Getting ready for LHC14:

Higgs distributions and ~~hunting electroweakinos~~

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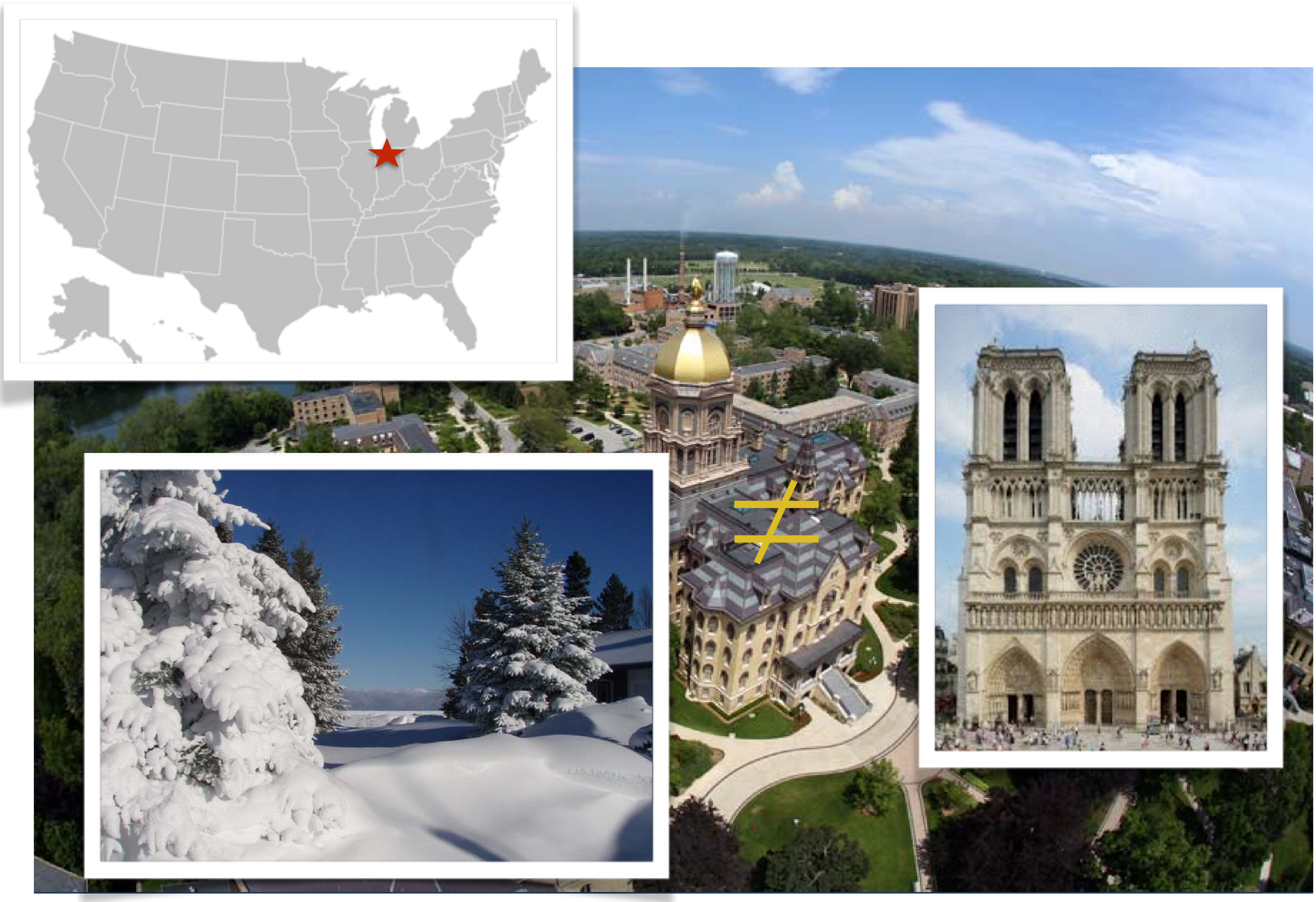
University of Notre Dame

Outline

1.) Introduction to Notre Dame High-Energy Physics

2.) Using Higgs distributions to look for new physics

University of Notre Dame



Particle Physics at Notre Dame

theory

Bigi

Delgado

Kolda

Martin

experiment

Hildreth

Jessop

Ruchti

Lannon

Wayne

LoSecco

Particle Physics at Notre Dame

students

Capdevilla, Rodolfo

Lehman, Landon

Alvarado, Carlos

Elahi, Fatemeh

Ostdiek, Bryan

postdoc

Joe Bramante

In addition to the topics I'll talk about
there are several other ideas we're interested in

simple MSSM extensions

inflation

FLAVOR

alternatives to freeze-out DM

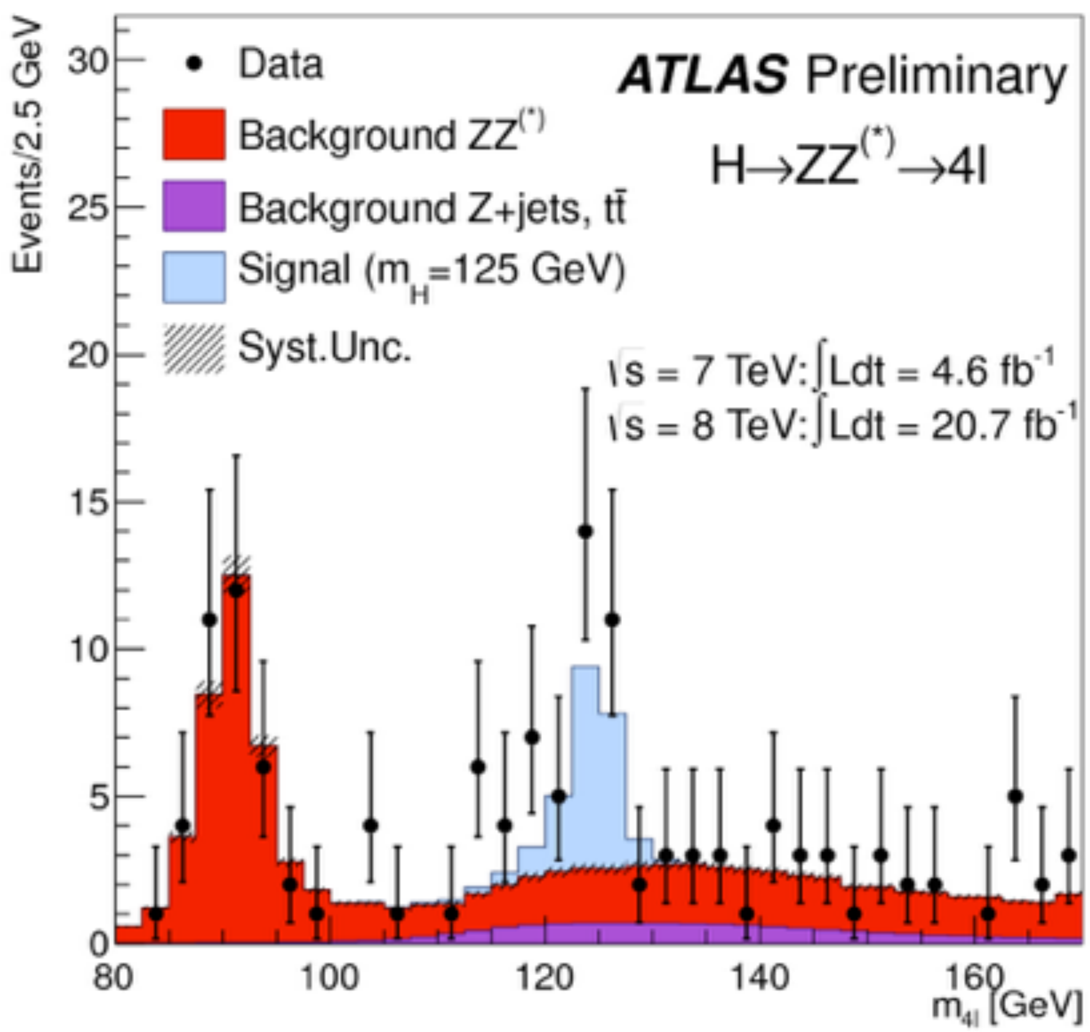
dark photons = very light Z'

