Few (semi-trivial) Directions for top-BSM Searches*

Gilad Perez

CERN & Weizmann Inst.

top LHCWG, May 2014, CERN

* Avoid obvious motivations related to top mass or tot' Xsection measurements.

Why the top is special from BSM perspective ?

- Given the Higgs the Standard Model (SM), is complete, with no new scales.

  (modulo gravity & the Landau pole of hypercharge & the universe decay lifetime)

- Neutrino masses, baryon asym' & dark matter => new physics scale unspecified!

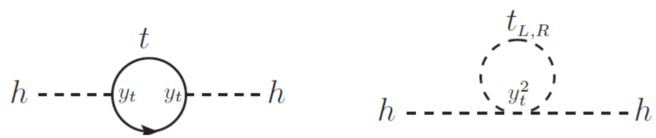
- A hint: Higgs mass is additive, sensitive to microscopic scales. Within the SM it translates to arbitrary UV sensitivity. See: Giudice (13)

- Beyond the SM: any scale that couples to the Higgs (or even to tops, gauge ...) will induce a large shift to the Higgs mass, $\delta m_H^2 \approx \frac{\alpha}{4\pi} M^2$. Farina, Pappadopulo & Strumia (13)

- Thus, even if we are to ignore gravity (strong assumption!) we are led to a desert-like scenario (end of phys., somehow resembles 19th century arguments ...).

Naturalness => vague scale => LHC perspective

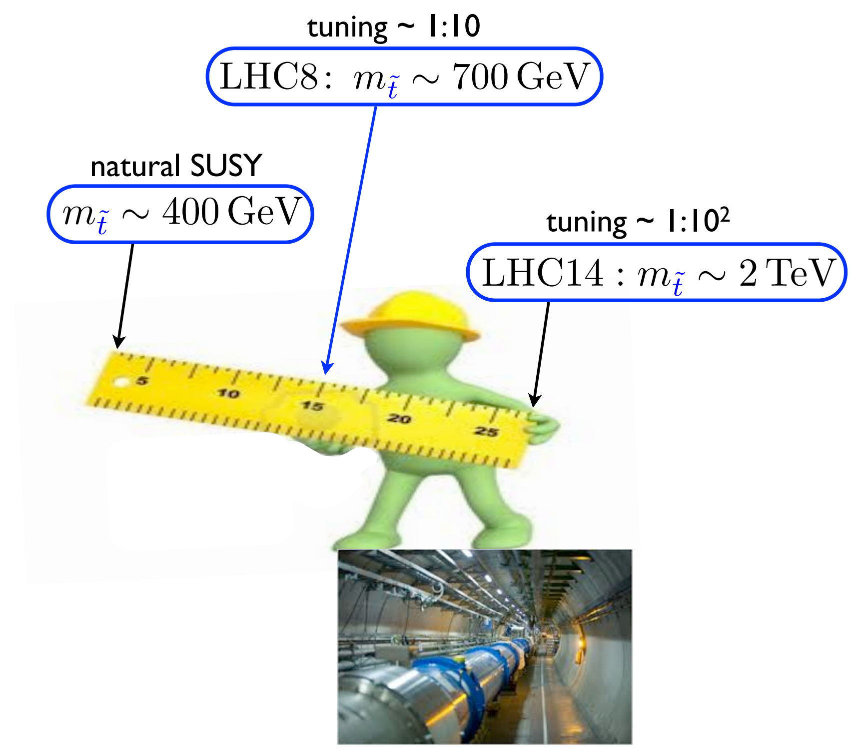
Screening away UV sensitivity => new partners, potentially within the LHC reach.



$$\frac{\delta m_h^2}{m_h^2} \sim \left(\frac{\tilde{m}_t}{400\,\mathrm{GeV}}\right)^2$$

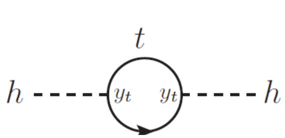
The LHC naturalness ruler:

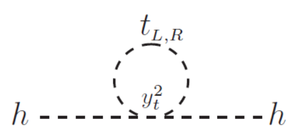
(less than half way through)



Top partners & naturalness

Naturalness => new colored partners, potentially within the LHC reach.





$$\frac{\delta m_h^2}{m_h^2} \sim \left(\frac{\tilde{m}_t}{400\,\mathrm{GeV}}\right)^2$$

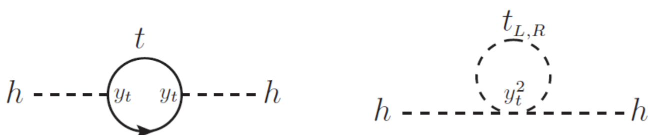
2 leading frameworks
of naturalness

Supersymmetry
top partners=stops

Composite Higgs
top partners = "T"

Top partners & LHC Searches

Naturalness => new colored partners, potentially within the LHC reach.

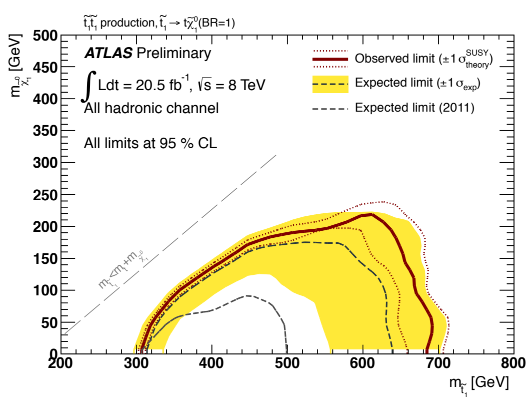


$$\frac{\delta m_h^2}{m_h^2} \sim \left(\frac{\tilde{m}_t}{400\,\mathrm{GeV}}\right)^2$$

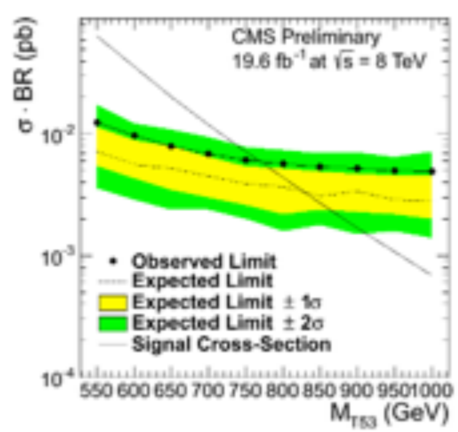
2 leading frameworks
of naturalness => top reach final state

SUSY

composite Higgs



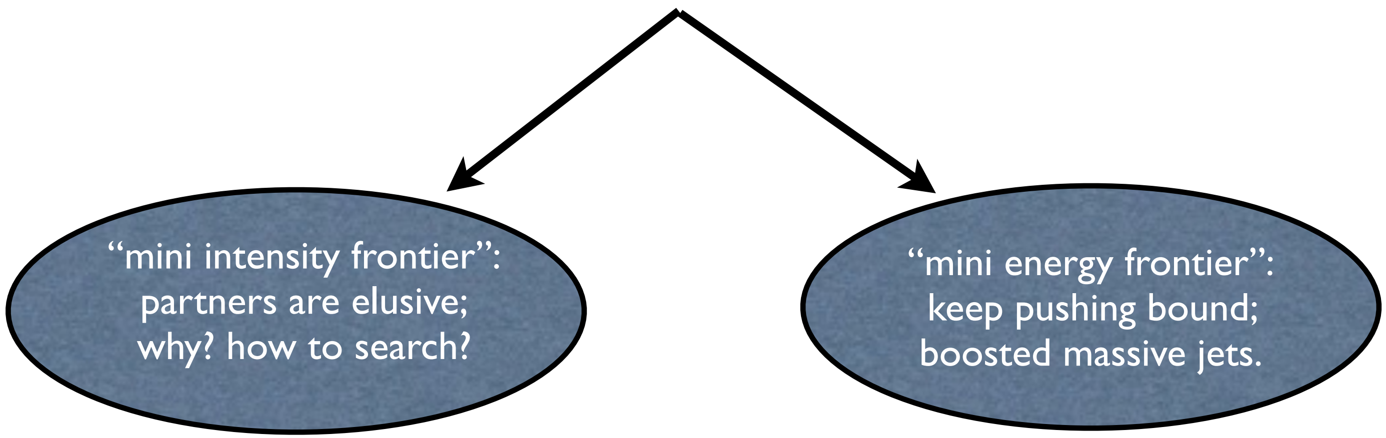
$m_{\mathrm{stop}} \gtrsim 700\,\mathrm{GeV}$



$m_{T^{5/3}} \gtrsim 800\,\mathrm{GeV}$

The (top)Battle for Naturalness

LHC8: where are the partners ??



Naturalness & the two top frontiers

tuning ~ 1:10

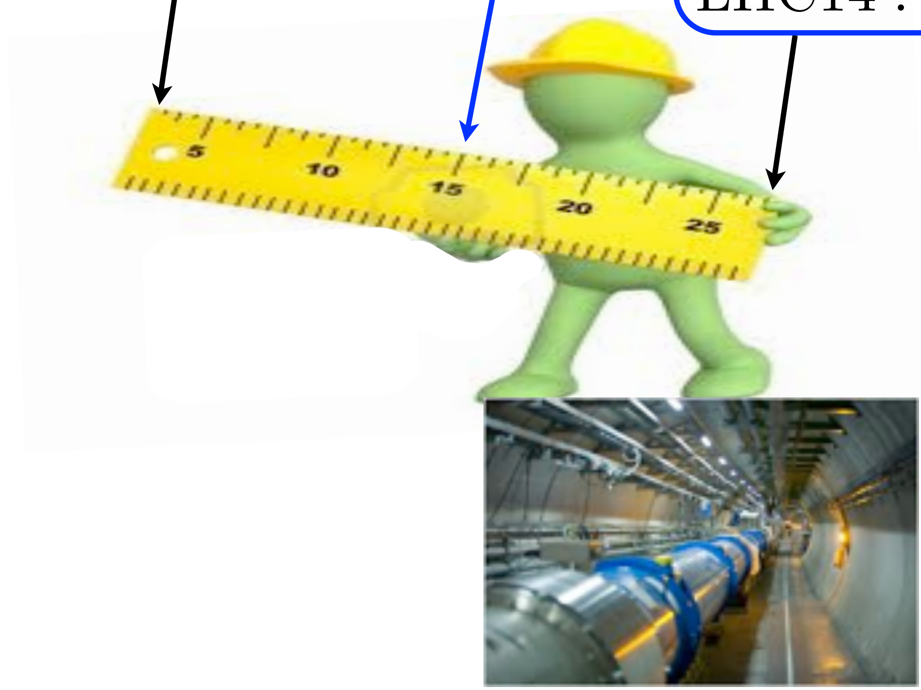
$\mathrm{LHC8:}\ m_{\tilde{t}} \sim 700\,\mathrm{GeV}$

natural SUSY

$m_{\tilde{t}} \sim 400\,\mathrm{GeV}$

tuning ~ 1:10^2

$\mathrm{LHC14:}\ m_{\tilde{t}} \sim 2\,\mathrm{TeV}$



Naturalness & the two top frontiers

tuning ~ 1:10

$\mathrm{LHC8:}\ m_{\tilde{t}} \sim 700\,\mathrm{GeV}$

Elusive regime

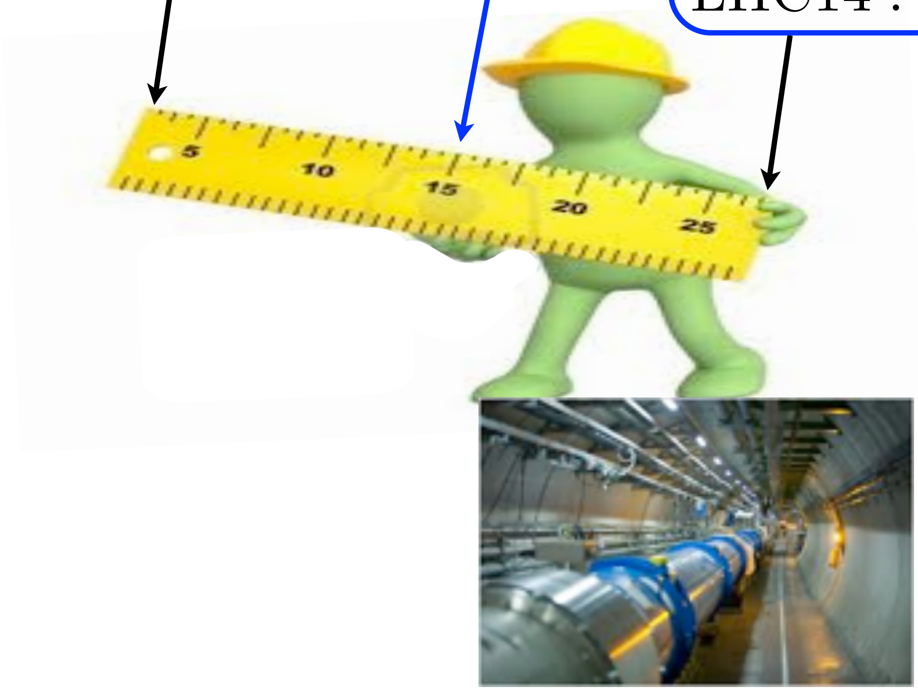
Boosted regime

natural SUSY

$m_{\tilde{t}} \sim 400\,\mathrm{GeV}$

tuning ~ 1:10^2

$\mathrm{LHC14:}\ m_{\tilde{t}} \sim 2\,\mathrm{TeV}$



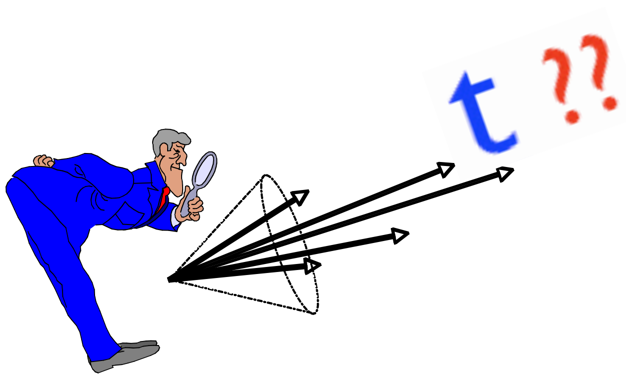
Outline

- Mini-energy frontier, boosted top physics:
  i. "graduate" from bump hunting, learn to control diff' distributions;
  ii. case study hybrid approach, the "elusive gluon".

- Mini-intensity frontier & top precision phys. connection:
  i. Getting rid of missing energy;
  ii. Importance of top-partner flavor violation.

- Conclusions.

“The mini energy frontier”:
Physics of boosted tops



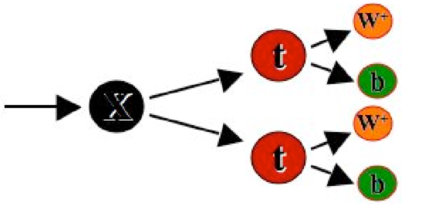
Boosted frontier => emergence of top jets

(i) Strong dynamics models (composite H, Randall-Sundrum ...) => heavy Kaluza-Klein (KK) resonances, S para': $m_{KKG} > 3$ TeV.

