SUSY2019
Corpus Christie
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Outline and partial summary – 240 talks – THANKS, BARBARA and …

- SUPERPARTNERS? – DARK MATTER? – *WHY PARTICLE PHYSICS IS SUPER-EXCITING NOW!*
- Top-down framework – We live in the ground state (vacuum) of a compactified string/M-theory – Cvetic, Cicoli, Ooguri, Li, Ratz, GK, Zavala, Nanopoulos, Quiros
- Bottom-up – Baer, Olive, Heinemeyer, Carena – "Intelligent naturalness"
- Higgs physics – what have we learned? – Is the Higgs boson *THE* Higgs boson (yes)?
- *Don't ignore gravity – UV completeness changes expectations – is the FINAL THEORY close?*
- Origin of scales – example of derivation of scales in compactified M-theory
- Hierarchy problem – DON'T GIVE UP ON CONNECTING TO LAWS AT PLANCK SCALE
    - Naturalness? – THE OPPOSITE OF NATURALNESS IS HAVING A THEORY – Baer, Olive, Sven, yes, it's natural
    - WHERE ARE THE SUPERPARTNERS? – example, superpartner masses in a compactified M-*theory*
    - *→Should have not expected to find gluinos lighter than about 1.5 TeV – maybe discover at upgraded LHC – FUTURE HADRON COLLIDER CRUCIAL TO SOLVE HIERARCHY PROBLEM [MAYBE 2XLHC IS ENOUTH]*
- Dark matter – WHAT IS THE DARK MATTER? – axions, hidden sector matter – LSP not stable
- Cool results for ultralight particles, long-lived particles – Pospelev, Curtin, Feng
- Future colliders? – Tao Han – Yes – GK, Hawking 1804.00682
- De Sitter Vacuum? - YES! – Acharya, GK, et al,2008; Cicoli – hidden sector matter uplifts
- Neutrino Physics – Yes –Scholberg, King , Dev – Dune , hyper K
- B decay anomalies? "Don't trust data until it is confirmed by a good theory" - Eddington
- Final remarks and perspectives – There will be many more susyXXXX

Consider the Standard Model:

– A relativistic quantum field theory

– A powerful and beautiful theory, an effective theory at the electroweak scale

- Describes all we perceive

- But much is still missing to make it a "Final Theory"

Steven Weinberg, 1992, “Dreams of a Final Theory”

Stephen Hawking, Lucasian Chair Inaugural talk, 1980 – “Is the end in sight for theoretical physics?”

Maybe no new ideas, ingredients needed to write the final theory – that’s now a defendable argument (I am about to do that) – just understand what we have better - work hard on main questions

How close are we to learning the Final Theory? – need to know DATA for dark matter and hierarchy problem – need better understanding of compactified string theories

Note historical example – in 1970 particle physics complete chaos, people leaving field, no field theory courses – by 1974 the Standard Model was completely in place and compelling – depended on ‘t Hooft proving renormalizability of non-Abelian Yang-Mills theories – analogous situation now?

FINAL THEORY VS THEORY OF EVERYTHING (ToE)

- ❖**FINAL THEORY** a relativistic quantum field theory of the Standard Model forces and particles including gravity – currently many issues solved, and *the rest are being worked on* – **COULD NOT MAKE THAT STATEMENT BEFORE ABOUT 20 YEARS AGO – more clear now**
- ❖Especially **what is the dark matter**, and **where are the superpartners** (to understand the hierarchy problem), both in sight
- ❖THEORY OF EVERYTHING asks for more more – quantum theory unique, not changing? – Standard Model inevitable? – black hole information problems – multiverse? – three space dimensions? – turbulence …

Today "Final Theory", ignore ToE

Now the most exciting time in 4 centuries to be doing particle physics

For most of 20th century, people had limited goals.

- In recent decades the boundaries of physics have expanded
- Began in 1970s with success of Standard Model, discovery of idea of supersymmetry, and approaches to unification of forces
- Then discovery of inflation and string theory in 1980s

PREVIOUS LIMITS ON GOALS DISAPPEARED (but you and your professors were trained about the older ones)

- "Scientists of the past were not just like scientists of today who didn't know as much as we do. They had completely different ideas of what there was to know or how you go about learning it."

  - Steven Weinberg

Wonderful time to be in particle physics!

- SM completed with Higgs physics, data and theory

- **Soon dark matter – took about 35 years to get to the current stage of probing nature – older detectors powerful, new kinds of detectors emerging – then signal – then untangle what DM actually is – calculate relic density**

Wonderful time to be in particle physics!

And colliders *will* get to how the hierarchy problem is solved (see below) – wonderful that civilization and science getting to the needed next stage (could have failed, as in the U.S.)

Wonderful time to be in particle physics!

Compactified string/M-theories have Yang-Mills Abelian and non-Abelian forces, chiral quarks and leptons, supersymmetry, dark matter candidates, etc – all the features needed, and UV complete

- **Theory reaching exciting new levels**

Who would know if we were close to a Final Theory?

- Experts in SM?
- Experts on detectors?
- Experts on neutrino physics?
- Experts on dark matter physics?
- Experts on string theory – string theorists study theories, not the world – mostly allergic to 4D – mostly don't know about hierarchy problem or dark matter?
- String phenomenologists? – Maybe!

- Sadly, too many string theorists not working on Final Theory, but on ToE – string theorists study theories, not much 4D ones – too many phenomenological theorists ignore need for UV completeness, probably working in swampland

The central problem in particle physics today is the hierarchy problem, as it has been for over four decades.

- Steven Weinberg wrote “for over fifteen years the hierarchy problem has been the worst bone in the throat of theoretical physics” *in 1992!*
- It is central because it points from the Planck scale, the natural scale for formulating a theory, to the electroweak (EW) scale and TeV scale, the present scale of experiments.
- But knowing the correct approach to the hierarchy problem is also crucial if we are to make theories that have a UV completion.
- The hierarchy problem is not a paradox. It is a mystery, and we expect to learn the solution when we finish the book.
- If we give up connecting to the Planck scale, we give up on obtaining a deep and comprehensive understanding of the laws of nature.

1985 – Green and Schwarz - String theory formulated in 10 (or 11) space-time dimensions, in order to have a mathematically consistent theory of gravity(!)

- **But we live in 4D!**

- **To describe our world: separate 10D (11D) into 4 large dimensions that form our world, plus 6 (7) small Planck-scale size dimensions forming a manifold that we don't directly experience [string or M-theory]**

- **Projecting to 4D called "COMPACTIFICATION" – unavoidable**
- ***We live in the ground state of a compactified string/M-theory***

Small dimensions – size, shapes, orientations – determine much about the physics of our world – If we did not know about gravity, or the strong force, or the electroweak force, or quarks, or families of particles, or supersymmetry, or small extra dimensions, and more, compactified string theory would make us think of them and look for them

- **Planck scale ok – in a particular theory we can calculate predictions for EW scale and test them – in asymptotically free theory can extrapolate data to Planck scale ~ 10^{18} GeV, via renormaliztion group equations (RGEs)**

- **Don’t have to be at Planck scale to test ideas about physics there – can test whether there was a big bang even though no one there, dinosaur extinction, etc**

- **If someone talks about testing “string theories” object immediately – string theories in 10D, but can only formulate tests in 4D, for *compactified* string theories**

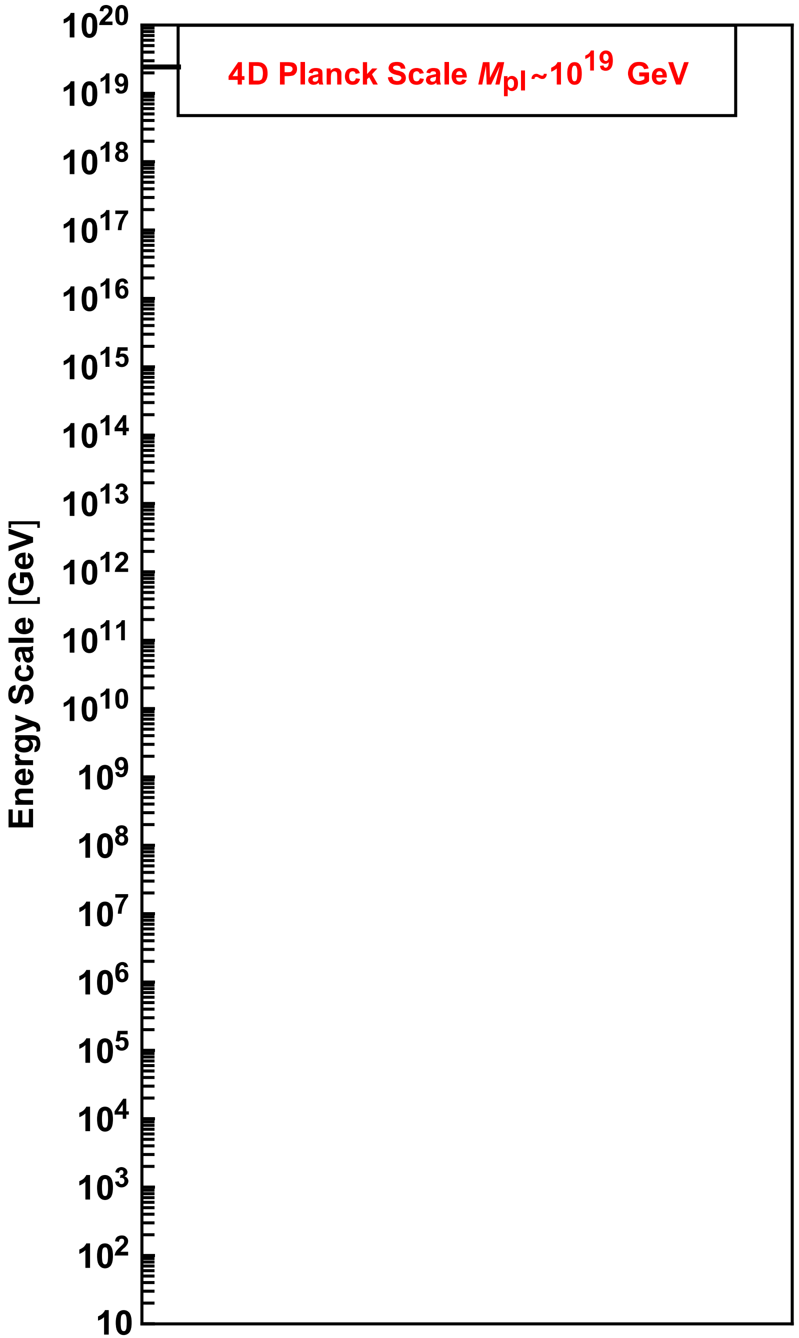
1995 – Edward Witten – generalize to M-theory with 10 space dimensions – formulate at or near Planck scale

