Decadal Mission for the New *Higgs/Flavor* Era

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Sept 22, 2020, Colloquium @ NTU

臺灣大學
National Taiwan University

Disclaimer: In this talk, not all wordings are precise.

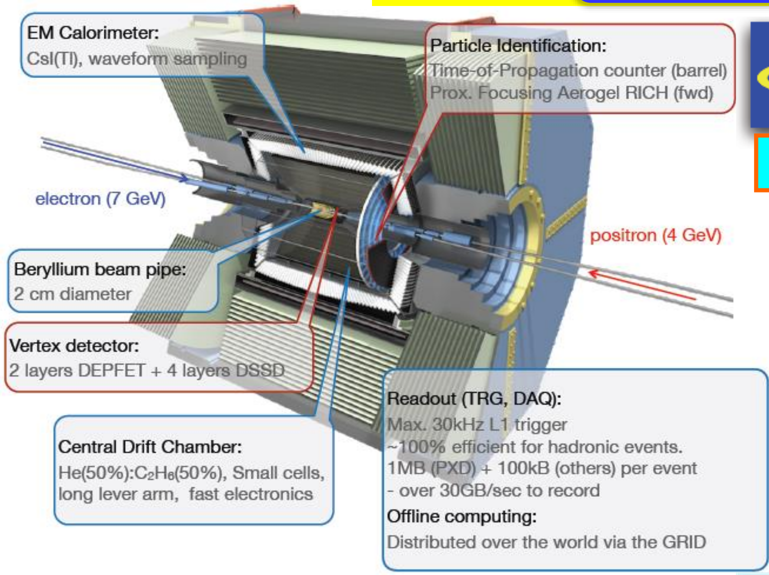
Decadal

Decadal Mission
for
the New *Flavor/Higgs* Era

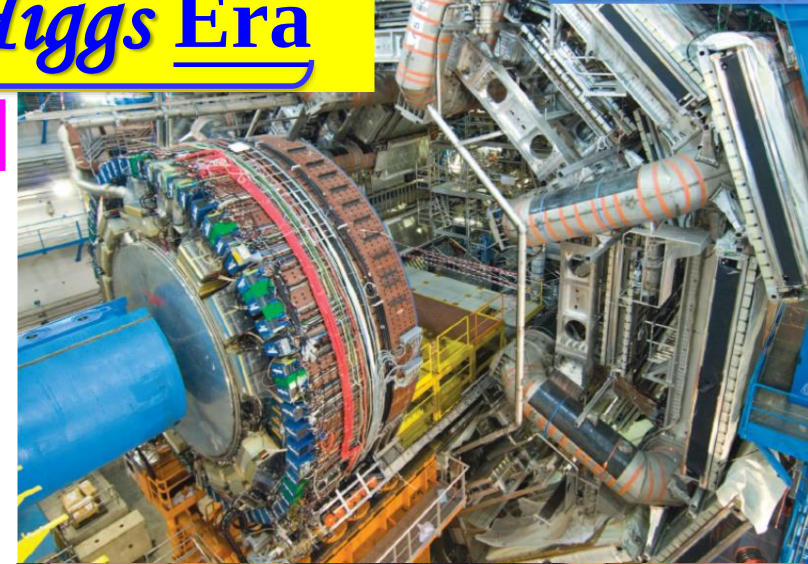
Expt'l

Belle II

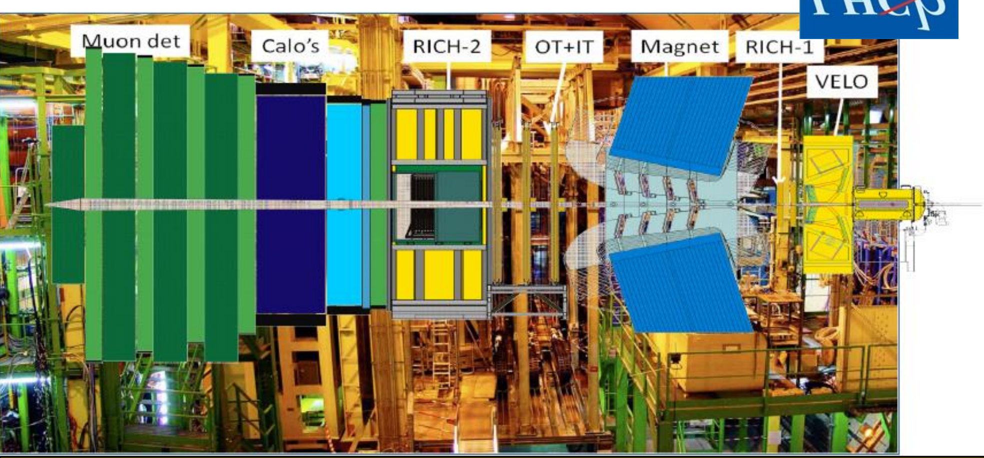
NTU

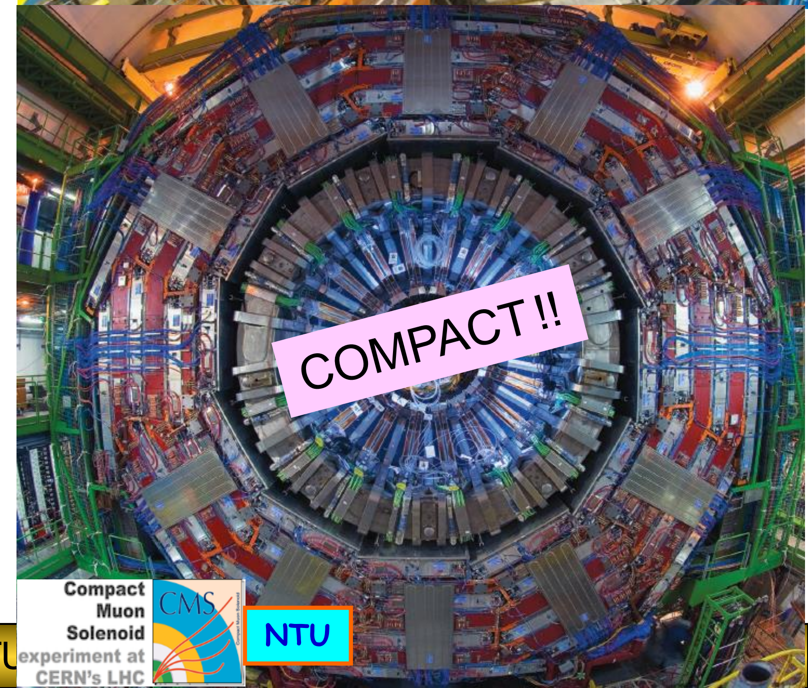


ATLAS EXPERIMENT



LHCb





Compact Muon Solenoid experiment at CERN's LHC

CMS

NTU

Decadal Mission
for
the New *Higgs/Flavor* Era

I. Prelude: Dynamics, Mass, "*Flavor*", Universe
e m_e μ e^+

II. Standard Model, the *Higgs*, and Mass Generation
e; g; g_s — $\Phi \to h$ — W, Z vs γ, g
V_{KM} — $V(\Phi)$

III. "Totalitarian Principle" & a Second *Higgs*
$\exists\ \Phi'? \to H, A, H^+$ — $V(\Phi, \Phi')$

⇩

IV. Big Issues & New *Higgs*/*Flavor* Era

Heaven/Earth; Spectrum *for* LHC; *Nature*'s *Design*

V. Conclusion: **Decadal Mission**

I. Prelude: Dynamics, Mass, "*Flavor*", Universe

Prehistory: 1896 – 1911

J.J. Thomson

electron

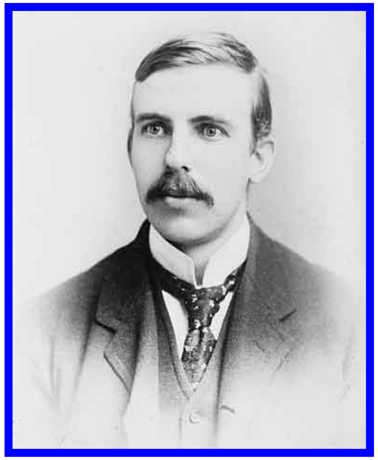
Henri Becqurel

radioactivity

H. Kamerlingh Onnes

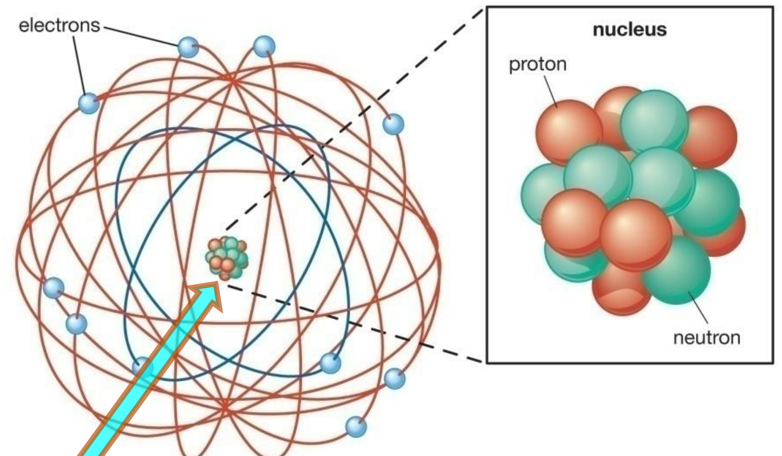
superconductivity

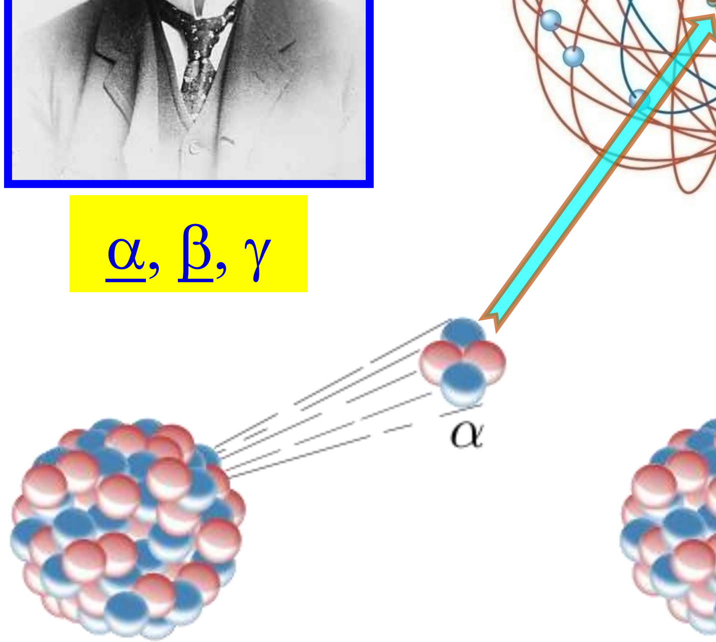
Ernest Rutherford

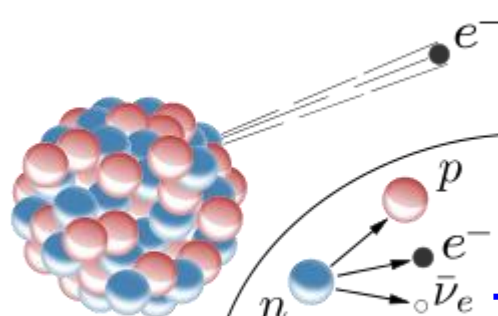


α, β, γ

Our Common Heritage



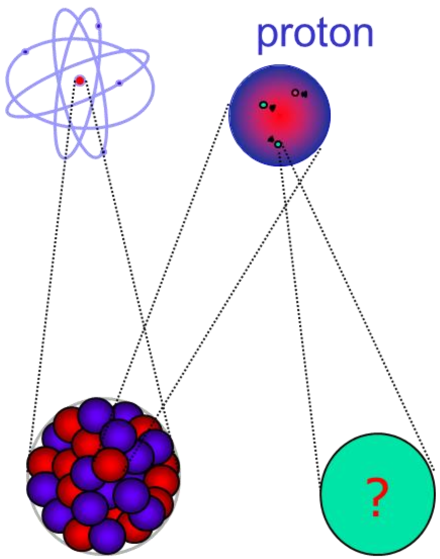




"Four-Fermi"

Weak Interaction

The Constituents of Matter



Elementary?!

fundamental

"structureless"

charge

charge	quarks	charge	electron	charge	muon (1937)
$+\frac{2}{3}e$	u				
$-\frac{1}{3}e$	d	$-e$	e	$-e$	μ

$m_\mu/m_e \simeq 207$

Protons contain **uud:** charge = +e

Neutrons contain **udd:** charge = 0

e: Why Real?

m_e: What Gives?

e^+: Where Gone?

