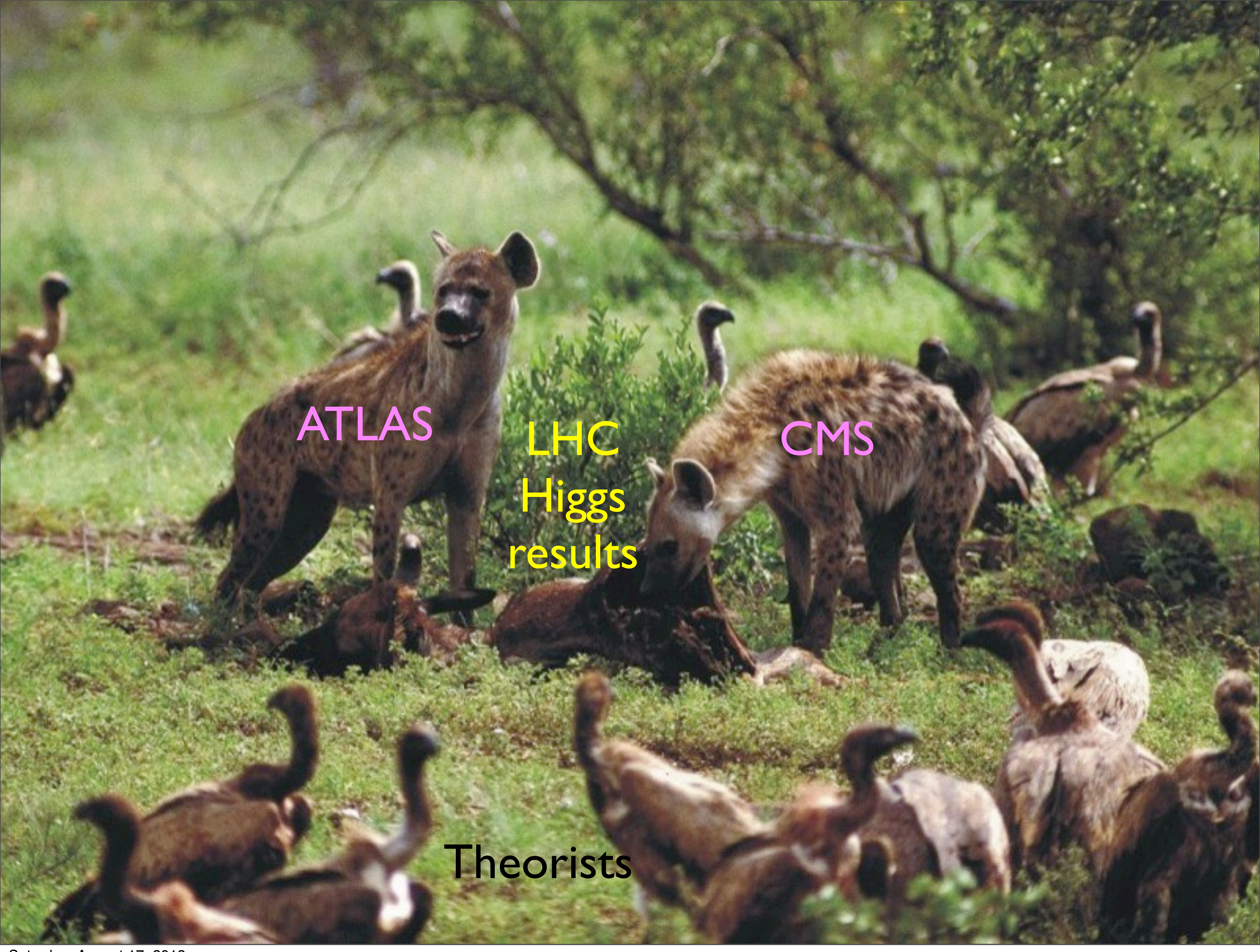
Selected Theory Highlights of the past year

Ann Nelson

DPF meeting, August 17, 2013


ATLAS
LHC
Higgs
results
CMS
Theorists

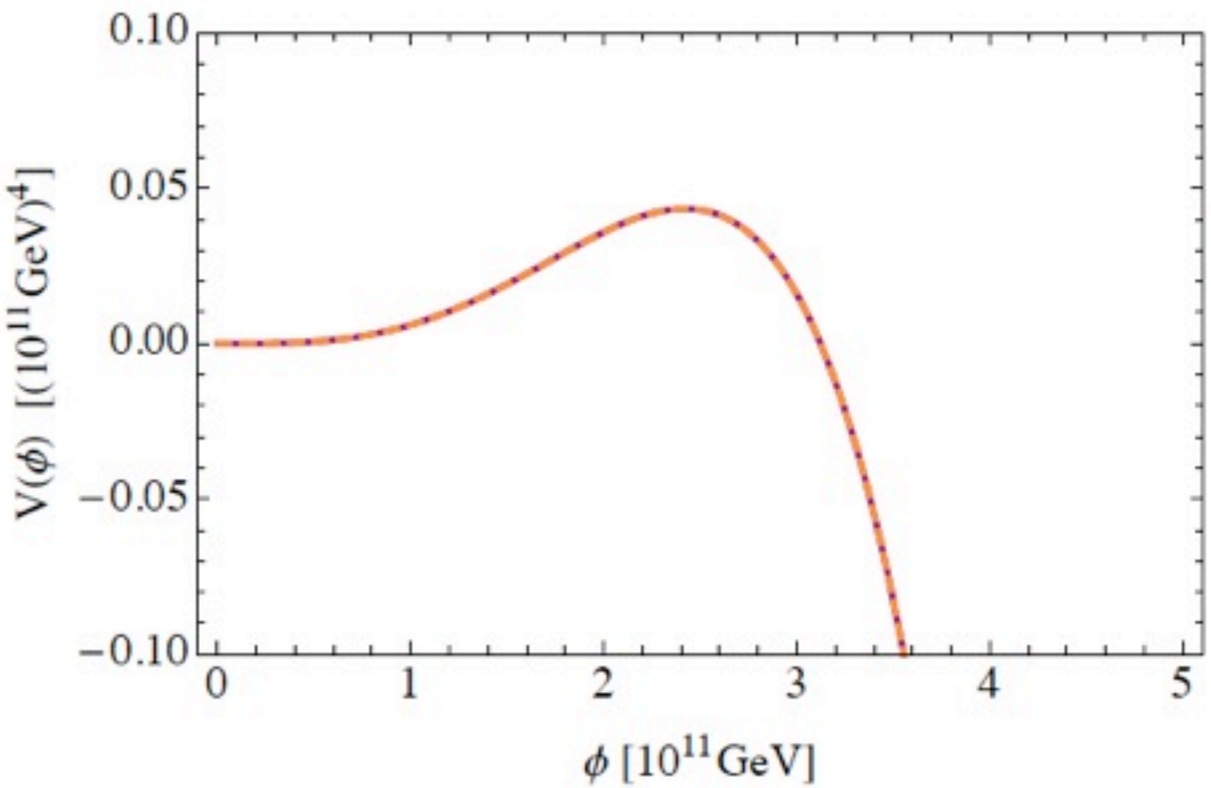
We have a Higgs!