SEVERAL POSSIBILITIES for compactifying – Heterotic – type II – M-theory – etc

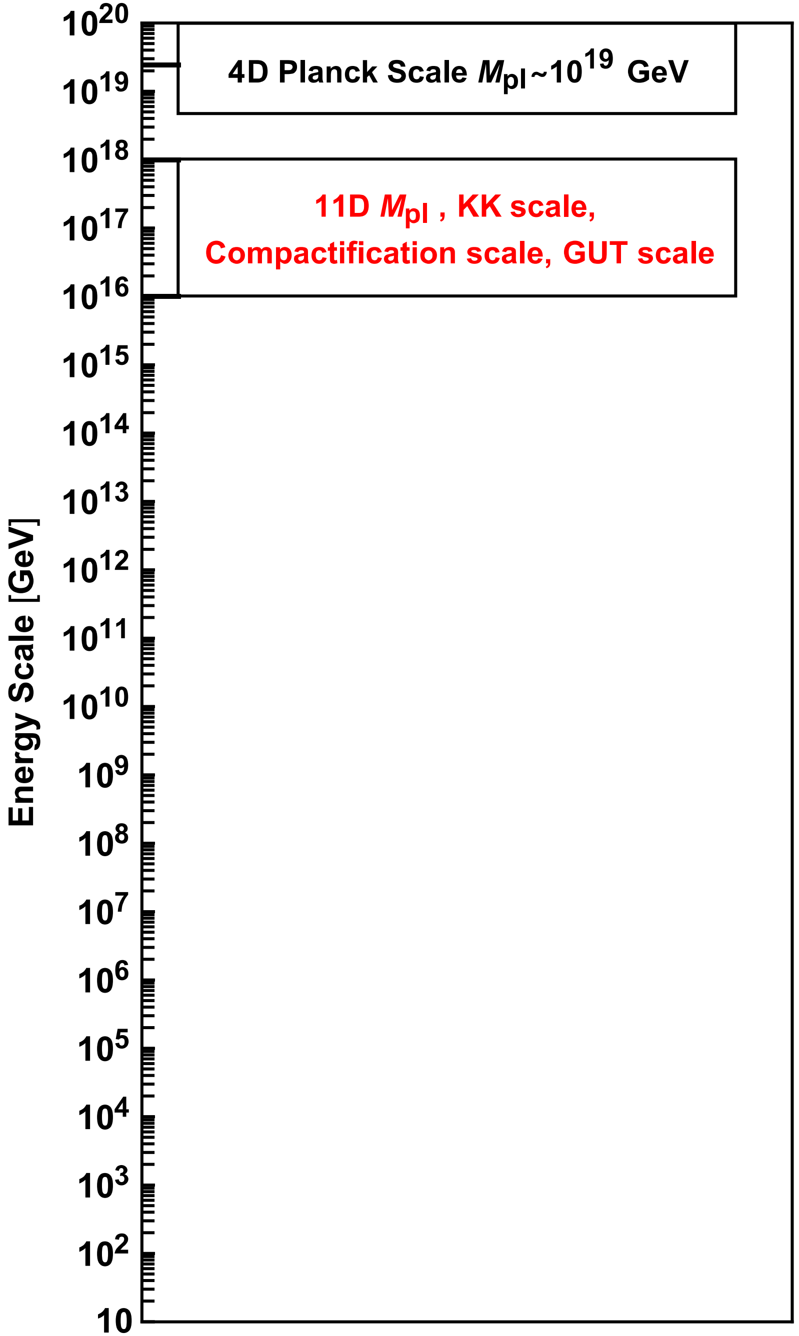
Just as various Yang-Mills theories were considered for the Standard Model in early 1970s, try these one at a time – probably different predictions – then SM emerged after testing, now maybe one of these will – looks like their predictions are different

- **Can we understand the all the scales? Susy breaking? Inflation?**
- **Planck scale only natural input**
  - **Universes $\sim 10^{-33}$cm diameter – anything larger needs explaining → inflation**
  - **Universe lifetimes $\sim 10^{-44}$sec – longer needs explaining → inflation**

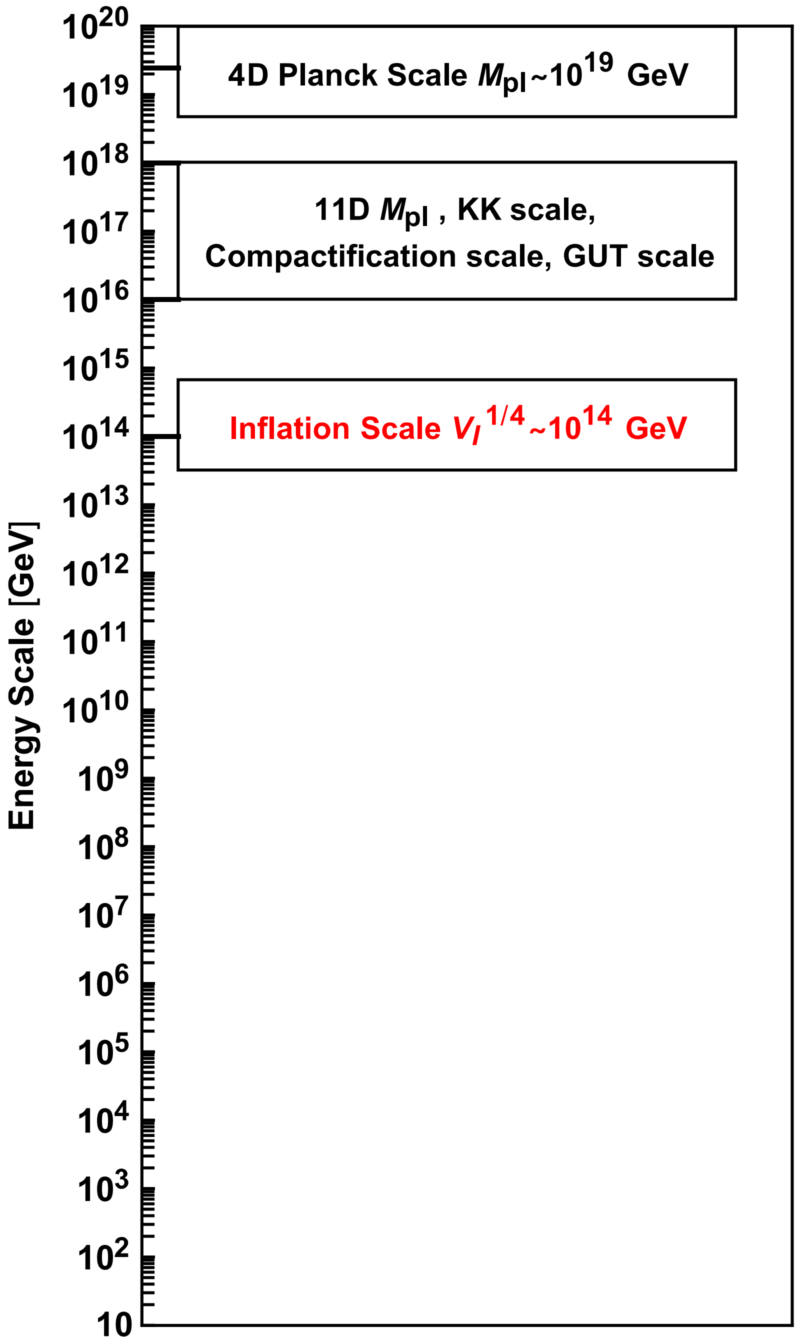
Scales in compactified M-theory, derived:



- The 4D Planck Mass

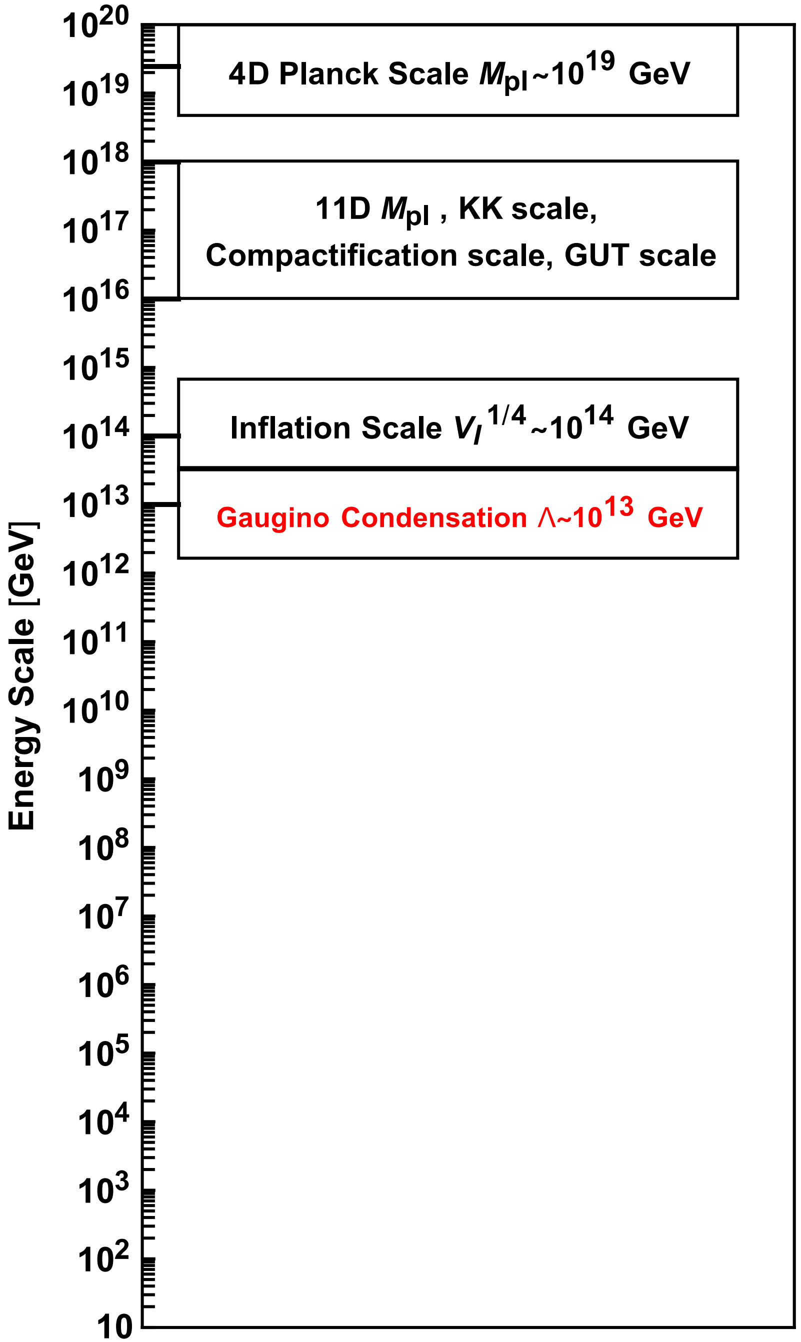


- The 4D Planck Mass



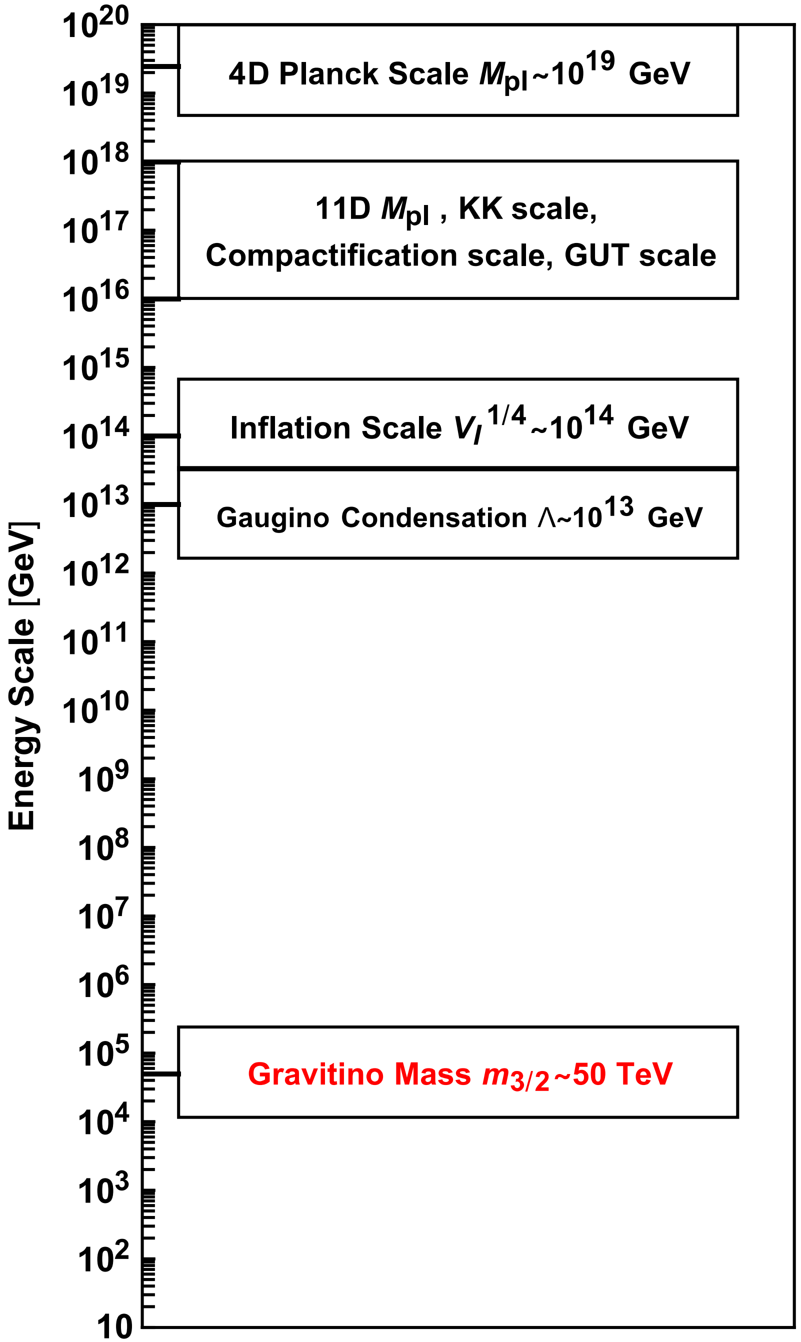
- The 4D Planck Mass

- GK, Martin Winkler, 1902.02365
- f_a, Acharya, Bobkov, Kumar 1004.5138



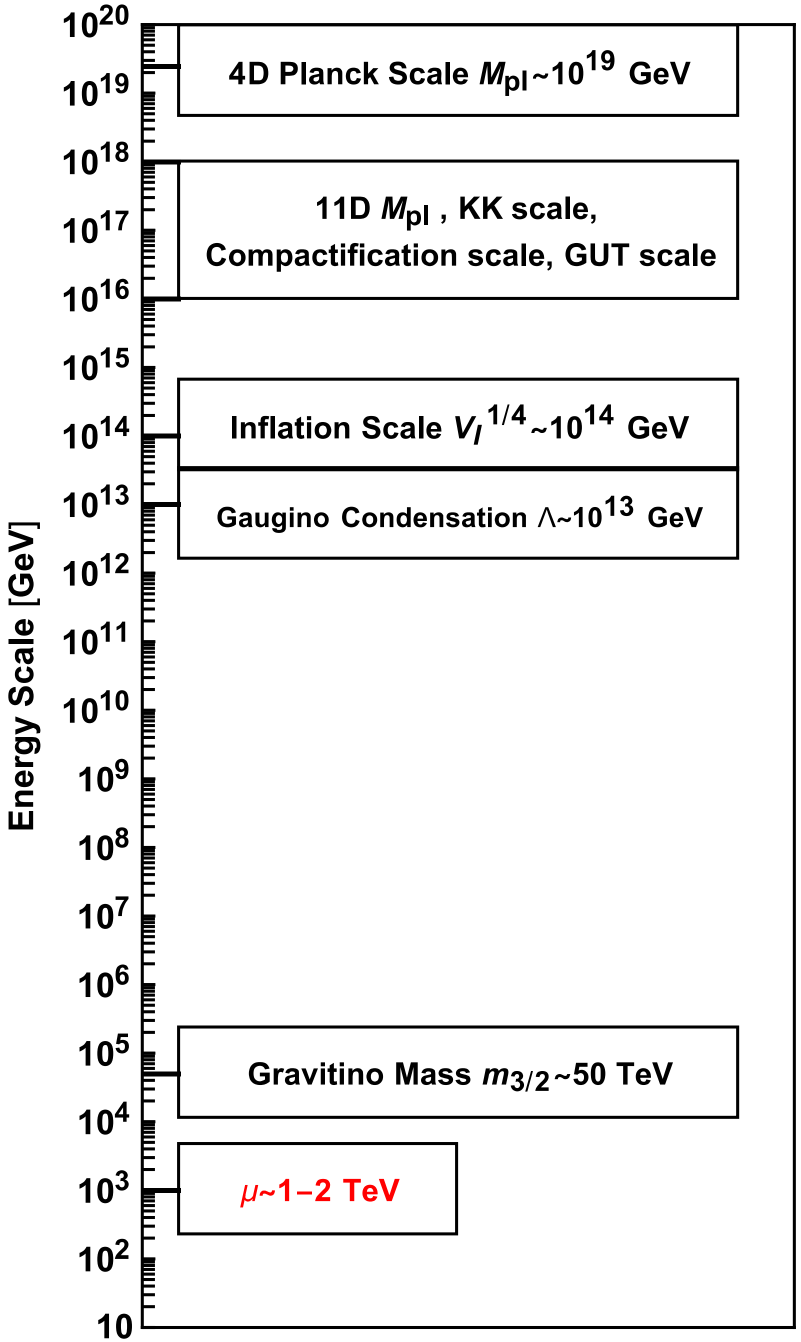
- **Supersymmetry cannot be broken in the visible sector**

- **At around 10^{13} GeV gaugino condensates in some hidden sector breaks supersymmetry, F-terms non-zero – calculable, W$\sim\Lambda^3$**



