HIGGS IN BOSONIC TECHNICOLOR

JURE ZUPAN
U. OF CINCINNATI

based on A. Kagan, A. Martin, P. Uttayarat, S. J. Lee, JZ, 150m.nnnnn

Portoroz 2015: Particle Phenomenology From the Early Universe to High Energy Colliders

OUTLINE

disclaimer: heavily borrowed from A. Kagan's talk at Naturalness 2014

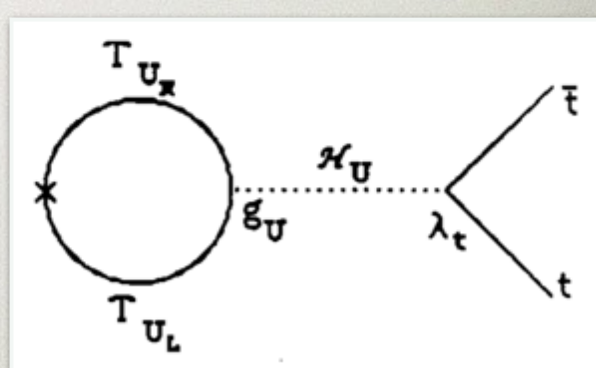
- bosonic technicolor
- higgs phenomenology in BTC
- electroweak precision tests, resonance searches,…

BOSONIC TECHNICOLOR

- Bosonic TC= SUSY+Technicolor

Dine, Kagan, Samuel, 1990

  - TC condensates trigger EW symmetry breaking
  - H_u, H_d from MSSM give masses to quarks and leptons
  - SUSY stabilizes scalar Higgs mass
  - Higgs vevs from couplings to TC condensates



$$\lambda_U \bar{U}_R T_L H_u + \lambda_D \bar{D}_R T_L H_d \Longrightarrow$$

$$\langle H_u \rangle \sim \lambda_U \frac{\langle \bar{U}_R U_L \rangle}{m^2_{H_u}}$$

$$\langle H_d \rangle \sim \lambda_D \frac{\langle \bar{D}_R D_L \rangle}{m^2_{H_d}}$$

  - Higgs mass params. taken positive $m^2_{H_u}, m^2_{H_d} > 0$
  - $\Rightarrow$ no EW symmetry breaking without TC

EW BREAKING IN BTC

- W, Z masses receive contribs from both TC condensates and the H_u, H_d vevs

$$v_W^2 = (246\ \mathrm{GeV})^2 \approx f_{\mathrm{TC}}^2 + f_u^2 + f_d^2 \qquad \langle H_{u,d}\rangle \equiv f_{u,d}/\sqrt{2}$$

  - this breaks direct correlation between m_Z and m_h
  - unlike MSSM $m_h > m_Z$ possible, in fact is generic
- perturbative top Yukawa requires

$$v_W^2 \approx f_u^2 + f_d^2 \gg f_{\mathrm{TC}}^2, \quad \text{e.g. } f_{\mathrm{TC}} \lesssim 100\ \mathrm{GeV}$$

  - bulk of W,Z mass comes from Higgs vev

Kagan, KITP08;
Azatov, Galloway, Luty, 1106.3346, 1106.4815

- but TC triggers EW symmetry breaking
  - the MSSM Higgs potential assumed not to break EW symmetry by itself

$$m_{H_u}^2 m_{H_d}^2 > (B\mu)^2, \qquad m_{H_u}^2 + m_{H_d}^2 > 0$$

MINIMAL BTC

- minimal BTC= MSSM+SU(2)$_{TC}$ techni-fermion fields

$$\hat{T}_L(2_{\rm TC}, 1_C, 2_L, 0), \quad \hat{U}_R(2_{\rm TC}, 1_C, 1_L, -1/2), \quad \hat{D}_R(2_{\rm TC}, 1_C, 1_L, +1/2),$$

- Yukawa superpotential couples TC and MSSM

$$W_{\rm Y} = \lambda_U \hat{U}_R \hat{T}_L \hat{H}_u + \lambda_D \hat{D}_R \hat{T}_L \hat{H}_d$$

- technigluino, technisquarks acquire masses > Λ_{TC}
- at lower energies only techni-fermions
  - acquire masses from the Higgs vev

$$m_U = \lambda_U f_u/\sqrt{2}, \qquad m_D = \lambda_D f_d/\sqrt{2}.$$

for future reference define also:

$$\hat{m} = \frac{m_U + m_D}{2}$$

- QCD-like TC theory at low energies
  - can use chiral perturbation theory+experimental+lattice knowledge of nonperturbative QCD

LOW ENG LAGRANGIAN

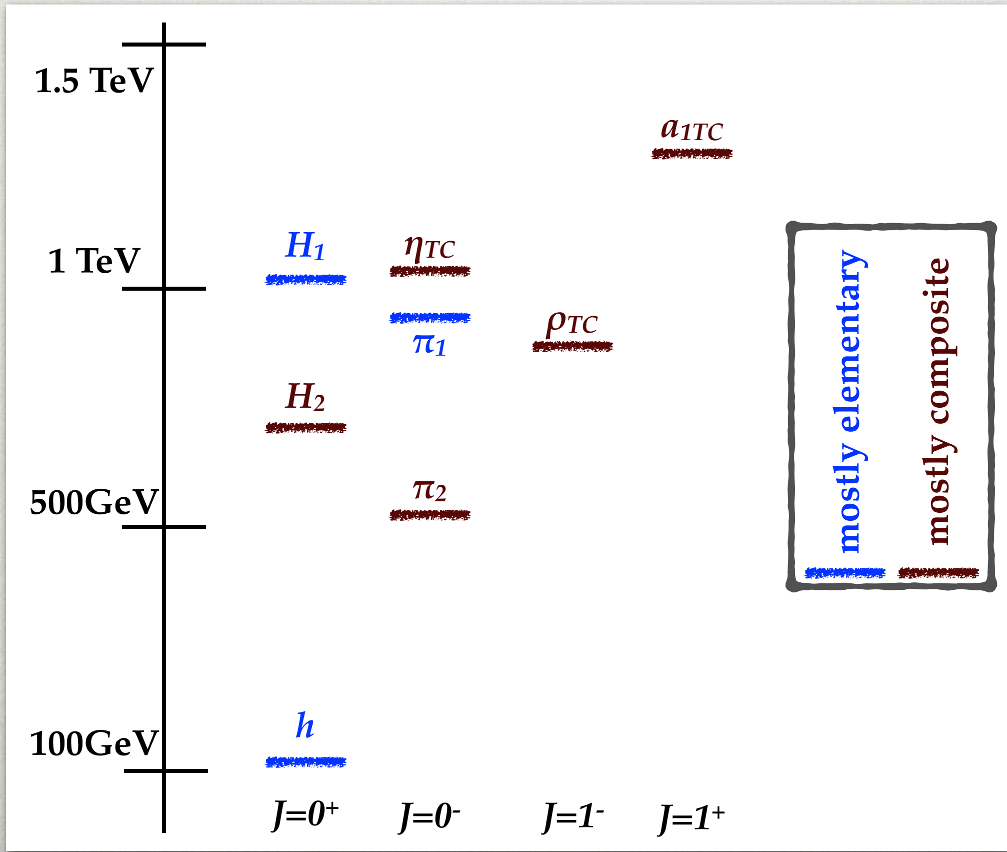
- in the limit $\lambda_{D,U} \to 0$ TC sector has SU(4) global symmetry
  - $(\bar{U}_R{}^C, \bar{D}_R{}^C, U_L, D_L)$ form fund. repres.
  - $\langle \bar{U}_R U_L \rangle$, $\langle \bar{D}_R D_L \rangle$ break $SU(4) \to Sp(4)$
- 5 pseudo Nambu Goldstone bosons
  - 2 "baryonic" states π_{UD}, $\pi_{\bar{U}\bar{D}}$, potential dark matter candidates
  - 3 usual pions from $SU(2)_L \times SU(2)_R \to SU(2)_V$
    - these are relevant for Higgs phenomenology, suffice to consider this subgroup
    - can describe their interactions using the usual ChPT

