Rare Higgs decays

Gino Isidori
[*University of Zürich*]

- Introduction
- Flavor-violating Higgs decays
- Light exotic states in h → 4l
- Rare exclusive semi-hadronic Higgs decays
- Conclusions

▶ Introduction

Despite all its successes, the SM is likely to be an *effective theory*, i.e. the limit (*in the experimentally accessible range of energies and effective couplings*) of a more fundamental theory, with new degrees of freedom

⬇

We need to search for New Physics

[*with a broad spectrum perspective given the lack of NP signal so far...*]

⬇

High-precision Higgs Physics

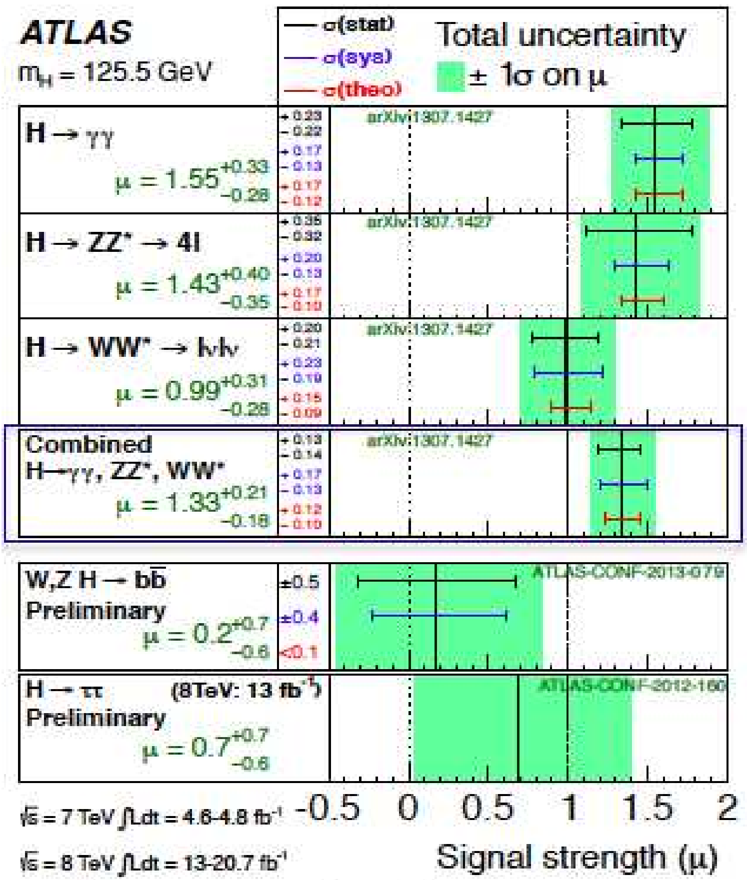
- The Higgs *seems* to be a fundamental scalar (*the only one?*) → could well be the "portal" toward a wide "secluded sector" of new particles/fields
- The vast majority of the allowed couplings of the Higgs are couplings to the SM fermions (still largely unexplored...) → large room for NP

⬇

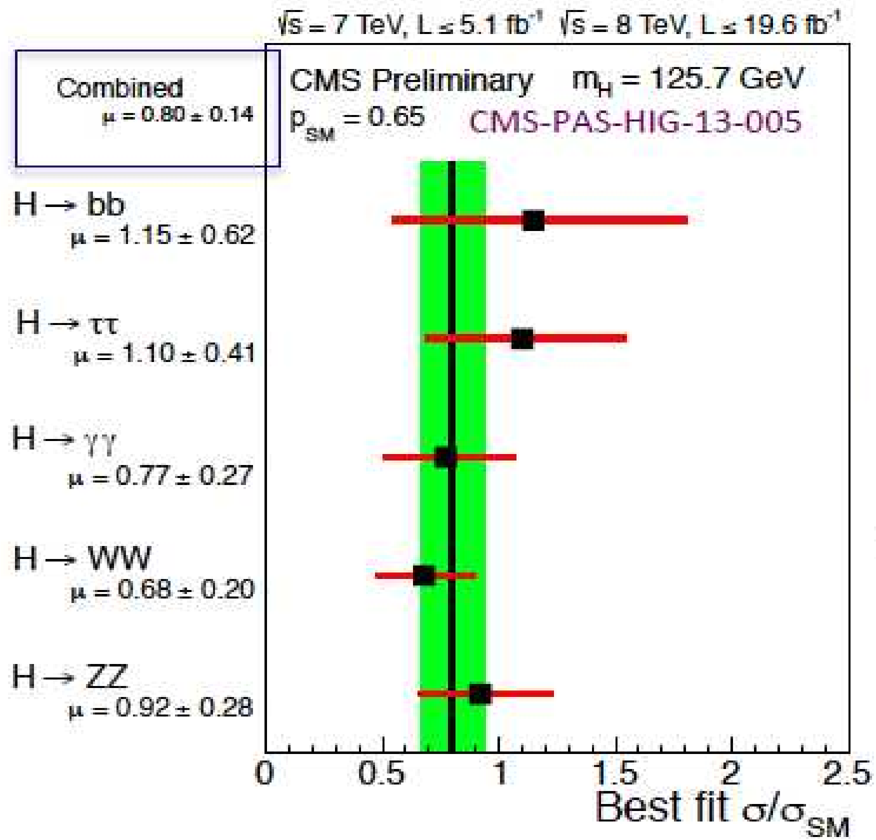
Exploration of the Higgs properties with "minimal theoretical bias"...

Introduction

Several attempts in this direction have already started...



Phys. Lett. B 726 (2013), 88-119

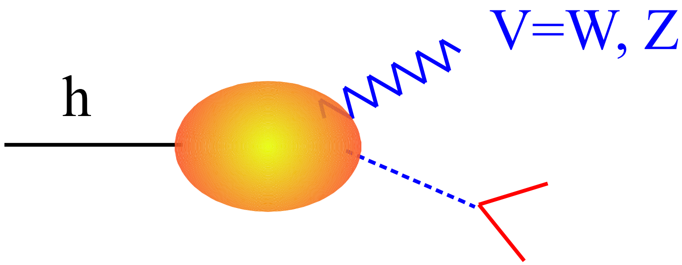


Introduction

Several attempts in this direction have already started...
…but the peculiar value of m_h ($\rightarrow$ *suppressed Higgs width*) offers many more interesting tests.

Three (almost) unexplored directions:

Kinematical studies in $h \rightarrow 4l$ & in V+h associated production



$$A(h \rightarrow 4l) \neq \text{“}A(h \rightarrow VV)\text{”} \neq A(pp \rightarrow Vh)$$

GI, Manohar, Trott, '13; Ellis, Sanz, You, '13
Grinstein *et al.* '13, GI, Trott, '13
Pomarol & Riva, '13; Buchalla *et al.*' 13, Beneke *et al.*' 14, ...

Rare SM modes [including *exclusive semi-hadronic* decays]

E.g.:
$h \rightarrow \Upsilon Z$ [$BR_{SM} \sim 1.6 \times 10^{-5}$]
$h \rightarrow \psi\gamma$ [$BR_{SM} \sim 2.5 \times 10^{-6}$]
...

GI, Manohar, Trott, '13
Bodwin *et al.* '13, Kagan *et al.* '14

Exotic/forbidden decay modes [e.g. *LFV* modes, *h → invisible*, *h → new light states*, ...]

E.g.:
$h \rightarrow \mu\tau$
$h \rightarrow Z+A$
...

Blankenburg, Ellis, GI, '12
Harnik *et al.* '12; Curtin *et al.* '13
Gonzales-Alonso, GI, '14
Falkowski, Vega-Morales, '14, ...