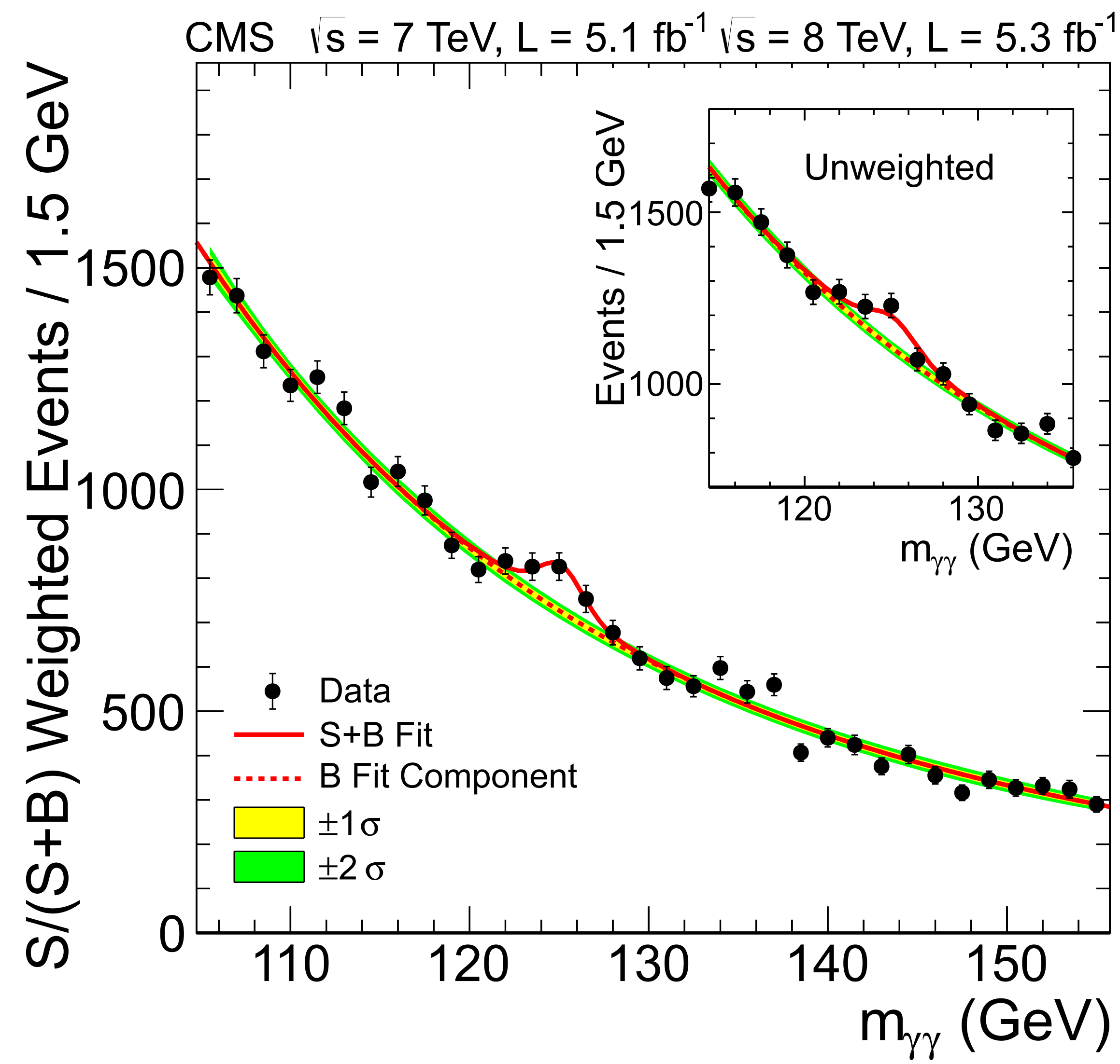
that I'd be happy to discuss

Using Higgs kinematic distributions to look for new physics

Motivation

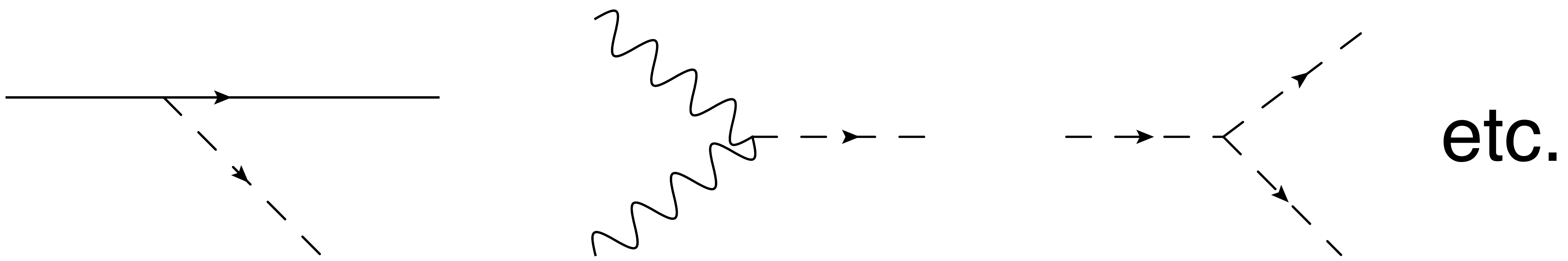
We've seen a Higgs boson!





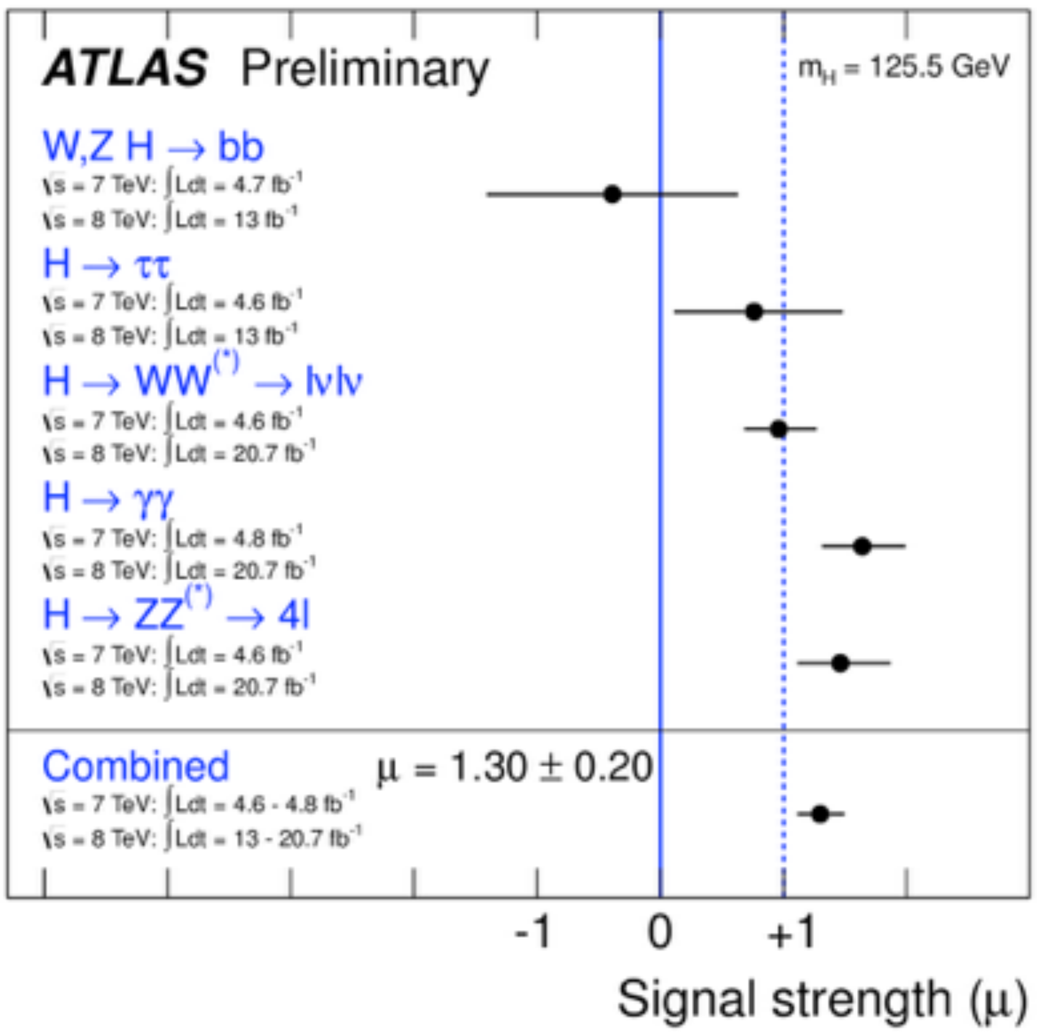

But nothing else

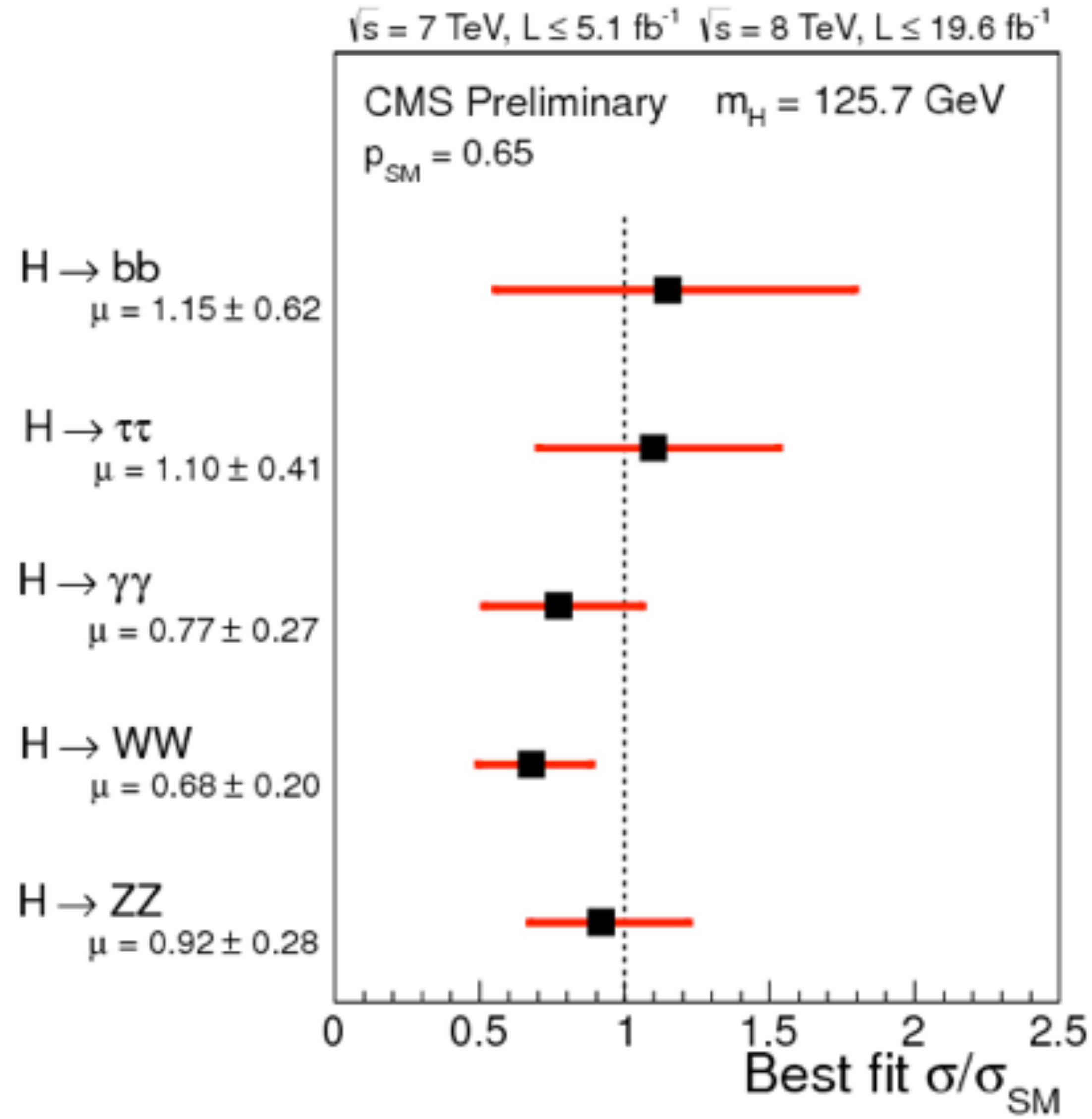
within the SM, **all** Higgs couplings completely determined



are functions of m_f, m_W, m_Z, v, m_H

so measuring **any** deviation in any Higgs coupling is a sign of new physics currently describe deviations from SM in terms of **μ** = ‘signal strength’





but what’s a signal strength?