LOW ENG STATES

- in addition there are MSSM Higgs sector fields
- we also include σ_{TC}, the $\bar{T}T$ bound state
  - unlike in QCD this is a narrow state
  - $\sigma_{TC} \to \pi_{TC}\pi_{TC}$ channel not kinem. allowed
- for Higgs sector we have 9 physical states $m_i \ll \Lambda_{TC}$
  - one light Higgs, h, two heavy Higgses, $H_{1,2}$
  - two charged pions $\pi_1^{\pm}$, $\pi_2^{\pm}$
  - two neutral pions π_1^{0}, π_2^{0}
- in addition TC resonances with $m_i \sim \Lambda_{TC}$
  - η_{TC}, ρ_{TC}, a_{1TC},...

TYPICAL SPECTRUM

- a typical spectrum



SCAN

- rescale QCD ChPT constants to TC scale
  - use latticeQCD, include N_C rescaling 3→2 ETM 0911.5061
  - gluonic content of η_{TC} from data on η-η′ mixing Kroll, hep-ph/0409141
- scan over TC parameters and compare to Higgs data

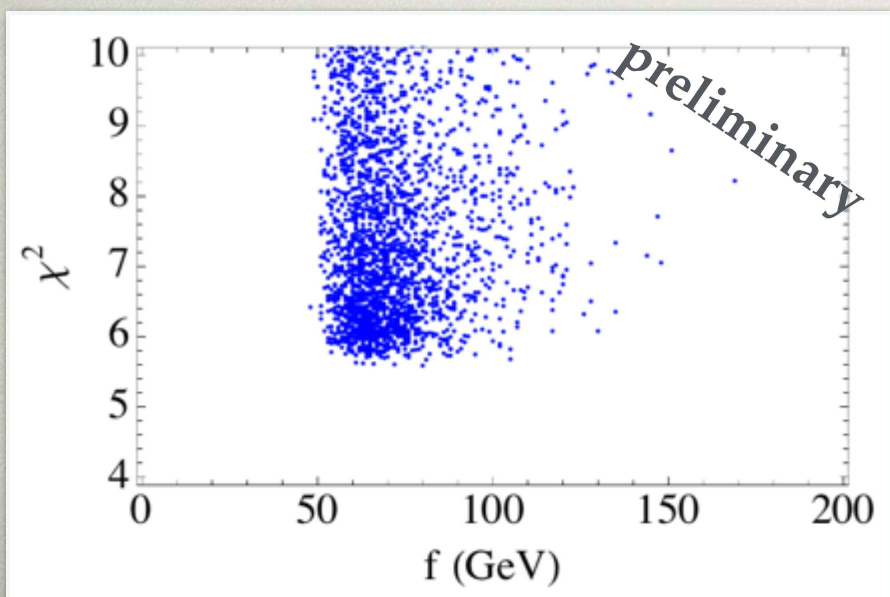
$$f \in [50, 170]\ \text{GeV} \qquad \frac{\hat{m}}{f} \in [0.2, 4],$$

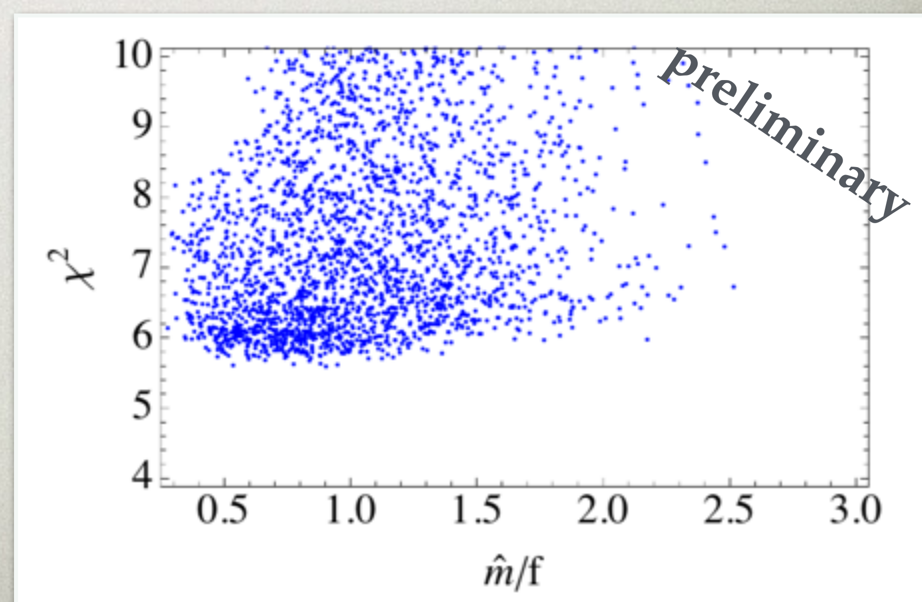
$$\tan\beta \in [1/3, 3], \qquad \lambda_u \in \pm[1/3, 4],$$

