Snowmass Top/NP WG: Spin-0 Top Partner (a.k.a. Stop)

Maxim Perelstein, Cornell/LEPP

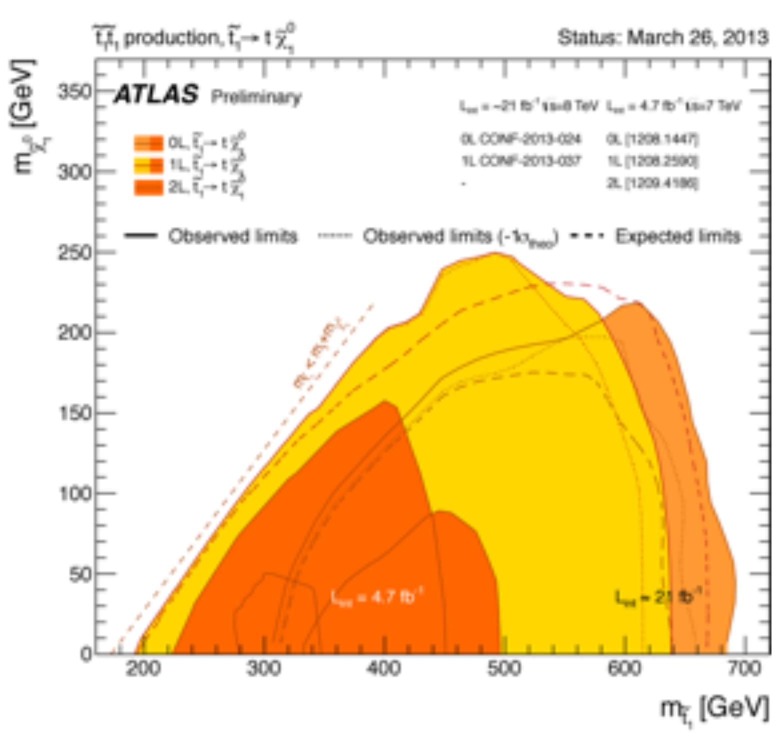
Seattle Workshop, July 1 2013

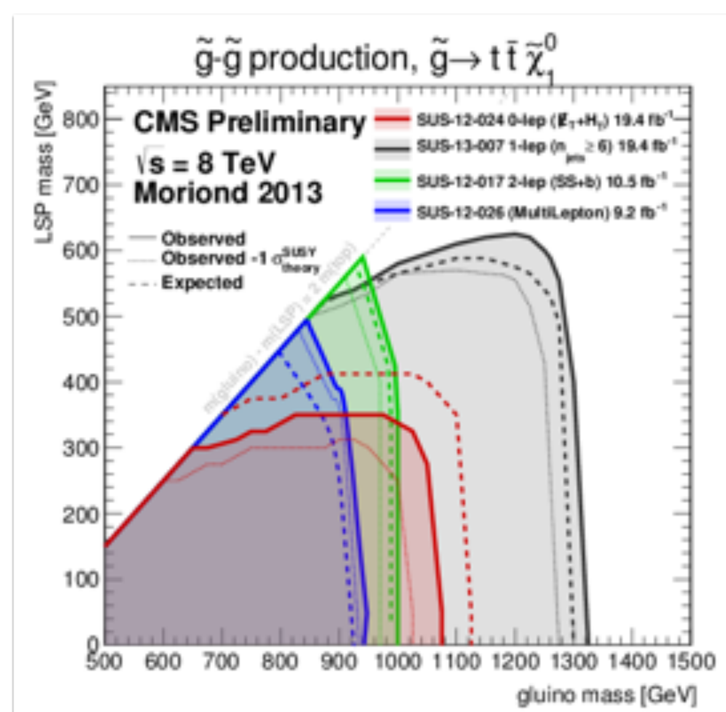
General Comments

- Main focus: determine discovery reach for "stops" at future collider experiments
- Most work on LHC-14 and HL-LHC, some work on 33 TeV (e+e- "simple"?)
- Two classes of studies:
  - "Official" ATLAS and CMS, essentially extrapolations of existing LHC-8 searches
  - "hep-ph Sandbox": try out new simplified models, new observables, focus on hard-to-find spectra, etc.
  - Second class is ground-up, community driven: accept all comers, some quality control

Vanilla Stops

- Spin-0 top partners - stops - are required to be below 1 TeV in natural SUSY models
- Stop masses themselves receive large rad. corr. naturalness bound on gluino mass: $m_g \lesssim 2m_t$
- “Vanilla Stop” simplified model: $\tilde{g}, \tilde{t}, \tilde{\chi}^0$
- Searches for stop: direct $\tilde{t} \to \tilde{\chi}^0 t$ + gluino cascade $\tilde{g} \to \tilde{t}t, \tilde{t} \to t\tilde{\chi}^0$