▶ *Introduction*

Several attempts in this direction have already started...
…but the peculiar value of m_h (→ *suppressed Higgs width*) offers many more interesting tests.

↓

Rare Higgs decays

On the TH side:

- Unique window on models where (light) NP couples directly (*effective tree-level coupling*) only to the Higgs field (*Higgs portal*, …)
- Large deviations from the SM less constrained by other observables (e.g. EWPO)

Curtin *et al.* '13

On the EXP side:

- Hopefully more room for improvement with increasing statistics vs. the (slow) improvement in measurements where we have already seen the SM signal...

Flavor-violating Higgs decays

Flavor-violating Higgs decays

If we consider the SM as a low-energy effective theory, it is natural to include possible flavor-violating couplings of the physical Higgs boson.

h-mediated FCNCs are unavoidable in models with more Higgs doublets and, more generally, can be viewed as the effect of higher-dimensional operators (in the EFT approach):

Azatov, Toharia, Zhu '09
Agashe & Contino '09

$$Y^{ij}\, \psi_L{}^i \psi_R{}^j\, \phi + \varepsilon^{ij}\, \psi_L{}^i \psi_R{}^j\, \phi^3 + \ldots$$

$$\varepsilon^{ij} = \frac{c^{ij}}{\Lambda^2}$$

$$\Downarrow$$

$$\underbrace{(vY^{ij} + v^3\, \varepsilon^{ij})}_{vY_{\text{eff}}}\, \psi_L{}^i \psi_R{}^j + (Y^{ij} + 3v^2\, \varepsilon^{ij})\, \psi_L{}^i \psi_R{}^j\, h + \ldots$$

h FCNC couplings if $Y^{ij} \neq c\, \varepsilon^{ij}$

Flavor-violating Higgs decays

$$\mathcal{L}_{\rm eff} = \sum_{i,j=d,s,b\ (i\neq j)} c_{ij}\ \bar{d}^i_L d^j_R h + \sum_{i,j=u,c,t\ (i\neq j)} c_{ij}\ \bar{u}^i_L u^j_R h + \sum_{i,j=e,\mu,\tau\ (i\neq j)} c_{ij}\ \bar{\ell}^i_L \ell^j_R h + \text{H.c.}$$

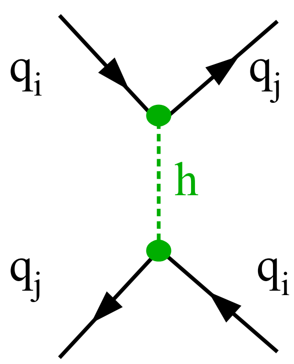
(fermion mass-eigenstate basis)

Flavor-violating Higgs decays

$$\mathcal{L}_{\rm eff} = \boxed{\sum_{i,j=d,s,b\ (i\neq j)} c_{ij}\ \bar{d}^i_L d^j_R h + \sum_{i,j=u,c,t\ (i\neq j)} c_{ij}\ \bar{u}^i_L u^j_R h} + \sum_{i,j=e,\mu,\tau\ (i\neq j)} c_{ij}\ \bar{\ell}^i_L \ell^j_R h + \text{H.c.}$$

(fermion mass-eigenstate basis)

Strongly bounded by ΔF=2
(except for terms involving the top)



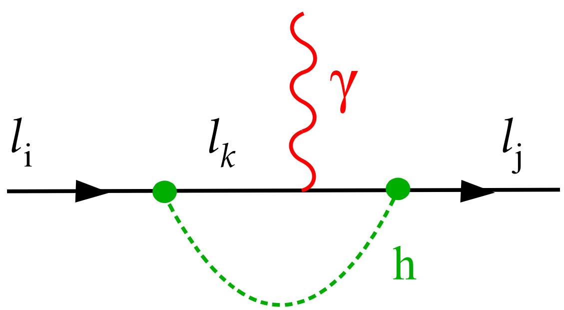
Operator	Eff. couplings	95% C.L. Bound		Observables
		$\lvert c_{\rm eff}\rvert$	$\lvert {\rm Im}(c_{\rm eff})\rvert$	
$(\bar{s}_R d_L)(\bar{s}_L d_R)$	$c_{sd}\ c^*_{ds}$	1.1×10^{-10}	4.1×10^{-13}	Δm_K; ϵ_K
$(\bar{s}_R d_L)^2,\ (\bar{s}_L d_R)^2$	$c^2_{ds},\ c^2_{sd}$	2.2×10^{-10}	0.8×10^{-12}	
$(\bar{c}_R u_L)(\bar{c}_L u_R)$	$c_{cu}\ c^*_{uc}$	0.9×10^{-9}	1.7×10^{-10}	Δm_D; $\lvert q/p\rvert, \phi_D$
$(\bar{c}_R u_L)^2,\ (\bar{c}_L u_R)^2$	$c^2_{uc},\ c^2_{cu}$	1.4×10^{-9}	2.5×10^{-10}	
$(\bar{b}_R d_L)(\bar{b}_L d_R)$	$c_{bd}\ c^*_{db}$	0.9×10^{-8}	2.7×10^{-9}	Δm_{B_d}; $S_{B_d\to\psi K}$
$(\bar{b}_R d_L)^2,\ (\bar{b}_L d_R)^2$	$c^2_{db},\ c^2_{bd}$	1.0×10^{-8}	3.0×10^{-9}	
$(\bar{b}_R s_L)(\bar{b}_L s_R)$	$c_{bs}\ c^*_{sb}$	2.0×10^{-7}	2.0×10^{-7}	Δm_{B_s}
$(\bar{b}_R s_L)^2,\ (\bar{b}_L s_R)^2$	$c^2_{sb},\ c^2_{bs}$	2.2×10^{-7}	2.2×10^{-7}	

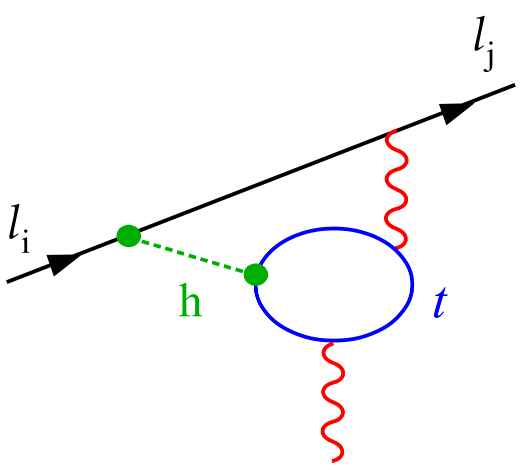
Blankenburg, Ellis, G.I. '12

Flavor-violating Higgs decays

$$\mathcal{L}_{\rm eff} = \sum_{i,j=d,s,b\ (i\neq j)} c_{ij}\ \bar{d}^i_L d^j_R h + \sum_{i,j=u,c,t\ (i\neq j)} c_{ij}\ \bar{u}^i_L u^j_R h + \boxed{\sum_{i,j=e,\mu,\tau\ (i\neq j)} c_{ij}\ \bar{\ell}^i_L \ell^j_R h + \text{H.c.}}$$

The bounds are significantly less severe in the lepton sector, especially for the τμ and τe effective couplings:





