# WIN'03 EWSB session

(Theoretical aspects)

What did we know?

What have we learned?

What hope is there for the future?

## EW precision data:

$M_H$ (SM) > **114** GeV direct searches

$M_H \sim 90$ GeV (< 216 @ $2\sigma$) indirect data

BUT if $m_t \uparrow$ 5 GeV, $M_H$ (best fit) $\uparrow$ 35 GeV

also keep in mind:

EW precision data fits change completely in presence of new physics

D. Rainwater

## SM Higgs sector:

perhaps least likely possibility

(all "problems" present: heirarchy, flavor, $m_\nu$, DM, ...)

also <<BORING>> → we gain only the minimum required satisfaction

## MSSM Higgs (2HDM w/SUSY)

→ solves heirarchy problem (unstable $M_H^2$), but introduces new one: **μ-problem**

superpotential $W = \cdots + \mu \hat{H}_u \hat{H}_d$

↳ mass dimension in a fundamental parameter??

and why is it $\neq 0, M_{Pl}$?? ($\mu \sim v$)

...leads us to the NMSSM (true MSSM?)

→ $\lambda S \hat{H}_u \hat{H}_d$, S gets vev, $\mu = \lambda v_s$

still has some problems, but things improve

# NMSSM phenomenology

scalar content is now 2 charged $H^{\pm}$
2 pseudoscalar $A_1, A_2$
3 scalar $H_1, H_2, H_3$

have new neutralino as well! (5 total)

In principle, S can solve the strong CP problem as well, but experiment doesn't see massless axions, so we have to break P-Q symmetry & it gets dodgy. (interesting theoretical avenue, however)

phenomenological "features":

- lightest neutralino $\chi_1^0$ unobservable (still count < 4)
- LEP limits constrain parm. space to large regions of unobservable $H_1$ (@ TeV, LHC, LC?)

Issue: if we find SUSY, will be very hard and take a looooong time to answer the deeper questions!

But SUSY, while well-motivated, is a tad too heavily weighted in pheno. + exper. studies —

what other options do we have?

Dynamical EWSB — *no* heirarchy problem, but many others

"Little Higgs" — put off $M_H^2$ stabilization problem w/ new matter content, until nearby scale (~ 10 TeV) of new physics

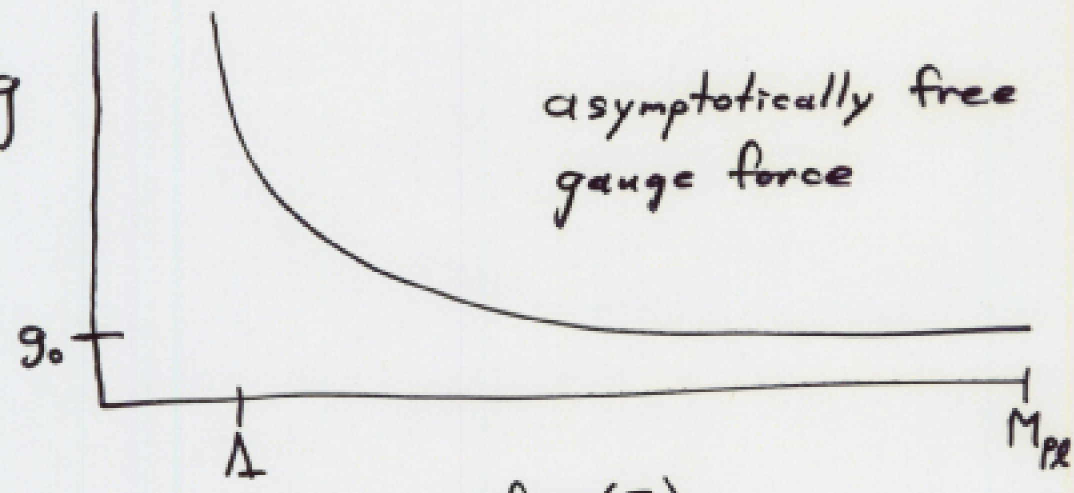
GUT Higgs sectors — SU(2) scalar triplets
→ cool $H^{++}$, $H^{--}$ states!

extra-dimensional — has it all, including kitchen sink, wet bar, jacuzzi, etc. etc.

