Alessandro Strumia, talk at

“Is SUSY alive and well?”

No

Madrid, September 29, 2016.

European Commission
Horizon 2020
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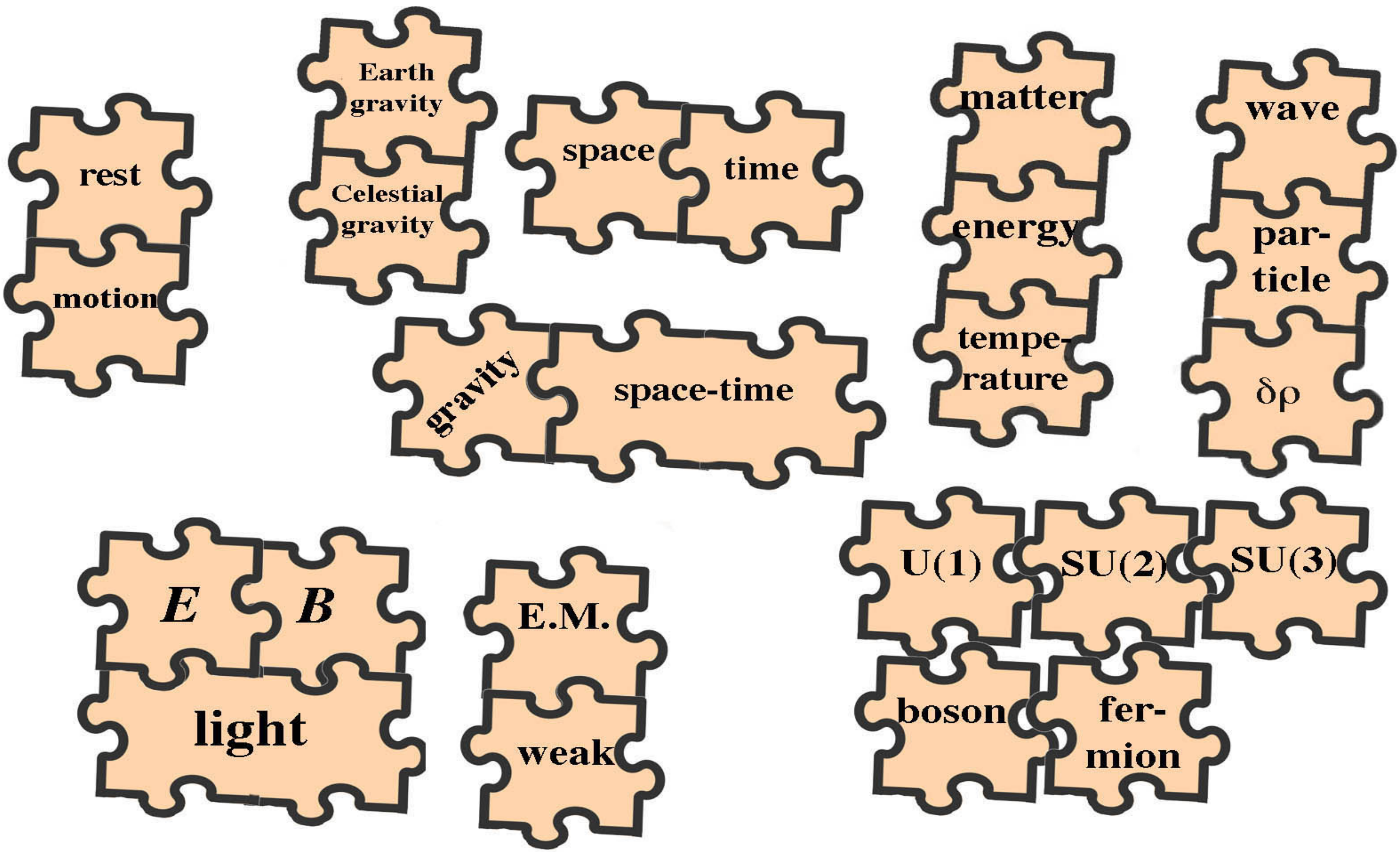
Was SUSY alive and well?

