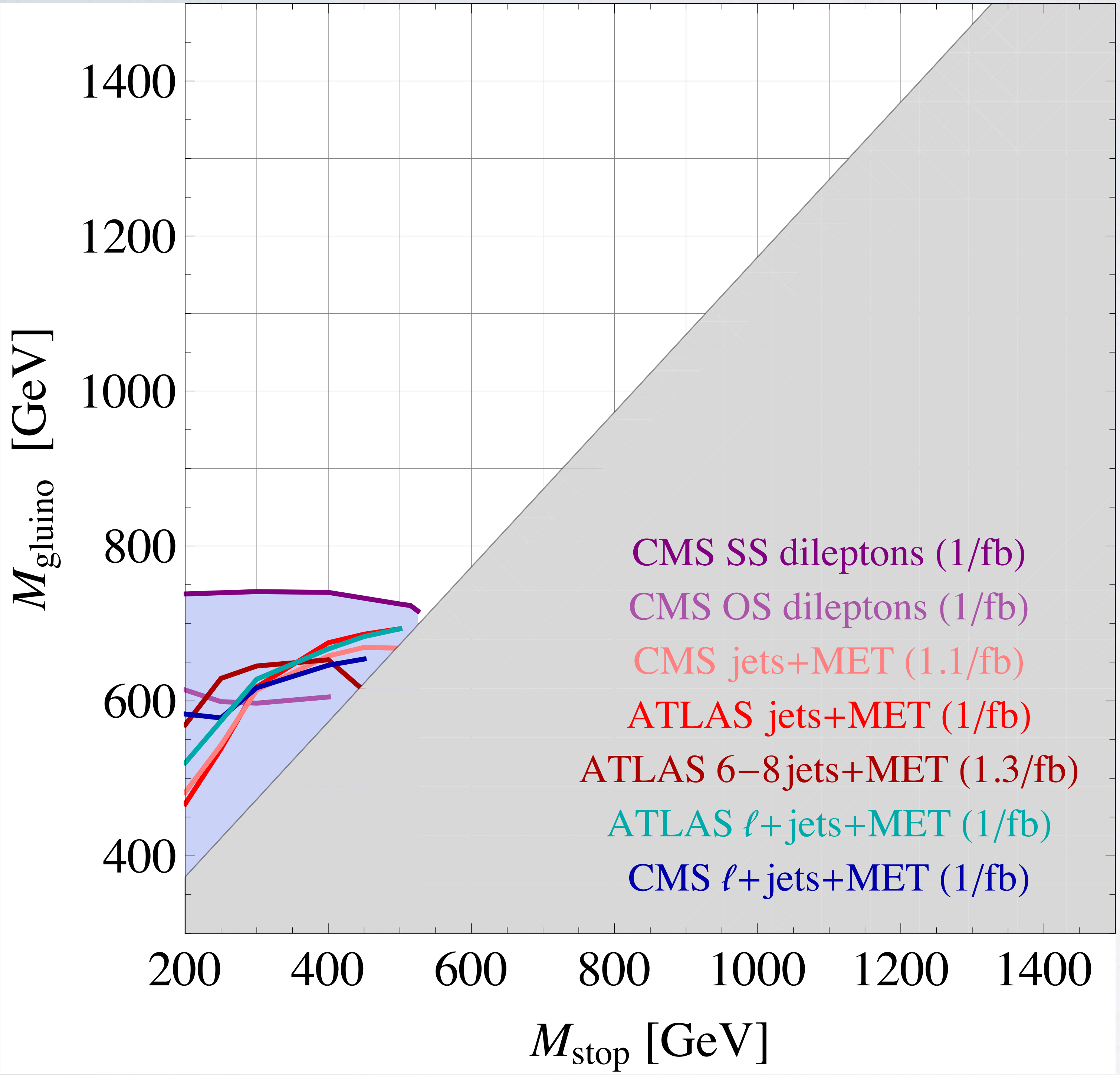
LIMIT RECASTING

- "The Status of GMSB After 1/fb," 1110.6444, by Y. Kats, P. Meade, MR, D. Shih
- Several simplified spectra

(similar work: Essig et al. 1110.6443, Brust et al. 1110.6670, Papucci et al. 1110.6926, Bi et al. 1111.2251, Desai et al. 1111.2830)

- Simulated with Pythia, FastJet, private code; validated against ATLAS & CMS plots
- Strong limits from:
  - jets + MET (very powerful, general purpose)
  - diphotons + MET, same-sign dileptons (low background)

GLUINOS & STOPS: GLUINO > 700 GEV



Gluino/stop/gravitino simplified model

Shows power of same-sign dileptons, CMS SUS-11-010

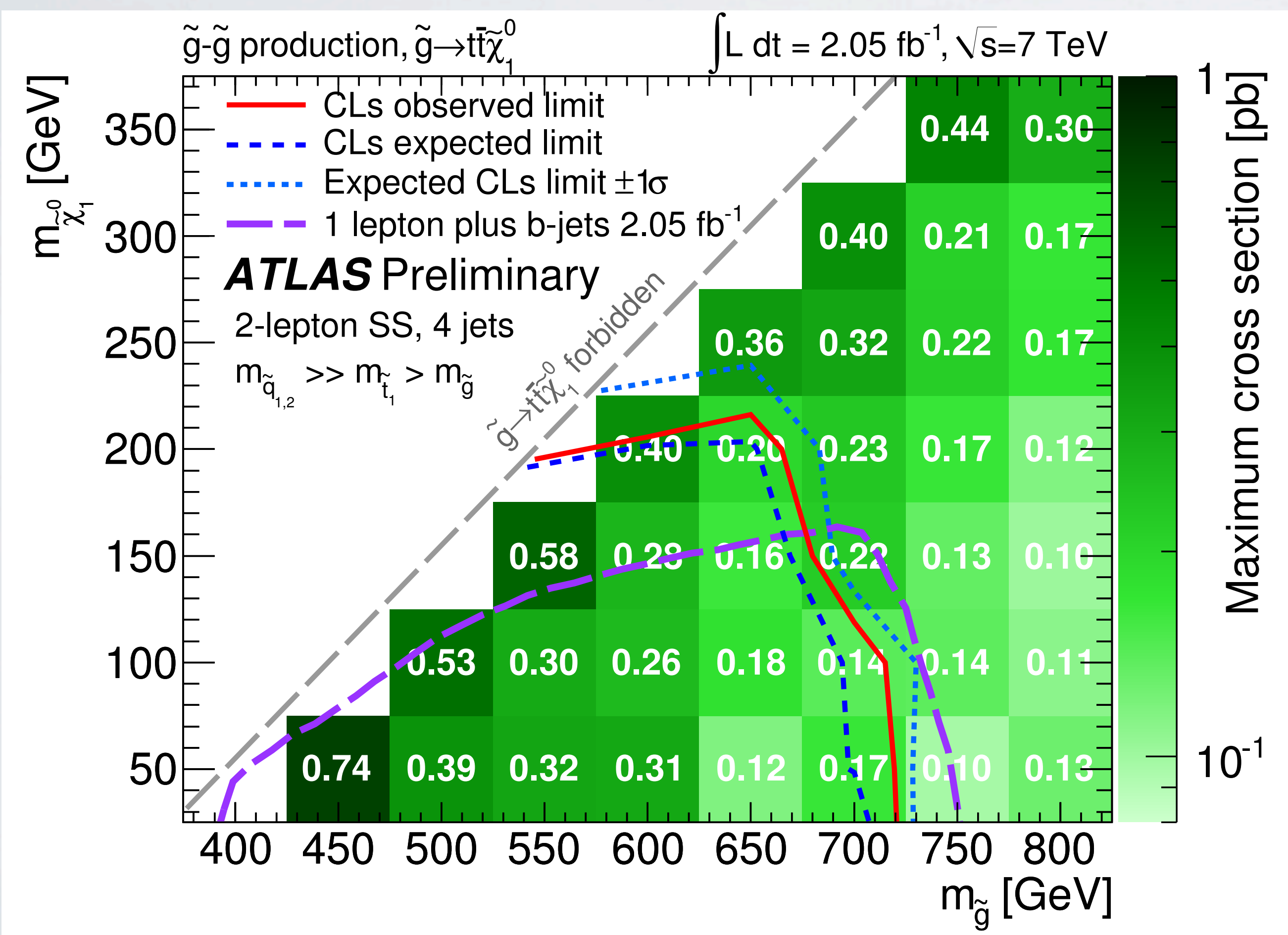
No reach for stop alone: LHC needs more than brute force

Y. Kats, P. Meade, MR, D. Shih '11 (with many more models)

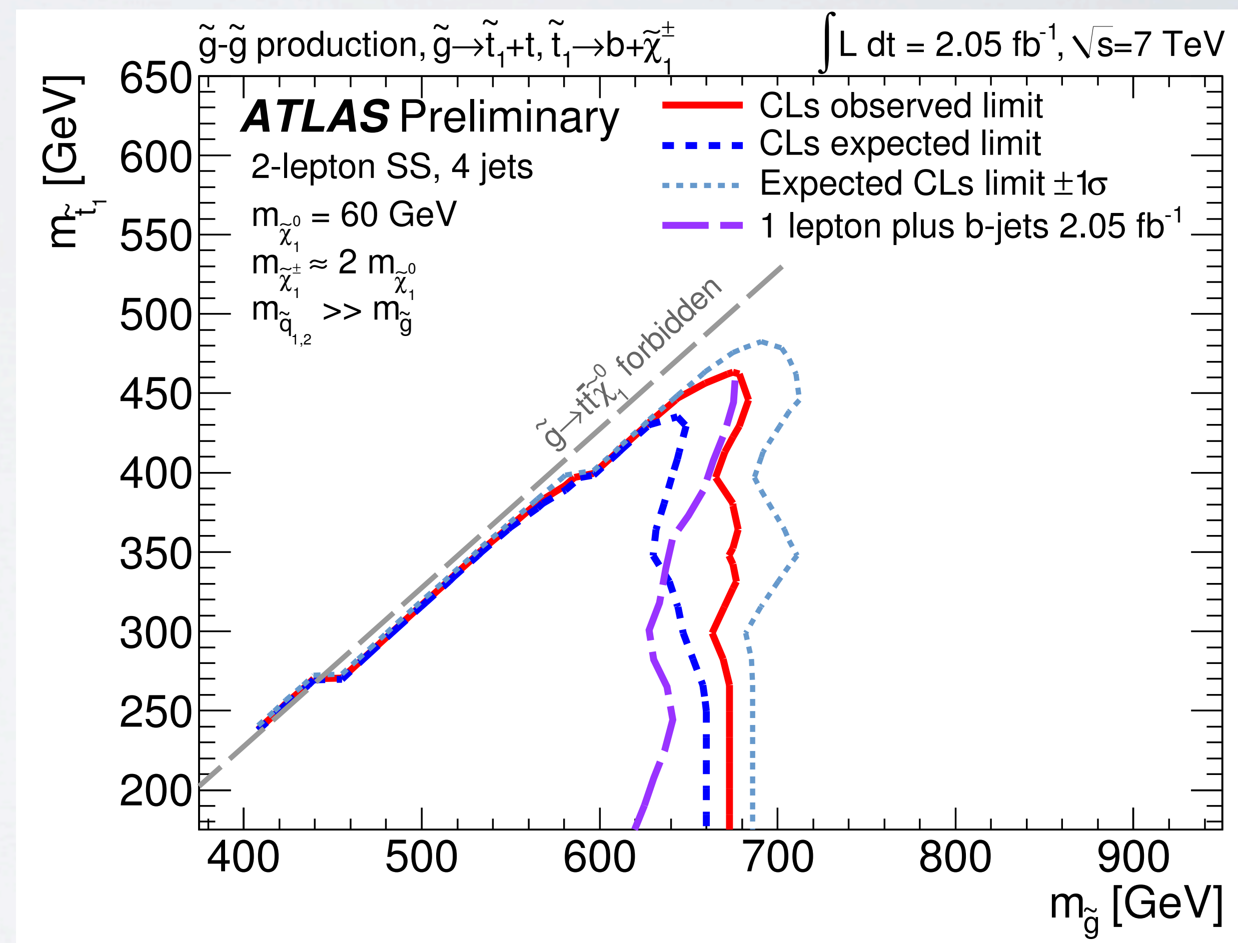
WINTER CONFERENCES...

ATLAS-CONF-2012-004, released Feb 2012: same-sign leptons, jets, MET

gluino through off-shell stop



gluino to on-shell stop

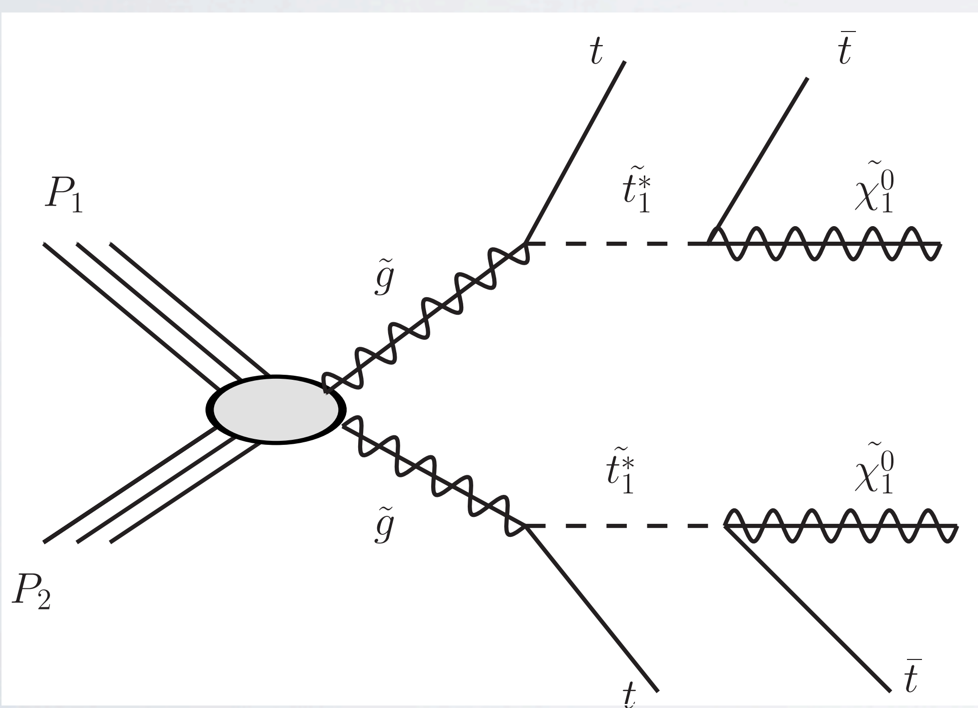


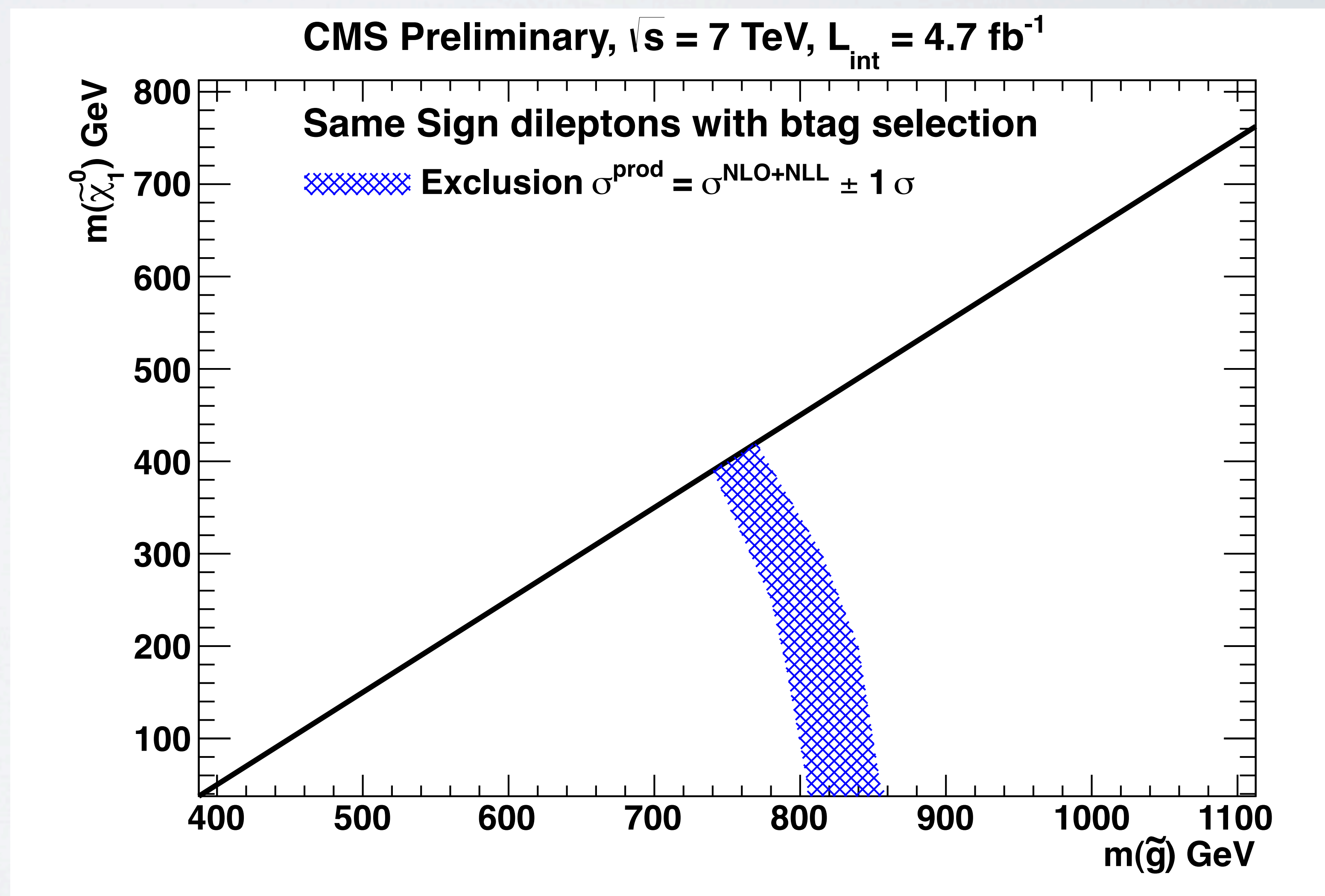
Confirms our estimates: **gluino above ~700 GeV**

AND MORE...

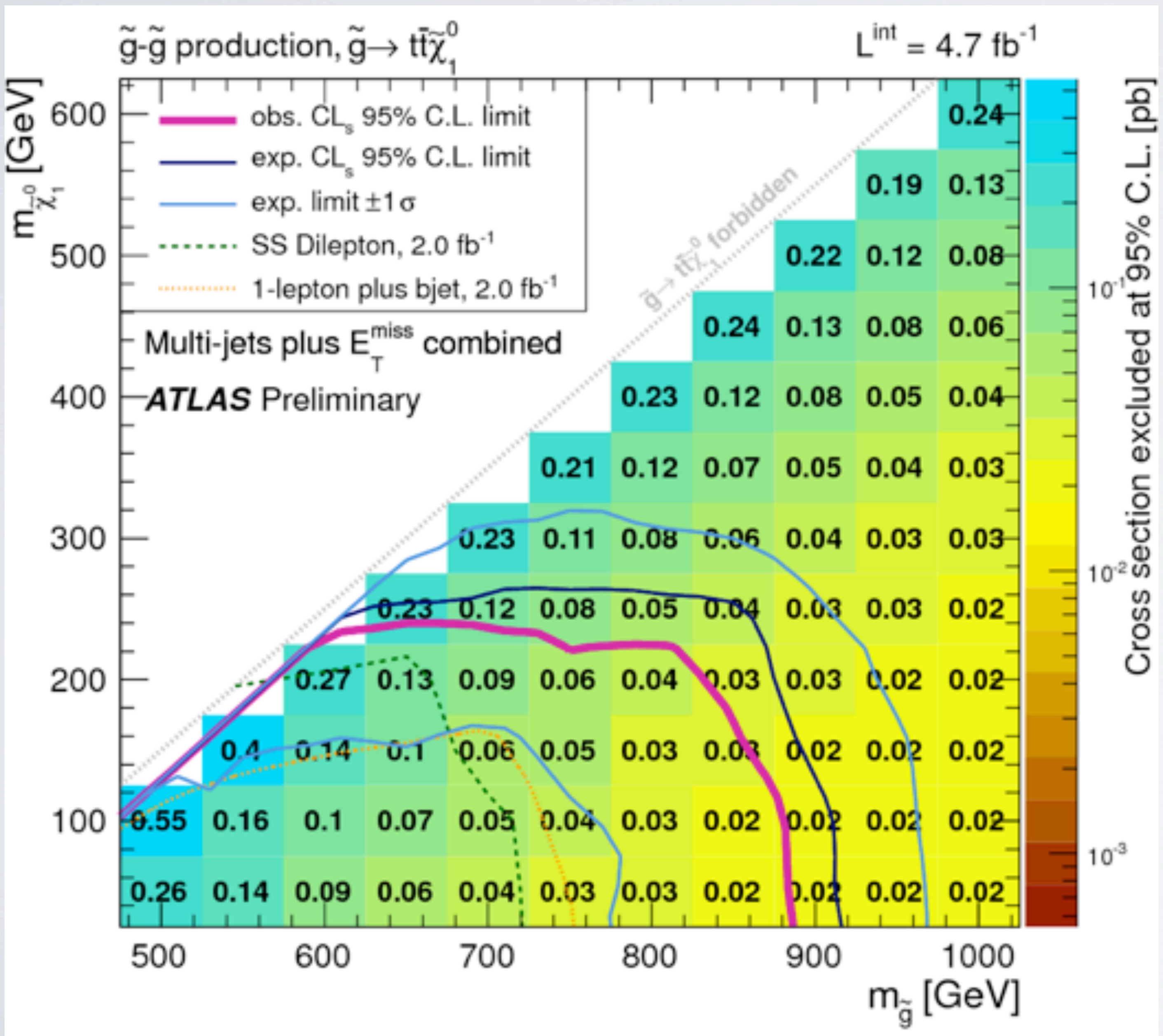
CMS-SUS-11-020, March, 2012

Same-sign dileptons and *b*-jets





AND MORE



ATLAS-CONF-2012-033

6 to 9 jets + MET

Experiments have learned this lesson well! Maybe need to think a bit more about compressed spectra.

GLUINO MASS & STOP MASS

A weakness of the "simplified model" approach where we set masses independently is that it misses the **RG**:

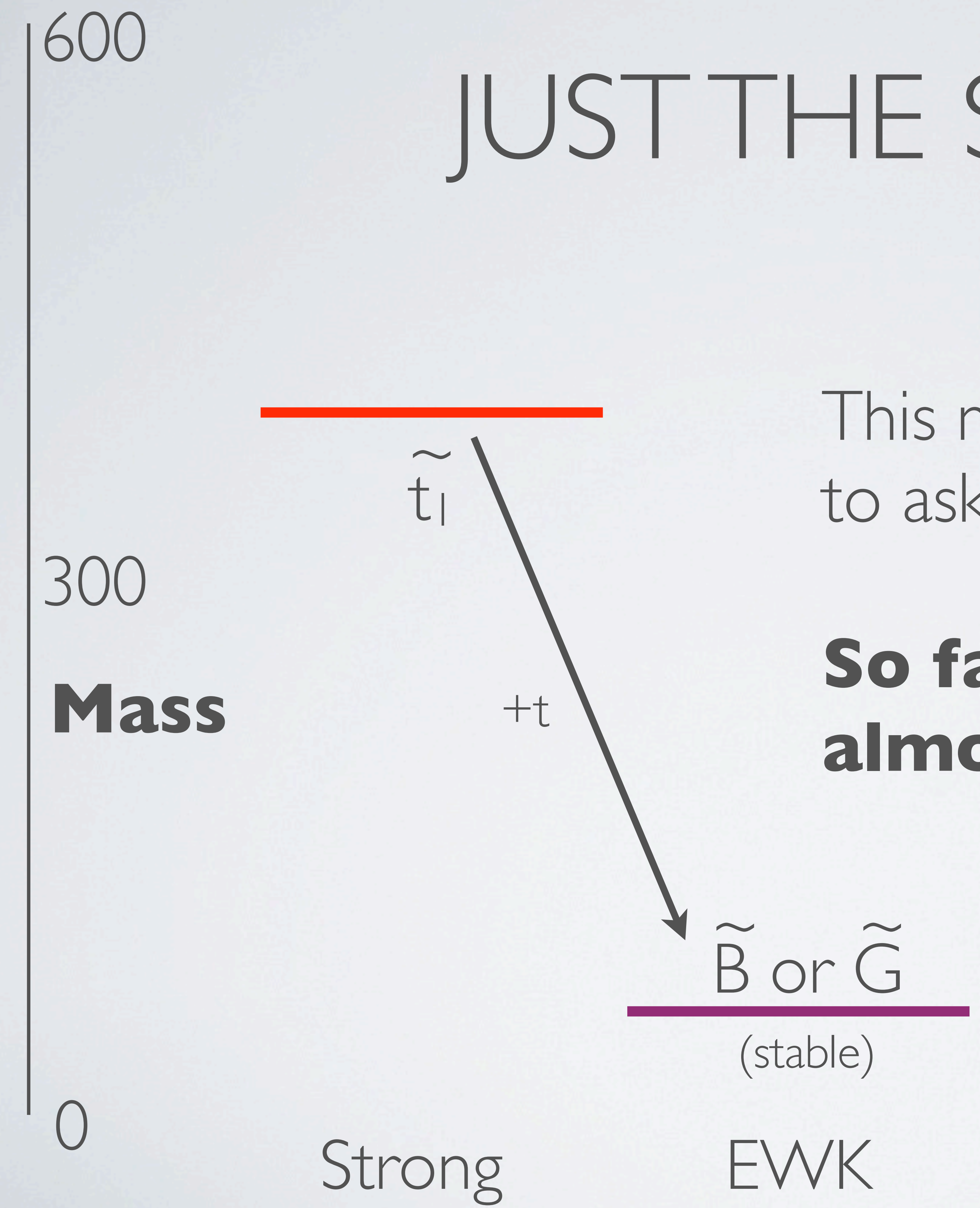
$$\frac{d}{d\log\mu} m^2_{\tilde{t}_L} = \frac{1}{16\pi^2}\left(-\frac{32}{3}g_3^2 M_3^2 - 6 g_2^2 M_2^2 + X_t + \cdots\right)$$

There is some model dependence, but roughly a bound of 900 GeV on gluinos means that **without tuning**

$$m_{\tilde{t}_L} \gtrsim 360 \text{ GeV}$$

Can have tachyonic stop masses at high scale. But naturalness really wants gluino below ~ 1.5 TeV. **Keep looking!**

JUST THE STOP?



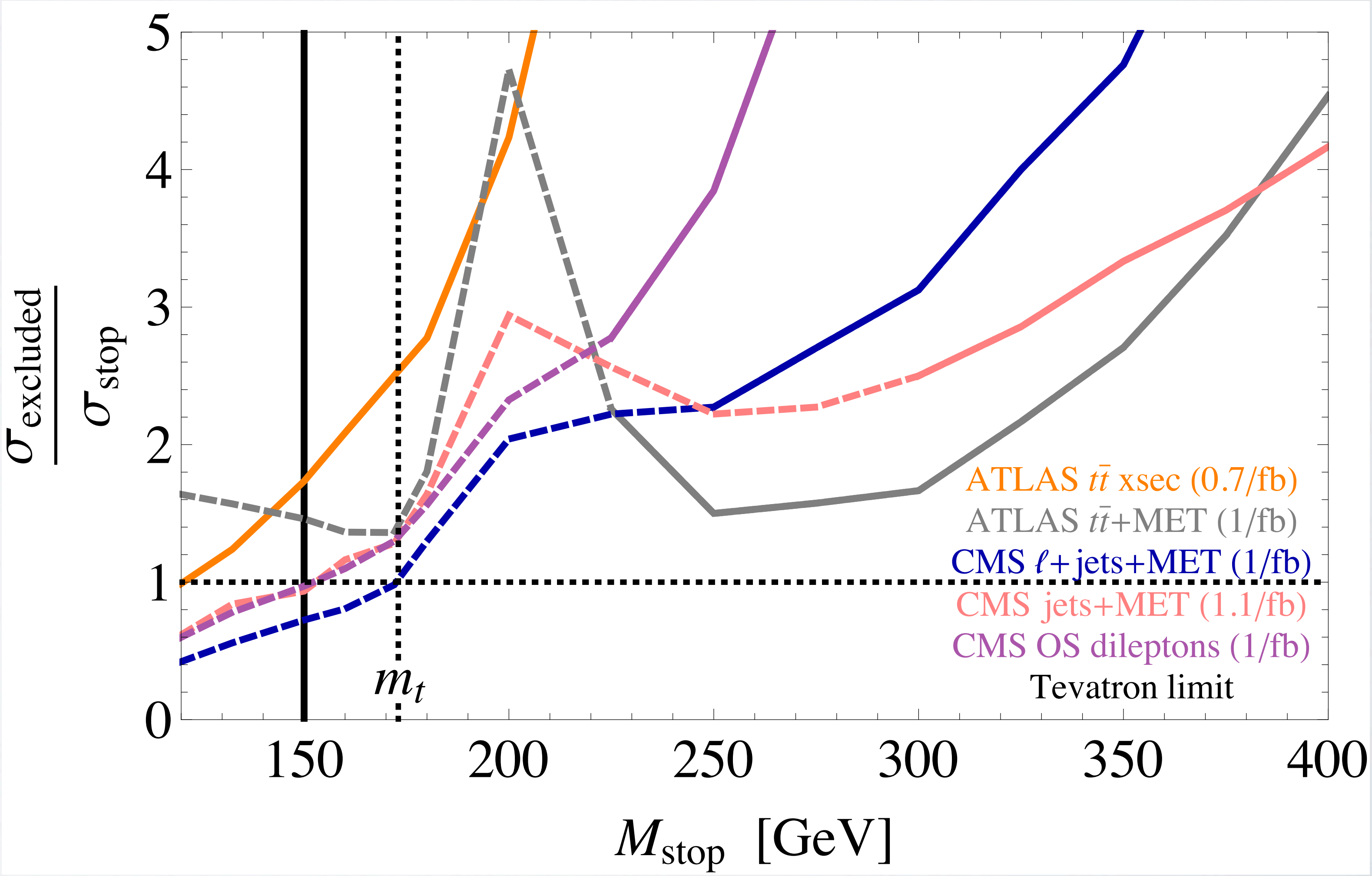
This more directly amounts to asking about naturalness.

So far, the LHC says almost nothing.

A STEALTHY STOP?

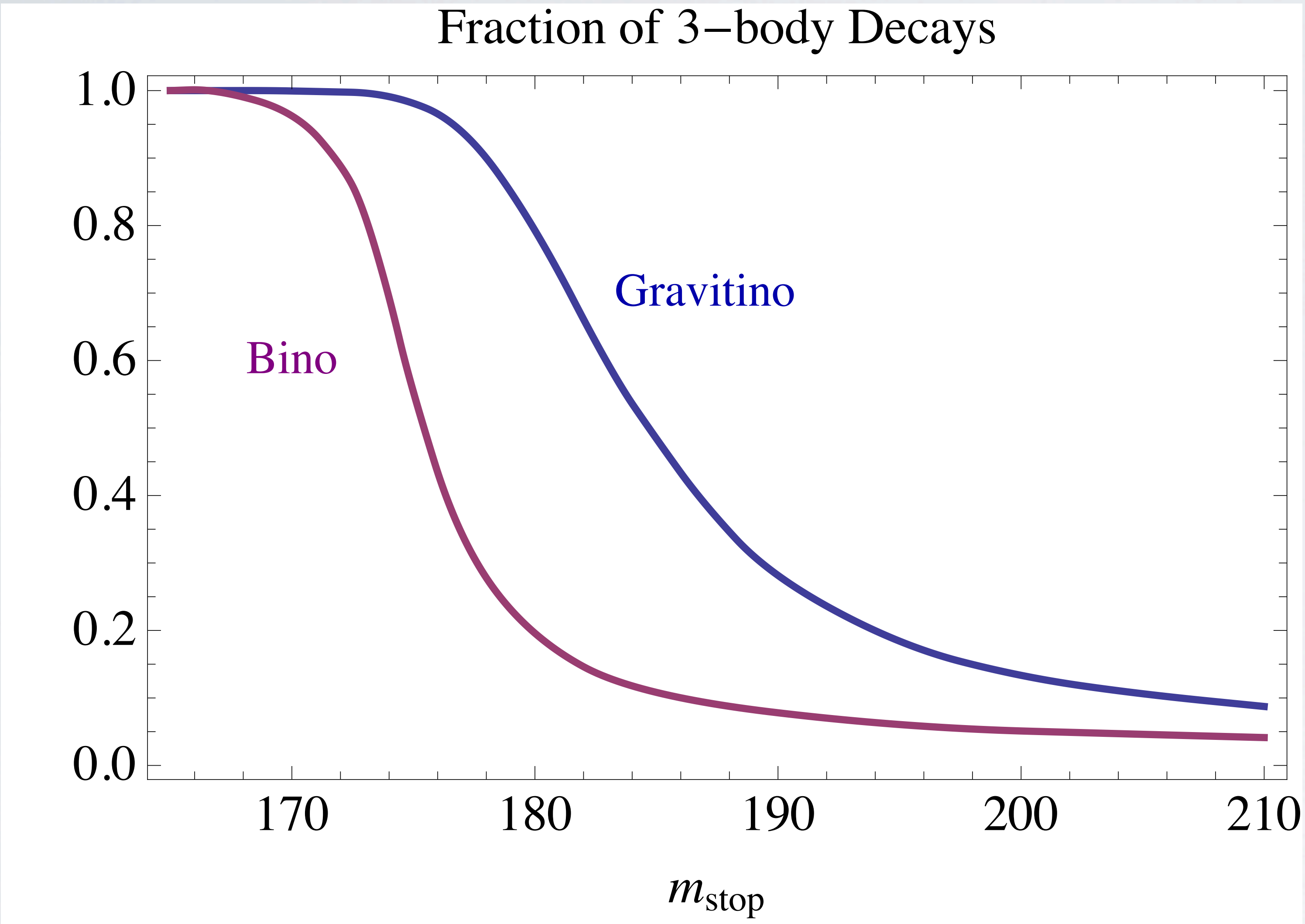
The stop could be lurking very near the top quark mass, canceling the Higgs mass corrections.

Very hard to see in this mass range; an instance of **“stealth supersymmetry”** (J. Fan, MR, J. Ruderman, ’11)



Y. Kats, P. Meade, MR, D. Shih ’11

THREE-BODY DECAYS?



If $m_{\mathrm{stop}} \sim m_{\mathrm{top}}$, have "stealthy" decays, but 3-body decays can have more MET.

More 3-body decays for gravitinos:

$$\Gamma_{2\ \mathrm{body}} = \frac{m_{\tilde{t}}^5}{16\pi F^2}\left(1 - \frac{m_t^2}{m_{\tilde{t}}^2}\right)^4$$

Two extra phase space factors from goldstino coupling to SUSY breaking

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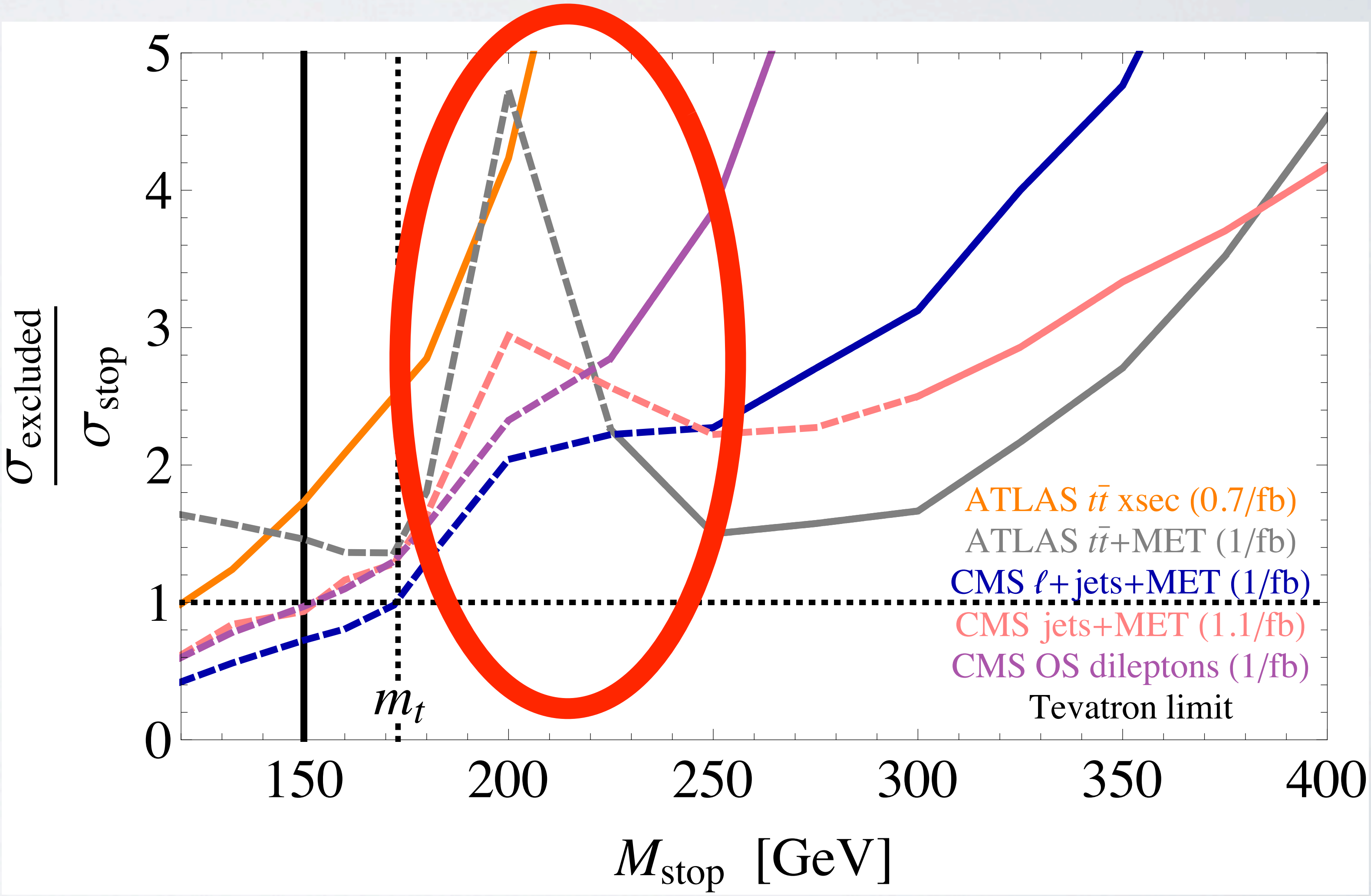
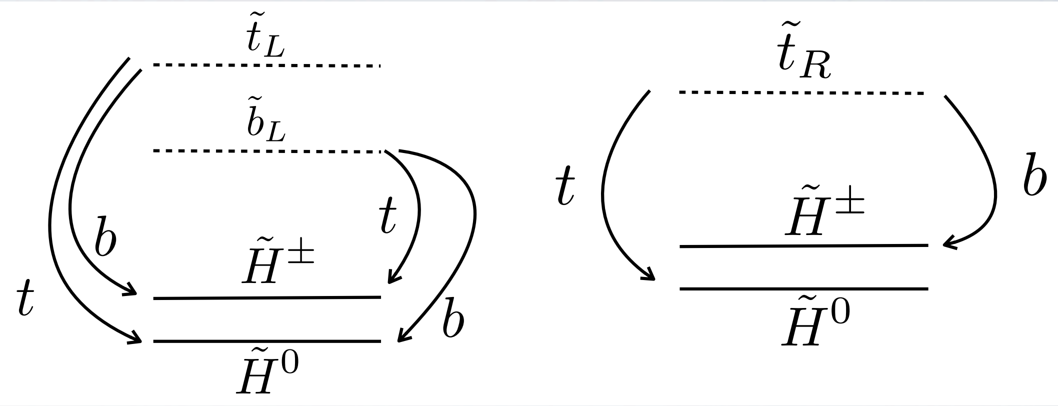
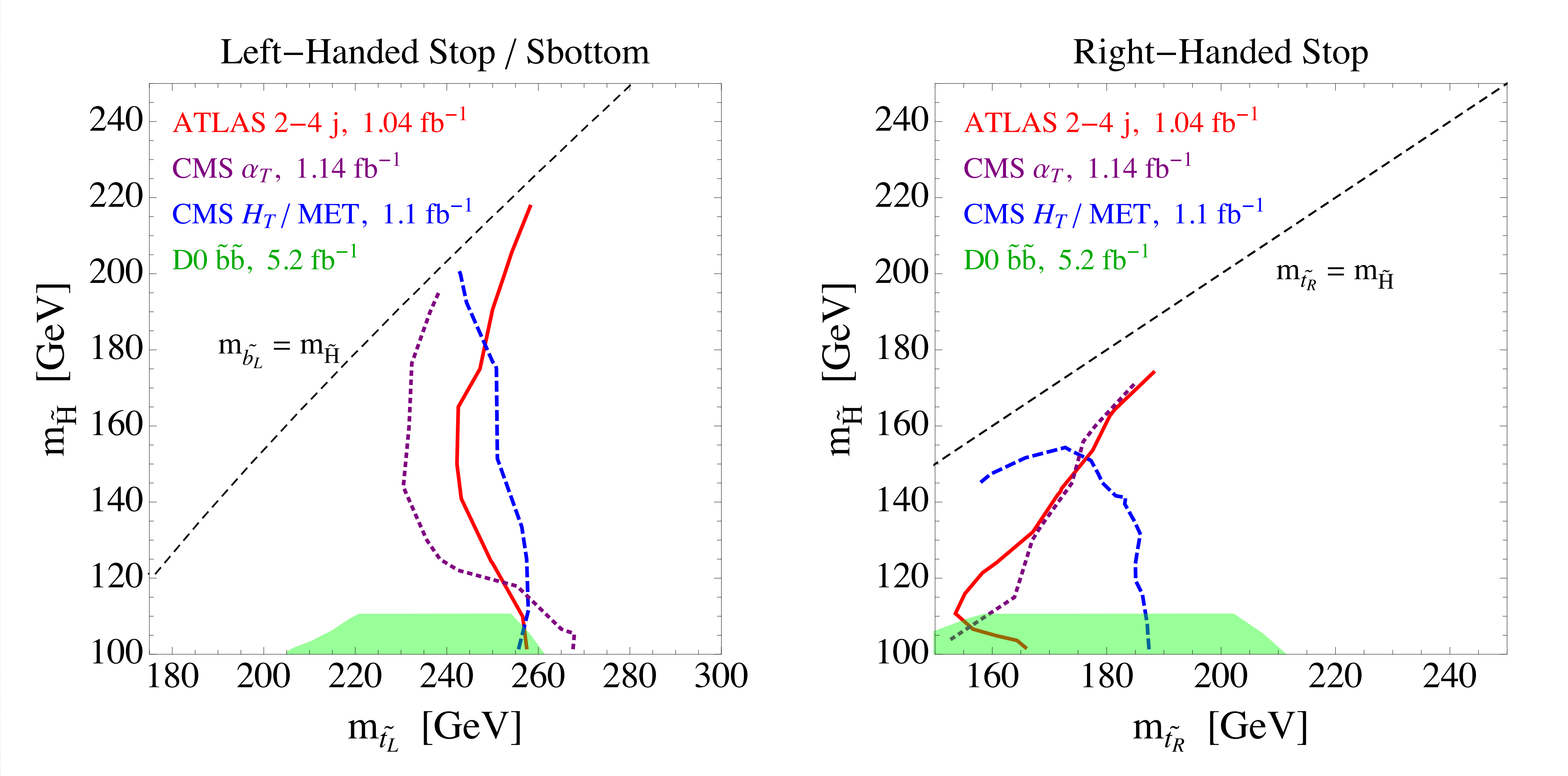


Y. Kats, P. Meade, MR, D. Shih '11

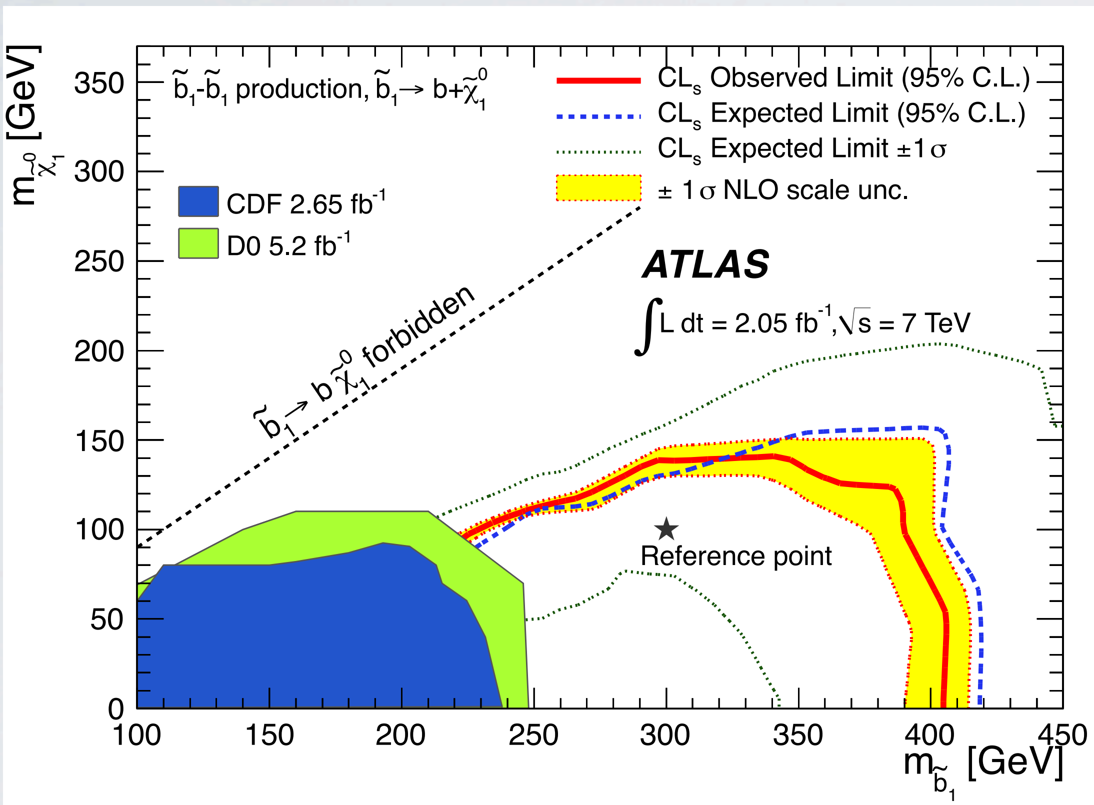
LSP DEPENDENCE

Stronger bounds for Higgsino LSP: Papucci, Ruderman, Weiler, 1110.6926





HEAVIER STATES?



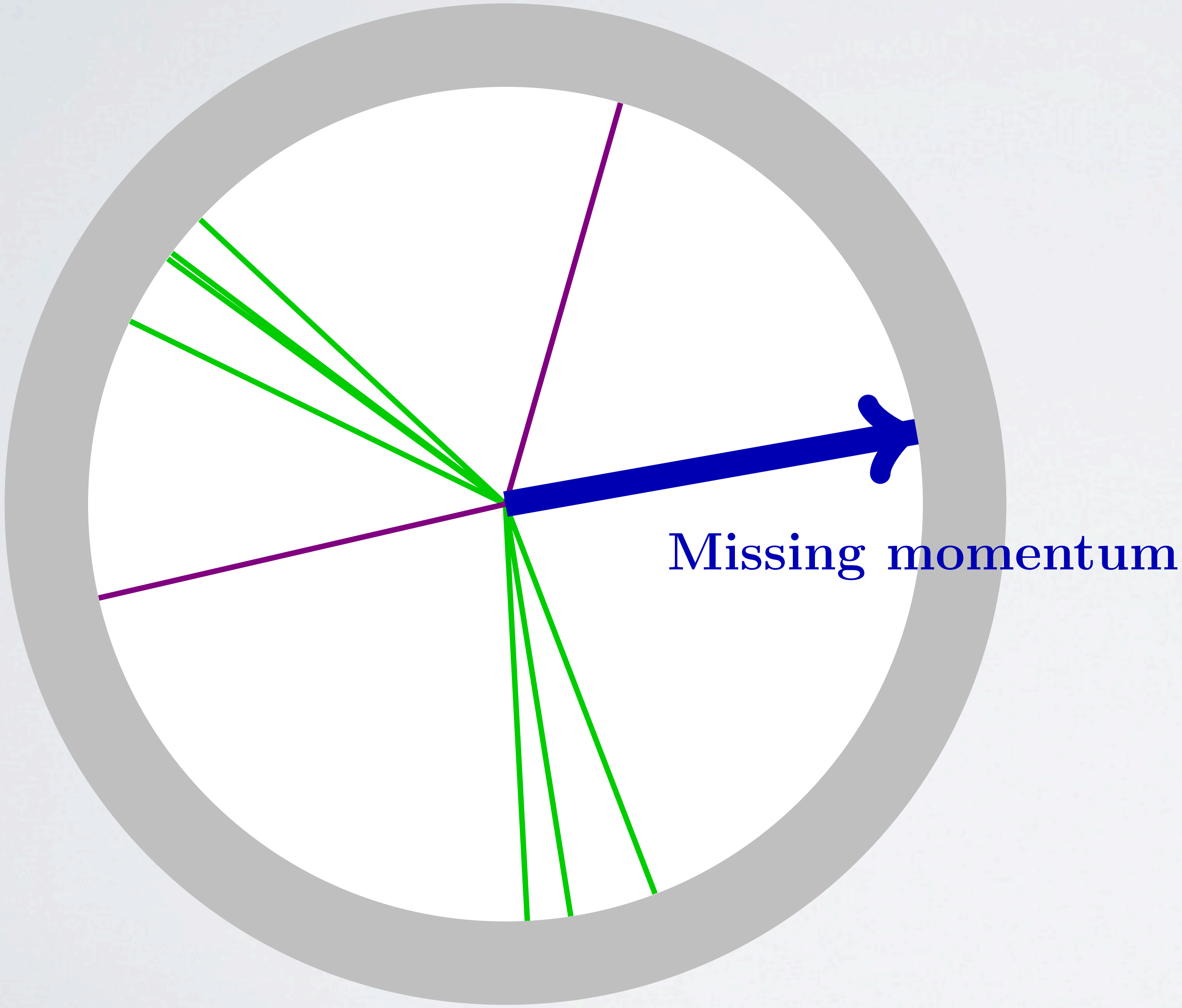
$\tilde{b} \to b\tilde{\chi}^0$ at ATLAS: bounded to ~ 400 GeV if neutralino < 150 GeV

Similar bounds on $\tilde{b} \to \tilde{t}W^-$ from same-sign dilepton

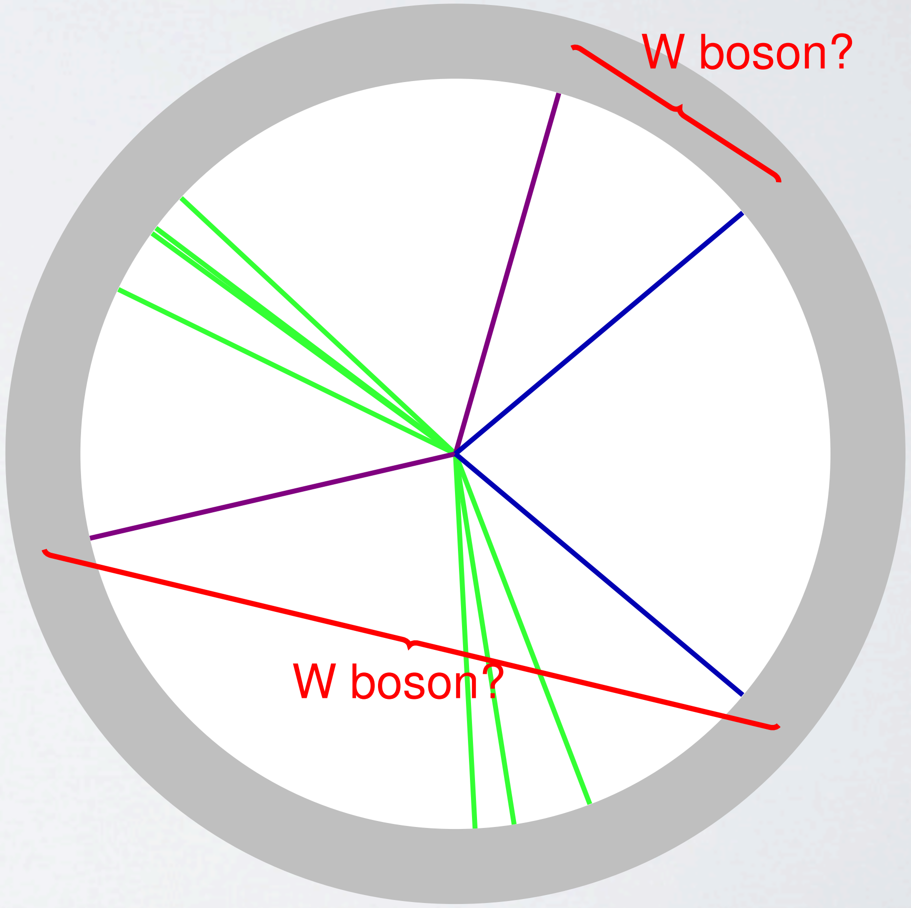
Perelstein, Spethmann hep-ph/0702038: $\tilde{t}_2 \to \tilde{t}_1 Z$ in the "supersymmetric golden region" (light stop, large A-term mixing stop-right and stop-left)

LIGHT STOPS

One idea: leptonic M_{T2}. (Kats, Meade, MR, Shih)



M_{T2} or "stransverse mass" variable from Lester, Summers hep-ph/9906349



Edge at the W mass (also: Cohen, Kuflik, Zurek 1003.2204)

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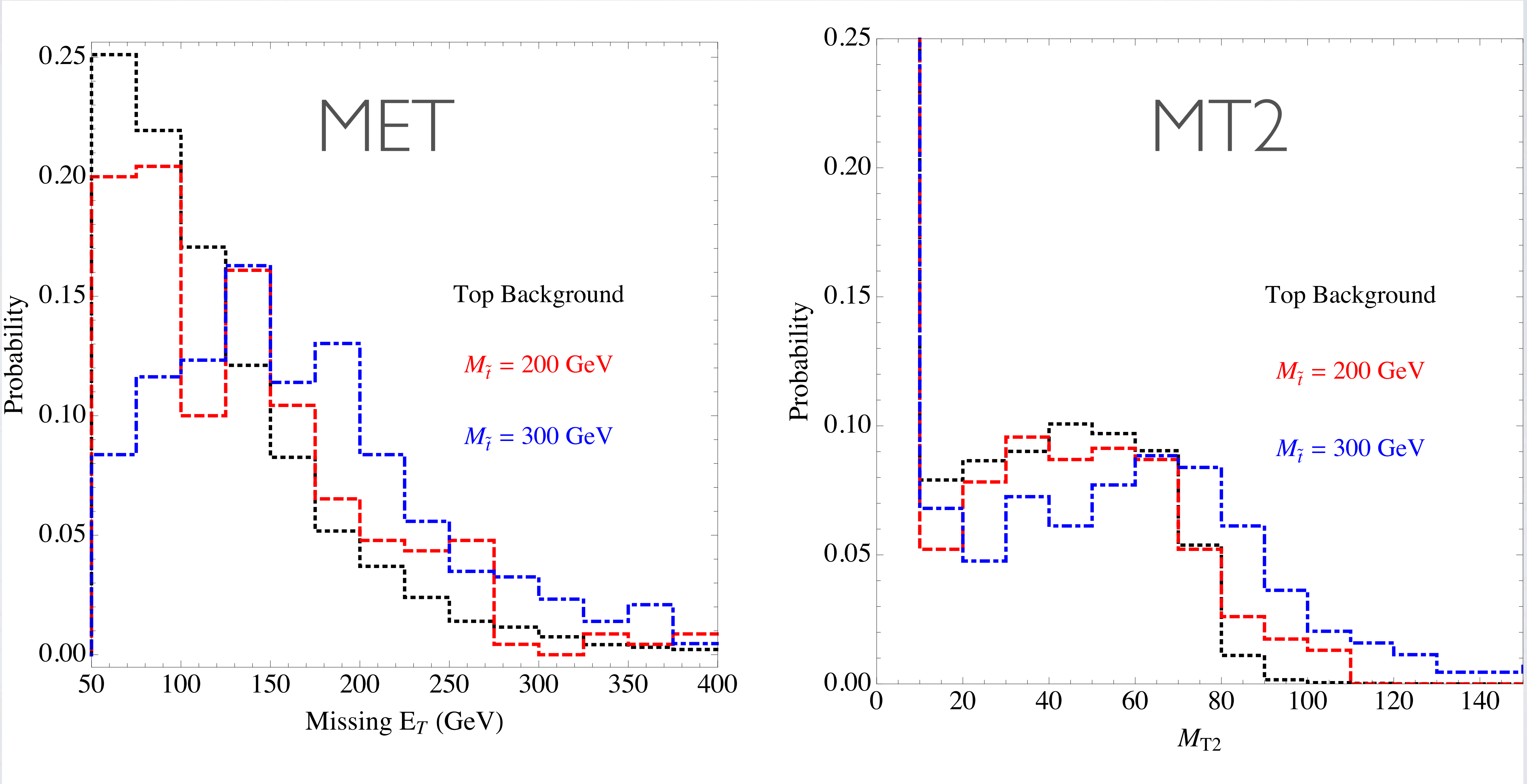

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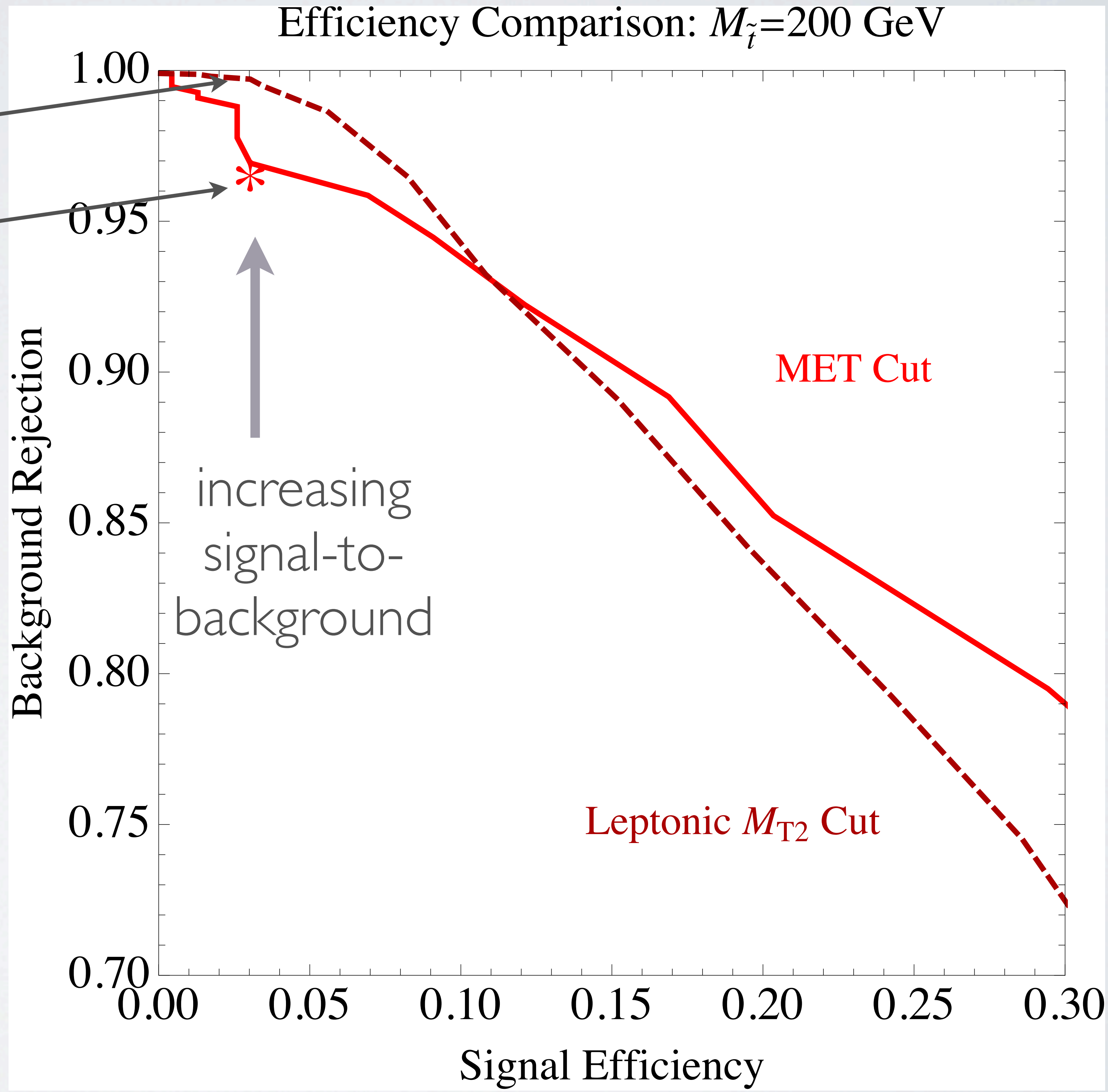
LEPTONIC MT2

our method

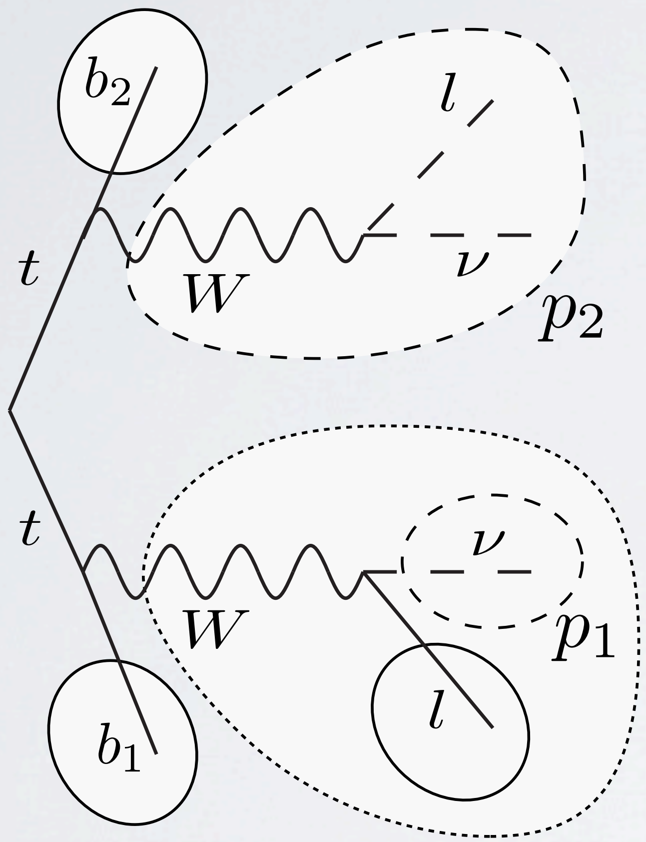
old dilepton search

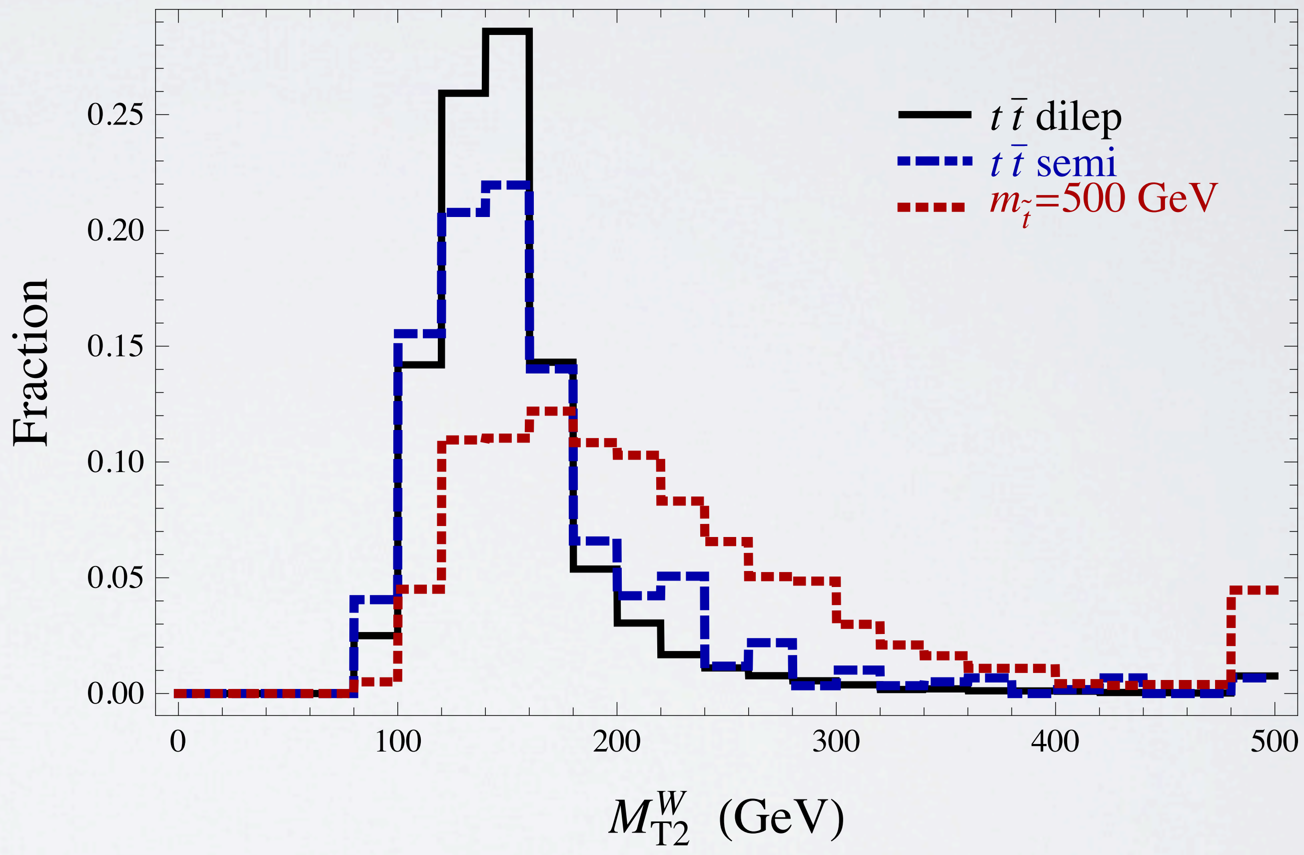


Use **whenever** two leptonically decaying *W* bosons appear in the background (e.g., tops); good for more than just stop searches.

ALONG SIMILAR LINES...

Bai, Cheng, Gallicchio, Gu 1203.4813

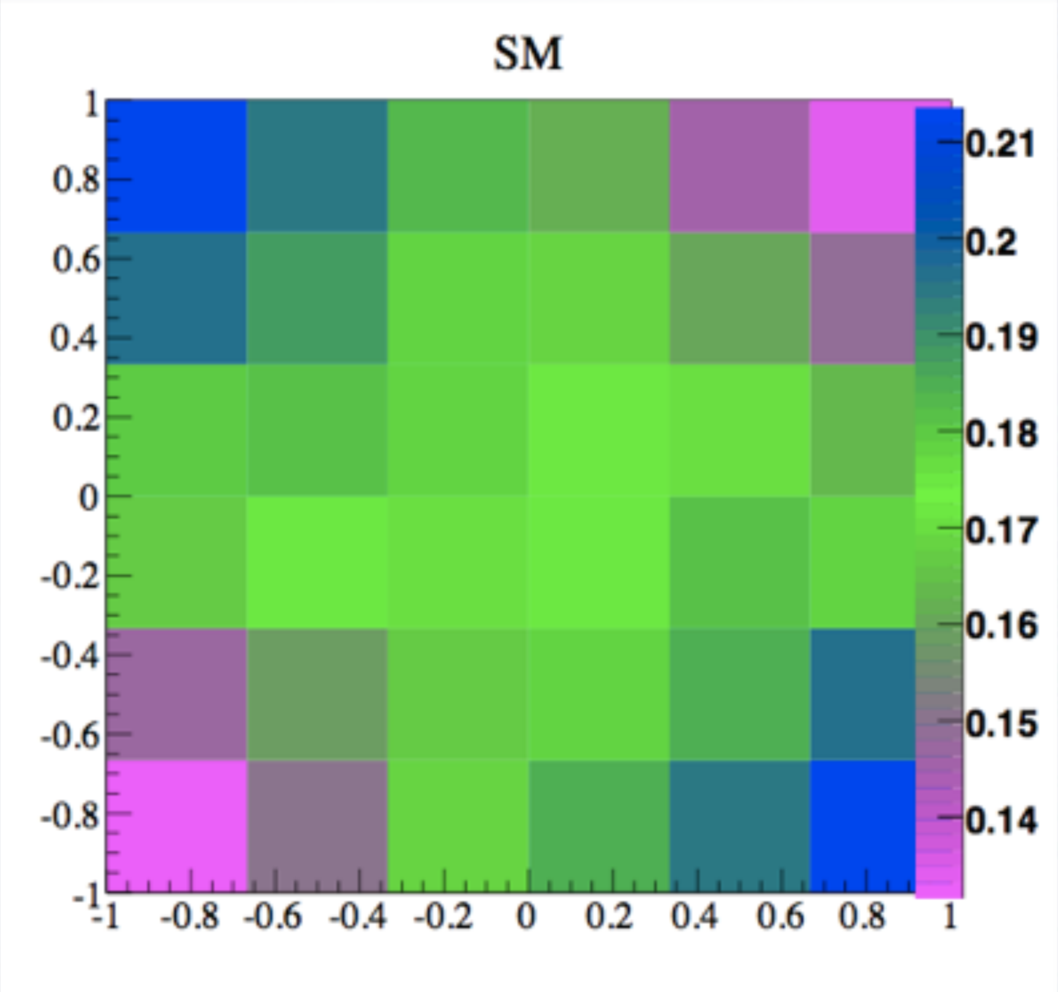


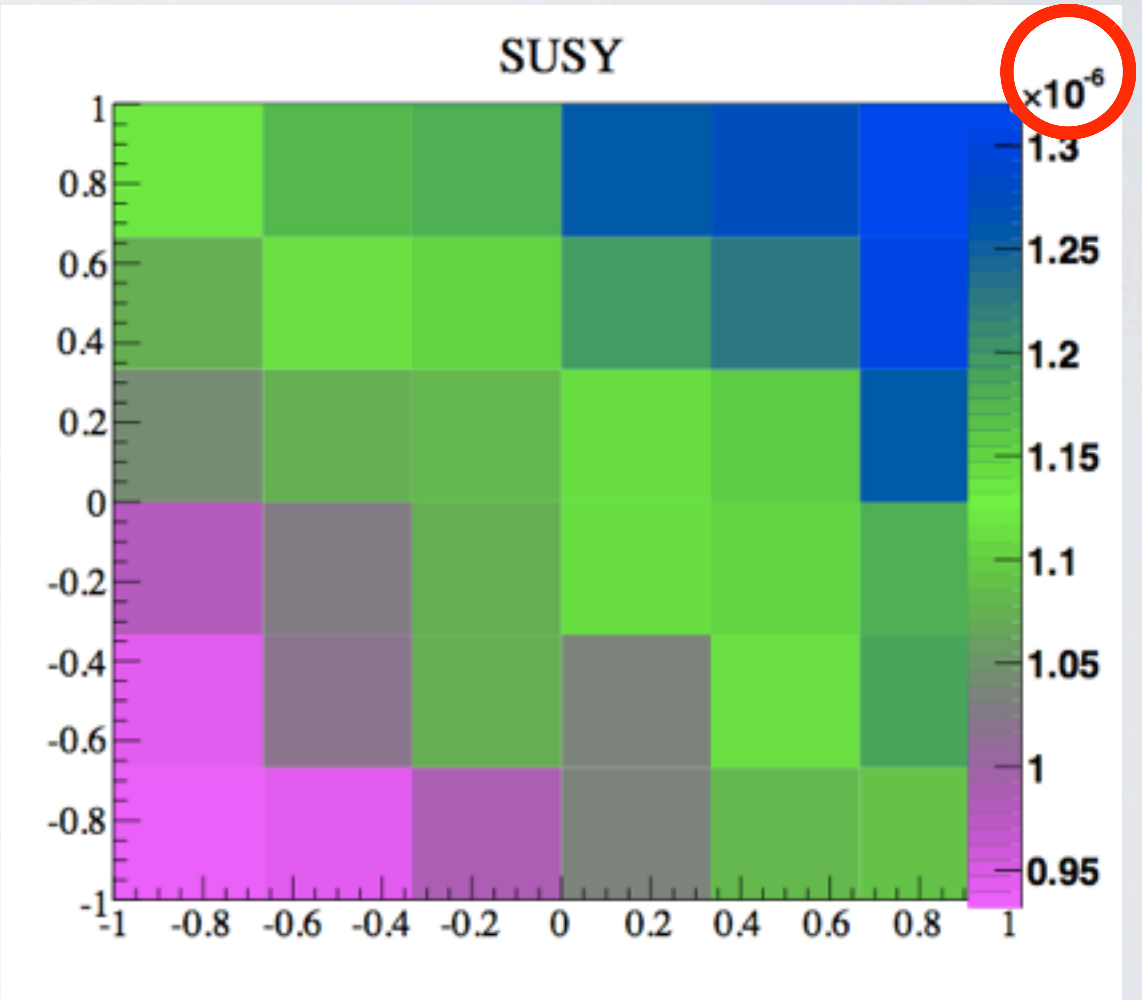


Analog of M_{T2} designed to reject *dileptonic* tops with missing lepton, which can contaminate a *semileptonic* stop search after M_T rejects semileptonic tops.

SPIN TESTS

Very light stop: need to supplement missing ET variables with more information. Work with Z. Han, A. Katz, D. Krohn...



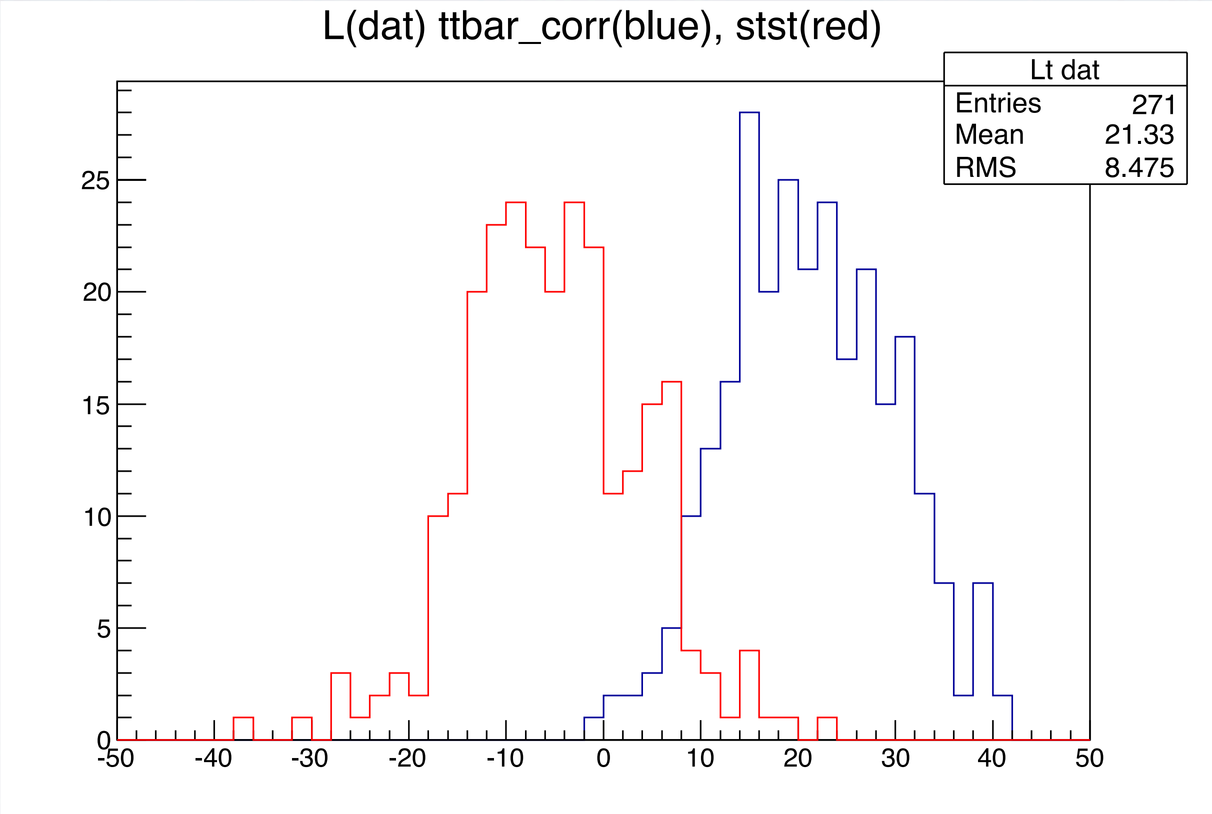


SM: Correlation

Supersymmetry: No correlation, but polarization

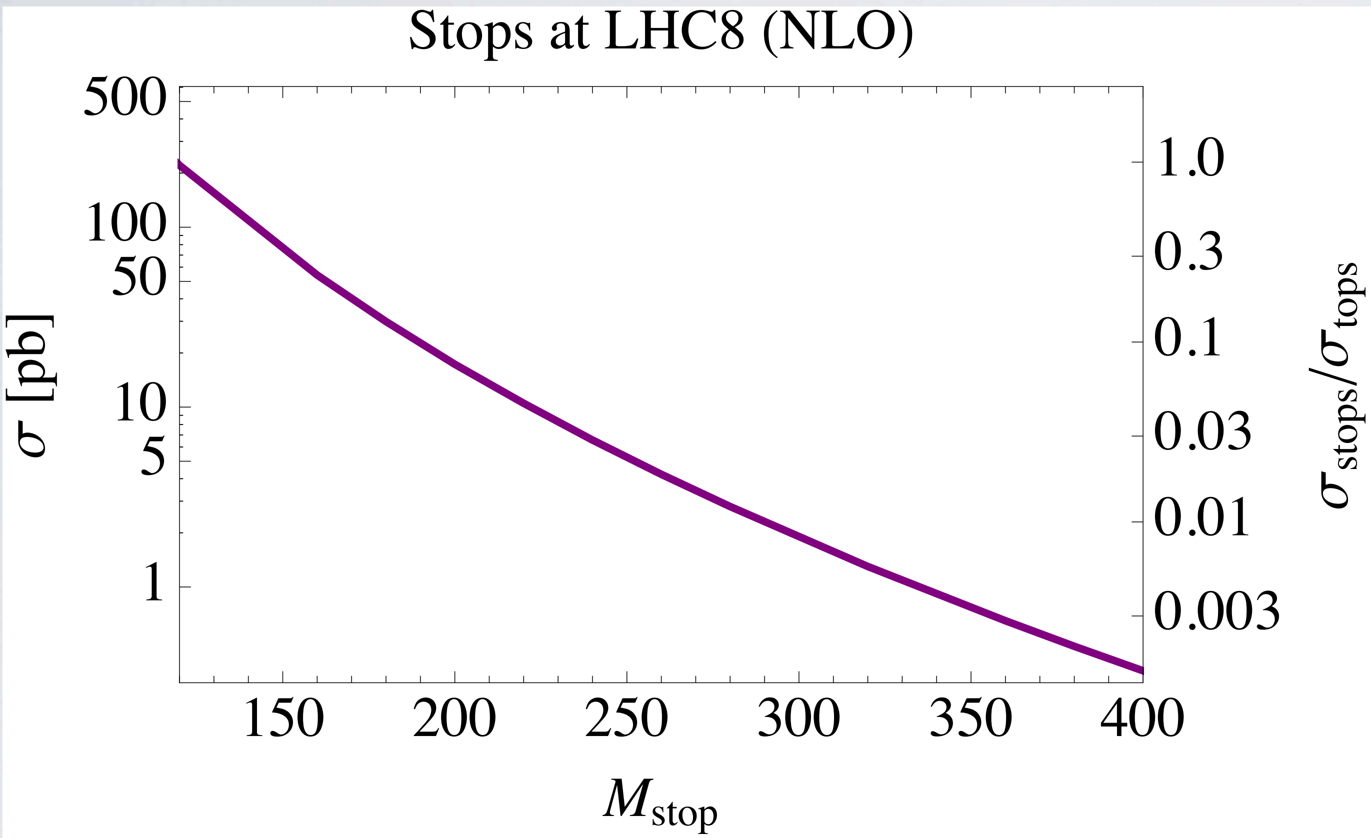
LIKELIHOOD RATIO

Adapt some work of Melnikov & Schulze to this context:



Each point is a sample of 500 events: stops (red) or tops (blue). Log likelihood is noticeably different. Really looking for a mixture of mostly tops with some stops; still a challenge.

STOP & TOP CROSS SECTION



At stop mass = top mass, rate is about 1/6 of top rate.

Why so small? Very naive: both color triplets, 1/2 the degrees of freedom, why not 1/2 the rate?

Madgraph LO:

$$\sigma(gg \to t\bar{t}) \approx 68 \text{ pb} \qquad \sigma(gg \to \tilde{t}_1 \tilde{t}_1^\dagger) \approx 11 \text{ pb}$$

$$\sigma(q\bar{q} \to t\bar{t}) \approx 23 \text{ pb} \qquad \sigma(q\bar{q} \to \tilde{t}_1 \tilde{t}_1^\dagger) \approx 1.6 \text{ pb}$$

THRESHOLD DEPENDENCE

Madgraph LO:

$$\sigma(gg \to t\bar{t}) \approx 68 \text{ pb} \qquad \sigma(gg \to \tilde{t}_1\tilde{t}_1^\dagger) \approx 11 \text{ pb}$$

$$\sigma(q\bar{q} \to t\bar{t}) \approx 23 \text{ pb} \qquad \sigma(q\bar{q} \to \tilde{t}_1\tilde{t}_1^\dagger) \approx 1.6 \text{ pb}$$

The smallness of stop production from q-qbar is related to the threshold behavior. Must produce the stops in a *p*-wave, so rate goes ~ β^3.

Top production and stops from gluons are ~ β, so need a better explanation of the small ratio of stops.

MASSLESS LIMIT

Production rate of stops from gluons:

$$\sigma(gg \to \tilde{t}_1 \tilde{t}_1^\dagger) \to_{s \gg m} \frac{5\alpha_s^2 \pi}{48 s}$$

Production rate of fermionic quarks from gluons:

$$\frac{d\sigma}{d\Omega}(gg \to q\bar{q}) = \frac{\alpha_s^2}{24 s}\left(t^2 + u^2\right)\left(\frac{1}{tu} - \frac{9}{4s^2}\right).$$

Have a forward singularity: cut off by the stop mass, but **enhances the top rate**.

Real kinematic difference we should try to exploit.

AMPLITUDES

Consider the even simpler example of $\gamma\gamma \to \tilde{e}^+\tilde{e}^-$

$$A(1^+, 2^-, 3_\phi, 4_\phi) = ie^2 \frac{[1\ 3]\,\langle 2\ 3\rangle}{\langle 1\ 3\rangle\,[2\ 3]}$$

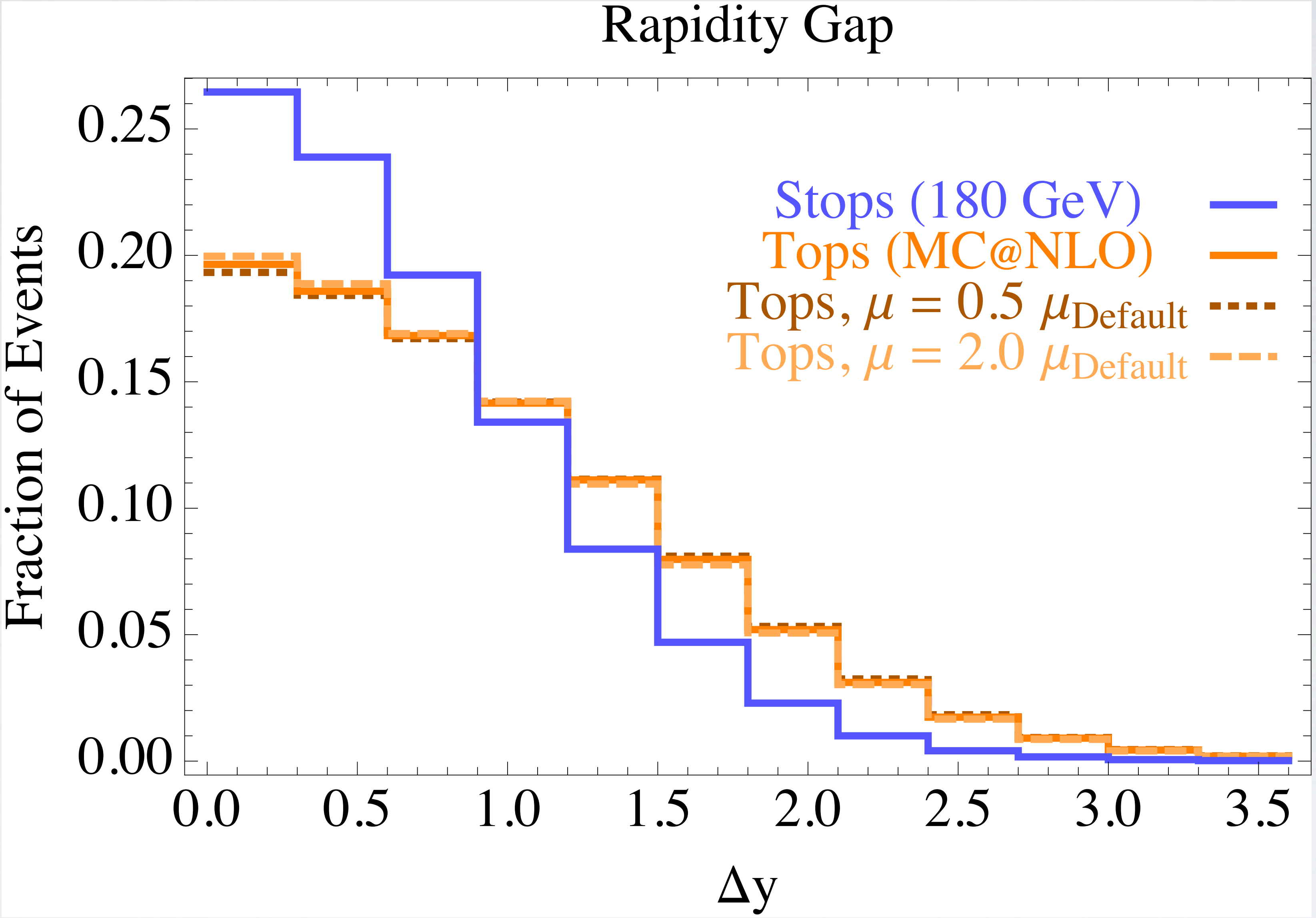
The amplitude is a pure phase.

The *t*-channel pole is absent; a photon can't split into collinear scalars while conserving angular momentum.

For fermions, the usual splitting amplitude story ameliorates the $1/t$ pole to a $1/\sqrt{t}$:

$$A^{\text{tree}}(1^+, 2^-, 3^+_{\bar\psi}, 4^-_{\psi}) = ie^2 \frac{[1\ 4]\,\langle 2\ 3\rangle}{\langle 1\ 3\rangle\,[2\ 3]} \sim ie^2 \sqrt{\frac{u}{t}} \times \ \text{phase}$$

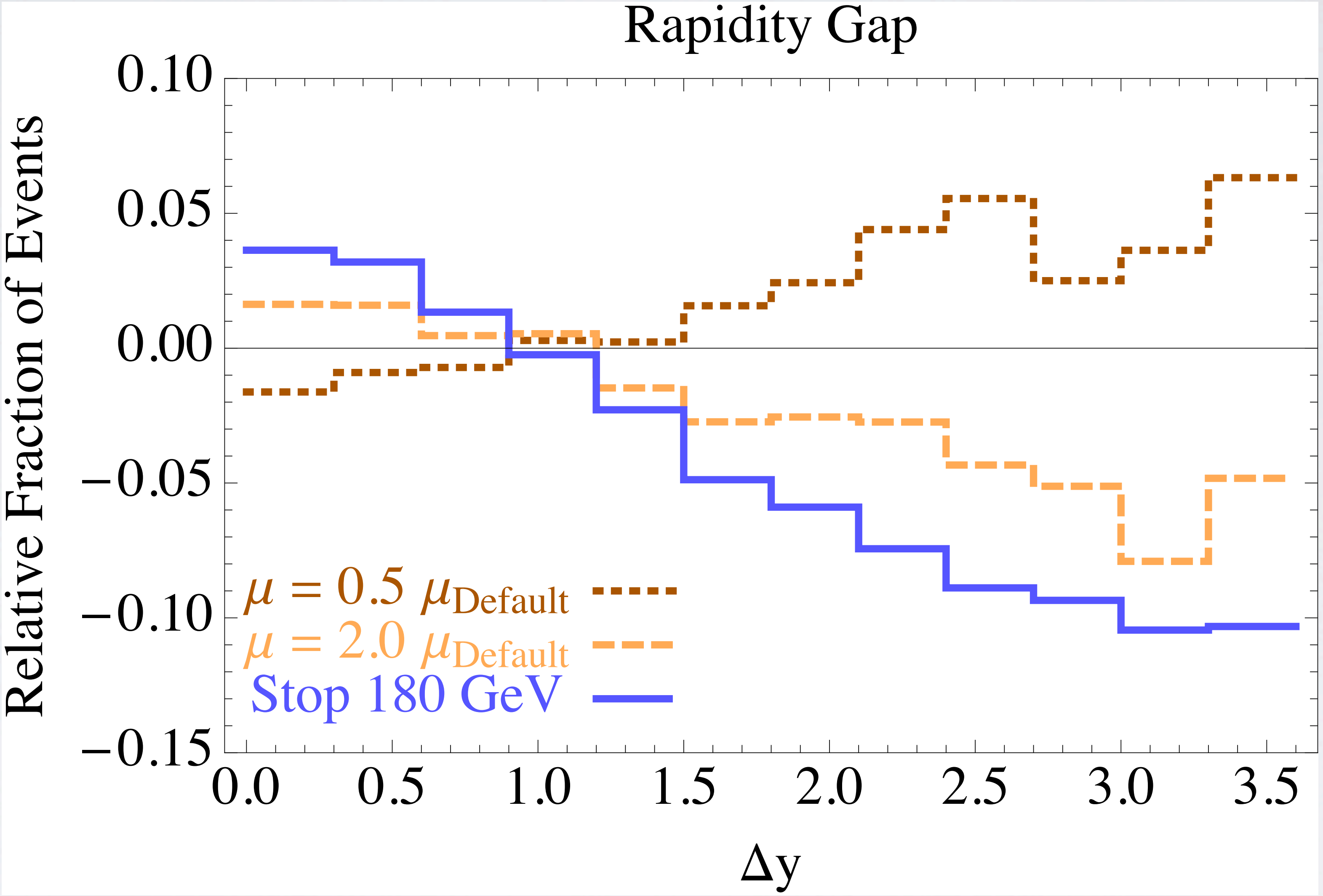
RAPIDITY DIFFERENCES



Result of the *t*-channel singularity for top production. Interesting stop/top difference, coming from **angular momentum conservation.**

HOWEVER...

Stop/top rate is small, so it's a small change in shape.



To some extent, mimicked by a larger RG scale choice in the NLO calculation. **Need better Standard Model theory! Understanding tops is key.**

MESSAGE

The key question for TeV-scale physics now is naturalness.

In the near future, the clues to look for are:
- light stops
- changes in Higgs branching ratios or production rates
- novel Higgs decay modes

Should also be looking for displaced gluinos; hints of unnaturalness.

We're eagerly awaiting 2012 data and analysis!