μ: Who Ordered?

I.I. Rabi

Decadal

The Fundamental Fermions

structureless

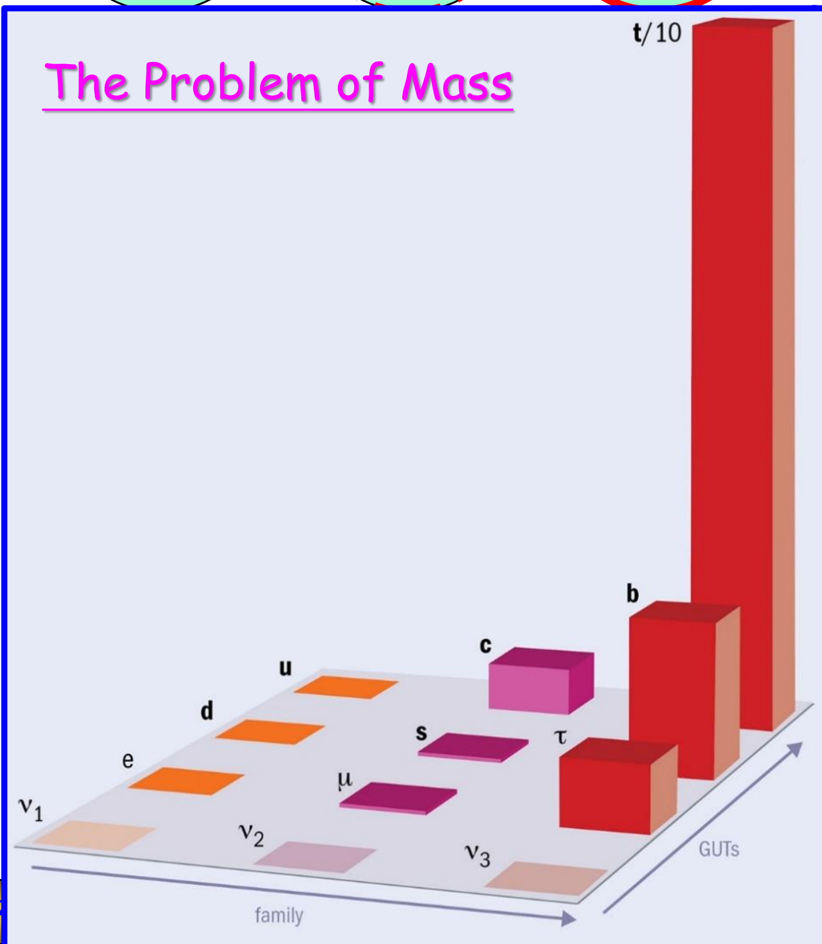
Heavy Flavor

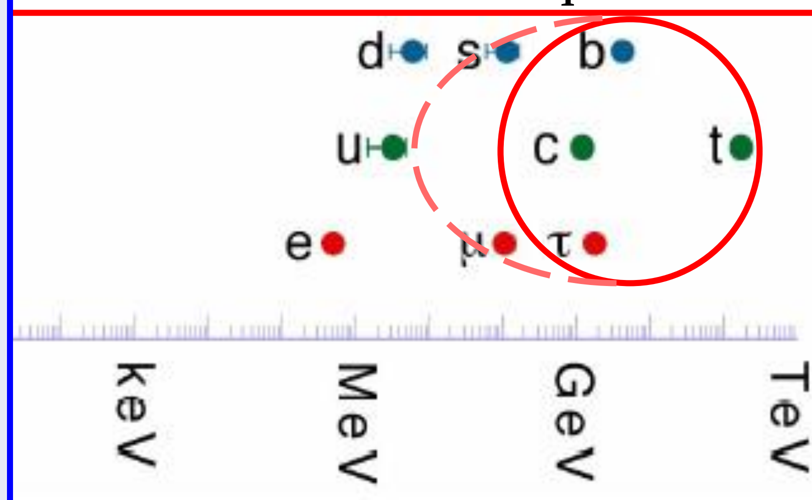
e	μ	τ
1895	1936	1975

u	c	t
	1974	1995
d	**s**	**b**
	1947	1977

copies

six quarks





the start of Particle Physics

e^+ anti-electron

μ Who Ordered That?

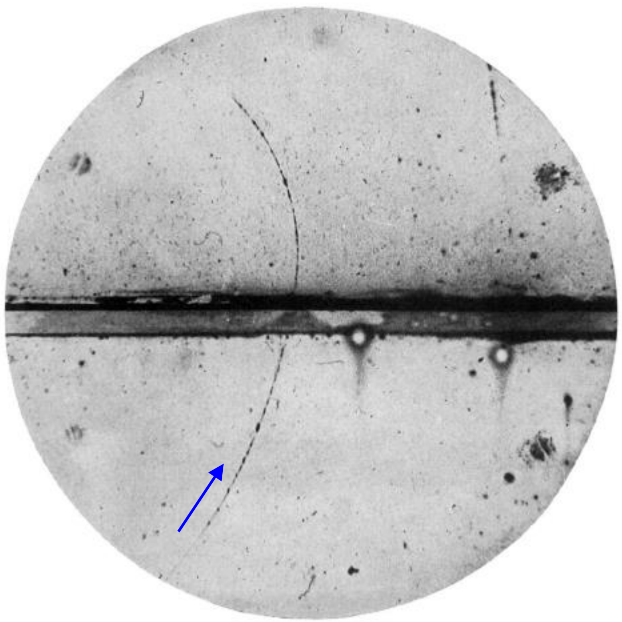
MARCH 15, 1933 PHYSICAL REVIEW VOLUME 43

The Positive Electron

CARL D. ANDERSON, *California Institute of Technology, Pasadena, California*
(Received February 28, 1933)

Out of a group of 1300 photographs of cosmic-ray tracks in a vertical Wilson chamber 15 tracks were of positive particles which could not have a mass as great as that of the proton. From an examination of the energy-loss and curvatures and ionizations produced require the mass to be less than twenty times the electron mass. These particles will be called positrons. Because they occur in groups associated with other tracks it is concluded that they must

Pb



e^+: Where Gone?

Baryon Asymmetry of the Universe (BAU)

MAY 15, 1937 PHYSICAL REVIEW VOLUME 51

Note on the Nature of Cosmic-Ray Particles

SETH H. NEDDERMEYER AND CARL D. ANDERSON
California Institute of Technology, Pasadena, California
(Received March 30, 1937)

NOVEMBER 1, 1937 PHYSICAL REVIEW VOLUME 52

LETTERS TO THE EDITOR

New Evidence for the Existence of a Particle of Mass Intermediate Between the Proton and Electron

J. C. STREET
E. C. STEVENSON
Research Laboratory of Physics, Harvard University, Cambridge, Massachusetts, October 6, 1937.

$m_\mu/m_e \simeq 207$

1 February 1948

Phys. Rev. 73 LETTERS TO THE EDITOR 257

Search for Gamma-Radiation in the 2.2-Microsecond Meson Decay Process

E. P. HINCKS AND B. PONTECORVO
National Research Council, Chalk River Laboratory, Chalk River, Ontario, Canada
December 9, 1947

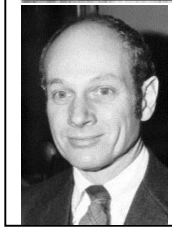
$\mu \not\to e\gamma$ ⇨ $\mu \neq e^*$

1932 – 1947: Birth of Particle Physics

Discovery of *CP V*iolation → BaryoGenesis
Sakharov Conditions

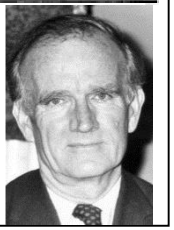
Backdrop: Parity Violation (宇稱不守恆, Lee-Yang–C.S. Wu, 1956)

VOLUME 13, NUMBER 4 PHYSICAL REVIEW LETTERS 27 JULY 1964



EVIDENCE FOR THE 2π DECAY OF THE K_2^0 MESON*†

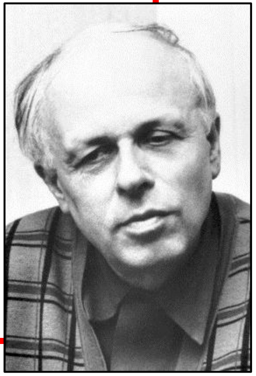
J. H. Christenson, J. W. Cronin,‡ V. L. Fitch,‡ and R. Turlay§
Princeton University, Princeton, New Jersey
(Received 10 July 1964)



Penzias & Wilson, ApJ'65 [CMB]

CPV & BAU (& U): The Sakharov View (1967)

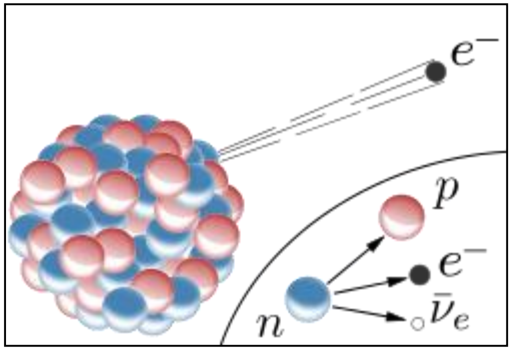
- ***Baryon Number Violation***
- (*C* &) *CP Violation*
- Deviation from Equilibrium (H-bomb ...)



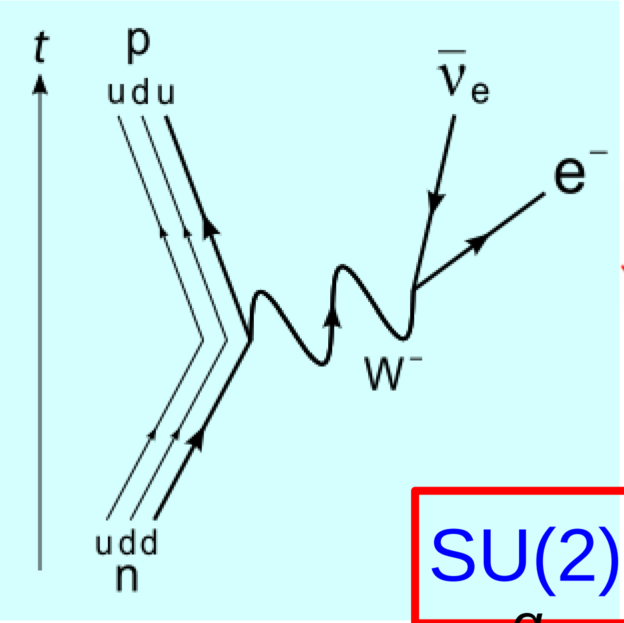
Peace Prize

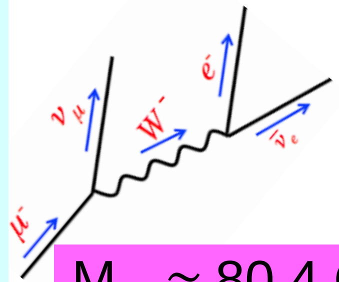
β/μ Decay, Weak Interaction, W/Z Vector Bosons