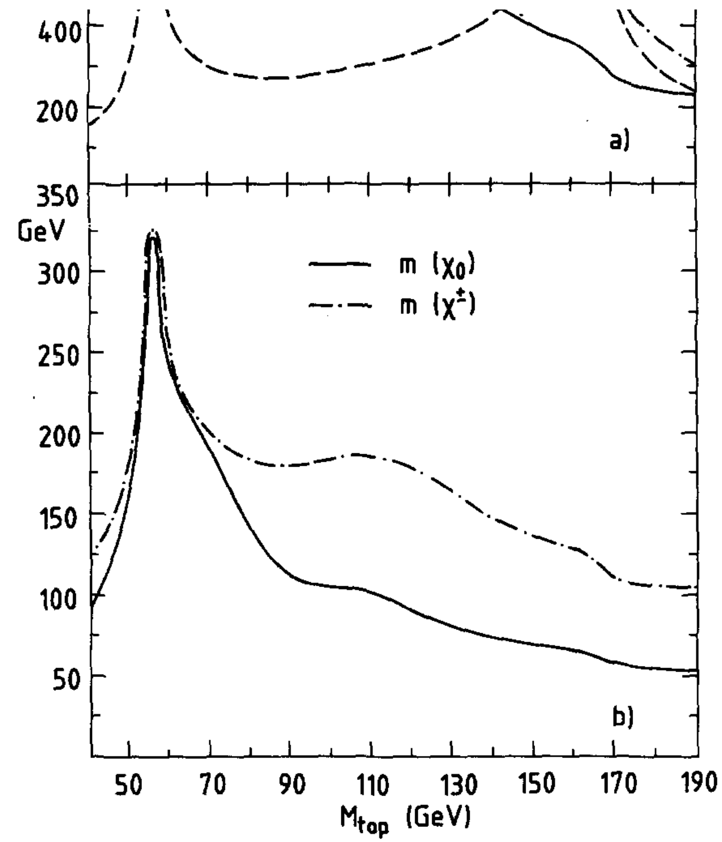
Yes

And for a good reason



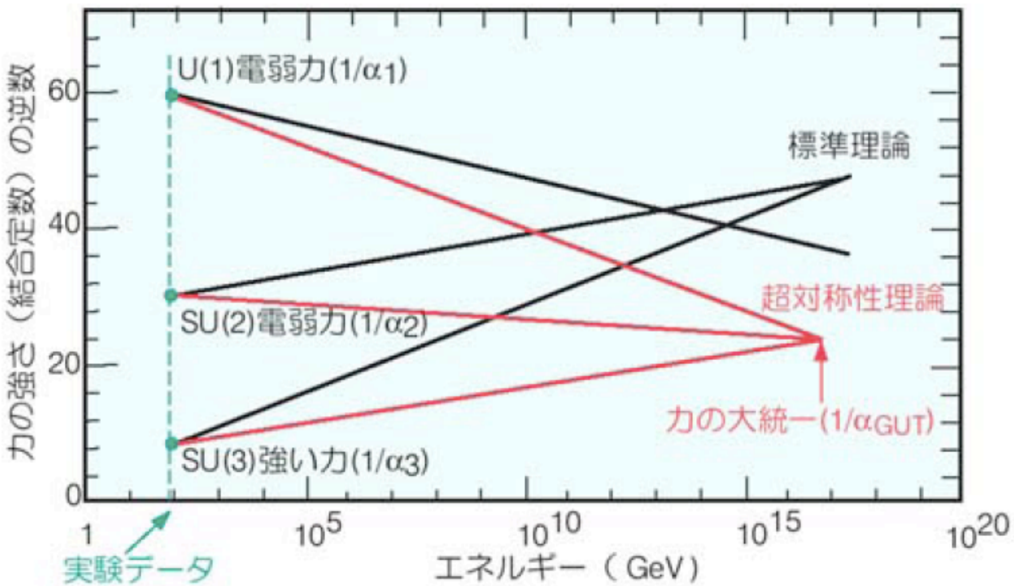
1988: naturalness bounds on sparticles

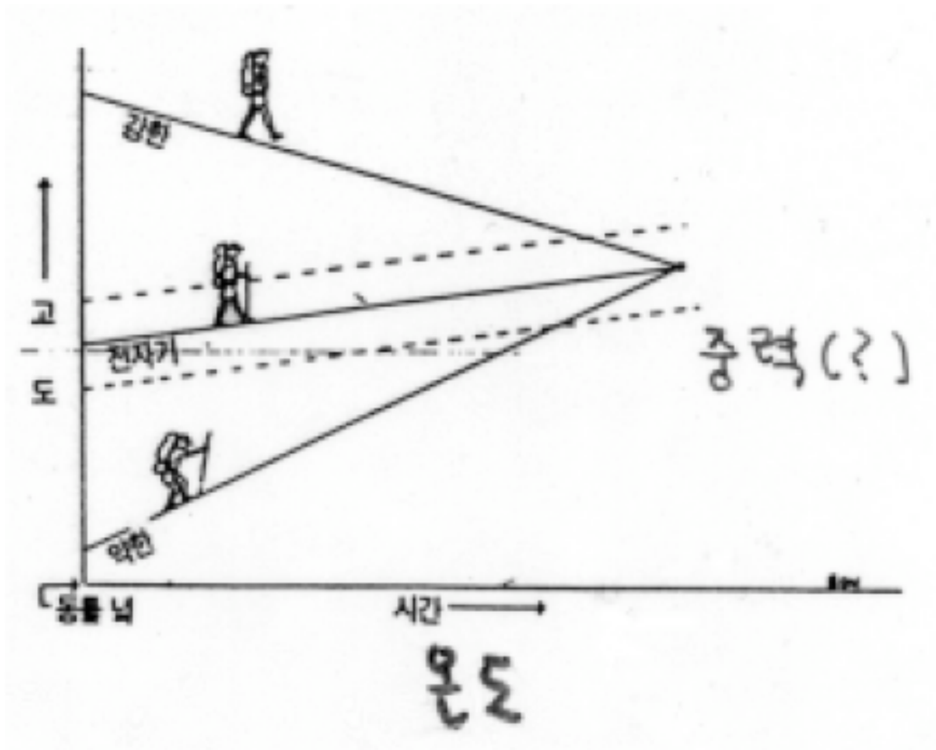
"Barbieri was grilling a kidney without enough fire, a student was going around excited like a stock operator, telling 'chargino 200! gluino 400!'"



Rattazzi expressed doubts but Barbieri said "bischero this a delicacy, eat it". So "it tasted weird, but my advisor thought it was gourmet, I ate it".

1990: LEP1 data speak





'Neutralino' was synonymous of Dark Matter

1998: SK, LEP and cosmology speak

SUSY needs $Z_{2,3}$ and universal $\tilde{m}$ to get B, L, L_i that come for free in the SM. Even so, if $\tilde{m} \sim M_Z$, p decay at dimension 5 is problematic in minimal SU(5).

"LEP2 experiments pose a serious naturalness problem for supersymmetric models". [hep-ph/9811386]. "About 95% of CMSSM parameter space is excluded" i.e. [hep-ph/9904247]

$$p(\text{no SUSY at LEP}|\text{CMSSM}) = 5\%$$

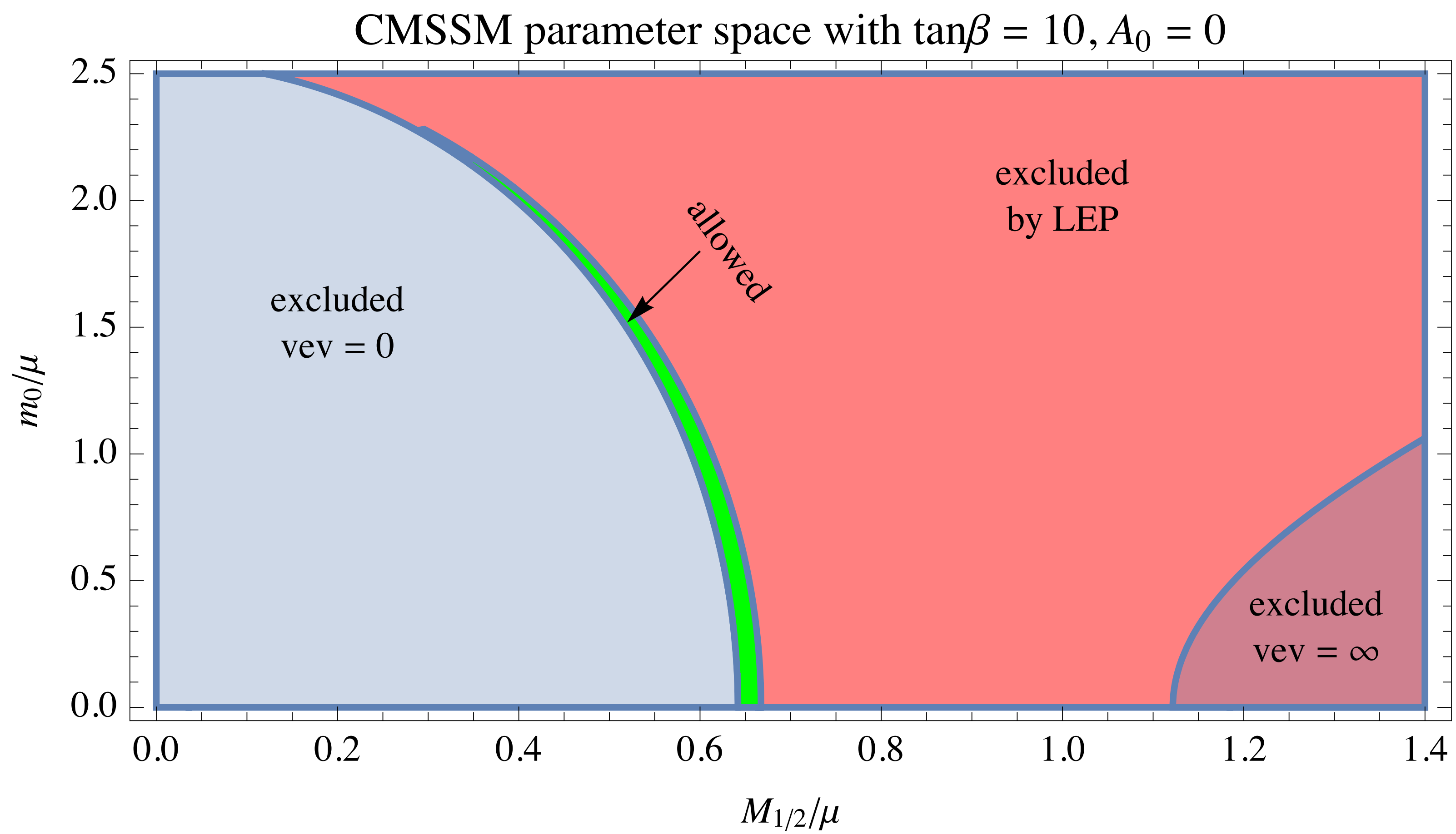
FT = Bayesian **probability** of numerical accidents. "The well known naturalness problem of the Fermi scale has gained a pure low energy aspect".

