# Rottura della Simmetria Elettrodebole:

## da LEP a LHC

Riccardo Rattazzi

# Outline

I. The legacy of LEP/SLC

II. New models of EWSB and their signals

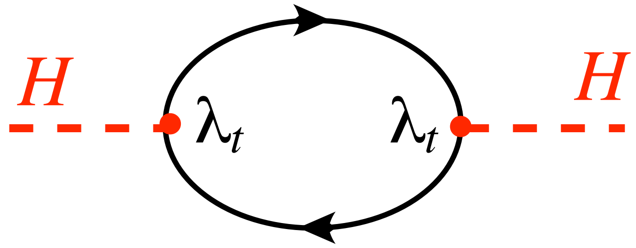
III. Signal for signal's sake: Large Extra Dimensions

IV. A new look at Supersymmetry

# The LEP Paradox

Barbieri, Strumia ‘00

- SM with light Higgs: impressive O($10^{-3}$) agreement with the data
- Hierarchy Problem:



$$\Rightarrow \quad \delta m_H^2 \sim -\frac{3}{4\pi^2}\lambda_t^2\Lambda_{NP}^2$$

$$m_H < 200GeV \longleftrightarrow \Lambda_{NP} < 600GeV$$

- If New Physics scale so low, why don’t we see any indirect effect in precision tests ?

- expect

$$\mathcal{L}_{eff}^{NP} = \frac{1}{\Lambda_{NP}^2}\{c_1(\bar{e}\gamma_\mu e)^2 + c_2 W_{\mu\nu}^I B^{\mu\nu} H^\dagger \tau_I H + \ldots\}$$

$$c_i = O(1) \xrightarrow{\text{LEP}} \Lambda_{NP} \gtrsim 2 \div 10\,\mathrm{TeV}$$

Barbieri, Strumia ‘99

Better for New Physics to affect low energy quantities via loops only $c_i \sim \frac{\alpha}{4\pi}$

$\Lambda_{NP} < 600\,\mathrm{Ge}V$ is OK

ex.: Supersymmetry

- But SUSY naturally forces us to be more ambitious, as it gives a plausible picture for physics up to the Planck scale

- unification
- ν-masses
- EW breaking
- dark matter

$$m_Z^2 \sim -2m_H^2 = -2\mu^2 + \frac{3}{2\pi^2}\lambda_t^2 m_{\tilde{t}}^2 \ln\frac{M_{Planck}}{m_{\tilde{t}}} + \ldots$$

$$\sim -2\mu^2 + O(1)\, m_{\tilde{t}}^2 + \ldots$$

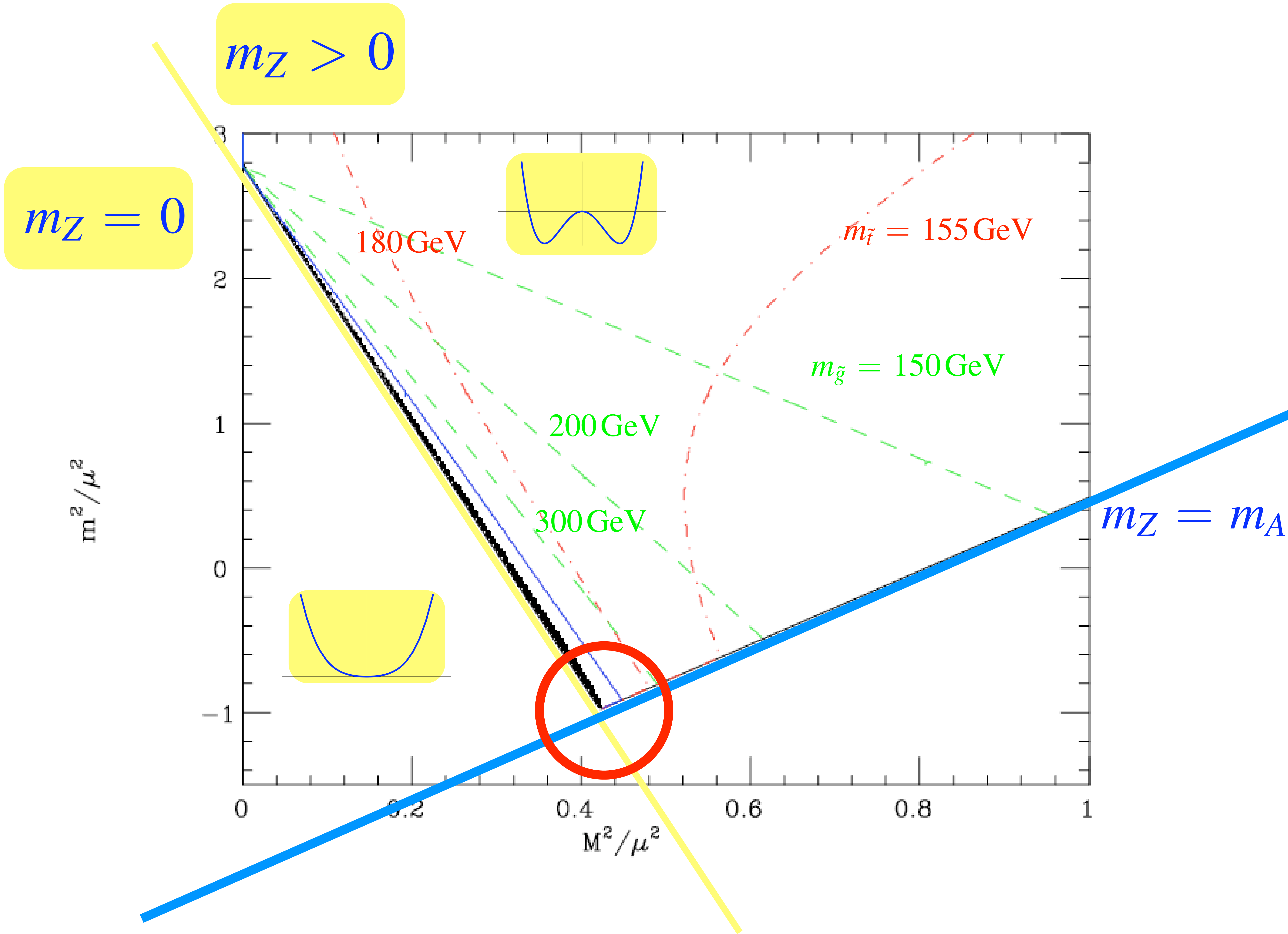
Natural expectation: $m_Z \sim m_{\tilde{t}} \sim \mu$ LEP scale SUSY

- upper bound on physical Higgs mass $m_h^2 \leq m_Z^2 + m_t^2 \frac{3\lambda_t^2}{2\pi^2} \ln m_{\tilde{t}}/m_t$

$m_h > 114.4\,\mathrm{GeV}$ ‘→’ $m_{\tilde{t}} \gtrsim 500 \div 1000\,\mathrm{GeV}$

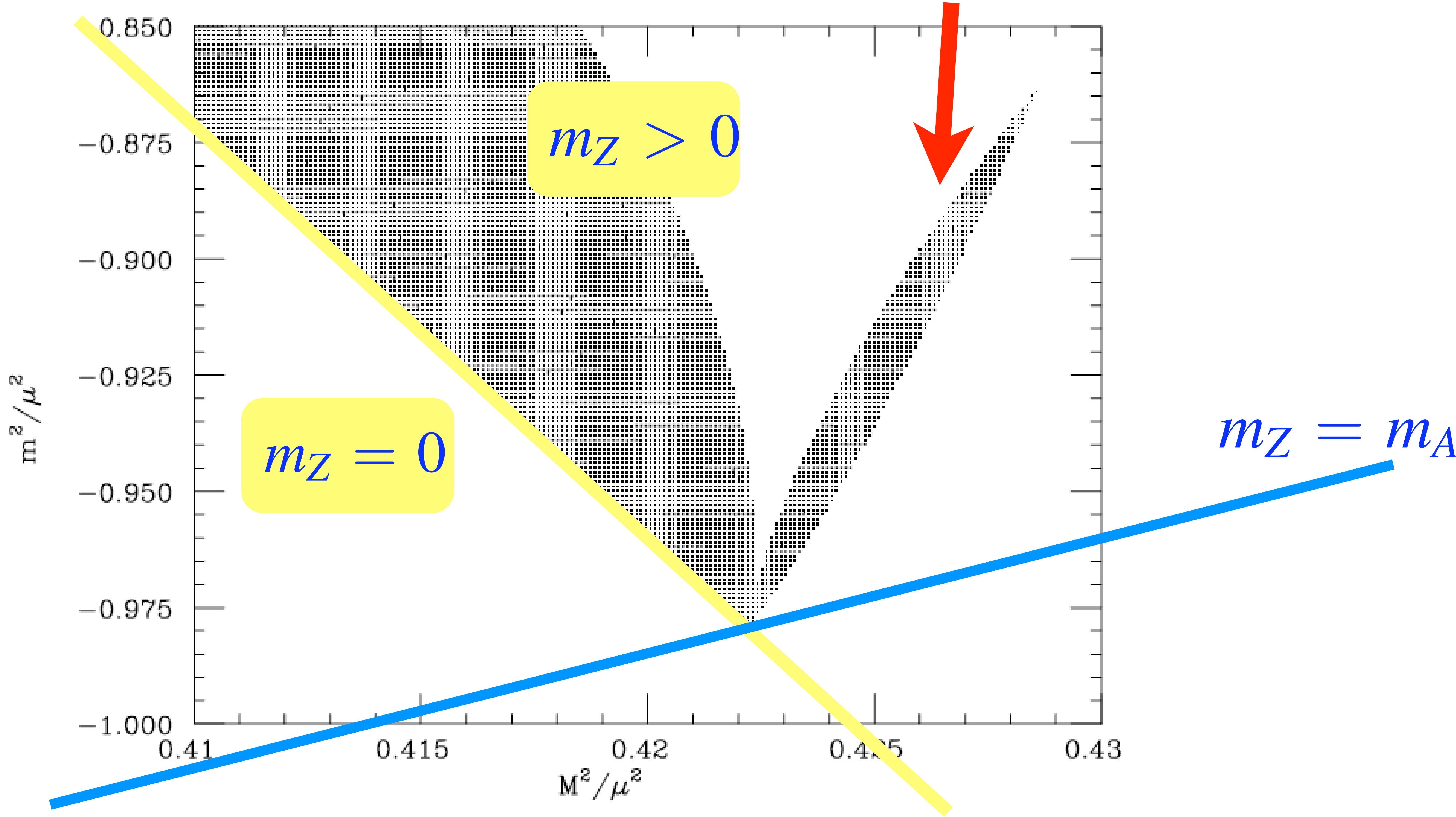
1 - 5 % cancellation in $m_Z^2$ is needed

Arkani-Hamed,Giudice,Rattazzi ‘06



# zooming in on $m_Z \sim m_A$ region

*famous* region where $m_h < 114.4\,\mathrm{GeV}$
is allowed by data



- In MSSM 'problem' is robust : does not depend significantly on the structure of soft terms

$\Big($ though in some cases the stops are lighter and the tuning is elsewhere
Ex: the light Higgs window $m_h, m_A < 115\,\mathrm{Ge}V$ $\Big)$

***Do we gain by modifying the MSSM?***

- ***Mild***: add a singlet field (NMSSM) → *only* 10% cancellation needed

Bastero-Gil, et al., ‘00

- ***Wild***: do not extrapolate up to Planck Mass, since theory is 5D above weak scale

Pomarol,Quiros
Barbieri, Hall, Nomura, & Co

$$-2m_H^2 \sim \frac{3}{2\pi^2}\lambda_t^2 m_{\tilde t}^2 \ln(\xcancel{\frac{M_{Planck}}{m_{\tilde t}}})$$

$$-2m_H^2 \sim \frac{3}{2\pi^2}\lambda_t^2 m_{\tilde t}^2 \ll m_{\tilde t}^2$$

- ***Clever***: extrapolate but without the big log

Berezhiani,Chankowski,Falkovski,Pokorski -- Schmaltz -- Csaki,Marandella,Shirman,Strumia 05

...or perhaps we should not worry about a few percent tuning

***but notice that with just a per mille tuning the LHC is blind to SUSY!***

# Technical parenthesis

LEP1/SLC & LEP2 bounds
on
New Physics in EW sector

# ▲ Simplest possibility = Universal models

1) $$\mathcal{L}_{int} = \bar{\Psi}\gamma^{\mu}\left(T^{A}W^{A}_{\mu} + \frac{Y}{2}B_{\mu}\right)\Psi$$ = Standard

2) $$\mathcal{L}_{NP} = W^{\mu}_{+}\Pi_{+-}(q)W_{+\mu} + W^{\mu}_{3}\Pi_{33}(q)W_{3\mu} + W^{\mu}_{3}\Pi_{3B}(q)B_{\mu} + B^{\mu}\Pi_{BB}(q)B_{\mu}$$

Peskin, Takeuchi ‘89

.....

