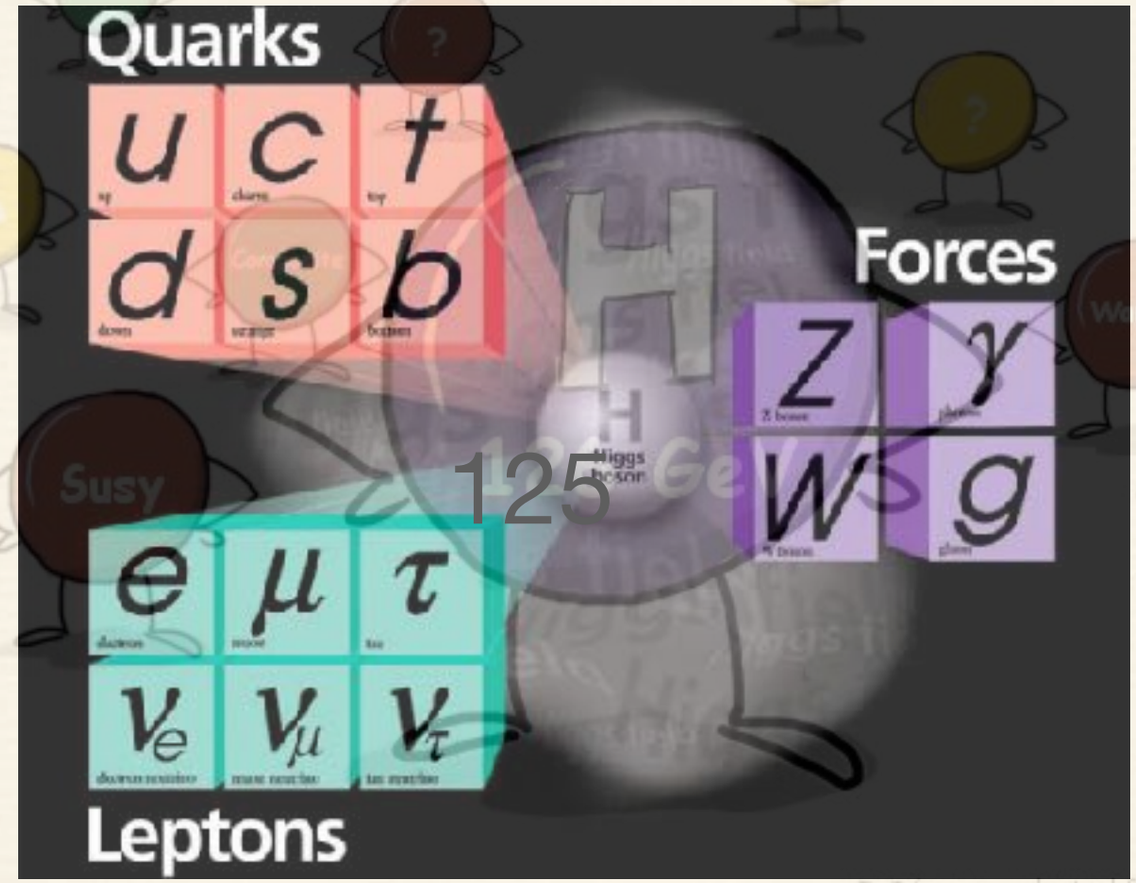
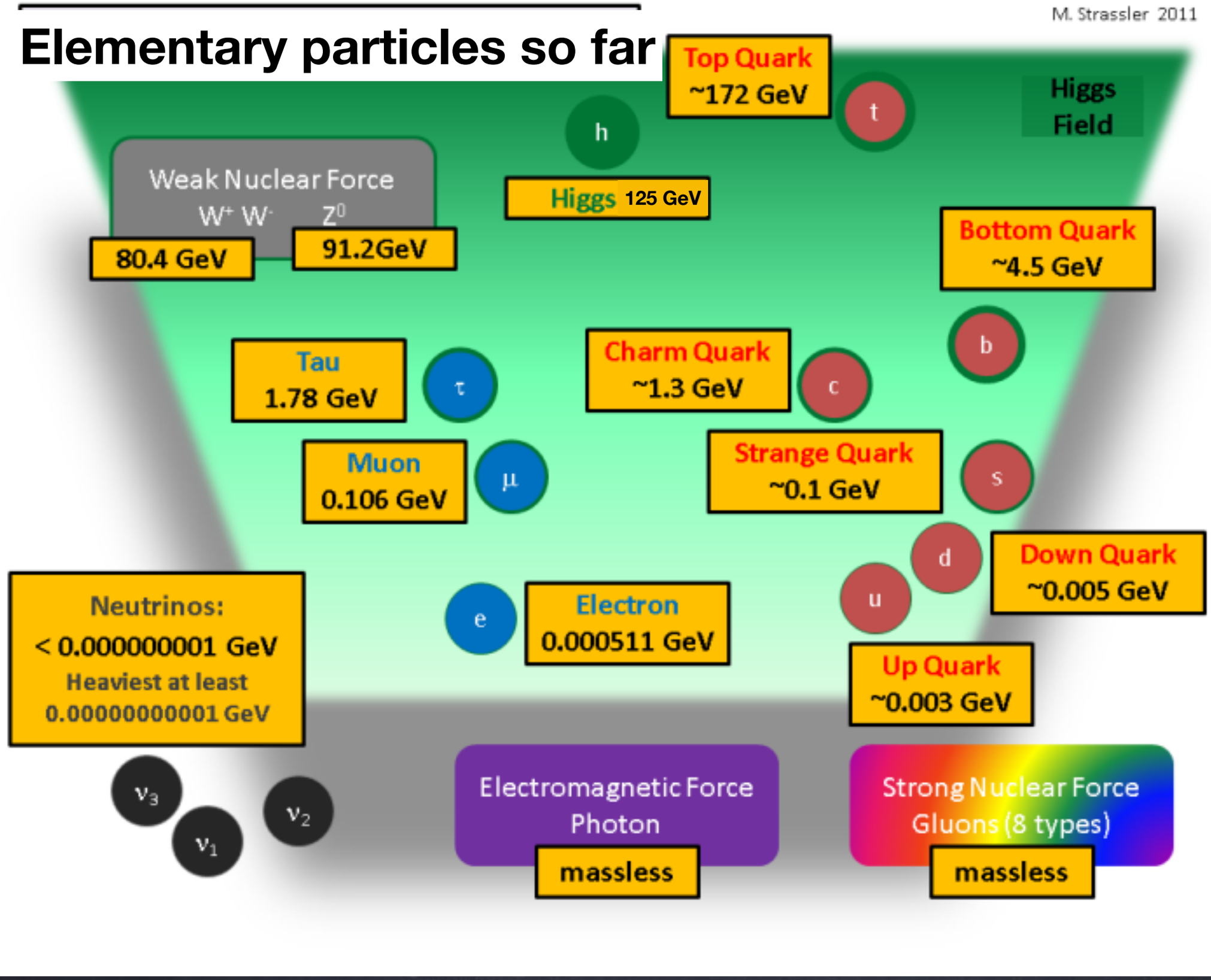
Journée des Nouveaux Entrants du Pôle Théorie