"The cosmological constant poses another serious unsolved problem, also related to power divergences". [hep-ph/0007265]

The CMSSM

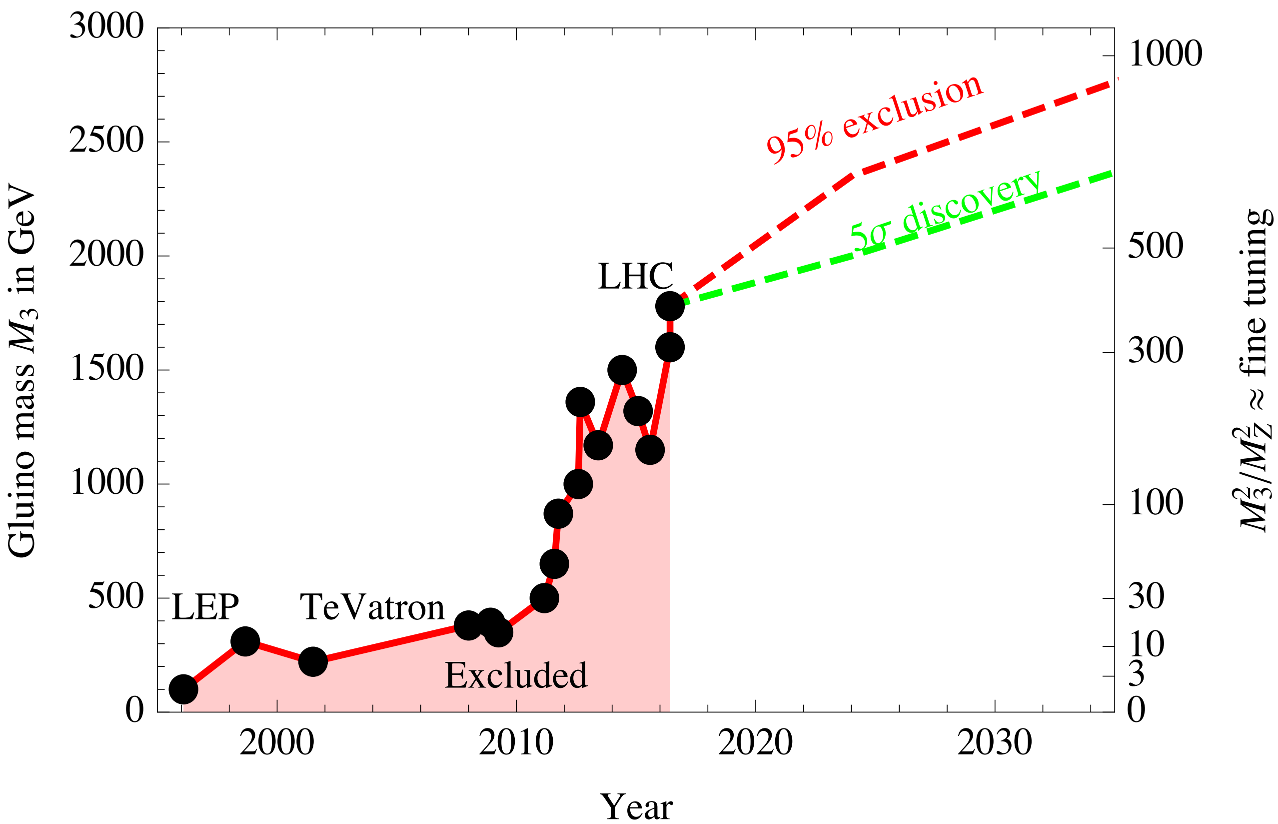
Use dimension-less ratios as parameters and fix the SUSY scale from

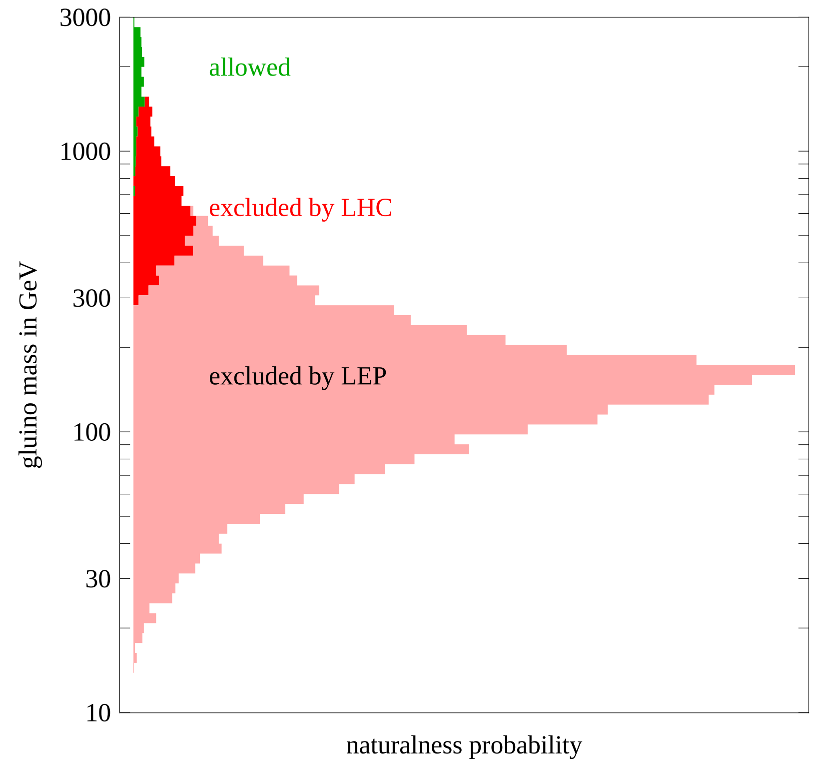
$$M_Z^2 \approx 0.2 m_0^2 + 0.7 M_3^2 - 2\mu^2 = (91\,\text{GeV})^2 \times (\frac{M_3}{110\,\text{GeV}})^2 + \cdots$$