- **Theory implies masses of scalars are of order $m_{3/2}$ - squarks, in particular top squark should not be observed so far, or at LHC upgrades**
- **Gravitino not light**

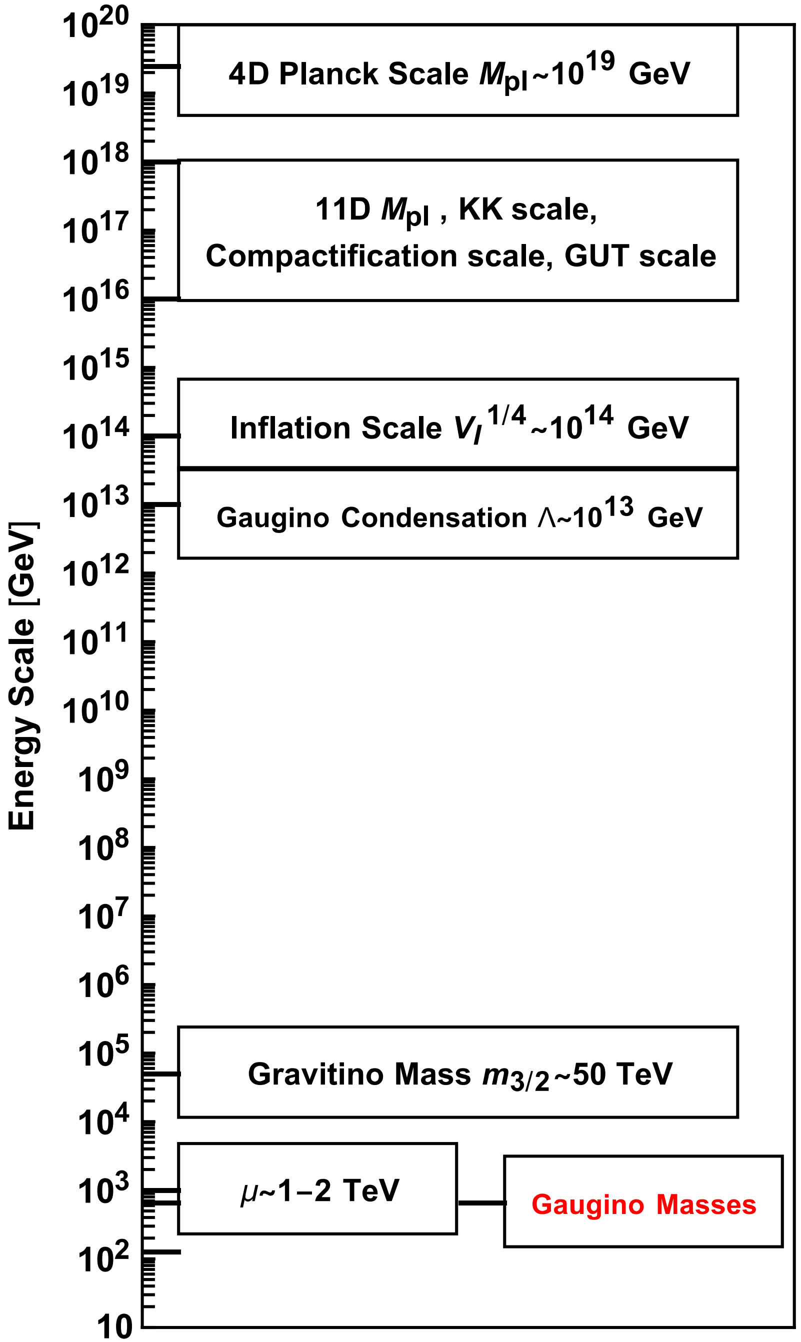
$$m_{3/2} = e^{K/2} W / M_{Pl}^2$$



- **The μ term is of order**

$$\mu \sim \frac{m_{3/2}\langle mod\rangle}{M_{pl}^2}$$

- **<mod> vevs of order 1/10 or 1/20 of Planck scale, so μ smaller than gravitino mass by that amount – Higgsino masses typically of order μ**

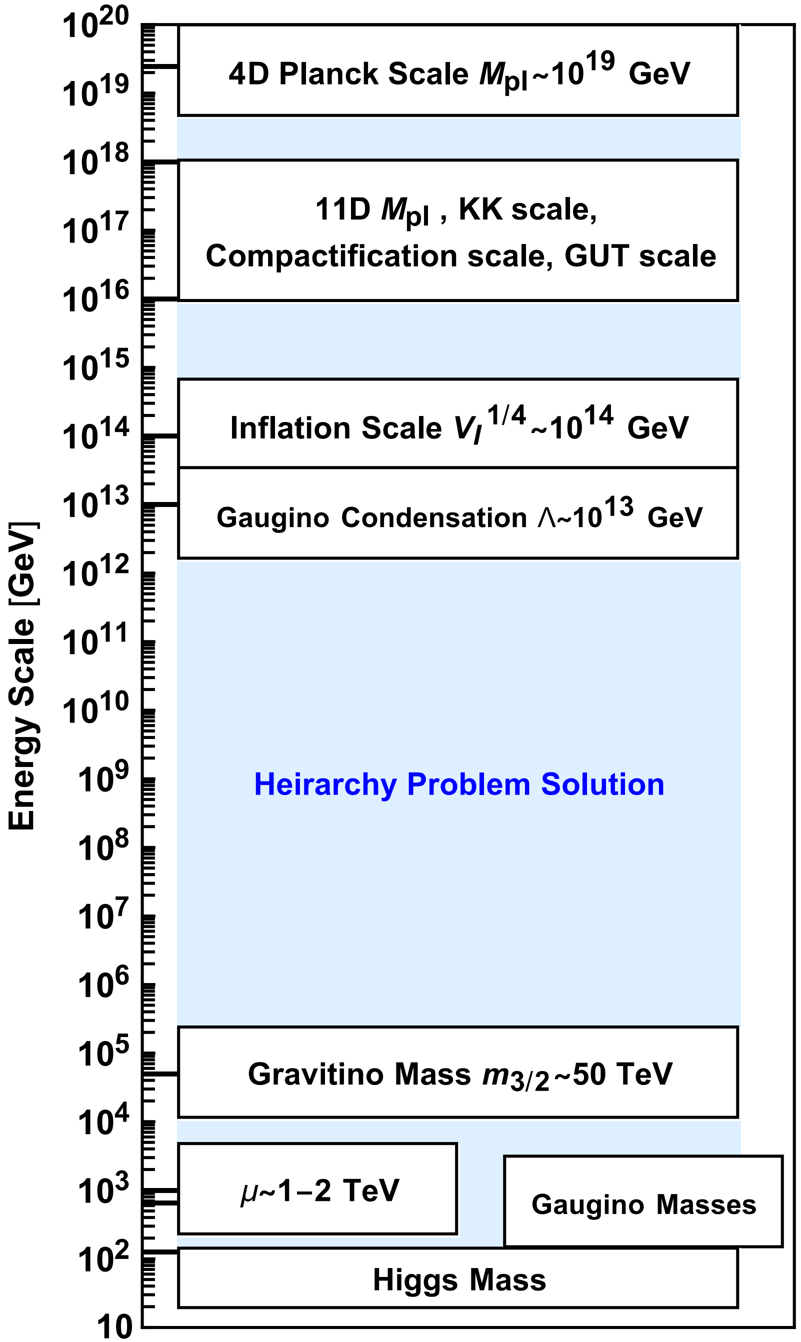


- In compactified string/M-theories gaugino masses are generically:≅

$$5\text{ TeV} \geq \mathrm{m}_{\tilde{g}} \geq 1.5\text{ TeV}$$

$$\mathrm{m}_{\tilde{c}} \geq 650\text{ GeV}$$

$$m_{\tilde{B}} \geq 450\text{ GeV}$$

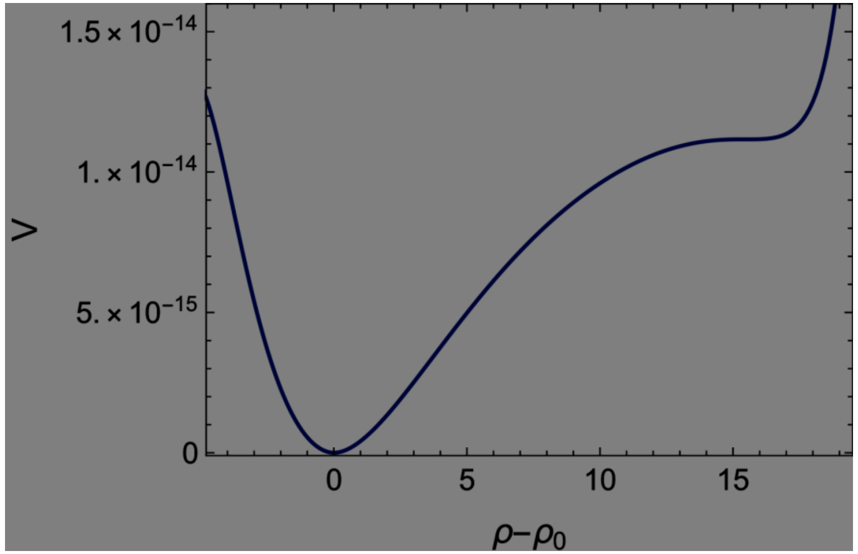


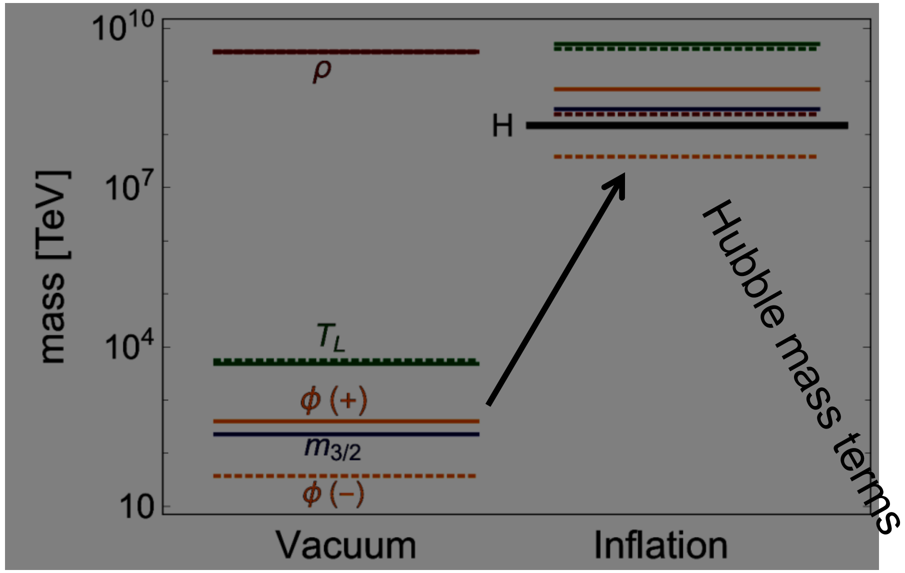
- Higgs $m_h = 125$ GeV
  Calculated from soft breaking Lagrangian at Planck scale, then run down, so no simple expression for m_h (Heinemeyer talk)