Rutherford



Fermi

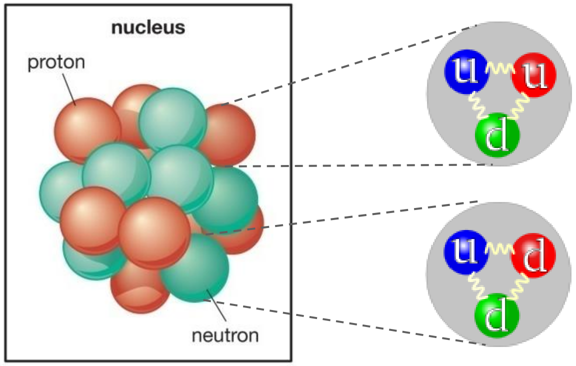


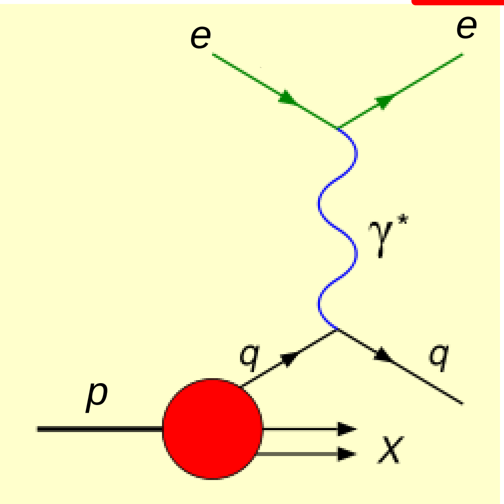


$M_W \simeq 80.4$ GeV/c²

$M_Z \simeq 91.2$ GeV/c²

$SU(2) \times U(1) \xrightarrow{\text{S.S.B.}} U_Q(1)$



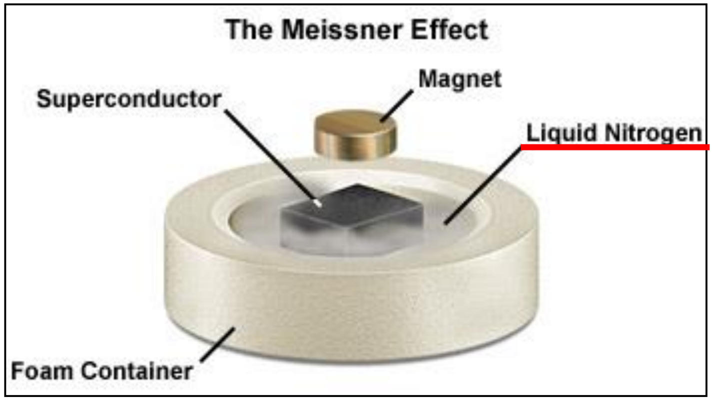


quark/parton

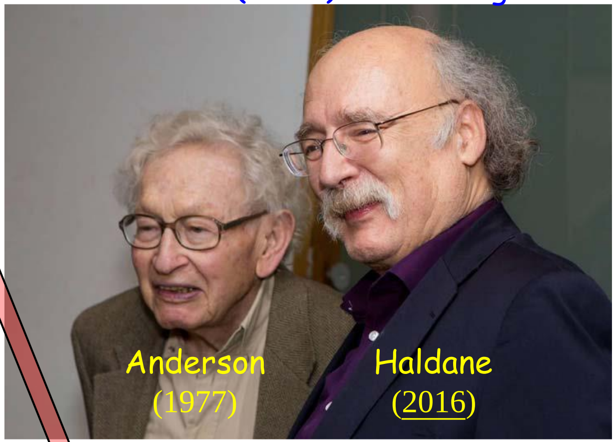
$M_\gamma \cong 0$

Deeply Inelastic Scattering

Meissner Effect — Photon Massive in Superconductor



Phil Anderson (R.I.P.) saw through it ...



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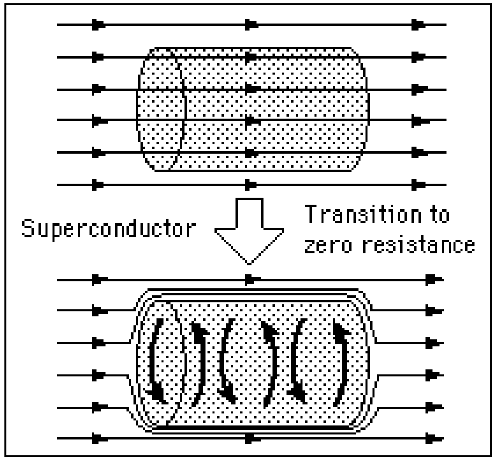
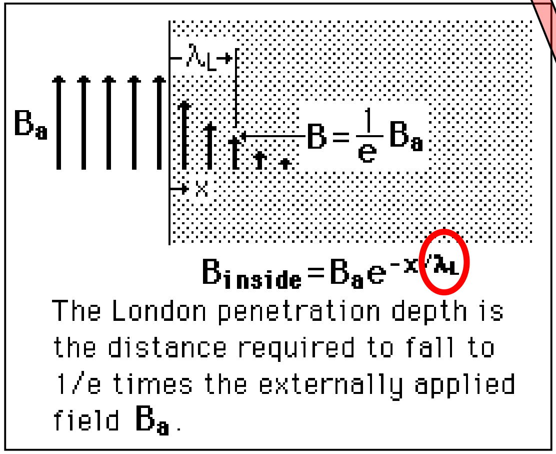


Absence of B in SC



Attentuation, or
penetration depth

Magnetic Field damped

↓

Photon acquires "Mass"

↓

Higgs Mechanism !
1964

II. Standard Model, the *Higgs*, and Mass Generation

My picture taken with "God" ...

a Higgstory

— Special Colloquium on the 2013 Nobel Prize in Physics

George W.S. Hou (侯維恕)
National Taiwan University

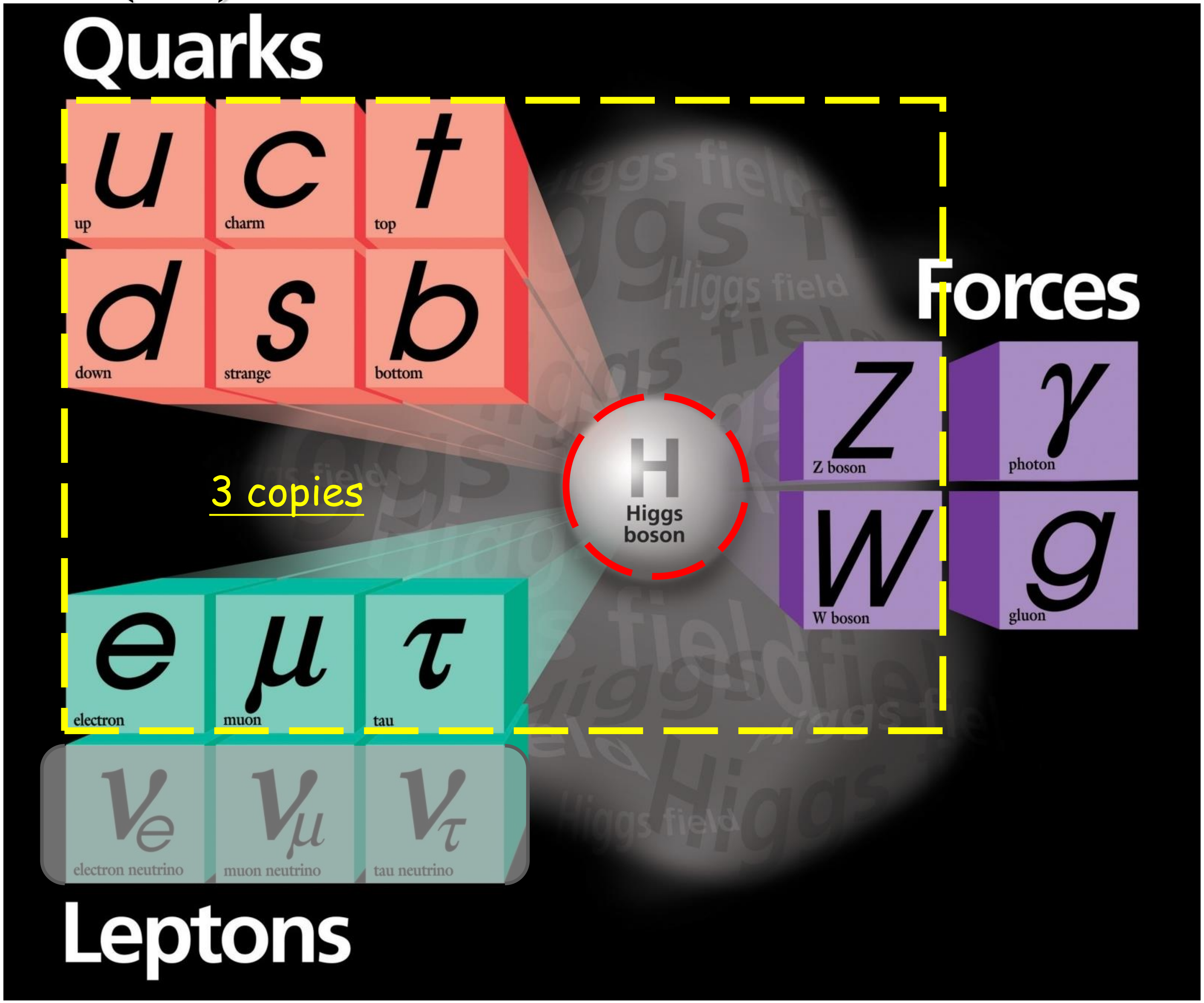
October 22, 2013, Joint Colloquium @ NTU

臺灣大學
National Taiwan University

Nobel 2013 – a Higgstory | George W.S. Hou (NTU) | NTU Colloquium, 10/22, '13 1

The "God" Particle: the Origin of Mass

h(125): observed 7/2012



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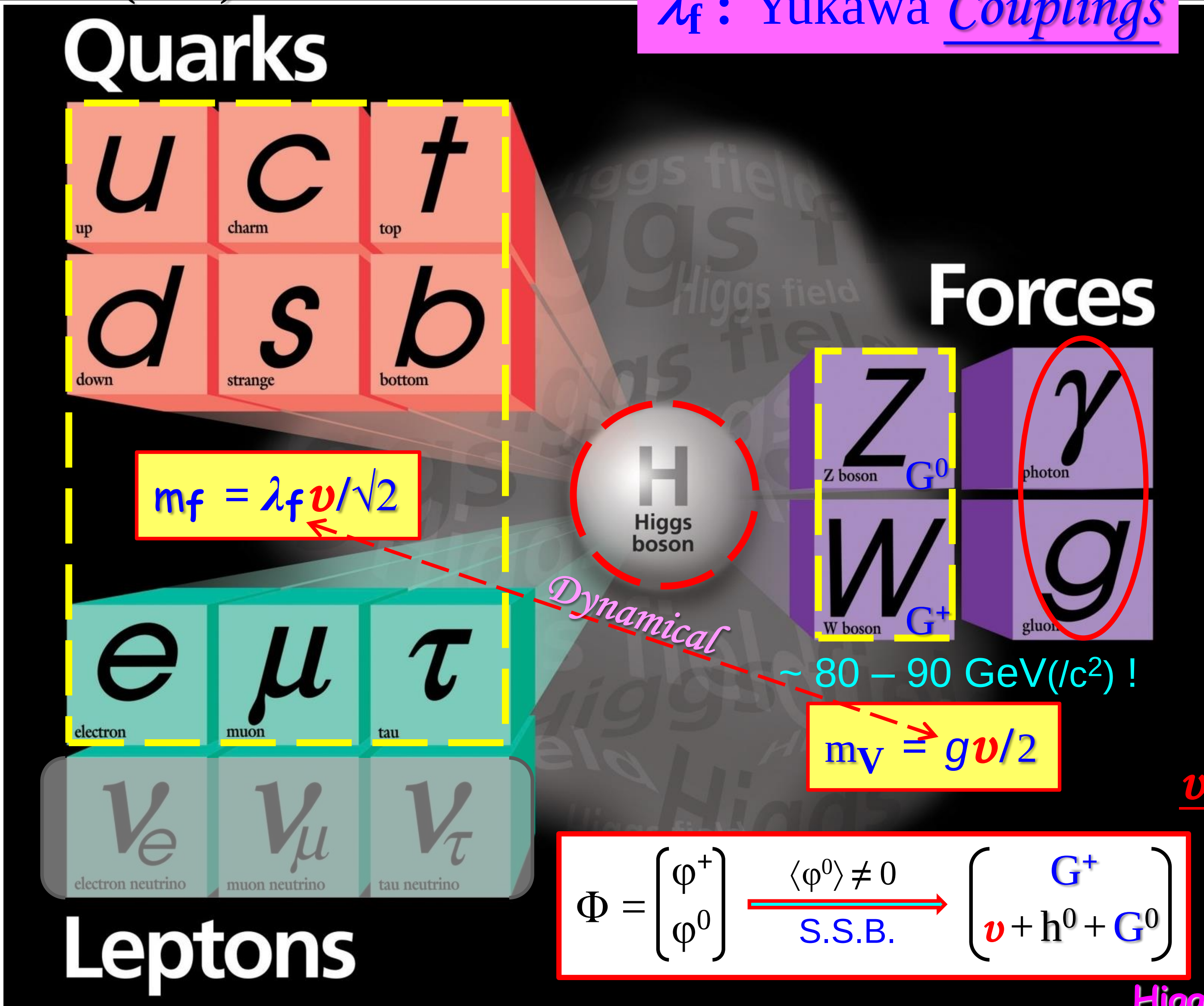
The "God" Particle: the Origin of Mass

h(125): observed 7/2012

λ_f : Yukawa *Couplings*

to ~ **173 GeV**

from ~ **0.5 MeV**



$m_f = \lambda_f v/\sqrt{2}$

~ 80 – 90 GeV(/c^2) !