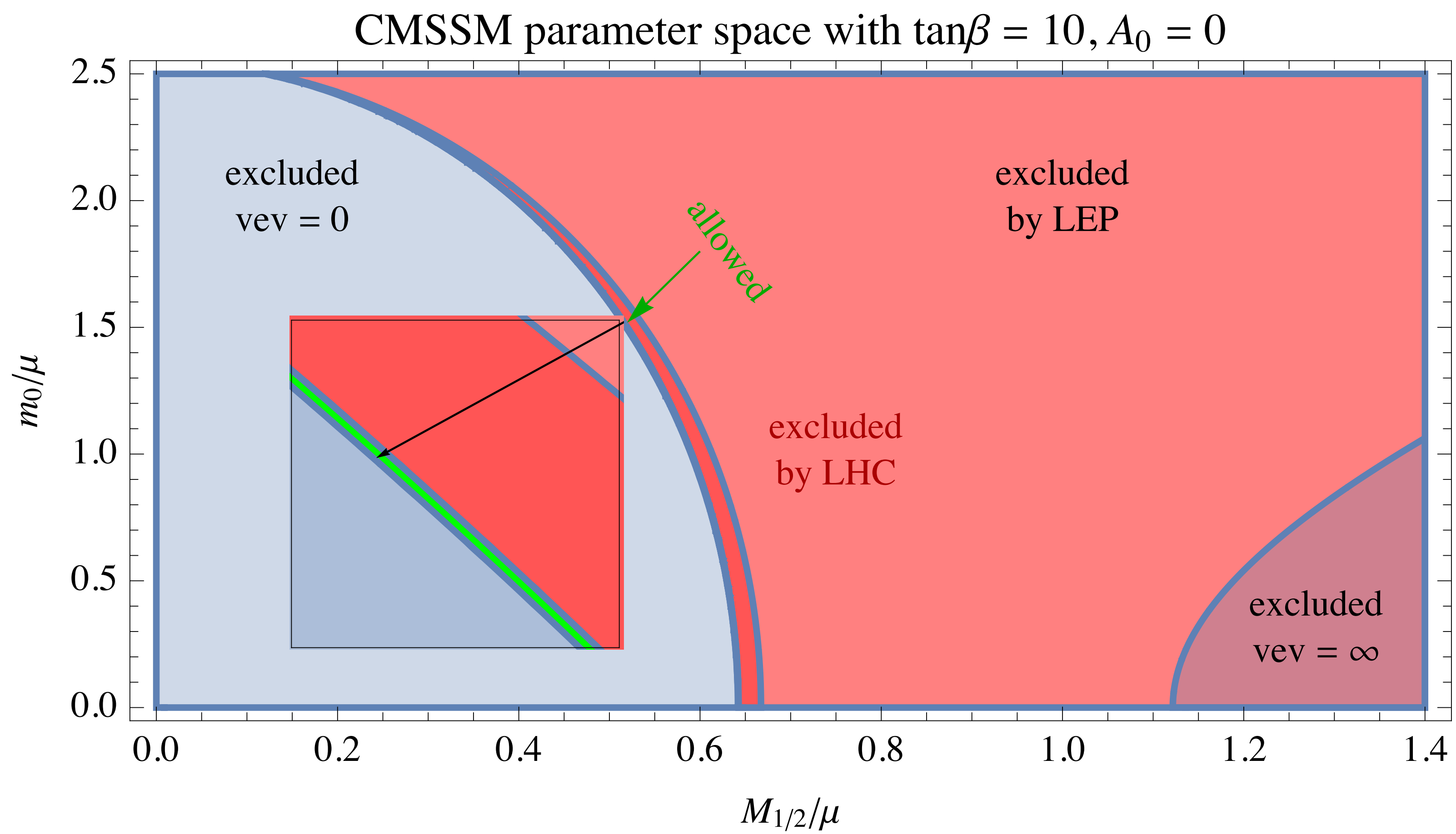
Main worry: so many sparticles at LHC that disentangling them will be hard.

2010: LHC data speak





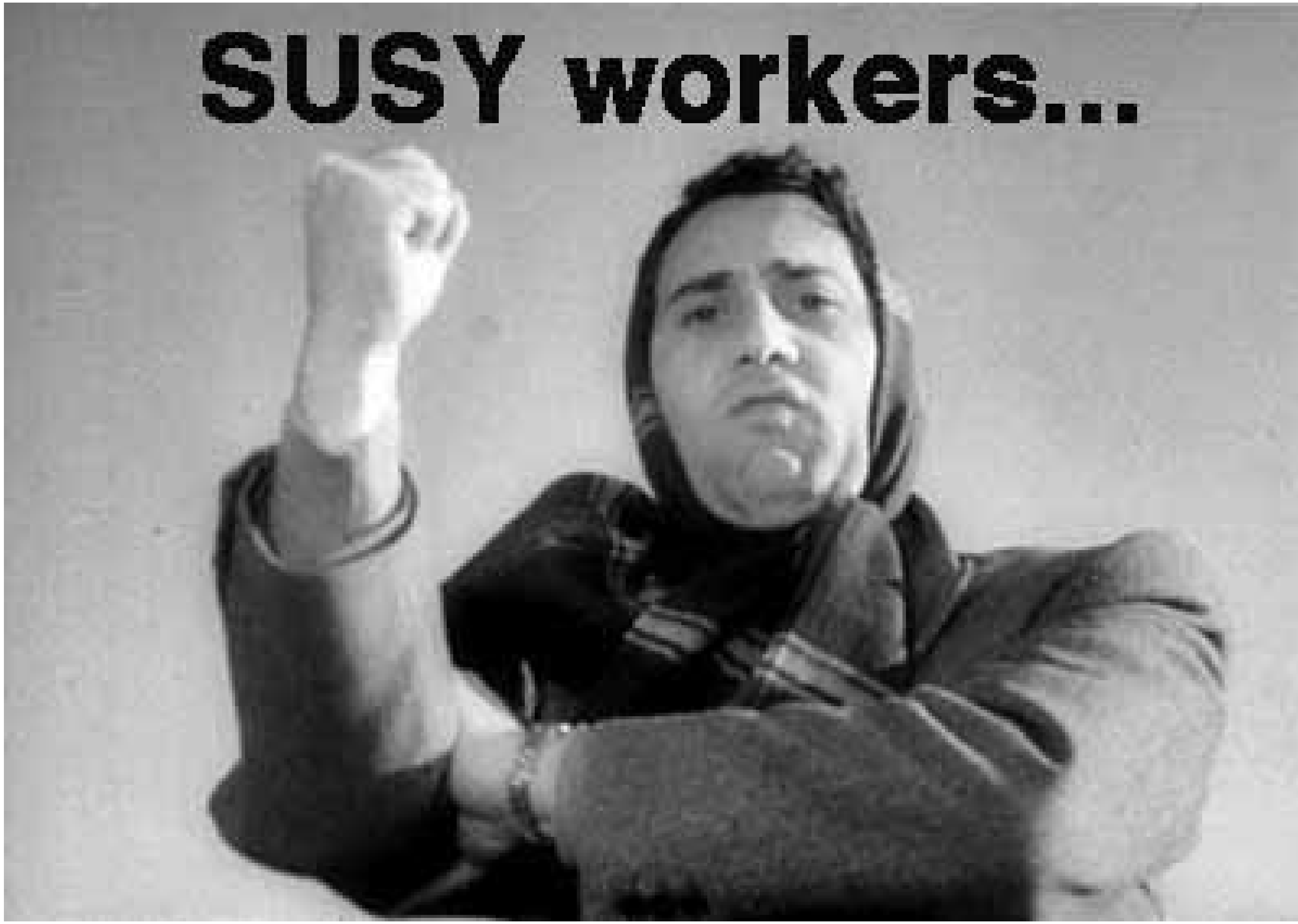
The CMSSM



Survives only only close to the critical line $v = 0$

Even one loop stop corrections start to be unnaturally big.