→ but does contain definitive signatures
→ interesting models not yet at mature stage

What are the general features & how can we study them?

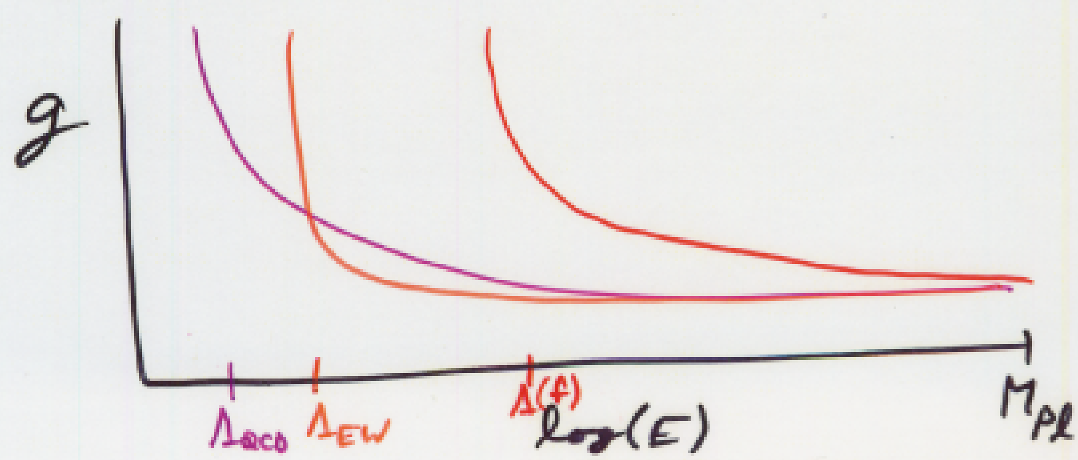
# Dynamical EWSB — no heirarchy problem




- no fine-tuning
- triggers spontaneous sym. breaking
- fields/particles confined

⟹ SUSY breaking, Little Higgs, EWSB, ...

could in fact solve multiple heirarchy problems (EWSB, fermion masses, ✓ see-saw, ...)



Many attempts to make dynamical EWSB theories, but has been quite difficult...

- Technicolor (TC) — can't accomodate large $m_t$ (annotation: condensate of techni-quarks)
- Extended TC (ETC) — FCNCs, large $\Delta S > 0$
- Topcolor-assisted TC (TC2)
  - → additional, heavy top-pions, and Z′
  - → ok w/ EW precision data!

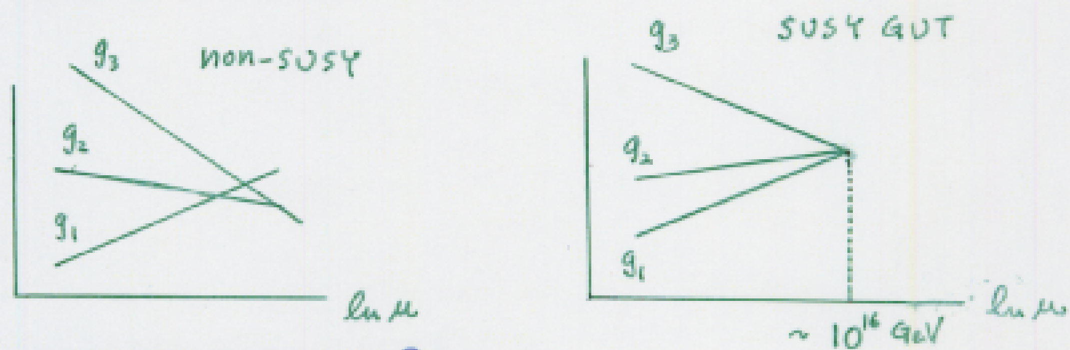
general TC problem (of any variety beyond simplest TC):
generates multiple heavy Goldstone bosons, which we don't observe

positive aspects:
- no hierarchy problem
- top-pions easier to see than Higgs
- add'tl states: (Z′) $m \sim \mathcal{O}(\text{TeV})$, fermions
- can (in principle) address the flavor problem
- alters VVV coups and VV scattering — observable!