- Planck scale only dimensionful input to theory

- Scale of inflation emerges from stabilizing moduli
- Overall volume modulus becomes inflaton
  - $V^{1/4} \sim 10^{15}$ GeV
  - $r \sim 10^{-6}$

Inflation and Supersymmetry Breaking





➢ HIGGS PHYSICS

- *Is the* Higgs boson observed? Often questioned -

  YES

- Spin zero, etc, ok

- Fermionic decays all ~ mass^2 by helicity suppression for scalars so not best criterion

Crucial point h → ZZ, WW observed!! *[1.10±0.08 CMS]*

  - *h is electroweak SU(2) doublet, Z or W are electroweak SU(2) triplets*
  - *Cannot combine two triplets (like spin 1) to make a doublet (like spin ½)*
  - *The decays h→ZZ, WW is forbidden by SM gauge invariance!*

They occur via the L ~ hhWW or hhZZ – one h gets a vev

→gives an effective L ~ <h>hWW or <h>hZZ term

→Higgs mechanism operates

h has electroweak charge and hypercharge, so vacuum also does

WHAT CLUES DO WE GET FROM THE HIGGS DATA?

- Correct prediction for mass approximately in MSSM (clue 1)
- And associated h decay BR within a few % of SM ones, as in data (clue 2)

So looks like two-doublet decoupling supersymmetry solution

- Plus hierarchy problem → TeV scale supersymmetry (clue 3)
- Plus vacuum stability (clue 4)

  - Assume pure Standard Model – then Higgs potential $V=\mu^2h^2+\lambda h^4$
  - SM λ runs negative as increase scale, around 10^{12} GeV → vacuum metastable
  - Large fluctuations during inflation lead to unphysical AdS vacua (can't just say lifetime of universe long)! [Hook, Kearney, Shakya, Zurek 1404.5953]
  - Supersymmetric λ positive definite, $\lambda>0.1$ in MSSM, vacuum stable
  - So higgs not SM

THESE FOUR CLUES POINT TO TeV SUPERSYMMETRY – *NOT* STANDARD MODEL HIGGS - NOT "NIGHTMARE" WORLD – Don't ignore clues

The higgs mass, decay BR, vacuum stability could have been different

The likely phenomenological solution known for decades $\rightarrow$ supersymmetry, 2 doublet decoupling sector with EWSB (not unique)

[Haber and Nir 1990; Gunion and Haber 2003; Carena]

10^{12}

- 2 doublets + EWSB tells us $m_h^{tree} \leq M_Z$
- Other four Higgs masses heavy $\sim$ multi TeV in M theory – one doublet effectively decouples – light Higgs boson has SM-like BR – one loop top-stop corrections raise Higgs mass few tens of GeV

- λ is positive definite for supersymmetry so no vacuum instability

- Usual hierarchy problem solution via TeV scale superpartners

BASIC LOGIC to get a theory:

- Want UV completion, so start from 10 or 11 D string/M-theory
- Compactify to 4D, Planck scale size manifold
- → Study 11 D M-theory (Witten, 1995), compactified near Planck scale
- Compactify on 7D manifold with G_2 holonomy – then **automatically N=1 supersymmetric** 4D quantum field theory (Papadoupoulos, Townsend 1995)
- Has two higgs doublets, radiative EW symmetry breaking, decoupling solution, as clues indicated

PAPERS ABOUT M-THEORY COMPACTIFICATIONS ON G_2 MANIFOLDS (11-7=4)

Earlier work 1995-2004 (stringy, mathematical) **; [Witten 1995]**

- **Papadopoulos, Townsend th/9506150, compactification on 7D manifold with G_2 holonomy → resulting quantum field theory has N=1 supersymmetry!!!**

- **Acharya, hep-th/9812205, non-abelian gauge fields localized on singular 3 cycles**

- **Acharya and Witten, hep-th/0109152, chiral fermions supported at points with conical singularities (massless quarks and leptons)**

Particles and forces!

- **Beasley and Witten, hep-th/0203061, generic Kahler form**

- **Lukas, Morris hep-th/0305078, generic gauge kinetic function**

- **Basic framework established – powerful, rather complete**

Few more Discrete Assumptions

- Compactify M-Theory on manifold with G_2 holonomy in fluxless sector – well motivated and technically robust

- Compactify to gauge matter group SU(5)-MSSM – can try others, one at a time – Witten, three early papers

- Can proceed to calculate – NO FREE PARAMETERS

- Assume needed singular mathematical manifolds exist – considerable progress recently – Simons Center $10M, 4 year grant

- **Indeed we showed that in M theory supersymmetry automatically was spontaneously broken via gaugino and chiral fermion condensation**

- **Simultaneously all moduli stabilized, in de Sitter vacuum**

[Acharya, Bobkov, GK, Piyush Kumar, Kuflik, Shao, Watson, Lu, Zheng, S.Ellis, Perry – over 20 papers, over 500 arXiv pages]

Calculated the supersymmetry soft-breaking Lagrangian
→ radiative electroweak symmetry breaking, two doublets, decoupling, Higgs boson

– precise ratio of M_h/M_Z and Higgs decays

– also soft terms have same phases so EDMs predicted to be small !

– approximate gluino and wino masses, etc

NO free parameters

Superpotential

Qualitative gravitino and gluino masses

$$W \sim \Lambda^3$$

Λ scale where F-terms non-zero, from gaugino condensation, so supersymmetry broken

$$M_{3/2} = \frac{e^{K/2} W}{M_{Pl}^{\;2}} \approx \left(\frac{\Lambda}{M_{Pl}}\right)^3 \frac{1}{V_3} M_{Pl}$$

Gravitino mass order 40 TeV

$$M_{gluino} \approx \left(\frac{\Lambda}{M_{Pl}}\right)^3 \frac{1}{V_3} \frac{V_3}{V_7} M_{Pl}$$

$\sim$ 1 TeV

➢GAUGINO MASSES ALWAYS SUPRESSED

$$M_{1/2} \sim \Sigma\, K_{mn}\, F_m\, \partial_n\, f_{SM}$$

Standard Model gauge kinetic function

-- f_{SM} doesn't depend on chiral fermions, whose F-term gives the largest contribution to supersymmetry breaking (2006)

-- $F_{\text{chiral fermion}} \sim V_7$ but $F_{\text{moduli}} \sim V_3$, $V_7 >> V_3$

-- Matter Kahler potential does not enter, so results more reliable

-- Moduli dependence is entirely in volume factors, so same for all G2 manifolds for tree level gaugino masses

- - Usually gaugino masses also suppressed in other compactifications

Many (compactified M-theory) results don't depend on G2 manifold details

- moduli all stabilized;
- supersymmetry breaking, gravity mediated;

! hierarchy problem solved, stability and scale

! *scalars heavy ~ few tens of TeV – not at LHC;*

! gauginos light (gluino, LSP etc) ~ 1 TeV;

- small EDMs;
- matter dominated cosmological history;
- EWSB, M_h/M_Z, h decay BR;