Groupe BSM



2 February 2023

Elementary particles so far



Borrowed from Matt Strassler's blog: http://profmattstrassler.com/

Is Standard Model enough ?

Standard Model is a perfectly consistent theory, and it very well describes a wide range of phenomena in collider and many other experiments

However, it is certainly not the ultimate theory of nature

WHY BSM?

A number of observations cannot be explained within the framework of the Standard Model:

- Neutrino Oscillations
- Dark Matter
- Baryon Asymmetry
- Inflation

All of them experimental facts!

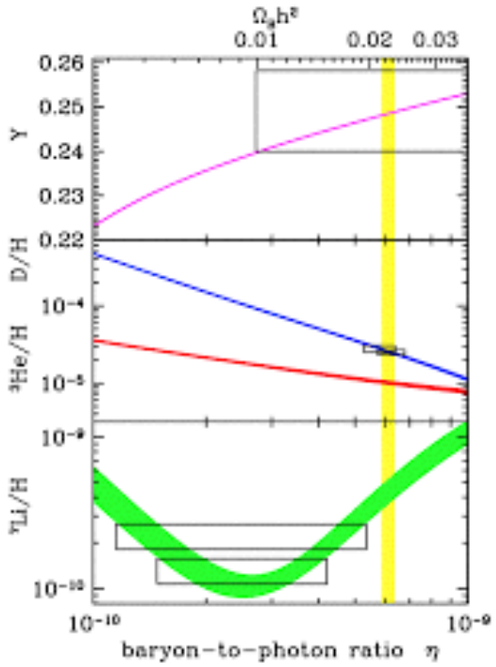
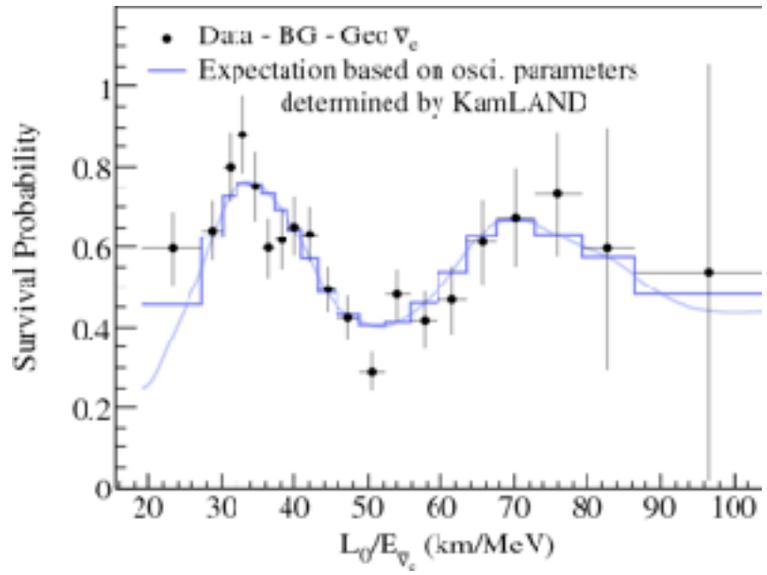
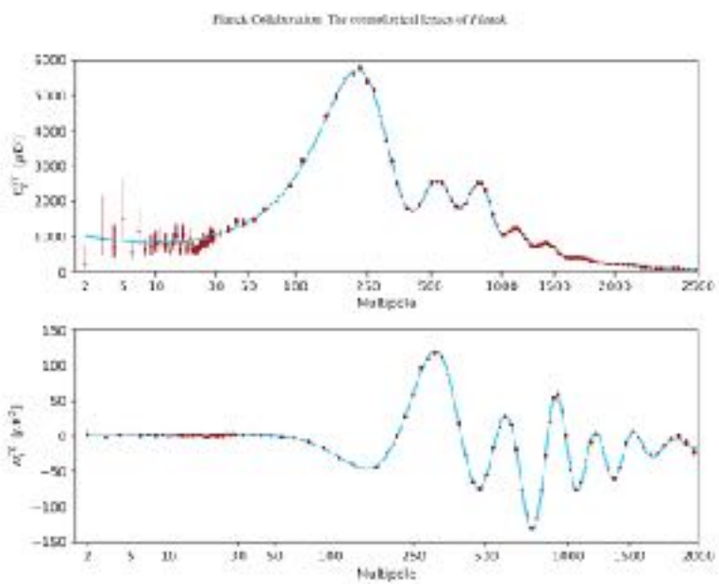
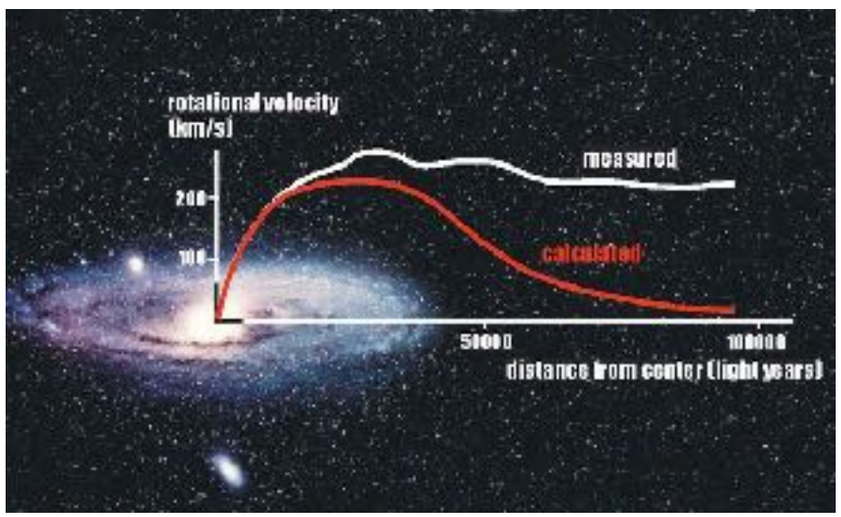