- 126 GeV
  - Upper end of MSSM
  - Lower end of SM to 10^{14} GeV (+ν mass from dim 5 operators, + DM with uberweak interactions)

SM to high scales

RG-improved Effective Potential at High Field Values

Patrick Draper



Adapted from
Degrassi, Di Vita, Elias-Miro,
Espinosa, Giudice, Isidori,
Strumia 2012

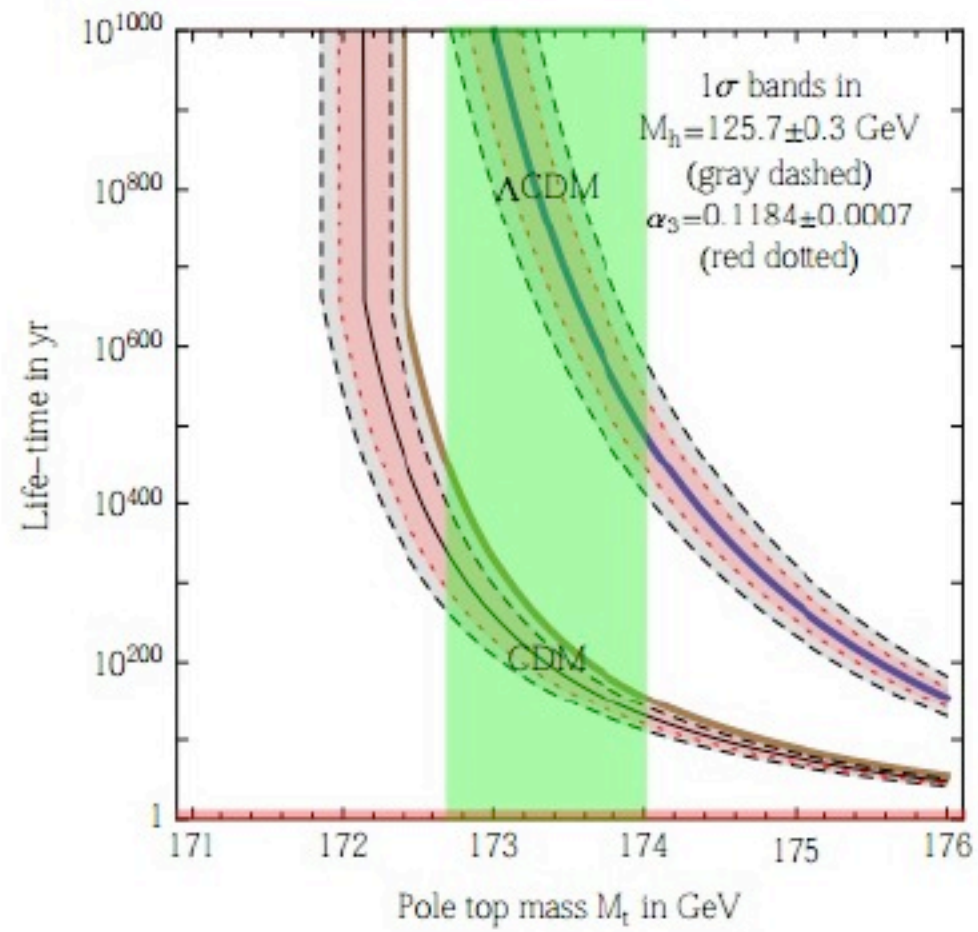
Potential turns over near 10^{11} GeV and is unbounded from below. New physics must stabilize it!

2 possibilities:

(1) new physics is below the instability scale.
Our vacuum probably stable.

(2) new physics is only above instability scale.
Our vacuum metastable, lifetime ~ 10^{100} y

