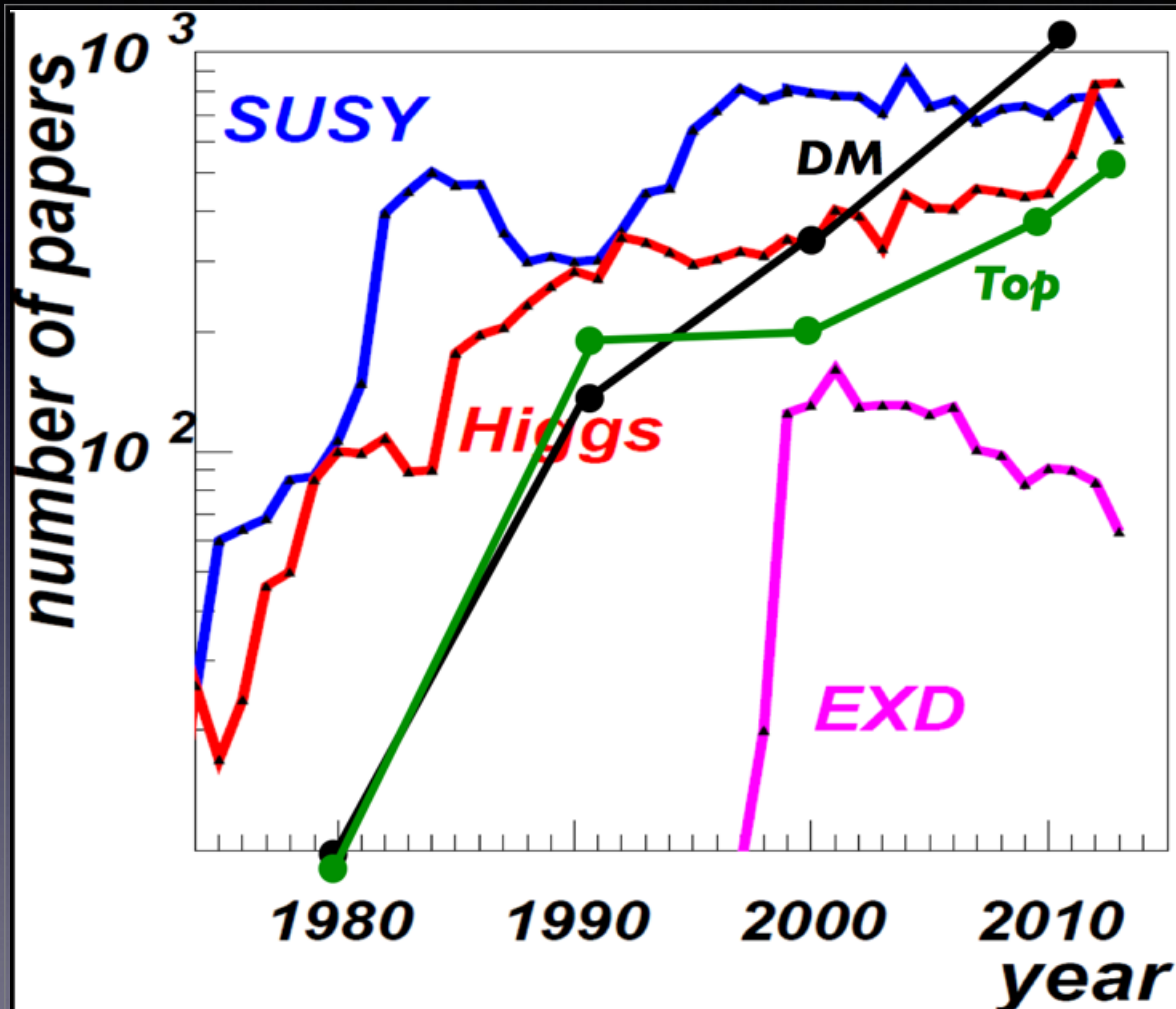
Top Yukawa Coupling and Four Top Quark Production

Qing-Hong Cao
Peking University

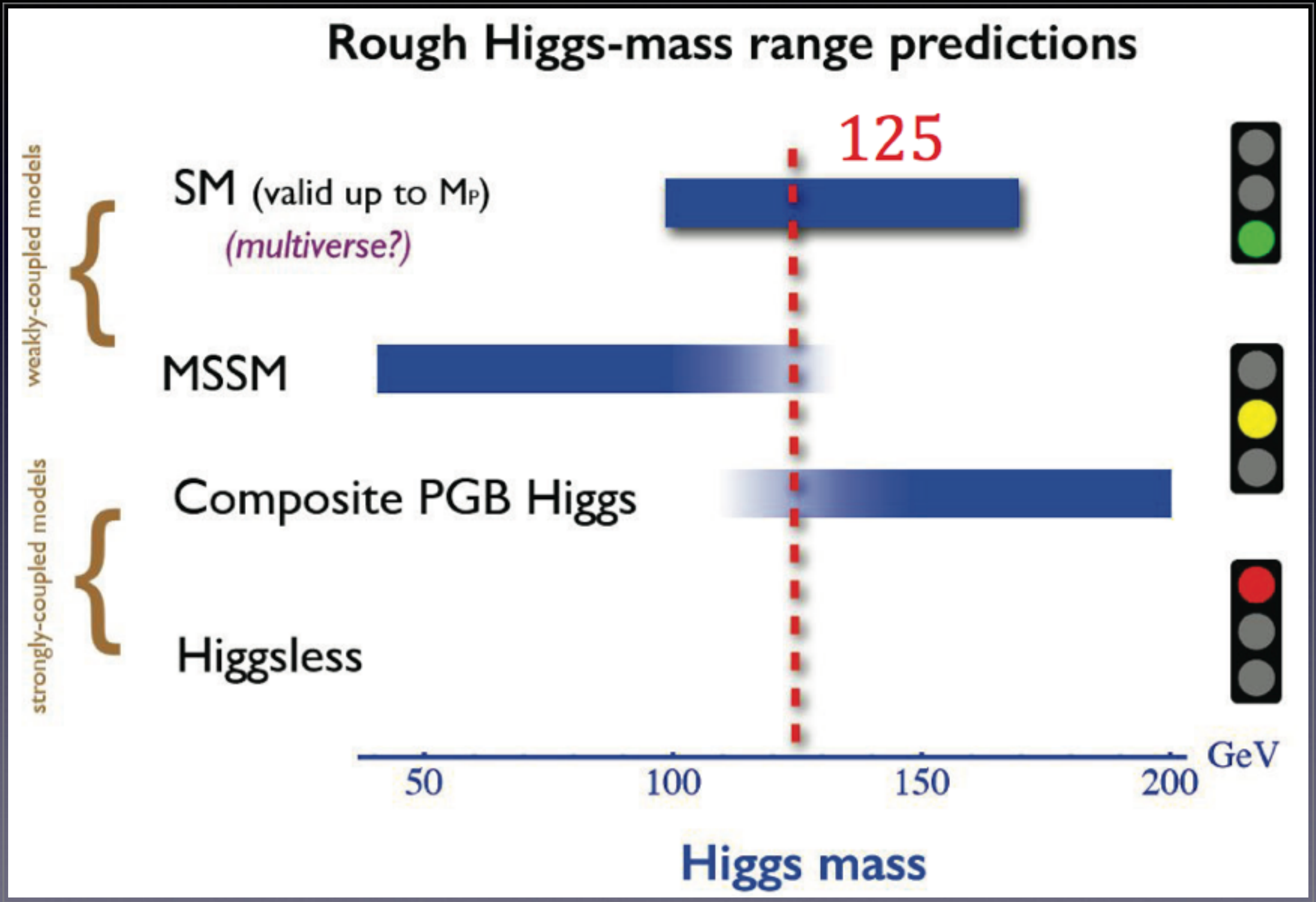
(QHC, Yandong Liu, arXiv:1410.xxxx)

1. Recent Measurements of Top Yukawa Coupling
2. Measuring/Bounding y_t in Four Top Quark Production
3. Sensitivities at LHC(14) and High Luminosity LHC

What inSpireHEP tells us



125GeV Higgs does not favor any New Physics paradigm



Pomarol, ESHEP 2014

Top Quark and Higgs Boson

SUSY, LH, Composite, RS, TC…

Weakly Interacting

Higgs
(125GeV)

Strongly Interacting

Natural NP models always have non-trial couplings between top quark and NP particles

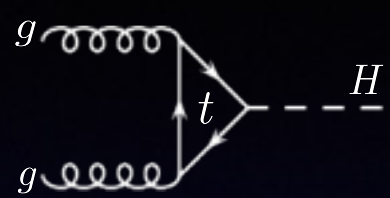
Top

Measuring Top Yukawa coupling (and its sign) is the next big step!