LHC data speak badly about SUSY

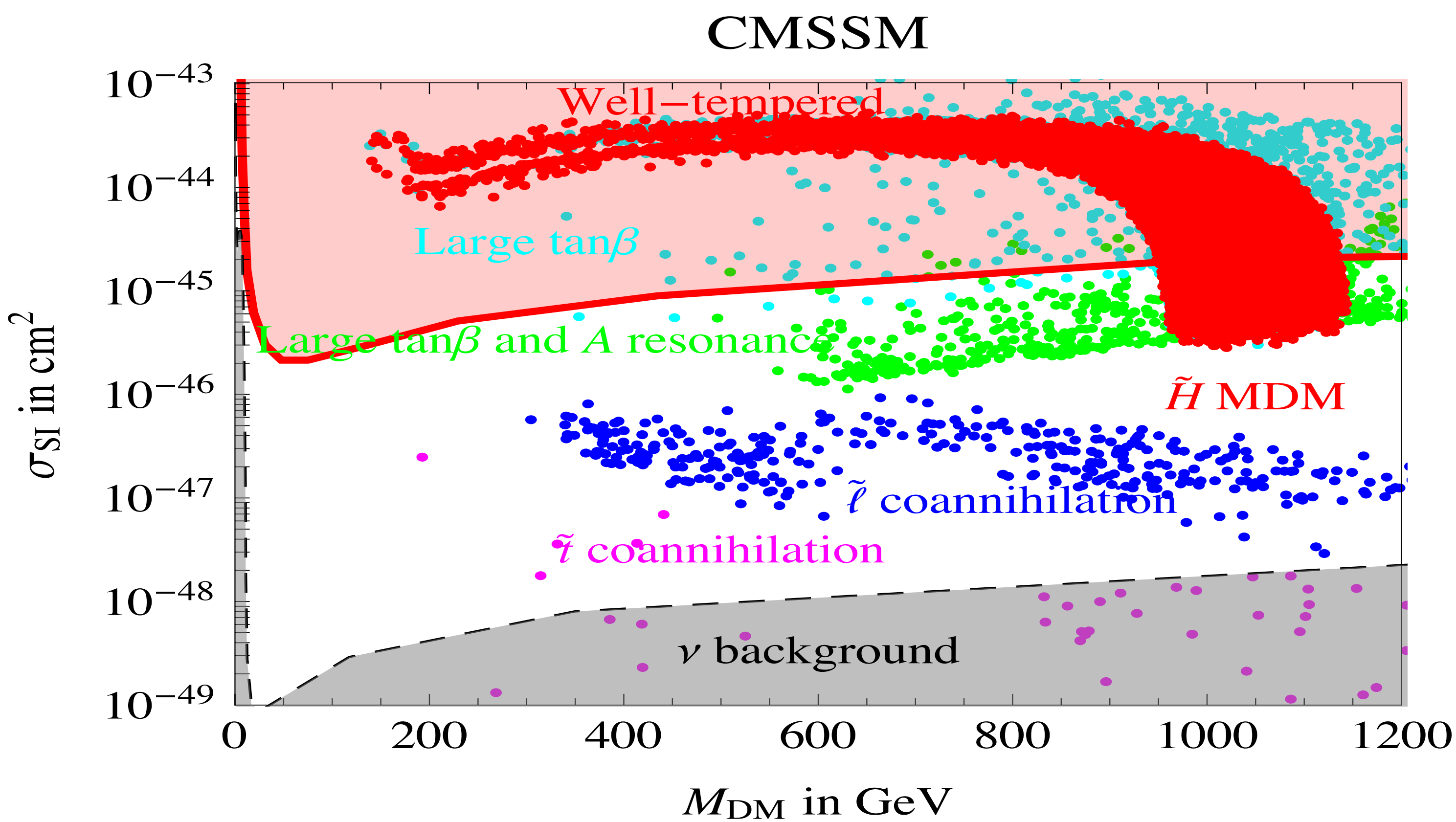


(Same message to workers on naturalness, diphoton...)

Dark Matter?

Thermal abundance: $$\frac{\Omega_{\rm DM}h^2}{0.11} = \frac{\sigma v}{0.1\,\text{pb}} \approx 1.$$

The CMSSM ‘**bulk**’ region where $\sigma v \sim e^4/4\pi\tilde{m}^2$ needs $\tilde{m} \sim 150\,\text{GeV}$. Excluded in the CMSSM. Dissecting the spherical cow, what remains is fine-tuned ‘**tails**’



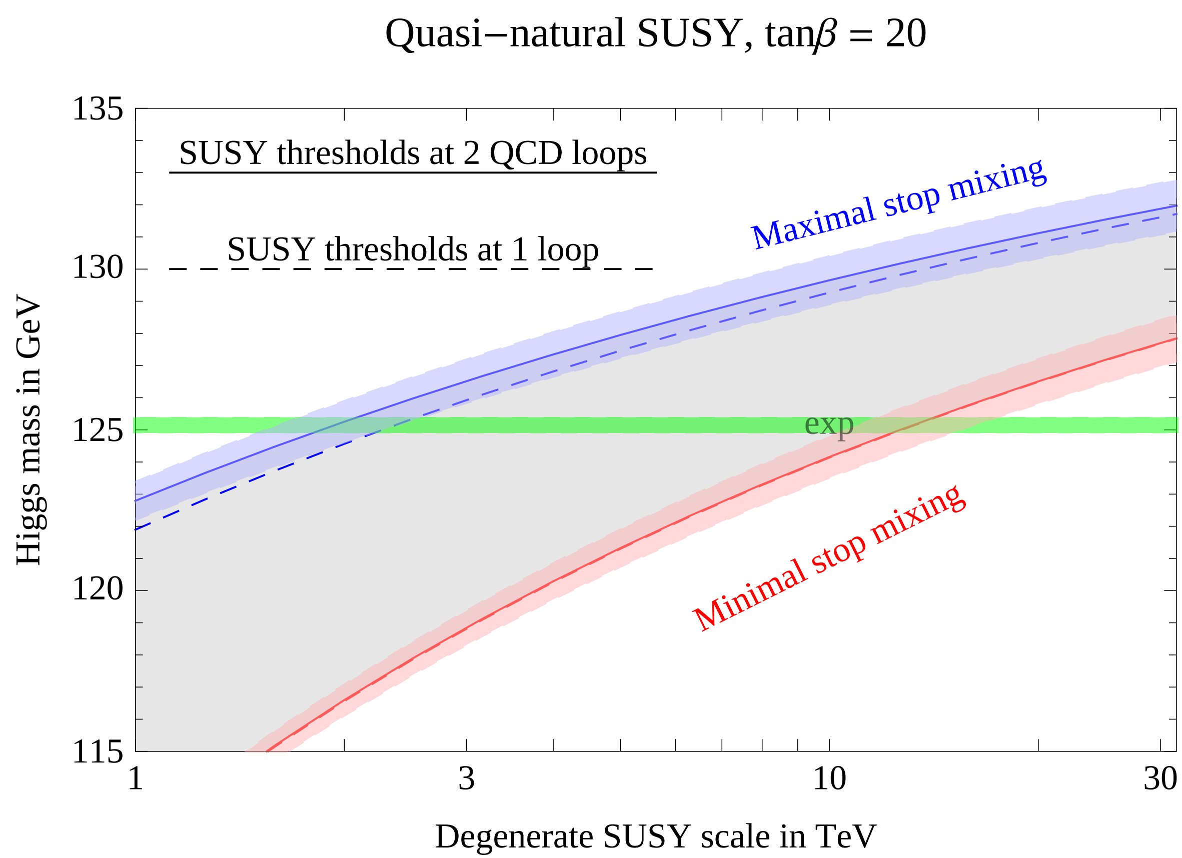
and ‘**Minimal Dark Matter**’ limit: higgsino at 1.1 TeV, wino at 2.5 TeV...