P.Draper



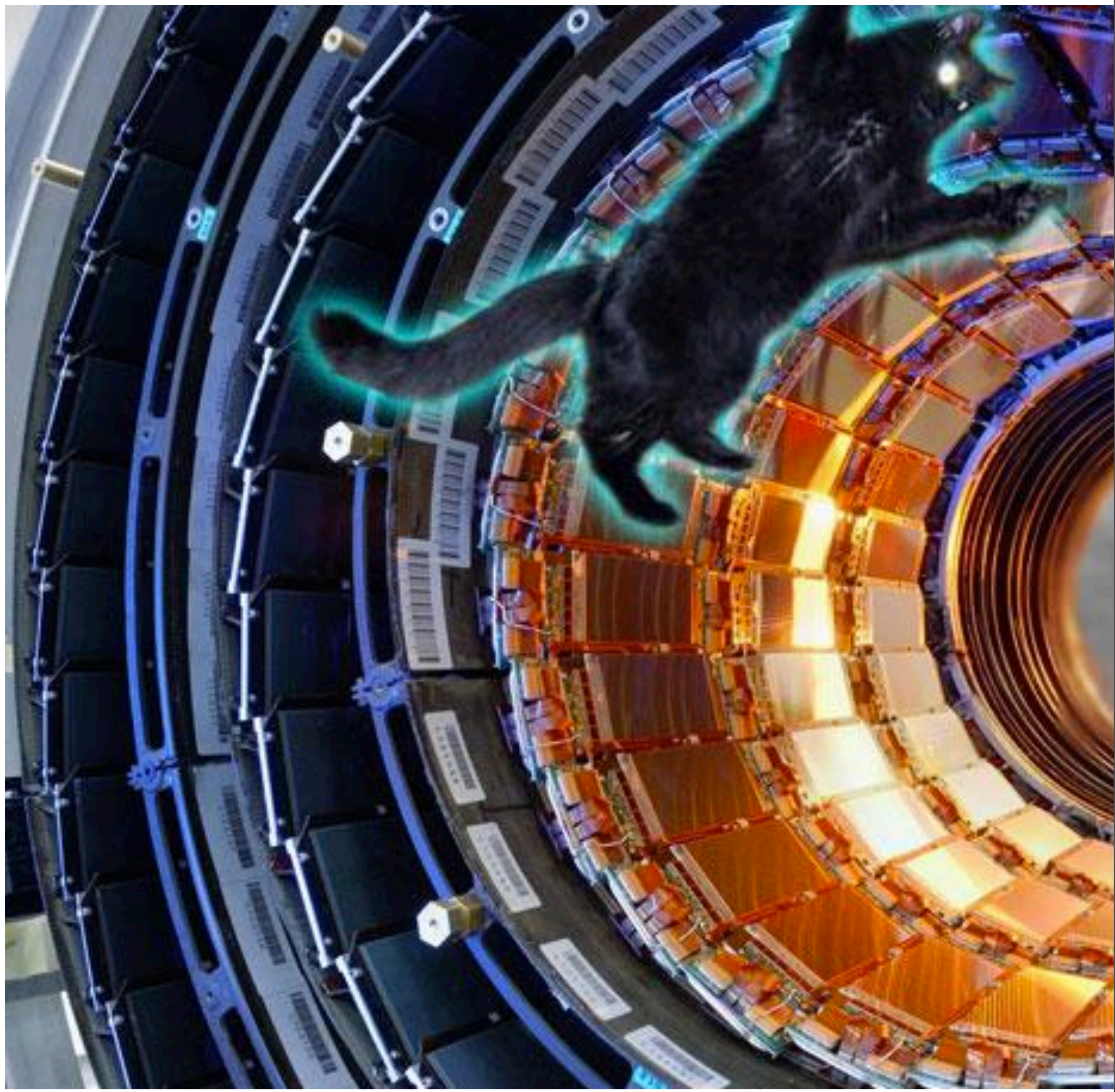
Buttazzo, Degrassi, Giardino, Giudice, Sala, Salvio, Strumia 2013

Naturalness

- SM parametrizes Higgs potential with 2 renormalized parameters
  - No mathematical/logical necessity for renormalized parameters to be predictable
  - If there is an underlying finite UV complete theory, the renormalized parameters can be computed from the fundamental ones
    - finely tune fundamental parameters to get hierarchy?
    - landscape: emotional reason to be ok with finetuning

Alternatives to fine-tuning are LHC testable, (but hiding)

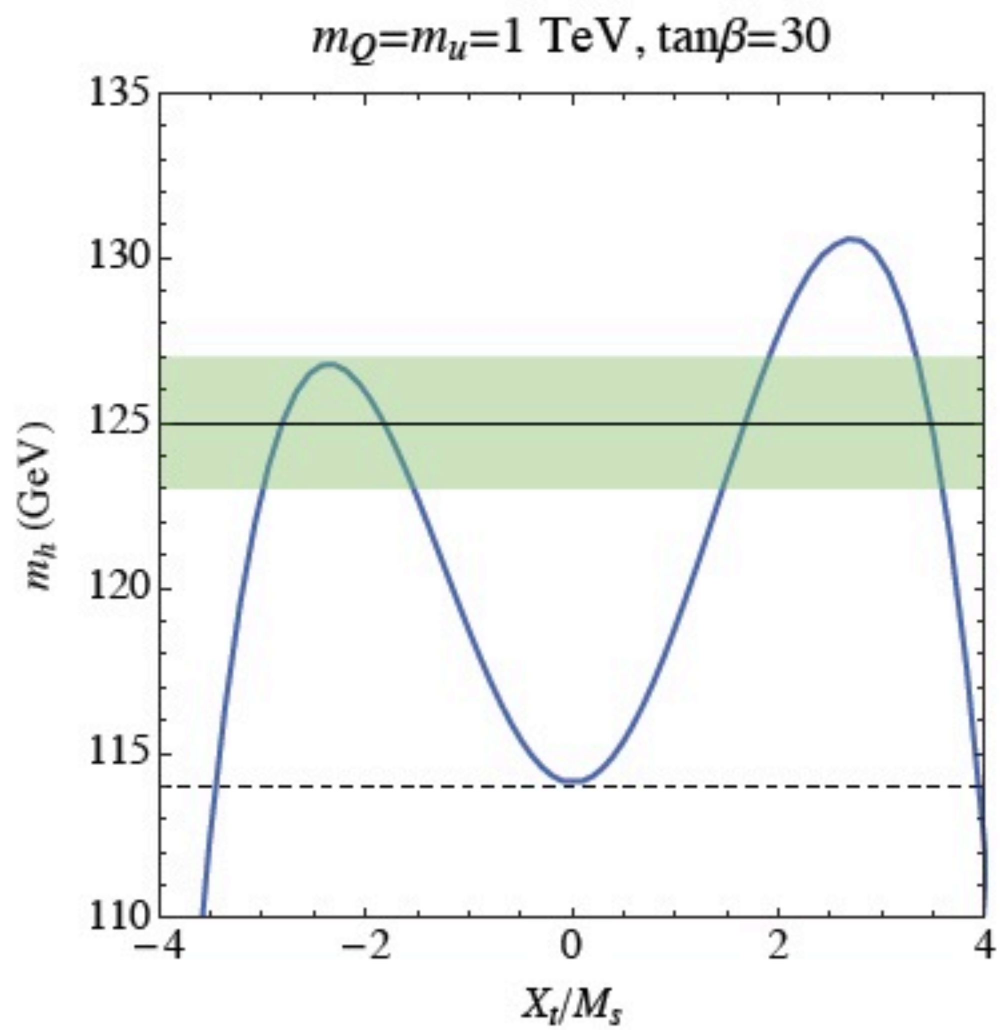
- SUSY
- Little Higgs/composite Higgs
- New dimensions
- low quantum gravity scale