Eff. couplings	Bound	Constraint
$\lvert c_{e\tau}c_{\tau e}\rvert$ $(\lvert c_{e\mu}c_{\mu e}\rvert)$	1.1×10^{-2} (1.8×10^{-1})	$\lvert\delta m_e\rvert < m_e$
$\lvert\mathrm{Re}(c_{e\tau}c_{\tau e})\rvert$ $(\lvert\mathrm{Re}(c_{e\mu}c_{\mu e})\rvert)$	0.6×10^{-3} (0.6×10^{-2})	$\lvert\delta a_e\rvert < 6\times10^{-12}$
$\lvert\mathrm{Im}(c_{e\tau}c_{\tau e})\rvert$ $(\lvert\mathrm{Im}(c_{e\mu}c_{\mu e})\rvert)$	0.8×10^{-8} (0.8×10^{-7})	$\lvert d_e\rvert < 1.6\times10^{-27}$ ecm
$\lvert c_{\mu\tau}c_{\tau\mu}\rvert$	2	$\lvert\delta m_\mu\rvert < m_\mu$
$\lvert\mathrm{Re}(c_{\mu\tau}c_{\tau\mu})\rvert$	2×10^{-3}	$\lvert\delta a_\mu\rvert < 4\times10^{-9}$
$\lvert\mathrm{Im}(c_{\mu\tau}c_{\tau\mu})\rvert$	0.6	$\lvert d_\mu\rvert < 1.2\times10^{-19}$ ecm
$\lvert c_{e\tau}c_{\tau\mu}\rvert,\ \lvert c_{\tau e}c_{\mu\tau}\rvert$	1.7×10^{-7}	$\mathcal{B}(\mu\to e\gamma) < 2.4\times10^{-12}$
$\lvert c_{\mu\tau}\rvert^2,\ \lvert c_{\tau\mu}\rvert^2$	0.9×10^{-2} [*]	$\mathcal{B}(\tau\to\mu\gamma) < 4.4\times10^{-8}$
$\lvert c_{e\tau}\rvert^2,\ \lvert c_{\tau e}\rvert^2$	0.6×10^{-2} [*]	$\mathcal{B}(\tau\to e\gamma) < 3.3\times10^{-8}$

Eff. couplings	Bound	Constraint
$\lvert c_{e\mu}\rvert^2,\ \lvert c_{\mu e}\rvert^2$	1×10^{-11} [*]	$\mathcal{B}(\mu\to e\gamma) < 2.4\times10^{-12}$
$\lvert c_{\mu\tau}\rvert^2,\ \lvert c_{\tau\mu}\rvert^2$	5×10^{-4} [*]	$\mathcal{B}(\tau\to\mu\gamma) < 4.4\times10^{-8}$
$\lvert c_{e\tau}\rvert^2,\ \lvert c_{\tau e}\rvert^2$	3×10^{-4} [*]	$\mathcal{B}(\tau\to e\gamma) < 3.3\times10^{-8}$

Flavor-violating Higgs decays

$$\mathcal{L}_{\rm eff} = \sum_{i,j=d,s,b\ (i\neq j)} c_{ij}\ \bar{d}^i_L d^j_R h + \sum_{i,j=u,c,t\ (i\neq j)} c_{ij}\ \bar{u}^i_L u^j_R h + \boxed{\sum_{i,j=e,\mu,\tau\ (i\neq j)} c_{ij}\ \bar{\ell}^i_L \ell^j_R h + \text{H.c.}}$$

The bounds are significantly less severe in the lepton sector, especially for the $\tau\mu$ and τe effective couplings.

Taking into account also the smallness of the Higgs width for m ~ 125 GeV (dominant partial width controlled by $y_b \sim 0.02$)

$\Downarrow$

Flavor-changing decays into lepton pairs -with one tau- are not strongly constrained: BR($h \to \tau\mu, \tau e$) $\lesssim$ 10% $\to$ worth a direct search !!

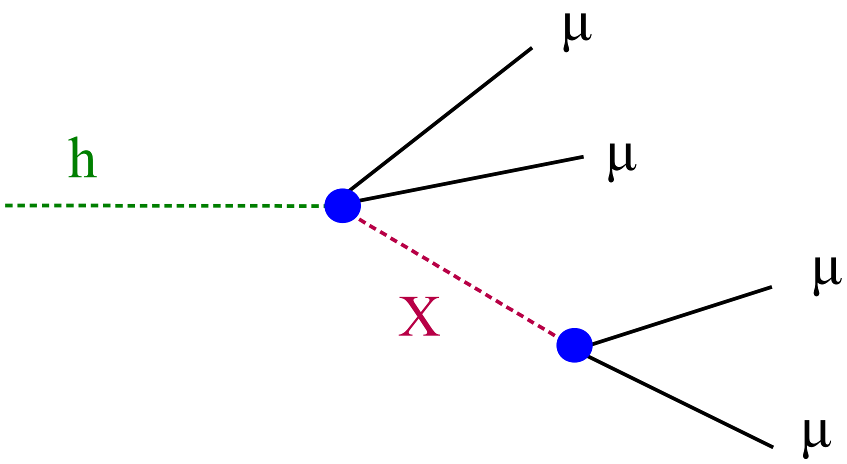
Blankenburg, Ellis, G.I. '12

ATLAS & CMS already have the sensitivity to set bounds on BR($h \to \tau\mu$) $\lesssim$ 1%

Harnik, Kopp, Zupan, '12
Davidson, Verdier, '12

... and of course a FCC-ee would allow to improve the sensitivity on such modes by several orders of magnitude

Light exotic states in $h \rightarrow 4l$



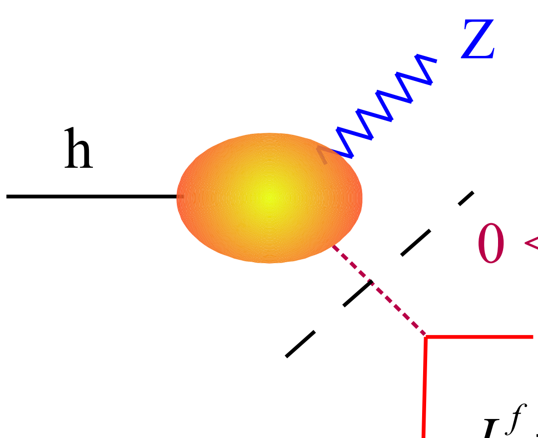
Light states in h → 4*l* decays

ATLAS and CMS have reported results about the $h \to ZZ^*$ couplings

However, what is really measured are 4-lepton modes.

With suitable cuts what can be probed in experiments is the $h \to Z + ll$ amplitude and, in general,

$$\boxed{A(h \to Z + ll) \neq A(h \to ZZ^*)}$$



$0 < q^2 < (m_h - m_V)^2$

$$J_\mu^f = \bar{l}\,\gamma_\mu (v^f + a^f \gamma_5)\, l$$

The "offshellness" of the second lepton pair allows to probe a richer dynamical structure:

- We are far enough from the pole of the amplitude at $q^2 = m_Z^2$ (*dominant pole within the SM*)
- Measuring the q^2 dependence we could reveal new "distant poles" (↔ *contact interactions*) or even new "light poles" (↔ *new light states coupled to h & fermions*)
- General parametrization in terms of $hZff$ form-factors