  - rescale ρ, a_1 masses from QCD
  - vary $m_{\sigma TC}^2 \in [0.4, 1.4] m_{\rho TC}^2$
  - derived λ_D need to be pert., $\lambda_D \leq 4$
  - in addition vary a set of constants that parametrize p^4 and higher effects, and errors in extrapolations

SCAN

- the minimal χ^2: for SM $(\chi^2)_{min}$=5.6, for BTC $(\chi^2)_{min}$=5.8
- we show points within 1σ coverage probability for estimating 5 parameters (f_{TC}, $\hat{m}/f_{TC}$, tanβ, λ_U, $m_{\sigma TC}^2$)
  - i.e. demand $(\chi^2)<(\chi^2)_{min}+5.9$ (keeps ~72% of points)
- Note: $\hat{m}/f$ much bigger than in QCD
  - since $m_U \neq m_D \Rightarrow$ in TC also large isospin breaking





Higgs pheno I

- the light Higgs is a mixture of three states, elem. σ_u,σ_d, and composite σ_{TC}

$$h = \sum_i V_{hi}\sigma_i,$$

  - to some extent similar to 3 Higgs doublet model
  - the mixing satisfy $\sum_i V_{hi}^2 \approx 1$
    - the relation approximate due to kinetic mixing
- the Higgs coupling to fermions only to MSSM
  - universally rescaled for up(down)-quarks by

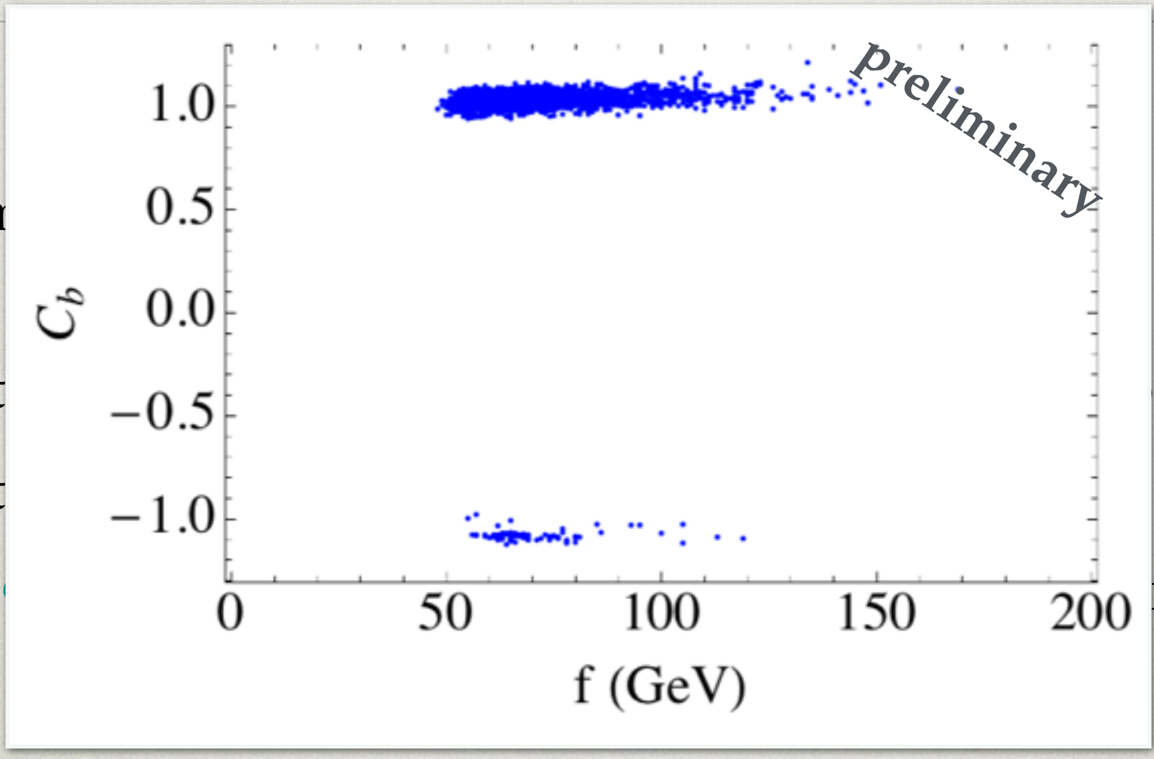
$$V_{h\sigma_u} Y_u \ (V_{h\sigma_d} Y_d)$$