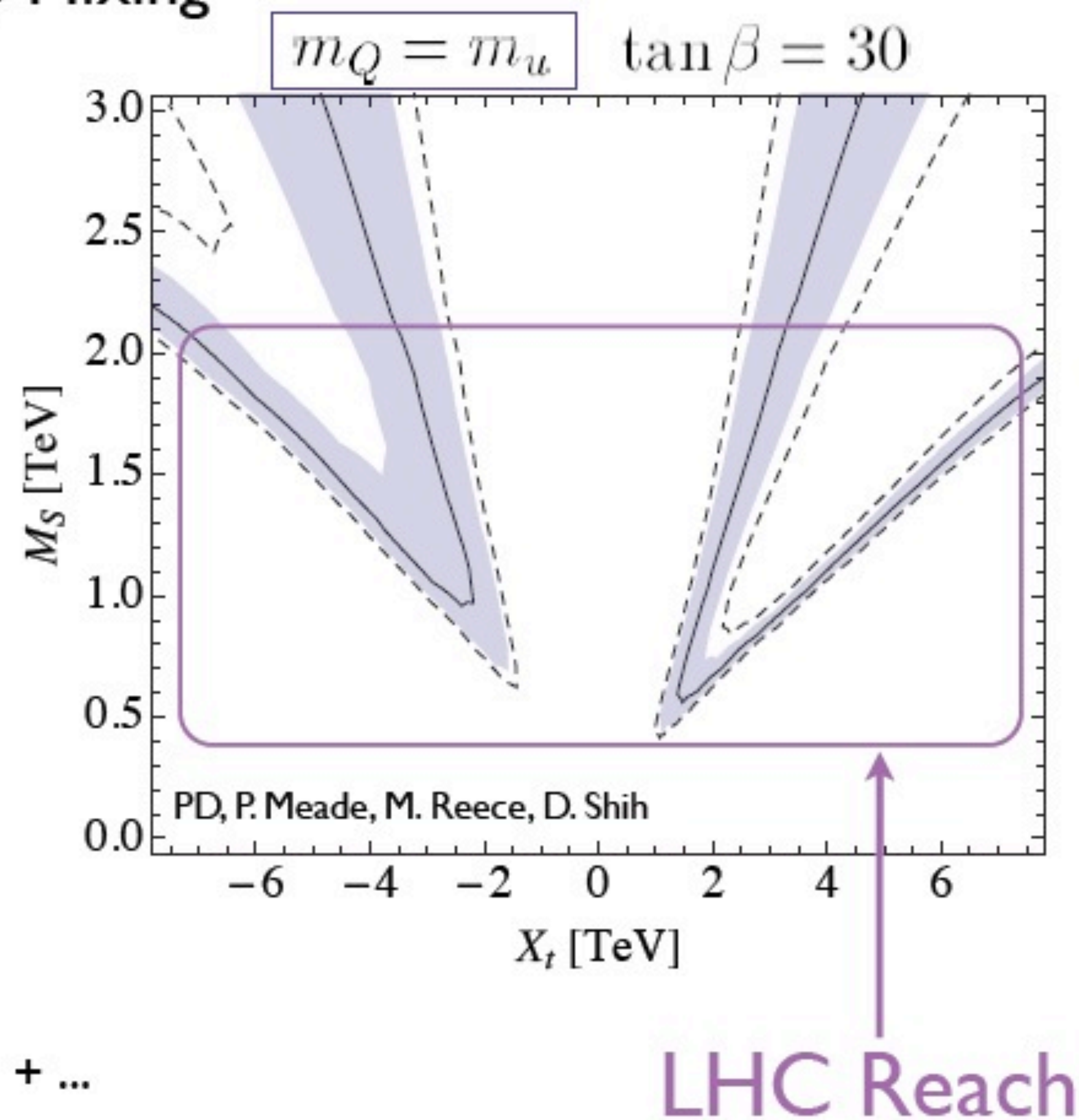


MSSM

P.Draper

Stop Mixing





$$m_h^2 = m_h^{2,\text{tree}} + \frac{3}{4\pi^2}\frac{\overline{m}_t^4}{v^2}\left\{t + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12M_S^2}\right)\right. \quad + \ldots$$

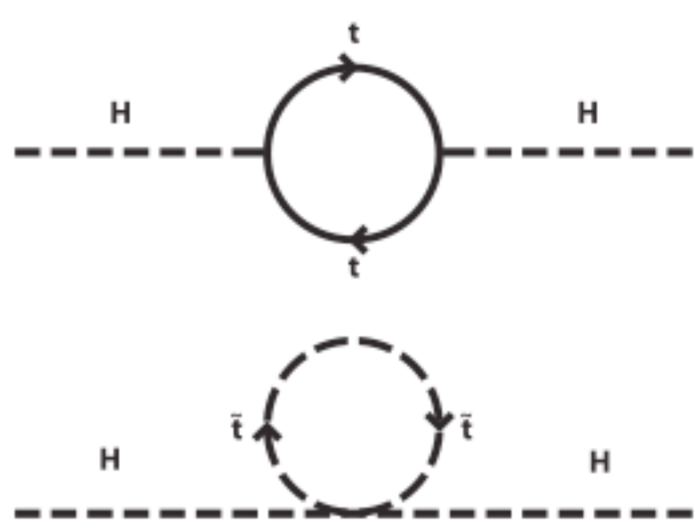
$\frac{X_t}{M_S} \approx -3, \ -1.7, \ 1.5, \ \text{or} \ 3.5$ $\qquad |X_t| \gtrsim 1000$ GeV, $\qquad M_S \gtrsim 500$ GeV

strongest direct-search limit on stop/sbottom is $M_{3rd\ gen}$ > 6-700 GeV
stronger limit if produced in gluino decays; M_{gluino} > 1.2 TeV
1st/2nd gen masses may or may not be tied to 3rd gen masses; $M_{1st\ gen}$ > 700 GeV if gluino decoupled

light stop?

