A FEELING OF FRUSTRATION:
IS IT JUSTIFIED?

MANY OF US EXPRESS FRUSTRATION ABOUT THE RECENT LACK OF EXCITING NEW DISCOVERIES...

DIFFERENT WAYS WE FACE THIS SITUATION(DEPENDING ON THE DEGREE
OF FRUSTRATION):

SM + GRAVITY IS THE END OF THE STORY

VARIOUS INCARNATION OF THIS ATTITUDE:

ANTHROPIC PRINCIPLE

ASYMPTOTIC SAFETY- THEORETICALLY INTERESTING

THERE IS SOMETHING IN ADDITION BUT LET'S WAIT FOR THE FCC

THERE IS STILL A LOT TO LEARN IN PARTICLE PHYSICS IN THE NEAR FUTURE!

FIRST, LET'S FACE THE FACTS

- THE SM AND THE STANDARD COSMOLOGICAL MODEL HAVE BEEN ESTABLISHED

- NO BIG SURPRISES FOR A LONG TIME: in going BSM- no hint in particle experiments; the latest surprise on the way to establish the SM - CP violation and the 3rd generation? neutrino masses?

- REMOTE PERSPECTIVES FOR HIGHER ENERGIES-

- WELL KNOWN UNANSWERED QUESTIONS ARE ALL THE TIME WITH US

ARE THOSE FACTS A GOOD REASON FOR FRUSTRATION?

AND LET'S TRY TO BE OBJECTIVE

- COMPLETION OF THE SM's →

 A GREAT ACCOMPLISHMENT, THE END OF A CERTAIN STORY 120 YEARS AFTER THE DISCOVERY OF STRONG AND WEAK INTERACTIONS (RADIOACTIVITY)

AT LEAST AT THE ELECTROWEAK SCALE, THE SM IS A CORRECT EFFECTIVE THEORY OF ELECTROWEAK INTERACTIONS (UP TO THE NEUTRINO MASSES)

IS THE SM A CONSISTENT THEORY UP TO THE PLANCK SCALE ?

YES!

RENORMALISABLE

NO LANDAU POLE UP TO Mp

(ALMOST) STABLE VACUUM UP TO Mp

THE LATTER CONCLUSION STRONGLY DEPENDS ON

$$m_t = 173 GeV, \qquad m_h = 125 GeV$$

THE SM IS A CONSISTENT THEORY UP TO THE PLANCK SCALE...

BUT....

ISNT IT INDEED JUST AN EFFECTIVE THEORY, AN APPROXIMATION TO A DEEPER ONE
(SIMILARLY AS QED, ALTHOUGH CONSITENT UP TO Mp, IS ONLY A LOW ENERGY APPROXIMATION TO SM)?

BY THE WAY, RENORMALISABILITY VERSUS EFFECTIVENESS- AN INTERESTING ISSUE?

RENORMALIZABILITY VERSUS EFFECTIVENESS

NO SENSITIVITY TO ANY POTENTIAL PHYSICAL CUT-OFF

EVEN IF WE FORGET GRAVITY- THE U(1) LANDAU POLES ARE THE SIGN OF EFFECTIVENESS;

THE U(1) LANDAU POLE$\rightarrow$ ASYMPTOTIC SAFETY IN SM +GRAVITY

RENORMALISABILITY IS A GREAT VIRTUE OF EFFECTIVE THEORIES BUT ALSO A BIG PROBLEM TO GO BEYOND

- **NO BIG SURPRISES FOR A LONG TIME..**

LET's TAKE A LONGER VIEW TO LEARN PATIENCE

NEWTONIAN GRAVITY SURVIVED INTACT FOR MORE THAN 200 YEARS

THE SM ITSELF

BOSE-EINSTEIN CONDENSATION

JUST RANDOM EXAMPLES; MANY OTHERS

BY THE WAY, A SMALL CURIOSITY: ARTIFFICIAL SATELLITES

The first published mathematical study of the possibility of an artificial satellite was [Newton's cannonball](), a thought experiment in [A Treatise of the System of the World]() by [Isaac Newton]() (1687). The first fictional depiction of a satellite being launched into orbit was a [short story]() by [Edward Everett Hale](), *The Brick Moon*.[3][4] The idea surfaced again in [Jules Verne]()'s *The Begum's Fortune* (1879).

A

B

C

D

E
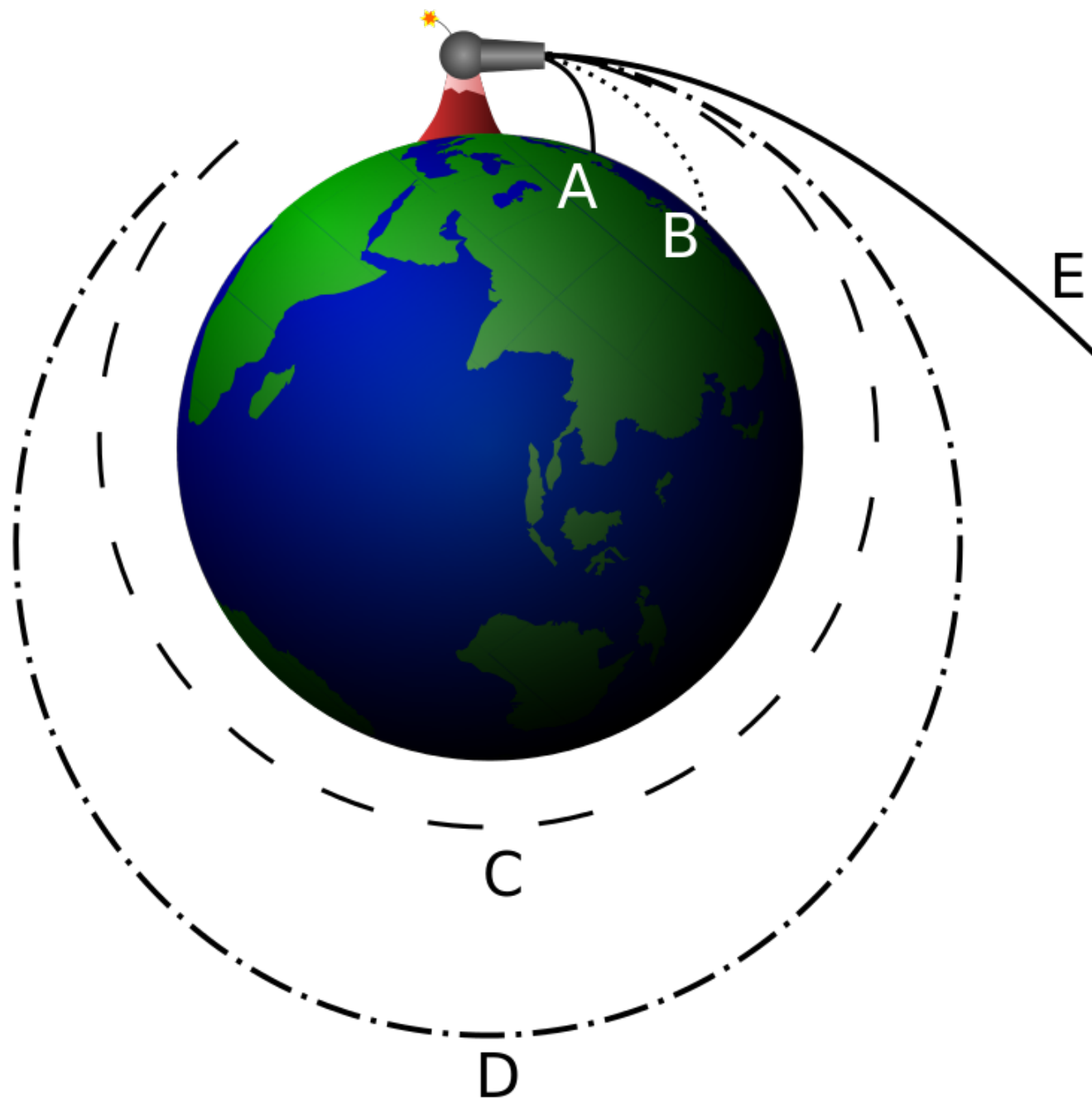
- REMOTE PERSPECTIVE FOR HIGHER ENERGIES;