Effective Field Theory

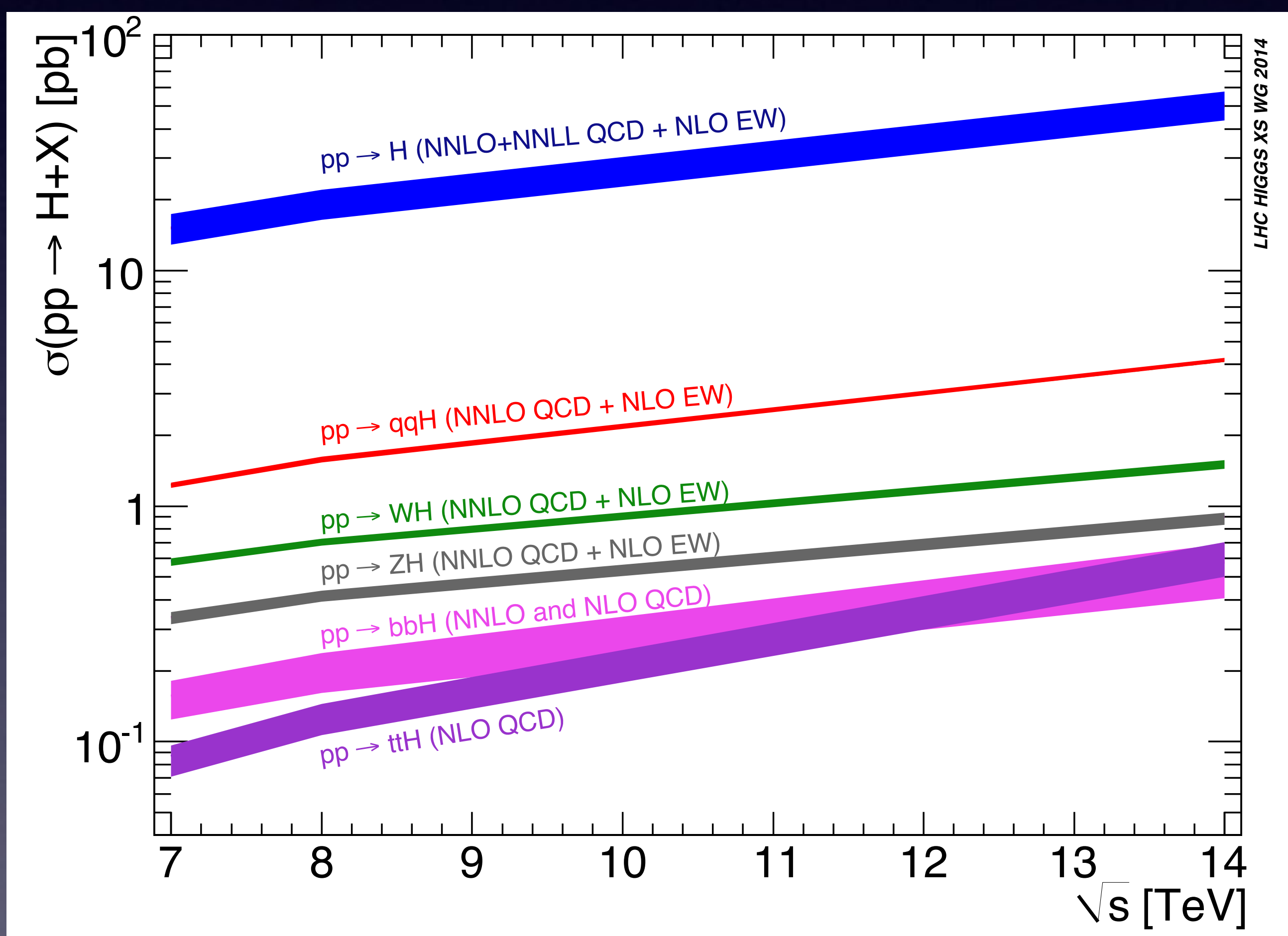
Experimental Data

Higgs Boson Production and Decay

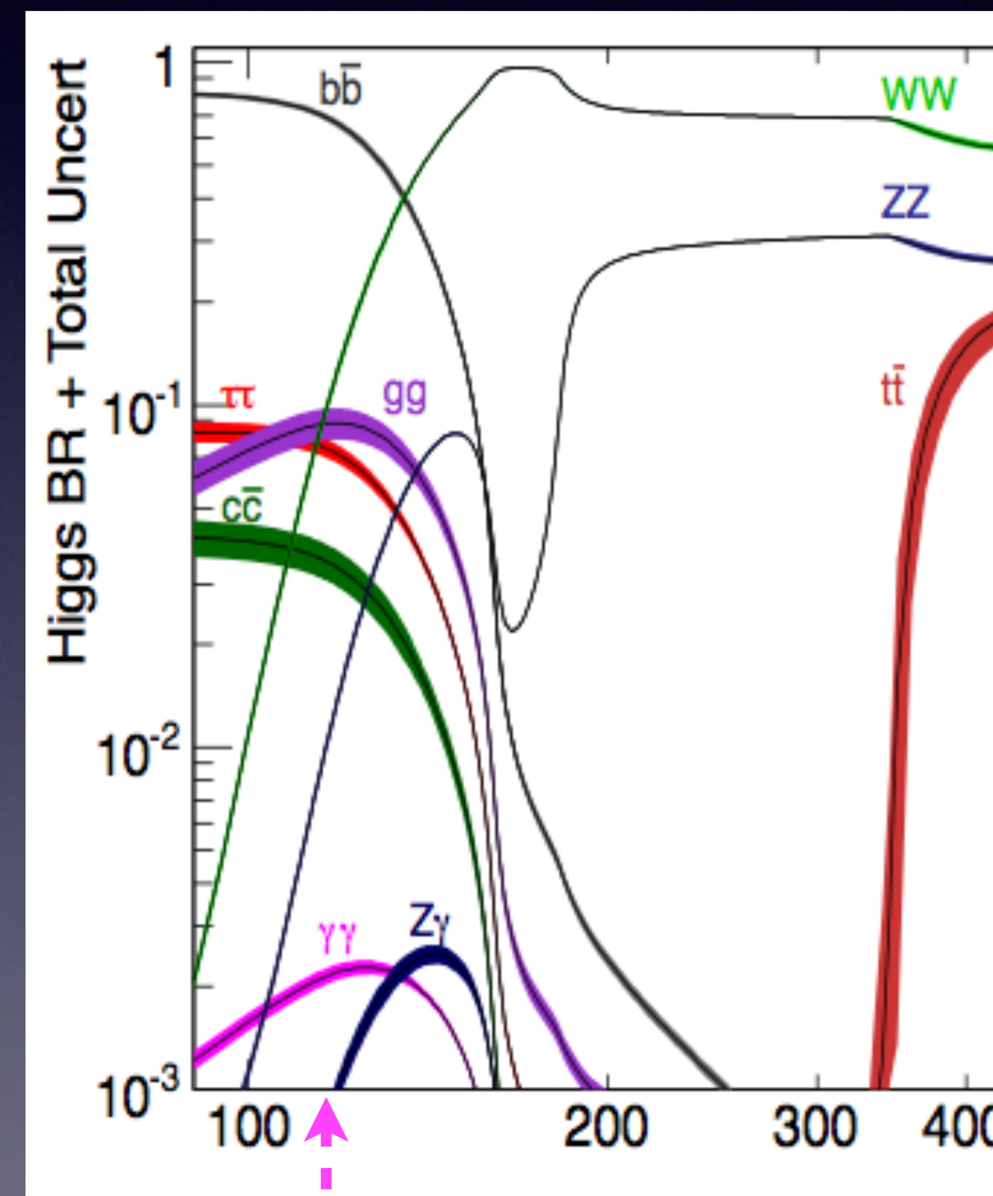


gluon-fusion

VBF

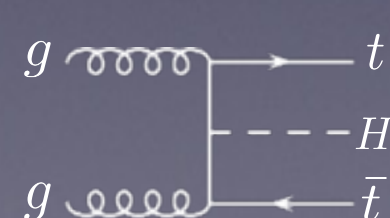


Higgs boson decay



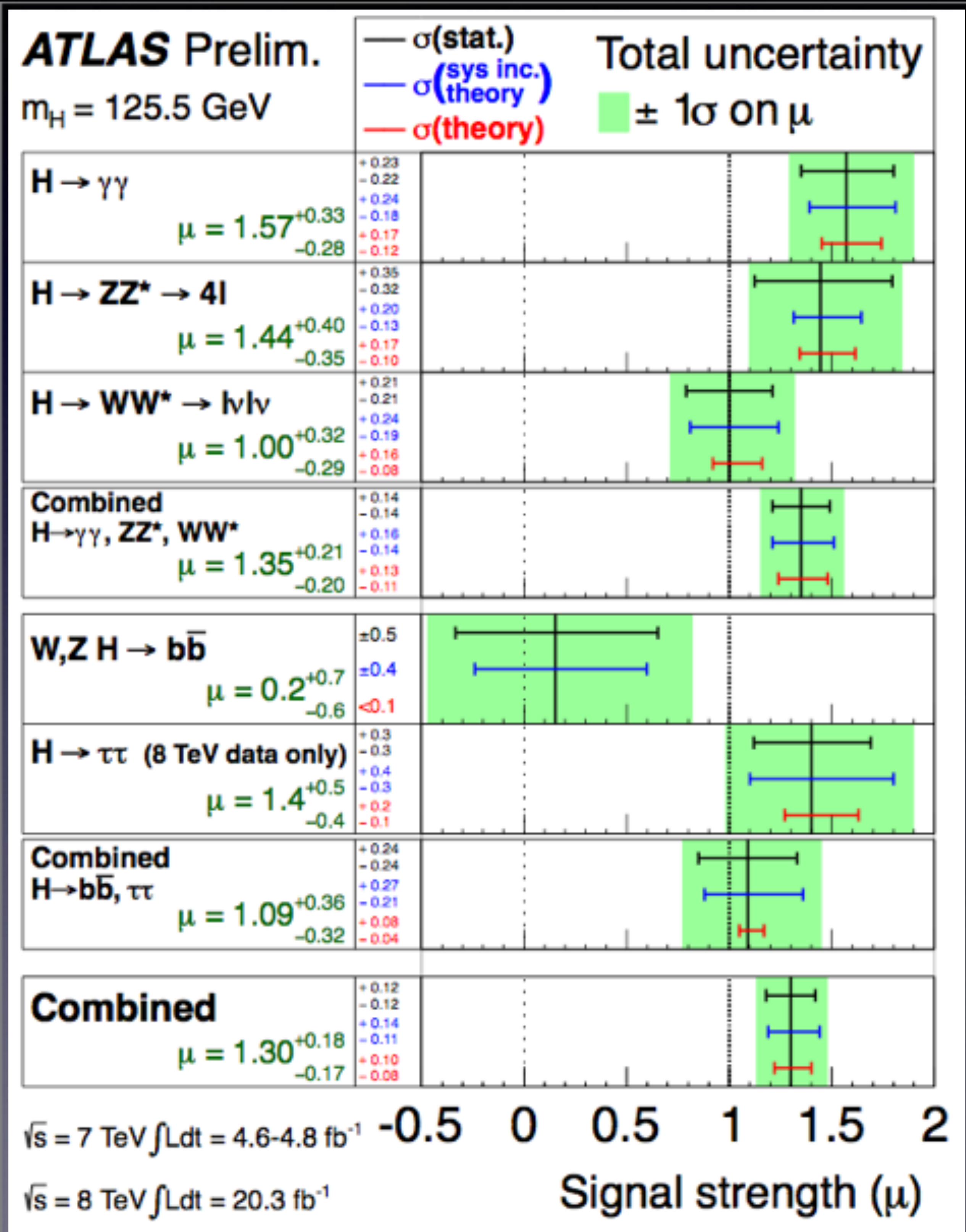
$m_H \sim 125$ GeV

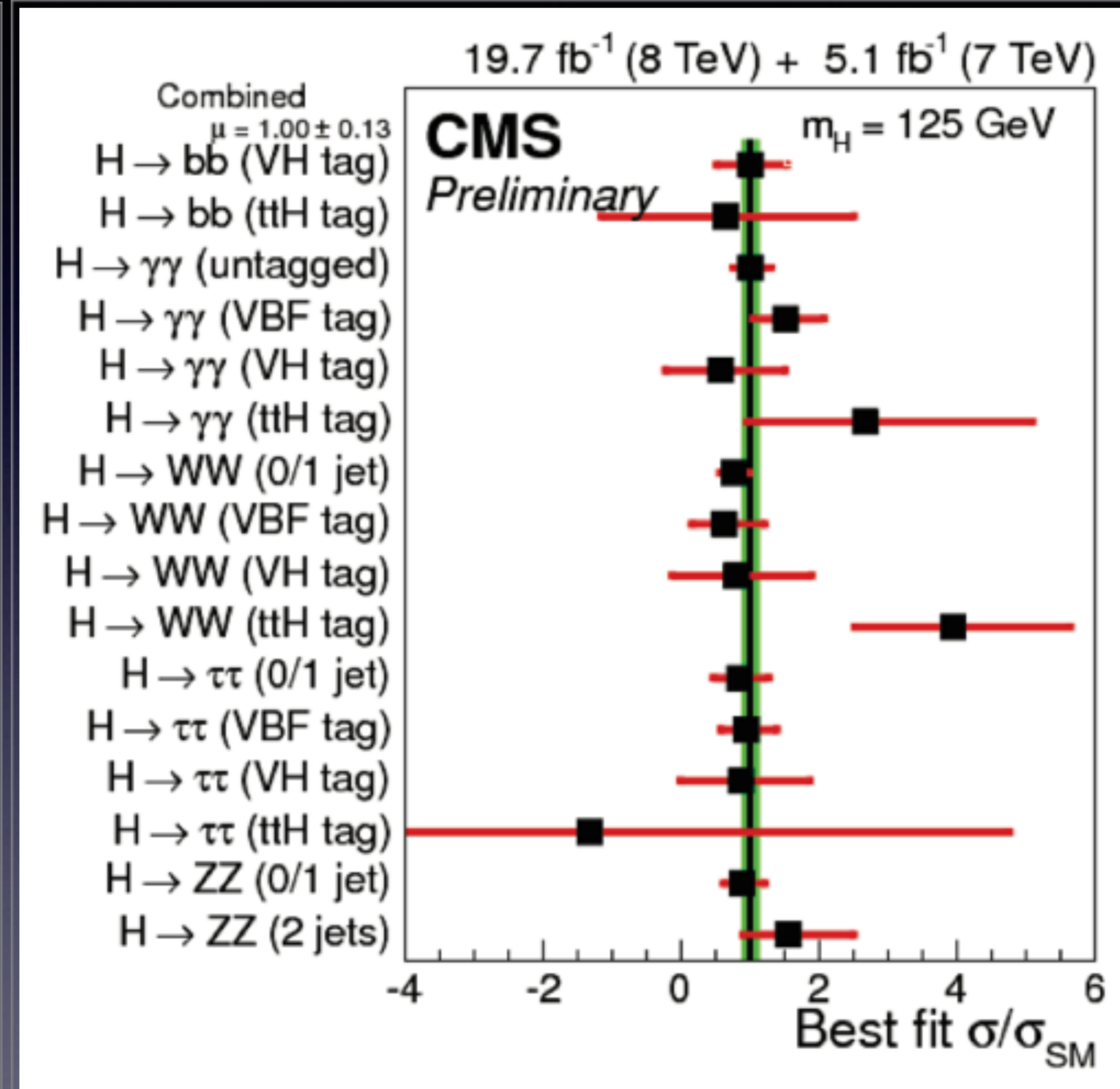
WH



ttH

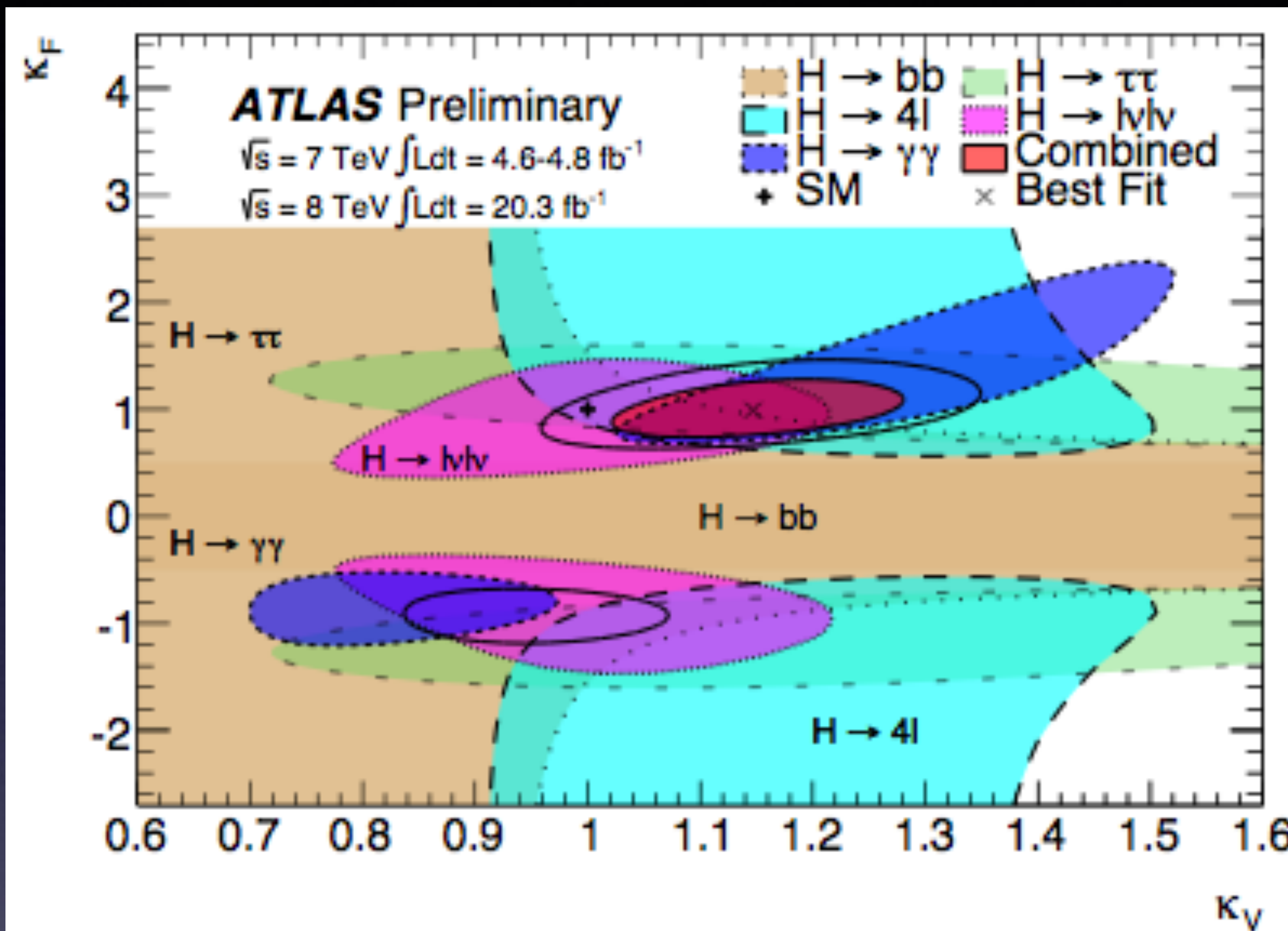
Higgs Measurements

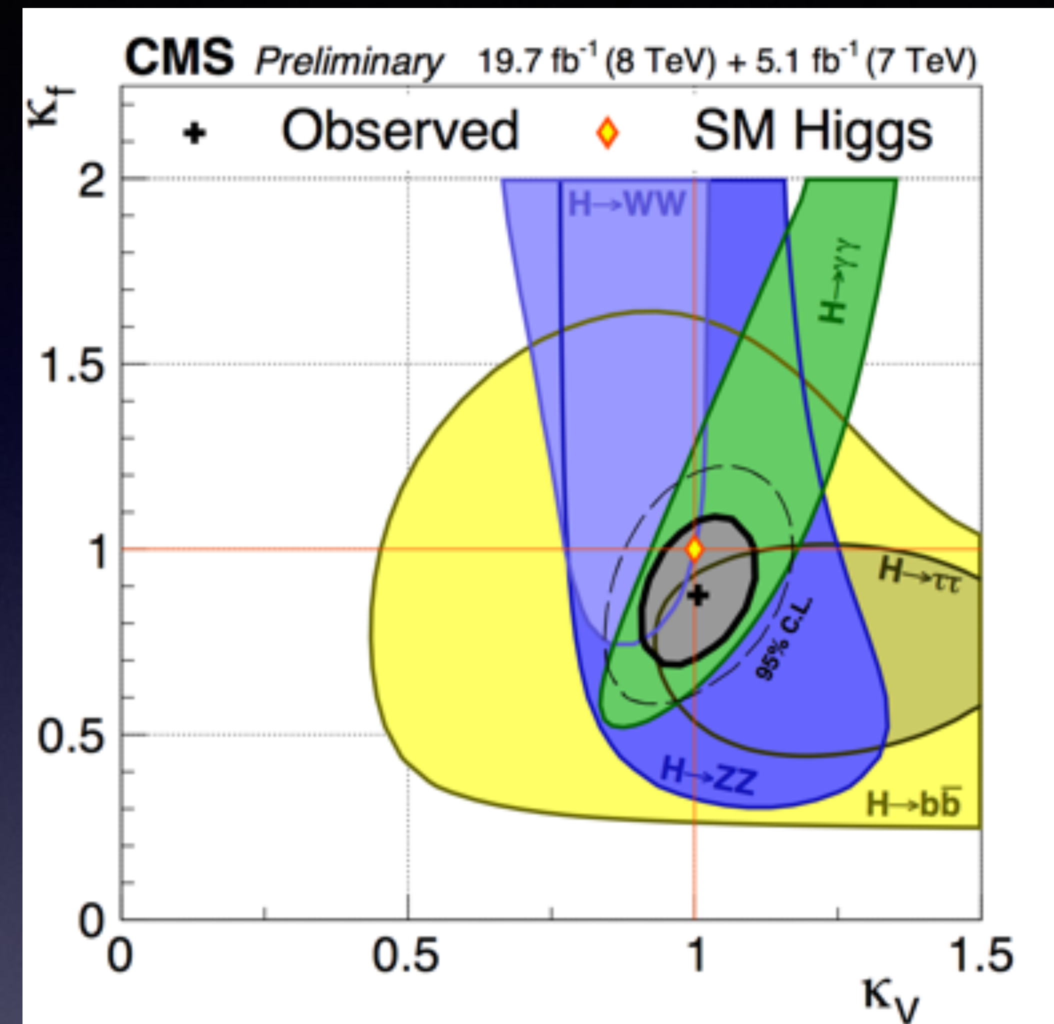




ATLAS-CONF-2014-009
CMS-PAS-HIG-14-009

Global Fit of Higgs Couplings

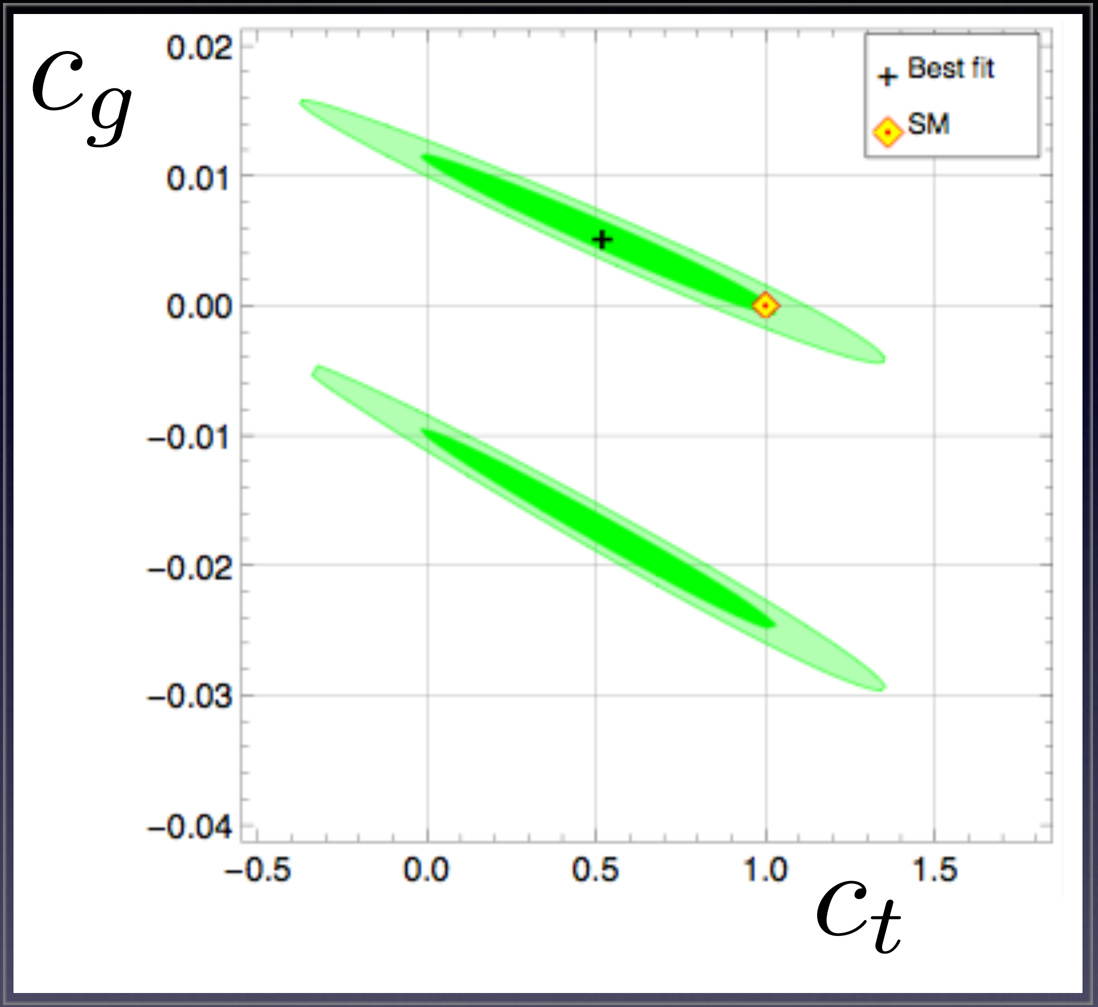




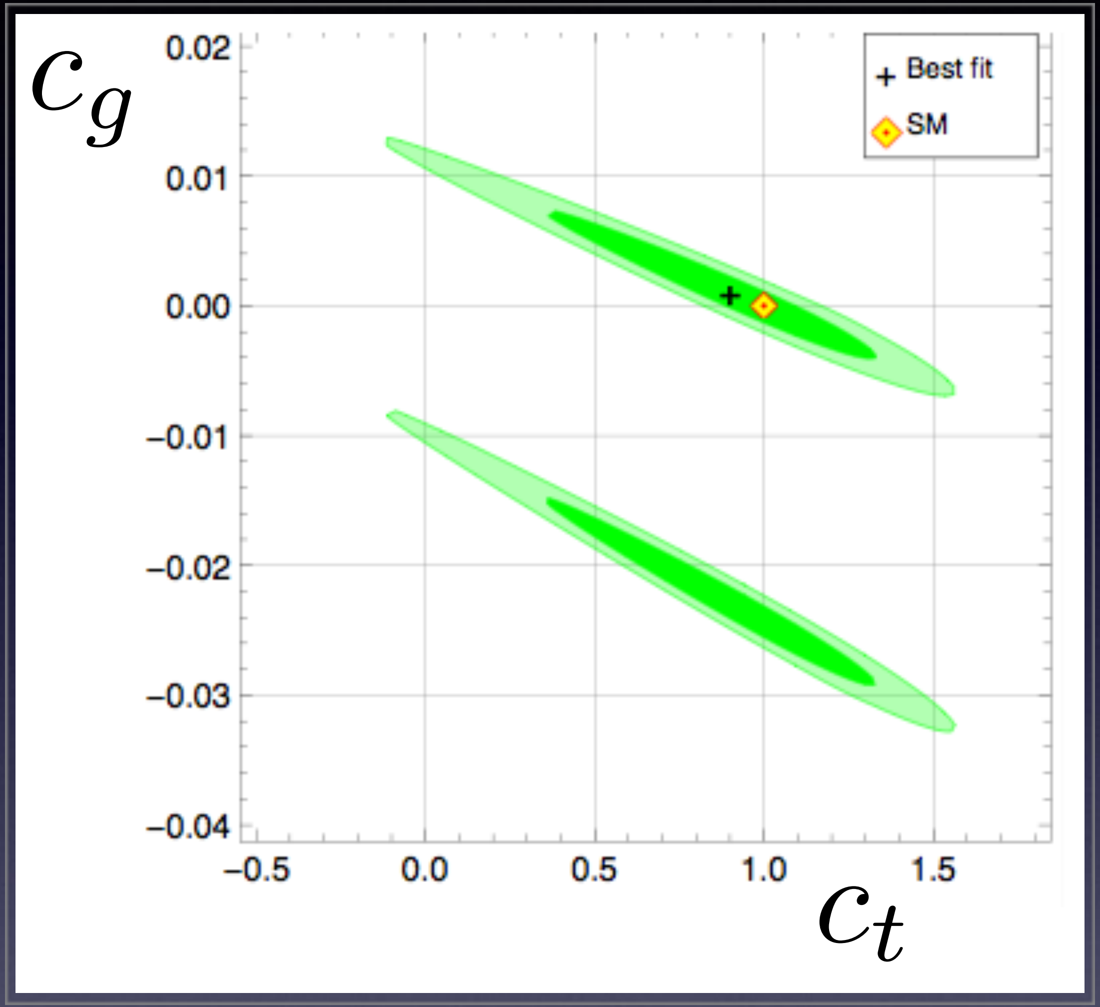
- ★ Coupling constraints from ATLAS+CMS under assumption of only SM contribution to total width