- Electroweak baryogenesis in MSSM predicts light right handed stop (lighter than top!)
- NMSSM allows stops to be light with Higgs at 126
- ‘natural’ and motivated to have stop be only light squark or slepton

➡ only scalar with large coupling to Higgs



Conclusions

RPV *Angelo Monteux*

- The LHC constraints on R-parity conserving SUSY are not too far from excluding low-energy supersymmetry.
- It is reasonable to expect that what decides the hierarchical flavor structure of the SM also fixes the RPV structure. E.g. a horizontal symmetry fixes the RPV textures (*without anomaly constraints*)
- while leptonic RPV has clear signatures and excludes superpartners above 1 TeV, baryonic RPV could still be hiding.
- There is still space for low energy RPV SUSY. Horizontal symmetries predict that the biggest RPV coupling is

$$\lambda''_{323}\bar{t}\bar{b}\bar{s}$$

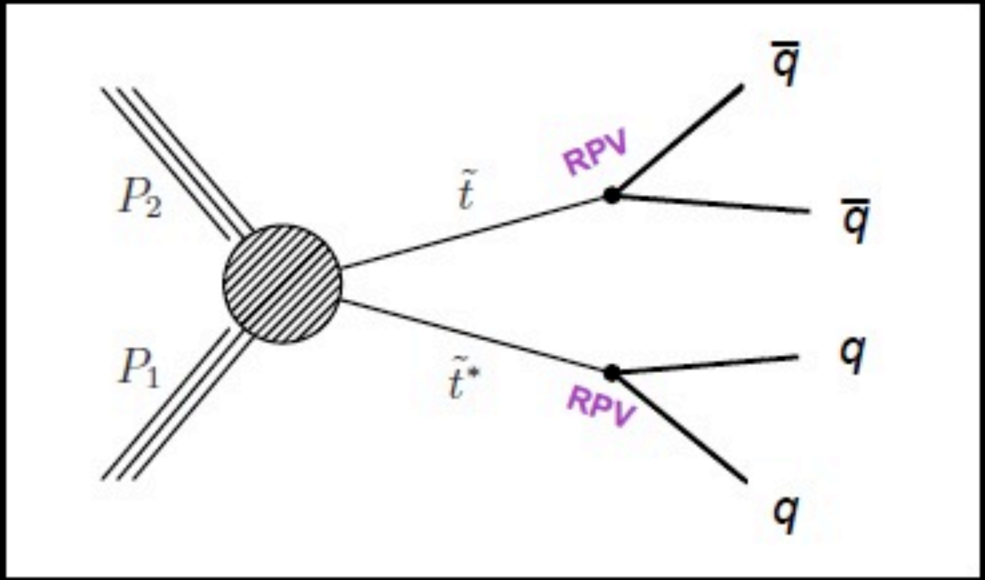
with $$10^{-9} < \lambda''_{323} < 10^{-2}$$

$\not{E}_T$, R-hadrons searches → 10^{-9}

low energy ΔB processes → 10^{-2}

Baryon # Violating Decay

Brock Tweedie



- Baryonic R-parity violation
  - $\lambda''_{3ij}\, \tilde{t}_R\, d_R^i\, d_R^j \quad (i \neq j)$
- 100% decays to 2 down-type quarks
  - prompt if $\lambda'' > 10^{-7}$
  - MFV: 96% contain bottom
- Direct pair production ⇒ fully jetty final-state
  - no handles like leptons or MET

* LNV decays also being explored. See e.g. Evans & Kats (1209.0764)

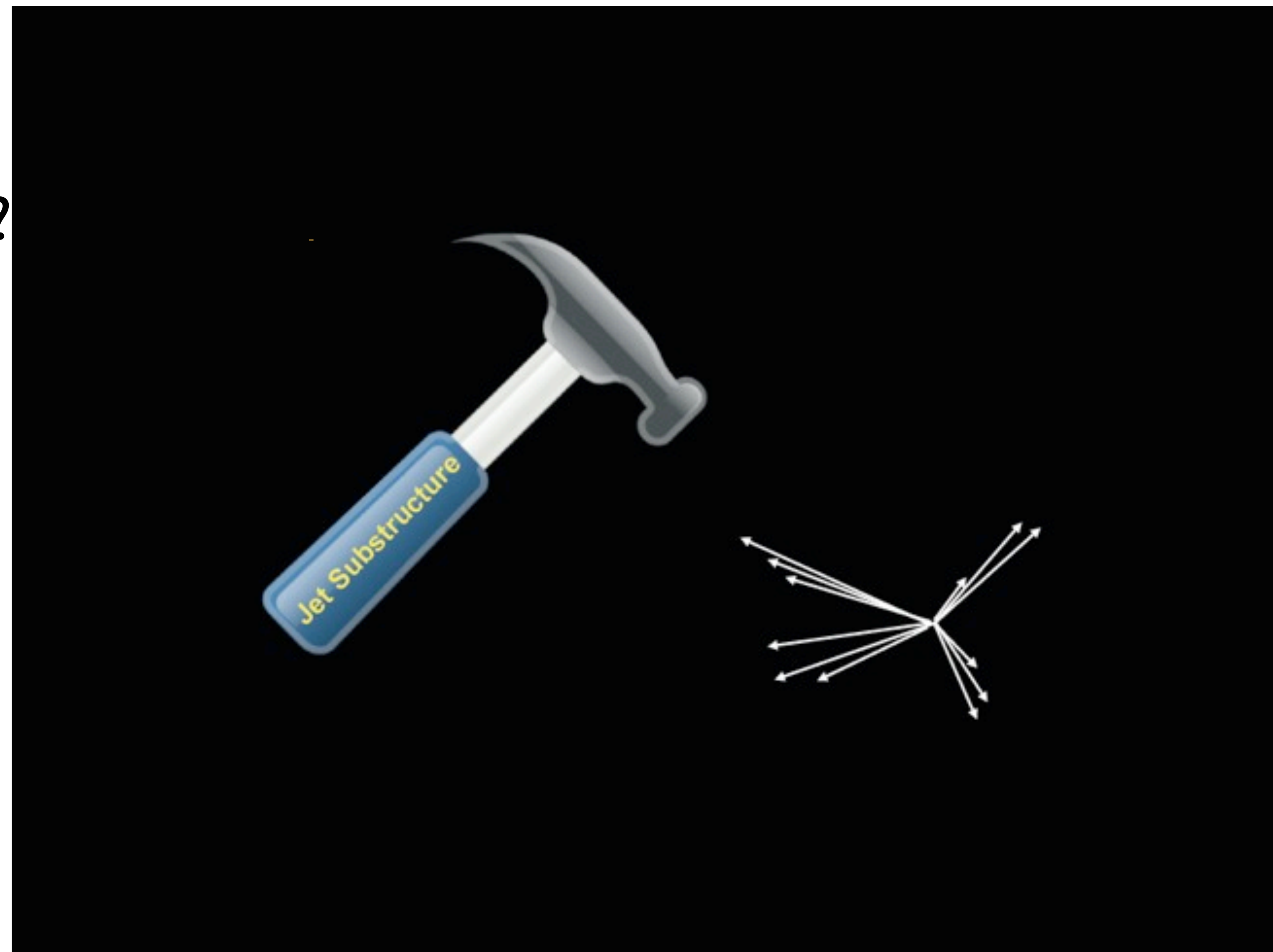
Using jet substructure

Brock
Tweedie

High p_T "boosted" signal

SUSY hiding in plain sight?

analysis which can be done now with exclusion sensitivity to ~300 GeV!