IT IS TRUE THAT SOME SIMPLEST MODELS MAY REMAIN UNTESTED UNTIL FCC

PURE HIGGSINO DM   PURE WINO DM

(WHEN SFERMIONS ARE HEAVY)

$$\Omega_h h^2 = 0.10 \left(\frac{\mu}{1\ TeV} \right)^2 \qquad \Omega_w h^2 = 0.13 \left(\frac{M_2}{2.5\ TeV} \right)^2$$

$$\Omega h^2 < 0.12 \ \text{ for} \qquad\qquad \Omega h^2 < 0.12 \ \text{ for}$$

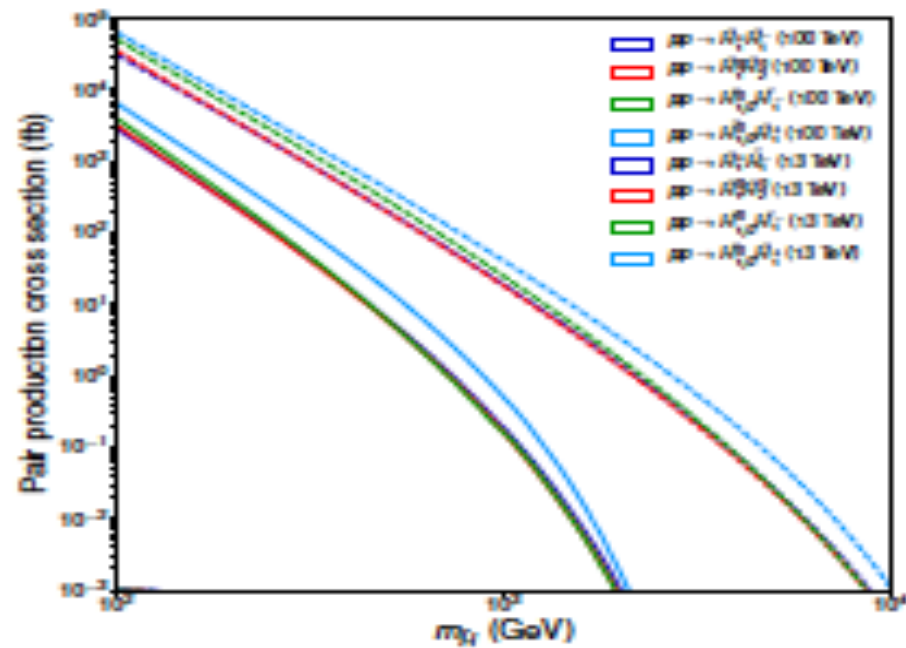$$\mu < 1 TeV \qquad\qquad\qquad M_2 < 2.2(2.8) TeV$$

Figure 15. 13 TeV (solid) and 100 TeV (dashed) NLO+NLL pure Higgsino pair production cross sections (assuming decoupled squarks) as a function of the Higgsino mass $m_{\tilde{H}}$ obtained with Resummino-2.0.1 with the PDF set MSTW 2008NLO90CL. The processes shown are $pp \to \tilde{H}_1^0 \tilde{H}_2^0$ (red), $pp \to H_{1/2}^0 \tilde{H}_1^-$ (green), $pp \to H_{1/2}^0 \tilde{H}_1^+$ (light blue) and $pp \to \tilde{H}_1^+ \tilde{H}_1^-$ (dark blue).

NO, TUNNEY, ZALDIVAR (2019)

THIS EXAMPLE SHOWS THAT IT MAY BE A REMOTE FUTURE
EVEN TO FULLY EXPLORE THE TEV SCALE

BUT, ON THE OTHER HAND, WE CAN STILL LEARN MANY
INTERESTING THINGS ABOUT THE TeV SCALE IN THE „NEAR"
FUTURE EXPERIMENTS, WITH HELP OF FURTHER INSIGHTS
FROM THEORY

NEAR FUTURE EXPERIMENTS AND THE PARALLEL THEORY RESEARCH, FOCUSED ON THE „WEAK" POINTS OF THE SM AND/OR EARLY COSMOLOGY

I'll NOT TALK ABOUT MANY EXCTING OPPORTUNITIES FOR NEW DISCOVERIES, LIKE

AXIONS(STRONG CP, DM)
NEUTRINO PHYSICS (CP VIOLATION, DOUBLE BETA DECAY)
FLAVOR PHYSICS (LEPTON NON-UNIVERSALITY, LEPTON FLAVOR NUMBER VIOLATION)

GRAVITATIONAL WAVES (PHASE TRANSITIONS IN THE EARLY UNIVERSE)

ON THE THEORY SIDE: THE ROLE OF GRAVITY IN THE BSM,

 PERTURBATIVE VS NON-PERTURBATIVE PHYSICS (E.G. SPHALERONS)

LINKING FLAVOUR PHYSICS TO FERMION MASS THEORIES.