Fig. 1. Primordial abundances versus η, courtesy of R. Cyburt

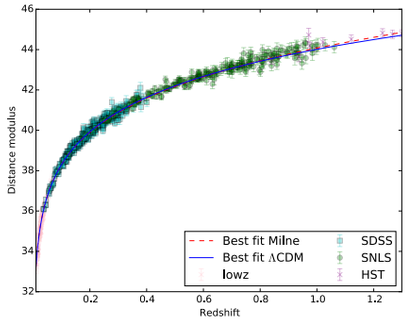


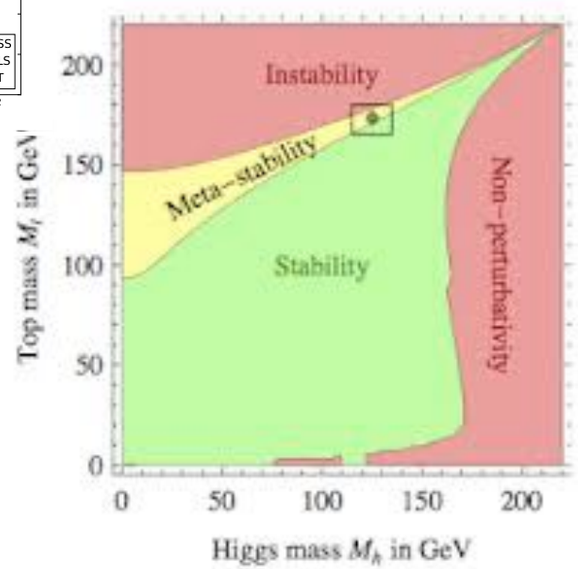




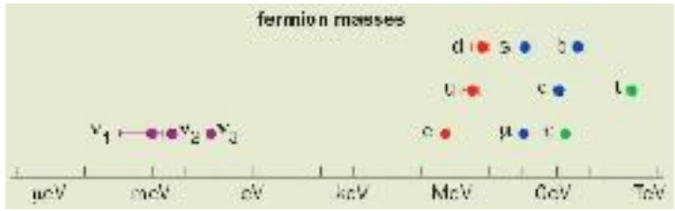
WHY BSM?

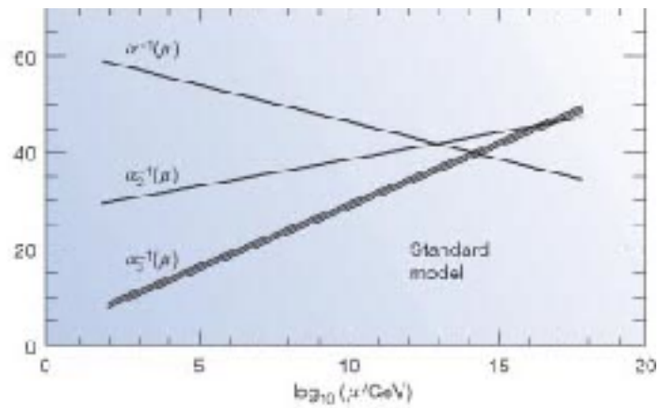
Certain features of the Standard Model appear ad-hoc or fine-tuned:

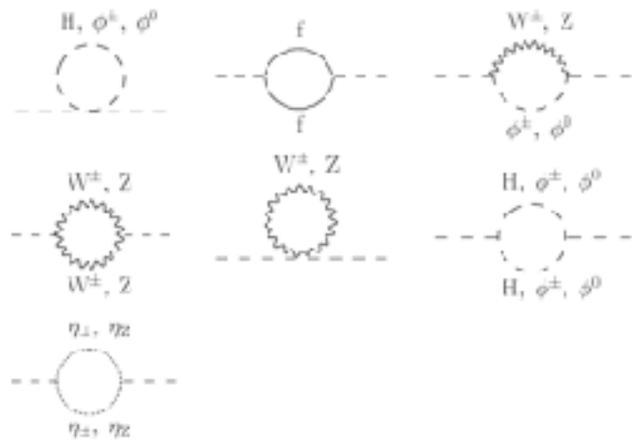




- Small cosmological constant
- Fermion generation structure and mass/mixing hierarchies
- Vacuum metastability
- Gauge coupling unification
- Strong CP problem
- Higgs naturalness problem

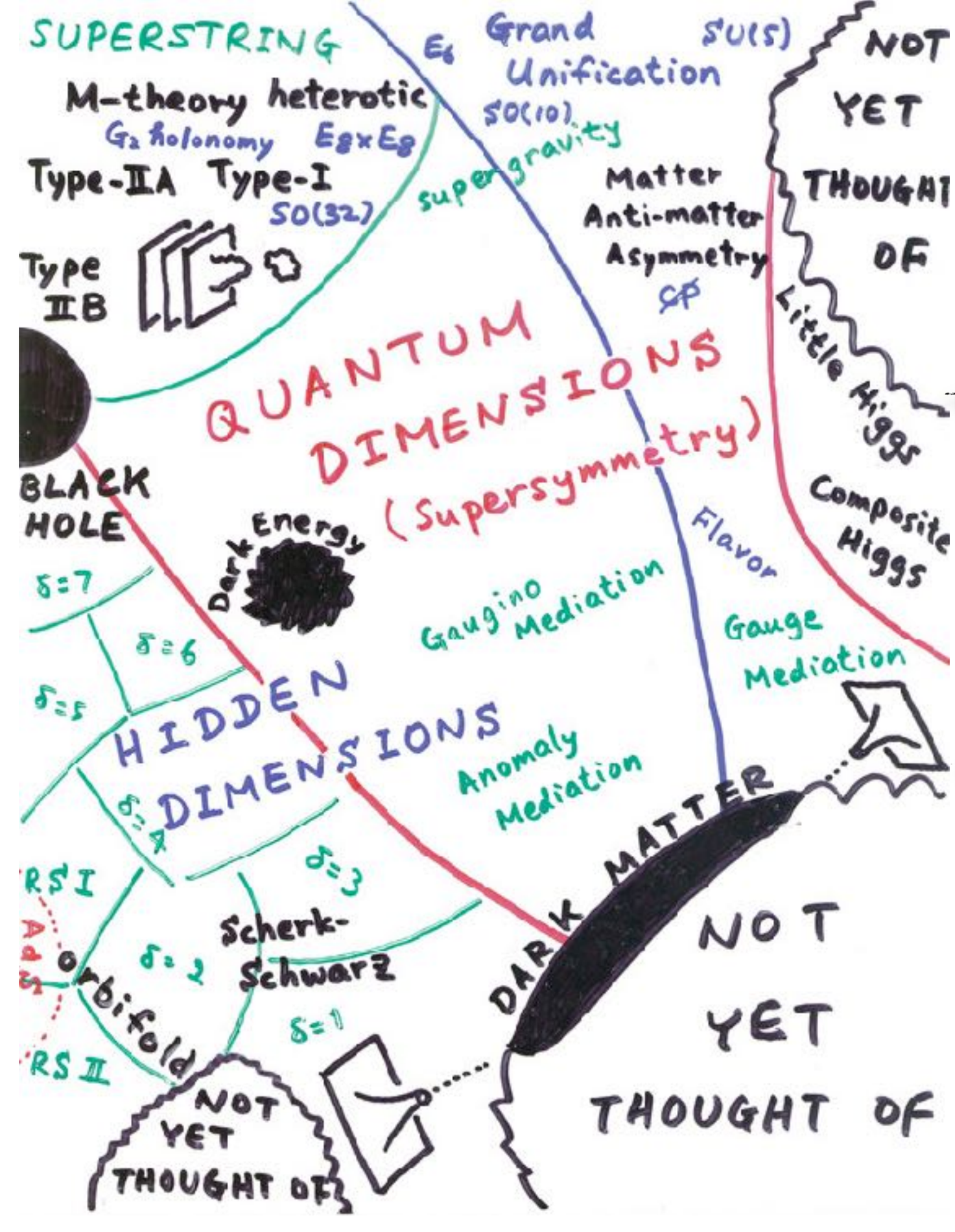






What do we know about BSM ?