what assumptions are involved?

signal strength

events in final state X $= \mathscr{L}\,\boldsymbol{\sigma}(pp \to h)\,BR(h \to X)\,A\,\boldsymbol{\varepsilon}$

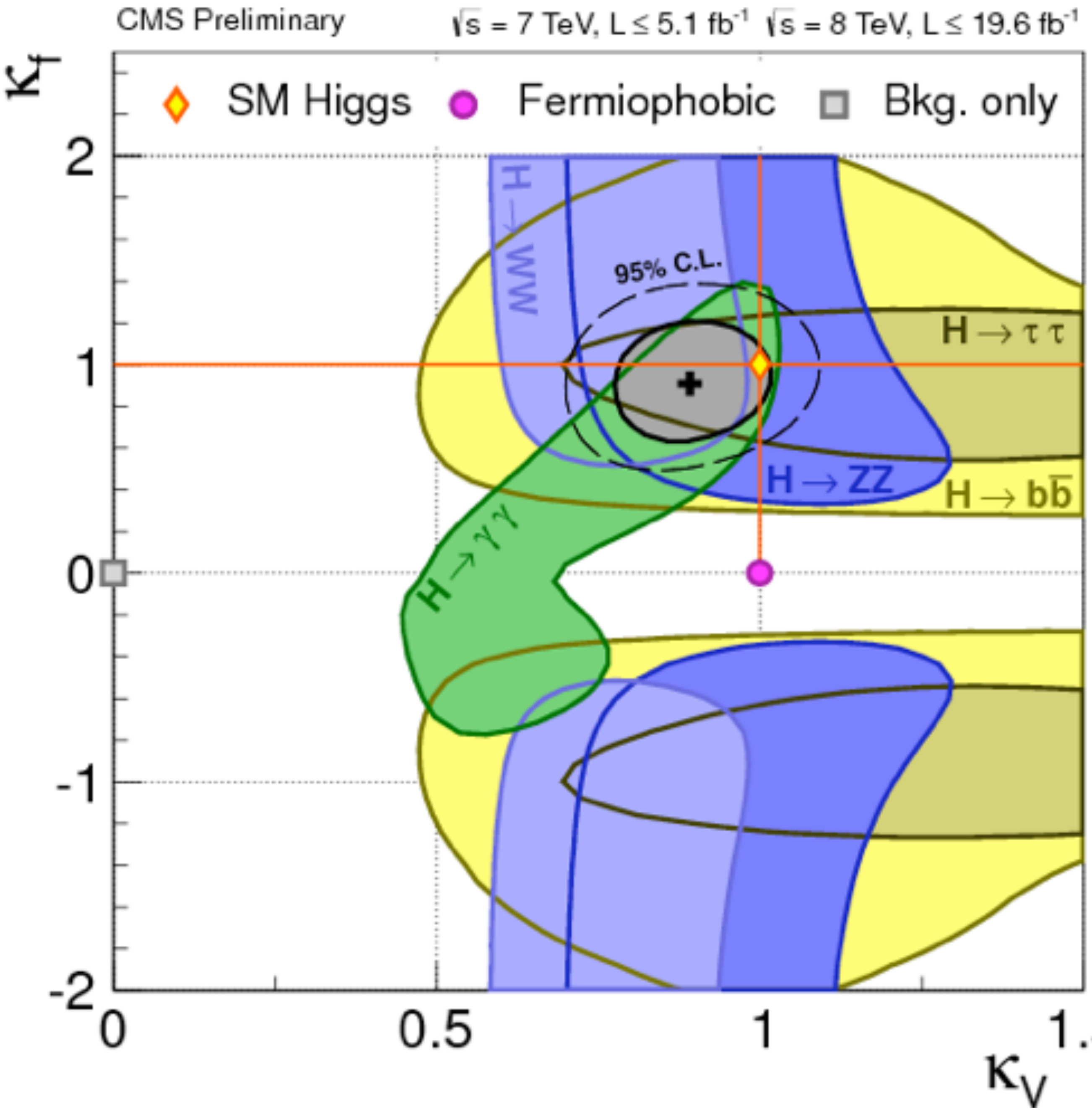
form ratio:

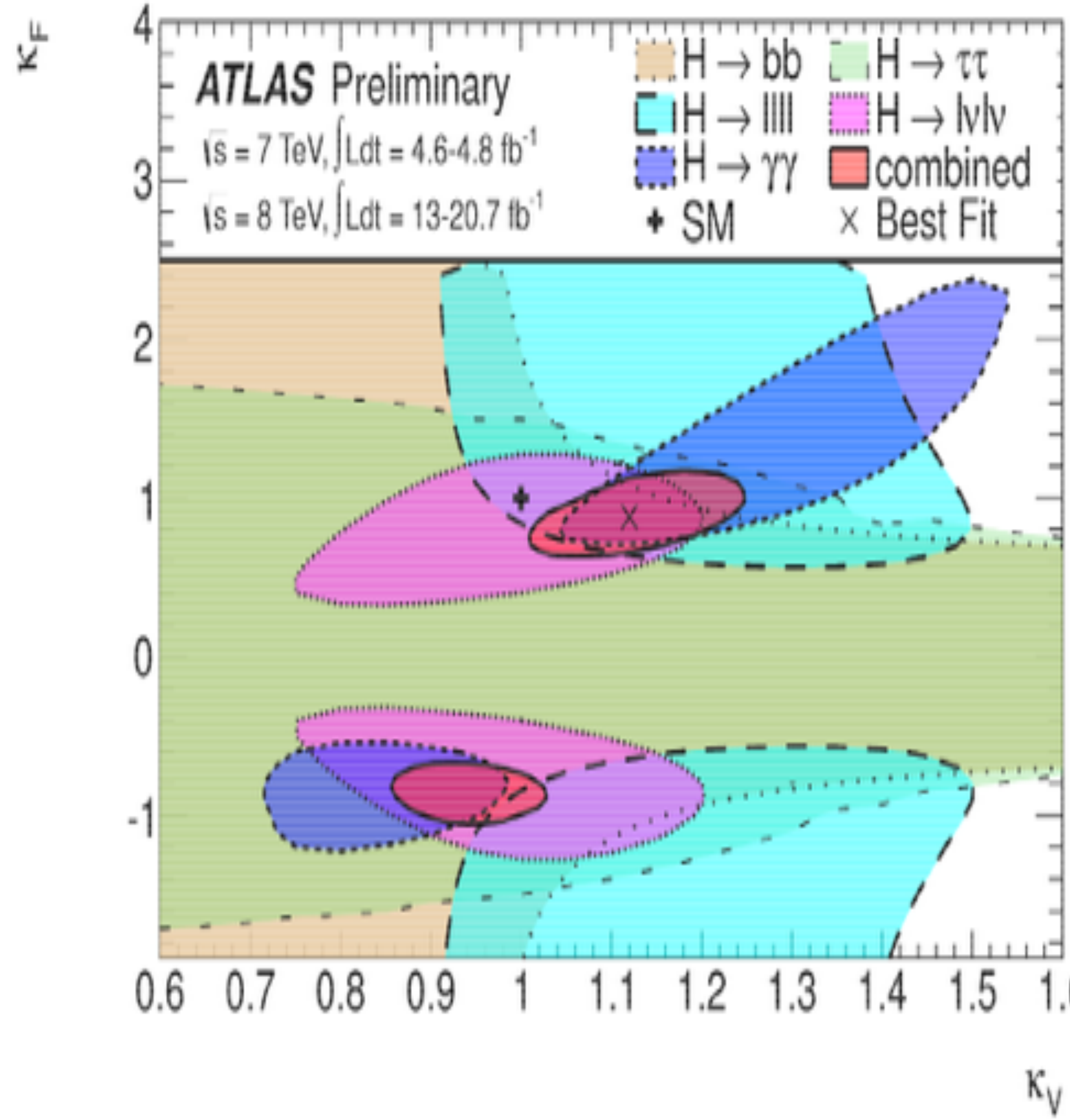
$$\mu = \frac{\cancel{\mathscr{L}}\,\sigma(pp \to h)\,BR(h \to X)\,\cancel{A}\,\cancel{\varepsilon}}{\cancel{\mathscr{L}}\,\sigma(pp \to h)_{SM}\,BR(h \to X)_{SM}\,\cancel{A_{SM}}\,\cancel{\varepsilon}}$$

only **if** we take the acceptances to be the same:

does: $\mu =$ the ratio of $\sigma \times BR$

interpretation requires assumption about NP



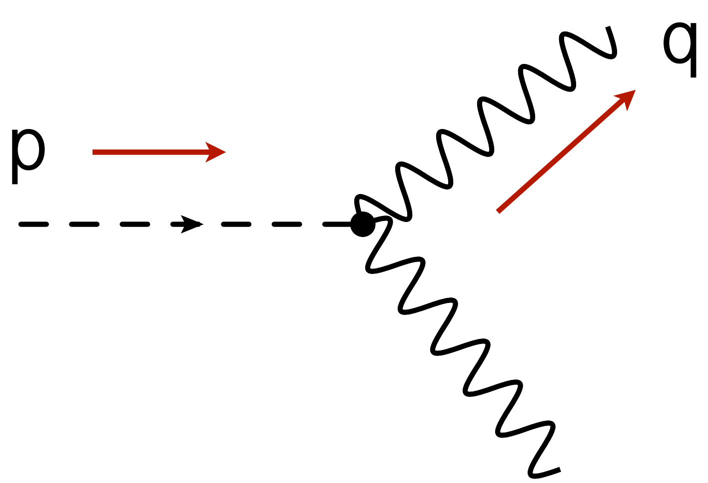


assuming SM acceptance, deviations from SM coupling values ≲ 0.1

Are we really restricted to deviations < 0.1?