$m_V = g v/2$

$$\Phi = \begin{pmatrix} \varphi^+ \\ \varphi^0 \end{pmatrix} \xrightarrow[\text{S.S.B.}]{\langle\varphi^0\rangle \neq 0} \begin{pmatrix} G^+ \\ v + h^0 + G^0 \end{pmatrix}$$

Unbroken
massless

$v \approx 246$ GeV

G^+, G^0 "eaten" by W, Z

Higgs Mechanism

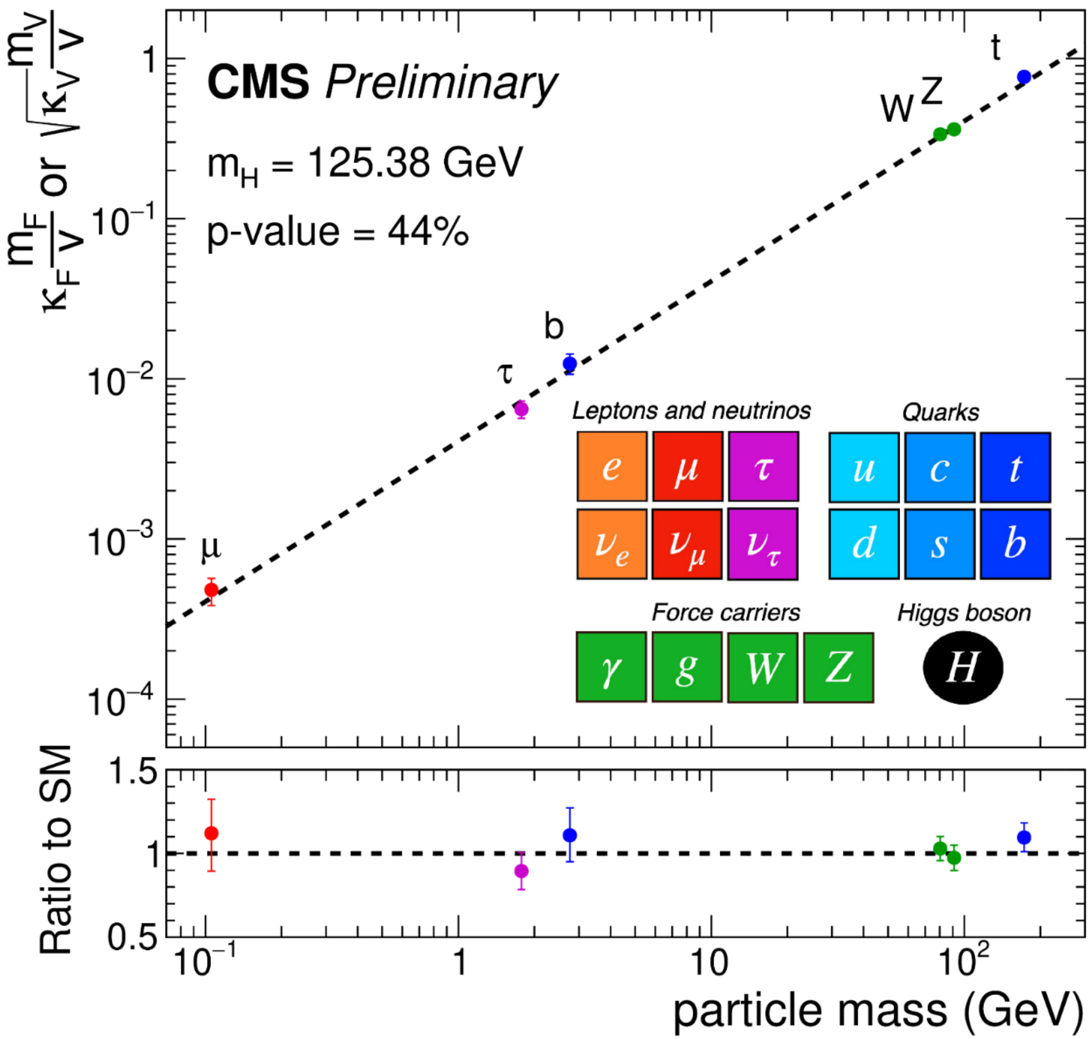
The "God" Particle: the Origin of Mass

h(125): observed 7/2012

λ_f : Yukawa *Couplings*

Expt'lly Affirmed!

35.9-137 fb^{-1} (13 TeV)



$g \simeq 2m_V/v$ ca. 2015

$\lambda_f \simeq \sqrt{2}m_f/v$ t/b/τ: 2018 μ: 2020

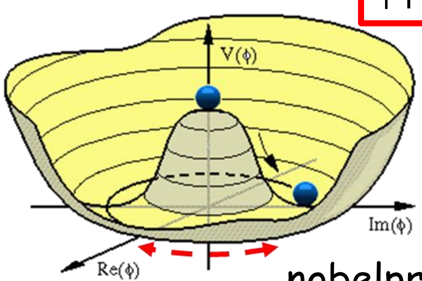
$v \approx 246$ GeV

$$\Phi = \begin{pmatrix} \varphi^+ \\ \varphi^0 \end{pmatrix} \xrightarrow[\text{S.S.B.}]{\langle\varphi^0\rangle \neq 0} \begin{pmatrix} G^+ \\ v + h^0 + G^0 \end{pmatrix}$$

Higgs "potential": Simple!!

$$V(\Phi) \sim -\mu^2|\Phi|^2 + \lambda|\Phi|^4$$

$$\Rightarrow \quad |\varphi^0|^2 = v^2 \sim \mu^2/\lambda$$

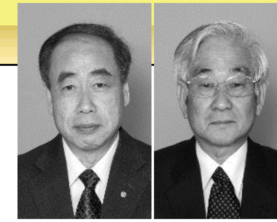


nobelprize.org

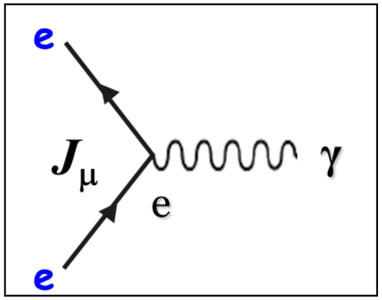
Decadal

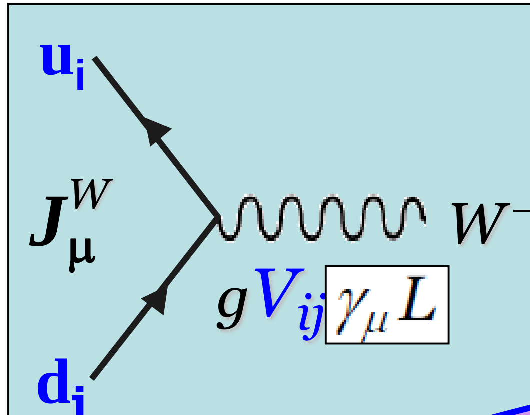
Complex Dynamics: Kobayashi-Maskawa Sector of SM

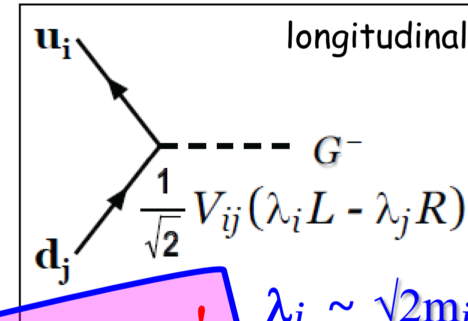
rooted in Yukawa *Couplings* 小林-益川



Only Charged Current Interactions Change *Flavor*







$\lambda_i \sim \sqrt{2} m_i / v$

But KM CPV by far *insufficient* for Sakharov Condition!

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \cong \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

Wolfenstein parametrization

3x3 "Rotation"

Unitary

(expt'lly affirmed)

Need presence of all 3 generations to exhibit CPV in Standard Model

III. "Totalitarian Principle" & a Second *Higgs*

W en.wikipedia.org › wiki › Everything_which_is_not_forbidden_is_all...

Everything which is not forbidden is allowed - Wikipedia

"Everything which is not forbidden is allowed" is a constitutional principle. Contents. 1 Induvidual rights. 1.1 Germany. 2 State rights. 2.1 International law; 2.2 ...

Induvidual rights · Germany · State rights · United Kingdom

W en.wikipedia.org › wiki › Totalitarian_principle

Totalitarian principle - Wikipedia

In quantum mechanics, the totalitarian principle states: "Everything not forbidden is compulsory. ... See also[edit]. Everything which is not forbidden is allowed ...

Origin

Gell-Mann, Nuovo Cim. **4** (1956) S2, 848-866

...

allowed (A) and which forbidden (F) by conservation of strangeness (*).

...

(*) If the designation (A) is taken to mean that a reaction so labeled will naturally occur with an appreciable cross-section, then use is being made of what we may call the « Principle of Compulsory Strong Interactions ». Among baryons, antibaryons, and mesons, any process which is not forbidden by a conservation law actually does take place with appreciable probability. We have made liberal and tacit use of this assumption, which is related to the state of affairs that is said to prevail in a perfect totalitarian state. Anything that is not compulsory is forbidden.

We know of No Reason to forbid a Second Higgs, so

Tot.: $\exists$ **New Scalars**

$$\Phi' = \begin{pmatrix}\varphi'^{+}\\ \varphi'^{0}\end{pmatrix} \xrightarrow{\langle\varphi'^{0}\rangle = 0} \begin{pmatrix} H^{+} \\ H^{0} + iA\end{pmatrix}$$

Where Are They?

What do They Do?

Totalitarian-ism Everywhere, then OverKill …?

Tot.-0: Weinberg's "Yukawa" Term — include in $\mathcal{L}$ all terms allowed by symmetry

VOLUME 19, NUMBER 21 PHYSICAL REVIEW LETTERS 20 NOVEMBER 1967

$SU(2) \times U(1) \xrightarrow[\Phi]{\text{S.S.B.}} U_Q(1)$

$m_V = g v/2$

A MODEL OF LEPTONS*

Steven Weinberg†
Laboratory for Nuclear Science and Physics Department,
Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received 17 October 1967)

Not forbidden!

$\lambda_e \bar{\ell}_L \Phi e_R$ + h.c. ⇨ $m_f = \lambda_f v/\sqrt{2}$

fermion mass generation!