Boosted frontier => emergence of top jets

(i) Strong dynamics models (composite H, Randall-Sundrum ...) => heavy Kaluza-Klein (KK) resonances, S para': $m_{KKG} > 3$ TeV.

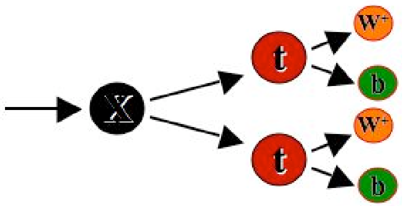
(ii) Naturalness => new states decay quickly to top pairs.



Boosted frontier => emergence of top jets

(i) Strong dynamics models (composite H, Randall-Sundrum ...) => heavy Kaluza-Klein (KK) resonances, S para': m_{KKG} >3 TeV.

(ii) Naturalness => new states decay quickly to top pairs.



(iii) Since $m_t \ll m_{\rm KK}$ the outgoing tops are ultra-relativistic,

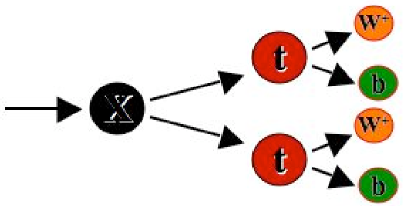
their products collimate => top jets.

Agashe, Belyaev, Krupovnickas, GP & Virzi (06);
Lillie, Randall & Wang (07).

Boosted frontier => emergence of top jets

(i) Strong dynamics models (composite H, Randall-Sundrum ...) => heavy Kaluza-Klein (KK) resonances, S para': $m_{KKG} > 3$ TeV.

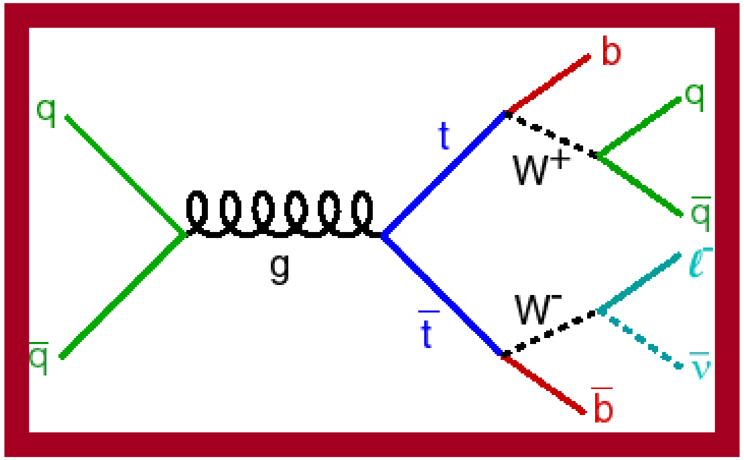
(ii) Naturalness => new states decay quickly to top pairs.



(iii) Since $m_t \ll m_{\rm KK}$ the outgoing tops are ultra-relativistic,

their products collimate => top jets.

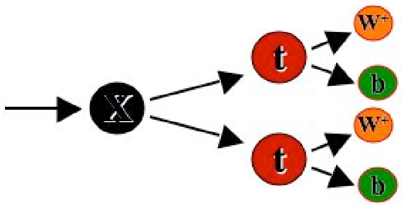
Agashe, Belyaev, Krupovnickas, GP & Virzi (06);
Lillie, Randall & Wang (07).



Boosted frontier => emergence of top jets

(i) Strong dynamics models (composite H, Randall-Sundrum ...) => heavy Kaluza-Klein (KK) resonances, S para': $m_{KKG} > 3$ TeV.

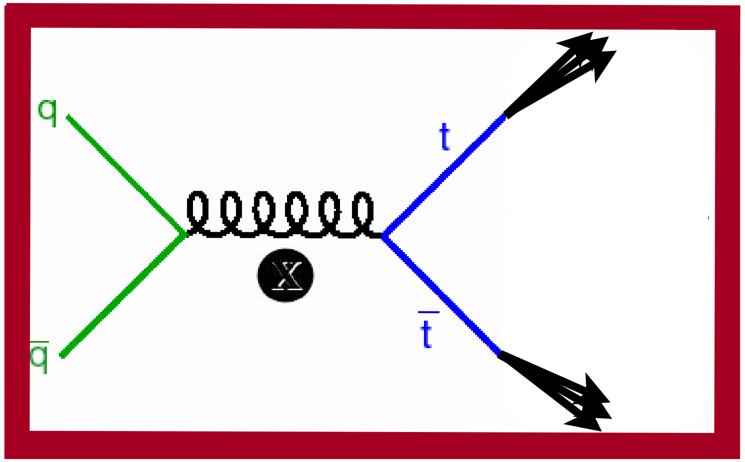
(ii) Naturalness => new states decay quickly to top pairs.



(iii) Since $m_t \ll m_{\rm KK}$ the outgoing tops are ultra-relativistic,

their products collimate => top jets.

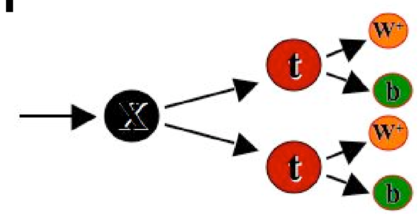
Agashe, Belyaev, Krupovnickas, GP & Virzi (06);
Lillie, Randall & Wang (07).



Boosted frontier => emergence of top jets

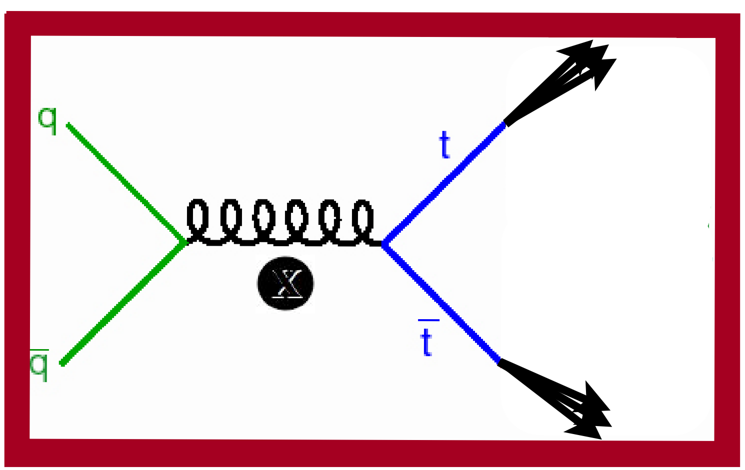
(i) Strong dynamics models (composite H, Randall-Sundrum ...) => heavy Kaluza-Klein (KK) resonances, S para': $m_{KKG} > 3$ TeV.

(ii) Naturalness => new states decay quickly to top pairs.

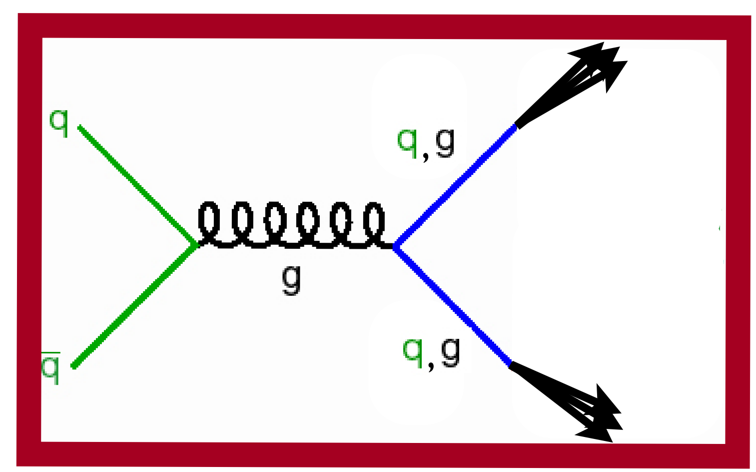


(iii) Since $m_t \ll m_{\mathrm{KK}}$ the outgoing tops are ultra-relativistic, their products collimate => top jets.

Agashe, Belyaev, Krupovnickas, GP & Virzi (06); Lillie, Randall & Wang (07).



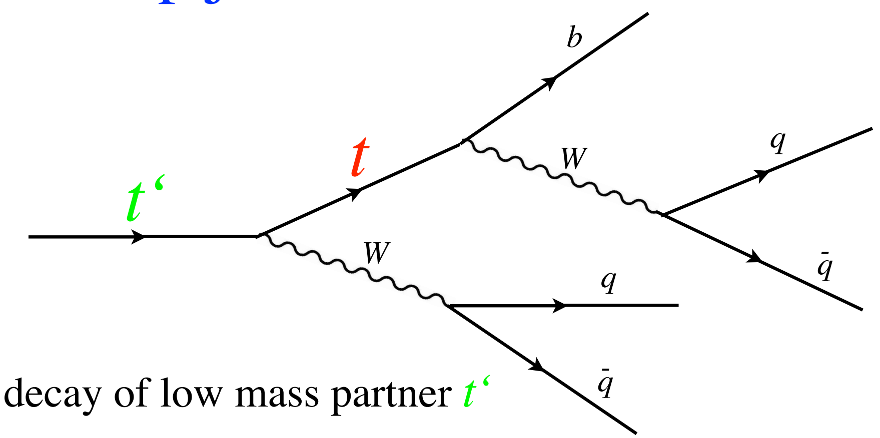
Similar to ordinary 2-jet QCD process impossible to observe ??



Similar challenge with top partners $m_{t'} \gg m_t$

As $m_{t'} \gg m_t$ outgoing tops are ultra-relativistic, their products collimate

=> top jets.

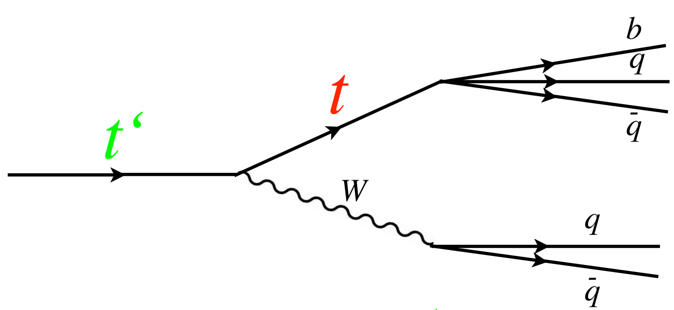


decay of low mass partner t'

Similar challenge with top partners $m_{t'} \gg m_t$

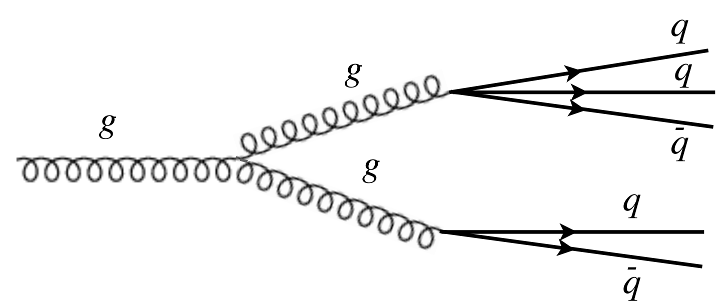
As $m_{t'} \gg m_t$ outgoing tops are ultra-relativistic, their products collimate

=> top jets.

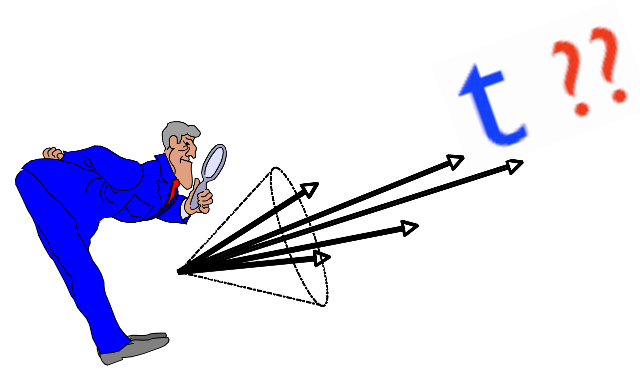


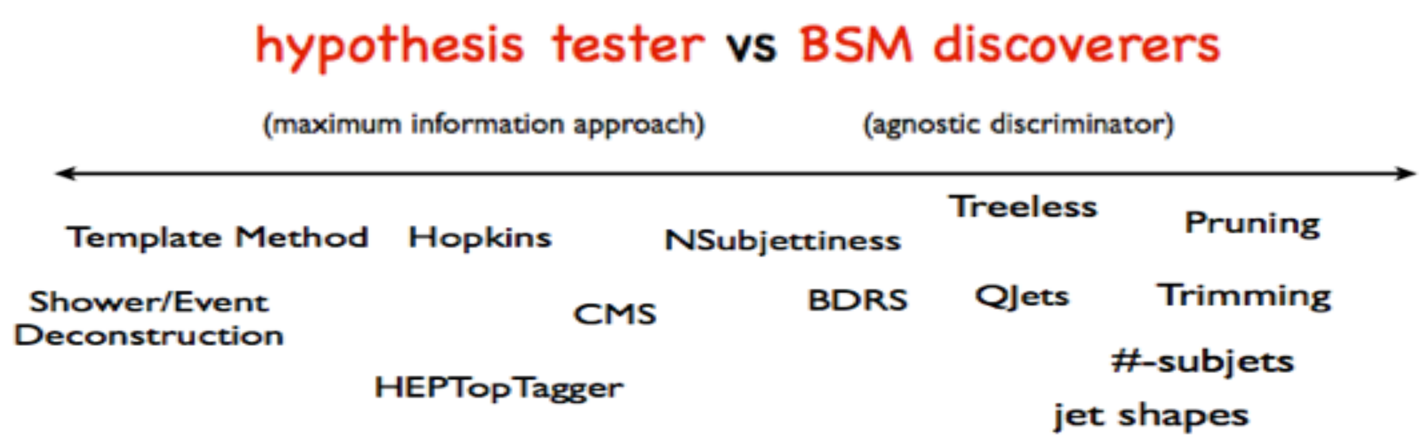
decay of heavy partner t'

Similar to ordinary 2-jet QCD process impossible to observe ??



Need to understand the energy deposition inside fundamentally narrow massive jets

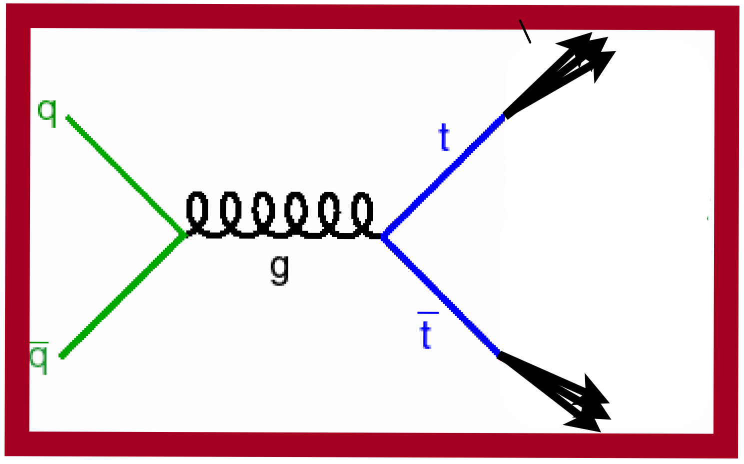




(credit to M. Spannowsky 14)

This does not imply that this field is reserved to resonance searches.
Next run many top-based searches will have a boosted component!