LHC, HL LHC

STANDARD QUESTIONS- THE HIERARCHY PROBLEM AND THE DM SEARCHES
BUT IN ADDITION SEVERAL LESS EXPLORED DIRECTIONS

HIERARCHY PROBLEM-FORGET IT OR NOT?

I THINK NOT, IF THE ELECTROWEAK VEV IS, AT LEAST IN

PRINCIPLE, CALCULABLE **IN TERMS OF MORE FUNDAMENTAL PARAMETERS OF** SOME DEEPER THEORY

THEN JUST ON THE DIMENSIONAL GROUND

$$m_H^2 = \Sigma_i g_i^2 \Lambda_i^2$$ (UP TO LOGARITHMIC FACTORS)

MORE DISPUTABLE IF THE v IS ACCEPTED AS A FUNDAMENTAL PARAMETER OF NATURE (TO BE TAKEN FROM EXPERIMENT) E.G. IN ASYMPTOTICALLY SAVE SM+GRAVITY

IN PRINCIPLE CALCULABLE

- **Supersymmetry (Ibanez, Ross 1982)**

- Higgs doublet as a pseudo-Goldstone boson (many models)

- Gravity (in suitably compactified extra dimensions) as a low cut-off to the SM; (many models)

- Relaxion ?

- Various combinations of those ideas

THE TOP PARTNERS MUST COUPLE TO THE HIGGS FIELD BUT NEED NOT TO BE COLORED. THEY CAN BE SCALARS AND /OR FERMIONS

	COLORED	UNCOLORED
SCALARS	SUSY	FOLDED SUSY
FERMIONS (HIGGS AS A PSEUDO-GOLDSTONE)	COMPOSITE HIGGS	TWIN HIGGS

Generic features of the scalar sector in (perturbative or non-perturbative) extensions of the SM with elementary (2HDM, supersymmetry) or composite scalars

- more than one scalar and/or other particles coupled to the higgs

- none of the scalars (in particular the lightest one) couple to WW and to fermions
  exactly like the SM Higgs boson (e.g.because of the mixing between them)

After SO(5) breaking

$$\Phi = (f + \tilde{S}) \begin{pmatrix} \frac{H}{|H|} \sin\left(\frac{|H|}{f}\right) \\ \cos\left(\frac{|H|}{f}\right) \end{pmatrix}$$

Eventually, we assume, H gets a vev v << f (from Δv) and

$$H = (\bar{v} + h) e^{i\frac{G^a T^a}{v}} \begin{pmatrix} \vec{0} \\ 1 \end{pmatrix}$$

G^a are Goldstone bosons eaten by W and Z

The electroweak scale is

$$v = f \sin(\bar{v}/f)$$

The higgs coupling to the "eaten" Goldstones is suppressed

$$\mathcal{L}_{G^2 h} \sim \frac{h}{v} \cos(\bar{v}/f) \, \partial_\mu G^+ \partial_\mu G^-$$

$$\cos(\bar{v}/f) = \left(1 - v^2/f^2\right)^{1/2}$$

Reason: h partially in S

VERY MODEL INDEPENDENT SIGNATURE: DEVIATIONS FROM THE SM PREDICTIONS IN THE HIGGS BOSON COUPLINGS

HIGGS COUPLINGS VERSUS NEW SCALES:

$$M = 1 TeV$$

less than (3- 5) % deviations from the SM couplings

VERY CHALLANGING: DEVIATIONS MAY BE OF THE ORDER OF THE PRESENT UNCERTAINITIES IN THE SM PREDICTIONS

HL LHC?

E.G. MONOJETS

THEY SIGNAL A DIRECT PRODUCTION OF NEUTRAL COLLIDER STABLE
PARTICLES OR THEIR INDIRECT PRODUCTION VIA CHARGED
PARTICLES

$$pp \to \chi\chi + jets \quad pp \to \eta\eta + jets$$

$$\eta \to \chi + X$$

X ARE SOFT OBJECTS AND THE DECAY IS PROMPT ENOUGH

DISAPPEARING TRACKS, DISPLACED VERTICES-SIMILARLY USEFUL FOR LONG-LIVED CHARGED

A LARGE VARIETY OF SCENARIOS GIVE MONOJET SIGNATURE

SUSY, DM BY FREEZE OUT, FREEZE IN, EXTRA DIMENSION (KK MODES,
RADION PRODUCTION), , HIDDEN SECTORS WITH U(1) KINETIC MIXING…

A SYSTEMATIC, (ALMOST) MODEL INDEPENDENT INTERPRETATION OF DATA IS
POSSIBLE IN TERMS OF VERY FEW PARAMETRS, PUTTING STRONG CONSTRAINTS
ON MANY MODELS AT THE SAME TIME

INTERESTING: MONOJET SEARCHES ARE INSENSITIVE TO THE NEUTRAL PARTICLE
COUPLING TO THE HIGGS BOSON, SO THEY CAN PROBE THE REGIONS NOT ACCESSIBLE
TO DD EXPERIMENTS

E.G. MONOJETS AND THE ROLE OF THE ELECTROWEAK SECTOR IN DISCOVERING SUPERSYMMETRY (SUPPOSE ALL COLOURED PARTICLES ARE BEYOND THE REACH)

HUGE PARAMETER RANGE WITH THE RELIC ABUNDANCE OF THE LSP MUCH SMALLER THAN 0.12 (MULTI-COMPONENT DARK MATTER)