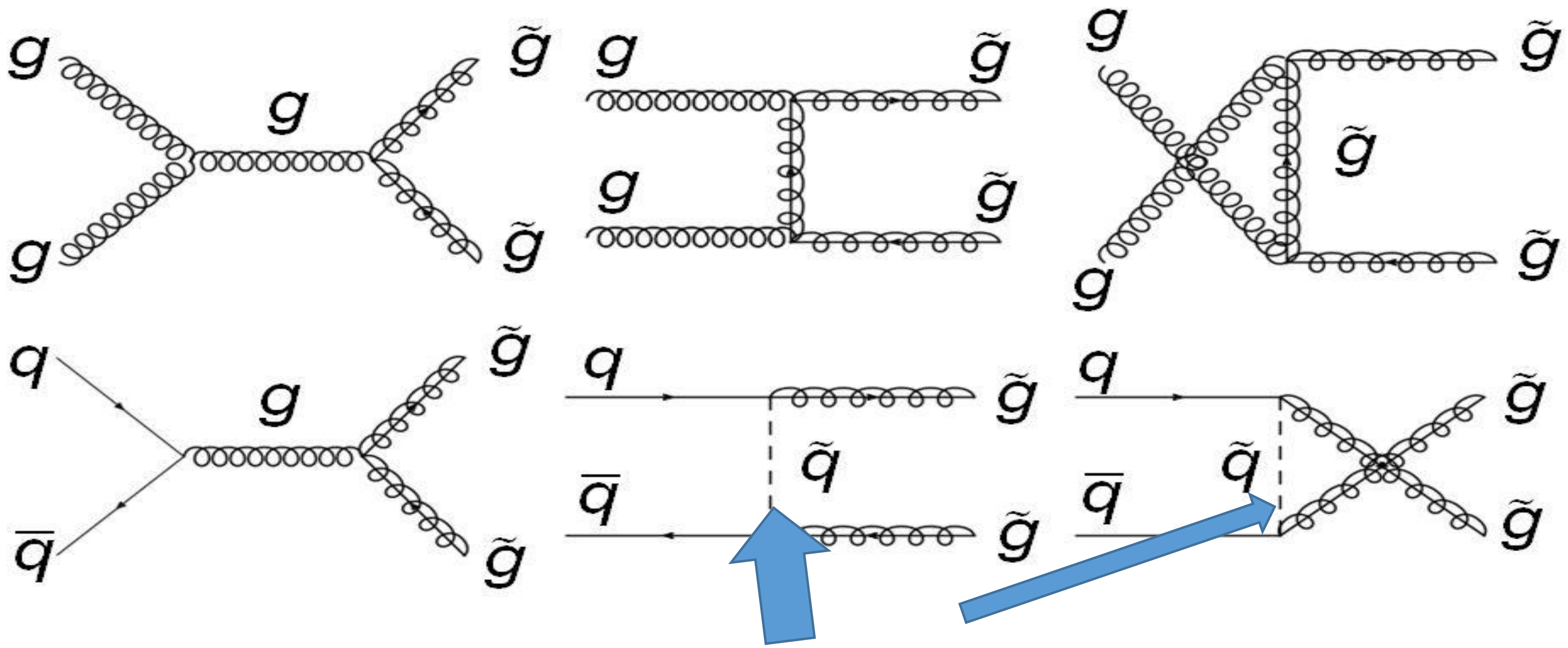
! LSP decays to hidden sector matter

- solve strong CP problem via axions

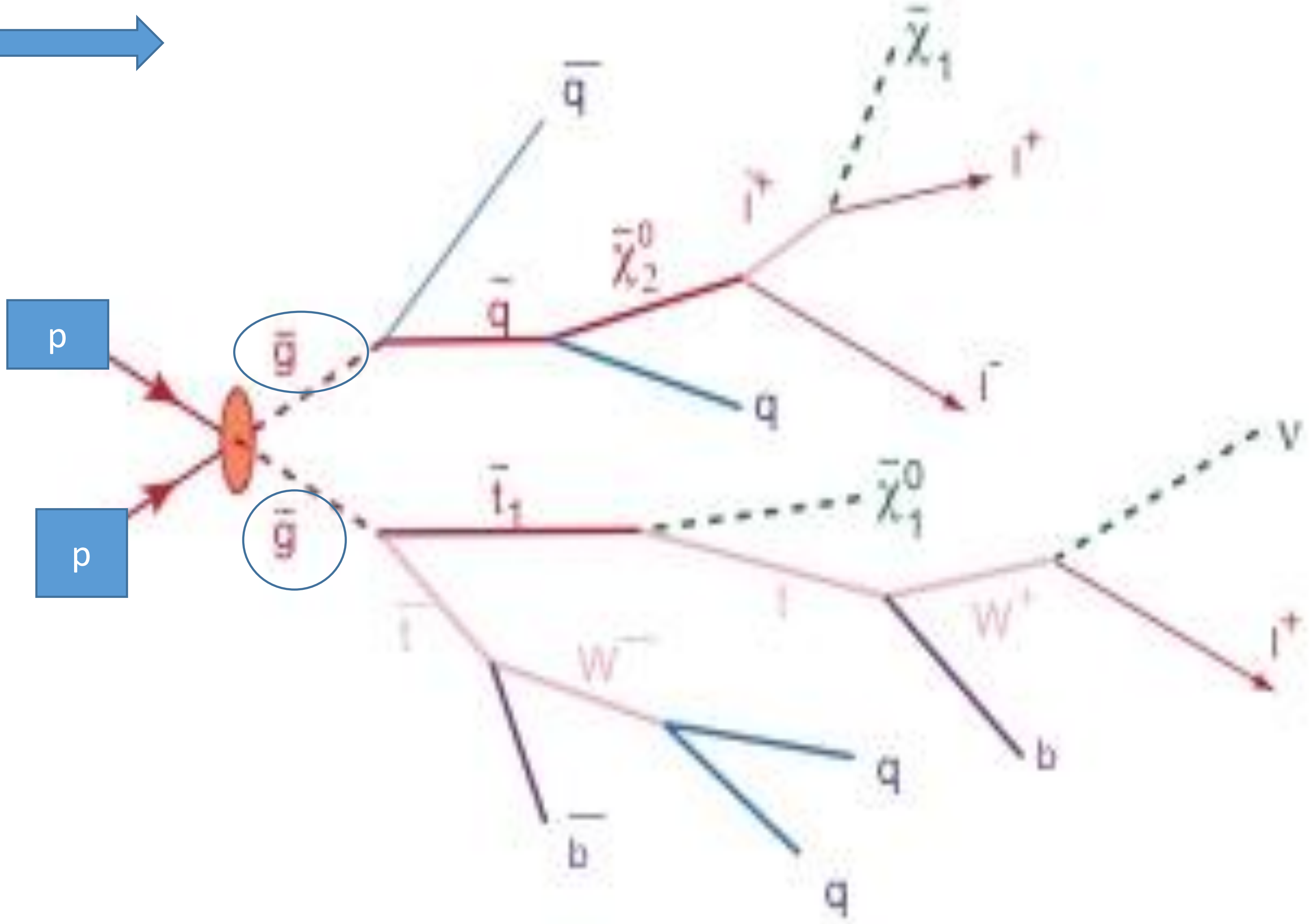
! inflation (GK, Winkler)

➢**WHERE ARE THE SUPERPARTNERS? Gluinos have largest production rate**

Gluino production in pp collisions



For production cross section calculations, the squark masses are often taken to be arbitrarily large – the "decoupling limit".



p
p
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GLUINO LIMITS?

- M-theory gluino decays about half the time to 3rd family particles, giving tops and bottoms in the detector
- The other half time decays to 1st and 2nd family particles, giving jets and leptons in the detector
- Produce two gluinos
- Both 3rd family ¼ of the time
- Both 1st+2nd families ¼ of the time
- Searches done for either signature set limits assuming production 100%
- So should set limits based on ¼ of assumed production rate
- Theories usually have heavy squarks that suppress squark exchange diagrams, about 1/3 of cross section absent
- So further reduction by ~ 2/3 because of heavy squarks
- e.g. for 3rd family search reduction by about 1/4x2/3 = 1/6
- So actual limits smaller than simplified model limits by 10-15%

Bottom line

– Real top-down theories imply gluinos from about 1.5 TeV to about 5 TeV

- so do “intelligent naturalness” models (Baer, Olive, Hienemene) →

Gluinos accessible at LHC upgrades

[My (our) earlier published predictions were too optimistic, calculation needs to be examined – 1.5 TeV excluded – but 2 TeV not excluded]

-- Squarks probably few tens of TeV – a firm prediction for compactified M-theory, most string theories

– Squarks accessible via squark-gluino associated production at “100 TeV” pp collider but not at LHC upgrades (GK; S. Ellis, B. Zheng) – characteristic of real theory rather than swampland models

- All superpartners can be found at full 100 TeV collider

➢DARK MATTER – Zurek, Graham, Pospelov, Slatyer, Wu, Dessert, Toro, Abe

- For decades expected DM to be either axions or lightest superpartner (wimps) or both
- Both motivated by other physics – axions to solve strong CP problem – stable lightest superpartner - wimps
- Recently, top-down analysis shows that generically in string/M-theories the **LSP is not stable** (1604.05230, S. Ellis, GK, B. Nelson, Perry) - [some hidden sector matter lighter than LSP, kinetic mixing or other portal exists, LSP decays to hidden sector matter]
- And increasingly good detectors not finding signals of wimps
- Recently several new ways to detect axions invented – extended to axion-like particles (alps) – Graham, Safdi
- Detection limits because lighter DM particle cause too soft a recoil whan they hit nucleus
- Several (many?) clever new ways to detect light and very light DM particles!
- Scatter off electrons, superconducting materials, absorbtion

FOUR CATEGORIES (help from Ben Safdi)

(1) Reduce detection thresholds

- **Sophisticated, powerful Xenon detectors observing recoil from scattering off electrons (Xenon1ton, LZ)**
- **Semiconductors, lower threshold detectors (SENTEI) - Zurek**

(2) Even lower threshold – break Cooper pairs in superfluids and superconductors - Zurek

(3) Ultralight DM – recoil very sensitive to velocity of DM in halo since largest velocity ones recoil more – use Gaia data – Lisati

(4) Even lower recoils – coherent absorption - axions

AXIONS – Graham

(1) Classic – resonant cavities – misalignment angles order 1 – ADMX, Haystac

(2) Higher mass – fill gap up to $\sim$ eV – not cavities, use materials with wavelengths $\sim$ axions – Wilczek, wire arrays, DM radio

(3) ABRACADABRA – technology changes – probe GUT scale f_a

(4) Much lighter axions – CASPAR, black hole superradience – couple to gluons instead of photons – using knowledge of black holes from LIGO

FUZZY DARK MATTER

- $M_a \sim 10^{-23}$eV, galactic size
- But strong Lyman-α constraints

➢ FUTURE COLLIDERS – Han, Baer, Canepa

China is considering a circular $e^+ e^-$ large tunnel collider with total energy of several hundred GeV, to study Higgs bosons, top quarks, and search for new physics – could begin construction in 2022 – CEPC