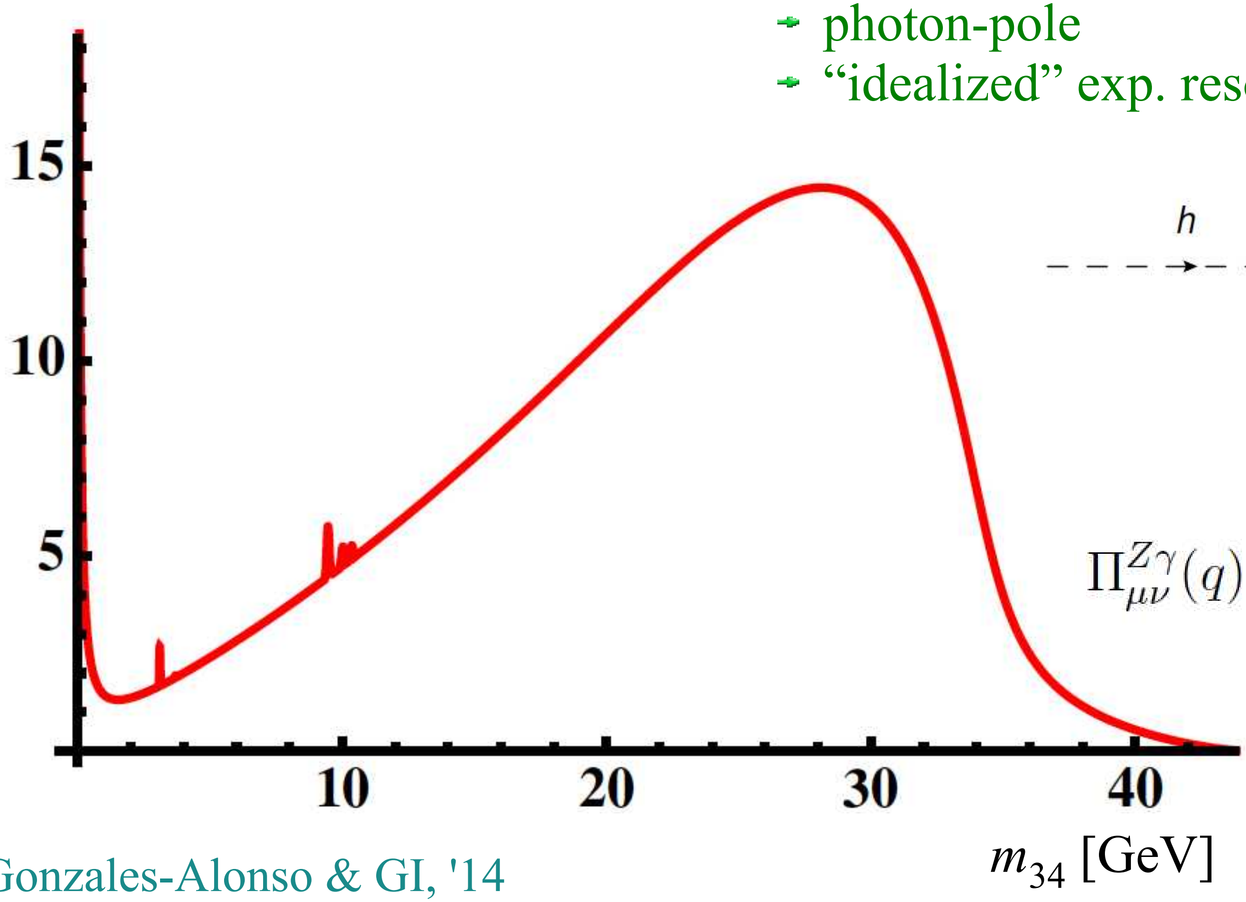
GI, Manohar, Trott, '13

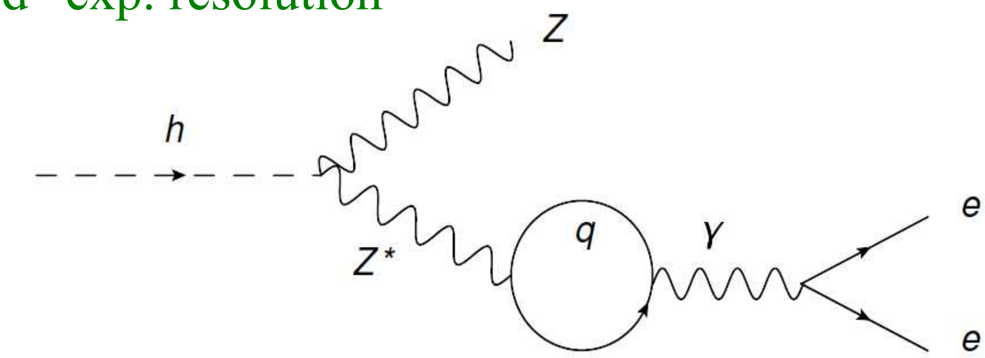
Light states in h → 4*l decays*

The $d\Gamma/dm_{34}$ spectrum ($m_{34} = \sqrt{q^2}$ = lightest invariant mass pair) is the most interesting distribution to identify possible light-poles → *very precise SM distribution*, even at low m_{34}, including charmonium/bottomonium states:

- Heavy-quarkonia effects
- off-shell Z
- photon-pole
- “idealized” exp. resolution

$d\Gamma/dm_{34}$





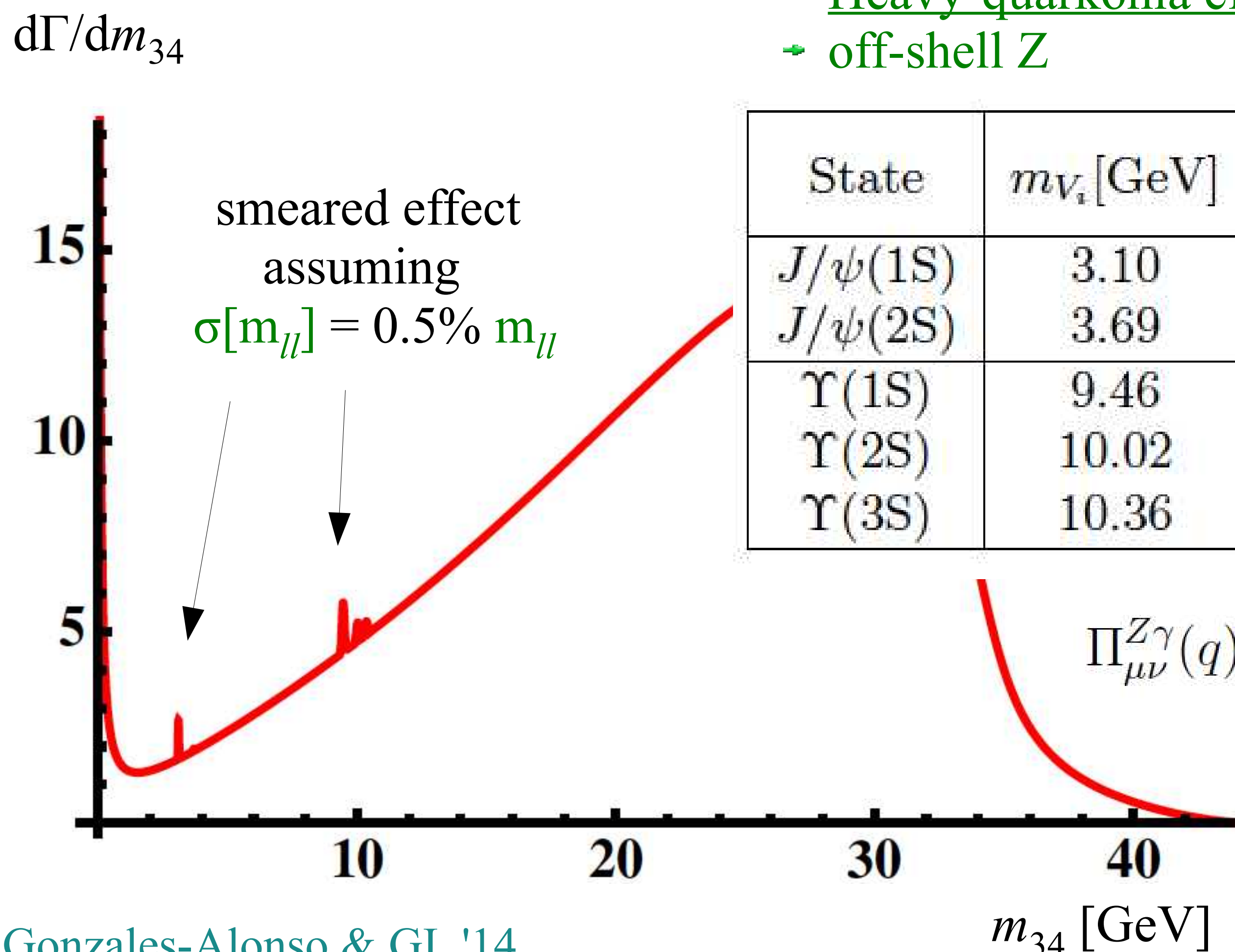
$$\Pi^{Z\gamma}_{\mu\nu}(q) \equiv i \int d^4x e^{iqx} \langle 0|T J^Z_\mu(x) J^\gamma_\nu(0)|0\rangle$$