PARTLY TESTED BY DD EXP BUT A SQUEEZED SPECTRUM NOT ACCESSIBLE
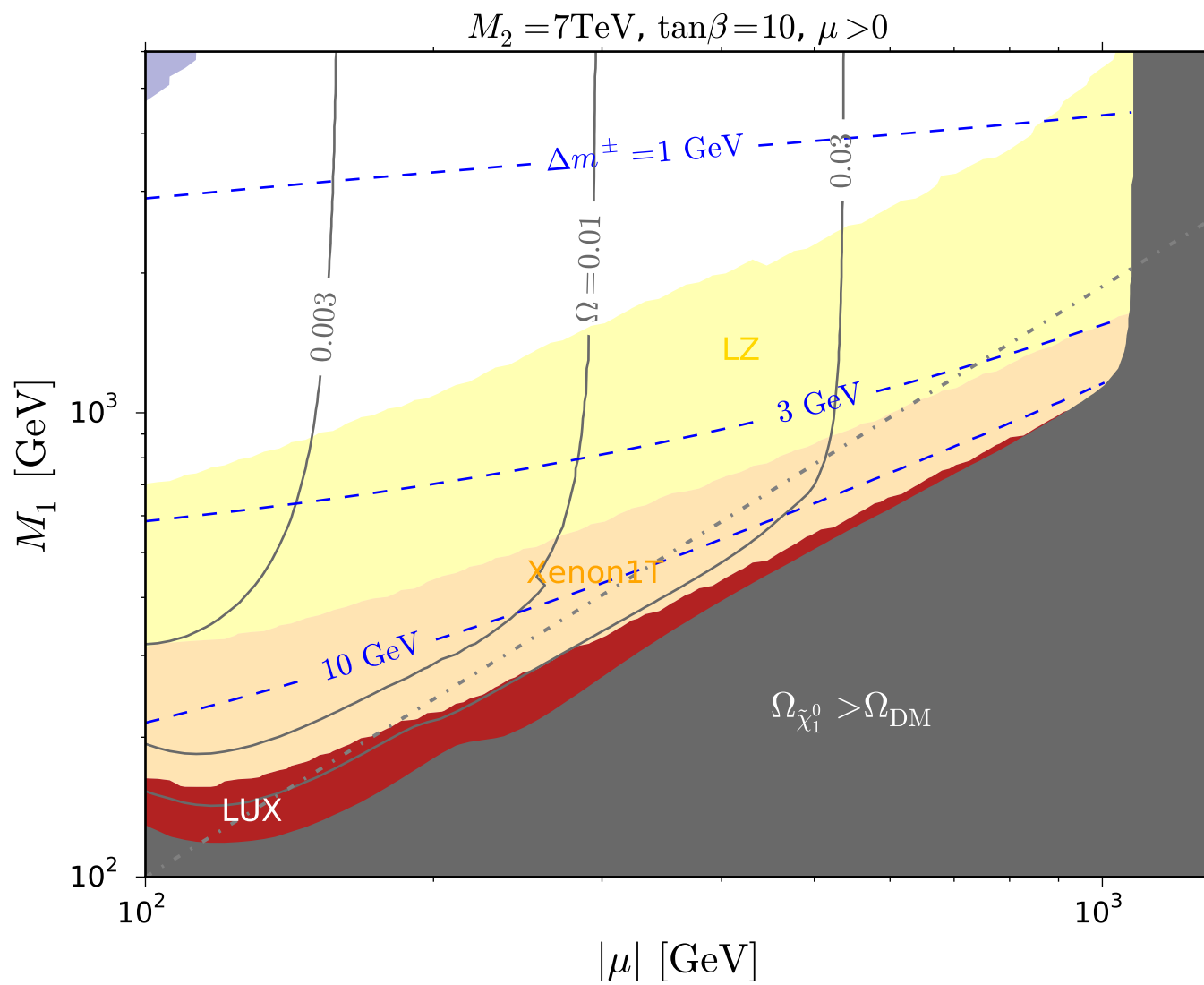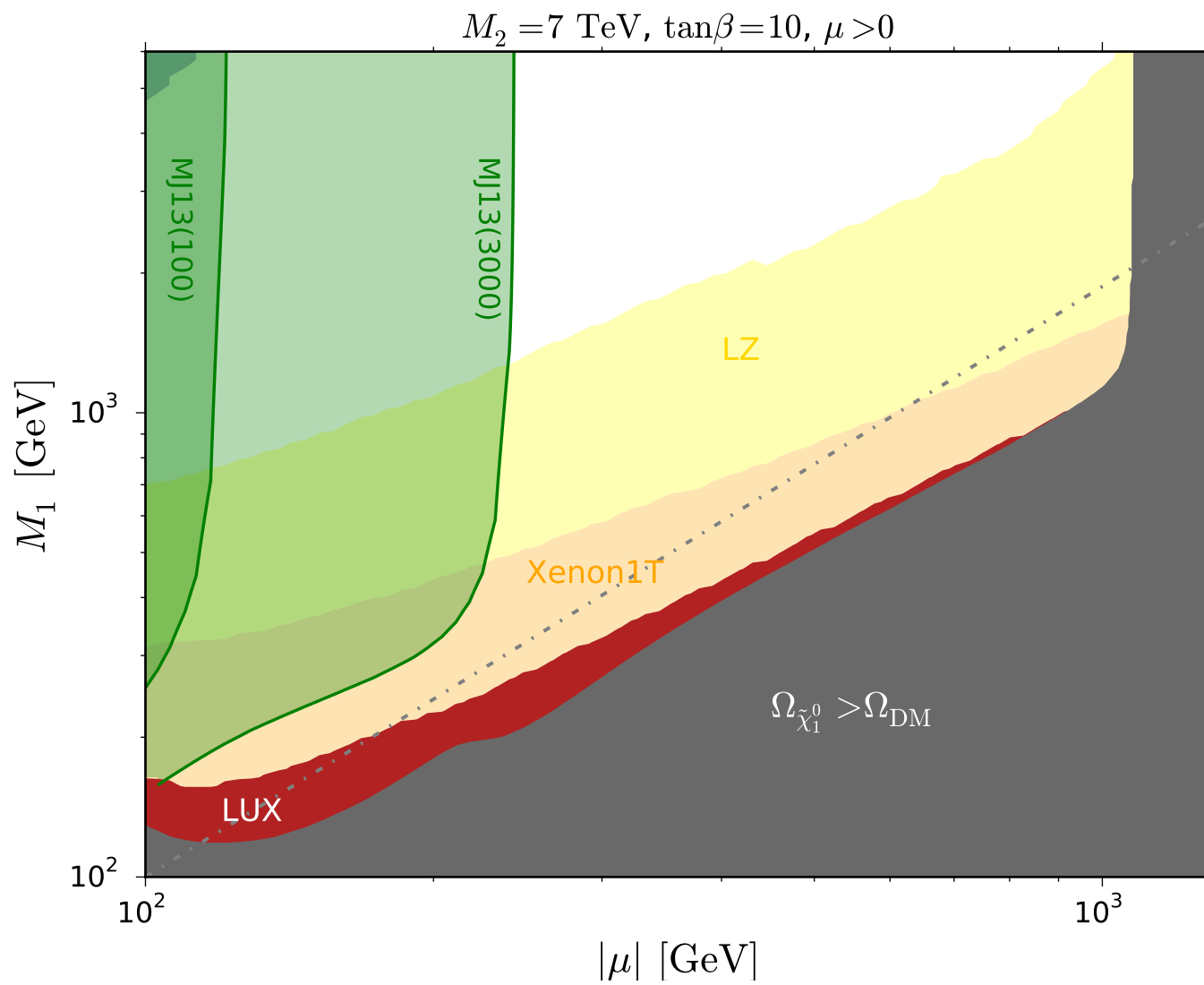
Collider