not much work in this area these days

## Why (SUSY) GUTs?

- charge quantization explained
- gauge coupling unification



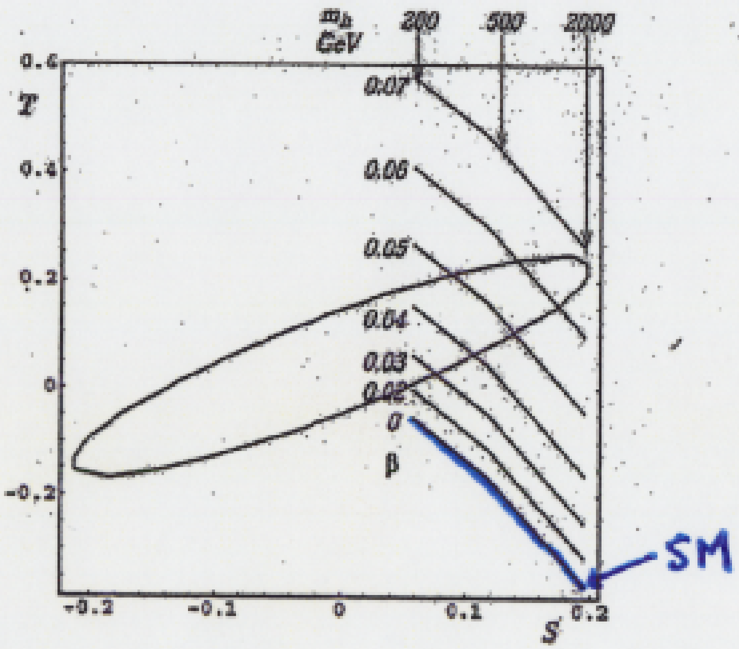

$\Rightarrow$ prediction for $sin^2\theta_w$

$$\sin^2\theta_w = \frac{Tr(I_3^2)}{Tr(Q^2)} = \frac{3}{8}$$

- $b - \tau$ unification
  $\Rightarrow$ good mass relation at $M_{GUT}$: $m_b/m_\tau \simeq 1$
- $\nu$ masses: natural setting for see-saw mechanism
- baryogenesis

  (B-L) gauged: Left-Right models, SO(10) models

(Forshaw et al, 2001)

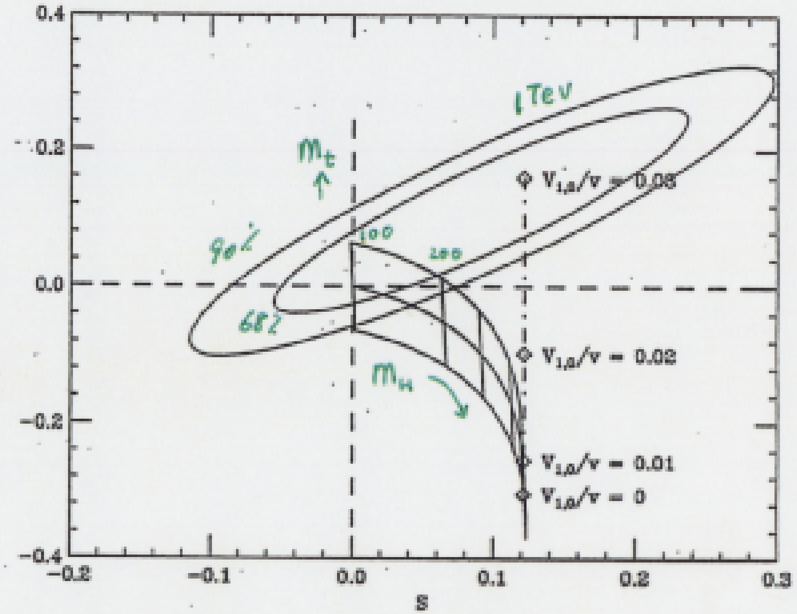



$\tan\beta \simeq 2 \frac{\langle \Delta^0 \rangle}{\langle h \rangle}$

Tree level dominant.