Higgs at 125 GeV?

The MSSM prediction for λ i.e. M_h can now be computed in a simpler way:
1) Weak scale: SM at 2 loops;
2) 3 loop RGE running up to $\tilde{m}$;
3) $\lambda = \frac{1}{8}g^2 c_{2\beta}^2 +$ 1-2 loop SUSY.

Sparticle corrections to y_t, g_3 can be neglected.

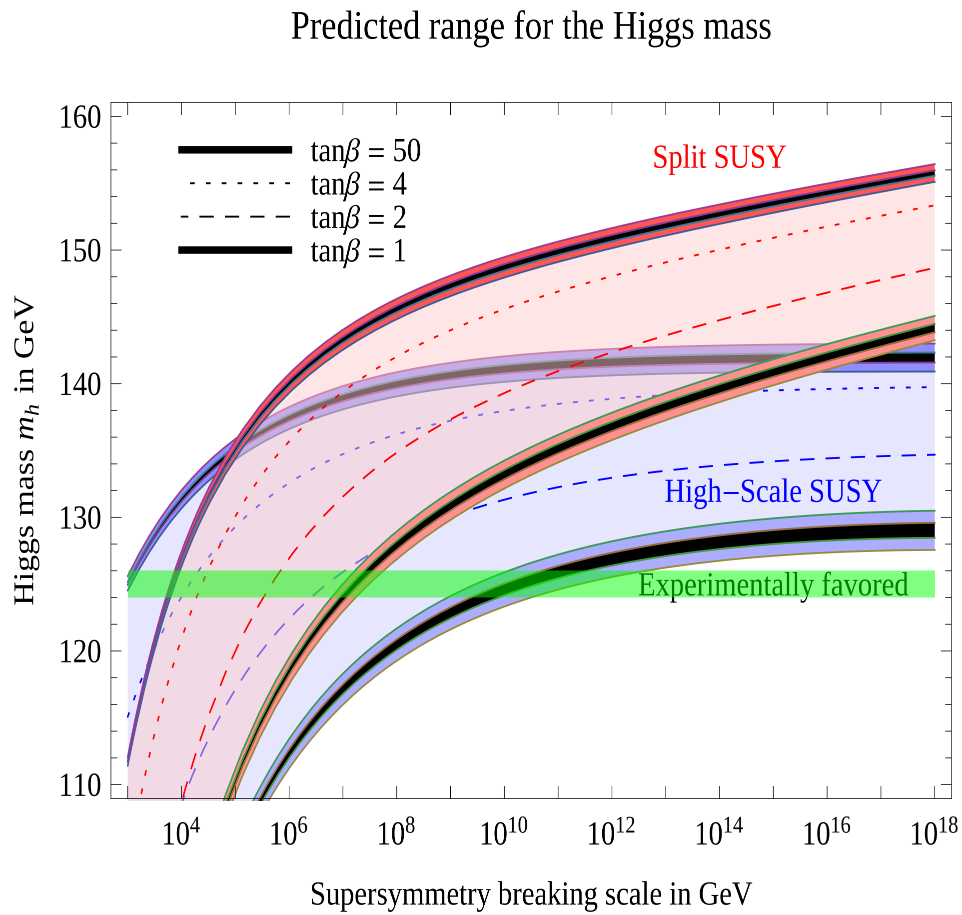
Result: predicted M_h gets lower and more precise, $\delta M_h \sim 1$ GeV



Multi-TeV stop, huger tuning

Options: USUSY or USUSY

U	**Ugly**	**Unnatural**
$\tilde{m}$	$\sim$ TeV	$\gg$ TeV
Naturalness	Bad	No
Higgs mass	Bad	Good
Dark Matter	Bad	Good
Unification	Bad	Good
Flavour	Bad	$\sim$Good
Models	Bad	Good
TeV signals	Yes	No
Makes sense?	Bah	An***pic?



For example mini-split: $\tilde{m} \sim 4\pi M_{1,2,3}$ with $\tilde{H}$ or $\tilde{W}$ as Minimal DM.

Does Unnatural SUSY make sense?

Does the anthropic multiverse justify Unnatural SUSY?

- $m_p \ll M_{\rm Pl}$ allows systems with $N \sim M_{\rm Pl}^3/m_p^3 \gg 1$ particles.
- $y_d v \approx \alpha_{\rm em}\Lambda_{\rm QCD}$ allows chemistry.

But natural solutions exist, difficult to argue that multiverse avoids them.

If we live in a multiverse with many low-energy SUSY vacua, the likely outcome is again natural SUSY with $\tilde{m} \sim M_Z$ (e.g. mini-split SUSY with $M_3 \sim m_p$).

If we live in a multiverse with many Planck-scale SUSY vacua, the likely low-energy physics is

- an anthropically acceptable alternative to the SM that does not involve an unnaturally light Higgs scalar;
- or (even within the Standard Model) a smaller y or a smaller $M_{\rm Pl}$.

To argue differently one needs to add ad hoc counting or DM restrictions.