Trivial case against resonance searches
&
Ex.: KK Gluon



RS/composite H <=> strong dynamics => width free parameter

Original models had relatively narrow KK's:

$$\frac{g_{\rm RS}^{q\bar{q},l\bar{l}\,G^1}}{g_{\rm SM}} \simeq \xi^{-1} \approx \frac{1}{5}\,, \quad \frac{g_{\rm RS}^{Q3\bar{Q}3G^1}}{g_{\rm SM}} \approx 1\,,$$

$$\frac{g_{\rm RS}^{t_R\bar{t}_R G^1}}{g_{\rm SM}} \simeq \xi \approx 5\,, \quad \frac{g_{\rm RS}^{GGG^1}}{g_{\rm SM}} \approx 0\,, \qquad (1)$$

Agashe, Belyaev, Krupovnickas, GP & Virzi (06);
Lillie, Randall & Wang (07).

"KK gluon above 1 TeV has width of $M_{KKG}/6$"

Later will implicit motivate: (and regardless of motivation …)

RS/composite H <=> strong dynamics => width free parameter

Original models had relatively narrow KK's:

$$\frac{g_{\rm RS}^{q\bar{q},l\bar{l}\,G^1}}{g_{\rm SM}} \simeq \xi^{-1} \approx \frac{1}{5}\,, \quad \frac{g_{\rm RS}^{Q3\bar{Q}3G^1}}{g_{\rm SM}} \simeq 1\,,$$

$$\frac{g_{\rm RS}^{t_R\bar{t}_R G^1}}{g_{\rm SM}} \simeq \xi \approx 5\,, \quad \frac{g_{\rm RS}^{GGG^1}}{g_{\rm SM}} \approx 0\,, \qquad (1)$$

Agashe, Belyaev, Krupovnickas, GP & Virzi (06); Lillie, Randall & Wang (07).

"KK gluon above 1 TeV has width of $M_{\rm KKG}/6$"

Later will implicit motivate: (and regardless of motivation …)

$$\frac{g_{\rm RS}^{q\bar{q},l\bar{l}\,G^1}}{g_{\rm SM}} \simeq \xi^{-1} \approx \frac{1}{5}\,, \quad \frac{g_{\rm RS}^{Q3\bar{Q}3G^1}}{g_{\rm SM}} \approx \xi \approx 5$$

$$\frac{g_{\rm RS}^{t_R\bar{t}_R G^1}}{g_{\rm SM}} \simeq \xi \approx 5\,, \quad \frac{g_{\rm RS}^{GGG^1}}{g_{\rm SM}} \approx 0\,,$$

$$\Rightarrow \quad \frac{\Gamma}{M_{\rm KKG}} \sim 50\%!$$

Case #2 against top-pair resonance searches
&
The "elusive" (narrow) KK Gluon

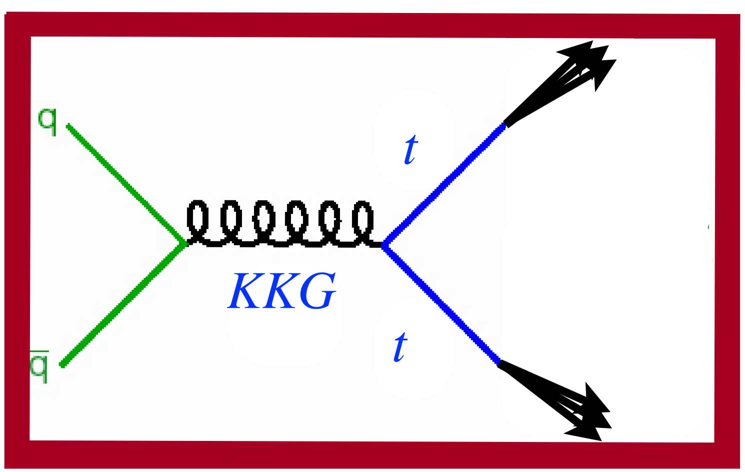
Chala, Juknevich, GP & Santiago, to appear.

Do we search for the right thing?

- The KK gluon is part of the composite sector, it decays to the most composite object allowed by kinematics (t, T).

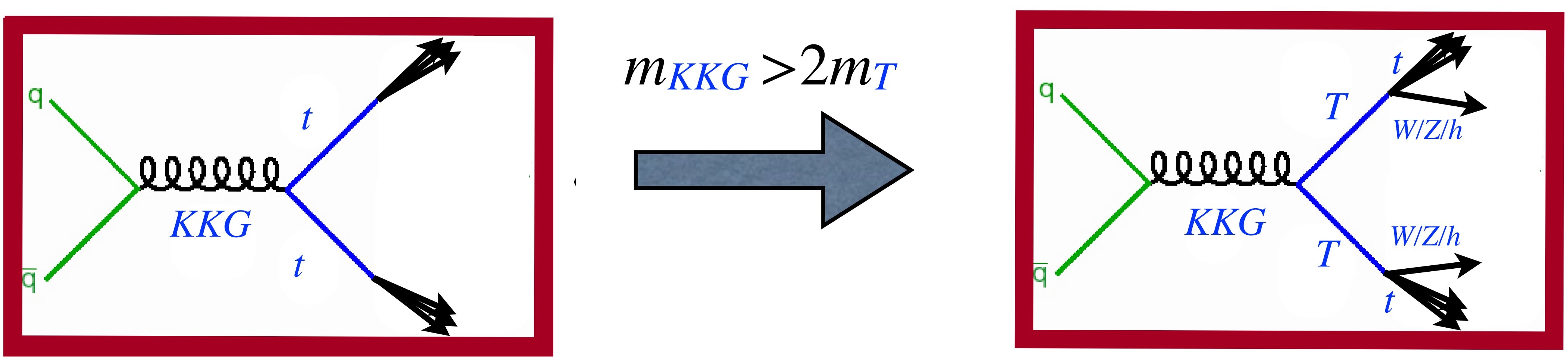
- S parameter: $m_{KKG} > 3$ TeV; naturalness: $m_T < 1$ TeV.

- Searches: $m_{KKG} > 2.5$ TeV; $m_T > 800$ GeV.



Do we search for the right thing?

- The KK gluon is part of the composite sector, it decays to the most composite object allowed by kinematics (t, T).
- S parameter: $m_{KKG} > 3$ TeV; naturalness: $m_T < 1$ TeV.
- Searches: $m_{KKG} > 2.5$ TeV; $m_T > 800$ GeV.

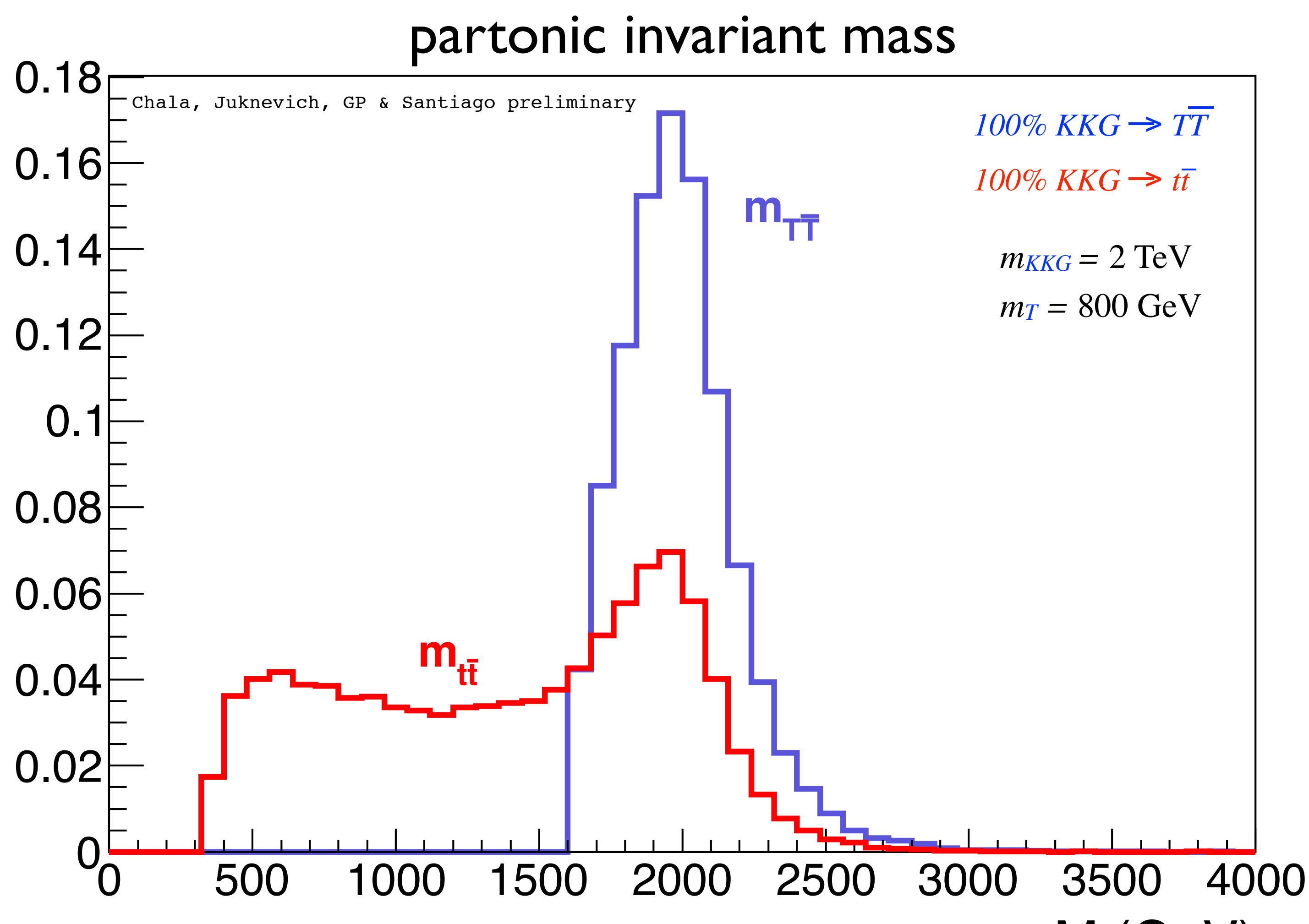


Implications for $KKG \to T\bar{T}$ decay

Chala, Juknevich, GP & Santiago, to appear.

- As T decays to $t + W/Z/h$ but we search only for tops =>

observed spectrum becomes **softer**, let us see it in steps:



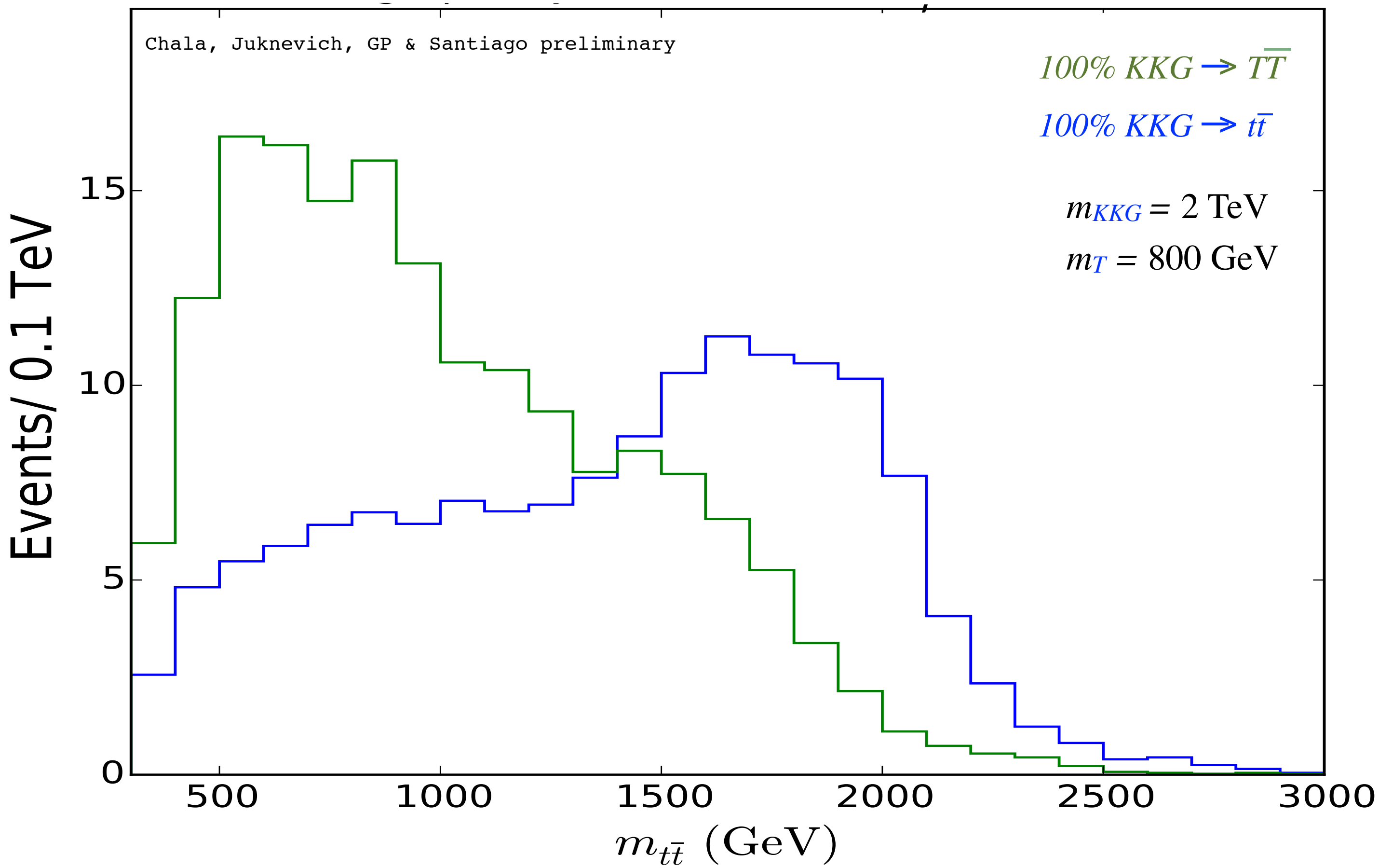
Implications for $KKG \to T\bar{T}$ decay

Chala, Juknevich, GP & Santiago, to appear.