Physics beyond the Standard Model
according to H. Murayama



We are not short of ideas
about what could be discovered ;)

More systematic, less ambitious approach

1. **Locality, unitarity, Poincaré symmetry**
2. **Mass gap: absence of non-SM degrees of freedom at or below the electroweak scale**
3. **Gauge symmetry: local SU(3)xSU(2)xU(1) symmetry strictly respected by all interactions**

If these assumptions are true we can organize the EFT as an expansion in 1/Λ, where Λ is identified with the mass scale of the UV completion of the SMEFT, and each term is a linear combination of SU(3)xSU(2)xU(1) invariant operators of a given canonical dimension D

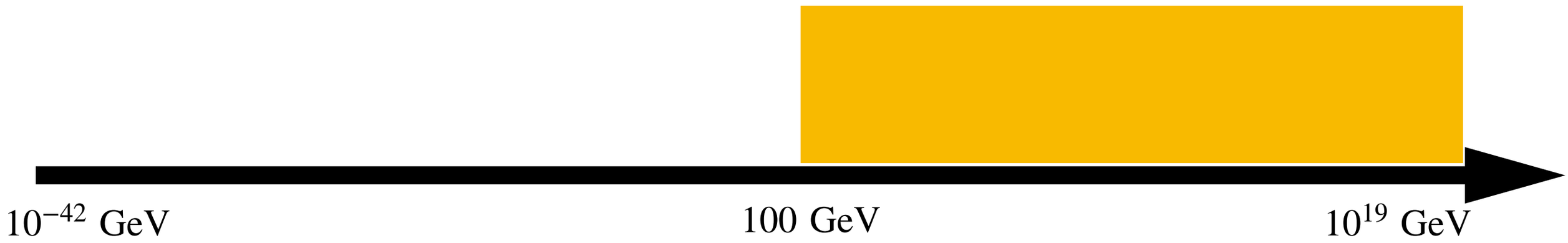
$$\mathscr{L}_{\text{SMEFT}} = \mathscr{L}_{D=2} + \mathscr{L}_{D=3} + \mathscr{L}_{D=4} + \mathscr{L}_{D=5} + \mathscr{L}_{D=6} + \mathscr{L}_{D=7} + \mathscr{L}_{D=8} + \cdots$$

SM Lagrangian

Higher-dimensional $SU(3)_C$ x $SU(2)_L$ x $U(1)_Y$ invariant interactions added to the SM

In the spirit of EFT, each $\mathscr{L}_D$ should include a <u>complete</u> and <u>non-redundant</u> set of interactions

What do we know about BSM ?



Pole N Theory

Pole S Theory

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Antonio RODRIGUEZ-SANCHEZ

Some recent production

Eur. Phys. J. C (2021) 81:1016
https://doi.org/10.1140/epjc/s10052-021-09754-w

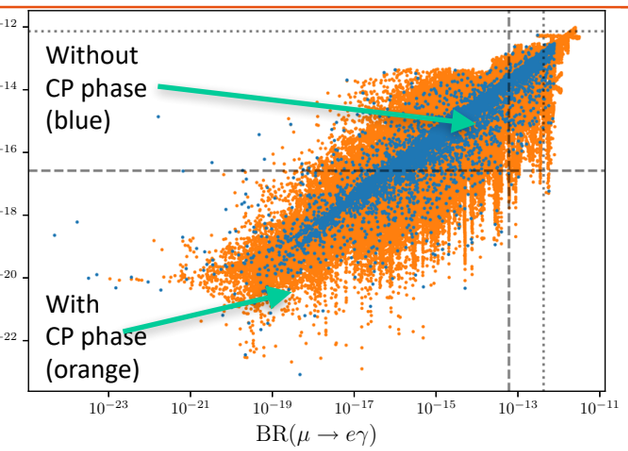
THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

On the role of leptonic CPV phases in cLFV observables

A. Abada[1], J. Kriewald[2,a], A. M. Teixeira[2]

Correlations between lepton-flavor-violating observables:



Eur. Phys. J. C (2022) 82:1030
https://doi.org/10.1140/epjc/s10052-022-11011-7

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

Collider searches for heavy neutral leptons: beyond simplified scenarios

Asmaa Abada[1,a], Pablo Escribano[2,b], Xabier Marcano[3,c], Gioacchino Piazza[1,d]

JHEP PUBLISHED FOR SISSA BY SPRINGER
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PUBLISHED: *August 16, 2021*

New physics from oscillations at the DUNE near detector, and the role of systematic uncertainties

Pilar Coloma,[a] Jacobo López-Pavón,[b] Salvador Rosauro-Alcaraz[a,c] and Salvador Urrea[b]

PHYSICAL REVIEW D **103,** 115009 (2021)

Eur. Phys. J. C (2022) 82:261
https://doi.org/10.1140/epjc/s10052-022-10216-0

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

Searching for stop LSP at the LHC

Essodjolo Kpatcha[1,2,3,a], Iñaki Lara[4,b], Daniel E. López-Fogliani[5,6,c], Carlos Muñoz[1,2,d], Natsumi Nagata[7,e], Hidetoshi Otono[8,f]

PHYSICAL REVIEW D **105,** 095042 (2022)

Gravitational portals with nonminimal couplings

Simon Cléry,[1,*] Yann Mambrini,[1,2,†] Keith A. Olive,[3,‡] Andrey Shkerin,[3,§] and Sarunas Verner[3,‖]

PHYSICAL REVIEW D **106,** 043537 (2022)

Inflaton freeze-out

Oleg Lebedev,[1] Thomas Nerdi,[1] Timofey Solomko,[2] and Jong-Hyun Yoon[1]