  - in terms of global fit parameters

$$\kappa_b = \kappa_\tau \neq \kappa_t,$$

Higgs pheno I

- the . σ_u,σ_d, and com
  - t del
  - t
    - xing



- the
  - universally rescaled for up(down)-quarks by

$$V_{h\sigma_u} Y_u \; (V_{h\sigma_d} Y_d)$$

  - in terms of global fit parameters

$$\kappa_b = \kappa_\tau \neq \kappa_t,$$

Higgs pheno II

- Higgs coupling to *W,Z* similar to 3HDM

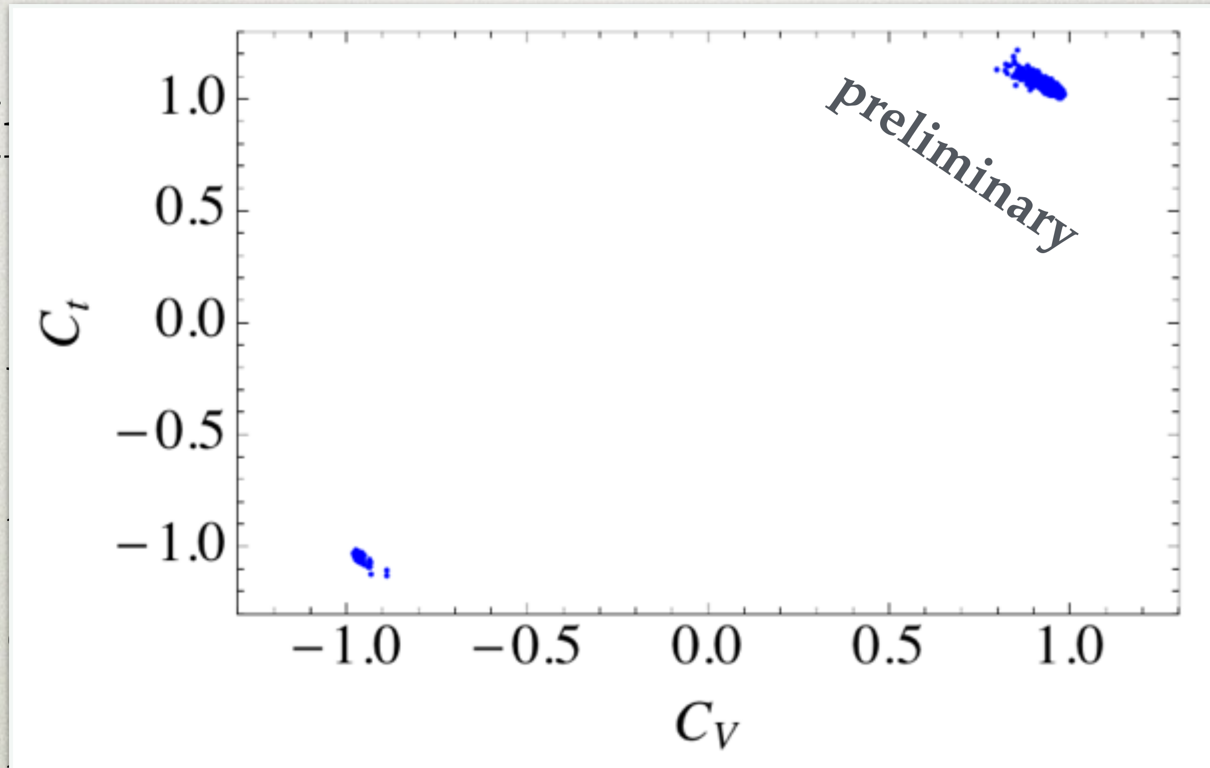
$$g_{h_i WW} \propto \langle h_i \rangle / v_W$$

  - were one to take $\langle \sigma_{TC} \rangle = f_{TC}$
  - the composite contrib. thus gets corrected at *O(1)*, the rest at $O(p^4)$
  - the couplings are custodially symmetric

$$\kappa_W = \kappa_Z .$$

Higgs pheno II

- H DM



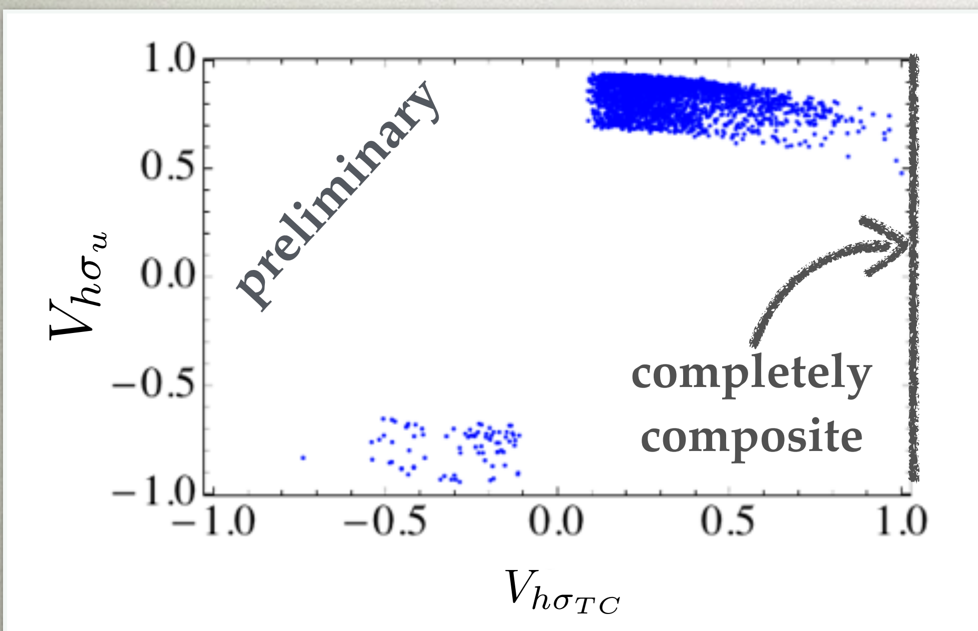
- the couplings are custodially symmetric