Gonzales-Alonso & GI, '14

Light states in h → 4*l decays*

The $d\Gamma/dm_{34}$ spectrum ($m_{34} = \sqrt{q^2}$ = lightest invariant mass pair) is the most interesting distribution to identify possible light-poles → *very precise SM distribution*, even at low m_{34}, including charmonium/bottomonium states:

- Heavy-quarkonia effects
- off-shell Z



State	m_{V_i} [GeV]	$\mathcal{B}(h \to ZV_i)$	relative shift 1 GeV bin
$J/\psi(1S)$	3.10	1.7×10^{-6}	2.6%
$J/\psi(2S)$	3.69	8.6×10^{-7}	0.2%
$\Upsilon(1S)$	9.46	1.6×10^{-5}	3.1%
$\Upsilon(2S)$	10.02	8.2×10^{-6}	1.2%
$\Upsilon(3S)$	10.36	6.2×10^{-6}	0.9%

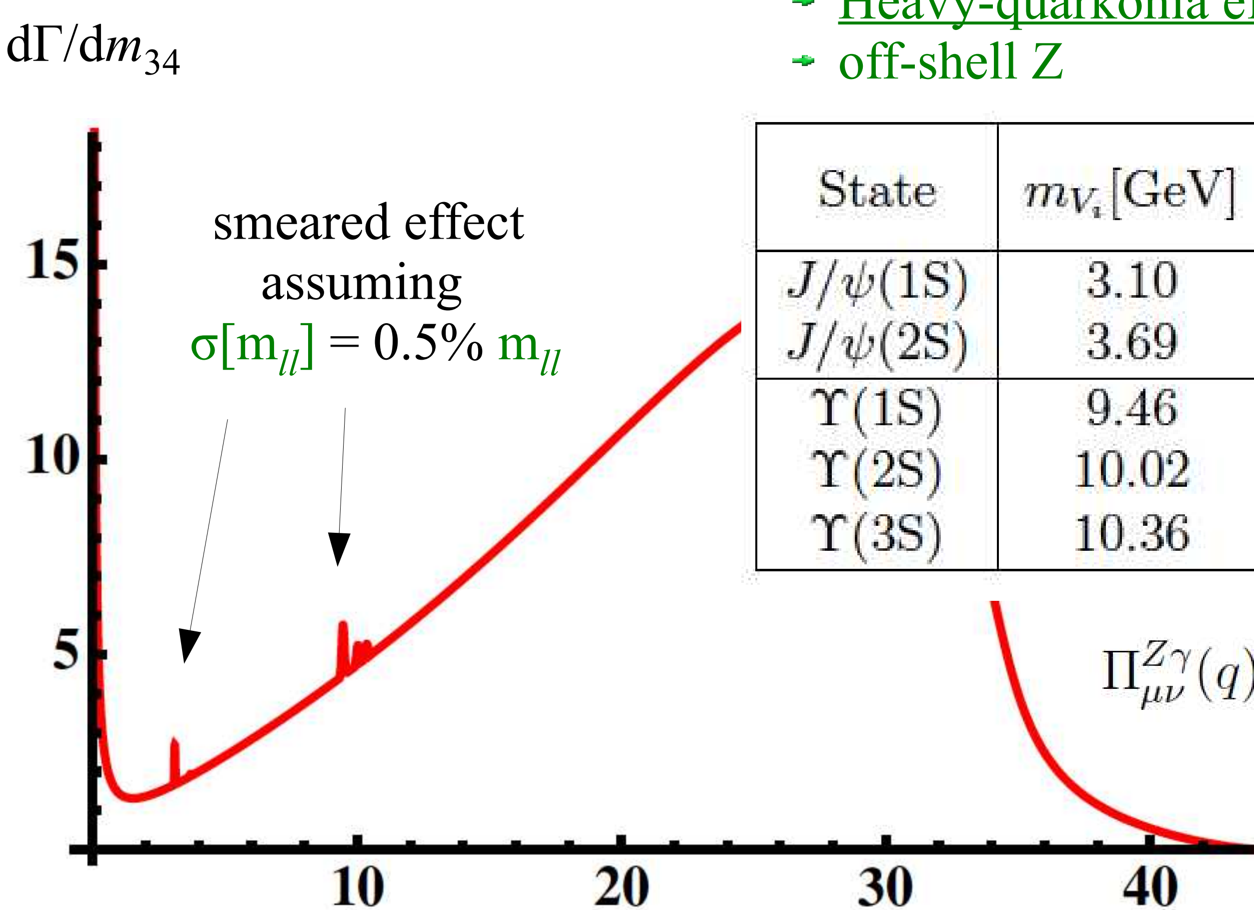
$$\Pi^{Z\gamma}_{\mu\nu}(q) \equiv i \int d^4x e^{iqx} \langle 0|T J^Z_\mu(x) J^\gamma_\nu(0)|0\rangle$$

Gonzales-Alonso & GI, '14

Light states in h → 4*l decays*

The $d\Gamma/dm_{34}$ spectrum ($m_{34} = \sqrt{q^2}$ = lightest invariant mass pair) is the most interesting distribution to identify possible light-poles → *very precise SM distribution*, even at low m_{34}, including charmonium/bottomonium states:

- Heavy-quarkonia effects
- off-shell Z



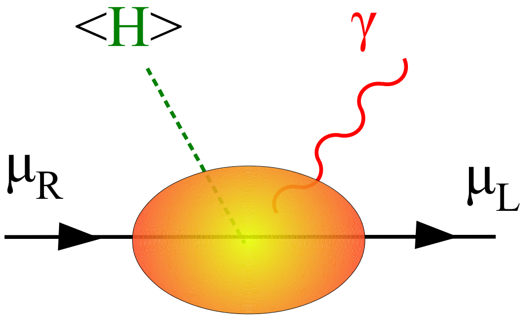
State	m_{V_i} [GeV]	$\mathcal{B}(h \to ZV_i)$	relative shift 1 GeV bin
$J/\psi(1S)$	3.10	1.7×10^{-6}	2.6%
$J/\psi(2S)$	3.69	8.6×10^{-7}	0.2%
$\Upsilon(1S)$	9.46	1.6×10^{-5}	3.1%
$\Upsilon(2S)$	10.02	8.2×10^{-6}	1.2%
$\Upsilon(3S)$	10.36	6.2×10^{-6}	0.9%

$$\Pi^{Z\gamma}_{\mu\nu}(q) \equiv i \int d^4x e^{iqx} \langle 0|T J^Z_\mu(x) J^\gamma_\nu(0)|0\rangle$$