3 copies

Yukawa matrices $\mathbf{Y}^f$: $\bar{\ell}_L \mathbf{Y}^e \Phi e_R \quad \bar{q}_L \mathbf{Y}^d \Phi d_R \quad \bar{q}_L \mathbf{Y}^u \tilde{\Phi} u_R$

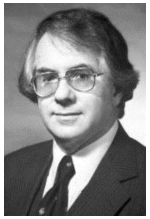
diagonlize $\mathbf{Y}^f$: fermion masses

Tot.-2: [**Tot.**: found h, remnant of Φ, so ∃ Φ', i.e. 2nd Higgs]

2nd Yukawa matrices $\mathbf{P}^f$: $\bar{\ell}_L \mathbf{P}^e \Phi' e_R \quad \bar{q}_L \mathbf{P}^d \Phi' d_R \quad \bar{q}_L \mathbf{P}^u \tilde{\Phi}' u_R$

diagonlize $\mathbf{P}^f$: ρ^f Yuk. matrices

in general nondiagonal (& *Complex*)



(Flavor Changing Neutral Higgs)

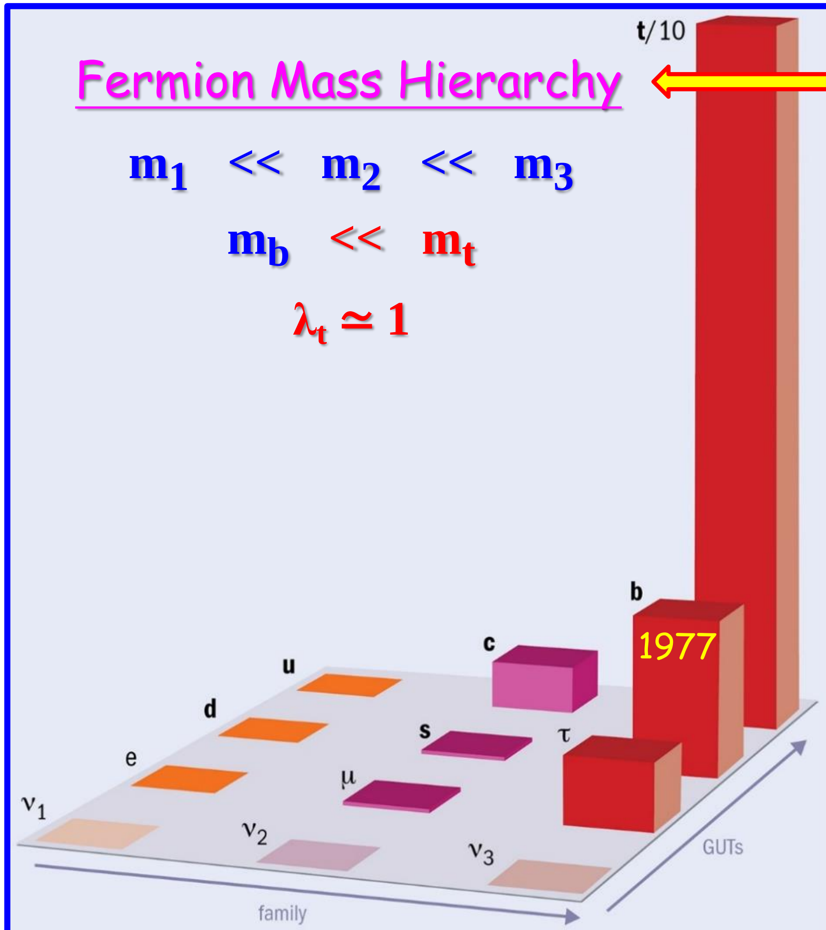
Glashow *feared* FCNH Couplings *too dangerous*, and with Weinberg *proposed* Natural Flavor Conservation: ~ Edict [Authoritarian] [*ad hoc*]

Absence of 2nd Yukawa!

- Usually implemented by a Z_2 symmetry
- "Model II" automatic w/ Supersymmetry — *Popular!*

Unbeknownst to Glashow-Weinberg in 1977

1995 ⇧



Fermion Mass Hierarchy ⟺ Quark Mixing Hierarchy

$m_1 << m_2 << m_3$

$m_b << m_t$

$\lambda_t \simeq 1$

Ca. 1983, w/ advent of Si-sensor: B decays

$|V_{ub}|^2 << |V_{cb}|^2 << |V_{us}|^2 << |V_{tb}|^2 \cong 1$

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

Wolfenstein parametrization (1983)

Cheng-Sher 1987:

FCNH may be “OK”, if $\rho^f \sim \sqrt{m_i m_j}$

Echoes Mass-Mixing Hierarchy

Flavor Changing Neutral Higgs

FCNH — an Experimental Question

PLB'92

Tree level $t \to ch^0$ or $h^0 \to t\bar{c}$ decays

Wei-Shu Hou [1]
Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland

PSI-PR-91-34
Received 25 June 1992

particularly well defined, amounts to a *third* type of two Higgs doublet model (**Model III**), so let us recapitulate its properties: The NFC condition is not imposed, but low energy FCNC constraints are evaded by mass-dependent couplings of eq. (4) that reflect fermion mass and mixing hierarchies. Neutral

In a third type of two Higgs model, where neutral scalar bosons possess flavor changing $u_i u_j h^0$ couplings proportional to $\sqrt{m_i m_j}$, low energy constraints are evaded. With the top as the heaviest fermion, *tree level* flavor changing $t \to ch^0$ or $h^0 \to t\bar{c}$ decays may be competitive with, if not dominant over, the corresponding $t \to bW^*$ or $h^0 \to b\bar{b}$ decays. The CDF limit of $m_t > 91$ GeV may be evaded by the $t \to ch^0$ mode if $m_{h^0} < m_t < M_W$, while the $h^0 \to t\bar{c}$ mode may be useful for the study of intermediate mass Higgs bosons at hadronic supercolliders. The scenario can be distinguished from the existence of exotic quarks since flavor changing Z couplings are absent.

per mille

< 1.1	10^{-3}	95	[1] AABOUD	19S	ATLS	combination of $t \to Hc$ ($H \to WW$, ZZ, $\tau\tau$, $\gamma\gamma$, $b\bar{b}$)

$t \to Hc$ …

sub%

< 7.9	95	[9] AAD	14AA	ATLS	$t \to Hq$ (q=u,c; $H \to \gamma\gamma$)
<13	95	[10] CHATRCHYAN	14R	CMS	$t \to Hc$ ($H \to \geq 2\ell$)
< 5.6	95	[11] KHACHATRY...	14Q	CMS	$t \to Hc$ ($H \to \gamma\gamma$ or lep-

per mille

<2.5 × 10^{-3}	95	[1] SIRUNYAN	18BH	CMS

$H^0 \to \mu\tau$ …

H here is h(125)

~~% hint!~~

[5] KHACHATRYAN 15Q search for $H^0 \to \mu\tau$ with τ decaying electronically or hadronically in 19.7 fb^{-1} of pp collisions at E_{cm} = 8 TeV. The fit gives B($H^0 \to \mu\tau$) = $(0.84^{+0.39}_{-0.37})$% with a significance of 2.4 σ.

O Lord, our Lord,
How Majestic is Thy Name
in all the Earth,
Who have set Thy Splendor
above the Heavens!

Psalm 8:1 (of David)

IV. Big Issues & New *Higgs/Flavor* Era

1. Heaven (Baryogenesis) & Earth (e EDM?)

2. H, A, H^+ Spectrum @ LHC
   Leading Production Modes

3. *Nature*'s *Design*: What Replaces (Un)*Natural* Flavor Conservation
   glimpse of the coming Era

PHYSICAL REVIEW D **101**, 011901(R) (2020)

FHS'20

Rapid Communications

Cancellation mechanism for the electron electric dipole moment connected with the baryon asymmetry of the Universe BAU

Kaori Fuyuto,[1,*] Wei-Shu Hou,[2,†] and Eibun Senaha[3,4,5,‡]

Beyond CKM **CPV**

EW BaryoGenesis (EWBG)

- more testable -

tension

LHC

- *No New Physics* -

tension

competition

eEDM: ACME14 → ACME18

- L.E. Precision Frontier -

$|d_e| < 1.1 \times 10^{-29}\ e\ \text{cm}$

mech. to render small?

See Cornell & Gabrielse talks

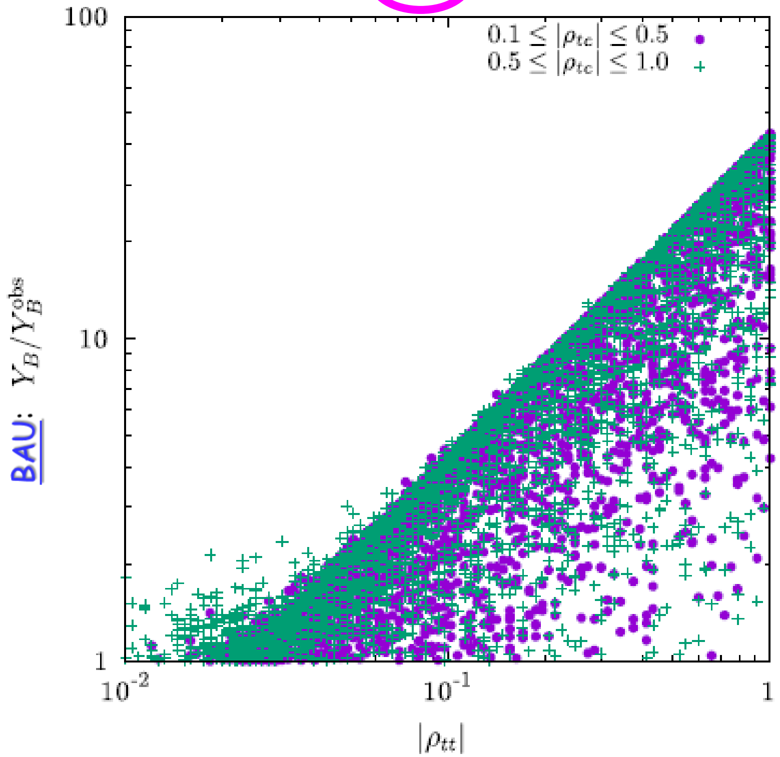
EWBG & ThO EDM

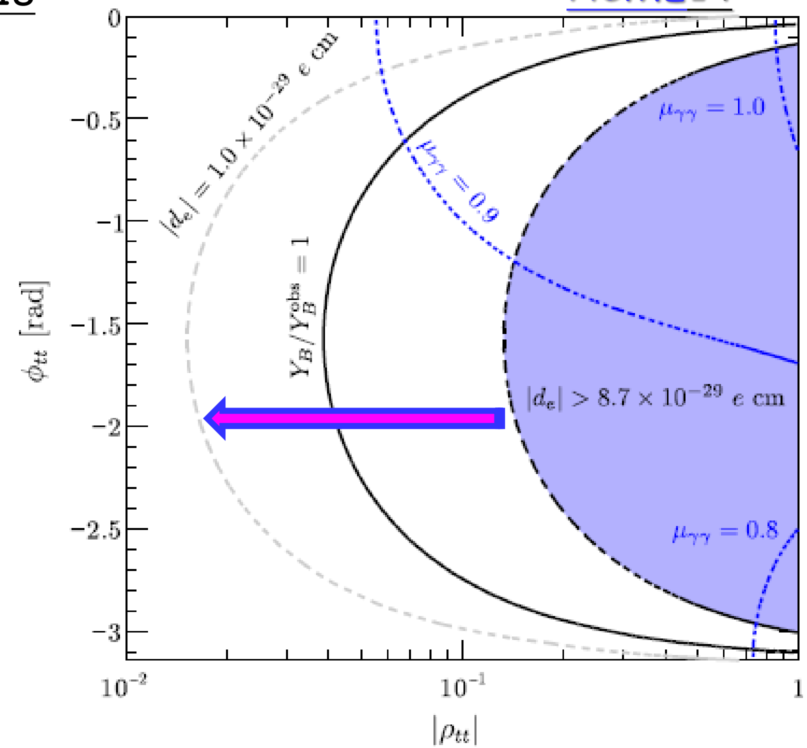
complex ρ_{tt}

K. Fuyuto et al. / Physics Letters B 776 (2018) 402–406

FHS'18

ACME14





EWBG $\Leftarrow$ $\lambda_t \mathrm{Im}\rho_{tt}$ robust driver

$\mathcal{O}(\lambda_t) \approx 1$

[ρ_{tc} as backup

$\oplus$

eEDM: $\lambda_e \mathrm{Im}\rho_{tt}$

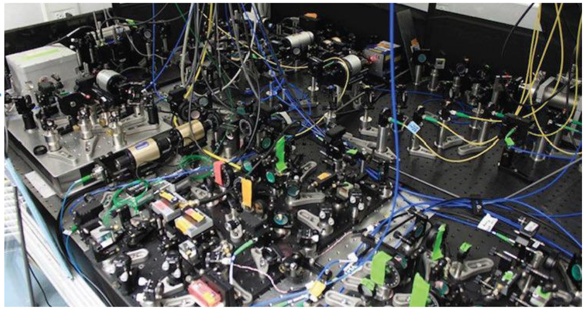
Ruled Out by ACME18!

Mech. to render small? Yes!

the Advanced Cold Molecule Electron EDM Experiment

Science AAAS

Order of Magnitude Smaller Limit on the Electric Dipole Moment of the Electron
The ACME Collaboration, J. Baron, W. C. Campbell, D. DeMille, J. M. Doyle, G. Gabrielse, Y. V. Gurevich, P. W. Hess, N. R. Hutzler, E. Kirilov, I. Kozyryev, B. R. O'Leary, C. D. Panda, M. F. Parsons, E. S. Petrik, B. Spaun, A. C. Vutha and A. D. West (December 19, 2013)
Science **343** (6168), 269-272. [doi: 10.1126/science.1248213]
originally published online December 19, 2013



Editor's Summary

Stubbornly Spherical

polar molecule thorium monoxide, we measured $d_e = (-2.1 \pm 3.7_{stat} \pm 2.5_{syst}) \times 10^{-29}$ $e\cdot$cm. This corresponds to an upper limit of $|d_e| < 8.7 \times 10^{-29}$ $e\cdot$cm with 90% confidence, an order of magnitude improvement in sensitivity relative to the previous best limit. Our result constrains T-violating physics at the TeV energy scale.

JILA'17 (Cornell): $< 13 \times 10^{-29}$ $e\cdot$cm

$$|d_e| < 1.1 \times 10^{-29} e\,\text{cm} \quad (5)$$

at 90% confidence level. This is 8.6 times smaller than the best previous limit, from ACME I[1,9]. Because paramagnetic molecules are sensitive to multiple time-reversal-symmetry-violating effects[34], our measurement can be more generally interpreted as $\hbar\omega^{\mathcal{NE}} = -d_e\mathcal{E}_{\text{eff}} + W_S C_S$, where C_S is a dimensionless time-reversal-symmetry-violating electron–nucleon coupling parameter and $W_S = -2\pi\hbar \times 282$ kHz is a molecule-specific constant[16,17,35]. For the d_e limit given above, we assume $C_S = 0$. Assuming $d_e = 0$ instead gives $|C_S| < 7.3 \times 10^{-10}$ (90% confidence level).

Because the values of d_e and C_S predicted by the standard model are many orders of magnitude below our sensitivity[2,3], this measurement is a background-free probe for new physics beyond the standard model. Nearly every extension of the standard model[4–6] introduces the possibility for new particles and new time-reversal-symmetry-violating phases, ϕ_T, that can lead to measurable EDMs. Within typical extensions of the standard model, an EDM arising from new particles

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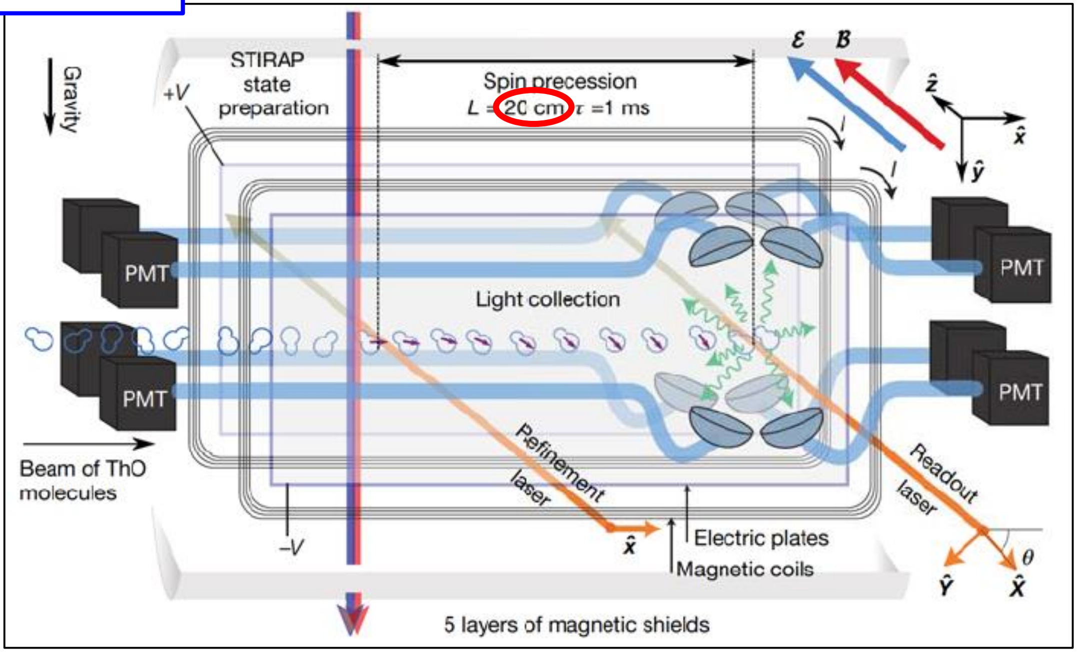
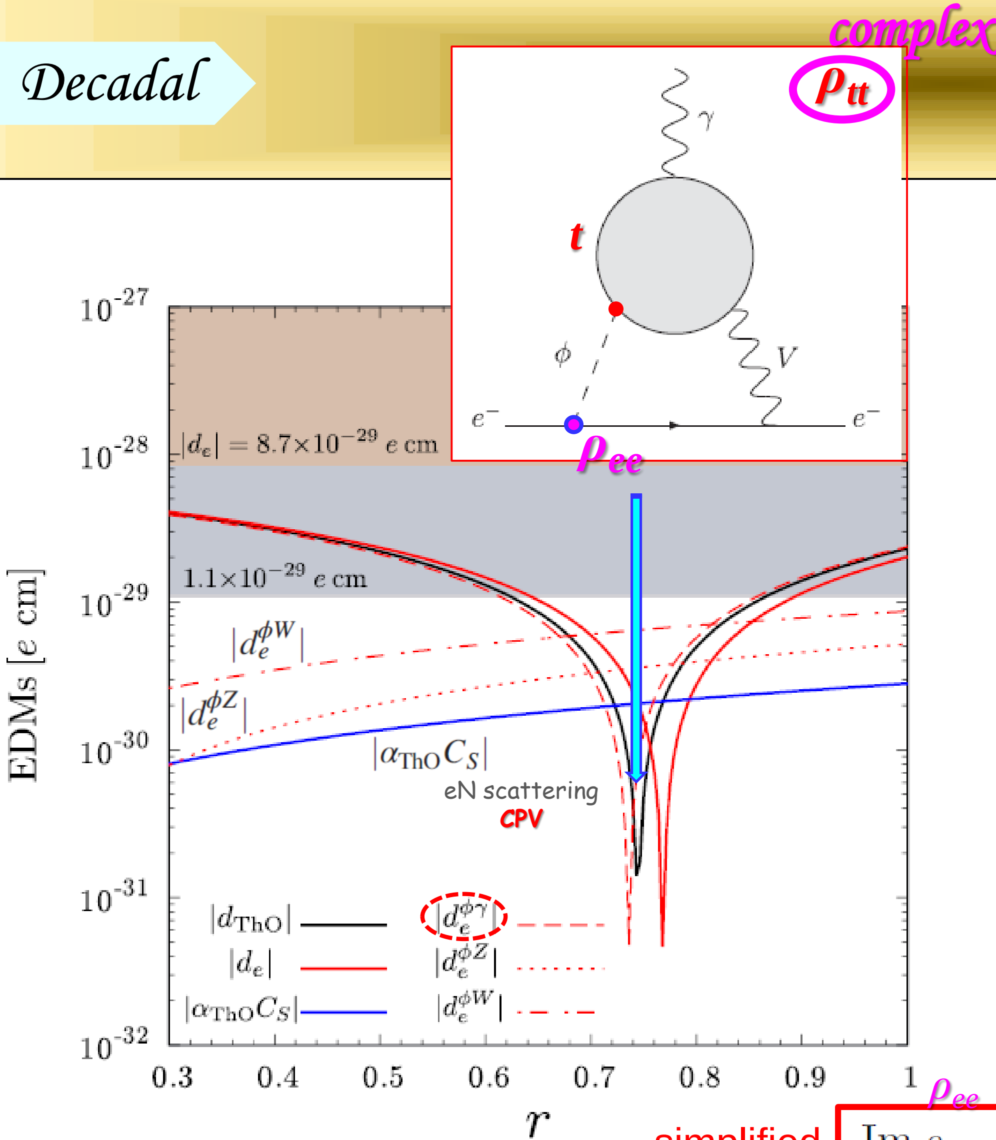


Decadal

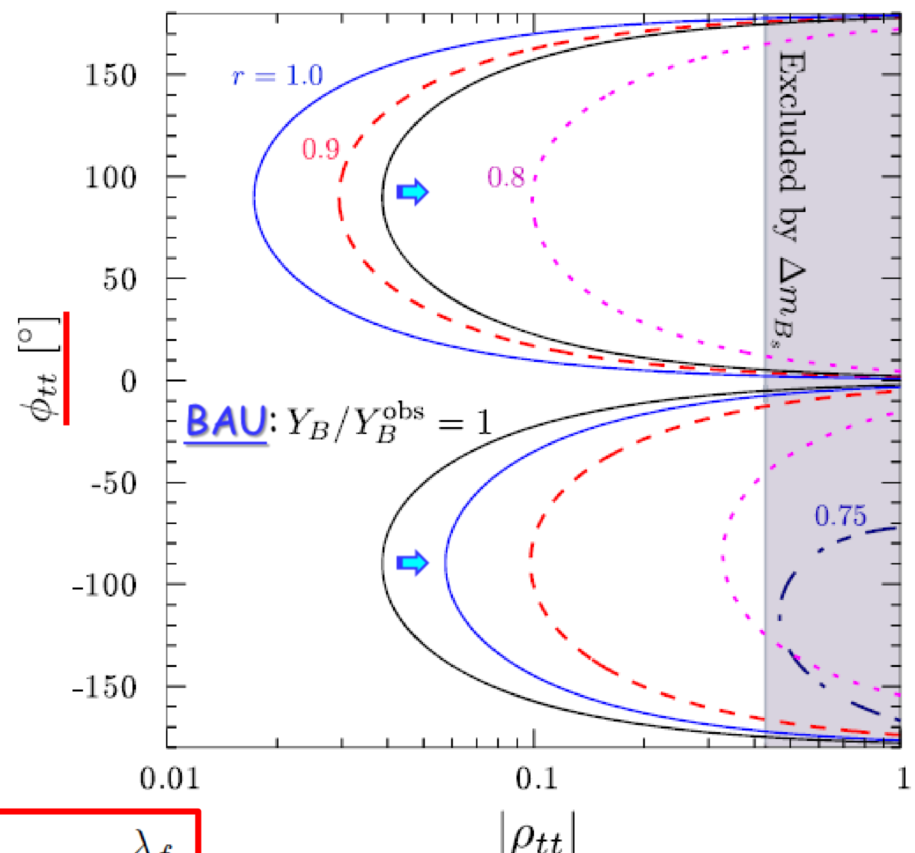
Mech. to render d_{ThO} small ? *Yes!*

FHS'20

Beautiful on Earth



Splendor in the Heavens



simplified "Ansatz"

$$\frac{\mathrm{Im}\,\rho_{ff}}{\mathrm{Im}\,\rho_{tt}} = r\,\frac{\lambda_f}{\lambda_t}$$

$$\frac{\mathrm{Re}\,\rho_{ff}}{\mathrm{Re}\,\rho_{tt}} = -r\,\frac{\lambda_f}{\lambda_t}$$

ρ_{ee}

Follow SM Hierarchy!

N.B. ***r*** depend on loop functions

Decadal **H, A, H^+ Spectrum Fit for the LHC** 14 TeV (c.m.s.)

$V(\Phi) \sim -\mu^2|\Phi|^2 + \lambda|\Phi|^4$ ⇨

$\upsilon^2 \sim \mu^2/\lambda$

$$V(\Phi,\Phi') = \mu_{11}^2|\Phi|^2 + \mu_{22}^2|\Phi'|^2 - (\mu_{12}^2\Phi^\dagger\Phi' + \text{h.c.}) + \frac{\eta_1}{2}|\Phi|^4 + \frac{\eta_2}{2}|\Phi'|^4 + \eta_3|\Phi|^2|\Phi'|^2 + \eta_4|\Phi^\dagger\Phi'|^2 + \left\{\frac{\eta_5}{2}(\Phi^\dagger\Phi')^2 + \left[\eta_6|\Phi|^2 + \eta_7|\Phi'|^2\right]\Phi^\dagger\Phi' + \text{h.c.}\right\}$$

$$\mu_{12}^2 = \frac{1}{2}\eta_6 v^2$$

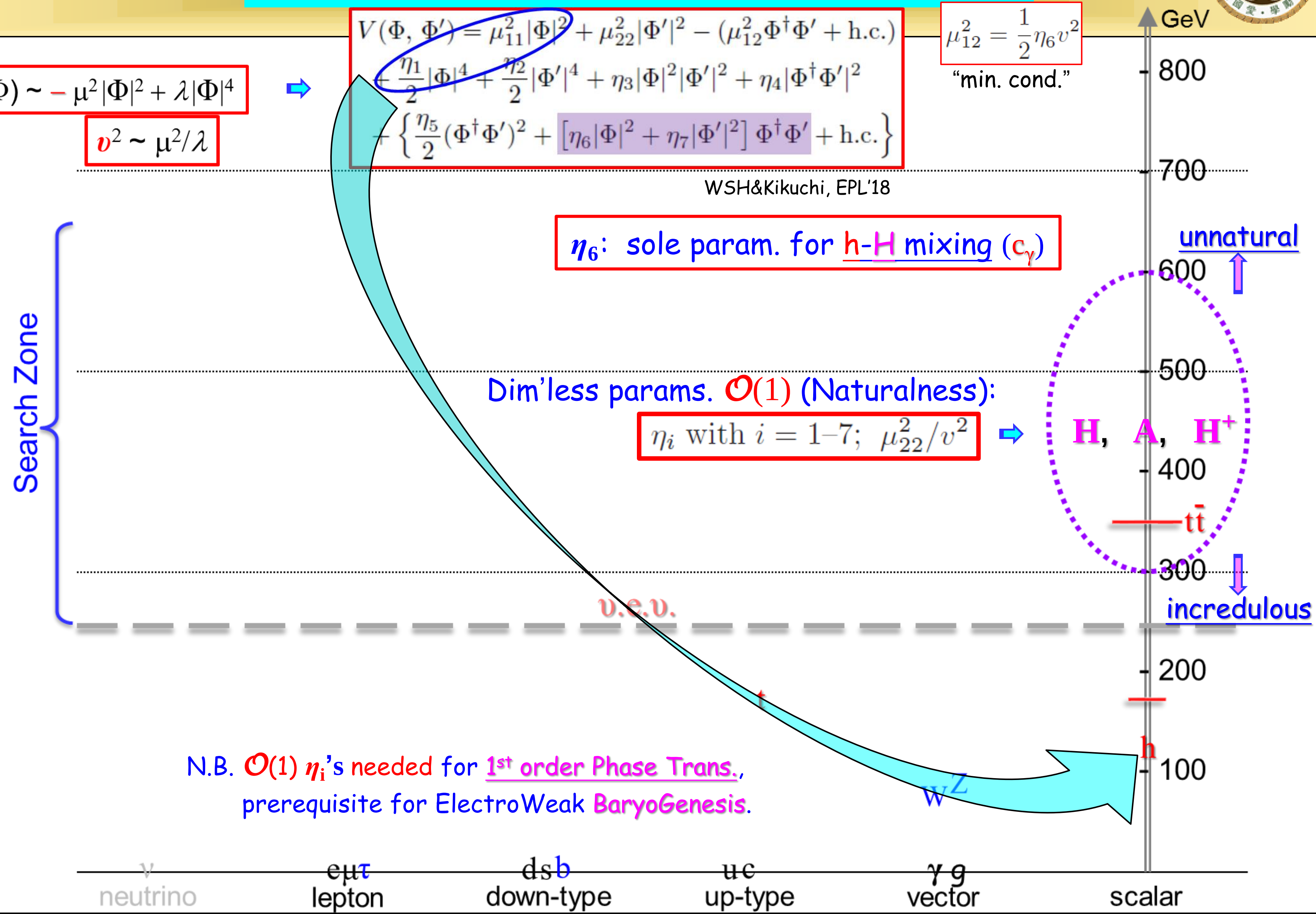
"min. cond."

WSH&Kikuchi, EPL'18

η_6: sole param. for h-H mixing (c_γ)

Dim'less params. $\mathcal{O}(1)$ (Naturalness):

η_i with $i = 1$–7; μ_{22}^2/v^2 ⇨ H, A, H^+



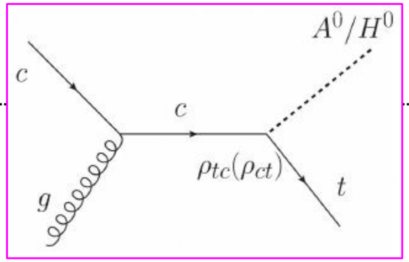
N.B. $\mathcal{O}(1)$ η_i's needed for 1st order Phase Trans., prerequisite for ElectroWeak BaryoGenesis.

Leading Search Modes at the LHC

14 TeV (c.m.s.)

GeV

Efe Yazgan @ CERN (NTU since 2/2020)



Kohda, Modak, WSH, PLB'18

Search Zone

cg $\xrightarrow{\rho_{tc}}$ tH/A $\xrightarrow{\rho_{tc}}$ ttc(bar) Same-Sign Top

$\xrightarrow{\rho_{tt}}$ ttt(bar) Triple-Top (High Lumi LHC; higher mass, more exquisite, tiny SM)

cg → bH$^+$ → btb(bar) Top w/ two p_T b-jets (H^+)

Ghosh, WSH, Modak, 1912,10613 (PRL pending)

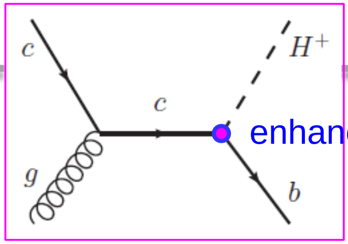
H, A, H$^+$

$t\bar{t}$

√

HKM, PLB'18

υ.e.υ.



enhanced

t

h

W Z

800
700
600
500
400
300
200
100

neutrino	lepton	down-type	up-type	vector	scalar
ν	eμτ	dsb	uc	γ g	

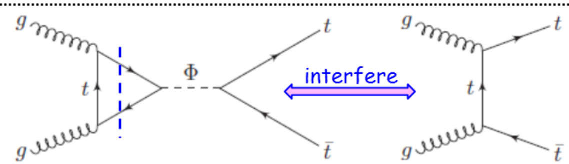
Decadal

Example: take CMS "A → tt(bar)" hint

CMS JHEP'20 — 35.6 fb^{-1} (2016 data)

"a signal-like excess for the pseudoscalar hypotheses (largest) at 400 GeV, $\Gamma_{tot} = 4\%$, 3.5σ local (1.9σ LEE)"

"multiple testing"



Single-state analysis / Custodial → A, H$^+$

- Consistent with $\rho_{tt} = 1.1$, $\rho_{tc} = 0.9$!
- Could be due to H if ρ_{tt} *imaginary*.

→ H

WSH, Kohda, Modak, PLB'19

Search Zone

v.e.v.

GeV: 800, 700, 600, 500, 400, 300, 200, 100

$t\bar{t}$

t

h

W Z

N.B. A *near-perfect* (Yukawa's a bit large) scenario now being checked by Kumar (*flavor*) and Jain (collider).

ATLAS and Full Dataset to come!

neutrino	lepton	down-type	up-type	vector	scalar
ν	e μ τ	d s b	u c	γ g	

Decadal

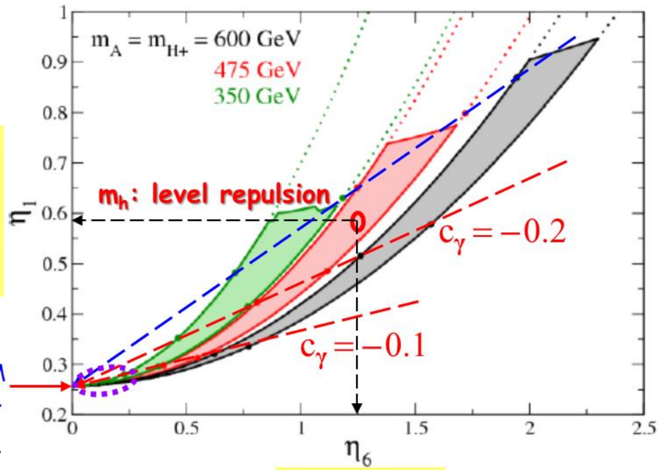
Flavor Design: replace (Un)*Natural* Flavor Conserv.

Where Are They? What hides **H**, **A**, $\mathbf{H^+}$ effects from our view?

1. *Mass-Mixing Hierarchy*: Yuk. matrices ρ^f trickle off off-diagonal

2. ***Alignment***: Expt. find h rather close to SM Higgs → **c_γ small!** ⇨ controls { t → ch ; h → τμ }

h-H mixing



$\eta_1 = \mathcal{O}(1)$

SM pt.

$\eta_6 = \mathcal{O}(1)$ υ.e.υ.

NOT in conflict w/ $\mathcal{O}(1)$ η_i's!

WSH&Kikuchi, EPL'18

Search Zone

H, **A**, $\mathbf{H^+}$

3. Near-diagonal ρ^d matrix! ***Nature*** has her *mysterious* ways!

[K^0, B^0 and B_s meson mixings our most sensitive probes!]

