Dilaton vs. Higgs

Discovering the Unexpected

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Higgs-boson

- **WHAT DO WE KNOW ABOUT HIGGS PHYSICS ?**

  MANY? TOO MANY? NOTHING …

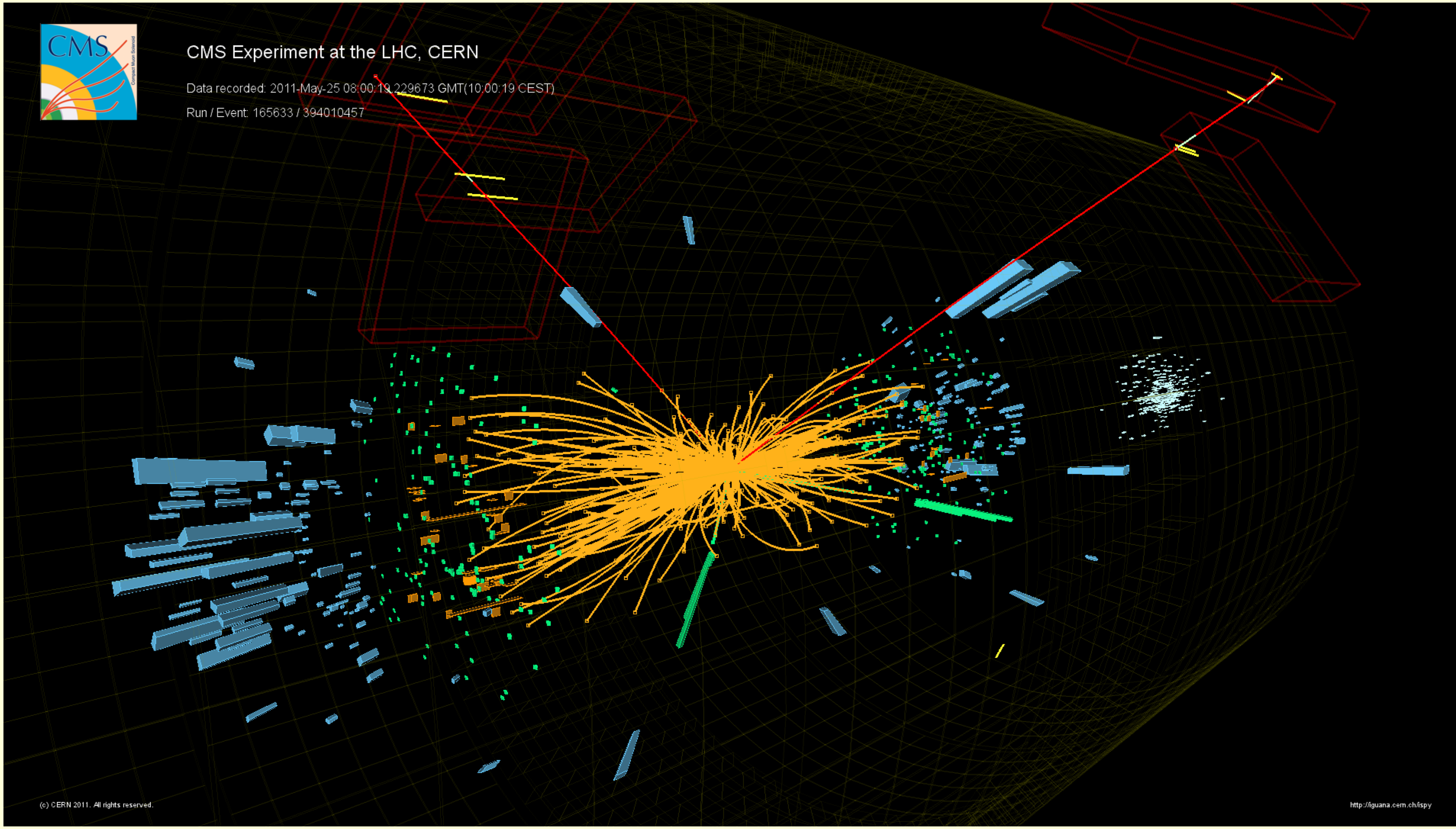
- **ELECTROWEAK SYMMETRY. BREAKING. SCALE.**
- **WHAT IS THE ORIGIN OF ELECTROWEAK SYMMETRY BREAKING**
- **WHAT TRIGGERS GAUGE SYMMETRY BREAKING IN THE SM?**
- **Theories, Models, People A LOT!**
- **However… Experiment(s)?**

New results at LHC are based on data recorded during running at an energy of 7 TeV in 2010 and 2011.

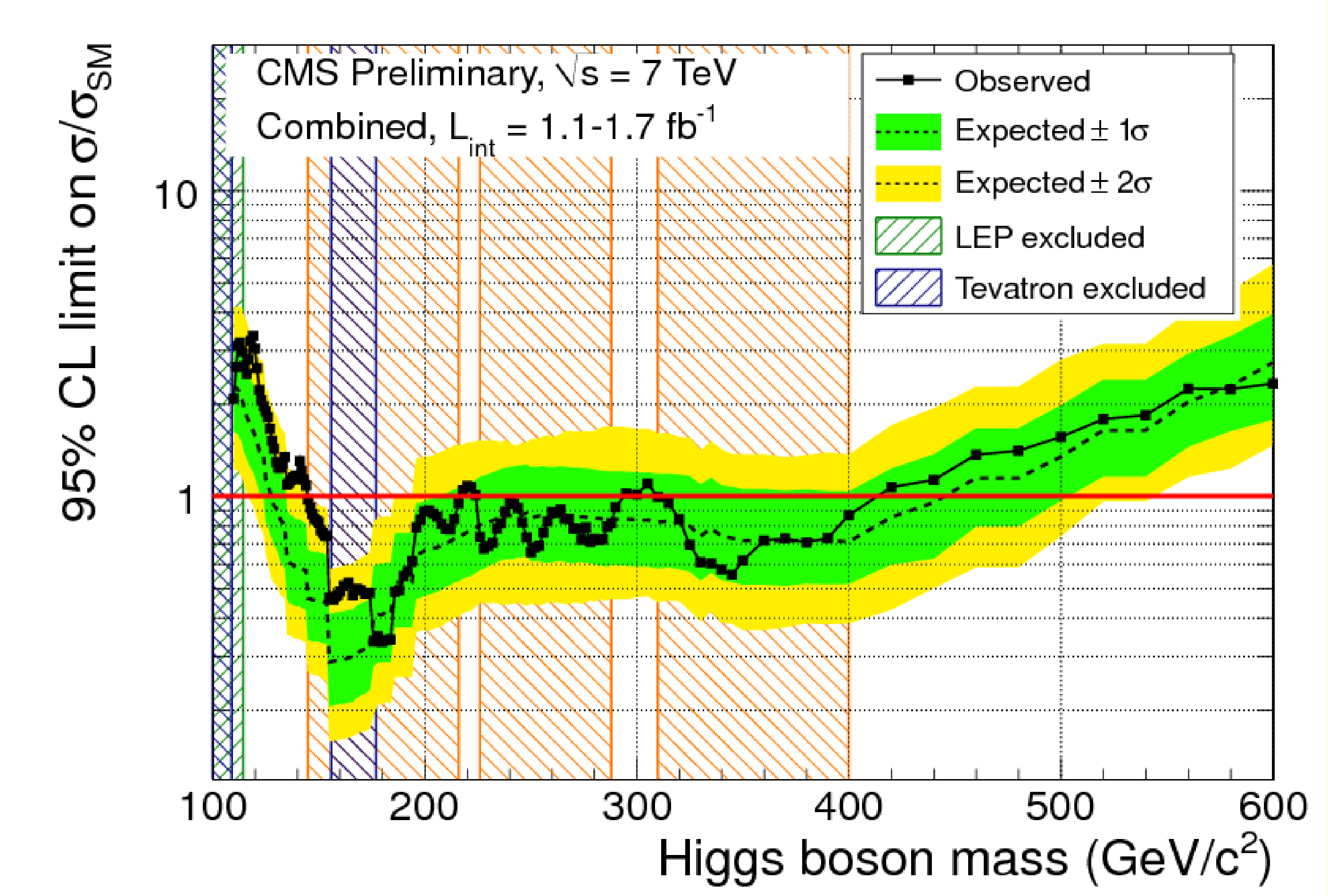
The analysis uses 1.1 – 1.7 inverse femtobarns (integrated luminosity) of data, depending on the channel — an inverse femtobarn corresponds to about 100 trillion proton-proton collisions.

LHC observes no convincing excess of events in the explored mass range of 110-600 GeV.

The analysis, e.g., by CMS excludes, with a confidence level (C.L.) of 95%, the existence of a Standard Model Higgs boson in three Higgs mass ranges: 145-216 GeV, 226-288 GeV and 310-400 GeV.



Event display of a candidate ZZ event, in which one Z decays to two electrons (green towers), the other to two muons (red lines).



On average one would expect to exclude the range 130-440 GeV in the absence of a signal. The two gaps between the three excluded mass ranges observed in data are consistent with statistical fluctuations. At 95% C.L., CMS excludes the SM Higgs boson in the mass range from 144-440 GeV, without interruptions.

With the data LHC will collect in the coming months there will be able to distinguish between the possible interpretations: the production of a SM Higgs boson or a statistical fluctuation of the backgrounds. Or something else?

New scalar object? Unexpected?

No EW symmetry breaking origin?

“Higher” symmetry breaking origin?

DILATON?

The pseudo-Goldstone boson of spontaneously broken scale invariance

Dilaton

- **WHAT DO WE KNOW ABOUT DILATON PHYSICS ?**

  MANY? TOO MANY? NOTHING …

- **DILATON PHYSICS IS NOT NEW PHYSICS BUT RATHER**

  A NEW GLANCE TO PHYSICS ON ELECTROWEAK

  SYMMETRY BREAKING

- **CONFORMAL SYMMETRY. BREAKING. SCALE.**

What does it mean? What do we know about it?

Full Theory

↓

Symmetry of Lagrangian — **Effective Theory**

$S\chi BS$ — **Scale invariance**

$x_\mu \to \lambda\, x_\mu$

WORLD

REAL — **HIDDEN**

$m = 0$

$\beta(g) = 0$

Scale invariance lost:

Symmetry broken

Finite mass, size

Attempt: Effective theory with (pseudo)-Goldstone boson- THE DILATON

Important: Conformal or Scale transformation does not affect any quantum numbers:

DILATON- scalar! **E.g. DM, Glueballs,…**

Conformal Field Theory & Applications

Three bright ideas

1. **SM $\in$ Conformal sector**
2. **Gluodynamics is an ideal conformal theory**
3. **Dilaton has a Higgs-like properties**

How dilaton is concerned with EWSB?

EWSB is triggered by Spontaneous Breaking nearly conformal sector **Goldberger, Grinstein, Skiba (2008)**

Kozlov (2011)

CONFORMAL INVARIANCE & SCALE INVARIANCE

- **Conformal invariance implies scale invariance**

theory "looks the same on all scales"

- **Scale transformations:** $x \to e^{-\alpha} x, \quad \varphi \to e^{d\alpha} \varphi$

- **Basic feature of Conformal Theory: NO MASSES in the theory**

- **Standard Model is not conformal even as a classical field theory:**

HIGGS MASS BREAKS CONFORMAL SYMMETRY

Application(s)

- **Not only for $\nu's$, $g's$ and $\gamma's$ but also for particles of such high $E > E_0$ that their rest masses $m \ll E$**

- **S-TCG might then be a (badly) broken approximate symmetry for $m \neq 0$ objects which improves as the $E's$ involved increase**

✓ **Similar: in $SU(3)$ internal symmetry group of hadrons**

$$\Downarrow$$

Relativistic wave equations become Conformal-Invariant when m-term is removed

Conformal Space-Time Transformations

- **Lorentz transformations**

$$x^{\mu} \to \tilde{x}^{\mu} = \vartheta^{\mu}_{\nu} x^{\nu}, \quad \vartheta^{\mu}_{\nu} \vartheta_{\mu\rho} = g_{\nu\rho},$$

- **Translations**

$$x^{\mu} \to \tilde{x}^{\mu} = x^{\mu} + t^{\mu}$$

- **Dilatations**

$$x^{\mu} \to \tilde{x}^{\mu} = \rho\, x^{\mu}, \quad \rho > 0$$

- **Special conformal transformations**

$$x^{\mu} \to \tilde{x}^{\mu} = \left(x^{\mu} - a^{\mu} x^{2}\right) / \sigma(x)$$

$$\sigma(x) \equiv 1 - 2a \cdot x + a^{2} x^{2}, \quad x^{\mu} = \left(x^{0}, \vec{x}\right), \; g_{\mu\nu} = (+1, -1, -1, -1)$$

Infinitesimal & Finite intervals:

$$dx^{2} \to d\tilde{x}^{2} = dx^{2} / \sigma^{2}(x), \quad (x_{1} - x_{2})^{2} \to (\tilde{x}_{1} - \tilde{x}_{2})^{2} = \frac{(x_{1} - x_{2})^{2}}{\sigma(x_{1})\, \sigma(x_{2})}$$

Noether's theorem:

if $S = \int d^4x\, L$ scale invariant $\Rightarrow \partial_\mu k^\mu = \partial_\mu \left(T_\nu^\mu x^\nu \right) = 0$

- ✓ Scalar theory: $k_\mu = \dfrac{\partial L}{\partial \left(\partial^\mu \phi \right)} \left(1 + x_\nu \partial^\nu \right) \phi - x_\mu L$

In general $\partial_\mu k^\mu = T_\mu^\mu$ Callan, Coleman, Jackiw (1970)

$$T_{\mu\nu} = \underbrace{\frac{\partial L}{\partial \left(\partial^\mu \phi \right)} \partial_\nu \phi - g_{\mu\nu} L}_{canonical\ \ energy-momentum\ \ tensor} - \frac{1}{6} \left(\partial_\mu \partial_\nu - g_{\mu\nu} \Delta \right) \phi^2$$

Scale invariance $\Rightarrow T_\mu^\mu = 0$

For $L = \dfrac{1}{2} \partial_\mu \phi\, \partial^\mu \phi - \dfrac{1}{2} m^2 \phi^2 - \dfrac{\lambda}{4!} \phi^4 \Rightarrow T_\mu^\mu = m^2 \phi^2$

Yang-Mills theory

$$T^{\mu}_{\mu} = -\frac{\beta(\alpha)}{\alpha} L_{YM} = +\frac{1}{4}\frac{\beta(\alpha)}{\alpha} G^{a}_{\mu\nu} G^{\mu\nu,a}$$

$$\beta(\alpha) = \mu \frac{d\alpha}{d\mu} \cong -\frac{11N\alpha^{2}}{6\pi}$$

- $\beta(\alpha) = 0$ **Banks, Zaks, Nucl. Phys. (1982)**
  - ➢ Theory is scale invariant!

○ **CFT invariance violated by quantum effects** **Migdal, Shifman (1982)**

- $\alpha(\mu) ; \mu -$ **dependent**
- **dimensional parameter** μ **generated**

$$\ln\left(\frac{\mu}{\mu_{0}}\right) \sim \frac{\pi^{2}}{g_{0}^{2}},$$

$\mu_{0} - UV$

$g_{0} - bare$ **coupling**

Dilaton origin:

- Beyond the SM

Full theory ∈ some sector (scale invariant) with SB(Scale) invar’s, where

Dilaton arises as PsGoldstone boson Bardeen (1986), Csaki (2007)

Dilaton mass:

Due to explicit Breaking Scale invar’s in scale inv. sector at $\sqrt{q^2} < f$

Dilaton couplings:

- with $T_{\mu}^{\mu}(x)$ (all the fields) in scale-invariant sector
- pick up add. coupl’s at loop level from scale anomaly

Simplest example of effective Dilaton :

Higgs-boson of the SM, $m_H < v$ = 246 GeV, $v = f$!

DILATONS at LHC

Production channels: $gg \to \sigma,\ q\bar{q} \to W/Z + \sigma,\ q\bar{q} \to t\bar{t} + \sigma, \ldots$

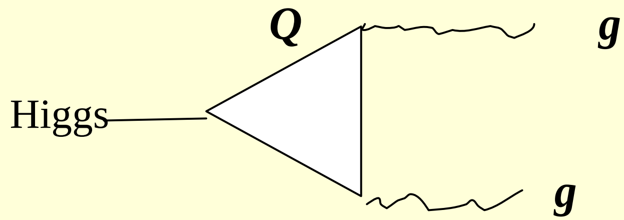
Most important:

σ **- dilaton couplings to** $q's$ **& gauge bosons**

! The same as $\left.\begin{array}{c} H\,g\,g,\quad H\,\gamma\,\gamma \\ \sigma\,g\,g,\ \chi\,\gamma\,\gamma \end{array}\right\}$ **Loop effects**

Important for LHC: $\sigma\ g\ g$ **enhanced ! Why?**

SM: $L_{hgg} = \frac{\alpha_s}{8\pi} \sum_Q b_o^Q \frac{h}{v} \left(G_{\mu\nu}^a\right)^2$



$\beta_Q(g) = b_o^Q g^3/16\pi^2,\quad m_Q > m_h \sim \sqrt{q^2}$

No Q **-quark mass dependence!**

Top-quark loop: $b_0^{top} = 2/3$

LHC APPLICATION

MODEL: QCD $\in$ Conformal Theory

$$\sum_i = \sum_{light} + \sum_{heavy}$$

Split over color fields $\qquad\uparrow\qquad\qquad\uparrow$

$$m_i < m_\sigma \qquad m_i > m_\sigma$$

Above the cutoff $E > \Lambda$**:** $\beta(g) \to 0$**, that means** $\sum_{light} b_0 + \sum_{heavy} b_0 = 0$

The effective coupling @ 1 loop: $\sum_{heavy} b_0 = -\sum_{light} b_0$

! Contributions of quarks lighter than the σ - dilaton:

LHC APPLICATION (cont'd)

! Contributions of quarks lighter than the σ- dilaton:

$$L_{\sigma gg} = -\frac{\alpha_s}{8\pi} b_0^q \frac{\bar{\sigma}}{f} \left(G_{\mu\nu}^a \right)^2, \qquad \bar{\sigma}(x) = \sigma(x) - f, \quad \langle \sigma \rangle = f$$

$b_0^q = -11 + \frac{2}{3} n_q,\ n_q = 6$ **(top-quark incl.)**

!!! Enhanced Dilaton production c/o gg- fusion (compared to Higgs case):

$$k^{LHC} = \frac{b_0^q}{b_0^Q} = \frac{33}{2} - n_q = \begin{cases} 11{,}5 & n_q = 5 \\ 10{,}5 & n_q = 6 \end{cases}$$

Collider phenomenology:

- Based on Effective theory $\Lambda_{cutoff} \sim 4\pi f$
- Below Λ_{cutoff} scale symmetry spontaneously broken

Collider phenomenology crucial point:

- Loop-induced couplings to $\gamma\gamma$ or $g\,g$

$$\frac{\sigma}{8\pi f}\left(c_{EM}F_{\mu\nu}F^{\mu\nu}+c_s G_{\mu\nu}G^{\mu\nu}\right), \quad \begin{cases} c_{EM}=-\alpha\cdot 17/9, m_W < m_\sigma < m_t \\ c_{EM}=-\alpha\cdot 11/3, m_\sigma > m_t \end{cases}$$

$$c_s=\alpha_s\left(11-2n_{light}/3\right)$$

CFT/SM loop increased:

$$\left(\frac{\sigma\, gg}{H\, gg}\right)_{coupling}=\left(\frac{33}{2}-n_{light}\right)_{factor}=\begin{matrix} 11+\varepsilon, n_{light}=5 \\ 10+\varepsilon, n_{light}=6 \end{matrix}$$

Upper limit of f

- Assume $gg \to \sigma$ dominant production

Dilaton signal significance: Significance of Higgs signal by rescaling

$$\left(\frac{S}{\sqrt{B}}\right)_\sigma = \frac{c_s^2}{\alpha_s^2}\frac{v^2}{f^2}\left(\frac{S}{\sqrt{B}}\right)_{Higgs}$$

Goldberger, Grinstein, Skiba P.R.L. (2008)

Lower bound: $\left(\frac{c_s^2}{\alpha_s^2}\right)\left(\frac{v^2}{f^2}\right) > \frac{1}{8}$ @ $100\, fb^{-1}$ **for** $m_\sigma > 160\, GeV$

Estimated upper limit: $\begin{cases} f < 5.33 TeV, m_\sigma < m_t \\ f < 4.87 TeV, m_\sigma > m_t \end{cases}$

Kozlov, Gorbunov Int. J. Mod. Phys. (2011)

Conformal Sector @ Collider(s)

- **All fields $\in$ Conformal Field Theory**

Scale invariant hidden sector. Contains:

Dilatons, Unparticles, …, Gauge bosons (continuous spectra)

H. Georgi P.R.L. (2007)

$$\downarrow$$

Conformal symmetry breaking $\downarrow$ **@** $f \sim O(TeV)$

$$\downarrow$$

Dilatons ($m_\sigma \neq 0$), Unparticles, …, Gauge bosons (continuous spectra)

- **Distinguishing of dilaton from Higgs at LHC & ILC**

Goldberger Grinstein Skiba (2008)

Conformal Sector @ Collider(s)

Exotic transitions:

$H \to U\gamma$ K. Cheung et al., Phys. Rev. D77 (2008) 097701

$BR \sim 5 \cdot 10^{-3}$ for $m_H < 130$ GeV

$Z \to U\gamma$ K. Cheung et al., Phys. Lett. B662 (2008) 436

$Z' \to U\gamma$ G. Kozlov, I. Gorbunov, Adv. High Energy Phys. 2011 (2011) 1

$\sigma \to U\gamma$ G. Kozlov, I. Gorbunov, Int. J. Mod. Phys. (2011)

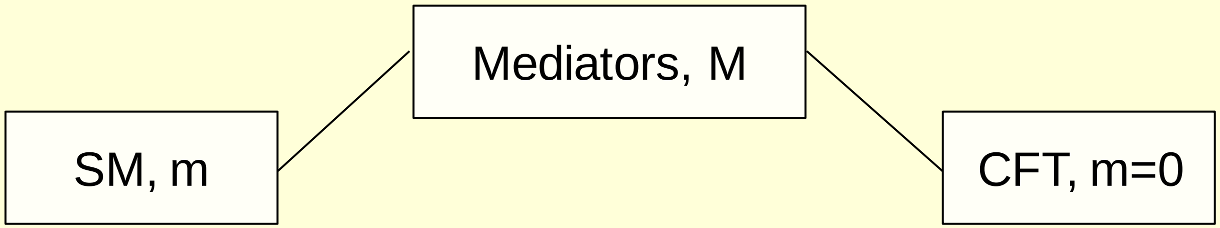
For experiments:

1) Monophoton’s continuous spectrum $d\Gamma / dE_\gamma$, BR, cross-section

2) Comparing with EW sector physics: $H \to U\gamma$

Unparticle's Stuff: Short Overview

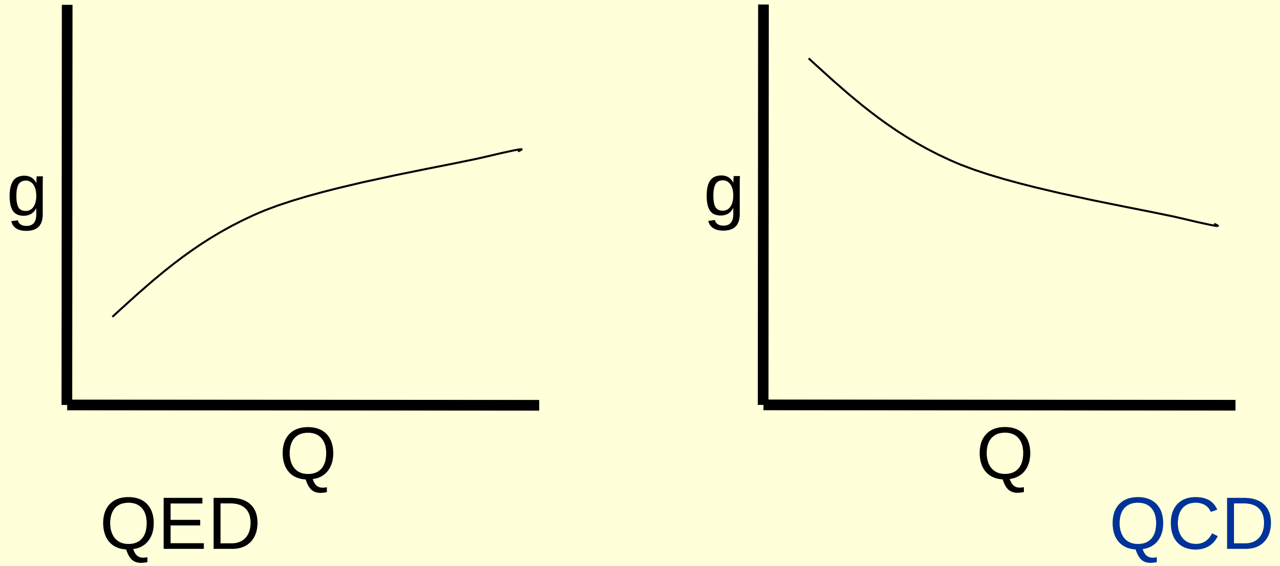
- New physics (CFT) weakly coupled to SM through heavy mediators



- A lot of papers since H. Georgi, P.R.L.98 (2007) 221601
- Many basic, outstanding questions
- Goal: provide groundwork for discussions and physical realization
  LHC & ILC phenomenology

CONFORMAL INVARIANCE

- At the quantum level, dimensionless couplings depend on scale: renormalization group evolution



are not conformal theories

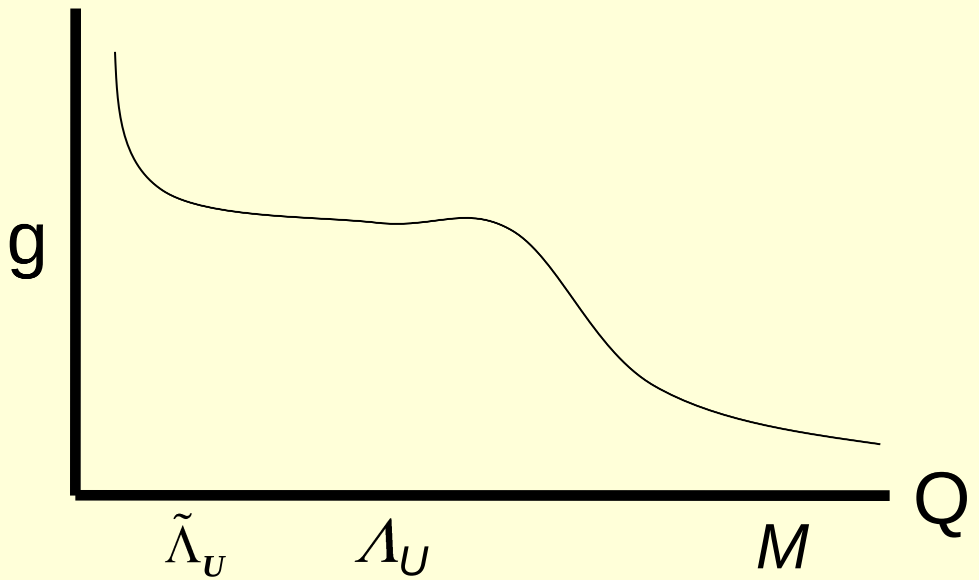
CONFORMAL Symmetry Breaking & High energy scale

3 characteristic scales: $M, \Lambda_U, \tilde{\Lambda}_U$

-Hidden sector couples at M

- Conformal $\tilde{\Lambda}_U < \Lambda_U < M$

- EWSB $\rightarrow$ CSB at $E < \tilde{\Lambda}_U$



- Unparticle physics is only possible in the conformal window
- Width of this window depends on $d, \tilde{\Lambda}_U, \Lambda_U, M$

UNPARTICLE PHASE SPACE

- The density of unparticle final states is the spectral density ρ, where

$$\langle 0|O_{\mathcal{U}}(x)O_{\mathcal{U}}^{\dagger}(0)|0\rangle = \int \frac{d^4P}{(2\pi)^4}\, e^{-iP\cdot x}\, \rho_{\mathcal{U}}(P^2)$$

- Scale invariance → $\rho_{\mathcal{U}}(P^2) = A_{d_{\mathcal{U}}}\,\theta(P^0)\,\theta(P^2)\,(P^2)^{d_{\mathcal{U}}-2}$

- This is similar to the phase space for n massless particles:

$$(2\pi)^4\delta^4\left(P-\sum_{j=1}^{n}p_j\right)\prod_{j=1}^{n}\delta\left(p_j^2\right)\,\theta\left(p_j^0\right)\,\frac{d^4p_j}{(2\pi)^3} = A_n\,\theta\left(P^0\right)\,\theta\left(P^2\right)\,\left(P^2\right)^{n-2}$$

$$A_n = \frac{16\pi^{5/2}}{(2\pi)^{2n}}\,\frac{\Gamma(n+1/2)}{\Gamma(n-1)\,\Gamma(2n)}$$

- Identifying n → d_U. "Unparticle" with $d_U = 1$ is a massless particle. "Unparticles" with some other dimension d_U look like a non-integer number d_U of massless particles

Georgi (2007)

SIGNALS

Colliders **Tevatron** **(already shut down 09/30/2011), LHC, ILC**

- U-stuff production in final state
  - monojets (LHC) $gg \to gU$
  - monophotons (ILC) $e^+e^- \to gU$

  [missing energy signals]
- Virtual extra gauge bosons $gg \to Z' \to ZU, \ \gamma U$
- Virtual U-stuff exchange
  - scalar U-stuff: $ff \to U \to \mu^+\mu^-, \ \gamma\gamma, \ ZZ, \ ...$

    [No interference with SM, No resonances, U-stuff massless]
  - vector U-stuff: $e^+e^- \to U_\nu \to \mu^+\mu^-, \ qq, \ ...$

    [Induce contact interactions, Eichten, Lane, Peskin (1983)]
- U-stuff decay in SM particles. Higgs/dilaton decays in U-stuff.

Our goal: Dilaton & U - stuff in Scale Inv. & Gauge Theories

- **U coupling to Dilaton & SM fields**
- **U and Dilaton both carry SM-like charges**
- SM criteria, however non-canonical $d \neq d_{UV}$
- Renormalizablity ($Re\ N$) :

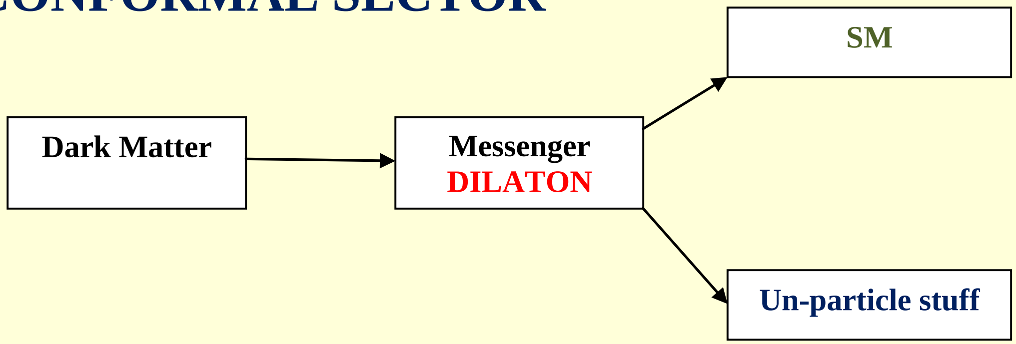
Dilaton guarantee $Re\ N$

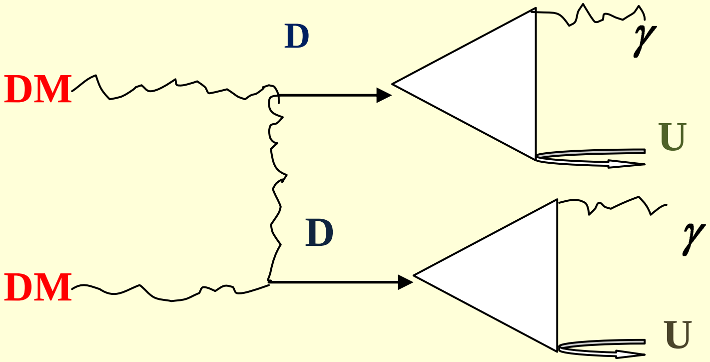
- Dilaton serves as portal to HIDDEN sector
- Basic feature of the theory : NO MASSES

Full Conformal Sector @ Collider(s)

$\sigma \rightarrow U\gamma$ G. Kozlov, I. Gorbunov. Int. J. Mod. Phys. (2011)

DM – CONFORMAL SECTOR





Toy Model for DILATON Decay $\sigma \to U\gamma$

- $L = L_{\sigma} + L_{O_U}$

$$L_{\sigma} = -B\partial_{\mu} A^{\mu} + \frac{1}{2\xi} B^{2} - \frac{1}{\Lambda_U^{d-3}} \left(A_{\mu} - \partial_{\mu}\sigma \right) O_U^{\mu} +$$

- $$+\bar{\psi} \left(i\hat{\partial} - m + g\hat{A} \right) \psi - \frac{\sigma}{f} \sum_{\psi} \left(m + \varepsilon\, y_{\psi} v \right) \bar{\psi}\psi$$

- $$L_{O_U} = \frac{1}{\Lambda_U^{d-1}} \left[\sum_{\psi} \bar{\psi} \left(c_v \gamma^{\mu} - a_v \gamma^{\mu}\gamma_5 \right) \psi\, O_{U\mu} + \frac{1}{\Lambda_U^{2}} W^{a}_{\mu\alpha} W^{a\mu}_{\beta} \left(\partial^{\alpha} O_U^{\beta} + \partial^{\beta} O_U^{\alpha} \right) \right]$$

- Scale symmetry is violated by ψ-operators
- Size of scale symmetry deviation $\varepsilon = m_{\sigma}^{2} / f^{2} < 1$ (or even <<1)

Dilaton mass m_{σ} is the measure for the symmetry breaking size

Basic Equations of Motion

- $\partial_\mu \sigma \approx A_\mu - \frac{1}{\Lambda_U^2}\bar{\psi}\left(v_\nu \gamma_\mu - a_\nu \gamma_\mu \gamma_5\right)\psi$
- $\partial_\mu A^\mu = \xi^{-1} B$
- $\partial_\mu B = -J_\mu + \frac{1}{\Lambda_U^{d-3}} O_{U\mu}, \quad J_\mu = g\bar{\psi}\gamma_\mu \psi$
- $\frac{1}{\Lambda_U^{d-3}}\partial_\mu O_U^\mu + \frac{1}{f}\left(m + \varepsilon\, y_\psi v\right)\bar{\psi}\psi = 0$

✓ **In the nearly Conformal Sector:**

$$\lim_{m_\sigma \to 0}\left[\Delta + m_\sigma^2\right]^2 \sigma(x) \approx 0, \quad \Delta \equiv \partial^2 / \partial x_\mu^2$$ **Dipole-type field! Flat!**

Supported by: weakly changing operator $O_U^\mu(x)$ in x_μ

current conservation

More theory…

$$\lim_{m_\sigma \to 0} \left(\Delta + m_\sigma^2\right)^2 \sigma(x) \approx 0, \quad \Delta \equiv \partial^2 / \partial x_\mu^2$$ **Dipole-type field!**

CCR's for all x_μ and y_μ:

$$[\sigma(x), \sigma(y)] = -iD(x-y), \quad [\dot{\sigma}(x), \sigma(y)] = -i\xi^{-1} F(x-y)$$

$$D(x) = (2\pi)^{-1} \delta(x^2)\, \mathrm{sgn}(x^0), \quad F(x) = (8\pi)^{-1} \theta(x^2)\, \mathrm{sgn}(x^0)$$

Properties: $\Delta D(x) = 0, \quad D(0, \vec{x}) = 0, \quad \partial_0 D(0, \vec{x}) = \delta^3(x)$

Propagator of the dilaton field in nearly Conformal sector:

$$\tilde{W}(p) = \frac{-1}{4\xi} i \frac{\partial^2}{\partial p^2} \left[\frac{\ln e^{2\gamma}\left(-p^2 l^2 - i\varepsilon\right)}{-p^2 - i\varepsilon} \right]$$

D. Zwanziger, Phys.Rev.D (1978)

G. Kozlov, Phys. Part. Nucl. (2010)

l^{-1} is the renorm. mass/ distinguishes the model from the SM EW

More theory…

Lowest order energy of the dilaton "charge"

$$E(r) = i\int d_3 p\, e^{i\vec{p}\vec{x}}\, \widetilde{W}(p^0 = 0, \vec{p}) \sim \frac{1}{8\pi\xi}\, r\,[const + 3\ln(r/l)]$$

RESULT: In Nearly Conformal sector:

Energy of the dilaton is linearly rising as $r = |\vec{x}|$ at large distances

Confinement ?!

From Theory through Phenomenology… to exp't?

Decay amplitude for $\sigma \rightarrow U\gamma$

$$Am\left(x_q, y_q\right) = \frac{3\alpha}{\pi\, m_W s_W \Lambda_U^{d-1}} \sum_q c_v e_q \left[I\left(x_q, y_q\right) - J\left(x_q, y_q\right)\right]$$

- **No** W **- boson contribution in the loop.**

Why? $L_{O_U} \sim \frac{1}{\Lambda_U^{d+1}} W_{\mu\alpha}^{a} W_{\beta}^{a\mu} \left(\partial^{\alpha} O_U^{\beta} + \partial^{\beta} O_U^{\alpha}\right)$ **suppression by** $\frac{1}{\Lambda_U^{d+1}}$ **factor**

$$\Lambda_U \sim O(f),\ \ f \sim O(TeV),\ d_U \geq 1$$

- **The quarks contribution only**

$$x_q = 4m_q^2 / m_\sigma^2,\quad y_q = 4m_q^2 / P_U^2$$

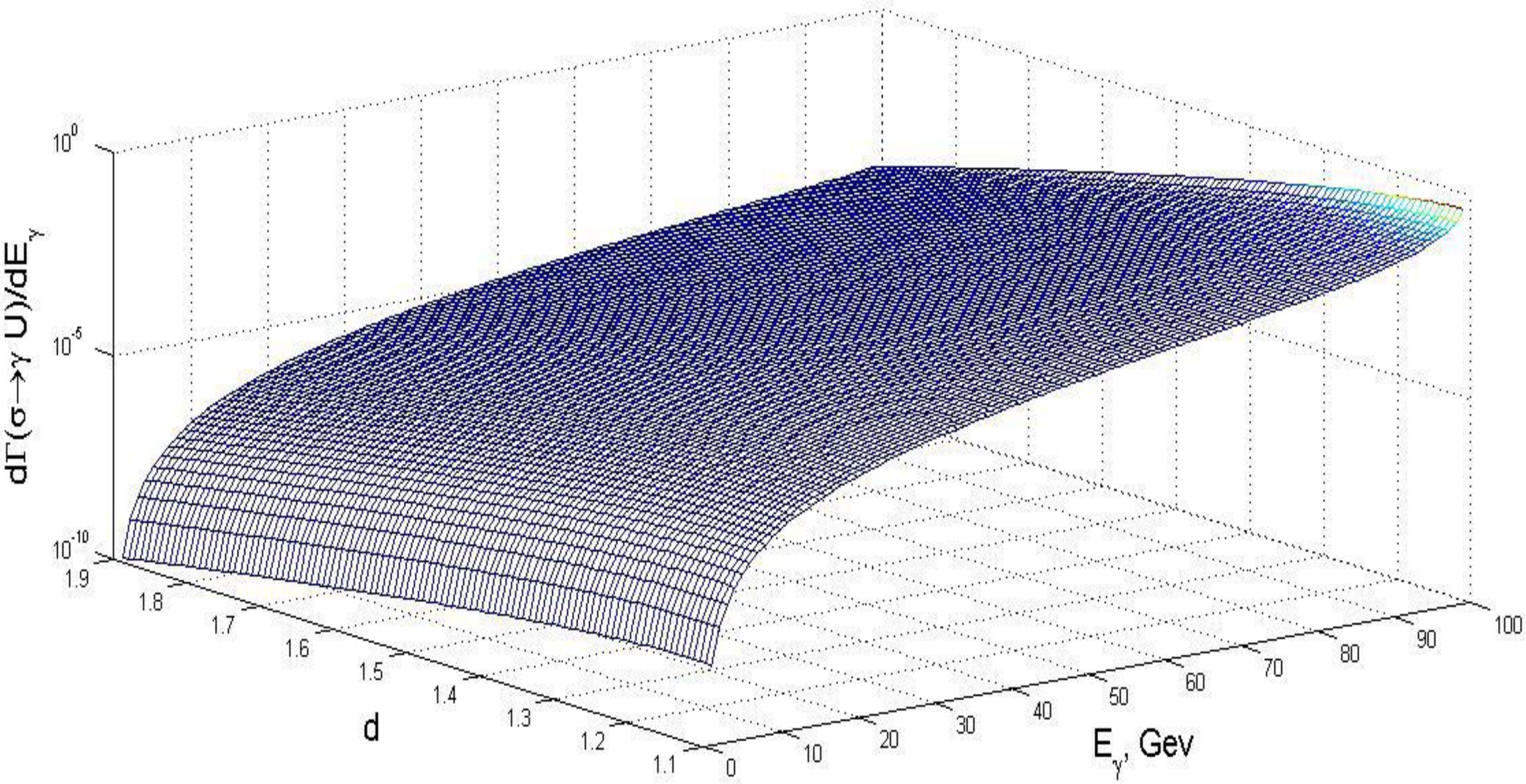
Energy distribution of emitted photons in $\sigma \to U\gamma$

$$\frac{d\Gamma(\sigma \to U\gamma)}{dE_\gamma} = \frac{A_d}{(2\pi)^2} m_\sigma E_\gamma^3 (P_U^2)^{d-2} \left| Am(x_q, y_q) \right|^2$$

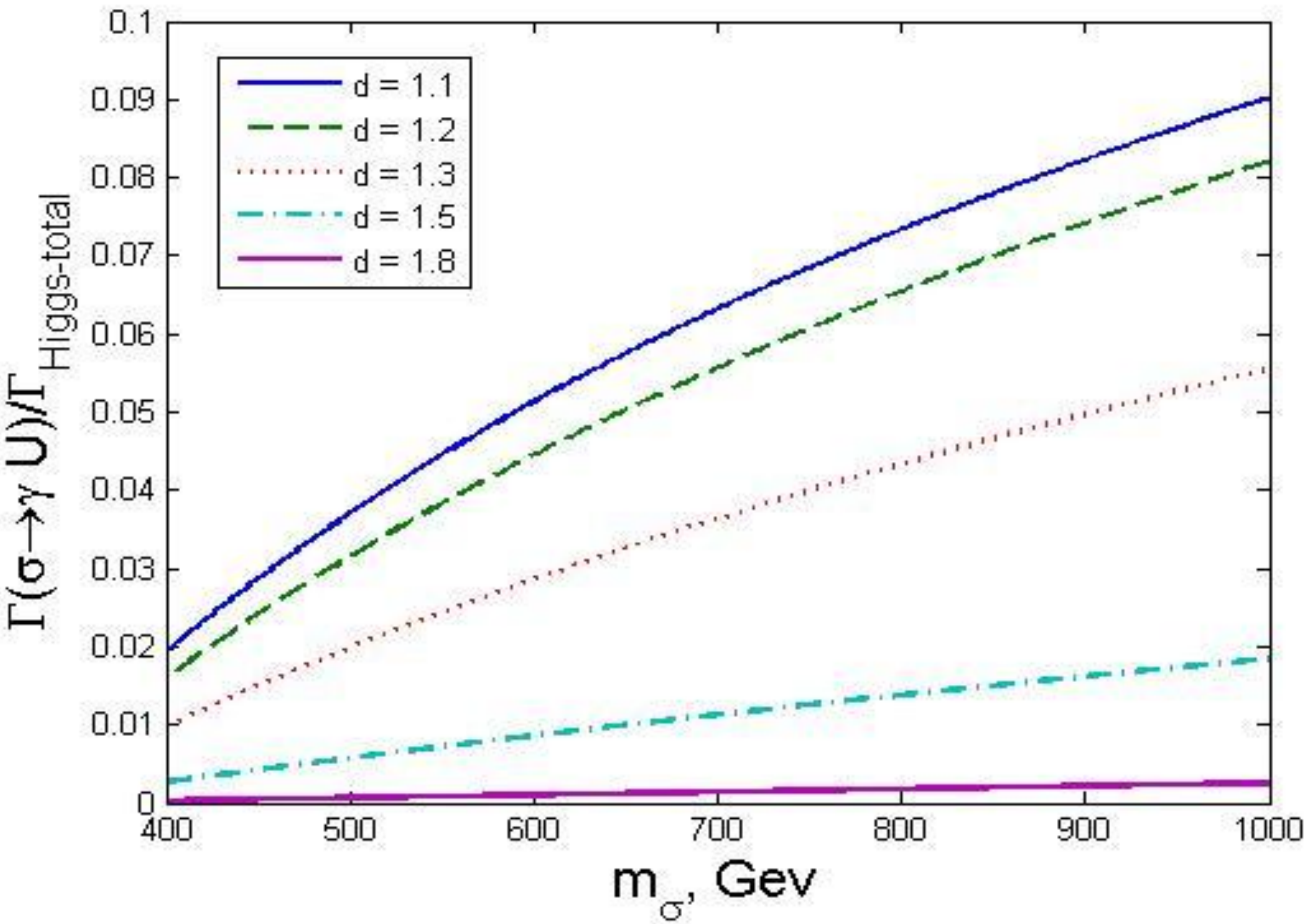
G. Kozlov, I. Gorbunov Int. J. Mod. Phys. (2011)

U-Phase-space factor $A_d = \frac{16\pi^{5/2}}{(2\pi)^{2d}} \frac{\Gamma(d+1/2)}{\Gamma(d-1)\Gamma(2d)}$ H. Georgi P.R.L. (2007)

- The only top-quarks in the loop are included.
- Light quarks contribution in amplitude $Am(x_q, y_q)$ is negligible, $x_q << 1$



dΓ(σ→γ U)/dE_γ
10^0
10^-5
10^-10
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
d
0
10
20
30
40
50
60
70
80
90
100
E_γ, Gev



0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
400
500
600
700
800
900
1000
d = 1.1
d = 1.2
d = 1.3
d = 1.5
d = 1.8
$\Gamma(\sigma \to \gamma\ U)/\Gamma_{Higgs\text{-}total}$
m_σ, Gev

Result. What we've realized?

- **When combined with $gg \to \sigma$, the decay $\sigma \to U\gamma$ provides especially valuable information regarding possible loop contributions from new particles lighter than a dilaton**

- **The lower rate $\Gamma(\sigma \to U\gamma)/\Gamma_{Higgs-total}$ is compensated by the enhancement of the order $(3/2 - n_{light})^2 \sim O(100)$ of the gluon fusion production cross-section compared to that of the SM Higgs**

  This is one of the main prospects for distinguishing the dilaton from the minimal Higgs-boson at the LHC (and ILC): potential enhancement of couplings to massless SM gauge bosons.

- **This study is very useful & instructive to probe at LHC (&ILC) the nearly conformal sector containing the dilaton and the unparticle stuff.**