Drell-Yan production of
a pair of gauginos + a hard jet

W, Z, γ

jet

$\chi_1^+ \chi_1^-$, $\chi_2^0 \chi_1^0$,

$\chi_1^+ \chi_1^0$, $\chi_2^0 \chi_1^+$ etc

$pp \rightarrow jet \; \not{E}_T + X$

$\oplus$

depends on mass
differences

Mass differences for $\Omega h^2 \leq 0.12$

$\Delta m = 20 - 40$ GeV (rare) soft leptons

$\Delta m \sim O(1$ GeV$)$ (most frequent, monojets, mono-Z, mono-gamma)

$\Delta m \sim O(200 - 300$ MeV$)$ (disappearing tracks)

HL LHC AND ELECTROWEAK BARYOGENESIS

REQUIRES AN EXRENSION OF THE SM FOR TWO REASONS:

1) TO MAKE THE ELECTROWEAK PHASE TRANSITION A FIRST ORDER ONE
(E.G. AN EXTENDED SCALAR SECTOR,   ESPINOSA, QUIROS (1993))

2) TO HAVE ADDITIONAL TO CKM SOURCES OF CP VIOLATION
(GAVELA, HERNANDEZ, ORLOFF, PENE (1993))

MULTITUDE OF MODELS FOR THE 1st ORDER ELECTROWEAK PT.
ONE FIELD (HIGGS FIELD) PT- JUST THE HIGGS FIELD GETS A TEMPERATURE DEPENDENT vev;

MULTI-FIELD PT-AT LEAST ONE MORE FIELD GETS A TEMPERATURE DEPENDENT vev

FINITE TEMPERATURE EFFECTIVE POTENTIAL

$$V_{eff}(h,T) = V_0(h) + V_0^{CW} + V_T(h,T)$$

$$\lambda_3 = \frac{1}{6} \frac{d^3[V_0(h) + V_0^{CW}(h)]}{dh^3}\Big|_{h=v}$$

DI-HIGGS PRODUCTION AT THE HL LHC? $pp \rightarrow hh$

FURTHER THEORETICAL WORK WOULD ALSO BE USEFUL (WHAT IS THE MINIMAL VALUE OF THE hhh COUPLING FOR THE 1st ORDER EWPT? MULTI-FIELD EWPT AND RS MODELS, COMPOSITE HIGGS MODELS...

THE CPV SHOULD MANIFEST ITSELF IN THE QUARK AND LEPTON INTERACTIONS IN THE PLASMA WITH THE WALLS OF THE EXPANDING BUBBLES OF THE BROKEN HIGGS VACUUM; THUS IN THE YUKAWA COUPLINGS

E.G. ONE CAN ADD TO THE SM CPV DIM 6 OPERATORS

$$\mathcal{L}_6 = i[c_u \bar{Q}\tilde{H}u_R + c_d\bar{Q}Hd_R + c_l\bar{L}He_R](H^\dagger H) + h.c.$$

IN THE FERMION MASS EIGENSTATE BASIS

$$\mathcal{L}_h = -\frac{m_f}{v}\bar{f}fh - c_f m_f \bar{f}i\gamma_5 f(vh + 3h^2/2 + h^3/(2v))$$

CPV VIOLATION IN THE hff COUPLINGS IS STRONGLY CONSTRAINED BY THE ELECTRON EDM (2-loop BARR-ZEE DIAGRAMS) BUT THIS IS AN INDIRECT CONSTRAINT- OTHER NEW PHYSICS CONTRIBUTIONS COULD CANCEL THAT EFFECT.

A DIRECT PROBE OF THE CPV IN THE hff COUPLINGS IS VERY IMPORTANT

CP SENSITIVE SPIN CORRELATION VARIABLES IN
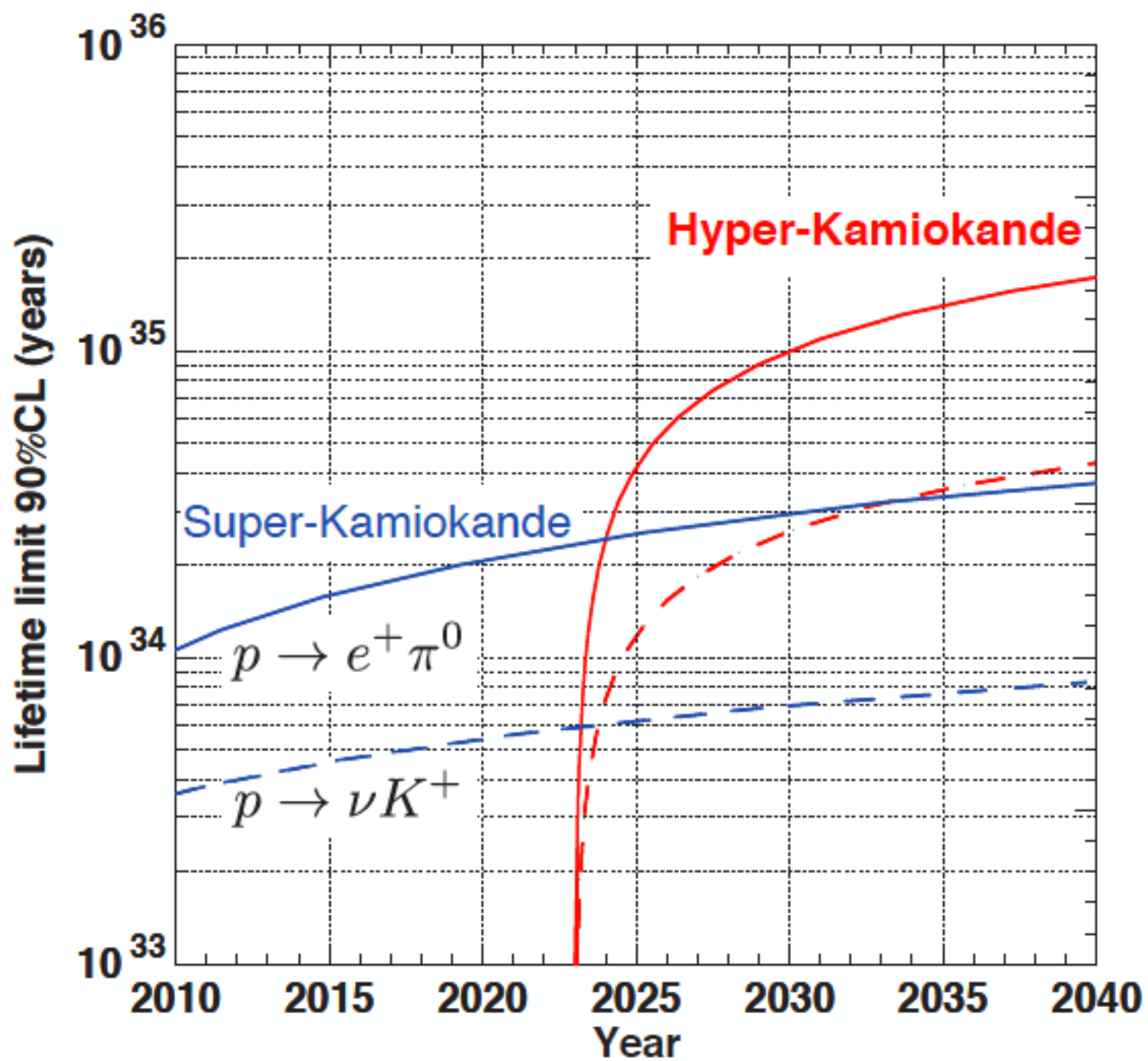
$$h \to \tau\tau$$