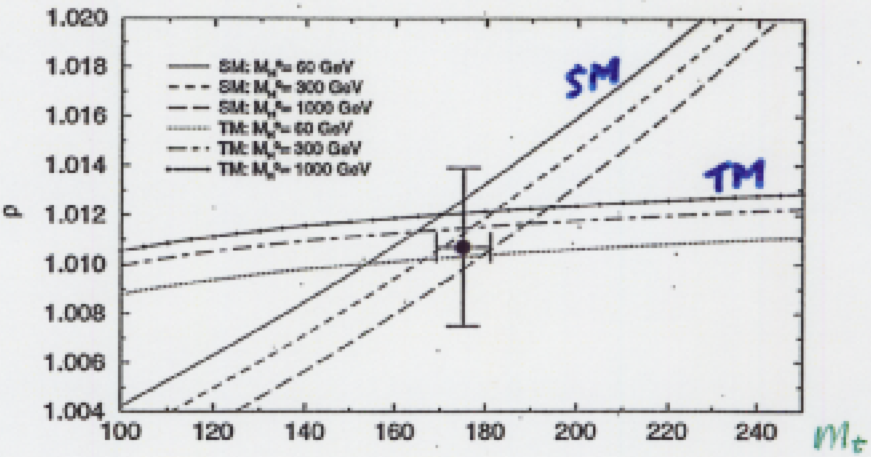
(J. Rosner 2002)

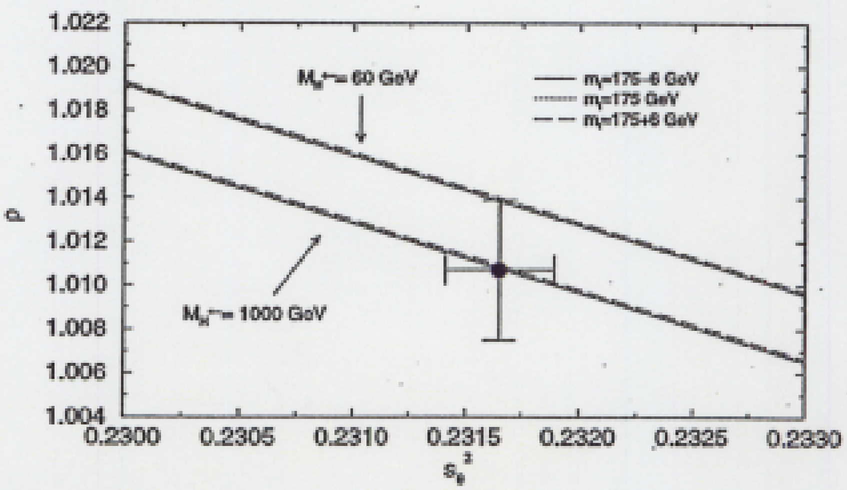
with APV




$(S, T) = 0$ : $m_t = 174.3$ GeV

$M_H = 100$ GeV


SM: $M_H^0$= 60 GeV
SM: $M_H^0$= 300 GeV
SM: $M_H^0$= 1000 GeV
TM: $M_H^0$= 60 GeV
TM: $M_H^0$= 300 GeV
TM: $M_H^0$= 1000 GeV
SM
TM
ρ
1.020
1.018
1.016
1.014
1.012
1.010
1.008
1.006
1.004
100
120
140
160
180
200
220
240
$m_t$


$M_H^{0}$= 60 GeV
$M_H^{0}$= 1000 GeV
$m_t$=175-6 GeV
$m_t$=175 GeV
$m_t$=175+6 GeV
ρ
1.022
1.020
1.018
1.016
1.014
1.012
1.010
1.008
1.006
1.004
0.2300
0.2305
0.2310
0.2315
0.2320
0.2325
0.2330
$s_\theta^2$

## *Open Questions*

Model Building:

- Can we have a light triplet in a realistic GUT model? – what is its effect on the prediction of $\sin^2\theta_w$?