JHEP PUBLISHED FOR SISSA BY SPRINGER
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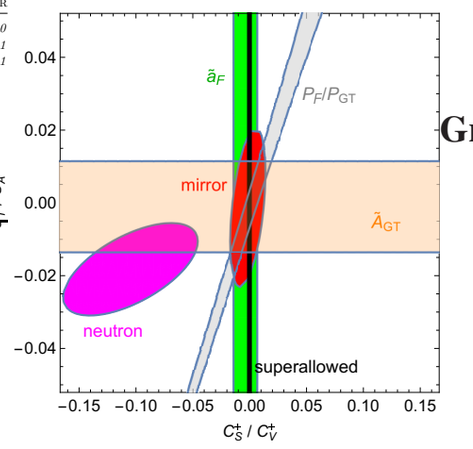
ACCEPTED: *March 4, 2021*
PUBLISHED: *April 14, 2021*

Comprehensive analysis of beta decays within and beyond the Standard Model

Adam Falkowski,[a] Martín González-Alonso[b] and Oscar Naviliat-Cuncic[c,d]

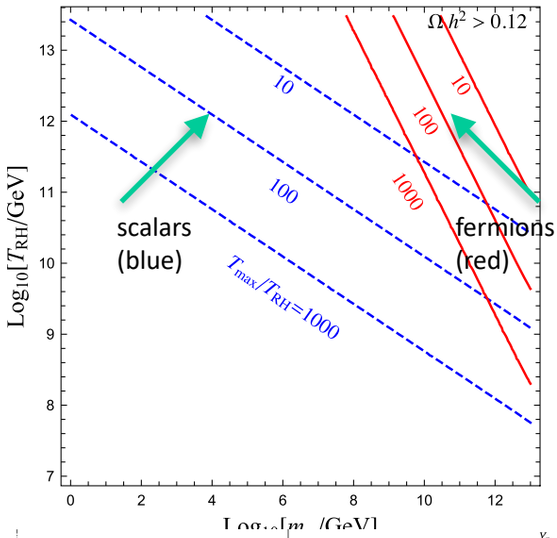
Constraints on new physics from various observables in nuclear beta decays:



Gravitational production of dark matter during reheating

Yann Mambrini[1,*] and Keith A. Olive[2,†]

Gravitational production can be responsible for all dark matter, for a wide range of dark matter masses:



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RECEIVED: *February 1, 2022*
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PUBLISHED: *May 24, 2022*

Gravitational causality and the self-stress of photons

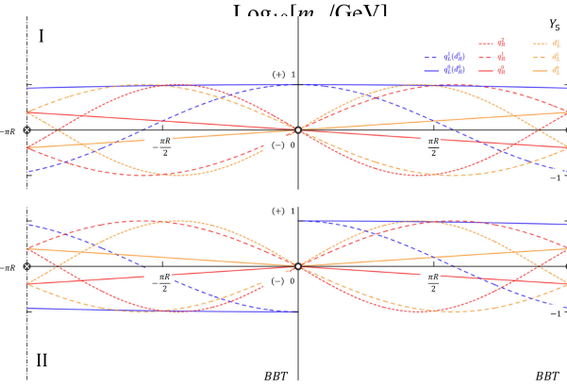
Brando Bellazzini,[a,b,c] Giulia Isabella,[a,d] Matthew Lewandowski[e] and Francesco Sgarlata[f]

PHYSICAL REVIEW D **103,** 075010 (2021)