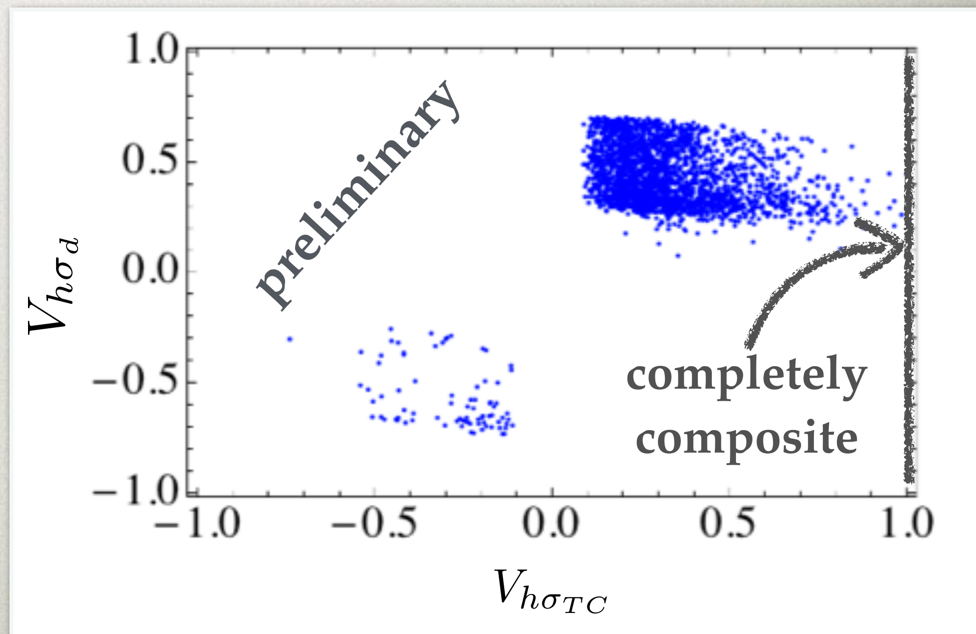
$$\kappa_W = \kappa_Z.$$

Higgs pheno III

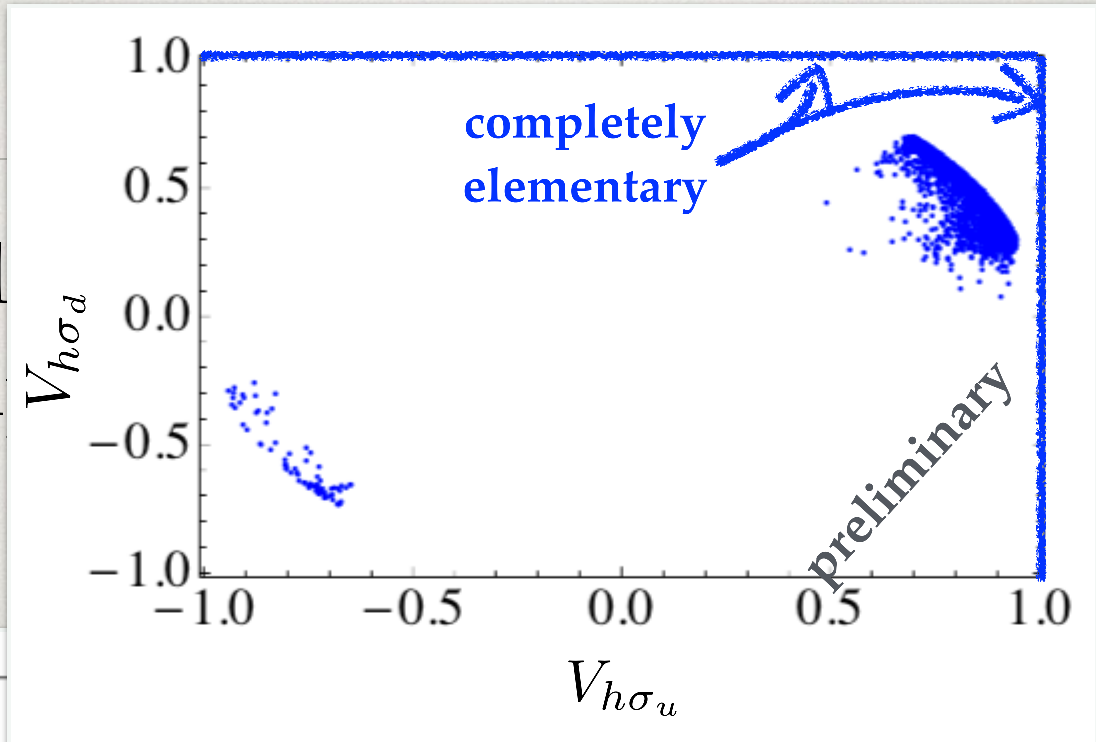
- the light Higgs can have sizeable composite component

$$h = V_{h\sigma_u}\sigma_u + V_{h\sigma_d}\sigma_d + V_{h\sigma_{TC}}\sigma_{TC}$$