Keep searching alternatives to anthropic nirvana

Subtle is the Lord

What is going on? We are confused but nature is surely following some logic

Data speak and tell Standardissimo Model

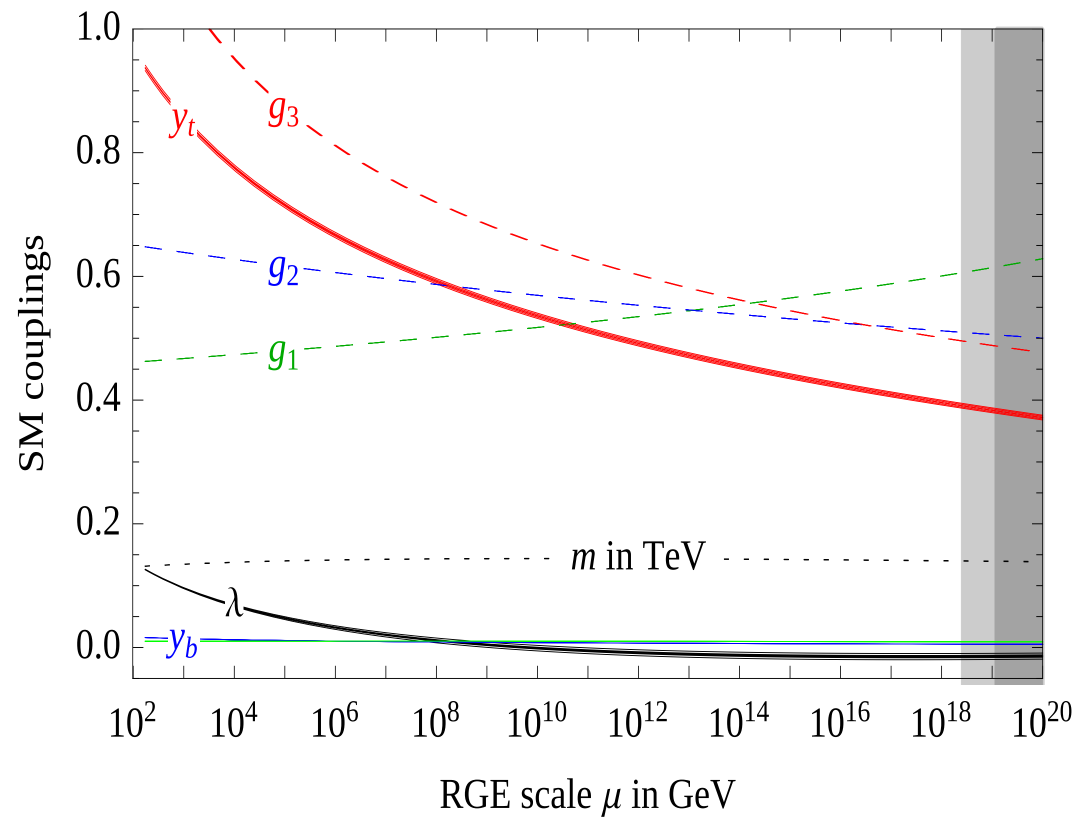
We now have all SM parameters, let's assume SM and see what happens.

Facts:

1: SM can be extrapolated above $M_{\rm Pl}$.

2: $\lambda(M_{\rm Pl}) \approx 0$ at $\approx 2\sigma$.

3: $\beta(\lambda)$ vanishes around $M_{\rm Pl}$.



Scalarphobic vs scalarfriendly

Scalarphobic theorists believe that scalars are unnatural because $\delta M_h \sim g_{\rm SM}\Lambda$. But power divergences give no physical effect. In quantum mechanics it's better to stick to observables, without adding realism. Maybe scalarphobic theorists over-interpret equations, as happened with the æther: "wave $\Rightarrow$ medium".

Scalarfriendly theorists can try new roads:

Finite naturalness. Upper bounds on new physics from naturalness of physical corrections: $\delta M_h \sim g_{\rm new} M_{\rm new}$ at 1/2/3 loops. Allows SM + DM + neutrino masses + baryogenesis + inflation + axions. No GUT, no string.

Dynamical generation of the weak scale. $\int dE\, E = 0$ if physics is dimensionless. Simple models where a vev ($\lambda < 0$) or a condensate ($g \to \infty$) generates M_h and DM. Even models with 0 new parameters: predict $m_h^2 < 0$, $M_{\rm DM}$, $\Omega_{\rm DM}$.

Gravity: $\delta M_h \sim E^2/M_{\rm Pl}$: natural at $E \lesssim \sqrt{M_h M_{\rm Pl}}$. New physics there could be the spin 2 negative-norm (?) graviton of agravity = dimension-less renormalizable gravity, where $\delta M_h \sim g^2_{\rm gravity} M_{\rm Pl}$.

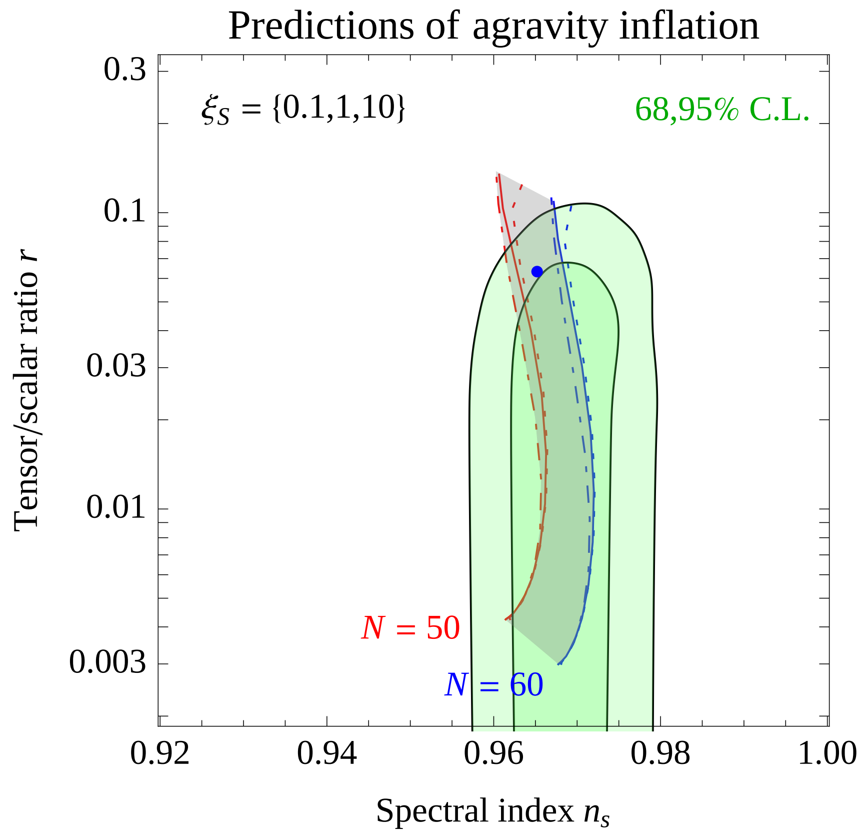
Dynamical generation of the Planck scale.

Inflation. Dimension-less theories allow super-Planckian vevs and give quasi-flat potentials:

$$\epsilon, \eta \sim \beta, \qquad P_R \sim M_h/\bar{M}_{\rm Pl}.$$

Total Asymptotic Freedom. Theories valid up to infinite energy with all couplings g, y, λ flowing to zero. No cut-off, predictions, e.g. $g_Y = 0$, $M_t = 186\,\text{GeV}$, $M_\tau = 0$ in the SM. Weak-scale extensions of the SM into $\text{SU}(3)^3$.

Fundamental models of composite Higgs.