Then collide protons in same large tunnel, energies 2-7 times LHC depending on magnets, SppC

CERN considering similar path probably later because HL-LHC locked in – FCCee, FCChh

- Probably 2-3xLHC would lead to discoveries

Full TDR's in arxiv

[New acceleration methods (e.g. wakefields) "require several breakthroughs before they might work", "don't know how to get the needed luminosity"]

- There are other programs for electron-positron colliders
  - – ILC in Japan, initial energy allows studying Higgs boson, requires international funding – very unlikely
  - -- CLIC at CERN being studied – could be built with long term CERN budget, only after LHC luminosity upgrade, maybe energy upgrade
- A great advantage of future circular $e^+ e^-$ colliders is that they can have a second phase with proton-proton collisions – tunnel would already be in place
- Strong physics motivation from compactified string/M-theories for gauginos and higgsinos accessable at 2-3xLHC – also from intelligent naturalness

– 27 TeV HE-LHC , or existing magnets in 100 km tunnel → 45 TeV

- Probably all superpartners accessible with 100 km tunnel, 15 Tesla magnets
- Many of us hope physics goals will dominate, and approach with early discovery potential will be chosen

➢DE SITTER VACUUM (Acharya and GK et al, th/0701034, section VIC,D) – Ooguri, Cicoli

(~ 600 papers on De Sitter vacuum in past two years – motivated by Vafa, Ooguri and Vafa)

- Scalar potential in compactified M-theory

$$V = \Sigma F^2 - 3W^2 \approx F^2_{moduli} + F^2_{HSmatter} - 3W^2 > 0 \rightarrow \text{De Sitter}$$

(where $F_i \sim DW/D\phi_I$)

$$\text{But } F^2_{moduli} - 3W^2 < 0 \rightarrow \text{Anti-De Sitter}$$

So if only consider moduli, find AdS vacuum

For compactified M-theory many hidden sectors [used Seiberg formalism for hidden sector quarks effective theory], new F-terms, large

(Similar result from Cicoli et al, with included hidden sector uplift)

Hidden sectors generic in compactifications, moduli stabilized, supersymmetry broken – quantum effects – conjecture that generic for compactified string/M-theories to have De Sitter vacua

➢B-decay anomalies?

- **LHCb, soon BELLE reporting new data**
- **Statistical strength of data decreased a little from 2016 to Moriond 2019**

where

$$R_{J/\psi} = \frac{\Gamma(B_c \to J/\psi \tau \nu)}{\Gamma(B_c \to J/\psi l \nu)}$$

and $l = e, \mu$

And LHCb gave in earlier data

$$R_{J/\psi} = 0.71 \pm 0.17(stat) \pm 0.18(sys)$$

SM theory in range 0.2-0.4 for $R_{J/\psi}$.

- Asadi and Shih, “there is no combination of dimension 6 Wilson operators that can come within 1σ of the observed $R_{J/\psi}$ value”.

- Saini et al, “We find that none of the new physics operators which provide a good fit to $b \rightarrow s\mu^+\mu^-$ can enhance the $Br(B_s^* \rightarrow \mu^+\mu^-)$ its Standard Model vlaue.”

- But Aebischer, Altmannshofer et al “…able to account for the potential discrepancies in $b \rightarrow c$ transitions. This scenario is naturally realized in the simplified U_1 leptoquark model.”

Recall Eddington “Don’t trust data until it is confirmed by a good theory”

CONCLUSIONS

Jure Zupan, B decays summary,
Pheno 2019, May 7

- Belle II coming online+ LHCb run2 analyses should give clearer view of B physics anomalies
- more long term: flavor program expects to significantly improve new physics reach

FINAL REMARKS

- Compactified 10/11 D String/M-theory with curled up small dimensions may seem complicated – but probably it is the SIMPLEST FRAMEWORK THAT COULD SIMULTANEOUSLY INCORPORATE AND *EXPLAIN* ALL THE PHENOMENA WE WANT TO UNDERSTAND – 10/11D needed to accommodate SM forces

- Normally assume can ignore gravity at EW scale, any field theory can be coupled to quantum gravity – NO – most field theories cannot be consistently connected to quantum gravity, they are in the SWAMPLAND – DON'T IGNORE UV COMPLETIONS – Affect allowed symmetries, forms of matter, Higgs sector, LSP stability, more

- Most important, including gravity, UV completion, forces us to not ignore the hierarchy problem
- Solving the hierarchy problem is essential to comprehend our world, and to define our goals – requires finding new physics experimentally, NEW COLLIDERS

- String theory is too important to leave it to the string theorists

  – String theorists who don't work on compactified string/M-theories may not understand them

- Compactified string/M-theories provide a comprehensive underlying theory

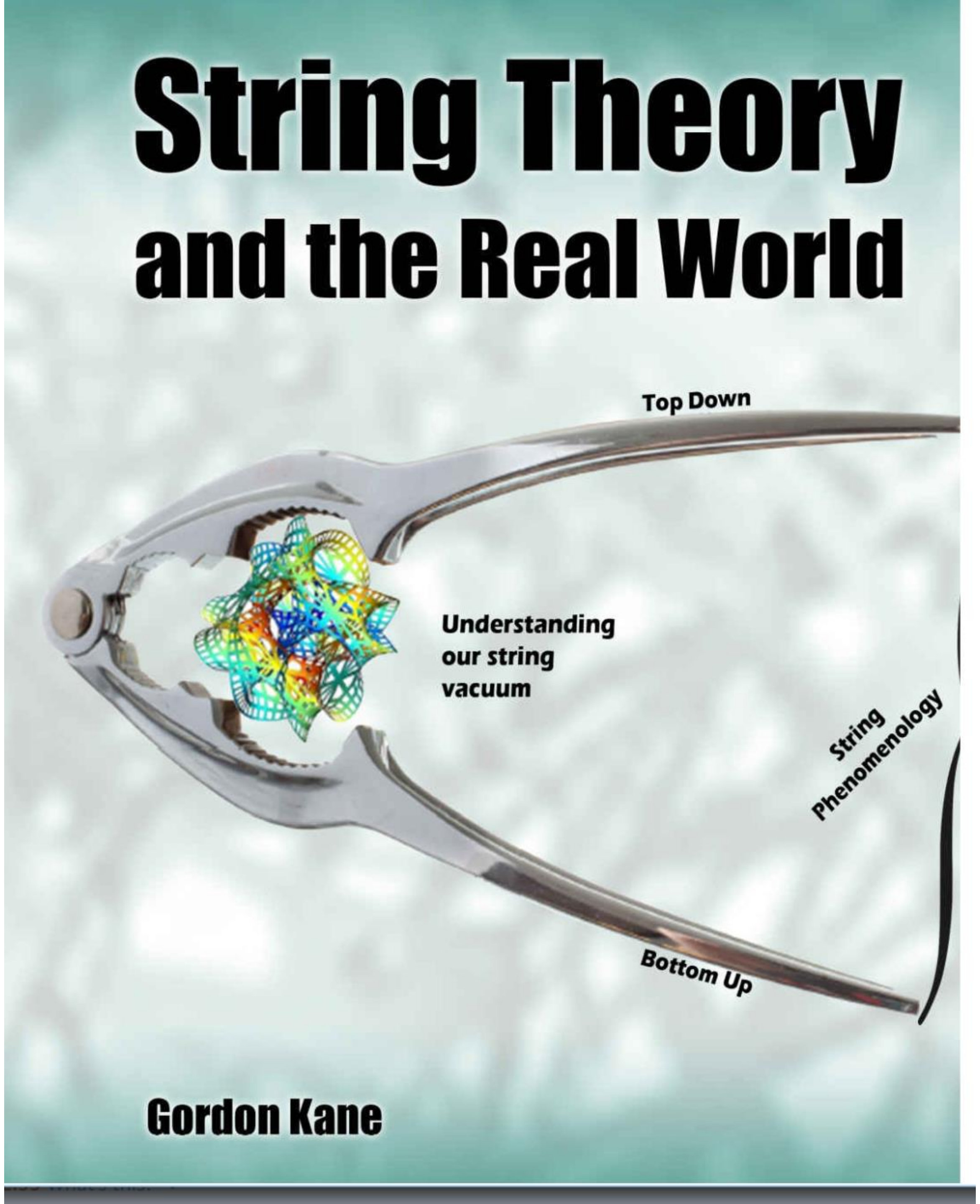
- Return of the WIMP? – galactic center excess?