SM resonance effects are small & under good th. control → *we can probe NP...*

A specific NP example motivated by the $(g\text{-}2)_\mu$ *anomaly*

Since a long time the experimental determination of $a_\mu = (g\text{-}2)_\mu$ is not in good agreement with the SM prediction:

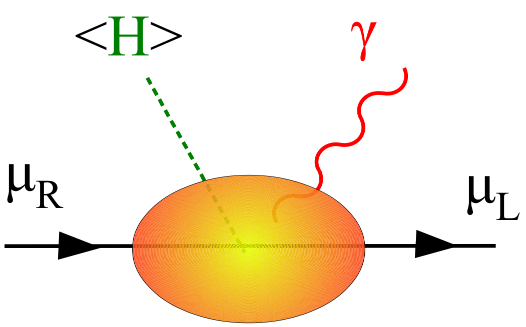


$$\boxed{\Delta a_\mu \equiv a_\mu^{\rm exp} - a_\mu^{\rm th} = (2.9 \pm 0.9) \times 10^{-9}}$$

The discrepancy is not extremely significant (~3σ), *but has survived a long list of scrutinies...*

A specific NP example motivated by the $(g\text{-}2)_\mu$ *anomaly*

Since a long time the experimental determination of $a_\mu = (g\text{-}2)_\mu$ is not in good agreement with the SM prediction:



$$\boxed{\Delta a_\mu \equiv a_\mu^{\rm exp} - a_\mu^{\rm th} = (2.9 \pm 0.9) \times 10^{-9}}$$

The discrepancy is not extremely significant (~3σ), *but has survived a long list of scrutinies...*

⬇

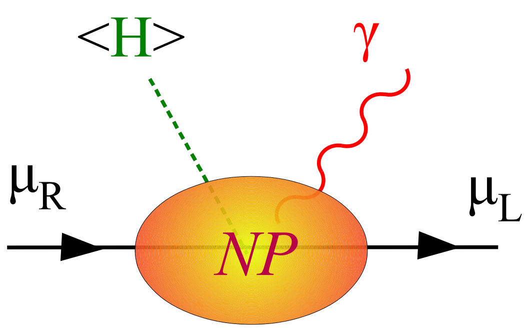
Solving the $(g\text{-}2)_\mu$ anomaly in terms of NP, requires the introduction of some new (*light or heavy...*) states coupled to muons.

⬇

In all cases there is a *natural connection* between NP effects in $(g\text{-}2)_\mu$ and $h \to 4l$

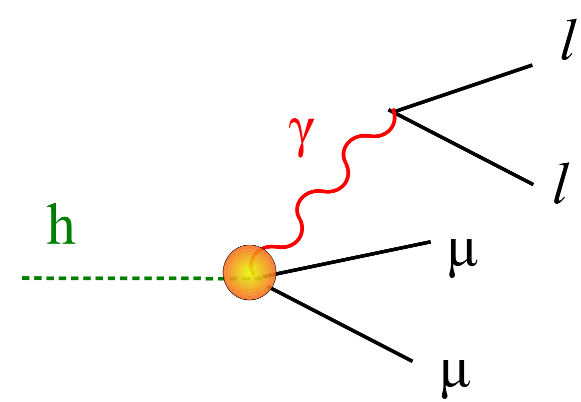
A specific NP example motivated by the $(g-2)_\mu$ *anomaly*

There is a *natural connection* between NP effects in $(g-2)_\mu$ and $h \to 4l$



$m_{NP} > m_h$

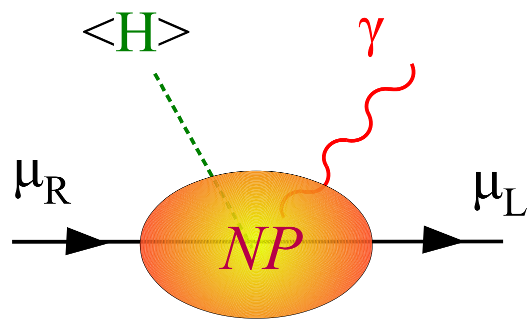
Tiny correction to $h \to 2\mu 2l$



$\sim 10^{-4}$ *correction with respect to* $BR(h \to 2\mu\gamma)_{SM}$
unmeasurable even in the HL phase of LHC

➨ *A specific NP example motivated by the* $(g\text{-}2)_\mu$ *anomaly*

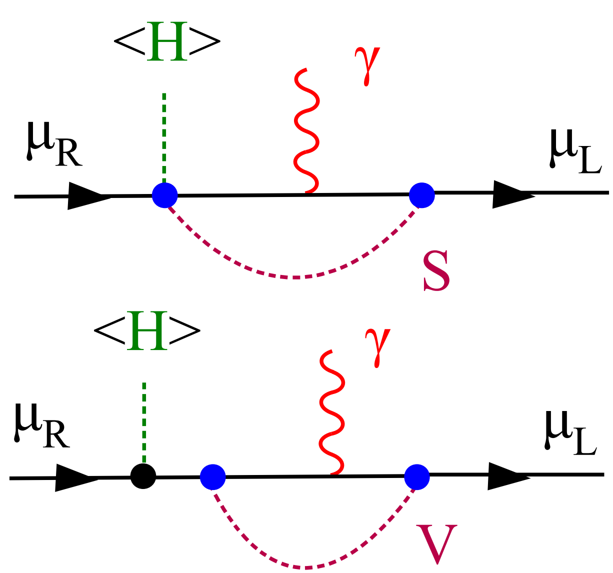
There is a *natural connection* between NP effects in $(g\text{-}2)_\mu$ and $h \to 4l$

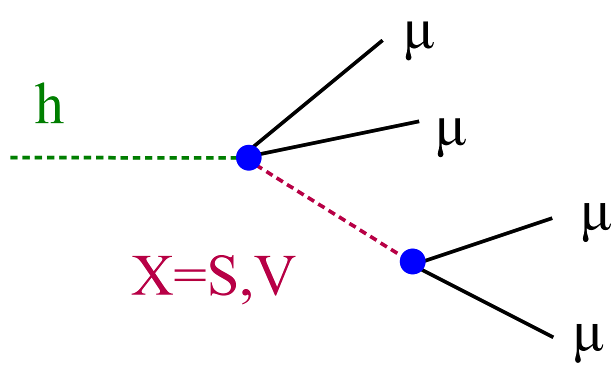


$m_{NP} > m_h$ → Tiny correction to $h \to 2\mu 2l$

$2m_\mu < m_{NP} \ll m_h$ → Possible "visible" non-standard peak in the $h \to 4\mu$ distribution

E.g.:





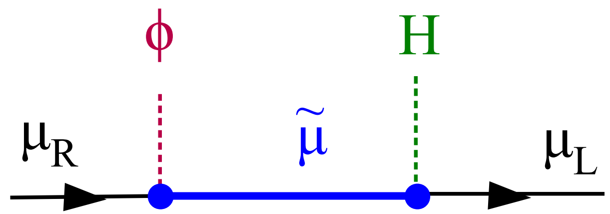
A specific NP example motivated by the $(g\text{-}2)_\mu$ *anomaly*

A "minimalistic & concrete" set-up:

- One light $SU(2)_L$-singlet scalar field, ϕ
- One effective coupling c_μ/Λ → Two parameter model (c_μ/Λ and m_ϕ):

$$\mathscr{L}_{\rm eff} = \mathscr{L}_{\rm kin}(\phi) + \left(\frac{c_\mu}{\Lambda}\, \bar{\mu}_L\, \mu_R\, H\, \phi + \text{h.c.} \right)$$

This $\mathscr{L}_{eff}$ can be generated, for instance, introducing an heavy vector-like μ-partner



- The ratio of the two free parameters is the fixed by $(g\text{-}2)_\mu$ anomaly:

$$\Delta a_\mu = \frac{|c_\mu|^2}{96\pi^2}\frac{v^2}{\Lambda^2}\frac{m_\mu^2}{m_\phi^2} \approx 6.4\times 10^{-9} \left| \frac{c_\mu/\Lambda}{(1\ \text{TeV})^{-1}} \right|^2 \left| \frac{10\ \text{GeV}}{m_\phi} \right|^2$$

- For $m_\phi \gtrsim 1$ GeV the model is consistent with all known bounds.