No! vertices have a much more general structure

hWW:



[Isidori, Manohar,Trott ‘13],
[Isidori & Trott ’13],
[Ellis, Sanz, You ’13]

$$g\, m_W \left(f_1(q^2)\eta_{\mu\nu} + f_2(q^2)\, q_\mu q_\nu + f_3(q^2)(p\cdot q\,\eta_{\mu\nu} - p_\nu q_\mu) + f_4(q^2)\epsilon^{\mu\nu\rho\sigma}\, p_\rho q_\sigma \right)$$

bounds so far come from only looking at the momentum-independent piece of f_1

when we allow a more general structure:

1.) different contributions can cancel (or add).. so individual terms could be larger

2.) contributions can depend on the momenta involved in the process, so different effects in different kinematical regions ($A \neq A_{sm}$)

signal strength alone is insufficient

parameterize these effects with EFT: higher dimensional operators, suppressed by some scale Λ

operators can have a variety of effects, e.g.

$$\frac{(H^\dagger H)(Q\, H\, d^c)}{\Lambda^2}$$

rescales SM coupling, or new vertices with more Higgses

$$\frac{(H^\dagger \overleftrightarrow{D}_\mu H)(Q^\dagger \gamma^\mu Q)}{\Lambda^2}$$

changes EW couplings (bounded!), vertices with Higgs + EW gauge bosons

$$\left.\begin{array}{c} \dfrac{(H^\dagger H)\, W_{\mu\nu} W^{\mu\nu}}{\Lambda^2} \\ \\ \dfrac{Q_L^\dagger\, H \sigma_{\mu\nu} u_R\, G^{\mu\nu}}{\Lambda^2} \end{array}\right\}$$

extra derivatives

↓

non-SM momentum dependence

↓

different kinematics

↓

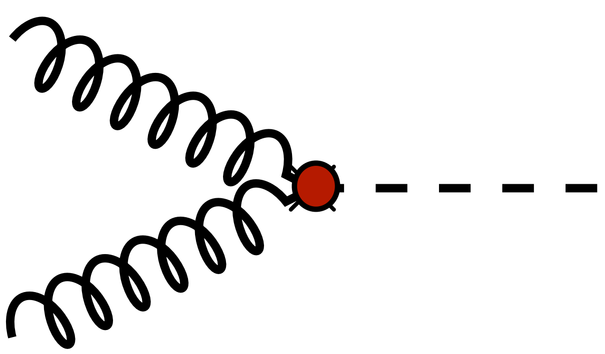
different acceptance

bounds from μ are less clear:

what are the effects? what's allowed?

Ex 1: Higgs + jet

[Banfi, AM, Sanz ’13],
[Azatov & Paul ‘13],
[Grojean et al ‘13]



if there are competing new physics effects such that

$$hG_{\mu\nu}G^{\mu\nu} \sim hG_{\mu\nu}G^{\mu\nu}{}_{SM},$$

pp → h will look just like SM

this happens in many composite Higgs/little Higgs theories!

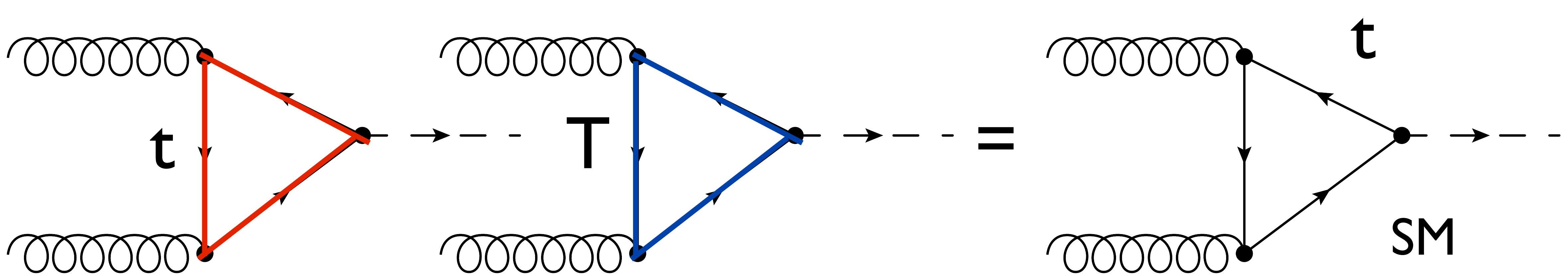
these models contain a top-quark partner $T_{L,R} = (3,1)_{-2/3}$

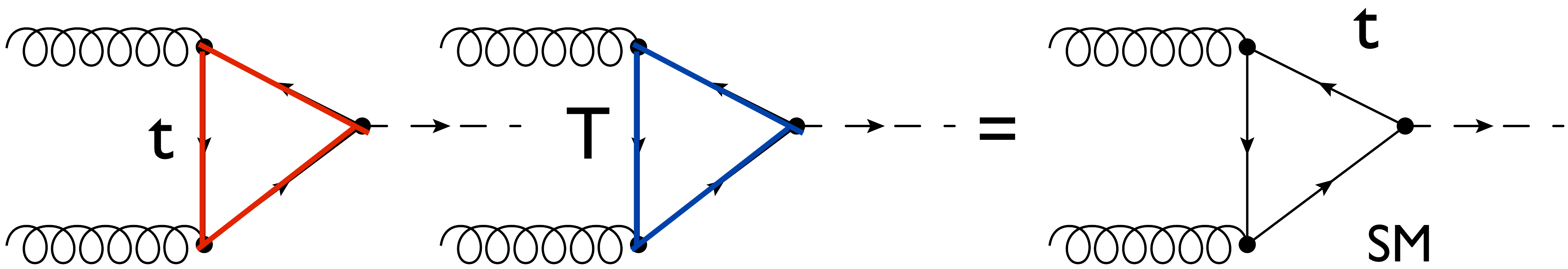
mixes with SM t_R

- top-Higgs coupling changed from SM value
- new colored fermion that couples to Higgs

} mixing angle θ_R

effects compensate each other (provided only one top-partner)





$$\cos^2(\theta_R)\; F\left(\frac{\hat{s}}{4\,m_t^2}\right) + \sin^2(\theta_R)\; F\left(\frac{\hat{s}}{4\,M_T^2}\right)$$

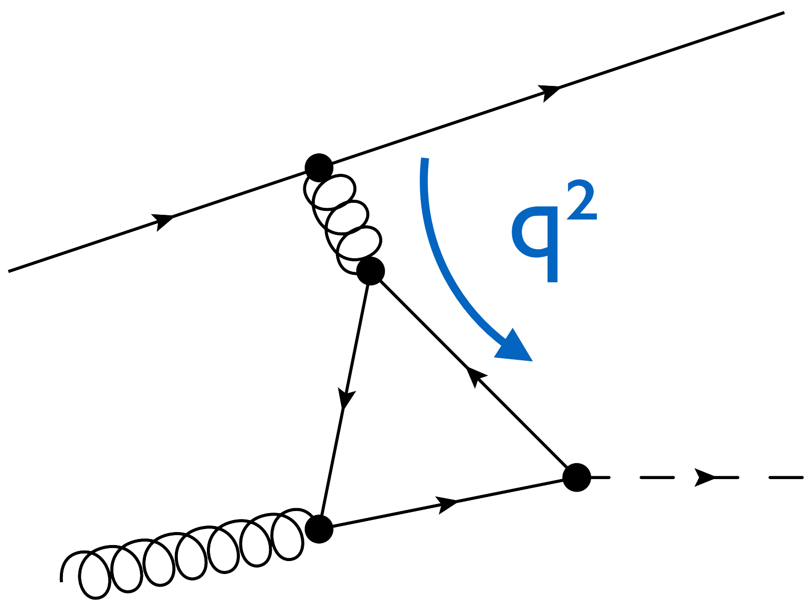
when $\hat{s} = m^2_H \ll 4\ m^2_t,\ 4\ M^2_T$, $F \sim F(0) = \text{const.}$