$$\to \rho\nu\rho\nu \qquad\qquad pp \to ht\bar{t}$$

$$\to \pi^+\pi^0\bar{\nu}\pi^-\pi^0\nu$$

VV SCATTERING AT THE HL LHC AS A TEST OF THE BSM PHYSICS

THE EFT APPROACH (SMEFT, HEFT); PARTIAL WAVE UNITARITY CONSTRAINT;

POLARIZED FINAL STATES; POSITIVITY BOUNDS...

PROTON DECAY-→ GUTs

GAUGE COUPLING UNIFICATION (GCU) OFTEN
CONSIDERED AS ONE OF THE MAIN MOTIVATION FOR
SUPERSYMMETRY (MSSM)

IMPLICIT ASSUMPTION- NO LARGE GUT THRESHOLD
CORRECTIONS,.

IF PRESENT, THEY WOULD MAKE THE GCU IN THE MSSM
TOTALLY ACCIDENTAL

INTERESTING LINK BETWEEN THE (LIMITS ON) PROTON
LIFE TIME AND THE SUSY SPECTRUM
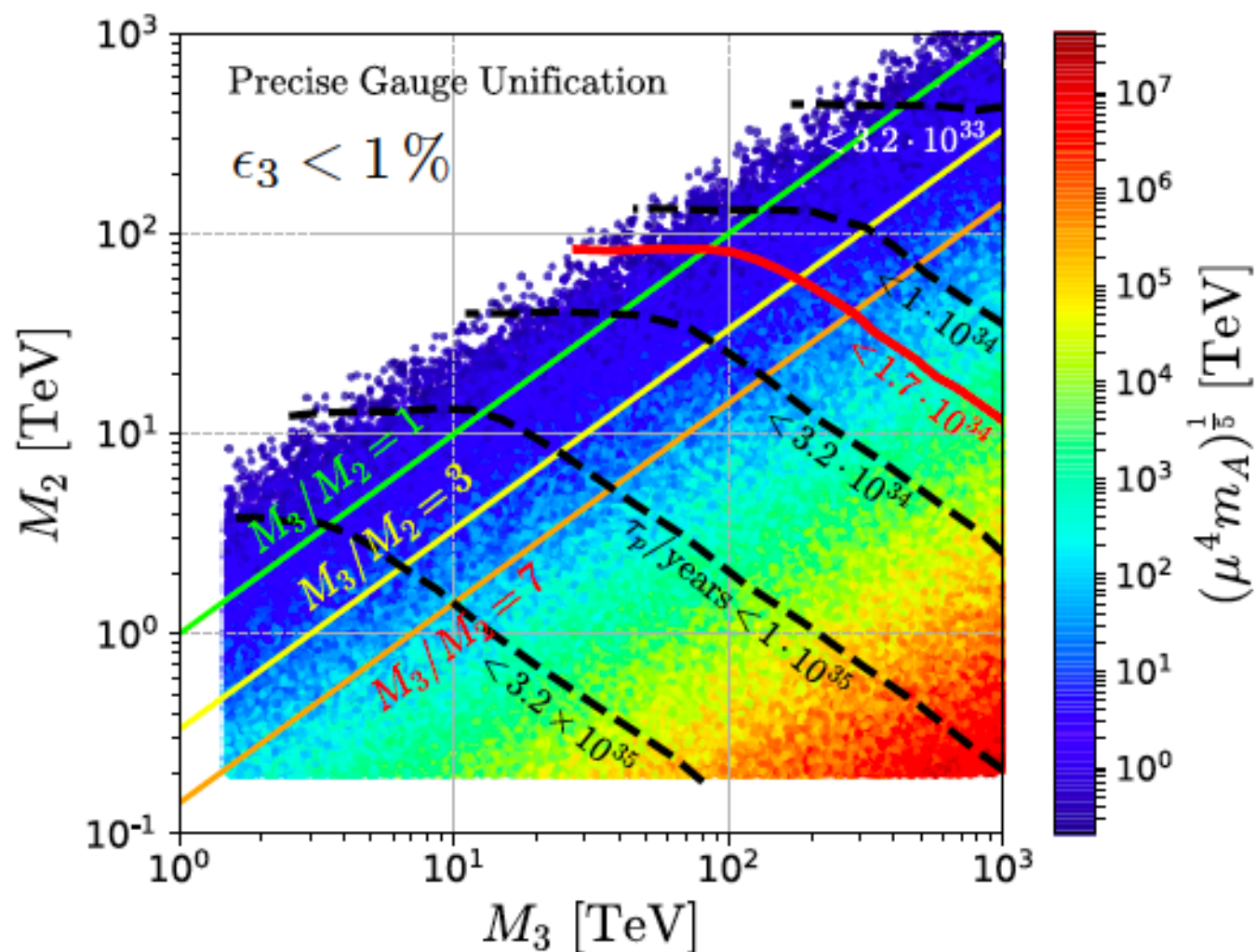
$$(M_3, M_2) < \begin{cases} (280, 40) \text{ TeV} & \text{(AMSB)} \\ (180, 60) \text{ TeV} & \text{(mSUGRA, GMSB)} \\ (90, 90) \text{ TeV} & \text{(Compressed)} \end{cases}$$
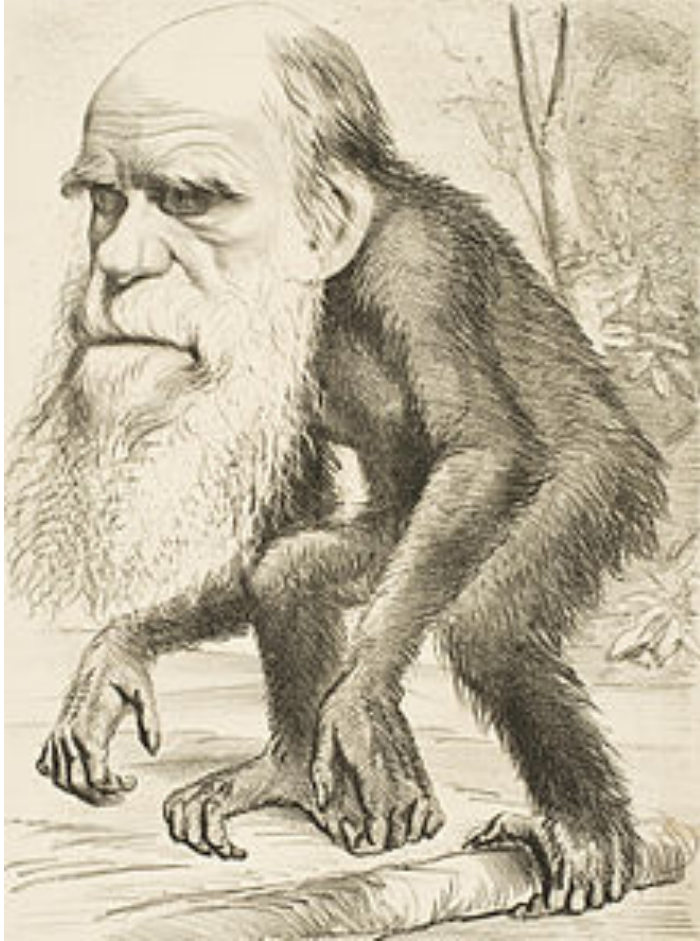
CONCLUSION