Gonzales-Alonso & GI, '14

A specific NP example motivated by the $(g\text{-}2)_\mu$ *anomaly*

A "minimalistic & concrete" set-up:

- One light $SU(2)_L$-singlet scalar field, ϕ
- One effective coupling c_μ/Λ → Two parameter model (c_μ/Λ and m_ϕ)
- The ratio of the two free parameters is the fixed by $(g\text{-}2)_\mu$ anomaly

$$\frac{\mathcal{B}(h\to 4\mu)_{(\phi)}}{\mathcal{B}(h\to 4\mu)_{\rm SM}} \approx 150\left(\frac{\Delta a_\mu}{2.9\times 10^{-9}}\right)\left(\frac{m_\phi}{10\ \mathrm{GeV}}\right)^2 \mathcal{B}(\phi\to\mu^+\mu^-)$$

A potential huge effect ! *Maybe already ruled out by present data...*

Unless BR ($\phi \to \mu\mu$) << 1 → quite possible if there are additional (invisible) decay modes of ϕ (ν's, DM states, etc...).

A specific NP example motivated by the $(g\text{-}2)_\mu$ anomaly

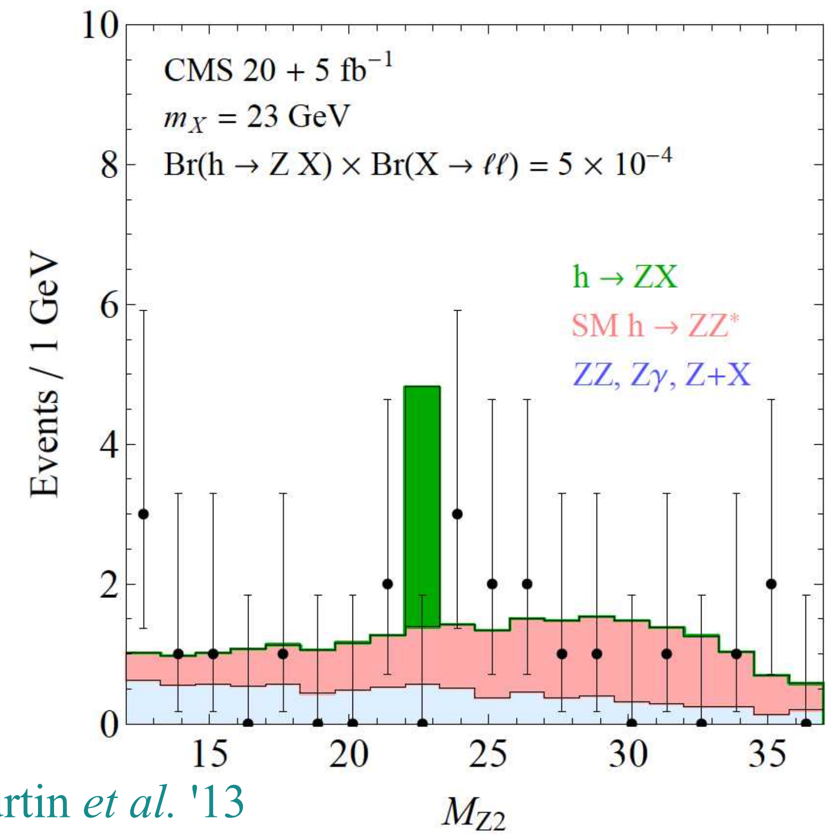
Going beyond this minimal set-up, it is fair to say that

- if the $h \to X + \mu\mu$ on-shell decay is kinematically allowed
- if we fix the couplings of the X particle to have an impact on $(g\text{-}2)_\mu$

⬇

- Not difficult to satisfy all existing constraints, especially for $m_X \sim$ few GeV
- Sizable *local* deviations in $h \to 4\mu$ naturally expected

Gonzales-Alonso & GI, '14



Curtin *et al.* '13

N.B.: In models addressing $(g\text{-}2)_\mu$ X is narrow and short-lived (*not necessarily true in general*)

N.B.: The light mass region ($1\text{ GeV} \lesssim m_X \lesssim 10\text{ GeV}$) is particularly motivated from the th. point of view ("*dark-Z world*"...)

A specific NP example motivated by the $(g-2)_\mu$ anomaly

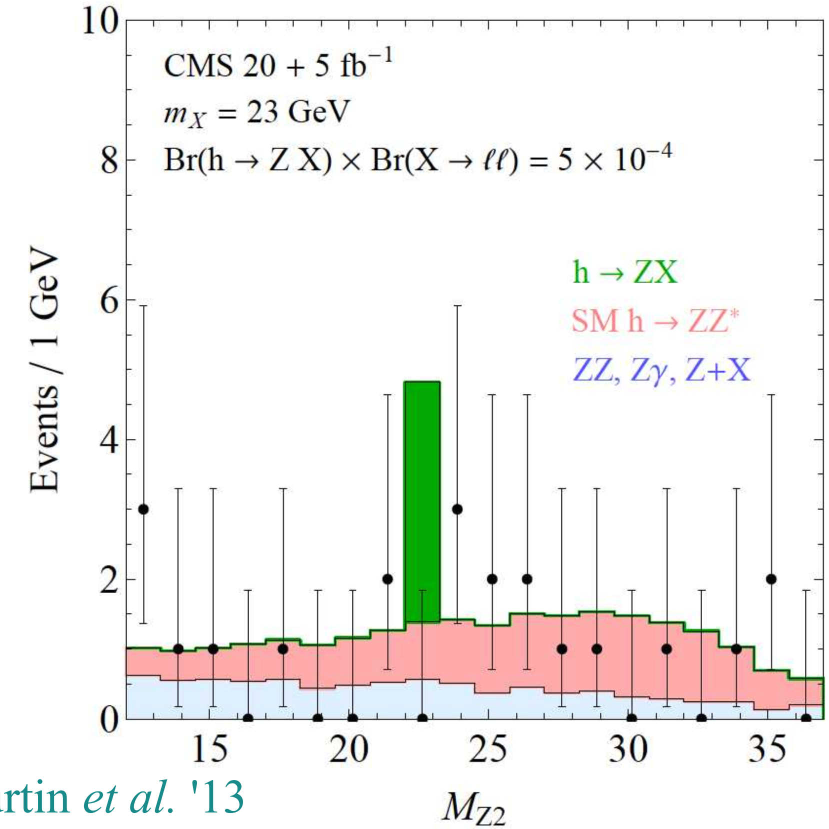
Going beyond this minimal set-up, it is fair to say that

- if the $h \to X+\mu\mu$ on-shell decay is kinematically allowed
- if we fix the couplings of the X particle to have an impact on $(g-2)_\mu$

⬇

- Not difficult to satisfy all existing constraints, especially for $m_X \sim$ few GeV
- Sizable *local* deviations in $h \to 4\mu$ naturally expected