▲ NP "heavy" $(\Lambda_{NP} > m_Z)$ → $\Pi(q) = \Pi(0) + \Pi'(0)q^2 + \frac{1}{2}\Pi''(0)q^4 + \dots$

Grinstein, Wise '91
Barbieri, Pomarol,
Rattazzi, Strumia '04

4 leading form factors

| | Symmetry property | |
|---|---|---|
| $\hat{T} = \frac{g^2}{m_W^2}\left(\Pi_{33}(0) - \Pi_{+-}(0)\right)$ | ~~custodial~~ | $\xcancel{SU(2)_L}$ |
| $\hat{S} = g^2 \Pi'_{3B}(0)$ | custodial | $\xcancel{SU(2)_L}$ |
| $Y = \frac{g'^2 m_W^2}{2}\Pi''_{BB}(0)$ | custodial | $SU(2)_L$ |
| $W = \frac{g^2 m_W^2}{2}\Pi''_{33}(0)$ | custodial | $SU(2)_L$ |

es.: $U = g^2\left(\Pi'_{33}(0) - \Pi'_{+-}(0)\right) \sim \frac{m_W^2}{\Lambda_{NP}^2}\hat{T} \ll \hat{T}$ is irrelevant

$Y, W$ → Z-pole + 4-fermi interactions (LEP2)

# Observables

Altarelli,Barbieri '90

- $\delta\rho|_{m_Z}, \quad m_W, \quad \sin^2\theta_W|_{current}$

$\left(G_F, m_Z, \alpha_{EM}\right)$ = inputs

$$\begin{cases} \varepsilon_1 = \varepsilon_1^{SM} + \hat{T} - W - \tan^2\theta_W Y \\ \varepsilon_2 = \varepsilon_2^{SM} - W \\ \varepsilon_3 = \varepsilon_3^{SM} + \hat{S} - W - Y \end{cases}$$

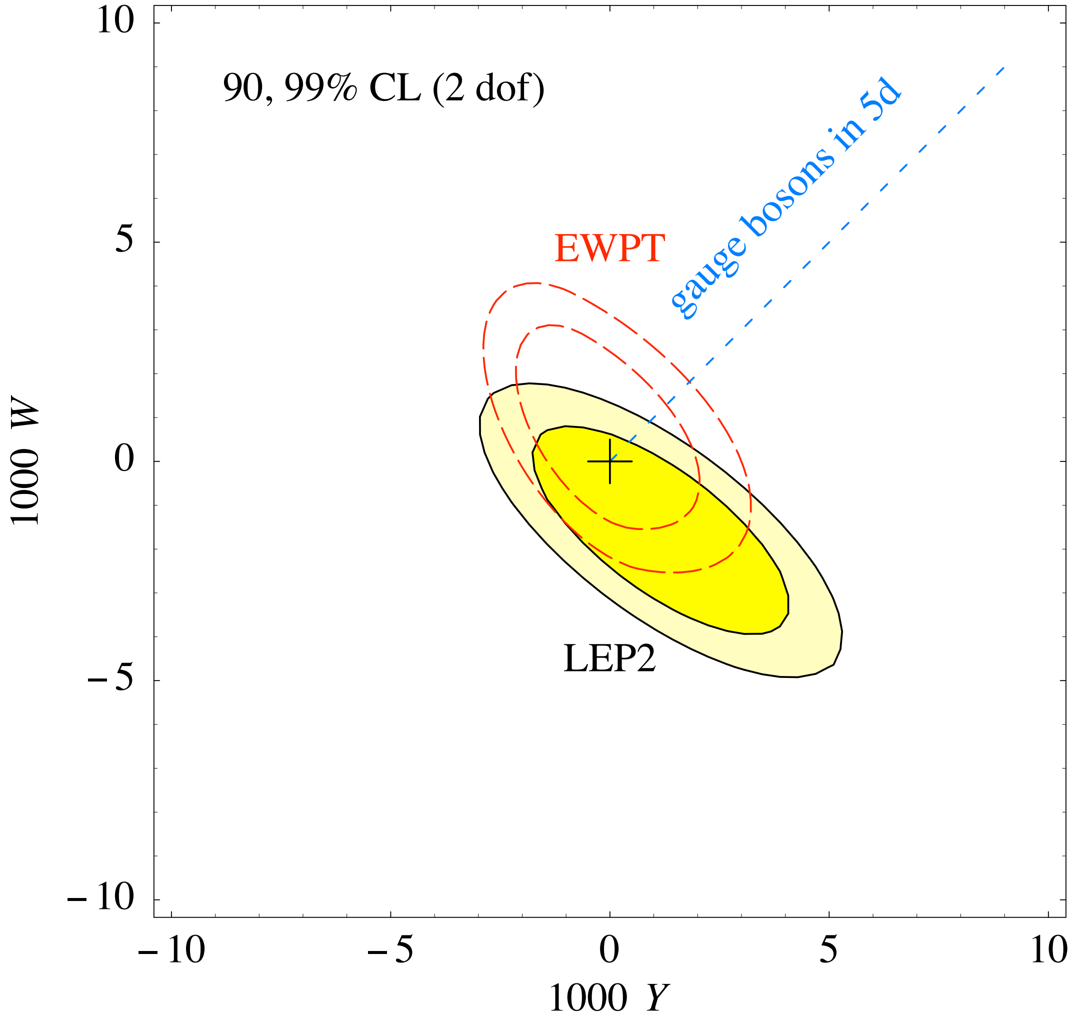
- $e^+e^- \to f\bar{f}$ at LEP2 (cross section + FB asymmetry)

- LEP1/SLC not sufficient to fully constrain the 4 form factors
- LEP2 less precise but energy higher ➡ as relevant as LEP1

# Experimental bounds

| Type of fit | $10^3\widehat{S}$ | $10^3\widehat{T}$ | $10^3 Y$ | $10^3 W$ |
|---|---|---|---|---|
| One-by-one (light Higgs) | $0.0 \pm 0.5$ | $0.1 \pm 0.6$ | $0.0 \pm 0.6$ | $-0.3 \pm 0.6$ |
| One-by-one (heavy Higgs) | — | $2.7 \pm 0.6$ | — | — |
| All together (light Higgs) | $0.0 \pm 1.3$ | $0.1 \pm 0.9$ | $0.1 \pm 1.2$ | $-0.4 \pm 0.8$ |
| All together (heavy Higgs) | $-0.9 \pm 1.3$ | $2.0 \pm 1.0$ | $0.0 \pm 1.2$ | $-0.2 \pm 0.8$ |

light Higgs = 115 GeV heavy Higgs = 800 GeV



bounds on W,Y

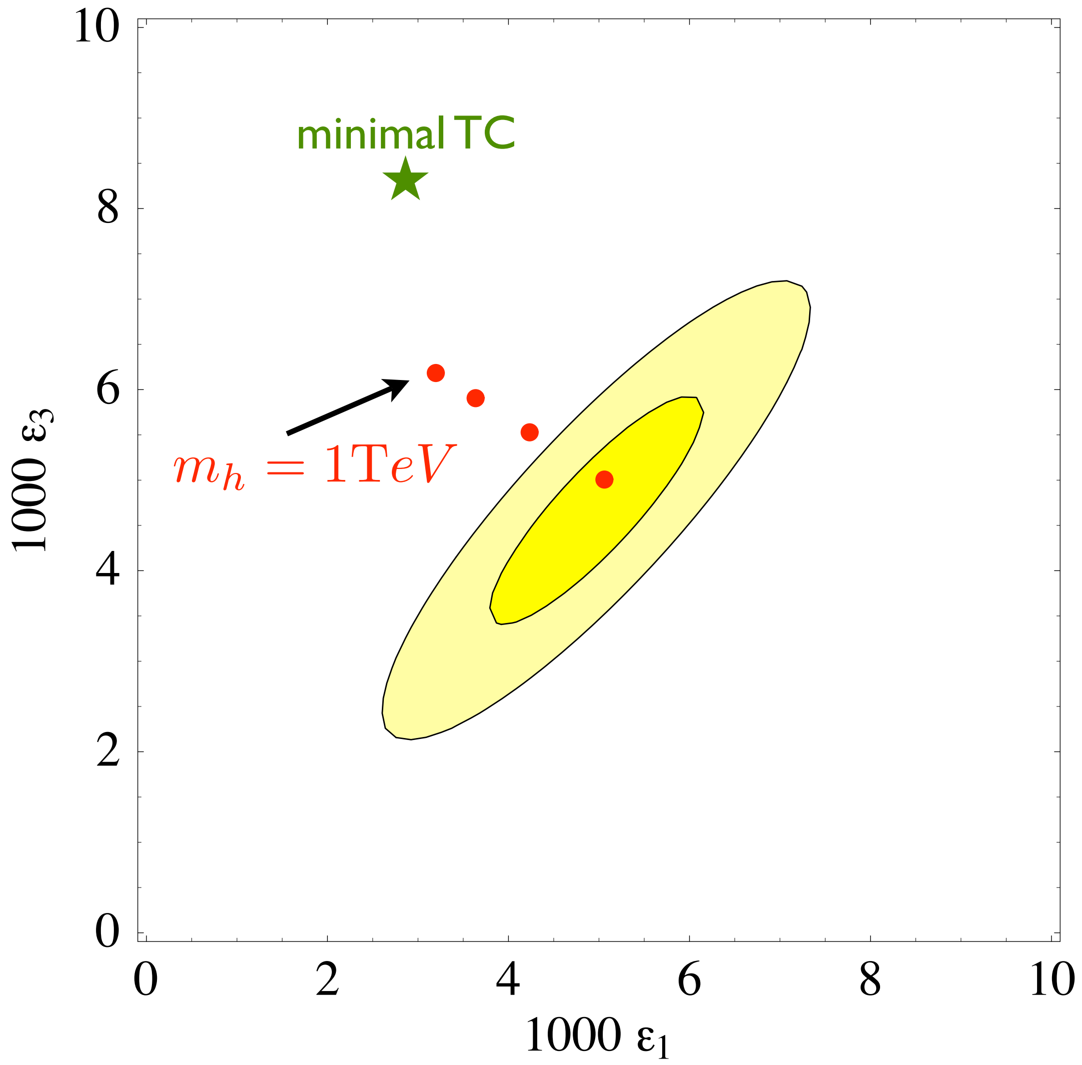
assuming $\hat{S}$, $\hat{T}$ = 0

# **Provocative** look at generic Strongly Coupled Higgsless Theory (ex. Technicolor)

$$\widehat{T} \sim \frac{\lambda_t^2}{16\pi^2} \sim 10^{-2} \qquad \widehat{S} \sim \frac{g_W^2}{16\pi^2} \sim 10^{-2}$$

No fundamental constraint of the possible signs of $\widehat{T}$ and $\widehat{S}$

Naively and roughly: expect all models to be distributed in the 10 x 10 square



Probability to end up in the central ellipse is a few per cent

***not worse than the MSSM !***

Of course we do not have any **calculable** such theory and Flavor is here much more problematic than in Supersymmetry