♦ As T decays to t + $W/Z/h$ but we search only for tops =>

observed spectrum becomes softer, let us see it in steps:

top pair reconstructed invariant mass (ATLAS reconstruction, ATLAS-CONF-2013-052)

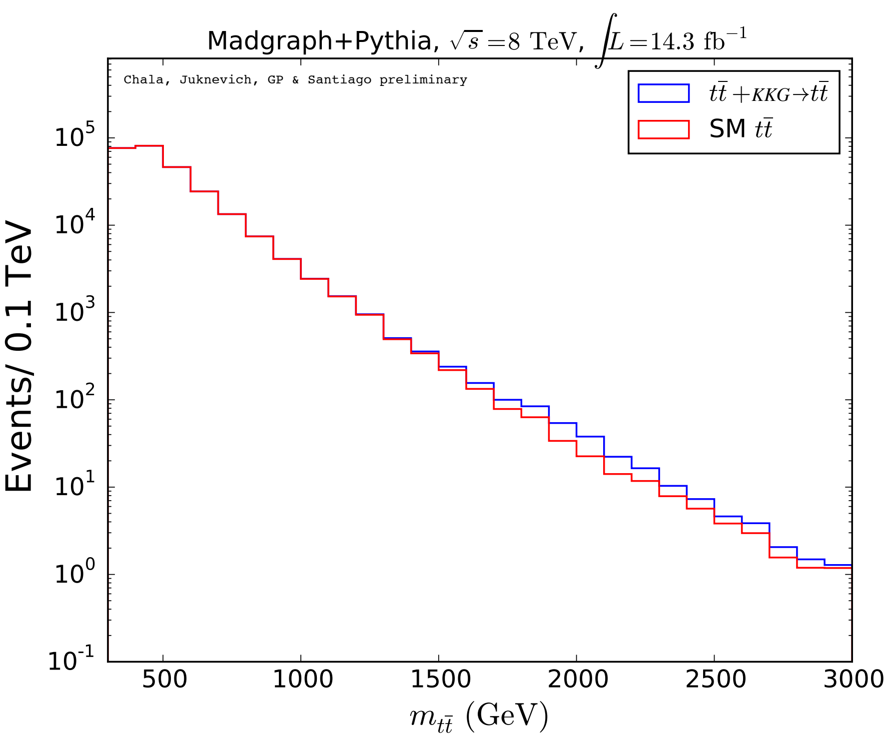


Implications for $KKG \to T\bar{T}$ decay

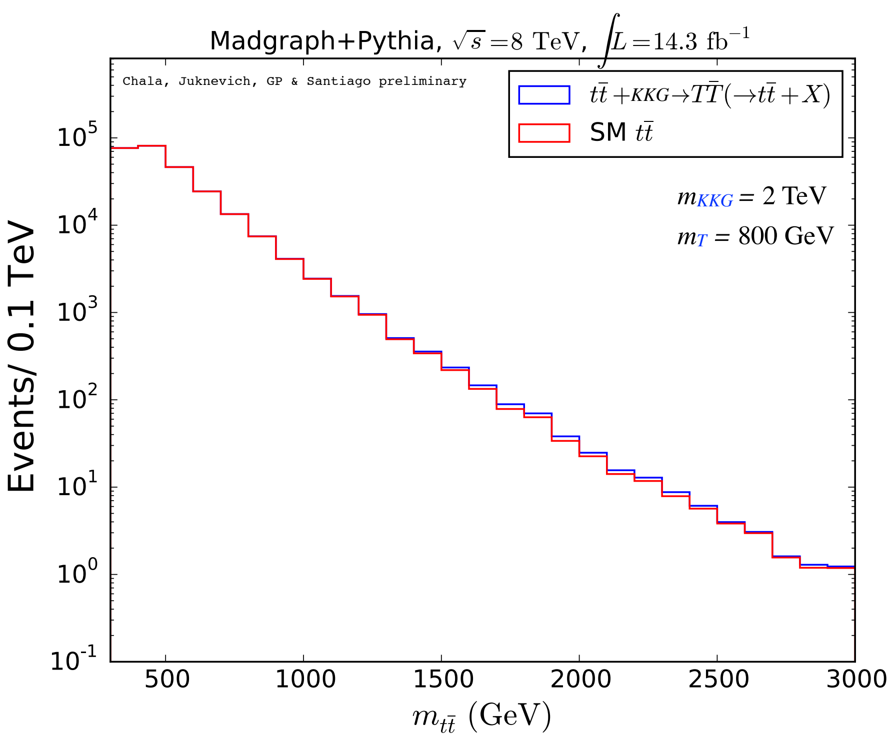
Chala, Juknevich, GP & Santiago, to appear.

- As T decays to $t + W/Z/h$ but we search only for tops => observed spectrum becomes softer, let us see it in steps:

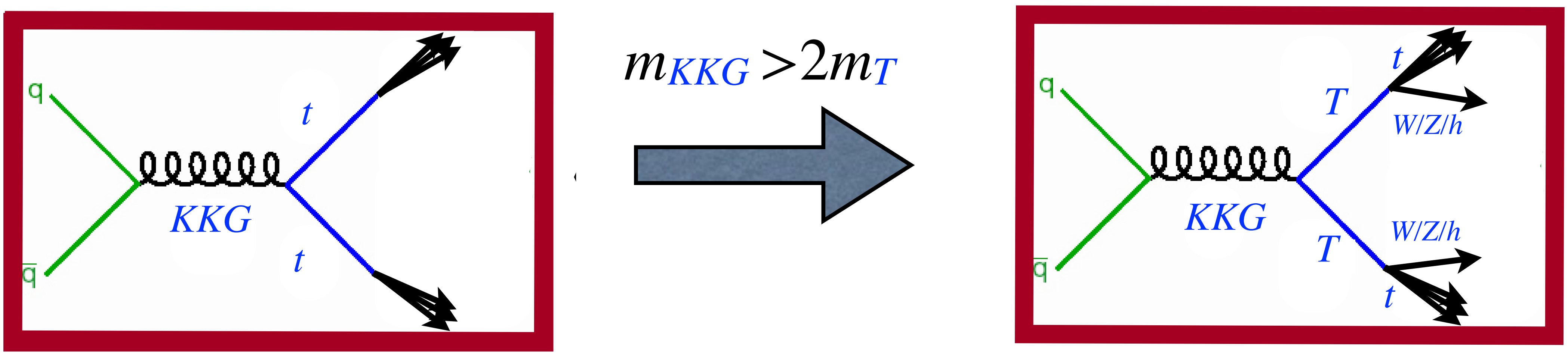
adding SM top pair reconstructed invariant mass



Elusive *KKG*



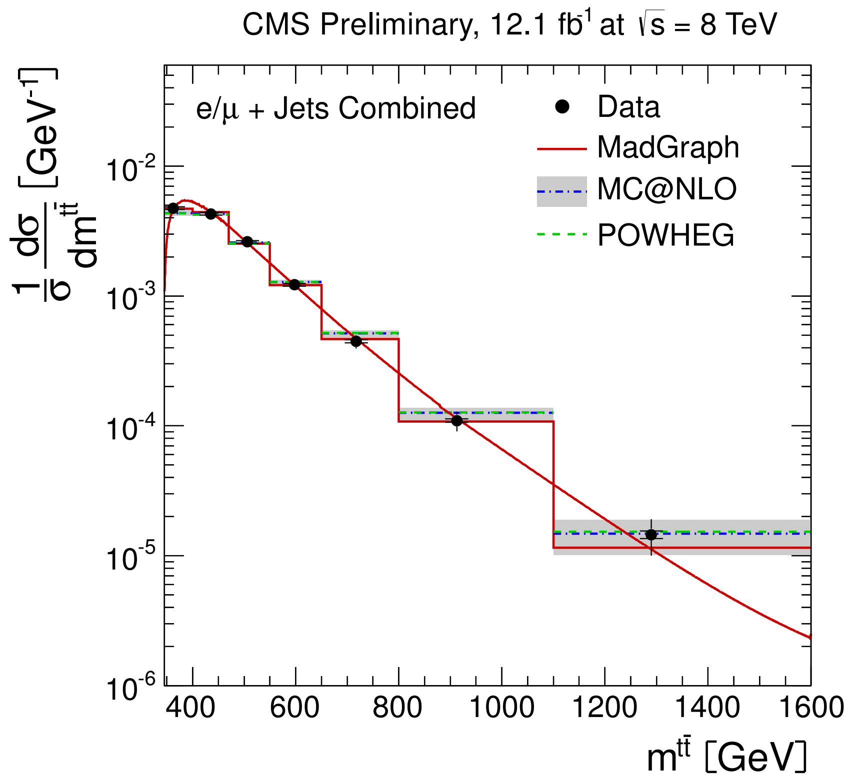
Implications for $KKG \rightarrow T\overline{T}$ decay



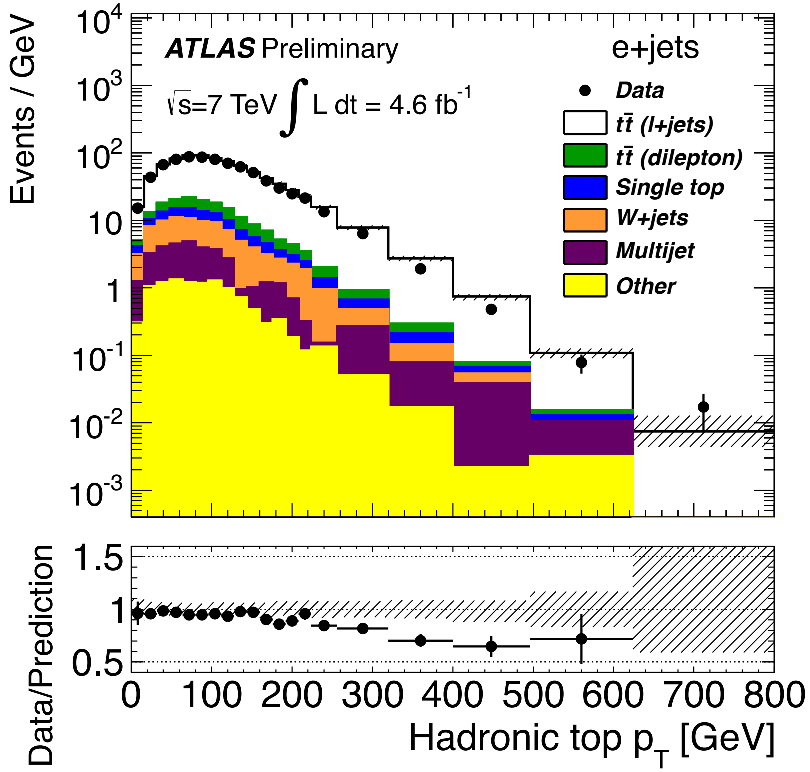
1. Need to be able to control m_{tt} at differential level.
2. Asks for a jet substructure-event-shape/final state hybrid treatment.

The status of boosted top-diff' distribution

Much more challenging, way more rewording, far more important!

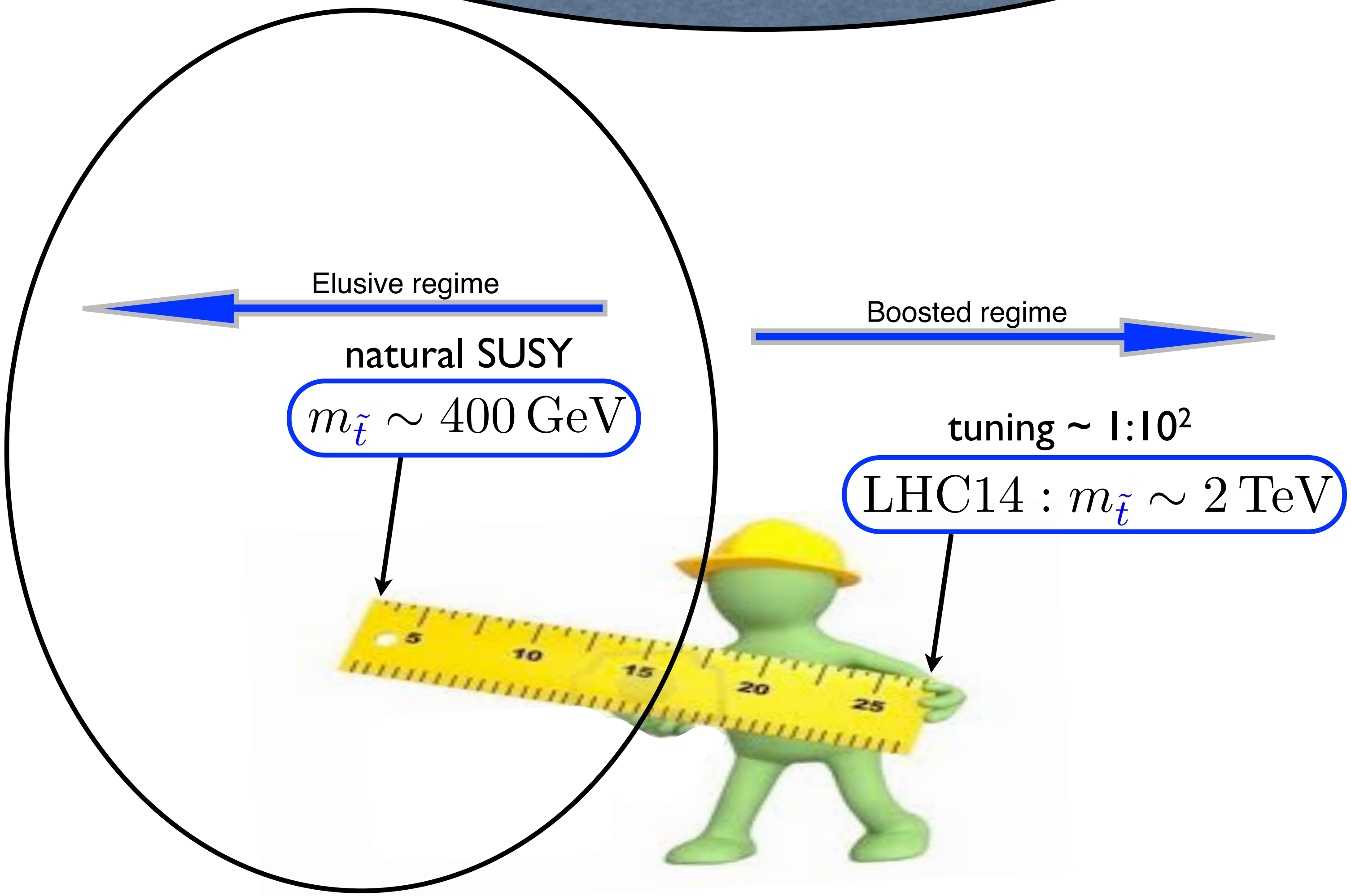


CMS PAS TOP-12-027



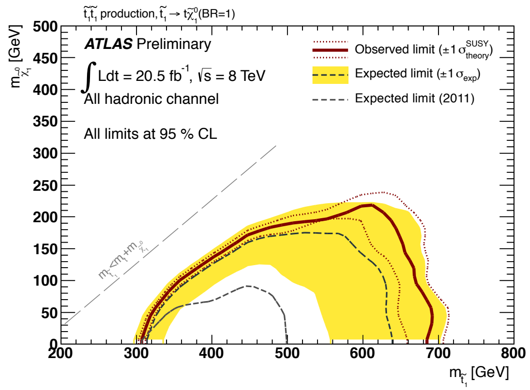
ATLAS-CONF-2013-099

“The mini intensity frontier”:
Elusive top physics

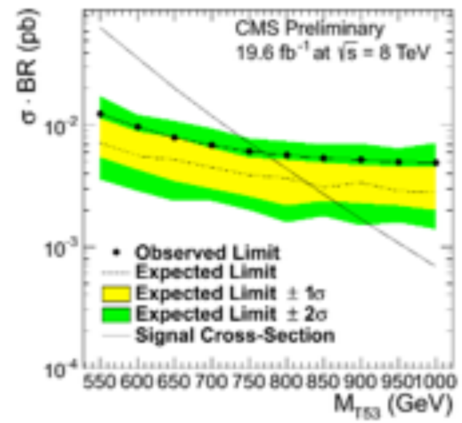


Could the stops/t' still be light?