Gonzales-Alonso & GI, '14



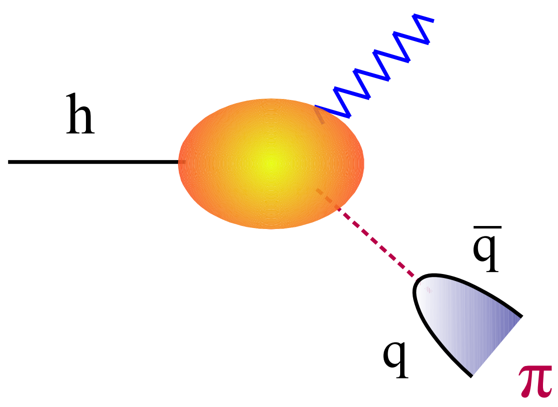
Curtin *et al.* '13

N.B.: In models addressing $(g-2)_\mu$ X is narrow and short-lived (*not necessarily true in general*)

N.B.: The light mass region ($1\ \text{GeV} \lesssim m_X \lesssim 10\ \text{GeV}$) is particularly motivated from the th. point of view

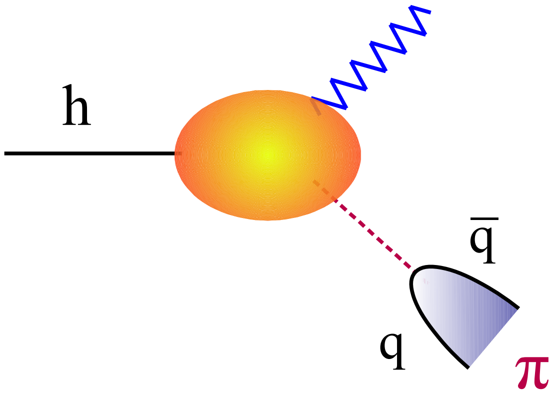
Here LHC experiments will have serious difficulties, contrary to the FCC-ee...

Rare exclusive semi-hadronic Higgs decays



The rare exclusive semi-hadronic h decays

Rare $h \to VP$ decays, where P is a single hadron state (*pseudo-scalar* or *vector-meson*) are a very interesting probe of the vacuum-structure of the theory



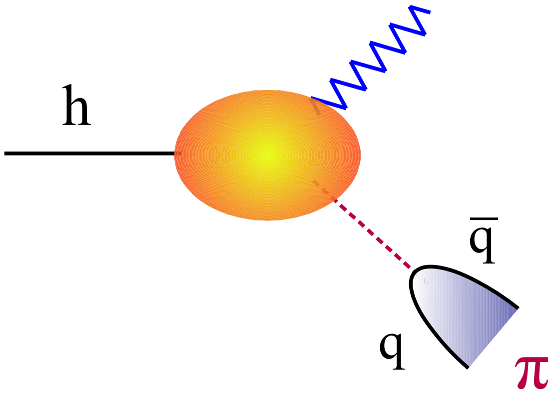
$$\boxed{A^{\rm SM} \propto \frac{f_P}{v}}$$

ratio of the two order parameters controlling the $SU(2)_L$ *breaking*

GI, Manohar, Trott, '13

The rare exclusive semi-hadronic h decays

Rare $h \to VP$ decays, where P is a single hadron state (*pseudo-scalar* or *vector-meson*) are a very interesting probe of the vacuum-structure of the theory

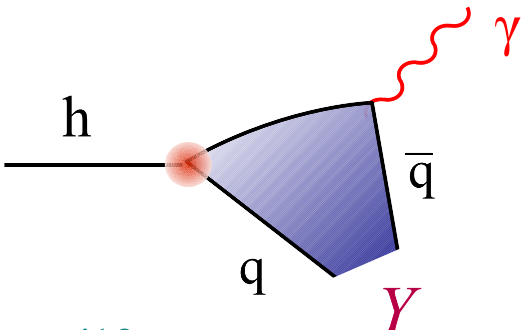


$$\boxed{A^{\mathrm{SM}} \propto \frac{f_P}{v}}$$

ratio of the two order parameters controlling the $SU(2)_L$ *breaking*

GI, Manohar, Trott, '13

Radiative modes of the type $h \to \gamma Y$ where Y is a quarkonium state have similar properties: more sensitivity to hqq couplings, but still dominated by $h \to \gamma Z^* \to \gamma Y$ within the SM



Bodwin, Petriello, Sonyev, Velasco, '13

In both cases, sizable deviations from the SM can be expected in presence of non-minimal couplings of the Higgs to fermions

Kagan *et al.* '14

The rare exclusive semi-hadronic h decays

The SM rates are suppressed but not outrageously small (*thanks to* m_h ~125 GeV), and some channels may have a (*relatively...*) clean signature

VP mode	$\mathcal{B}^{\mathrm{SM}}$	VP^* mode	$\mathcal{B}^{\mathrm{SM}}$
$W^-\pi^+$	0.6×10^{-5}	$W^-\rho^+$	0.8×10^{-5}
W^-K^+	0.4×10^{-6}	$Z^0\phi$	2.2×10^{-6}
$Z^0\pi^0$	0.3×10^{-5}	$Z^0\rho^0$	1.2×10^{-6}
$W^-D_s^+$	2.1×10^{-5}	$W^-D_s^{*+}$	3.5×10^{-5}
W^-D^+	0.7×10^{-6}	W^-D^{*+}	1.2×10^{-6}
$Z^0\eta_c$	1.4×10^{-5}	$Z^0 J/\psi$	1.7×10^{-6}
$h \to \gamma J/\psi$	2.5×10^{-6}	$h \to Z\Upsilon$	1.6×10^{-5}

Sizable modifications possible in various BSM frameworks

GI, Manohar, Trott, '13

Bodwin *et al.* '13
GI, Gonzales-Alonso '14

The rare exclusive semi-hadronic h decays

The SM rates are suppressed but not outrageously small (*thanks to* m_h ~125 GeV), and some channels may have a (*relatively...*) clean signature

VP mode	$\mathcal{B}^{\rm SM}$	VP^* mode	$\mathcal{B}^{\rm SM}$
$W^-\pi^+$	0.6×10^{-5}	$W^-\rho^+$	0.8×10^{-5}
W^-K^+	0.4×10^{-6}	$Z^0\phi$	2.2×10^{-6}
$Z^0\pi^0$	0.3×10^{-5}	$Z^0\rho^0$	1.2×10^{-6}
$W^-D_s^+$	2.1×10^{-5}	$W^-D_s^{*+}$	3.5×10^{-5}
W^-D^+	0.7×10^{-6}	W^-D^{*+}	1.2×10^{-6}
$Z^0\eta_c$	1.4×10^{-5}	Z^0J/ψ	1.7×10^{-6}
$h\to\gamma\, J/\psi$	2.5 x 10^{-6}	$h\to Z\Upsilon$	1.6 x 10^{-5}

Sizable modifications possible in various BSM frameworks

GI, Manohar, Trott, '13

Bodwin *et al.* '13
GI, Gonzales-Alonso '14

$BR[\, h \to W^\pm D_s^\mp(\gamma)\,] \approx 10^{-4}$

They definitely deserve a dedicated experimental search !

▶ *Conclusions*

We need to search for New Physics
[*with a broad spectrum perspective given the lack of NP signal so far...*]

⬇

Exploration of the Higgs properties with "minimal theoretical bias"...

⬇

Rare Higgs decays
[*those discussed in this talk & many more...*]
provide a unique opportunity in this respect:
unexplored windows toward a large class of NP models