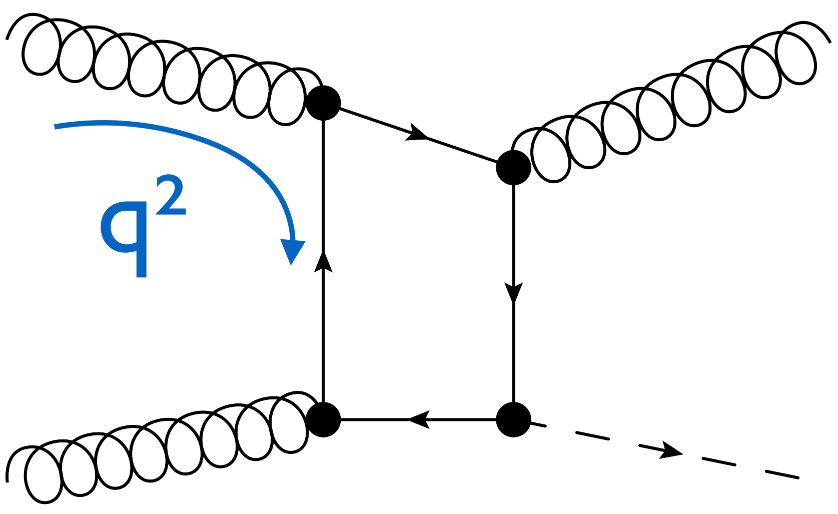
effect of mixing vanishes

$$\cong \Big(\sin^2(\theta_R) + \cos^2(\theta_R)\Big)\, F(0)$$

don’t see the effects of the extra state

but: cancellation breaks breaks down once we include energetic radiation

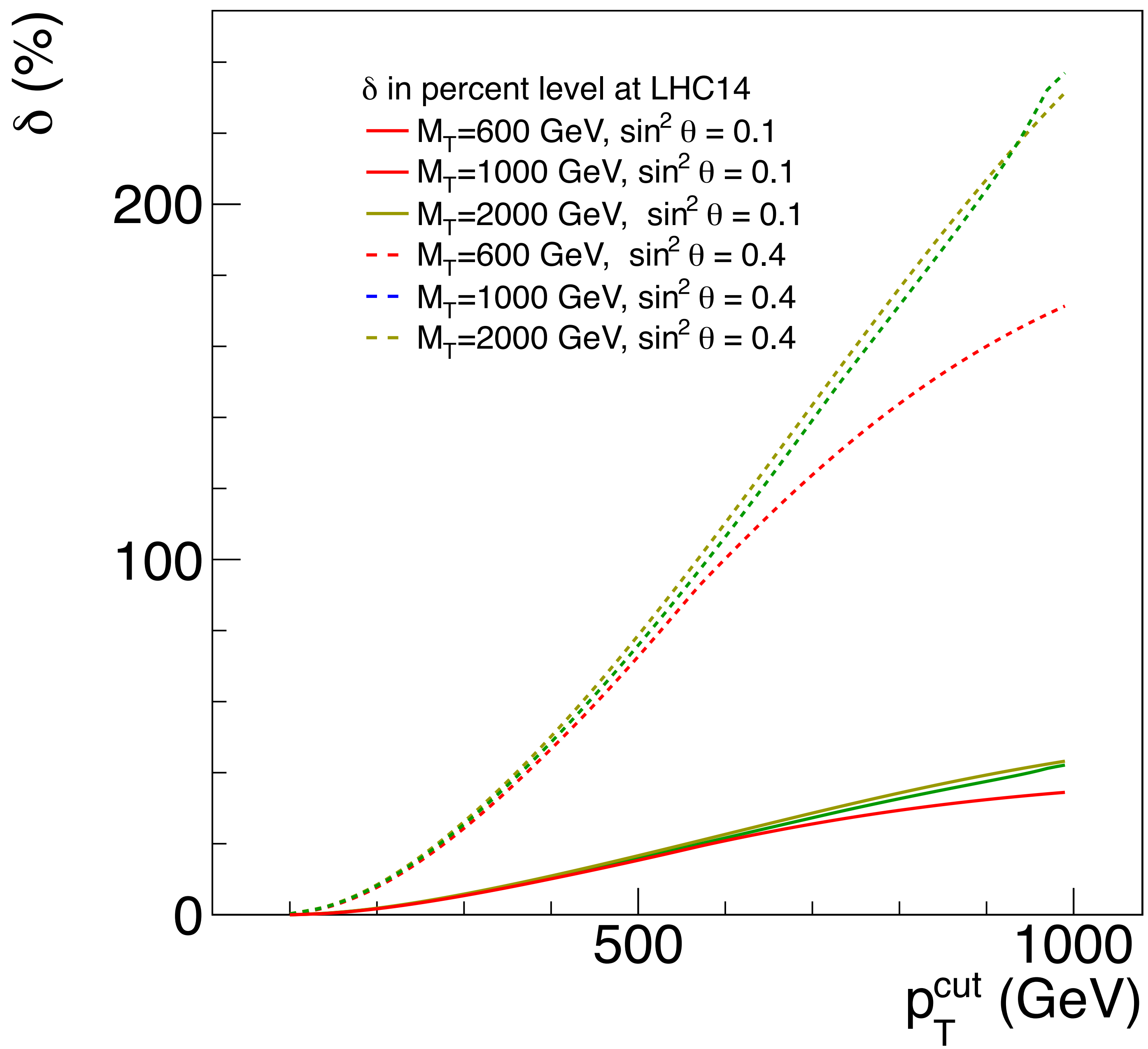




once $\hat{s} \sim q^2 \sim 4m^2_t$, $F(\hat{s}/4m^2_t) \neq F(0)$,
h + jet becomes sensitive to θ_R

$$\cos^2(\theta_R)\; F\left(\frac{\hat{s}}{4\,m_t^2}\right) + \sin^2(\theta_R)\; F\left(\frac{\hat{s}}{4\,M_T^2}\right)$$

so, Higgs + jet can reveal new physics that gg → h misses



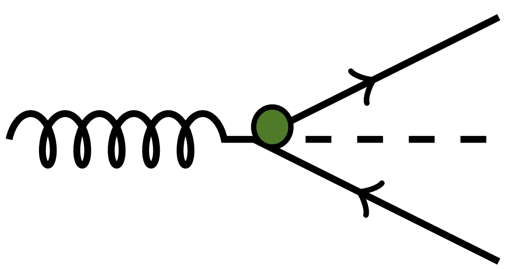
δ = how many Higgses with $p_T > p_{T,cut}$ compared to SM

[Banfi, AM, Sanz 1308.4771]

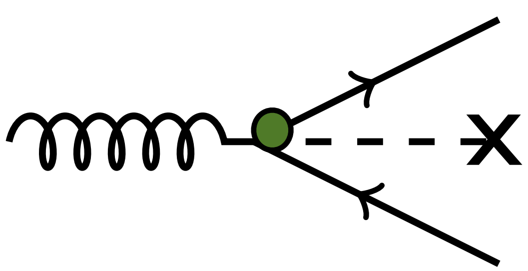
Ex. 2: chromomagnetic dipole for heavy quarks

$$c_{hgb} \quad \frac{y_b\, Q_L^\dagger\, H \sigma_{\mu\nu} b_R\, G^{\mu\nu}}{\Lambda^2}$$

(bottom-up)



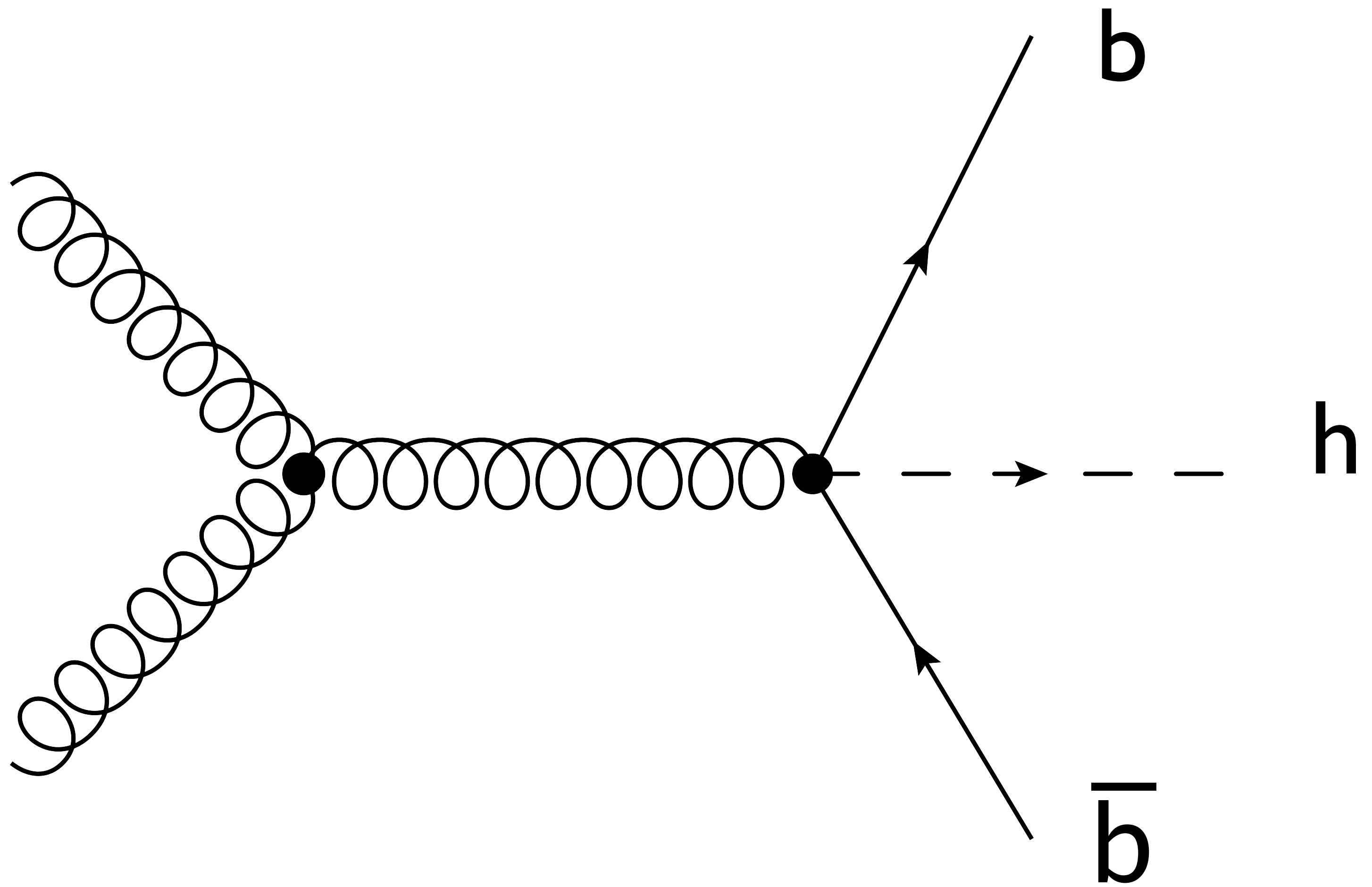
'chromo-magnetic moment' operator.. new 4-point vertex between $b\,\bar{\mathbf{b}}$, H and G