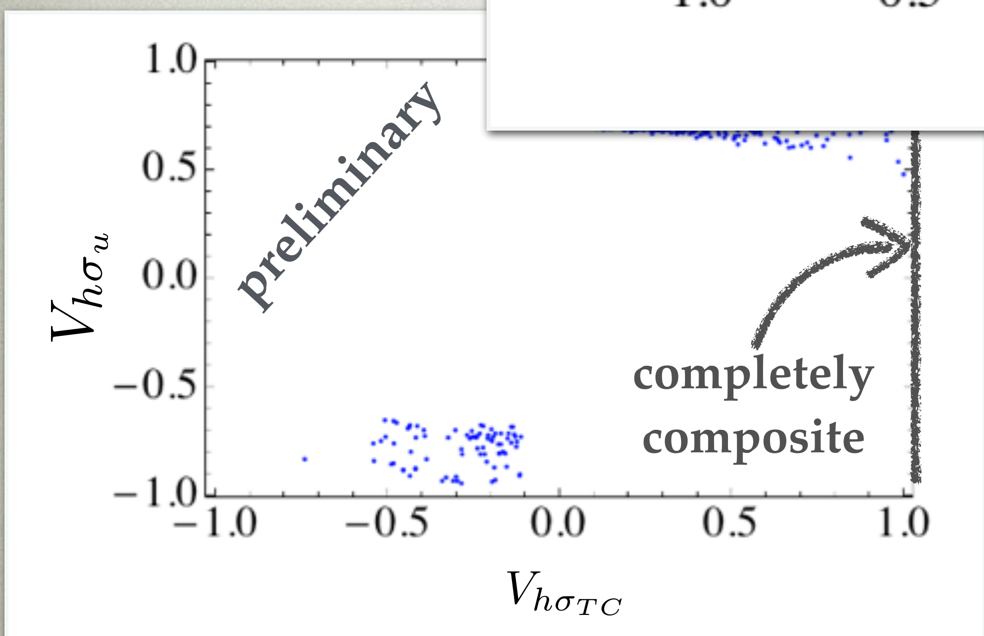




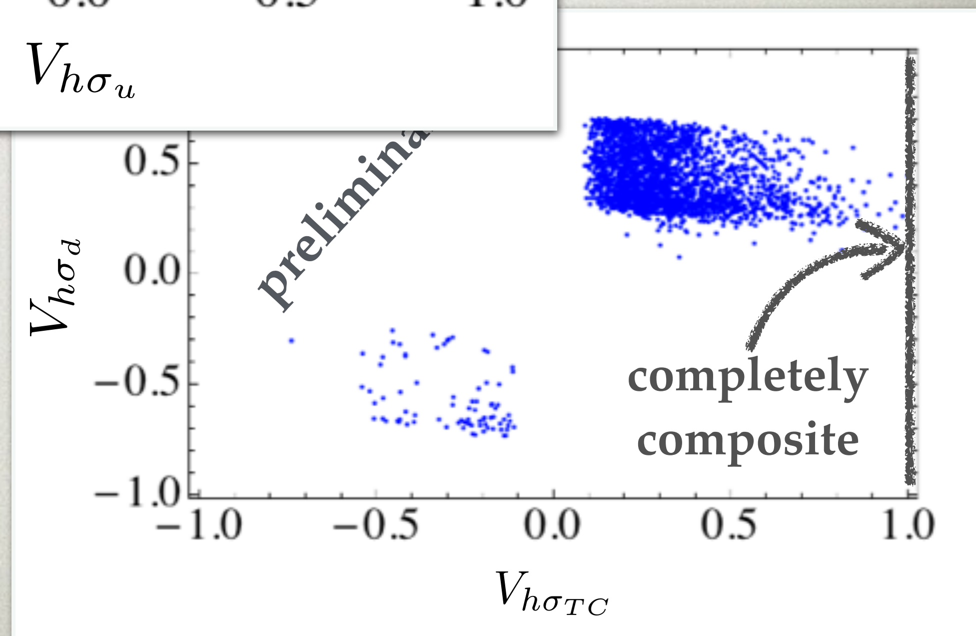
- the l…
com…



completely
elementary
preliminary
$V_{h\sigma_d}$
$V_{h\sigma_u}$



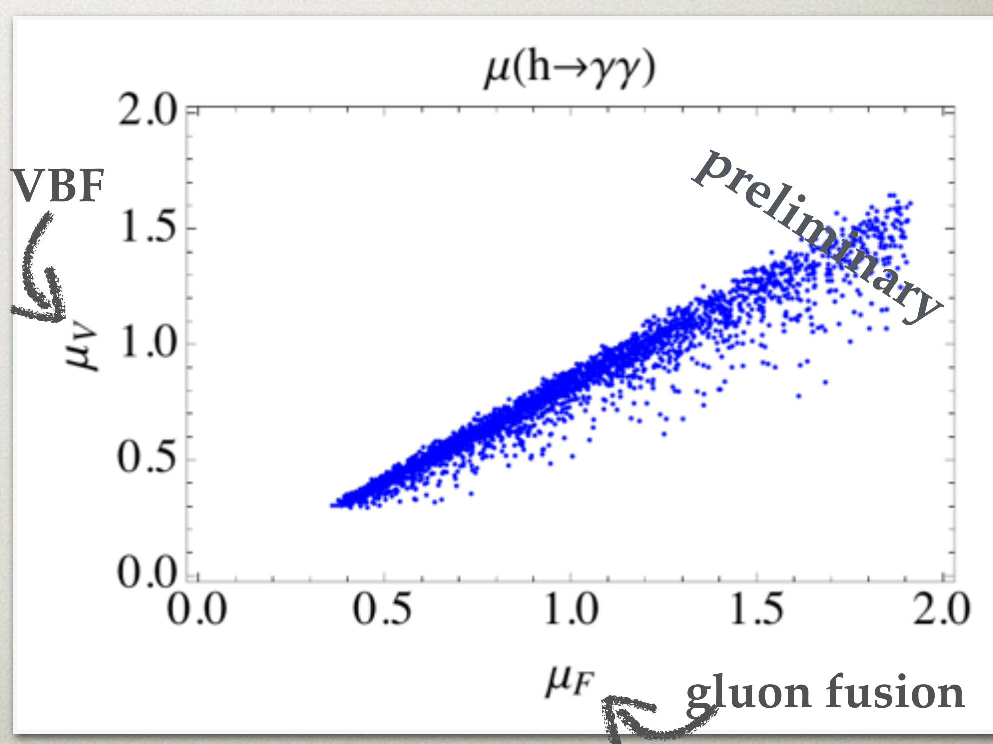
preliminary
completely
composite
$V_{h\sigma_u}$
$V_{h\sigma_{TC}}$



prelimina…
completely
composite
$V_{h\sigma_d}$
$V_{h\sigma_{TC}}$

Higgs pheno IV

- couplings to photons, $h\rightarrow\gamma\gamma$, not calculable
- use NDA to estimate it
- large deviations possible
  - comparable to present exp. errors

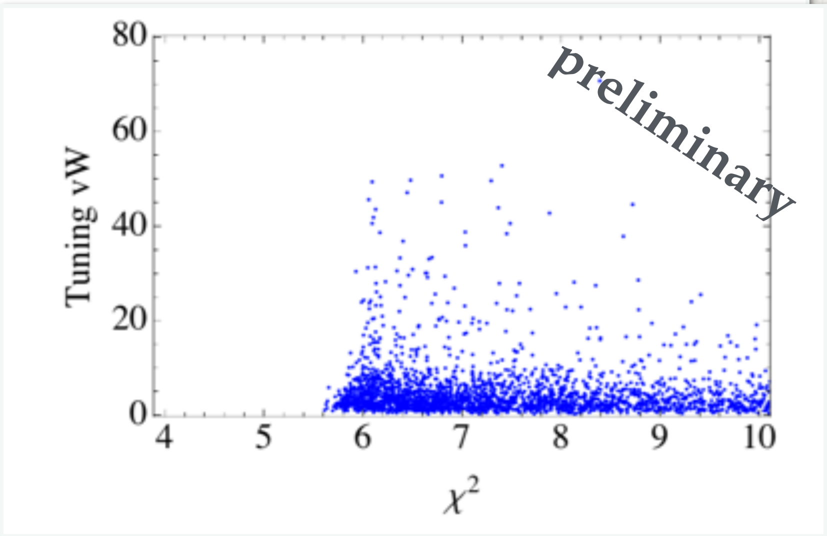


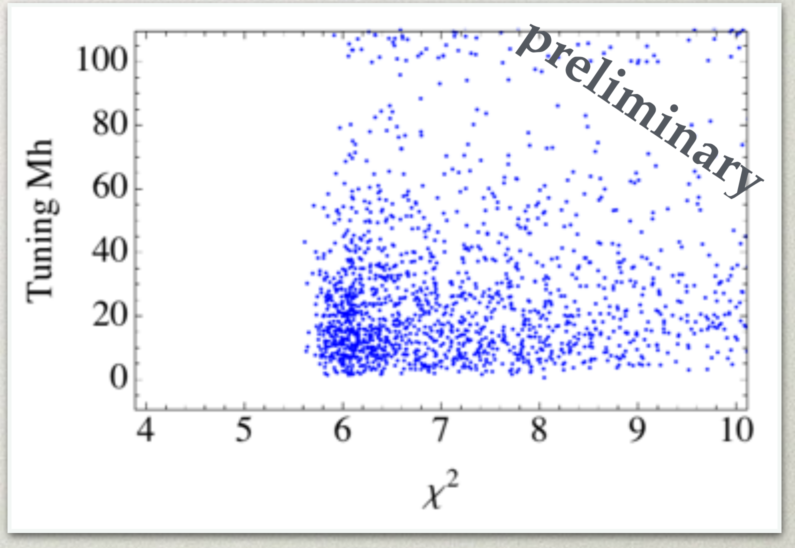
FINE-TUNING

- tuning from low energy scale perspective
- consider Barbieri-Giudice type measure

$$\text{tuning}_{v_W\ (m_h)} = \text{Max}\left[\frac{\partial \log v_W(m_h)}{\partial \log p_i}\right]$$