SUSY



composite Higgs



- ♦ Almost all approaches have implications to top phys.:

(i) SUSY, get rid of missing energy in a systematic way:

RPV, stealth, compressed … (no time to review it all …)

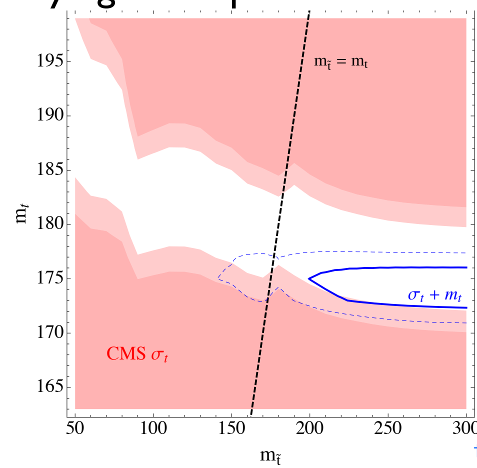
Could the stops/t' still be light?

Mass & Xsection precision could be helpful:

via Josh Ruderman, NNLO theory applied to SUSY:

stop + top

varying the top mass:



LHC top mass (5/fb)

$173.3 \pm 0.5 \pm 1.3$ GeV

2 and 3 sigma contours

what is mt in the presence of stop contamination?

take blue curve as guide to what might be accomplished when this is answered

Czakon, Mitov, Papucci, JTR, Weiler, *to appear.*

As well as differential distribution (angular)

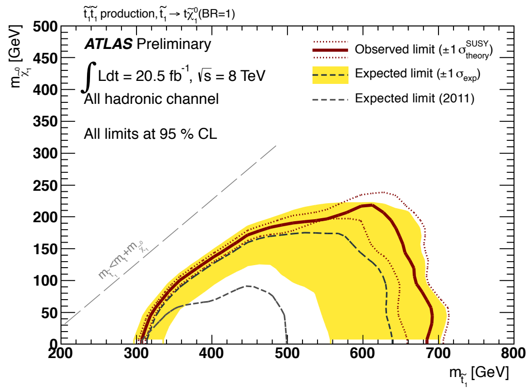
Han, Katz, Krohn and Reece; Belanger, Godbole, Hartgring and Niessen (12); Buckley, Plehn and Ramsey-Musolf (13); Li, Si, Wang, Wang, Zhang and Zhu; Mukhopadhyay, Nojiri and Yanagida (14).

More generically understanding top+jets & thinking about gluinos.

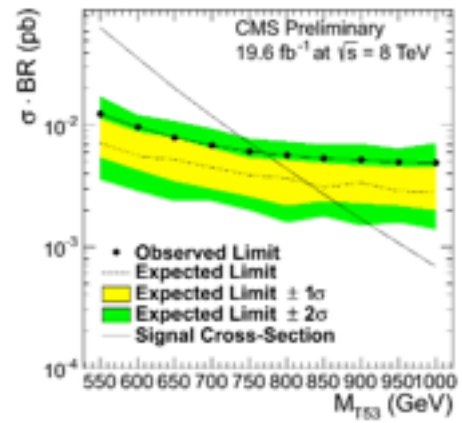
Evans, Kats, Shih and Strassler (13)

Could the stops/t' still be light?

SUSY



composite Higgs



- Almost all approaches have implications to top phys.:

  (i) SUSY, get rid of missing energy in a systematic way:

  RPV, stealth, compressing the spectrum. (no time to review it all …)

  (ii) Get rid of tops in the final state => flavor & connection.

  Applies not only to SUSY.

Flavourful naturalness

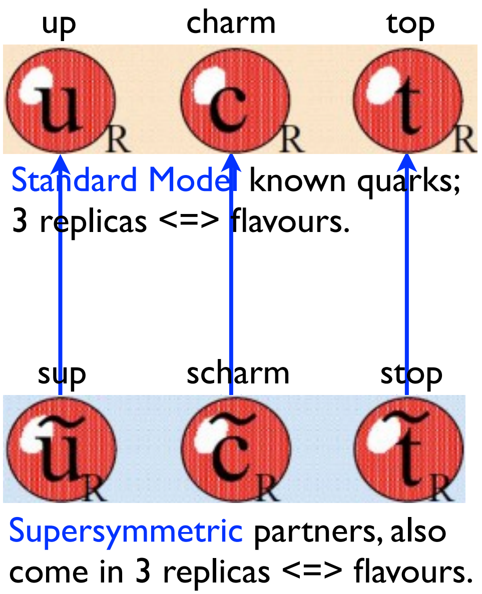
- Standard model: 3 copies (flavours) of quarks;

  same holds for new physics. (say supersymmetry)

- “Hardwired” assumption:

  top partner (stop) is mass eigenstate.

  Dine, Leigh & Kagan, Phys.Rev. D48 (93); Dimopoulos & Giudice (95); Cohen, Kaplan & Nelson (96)



Flavourful naturalness

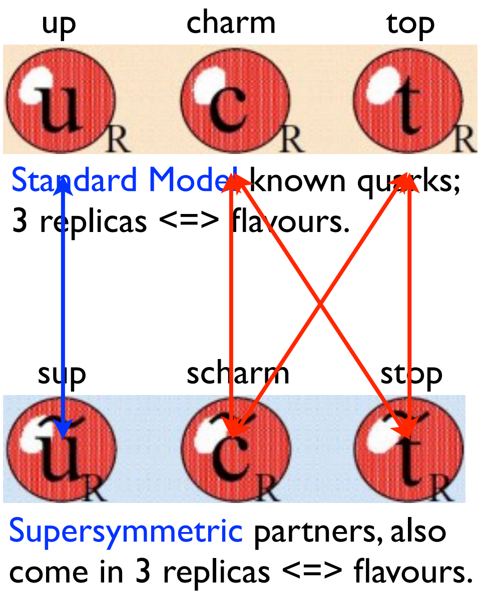
- Standard model: 3 copies (flavours) of quarks;

  same holds for new physics. (say supersymmetry)

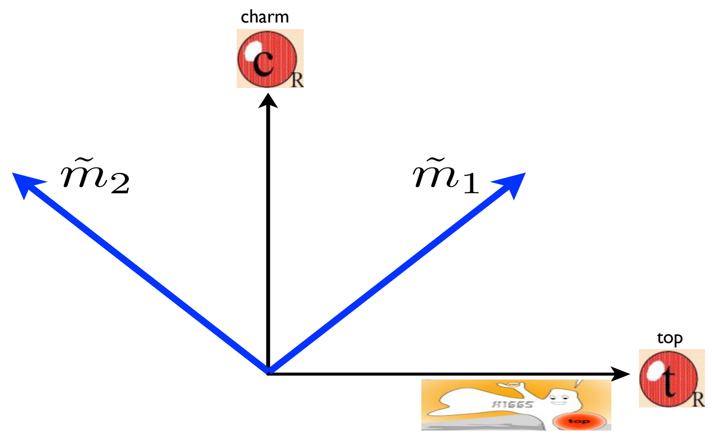
- "Hardwired" assumption:

  top partner (stop) is mass eigenstate.

  Dine, Leigh & Kagan, Phys.Rev. D48 (93); Dimopoulos & Giudice (95); Cohen, Kaplan & Nelson (96) > 1000 citations !

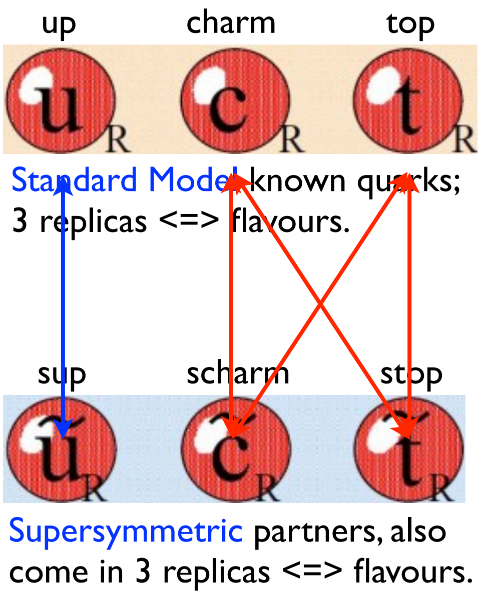


- This need not be the case, top-partner => "stop-scharm" admixture.



Flavourful naturalness

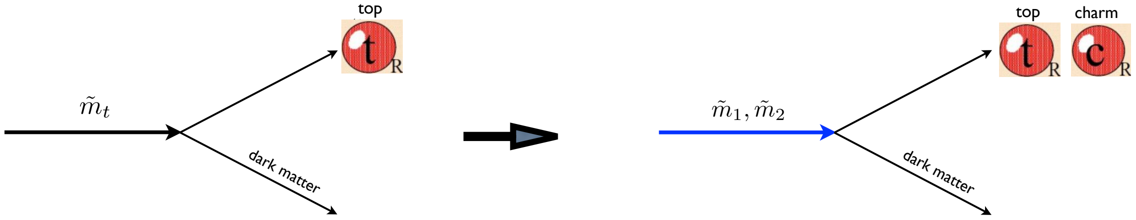
- Standard model: 3 copies (flavours) of quarks; same holds for new physics. (say supersymmetry)



- “Hardwired” assumption: top partner (stop) is mass eigenstate.

Dine, Leigh & Kagan, Phys.Rev. D48 (93); Dimopoulos & Giudice (95); Cohen, Kaplan & Nelson (96) > 1000 citations ...

- This need not be the case, top-partner => “stop-scharm” admixture.



Flavorful naturalness, ameliorating stops bounds

- The relevant parameters to constrain are: Blanke, Giudice, Paride, GP & Zupan (13)

Define relative tuning measure: $\xi = \frac{\tilde{m}_1^2 c^2 + \tilde{m}_2^2 s^2}{m_0^2}, \quad (m_0 = 570\,\mathrm{GeV})$

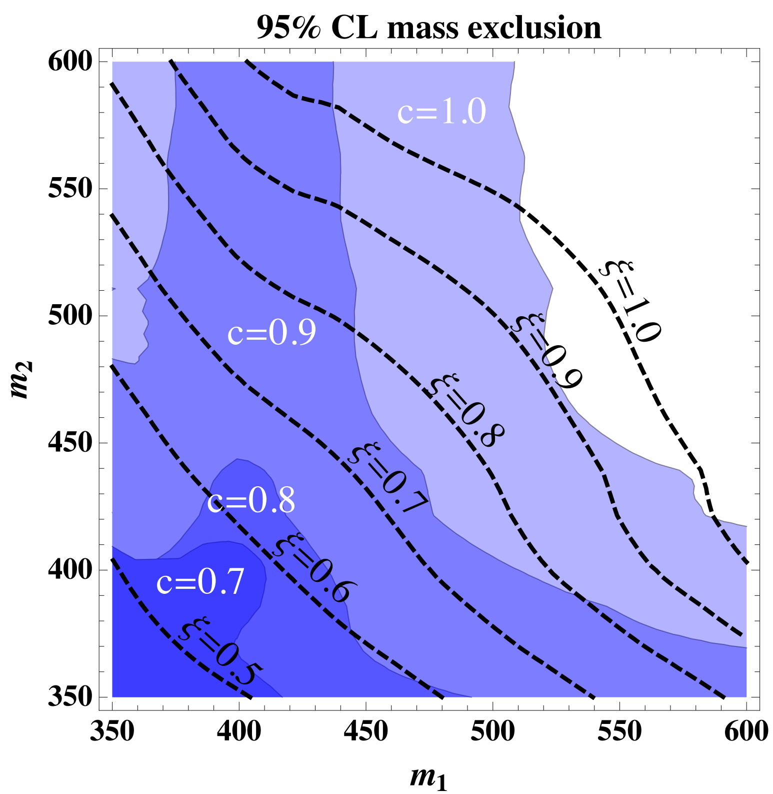
stop,scharm like squark mass, $m_{1,2}$ & $C \equiv \cos\theta_{23}^{RR}$

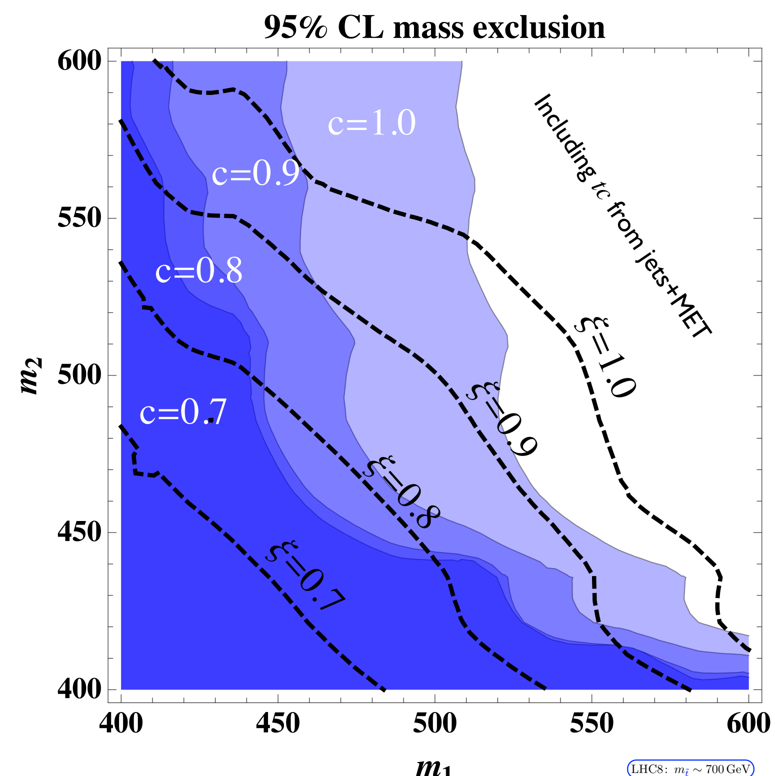
Flavorful naturalness, ameliorating stops bounds

- The relevant parameters to constrain are: Blanke, Giudice, Paride, GP & Zupan (13)