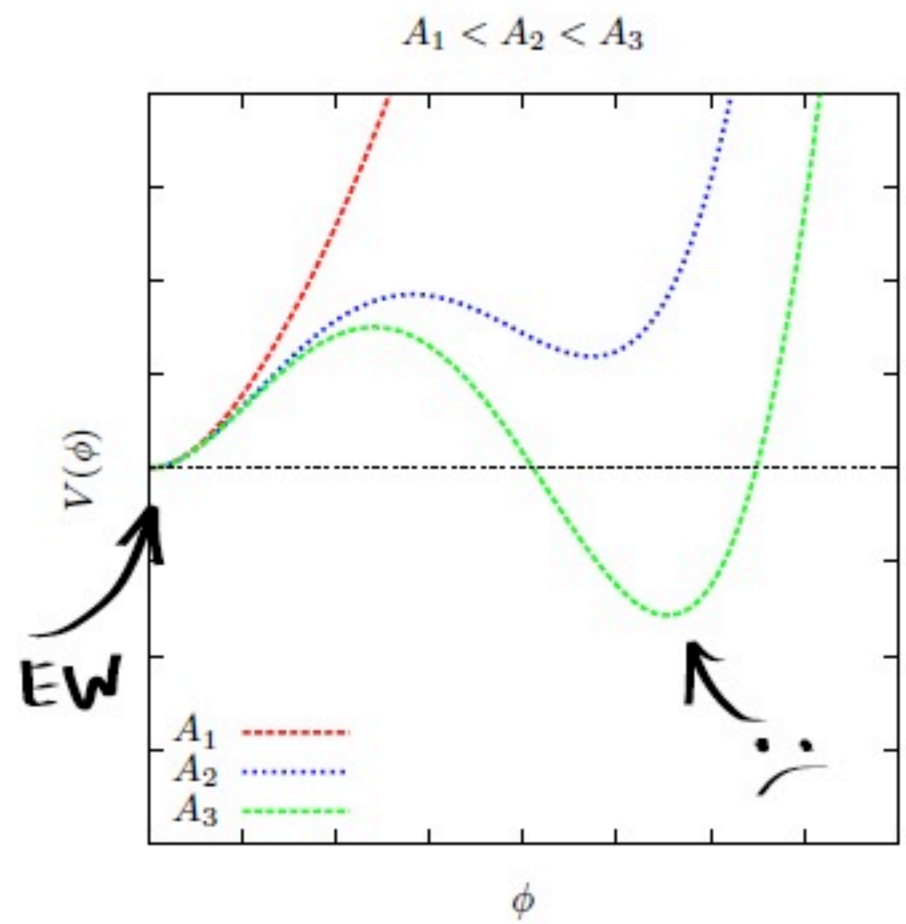


theoretical constraints on light stop/large mixing

Blinov/Morrissey

Supersymmetry and Stability

- Supersymmetry is good: naturalness, gauge unification, dark matter
- SM fermions have charged and colored scalar partners ⇒ more complicated scalar potential
- Quantum tunneling can destabilize the electroweak vacuum

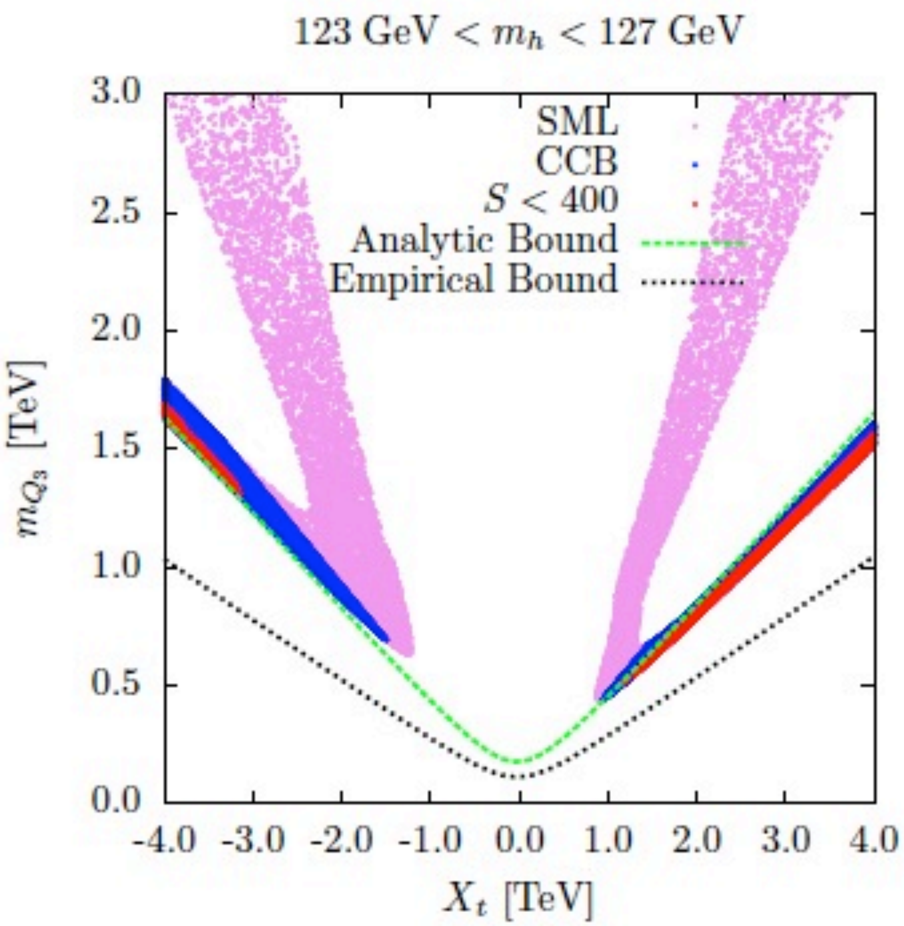


possible true ground state has color and charge breaking

new results including more reliable numerics, loop corrections... *Blinov/Morrissey*