- ★ NP contributions to the loops in the $H\gamma\gamma$ and Hgg couplings could relax the bounds

Global Fit Constraint on c_t/c_g Plane

Bélusca–Maïto, 1404.5343



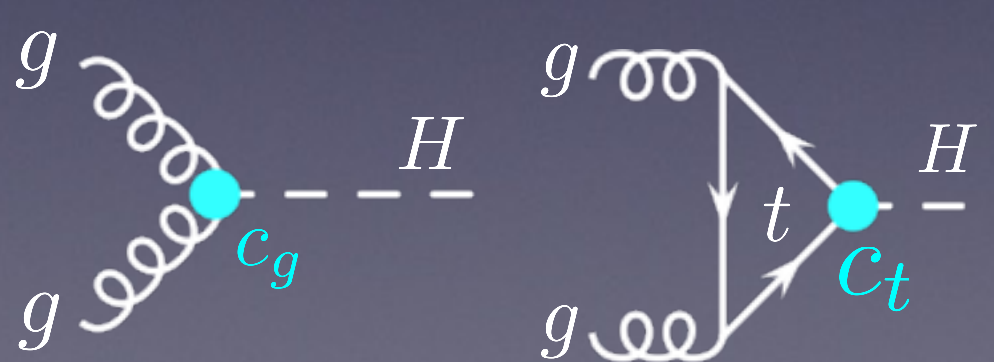
with ttH data



c_t is poorly determined

ggH could be entirely NP-driven!

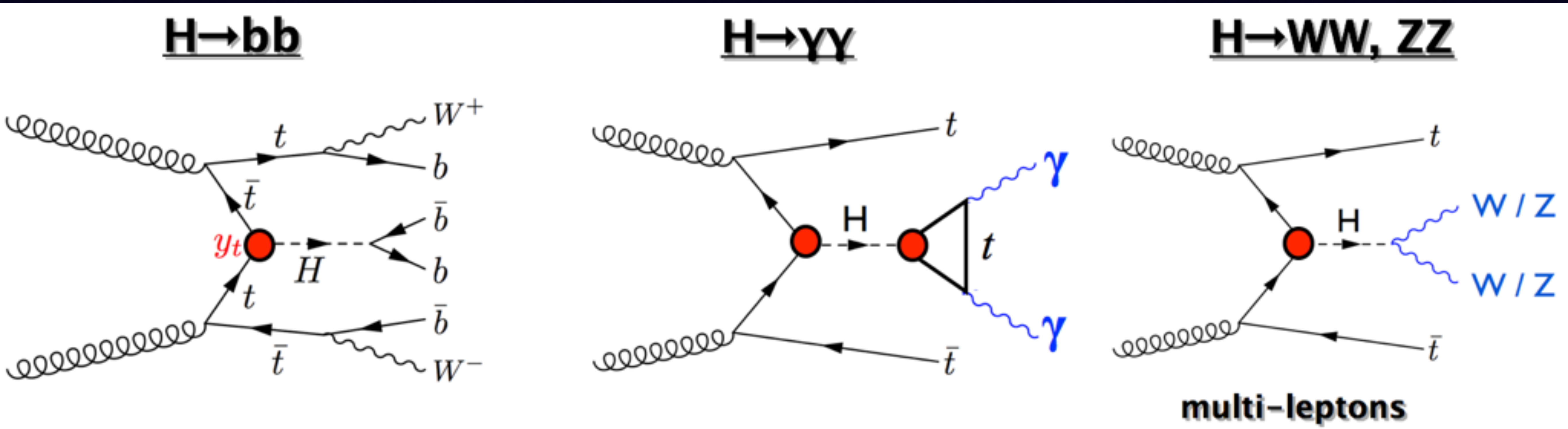
Only $\left|c_g + \frac{\alpha_s}{3\pi} c_t\right|^2$ constrained



$c_t = y_t / y_t^{\rm SM}$

Measuring c_t in ttH Production

$\sigma_{ttH}(8\ \mathrm{TeV}) \approx 127\ \mathrm{fb}$ rare rate + huge backgrounds



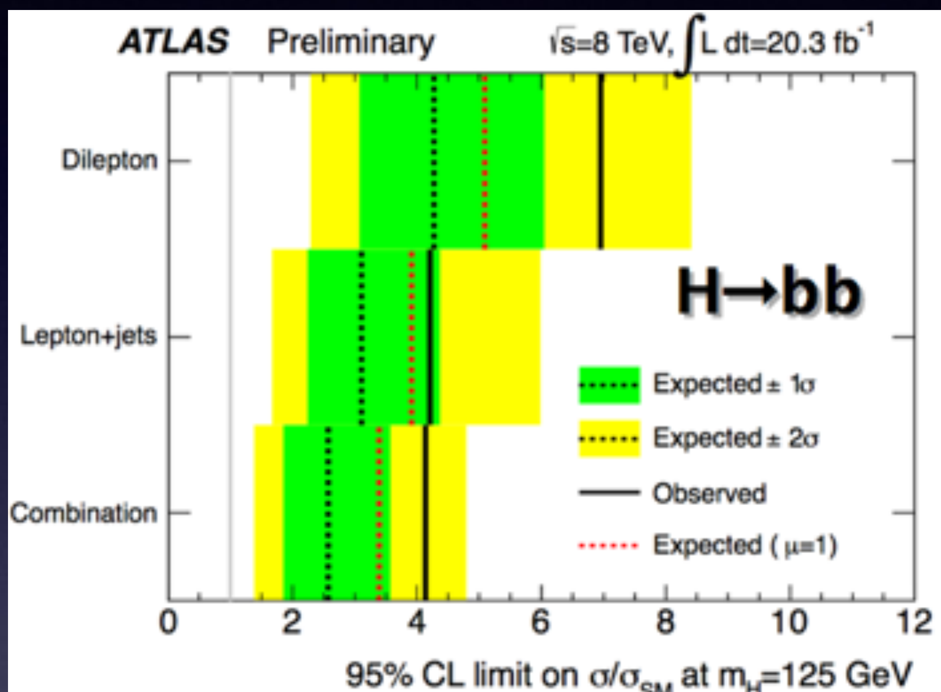
ATLAS:
ATLAS-CONF-2014-011
CMS:
arXiv:1408.1682
CMS-PAS-HIG-14-010

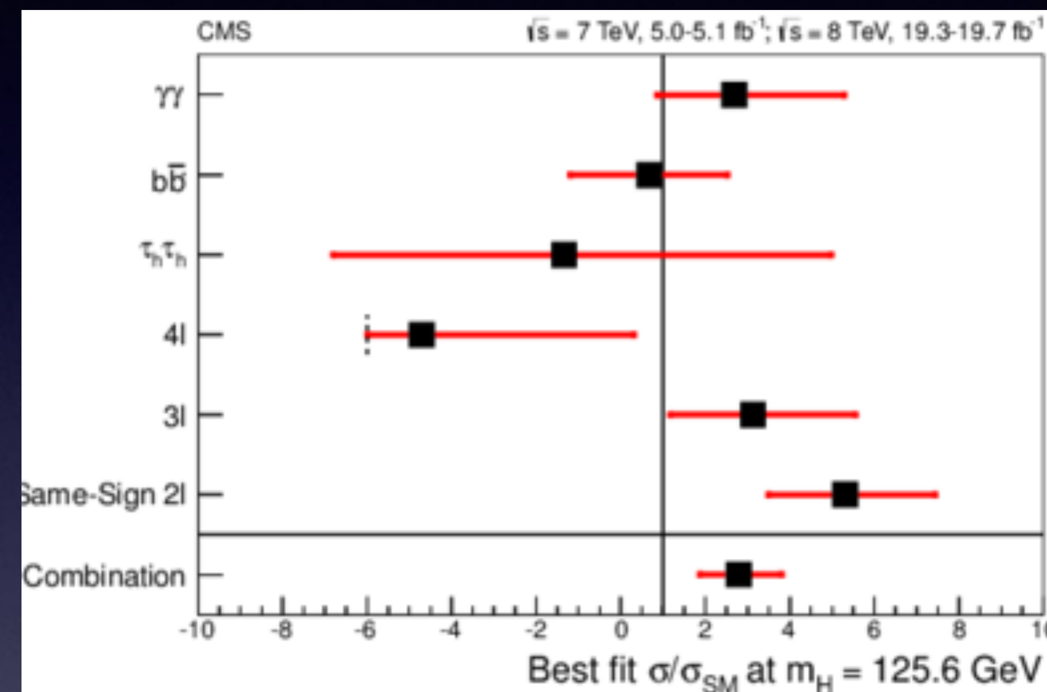
ATLAS:
arXiv:1409.3122
CMS:
arXiv:1408.1682