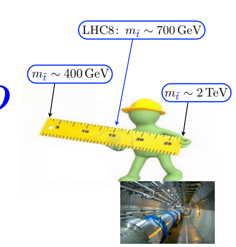
Define relative tuning measure: $\xi = \frac{\tilde{m}_1^2 c^2 + \tilde{m}_2^2 s^2}{m_0^2}$, $(m_0 = 570\,\mathrm{GeV})$

stop,scharm like squark mass, $m_{1,2}$ & $C \equiv \cos\theta_{23}^{RR}$





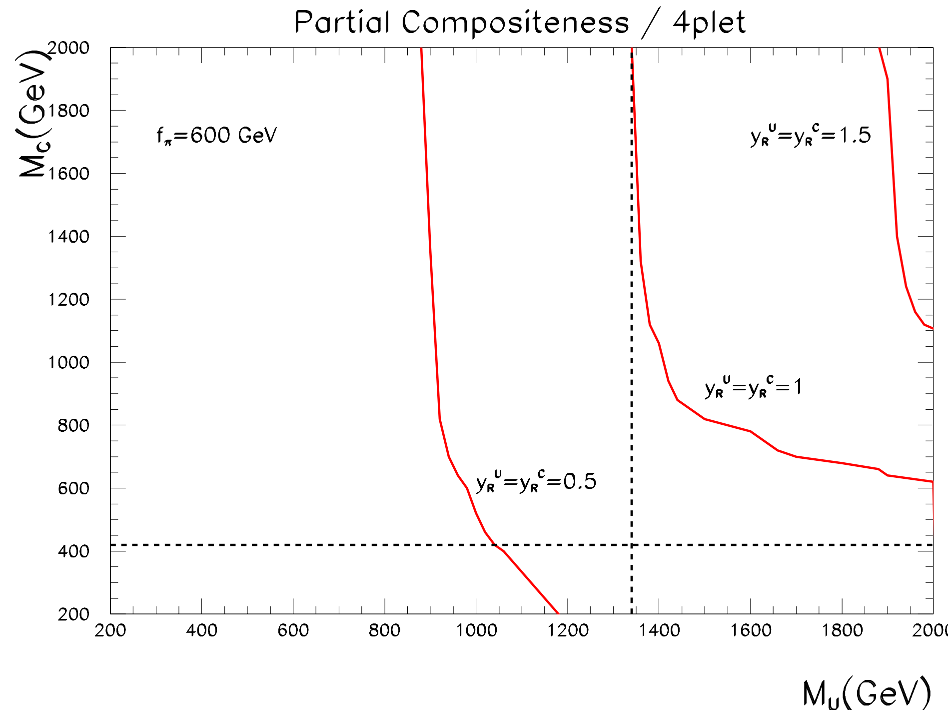
Can get $\xi \sim 0.5 - 0.8$ for $\theta_{23}^{RR} \sim 45^o$



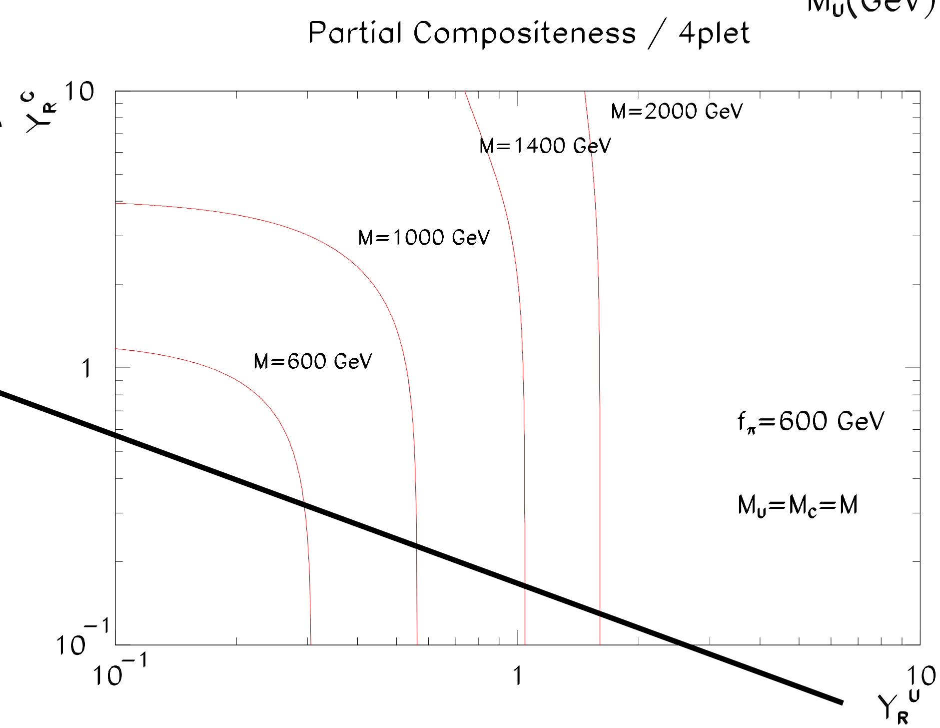
Compositeness: split 2 gen’ LHC bounds (similar to SUSY case)

Delaunay, Fraille, Flacke, Lee, Panico & GP (13).

$$M_c \ll M_U$$



$$y_c \gg y_u$$



Composite natural $t \to cZ$

- $t \to cZ$ null test of the SM.
- $t \to cZ$ in composite models could be large.

Agashe GP & Soni (06)

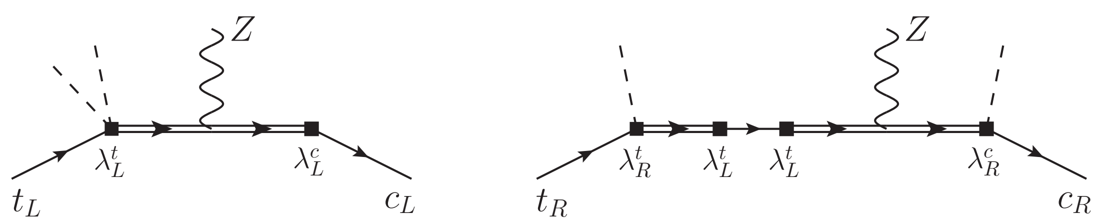
- $t \to cZ$ in custodial composite models could be small.

Agashe, Contino, Da Rold & Pomarol (06)

- $t \to cZ$ in natural custodial composite models should be large.

As both LH & RH tops needs to be composite, Azatov, Panico GP & Soreq, to appear

$$\mathrm{BR}(t \to cZ) \sim 10^{-5} \left(\frac{700}{M_*}\right)^4 .$$



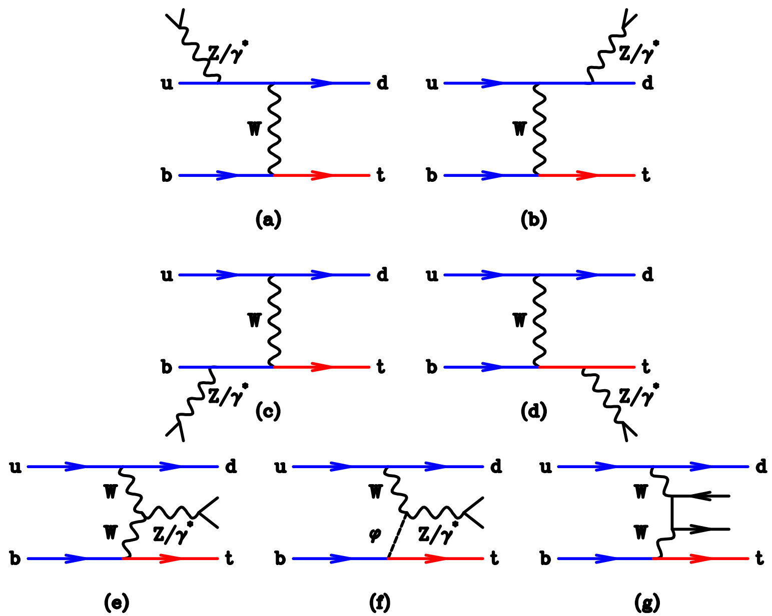
- One extra prediction tops should be RH polarized.

Azatov, Panico GP & Soreq, to appear

The SM semi-irreducible wall

- tZj in the SM is important once BR($t \to cZ$) < 10^{-5} is reached.

Campbell, Ellis & Rontsch (13)



- Current bound is BR($t \to cZ$)~ $5\text{x}10^{-4}$, more serious studies required before the experimentalists actually go below 10^{-4} …

Conclusions

- Top phys. is one of the few motivated windows for new physics searches.

- Two frontiers of the (top) battle of naturalness at the LHC (run II) -

(i) "mini-energy" boosted frontier of heavy top-partner:

- robust searches <=> differential distribution measurement \w boosted tops;

- rich final states involving boosted tops + EW/h and/or missing energy.

(ii) "mini-intensity" precision frontier of elusive top-partners:

- SUSY <=> getting rid of missing energy, signal looks like $\bar{t}t, \bar{t}t + j$;

- SUSY+composite Higgs <=> flavor violation => t<=>c interchanged;

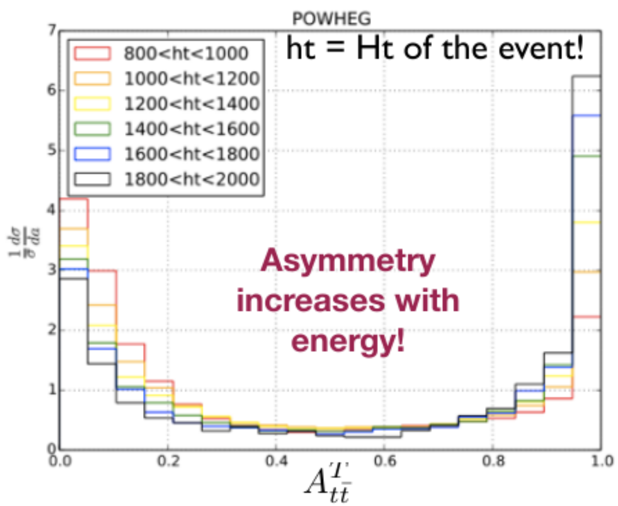
- composite Higgs => large $t \to cZ$, tZj in the SM will become relevant.

Asymmetric $t\bar{t}$ events and top tagging

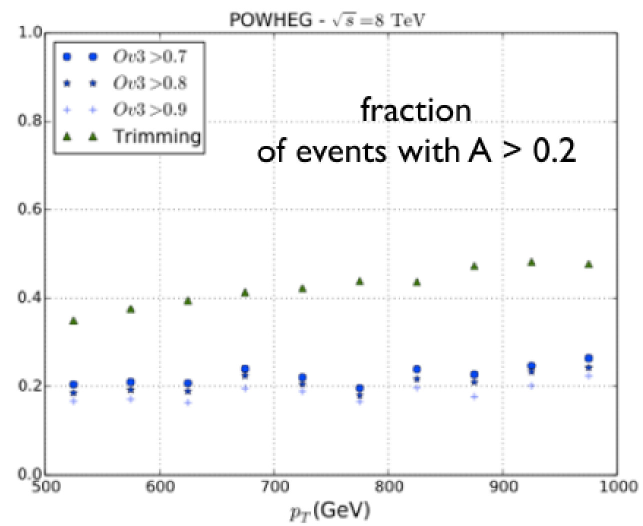
Backovic, JJ, Perez, Soreq

We define an asymmetry for truth level tops to quantify the p_T imbalance in $t\bar{t}$ events

$$A_{t\bar{t}}^{SV} = \frac{|\vec{p}_{T,t} + \vec{p}_{T,\bar{t}}|}{p_{T,t} + p_{T,\bar{t}}}$$



Asymmetric events are also a background to $t\bar{t}$ resonance searches

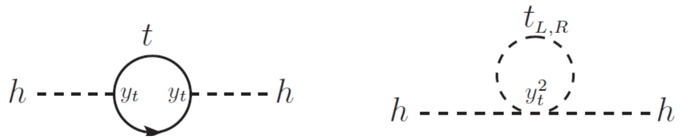


Top template tagger can remove more asymmetric events than d_{12} + mass cut

What is the impact of stop-flavor-violation on tuning ? (flavored naturalness)

- Flavor: only $\tilde{t}_R - \tilde{u}_R$ or $\tilde{t}_R - \tilde{c}_R$ sizable mixing is allowed.
- Naively sounds crazy ...

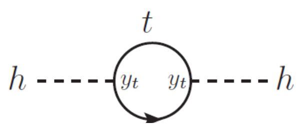
Dine, Leigh & Kagan (93); Dimopoulos & Giudice (95).

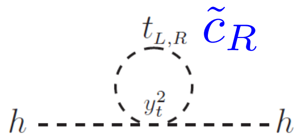


What is the impact of adding flavor violation on stop searches ? (flavorful naturalness)

- Flavor: only $\tilde{t}_R - \tilde{u}_R$ or $\tilde{t}_R - \tilde{c}_R$ sizable mixing is allowed.

- Naively sounds crazy as worsening the fine tuning problem.





$$\delta m^2_{Hu} = -\frac{3y_t^2}{8\pi^2}\left(m^2_{\tilde{t}_L} + \cos^2\theta^{RR}_{23} m_1^2 + \sin^2\theta^{RR}_{23} m_2^2\right)$$

- However, as you'll see soon the scharm can be light...

- The "$\tilde{t}_R \tilde{t}^*_R$" $\rightarrow t_R t^*_R$ production is suppressed by $\left(\cos\theta^R_{23}\right)^4$.

Potentially: new hole in searches, possibly improve naturalness

Constraining (RH) flavorful naturalness

- RH stops & naturalness, $m_{\tilde{t}_R} \gtrsim m_0 = 570\,\mathrm{GeV}$

Analysis applies for ATLAS (12); now new bounds from ATLAS and CMS around 670 GeV.

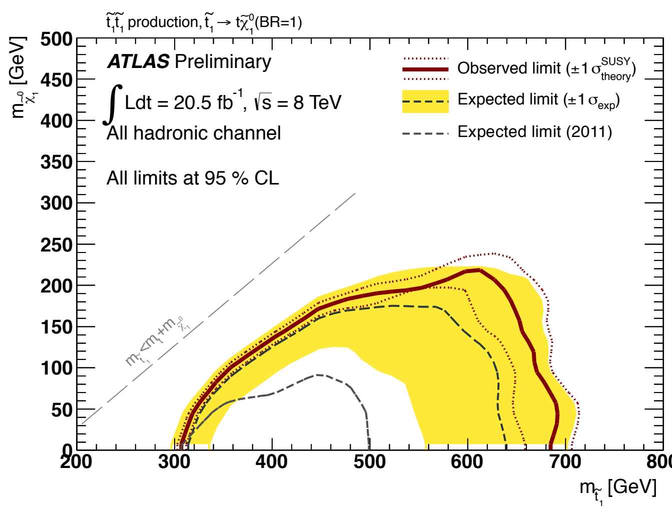
- To constrain, look for: *tt*, *cc* & *tc* + MET (very qualitative).