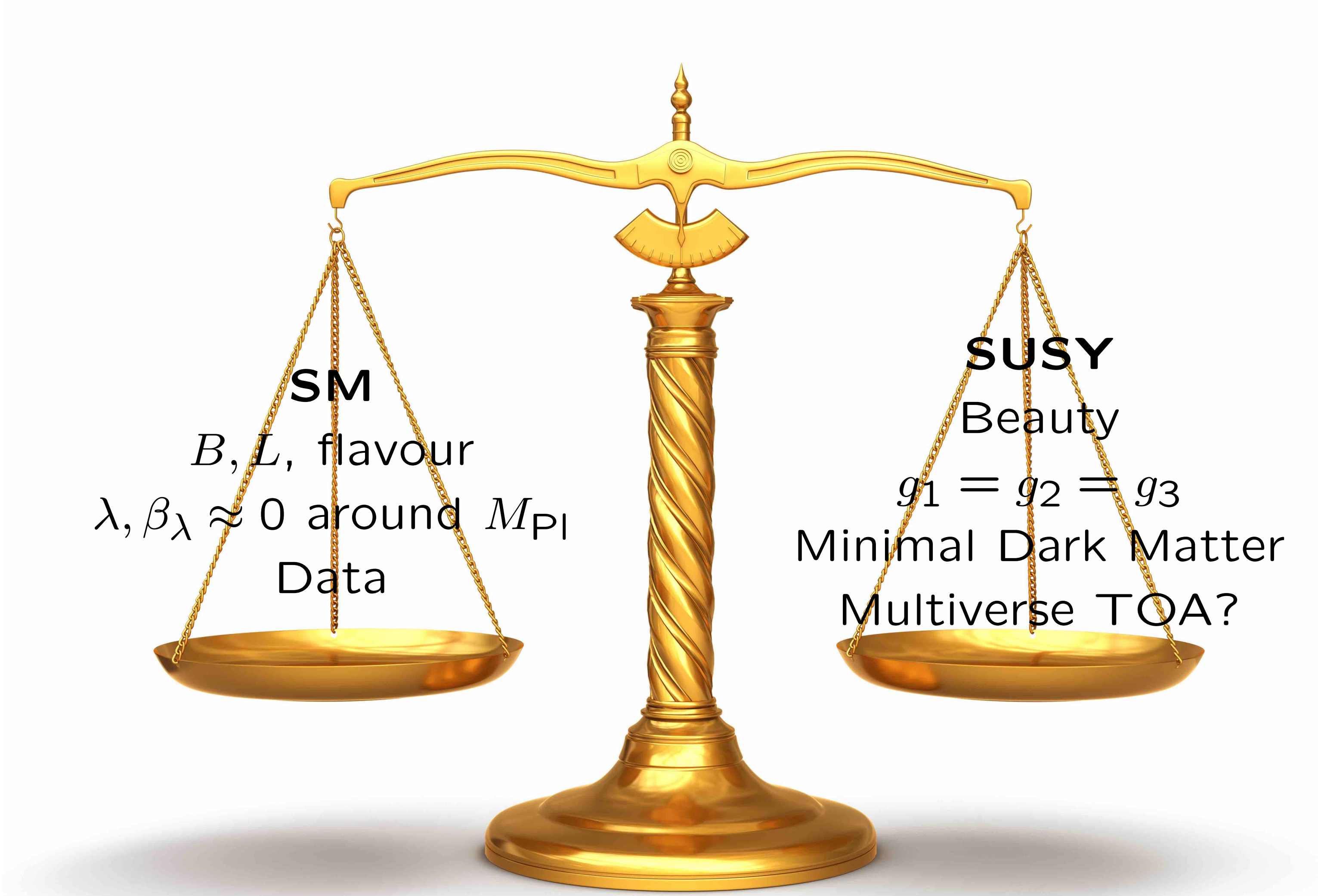


Tony Gherghetta said: “Wow! Better than Trump!”
But: cosmological constant?
$\text{U}(3)^5 \to \text{U}(1)_{B,L_i}$ suggests some unification.

Is SUSY well?

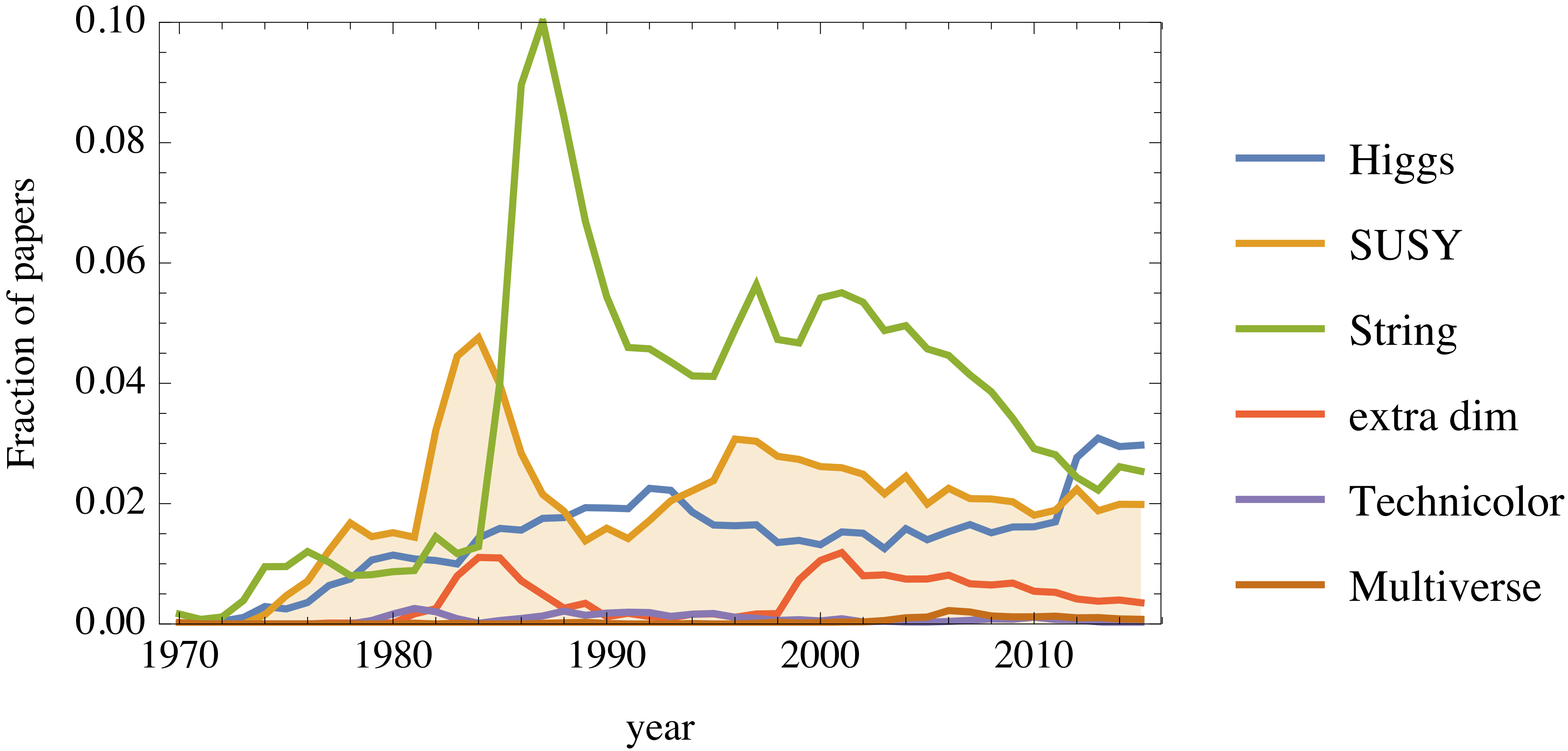
No

Giving up naturalness maybe better than giving up the rest



Is SUSY popular?

Yes



Is SUSY alive?

"Ibis redibis non morieris in bello"