WE ARE BORED WHEN THE DISCOVERIES CONFIRM OUR EXPECTATIONS (COMPLETION OF THE SM)

WE ARE FRUSTRATED WHEN THERE IS NO DISCOVERIES CONFIRMING OUR EXPECTATIONS

IS THERE ANY WAY TO MAKE US HAPPY?

ANYWAY, FRUSTRATED OR NOT, IT IS GOOD TO ADJUST ONE WAY OR ANOTHER TO THE SITUATION (FOR SURVIVAL- CHARLES DARWIN)

As many more individuals of each species are born than can possibly survive and as, consequently, there is a frequently recurring struggle for existence, it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and sometimes varying conditions of life, will have a better chance of surviving, and thus be *naturally selected*.
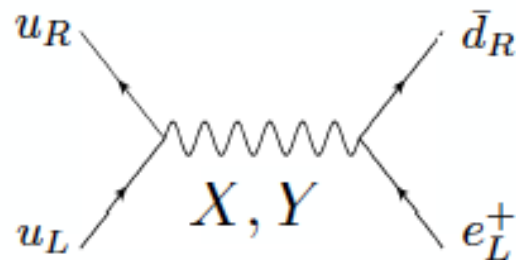
BACKUP

D=5
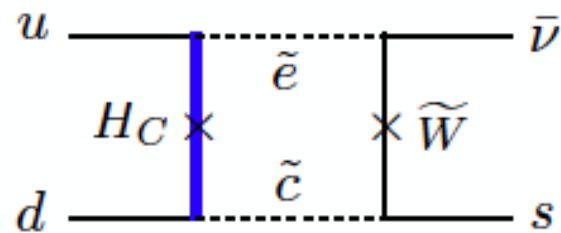
$\tau(p \to K^+ \bar{\nu}) = $ function of many parameters

- generally gives a stringent constraint
- depends on the details of GUT models
- mechanisms to suppress this mode are known
- we do not consider this mode

D=6

$$\tau(p \to e^+ \pi^0) \propto \frac{1}{\alpha_G^2} \frac{M_{X,Y}^4}{m_p^5}$$

For models with small GUT threshold correction, $M_{X,Y} = M_G$ in good approximation

introduce an lower limit on the GUT scale from D=6 proton decay:

$$M_G > M_{\mathrm{PD}}$$

All SUSY masses are degenerate with M_s

$$\delta_i \equiv b_i - b_i^{\text{SM}}$$

$$\frac{2\pi}{\alpha_G^*} = \frac{2\pi}{\alpha_i(m_Z)} - b_i \ln\left(\frac{M_G^*}{m_Z}\right) + \delta_i \ln\left(\frac{M_s^*}{m_Z}\right) + \gamma_i + \Delta_i$$