Preliminary Results - Higgs

- • - SM absolutely stable, • - SM metastable, • - SM unstable
- CCB minima appear for $|X_t| \gtrsim 1$ TeV
- Most CCB points $X_t \gtrsim 1$ TeV not metastable ⇒ excluded



Electroweak Baryogenesis

Cohen, Morrissey, Pierce

- new colored scalar (stop?) coupled to Higgs can make phase transition strongly enough 1st order for electroweak baryogenesis
- The viable regions of parameter space lead to changes in the Higgs gluon fusion rate and branching ratio to di-photons ofO(50%) or more with respect the standard model values.

•This statement applies to the MSSM in the baryogenesis window

Flavor (and CP)

FLAVOR PHYSICS – THEORETICAL ISSUES 1/15

J. Rosner – DPF 2013, UC Santa Cruz – August 15, 2013

Masses and mixings of quarks and leptons – pattern?

- Status of mixings
- Apparent suppression of new flavor-changing effects
- New measurements of CP violation in heavy quark decays

Present and proposed measurements to advance that goal

- Forthcoming $g-2$ measurements
- Forthcoming $\mu \to e$ conversion and $\mu \to e\gamma$ searches
- What do we expect to learn from electric dipole moments?

The elephant in the room: Dark Matter

- We know it exists (galaxies, clusters, structure, Bullet Cluster, ...)
- Five times as much of it as ordinary matter
- Like trying to guess the structure of the periodic table knowing only Li, Be, and their relatives

Flavor Changing Neutral Currents

- generic argument that new physics scale > 10000 TeV
- "Minimal Flavor Violation" Assume new physics at TeV scale respects same approximate symmetries and has same symmetry breaking pattern as SM
- Frogatt-Nielsen U(1) symmetries: e.g. in SUSY can enforce quark-squark alignment, produce phenomenologically viable/interesting patterns of flavor violation
- Little Flavor: large approximate symmetries of Little Higgs theories kill generic argument

Generic argument

Some allowed dim 6 FCNC operators:

$$\frac{c_{sd}}{\Lambda^2}\left(\bar{s}\gamma_\mu d\right)^2 \qquad \frac{c_{uc}}{\Lambda^2}\left(\bar{u}\gamma_\mu c\right)^2 \qquad \frac{c_{bd}}{\Lambda^2}\left(\bar{b}\gamma_\mu d\right)^2$$

- $\mathrm{Im}[c_{sd}] = O(1) \Rightarrow \Lambda > O(10^4)$ TeV... $10^5 \times M_Z$!
- $\mathrm{Re}[c_{sd}] = O(1) \Rightarrow \Lambda > O(10^3)$ TeV
- $c_{uc} = O(1) \Rightarrow \Lambda > O(10^3)$ TeV
- $c_{bd} = O(1) \Rightarrow \Lambda > O(10^2)$ TeV

Focus on Top

- top fcnc motivated by flavor models, and naturalness
- just getting started
- fcnc in charge ⅔ quark sector?
  - CPV in $D \rightarrow KK, \pi\pi$ could be BSM?

up sector minimal flavor violation

(Bai, Berger, Hewett, Li)

The Punchline

- New model possible with extremely light (< 100 GeV) new states
- Gives novel signatures in top production and decay
- Could explain D-meson CP violation

The Model

(Bai, Berger, Hewett, Li)

- New gauge-neutral particle w/ flavor charge
- Can be as light as 10 GeV
- Couples only to quarks w/ FV suppressed by Yukawas + CKM
- Several flavor charges allowed

lots to do!

(Bai, Berger, Hewett, Li)

- single top
- corections to top cross section
- rare top decays to new particle

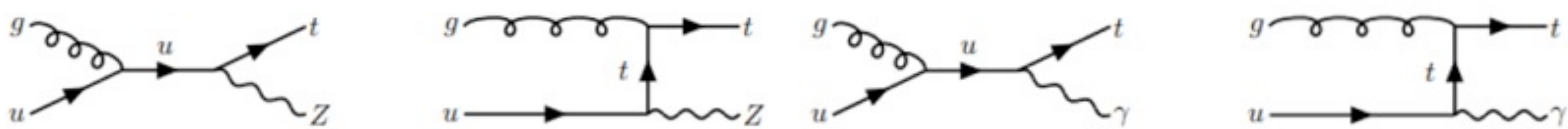
Testing top FCNC at LHC

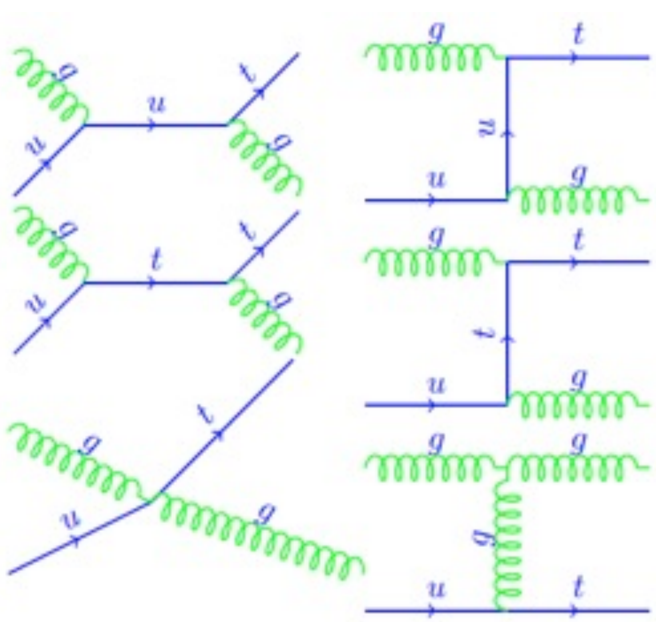
Martin and Kidonakis

Effective Lagrangians

Effective Lagrangians

$$\Delta\mathcal{L}_1 = \frac{1}{\Lambda} e \kappa_{tqV} \bar{t} \sigma_{\mu\nu} F_V^{\mu\nu} + h.c., \quad \Delta\mathcal{L}_2 = \frac{g_s \kappa_{qgt}}{\Lambda} \bar{t} \sigma^{\mu\nu} T^a \chi q G^a_{\mu\nu} + h.c.$$