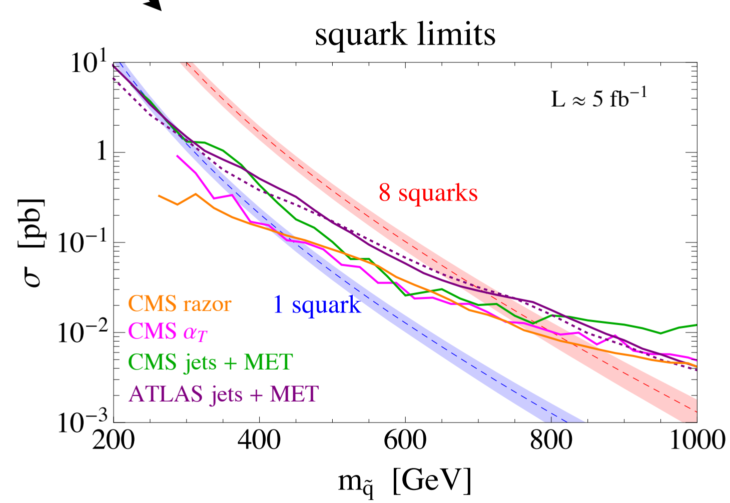
Constraining (RH) flavorful naturalness

- RH stops & naturalness, $m_{\tilde{t}_R} \gtrsim m_0 = 570\,\mathrm{GeV}$

Analysis applies for ATLAS (12); now new bounds from ATLAS and CMS around 670 GeV.

- To constrain, look for: *tt*, *cc* & *tc* + MET (very qualitative).





Mahbubani, Papucci, GP, Ruderman & Weiler (12).

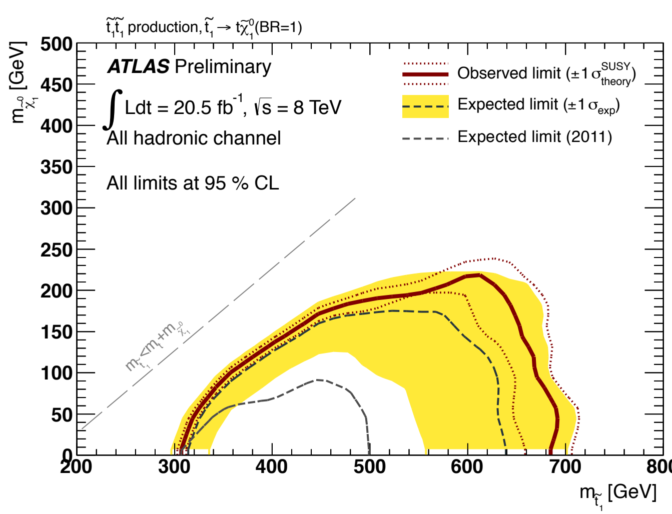
Constraining (RH) flavorful naturalness

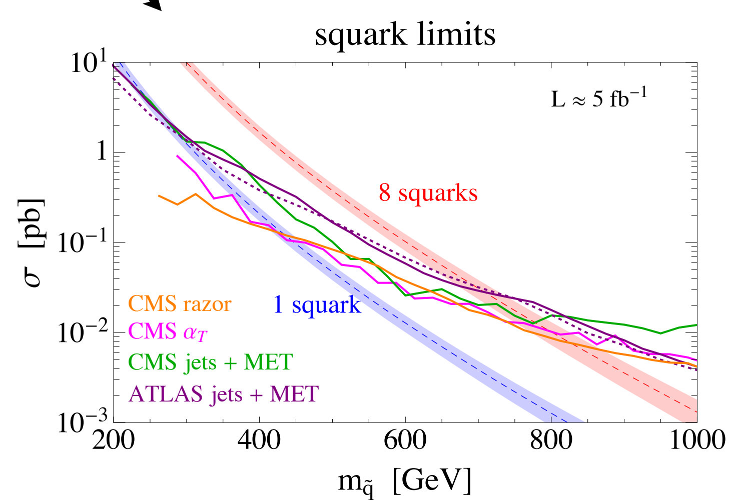
- RH stops & naturalness, $m_{\tilde{t}_R} \gtrsim m_0 = 570\,\mathrm{GeV}$

Analysis applies for ATLAS (12); now new bounds from ATLAS and CMS around 670 GeV.

- To constrain, look for tt, cc & tc + MET (very qualitative).

??





Mahbubani, Papucci, GP, Ruderman & Weiler (12).

Constraining (RH) flavorful naturalness

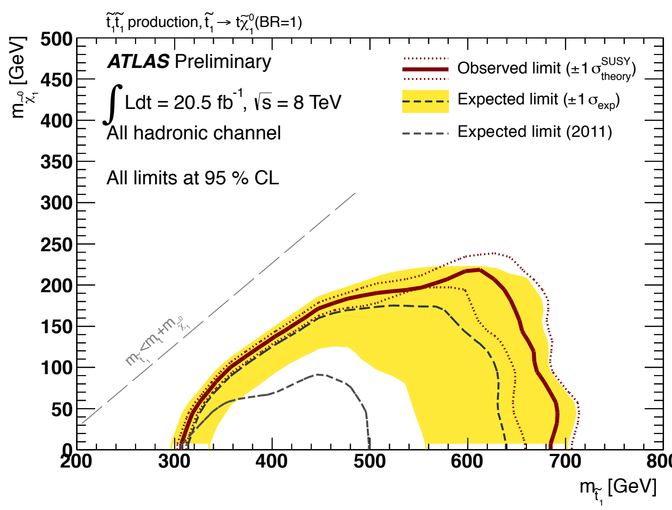
- RH stops & naturalness, $m_{\tilde{t}_R} \gtrsim m_0 = 570\,\mathrm{GeV}$

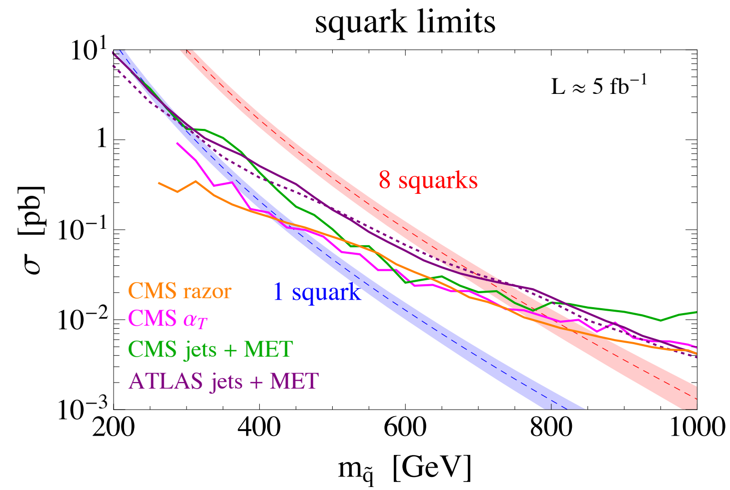
Analysis applies for ATLAS (12); now new bounds from ATLAS and CMS around 670 GeV.

- To constrain, look for tt, cc & tc + MET (very qualitative).

??

compromise





Mahbubani, Papucci, GP, Ruderman & Weiler (12).

Conclusions

♦ Subjective: despite entering the "boosted" era (not in Higgs) the "jet-substructure" field is behind the rest of the PQCD one.

♦ More energy => about to enter "hybrid-boosted" era.

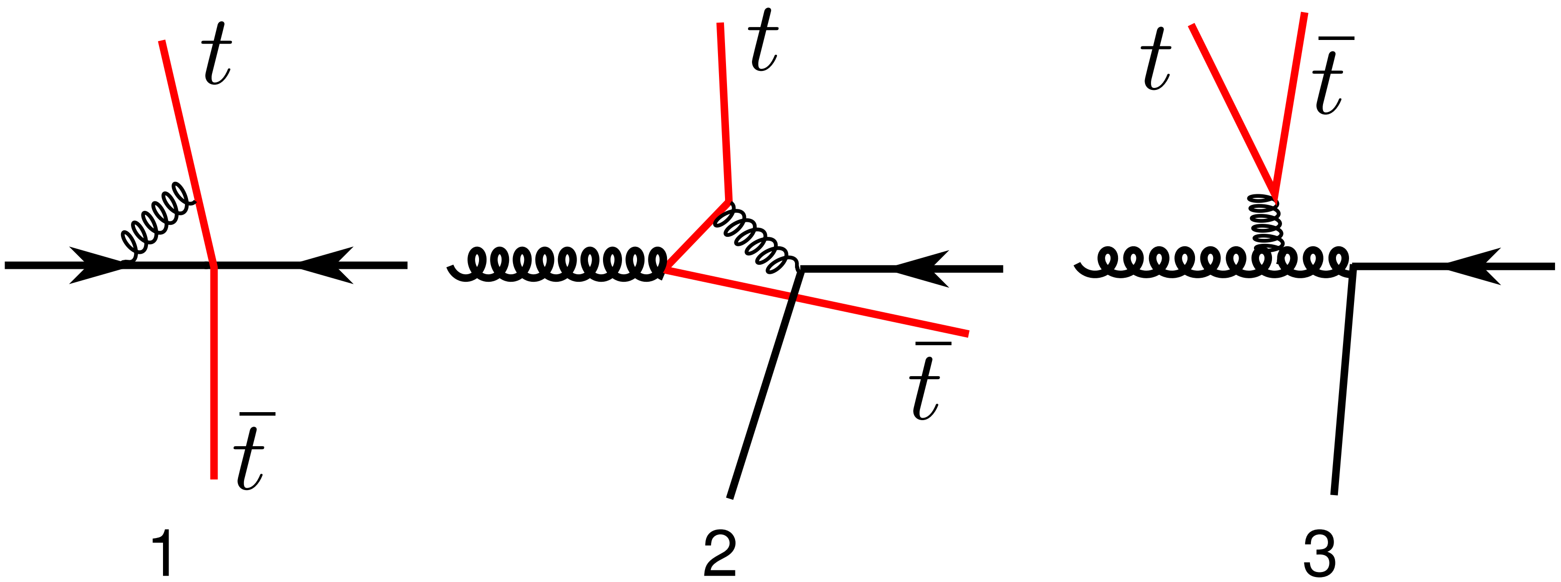
♦ Elusive: light (non-"sups") squarks/partners maybe buried.

♦ Stop-scharm mixing might lead to improve naturalness.

♦ Ask for new type of searches, charm tagging important, linked to CPV in D mixing, soon to be tested at LHCb.

Next-to-leading order effects

Are top pairs in high-p_T events always back to back?



How do 2 and 3 change distributions?

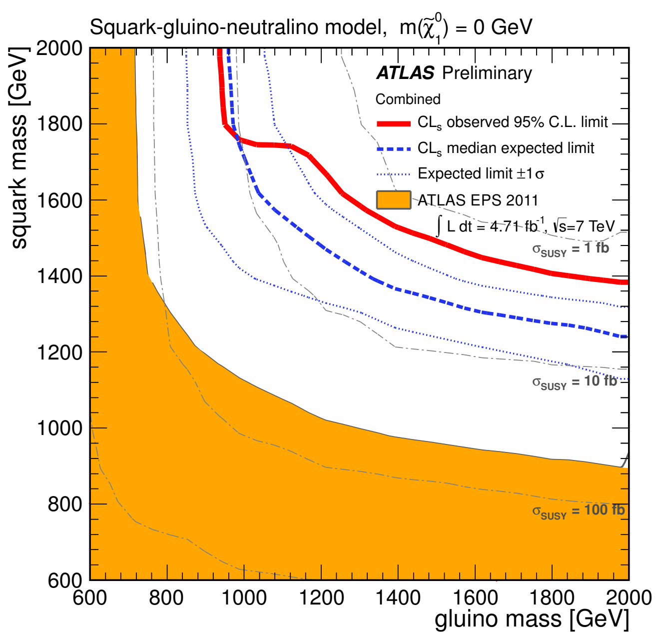
Salam, '13, ATLAS Top WG

Backovic, Gabizon, Juknevich, GP & Soreq (13)

Light scharms at the LHC

Putting stops aside, what are the bounds on first 2-generation “light” squarks?

Summer bounds from ATLAS & CMS :



Light squarks > 1.4 TeV?

What drives the experimental limits?

- Squark multiplicity;
- Signal efficiencies;
- Production rate, PDFs.

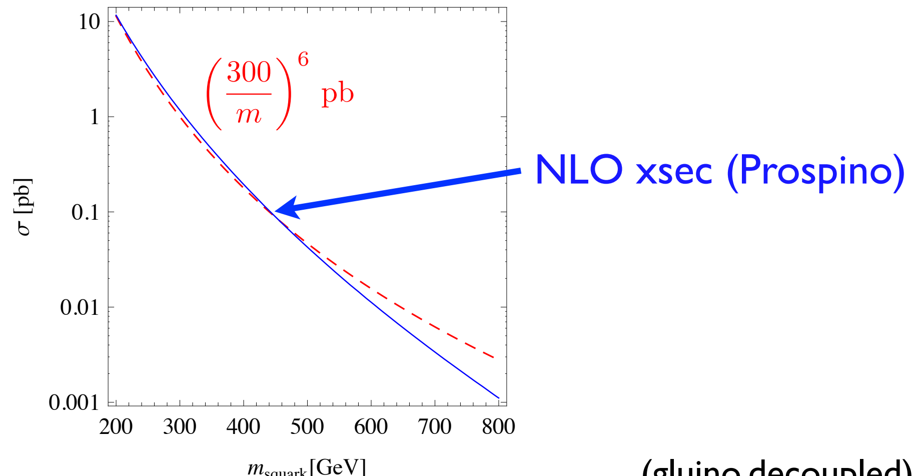
What drives the experimental limits?

- Squark multiplicity;
- Signal efficiencies;
- Production rate, PDFs.

Multiplicity: how bound changes when one doublet is made lighter ?