$M_s = M_s^*$

α_G^*

m_Z

$Q = M_G^*$
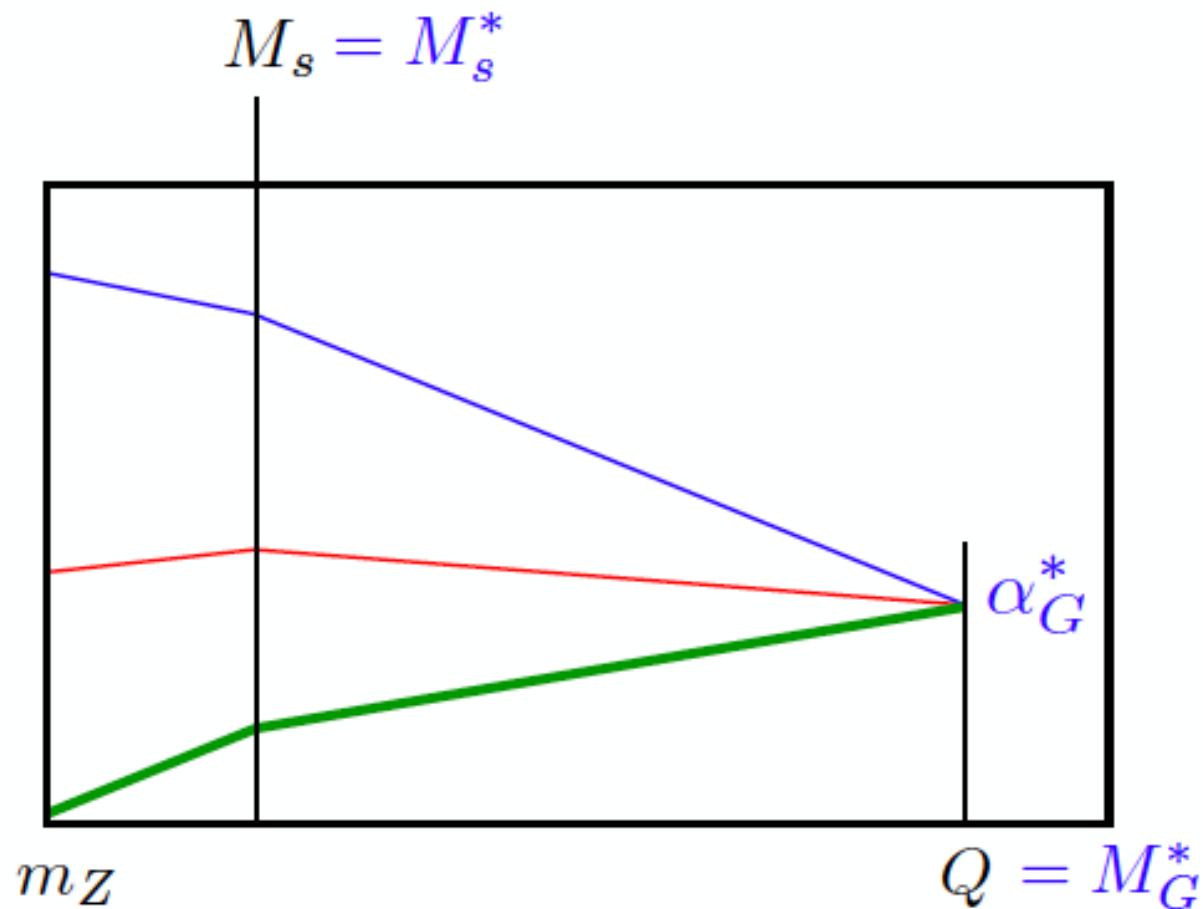
$M_s^* = 2.1\,\text{TeV}$

$M_G^* = 1.3 \cdot 10^{16}\,\text{GeV}$

$\alpha_G^{*-1} = 25.5$

General case

$$\overset{\vec{s}}{\left(s_i\right)} = \sum_{\eta=\tilde{g},\tilde{q},\cdots} b_i^\eta \ln\left(\frac{m_\eta}{m_Z}\right) = \overset{\vec{v}_1}{\left(b_i\right)}\ln \Omega + \overset{\vec{v}_2}{\left(\delta_i\right)}\ln\left(\frac{T}{m_Z}\right) + C\overset{\vec{v}_3}{\left(1\right)}$$

$$\frac{2\pi}{\alpha_i(Q)} = \frac{2\pi}{\alpha_i(m_Z)} - b_i \ln\left(\frac{Q}{m_Z}\right) + s_i + \gamma_i + \Delta_i$$

η	$\tilde{B}$	$\tilde{W}$	$\tilde{g}$	$\tilde{h}$	A	$\tilde{d}_R$	$\tilde{l}$	$\tilde{u}_R$	$\tilde{q}$	$\tilde{e}_R$
m_η	M_1	M_2	M_3	μ	m_A	$m_{\tilde{d}_R}$	$m_{\tilde{l}}$	$m_{\tilde{u}_R}$	$m_{\tilde{q}}$	$m_{\tilde{e}_R}$
b_1^η	0	0	0	$\frac{2}{5}$	$\frac{1}{10}$	$\frac{1}{15}$	$\frac{1}{10}$	$\frac{4}{15}$	$\frac{1}{30}$	$\frac{1}{5}$
b_2^η	0	$\frac{4}{3}$	0	$\frac{2}{3}$	$\frac{1}{6}$	0	$\frac{1}{6}$	0	$\frac{1}{2}$	0
b_3^η	0	0	2	0	0	$\frac{1}{6}$	0	$\frac{1}{6}$	$\frac{1}{3}$	0

$$T = \left[M_3^{-28} M_2^{32} \mu^{12} m_A^3 X_T \right]^{\frac{1}{19}}$$

$$X_T \equiv \prod_{i=1\ldots3} \left(\frac{m_{\tilde{l}_i}^3}{m_{\tilde{d}_{Ri}}^3} \right) \left(\frac{m_{\tilde{q}_i}^7}{m_{\tilde{e}_{Ri}}^2 m_{\tilde{u}_{Ri}}^5} \right)$$

$$\Omega = \left[M_3^{-100} M_2^{60} \mu^{32} m_A^8 X_\Omega \right]^{\frac{1}{288}}$$

$$X_\Omega \equiv \prod_{i=1\ldots3} \left(\frac{m_{\tilde{l}_i}^8}{m_{\tilde{d}_{Ri}}^8} \right) \left(\frac{m_{\tilde{q}_i}^6 m_{\tilde{e}_{Ri}}}{m_{\tilde{u}_{Ri}}^7} \right)$$

$$C = \frac{125}{19} \ln M_3 - \frac{113}{19} \ln M_2 - \frac{40}{19} \ln \mu - \frac{10}{19} \ln m_A$$

$$+ \sum_{i=1\ldots3} \left[\frac{79}{114} \ln m_{\tilde{d}_{Ri}} - \frac{10}{19} \ln m_{\tilde{l}_i} - \frac{121}{114} \ln m_{\tilde{q}_i} + \frac{257}{228} \ln m_{\tilde{u}_{Ri}} + \frac{33}{76} \ln m_{\tilde{e}_{Ri}} \right]$$

For most models $\quad X_T \sim X_\Omega \sim 1 \quad \begin{cases} m_{\tilde{l}_i} \simeq m_{\tilde{d}_{R_i}} & \Rightarrow \; \overline{\mathbf{5}}_i \\ m_{\tilde{q}_i} \simeq m_{\tilde{u}_{R_i}} \simeq m_{\tilde{e}_{R_i}} & \Rightarrow \; \mathbf{10}_i \end{cases}$

General case

condition of GCU $\longrightarrow$ $T = 2.1\,\mathrm{TeV}$

unification sale $\longrightarrow$ $M_G = \Omega \times 1.3 \cdot 10^{16}\,\mathrm{GeV}$

unified coupling $\longrightarrow$ $\alpha_G^{-1} = 25.5 + \dfrac{C}{2\pi}$

$$\frac{2\pi}{\alpha_i(Q)} - \frac{2\pi}{\alpha_G^*} = b_i \ln\left(\frac{M_G^*\Omega}{Q}\right) + \delta_i \ln\left(\frac{T}{M_s^*}\right) + C$$

$$\xrightarrow{\begin{array}{c} T = M_s^* \\[4pt] \hline Q = M_G^*\Omega \equiv M_G \end{array}} \quad \alpha_i^{-1}(M_G) = \alpha_G^{*-1} + \frac{C}{2\pi}$$

$$\text{F.T.} = \frac{2v^2}{f^2} \qquad \text{(A SHORT CALCULATION)}$$

IT IS DETERMINED BY THE QUADRATIC TERMS IN THE POTENTIAL

CANCELLATION OF QUADRATIC DIVERGENCES IN NON-LINEAR PARAMETRIZATION, AFTER INTEGRATING OUT THE HEAVY RADIAL MODE: