The Higgs Boson and Heavy Quarks

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National Taiwan University

January 9, 2013, Colloquium @ NTHU Physics

The Higgs Boson & Heavy Quarks

I. The Holy Grail  vs. the Quixotic Quest 

II. Meissner Effect, Higgs Mechanism, & the God Particle

III. The Quixotic Trail: from Pheno to Geno

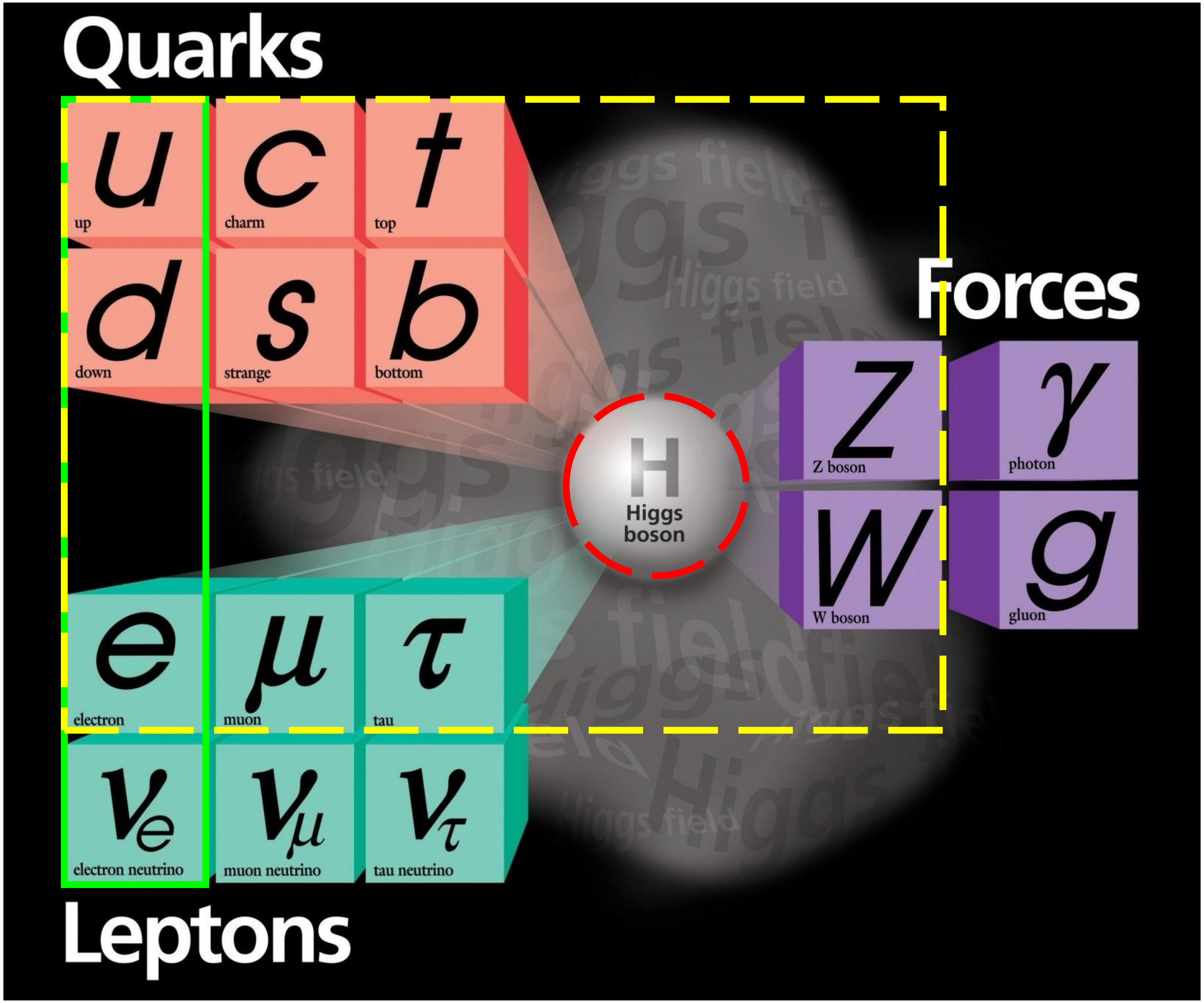
IV. Pairing, Dynamical EWSB, & the Dilaton Bonus

V. Discussion & Conclusion

I. The Holy Grail  vs. the Quixotic Quest 

The “God” Particle: the Origin of Mass

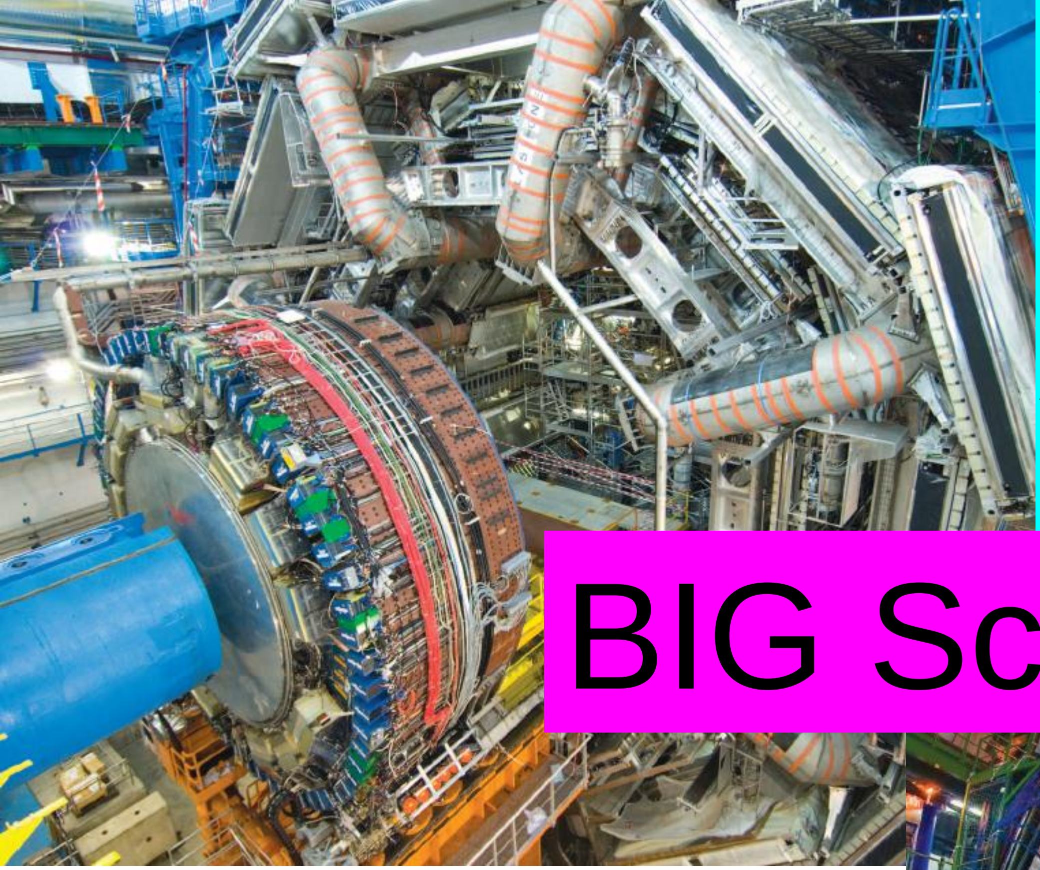
“Us”



TIME
&
Science

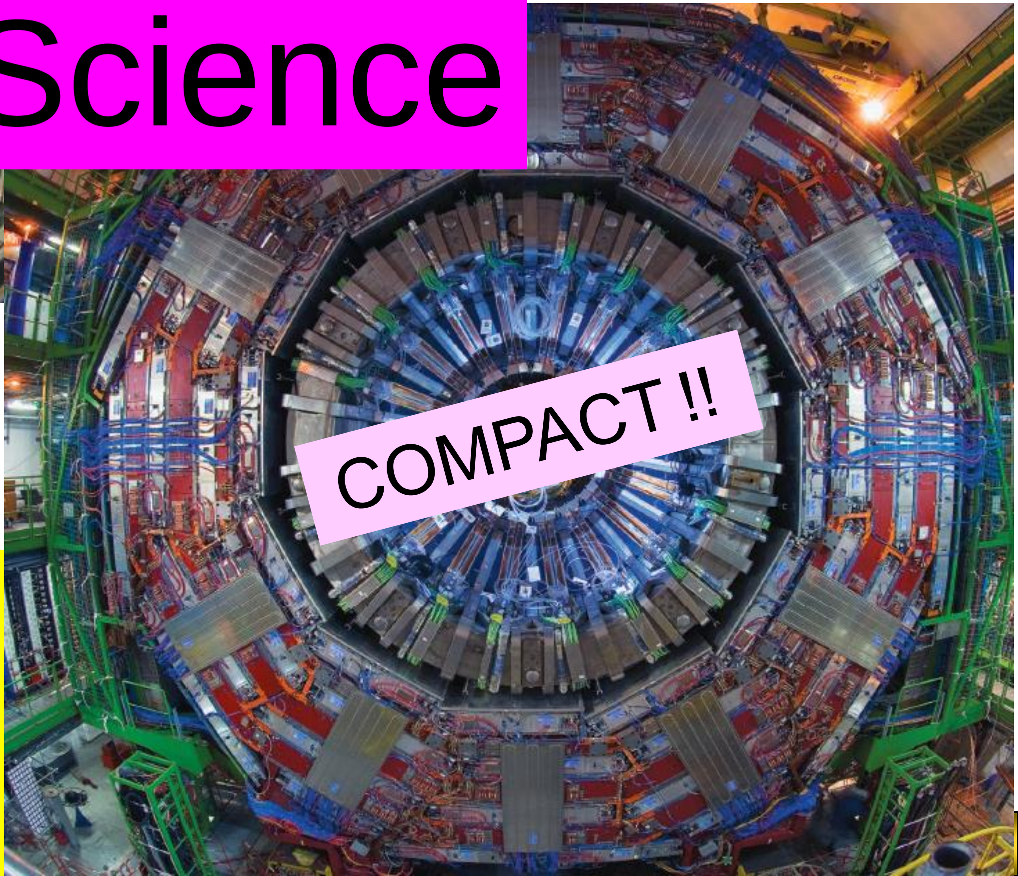
Triumphal at CERN, July 4th, 2012

Higgs "music":
http://www.livescience.com/21520-higgs-boson-music-what-might-quarks-sound-like-video.html



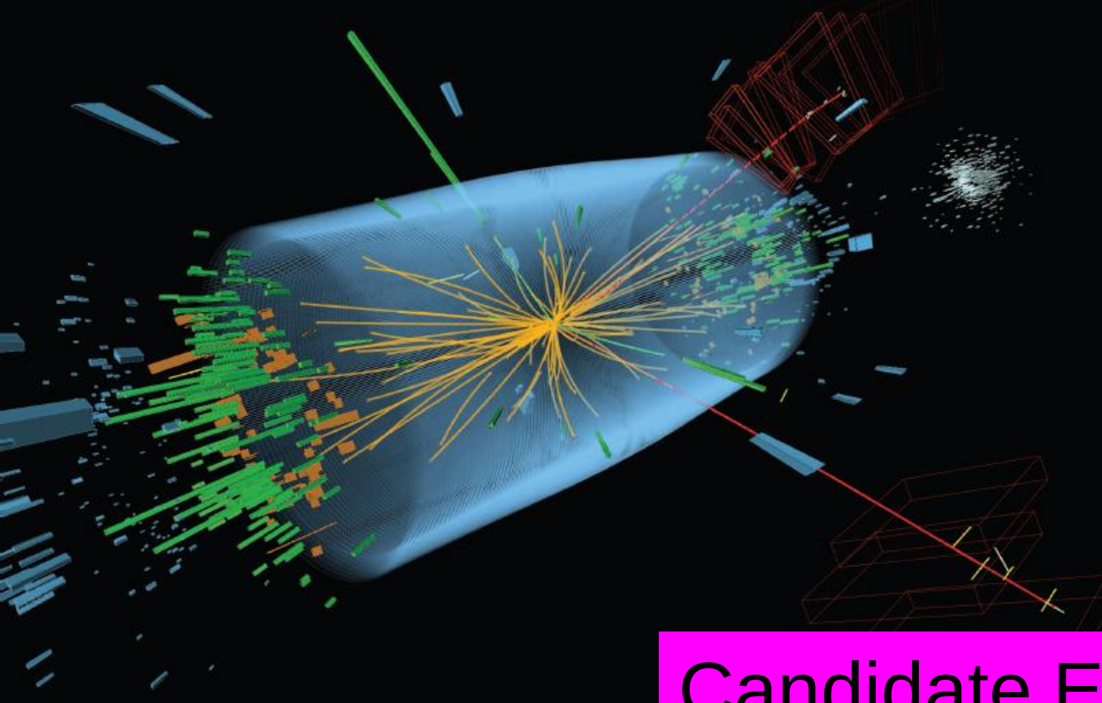
A
Toroidal
LHC
ApparatuS
S

BIG Science



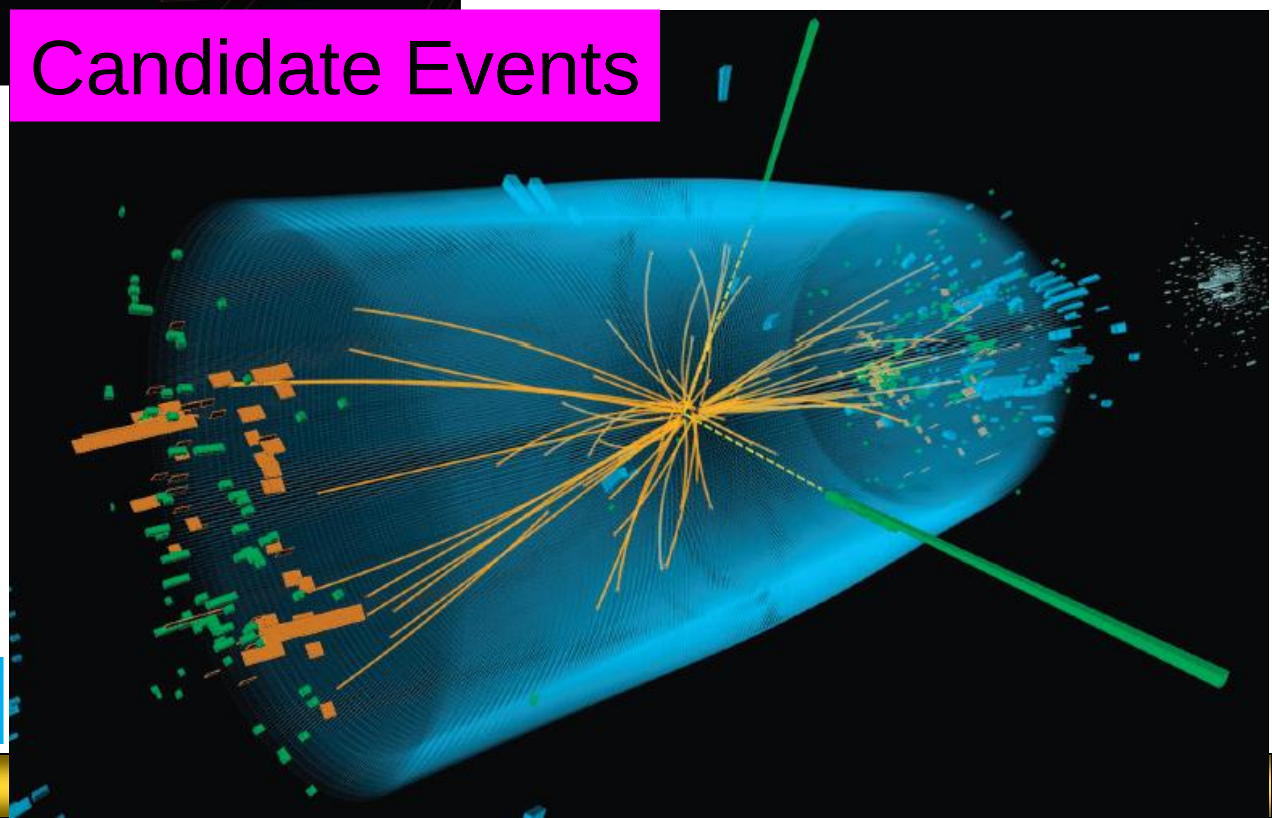
Compact
Muon
Solenoid

C
M
S



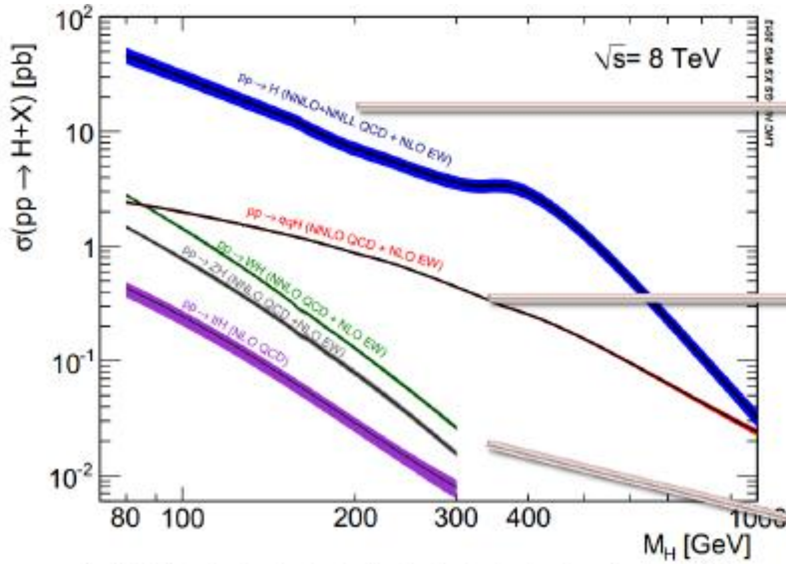
H → ZZ* → eeμμ

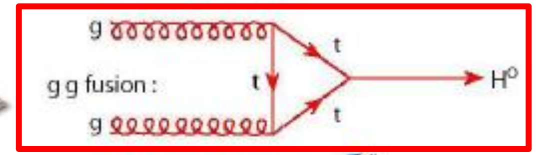
Candidate Events



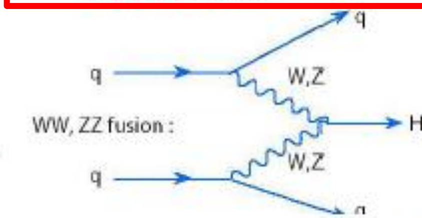
H → γγ

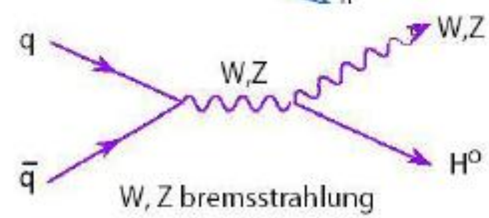
Production Processes

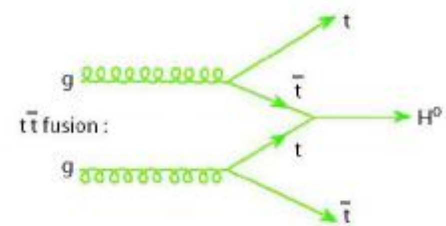


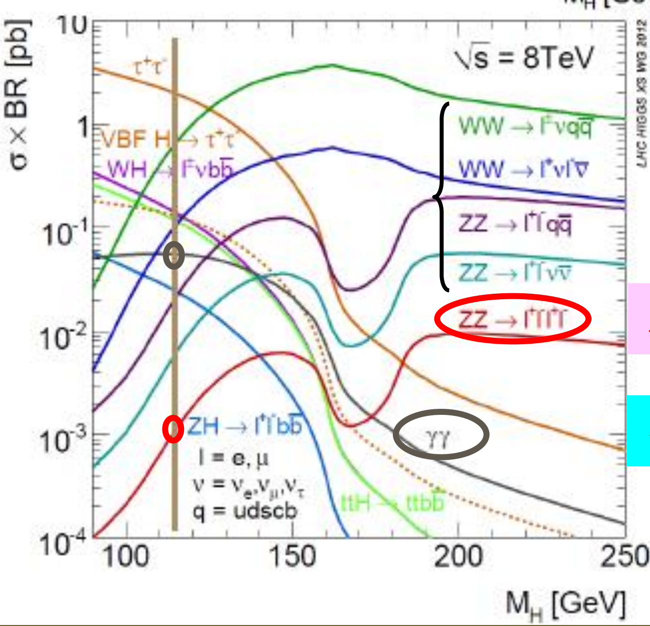


dominant







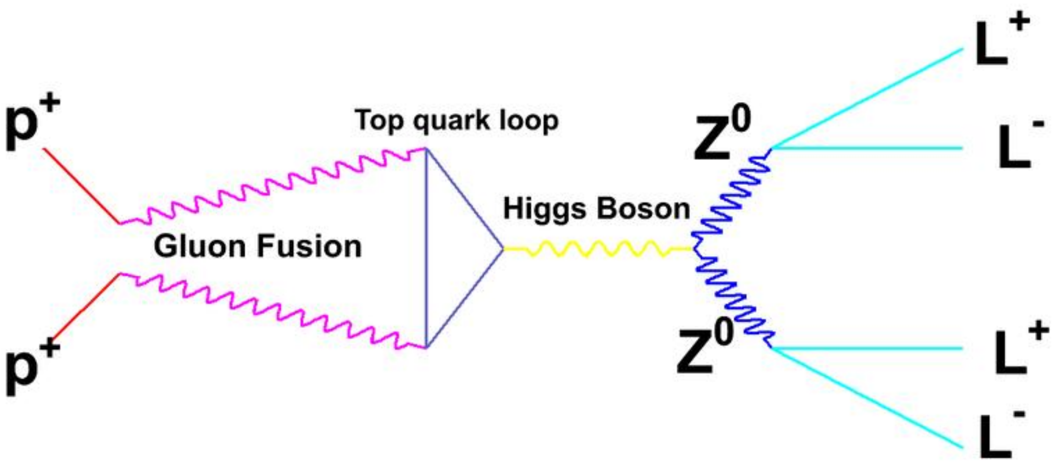


乾淨, 但很小

顯著, 但較髒

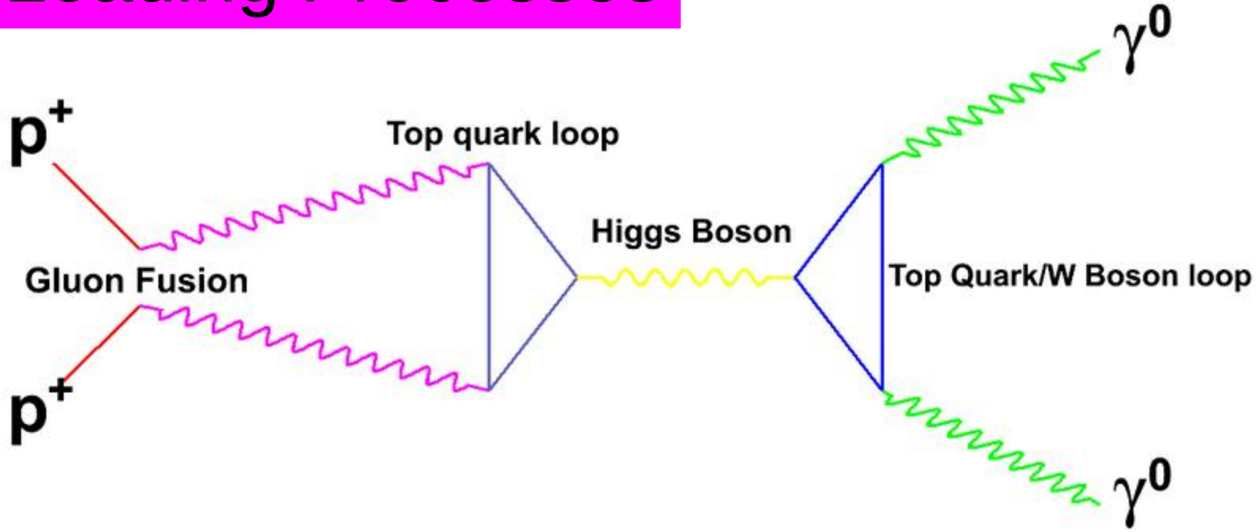
Production & Decay:
Complex Processes

$H \rightarrow ZZ^* \rightarrow ee\mu\mu$



vents

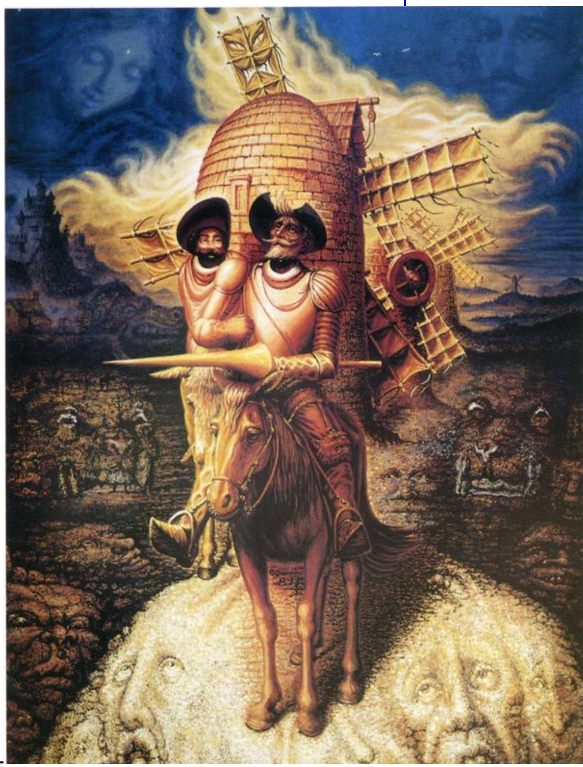
Leading Processes



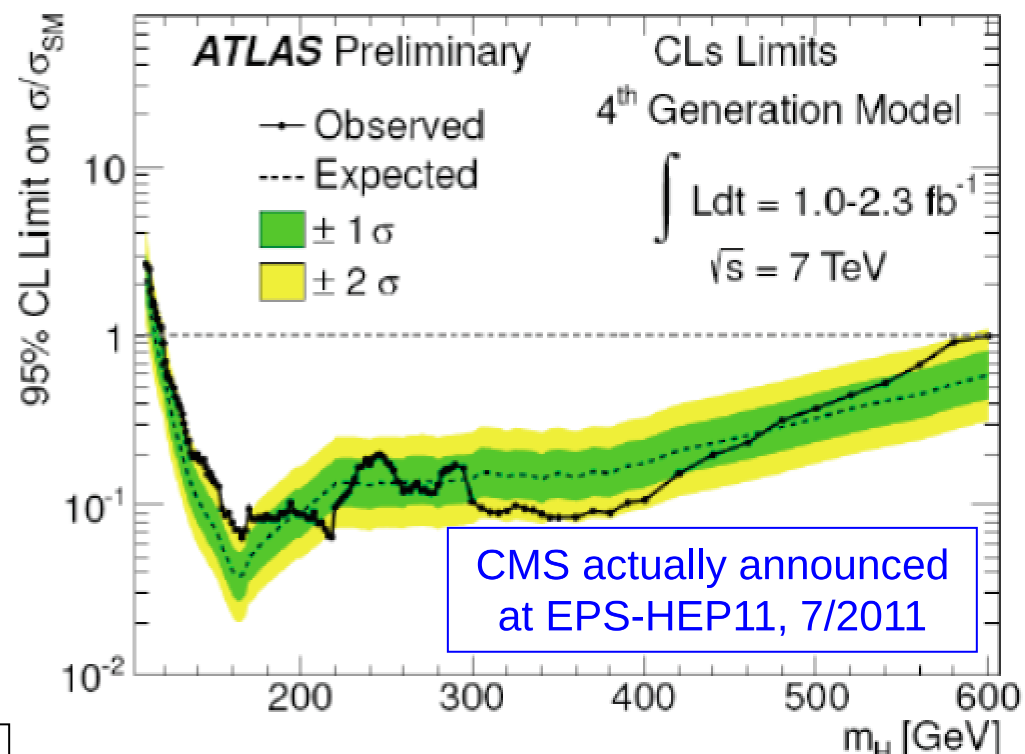
$H \rightarrow \gamma\gamma$

Michael Peskin (SLAC), Summary of LP11, Mumbai, 8/2011

Higgs limits assuming a 4th generation of quarks and leptons:



How I often looked ... Since 20 yrs



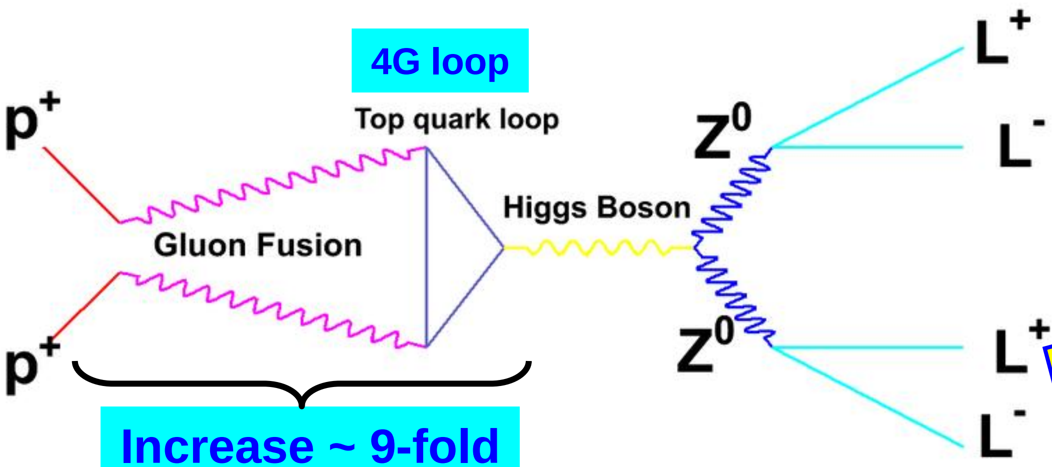
CMS actually announced at EPS-HEP11, 7/2011

Other exotic fermions are still alive and interesting, but the sequential 4th generation is in deep troupble!

Why is Sequential 4G in Deep Trou(p)ble?

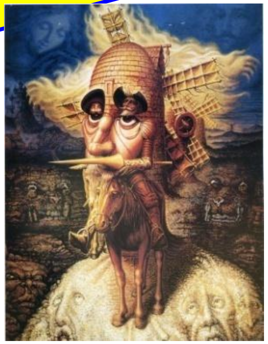
$H \to ZZ^* \to ee\mu\mu$

4G loop

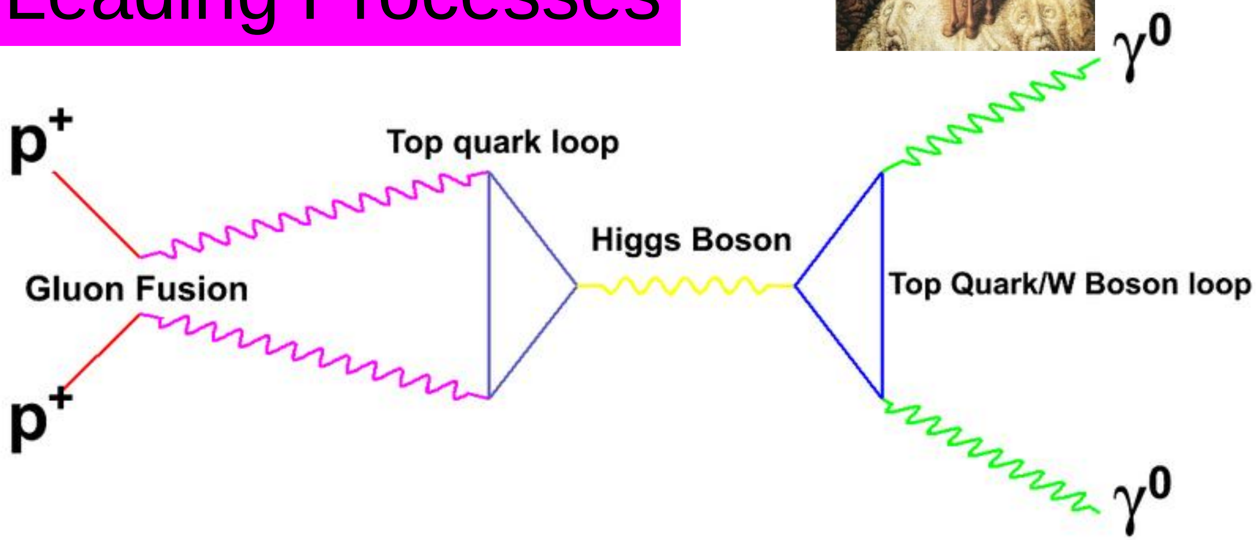


Increase ~ 9-fold

Enhancement NOT observed

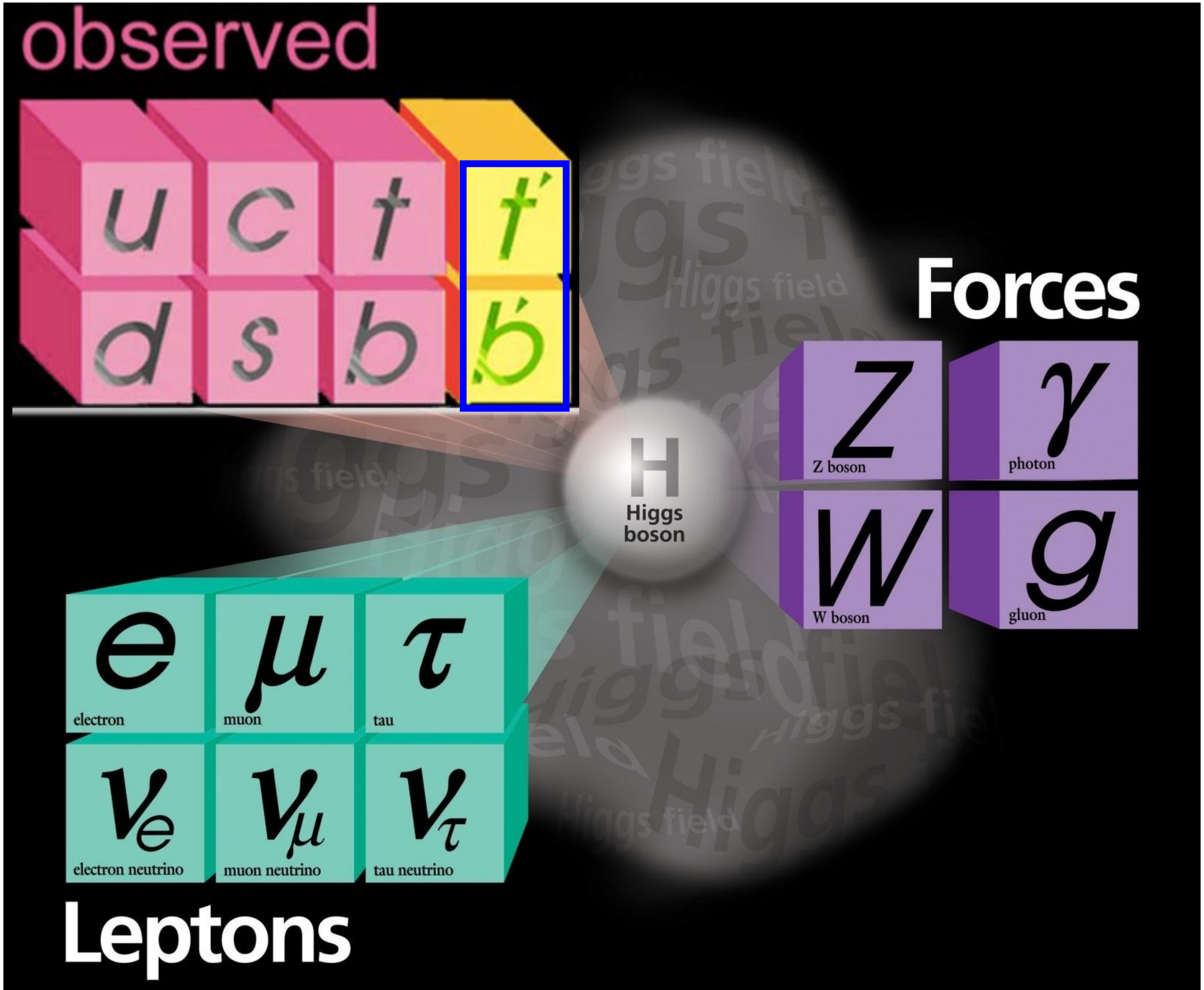


Leading Processes



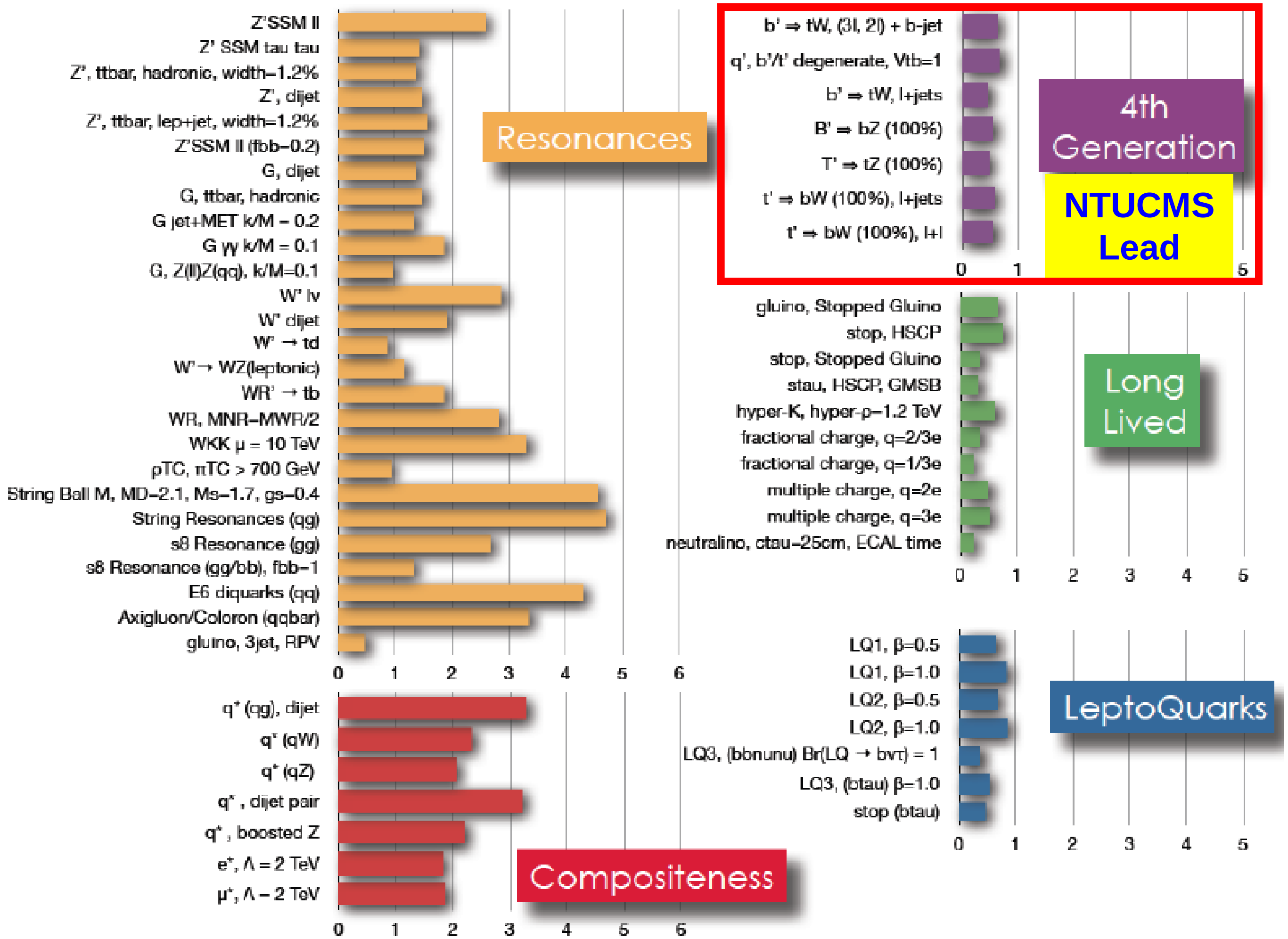
$H \to \gamma\gamma$

What is Sequential 4G?



Direct Search for “4G” at LHC

CMS Results Summary



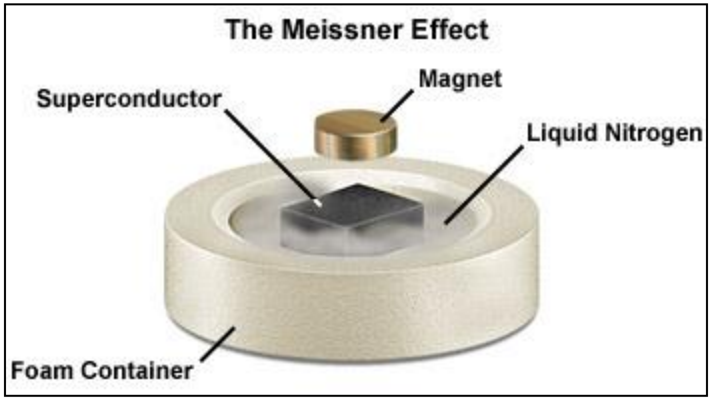
ATLAS as well

Bernd Stelzer, SFU HCP 2012, Kyoto 32

II. Meissner Effect, Higgs Mechanism, & the God Particle

What is Meissner Effect?

Walther Meissner
(1882-1974)



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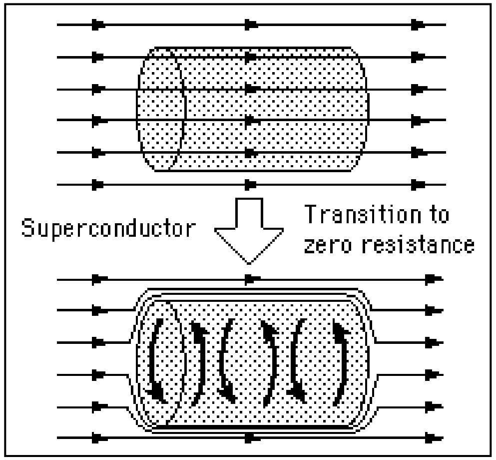
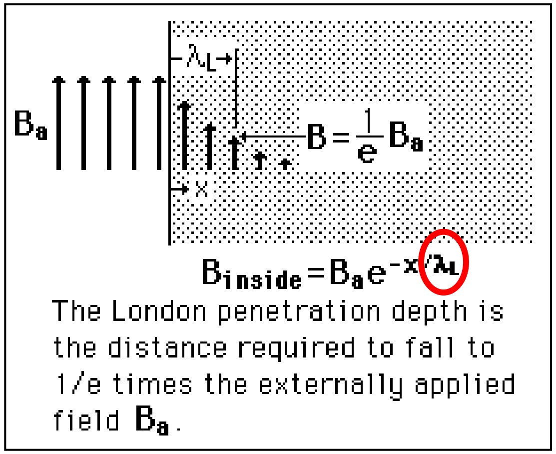


Absence of B in SC



Attentuation, or
penetration depth

Magnetic Field damped

Photon acquires “Mass”

Higgs Mechanism !

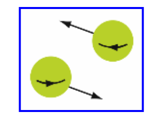
From Yoichiro Nambu's 2008 Nobel Lecture

Broken symmetry and the mass of gauge vector mesons

P. W. Anderson, Phys. Rev. **130**, 439 (1963)
F. Englert, R. Brout, Phys. Rev. Lett. **13**, 321 (1964)
P. W. Higgs, Phys. Rev. Lett. **13**, 508 (1964)

A simple example (Englert, Brout). Consider a complex scalar field $\varphi = (\varphi_1 + i\varphi_2)/\sqrt{2}$ interacting with an abelian gauge field A_μ

condensation



Cooper pair

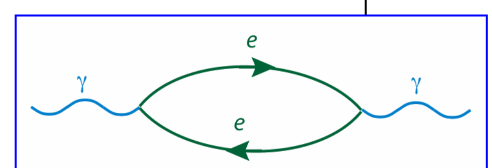
φ ~ Ginzburg-Landau "order parameter"

$$H_{\text{int}} = ieA_\mu \varphi^\dagger \overleftrightarrow{\partial_\mu} \varphi - e^2 \varphi^\dagger \varphi A_\mu A_\mu$$

v

If the vacuum expectation value of φ is $\neq 0$, e.g. $\langle\varphi\rangle = \langle\varphi_1\rangle/\sqrt{2}$, the polarization loop $\Pi_{\mu\nu}$ for the field A_μ in lowest order perturbation theory is

$$\Pi_{\mu\nu}(q) = (2\pi)^4 ie^2 \langle\varphi_1\rangle^2 \left[g_{\mu\nu} - (q_\mu q_\nu / q^2)\right]$$



Therefore the A_μ field acquires a mass $\mu^2 = e^2\langle\varphi_1\rangle^2$ and gauge invariance is preserved, $q_\mu \Pi_{\mu\nu} = 0$.

Superconductor ~ Charged Superfuild

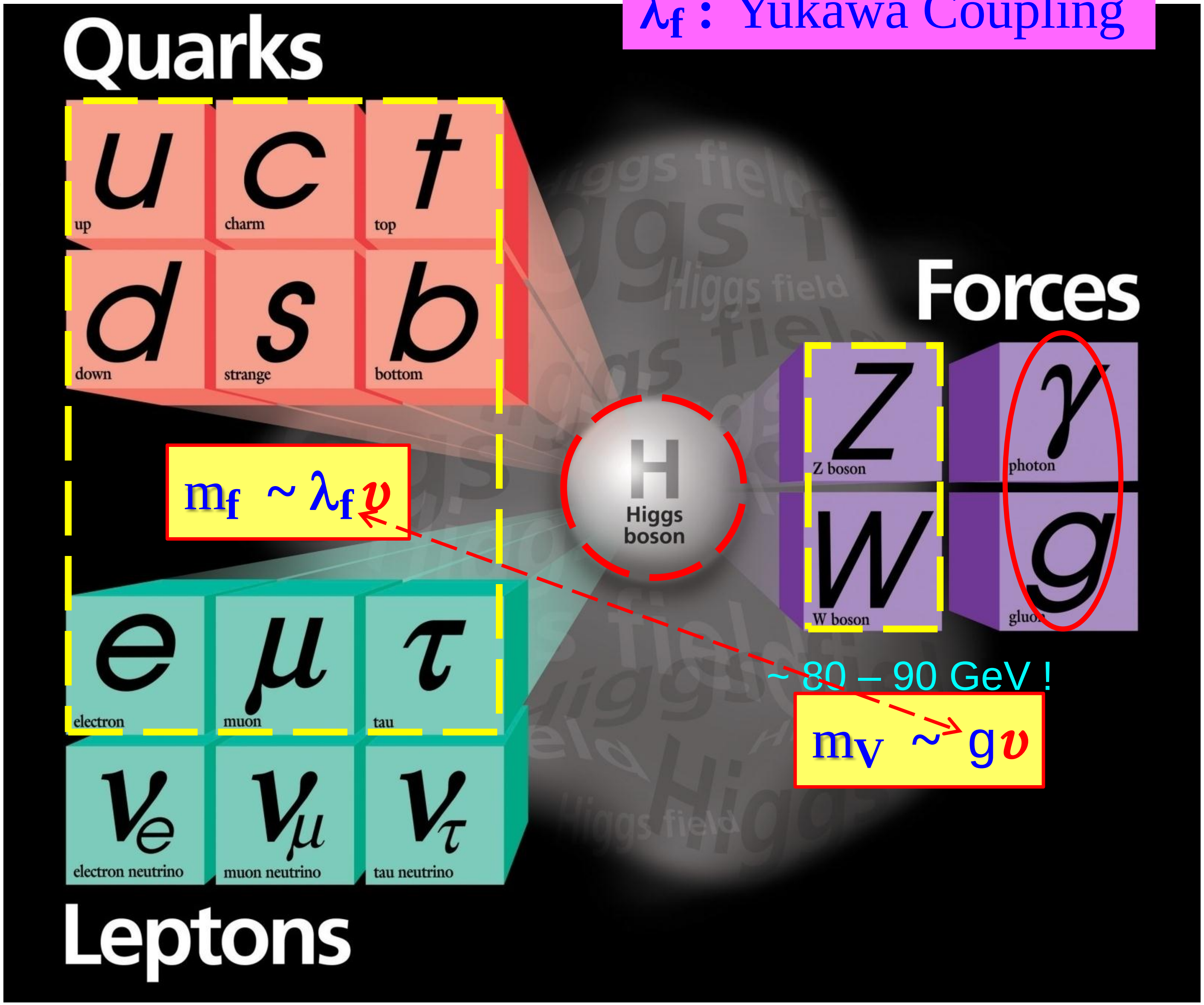
18 / 25

The "God" Particle: the Origin of Mass

to
~ **173 GeV**

Unintended
or
Intended?

from
~ **0.5 MeV**



Unbroken
massless

The Fundamental Fermions

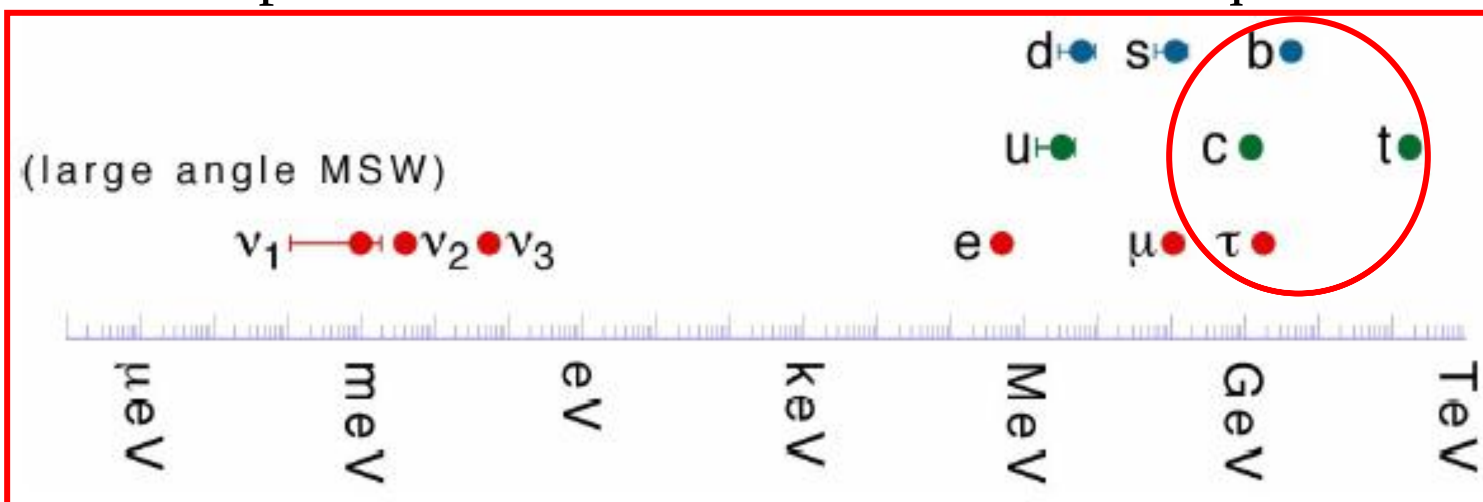
$m_f \sim \lambda_f \, v$

Heavy Flavor

ν_e 1956	ν_μ 1962	ν_τ 2000		u	c 1974	t 1995
e 1895	μ 1936	τ 1975		d	s 1947	b 1977

six leptons

six quarks



Where is our Mendele'ev ?

The Nobel Prize in Physics 2008

SSB

"for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics"

Photo: Universtity of Chicago

Yoichiro Nambu

1/2 of the prize

USA

Enrico Fermi Institute,
University of Chicago
Chicago, IL, USA

b. 1921
(in Tokyo, Japan)

"for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature"

Photo: KEK

Makoto Kobayashi

1/4 of the prize

Japan

High Energy Accelerator Research Organization (KEK)
Tsukuba, Japan

b. 1944

Photo: Kyoto University

Toshihide Maskawa

1/4 of the prize

Japan

Kyoto Sangyo University;
Yukawa Institute for Theoretical Physics (YITP),
Kyoto University
Kyoto, Japan

b. 1940

CP Violation in SM

BELLE

naturenews
7 October 2008

The Belle detector in Japan helped to confirm the symmetry breaking effects predicted by theoretical physicists.

KEK

B Factories
(BaBar & Belle)

Nambu's comment

Y. Nambu, preliminary Notes for the Nobel Lecture

In hindsight I regret that I should have explored in more detail the general mechanism of mass generation for the gauge field. But I thought the plasma and the Meissner effect had already established it. I also should have paid more attention to the Ginzburg-Landau theory which was a forerunner of the present Higgs description.

Other examples of BCS type SSB

- ^3He superfluidity
- Nuleon pairing in nuclei
- Fermion mass generation in the electro-weak sector of the standard model

Pairing

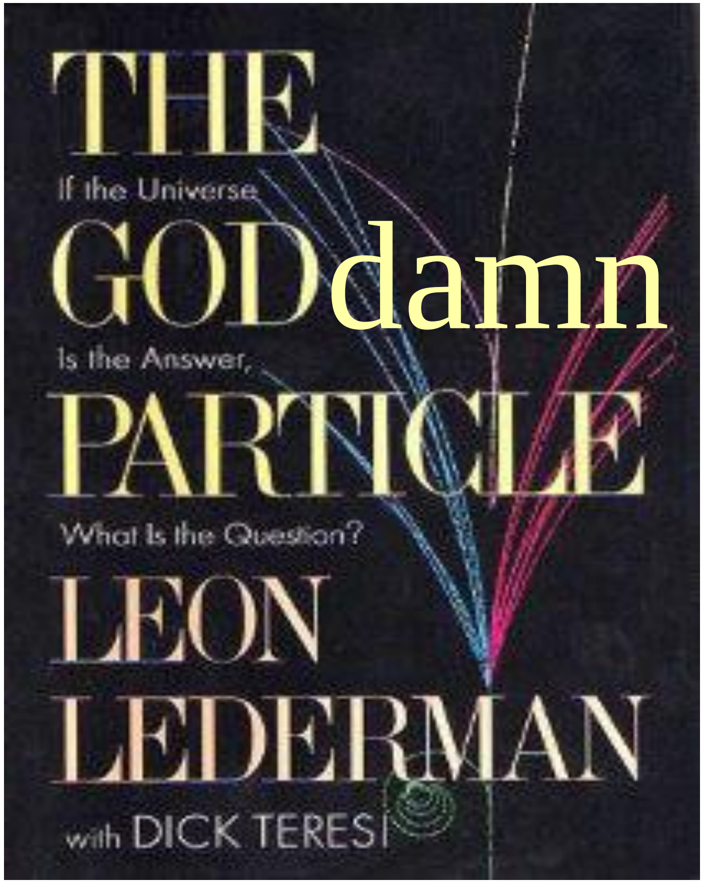
$\boxed{m_f \sim \lambda_f v}$

Nambu calls the last entry

my biased opinion, there being other interpretations as to the nature of the Higgs field

God, or Goddamn, Particle: Hope, or Dispair

熊怡
老闆



- Elusive … till July 4th, 2012
  — 48 yrs stretch

Which is "Real"?

- First "**elementary**" scalar, ever !
  NOT provided in QED, nor QCD
- **Fermion Mass Generation**
  seem fortuitous:

$$\boxed{m_f \sim \lambda_f\, \upsilon}$$

- Opens a "Can of Worms":
  – Hierarchy Problem
  – Vacuum Stability   … etc.

Thoughts on the other 1/2 Nobel Prize

SSB

"for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics"

Photo: Universtity of Chicago

Yoichiro Nambu

1/2 of the prize

USA

Enrico Fermi Institute,
University of Chicago
Chicago, IL, USA

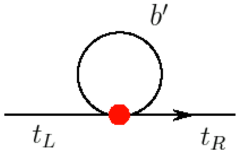
b. 1921
(in Tokyo, Japan)

$\langle \overline{Q}Q \rangle$ can Condense by Large Yukawa !

Could EWSB be due to b′ and t′ above unitarity bound ~ 500-600 GeV ?

Bob Holdom: N–J-L

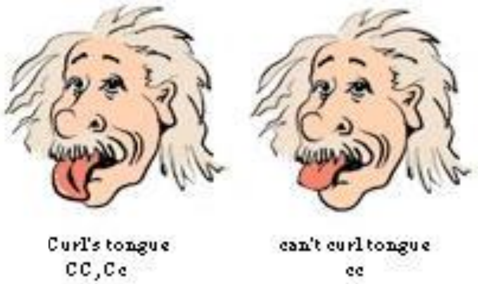
[Bardeen, Hill, Lindner



Gustavo Burdman: "Holographic" 4th gen.

III. The Quixotic Trail: from Pheno to Geno

many episodes



Implications of a Heavy Top Quark and a Fourth Generation on the Decays $B \to Kl^+l^-$, $K\nu\bar{\nu}$

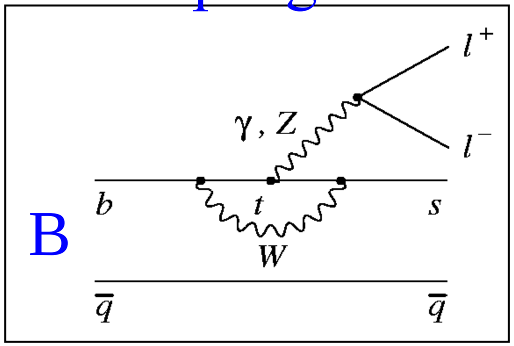
Wei-Shu Hou and R. S. Willey
Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania 15260

and

A. Soni
Department of Physics, University of California, Los Angeles, Los Angeles, California 90024
(Received 12 November 1986)

We point out the importance of the Z and box diagram to the decays $B \to Kl^+l^-$, $K\nu\bar{\nu}$. The rate for $B \to Kl^+l^-$ grows rapidly for internal quark masses >100 GeV. With three generations and 25 GeV $\lesssim m_t \lesssim 200$ GeV the branching ratio ranges roughly from 10^{-6} to 10^{-5}. With four generations, this rate could go up another order of magnitude. The mode $B \to K\nu\bar{\nu}$ typically has a higher branching ratio, but is harder to detect experimentally. The rare B decays combined with information from $K \to \pi\nu\bar{\nu}$ studies may provide a test of the symmetry-breaking mechanism of the standard model and/or evidence for a fourth generation.

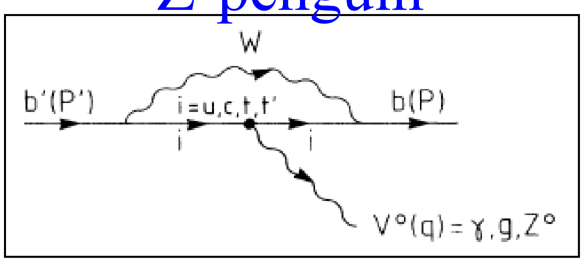
"Z-penguin"



Possibility of Discovering the Next Charge $-\frac{1}{3}$ Quark through Its Flavor-Changing Neutral-Current Decays

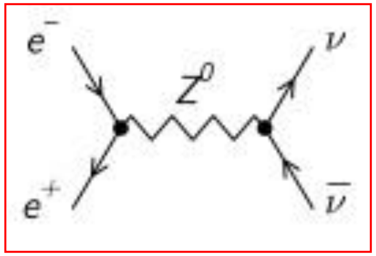
Wei-Shu Hou and Robin G. Stuart
Max-Planck-Institut für Physik und Astrophysik, Werner-Heisenberg-Institut für Physik, P.O. Box 401212, Munich, Federal Republic of Germany
(Received 3 October 1988)

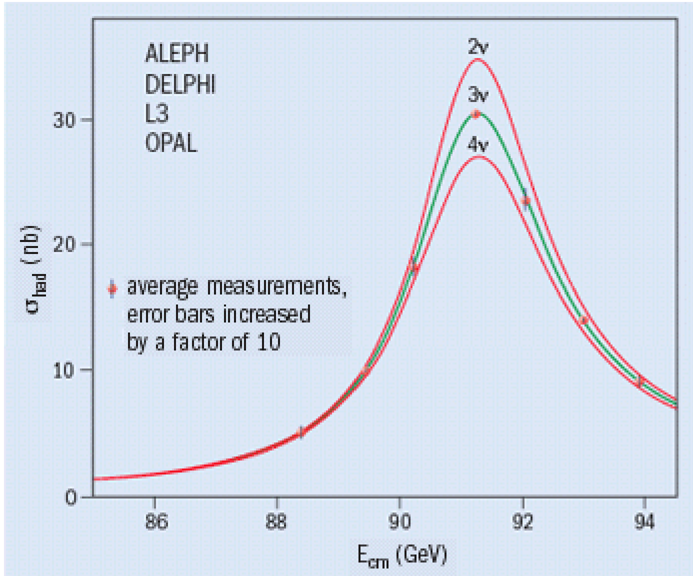
"Z-penguin"



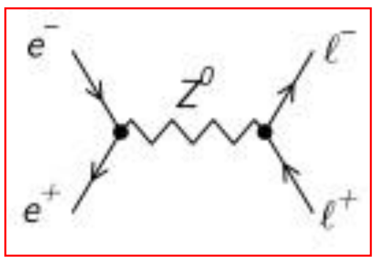
If a fourth fermion generation exists, it is possible that the next charge $-\frac{1}{3}$ quark (b') is lighter than the top. The leading charged-current transition $b' \to cW^*$ is expected to be strongly suppressed by mixing angles. This leads to the interesting and likely consequence that the b'-quark decay is completely dominated by loop-induced flavor-changing neutral currents, which have distinctive experimental signatures. The relative importance of $b' \to bg^*$, $b' \to b\gamma$, and $b' \to bZ$ transitions (as well as comparisons with $b' \to cW^*$) are explored for b' masses up to 130 GeV.

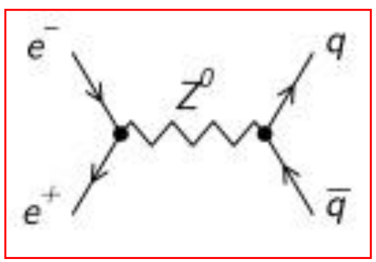
Measure





$N_\nu = 3$





Electroweak Precision Tests

An extra generation of ordinary fermions is excluded at the 99.999% CL on the basis of the S parameter alone, corresponding to $N_F = 2.81 \pm 0.24$ for the number of families. This result assumes that there are no new contributions to T or U and therefore that any new families are degenerate. In principle this restriction can be relaxed by allowing

July 14, 2006 10:37

N.B. use 2006 just for illustration

Difference in B^+ and B^0 Direct CP Asymmetry as an Effect of a Fourth Generation

Wei-Shu Hou, Makiko Nagashima, and Andrea Soddu

Department of Physics, National Taiwan University, Taipei, Taiwan 106, Republic of China

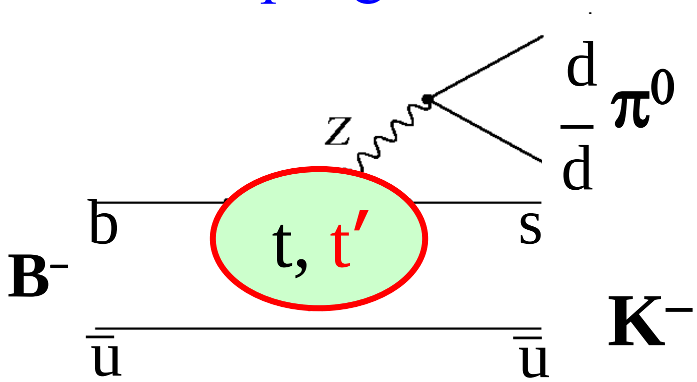
(Received 8 March 2005; revised manuscript received 20 June 2005; published 30 September 2005)

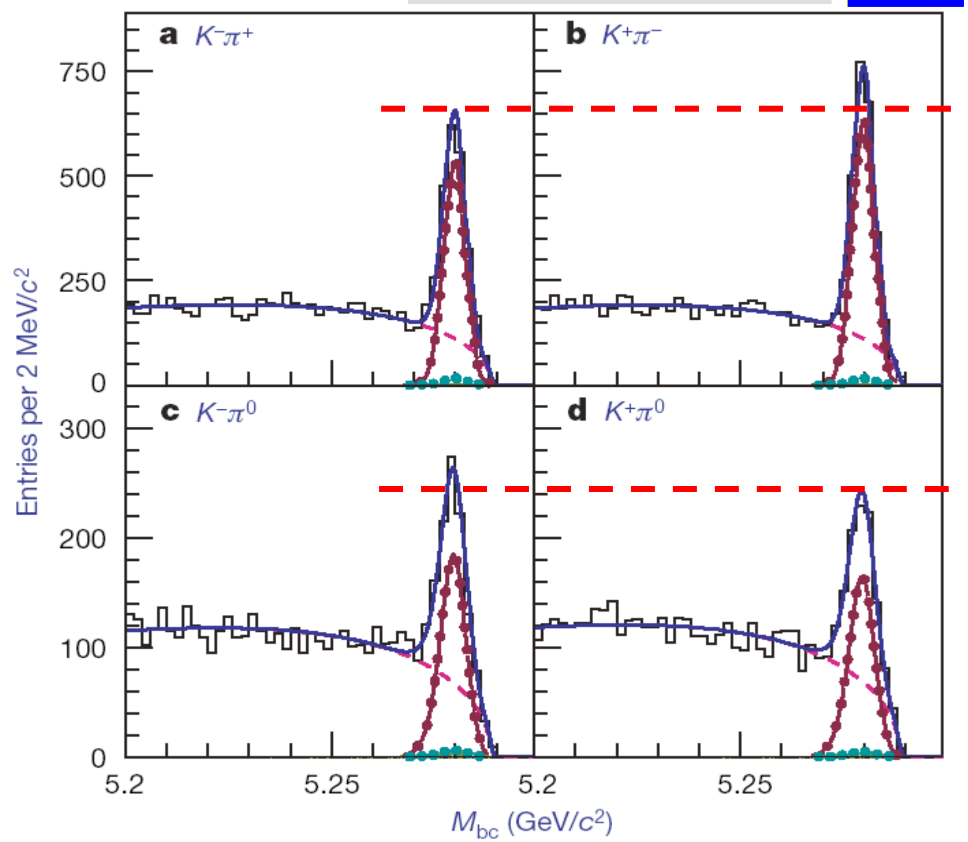
Direct CP violation in $B^0 \to K^+\pi^-$ decay has emerged at the -10% level, but the asymmetry in $B^+ \to K^+\pi^0$ mode is consistent with zero. This difference points towards possible new physics in the electroweak penguin operator. We point out that a sequential fourth generation, with sizable $V^*_{t's}V_{t'b}$ and near maximal phase, could be a natural cause. We use the perturbative QCD factorization approach for $B \to K\pi$ amplitudes. While the $B^0 \to K^+\pi^-$ mode is insensitive to t', we critically compare t' effects on direct CP violation in $B^+ \to K^+\pi^0$ with $b \to s\ell^+\ell^-$ and B_s mixing. If the $K^+\pi^0 - K^+\pi^-$ asymmetry difference persists, we predict $\sin 2\Phi_{B_s}$ to be negative.

NATURE| Vol 452| 20 March 2008

BELLE

"Z-penguin"





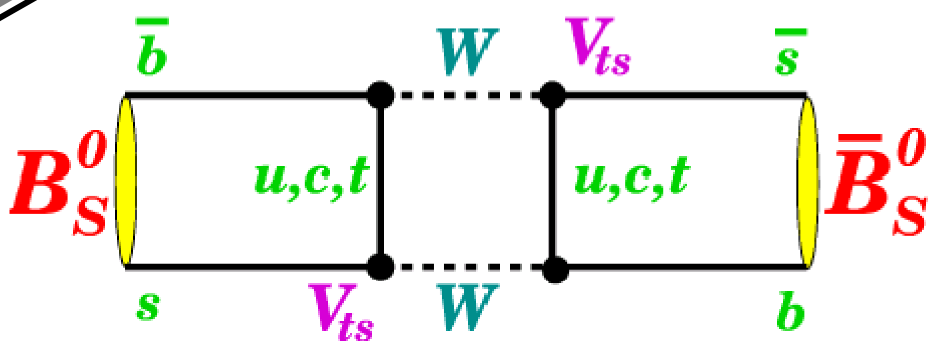
An Updated Measurement of the CP Violating Phase $\beta_s^{J/\psi\phi}$

The CDF Collaboration[1]

CDF/ANAL/BOTTOM/PUBLIC/9458
Version 1.0
August 7, 2008

The LHCb Massacre @ LP2012, Mumbai: All Hints for “Godot” Gone !

It is interesting to note that the Belle and *BABAR* collaborations have observed an asymmetry between direct CP asymmetries of charged and neutral $B \to K\pi$ decays with 5σ significance [5, 6]. In the absence of an under-estimation of the contribution from color-suppressed tree decays, it is difficult to explain this discrepancy without some source of new physics contributing to the electroweak penguin which governs the $b \to s$ transition. In the standard model, this isospin-violating diagram should be highly suppressed, but if a new source of physics is indeed present in these transitions it may be enough to cause the different CP asymmetries that have been observed.. In the $B_s^0 \to J/\psi\,\phi$ decay, the $b \to s$ transition occurs through the mixing box diagram shown in Fig. 1. It is possible that new particles could enter this transition through the $b \to s$ quark transition. While there are surely a number of possible sources of new physics that might give rise to such discrepancies, George Hou predicted the presence of a t' quark with mass between ~ 300 and $1{,}000$ GeV$/c^2$ in order to explain the Belle result and predicted *a priori* the observation of a large CP-violating phase in $B_s^0 \to J/\psi\,\phi$ decays [7, 8]. Another result of interest in the context of these measurements is the excess observed at ~ 350 GeV$/c^2$ in the recent t' search at CDF using 2.3 fb^{-1} of data [9]. In this direct search for a fourth generation up-type quark, a significance of less than 2σ is obtained for the discrepancy between the data and the predicted backgrounds, so that the effect, while intriguing, is presently consistent with a statistical fluctuation. A updated search with more data would also clearly be of interest, particularly if a large value of $\beta_s^{J/\psi\phi}$ persists with the addition of more data.



Planning for NTUCMS Analysis Strategy, ca. 2/2006

天 地

CP Violation for the Heaven and the Earth

— Sighting the 4th Generation ?

George W.S. Hou (侯維恕)

National Taiwan University

February 6, 2009, Wine & Cheese Seminar, Fermilab

Sighting

Vision ~ Early '06

4th generation? — The jury is out …

In era of LHC, can Directly Search for b′, t′
Once and For All !

Find b′, t′, or Rule Out @ LHC

It's a Duty.

Strategy Considerations (漢中策略)

- **Well shielded training ground — All Tools**
  - ☞ **Move on to Greener Pastures ~ in 2 years**
- **Publish early — Large Cross Section**
  - **- If "Limits", then easy to publish**
  - **- If "Signal", Lucked Out!**

b′ Signatures

For $m_{b'} < m_t + M_W = 255$ GeV

$b' \to cW$ dominance for sizable $V_{cb'}$

$b' \to tW^*$ dominance for suppressed

Kinematic suppressed for $m_{b'} \lesssim 230$ GeV

Initial discovery should consider

$b' \to cW \sim b' \to bZ, bH \sim b' \to tW^*$

Rich Signature

cc(bar)WW; cWbZ; cWbH;

tc(bar)WW*;

tt(bar)W*W*; tW*bZ; tW*bH;

Bonus !!

For $m_{b'} > m_t + M_W = 255$ GeV

$b' \to tW$ dominance; FCNC searchable

$t\bar{t}WW \to b\bar{b}W^+W^-W^+W^-$

4 W's + 2b's

Heavy Q related To EWSB ?

A New Drive since 2010 for CMS Participation

Research Proposal **Academic Summit**

攻頂計畫
2010-2015

Beyond Kobayashi-Maskawa

— Towards Discovery of 4th Generation Quarks at the LHC —

George W.S. Hou (NTU)

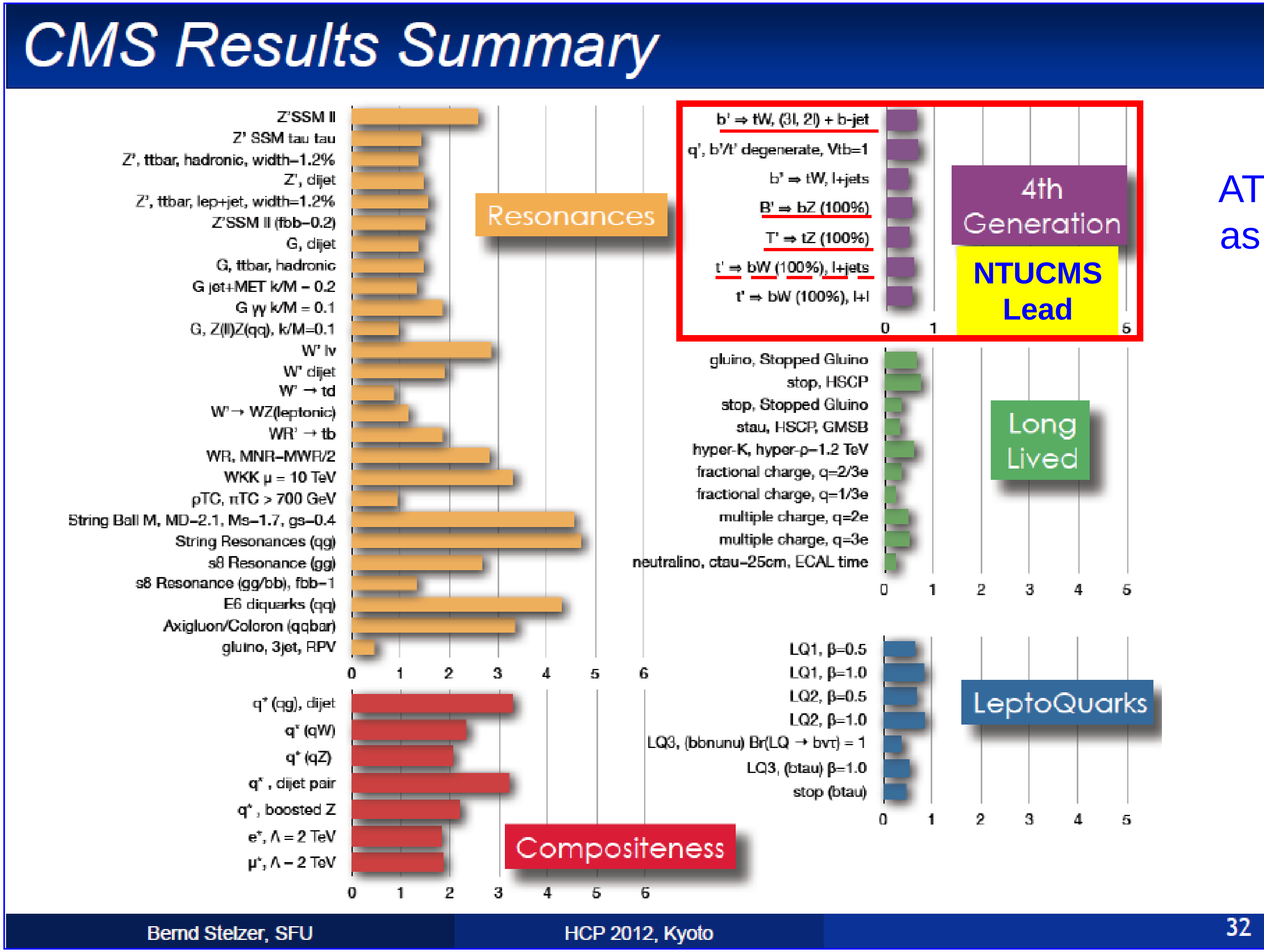
This Project aims at discovering the 4th generation quarks at the LHC with the CMS detector, and fully exploring their properties and implications. The goal would likely not be fully attained within the 2010-2015 timeframe. Therefore, a "3 + I" approach is devised for the longer term:

* A Three-pronged Study of New Heavy Quarks

- Direct Search at CMS - Collider Phenomenology - Lattice Yukawa study

* CERN/Taiwan Center for CMS Pixel Upgrade Phase I

Direct Search for “4G” at LHC

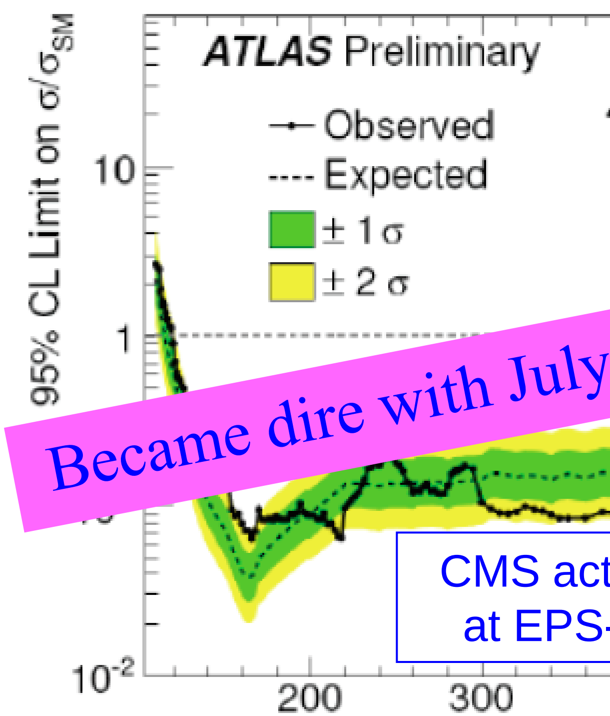


ATLAS as well

Michael Peskin (SLAC), Summary of LP11, Mumbai, 8/2011

Higgs limits assuming a 4th generation of quarks and leptons:

How I often looked ... Since 20 yrs



Became dire with July 4th Announcement

CMS actu
at EPS-

Other exotic fermions are still alive and interesting, but the sequential 4th generation is in deep troupble!

PostMortem …

Alex Pomarol @ ICHEP

But not so excellent for all theorists:

Specially for fans of **Higgsless models:**

4G included

PostMortem ...; or (future) Resurrection

Alex Pomarol @ ICHEP

but be careful about resurrections...

It is *not unconceivable* that a light dilaton appears
in Higgsless theories

4G included

Dilaton

(Goldstone of the spontaneous breaking of scale invariance)
Couples as a Higgs up to an overall scale → **A Higgs impostor**

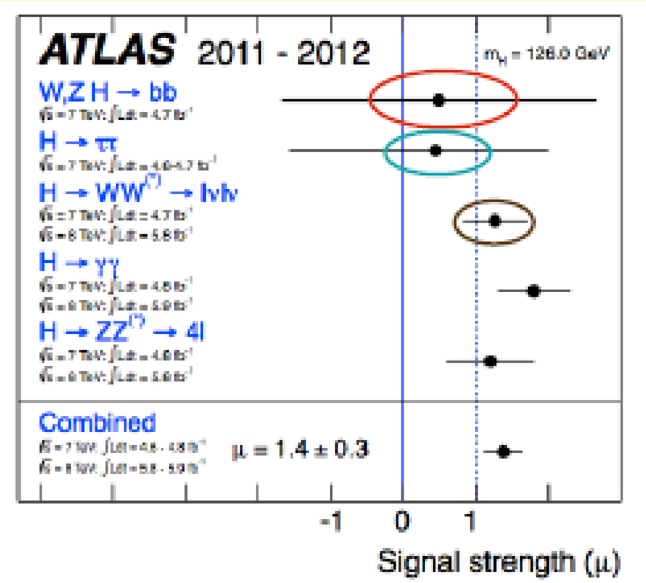
Kingman

But it’s hard to ***believe*** we are seeing a Dilaton “*just now*” ...

depression: Jun - Nov

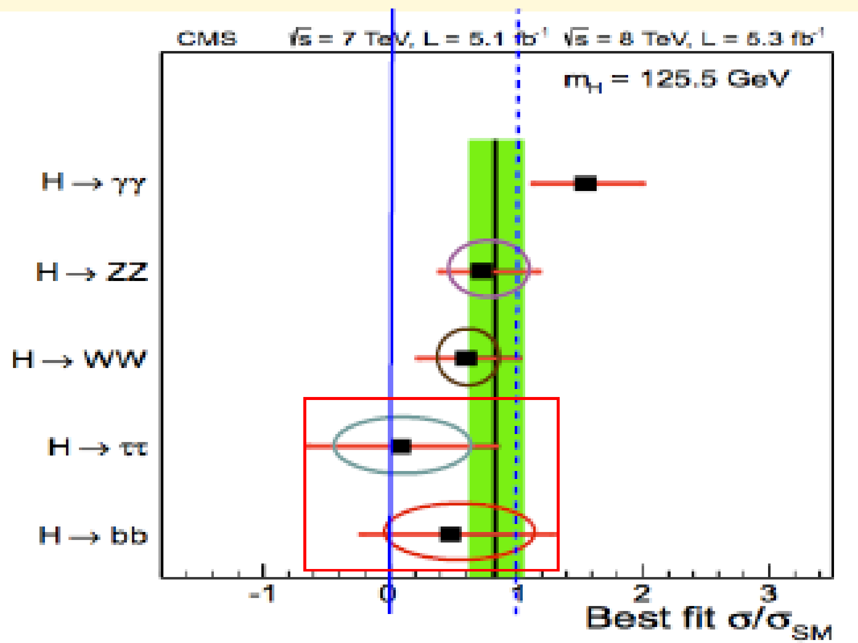
July, Phys Lett B

Summary by Michelangelo Mangano @ HCP 2012, Kyoto, 11/2012



December

MASS !?

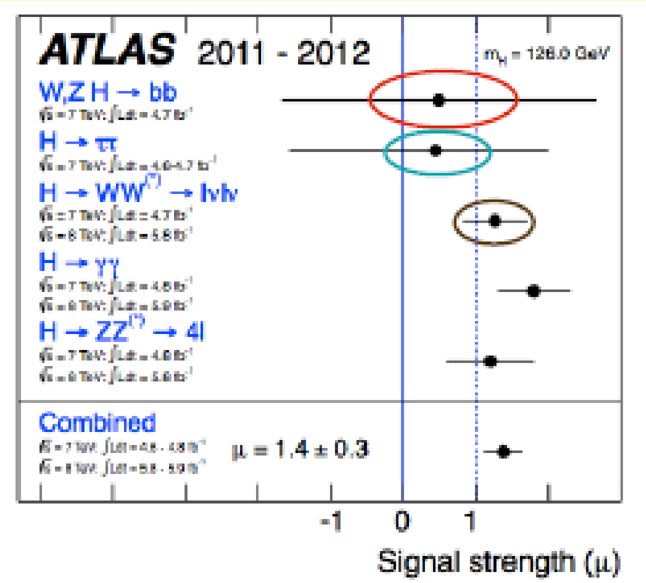


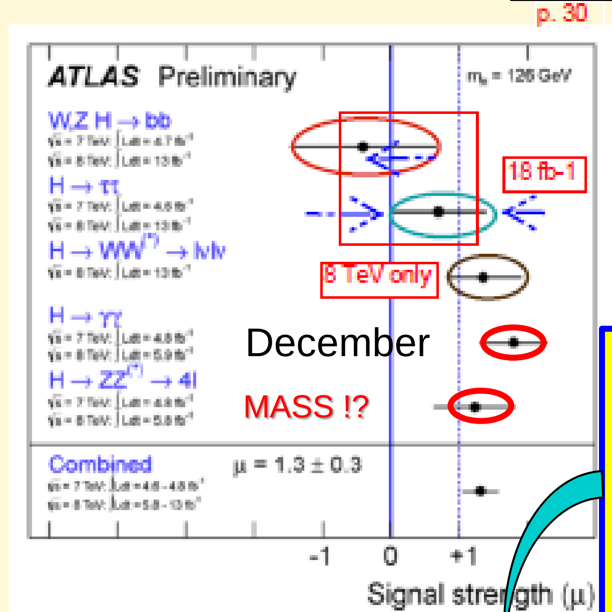
	μ July	μ HCP
ATLAS	1.4±0.3	1.3±0.3
CMS	0.87±0.23	0.88±0.21

July, Phys Lett B

Nov 15, HCP

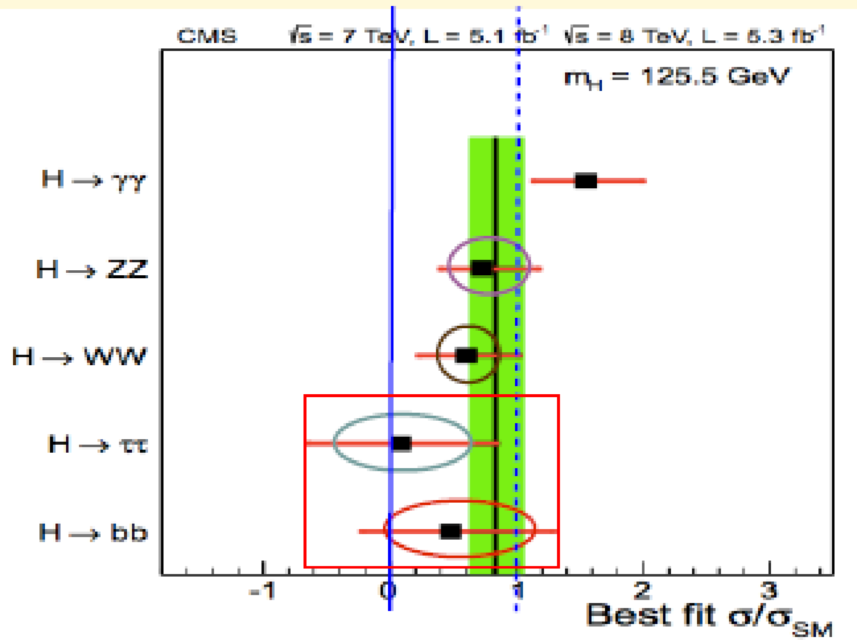
Summary by Michelangelo Mangano
@ HCP 2012, Kyoto, 11/2012

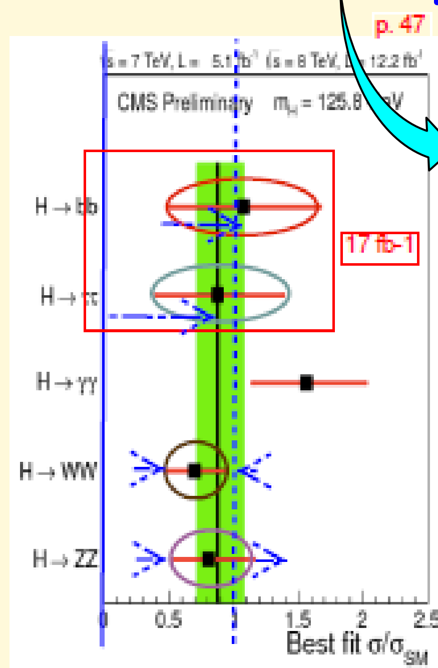




K. Einsweiler: ATLAS

- γγ mode > SM
- no convincing evidence for VBF (Vector Boson Fusion) or VH (Higgsstrahlung off V), e.g. fermion/γγ modes





C. Pauss: CMS

Dilaton Not Ruled Out !

Coupling weaker by v/f, except to γγ & gg

	μ July	μ HCP
ATLAS	1.4±0.3	1.3±0.3
CMS	0.87±0.23	0.88±0.21

Verify Higgs, or Rule Out Dilaton

Not beyond doubt before 2015.

13 TeV run start late 2014

Which is “Real”?

SSB

"for the discovery of the mechanism of spontaneous broken symmetry in subatomic physics"

Photo: Universtity of Chicago

Yoichiro Nambu

1/2 of the prize

USA

Enrico Fermi Institute,
University of Chicago
Chicago, IL, USA

b. 1921
(in Tokyo, Japan)

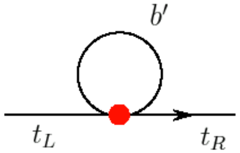
$\langle \overline{Q}Q \rangle$ can Condense

by Large Yukawa !

Could EWSB be
due to b′ and t′
above unitarity bound ~ 500-600 GeV ?

Bob Holdom: N–J-L

[Bardeen, Hill, Lindner



Gustavo Burdman: “Holographic” 4th gen.

Have been pondering this since 2008,
and major progress first half 2012 !

IV. Pairing, Dynamical EWSB, & the Dilaton Bonus

VOLUME 13, NUMBER 16 PHYSICAL REVIEW LETTERS 19 OCTOBER 1964

BROKEN SYMMETRIES AND THE MASSES OF GAUGE BOSONS

Peter W. Higgs
Tait Institute of Mathematical Physics, University of Edinburgh, Edinburgh, Scotland
(Received 31 August 1964)

In a recent note[1] it was shown that the Goldstone theorem,[2] that Lorentz-covariant field theories in which spontaneous breakdown of symmetry under an internal Lie group occurs contain zero-mass particles, fails if and only if the conserved currents associated with the internal group are coupled to gauge fields. The purpose of the present note is to report that, as a consequence of this coupling, the spin-one quanta of some of the gauge fields acquire mass; the longitudinal degrees of freedom of these particles (which would be absent if their mass were zero) go over into the Goldstone bosons when the coupling tends to zero. This phenomenon is just the relativistic analog of the plasmon phenomenon to which Anderson[3] has drawn attention: that the scalar zero-mass excitations of a superconducting neutral Fermi gas become longitudinal plasmon modes of finite mass when the gas is charged.

The simplest theory which exhibits this behavior is a gauge-invariant version of a model about the "vacuum" solution $\varphi_1(x)=0$, $\varphi_2(x)=\varphi_0$:

$$\partial^\mu\{\partial_\mu(\Delta\varphi_1)-e\varphi_0A_\mu\}=0, \tag{2a}$$

$$\{\partial^2-4\varphi_0^2V''(\varphi_0^2)\}(\Delta\varphi_2)=0, \tag{2b}$$

$$\partial_\nu F^{\mu\nu}=e\varphi_0\{\partial^\mu(\Delta\varphi_1)-e\varphi_0A_\mu\}. \tag{2c}$$

Equation (2b) describes waves whose quanta have (bare) mass $2\varphi_0\{V''(\varphi_0^2)\}^{1/2}$; Eqs. (2a) and (2c) may be transformed, by the introduction of new variables

$$B_\mu=A_\mu-(e\varphi_0)^{-1}\partial_\mu(\Delta\varphi_1),$$
$$G_{\mu\nu}=\partial_\mu B_\nu-\partial_\nu B_\mu=F_{\mu\nu}, \tag{3}$$

into the form

$$\partial_\mu B^\mu=0,\quad \partial_\nu G^{\mu\nu}+e^2\varphi_0^2B^\mu=0. \tag{4}$$

It is worth noting that an essential feature of the type of theory which has been described in this note is the prediction of incomplete multiplets of scalar and vector bosons.[8] It is to be expected that this feature will appear also in theories in which the symmetry-breaking scalar fields are not elementary dynamic variables but bilinear combinations of Fermi fields.[9]

[1]P. W. Higgs, to be published.
[2]J. Goldstone, Nuovo Cimento 19, 154 (1961); J. Goldstone, A. Salam, and S. Weinberg, Phys. Rev. 127, 965 (1962).
[3]P. W. Anderson, Phys. Rev. 130, 439 (1963).

See S. Coleman and S. L. Glashow, Phys. Rev. 134, B671 (1964).
[8]Tentative proposals that incomplete SU(3) octets of scalar particles exist have been made by a number of people. Such a rôle, as an isolated $Y=\pm1$, $I=\frac{1}{2}$ state, was proposed for the κ meson (725 MeV) by Y. Nambu and J. J. Sakurai, Phys. Rev. Letters 11, 42 (1963). More recently the possibility that the σ meson (385 MeV) may be the $Y=I=0$ member of an incomplete octet has been considered by L. M. Brown, Phys. Rev. Letters 13, 42 (1964).
[9]In the theory of superconductivity the scalar fields are associated with fermion pairs; the doubly charged excitation responsible for the quantization of magnetic flux is then the surviving member of a U(1) doublet.

ever heard of BCS Higgs ?

I re-entered 4G study, since 2004, due to flavor/CPV [CPV-4-BAU]

Since 2006-7, start to think about Physics at CMS/LHC

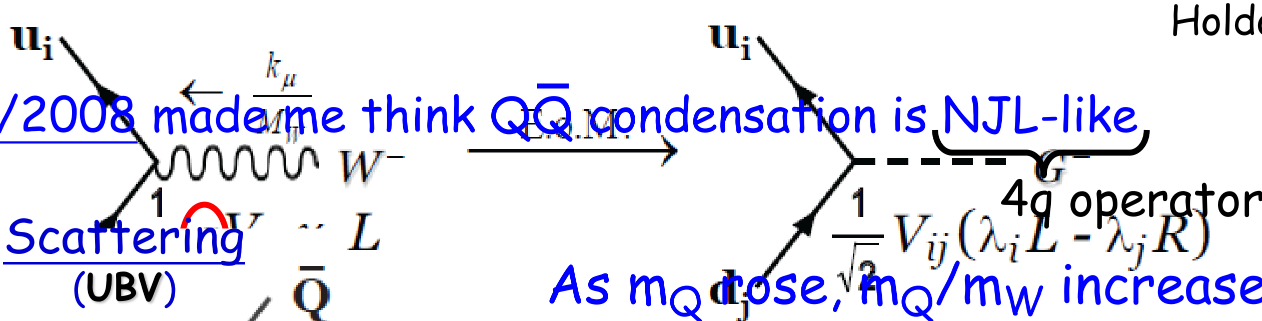
→ Set-up 4G quark search as program for NTU CMS group (influenced, e.g. Francois)

Since 2008, as bounds rose (Tev ↷ LHC), re-learned Yukawa-induced condensate

Holdom '06

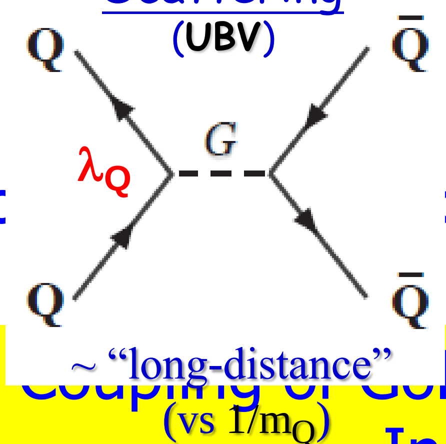
Nambu's prize in 10/2008 made me think $Q\bar{Q}$ condensation is NJL-like

Intuitively saw



Puzzled:
(ca. 2009)

Scattering
(UBV)



Associated ... ded gauge coupling:

As m_Q rose, m_Q/m_W increased;
the scattering that sets
the Unitarity Bound
is a "long distance" effect

$$\boxed{\lambda_Q = \frac{\sqrt{2}m_Q}{v}}$$

Not quite NJL-like.

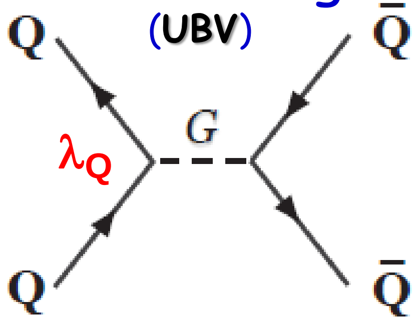
Yukawa Coupling of Goldstone Mode Established,
Independent of Higgs' Existence

Of course leading UBV occurs
for G in s-channel (but this is repulsive).

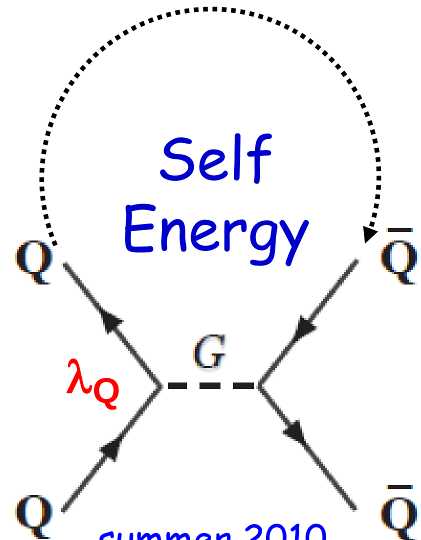
Unitarity Bound, $\underbrace{Q\bar{Q}\text{ Scattering}}_{\text{self-energy}}$

$\Rightarrow$ **Gap Equation**

Scattering



~ "long-distance"
(vs $1/m_Q$)



summer 2010,
while discussing w/
Felipe Llanes-Estrada

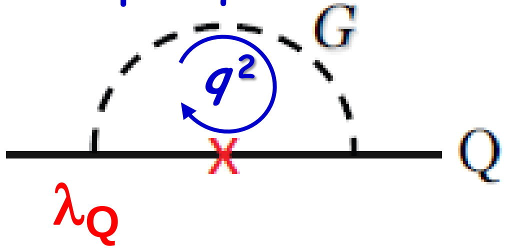
Summing over large range of exchange momentum q

WSH, ICHEP2010;
& arXiv:1201.6029
(Chin. J. Phys., 6/2012)

1-2-3 TeV

summer 2011: No New Physics

Gap Equation?

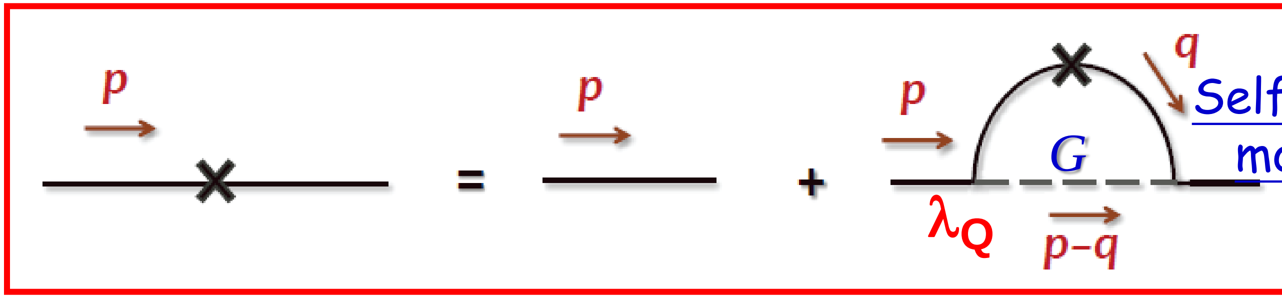


Gap Equation: Yukawa "Bootstrap"

Gap equation for large Yukawa in the **ladder approx.** (and neglect gauge couplings)

w/ $m_0 = 0$

(gauge symm.)



Self-energy momentum-dep.

$$S(p)^{-1} = A(p^2)\,\not{p} - B(p^2)$$

$$\text{Goldstone propagator}: \; D(q) = 1/q^2$$

"**Mass**" = ***B***/***A***

$$B(p^2) = +\frac{3\lambda_Q^2}{2}\int \frac{d^4q}{i(2\pi)^4}\frac{1}{(p-q)^2}\frac{B(q^2)}{A^2(q^2)q^2 - B^2(q^2)}$$
$$\cancel{-\frac{\lambda_Q^2}{2}\int \frac{d^4q}{i(2\pi)^4}\frac{1}{(p-q)^2 - m_h^2}\frac{B(q^2)}{A^2(q^2)q^2 - B^2(q^2)}}$$

$$A(p^2)p^2 = p^2 + \frac{3\lambda_Q^2}{2}\int \frac{d^4q}{i(2\pi)^4}\frac{p\cdot q}{(p-q)^2}\frac{B(q^2)}{A^2(q^2)q^2 - B^2(q^2)}$$
$$\cancel{+\frac{\lambda_Q^2}{2}\int \frac{d^4q}{i(2\pi)^4}\frac{p\cdot q}{(p-q)^2 - m_h^2}\frac{B(q^2)}{A^2(q^2)q^2 - B^2(q^2)}}$$

Drop Higgs for now; return later.

Gap Equation: Yukawa "Bootstrap"

Higgs or not, absorbed in κ_b and κ_a

So,
$$\begin{cases} B(x) = \kappa_b \left(\dfrac{1}{x} \displaystyle\int_0^x dy \frac{yB(y)}{yA^2(y)+B^2(y)} + \int_x^{\Lambda^2} dy \frac{B(y)}{yA^2(y)+B^2(y)} \right) \\ A(x) = 1 + \kappa_a \left(\dfrac{1}{x^2} \displaystyle\int_0^x dy \frac{y^2A(y)}{yA^2(y)+B^2(y)} + \int_x^{\Lambda^2} dy \frac{A(y)}{yA^2(y)+B^2(y)} \right) \end{cases}$$

$$\boxed{p^2 = x = e^{2t}}$$

$$xB'' + 2B' + \frac{\kappa_b B}{xA^2+B^2} = 0,$$
$$xA'' + 3A' + \frac{2\kappa_a A}{xA^2+B^2} = 0,$$

the boundary conditions

$$B'(x)|_{x=\Lambda_{\rm IR}^2} = 0,\ \ (xB'(x)+B(x))\,|_{x=\Lambda^2} = 0,$$
$$A'(x)|_{x=\Lambda_{\rm IR}^2} = 0,\ \ \left(\frac{1}{2}xA'(x)+A(x)\right)|_{x=\Lambda^2} = 1$$

$$\ddot{B} + 2\dot{B} + \frac{4\kappa_b B}{A^2+B^2e^{-2t}} = 0,$$
$$\ddot{A} + 4\dot{A} + \frac{8\kappa_a A}{A^2+B^2e^{-2t}} = 0,$$
$$\dot{B}(t_{\rm IR}) = 0, \qquad \dot{B}(t_{\rm UV}) + B(t_{\rm UV}) = 0$$
$$\dot{A}(t_{\rm IR}) = 0, \quad \frac{1}{4}\dot{A}(t_{\rm UV}) + A(t_{\rm UV}) = 1$$

We find, numerically, $\kappa_b = 2\kappa_a = 3\alpha_Q/8\pi$ ~ 1.4

→ $\boxed{\lambda_Q^c \simeq 12}$ → $\boxed{m_Q^c > 2.1\ \text{TeV},\ \ \text{(No Higgs)}}$!!

So, what about 126 GeV boson ? Has to be Dilaton!

4G (chiral Q) seemingly bites the dust, again ... (not that it did not happen before)

My first reaction: Hard to *believe* we are seeing a Dilaton "*just now*" ...

But the Bootstrap Gap Eq. is nominally Scale-Inv. (no scale, $m_0 = 0$) !

$$\begin{aligned} &x \to a^2 x \qquad (t \to t + \log a), \\ &\Lambda_{\rm UV,IR} \to a\Lambda_{\rm UV,IR}, \\ &B \to aB, \quad A \to A. \end{aligned}$$

Used in aid of numerical solution.

$p^2 = x = e^{2t}$

What is the true source of Scale Breaking ?

Dynamical Mass Generation also means Breaking of Scale Invariance.

Could there be a Dilaton ?

(Radion via AdS/CFT or warped)

Chacko, Franceschini, Mishra, 9/12

Goldberger, Grinstein, Skiba, '08
Barger, Ishida, Keung, '12
Campbell, Ellis, Olive, '12
Coleppa, Gregroire, Logan, '12
Matsuzaki, Yamawaki, '12; 7/12; 9/12
Elander, Piai, 8/12

Cheung, Yuan, '12
Grzadkowski, Gunion, Toharia, '12

etc.

Treat 3 parameters

$\boxed{a = v/F, \;\; c_g, \;\; c_\gamma}$

"holographic techni-dilaton gives as good a fit as SM Higgs"

Even after HCP

Not Yet Ruled Out

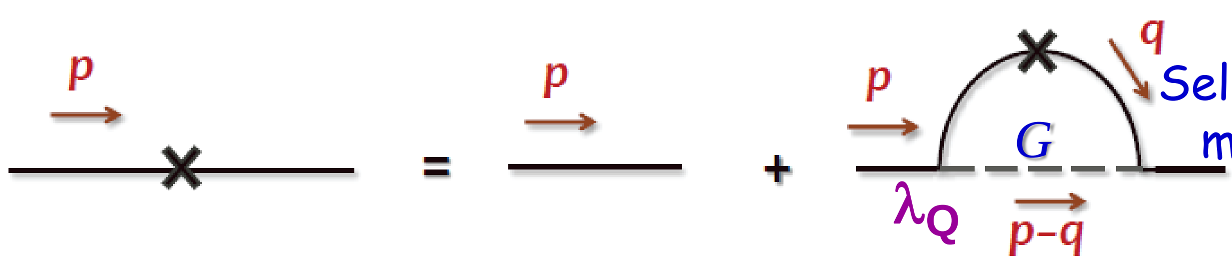
N.B. We did not touch UV ... (our whole development is empirical)
N.B. 4G → 2HDM? Perhaps, but 1) Why h^0 light; 2) Gap Eq. not applicable

Gap Equation: Yukawa "Bootstrap"

Gap equation for large Yukawa in the **ladder approx.** (and neglect gauge couplings)

w/ $m_0 = 0$

(gauge symm.)



Self-energy momentum-dep.

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$$\boxed{\text{Goldstone propagator}: \ D(q) = 1/q^2}$$

$$B(p^2) = +\frac{3\lambda_Q^2}{2}\int \frac{d^4q}{i(2\pi)^4}\frac{1}{(p-q)^2}\frac{B(q^2)}{A^2(q^2)q^2 - B^2(q^2)}$$

$$\cancel{-\frac{\lambda_Q^2}{2}\int \frac{d^4q}{i(2\pi)^4}\frac{1}{(p-q)^2 - m_h^2}\frac{B(q^2)}{A^2(q^2)q^2 - B^2(q^2)}}$$

"Mass" = ***B*/*A***

$$A(p^2)p^2 = p^2 + \frac{3\lambda_Q^2}{2}\int \frac{d^4q}{i(2\pi)^4}\frac{p\cdot q}{(p-q)^2}\frac{B(q^2)}{A^2(q^2)q^2 - B^2(q^2)}$$

$$\cancel{+\frac{\lambda_Q^2}{2}\int \frac{d^4q}{i(2\pi)^4}\frac{p\cdot q}{(p-q)^2 - m_h^2}\frac{B(q^2)}{A^2(q^2)q^2 - B^2(q^2)}}$$

Dropped "Higgs"; **if dilaton, v^2/F^2 suppressed**.

→ self-consistent

V. Discussion and Conclusion

Search for "Vector-like" Quarks at LHC

A general feature of these models is the appearance of partners of W, Z, top that approximately cancel the radiative corrections from those particles to the Higgs mass.

The top partner is not a sequential 4th generation T, but rather a vectorlike T decaying via

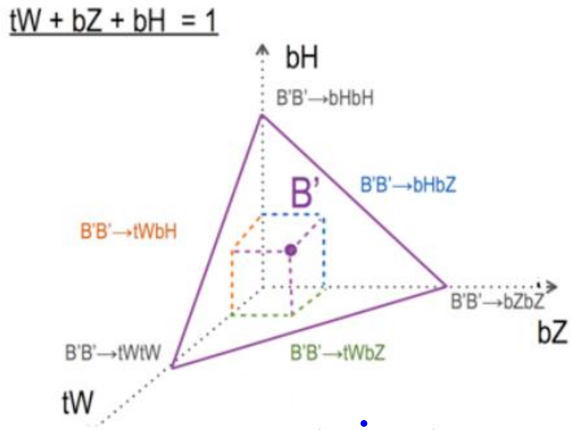
$$\boxed{T \to tZ^0,}\, bW^+, th^0 \quad (25\%, 50\%, 25\%)$$

"Exclude triangles, not points", Peskin slogan, 3/2012

The LHC experiments have begun to constrain these particles, but not very strongly yet.

Peskin, LP'11, pp. 113-114

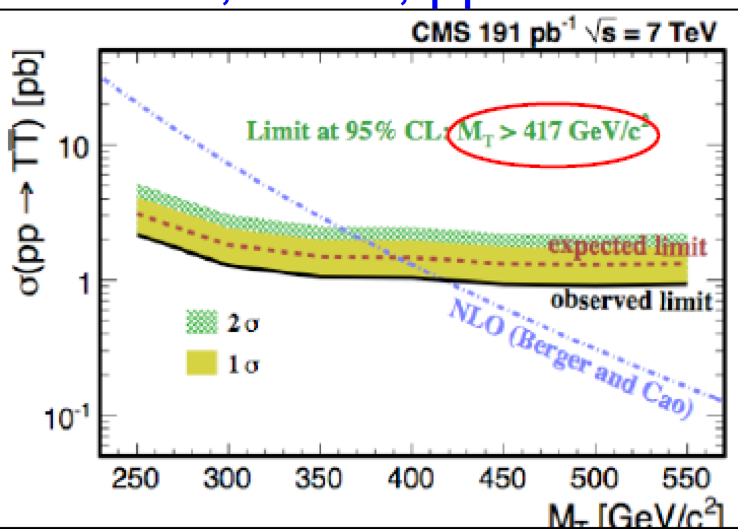
Actually, I don't like cancell -ation mechanisms, but this study has to be done, e.g.

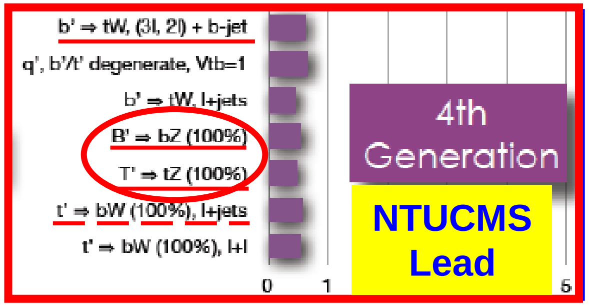


ongoing

current limits on
$T \to tZ^0$

NTUCMS !





Touch CPV (of Universe) only Briefly

Experimental Verification at B-Factories

Kobayashi slides

Present Status of CP Violation

B-factory results show that quark mixing is the dominant source of CP violation

B-factory results allow room for additional source from new physics

Matter dominance of the Universe seems requiring new source of CP violation

J seems short by at least 10^{-10}

- 4G does not take anything that did not exist in SM

- Sakharov Conditions for Baryon Asymmetry of Universe (BAU)

Baryon Number Violation; CP Violation; Out of Equilibrium

Matter dominance of the Universe seems requiring new source of CP violation

Kobayashi, Nobel Lecture

- Jarlskog Invariant for CP Violation

$$\mathrm{Im}\det\left[m_u m_u^\dagger,\ m_d m_d^\dagger\right]$$

$$\boxed{J = (m_t^2 - m_u^2)(m_t^2 - m_c^2)(m_c^2 - m_u^2)(m_b^2 - m_d^2)(m_b^2 - m_s^2)(m_s^2 - m_d^2)A}$$ 3G

CPV *iff* $J \neq 0$ ⟹ J seem short by 10^{-10}

- If shift by One Generation in 4G

by-product of Nature writing

$$J^{sb}_{(2,3,4)} \simeq (m_{t'}^2 - m_c^2)(m_{t'}^2 - m_t^2)(m_t^2 - m_c^2)(m_{b'}^2 - m_s^2)(m_{b'}^2 - m_b^2)(m_b^2 - m_s^2)A^{sb}_{234}$$

$$\sim \frac{m_{t'}^2}{m_c^2}\left(\frac{m_{t'}^2}{m_t^2} - 1\right)\frac{m_{b'}^4}{m_b^2 m_s^2}\frac{A^{sb}_{234}}{A}J$$

$\sim 10^{+15}$ Gain

Large Yukawa !

- detailed algebraic check: WSH, Mao and Shen, **arXiv:1003.4361** [hep-ph]

⇨ indeed Leading Effect; due to mass hierarchy mostly; subleading at ~ 1/10

My own busy slide from ICHEP2010 (and ICHEP2008).

Point is, great gain in CPV from 3G means

CPV-4-BAU

WSH, CJP 47 (2009) 134 [arXiv:0803.1234]

Conclusion

- From empirical nature of Yukawa Coupling, λ_Q, a Gap Eq. is built thru Goldstone (or V_L) exch. with 4G quark Q. Numerical solution is found, giving

λ_Q above 10 !! $\boxed{\lambda_Q \gtrsim 4\pi}$ [~ π-p]

which, in principle, can replace usual Higgs Condensation, and implies 4G masses in 2-3 TeV Range.

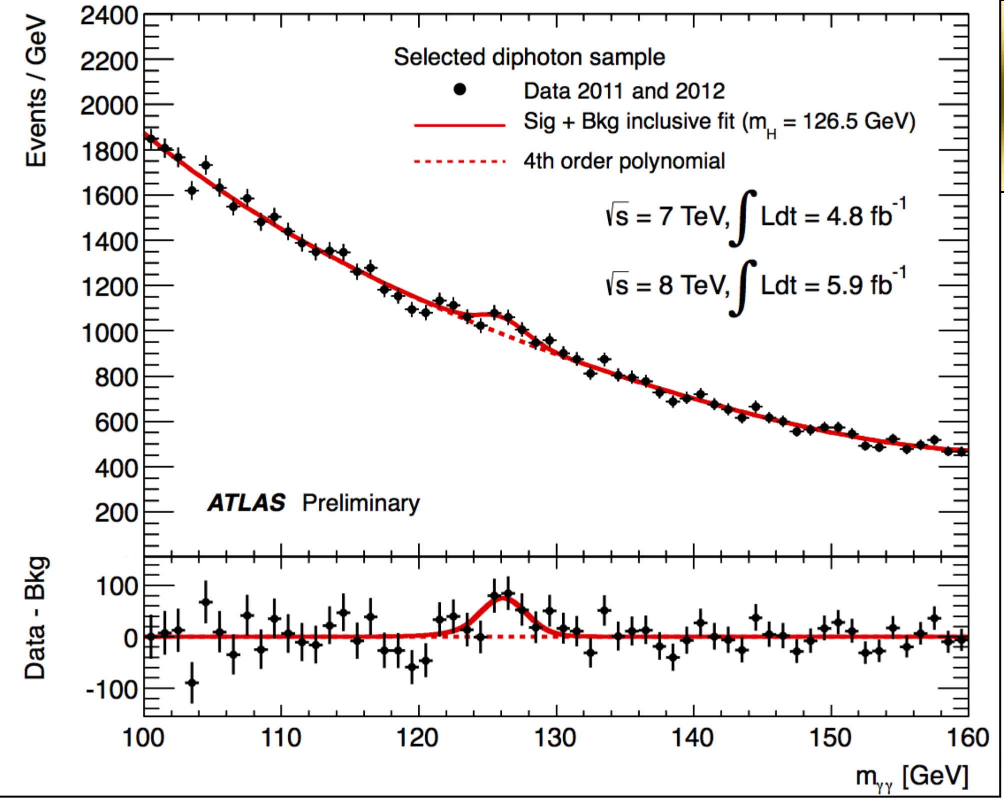
  → Boundstate Resonance Production w/ Decay into Multi-V_L (backup slide)

- Existence of 4G could enhance CPV3 by 1000 trillion+; CPV-4-BAU exponentiates further the motivation.
- The new 126 GeV Boson poses difficulties for 4G. It would have to be a Dilaton ...

Messenger from UV !?

[Our Gap Eq. is nominally Scale-invariant !]

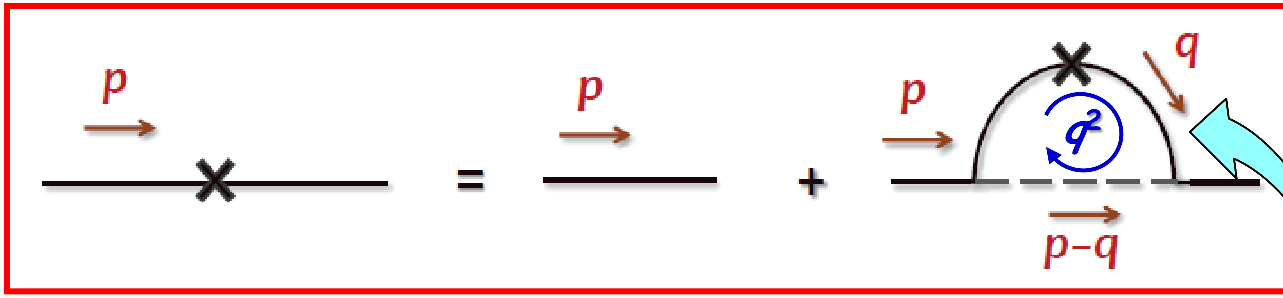
Let's wait what Nature reveals to us, thru the LHC

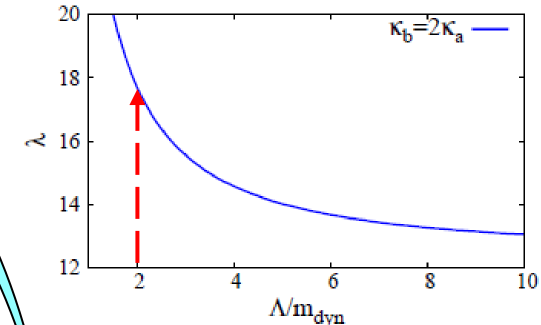


Higgs Boson (ATLAS Preliminary data)

http://www.livescience.com/21520-higgs-boson-music-what-might-quarks-sound-like-video.html

Gap Equation: Yukawa "Bootstrap"





- Gap Eq.: Integrate over q^2, but need $\Lambda < 2m_Q$ for G to remain Goldstone

→ Λ cannot be taken arbitrarily large

This raises $\lambda_Q^c \simeq 12$ to $\lambda_Q^c \sim 17.7$,

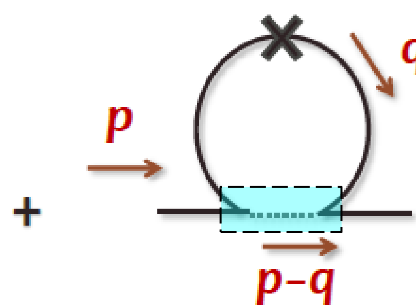
Pion-Nucleon very analogous!

OR $\boxed{m_Q \sim 3\ \mathrm{TeV}, \qquad (\text{No Higgs; } \Lambda = 2m_Q)}$

depressingly large !

- Can this be made Lower?

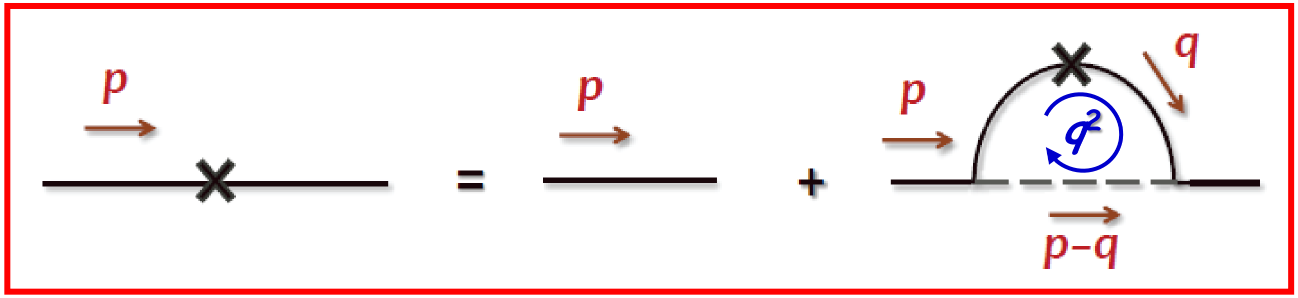
Perhaps:

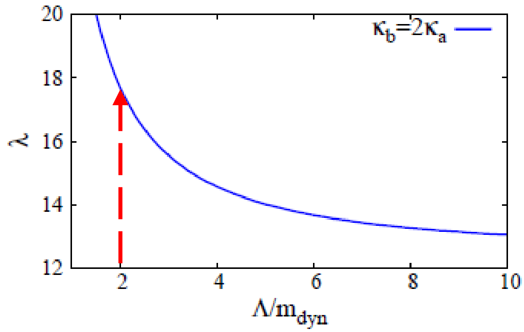


~ NJL (but much q-dep.)

Yes, other tight Bound States → Heavy "meson"

Enkhbat





- Gap Eq.: Integrate over q^2, but need $\Lambda < 2m_Q$ for G to remain Goldstone

$\rightarrow$ Λ cannot be taken arbitrarily large

depressingly large !

- Put back the light Higgs (126 GeV close to 80 GeV) ?

$\kappa_b = 2\kappa_a = 3\alpha_Q/8\pi$ ~ 1.4

$\rightarrow$ $\boxed{\lambda_Q^c \simeq 12}$ $\rightarrow$ $\boxed{m_Q^c > 2.1\ \mathrm{TeV}, \quad (\mathrm{No\ Higgs})}$

$\kappa_b = \kappa_a = \alpha_Q/4\pi$ ~ 13.7 !

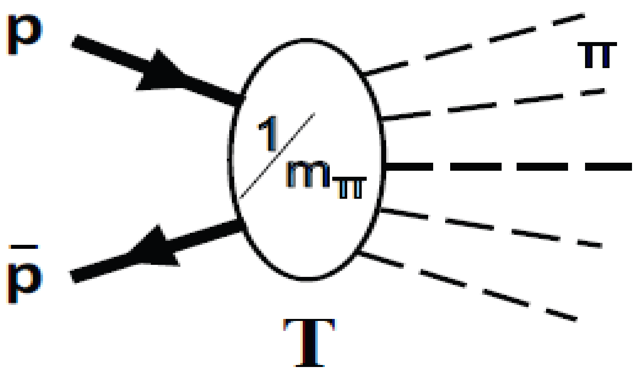
No Good !

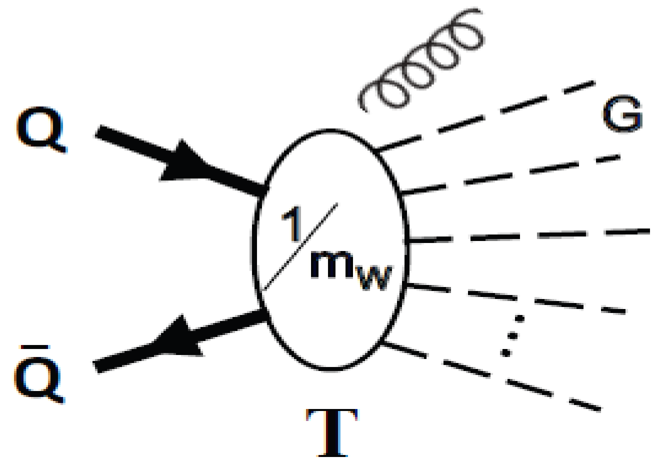
$\rightarrow$ $\boxed{\lambda_Q^c \simeq 46}$ $\rightarrow$ $\boxed{m_Q^c > 8.1\ \mathrm{TeV}, (\mathrm{massless\ Higgs})}$

Possible Phenomenology: $Q\bar{Q} \to nV_L$

$$\boxed{g_{\pi NN} \simeq \lambda_{\pi NN} \equiv \sqrt{2} m_N / f_\pi \simeq 14} \Rightarrow \boxed{m_Q \gtrsim 2 \text{ TeV}}$$

An Intriguing Analogy





annihilation "fireball"

data

- Size of order $1/m_\pi$;
- Temperature $T \simeq 120$ MeV;
- Average number of emitted pions $\langle n_\pi \rangle \simeq 5$;
- A soft-pion p_π^2/E_π^2 factor modulates the Maxwell–Boltzman distribution for the pions.

Example

$$T \sim \frac{2}{3} v \sim 160 \text{ GeV}$$
$$\langle |p_G| \rangle \sim 310 \text{ GeV},$$
$$\langle n_G \rangle \sim 6.25 \ (12.5),$$

$$P(n_G) \simeq 0.319\, e^{-\frac{(n_G - 6.25)^2}{3.13}} \quad \left(0.226\, e^{-\frac{(n_G - 12.5)^2}{6.25}}\right)$$

WSH, PRD'2012 [arXiv:1206.1453]