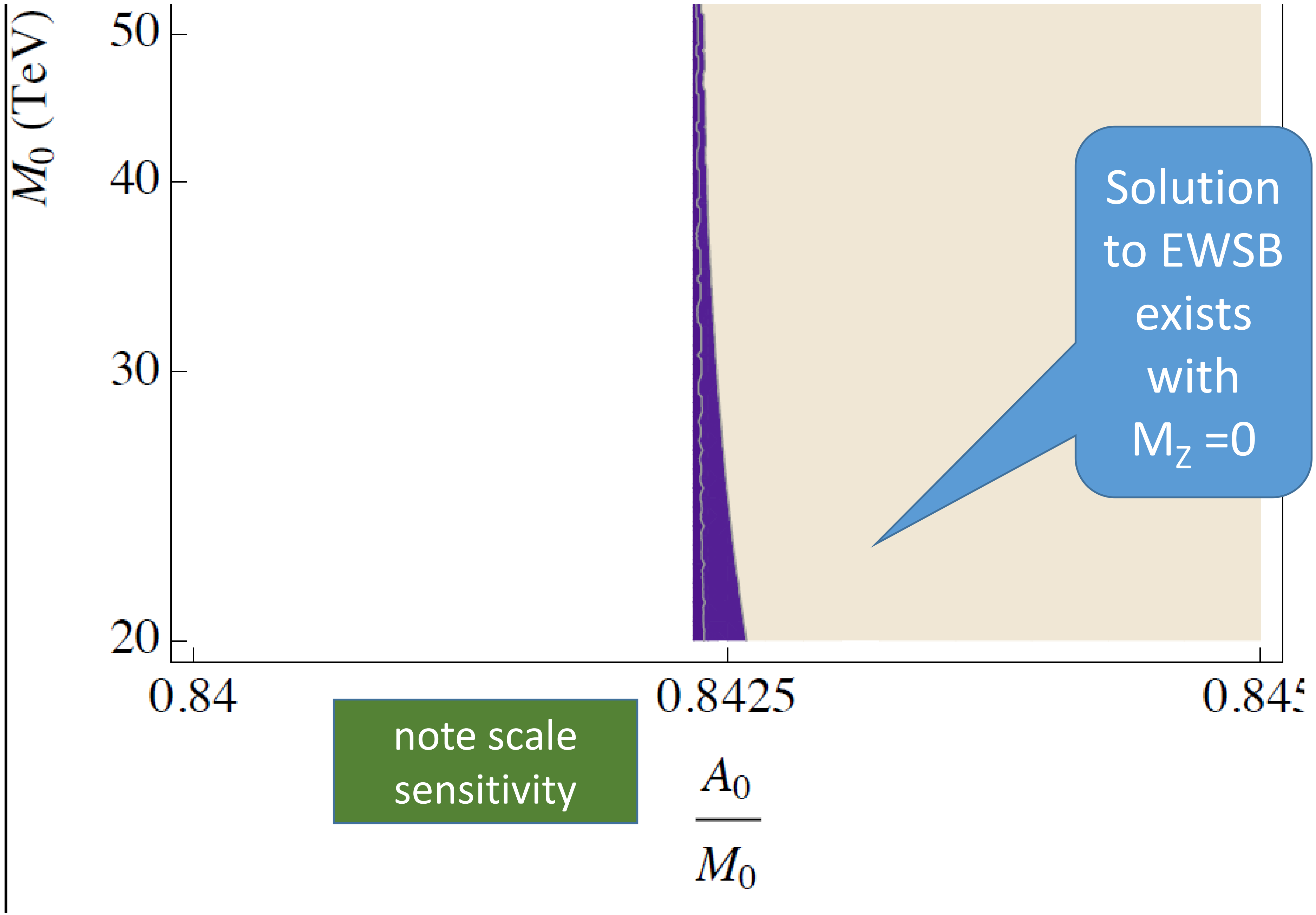
- Compactified string/M-theories probably imply gluinos 1.5 to about 5 TeV – similar from intelligent naturalness

- We have learned best motivated dark matter candidates are axions and hidden sector matter – much better recent understanding, and detectors!!!

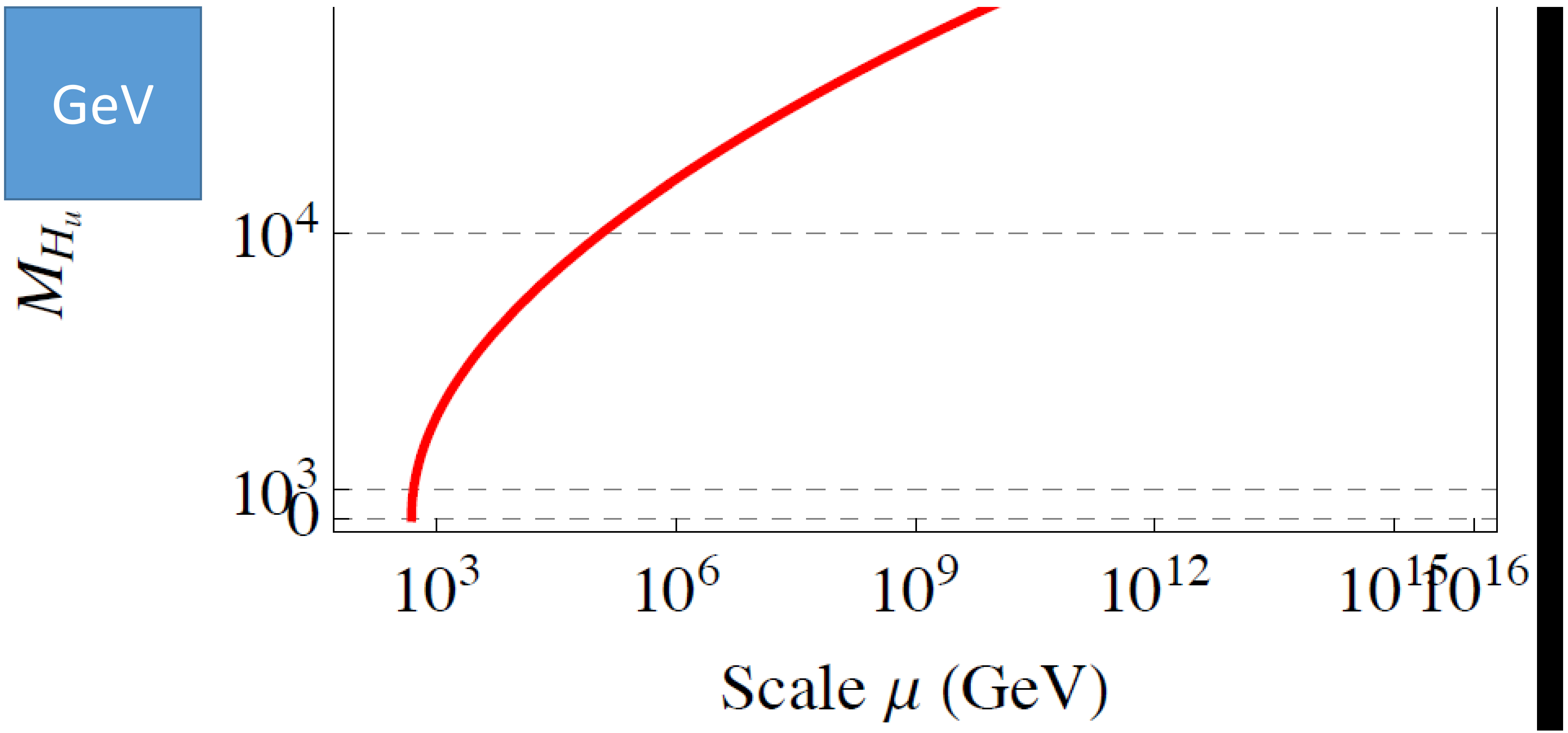
“if people don’t want to come to the ballpark nobody’s going to stop them”

Yogi Berra





M_0 (TeV)
50
40
30
20
0.84
0.8425
0.845
$\frac{A_0}{M_0}$
Solution to EWSB exists with M_Z =0
note scale sensitivity


GeV
M_{H_u}
10^4
10^3
0
10^3
10^6
10^9
10^{12}
10^{15}
10^{16}
Scale μ (GeV)

LITTLE HIERARCHY ~ 2 TEV, NOT 40 TEV – MAYBE EVEN SOLVED

-- need to derive $\tan\beta$ too

Usual EWSB conditions [so higgs potential minimum away from origin]:

$M_Z^2 = -2\mu^2 + 2(M^2_{Hd} - M^2_{Hu} \tan^2\beta)/\tan^2\beta = \mathbf{-2\mu^2 + 2M^2_{Hd}/\tan^2\beta - 2M^2_{Hu}}$

$2B\mu = \sin 2\beta\,(M^2_{Hu} + M^2_{Hd} + 2\mu^2)$

M^2_{Hu} runs to be negative, M^2_{Hd} and B don't run much, μ suppressed, $\sin 2\beta \approx 2/\tan\beta$

If no μ from superpotential, and visible sector Kahler metric and Higgs bilinear coefficient independent of meson field, and if $F_{mod} \ll F_\phi$ then B (high scale)$\approx 2M_{3/2}$ – recall $\mu < 0.1M_{3/2}$

$\rightarrow \tan\beta \approx M^2_{Hd}/B\mu \approx M^2_{3/2}/B\mu \rightarrow$ $\mathbf{\tan\beta \approx M_{3/2}/2\mu\ (\sim 6)}$

- **Calculations of kahler potential, trilinears have corrections**
    - **not yet calculable – so can't calculate running - but**
- **There are M_0 and A_0 and μ in the range $M_Z \approx 0$**

Well known theorist: “The total cost of the Planck satellite, which arguably brings us much closer to understanding the mysteries of the universe than LHC, is about $1 billion” !!![added]

- this is an example of inflating

- Actually no amount of study of inflation can explain most mysteries of the universe, such as electroweak symmetry breaking, or dark matter, or the hierarchy problem, or the matter asymmetry

- Planck can tell us about how the universe began, and that it is old and cold and dark (though not why)

- Neither Planck, nor any amount of cosmology, can tell us why there are not equal amounts of matter and antimatter that keep annihilating, or why there is dark matter or what the dark matter is, or why all atoms are not infinitely large, or why the electroweak scale and QCD scale are what is needed for an interesting world – LHC can tell us those things and more

- Need LHC (and extensions) to make physics great again

De Sitter Swampland Conjectures

et al evidence based on no go theorems like Maldecena-Nunez:

ed, no de Sitter vacua in classical limit of string/ M-theory

ar, no evidence against dS when quantum effects (e.g. gaugino condensation) included.

mpactified M-theory non-perturbative quantum effects are crucial to generate hierarchies

$$M_{\mathrm{P}} \gg M_{\mathrm{inflation}} \gg M_{\mathrm{SUSY}}$$