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# “New” ideas on Electroweak Symmetry Breaking

$m_H^2$ calculable ⟷ protect it from ultraviolet quantum corrections

⬇

**Symmetries**

- Supersymmetry

*boson* *fermion*

$$H \longleftrightarrow \Psi$$

- Gauge symmetry

$$H \longleftrightarrow A_\mu$$

$$\delta A_\mu = \partial_\mu \phi$$

⬇

$$m_A = 0$$

*need extra dimension* $H \equiv A_5$

- Global symmetry

$$H(x) \rightarrow H(x) + c$$

$H \sim$ *Nambu-Goldstone boson* $\mathcal{L}(H) \equiv \mathcal{F}(\partial_\mu H)$

# Higgs as an approximate Nambu-Goldstone boson

$$H \in \mathcal{G}/\mathcal{H}$$

⬇

## Little Higgs Models

Georgi, Kaplan ‘84
Arkani-Hamed, Cohen, Georgi ‘01
Arkani-Hamed, Cohen, Katz, Nelson ‘02
Arkani-Hamed, Cohen, Katz, Nelson, Gregoire, Wacker ‘02

**Aim**: make the Higgs mass naturally smaller than $\Lambda_{NP}$

**Idea**: make $H$ a pseudo Goldstone boson (composite of a new strong force)

**Inspiration**: $\pi^+, \pi^0$ mass in QCD

$$\boxed{\pi^+, \pi^0 \in [SU(2)_L \times SU(2)_R] / SU(2)_{\text{Isospin}}}$$

$m_{\text{quark}} \to 0$
$\alpha_{EM} \to 0$
➡ $SU(2)_L \times SU(2)_R$ *is exact* ➡ $m_{\pi^+} = m_{\pi^0} = 0$

$\alpha_{EM} \neq 0$ ➡ $m^2_{\pi^+} \approx \frac{\alpha_{EM}}{4\pi} \Lambda^2_{QCD}$

Standard Model couplings allow
H to be at most an
approximate Goldstone boson
➡ $m^2_H \approx \frac{\alpha_{top}}{4\pi} \Lambda^2_{strong}$ ➡ $\Lambda_{strong} < 1\,TeV$

Back to LEP paradox !

- In general: $$m_H^2 = \left( \boxed{c_i}\frac{\alpha_i}{4\pi} + \boxed{c_{ij}}\frac{\alpha_i\alpha_j}{(4\pi)^2} + \dots \right)\Lambda_{strong}^2$$

controlled by selection rules

- Collective Symmetry Breaking $\longleftrightarrow$ $c_i \equiv 0$

*Goldstone symmetry partially restored when any single coupling vanishes*

$$m_H^2 \sim (\frac{\alpha}{4\pi})^2 \Lambda_{strong}^2 \Rightarrow \Lambda_{strong} \sim 10\,TeV$$

- Must add new states to SM in order to enlarge the group of approximate symmetry

Ex.: top sector $q_L = \begin{pmatrix} t_L \\ b_L \end{pmatrix}$ $t_R$ $\rightarrow$ $\begin{pmatrix} t_L \\ b_L \\ T'_L \end{pmatrix}$ $T'_R$ $t_R$

Ex.: EW bosons $\mathrm{SU}(2)_L \times U(1)_Y \rightarrow SU(2)_1 \times SU(2)_2 \times U(1)_Y$

New $W_H^\pm, Z_H$

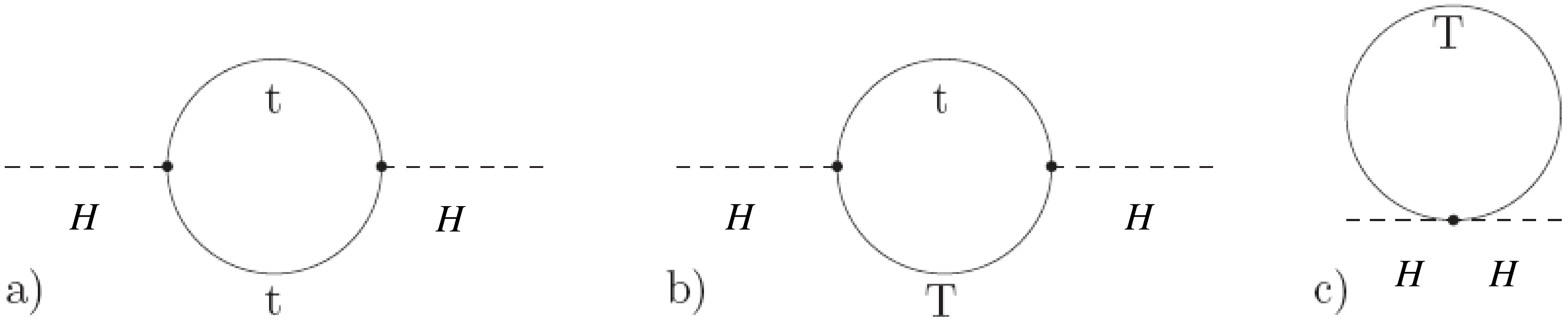
New states have naturally mass $\sim \frac{\alpha}{4\pi}\Lambda^2_{strong} \equiv e^2 f^2$

$$\boxed{f \equiv \frac{\Lambda_{strong}}{4\pi}}$$

$\sim 1\,\mathrm{T}eV$

New states cut-off quadratically divergent contribution to Higgs mass

*Ex.: littlest Higgs model* $H \in SU(5)/SO(5)$



$$\frac{\Lambda^2}{16\pi^2}\Big( \qquad +\lambda_t^2 \qquad +\lambda_T^2 \qquad -2\frac{\lambda_T m_T}{f}\Big) = 0$$

At quartic order $$\delta m_H^2 = -\frac{3}{8\pi^2}\lambda_t^2 m_T^2 \ln(\frac{\Lambda}{m_T}) < 0$$

analogous to effect of stop loops in supersymmetry

# Precision tests

Marandella et al. ‘05
Han, Skiba ‘05
Casas et al. ‘05

*in broad class of models*

$SU(5)/SO(5)$
$SU(6)/Sp(6)$
.....

$$\widehat{S} = \frac{m_W^2}{2m_{W_H}^2}\frac{1}{\sqrt{1-\frac{\alpha_W}{\alpha_H}}}$$

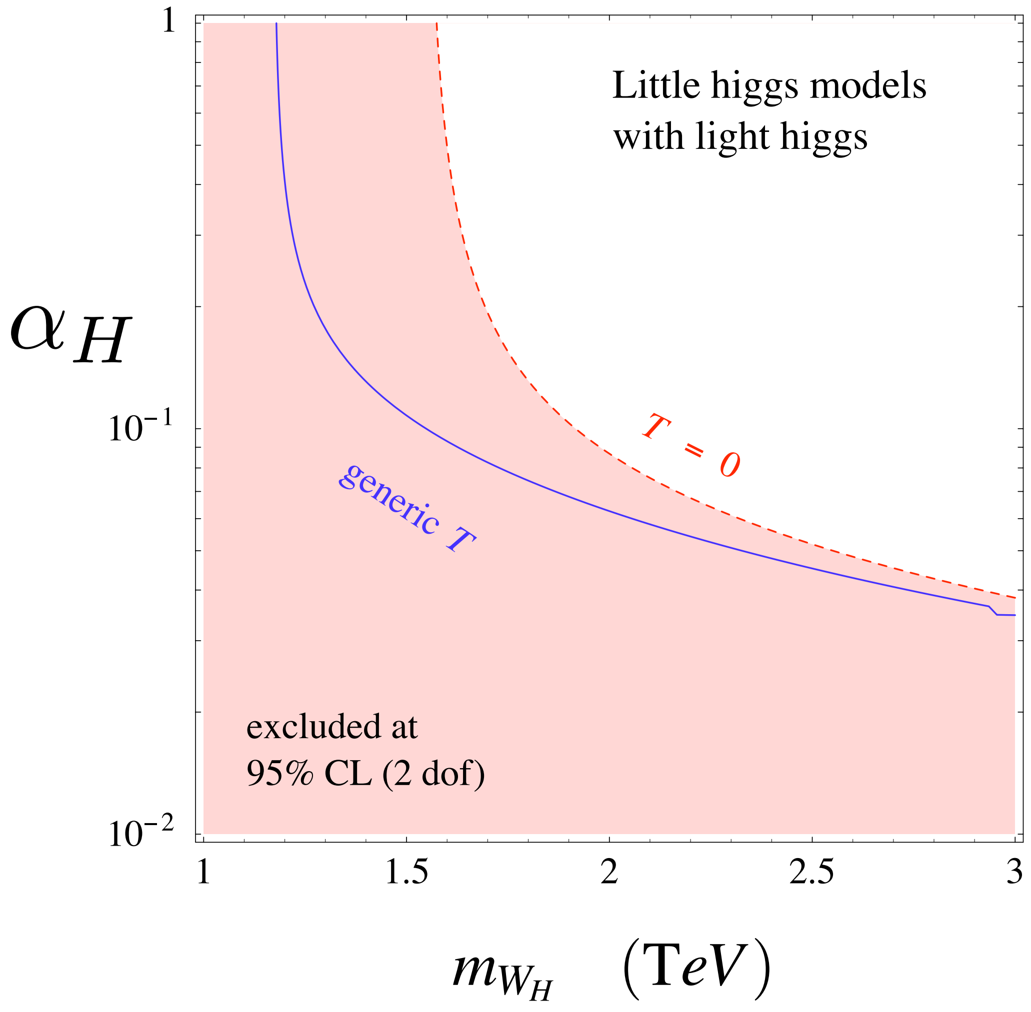
$$W = \frac{m_W^2}{2m_{W_H}^2}\frac{\frac{\alpha_W}{\alpha_H}}{\sqrt{1-\frac{\alpha_W}{\alpha_H}}}$$

$\widehat{T}, Y$ = *more model dependent*

*tree level mixing of EW bosons with heavy partners*
***(LEP paradox !!)***

*thanks to LEP2, can keep $\widehat{T}, Y$ free and get significative bounds*

$$m_T \gtrsim \frac{1}{\sqrt{\alpha_H}}\mathrm{TeV}$$



$\delta m_H^2 \propto m_T^2$ ⟷ *tuning minimized for large coupling* $\alpha_H \sim 1$

$\alpha_H = 0.1$ → must tune to better than 5 %

# Cancellation of quadratic divergence in Higgs mass does not rely on mixing between light and heavy vectors

Cheng,Low ‘03, 04
Low ‘04

T-parity:

- heavy vectors are odd
- SM particles are even

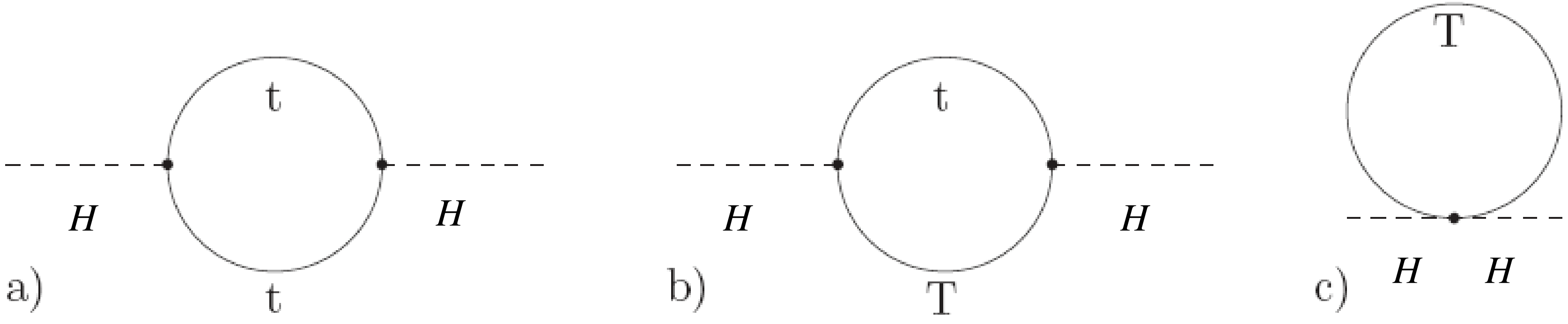
→ $\widehat{S} = 0$ at tree level

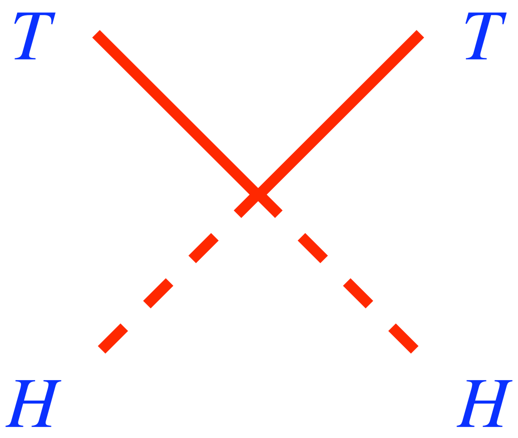
...however there are important loop effects, that were absent in models without T-parity

must add a partner for each SM fermion with mass ~ 500 GeV in order to cut-off the new loop effects