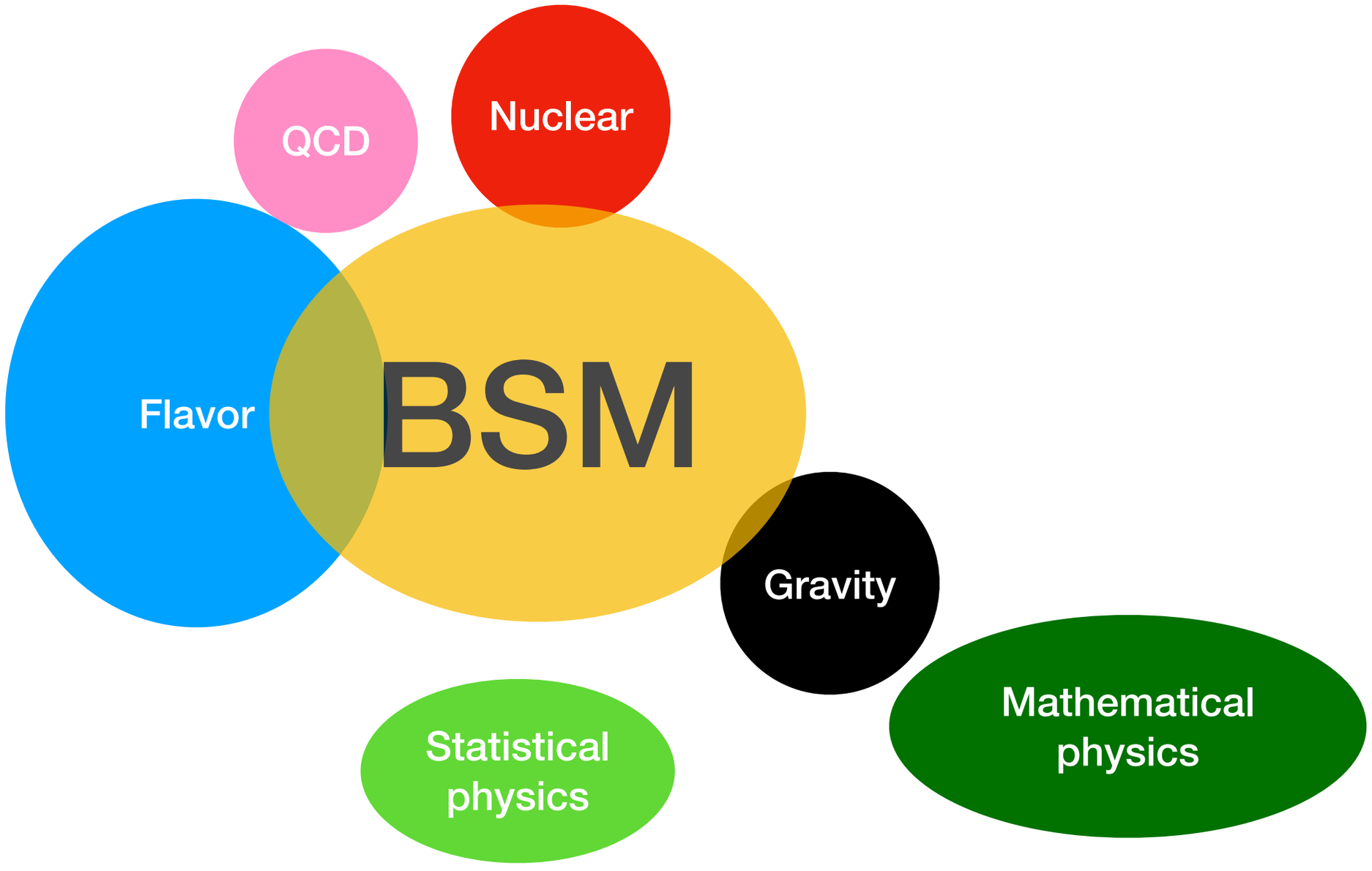
Rigorous treatment of the $\mathcal{S}^1/\mathbb{Z}_2$ orbifold model with brane-Higgs couplings

Ruifeng Leng,[*] Grégory Moreau,[†] and Florian Nortier[‡]

Careful study boundary conditions for fields propagating in a flat extra dimension:



Venn Diagram

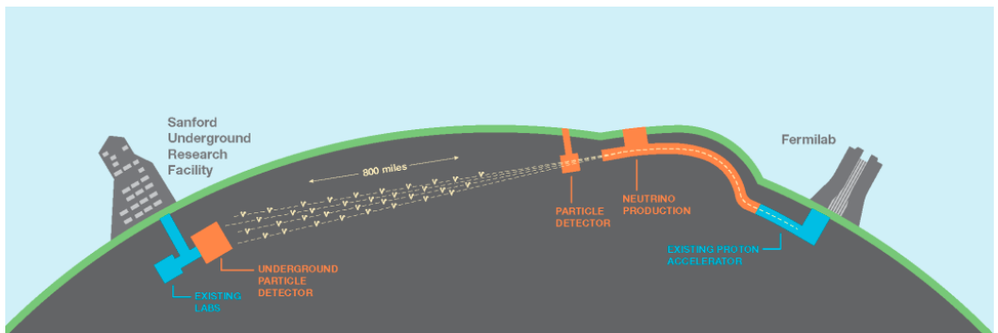


Biggest questions for BSM physics

1 *Is there CP violation in the neutrino sector?*

$$\mathscr{L}_5 = \frac{1}{\Lambda_5}(HL)Y_\nu(HL)\ldots \to \frac{1}{2\Lambda_5}\nu Y_\nu \nu$$

Neutrino masses and mixing show that
$\Lambda_5 \sim 10^{15}$ GeV **for** $\mathcal{O}(1)$ Y_ν



$$\begin{aligned} P(\nu_\mu \to \nu_e) \simeq\ & \sin^2\theta_{23}\sin^2 2\theta_{13}\frac{\sin^2(\Delta_{31}-aL)}{(\Delta_{31}-aL)^2}\Delta_{31}^2 \\ & + \sin 2\theta_{23}\sin 2\theta_{13}\sin 2\theta_{12}\frac{\sin(\Delta_{31}-aL)}{(\Delta_{31}-aL)}\Delta_{31}\frac{\sin aL}{aL}\Delta_{21}\cos(\Delta_{31}+\delta_{\mathrm{CP}}) \\ & + \cos^2\theta_{23}\sin^2 2\theta_{12}\frac{\sin^2 aL}{(aL)^2}\Delta_{21}^2, \end{aligned}$$

2 What is the scale of dimension-6 SMEFT operators ?

So far only limits:

$C_{duu}(d^c u^c)(u^c e^c)$ $\qquad |C_{duu}| \leq \left(\frac{1}{3.5\times 10^{15}\ \text{GeV}}\right)^2 .$

$[C_{eB}]_{12}(\bar{L}_1 H \bar{\sigma}^{\alpha\beta}\bar{\mu}^c)B_{\alpha\beta}$ $\qquad \left|[C_{eB}]_{12}\right| \leq \frac{1}{\left(65\ \text{PeV}\right)^2} .$

$[C_{dd}]_{2121}(s^c\sigma_\mu \bar{d}^c)(s^c\sigma^\mu \bar{d}^c)$ $\qquad -\frac{1}{(25\ \text{PeV})^2} \lesssim \text{Im}[C_{dd}]_{2121} \lesssim \frac{1}{(44\ \text{PeV})^2},$

$C_H |H|^6$ $\qquad |C_H| \lesssim \frac{1}{(1\ \text{TeV})^2}$

3

Are there additional light weakly interacting particles?