Cross-sections vs. mass

$$\sigma(pp \to \tilde{u}_R \tilde{u}_R^*) \propto \frac{1}{m^6}$$ (roughly)



(gluino decoupled)

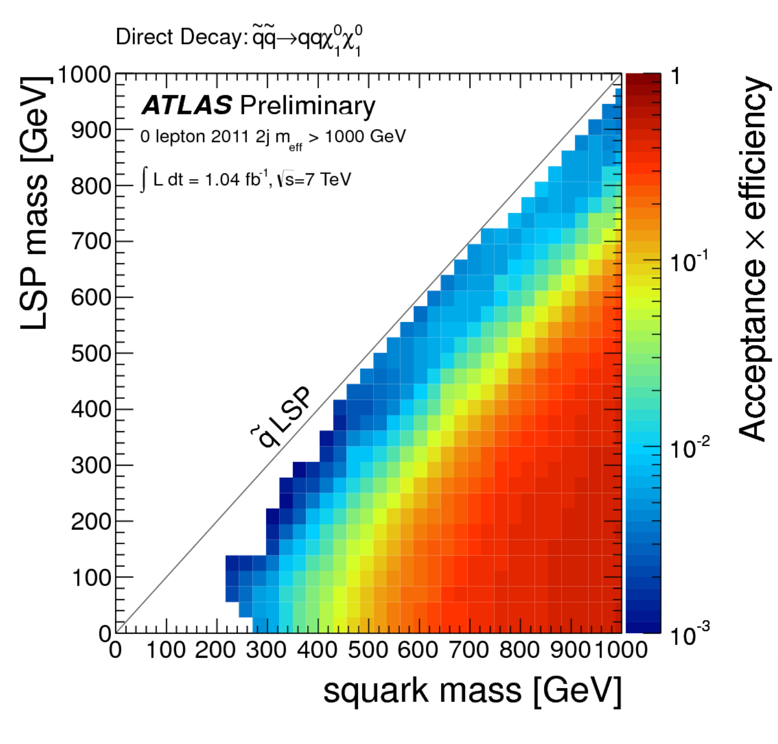
$$8/m^6 = 6/m_H^6 + 2/m_L^6$$

$$(m_L/m_H) = (1/4)^{1/6} \sim 0.8$$

gain is marginal

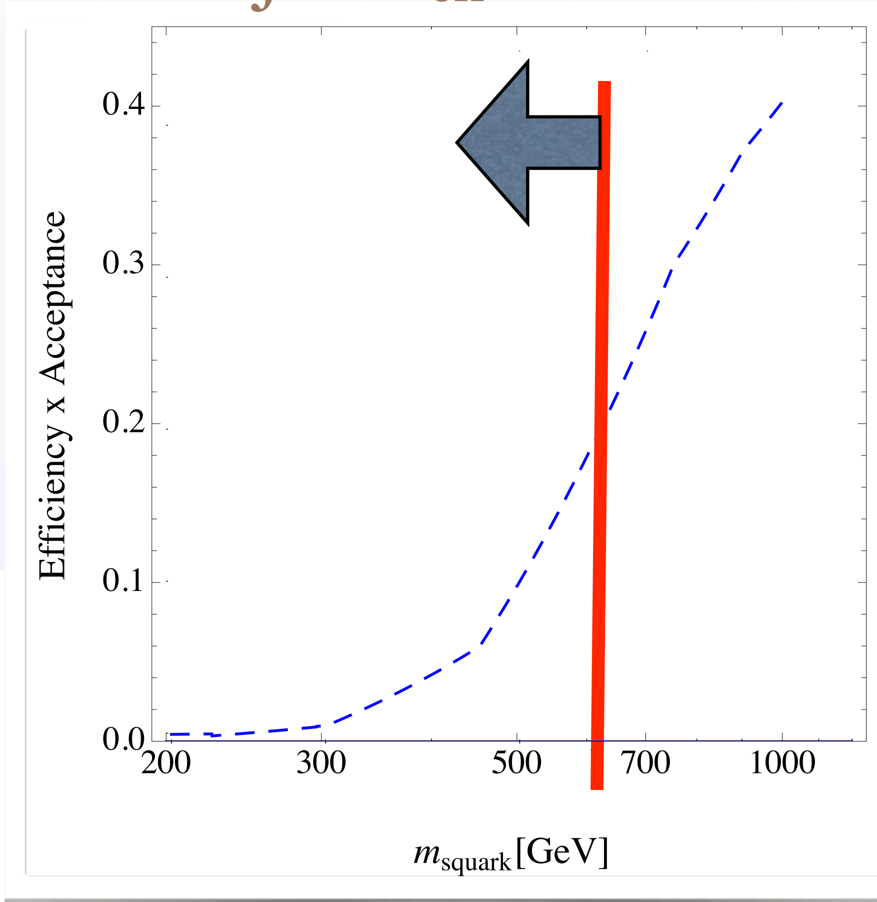
Efficiencies, strong mass dependence!

Signal efficiency falls very rapidly with decreasing squark mass



Below $\sim$ 600 GeV $\epsilon\sigma = 1$

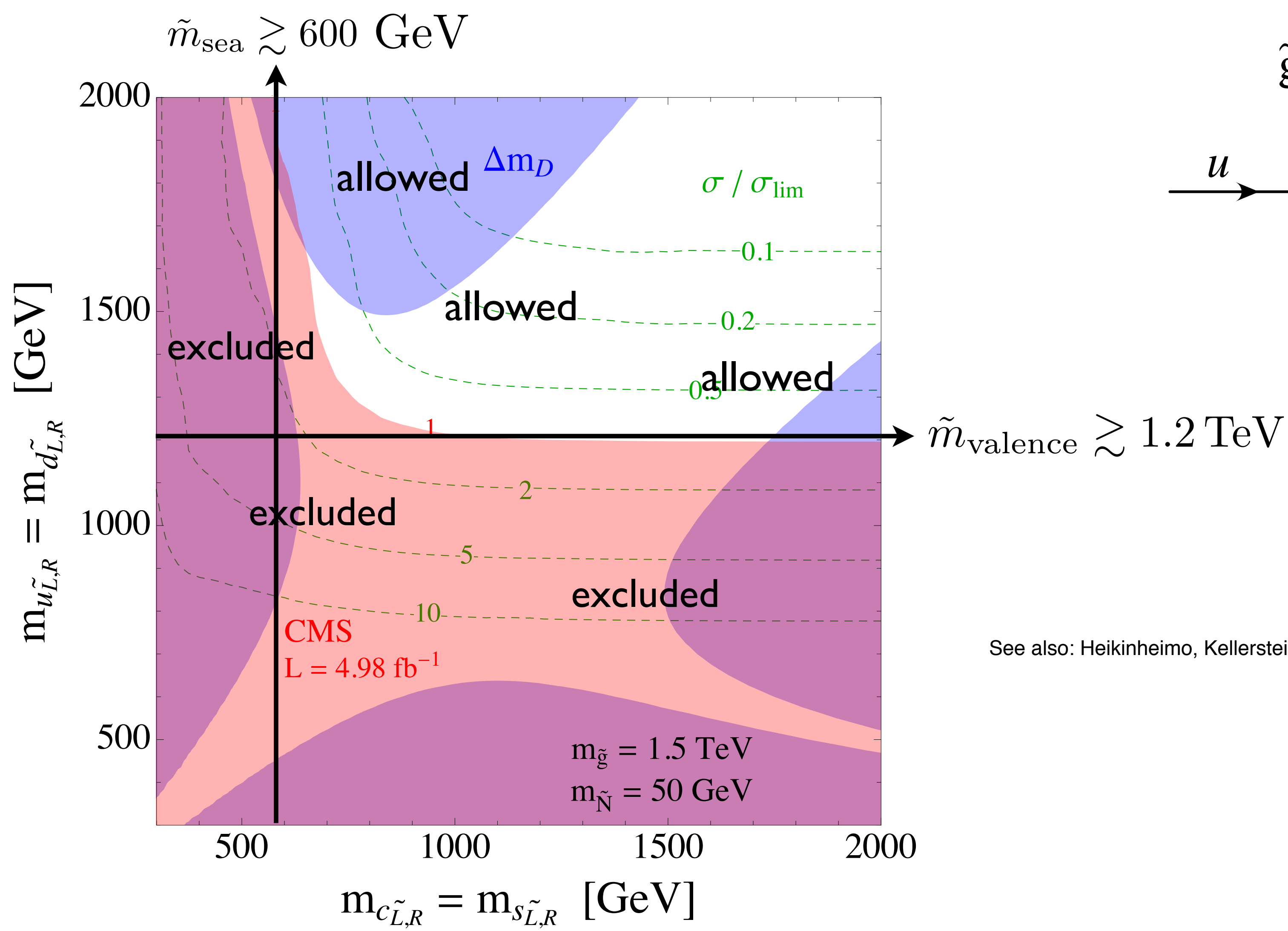
ATLAS 1/fb,
2jet Meff>1TeV

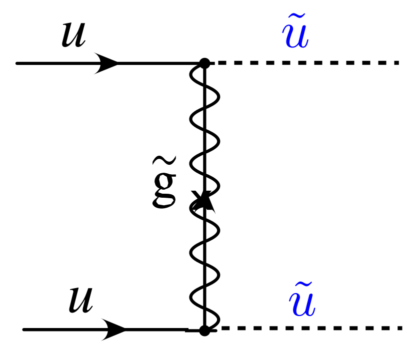


meff is the scalar sum of transverse momenta of the leading N jets with E^{miss}.

PDFs: all 4 flavor "sea" squarks can be light!

sea vs. valence

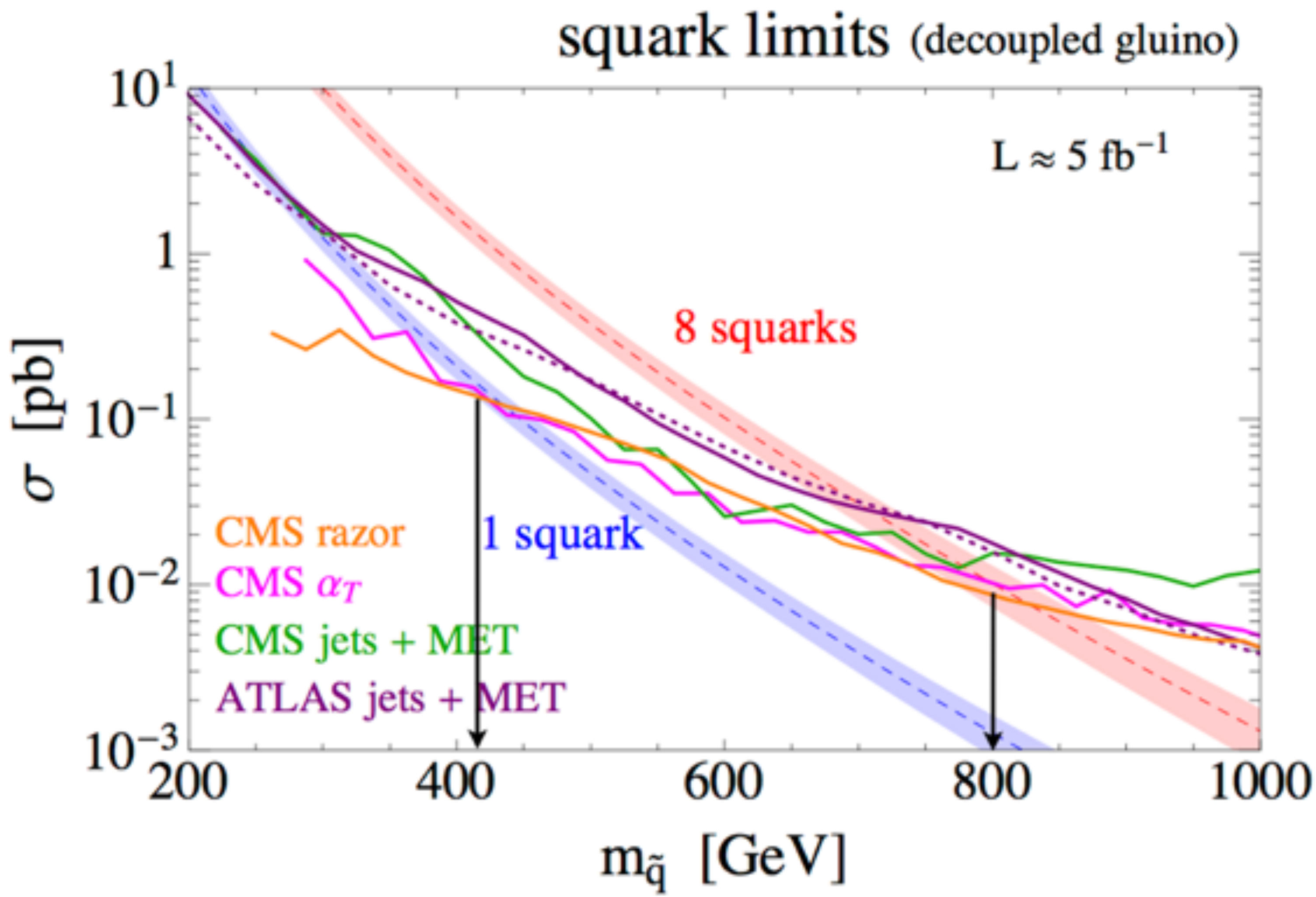




See also: Heikinheimo, Kellerstein & Sanz (11); Kribs & Martin (12),

Mahbubani, Papucci, GP, Ruderman & Weiler (12).

Single squark can be as light as 400-500 GeV!



Mahbubani, Papucci, GP, Ruderman & Weiler (12).

Open parenthesis

Charm tagging at the LHC   ATLAS EPS 2013

- In new ATLAS search for stop decay to charm + neutralino ($\tilde{t} \to c + \chi^0$) charm jet tagging has been employed for the first time at LHC

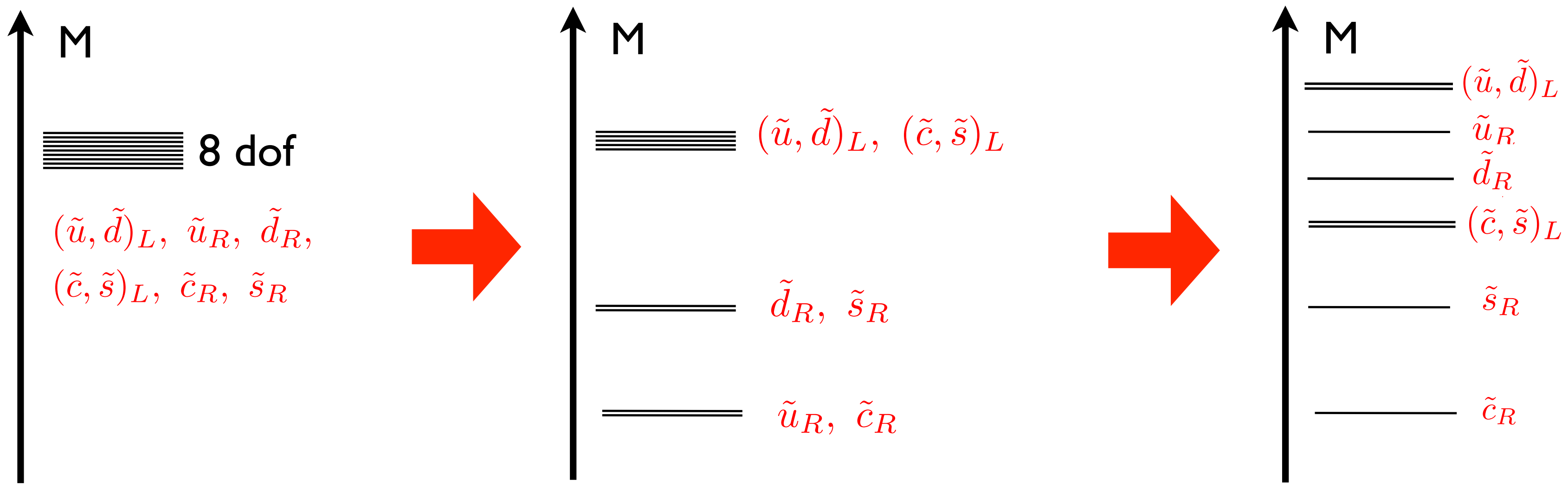
ATLAS-CONF-2013-068

- charm jets identified by combining "information from the impact parameters of displaced tracks and topological properties of secondary and tertiary decay vertices" using multivariate techniques

  - 'medium' operating point: c-tagging efficiency = 20%, rejection factor of 5 for b jets, 140 for light jets. #'s obtained for simulated $t\bar{t}$ events for jets with $30 < p_T < 200$, and calibrated with data

Spectrum of flavorful natural models

Mahbubani, Papucci, GP, Ruderman & Weiler (12).



Everything degenerate

Split, but MFV

Anarchy!