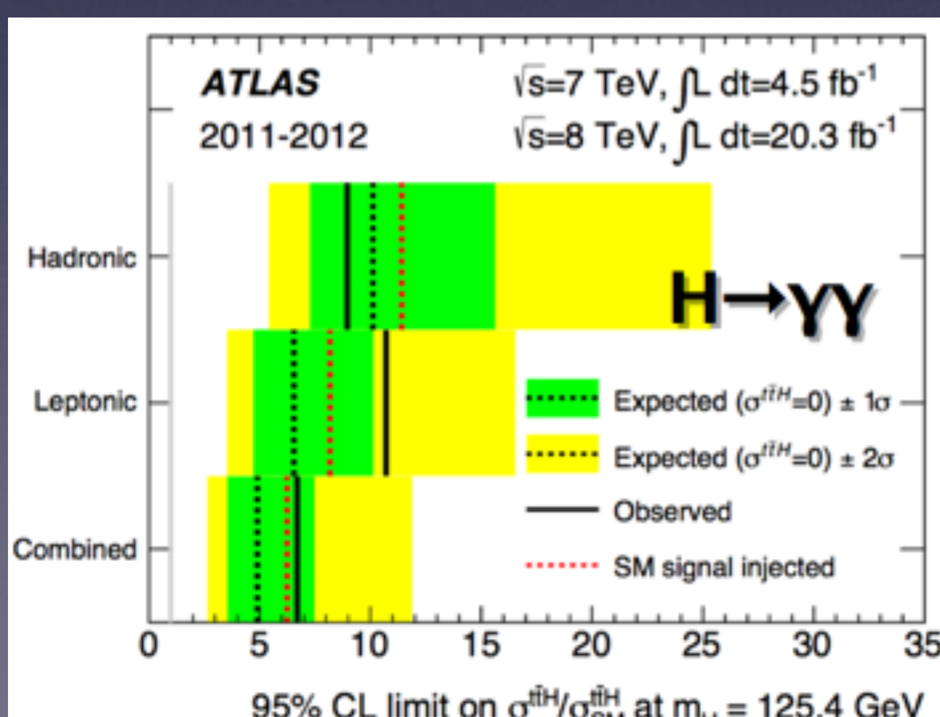
CMS:
1408.1682

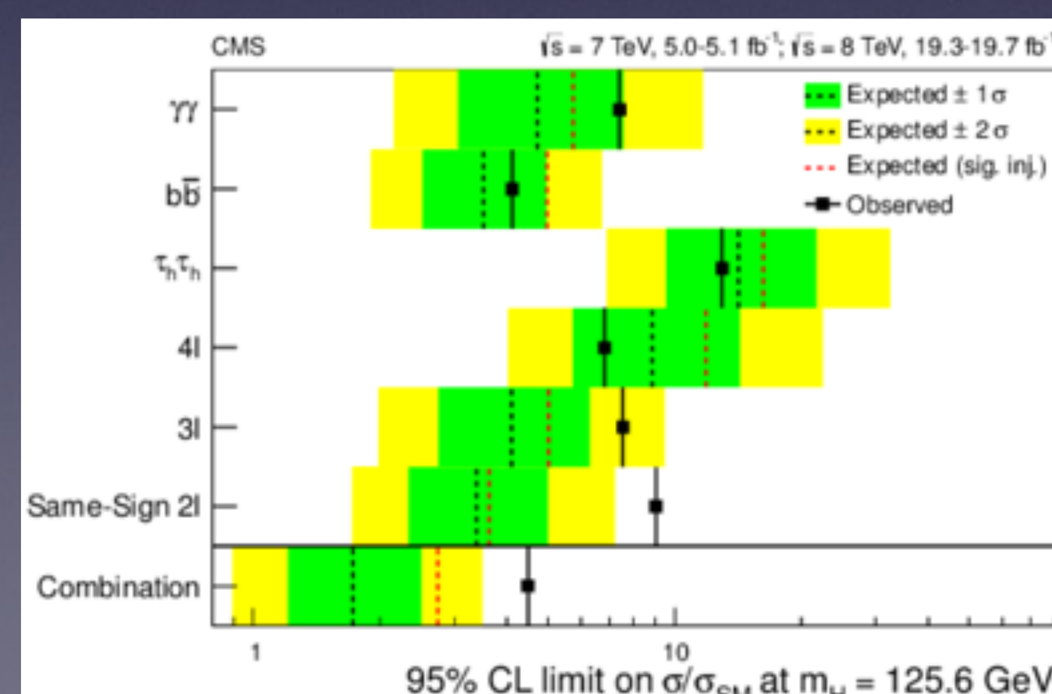
Measuring c_t in ttH Production

Assume SM Higgs branching ratio,
so free parameter is the ttH signal strength

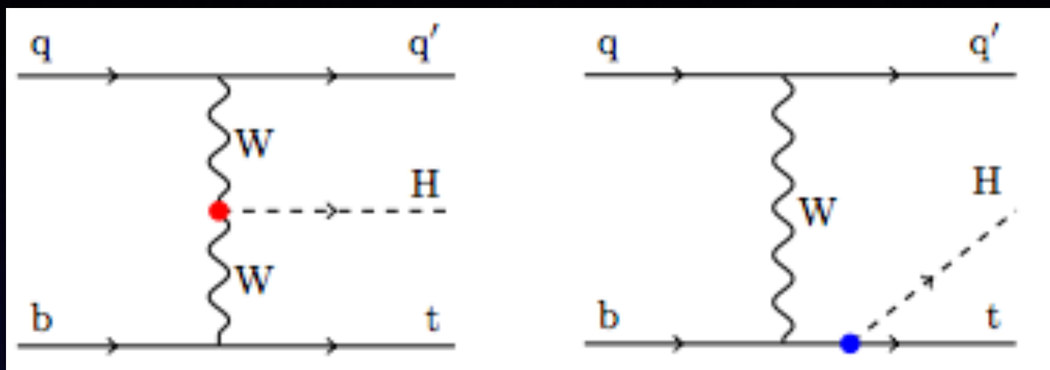








Measuring c_t in Htq Production



$$\sigma_{tHq}^{\mathrm{SM}} = 18.3\mathrm{fb}$$

$$\mathcal{M}_{tHq} \propto c_V - c_t$$

Chang, Cheung, Lee, Lu, 1403.2053

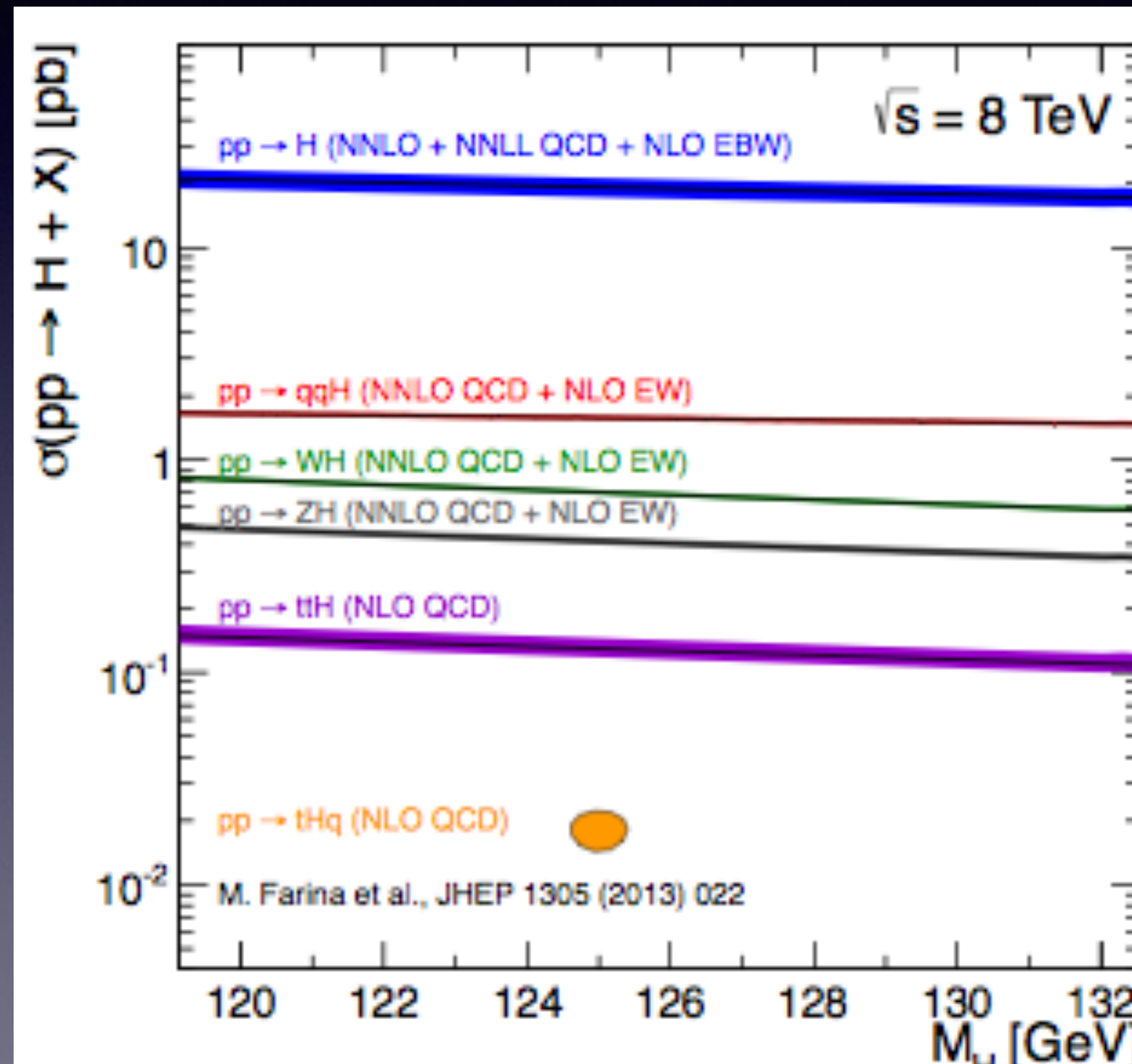
With $c_t = -1$

$$\sigma_{tHq} = 234\mathrm{fb}$$

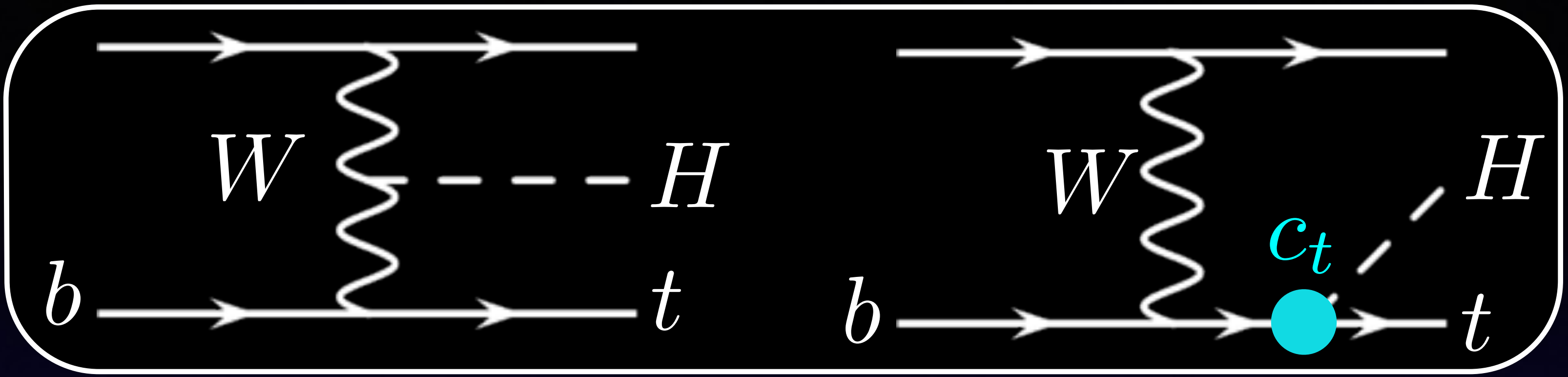
13 times enhanced

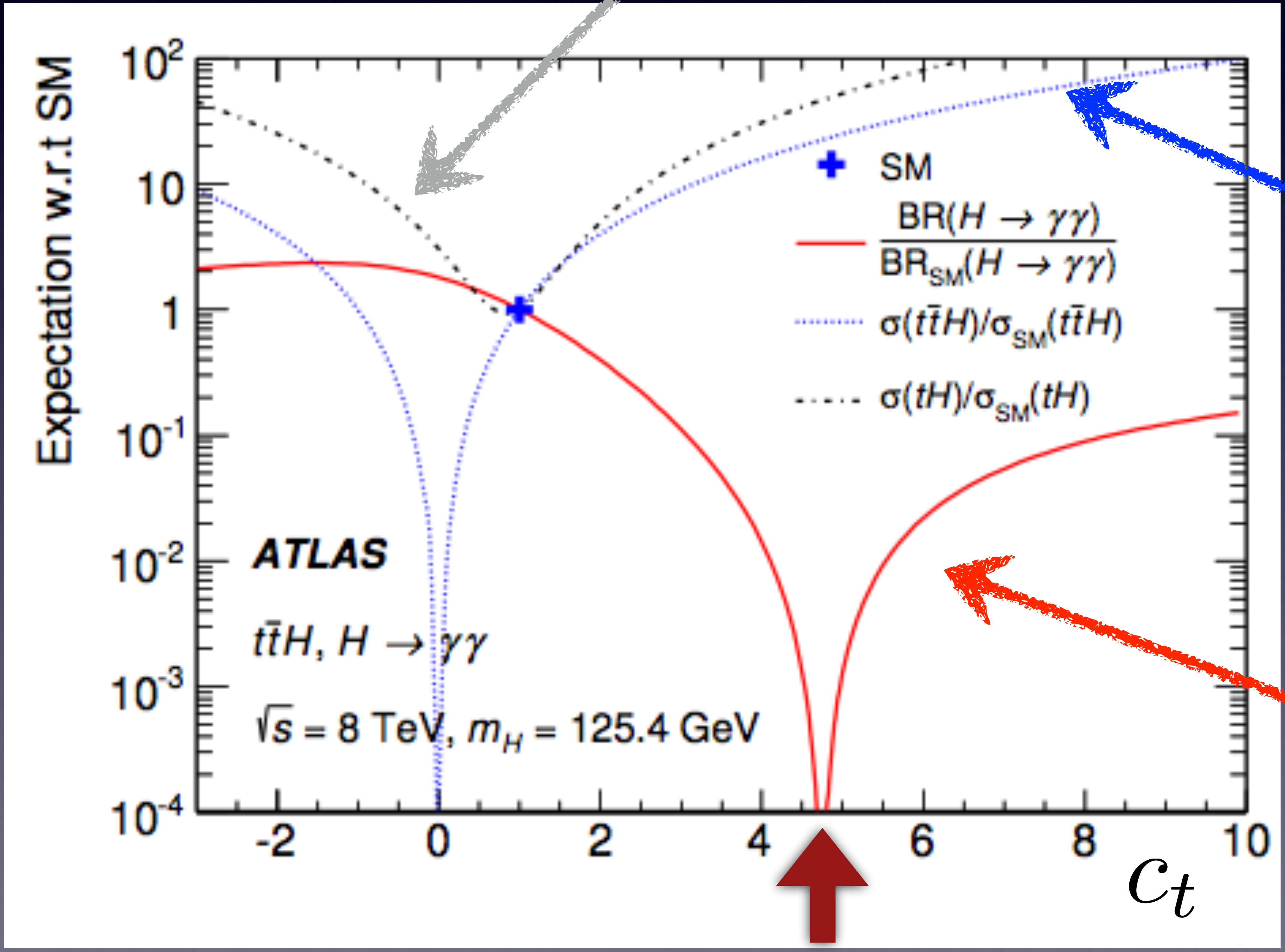
$$Br(H \to \gamma\gamma)$$

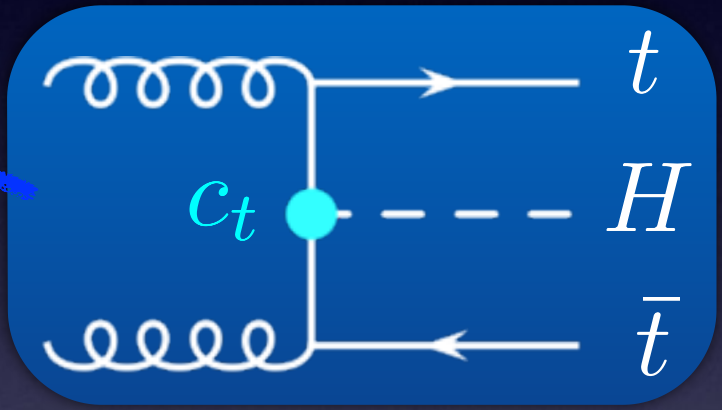
2.4 times enhanced

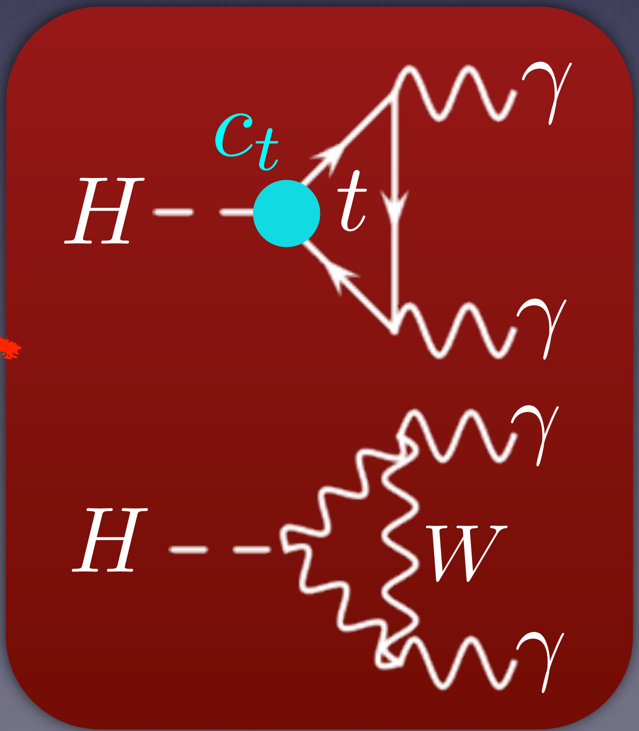


c_t Changes X-sections and $\mathrm{Br}(H \to \gamma\gamma)$