# Testing LH at LHC  (Littlest Higgs and product group models)

$$+\lambda_t^2 \qquad +\lambda_T^2 \qquad -2\frac{\lambda_T m_T}{f} \quad = \quad 0$$



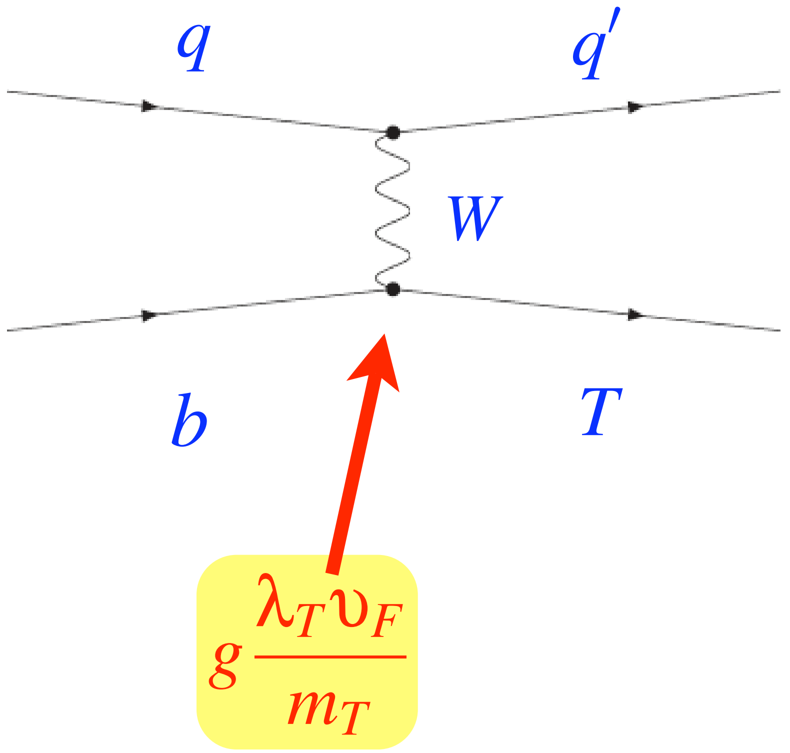


Cannot measure quartic vertex at LHC

Must perform indirect test of top loop cancellation → model dependence

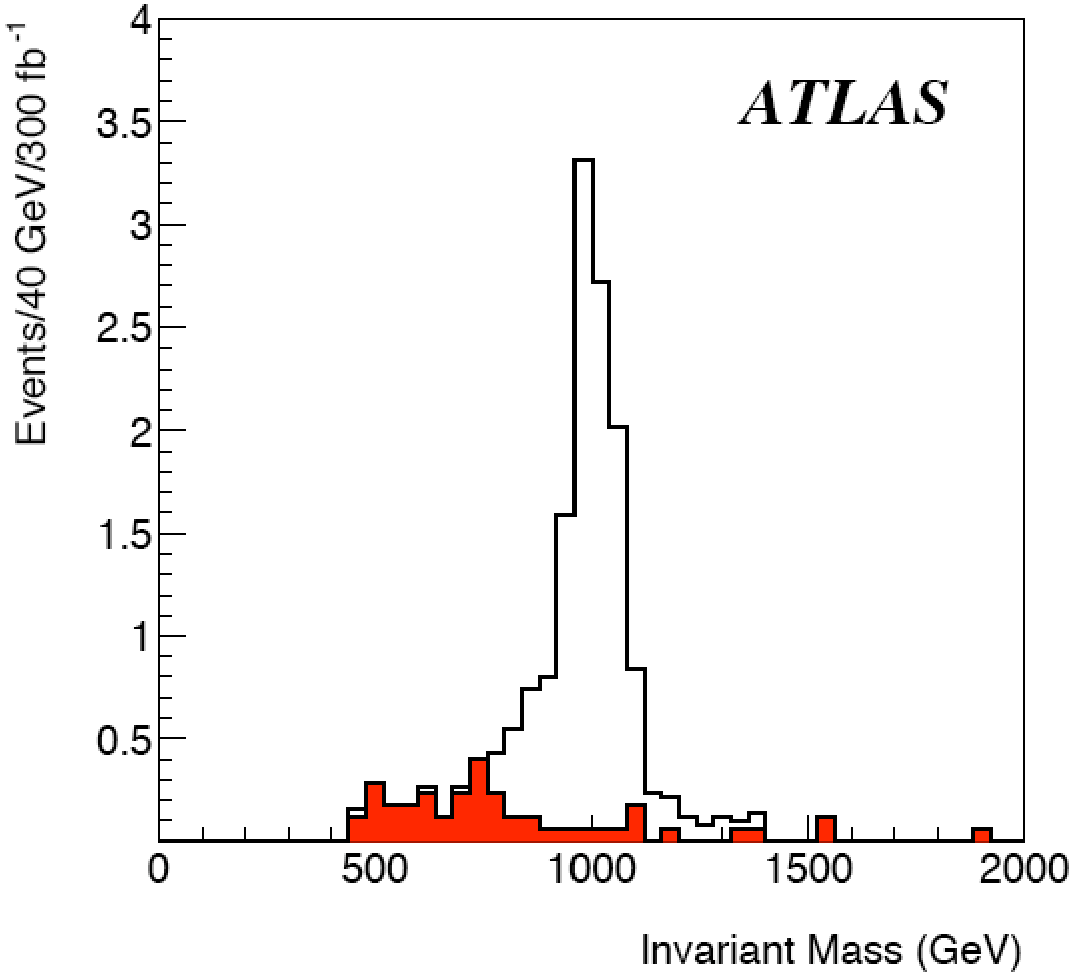
# $m_T, \lambda_T$

from T production ad decay



Perelstein,Peskin,Pierce '04
Han, Logan,Wang '05

- $\Gamma(T \to bW) = 2\Gamma(T \to tZ) = 2\Gamma(T \to bh)$
- cleanest mass peak from $T \to Zt \to \ell^+\ell^- b\ell \not{E}_T$
- In order to precisely extract $\lambda_T$ from measured cross section must control b-quark partonic density up to $x_b \sim 0.2$

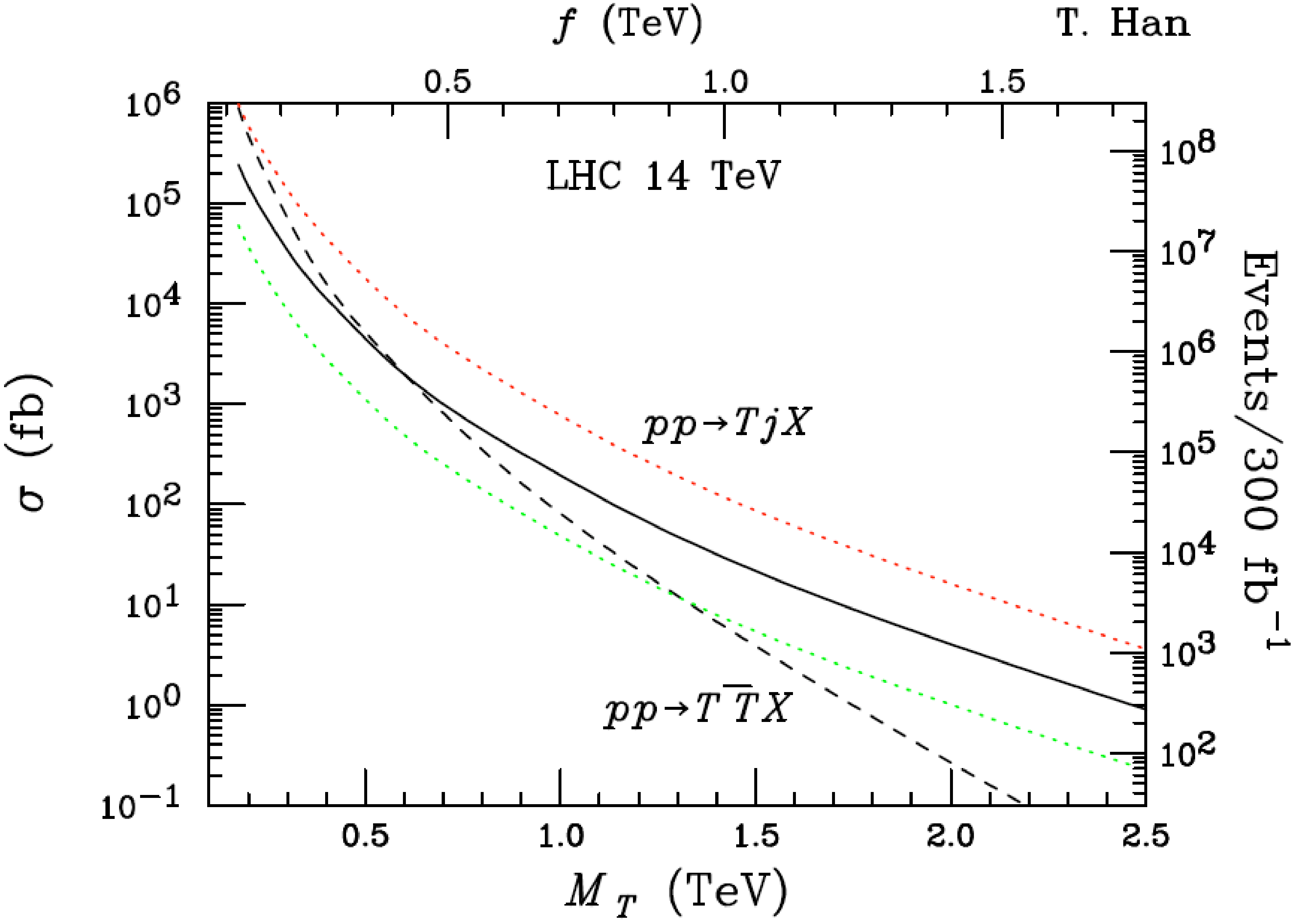


- Three isolated leptons (either $e$ or $\mu$) with $p_T > 40$ GeV and $|\eta| < 2.5$. One of these is required to have $p_T > 100$ GeV.

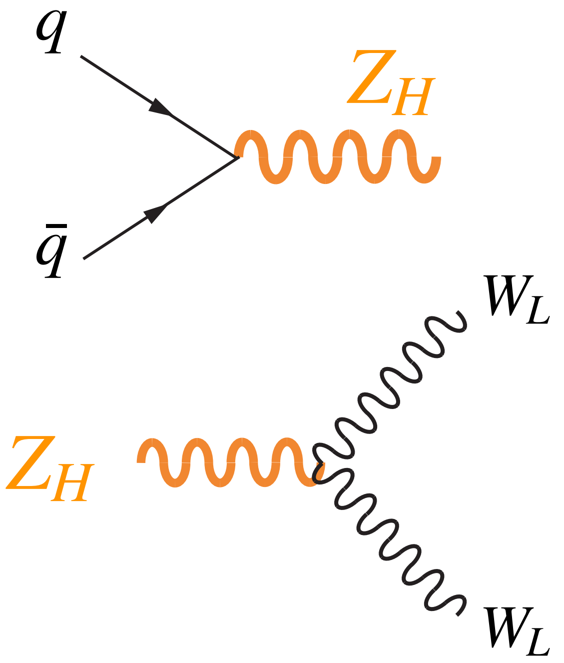
- No other leptons with $p_T > 15$ GeV.

