An Exclusive Window onto Higgs Yukawa Couplings

Jure Zupan
u. of cincinnati

Higgs/EWSB group, workplan discussion, Nov 24 2014, CERN

PROBING LIGHT YUKAWAS?

- light quark Yukawas poorly constrained
  - from global fits, varying all of the higgs couplings (95%CL, and normalized to $y_{b,SM}$)

$$|\bar{\kappa}_u| < 1.3\,, \quad |\bar{\kappa}_d| < 1.4\,, \quad |\bar{\kappa}_s| < 1.4$$

- can one probe light yukawas directly?
- the problem with light quark Yukawas is that they are very small
  - statistics will always be a problem to reach the SM
  - a nontrivial challenge is even to find a channel where measurement at least in principle is possible

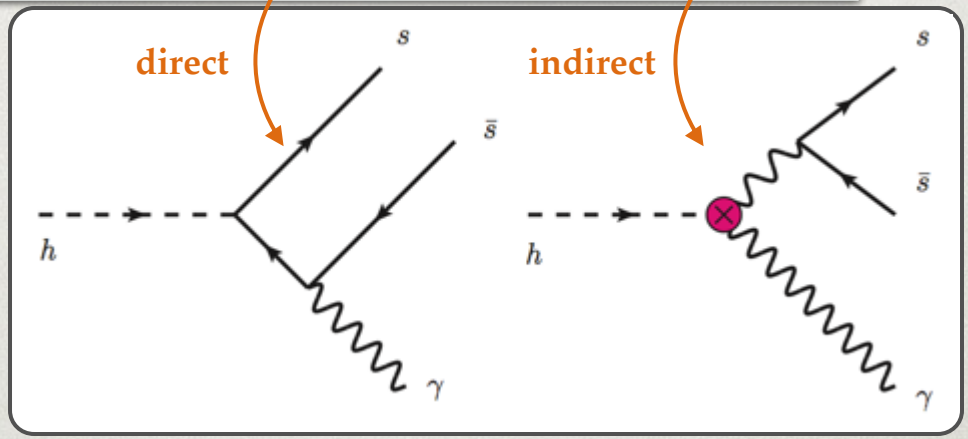
Kagan, Perez, Petriello, Soreq, Stoynev, JZ, 1406.1722

$h \to \phi\gamma$

- for s Yukawa $h \to \phi\gamma$ (where $\phi \sim \bar{s}s$; $J^{PC}=1^{--}$; $m_\phi=1.02$GeV)

$$M_{ss}^{\phi} = \frac{Q_s e_0}{2}\epsilon^{\phi}\cdot\epsilon^{\gamma}\left(Y_{ss} f_\perp^{\phi}\langle 1/u\bar{u}\rangle_{\phi,\perp} + \frac{4\alpha}{\pi v}\kappa_\gamma A_\gamma \frac{f_\phi m_h^2}{m_\phi}\right)$$

$$Y_{ss} = \bar{\kappa}_s m_b / v$$



- hadronic matrix elements are
  - ϕ decay constant $\langle\phi|J^{\mu}_{\rm EM}(0)|0\rangle = f_\phi m_\phi \epsilon_\phi^{\mu}$ (from experiment, $\phi \to e^+e^-$)

$$J^{\mu}_{\rm EM} = \sum_f Q_f \bar{f}\gamma^{\mu} f$$

  - inverse moment of the leading twist chiral odd LCDA

from lattice QCD

$$\langle 1/u\bar{u}\rangle_\perp^{\phi} = \int_0^1 du \frac{\phi_\perp^{\phi}(u)}{u(1-u)}$$

$$\langle\phi(p,\varepsilon_\perp)|\bar{s}(x)\sigma_{\mu\nu}s(0)|0\rangle = -if_\perp^{\phi}\int_0^1 du e^{iup\cdot x}(\varepsilon_{\perp\mu}p_\nu - \varepsilon_{\perp\nu}p_\mu)\phi_\perp^{\phi}(u)$$

from lattice QCD

COUPLINGS TO LIGHT QUARKS

Kagan, Perez, Petriello, Soreq, Stoynev, JZ, 1406.1722

- similar analysis for $h \to \rho\gamma$, $h \to \omega\gamma$

$$\frac{Br_{h\to\phi\gamma}}{Br_{h\to b\bar{b}}} = \frac{\kappa_\gamma\left[(3.0\pm 0.13)\kappa_\gamma - 0.78\bar{\kappa}_s\right]\cdot 10^{-6}}{0.57\bar{\kappa}_b^2},$$

$$\frac{Br_{h\to\rho\gamma}}{Br_{h\to b\bar{b}}} = \frac{\kappa_\gamma\left[(1.9\pm 0.15)\kappa_\gamma - 0.24\bar{\kappa}_u - 0.12\bar{\kappa}_d\right]\cdot 10^{-5}}{0.57\bar{\kappa}_b^2},$$

$$\frac{Br_{h\to\omega\gamma}}{Br_{h\to b\bar{b}}} = \frac{\kappa_\gamma\left[(1.6\pm 0.17)\kappa_\gamma - 0.59\bar{\kappa}_u - 0.29\bar{\kappa}_d\right]\cdot 10^{-6}}{0.57\bar{\kappa}_b^2},$$

  - interference with the indirect term essential
  - direct (SM) amplitude only $\Rightarrow Br \sim O(10^{-11})$

- similarly also h-$c\bar{c}$ from $h \to J/\Psi\gamma$

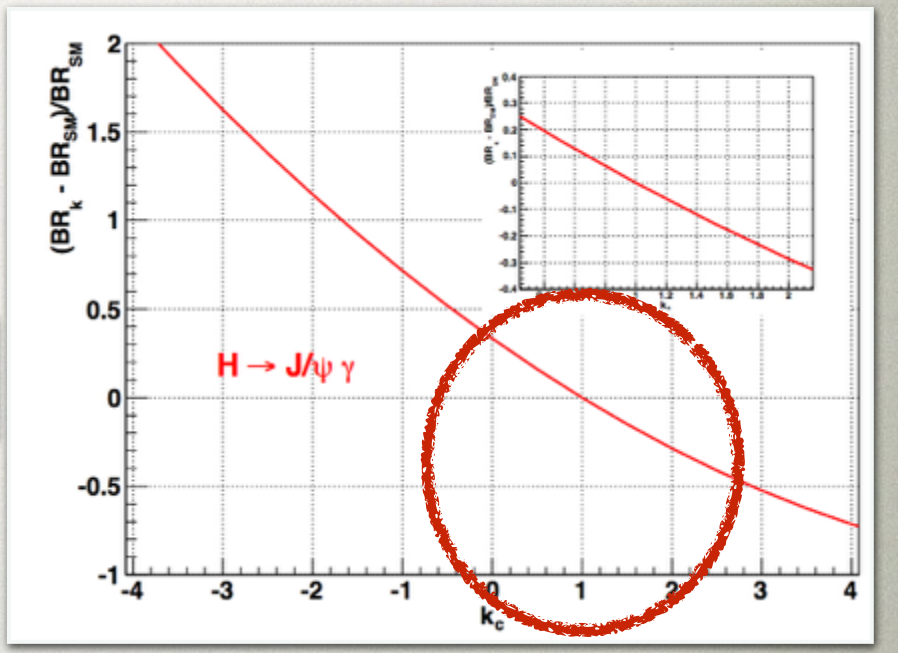
Bodwin, Petriello, Stoynev, Velasco, 1306.5770

CHARM YUKAWA

Bodwin, Petriello, Stoynev, Velasco, 1306.5770

- also a sum of direct and indirect contributions

$$\mathrm{BR}_{\mathrm{SM}}(H \to J/\psi\,\gamma) \;=\; (2.46^{+0.26}_{-0.25}) \times 10^{-6},$$



- need O(30%) sensit. for SM y_c
- *3000*fb^{-1} at a 14 TeV LHC would produce ~50 $J/\psi \to l^+l^-$ events (ATLAS+CMS, l=μ,e)
  - estimate now is B/S <10
  - if B/S~1 may be enough to be sensitive to SM y_c

EXPERIMENTAL PROSPECTS FOR STRANGE YUKAWA

Kagan, Perez, Petriello, Soreq, Stoynev, JZ, 1406.1722

- focus on $h \to \phi\gamma$, use **`Pythia 8.1`**
  - main decay modes: $\phi \to K^+K^-(49\%)$, $K_LK_S(34\%)$, $\pi^+\pi^-\pi^\circ(15\%)$
  - for $pp \to h \to \phi\gamma$ at 14TeV LHC in 70 to 75% cases the kaons/pions and the prompt photon have $|\eta| < 2.4$
    - within the minimal fiducial volume of the ATLAS and CMS experiments
  - adopt the geometrical acceptance factor $A_g = 0.75$
    - do not include other efficiency or trigger factors
- assume $\kappa_\gamma = 1$, negligible background, 3σ reach

no theory error

two detectors

one detector

$\sqrt{s}$ [TeV]	$\int \mathcal{L}\,dt\,[\mathrm{fb}^{-1}]$	# of events (SM)	$\bar{\kappa}_s >$ (<)	$\bar{\kappa}_s^{\mathrm{stat.}} >$ (<)
14	3000	770	0.39 (−0.97)	0.27 (−0.81)
33	3000	1380	0.36 (−0.94)	0.22 (−0.75)
100	3000	5920	0.34 (−0.90)	0.13 (−0.63)

6x SM strange Yukawa

CONCLUSIONS

- have discussed a potential probe of enhanced Higgs couplings to *s,d,u,c*
  - using exclusive $h \to M\gamma$ decays

BACKUP SLIDES

BOUNDS ON LIGHT QUARK YUKAWAS

Kagan, Perez, Petriello, Soreq, Stoynev, JZ, 1406.1722

- the higgs couplings to light quarks assumed to be negligible in the global fits (as in the SM)
- varying $\kappa_{u,}\ \kappa_{d,}\ \kappa_{s}$
  - total width modified
  - sublead.: $gg\to h$, $h\to\gamma\gamma$ modified, $u\bar{u}\to h$, $d\bar{d}\to h$, $s\bar{s}\to h$ prod.
- varying only one at the time (95%CL, and normalized to $y_{b,SM}$)

$$|\bar{\kappa}_u| < 0.98\,, \quad |\bar{\kappa}_d| < 0.93\,, \quad |\bar{\kappa}_s| < 0.70$$

- varying all of the higgs couplings

$$|\bar{\kappa}_u| < 1.3\,, \quad |\bar{\kappa}_d| < 1.4\,, \quad |\bar{\kappa}_s| < 1.4$$

- for FV Yukawas (varying only one at the time)

$$|\bar{\kappa}_{qq'}| < 0.6\,(1) \qquad \text{for } q, q' \in u, d, s, c, b \text{ and } q \neq q'$$

  - from FCNCs stronger (model dep.) constr, e.g., $|\bar{\kappa}_{bs}| < 8 \cdot 10^{-2}$

Harnik, Kopp, JZ, 1209.1397; see also Blankenburg, Ellis, Isidori, 1202.5704; Goertz, 1406.0102