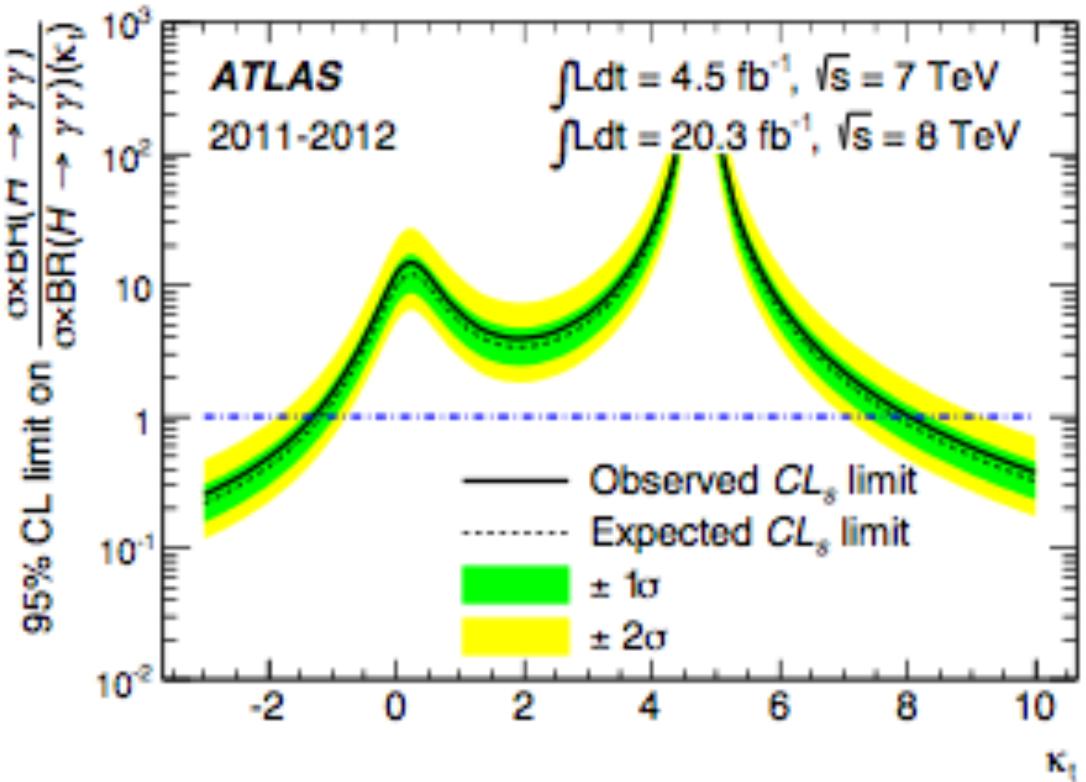


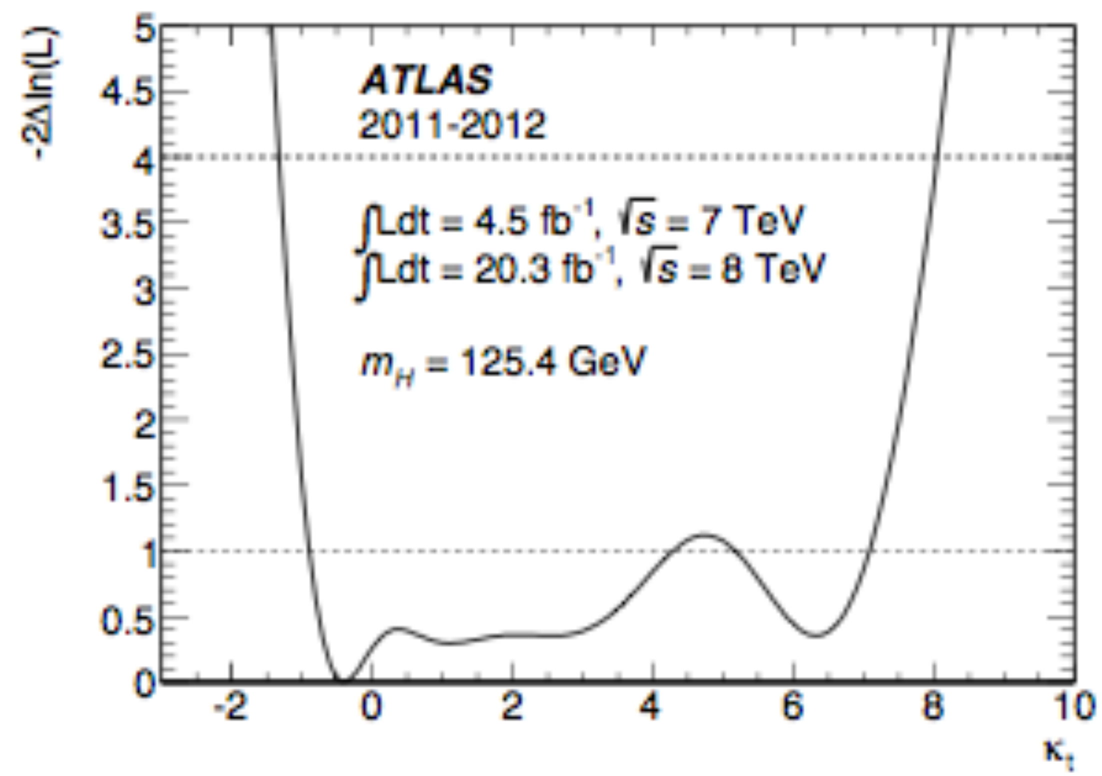




Accidental cancellations at c_t=+4.7

95% C.L. Limit on c_t





- Scan κ_t, set other couplings to SM values
- Null hypothesis: background + SM Higgs production

95% C.L. Limit on κ_t

	Observed	Expected
Upper Limit	$+\mathbf{8.0}$	+7.8
Lower Limit	$-\mathbf{1.3}$	-1.2

- Consistent with SM expectation of $\kappa_t = 1$
- Best fit for κ_t slightly below 0

$\kappa_t = c_t$

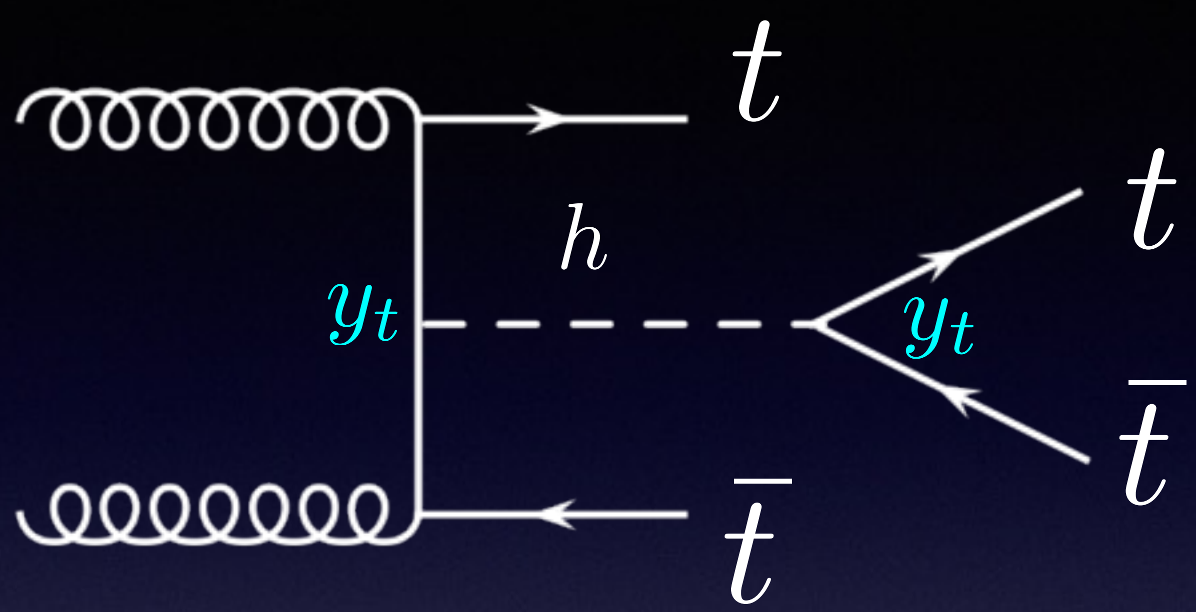
Boser, Top2014

Can we measure c_t without any assumption on Higgs boson decay?

Find a process

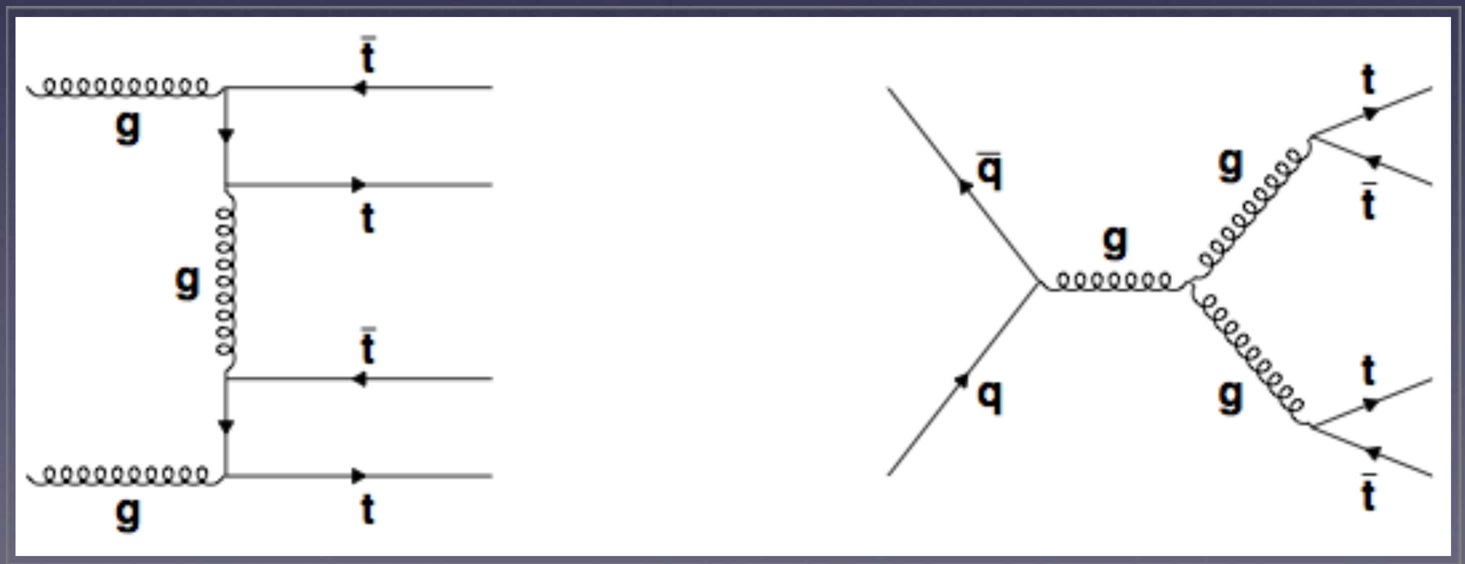
(1) Sensitive to top-Higgs Yukawa coupling
(2) Insensitive to Higgs boson decay (total width)
(3) No interference with other Higgs coupling, e.g. Vector-boson-Higgs coupling
(4) With small backgrounds