- $\not{E}_T > 100$ GeV.

- At least one tagged $b-$jet with $p_T > 30$ GeV.


f (TeV)
T. Han
0.5
1.0
1.5
LHC 14 TeV
σ (fb)
Events/300 fb⁻¹
pp→TjX
pp→TT̄X
M_T (TeV)
0.5
1.0
1.5
2.0
2.5
10⁶
10⁵
10⁴
10³
10²
10¹
10⁰
10⁻¹
10⁸
10⁷
10⁶
10⁵
10⁴
10³
10²

## $f, \alpha_H$ from DY production of heavy vectors



$$= \frac{g_W^2}{g_H}$$

$$= g_H$$

Production rate and Br into leptons suppressed in region favored by LEP

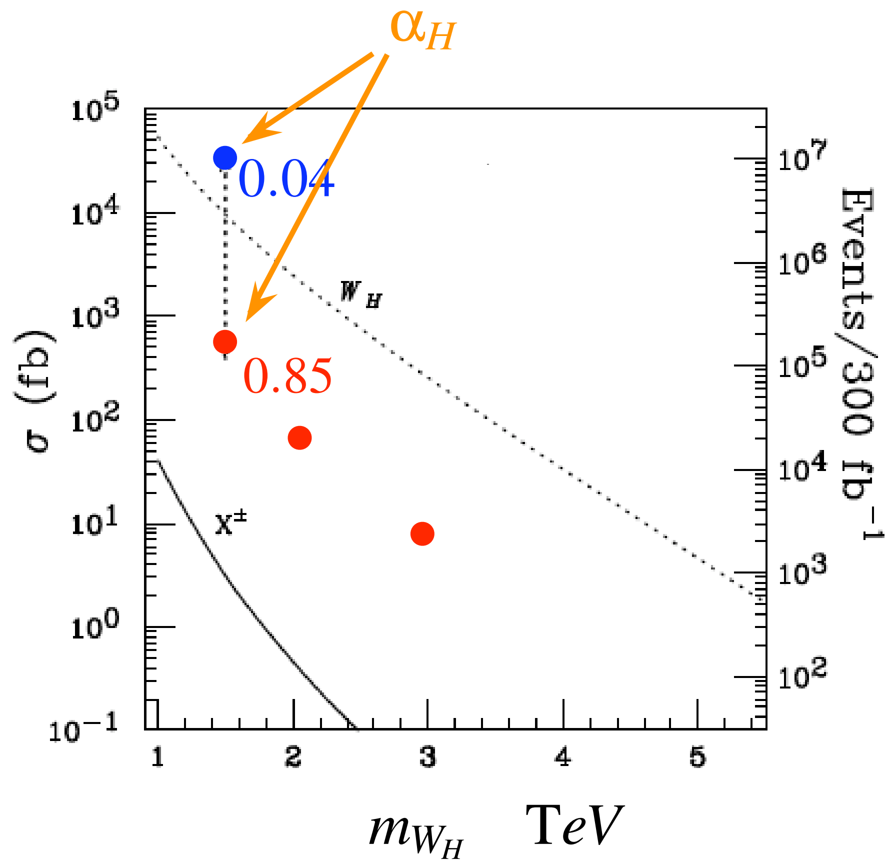
$$g_H \gg g_W$$

Coupling to fermions $\propto g_W^2$
like for $\rho$ meson in QCD

Can produce more than a few tens of events with $e^+e^-$ and $\mu^+\mu^-$ final states up to a heavy vector mass of 3 TeV

can realistically test at 10% accuracy mechanism for canceling quadratic divergences in Higgs mass for

$$m_T < 2.5\,\mathrm{TeV} \qquad m_{Z_H} < 3\mathrm{TeV}$$



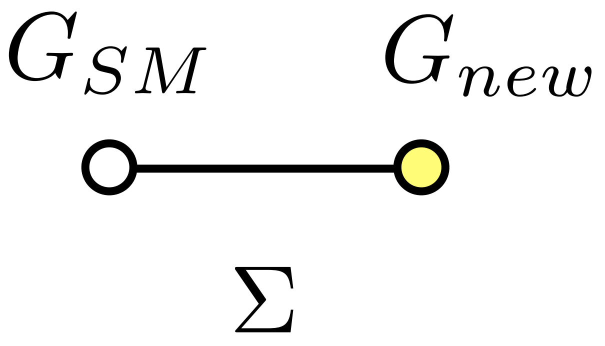
# Higgs as ``Holographic” Golstone boson

or

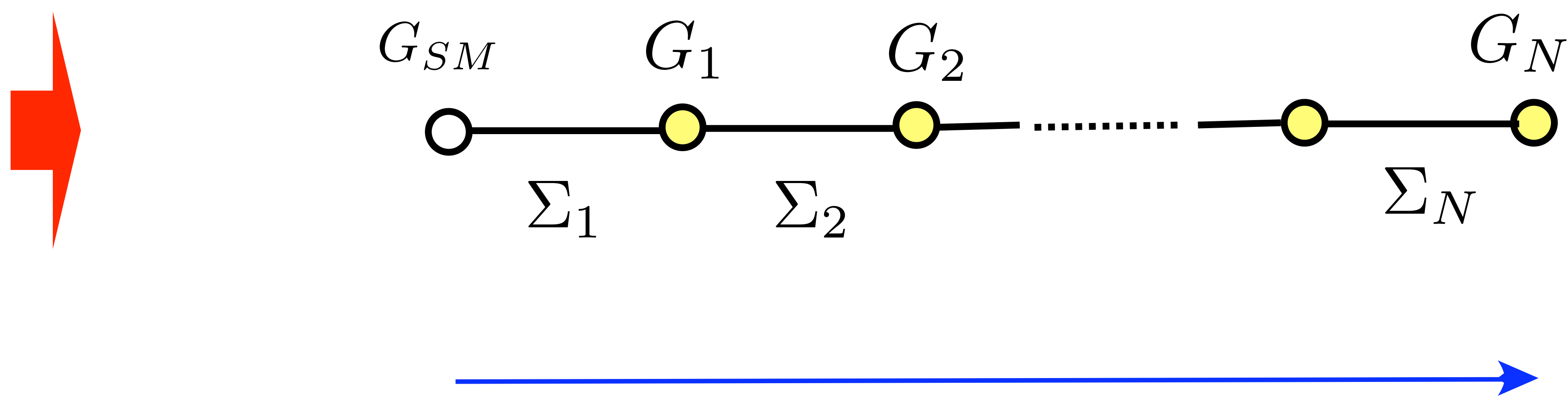
$$H \quad = \quad A_5$$

Manton ‘79
....
Hosotani ‘89
....
Antoniadis,Quiros,Benakli ‘01
Scrucca,Serone,Silvestrini ‘03
Csaki,Grojean,Murayama ‘03
....

# Diagrammatic representation of LH models



$H \in \Sigma$



~ 5th dimension

**large N ~ (discrete) extra dimension**

$$\Sigma_i \equiv A_5(i)$$

- $N \sim \frac{\Lambda_{strong}}{m_{KK}}$ = number of weakly coupled Kaluza-Klein modes
- Higgs mass is now cut-off by Kaluza-Klein particles!

$$m_H^2 \sim \frac{3\lambda_t^2}{16\pi^2} m_{KK}^2$$

More directly (a la Bohr-Sommerfeld)

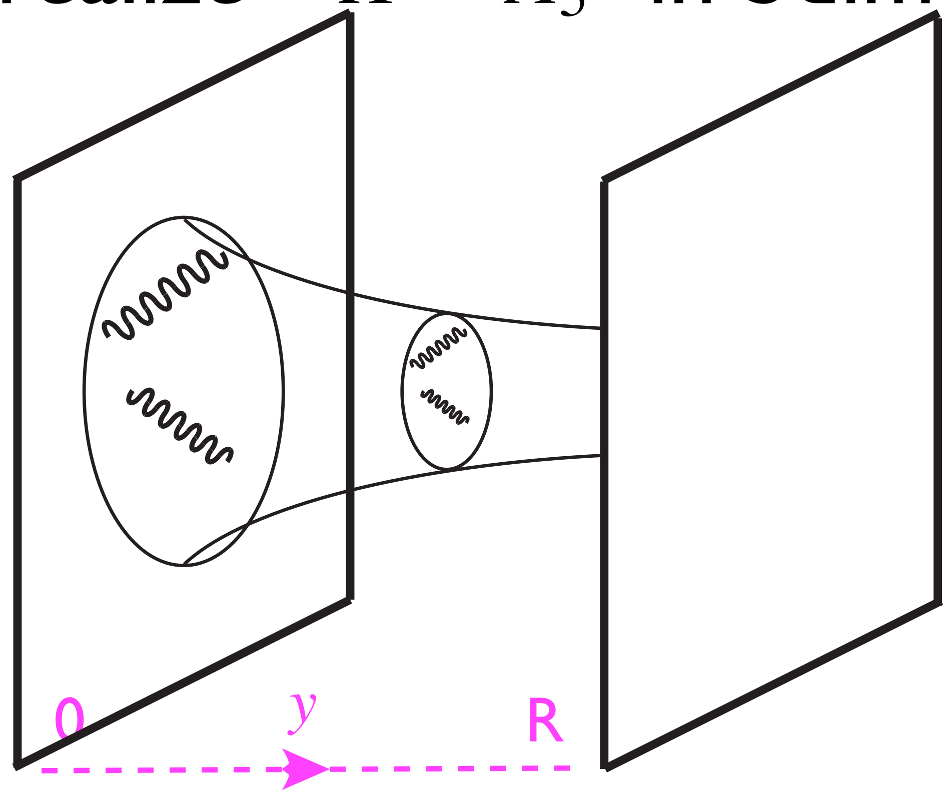
Number of states (KK-modes) in 5D gauge theory with cut-off $\Lambda$

$$N \sim \int dp\, dq = \Lambda R$$

The number N parametrizes how strongly coupled the 5D theory is at energies of order 1/R

$$n - \text{loops} \quad \propto \quad \frac{1}{N^n}$$

▲ can realize $H \sim A_5$ in 5dimensional Randall-Sundrum scenario



Contino,Nomura,Pomarol '03
Contino,Agashe,Pomarol '04

$$ds^2 = e^{-2y/L} dx_\mu dx^\nu + dy^2$$

- Big Hierarchy solved by gravitational redshift $\frac{m_{KK}}{M_{\rm Planck}} \sim e^{-R/L} \ll 1$

$R/L \sim 35$ ➡ $m_{KK} \sim \mathrm{TeV}$

- $H = \int_0^R A_5 dy$ ➡ Higgs potential calculable

***Realizes calculable EW breaking***
***in a model valid up to the Planck scale***

# Extrapolation to Planck scale is rather constraining

- There are KK resonances for each particle of the SM
- $N \lesssim 10$ coupling among KK's is large $g_{KK} \sim \frac{4\pi}{\sqrt{N}}$
- Can nicely explain the quark and lepton mass spectrum via their localization in 5D, and implement a GIM mechanism of FCNC suppression

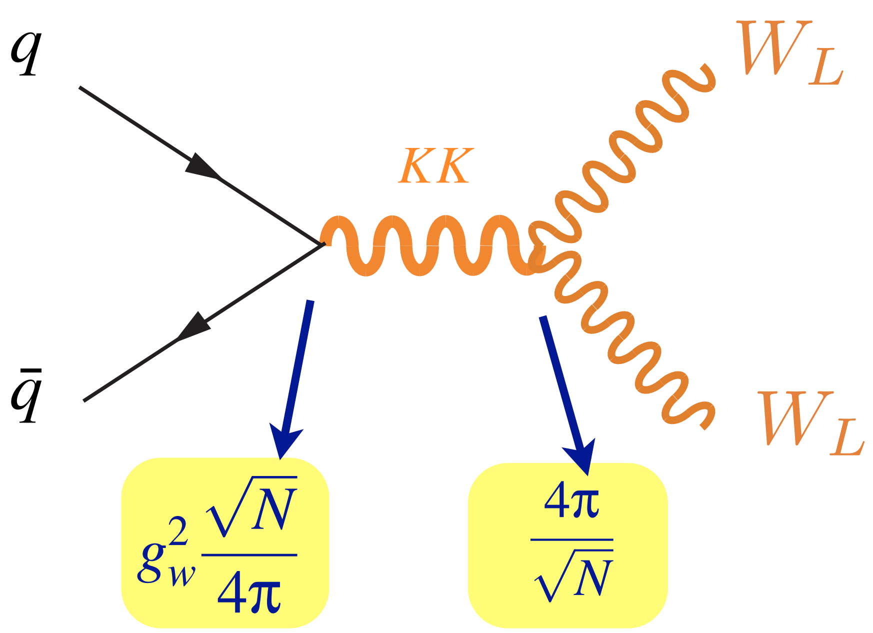
Grossman,Neubert '99
Gherghetta,Pomarol '00
Huber,Shafi '00

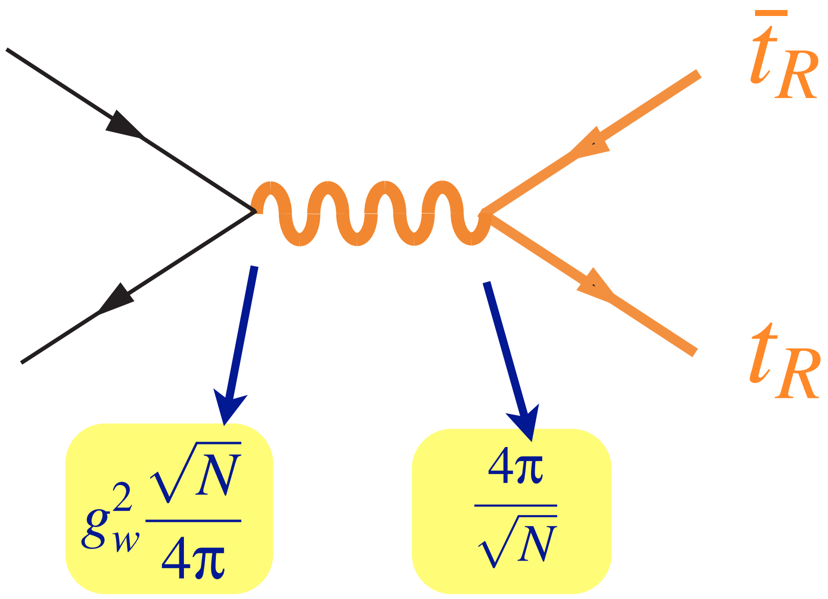
- $t_R$ strongly interacts with KK modes (it is a composite !)
- EW constraints similar to Little Higgs case: 10% tuning already needed

$\widehat{S}$ ➡ $m_{W_H} > 2.5\,\text{TeV}$

stronger than
in Little Higgs case

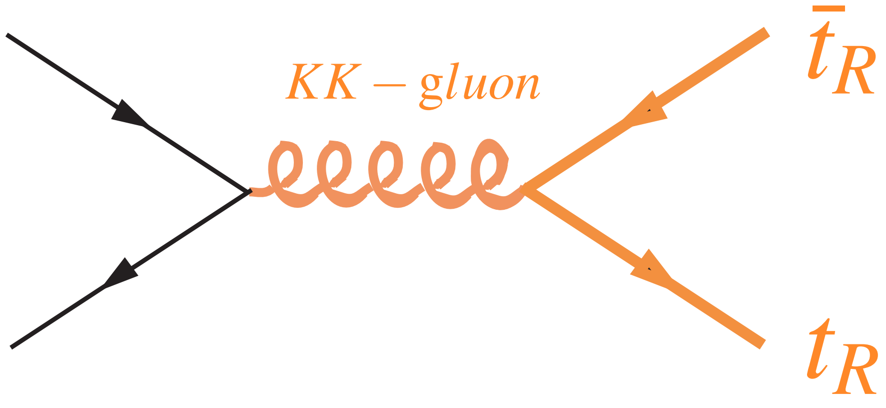
# Phenomenology partially resembles Little Higgs





- Electroweak KK's are strongly coupled to longitudinal W, Z and to right-handed top
- Br to lepton pairs is further reduced with respect to LH

- Distinction with respect to LH is the presence of KK-gluons strongly coupled to right-handed top



- To fully test cancellation of quadratic corrections to Higgs mass need to measure the first KK states → VLHC

***Phenomenology study is still work in progress***

# *Signal for signal's sake*: Large Extra Dimensions

Arkani-Hamed,Dimopoulos,Dvali '98

A quantum gravity scale in the few TeV range is somewhat at odds with LEP data ⇔ Contact interactions (ex 4-fermions) are in general expected

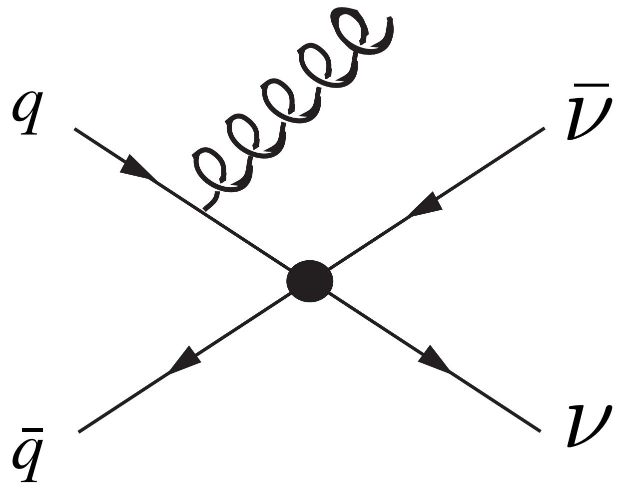
.... still a direct test is obviously preferable

**Standard signal:** $\text{parton} + \text{parton} \to \text{parton} + \text{graviton} = \text{jet} + \not{E}_T$

However

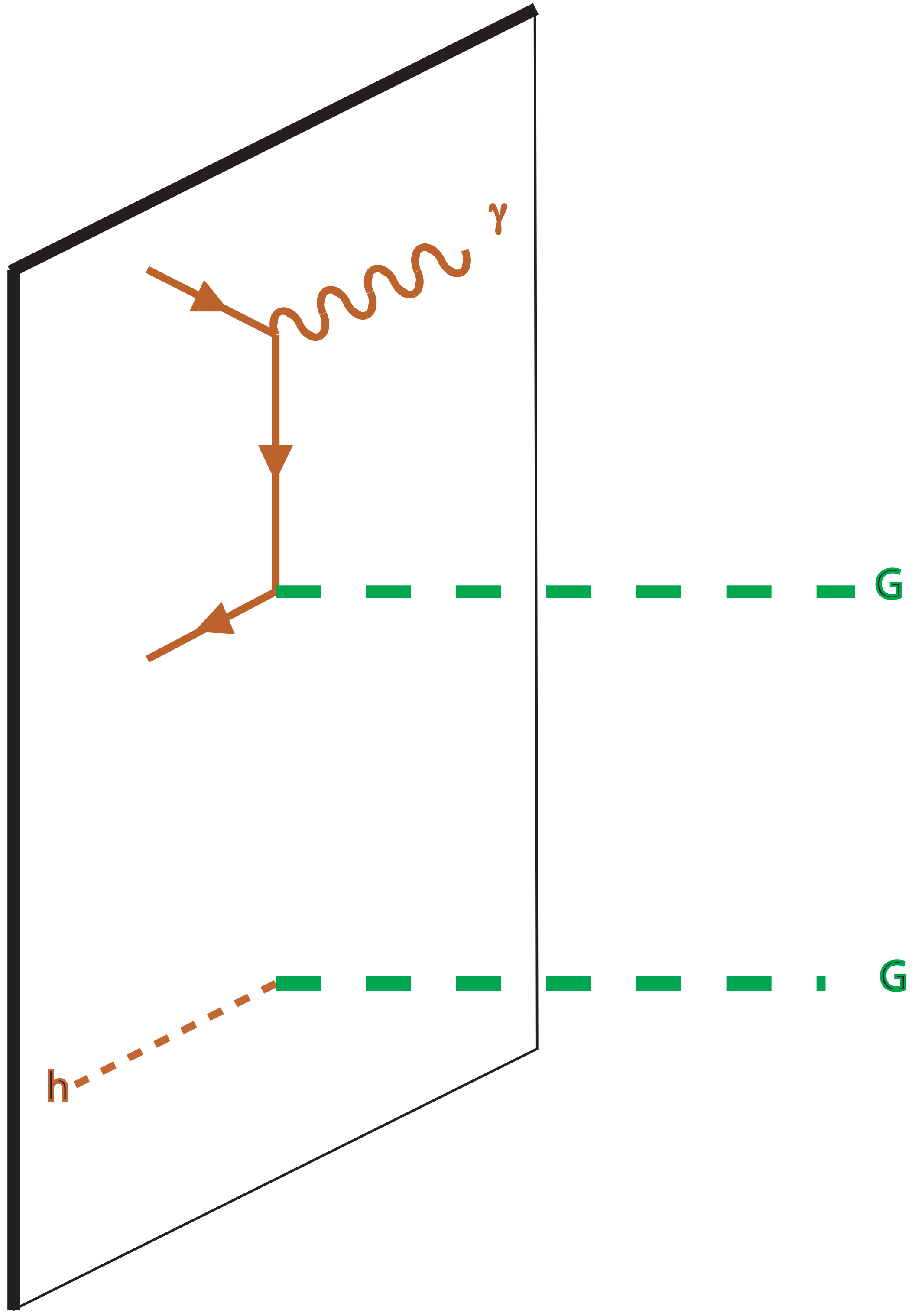
- Missing energy signal can in principle be faked by other effects

*example*



- For 4 or more extra dims, rate at LHC either negligible or dominated by uncalculable regime

$$\sigma(q\bar{q} \to \text{gluon} + \text{graviton}) \propto \frac{E^n}{M_D^{2+n}}$$


γ
G
G
h

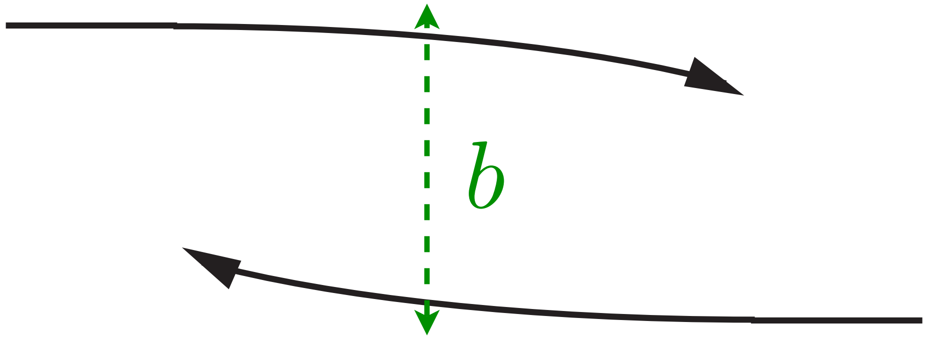
Unmistakable consequence of low gravity scale → long distance classical gravity effects at $\sqrt{s} \gg M_D$

't Hooft '87
Amati,Ciafaloni,Veneziano '87
Muzinich,Soldate '88

scattering angle

$$G_D \equiv \frac{1}{M_D^{n+2}}$$

$$\theta \sim \frac{G_D \sqrt{s}}{b^{n+1}} \equiv \left(\frac{R_S}{b}\right)^{n+1}$$



fixed angle scattering for

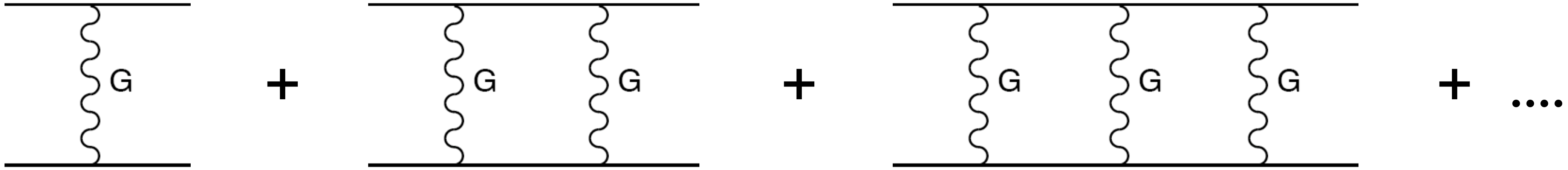
- $\sqrt{s} \to \infty$
- $b \to \infty$

with $\frac{\sqrt{s}}{b^{n+1}}$ fixed

***Cross section at fixed angle grows with energy!!***

For large impact parameter process described by classical gravity:
no need to know string theory

# Forward amplitude dominated by ladder diagrams (eikonal approximation)



$\text{parton} + \text{parton} \rightarrow \text{parton} + \text{parton}$ ➡ $pp \ \rightarrow \ 2\text{jets}$

gravity is universal: all partons contribute

Giudice,Rattazzi,Wells '01

event selection

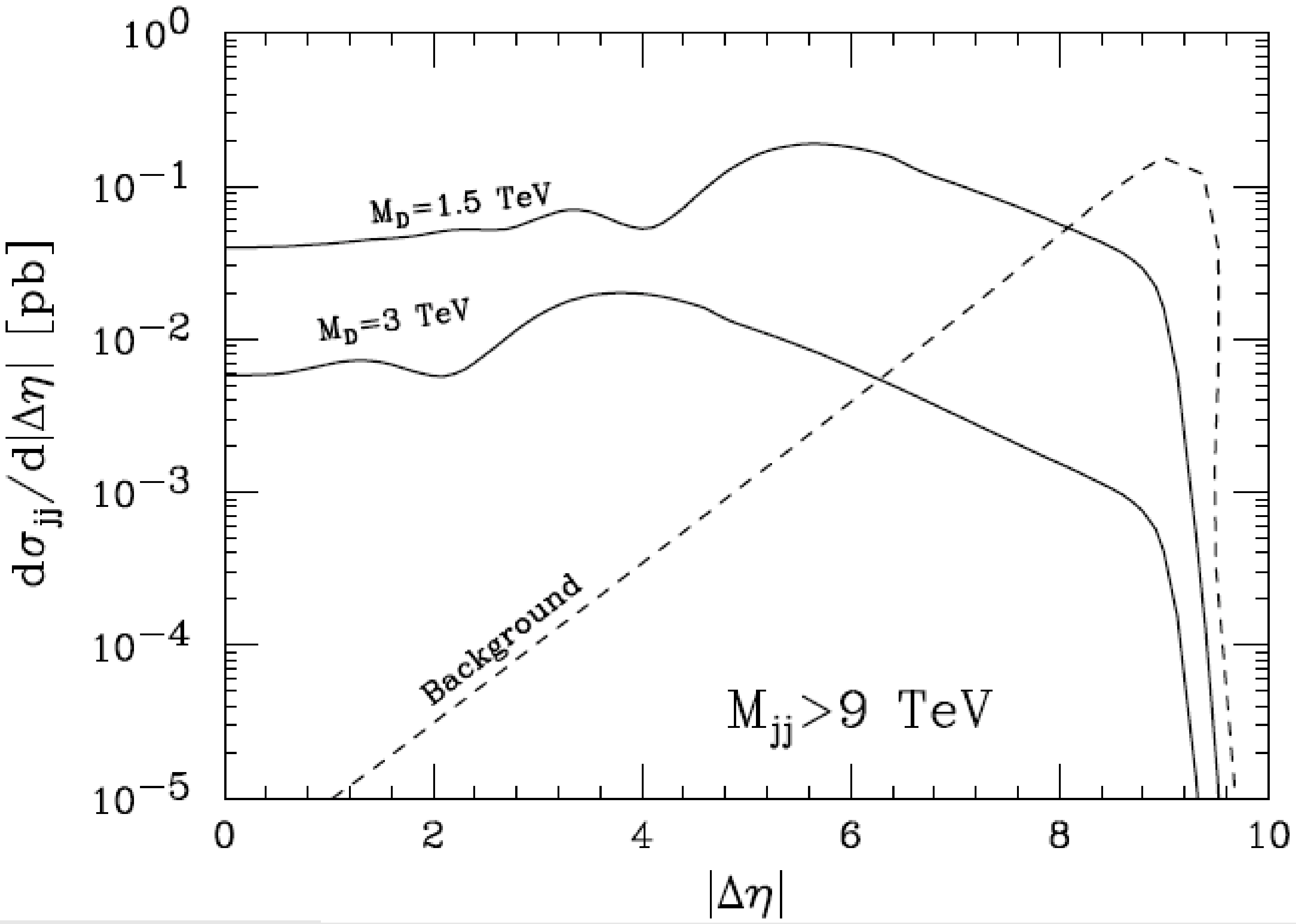
- *transplanckianity*

$$\frac{\sqrt{\hat{s}}}{M_D} \gg 1 \quad ➡ \quad M_{jj} \gg M_D$$

- *eikonality*

$$\Delta\eta = \ln \frac{1 - \cos\theta_{CM}}{1 + \cos\theta_{CM}} \gg 1$$

$n \ = \ 6$

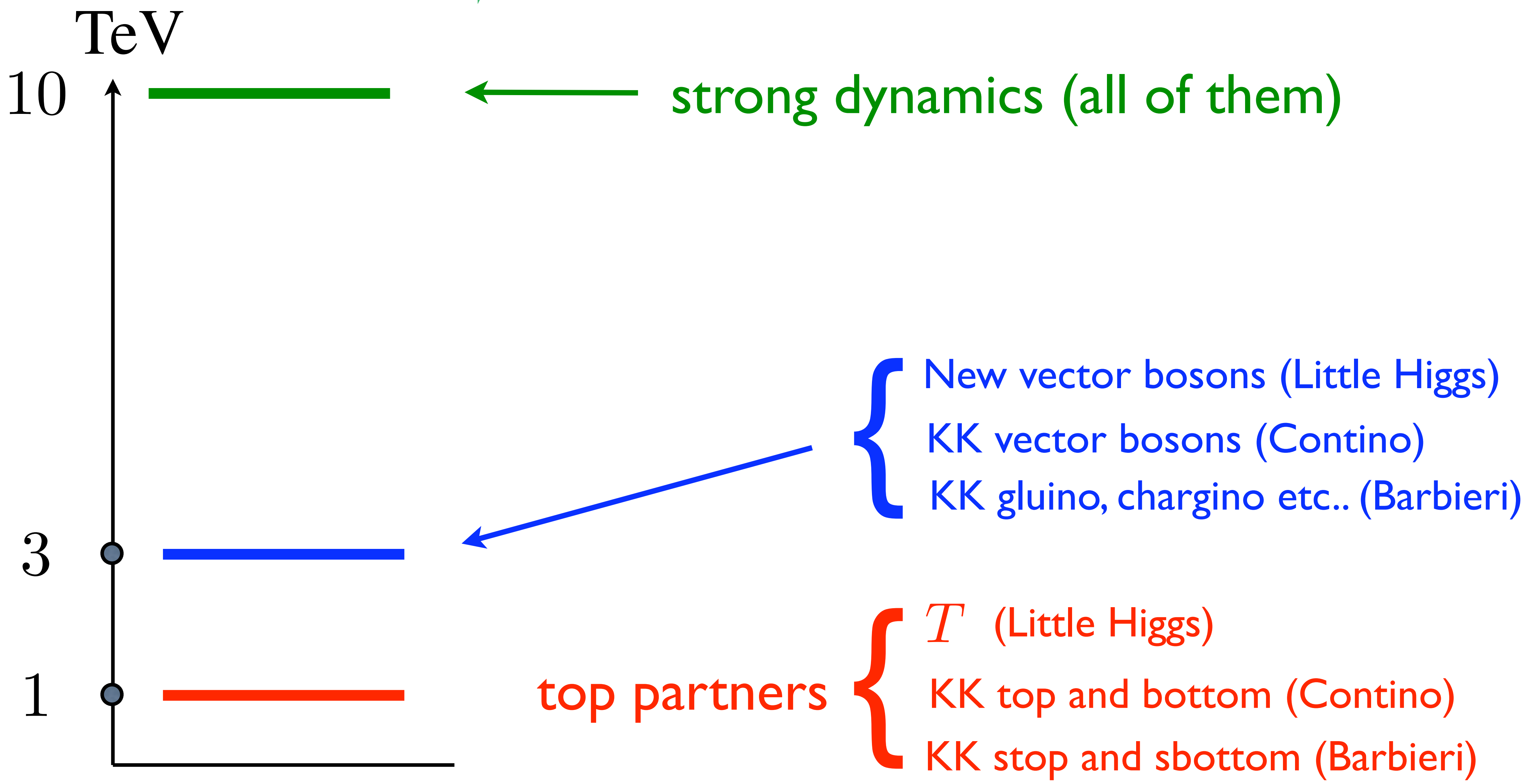


The observation of a cross section at finite angle growing like a power of C.M. energy would be a clean signal that the high energy dynamics of gravity has been detected

It is hard to imagine anything else than gravity, a gauge interaction whose charge is energy itself, that could give rise to such a phenomenon

# Summary

- LEP/SLC data → many new proposals for calculable EW breaking



strong dynamics (all of them)

- New vector bosons (Little Higgs)
- KK vector bosons (Contino)
- KK gluino, chargino etc.. (Barbieri)

top partners

- $T$ (Little Higgs)
- KK top and bottom (Contino)
- KK stop and sbottom (Barbieri)

- Some tension with EWPT data exists already, but not dramatic yet

- Models are not significantly worse than MSSM (secondo me)

- Wonderful playground to sharpen our ability to do physics with the LHC

# Anthropic approach to hierarchy problem(s)

- Assume we inhabit one of **very many** possible universes
- The value of some physical quantities may have environmental origin and **not be** fundamental

▲ *' Structure Principle '* :

Weinberg '87

- The value of $\Lambda_{cosm}$ is not fundamental
- $\Lambda_{cosm}$ should be small enough to allow the formation of galaxies

If the distribution of $\Lambda_{cosm}$ is reasonably flat then one expects

$$\Lambda_{cosm} \sim \Lambda_{crit}$$

Martel,Shapiro,Weinberg '98

Riess et al., '98
Perlmutter et al., '98

Type Ia Supernovae data

$$\Lambda_{cosm} = 0.1\,\Lambda_{crit}$$

!!

- Recent advances is string theory indicate that the many vacua hypothesis (The Landscape) may indeed be realized in Nature

Bousso,Polchinski ‘00
Giddings,Kachru,Polchinski ‘01
Kachru,Kallosh,Linde,Trivedi ‘03
Susskind ‘03
Douglas ‘03

- The anthropic viewpoint has also been applied to the electroweak hierarchy problem

Agrawal,Barr,Donoghue,Seckel ‘97
Arkani-Hamed,Dimopoulos ‘04
Giudice,Romanino ‘04

Split SUSY ←

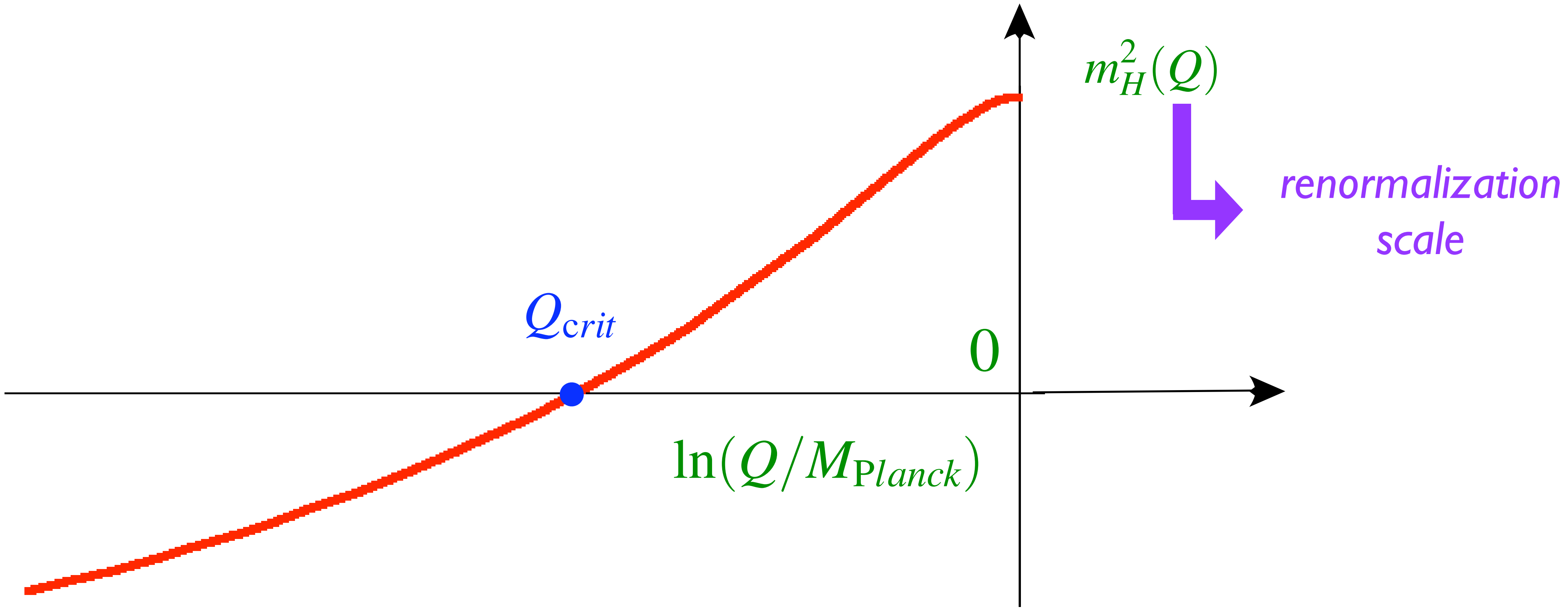
↓

squarks and sleptons = superheavy

gauginos and higgsinos ~ weak scale (to provide DM and unification)

distinctive gluino phenomenology

# Back to SUSY



$$m_H^2|_{\rm phys} = m_H^2(Q = m_{SUSY})$$

*natural situation* → $Q_{crit} \gg m_{SUSY}$ → $m_H^2|_{\rm phys} \sim -m_{\tilde{t}}^2 \sim -m_{SUSY}^2$

*situation favored by data* $-m_H^2|_{\rm phys} \ll m_{\tilde{t}}^2$ → $m_{SUSY} \simeq Q_{crit}$

**Why?**

# Assume overall SUSY scale value $m_{SUSY}$ is environmental

Arkani-Hamed, Giudice,Rattazzi '05

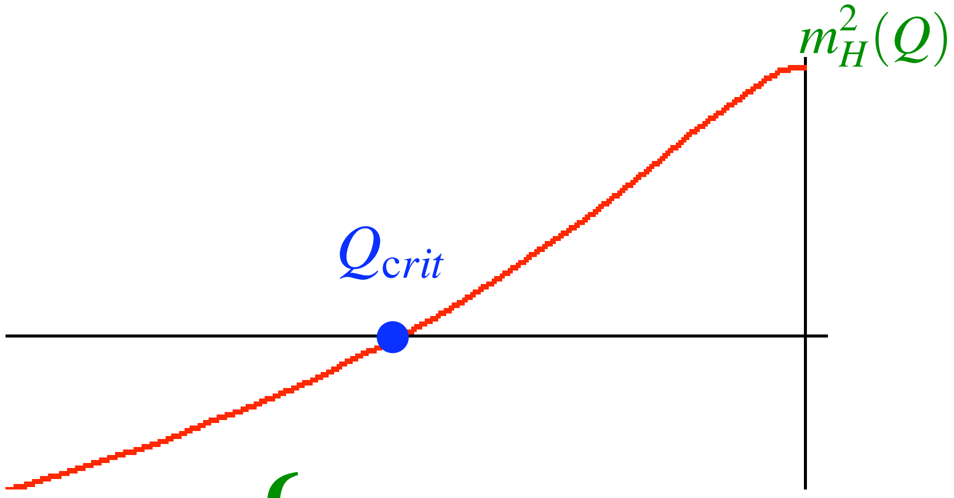
*for simplicity*
*assume at* $Q = M_{\rm Planck}$ ➡

$$\left\{ \begin{array}{l} m_i^2 = c_i \, m_{SUSY}^2 \\ \alpha_i, \ \lambda_{top} \ldots \end{array} \right.$$

$c_i$, $\alpha_i$, $\lambda_{top}$ → *fixed*

⇓

$Q_{crit}$ *is also fixed*



2 cases
$$\left\{ \begin{array}{llll} m_{SUSY} > Q_{crit} & \rightarrow \ m_H^2|_{\rm phys} > 0 & \rightarrow \ <H>=0 \\ m_{SUSY} < Q_{crit} & \rightarrow \ m_H^2|_{\rm phys} < 0 & \rightarrow \ <H> \neq 0 \end{array} \right.$$

*we do not live here!*

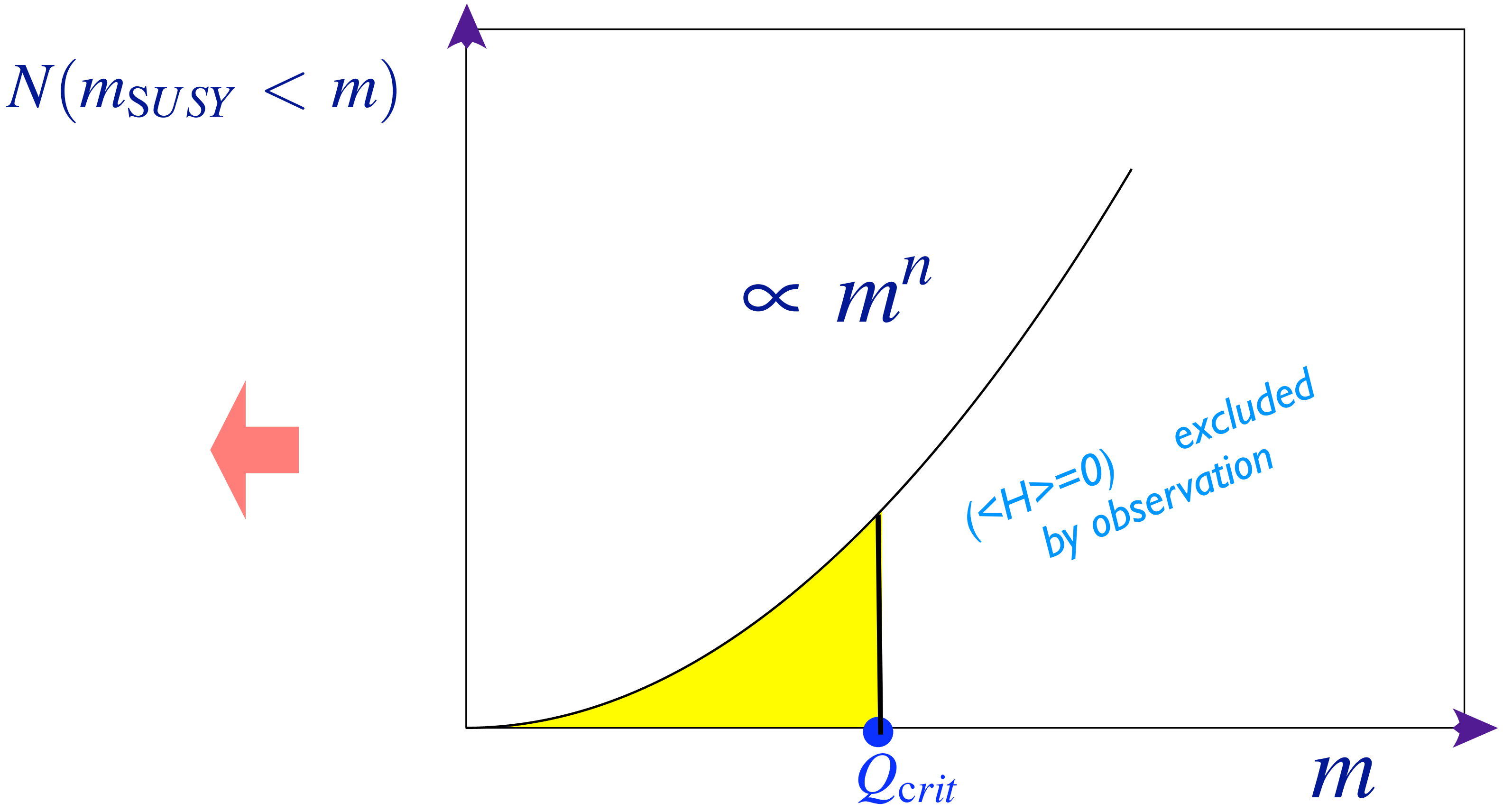
Natural expectation: $m_{SUSY} \sim Q_{crit}$ ➡

$$\boxed{\frac{m_H^2|_{\rm phys}}{m_{\tilde{t}}^2} \simeq \frac{3\lambda_t^2}{2\pi^2} \ln(\frac{m_{SUSY}}{Q_{crit}}) \sim -\frac{3\lambda_t^2}{2\pi^2}}$$

## more precisely

$$< \frac{m_H^2|_{phys}}{m_{\tilde{t}}^2} > \simeq \frac{3\lambda_t^2}{2\pi^2} \times \frac{1}{n}$$

easily 0.1 to 0.01
but not much less



SUSY will look tuned because there are many more vacua with $<H>=0$ than there are with $<H>\neq 0$

A specific type of tuning is ``predicted” and related to more fundamental properties (vacuum statistics and the mediation of SUSY breaking)

## The scenario will be disfavored or even falsified if SUSY will turn out tuned in a different way

Ex.: in the window with ``light'' sparticles and hardly visible lightest Higgs with $m_h < 115\,GeV$ the scenario would be disfavored

If $Q_{crit} \gg 1\,TeV$

or

If $\frac{d\,m_H^2}{d\,\ln Q} < 0$

just above SUSY scale

**the scenario will be ruled out**

# Summary

- LEP/SLC data ⇒ many new proposals for calculable EW breaking
- In practically all cases there are two energy scales
  - $\Lambda_{NP} \sim 1\mathrm{T}eV$ *mass of particles regulating Higgs mass divergence*
  - $\Lambda_{strong} \sim 10\mathrm{T}eV$ *scale of the underlying new dynamics*
- Some tension with EWPT data exists already, but not dramatic yet

  *(can be relaxed at the price of some extra complication)*
- LHC at 14 TeV will test the lower layer $\Lambda_{NP}$
- Comparing to SUSY
  - → *Dark Matter: non so bad*
  - → *Unification: not as good*

- Supersymmetry and the Anthropic Landscape:

  - new viewpoint offering some interesting considerations and even some dramatic signal, like in Split SUSY.

  ...but be careful not to get on a theoretical slippery slope !

**Luckily the age of speculations will end in a couple of years**