- We presented NNLO-NLL calculations for $pp \to tZ$ and $pp \to t\gamma$ at 7, 8, and 14 TeV
- We find that the corrections at NLO are large, mostly between 25% & 37%; NNLO corrections were on the order of $\sim$ few%
- And scale dependence is only minimally improved by NLO, but is less pronounced at higher energies; NNLO scale dependence is bad at low scale factors, but evens out for around m and above.
- Our immediate next step will be the completion of the $gu \to tg$ cross section
- Afterwards? TBD

Little Flavor/Little Higgs

How Little Higgs models work:

(Arkani-Hamed, Cohen, Georgi (2001); Arkani-Hamed, Cohen, Katz, Nelson (2002))

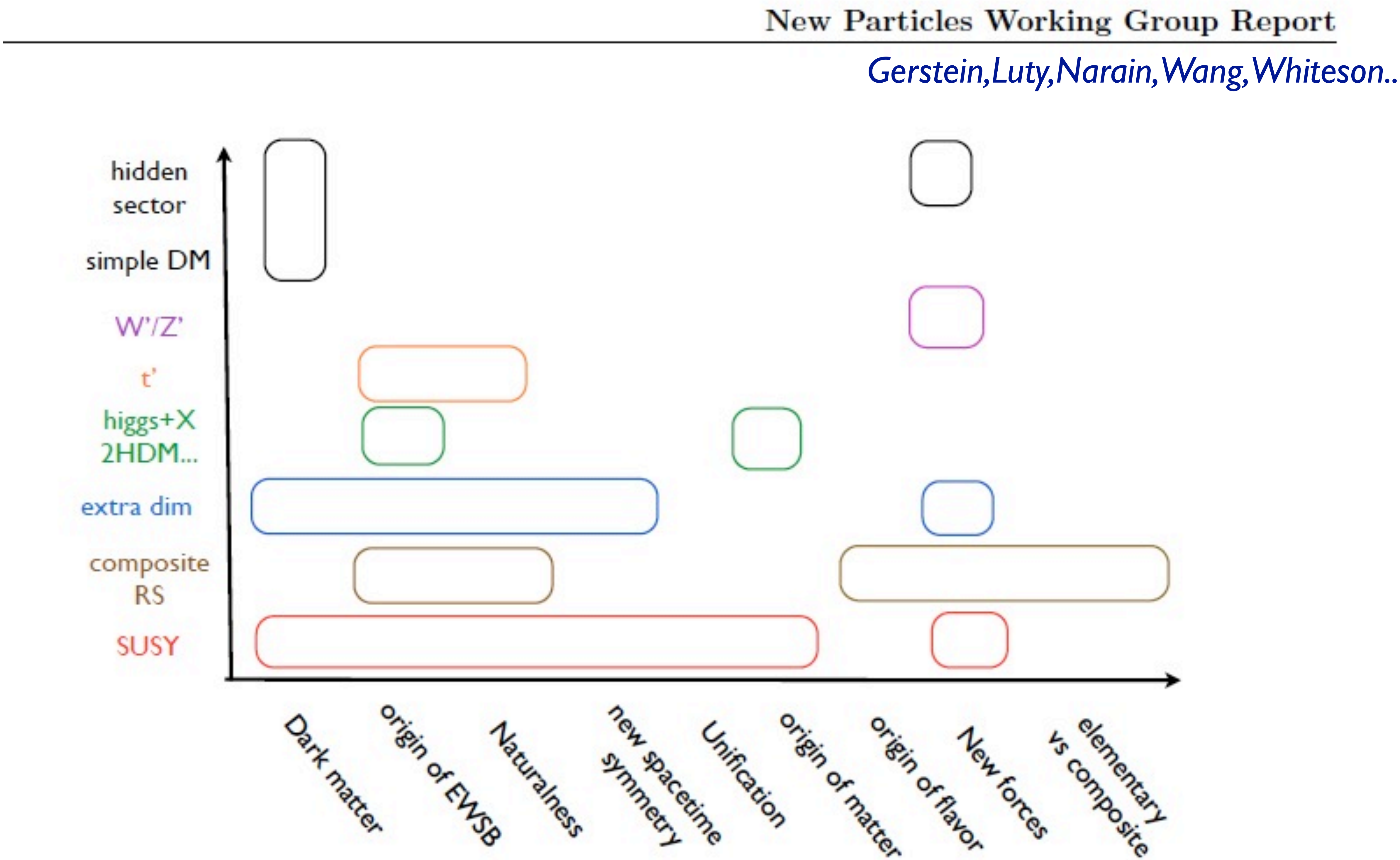
- Start with Higgs as a Goldstone boson of G/H, with scale f; $h \to h+f$ forbids Higgs potential (Kaplan, Georgi, 1984)
- Include "sparse" spurions $\varepsilon_{1,2}$ which break $G \Rightarrow G_{1,2}$, two different subgroups of G
- Both $G_{1,2}$ individually retain an exact shift symmetry for the Higgs, $h \to h+f$, but the $\varepsilon_{1,2}$ spurions break it when both are combined
- Higgs potential starts at order $m^2 \propto \varepsilon_1 x\, \varepsilon_2 f^2$, typically at 2-loops for extra $1/(4\pi)^4$...so Higgs is much lighter ("littler") compared to scale of new physics f than naive naturalness estimates
- New physics can start at the few TeV scale
- New top partner at ~ 1 TeV to cancels quadratic contribution to Higgs mass^2

“Little Flavor”: use LH ingredients for flavor

Kaplan, A.N., Sun

- Little Higgs theories have large approximate global symmetries
- Same approximate symmetry that protects Higgs mass in Little Higgs theories forbids fermion masses
- sparse pattern of spurions
  - fermion masses
  - higgs potential
  - suppression of FCNC with flavor at TeV

From Snowmass



Conclusions

- Congratulations to the LHC experiments!