setting Higgs to vev, nonstandard $b\bar{\mathbf{b}}$ g interaction

(also vertices w/ 2 gluons)

at the LHC, new source of $b\bar{b}h$ production

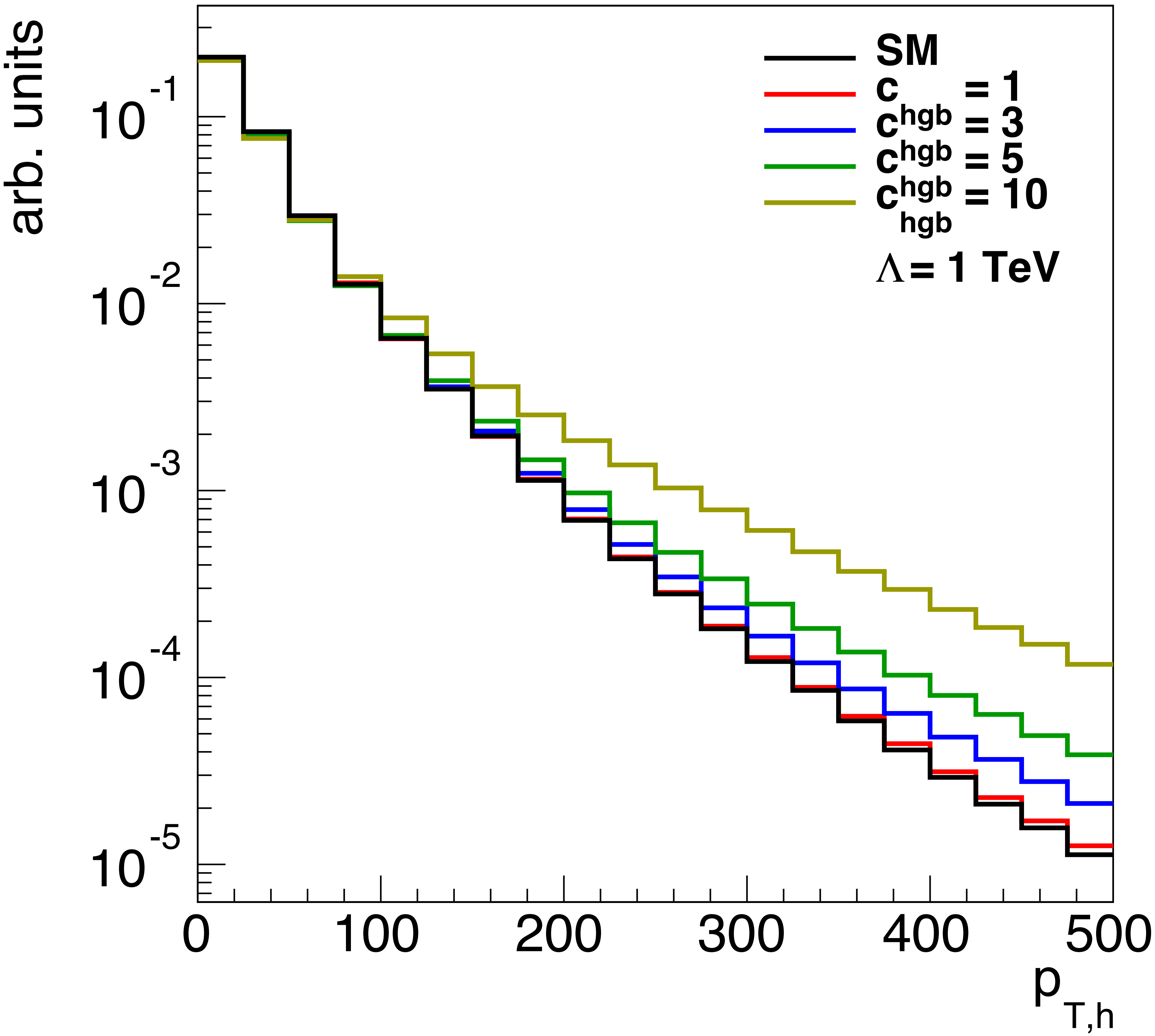


$$\sigma_{SM}(pp \rightarrow b\,\bar{b}\,h) \sim 2 \times \sigma_{SM}(p\,p \rightarrow t\,\bar{t}\,h)$$

though little, if any, attention at LHC 8

(backgrounds are much worse)

8 TeV



normalization:

$$c_{hgb}\left(\frac{y_b}{\Lambda^2}\right)$$

$$\Lambda = 1\,\mathrm{TeV}$$

$$\cong\ c_{hgb}\left(\frac{1}{(6\,\mathrm{TeV})^2}\right)$$

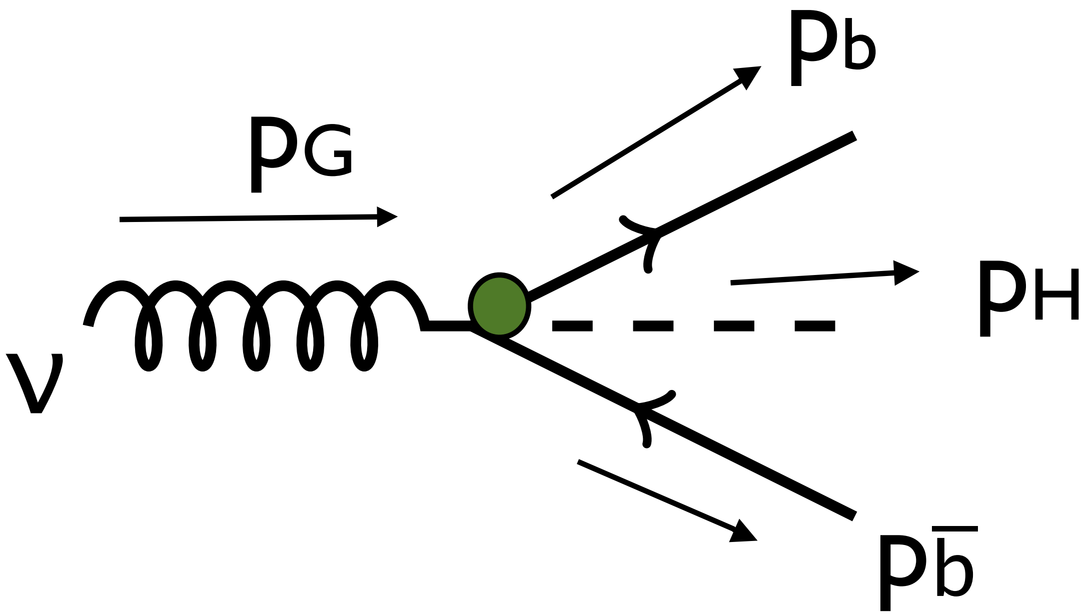
harder Higgs p_T spectrum

[Bramante, Delgado, Lehman, AM 1410.3484]

why this effect?

$$Q^\dagger H \sigma_{\mu\nu} b^c G^{\mu\nu} \sim \bar{u}(p_b)[\gamma_\mu, \gamma_\nu]\, v(p_{\bar{b}})\, p_G^\mu\, \epsilon^\nu$$

vertex is proportional to
the gluon momentum
$= p_b + p_{\bar{b}} + p_H$

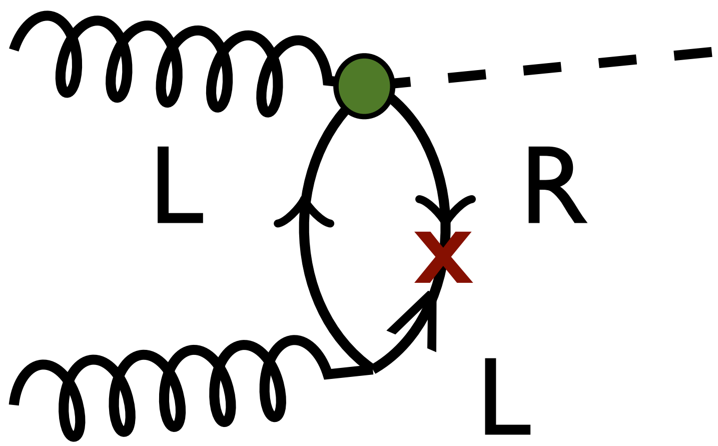


more momentum in final state → larger effect

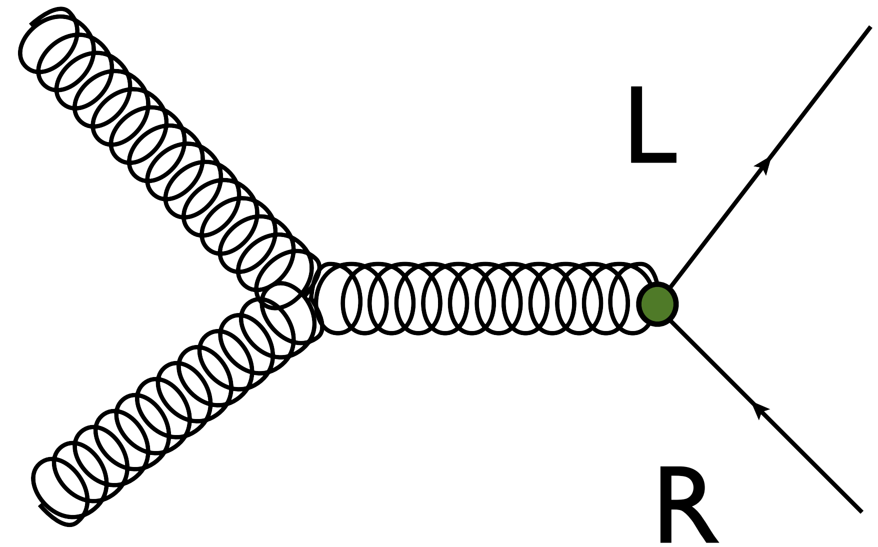
no analogous momentum dependent piece in SM