For example sterile neutrinos, or axions

If yes, that would imply a slight modification of the particle physics framework used to describe our experiments

$$\mathscr{L} = \mathscr{L}_1 + \mathscr{L}_2 + \mathscr{L}_3 + \mathscr{L}_4 + \mathscr{L}_5 + \mathscr{L}_6 + \ldots$$

add new terms with the new degrees of freedom

4 What is the nature of dark matter?

~~The Evidence for DM~~

1) galaxy rotation curves

$$m\frac{v_c^2(r)}{r} = \frac{G_N m M(r)}{r^2}$$

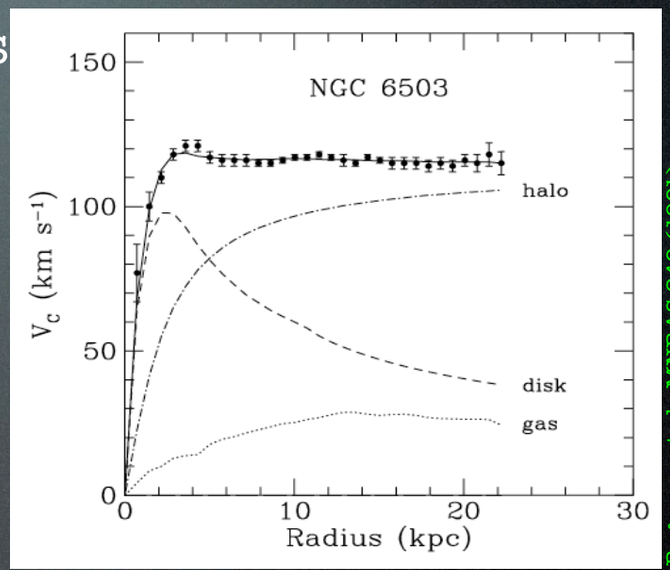
'centrifugal' 'centripetal'

$$v_c(r) = \sqrt{\frac{G_N M(r)}{r}}$$

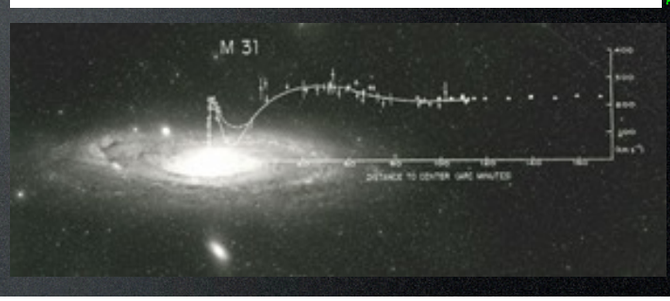
with $M(r) = 4\pi \int \rho(r)\, r^2 dr$

$$v_c(r) \sim \text{const} \Rightarrow \rho_M(r) \sim \frac{1}{r^2}$$

$$\Omega_{\rm M} \gtrsim 0.1$$

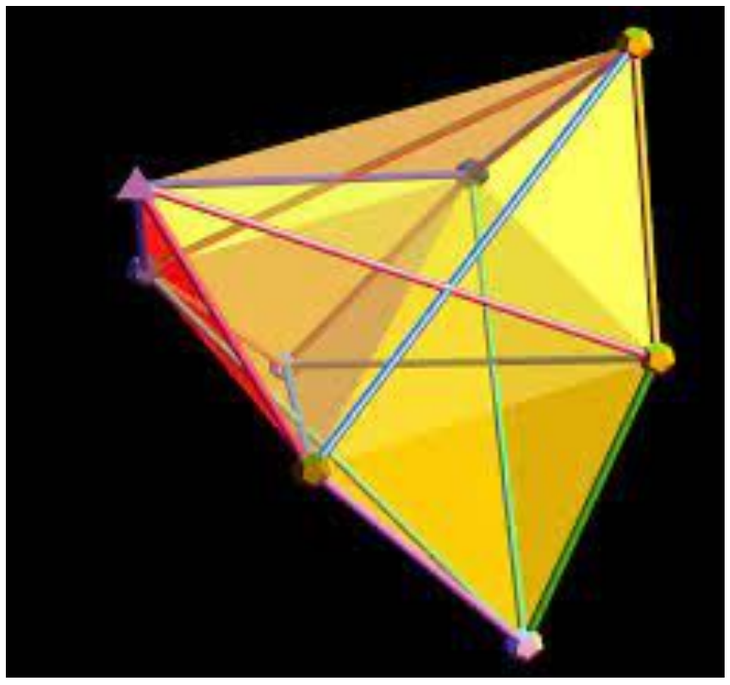


Begeman et al., MNRAS 249 (1991)



However, so far we only see gravitational effects of dark matter, and we know almost nothing about it's particle (or another) nature

5 Is there another formulation of quantum field theory?



Unitarity, causality, locality, Lorentz invariance impose unexpected constraints on consistent quantum field theories

UV-IR connections?

Connections to classical physics

Recent attempts at alternative formulations where spacetime and locality is emergent rather than fundamental concept

Thank you