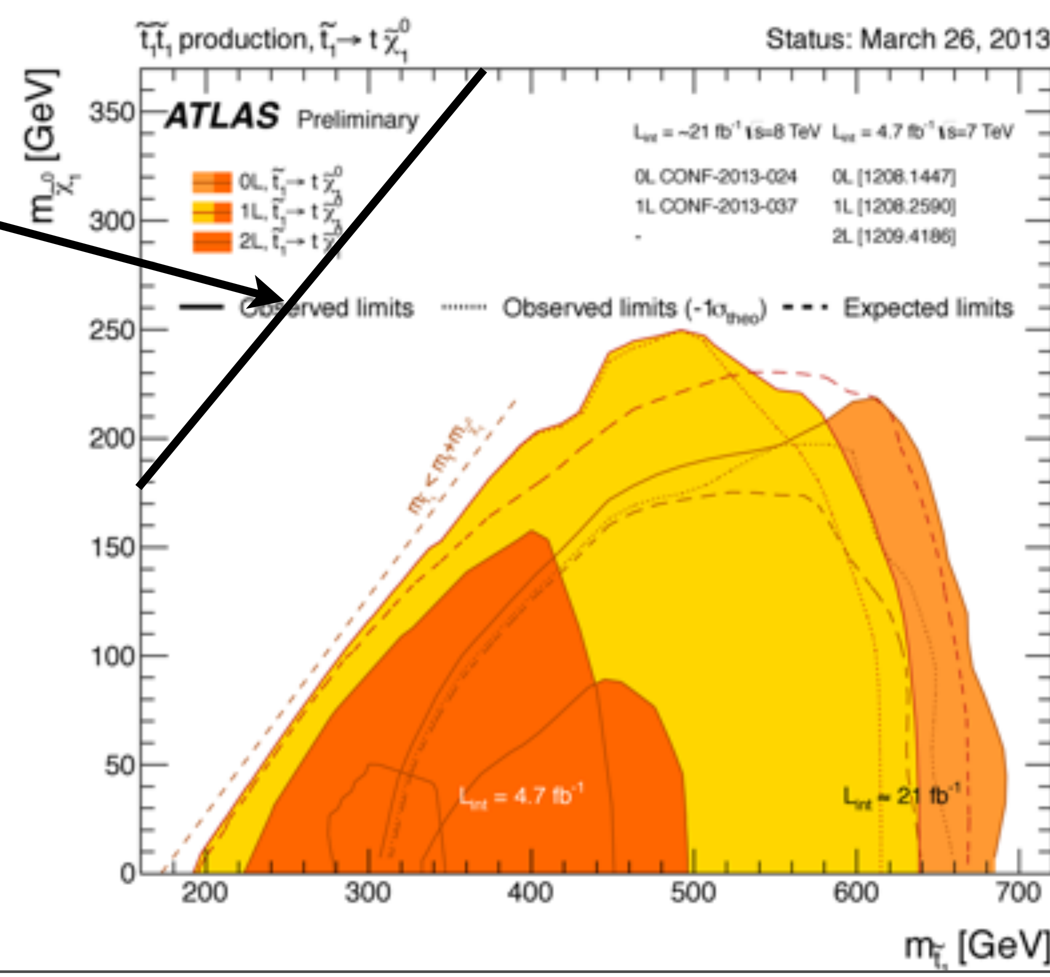




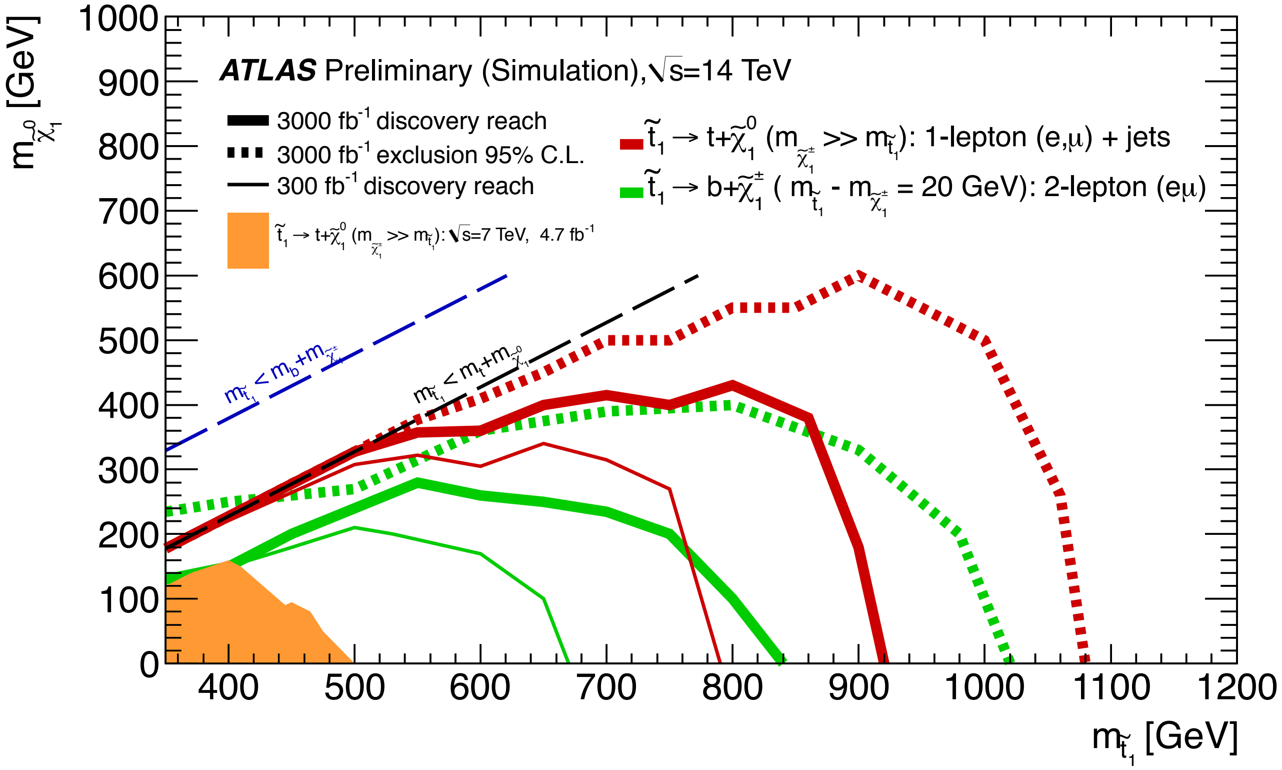
Obvious but Important

- Current LHC stop bounds do not preclude the possibility of stops within reach of a 500 GeV or 1 TeV e+e- collider

stop LSP
above this line



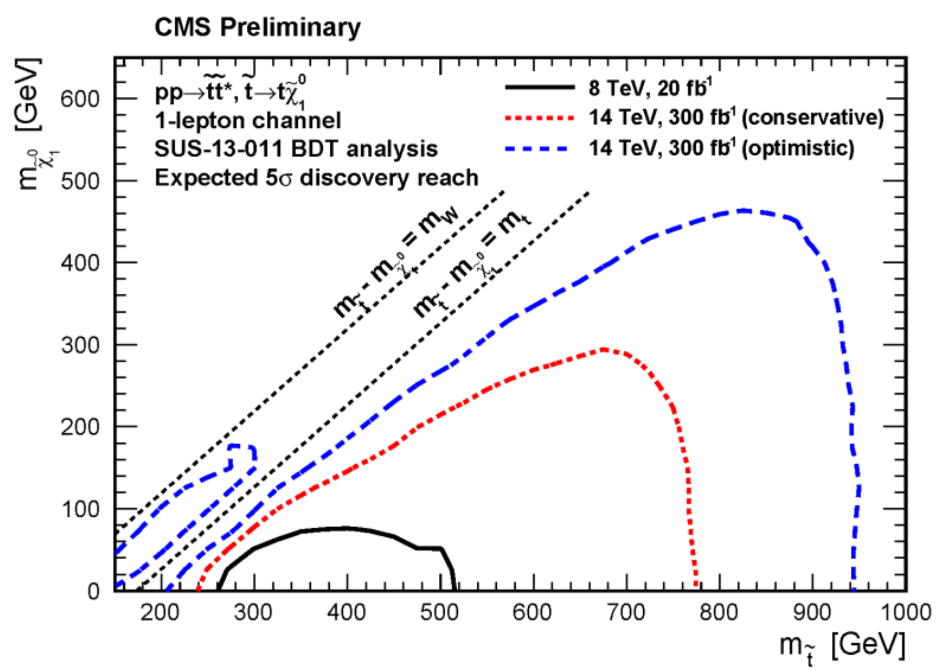
- Previous studies of LHC potential: ATLAS for ESPP 2012



- Updates for Snowmass: ATLAS [George Redlinger et al]: better background estimates, include 0-lepton channel, vary Br, (maybe) explore using boosted top tags

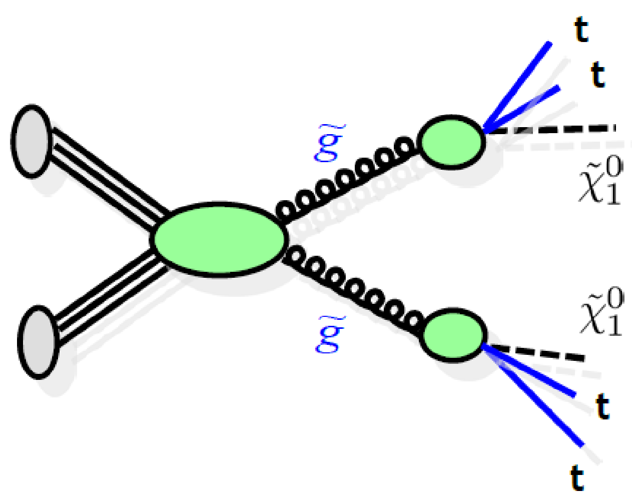
- Results expected by Minneapolis meeting

- CMS for Snowmass [Jim Olsen et al]:
  - Direct production, 1-lepton channel
  - Gluino cascade $\tilde{g} \to \tilde{t}t, \tilde{t} \to \tilde{\chi}^0 t$, all-had channel
- Preliminary reach estimates (300 fb-1): this morning's talk

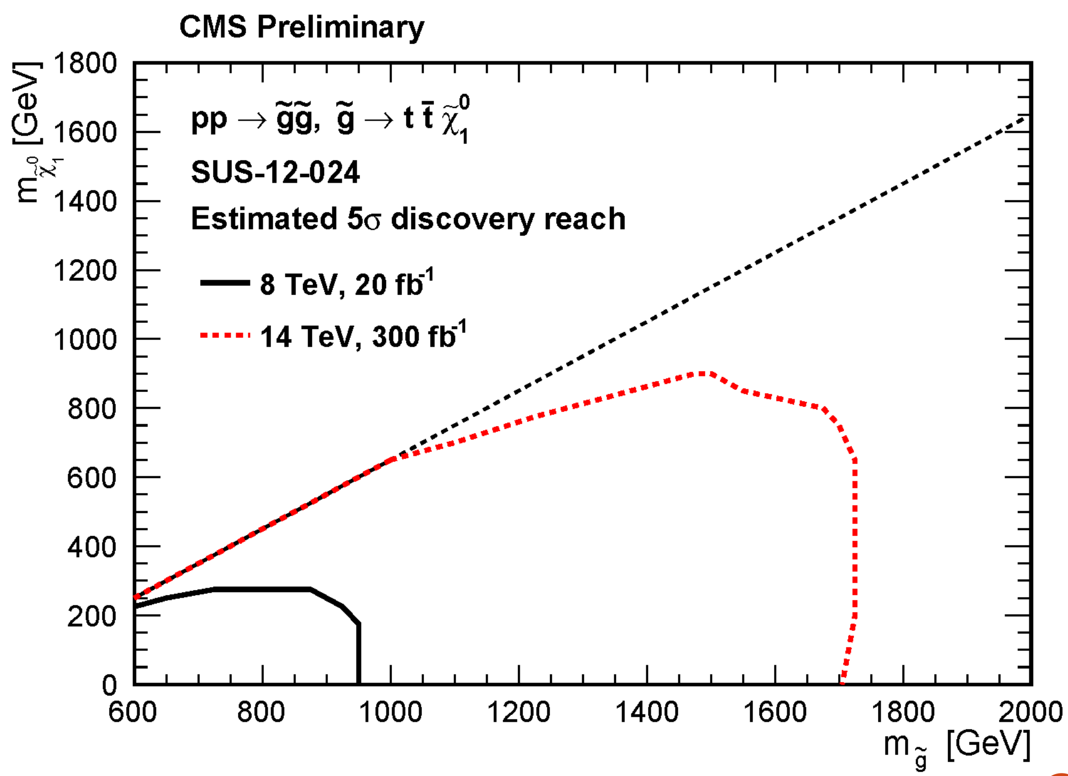


SUSY Discovery Potential: Gluinos

- Conservative approach
  - Assume same systematic uncertainties as 8 TeV analysis
  - Optimistic approach has small impact on discovery reach (~50 GeV)
- Can discover (5σ) gluinos up to **1.7 TeV with 300 fb^{-1} @ 14 TeV**



Search in the final state with: 0-lepton + jets + MET + btags



Reconstructed Tops

Searching for Top Squarks at the LHC in Fully Hadronic Final State

50 fb^{-1}, LHC8

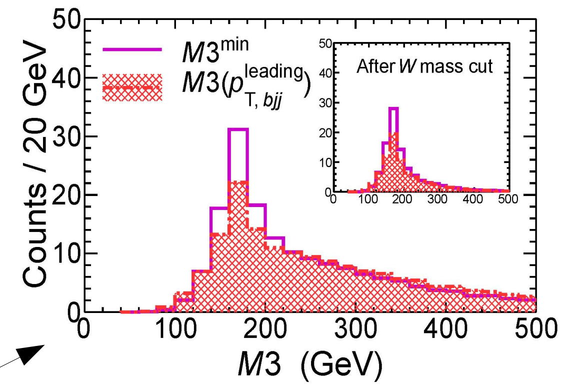
Bhaskar Dutta, Teruki Kamon, Nikolay Kolev, Kuver Sinha, Kechen Wang
Phys.Rev. D*86 (2012) 075004 [arXiv:1207.1873*

Texas A&M University

$\tilde{t}_1 \rightarrow t\, \tilde{\chi}_1^o$ (100%)

Baseline Selection:
4 jets + 2 loose b's (>100, 30's) + MET (> 100)
+ Lepton veto

Surviving mode: "Lost leptons" + jets+ MET



$m_{\chi_1^o}$ = 113 GeV,
$m_{\tilde{t}}$ = 350-450 GeV

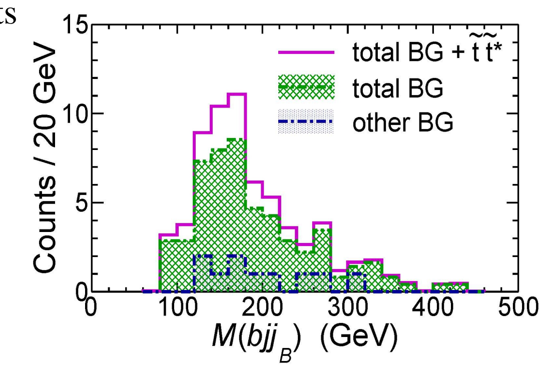
Significance ~ 1.3-1.7

Comparable with
HEPTOPTAGGER

Final selection cuts
- Tagging leading pT top (j1, j2, b) using trijet **invariant mass M3**

- Probing (j1 ', j2 ', b') (lost lepton) with angular cuts

- M3 again to identify second top



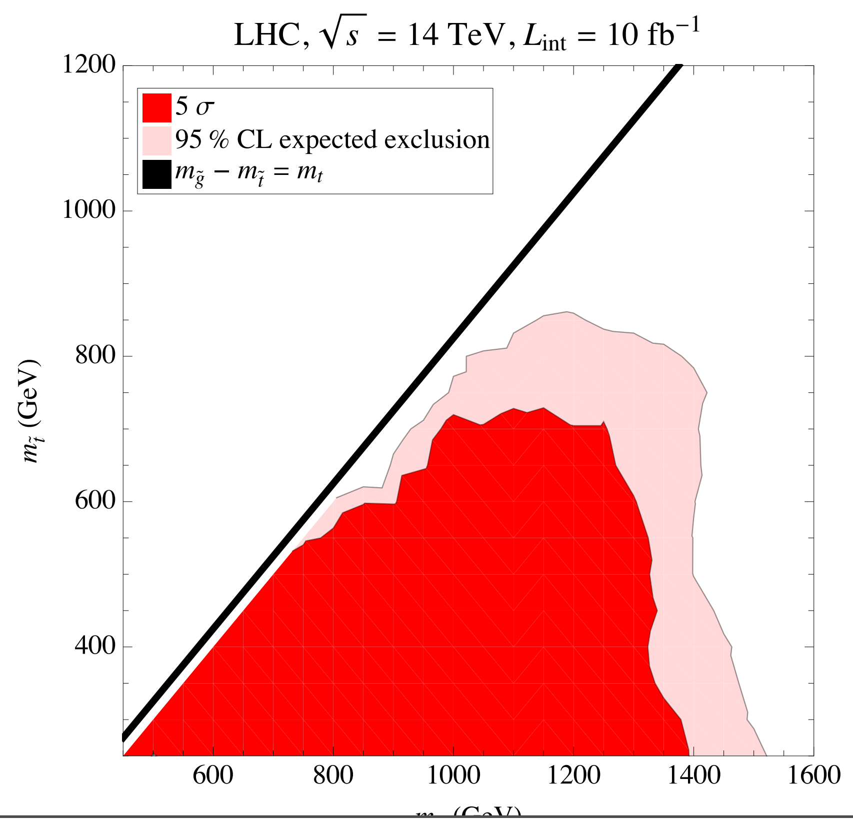
BG data simulation:
ALPGEN + PYTHIA + PGS4
Signal data simulation:
ISAJET + PYTHIA + PGS4

LHC-14 numbers coming soon

[from K. Sinha]

Boosted Tops

- Consider stops from gluino cascade
- 4 tops are produced in each event
- Bounds are pushing into the regime boosted tops!
- Use top tag techniques developed for exotics searches to search for SUSY



[Berger, MP, Saelim, Spray, 1111.6594]

[NO detector simulation - HELP NEEDED!!!]

Compressed Spectra

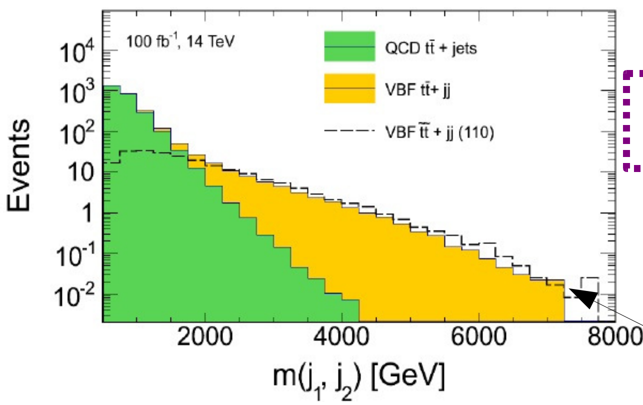
Stop Study 1

Using Vector Boson Fusion to Probe Top Squarks near the $m_{\tilde{t}} \simeq m_t + m_{\rm LSP}$ Rubicon

Andres G. Delannoy, Bhaskar Dutta, Will Flanagan, Alfredo Gurrola, Will Johns, Teruki Kamon, Eduardo Luiggi, Andrew Melo, Paul Sheldon, Kuver Sinha, Kechen Wang, Sean Wu*

(Texas A&M University, Vanderbilt University, UC Boulder)
(*Talk by Kuver Sinha)

- Top squarks produced by vector boson fusion (VBF) processes
- Tagging jets of VBF effective in reducing SM background
- Effective probe in the "Rubicon" region $m_{\tilde{t}} \simeq m_t + m_{\rm LSP}$
- Selections: Events with at least 2 jets, each with pT > 50 GeV, $|\Delta\eta(j1,j2)| > 4.2$, $\eta j1 \eta j2 < 0$, $M(j1j2) > 2750$ GeV
- MET cut more effective than the usual case where stop is produced directly by QCD in the mass-degenerate region

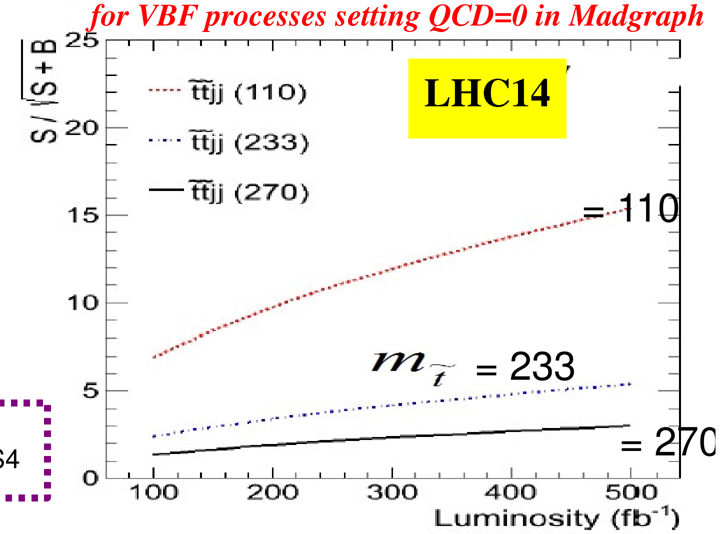


BG + Signal data simulation: MadGraph 5 + PYTHIA + PGS4

- Clear enhancement in high dijet mass region

Signal significance vs luminosity

for VBF processes setting QCD=0 in Madgraph



VBF stop production keeping QCD = 2,4 contributions in Madgraph is underway.
Preliminary results:
Much higher significance.

[from K. Sinha]

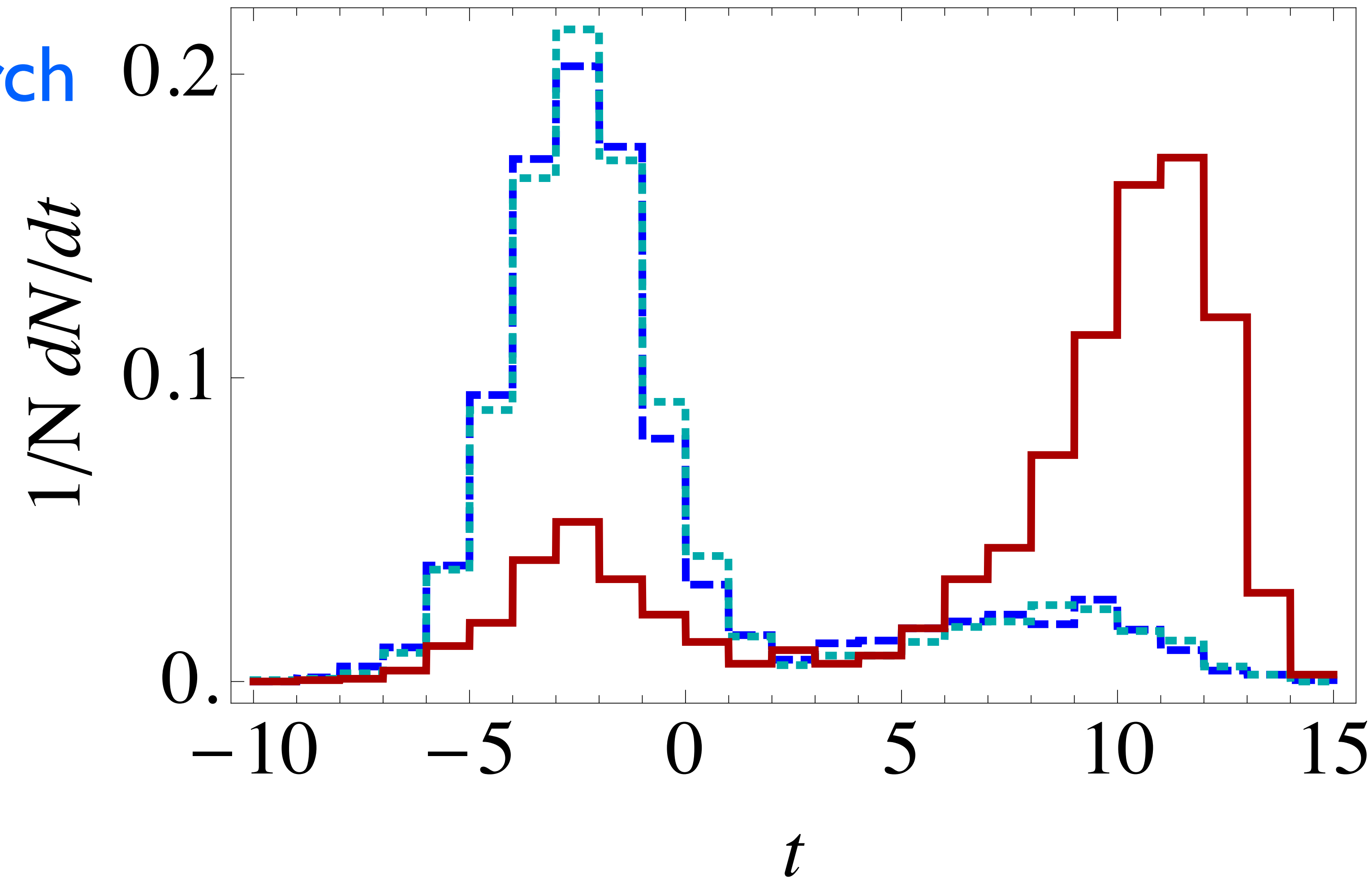
Asymmetric Stops

- Light Higgsino is also required by naturalness in SUSY $\Rightarrow$ light charginos are generic
- A simplified model to capture this: $(\tilde{t}, \tilde{\chi}^0, \tilde{\chi}^\pm)$
- In this model ttbar+MET rates are suppressed, "asymmetric" events are common: $\tilde{t}^*\tilde{t} \to (\tilde{\chi}^0 t)(\tilde{\chi}^\pm b)$
- Now kinematic variable, "topness", introduced to suppress backgrounds in this final state [LHC-8 analysis in 1212.4495 by Graesser and Shelton]
- A Delphes-level study for LHC-14 in progress [Michael Graesser]

Proposed a new search strategy, targeting simplified model "asymmetric decay"

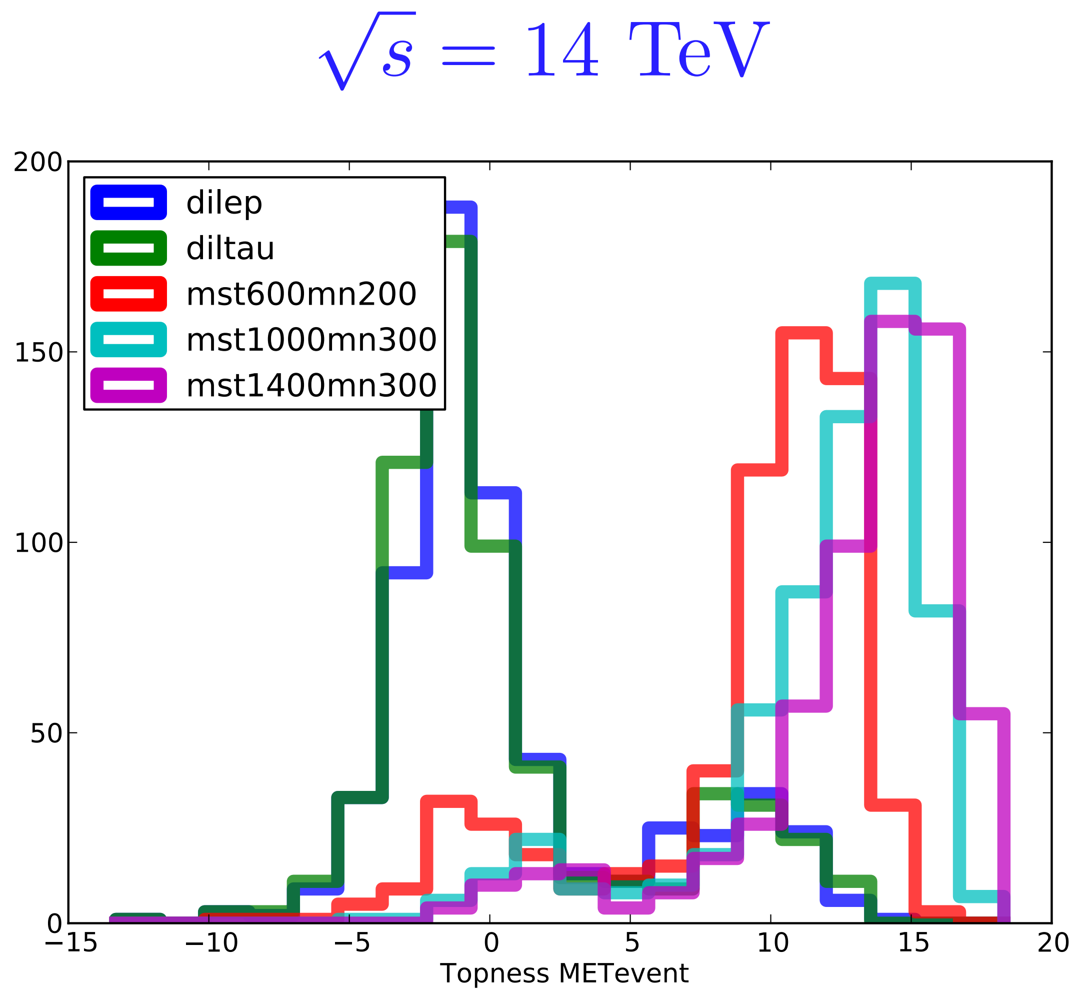
- introduced a new kinematic variable, *topness*, crucial

- topness effectively suppresses the dominant backgrounds from top quark pair production, in single lepton final states



[LHC-8 from Graesser +Shelton paper]

Current progress: very preliminary!!!!!



- Good separation power at higher energy (!)
- caveats:
  - LO MadGraph/Pythia only for distributions
  - with NLO+NLLT K-factor on normalization
  - no detector effects
  - no pileup
  - still to add tW bkg

(on sample of events passing a pre-selection)

[from M. Graesser]

Top Squark Searches Using Dilepton Invariant Mass Distributions and Bino-Higgsino Dark Matter at the LHC

Bhaskar Dutta, Teruki Kamon, Nikolay Kolev, Kuver Sinha, Kechen Wang, Sean Wu

Phys Rev D*.87.095007 [arXiv:1302.3231]*

Texas A&M University

Benchmark: stop = 500 GeV,
$\tilde{\chi}_2^0, \tilde{\chi}_3^0$ = 175 GeV, $\tilde{\chi}_1^0$ = 113 GeV,

Goal:
$\tilde{t}$ decay ⟶ dark matter sector
in a scenario: $\tilde{\chi}_1^0 \sim (\tilde{B}+\tilde{H})$ ⟵ Correct relic density

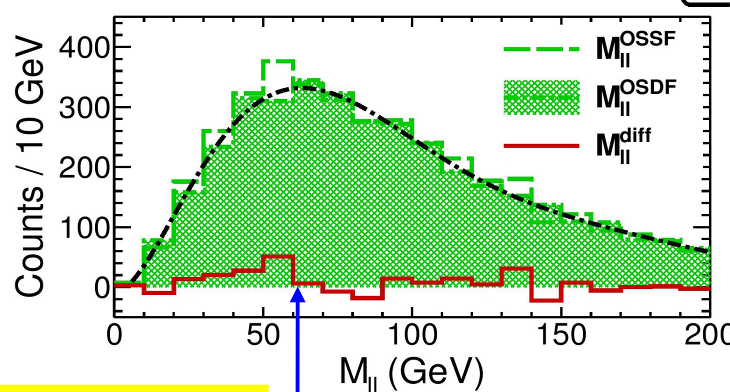
Direct Stop production, followed by

$$\tilde{t} \rightarrow \tilde{\chi}_{3,2}^0 + t \ (39\,\%)$$
$$\tilde{t} \rightarrow \tilde{\chi}_1^+ + b \ (53\%)$$
$$\tilde{\chi}_{3,2}^0 \rightarrow \tilde{\chi}_1^0 + l^{\pm} + l^{\mp} \ (100\,\%,\, via\ \tilde{e}^{\pm} \text{ or } \tilde{\mu}^{\pm})$$

$$M_{ll}^{edge} \sim \Delta M = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$$

Final State:
2 l + 2 j + 1 b + large MET
MET > 150 GeV
H_T > 100 GeV

- OSSF - OSDF subtraction in dilepton mass distribution gives clear edge if a light slepton is present to boost BR.



30 fb^{-1}, LHC8

significance $\sim 3\,\sigma$, for $m_{\tilde{t}} = 500\,GeV$.

BG data simulation:
MadGraph + PYTHIA + PGS4
Signal data simulation:
ISAJET + PYTHIA + PGS4

A clear egde around
$\Delta M = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} = 63\ GeV$.

[from K. Sinha]

LHC-14 numbers coming soon

Stealthy Stops

- Stealthy stops: $m(\tilde{t}) \approx m_t \gg m(\tilde{\chi}^0)$
- Challenge for the LHC: Events look very similar to SM ttbar, with stop cross section ~10% of the SM
- Ideas: Precision measurement of the ttbar cross section [requires NNLO QCD calculation - Mitov et.al.]; or Use details of kinematics [LHC-14 study- Zhenyu Han, Andrey Katz]
- Compare approaches, determine the ultimate LHC sensitivity [Z. Han, Andrey Katz]
- e+e- very sensitive to stealthy stops via top threshold scan; any room left after the LHC? (If LHC discovery, detailed measurements at e+e-)

Spin correlation

Basic idea: tops are fermions, their spins are correlated with one another. Should not expect anything similar for stops. Use full matrix-element spin-correlation. Advantages of this approach:

- Stops roughly behave as spin-uncorrelated particles
- Robust with respect to NLO corrections (*Melnikov, Schulze; 2011*)

This approach was suggested to be used at 8 TeV LHC (*Han, Katz, Krohn, Reece, 2012*), but the sensitivity of LHC 8 is not ideal ($\sim 2\ldots 3\sigma$ at best).

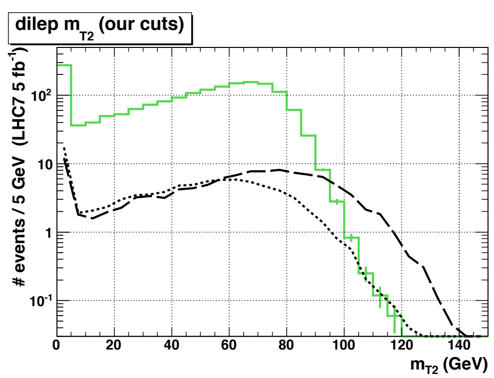
Preliminary: for LHC14, $\mathcal{L}100$ fb^{-1} expect factor of $\sim$4 improvement in significance. Namely clear discovery or firm exclusion should be possible.

[from A. Katz]

Combination with other techniques

Another approach – use tiny differences in M_{T2} distributions between $t\bar{t}$ and $\tilde{t}\tilde{t}^*$ (*Kilic & Tweedie, 2012*)

- Takes advantage of a small fraction of 3-body decays near the top threashold.
- Can be a relatively easy way to discover/ exclude stealthy stops.
- Polarization effects are important. $\tilde{t} \to t_R \tilde{B}$ are easier than $\tilde{t} \to t_L \tilde{B}$ or $\tilde{t}_R \to t\tilde{H}$.



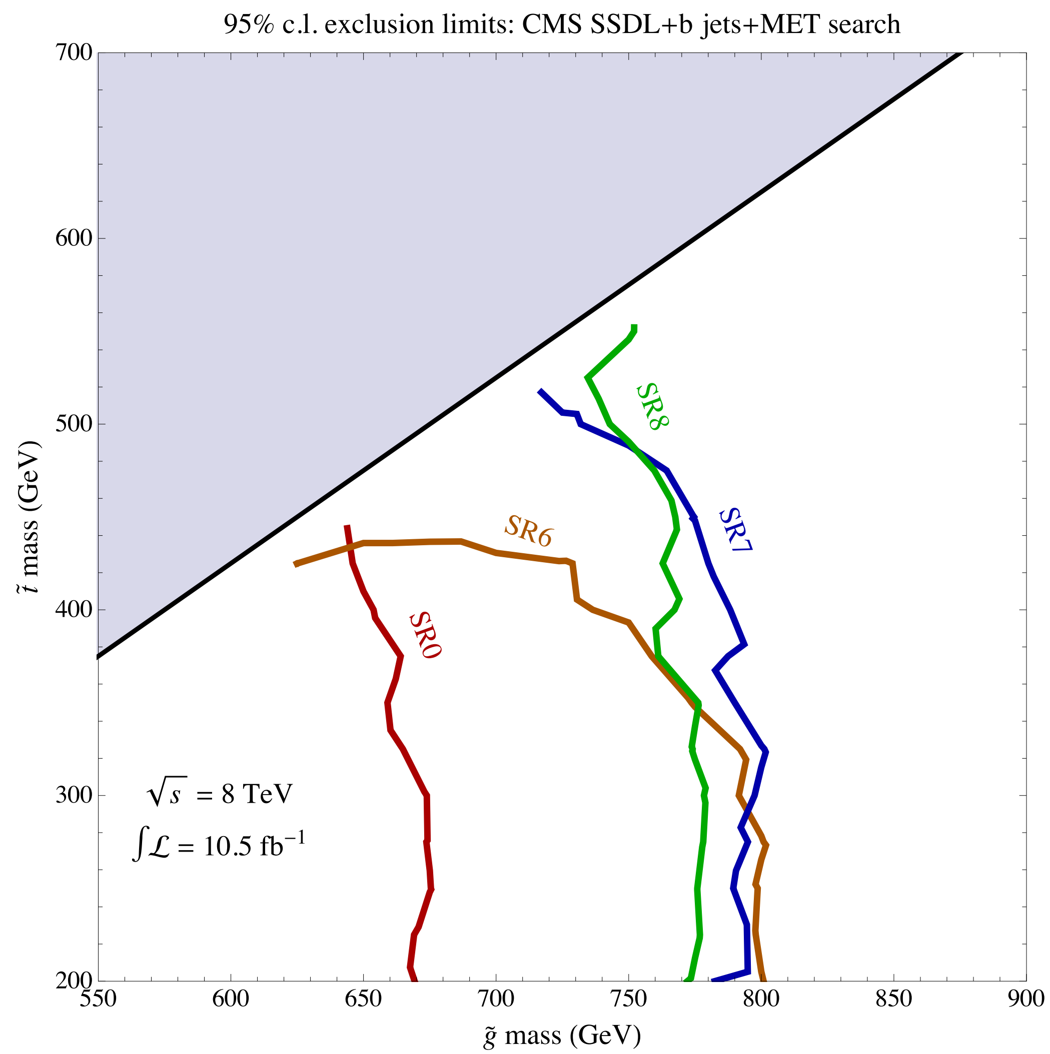
Green - $t\bar{t}$, dashed - $\tilde{t}_R \to t\tilde{B}$, dotted - $\tilde{t}_R \to \tilde{H}$.
In practice the stealth stop is likely heavily mixed. What is the reach? What can we do at LHC14 (partially has been also discussed in the original paper)? How can it can be combined with spin-correlation measurements?

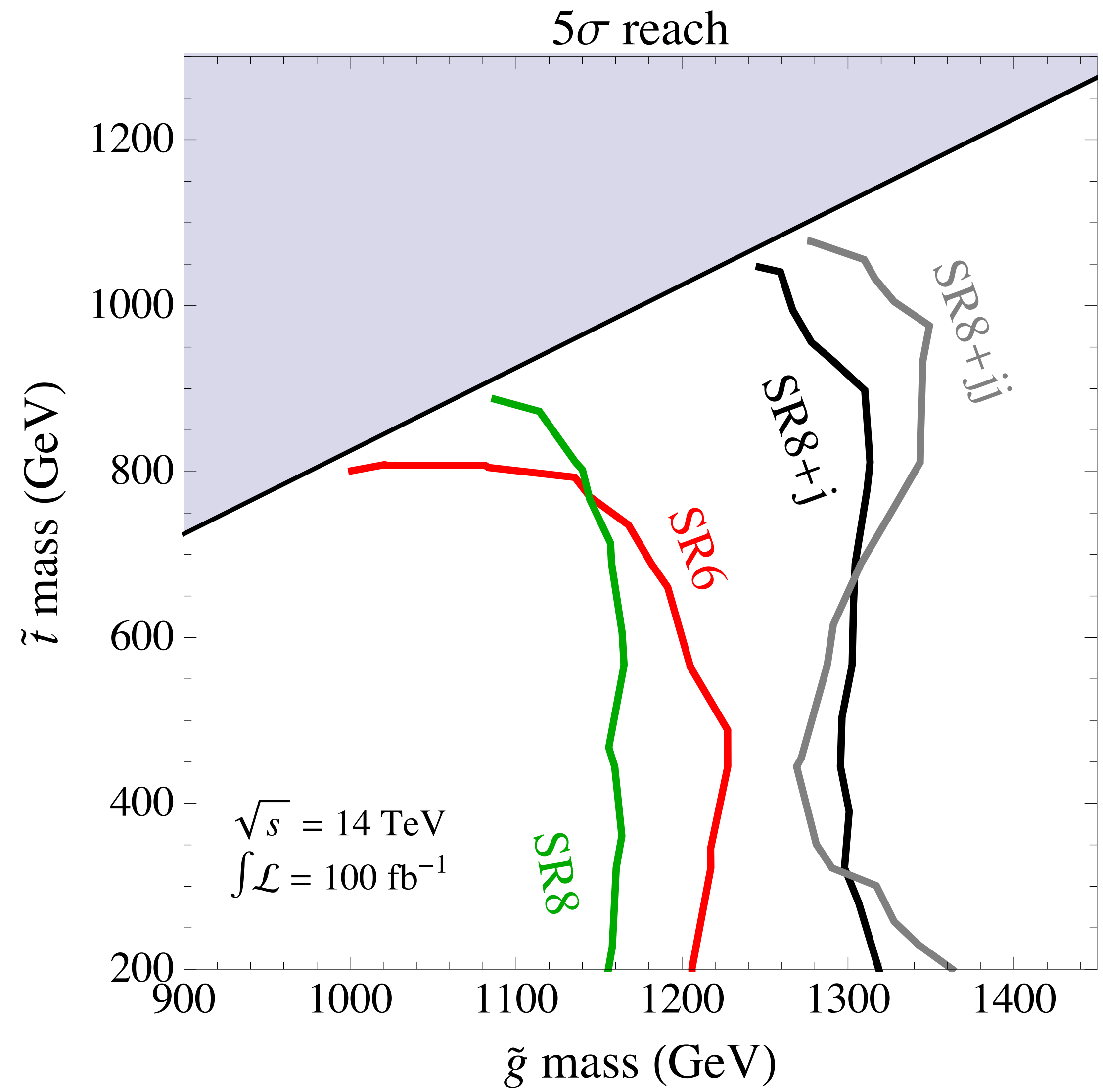
[from A. Katz]

R-Parity Violation

- RPV would invalidate all searches relying on MET light stops are allowed
- Baryonic RPV stop is well-motivated (as in e.g. MFV SUSY models) and challenging:
- Direct searches are hard; gluino-initiated cascades provide a handle
- Same-sign dilepton channel studied by Berger, MP, Saelim, Tanedo in 1302.2146
- Alternative: one-lepton channel, higher rates fr both signal and Bg, use dijet mass ~ Mstop (Han, Katz, Son, Tweedie). Also works for Dirac gluino!

SSDL search for RPV gluinos+stops



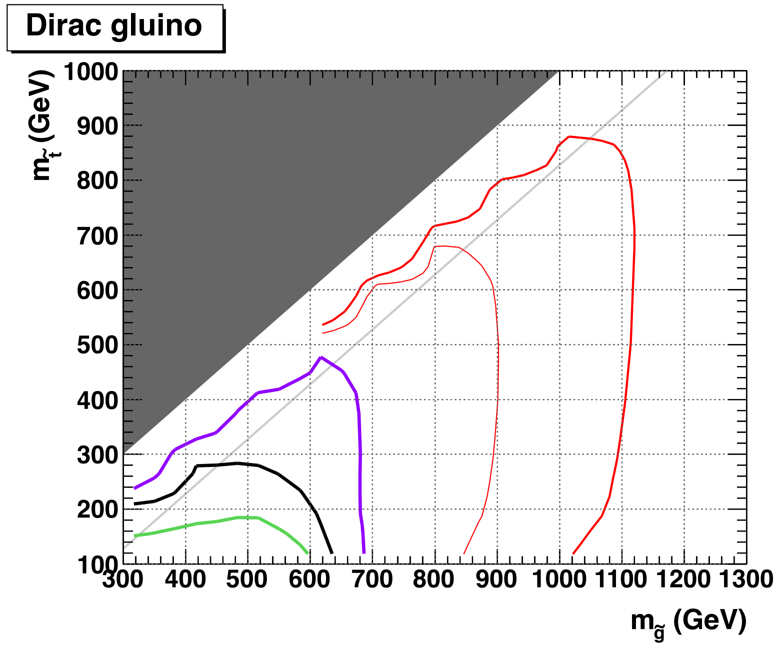


[from 1302.2146]

Basic idea

Based on Han, Katz, Son, Tweedie, 2012

- Use an abundant semi-leptonic channel
- No extra $\not{E}_T$, but can use number of jets and H_T as a zero-order discriminator
- Use boosted techniques (especially for large mass gap between the stop and the gluino) to reduce combinatorial uncertainties and reconstruct the stop mass.



Solid red - expected reach of LHC8
Scope of this project: Extend these techniques to LHC14, estimate the reach. Probably boosted regime becomes more important here.

[from A. Katz]