Four Top Production in SM



$$\sigma(tt\bar{t}\bar{t}) \propto y_t^4$$

X-section is 0.16fb at 8TeV

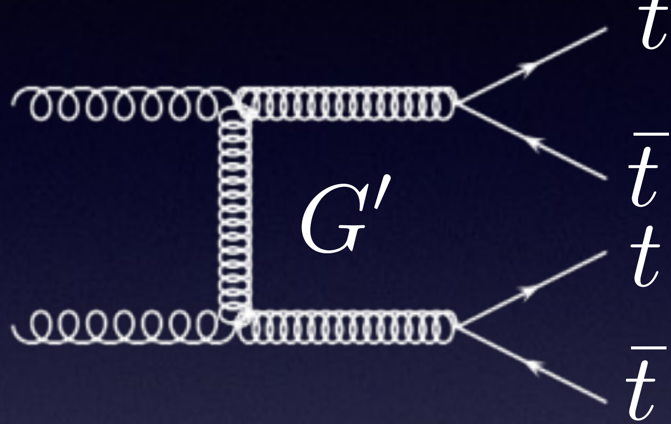


X-section is 1fb at 8TeV

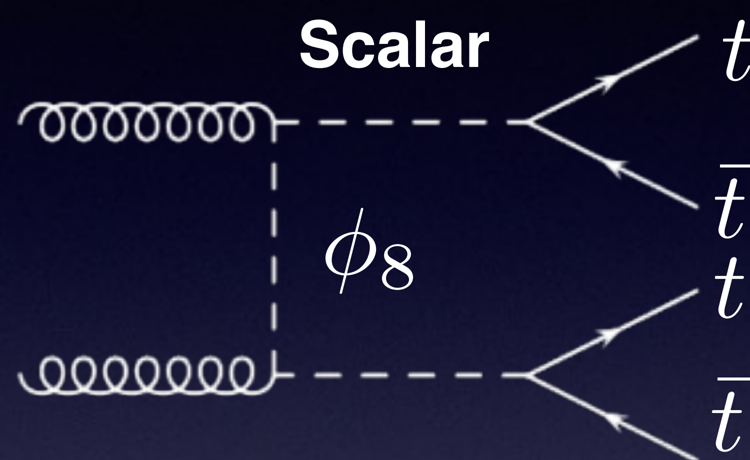
SM QCD production @ NLO,
Bevilacqua and Worek, 1206.3064

Four Top Production and New Physics

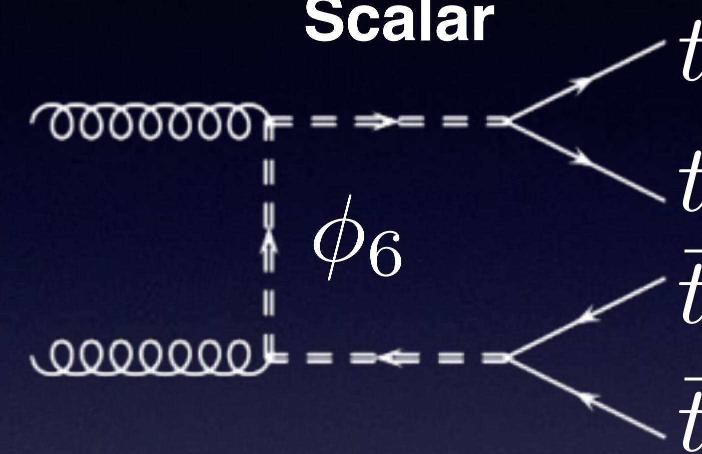
Axigluon
KK Gluon



Color Octet
Scalar

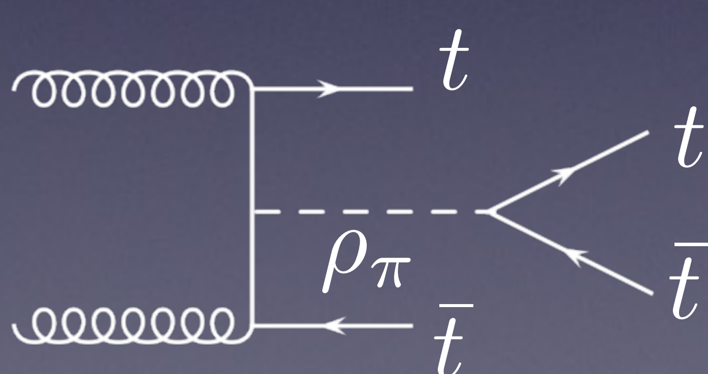


Color Sextet
Scalar



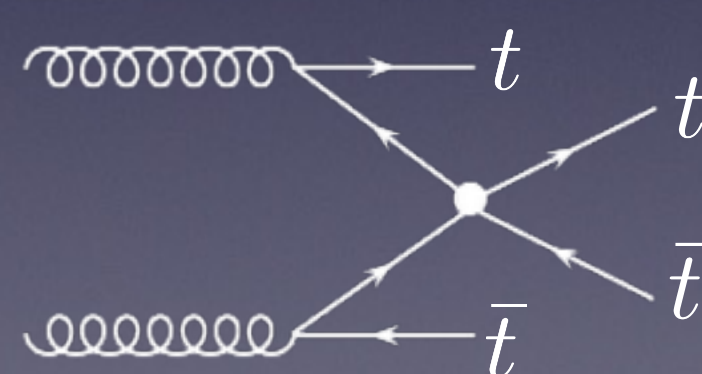
Chen, Klemm, Rentala, Wang (2008)

TC2



Han, Liu, Wu, Yang (2012)

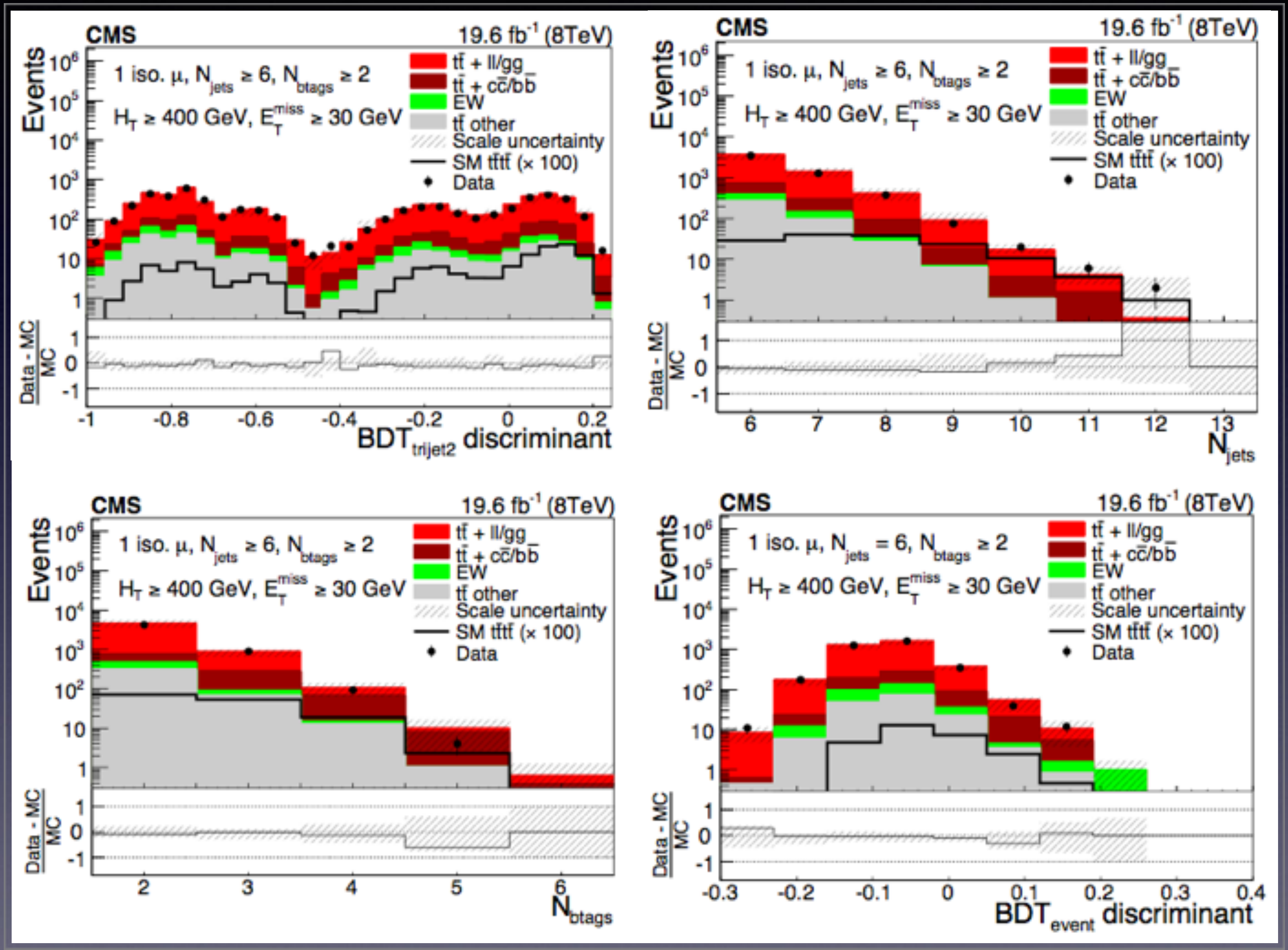
Top Compositeness



Lillie, Shu, Tait (2007)

Kumar, Tait, Veg-Morale (2009)

CMS Measurements of $\sigma(tt\overline{tt})$



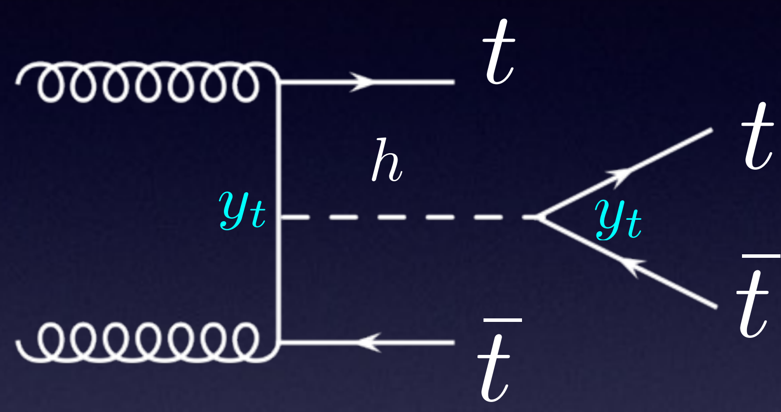
8TeV, $19.6 fb^{-1}$

arXiv:1409.7339

$$\rightarrow \sigma(tt\overline{tt}) \leq 32 \text{ fb}$$

Implication of $\sigma(t\bar{t}t\bar{t})$ on c_t

If we interpret the upper bound of $\sigma(t\bar{t}t\bar{t})$ as an upper limit of the cross section of



i.e.

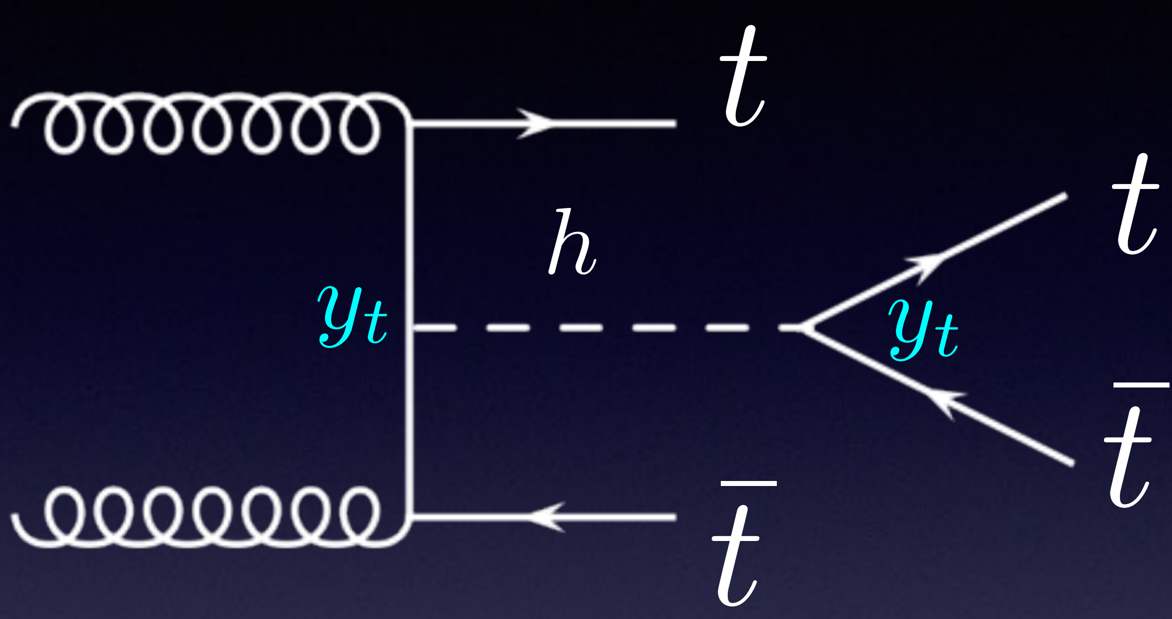
$$\sigma(tt\bar{t}t)_{\mathrm{QCD}} + \sigma(tt\bar{t}\bar{t})_{\mathrm{H}}^{\mathrm{SM}} \times c_t^4 \leq 32 \text{ fb}$$

then it yields a tight bound on top-Higgs coupling

$$c_t \leq 3.72$$

ATLAS ttH (H->AA) channel (8TeV, 19.6fb^{-1}): $-1.3 < c_t \leq 8$

Sensitivity of c_t at LHC(14)



Backgrounds:

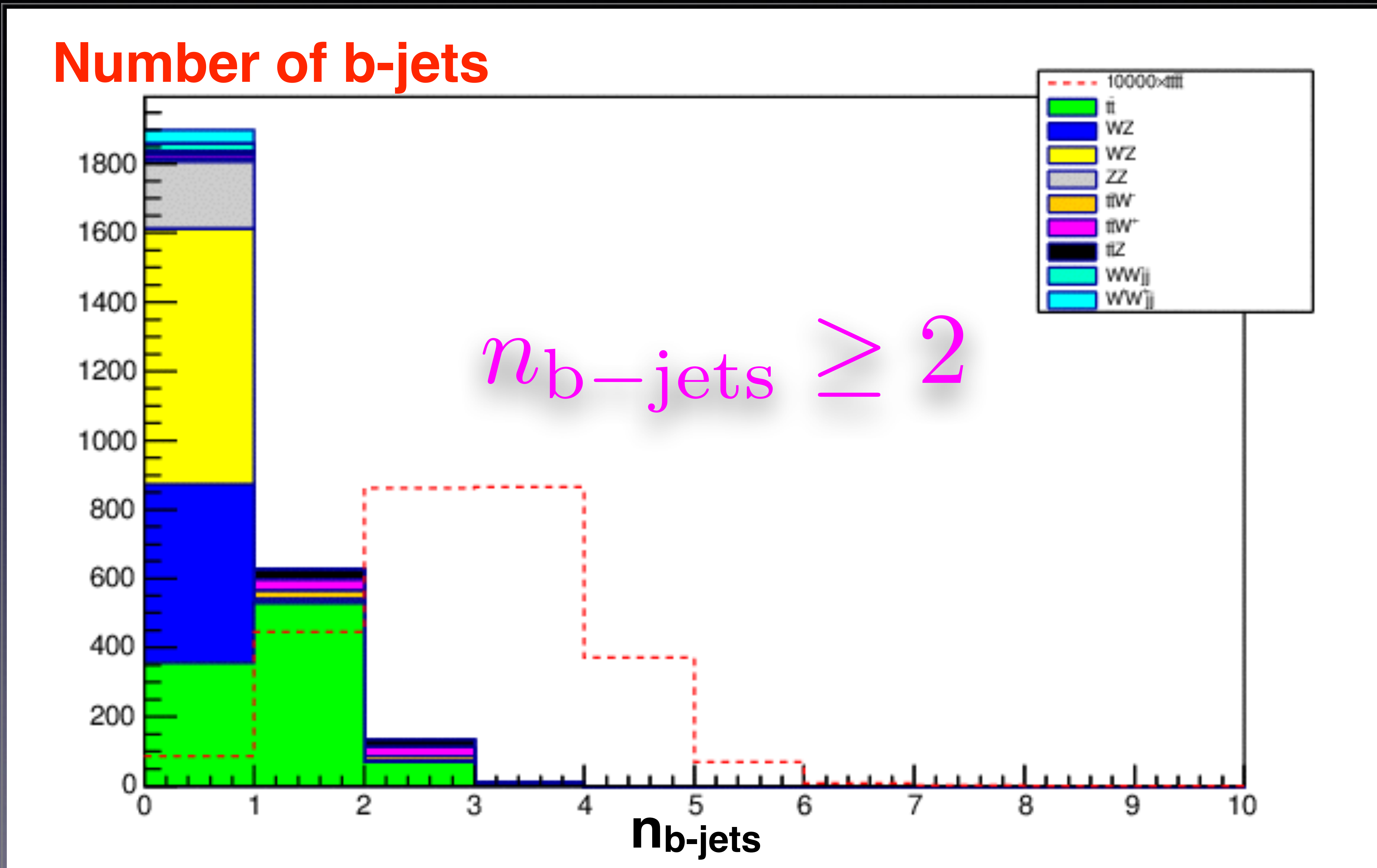
$$t\bar{t} + (0,1,2)j$$
$$t\bar{t}W^{\pm} + (0,1,2)j$$
$$t\bar{t}Z + (0,1,2)j$$
$$W^{\pm}Z + (0,1,2)j$$
$$ZZ + (0,1,2)j$$

+ other backgrounds

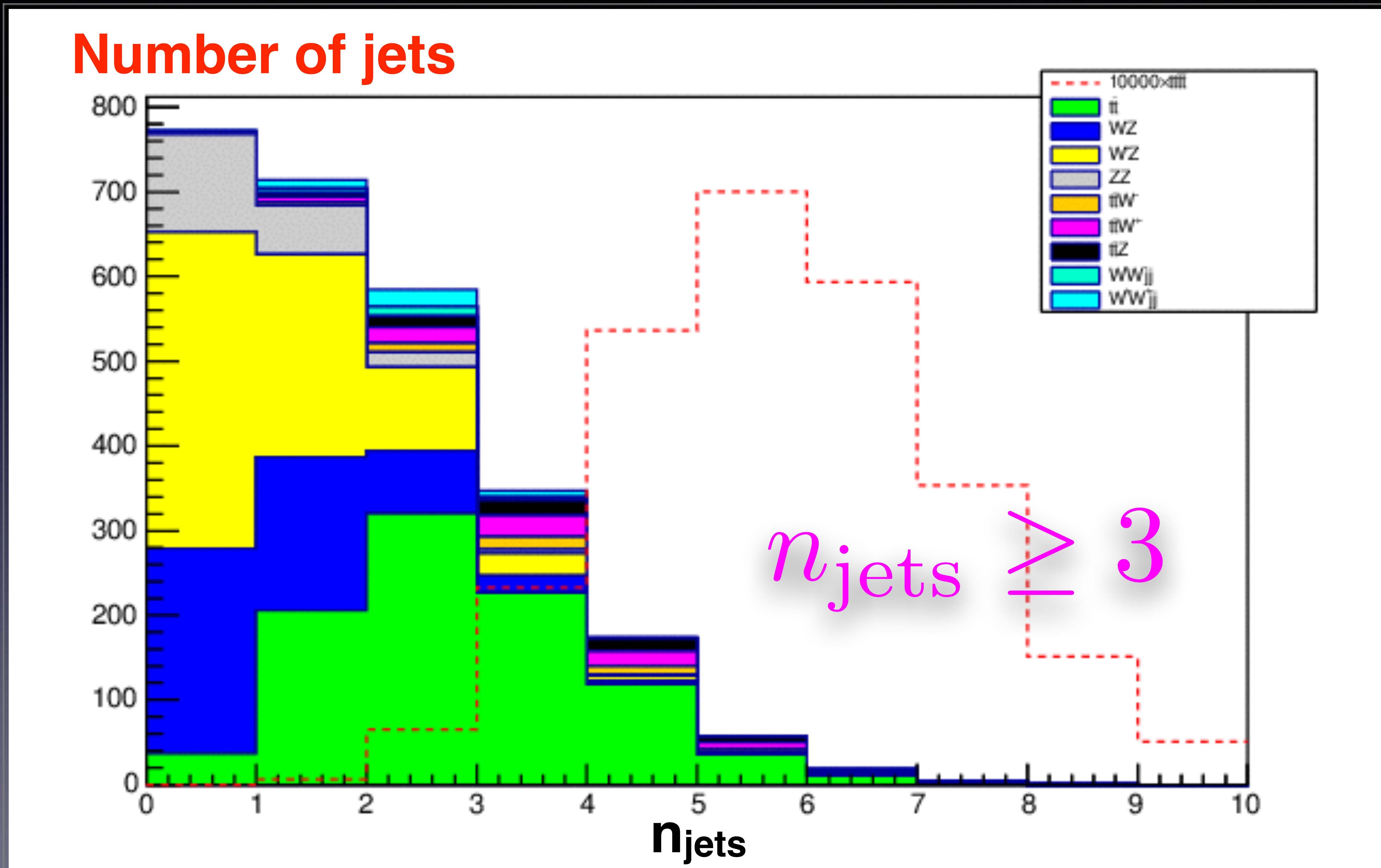
Event selection:

- ★ Same-sign di-leptons
- ★ At least two b-tagged jets
- ★ At least three tagged jets
- ★ $\not{E}_T \geq 150\ \mathrm{GeV}$
- ★ $m_T \geq 100\ \mathrm{GeV}$
- ★ $H_T \geq 700\ \mathrm{GeV}$