Other effects?

contribute to gg → h

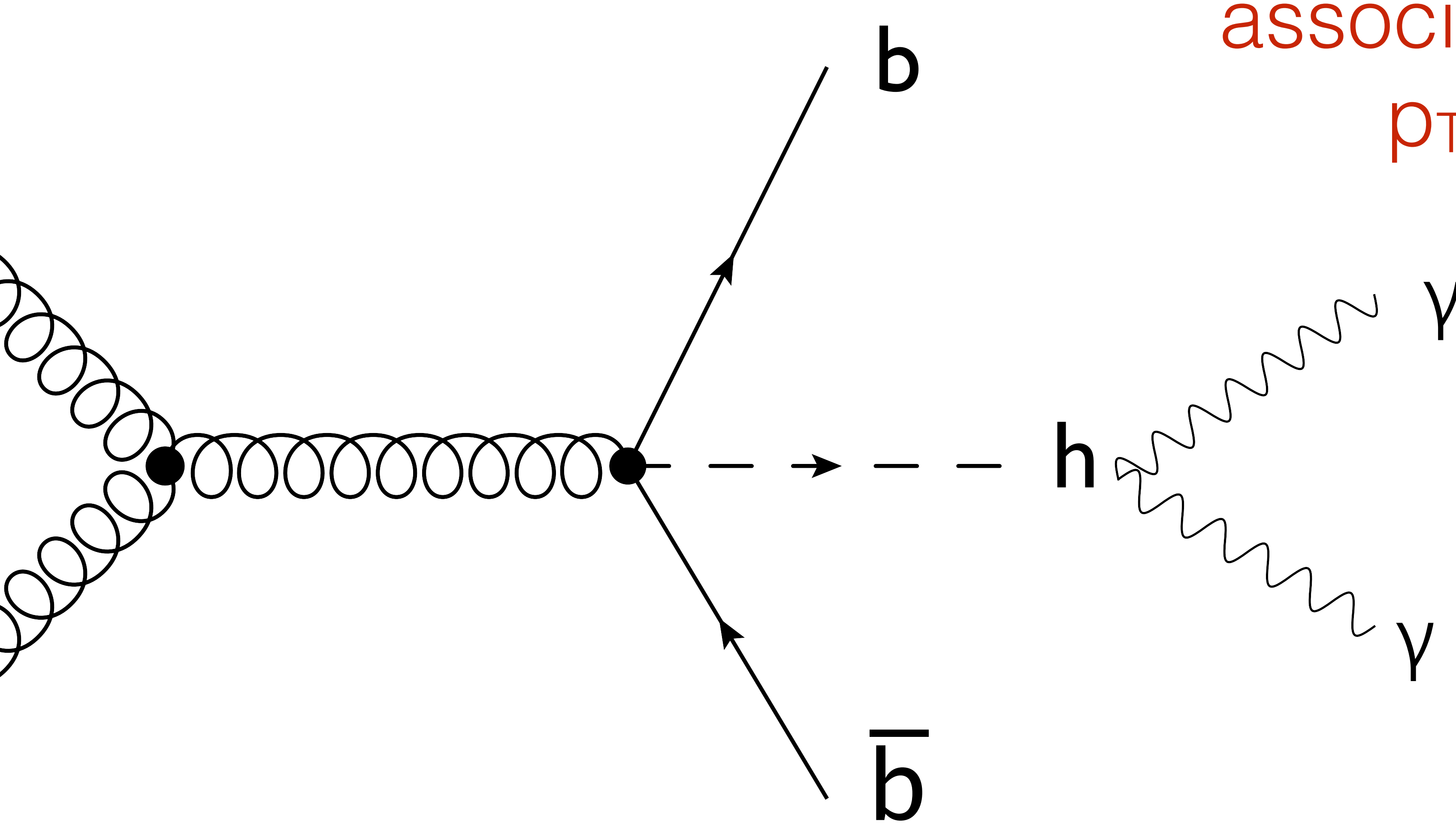


and to pp → $b\bar{b}$



but chromomagentic operators have different chirality structure (LR) than SM (LL, RR), interference suppressed by y_b → small!

∴ opportunity to discover/bound chromo-b at LHC14 search for **highly boosted** Higgses produced in association with 2 b-jets $p_{T,H} > 200$ GeV



which Higgs final state is the best to look in?

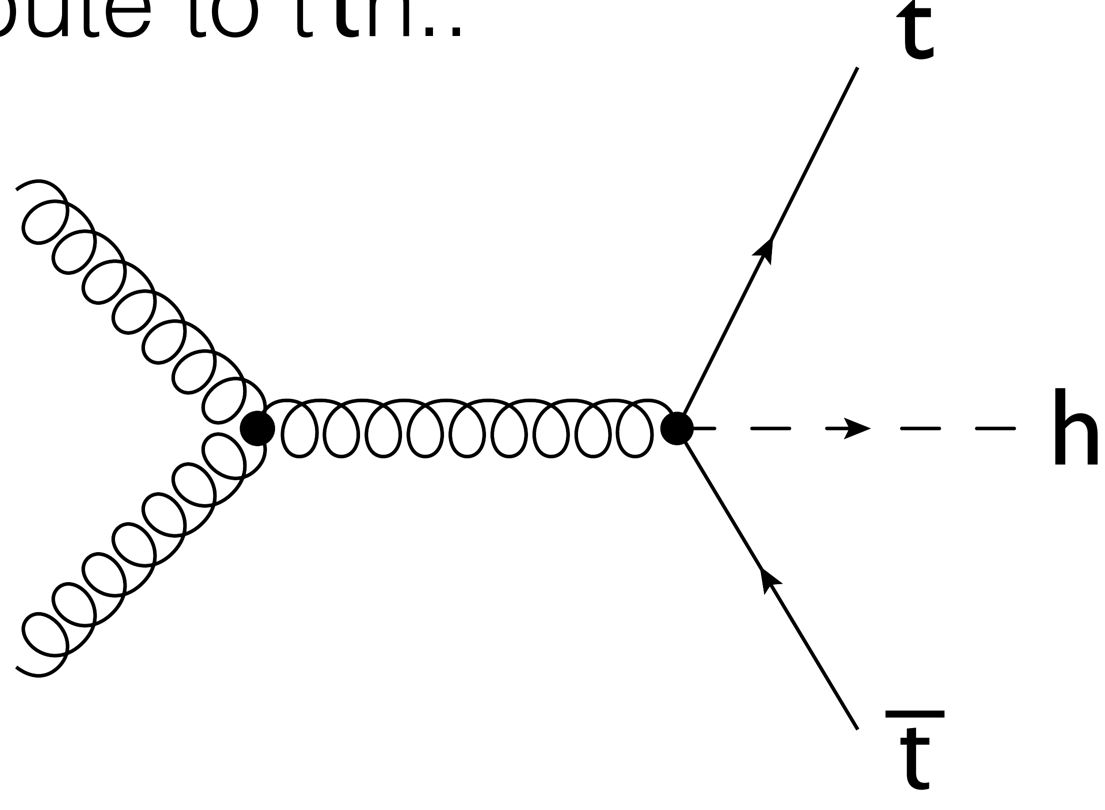
$h \to \gamma\gamma$ is very clean, but rare: sensitive to $\Lambda = 3$ TeV by the end of the LHC run. Very statistics limited

other decay modes ($h \to \tau\tau$) may be better!

Ex. 3: what about top quark chromo-dipole?

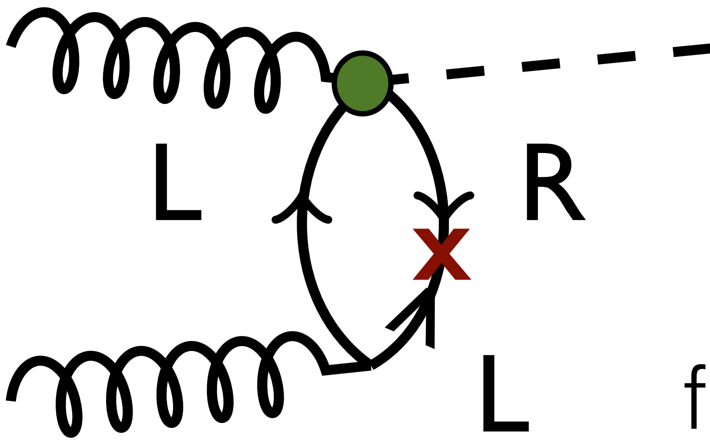
$$c_{hgt}\, y_t \,\frac{Q^\dagger\, H\, \sigma_{\mu\nu}\, t^c\, G^{\mu\nu}}{\Lambda^2}$$

would contribute to $t\bar{t}h$..



important process to measure since it directly measures y_t

however, as $y_t \sim 1$,



chirality mismatch is no longer a suppression

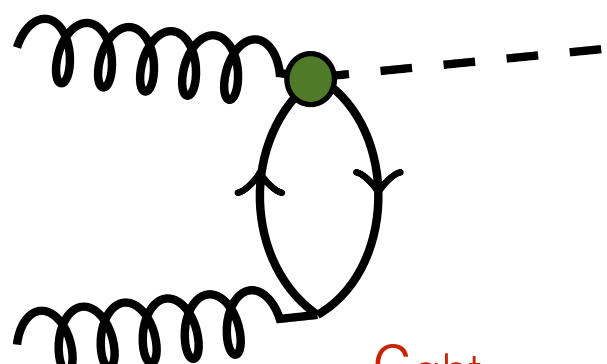
for $\Lambda \sim$ TeV, $c_{ght} \sim 1$, screws up gg → h!