$p_i = f, \lambda_u, \lambda_d, m^2_{H_u}, m^2_{H_d}, B\mu, Z_i$ fudge factors



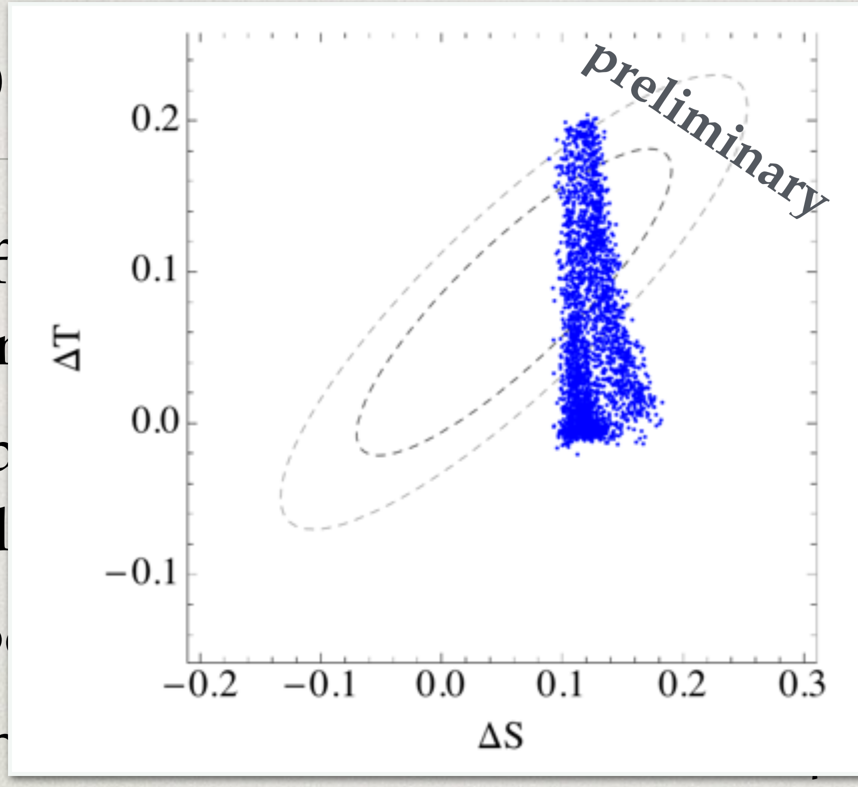


- no tuning in v_W
- moderate tuning ~$O(10)$ for m_h

OTHER CONSTRAINTS

- $b \to s\gamma$ from pion loop, mostly within one sigma of experiment
- contribs. to S, T at tree level from ρ_{TC}, a_{1TC}, at 1loop from (pseudo)scalars
  - important that away from chiral limit
    - increased cancellation between ρ_{TC}, a_{1TC}
- BTC: a technicolor example satisfying S and T at 1σ via QCD-like dynamics
  - no need to invoke unproven conjectures about exotic strong interactions, e.g., conformal or walking dynamics

O INTS



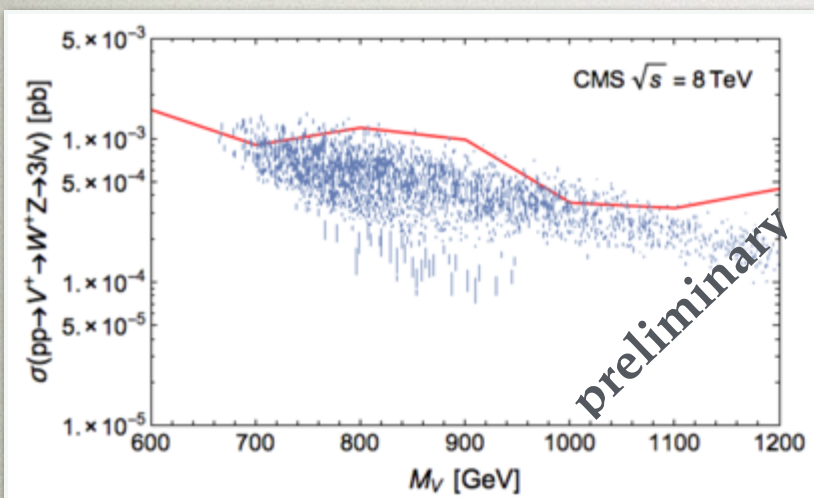
- $b \to s\gamma$ f ne sigma of experi
- contrib $_{1TC}$, at 1loop from (pseud
  - imp it
    - in $_{TC}$, a_{1TC}
- BTC: a technicolor example satisfying S and T at 1σ via QCD-like dynamics
  - no need to invoke unproven conjectures about exotic strong interactions, e.g., conformal or walking dynamics

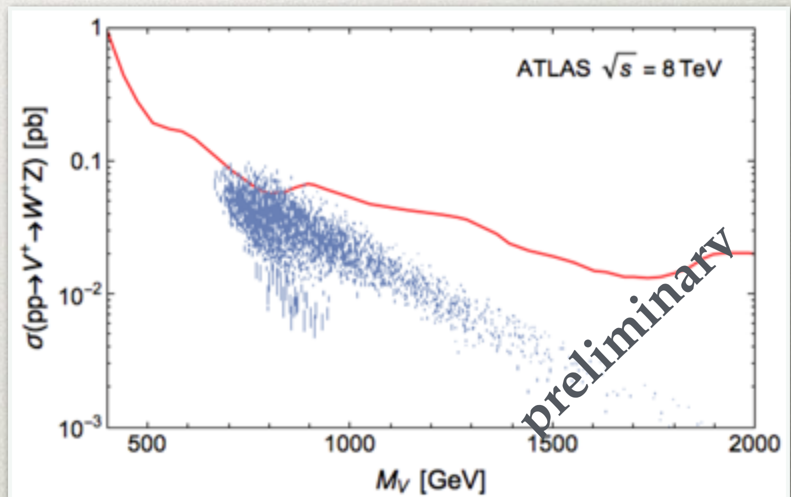
VECTOR PHENOMENOLOGY

- LHC bounds on vector resonances from Drell-Yan production

$$\sigma(pp \to \rho^\pm \to W^\pm Z)$$

  - CMS 19.6 fb−1 W′ → WZ trilepton search @ 8 TeV CMS PAS EXO-12-025
  - ATLAS 20 fb−1 W′ → W Z lljj search @ 8 TeV ATLAS, 1409.6190

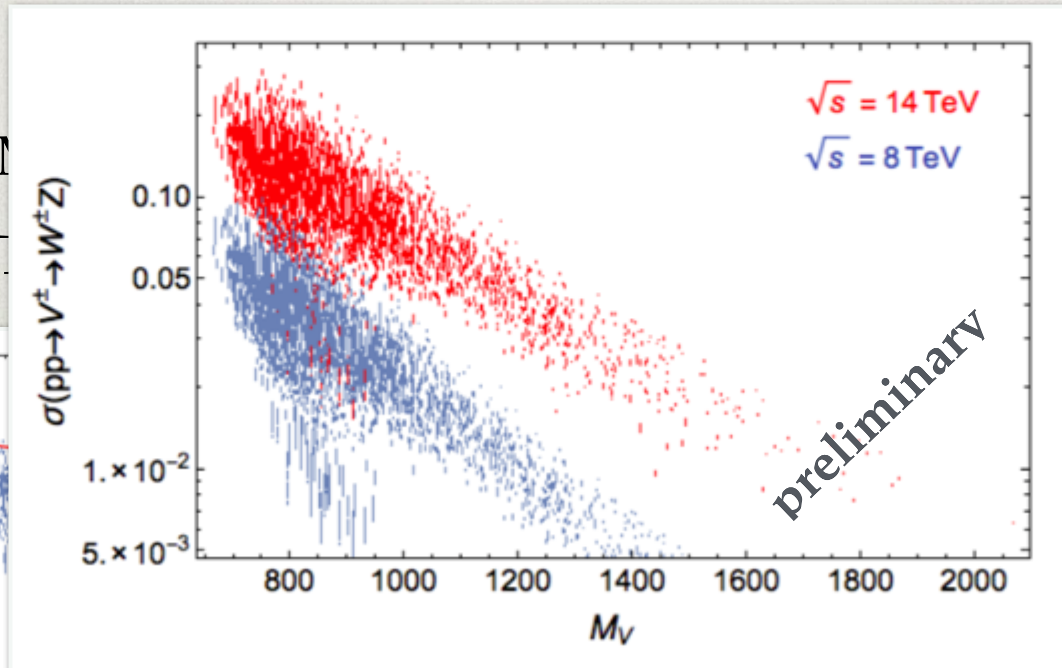


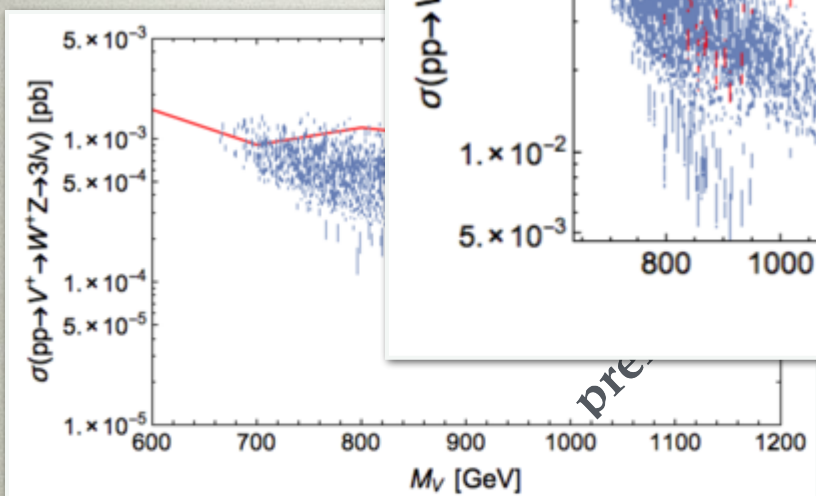


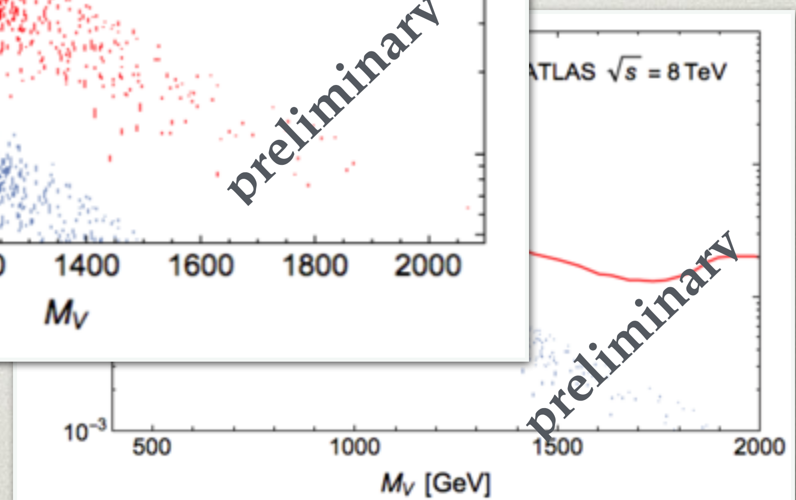
- the di-jet bounds evaded since $\rho_{TC} f\bar{f}$ coupl. « $\rho_{TC} WW$ coupl.
  - ⇒ $Br(\rho_{TC} \to jj) \ll Br(\rho_{TC} \to WW, WZ)$

VECTOR PHENOMENOLOGY

- LHC bounds on vector resonances from Drell-Yan production
    - CM... TeV CMS PAS EXO-12-025
    - AT... ATLAS, 1409.6190







- the di-jet bounds evaded since $\rho_{TC} f\bar{f}$ coupl. « $\rho_{TC} WW$ coupl.
    - $\Rightarrow Br(\rho_{TC} \to jj) \ll Br(\rho_{TC} \to WW, WZ)$

CONCLUSIONS

- covered low scale (f_{TC}~*70* GeV) minimal bosonic technicolor = MSSM+ SU(2) technicolor sector
- Higgs can have significant composite component and still be phenomenologically viable

BACKUP SLIDES

ISOSPIN BREAKING