GeV: 800, 700, 600, 500, 400, 300, 200, 100

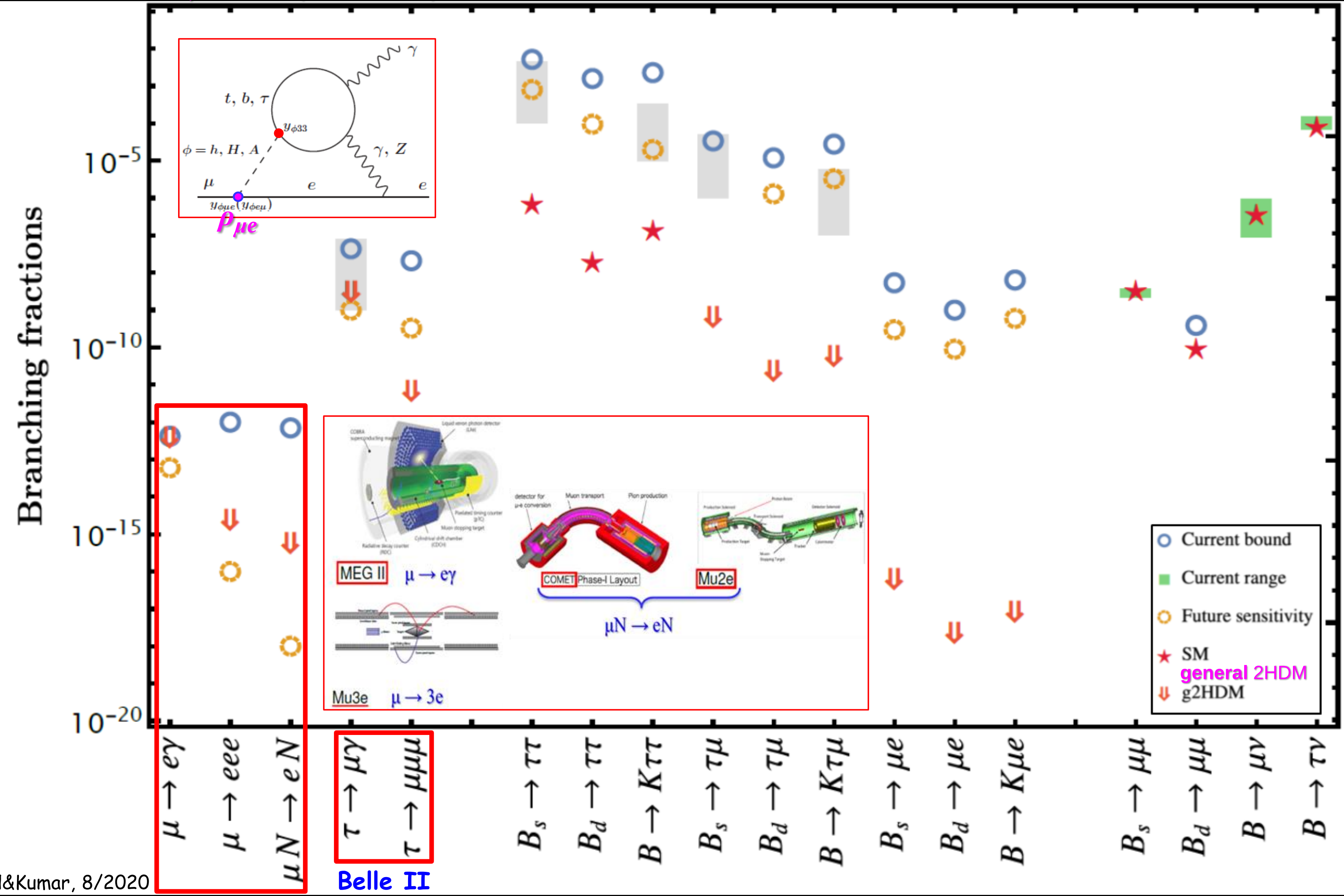
$t\bar{t}$ — t — h — W Z

ν neutrino | eμτ lepton | dsb down-type | uc up-type | γ g vector | scalar

Decadal

Glimpse of coming New *Flavor* Era

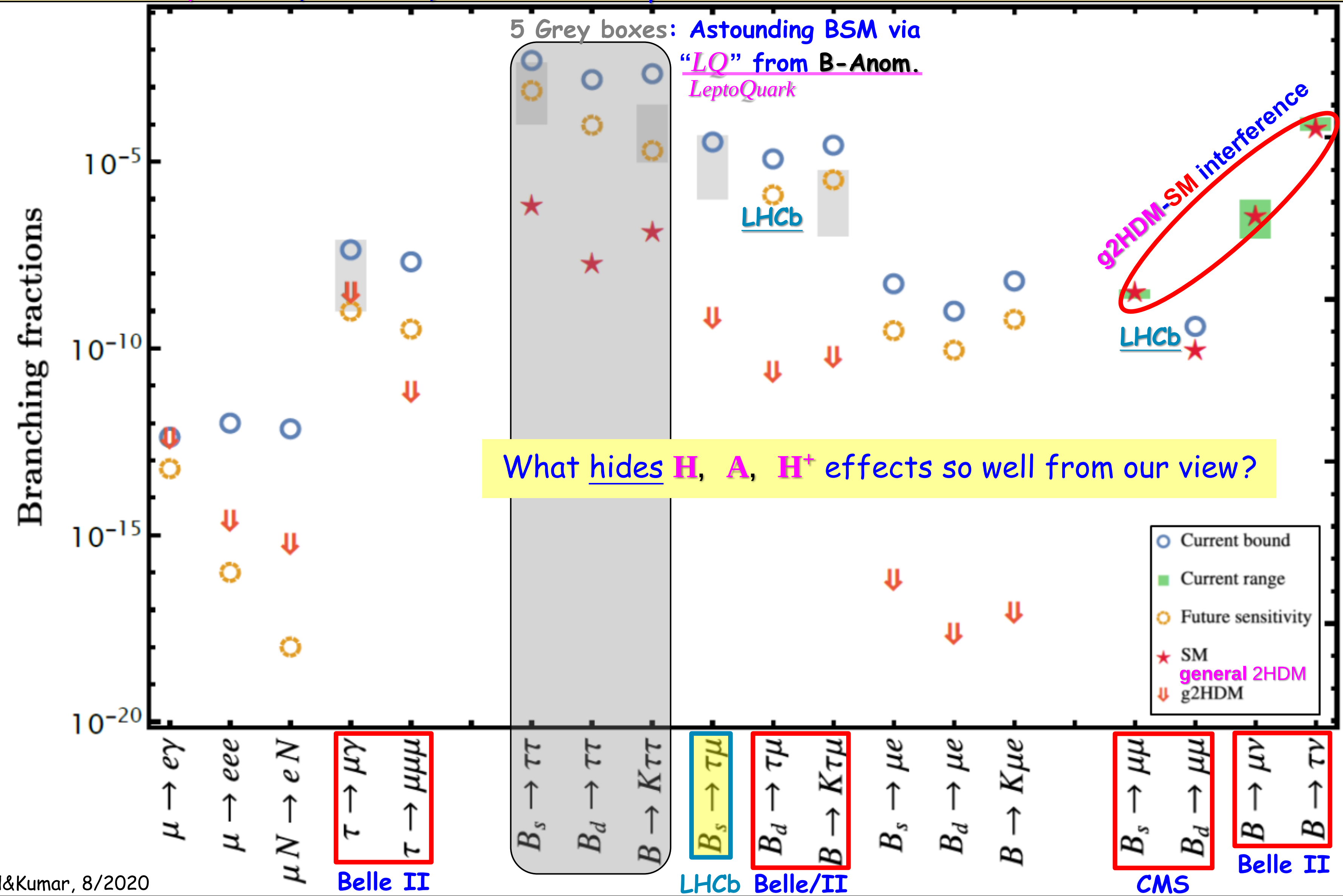
μ & τ FV (Flav.Viol.)



WSH&Kumar, 8/2020

Glimpse of coming New *Flavor* Era

μ & τFV (Flav.Viol.) in B decay



WSH&Kumar, 8/2020

V. Conclusion: Decadal Mission

- Since Higgs discovery, with No New Physics in sight, HEP seems rudderless, or, too many rudders/engines.

- A most likely New Physics in plain sight, but See Not: a 2nd *Higgs* doublet
  - Extra Yukawa ρ_{tt} drive Baryogenesis; ρ_{ee} help evade ACME18 d_e bound

    Godspeed their Success
  - Sub-TeV **H**, **A**, **H$^+$** and their effects *well hidden* so far from view, by: *Flavor* strucure (mass-mixing) and emergent *Alignment* (small h-H mixing).
  - Direct Search Modes (collider) and Indirect (flavor) effects proposed.

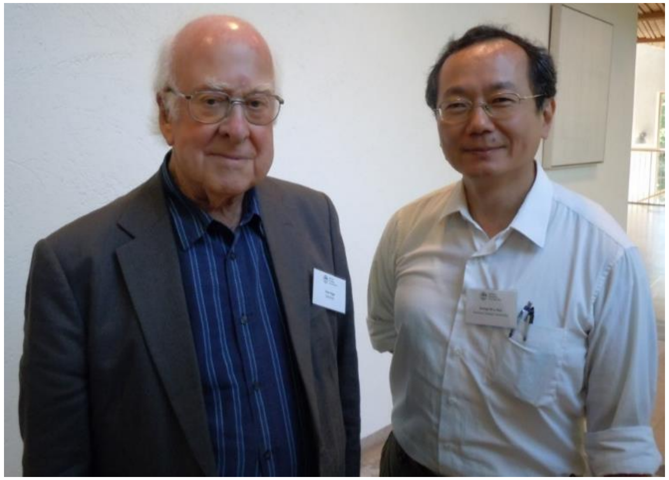
Decadal Mission:

Find the extra **H**, **A**, **H$^+$** bosons and crack the ***Flavor*** code**!**

CMS & Belle II provide us the means to do so at NTU.

Started! (also ATLAS: "Barcelona FC")

Thank you !



a Higgs, and a 2nd Higgs …

"The Higgs boson may be fictitious!"

(Phil Anderson, Nature Physics 2/2015)

news & views

SUPERCONDUCTIVITY

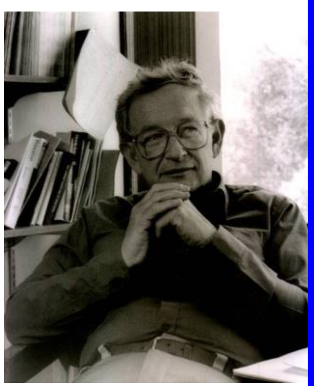
Higgs, Anderson and all that

The Higgs mechanism is normally associated with high energy physics, but its roots lie in superconductivity. And now there is evidence for a Higgs mode in disordered superconductors near the superconductor-insulator transition.

Philip W. Anderson

…

NATURE PHYSICS | VOL 11 | FEBRUARY 2015 | www



fictitious?

Anderson replied to me after 3 yrs!!

Philip W. Anderson <pwa@princeton.edu> 2018年2月10日 上午12:36

收件者: George Wei-Shu Hou <wshou@phys.ntu.edu.tw>

In superconductors people have been talking about a "Higgs" mode which appears spontaneously as a collective superposition of all the pair degrees of freedom and is not introduced formallyas a component of the Lagrangian. It is to me an open question whether or not the observed Higgson is similar and need not be formally introduced, hence "fictitious".

On Apr 3, 2015, at 6:57 AM, George Wei-Shu Hou <wshou@phys.ntu.edu.tw> wrote:

> Dear Prof. Anderson,
> A condensed matter colleague brought your News and Views to my
> (a multigigavolt friend) attention. I am intrigued by your jesting. May
> I ask what you meant by "fictitious", in referring to the 126 GeV mode?
> That it is a composite (like Cooper pair)?
> In the Standard Model, if "the Higgs" is the mass giver, then the
> 126 GeV mode must couple to vector bosons exactly according to
> prescription. This has not been punctiliously tested yet (will be at
> LHC Run 2), but sadly, most multigigavolt friends already tacitly
> believe in it. … …

Merriam-Webster

dissymmetry

noun

dis·sym·me·try | \ (ˌ)di(s)-ˈsi-mə-trē \

Definition of *dissymmetry*

: the absence of or the lack of symmetry

No Sign of New Symmetry @ LHC

⇨ Long-held/Unverified Symmetries are Suspect

Flavor & CPV

$B \to \mu\nu$

1903.03016 [PLB'20]

Enhanced $B \to \mu\bar{\nu}$ Decay at Tree Level as Probe of Extra Yukawa Couplings

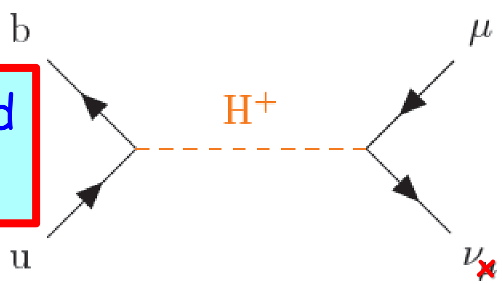
Wei-Shu Hou, Masaya Kohda, Tanmoy Modak and Gwo-Guang Wong
Department of Physics, National Taiwan University, Taipei 10617, Taiwan
(Dated: April 26, 2019)

With no New Physics seen at the LHC, a second Higgs doublet remains attractive and plausible. The ratio $\mathcal{R}_B^{\mu/\tau} = \mathcal{B}(B \to \mu\bar{\nu})/\mathcal{B}(B \to \tau\bar{\nu})$ is predicted at 0.0045 in both the Standard Model and the type II two Higgs doublet model, but it can differ if extra Yukawa couplings exist in Nature, which we deem an experimental issue. Considering recent Belle update on $B \to \mu\bar{\nu}$, we show that in the general two Higgs doublet model, the ratio could be up by a factor of two, which can be probed by the Belle II experiment with just a few ab^{-1}.

competitive with ATLAS/CMS: probe $\rho_{tu}\rho_{\tau\mu}$

$$\mathcal{B}(B \to \ell\bar{\nu}_\ell)|^{\rm 2HDM\,II} = r_H\, \mathcal{B}(B \to \ell\bar{\nu}_\ell)|^{\rm SM}$$

WSH, PRD'93



ρ_{tu} enhanced by V_{tb}/V_{ub}

$\rho_{\tau\mu}$ enters!

Conclusion.— With a second Higgs doublet quite plausible, the existence of extra Yukawa couplings is an experimental issue. The SM and 2HDM II predict the ratio $\mathcal{R}_B^{\mu/\tau} = \mathcal{B}(B \to \mu\bar{\nu})/\mathcal{B}(B \to \tau\bar{\nu})$ to be 0.0045, which offers a unique test. Through $\bar{\nu}_\tau$ flavor, the $\rho_{\tau\mu}$ coupling can enhance $B \to \mu\bar{\nu}$, while $B \to \tau\bar{\nu}$ is SM-like. If enhancement of $\mathcal{R}_B^{\mu/\tau}$ is uncovered by Belle II with just a few ab^{-1}, then the many extra Yukawa couplings — fundamental flavor parameters associated with a second Higgs doublet — would need to be unraveled.