Higgs kinematics still useful?

yes, as there can be cancellations

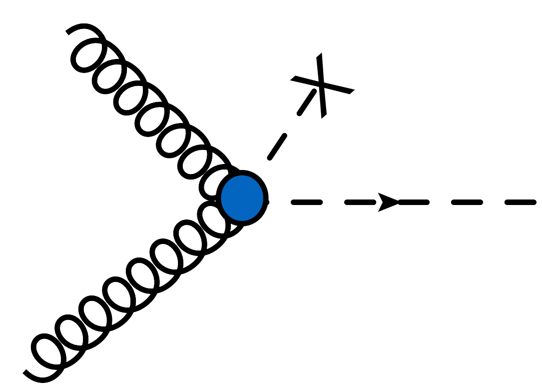
if multiple operators present, can cancel out!

{ -



c_{ght}

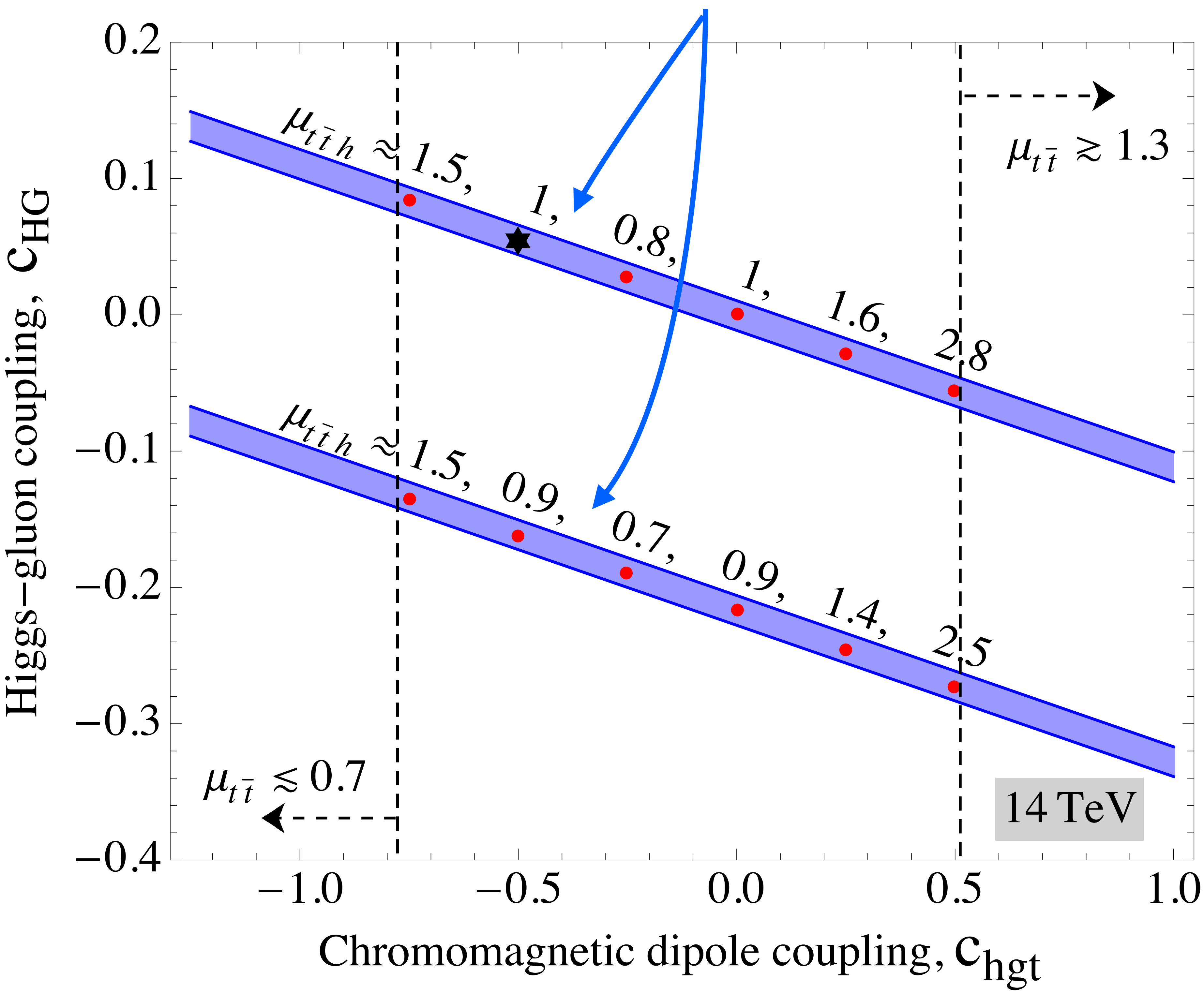
+

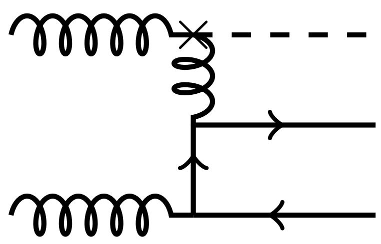


~ 0

$c_{HG} \dfrac{(H^\dagger H)\, G^{\mu\nu} G_{\mu\nu}}{\Lambda^2}$

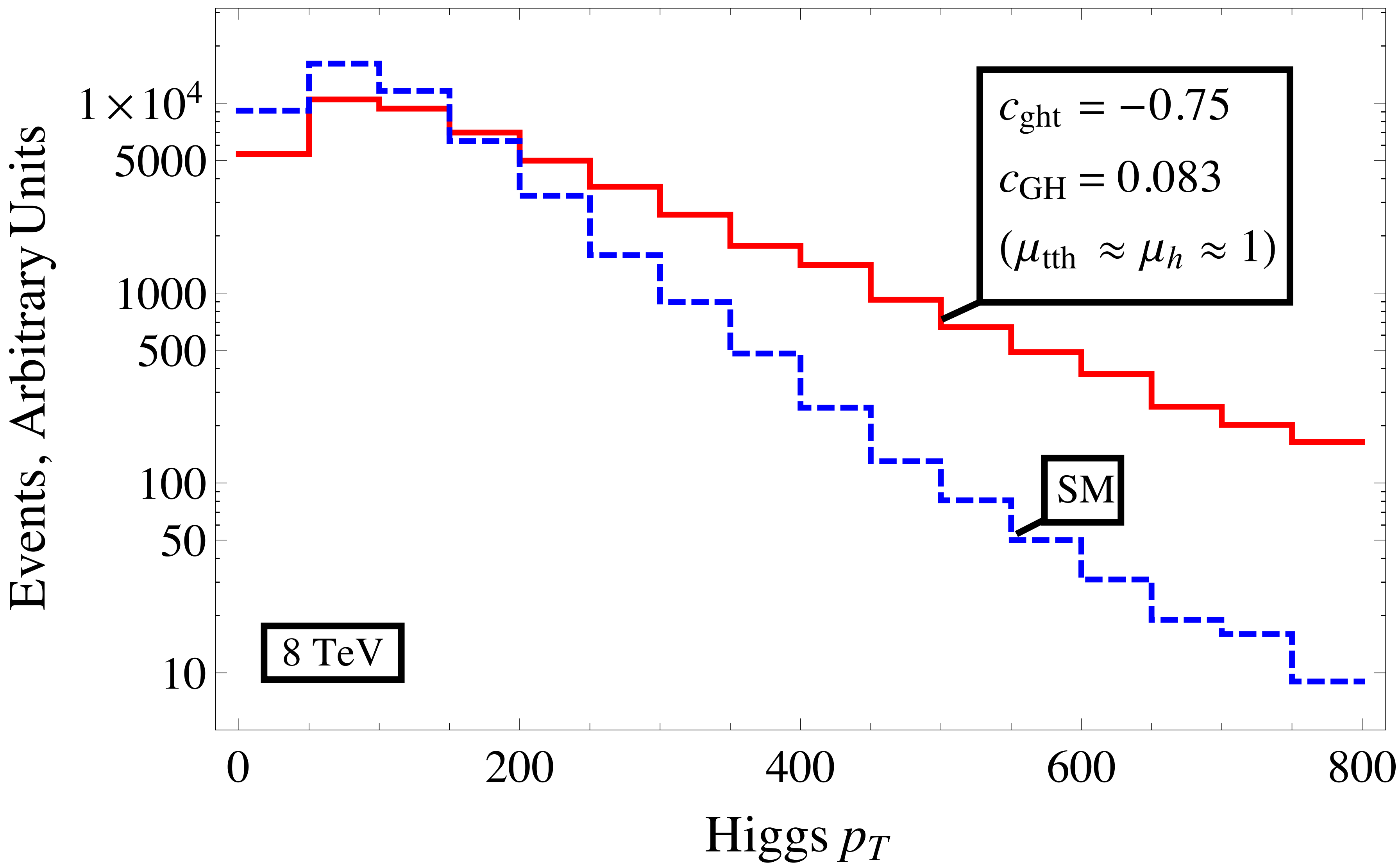
two effects cancel to some degree





assumes only HHGG and QHtG operators, Λ = TeV

Higgs distributions break degeneracy



even if pp → h and $t\bar{t}h$ cross sections match SM values, Higgs kinematics differ

[Bramante, Delgado, AM 1402.5985]

Summarizing

in the SM, **all** couplings predicted

signals strengths tell us some things, but they are not the end of the story. Higgs distributions will tell us more

Higgs p_T is a powerful observable

- reveals new physics not seen in rate alone (h+j, $t\bar{t}h$)
- useful way to test momentum-dependent effects (bbh)

THANK YOU!