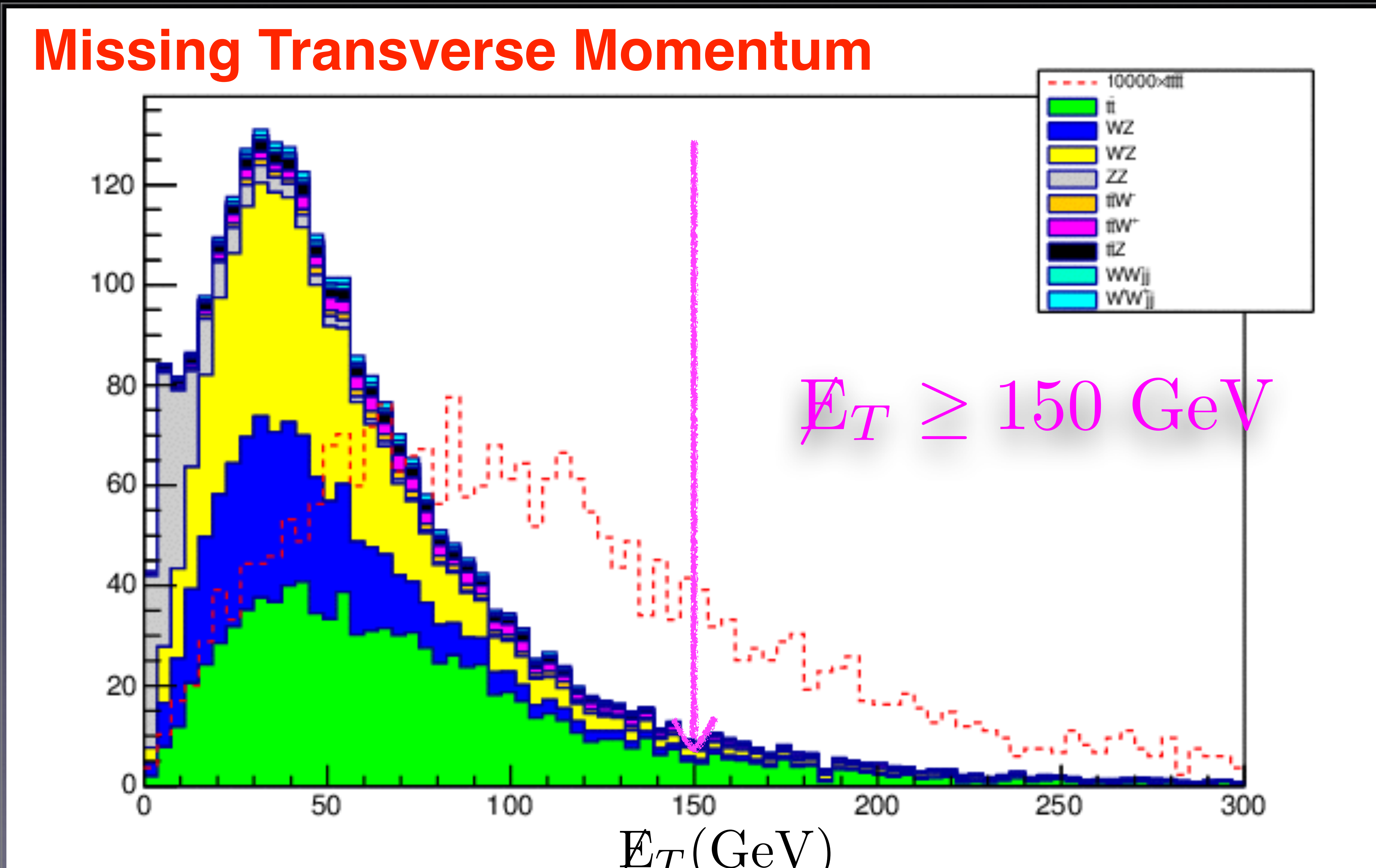
Signal versus Backgrounds



Signal versus Backgrounds

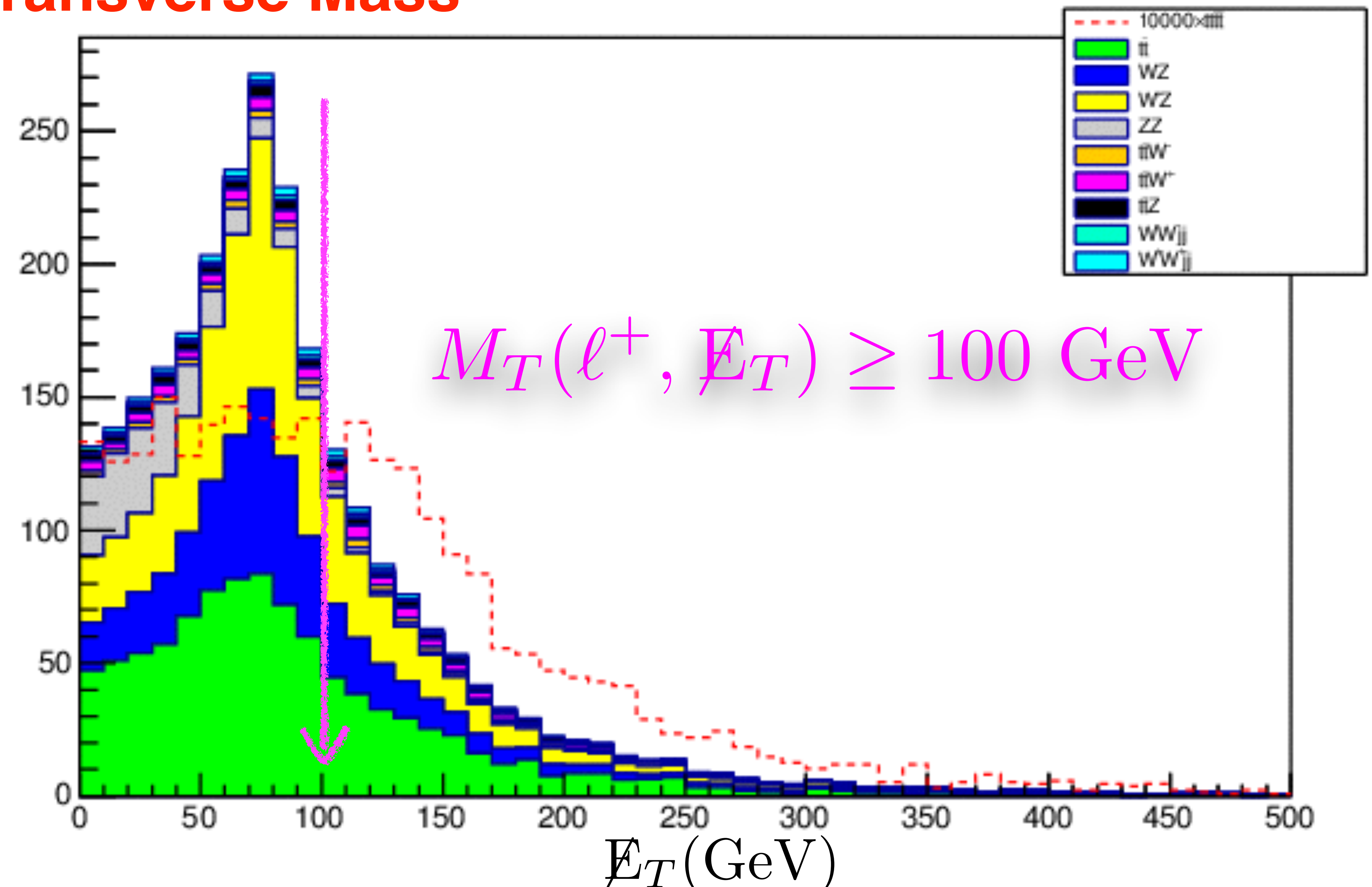


Signal versus Backgrounds

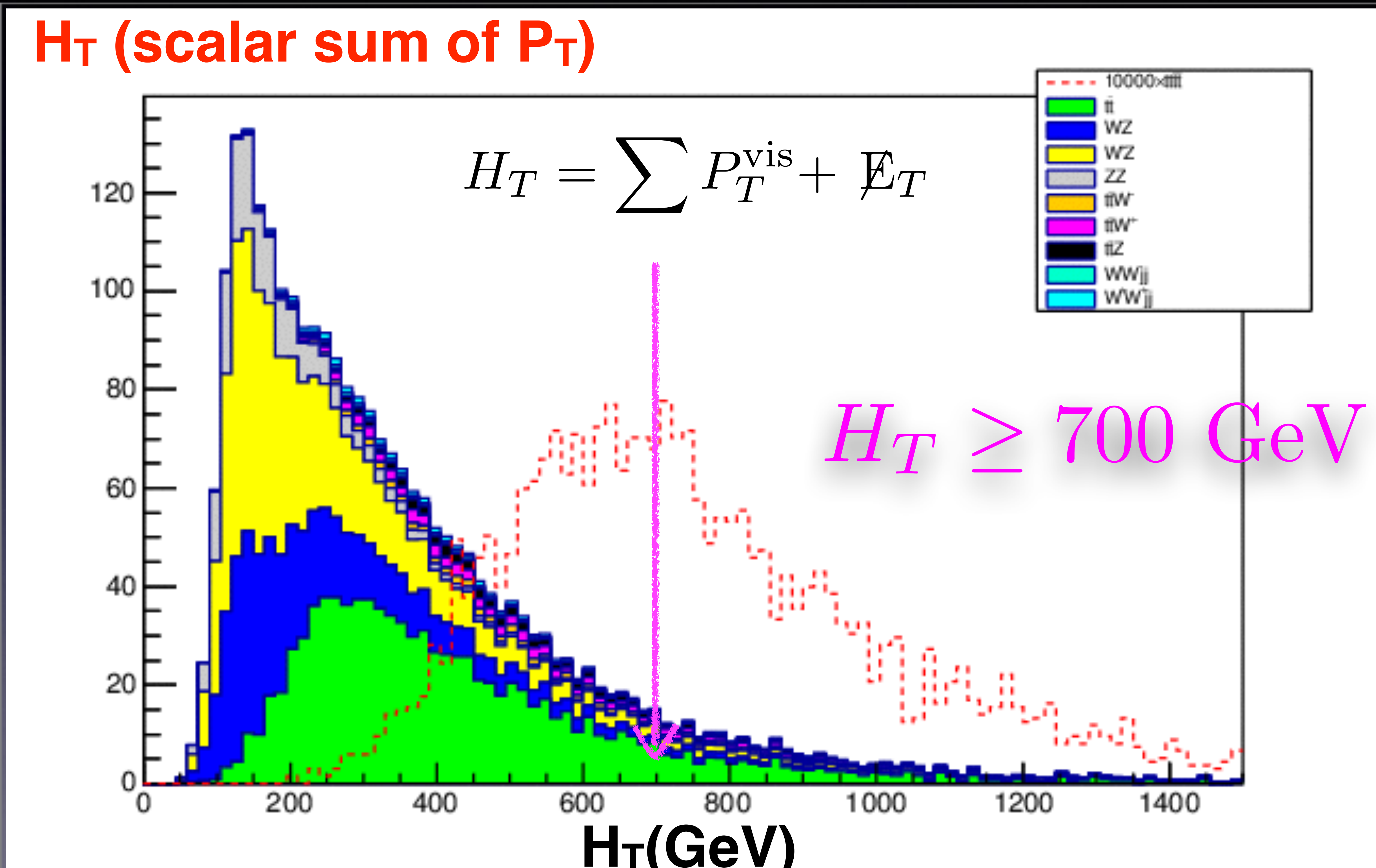


Signal versus Backgrounds

Transverse Mass



Signal versus Backgrounds



Signal versus Backgrounds

All the background processes are produced in association with up to two additional jets

Event rate at 14TeV, $10fb^{-1}$

	$t\bar{t}$	$t\bar{t}W^+$	$t\bar{t}W^-$	$t\bar{t}Z$	$tt\bar{t}\bar{t}$
b-jet	73.8272	30.081	17.8695	23.2867	0.217413
jets	59.1507	24.8343	14.5614	19.7812	0.215194
$E_T^{\rm miss}$	7.11588	4.8969	2.42198	2.37875	0.0547969
m_t	3.33557	3.0871	1.2996	1.5441	0.0333514
$m_{\rm eff}$	2.00134	2.15697	0.856553	1.29371	0.0269917

	W^+Z	W^-Z	ZZ
ssl	745.862	521.433	196.45
b-jet	0.0765887	0.0981645	0.00448526

negligible

Sensitivity of c_t at LHC(14)

The 95% C.L. limits on c_t at LHC (14TeV) is

$$c_t^4 \sqrt{\frac{\mathcal{L}}{\mathrm{fb}^{-1}}} \leq 702.2$$

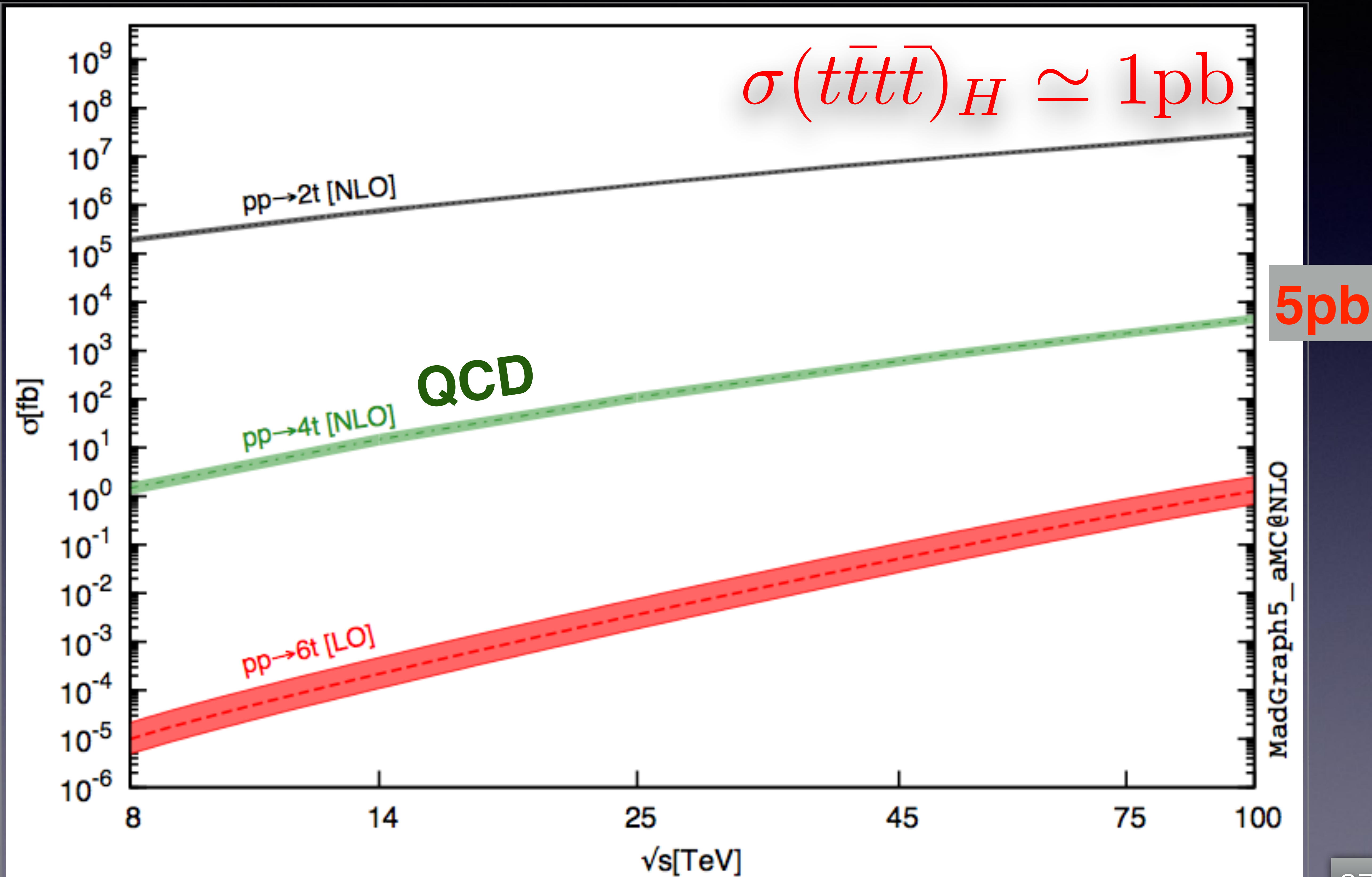
With an integrated luminosity of 300 fb^{-1}

$$c_t \leq 2.52$$

With an integrated luminosity of 3000 fb^{-1}

$$c_t \leq 1.89$$

SppC (100TeV)



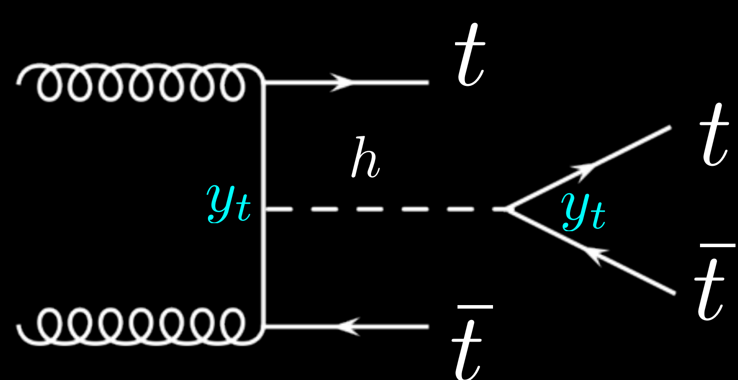
$\sigma(t\bar{t}t\bar{t})_H \simeq 1\text{pb}$
5pb
QCD
pp→2t [NLO]
pp→4t [NLO]
pp→6t [LO]
σ[fb]
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
8
14
25
45
75
100
√s[TeV]
MadGraph5_aMC@NLO

Summary

★ Top-Higgs coupling is poorly determined so far.

ATLAS ttH channel (8TeV, 19.6fb^{-1}): $-1.3 < c_t \leq 8$

★ Four top-quark production is sensitive to top-Higgs coupling to the fourth power



$\sigma(tt\bar{t}\bar{t}) \propto y_t^4$

Pros: Good to bound on the coupling
Cons: Small rate limiting the discovery potential

★ CMS 4-Top production

(8TeV, 19.6fb^{-1})

$c_t \leq 3.72$

★ LHC (14TeV)

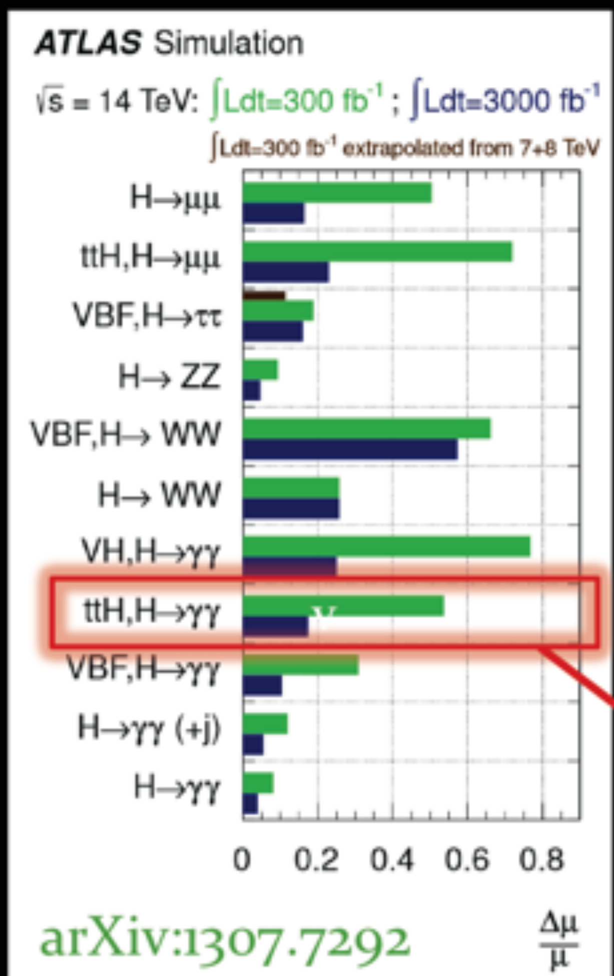
$c_t \leq 2.52$ for $\mathcal{L} = 300\text{fb}^{-1}$

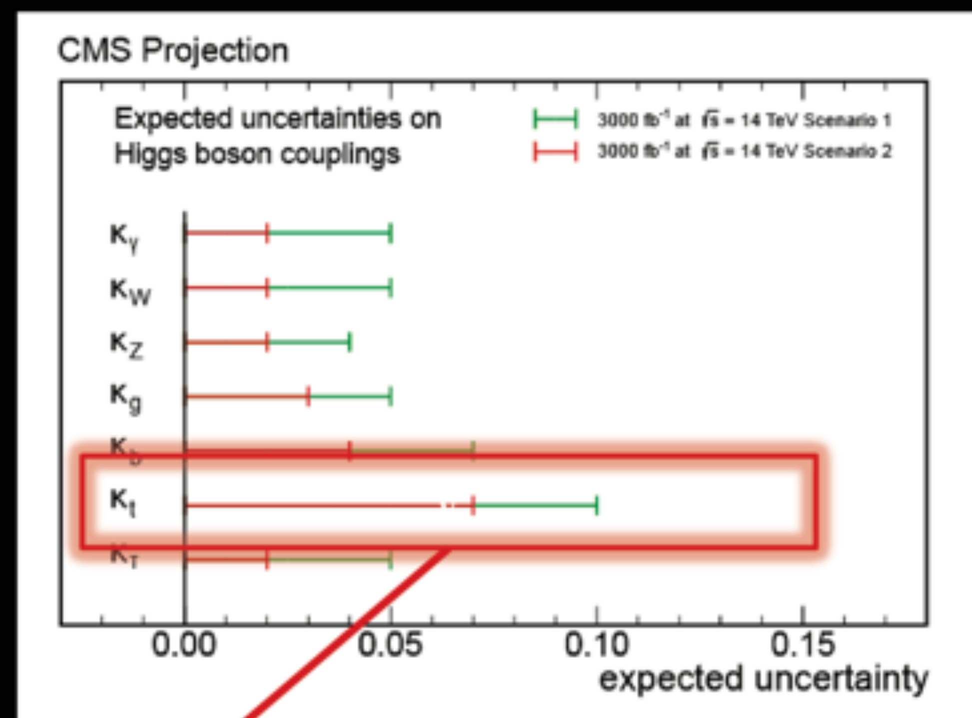
$c_t \leq 1.89$ for $\mathcal{L} = 3000\text{fb}^{-1}$

ttH prospects at 13/14TeV

- cross-section more sensitive to pdfs fall: $\sigma_{tth}^{14\mathrm{TeV}} \approx 4.6 \times \sigma_{tth}^{8\mathrm{TeV}}$

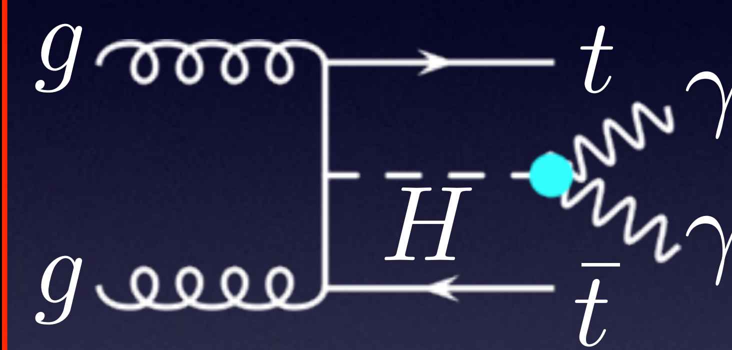
$(\sigma_{h}^{14\mathrm{TeV}} \approx 2.6 \times \sigma_{h}^{8\mathrm{TeV}})$





$\Delta c_t / c_t \approx 10\%$ by ~2030

(ILC: ~5%)



Complementary channels will help improving our knowledge of top-Higgs coupling and unveiling top-partner presence + spectrum, properties

Thank You!