Phenomenology:

- If we find the doubly charged Higgs $\Delta^{++}$, how do we go after its partners $\Delta^0$, $\Delta^+$?

# "Little Flavons"

essentially a Little Higgs model w/ lots of textures

- general 2-doublet potential modified by $U(1)_p$ symmetry
  - forbids some terms
- has heavy gauge bosons $Z'$, $W'$
- 3 stable scales: $f, v_1, v_2$ → successively break large gauge group down to SM

shockingly good CKM and $m_f$ predictions

has definitive predictions for extra states, so perhaps worth a closer look

# CP violation in Higgs sector

1. explicit $\longrightarrow Y_{ij} \neq Y_{ij}^{+}$
2. spontaneous $\longrightarrow \langle \Phi_1 \rangle = v_1 , \langle \Phi_2 \rangle = v_2 e^{i\delta}$ (at least 2HDM)

$\hookrightarrow$ interesting theory debate over whether these are really the same thing in different parameterizations [Mrenna, Martin]

possible phenomenology : $\Gamma(H^+) \neq \Gamma(H^-)$ @ 10-20% level

## CPV in MSSM:

doesn't exist @ tree-level

with CPV, h/H/A mix $\longrightarrow$ get $ZZh_i$ & $Zh_ih_j$ coups $\forall i,j$

but still have sum rules!

1. WBF very important @ LHC
2. TeV2 has some access for low $\tan\beta$ & $\underbrace{M_{H^\pm}}_{\text{note parm}^{zn}} \simeq 130$ GeV

lots of unexplored phenomenology here

| feature | SM Higgs | MSSM | NMSSM | dynamical | extra-D | GUTs | Little Higgs | |
|---|---|---|---|---|---|---|---|---|
| light scalar | Y | Y | Y | OK | OK | OK | Y | |
| heavy/chgd. scalars | N | Y | Y | OK | OK | Y | OK | |
| extra (add'tl) light S. | N | N | Y | OK | OK | OK | N | |
| doubly-charged scal. | N | N | N | N | OK | Y | N | |
| spartners | N | Y | Y | N | (OK) | (OK) | N | |
| heavy fermions | N | N | N | Y | OK | OK | Y | |
| Z', W' | N | N | N | Y | OK | Y | Y | |
| DM candidate | N | Y | Y | N | Y | N | ? | |
| particle towers | N | N | N | N | Y | N | N | |
| explains $m_\nu$ | N | N | N | ? | ? | Y | N | |
| leptogenesis | OK | OK | ? | ? | ? | Y | ? | |
| solves strong CP problem | N | N | N | N | ? | Y | N | |
| solves flavor | N | N | N | OK | (OK) | ? | N(Y) | |

# Special goals for Tevatron

revised Run II Higgs report due in 5 mo.!

⇒ what exactly can TevZ contribute to EWSB physics?

① revise existing studies:

- $H^{\pm}$ (MSSM) not handled well — NLO correc$^s$ signif. but not always used
- extra-D

② perform new studies:

- $gg \to$ radion $\to \gamma\gamma$
- GMSB signatures
- fermiphobic Higgs sector
- NMSSM scan
- bbh (b-parton issue)
- constrain EWSB models via Z', W', heavy f, etc. constraints

③ TeV-LHC connection:

- understand QCD processes better (Higgs search backgrounds)

Steve Mr. : $\overset{gg \to}{\text{radion}} \to \gamma\gamma$ E

suggestion : GMSB (no/tiny − B scenarios) E

fermiphobia : Sally + Dave R.

ED : Young-Kee?

Joanne? : constraining models via exclusion of add'tl states

David M. : NMSSM scan for TeV 2 poss.

Markus : ~~ep~~ @ LHC

bbh issue (new analysis) : Pete M.